LAUNCH09, MPIK Heidelberg

"Contributions to Neutrino Physics with Penning Traps"

Klaus Blaum

11.11.2009

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Outline

- Introduction, history and methods
- Principle of Penning traps
- Setup and measurement procedure
- Neutrino physics with Penning traps

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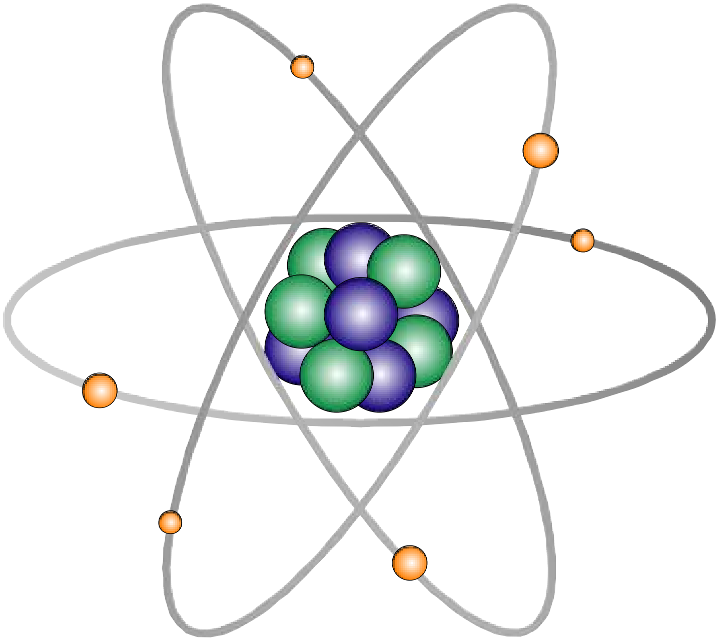
Precision mass measurements

High-accuracy mass measurements allow one to determine the atomic and nuclear binding energies reflecting all forces in the atom/nucleus.



= *N* · (neutron) + *Z* · (proton) + *Z* · (electron)

– binding energy

$$M_{\text{Atom}} = N \bullet m_{\text{neutron}} + Z \bullet m_{\text{proton}} + Z \bullet m_{\text{electron}} - (B_{\text{atom}} + B_{\text{nucleus}})/c^2$$

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A brief history of mass spectrometry

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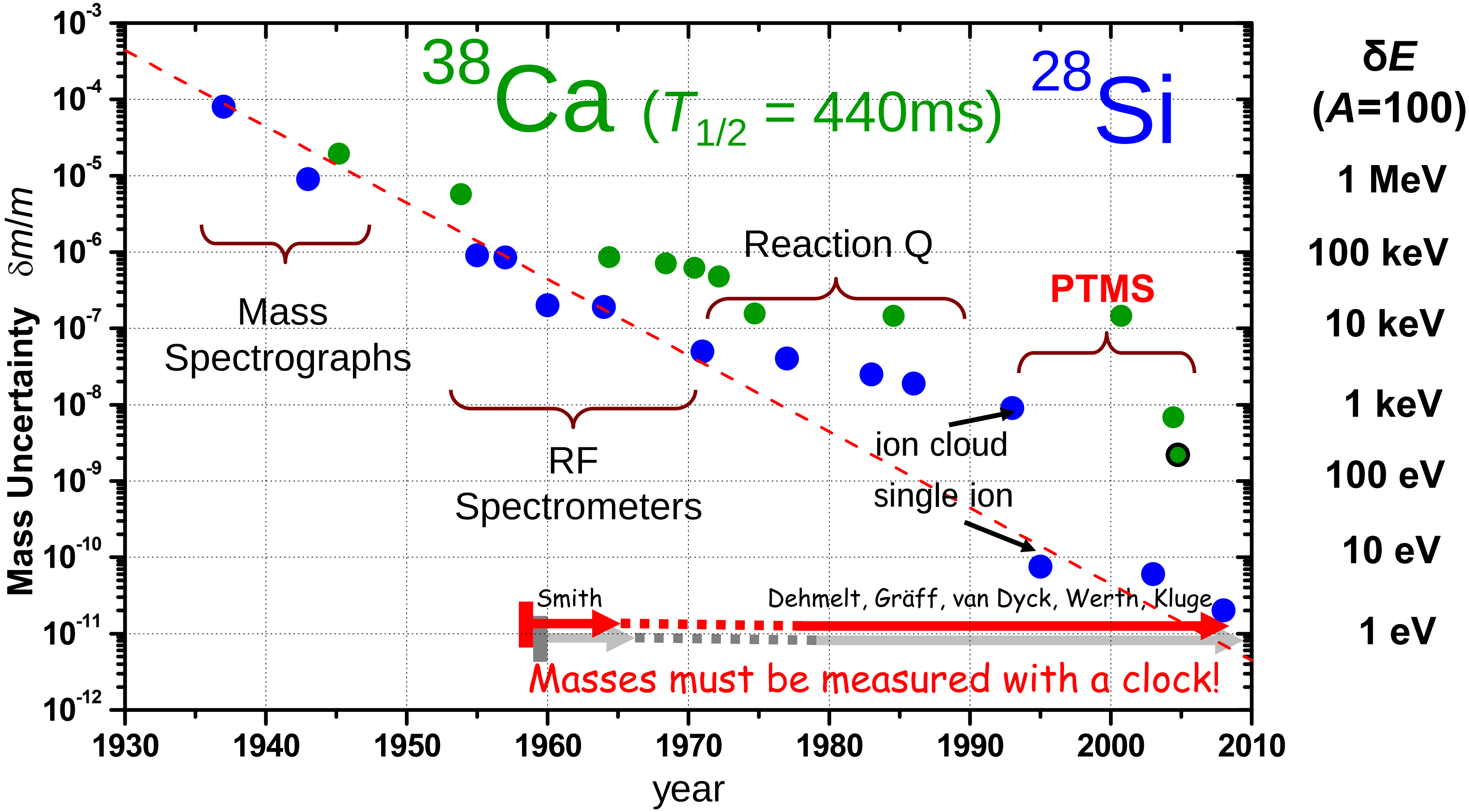
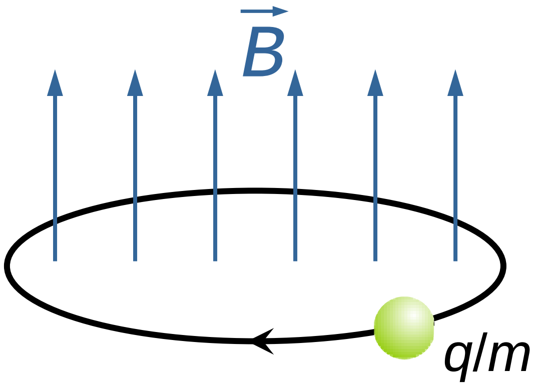
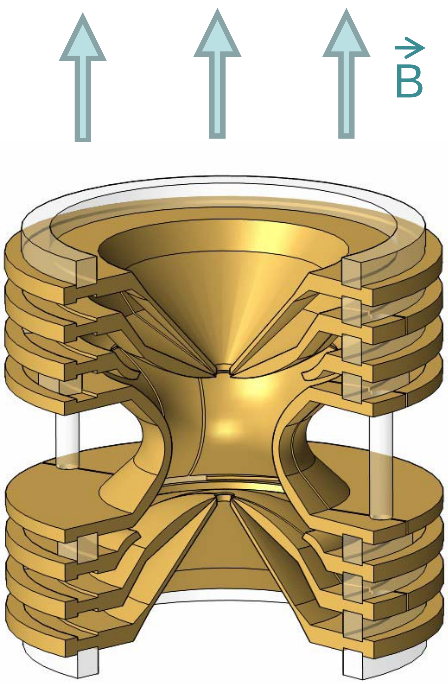


Principle of Penning trap mass spectrometry



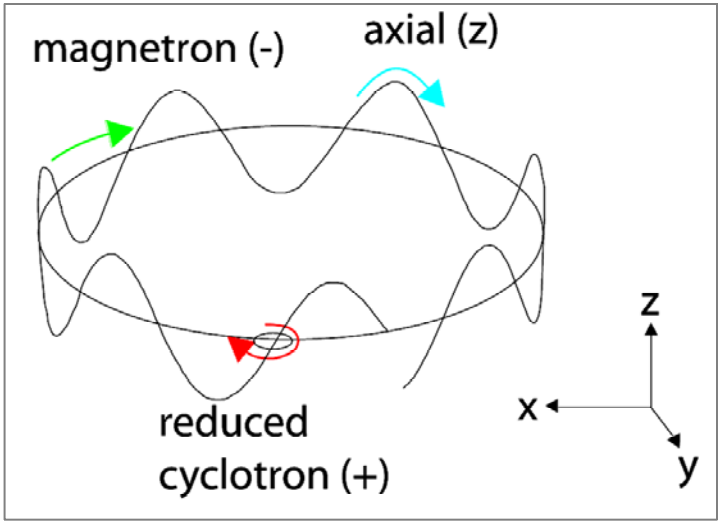


Cyclotron frequency:

$$f_c = \frac{1}{2\pi} \cdot \frac{q}{m} \cdot B$$

PENNING trap

- Strong homogen. magnetic field
- Weak electric 3D quadrupole field



Typical freq.
q = e
m = 100 u
B = 6 T

$\Rightarrow$ $f_- \approx$ 1kHz
$f_+ \approx$ 1MHz

Brown & Gabrielse, Rev. Mod. Phys. 58, 233 (1986)

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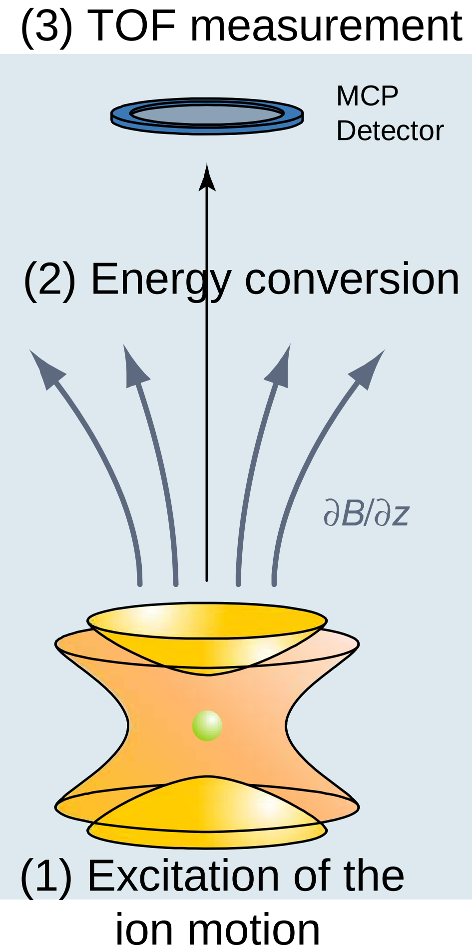
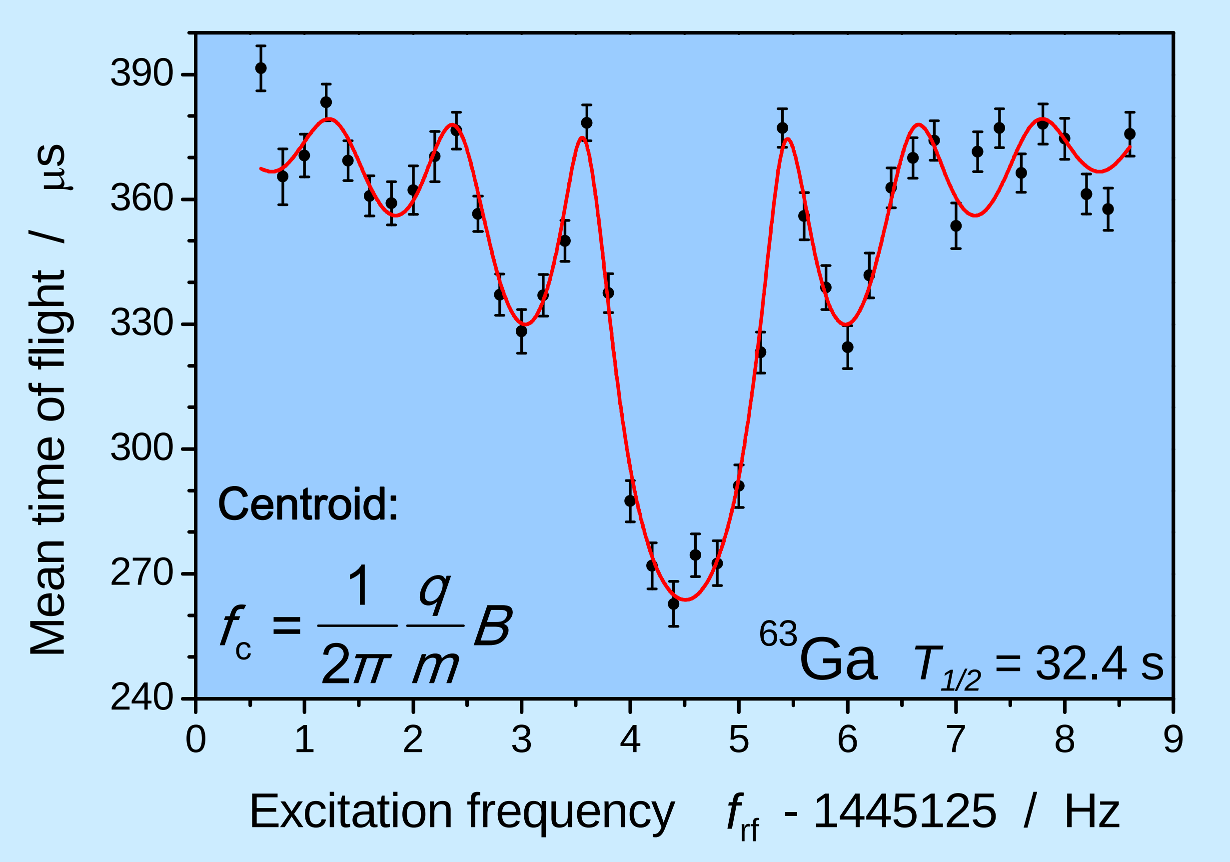
TOF cyclotron resonance detection





Determine atomic mass from frequency ratio with a well-known “reference mass”.

$$\frac{f_{c,ref}}{f_c} = \frac{m - m_e}{m_{ref} - m_e}$$

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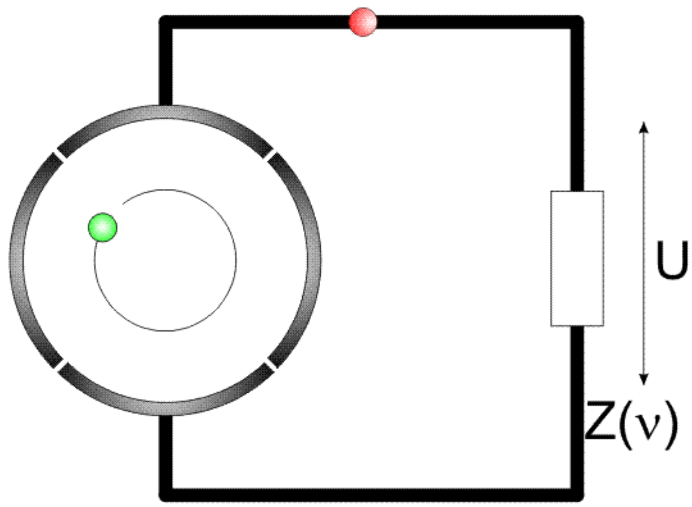
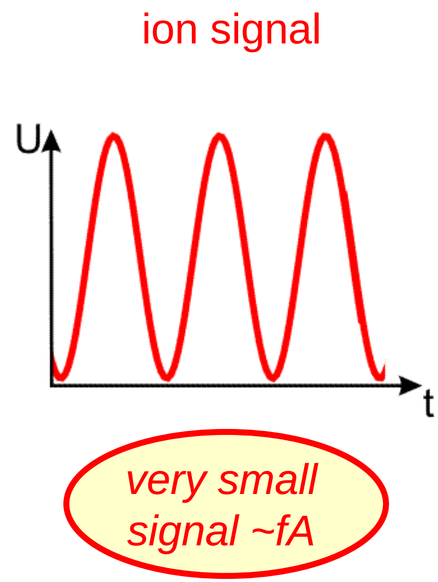
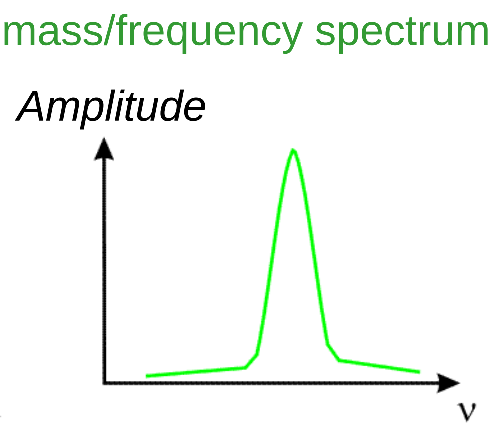
Non-destructive ion detection







„FT-ICR“
Fourier-**T**ransform-
Ion **C**yclotron **R**esonance

Induced current: $I_{eff} = 1/\sqrt{2} \cdot r_{ion} / D \cdot \omega \cdot q$

(Schottky et al. ...)

Signal / Noise $S/N \sim 1 / T^{1/2}$

Operation of traps and electronics at **cryogenic** (4 K) temperature.

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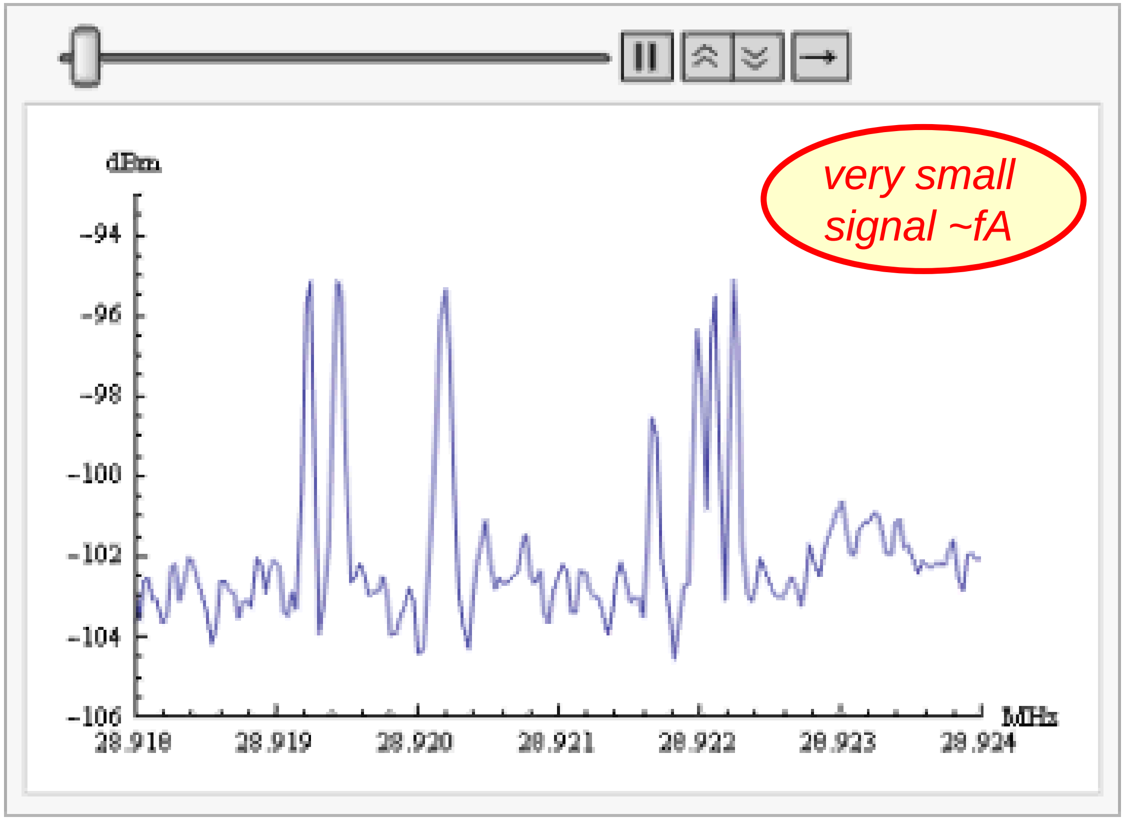
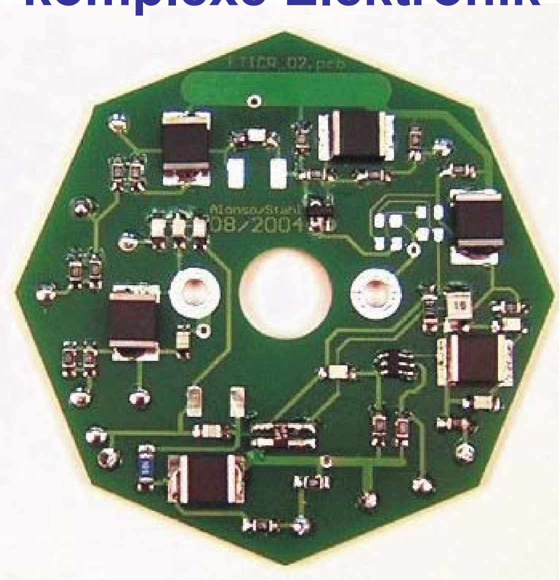
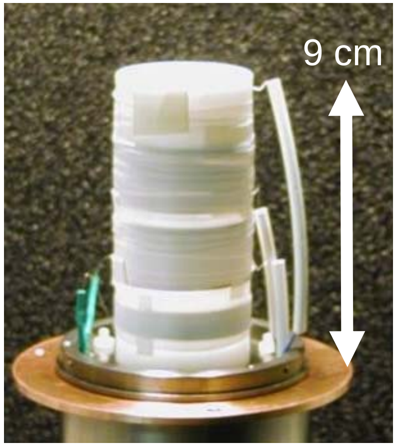
Single ion signals



komplexe Elektronik





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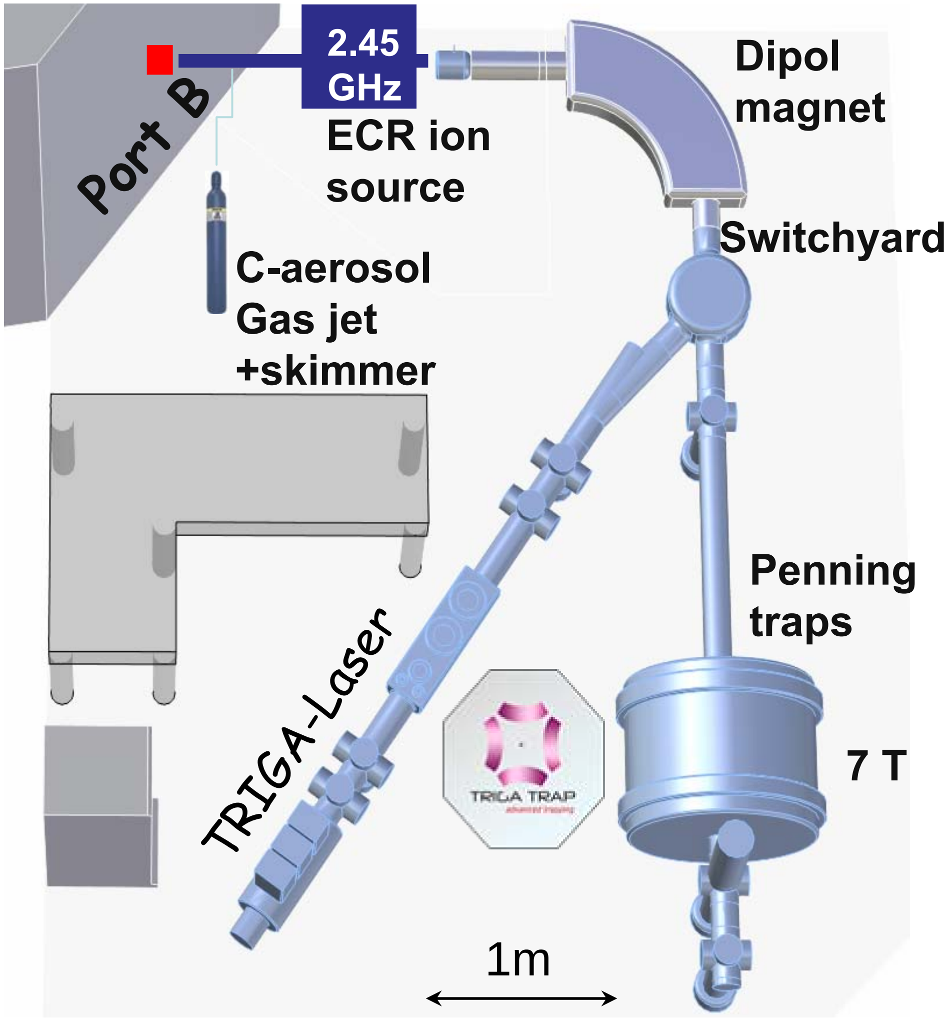
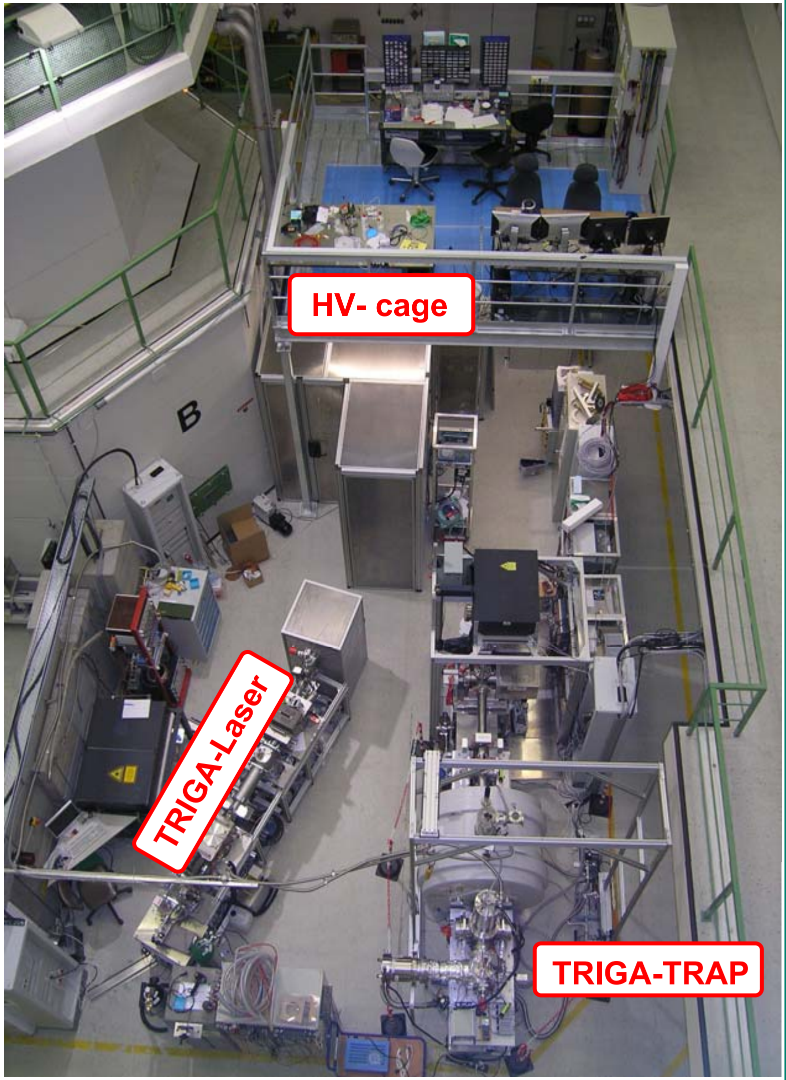
The TRIGA-TRAP experiment





J. Ketelaer *et al.*, *Nucl. Instr. Meth.* A **594** (2008) 162–177

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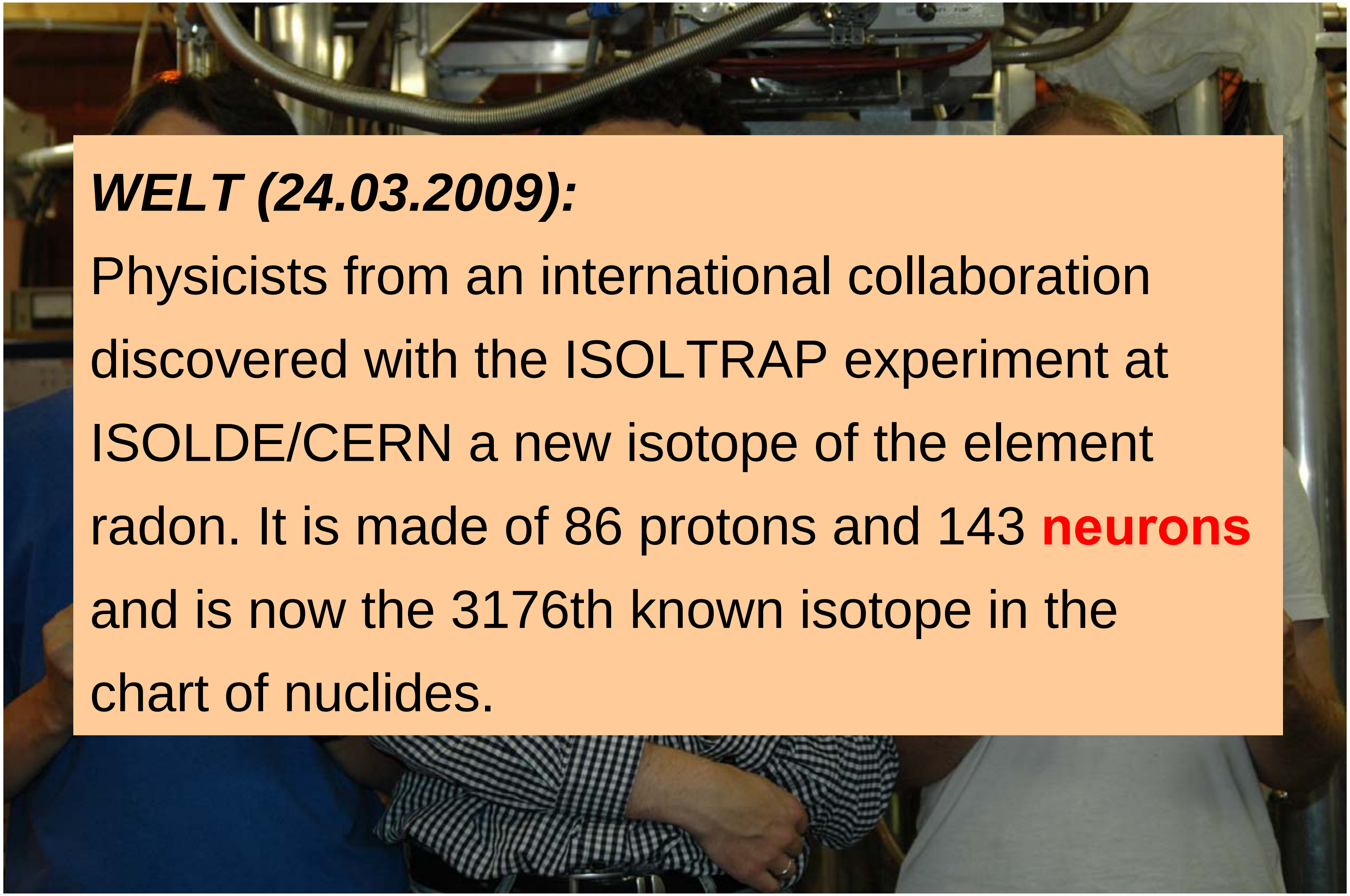
Highest sensitivity: Discovery of a new isotope



WELT (24.03.2009):

Physicists from an international collaboration discovered with the ISOLTRAP experiment at ISOLDE/CERN a new isotope of the element radon. It is made of 86 protons and 143 **neurons** and is now the 3176th known isotope in the chart of nuclides.

26.08.2008, 4:24 am

D. Neidherr *et al.*, Phys. Rev. Lett. 102, 112501 (2009)

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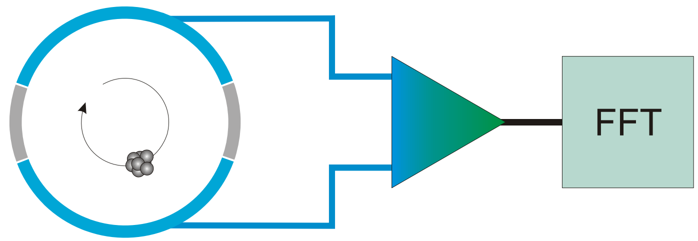
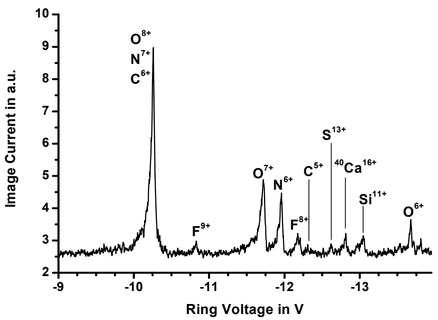
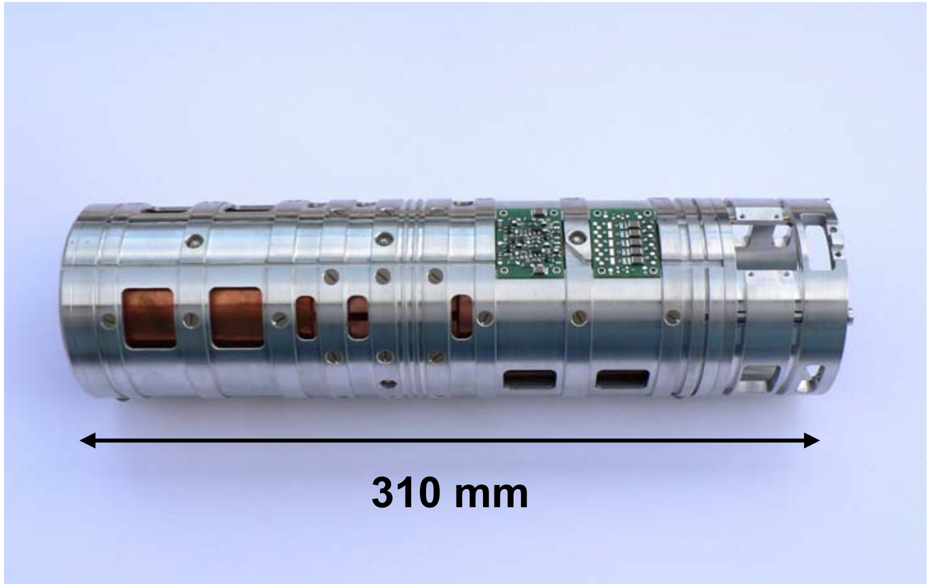
KATRIN-TRAP

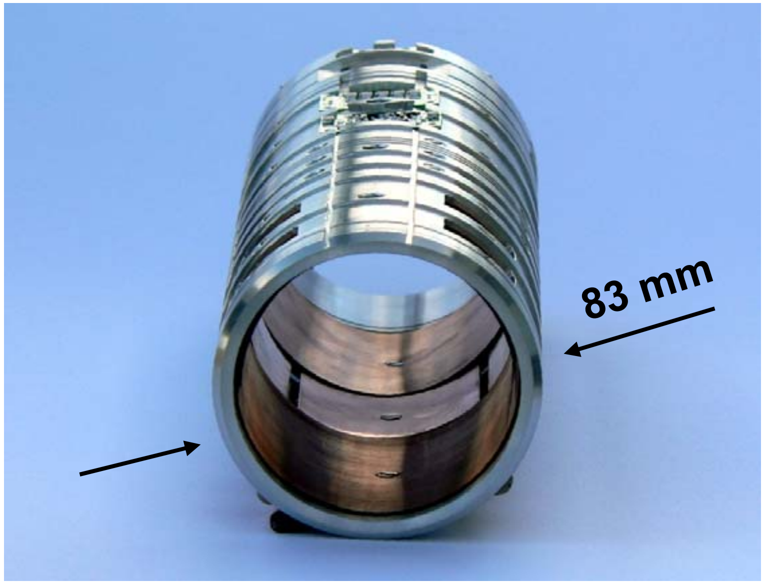
Penning traps as high-precision "rest-gas analyser"

Broad-band
FT-ICR
kHz-MHz









M. Ubieto Díaz *et al.*, Int. J. Mass Spectrom. 288, 1 (2009)

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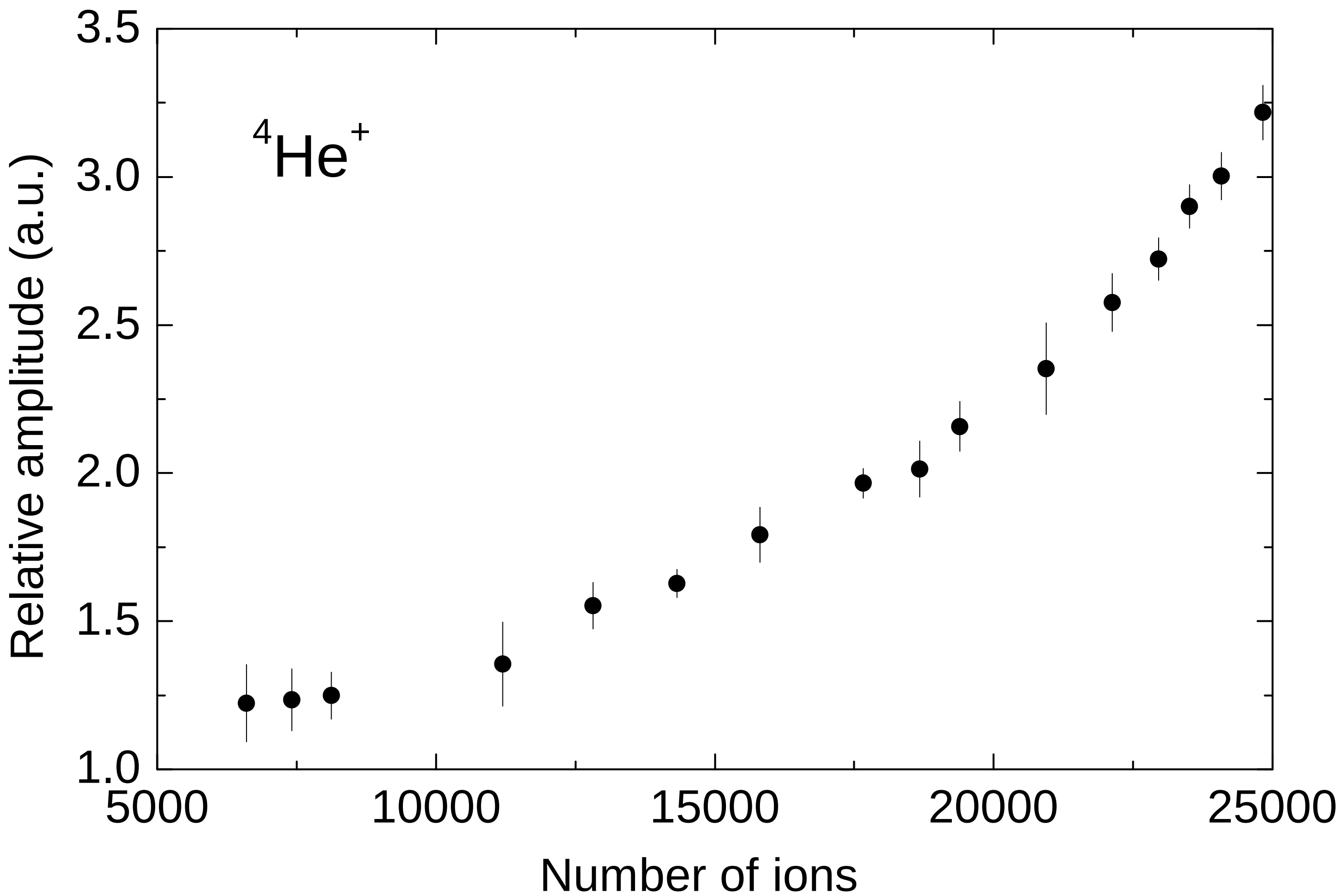
Detection limit



Minimum number of detected ions (helium) ~ 6000 ions.

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Masses of interest for neutrino physics

- $0\nu\beta\beta$
- EC
- ^{3}T-^{3}He

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Q-value of the decay of ^{76}Ge to ^{76}Se

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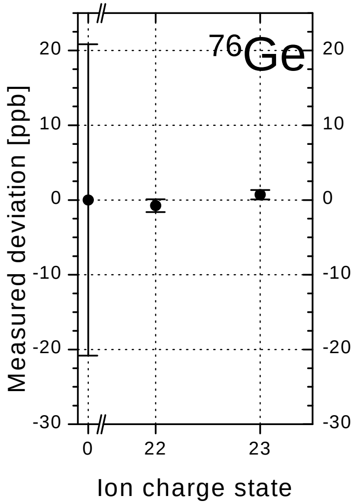
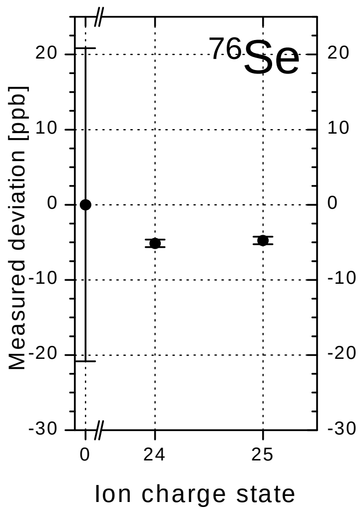
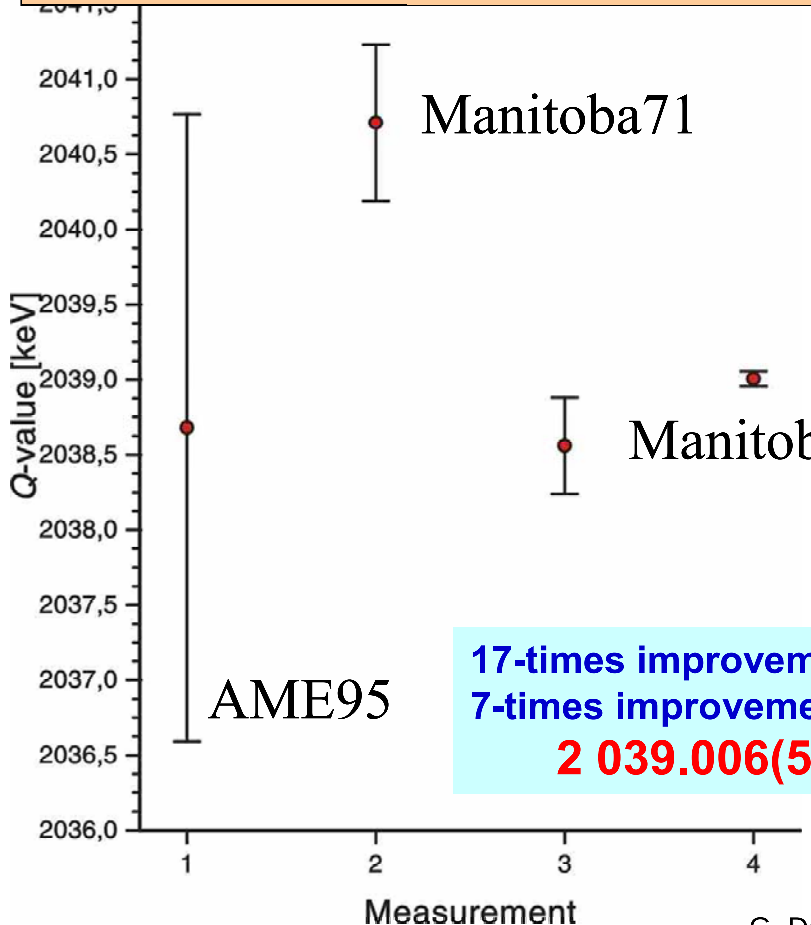




Energy for 2e- by Q-value for

Reaction: $^{76}_{32}Ge \rightarrow ^{76}_{34}Se + 2e^{-} (+2\bar{\nu}_e\ ?)$



17-times improvement in both masses

7-times improvement in the *Q*-value

2 039.006(50) keV

G. Douysset *et al*. PRL 86, 2001

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More interesting candidates

Decay	$\beta\beta$ *Q*-value	Precision
$^{76}Ge - ^{76}Se$	2039.006(50) G. Douysset et al., PRL 86, 4259 (2001)	6E-10
$^{130}Te - ^{130}Xe$	2527.518(13) M. Redshaw et al., PRL 102, 212502 (2009)	1E-10
$^{136}Xe - ^{136}Ba$	2457.83(37) M. Redshaw et al., PRL 98, 053003 (2007)	3E-09
	ECEC	
$^{112}Sm - ^{112}Cd$	1919.82(16) S. Rahaman et al., PRL 103, 042501 (2009)	1E-09
$^{120}Te - ^{120}Sm$	1714.81(1.25) N. Scielzo et al., PRC 80, 025501 (2009)	1E-08

In principle all *Q*-values can be improved to δQ < 300 eV, but we need your input concerning the importance.

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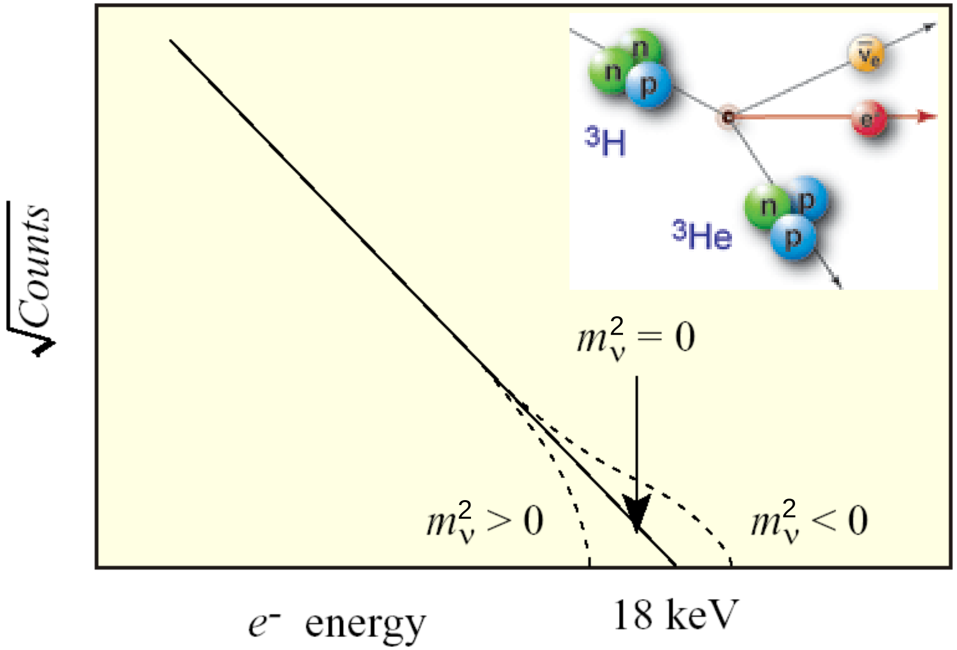
Determination of the $^3H \rightarrow {}^3He$ *Q*-value

Important parameter for the determination of the electron neutrino rest mass.

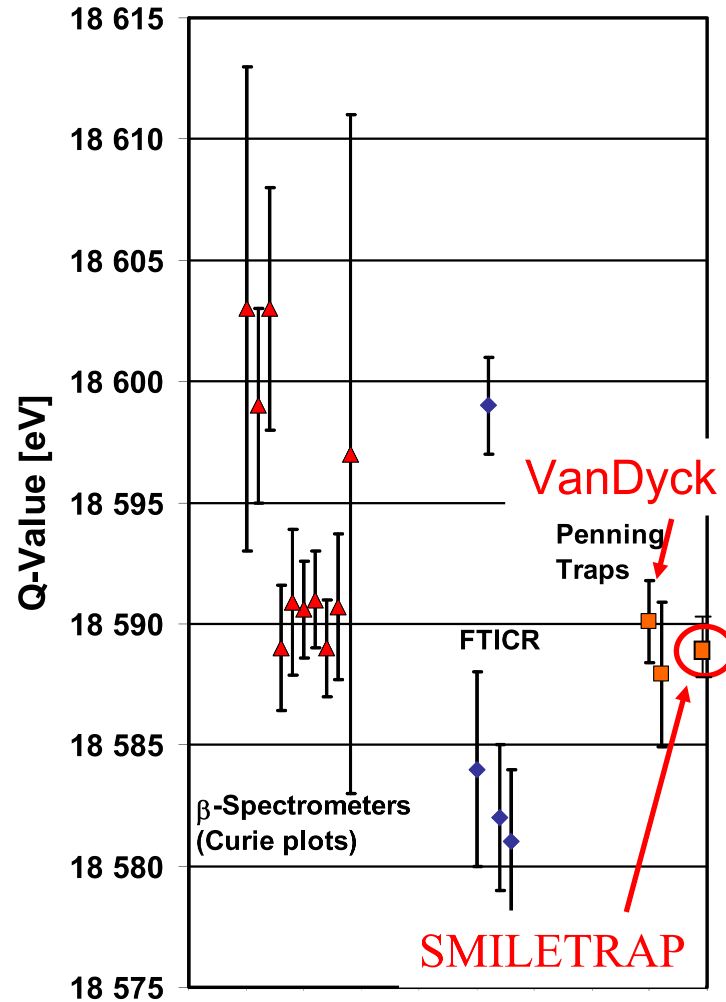


- *Q*-value of Tritium beta decay

$$^3_1H \rightarrow {}^3_2He + e^- + \overline{\nu}$$

Q=18 589.8 (1.2) eV

Sz. Nagy *et al.*, Europhys.Lett. 74, 404 (2006)



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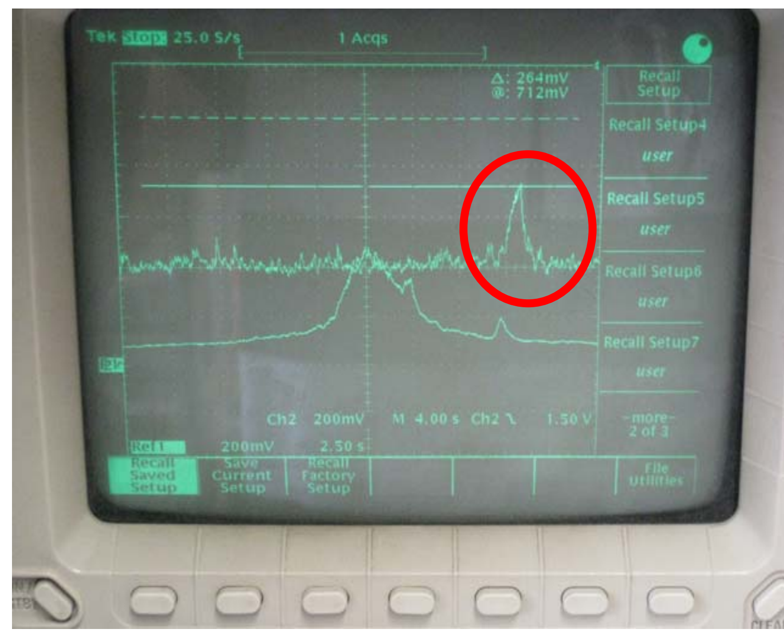
… in the new lab at MPIK

Temperature stabilized room:
$\Delta T < 0.1$ K

Magnetic field stability:
$\Delta B/B < 17$ ppt / h

Vibrationally isolated floor:
$\Delta x \leq 0.1\ \mu$m



We aim for:
$\delta Q(^3\mathrm{T} \rightarrow {}^3\mathrm{He}) = 20$ meV
$\delta m/m = 7 \cdot 10^{-12}$

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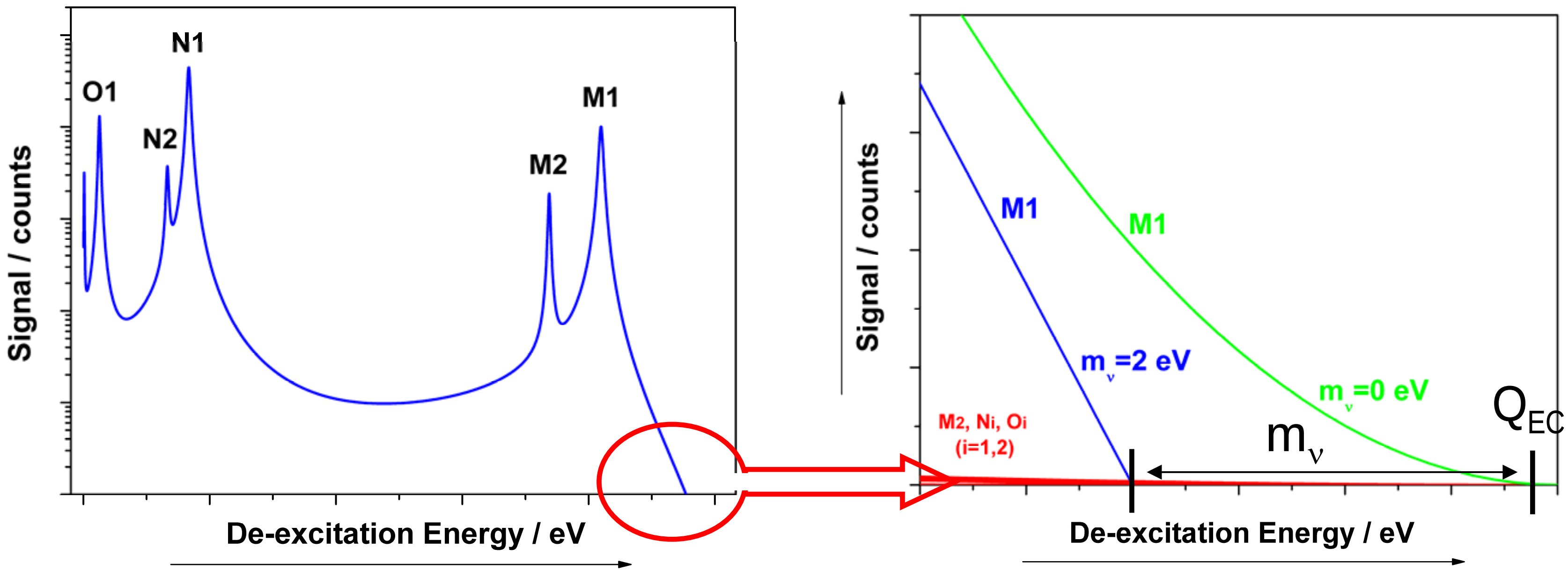
Electron neutrino mass

Typical μ-calorimetric de-excitation spectrum of EC in ^{163}Ho



Cryogenic μ-calorimeters (Group of Prof. Enss, KIP, Uni Heidelberg)
end point with accuracy ~ 1 eV

PENTATRAP (MPI-K, HD)
Q_{EC}-value with accuracy ~ 1 eV

→ m_ν ~ 1 eV

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Electron capture – General information

$(Z,A) + e \Rightarrow (Z\text{-}1,A)^h + Q_\nu$

$\Downarrow$

$(Z\text{-}1,A)^g + B_i$

cryogenic μ-calorimeters

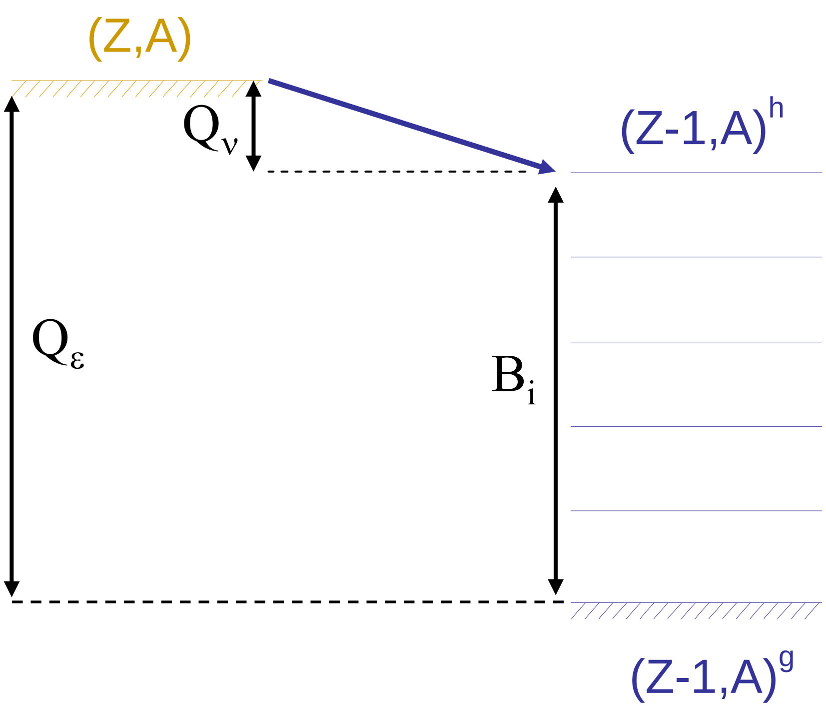
Penning traps

$$Q_\nu = E_\nu + m_\nu = Q_\varepsilon - B_i$$

Smaller $Q_\nu \rightarrow$ higher contribution of m_ν

$Q_\varepsilon - B_i$ should be as small as possible

$Q_\varepsilon < 100$ keV



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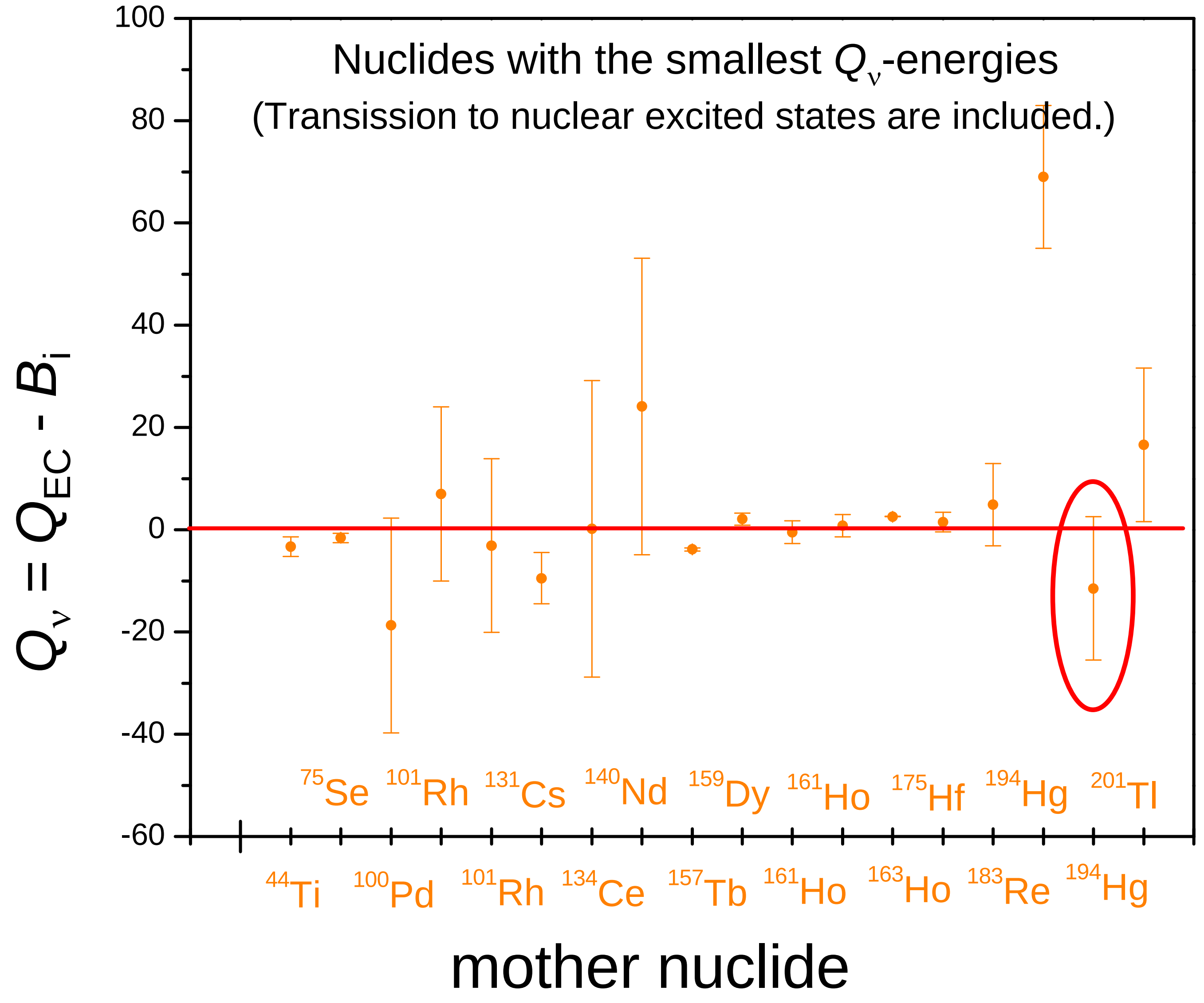
Interesting candidates



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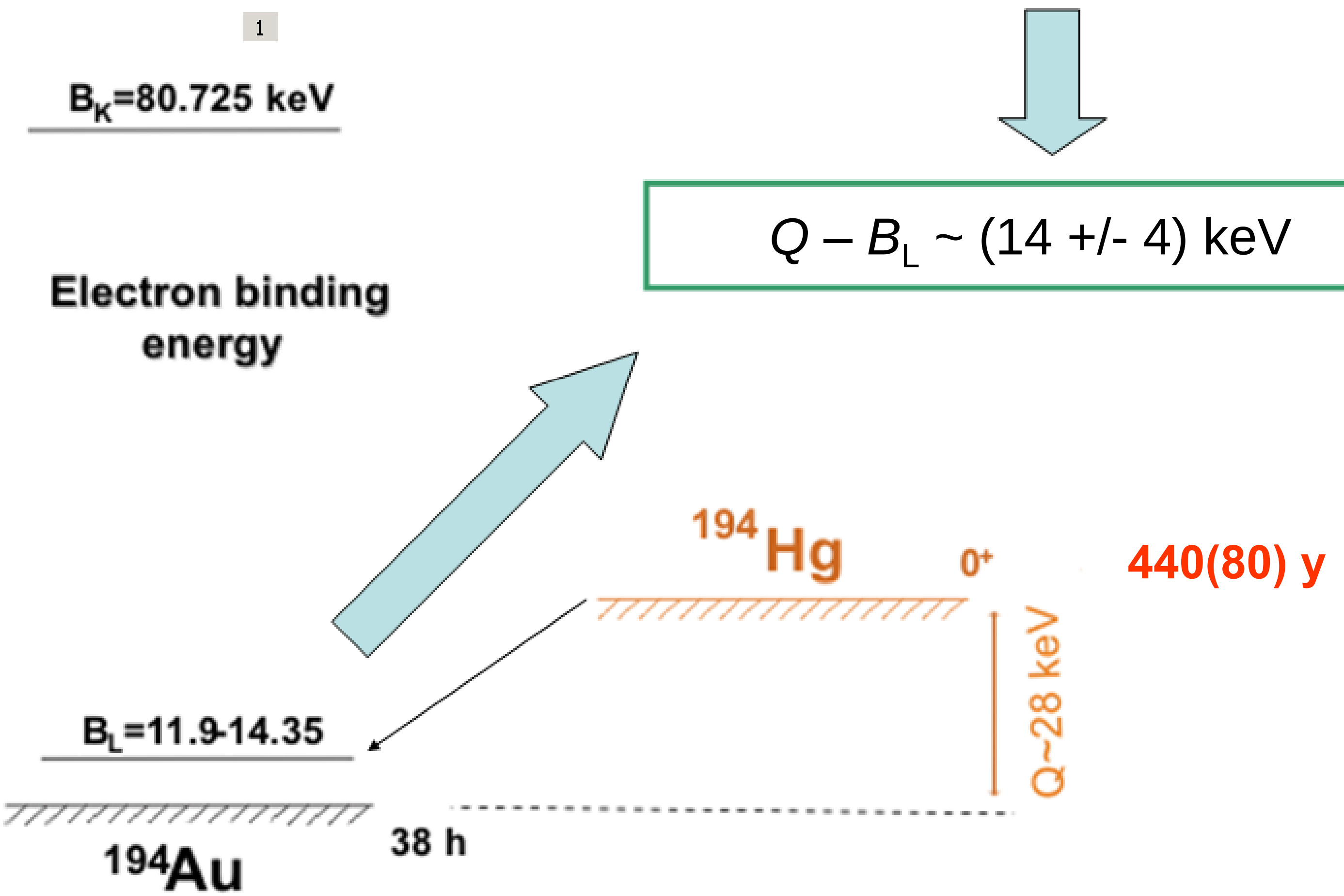
Results from ^{194}Hg - ^{194}Au

Q (^{194}Hg – ^{194}Au) ~ (28 ± 4) keV

$Q - B_L$ ~ (14 +/- 4) keV



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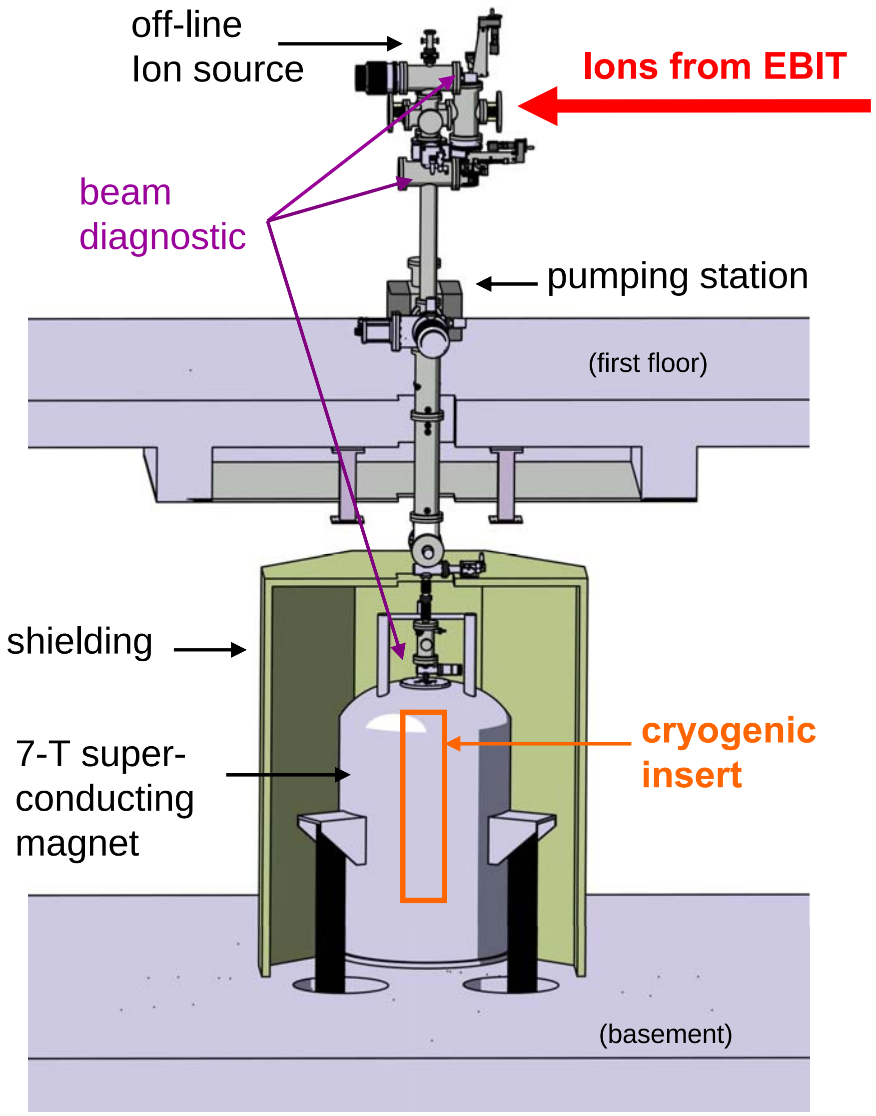
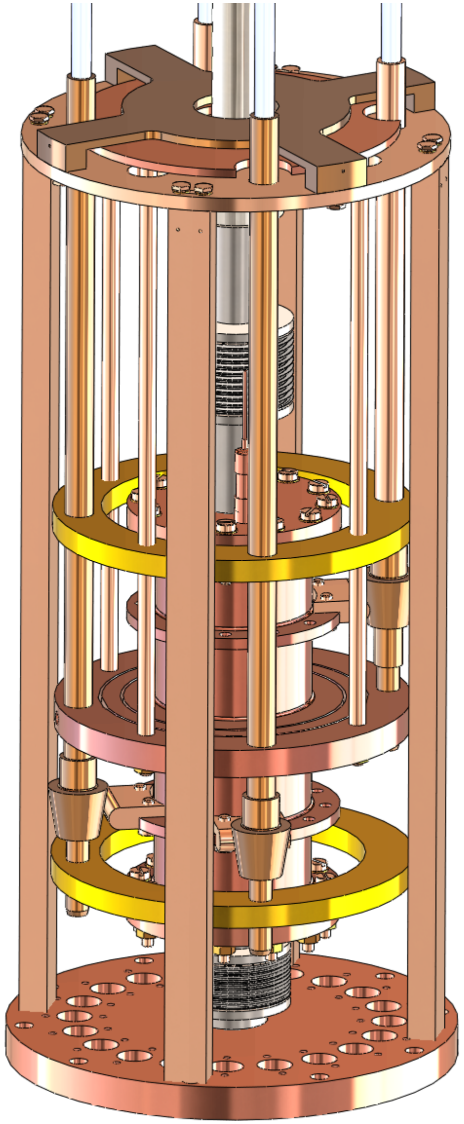
PENTATRAP – Masses with $\delta m/m = 10^{-11}$





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Conclusion

Precision Penning trap mass measurements can contribute in various ways to neutrino physics research!

Thanks a lot for the invitation and your attention!

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WWW: **www.mpi-hd.mpg.de/blaum/**