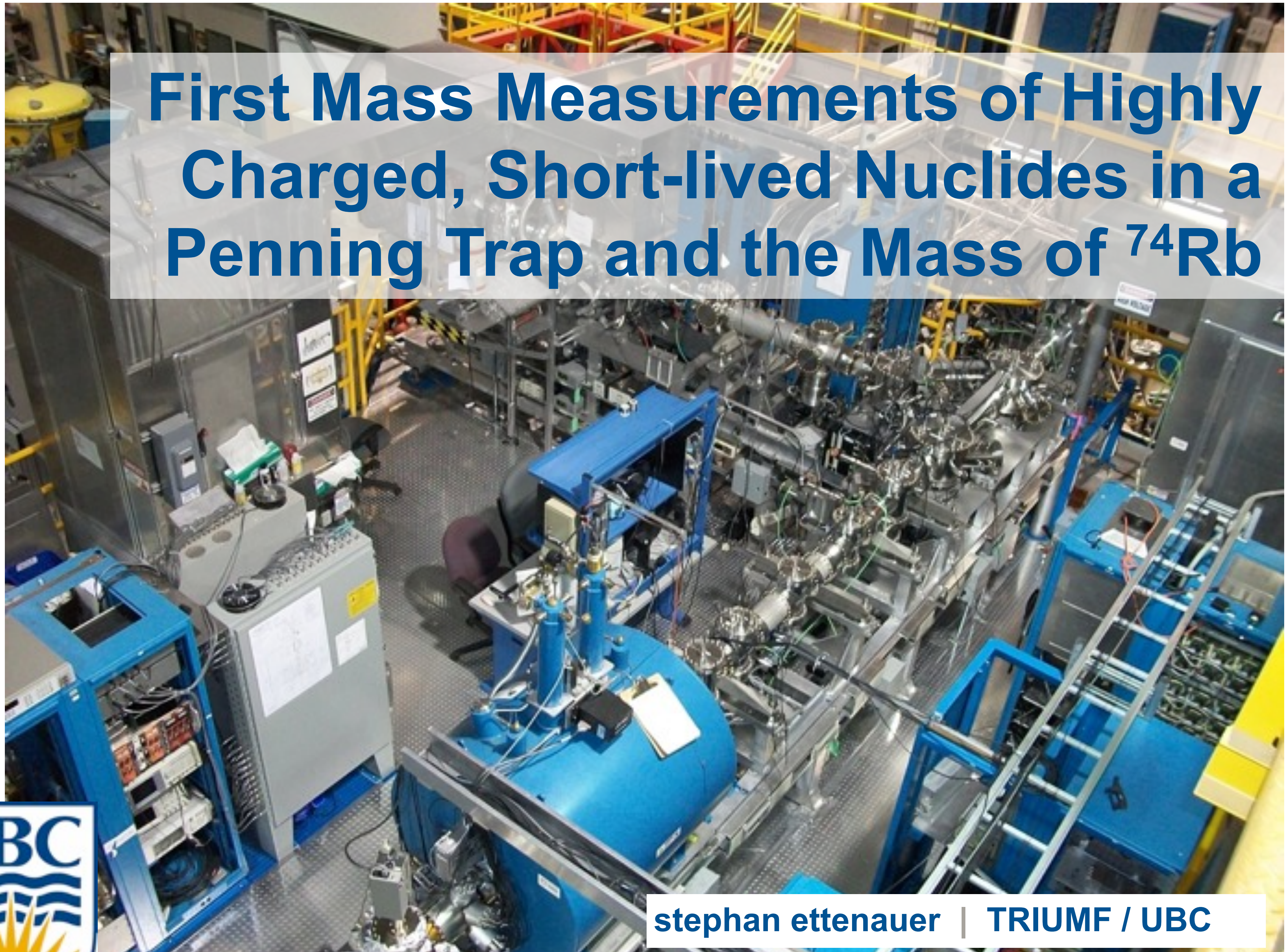
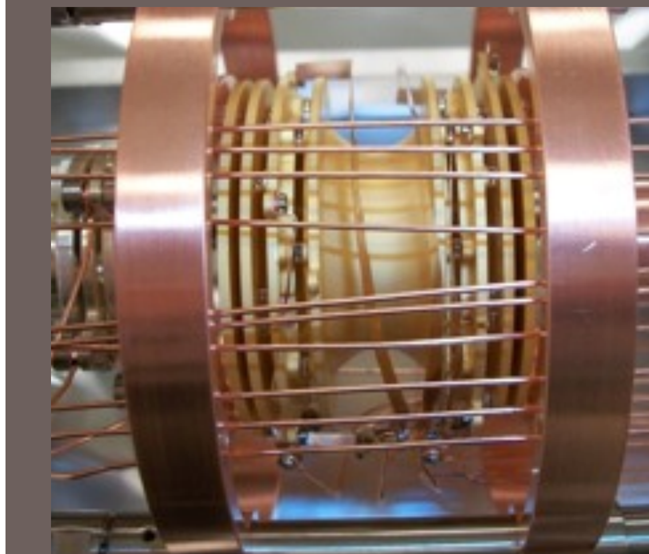


First Mass Measurements of Highly Charged, Short-lived Nuclides in a Penning Trap and the Mass of ^{74}Rb

stephan ettenauer | TRIUMF / UBC



Owned and operated as a joint venture by a consortium of Canadian universities via a contribution through the National Research Council Canada
Propriété d’un consortium d’universités canadiennes, géré en co-entreprise à partir d’une contribution administrée par le Conseil national de recherches Canada

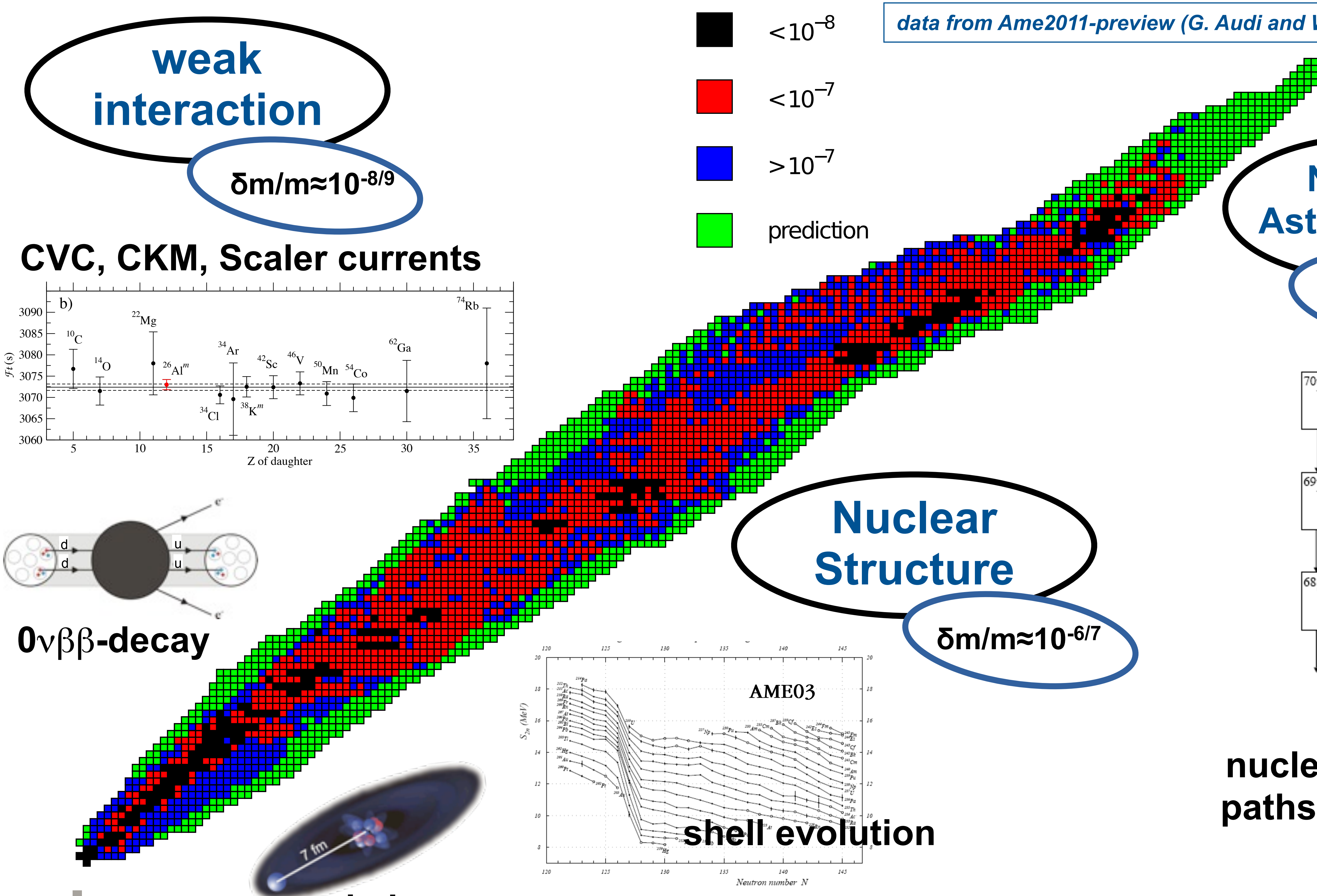
nuclear masses: S_n, Q-value, ...

data from Ame2011-preview (G. Audi and W. Meng)

weak interaction

δm/m≈$10^{-8/9}$

CVC, CKM, Scaler currents



0νββ-decay

halos

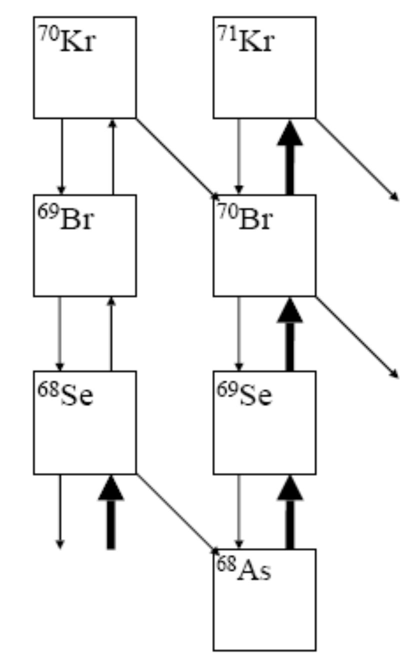
shell evolution

Nuclear Structure

δm/m≈$10^{-6/7}$

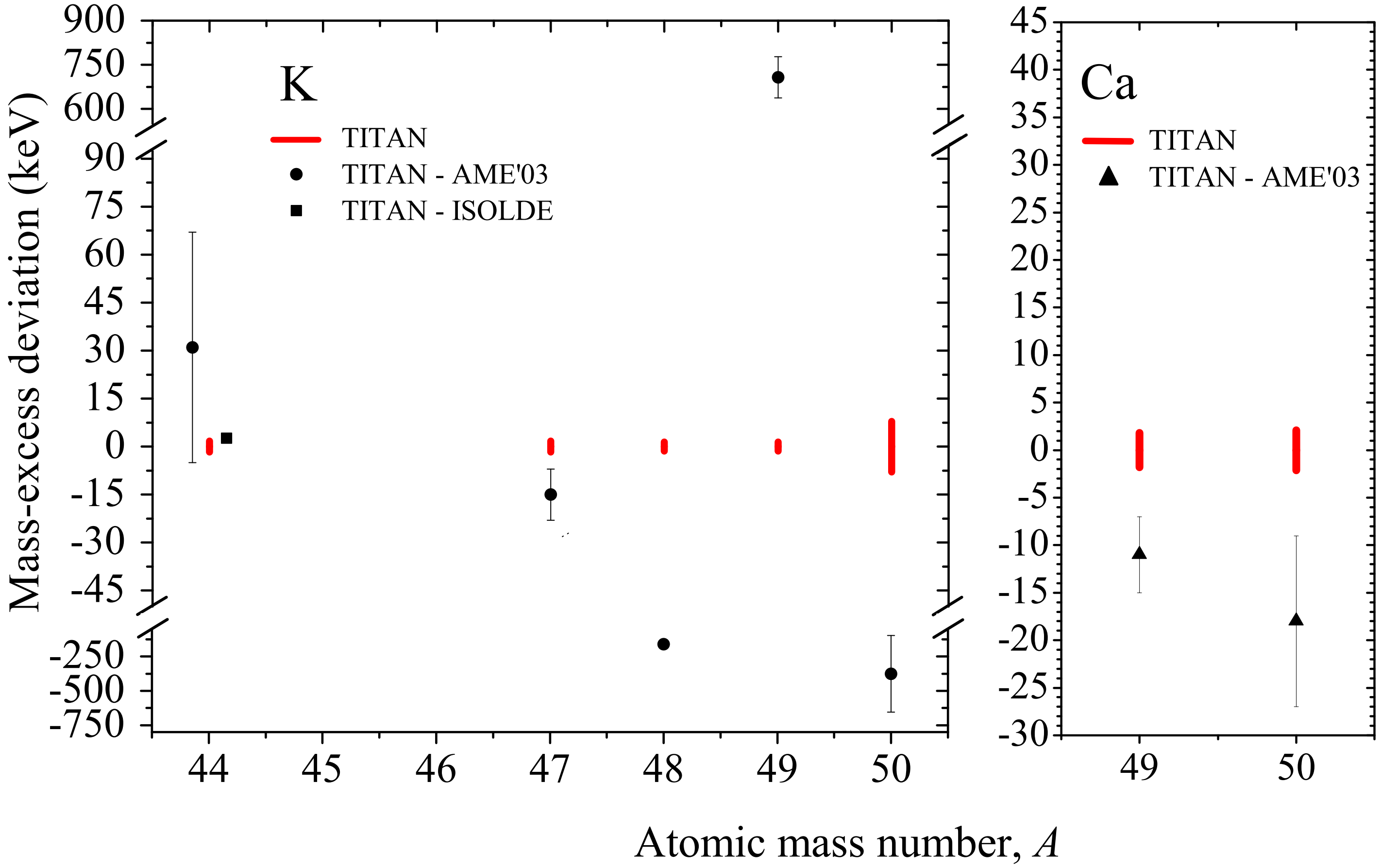
Nuclear Astrophysics

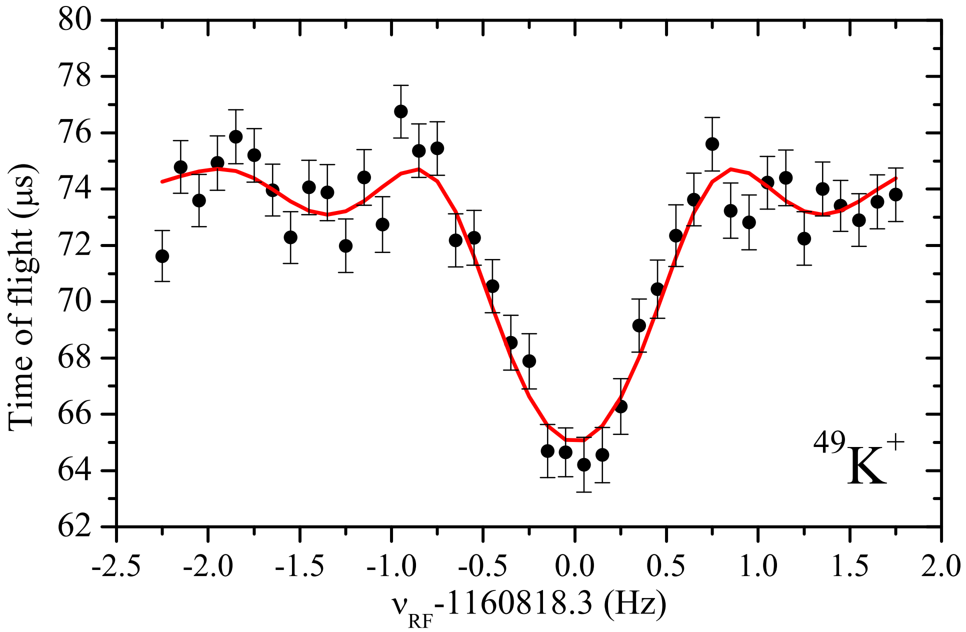
δm/m≈10^{-7}



nucleo-synthesis paths and waiting points

reliability?

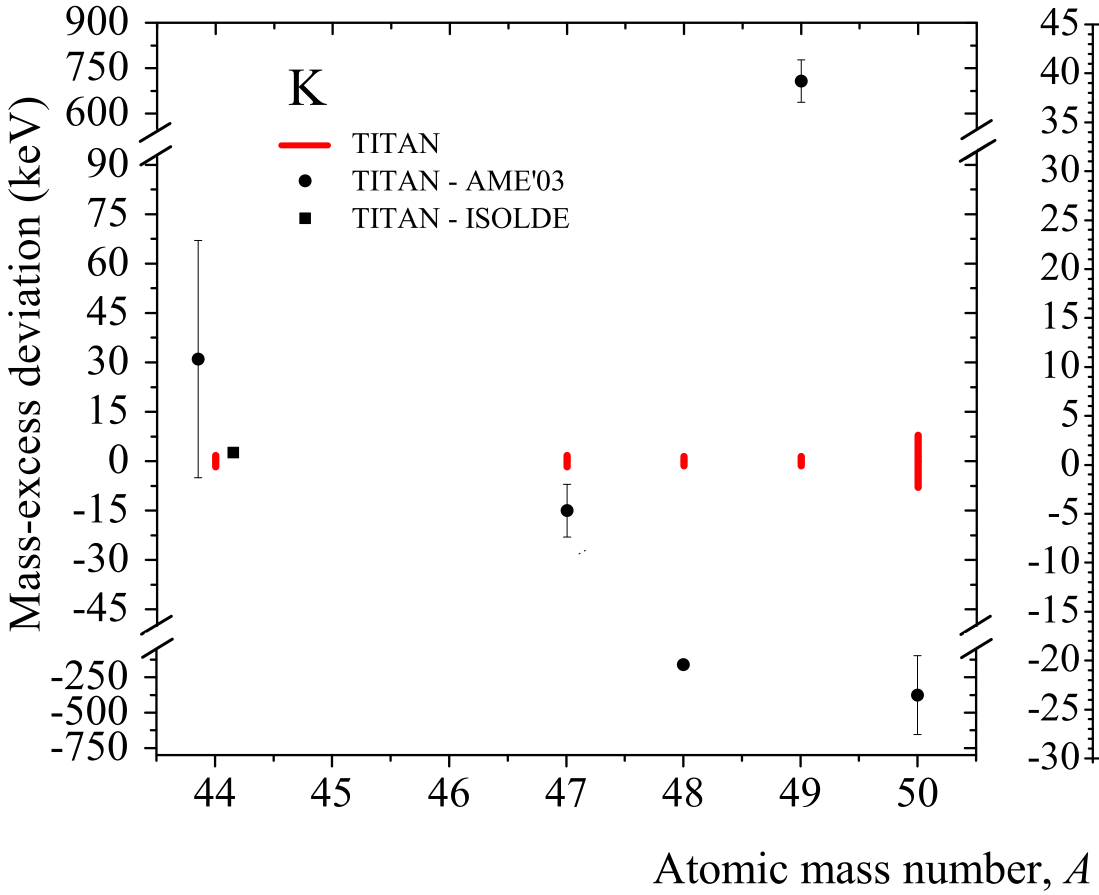


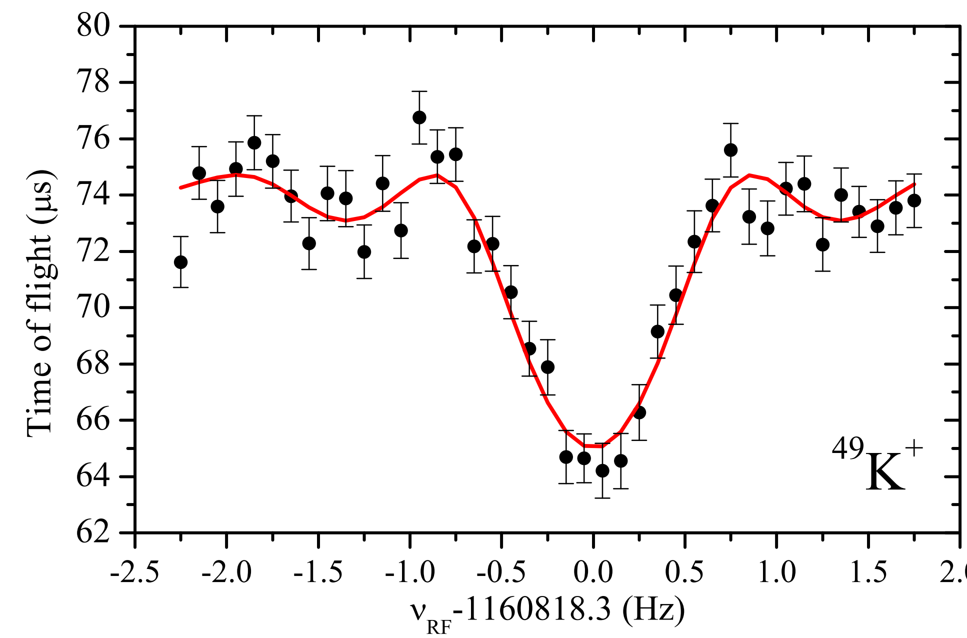


A. Lapierre et al., to be submitted to PRC

- large deviations from previous measurements up to 10 σ
- N=28 shell gap in fact ≈1 MeV larger

reliability?

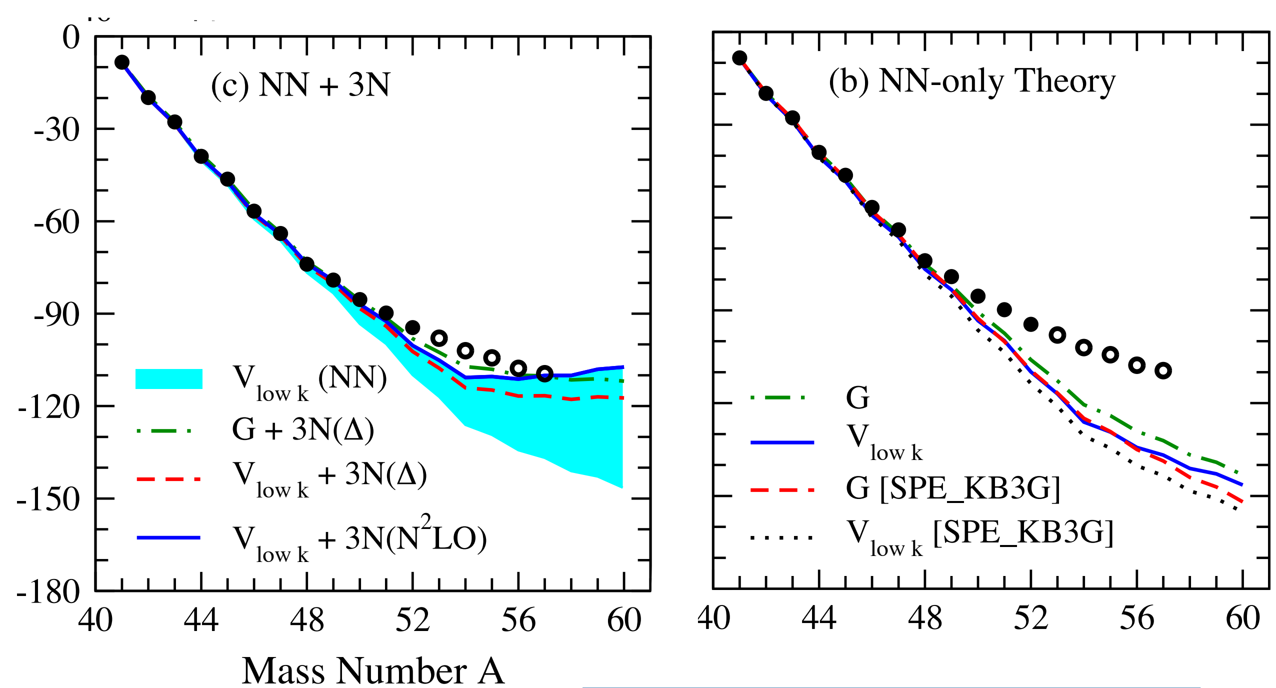




A. Lapierre et al., to be submitted to PRC

- large deviations from previous measurements up to 10 σ
- N=28 shell gap in fact ≈1 MeV larger

relevant for nuclear theory

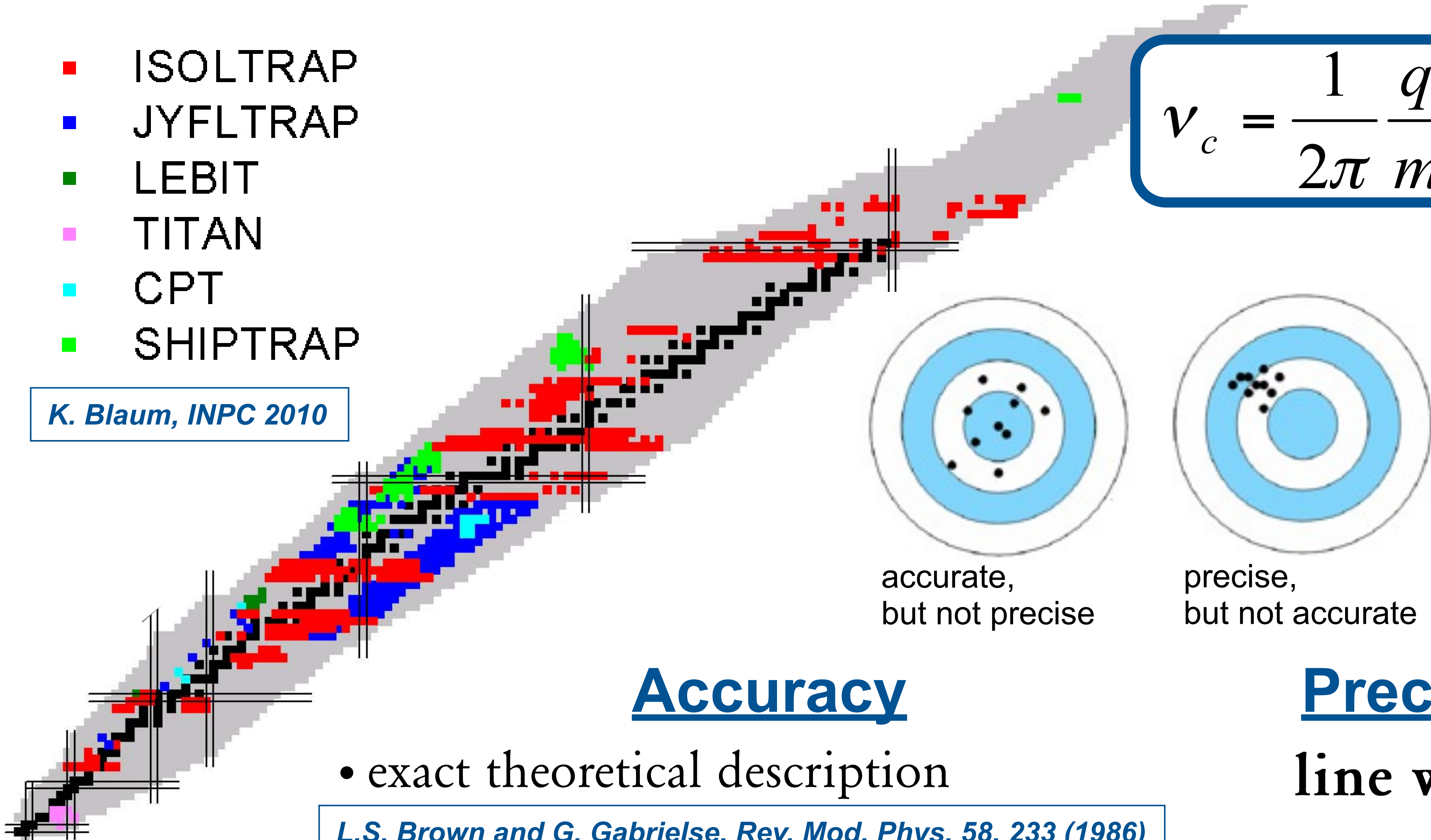


J. D. Holt et al., arXiv:1009.5984

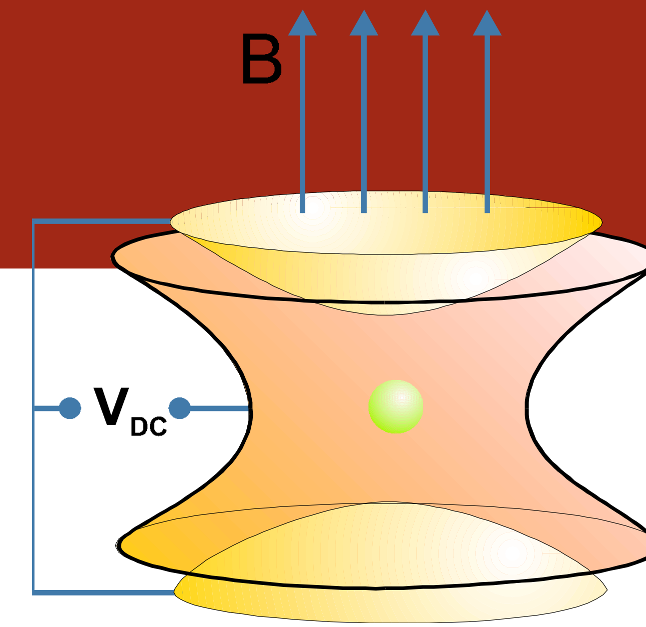
Penning traps

- ISOLTRAP
- JYFLTRAP
- LEBIT
- TITAN
- CPT
- SHIPTRAP

K. Blaum, INPC 2010



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



Accuracy

- exact theoretical description

L.S. Brown and G. Gabrielse, Rev. Mod. Phys. 58, 233 (1986)
G. Bollen et al., J. Appl. Phys. 88, 4355 (1990)
M. König et al., Int. J. Mass Spect. 142, 95 (1995)
M. Kretzschmarr, Int. J. Mass Spect. 246, 122 (2007)

- even for non-ideal traps

G. Bollen et al., J. Appl. Phys. 88, 4355 (1990)

- off-line tests with stables

Precision

line width (FWHM):

$$\Delta\nu \approx 1/T_{rf}$$

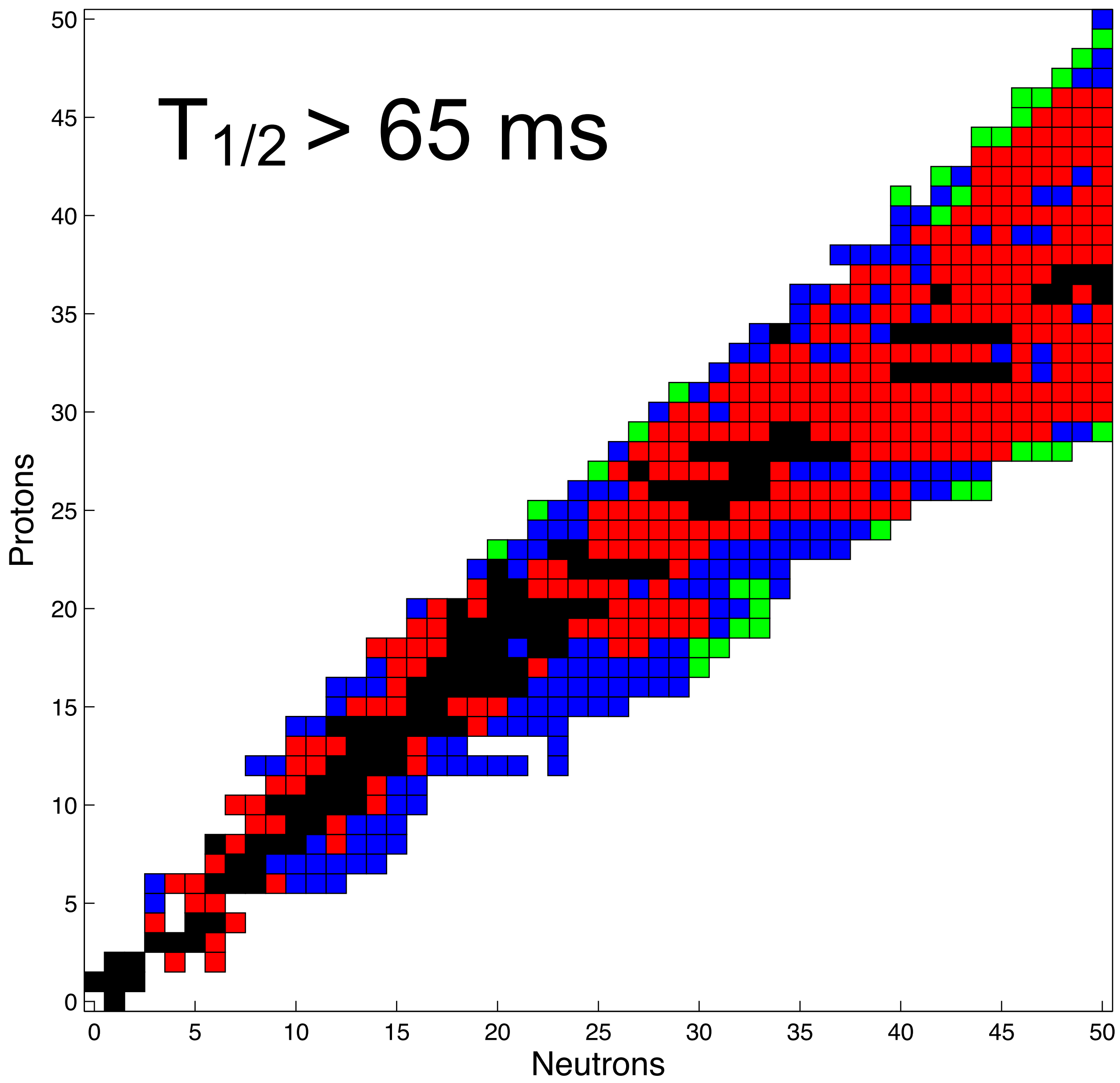
⇒ resolution:

$$R = \frac{m}{\Delta m} = \frac{\nu_c}{\Delta\nu_c} \approx \nu_c T_{rf} \approx \frac{qBT_{rf}}{2\pi m}$$

Penning traps and short half-lives

previously shortest ^{74}Rb with $T_{1/2}$=65 ms

ISOLTRAP A. Kellerbauer et al., PRL 93, 072502 (2004)



Penning traps and short half-lives

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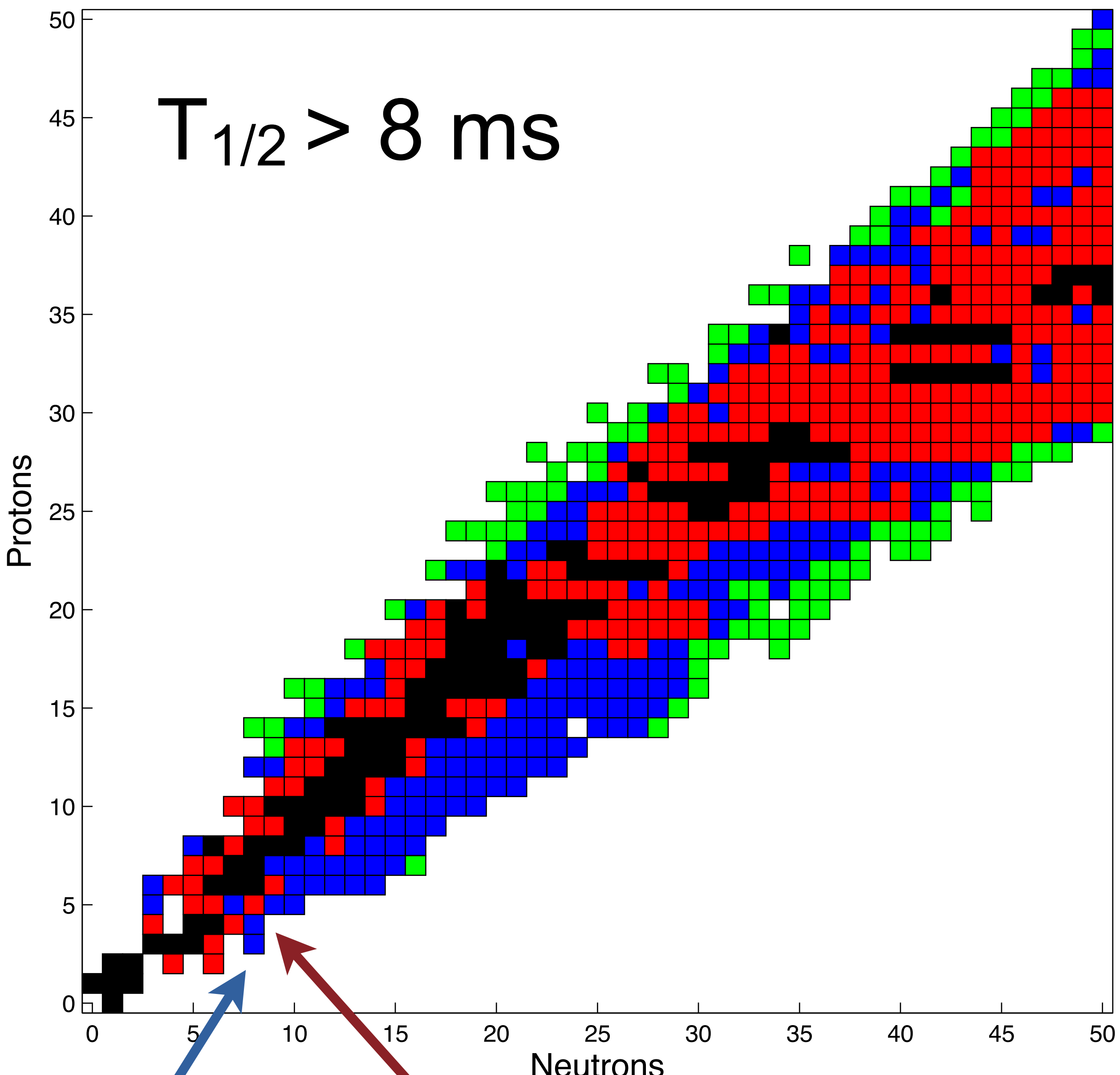
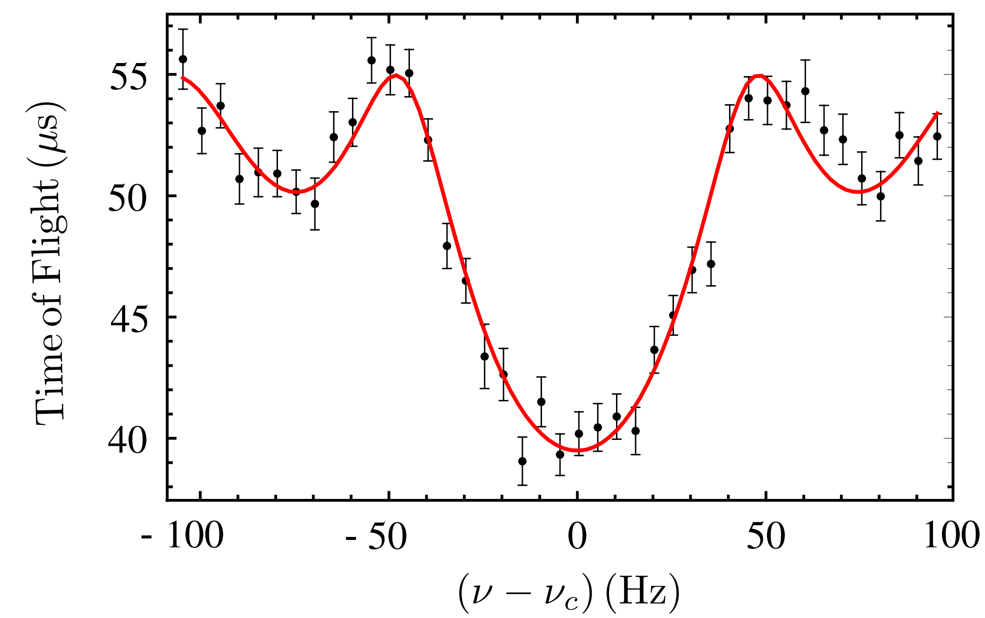
ISOLTRAP *A. Kellerbauer et al., PRL 93, 072502 (2004)*

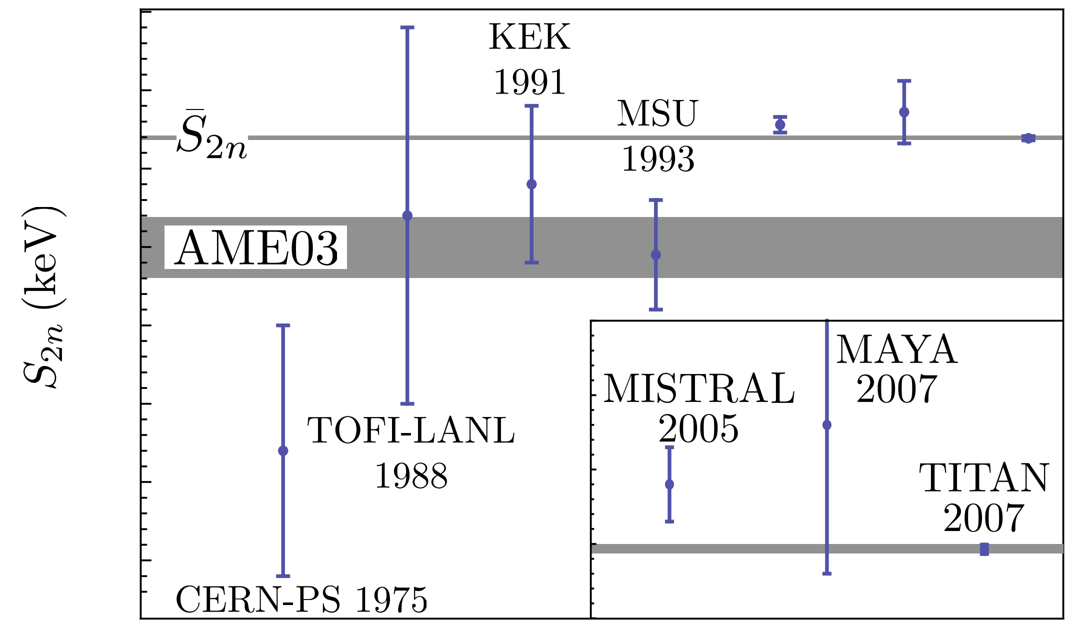


^{11}Li **^{12}Be** $T_{1/2}$ = 24 ms; yield <300 ions/s

S. Ettenauer et al., PRC 81, 024314 (2010)

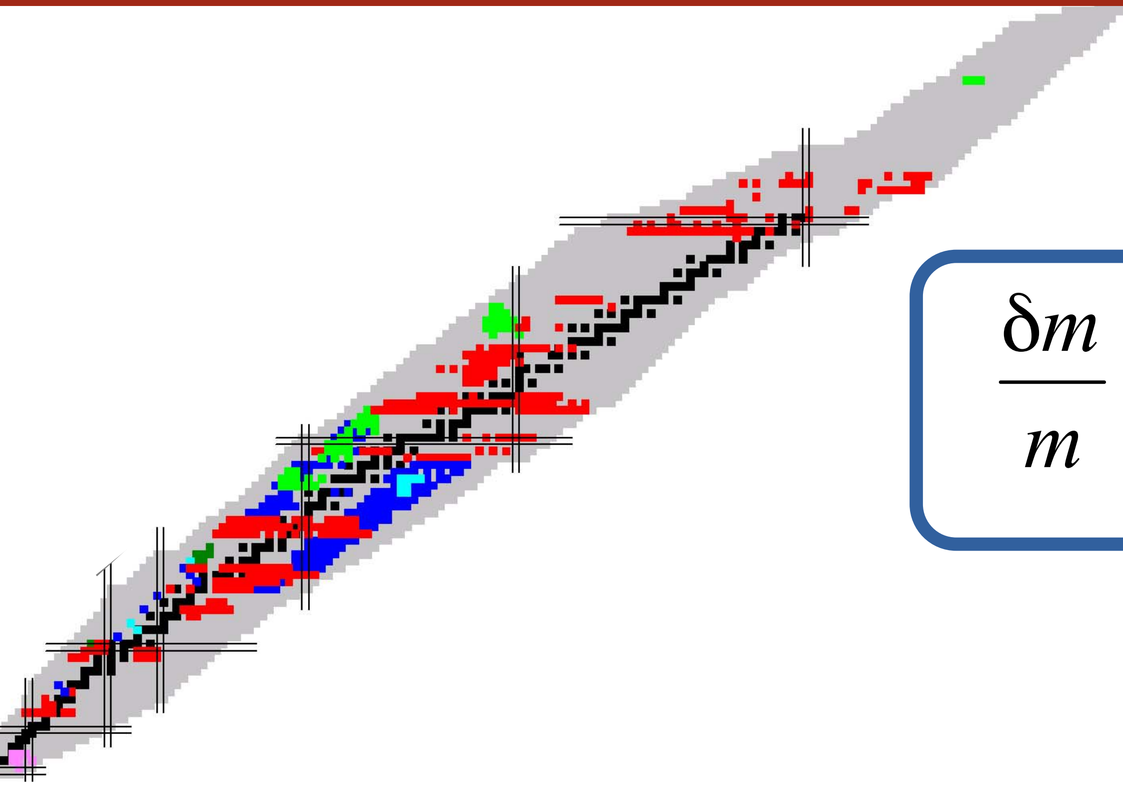
^{11}Li: 8.8 ms





M. Smith et al., PRL 101, 202501 (2008)

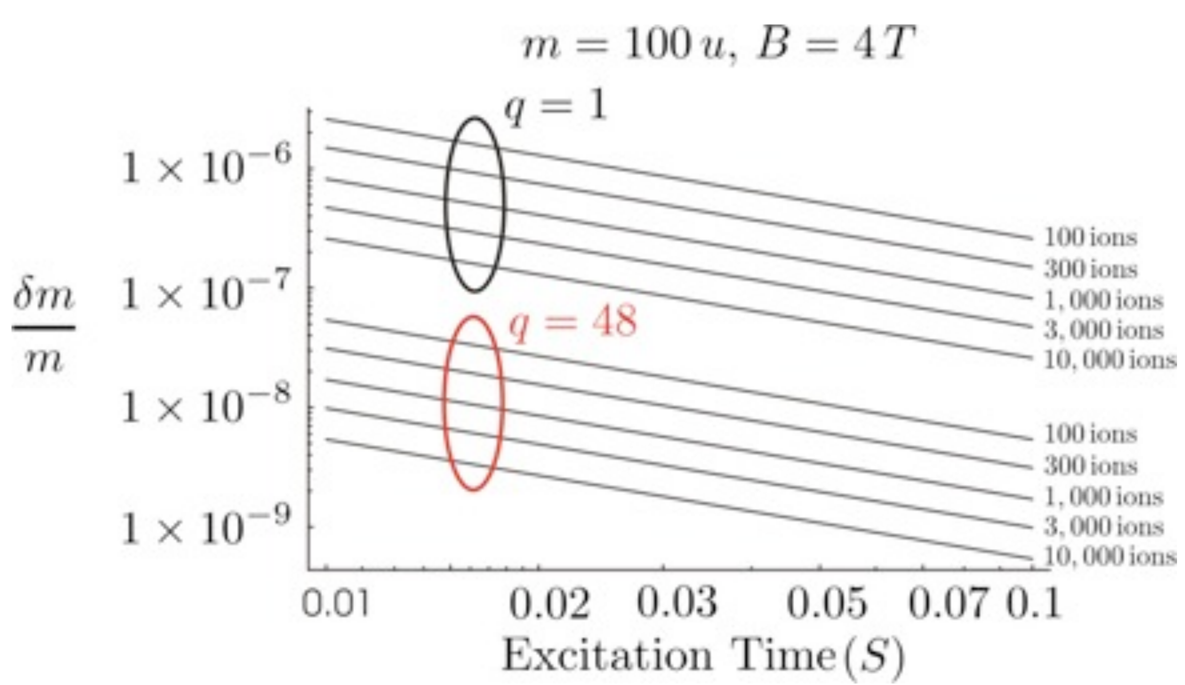
higher precision



$$\frac{\delta m}{m} \propto \frac{m}{q} \frac{1}{BTN^{1/2}}$$

- ➡ longer excitation time
- ➡ larger B
- ➡ more ions
- ➡ highly charged ions

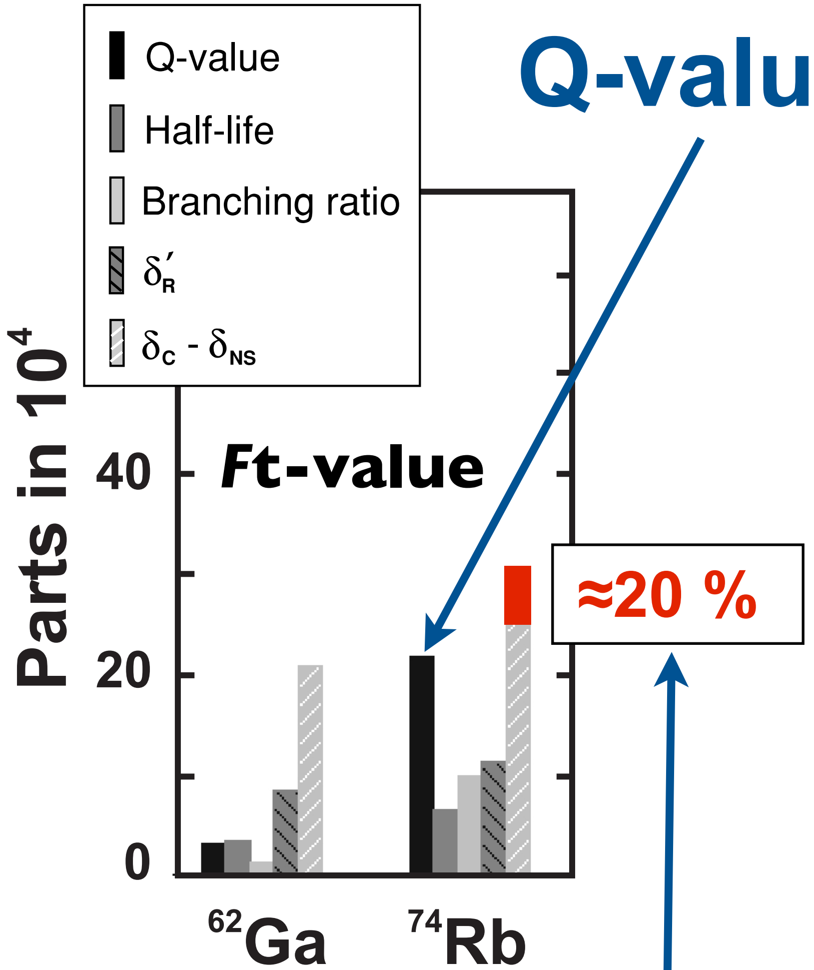
⟹ CHARGE BREEDING



<u>Advantages:</u>

- ➡ more precise or
- ➡ same precision in shorter time
- ➡ same precision with lower yield
- ➡ higher resolving power (isomers!)

precision case: ^{74}Rb for V_{ud} (CKM)



J. C. Hardy & I.S. Towner, Phys. Rev. C 79, 055502 (2009)

uncertainty of δ_C due to charge radius
⇒ **reduced by laser spectroscopy!**

see talk by E. Mané

direct mass measuremnts in Penning trap:

- highest precision
- ISOLTRAP @ CERN

A. Kellerbauer et al., PRL 93, 072502 (2004)
PRC 76, 045504 (2007)

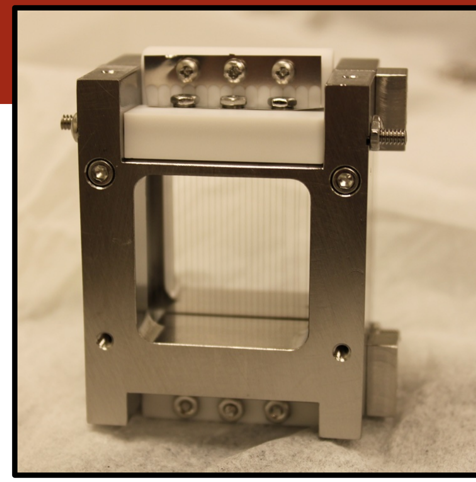
Nuclide	D_{exp} (keV) 2000	2002	2003	mean
^{64}Zn		−65 998.6(7.8)		−65 998.6(7.8)
^{71}Ga		−70 137.5(1.2)		−70 137.5(1.2)
^{74}Ga	−68 047(21)		−68 019(32)	−68 041(18)[a]
^{74}Rb	−51 905(18)[b]	−51 917.3(4.8)[c]	−51 910.7(7.0)[c]	−51 914.7(3.9)

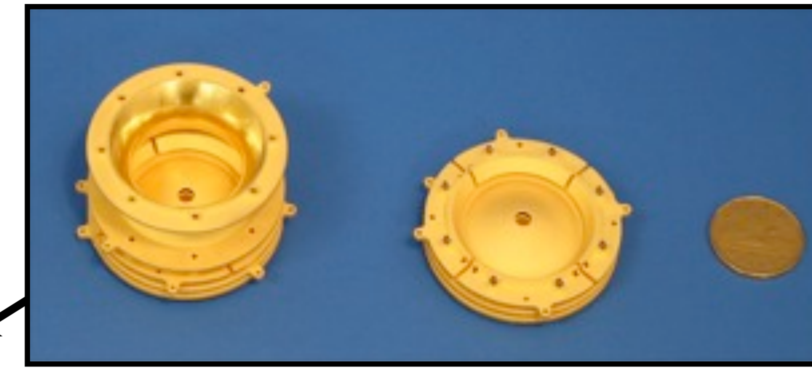
- limitation due to $T_{1/2}$ = 65 ms

$$\frac{\delta m}{m} \propto \frac{m}{q} \frac{1}{B T N^{1/2}}$$

to improve precision further: HCI

TITAN @ TRIUMF

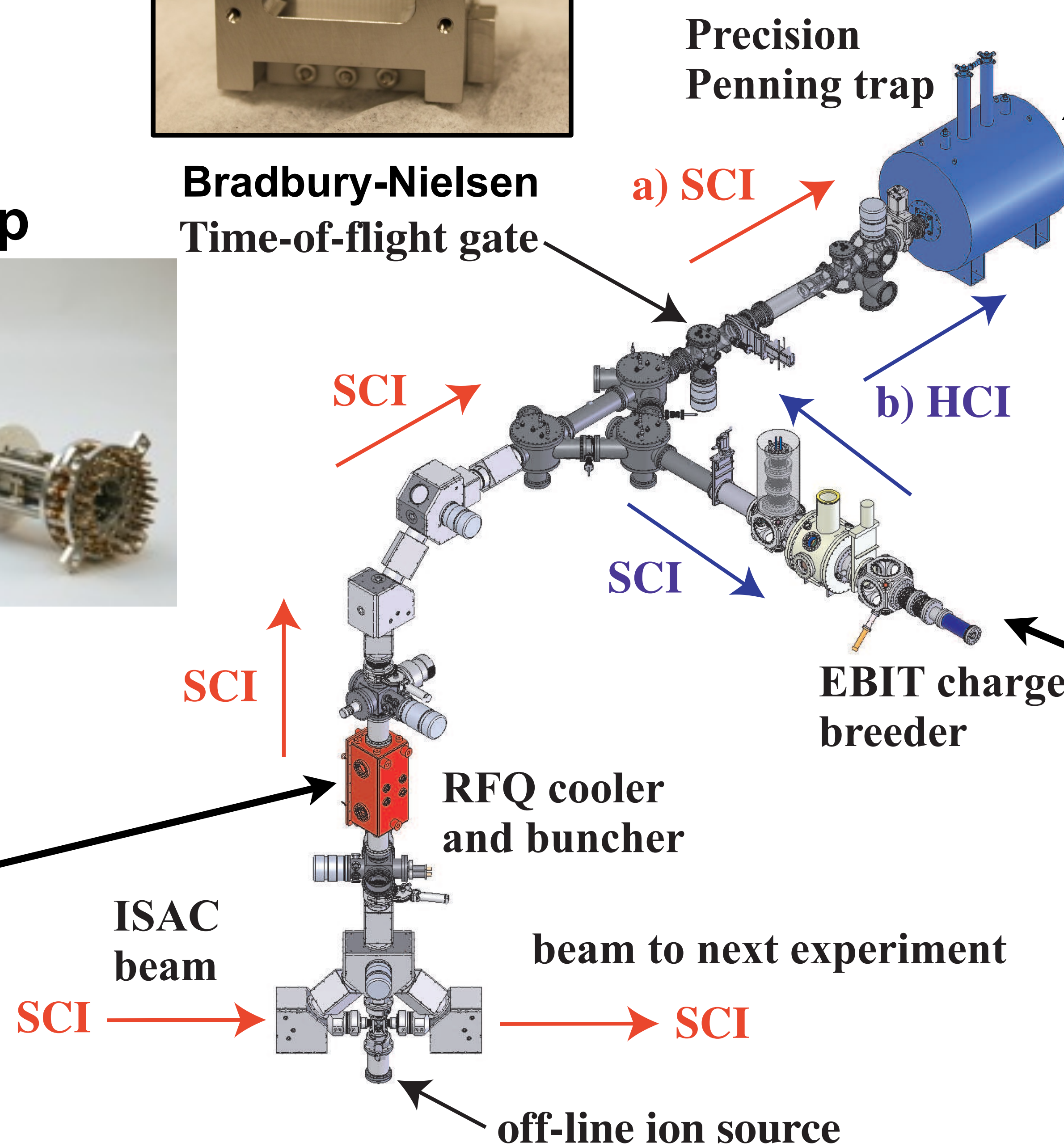




to be tested soon:

Cooler Penning trap

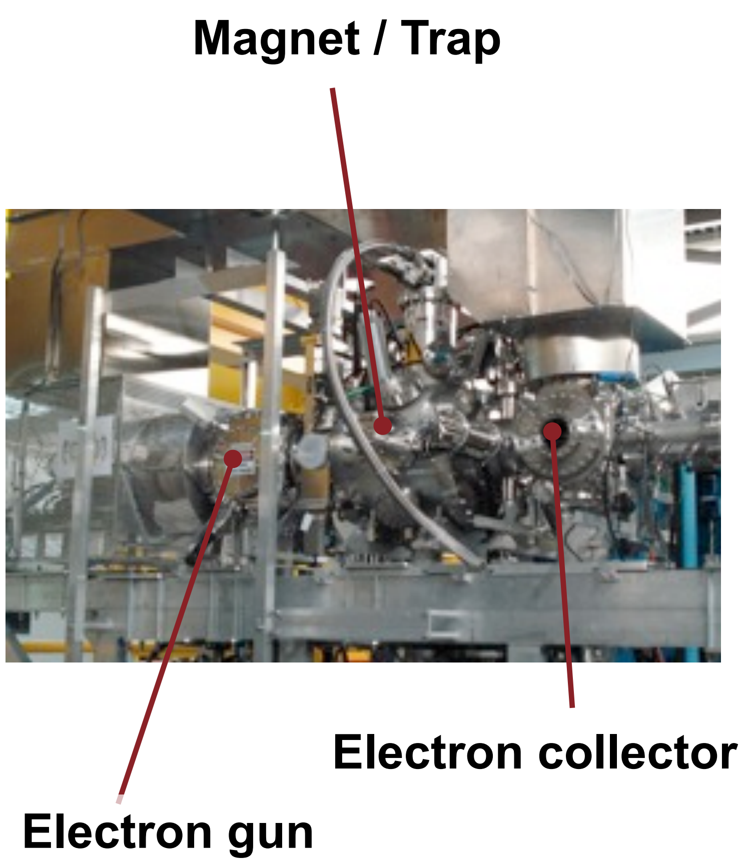
see poster #934
V. V. Simon

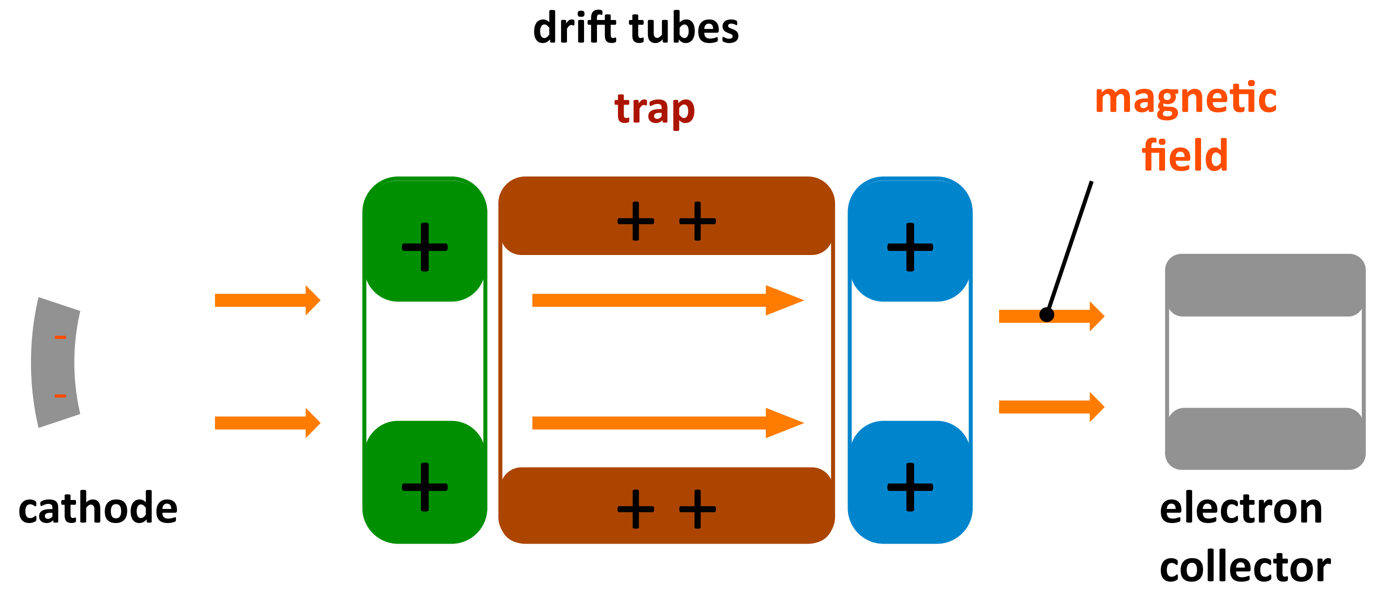


$$\frac{\delta m}{m} \propto \frac{m}{q} \frac{1}{BTN^{1/2}}$$

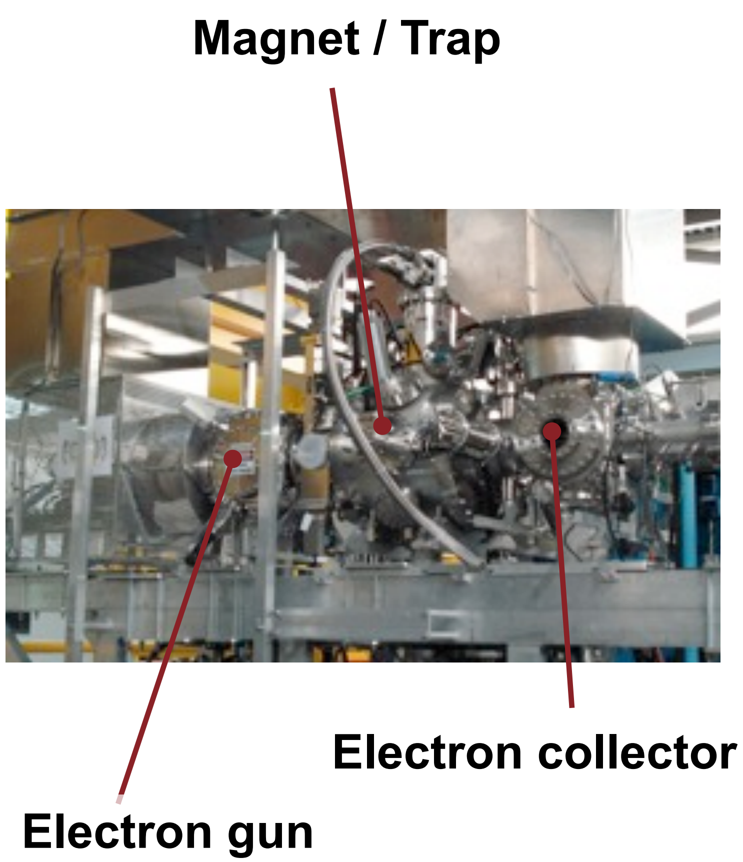
see poster #310: A.T. Gallant

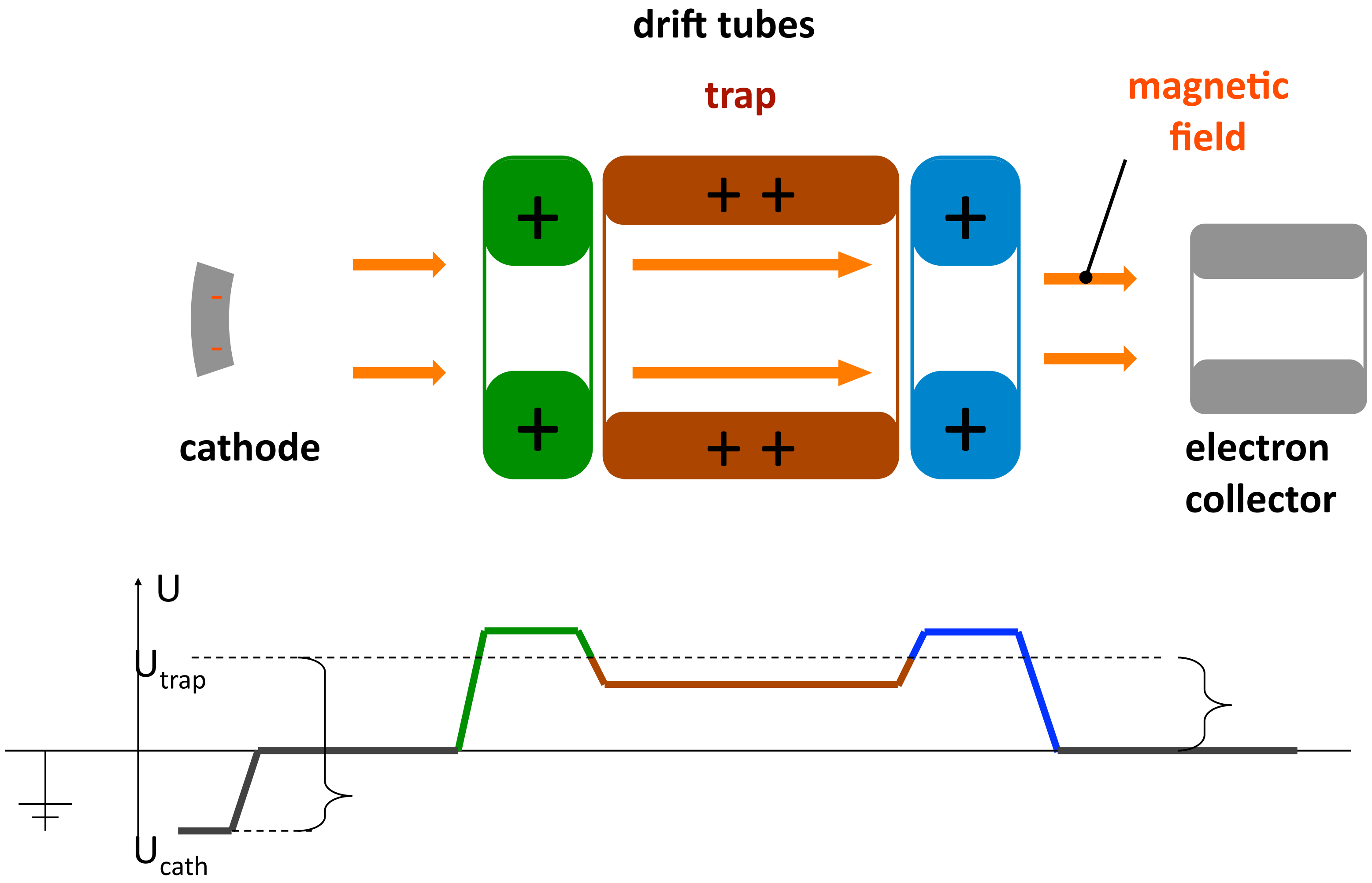
Electron Beam Ion Trap



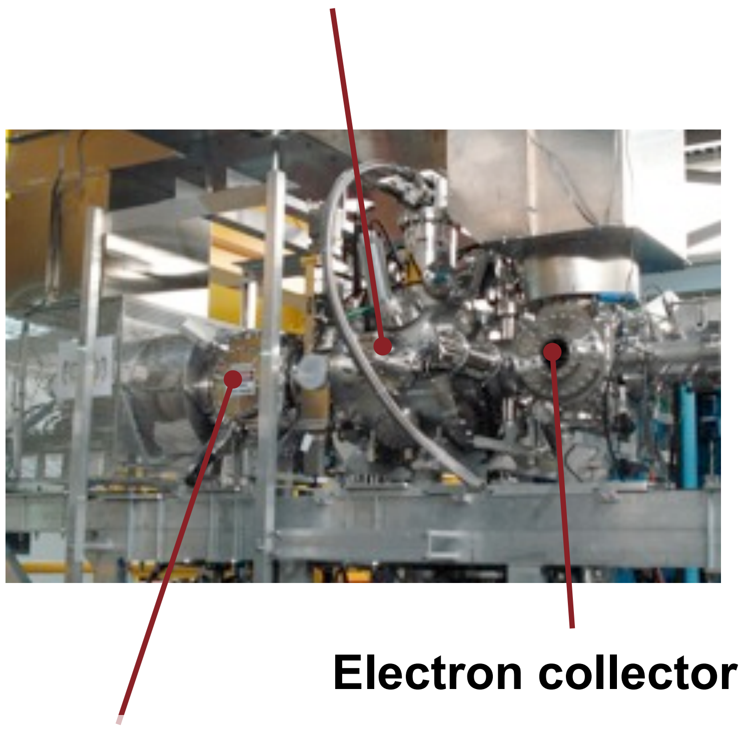


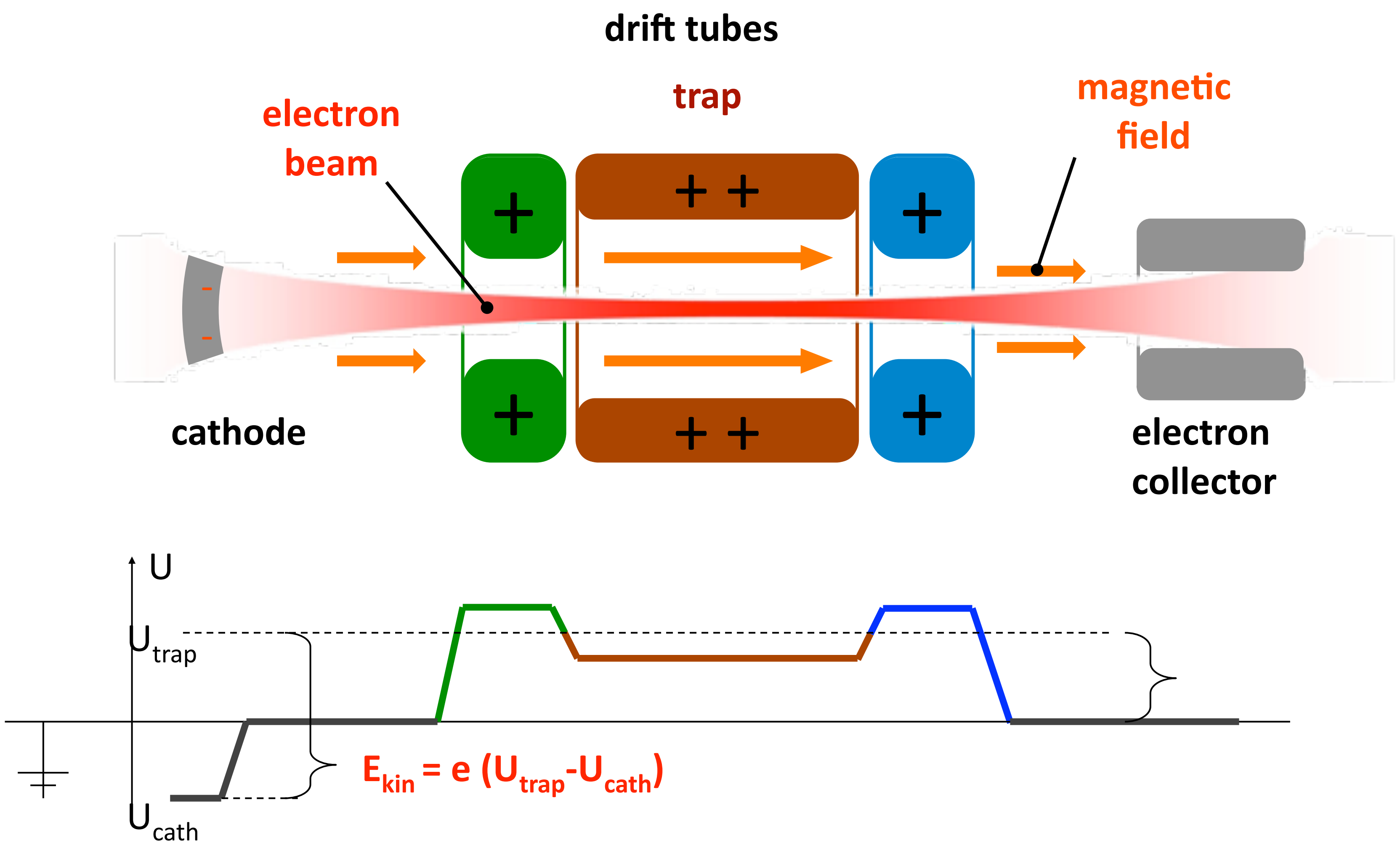
Electron Beam Ion Trap



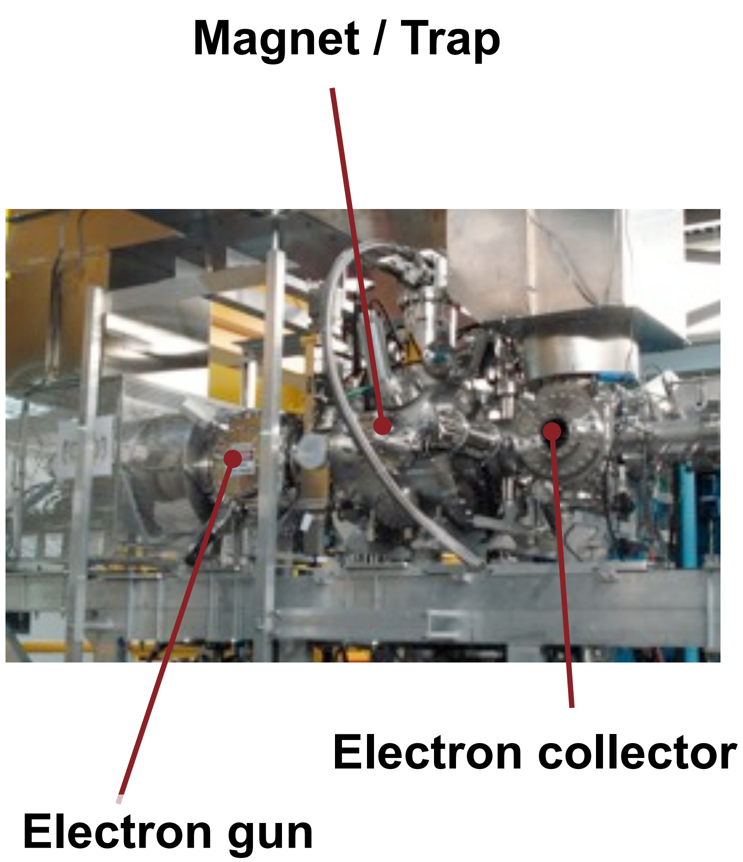


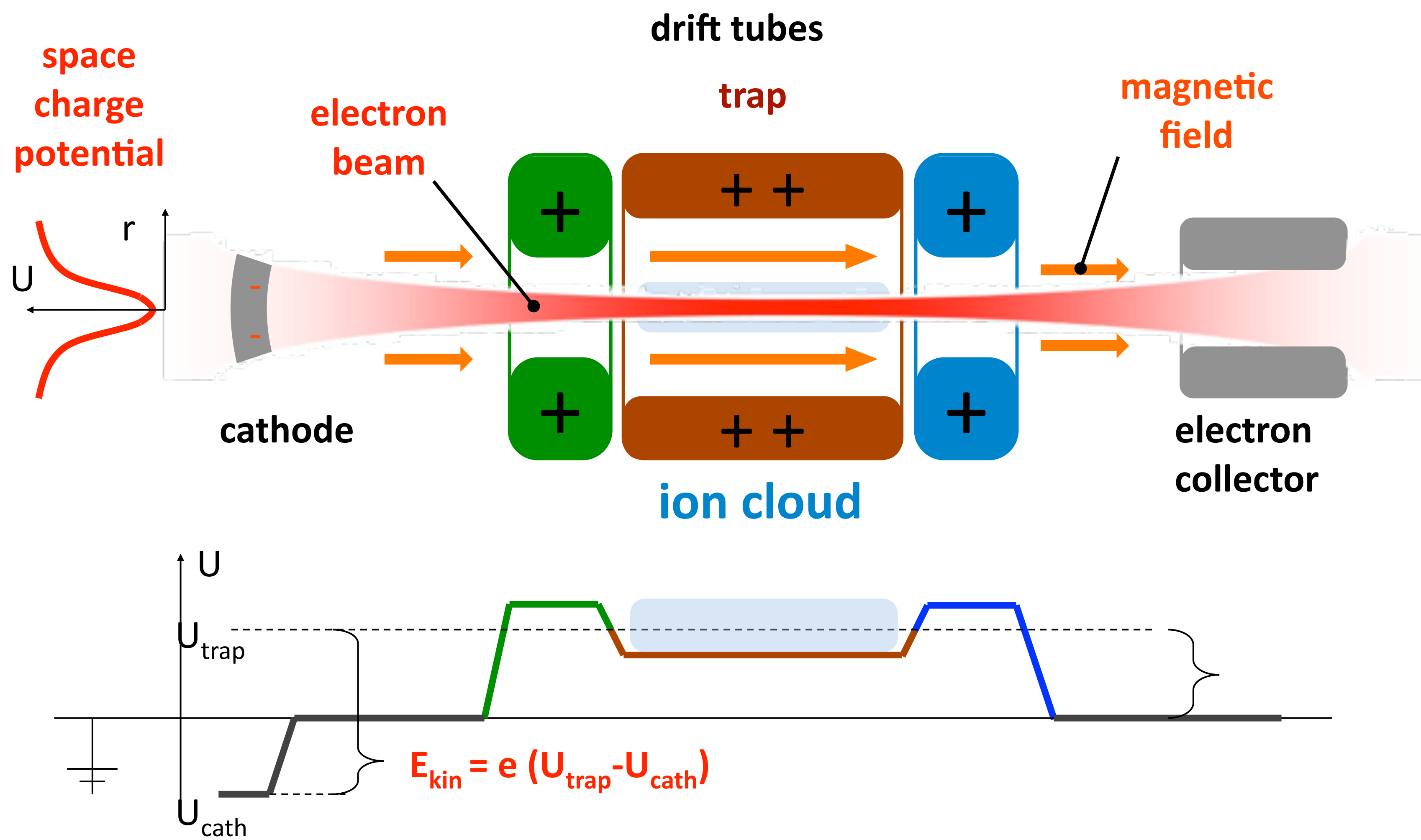
Electron Beam Ion Trap



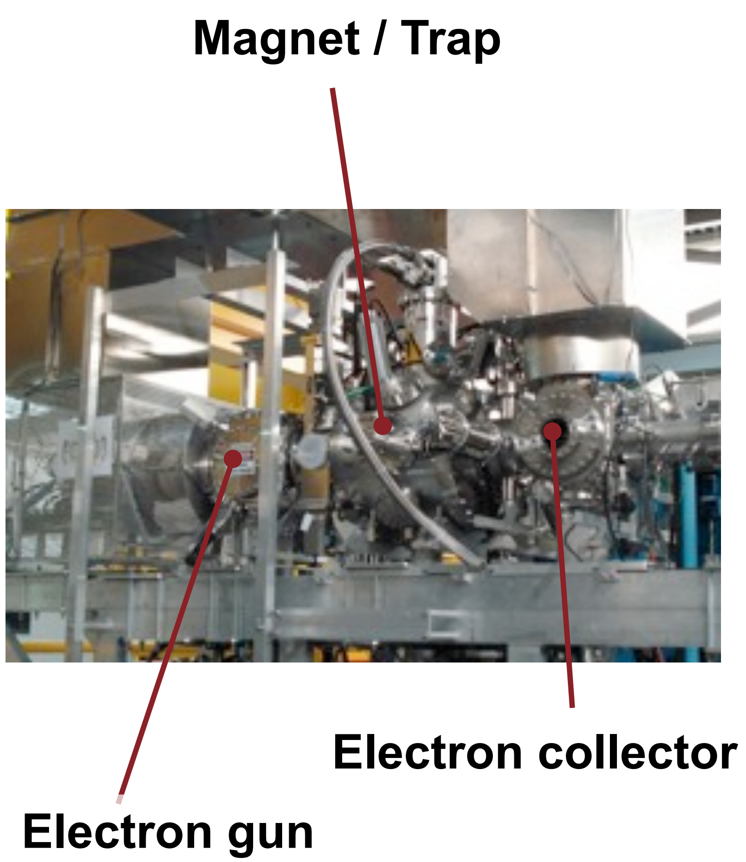


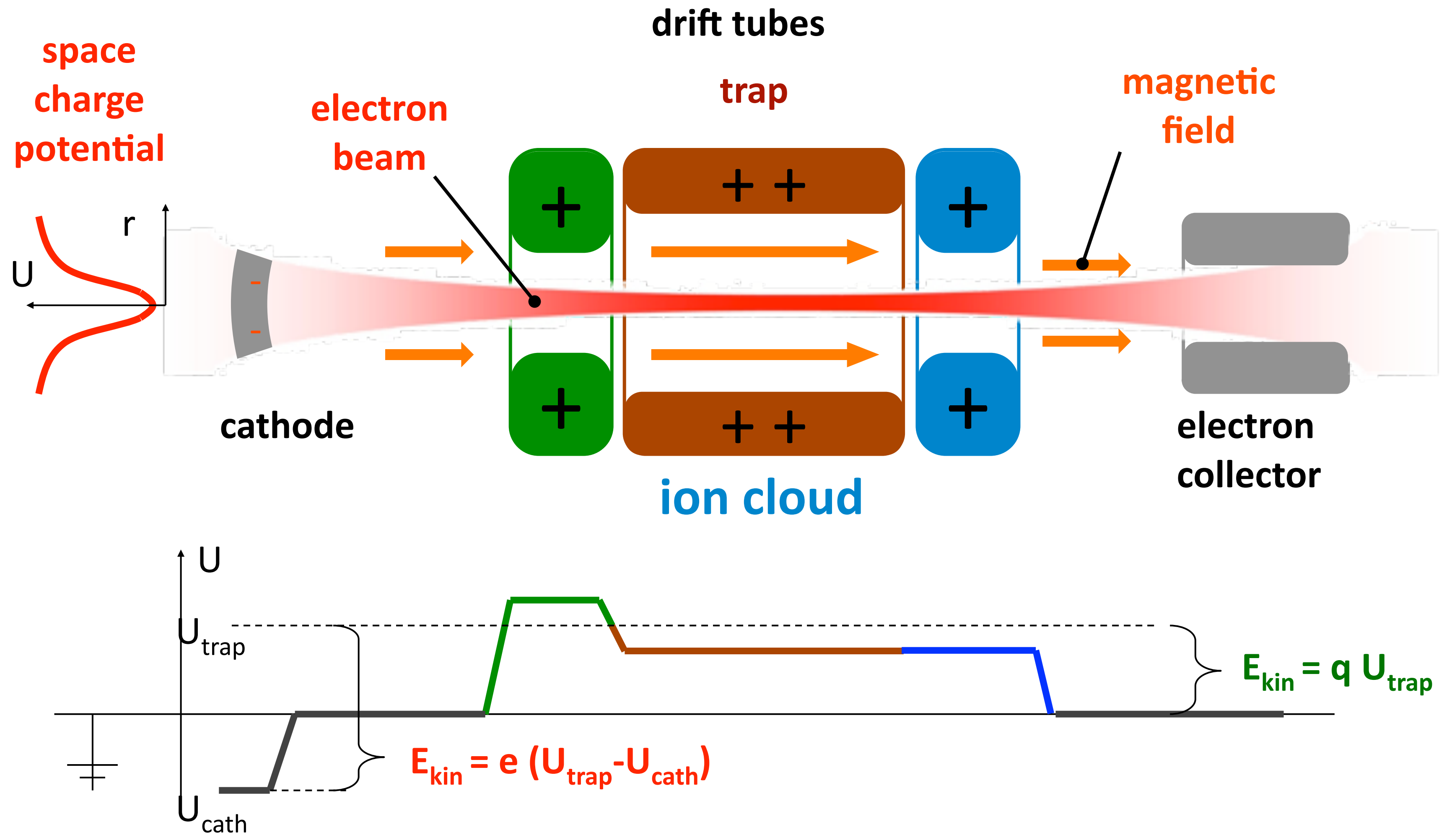
Electron Beam Ion Trap





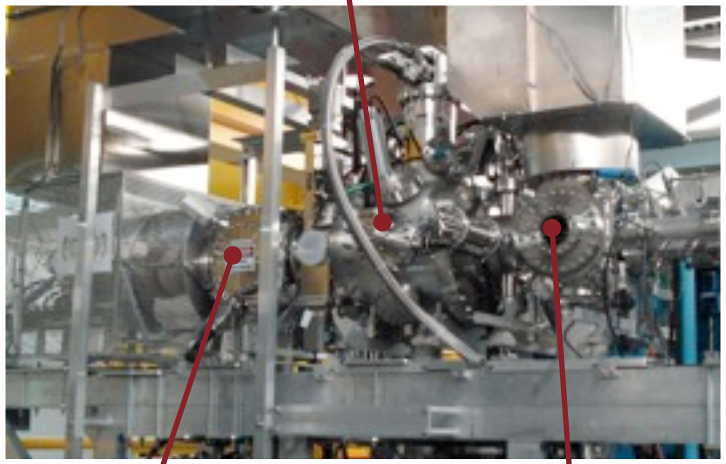
Electron Beam Ion Trap





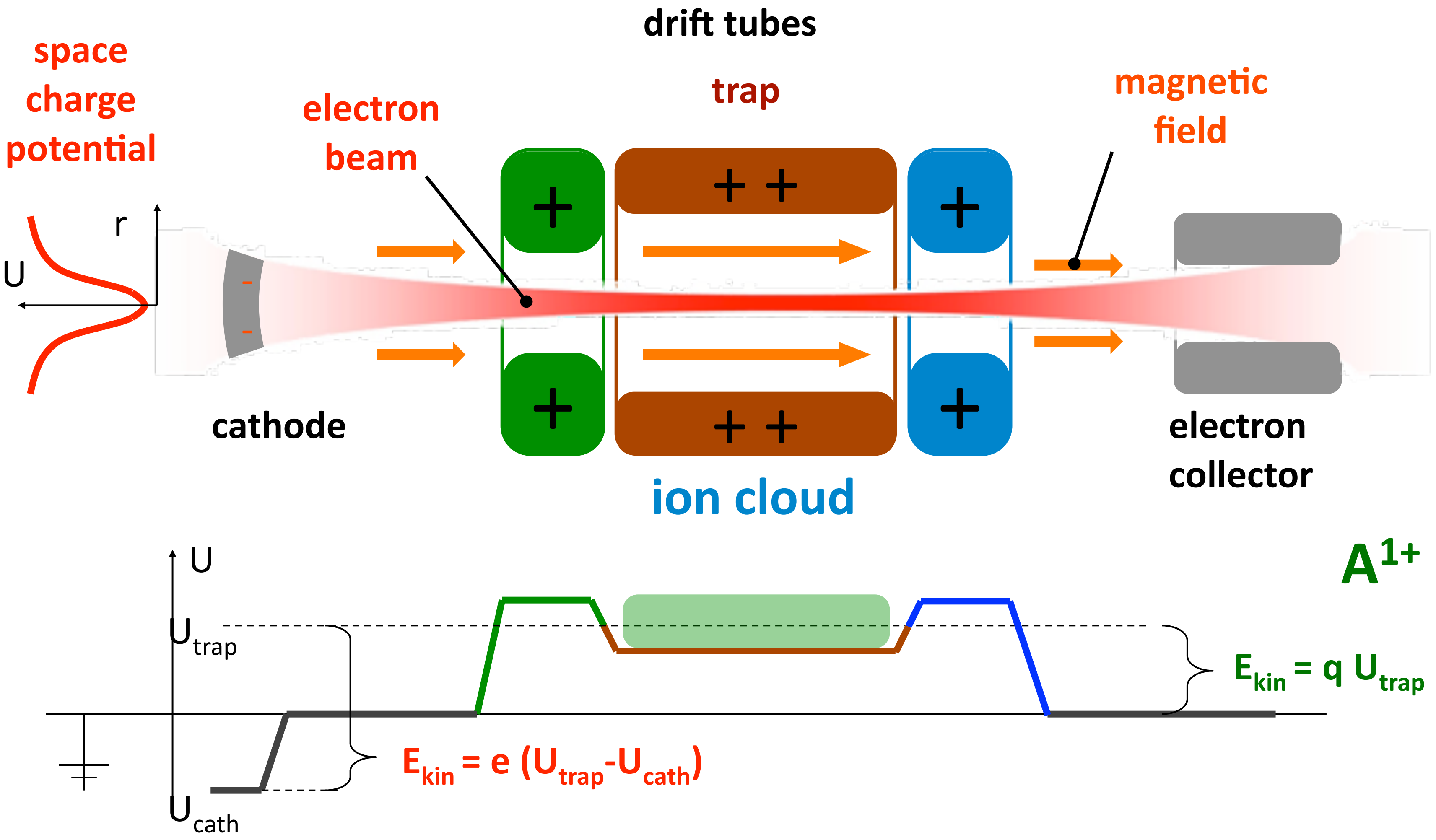
Electron Beam Ion Trap

Magnet / Trap

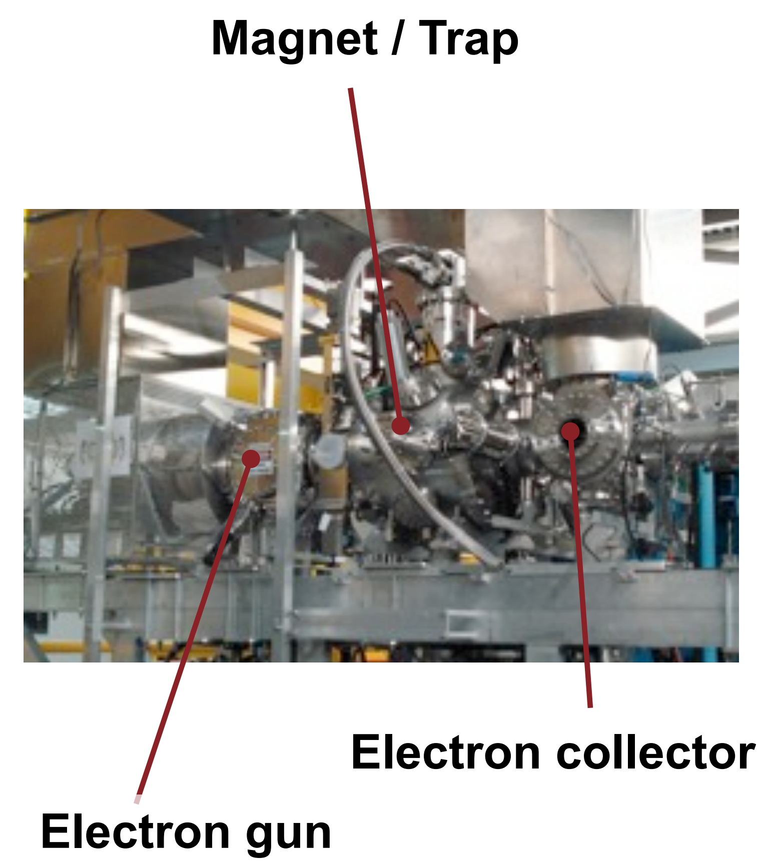


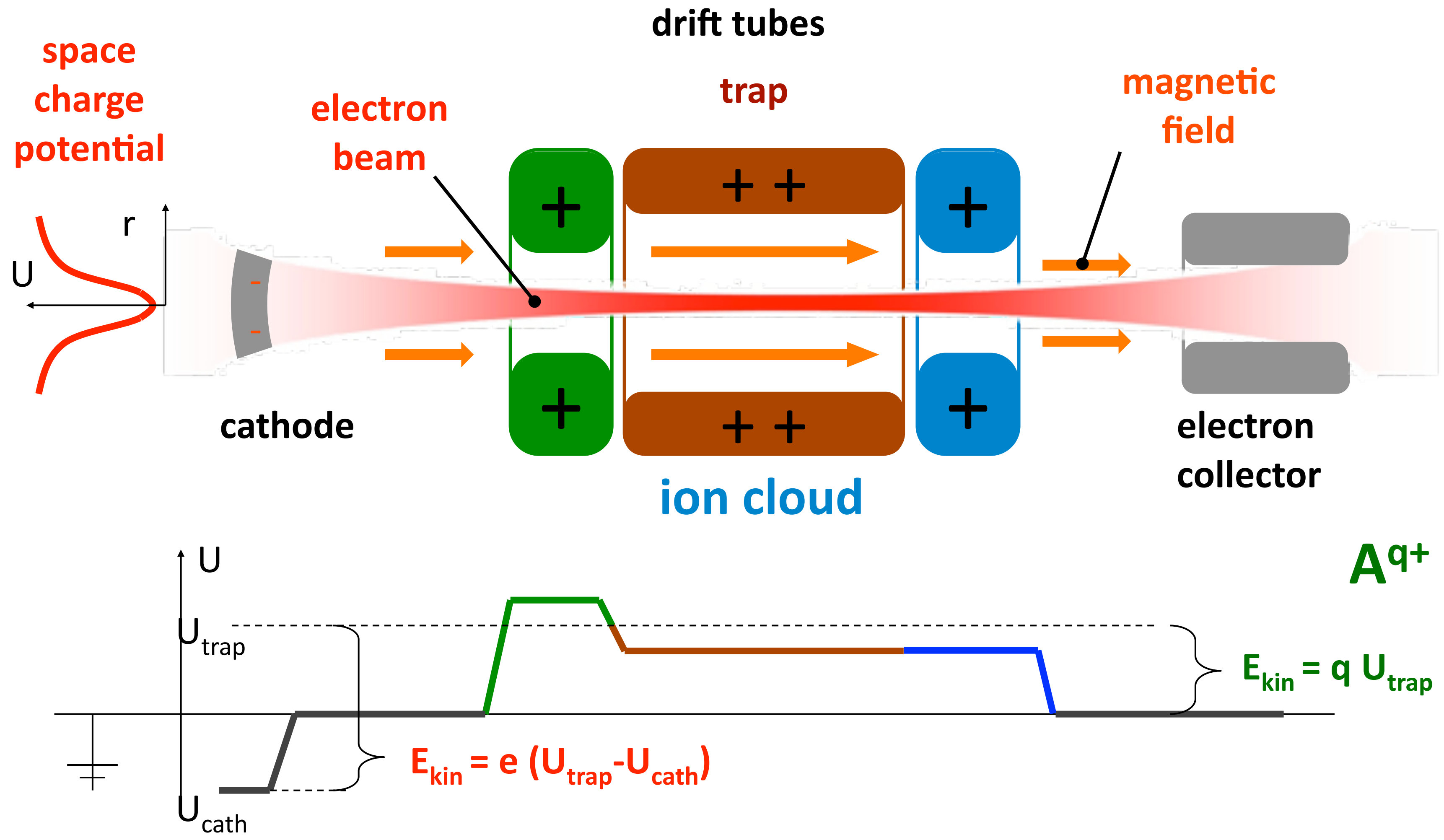
Electron collector

Electron gun

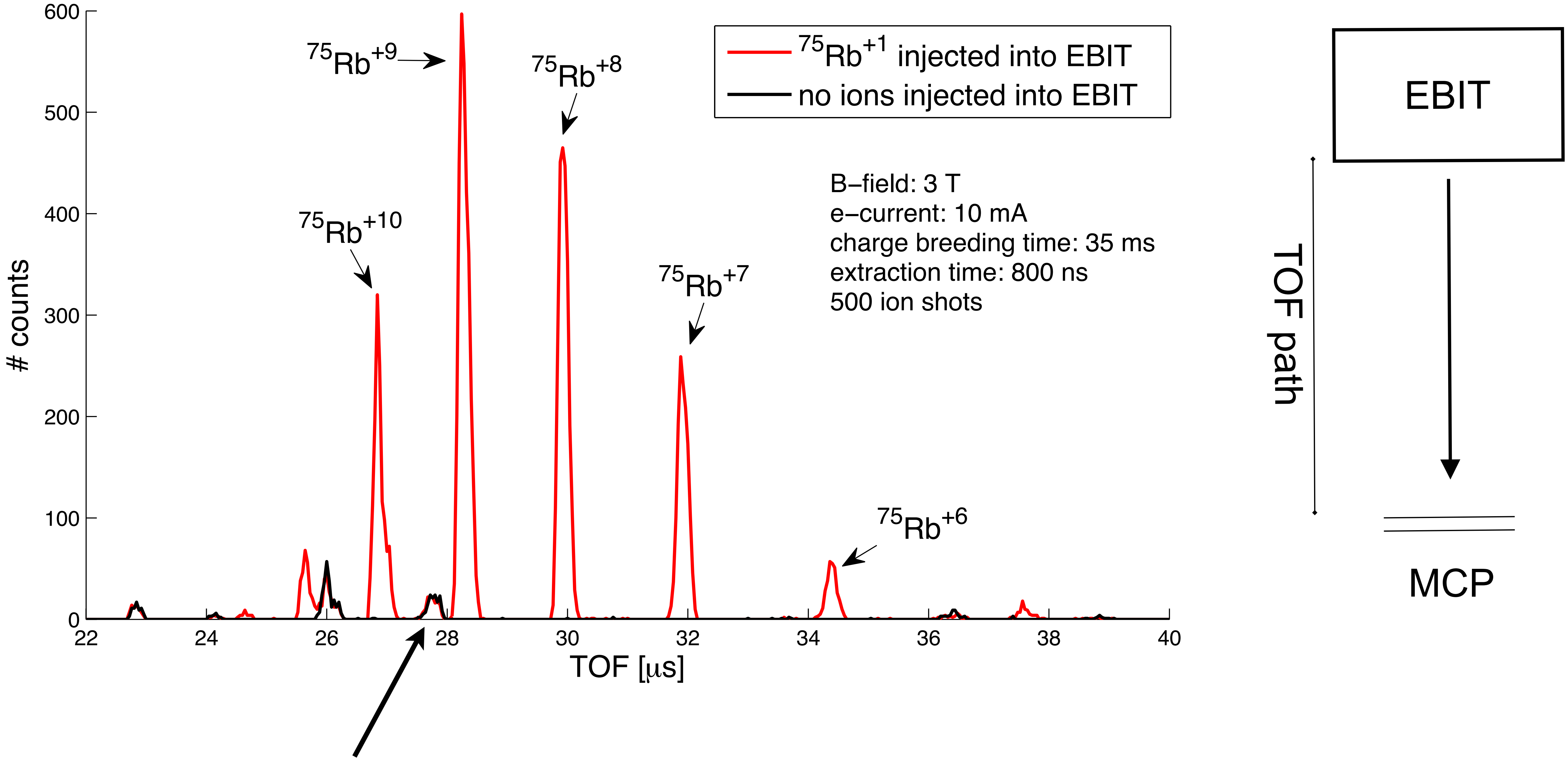


Electron Beam Ion Trap





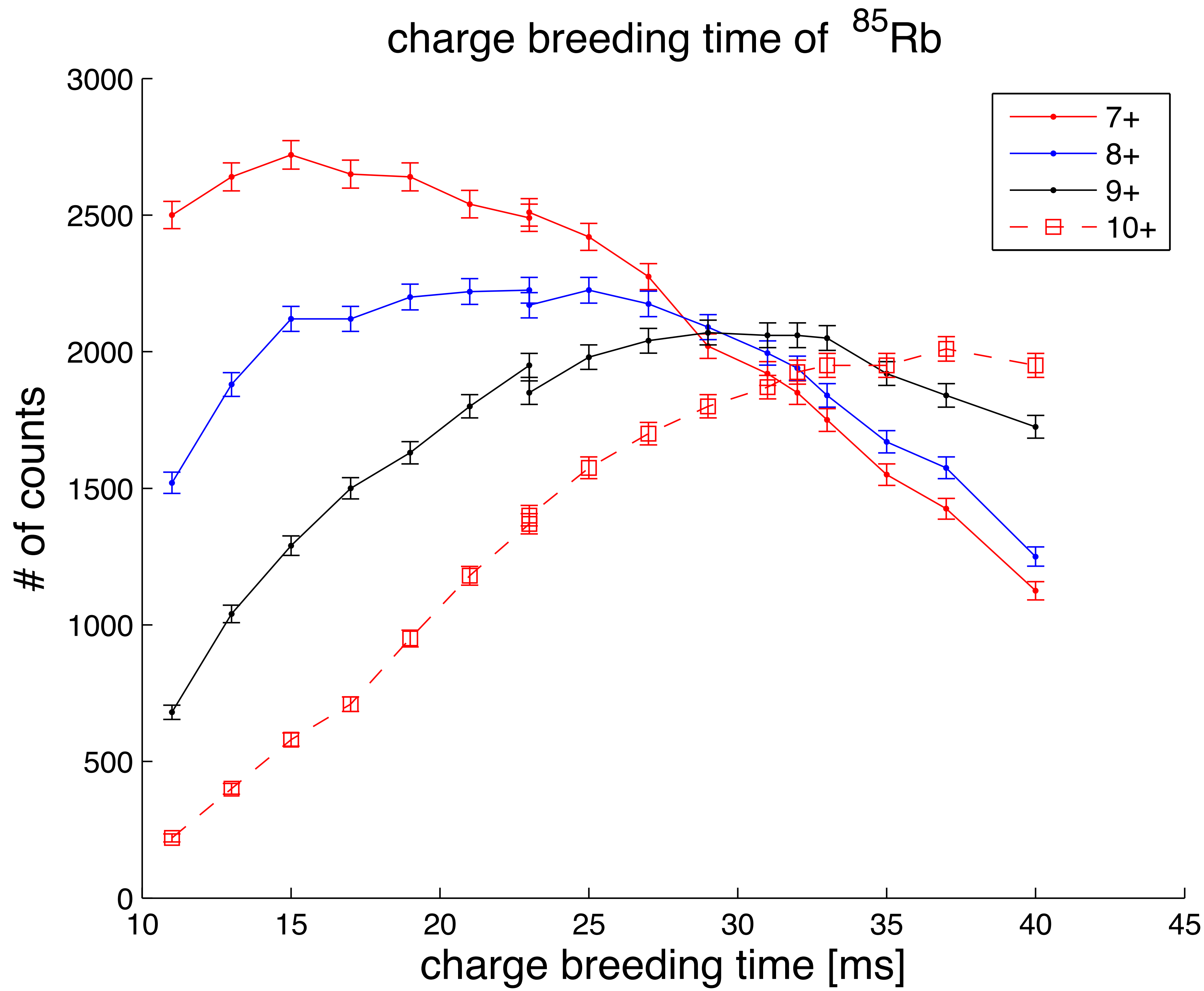
charge breeding of ^{75}Rb



charge bred residual gas

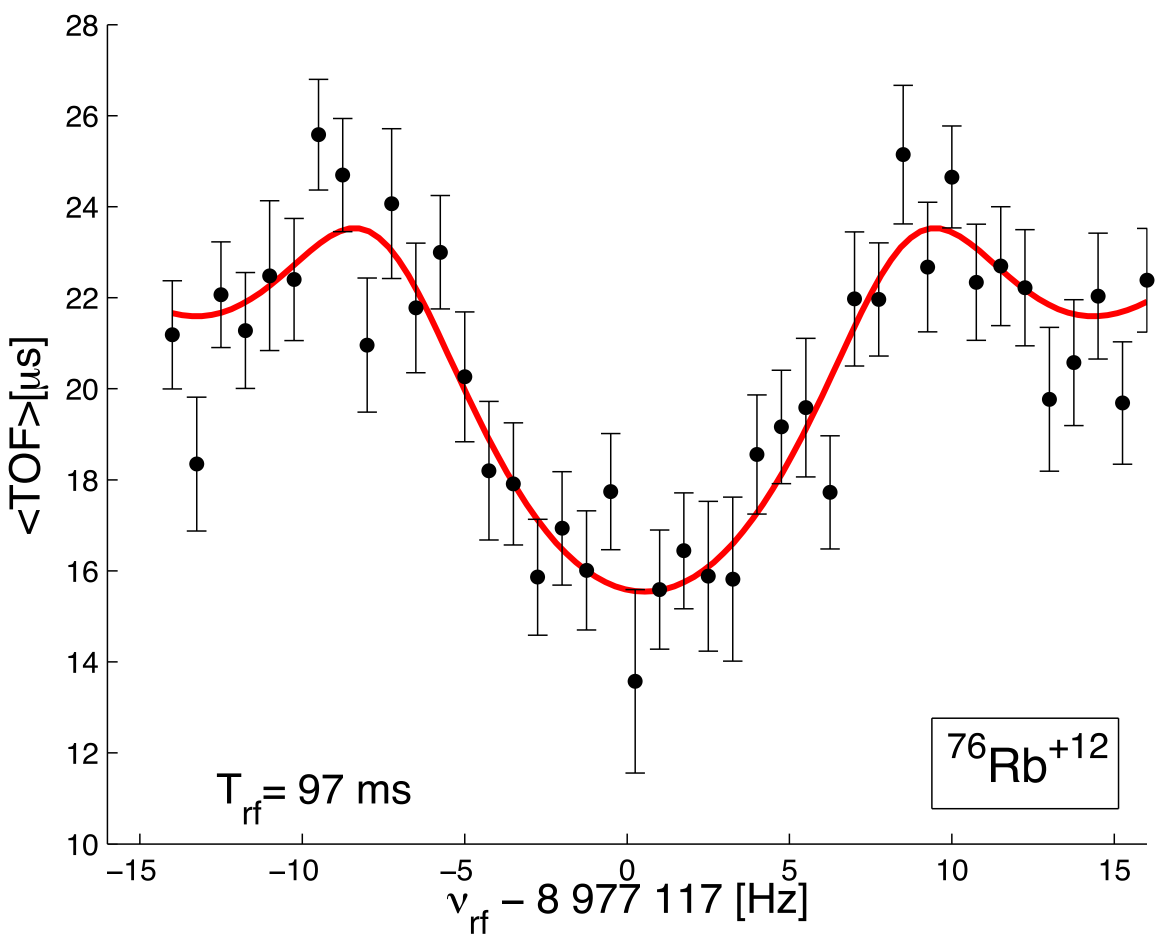
TRIUMF

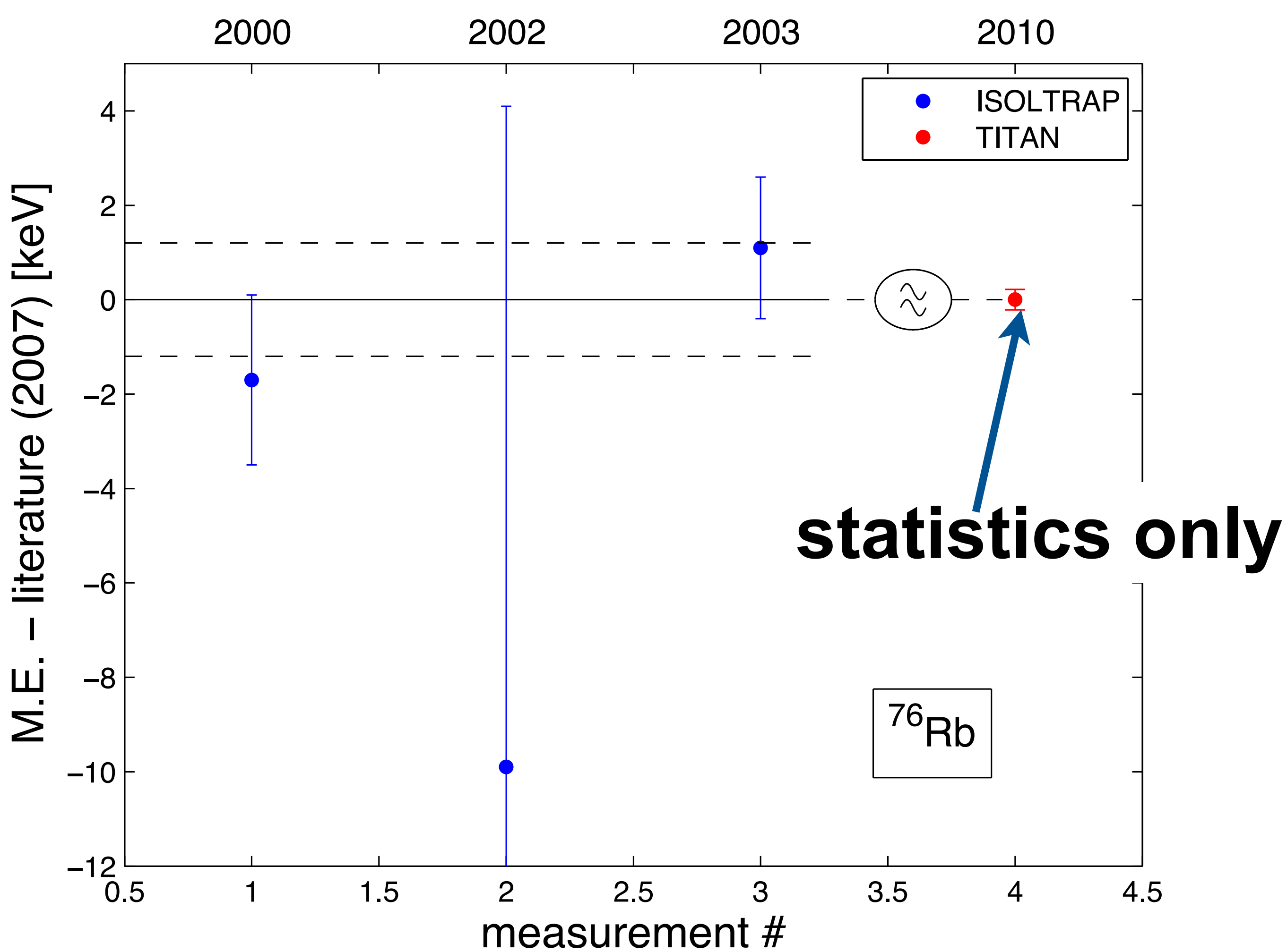
charge breeding time



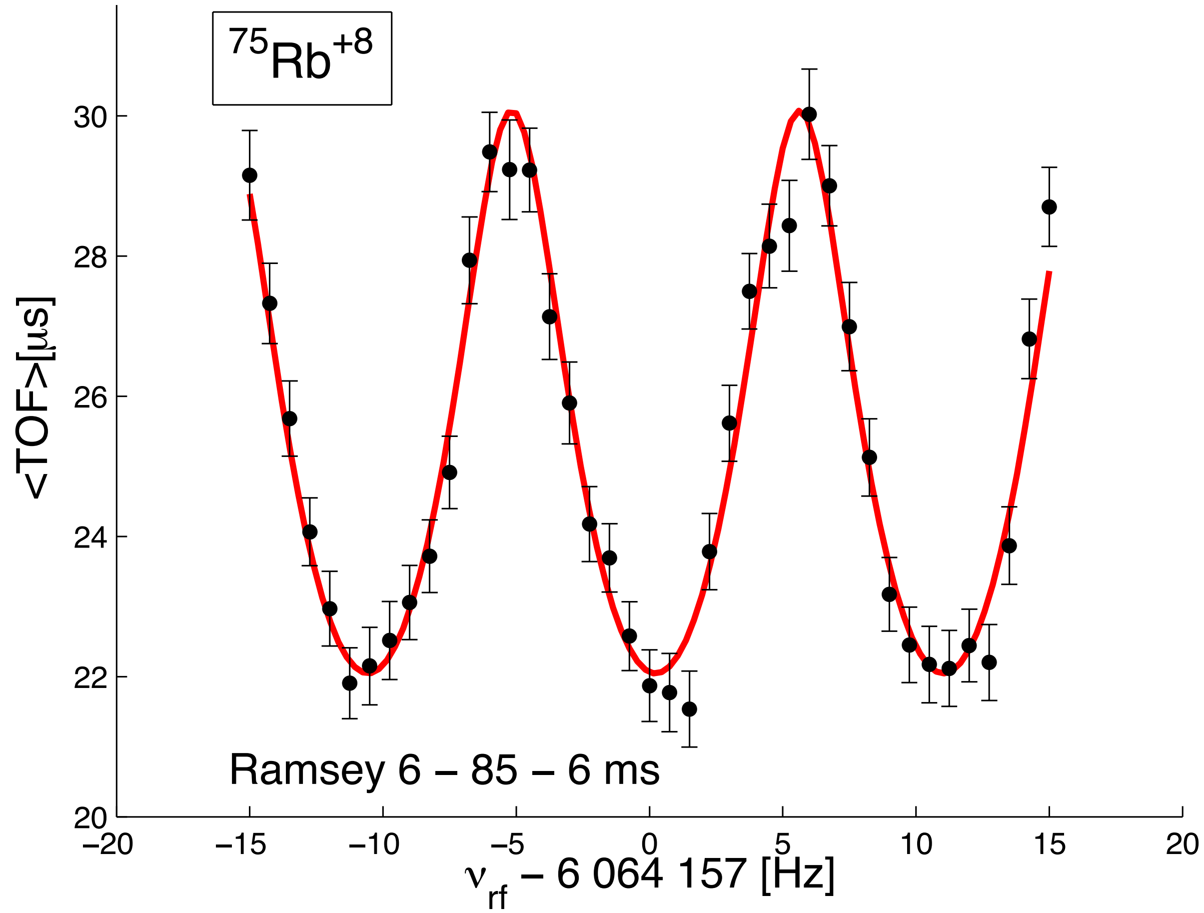
^{76}Rb

- first mass measurement of radioactive HCIs
- stat. uncertainty of < 300 eV achieved in a few hours





Ramsey excitation of ^{75}Rb



Ramsey excitation:

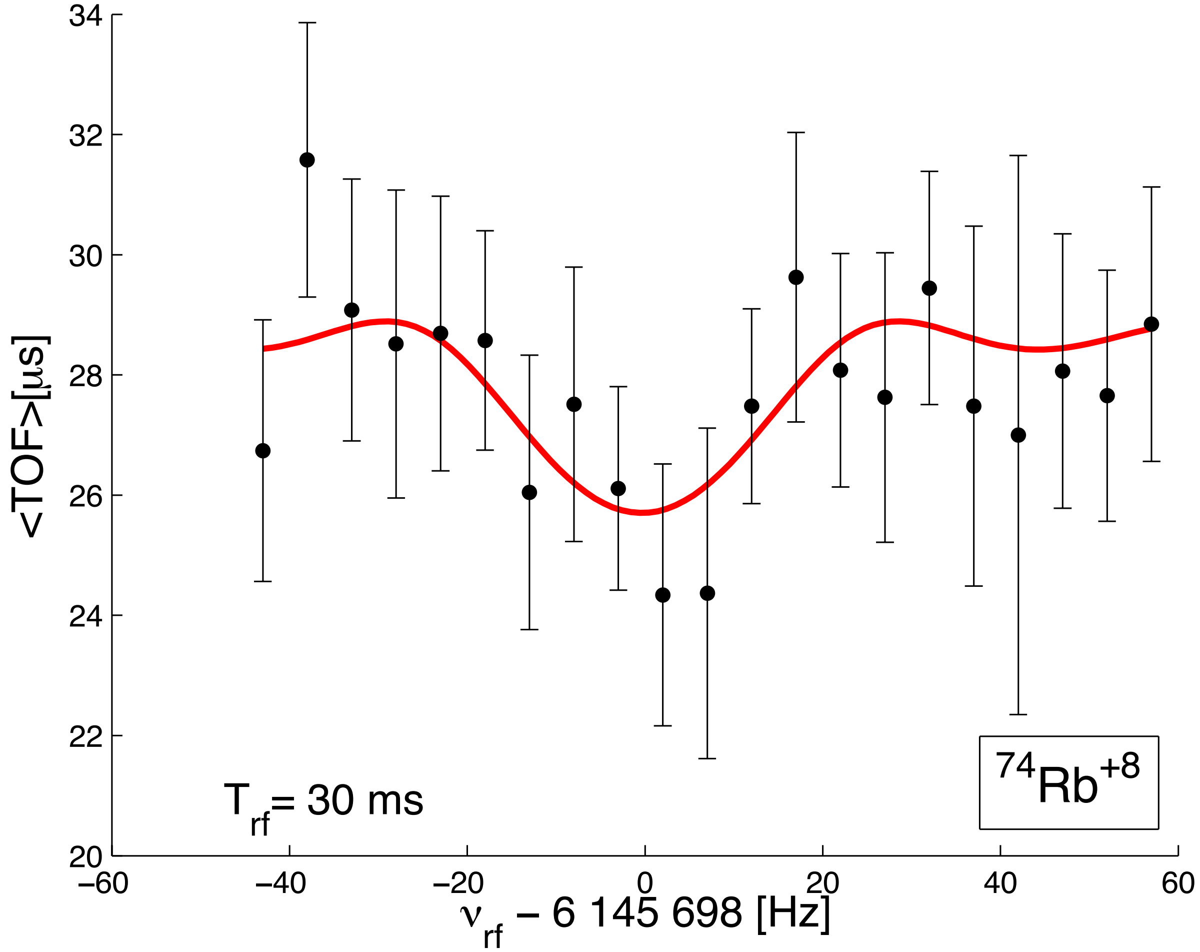
- 2 excitation pulses
- improves precision by a factor 2 - 3

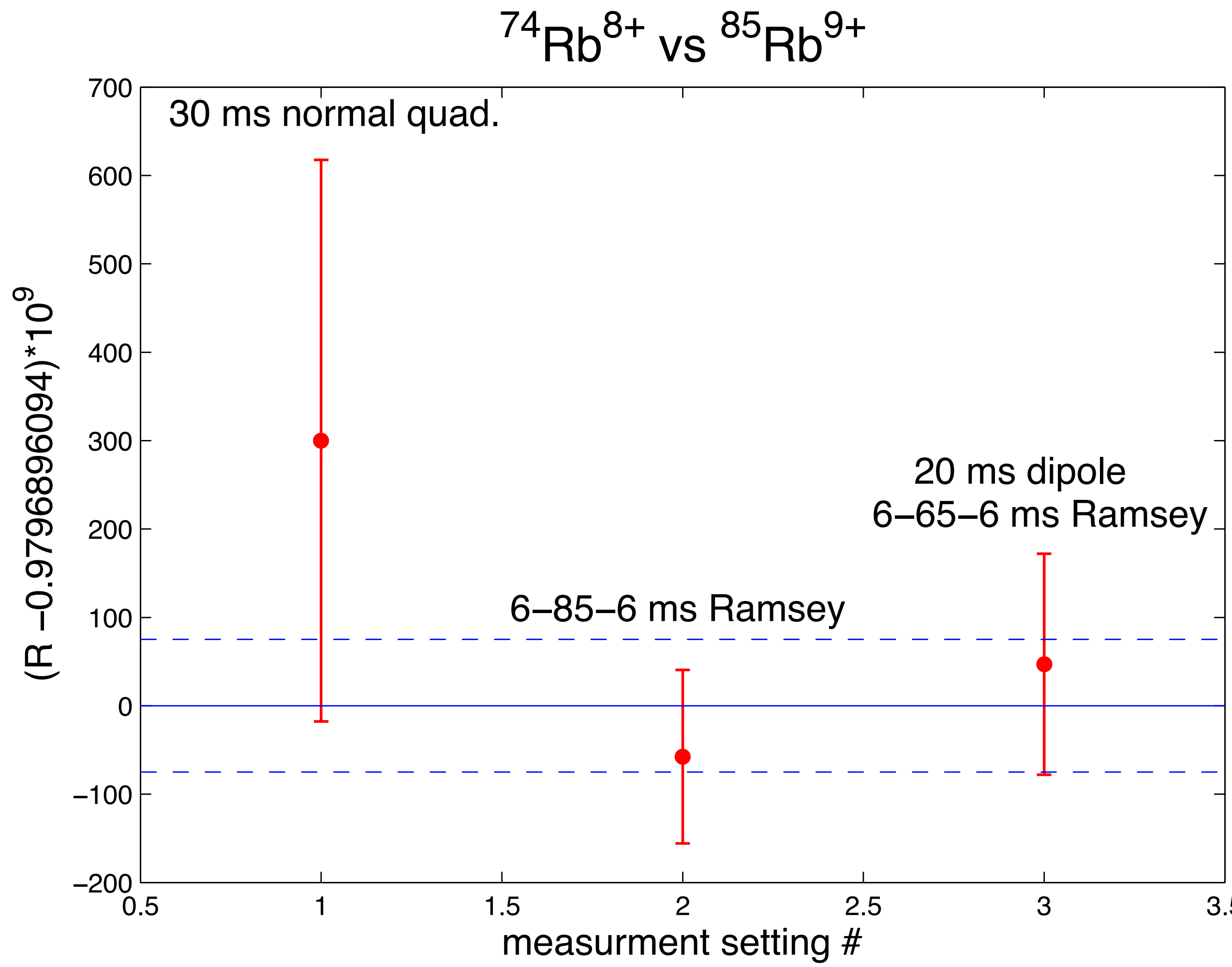
HCI

during this beamtime demonstrated up to q=12+

compared to conventional method: improvement by factor >24

^{74}Rb





^{74}Rb:

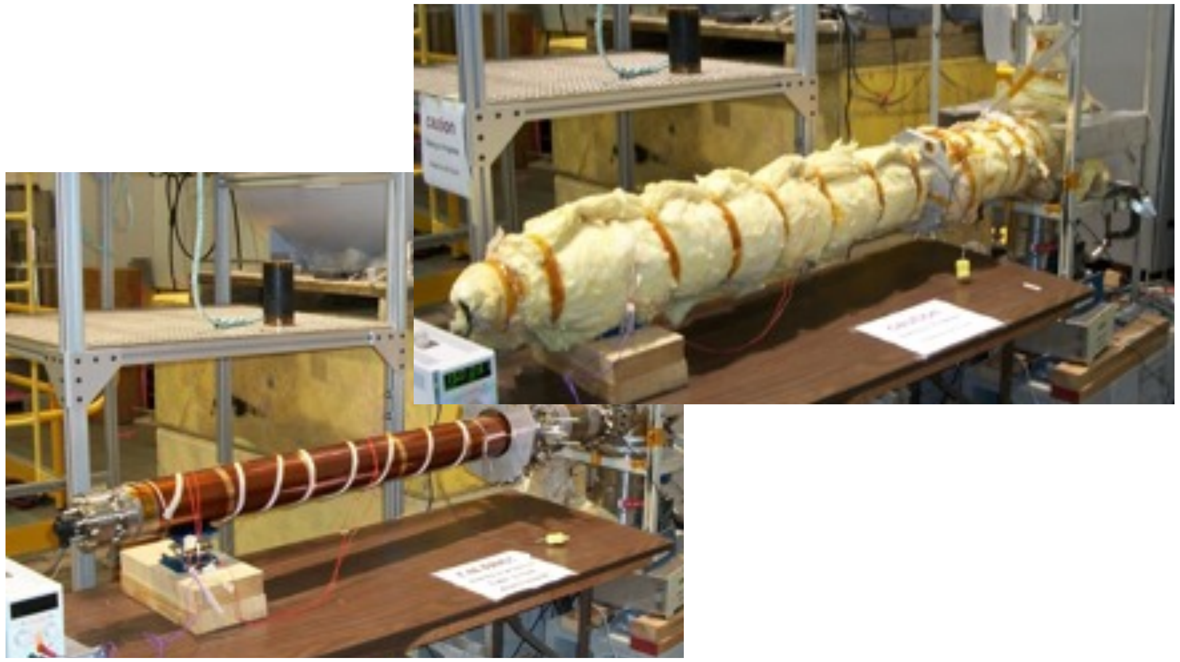
- Yield: around 2000/s + contamination from ^{74}Ga
- precision already comparable to ISOLTRAP (2007)

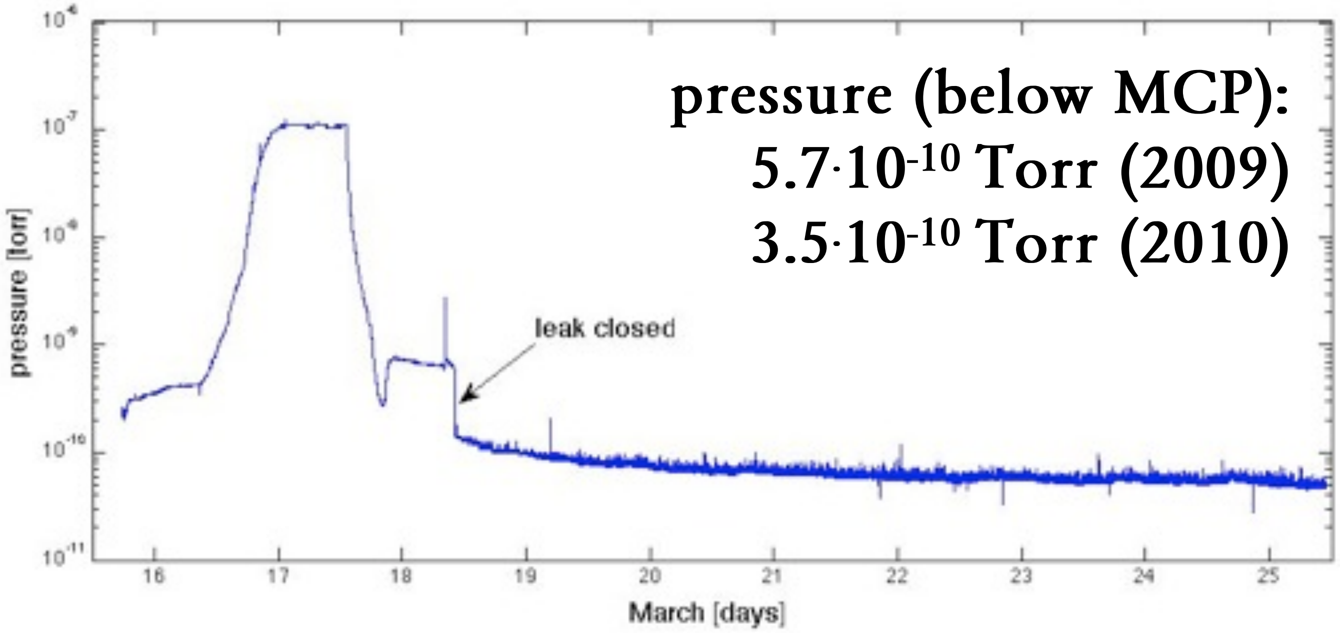
BUT

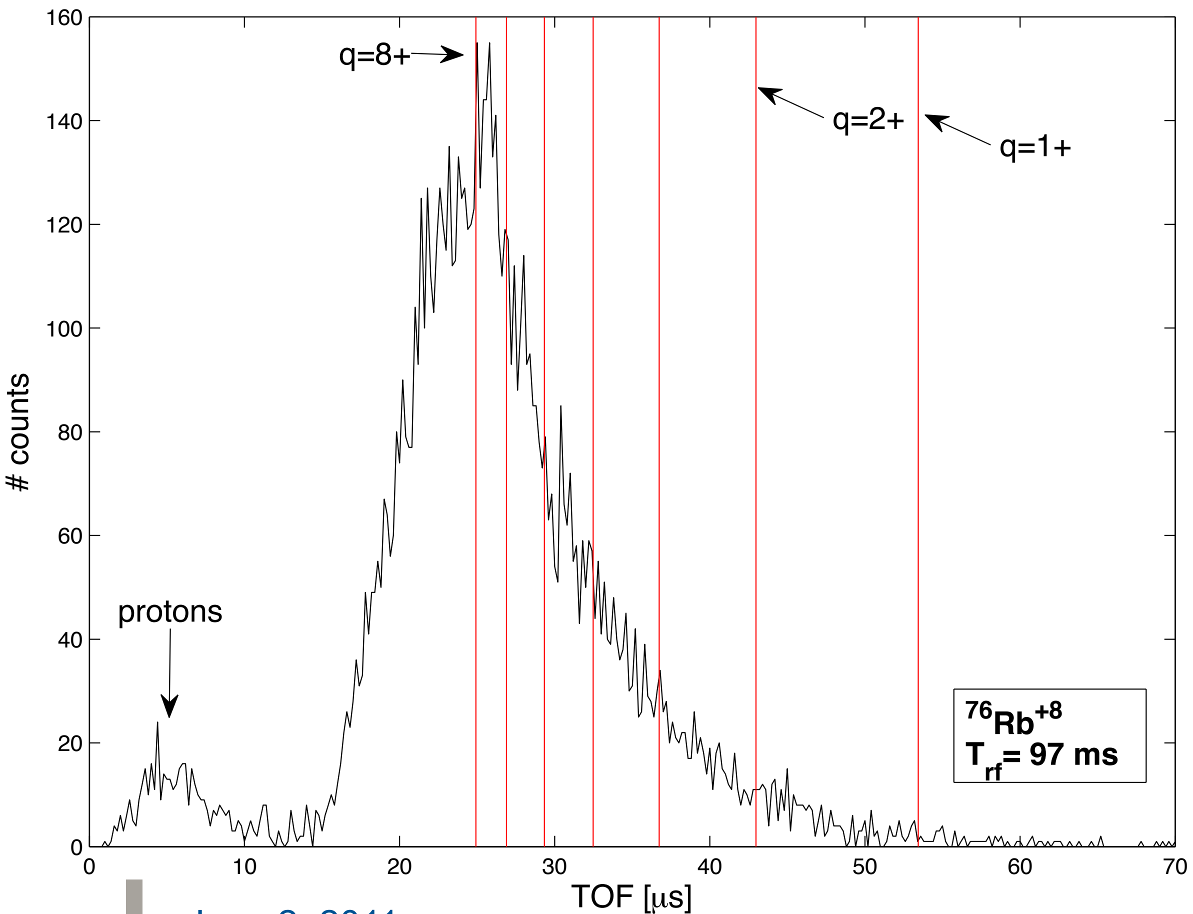
- data of < 20 hours
- power outage during ^{74}Rb => reconditioning of EBIT => lower efficiency

=> “easy” improvement next time

charge exchange with residual gas







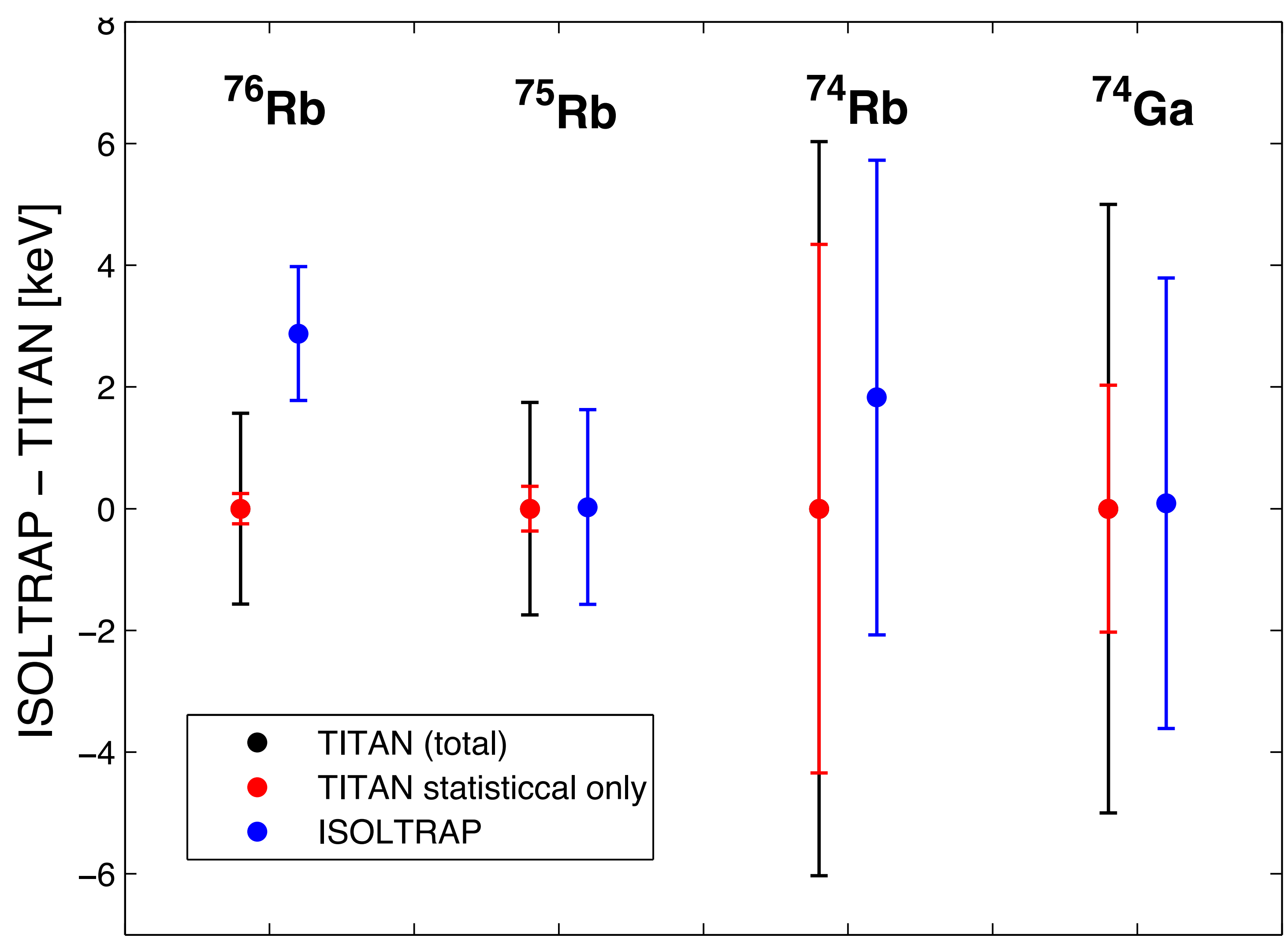
Open questions:

- impact of charge exchange on f_c?
- ion-ion interaction?
- what is the 'right' TOF range?

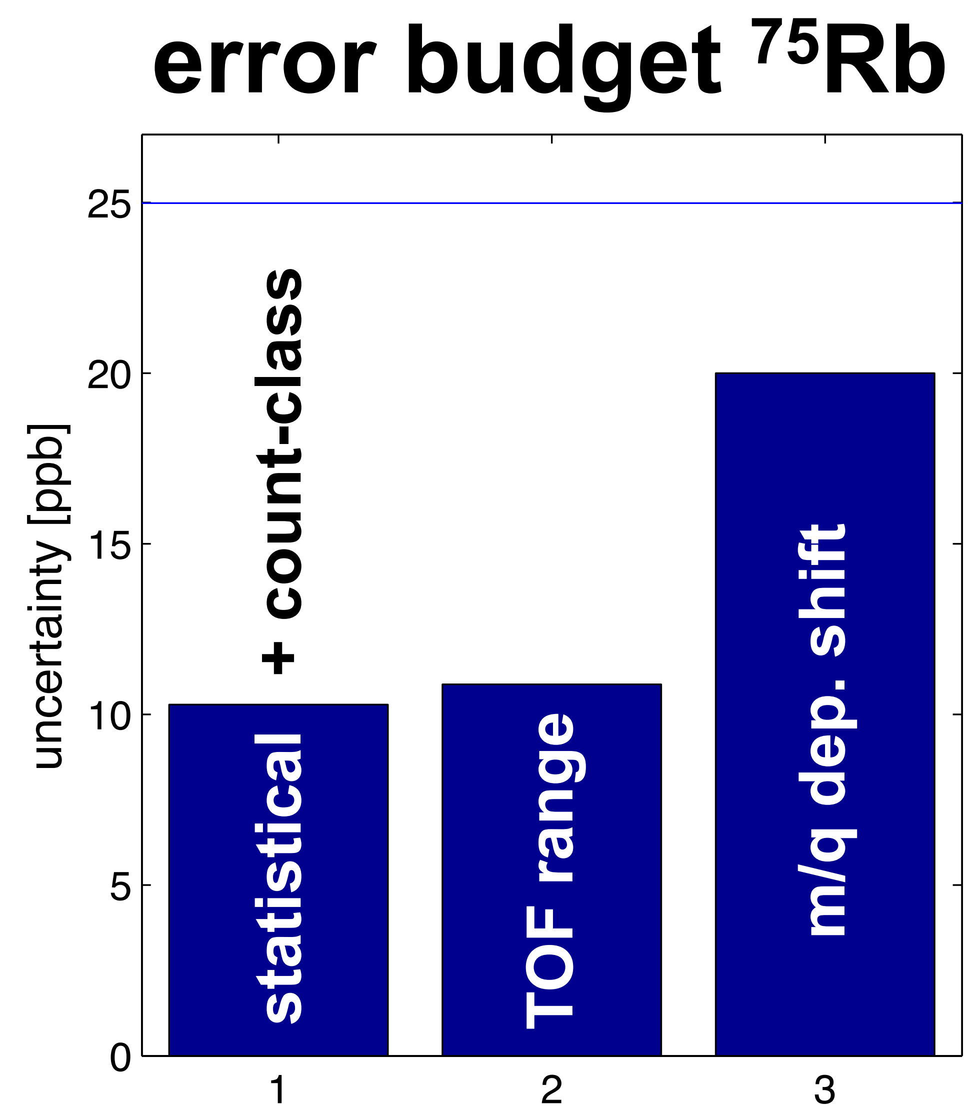
⇒ improvement of vacuum desirable

but demonstrated T_{rf} = 1 s with $^{76}Rb^{8+}$

results

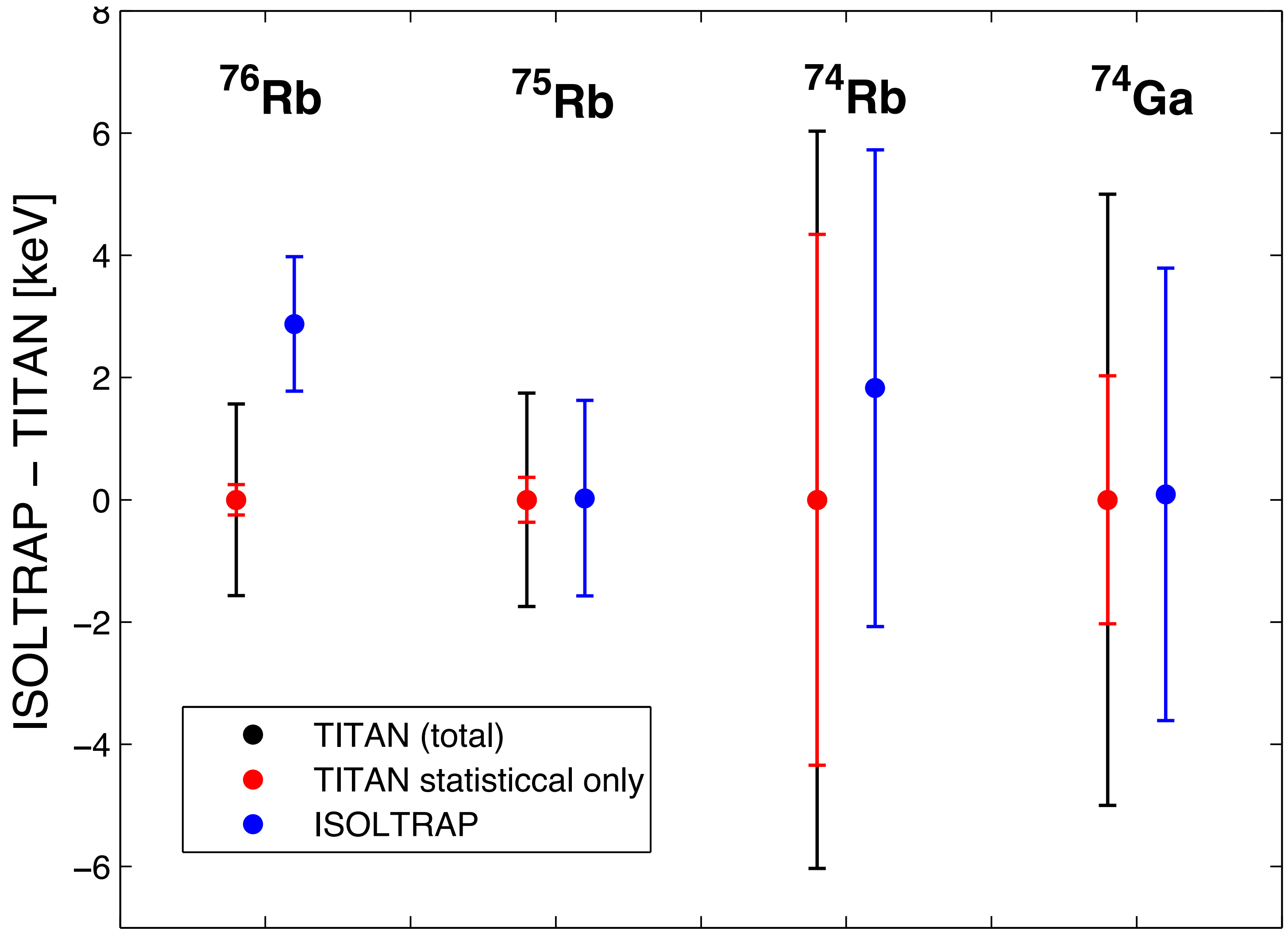


^{76}Rb
^{75}Rb
^{74}Rb
^{74}Ga
ISOLTRAP – TITAN [keV]
8
6
4
2
0
−2
−4
−6
TITAN (total)
TITAN statisticcal only
ISOLTRAP

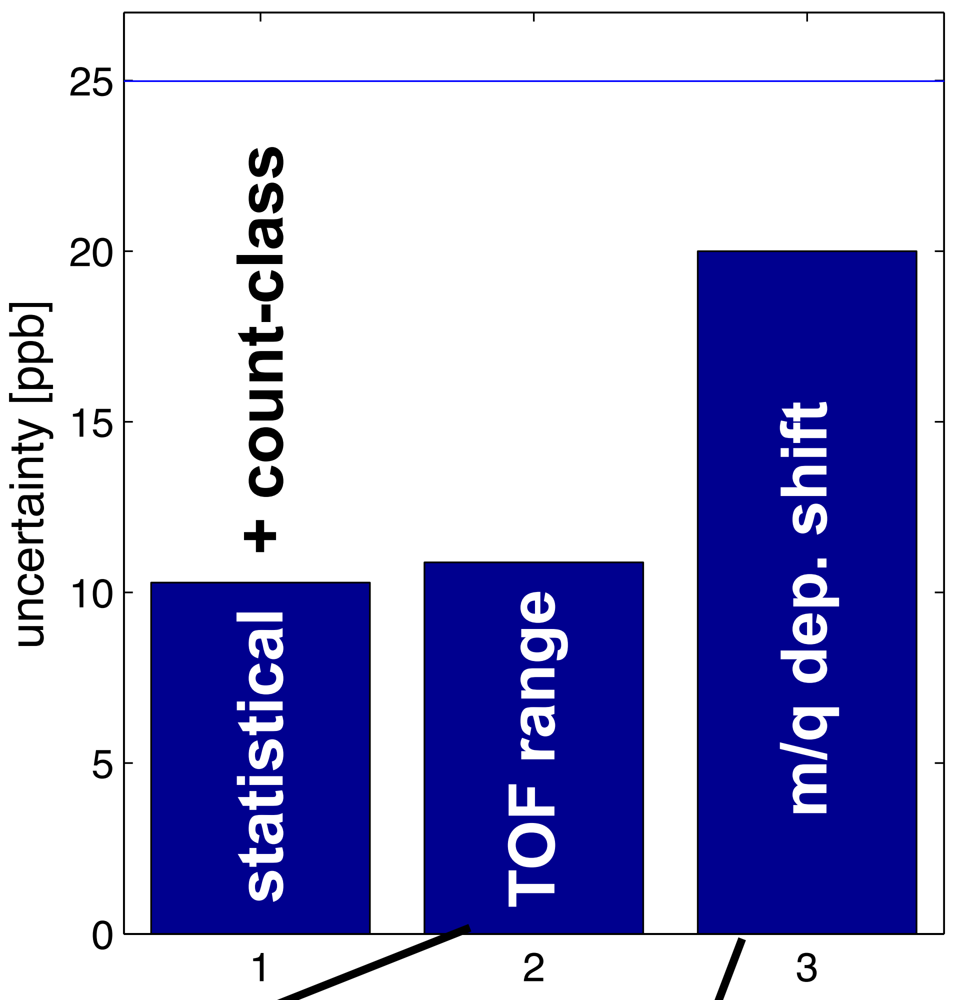


error budget ^{75}Rb
uncertainty [ppb]
0
5
10
15
20
25
statistical
+ count-class
TOF range
m/q dep. shift
1
2
3

results



error budget ^{75}Rb



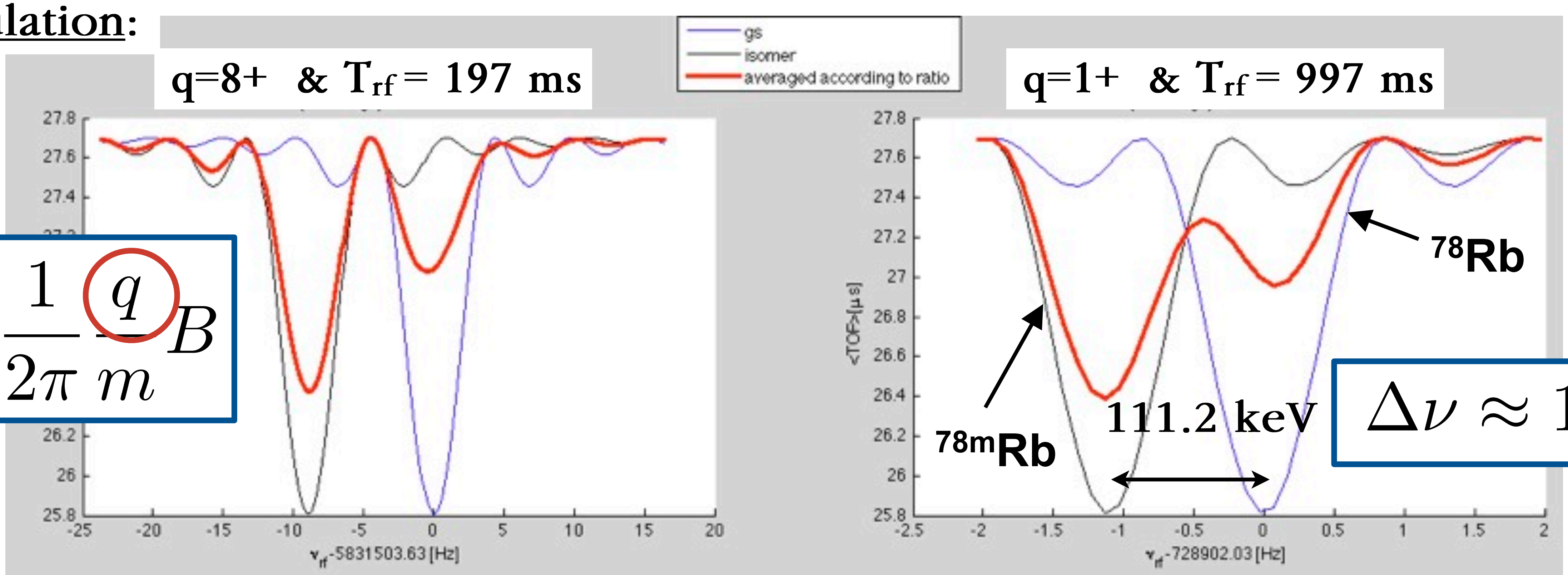
further vacuum improvements

< 5 ppb demonstrated already

M. Brodeur et al, PRC 80, 044318 (2009)

HCI and isomers

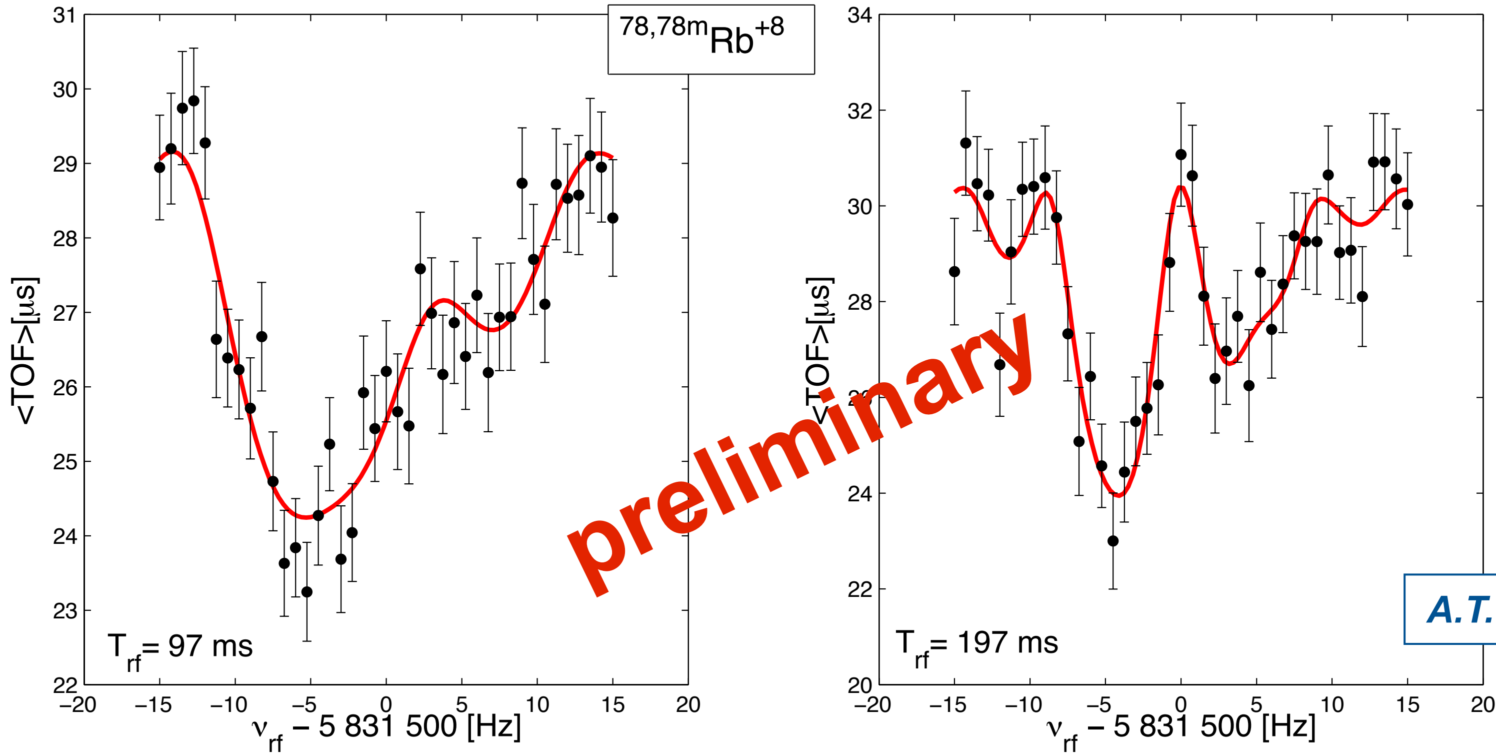
Calculation:



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

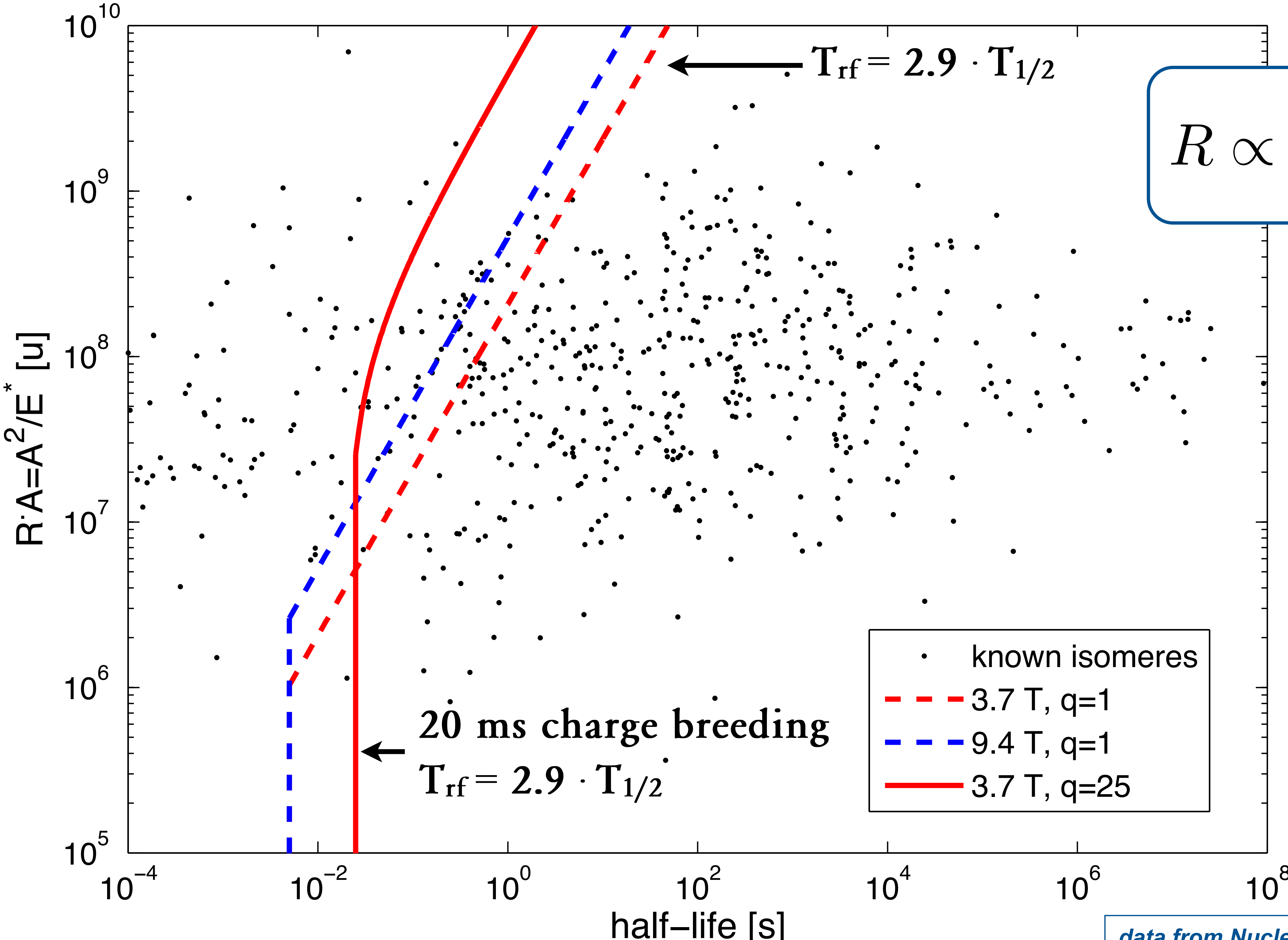
$$\Delta\nu \approx 1/T_{rf}$$

Measurement:



A.T. Gallant et al., in preparation

HCI and isomers



$$R \propto \frac{qBT_{rf}}{m}$$

data from Nuclear Wallet Cards

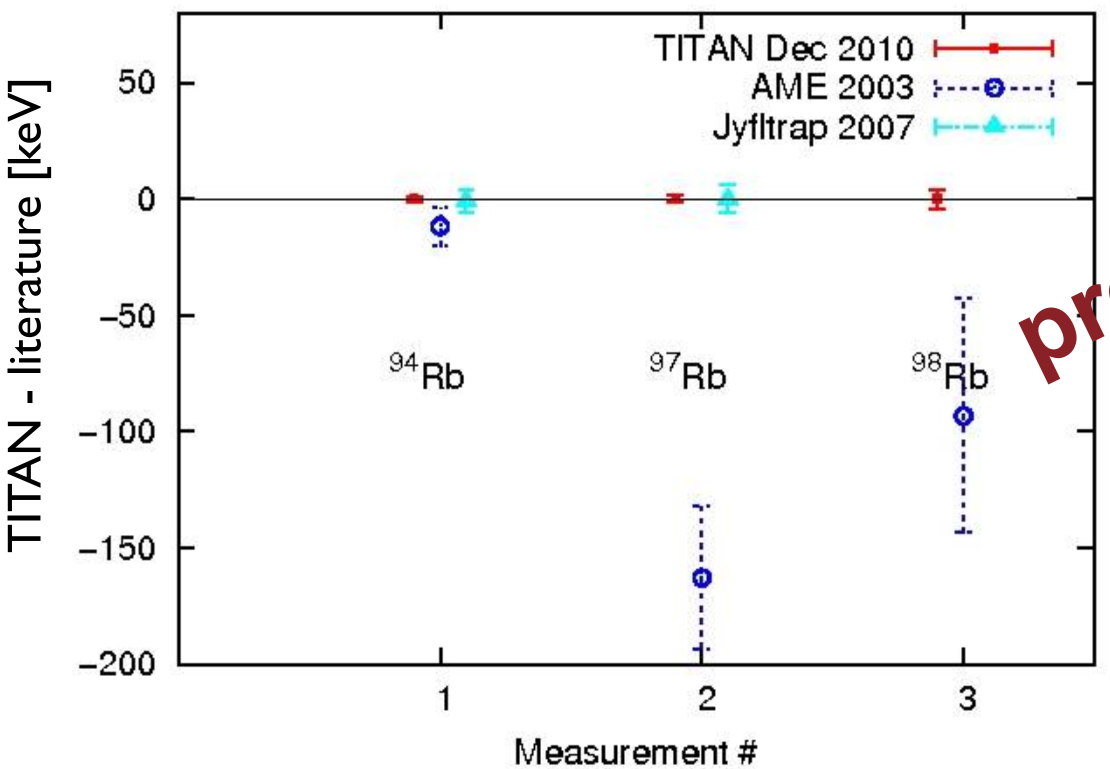
n -rich Rb,Sr

first UC-target @ TRIUMF

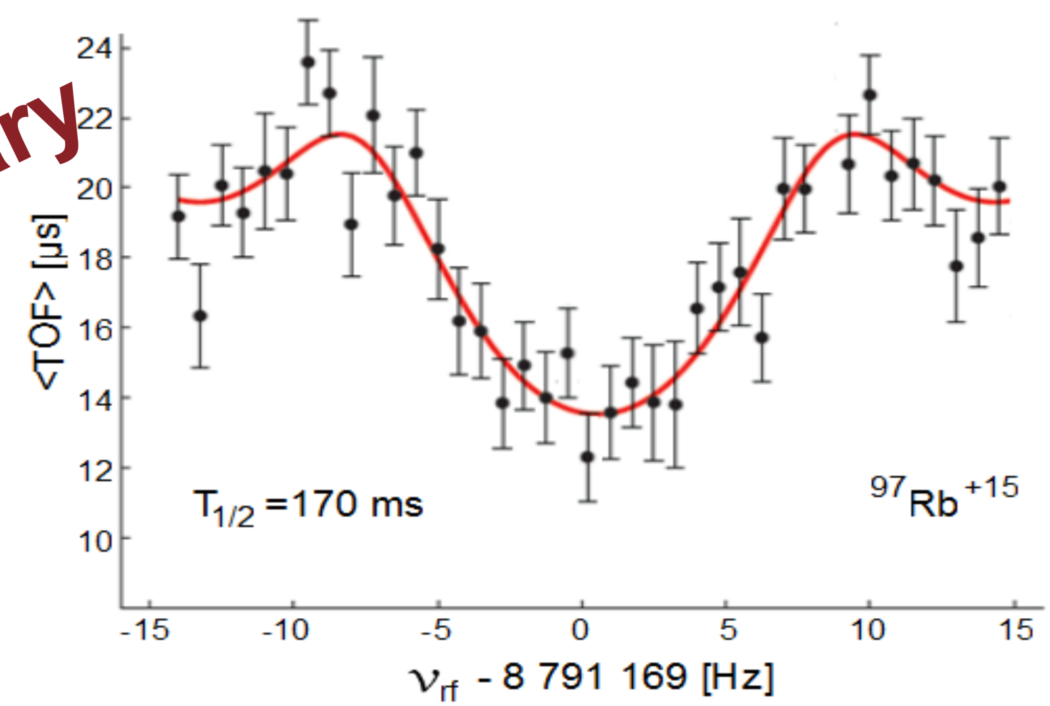
see talk by P. Kunz

charge breeding in EBIT
electron beam: 10 → 30 mA
breeding time: 23 - 35 → 80 ms

⇒ charge state q=15+



preliminary



V. V. Simon et al., in preparation

n -rich Rb,Sr

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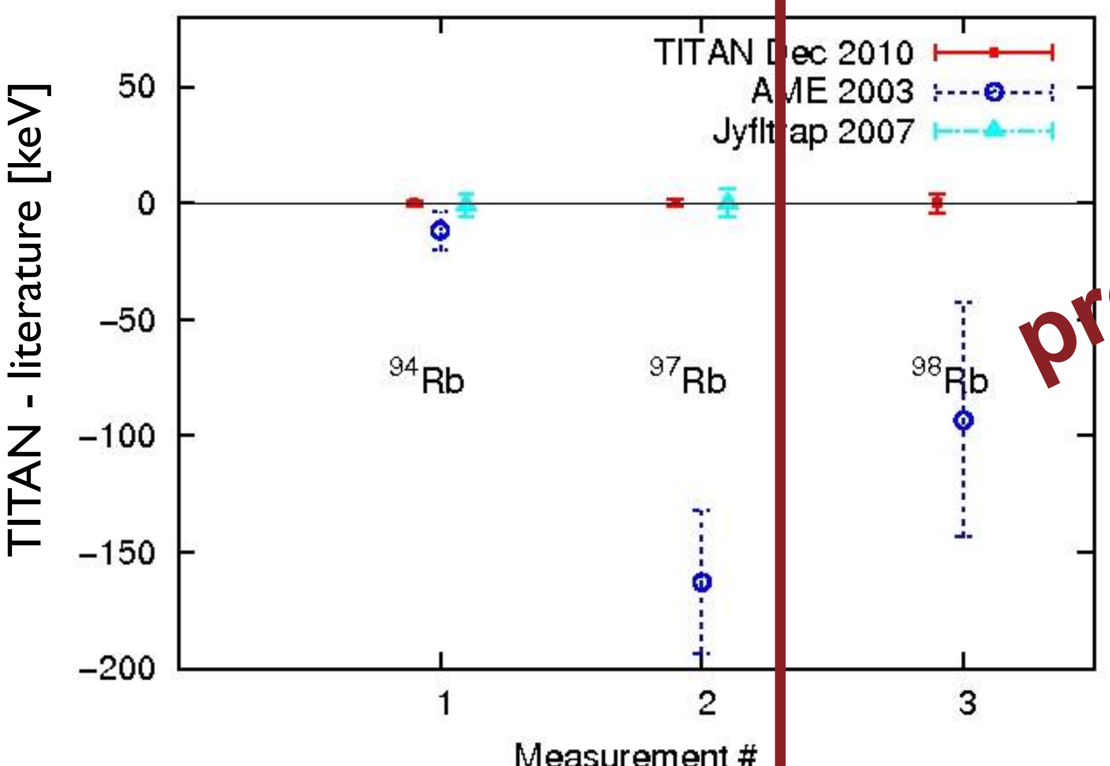
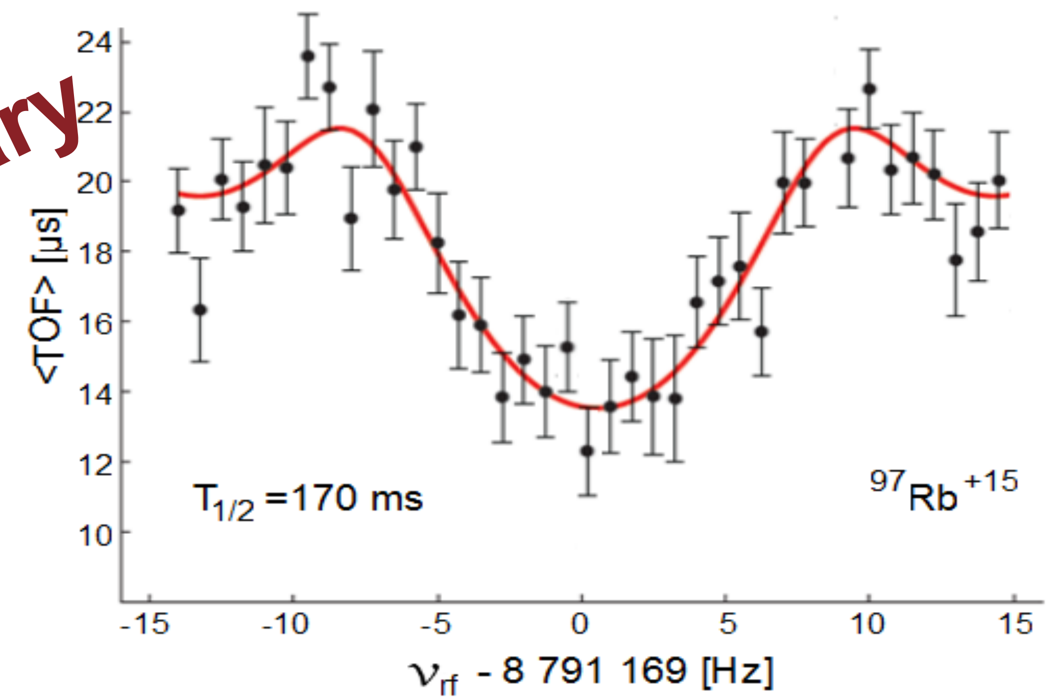


preliminary



V. V. Simon et al., in preparation

maximal electron beam: 500 mA (400 mA demonstrated)

summary

- accurate and precise masses are essential ⇒ Penning traps
- HCI boost precision by factor q
  - ➡ more precise (required for weak interaction studies)
  - ➡ same precision in shorter time
  - ➡ same precision with lower yield
  - ➡ higher resolving power (isomers)
- first mass measurement of highly charged, short-lived nuclides
- Rb, Ga, and Sr isotopes measured with q= 8 - 15+
- superallowed beta emitter ^{74}Rb (65 ms): improved Q-value
- demonstrated potential for resolving isomers: ^{78m,78}Rb
- **BUT**
  - ➡ reduce systematics to demonstrated level for SCI
  - ➡ improve vacuum further to avoid charge exchange
  - ➡ improve charge breeding (higher current, efficiency,...)

Thank you! Merci!

- The TITAN Group: Jens Dilling, Paul Delheij, Gerald Gwinner, Melvin Good, Alain Lapierre, David Lunney, Mathew Pearson, Ryan Ringle, Corina Andreoiu, Maxime Brodeur, Ankur Chaudhuri , Alexander Grossheim, Ernesto Mané, Brad Schultz, Martin C. Simon, Thomas Brunner, Usman Chowdhury, Benjamin Eberhart, Stephan Ettenauer, Aaron Gallant, Vanessa Simon, Mathew Smith

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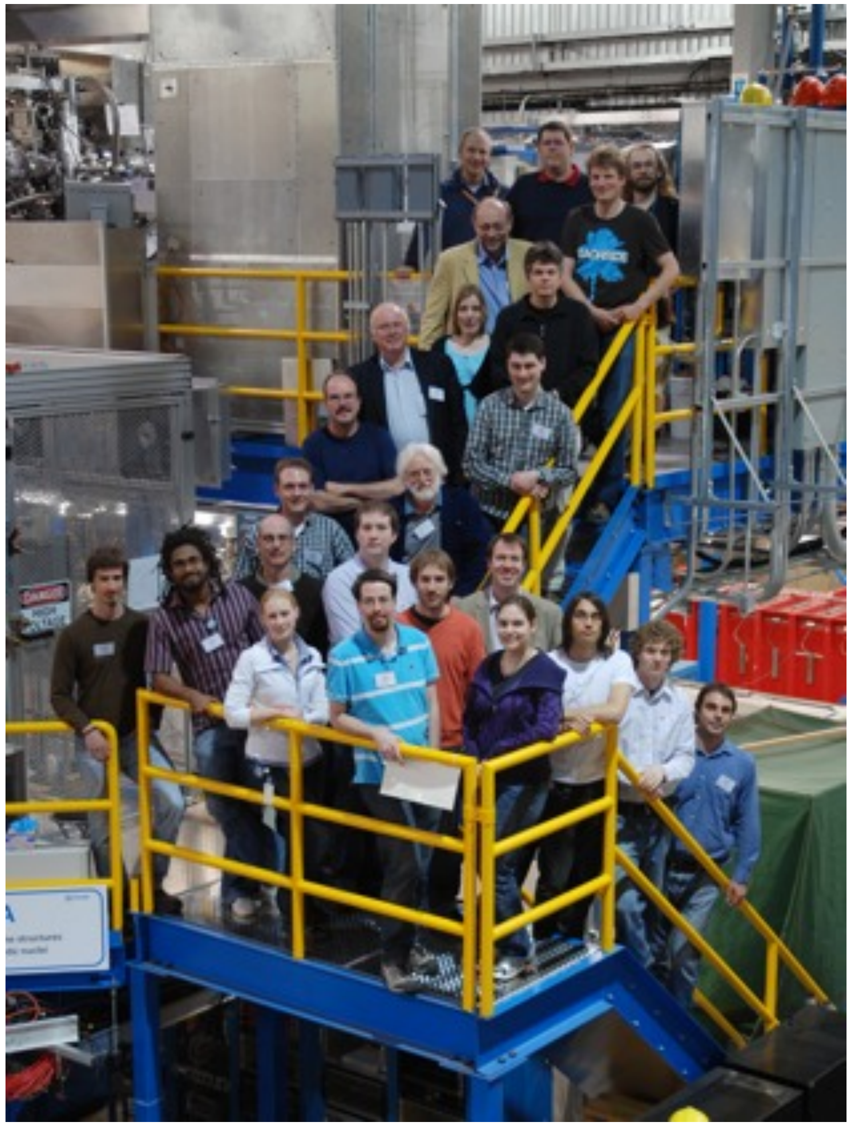

And the rest of the TITAN collaboration....

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Muenster U.,	Colorado School of Mines
Max Plank Inst. of Heidelberg	TRIUMF
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