S966

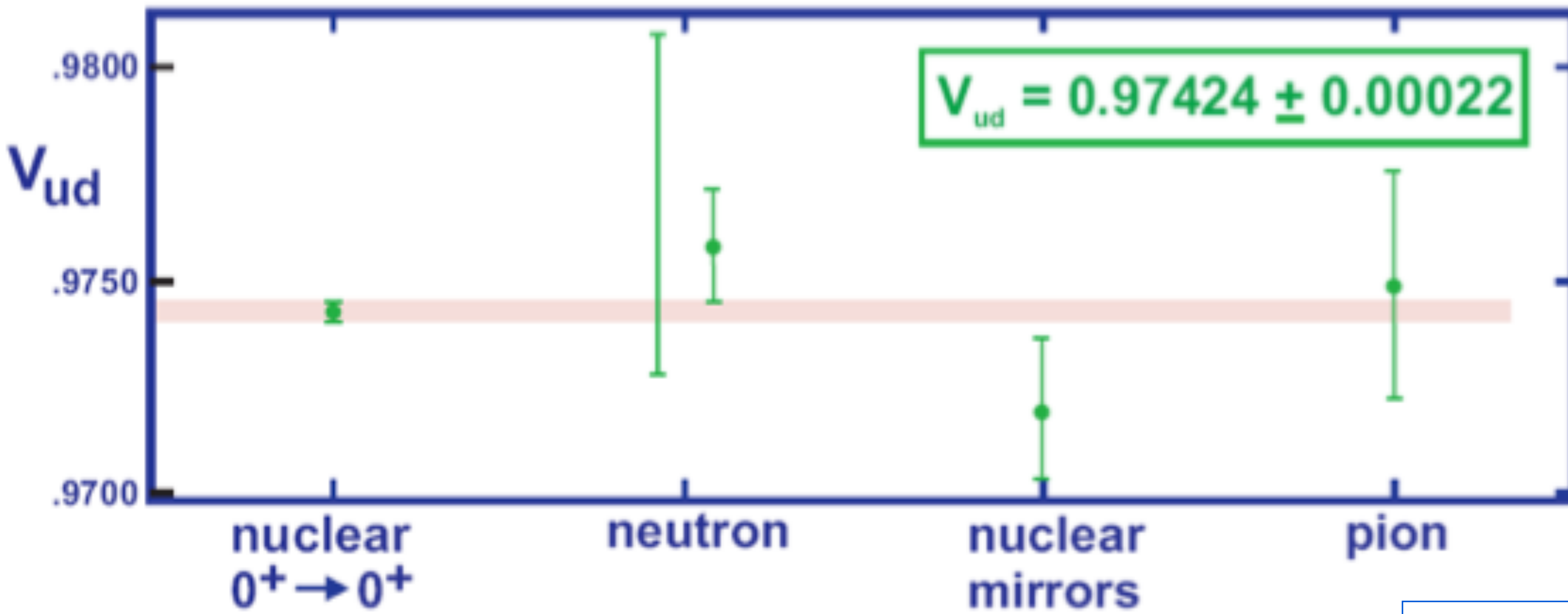
The Mass of ^{74}Rb: First Mass Measurements of Highly Charged, Short- lived Nuclides in a Penning Trap

stephan ettenauer
for the TITAN collaboration

TITAN
ISAC-TRIUMF

ISAC Science Forum, Feb. 8th, 2011

V_{ud} measurements



J. Hardy, CIPANP 2009

⇒ superallowed $0^+ \rightarrow 0^+$ decays most precise way to extract V_{ud}

$$Ft = ft(1+\delta_R)(1+\delta_{NS}-\delta_C) = \frac{K}{2G_V^2(1+\Delta_R^V)} = \text{const}$$

CVC hypothesis

f … phase space integral (dep. on Q-value)

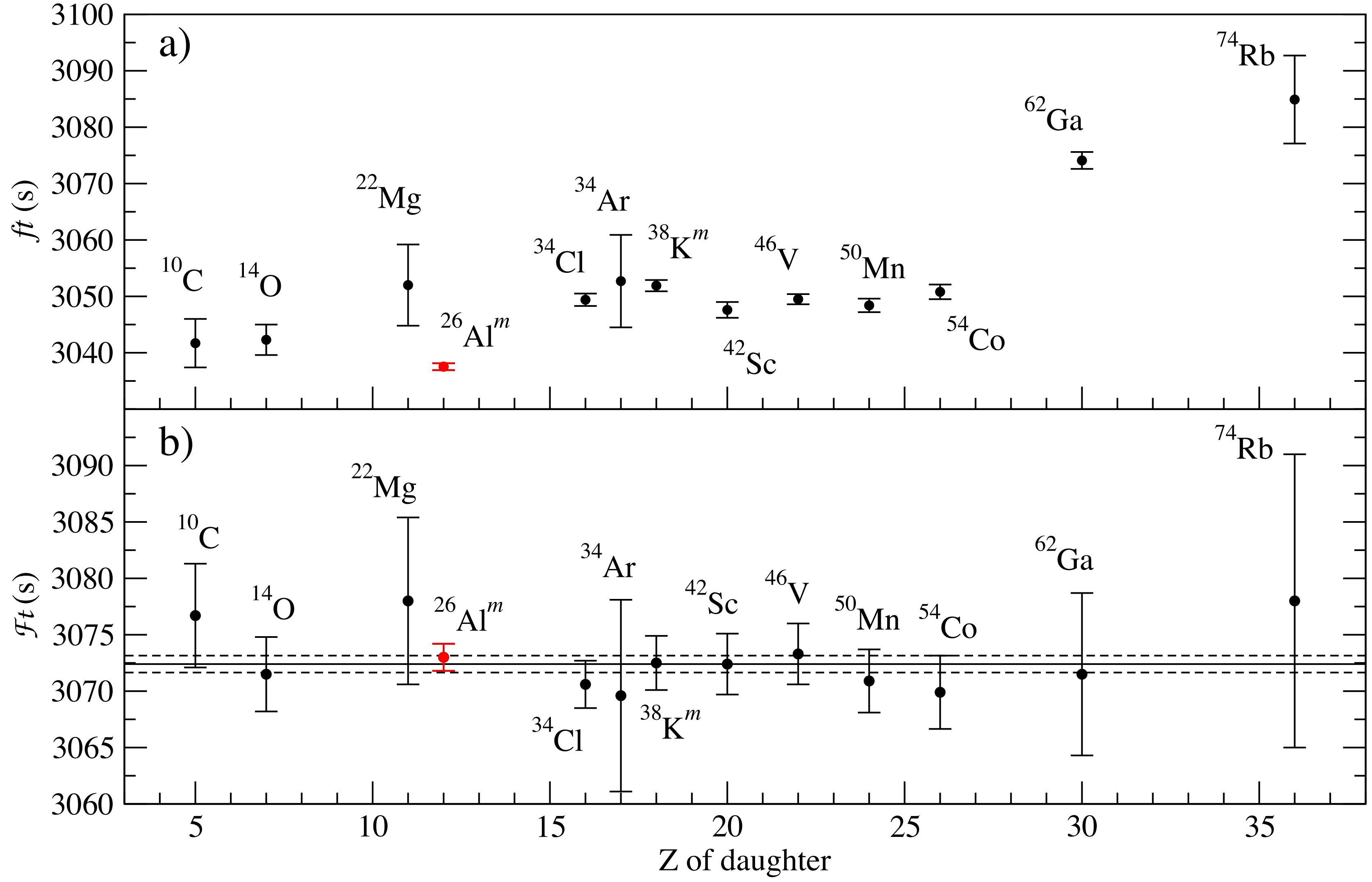
t … „partial halflife“ (dep on. BR and T)

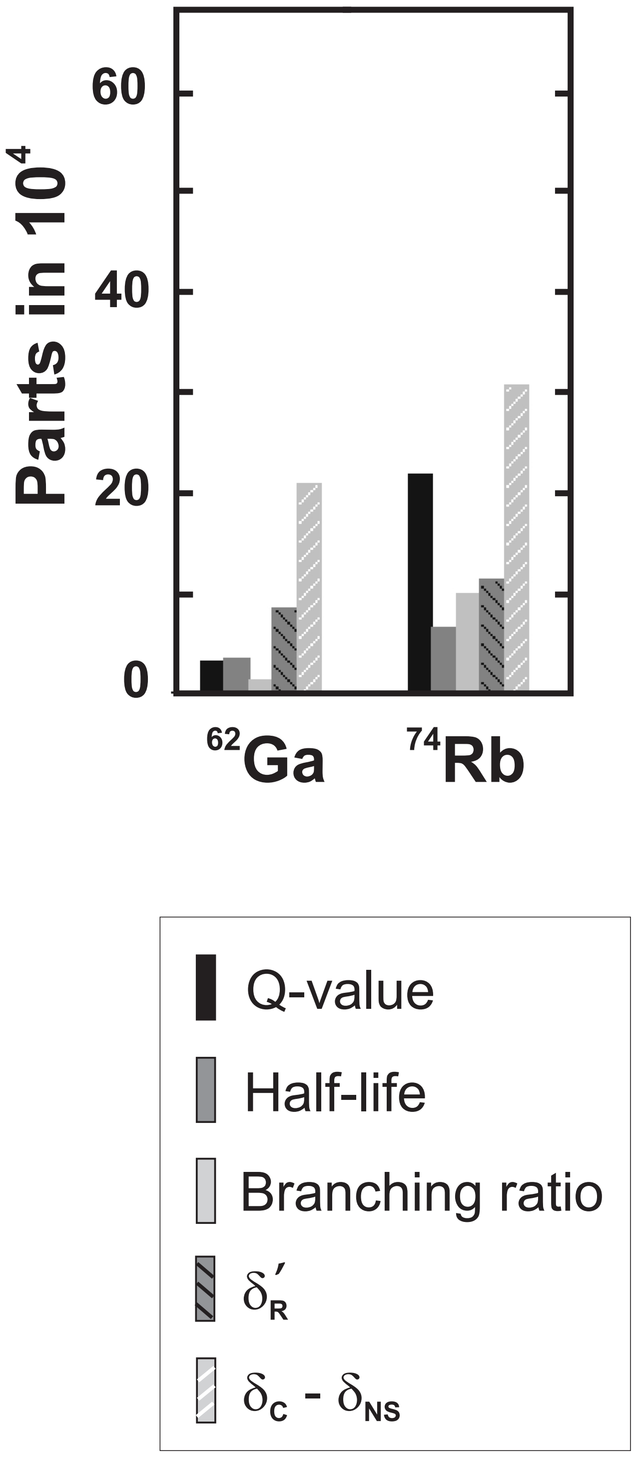
K … numerical constant

The case of ^{74}Rb

J. C. Hardy and I. S. Towner
PRC 79, 055502 (2009)

P. Finlay et al., PRL 106, 032501 (2011)



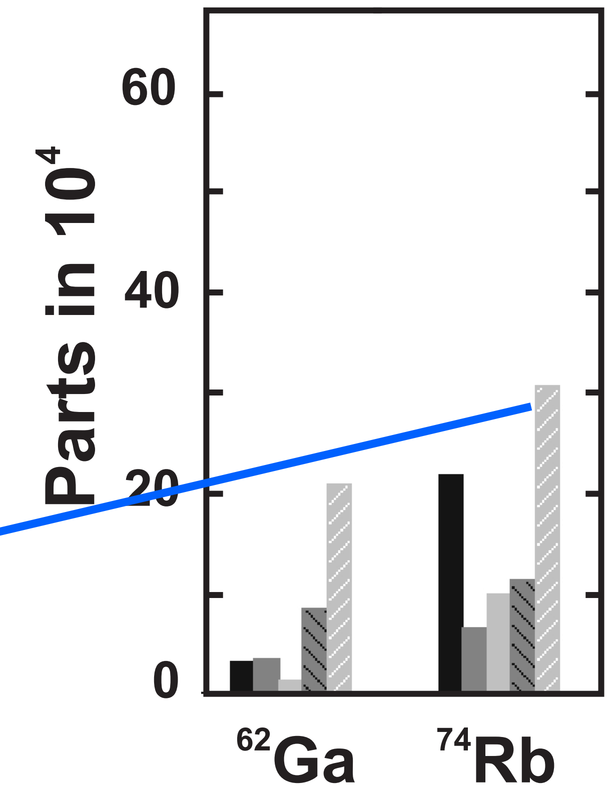


Radial overlap correction δ_{C2}

TABLE II. Calculations of δ_{C2} with Saxon-Woods radial functions, without parentage expansions (δ^I_{C2}) and with parentage expansions (δ^{II}_{C2}, δ^{III}_{C2}, and δ^{IV}_{C2}). Note that only one sample result is shown in each case for δ^I_{C2}, δ^{II}_{C2}, δ^{III}_{C2} and δ^{IV}_{C2}, while the adopted δ_{C2} value in column 7 reflects the results from all multiple-parentage calculations for that case; see text.

Parent nucleus	2002 δ_{C2}(%) Ref. [4]	This work				
		δ^I_{C2}(%)	δ^{II}_{C2}(%)	δ^{III}_{C2}(%)	δ^{IV}_{C2}(%)	δ_{C2}(%) adopted
^{62}Ga	1.05(15)	1.31	1.22	1.19	1.14	1.20(20)
^{66}As	1.15(15)	1.32	1.41	1.34	1.24	1.35(40)
^{70}Br	1.00(20)	1.43	1.41	1.31	1.10	1.25(25)
^{74}Rb	1.30(40)	1.68	1.60	1.47	1.12	1.50(30)

I. S. Towner and J. C. Hardy, PRC 77, 025501 (2008)



combined Δ of:

- charge radius
- effective interaction
- procedure

TABLE V. Calculations of δ_{C2} with Woods-Saxon radial functions, without parentage expansions δ^{I}_{C2} and with parentage expansions δ^{II}_{C2} , δ^{III}_{C2} , and δ^{IV}_{C2} .

Parent nucleus	Radius parameters (fm) $\langle r^2\rangle^{1/2}_{ch}$	r_0	δ^I_{C2}(%)	δ^{II}_{C2}(%)	δ^{III}_{C2}(%)	δ^{IV}_{C2}(%)	Adopted value δ_{C2}(%)
^{62}Ga	3.94(10)	1.271(42)	1.31(11)	1.10(11)	1.07(11)	1.01(8)	1.05(15)
^{66}As	4.02(10)	1.264(41)	1.32(12)	1.25(12)	1.18(14)	1.07(8)	1.15(15)
^{70}Br	4.10(10)	1.264(39)	1.43(13)	1.11(13)	1.03(14)	0.85(6)	1.00(20)
^{74}Rb	4.18(10)	1.276(37)	0.68(9)	1.51(14)	1.38(18)	1.20(12)	1.30(40)

I. S. Towner and J. C. Hardy, PRC 66, 035501 (2002)

extrapolated from stables→ uncertainty? **recent Laser Spec. at TRIUMF (S1148)**

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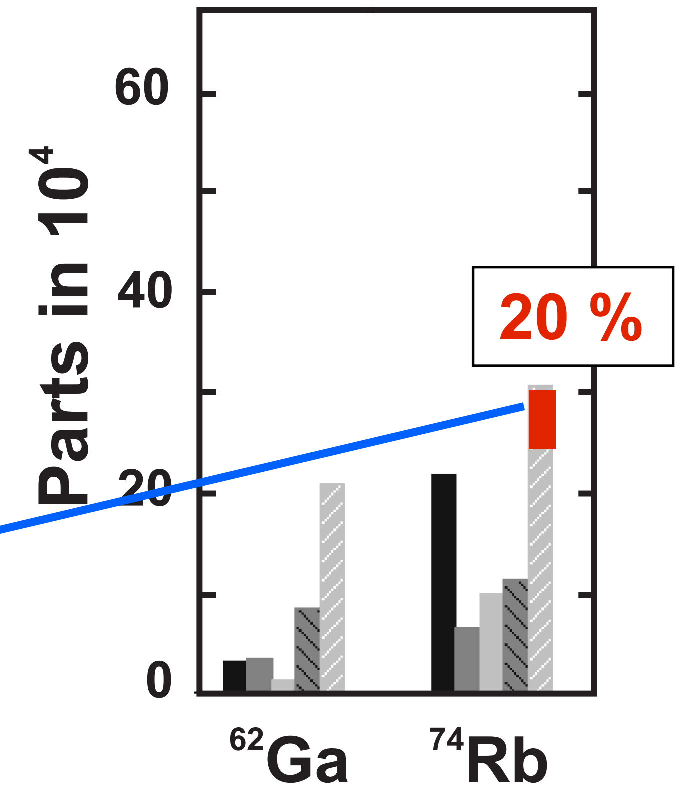
I. S. Towner and J. C. Hardy, PRC 77, 025501 (2008)



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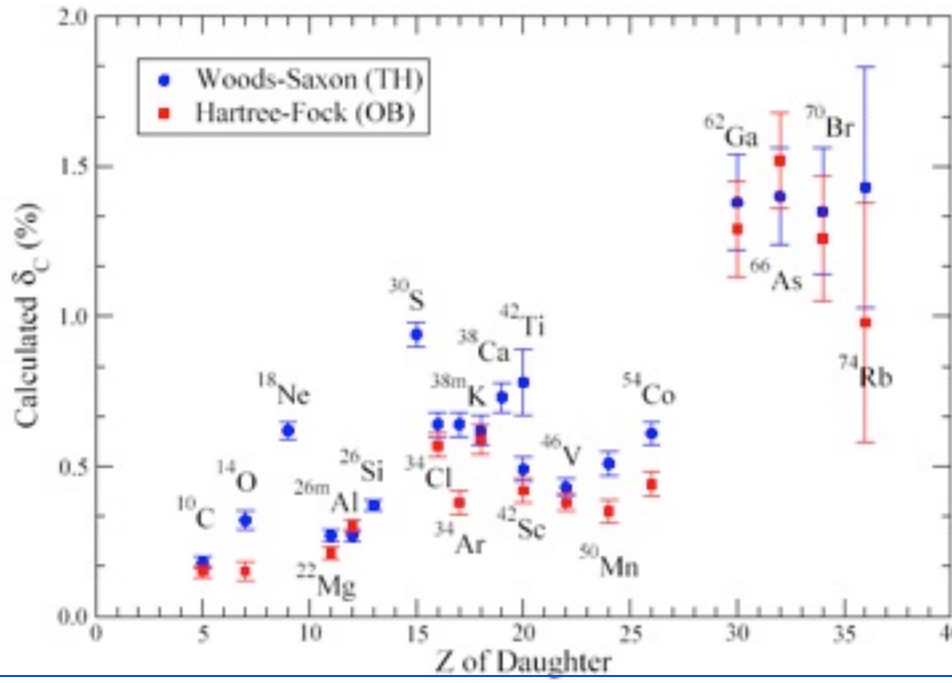
I. S. Towner and J. C. Hardy, PRC 66, 035501 (2002)

extrapolated from stables→ uncertainty?

recent Laser Spec. at TRIUMF (S1148)

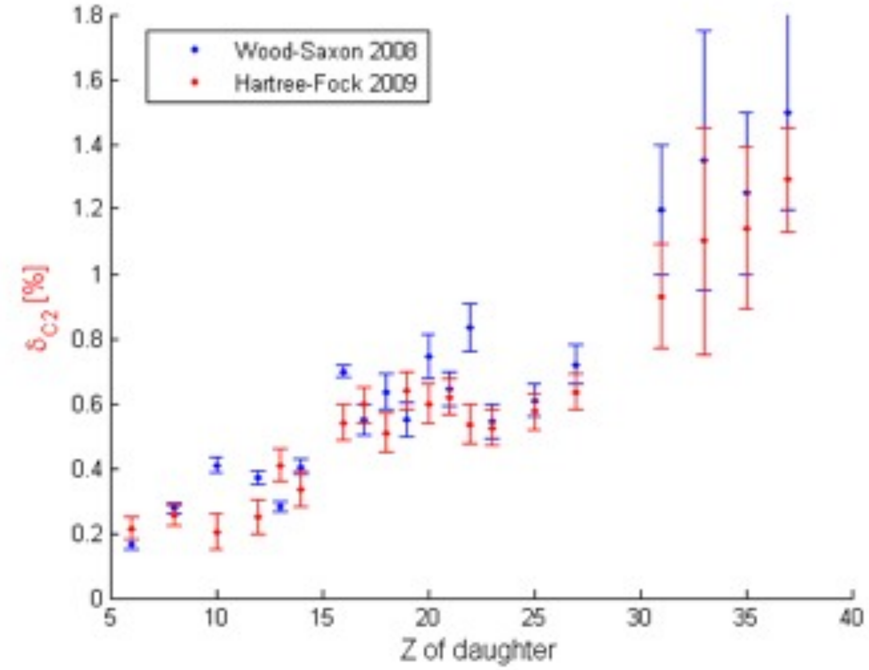
δ_c : comparisons between models

T&H (2005) ↔ O&B



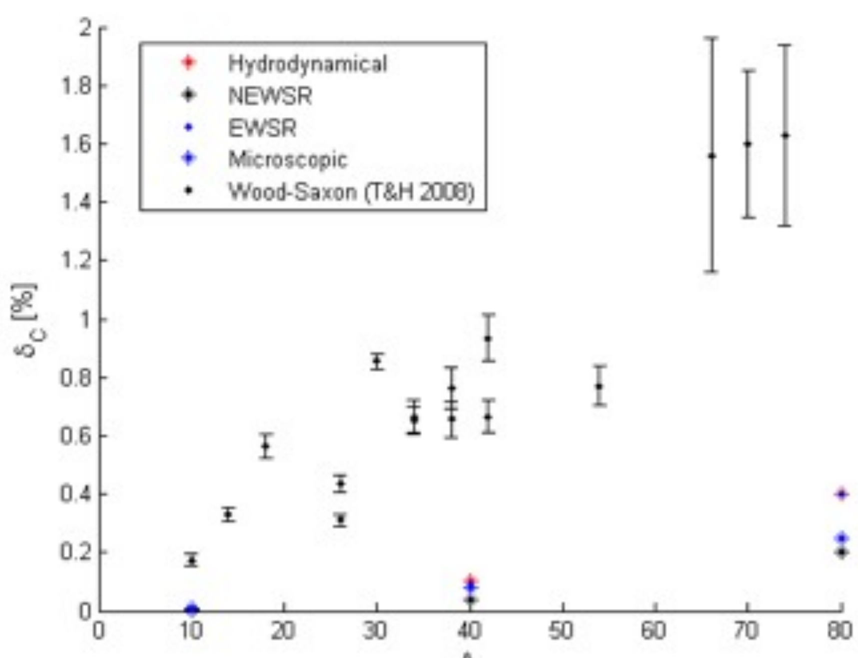
J.C. Hardy and I.S. Towner, PRC66, 035501 (2002), PRC71, 055501 (2005)
W. E. Ormond and B. A. Brown, PRC 52, 2455 (1995), Nucl. Phys. A 440, 274 (1985)

T&H: WS (2008) ↔ HF (2009)



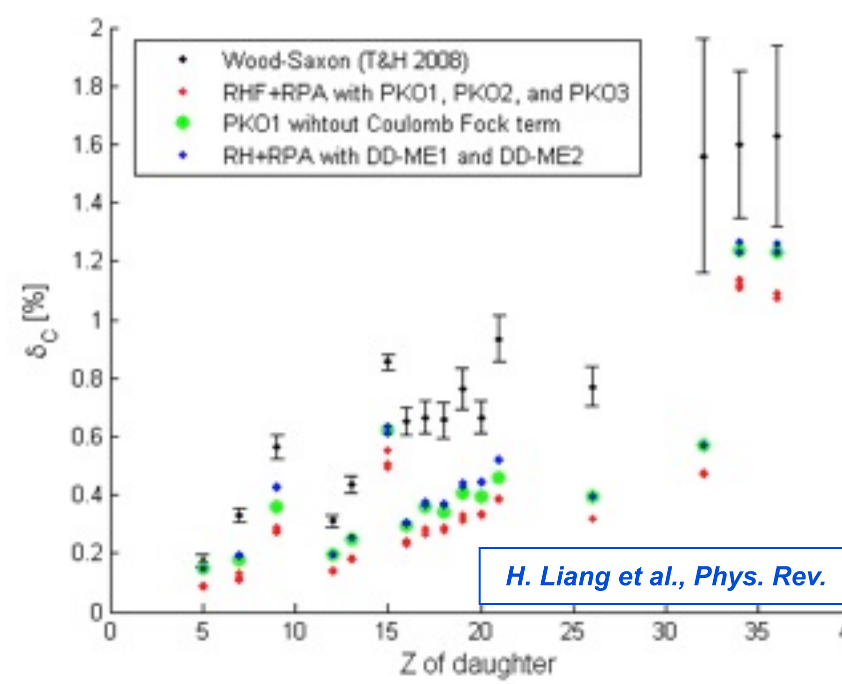
J. C. Hardy & I.S. Towner, PRC C77, 025501 (2008), PRC C 79, 055502 (2009)

T&H (2008) ↔ Perturbation theory



N. Auerbach, Phys. Rev. C 79, 035502 (2009)

T&H (2008) ↔ RPA

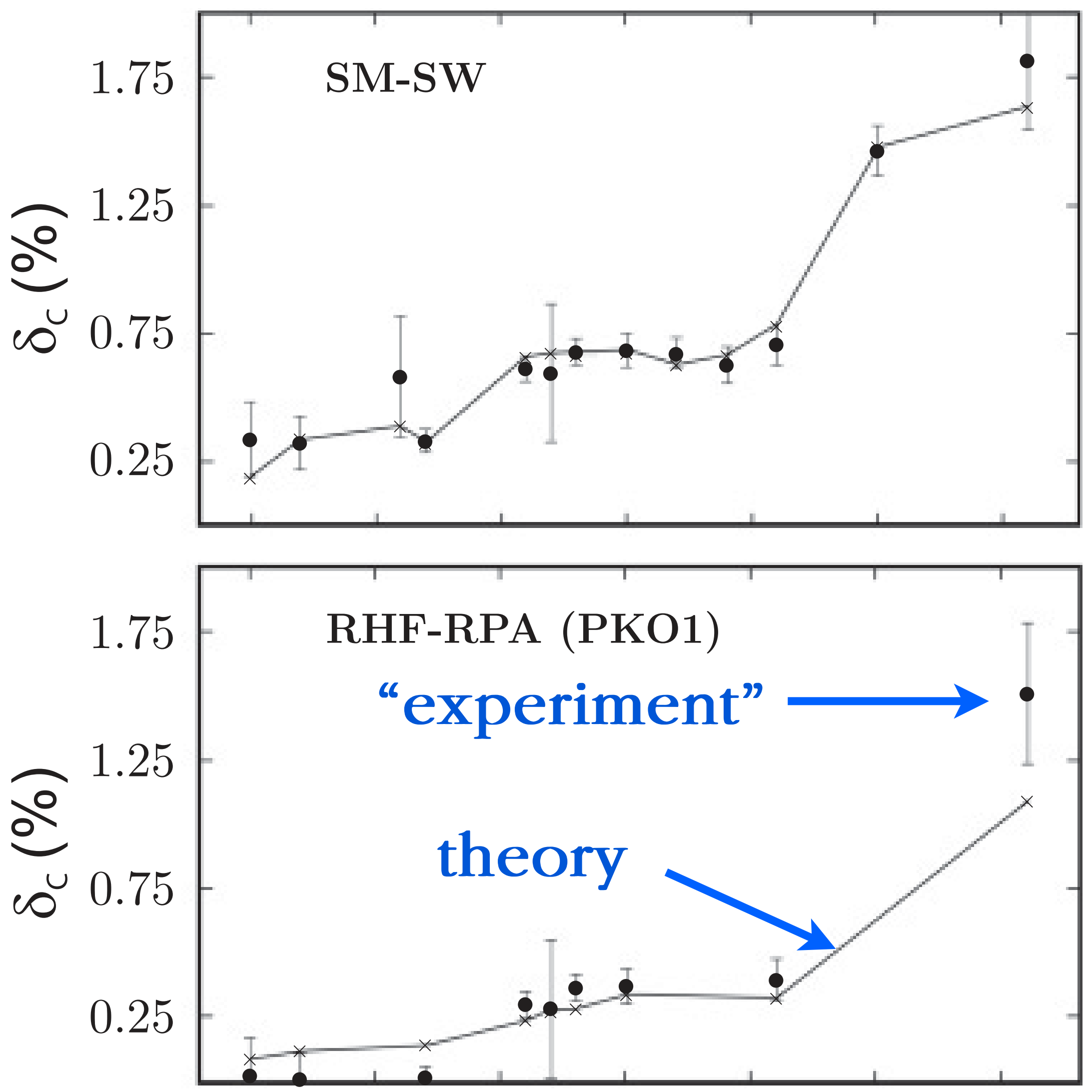


H. Liang et al., Phys. Rev. C, 064316 (2009)

“Tests” of Models (assumes CVC)

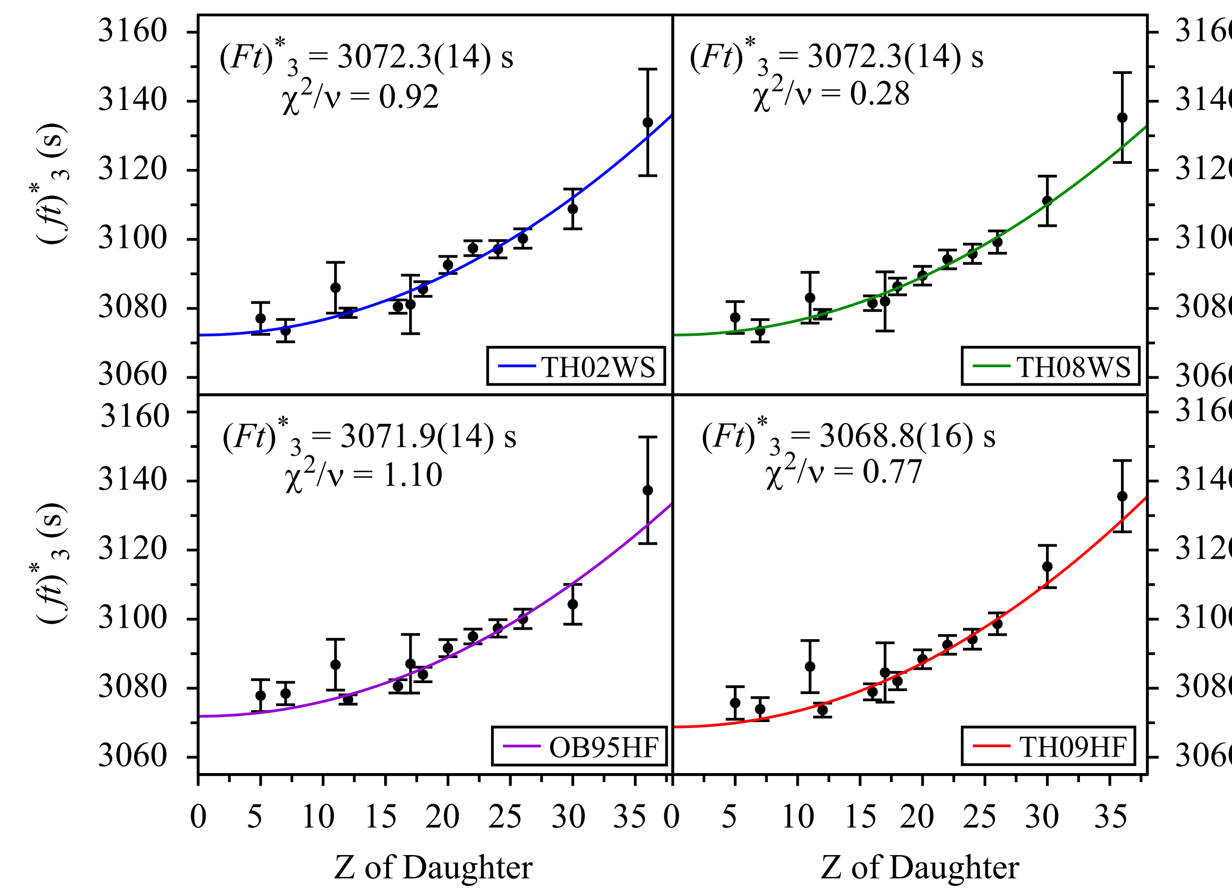
$$\delta_C = 1 + \delta_{NS} - \frac{\overline{\mathcal{F}t}}{ft(1+\delta'_R)}.$$

χ^2 minimization



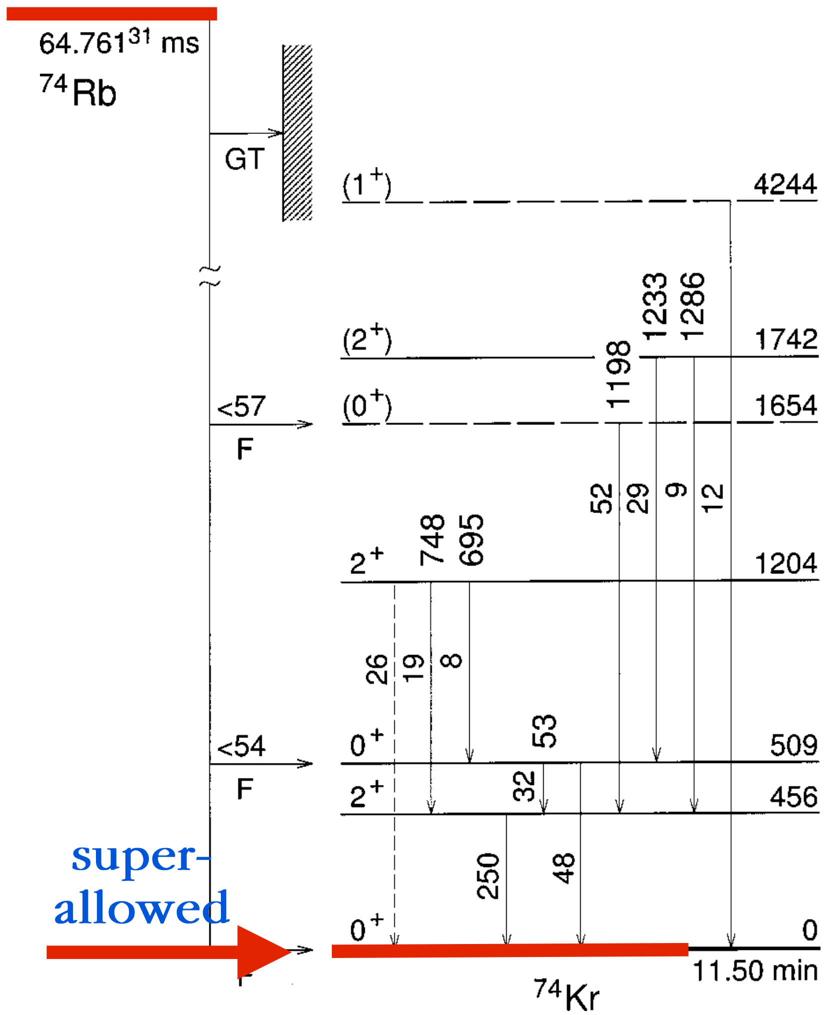
I. S. Towner* and J. C. Hardy, PRC 82, 065501 (2010)

- extrapolate to charge-independent limit $\propto Z^2$
- subtract non Z^2 components from models



G.F. Grinyer, C.E. Svensson, B.A. Brown, NIM A 622, 236 (2010)

Q-value for ^{74}Rb



A. Piechaczek et al., PRC 67, 051305(R) (2003)

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)

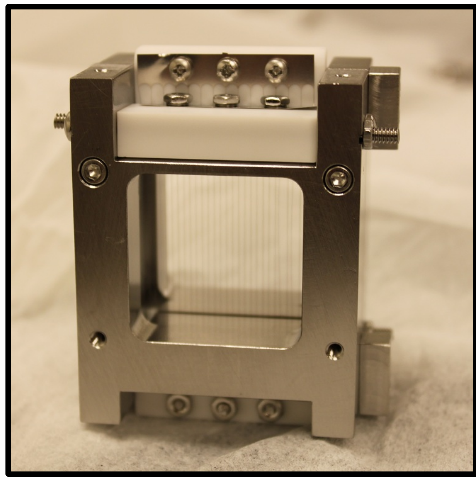
- limitation due to $T_{1/2}$

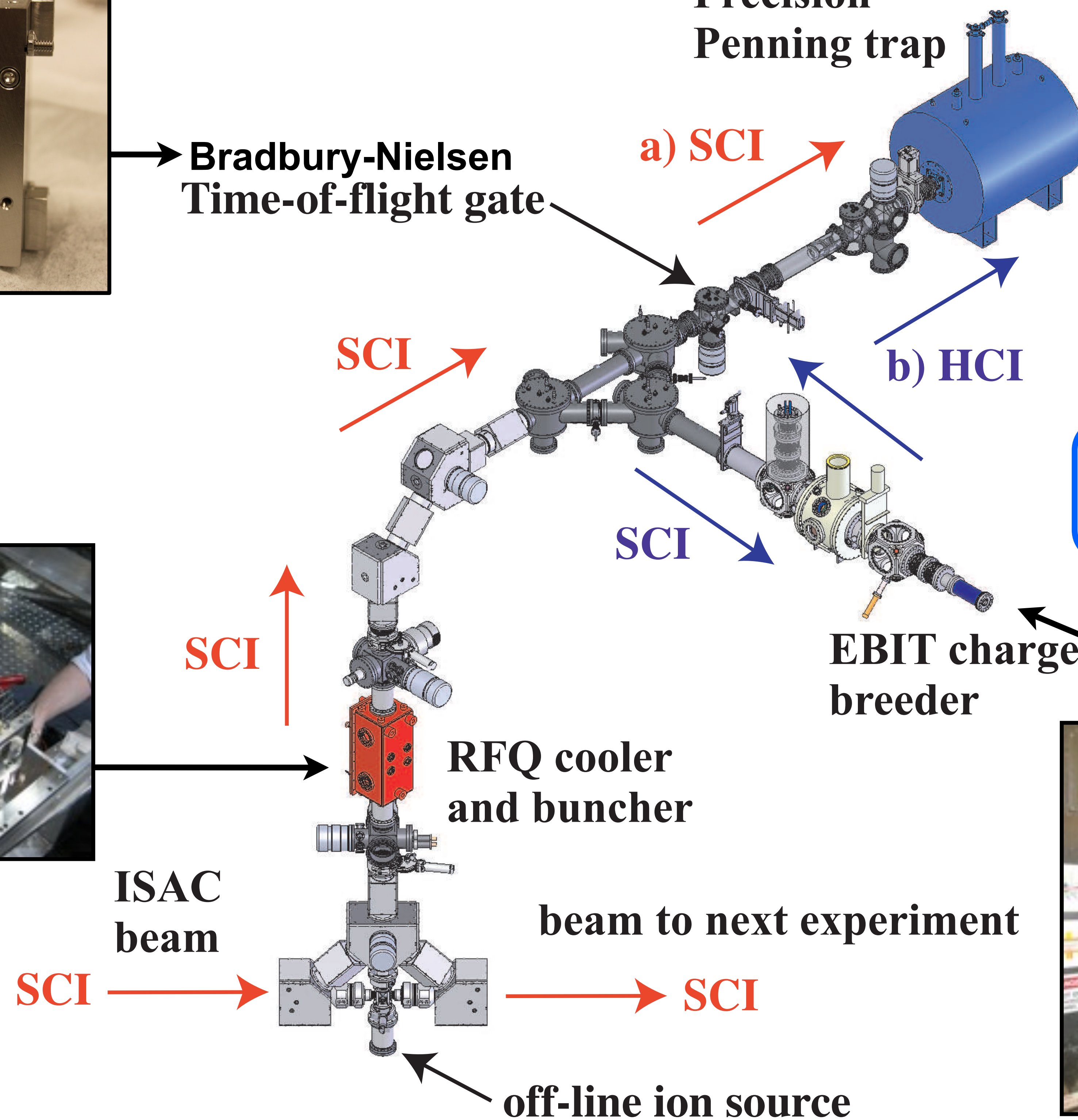
$$\frac{\delta m}{m} \propto \frac{m}{q} \frac{1}{B T N^{1/2}}$$

- to improve precision further: HCI
- **TITAN only online facility to use HCI**

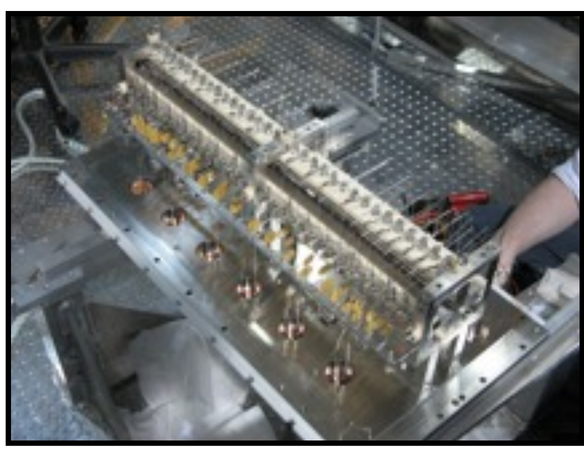
TRIUMF ISAC

TITAN





$$\frac{\delta m}{m} \approx \frac{m}{q \cdot B \cdot T_{RF} \cdot \sqrt{N_{ion}}}$$



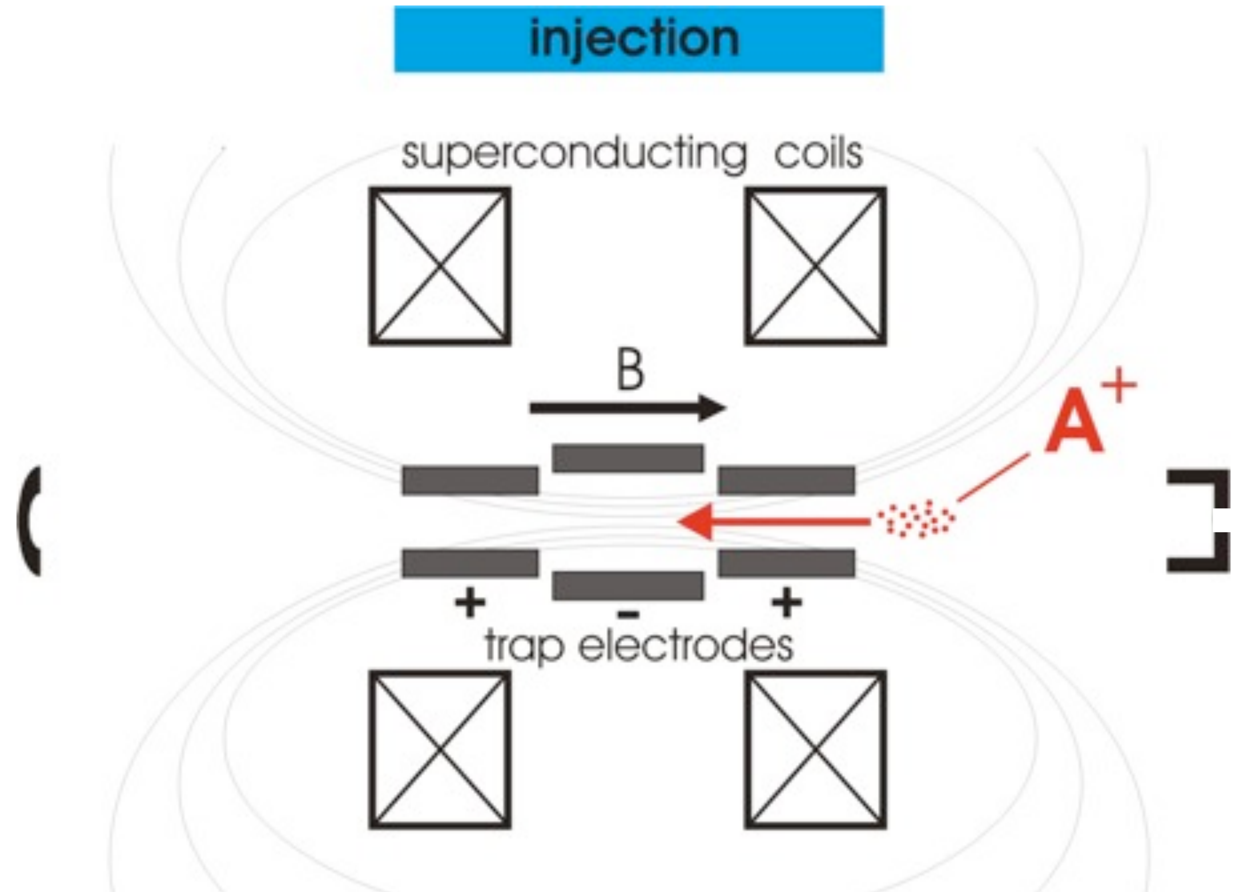
Electron Beam Ion Trap (EBIT)

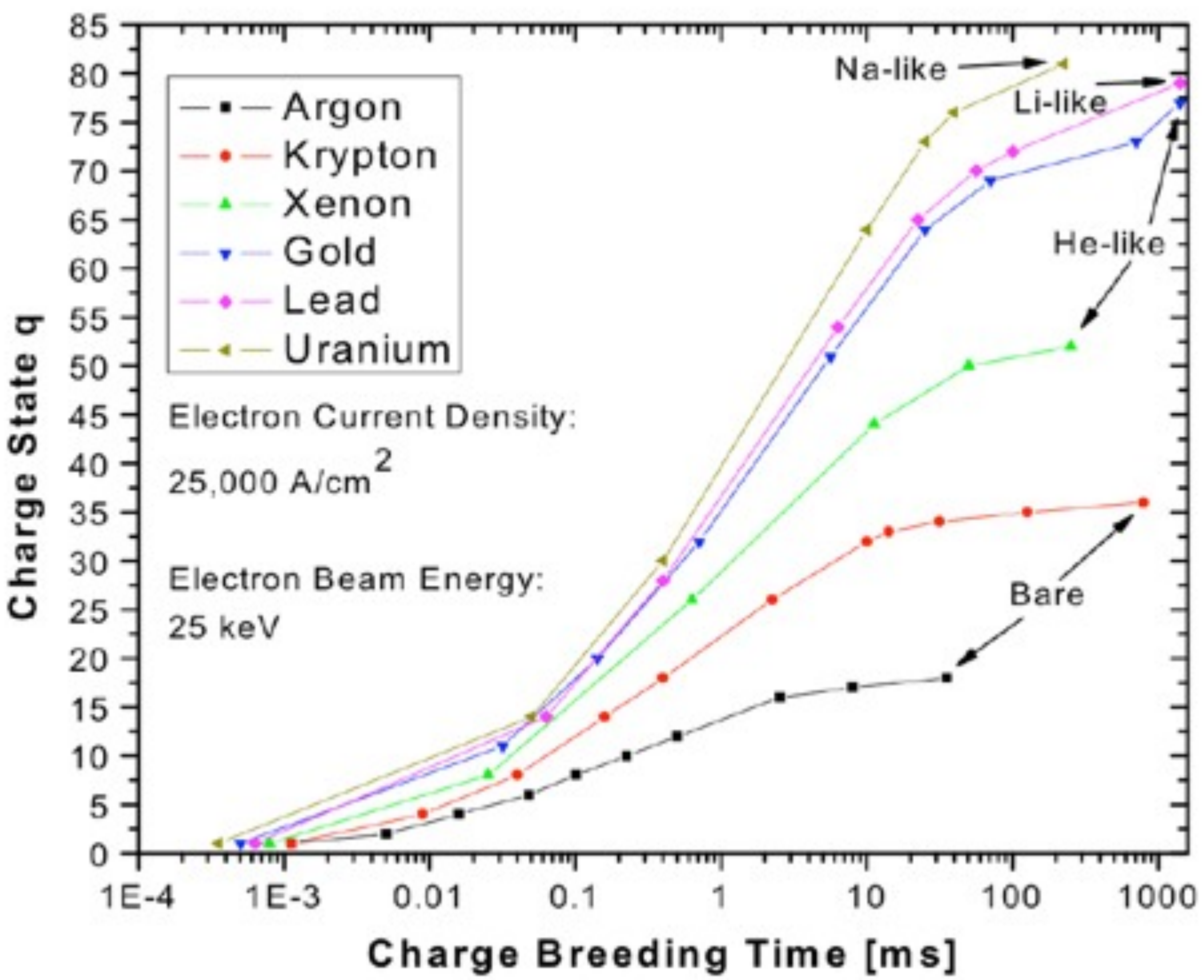
confinement:

– axial by electrostatic field

– radial by electron beam + B- field

B-field (up to 6 T) compresses e⁻ beam





requirements for charge breeding:

- efficient
- fast

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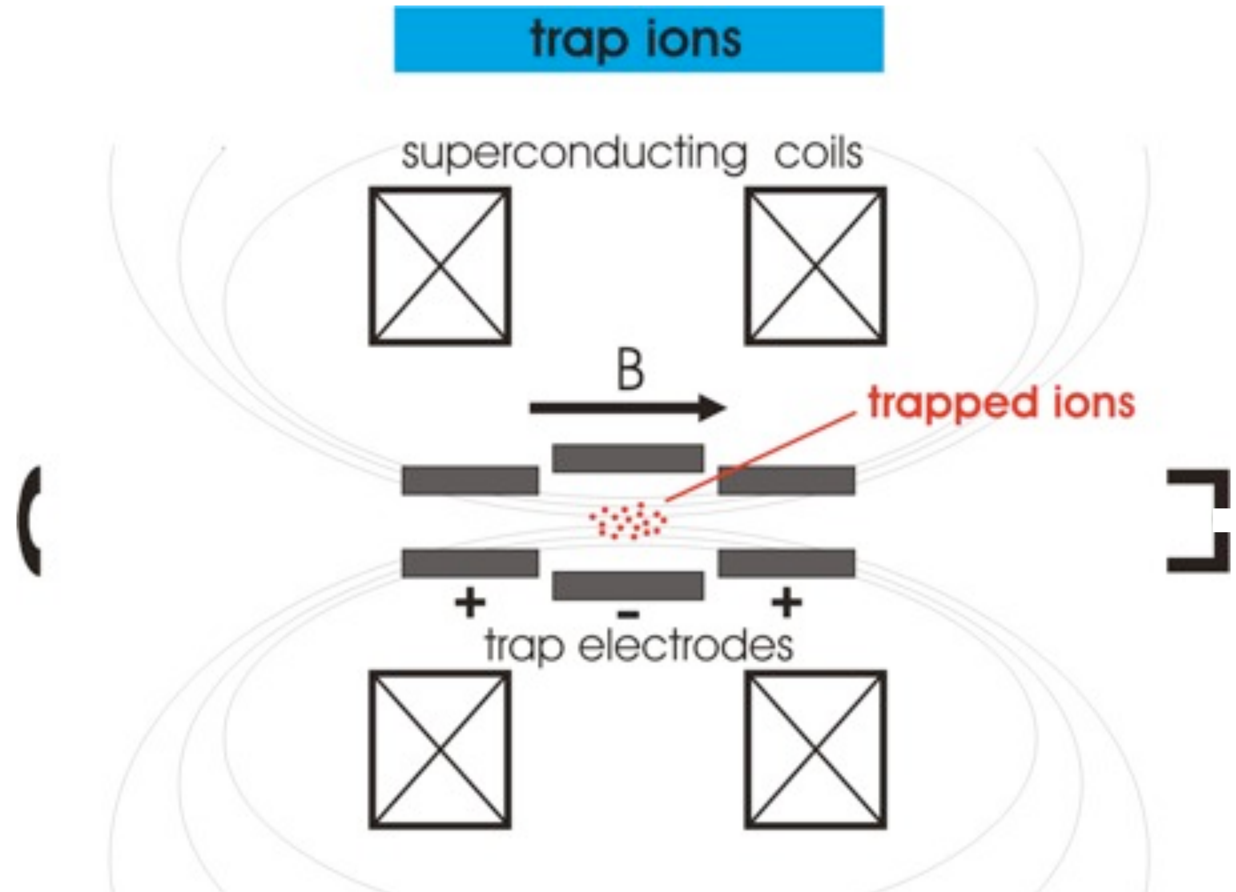

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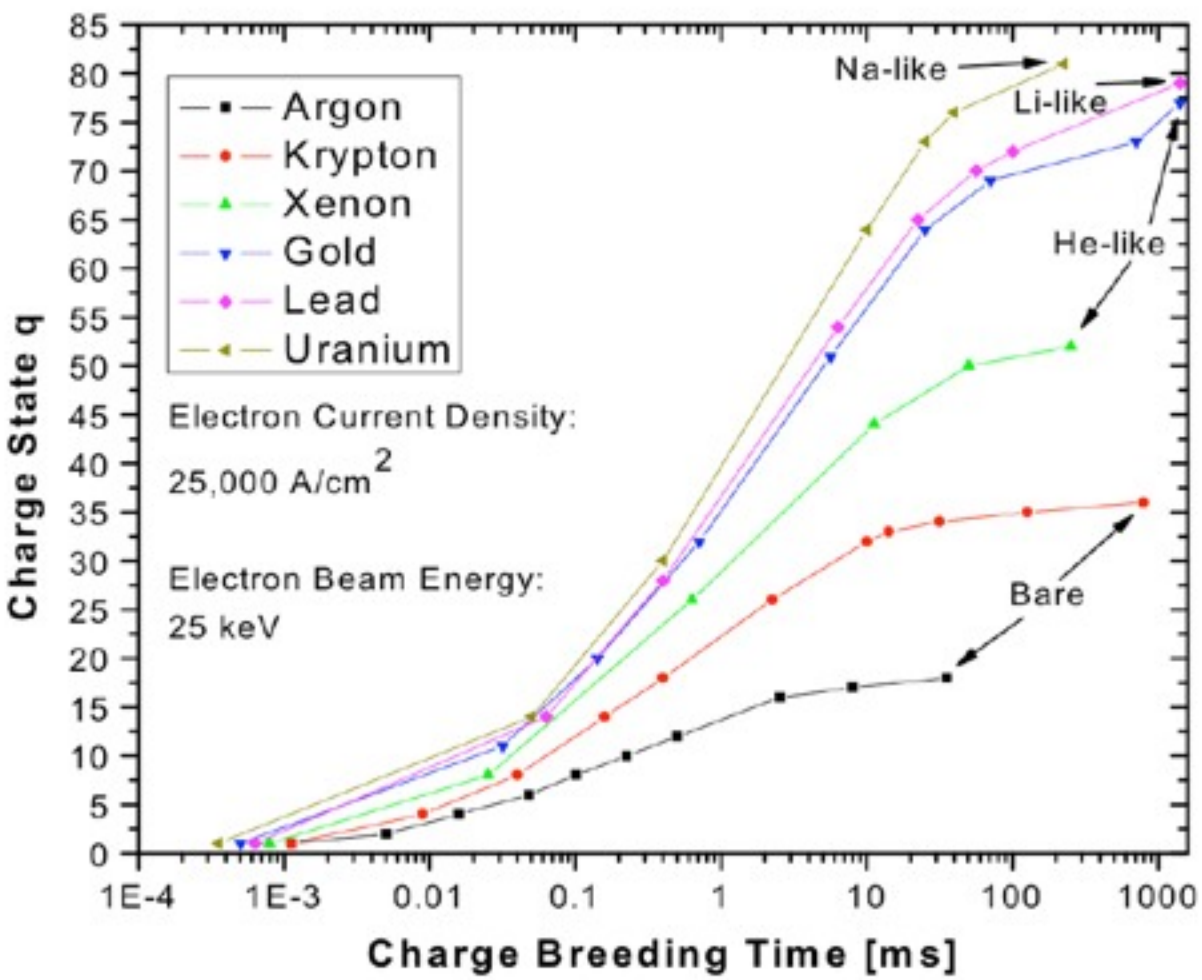

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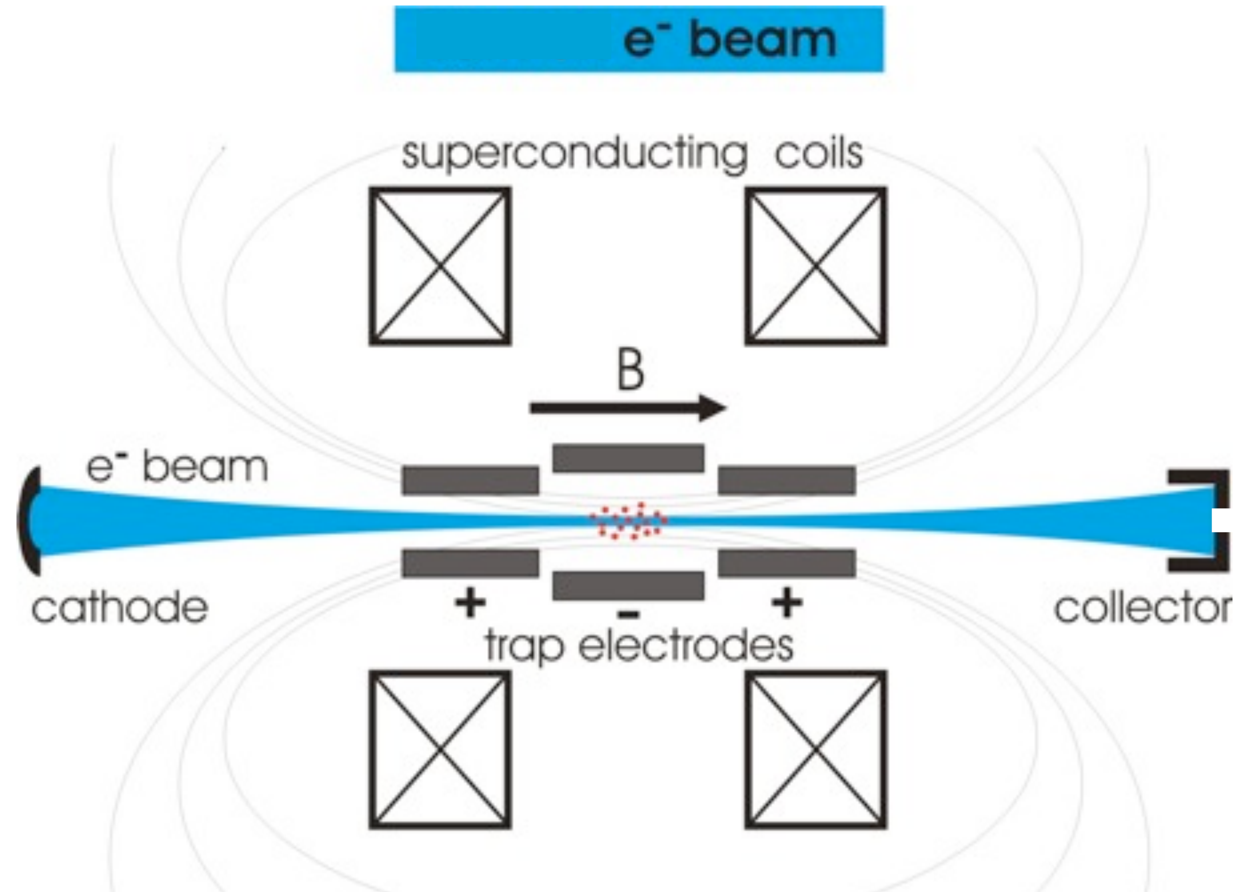

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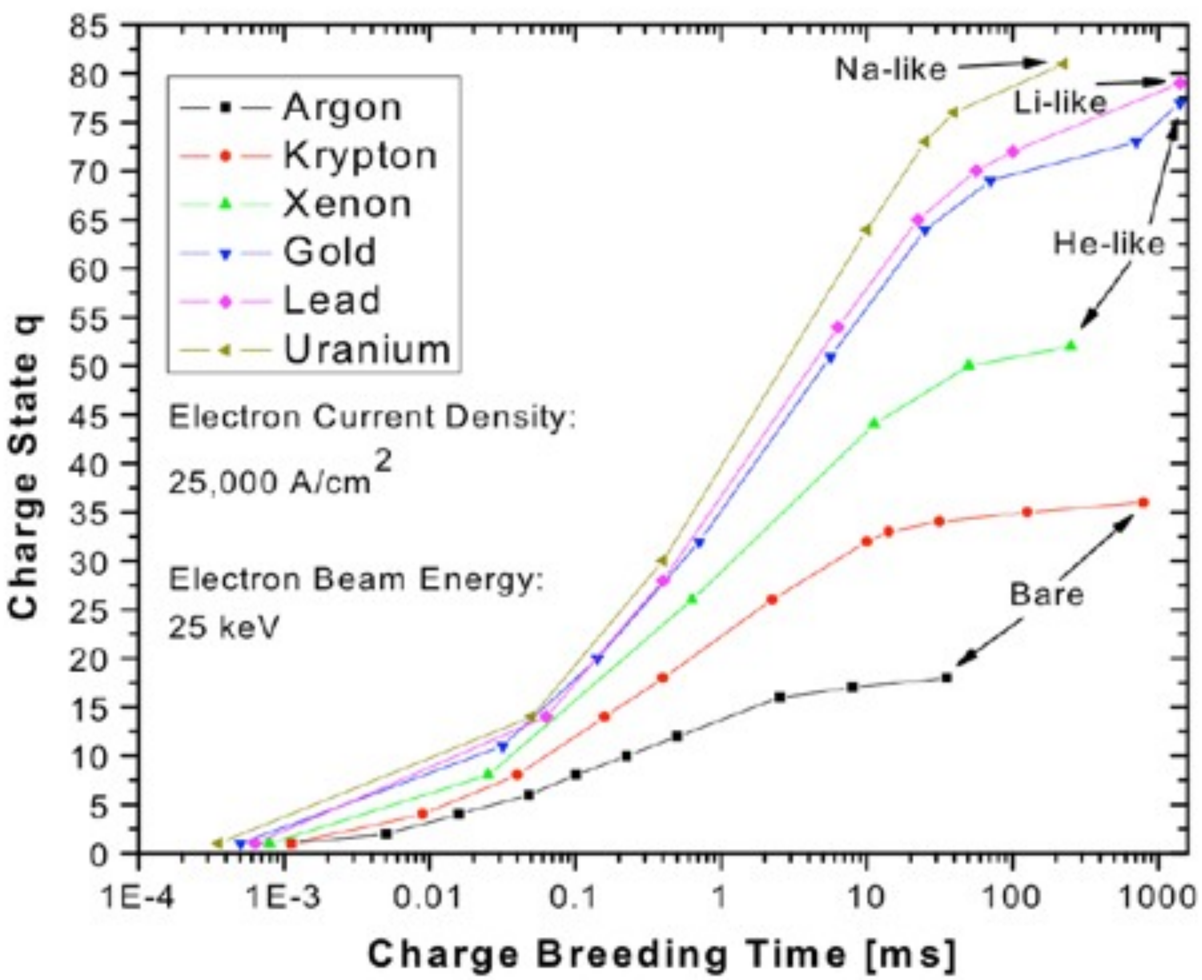

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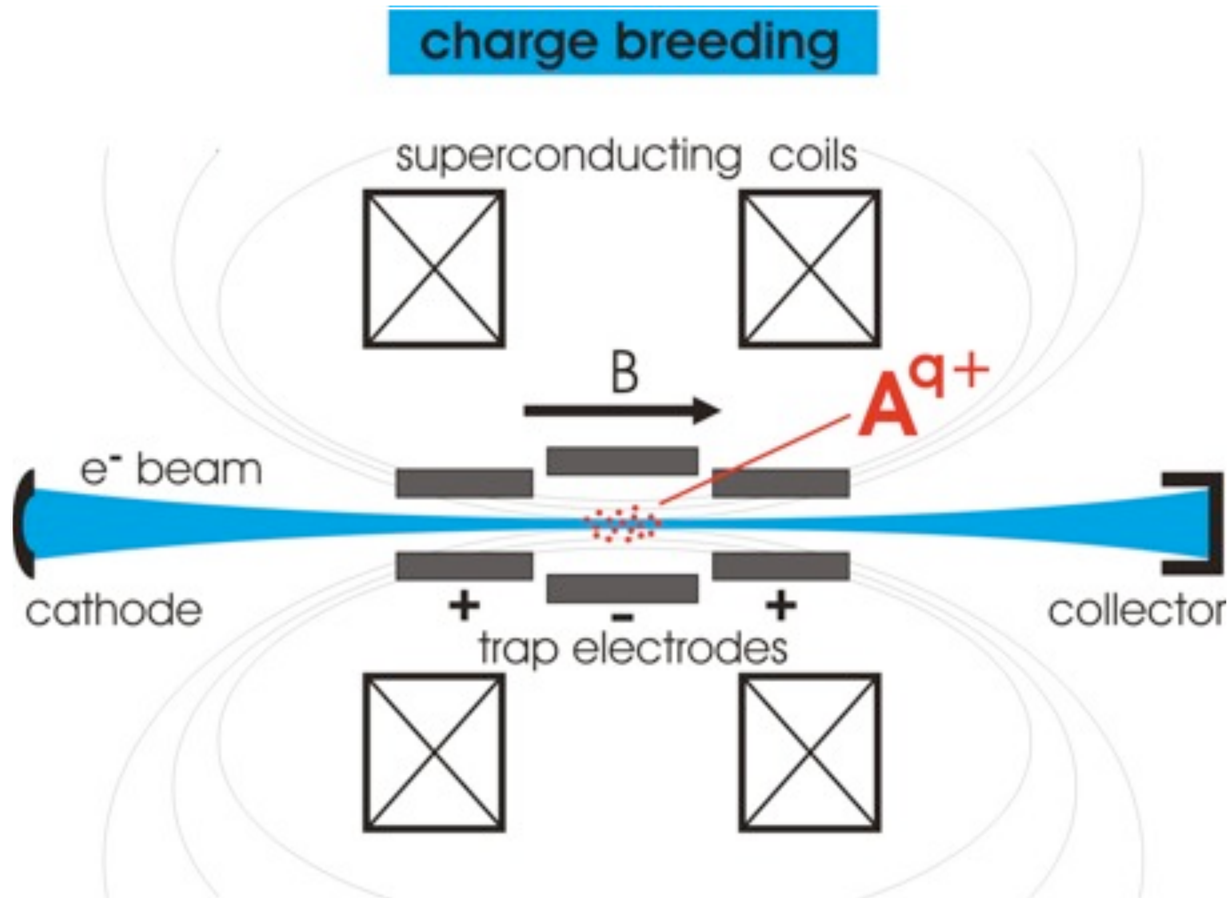

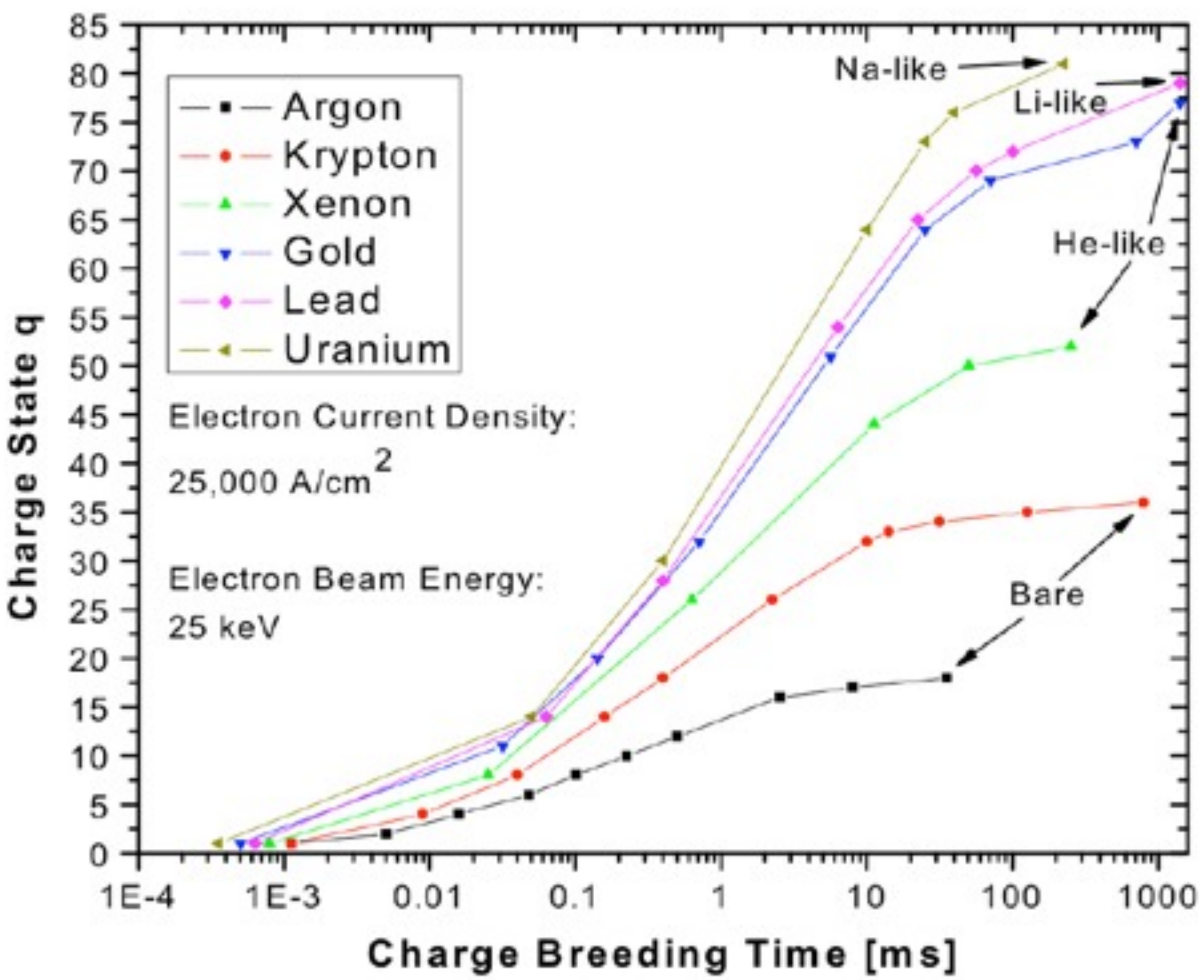

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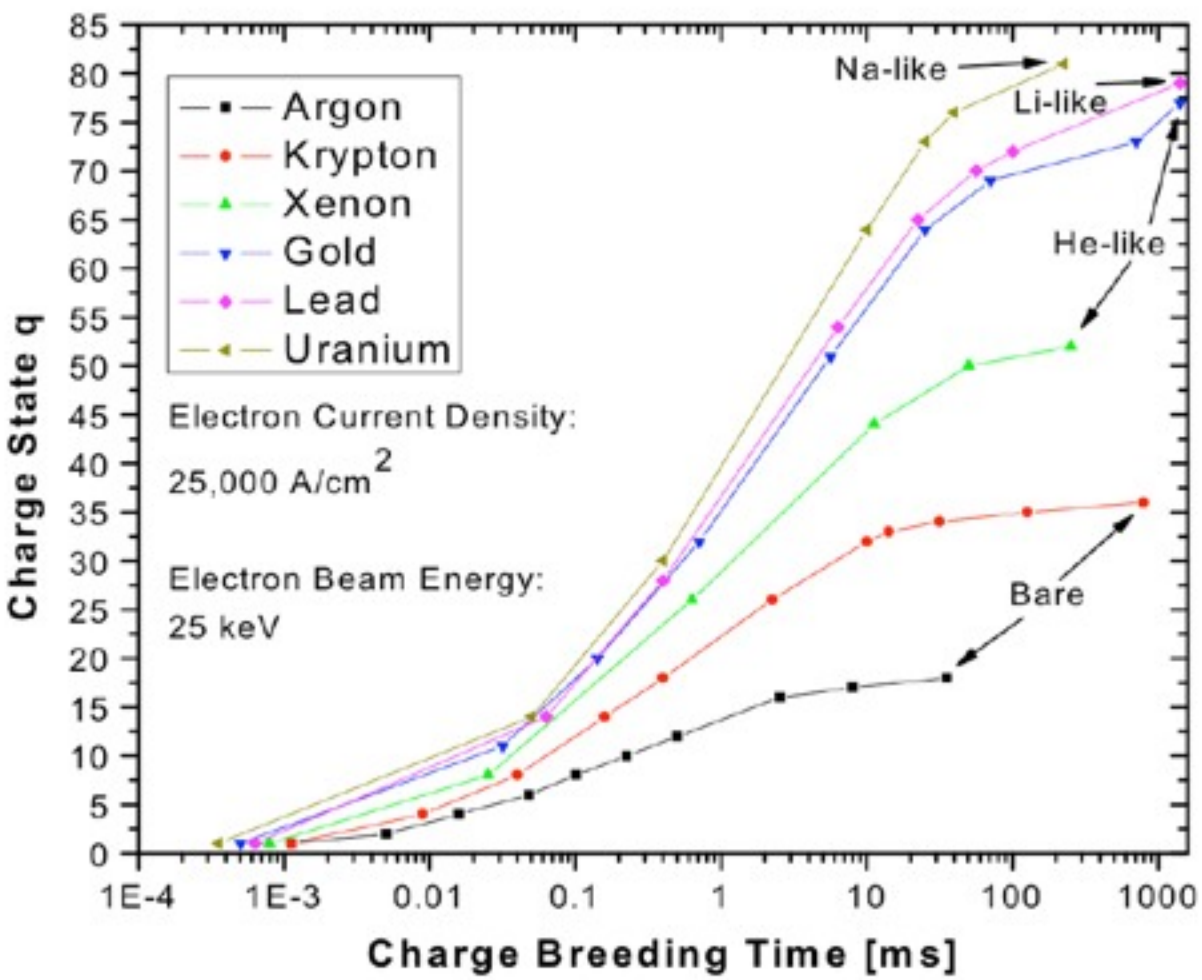

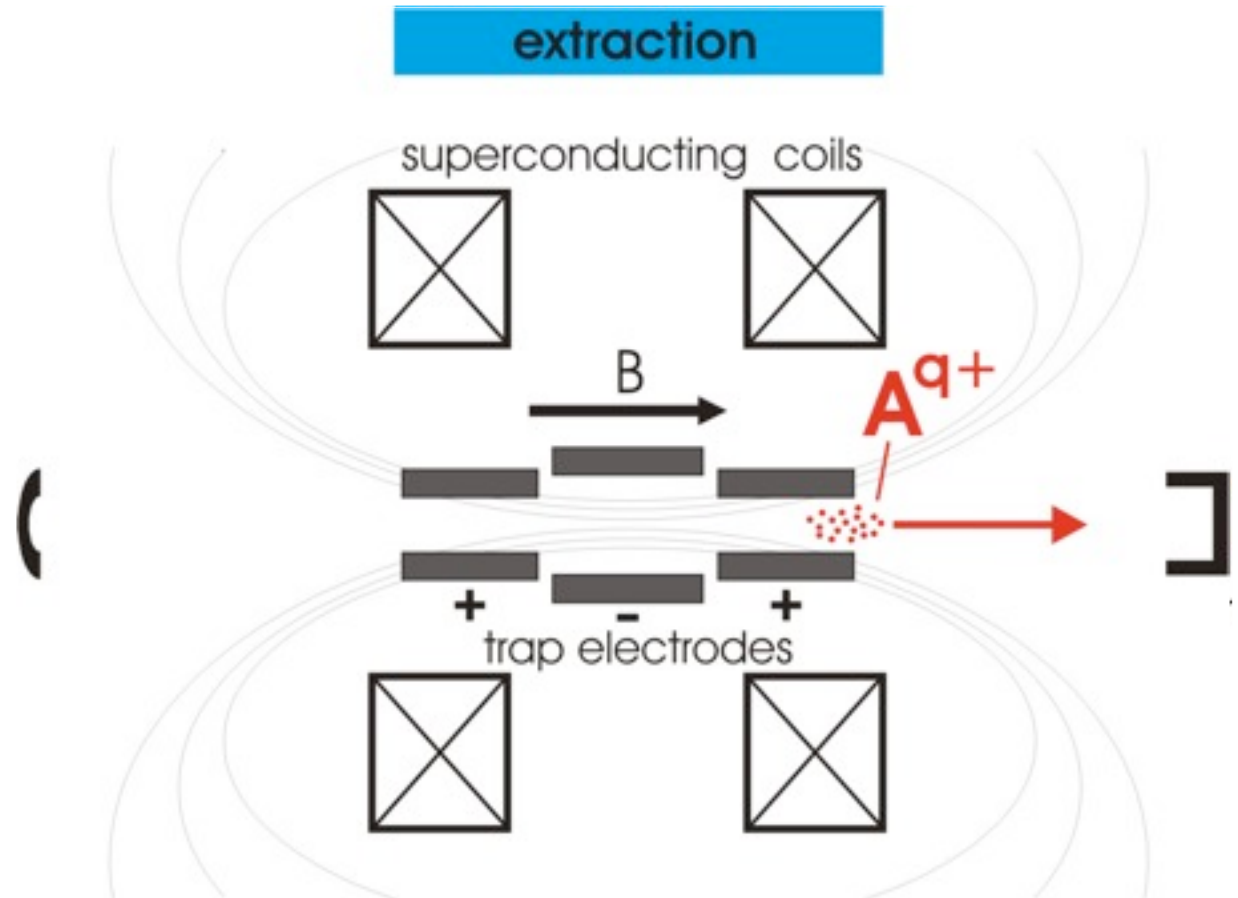

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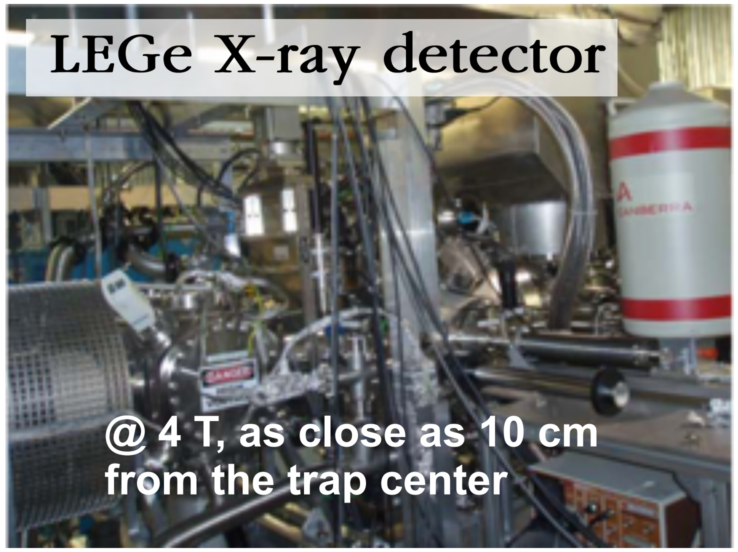
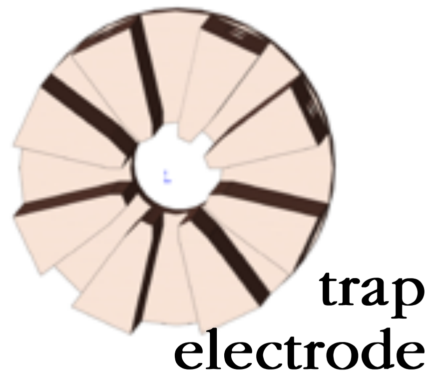
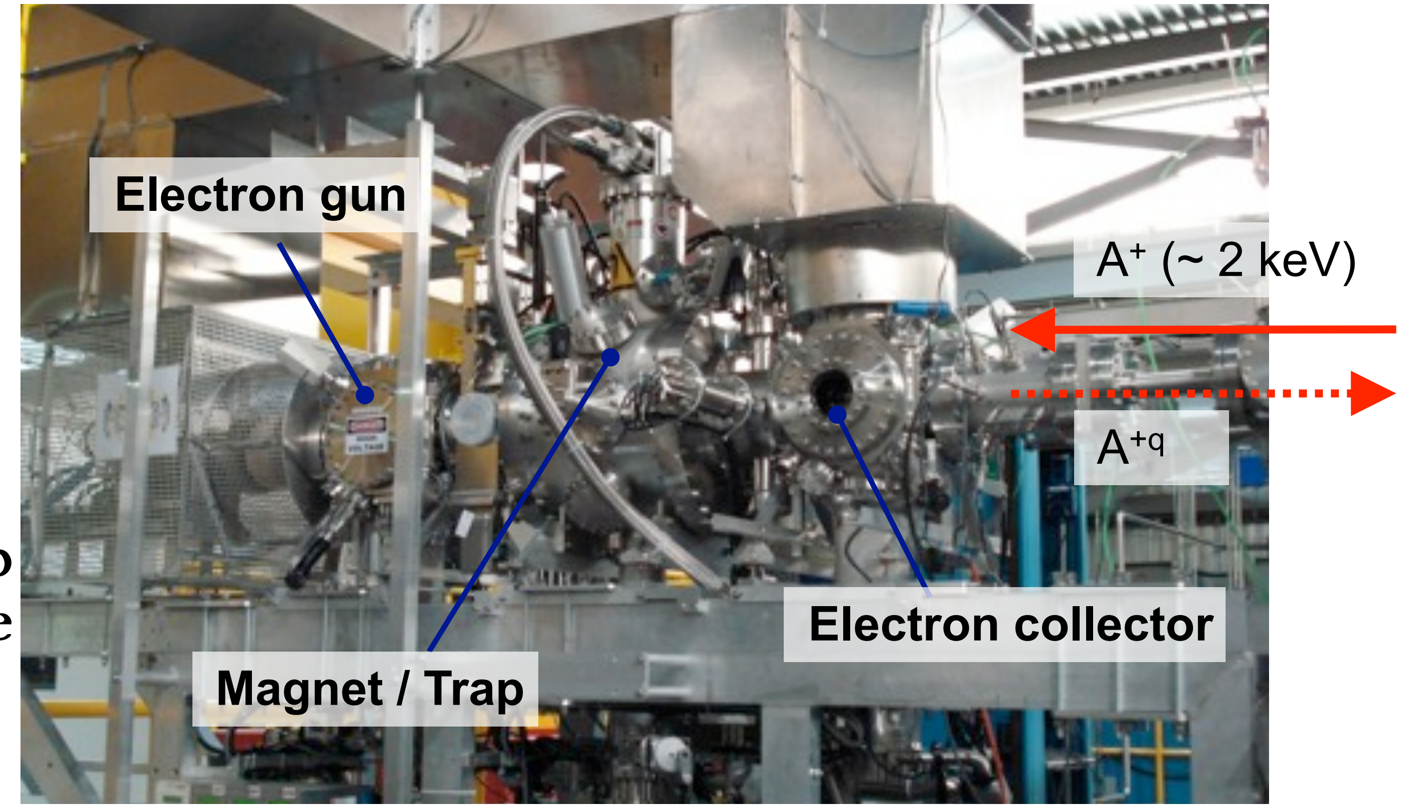
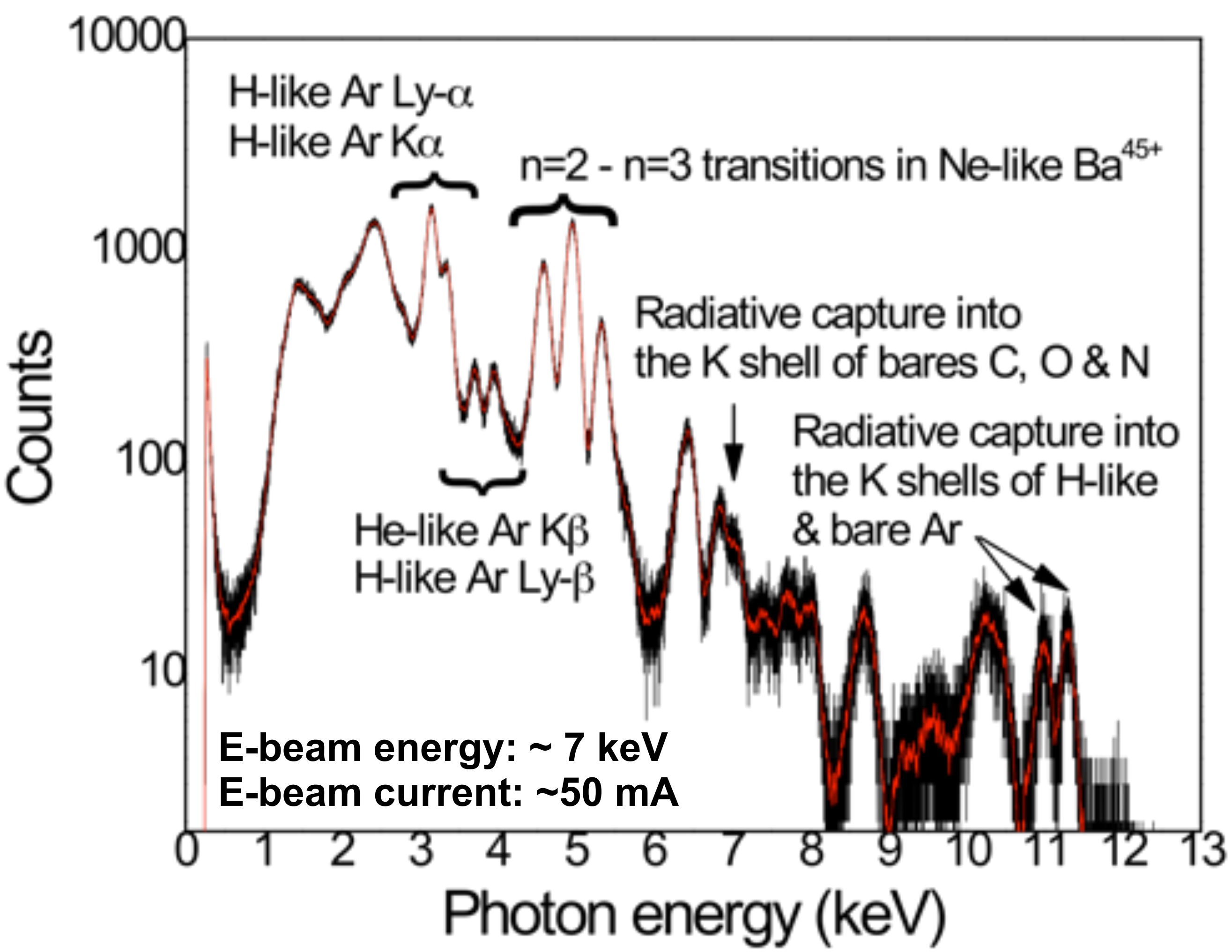
TITAN's EBIT









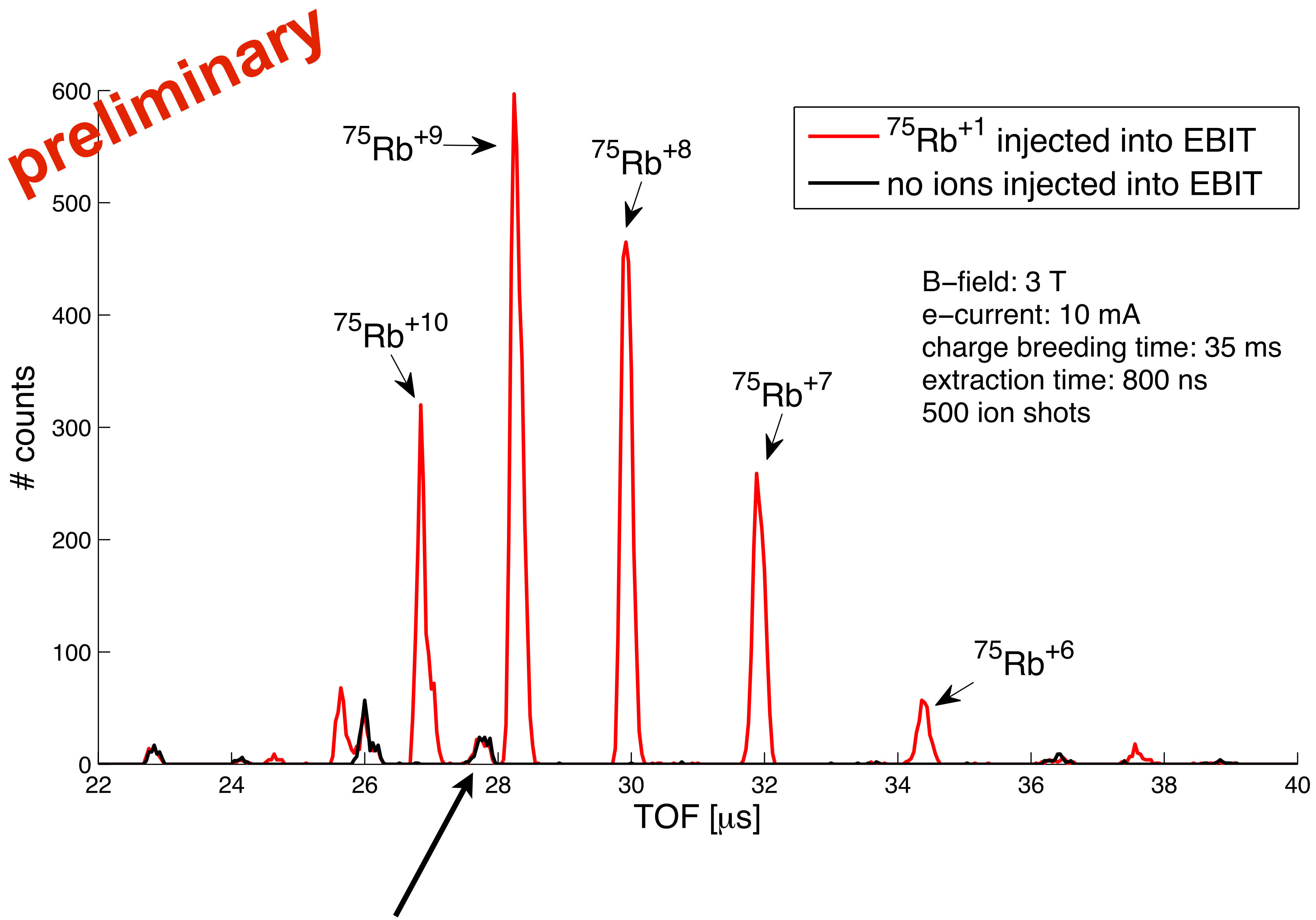
<u>X-ray spectroscopy:</u>

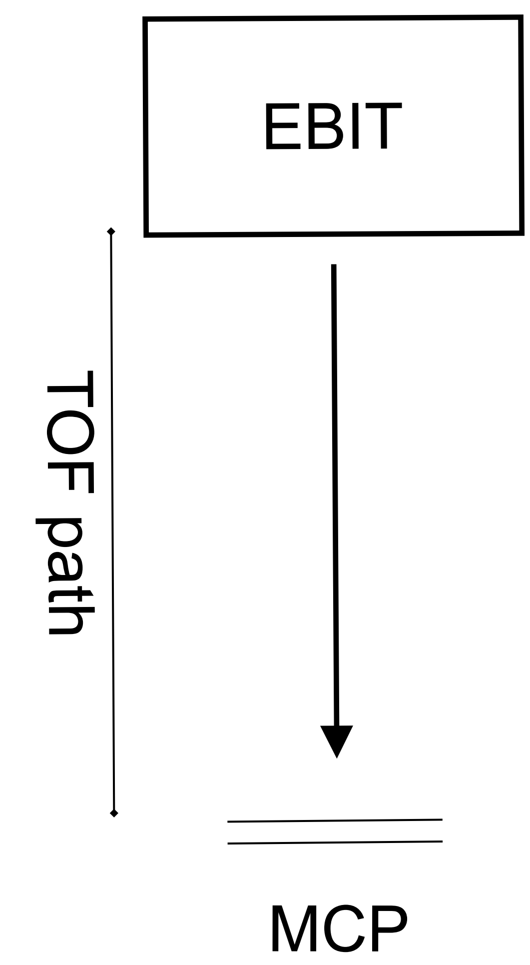
- diagnostics tool for charge breeding
- EC-BR measurement

T. Brunner et al., NIM B 266, 4643 (2008)

S. Ettenauer et al., AIP Conf. Proc. 1182(2009)100

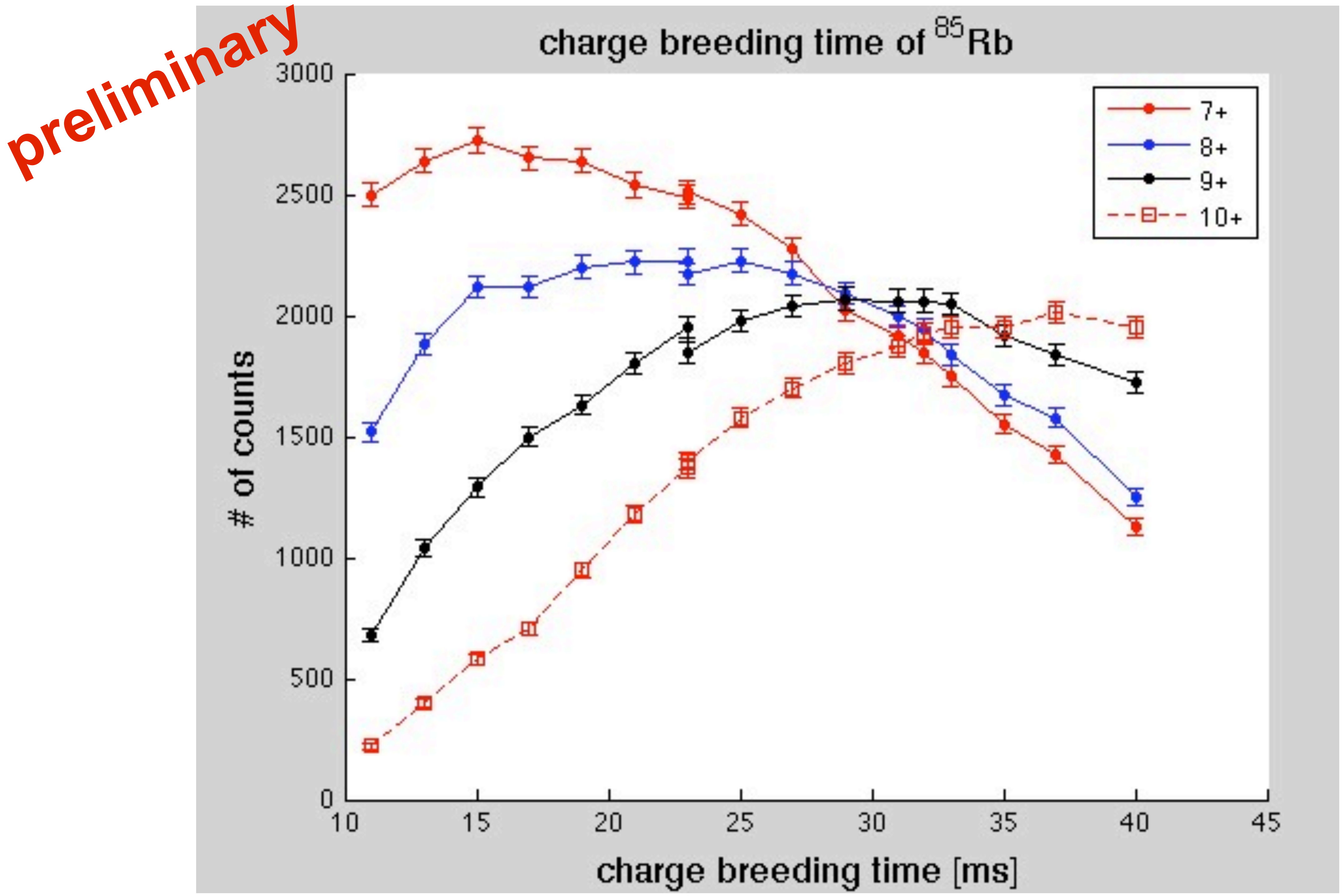
Charge Breeding of ^{75}Rb





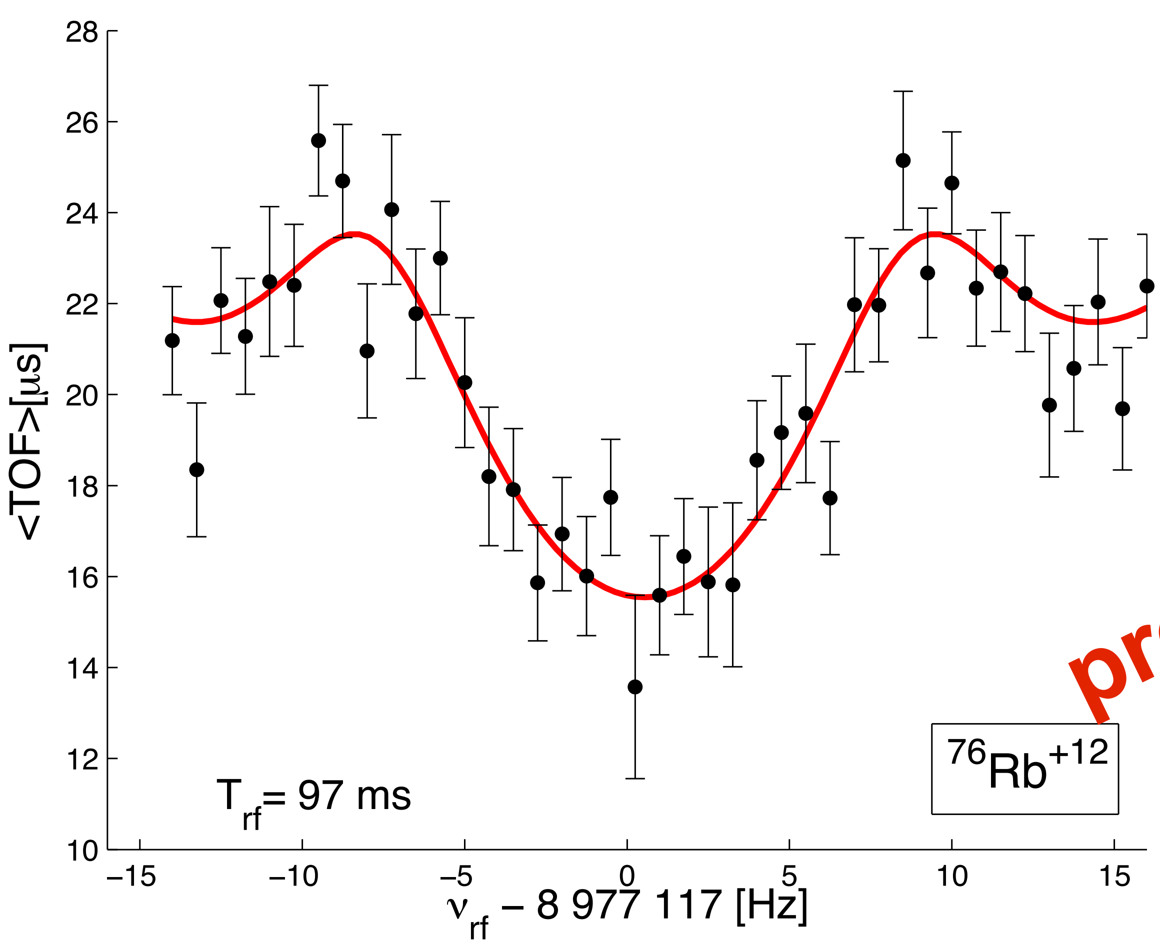
charge bred residual gas

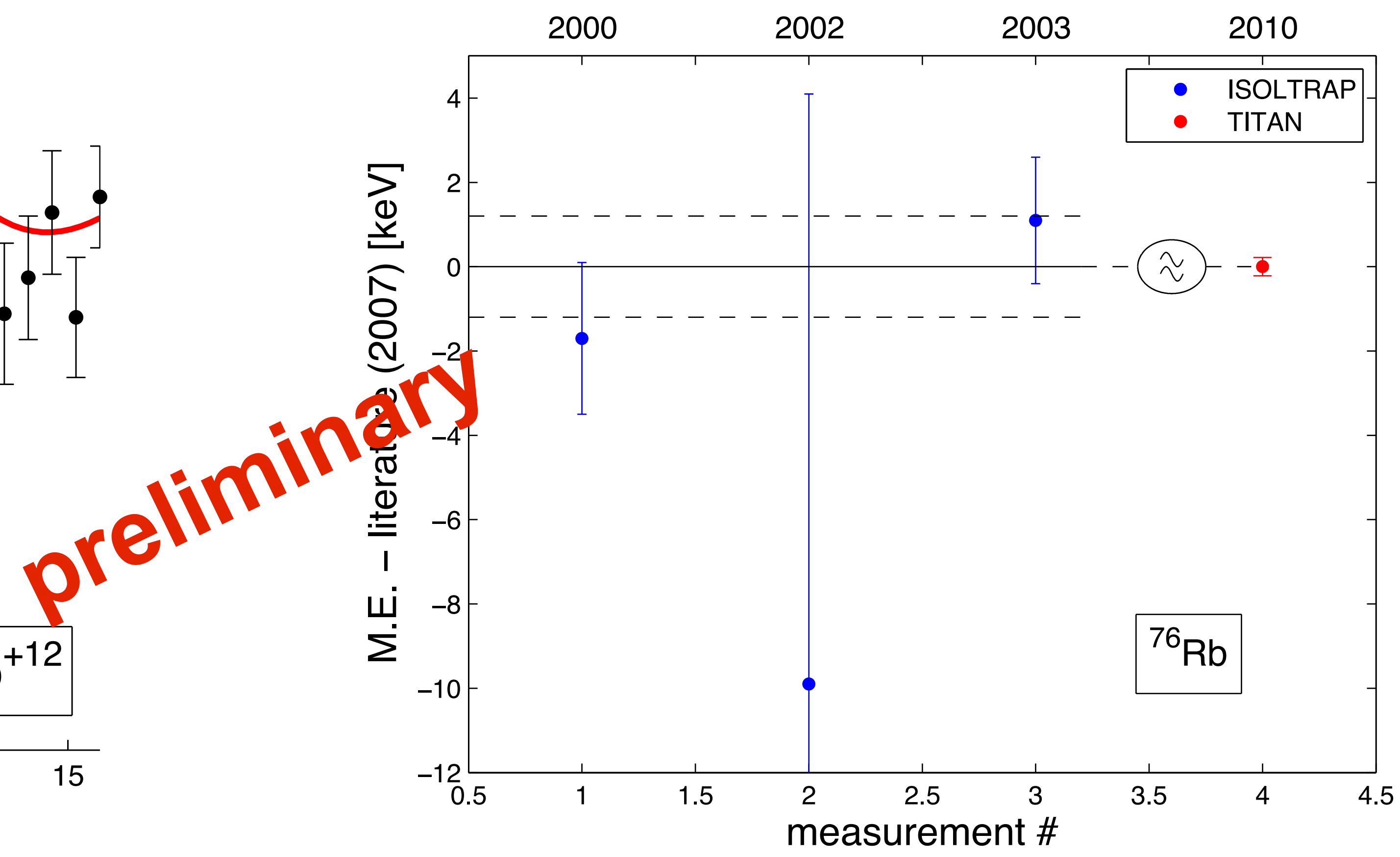
charge state VS breeding time



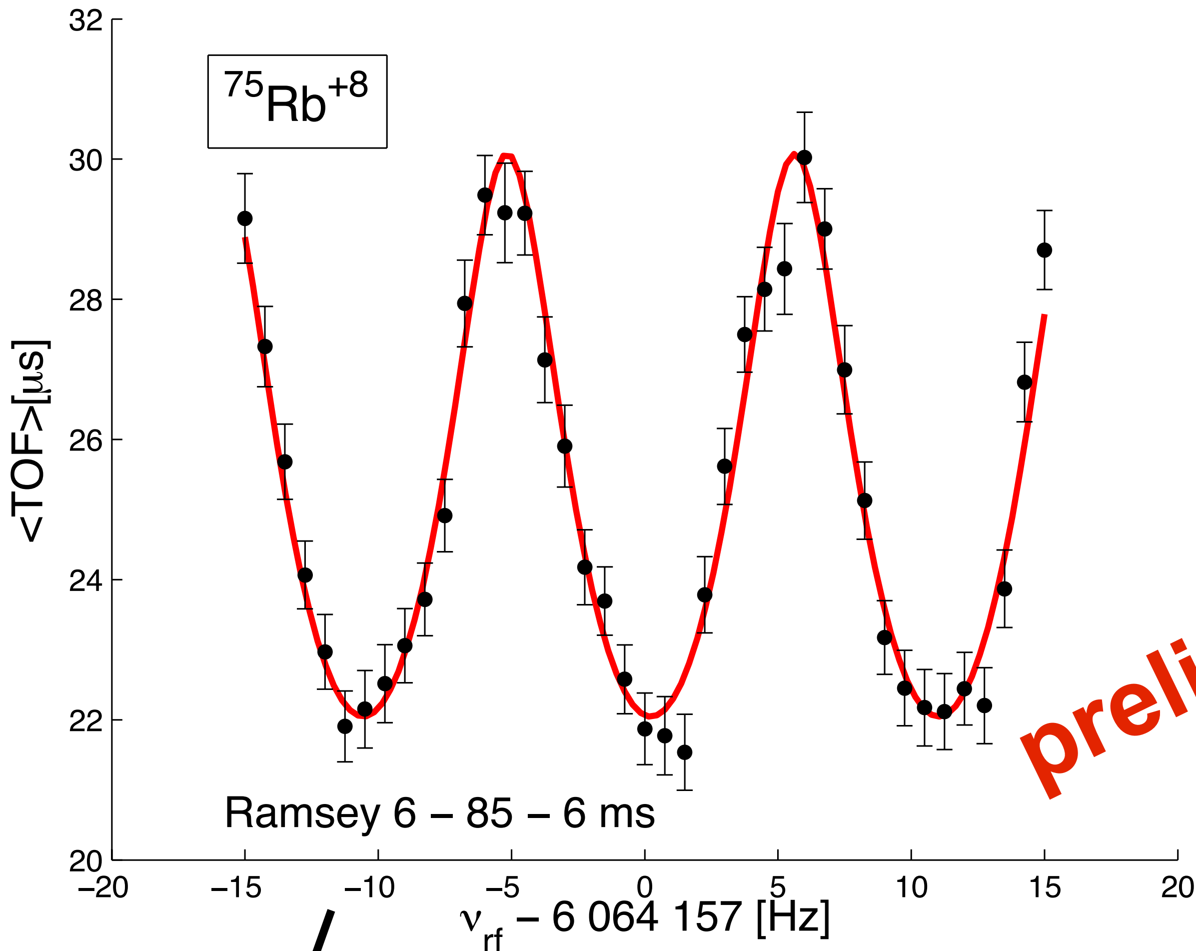
^{76}Rb

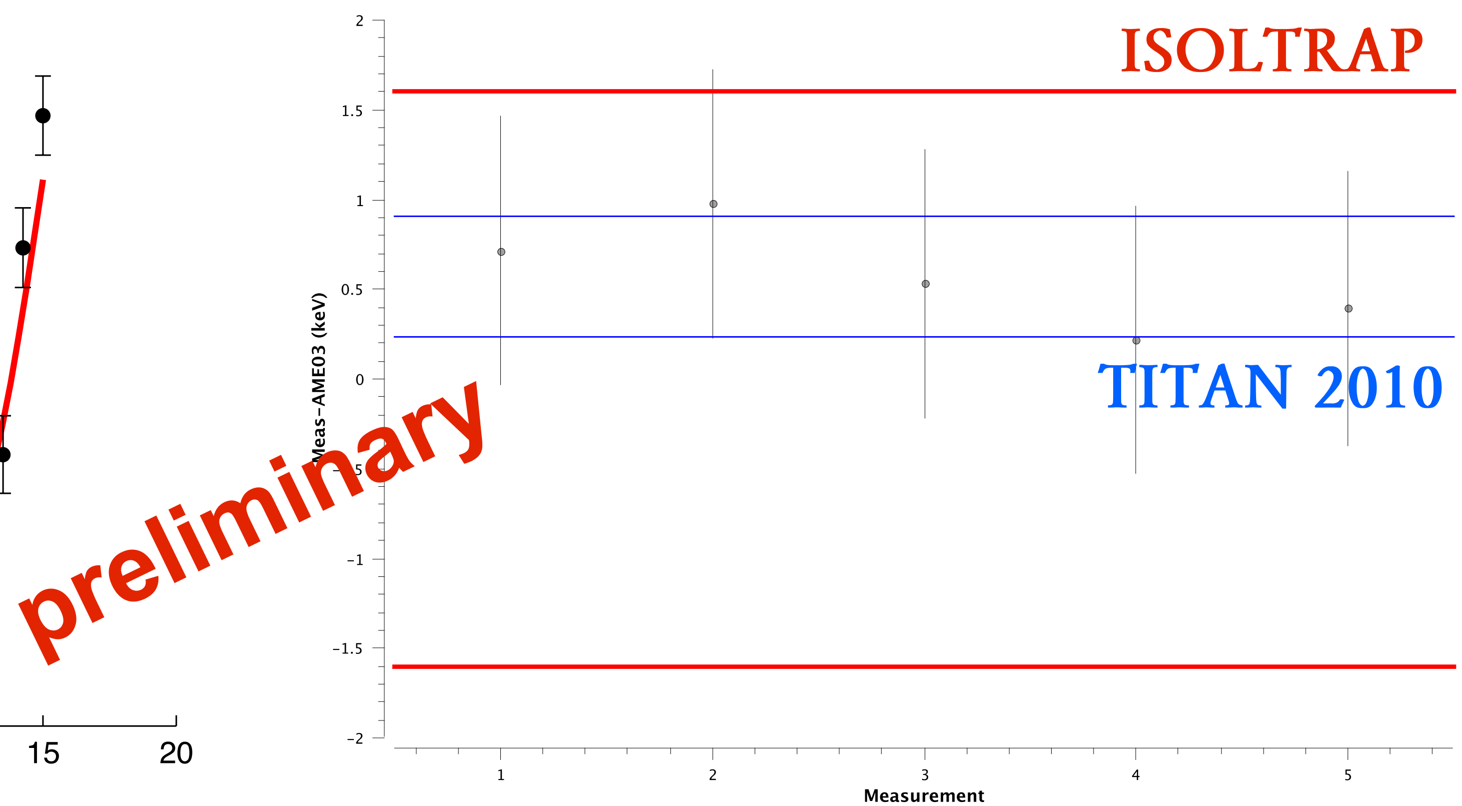
- very first mass measurement of radioactive HCIs
- stat. uncertainty of < 300 eV achieved in a few hours





Ramsey excitation & ^{75}Rb





Ramsey excitation:

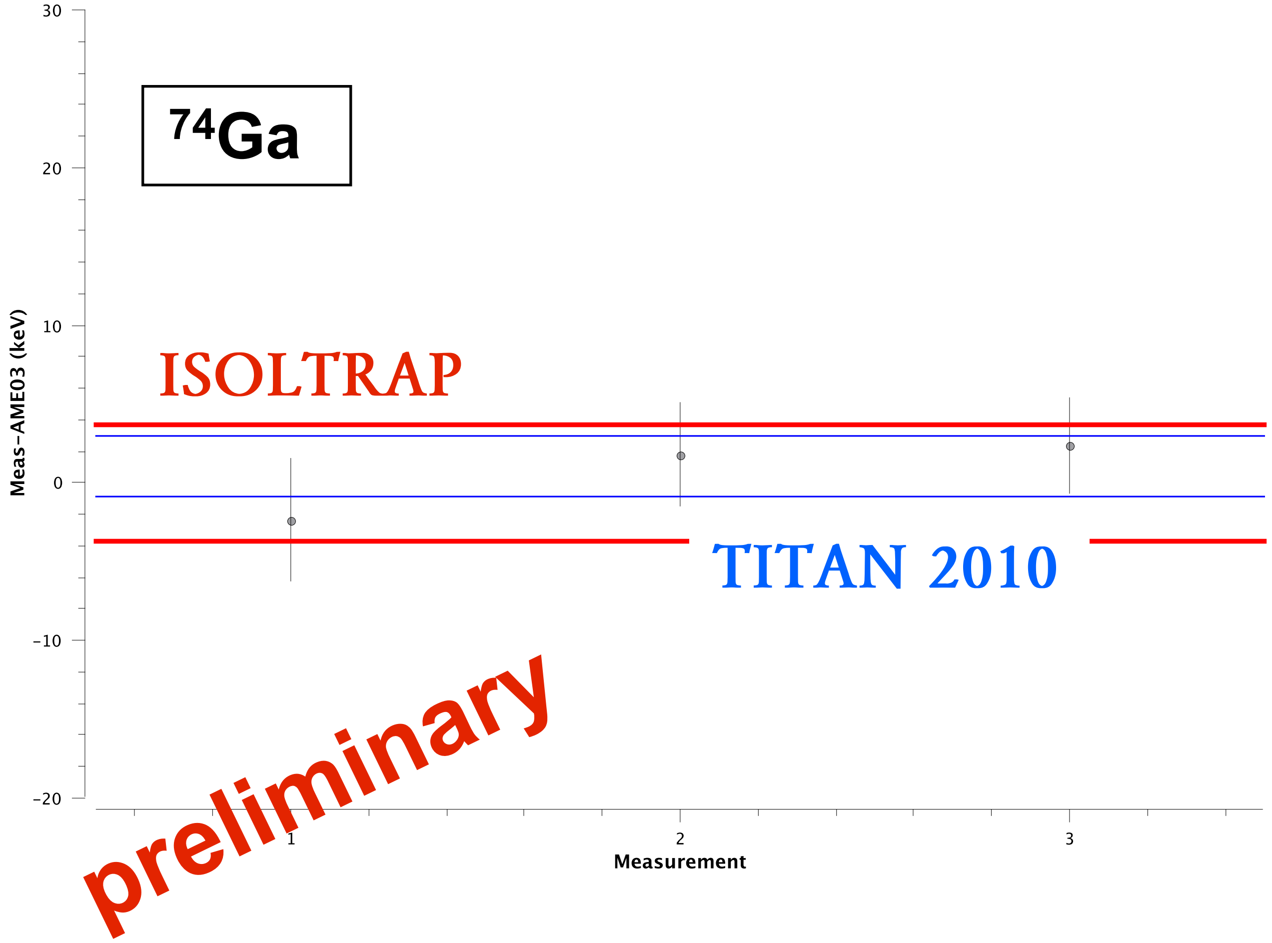
- 2 excitation pulses
- improves precision by a factor 2 - 3

HCI

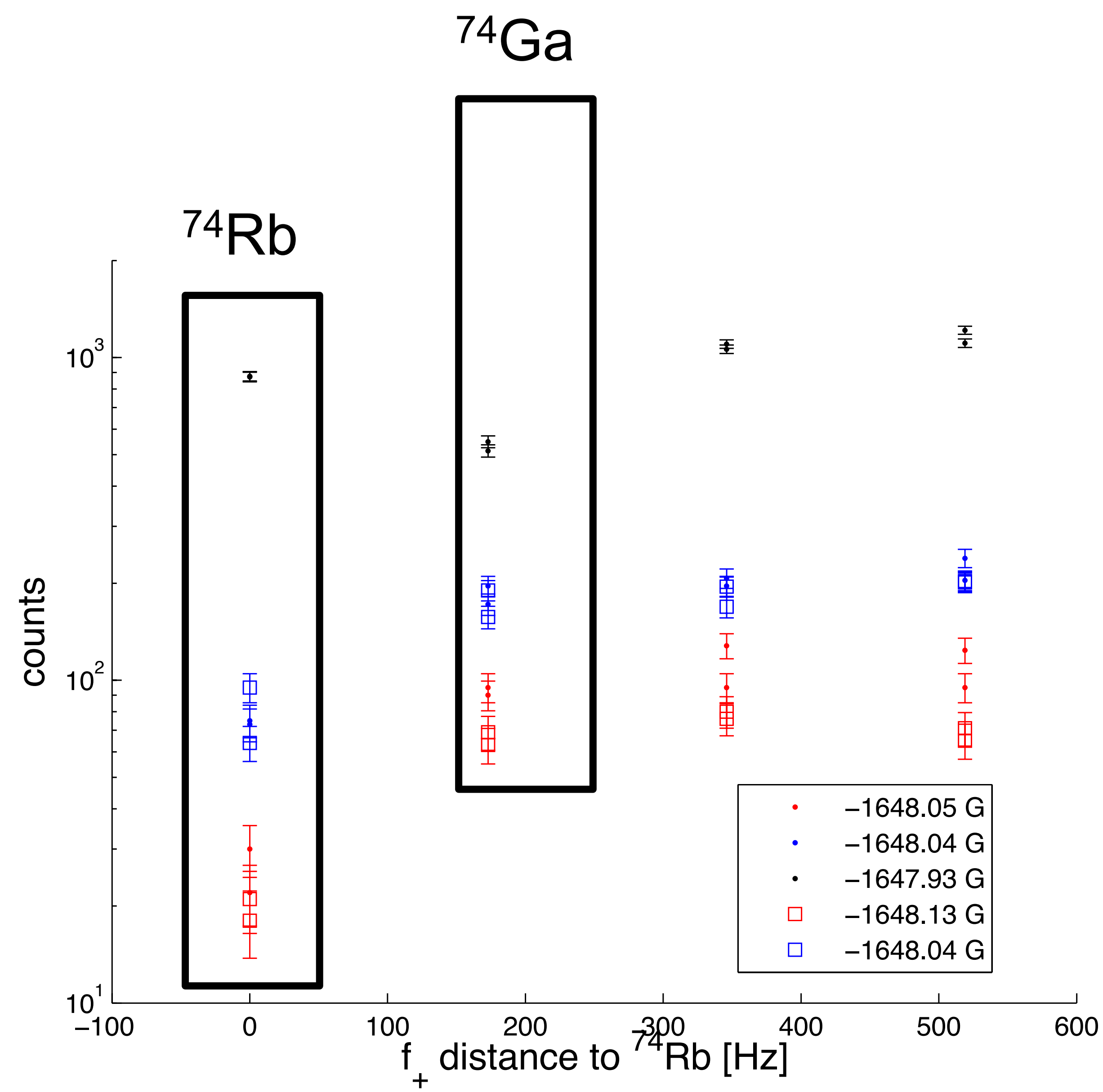
during this beamtime demonstrated up to q=12+

compared to conventional method: improvement by factor >24

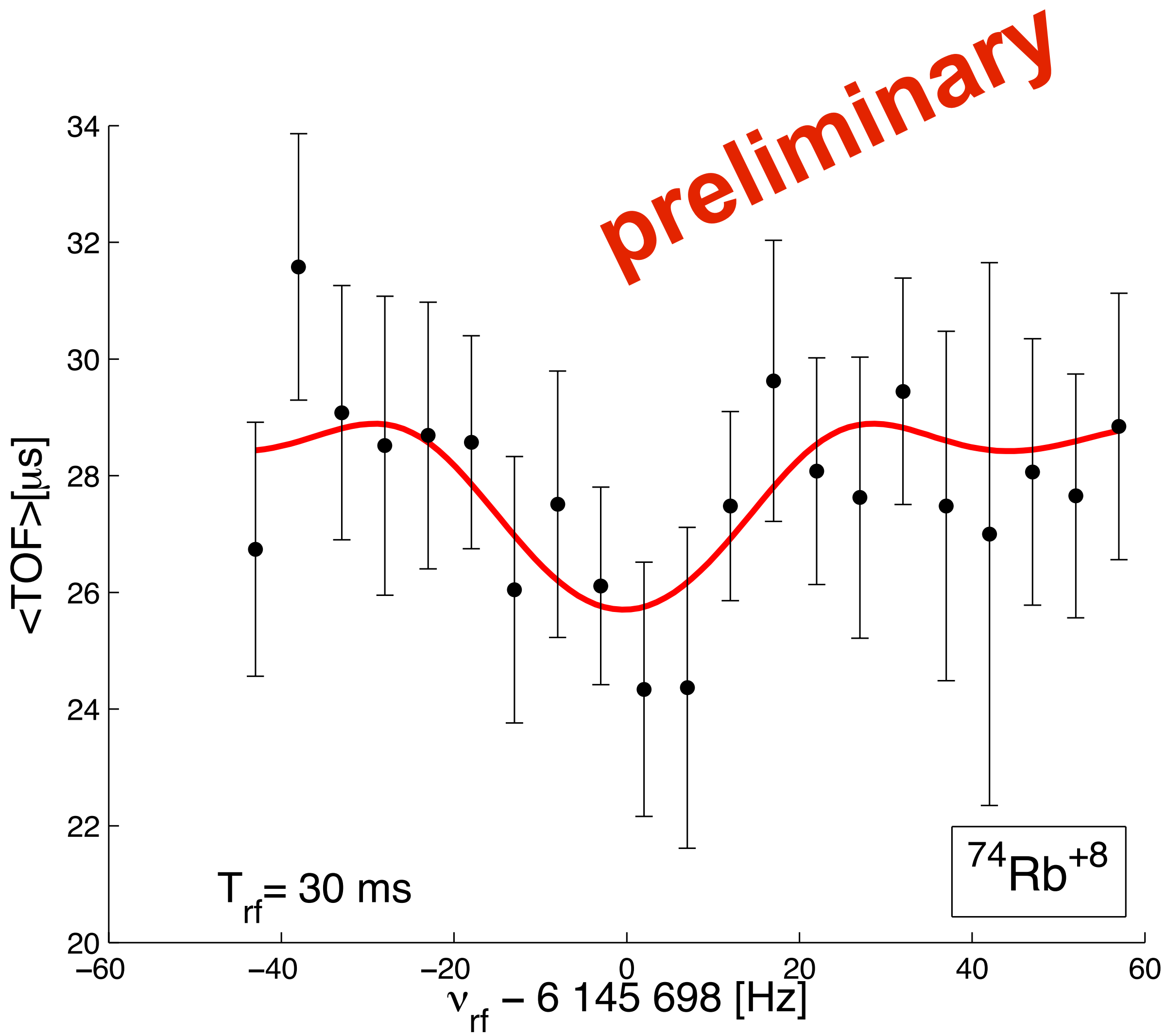
A=74: ^{74}Ga & ^{74}Rb

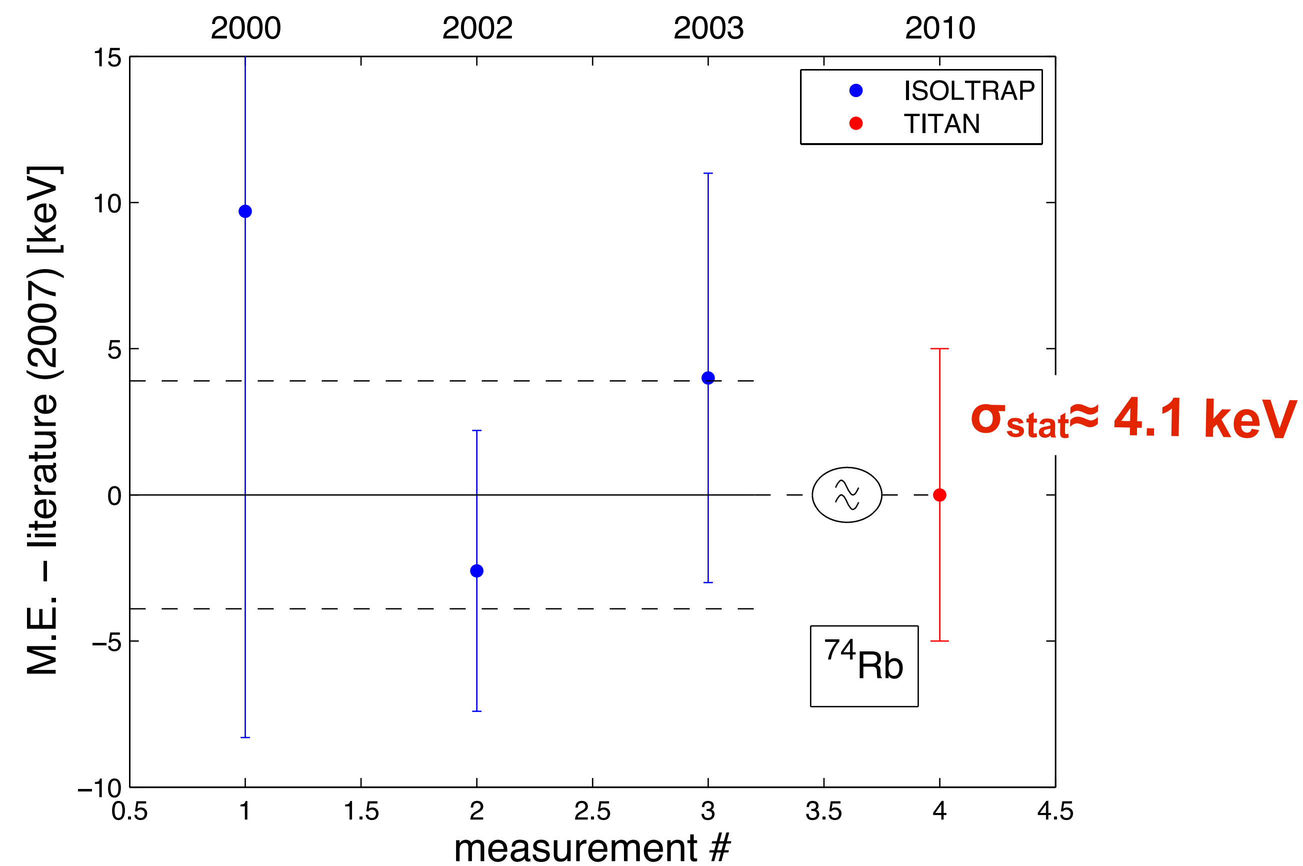


Dipole Cleaning & Separator Tuning



Results ^{74}Rb





<u>^{74}Rb:</u>

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

<u>BUT</u>

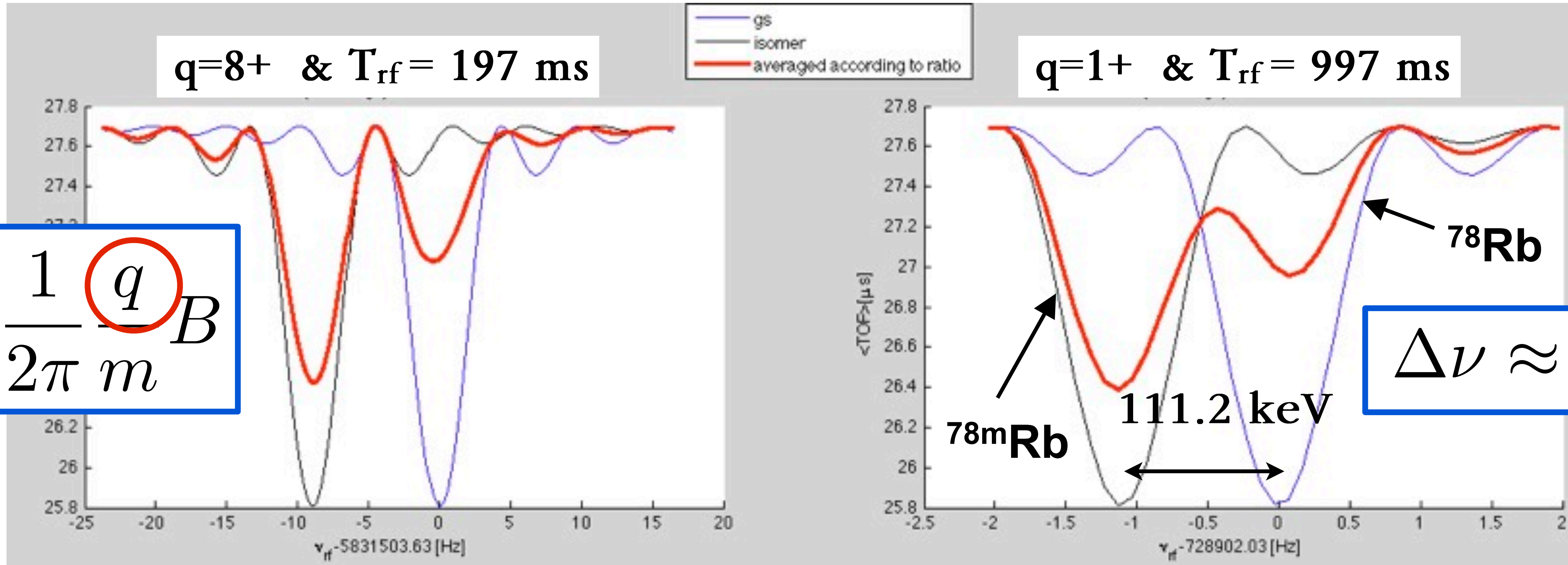
- data of < 20 hours
- power outage during ^{74}Rb => reconditioning of EBIT => lower eff.

=> "easy" improvement next time

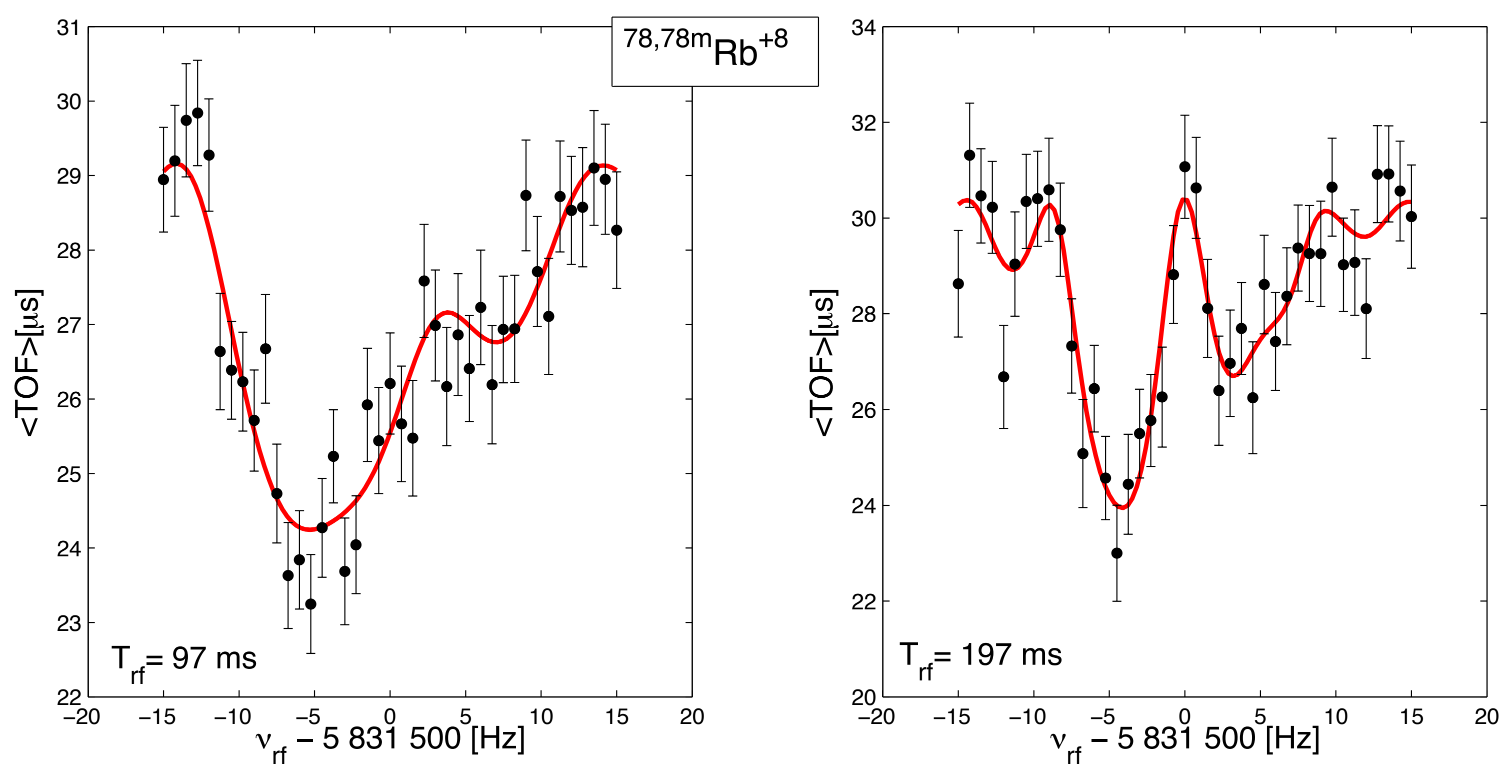
HCI and Isomers

Calculation:

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



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



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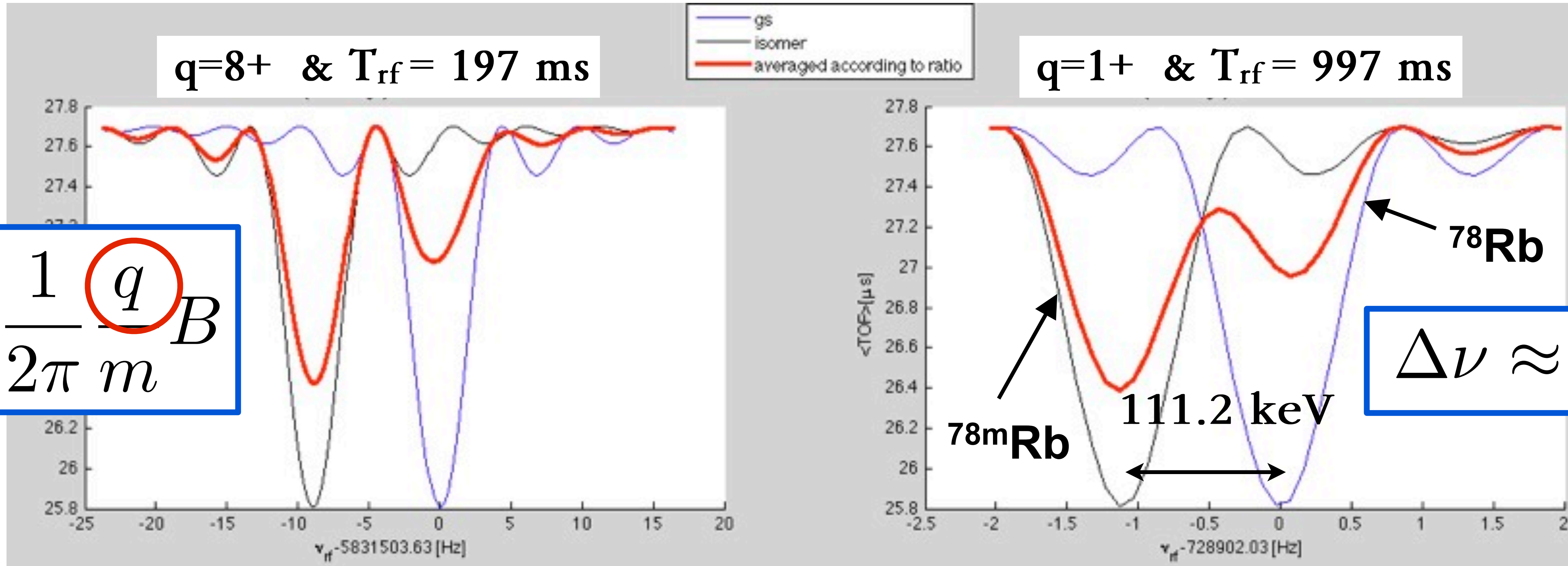

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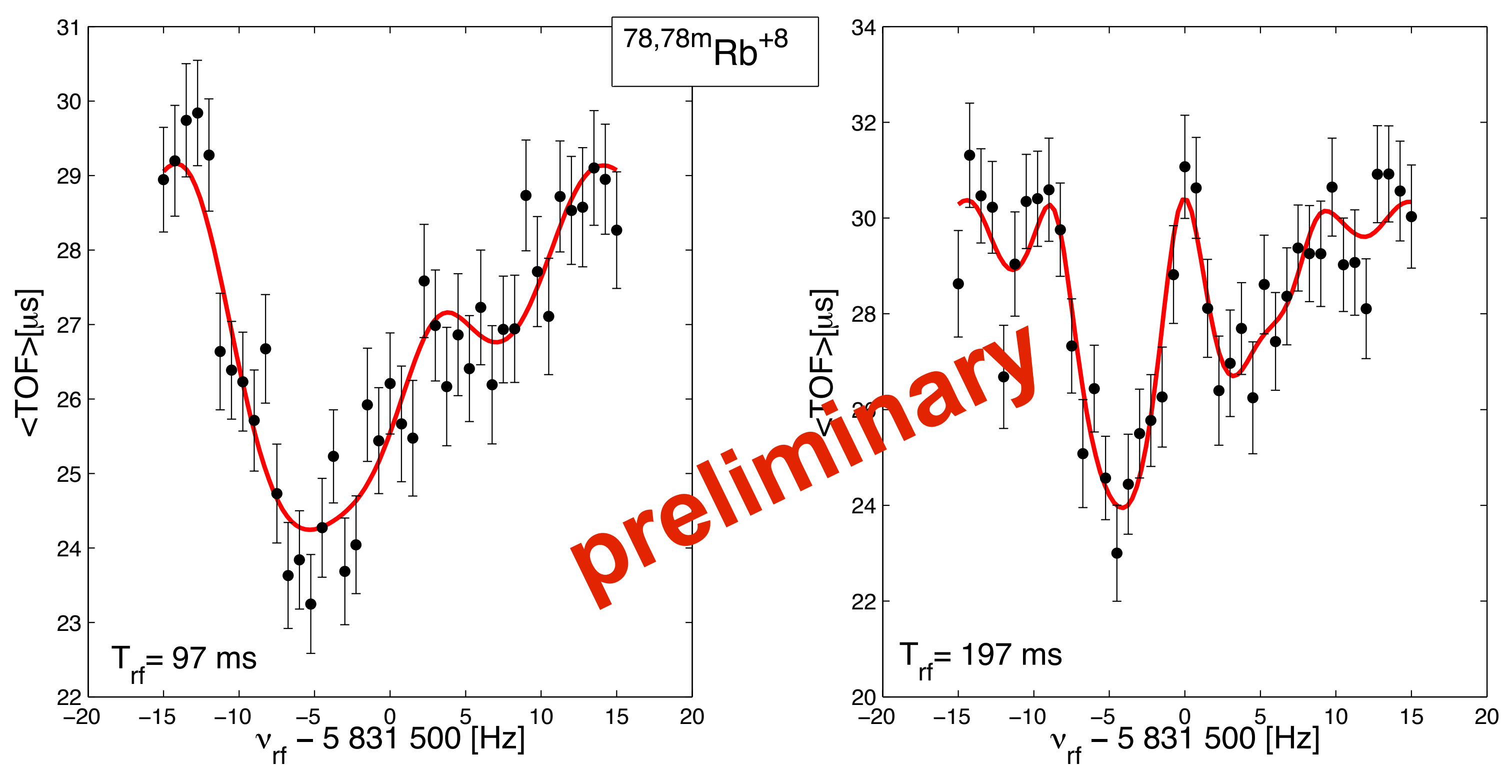
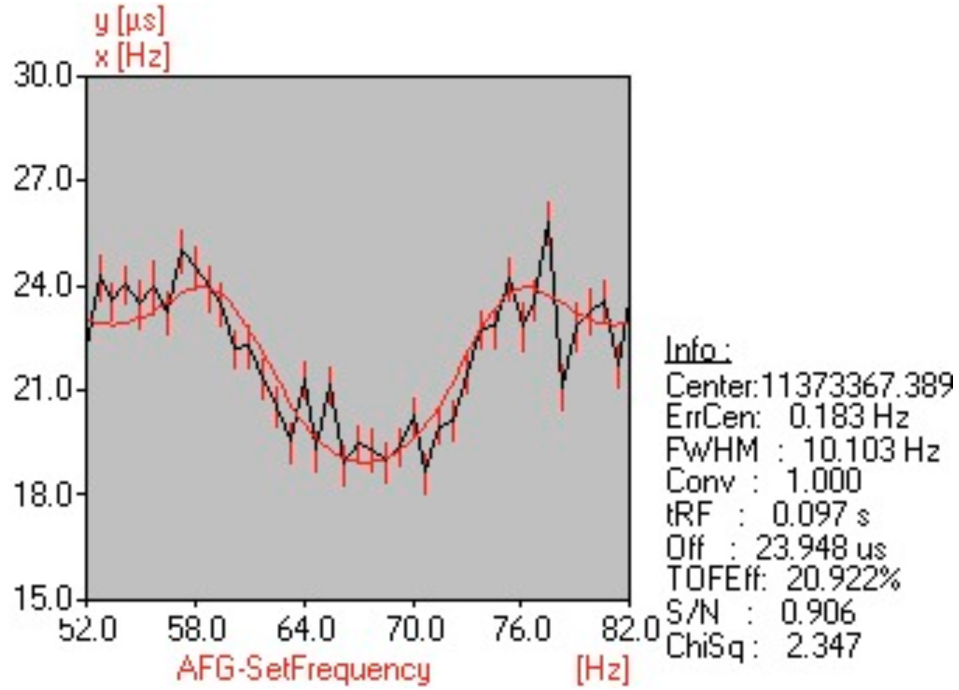
Measurement:



Implications & Conclusions

- with yields > 2000 ions/s HCI feasible
- precision improved by factor q
- **<u>OR</u>** same precision q times faster
- resolving power => close lying isomers
- measured mass of ^{78,76,75,74}Rb and ^{74}Ga
- precision of ^{74}Rb possibly sufficient already to have science impact



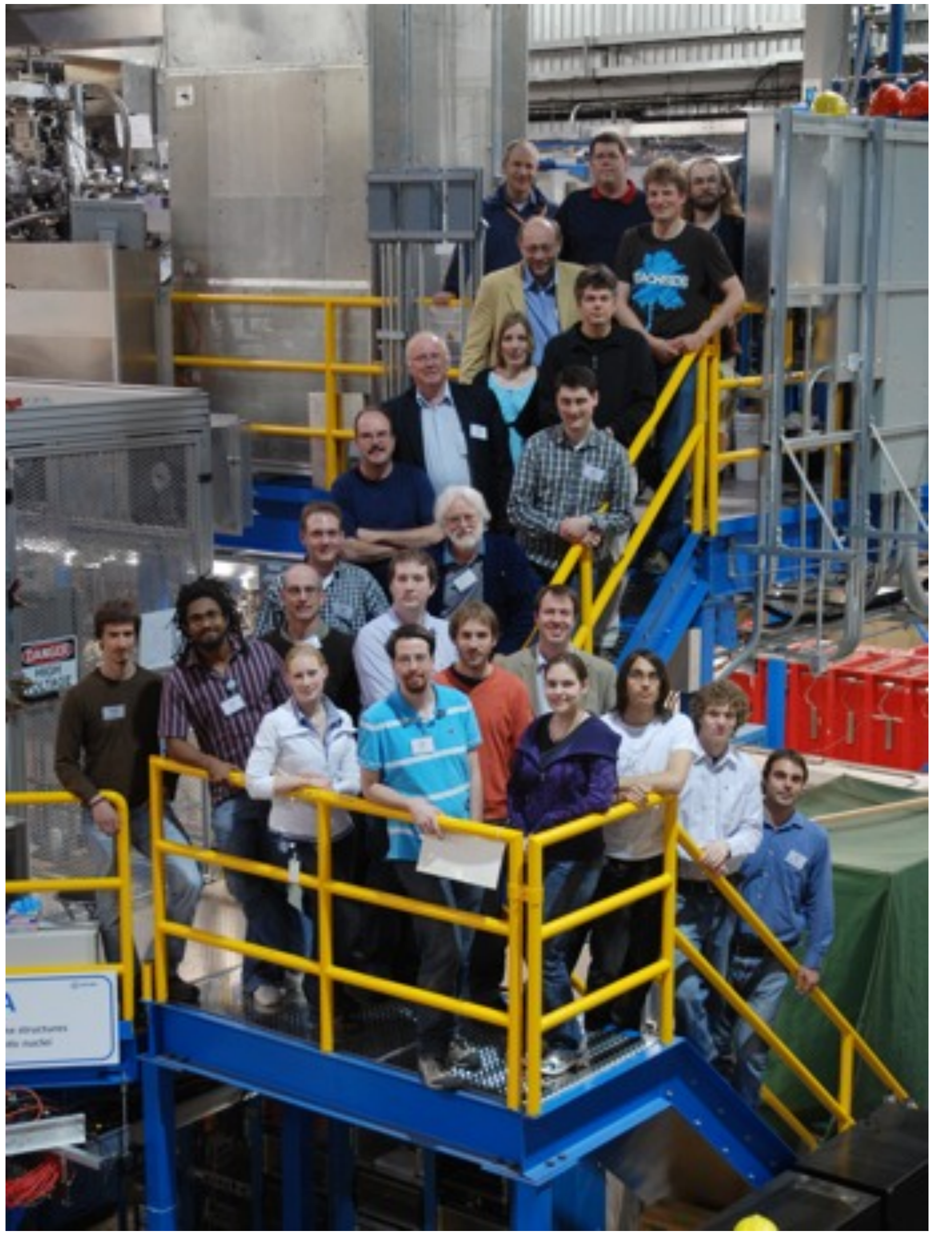
^{85}Rb+^{17}
e-beam: 14 mA
breeding time: 197 ms
T_{rf} = 97 ms

TRIUMF ISAC

TITAN collaboration

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

- TRIUMF Staff: Pierre Bricault, Ames Friedhelm, Jens Lassen, Marik Dombsky, Peter Kunz, Rolf Kietel, Don Dale, Hubert Hui, Kevin Langton, Mike McDonald, Raymond Dubé, Tim Stanford, Stuart Austin, Zlatko Bjelic, Daniel Rowbotham, Daryl Bishop



And the rest of the TITAN collaboration....

U. of Manitoba
McGill U.
Muenster U.,
Max Plank Inst. of Heidelberg
GANIL
CNRS-CSNSM
U. of Windsor
Colorado School of Mines
TRIUMF
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