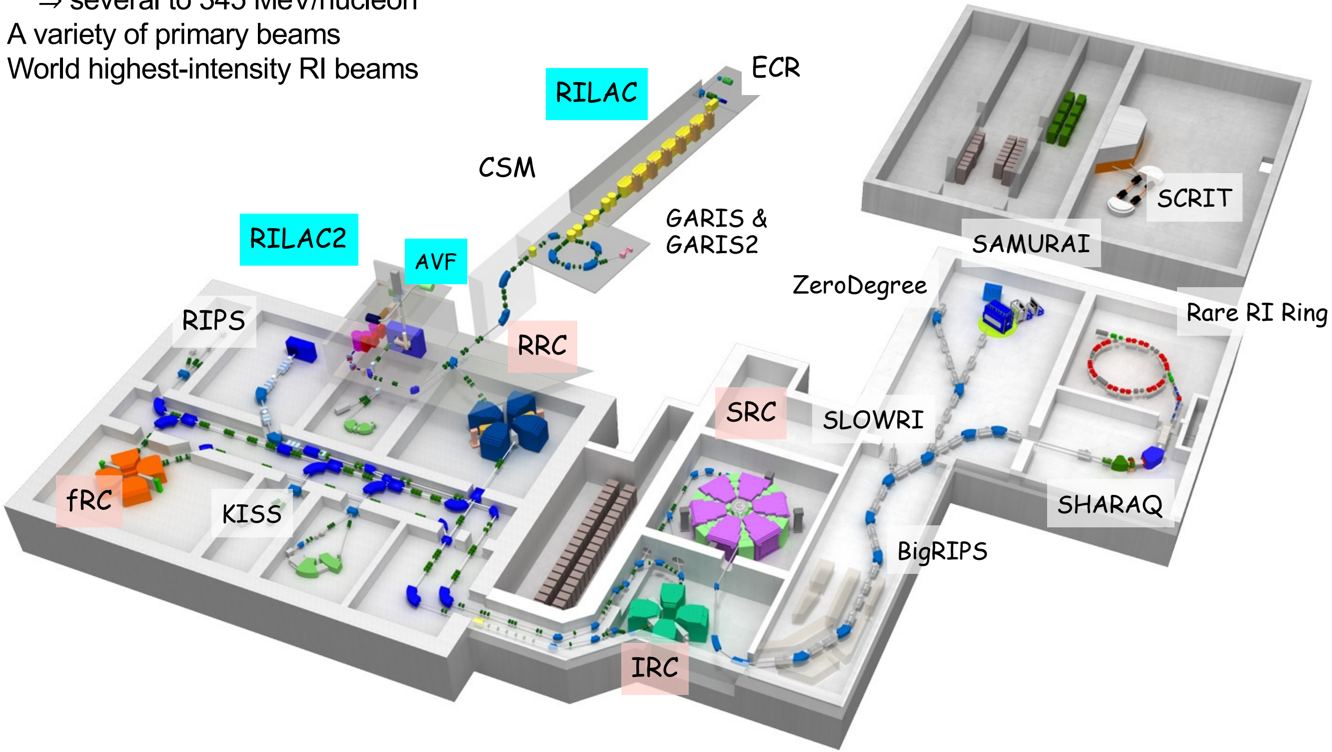
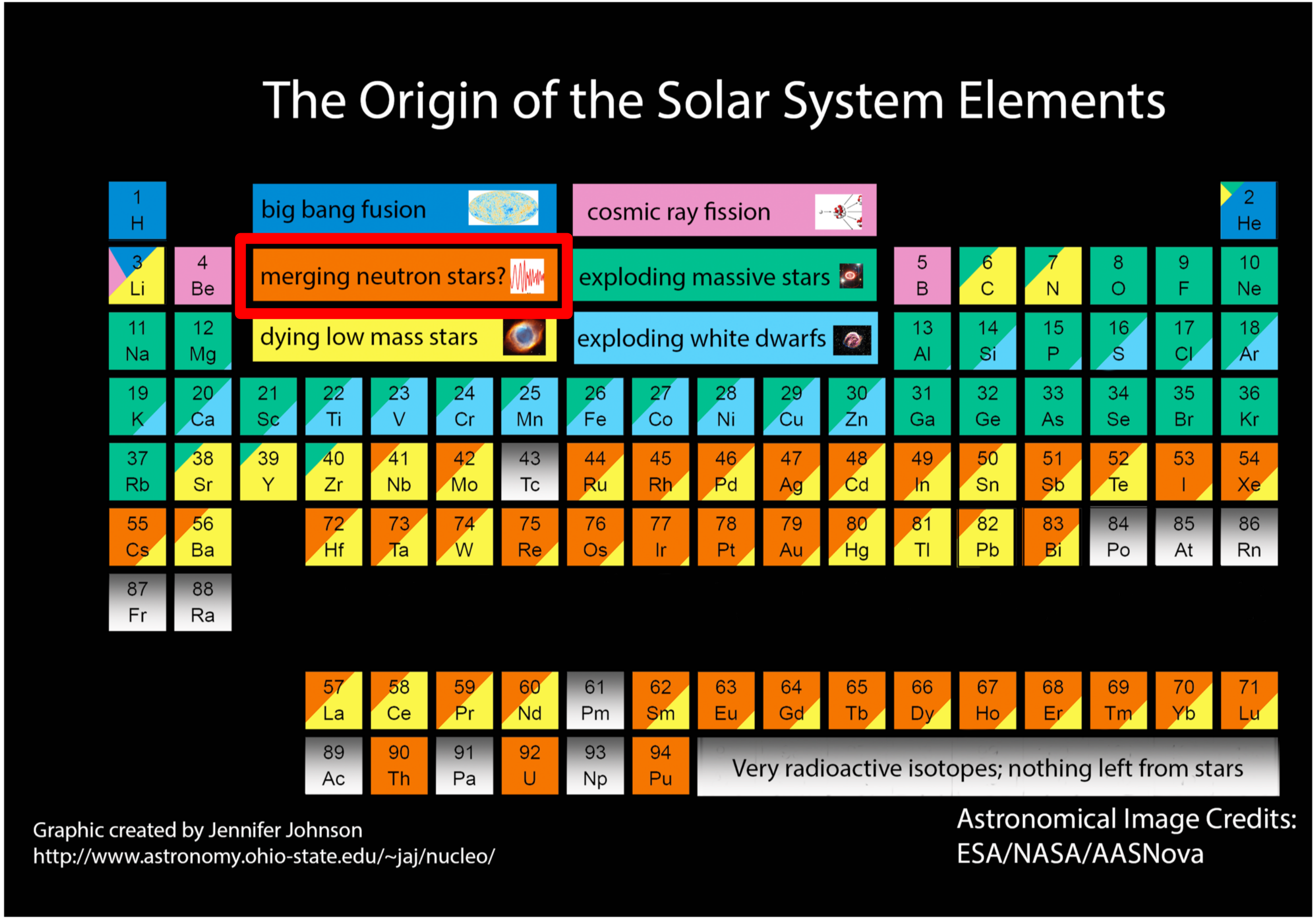
Development of a large-area position-sensitive detector for the Rare-RI Ring at Riken

Sarah Naimi (Riken)

RI Beam Factory at RIKEN

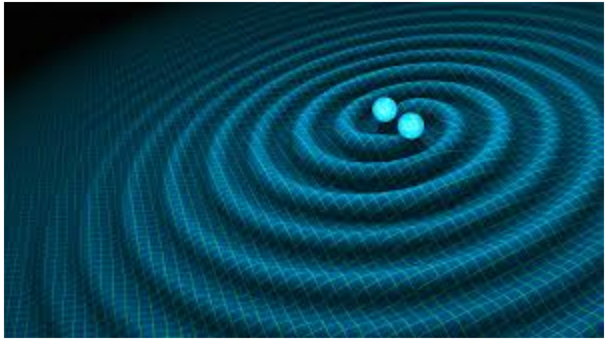
3 injectors + cascade of 4 cyclotrons
⇒ several to 345 MeV/nucleon
A variety of primary beams
World highest-intensity RI beams




The Origin of the Solar System Elements
big bang fusion
cosmic ray fission
merging neutron stars?
exploding massive stars
dying low mass stars
exploding white dwarfs
1 H
2 He
3 Li
4 Be
5 B
6 C
7 N
8 O
9 F
10 Ne
11 Na
12 Mg
13 Al
14 Si
15 P
16 S
17 Cl
18 Ar
19 K
20 Ca
21 Sc
22 Ti
23 V
24 Cr
25 Mn
26 Fe
27 Co
28 Ni
29 Cu
30 Zn
31 Ga
32 Ge
33 As
34 Se
35 Br
36 Kr
37 Rb
38 Sr
39 Y
40 Zr
41 Nb
42 Mo
43 Tc
44 Ru
45 Rh
46 Pd
47 Ag
48 Cd
49 In
50 Sn
51 Sb
52 Te
53 I
54 Xe
55 Cs
56 Ba
72 Hf
73 Ta
74 W
75 Re
76 Os
77 Ir
78 Pt
79 Au
80 Hg
81 Tl
82 Pb
83 Bi
84 Po
85 At
86 Rn
87 Fr
88 Ra
57 La
58 Ce
59 Pr
60 Nd
61 Pm
62 Sm
63 Eu
64 Gd
65 Tb
66 Dy
67 Ho
68 Er
69 Tm
70 Yb
71 Lu
89 Ac
90 Th
91 Pa
92 U
93 Np
94 Pu
Very radioactive isotopes; nothing left from stars
Graphic created by Jennifer Johnson
http://www.astronomy.ohio-state.edu/~jaj/nucleo/
Astronomical Image Credits:
ESA/NASA/AASNova

Gravitational Waves discovery

Neutron star mergers!

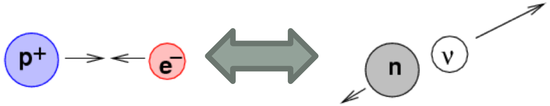


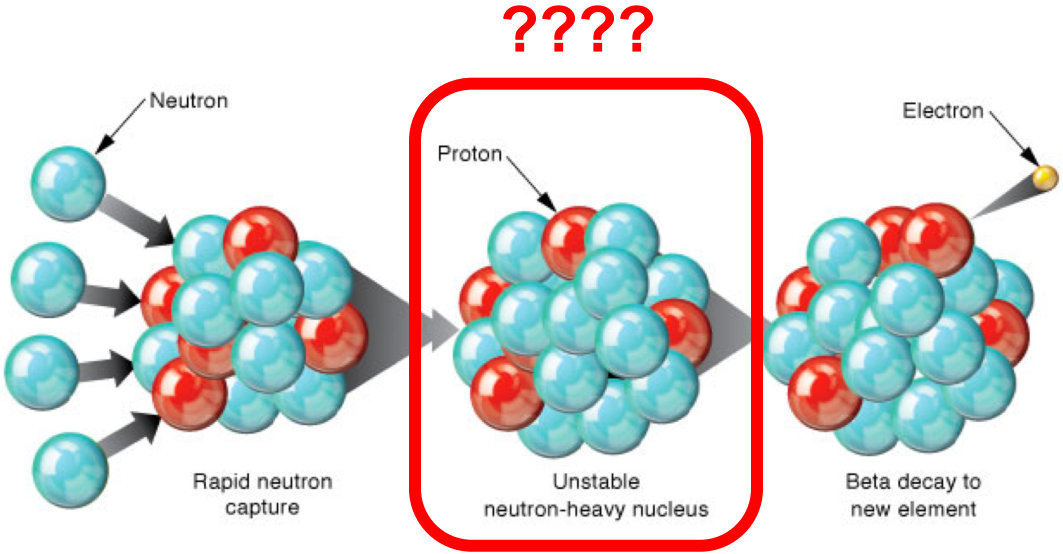
LIGO observatory in USA

The light was also observed

This is very exciting for our field!!!

The nuclear physics

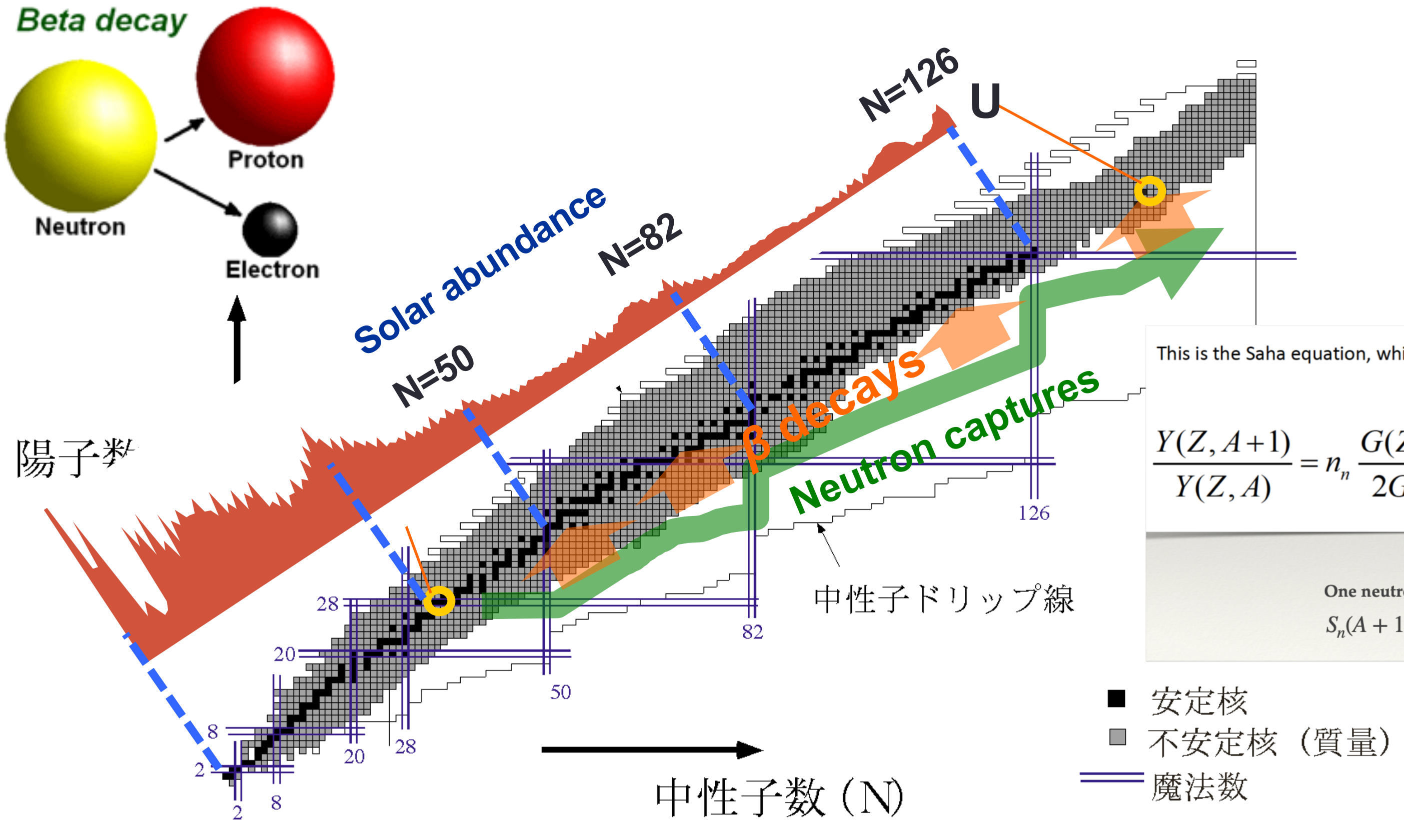




Neutron is converted to proton via beta decay. Number of protons defines the element.

『How were heavy elements made ?』

rapid neutron capture: r-process



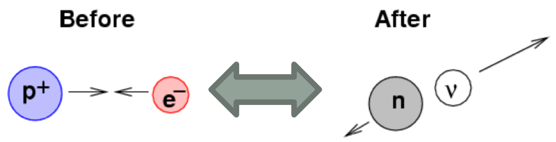
This is the Saha equation, which is true when (n,g)=(g,n) equilibrium holds:

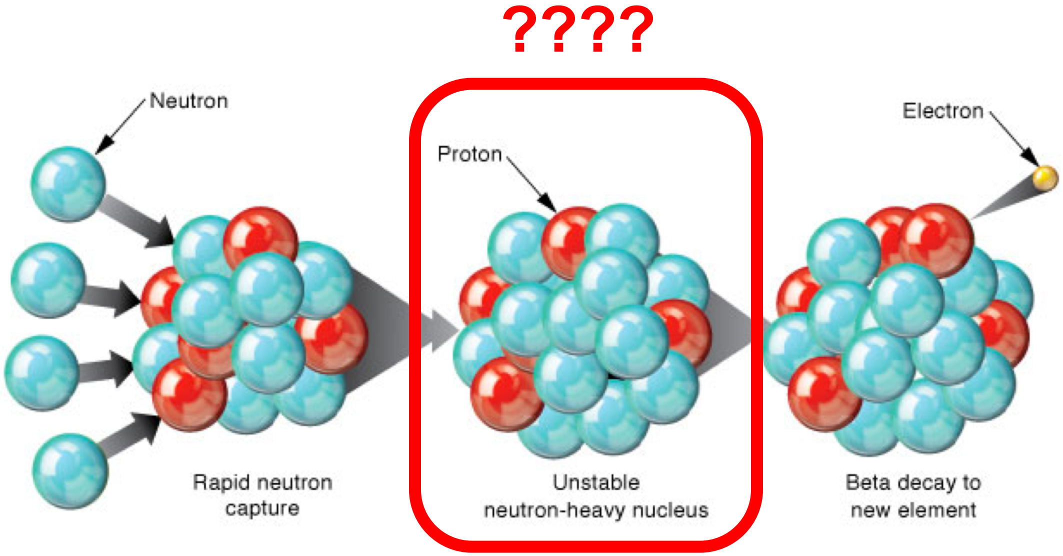
$$\frac{Y(Z,A+1)}{Y(Z,A)} = n_n \frac{G(Z,A+1)}{2G(Z,A)} \left[\frac{A+1}{A} \frac{2\pi\hbar^2}{m_u kT} \right]^{3/2} \exp(S_n / kT)$$

One neutron separation energy:

$$S_n(A+1,Z) = M(A,Z) + m_N - M(A+1,Z)$$

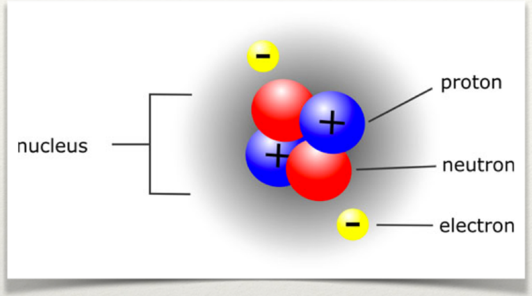
The nuclear physics





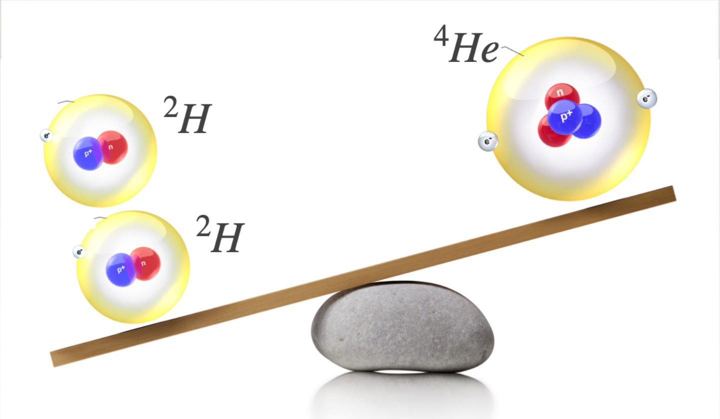
Neutron is converted to proton via beta decay. Number of protons defines the element.

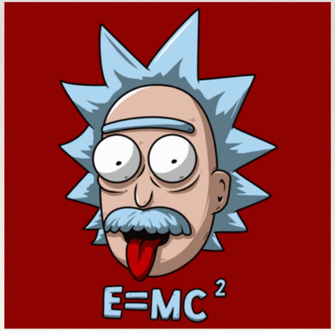
Nuclear binding energy

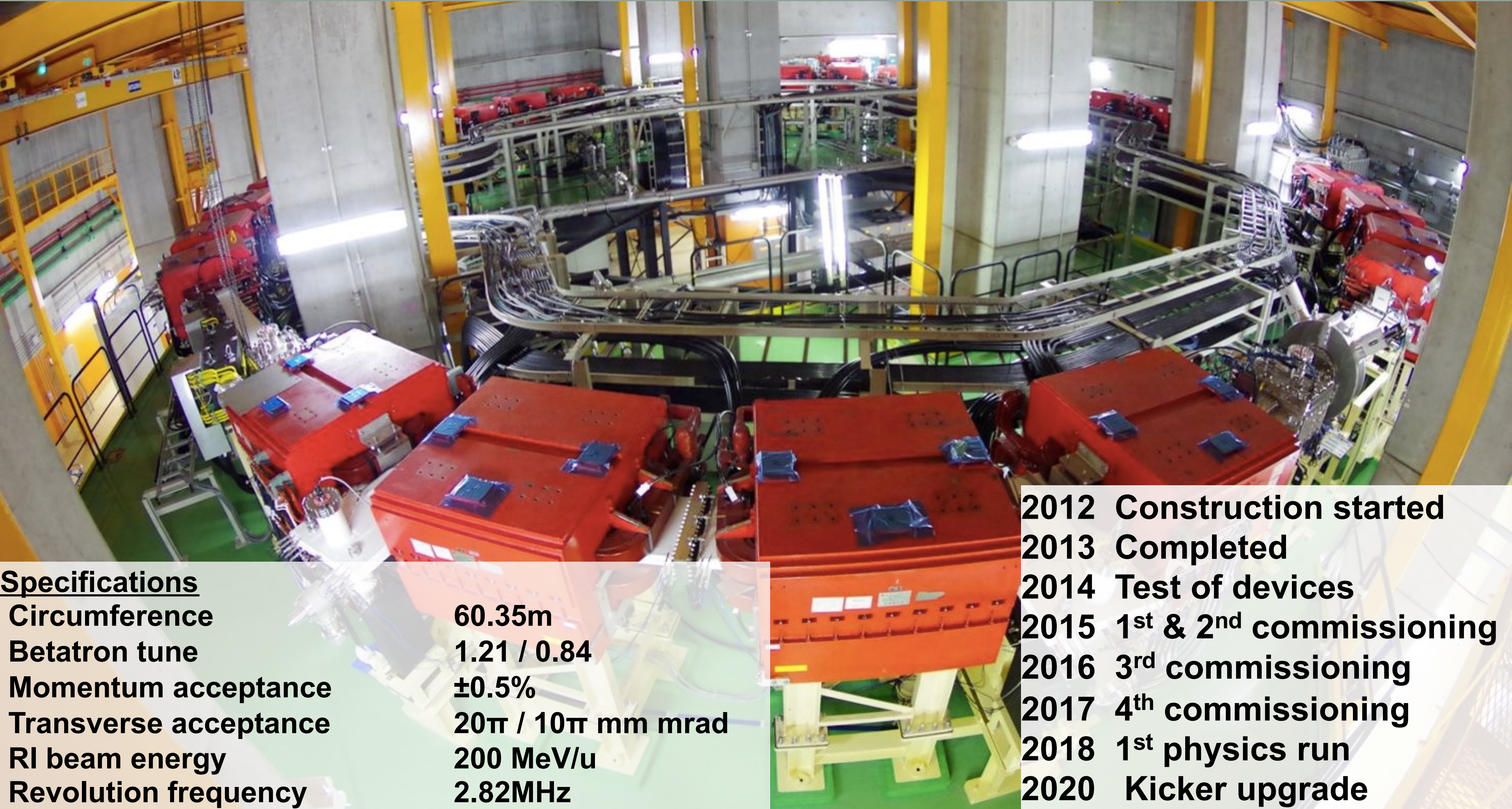


$$M(^4He) = 2 \cdot m_p + 2 \cdot m_n + 2 \cdot m_e$$

- Binding Energy







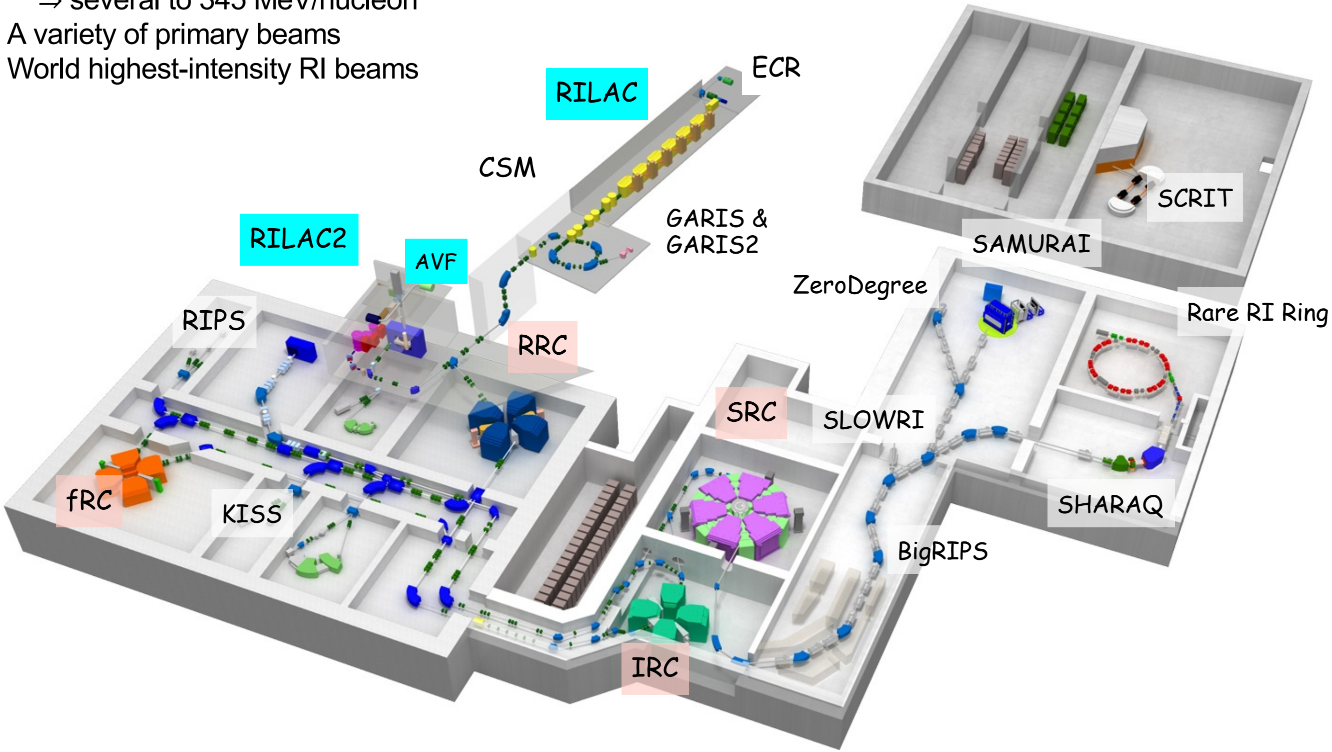
Specifications

Circumference	60.35m
Betatron tune	1.21 / 0.84
Momentum acceptance	±0.5%
Transverse acceptance	20π / 10π mm mrad
RI beam energy	200 MeV/u
Revolution frequency	2.82MHz

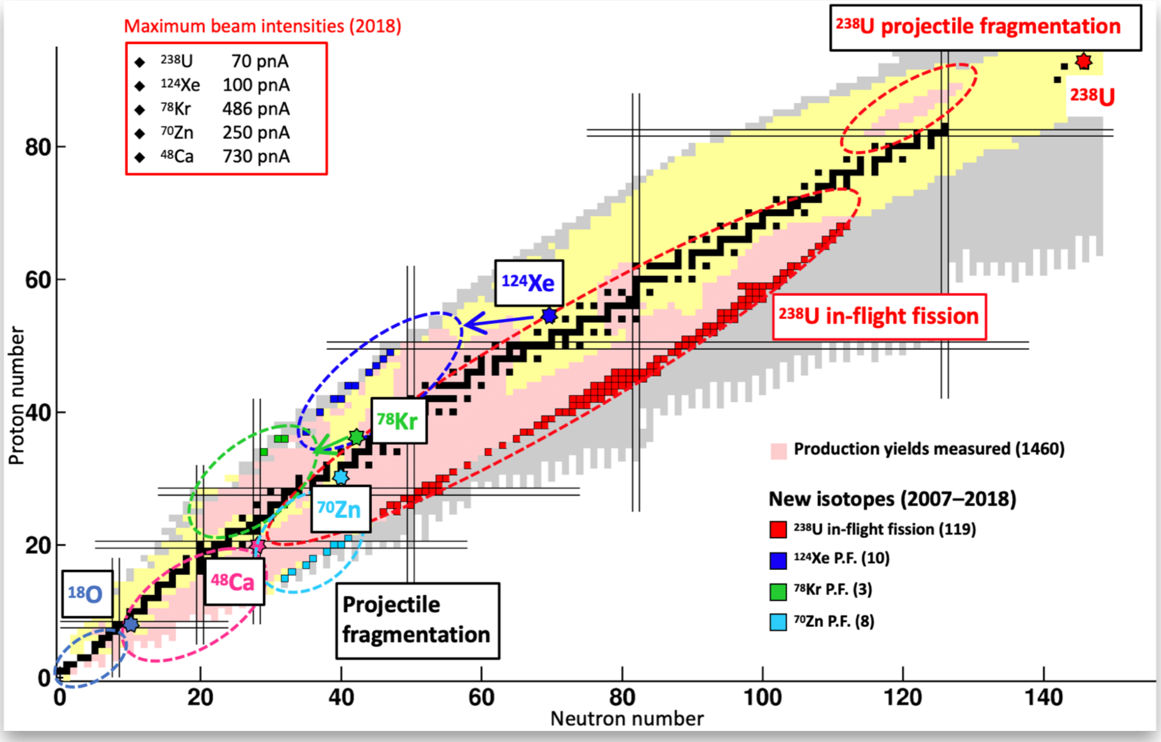
2012 Construction started
2013 Completed
2014 Test of devices
2015 1st & 2nd commissioning
2016 3rd commissioning
2017 4th commissioning
2018 1st physics run
2020 Kicker upgrade

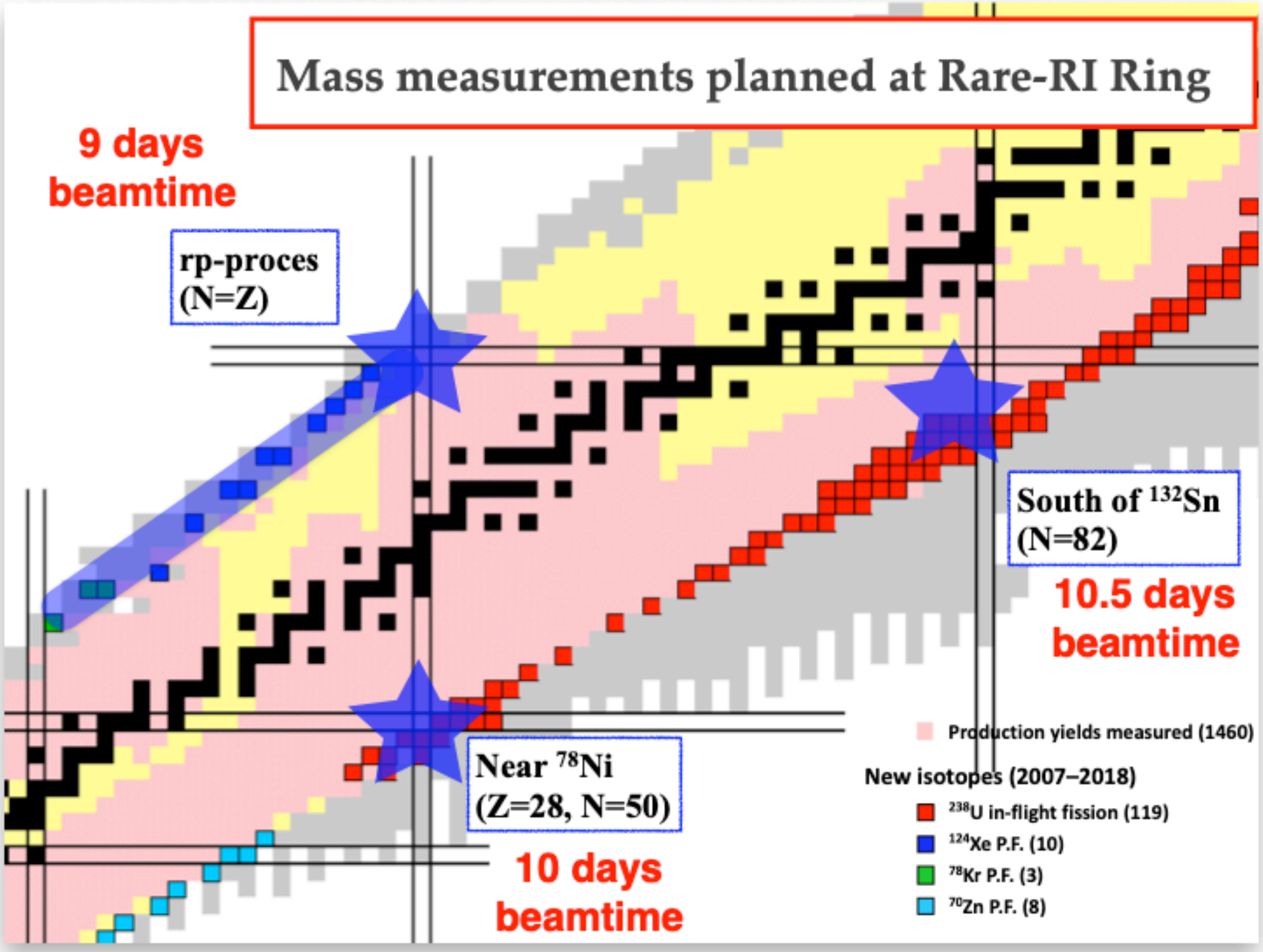
RI Beam Factory at RIKEN

3 injectors + cascade of 4 cyclotrons
⇒ several to 345 MeV/nucleon
A variety of primary beams
World highest-intensity RI beams

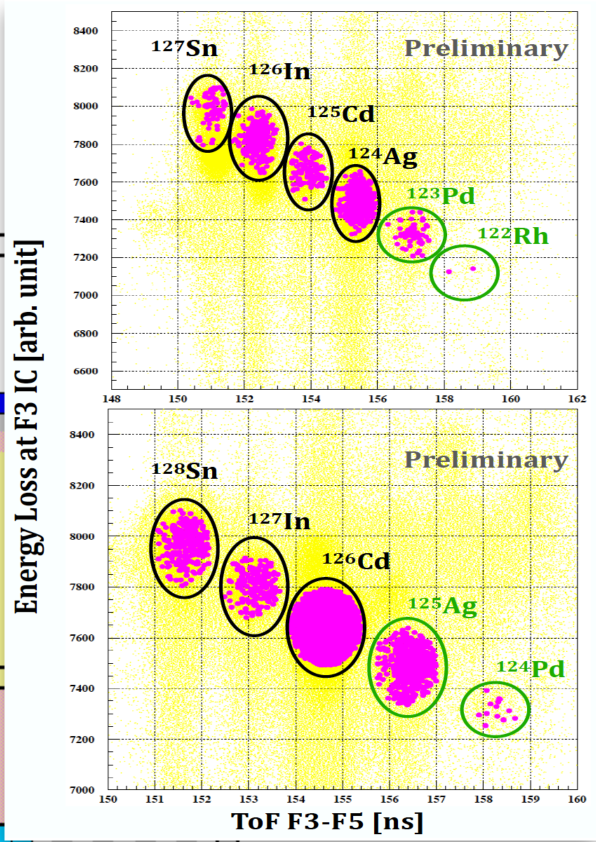


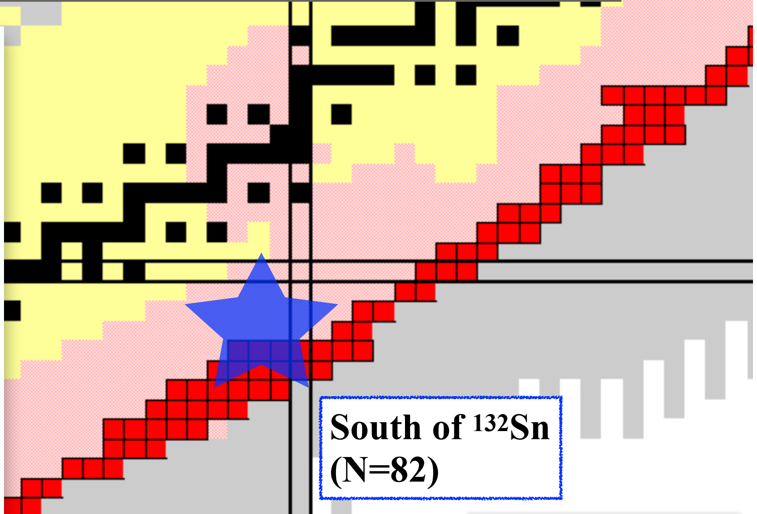
Production of RI beam at RIBF



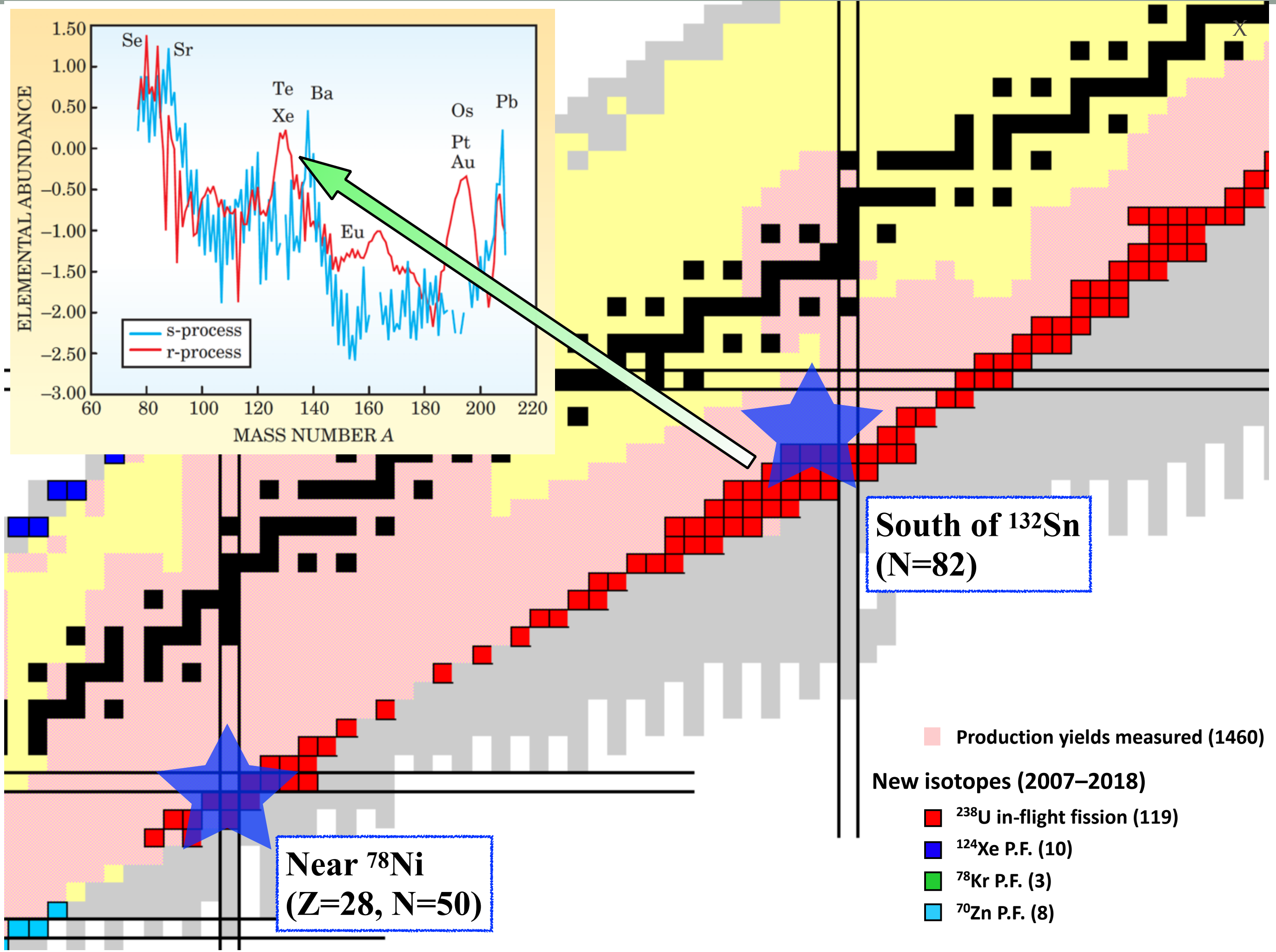

Mass measurements planned at Rare-RI Ring
9 days beamtime
rp-proces (N=Z)
South of 132Sn (N=82)
10.5 days beamtime
Near 78Ni (Z=28, N=50)
10 days beamtime
Production yields measured (1460)
New isotopes (2007–2018)
238U in-flight fission (119)
124Xe P.F. (10)
78Kr P.F. (3)
70Zn P.F. (8)

In November 2018: ^{122}Rh, ^{123,124}Pd, ^{125}Ag isotopes were measured
^{125}Pd, ^{126}Ag isotopes are planned to be measured in 2021





Hongfu Li
PhD student at Riken


Se
Sr
Te
Xe
Ba
Eu
Os
Pt
Au
Pb
ELEMENTAL ABUNDANCE
MASS NUMBER A
s-process
r-process
South of ^{132}Sn (N=82)
Near ^{78}Ni (Z=28, N=50)
Production yields measured (1460)
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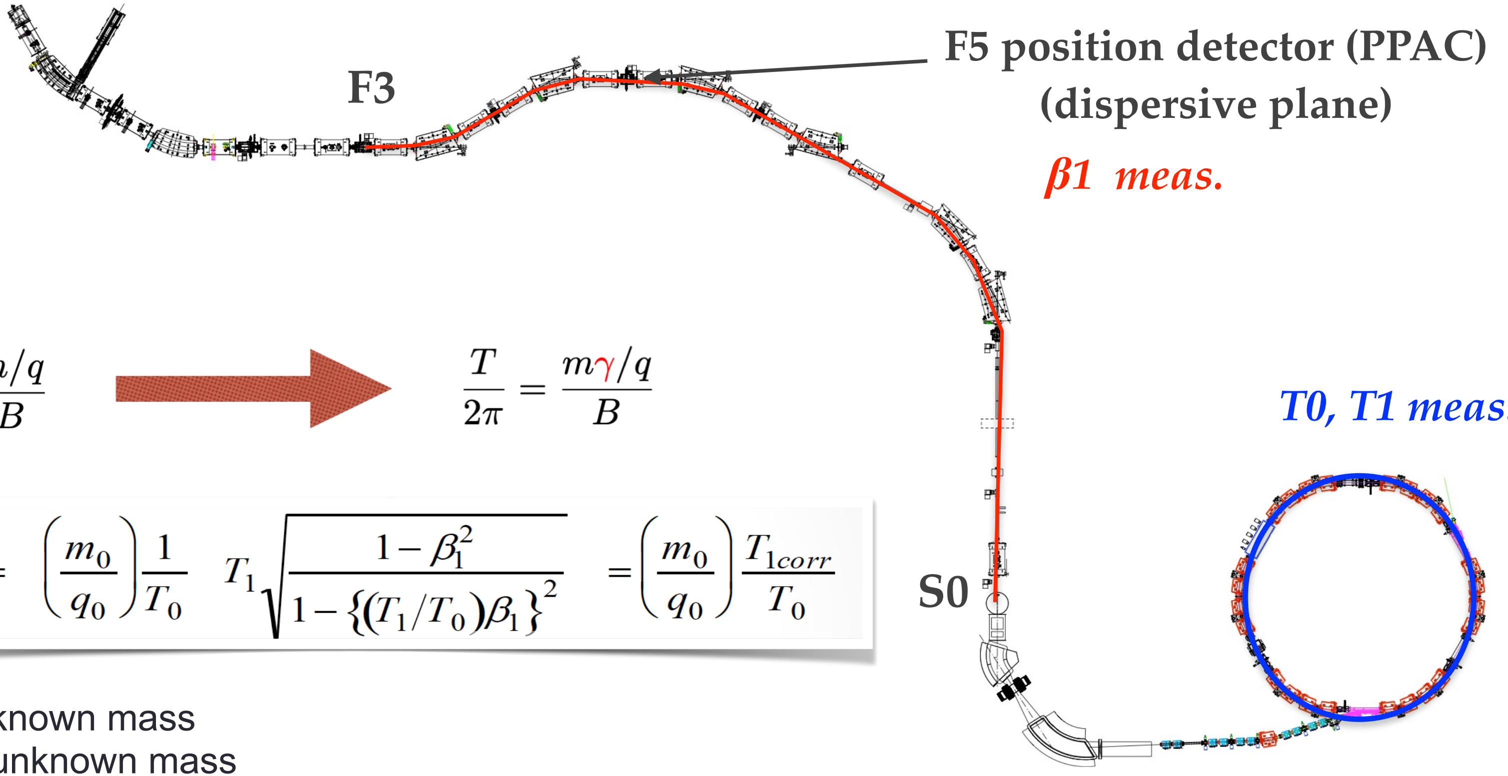
^{238}U in-flight fission (119)
^{124}Xe P.F. (10)
^{78}Kr P.F. (3)
^{70}Zn P.F. (8)

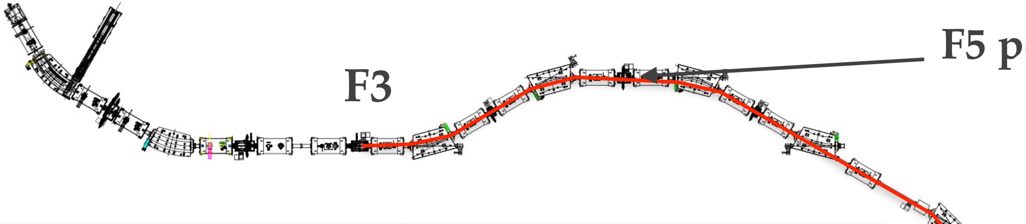
Mass measurement principle

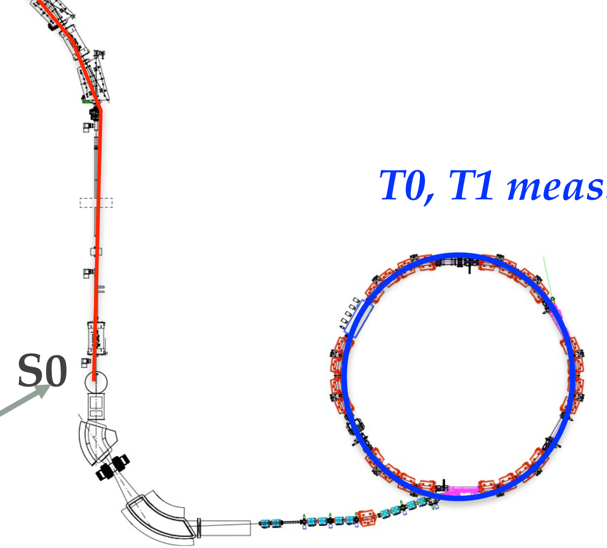


$$\frac{T}{2\pi} = \frac{m/q}{B} \quad \Rightarrow \quad \frac{T}{2\pi} = \frac{m\gamma/q}{B}$$

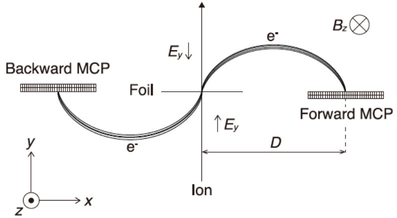
$$\frac{m_1}{q_1} = \left(\frac{m_0}{q_0}\right)\frac{1}{T_0} \quad T_1\sqrt{\frac{1-\beta_1^2}{1-\{(T_1/T_0)\beta_1\}^2}} = \left(\frac{m_0}{q_0}\right)\frac{T_{1corr}}{T_0}$$

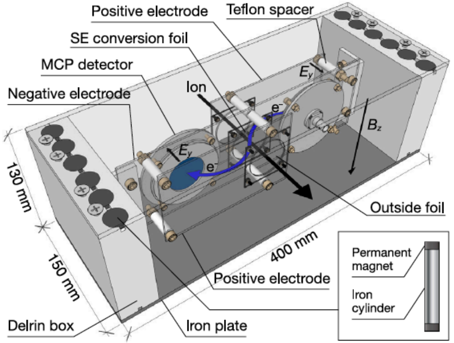
m_0 is known mass
m_1 is unknown mass





$$\frac{m_1}{q_1} = \left(\frac{m_0}{q_0}\right)\frac{1}{T_0}\, T_1\sqrt{\frac{1-\beta_1^2}{1-\{(T_1/T_0)\beta_1\}^2}} = \left(\frac{m_0}{q_0}\right)\frac{T_{1corr}}{T_0}$$



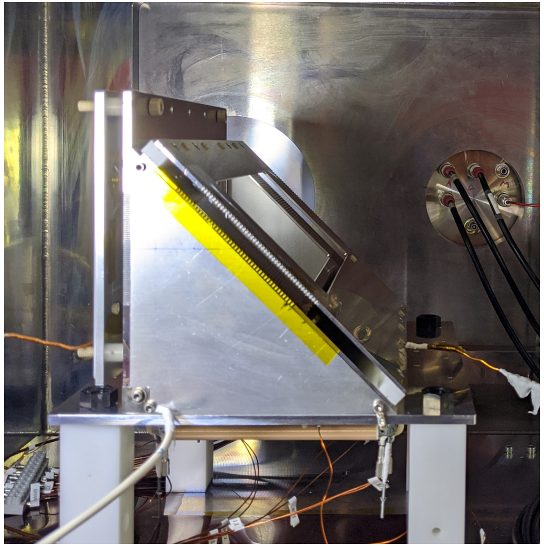


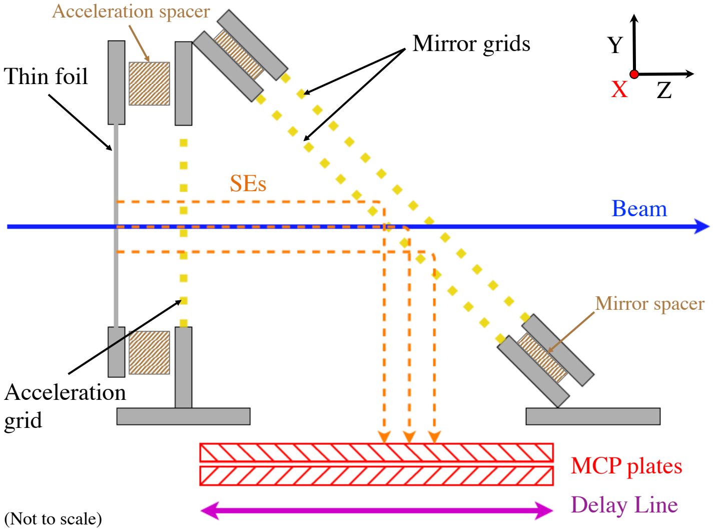
S. Suzuki, NIMA 965 (2020)

σ = 38ps, eff = 95%, dE/E<10^{-5}

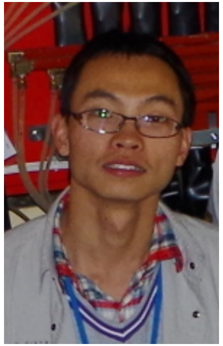
Large area position-sensitive DL-E-MCP

Thin C-foil → low energy loss

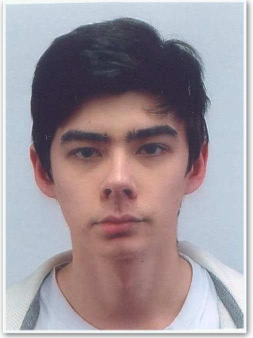




G. Hudson-Chang
Master (Surrey Uni.)

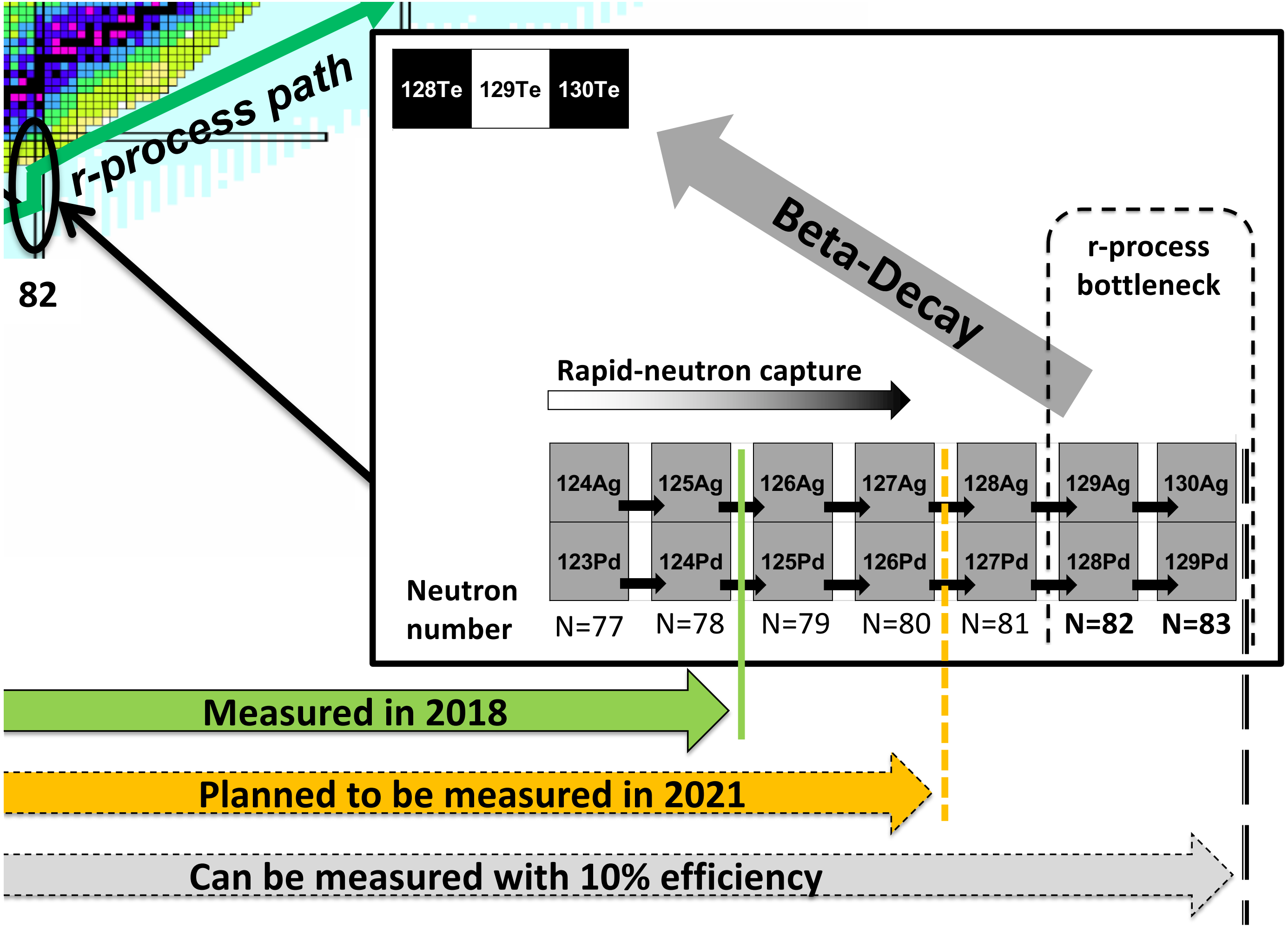


Z. Ge, PhD
(IMP/Riken)

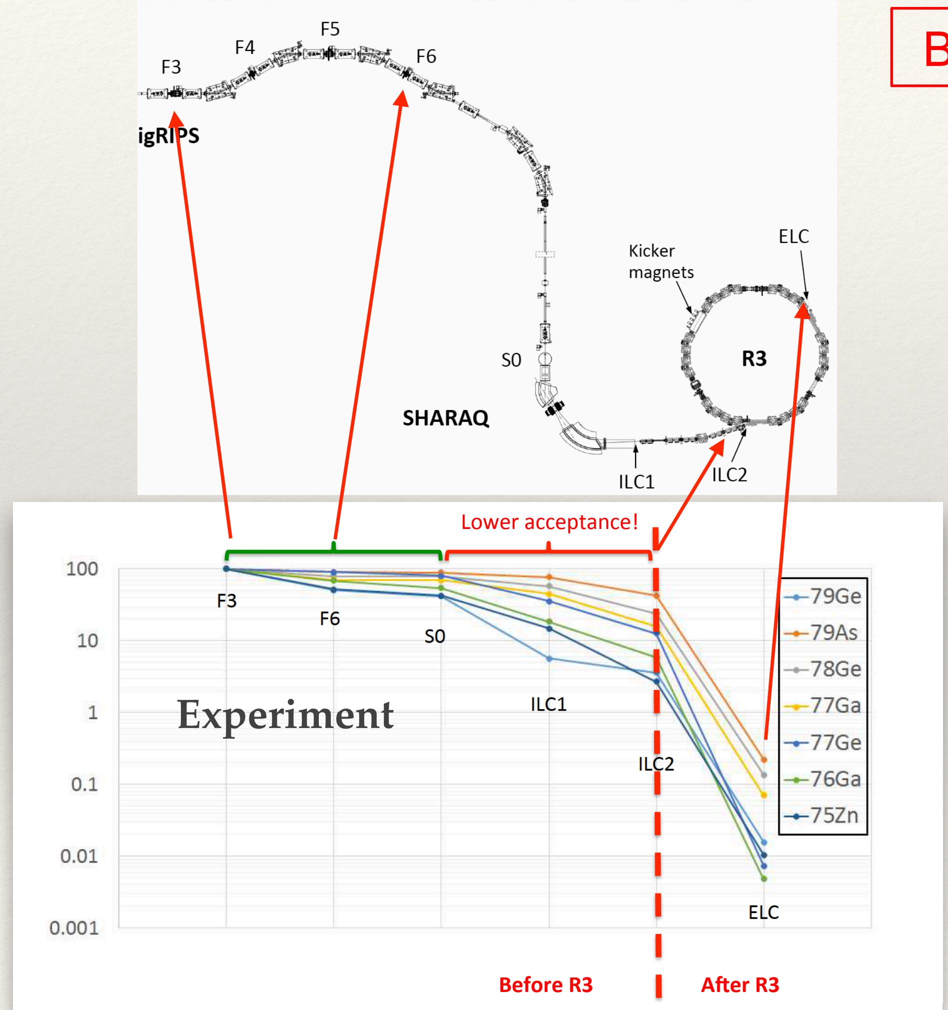


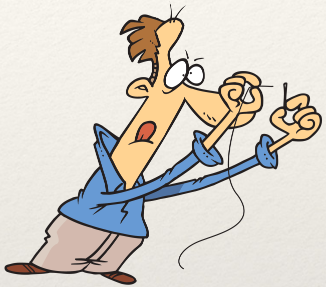
R. Crane
Master (Surrey Uni)

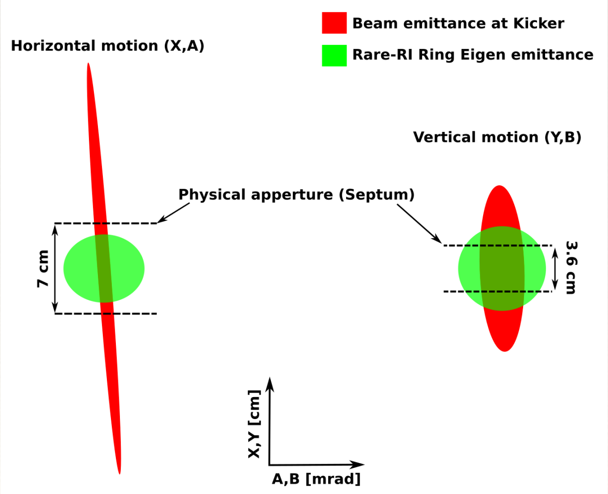
Foil (Mylar:1um) << PPAC thickness (Mylar:10um)
DL-MCP: ø120mm ~ PPAC (240x150mm)


r-process path
82
128Te
129Te
130Te
Beta-Decay
r-process bottleneck
Rapid-neutron capture
124Ag
125Ag
126Ag
127Ag
128Ag
129Ag
130Ag
123Pd
124Pd
125Pd
126Pd
127Pd
128Pd
129Pd
Neutron number
N=77
N=78
N=79
N=80
N=81
N=82
N=83
Measured in 2018
Planned to be measured in 2021
Can be measured with 10% efficiency

Before 2018: Efficiency issue

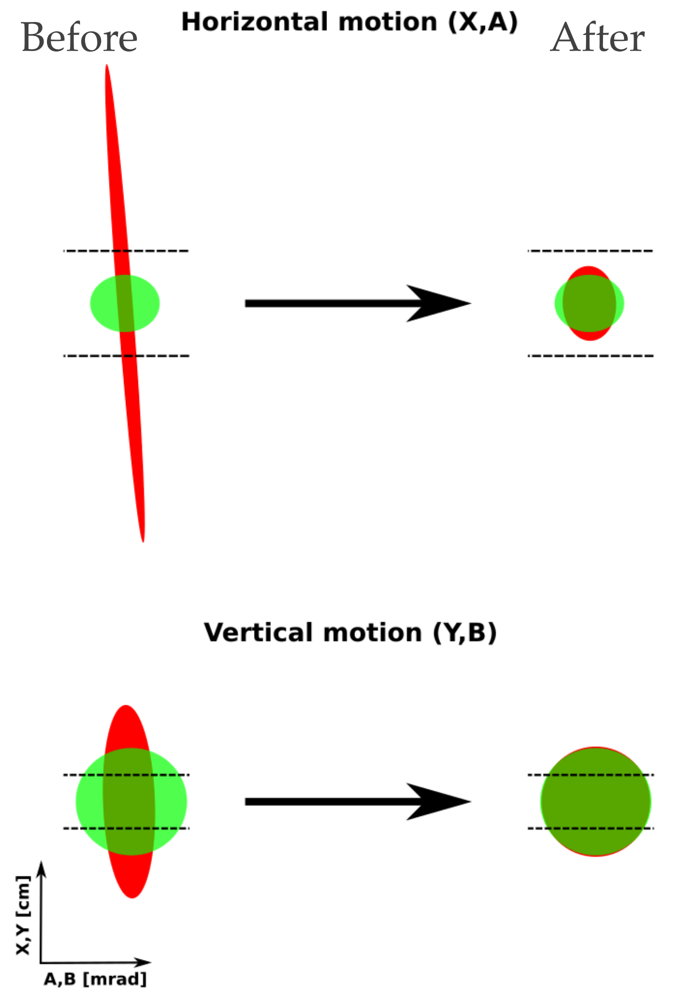




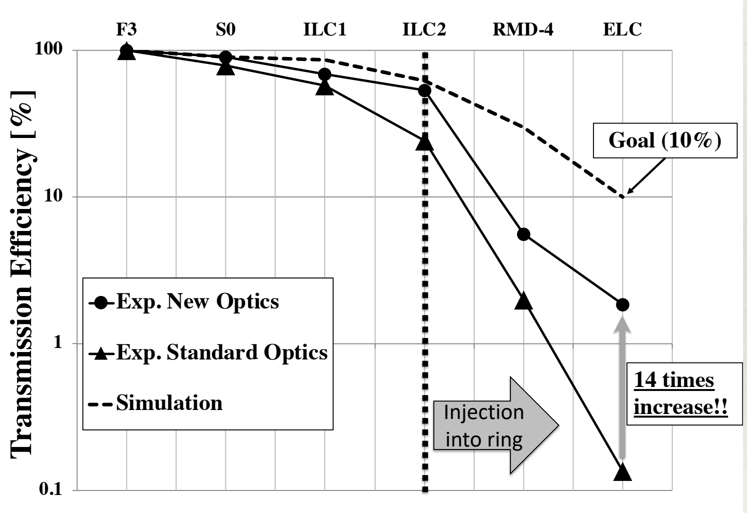


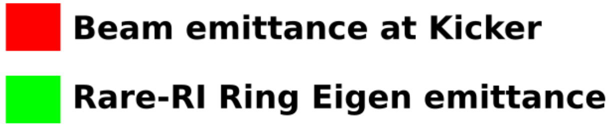
Emittance at Kicker magnets center

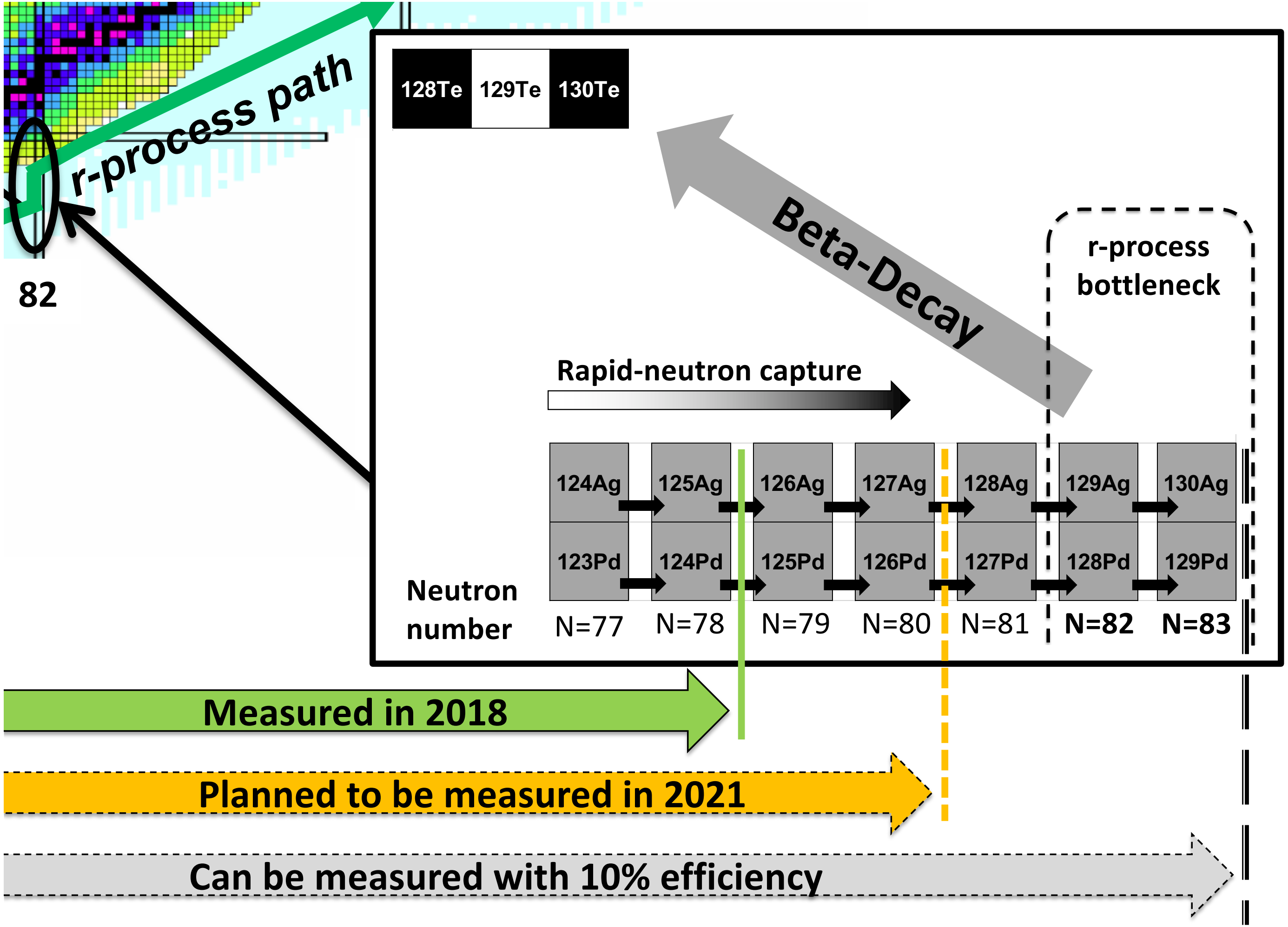
Redesign the injection optics for Rare-RI Ring



Efficiency: x14 times
Total R3 eff. 2%



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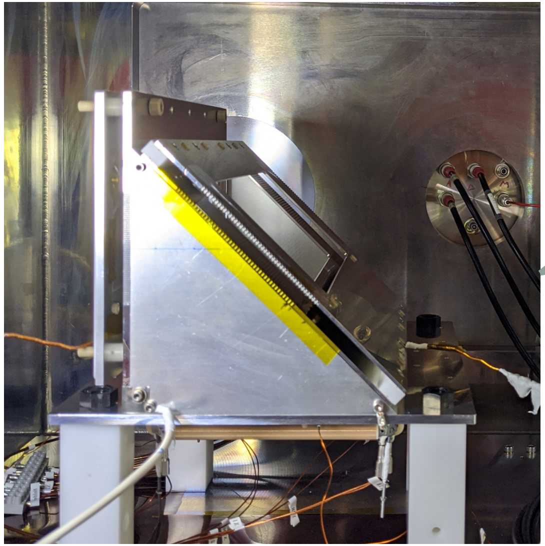
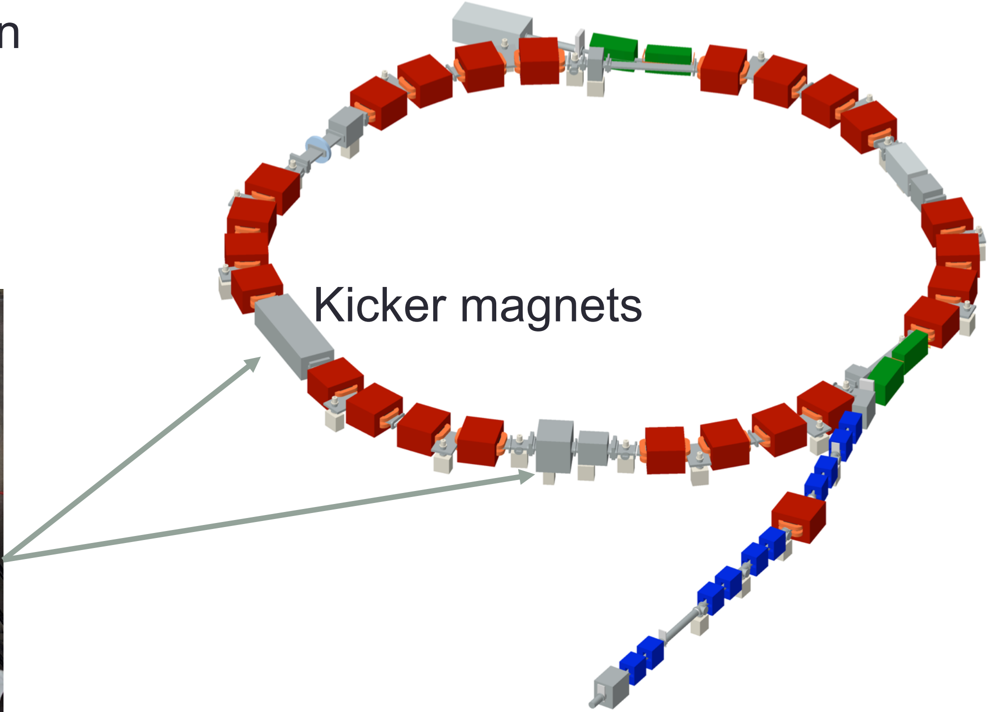
Neutron number
N=77 N=78 N=79 N=80 N=81 N=82 N=83
Measured in 2018
Planned to be measured in 2021
Can be measured with 10% efficiency

Large area position-sensitive DL-E-MCP

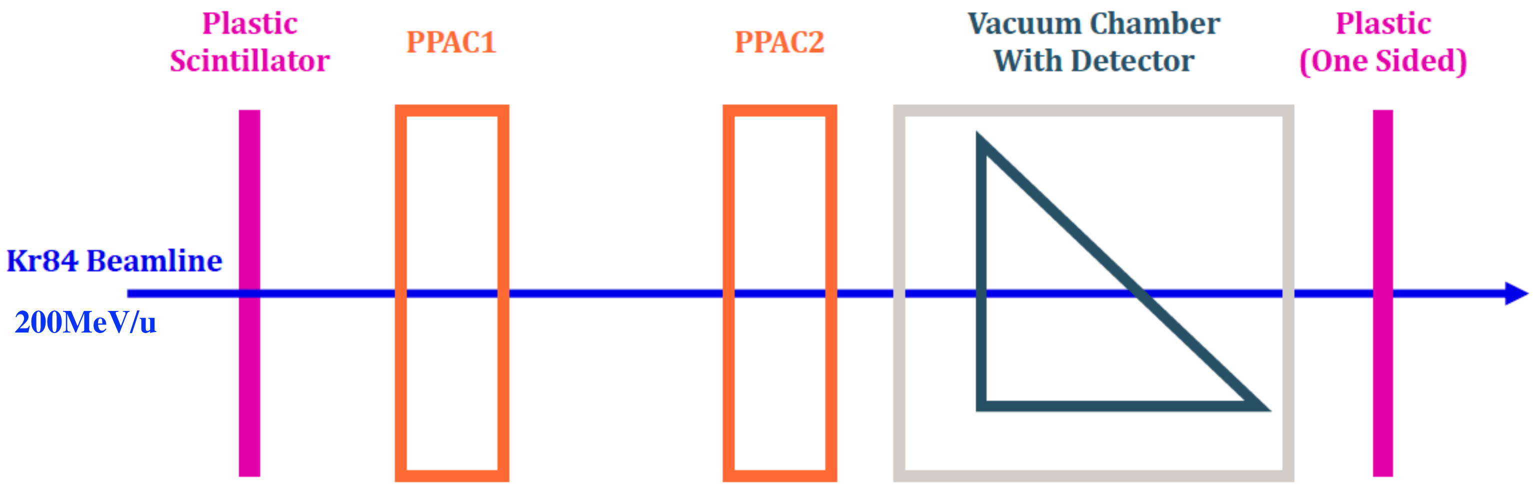
New kicker magnets configuration



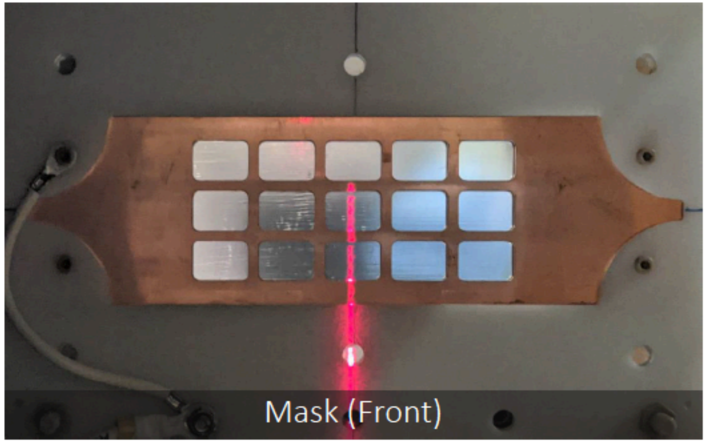


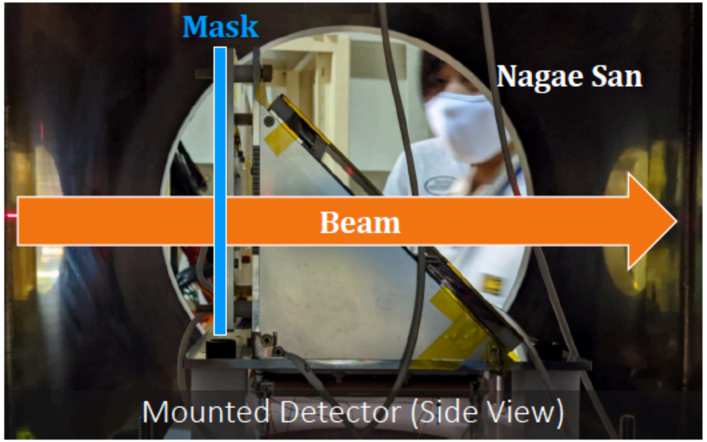
DL-E-MCP could be placed inside the kicker magnet to monitor emittance or just after

HIMAC test experiments



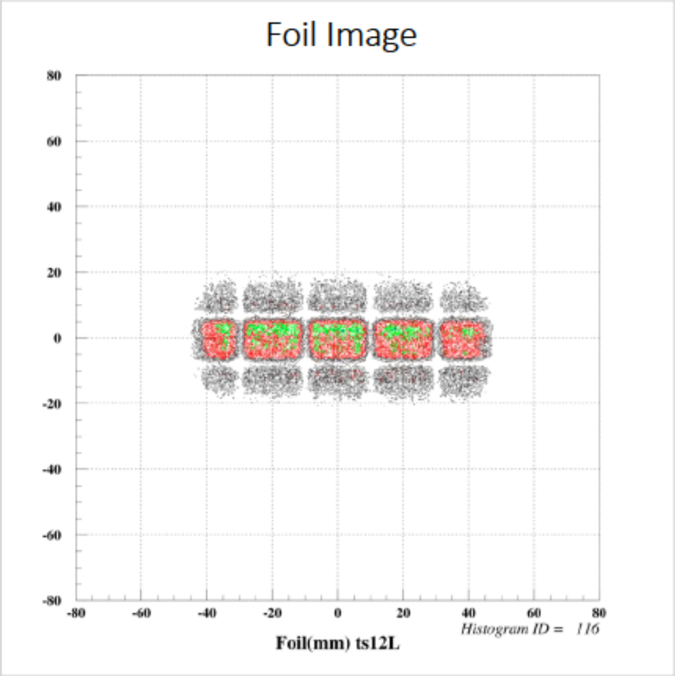
HIMAC test experiments

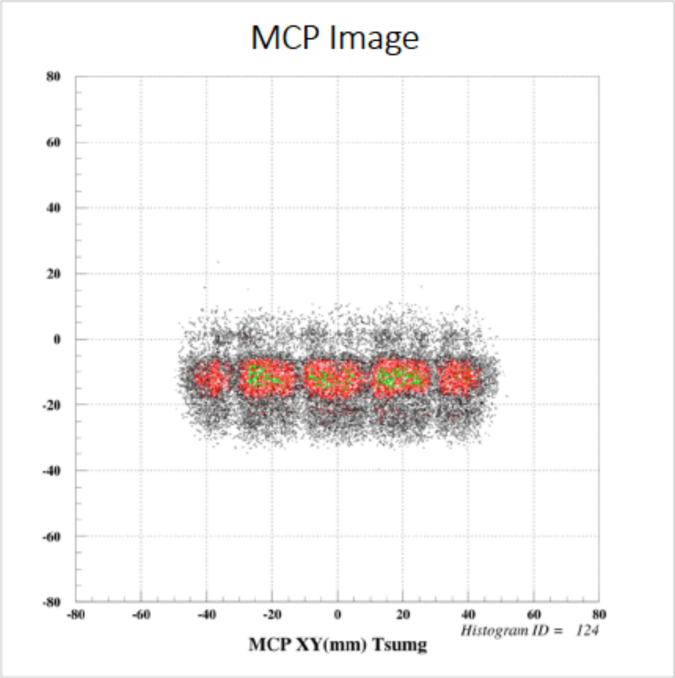




A copper mask is put in front of the foil to make sure PPACs and DL-E-MCP are aligned

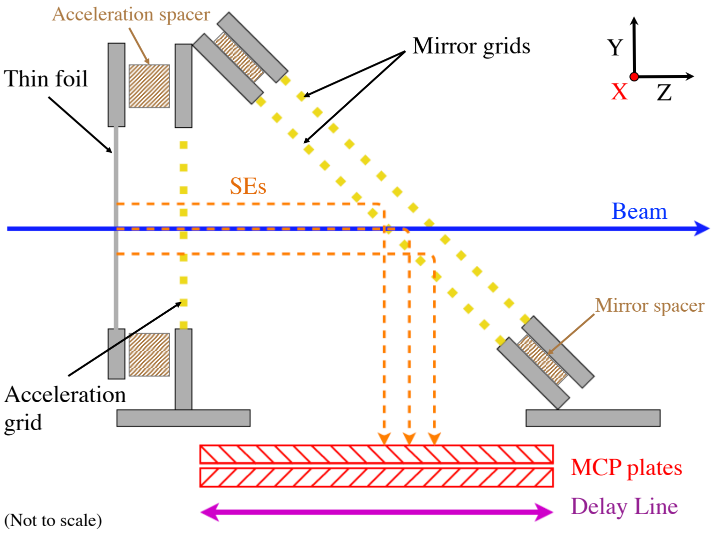
HIMAC test experiments





HIMAC test experiments

	Jul19	Nov19	Oct20(1)	Oct20(2)
New wiring method	X	O	O	O
Pitch of girds [mm]	1	2	1	1
Mirr Spacer [mm]	8	8	8	6
Acc Spacer [mm]	10	10	10	8
Acc. Potential [kV]	3	4	4	7



Good position resolution overall the large area:

- Homogenous electric field
- High acceleration voltage (less spread)

Homogenous electric field

- New wiring method (tighter wires and same tension)
- Smaller pitch

High acceleration voltage

- Changed acceleration and mirror spacers

HIMAC test experiments

	Jul19	Nov19	Oct20(1)	Oct20(2)
New wiring method	X	O	O	O
Pitch of girds [mm]	1	2	1	1
Mirr Spacer [mm]	8	8	8	6
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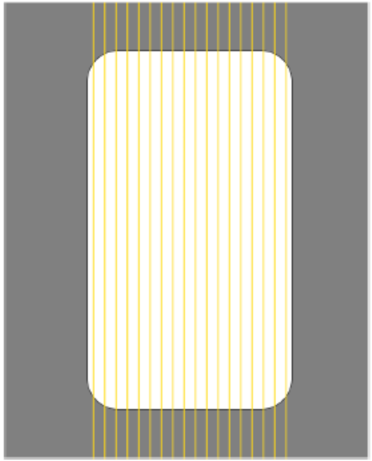
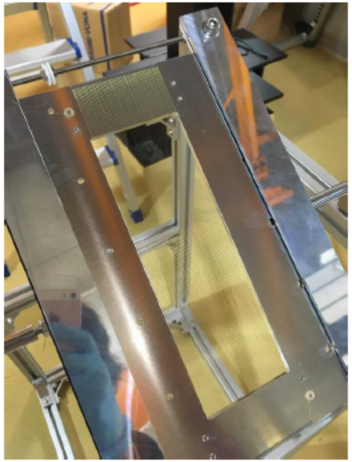
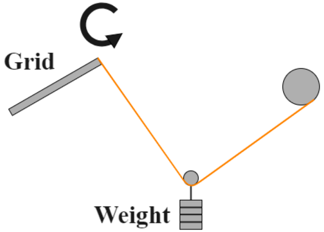
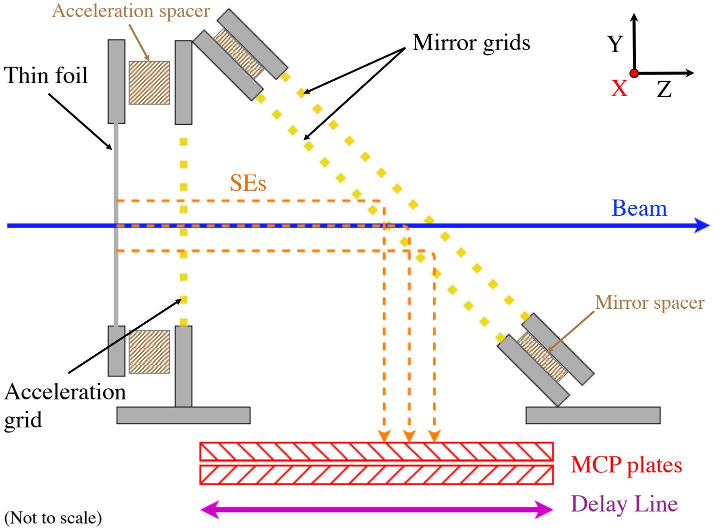
Acc. Potential [kV]	3	4	4	7

Pitch: distance between neighboring wires





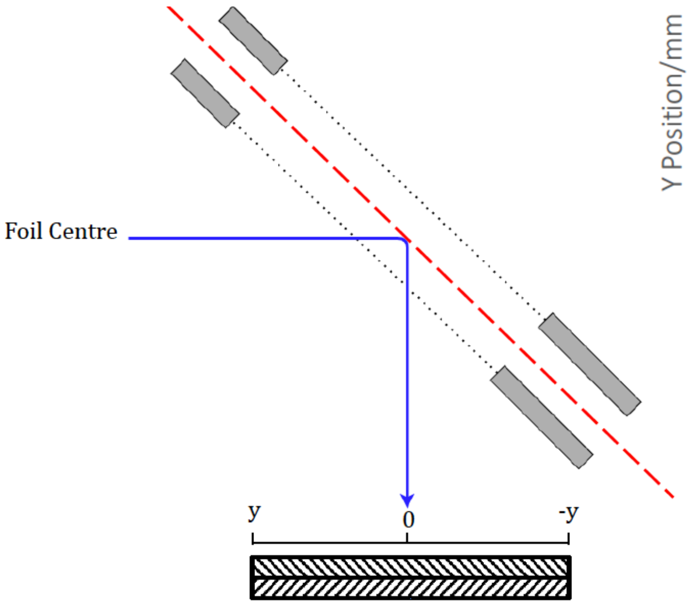




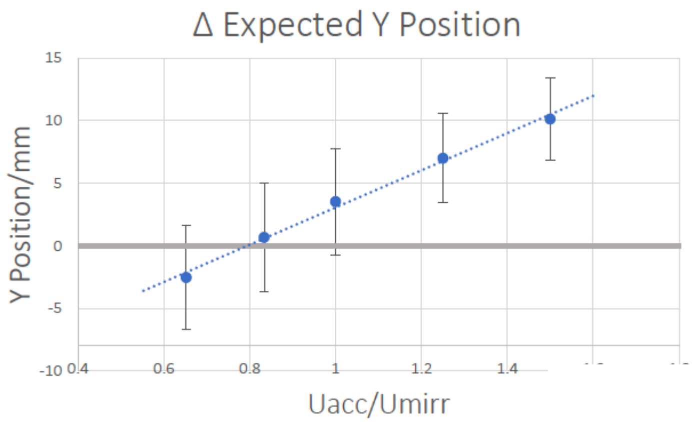
Higher acceleration voltage leads to less spread and therefore better resolution.
Spacer thickness is important to prevent discharge at higher voltage.

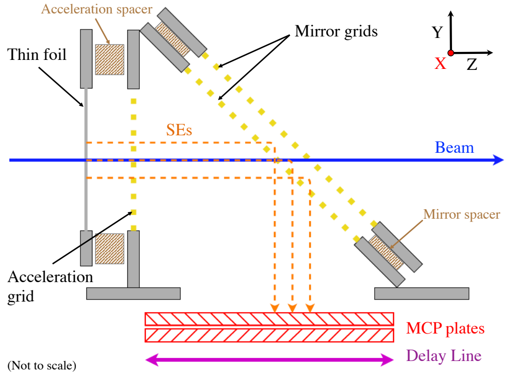
Voltage optimization method

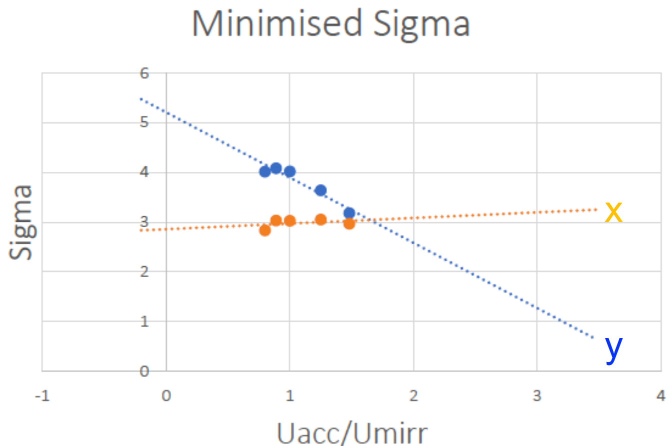
Keep acceleration voltage fixed and varying mirror voltage



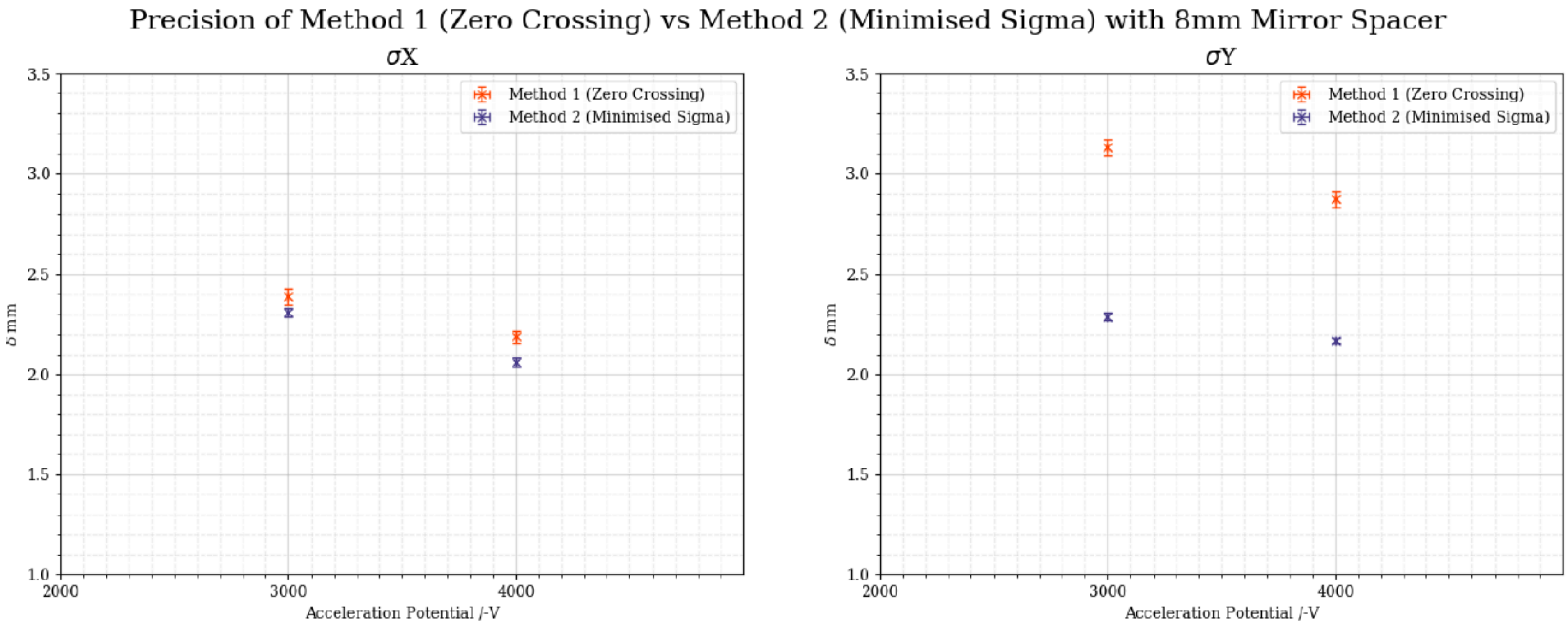
Zero crossing method to Calibrate for centre position on the mirrors corresponding to the centre position on the MCP







Comparing two optimization methods



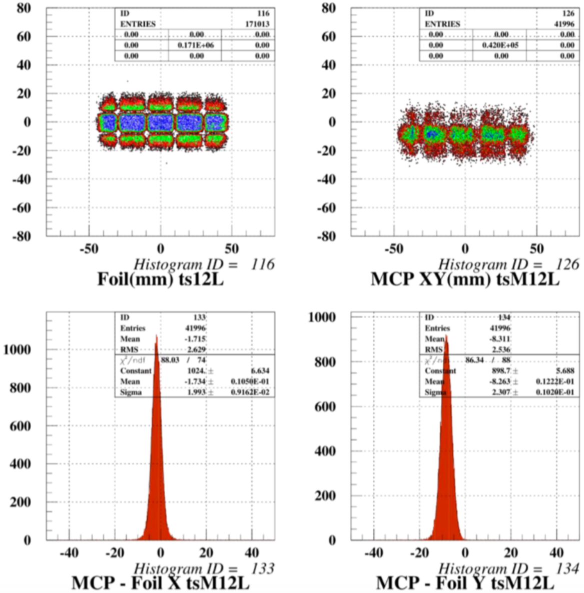
Position resolution in Y improved for method 2 without compromising position resolution in x

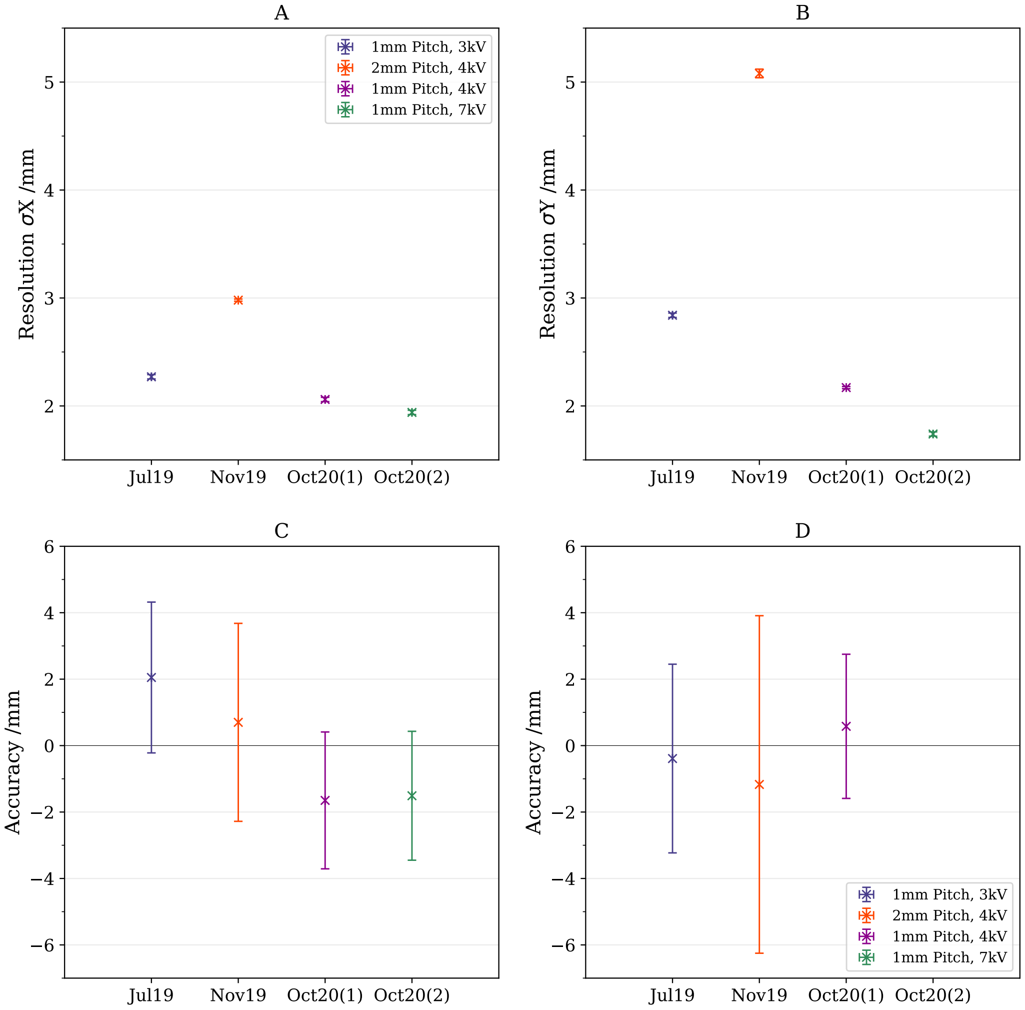
Test results

	Jul19	Nov19	Oct20(1)	Oct20(2)
New wiring method	X	O	O	O
Pitch of girds [mm]	1	2	1	1
Mirr Spacer [mm]	8	8	8	6
Acc Spacer [mm]	10	10	10	8
Acc. Potential [kV]	3	4	4	7

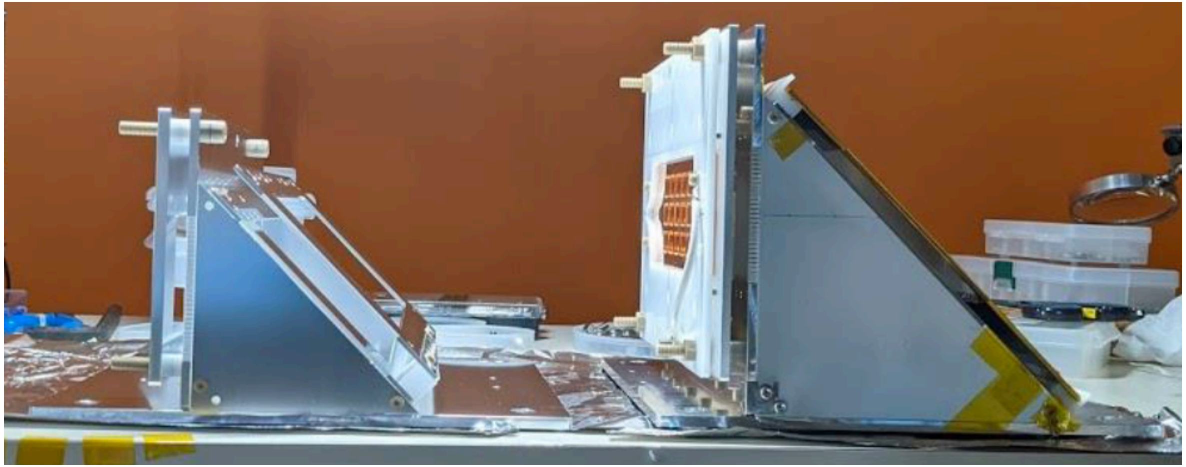
Resolution = Sigma of MCP – Foil

Ideally <1mm



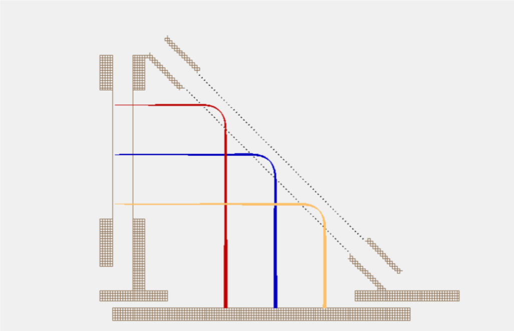


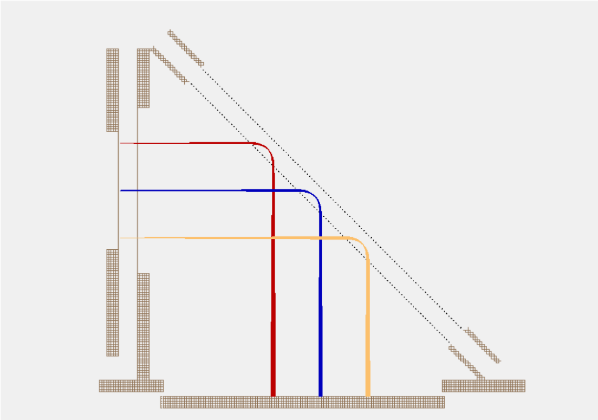
Planned improvement of position resolution

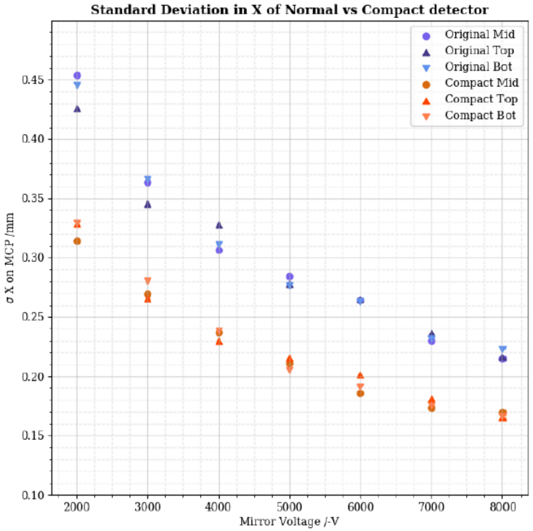


G. Hudson-Chang
Master (Riken/Surrey)

Compact



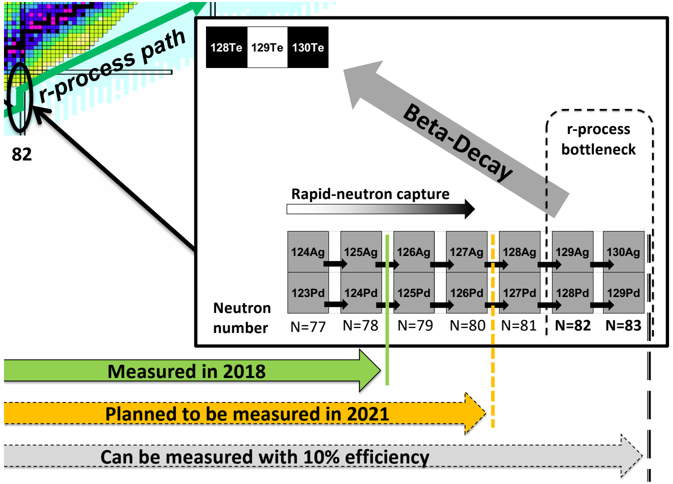


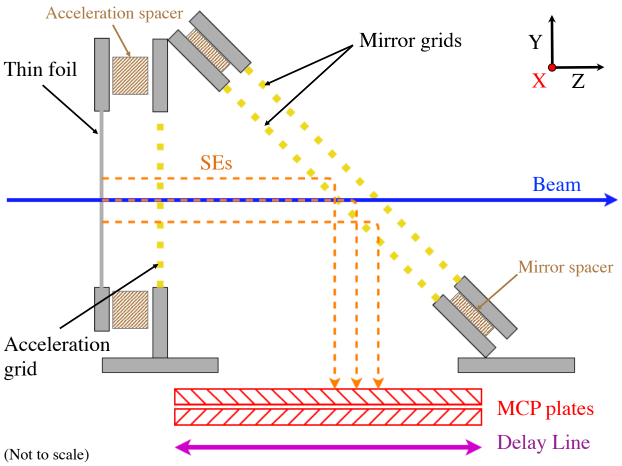


Test experiment planned July 2021 at HIMAC

Summary

- **Goal:** Measure mass of n-rich nuclei beyond N=82 for r-process study
- **Challenge:** efficiency of the Rare-RI Ring should be increased.
- **Solution:** Large area thin-foil position-sensitive DL-E-MCP detector for in-ring diagnostics and reduction of mass uncertainty systematic.
- **Progress:** Position resolution less than 2mm relative to conventional detectors. Ideally it should be less than 1mm
- **Improvement:** Design of compact detector to reduce the spread and apply higher voltage. Digital DAQ for better signal processing (collab. Korea).





ありがとうございました

Thank you for your attention