TITAN Mass Measurement of ^{11}Li (and other halo nuclei)

Ryan Ringle, TRIUMF

The weather in Vancouver

(according to the tourist board)

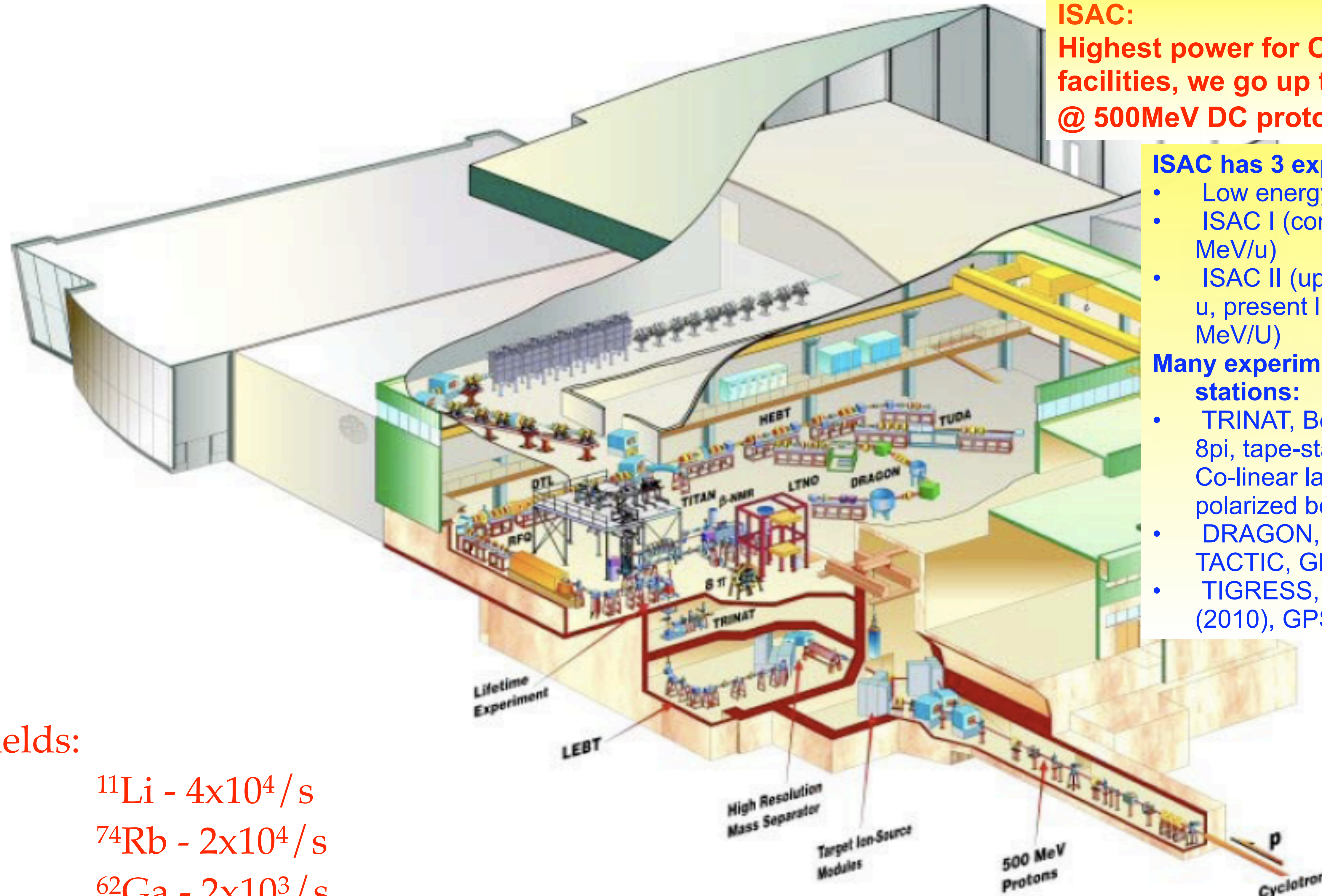
The weather in Vancouver

(the other 364 days of the year)

Outline

- ISAC @ TRIUMF
- The TITAN experiment
- Penning trap mass spectrometry
- Towards shorter half lives
- Results of ^{11}Li measurement
- Results of other halo nuclei mass measurements

ISAC at TRIUMF



ISAC:
Highest power for On-Line facilities, we go up to 100μA @ 500MeV DC proton

ISAC has 3 exper. areas:

- Low energy (60keV)
- ISAC I (cont. up 1.8 MeV/u)
- ISAC II (up to 10 MeV/u, present license to 5 MeV/U)

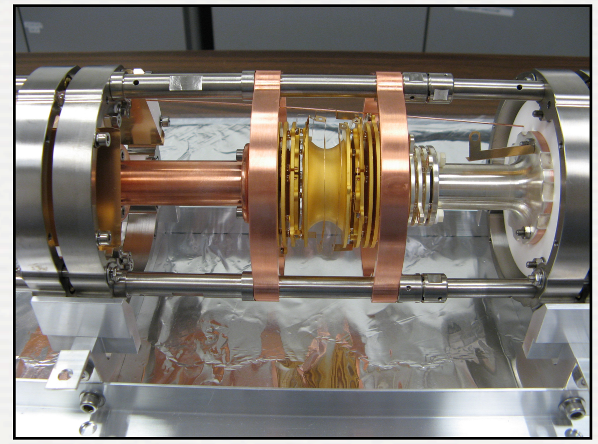
Many experimental stations:

- TRINAT, Beta-NMR, 8pi, tape-station, TITAN, Co-linear laser spec, polarized beam line, etc
- DRAGON, TUDA, TACTIC, GPS (Leuven)
- TIGRESS, EMMA (2010), GPS (Maya)

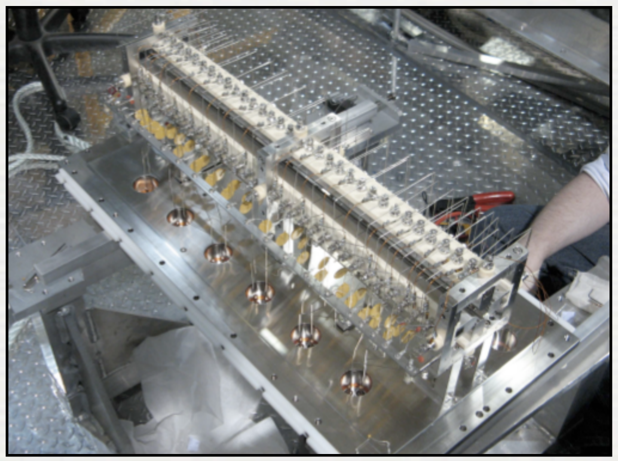
Yields:

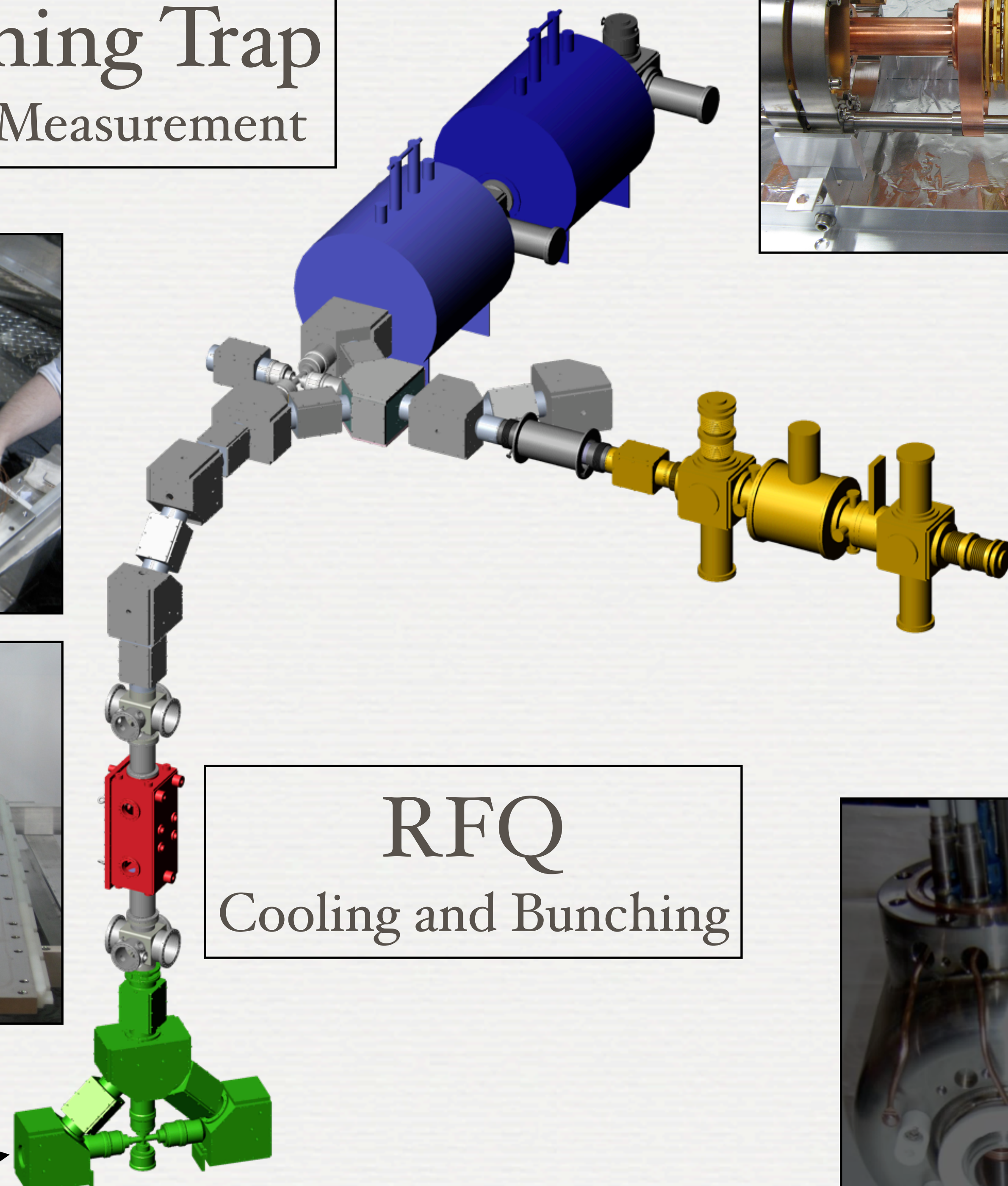
^{11}Li - $4x10^4$/s
^{74}Rb - $2x10^4$/s
^{62}Ga - $2x10^3$/s

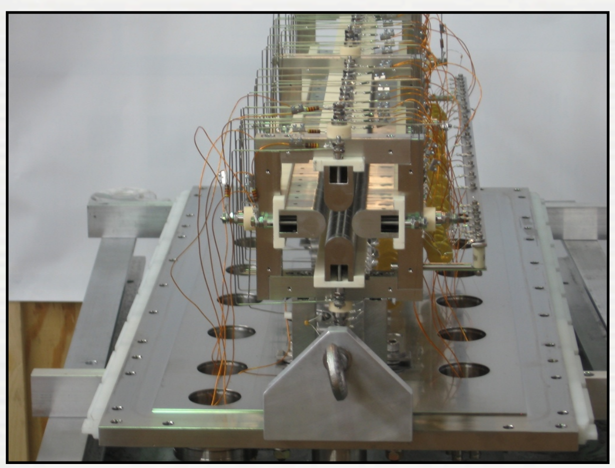
The TITAN Experiment



Penning Trap
Mass Measurement

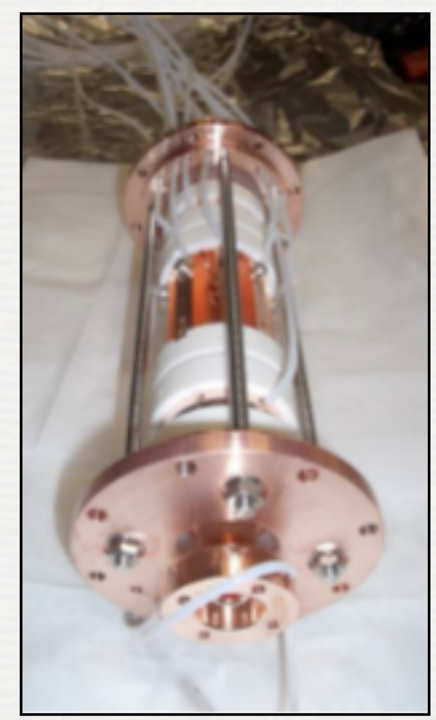






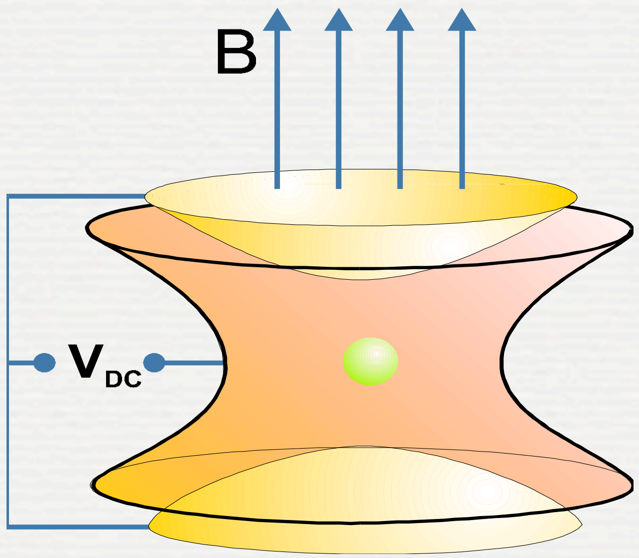
EBIT
Charge State Breeding
(talk by T. Brunner)

RFQ
Cooling and Bunching

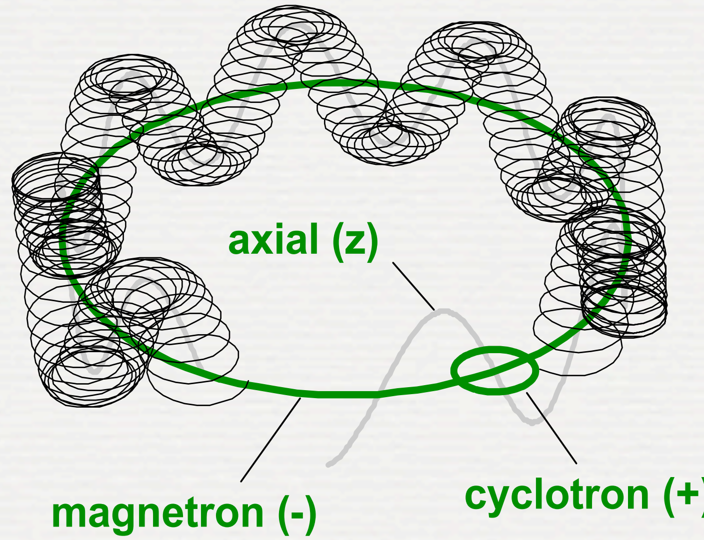


ISAC Beam
(E ~ 20-60 keV)

Penning Trap Mass Spectrometry



3D ion confinement:
linear magnetic field
+quadrupolar electric field

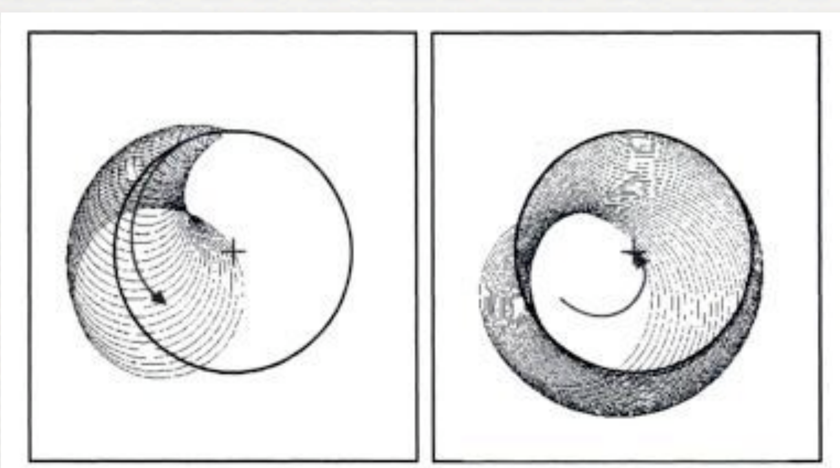


Resulting ion motion:
3 independent eigenmotions
$\omega_+, \omega_-, \omega_z$

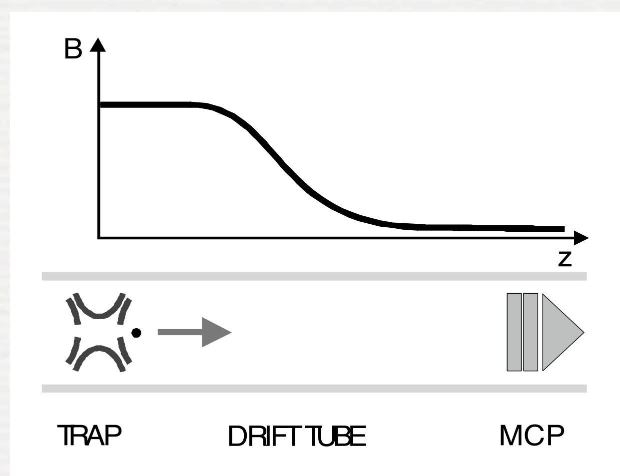
$$\omega_- < \omega_z < \omega_+$$

$$\omega_c = \omega_+ + \omega_- = \frac{q}{m} B$$

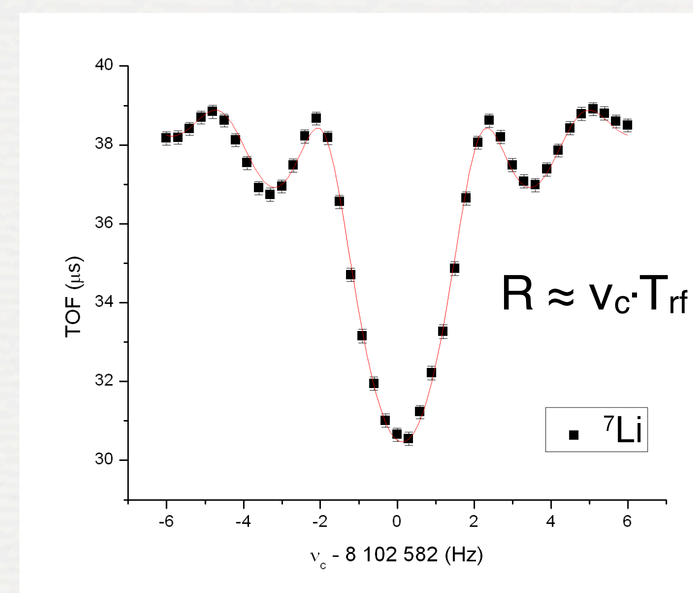
True cyclotron frequency is the
sum of radial eigenmotions



Application of quadrupolar RF field
causes beating between reduced
cyclotron and magnetron motions



Extraction through magnetic
field converts radial energy to
longitudinal energy



Measure TOF to determine
the center frequency

Towards Shorter Half Lives

Measurement time scales:

initial magnetron preparation

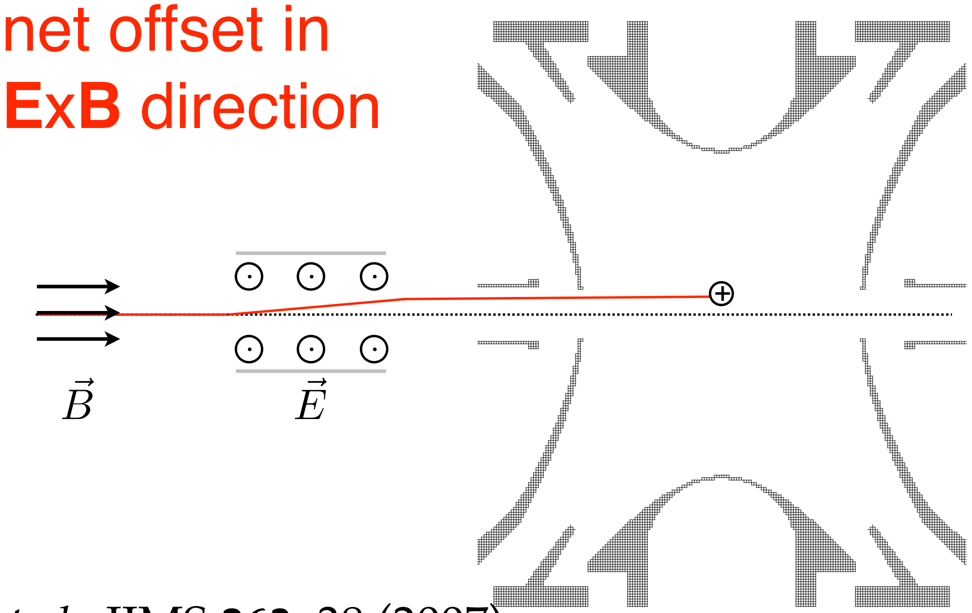
dipolar RF excitation ~ 10 ms

Lorentz steerer FREE

Principle: generate electric dipole field in strong magnetic field region to move ions off axis

$$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$$

→ net offset in ExB direction



R. Ringle *et al.*, IJMS **263**, 38 (2007)

cyclotron motion excitation (limited by half life)

$R \approx \nu_c \cdot T_{rf} = (q/m) \cdot B \cdot T_{rf}$ →

buy a bigger magnet (increase B)

charge breeding (increase q)

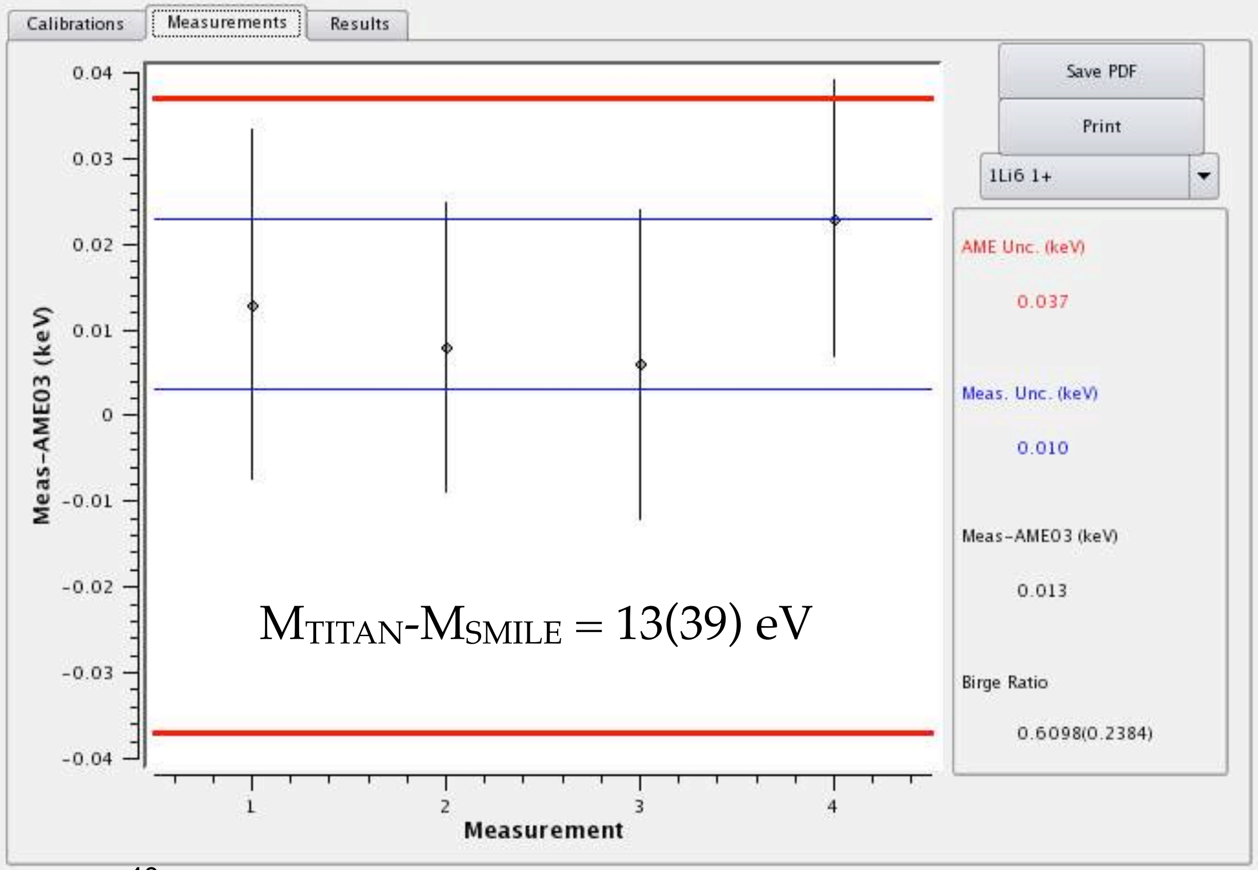
different RF excitation scheme (reduce FWHM)

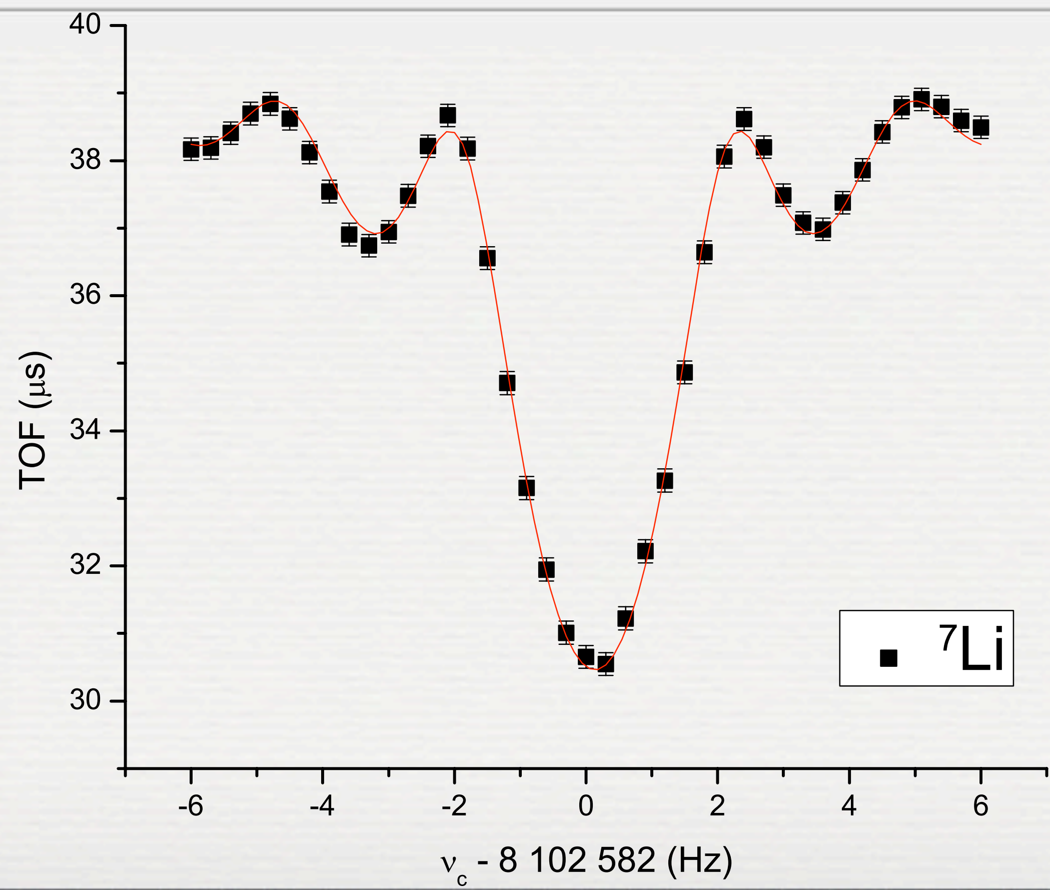
Ramsey excitation - S. George *et al.*, PRL **98**, 162501 (2007)

Octupolar excitation - R. Ringle et al., IJMS **262**, 33 (2007)

S. Eliseev *et al.*, IJMS **262**, 45 (2007)

Penning trap benchmarks





^{6,7}Li mass comparison

Compare to SMILETRAP* values

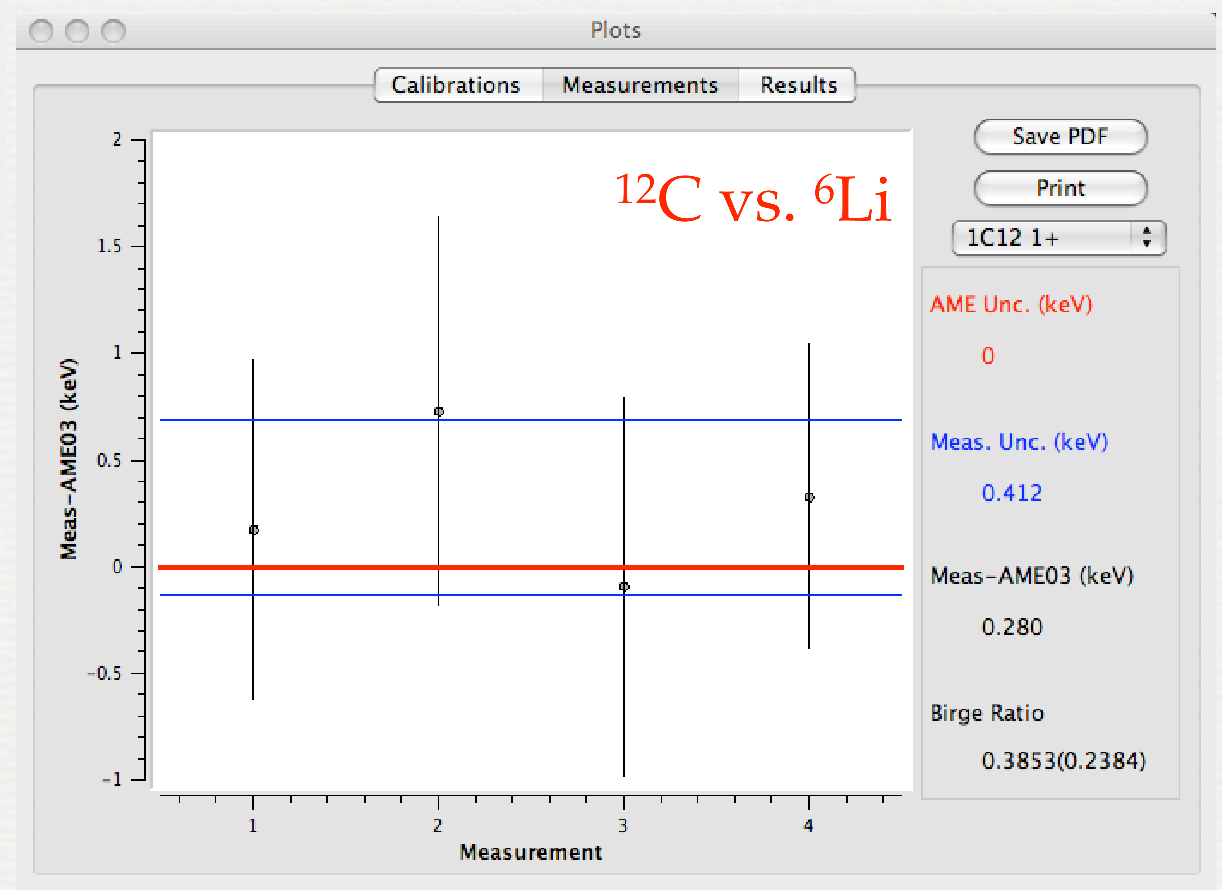
*14σ deviation of m(^{7}Li) from AME03

*Sz. Nagy *et al.*, PRL **96**, 163004 (2006)

^{7}Li δm/m ~ 5×10^{-10}

Agreement is observed on the $2(7)\times10^{-9}$ level

Mass dependent frequency shifts

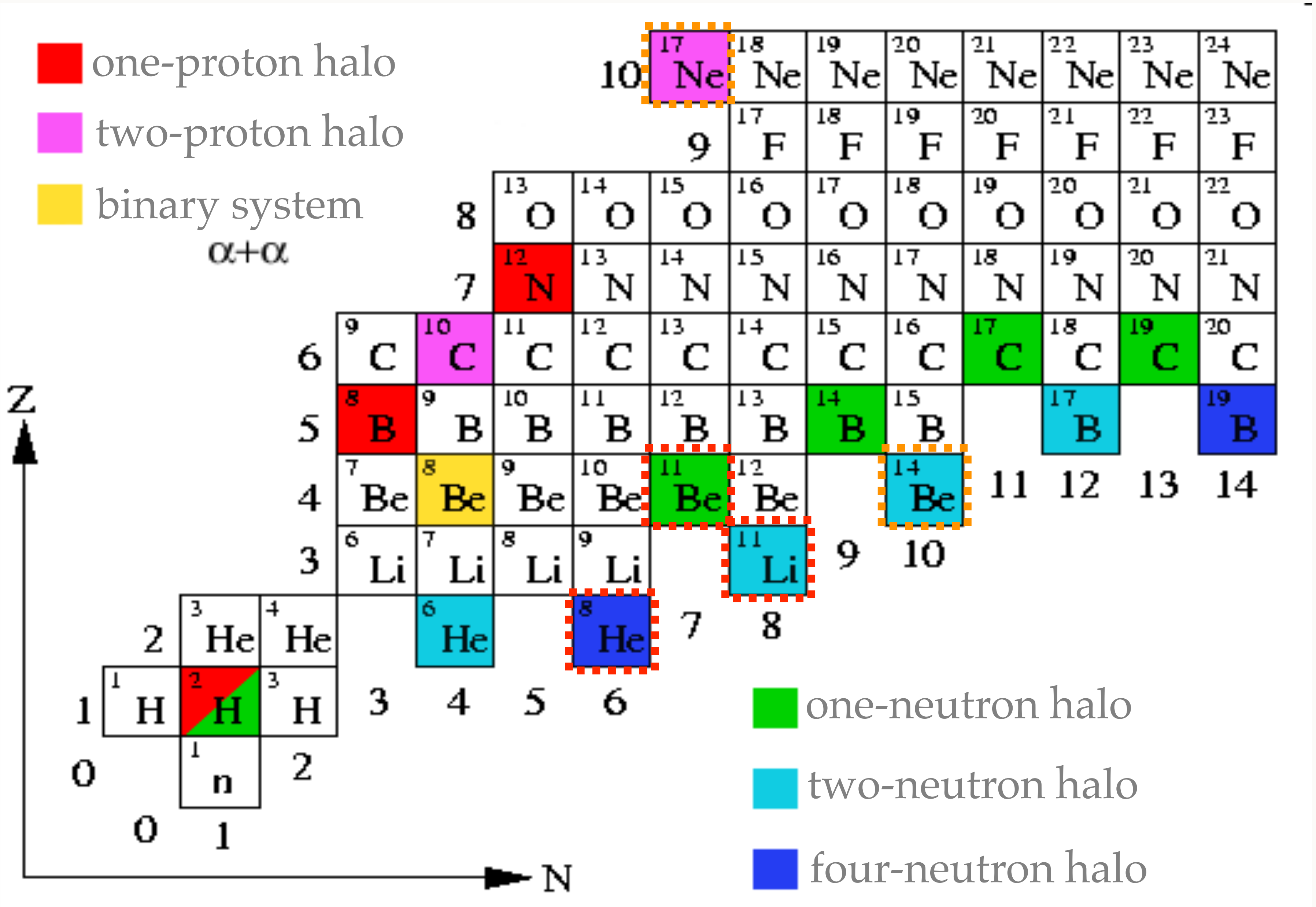


mass shift insignificant on the $3(4)\times10^{-8}$ level over six mass units

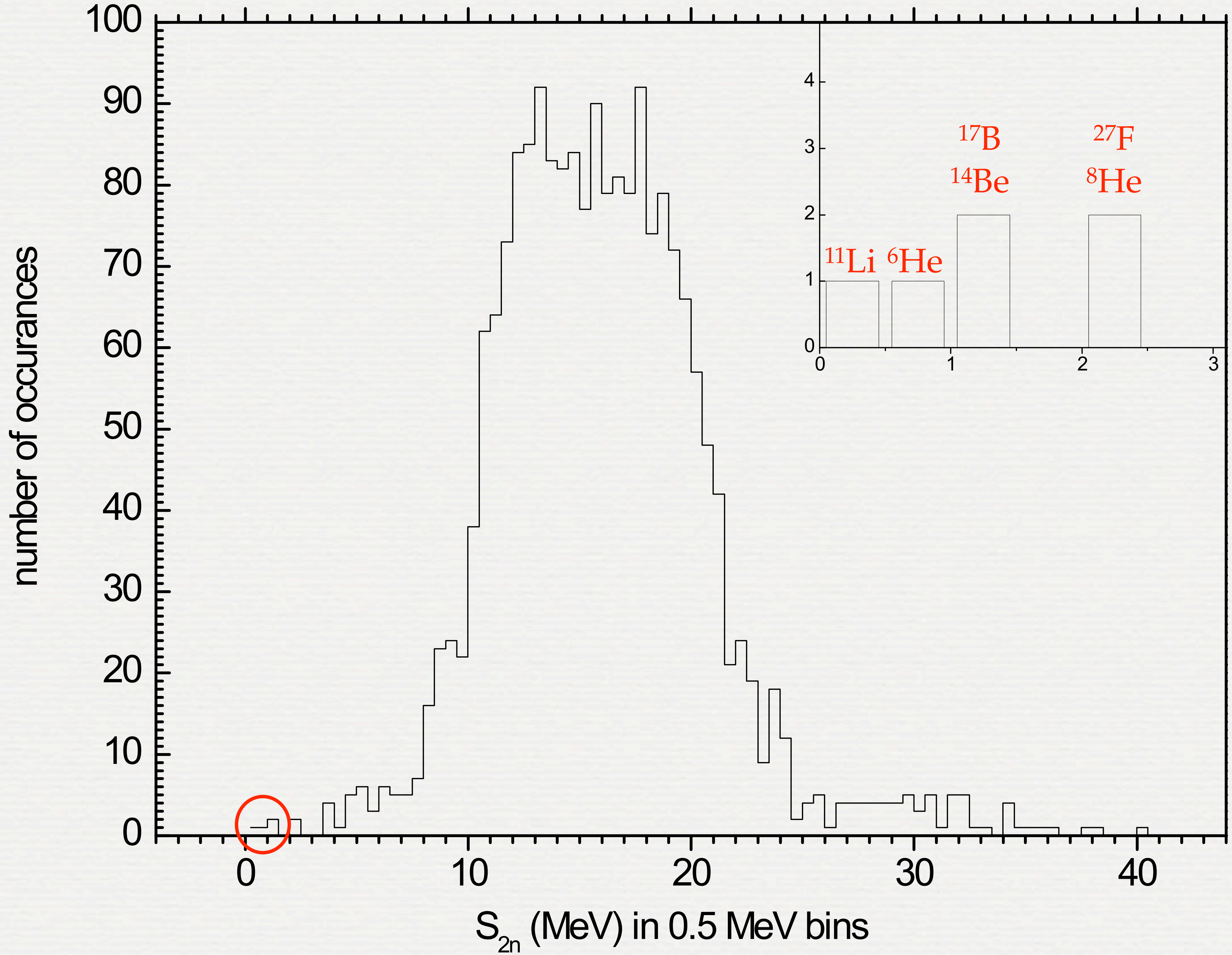
Halo Nuclei

measured with TITAN

proposed



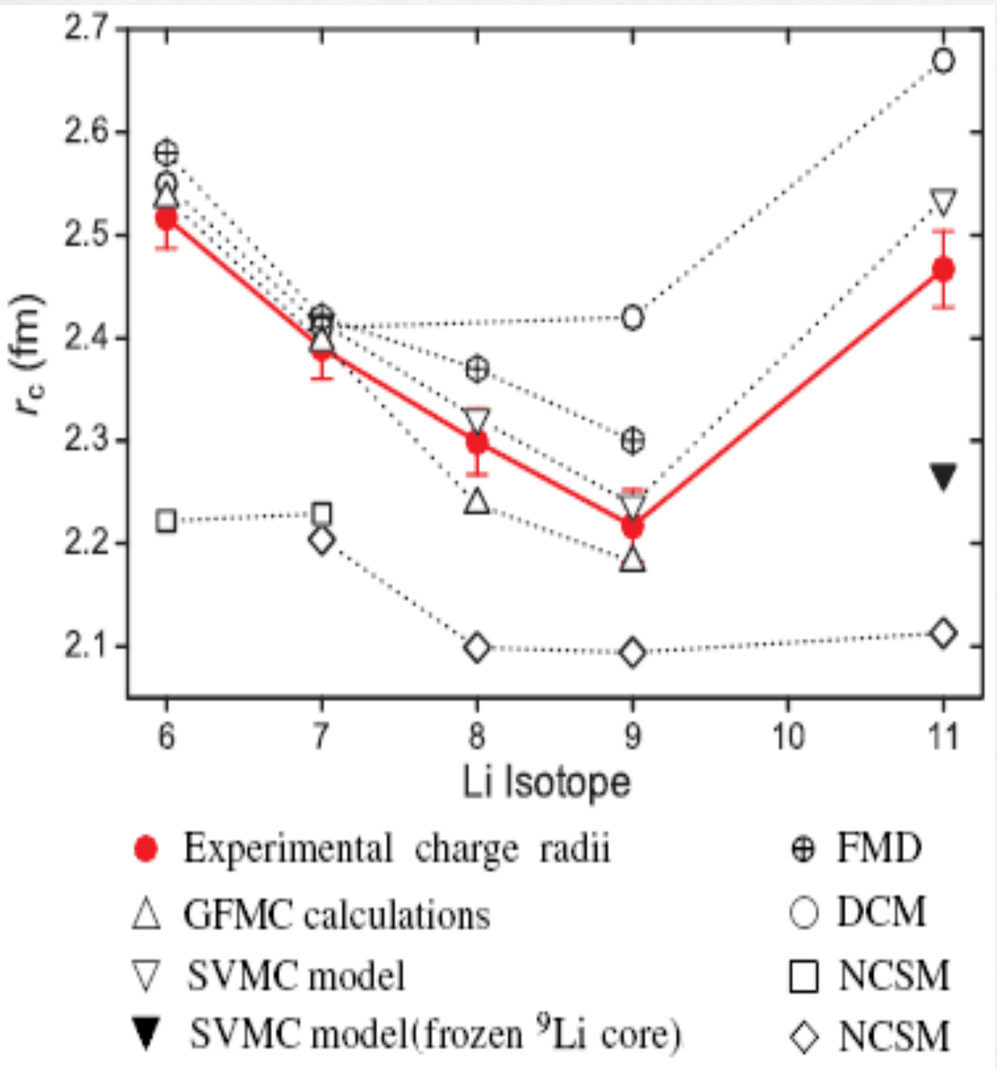
S_{2n} of All Bound Nuclei



slide from D. Lunney

Li Isotope Shifts

altered charge radius, r_c, of ^{11}Li could indicate a perturbed ^{9}Li core



R. Sánchez et al., PRL **96**, 033002 (2006)

Isotopic Shift

$$\delta\nu_{exp}^{A,A'} - \delta\nu_{MS}^{A,A'} = F\delta < r_c^2 >^{A,A'}$$

mass shift term (MS)
~ 10 GHz for Li

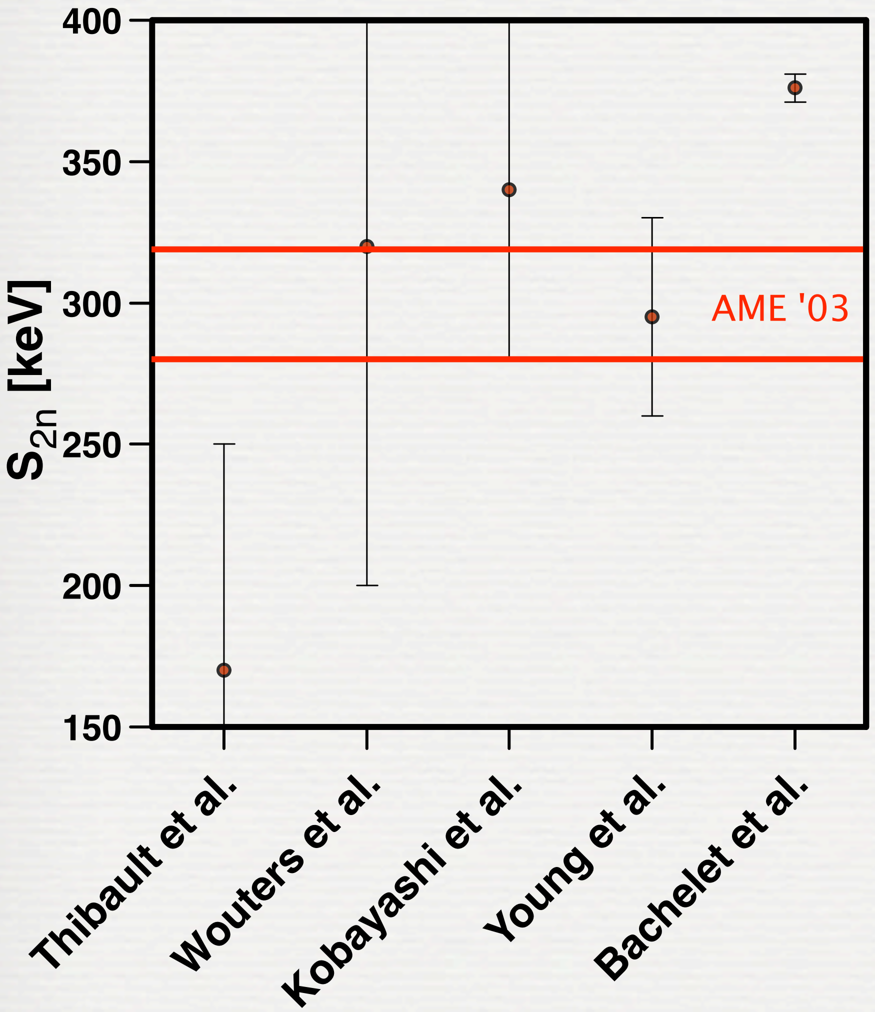
field shift term
~ 0.001 GHz for Li

- optical isotope shift measurements provide relative shift
- ^{6,7}Li r_c determined via elastic electron scattering
  C.W. de Jager et al., At. Data Nucl. Data Tables **14**, 479 (1974)

- mass shift terms calculated by Z.-C. Yan and G.W.F. Drake
  Z.-C Yan and G.W.F. Drake, PRL **91**, 113004 (2003)
- ^{11}Li mass measurement with $\delta m \leq 1$ keV/c^2 required to remove it as a source of significant uncertainty

^{11}Li S_{2n} Value

Five previous measurements of $S_{2n}(^{11}Li)$



Reference	Method	S_{2n} [keV]	
Thibault *et al.*	Mass Spec.	170 ± 80	PRC **12**, 644 (1975)
J.M. Wouters *et al.*	TOF	320 ± 120	Z. Phys. A **331**, 229 (1988)
T. Kobayashi *et al.*	$^{11}B(\pi^-,\pi^+)^{11}Li$	340 ± 50	KEK Rep. 91-22 (1991)
B.M. Young *et al.*	$^{14}C(^{11}B,^{11}Li)^{14}O$	295 ± 35	PRL **71**, 4124 (1993)
Bachelet *et al.*	Mass Spec.	376 ± 5	Eur. Phys. J. A **25**, 31 (2005)

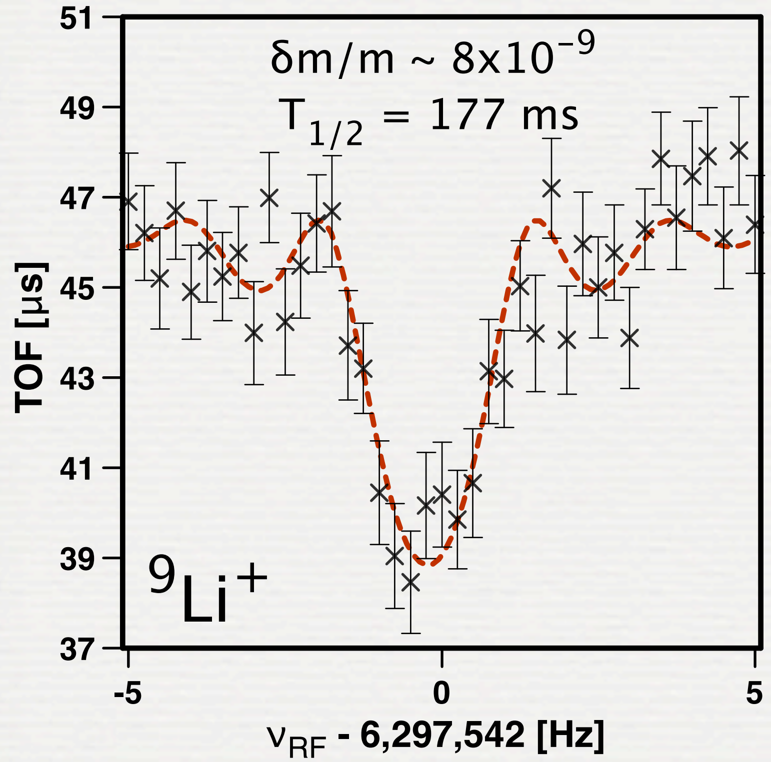
AME '03: $S_{2n}(^{11}Li) = 300 \pm 20$ keV

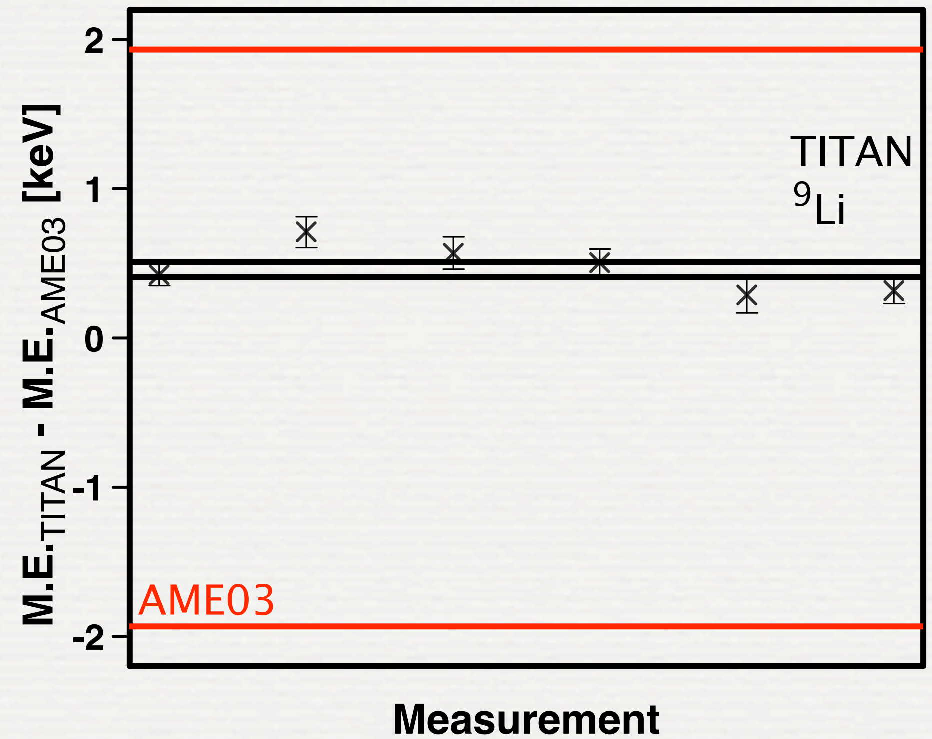
G. Audi *et al.*, Nucl. Phys. A **729**, 129 (2003)

- Need a precision of $\delta m \leq 5$ keV/c^2 to confirm accuracy of Bachelet et al.
- An $S_{2n}(^{11}Li)$ value with 1% uncertainty, $\delta m \leq 3$ keV/c^2, would provide a solid test for nuclear theory.
- Need a precision of $\delta m \leq 1$ keV/c^2 for charge radius calculations.

TITAN Mass Measurement of ^{9,11}Li

(preliminary)

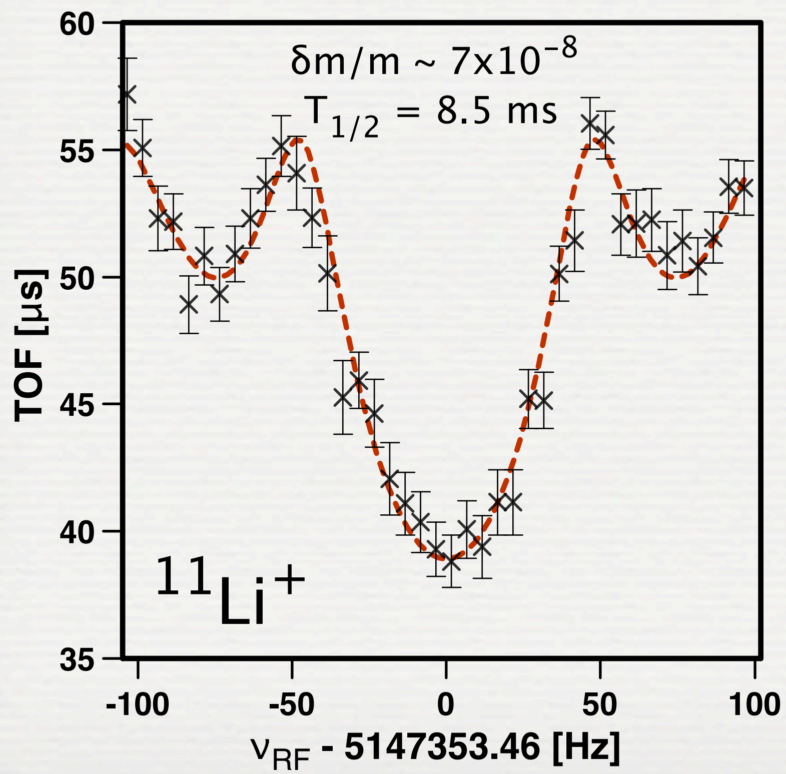


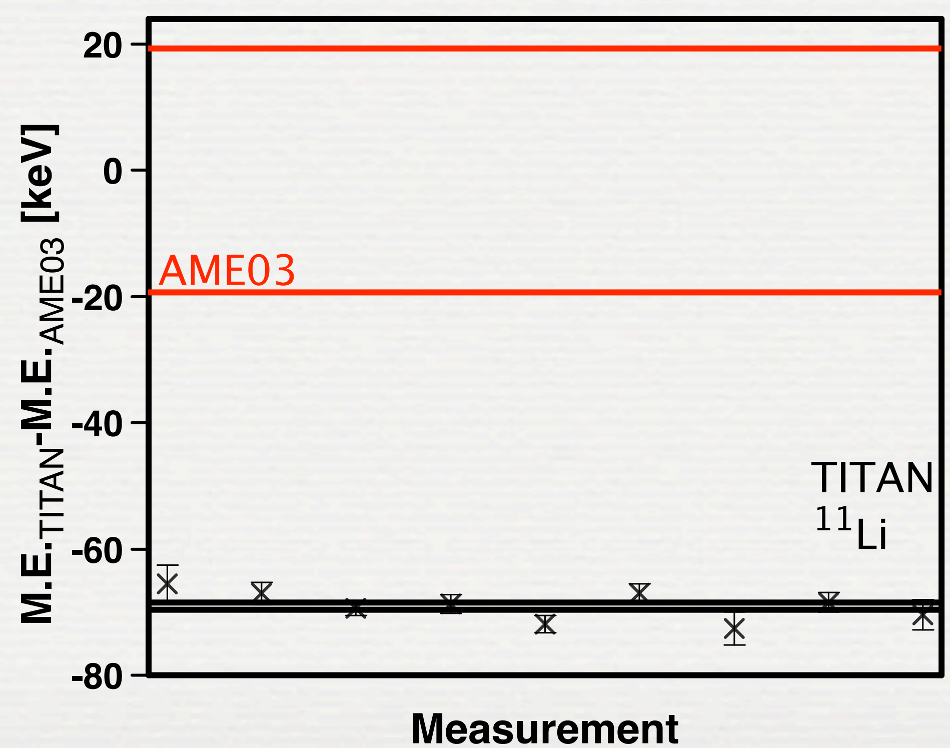


6 measurements

$\delta m/m \sim 3\text{x}10^{-9}$

$\delta m \sim 50$ eV





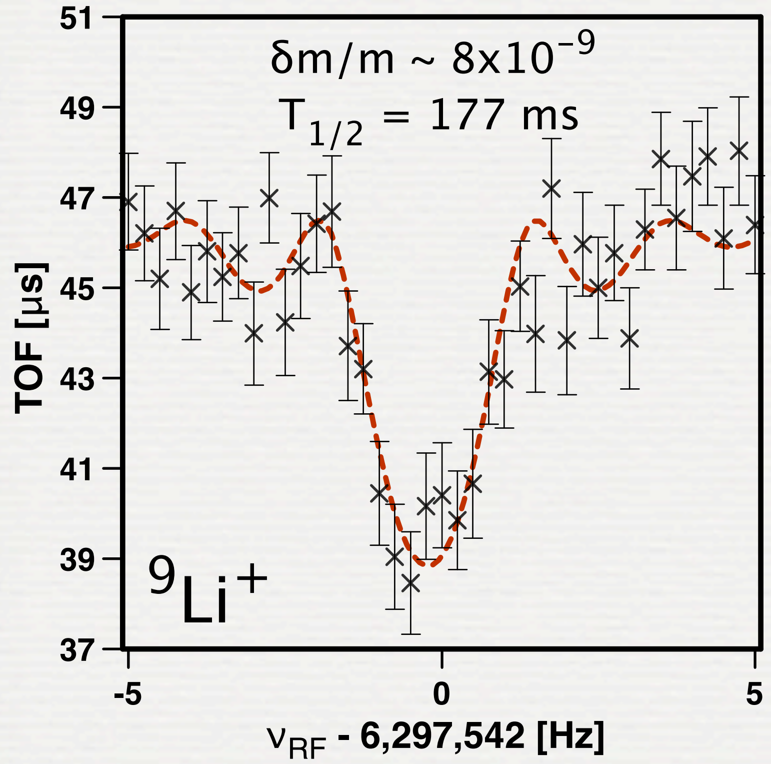
9 measurements

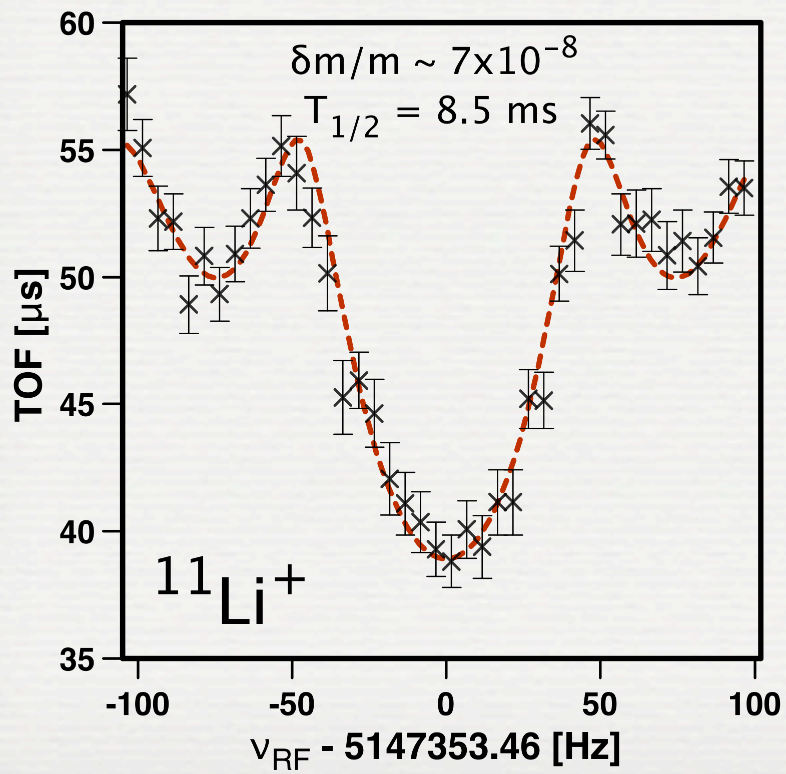
$\delta m/m \sim 3\text{x}10^{-8}$

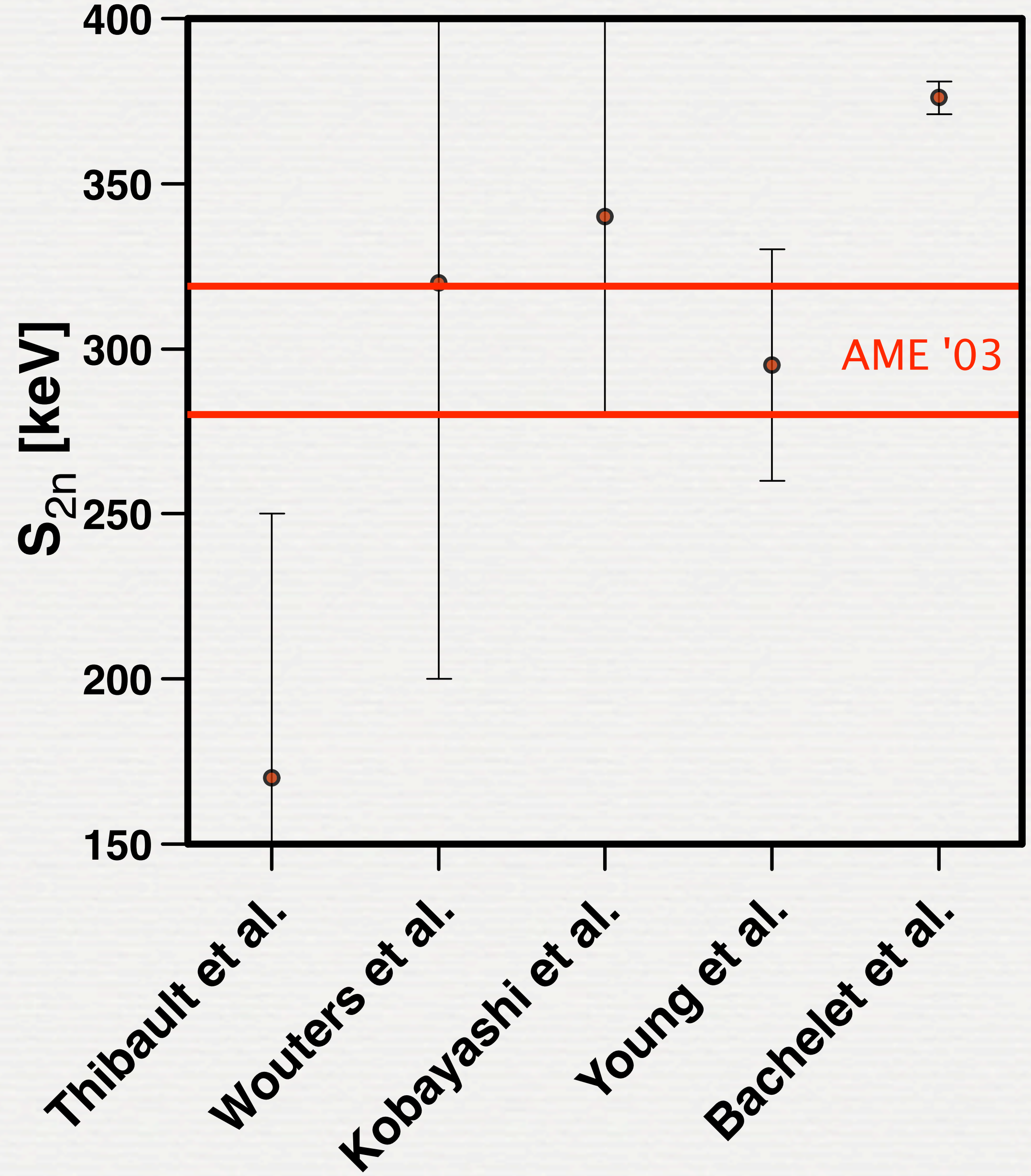
$\delta m \sim 550$ eV

TITAN Mass Measurement of $^{9,11}Li$

(preliminary)

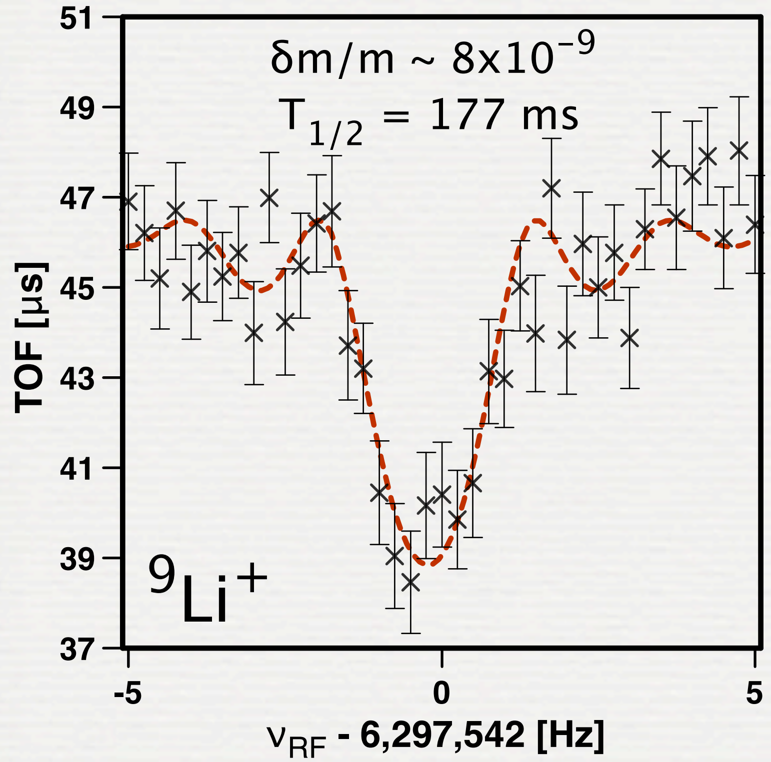


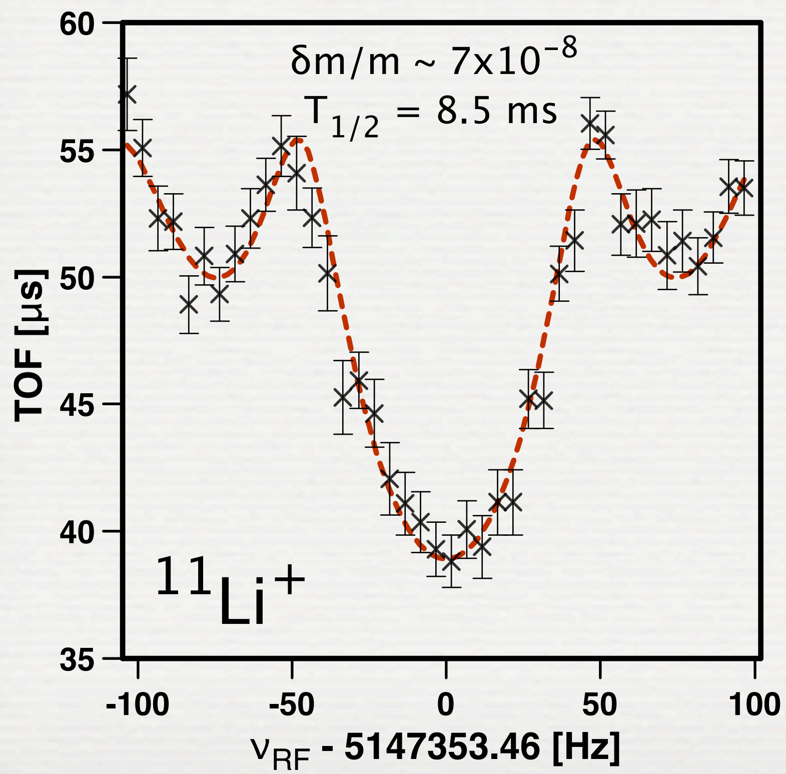


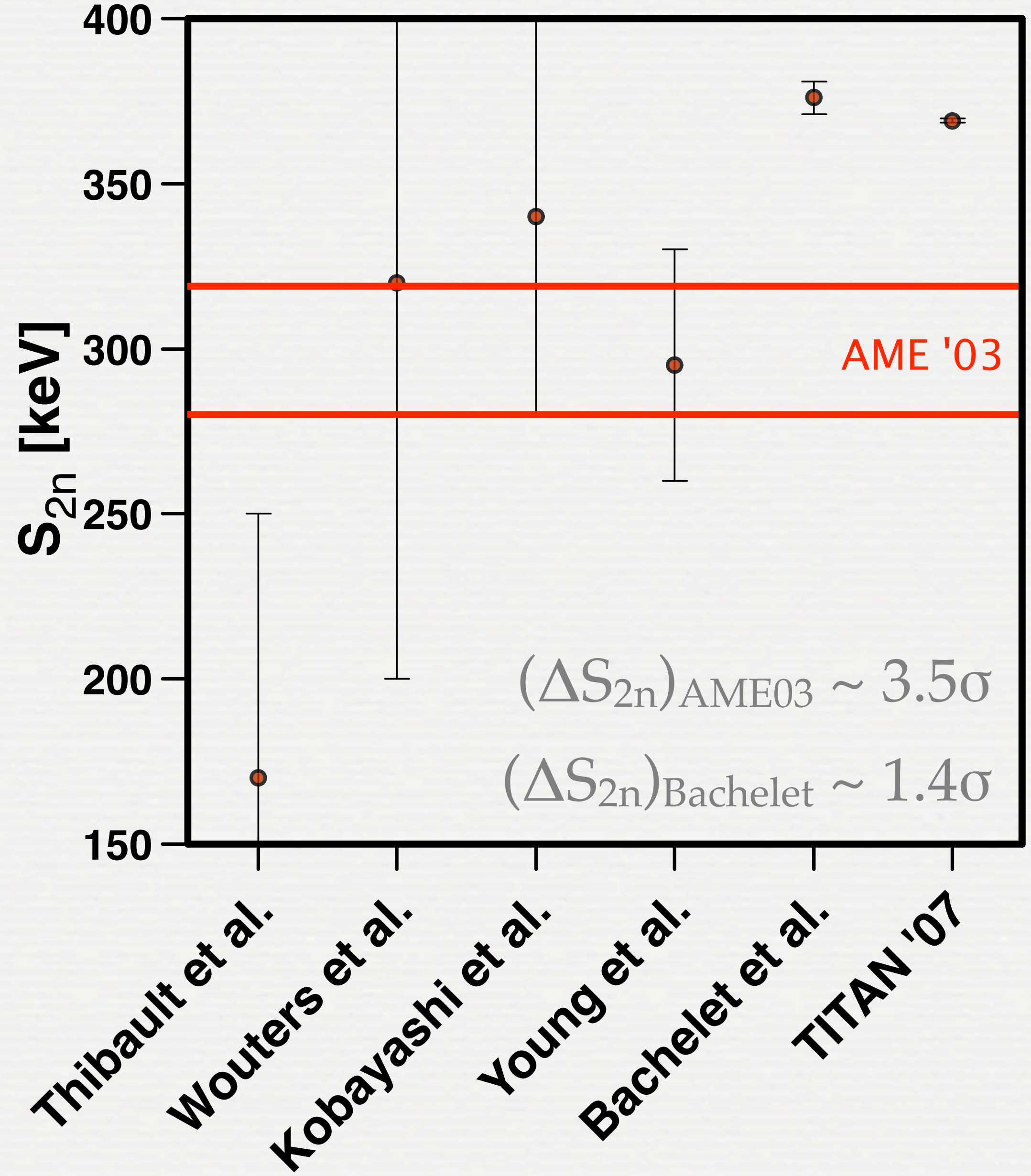


TITAN Mass Measurement of $^{9,11}Li$

(preliminary)

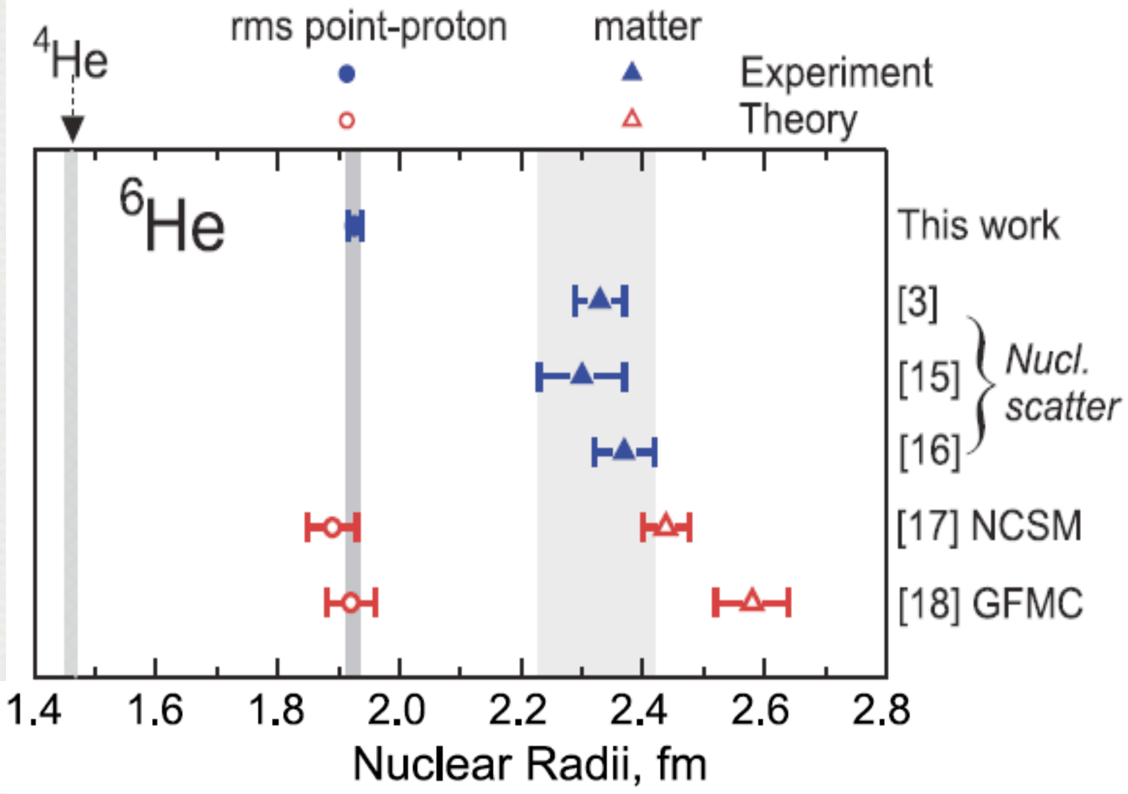






How Big is ^{8}He?

P. Mueller *et al.*, PRL 99, 252501 (2007)



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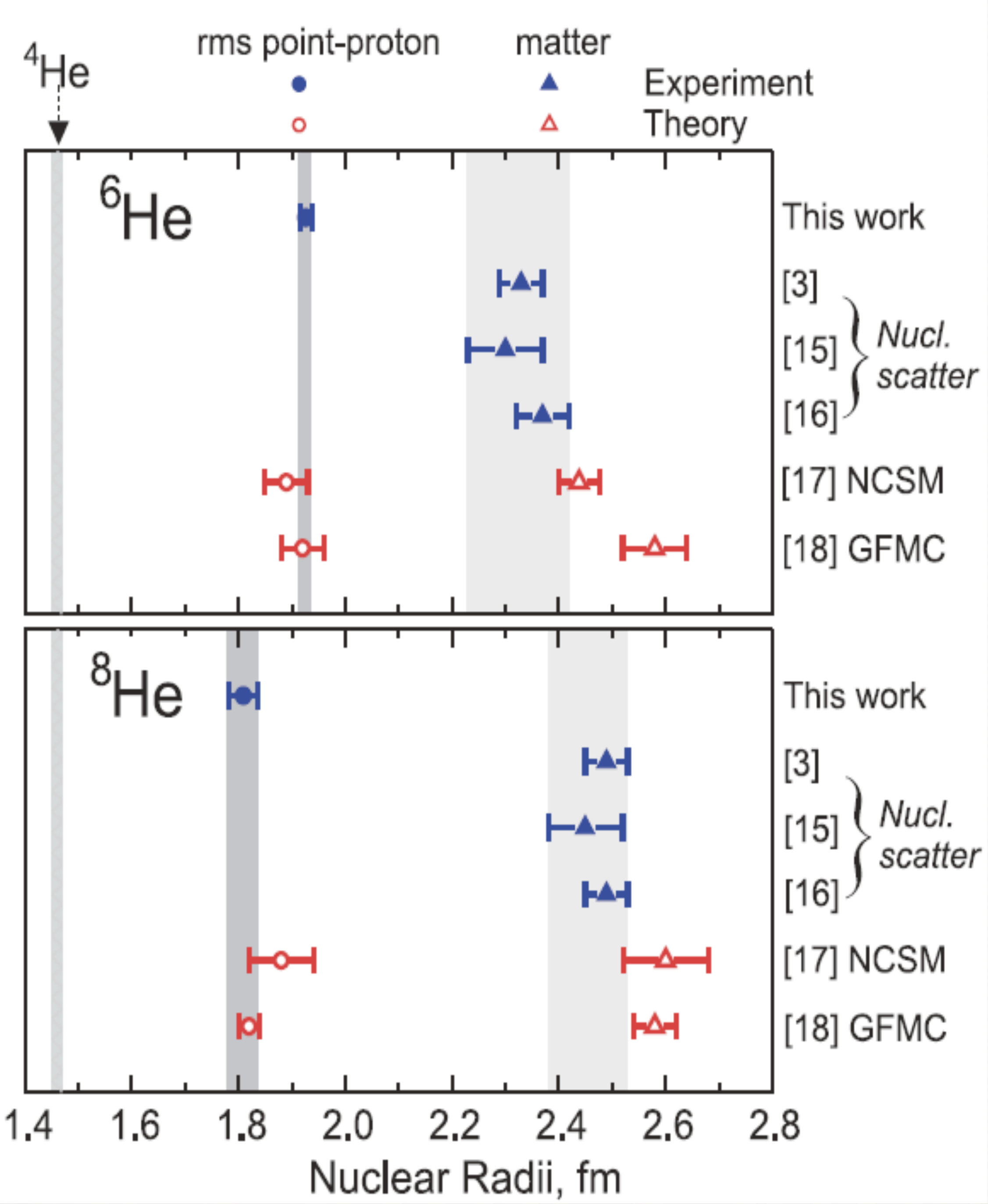

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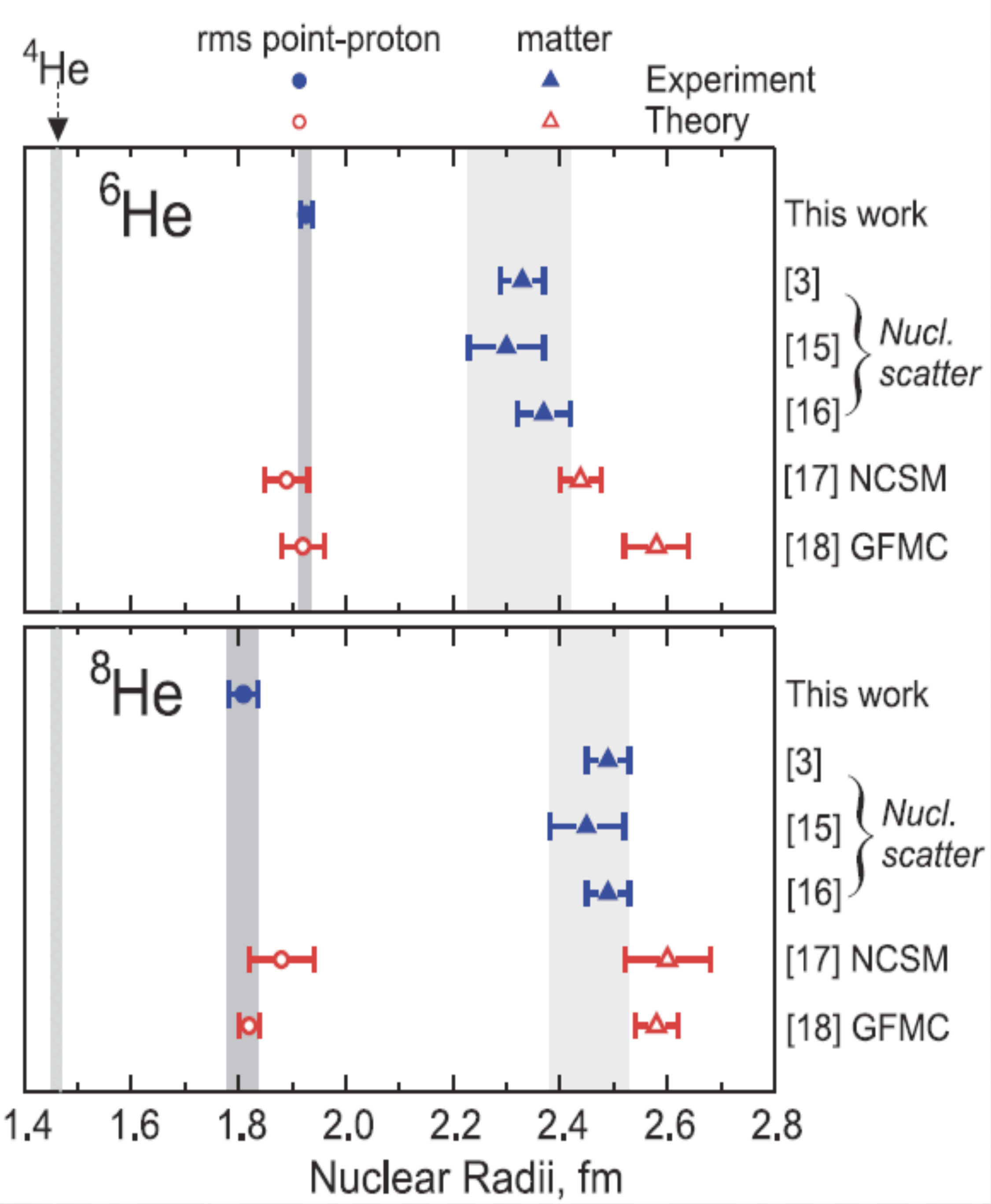
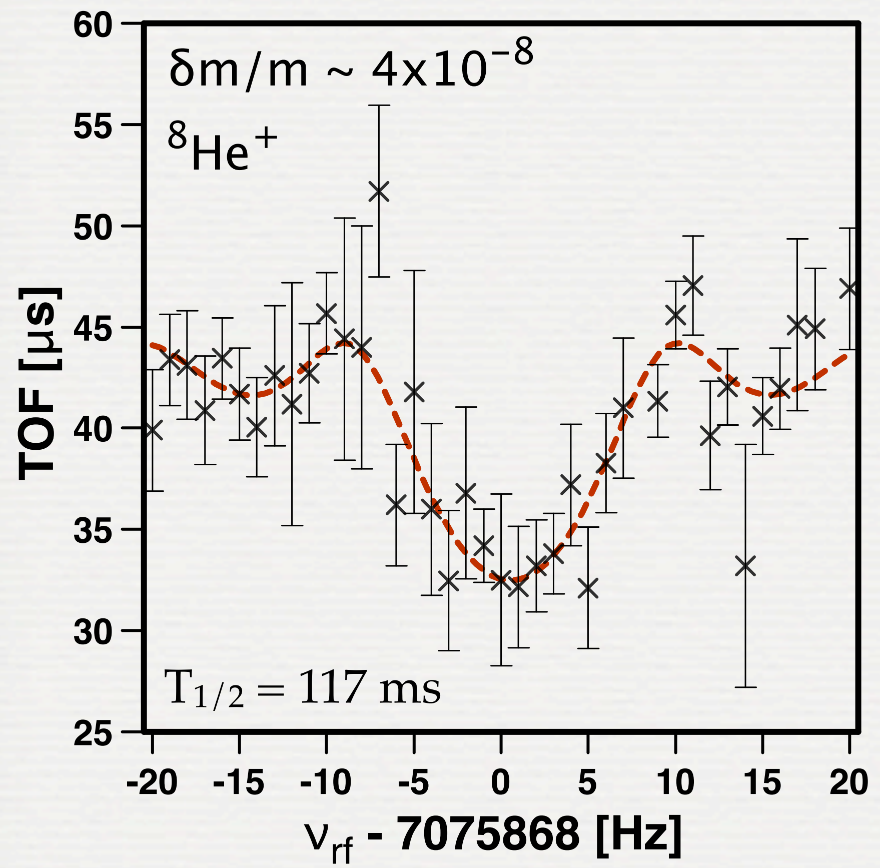
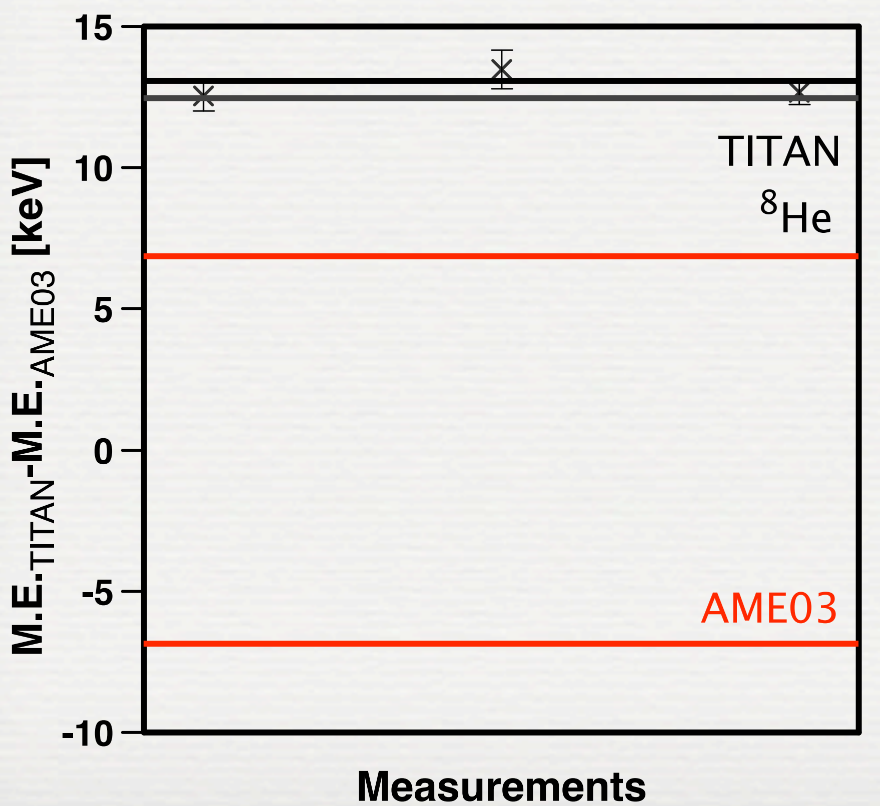


	^{6}He		^{8}He	
	value	error	value	error
Statistical				
Photon counting		0.008		0.032
Probing laser alignment		0.002		0.012
Reference laser drift		0.002		0.024
Systematic				
Probing power shift				0.015
Zeeman shift		0.030		0.045
Nuclear mass		0.015		0.074
Corrections				
Recoil effect	0.110	0.000	0.165	0.000
Nuclear polarization	-0.014	0.003	-0.002	0.001
$\delta\nu^{FS}_{A,4}$ combined	-1.478	0.035	-0.918	0.097

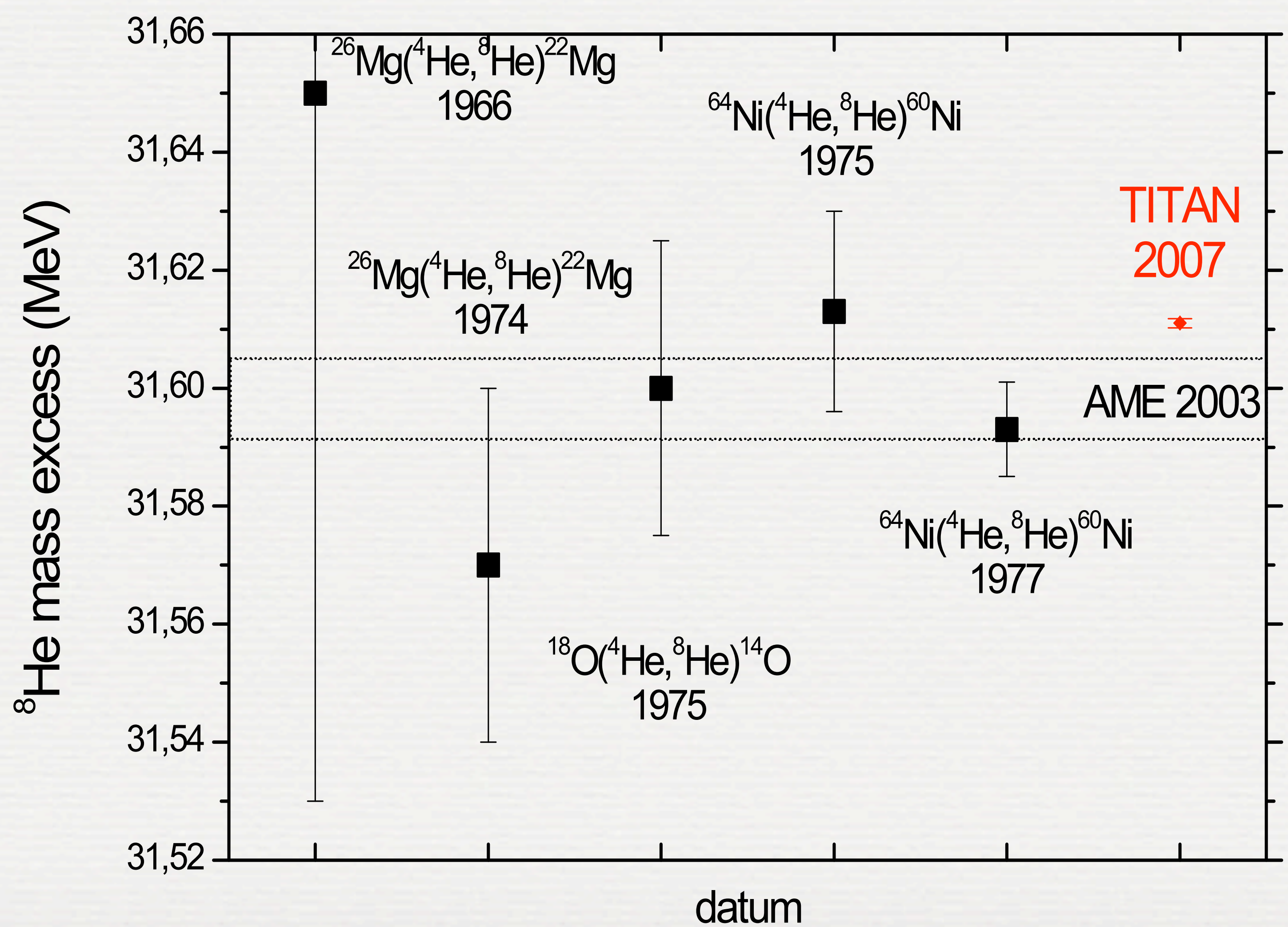
TITAN Mass Measurement of ^{8}He

(preliminary)



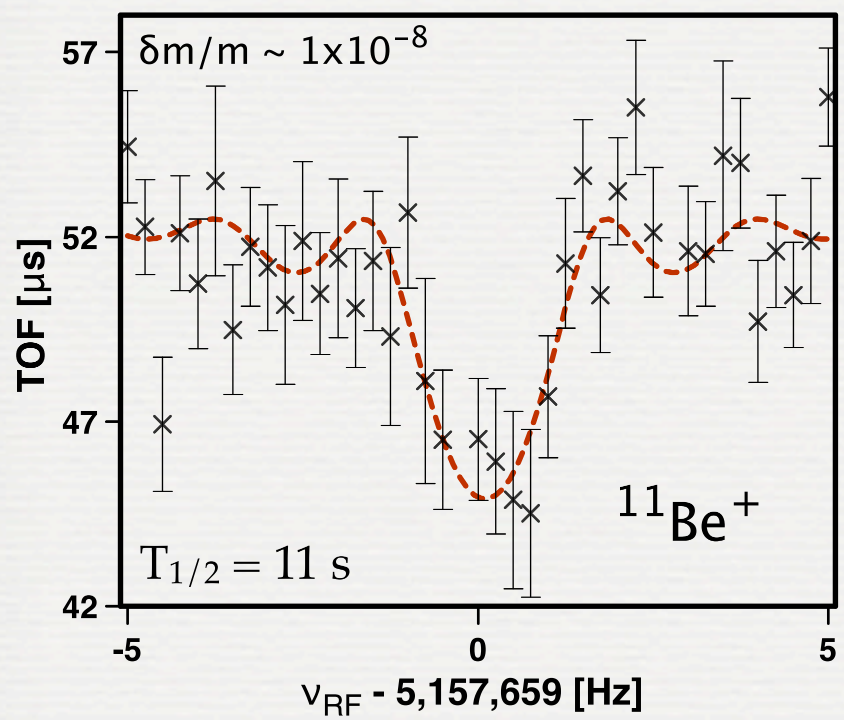


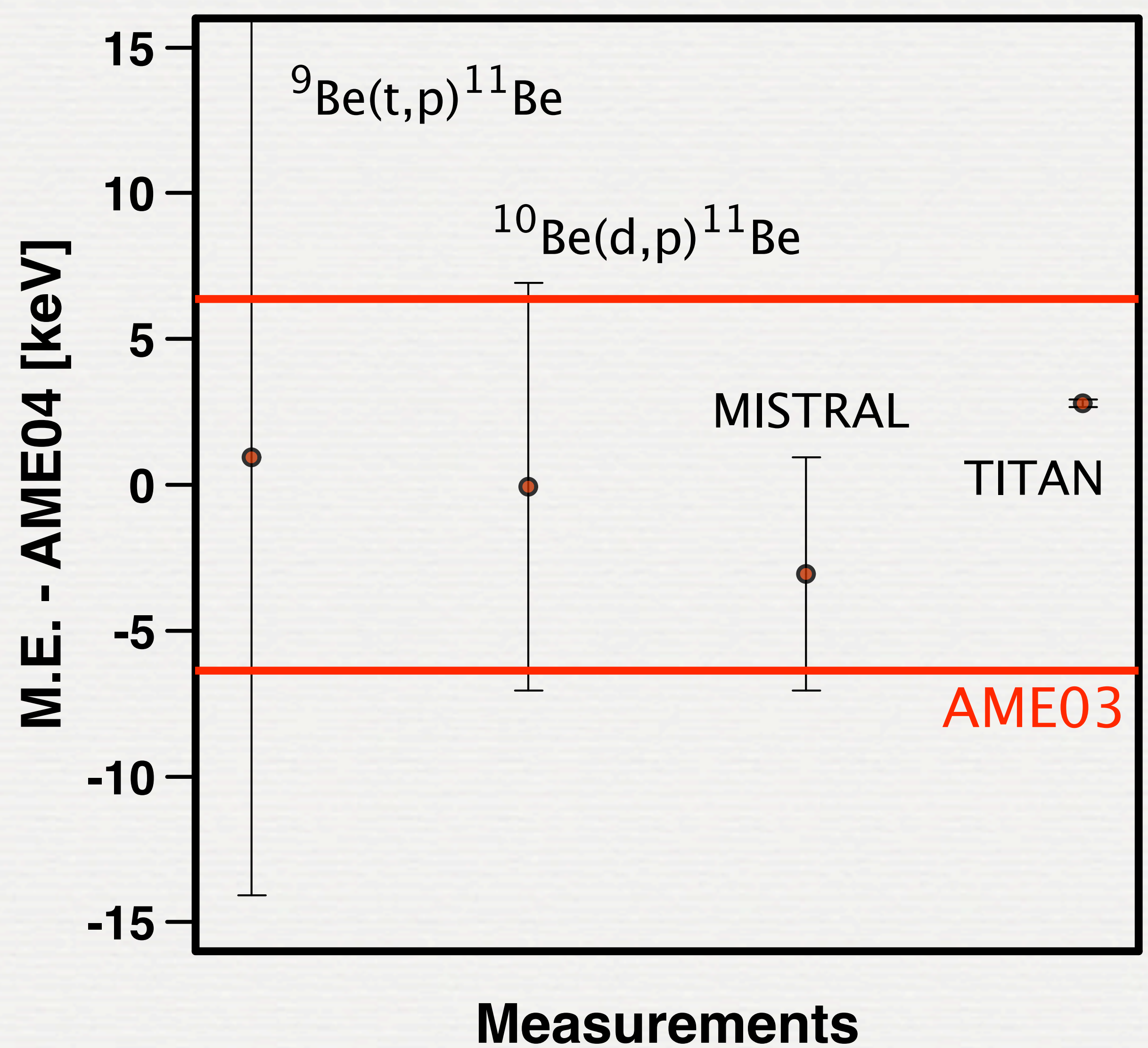
- First direct mass measurement of ^{8}He
- H_2 used as buffer gas in RFQ
- Produced with "broken" FEBIAD ion source
- $\delta m \sim 300$ eV
- $\Delta m \sim 1.9\sigma$

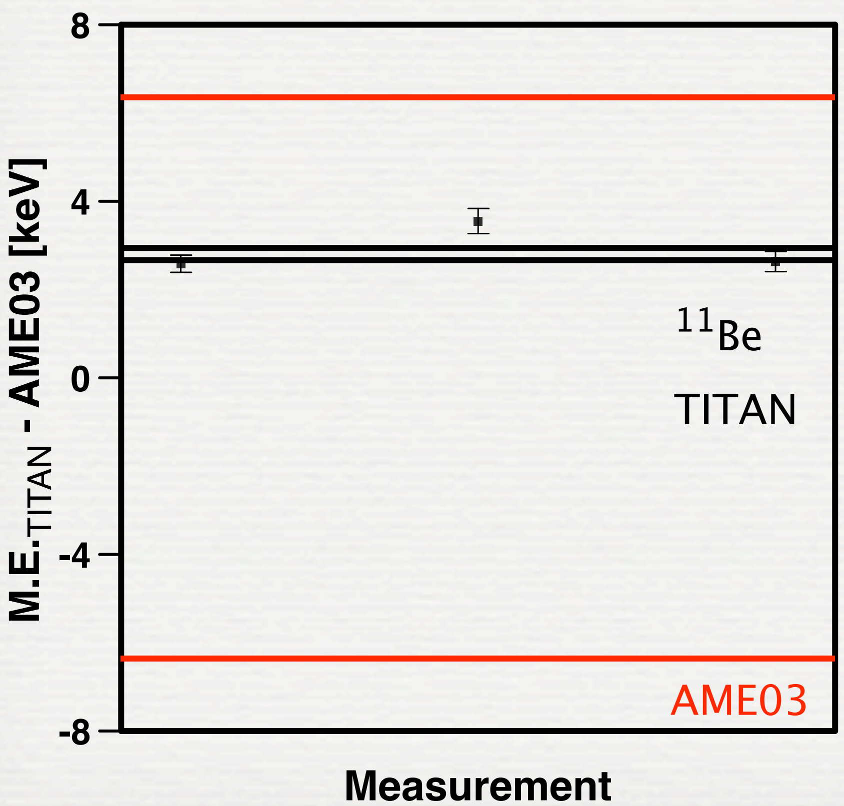


TITAN Mass Measurement of ^{11}Be

(preliminary)







$\delta m/m \sim 7\text{x}10^{-9}$ (reduced by a factor of ~ 50)

Conclusions & Outlook

- The TITAN mass spectrometer has been commissioned and is capable of making high-precision mass measurements of very short lived nuclei
- TITAN has performed precision mass measurements of He, Li and Be halo nuclei (final analysis pending).
- New halo mass measurements allow a refined charge radius determination and shed new light on the structure of halo nuclei
- More mass measurements to come this year (halo, CKM, structure, HCI, etc.)
- Neutrinoless $\beta\beta$-decay measurements using EBIT (T. Brunner on Friday)

The TITANs

M. Brodeur, T. Brunner, C. Champagne, J. Dilling, P. Delheij, S. Ettenauer, M. Good, A. Lapierre, D. Lunney, R. Ringle, V. Ryjkov, M. Smith, and the TITAN collaboration

U. of Manitoba	U. of Calgary
McGill U.	U. of Windsor
Muenster U.,	Colorado School of Mines
Max Plank Inst. of Heidelberg	TRIUMF
GANIL	UBC