Online Commissioning of MR-TOF mass spectrograph at RIKEN

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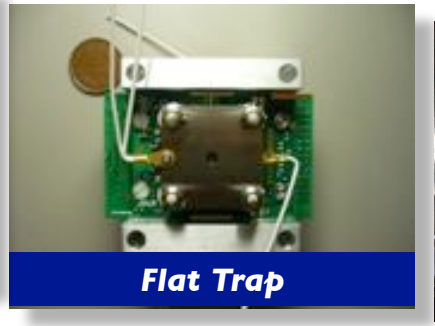
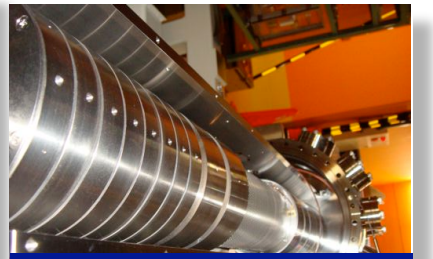
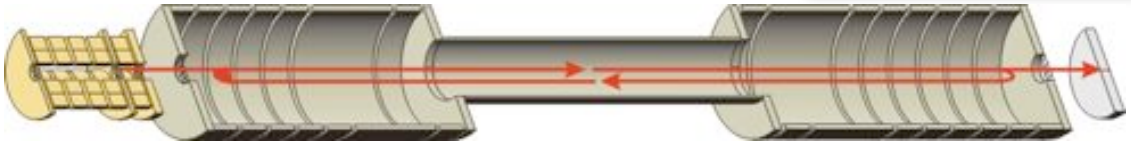
Taper Trap

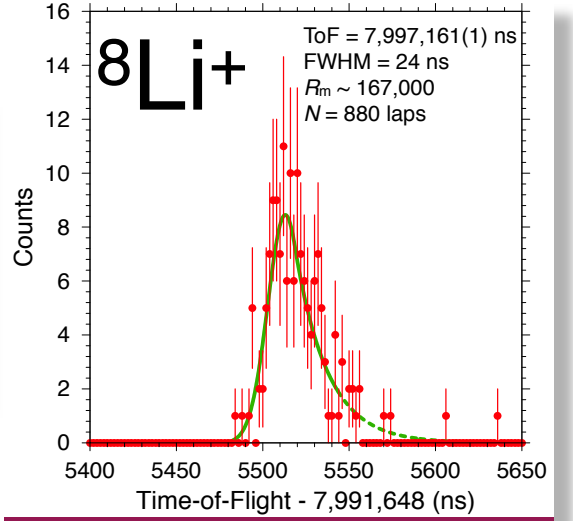


Flat Trap



MR-TOF

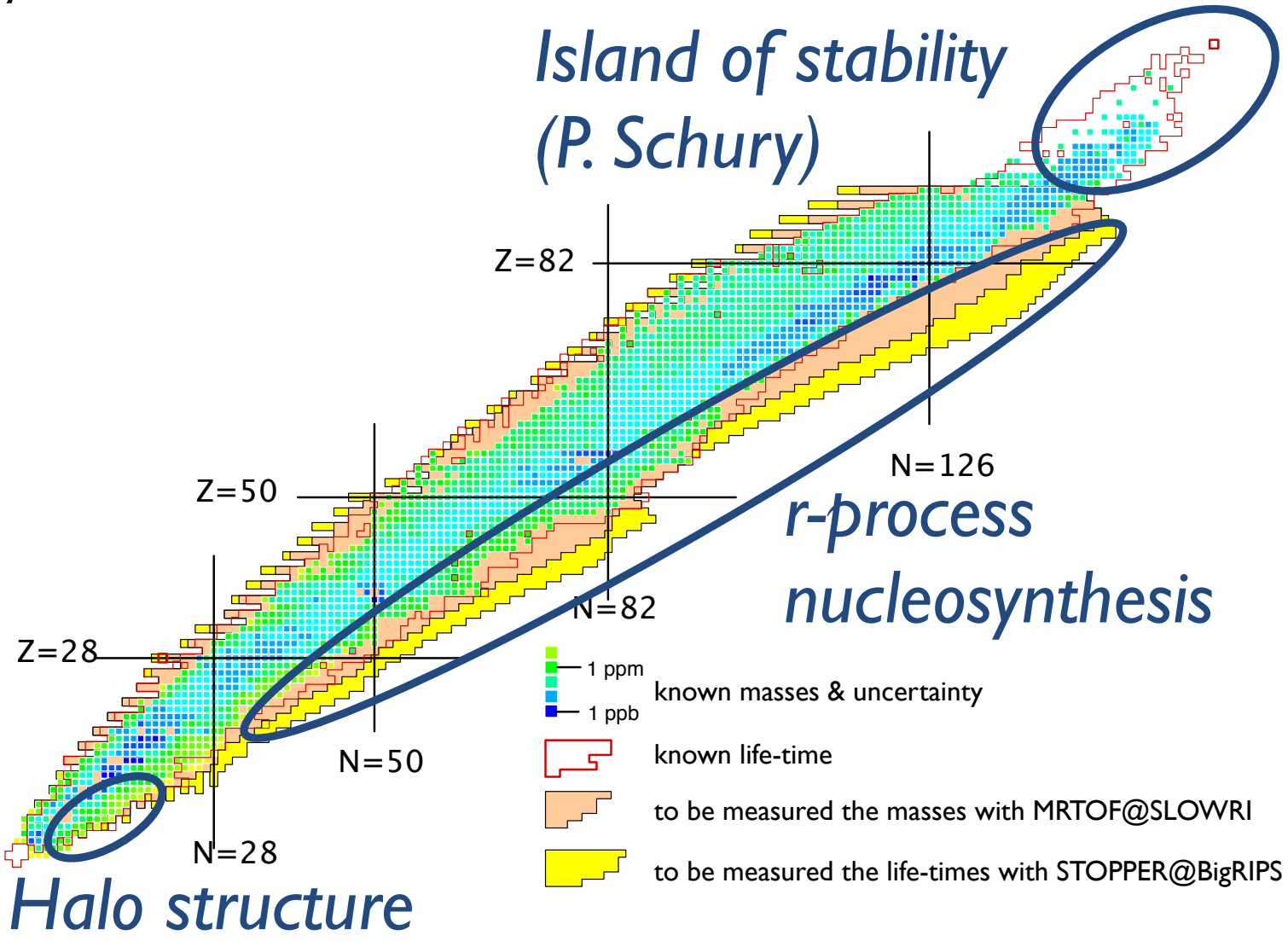




1st Online Mass Measurement

- Motivation
- Experimental Setup
- Results

Physics Motivation



Requirements

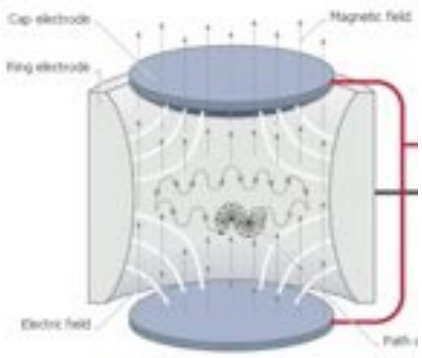
- Low production yield
  - ◇ *High efficiency*
- Short-lived
  - ◇ *Fast measurement*
- Heavy
  - ◇ *Small mass dependence of mass resolving power (MRTOF vs. PTMS)*

Experimental Motivation

- Whole system check with unstable nuclei online
- Efficiency check
  - ^{8}Li: $T_{1/2}$ = 840 ms, ^{8}Li(β-)^{8}Be(2α)
  - Easy evaluation
- Systematic error evaluation
- Accuracy and precision of MRTOF-MS
  - Calibration by non-isobaric references

- Motivation
- **Experimental Setup**
- Results

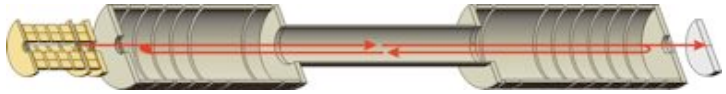
PTMS vs. MRTOF-MS



$$f_{\mathrm{cyc}} = \frac{qB}{2\pi m}$$

$$R_{\mathrm{m}} \equiv \frac{m}{\delta m} \approx \frac{qB}{m} t_{\mathrm{obs}} \qquad t_{\mathrm{obs}} \leq \sim 2T_{1/2}$$

- t_{obs} > 100 ms (typically)
- Frequency scan: *Spectrometer*



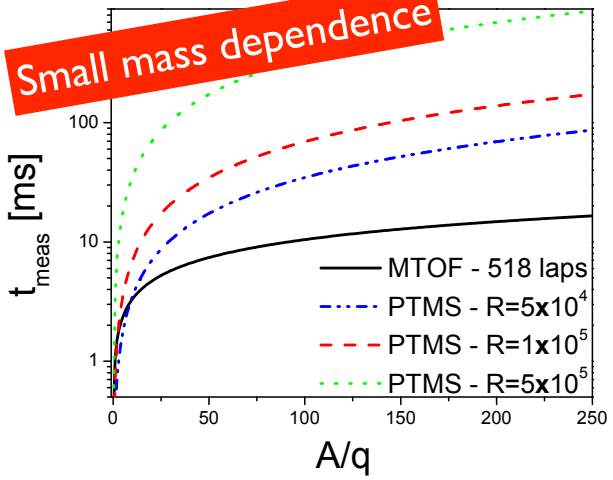
$$t_{\mathrm{tof}} = L\sqrt{\frac{m}{2K}}, \qquad \frac{\partial t_{\mathrm{tof}}}{\partial K} \approx 0$$

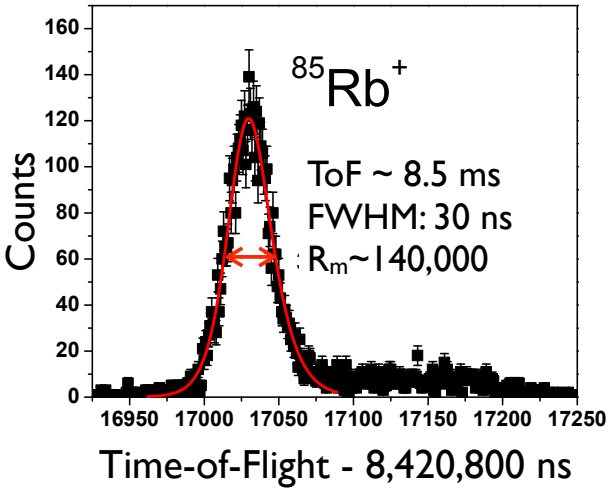
Isochronous!

$$R_{\mathrm{m}} \equiv \frac{m}{\Delta m} = \frac{1}{2}\frac{t_{\mathrm{tof}}}{\Delta t} \propto \frac{1}{\sqrt{m}}$$

- t_{obs} < 10 ms (typically) **Fast measurement**
- All ions contribution: *Spectrograph*

Small mass dependence



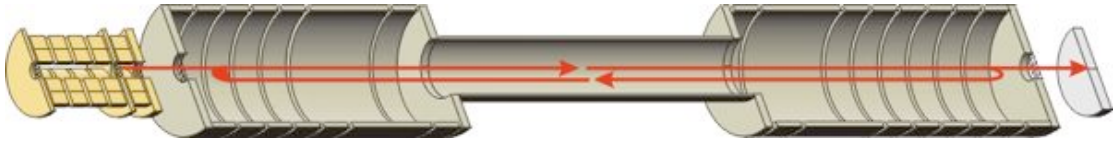


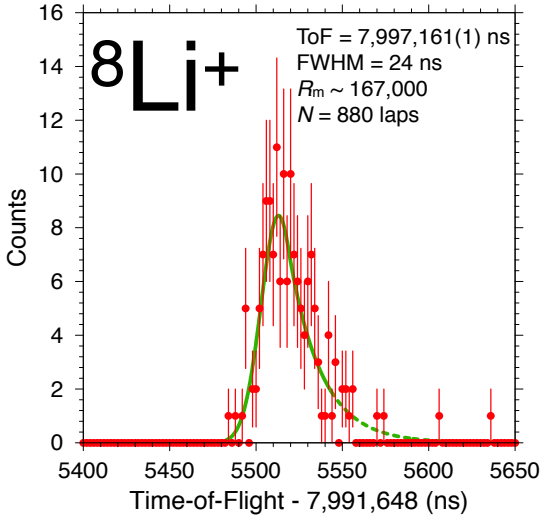
High efficiency

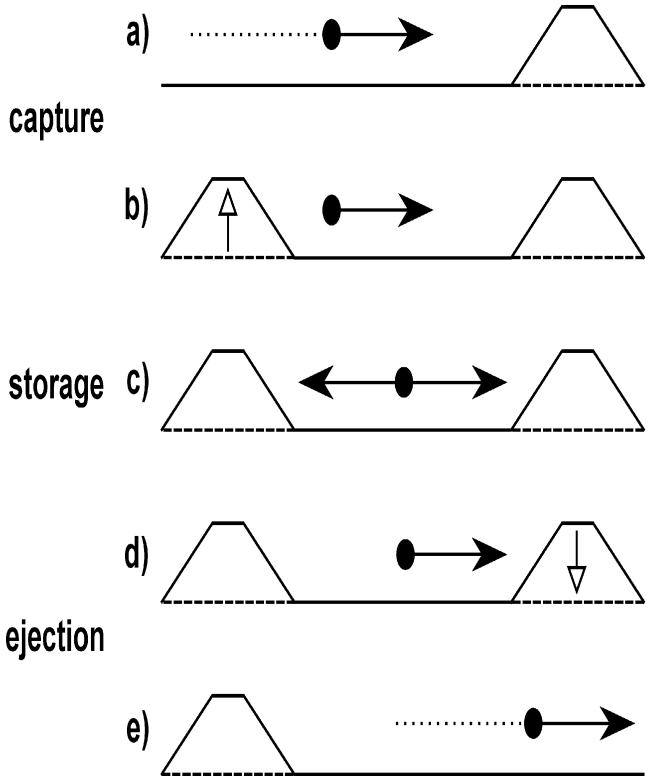
$$\frac{\delta m}{m} = \frac{a}{R_m\sqrt{N}}$$

- ◇ R_m = 100,000
- ◇ N < 400
- ◆ $\delta m/m \sim 0.5$ ppm

MRTOF

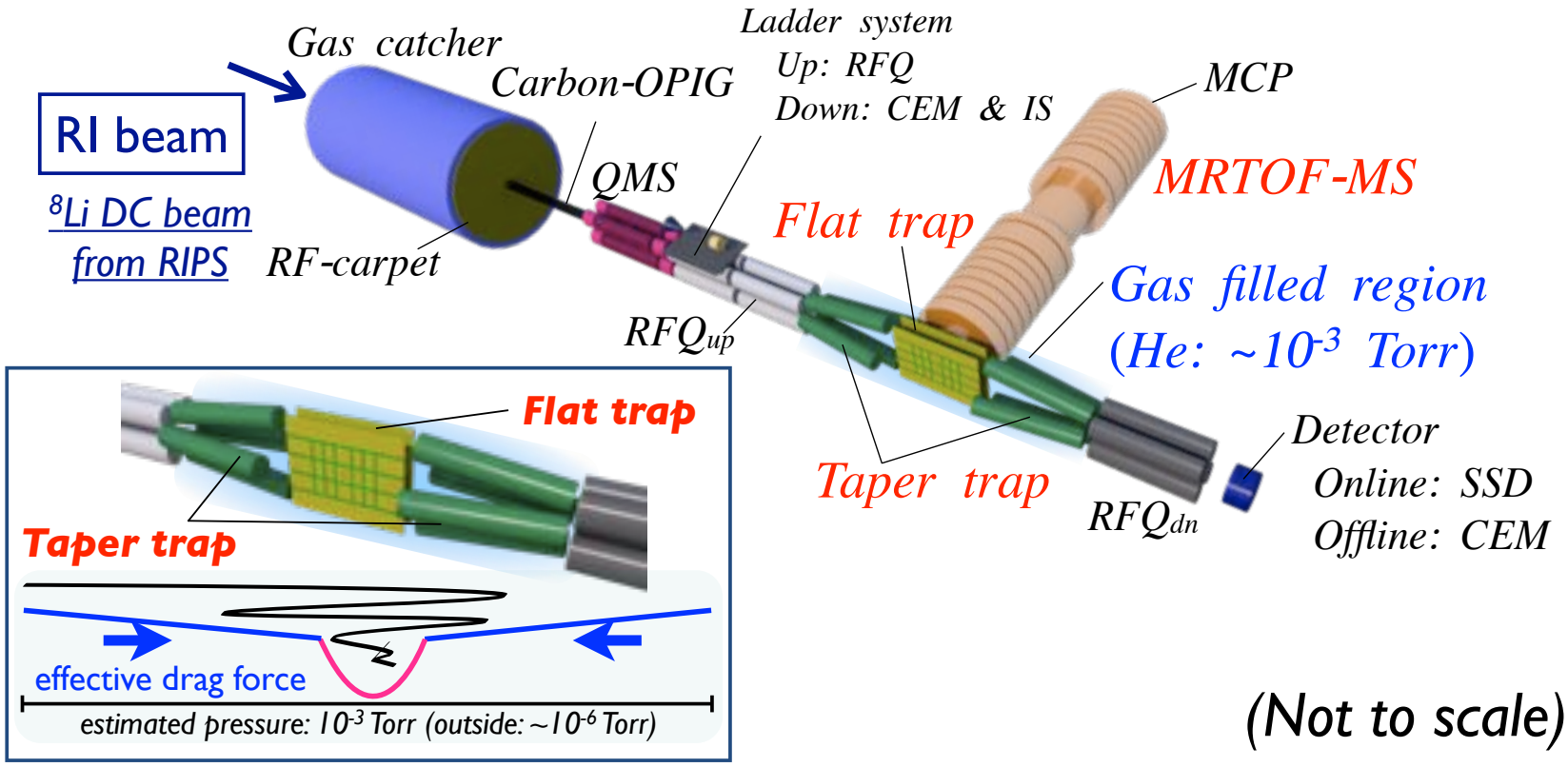






1. Cool ions in buffer gas filled trap
2. Open front end of MRTOF and eject from trap: (a)
3. Close front end: (b)
4. Ions will reflect between isochronous mirrors: (c)
5. Open back end: (d)
6. Detect at MCP

Experimental Setup



GeV - MeV	MeV - eV	eV - sub-eV

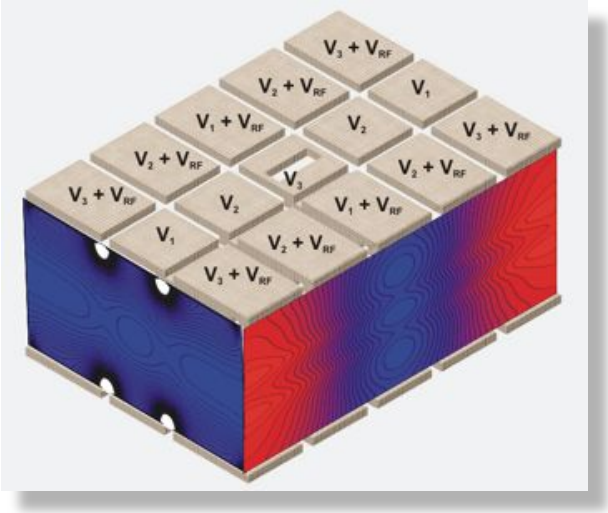
Degrader
(energy compression)

Gas catcher
(He: 20 Torr)

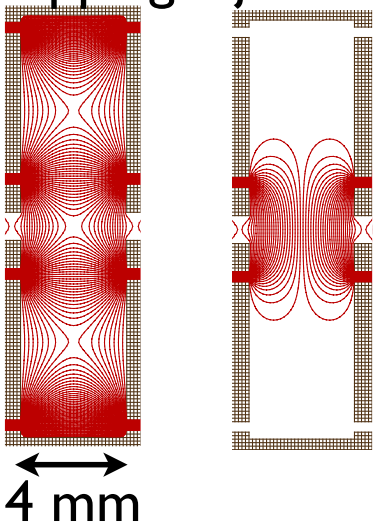
Carbon-OPIG: transport in differential pumping, ~0.5 m
QMS: rough mass-separation
RFQ_{up}: transport line, ~0.7 m
Taper Trap: pre-cooling, extended trap
Flat trap: accumulation, cooling, ToF start for MR-TOF

Flat Trap

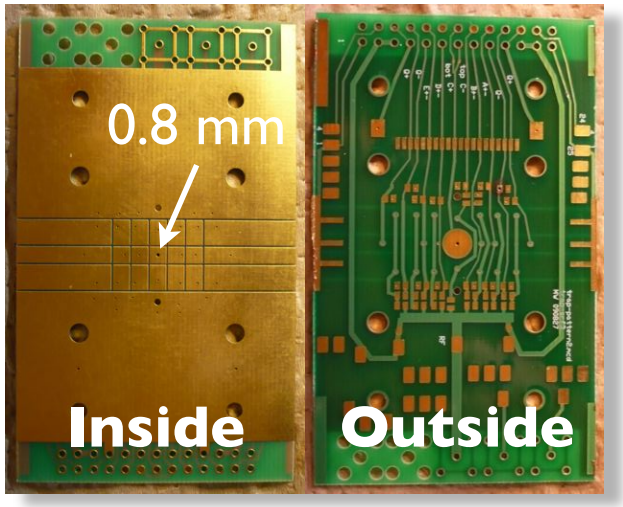
Potential Contour



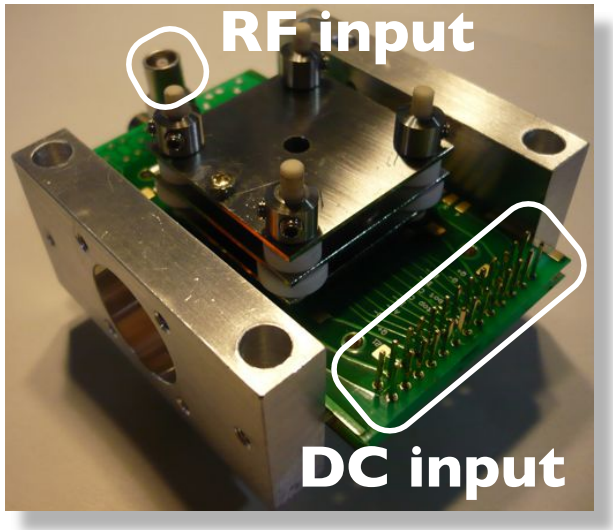
Trapping Ejection

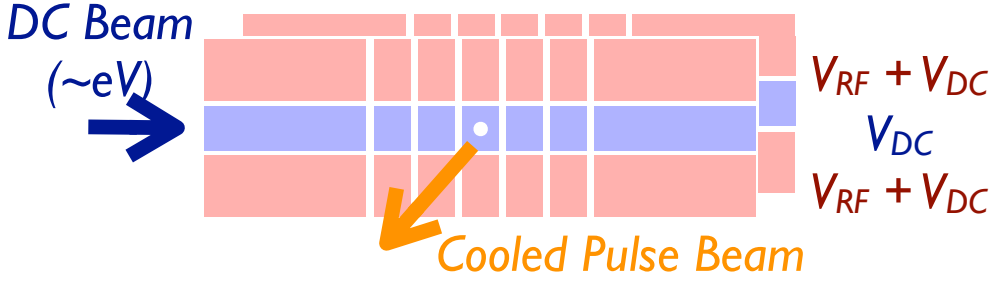


Printed Circuit Boards

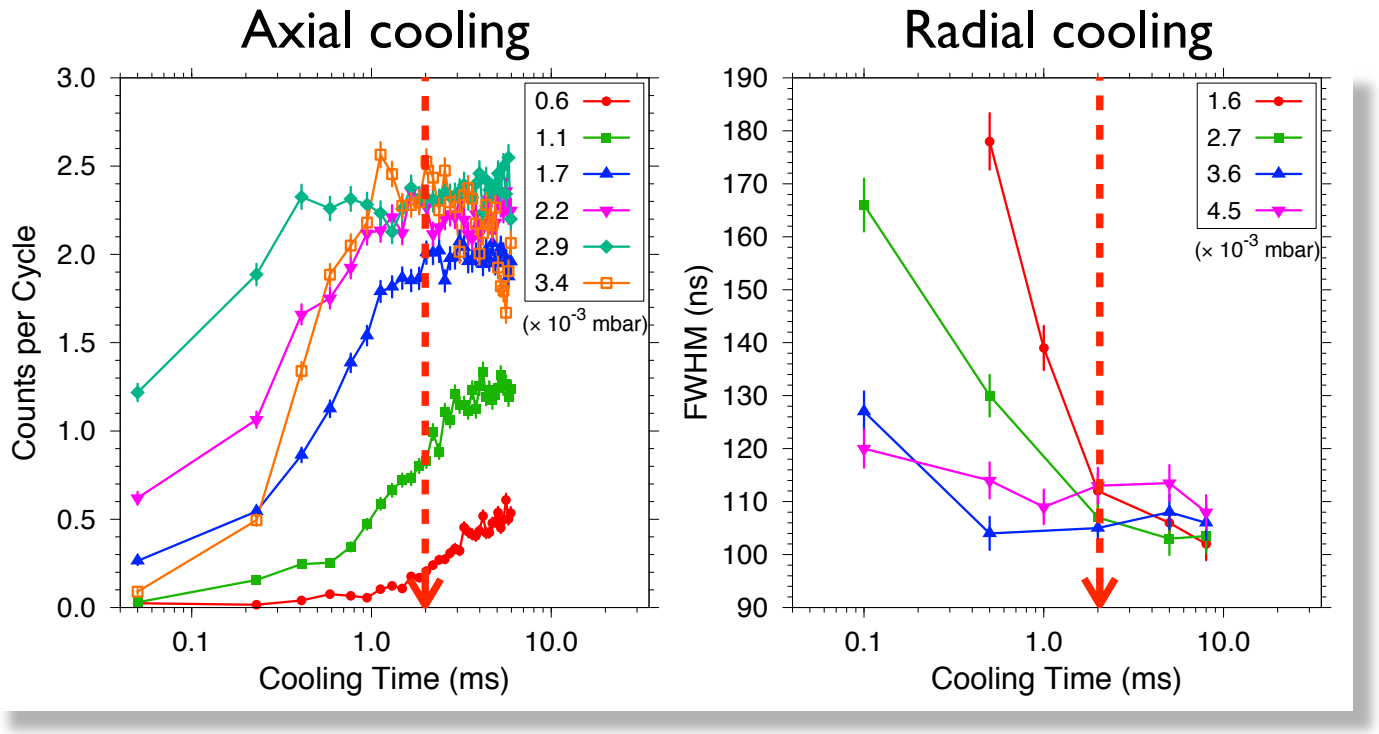


Assembly



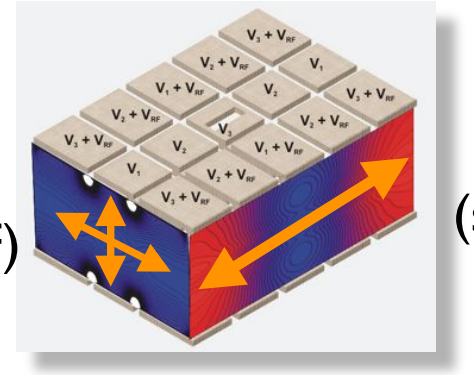


Cooling Time



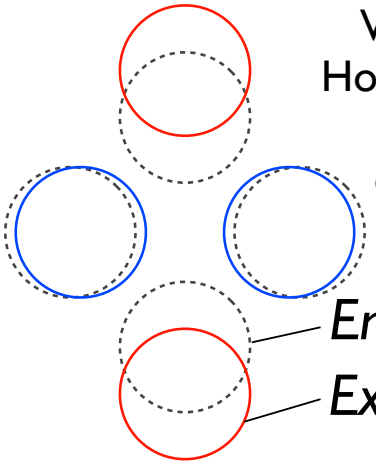
Cooling requires only 2 ms

Radial cooling (RF)

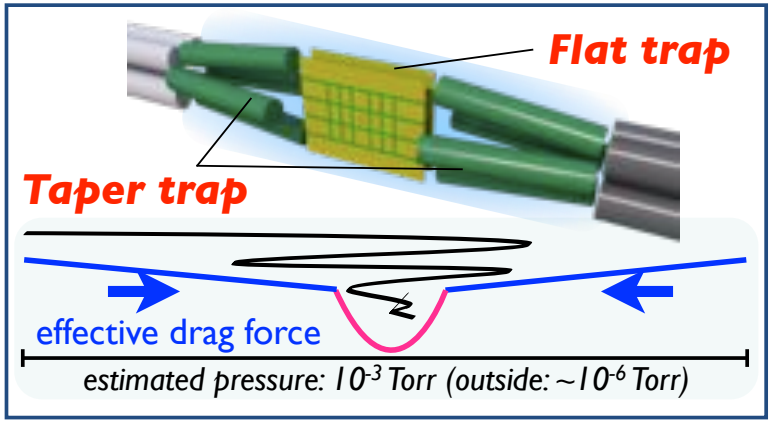


Axial cooling
(segmented DC)

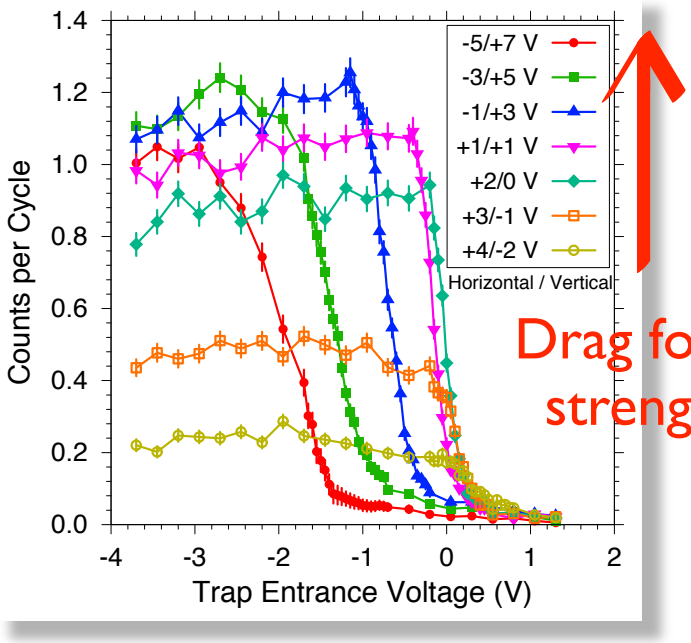
Taper Trap

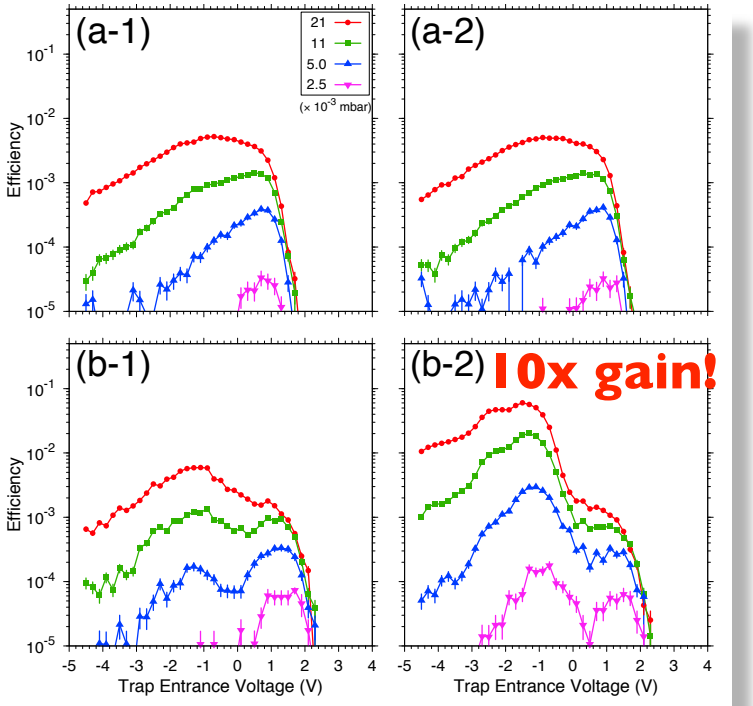


Vertical: r_0 + 1 mm
Horizontal: r_0 - 0.2 mm
+
different DC bias

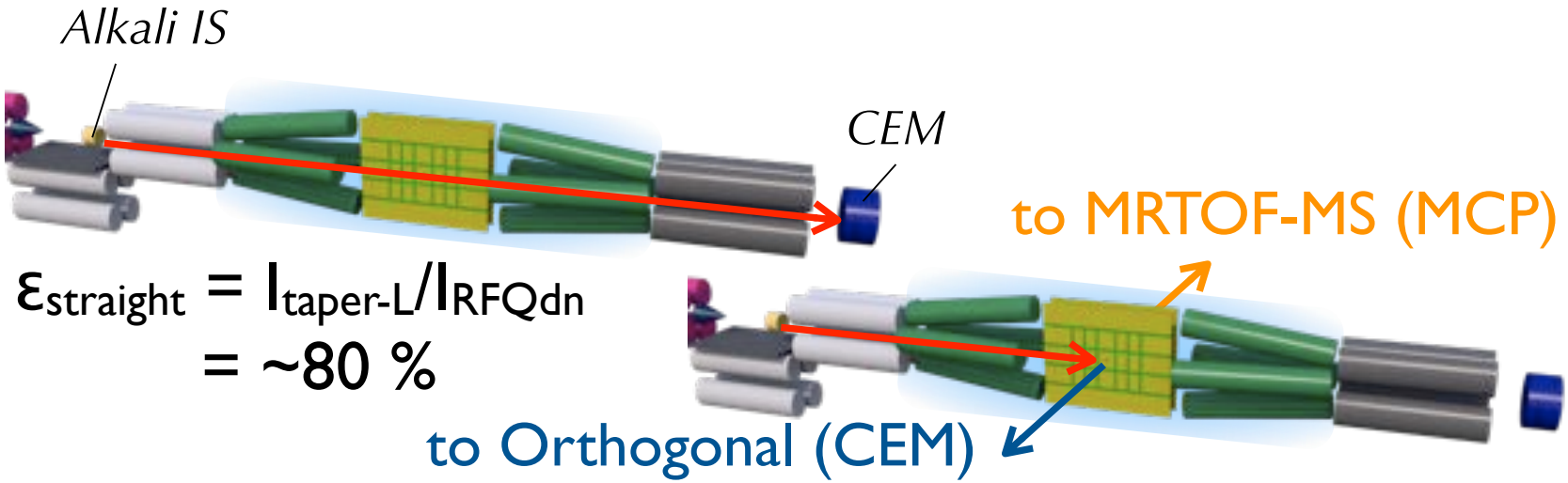


a, b: Parallel or Taper geometry
1, 2: without or with pre-cooling





Efficiency



$\varepsilon_{straight} = I_{taper\text{-}L}/I_{RFQdn}$

$= \sim 80\ \%$

		Trapping efficiency (%)	
		to MRTOF-MS	to Ortho-CEM*
Offline	$^{7}Li^{+}$	**2.4**	**5.1**
	$^{23}Na^{+}$	**12.1**	**26.7**

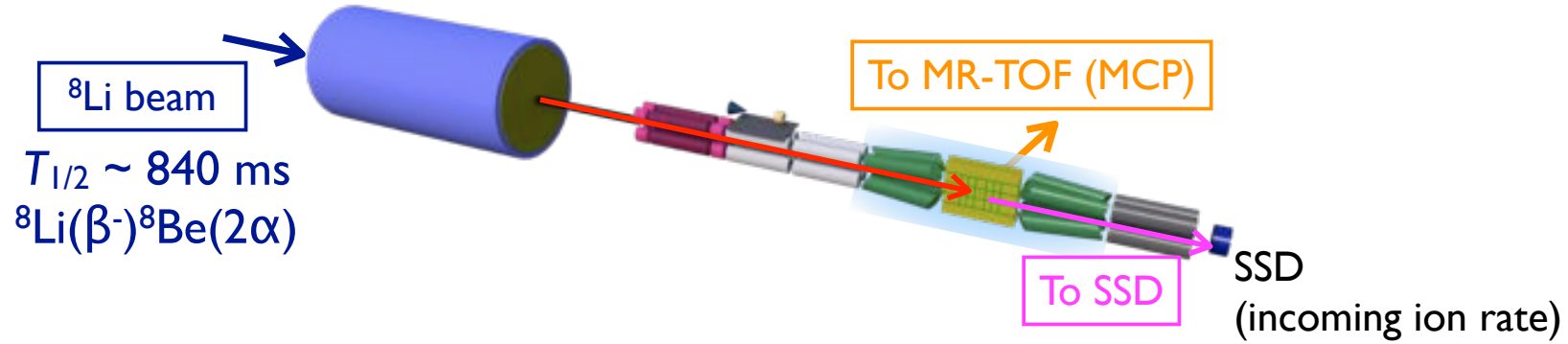
*gain by detection efficiency

^{8}Li Online Experiment

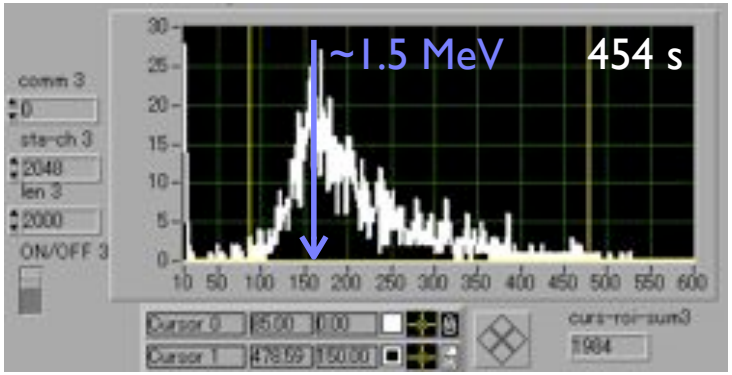
- ^{8}Li was produced by projectile fragmentation
  - ^{13}C: 100 MeV/u, Be: 1.86 g/cm^{2}
- ^{8}Li ions were selected by RIPS fragment separator
- Ions were stopped in 20 mbar, extracted by Carbon-OPIG and RF-carpet, purified by QMS, then transported to MRTOF preparation trap system
- ToF measurements of $^{8}Li^{+}$ were interleaved with that of $^{7}Li^{+}$, ($^{4}He_{2}^{+}$), $^{9}Be^{+}$, ($^{9}BeH^{+}$), $^{12}C^{+}$
- $^{8}Li^{+}$ could also be sent straight through trap to SSD for efficiency measurement

- Motivation
- Experimental Setup
- **Results**

Efficiency Measurement

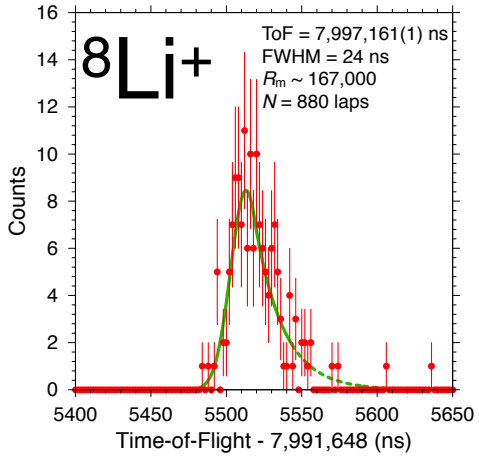


^{8}Be α-decay spectrum at SSD



SSD DC rate: ~18 cps

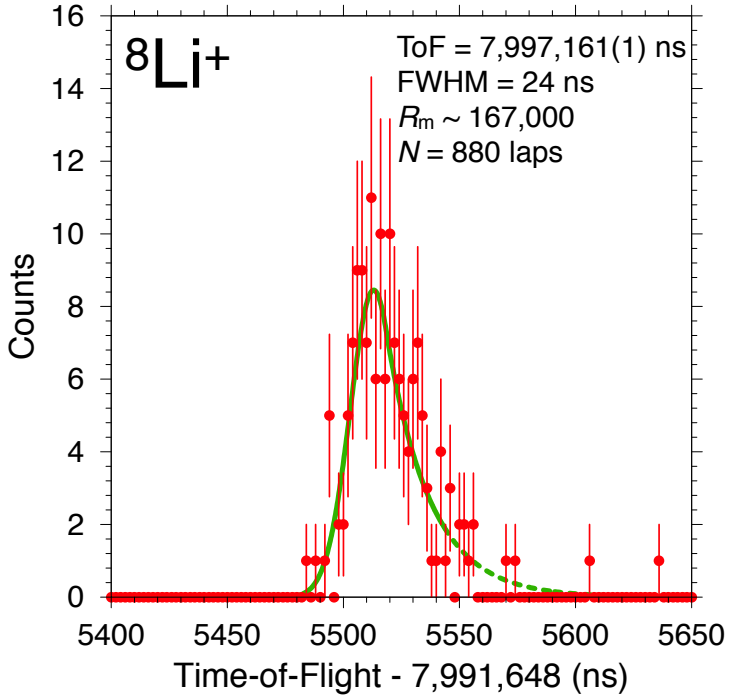
^{8}Li^{+} ToF spectrum at MCP

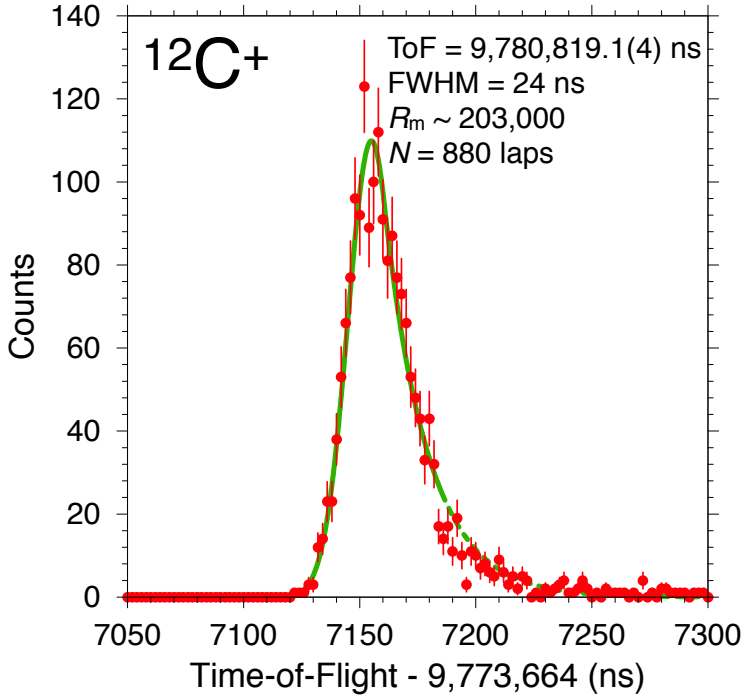


MCP rate: ~0.26 cps (2x at n=0)

$\varepsilon_{@MCP}$ = 2.9 % *$\varepsilon_{@MCP}(^{7}Li)$ = 2.4% offline

ToF Spectra





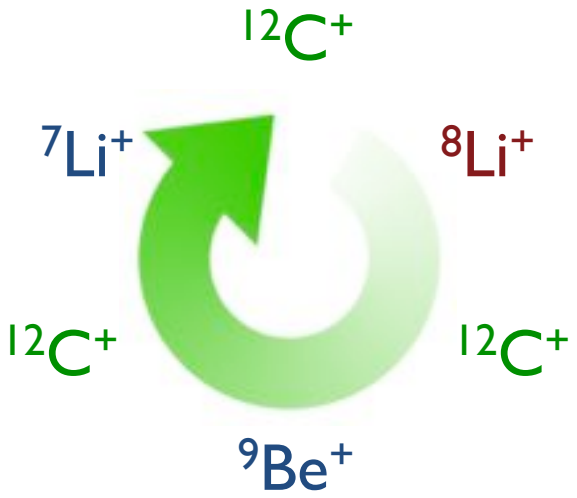
Fitting function (Gaussian with Exponential tail)

At t_m+t_c, the differential is connected smoothly.
The t_c and σ determined by reference ion $^{12}C^{+}$.

$$f(t) = \begin{cases} f_1(t) = A \cdot \exp\left\{-\dfrac{(t-t_m)^2}{2\sigma^2}\right\} & (t \le t_m + t_c) \\ f_2(t) = A \cdot \exp\left\{t_c \dfrac{2t_m - 2t + t_c}{2\sigma^2}\right\} & (t \ge t_m + t_c) \end{cases}$$

M.J. Koskelo *et al.*, Comp. Phys. Commun. 24 (1981) 11

^{8}Li Mass Analysis Flow



$^{8}Li^{+}$: Ion of interest

$^{7}Li^{+}$, $^{9}Be^{+}$: Mass calibrants

$^{12}C^{+}$: Drift compensator

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1. Using $^{12}C^{+}$ ToFs before/after measurement, $^{12}C^{+}$ ToF at the time, t_{cor}, is derived for each measurement.
2. Calculate the ratio, $R_s = t_s / t_{cor}$
3. Calibrate the ToF using R_{7Li} and R_{9Be}
4. Derive the mass of $^{8}Li^{+}$

^{8}Li Mass

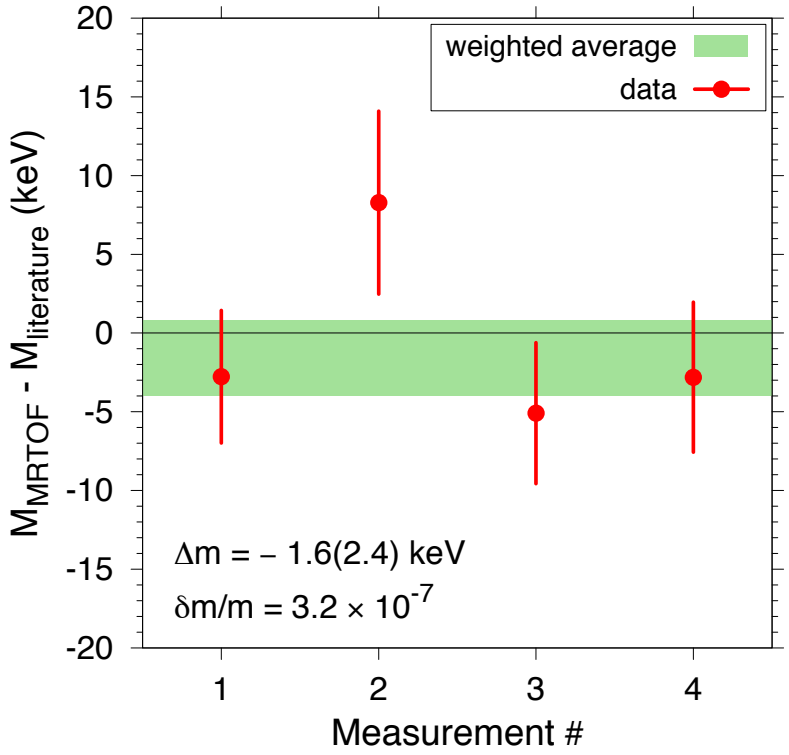
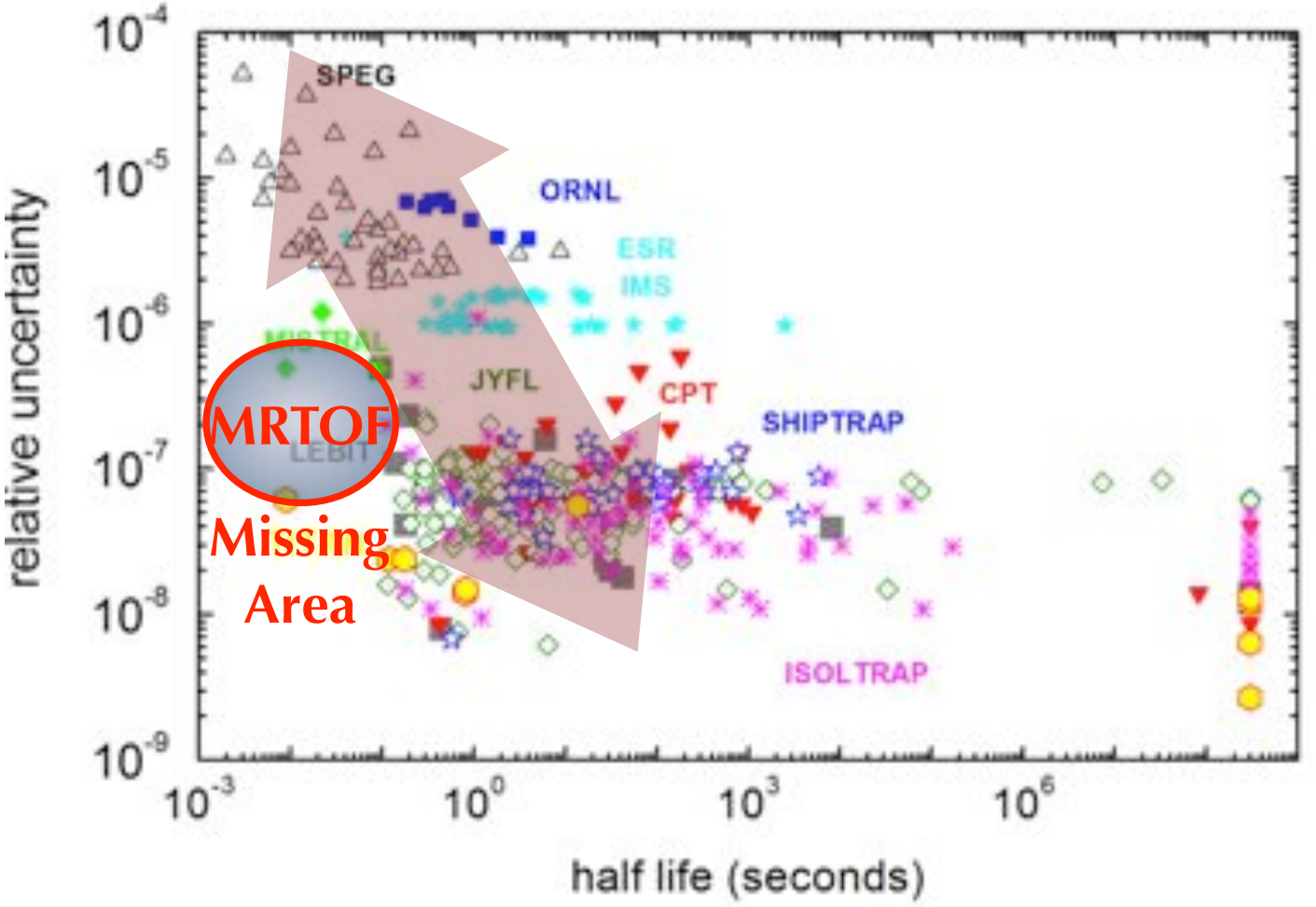


Table 4: Derived mass of $^{8}Li^{+}$ and its precision. Also shown are the literature value m_{lit}[1], and the deviation of m_{exp} from m_{lit}. The deviation of -1.1 keV was smaller than the error of experimental value 3.7 keV. Therefore, our mass measurement of MRTOF-MS was performed reasonably.

	m_{exp} (keV)	$\delta m_{exp}/m_{exp}$	m_{lit} (keV)	Δm (keV)
$^{8}Li^{+}$	7472385.8(2.4)	3.2×10^{-7}	7472386.88(5)	-1.6

Conclusion


SPEG
ORNL
ESR
IMS
JYFL
CPT
SHIPTRAP
ISOLTRAP
MRTOF
Missing
Area
relative uncertainty
half life (seconds)
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
10^-3
10^0
10^3
10^6

Summary

- We performed online commissioning of MRTOF-MS with unstable nuclei ^{8}Li
- Newly developed devices worked fine
- Overall trapping efficiency: 2.9% for $^{8}Li^{+}$
- Mass precision: $\delta m/m = 3.2 \times 10^{-7}$
- (Mass deviation: -1.6 keV) < (Mass uncertainty: 2.4 keV)
- Move to GARIS for SHE mass measurement

  (*and connect to BigRIPS, PALIS, KISS, and any other RI sources)*

Thank you for your attention