TAMUTRAP:
Texas A&M University Penning trap facility

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Outline

- Motivation
- TAMUTRAP facility
- Mass Measurement
- Future outlook

Motivation

- Make a precision measurement of the angular correlation parameter.
- Compare the SM predictions to observation.

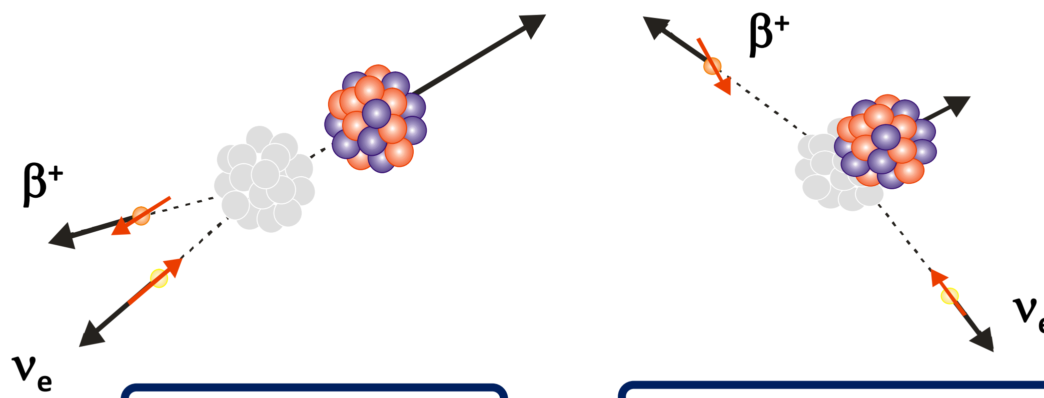
$$a_{\beta\nu}^{expt.} \stackrel{?}{=} a_{\beta\nu}^{theory}$$

- Look for deviations as an indication of new physics

How do we plan to test the Standard Model (SM) ?

In Standard Model (SM) weak interaction is **V-A**

Pure Fermi transition

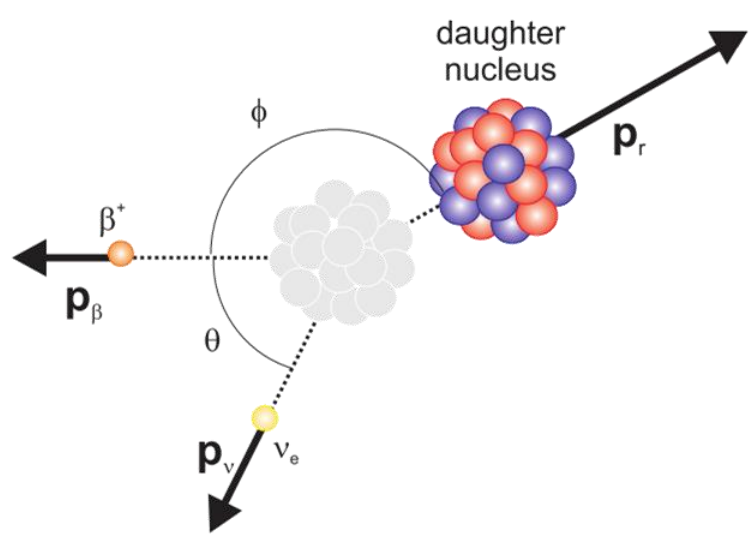


SM Interaction

Non SM Interaction

Correlation parameter

$$W(\theta) \cong \left(1 + a_{\beta\nu}\frac{p_e p_\nu}{E_e E_\nu}\cos\theta_{e\nu} + b\frac{m_e}{E_e}\right)$$

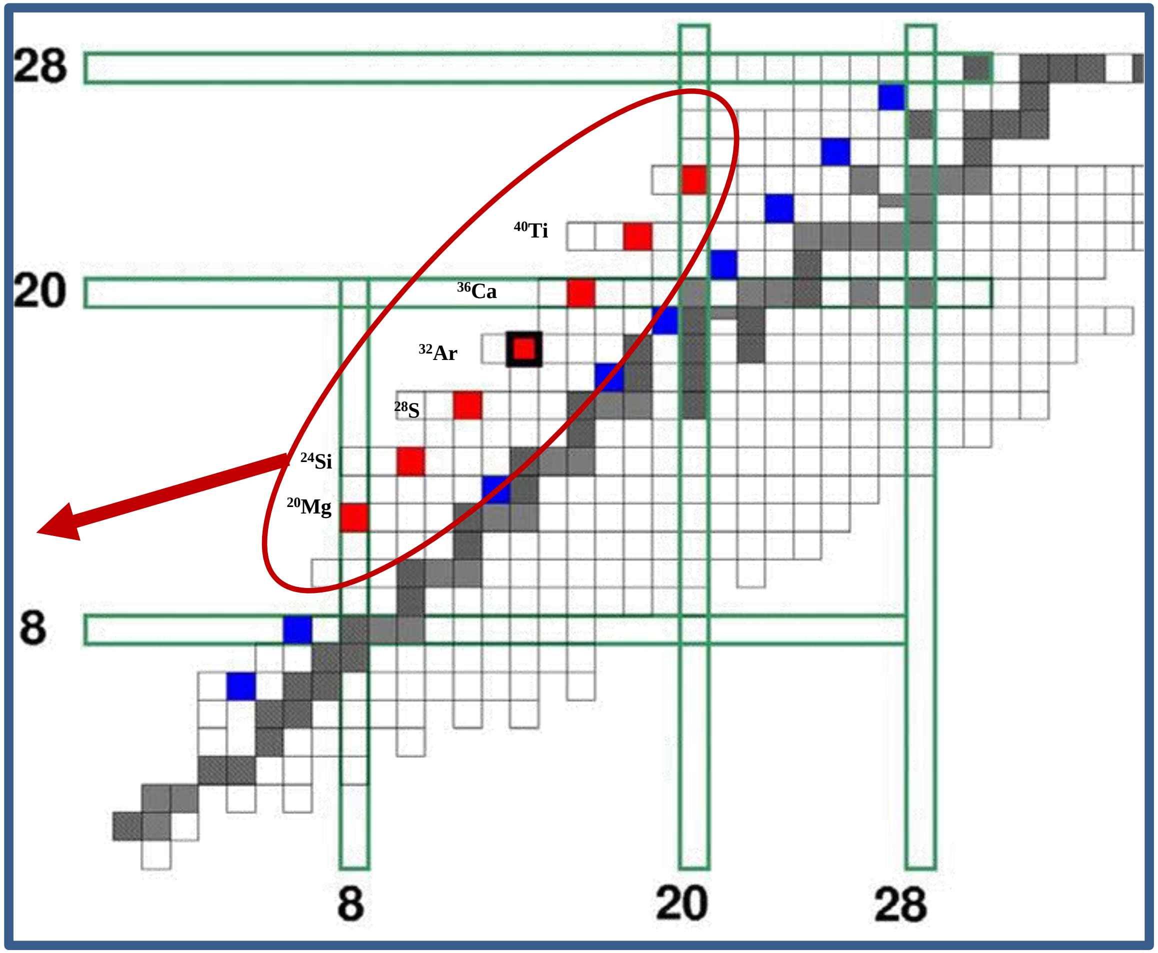


$$a_{\beta\nu} \stackrel{?}{=} 1$$

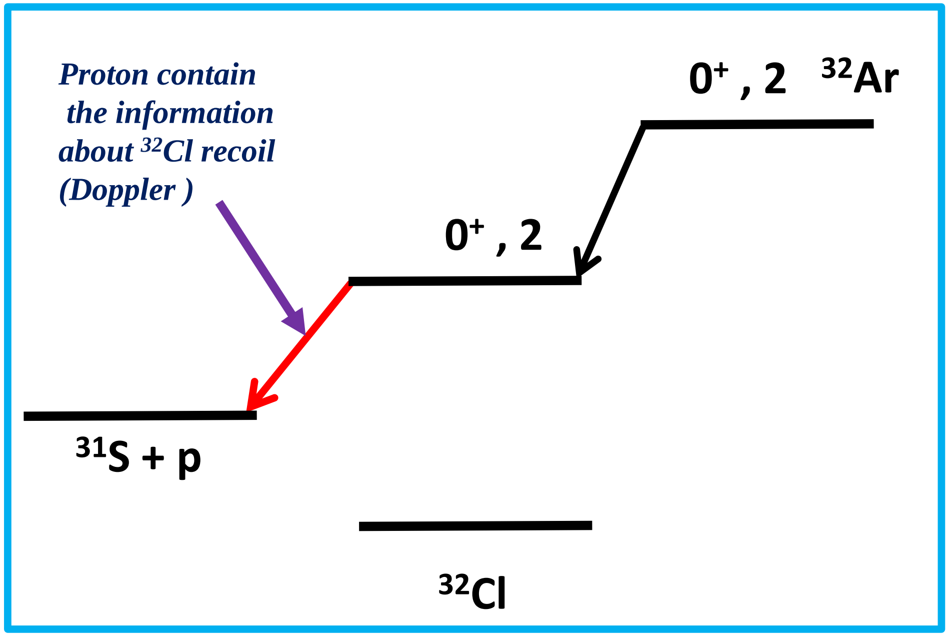
Test of SM

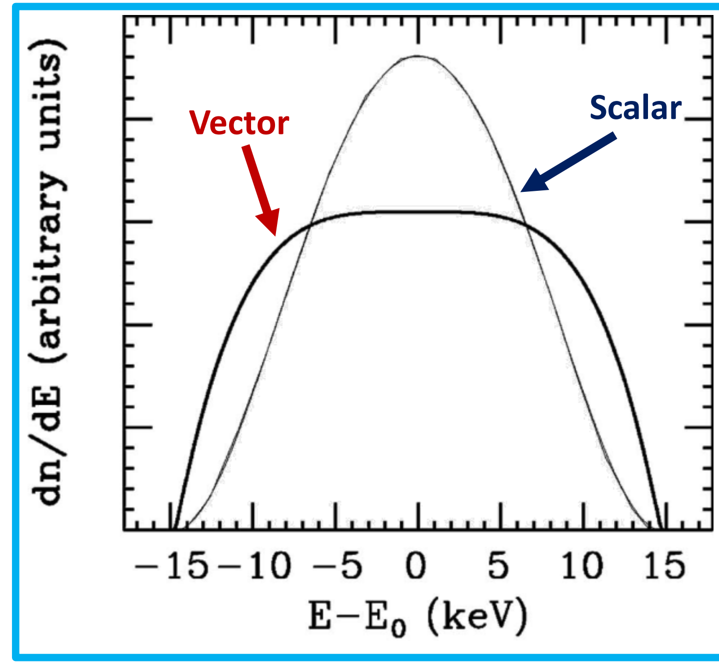
Beta delayed proton emitters

RIB	Projectile	$t_{1/2}$ [ms]
^{40}Ti	^{40}Ca	53
^{36}Ca	^{36}Ar	102
^{32}Ar	^{32}S	98
^{28}S	^{28}Si	125
^{24}Si	^{24}Mg	140
^{20}Mg	^{20}Ne	90

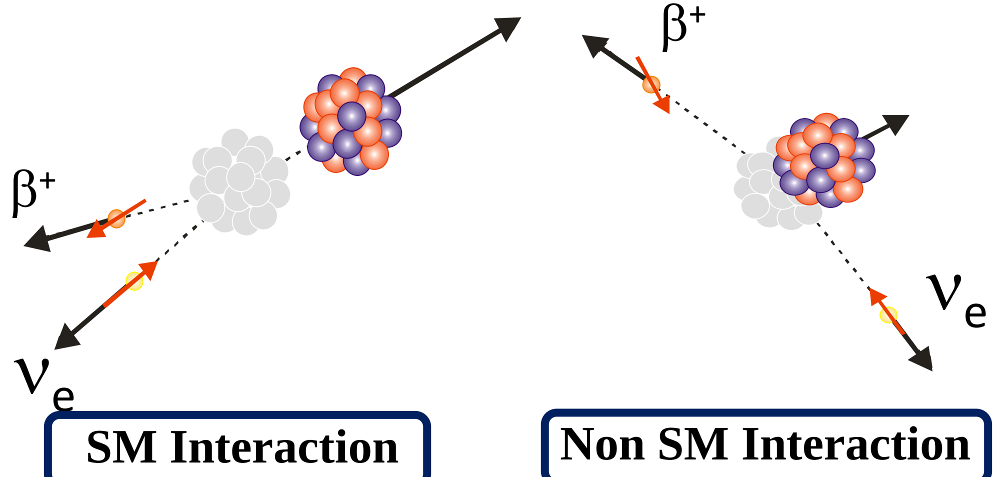


Beta delayed proton emitters

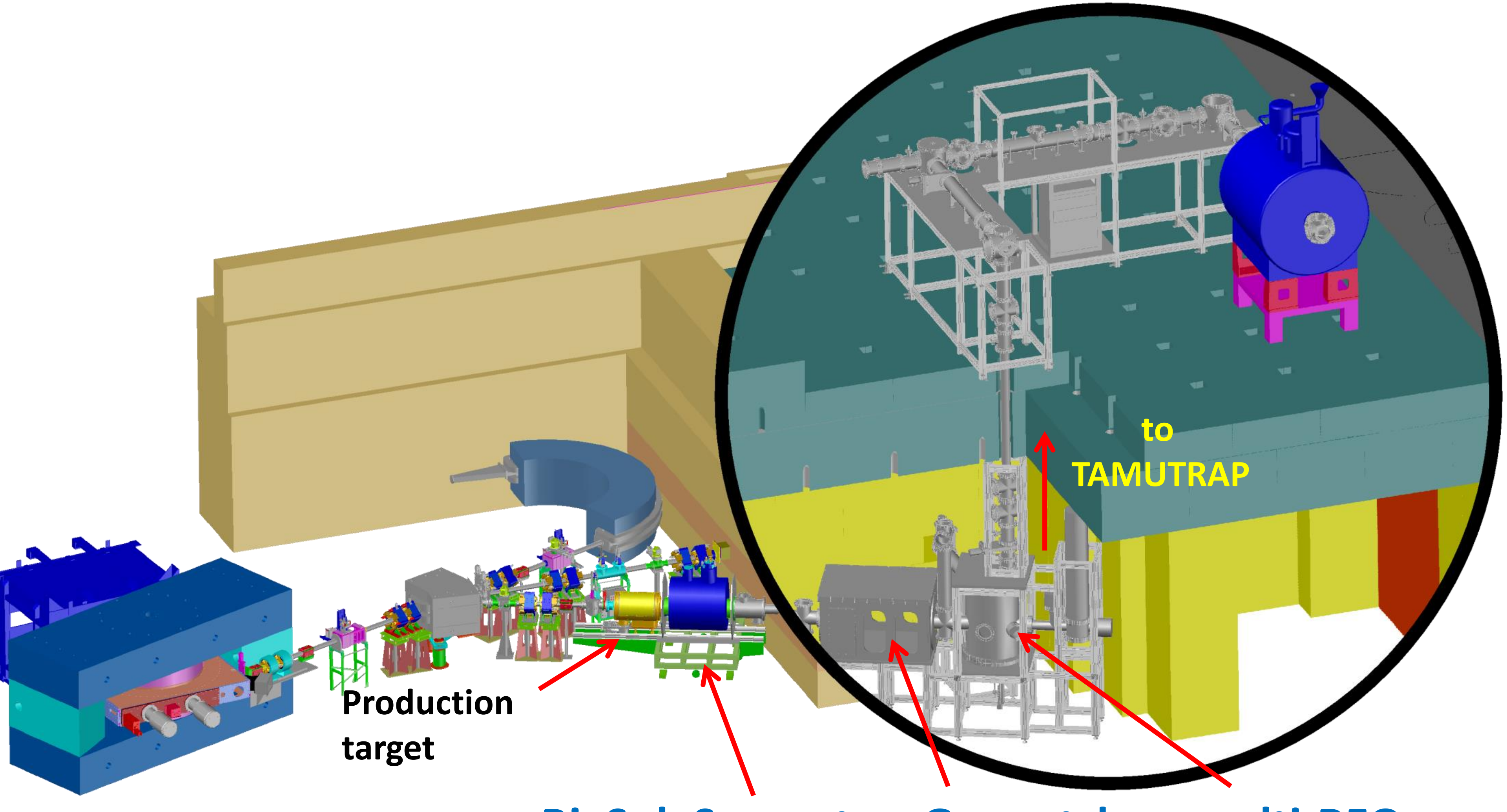




Adelberger E.G. et al. Phys. Rev. Lett. 1299 ***83*** *(1999)*



Coupling of T-REX to TAMUTRAP facility



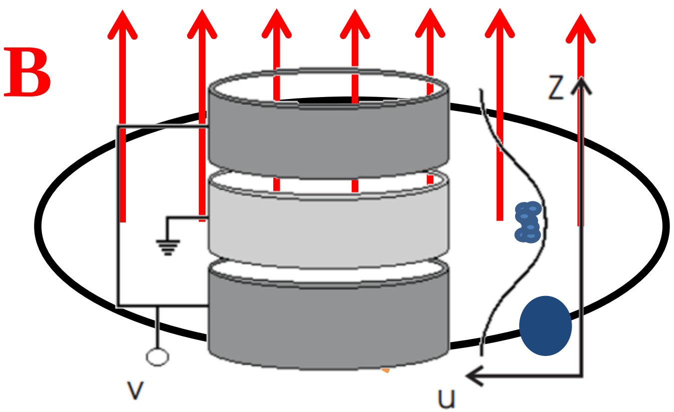
BigSol, Separator; Gas-catcher; multi-RFQ

Or

Light Ion Guide; 90^0 bending magnet (purification)

Ion Traps

Penning Trap

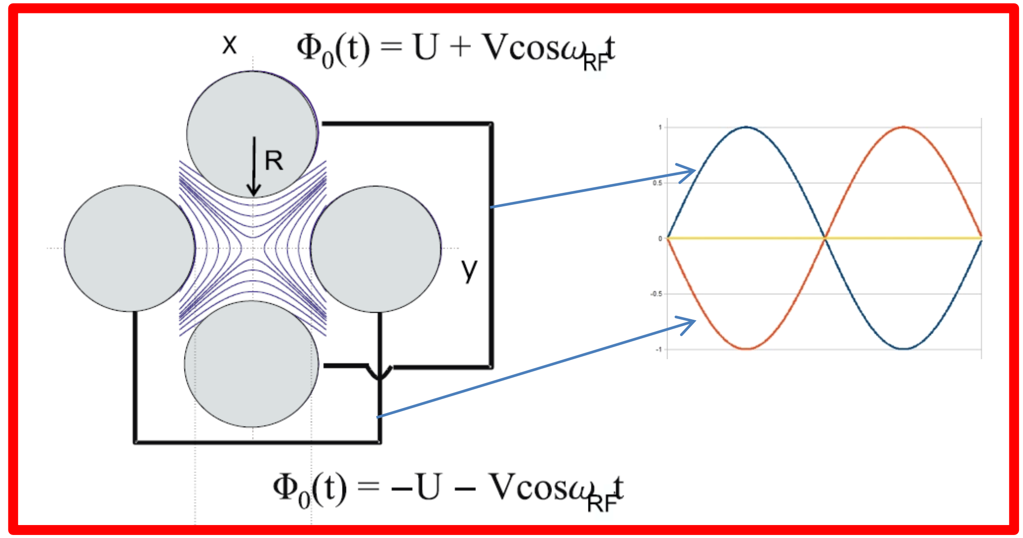


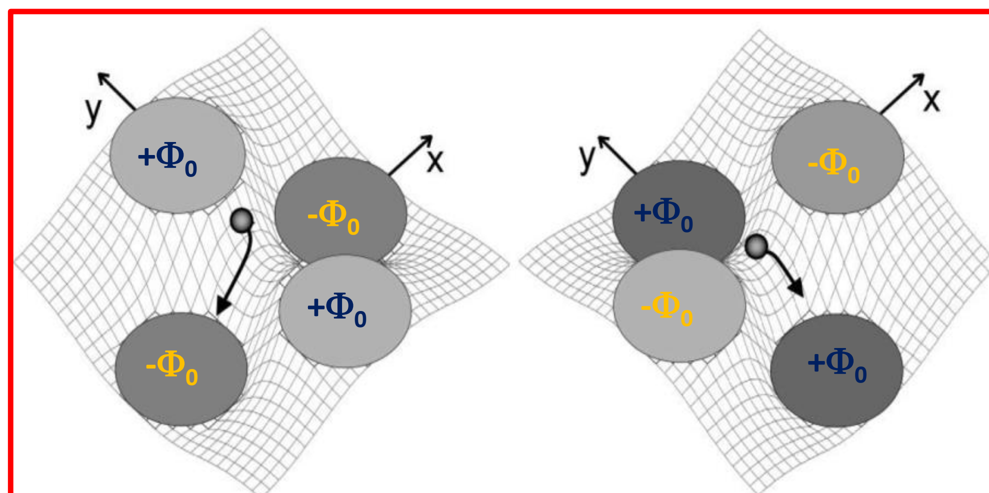
Radial confinement of ions (Linear Magnetic field)

+

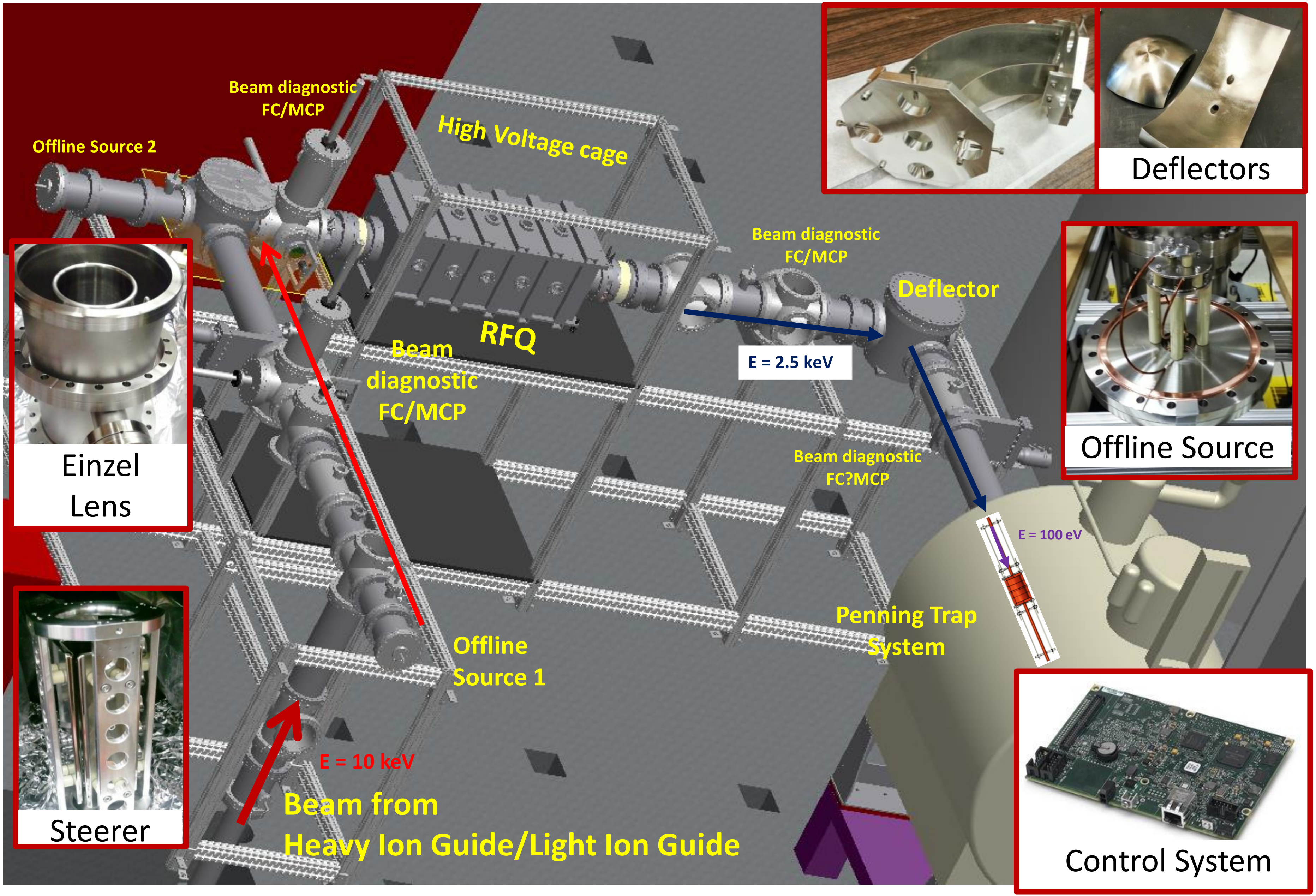
Trapping ions in one dimension (Electrostatic field)

Paul Trap

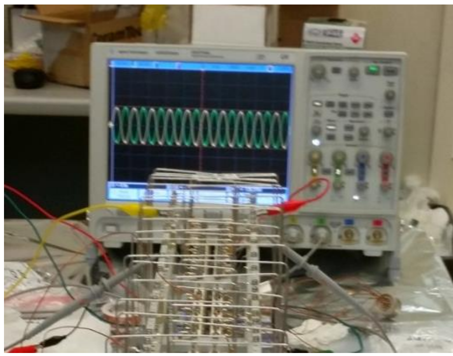


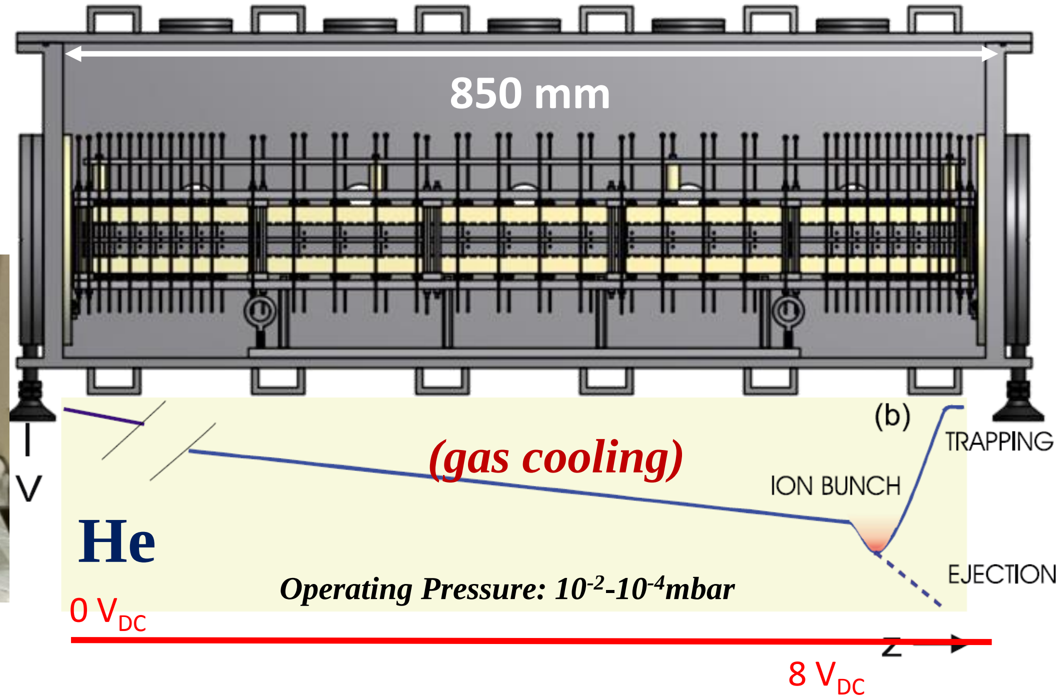


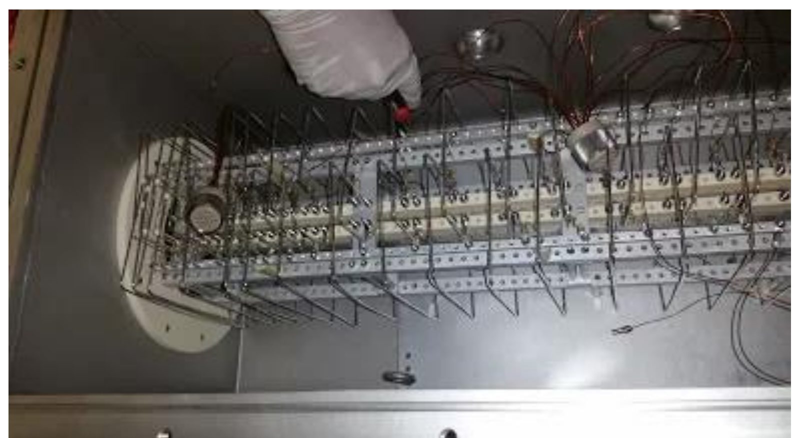
Commissioning of TAMUTRAP facility



TAMUTRAP: Cooler/Buncher



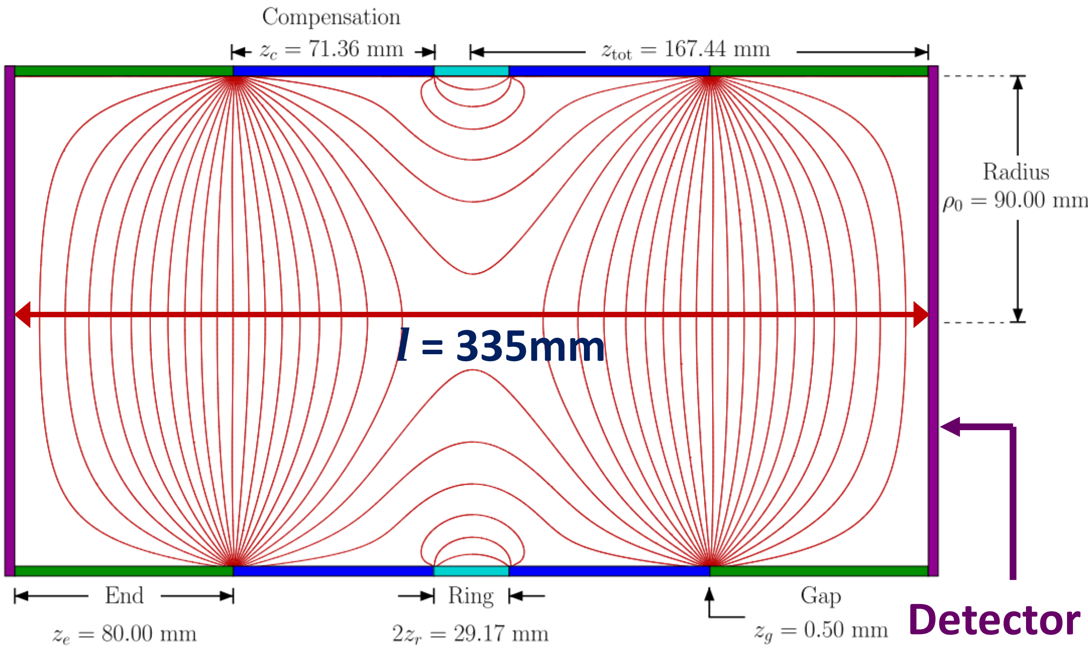




M. Mehlmann (Ph.D. Thesis)

TAMUTRAP: Penning Trap

Cylindrical Penning Trap



*M. Mehlman et al. NIMA **712** (2013) 9*

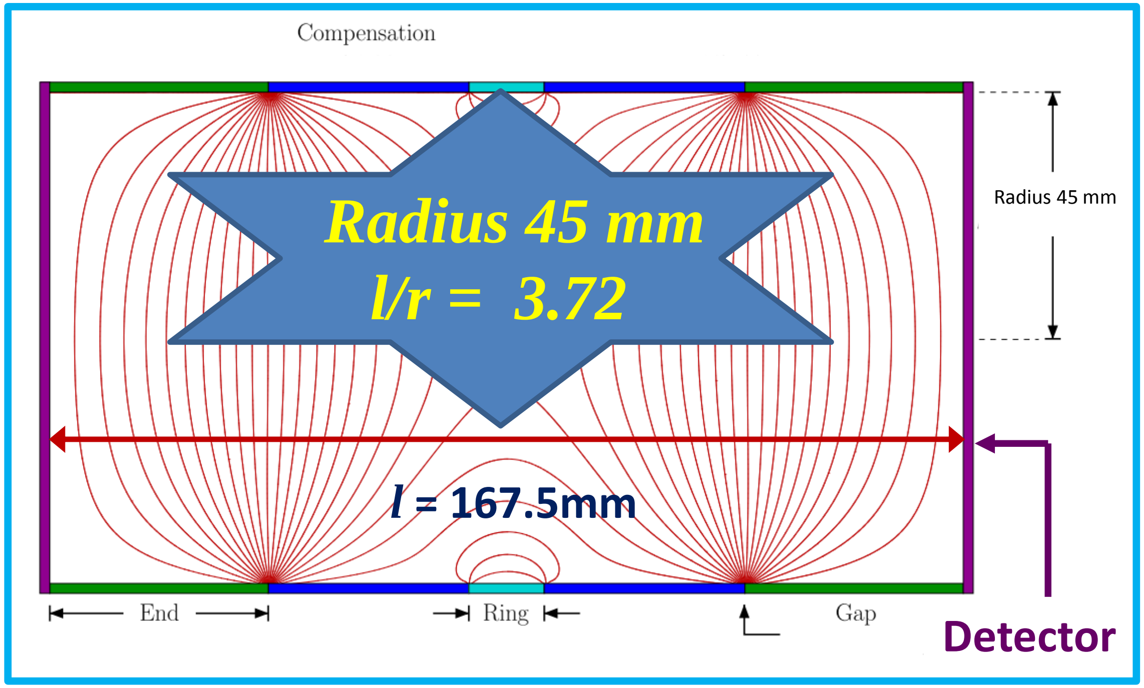
Nuclide	Lifetime (ms)	Proton Energy (MeV)	Larmour radii (mm)
^{20}Mg	137.05	4.28	42.7
^{24}Si	147.15	3.91	40.8
^{28}S	180.33	3.70	39.7
^{32}Ar	141.38	3.36	37.8
^{36}Ca	141.15	2.55	33.0
^{40}Ti	72.13	3.73	39.9
^{48}Fe	63.48	1.23	22.9

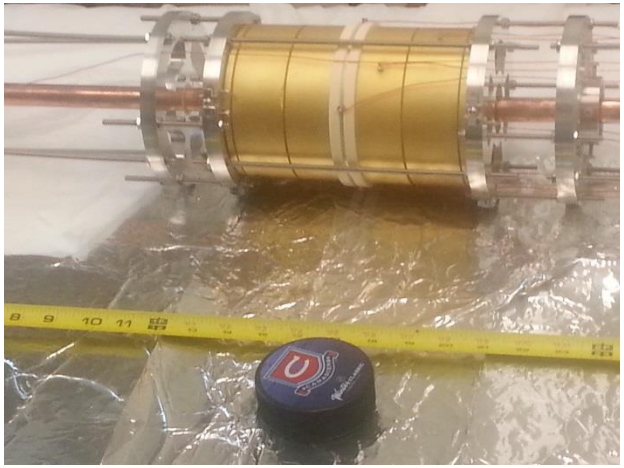
Other existing Cylindrical Penning Trap

Radius : 90 mm
l/r = 3.72

l/r = 11.75

Prototype Penning Trap(Commissioned)

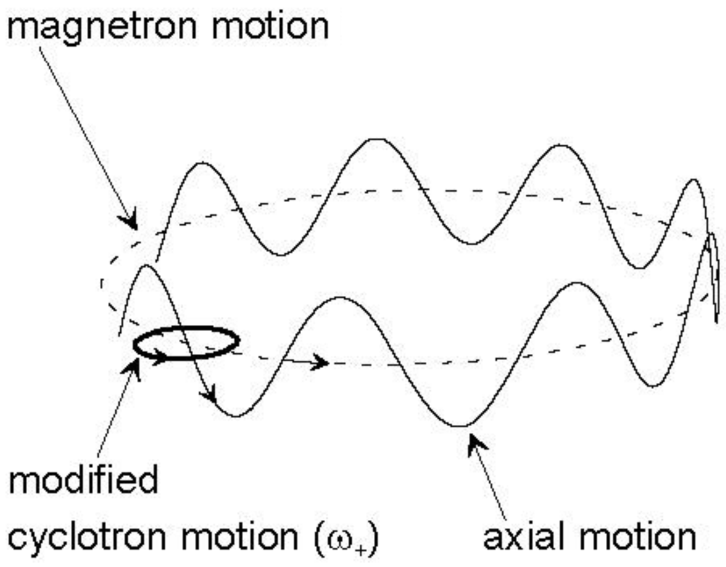




Ion motion in Penning trap

Three characteristic harmonic motions:

- **axial motion (frequency f_z)**
- **magnetron motion (frequency f_-)**
- **modified cyclotron motion (frequency f_+)**



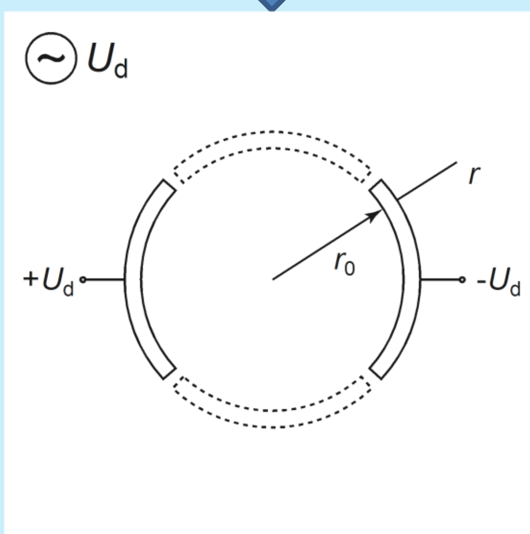
$$f_- + f_+ = f_c \ ; \quad where\ \ f_c = \frac{1}{2}\cdot\frac{q}{m}\cdot B$$

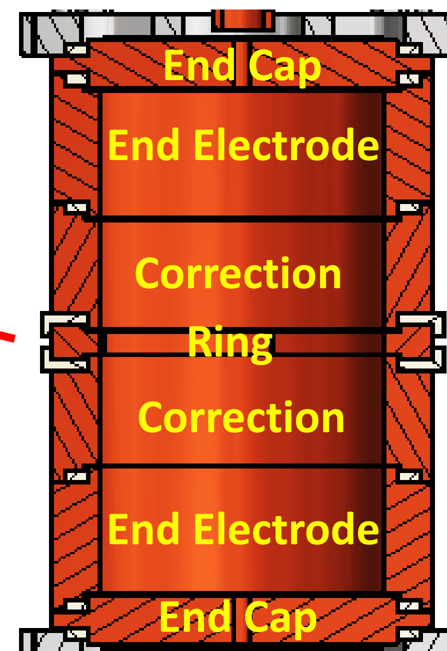
Mass measurement

Time-of-flight resonance technique

Dipolar radial excitation at f_-

$\Rightarrow$ increase of r_-





Mass measurement

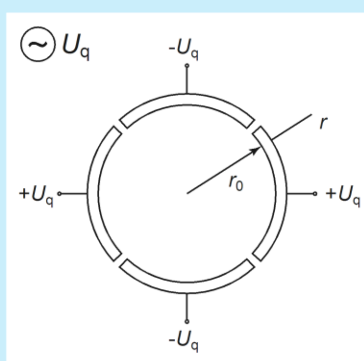
Time-of-flight resonance technique

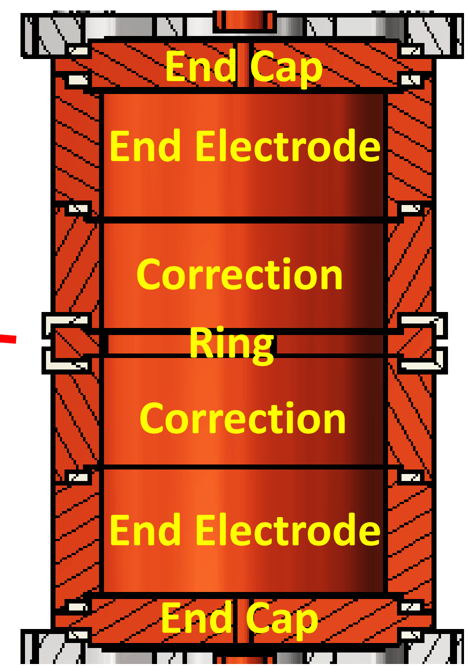
Dipolar radial excitation at f_-

$\Rightarrow$ increase of r_-

Quadrupolar radial excitation near f_c

$\Rightarrow$ coupling of radial motions, conv.





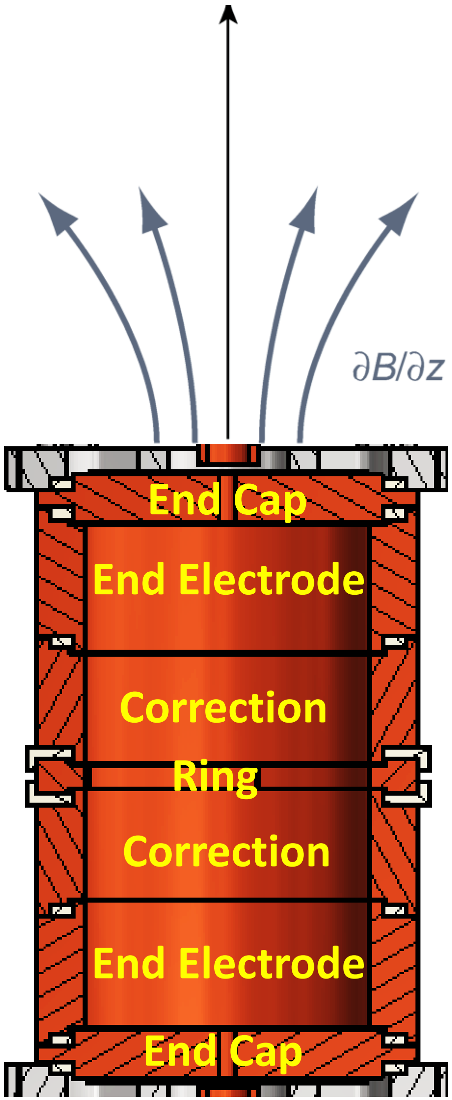
Mass measurement

Time-of-flight resonance technique

Dipolar radial excitation at f_-
$\Rightarrow$ increase of r_-

Quadrupolar radial excitation near f_c
$\Rightarrow$ coupling of radial motions, conv.

Ejection along the magnetic field lines
$\Rightarrow$ radial energy converted to axial energy



Mass measurement

Time-of-flight resonance technique

Dipolar radial excitation at f_-
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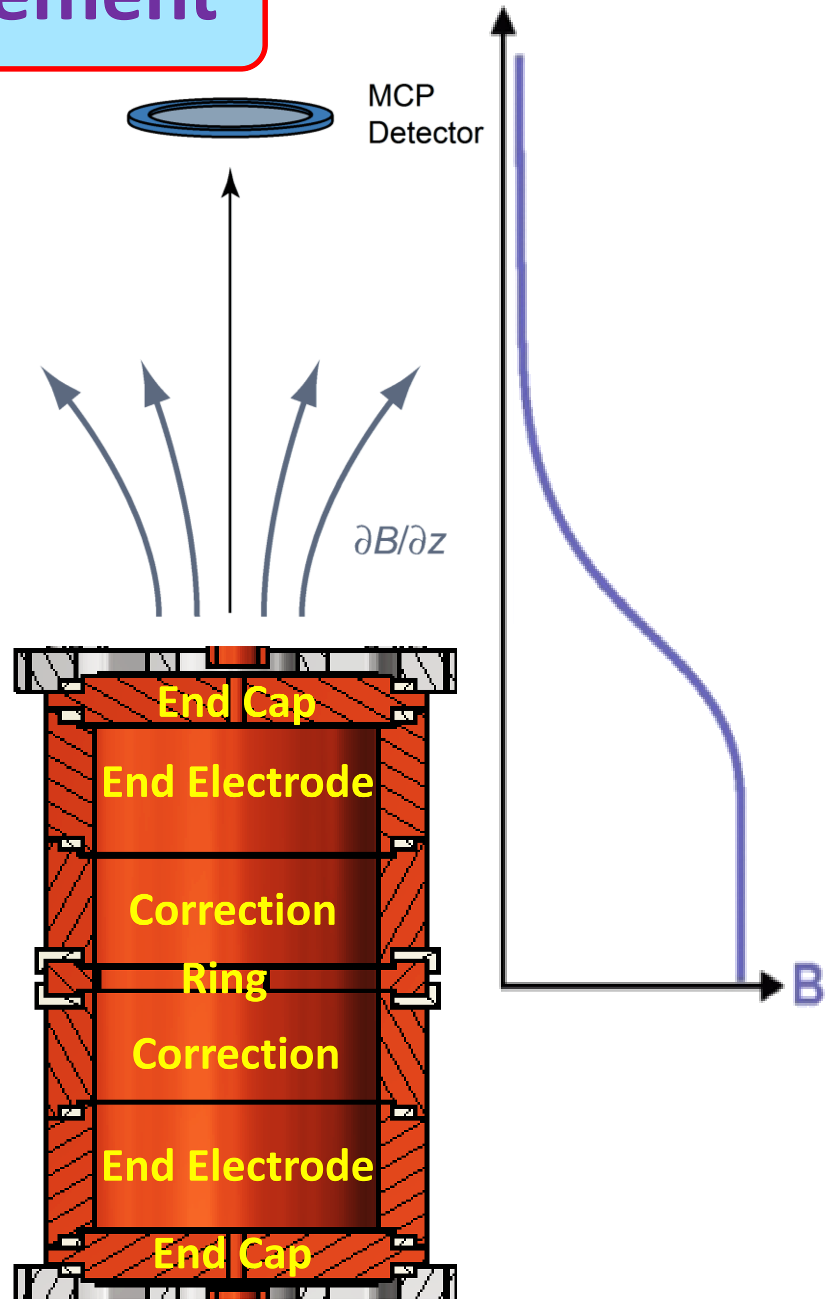
Time-of-flight (TOF) measurement



Mass measurement

Time-of-flight resonance technique

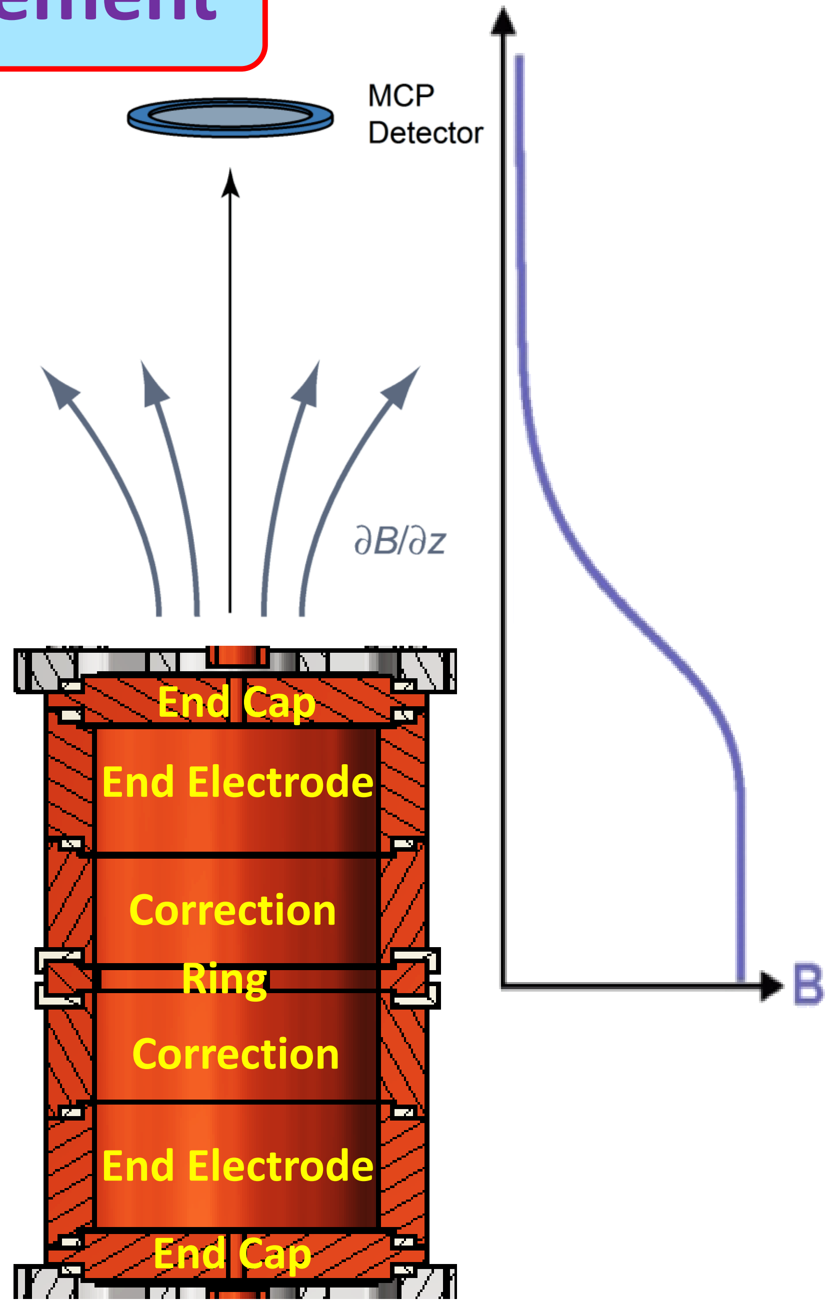
Scan of excitation frequency

Dipolar radial excitation at f_-
$\Rightarrow$ increase of r_-

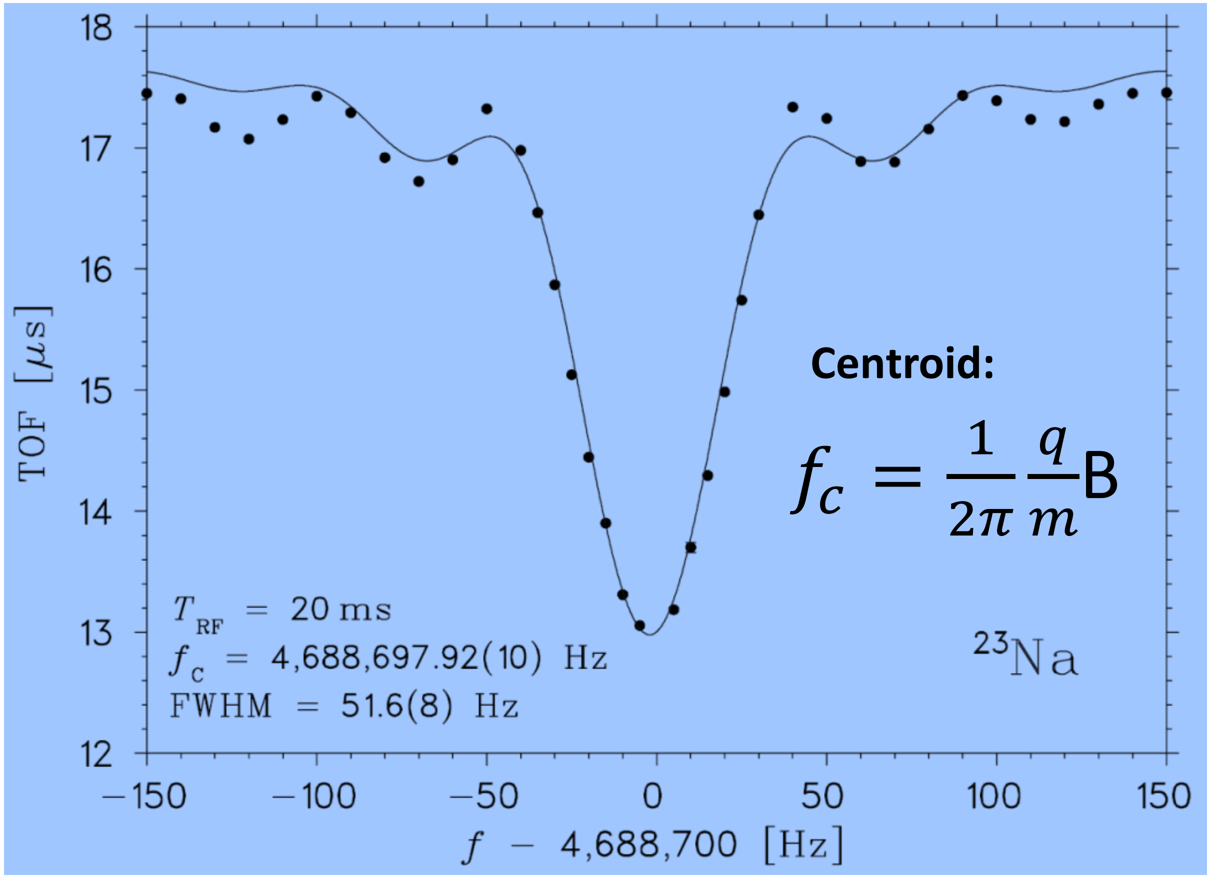
Quadrupolar radial excitation near f_c
$\Rightarrow$ coupling of radial motions, conv.

Ejection along the magnetic field lines
$\Rightarrow$ radial energy converted to axial energy

Time-of-flight (TOF) measurement



TOF as a function of the excitation frequency



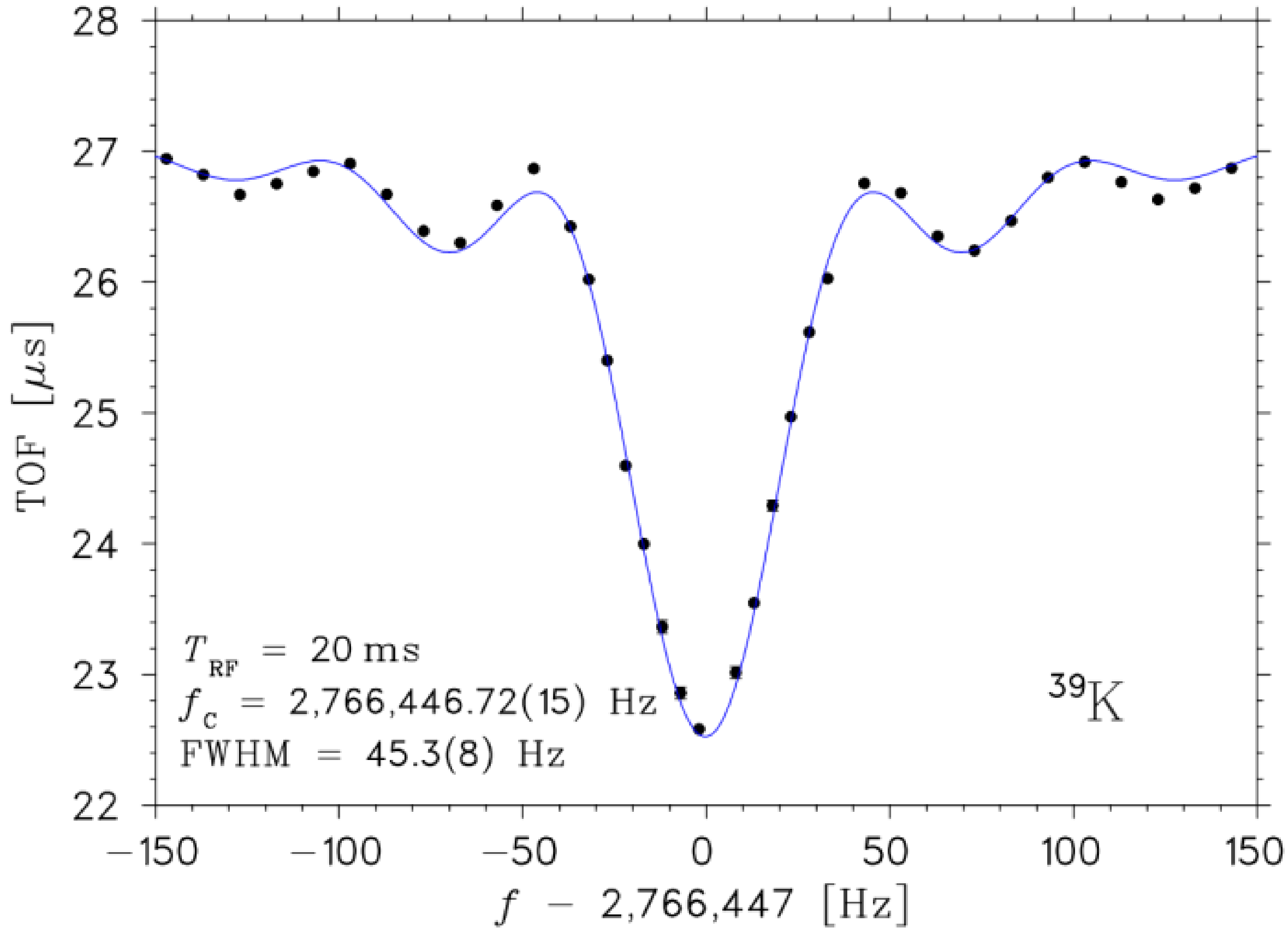
Centroid:

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

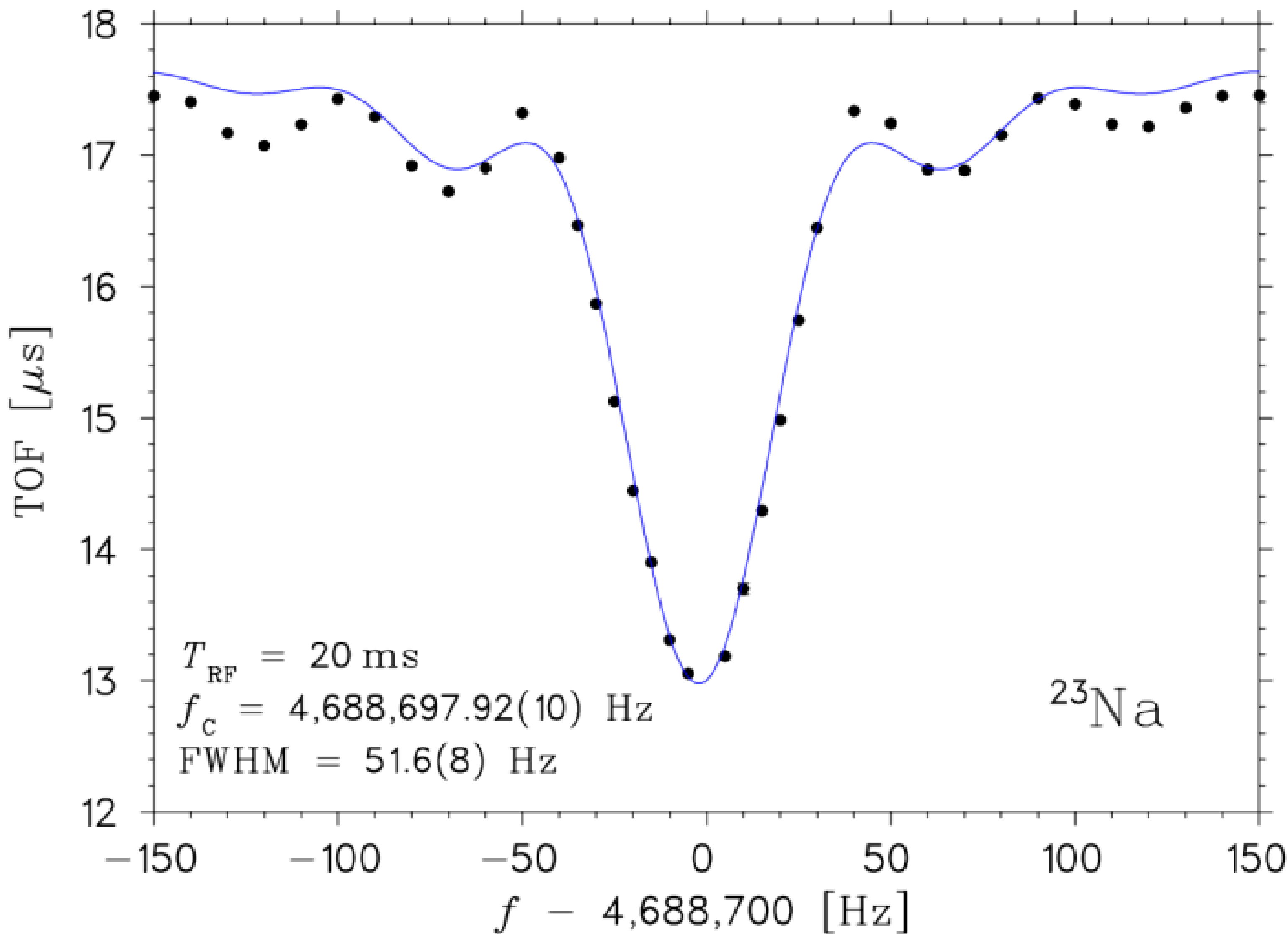
Determine atomic mass from frequency ratio:

$$(2\pi f_{c\,ref}) = \frac{q_{ref}B}{m_{ref}};\ (2\pi f_c) = \frac{qB}{m};\ m = (m_{ref})\left(\frac{f_{c\,ref}}{f_c}\right)$$

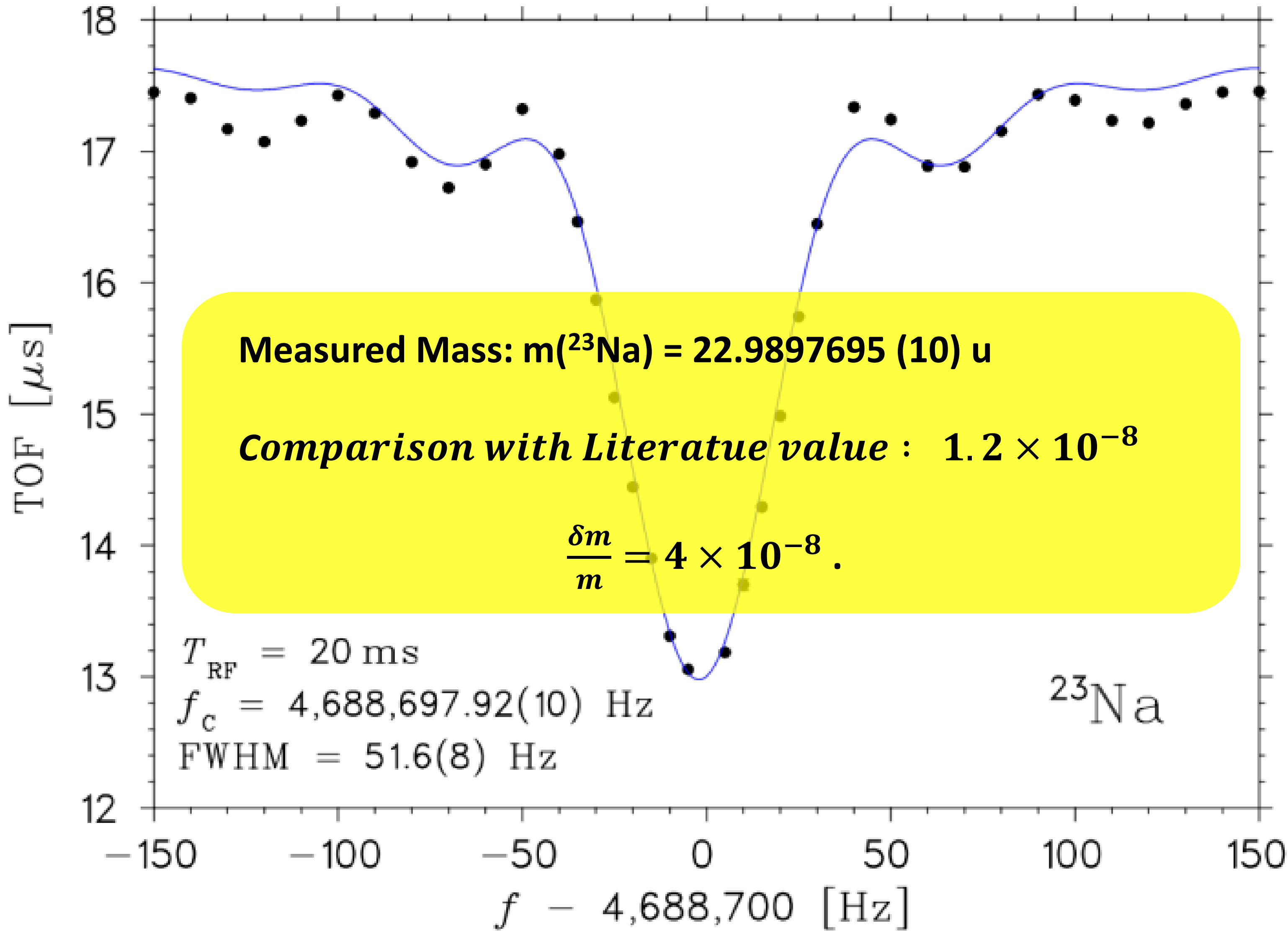
Reference mass: ^{39}K



Measured mass: ^{23}Na



Measured mass: ^{23}Na



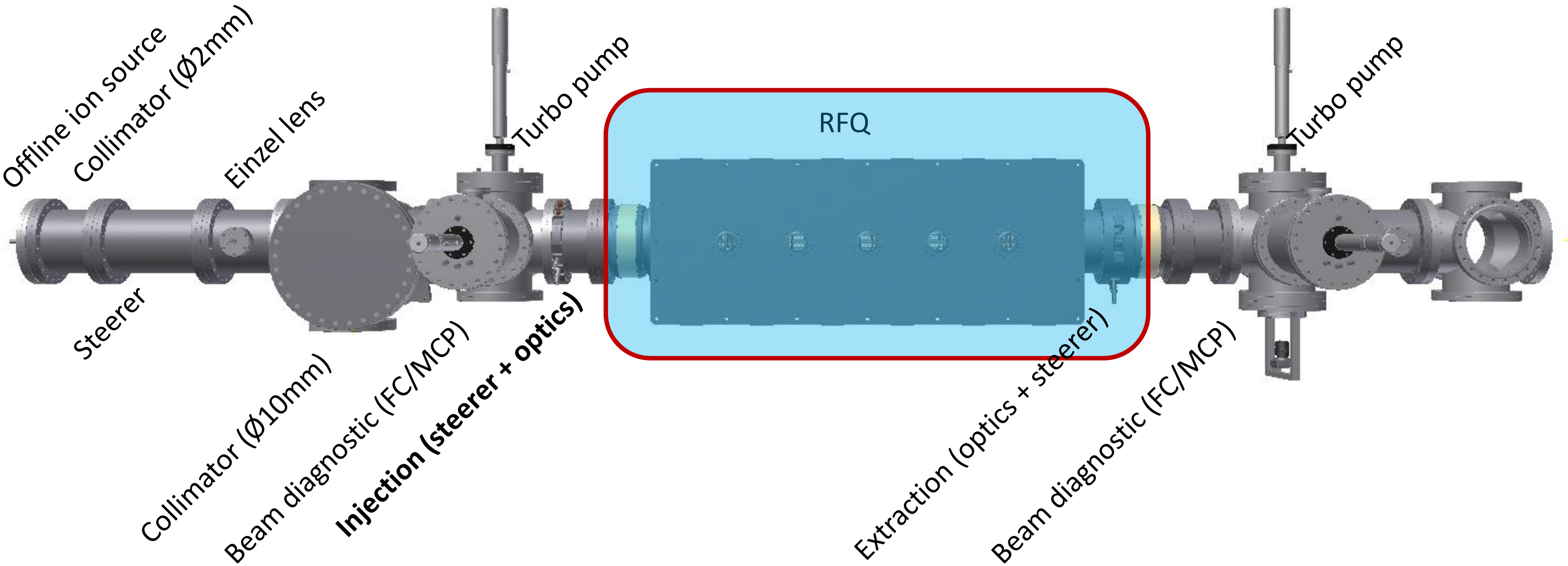
Measured Mass: m(^{23}Na) = 22.9897695 (10) u

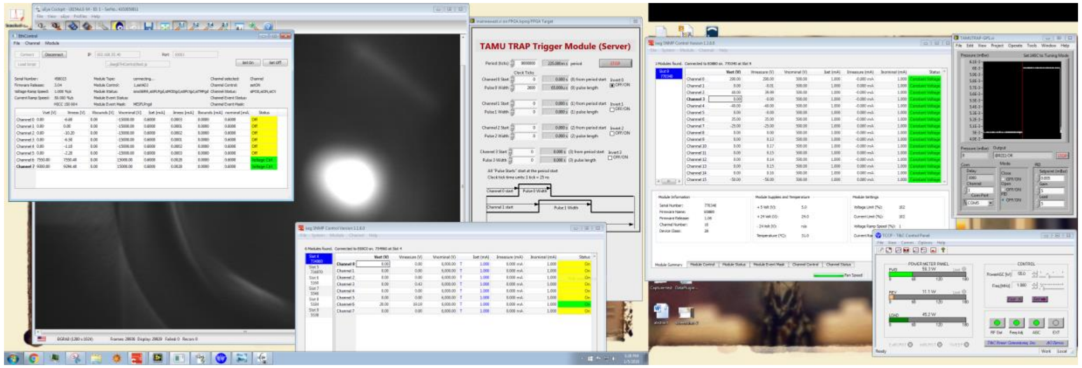
Comparison with Literatue value : $\mathbf{1.2 \times 10^{-8}}$

$$\frac{\delta m}{m} = 4 \times 10^{-8}\,.$$

Transport Efficiency

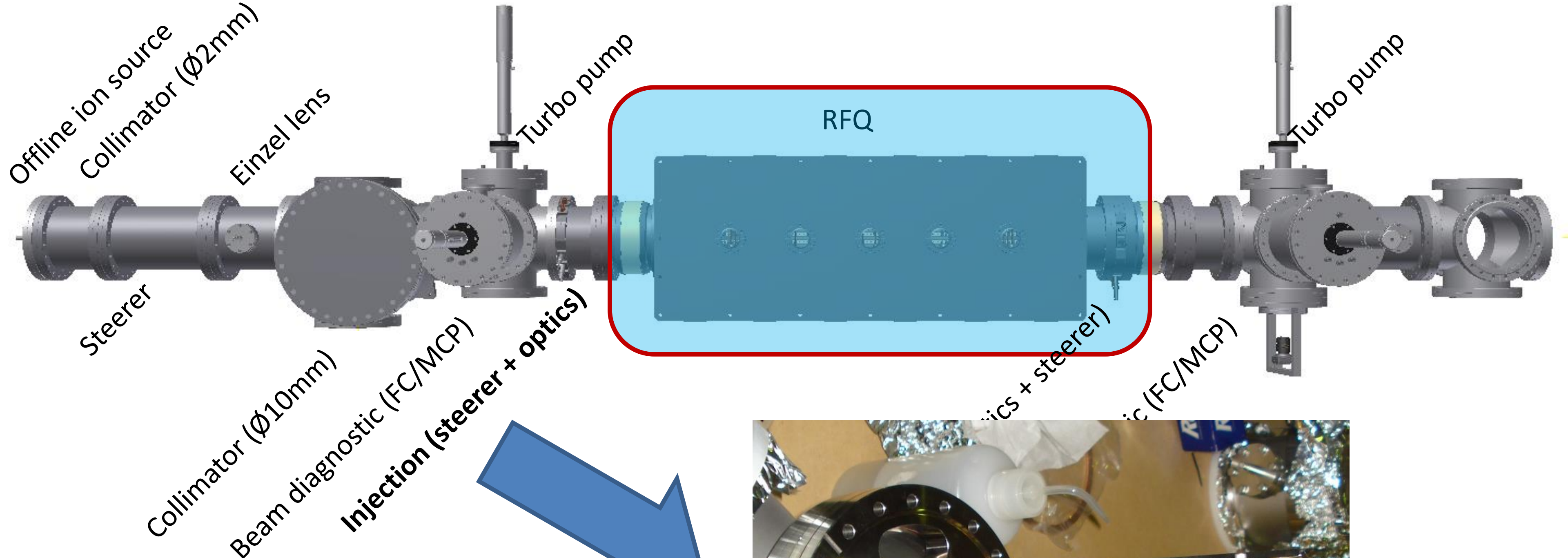
- RFQ efficiency ≈ 70% -75 % (Continuous Mode)

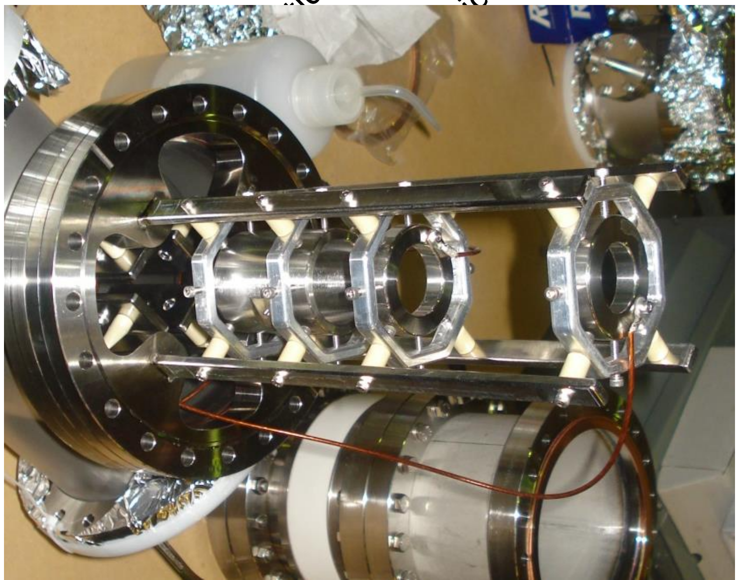




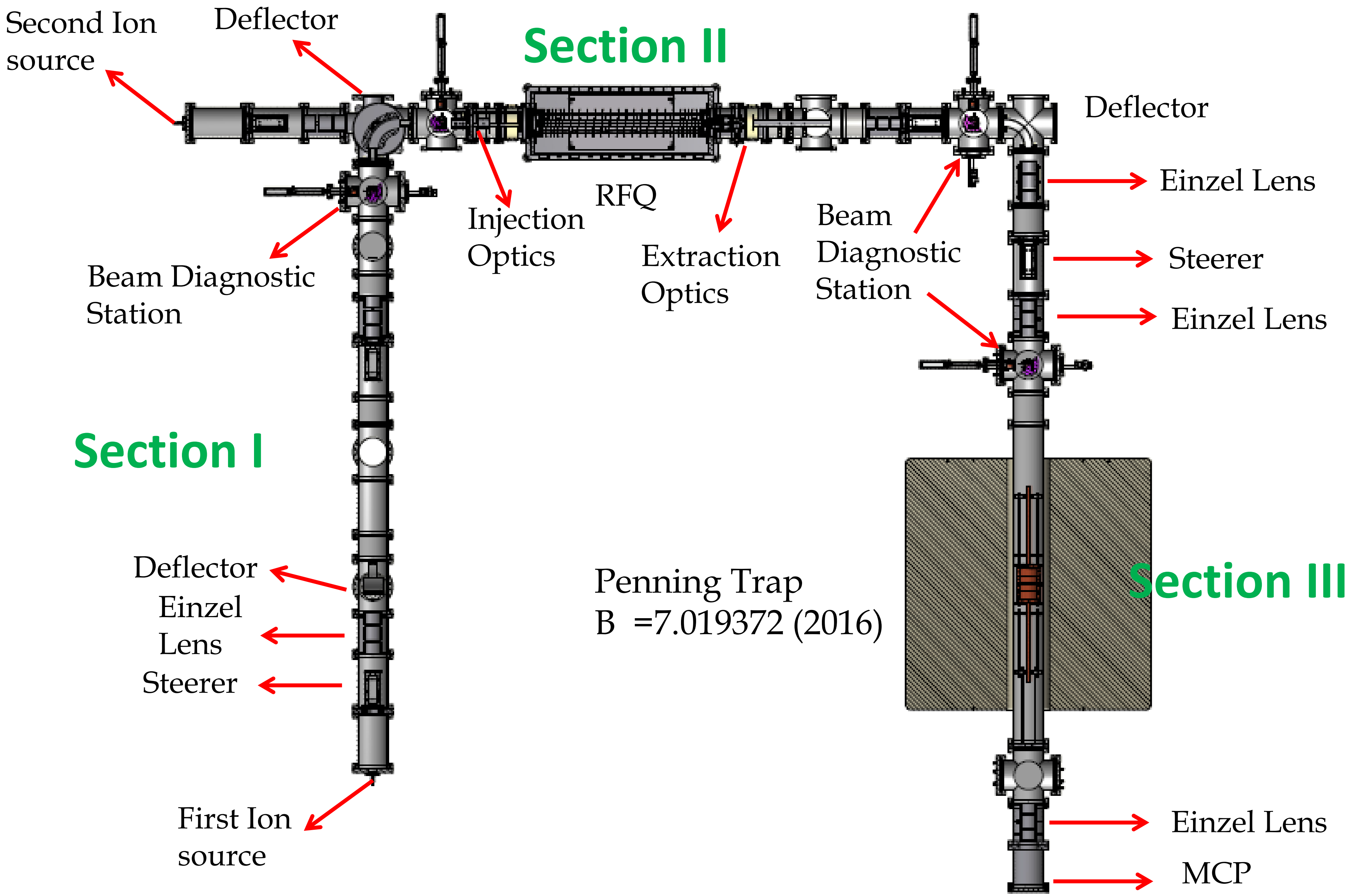
TAMUTRAP: Transport Efficiency

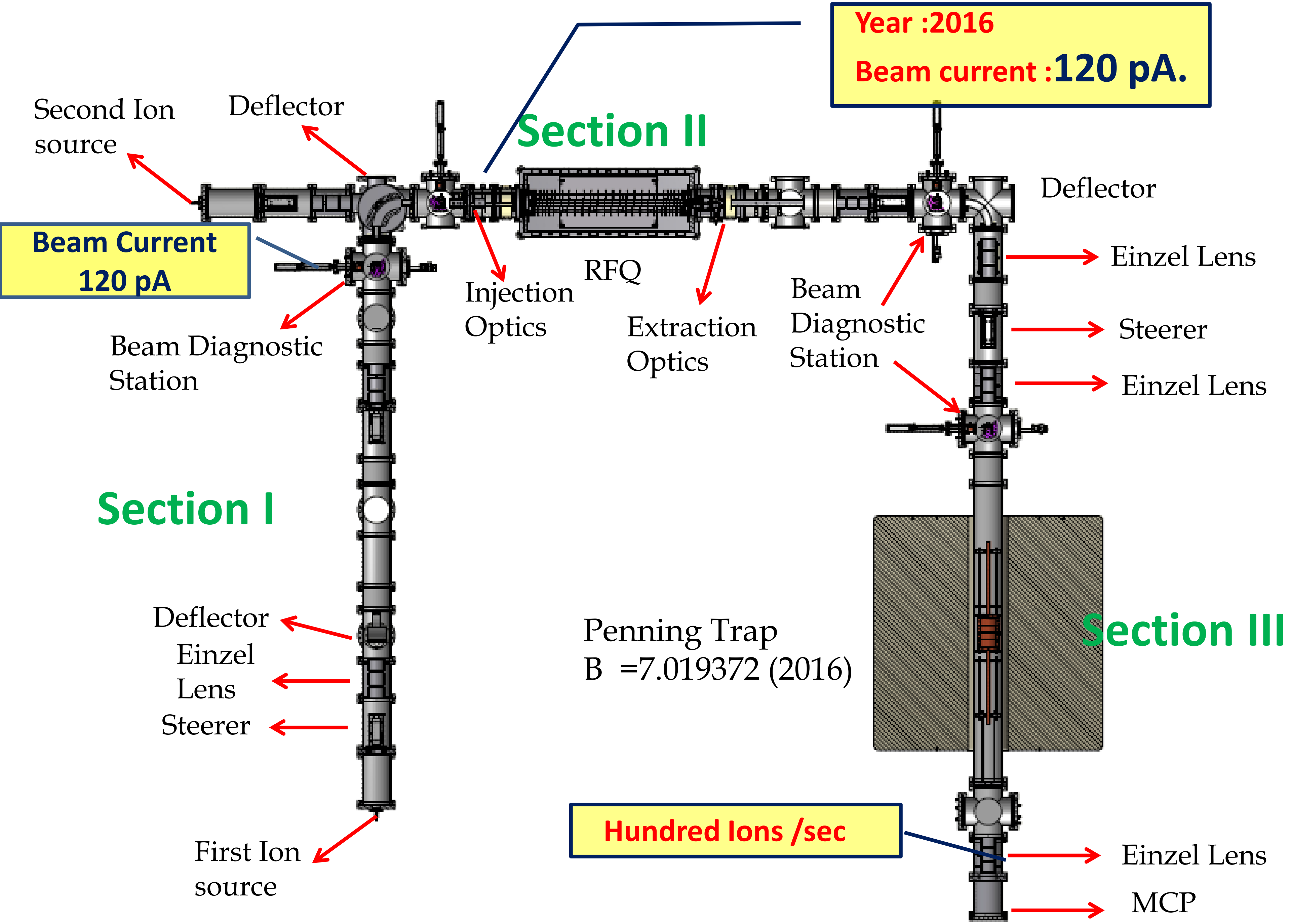
➢ **Injection optics Efficiency : 80% -85 %**



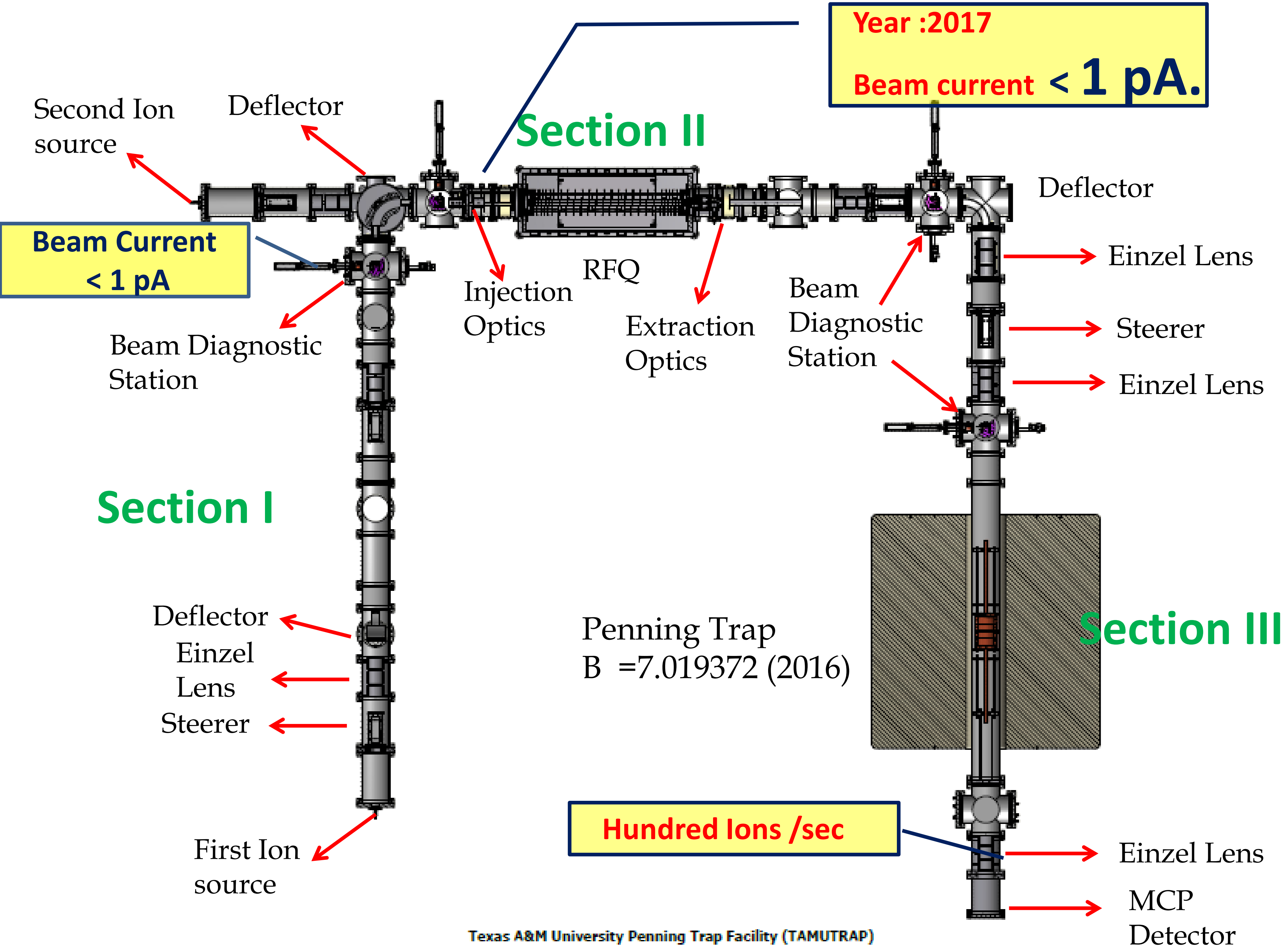


TAMUTRAP: Transport Efficiency

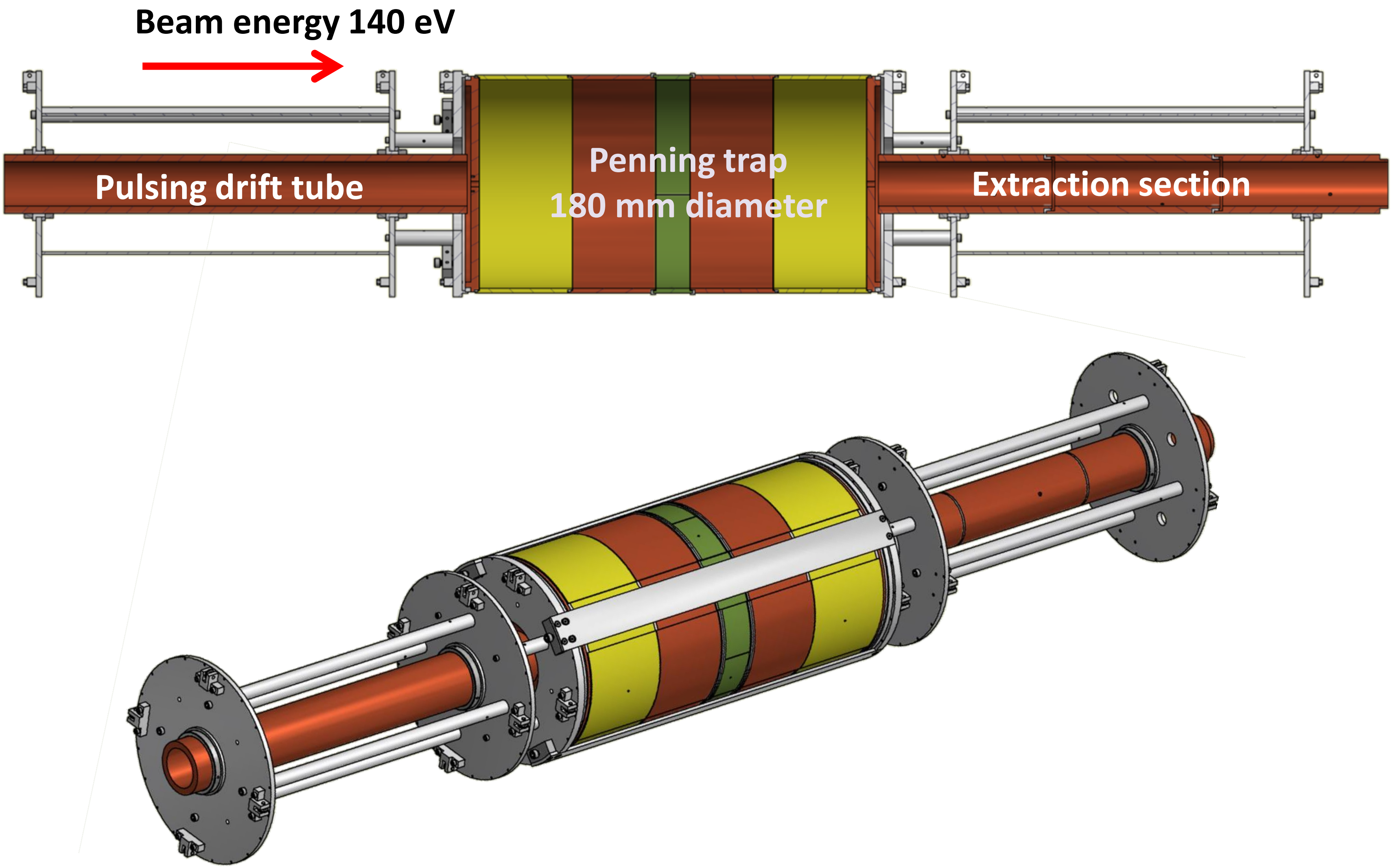




Texas A&M University Penning Trap Facility (TAMUTRAP)

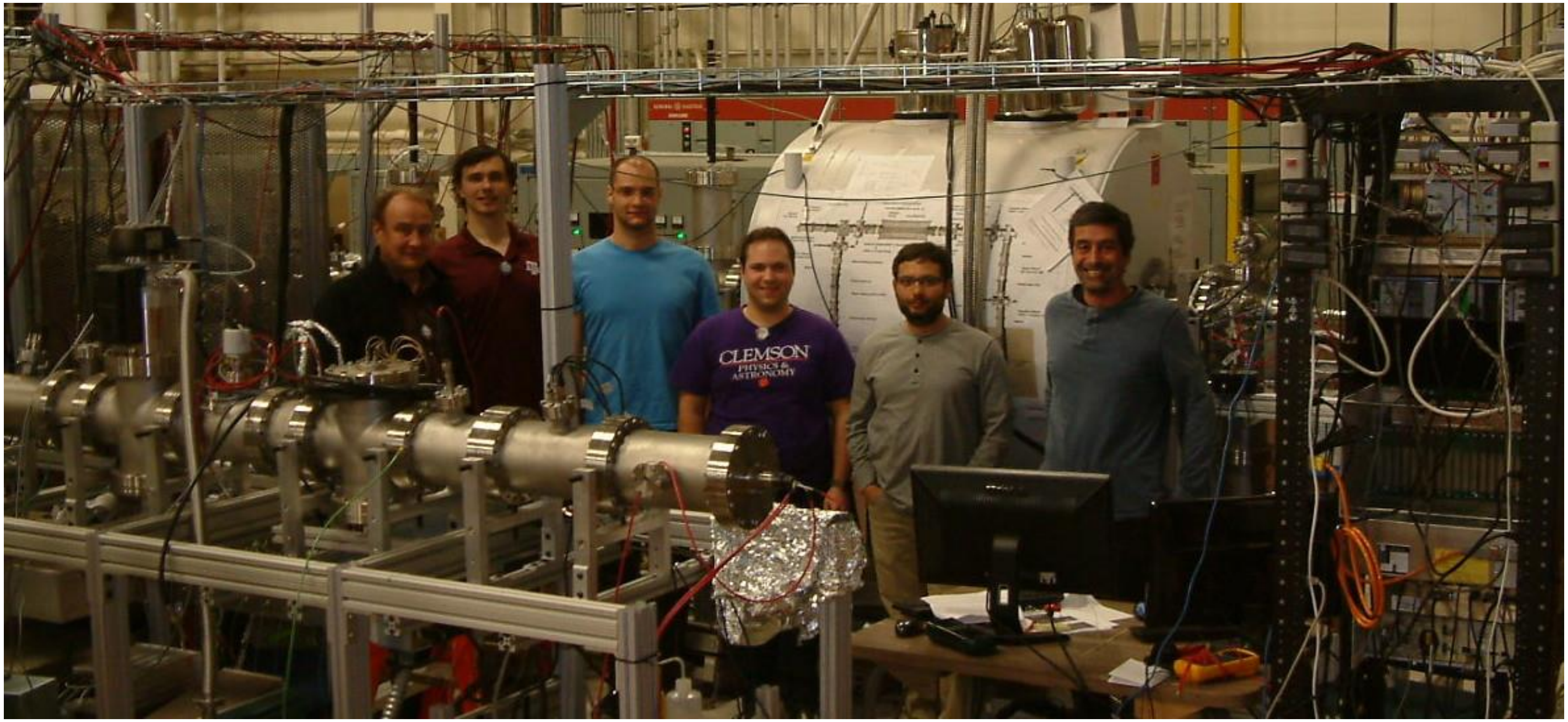

Year :2017
Beam current < 1 pA.
Section II
Second Ion source
Deflector
Beam Current < 1 pA
Beam Diagnostic Station
Injection Optics
RFQ
Extraction Optics
Beam Diagnostic Station
Deflector
Einzel Lens
Steerer
Einzel Lens
Section I
Deflector
Einzel Lens
Steerer
First Ion source
Penning Trap
B =7.019372 (2016)
Section III
Hundred Ions /sec
Einzel Lens
MCP Detector
Texas A&M University Penning Trap Facility (TAMUTRAP)

TAMUTRAP Penning trap system (180 mm diameter)



Future outlook

- Install Penning Trap system (180 mm) by September 2018.
- Complete GEANT4 simulation and finalize the detectors.
- Couple TAMUTRAP facility to HIG/LIG.
- Begin RIB Program.



Thank you

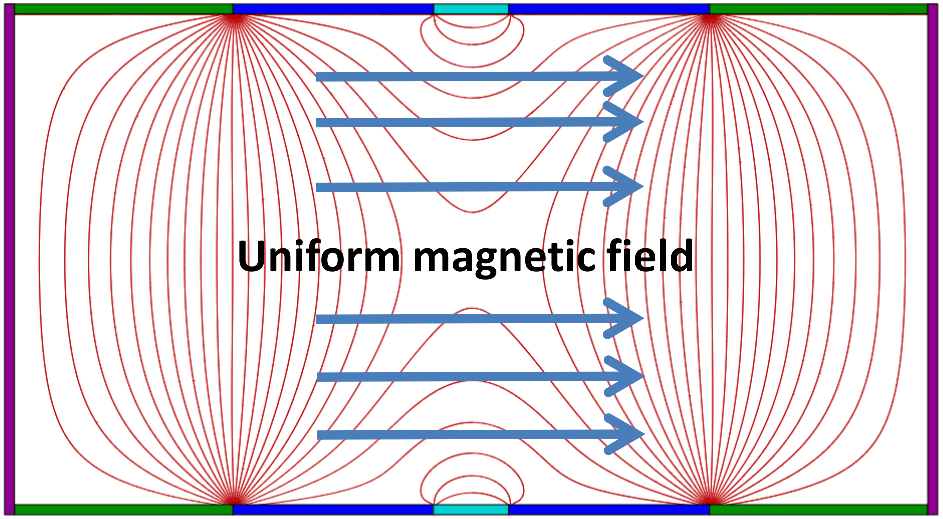
Calculating ^{32}Ar requirements		DOWN
Element	Efficiency (%)	Rate After Element (p/s)
Measurement trap	100	250
Beamline	95	250
Purification Trap	100	263
Beamline	95	263
RFQ (bunched mode)	50	277
Beamline	95	554
Magnet (coarse selection)	100	583
Multi-RFQ	80	583
Gas catcher	15	729
Big Sol	35	4,860
Production	100	13,886

Table 1. – Expected 88" beam intensities and energies assuming ECR2 type source, K=140 and 25% transmission.

Isotope	*Energy* MeV/u	*Intensity* pμA		*Isotope*	*Energy* MeV/u	*Intensity* pμA
p	55	27 (14)		^{20}Ne	28	3.0 (1.5)
d	35	21 (10.5)		^{22}Ne	29	0.5 (0.25)
^{3}He	45	11 (5.5)		^{34}S	20	0.7 (0.35)
^{4}He	35	10 (5.0)		^{40}Ar	17	1.4 (0.7)
^{6}Li	35	7 (3.5)		^{40}Ca	17	1.5 (0.75)
^{7}Li	25	8 (4.0)		^{59}Co	11	0.9 (0.45)
^{10}B	35	4 (2.0)		^{78}Kr	10	0.6 (0.3)
^{11}B	29	4.7 (2.35)		^{86}Kr	8.3	0.6 (0.3)
^{16}O	35	2.3 (1.15)		^{129}Xe	5.6	0.5 (0.25)

RIB	Beam	Beam Energy (E/A)(MeV)	Target Thickness (mg/cm²)	Beam Current (pnA)	Production Rate (p/s) (Target chamber)
^{32}Ar	^{32}S	20 – 24 MeV/u	22.5 mg/cm² (42 mg/cm²)	350 (700)	4.55×10^4 (1.7×10^5)
^{28}S	^{28}Si	22 -30 MeV/u	22.5 mg/cm² (60 mg/cm²)	600 (1200)	7.45×10^4 (3.97×10^5)
^{24}Si	^{24}Mg	22-30 MeV/u	22.5mg/cm² (70 mg/cm²)	600 (1200)	2.6×10^5 (1.6×10^6)
^{20}Mg	^{20}Ne	23 -30 MeV/u	22.5mg/cm² (66 mg/cm²)	1500 (3000)	6.8×10^5 (4.0×10^6)
^{36}Ca	^{36}Ar	23-30 MeV/u	22.5mg/cm² (28 mg/cm²)	700 (1400)	1.25×10^5 (3.1×10^5)
^{40}Ti	^{40}Ca	23-30MeV/u	22.5mg/cm² (26 mg/cm²)	750 (1500)	3.6×10^4 (8.4×10^4)

β-ν correlation measurements

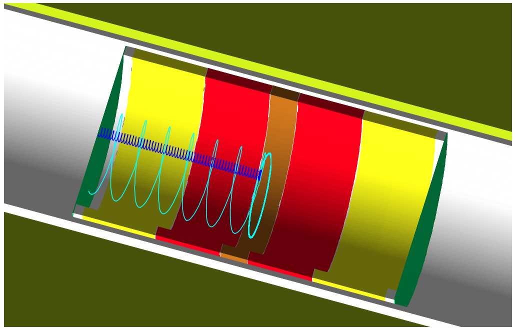


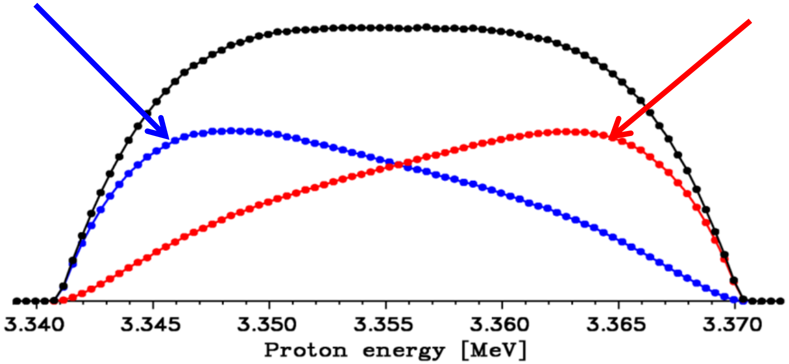
Penning traps

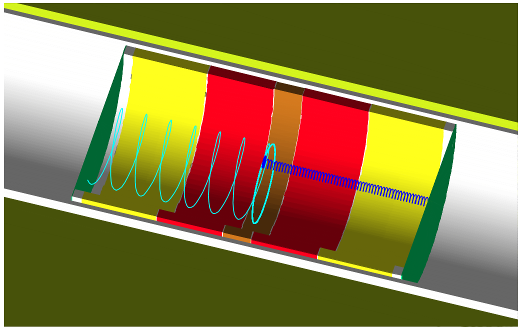
- *Increase solid angle.*
- *Increase sensitivity.*
- *Allows to detect e along with p*

Beta & Proton in same hemisphere

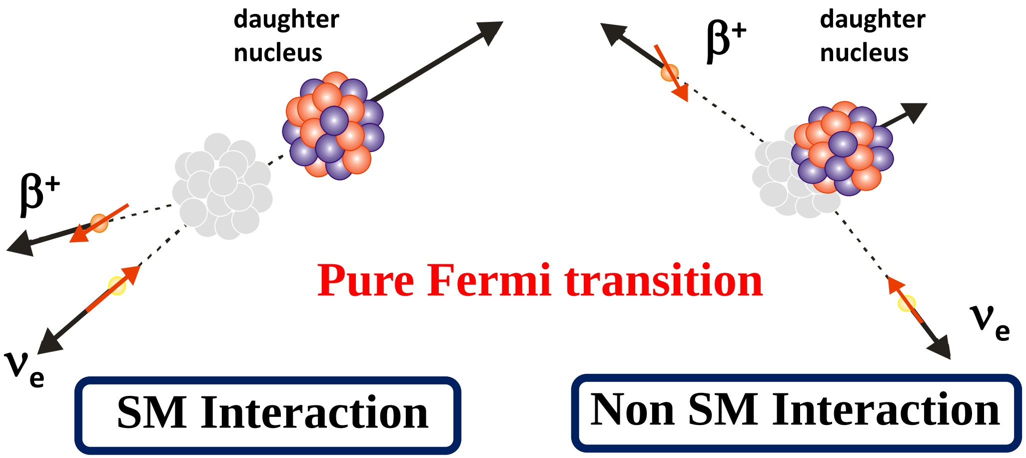
Beta & Proton in different hemisphere

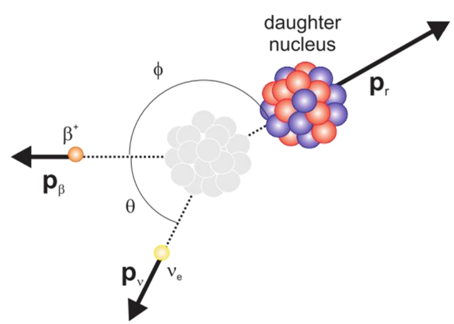






How do we plan to test the Standard Model (SM) ?





$$W(\theta) \cong \left(1 + a_{\beta\nu}\frac{p_e\, p_\nu}{E_e\, E_\nu}\cos\theta_{e\nu} + b\frac{m_e}{E_e}\right)$$

β-ν angular correlation parameter

- Perform a β decay experiment on short-lived isotopes.
- Make a precision measurement of the angular correlation parameter.
- Compare the SM predictions to Observation.
- Look for *deviations* as an indication of new physics.

$$a_{\beta\nu} \stackrel{?}{=} 1$$

Test of SM