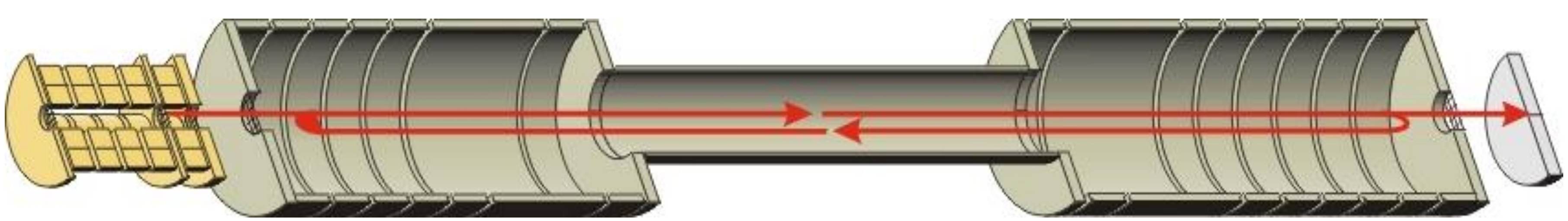
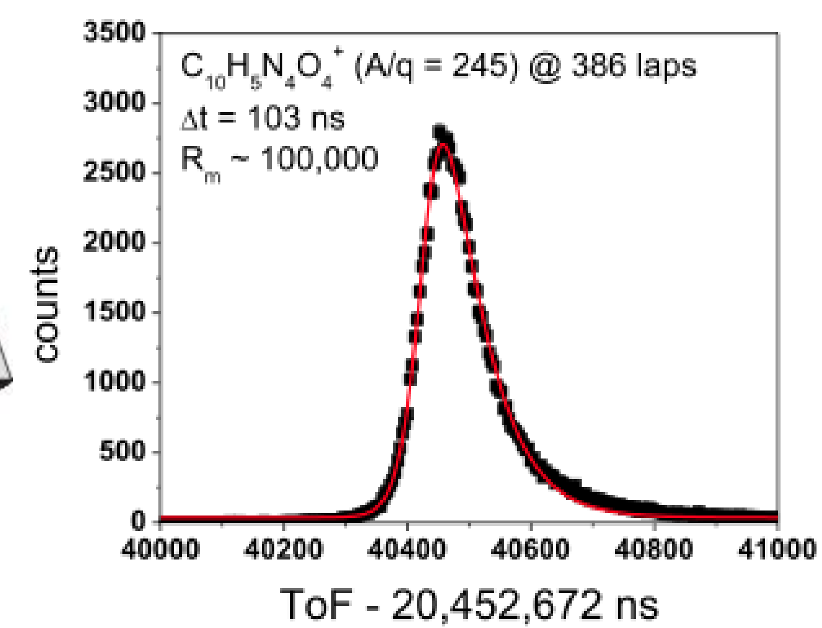
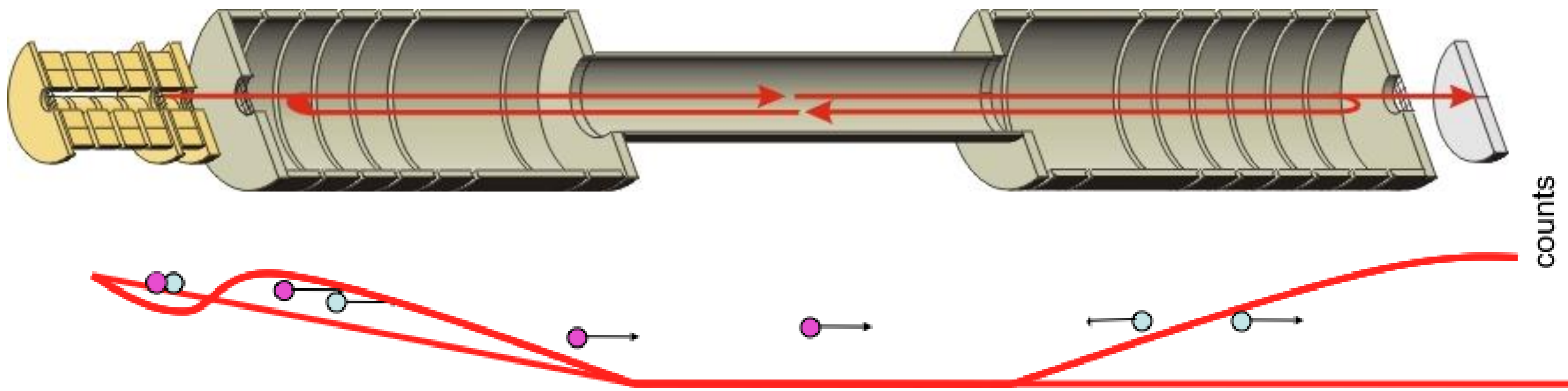
A multi-reflection time of flight mass spectrograph for short-lived and super-heavy nuclei

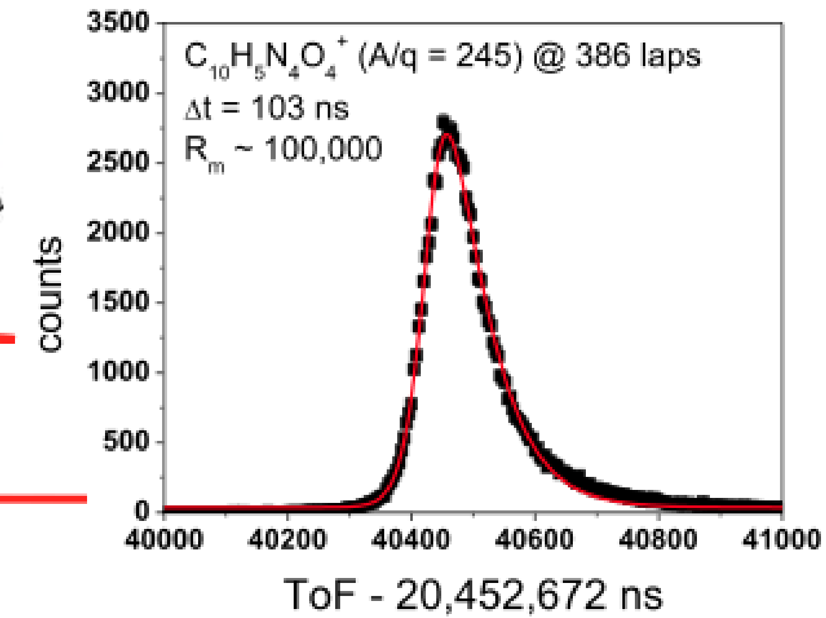
Peter Schury for the RIKEN SLOWRI Group





Operational Concept

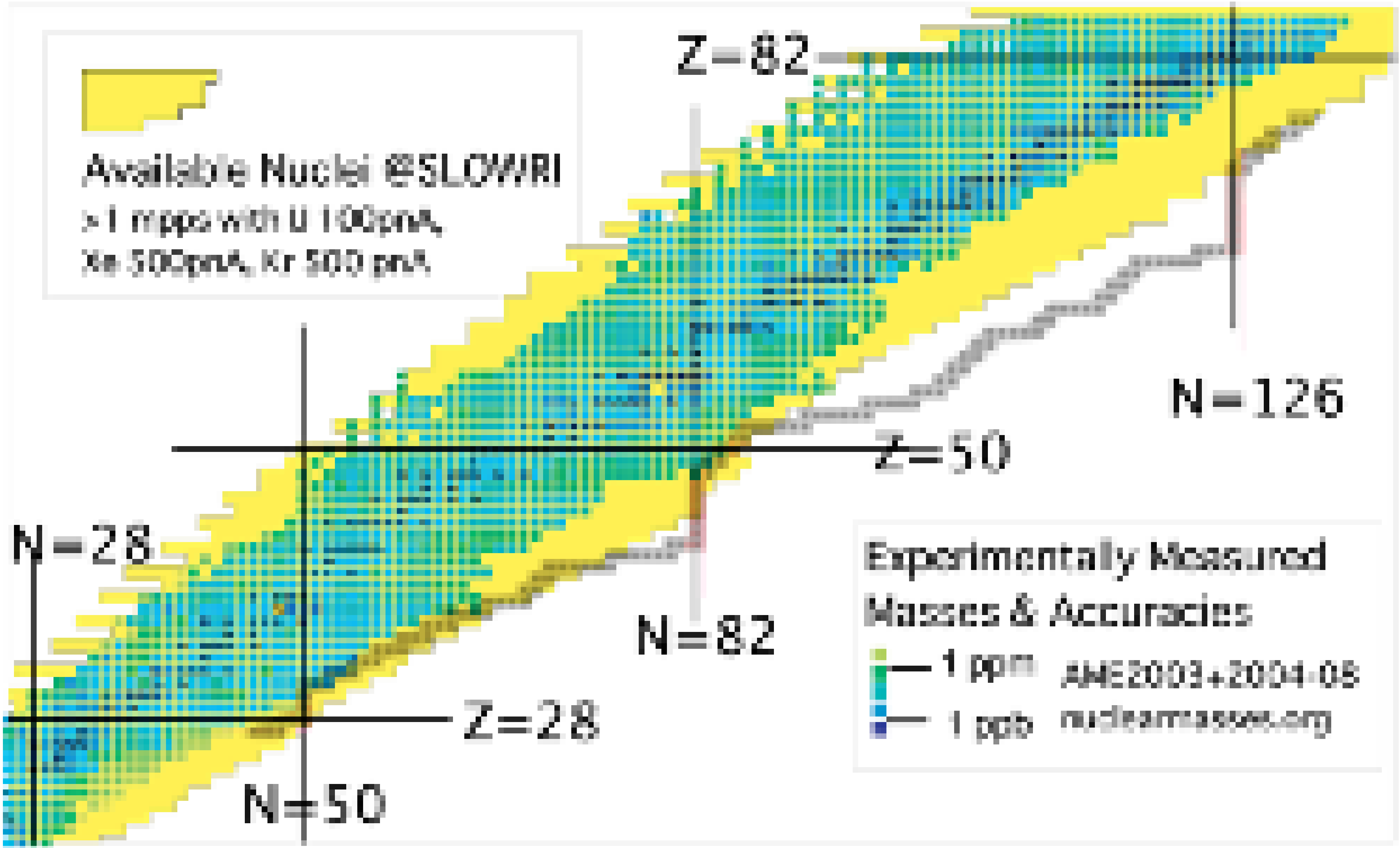




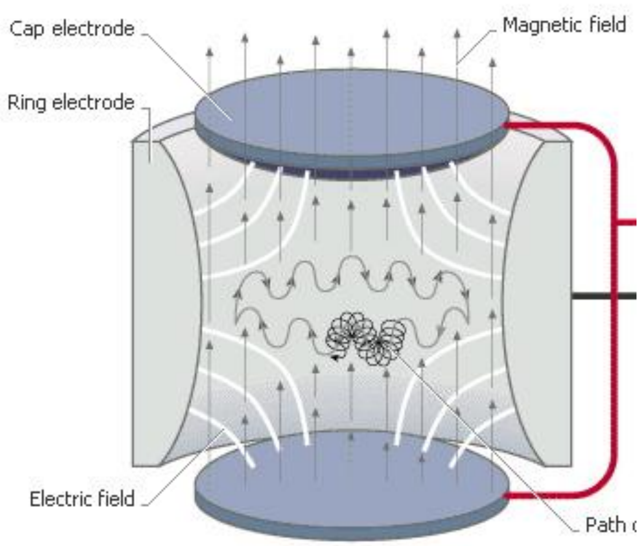
1. Cool ions in buffer gas filled trap
2. Open front end of MRTOF and eject from trap
3. Close front end
   - Ions will reflect between isochronous mirrors
   - Next batch of ions can accumulate and cool
4. Open back end
5. Measure TOF

Motivations

High precision mass measurement for r-process

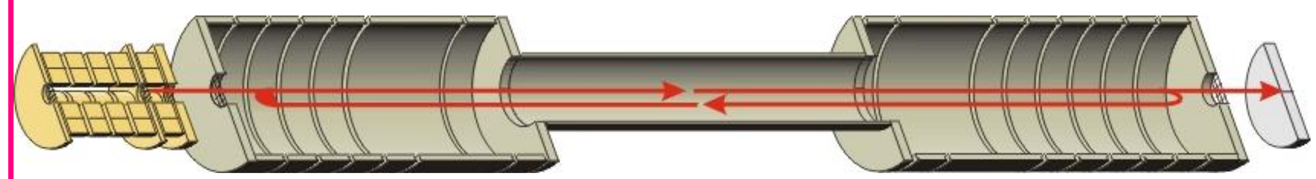


Comparison to PTMS



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

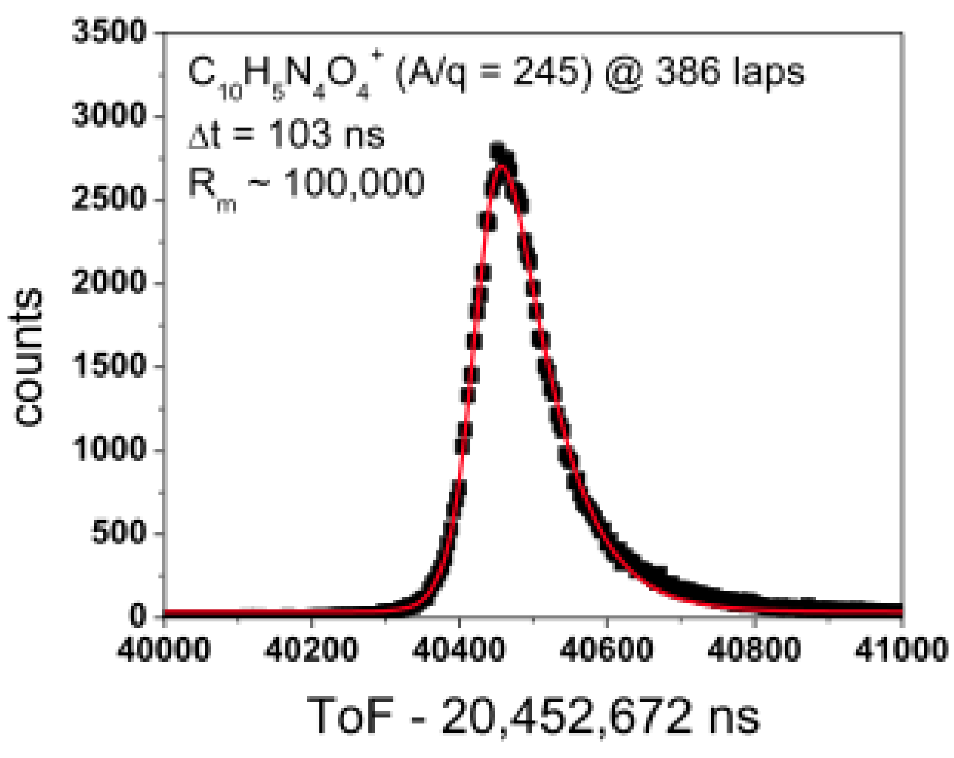
$$R_{\rm m} \equiv \frac{m}{\delta m} \approx \frac{qB}{m} t_{\rm obs} \qquad t_{\rm obs} \leq \sim 2T_{1/2}$$



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

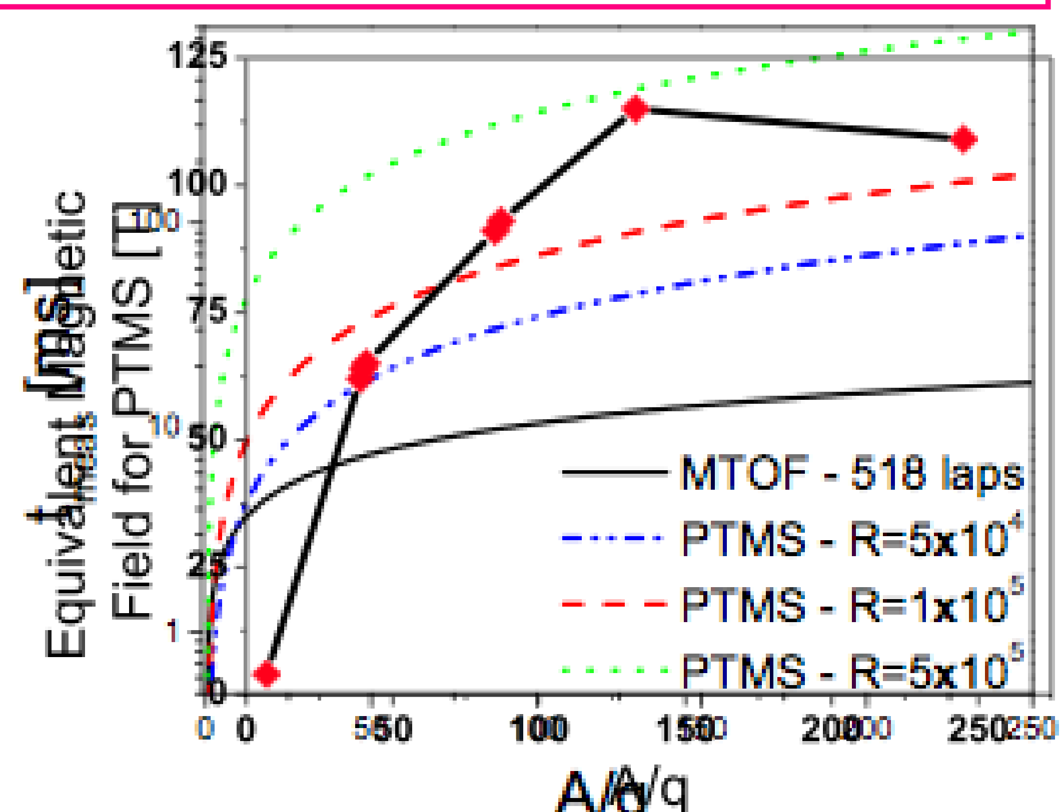
Isochronous!

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



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

R_m=100,000
N≤400
δm/m~0.5ppm



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Ion preparation prior to MRTOF

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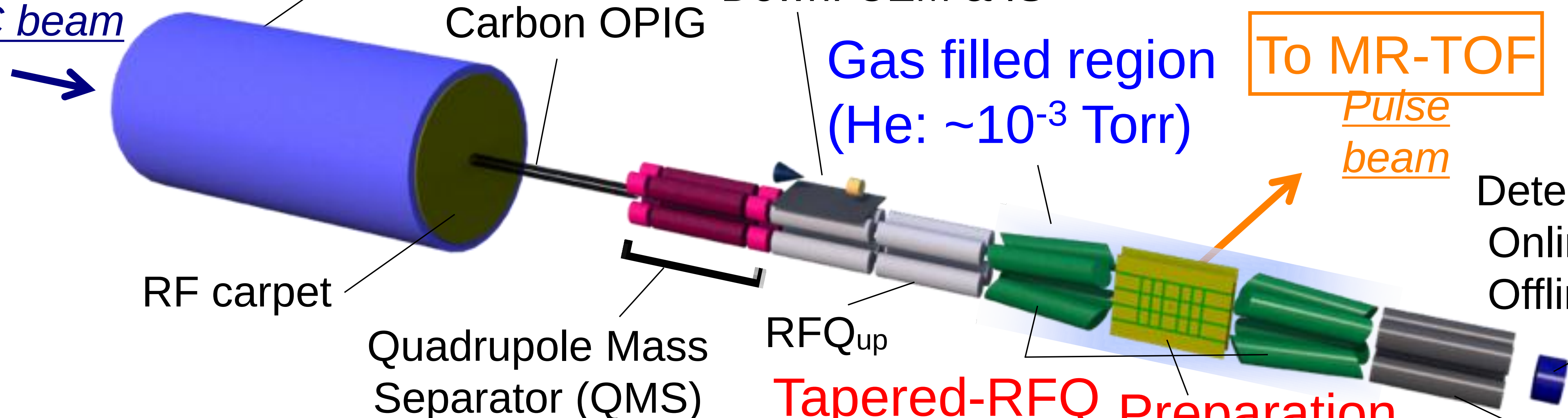


Poster
Y. Ito

Transport to trap within >1 ms
Cooling time ≈2 ms

Efficiency, extraction to detection:
$\varepsilon(^{7}Li^{+}) = 2.4\%$
$\varepsilon(^{8}Li^{+}) = 2.9\%$
$\varepsilon(^{23}Na^{+}) = 12.1\%$

First Online Test - $^{8}Li^{+}$ ($T_{1/2}$ = 840 ms)

- ^{13}C ions at 100 A·MeV were fragmented by Be target (1.86 g/cm^2)
- ^{8}Li ions were selected by RIPS fragment separator
- Ions were stopped in 20 mbar He and extracted by RF-carpet, transported to MR-TOF preparation trap
- ToF-MS measurements of $^{8}Li^{+}$ were interleaved with ToF-MS measurements 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

Online commissioning with ^{8}Li

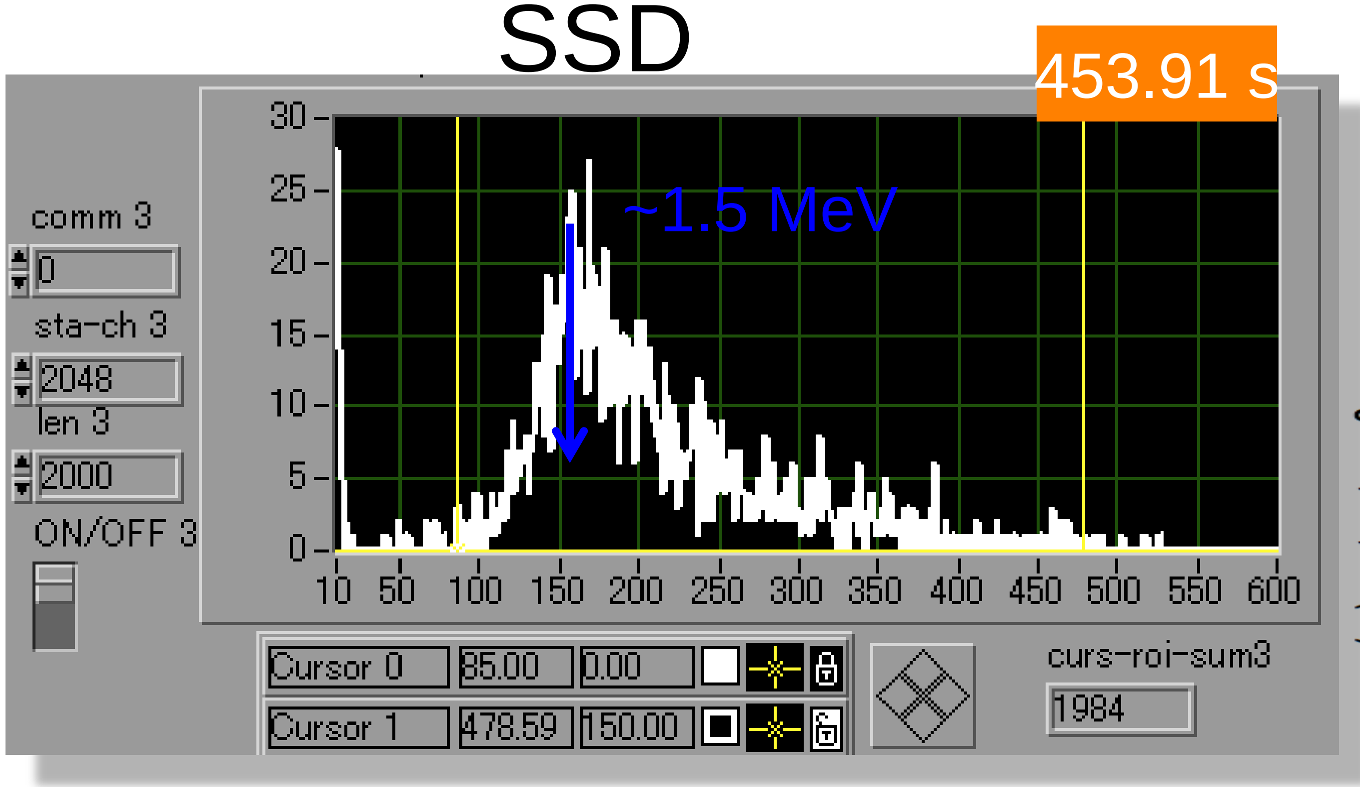
^{8}Li beam

$T_{1/2}$ ~ 838 ms

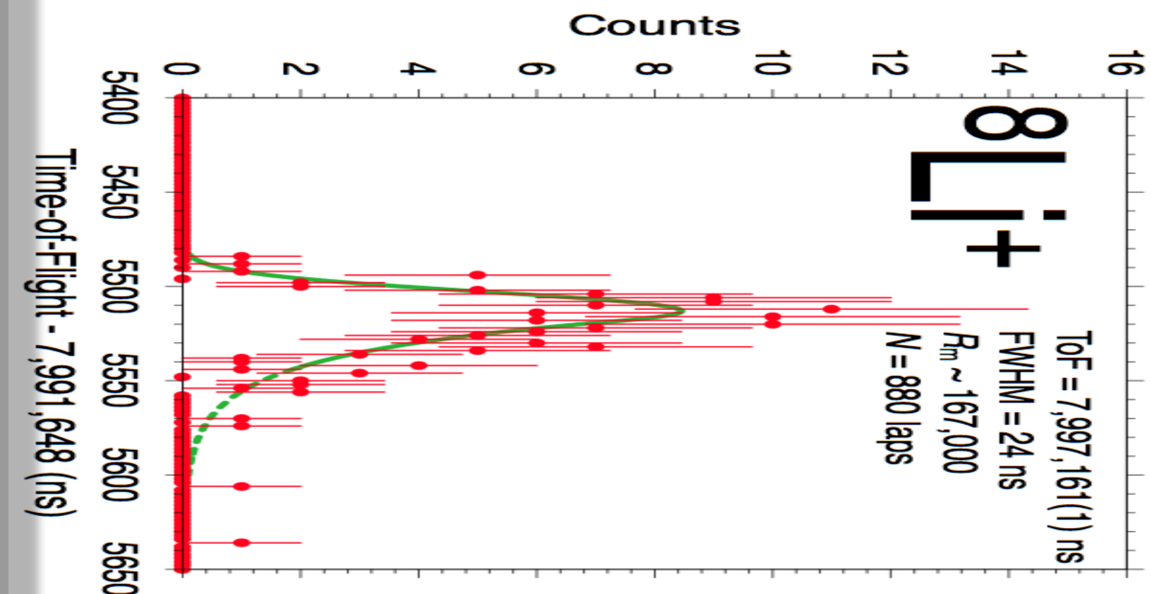
$^{8}Li(\beta^{-})^{8}Be(2\alpha)$

SSD (normalization factor for trapping efficiency)

^{8}Be α-decay spectrum at SSD



$^{8}Li^{+}$ ToF spectrum



SSD DC rate ~ 18 cps

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

for DC ^{8}Li RI beam:

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

Online commissioning with ^{8}Li

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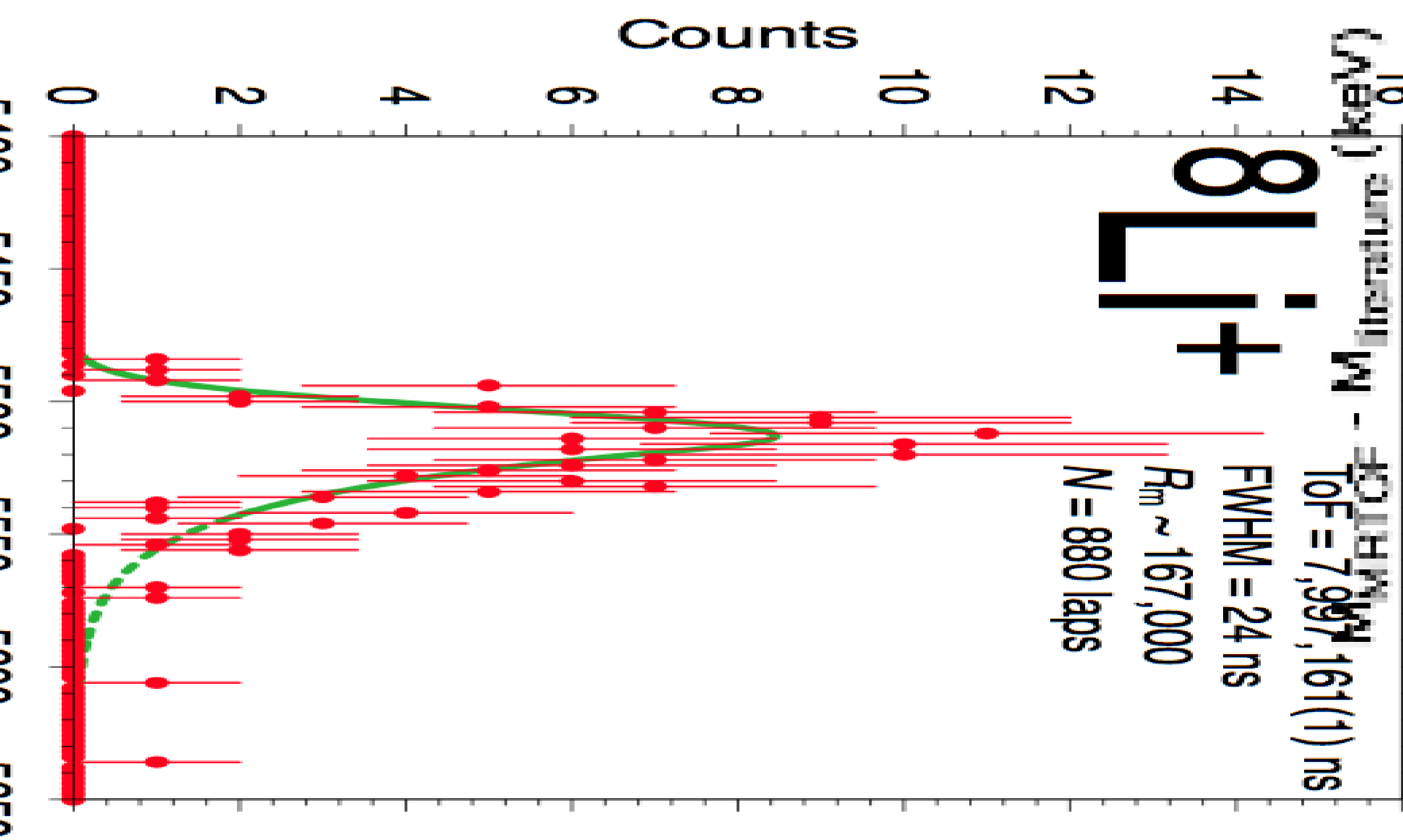
Fitting function (Gaussian with Exponential tail)

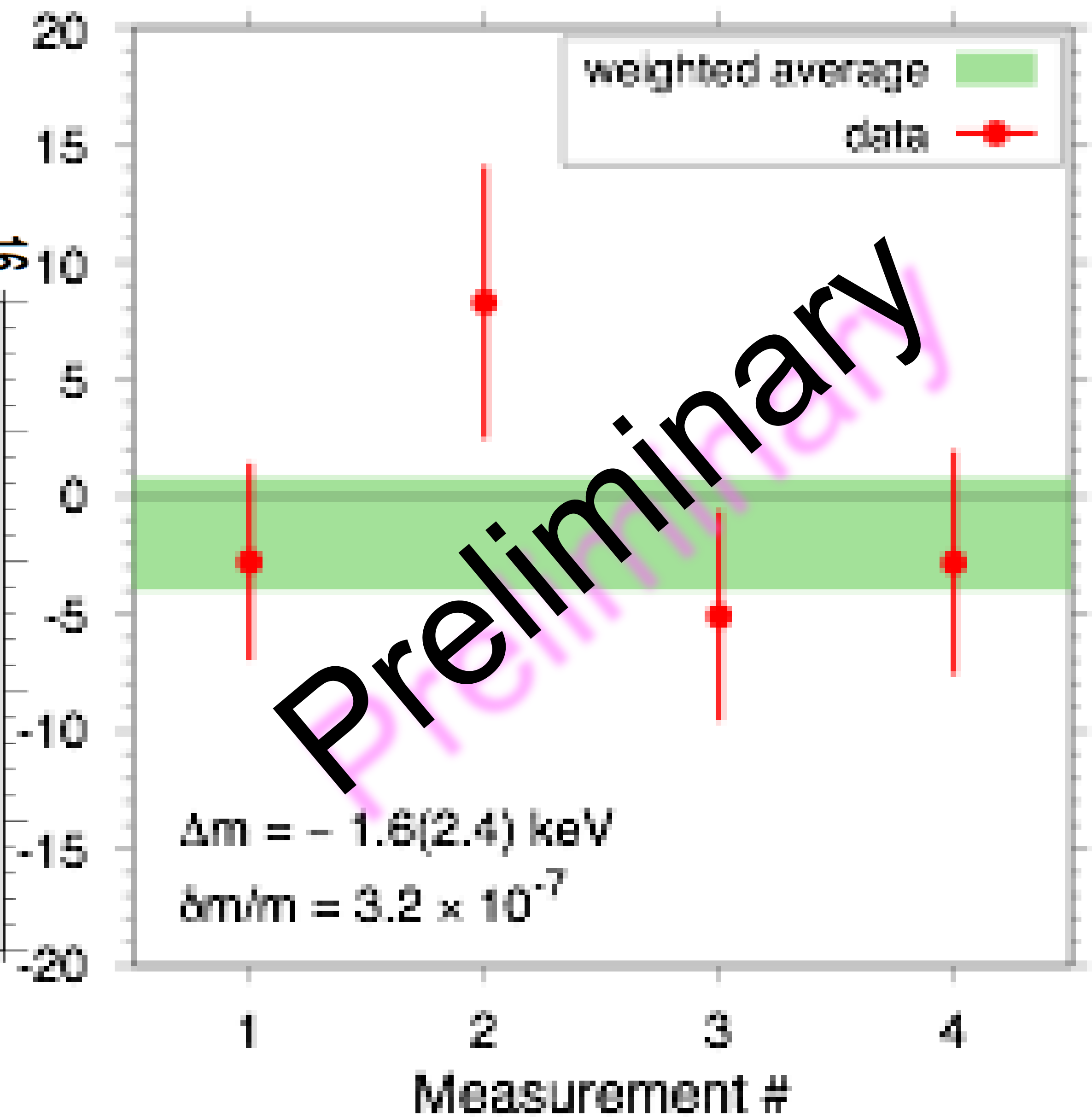
At t_m+t_c, the differential is connected smoothly.
The t_c and σ determined by reference ion $^{12}C^{+}$.

$$f(t)=\begin{cases} f_1(t)=A\cdot\exp\left\{-\dfrac{(t-t_m)^2}{2\sigma^2}\right\} & (t\le t_m+t_c) \\ f_2(t)=A\cdot\exp\left\{t_c\dfrac{2t_m-2t+t_c}{2\sigma^2}\right\} & (t\ge t_m+t_c)\end{cases} \quad (1)$$

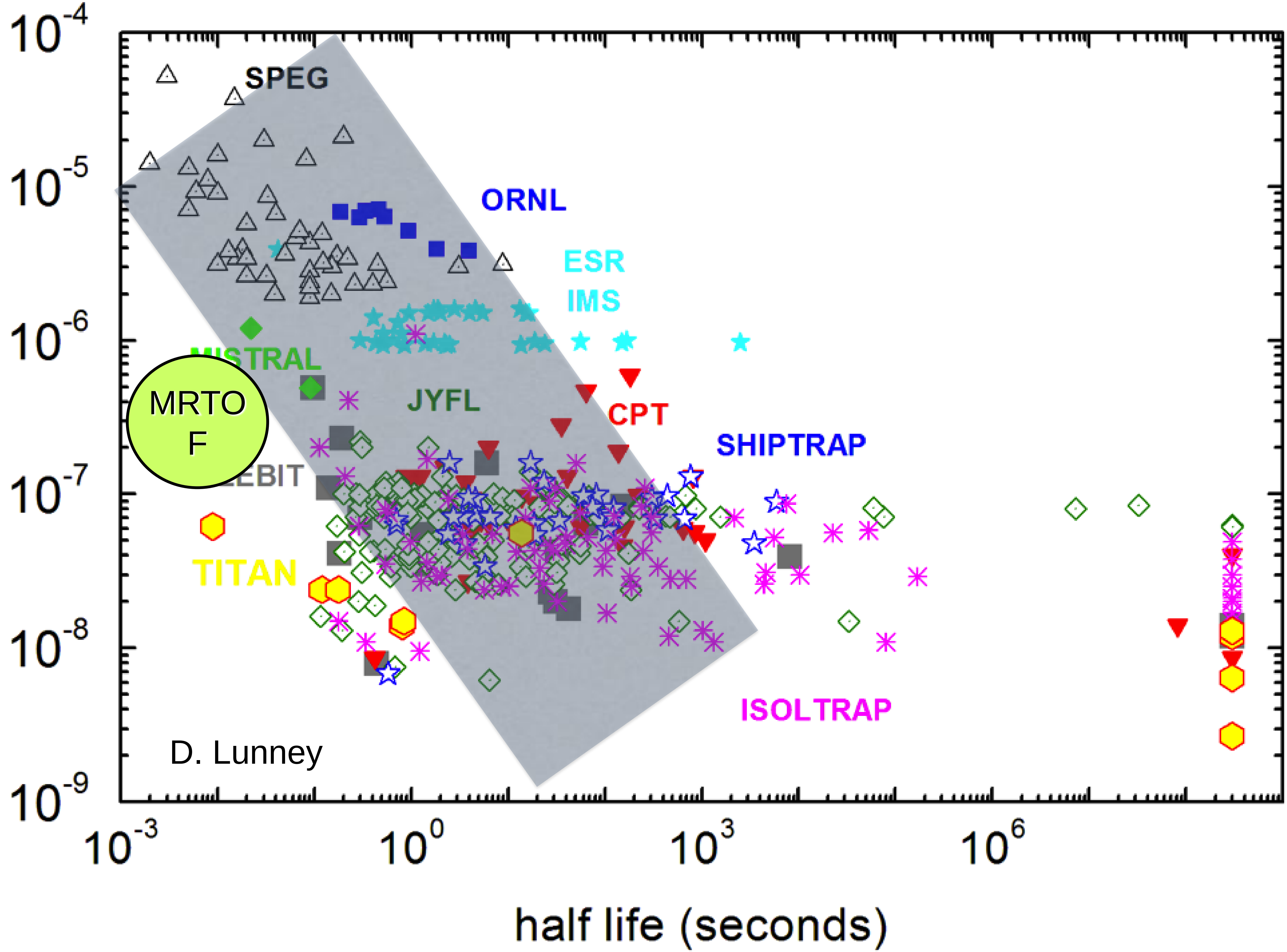
where A is the peak height of the Gaussian, t_m is the time of the peak of the Gaussian, σ is the standard deviation of the Gaussian, t_c is the distance from t_m to the switching point of the exponential tail.

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

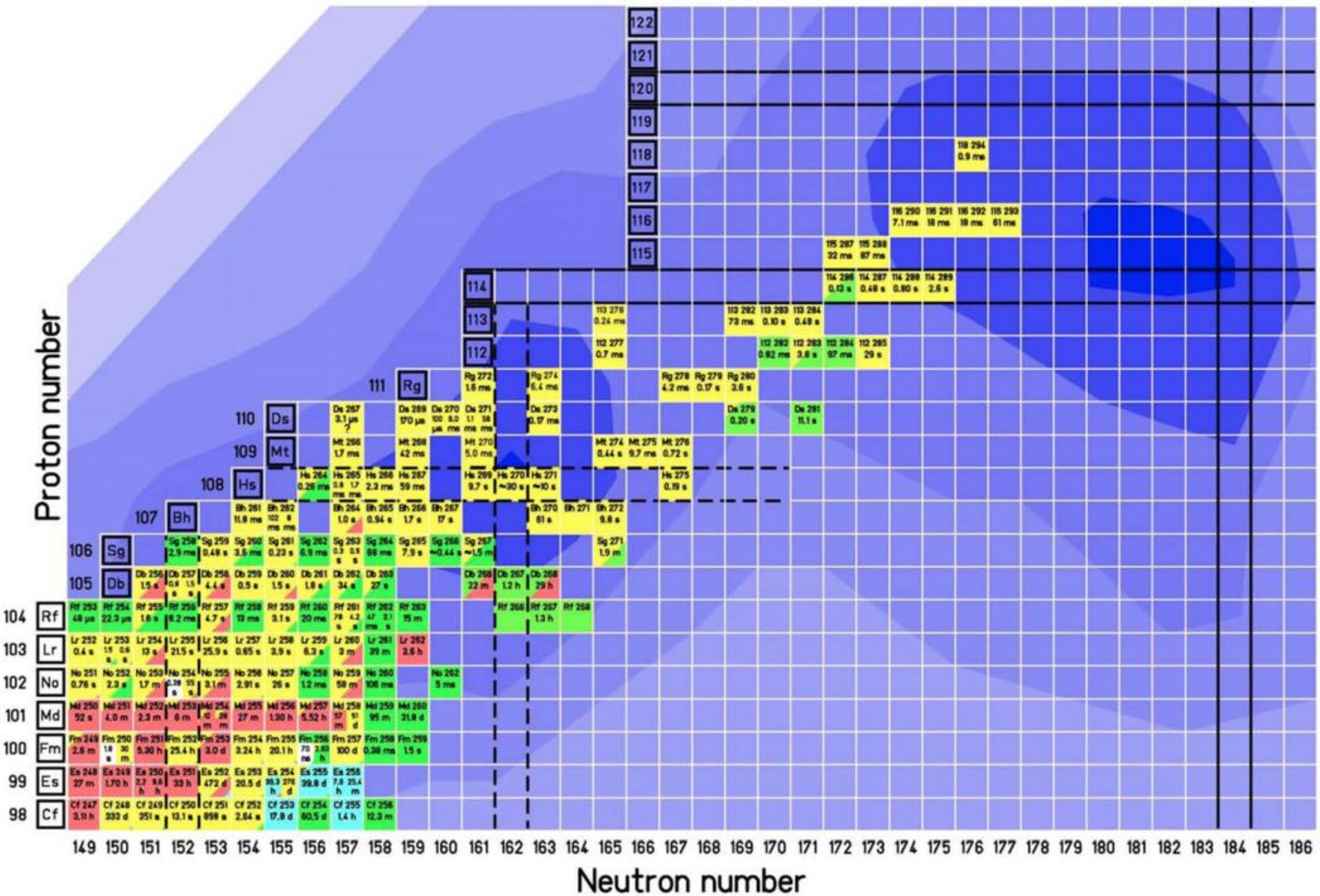




MRTOF-MS Relative Capability



ESI for SHE calibrants



- yield and
- differential pumping

- SHE do not have atomic isobars
- Need to use molecular reference ions

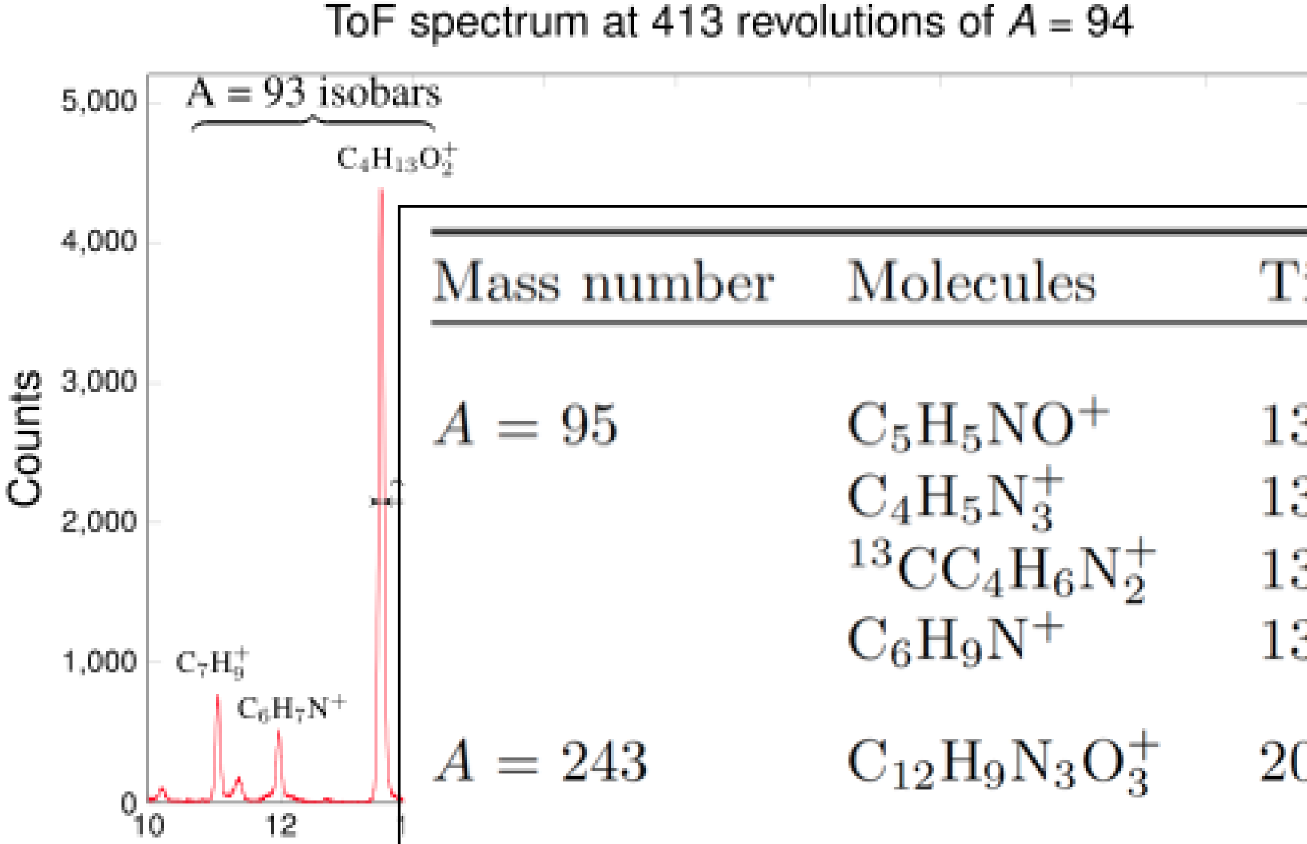
Poster
S. Naimi

ESI for SHE calibrants

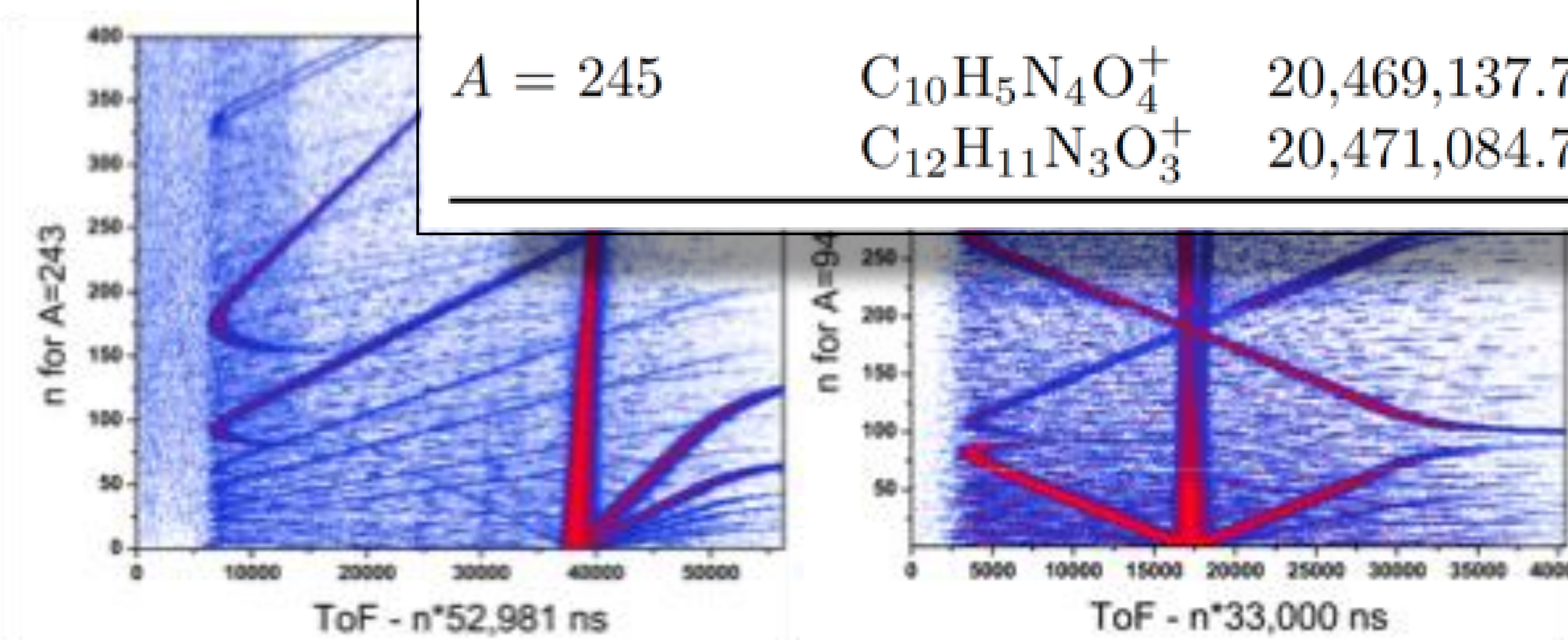
-SHE do not have atomic isobars

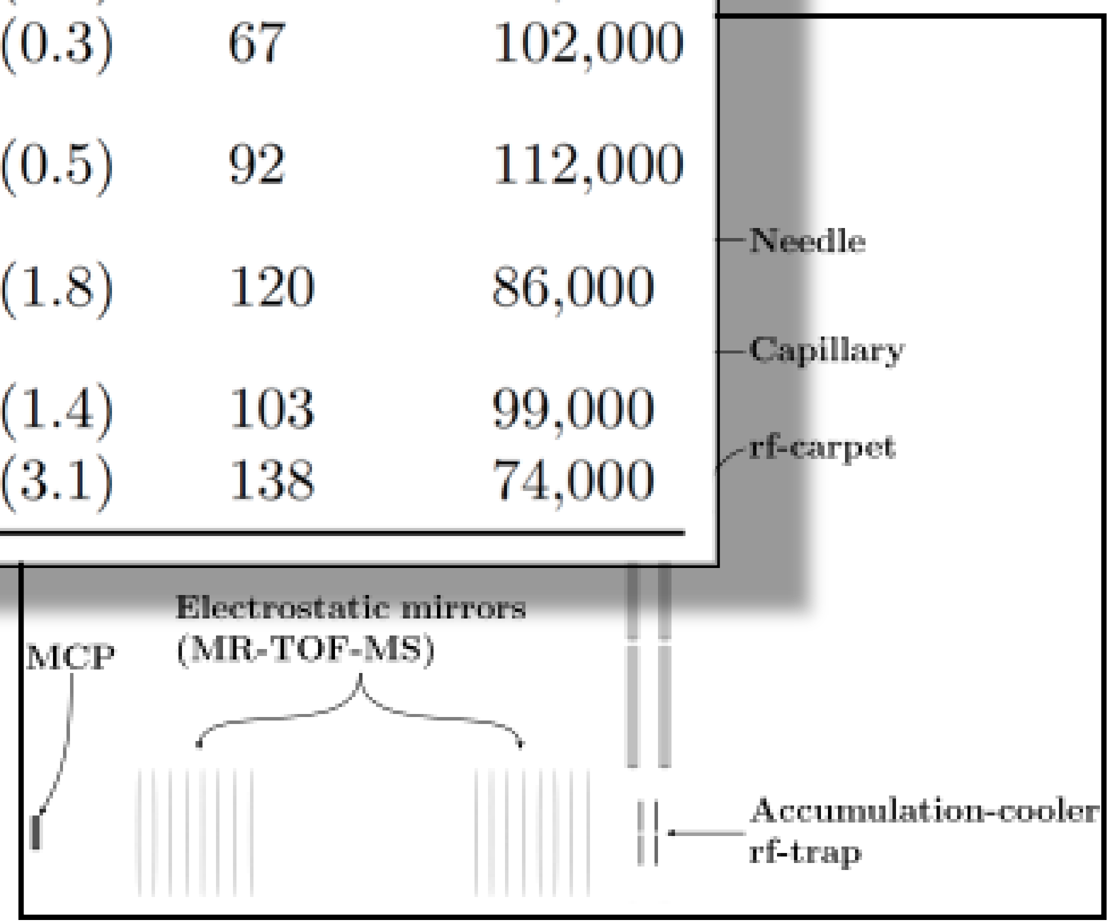
isobaric

ants



Mass number	Molecules	Time-of-flight (ns)	Δt (ns)	R_m
A = 95	$C_5H_5NO^+$	13,626,528.8(0.3)	70	97,000
	$C_4H_5N_3^+$	13,627,327.0(0.6)	62	110,000
	$^{13}CC_4H_6N_2^+$	13,627,916.1(0.6)	71	97,000
	$C_6H_9N^+$	13,629,136.0(0.3)	67	102,000
A = 243	$C_{12}H_9N_3O_3^+$	20,493,142.0(0.5)	92	112,000
A = 244	$C_{12}H_{10}N_3O_3^+$	20,482,317.1(1.8)	120	86,000
A = 245	$C_{10}H_5N_4O_4^+$	20,469,137.7(1.4)	103	99,000
	$C_{12}H_{11}N_3O_3^+$	20,471,084.7(3.1)	138	74,000



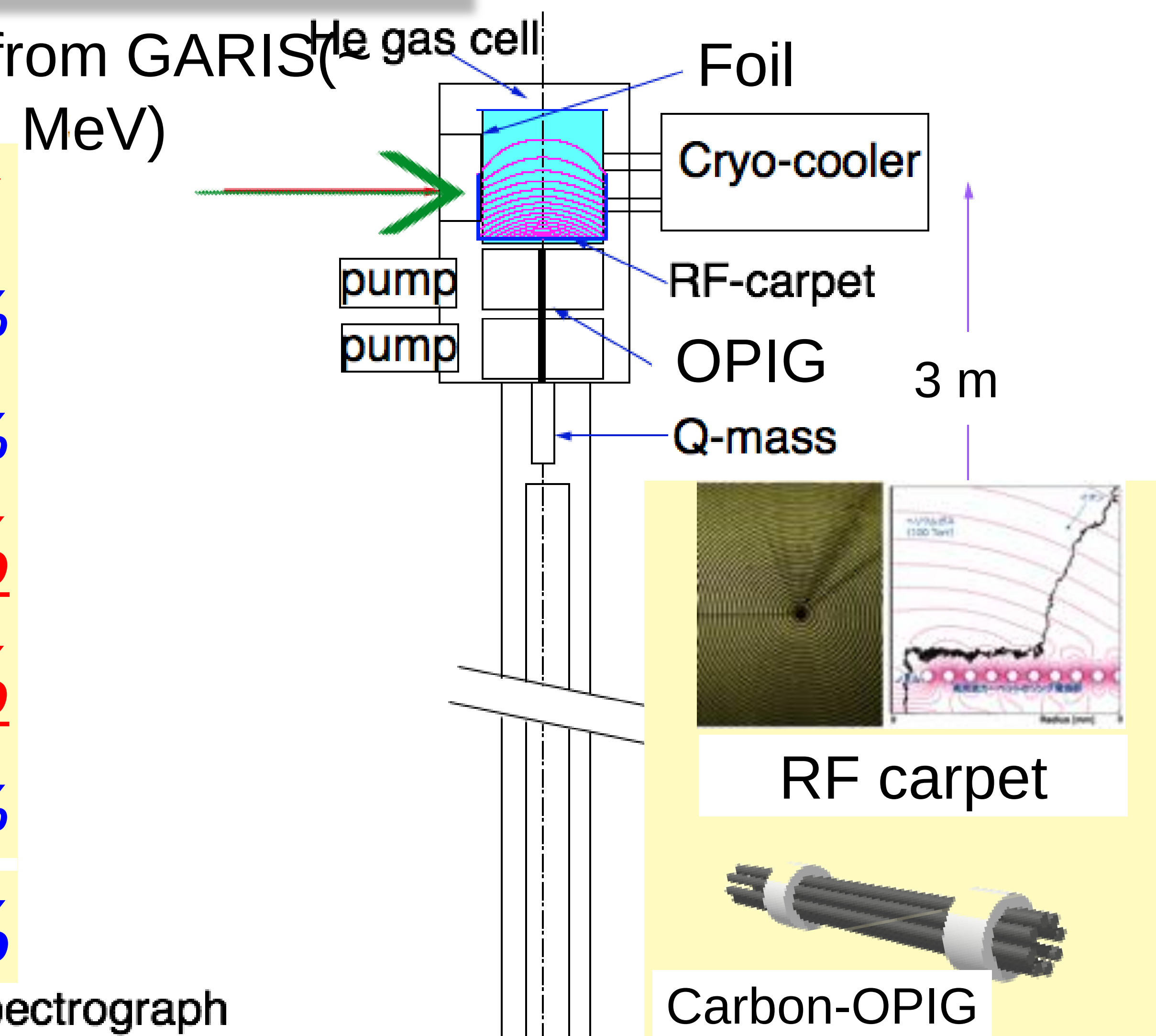


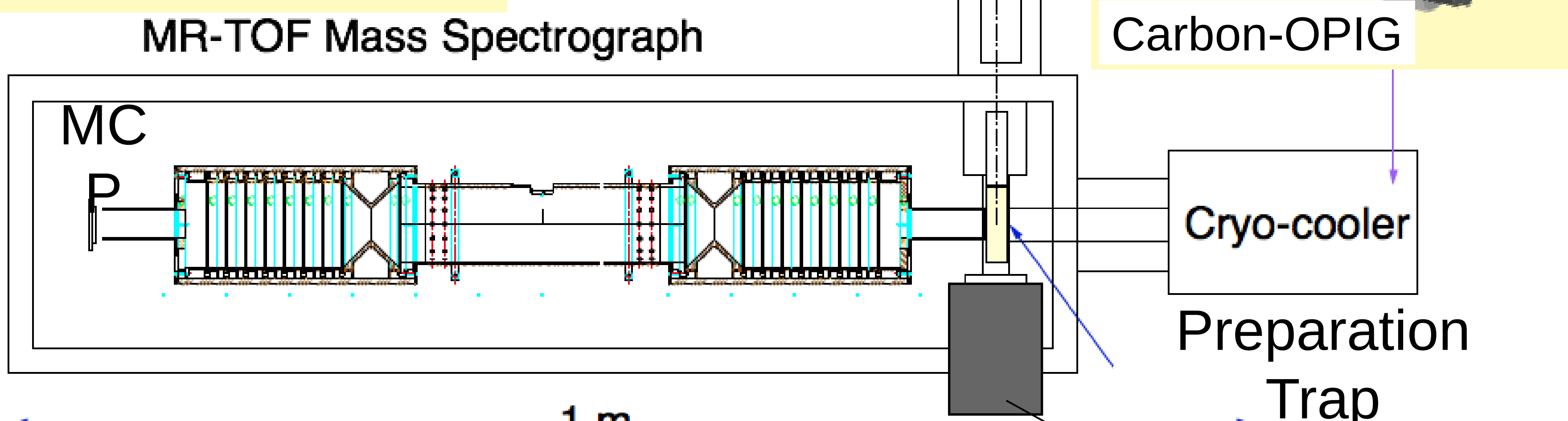
S. Naimi et al., submitted to IJMS

Toward SHE mass measurements

GARIS (RIKEN Gas-filled Recoil Ion Separator) + MR-TOF

Process	Efficiency
1. He Gas Cell Stopping	≈100%
2. Extraction via RF-Carpet: 0-5 ms	≈50%
3. OPIG Transport: < 1ms	≈100%
4. Ion Cooling: ≈2 ms	≈50%
5. MRTOF ToF-MS: 2~10 ms	≈100%
Total: ≈5~20 ms	≈20%





Electro-spray ion source for calibrants

Candidate Nuclei:

$^{252-254}$No: ~6 cps

$^{255-257}$Rf: ~0.04 cps

etc ...

MRTOF-MS @ GARIS

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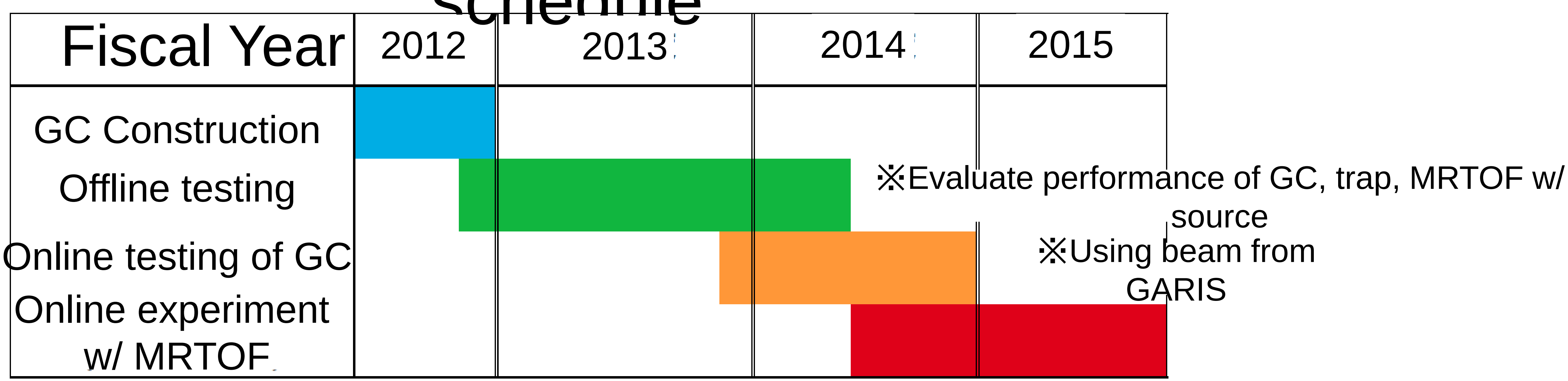
Measurement candidate rates

質量数	元素	半減期	断面積(b)	収量(/s)	収量(/day)
252-254	No	2.3s,1.6m,51s	2.00E-06	6.24E+00	5.39E+05
255-257	Rf	1.7s,6.4ms,4.7s	1.20E-08	3.74E-02	3.23E+03
261	Sg	0.23s	3.00E-09	9.36E-03	8.09E+02
261	Bh	12ms	8.00E-10	2.50E-03	2.16E+02
264-265	Hs	7.8ms,2ms	6.00E-11	1.87E-04	1.62E+01
266	Mt	6ms	9.00E-12	2.81E-05	2.43E+00
270-271	Ds	6ms,69ms	1.50E-11	4.68E-05	4.04E+00
272	Rg	3.8ms	3.00E-12	9.36E-06	8.09E-01
277	Cn	0.7ms	4.00E-13	1.25E-06	1.08E-01

図4 理研GARISで収量が確認されている主な核種と収量（森田）

- Start with verification of No isotopes previously measured by SHIPTrap
- Rf, Sg and maybe Bh feasible in first effort
  - ≲2 days observation required for each
- For heavier, even one count *is* a measurement!

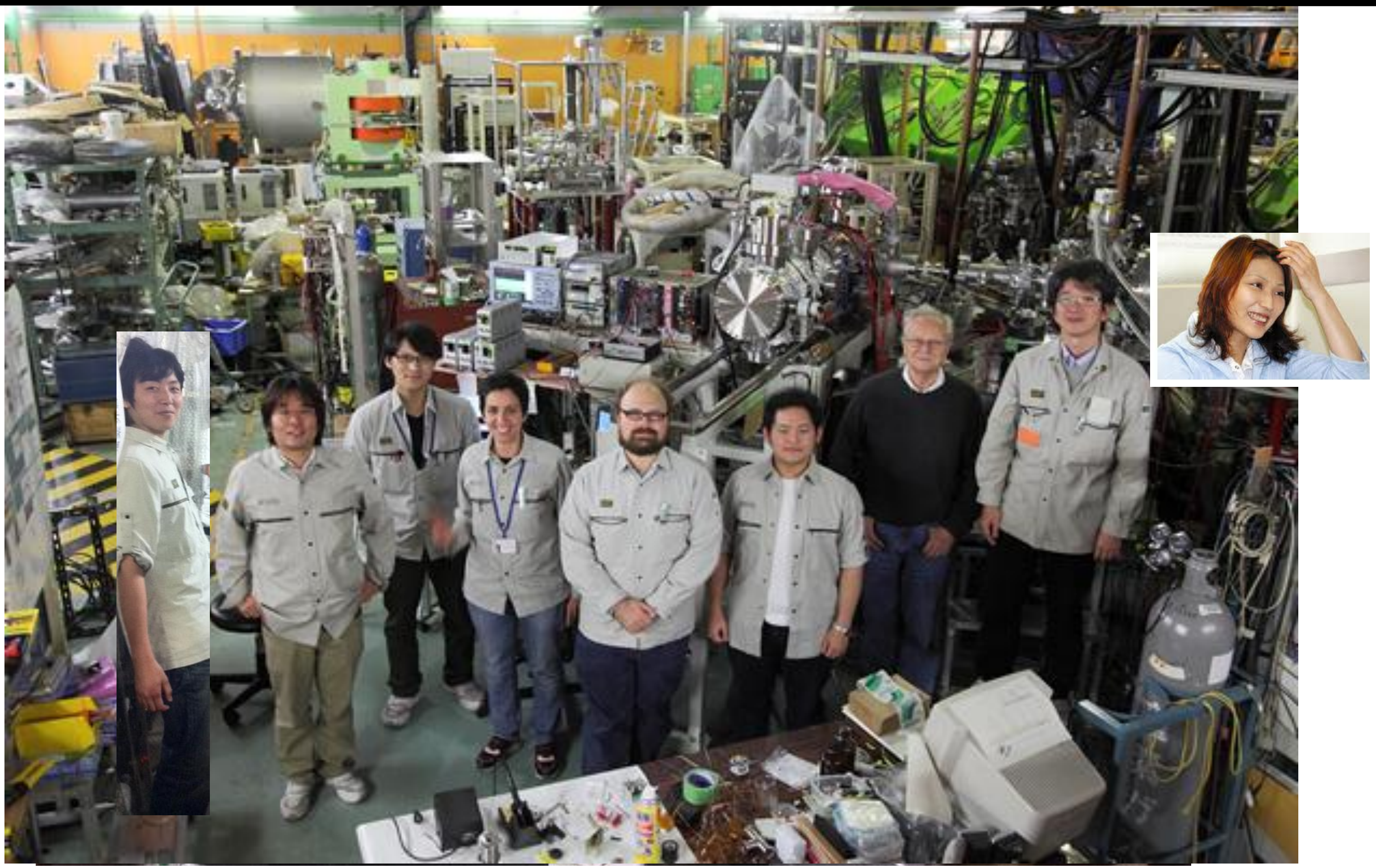
MRTOF-MS SHE campaign schedule



※Begin w/ accuracy check using Penning trap measured No isotopes

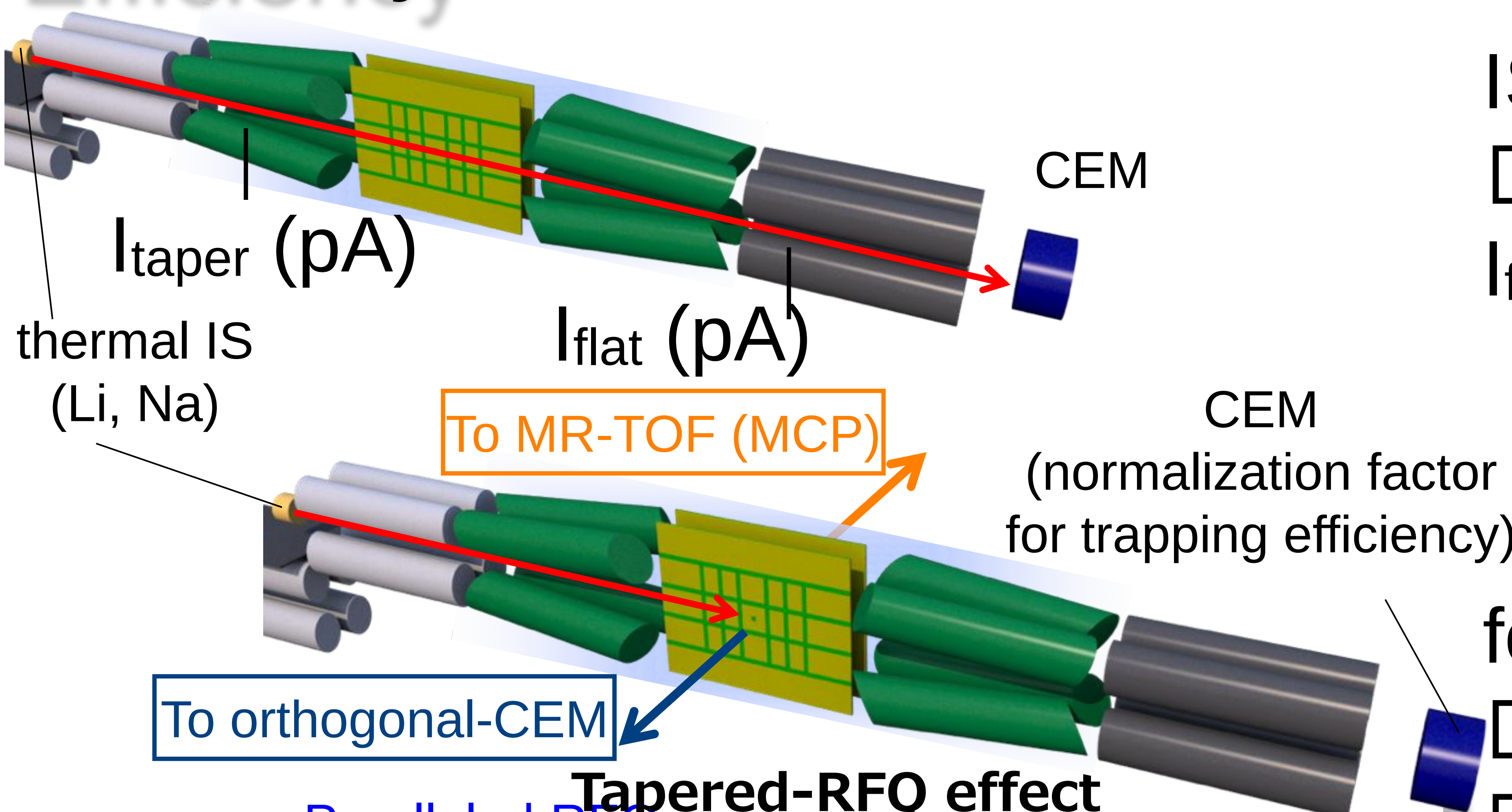
Summary and Outlook

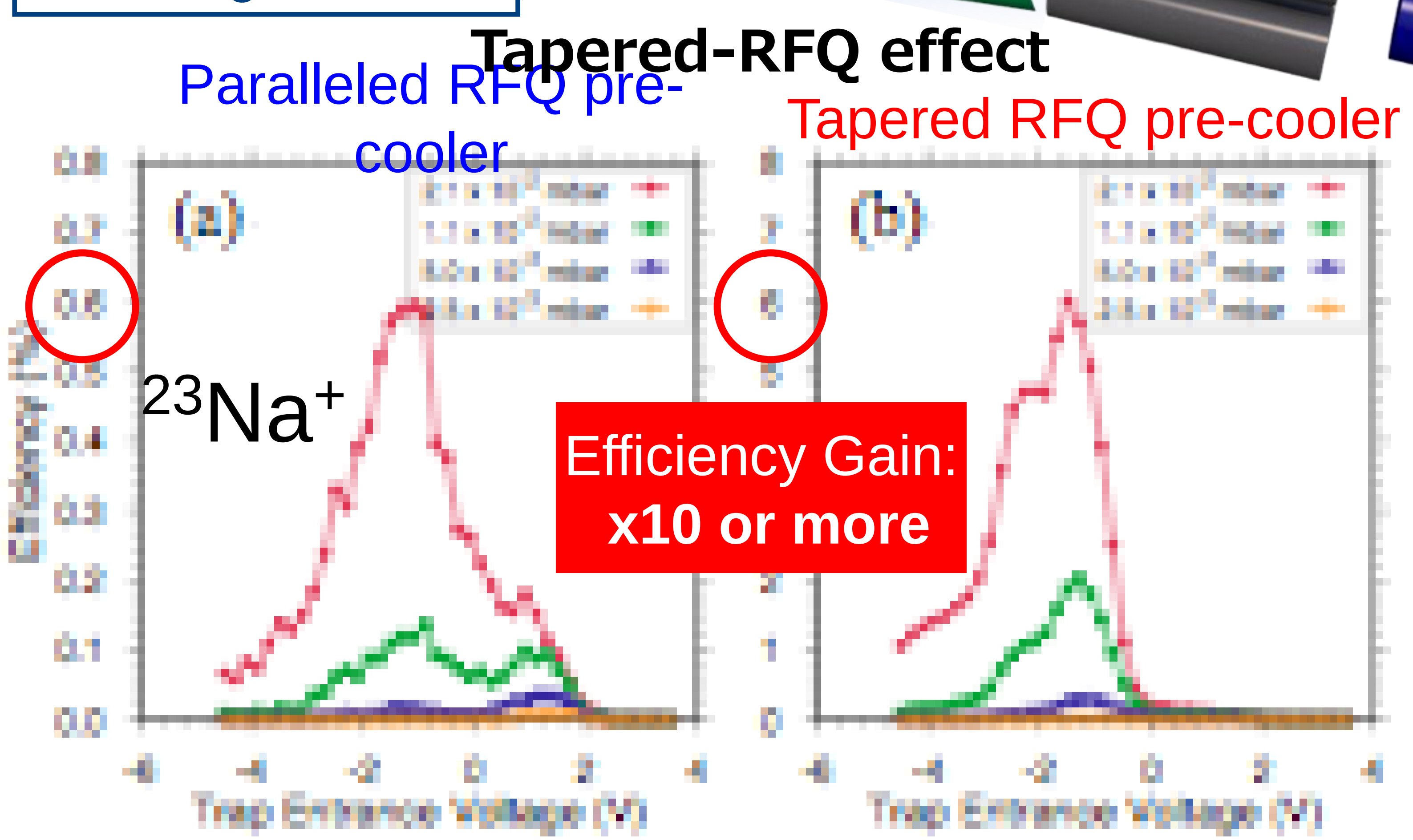
- Ion preparation trap working well
  - Fast cooling, $T_{cool} \approx 2ms$
  - High efficiency, anticipate 50% for SHE
- Online MRTOF-MS commissioning successful
  - $\delta m/m < 5x10^{-7}$
- Preparations for SHE campaign underway
  - New α/β/ToF detector under development (F. Arai)



Left to right:
H. Mita (Master Student)
T. Sonoda
Y. Ito (Doctoral Student)
S. Naimi (Post Doc)
PHS
K. Nakamura (Master Student)
H. Wollnik
M. Wada
A. Takamine

Efficiency





IS-CEM:

- ☐ $\varepsilon_{straight} = I_{flat}/I_{taper}$ $= \sim 80$ %

for DC ^{23}Na beam:

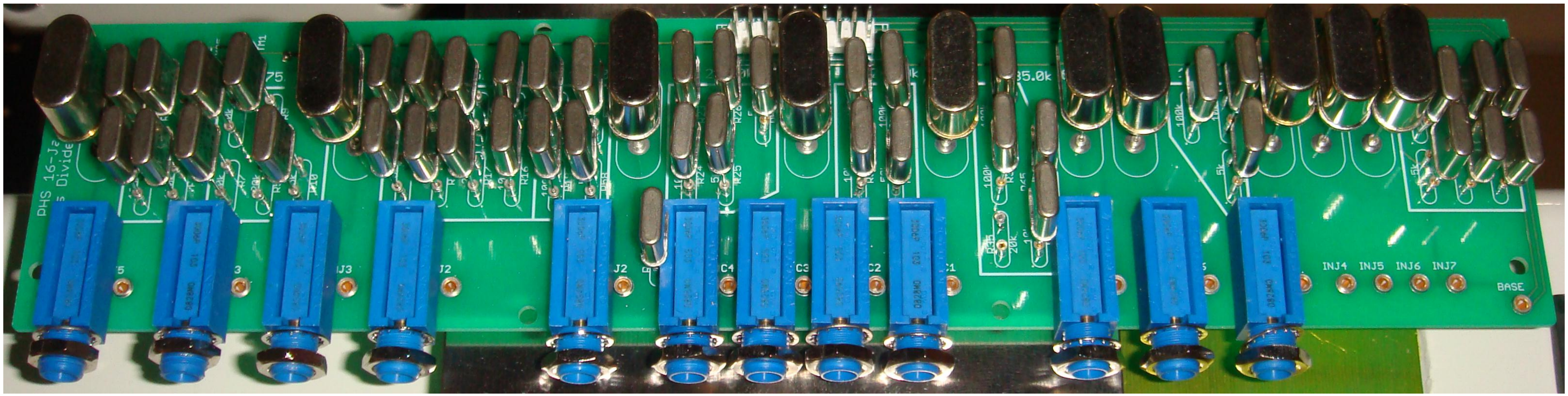
- ☐ **ε_{MCP} = 12.1 %**
- ☐ $\varepsilon_{ortho\text{-}CEM}$ = 26.7 %*

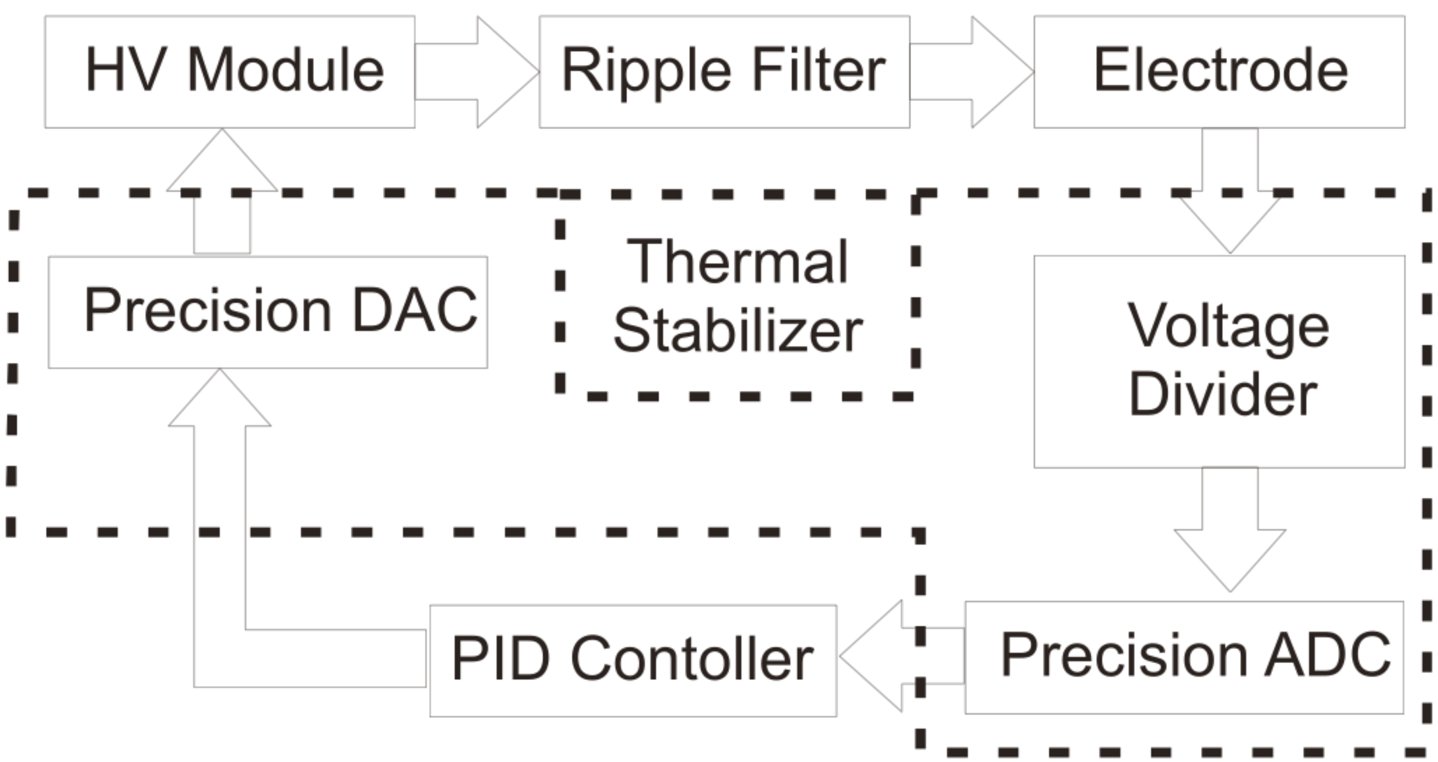
for DC ^{7}Li beam:

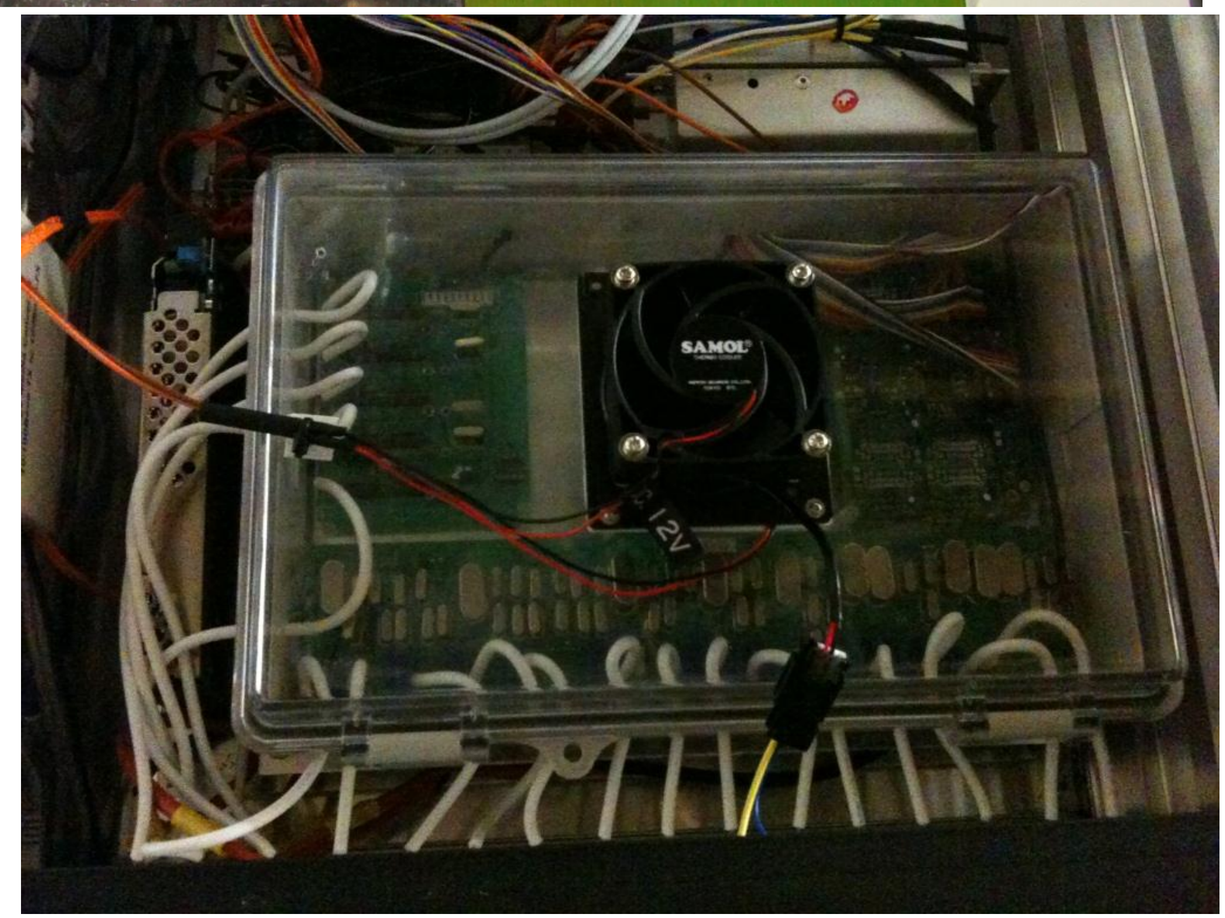
- ☐ **ε_{MCP} = 2.4 %**
- ☐ $\varepsilon_{ortho\text{-}CEM}$ = 5.1 %*

(*detection efficiency gai

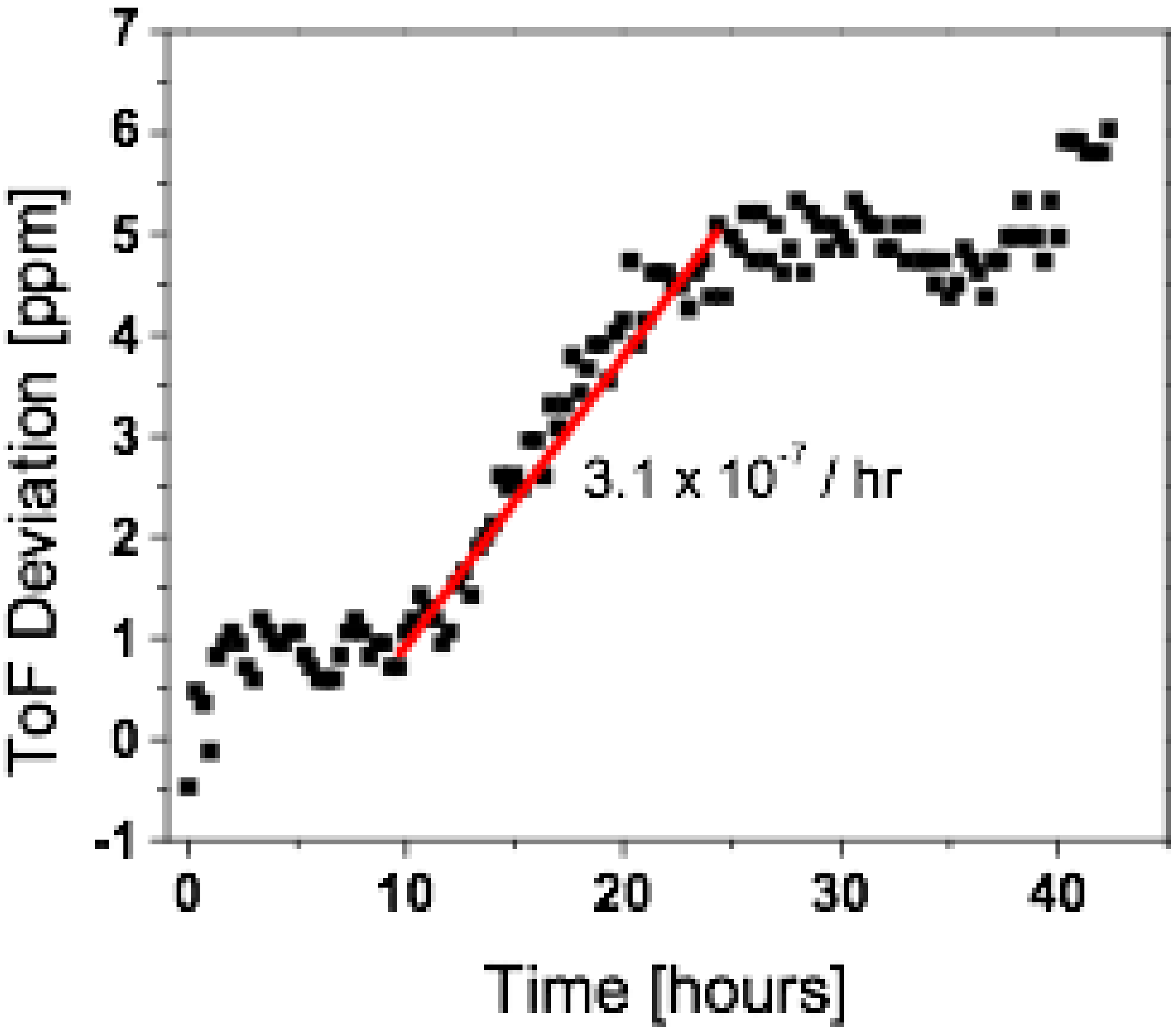
Ultra high stability high voltage source







Stability of MRTOF



- Drift is of similar order to field decay rate in PTMS
- “Fast” component consistent with ΔT~0.5^{o}C in Ti support structure
- Unlike PTMS we can rejigger

Vacuum / emmitance