TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

ATOMINSTITUT

138.039 Einführung in die Forschungsgebiete der Fakultät für Physik

Willkommen am Atominstitut!

26. März 2021, Vienna University of Technology

Was ist das Atominstitut?

- 1 von 4 Instituten der Fakultät für Physik
- Standort Prater + Freihaus + Operngasse + MedAustron + HEPHY
- gegründet/gebaut 1959 als „Atominstitut der österr. Universitäten“
- 2002 in TU Wien integriert
- ~150 Mitarbeiter_innen + ~50 Studierende
- beheimatet *TRIGA Center Atominstitut* + *CLIP* (E141 und E057-14)
- 8 Forschungsbereiche + 3 Junior research groups
- …eine großartige Umgebung für Forschung und Lehre und mehr!

Was machen wir am Atominstitut?

…urviel…!

Anschnallen, los geht’s!

…freuen Sie sich auf 12 spannende Präsentationen!

TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

ATOMINSTITUT

Forschungsbereich
Quantum Metrology

Thorsten Schumm

Stephanie Manz, Tomas Sikorsky, Nadine Hilmar
Joszef + Enikoe Seres, Georgy Kazakov

+ 10 PhD students + 2 Master students

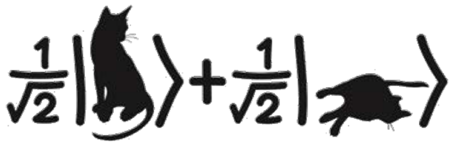
+ YOU?

thorsten.schumm@tuwien.ac.at

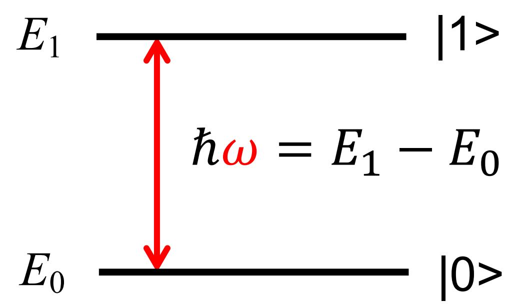
Was macht „Quantum Metrology“?

Erforschung neuartiger Messverfahren auf der Basis der Quantenmechanik

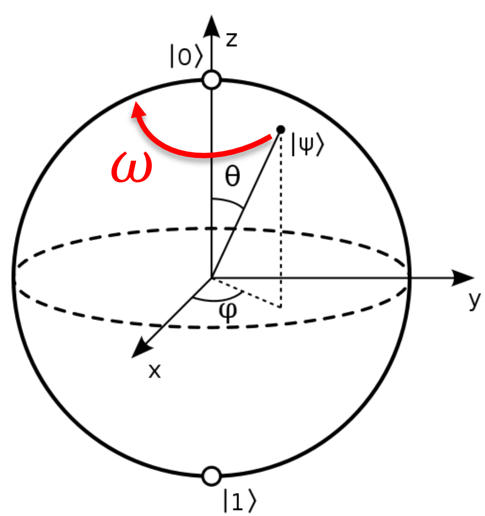
Ausgangspunkt: Quanten-Superposition



Physikalische Realisierung: 2-Niveau system



Darstellung als Zustandsvektor



Zwei Beispiele zur Quantenmetrologie

Beispiel 1:
Wähle die 2 Zustände möglichst „robust“
→ **eine Quanten-Uhr**

Atomic clocks for satellite-based navigation:
GPS, Galileo, GLONASS, BDS...

Thorium-Kern-Uhr

- Konzept: Quanten-**Kernzustände**
- (fast) nur möglich am Atominstitut
- Thorium-229 in Kristallen

Beispiel 2:
Wähle die 2 Zustände „empfindlich“
→ **ein Quanten-Sensor**

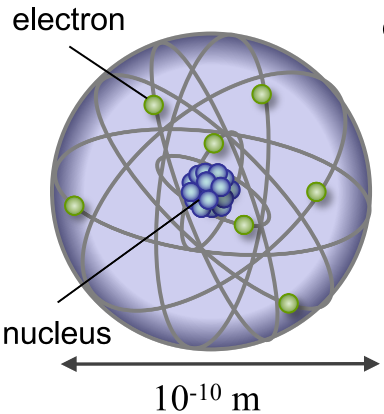
Atomic magnetometers, accelerometers,
motion sensors, gravimeters...

Cäsium-Gravimeter

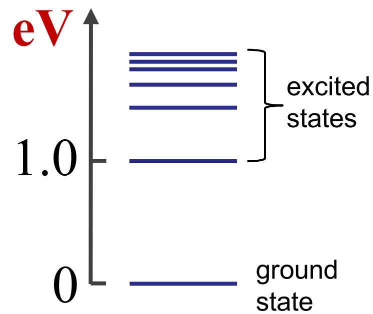
- Konzept: **räumliche Zustände**
- ein Schrödinger-Kätzchen
- …going to space

Beispiel 1: Thorium-229 Kernuhr

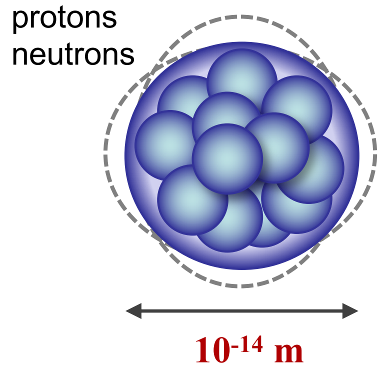
Atomic physics



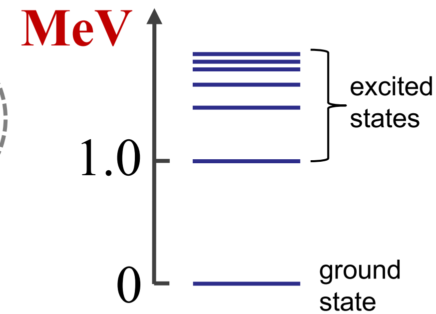
discrete energy levels

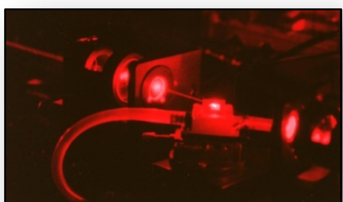


Nuclear physics



discrete energy levels





main tool
of study:
laser spectroscopy

main tool
of study:
particle accelerators

Atomic spectroscopy for metrology

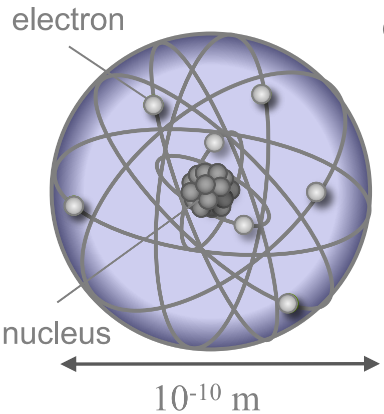
- provides a frequency standard
- 1s ≡ 9.192.631.770 oscillations in Cs
- crucial for fundamental research
- applications: GPS, communication
- miniaturization possible

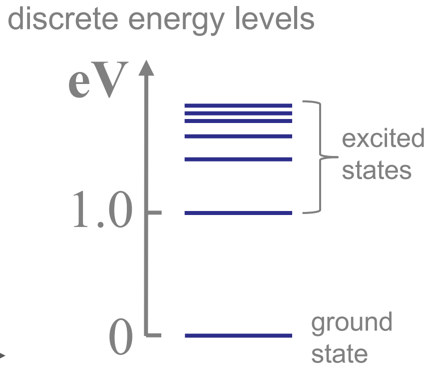
Nuclear spectroscopy for metrology

- no frequency standard (although suited!)
- used in fundamental research
- (Mössbauer spectroscopy, dating)
- no direct metrology applications
- no miniaturization

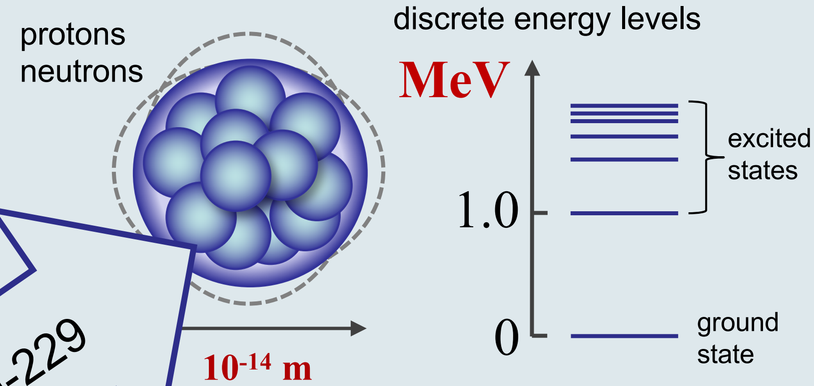
Beispiel 1: Thorium-229 Kernuhr

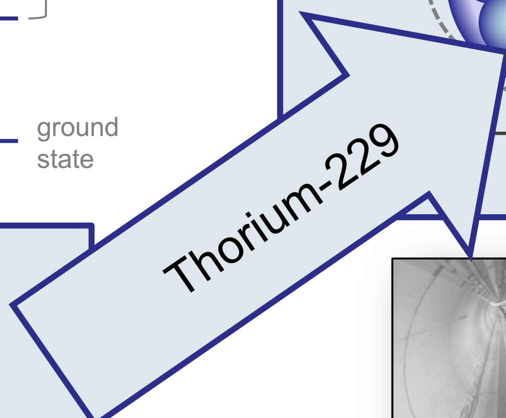
Atomic physics

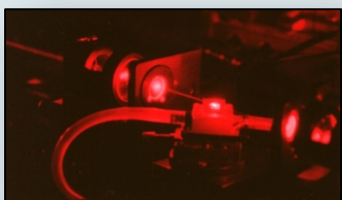




Nuclear physics







main tool
of study:
laser
spectroscopy

main tool
of study:
particle
accelerators

Atomic spectroscopy for metrology

- provides a frequency standard
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- applications: GPS, communication
- miniaturization possible

Nuclear spectroscopy for metrology

- **NEW frequency standards ?**
- **new fundamental research possible !**
- (Mössbauer spectroscopy, dating)
- **miniaturization possible**
- **applications ahaid?**

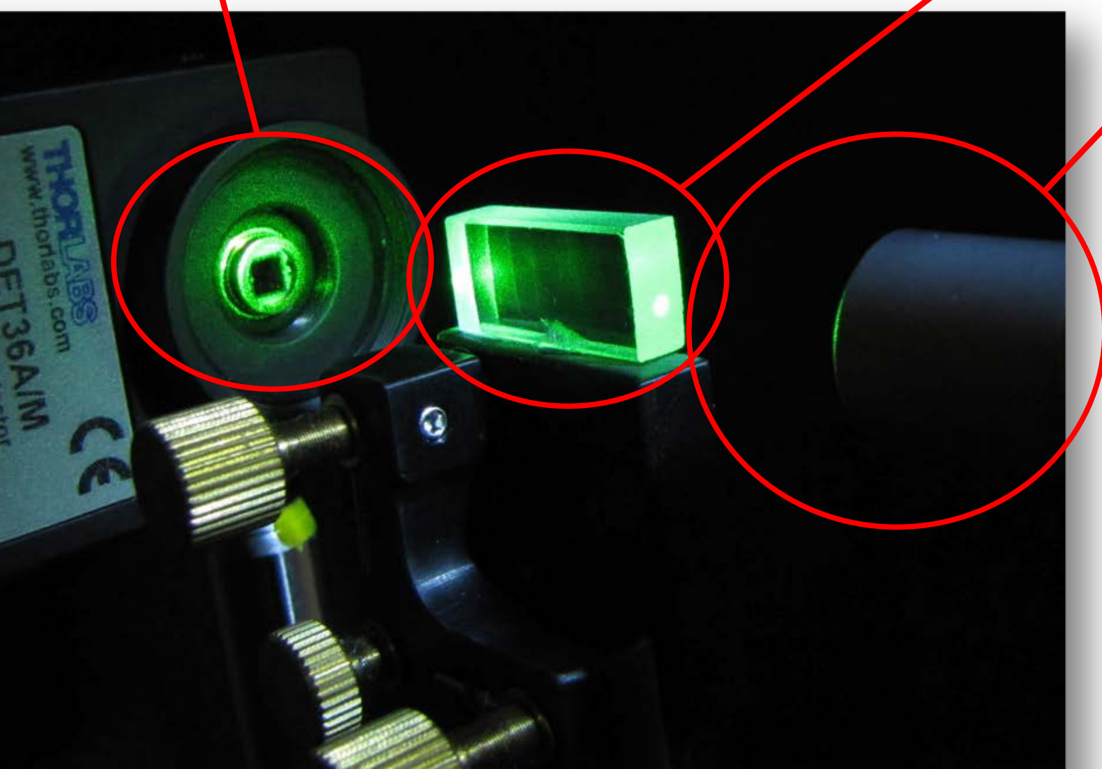
Beispiel 1: Thorium-229 Kernuhr

Was ist daran so schwierig? Alles!

Detektion: einzelne VUV Photonen
- Signal: wenige counts pro Minute
- kosmische Hintergrundstrahlung
- Radioaktivität der Probe

Kristall: Thorium-dotiertes CaF2
- völlig unbekanntes Material
- einziger „Hersteller“ weltweit
- Kosten: 1 mg Th-229 ca. 120 k€

Laser: 150 nm VUV
- nicht kommerziell erhältlich
- 5-6 Systeme weltweit
- füllt 2 Labors



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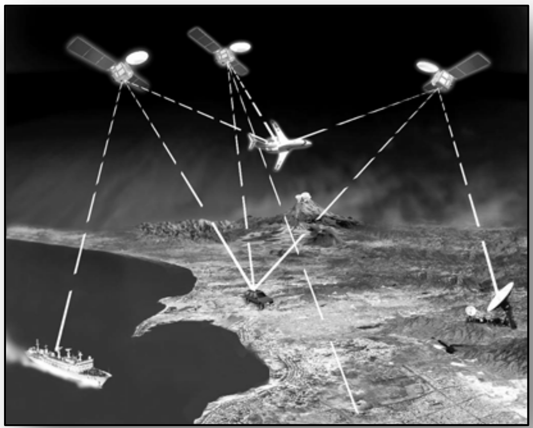

Atomic clocks for satellite-based navigation:
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Wähle die 2 Zustände „empfindlich“
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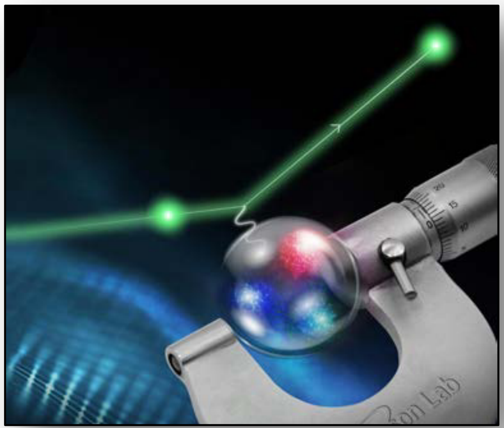

Atomic magnetometers, accelerometers,
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Cäsium-Gravimeter

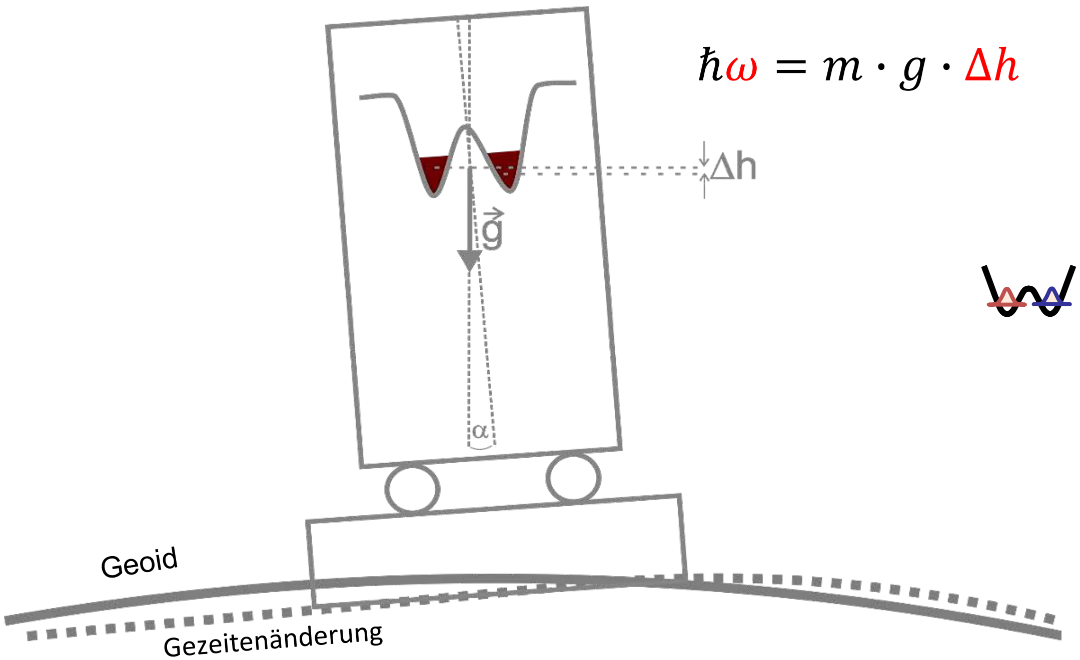
- Konzept: **räumliche Zustände**
- ein Schrödinger-Kätzchen
- …going to space

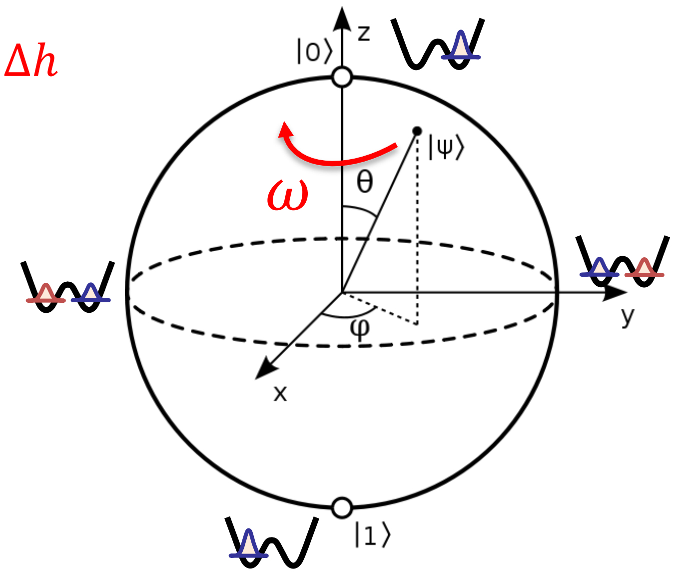
Beispiel 2: Cäsium-Gravimeter

Konzept: räumliche Überlagerung: $\frac{1}{\sqrt{2}}\left|atom\ links\right\rangle + \frac{1}{\sqrt{2}}\left|atom\ rechts\right\rangle$

…wieder ein 2.Niveau system

$\hbar\omega = m \cdot g \cdot \Delta h$

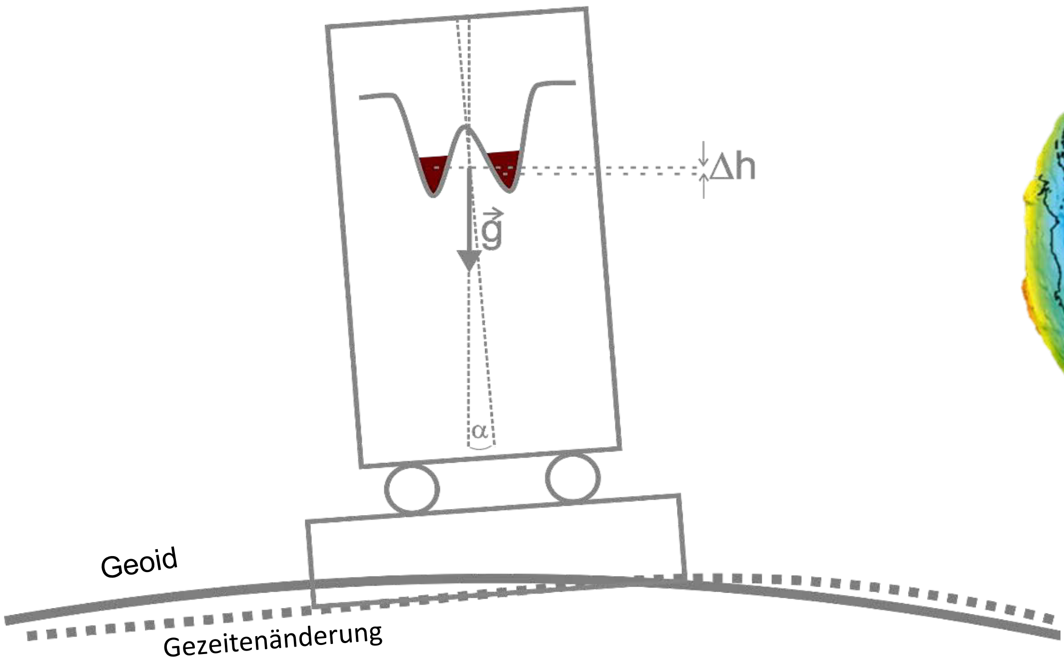


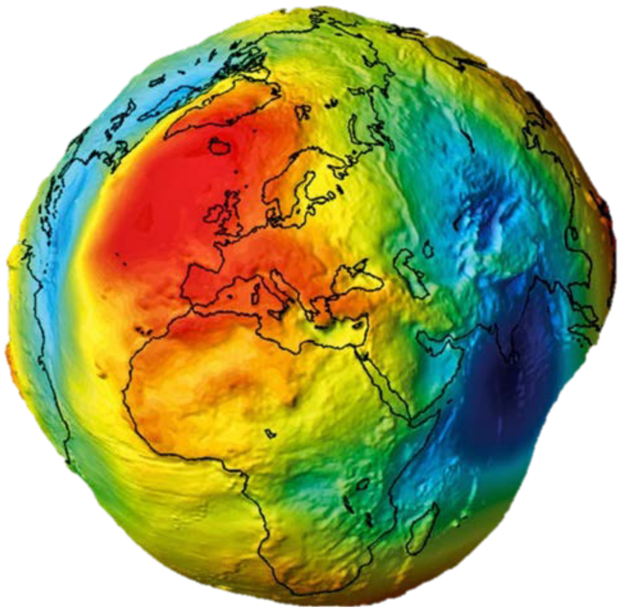


Höhenunterschied Δh lässt sich sehr exakt messen → ein **Quanten-Tiltmeter**

Beispiel 2: Cäsium-Gravimeter

Konzept: räumliche Überlagerung: $\frac{1}{\sqrt{2}}\left|atom\ links\right\rangle + \frac{1}{\sqrt{2}}\left|atom\ rechts\right\rangle$





Earth's geoid, fluctuations amplified x1000

Höhenunterschied Δh lässt sich sehr exakt messen → ein **Quanten-Tiltmeter**

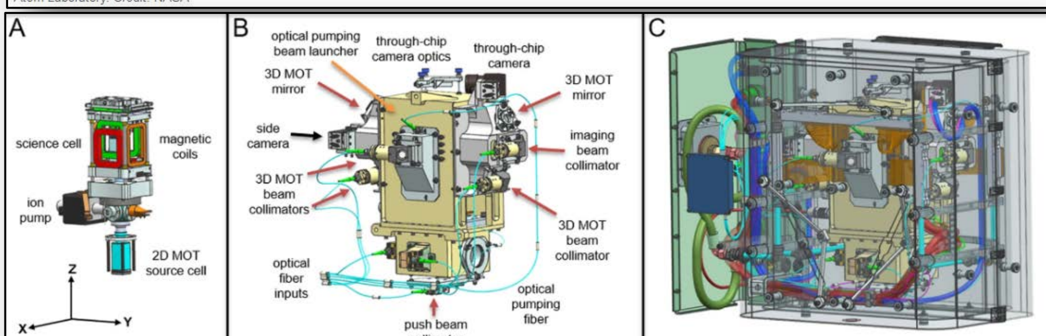
Beispiel 2: Cäsium-Gravimeter

NASA ISS Atomchip platform


NEWS | JULY 27, 2018

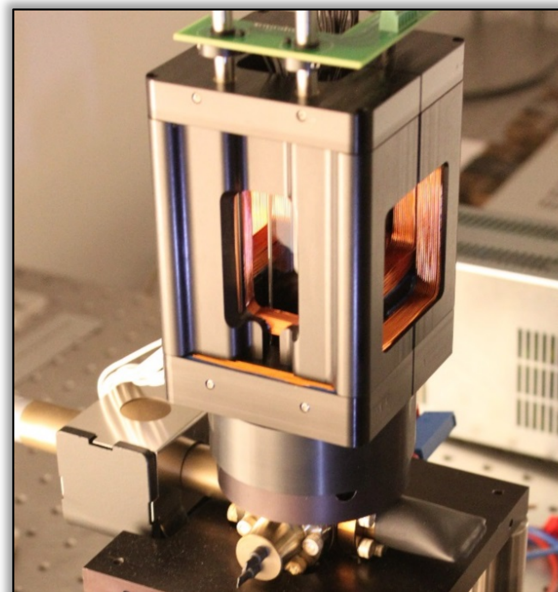
Space Station Experiment Reaches Ultracold Milestone

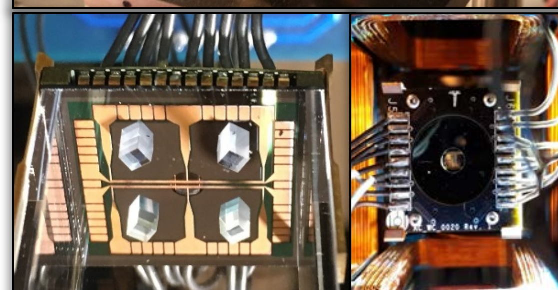
Taken from inside the Cupola on the International Space Station, this image shows the Northrop Grumman (formerly Orbital ATK) Cygnus spacecraft arriving at the station on May 24, 2018. The vehicle carried, among other things, NASA's Cold Atom Laboratory. Credit: NASA



in Zusammenarbeit mit ColdQuanta (Boulder)

TU Wien System





TU Wien Beitrag:

- Micro-Optik-Elemente
- integrierte MW Antennen

Quantenmetrologie hä?

viel mehr auf www.quantummetrology.at

Fragen

- jetzt gleich?
- nachher im „breakout room“
- an thorsten.schumm@tuwien.ac.at

Theoretische Quantenoptik

Peter Rabl

Start

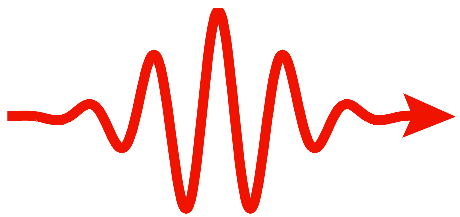
Der Wissenschaftsfonds.

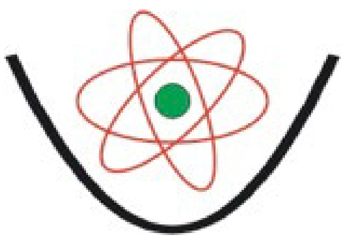
European Commission

CoQuS
ComplexQuantumSystems

ATOMINSTITUT
www.ati.ac.at

Was ist Quantenoptik ?

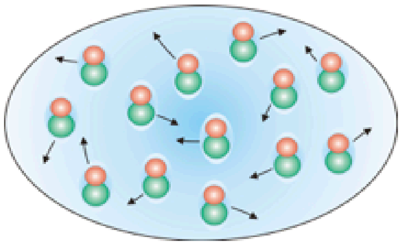




Licht-Materie-Wechselwirkungen mit einzelnen Atomen und Photonen:

- *Spektroskopie*
- *Laserkühlen und Fangen von Atomen*
- *Nichtklassische Lichtfelder & Verschränkung*
- *...*

Was ist Quantenoptik ?

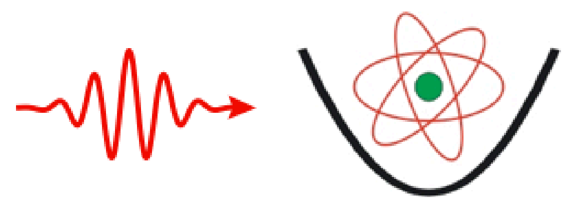


Materie = Atome

Licht = Photonen

“We never experiment with a single electron or atom” (E. Schrödinger 1952)

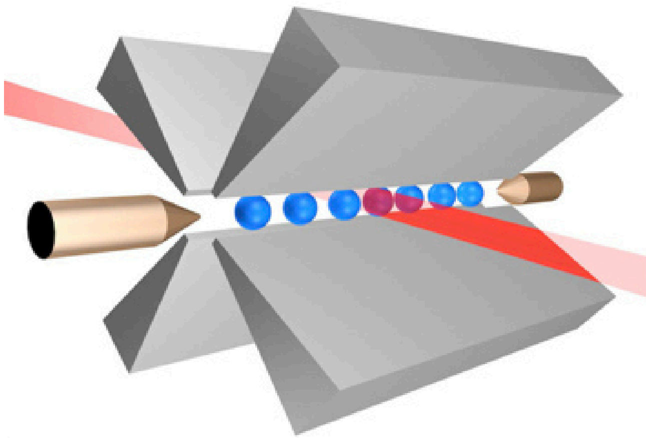
- Laser Spektroskopie
- Laserkühlen & Atomfallen



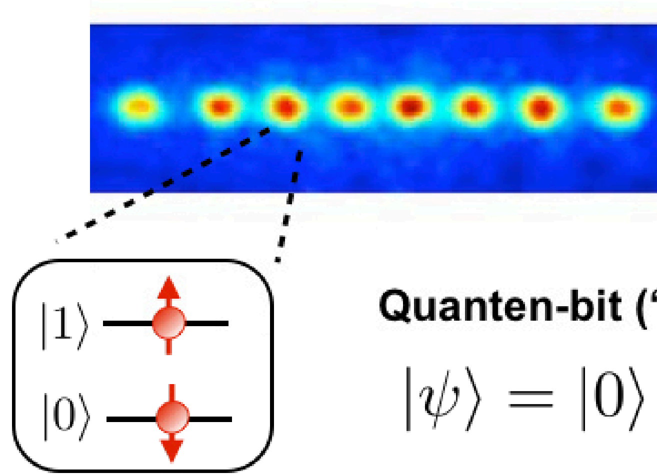
... Experimente mit einzelnen Quantensystemen !!

1900 — 20th century — 2000

Anwendungen



Ionenfallen (z.B Innsbruck, NIST,...)

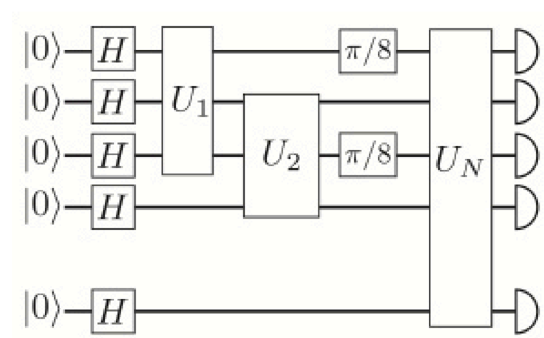


Quanten-bit ("qubit")

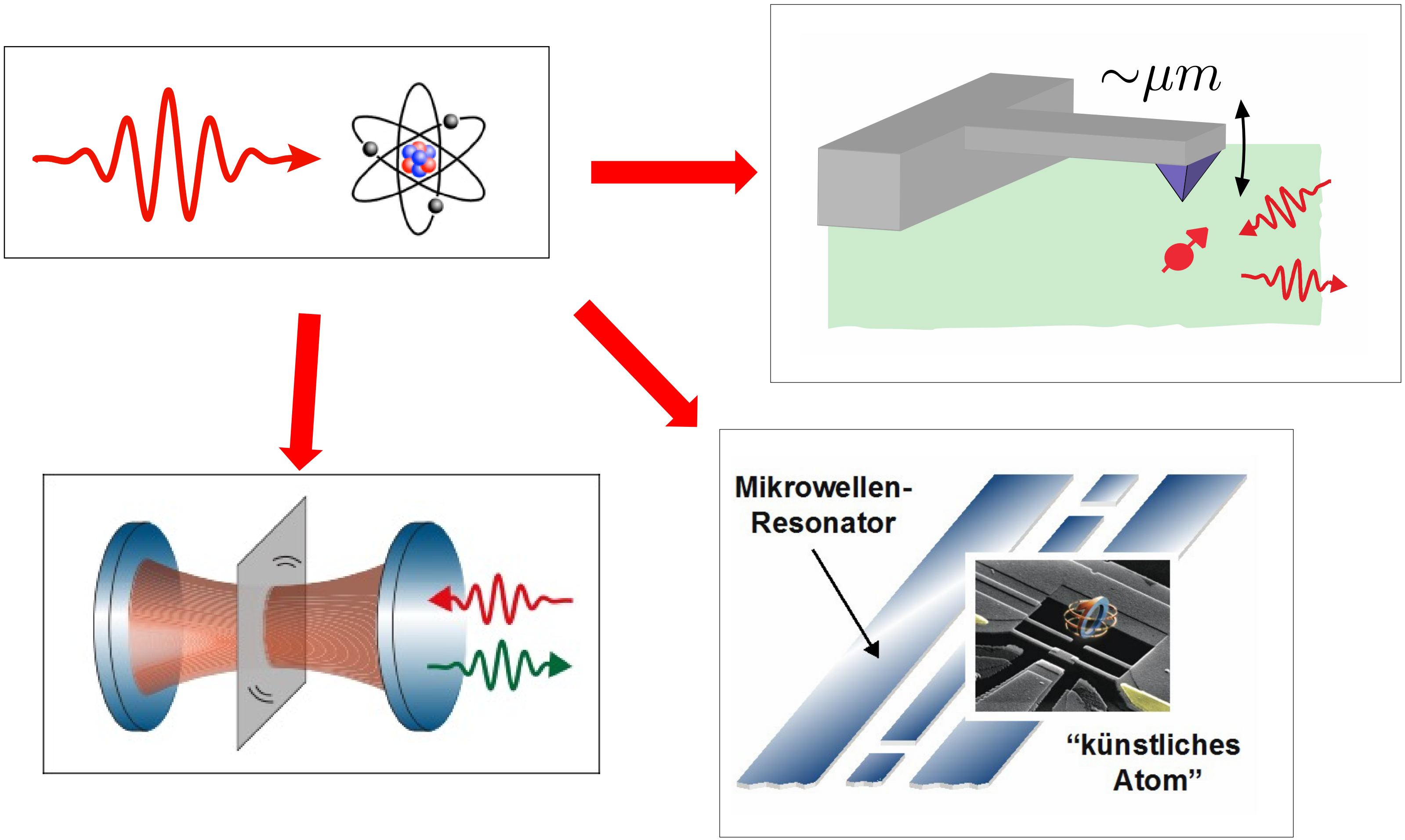
$$|\psi\rangle = |0\rangle + |1\rangle$$

Neue Q-Technologien:

- *Quantencomputer & Quantensimulation*
- *abhörsichere Quantenkommunikation*
- *Senortechnologie, ...*

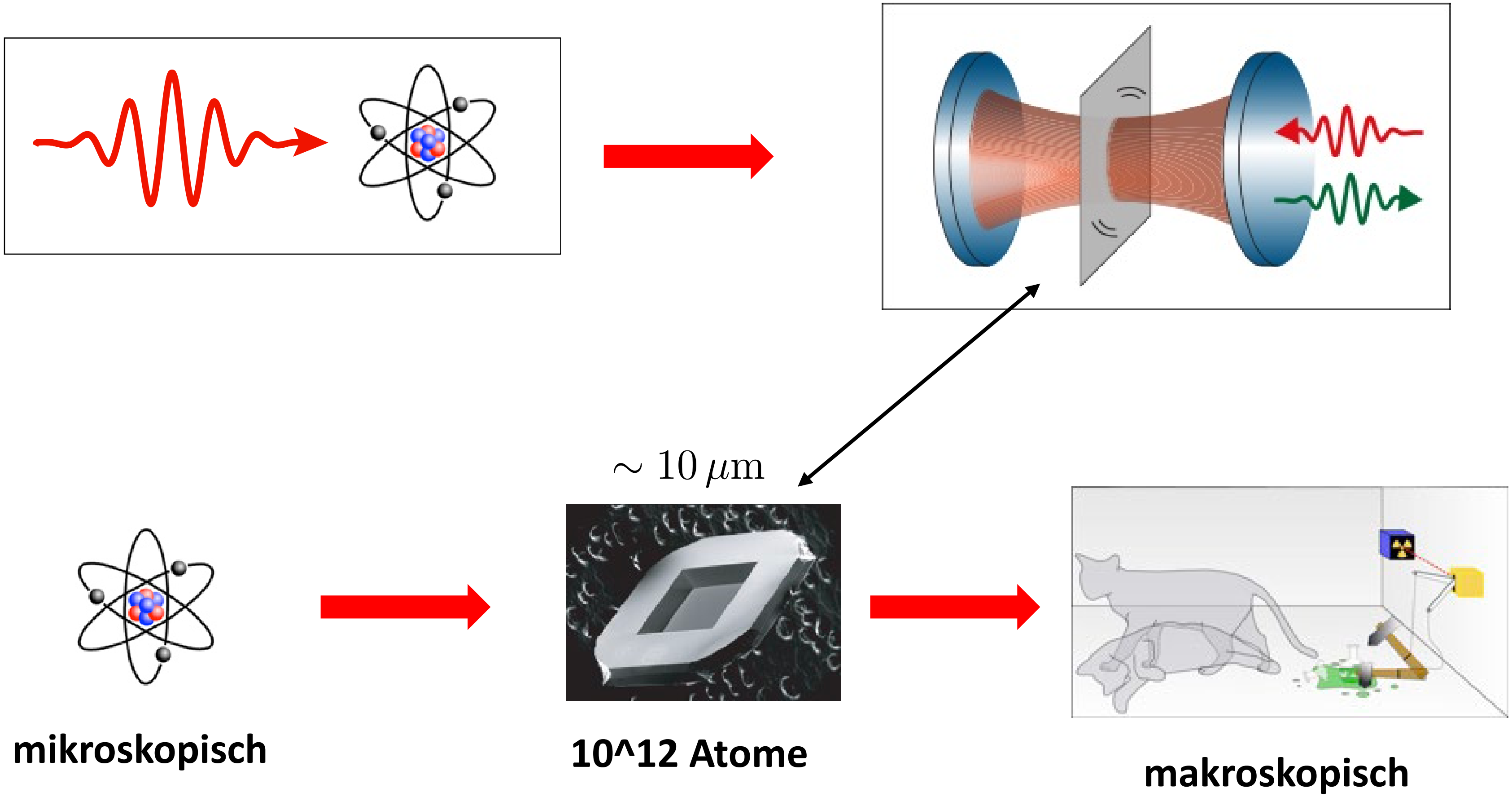


Unsere Forschung …



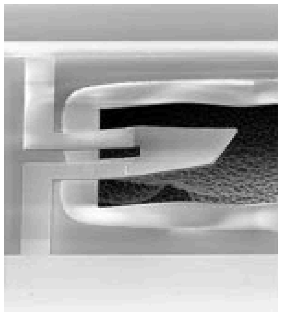
Quantenoptik mit „makroskopischen" und „künstlichen" Systemen

Mikro- und nanomechanische Resonatoren…

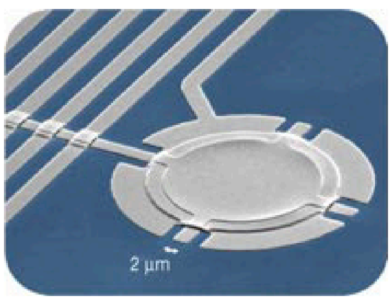


Quantenmanipulation von markoskopischen Objekten?

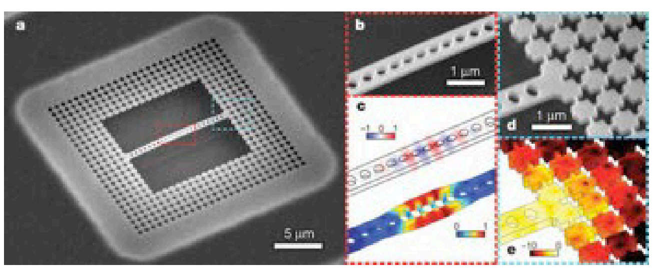
Makroskopische Objekte im Quantenregime …



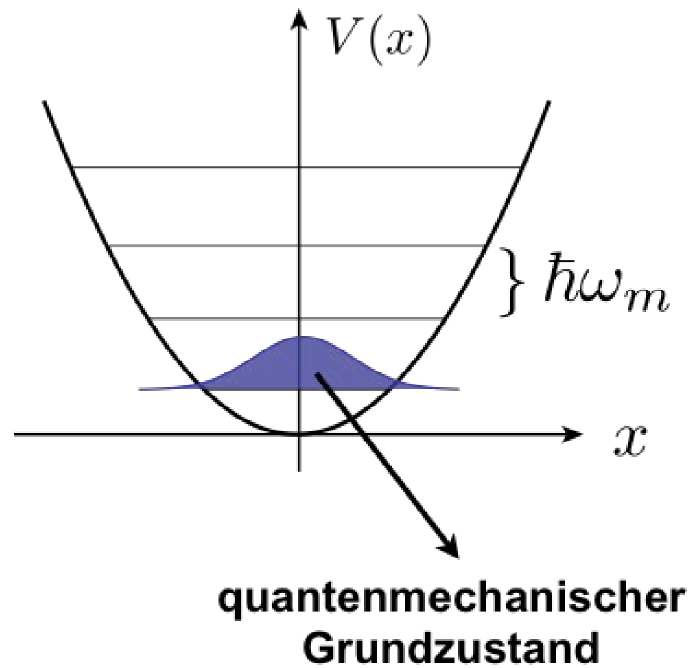
O'Connell *et al.*,
Nature **464**, 697 (2010)



Teufel *et al.*,
Nature **471**, 204 (2011)

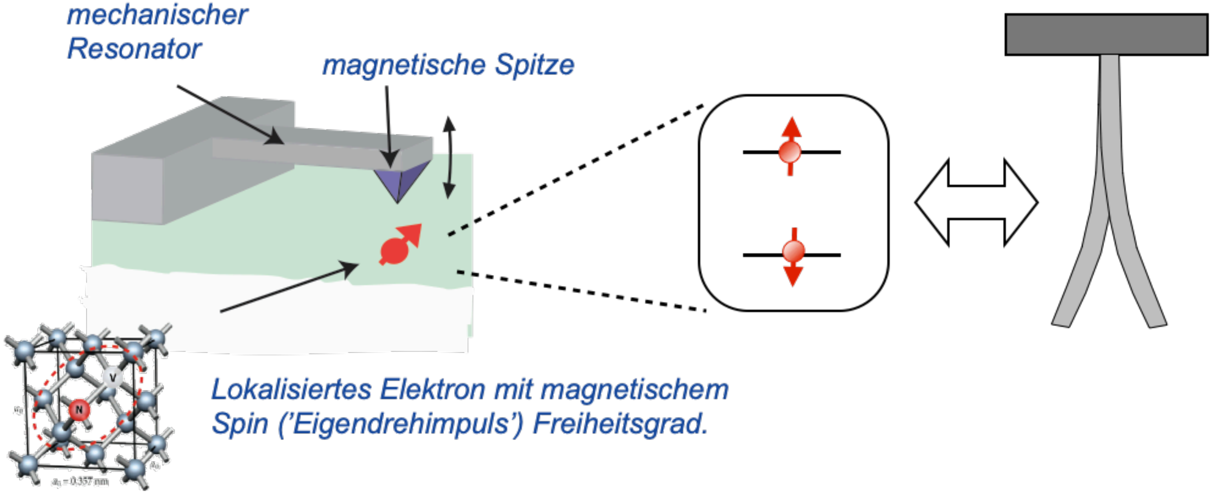


Chan *et al.*,
Nature **478**, 89 (2011)



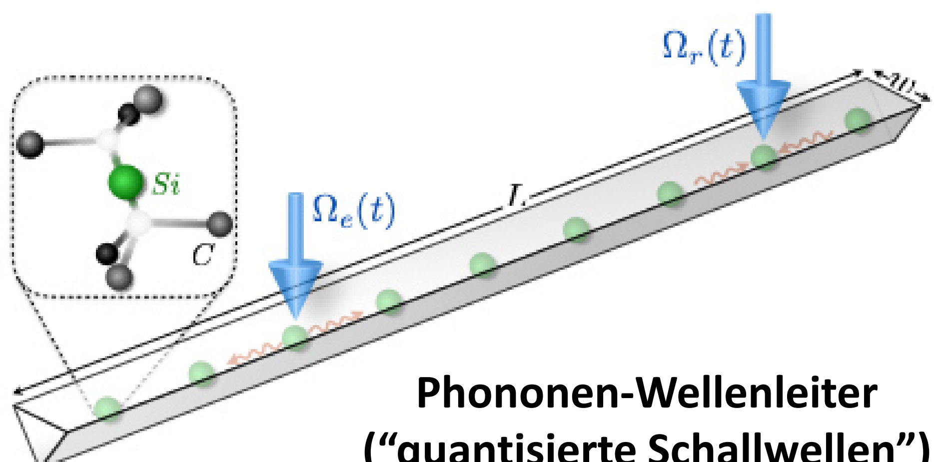
$$T \approx 50\,\mu\mathrm{K}$$

Makroskopische Objekte im Quantenregime …



Quanten-Superposition?

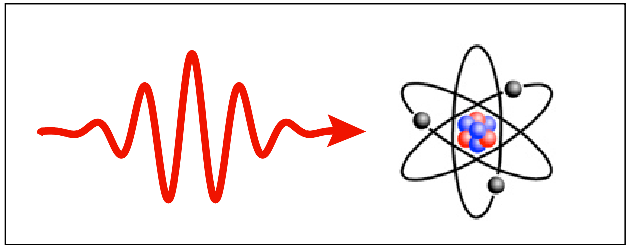
Mechanische Quantennetzwerke ?



Phononen-Wellenleiter
(“quantisierte Schallwellen”)

Supraleitende Schaltkreise

supraleitende “künstliche Atome”

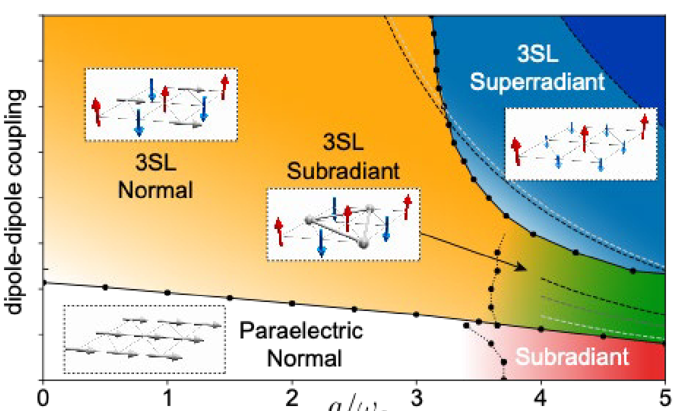


schwache Kopplung

$$a \sim 10^5 a_B$$

“ultra-starke” Kopplung

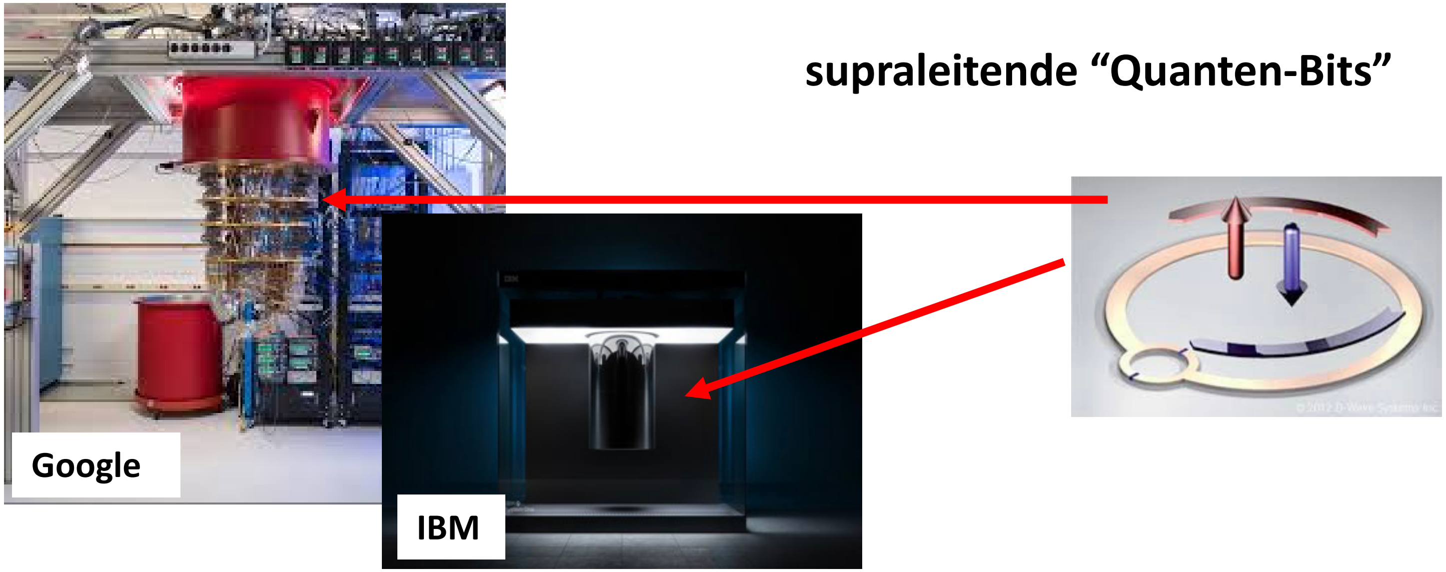
(nicht-perturbative QED)



Neuartige Licht-Materie Zustände und Phasenübergänge.

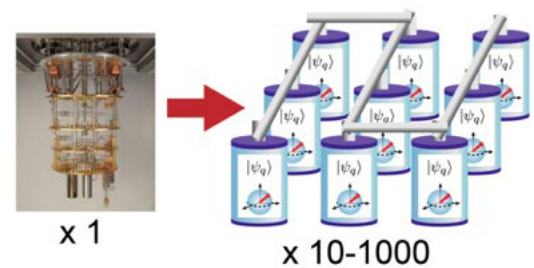
Supraleitende Schaltkreise

supraleitende "Quanten-Bits"



Quantencomputer & Quantensimulatoren:

- *ultraschnelle Quantengatter*
- *Quanten-Netzwerke*
- *neuartige Vielteilchensysteme*

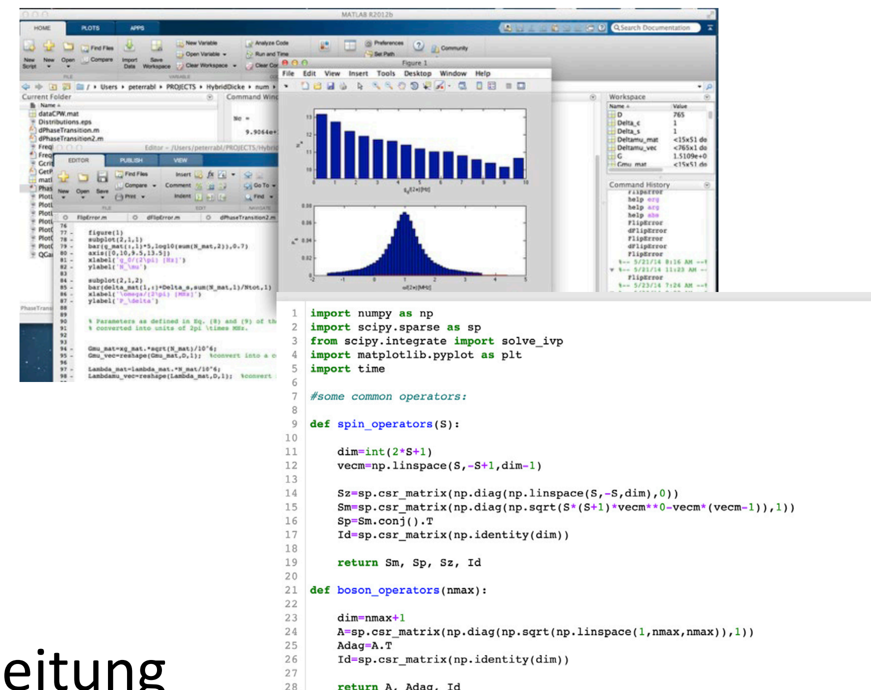


Bachelor-, Projekt- und Masterarbeiten

1) Theoretische Grundlagen (z.B. Modellierung dissipativer Quantensysteme)

$$\dot{\rho} = -i[H,\rho] + \frac{\Gamma}{2}\left(2\sigma_-\rho\sigma_+ - \{\sigma_+\sigma_-,\rho\}\right)$$

2) Numerische Simulationen (z.B. MATLAB, Python)



Aktuelle Fragestellungen zu

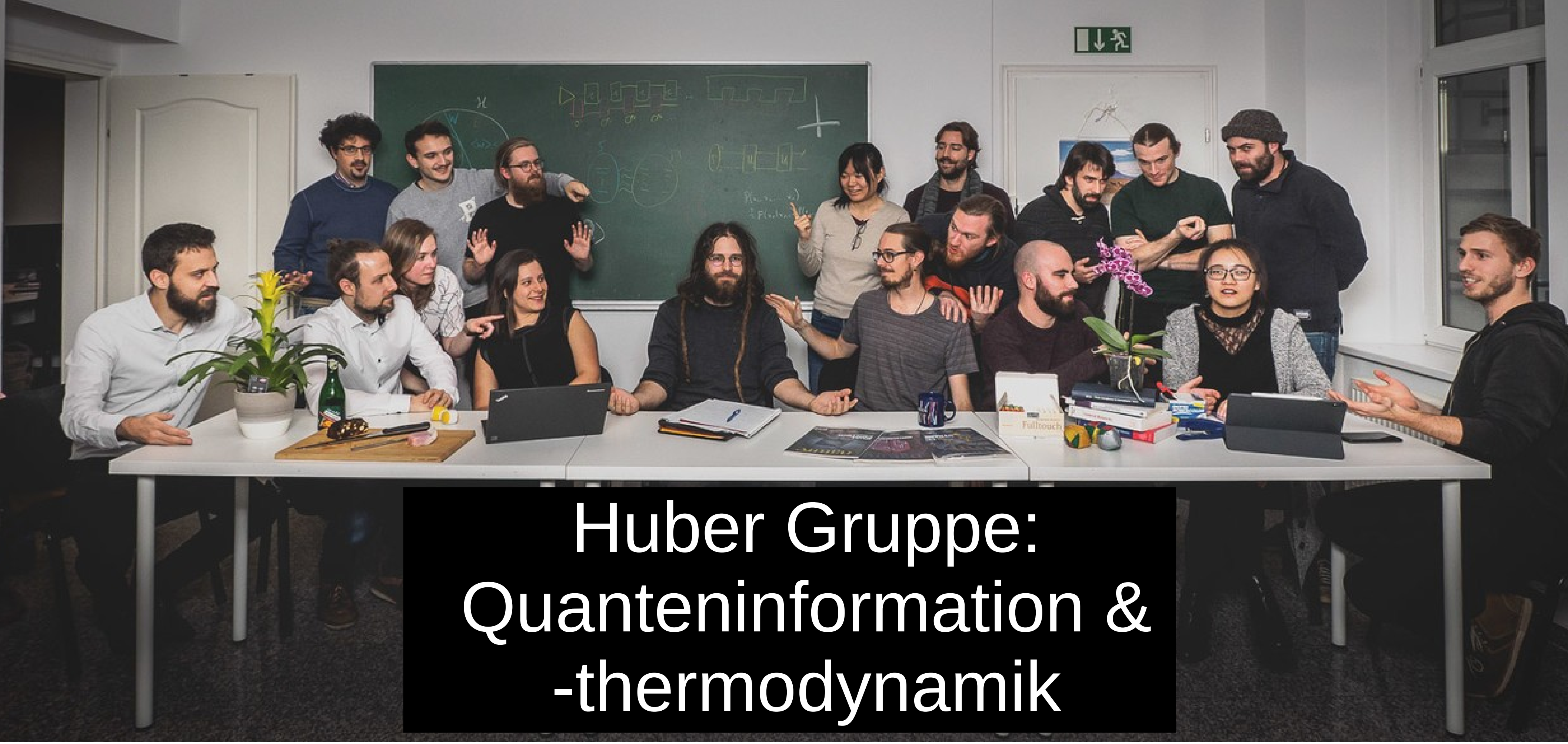
- Optomechanik,
- Cavity & circuit QED,
- Quanteninformationsverarbeitung

Das war‘s!

- Vorlesungen
  - Statistische Physik I & II
  - Quantenoptik I&II / Theoretical Quantum Optics
  - Quantentechnologie I&II
  - ...
- Projekt-, Bachelor- & Masterarbeiten
  - bei Interesse, einfach melden (**Freihaus, gelb, 6. Stock**)
- Weitere Fragen ?

email: peter.rabl@ati.ac.at

webpage: http://ati.tuwien.ac.at/tqo



Huber Gruppe: Quanteninformation & -thermodynamik

- Seit Dezember 2020 an der TU (davor IQOQI)
- Gruppenleiter: Marcus Huber (Vertretung heute: Felix Binder)
- Hauptsächlich Theorie
- 6 Promovierende (+2 zu Besuch), 11 Postdocs
- Hauptthemen:
  - Quantenthermodynamik
  - Verschränkung (v.a.: multipartite, hochdimensional)
  - Quanteninformationstheorie

Quantenthermodynamik

Grundlagen der der Quantenthermodynamik, z.B.:

- Optimales Kühlen und Landauer-Löschen
- Quantenbatterien
- Autonome Quantenuhren
- Energetik von Quantenmessungen
- Thermodynamische Kosten von Korrelationen

Verschränkungstheorie

Vor allem hochdimensional und multipartite, z.B.:

- Zertifizierung von hochdimensionaler Verschränkung
- Vielteilchenverschränkung in Ionenfallen
- Entropieungleichungen

Weitere Themen

- Quantenprozesse:
  - Kausalität in der Quantenmechanik
  - Nicht-markovsche Prozesse
  - Quantensimulation von stochastischen Prozessen
- Quantenmetrologie
- Quantenoptik (Theorie und Experimente!)
- Quantenresourcentheorien
- ‘quantum speed limits’ und Quantenkontrolle
- Quantencomputer (z.B. ‘measurement-based’)
- Maschinelles Lernen für Quantensysteme

Weitere Infos

- Verschiedene BSc, MSc, Dr Themen verfügbar
- Weitere Infos:
  - Website (tuwien.ac.at → Suche)
  - Pdf-Version (Poster-Anhang)
- Anfragen:
  - marcus.huber@tuwien.ac.at oder marcus.huber@oeaw.ac.at (in Karenz bis Mai)
  - bzgl. Präsentation: quantum@felix-binder.net

Resources in Quantum Thermodynamics

Huber Group - Quantum Thermodynamics Research

Marcus Huber, Faraj Bakhshinezhad*, Felix Binder, Fabien Clivaz*, Tiago Debarba*, Paul Erker, Nicolai Friis, Maximilian Lock, Emanuel Schwarzhans, Philip Taranto, Armin Tavakoli, Giuseppe Vitagliano

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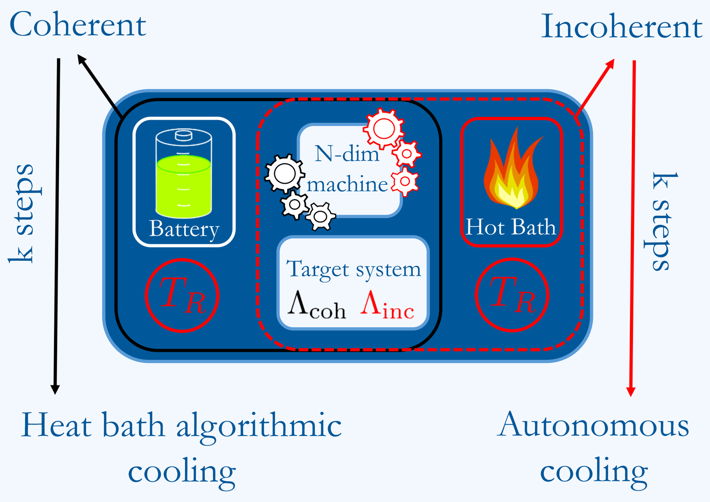
Quantum Thermodynamics

Quantum thermodynamics is comprised of multiple research directions originating from different areas of physics [1]: from the emergence of equilibrium [2], characterization and quantification of work [3], and foundational derivations of thermodynamic laws, to the study of machines working at the quantum scale [4,5,6,7]. Our group works across these topics and one of our foci is the unification of approaches and, with it, the resolution of paradoxes that arise within different treatments of these questions. In particular, we are interested in understanding the emergence of a classical world and the resources for harnessing quantum effects by studying measurements [8,9] and their underlying correlations [12,13] from a thermodynamic perspective, complementing resource theoretic approaches by notions of complexity [6,12-16], and building models of relevant quantum machines to see which could ultimately harness out-of-equilibrium resources to perform useful tasks [14,15].

Refrigeration [6,7]



- Target system initially in ρ_S: thermal at T_R
- In each cycle, machine initially in ρ_M (thermal at T_R) or $\rho_M^{(H)}$ (part at T_R, part at T_H)
- Compare 2 refrigeration scenarios:

Coherent: $\Lambda_{\text{coh}}(\rho_S) := \text{Tr}_M[U_{\text{coh}}\rho_S \otimes \rho_M U_{\text{coh}}^\dagger]$ for any unitary U_{coh}

Incoherent: $\Lambda_{\text{inc}}(\rho_S) := \text{Tr}_M[U_{\text{inc}}\rho_S \otimes \rho_M^{(H)} U_{\text{inc}}^\dagger]$ for energy cons. unitary U_{inc}

- Allow for repeated cycles & rethermalization

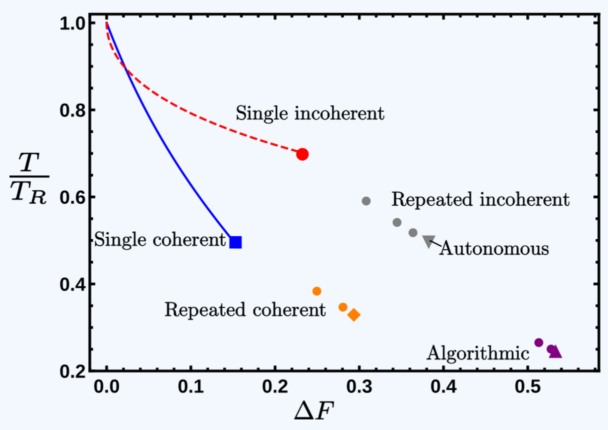
Results:

- 2-qubit machine (B,C) and qubit target (S) with $E_S = E_B - E_A$ ➡
- Arbitrary machine and target:

Theorem: In both scenarios for unbounded cycles, ground state cooling is upper bounded by

$$\rho_S^* = \left(\sum_{n=0}^{d_S-1}(\exp -\beta_R \mathcal{E}_{\max})^n\right)^{-1},$$

with $d_S =$ dim. of system, $\mathcal{E}_{\max} =$ max. energy gap of machine, $\beta_R = 1/T_R$.



Non-Ideal Measurements [8,9]

Apparent conflict between **QM Projection Postulate & 3rd Law of Thermodynamics**

Pure post-measurement state vs. infinite resource costs for reaching ground state

Model: Interaction between system ρ_S and initially mixed pointer τ_P : ➡ $\tilde{\rho}_{SP}$

Outcomes: $|n\rangle\langle n|$ associated with pointer projectors Π_n

Ideal measurements: Independent properties but two imply third

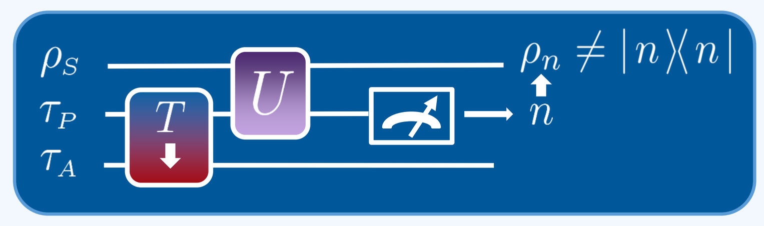
(i) **Unbiased**: $\text{Tr}[\mathbb{I} \otimes \Pi_i \tilde{\rho}_{SP}] = \text{Tr}[\,|i\rangle\langle i|_S\, \rho_S]\ \forall i\ \forall \rho_S$

(ii) **Faithful**: $C(\tilde{\rho}_{SP}) := \sum_i \text{Tr}[\,|i\rangle\langle i| \otimes \Pi_i\, \tilde{\rho}_{SP}] = 1\ \forall \rho_S$

(iii) **Non-invasive**: $\text{Tr}[\,|i\rangle\langle i|_S\, \tilde{\rho}_{SP}] = \text{Tr}[\,|i\rangle\langle i|_S\, \rho_S]\ \forall i\ \forall \rho_S$

Resolution: finite resources ➡ mixed pointer ➡ non-perfect correlations $C(\tilde{\rho}_{SP}) < 1$

Non-ideal measurements can be unbiased [7]



For **unbiased measurements** we can:

- maximize correlations: $C(\tilde{\rho}_{SP}) = C_{\max}$
- minimize energy cost: $\Delta E = \Delta E_{\min}$ ➡ Quantify energy cost of measurements
- minimize invasiveness: ➡ Relevant for work estimation: recover Jarzynski relation [8]

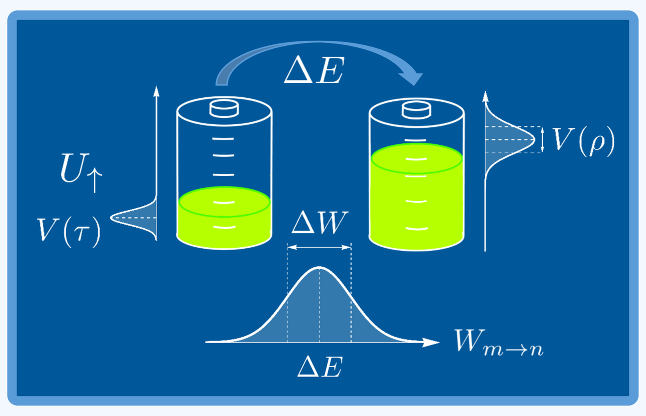
Quantum Batteries [10,11]

Task: Transfer energy ΔE to battery via unitary

Battery initially empty ➡ no extractable work

➡ Initially thermal $\tau(\beta)$

Unitaries $U_\uparrow : \tau \mapsto \rho$ with $E(\rho) > E(\tau)$ generally exist but differ in properties of $U_\uparrow$ and ρ, e.g.



Precision (energy variance): $V(\rho) = (\Delta H_\rho)^2 = \langle H^2 \rangle_\rho - \langle H \rangle_\rho^2$

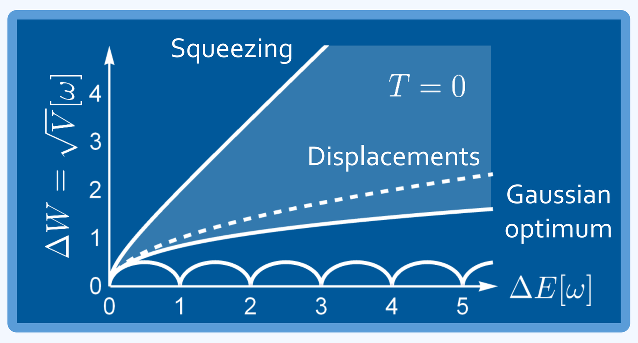
Work fluctuations $(\Delta W)^2 = \sum_{m,n} p_{m\to n}(W_{m\to n} - \Delta E)^2$ with $W_{m\to n} = E_n - E_m$

and transition probability $p_{m\to n} = p_m\, |\langle n|U_\uparrow|m\rangle|^2$ where $p_m = \langle m|\tau|m\rangle$

➡ Interested in **Fundamental limits** vs. **practical limits** (e.g., Gaussian operations)

Results: for harmonic oscillator batteries

- Protocol for optimal precision charging
- Protocol for minimal fluctuation charging
- Optimal Gaussian precision & fluctuations



- Characterization of Gaussian work extraction for any ρ ➡ *Gaussian passivity*

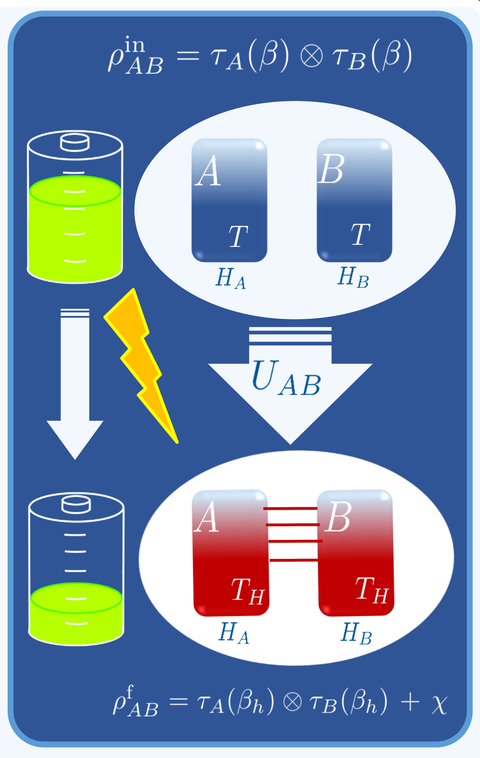
Optimal Creation of Correlations [12,13]

Fundamental limit for **energy cost ΔE** of creating **correlations?**

- System AB with initial uncorrelated thermal states at T
- Correlated by any unitary operation U_{AB}
- Hamiltonian: symmetric $H_A = H_B$ or asymmetric $H_A \neq H_B$

Mutual Information: $\mathcal{I}(\rho_{AB}) = S(\rho_A) + S(\rho_B) - S(\rho_{AB})$

Energy cost: $E(\rho_{AB}) = \text{Tr}[\rho_{AB}(H_A + H_B)]$

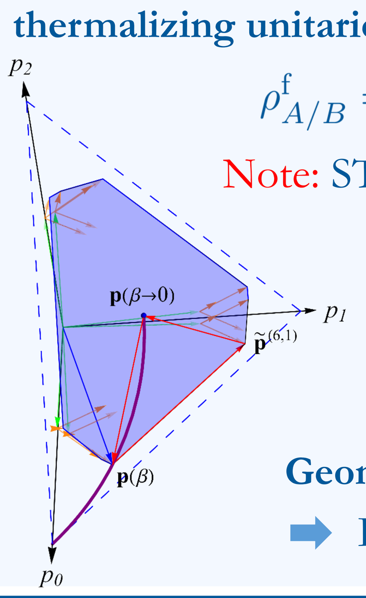


Bound on the amount of created correlations: $\Delta\mathcal{I}(\rho_{AB}) \leq \beta\Delta E$

Optimal conversion in symmetric case if there exist **symmetrically thermalizing unitaries (STU)** U_{AB} for any $\beta_H \leq \beta$ such that

$$\rho_{A/B}^{\text{f}} = \text{Tr}_{B/A}[U_{AB}\tau(\beta) \otimes \tau(\beta) U_{AB}^\dagger] = \tau(\beta_H)$$

Note: STUs generally do not exist in assymetric case.



Method : decompositions into subspaces supporting only states with diagonal marginal ➡ vectorized marginals & tools from majorization theory

➡ Existence of STU for any **equally spaced Hamiltonians**

Geometric Approach

➡ Existence of STU for **any** symmetric case in dimensions $d = 3\,\&\,4$

Autonomous Quantum Clocks [14,15,16]

Fundamental bounds on how well we can measure time? What are the relevant resources?

How do we measure time?

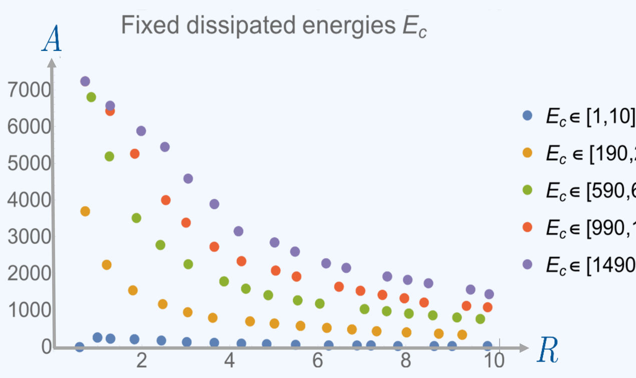
Clocks: Continuously provide time reference

Stop watch: Measures a time interval

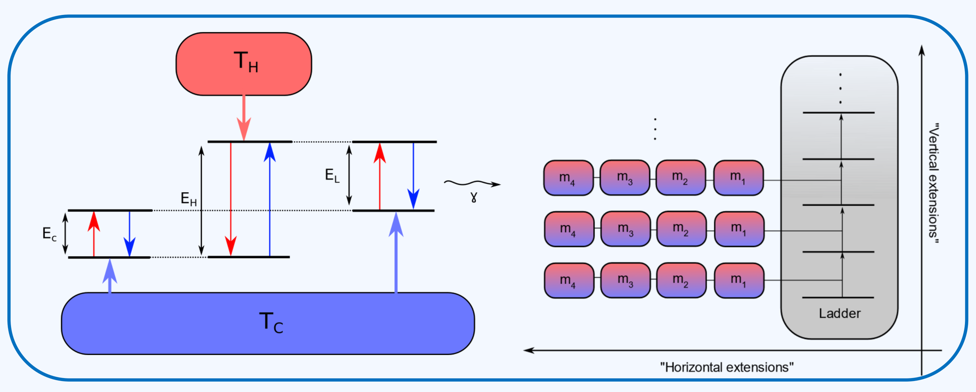
Autonomous clocks:

Thermally driven without external control

Allow fair book keeping of the resources used



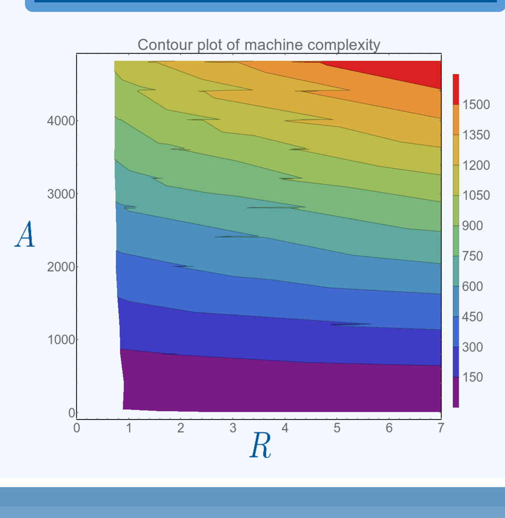
The model:



Figures of merit

Resolution $R = 1/\bar{t}$

Accuracy $A = \left(\frac{\bar{t}}{\Delta t}\right)^2$



Fundamental limits:

- The *dissipated energy* limits the tick quality
- High tick quality requires high *clock complexity*

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Entanglement Certification – From Theory to Experiment

Huber Group - Quantum Information Research

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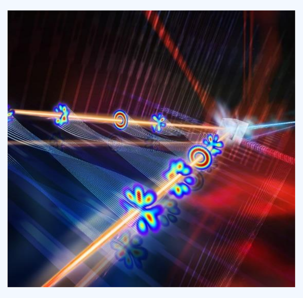
Entanglement in Modern Quantum Information

Quantum information has long focused on quantum bits (qubits) as fundamental units of information. Classical encoding of information is usually redundant, robust and fully controllable, rendering physical constraints less relevant and justifying a focus on information processing only. For quantum systems, on the other hand, physical constraints matter and redundancy through copying information is not an option, making direct encodings into multiple degrees of freedom an exciting option to push the limits of the field. Our group is concerned with understanding high-dimensional and multipartite systems and entanglement of quantum states therein, connecting theoretical concepts with experiments [1]: From characterizing [2] and efficiently certifying and controlling entanglement in high-dimensional [3-6] or multipartite systems [7], studying fundamental entropy inequalities in arbitrary dimensions [8,9], or proving genuine advantages of high-dimensional encodings [10], our group's efforts cover a wide range of aspects.

Certifying high-dimensional entanglement [3,4,5,6]

Theorem Every pure state is uniquely determined by measurements in Schmidt basis $\{|ij\rangle\}_{i,j}$ and one 'tilted' basis $\{|\tilde{i}_k\tilde{j}_k^*\rangle\}_{i,j}$.

We can also use these two measurements to lower bound the target state fidelity for mixed states and use this bound to certify Schmidt number (Experiment **b**, [4])



Measure: $C_{ij} = \langle ij|\rho|ij\rangle$ and $\tilde{C}_{ij} = \langle \tilde{i}_k\tilde{j}_k^*|\rho|\tilde{i}_k\tilde{j}_k^*\rangle$

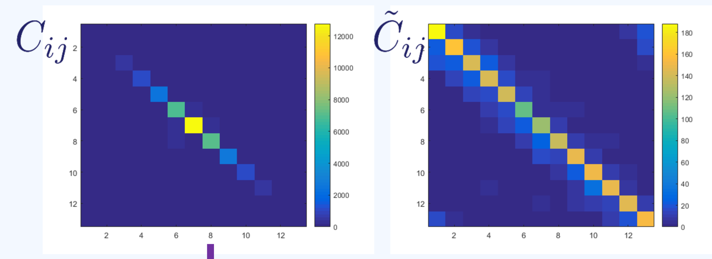
Bound fidelity: $f(C_{ij}, \tilde{C}_{ij}) \leq \mathcal{F}(|\psi_T\rangle, \rho)$

⇨ Bound Schmidt number

$k(\rho) = \inf_{\mathcal{D}(\rho)} \left\{ \max_{|\psi_i\rangle \in \{(p_i, |\psi_i\rangle)\}_i} \left\{ \mathrm{rank}\left(\mathrm{Tr}_B |\psi_i\rangle\langle\psi_i|\right) \right\} \right\}$

Results:

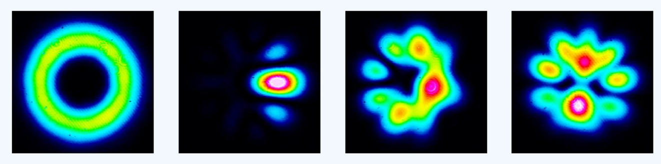
- **Fidelity bounds** obtained from measurements in M+1 global product basis:
  - Exact for dephased pure states with only two bases (M = 1)
  - Exact in prime dimensions for M = d
  - Free of assumptions about the state
- **Schmidt number witness**
  - Exact for all pure states and for dephased max. entangled states



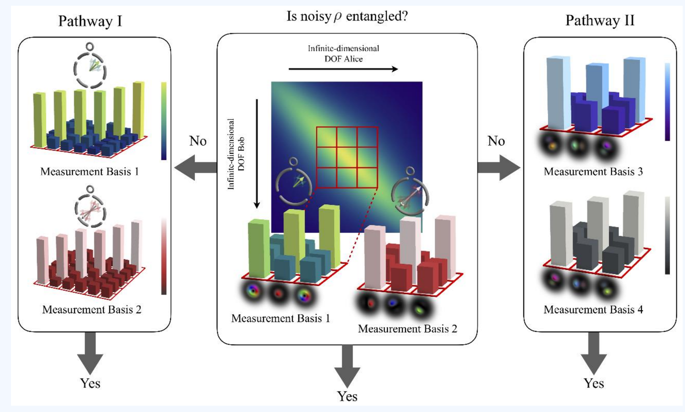
$|\psi_T\rangle$ ➡
Target state

Experimental results

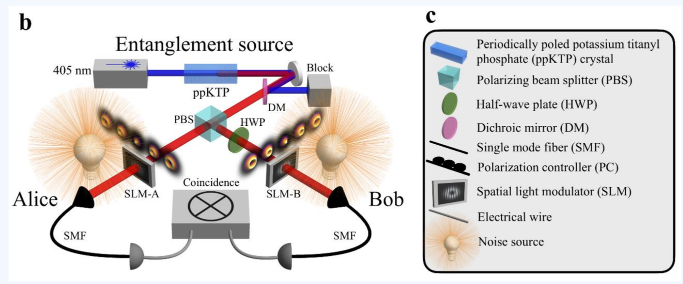
d	d_{ent}	$\tilde{F}(\rho,\Phi^+)$	$\tilde{F}(\rho,\Phi)$
3	3	91.5±0.4%	92.5±0.4%
5	5	89.9±0.4%	90.0±0.5%
7	6	84.2±0.5%	86.9±0.6%
11	9	74.8±0.4%	76.2 ±0.6%

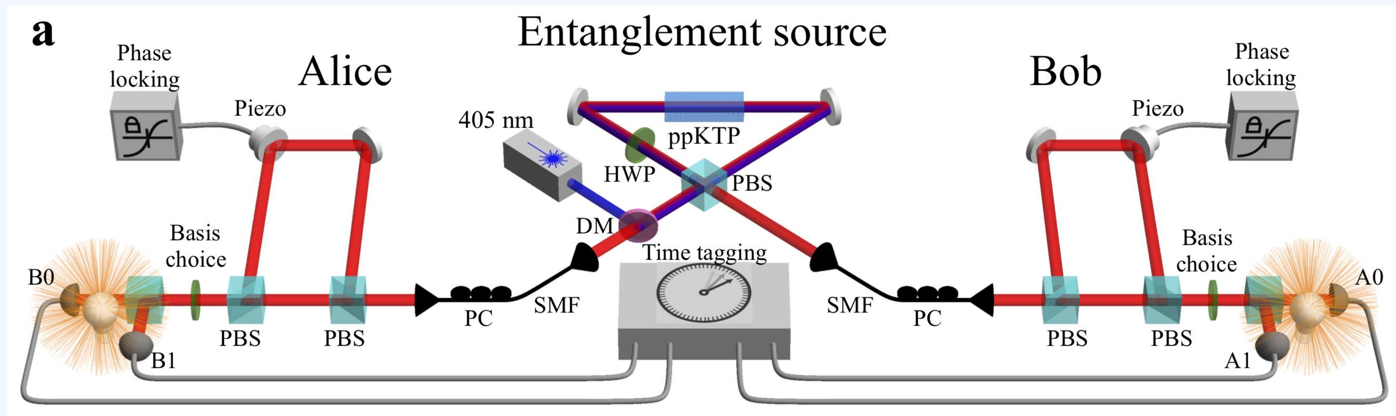


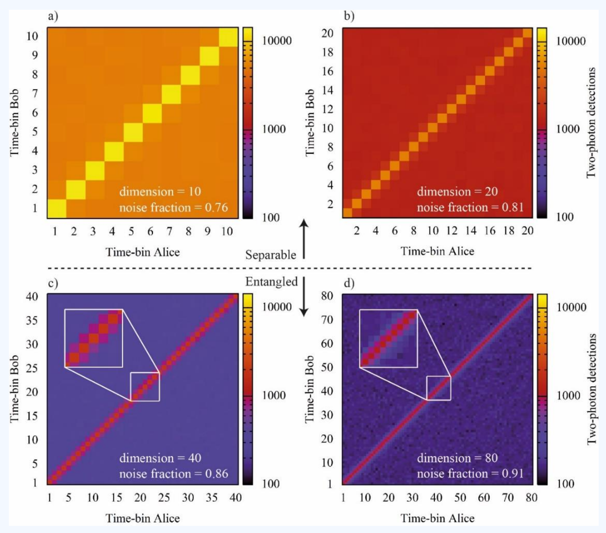
Exemplary OAM mode plus three unbiased states [4,5]



Fine grain continuous variable entanglement to dilute the noise (Pathway I and experiment **a** [6]) and/or measure in additional bases (Pathway II and experiment **b** [4,6]), thus realizing a central promise of high-dimensional encoding: ***resilience to noise***







Experimental data of experiment **b**, showcasing the noise dilution that reveals entanglement by fine-graining the data (Pathway I).

Multipartite Entanglement in Ion Traps [7]

Ion trap with 20 $^{40}Ca^{+}$ ions 

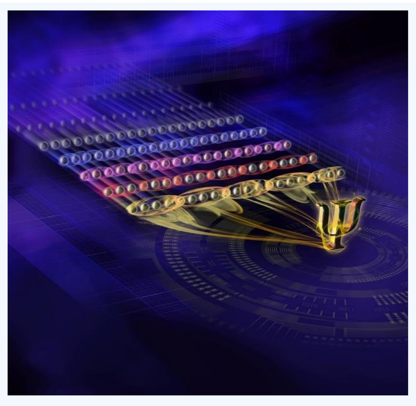
Experimental quantum simulation of an XY Hamiltonian

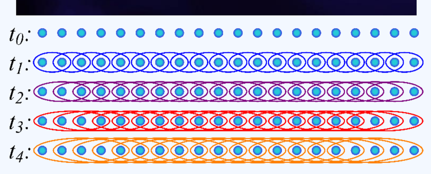
Time evolution $|\psi(0)\rangle$ ➡ $|\psi(t)\rangle = \exp(-iH_{XY}t)|\psi(0)\rangle$

➡ Complex multipartite entanglement structure

Measurements in 3^3 global product bases for several time steps

Task: track multipartite entanglement dynamics from limited data





Approach (i) Average Bell Fidelities

$\bar{\mathcal{F}}^{(k)}_{\mathrm{Bell}} := \frac{1}{4b_k}\Big(b_k + \sum_{\substack{i,j=1\\ i<j}}^{k} \big(|\langle \tilde{X}_i\tilde{X}_j\rangle| + |\langle \tilde{Y}_i\tilde{Y}_j\rangle| + |\langle \tilde{Z}_i\tilde{Z}_j\rangle|\big)\Big)$ with $\tilde{O}_i = U_i O U_i^\dagger$

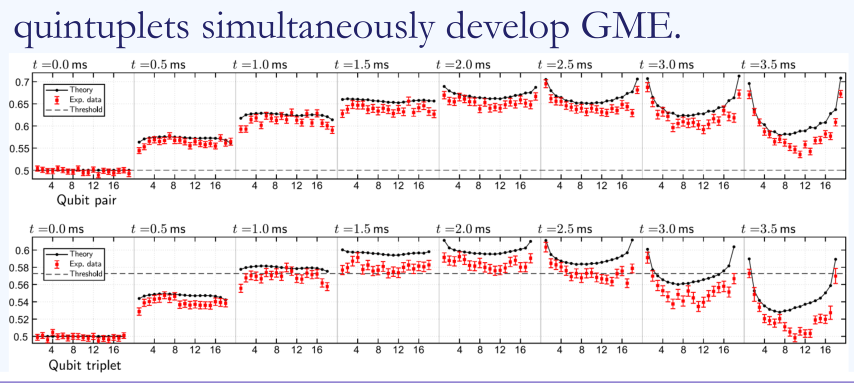
Quantum state of k qubits for which $\bar{\mathcal{F}}^{(k)}_{\mathrm{Bell}} > \begin{cases} \frac{1}{12}(3+\sqrt{15}) & \text{for } k=3 \\ \frac{1}{4}(1+\sqrt{3}) - \frac{1}{2k}(\sqrt{3}-1) & \text{for } k \geq 4 \end{cases}$

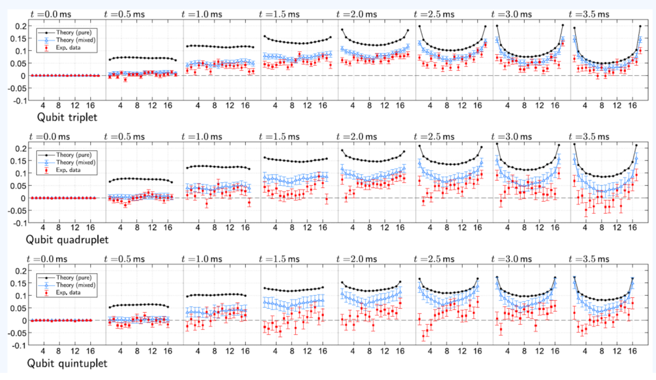
is GME for any choice of $U_1, \ldots, U_k$.

Approach (ii) Numerical Search

Based on genuine multipartite negativity

➡ All neighbouring qubit pairs, triplets, most quadruplets and some quintuplets simultaneously develop GME.





Entropy Inequalities [8,9]

Linear entropy: $S_L(\rho) := 1 - \mathrm{Tr}(\rho^2)$ is of interest for quantum information theory

- Useful for constructing entanglement witnesses
- Related to purity: $\gamma(\rho) = 1 - S_L(\rho)$
- Is an easy to calculate approximation to Von Neumann entropy
- Related to Rényi 2-entropy: applications in privacy amplification in quantum cryptography

Our approach: Exploit relation to Bloch decomposition $S_L(\rho) = 1 - \frac{1}{d}\left(1 + \|\vec{\mathbf{b}}\|^2\right)$

Use high-dim. & multipartite Bloch decomp. to derive tight dimension-dependent inequalities

Theorem 1 Let $\rho_{AB} \in \mathcal{H}_A \otimes \mathcal{H}_B$ be the state of a bipartite quantum system. Then:

Dimensionally sharp subadditivity: For $D_A = \frac{d_A - 1}{d_A}$ and $D_B = \frac{d_B - 1}{d_B}$

$$S_L(\rho_{AB}) \leq S_L(\rho_A) + S_L(\rho_B) - 2D_AD_B\left(1 - \sqrt{1 - \frac{S_L(\rho_A)}{D_A}}\right)\left(1 - \sqrt{1 - \frac{S_L(\rho_B)}{D_B}}\right)$$

when $S_L(\rho_A) \leq D_A\left(\frac{S_L(\rho_B)}{D_B} - 1 + 2\sqrt{1 - \frac{S_L(\rho_B)}{D_B}}\right)$

Inhomogeneous subadditivity: $S_L(\rho_{AB}) \leq \frac{1}{d_B}S_L(\rho_A) + \frac{1}{d_A}S_L(\rho_B) + \frac{(d_A-1)(d_B-1)}{d_Ad_B}$

Together, inequalities give a tight upper bound for $S_L(\rho)$ of a bipartite system of any dimension.

Theorem 2 Let $\rho_{ABC} \in \mathcal{H}_A \otimes \mathcal{H}_B \otimes \mathcal{H}_C$ be the state of a tripartite system. Then:

Strong inhom. subadditivity $S_L(\rho_{ABC}) + \frac{1}{d_Ad_B}S_L(\rho_C) \leq \frac{1}{d_B}S_L(\rho_{AC}) + \frac{1}{d_A}S_L(\rho_{BC}) + \frac{d_Ad_B + 1 - d_A - d_B}{d_Ad_B}$

And much more…

- Thermal machines generating entanglement [11]
- Characterization of genuine multilevel entanglement [12]
- Entanglement between two spatially separated atomic modes [13]
- High-dim temporal mode entanglement in photon pairs encoded in temporal modes [14,15]

For more information on recent work in these directions see our recent review:
[1] **Entanglement certification from theory to experiment**, *Nat. Rev. Phys.* **1**, 72 (2019).

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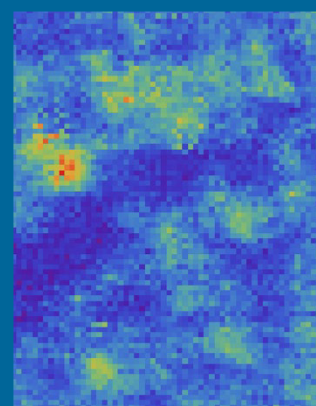
This work was supported by the Austrian Science Fund (**FWF**) through the **START project Y879-N27**, the **Lise-Meitner project M 2462-N27**, the **stand-alone project P 31339-N27**, the **Zukunftskolleg ZK03** and the joint **Czech-Austrian project MultiQUEST** (I 3053-N27 & GF17-33780L), as well as by the **Erwin Schrödinger Center for Quantum Science & Technology** (**ESQ**) through the **ESQ Discovery grants OESQ0002X2** and **OESQ0003X2**.

TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

Angewandte Quantenphysik

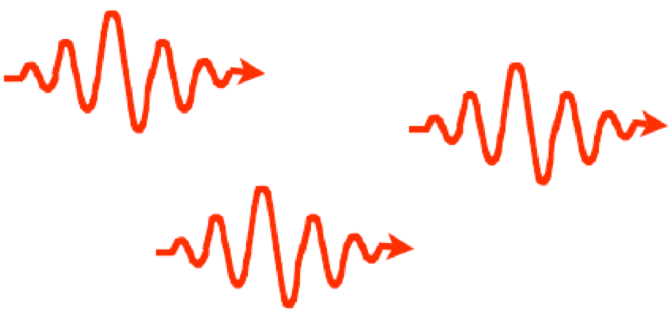
Sarah M. Skoff
Atominstitut
TU Wien

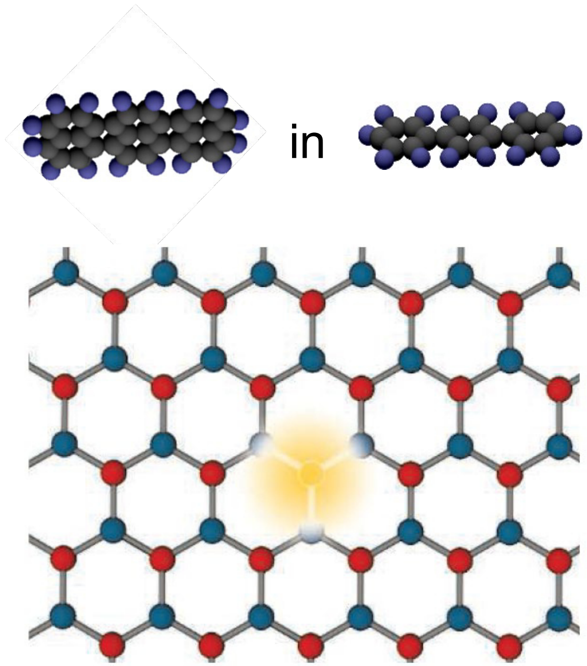


Schnittstellen zwischen Licht und Materie

- Wir nutzen die Wechselwirkung von Photonen und Quantenemittern für Sensorik und neue Quantentechnologien

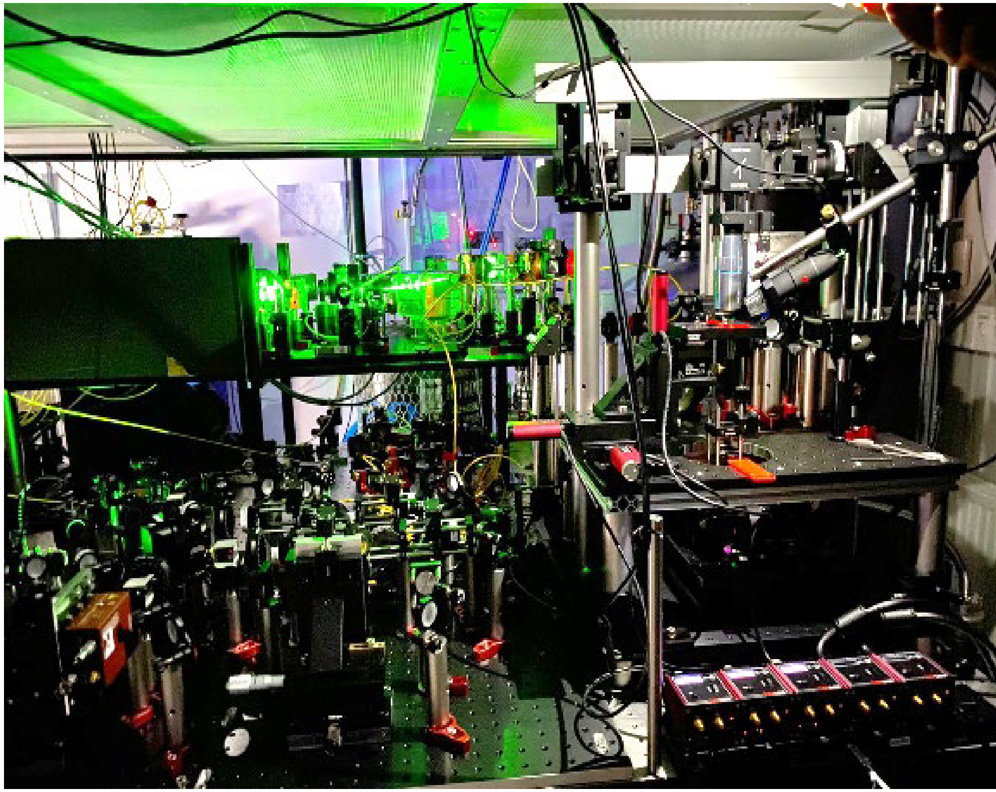
- Unser Medium der Wahl sind Festkörperquantenemitter:
  einzelne Moleküle in Festkörpern und Farbzentren in 2D Materialien

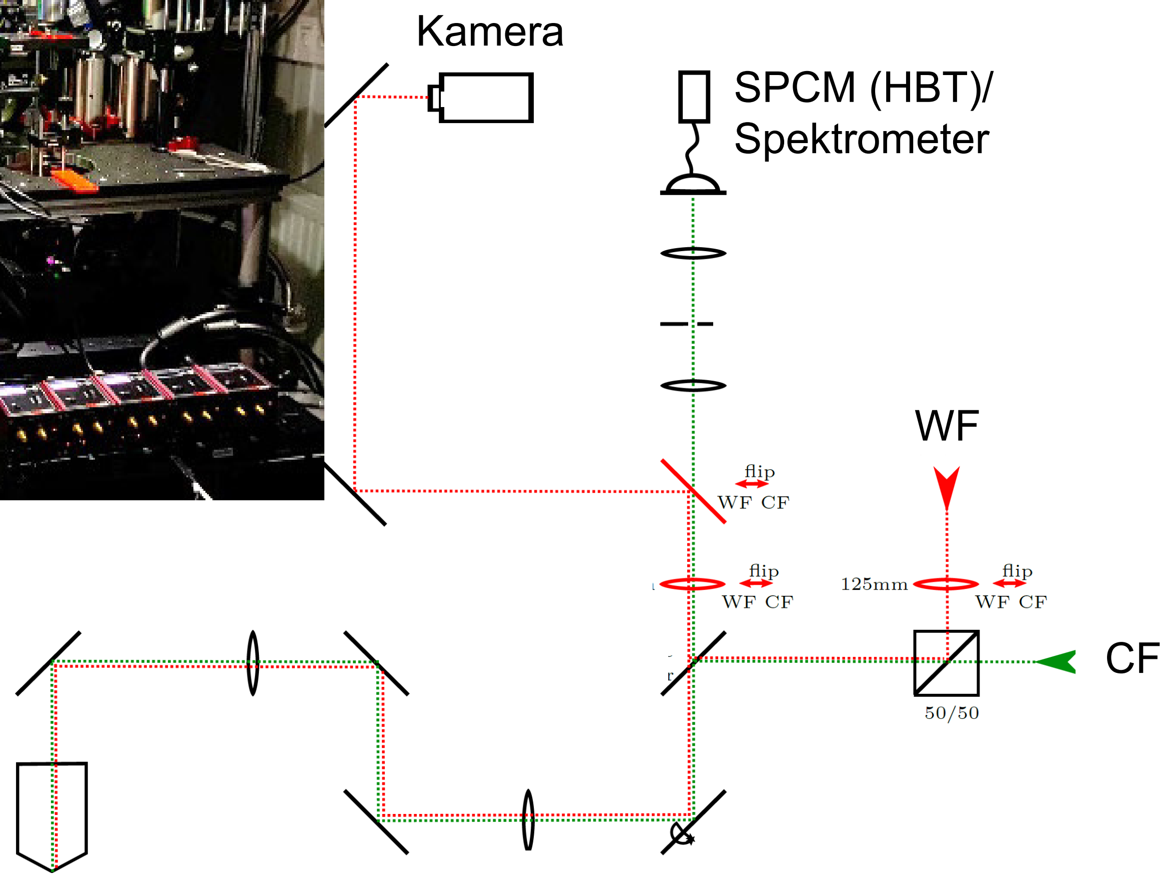




Science ,358, 6360, 170-171(2017)

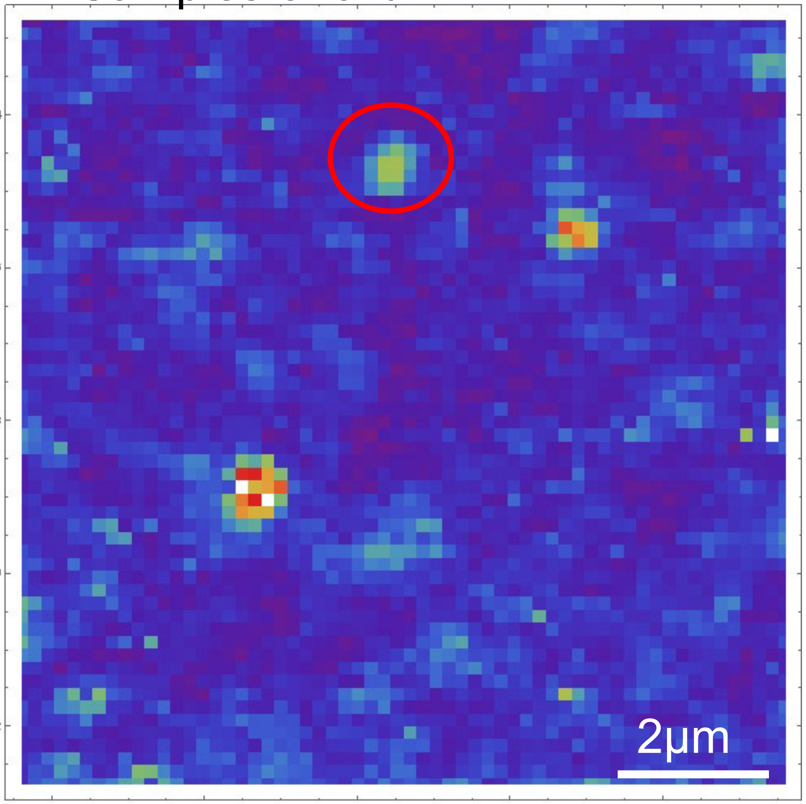
Experimenteller Aufbau

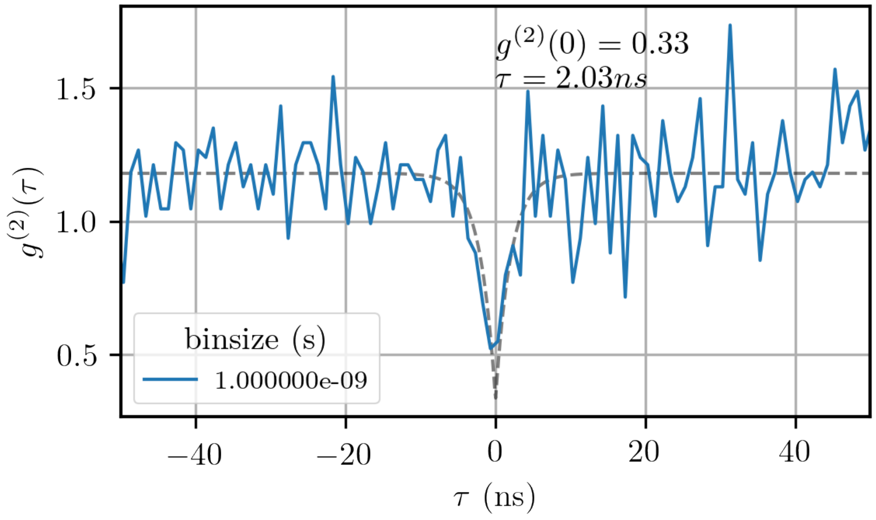


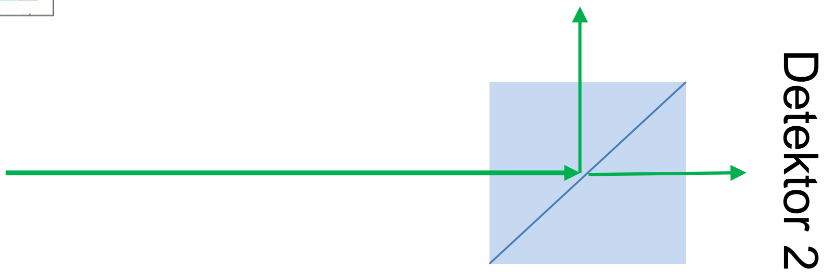


Quantenemitter in 2D Materialien

Samples of cvd hBN:

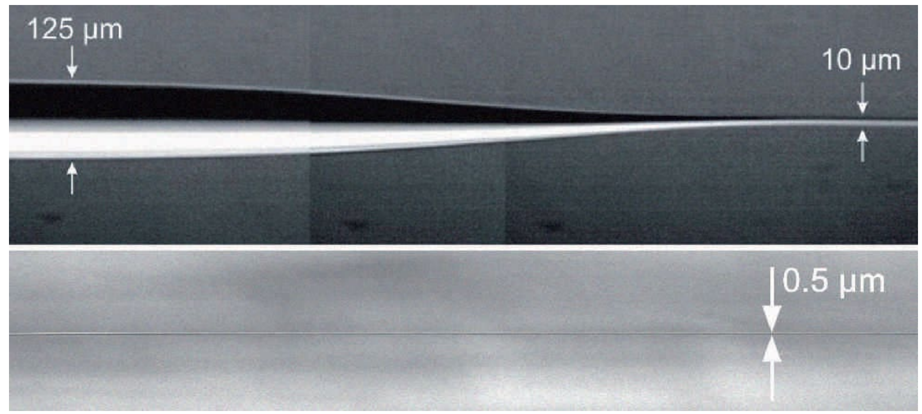


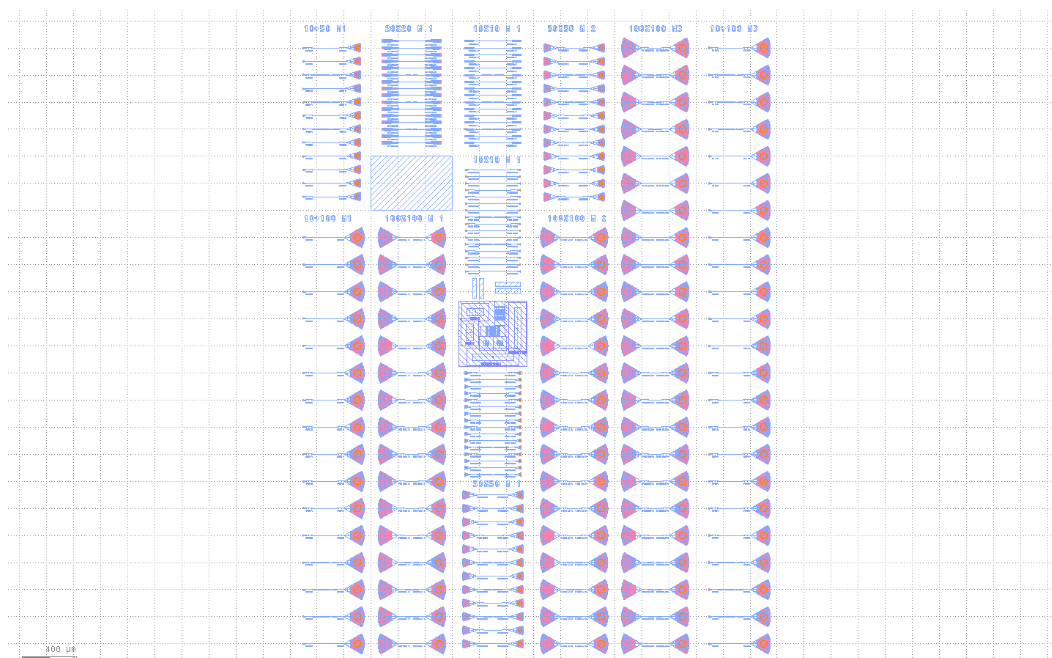




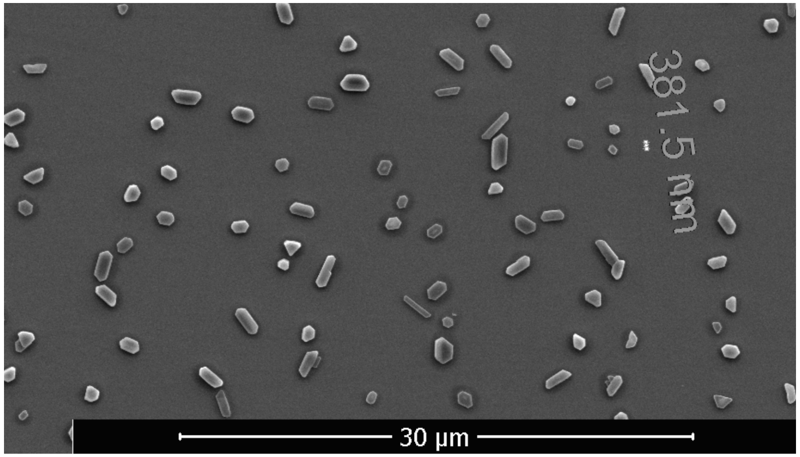
Optische Wellenleiter

Wellenleiter als Schnittstellen
für Quantenemitter und Licht

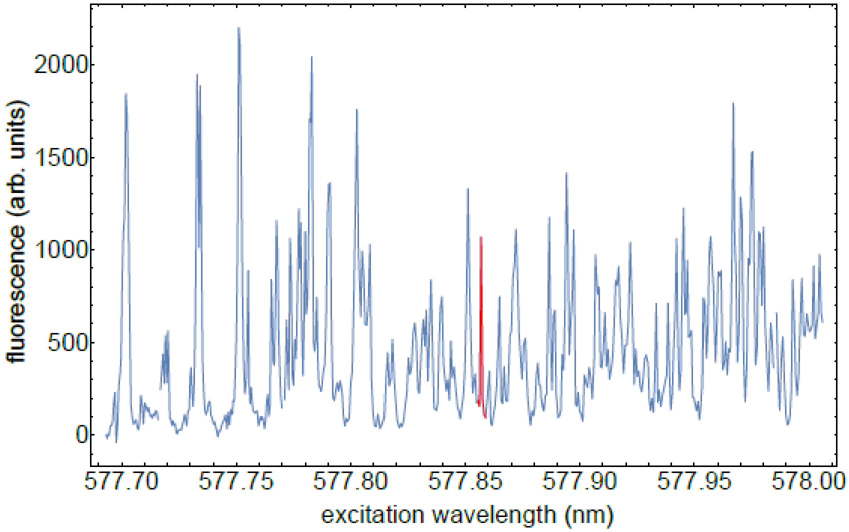




Einzelne Moleküle in Festkörpern



Spektren einzelner Terrylen Moleküle in einem p-Terphenyl Nanokristall



Möglichkeiten für Bachelor -und Masterarbeiten

- Spektroskopie von Quantenemittern in 2D Materialien und einzelnen Molekülen in Festkörpern
- Sensorik mit nanophotonischen Wellenleitern
- Kleinere Aufbauprojekte im Bereich der Laserphysik, Spektroskopie und experimenteller Automatisierung

Für weitere Informationen:

Sarah Skoff (www.skofflab.com)

sarah.skoff@tuwien.ac.at

Strahlenphysik / X-ray physics

Christina Streli – Christina.Streli@tuwien.ac.at

Atominstitut

Proseminar SS 2021

Peter Wobrauschek
Dieter Ingerle
Peter Kregsamer
Michael Iro
Anna Turyanskaya

(EDXRF)

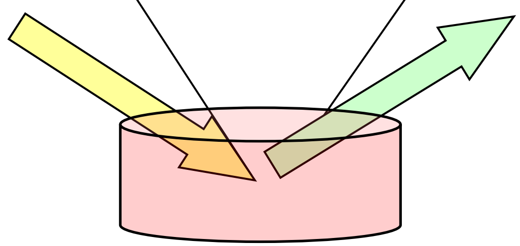
Interaction:

- Photoeffect / Auger effect
- Elastic (coherent) scattering
- Inelastic (incoherent) scattering

X-Ray source

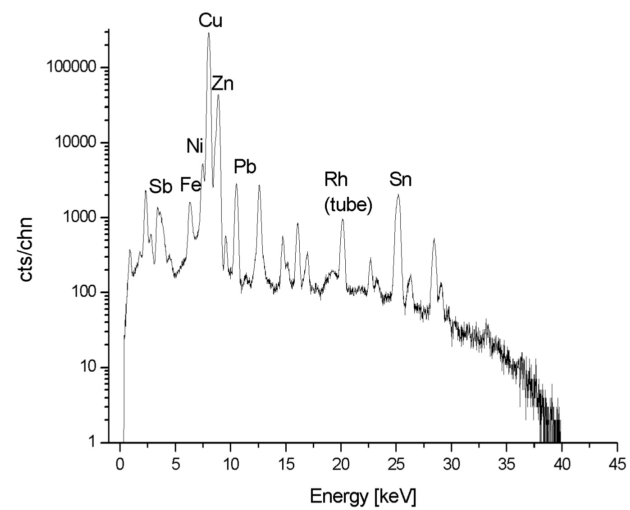
X-ray tube

Synchrotron radiation



Sample/Specimen

Energy dispersive X-Ray detector



Spectrum deconvolution

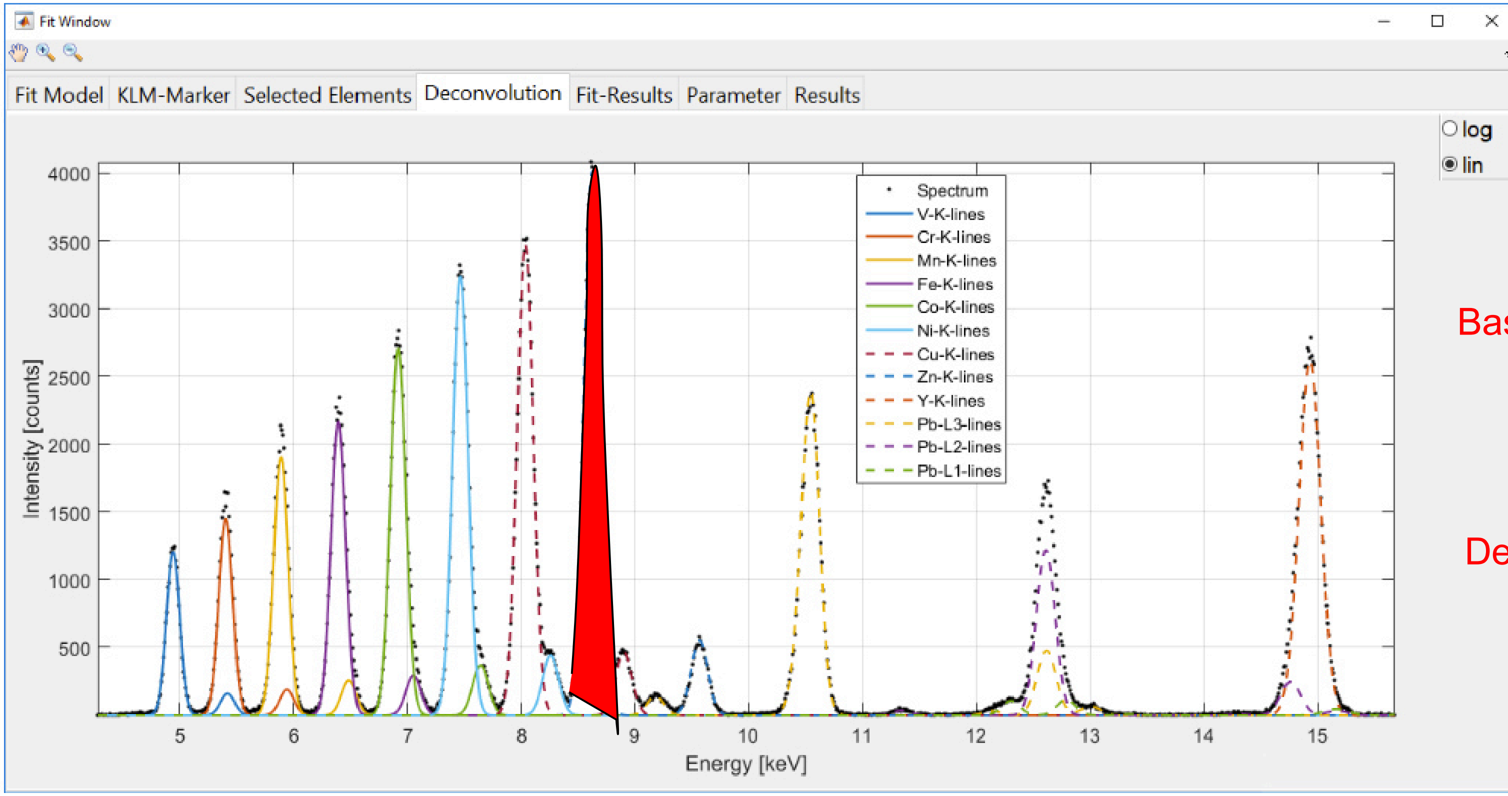


Figure 52: "Deconvolution" tab of the MKFIT-Software

Net peak area

Basis for quantification

Peak overlap

Deconvolution required

From: M.Kraihamer, diplom thesis, TU Wien, Oktober 2017

EDXRF at Atominstitut

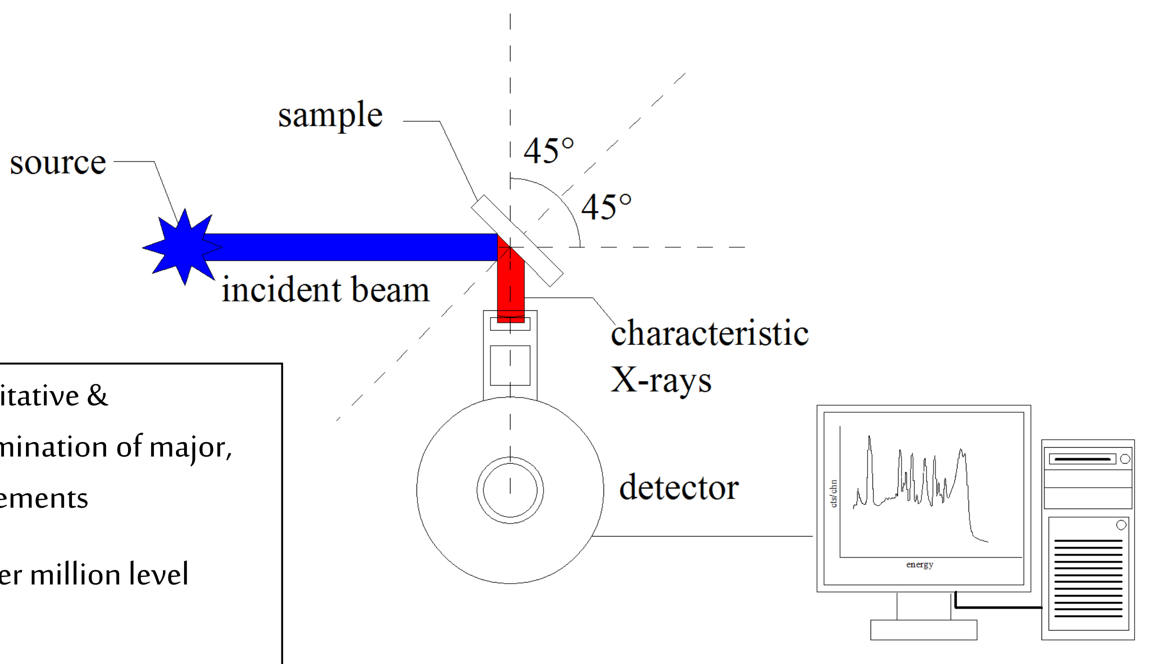
E D X R F

Standard XRF

Micro XRF
(μ-XRF)

Total Reflection XRF
(TXRF)

Absorption Spectroscopy
in fluorescence mode (XAS)

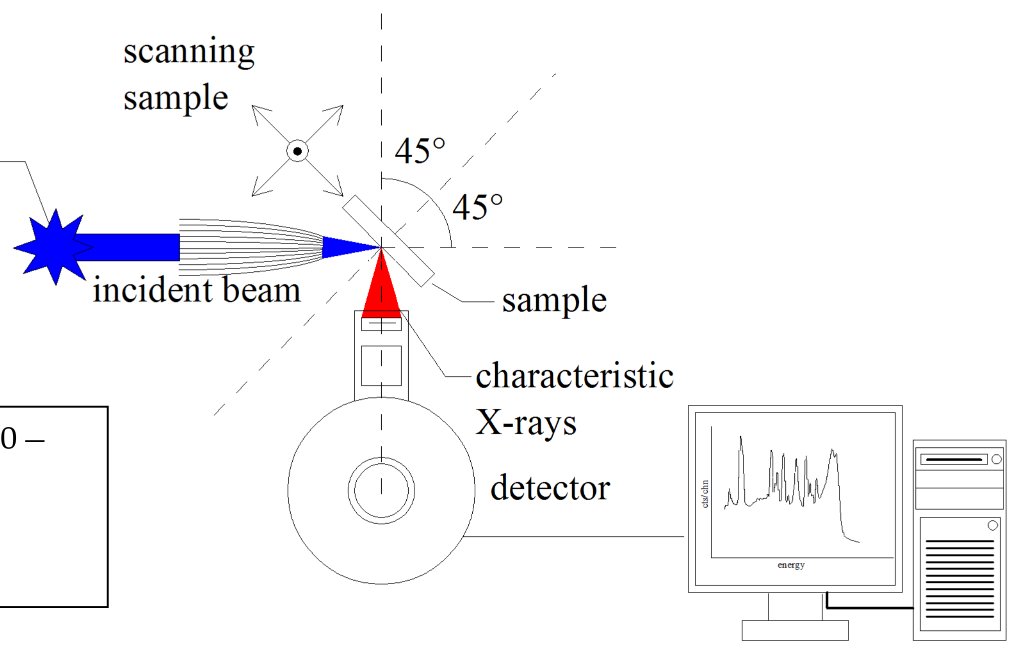


- simultaneous qualitative & quantitative determination of major, minor and trace elements
- down to the part per million level

EDXRF at Atominstitut

E D X R F

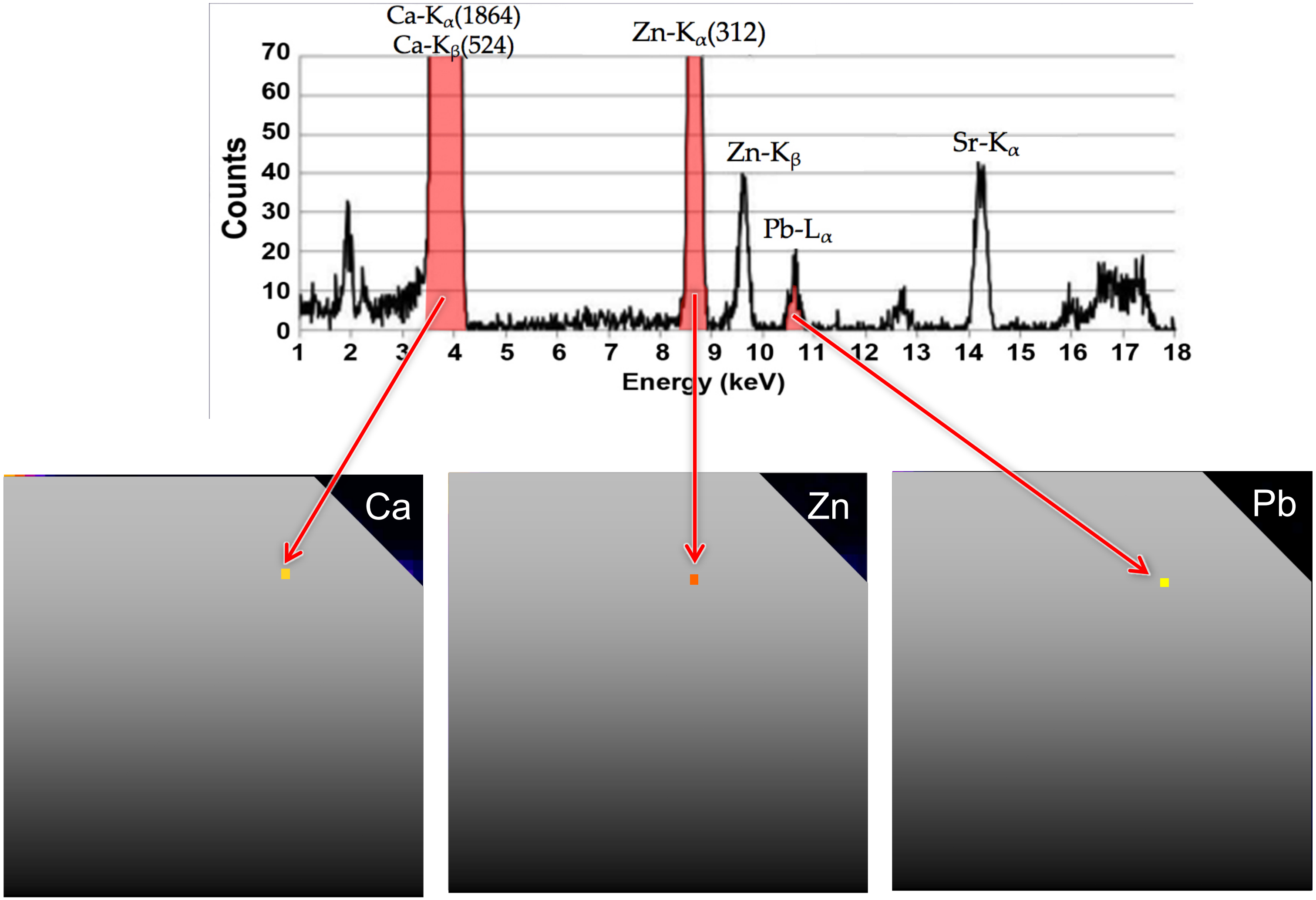
- Standard XRF
- Micro XRF μ-XRF
- Total Reflection XRF TXRF
- Absorption Spectroscopy in fluorescence mode (XAS)



- spatially resolved analysis (10 – 60μm)
- 2D & 3D resolution

Micro-analysis (bone specimen)

Generation of the Element Maps:

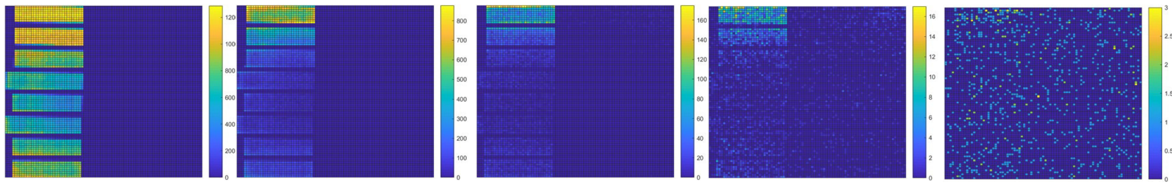


x,y,z-Scan: micro SD card

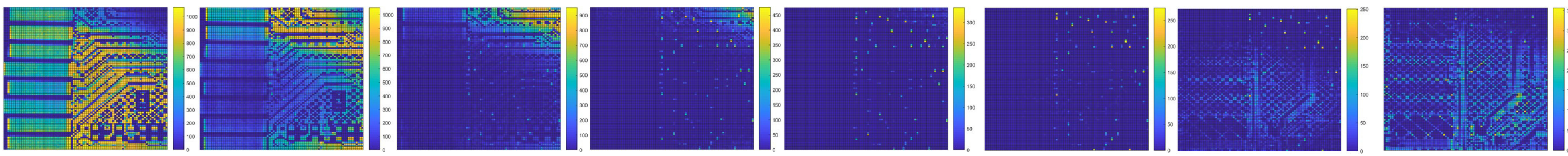
Depth from Surface (z)

-15 µm -30 µm -45 µm -60 µm -75 µm -90 µm -105 µm

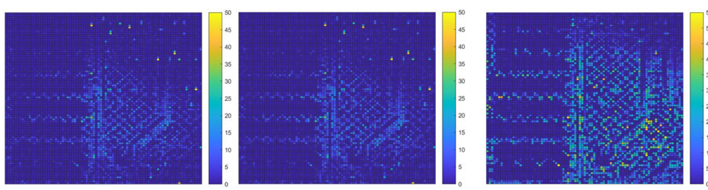
Nickel



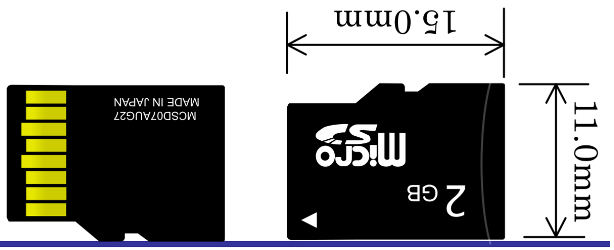
Copper



Barium



- Confocal scan of a micro SD card
- 100 µm step size in x and y, 15 µm in z
- 15 seconds per point; in total ~11 days

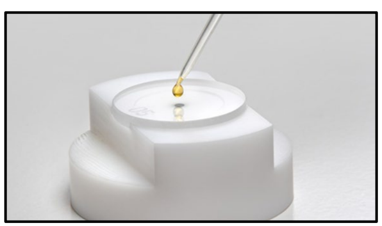


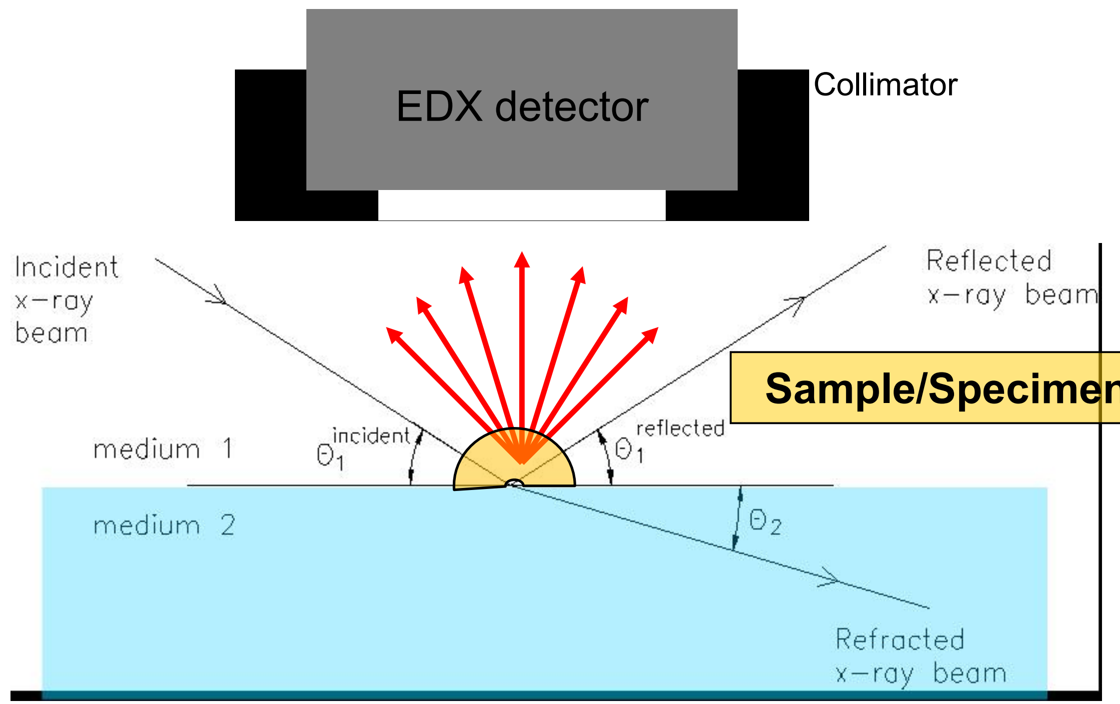
EDXRF at Atominstitut

E D X R F

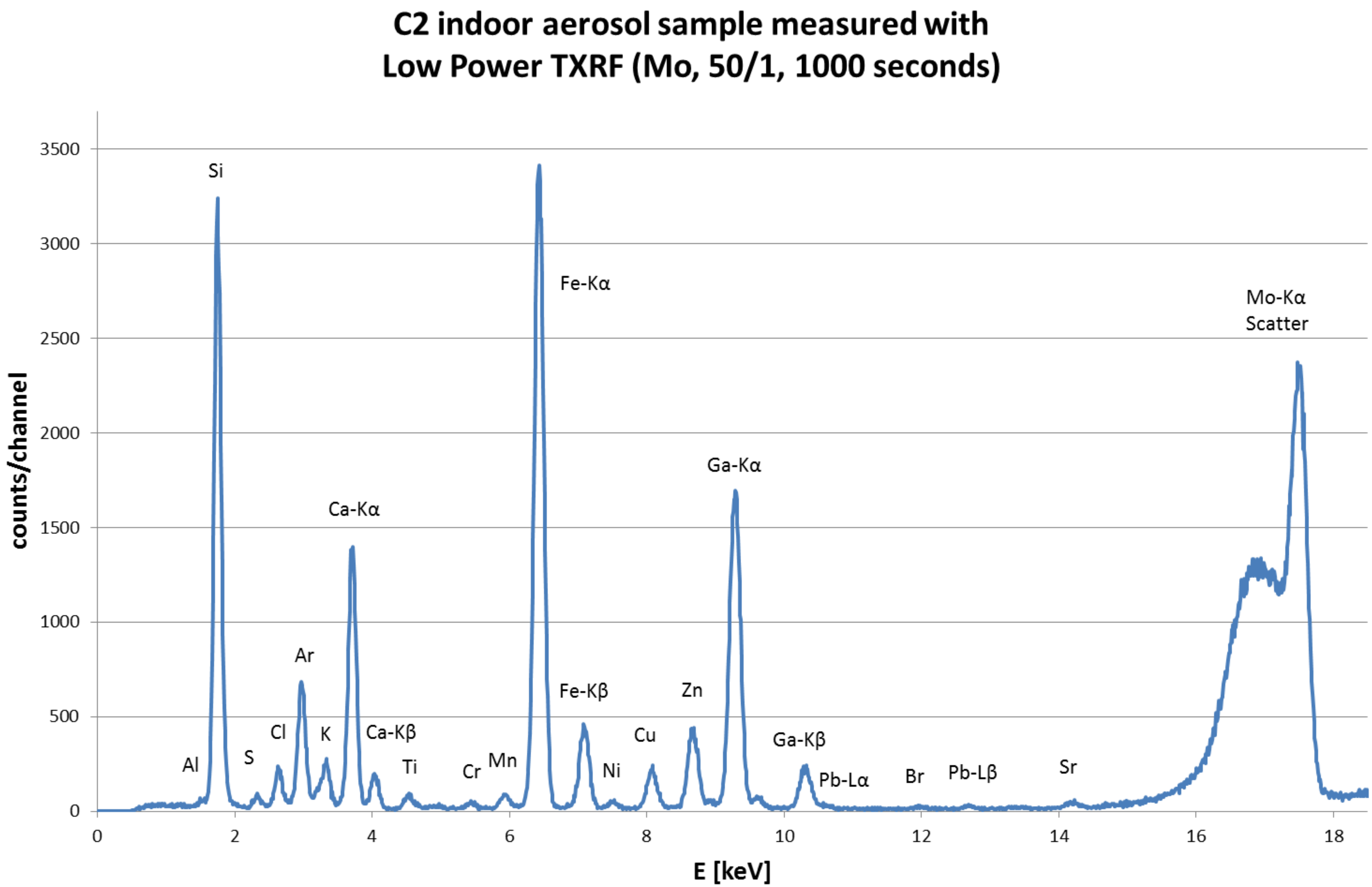
- Standard XRF
- Micro XRF μ-XRF
- **Total Reflection XRF TXRF**
- Absorption Spectroscopy in fluorescence mode (XAS)

- Low detection limits (parts per billion)
- low sample mass required (few μ - liters)



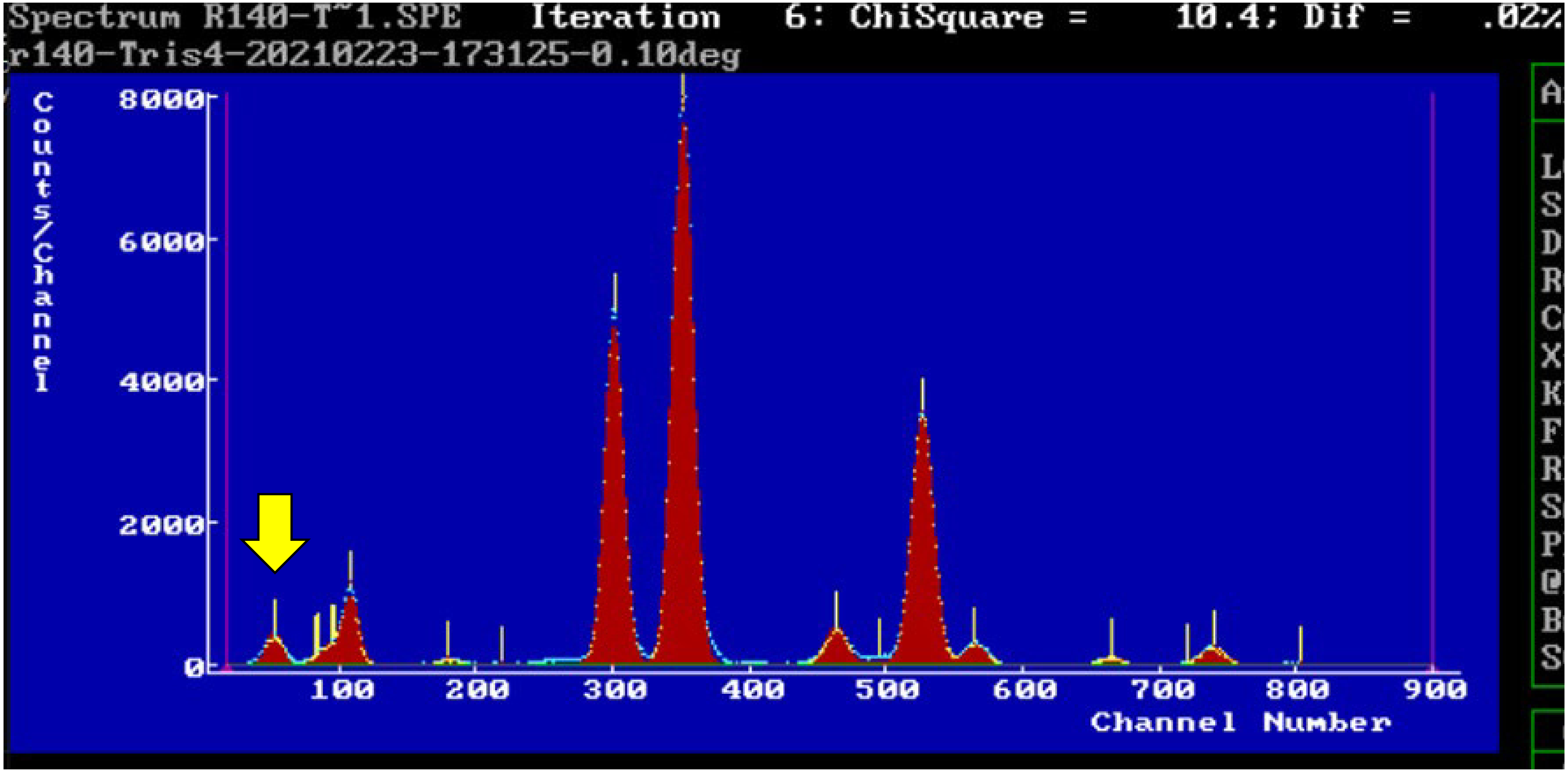


Air pollution - aerosols



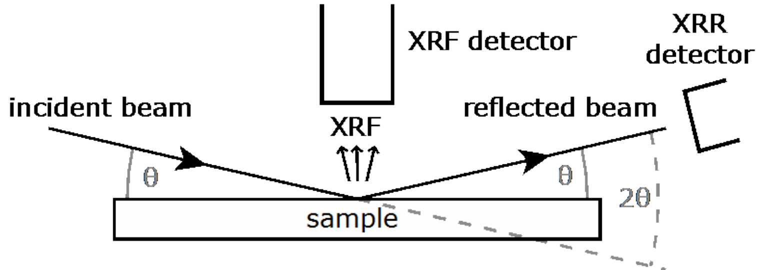
Pollution of sea water by Nano-plastic

Determination of **Carbon** as representation of nano-plastic in sea water



Glancing-Incidence X-ray analysis

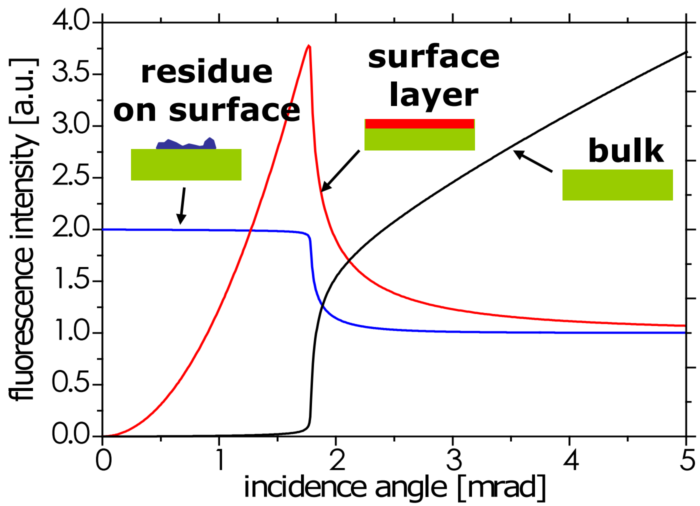
Combined GIXRF+XRR setup



Controlled variation of the angle of incidence

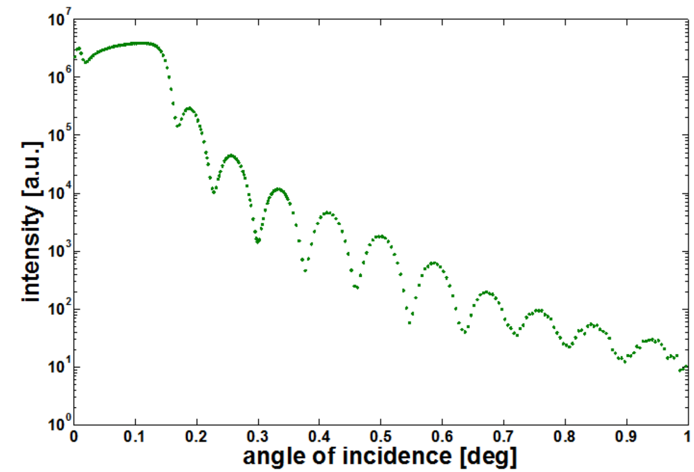
GIXRF:

XRF of elements in the sample



XRR:

Information on electron density in the sample



18 nm nominally thick titanium layer deposited on silicon:

Layer	thickness	Density	roughness
Ti	18.9 nm	4.5 g/cm^3	0.3 nm
TiO2	3.9 nm	4.1 g/cm^3	0.1 nm
TiO2	0.9 nm	3.5 g/cm^3	0.8 nm

TECHNISCHE
UNIVERSITÄT
WIEN

Medizinische Strahlenphysik @ MedAustron

Forschung & Therapie

A. Hirtl

✉ albert.hirtl@tuwien.ac.at

Atominstitut, Technische Universität Wien

Proseminar Physik, 26. März 2021

Das MedAustron

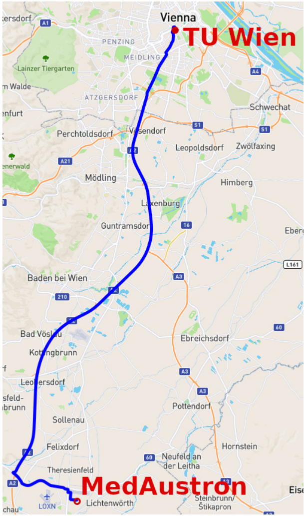


Image: OpenStreetMap

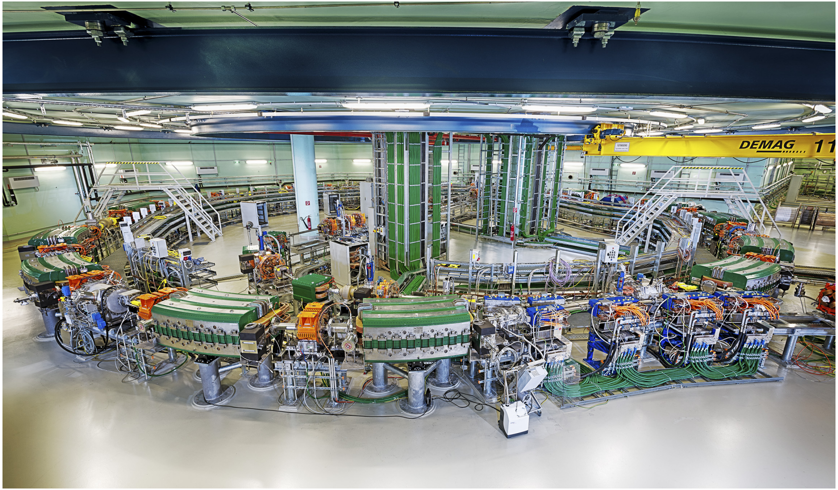


Bild: MedAustron

MedAustron – Allgemein

- Protonen und Kohlenstoff Strahlen
- besteht aus
  - einem klinischen Teil für Krebstherapie
  - einem Teil für nichtklinische Forschung

Vier Gruppen für nichtklinische Forschung

- *Medical Radiation Physics with Specialisation in Ion Therapy* ⇐ TU Wien (J. Schieck, A. Hirtl)
  - *Institute of High Energy Physics (Hephy), Austrian Academy of Sciences* ⇐ J Schieck, T. Bergauer
- Accelerator Physics ⇐ TU Wien (M. Benedikt)
- Medical Radiation Physics and Oncotechnology ⇐ MedUni Wien (D. Georg)
- Applied and Translational Radiation Biology ⇐ MedUni Wien (currently vacant)

Vorteile der Ionentherapie

Dosisprofil

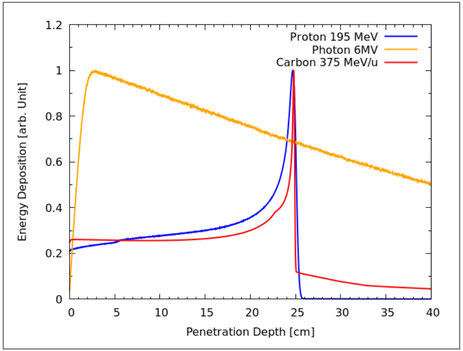


Bild: H. Fuchs

Physikalische und biologische Vorteile

- invertiertes Tiefendosisprofil
- gut definierte Eindringtiefe der Ionen
- Behandlung von resistenten Tumoren (Kohlenstoff Ionen!)

  ⇒ erhöhte radiobiologische Wirksamkeit

Medizinische Vorteile

- Behandlung von Tumoren nahe an radiosensitiven Organen, z. B. optischer Nerv
- Reduktion der integralen Dosis
  - vorteilhafte Behandlung von Kindern
  - geringeres Risiko für Sekundärtumore

Herausforderung (eine von vielen)

- Unsicherheit der Reichweite

Bestrahlungsräume am MedAustron

treatment & clinical research:
- proton gantry (IR 4)
- horizontal fixed beam (IR 3)
- horizontal & vertical fixed beam (IR 2)

non-clinical research:
- horizontal fixed beam (IR 1)

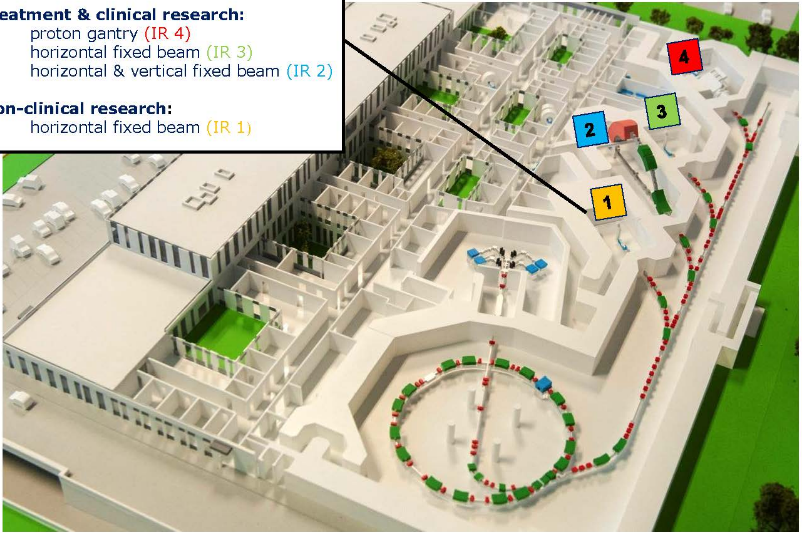
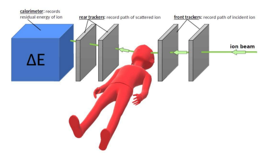


Bild: MedAustron

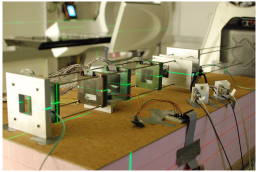
Tätigkeitsfelder der MedAustron Gruppe

- Bildgebung mittels Ionen (CT mit Protonen, pCT) $\Rightarrow$ Reichweite
- Dosimetrie mittels Thermoluminiszenzdosimetern (TLD)
- Bestimmung des linearen Energietransfers (LET)
  - mikrodosimetrische Messungen zur Korrelation mit biologischen Effekten
- Monte Carlo Simulation (diverse Frameworks)
- Hardwarenahe Programmierung (VHDL, FPGA)

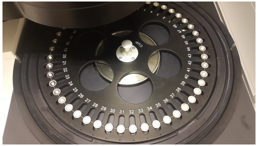
pCT Prinzip



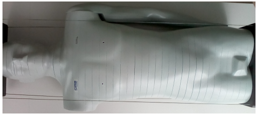
pCT Aufbau



TLDs



Torsophantom



Atominstitut
Institute of Atomic and Subatomic Physics

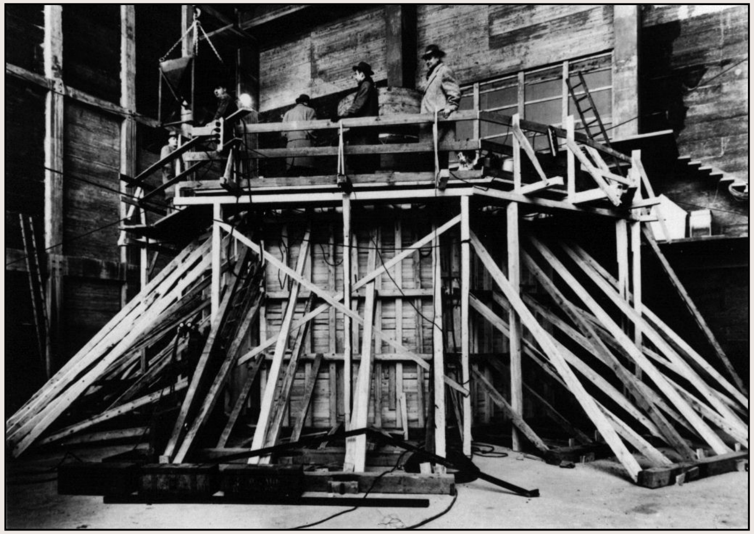
ATOMINSTITUT

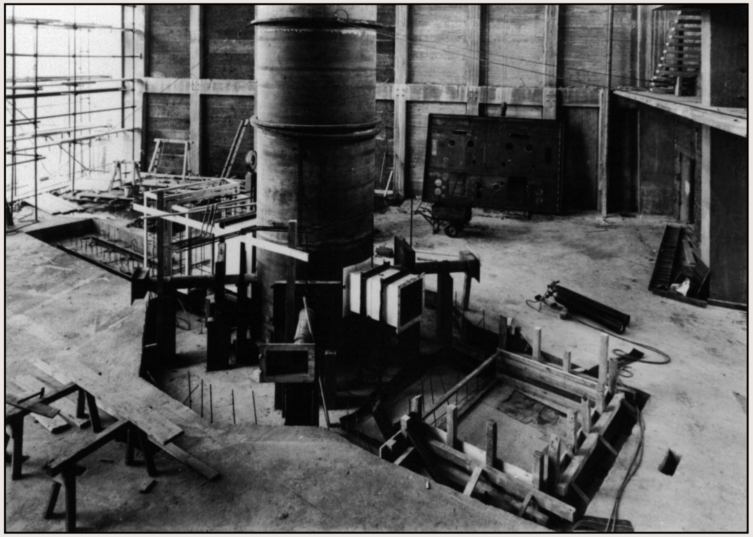
Der TRIGA MARK II Reaktor

Technische Universität Wien
TRIGA Center Atominstitut
Stadionallee 2, 1020 Vienna, Austria
++43-1-58801 141371
mario.villa@tuwien.ac.at

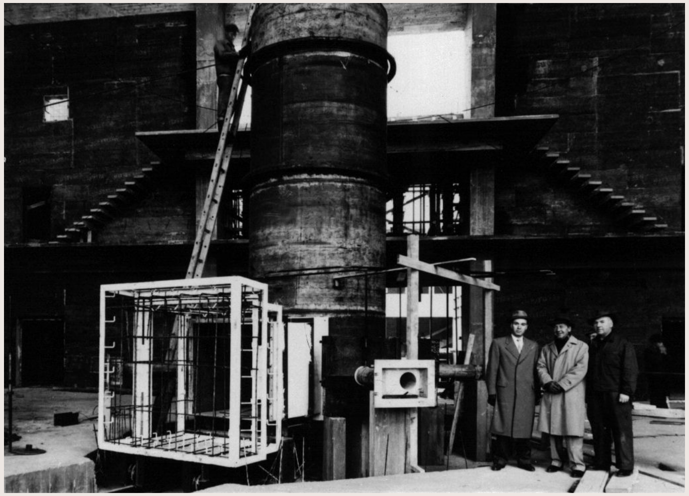
Der TRIGA MARK II Reaktor

- Gebaut von General Atomics (1959 bis 1962)
- Inbetriebnahme am 7. März 1962, 12:04 Uhr





Bauphasen




IAEA (VIC)
Downtown
ATI
© 2005 Google
Pointer 48°12'51.80" N 16°23'28.05" E
Eye alt 19573 ft

Lehrveranstaltungen um den Reaktor

- Reaktorphysik (VO – 2.0)
- Grundlagen der Reaktorphysik

- Reaktortechnik I – Nuclear Engineering I (VO – 2.0)
- Aufbau und Funktionsweise moderner Kernkraftwerke

- Reaktortechnik II (VO – 2.0)
- Grundlagen des Brennstoffkreislaufes

- Praktische Übungen am Reaktor (PR – 4.0)
- 12 Übungen rund um den Reaktor

- Praktische Übungen aus Reaktorinstrumentierung (PR – 4.0)
- Signalverarbeitung am einzigen Forschungsreaktor Österreichs

- Seminar aus Reaktorsicherheit (SE – 2.0)
- Aktuelle Themen zur Kernenergie

TRIGA MARK II
Atominstitut Vienna

1962

2021

TRIGA Mark II Research Fields

- Thermal white beam: general purpose neutron facility
- Neutron interferometry, material science
- Reactor physics, neutron activation in tubes, CIT
- Fully automized ultra fast NAA (planned)
- Neutron spin manipulations, uncertainty relations
- Neutron radiography

Technische Daten des Triga Mark II Reaktor Wien (1)

1. Reaktor

Brennstoff-Moderator Material	8,5 wt% Uran 89,9 wt% Zirkon 1,6 wt% Wasserstoff
Urananreicherung	19,8 % Uran-235
Aktives Kernvolumen	49,5 cm Durchmesser 38,1 cm Höhe
Kernladung	82 Brennelemente
U-235 Menge je Brennelement	ca. 38 g
Reflektor	Graphit
Regeleinrichtung	2 Borkarbidregelstäbe mit Elektromotor 1 Borkarbidregelstab mit Druckluft prompter negativer Temperaturkoeffizient des Brennstoffes

Technische Daten des Triga Mark II Reaktor Wien (2)

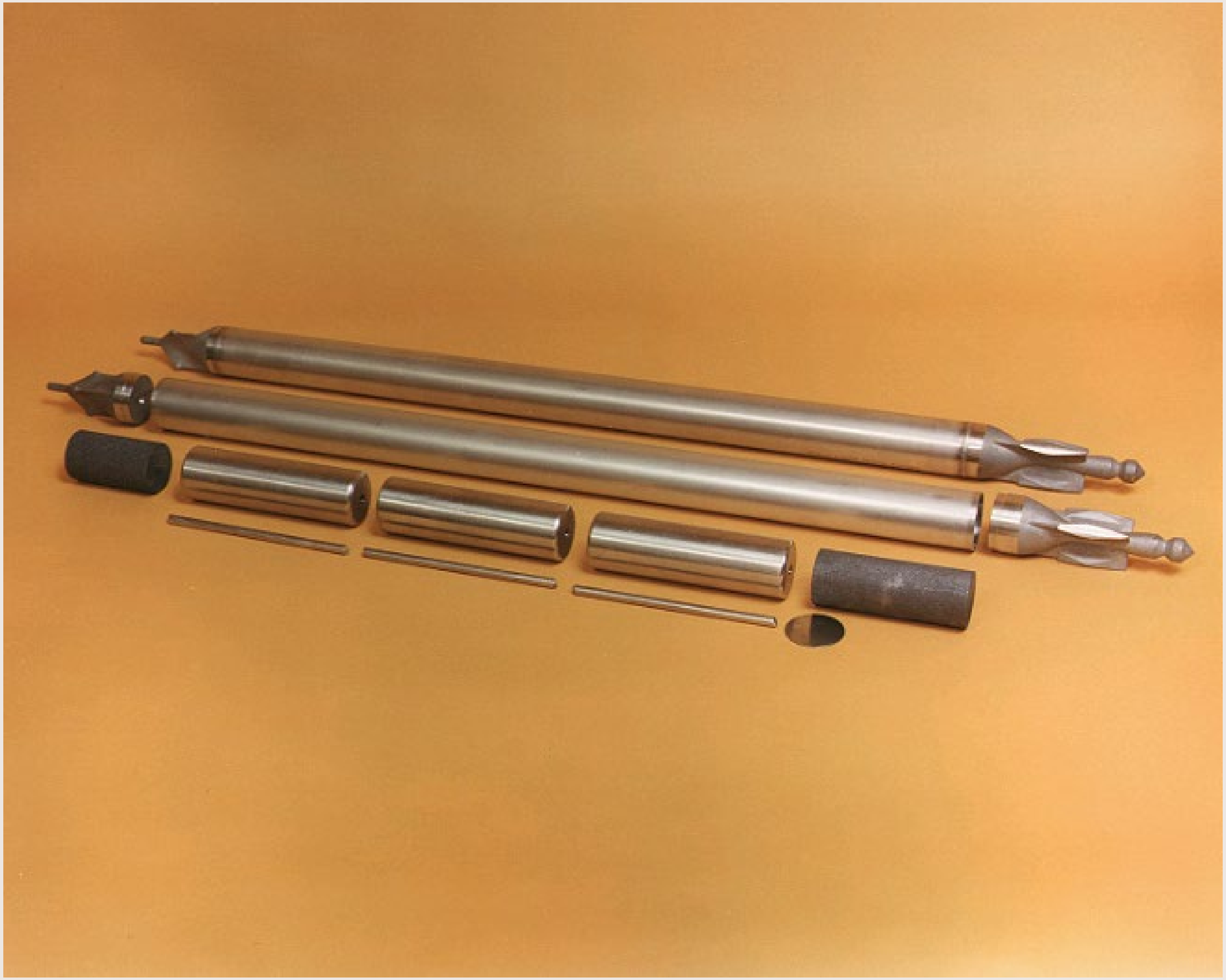
2. Dauerbetrieb

Maximale thermische Leistung	250 kW
Maximale thermische Neutronenflußdichte	$1 \times 10^{13}\ cm^{-2}s^{-1}$
Maximale Brennstofftemperatur	220 °C
Maximale Primärwassertemperatur	35 °C

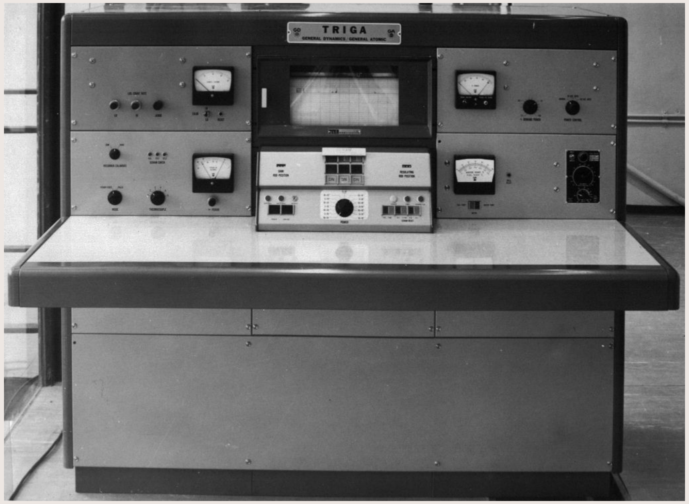
3. Impulsbetrieb

Spitzenleistung	250 MW
Impulsarbeit	12 MWs
Dauer des prompten Impulses	40 ms
Minimale Reaktorperiode	10 ms
Maximale Brennstofftemperatur	360 °C

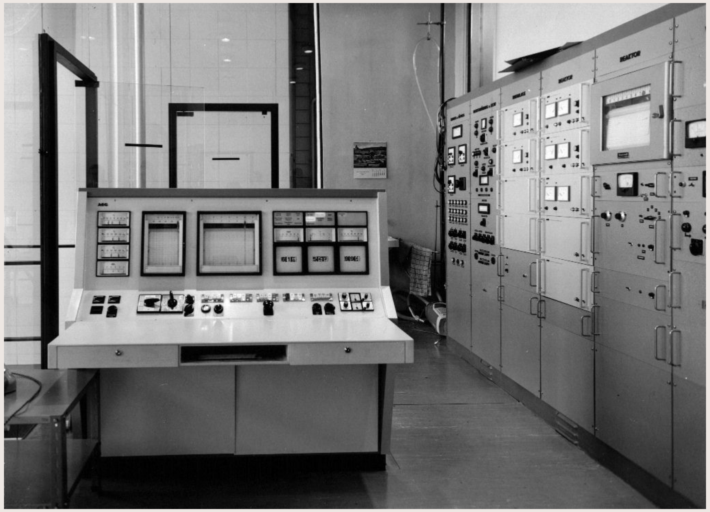
Bestandteile eines TRIGA Brennstabes



Reaktor Instrumentierung



1962

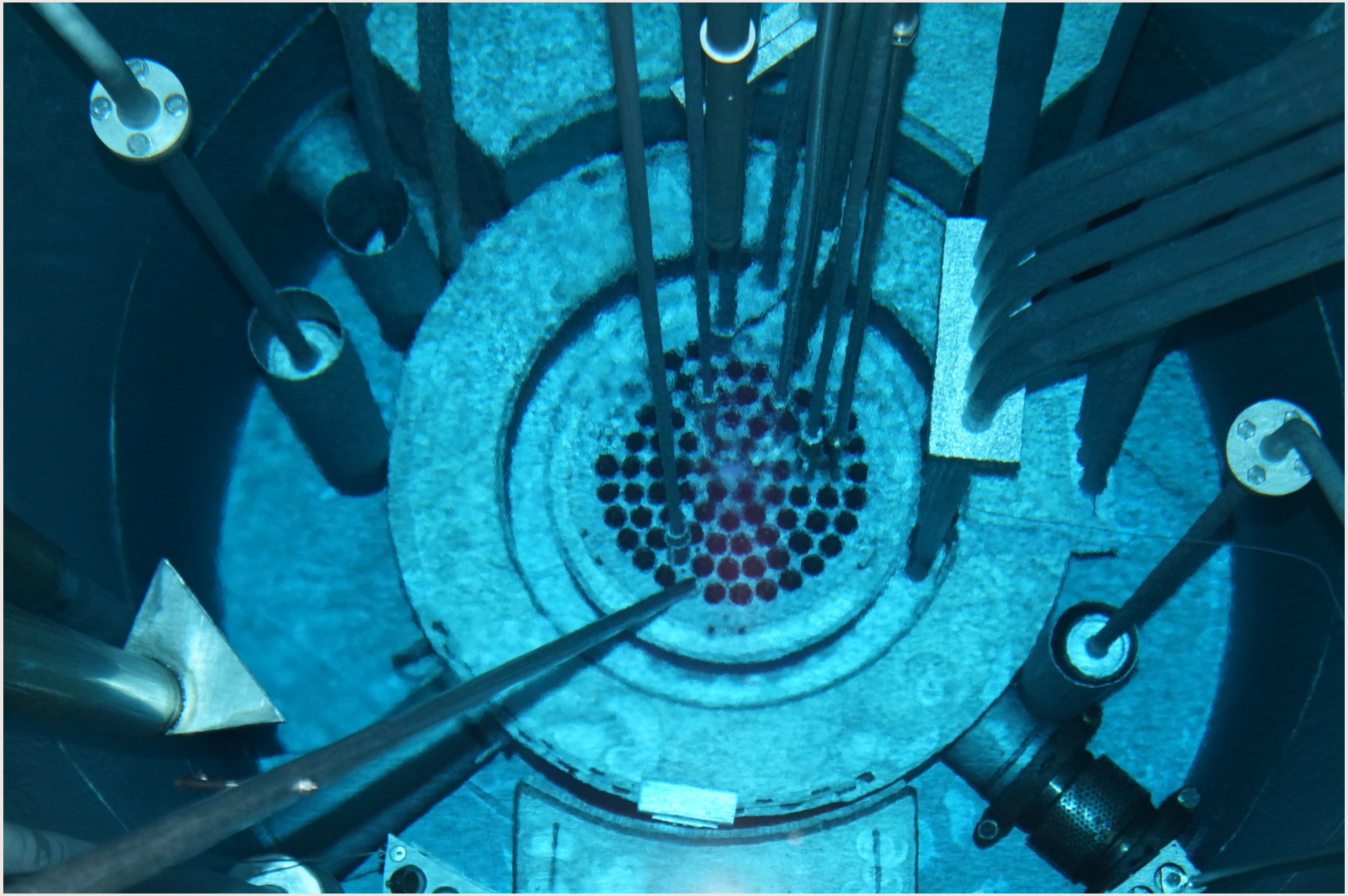


1968

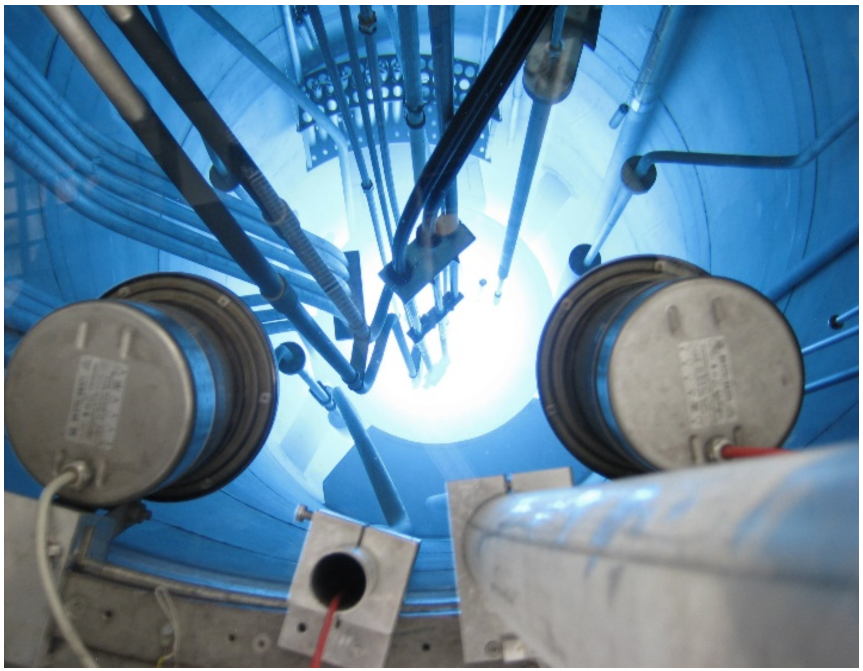
1992

Die neue Instrumentierung

Blick in den Reaktor!

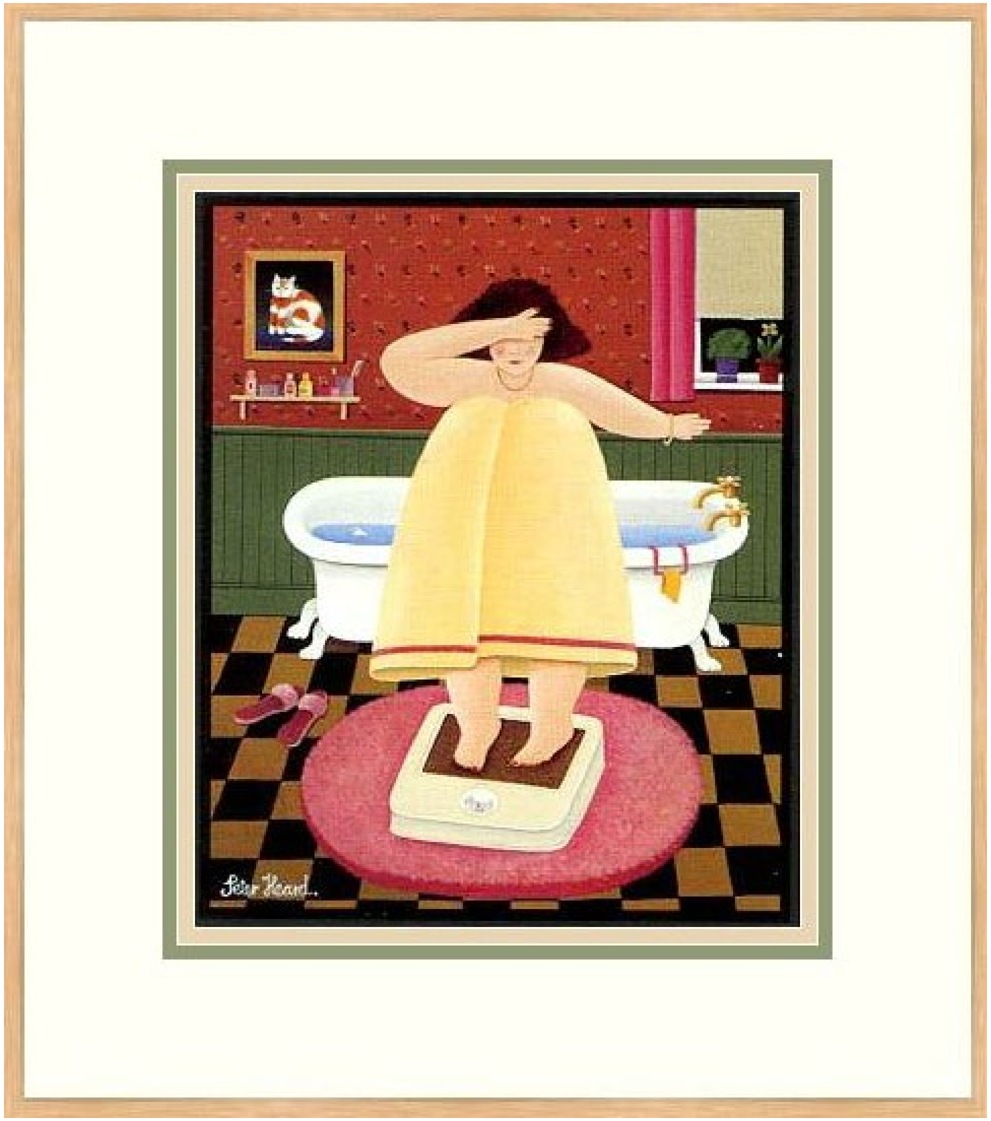


Particle Physics @ Atominstitut
Neutronen- und Quantenphysik



Information by Y. Hasegawa, A. Ivanov, E. Jericha, M. Pitschmann, I. Pradler, S. Sponar, R. Sedmik, M. Zawisky, H. Abele

Das Neutron und seine Eigenschaften

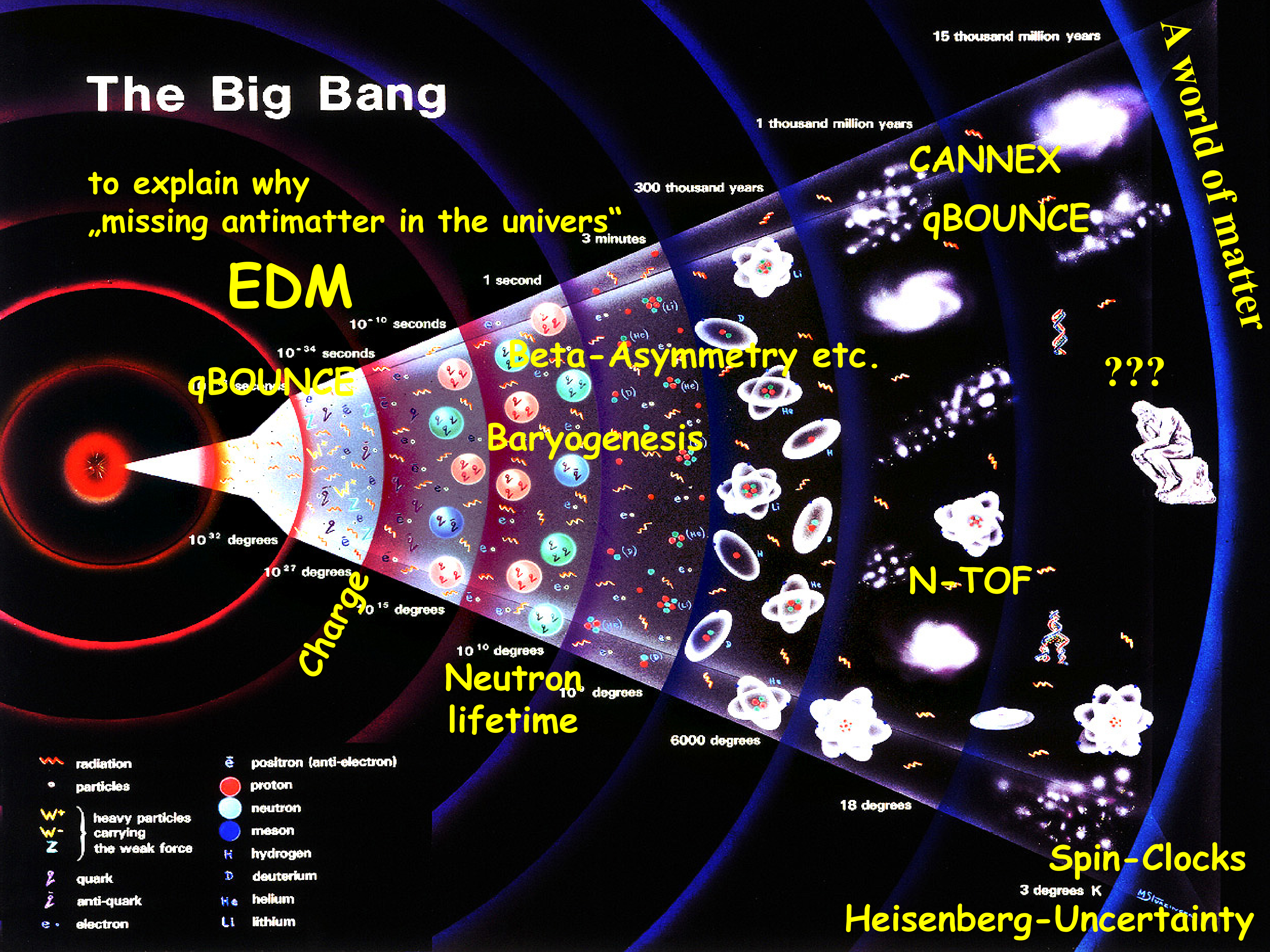


Vorkommen

- Erde: 50% n 50% p
- Universum: 14% n, 86 % p
- 1s nach Big Bang: 17% n, 83% p

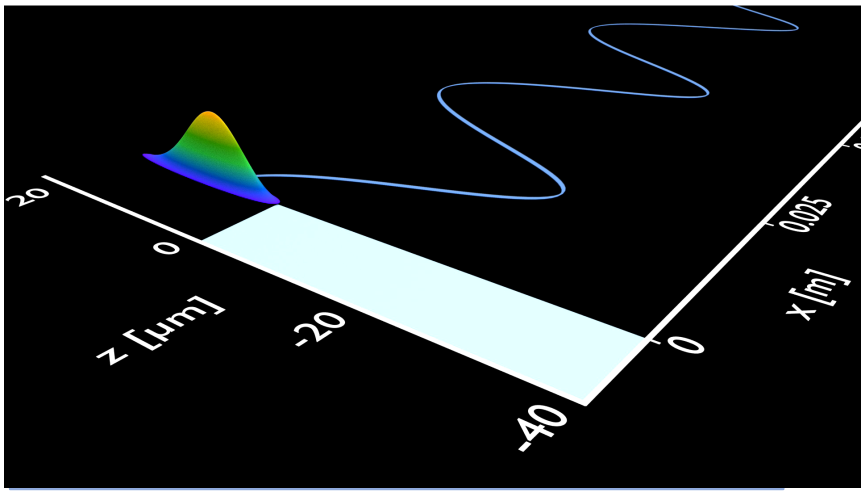
Zerfall

- Lebensdauer 881s

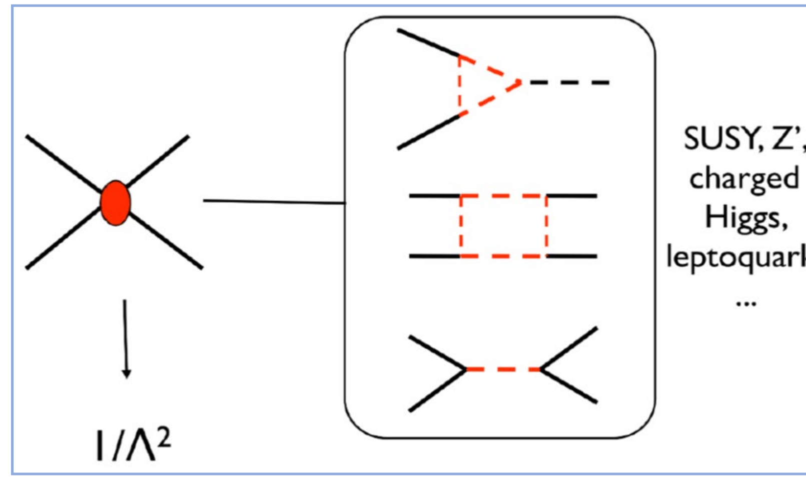

The Big Bang
to explain why
„missing antimatter in the univers"
EDM
qBOUNCE
Charge
Neutron
lifetime
Beta-Asymmetry etc.
Baryogenesis
CANNEX
qBOUNCE
N-TOF
???
A world of matter
Spin-Clocks
Heisenberg-Uncertainty
15 thousand million years
1 thousand million years
300 thousand years
3 minutes
1 second
10^{-10} seconds
10^{-34} seconds
10^{32} degrees
10^{27} degrees
10^{15} degrees
10^{10} degrees
10^{9} degrees
6000 degrees
18 degrees
3 degrees K
radiation
particles
heavy particles carrying the weak force
quark
anti-quark
electron
positron (anti-electron)
proton
neutron
meson
hydrogen
deuterium
helium
lithium

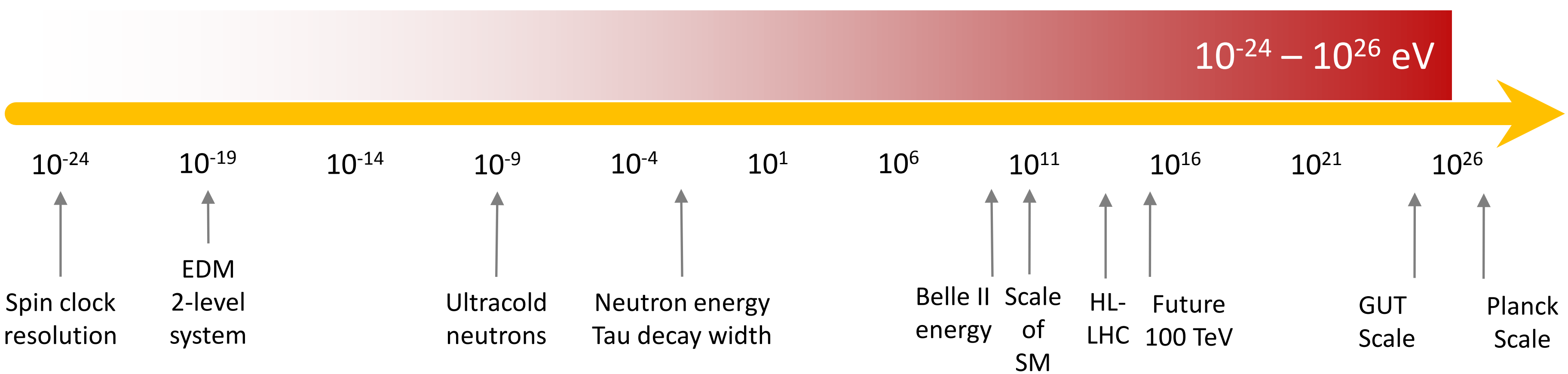
Neutron and Quantum

Quantum bouncing ball

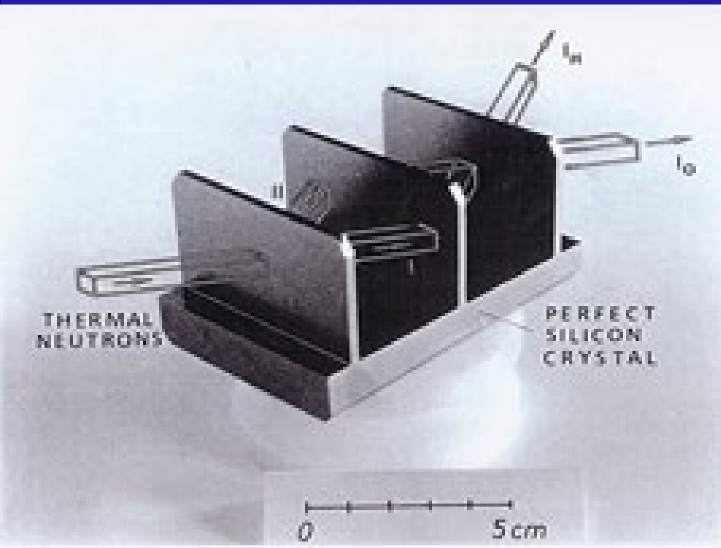


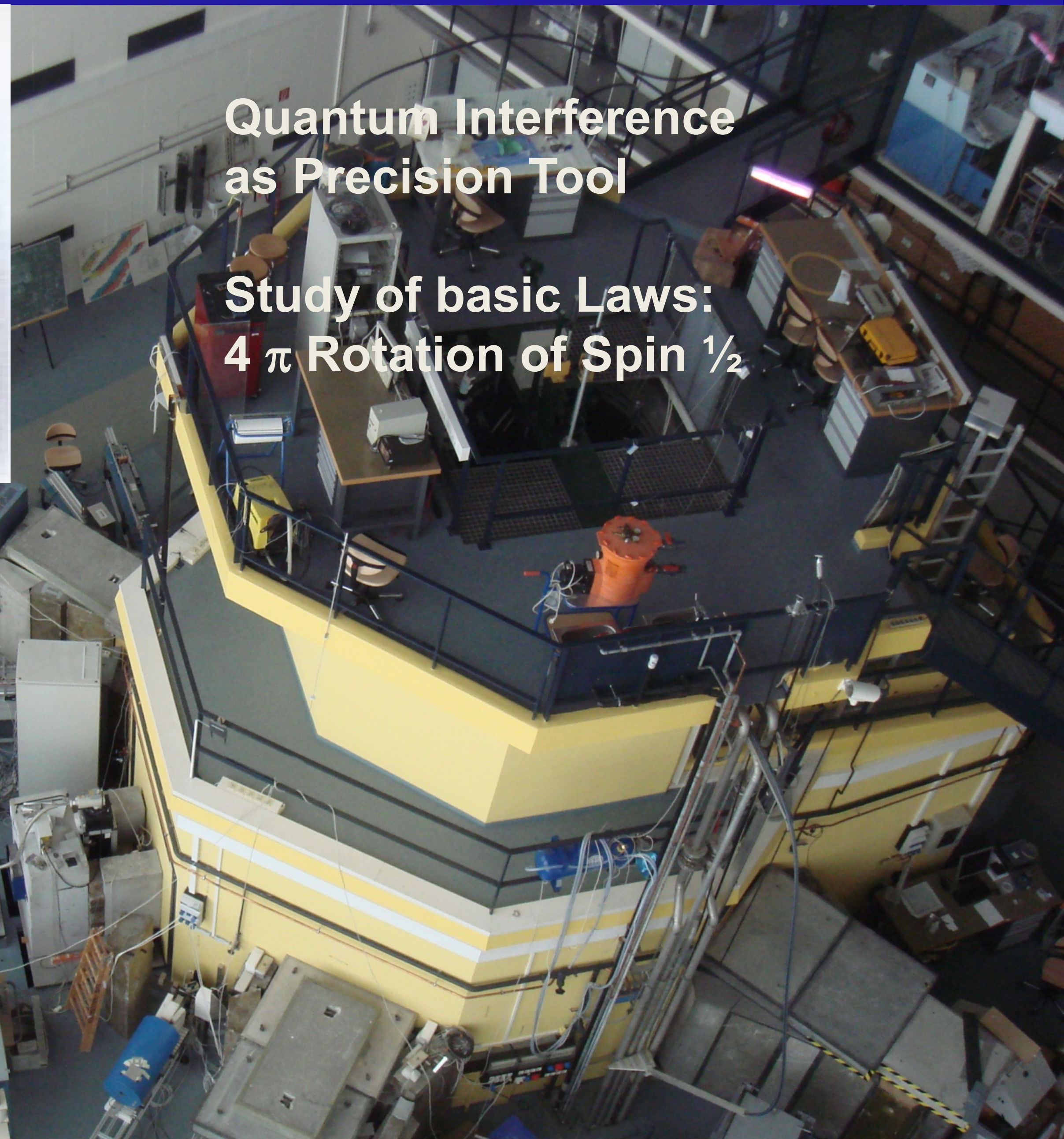
Search for New Physics through EFTs





Das Neutron und seine Eigenschaften





Quantum Interference as Precision Tool

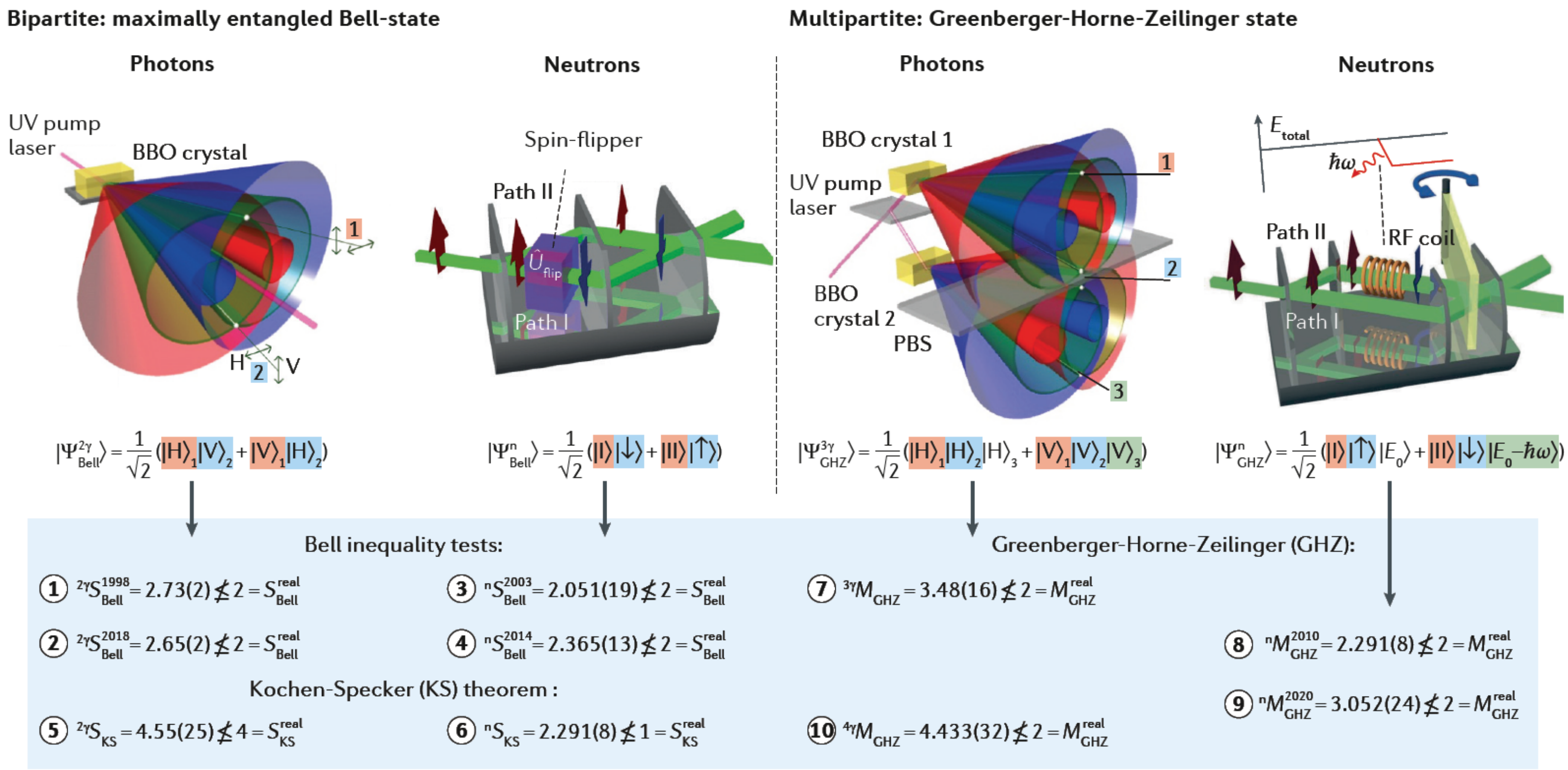
Study of basic Laws:
4 π Rotation of Spin ½

… with Experiments at TRIGA Wien, ILL, CERN, TUM

Topics 2021:

- Gravitation and Cosmology
  - Interferometry: Spin Rotation Coupling
  - CANNEX: Casimir Forces
  - qBOUNCE: Einstein – Cartan - Gravity

Hasegawa, Sponar et al.: Interferometer



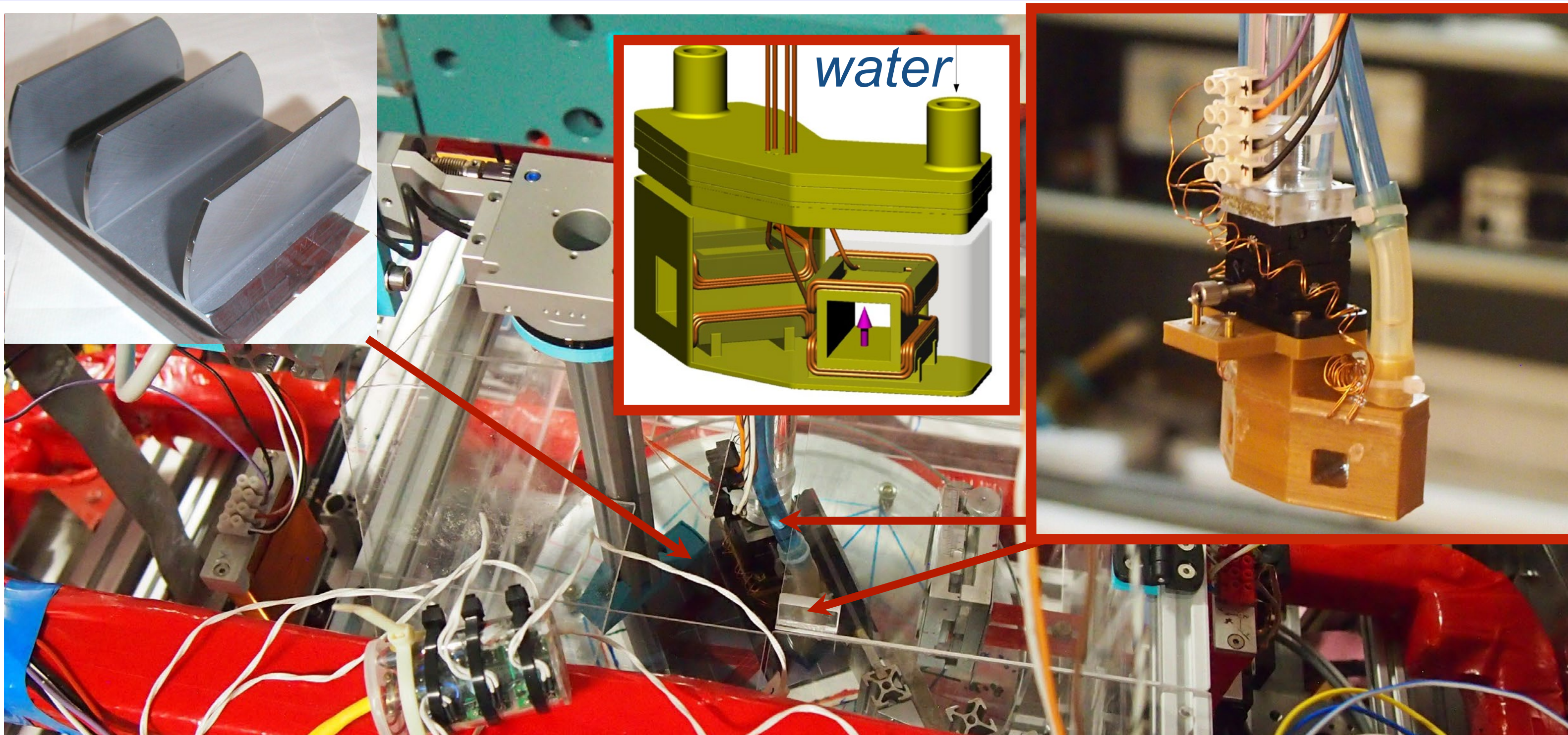
- Entanglement

Nature Review, in print

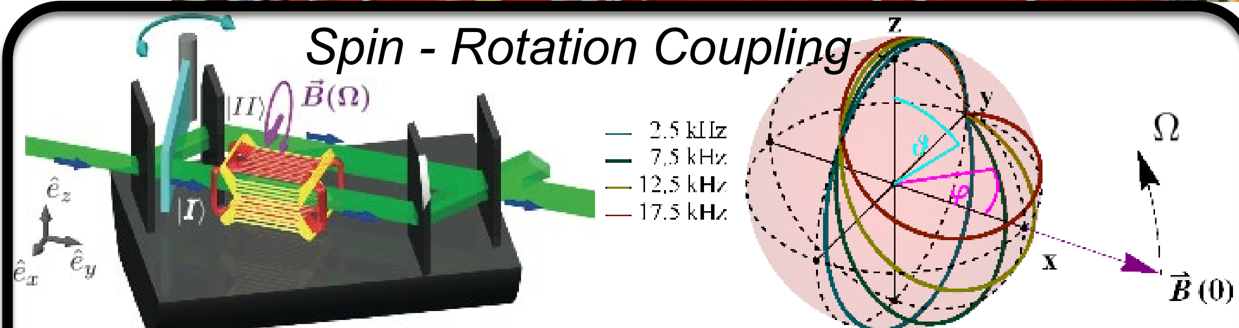
  - Between path and spin
  - And path, spin and energy

- Spin Rotation Coupling

Sponar, Hasegawa: Neutron Interferometer Setup @ S18 (ILL)



Spin - Rotation Coupling

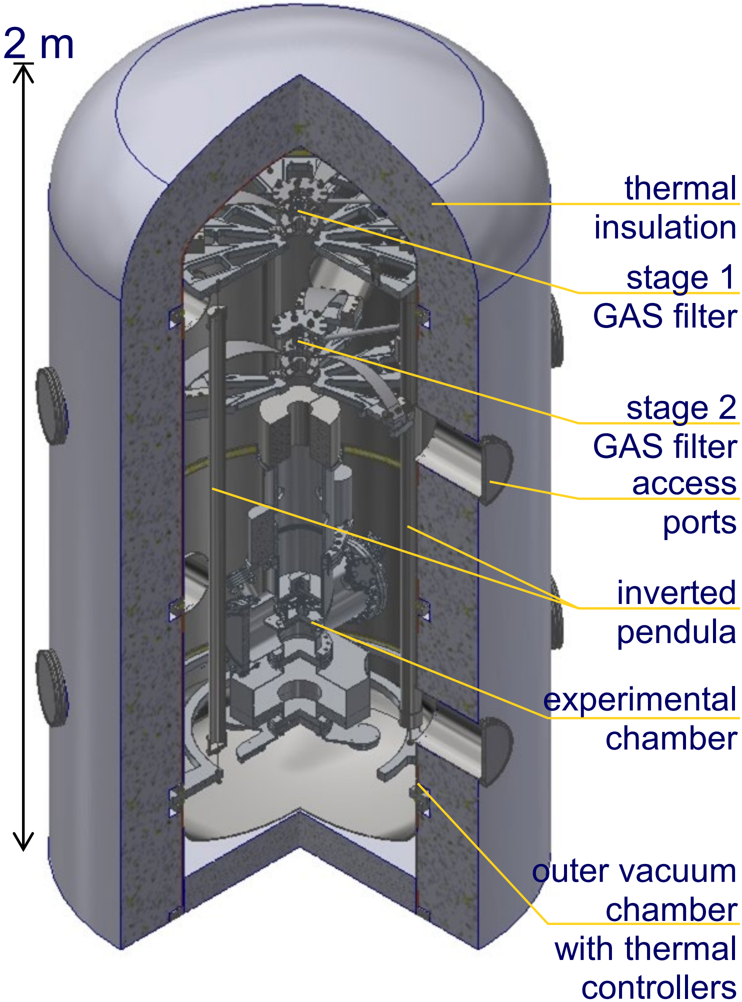


A. Danner, S. Sponar, and Y. Hasegawa, npj Quantum Information 6,23 (2020)

H. Geppert, T. Denkmayr, Stephan. Sponar, H. Lemmel, T. Jenke and Y. Hasegawa, *Phys. Rev. A* **97**, 052111 (2018)
T. Denkmayr, H. Geppert, H. Lemmel, M. Waegell, J. Dressel, Y. Hasegawa, and S. Sponar, *Phys. Rev. Lett.* **118**, 010402 (2017)
T. Denkmayr, H. Geppert, S. Sponar, H. Lemmel, A. Matzkin, J. Tollaksen, and Y. Hasegawa, Nature Communications **5**, 4492 (2014)
S. Sponar, Tobias Denkmayr, H. Geppert, H. Lemmel, A. Matzkin, J. Tollaksen, and Y. Hasegawa, *Phys. Rev. A* **92**, 062121 (2015)

René Sedmik: Casimir Force Measurements

CANNEX – Casimir And Non-Newtonian force EXperiment



Worldwide only force metrology platform operating in the geometry of plane parallel plates.

Recent progress:

Design for two-staged active/passive seismic isolation system to form
"*the most quiet space in Austria*"

Updated core design for perfect thermal control with mK precision.
Prospective limits for chameleon, symmetron, dilaton dark energy, scalar axions, scalar-pseudoscalar interactions, Yukawa forces... as well as the most precise measurements of Casimir forces.

In preparation:

- Financing for construction phase

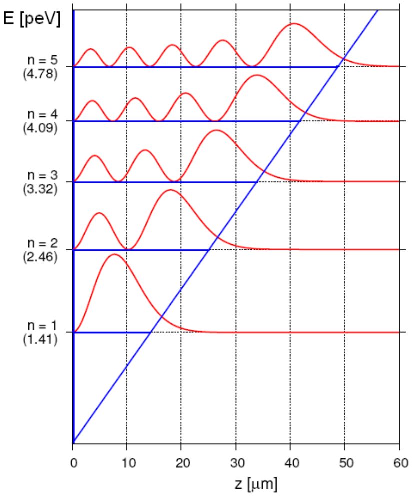
René Sedmik et al.: *q*BOUNCE- Experiment

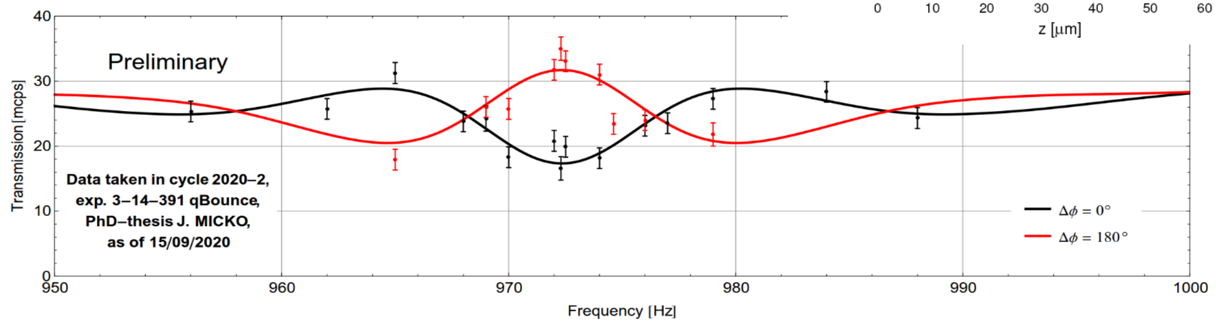
Ramsey spectroscopy with gravitational quantum states of neutrons

qBounce Experiment

Recent progress:

Reduction of systematics.
Sensitivity improved to 8×10^{-16} eV/√days
First observation of transition





In preparation:

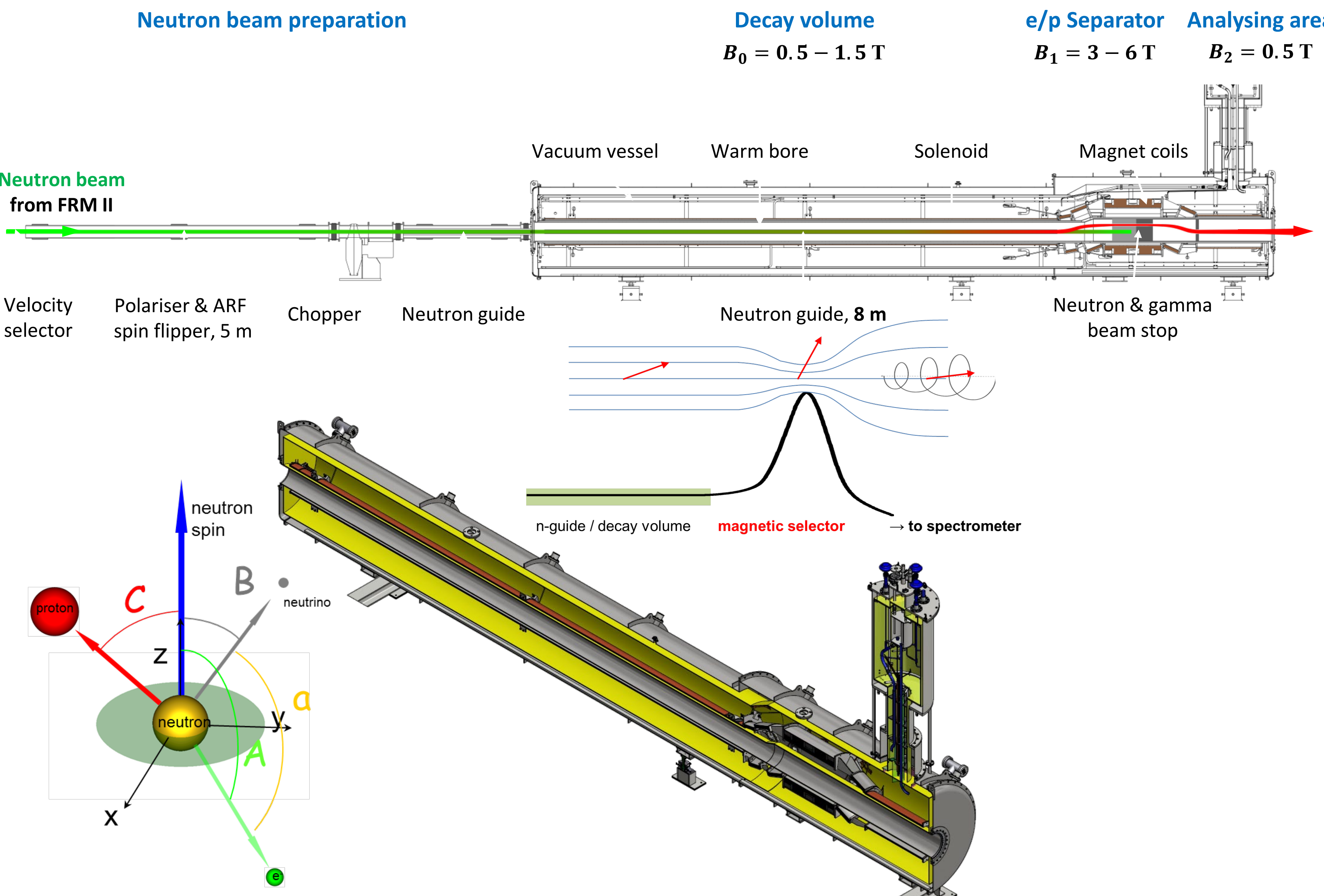
Weak Equivalence Principle test with neutrons and ^{87}Rb
UCN quantum waveguides in Si channels
Search for Einstein Cartan Gravity

… with Experiments at TRIGA Wien, ILL, CERN, TUM

Topics 2021:

- Particle Physics
  - Neutron Beta Decay
    - Delivery of PERC Facility @ TUM
    - Cyclotron Radiation Emission Spectroscopy (CRES)
  - Coherent Neutrino Scallering
  - nTOF @ CERN

Neutron Beta Decay & High Precision Experiments with PERC



Spokesperson: B. Maerkisch, Time and Project Manager: E. Jericha

PERC @ BNG


Traglast 2000 kg
BILFINGER
BILFINGER
NOELL GMBH
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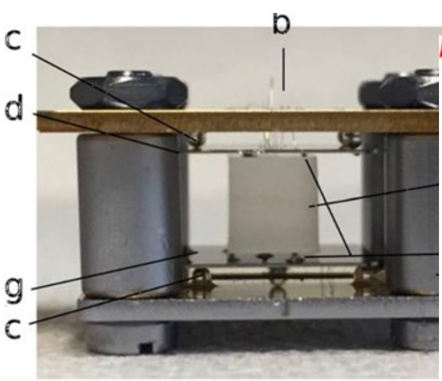
Jericha et al.: Betas, PERC Facility & the CRAB Experiment

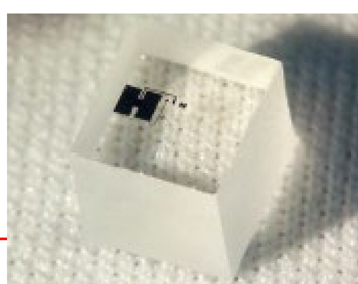
PERC Magnet System

Delivery to FRM II
Early spring 2021

CRES

I. Pradler: Cyclotron Radiation Emission Spectroscopy

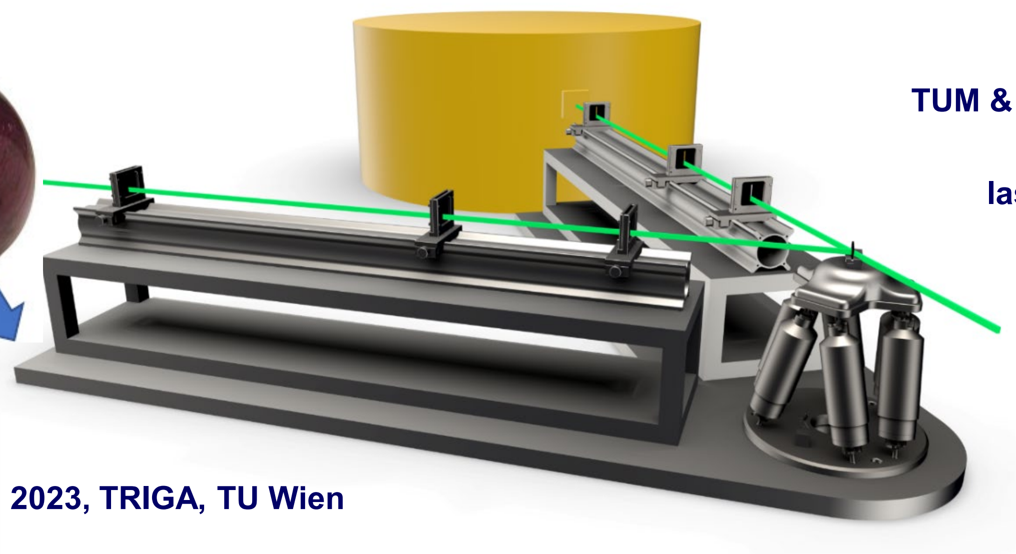




Neutrinos and Dark Matter CRC – Project N07

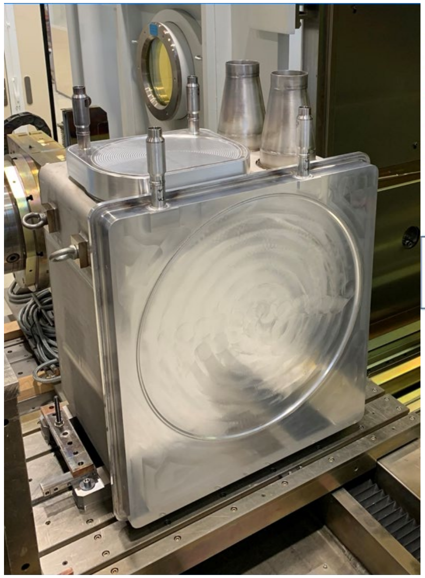
TUM & TU Wien

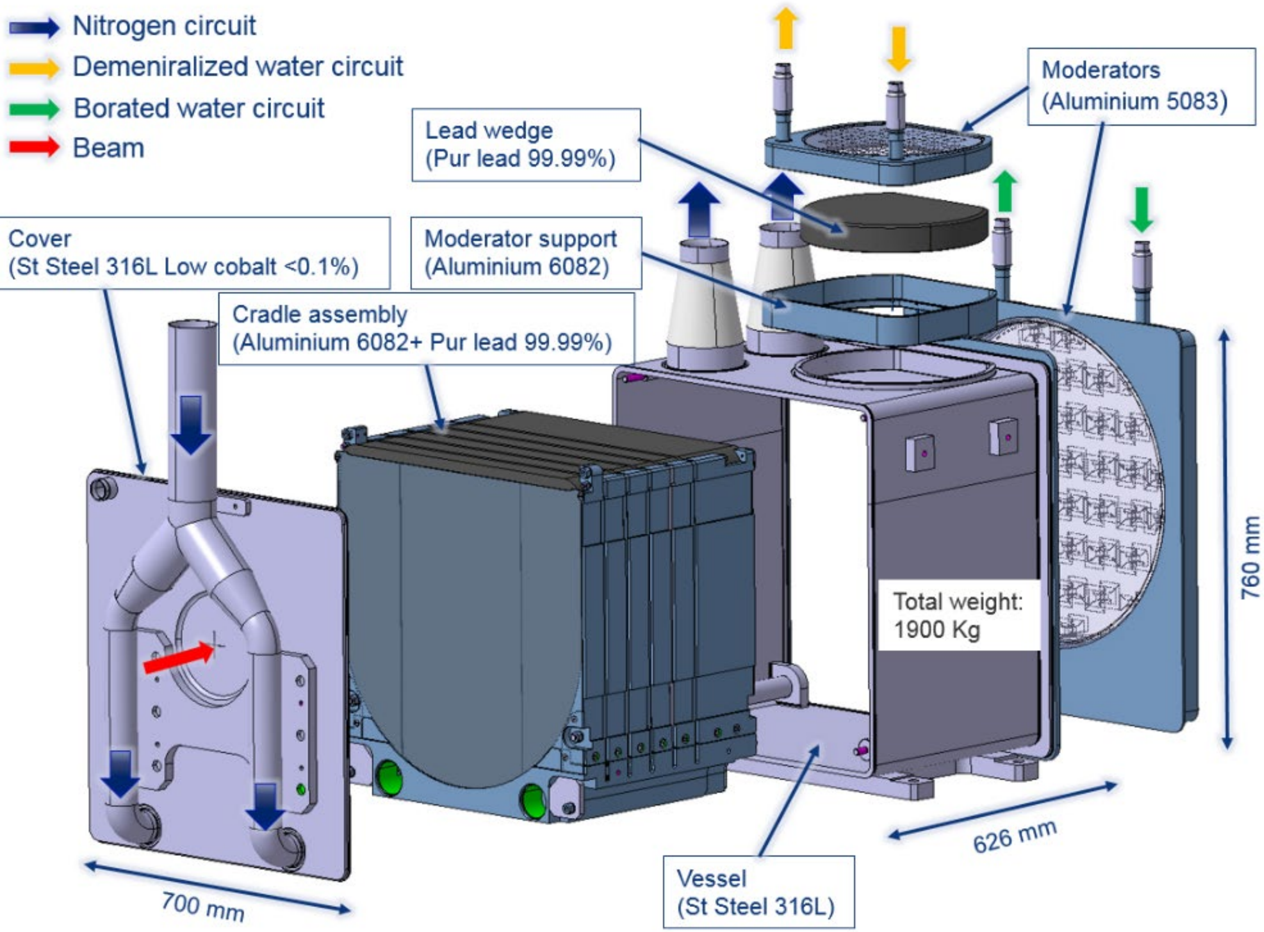
Review last 2 days



CRAB: 2023, TRIGA, TU Wien

Jericha: n_TOF @ CERN: Pb Spallation Target #3





- **Tests with cold nitrogen: operational – February 2021**
- **Installation in the target pit – March 2021**
- **Beamline installations – finished by end of June 2021**
- **1st proton beam on target – planned 19.07.2021**

Pitschmann et al.: Theory Group @ ATI

- Search for Dark Energy and Modified Gravity with Tabletop Experiments
- Standard Model Tests on the 10^{-4} level

… with Experiments at TRIGA Wien, ILL, CERN, TUM

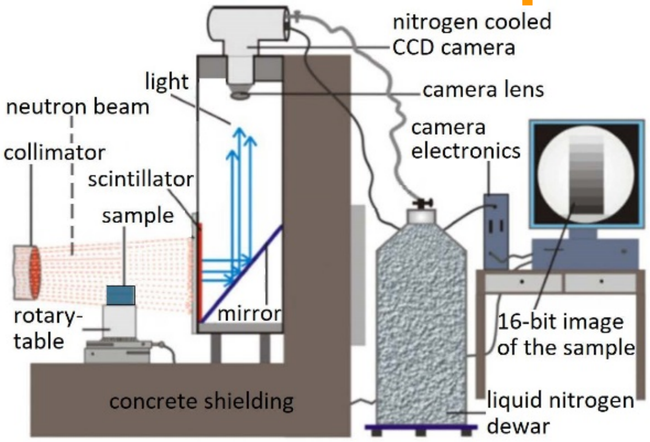
Topics 2020/21:

- Neutron Radiography
  - Rock Analysis
  - Dental Checks
  - Floor Screed Analysis

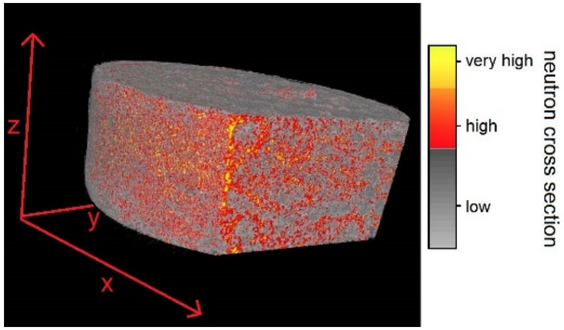
Zawisky et al.: Neutron Radiography

Drying Process of Screed Samples

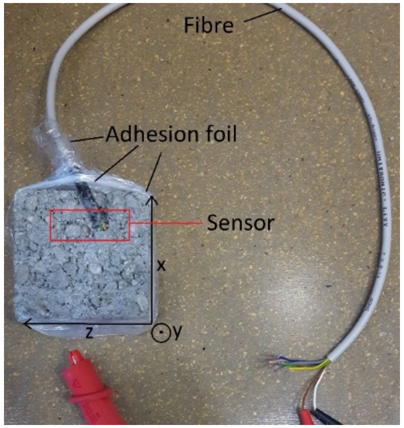
Estrichproben



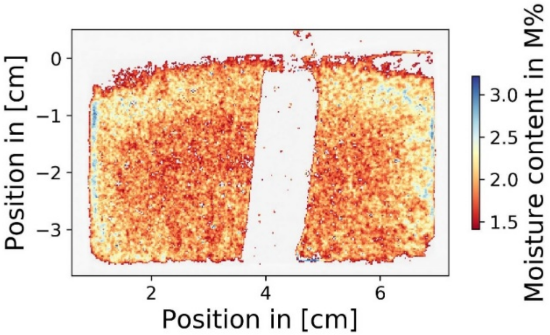
Neutronenradiographie am ATI



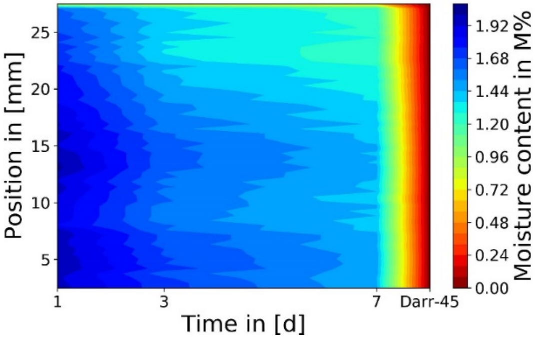
3D Feuchteverteilung



Estrichprobe mit Feuchtesensor zum Vergleich



2D Feuchteverteilung



Trocknungsverhalten

Abteilung für Tieftemperaturphysik und Supraleitung

M. Eisterer, ***Atominstitut, TU Wien***

ATI, 25. März 2021

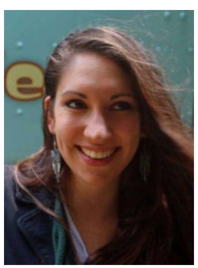
Tieftemperaturphysik und Supraleitung (LTP)

Universitätspersonal

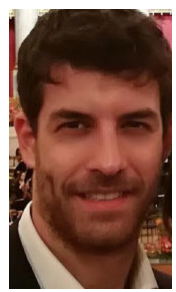

Franz Sauerzopf


Michael Eisterer

ProjektassistentInnen:


Sigrid Holleis


David Bader


Mattia Ortino


Florian Semper

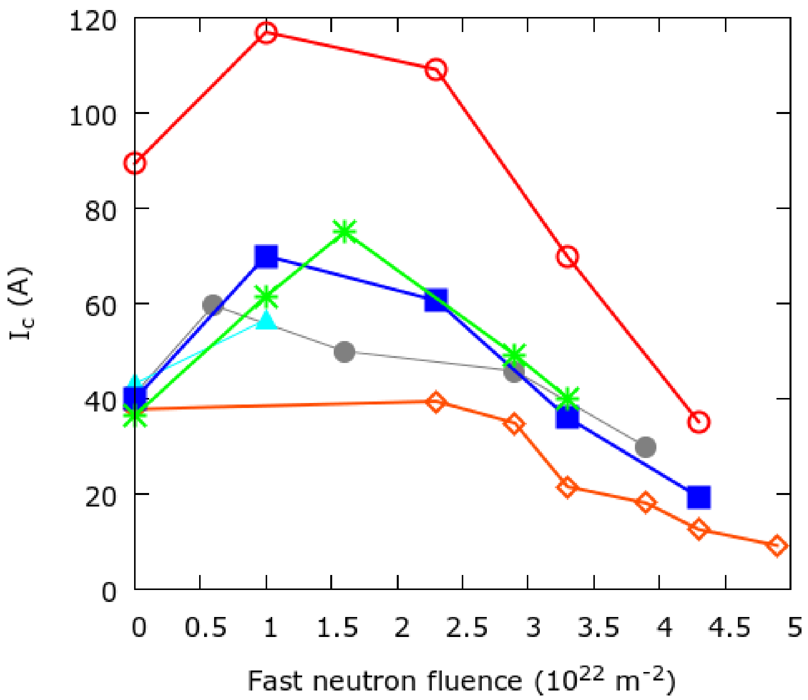

Raphael Unterrainer

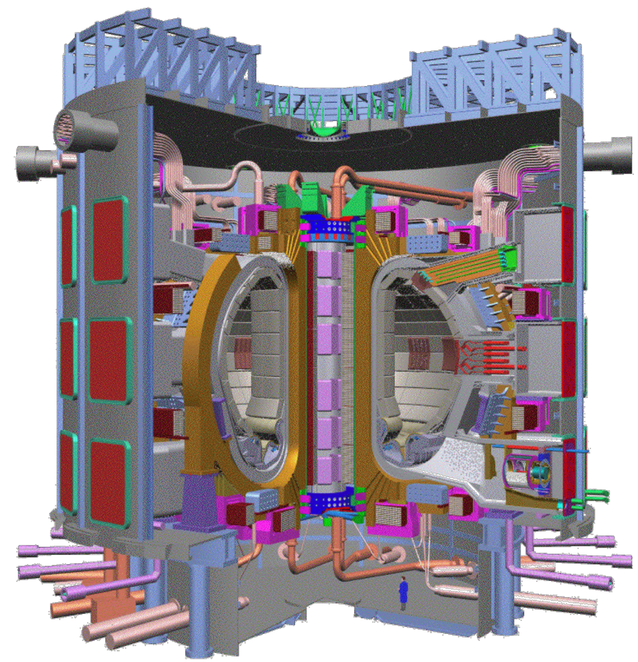
1 Masterstudent, 9 Projektstudierende

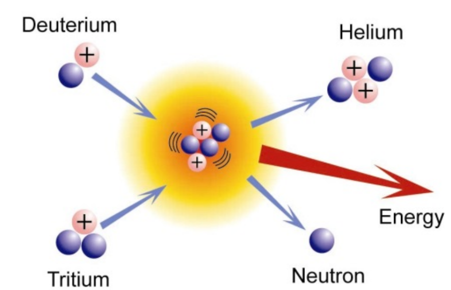
AKTUELLE PROJEKTE

EUROfusion

Influence of neutron radiation on coated conductor performance



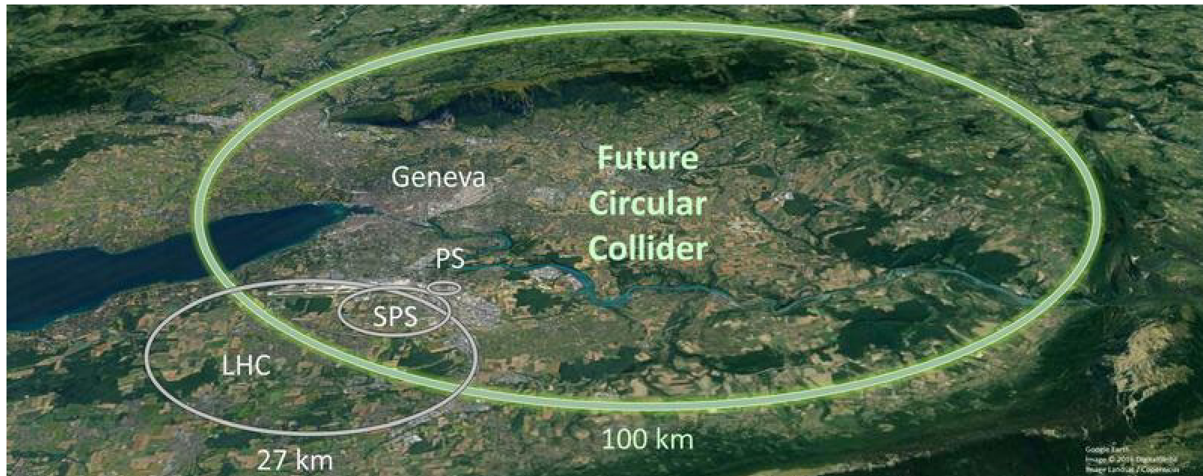




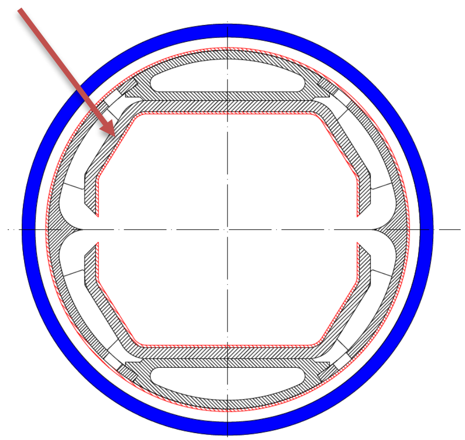
Zusammenarbeit mit MIT, Universität Oxford...

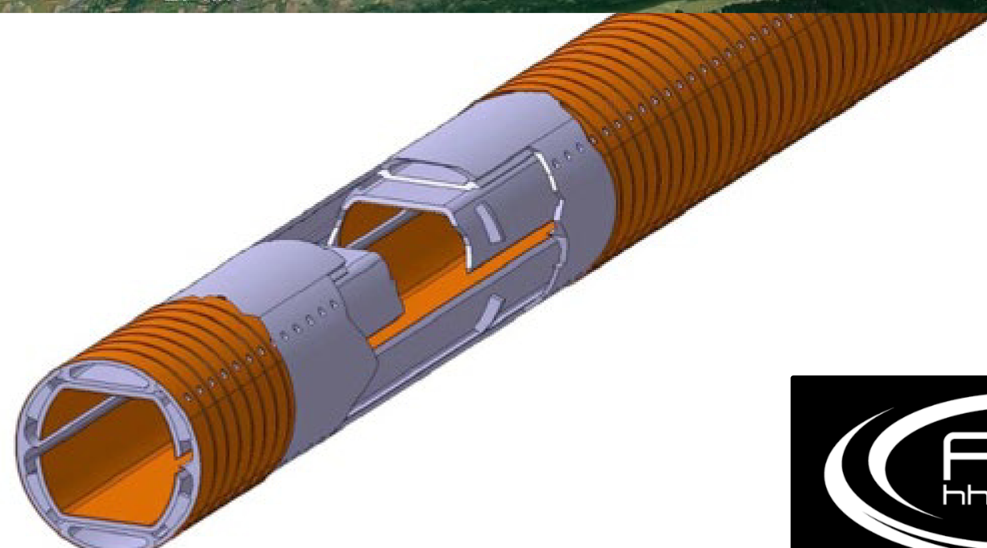
Zusammenarbeit mit dem CERN (FCC)

Entwicklung einer supraleitenden Strahlabschirmung



Supraleitende Beschichtung





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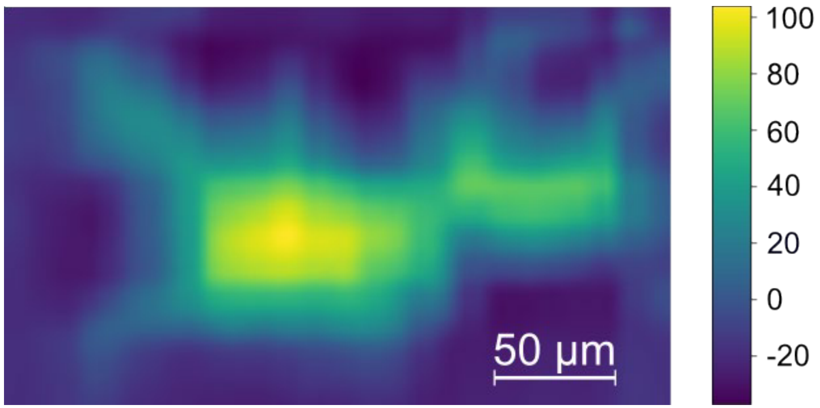

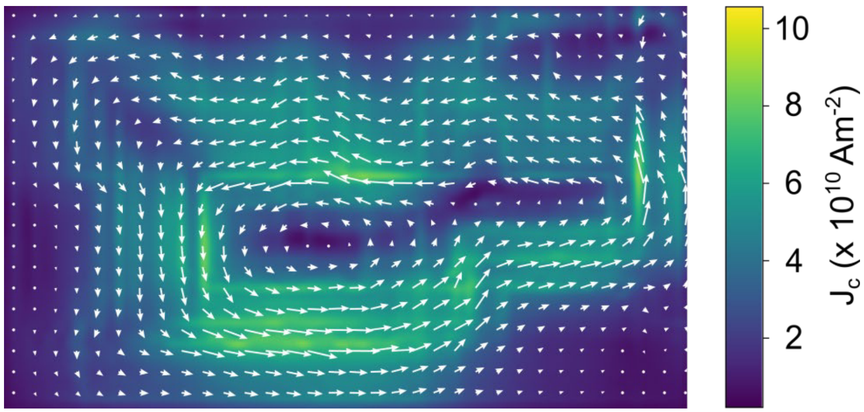

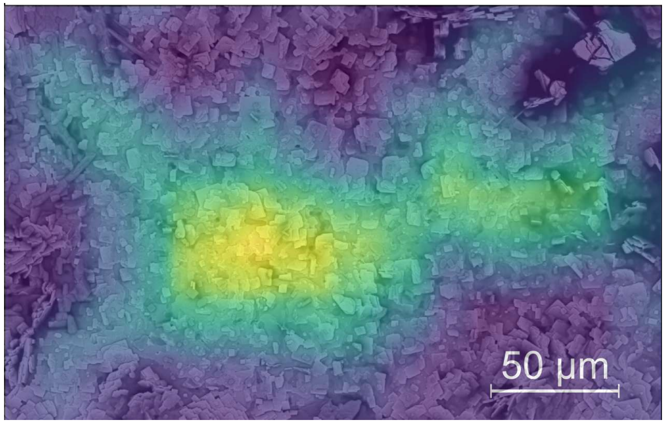

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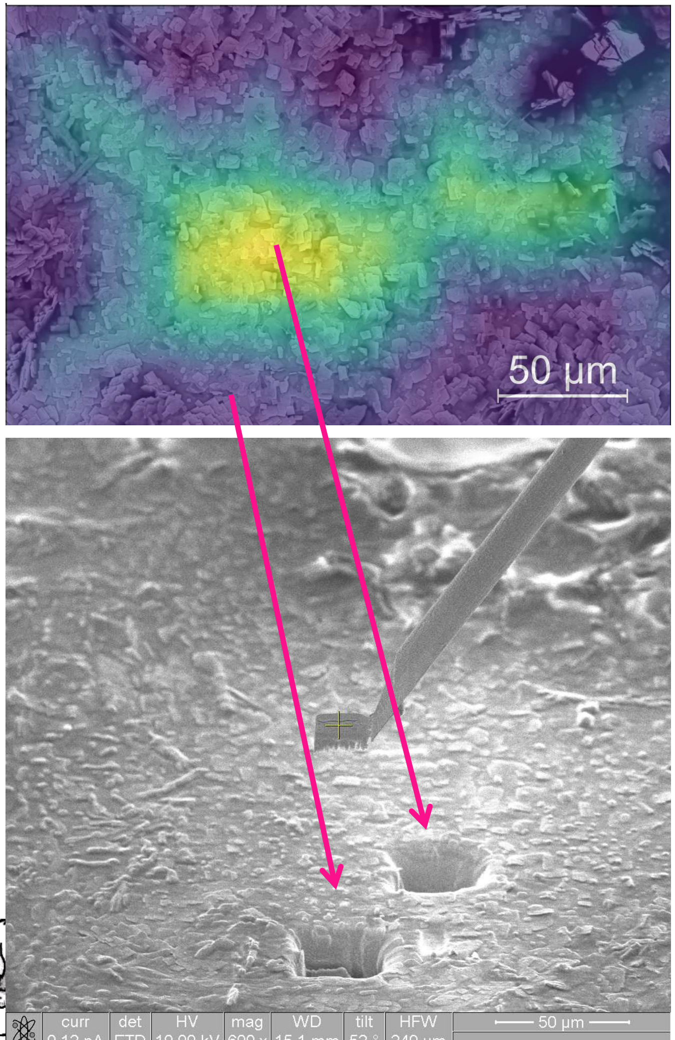

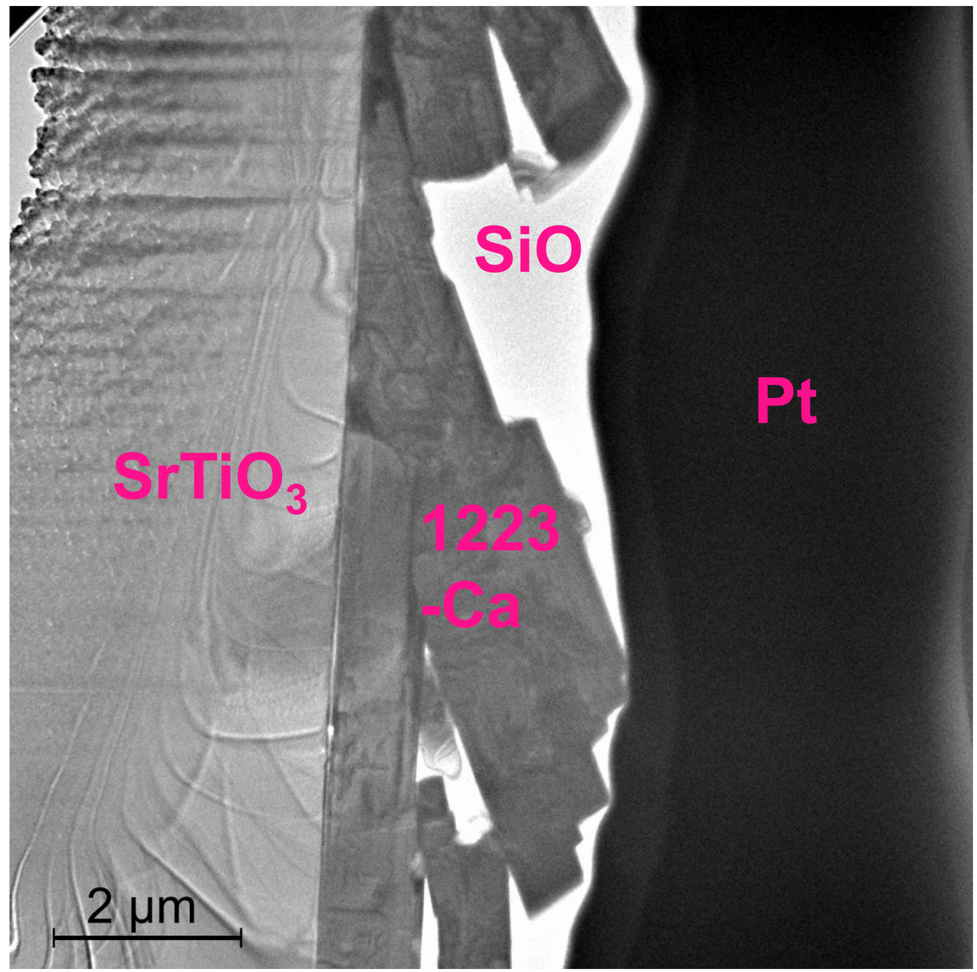

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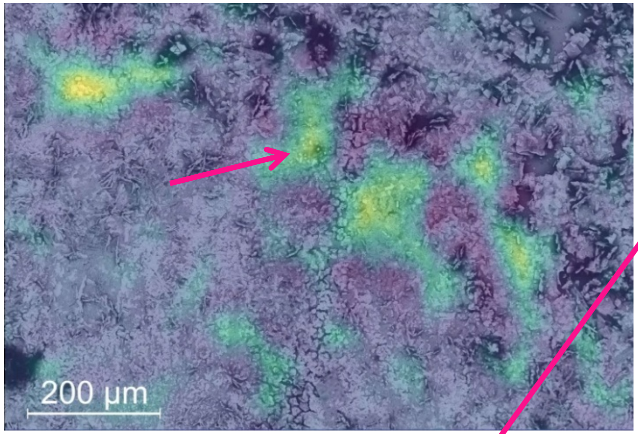
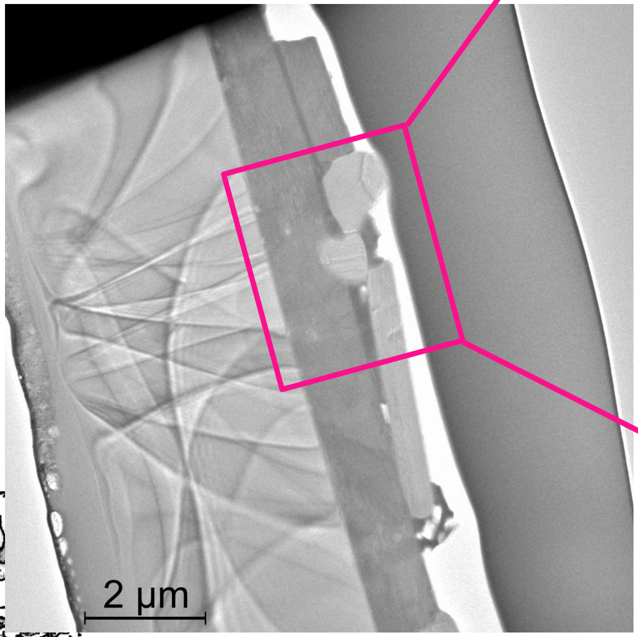
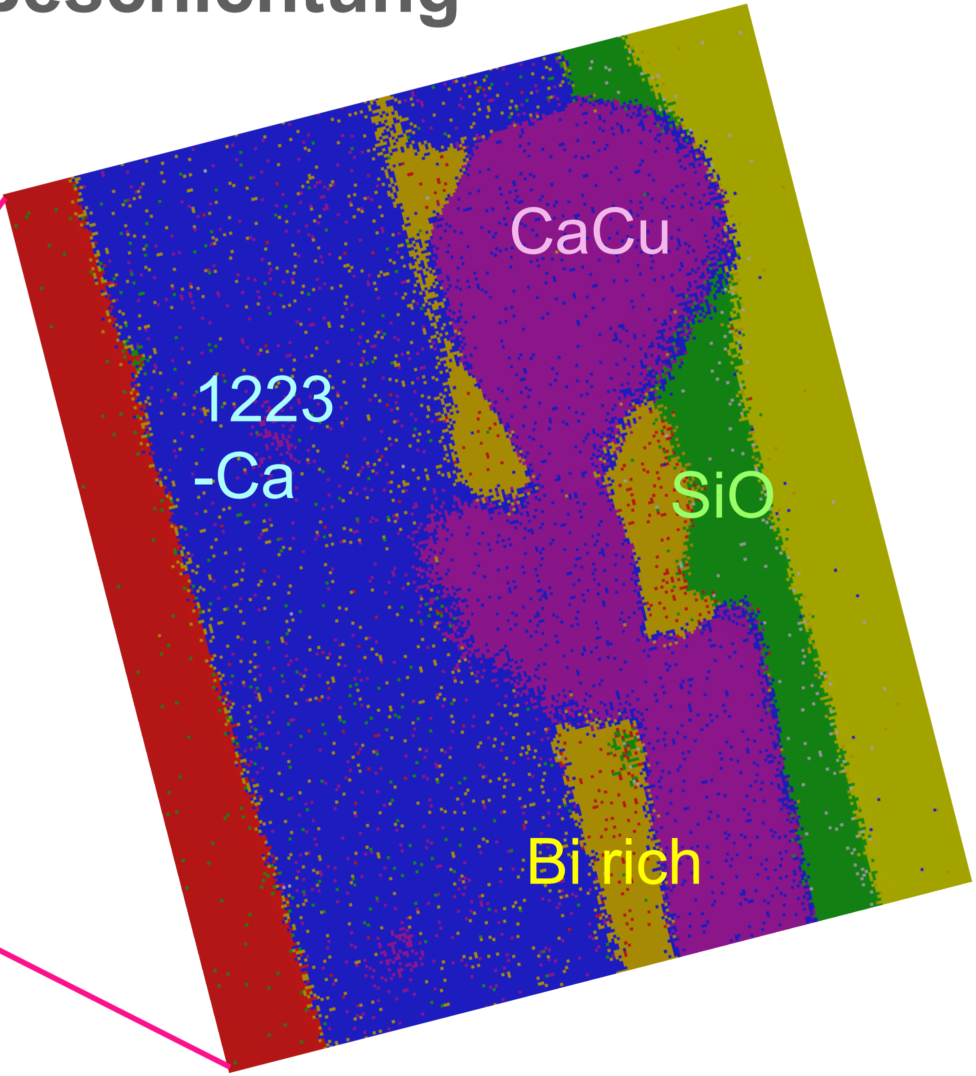


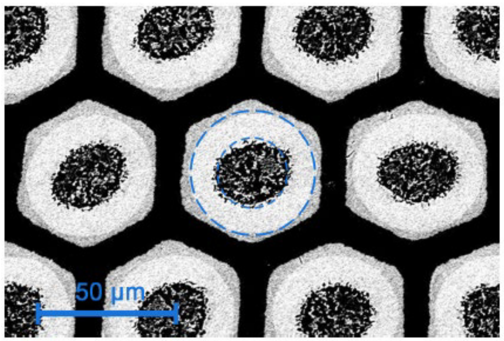


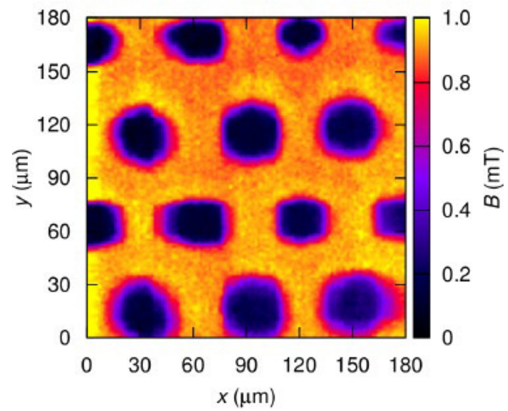


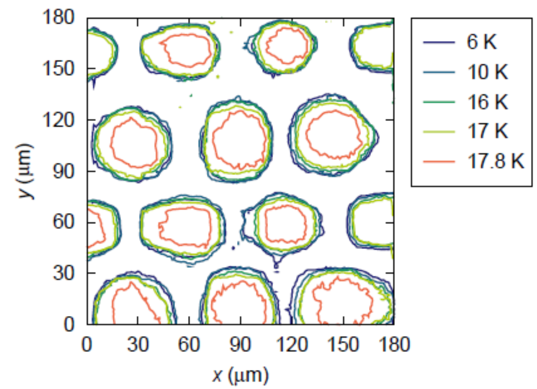
Mikrostrukturuntersuchungen am USTEM

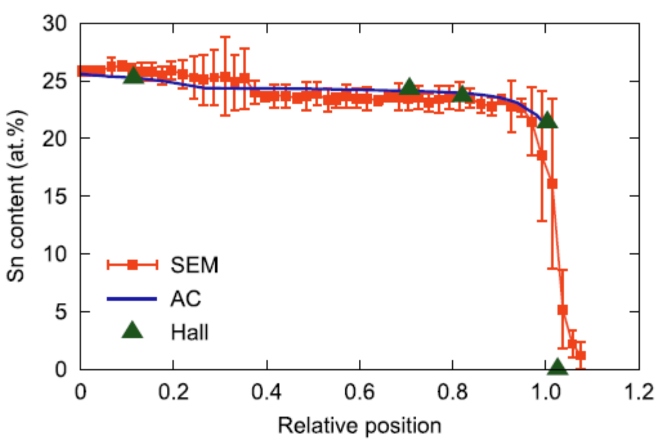
Zusammenarbeit mit dem CERN (FCC)

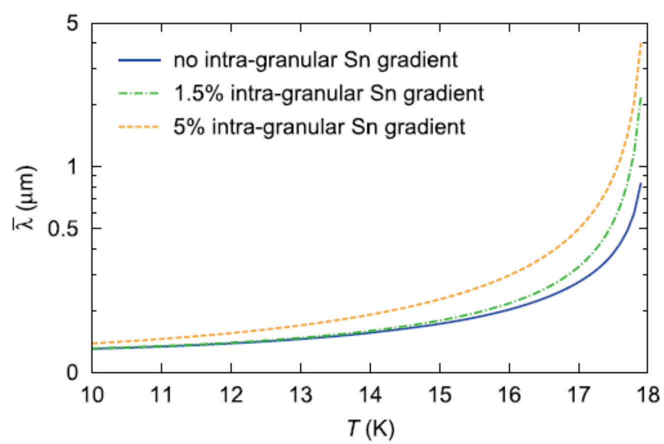
- Leiterentwicklung für die 16 T Dipol-Magnete:



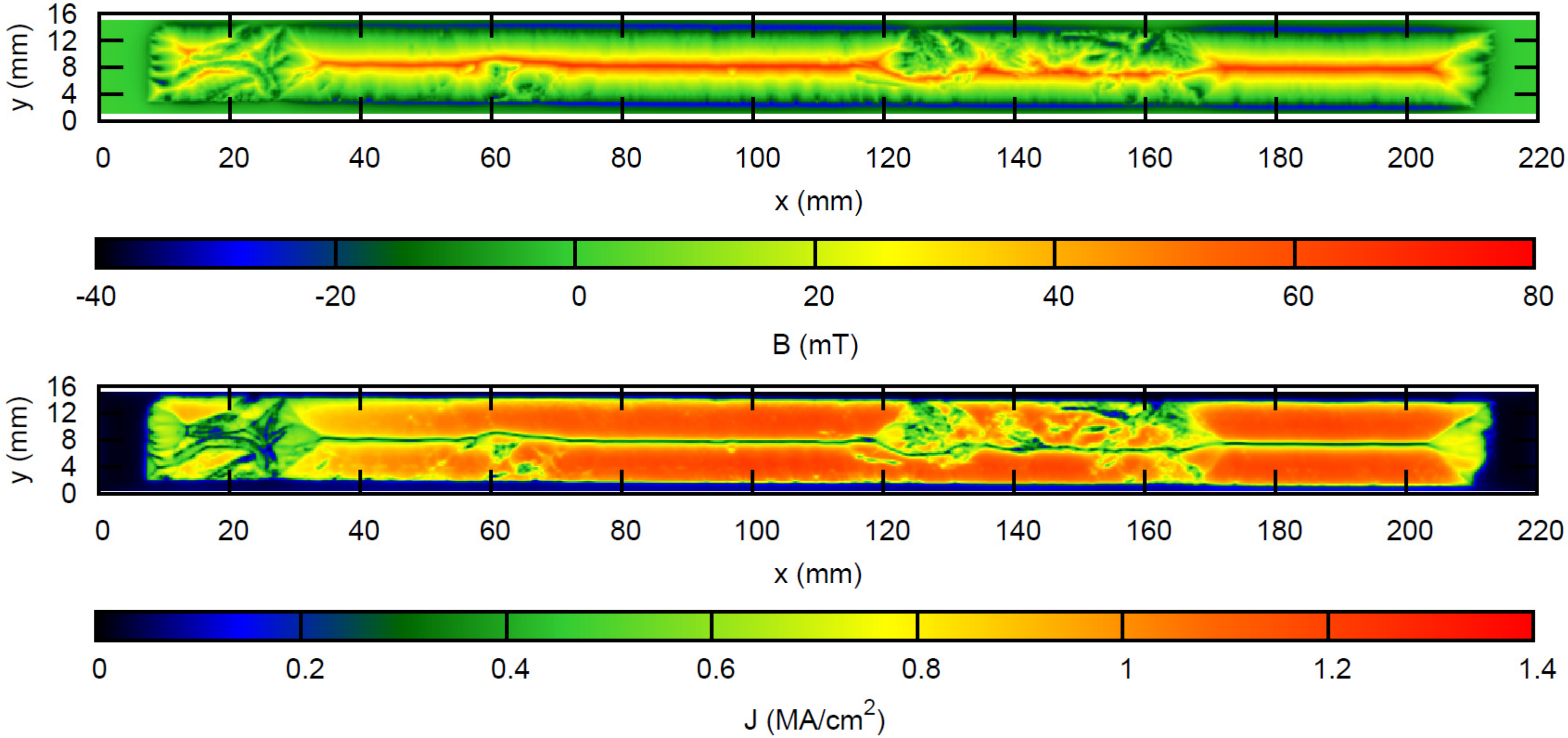






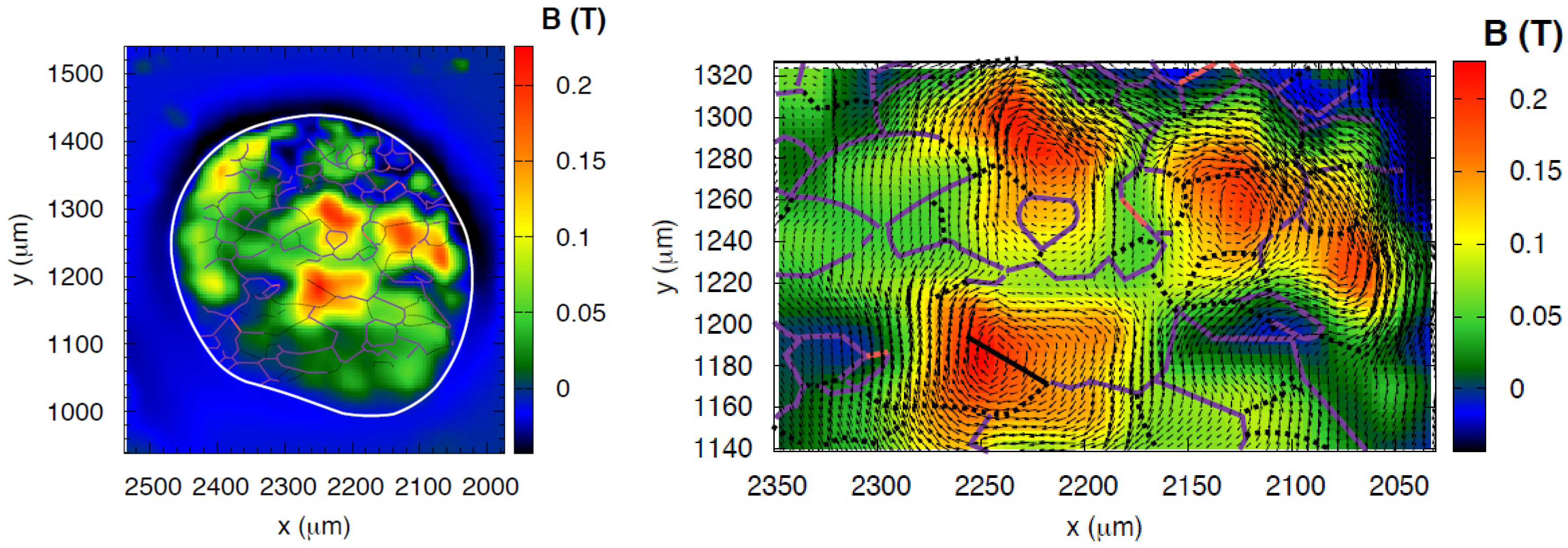


Supraleitende Bandleiter (FP-7, FWF)



Raster-Hallsondenmikroskopie

Supraleitende Bandleiter (FP-7, FWF)



Was behindert den Stromfluss?

Aufgabenstellungen für Bachelor-, Projekt- und Masterarbeiten

- In aktuelle Forschung eingebunden
- Messungen/Auswertung/Interpretation
- Numerische Simulationen
- Experimentelle Aufbauten
- Prozesssteuerung

Video Laborführung ☜

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Atom-interferometrie

Philipp Haslinger

www.haslingerlab.com

Start

Der Wissenschaftsfonds.

ESQ Discovery

VCQ
Vienna Center for Quantum Science and Technology

Lattice Atom Interferometry

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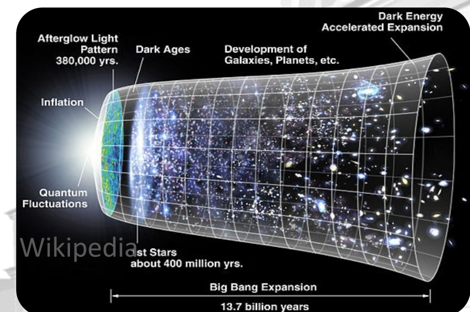
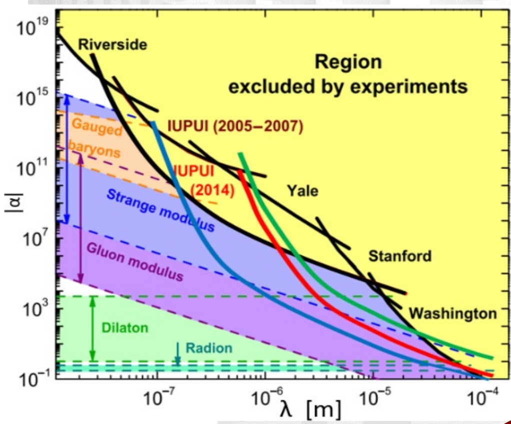
The Dark Universe

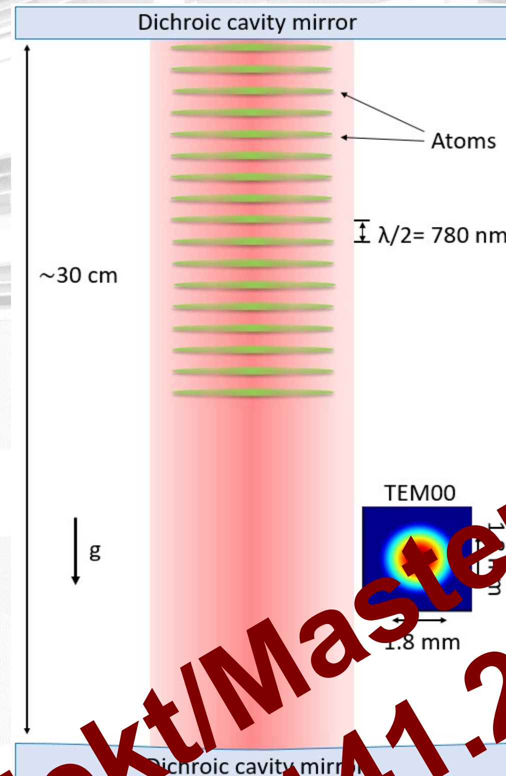


- Discover or rule out many models

Short Range Forces



- At 10 μm, forces $>10^4$ x gravity possible
- Sense effects beyond the standard model: string theory...

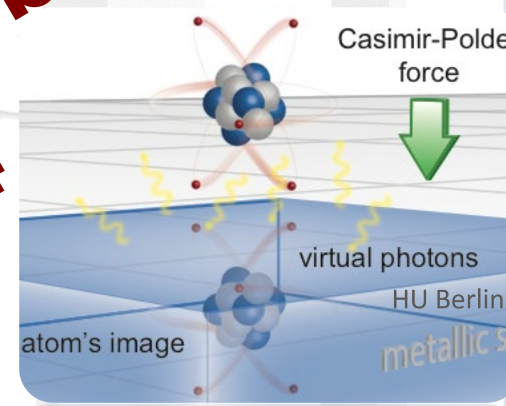


- ➢ Atoms: perfect test-particles
- ➢ Ultra long interaction times
- ➢ Map pot. energy landscape
- ➢ Miniaturized quantum sensor

Light-Induced Interaction

- Mechanical effects of thermal light
- BEC, Ultracold gasses, astrophysics,...

Casimir–Polder Interaction



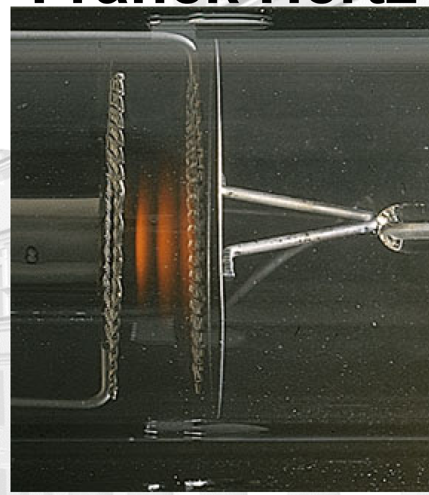
- Interaction from quantum fluctuations
- Temperature & spatial dependence

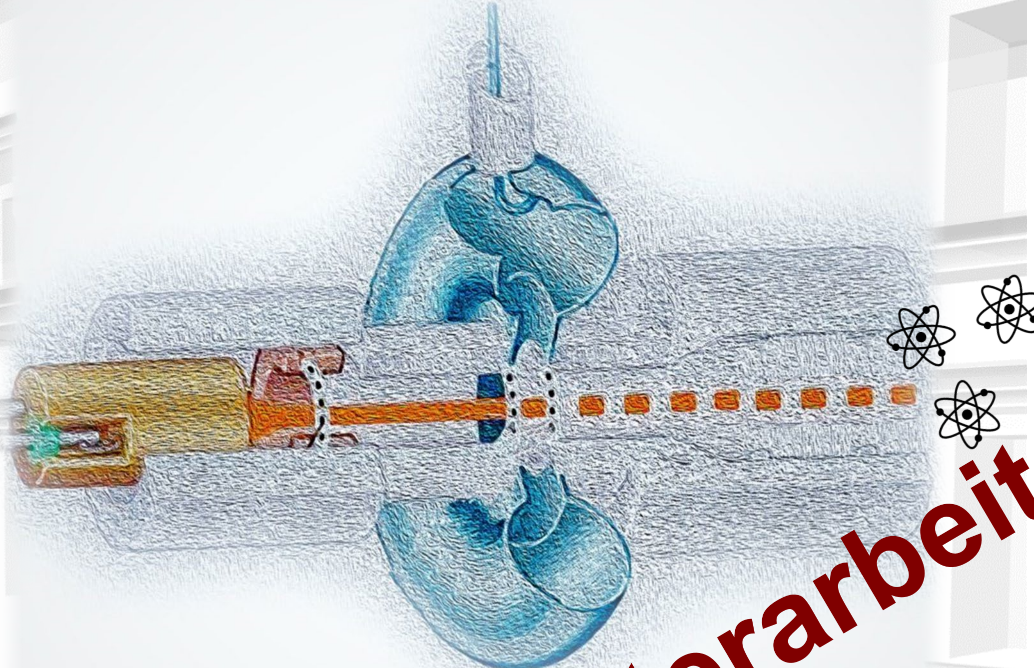
Projekt/Masterarbeiten 141.214

Quantum Klystron

Coherent Electron – Matter Interaction

Franck Hertz





A Quantum Klystron –
Controlling Quantum Systems with Modulated Electron Beams
D. Rätzel, D. Hartley, O. Schwartz, P. Haslinger
arXiv:2004.10168

Projekt/Masterarbeiten 141.214

ESQ
Discovery

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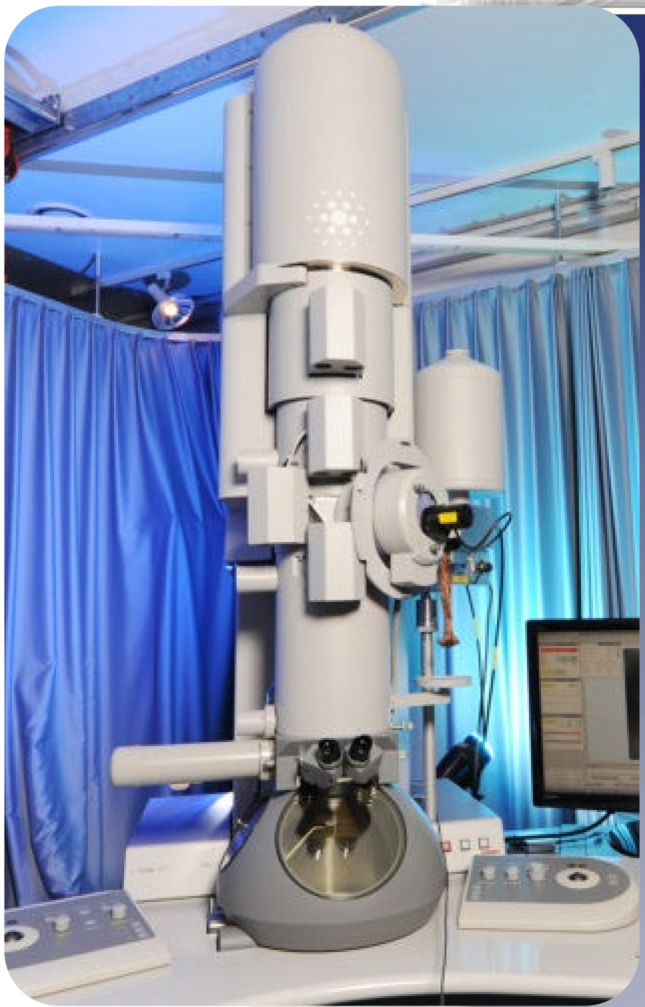
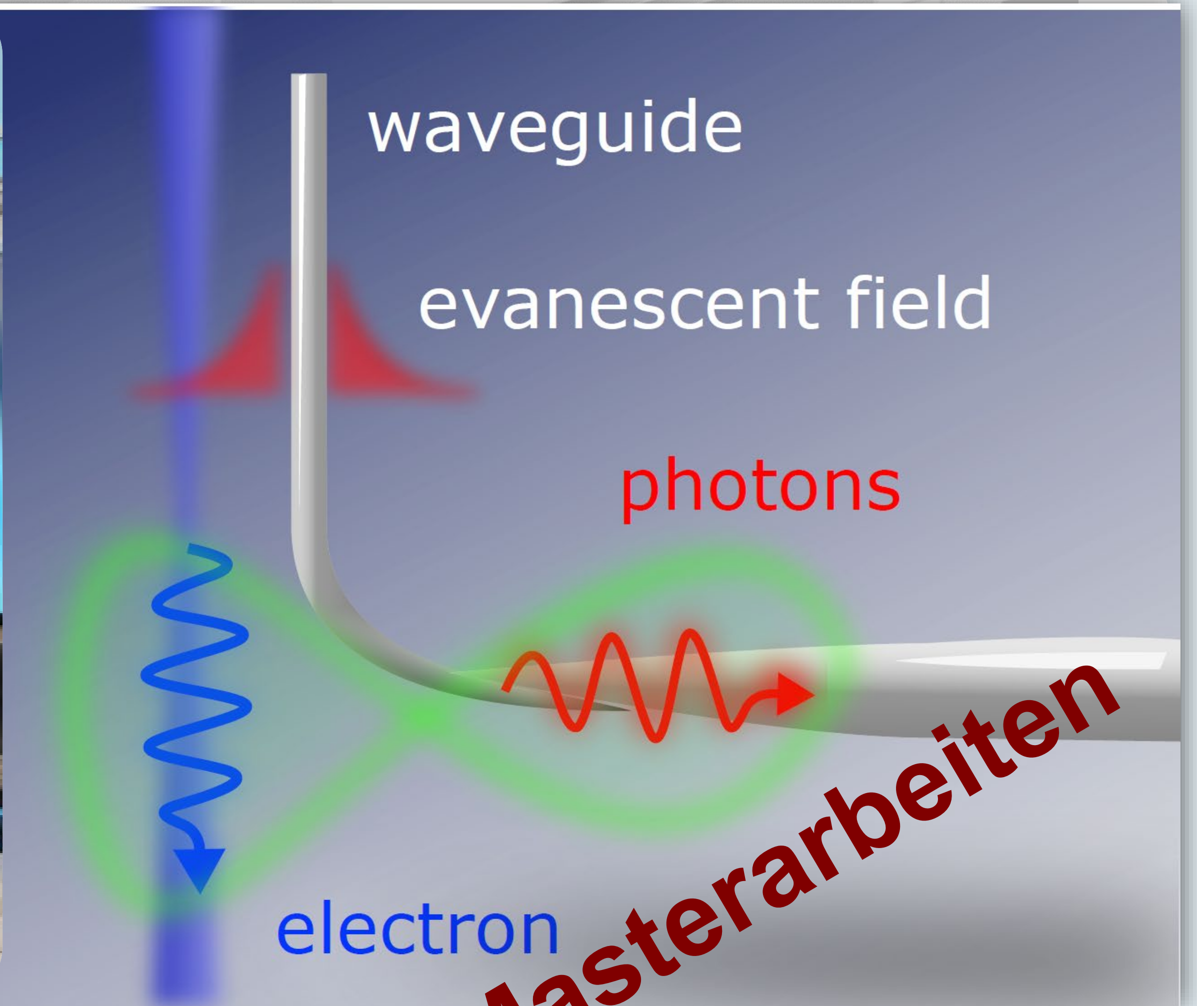
Electron – Photon Pairs

for Electron microscopy





Masterarbeiten

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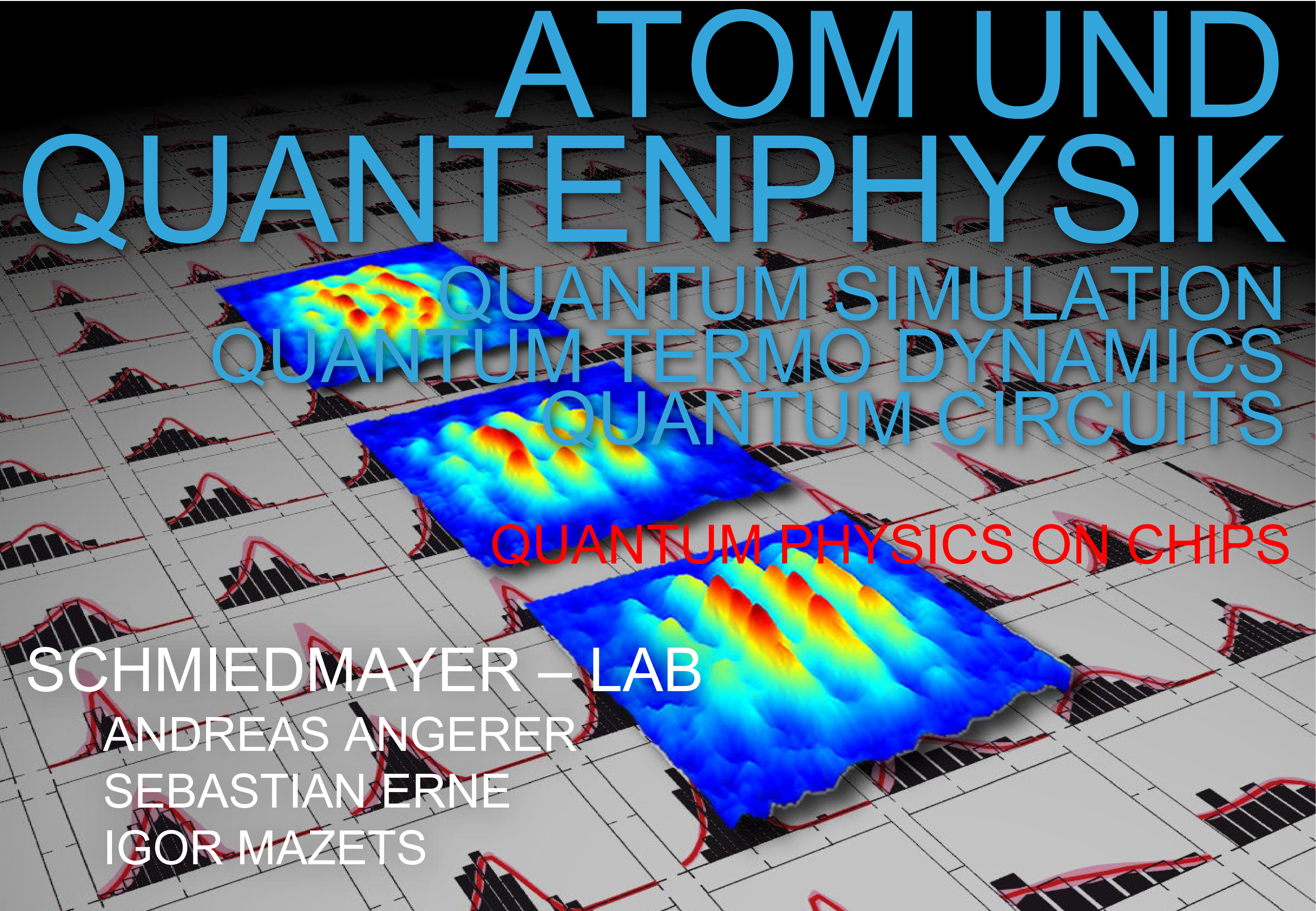
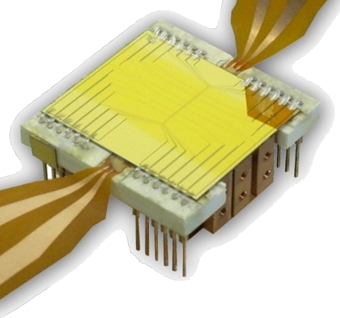
philipp.haslinger@tuwien.ac.at

ESQ Discovery


ATOM UND
QUANTENPHYSIK
QUANTUM SIMULATION
QUANTUM TERMO DYNAMICS
QUANTUM CIRCUITS
QUANTUM PHYSICS ON CHIPS
SCHMIEDMAYER – LAB
ANDREAS ANGERER
SEBASTIAN ERNE
IGOR MAZETS



Our Quantum Systems

VCQ
Vienna Center for Quantum Science and Technology

Ultracold Quantum Gases

- Bose Einstein Condensate of Atoms and Molecules
- Degenerate Fermi Gas
- Low dimensional systems

Trapped and manipulated in microscopic traps (AtomChip)

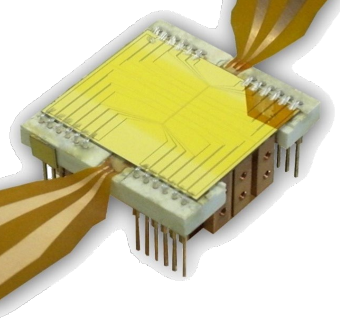
Single atom detection

Spins on quantum circuits

- Superconducting electronics
- Electron spins in Diamant
- Impurities in Quantum Crystals

20 mK environments in Cryostats

MW electronics

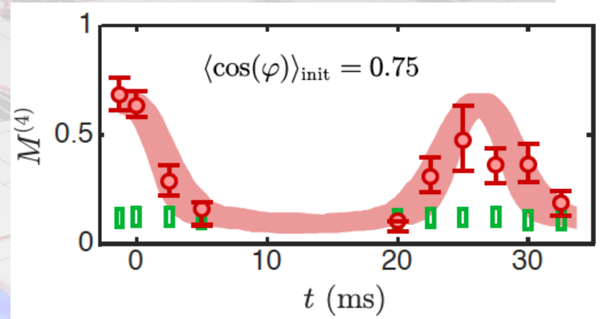


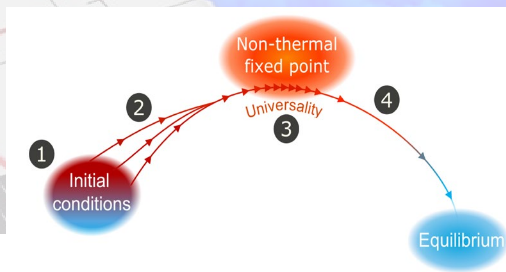
Quantum Simulation
quantum systems out of equilibrium

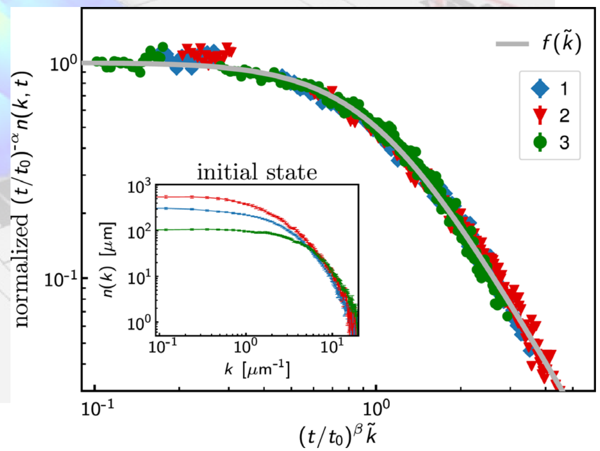
Vienna Center for Quantum Science and Technology

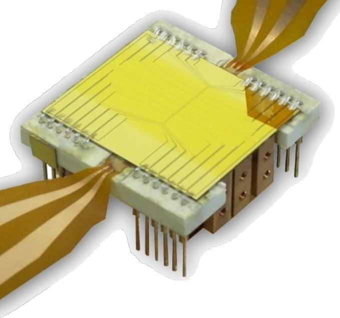
Does an isolated Quantum System Relax?

- How does classical physics emerge from the unitary evolution of quantum systems at the microscale?
- How to describe quantum systems far from equilibrium?
- Emergent physics from quantum evolution
- Universality







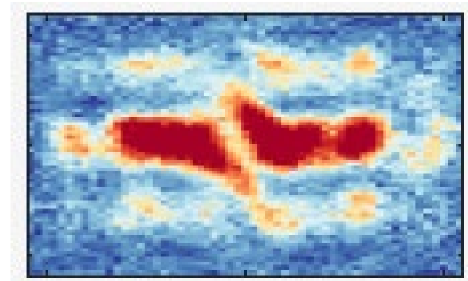


Quantum Simulation
Quantum Filed Theory in the Lab

VCQ Vienna Center for Quantum Science and Technology

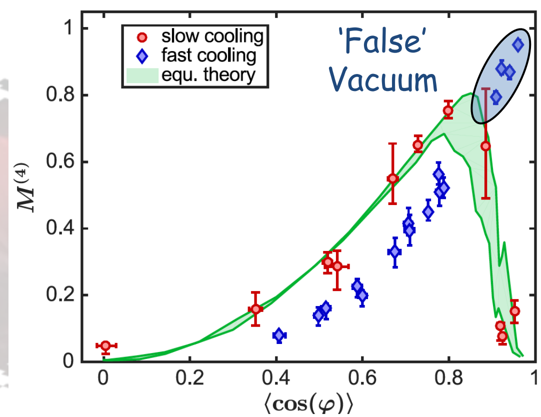
Quantum Gases are ideal tools to quantum simulate QFTs

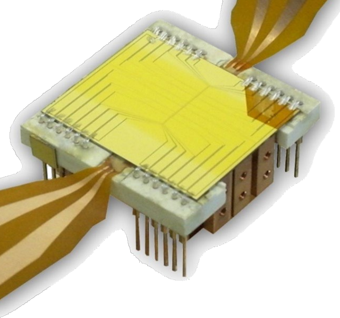
T=0	<->	vacuum
excitations	<->	particles
energy density	<->	geometry
…		



Building and probing Quantum Field Theories in the Lab

- Sine-Gordon Model
- What is the quantum Vacuum
  - Unruh radiation (what sees accelerated detector?)
  - Decay of false vacuum
  - Cosmological particle creation and Inflation
- Quantum simulating physics in curved spacetime





Quantum Thermo Dynamics

Thermal machines in the quantum world

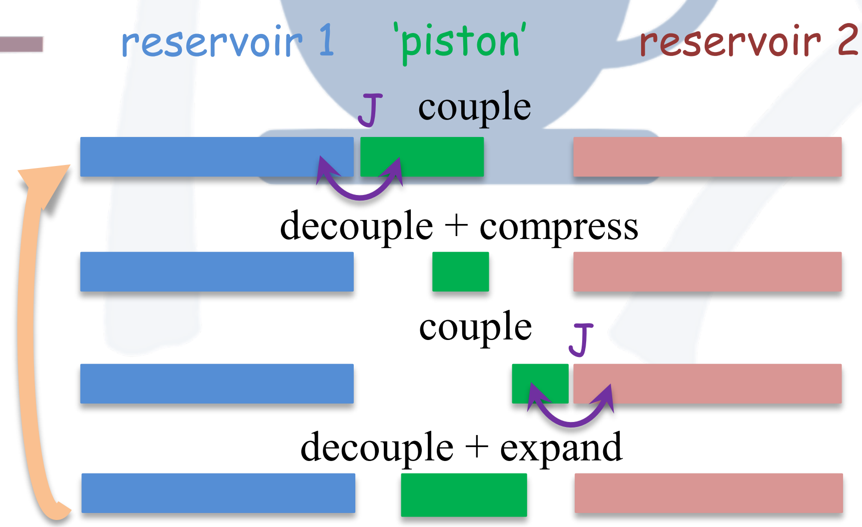
Vienna Center for Quantum Science and Technology

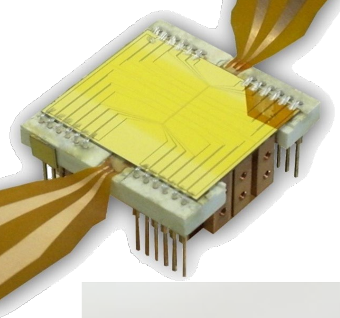
Quantum Field Machine

Build small thermal machines from quantum fields

Study interface between quantum physics and thermo dynamics

- What are the roles of quantum correlation?
- Can information fuel thermal machines?
- What is work and heat in the quantum world

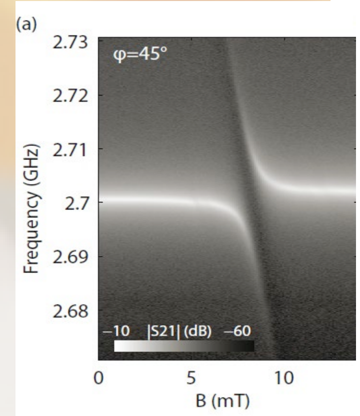


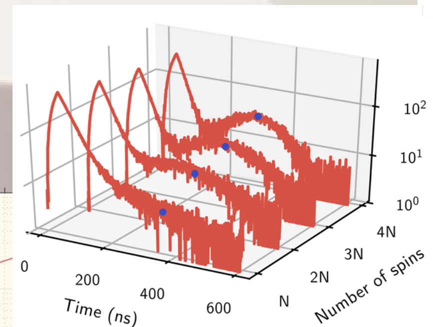


Superconducting Quantum Circuits

Couple Spins trapped in a solid state environment to Superconducting Quantum Circuits

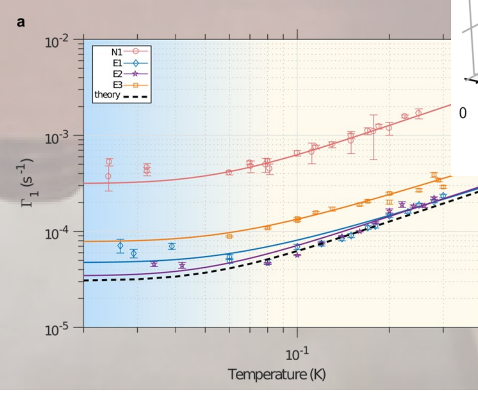
- NV⁻ color center in Diamond
- Novel system: impurities in quantum crystals
  - Para-Hydrogen
  - Solid He
  - Other spin-0 noble gas crystals





Physics:

- Superradience
- Quantum battery
- Quantum memory
- Quantum sensors



ATOM UND QUANTENPHYSIK

QUANTUM SIMULATION
QUANTUM TERMO DYNAMICS
QUANTUM CIRCUITS
QUANTUM PHYSICS ON CHIPS

BATCHELOR, UND MASTER ARBEITEN IM SCHMIEDMAYER – LAB

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Experimentelle Hochenergiephysik

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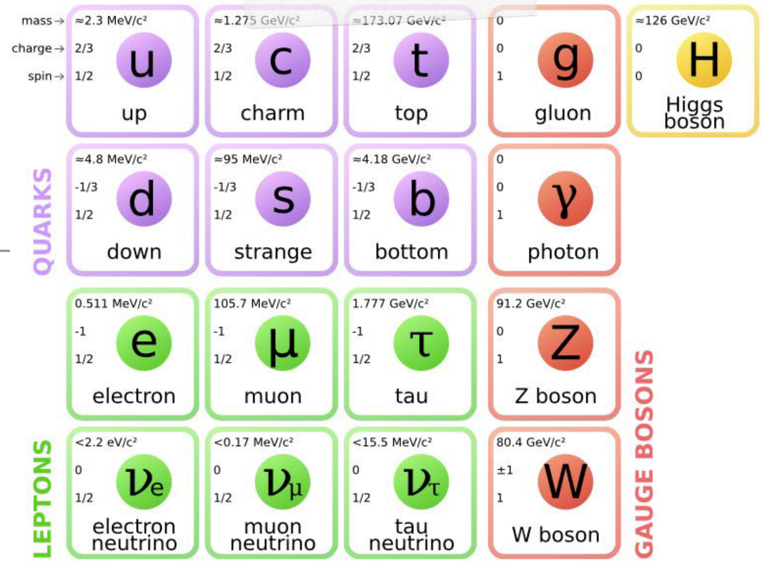
www.hephy.at

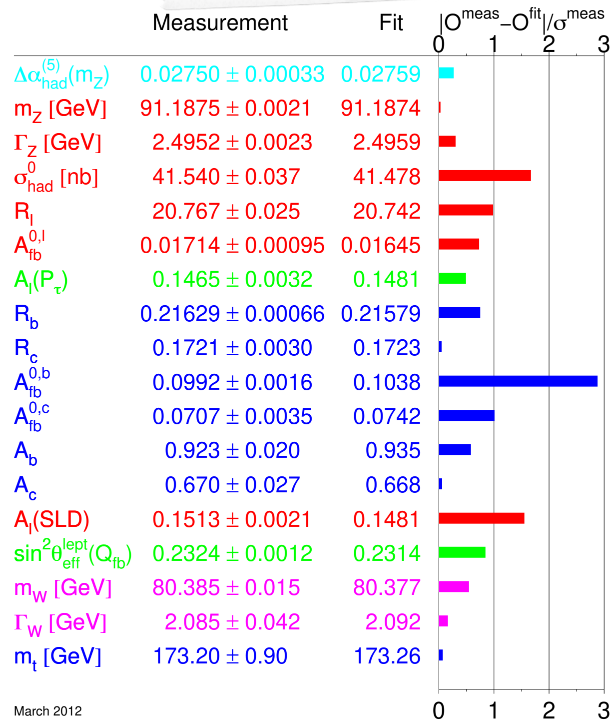
Experimentelle Hochenergiephysik

- Womit beschäftigt sich die Hochenergie(=Teilchen)physik?
    - Untersuchung der Eigenschaften der fundamentalen Bausteine des Universums
    - Wechselwirkung der fundamentalen Bausteine untereinander
- Mit welchen experimentellen Methoden wird untersucht?
    - Detektoren zum Nachweis der fundamentalen Bausteine
    - Beschleuniger um unentdeckte Massenzustände zu finden und zu untersuchen (“$E=mc^2$”)

Einleitung

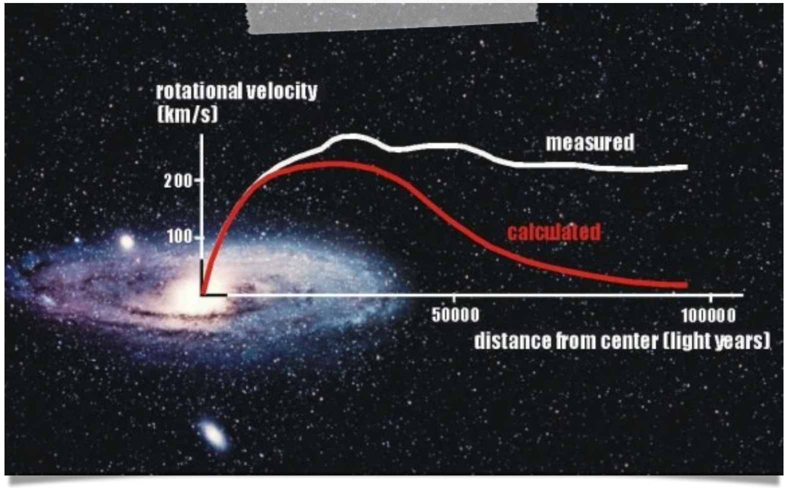
- mit dem Standardmodell der Teilchenphysik können alle mikroskopischen Phänomene erfolgreich beschrieben werden
- mit dem Higgs-Boson wurden alle Teilchen des Standardmodells experimentell nachgewiesen
    - das am LHC beobachteten Higgs-Boson hat die Eigenschaften des Higgs-Boson des Standardmodells
- **man erwartet, daß das Standardmodell der Teilchenphysik nur eine “effektive Theorie" einer umfangreicheren Theorie ist**

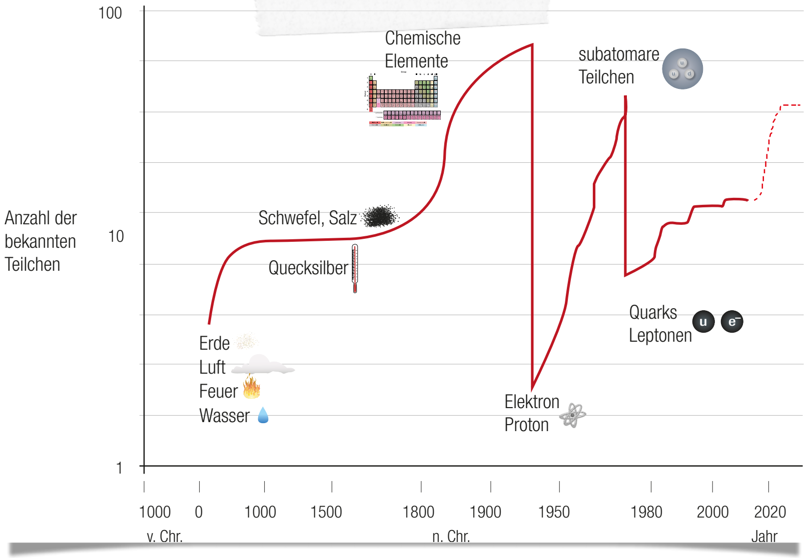




Das Standardmodell: offene Fragen

- es existieren Beobachtungen auf astrophysikalischen Skalen, die sich nicht mit Teilchen und Wechselwirkungen aus dem Standardmodell beschreiben lassen
- das Standardmodell der Teilchenphysik
  - erklärt nicht die Gravitation
  - enthält keinen Kandidaten für die “Dunkle Materie”
  - enthält nicht genug CP-Verletzung um die Baryon-asymmetrie zu erklären
- Standpunkt eines Teilchenphysikers: diese neuen Phänomene müssen durch neue Teilchen und Kräfte beschrieben werden
- **Suche nach neuen Teilchen und neuen Symmetrien**





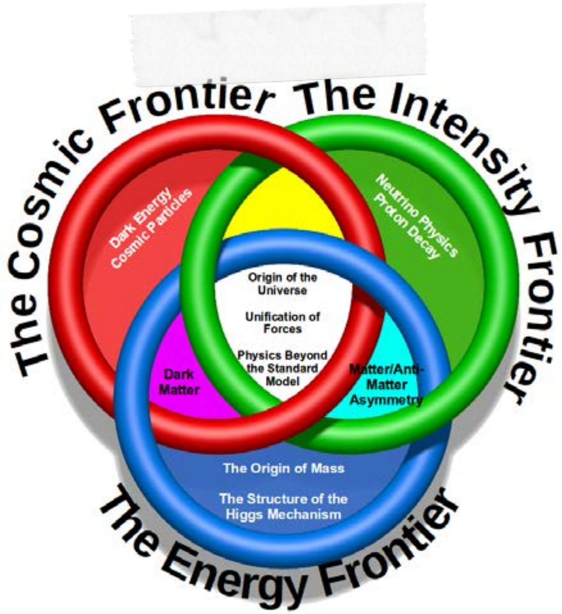
Trinität der Teilchenphysik

- ein schlüssiges Bild der Physik jenseits des Standardmodells erfordert eine kohärente Interpretation mit unterschiedlichen Ansätzen

  - **Energie:** $E=mc^2$
    ("Entdeckung des Higgs")

  - **Intensität:**
    Vergleich von Präzisionsmessungen mit theoretischen Vorhersagen

  - **Kosmische Untersuchungen:**
    Bestätigung des Teilchencharakters als Ausgangspunkt der astrophysikalischen Beobachtungen



Das Institut für Hochenergiephysik (HEPHY)

- zentraler Punkt der modernen Hochenergiephysik:
  Suche nach einer Physik jenseits des Standardmodells

- Am HEPHY werden alle drei Ansätze verfolgt

  - Forschung am CMS-Experiment am LHC am CERN

  - B-Flavour-Physik am Belle / Belle II-Experiment am KEK in Tsukuba (Japan)

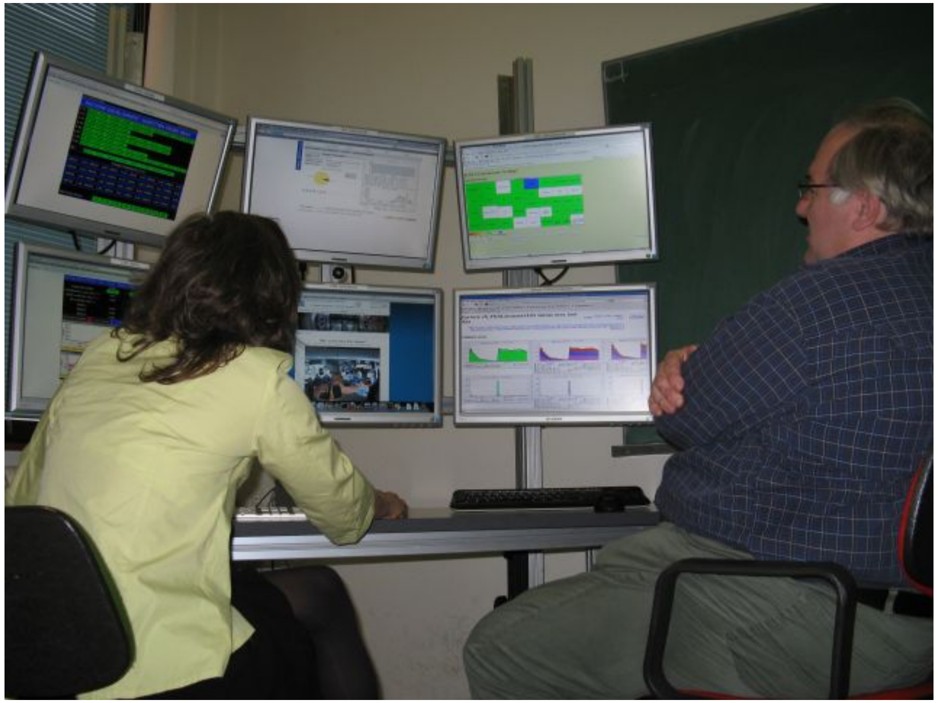
  - Suche nach “Dunkler Materie” mit dem CRESST /EURECA-Detektor

Institut für Hochenergiephysik
Österreichischen Akademie der Wissenschaften
Nikolsdorfer Gasse 18
1050 Wien

www.hephy.at

Forschung am HEPHY

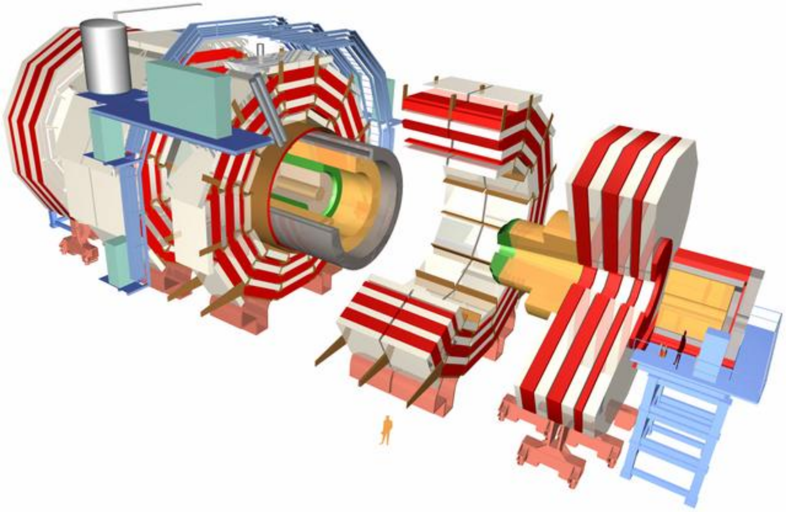
- experimentelle Hochenergiephysik am HEPHY umfasst zwei Schwerpunkte (die man eigentlich nicht strikt trennen kann…)
  - Entwicklung und Bau von Experimenten für die Teilchenphysik
  - Analyse von Daten aus den Experimenten der Teilchenphysik



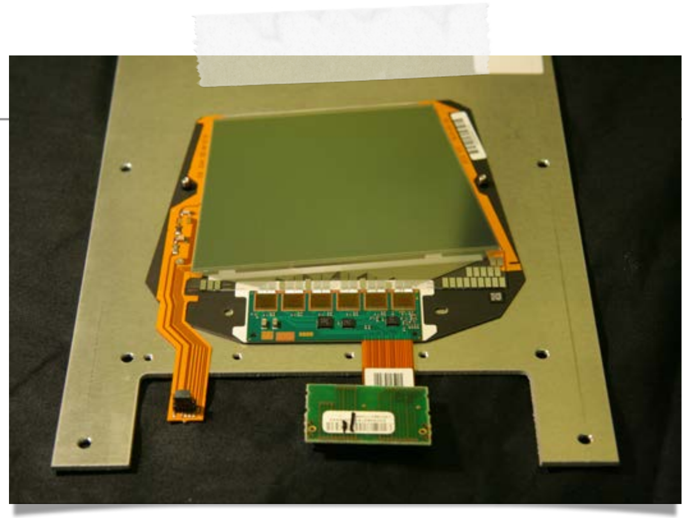
Physik am CMS-Experiment am LHC

- **Large Hadron Collider:**
  Proton-Proton-Kollisionen bei einer Schwerpunktsenergie von 13 TeV
  leistungsstärkster Beschleuniger weltweit
  Entdeckung des Higgs-Bosons im Jahr 2012

- **CMS (Compact Muon Solenoid):**
  eines von zwei Mehrzweck-experimenten am LHC

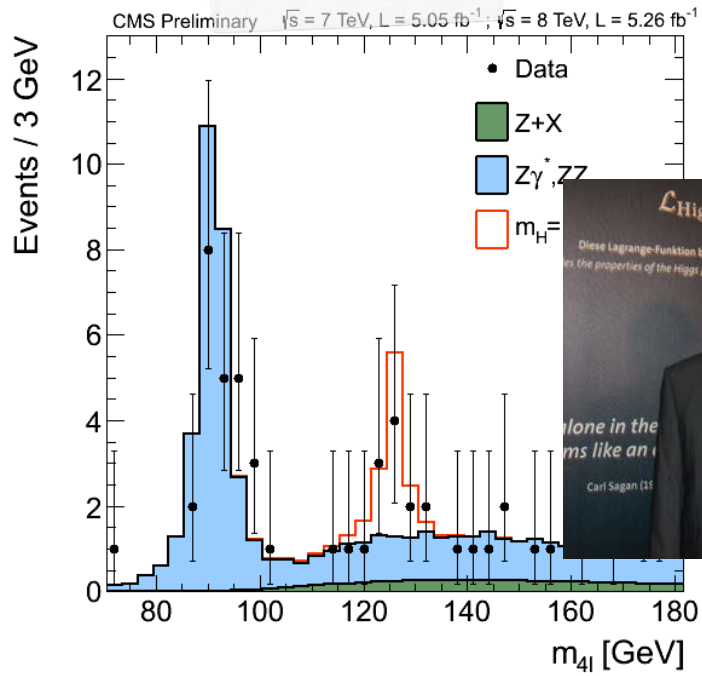


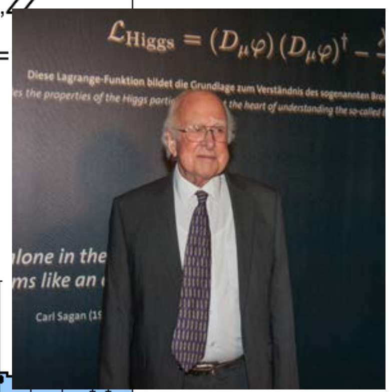
Beiträge von HEPHY zu CMS



- **Entwicklung & Bau & Betrieb**
  Trigger des Experiments
  Spurdetektor und
  Kalorimeter des Experiments
  Rekonstruktionsalgorithmen

- **Datenanalyse**
  Studien zur Starken
  Wechselwirkung (QCD)
  Suche nach Supersymmetry
  Charakterisierung des Higgs-Bosons



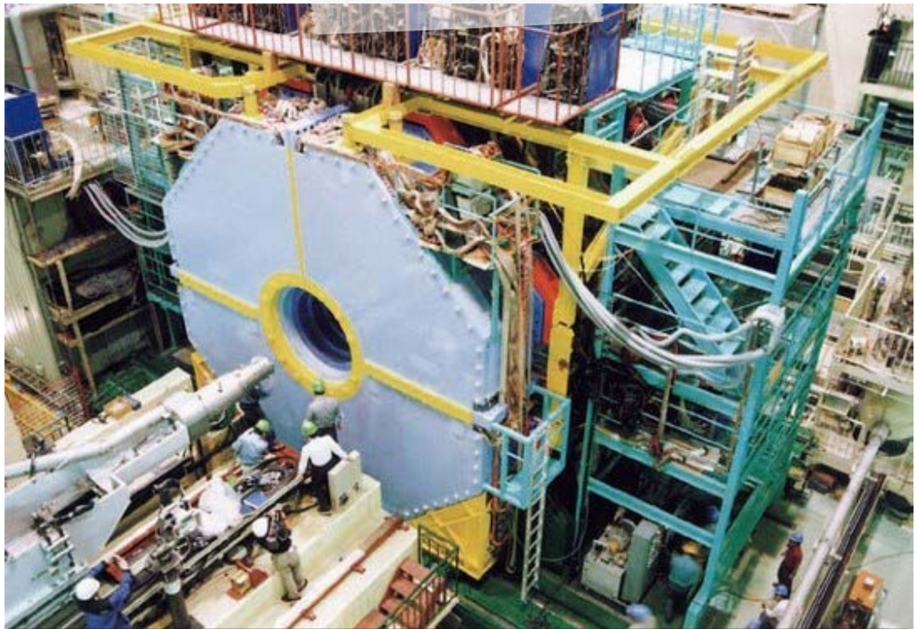


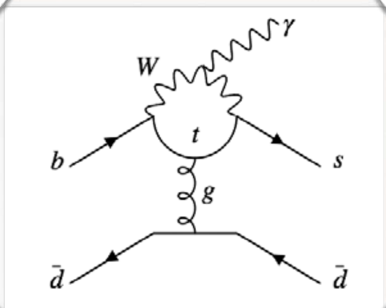
Präzisionsmessungen am Belle II-Experiment

- Belle / Belle II zeichnet Daten aus e^+e^-- Kollisionen am KEK auf

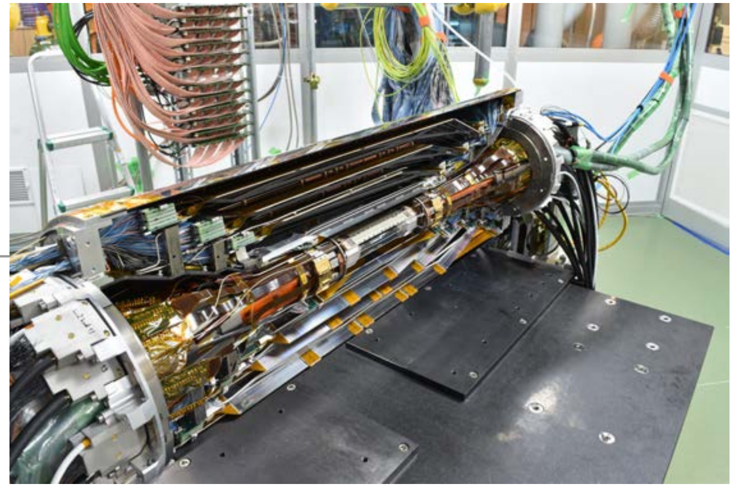
- Präzisionsmessungen aus dem Zerfall des B-Mesons

- Entdeckung der CP-Verletzung im B-System

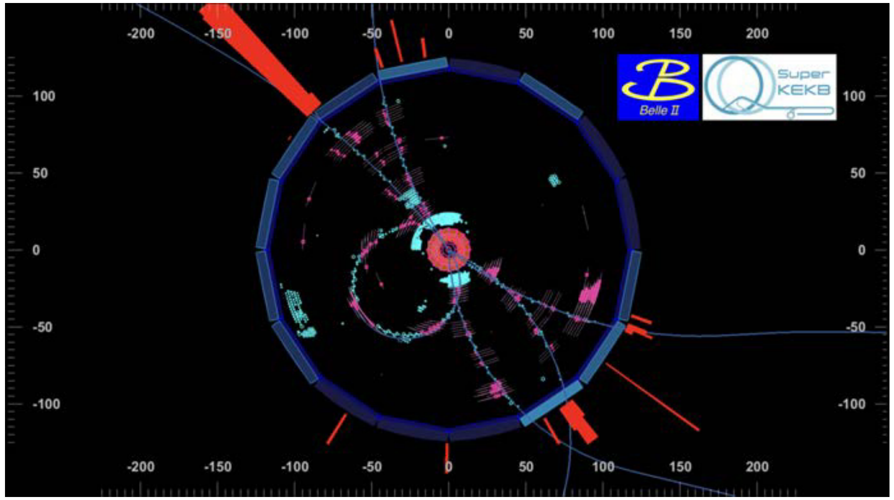




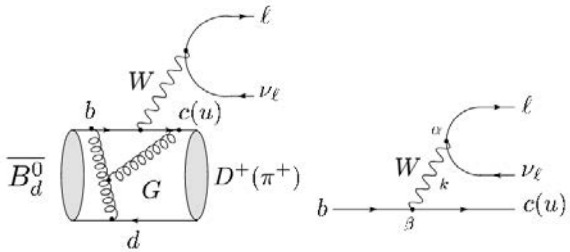
Beiträge von HEPHY zu Belle II



- Entwicklung und Bau des Siliziumstreifendetektor des Experiments
    - start Experiments im März 2019



- Entwicklung von Rekonstruktionsalgorithmen
- Analyse von B-Meson-zerfällen mit Leptonen im Endzustand



 Dienstag, 26. März 2019

Fluglotsen-Streik führte zu Ausfällen

Die Austrian Airlines strichen am Montag fünf Flüge. Auch bei anderen Fluglinien kam es zu Ausfällen und Verzögerungen, weil der Flughafen Wien die Zahl der Landungen von 48 auf 16 kürzen musste. Grund dafür war eine Betriebsversammlung der Fluglotsen. Im Hintergrund tobt ein wilder Streit um die Gehälter.

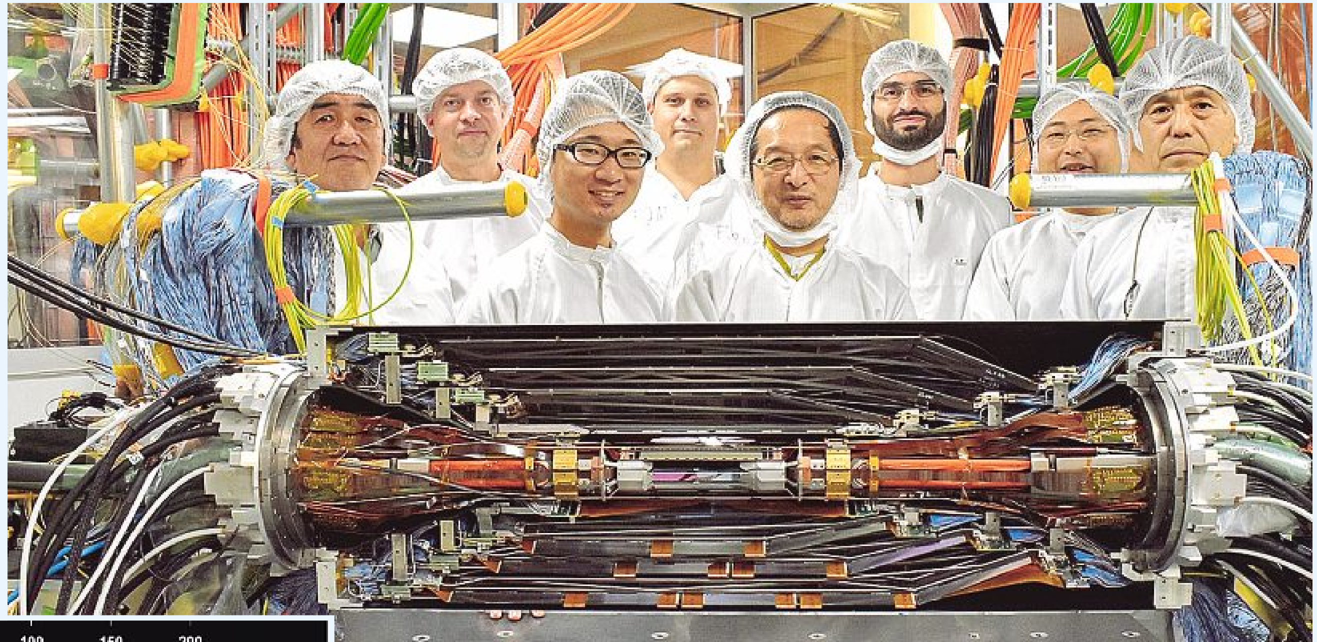


Foto: KEK

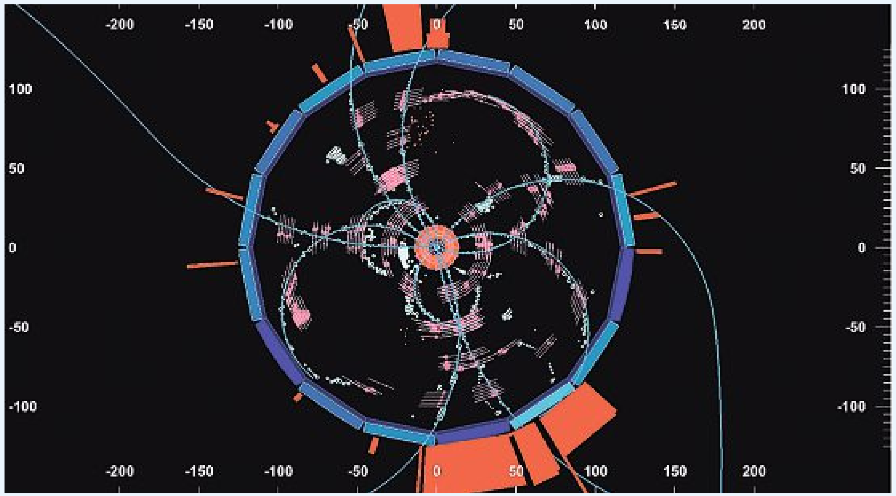


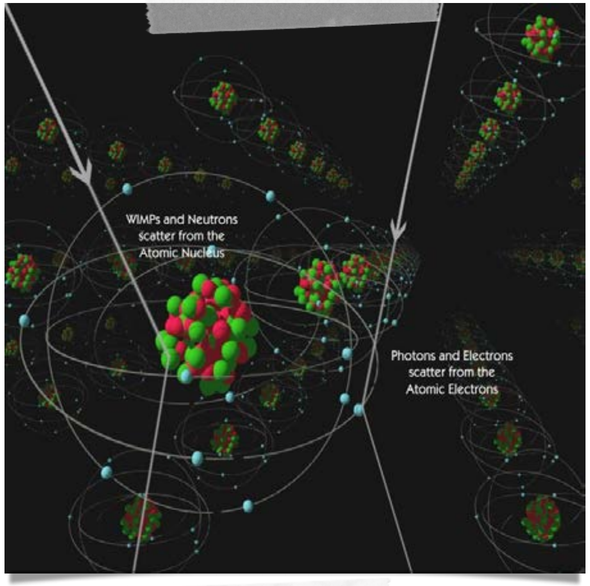
Foto: KEK

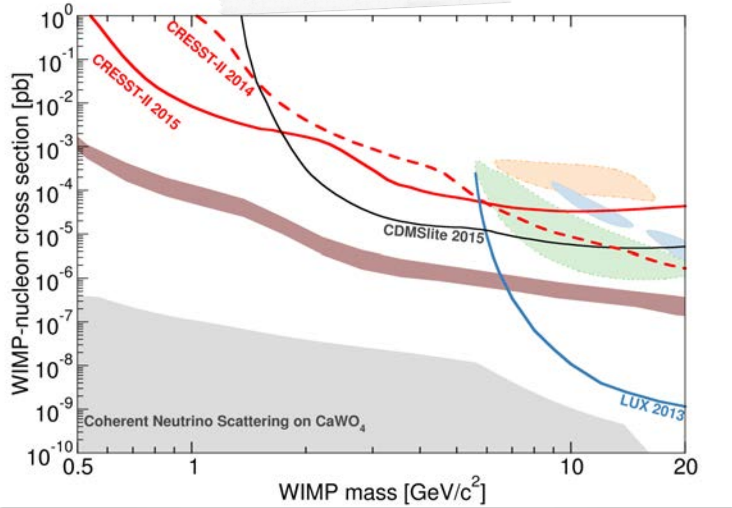
Heimische Physiker in Japan

Neues Teilchenbeschleuniger-Experiment in Japan gestartet: Derzeit lassen sich fünf Prozent des Energieinhaltes beschreiben, nicht aber die Eigenschaften dunkler Energie und dunkler Materie. Der Teilchenbeschleuniger in Tsukuba besteht aus einem unterirdischen, drei Kilometer langen Ring, in dem auf zwei gegenläufigen Umlaufbahnen Elektronen und ihre Antiteilchen beschleunigt werden. Im Inneren des Detektors stoßen sie zusammen. Beim Bau war ein elfköpfiges Team der Akademie der Wissenschaften federführend. Dieses Instrument vermisst die Teilchenbahnen nahe dem Kollisionspunkt.

Suche nach “Dunkler Materie” mit CRESST

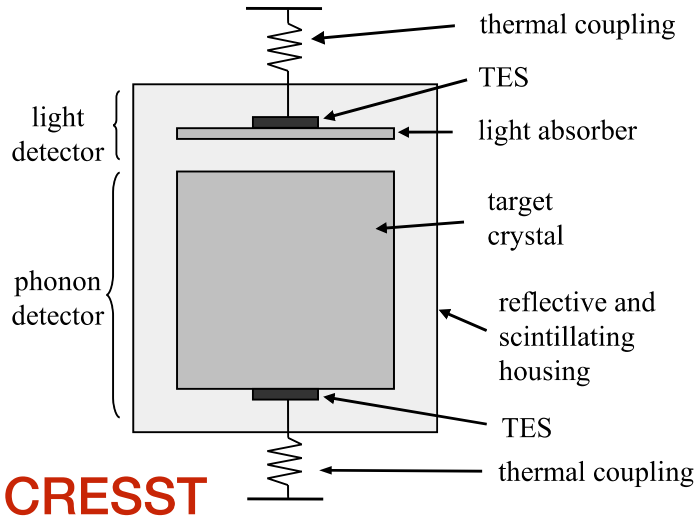
- Erklärung der “Dunklen Materie” über schwach wechselwirkende massive Teilchen sehr vielversprechend
- Nachweis über elastische Streuung an einem Kern
- bisher noch kein Signal beobachtet und nur Ausschlussgrenzen bestimmt





Suche nach “Dunkler Materie” am HEPHY

- neue experimentelle Arbeitsgruppe gemeinsam mit der TU Wien seit Oktober 2013
- Beiträge zum Bau der Elektronik für CRESST III und zukünftige Dunkle Materie Experimente
- Simulation des Untergrunds und Datenanalyse
- Neu: Spin-off - Neutrinophysik



Suche nach “Dunkler Materie” am HEPHY

AUSTRIA PRESSE AGENTUR

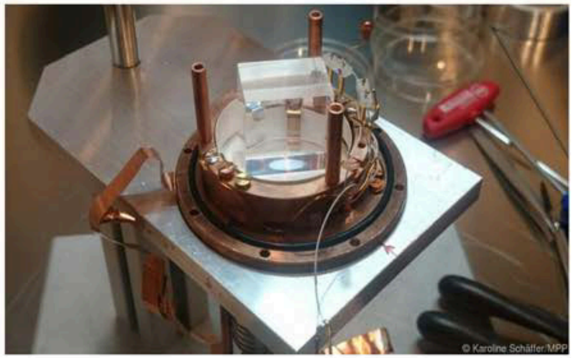
SCIENCE News Themen Termine & Tipps Partner Suche Über uns ANMELDEN

Feb. 2021

TECH | APA / 09.02.2021, 10:15

Österreichische Physiker suchen tief im Berg nach Dunkler Materie

Mit einem neuen Experiment hofft ein internationales Forscherteam mit österreichischer Beteiligung der rätselhaften Dunklen Materie im Universum auf die Spur zu kommen. Mit speziellen Tieftemperatur-Detektoren wollen sie im italienischen Untergrundlabor Gran Sasso in 1.400 Meter Tiefe Signale eines anderen Versuchs überprüfen, der seit 20 Jahren Hinweise auf die Existenz der Dunklen Materie liefert. Bisher ist das mit noch keinem anderen Experiment gelungen.



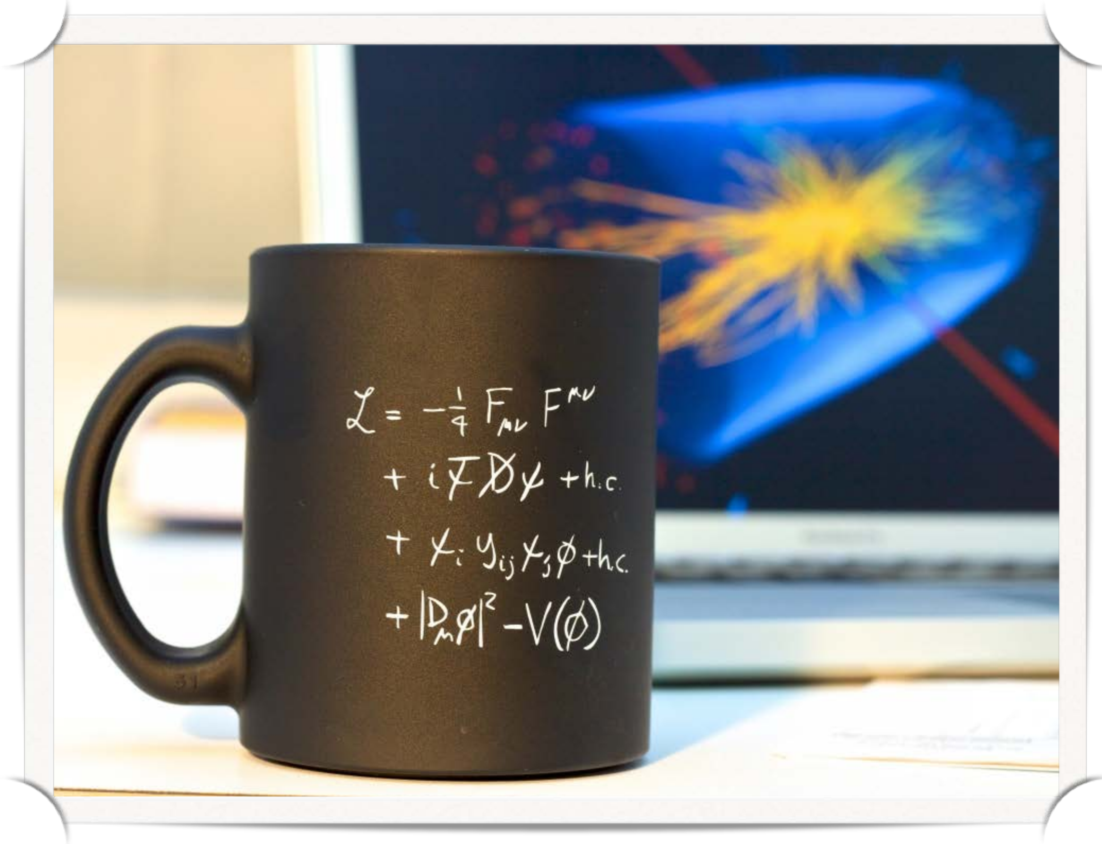
Karoline Schäffer/MPP

Offenes Detektormodul des COSINUS-Experiments

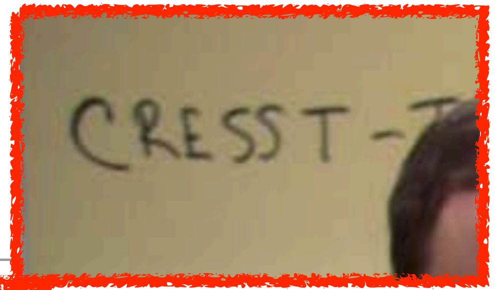
https://science.apa.at/power-search/12250287245088929339

Hochenergiephysik am HEPHY

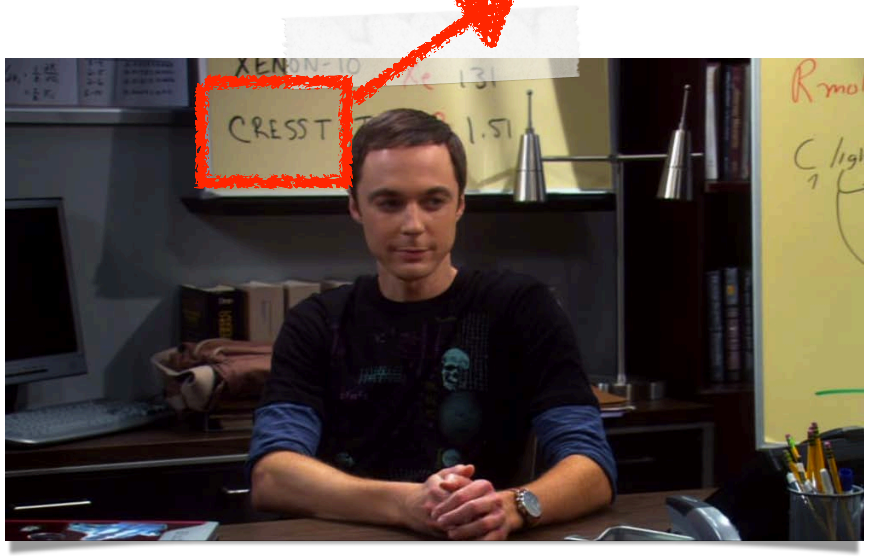
- die experimentelle Forschung am HEPHY wird komplementiert durch eine kleine Theoriegruppe
    - Starke Wechselwirkung
    - Supersymmetry
    - Dunkle Materie

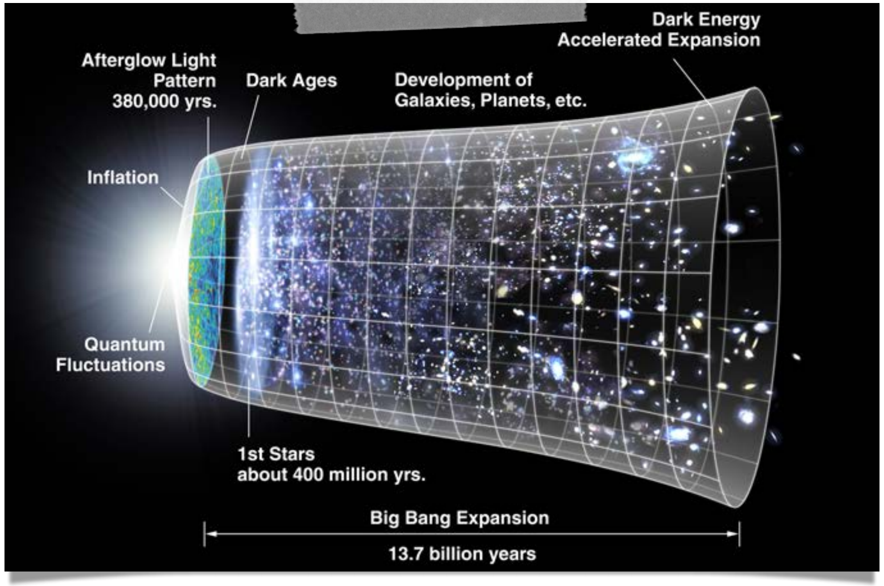


Experimentelle Hochenergiephysik



- experimentelle Hochenergiephysik ist “Big Bang Experiment”
- Die TU Wien und das HEPHY tragen zu den führenden Experimenten der Teilchenphysik bei
- sie sind herzlich eingeladen uns jederzeit am HEPHY zu besuchen

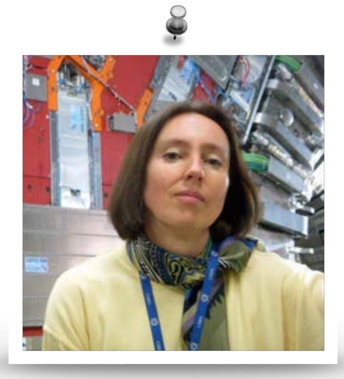


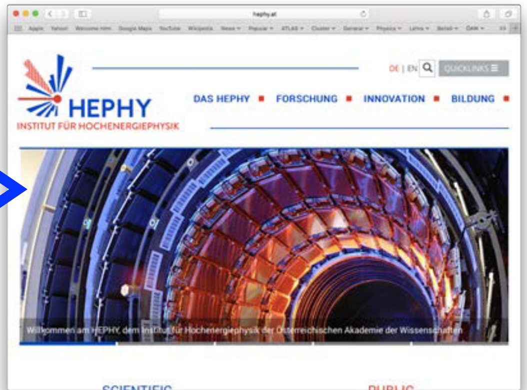


Dozenten am Atominstitut und HEPHY

- **Manfred Krammer***
- **Manfred Jeitler**
- **Christoph Schwanda**
- **Jochen Schieck**
- **Robert Schöfbeck**
- **Claudia Wulz**

www.hephy.at





* momentan CERN

https://www.youtube.com/watch?v=Fnk4cUcMYog