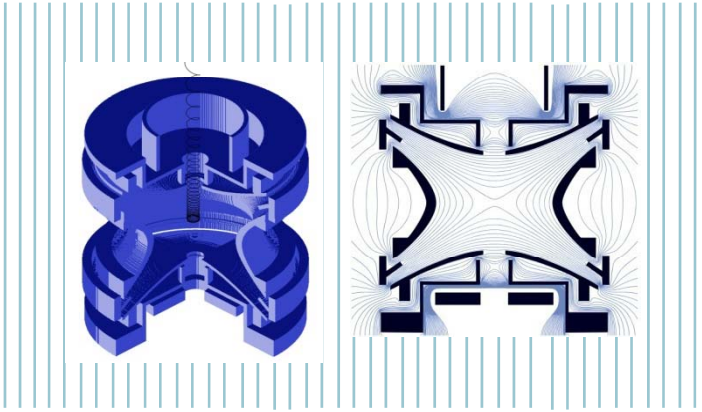
Contribution of Penning trap mass spectrometry to neutrino physics



Szilárd Nagy

MPI-K Heidelberg, Germany

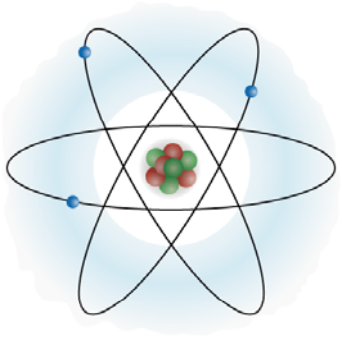
New Instruments for Neutrino Relics and Mass, CERN, 8-Dec-2008

Outline

- Introduction
- Techniques in high-precision Penning trap mass spectrometry
- Results related to neutrino physics
- Outlook

If m=100kg and δm=0.1kg,
Rel. Precision $\delta m/m = 0.001 = 10^{-3}$

Mass: fundamental information for fundamental physics

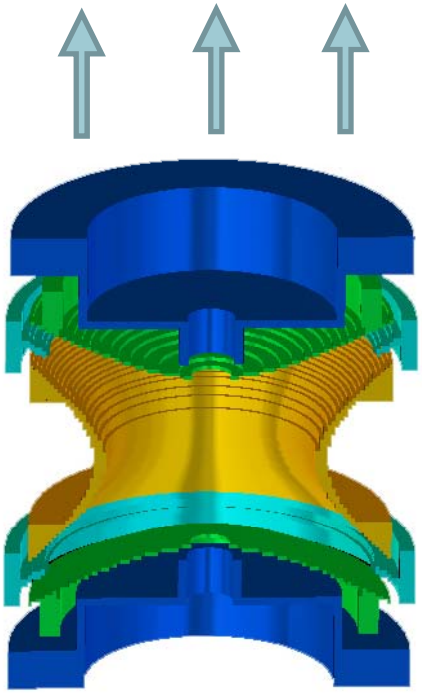


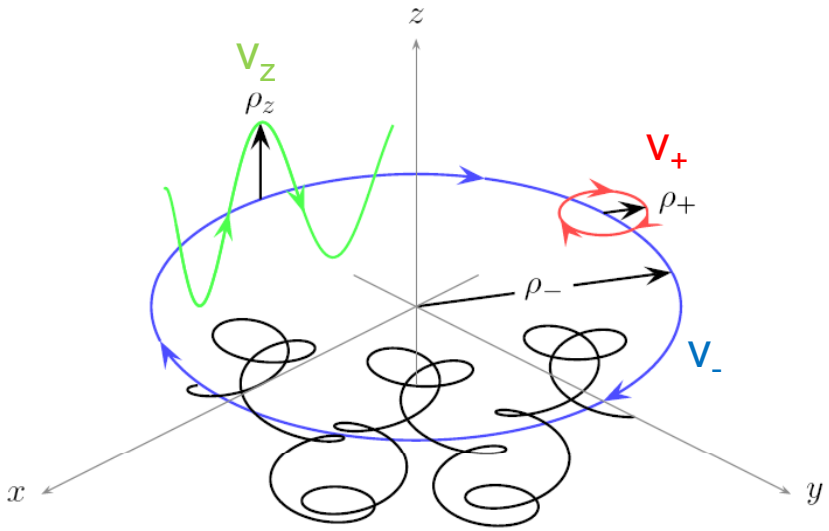
$$M = Z \cdot m_p + N_n \cdot m_n + Z \cdot m_e - E_b^{nuclear} - E_b^{atomic}$$

$E = mc^2$: Is Einstein right?
How much is really 1kg?
Where does QED theory fail?
Is there physics beyond the Standard Model ?
What is the rest mass of a neutrino?

Penning trap

PENNING trap: Combination of a strong homogeneous magnetic field and weak electric quadrupole field



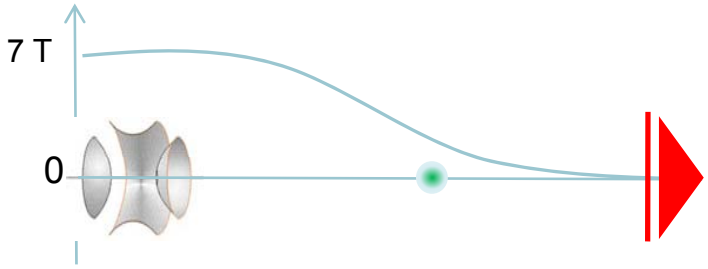


Cyclotron frequency:

$$\nu_c = \frac{1}{2\pi}\frac{qeB}{m} = \sqrt{\nu_-^2 + \nu_z^2 + \nu_+^2}$$

Destructive and non-destructive detection

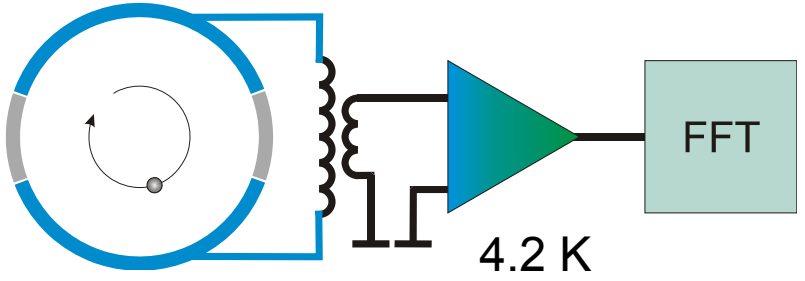
TOF-ICR



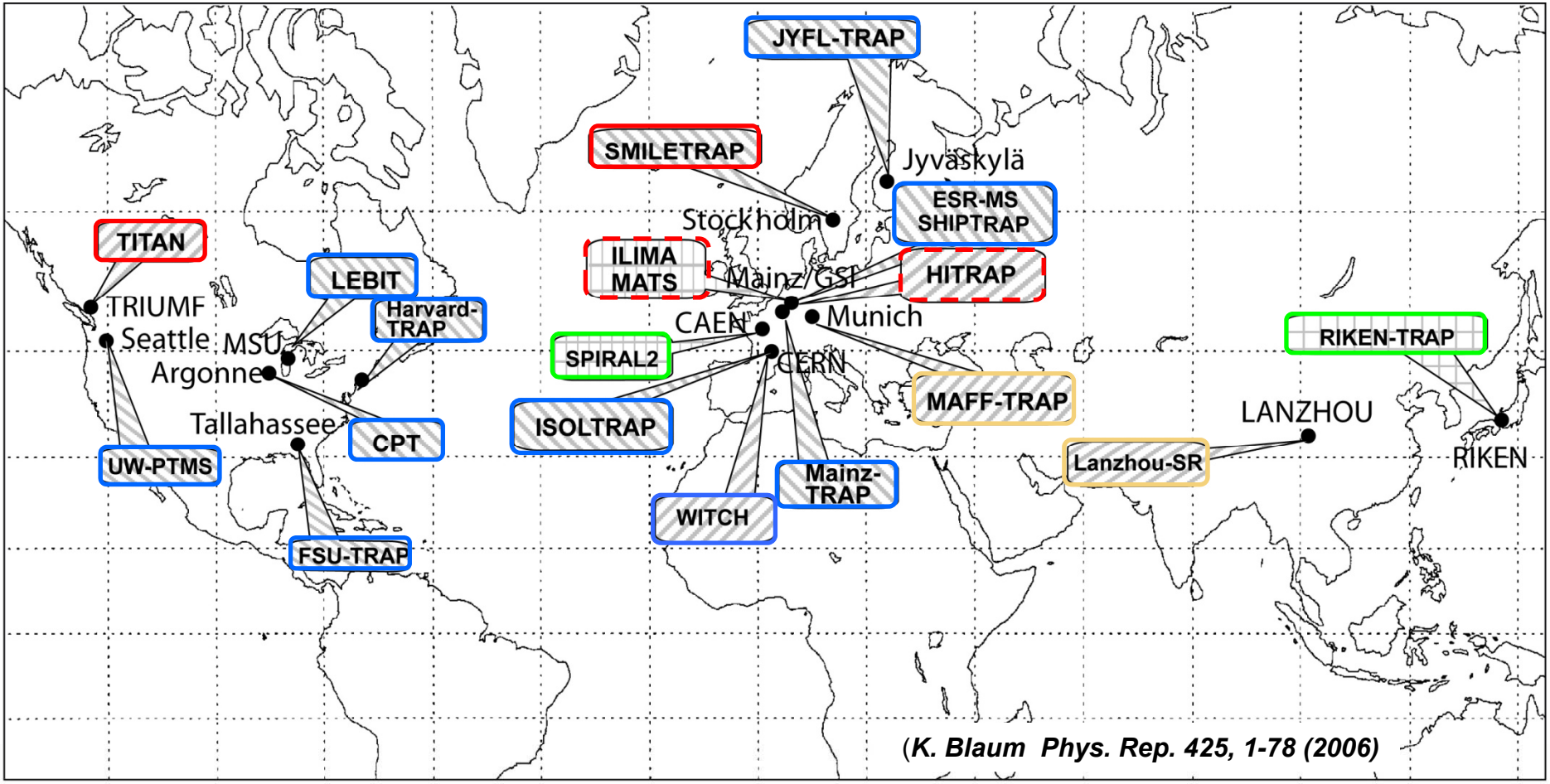
radial energy ⇒ axial energy

G. Gräff et. al Z. Phys. ***297*** *35 (1980)*

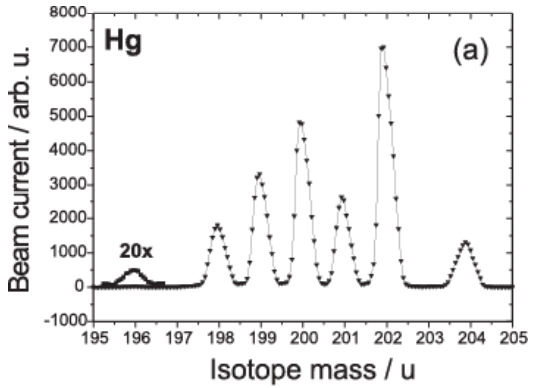
Narrow-band FT-ICR

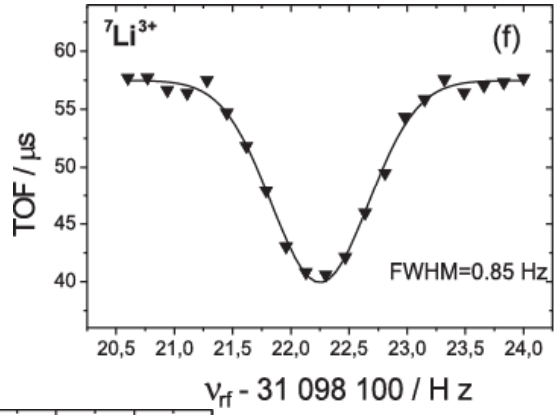


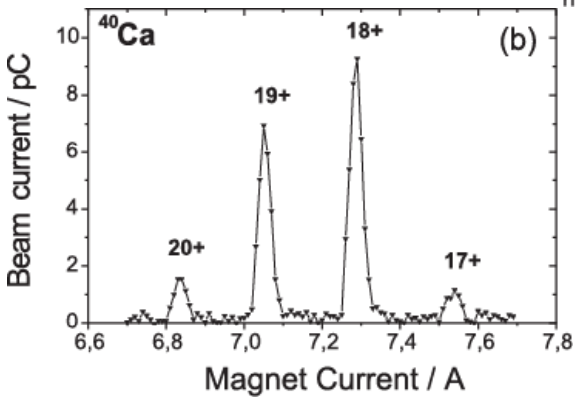
Penning trap mass spectrometer facilities worldwide



Stockholm-Mainz-Ion LEvitation-TRAP



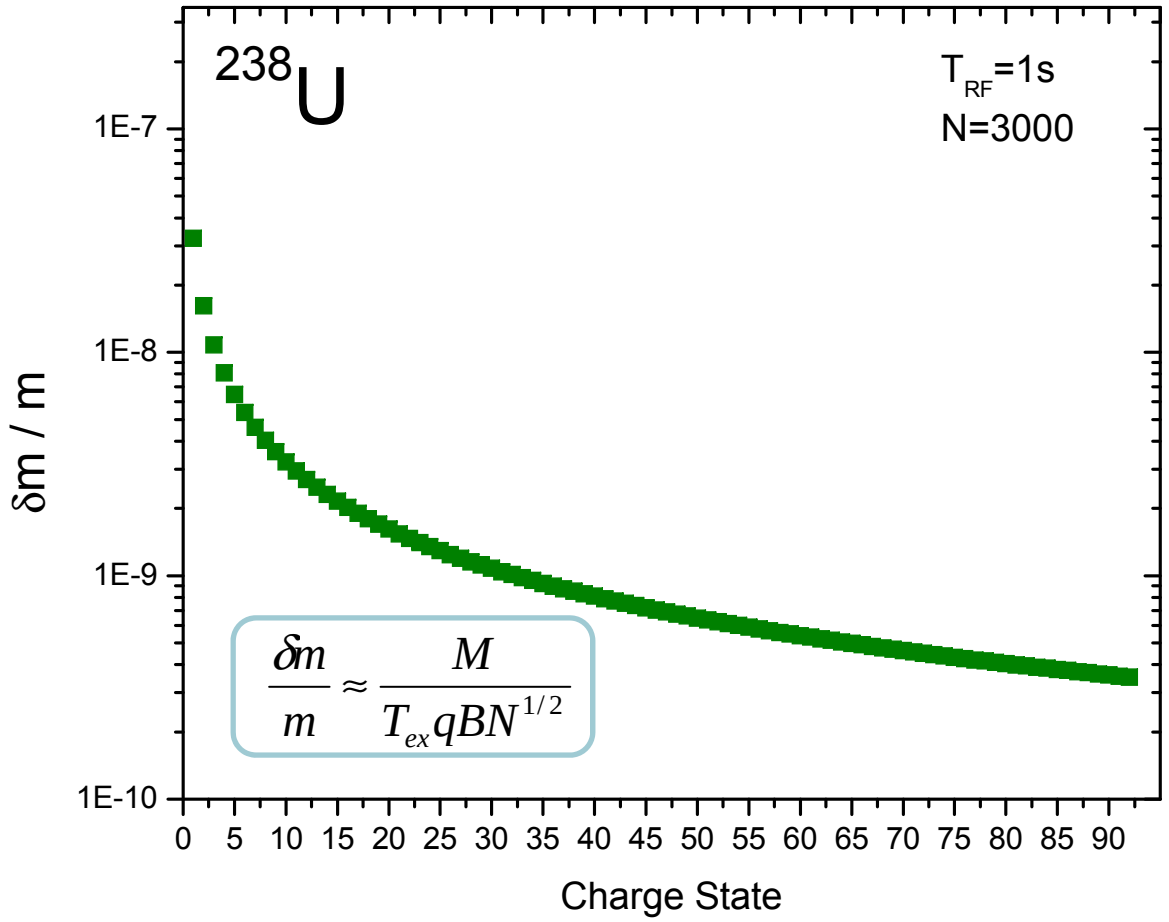




I. Bergström et al. NIM A 487, 618 (2002)

Why to use highly-charged ions for mass measurements?

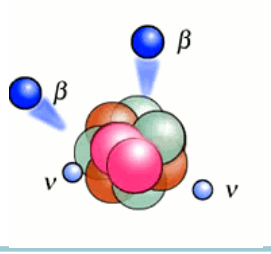
$$\nu_c = \frac{1}{2\pi}\frac{qeB}{m}$$



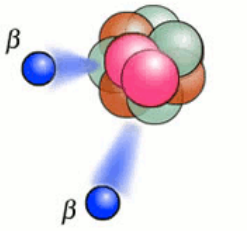
In the case of ^{238}U 92 *X* higher resolving power can be achieved by using *q*=92+ ions.

On the Q-value of the ^{76}Ge $\beta\beta$ -decay

$$^{76}Ge \rightarrow {}^{76}Se + 2\beta + 2\nu$$

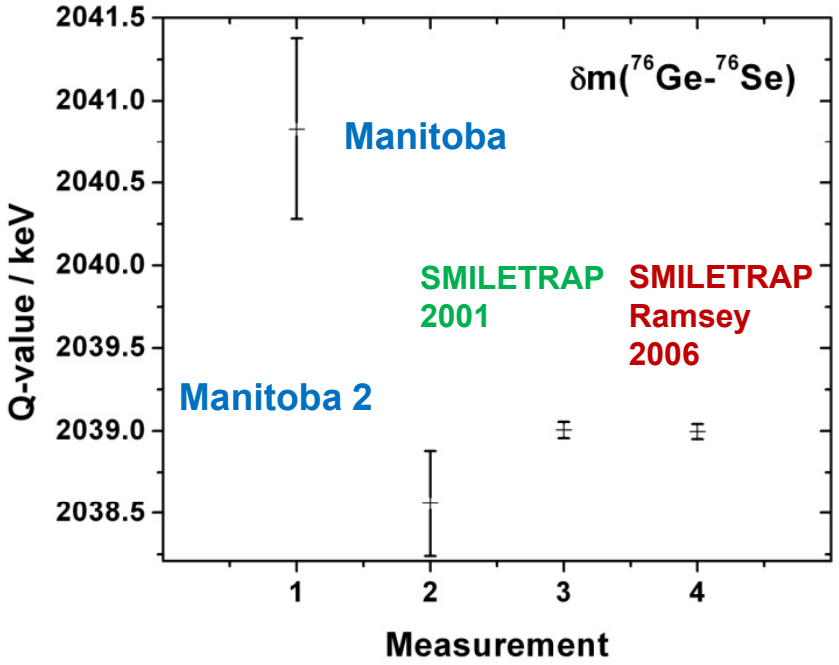


$$^{76}Ge \rightarrow {}^{76}Se + 2\beta$$

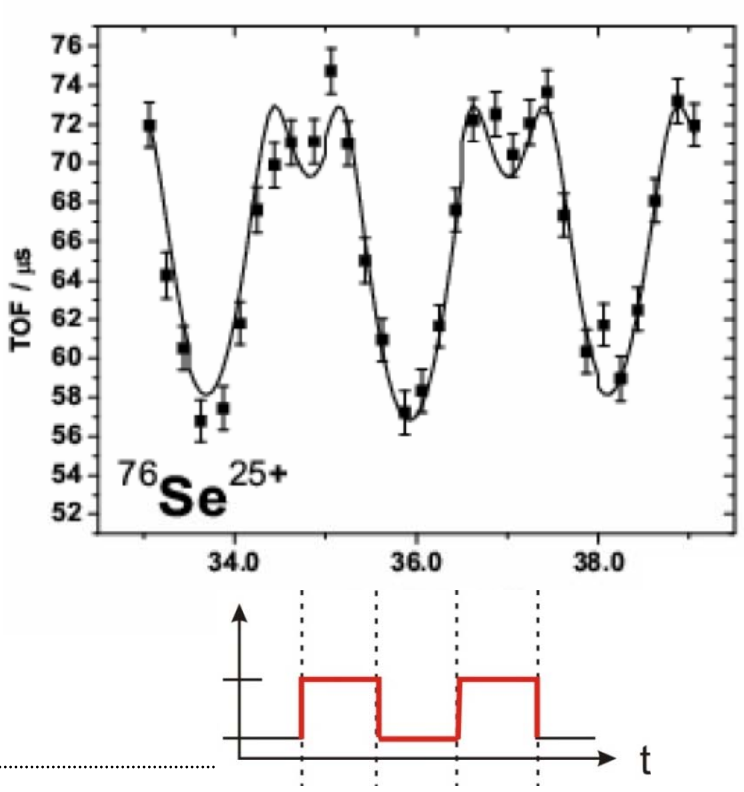


Not allowed by SM

$$T_{1/2} = 10^{21}\ years$$



Q=2039.006(46) keV



G. Douysset Phys. Rev. Lett. 86, 4259 (2001)

M. Suhonen et al. JINST 2 P06003 (2007)

The Q-value of the ^{136}Xe $\beta\beta$ -decay

Candidate	Q (MeV)	Abund. (%)
$^{48}Ca \rightarrow ^{48}Ti$	4.271	0.187
$^{76}Ge \rightarrow ^{76}Se$	2.040	7.8
$^{82}Se \rightarrow ^{82}Kr$	2.995	9.2
$^{96}Zr \rightarrow ^{96}Mo$	3.350	2.8
$^{100}Mo \rightarrow ^{100}Ru$	3.034	9.6
$^{110}Pd \rightarrow ^{110}Cd$	2.013	11.8
$^{116}Cd \rightarrow ^{116}Sn$	2.802	7.5
$^{124}Sn \rightarrow ^{124}Te$	2.228	5.64
$^{130}Te \rightarrow ^{130}Xe$	2.533	34.5
$^{136}Xe \rightarrow ^{136}Ba$	2.479	8.9
$^{150}Nd \rightarrow ^{150}Sm$	3.367	5.6

Ion pair
$^{136}Xe^{3+}/^{13}CO_2^+$
$^{136}Xe^{4+}/^{28}SiD_3^+$
$^{136}Xe^{5+}/^{14}N_2^+$
$^{136}Xe^{3+}/^{13}CO_2^+$

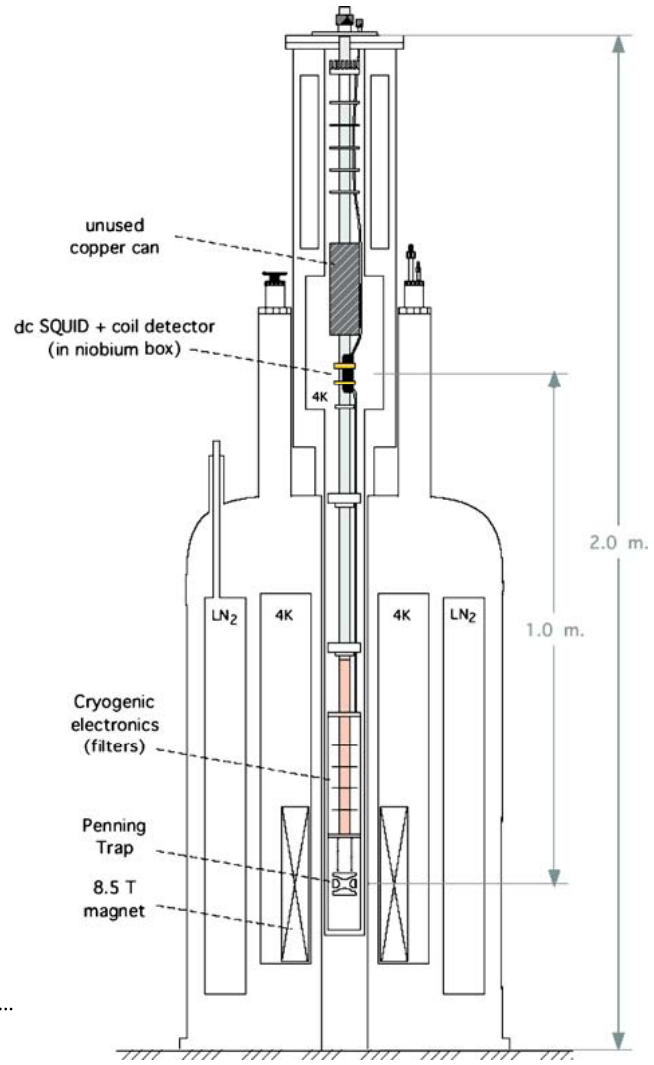
m(^{136}Xe) =135.907 214 484 (11) u

8x10^{-11} improvement by factor 380x

m(^{136}Xe) –m(^{136}Ba)=2457.83(37) keV

M. Redshaw et al., Phys. Rev. Lett. ***98,*** *053003 (2007)*

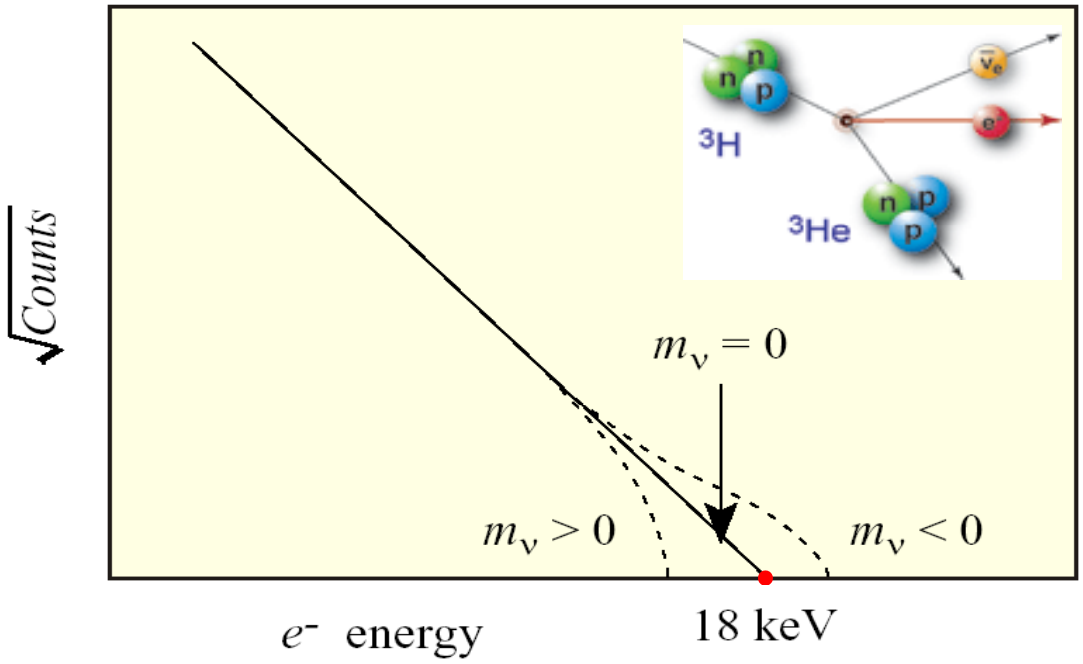
E. G. Myers et al.
formerly D. Pritchard MIT



The Q-value of the Tritium β-decay

$$^{3}_{1}H \rightarrow ^{3}_{2}He + e^{-} + \bar{\nu}$$

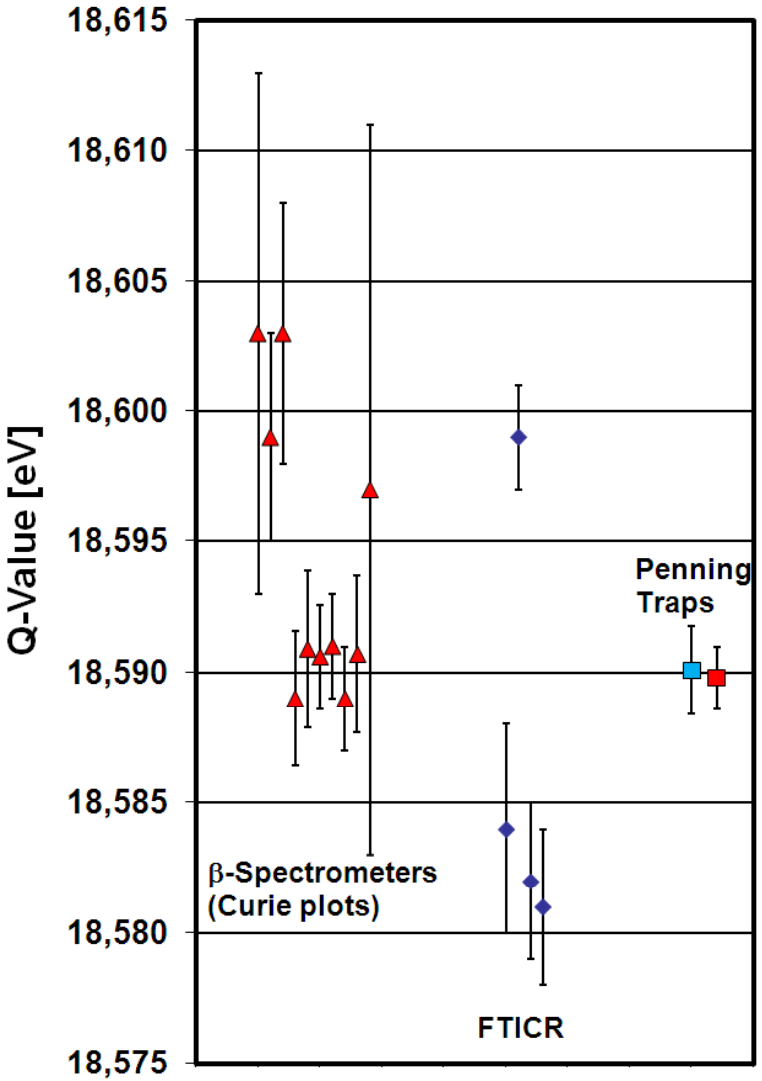
$$E_{\text{endpoint}} = Q = m(^{3}He) - m(^{3}H)$$



■ **KATRIN will examine the shape of the tritium β spectrum at the highest energies.**

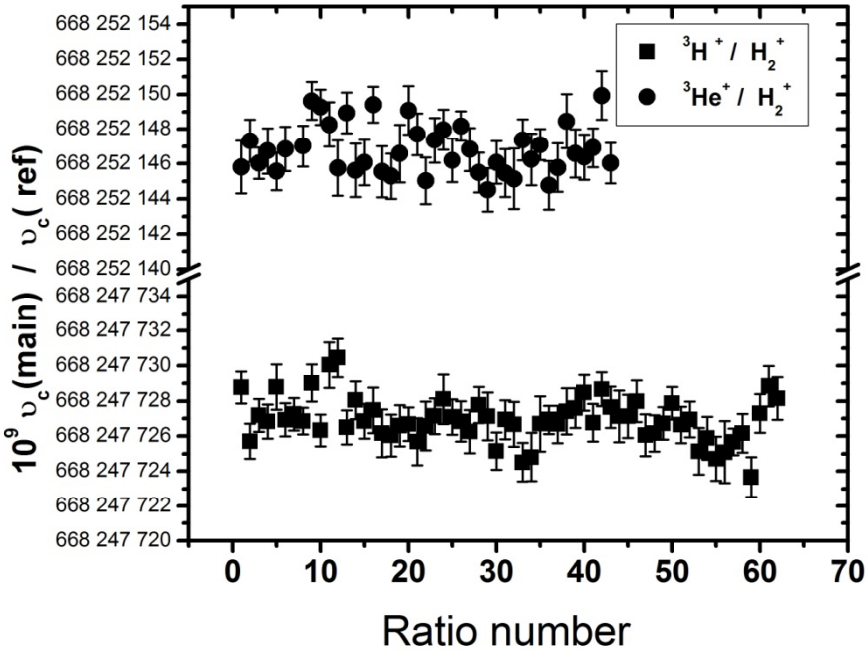
■ **If electron neutrinos had a nonzero mass, the maximum electron energy would be lower, and the shape of the spectrum different**

Q-value of ^{3}H β-decay



Stockholm

Seattle



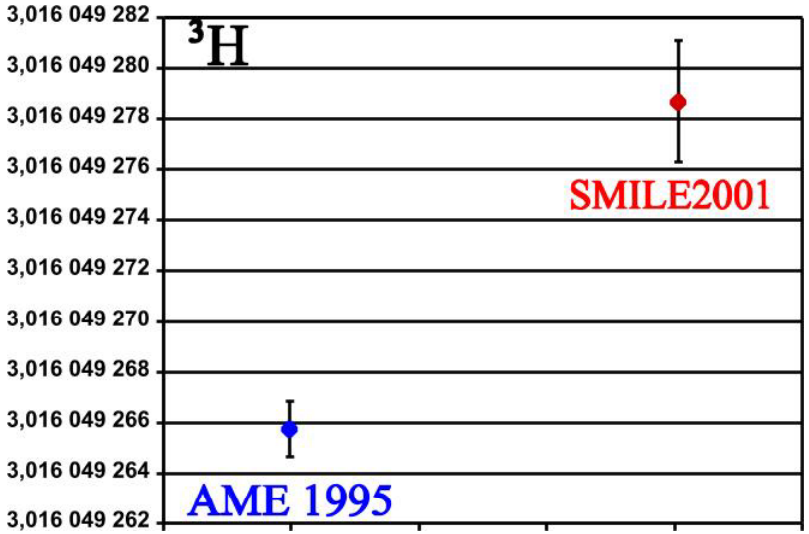
Stockholm value:
***Q*= 18 589.8 eV**
***Uncertainty*: 1.2 eV**

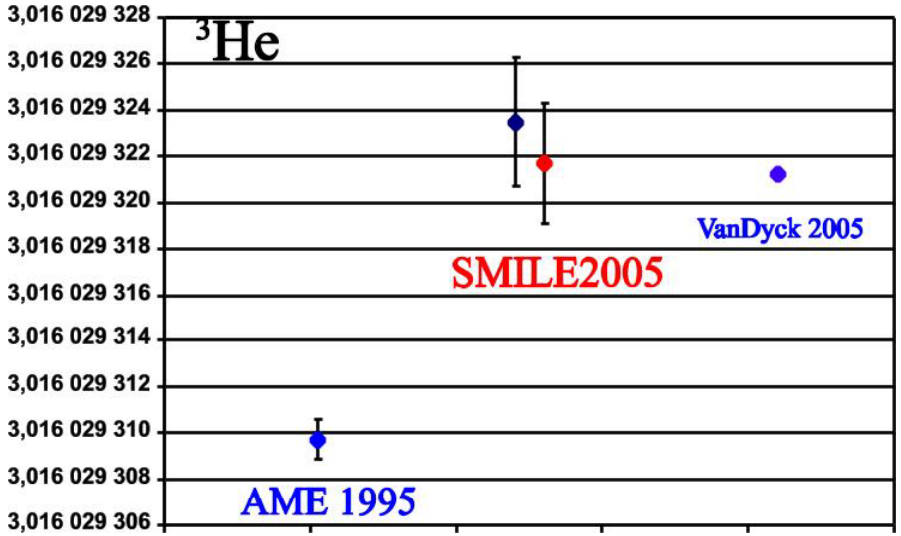
Sz. Nagy et al. Europhys. Lett., 74, 404 (2006)

Mass measurement of ^{3}He and ^{3}H

^{3}H	3,016,049,278 7 (25) u	0.8 ppb

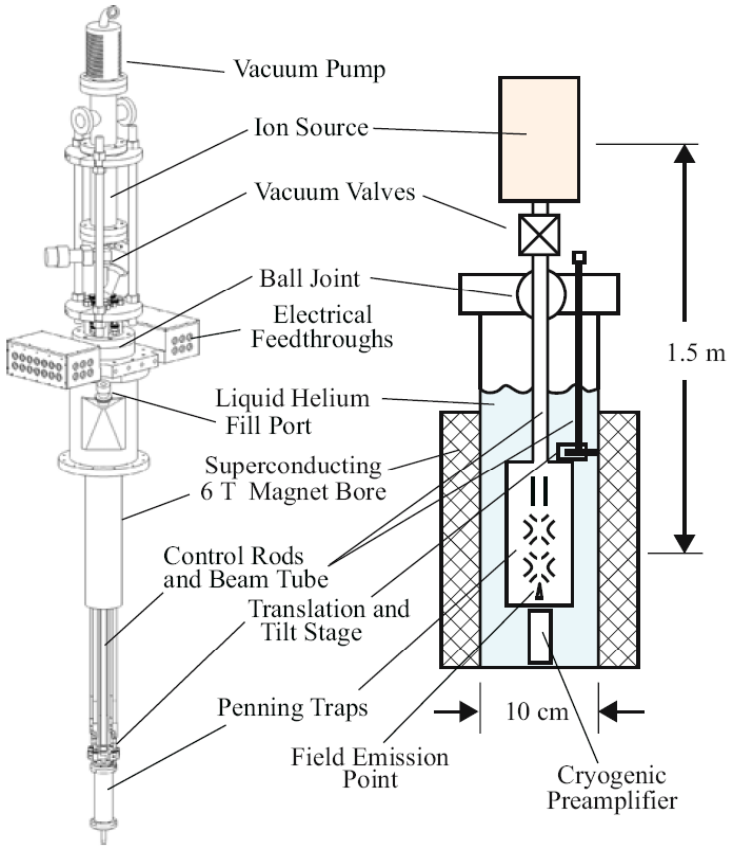
SMILE05	3,016,029,321 7 (26) u	0.8 ppb





Outlook

VanDyckPTMS@Heidelberg



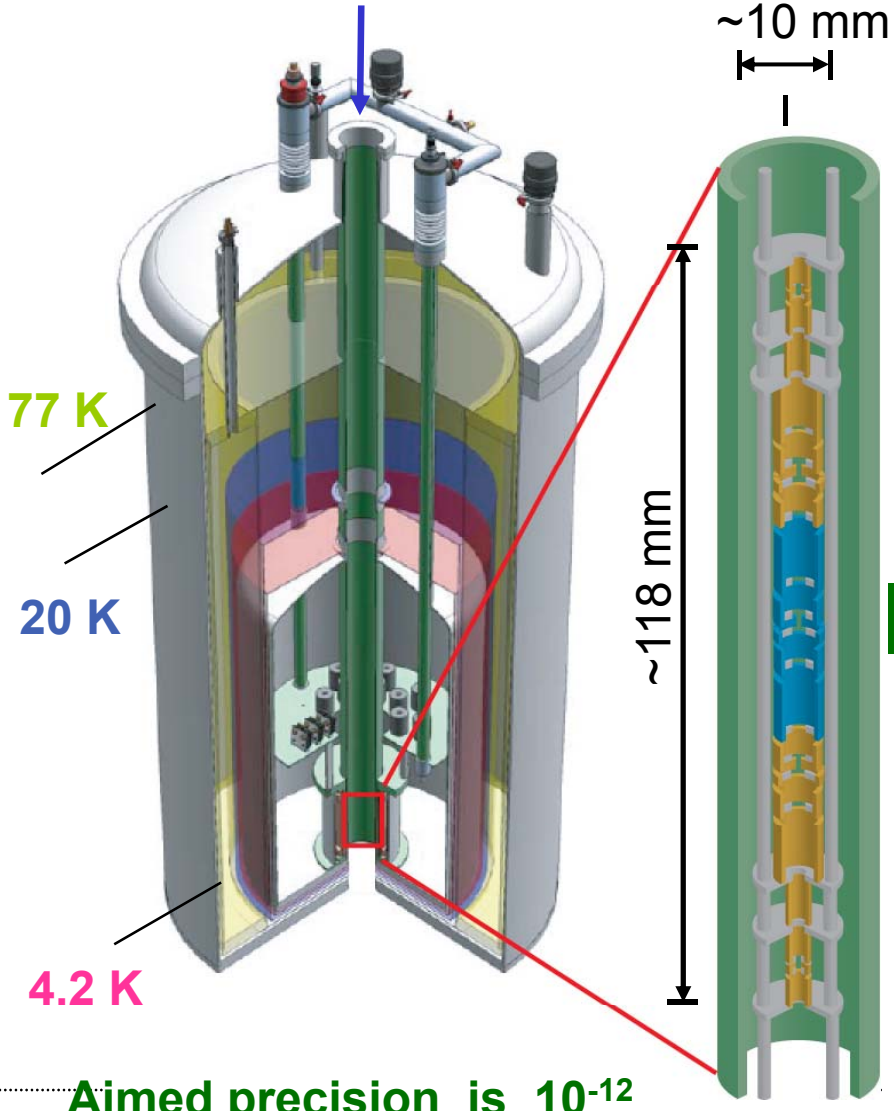
UW-PTMS is relocated to MPI-K Heidelberg
and is being built up in a new tritium-proof laboratory
within the group of K. Blaum

The layout of the PENTATRAP in Heidelberg

Merge into one novel setup:
HCI+Cooling+cryogenic trap+FT-ICR+ external ion injection

- Shielded room
- External ion injections
- Cryogenic temperatures
- No ion-ion interaction
- Short measurement cycle
- Continuous *B*-field monitoring/ calibration

HCI from Heidelberg EBIT



B=7 T
T=4.2K
P=10^{-13}mbar
$\delta B/B<10^{-7}/cm^3$
$(\delta B/dt)\cdot(1/B)<10^{-10}/h$

Aimed precision is 10^{-12}

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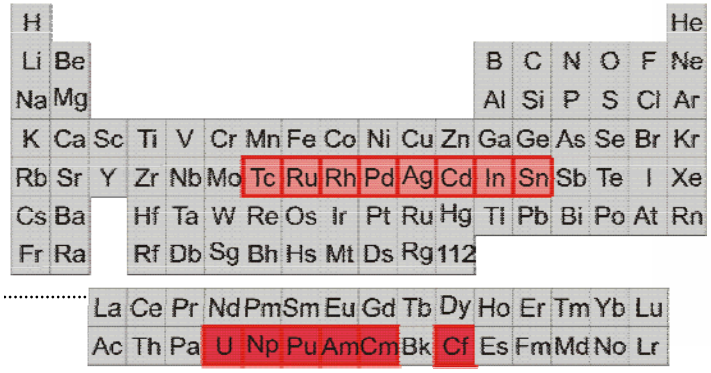
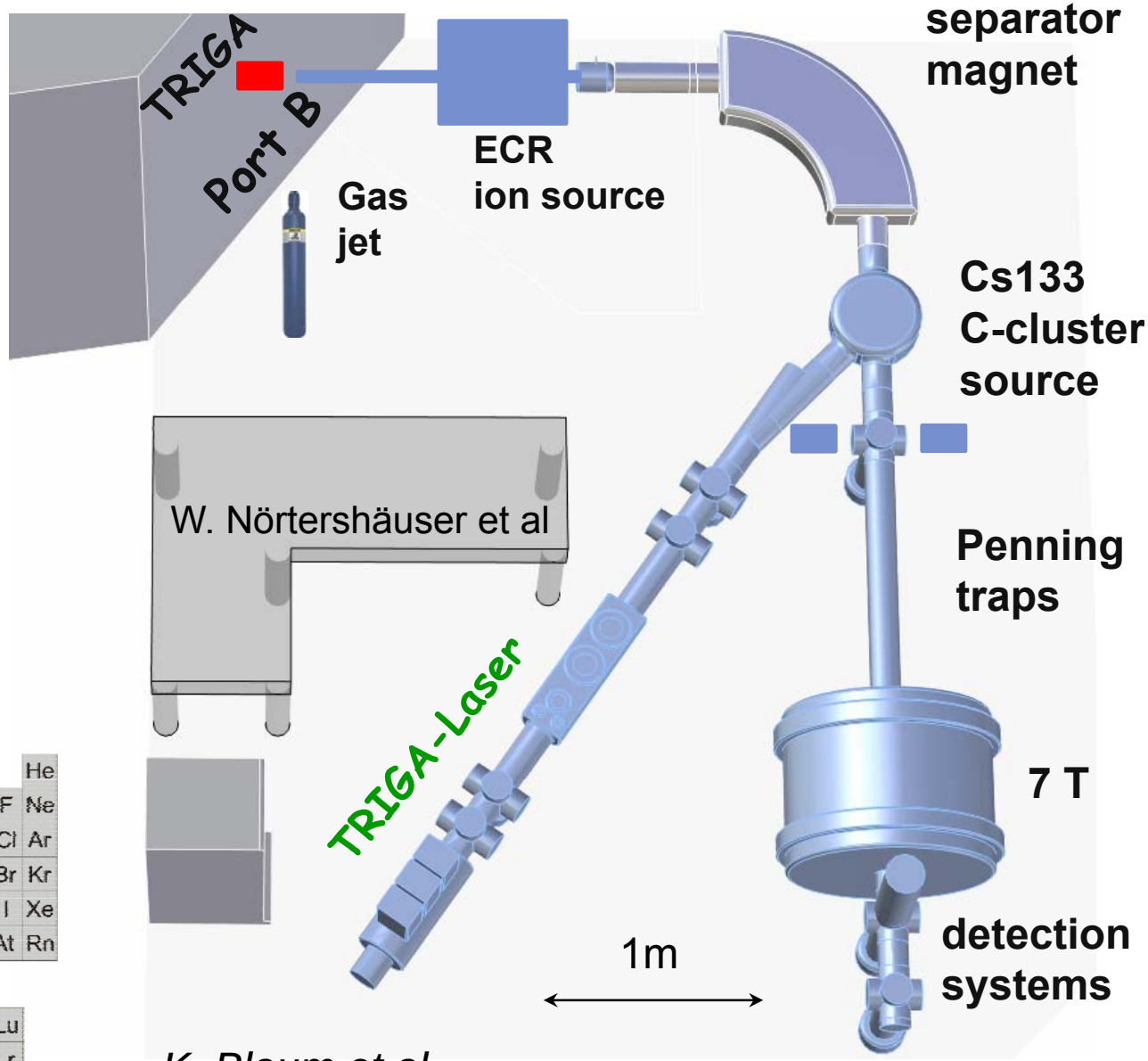
TRIGA-SPEC: TRIGA-TRAP and TRIGA-LASER

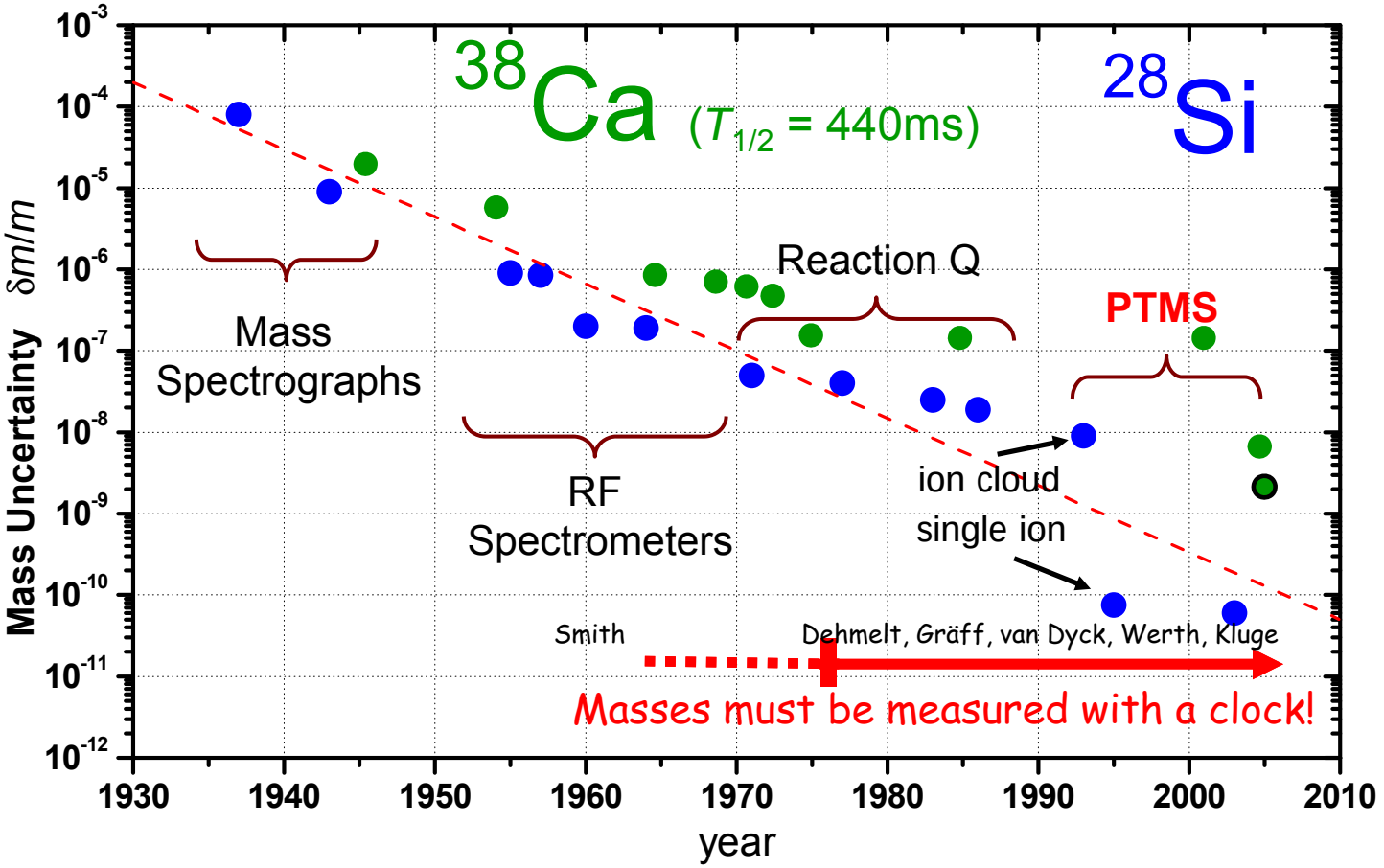




K. Blaum et al

TRIGA-TRAP is operational

Summary



2009: ^{3}H Q-value in Heidelberg with 30 meV precision

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