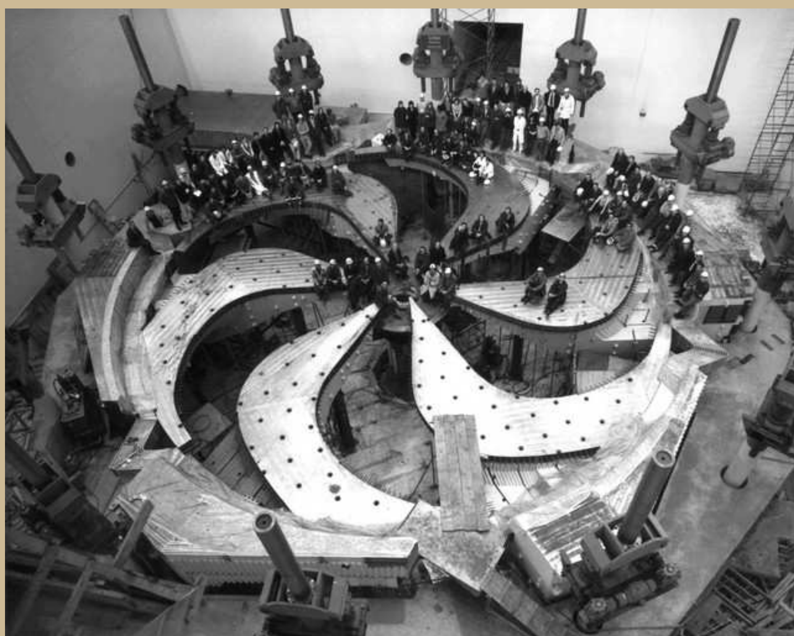
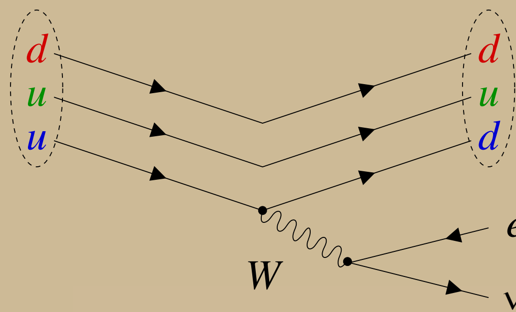
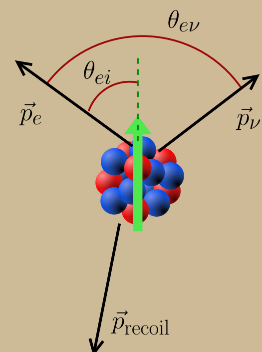
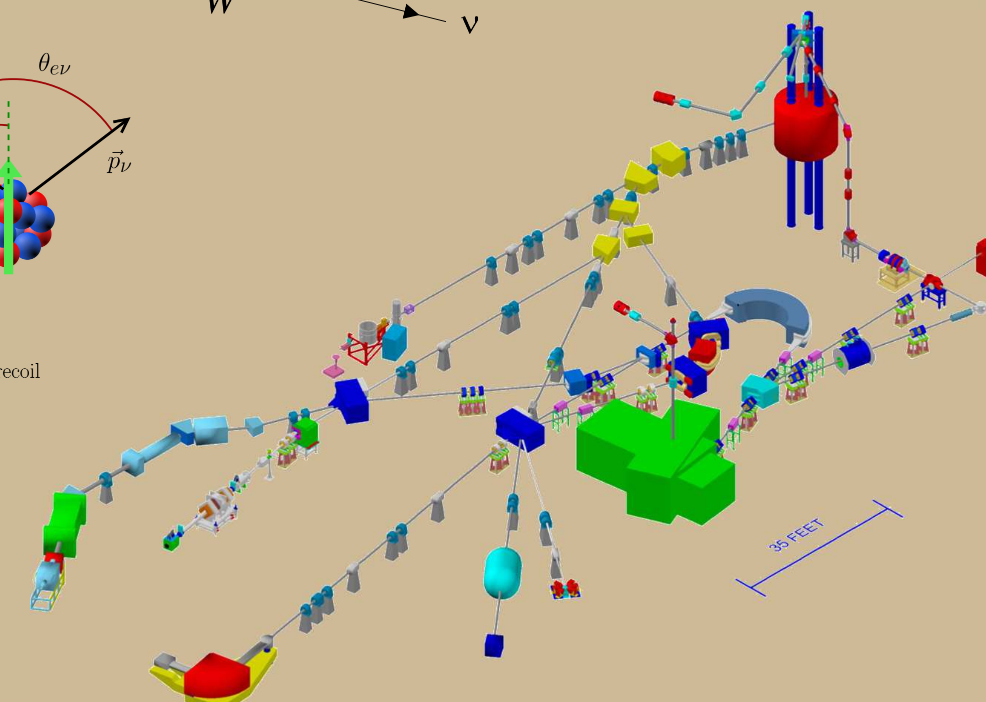
First Mass Measurement using TAMUTRAP









Dan Melconian

BB Lunch, Aug 9, 2017

Overview

1. The real motivation for TAMUTRAP

2. Overview of the TAMUTRAP facility at the Cyclotron Institute

3. Measuring the mass of ^{23}Na

4. Future outlook

How β-decay can test the SM?

Start with (part of) the often-quoted **angular distribution** of the decay:

(Jackson, Treiman and Wyld, Phys Rev **106** and Nucl Phys **4**, 1957)

$$\frac{d^5W}{dE_e d\Omega_e d\Omega_{\nu_e}} = \overbrace{\frac{G_F^2 |\boldsymbol{V_{ud}}|^2}{(2\pi)^5} p_e E_e (A_\circ - E_e)^2 \xi}^{\text{basic decay rate}} \left(1 + \overbrace{\boldsymbol{a_{\beta\nu}} \frac{\vec{p_e} \cdot \vec{p}_{\nu_e}}{E_e E_{\nu_e}}}^{\beta-\nu \text{ correlation}} + \overbrace{\boldsymbol{b} \frac{\Gamma m_e}{E_e}}^{\text{Fierz term}} + \ldots \right)$$

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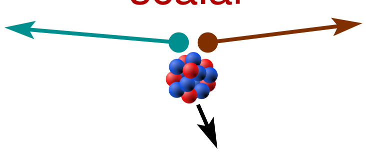
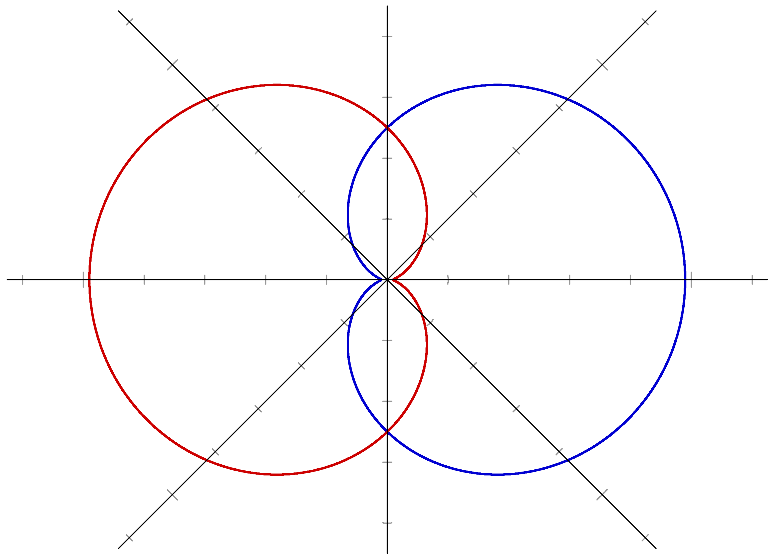
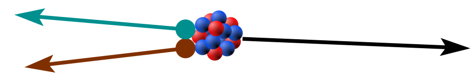
scalar



$$a_{\beta\nu} = \frac{-|C_S|^2 - |C_S'|^2}{|C_S|^2 + |C_S'|^2}$$



vector



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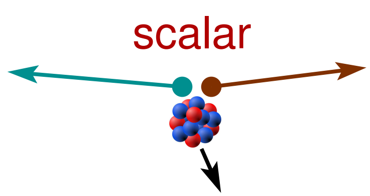

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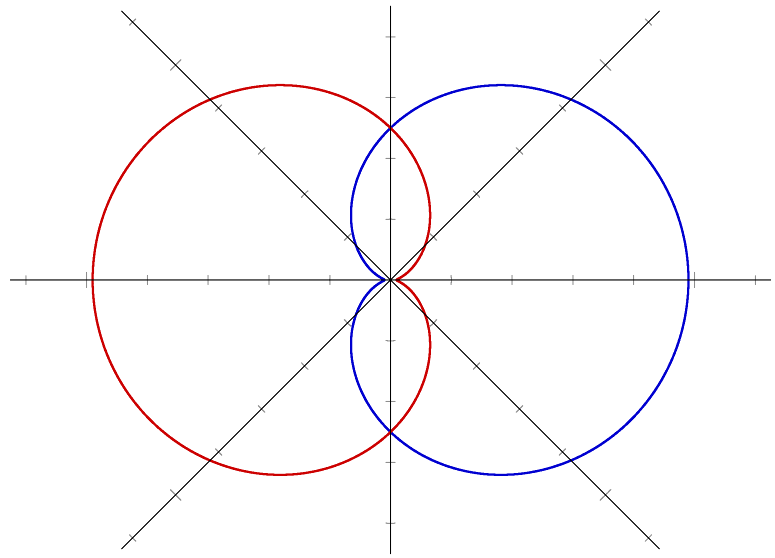

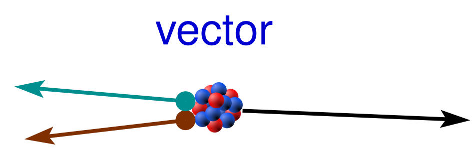

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This correlation is quadratic in the couplings. . . not as sensitive as the Fierz parameter, which is linear:

$$b_F = \frac{-2\Re e(C_S^* C_V + C_S'^* C_V')}{|C_V|^2 + |C_V'|^2 + |C_S|^2 + |C_S'|^2} = 0??$$

see González-Alonso and Naviliat-Čunčić, Phys. Rev. C **94**, 035503 (2016)

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β-decay parameters depend on the currents mediating the weak interaction

$\Rightarrow$ sensitive to **new physics** $\Leftarrow$

Th ... the

Goal must be $\lesssim \mathbf{0.1\%}$ to complement LHC

Naviliat-Čunčić and González-Alonso, Ann. Phys. **525**, 600 (2013)
Cirigliano, González-Alonso and Graesser, JHEP **1302**, 046 (2013)
Vos, Wilschut and Timmermans, RMP **87**, 1483 (2015)

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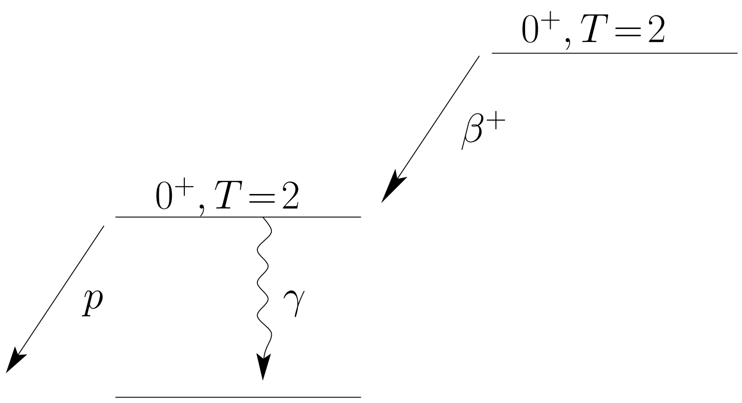
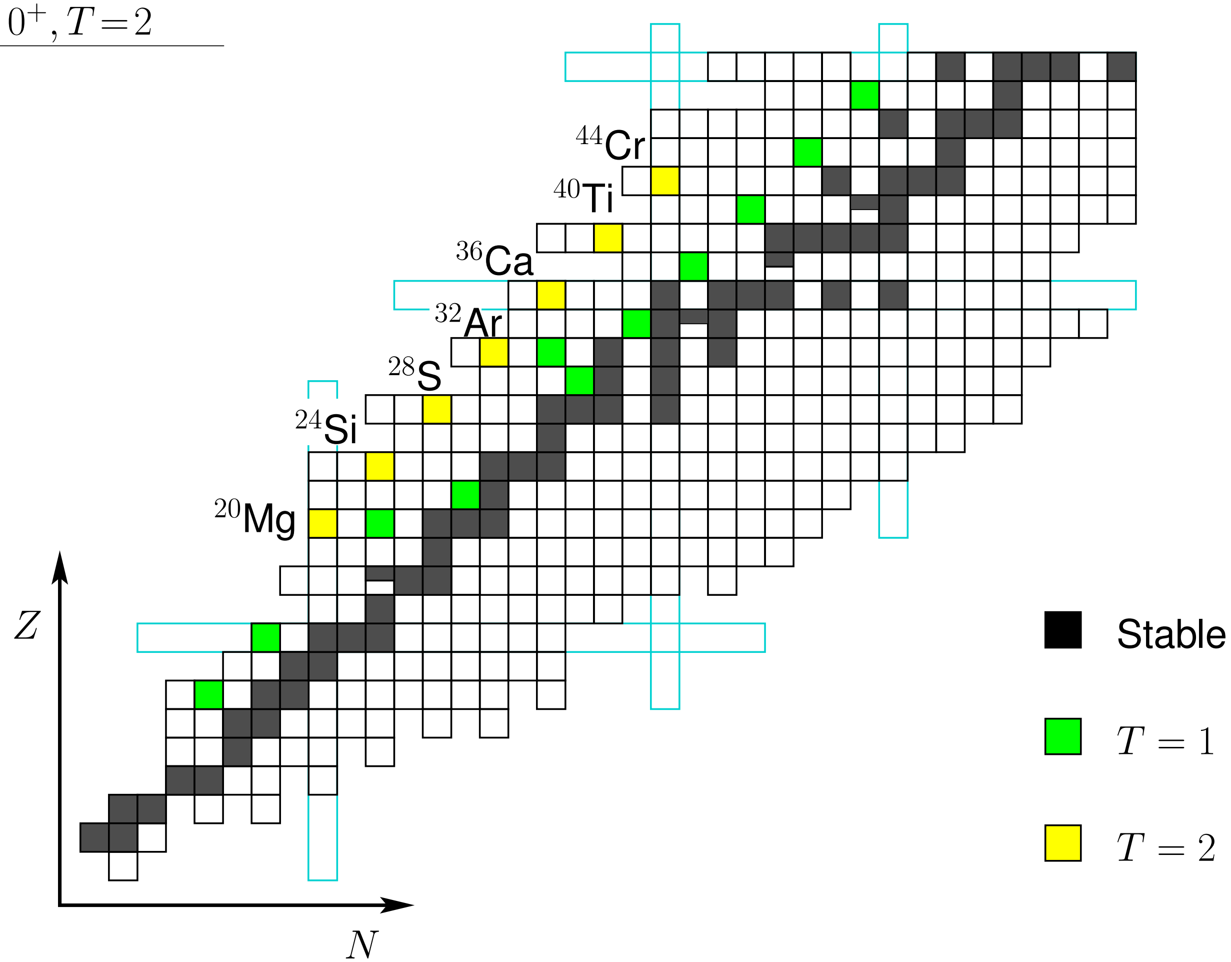
$T = 2$ *Superallowed Decays*





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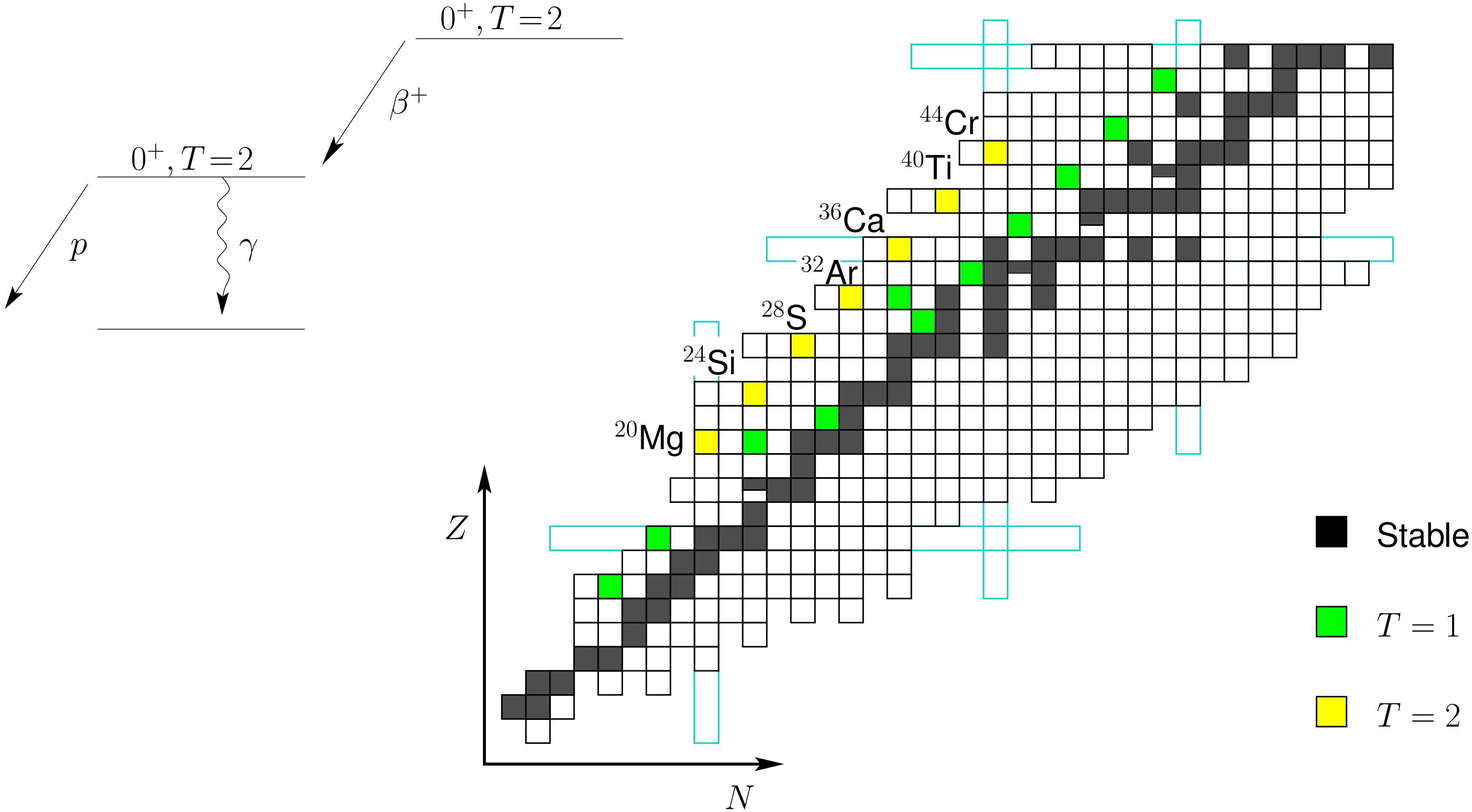

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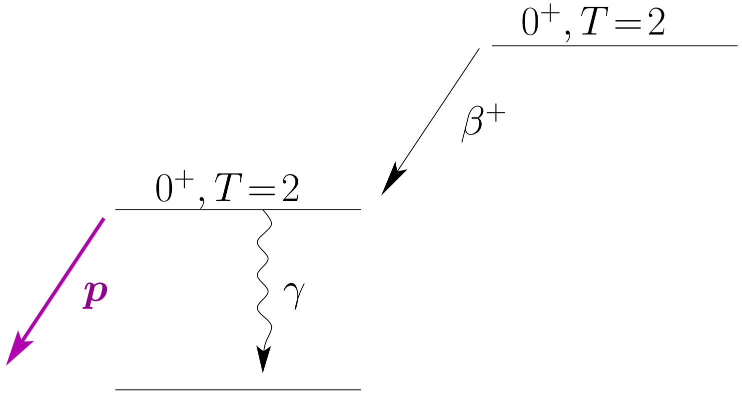

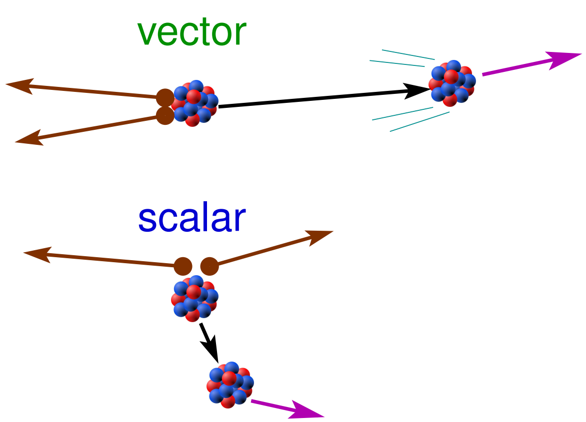

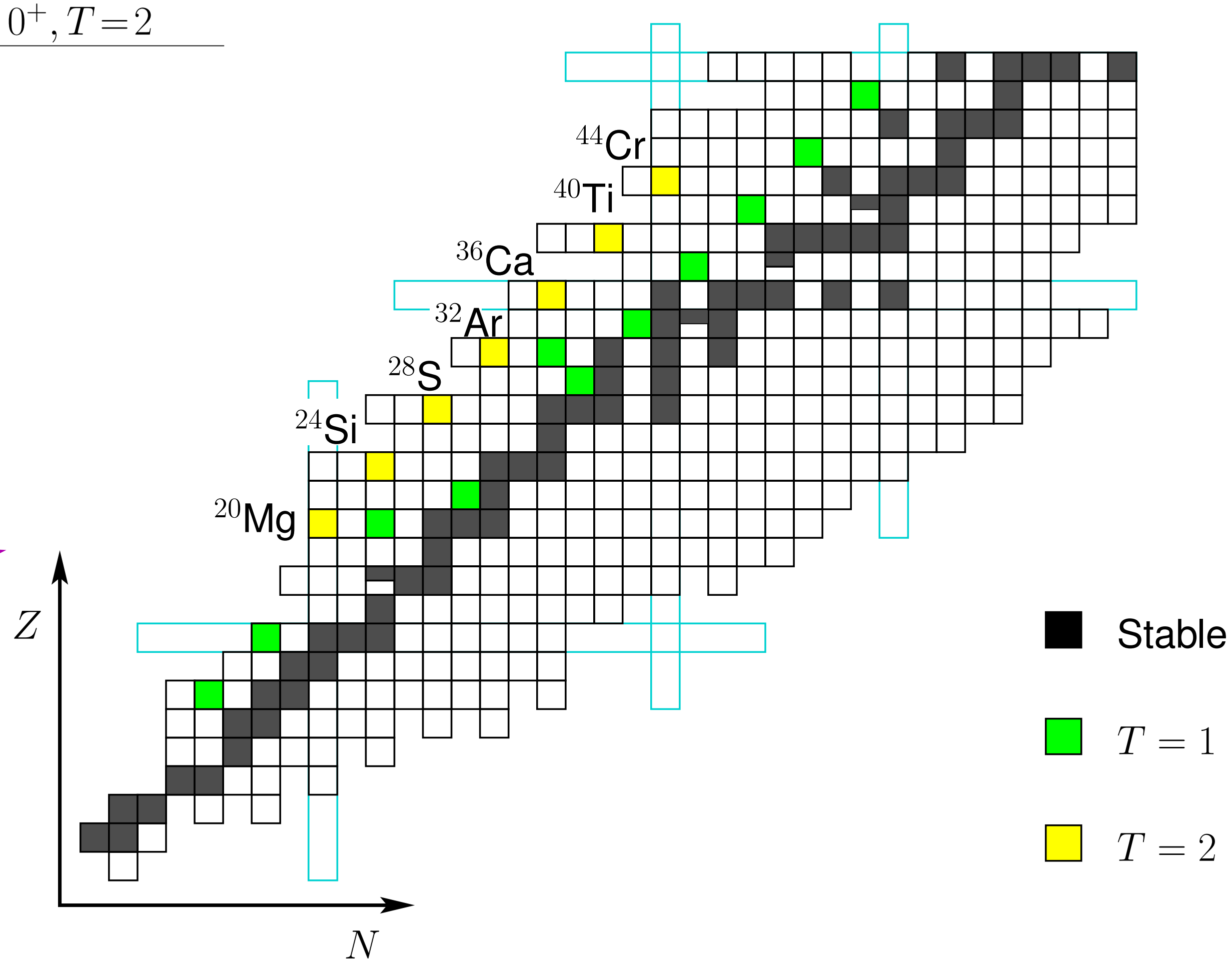

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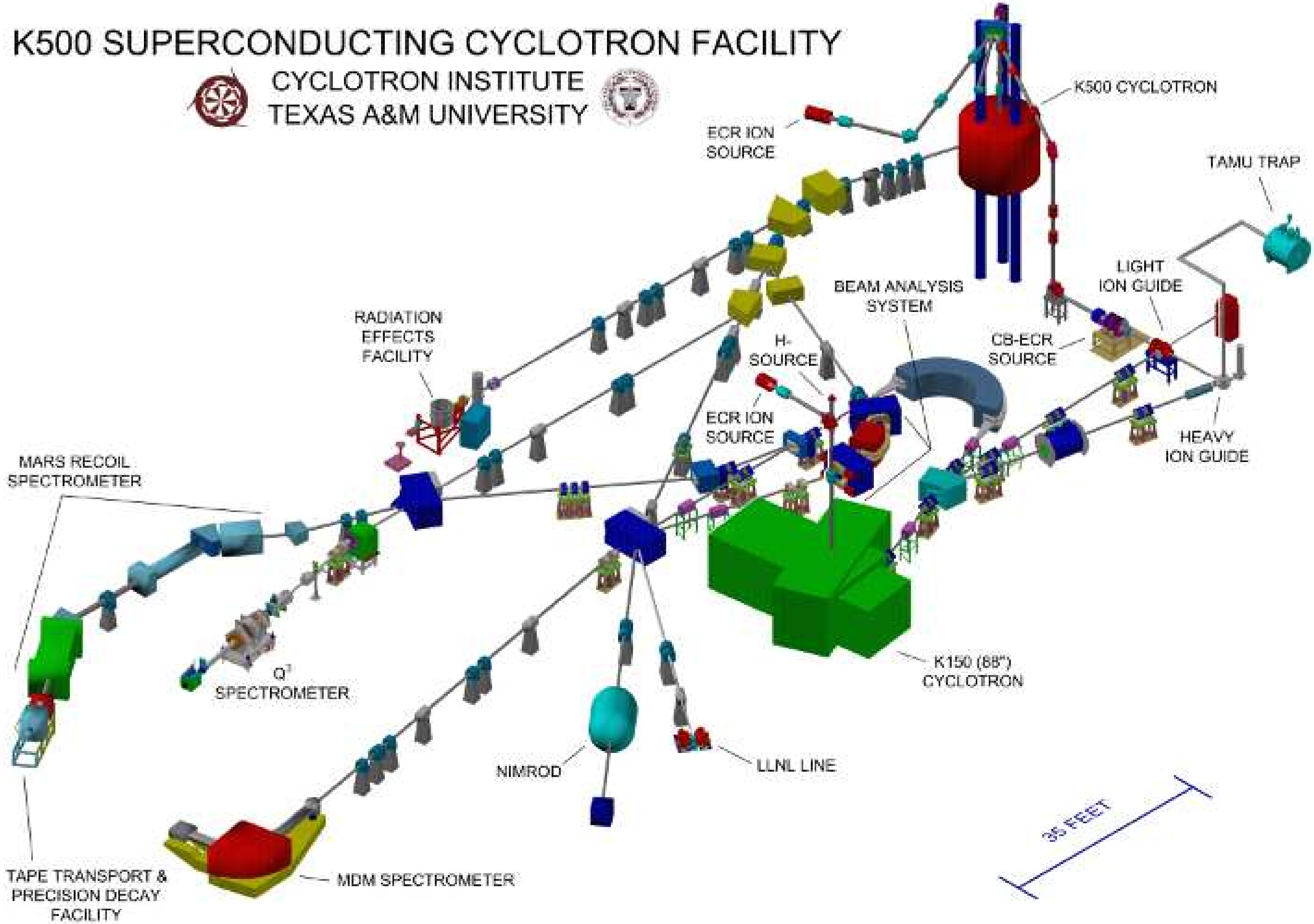
A Penning trap at T-REX CI/TAMU



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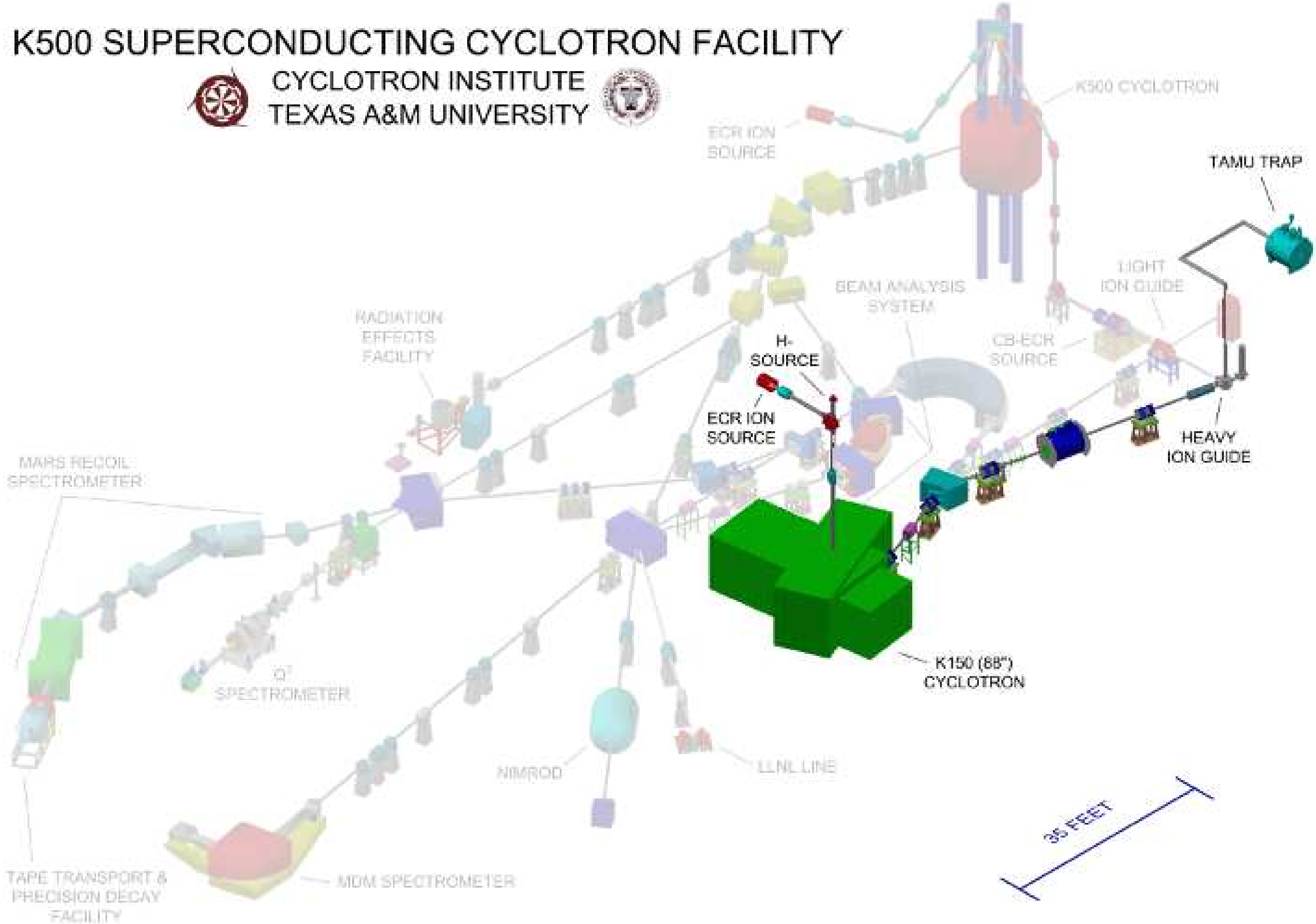

The Texas A&M University Penning Trap

- The **world's most open-geometry** Penning trap!
- Uniquely suited for studying β-delayed proton decays:
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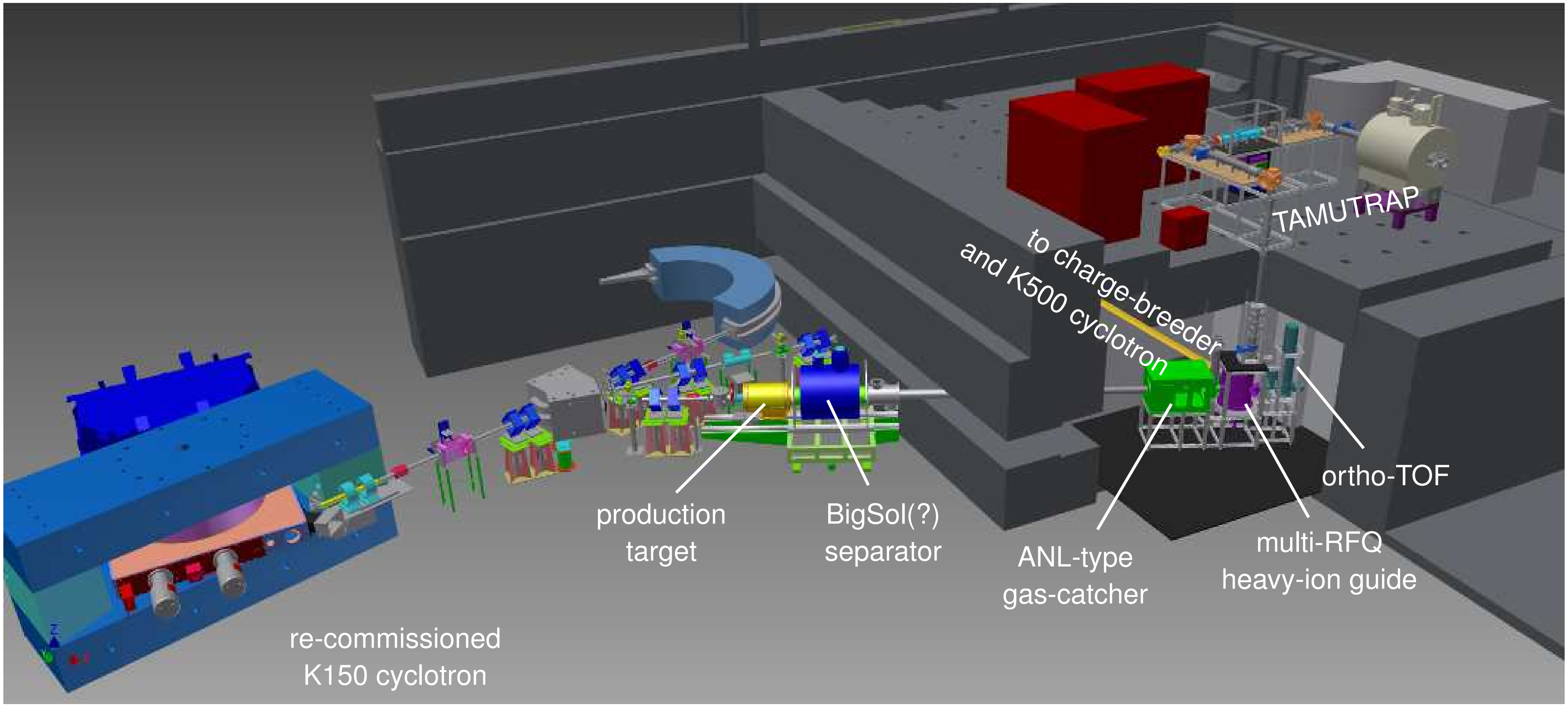
- Mass measurements, EC studies, laser spectroscopy, . . .



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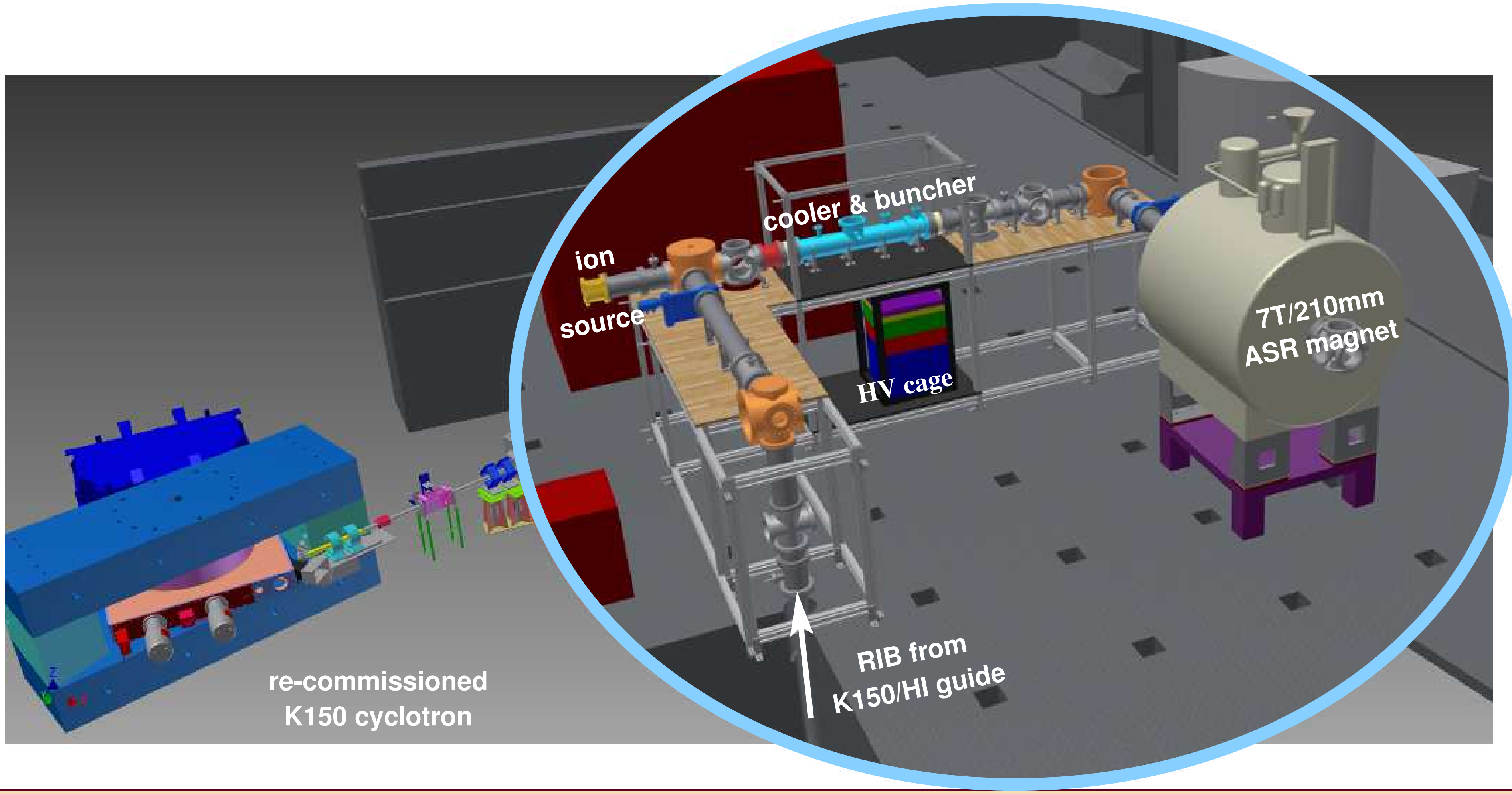

Expected rates at T-REX

Estimated rate of $T = 2$ superallowed proton emitters from T-REX at the trap (^{3}He target, overall $\sim 10\%$ efficiency)

RIB	$t_{1/2}$ [ms]	projectile	beam energy [MeV/u]	LISE prediction	expected rate [pps]
^{20}Mg	90	^{20}Ne	21	0.002 mb	1×10^{3}
^{24}Si	140	^{24}Mg	20	0.02 mb	1×10^{4}
^{28}S	125	^{28}Si	20	0.4 mb	2×10^{5}
^{32}Ar	98	^{32}S	20	7 mb	6×10^{6}
^{36}Ca	102	^{36}Ar	20	6 mb	5×10^{6}
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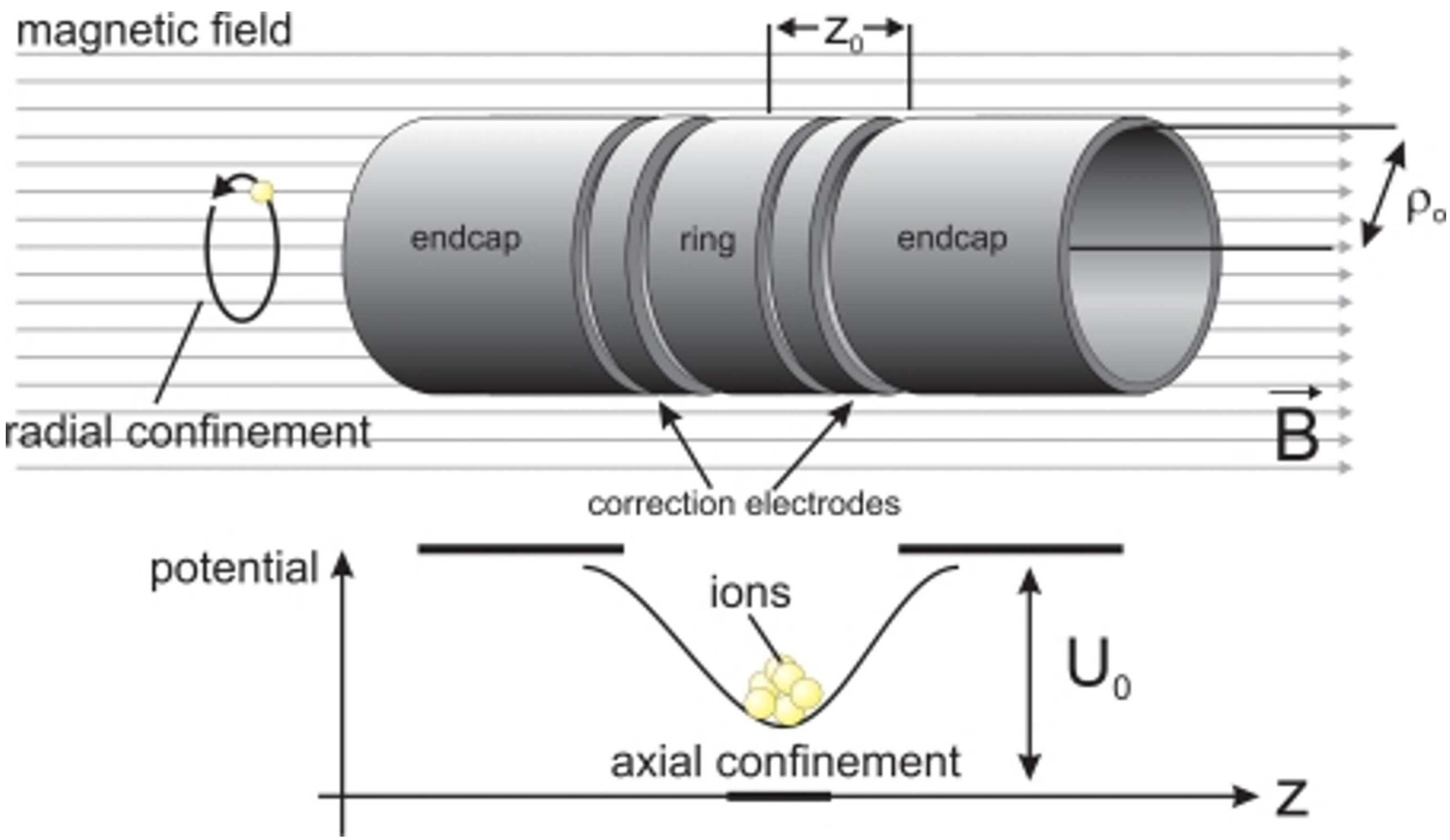
- all have similar decay schemes $\Rightarrow$ ^{32}Ar proof-of-principle
- very small backgrounds $\Rightarrow$ sufficient rates
- many branches, lifetimes and correlations to measure $\Rightarrow$ fruitful program

The Penning Trap Design

Existing traps are long and thin: $l/\rho_0 \sim 12$



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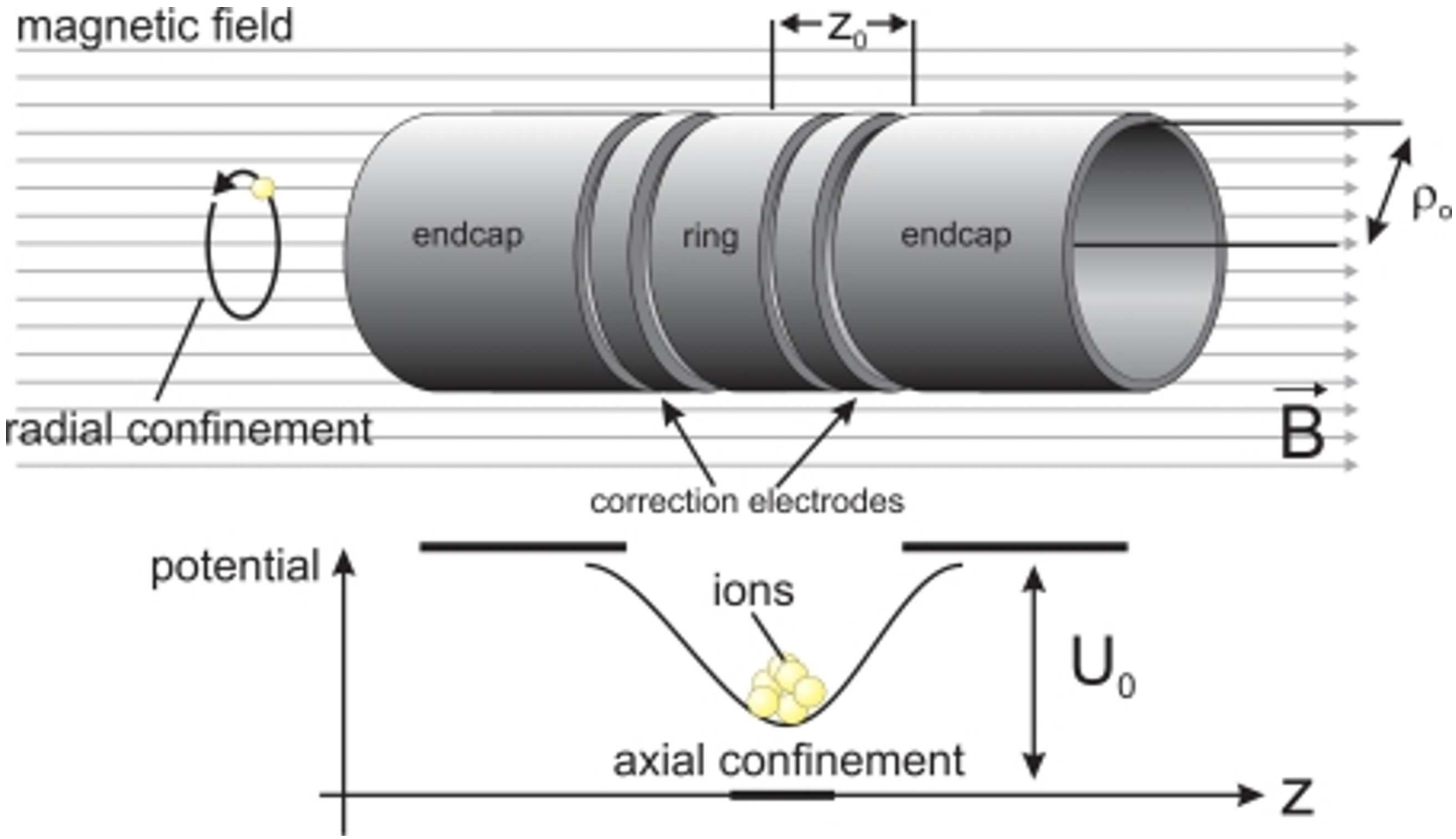

Over 1 m long if scaled up to $R = 90$ mm $\Rightarrow$ will not fit in the magnet

The New Penning Trap Design

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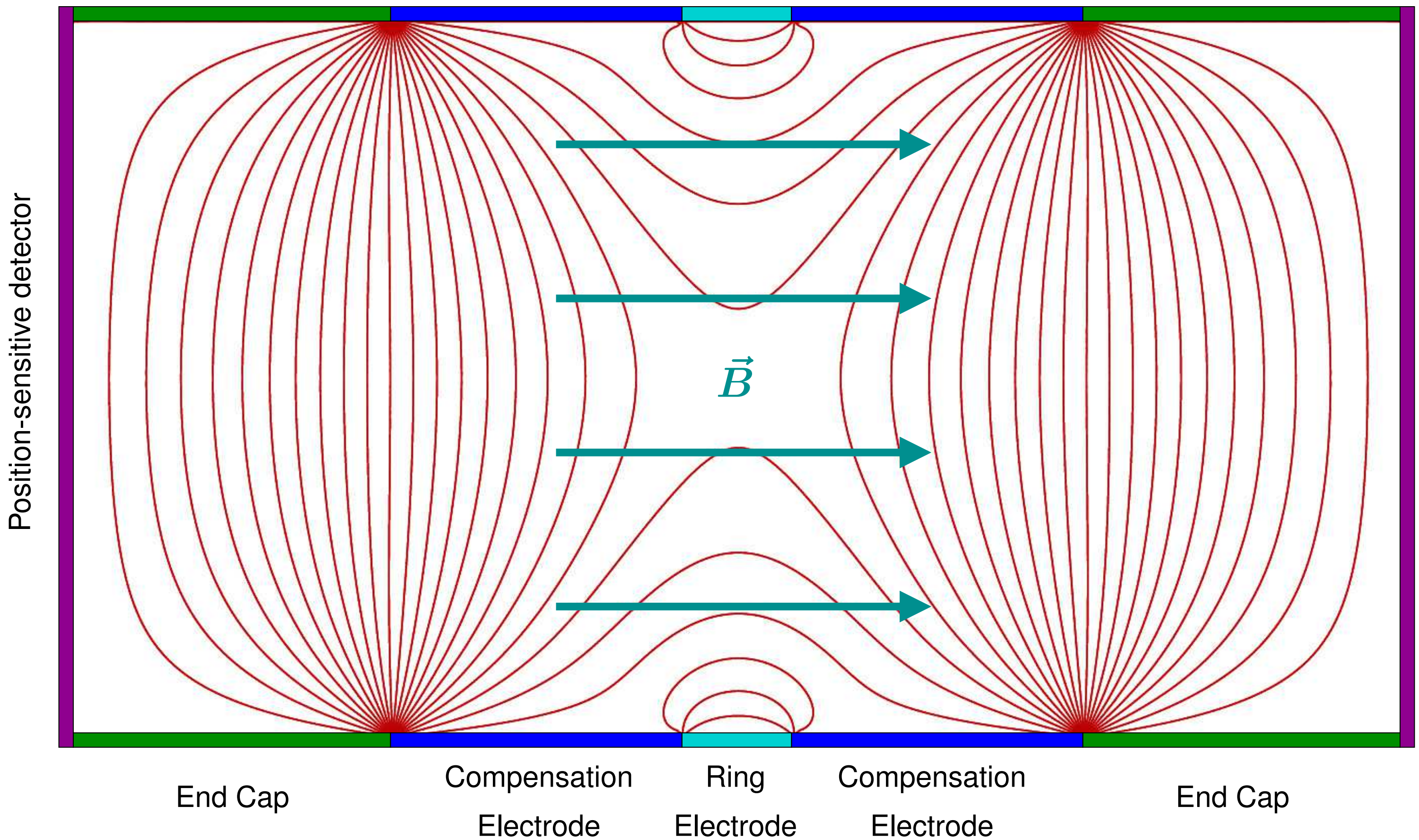
Mehlman *et al.*, NIM **A712**, 9 (2013): $l/\rho_0 = 3.72$
does **not** use the long endcap approximation



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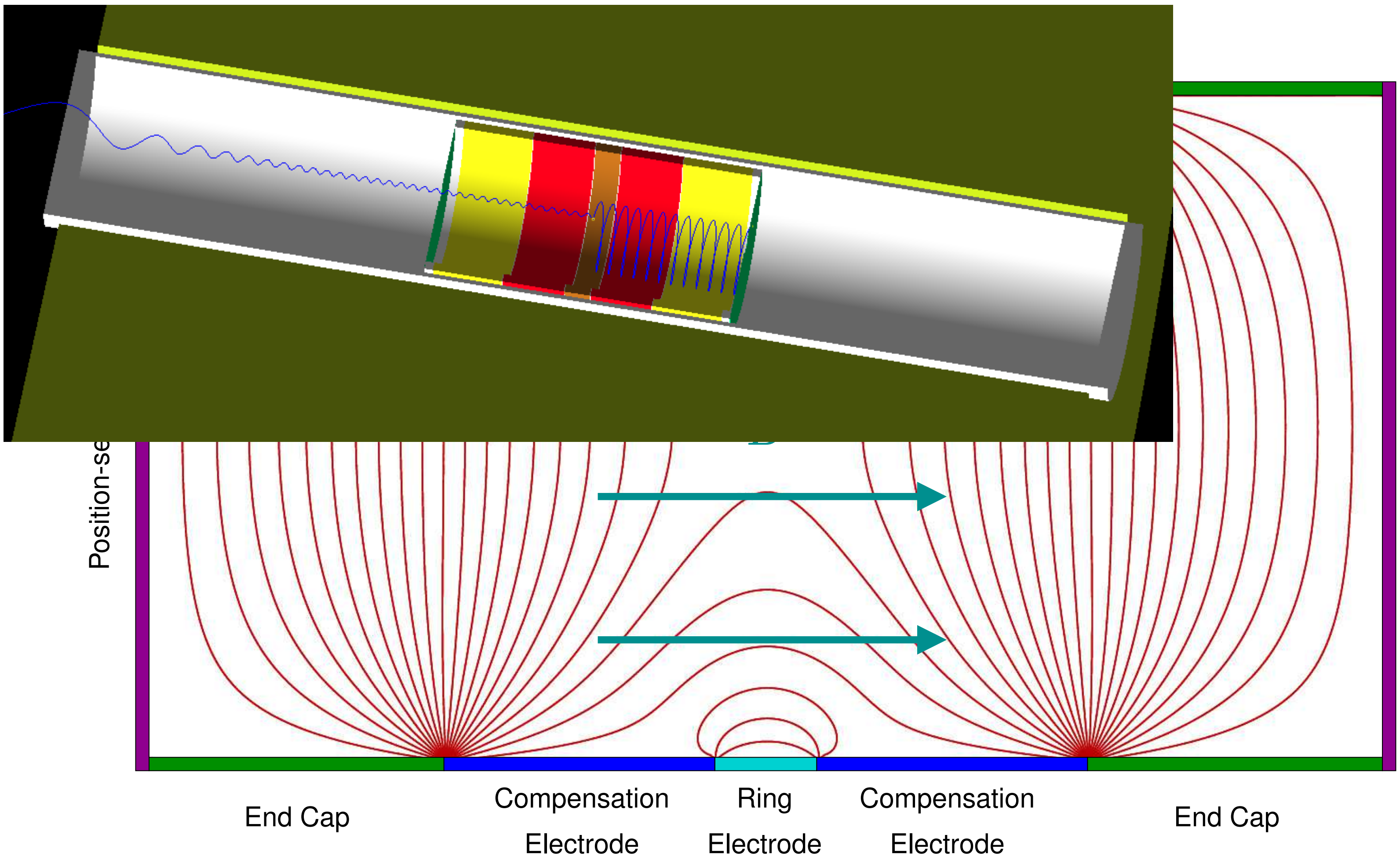

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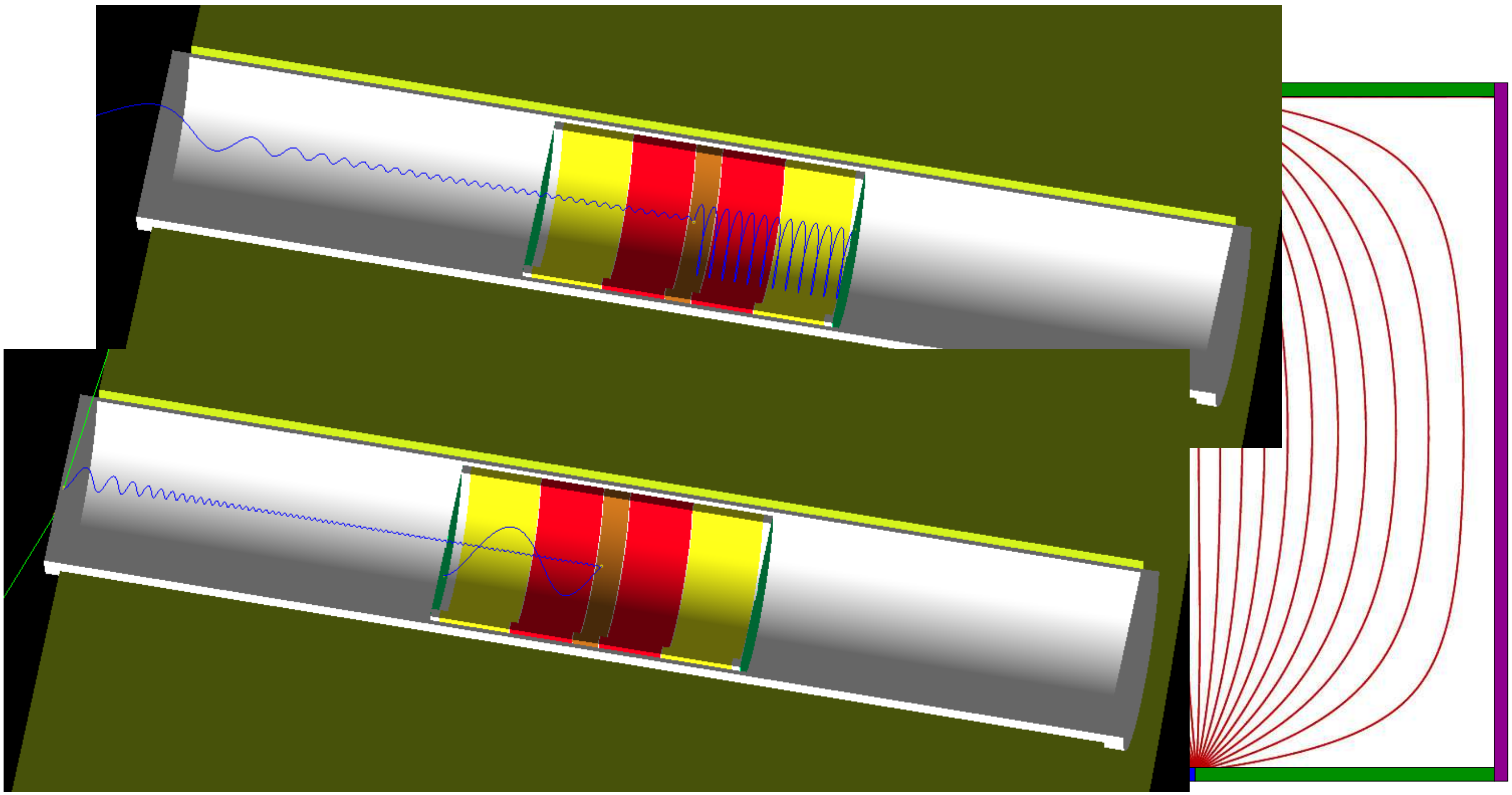

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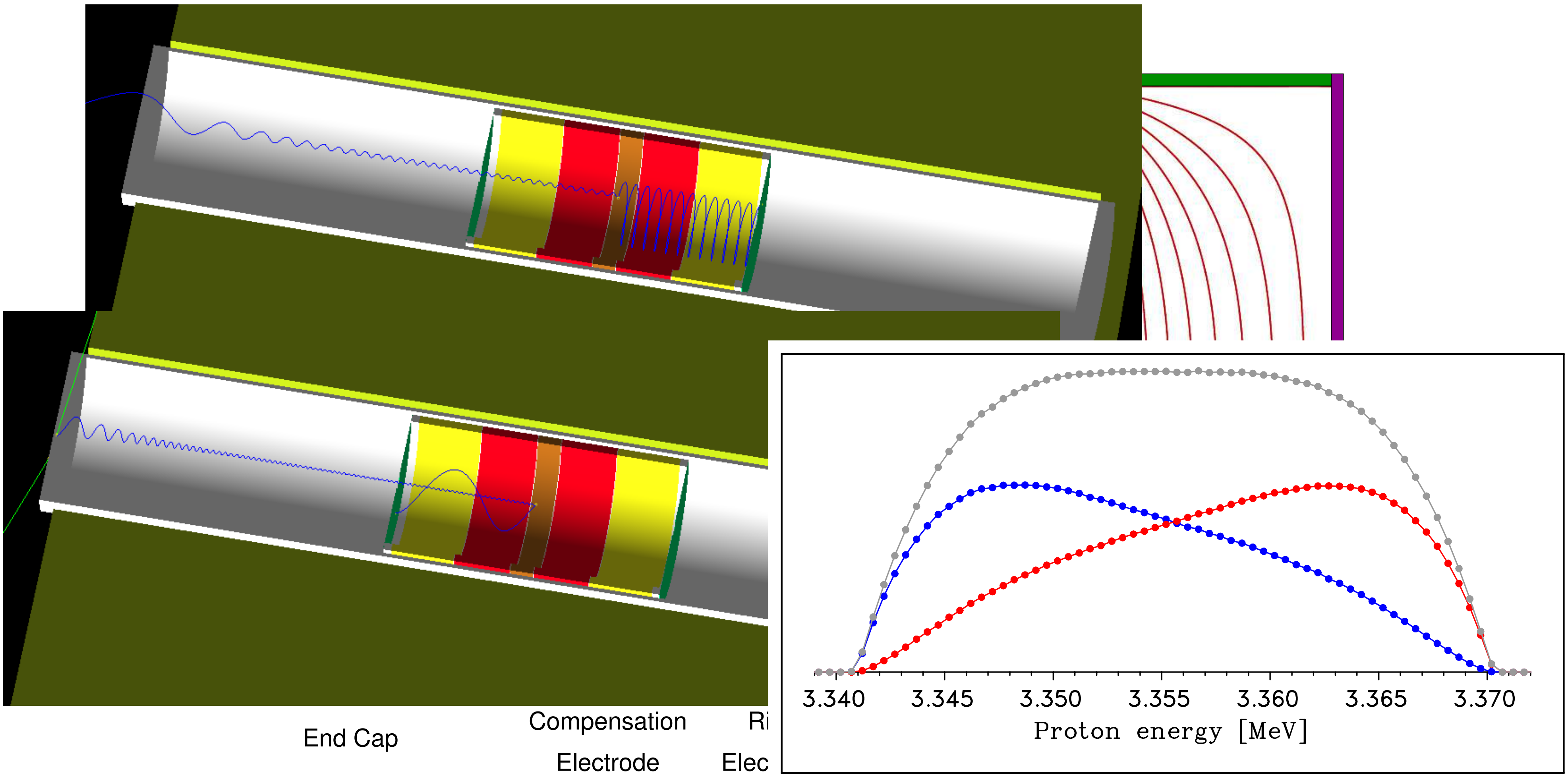

Commissioning the Prototype

- Heavy Ion Guide not yet giving RIB
- Want to practice with prototype before designing final trap
- Have 2 offline ion sources: ^{39}K and ^{23}Na

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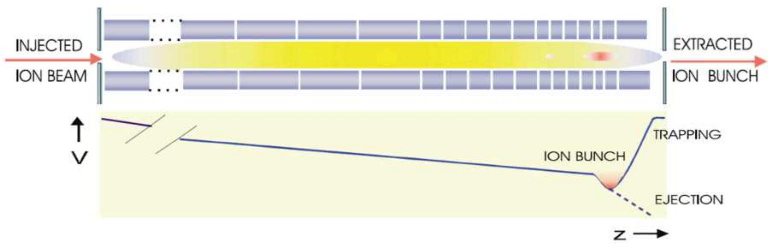
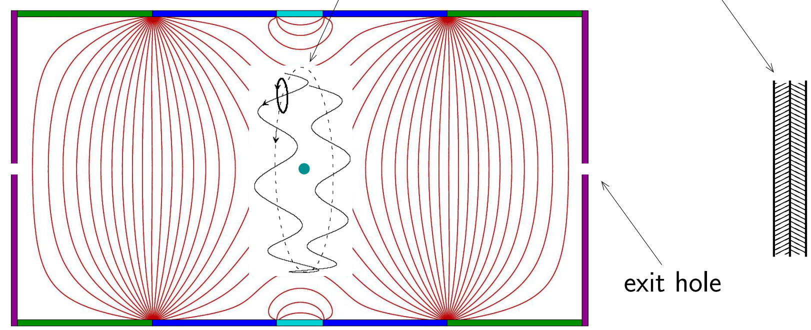
⇒ **Commission TAMUTRAP by demonstrating ability to perform a mass measurement** ⇐

- Make it a frequency measurement for high precision:

$$\nu_C = \frac{1}{2\pi}\frac{qB}{m}$$

1^{st} Step: Magnetron Excitation (ω_-)





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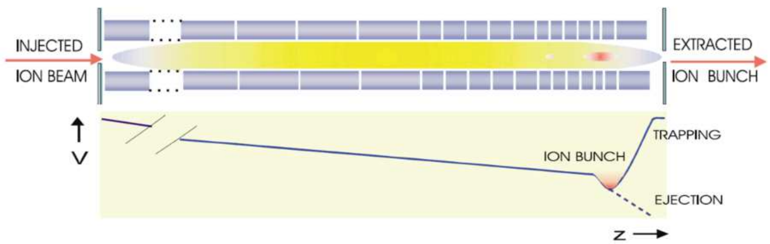
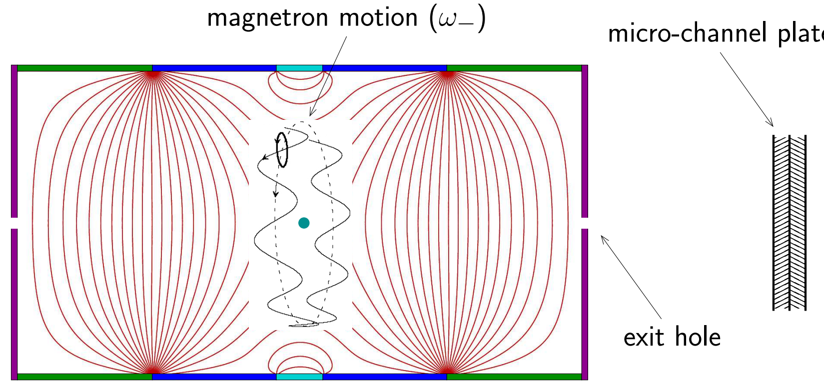
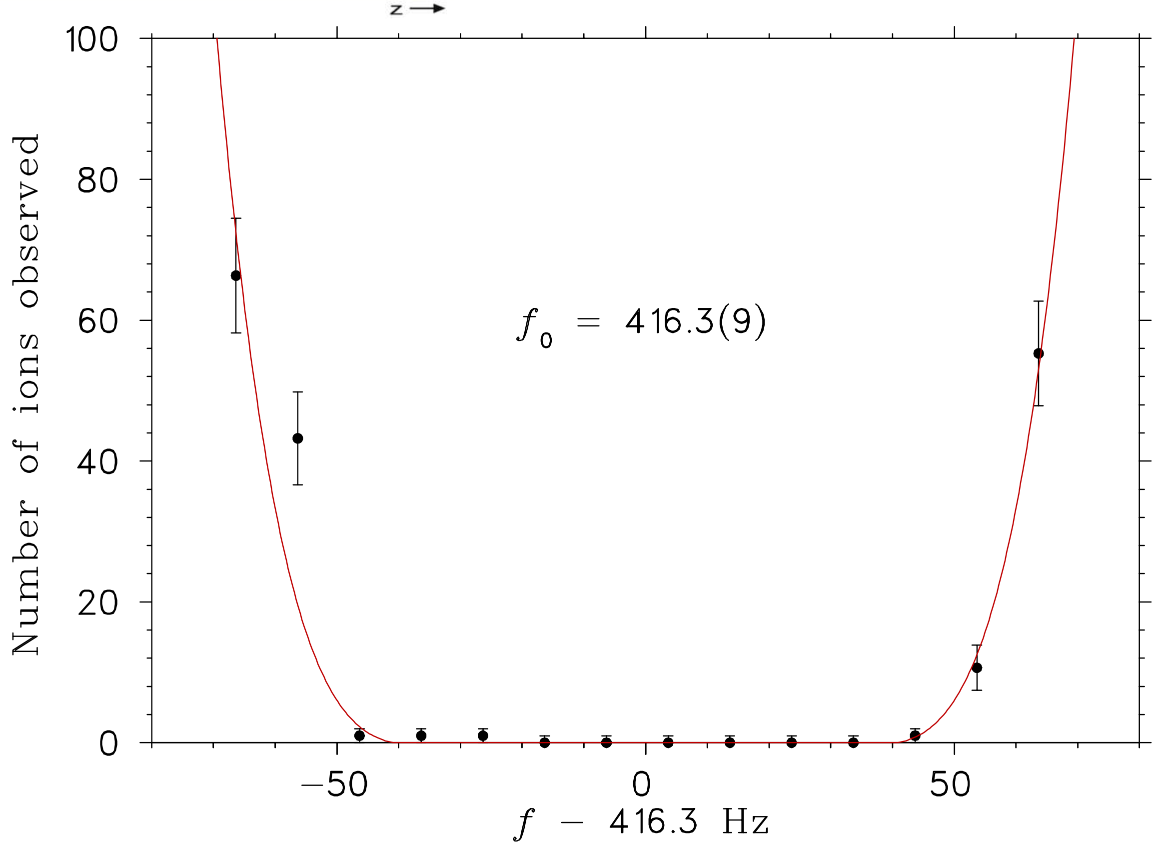
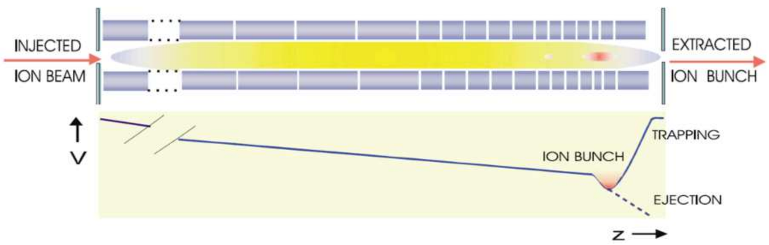
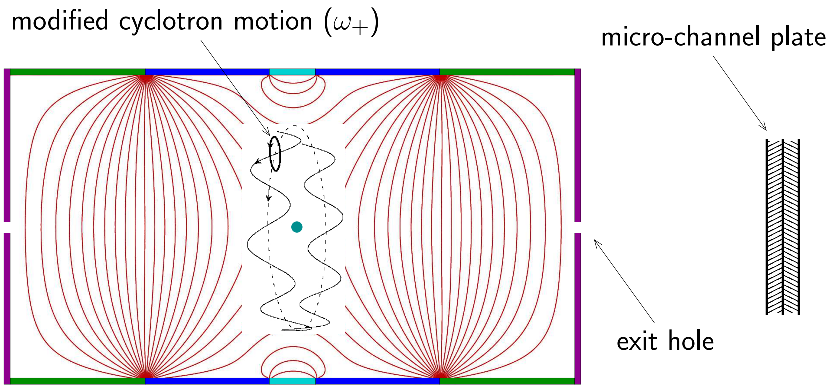


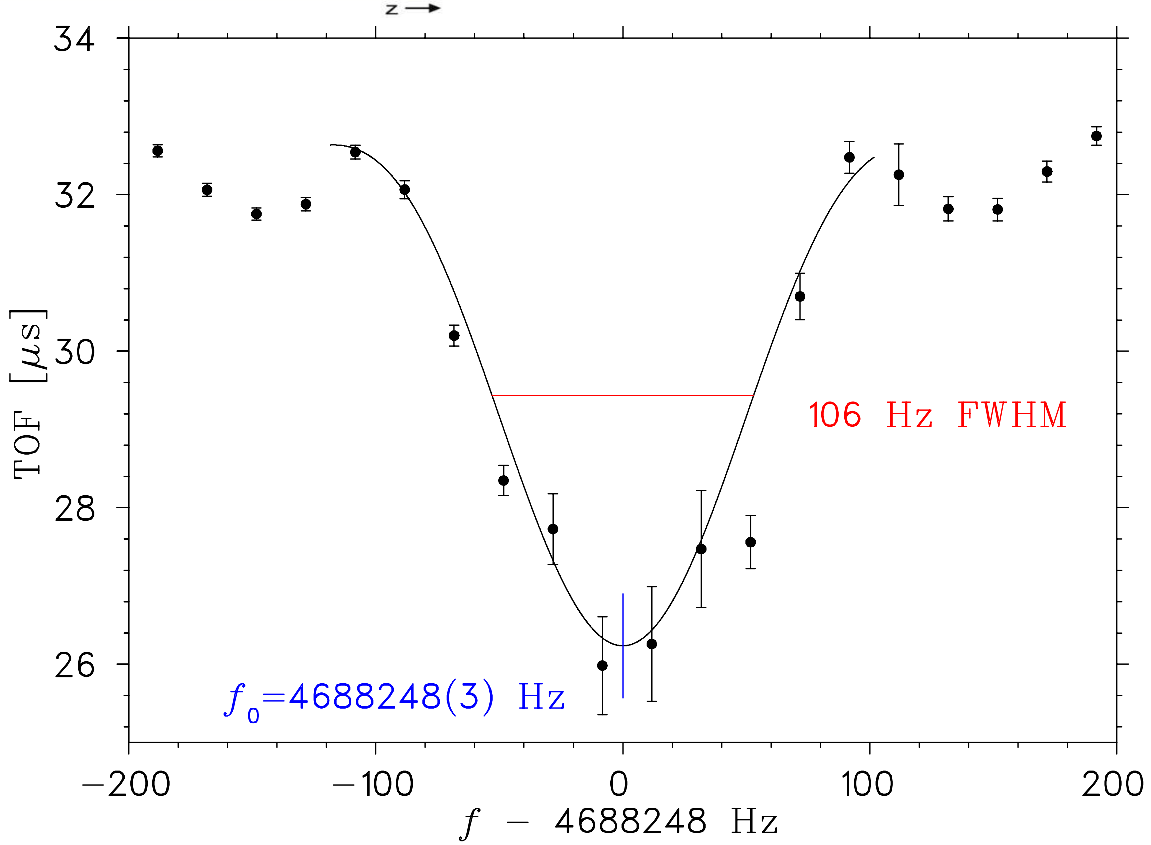




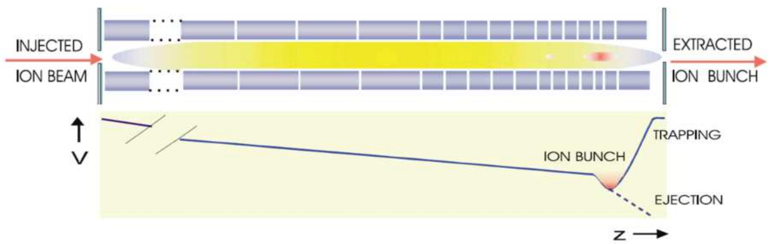
2nd Step: Reduced Cyclotron Excitation (ω_+)

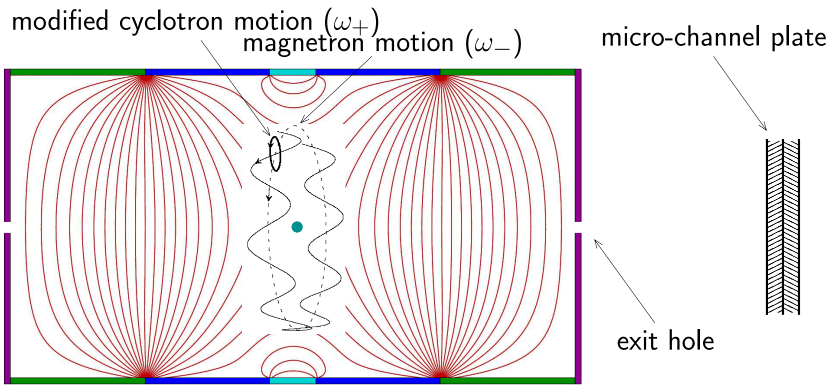


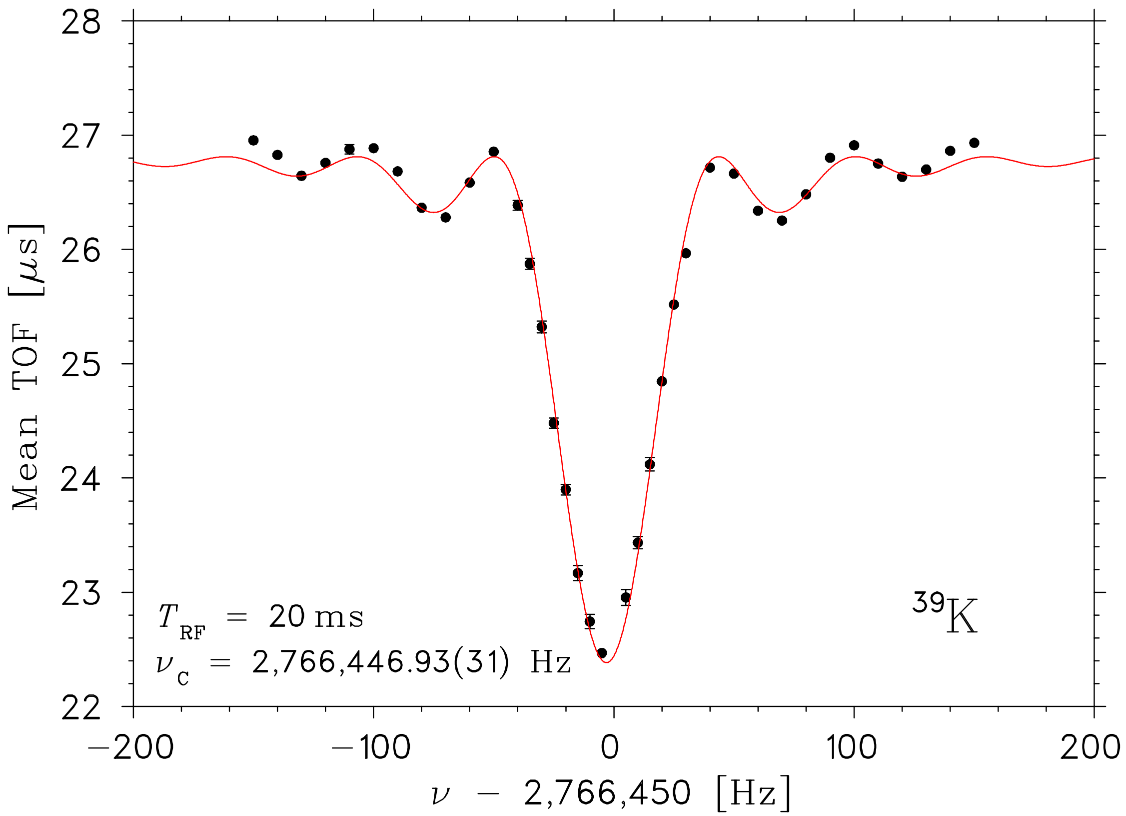




3rd Step: TOF-ICR on ^{39}K ($\omega_C = \omega_- + \omega_+$)







4^{th} Step: Calibrate the field & same using ^{23}Na

Resonant frequency given by: $\nu_C = \frac{1}{2\pi}\frac{qB}{m}$

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- Known mass of $^{39}K^+$: $38.963\,157\,906\,701$ GeV
- Observed cyclotron frequency: $\nu_C = 2\,766\,446.93(31)$ Hz

$$\Rightarrow B = 2\pi\nu\, m$$
$$= \boxed{7.019\,320\,3(8)\ \mathrm{T}}$$

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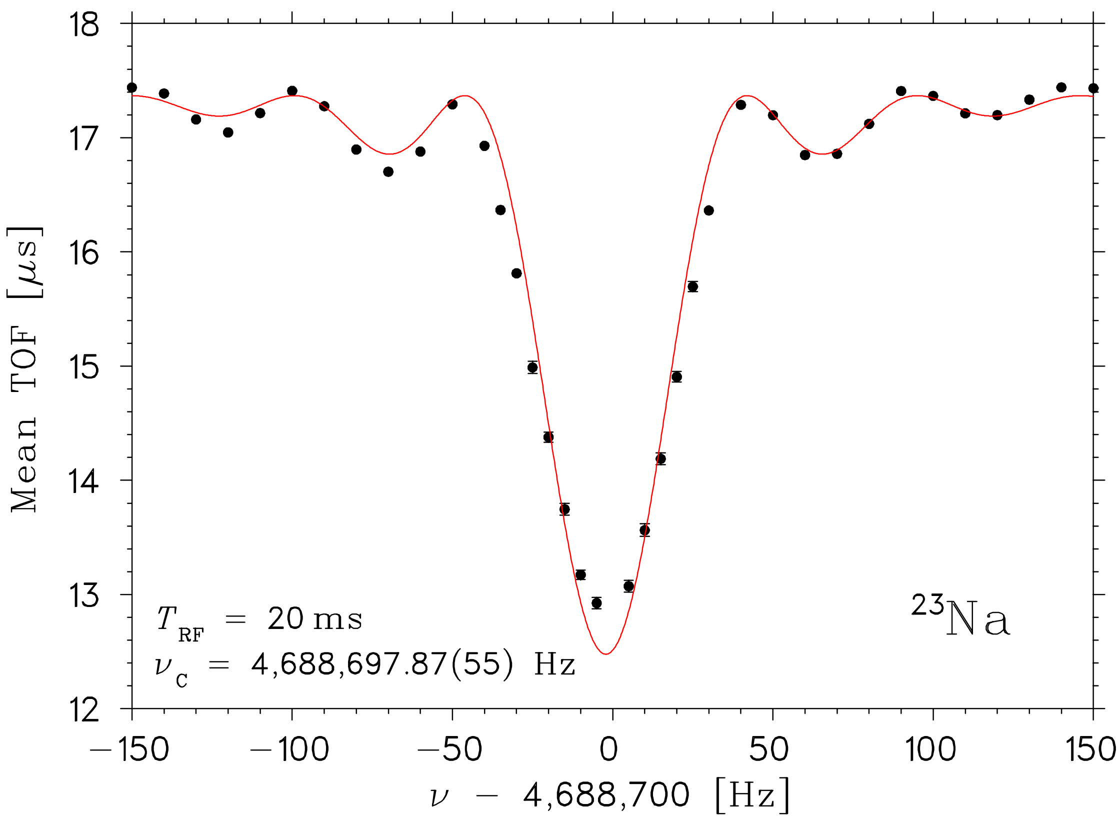

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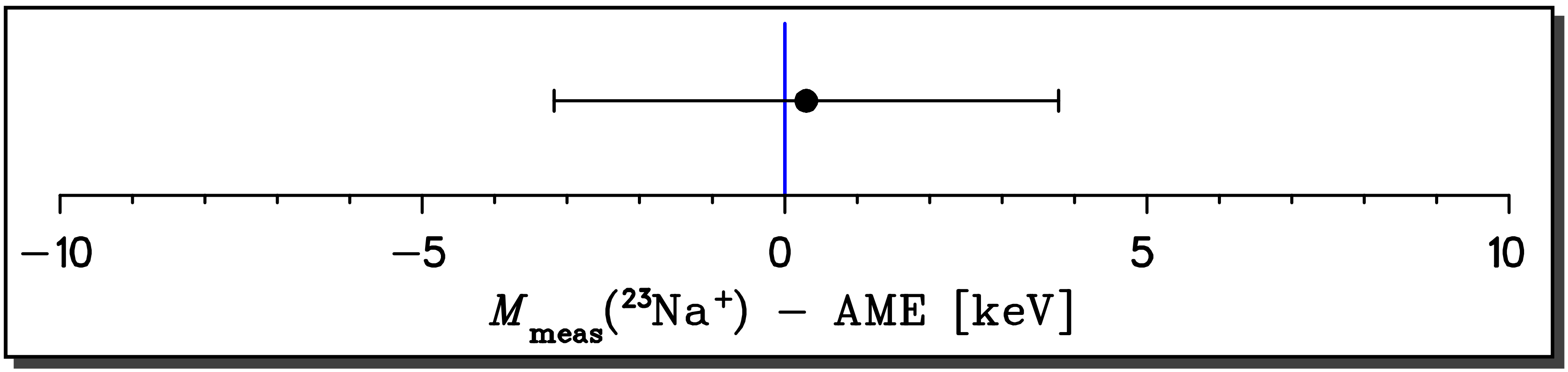
versus known: $21\ 414\ 323.3$ keV



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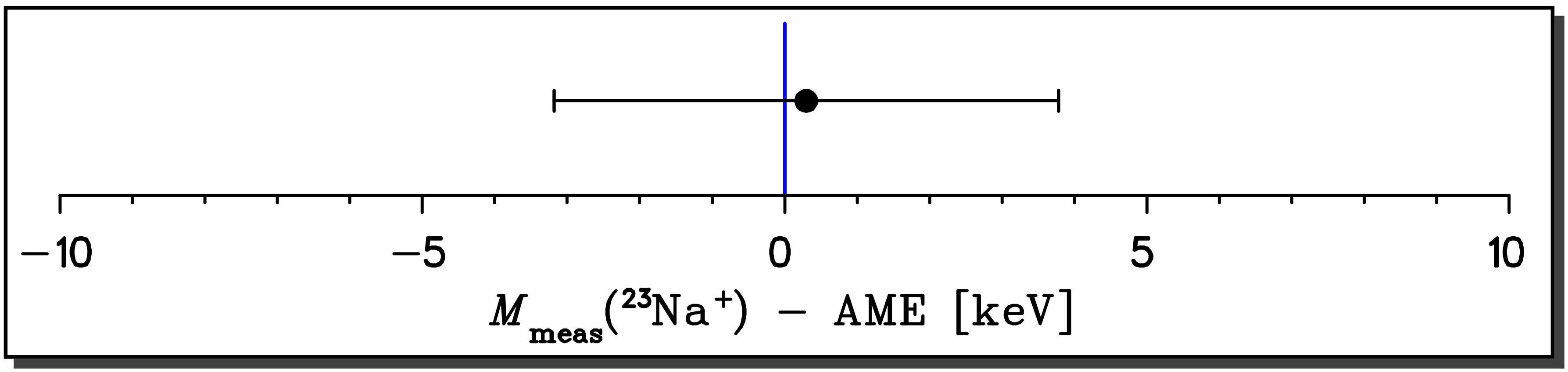

Will improve precision with longer exciation times (better vacuum)

The next steps

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- Final alignment and optimization of beamlines
- Design and build 180-mm-diameter trap with detectors
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- Begin RIB program!

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- Install and commission final trap with offline sources
- Couple to heavy-ion guide

- Begin RIB program!

- Oh, and Ben Fenker measured A_β to **0.3%** in ^{37}K. . . !

The Mad Trappers

Mike Mehlman, MSc (2012), Applied Physics PhD (2015)

Praveen Shidling, Research scientist (2010–present)

Ben Schroeder, Physics PhD (summer 2017–present)

Veli Kolhinen, Post-doc (summer 2017–present)

plus help from T. Eronen, R. Ringle, A. Kwiatkowski,. . .

Alumni:

- Yakup Boran, MSc (2013)
- REU students ($\times 7$), French interns ($\times 3$), PHYS 491 students ($\times 2$)

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