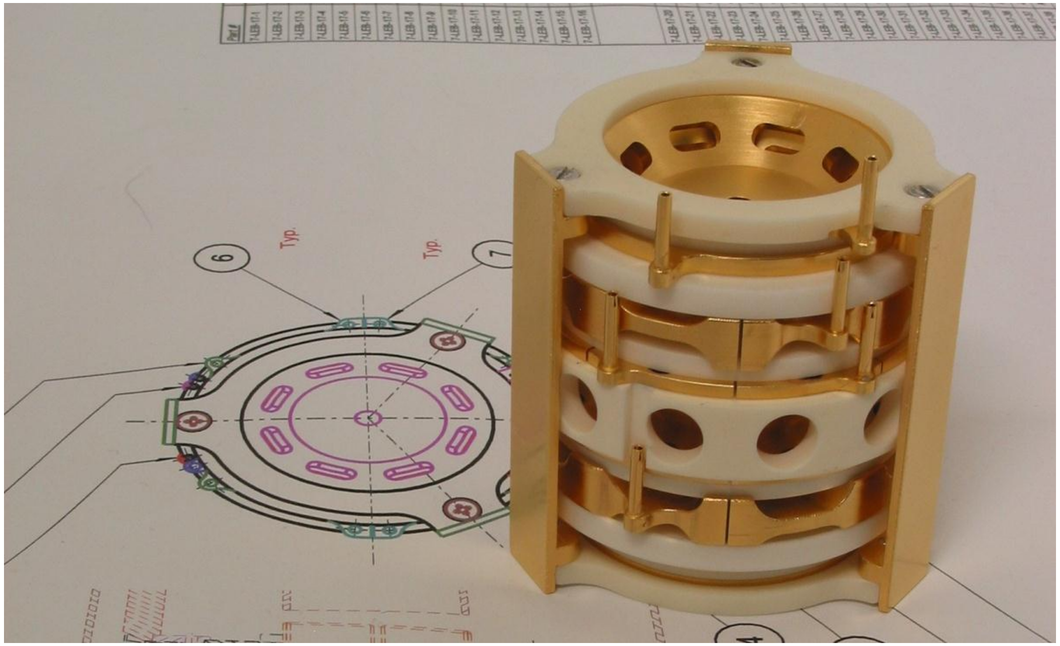
LEBIT II: Upgrades and Developments for High Precision Mass Measurements with Rare Isotopes



Matthew Redshaw, Central Michigan University

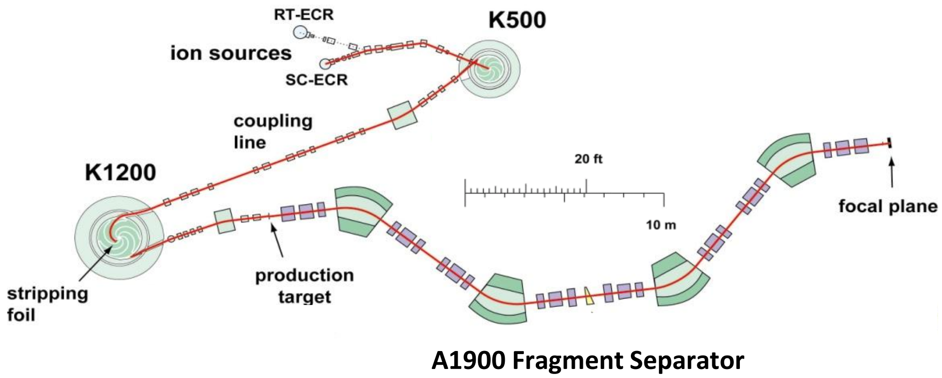
EMIS XVI, Matsue

Dec 7th 2012

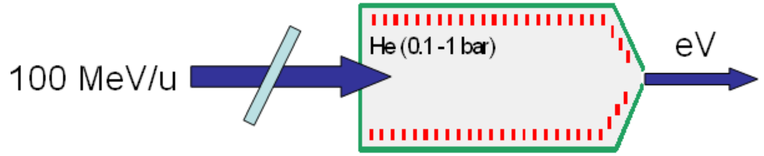
LEBIT:
Low Energy Beam and Ion Trap

Fast-beam Fragmentation

100 MeV/u

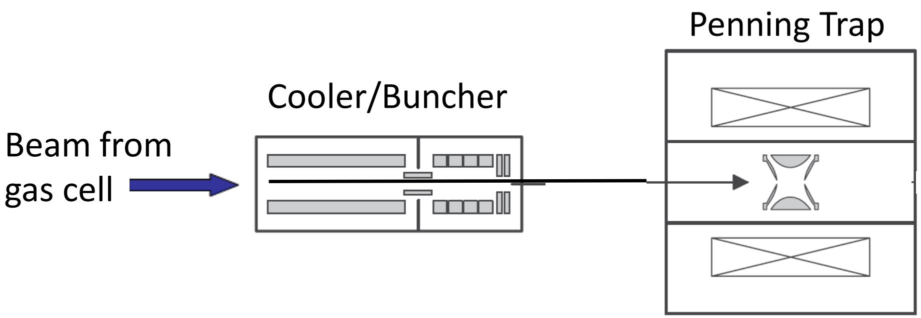


Gas Stopping



Penning Trap

~1 eV



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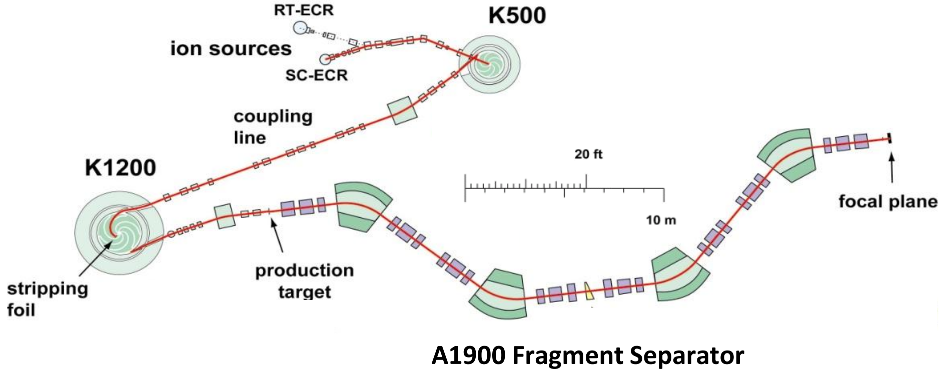
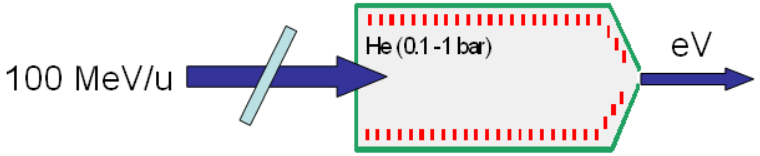
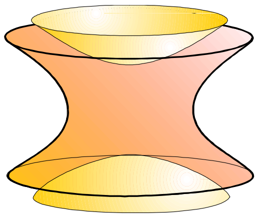


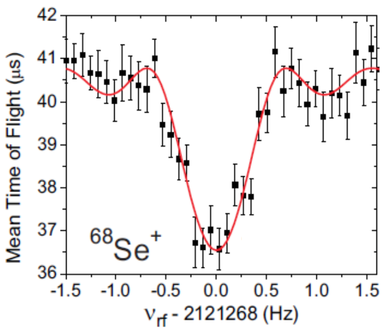
Gas Stopping



Penning Trap

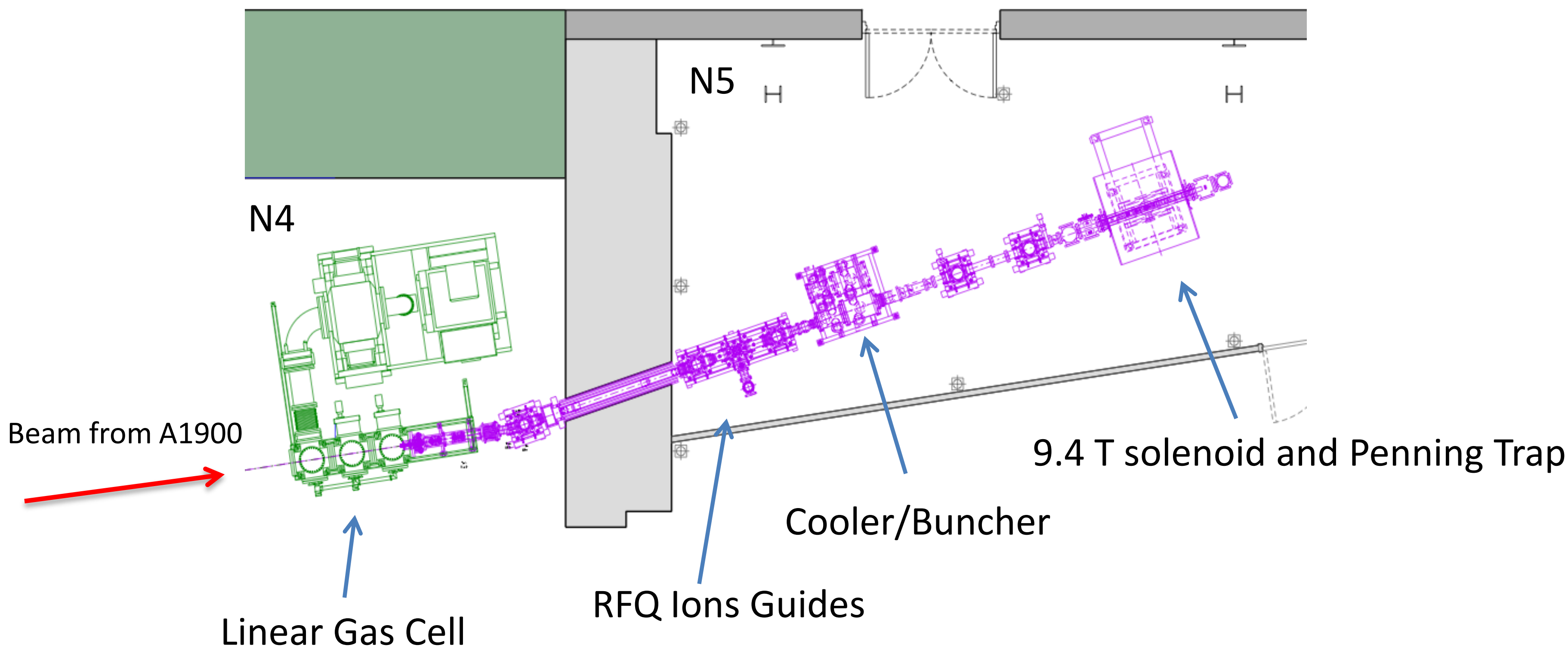
~1 eV





LEBIT I: 2000 - 2009

- Single linear gas cell
- Delivers low energy beams only to LEBIT



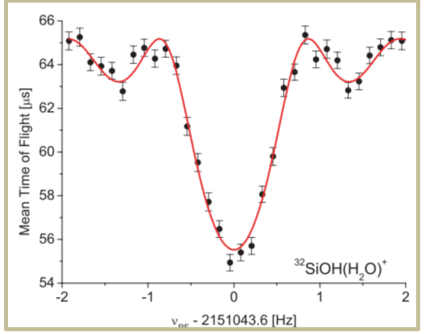
Results from LEBIT I (2005 – 2009)

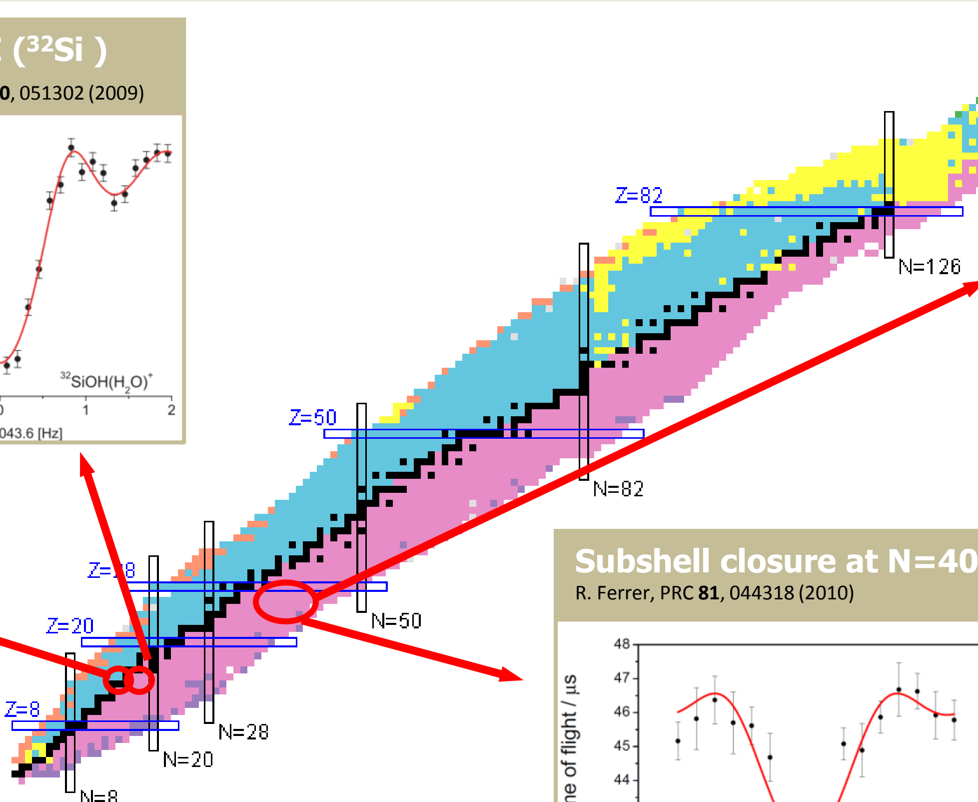
Precise masses for more than 30 isotopes and more than 10 elements

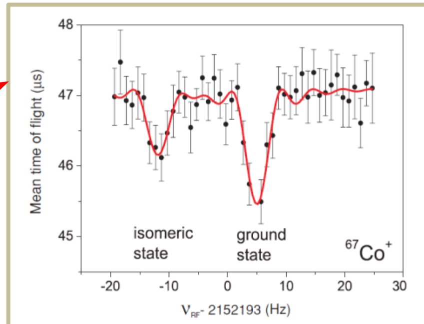
^{26}Si, ^{32}Si, ^{33}Si, ^{29}P, ^{34}P, ^{37}Ca, ^{38}Ca, ^{40}S, ^{41}S, ^{42}S, ^{43}S, ^{44}S, ^{63}Fe, ^{64}Fe, ^{65}Fe, **^{66}Fe,** ^{64}Co, ^{65}Co, ^{66}Co , **^{67}Co,** ^{63}Ga, ^{64}Ga, ^{64}Ge, ^{65}Ge, ^{66}Ge, ^{66}As, ^{67}As, ^{68}As, ^{80}As, ^{68}Se, ^{69}Se, ^{70}Se, ^{81}Se, ^{81m}Se, ^{70m}Br, ^{71}Br

Test of IMME (^{32}Si)

A.A. Kwiatkowski, PRC **80**, 051302 (2009)

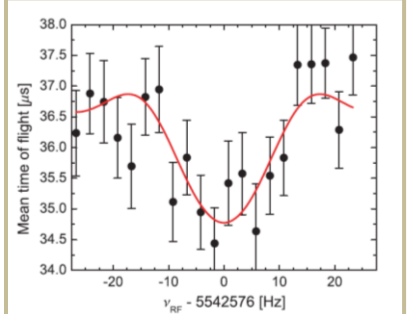






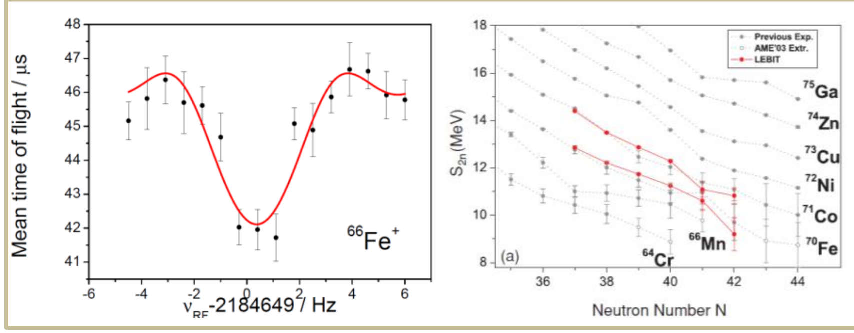
Superallowed β-emitter (^{26}Si)

A. Kwiatkowski, PRC **81**, 58501 (2010)



Subshell closure at N=40 ($^{63-66}$Fe, $^{64-67}$Co)

R. Ferrer, PRC **81**, 044318 (2010)



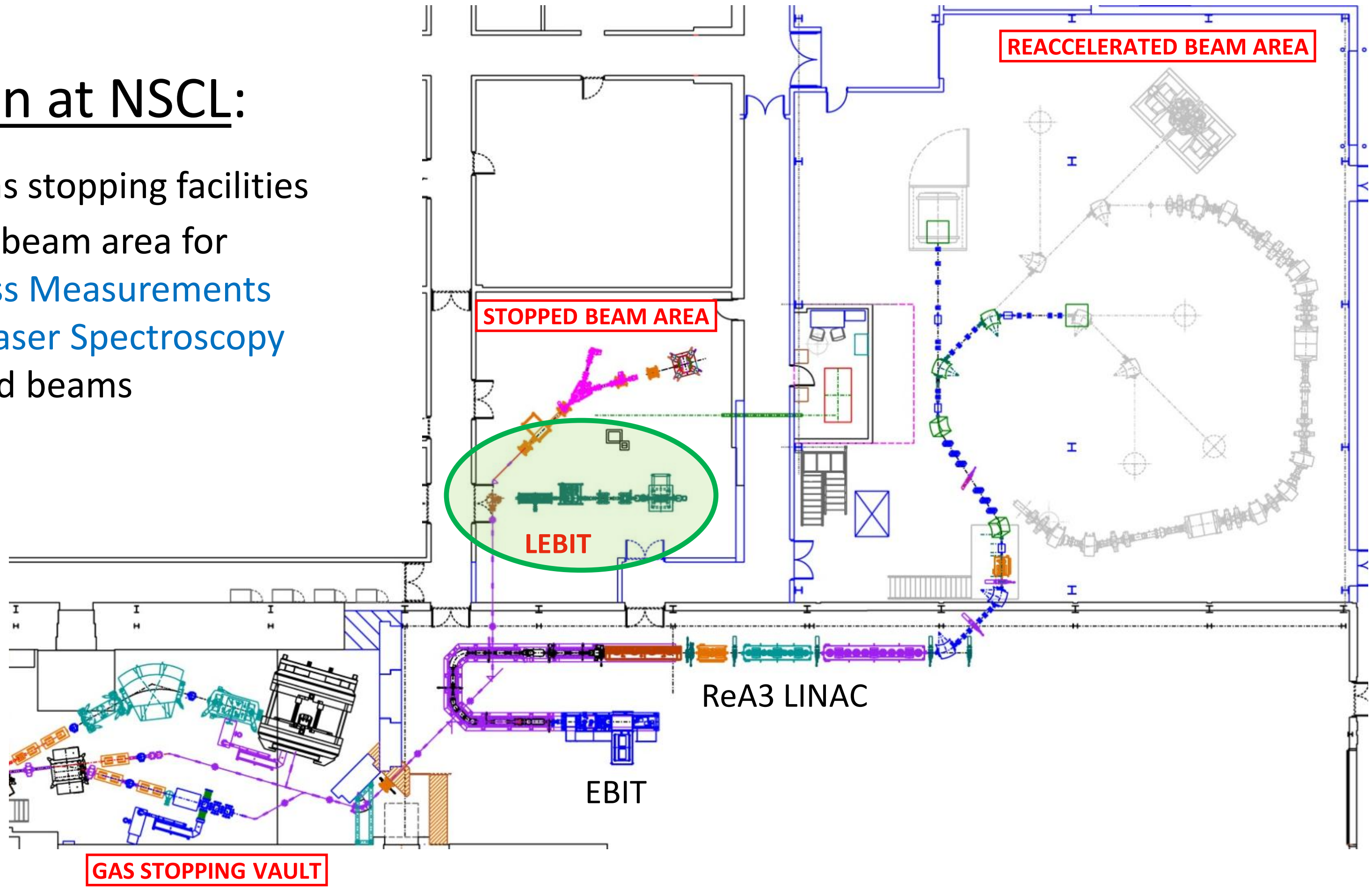
LEBIT II: 2009+

D. Leitner

Expansion at NSCL:

- Upgrade of gas stopping facilities
- New stopped beam area for
  - LEBIT – Mass Measurements
  - BECOLA – Laser Spectroscopy
- Re-accelerated beams

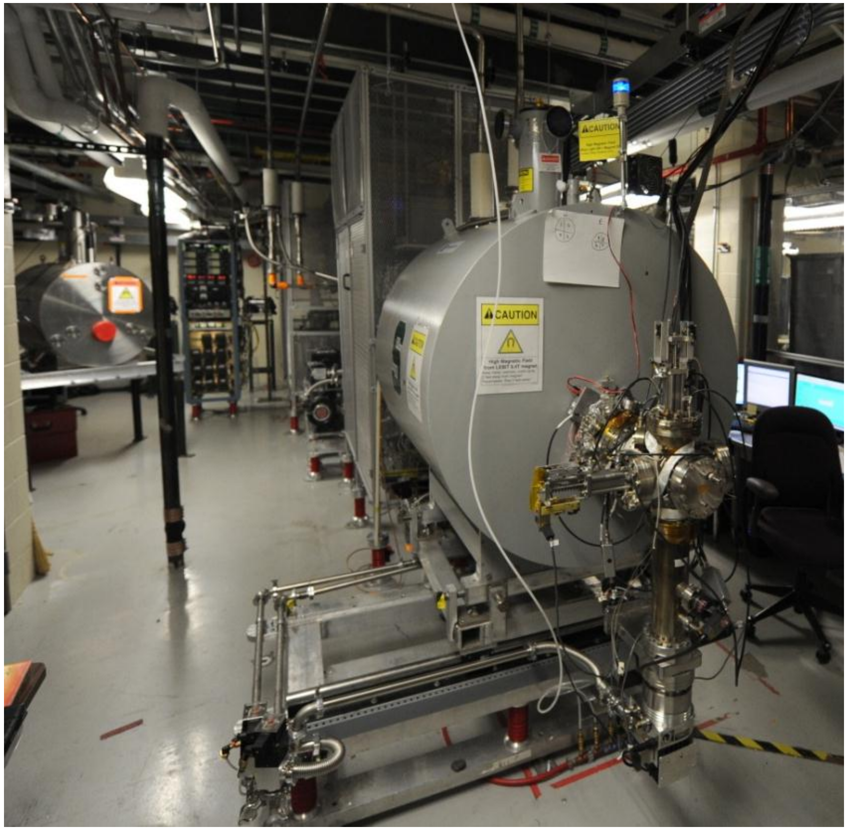
Beam from A1900



S. Schwarz, M. Brodeur

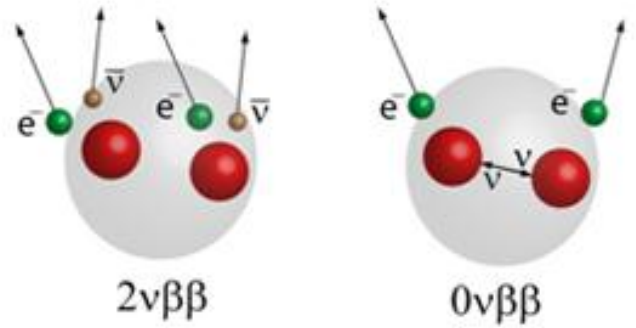
LEBIT II: Status

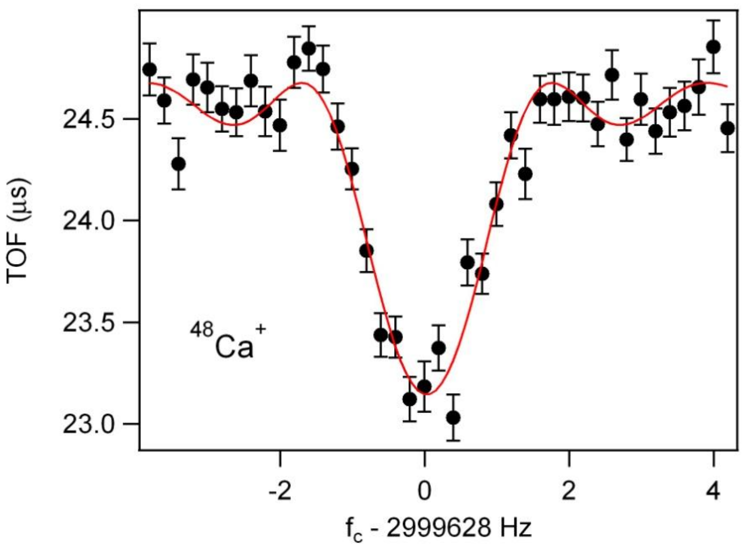
- **2009 – 2010:** LEBIT relocated to new stopped beam area
- **2011:** LEBIT successfully recommissioned with offline ion source
- **2011 – 2012:** Program of mass measurements with stable isotopes initiated
- **Early 2013:** Delivery of rare isotope beams to LEBIT expected



LEBIT II: Recent Offline Results

- Determination of ββ-decay Q-values for 0νββ-decay experiments





High-precision $Q_{\beta\beta}$ values using LEBIT

^{48}Ca-^{48}Ti:	$Q_{\beta\beta}$ = 4262.93(85) keV [1]
	ELEGANT, CANDLES, CARVEL
^{82}Se-^{82}Kr:	$Q_{\beta\beta}$ = 2997.87(23) keV [2]
	NEMO, SuperNEMO
^{78}Kr-^{78}Se:	Q_{2EC} = 2847.75(27) keV

[1] M. Redshaw, *et al.*, PRC **86**, 041306 (2012)
[2] D.L. Lincoln, *et al.*, PRL (in press)

Developments to extend measurements to the most exotic isotopes available

Challenges

- Low Production Rates
- Short Lifetimes
- Contamination

Solutions

- Increase Sensitivity
- Increase Efficiency
- Minimize Stopping Times
- Optimal use of Beam Time
- Increase Precision

FACILITY FOR RARE ISOTOPE BEAMS

- Next Generation Gas Cells
- More Efficient Removal of Contaminant Ions *
- Magnetic Field Monitoring *
- Implementation of New Measurement Techniques *

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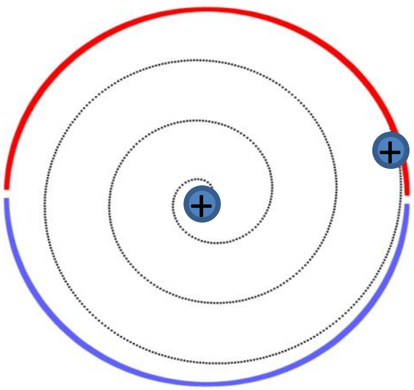
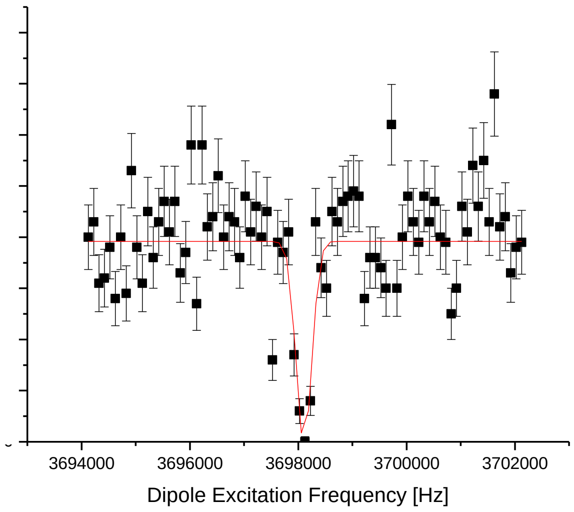
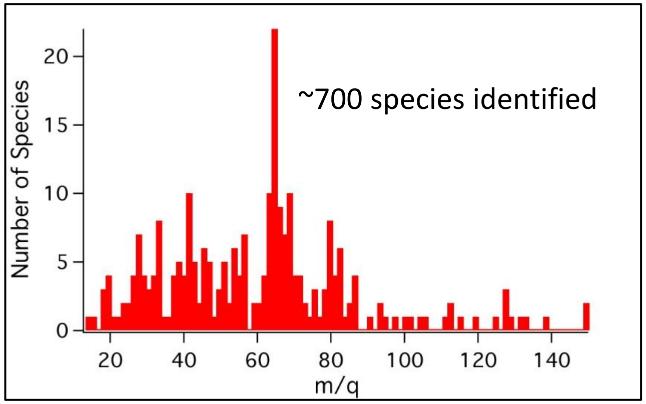
Removal of Contaminant Ions

Dipole Excitation inside Penning trap





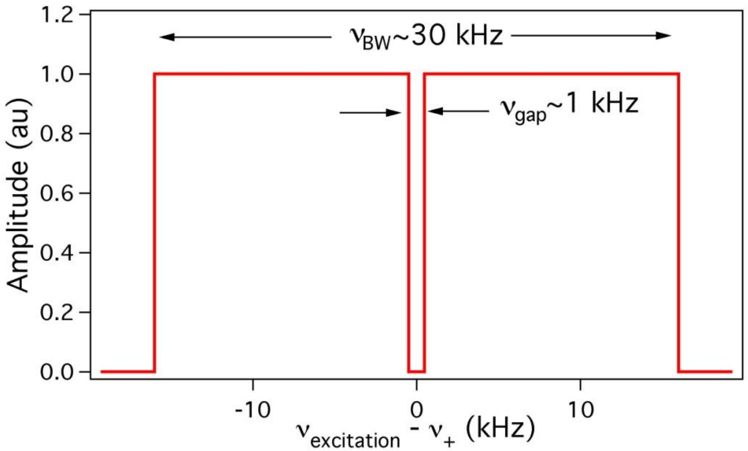
- Resolving power ~10^6
- Can selectively target any *known* contaminant ion



- Need to identify each contaminant during beam time
  Non-optimal use of beam time

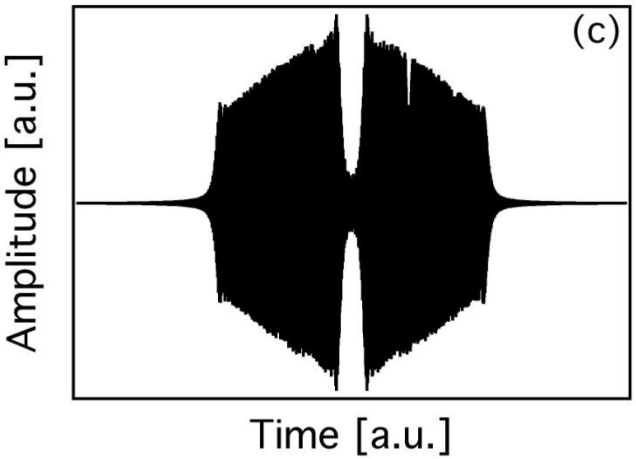
SWIFT
(Stored Waveform Inverse Fourier Transform)

Frequency domain signal



Inverse
Fourier
Transform

Time domain signal



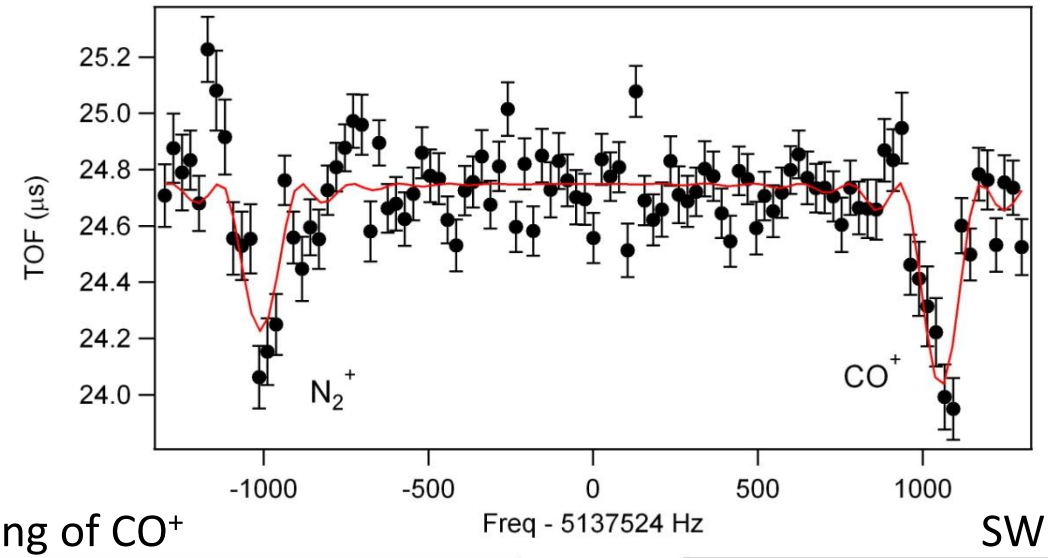
- Fast
- Same excitation scheme for all ions

Developed for analytical chemistry FT-ICR mass spectrometers

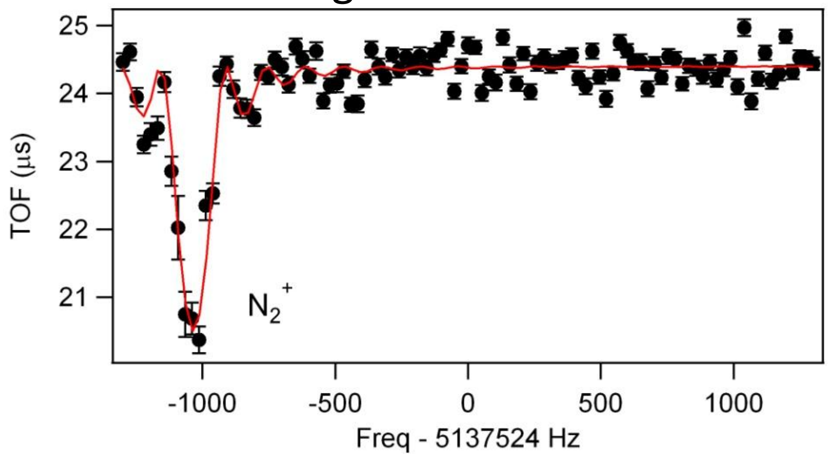
S.Guan and A.G.Marshall, IJMS Ion Proc. 5, **157/158** (1996)

SWIFT: Implementation at LEBIT

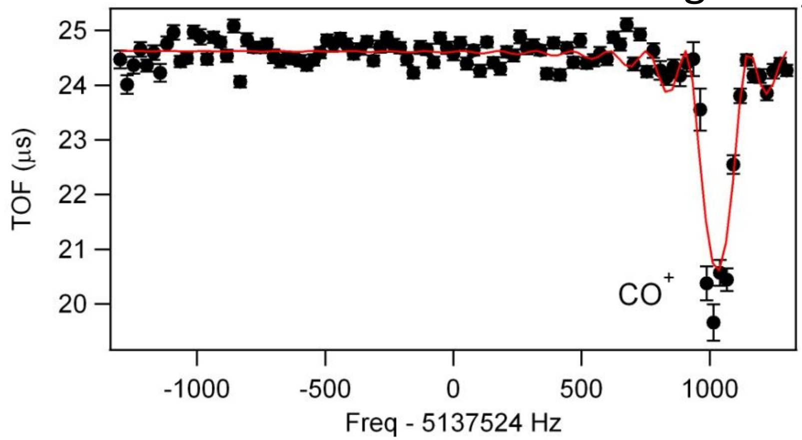
Simultaneously Trapped N_2^+ and CO^+



SWIFT Cleaning of CO^+



SWIFT Cleaning of N_2^+



A.A. Kwiatkowski, PhD Thesis (2011)

Separation of 2 kHz $\Rightarrow$ ~1 keV

Developments to extend measurements to the most exotic isotopes available

Challenges
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- Contamination

Solutions
- Increase Sensitivity
- Increase Efficiency
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- Increase Precision

FACILITY FOR RARE ISOTOPE BEAMS

Next Generation Gas Cells

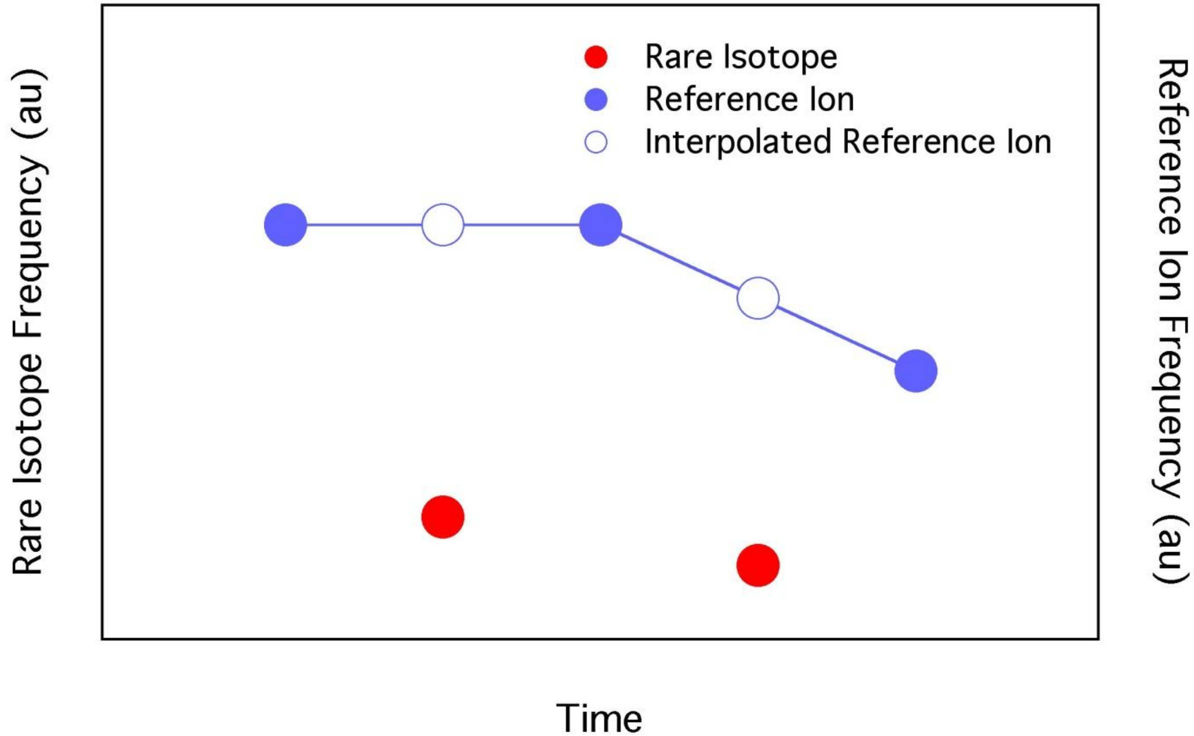
More Efficient Removal of Contaminant Ions *

Magnetic Field Monitoring *

Implementation of New Measurement Techniques *

B-Field Calibration with Reference Ion

Magnetic field is calibrated with a mass measurement of a reference ion before and after each RI ion measurement

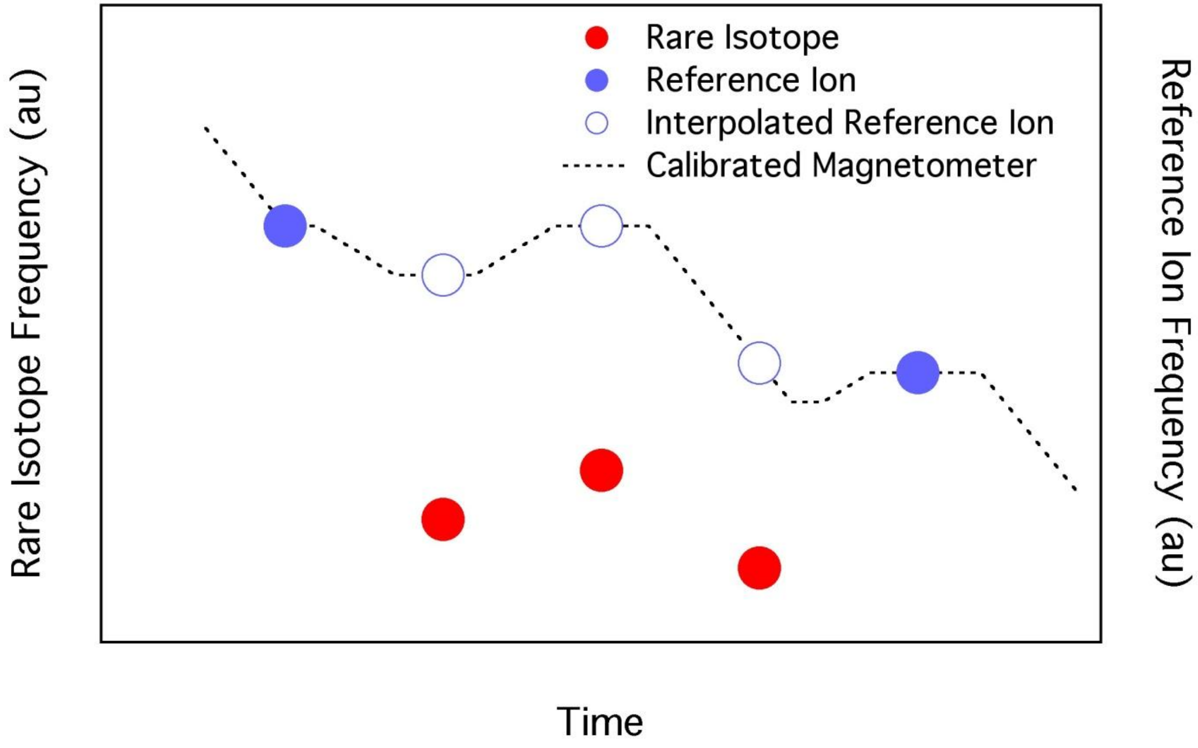


$$\nu_c = \frac{1}{2\pi}\frac{qB}{m}$$

- Valuable beam time is spent on reference ion measurements
- Does not account for non-linear field drifts

B-Field Calibration with Magnetometer

<u>Aim</u>: Use a magnetometer to keep track of magnetic field variations during rare isotope ion measurements



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

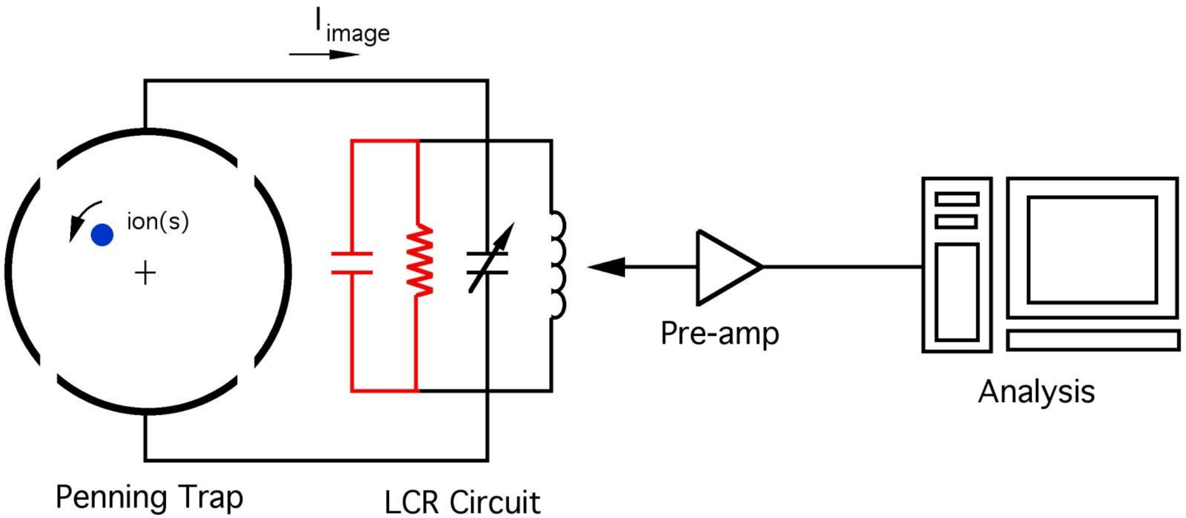
MiniTrap:
Miniature Penning Trap as a Magnetometer

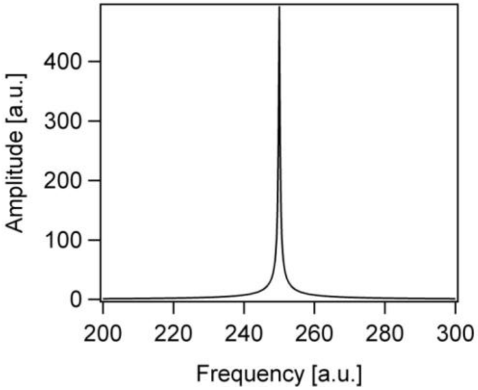
Monitor cyclotron frequency to monitor Magnetic Field

$$\nu_c = \frac{1}{2\pi}\frac{qB}{m} \Rightarrow \frac{\Delta\nu_c}{\nu_c} = \frac{\Delta B}{B} \Rightarrow$$

Use light ions (high ν_c)
i.e. H_2^+

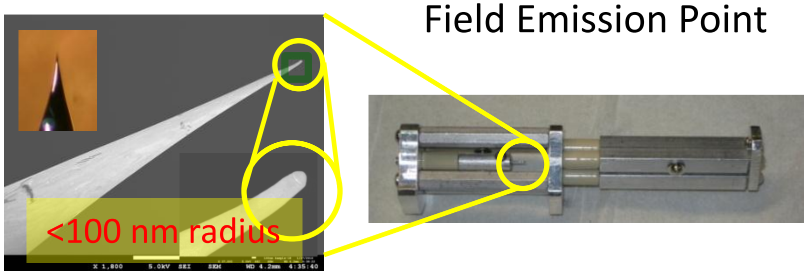
Use FT-ICR Image Charge Detection



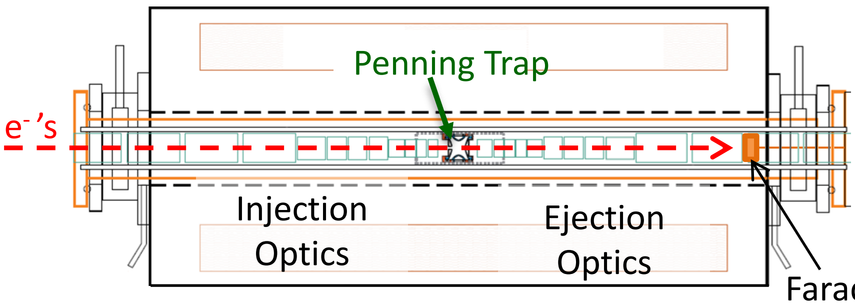


Proof of Concept

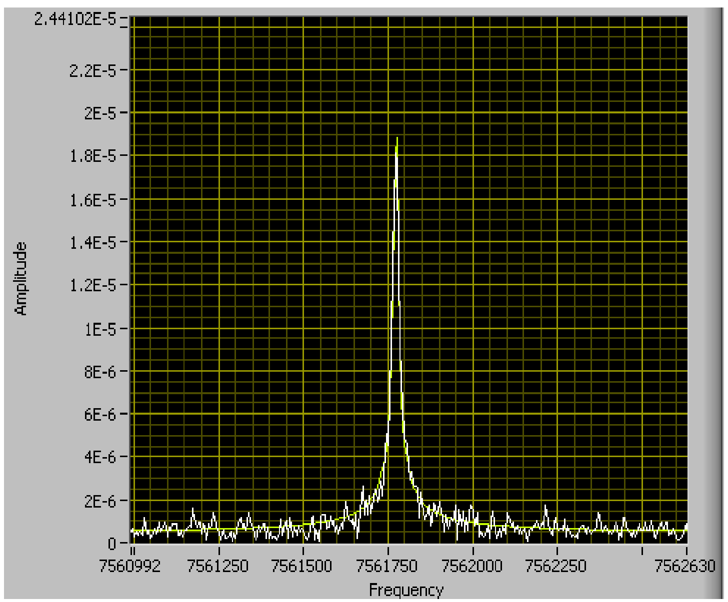
Field Emission Point



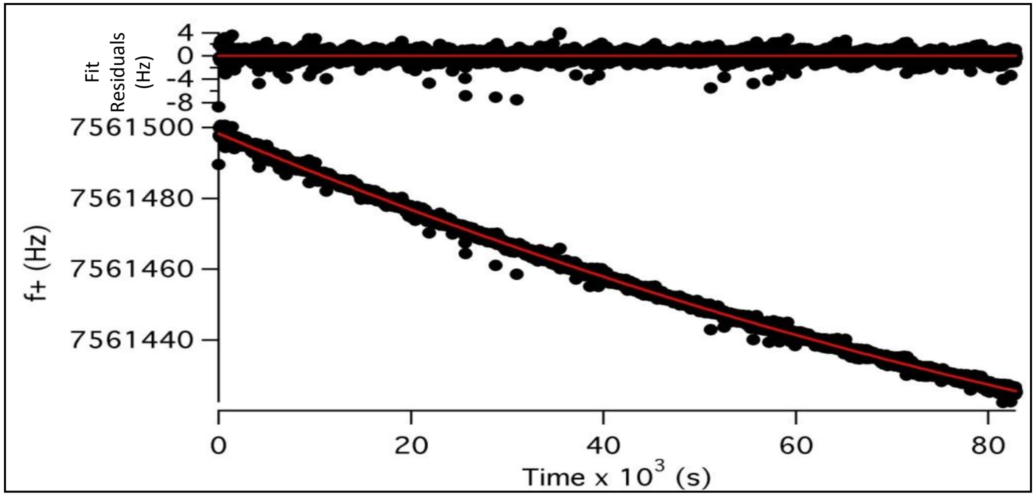
Sideview of LEBIT Solenoidal Magnet



FFT Resonance of H_3O^+



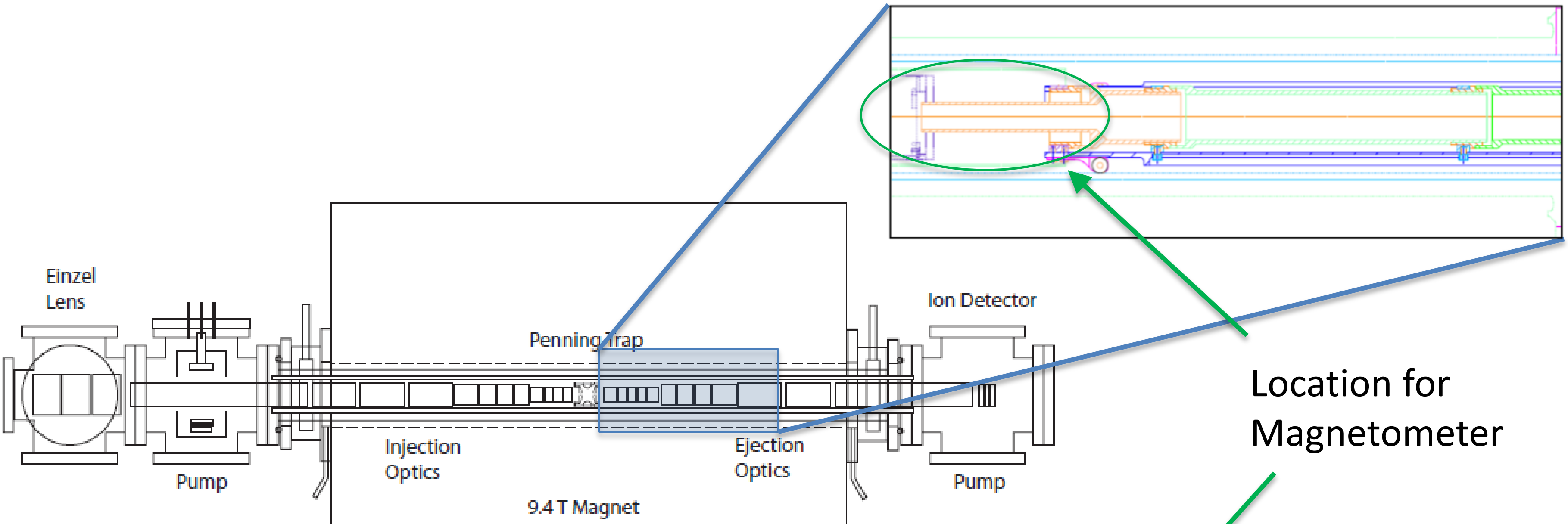
- ~ 2000 ions
- FWHM of 5 Hz (at 10^{-8} mbar)



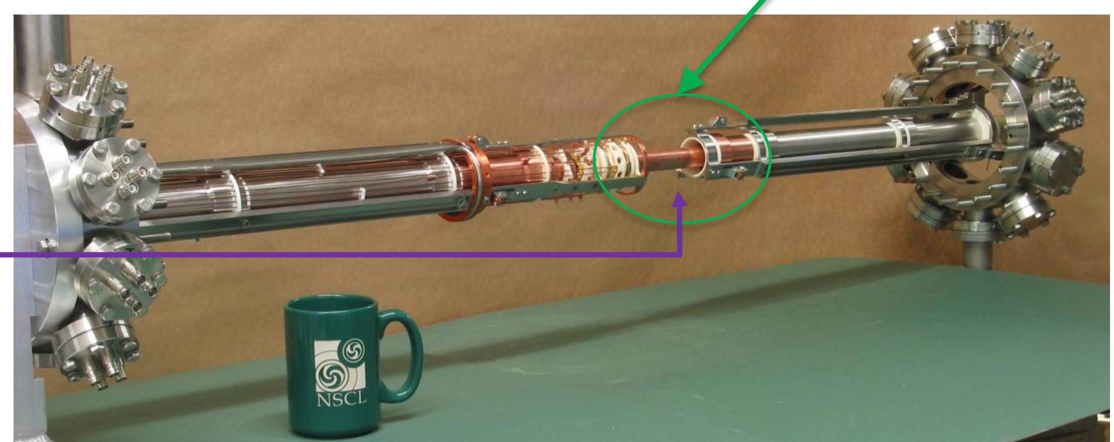
Results:

- Precision of 1 part in 10^7
- Improve precision using a smaller trap and lighter masses

MiniTrap: Magnetometer Location

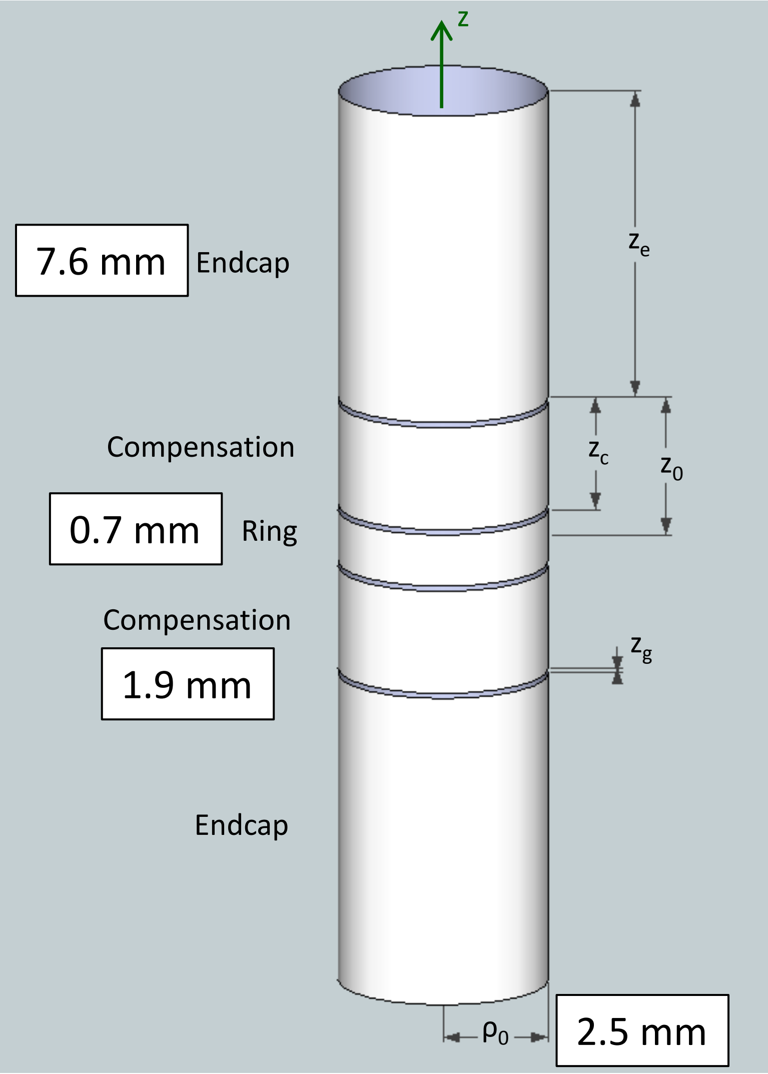


Location for Magnetometer



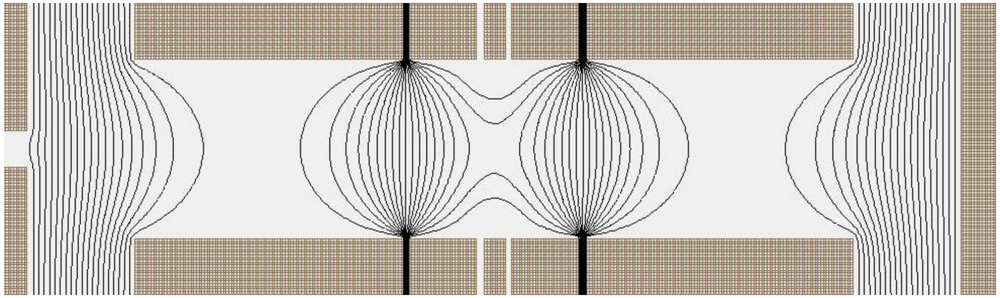
1 inch annular radius

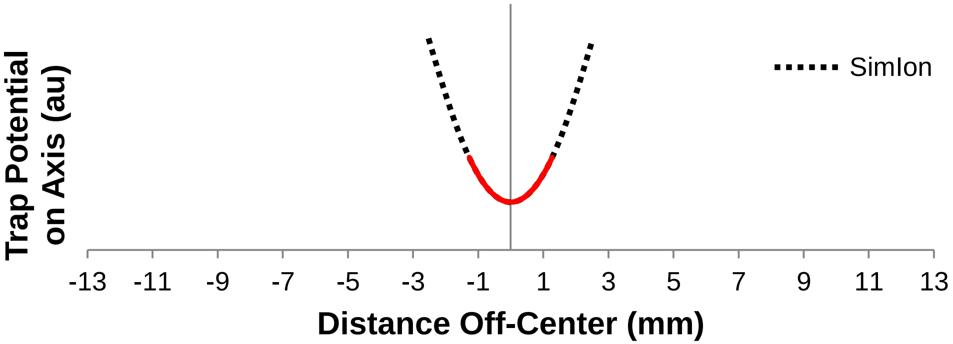
MiniTrap:
Penning Trap Electrodes



Orthogonalized Cylindrical Geometry

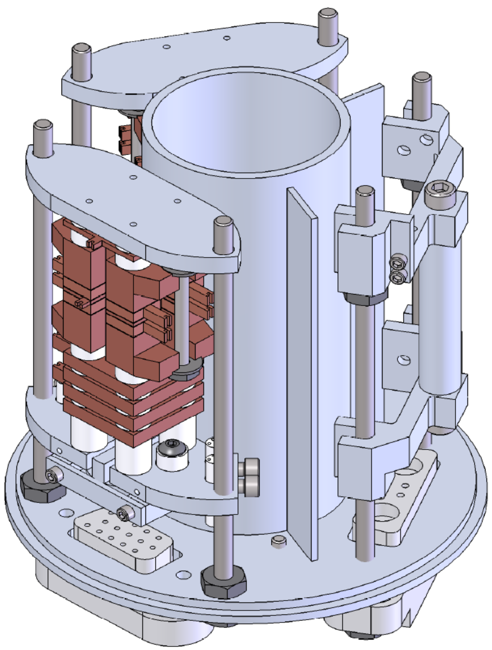
- open access for e-beam
- efficient pumping
- relatively straight forward to machine
- field imperfections can be minimized
- trap potential independent of tuning

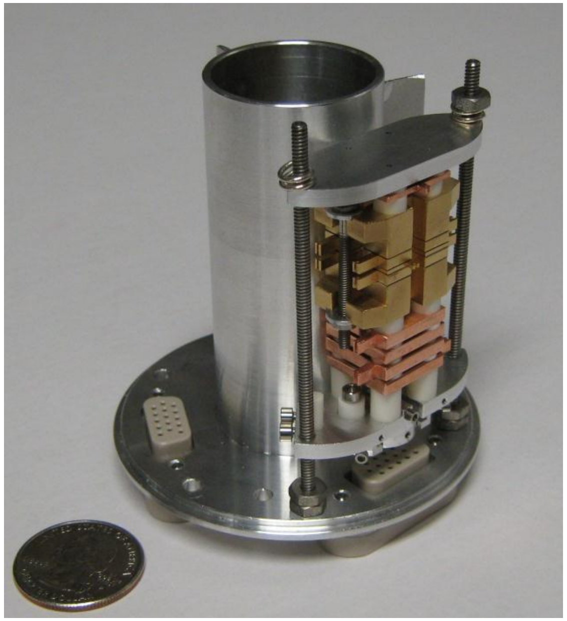


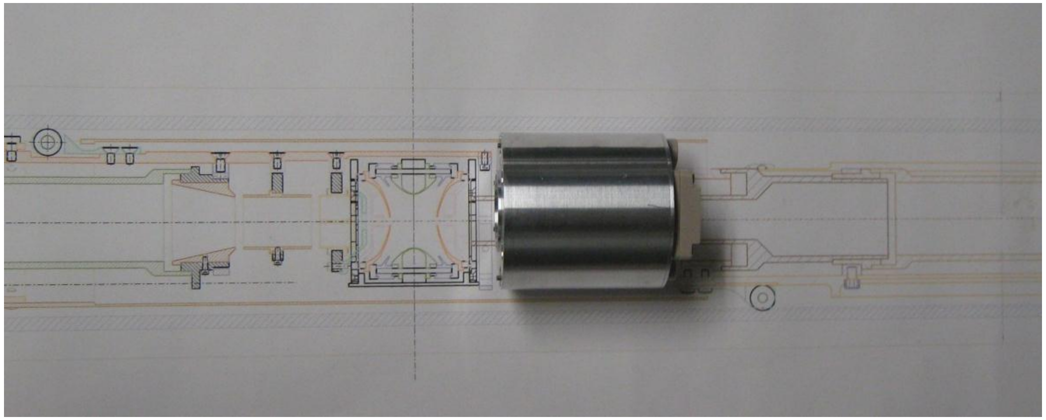


MiniTrap: Status

Components designed, fabricated and assembled
Ready for testing in magnet







Developments to extend measurements to the most exotic isotopes available

Challenges
- Low Production Rates
- Short Lifetimes
- Contamination

Solutions
- Increase Sensitivity
- Increase Efficiency
- Minimize Stopping Times
- Optimal use of Beam Time
- Increase Precision

FACILITY FOR RARE ISOTOPE BEAMS

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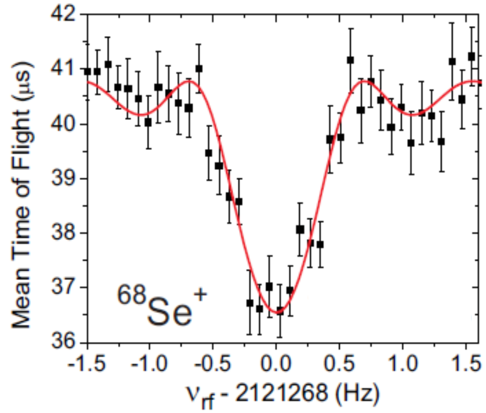
- Implementation of New Measurement Techniques *

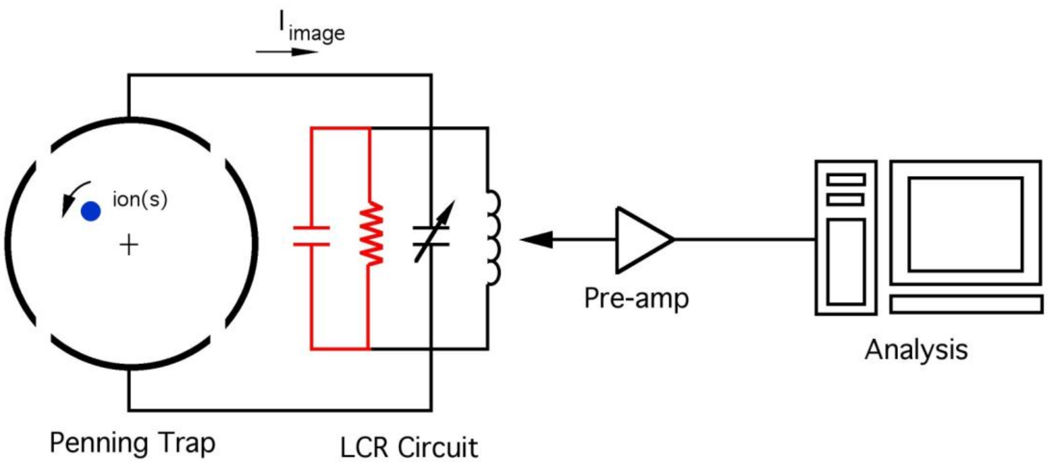
Development of New Measurement Techniques

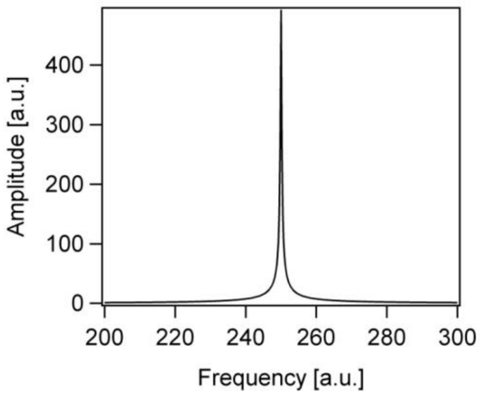
Mass measurements on isotopes with very low production rates



- TOF Techniques requires ~100s of ions
- Becomes difficult for production rates of 1 ion/hr or less

<u>Alternative Approach</u>: FT-ICR image charge detection

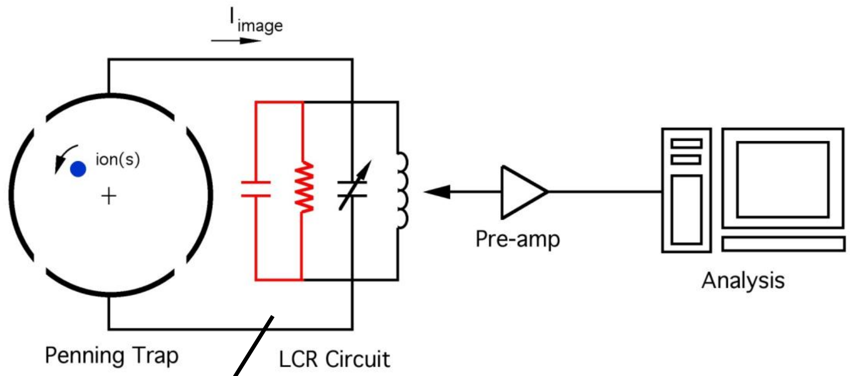


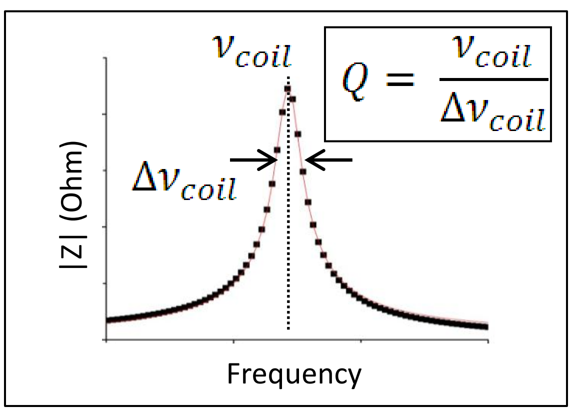


Also being pursued at TRIGA-TRAP and SHIP-TRAP

SIPT: Single Ion Penning Trap

- **Make use of the FT-ICR Image Charge Detection Technique**





$$\frac{S}{N} \sim Nq\left(\frac{\rho}{\rho_0}\right)\sqrt{\frac{\nu_c}{\Delta\nu_c}}\sqrt{\frac{Q}{kTC}}$$

High-Q

Low T

- **High-Q, low temperature resonant detection circuit**

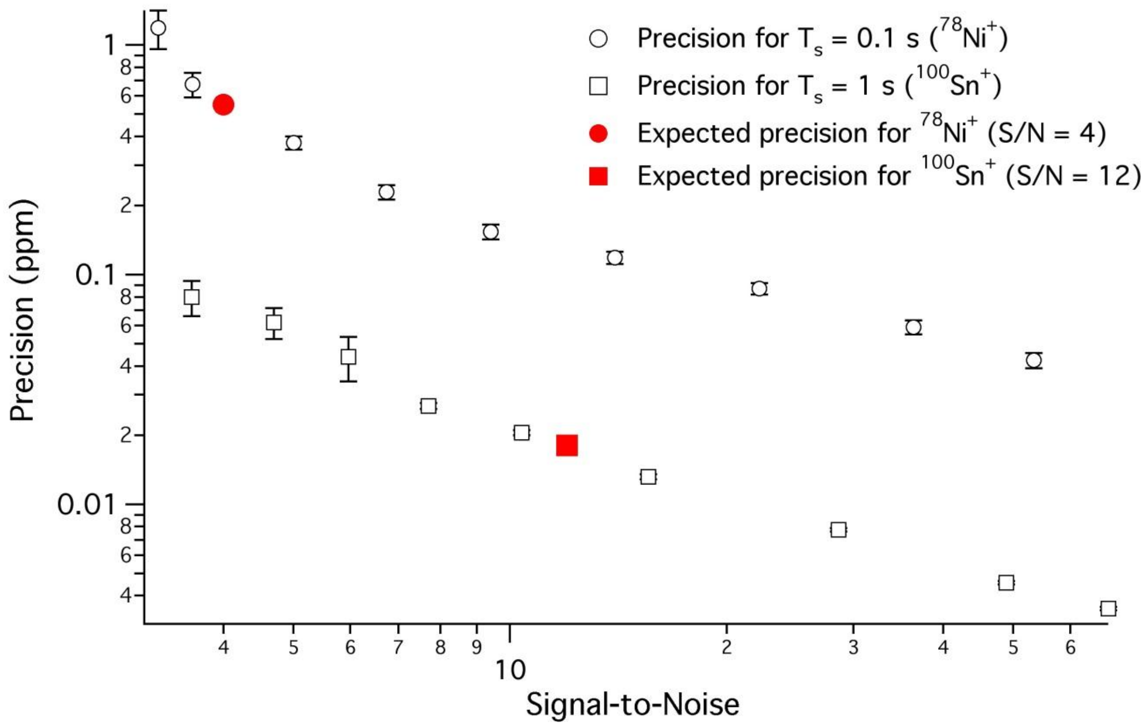
SIPT: Signal to Noise and Precision

$$\frac{S}{N} \sim Nq\left(\frac{\rho}{\rho_0}\right)\sqrt{\frac{\nu_c}{\Delta\nu_c}}\sqrt{\frac{Q}{kTC}}$$

$^{100}Sn^{+}$ ($T_{1/2}$ = 1 s) $\Rightarrow$ S/N $\approx$ 12
$^{78}Ni^{+}$ ($T_{1/2}$ = 0.1 s) $\Rightarrow$ S/N $\approx$ 4

Q = 1000
T = 20 K
C = 10 pF
ρ/ρ_0 = 0.5

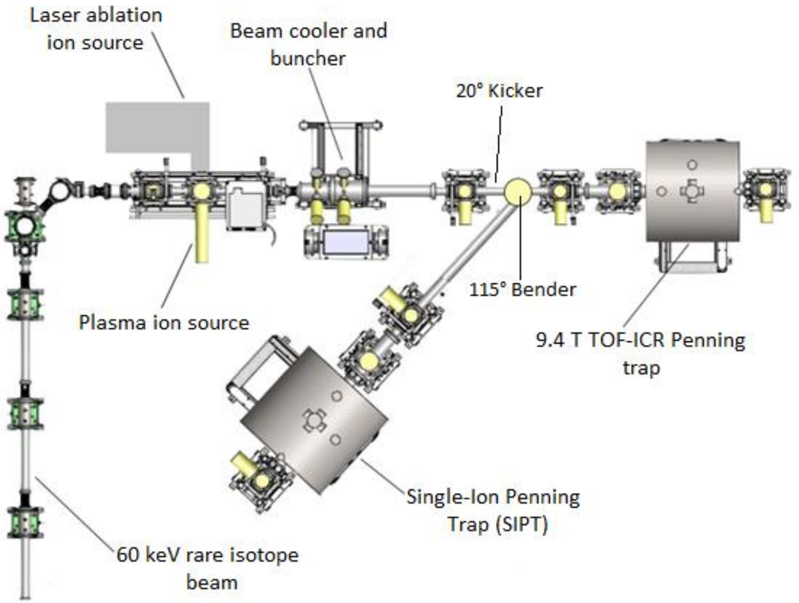
Analysis of FFT of simulated time domain signal + noise

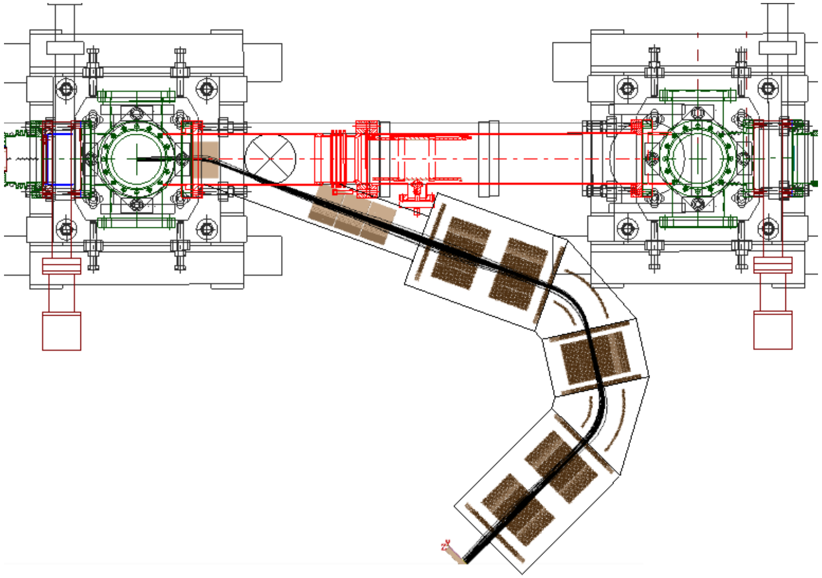


SIPT: Status

- NSF Major Research Instrumentation Grant (Sep. 2011)

- Additional 7 T Superconducting Solenoid Magnet





Summary

- Over 30 rare isotopes measured with LEBIT 2005 – 2009
- LEBIT relocated to new stopped beam area
- Double-β-decay Q-values of ^{48}Ca, ^{82}Se, ^{78}Kr measured with LEBIT-II
- Radioactive beam expected Spring 2013
- SWIFT implemented
- Magnetic field monitoring with MiniTrap ready for testing
- Single Ion Penning Trap project initiated

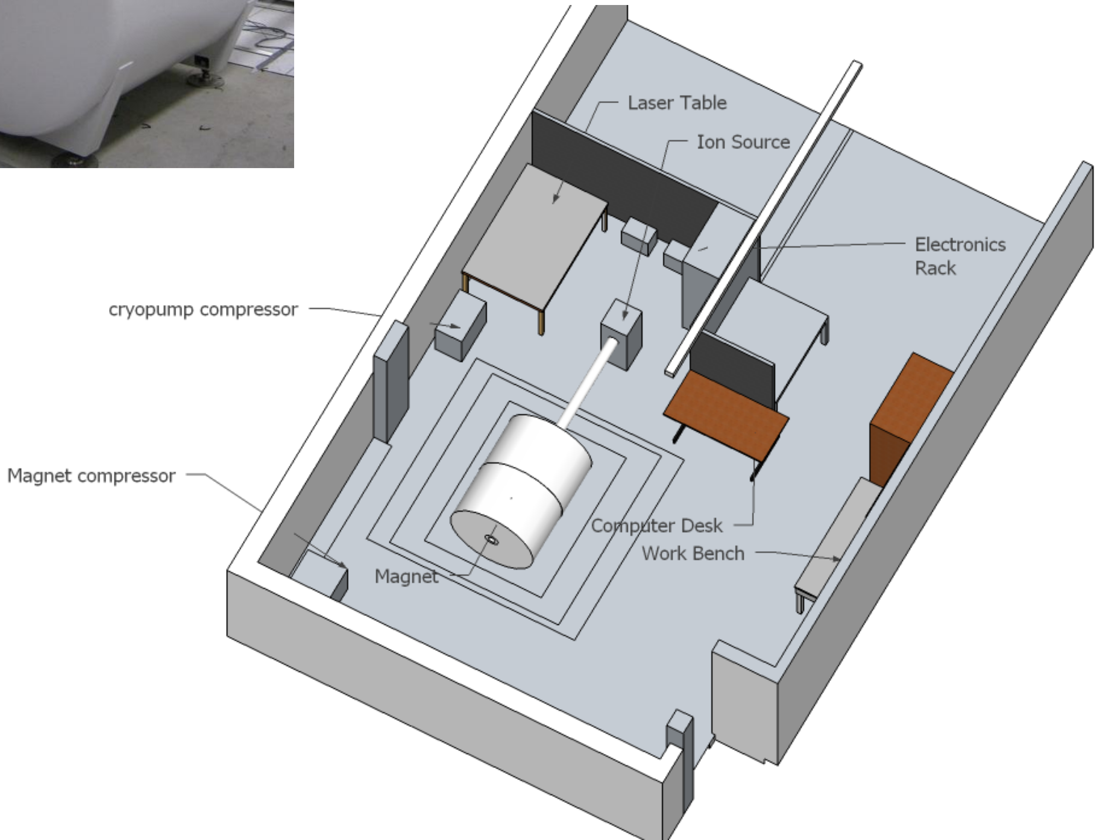
LEBIT team:
B.R. Barquest, G. Bollen, M. Brodeur, S.E. Bustabad, A. Gehring, D.L. Lincoln, D.J. Morrissey, M. Redshaw, S. Novario, R. Ringle, S. Schwarz, A. Valderez

LEBIT alumni:
C. Bachelet, M. Block, C.M. Campbell, M. Facina, R. Ferrer , C.M. Folden III, C. Guenaut, A.A. Kwiatkowski, G.K. Pang, A.M. Prinke, J. Savory, P. Schury, T. Sun

Thanks for listening!

CMU Trap

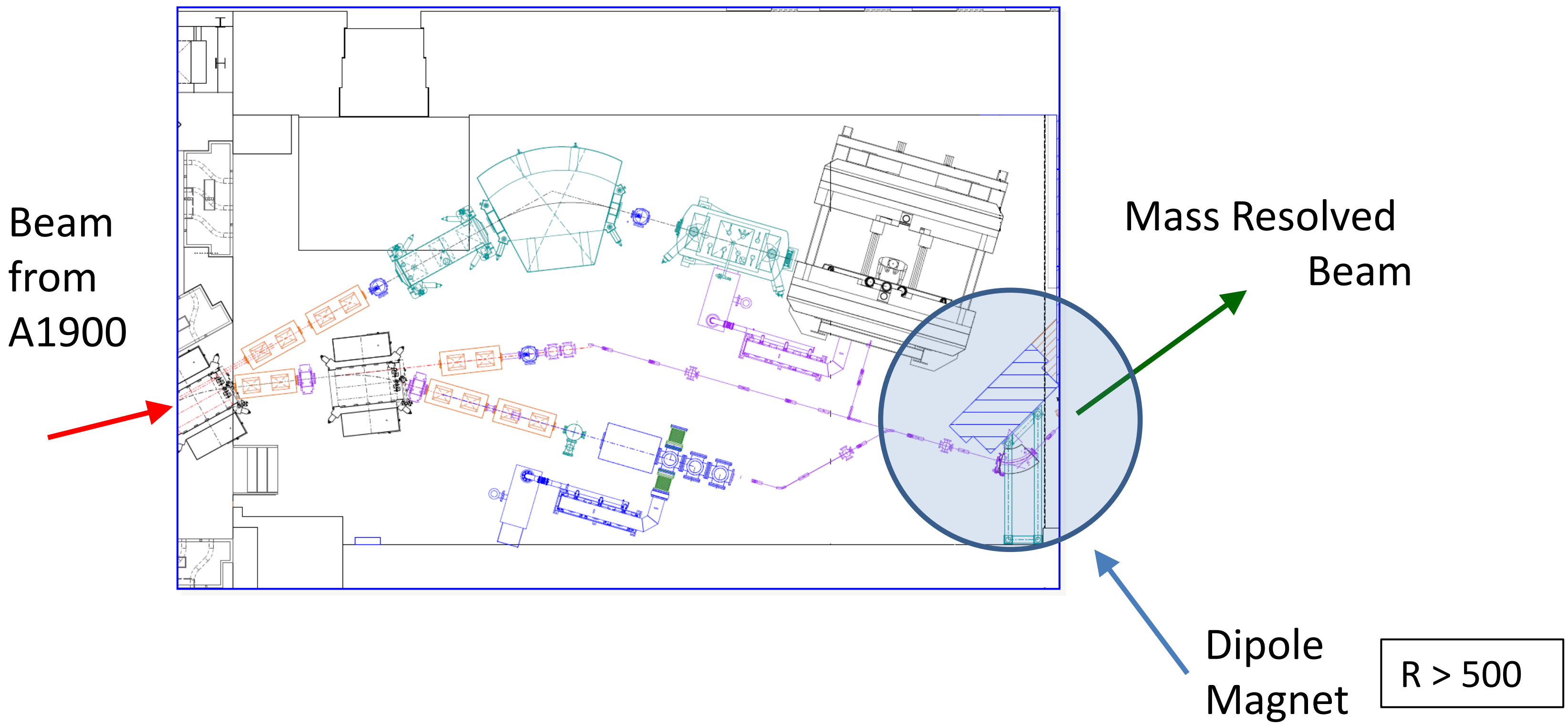
- 12 T magnet
- External Ion Source
- Single Ion Image Charge Detection
- Double Penning Trap
- Precision goal of $<10^{-11}$



Former FT-ICR magnet from University of Texas

Removal of Contaminant Ions
Before the Penning Trap

- Beam from gas cell contains ions of a single m/q ratio



Removal of Contaminant Ions

Before the Penning Trap