Measurement of Total Decay Energies of T=1 and T=1/2 Nuclei at LEBIT for the Search of Physics beyond the Standard Model

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The CVC hypothesis

corrected $\mathcal{Ft}$–value should be equal for all β-decays in the same subset

- Two subsets of nuclear β-decays investigated: superallowed $0^+ \rightarrow 0^+ (J^\pi=0^+, T=1)$ and T=1/2 mirror nuclei
- important for tests of the Standard Model by setting tight limits on the existence of scalar currents
- provides the most precise value for V_{ud} to test **the unitary of CKM matrix**.

$$\mathcal{F}t = f^V t\,(1+\delta'_R)\,(1+\delta_{NS}-\delta_C)\,[1+(f_A/f_V)\,\rho^2] \qquad \sim Q^5 \sim t_{1/2} \sim BR$$

Statistical rate function

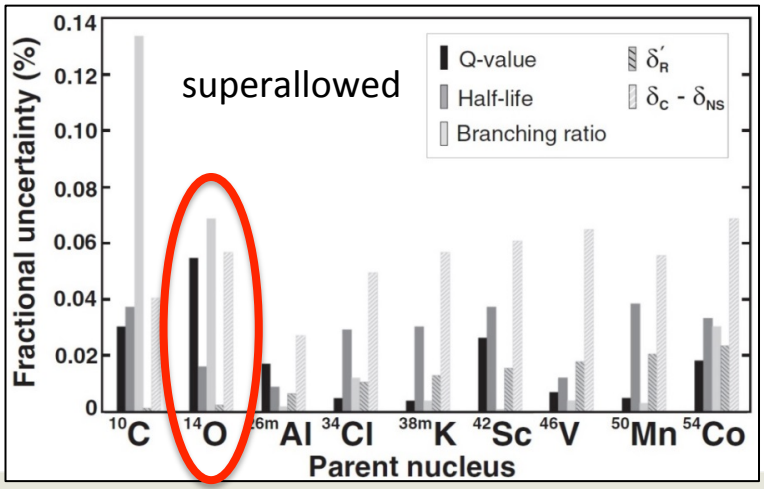
Partial half-life

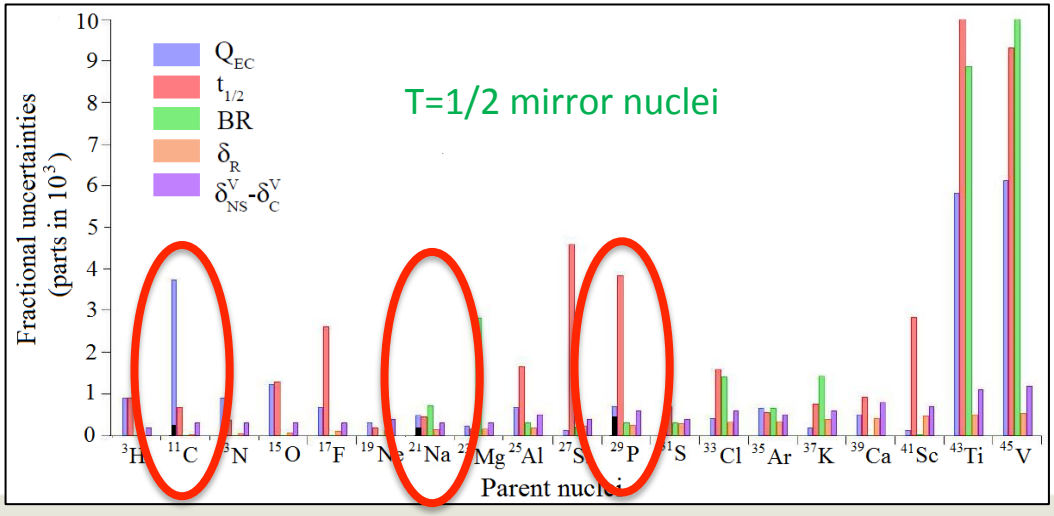
Transition-dependent parts of the radiative correction

Isospin-symmetry-breaking correction

Fermi/Gamow-Teller mixing ratio

Experimental values





The CVC hypothesis

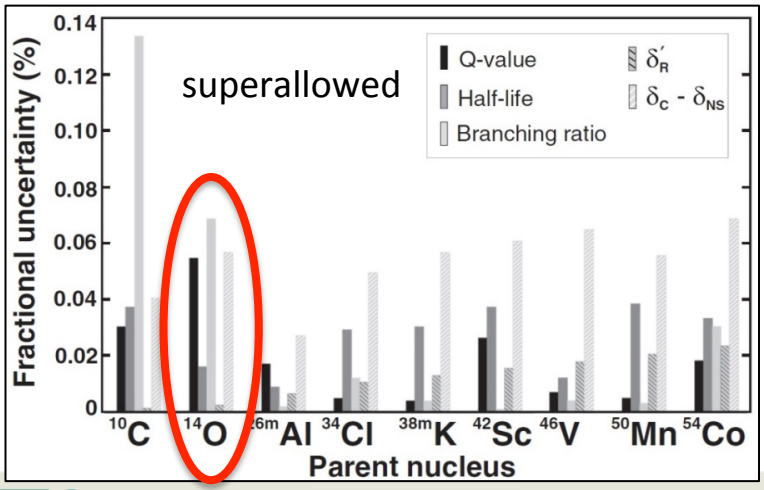
Low-Z isotopes: most sensitive to scalar interaction due to low Q

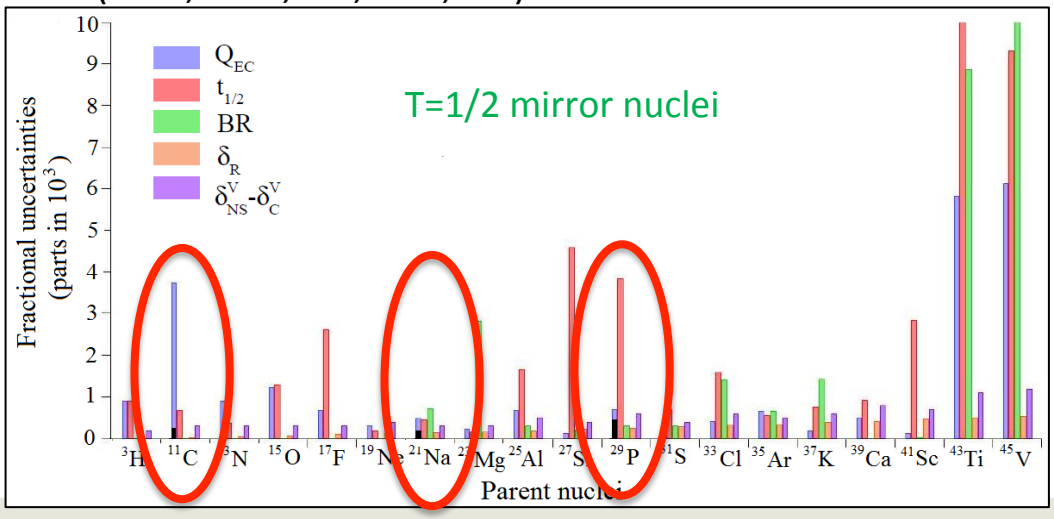
- Three (four) experimental quantities contribute to the determination of $\mathcal{F}t$:

  Q, half-life $t_{1/2}$, branching ratio **BR**, Fermi/GT mixing ratio ρ
- If there is a scalar interaction an additional term approximately inversely proportional to Q would be present in $\mathcal{F}t$.

- Only the Q-value of ^{14}O was not measured with a Penning trap.
- Lower dominance of experimental uncertainties in mirror nuclei.

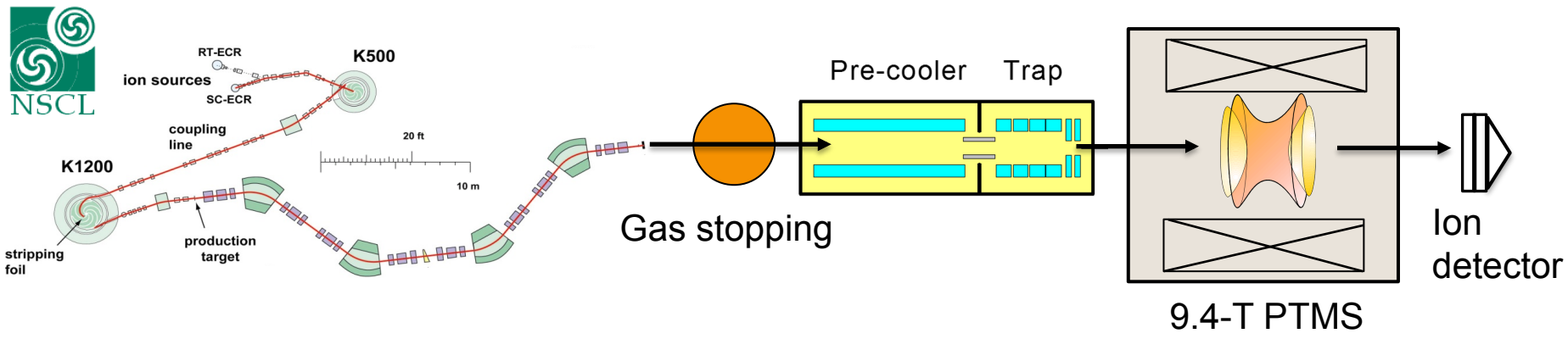
- **Important:** ρ is only determined for five nuclei (^{19}Ne, ^{21}Na, ^{29}P, ^{35}Ar, ^{37}K)





LEBIT (Low Energy Beam Ion TRAP)

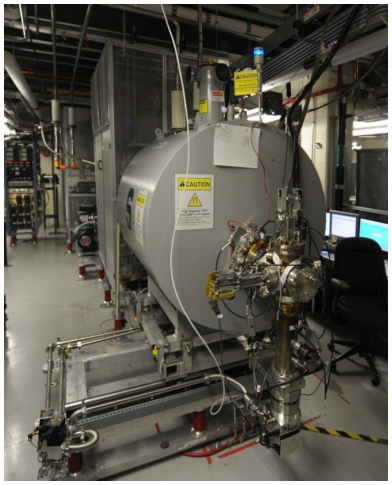
The only Penning trap mass spectrometry at a fragment separator



100 MeV/u → **1 eV**

- Projectile Fragmentation and In-Flight Separation
  - ✓ Fast
  - ✓ Universal
  - ✓ Chemistry independent

- Penning Trap Mass Spectrometry
  - ✓ High-precision
  - ✓ High Sensitivity



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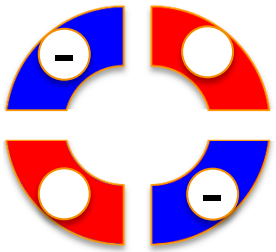
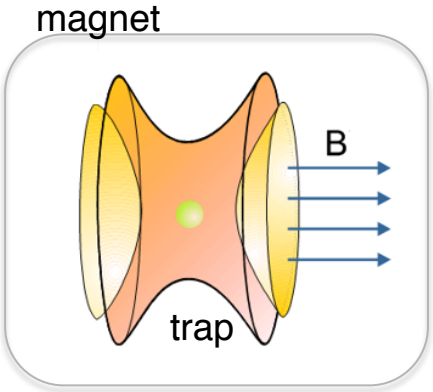
More about NSCL/FRIB: tomorrow, 15:50, L3

Time-of-Flight Ion Cyclotron Resonance (TOF-ICR)

From time-of-flight to *Q* value



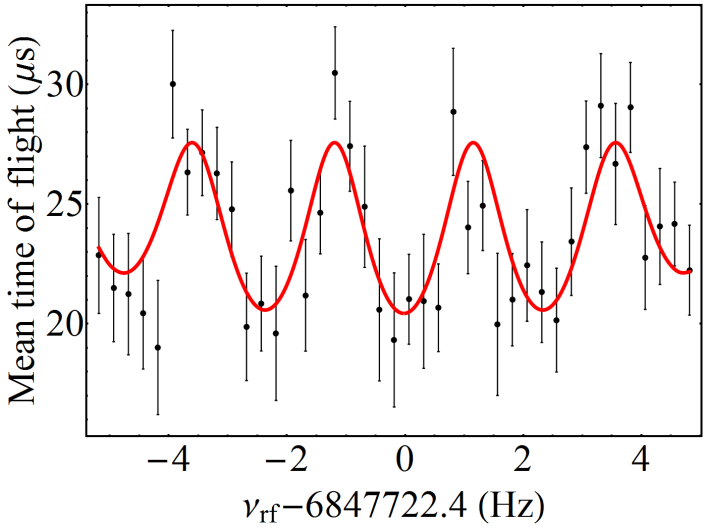
Quadrupole RF near f_c is scanned while time of flight is recorded.



Measure TOF

$$\omega_c = \frac{q}{m} B$$

$^{21}Na^+$ - 500ms Ramsey excitation



- measure cyclotron frequency
- known charge state
- track B-field with calibrant of well-known mass

determine mass(difference)

***Q*=[m(mother) - m(daughter)] c^2**

Ideal: Calibrant nuclide is part of the decay

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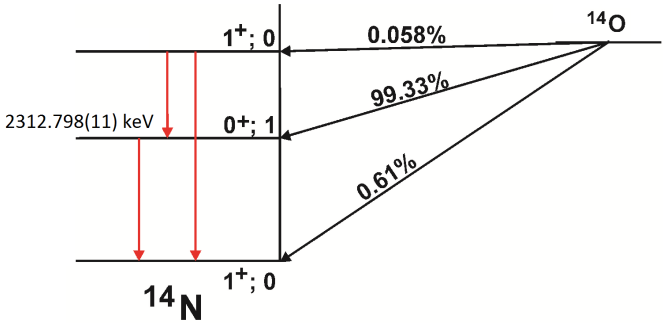
Measurements at LEBIT and their impact

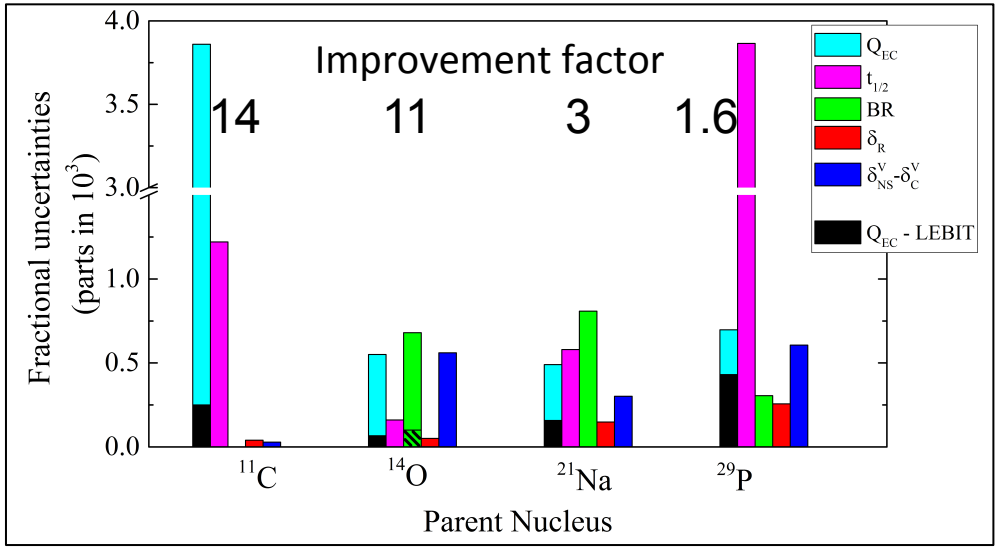
Uncertainty of the *Q* value was pushed to insignificant levels

- ^{14}O and ^{21}Na: measured directly
- ^{11}C and ^{29}P: determined via mass measurement

	ΔQ_{old} (kev)	ΔQ_{LEBIT} (kev)
^{11}C	1982.4(9)	1981.690(61)
^{14}O	5144.32(28)	5144.364(25)
^{21}Na	3547.14(28)	3547.11(9)
^{29}P	4942.45(60)	4942.18(37)



^{14}O decays to exited state:
Q_{EC}(sa) = 2831.566(28) keV



K. Gulyuz, et al., Phys. Rev. Lett. **116**, 012501 (2016)
M. Eibach, et al., Phys. Rev. C **92**, 045502 (2015)
A. A. Valverde, et al., Phys. Rev. Lett. **114**, 232502 (2015)
P. A. Voytas and E. A. George, Phys. Rev. C **92**, 065502 (2015)

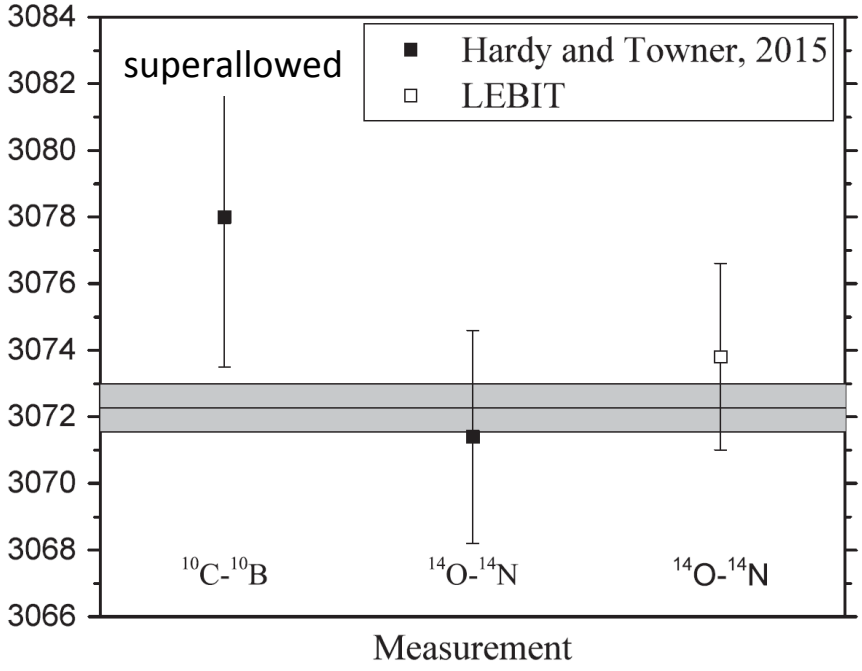
Measurements at LEBIT and their impact

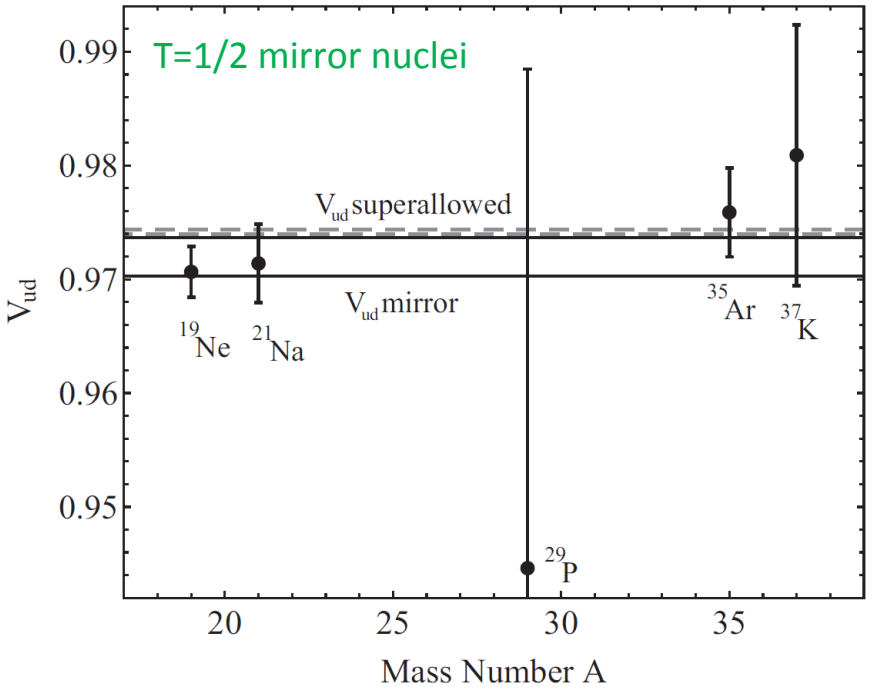
Independent unitarity test for CKM matrix

$\mathcal{F}t = ft(1+\delta'_R)(1+\delta_{NS}-\delta_C) = 3073.8(2.8)$ s

Uncertainty reduced to 1.9s with new branching ratio.

T=1/2 mirror nuclei provide a complementary, independent approach to determine V_{ud} element of the CKM matrix.





With Ft from superallowed $0^+ \rightarrow 0^+$ decays and from T=1/2 mirror decays:

Prediction of ρ for ^{11}C : $\rho = 0.7493(5)$

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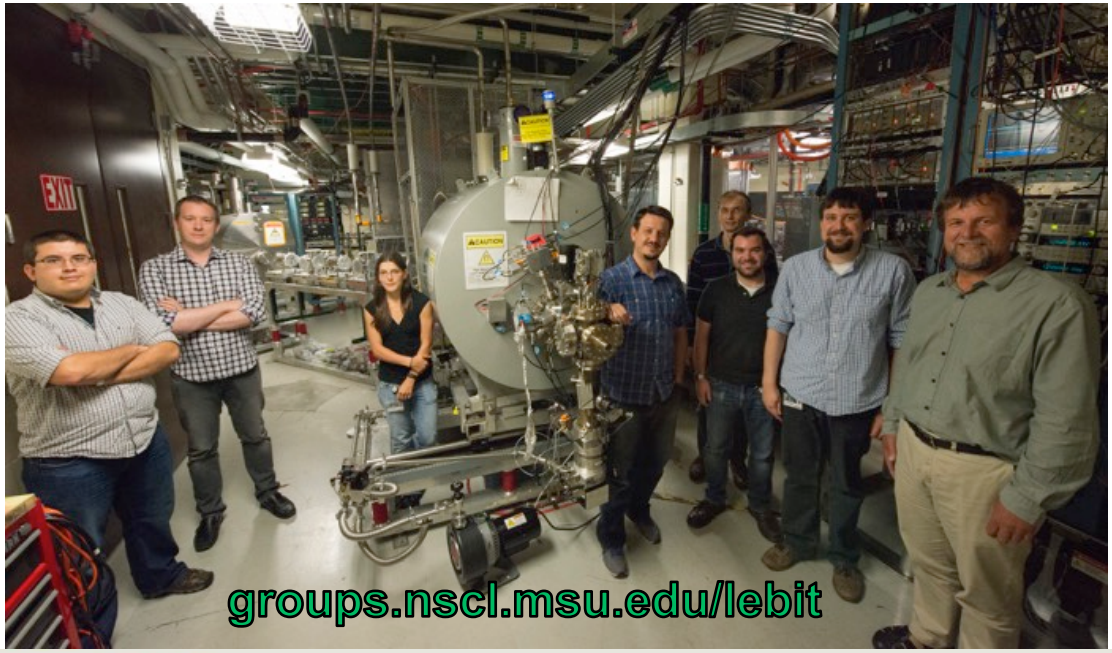
Parametrization of f: I. S. Towner and J. C. Hardy, Phys. Rev. C **91**, 015501 (2015).

Summary and Outlook

- Penning trap mass spectrometer LEBIT is an excellent tool for mass measurements
- Q_{EC} values of ^{21}Na, ^{29}P, and ^{11}C to study T=1/2 mirror nuclei
- Q_{EC} value of ^{14}O to study superallowed beta emitters
- Active community
  - → Recent half-life measurements

- Q_{EC} value measurements of Tz=-1 nuclei



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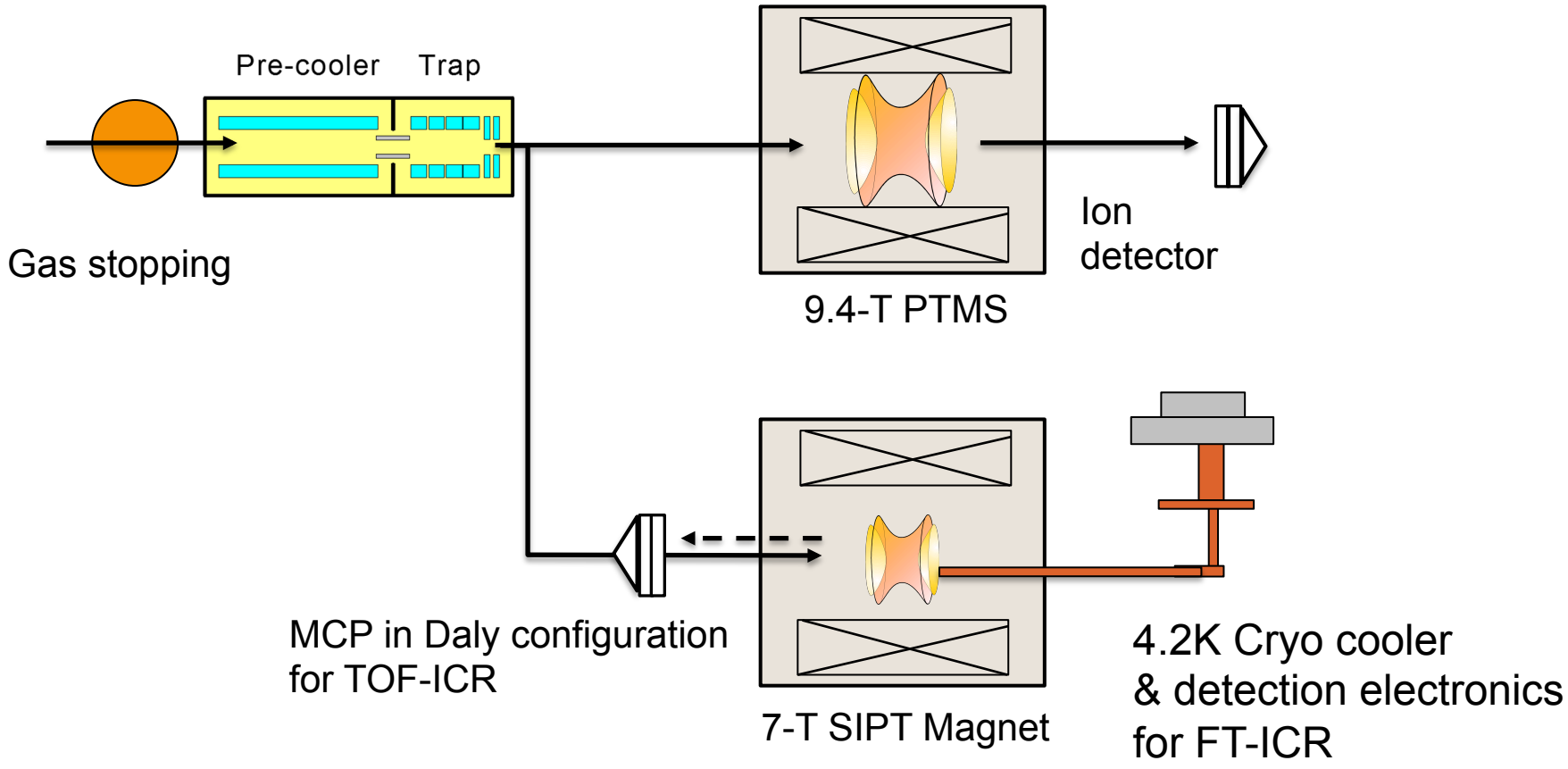
Grinyer et al., Phys. Rev. C **92**, 045503 (2015)
P. A. Voytas and E. A. George, Phys. Rev. C **92**, 065502 (2015)
M. R. Dunlop, et al., Phys. Rev. Lett **116**, 172501 (2016)

The Single Ion Penning Trap (SIPT) project

Advancing sensitivity of LEBIT



TOF-ICR and FT-ICR at SIPT for comparison

TOF-ICR measurement at SIPT

available with backwards extraction

SIPT Magnet

Daly configuration

MCP
-1950 V

Trap

DT1
-200 V

DT2
-300 V

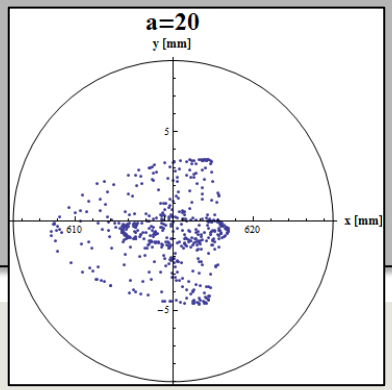
DT3
-1500 V

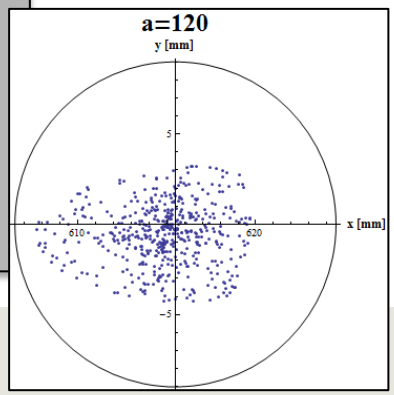
DT4
-2000 V

DT5
-500 V

DT6
-2000 V

Collector
-5700 V





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