Slow RI beam production using an RF gas catcher and precision mass spectroscopy using MRTOF-MS

Aiko Takamine
(Nuclear spectroscopy lab., RIKEN)

August 8th, 2023, 3rd NUSYS-2023
Fudan university, Shanghai

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+ 9 kg

result

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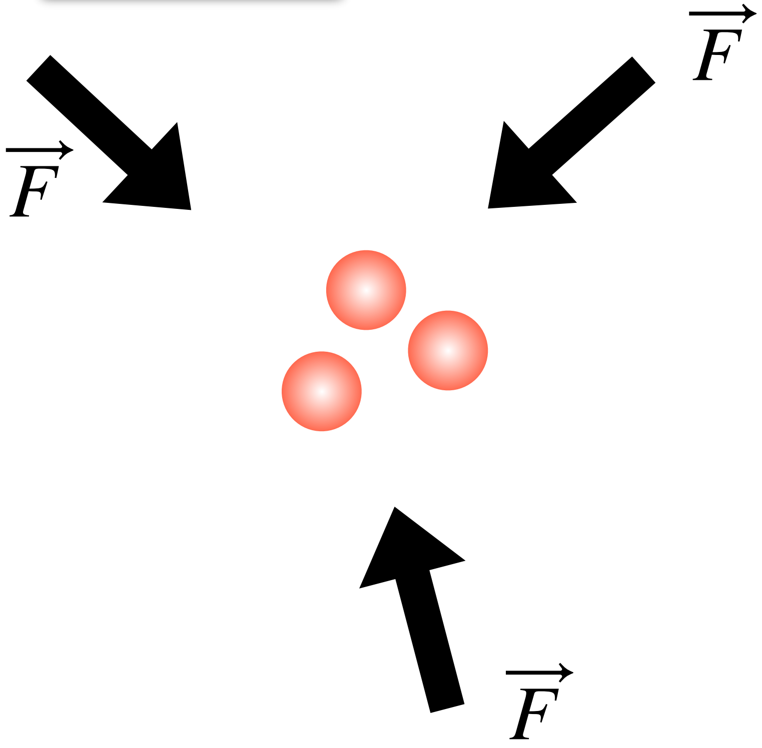
SLOWRI collaboration

Nuclear spectroscopy lab.

Contents

- **Very basics of RF traps (Paul trap)**
- How to convert high energy RI beams to ultra-slow RI beams?
- How to precisely measure masses of exotic nuclei?

Ion trap



To trap ions…

requirement: 3 dimensional forces to the center

$$\vec{F} = -\nabla\phi$$

ϕ: potential

convenience: harmonic force

$$\vec{F} \propto x, y, z$$

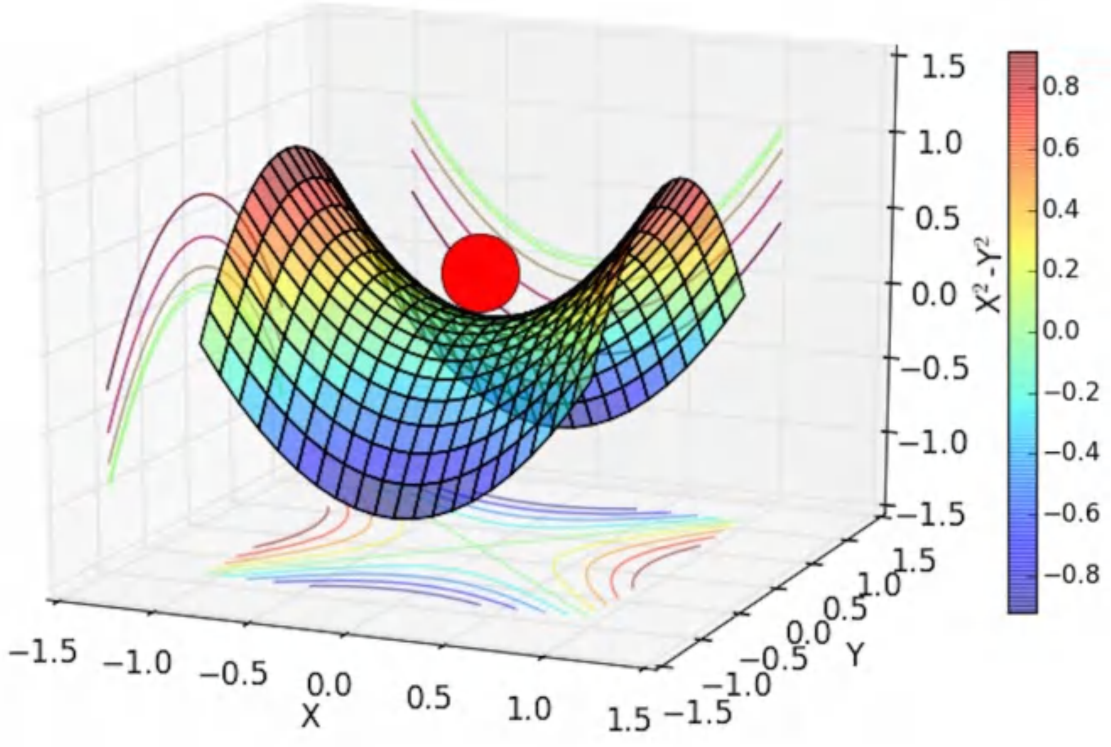
$$\rightarrow \phi = a_x x^2 + a_y y^2 + a_z z^2$$

Laplace equation $\Delta\phi = 0$

$$\Rightarrow a_x + a_y + a_z = 0$$

Could be saddle shaped.
However, 3-D trapping is impossible with static fields.

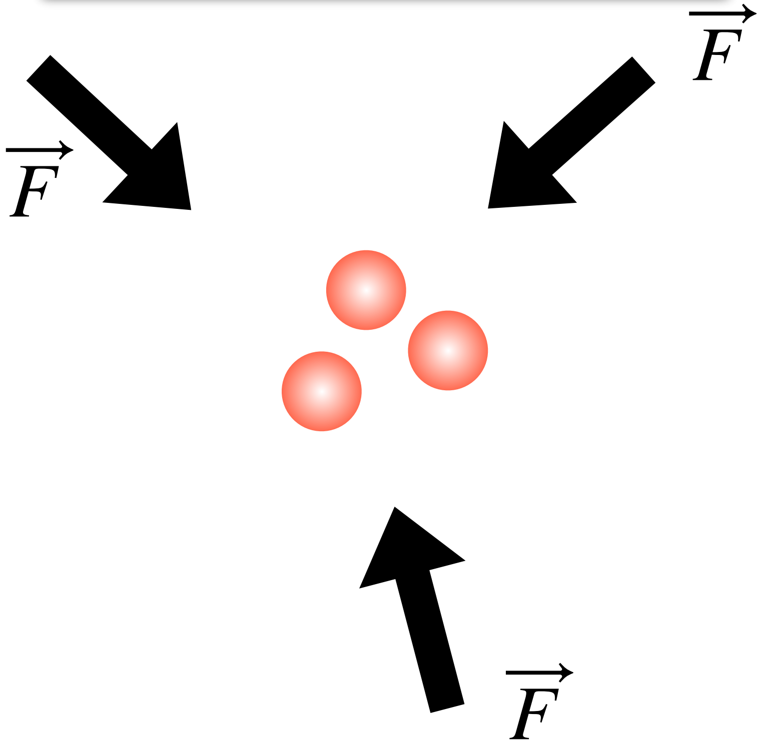
"Earnshaw's theorem"



Add a magnetic field ⇒ Penning trap

Add oscillating fields ⇒ **Paul trap**

Ion trap (Paul trap)



$$\phi(x,y,z,t) = (c_x x^2 + c_y y^2 + c_z z^2)$$
$$+\boxed{\cos(\omega t)}(\tilde{c}_x x^2 + \tilde{c}_y y^2 + \tilde{c}_z z^2)$$

oscillating fields

again,

$$c_x + c_y + c_z = 0,$$
$$\tilde{c}_x + \tilde{c}_y + \tilde{c}_z = 0$$

geometric constraints

case I

$c_x + c_y = 0, c_z = 0,$

$\tilde{c}_x + \tilde{c}_y = 0, \tilde{c}_z = 0$

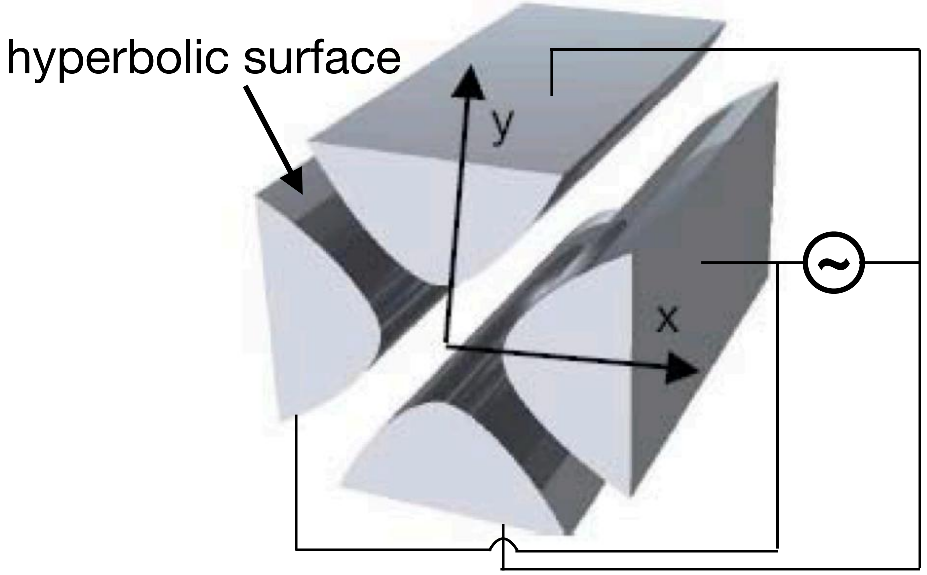
$$\phi = (U - V\cos\omega t)\frac{x^2 - y^2}{2r_0^2}$$

case II

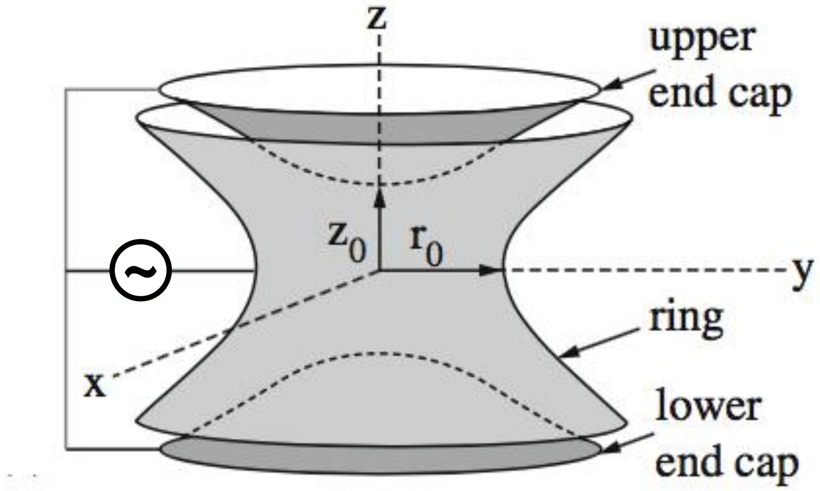
$c_x = c_y,\ c_z = -2c_x,$

$\tilde{c}_x = \tilde{c}_y = 0\ \tilde{c}_z = -2\tilde{c}_x$

$$\phi = (U - V\cos\omega t)\frac{x^2 + y^2 - 2z^2}{2r_0^2}$$



2D trapping



3D trapping

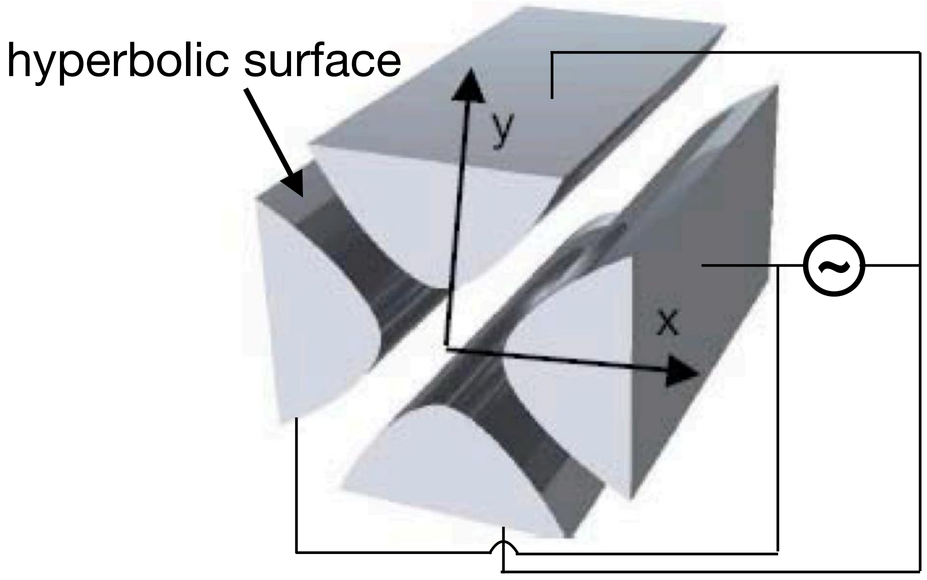
Ion trap (Paul trap)

case I

$c_x + c_y = 0, c_z = 0,$

$\tilde{c}_x + \tilde{c}_y = 0, \tilde{c}_z = 0$

$$\phi = (U - V\cos\omega t)\frac{x^2 - y^2}{2r_0^2}$$



Solution for stable conditions:

$$x, y(t) = A\sum_{n=0}^{\infty} c_{2n}\cos(\beta + 2n)\frac{\omega t}{2}$$

c_{2n}, β are complex functions of a, q

Approximate solution for $a, q \ll 1$

$$x, y(t) = A[1 + (q/2)\cos\Omega t]\cos\omega t$$

$$\Omega = \frac{\beta}{2}\omega$$

$$\beta^2 = a + q^2/2$$

Particle's equations of motion

$$\ddot{x} + \frac{Q}{mr_0^2}(U - V\cos\omega t)x = 0$$

Q: charge

$$\ddot{y} + \frac{Q}{mr_0^2}(U - V\cos\omega t)y = 0$$

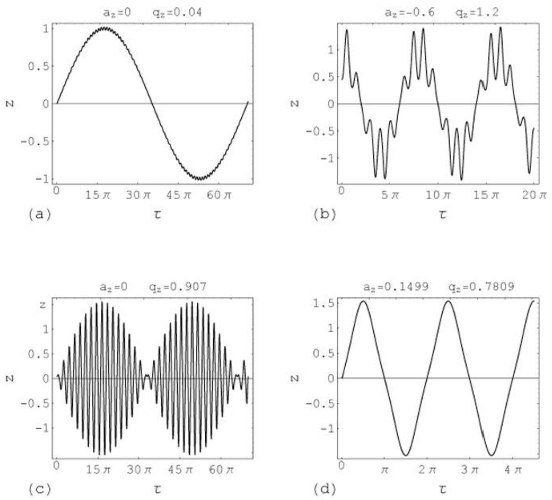
$\ddot{z} = 0$ ← we apply an additional DC field in z direction for axial confinement

If we use the substitutions $a = \frac{4QU}{mr_0^2\omega^2}, q = \frac{2QV}{mr_0^2\omega^2}$

$$\frac{d^2x}{d\xi^2} + (a - 2q\cos(2\xi))x = 0$$

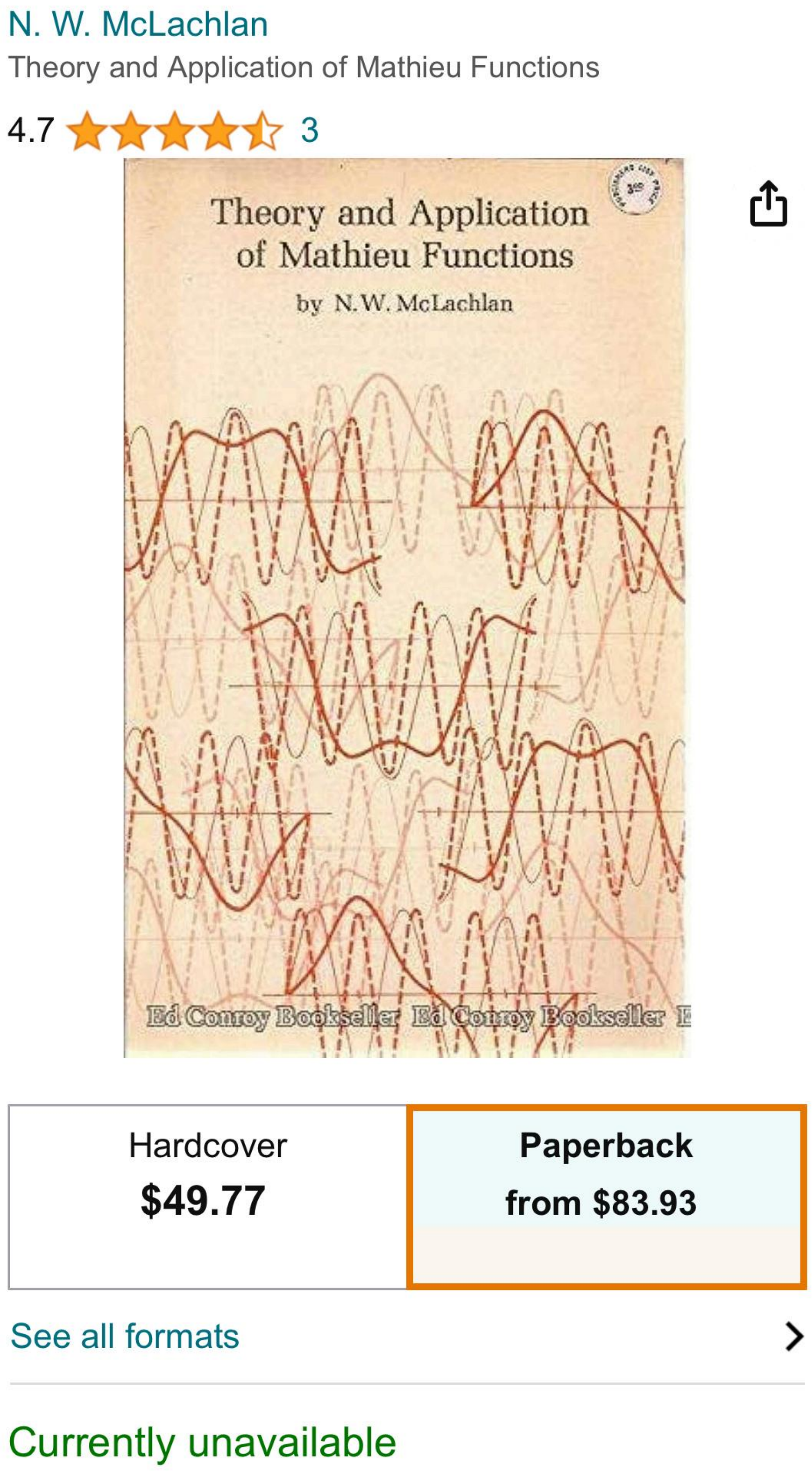
"Mathieu's equation"

$$\frac{d^2y}{d\xi^2} + (a - 2q\cos(2\xi))y = 0$$



Harmonic oscillation at Ω (secular motion) modulated by an oscillation at ω (micromotion)

As for the details of Mathieu's equation…



N. W. McLachlan

Theory and Application of Mathieu Functions

4.7 ★★★★☆ 3

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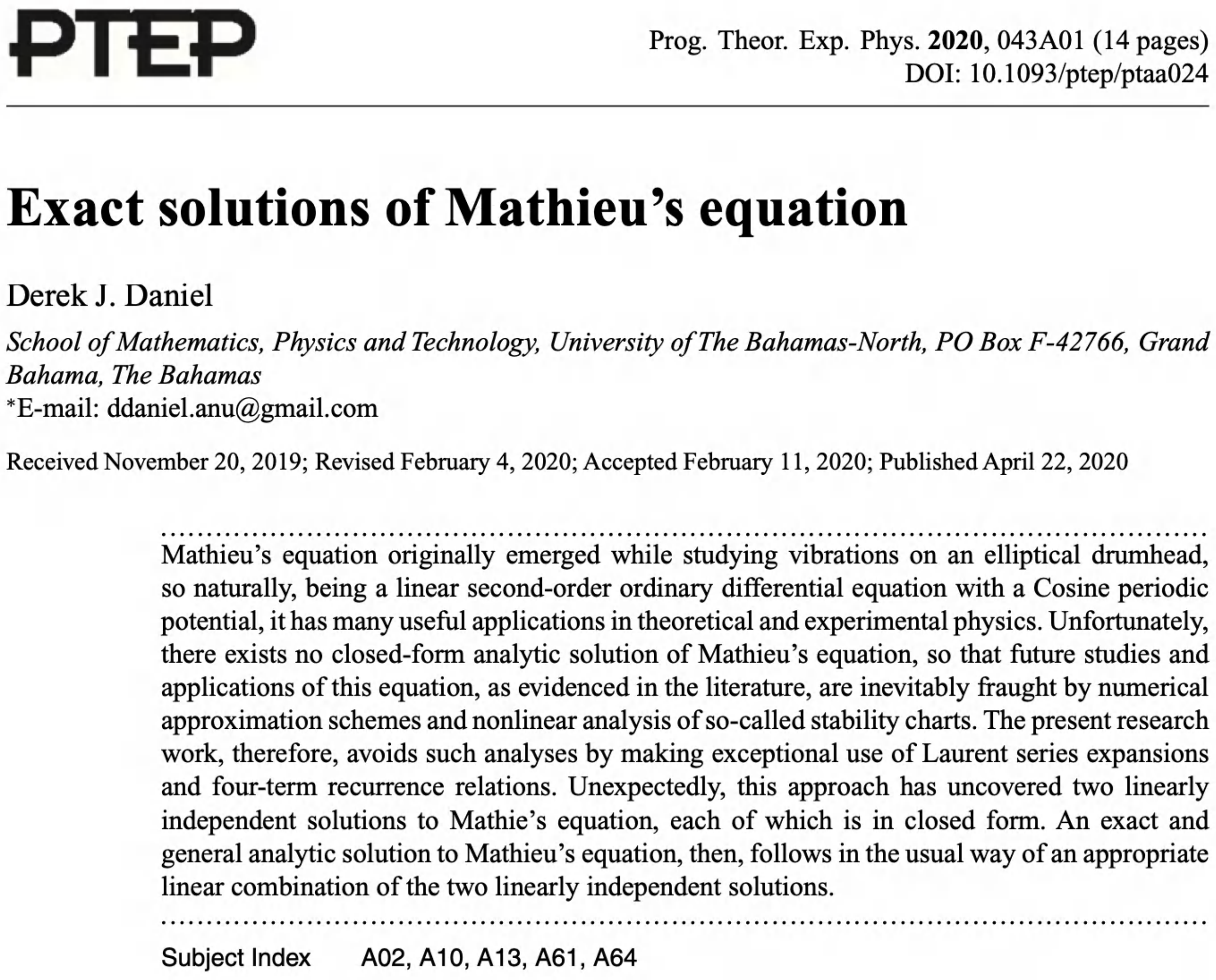

Prog. Theor. Exp. Phys. **2020**, 043A01 (14 pages)
DOI: 10.1093/ptep/ptaa024

Exact solutions of Mathieu's equation

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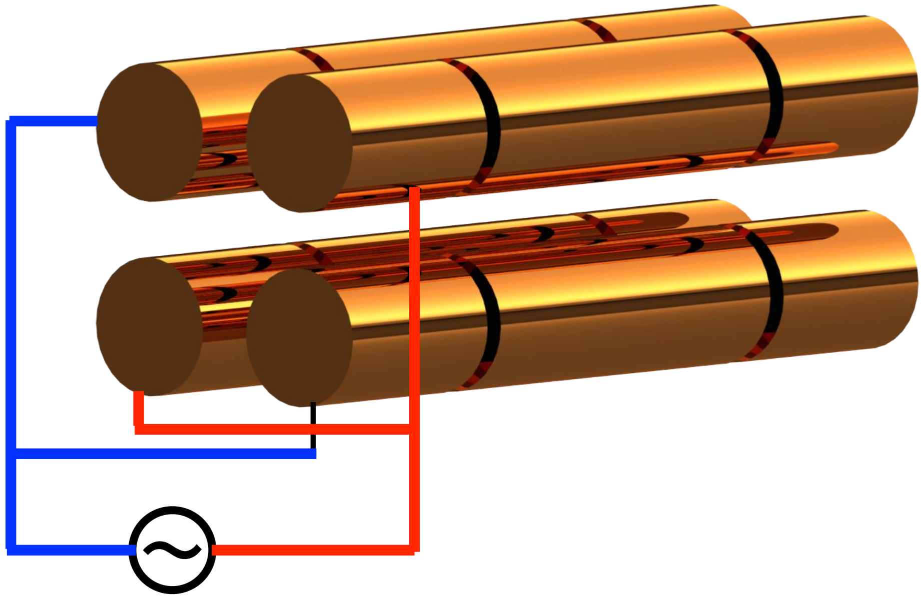
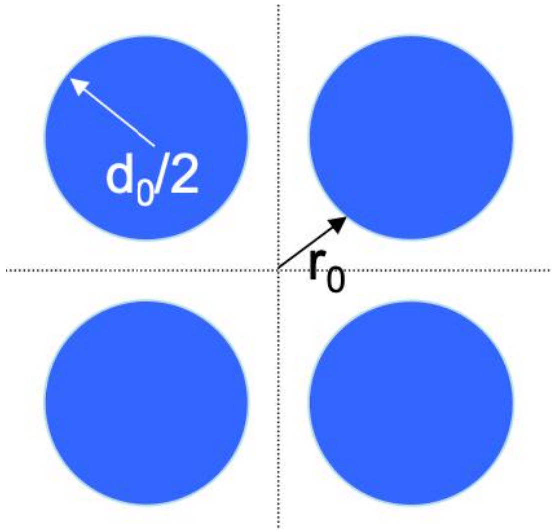
Mathieu's equation originally emerged while studying vibrations on an elliptical drumhead, so naturally, being a linear second-order ordinary differential equation with a Cosine periodic potential, it has many useful applications in theoretical and experimental physics. Unfortunately, there exists no closed-form analytic solution of Mathieu's equation, so that future studies and applications of this equation, as evidenced in the literature, are inevitably fraught by numerical approximation schemes and nonlinear analysis of so-called stability charts. The present research work, therefore, avoids such analyses by making exceptional use of Laurent series expansions and four-term recurrence relations. Unexpectedly, this approach has uncovered two linearly independent solutions to Mathie's equation, each of which is in closed form. An exact and general analytic solution to Mathieu's equation, then, follows in the usual way of an appropriate linear combination of the two linearly independent solutions.

Subject Index A02, A10, A13, A61, A64

Linar Paul trap

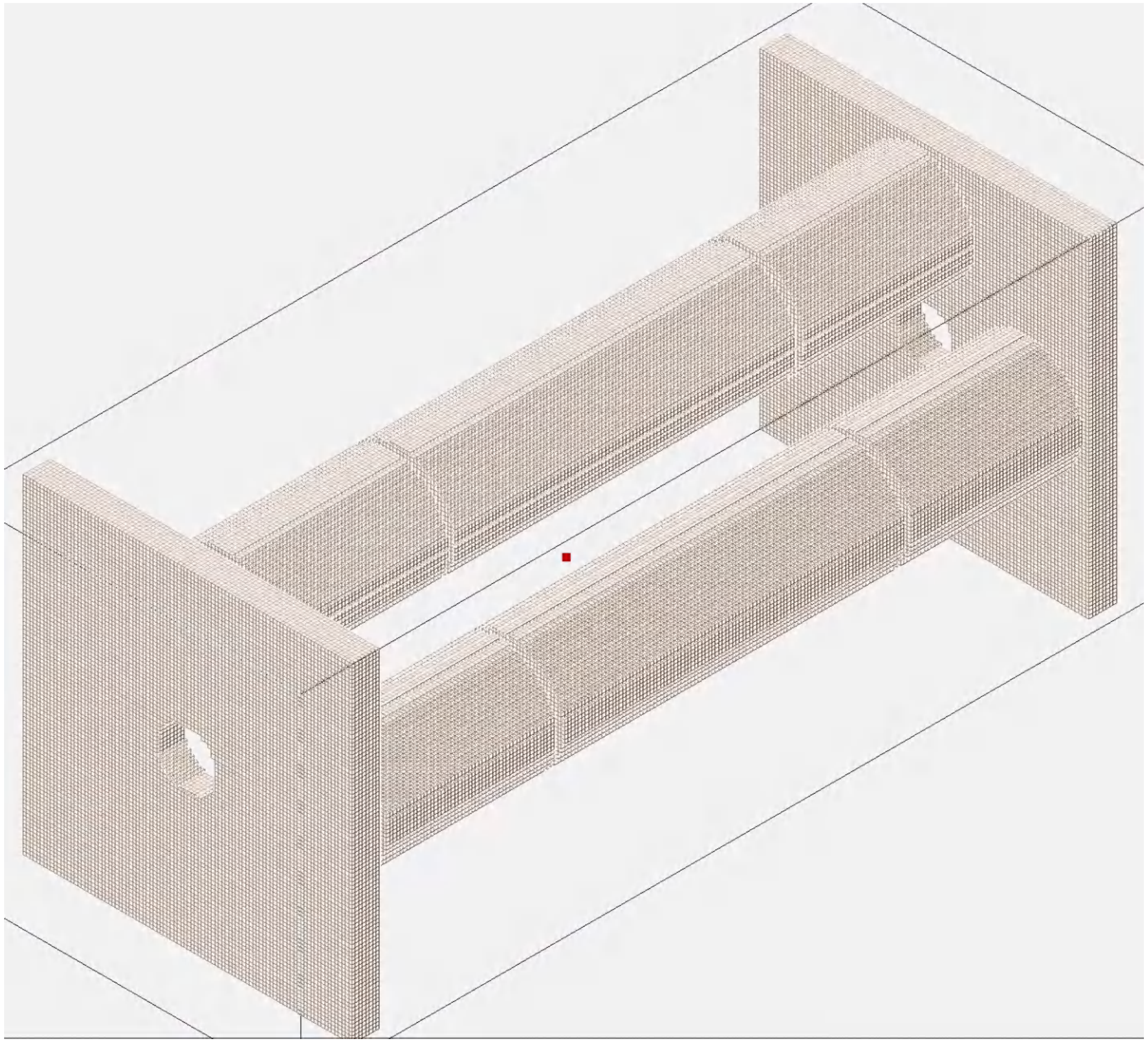


Not ideal but a circular surface (just a rod) is practically ok.



"ideal" case: $d_0/2 = 1.1468 r_0$

Reuben et al.,IJMS **154**, 43-59 (1996)



In a dense gas

E potential: $\phi = (V\cos\omega t)\dfrac{x^2 - y^2}{2r_0^2}$

E field: $\overrightarrow{E}(\vec{r}, t) = -\nabla\phi = \dfrac{V}{r_0^2}\begin{pmatrix} -x \\ y \end{pmatrix}\cos\omega t$

Divide the motion into mean and micro motions

$$\vec{r} = \tilde{r}(t) - \vec{\rho}(t) = \tilde{r}(t) - \frac{Q}{m\omega}\frac{\overrightarrow{E}(\vec{r})}{\sqrt{\omega^2 + D^2}}\cos(\omega t + \beta) \qquad \tan\beta = D$$

D: damping constant
$\overrightarrow{F}_{\text{damp}} = -mD\vec{v}$

Then, time-averaged force over one period,

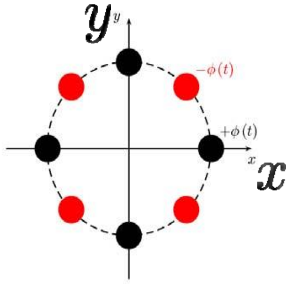
$$\overrightarrow{\tilde{E}}(\vec{\tilde{r}}) = Q\langle\overrightarrow{E}(\vec{\tilde{r}})\cos\omega t + \vec{\rho}(t)\nabla\cdot\overrightarrow{E}(\vec{\tilde{r}})\cos\omega t\rangle = -\nabla\overrightarrow{E}^2(\vec{\tilde{r}})\frac{Q^2}{4m}\frac{1}{\omega^2 + D^2}$$

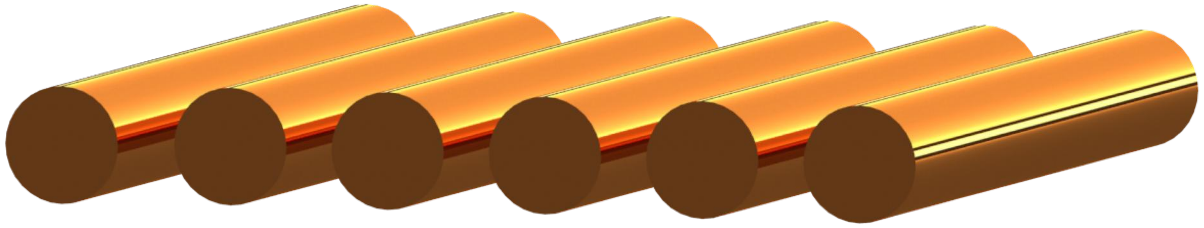
So, time-averaged pseudo-potential is

$$U(\vec{\tilde{r}}) = \frac{Q^2}{4m}\frac{1}{\omega^2 + D^2}\overrightarrow{E}^2(\vec{\tilde{r}}) = \frac{Q^2V^2}{4m(\omega^2 + D^2)r_0^2}\left(\frac{r}{r_0}\right)^2$$

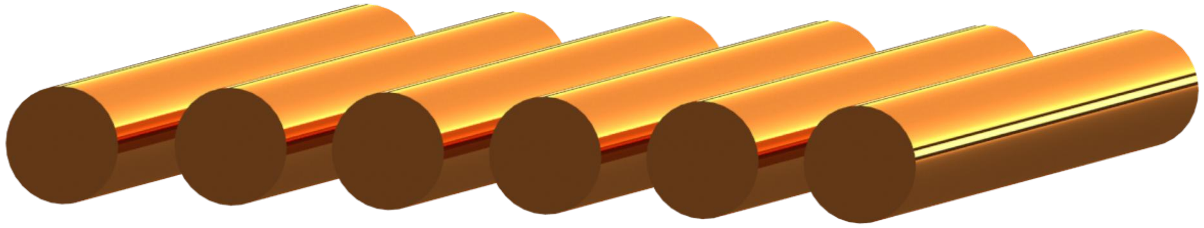
This can be extended to $2n$ poles pseudo-potential:

$$U(r) = \frac{Q^2n^2V^2}{4m(\omega^2 + D^2)r_0^2}\left(\frac{r}{r_0}\right)^{2n-2}$$

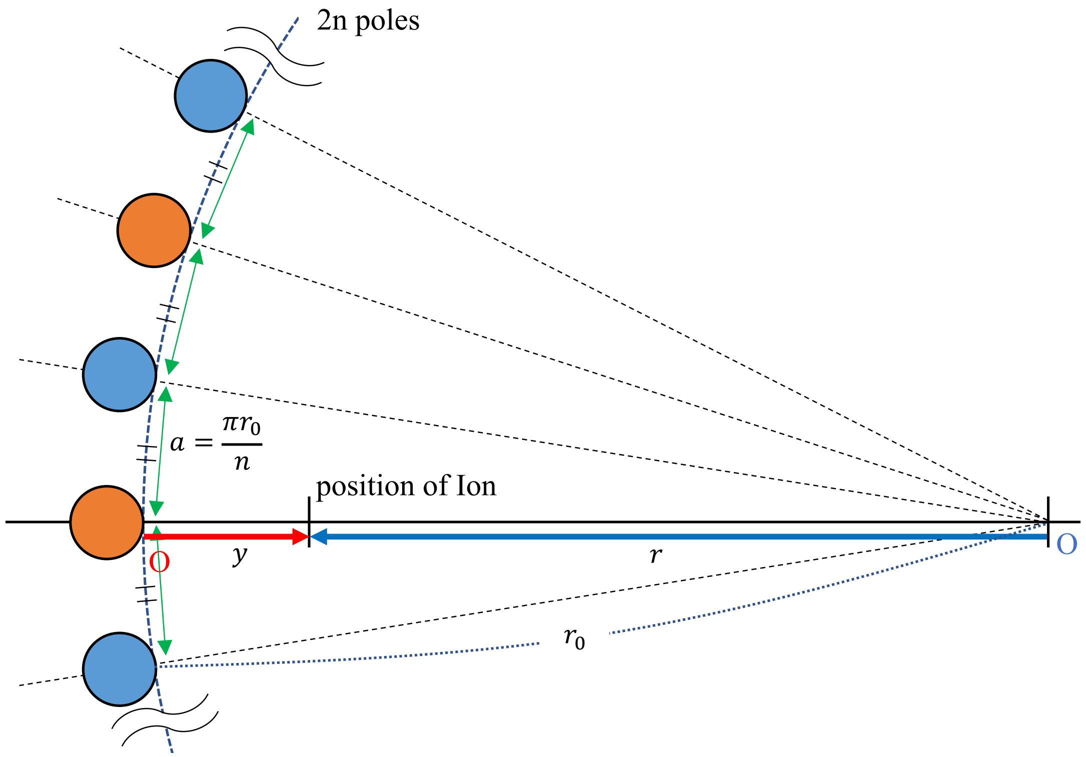




What will happen with this configuration?



What will happen with this configuration?



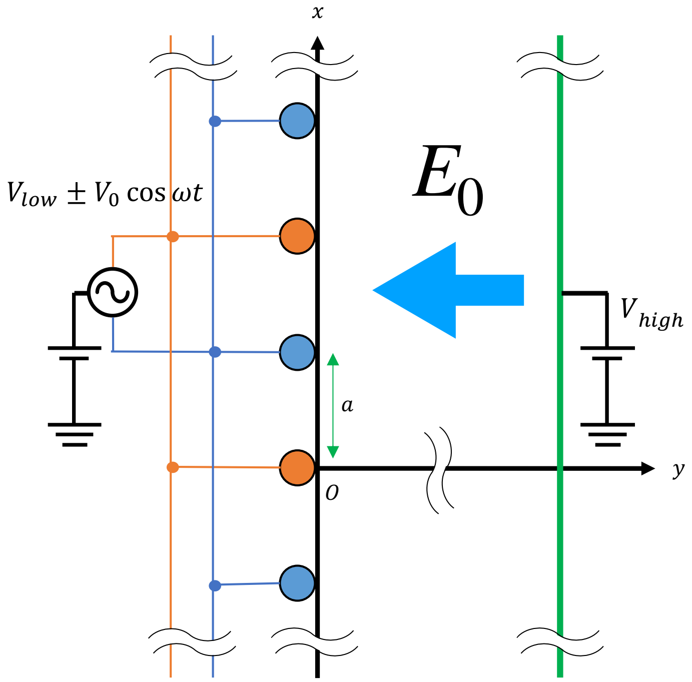
Let's think of $2n$ pole traps

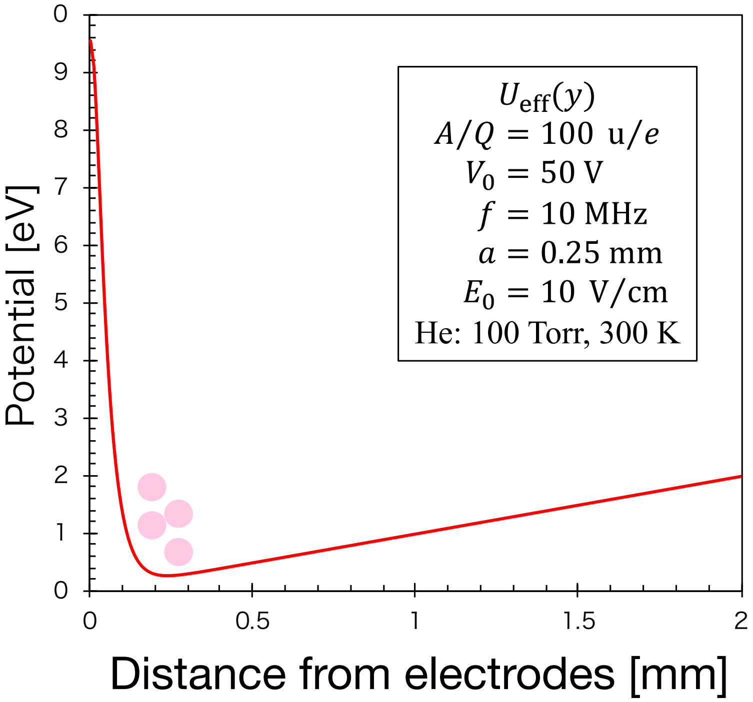
Use: $r = r_0 - y$ and $a = \frac{\pi r_0}{n}$ a: 'pitch' of electrodes

When $n \to \infty$, the electrodes can be considered to be aligned flat

$$U_{\mathrm{eff}}(y) = \frac{\pi^2 Q^2 V^2}{4m(\omega^2 + D^2)a^2} \lim_{n \to \infty} \left(1 - \frac{\pi y}{na}\right)^{2n-2}$$

$$= \frac{\pi^2 Q^2 V^2}{4m(\omega^2 + D^2)a^2} \exp\left(-\frac{2\pi}{a} y\right)$$





Let's impose a static electric field E_0 to push ions

$$U_{\mathrm{eff}}(y) = = \frac{\pi^2 Q^2 V^2}{4m(\omega^2 + D^2)a^2} \exp\left(-\frac{2\pi}{a} y\right) + QE_0 y$$

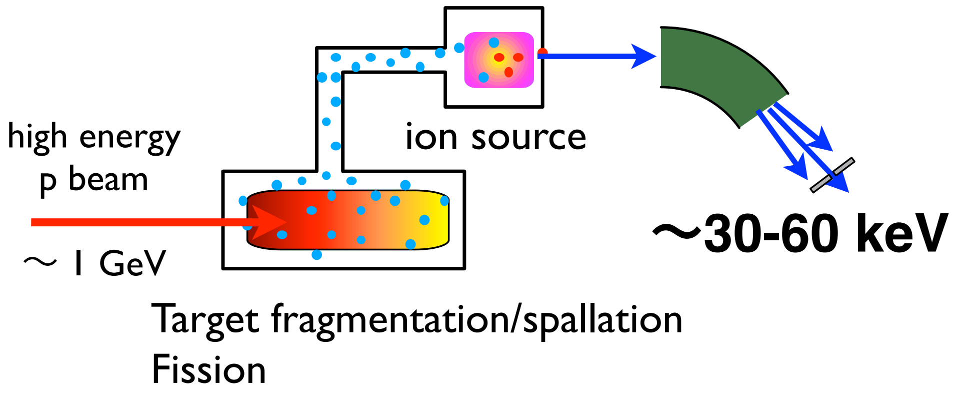
Ions will be trapped just a bit above the electrodes🥳🎉🎊

Contents

- Very basics of RF traps (Paul trap)
- **How to convert high energy RI beams to ultra-slow RI beams?**
- How to precisely measure masses of exotic nuclei?

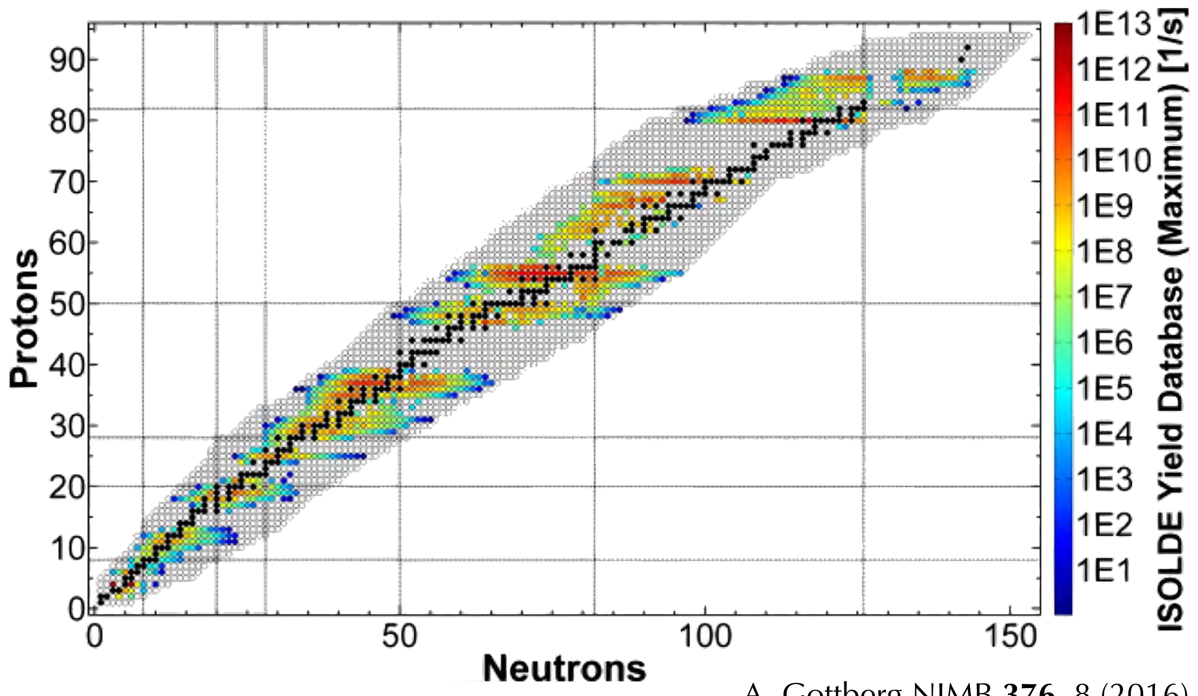
Production of RI beams

ISOL type p beam +
thick target (UC$_x$ etc.)



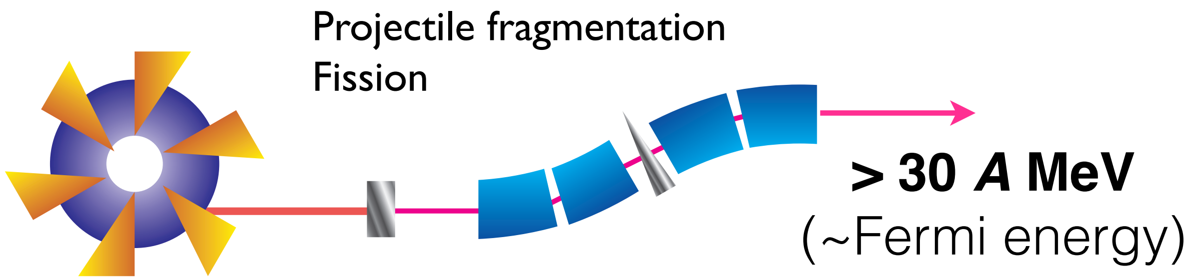
Slow RI beams with a high quality
Chemical property dependence

CERN ISOLDE yields



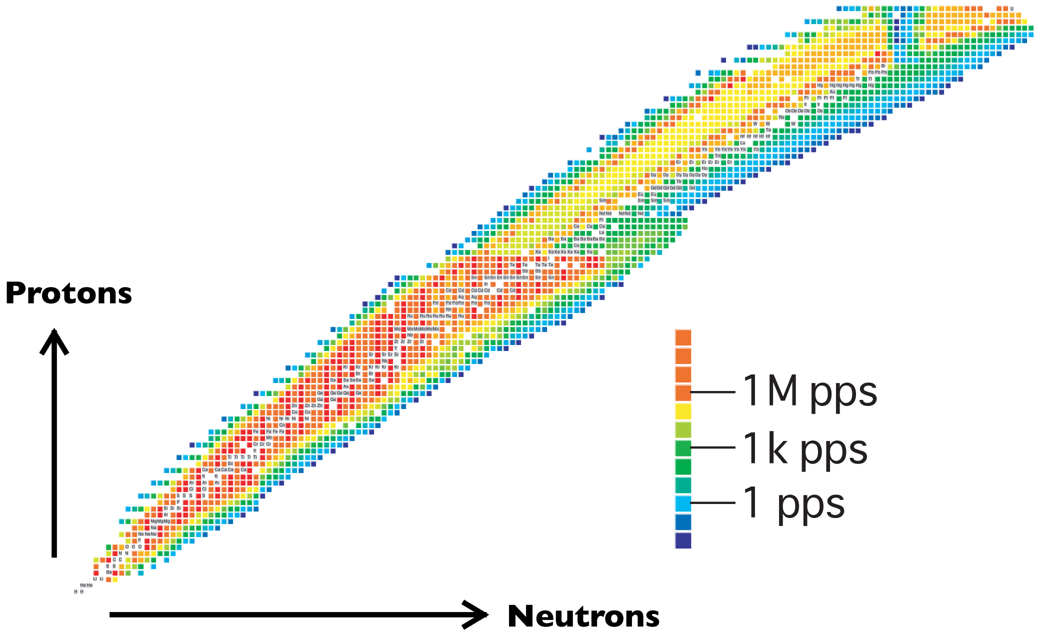
A. Gottberg NIMB **376**, 8 (2016)

In-flight type heavy ion beams +
thin target (Be, C etc.)

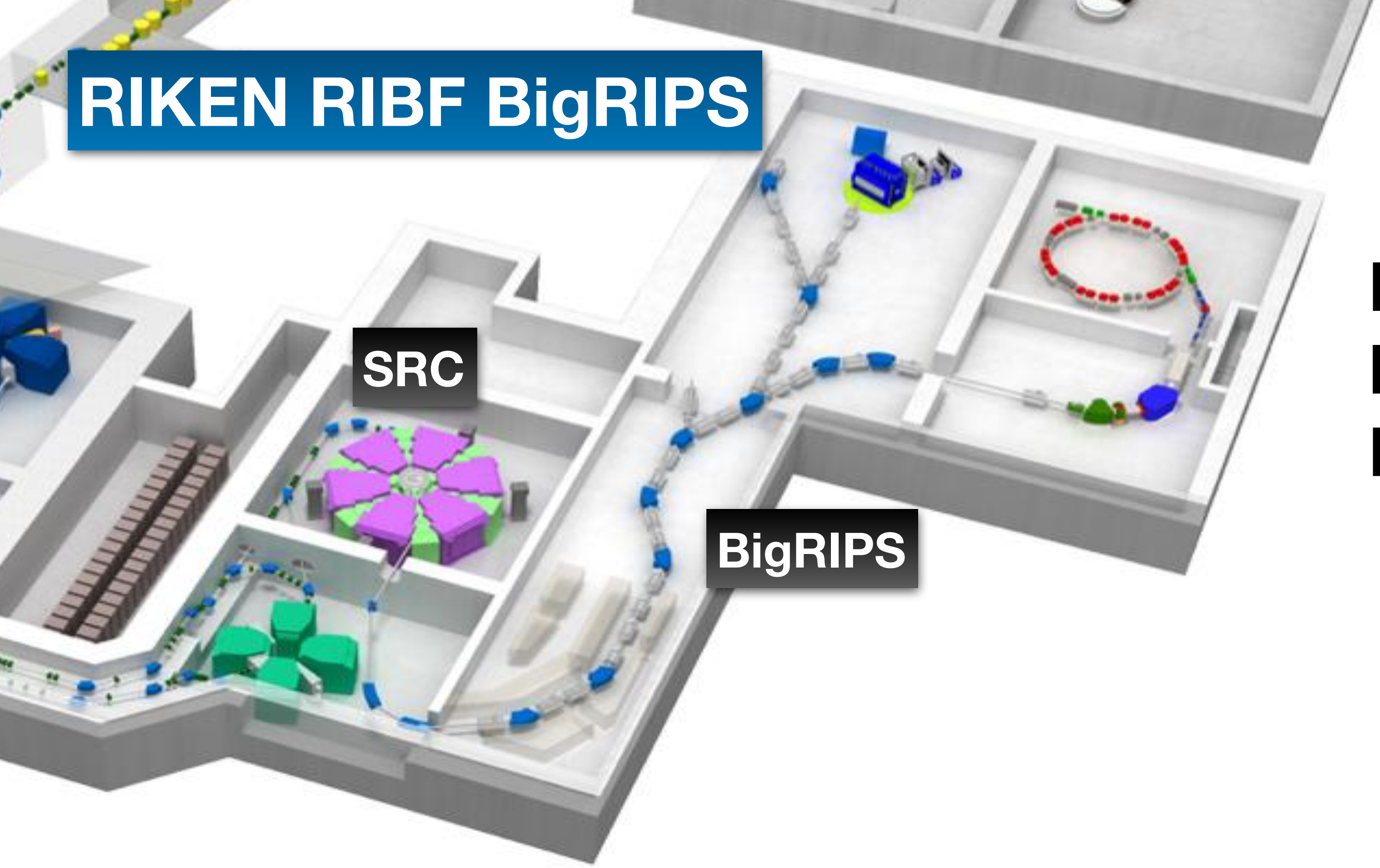


No chemistry dependence
High energy RI beams
(with a large energy spread)

In-flight method yields



RIKEN RIBF BigRIPS



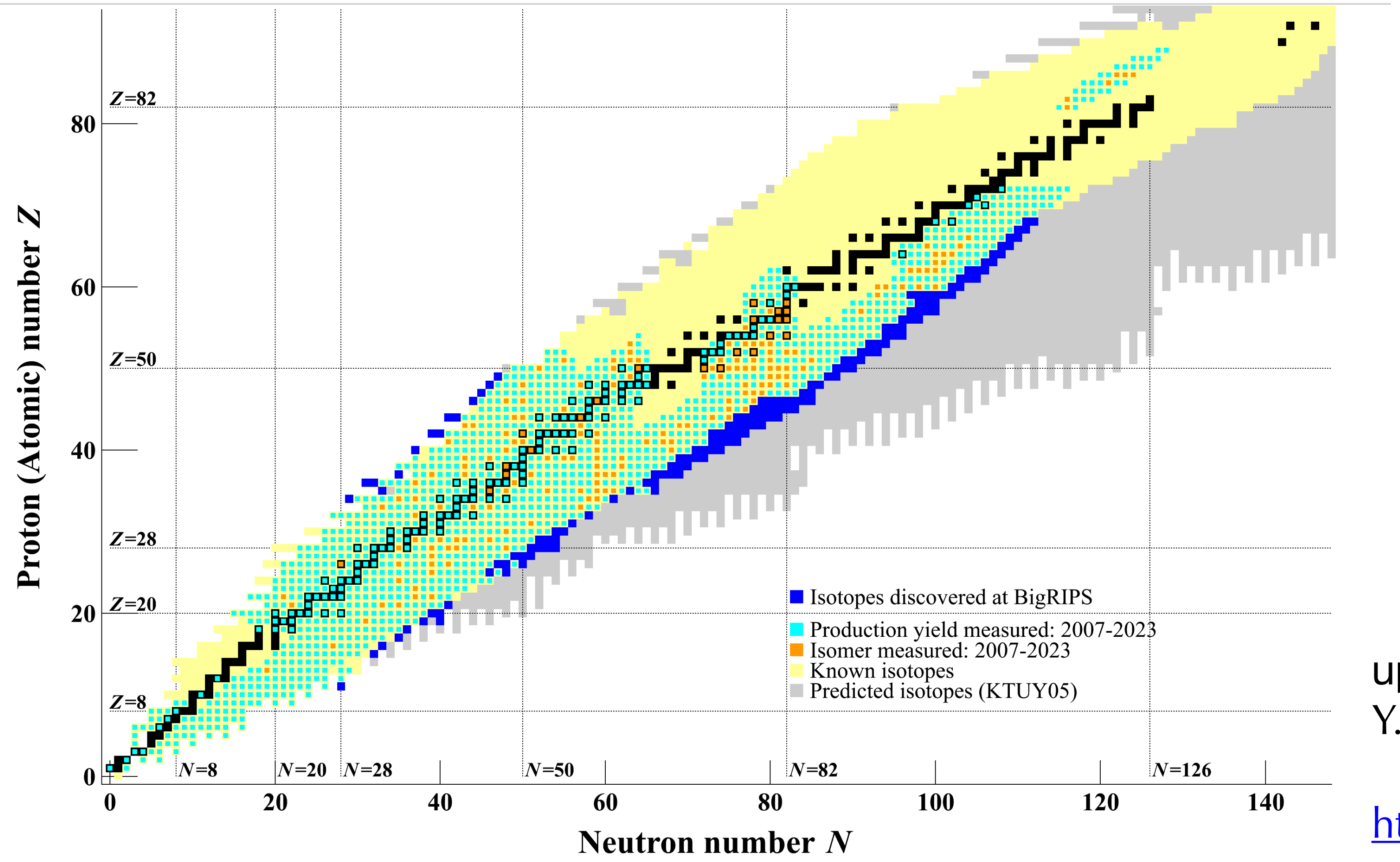
Beam energy: (230-) 345 *A* MeV

In-flight fission: ^{238}U + Be target

Fragmentation:

^{124}Xe, ^{78}Kr, ^{70}Zn, ^{48}Ca, ^{18}O +Be target

RI beams produced from May 2007 to 2023 @ BigRIPS



A large variety of radioactive ion beams

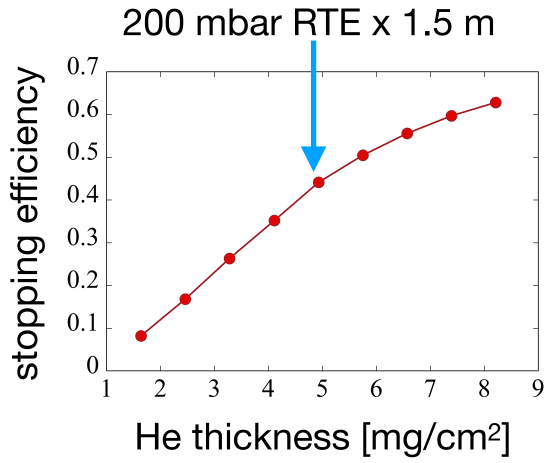
at ~ 300 *A* MeV

updated by Shimizu-san (BigRIPS team) from Y. Shimizu et al., NIM B **463**, 158 (2020)

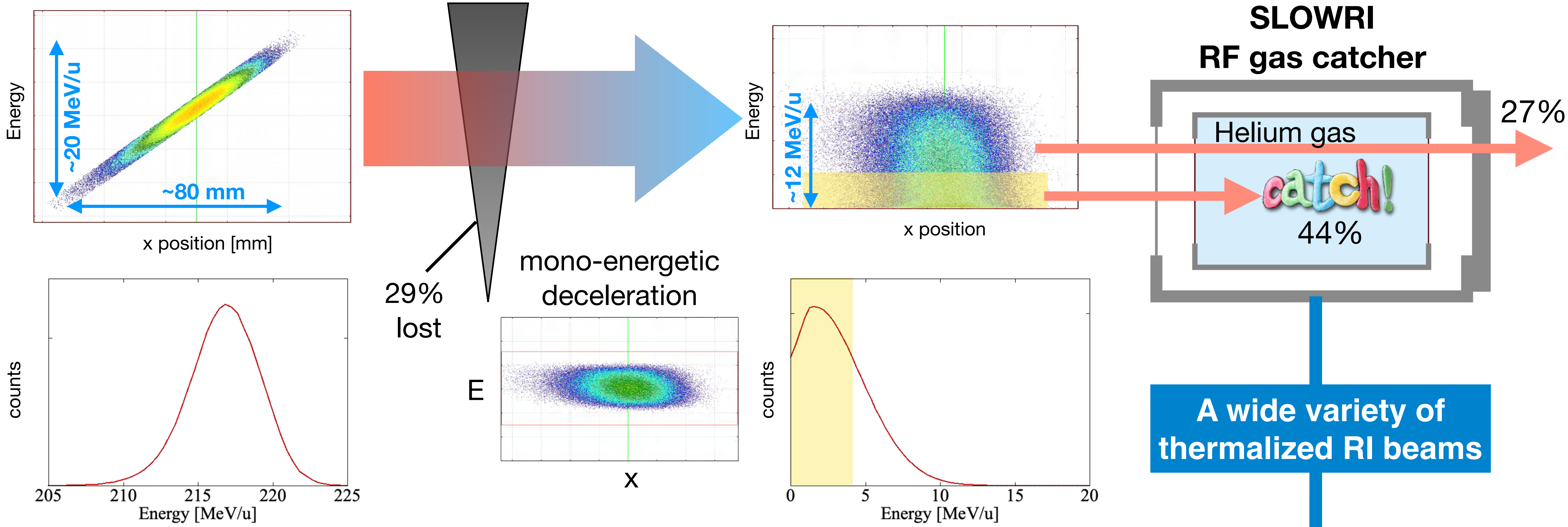
https://ribeam.riken.jp/welcome.php

Stopping BigRIPS beams

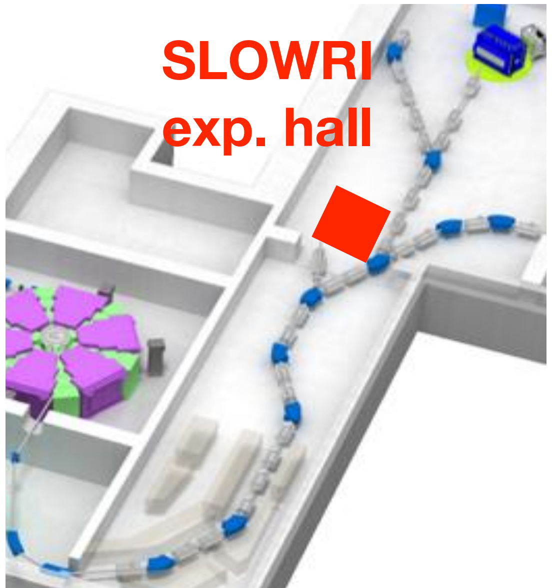
e.g. ^{124}Xe (342.5 MeV/u) + Be 3mm → ^{100}Sn case

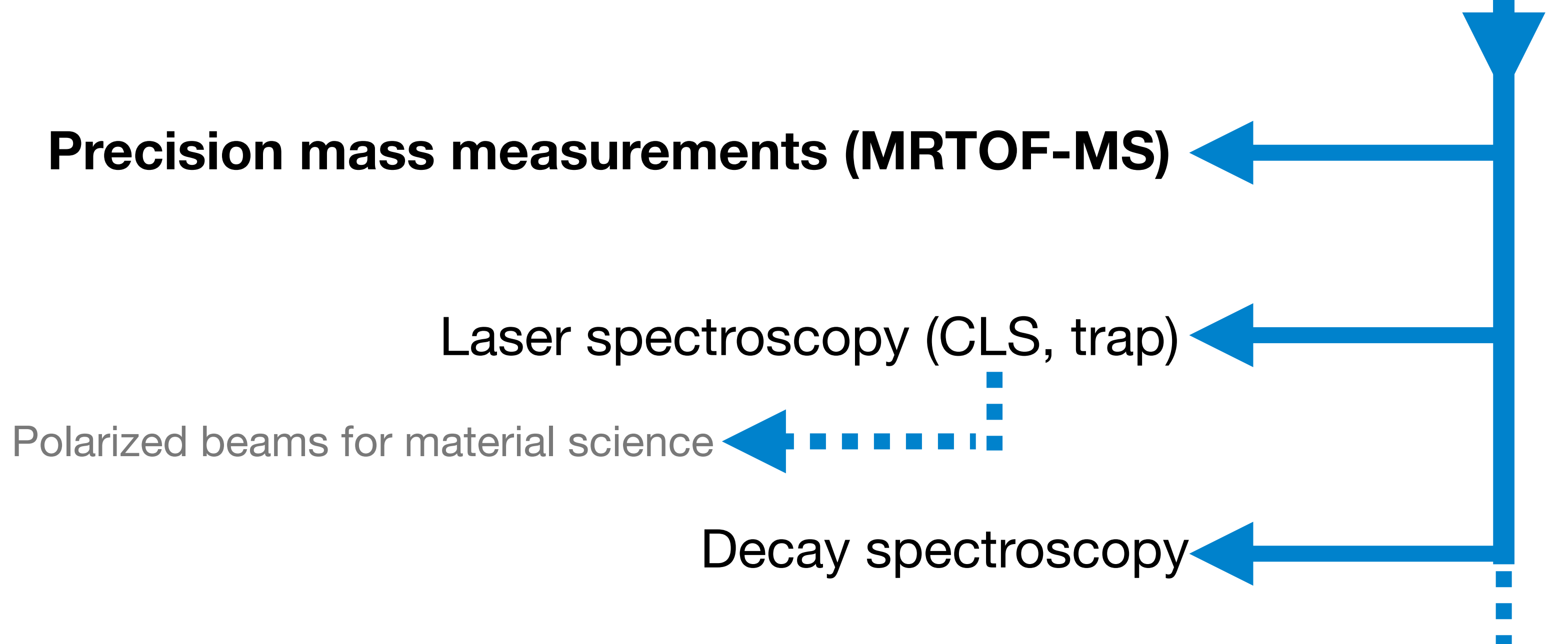


High energy RI beams
with momentum dispersion



A wide variety of thermalized RI beams





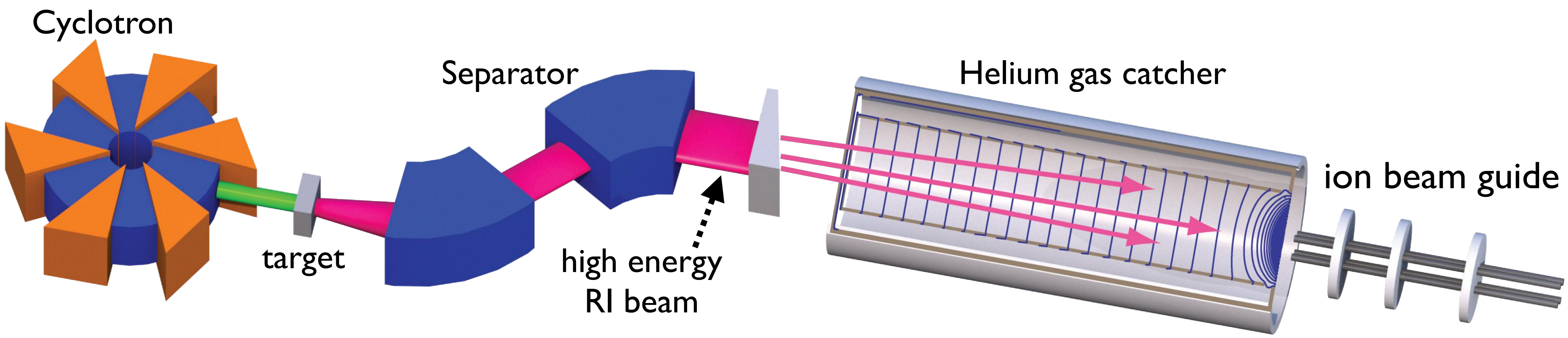
Precision mass measurements (MRTOF-MS)

Laser spectroscopy (CLS, trap)

Polarized beams for material science

Decay spectroscopy

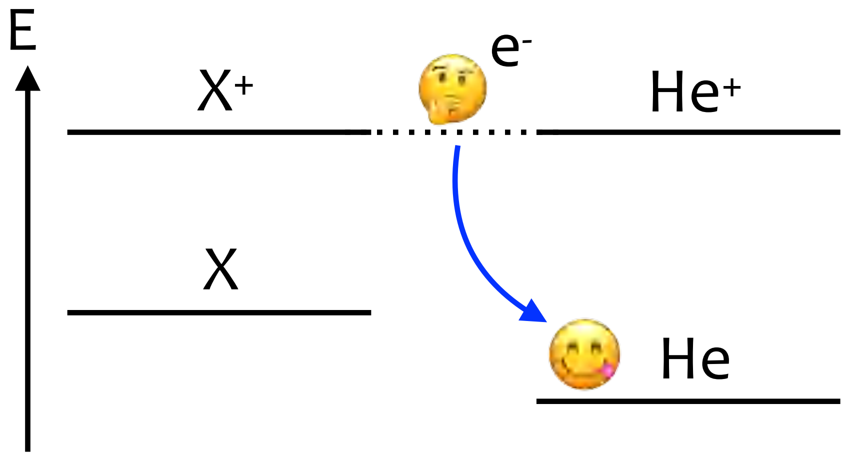
Principle of an RF gas catcher



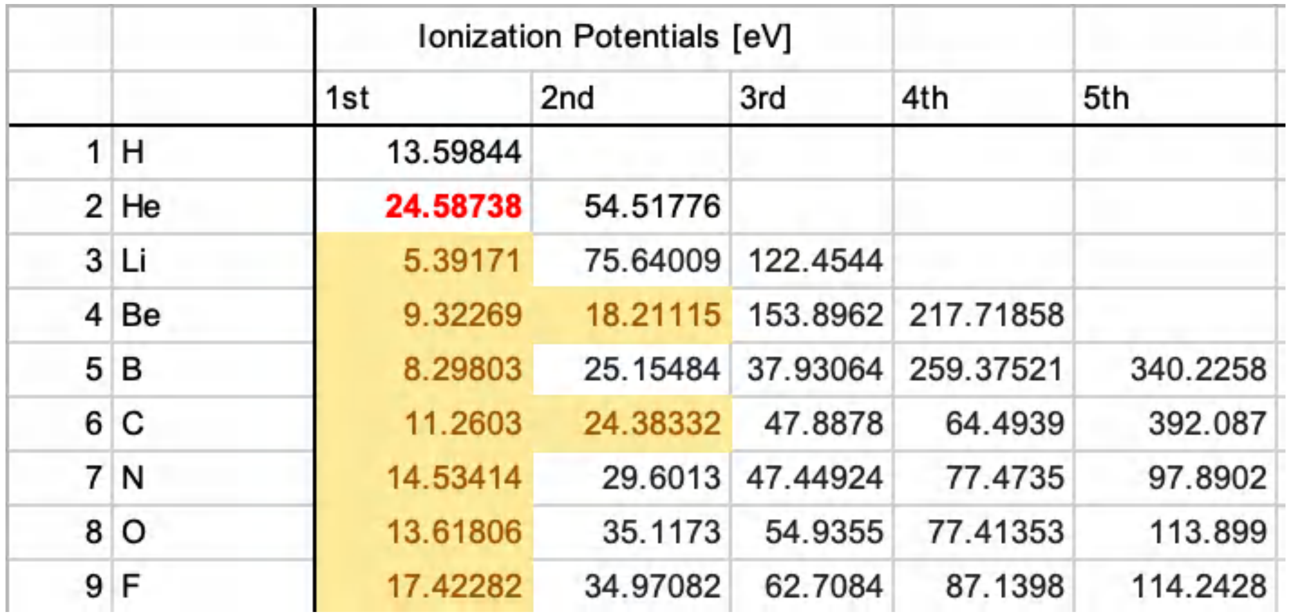
High energy RI beams are …

1. Stopped in He (~0.1 bar)
2. Settled down to charged states (1+, 2+, 3+)

because the 1st ionization potential of helium is higher than any other elements



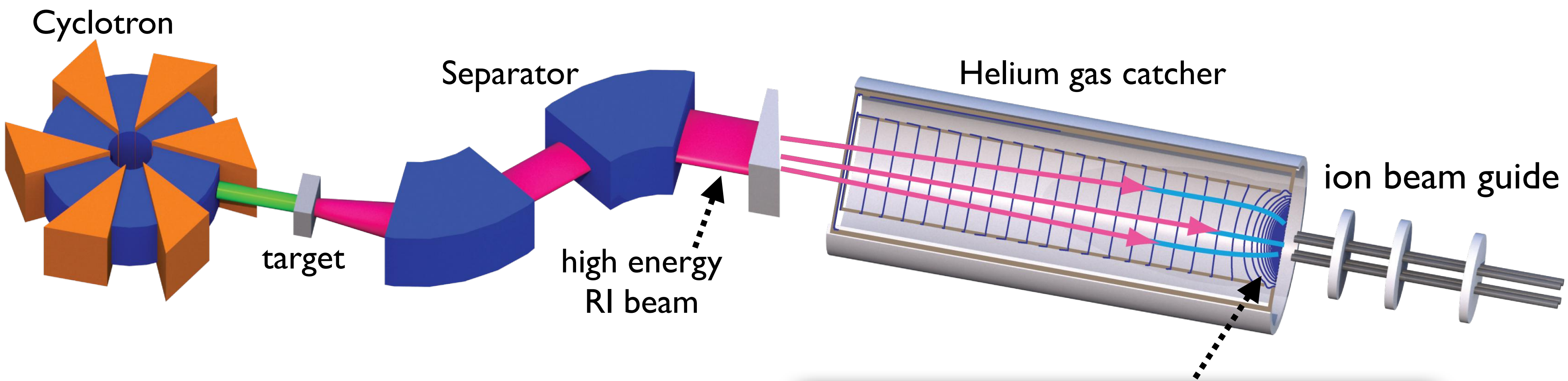
Save more energy
if electrons recombine with He^+.



		Ionization Potentials [eV]				
		1st	2nd	3rd	4th	5th
1	H	13.59844				
2	He	**24.58738**	54.51776			
3	Li	5.39171	75.64009	122.4544		
4	Be	9.32269	18.21115	153.8962	217.71858	
5	B	8.29803	25.15484	37.93064	259.37521	340.2258
6	C	11.2603	24.38332	47.8878	64.4939	392.087
7	N	14.53414	29.6013	47.44924	77.4735	97.8902
8	O	13.61806	35.1173	54.9355	77.41353	113.899
9	F	17.42282	34.97082	62.7084	87.1398	114.2428

➡ RI ions can be manipulated by electric fields.

Principle of an RF gas catcher



High energy RI beams are …

1. Stopped in He (~0.1 bar)
2. Settled down to charged states

In a dense gas, ions move along electric field lines.

$$m\frac{d}{dt}\vec{v} = q\overrightarrow{E} - mD\vec{v}$$

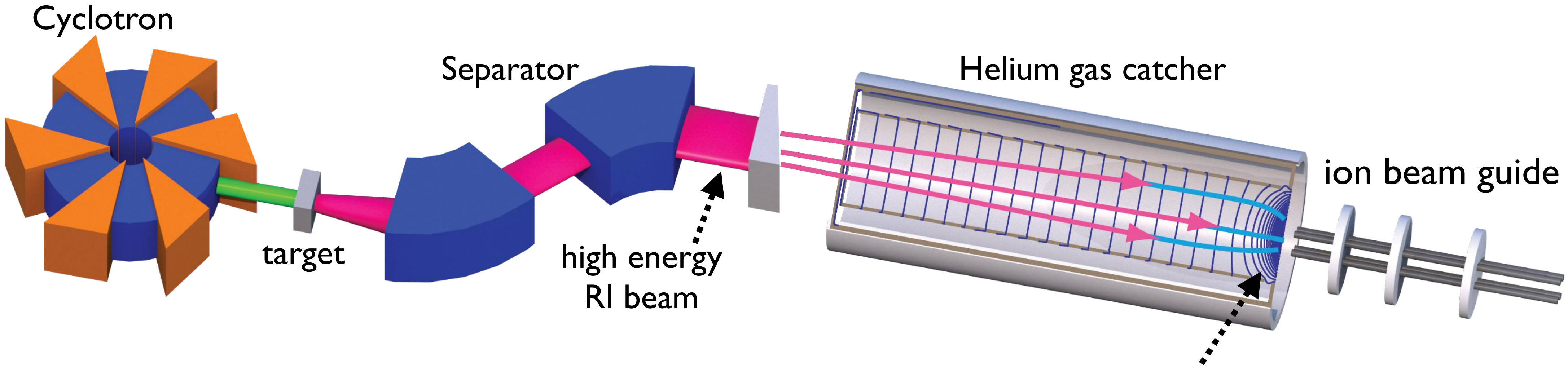
$$\Rightarrow \vec{v} \approx \frac{q}{mD}\overrightarrow{E}$$

➡ Ions stick to the cathode! 😭

$\because$ Any cathode is the terminal point of all electric field lines.

equipotential lines

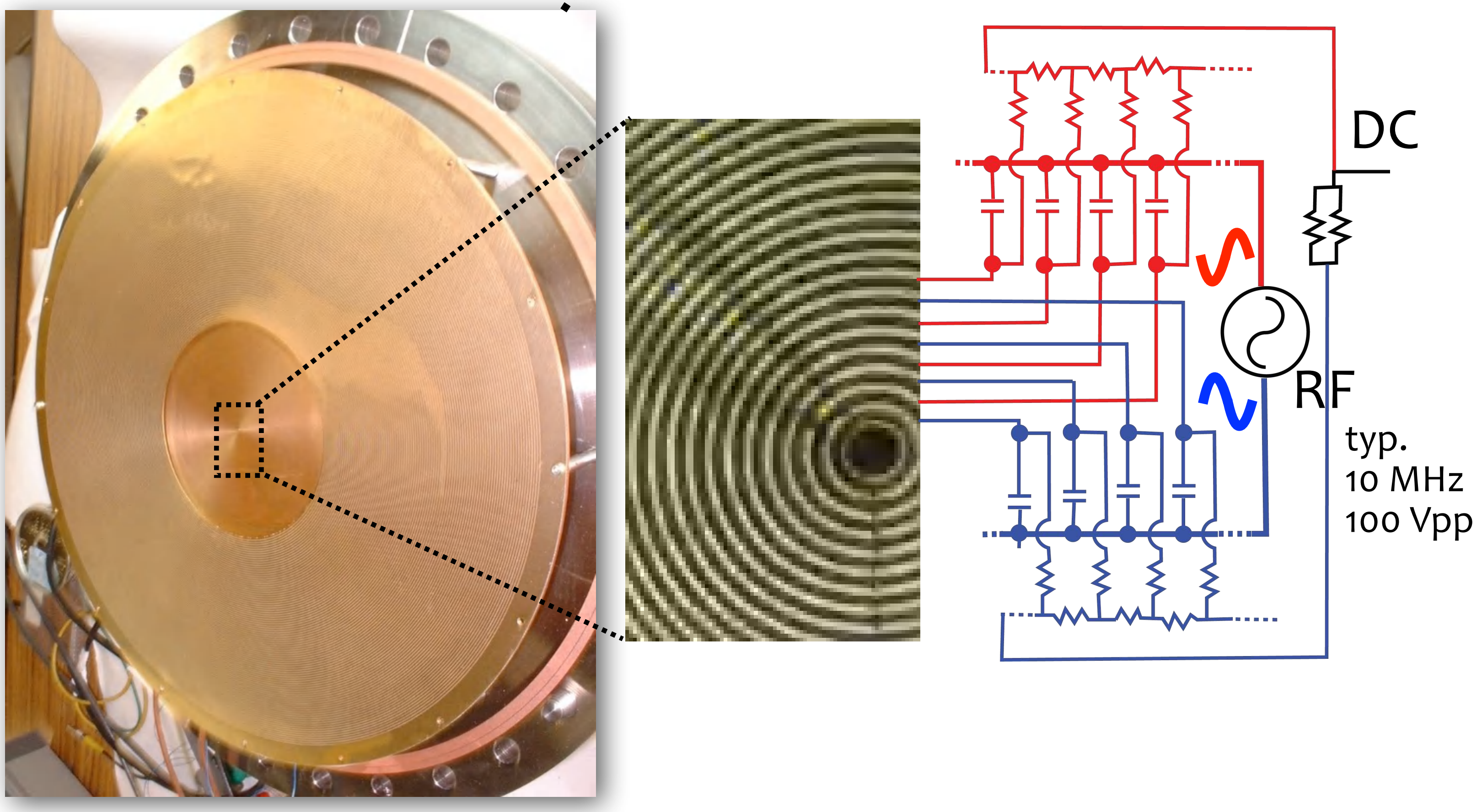
Principle of an RF gas catcher



High energy RI beams are …

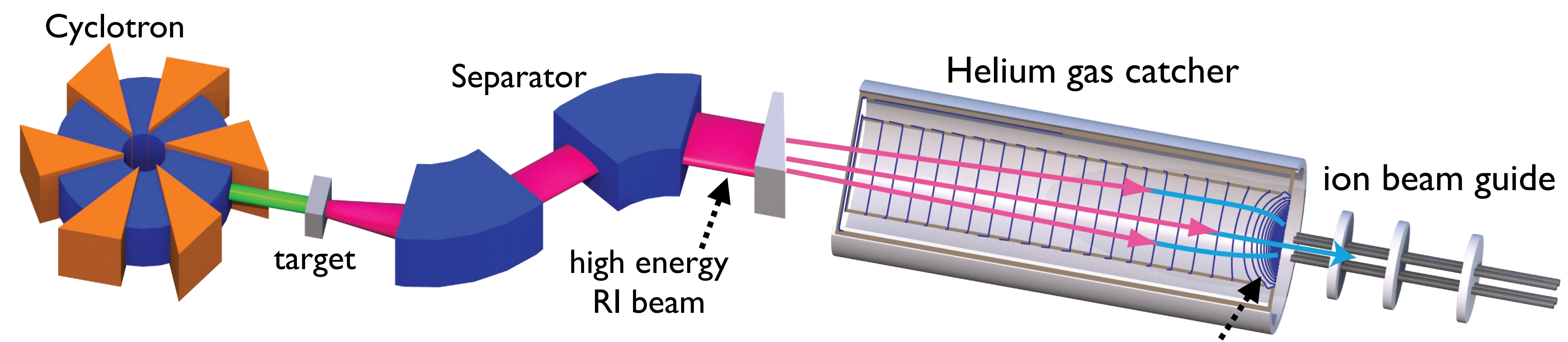
1. Stopped in He (~0.1 bar)
2. Settled down to charged states

We use a magical cathode electrode called "RF carpet" !



M. Wada

Principle of an RF gas catcher



High energy RI beams are …

1. Stopped in He (~0.1 bar)
2. Settled down to charged states
3. Extracted by DC & RF fields (efficiency ～30%)

RF repulsive force

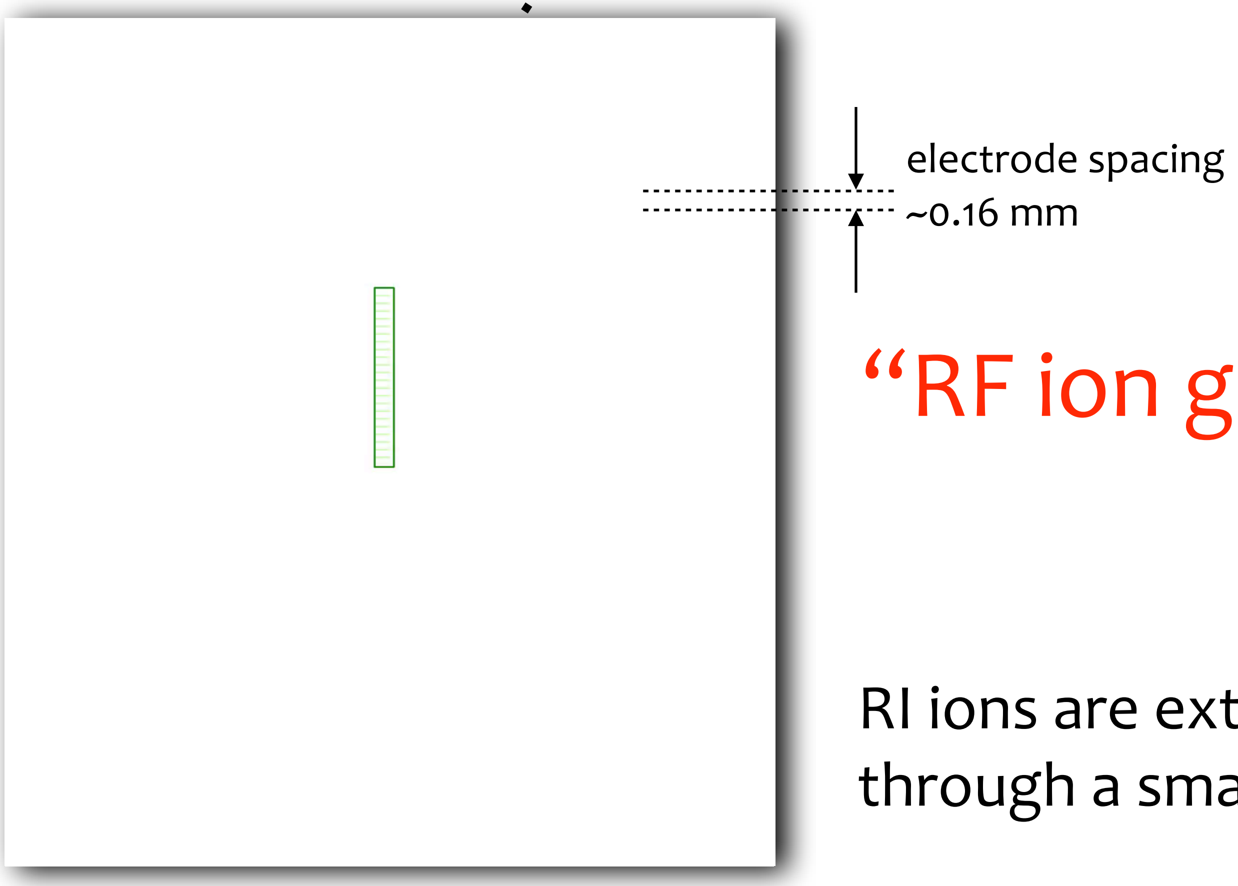
$$U_{\mathrm{eff}}(y) = = \frac{\pi^2 Q^2 V^2}{4m(\omega^2 + D^2)a^2} \exp\left(-\frac{2\pi}{a} y\right)$$

$$\Rightarrow E_{\mathrm{eff}}(y) = -\frac{1}{Q} \nabla U_{\mathrm{eff}} y$$

$$= \mu \frac{m}{Q} \frac{\pi^3 V^2}{2a^3} \exp\left(-\frac{2\pi}{a} y\right)$$

μ : ion's mobility
a : electrode spacing

- advantageous to heavier elements
- challenging for higher gas pressure

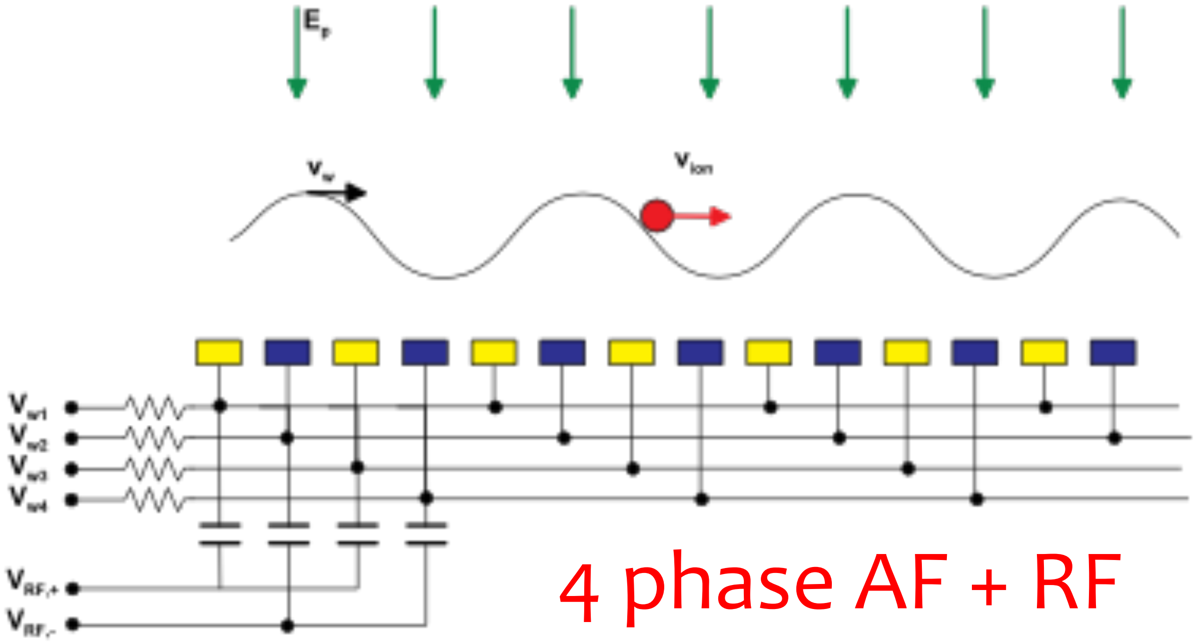


“RF ion guide”

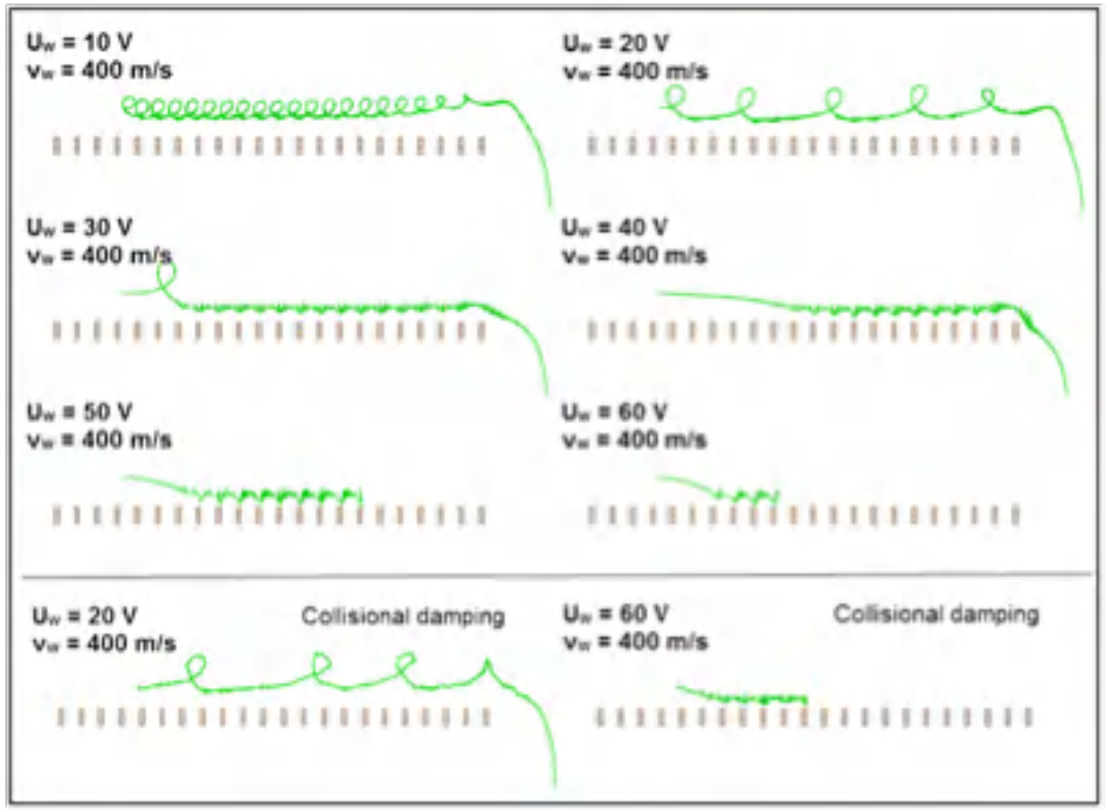
RI ions are extracted through a small hole.

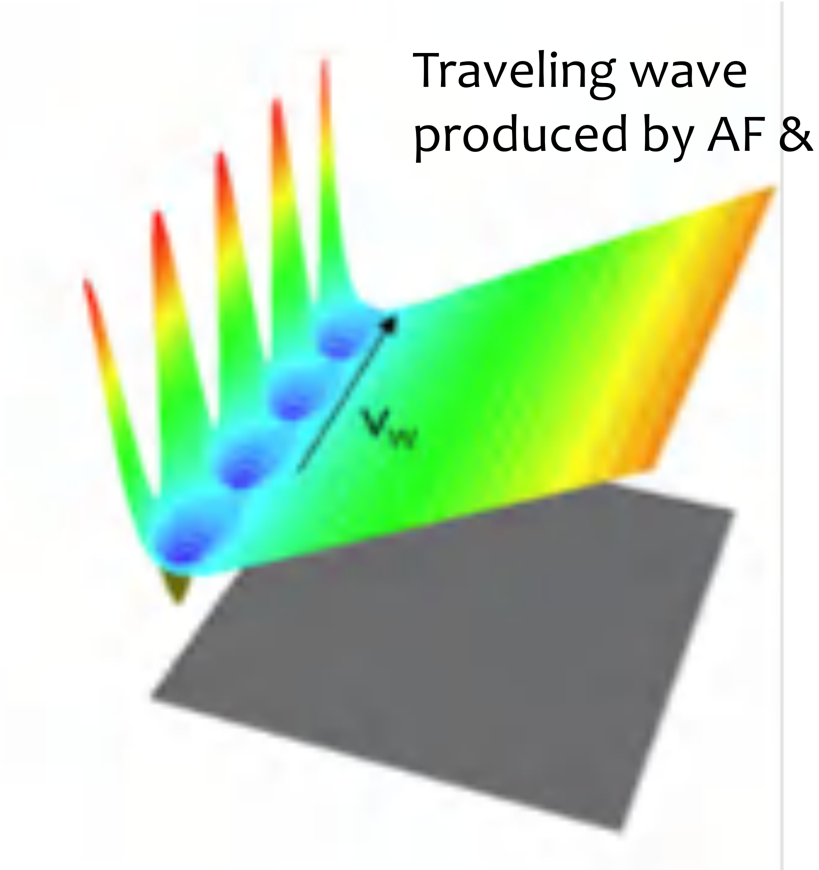
M. Wada *et al.*, NIMB **203**, 570 (2003)
A. Takamine *et al.*, RSI **76**, 103503 (2005)

Alternative technique ~ion surfing~



4 phase AF + RF



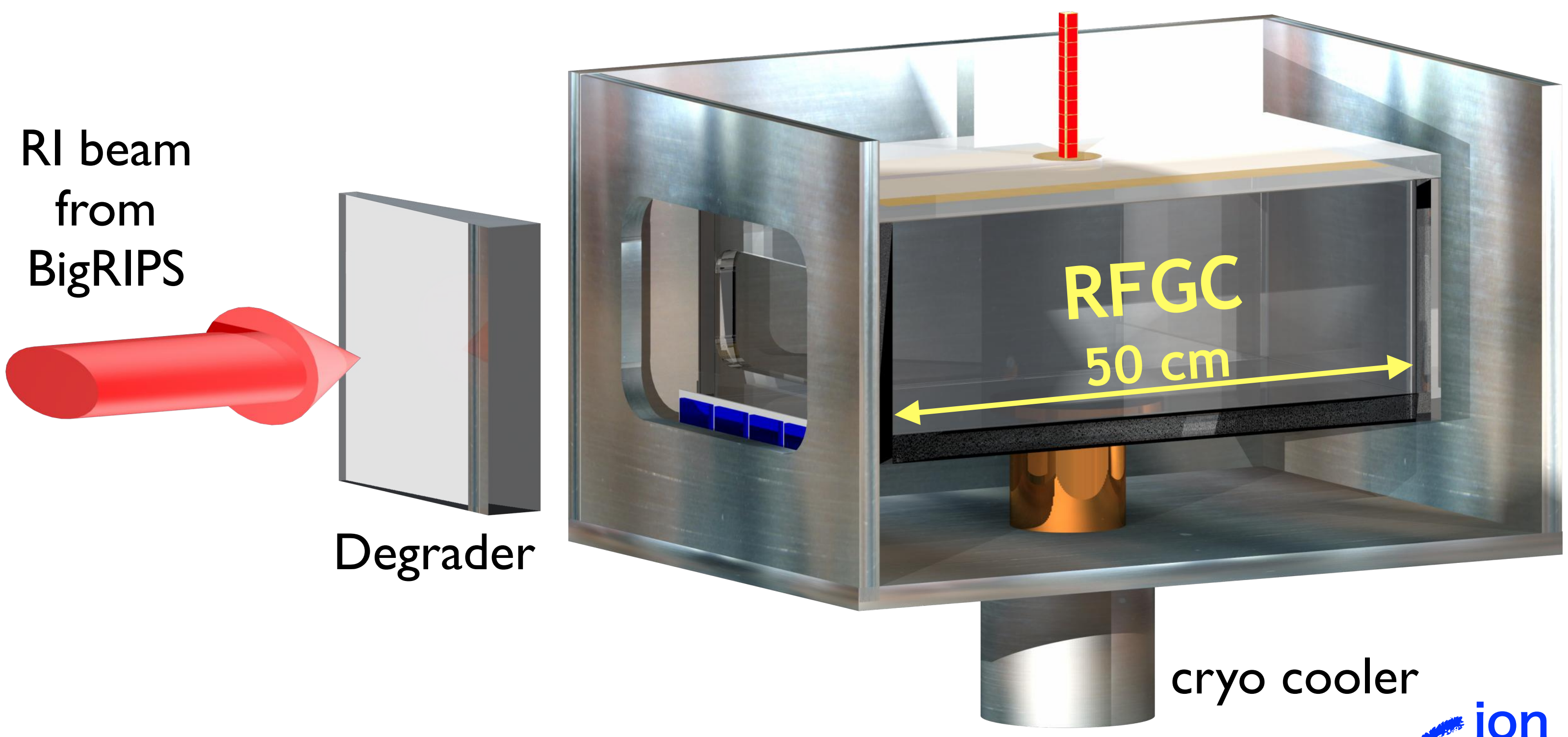


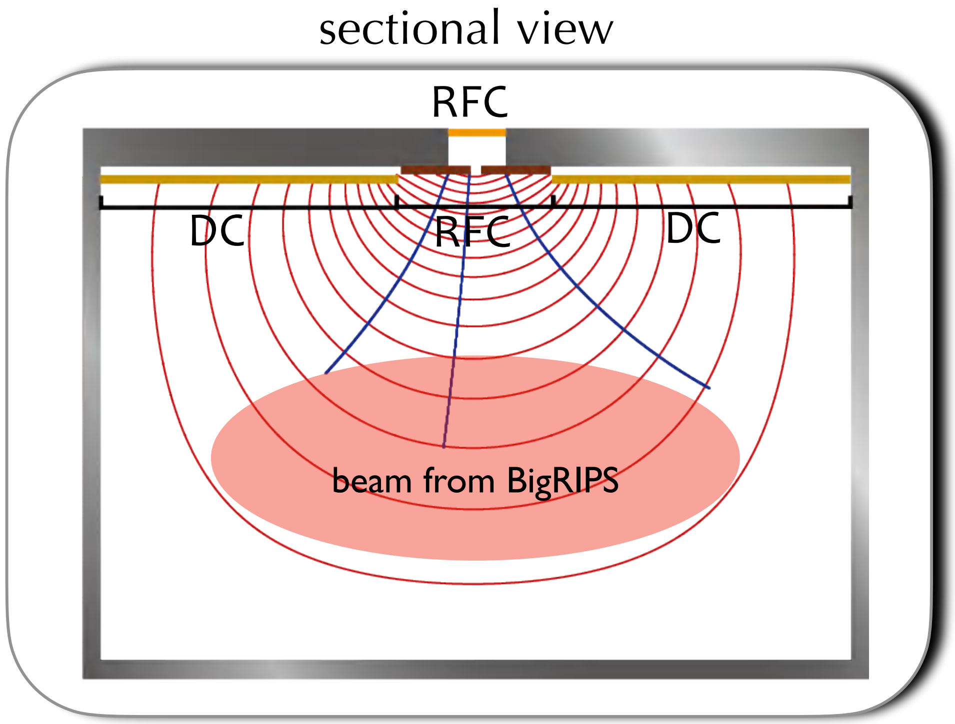
Traveling wave
produced by AF & RF fields.

If you lock ions to the traveling wave,
you can very quickly transport and extract ions.

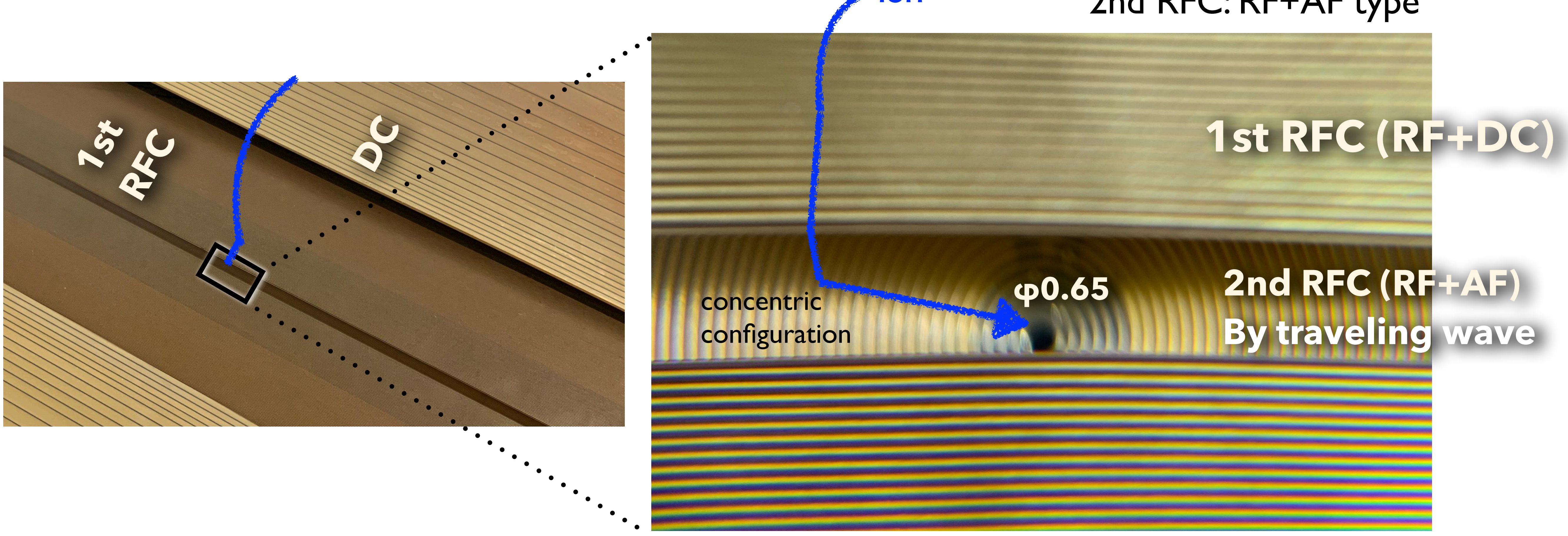
S. Masuda *et al.*, Elect. Eng. Jpn. **92,** 43 (1972).
G. Bollen, IJMS **299**, 131 (2011)

New configuration gas catcher



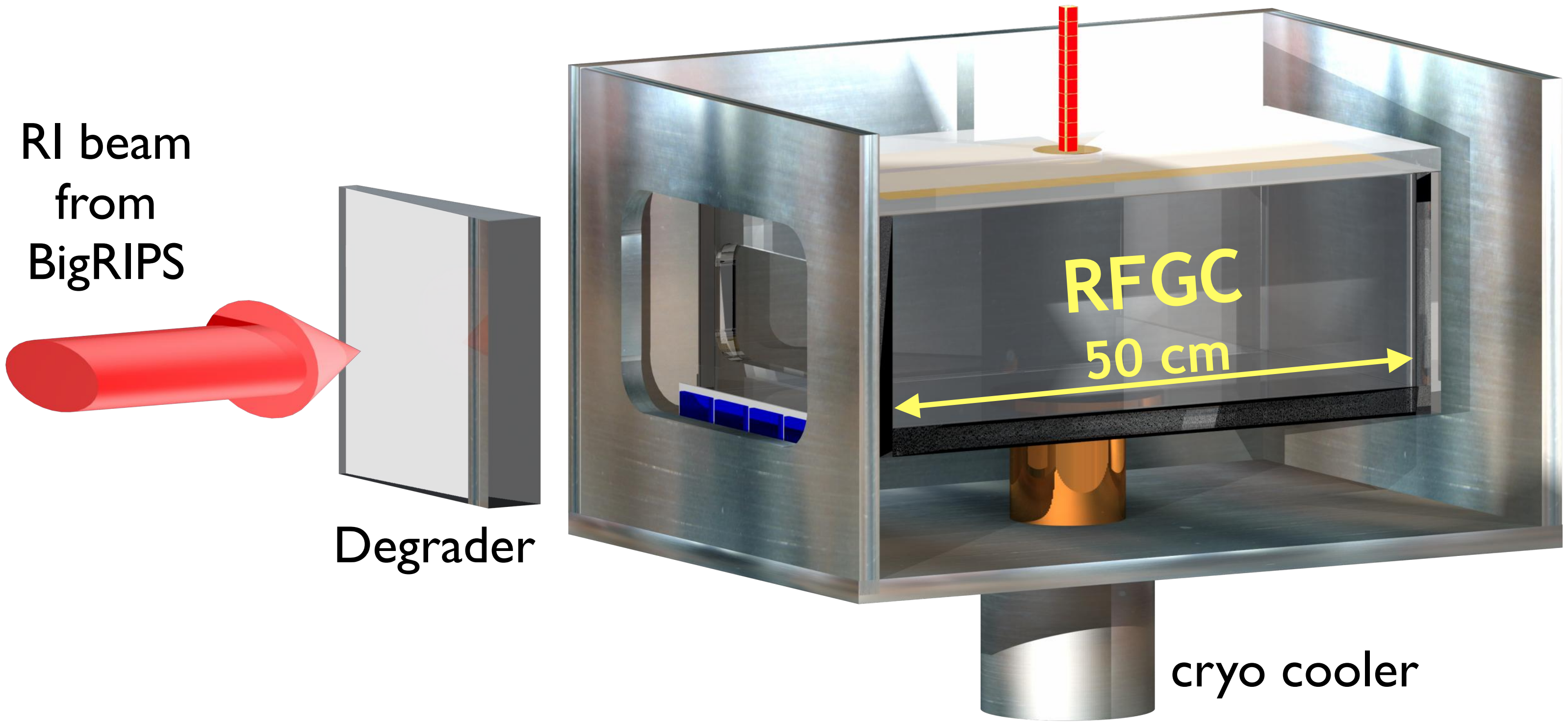


2nd RFC: RF+AF type

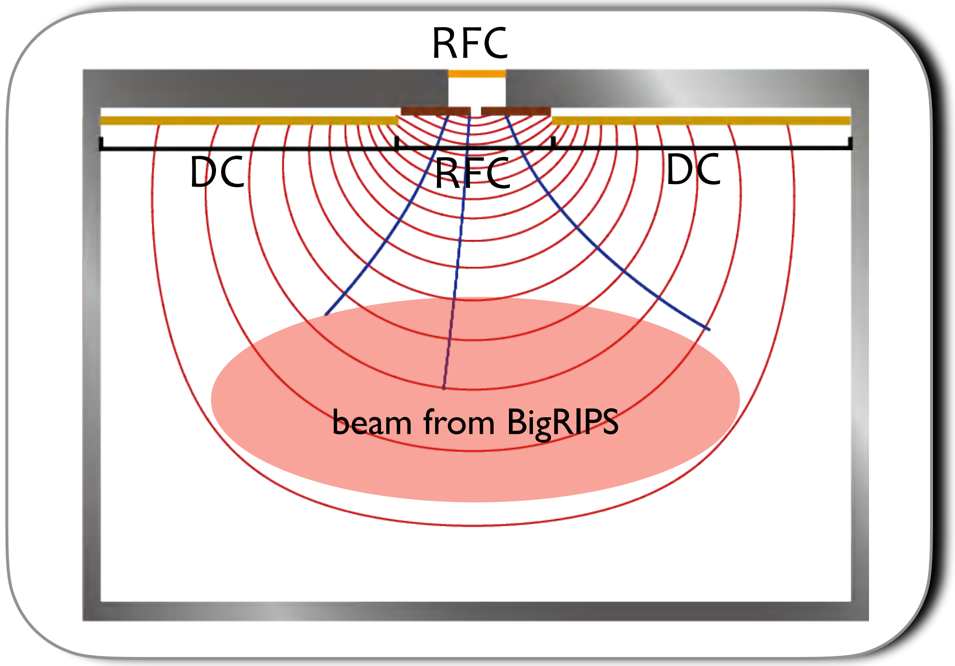


Quick transport over a long distance

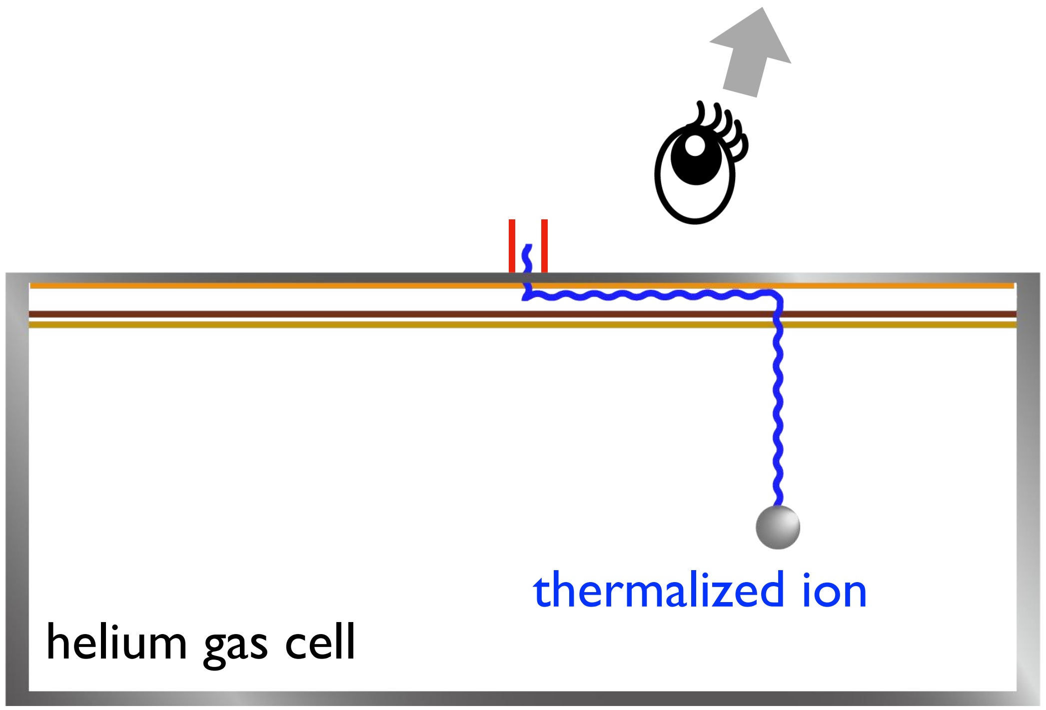
New configuration gas catcher

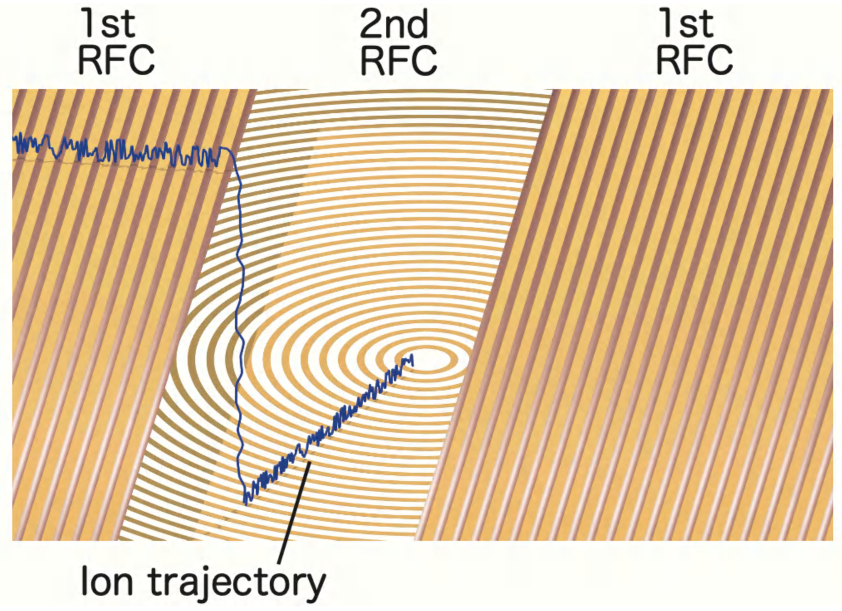


sectional view



2nd RFC: RF+AF type





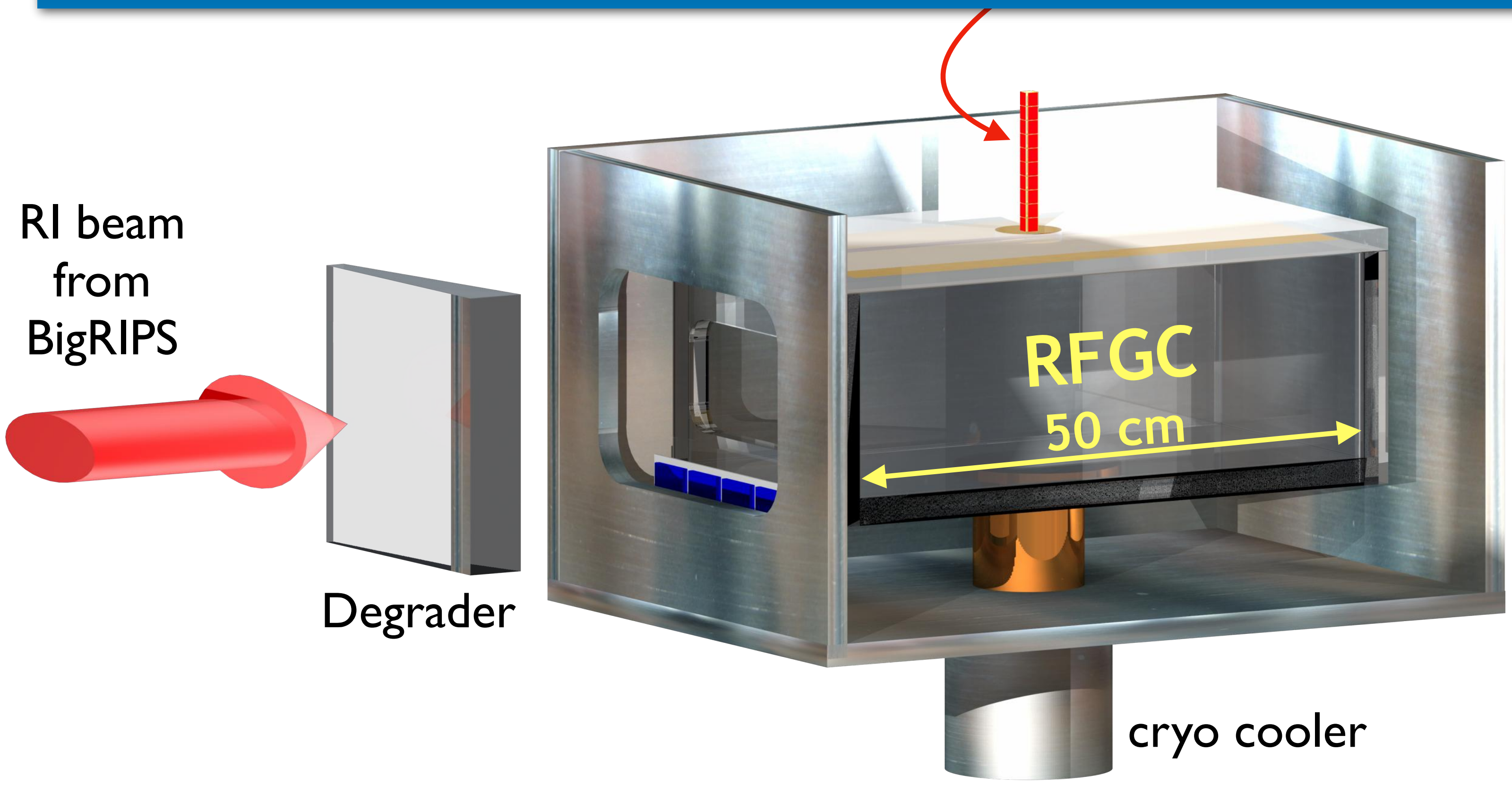
1st RFC: RF+DC

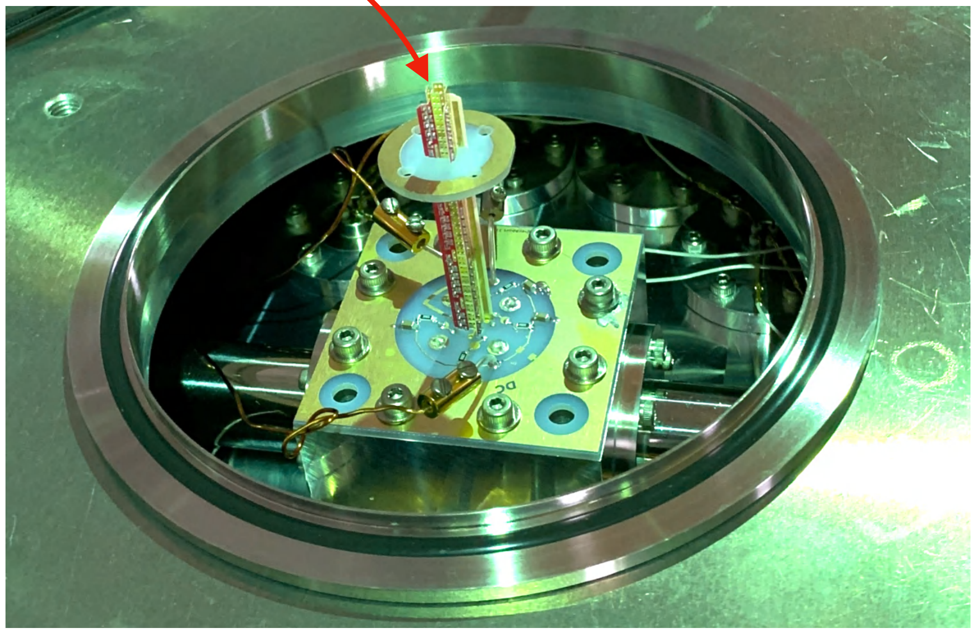
M. Wada et al., NIMB **203**, 570 (2003)

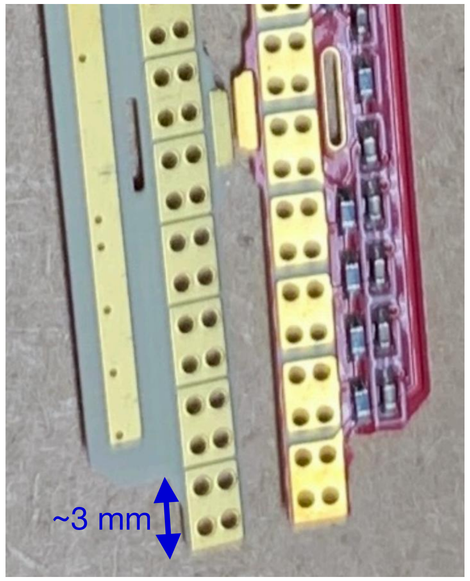
2nd RFC: RF+AF; ‘traveling wave’

S. Masuda et al., Elect. Eng. Jpn. **92**, 43 (1972)
G. Bollen, IJMS **299**, 131 (2011)

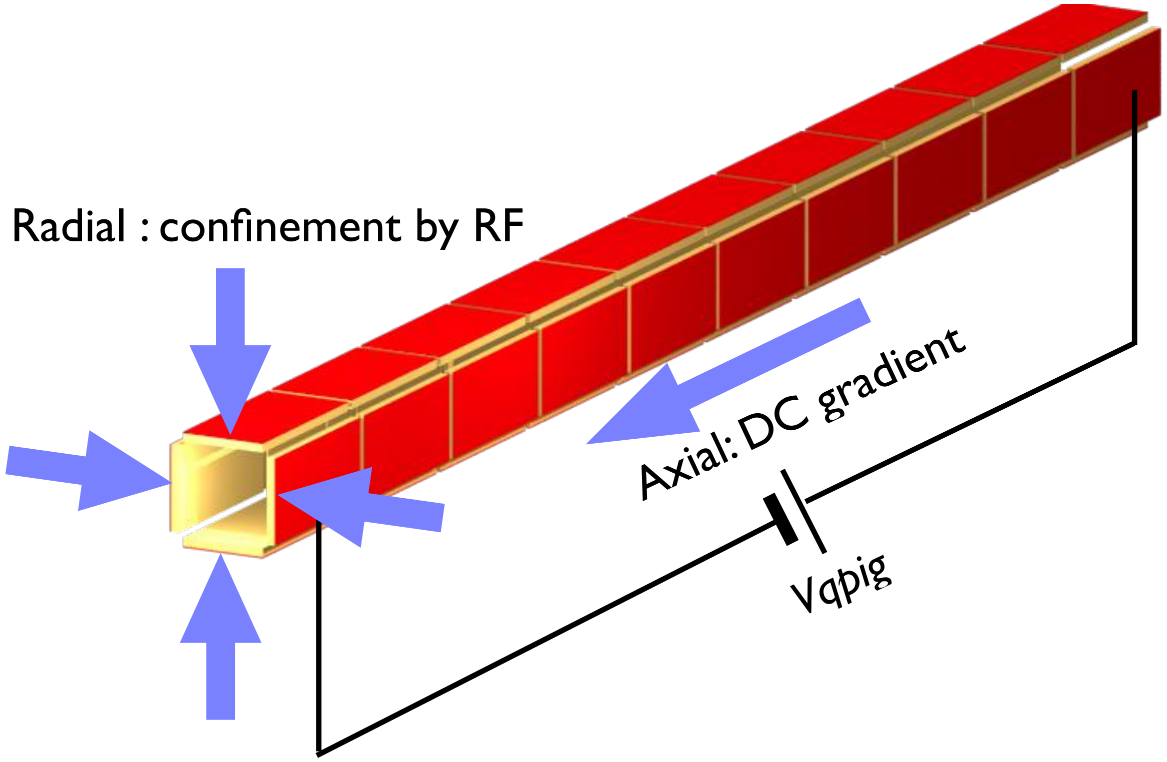
Micro-segmented quadrupole ion beam guide (μs-qpig)

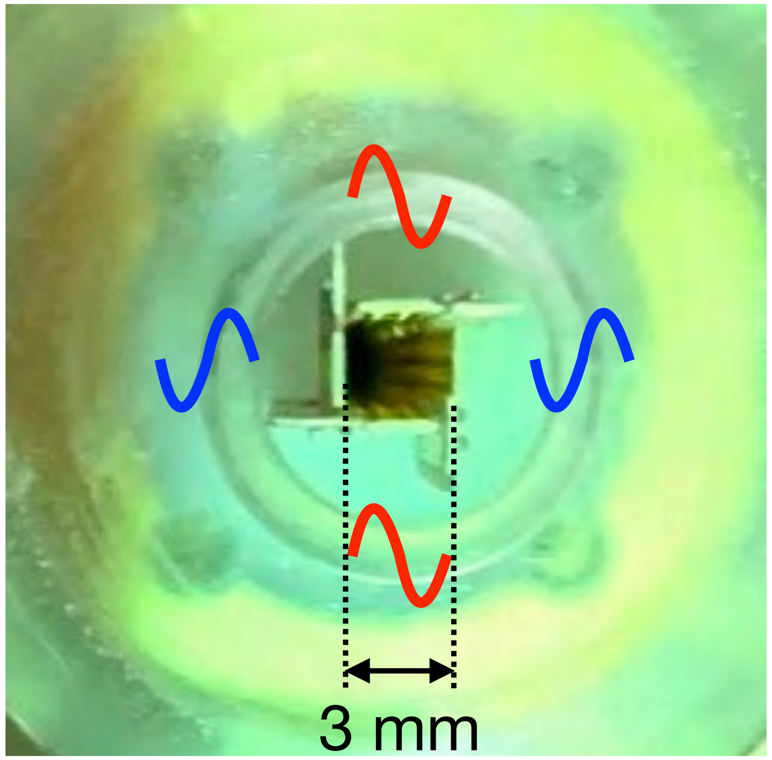




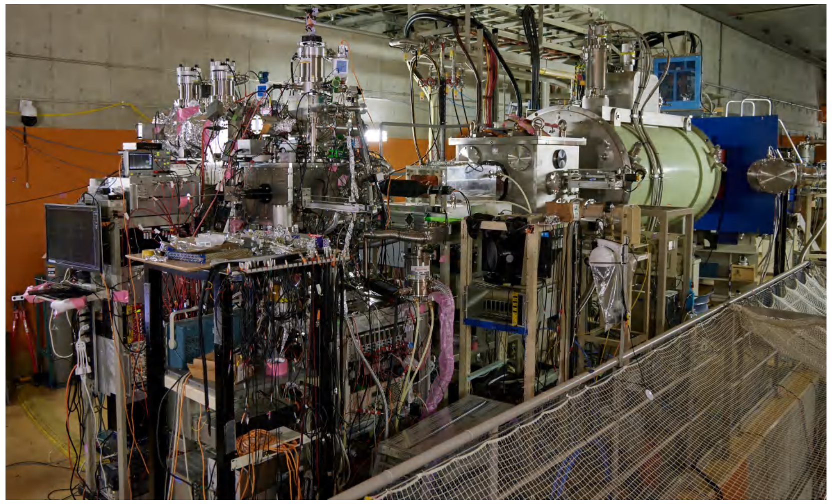


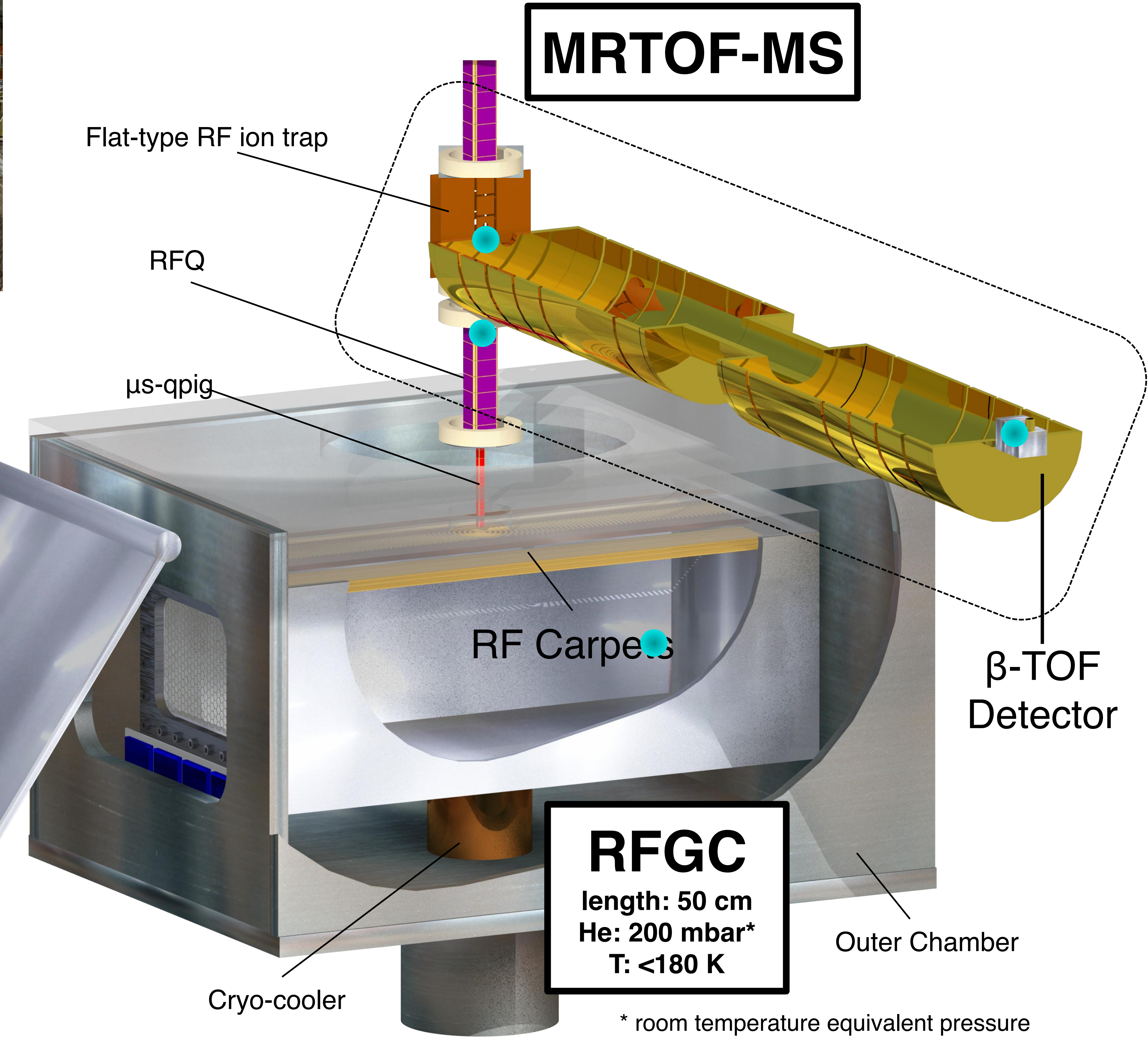
manufactured with
Rogers 4350B





ZD MRTOF-MS: RFGC + MRTOF-MS behind ZD spectrometer





RFGC

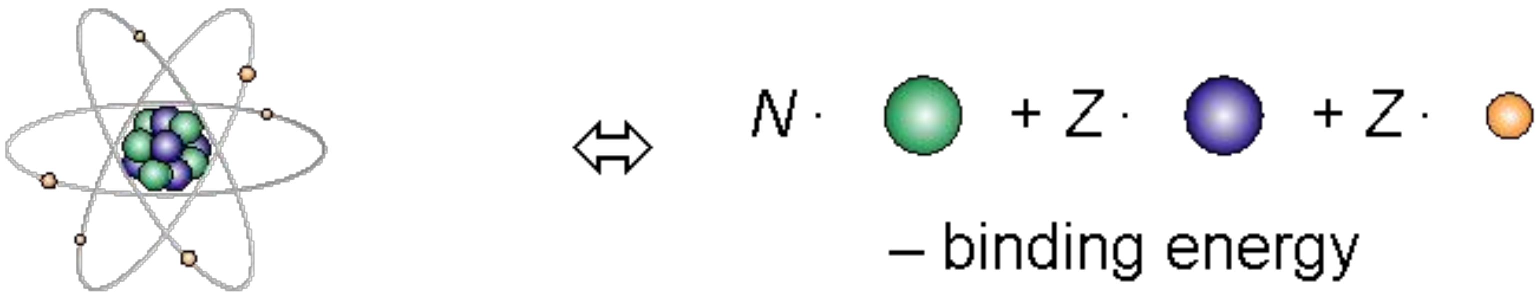
length: 50 cm
He: 200 mbar*
T: <180 K

* room temperature equivalent pressure

Contents

- Very basics of RF traps (Paul trap)
- How to convert high energy RI beams to ultra-slow RI beams?
- **How to precisely measure masses of exotic nuclei?**

Atomic masses

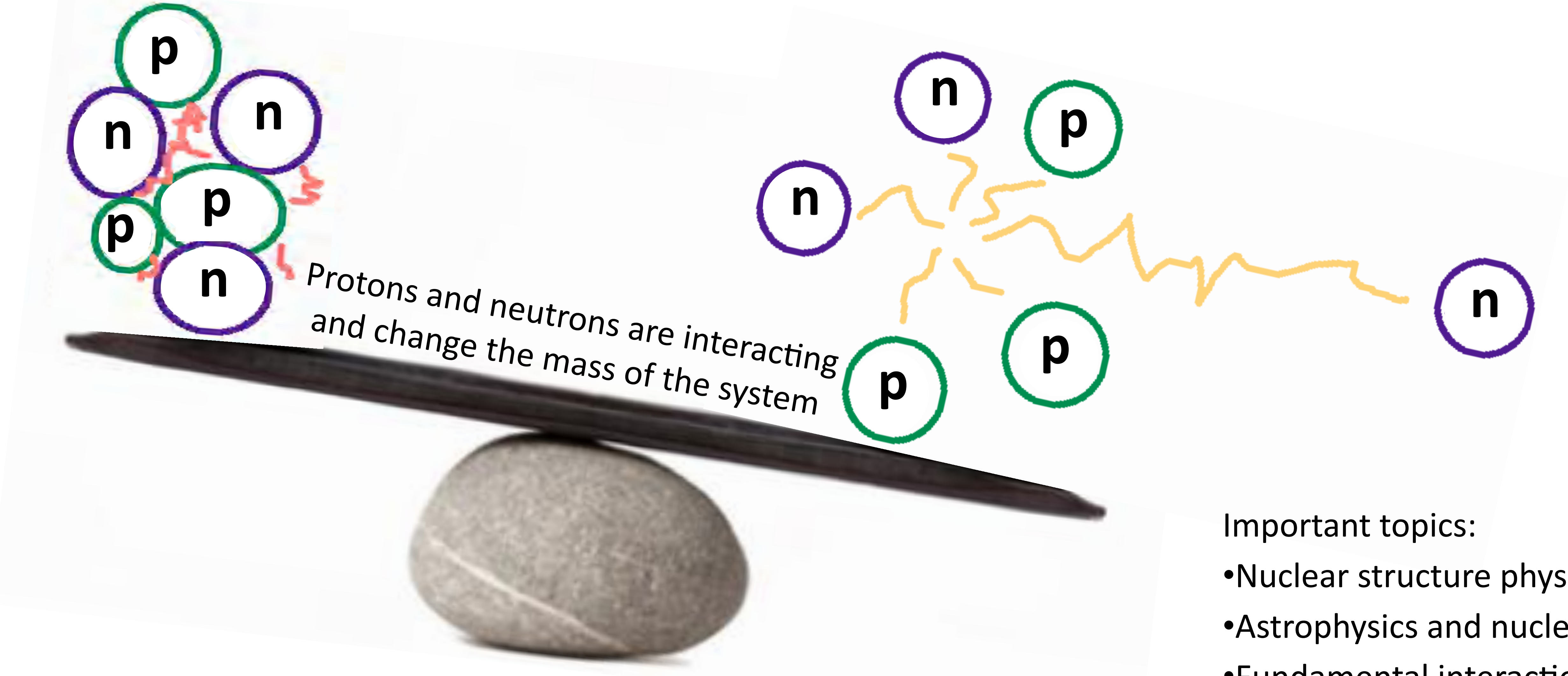


⇔ $N \cdot$ ● $+ Z \cdot$ ● $+ Z \cdot$ ●

– binding energy

$$BE(N,Z) = (Nm_n + Zm_p + Zm_e - m(N,Z)) \cdot c^2$$

- **Binding energy → sum of all interactions**
- **We can learn about the inner forces through the mass**

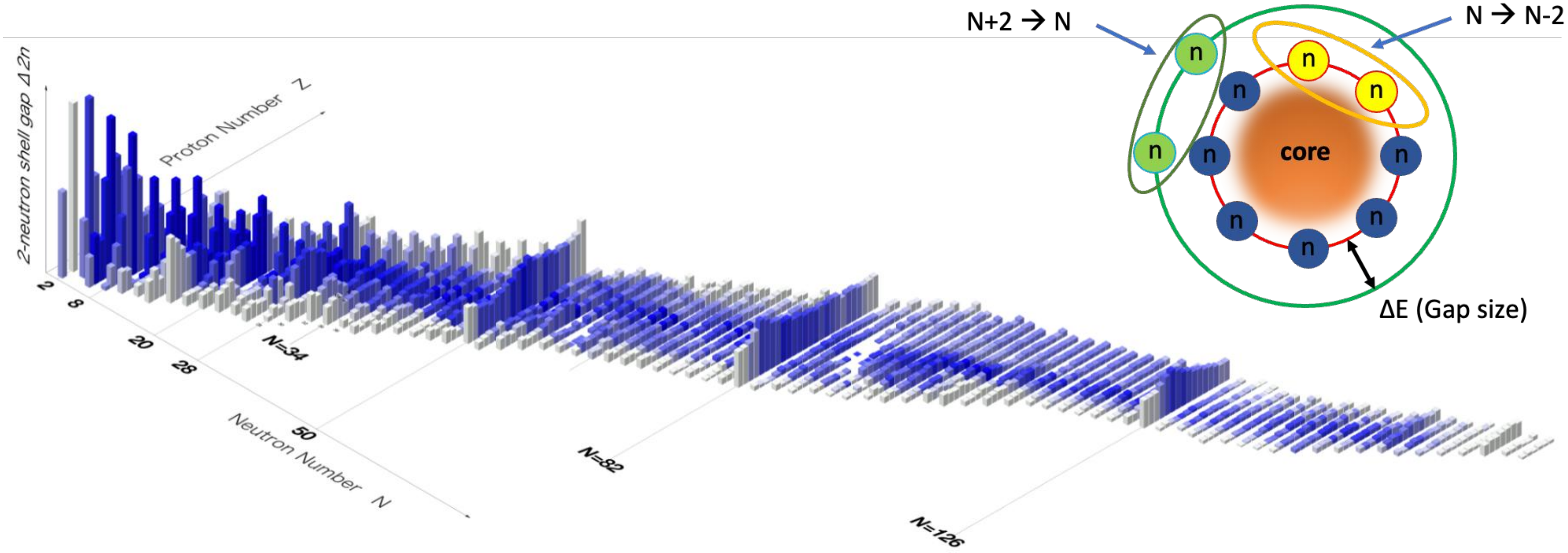


Protons and neutrons are interacting and change the mass of the system

Important topics:

- Nuclear structure physics
- Astrophysics and nucleosynthesis
- Fundamental interactions

Masses for nuclear structure



Two-nucleon separation energies

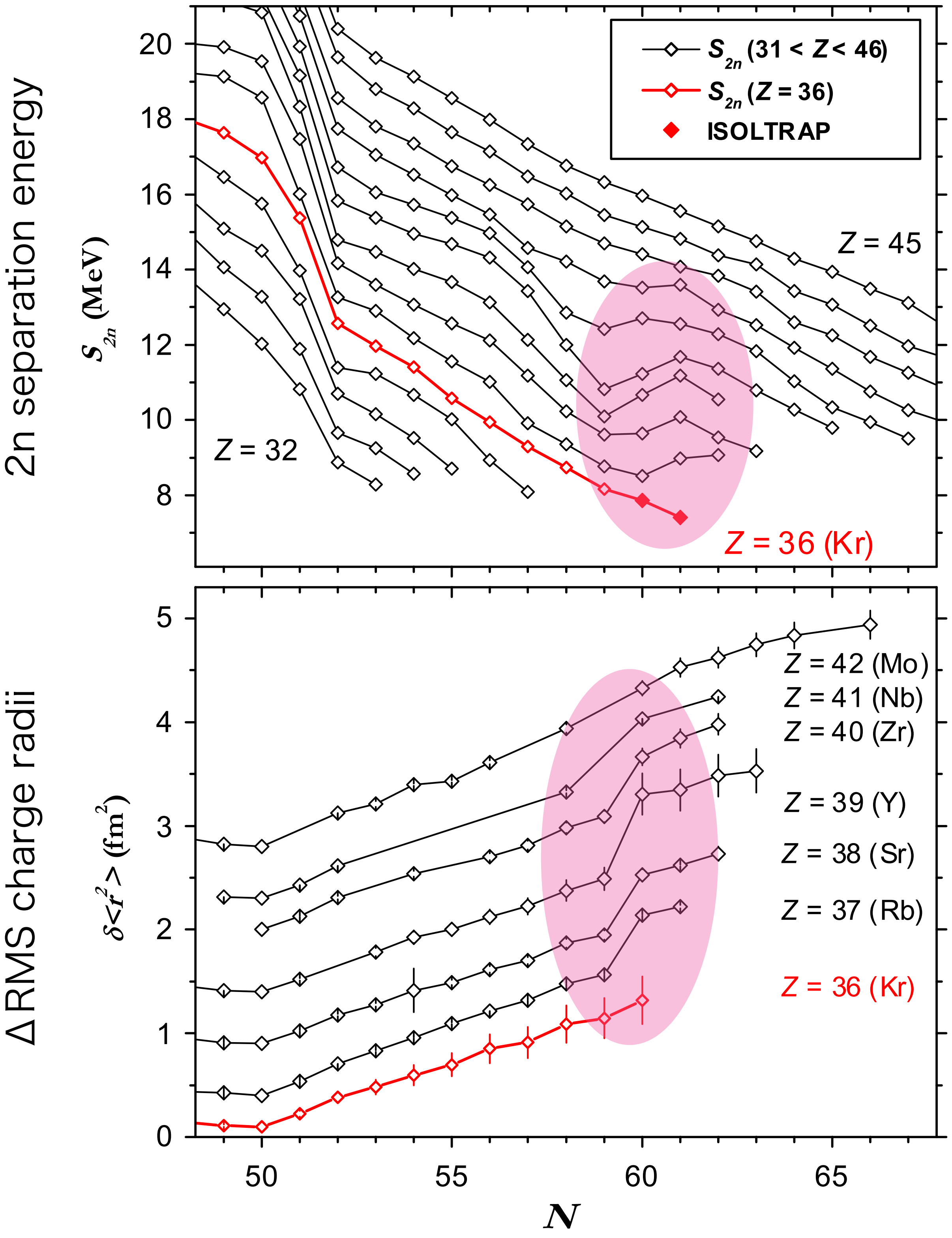
$$S_{2n}(Z,N) = m(Z,N-2) - m(Z,N) + 2m_n$$

Empirical shell gaps

$$\delta_{2n}(Z,N) = S_{2n}(Z,N) - S_{2n}(Z,N+2)$$

Nuclear structure by finite difference formulae

Masses for nuclear structure



2n separation energy is increased by

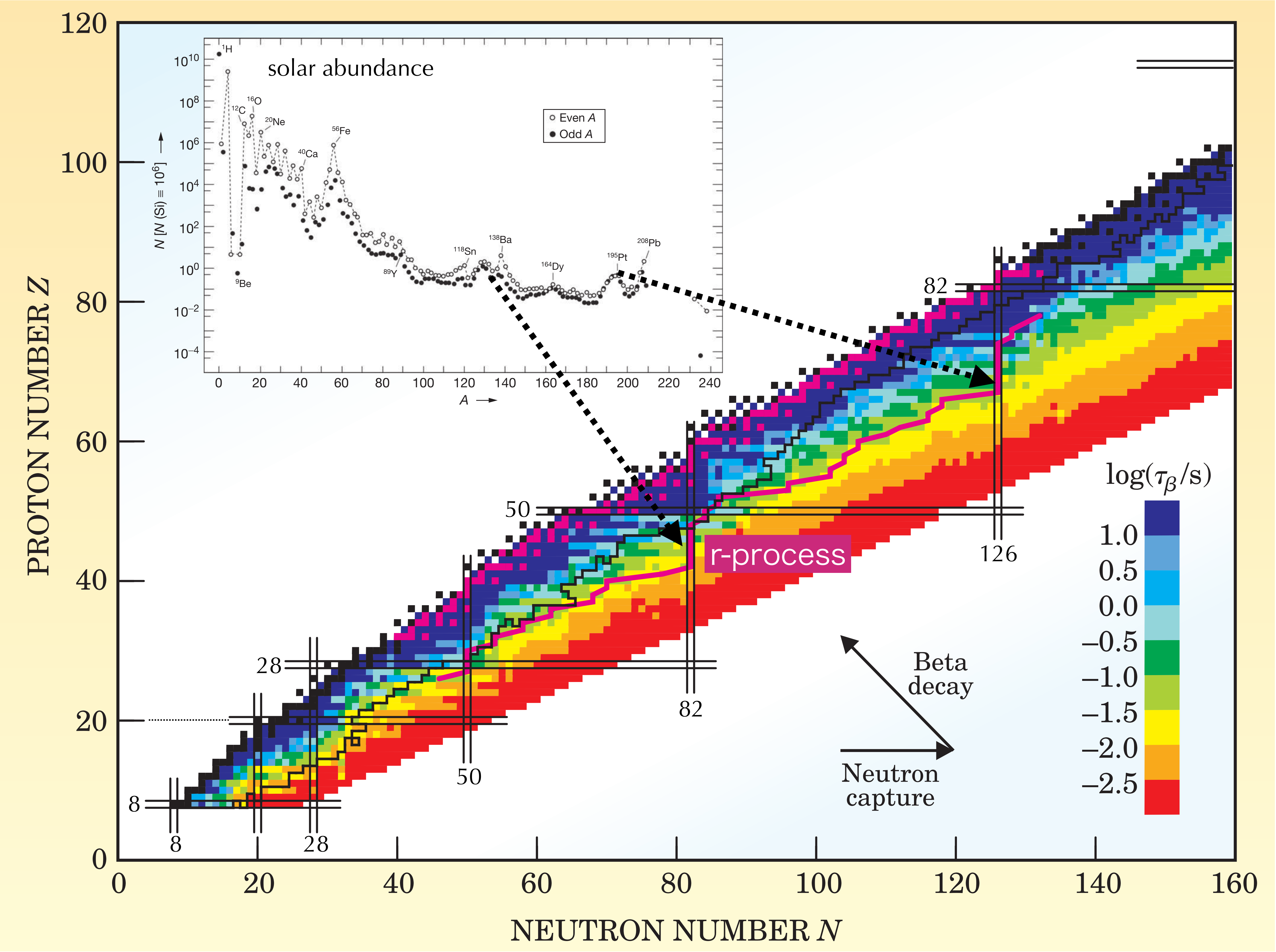
- closed shell or
- nuclear deformation (shape transition)

Z=37- 41: kink at N~60
Z=36: smooth trend

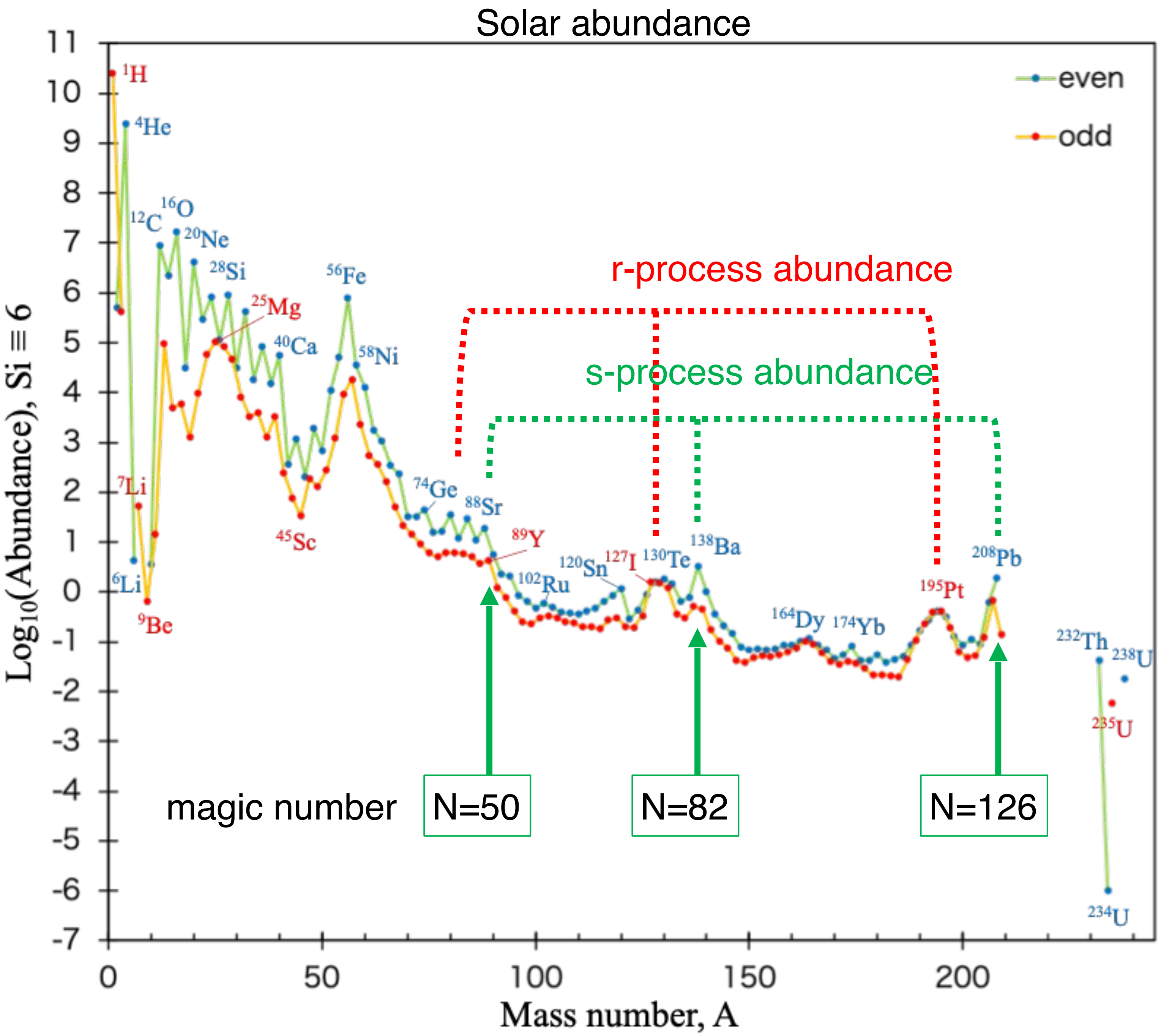
"nuclear quantum phase transition"

S. Naimi *et al.*, PRL 105, 032502 (2010)

Masses for astrophysics



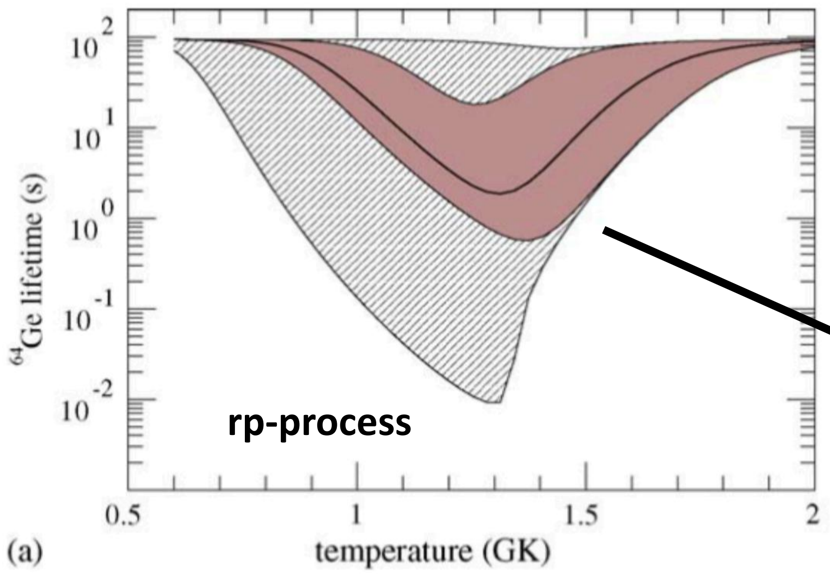
Masses for astrophysics

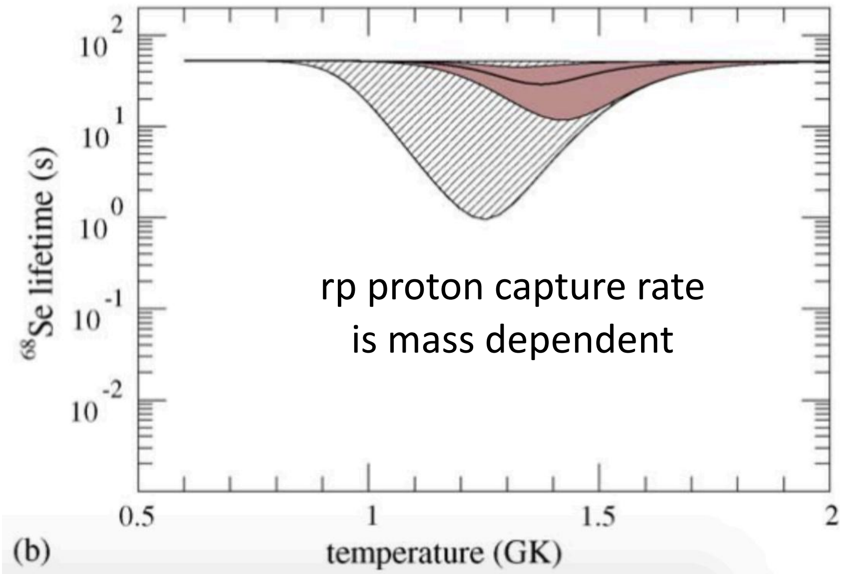


The magicity of neutron-rich nuclei largely affects r-process abundance

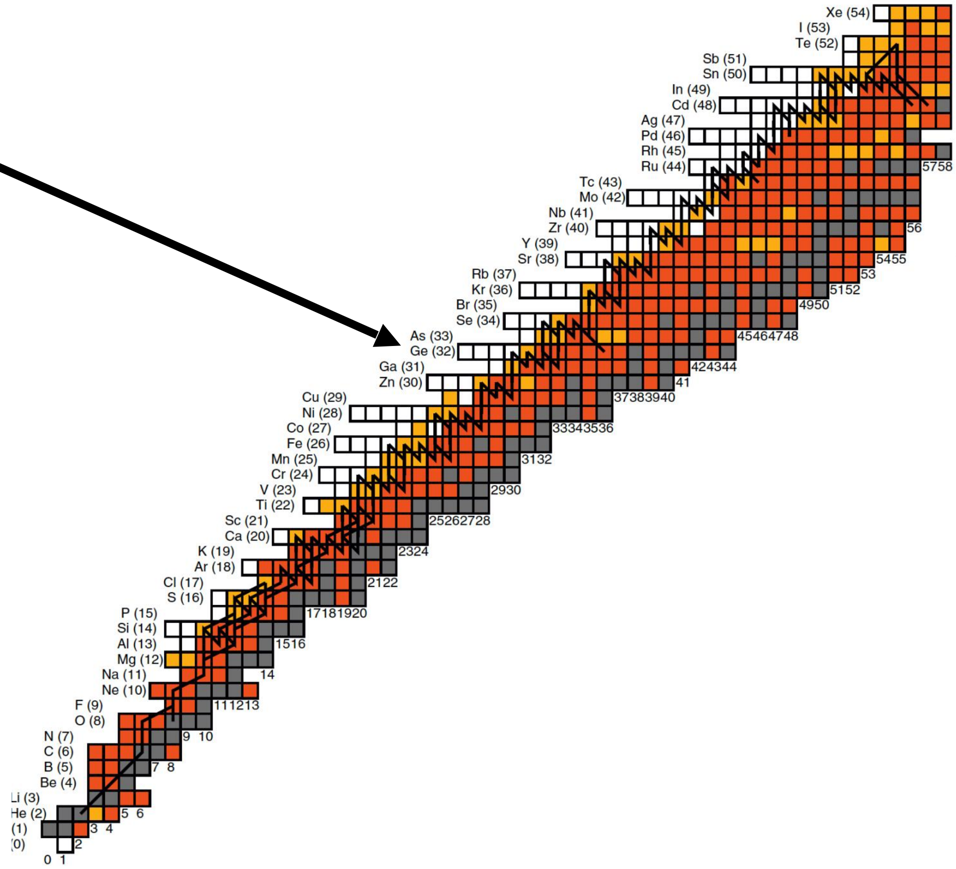
Masses for astrophysics

Nucleosynthesis





rp proton capture rate
is mass dependent

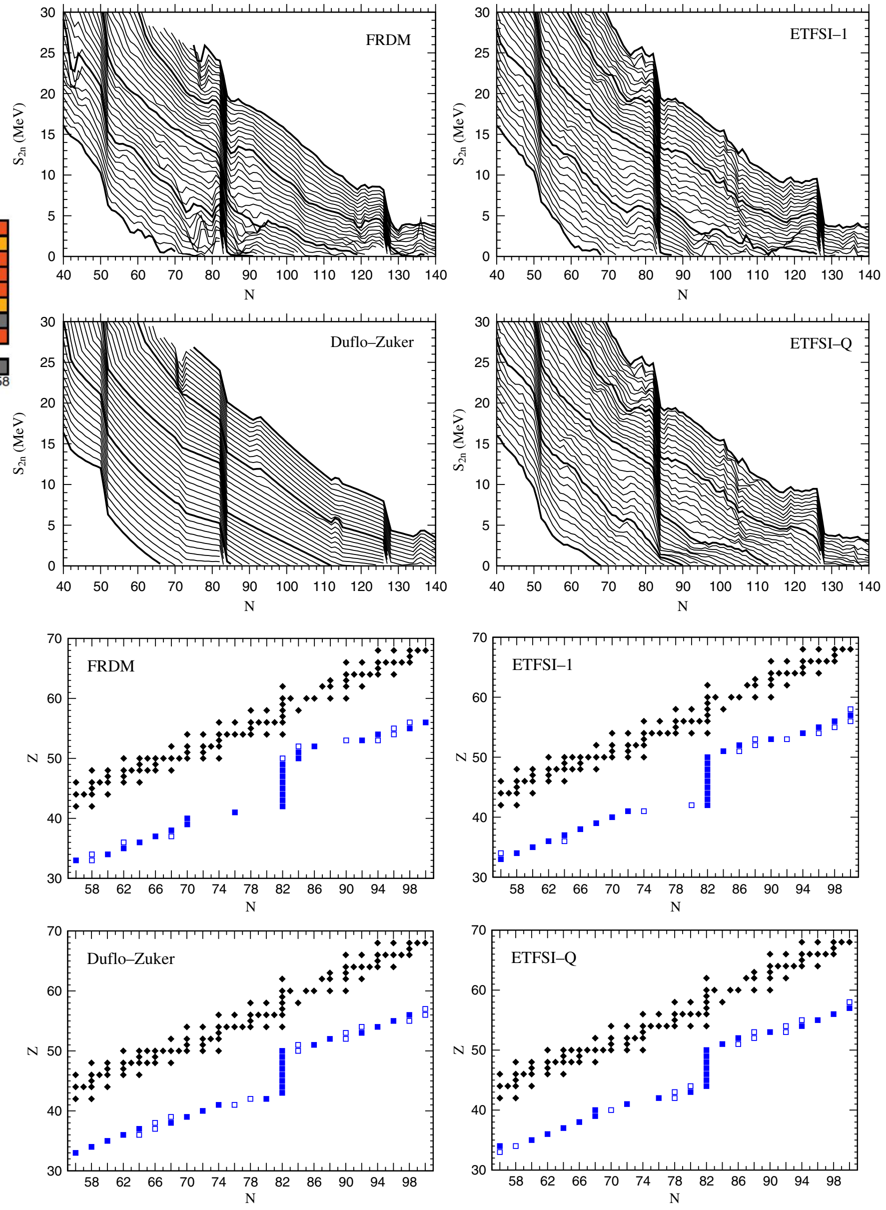


**High precision
and mass accuracy required**

**H. Schatz, Int J. Mass spectrom. 251, 293 (2006),
Int J. Mass spectrom. 349-350, 181 (2013)**

$$\frac{Y(Z,N+1)}{Y(Z,N)} \propto \frac{G(Z,N+1)}{2G(Z,N)}\,\frac{N_n}{(kT)^{3/2}}\,\exp\left[\frac{S_n(Z,N+1)}{kT}\right]$$

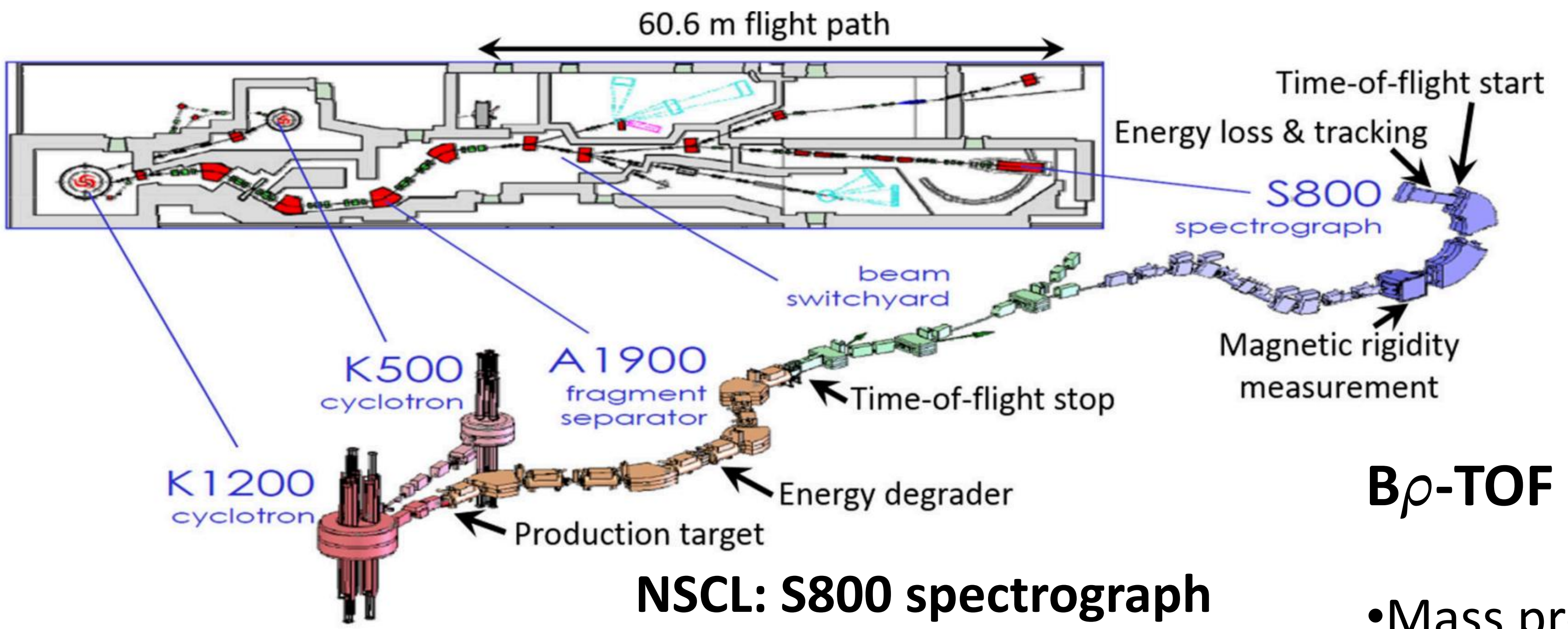
r-process



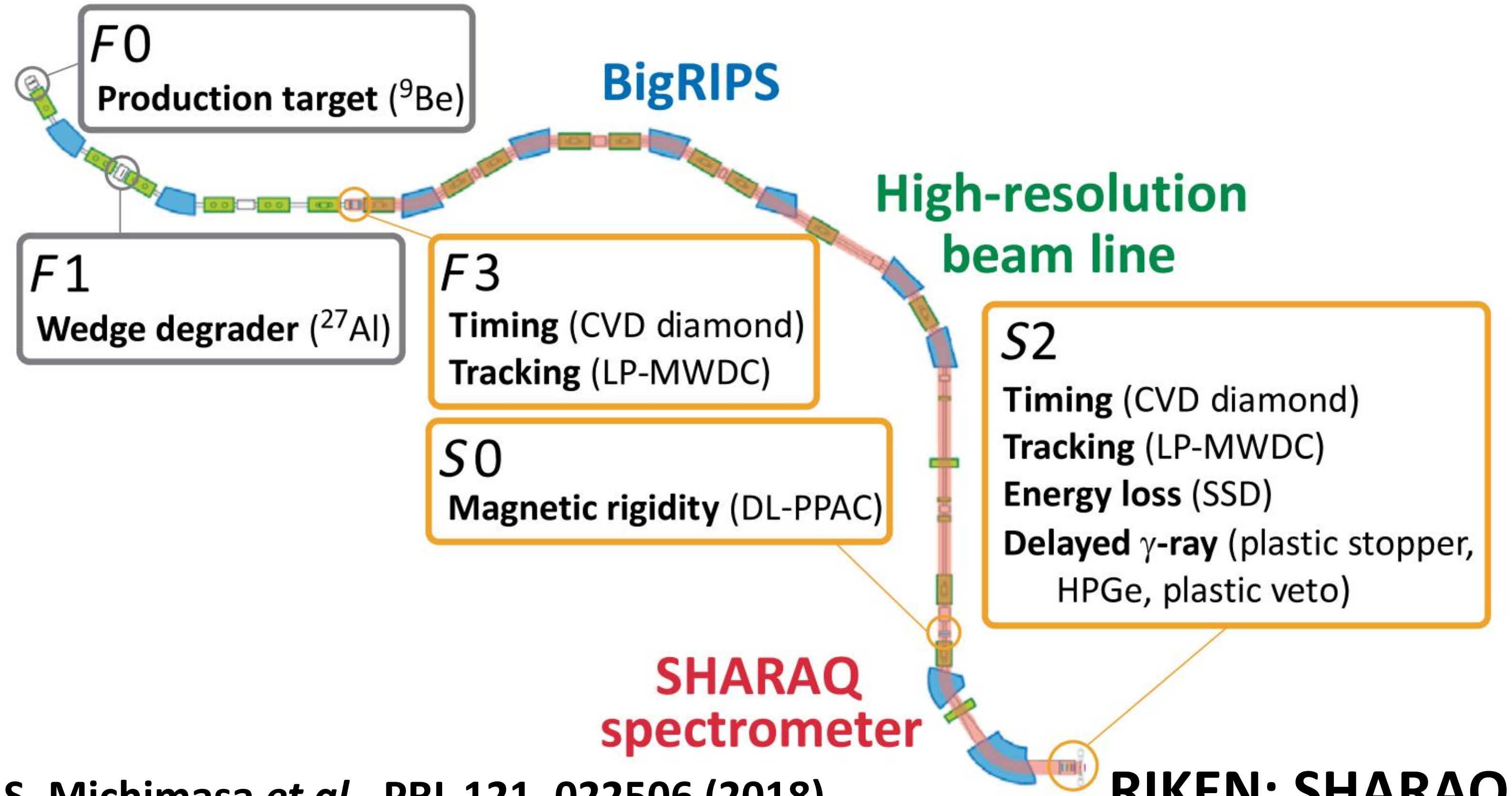
H. Grawe *et al.*, Rep. Prog. Phys. **70**, 1525 (2007)

Shell gap position would change
the r-process path

Z. MEISEL *et al.* PHYSICAL REVIEW C **93**, 035805 (2016)



NSCL: S800 spectrograph



S. Michimasa *et al.*, PRL 121, 022506 (2018)

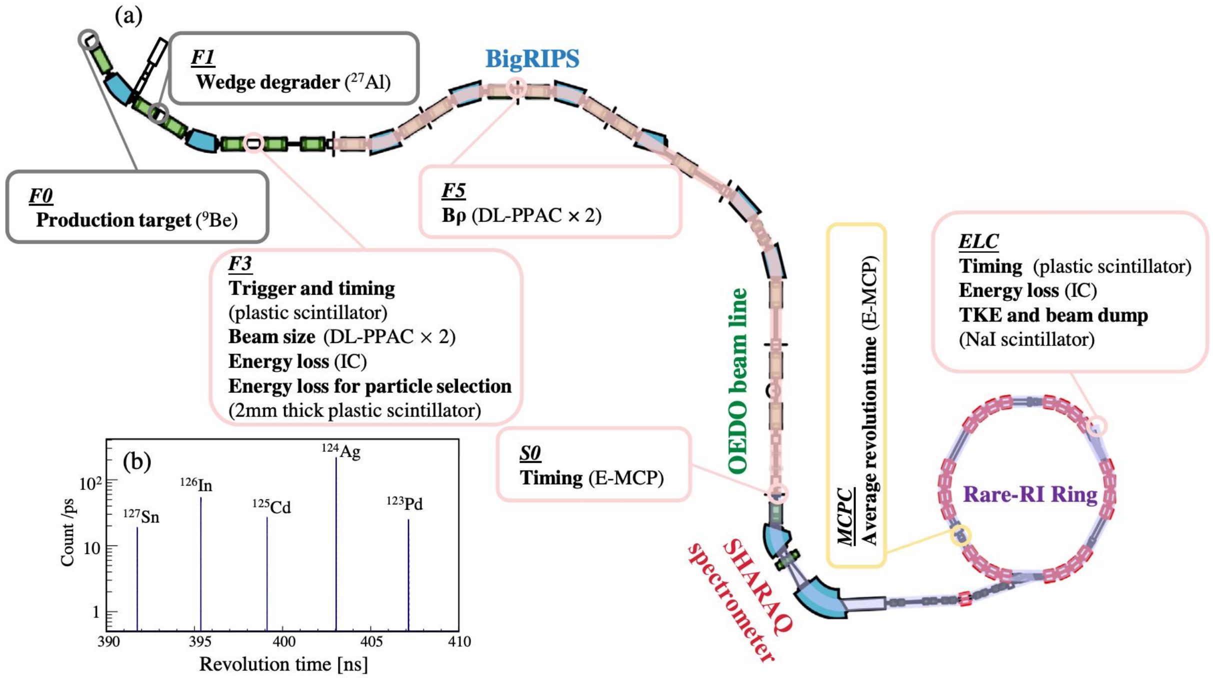
RIKEN: SHARAQ

Bρ-TOF measurements

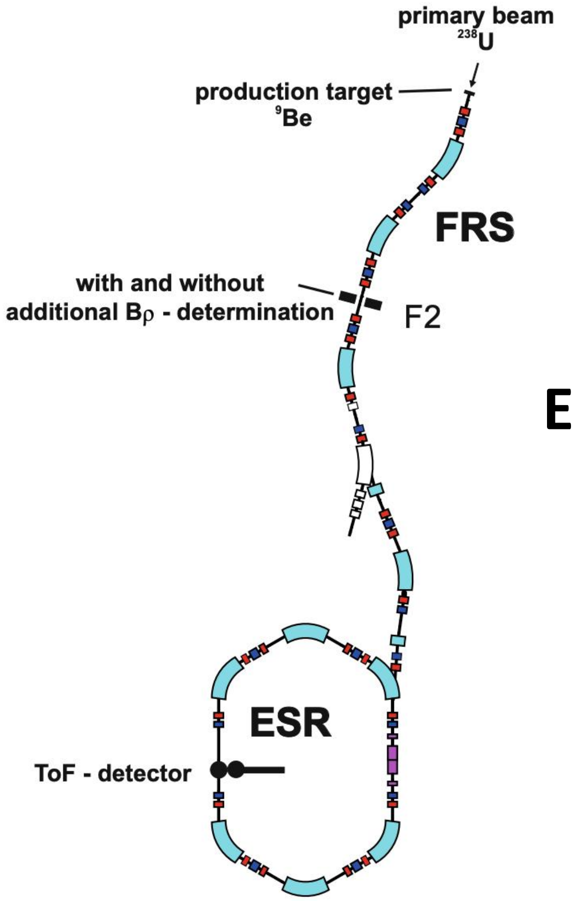
- Mass precision $\delta m/m < 10^{-5}$
- Mass resolving power $m/\Delta m > 10^{4}$
- Perfectly suited for very short half-lives (single pass)
- Challenge: mass accuracy, accurate references, isomer mixtures

Isochronous mass spectrometry with storage rings:

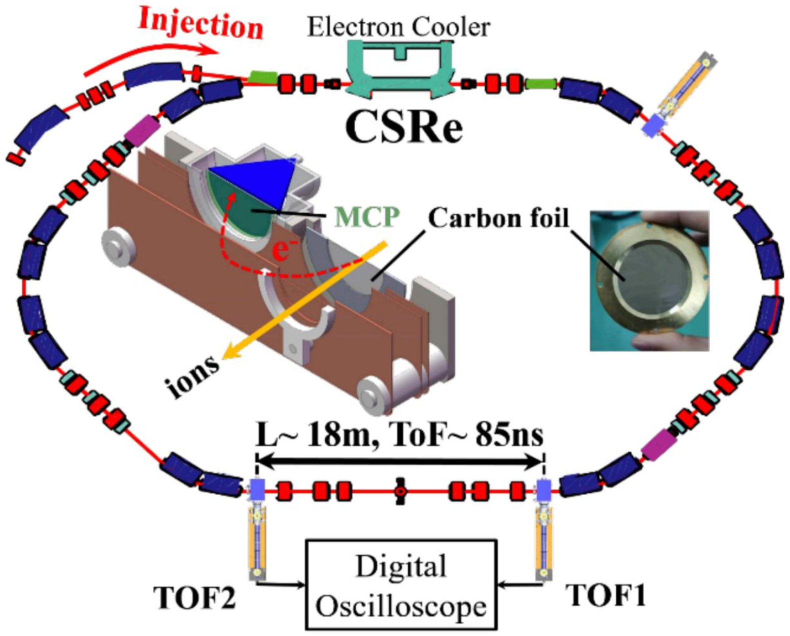
- Good mass precision reached:
  $\delta m/m \approx 10^{-5} - <10^{-6}$
- Short half-lives can be addressed
  → time limit < 1ms
- Challenge:
  - Momentum acceptance
  - Mass accuracy, mass references, isomer mixtures
  - Expensive costs



R3 new results:
H. F. Li, S. Naimi *et al.*, PRL 128, 152701 (2022)

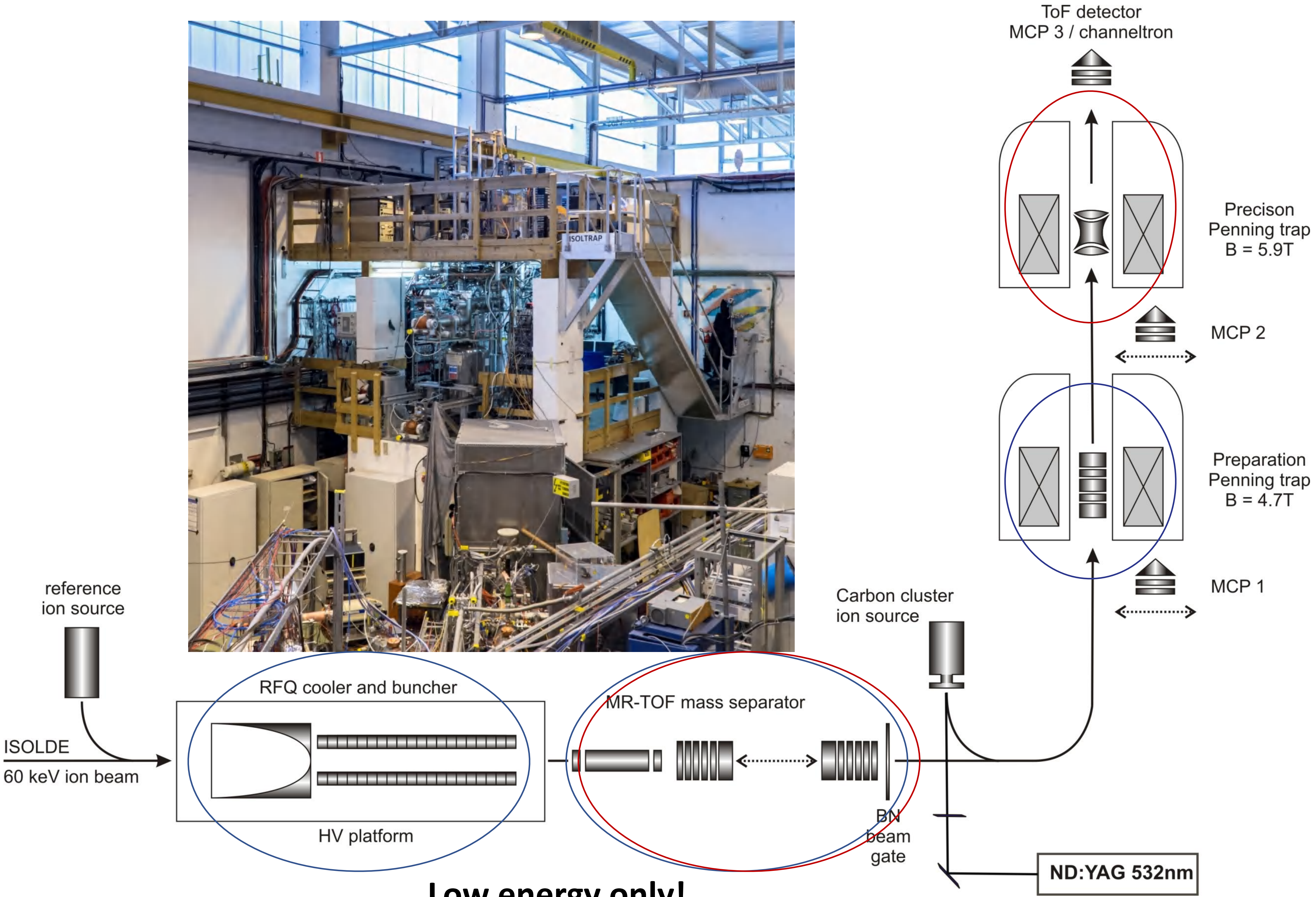


ESR storage ring at GSI



CSRe with new results: $\Delta m/m \approx 2\times10^{-7}$
M. Zhang *et al.*, https://doi.org/10.48550/arXiv.2209.05701

Penning trap mass spectrometry



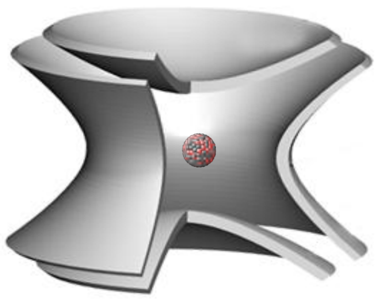
Low energy only!

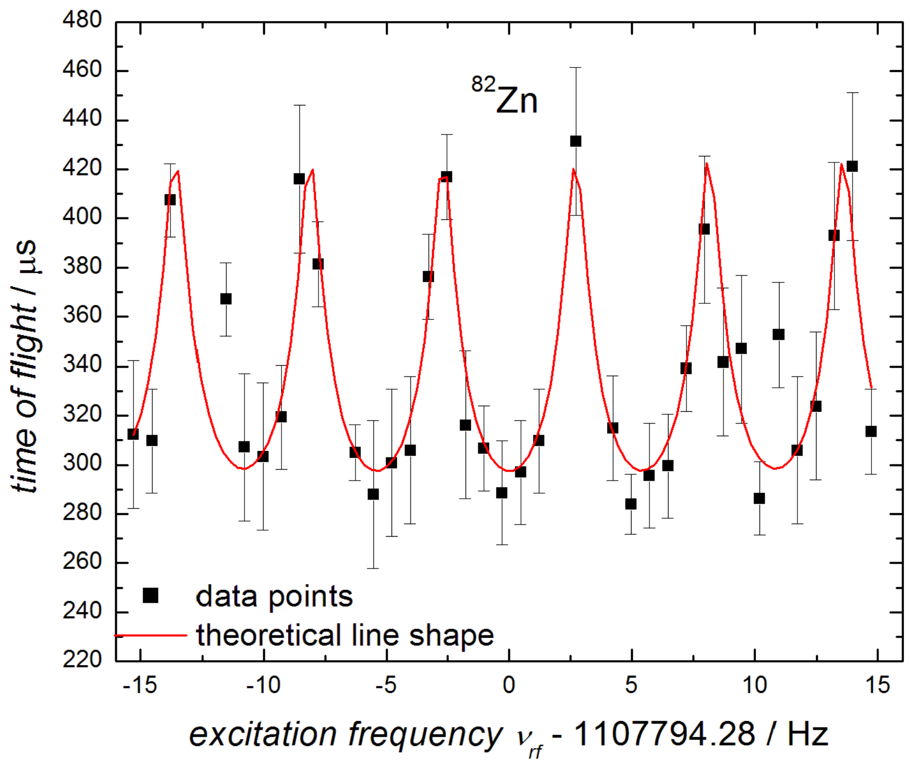
preparation measurement

M. Mukherjee *et al.*, Eur. Phys. J A **35**, 1 (2008)

R. N. Wolf *et al.*, NIM A **686**, 82 (2012)

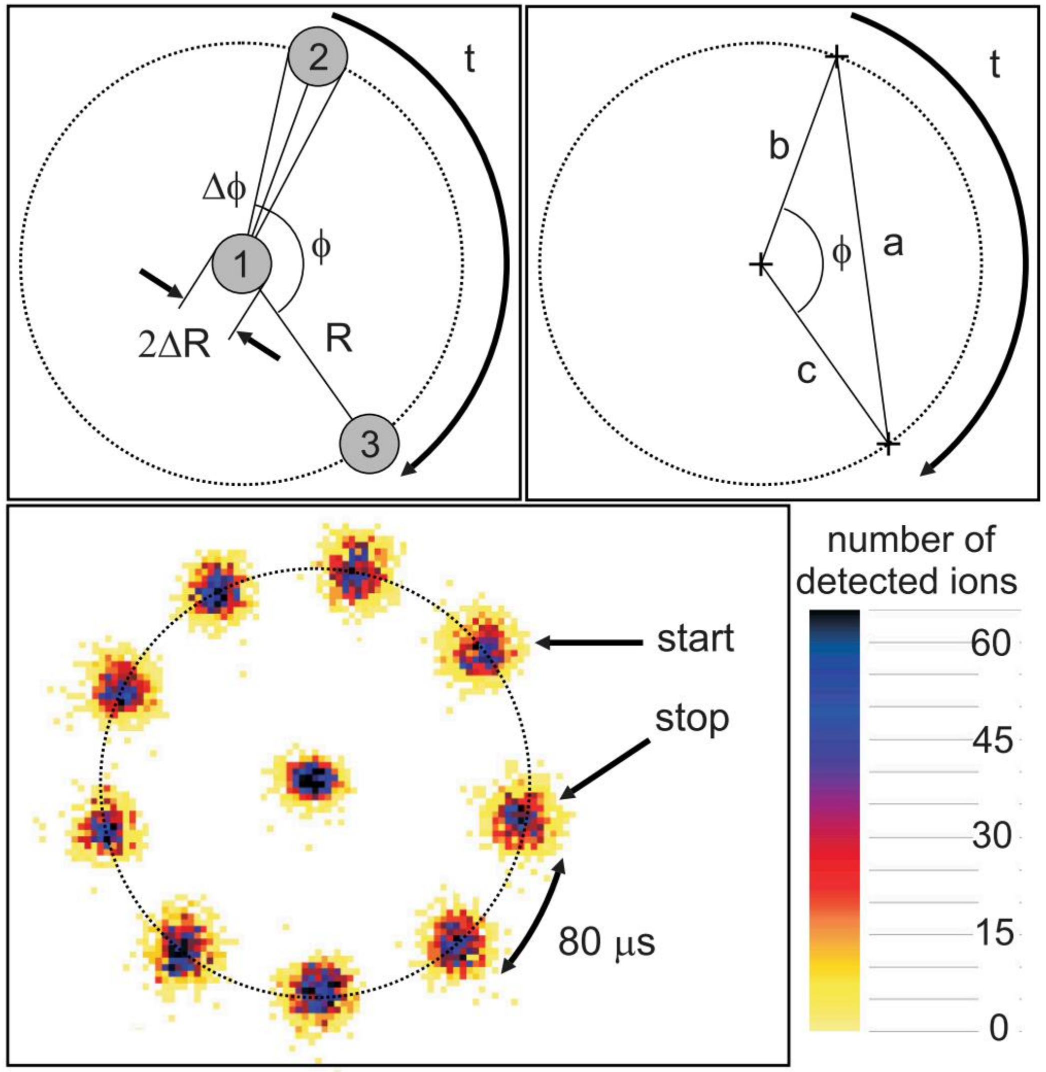
Time-of-flight ion-cyclotron-resonance method (TOF-ICR)





- Very high precision: $\delta m/m < 10^{-8}$
- Challenge:
  - Relatively slow (t_{exc} = 200-1000ms)
  - Needs careful ion preparation
  - Low energy only

Phase imaging ion-cyclotron-resonance method (PI-ICR)



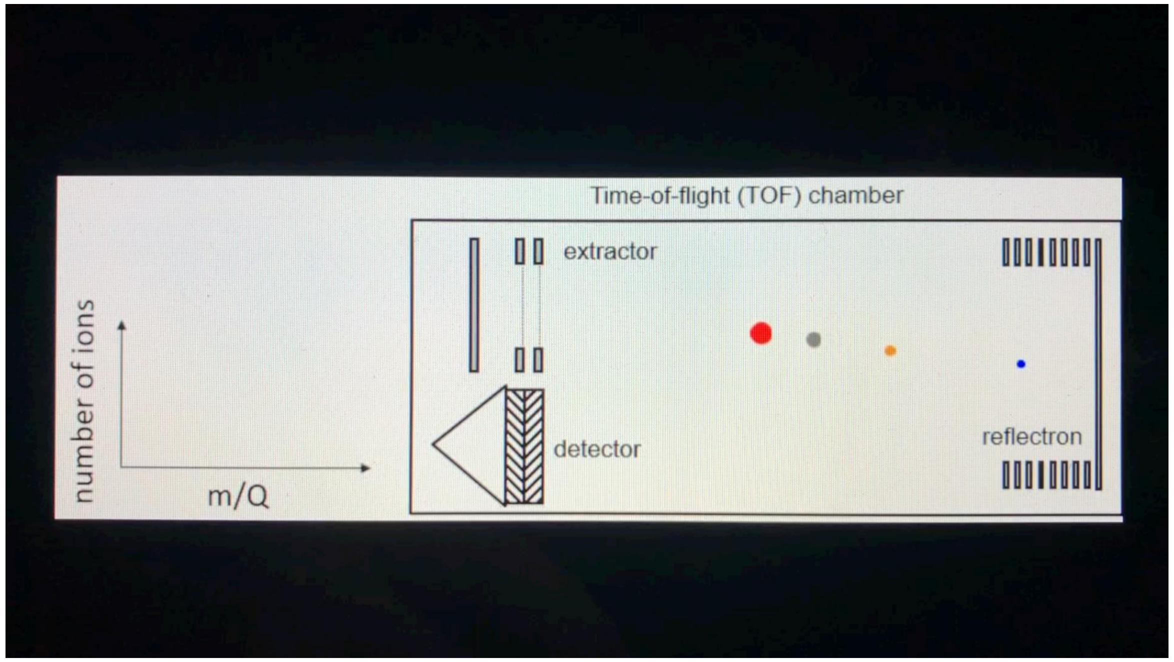
- Break-through precision: $\delta m/m < 10^{-9}$
- Much faster method to gain precision
- Challenge:
  - Needs careful ion preparation
  - Low energy only

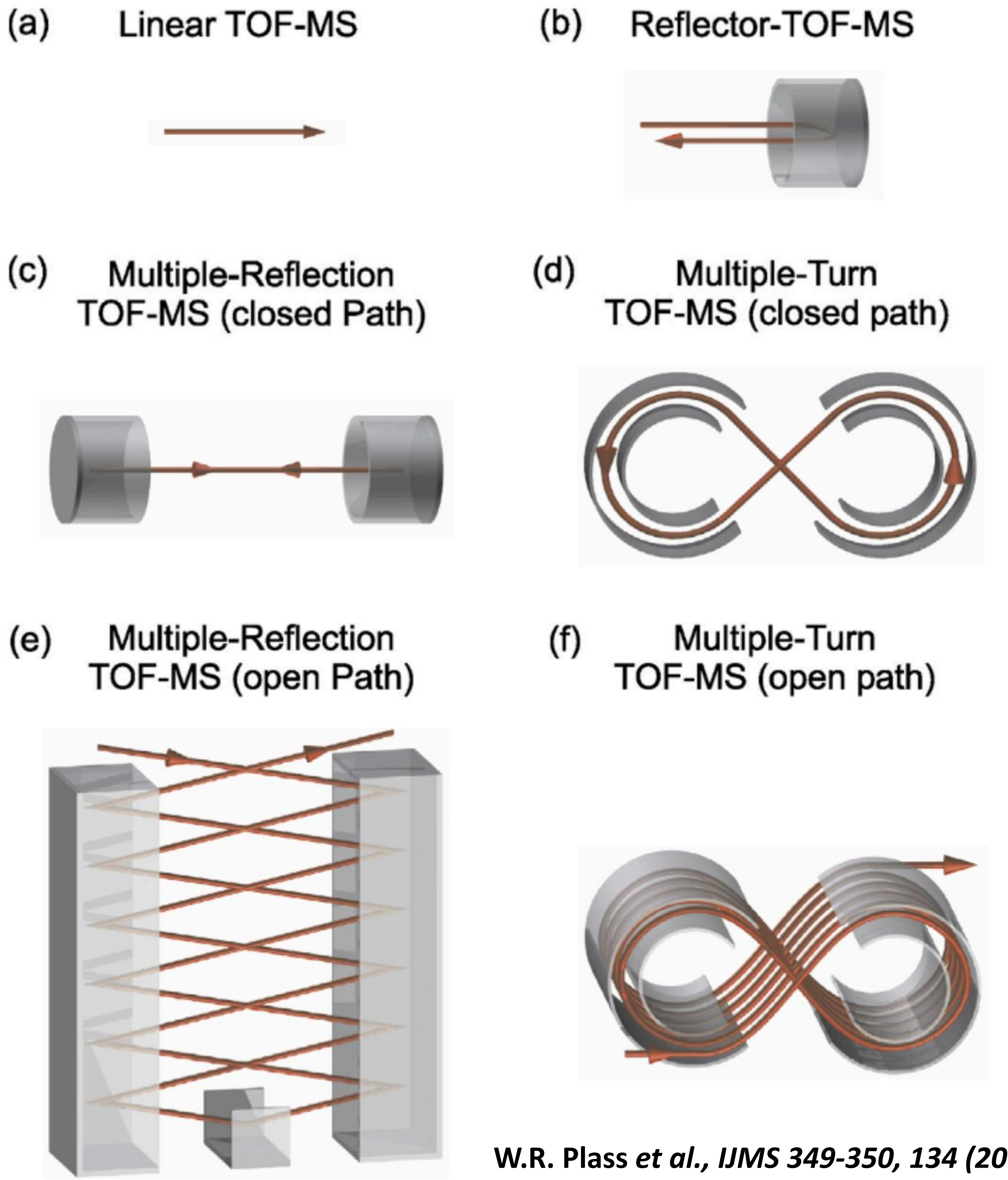
Electrostatic time-of-flight mass spectrometry

Mass resolving power:

- **linear TOF-MS: m/Δm > 100**
- **reflector-TOF-MS: m/Δm > 5,000**
- **MRTOF-MS: m/Δm > 100,000**

Δm = 2Δt = FWHM of ion TOF distribution

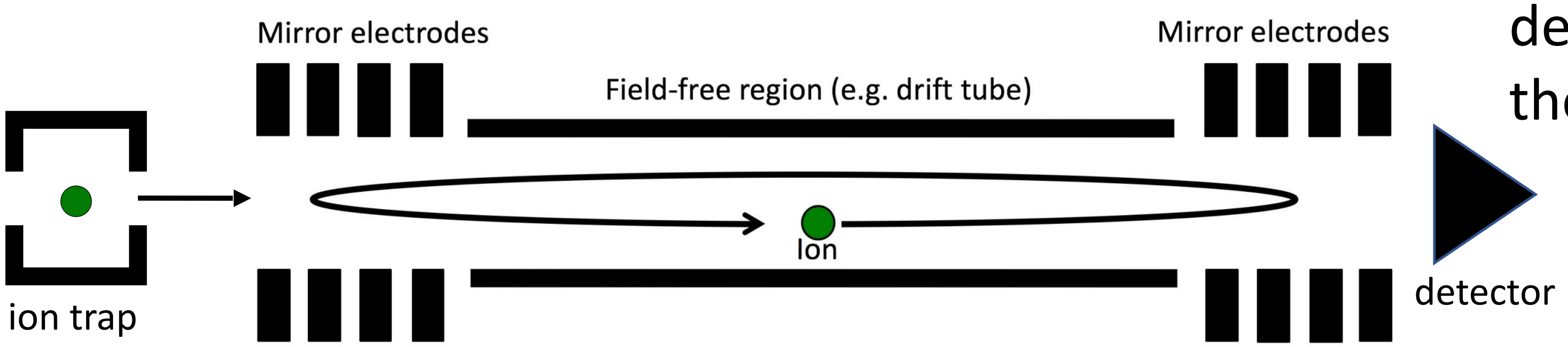




W.R. Plass *et al., IJMS 349-350, 134 (2013)*

The multi-reflection time-of-flight (MRTOF) technique

H.Wollnik and M. Przewloka, Int. J. Mass Spectrom. Ion Proc. 96, 267 (1990)



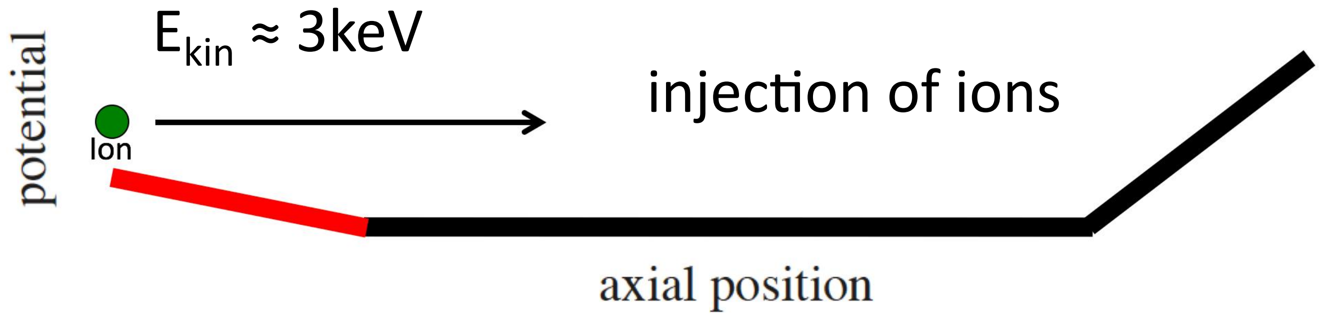
Total time of flight predominantly determined by the electrostatic term of the system

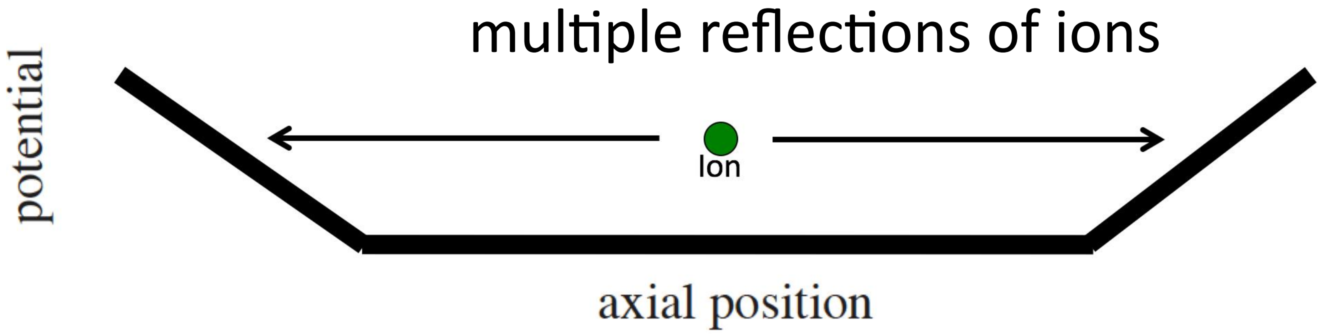
device constant

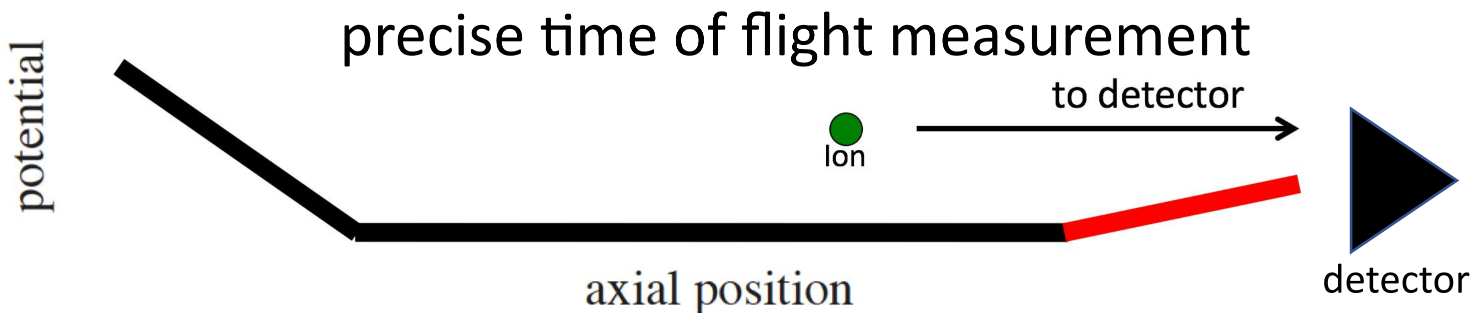
$$\overline{t(q,m)} = \boxed{A \cdot \sqrt{\frac{m}{q}}}$$

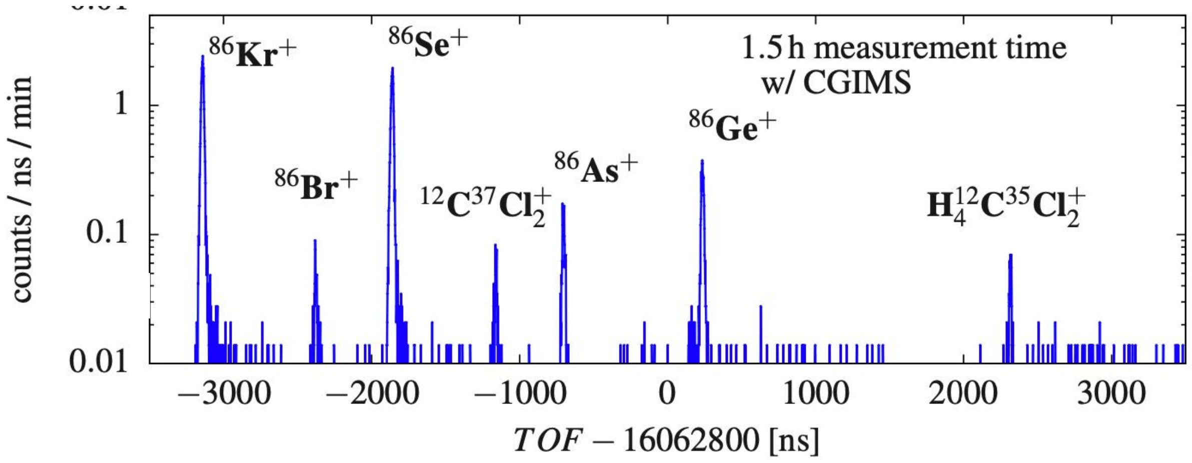
average from ion distribution

electrostatic contribution









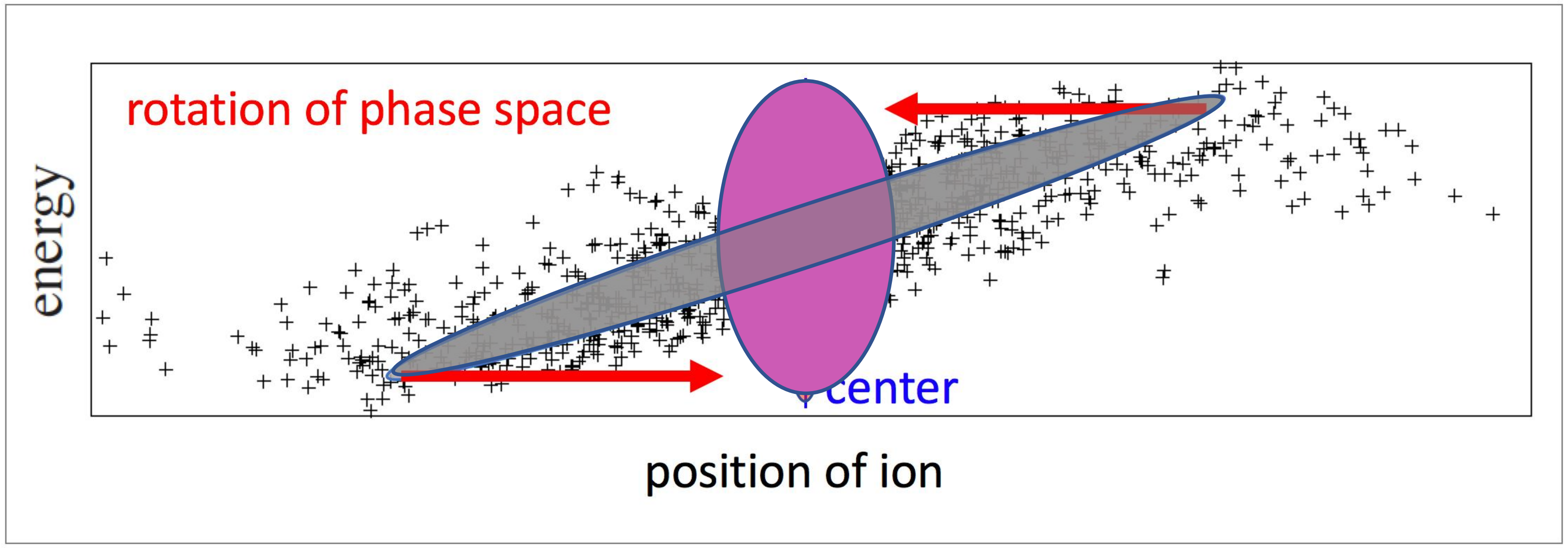
- Flight path of a few kilometers possible
- Short measurement time ≈ 10-20 ms
- Mass resolving power $R_m > 100{,}000$
- Relative mass precision $\delta m/m < 10^{-7}$
- High accuracy (acceptable syst. effects)

Ion focusing

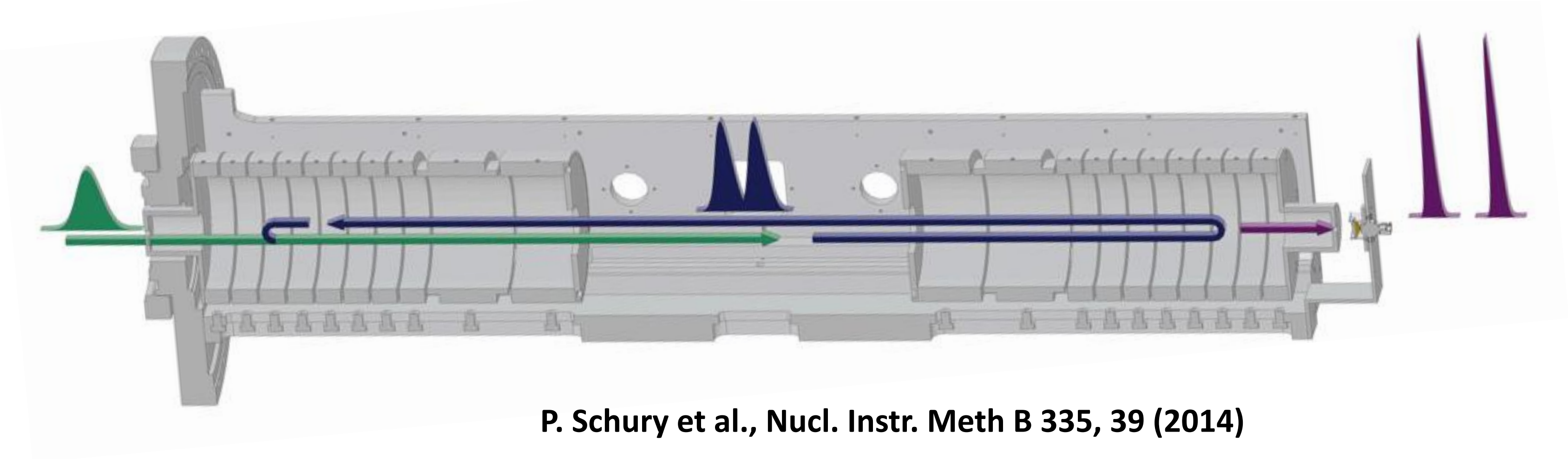
- Axial potential shape allows to modify the phase space of the ions via the penetration depth into the ion mirror

- Narrow time-of-flight focus achieved at the detector

→ high resolution by long flight path and focusing

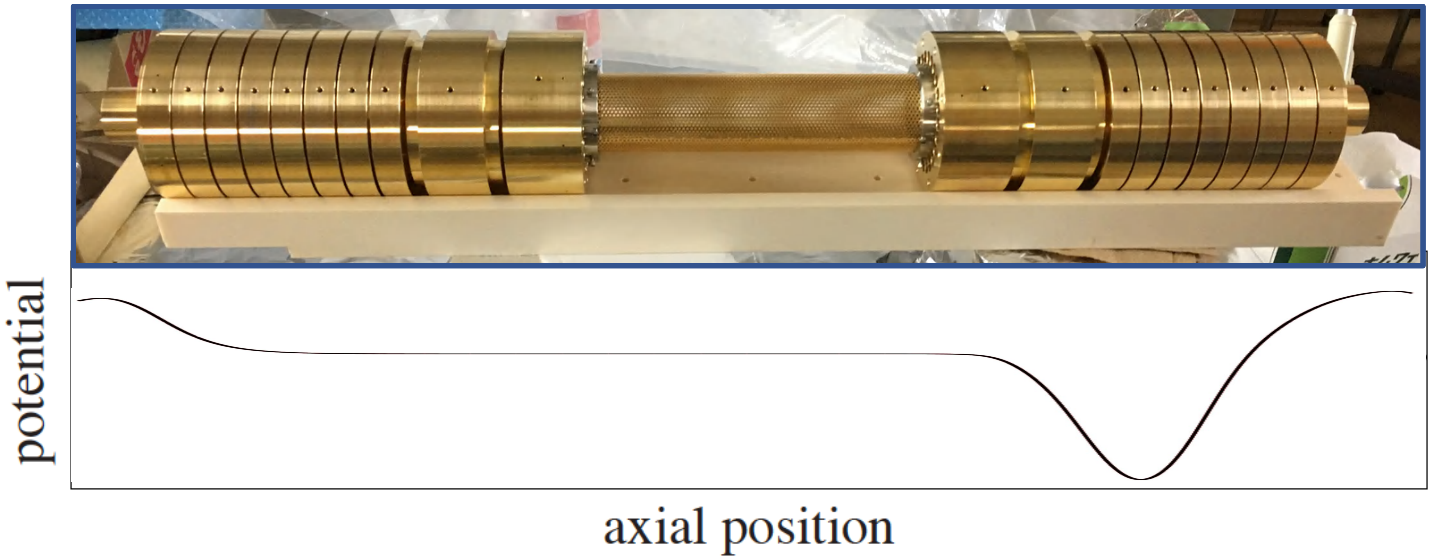


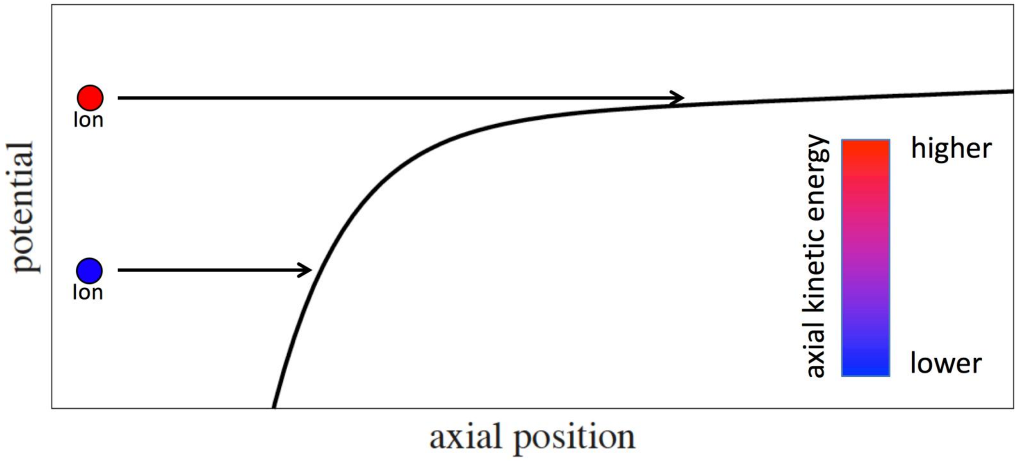
MRTOF mass spectrograph



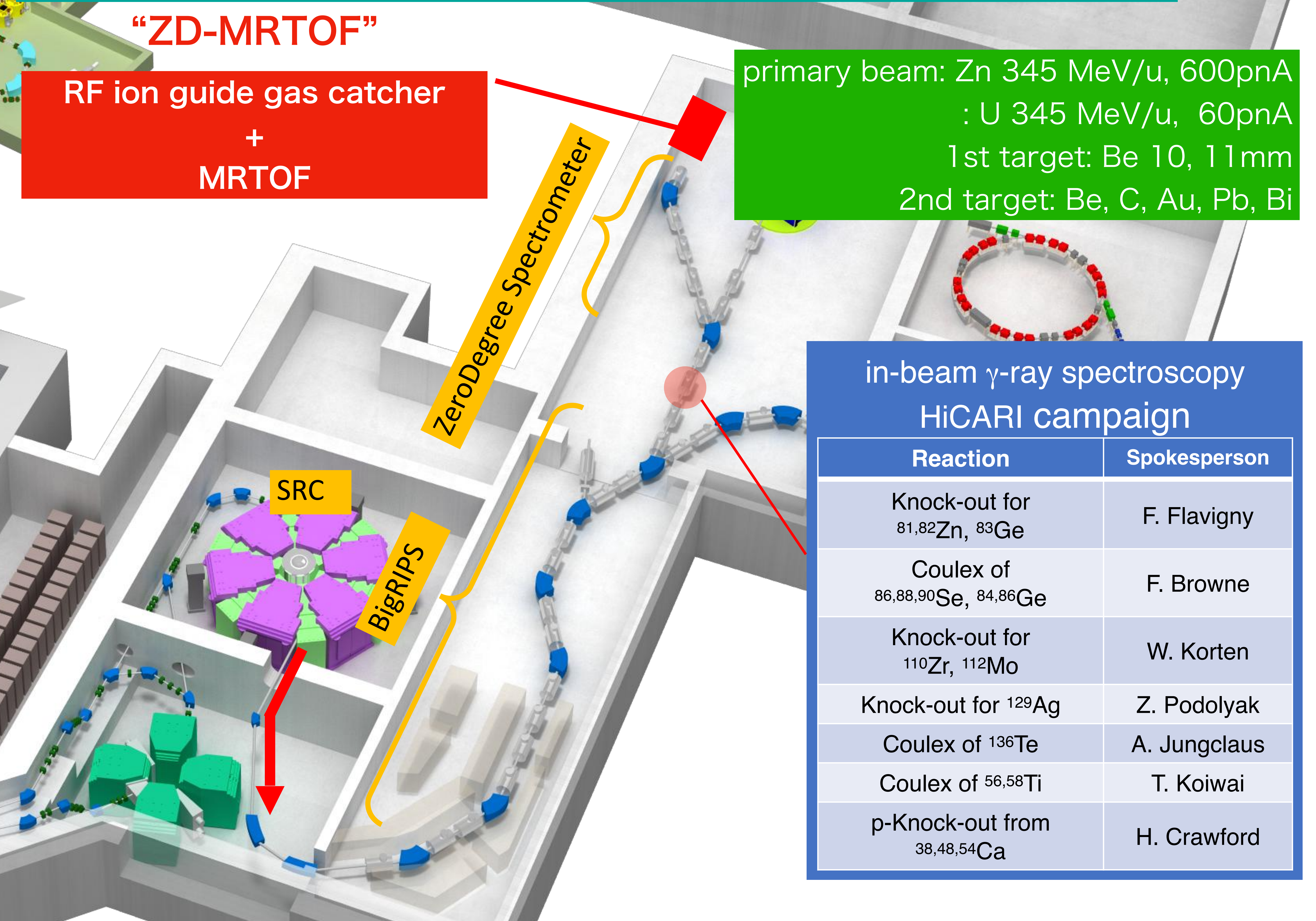
P. Schury et al., Nucl. Instr. Meth B 335, 39 (2014)

M. Rosenbusch et al., Nucl. Instr. Meth B 463, 184 (2020)





Symbiotic experiments with HiCARI campaign (2020)



“ZD-MRTOF”

RF ion guide gas catcher
+
MRTOF

primary beam: Zn 345 MeV/u, 600pnA
: U 345 MeV/u, 60pnA
1st target: Be 10, 11mm
2nd target: Be, C, Au, Pb, Bi

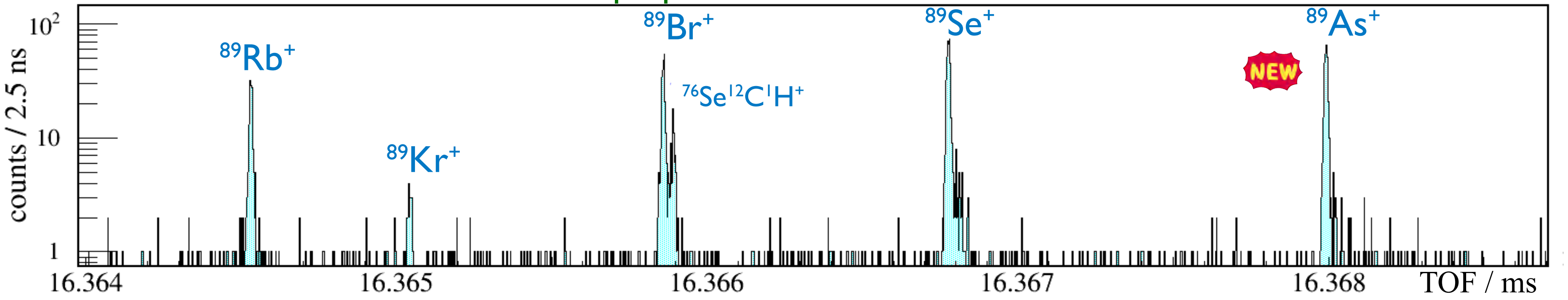
in-beam γ-ray spectroscopy
HiCARI campaign

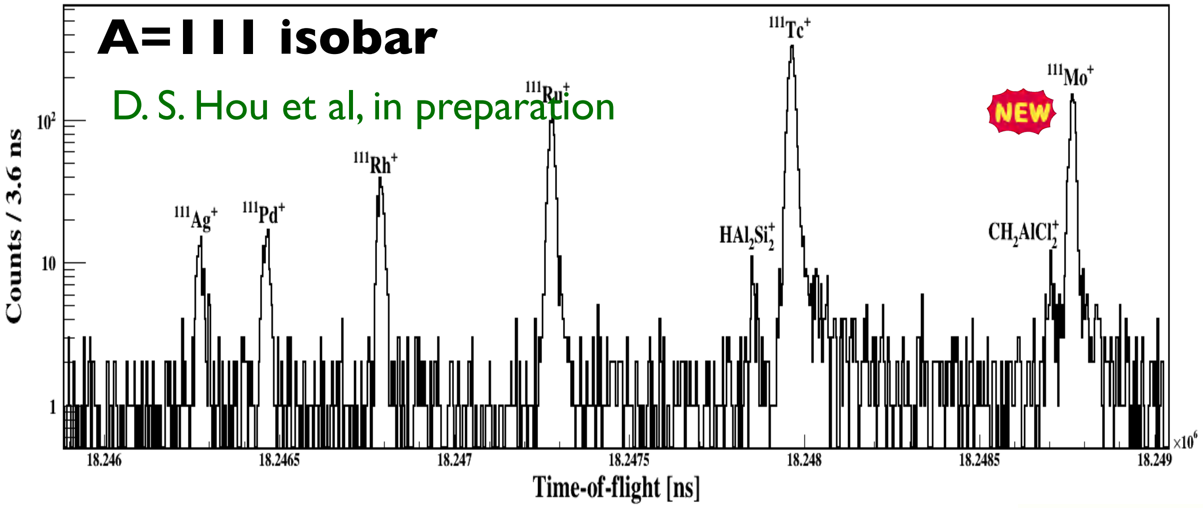
Reaction	Spokesperson
Knock-out for ^{81,82}Zn, ^{83}Ge	F. Flavigny
Coulex of ^{86,88,90}Se, ^{84,86}Ge	F. Browne
Knock-out for ^{110}Zr, ^{112}Mo	W. Korten
Knock-out for ^{129}Ag	Z. Podolyak
Coulex of ^{136}Te	A. Jungclaus
Coulex of ^{56,58}Ti	T. Koiwai
p-Knock-out from ^{38,48,54}Ca	H. Crawford

Symbiotic experiment results with HiCARI campaign

>70 atomic masses, 3 first masses, >10 greatly improved mass

A=89 isobar W. Xian et al, in preparation

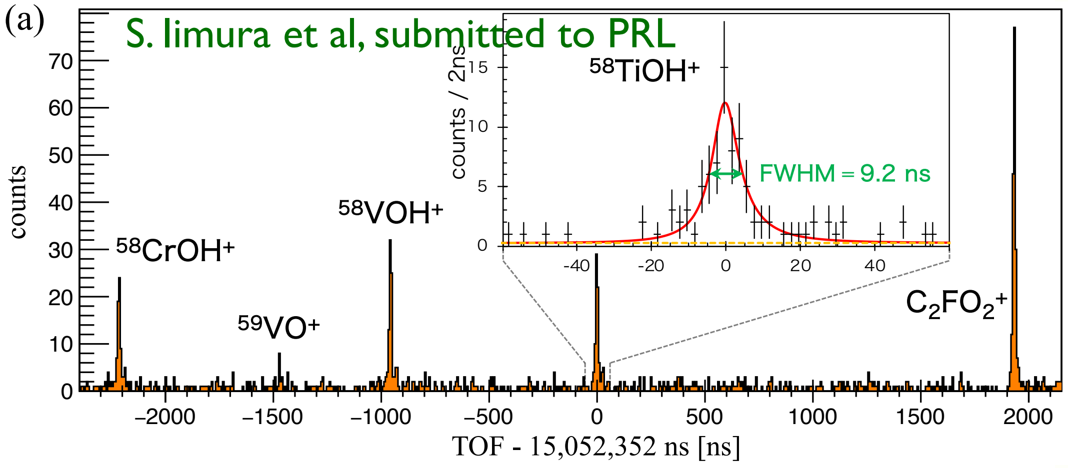




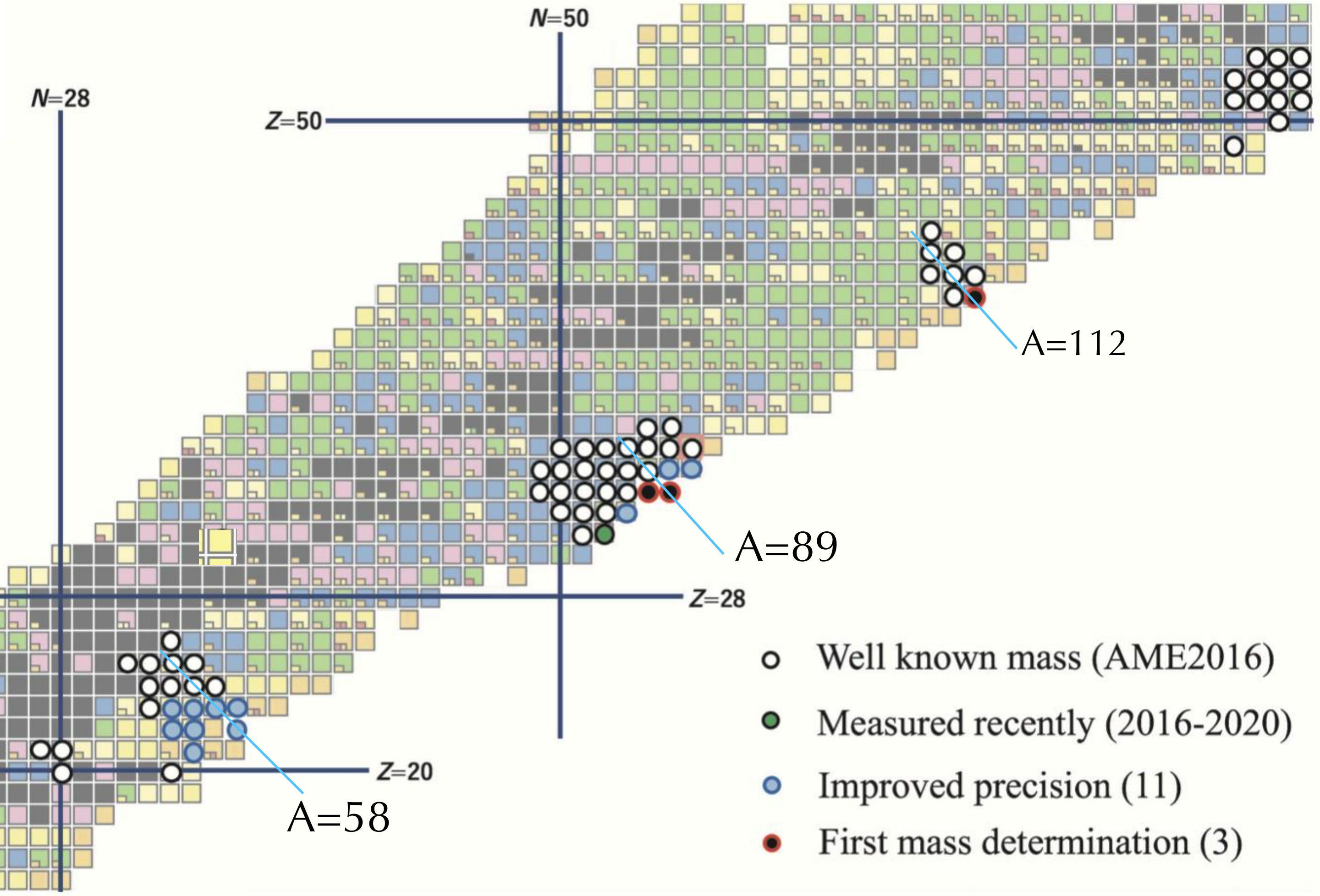
A=111 isobar

D. S. Hou et al, in preparation

Ti-58, V-58 as molecule

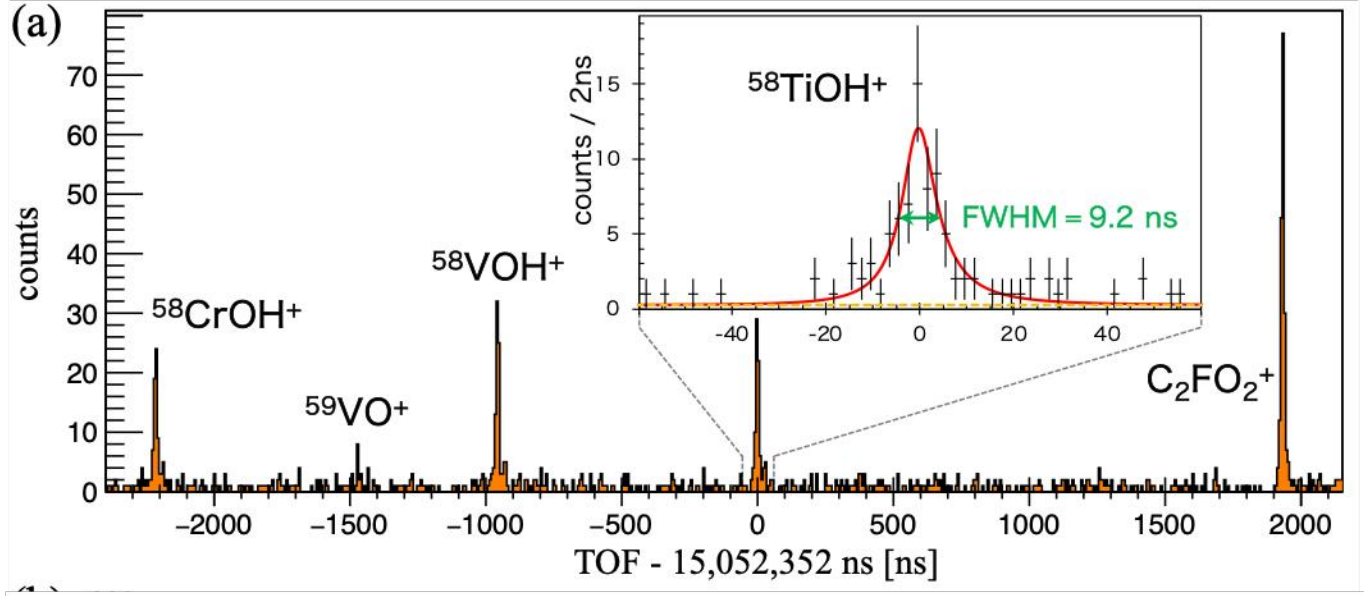


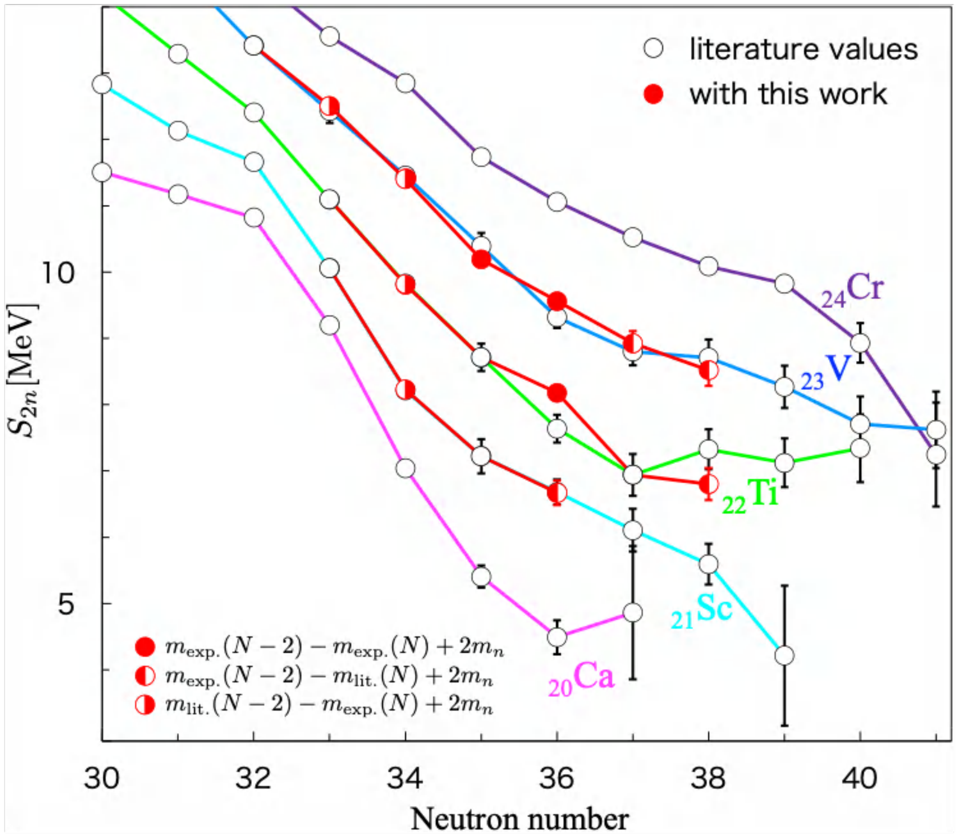
S. Iimura et al, submitted to PRL

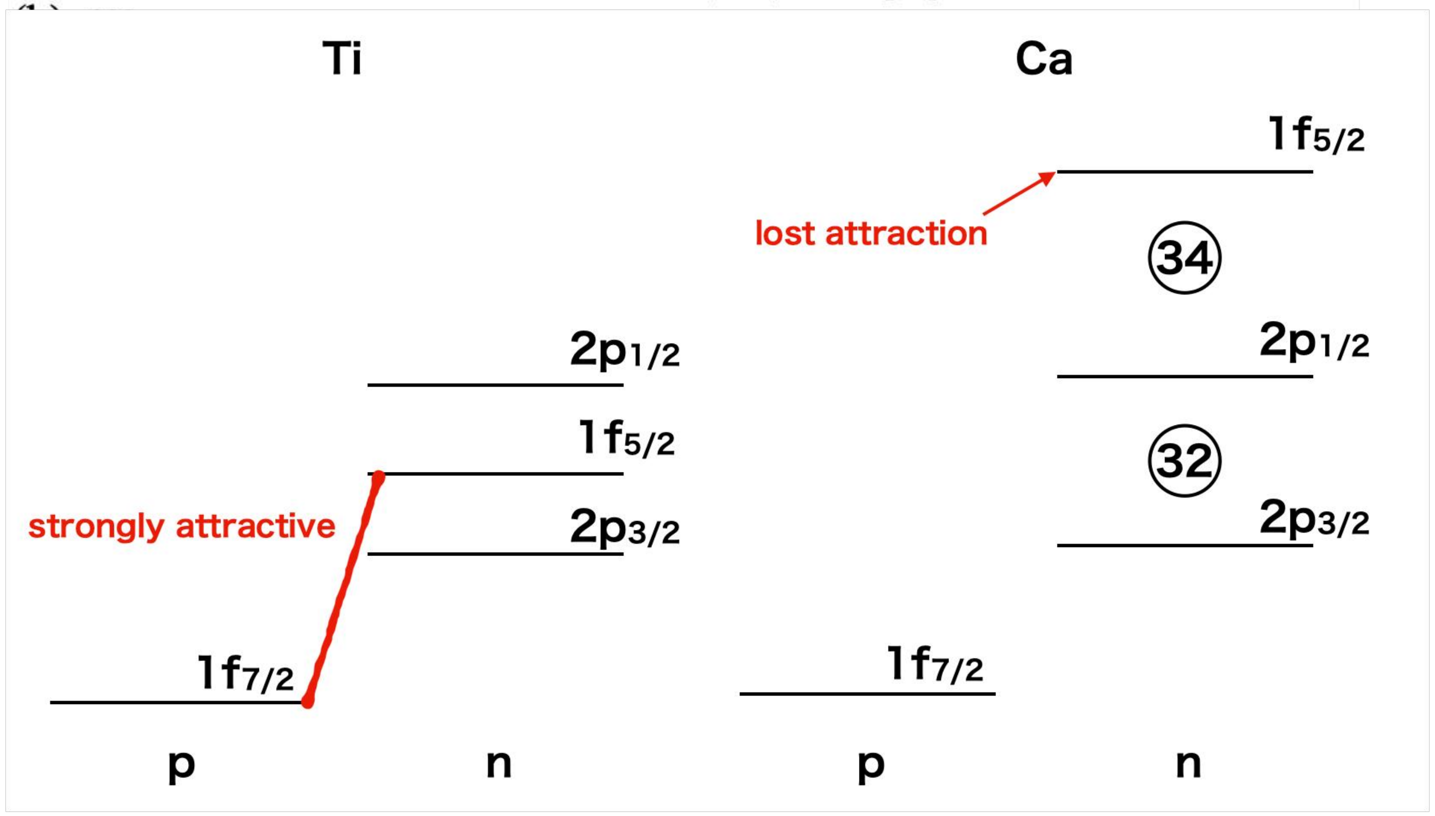


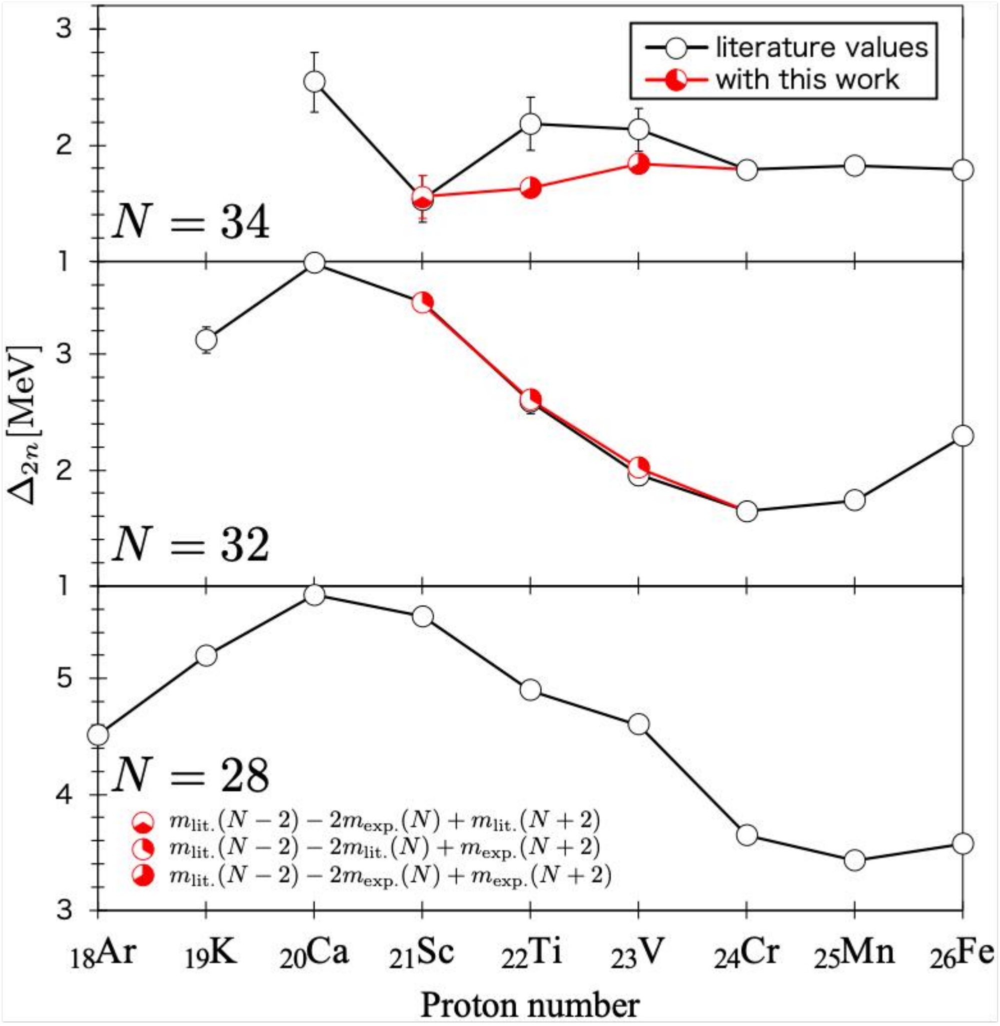
Ti-58, V-58 molecular ions

S. Iimura et al, PRL 130, 012501 (2023)









no proton in $f_{7/2}$ orbit for Ca

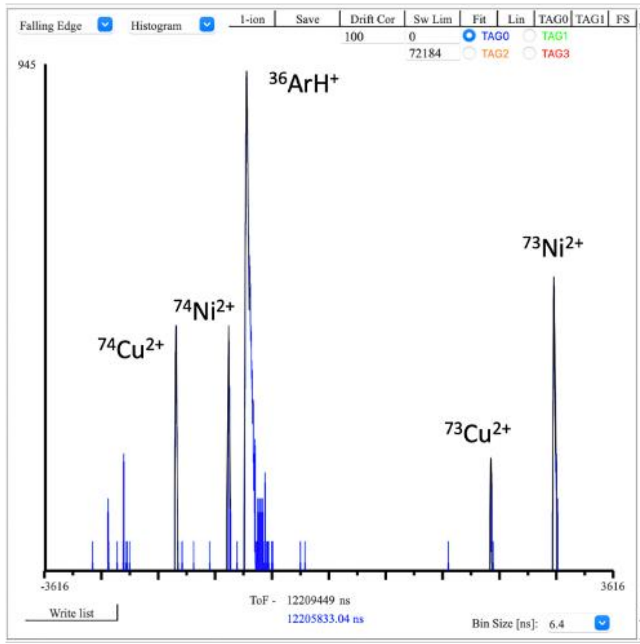
→ weaker tensor force

→ shell gap

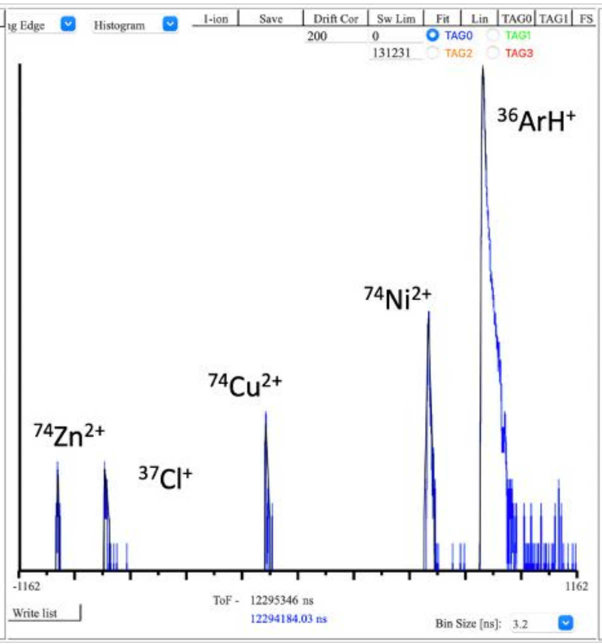
n-rich Ni region

December 2021

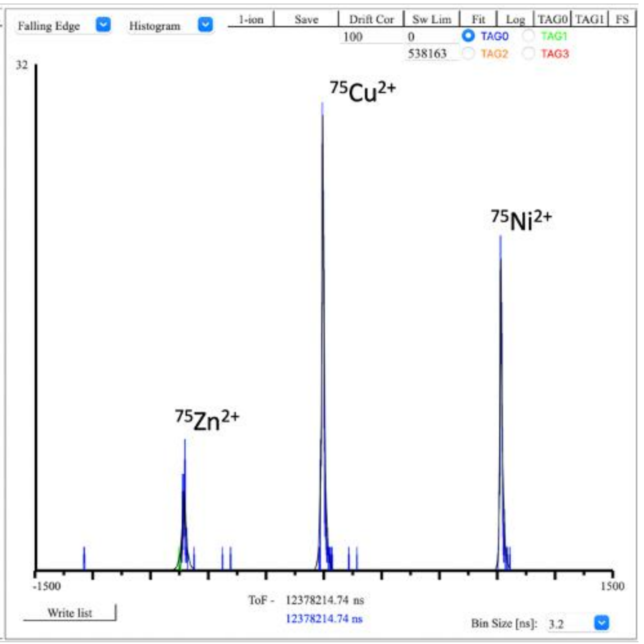
73Ni: 134 cts. / 30 min
74Ni: 58 cts. / 30 min

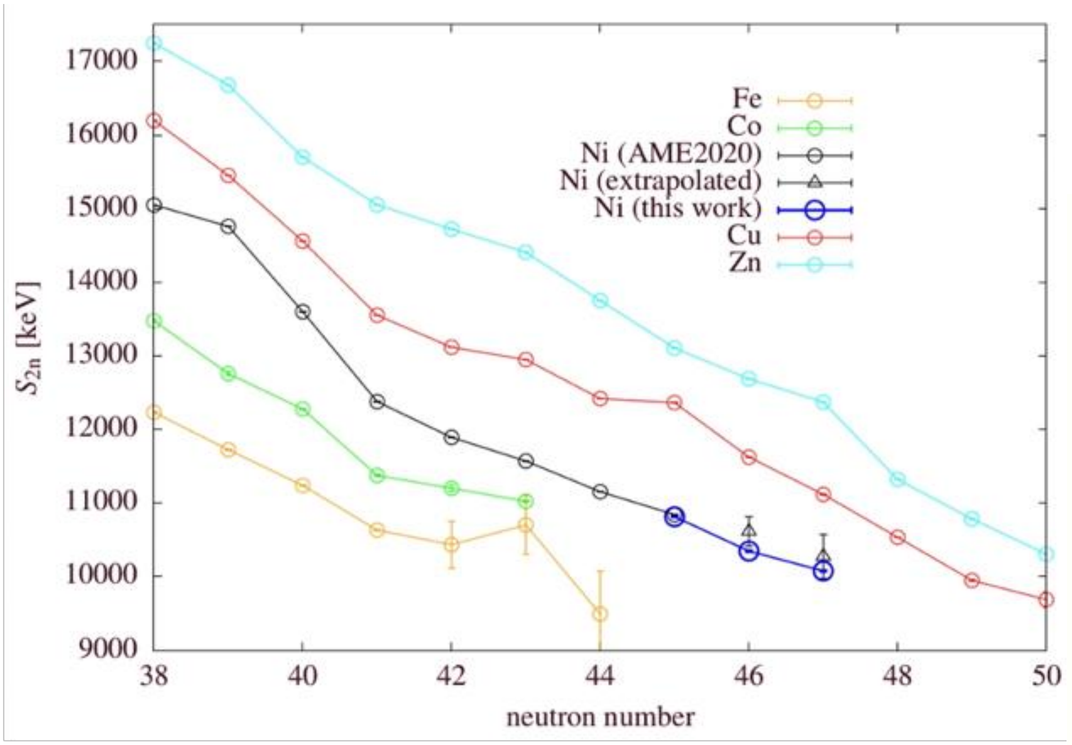


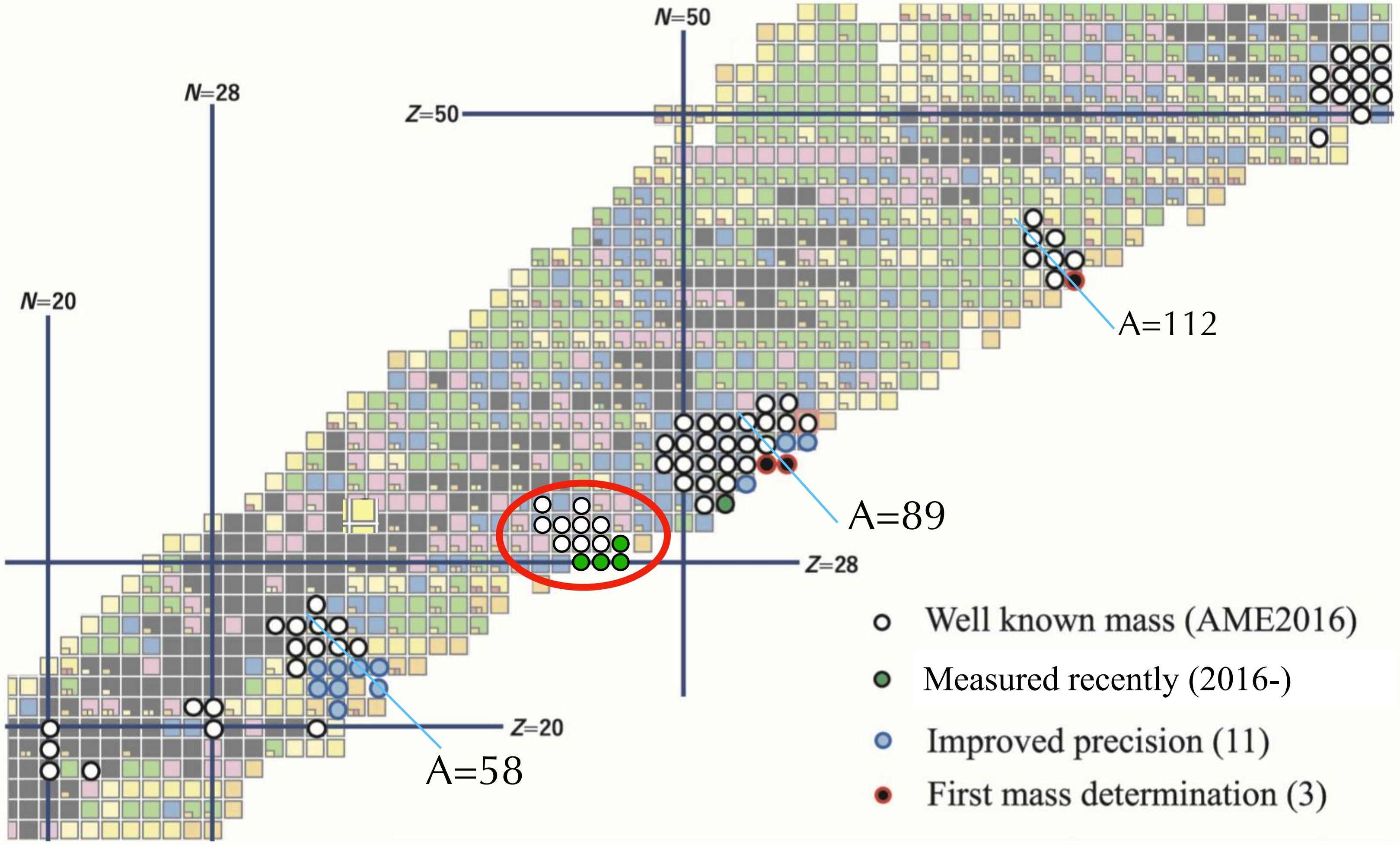
144 cts. / 54 min



83 cts. / 220 min

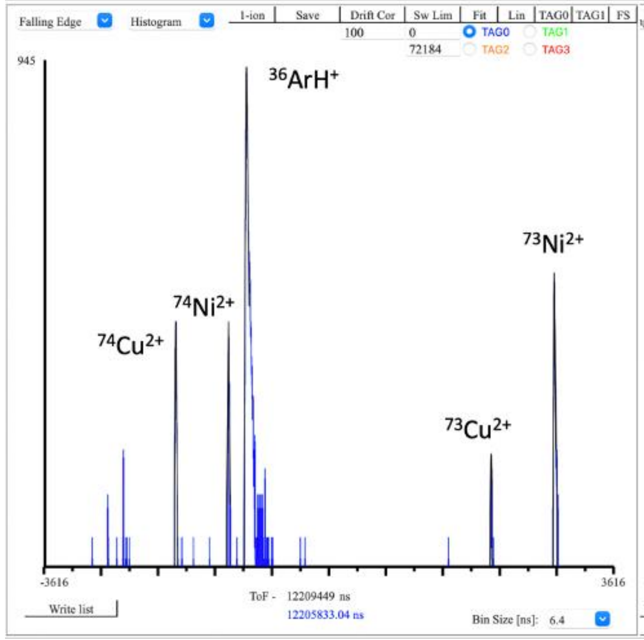




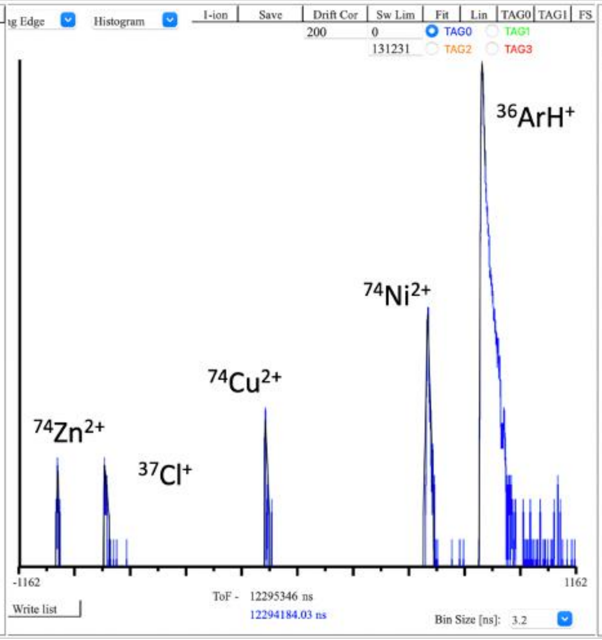


n-rich Ni region

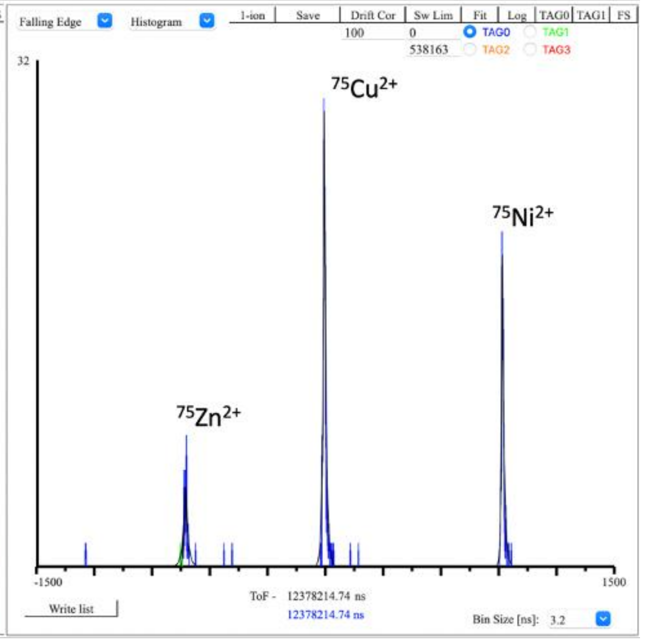
73Ni: 134 cts. / 30 min
74Ni: 58 cts. / 30 min

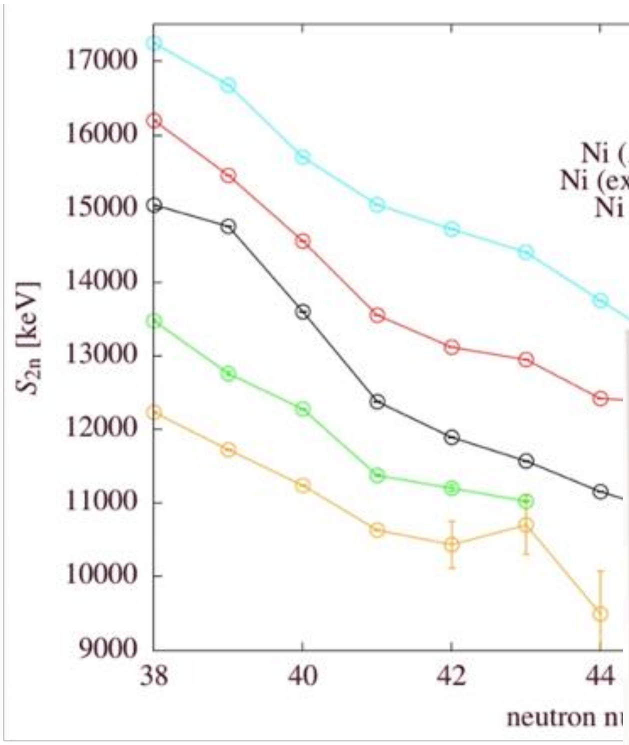


144 cts. / 54 min

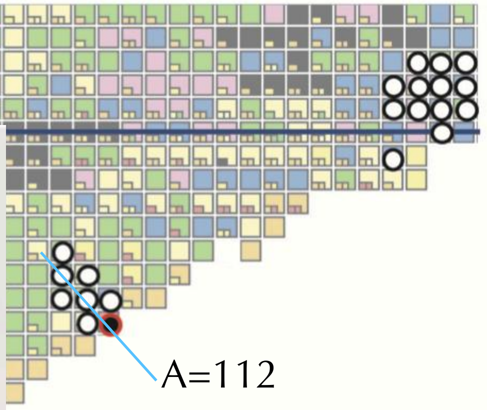


83 cts. / 220 min





FIRE ALARM during the measurement



l known mass (AME2016)

sured recently (2016-)

roved precision (11)

● First mass determination (3)

n-rich Ni region

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^{74}Ni: 58 cts. / 30 min

144 cts. / 54 min

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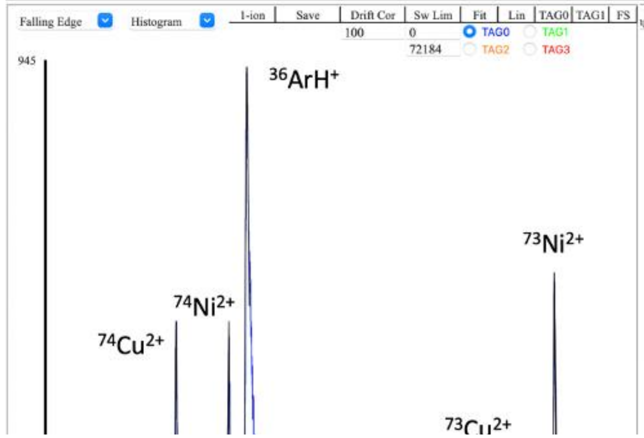

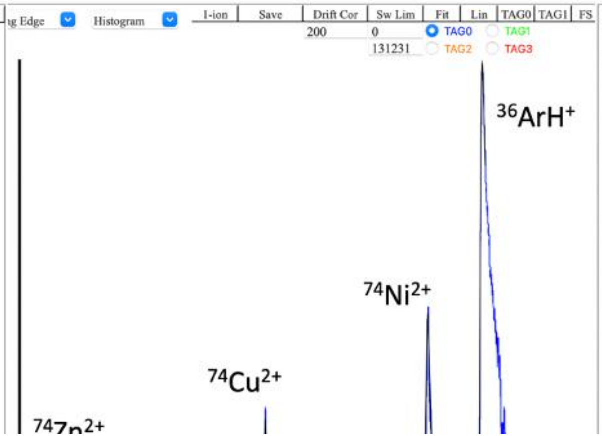

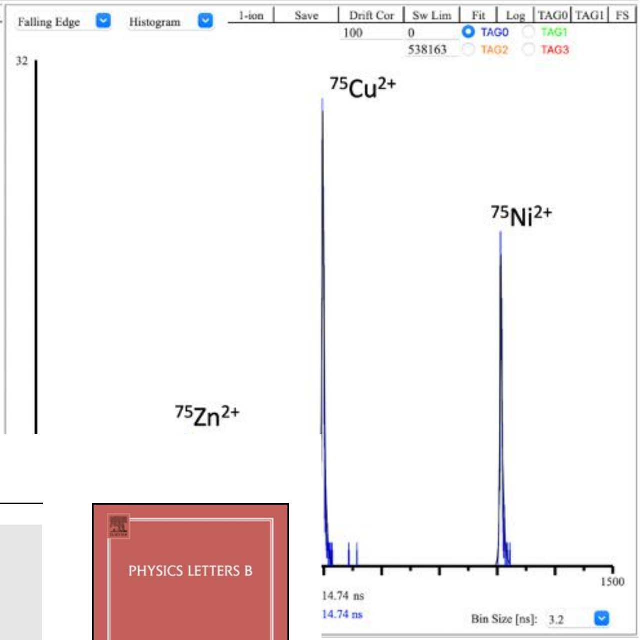

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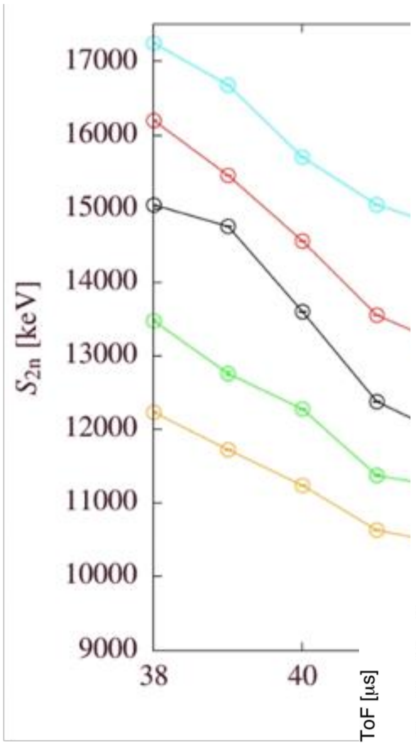
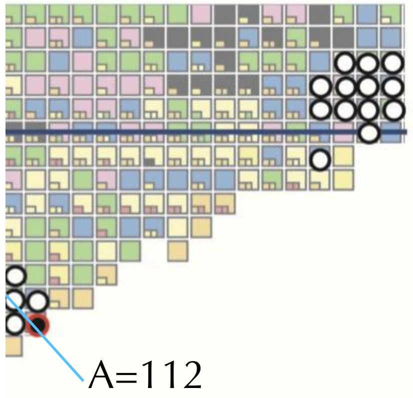
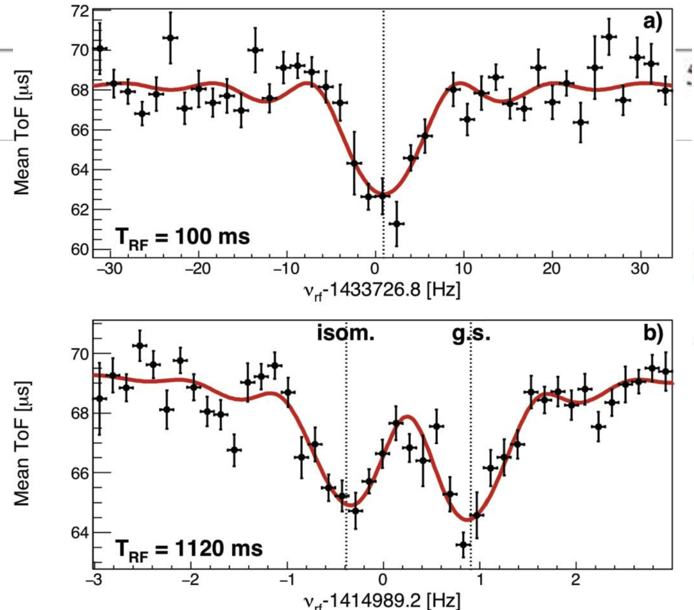
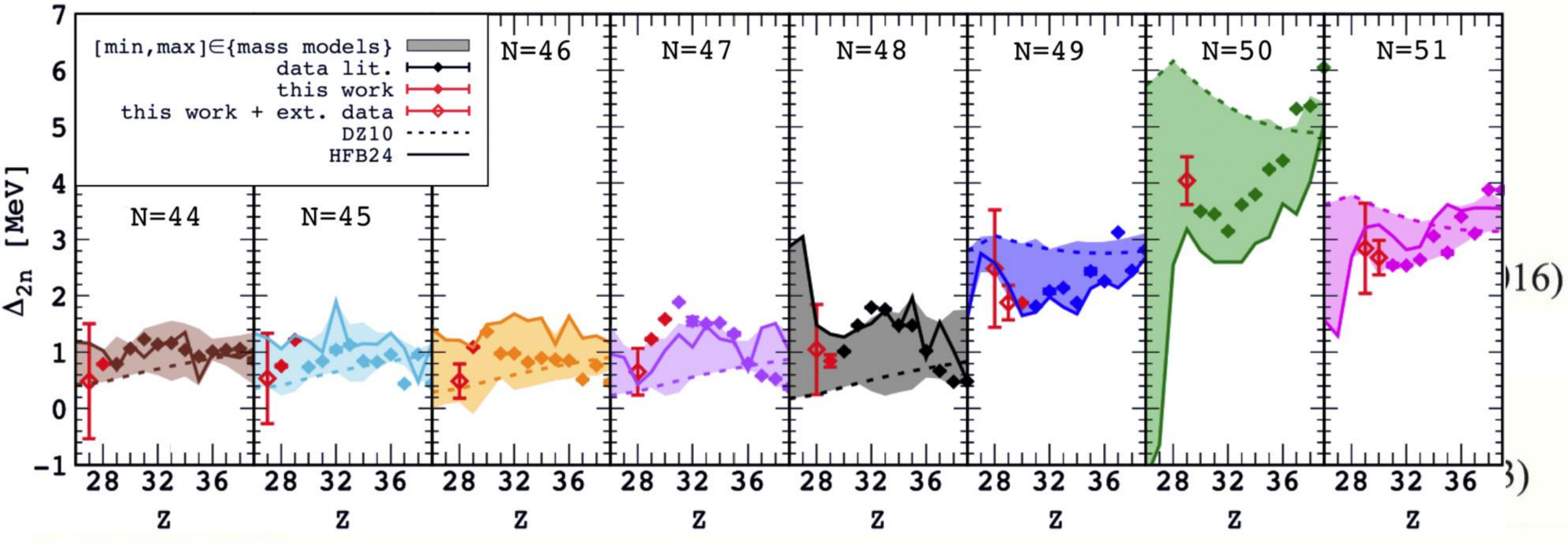
Mass measurements towards doubly magic ^{78}Ni: Hydrodynamics versus nuclear mass contribution in core-collapse supernovae

S. Giraud [a,b,*], L. Canete [c,d], B. Bastin [a], A. Kankainen [c], A.F. Fantina [a], F. Gulminelli [e], P. Ascher [f], T. Eronen [c], V. Girard-Alcindor [a,j,k], A. Jokinen [c], A. Khanam [g,h,c], I.D. Moore [c], D.A. Nesterenko [c], F. de Oliveira Santos [a], H. Penttilä [c], C. Petrone [i], I. Pohjalainen [c], A. De Roubin [c], V.A. Rubchenya [c,1], M. Vilen [c,l], J. Äystö [c]









Outlook

- The typical transport time in the gas catcher is currently >50 ms. We will improve it by modification of the inner structure. *How?*
- We also have even another parasitic measurement plan behind the gas cell. *What kinda?*
- We continue the precision mass measurements of exotic nuclei using ZD-MRTOF setup. *Which ones?*
- We also plan to use the slow RI beams for other projects besides MRTOF. *Which one?*

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If you wanna know them, please join us! 😈