WESTFÄLISCHE WILHELMS-UNIVERSITÄT MÜNSTER

The activities of our research group

Annual reteat of DFG Research Training Group
"Strong and Weak Interactions
– from Hadrons to Dark Matter"
November 24-26, 2015, Telgte

Christian Weinheimer

- Direct search for the neutrino mass
with the KATRIN experiment

- Search for Dark Matter
search for (k)eV sterile neutrinos with KATRIN
search for WIMPs with XENON

- QED precision tests by laser spectroscopy with highly charged within APPA/SPARC

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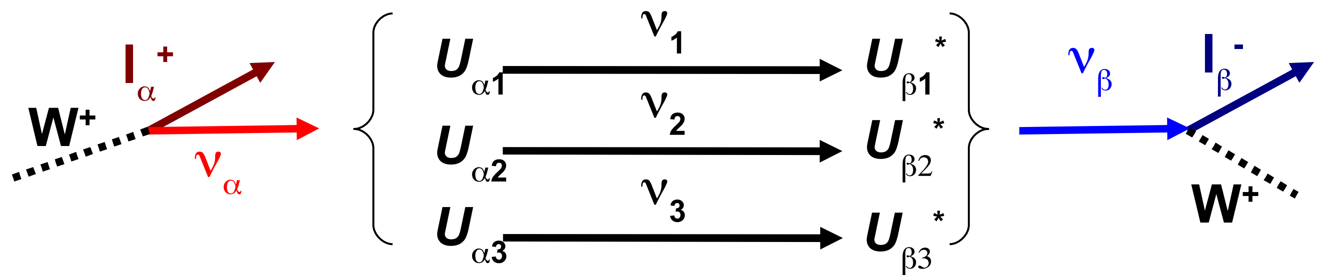
Evidence for hot (neutrinos) and warm/cold dark matter (WIMPs?)

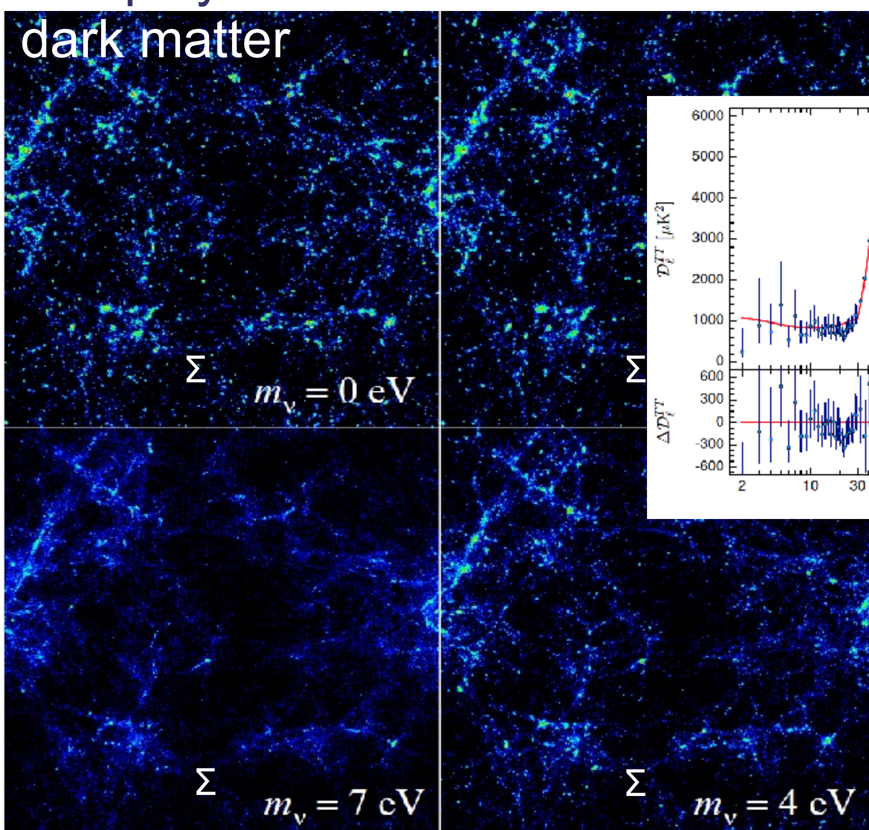
Neutrino oscillations

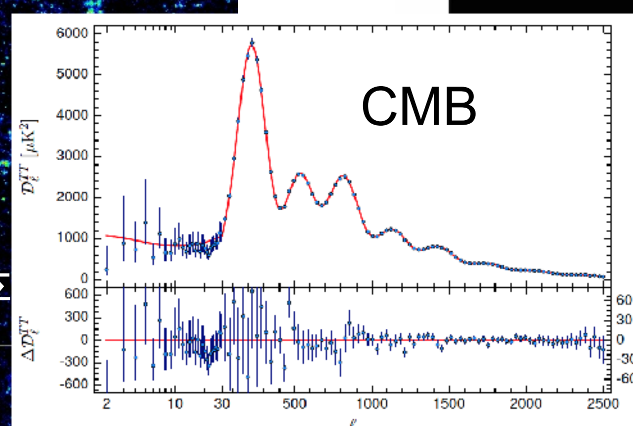
→ non-zero neutrino masses
→ beyond the Standard Model



Structure formation

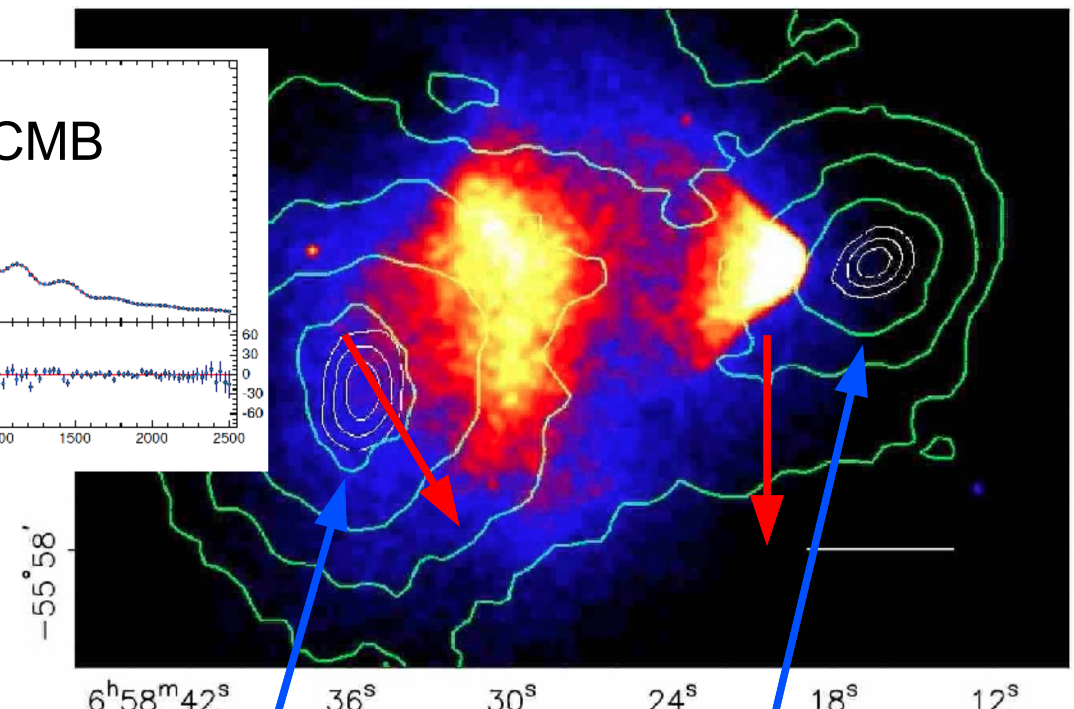
interplay between hot and warm/cold dark matter





Evidence for exotic dark matter

gas from Chandra x-ray telescope



mass from gravitational lensings with HST

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Direct determination of $m(\nu_e)$ from β decay

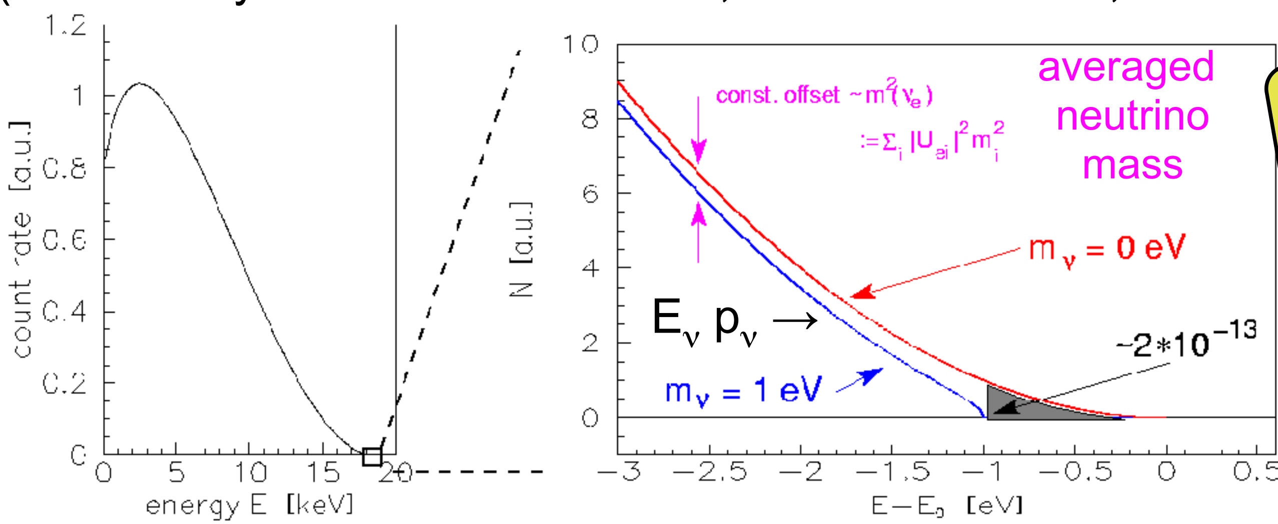
β decay: $(A,Z) \rightarrow (A,Z+1)^+ + e^- + \bar{\nu}_e$

Complementary to $0\nu\beta\beta$ and cosmology

β: $dN/dE = K\ F(E,Z)\ p\ E_{tot}\ (E_0-E_e)\ \sqrt{(E_0-E_e)^2 - \text{"}m(\nu_e)\text{"}^2}$

phase space: p_e (from p), E_e (from E_{tot}), E_ν (from (E_0-E_e)), p_ν (from the square-root term)

(modified by electronic final states, recoil corrections, radiative corrections)



E.W. Otten & C. Weinheimer, Rep. Prog. Phys. 71 (2008) 086201

G. Drexlin, V. Hannen, S. Mertens, C. Weinheimer, Adv. High Energy Phys., 2013 (2013) 293986

Need: **low endpoint energy** $\Rightarrow$ **Tritium ^3H (^{187}Re, ^{163}Ho)**

very high energy resolution &
very high luminosity &
very low background
$\Rightarrow$ **MAC-E-Filter** **(or bolometer for ^{187}Re, ^{163}Ho)**

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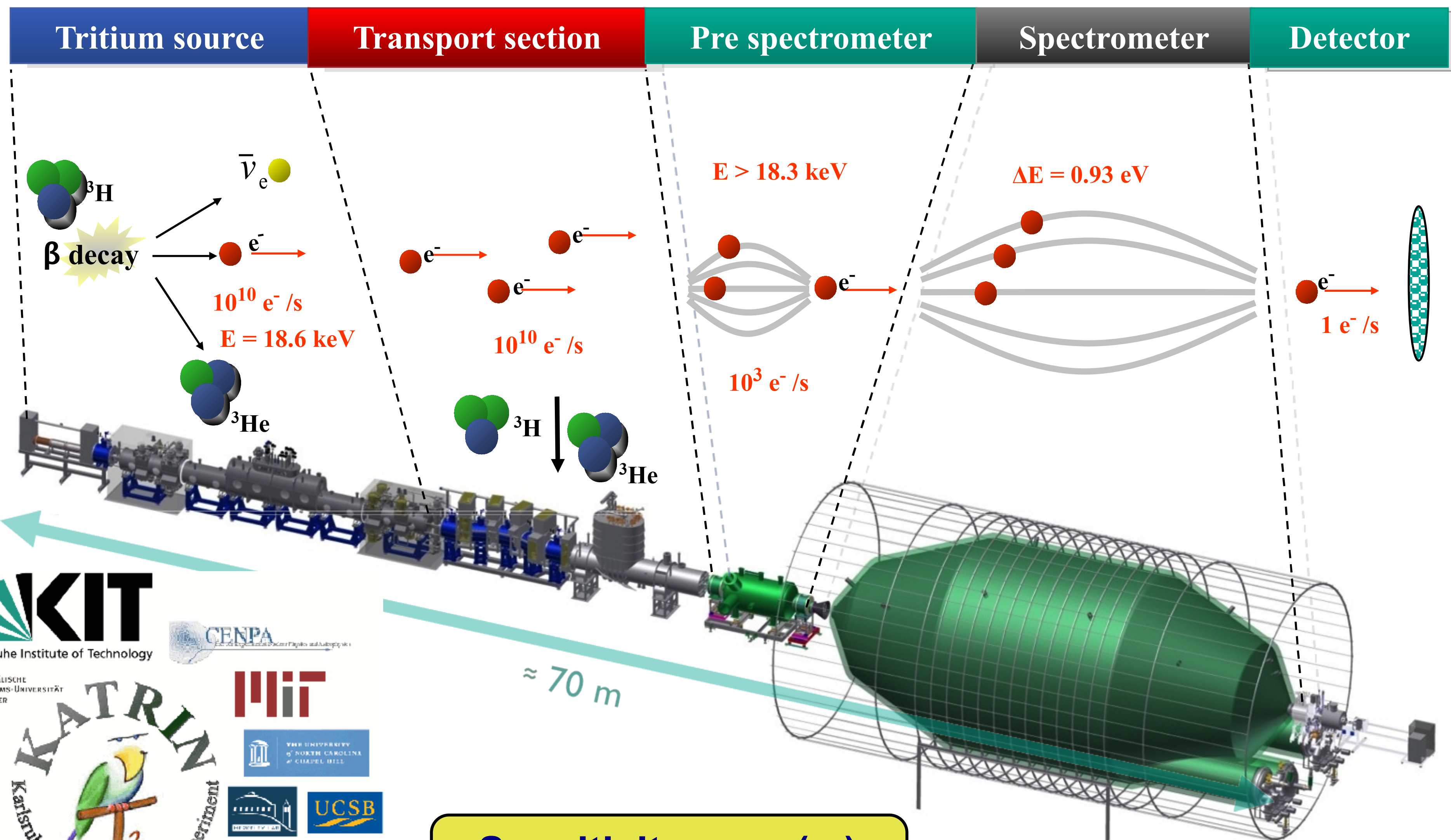
The Karlsruhe Tritium Neutrino Experiment
KATRIN - overview

Dr. Volker Hannen

Dr. Philipp Ranitzsch



Sensitivity on $m(\nu_e)$:

$2\ eV/c^2 \rightarrow 200\ meV/c^2$

Suppress secondary electron background from walls on high potential

Secondary electrons from wall/electrode

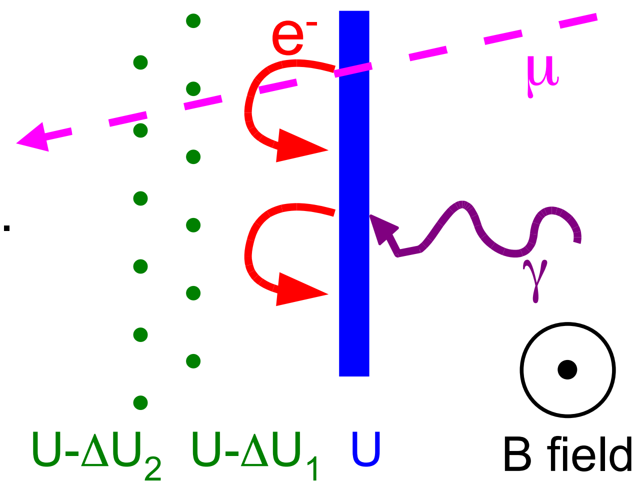
by cosmic rays, environmental radioactivity, ...

Excellent magnetic shielding by nearly perfect axial sym.

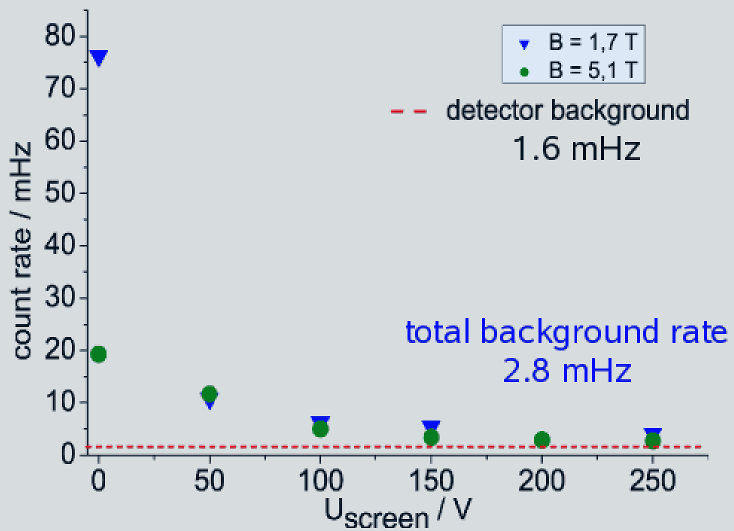
Additionally double layer wire electrode

on slightly more negative potential

(ca. 23,000 wires, 200 μm precision, UHV compatible)

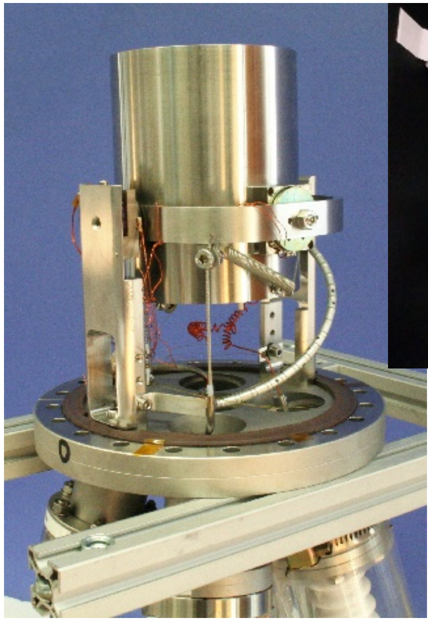


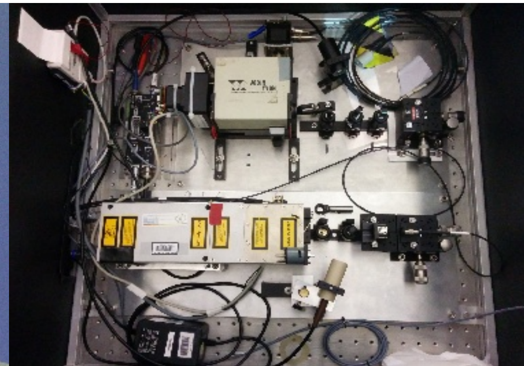
Background suppression successfully tested at the Mainz MAC-E filter:

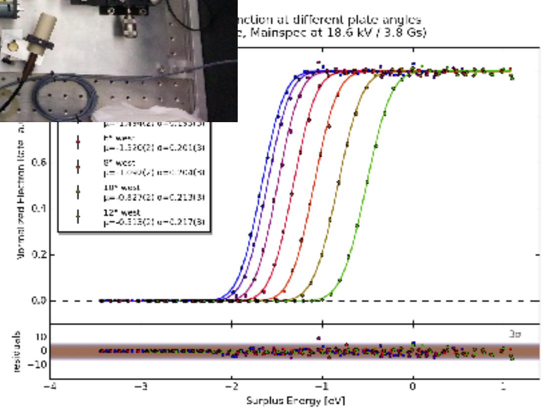


Dipl. thesis B. Ostrick (U Mainz, 2002), PhD thesis B. Flatt (U Mainz, 2004)

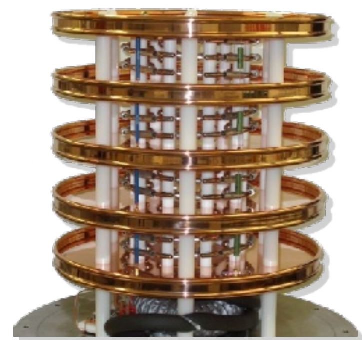
Other developments and contributions to KATRIN



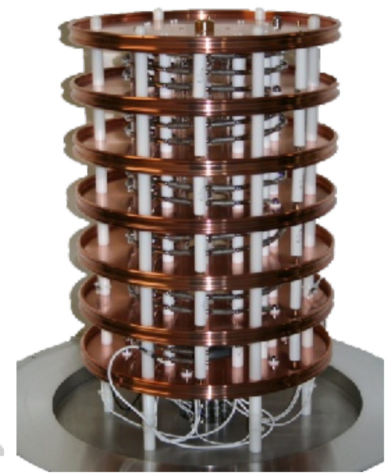




35 kV

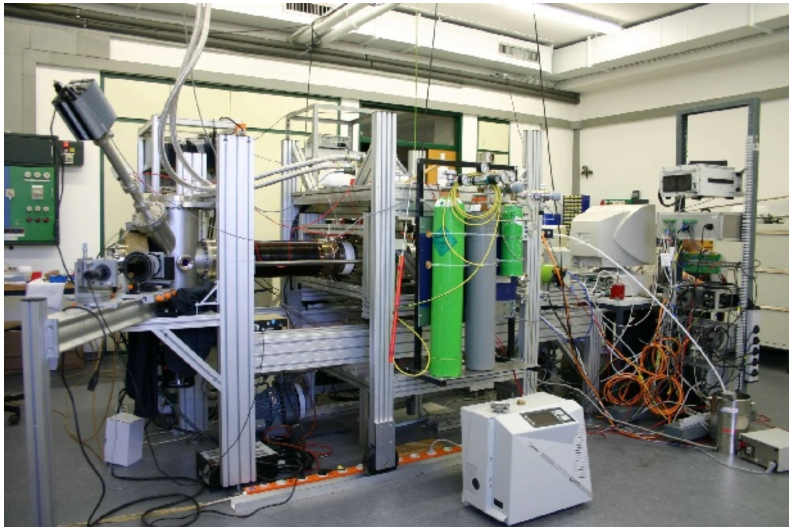


65 kV

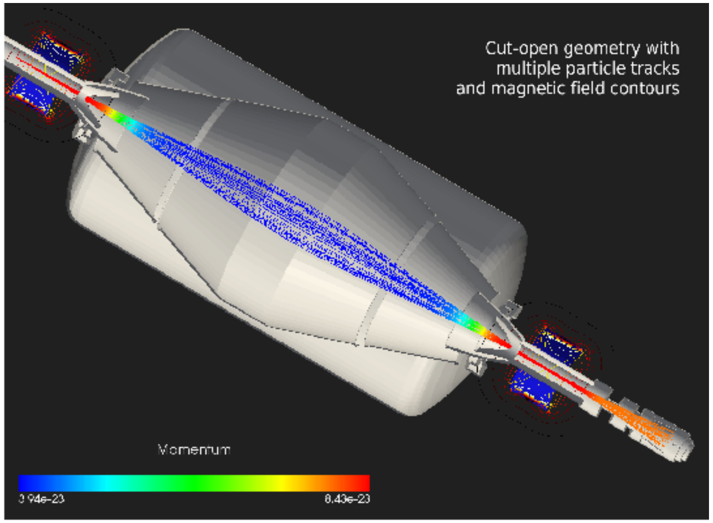


ppm precision high voltage supply and measurements

Calibration electron sources, e.g. angular-selective pulsed UV-laser photo-electron source



Condensed ^{83m}Kr conversion electron calibration source



Simulations, software development,analysis

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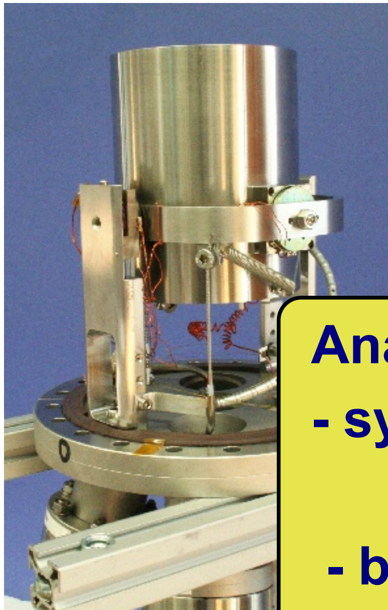
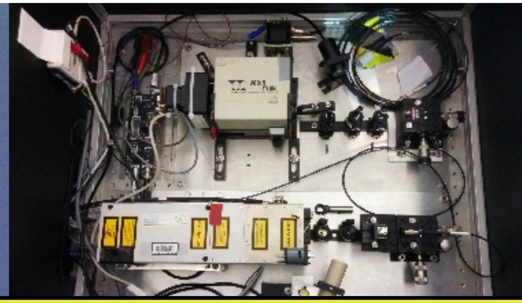
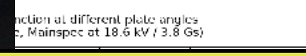
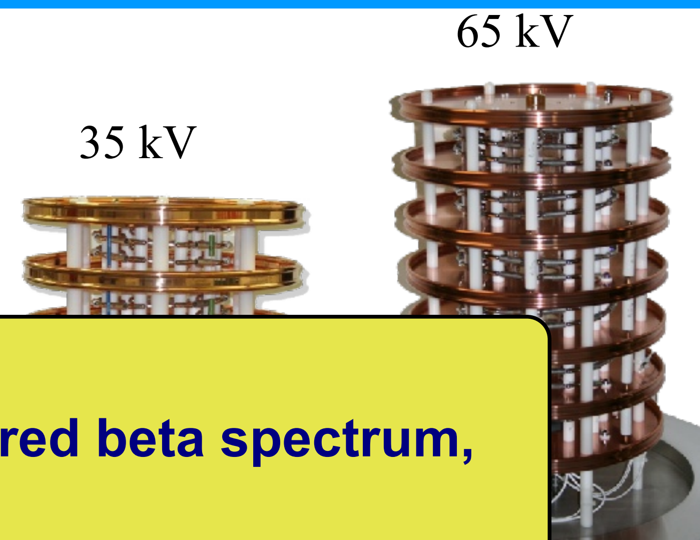
Other developments and contributions to KATRIN







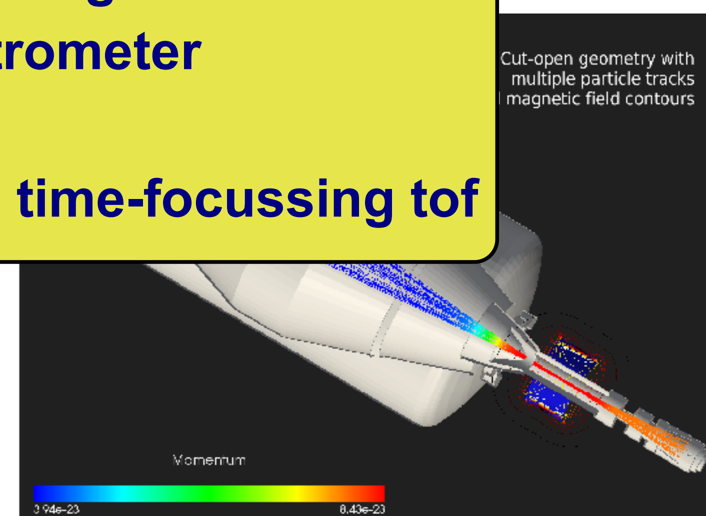


...ge supply

Analysis and simulation topics:
- **systematics of understanding measured beta spectrum, e.g. inelastic scattering**
- **background of the KATRIN spectrometer, creation, suppression, breaking of storage conditions**
- **transmission of the KATRIN main spectrometer**
- **all kind of time-of-flight spectroscopy, neutrino mass, keV sterile neutrinos, time-focussing tof**

Calibration e...
pulsed UV-la...

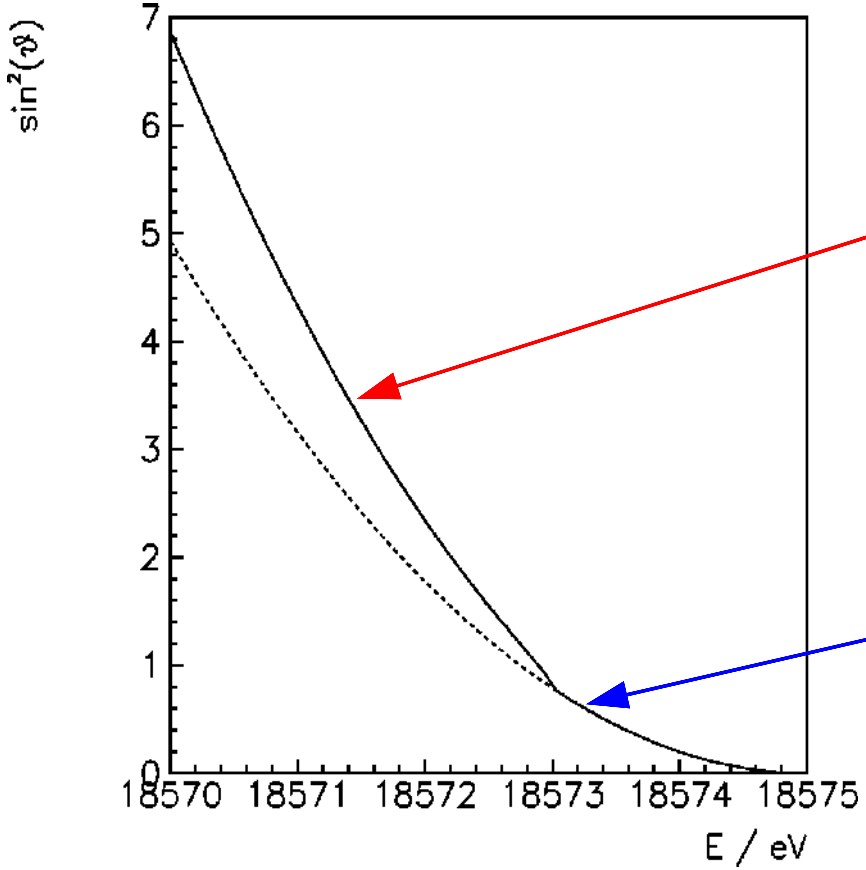
Condensed Kr
conversion electron
calibration source



Simulations, software development,analysis

Influence of a 4th sterile neutrino near or further below the endpoint E_0

$$dN/dE = K\ F(E,Z)\ p\ E_{tot}\ (E_0-E_e) \left(\cos^2(\theta) \sqrt{(E_0-E_e)^2 - m(\nu_{1,2,3})^2} + \sin^2(\theta) \sqrt{(E_0-E_e)^2 - m(\nu_4)^2} \right)$$



e.g.

$m(\nu_4) = 2$ eV

$\sin^2(\theta) = 0.3$

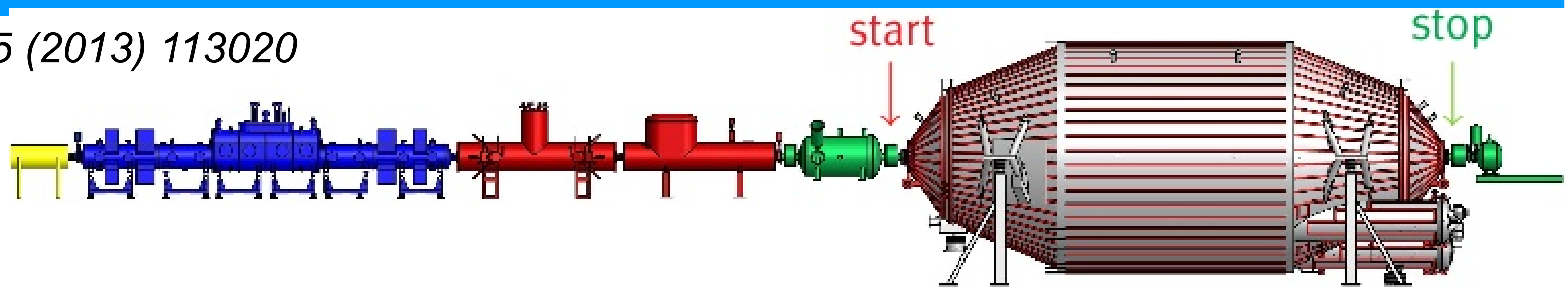
e.g.

$m(\nu_{1,2,3}) \approx 0$ eV

$\cos^2(\theta) = 0.7$

Alternative spectroscopy: measure time-of-flight through KATRIN spectrometer

N. Steinbrink et al., NJP 15 (2013) 113020



Advantage: measure full β-spectrum by time-of-flight at one (a few) retarding potential

Stop: Can measure time-of-arrival with KATRIN detector with Δt = 50 ns → ok

Start: e^--tagger: Need to determine time-of-passing-by of e^- before main spectrometer without disturbing energy and momentum by more than 10 meV:

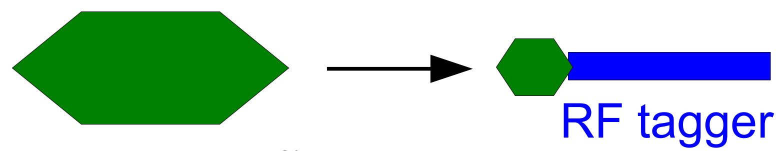
→ Need „detector" with 10 meV threshold

seems not to be forbidden but very difficult for the near future !

→ factor 5 in $\Delta m(\nu)^2_{stat}$ under ideal cond.

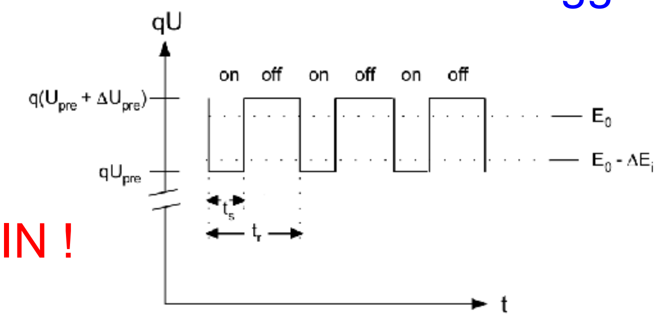
Added value: significant background reduction by coincidence !

An implementation: reduce pre spectrometer and add a Project 8-type tagger within a long solenoid

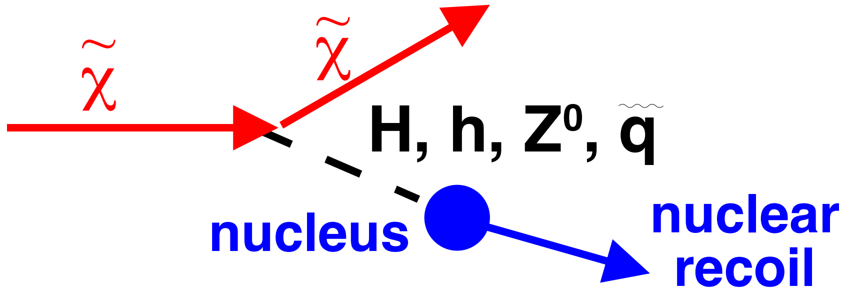


or: Use pre spectrometer as a „gated-filter" by switching fast the retarding voltage

→ As sensitive on the neutrino mass as standard KATRIN !



Direct search for WIMPs



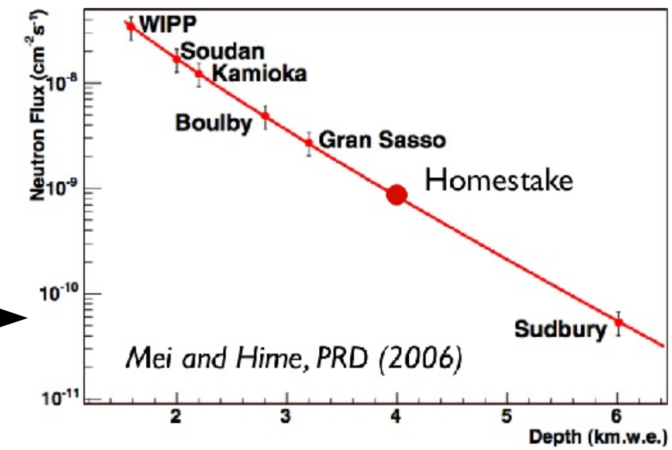
⇒ **exponential recoil energy spectrum:**

$$\frac{dR}{dE_r} = \frac{\rho_0 \cdot \sigma_0 \cdot F^2(q^2)}{2 \cdot m_{\tilde\chi} \cdot \mu_r^2} \cdot \langle \frac{1}{v} \rangle = \frac{\rho_0 \cdot \sigma_0 \cdot F^2(q^2)}{\sqrt{\pi} \cdot m_{\tilde\chi} \cdot \mu_r^2 \cdot v_0} \cdot e^{-\frac{E_r \cdot m_A}{2 \cdot \mu_r^2 \cdot v_0^2}}$$

but very low rate & very low recoil energy

⇒ **go underground to reduce μ`s and μ-induced n`s**

& shielding, very clean materials, ..



⇒ **special techniques to suppress γ, e, α background**

a) large detector mass to see annual modulation (DAMA/LIBRA)

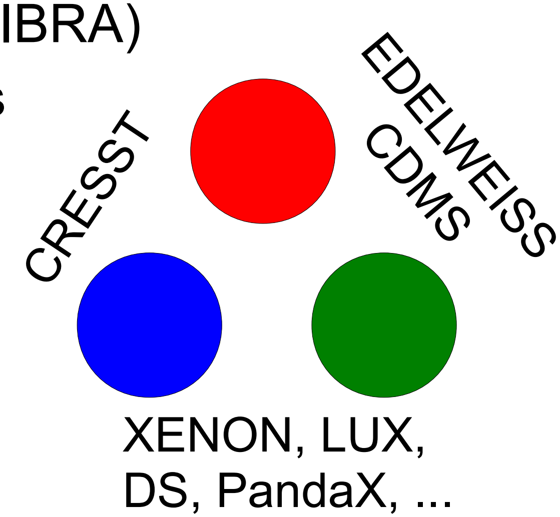
b) double read-out to distinguish nuclear recoil from others

- cryobolometers:

  heat + ionsiation or heat + light

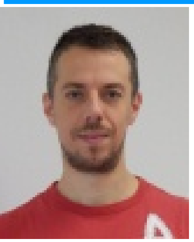
- liquid noble gas detectors:

  light + ionisation

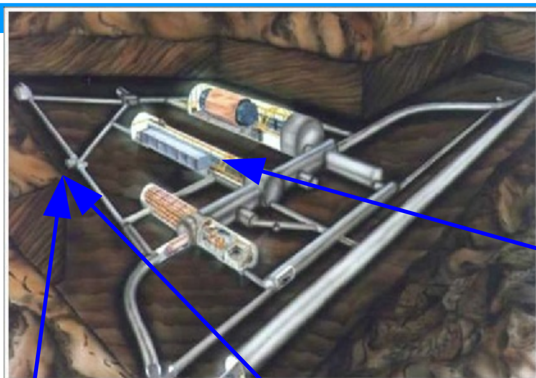


c) directional (but not enough target mass)

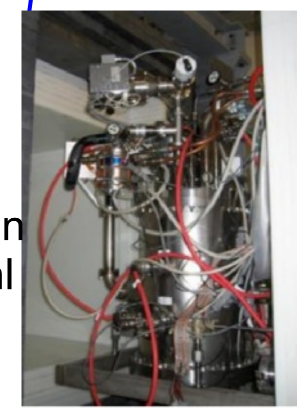
XENON: staged WIMP search @LNGS

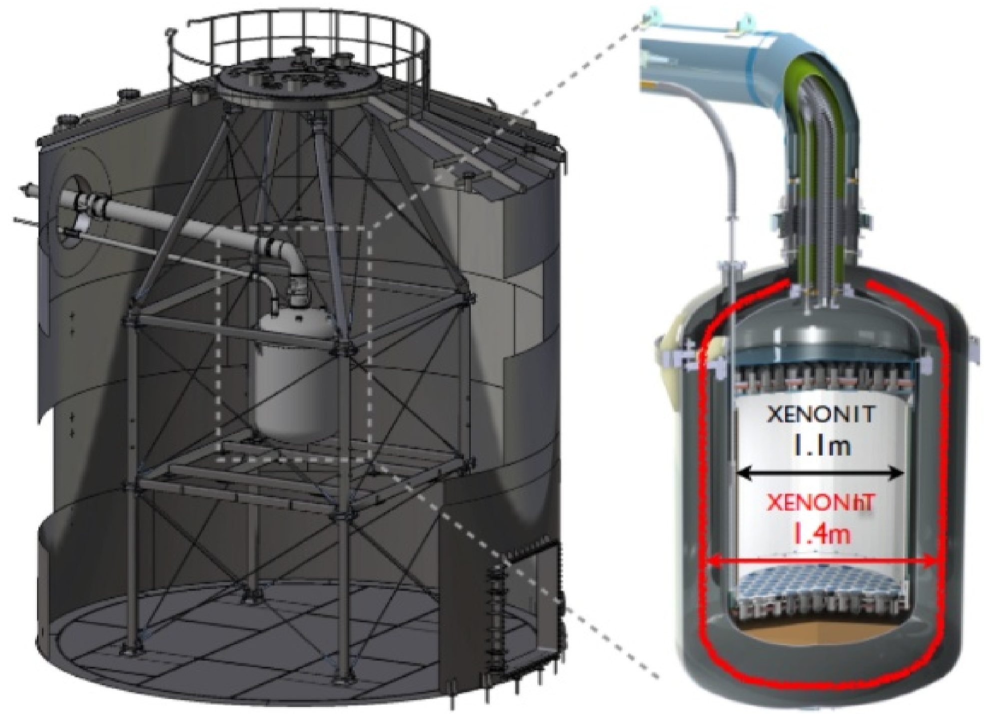


Dr. Gianmarco Bruno



Dr. Stephan Rosendahl





XENON10

2005 - 2007

15 cm drift TPC

25 kg xenon

$\sigma_{SI} < 8.8 \cdot 10^{-44}$ cm^2

XENON100

2008 - 2015

30 cm drift TPC

161 kg xenon

$\sigma_{SI} < 2.0 \cdot 10^{-45}$ cm^2

XENON1T (XENONnT)

2012 -

1000 cm drift TPC

3300 (7000) kg xenon

$\sigma_{SI} < 1.2 \cdot 10^{-47}$ cm^2 (< $2 \cdot 10^{-48}$ cm^2)

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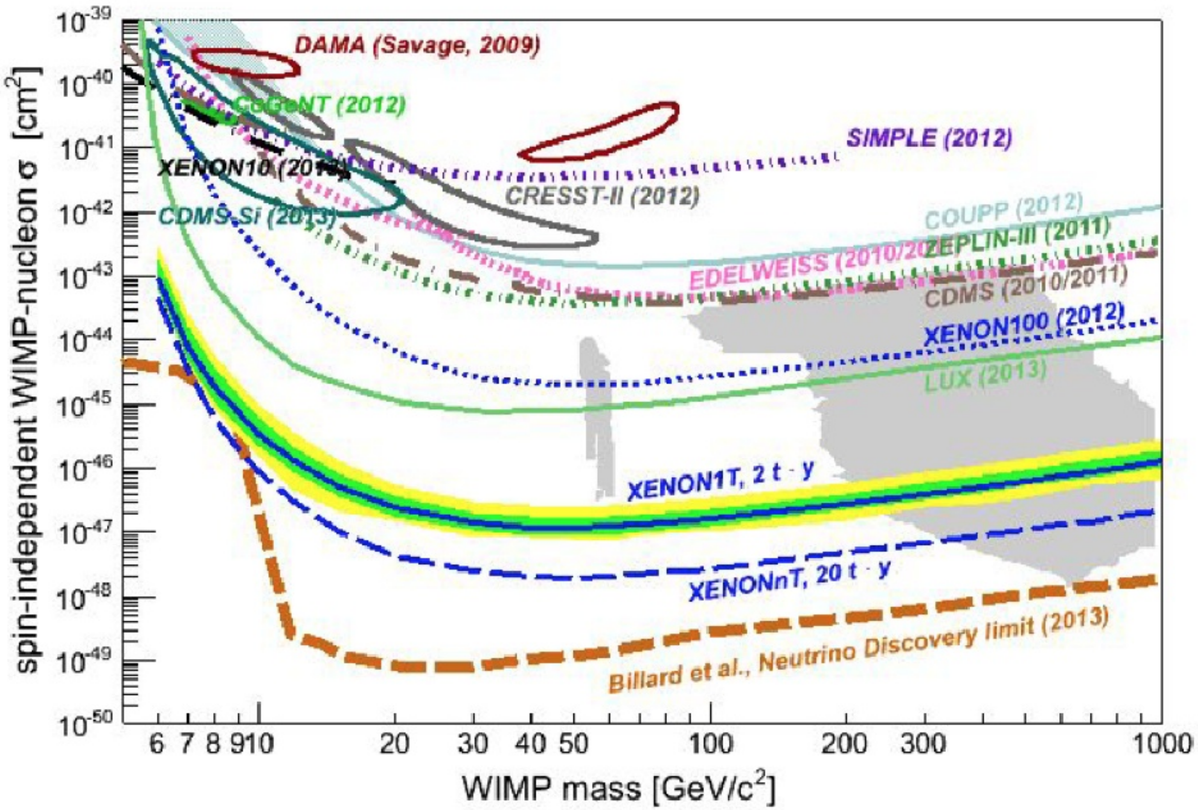
Search for dark matter



additional within the XENON program:

- spin dependent interaction
- electronic recoils
- annual modulations

XENON1T@LNGS:
water tank, service building, cryostat

Custom-made cryogenic distillation column for XENON1T(nT)

Cryogenic distillation:

multi-stage separation by different vapor pressure

^{85}Kr:

$2 \cdot 10^{-11}$ fraction of ^{85}Kr in ^{nat}Kr

10^{-8} - 10^{-5} fraction in commercial xenon gas,
but XENON1T requires $< 2 \cdot 10^{-13}$

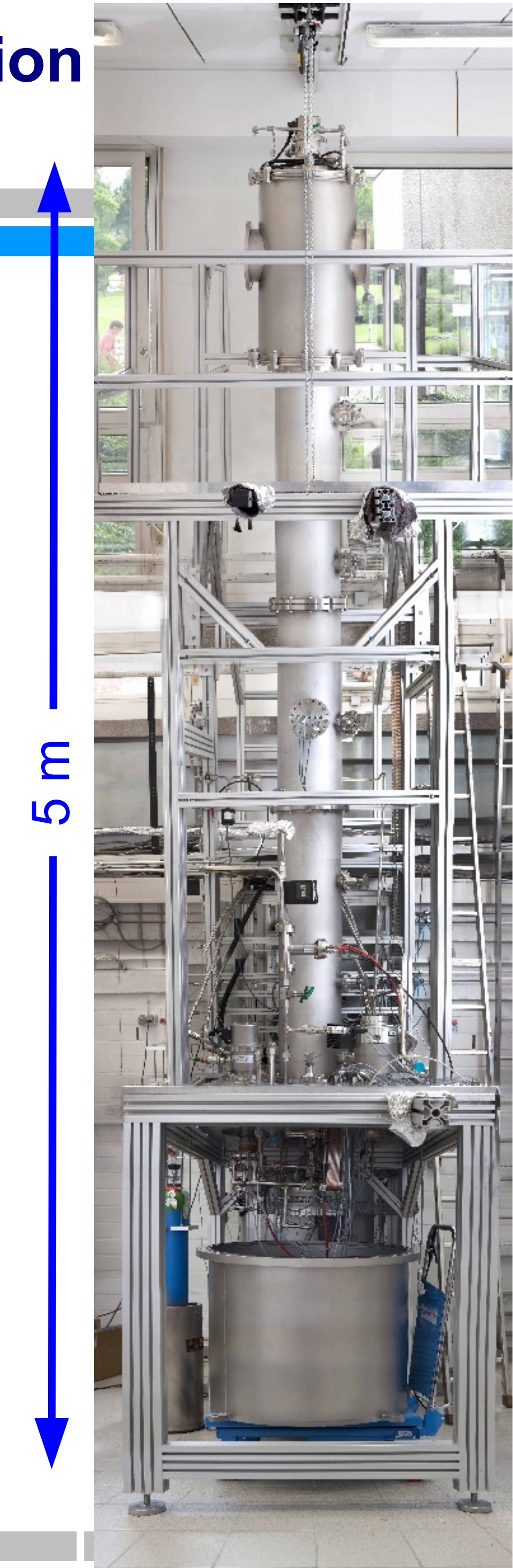
→ need very efficient purification method

up to now published Kr-in-Xe fraction concentrations reached by
LUX, PandaX, XENON100, XMASS: 1-3 ppt

cryogenic distillation with custom-made Münster column:
< 0.026 ppt (RGMS measurement by MPIK), 3 kg/h

^{219}Rn, ^{220}Rn, ^{222}Rn:

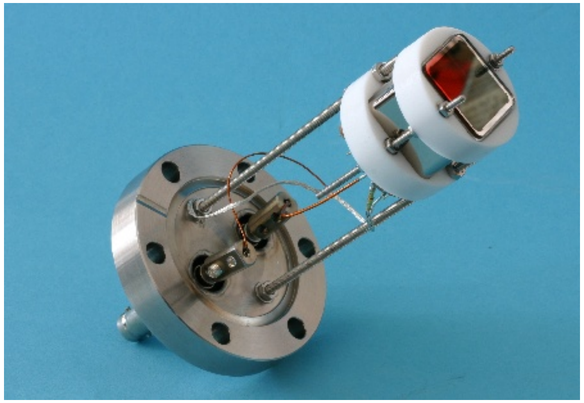
comes from walls, weldings, ..
→ rigorous screening of materials
Rn reduction by continuous cryogenic distillation for XENONnT

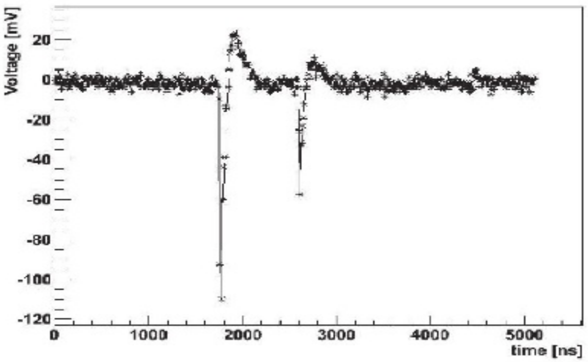


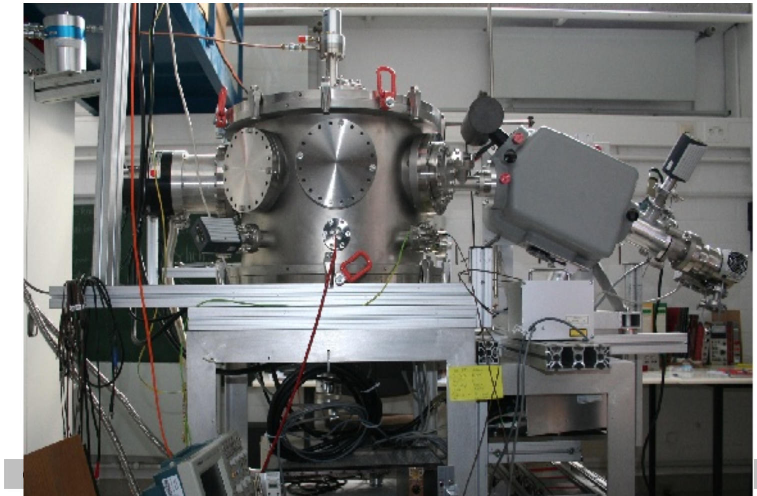
Other contributions to XENON100/XENON1T/XENONnT

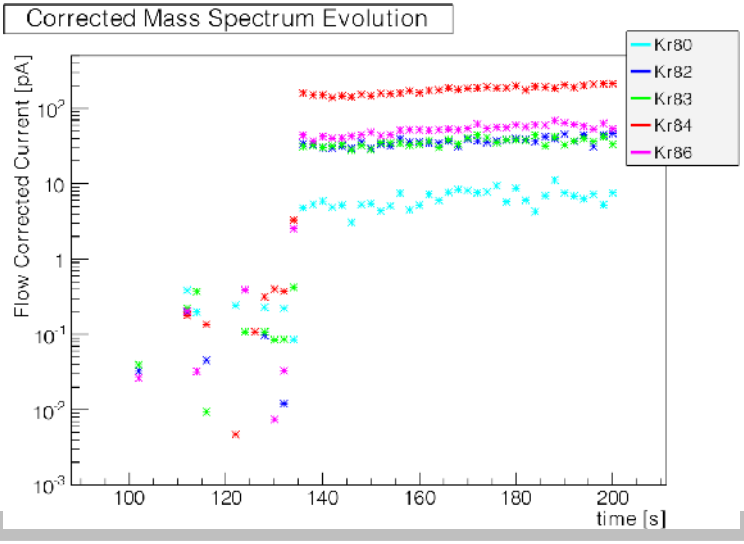
Westfälische Wilhelms-Universität Münster

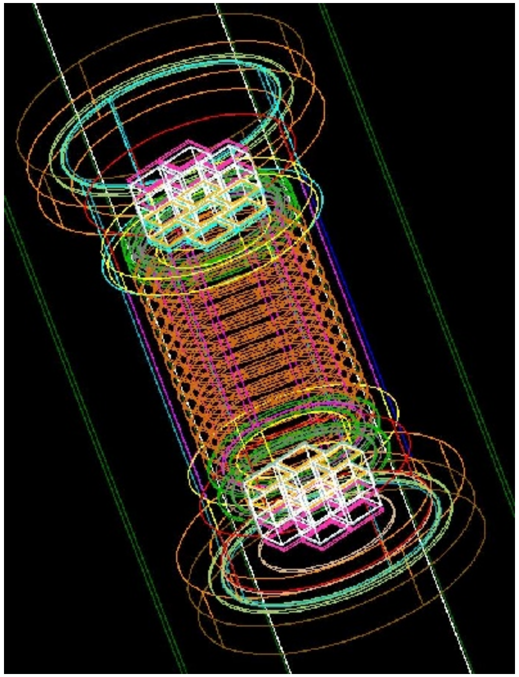
Ultra-pure Xe gas, cryo-genic distillation, calibration, simulation, analysis





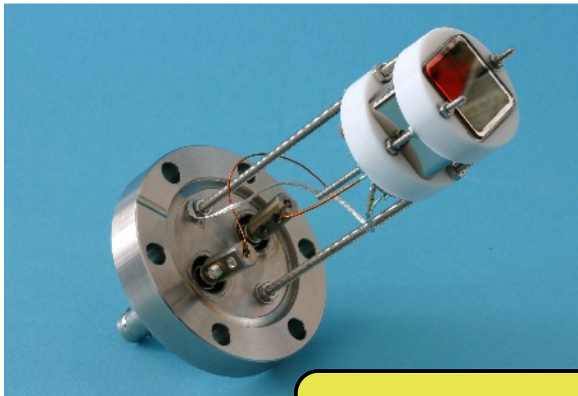


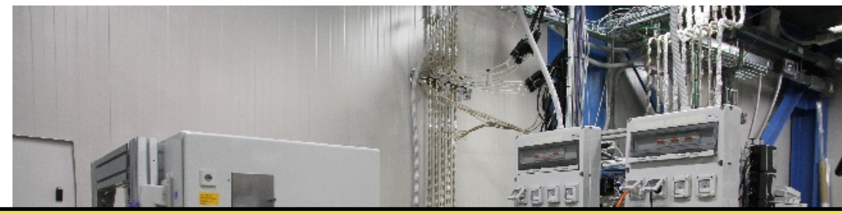


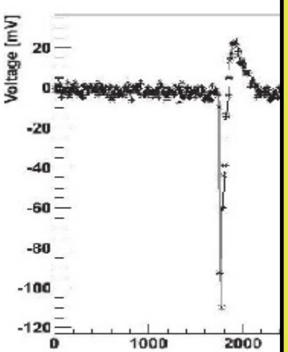


Other contributions to XENON100/XENON1T/XENONnT

Ultra-pure Xe gas, cryo-genic distillation, calibration, simulation, analysis

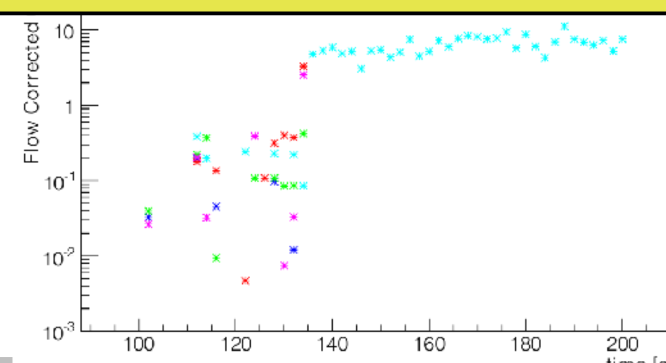






Analysis and simulation topics:

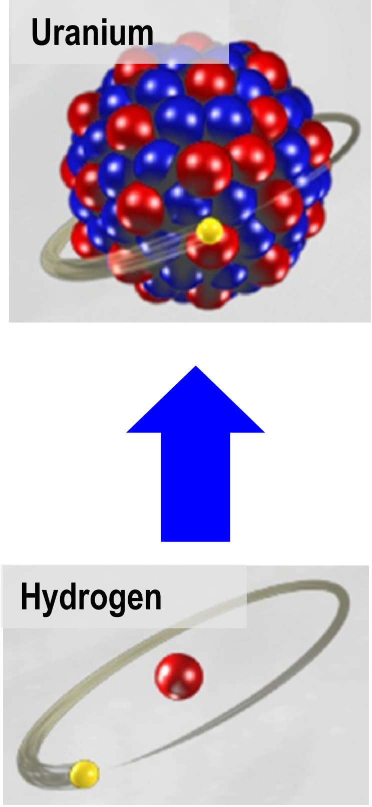
- LY and reflection properties
- Calibration to electronic recoils
- Measurement of impurities
- WIMP search with XENON100 using the new software PAX
- WIMP search with XENON1T
- ECEC ^{124}Xe

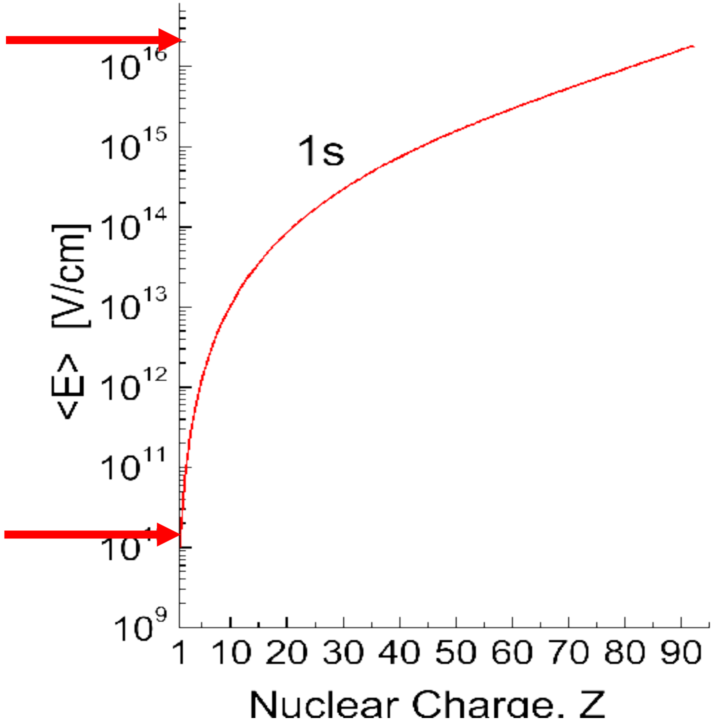


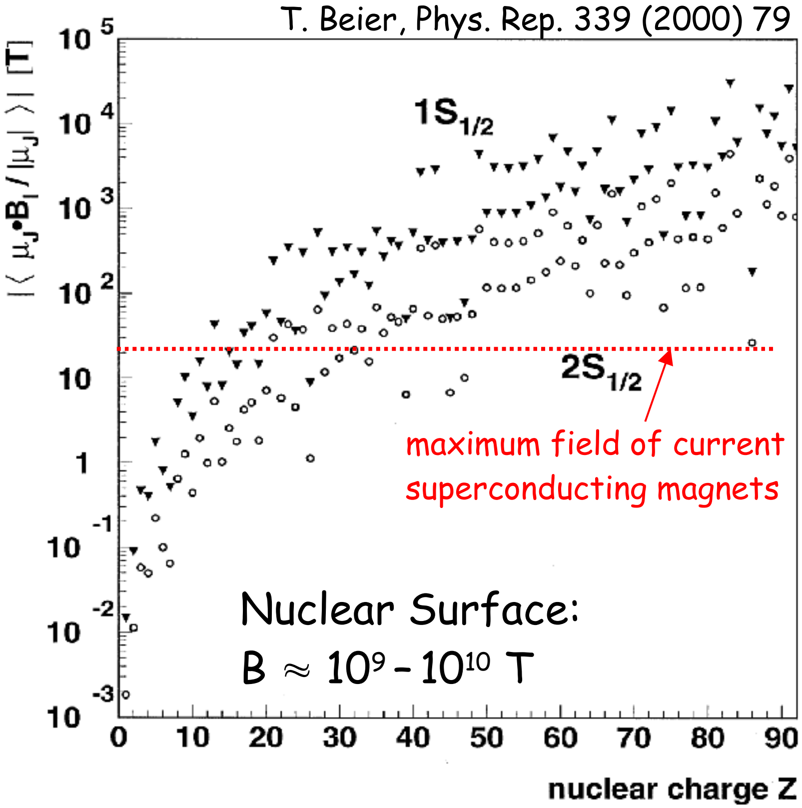
QED Precision tests at GSI

- Highly charged ions (HCI) can be used as laboratories to test QED predictions in extreme electric and magnetic fields

  → perform laser spectroscopy experiments at storage rings (ESR / CRYRING) or at Penning trap experiments (SPECTRAP) at GSI



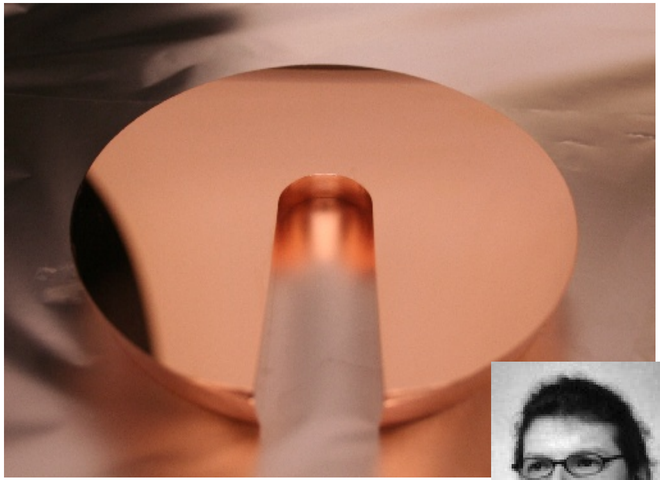


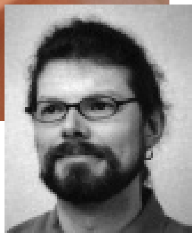


- Caveat: in highly charged heavy ions the nucleus cannot be treated as a point particle anymore → nuclear structure effects start to play a role

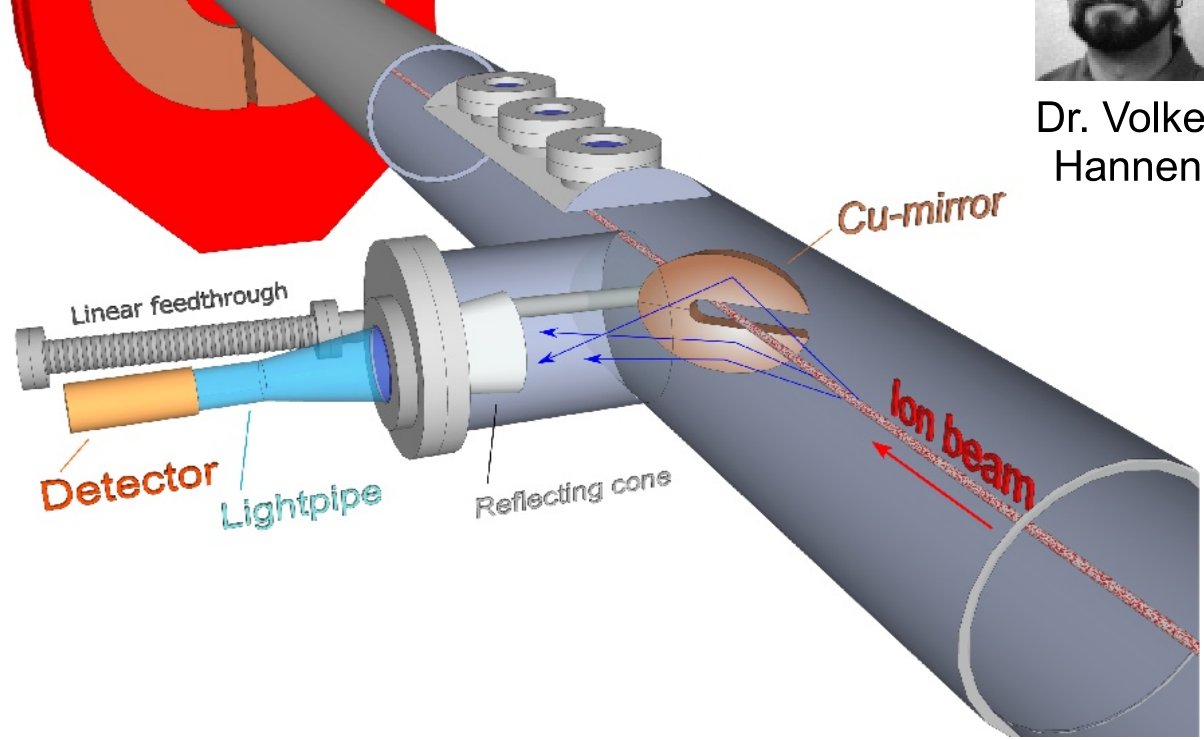
H-like and Li-like ^{209}Bi at ESR/GSI

- The LIBELLE experiment aimed at a measurement of the HFS transitions in H-like and Li-like Bismuth
- While the H-like transition has been observed already with the existing detection system at ESR, the search for the Li-like HFS transition failed in previous experiments
- Therefore, a dedicated detection system based on a movable parabolic mirror with a central slit for the ion beam was constructed to collect forward emitted fluorescence photons





Dr. Volker Hannen



- This effort enabled the first detection of the Li-like resonance in a laser spectroscopy experiment in 2011 yielding a transition wavelength of:

$\lambda^{(80+)}$ = 1554.66(33)(10) nm

M. Lochmann et al., Phys. Rev. A, 90 (2014

- A second run with significantly improve

H-like and Li-like ^{209}Bi at ESR/GSI

- The LIBELLE experiment aimed at a measurement of th
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M. Lochmann et al., Phys. Rev. A, 90 (2014

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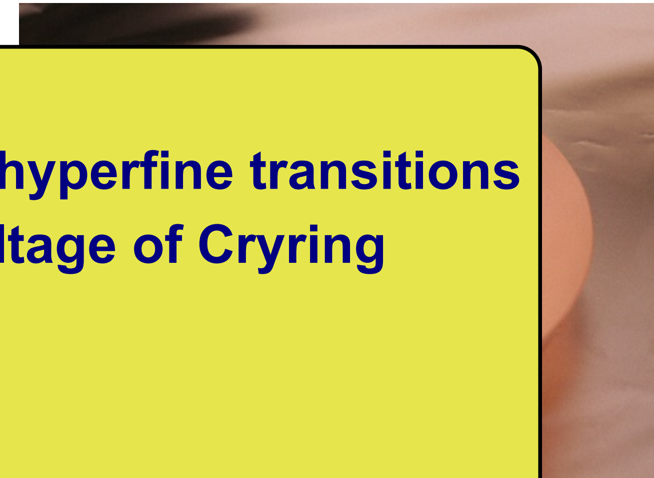

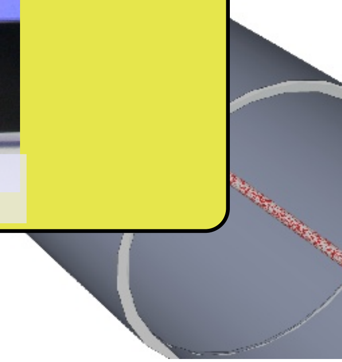

Other activities:

- Lifetime determination of H-like and Li-like ^{209}Bi hyperfine transitions

- ppm precision HV measurements of e-cooler voltage of Cryring

- Single photon detection system for Cryring

- Single photon detectors for SpecTrap

- XUV detector for ESR, etc.