Developments for future experiments in the storage rings

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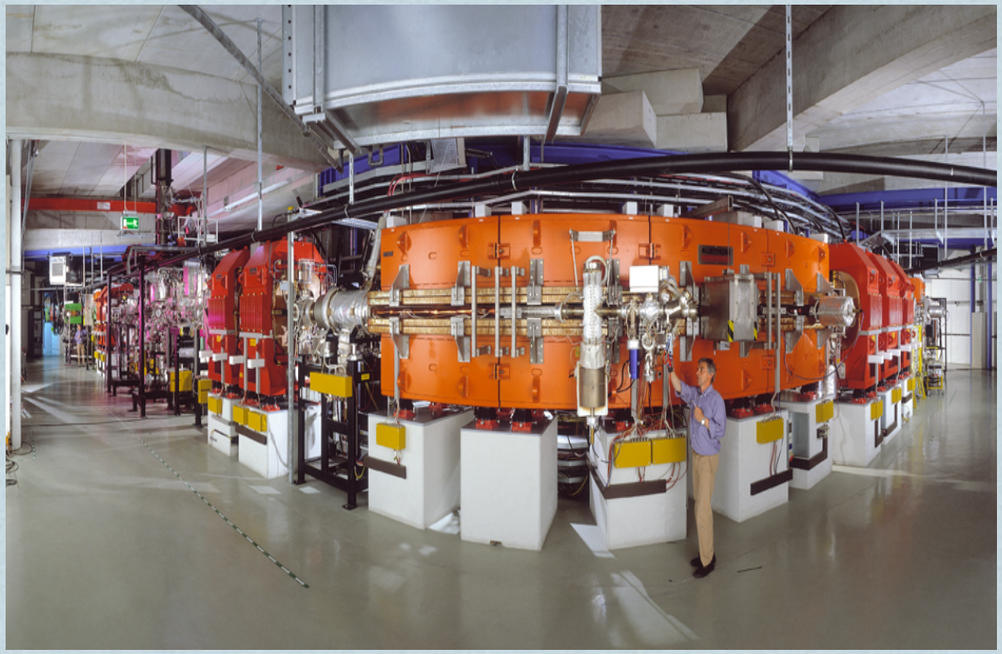
Workshop on Physics of Rare-RI Ring
RIKEN, 10-12 Nov. 2011

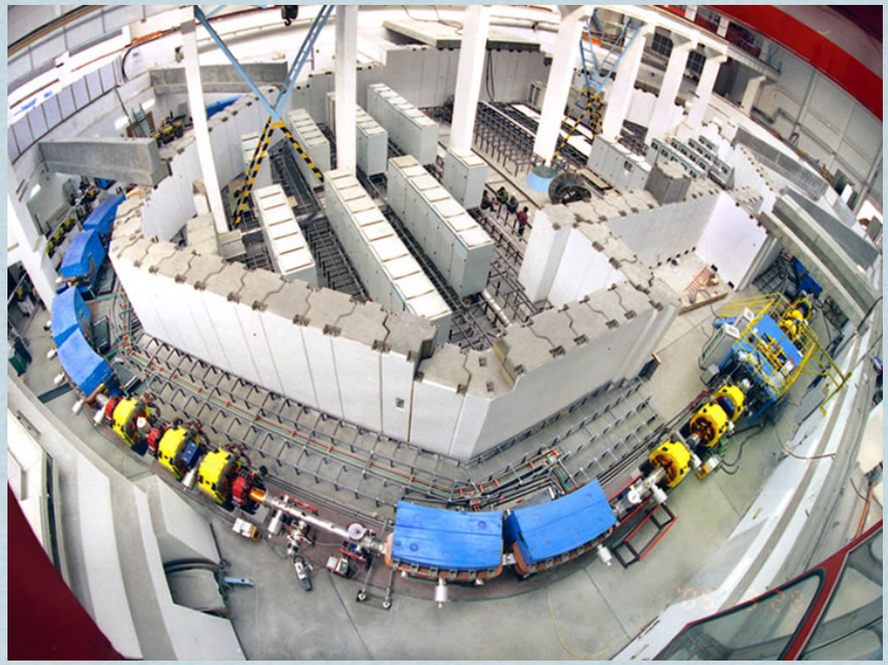
Outline

- Possible in-ring experiments
  - I. (Masses)
  - II. Lifetimes
  - III. Reactions
- Detector developments related
  - Si strip detectors for energy-loss and position
  - Fiber scintillation counters for precise position

Storage rings in the World

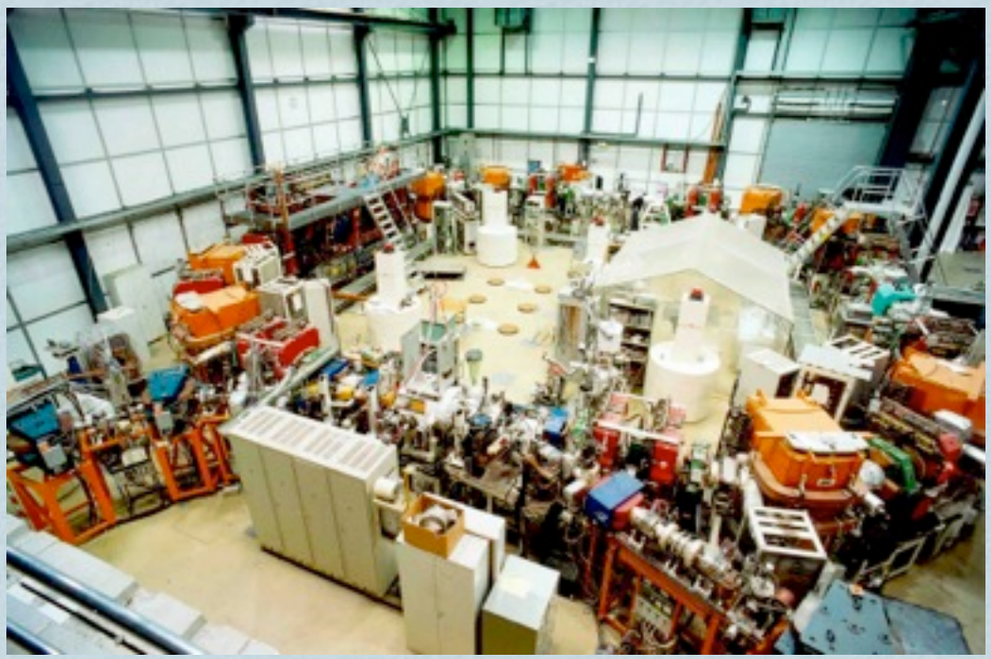
ESR

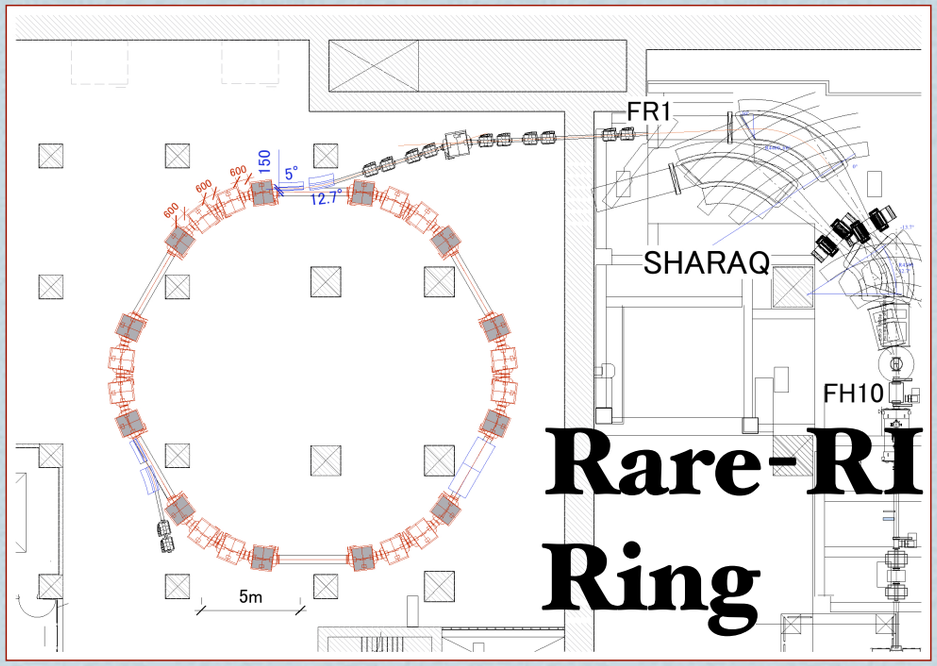




CSRe

TSR



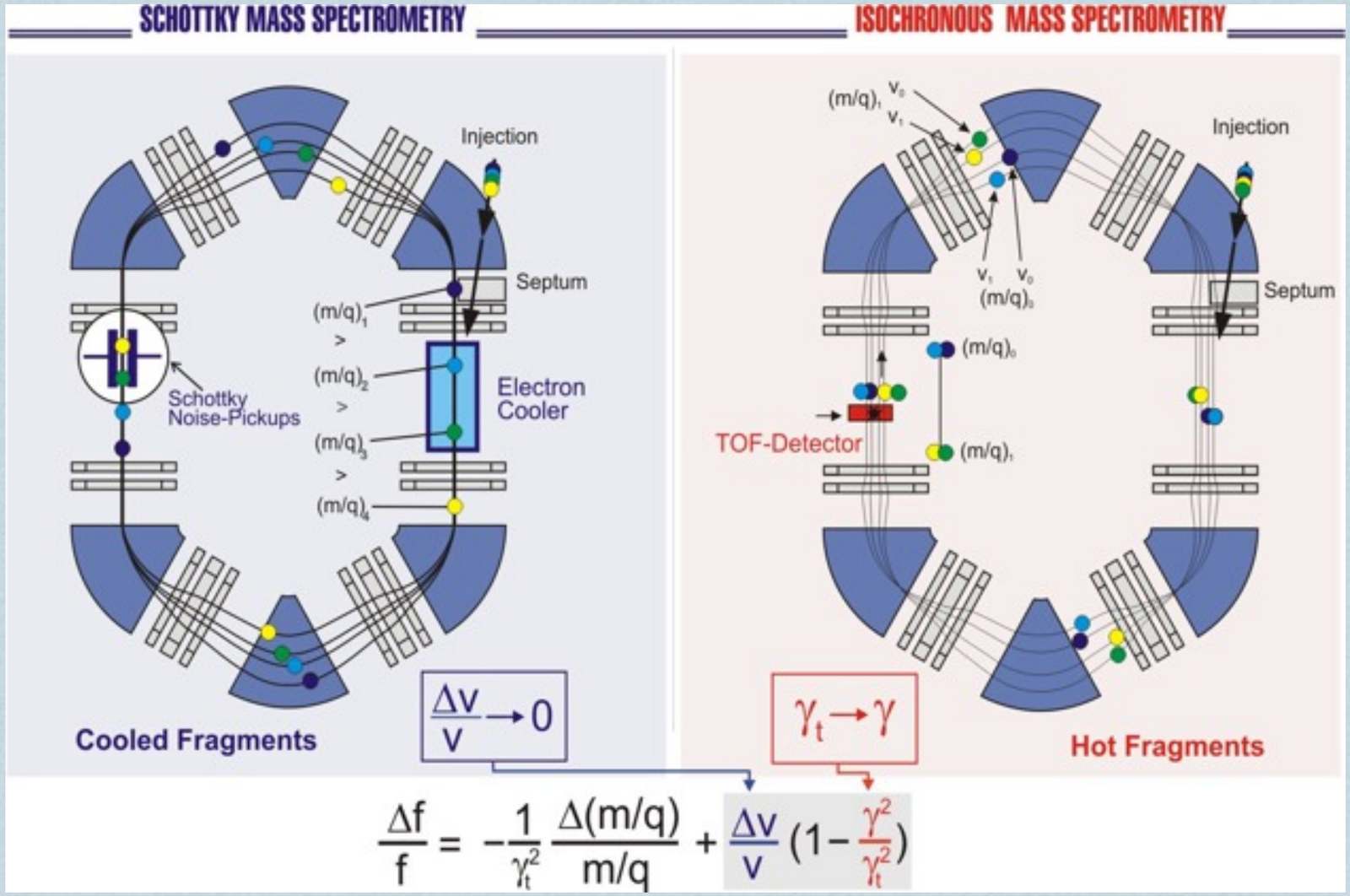


Merit of storage rings

- **High charged ions stored :**
  - *unique decay modes* (bound-beta, ... @ ESR)
- **Cooling :**
  - *very small emittance*
- **High resolving power :**
  - *isobar(isomer) separation* (SMS @ ESR)
- **Thin internal target / revolution :**
  - *low momentum transfer* (e.g. EXL)

I. *Masses*

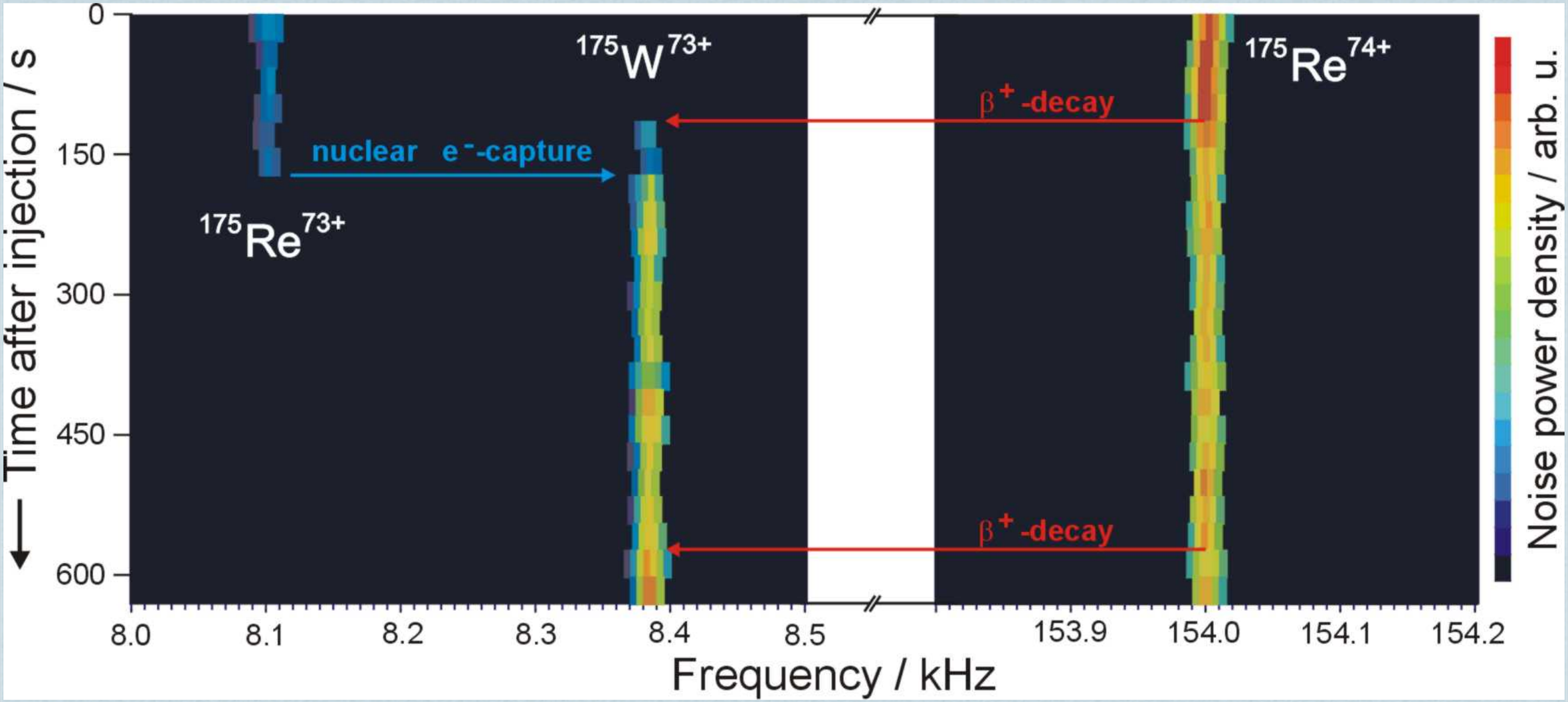
- Schottky mass spectrometry for long-lived nuclei (ESR)
- Isochronous mass spectrometry for short-lived nuclei (ESR/CSRe)



II. *Lifetimes*

- Lifetime measurements in the rings (SMS)
  - Decay of highly-charged radioactive ions : *astrophysical importance*
    - Electron **screening** effect
      - EC and IC decays
    - **Bound-state beta decay** mode
      - *M. Jung et al., Phys. Rev. Lett. 69 (92) 2164.*
      - *F. Bosch et al., Phy. Rev. Lett. 77 (96) 5190.*
      - *T. Ohtsubo et al., Phys. Rev. Lett. 95 (05) 052501.*
  - **Hyperfine** effect / electron spin (total angular momentum)
    - *Y. Litvinov et al., Phys. Rev. Lett. 99 (07) 262501.*
    - *N. Winckler et al. Phys. Lett. B 679 (09) 36.*

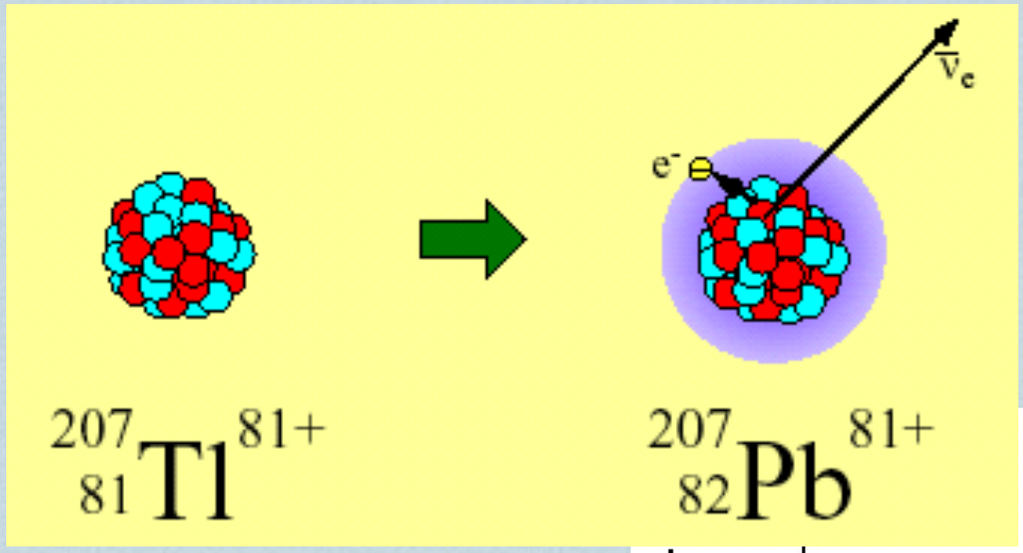
Decays in the ring



observed by old Schottky pickup

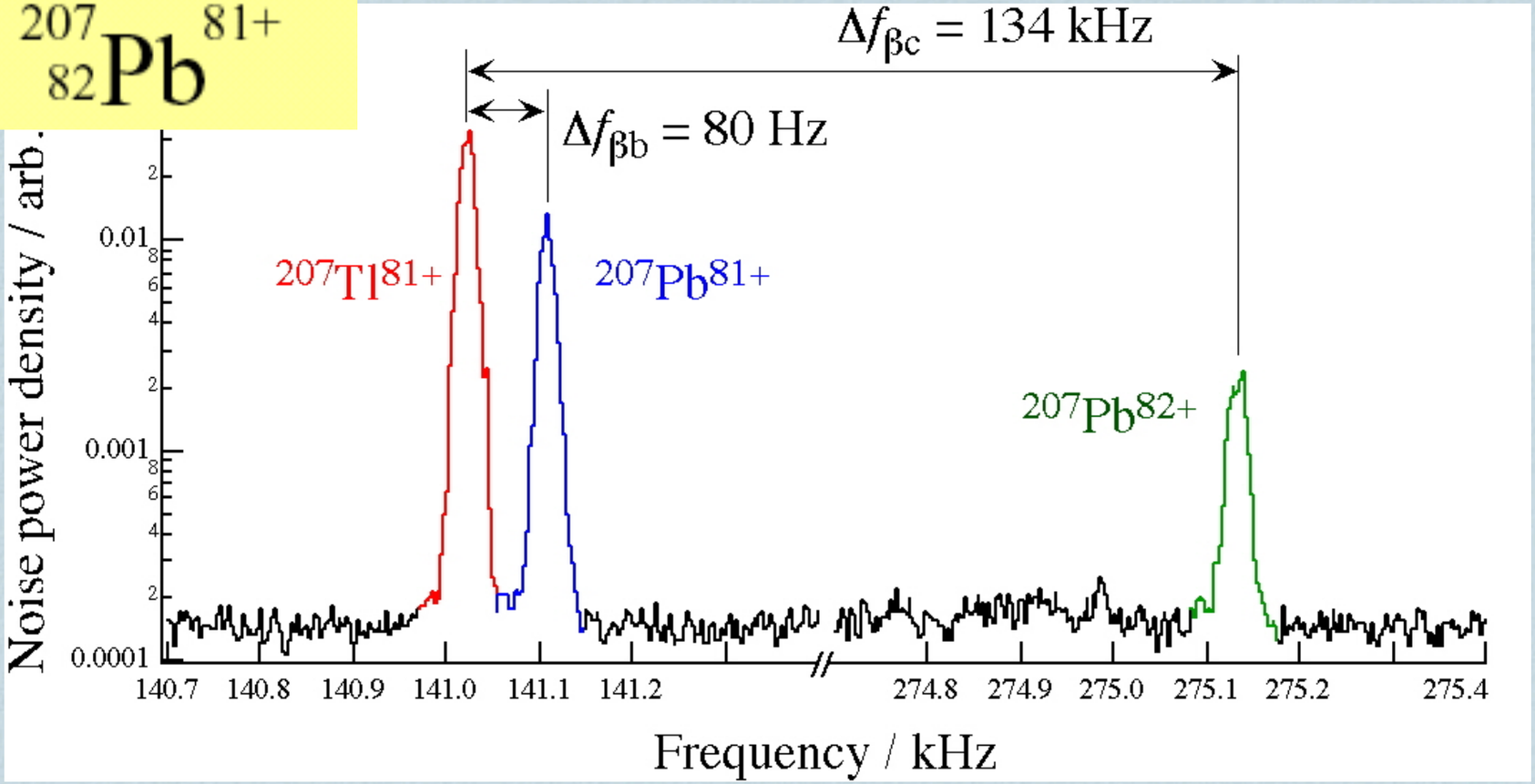
FRS-ESR collaboration

Simultaneous observation of Continuum and Bound state beta decay



observation at FRS-ESR

T. Ohtsubo et al., PRL 95 (2005) 052501.



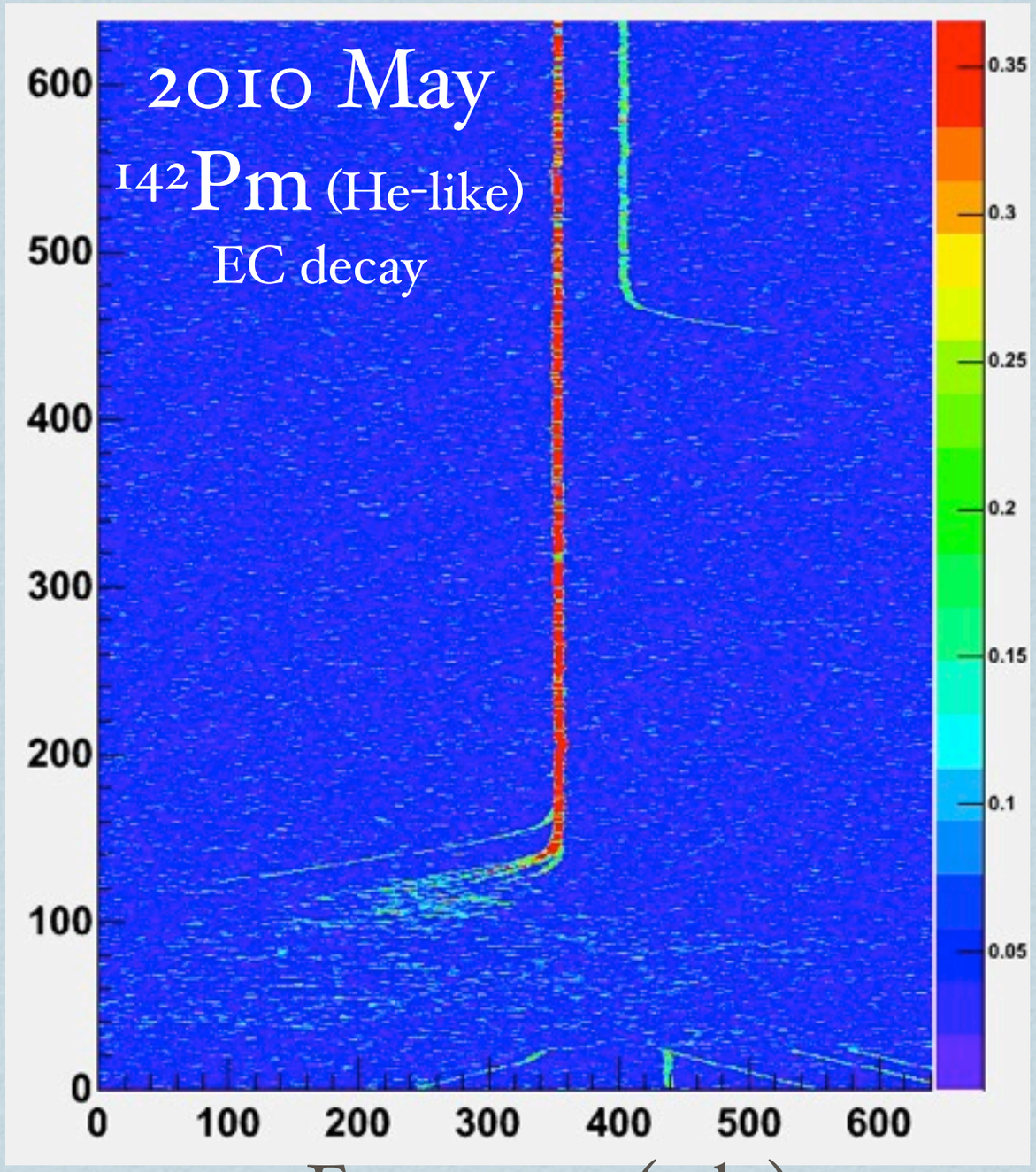
simultaneous observation

in the broadband spectra

New Schottky Resonator

- S/N greatly improved
- Recoil effect detected

F. Nolden et al., NIM A659 (2011) 69.

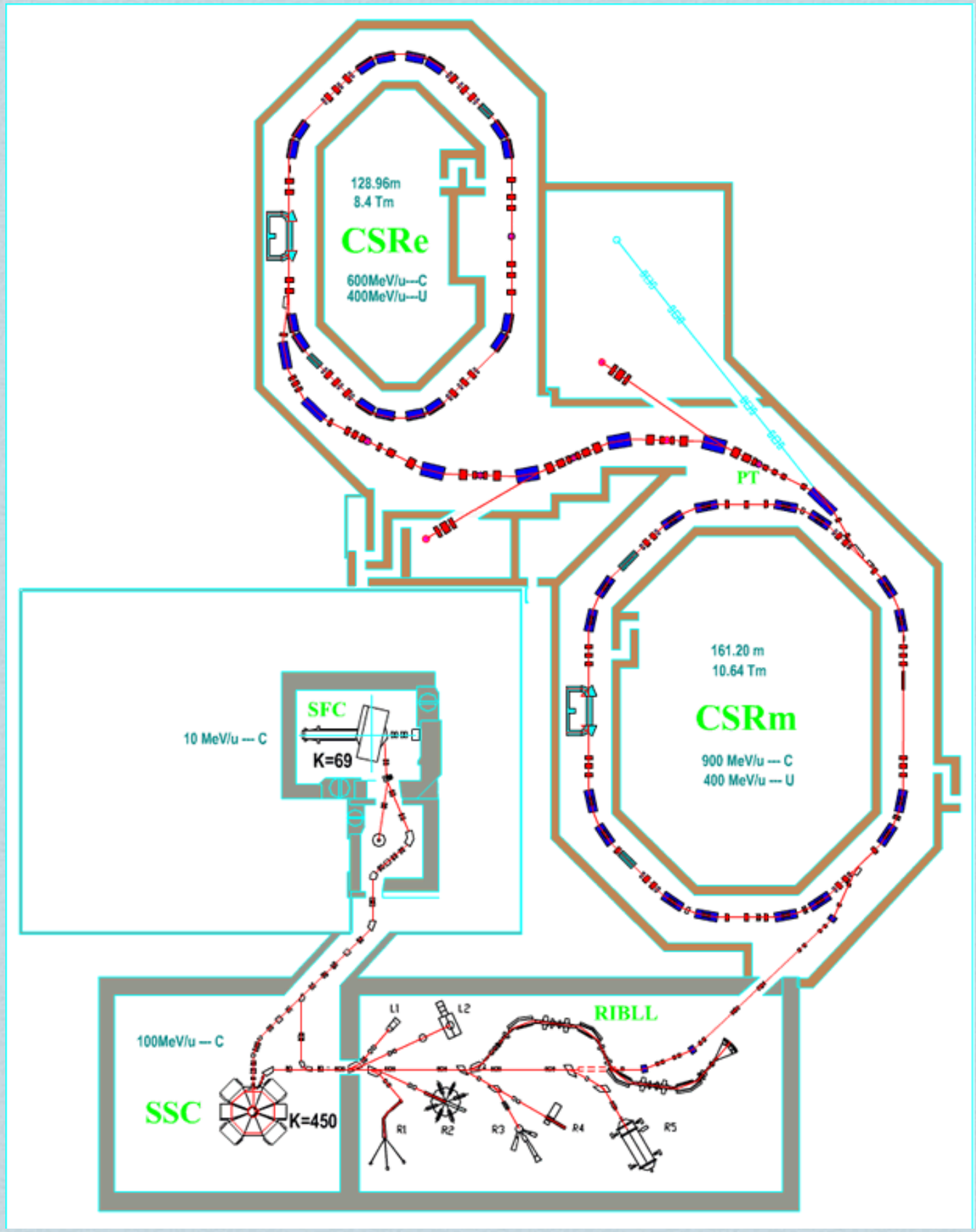


A possible experiment at CSRe (Lanzhou)

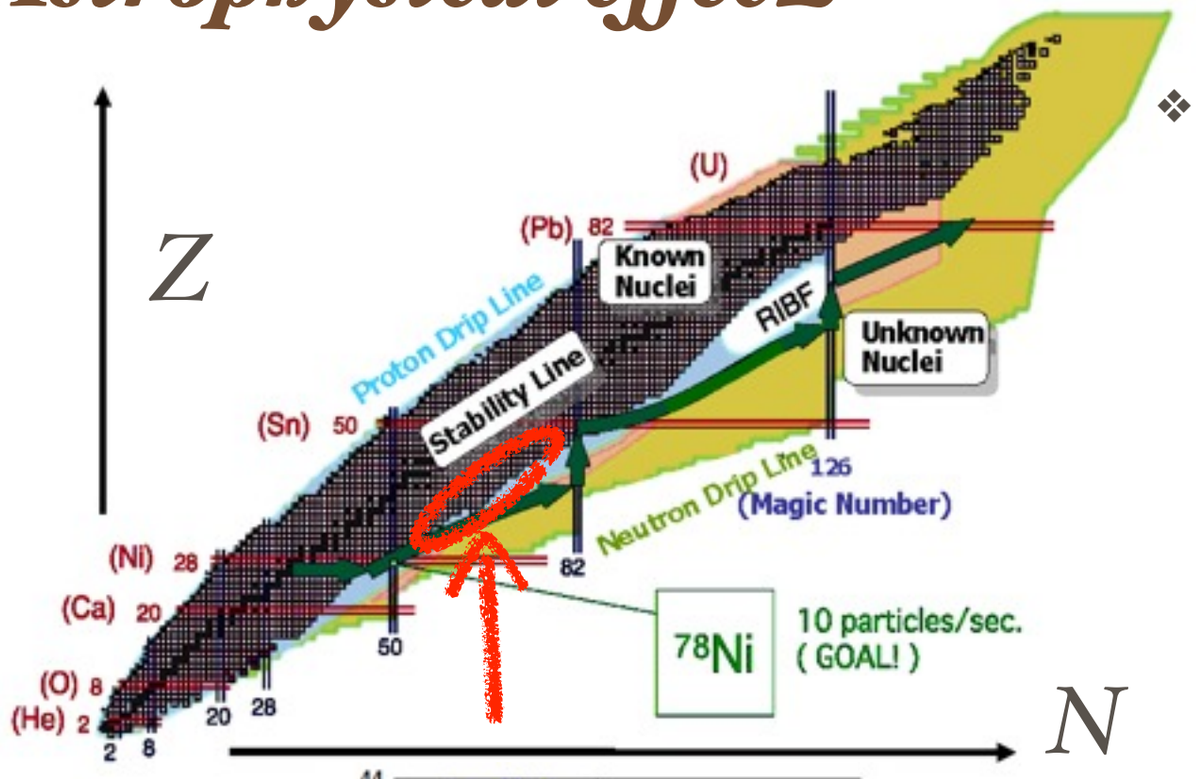
- Lifetimes of HCI

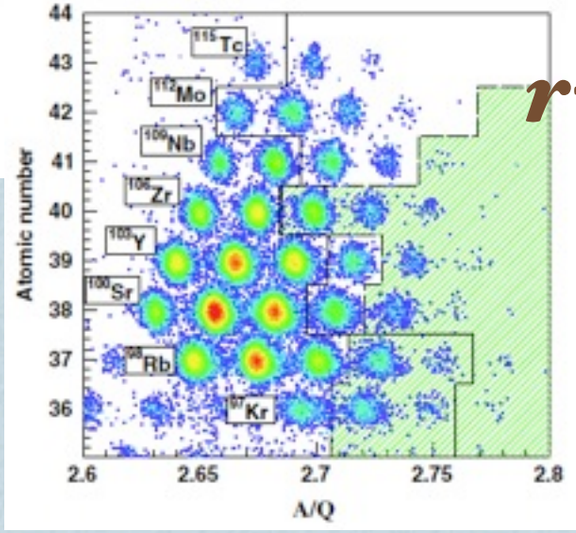
- Fragment separator RIBLL2
- Resonant Schottky
  - *recently installed !*
- Electron Cooler

Parameter of CSRe
Max. energy: 400 MeV/u (U^{90+})
Brho: 8.4 Tm



Astrophysical effect



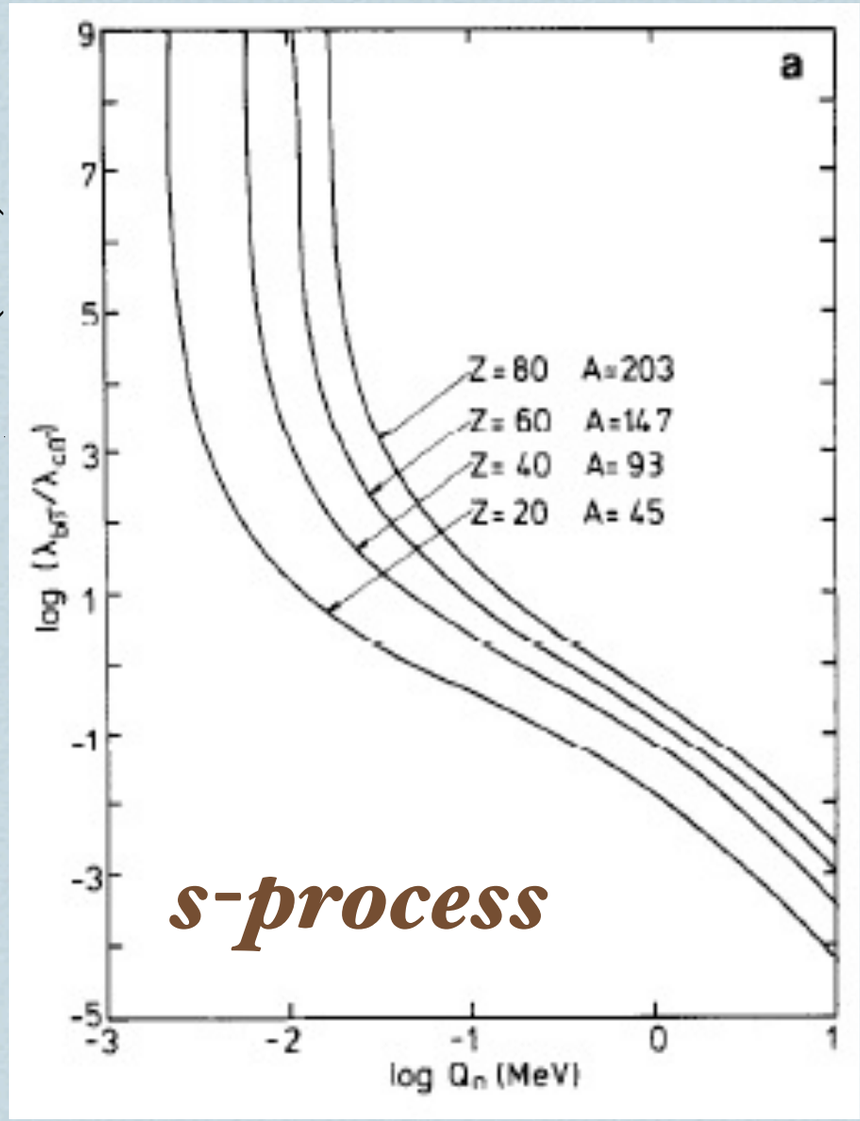


r-process

~ r-process & s-process ~

- Lifetimes of neutron-rich nuclei close to the r-process were measured.

S. Nishimura et al., PRL 106 (2011) 052502.



logQ

- **Bound-state beta decays may affect the decay rate calculations in the s-process.**

Nucl.	$T_{1/2}$	Q (keV)	$\epsilon(\%)$
^{63}Ni	100.1 y	67	220
^{65}Ni	2.52 h	2136	~1
^{66}Ni	5.6 h	226	30

K. Takahashi and K. Yokoi, ADNDT 36 (87) 375.

III. *Reactions in the rings*

Storage rings provide unique conditions for nuclear reaction experiments.

Keywords:

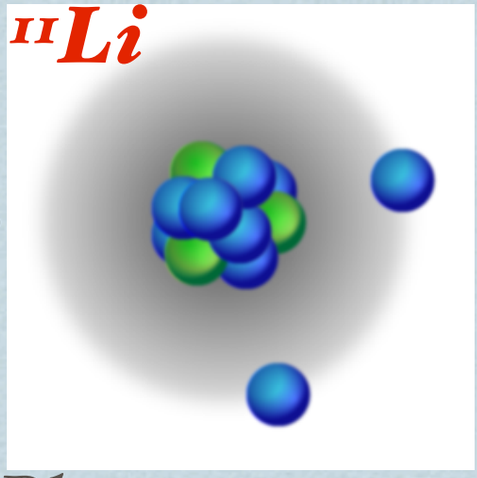
high charge state, cooling, thin internal target, revolution frequency, high resolution, ...

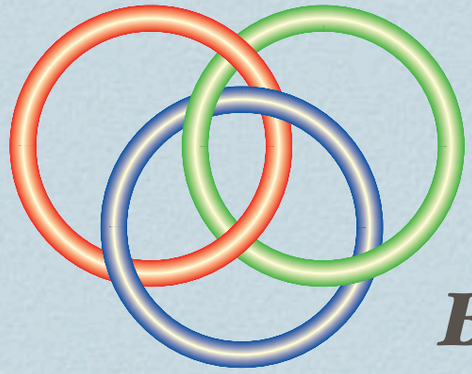
Exotic structure discovered by σ_R and $p_{||}$

Neutron halo in ^{11}Li

$^{11}Li = {}^{9}Li + 2n$

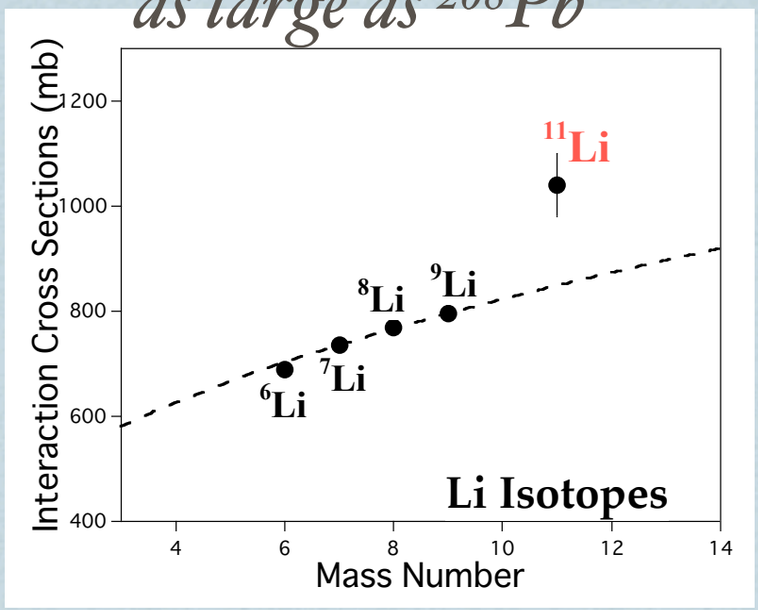
$S_{2n} = 370\ keV$



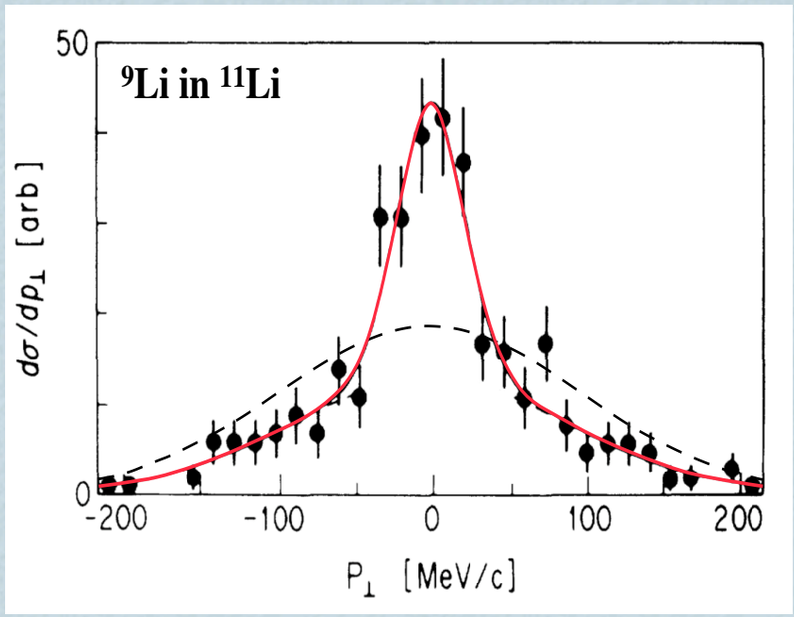


Borromean

as large as ^{208}Pb



Tanihata, PRL55, 2676 (1985)



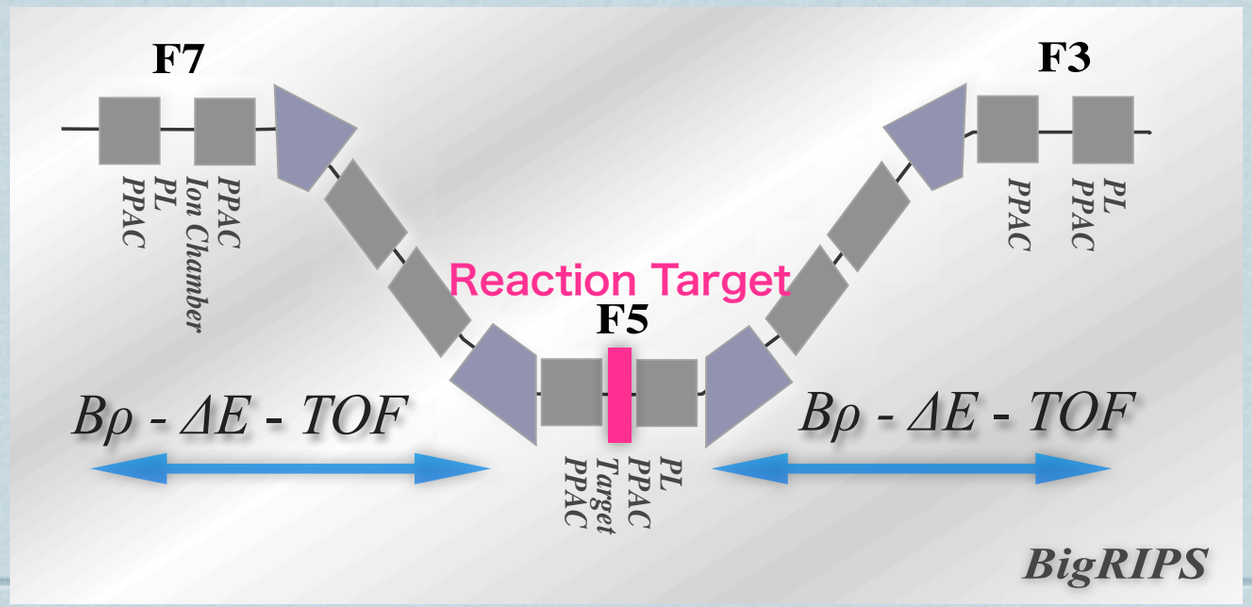
Kobayashi, PRL60, 2599 (1989)

New results @ RIBF, 2011

Interaction cross sections : Ne isotopes @250MeV/u

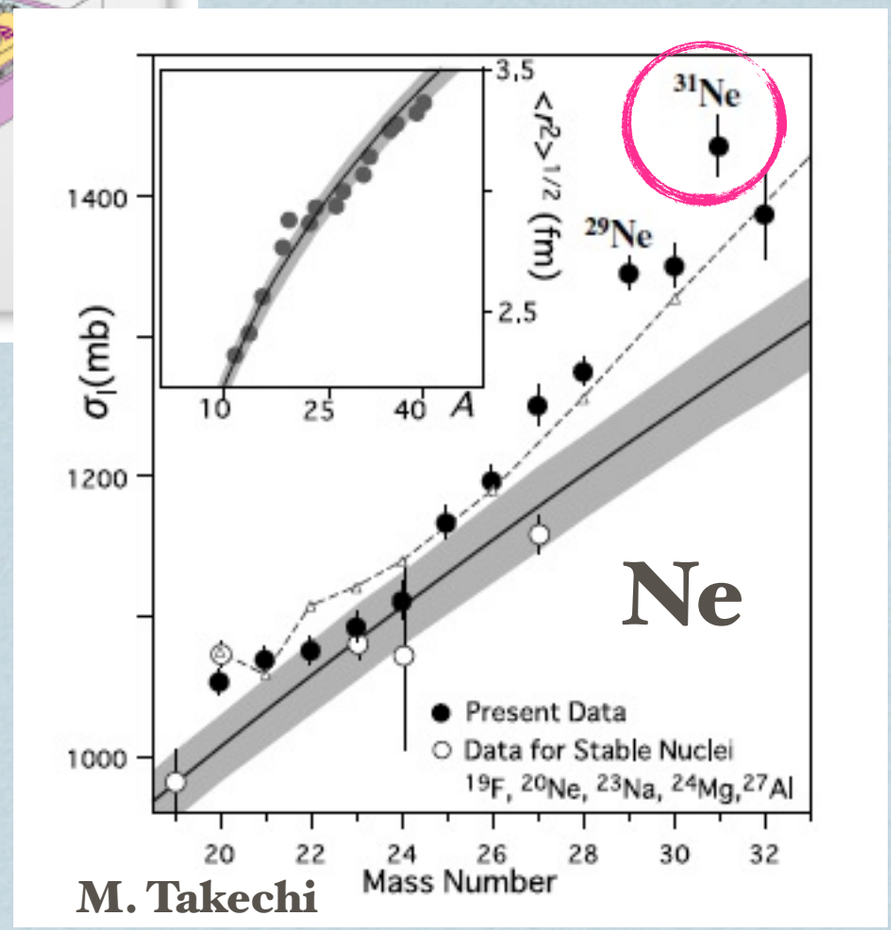
SRC

BigRIPS fragment separator



T. Nakamura et al.,
PRL 103 (2009) 262501.

Coulomb breakup of ^{31}Ne the largest halo !



Very difficult for heavy nuclei

Reactions in the rings

easy ?

- ***Total x-sections*** → matter radius (density)

  e.g. ^{56}Ni + p : interaction cross sections

- ***Momentum distributions of breakup fragments***

- ***Nucleon removal x-sections***

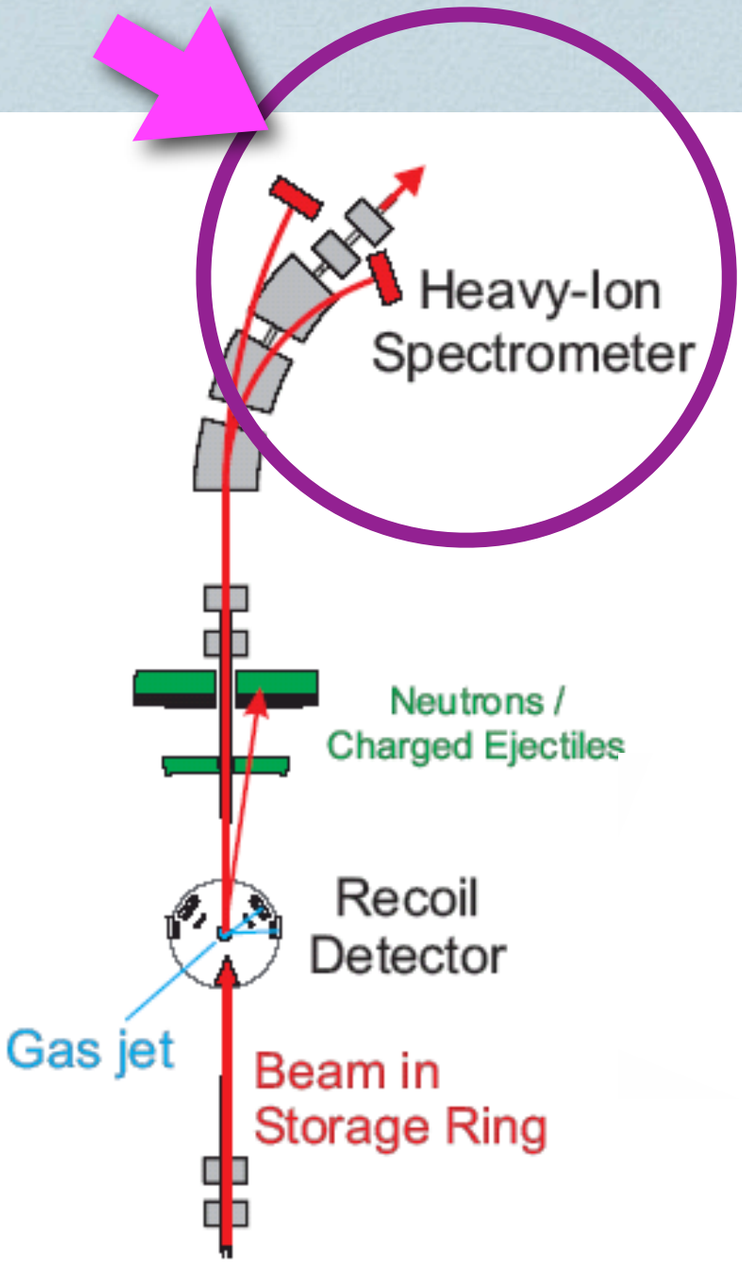
  → position distribution at dispersive focus

  e.g. ^{56}Ni + p → ^{55}Ni : one neutron removal reaction
  to study shell structure change

difficult ?

Setup at ESR

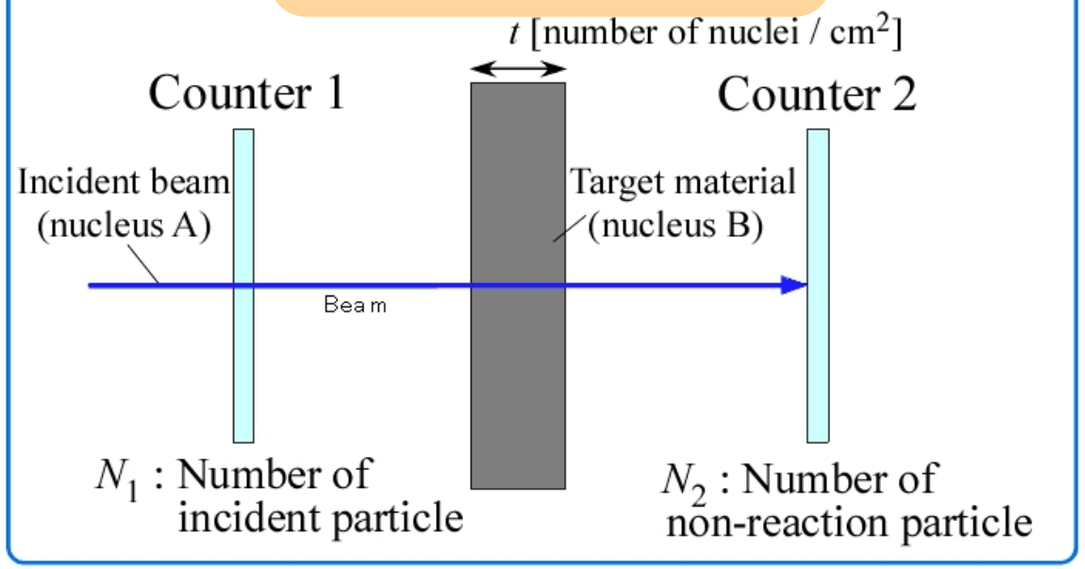
for decay products



Total Cross sections

"Beam line experiment"
(fixed external target)

transmission method



$$\sigma_I = -\frac{1}{t}\ln\left(\frac{N_2}{N_1}\right)$$

interaction cross section

EXL LOI

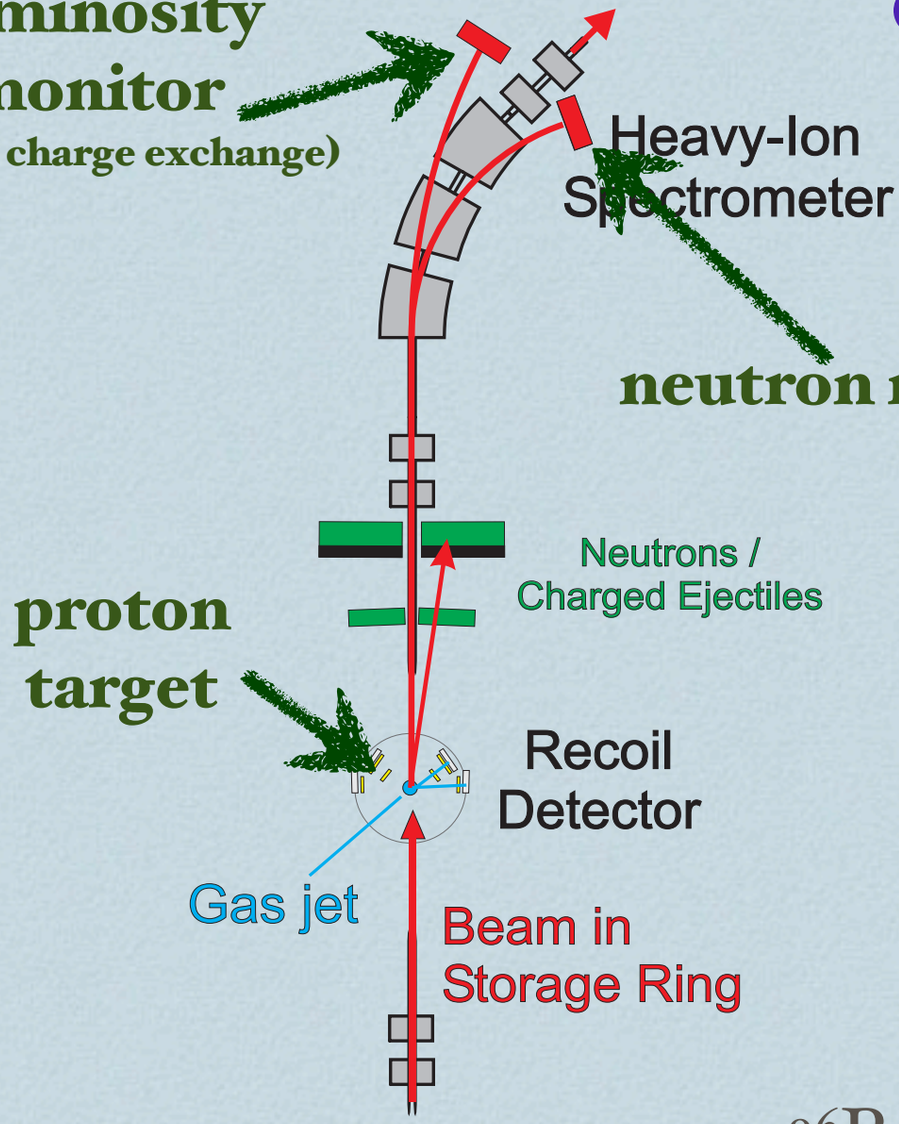
The decrease of beam intensity gives a reaction probability.
Problem : atomic effect much larger !

Momentum distributions

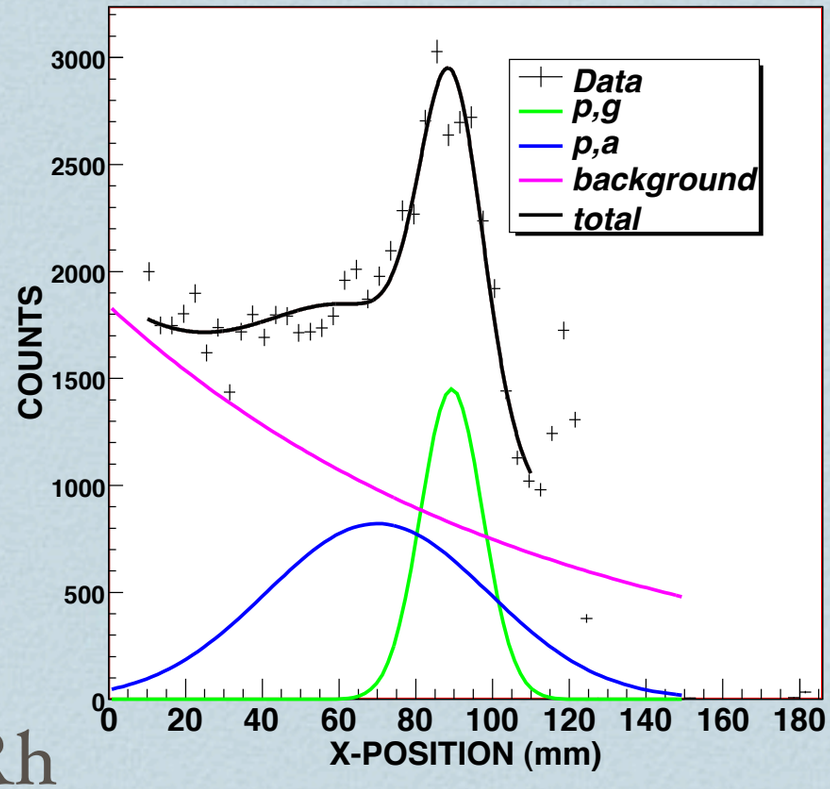
The sector magnet after the jet target works as a spectrometer.

excellent separation
(isomeric and ground states)

luminosity monitor
(atomic charge exchange)



position distribution gives a momentum distribution of the breakup fragment

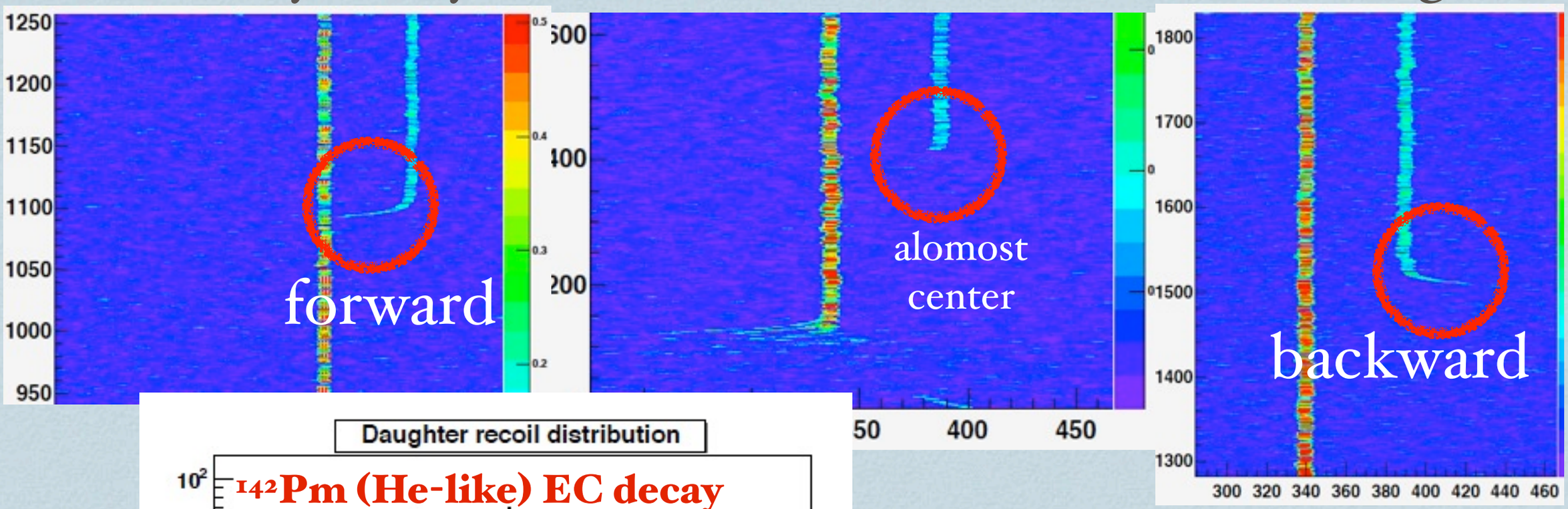


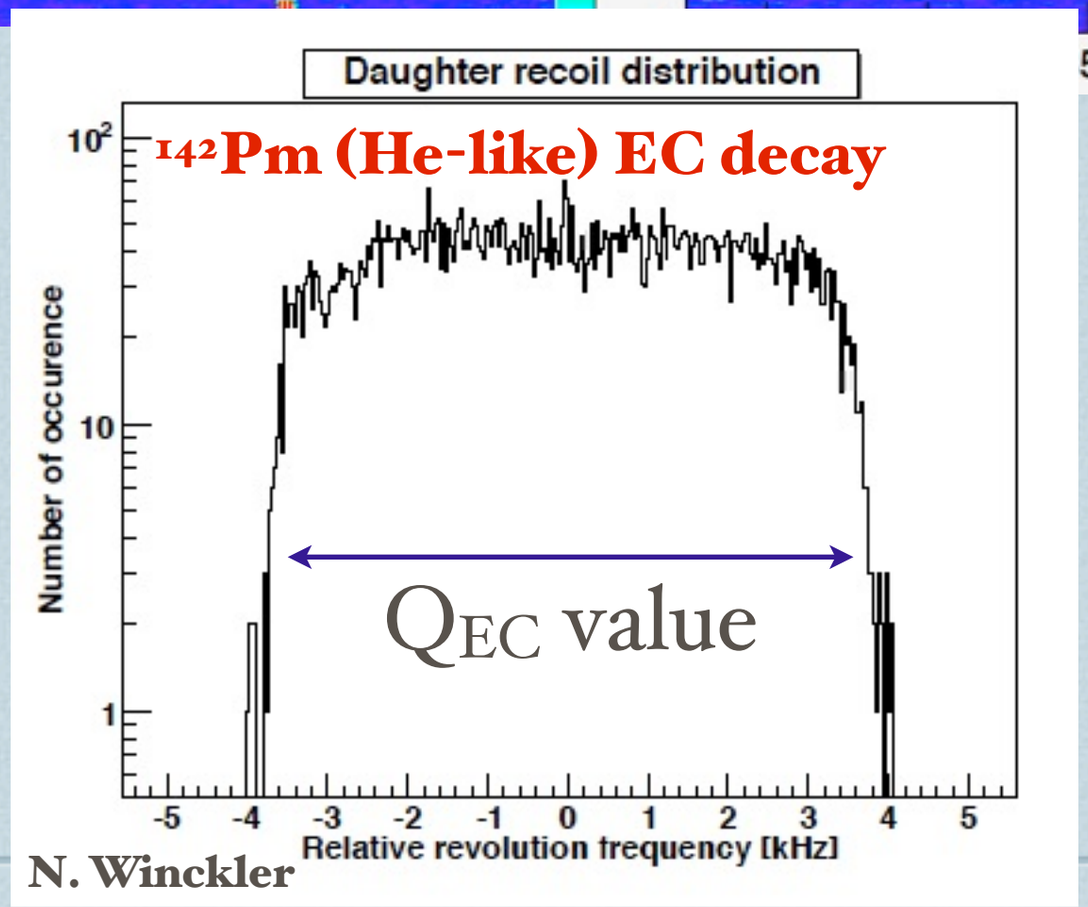
$^{96}Ru(p, g)^{97}Rh$

Zhong, IOP 202 (2010) 012011

Resonator for decay study

two-body decay - detection of neutrino emission angle





Neutrinos emitted isotropically.

Requirements for detectors in the pocket

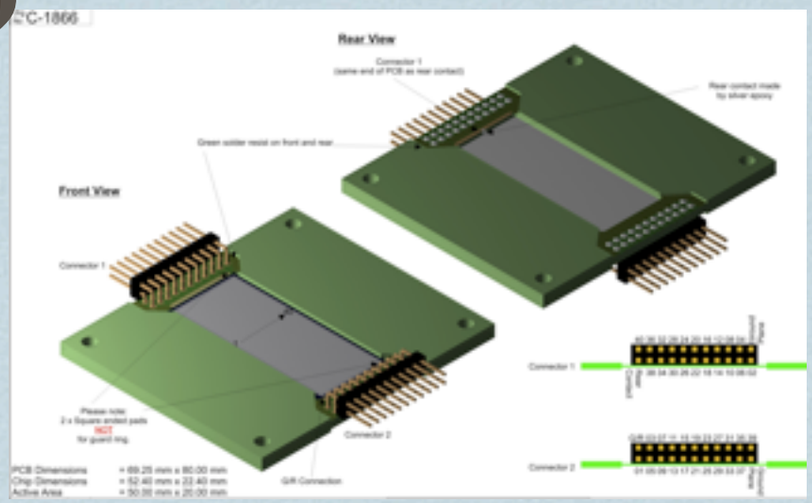
- excellent resolution (position, energy-loss, timing)
- compact (limited by magnet gap)
- easy to handle, (easy to analyze)
- low background
- strong magnetic field
- (high vacuum compatible, but) use pocket system

Performance of Si strip detectors

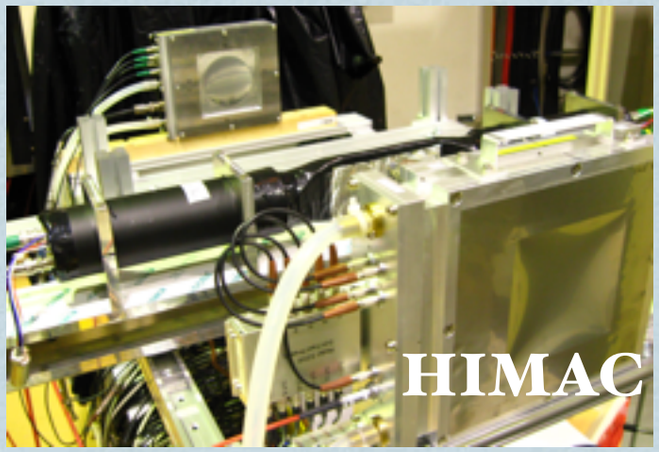
EE1, EE2 (Micron)

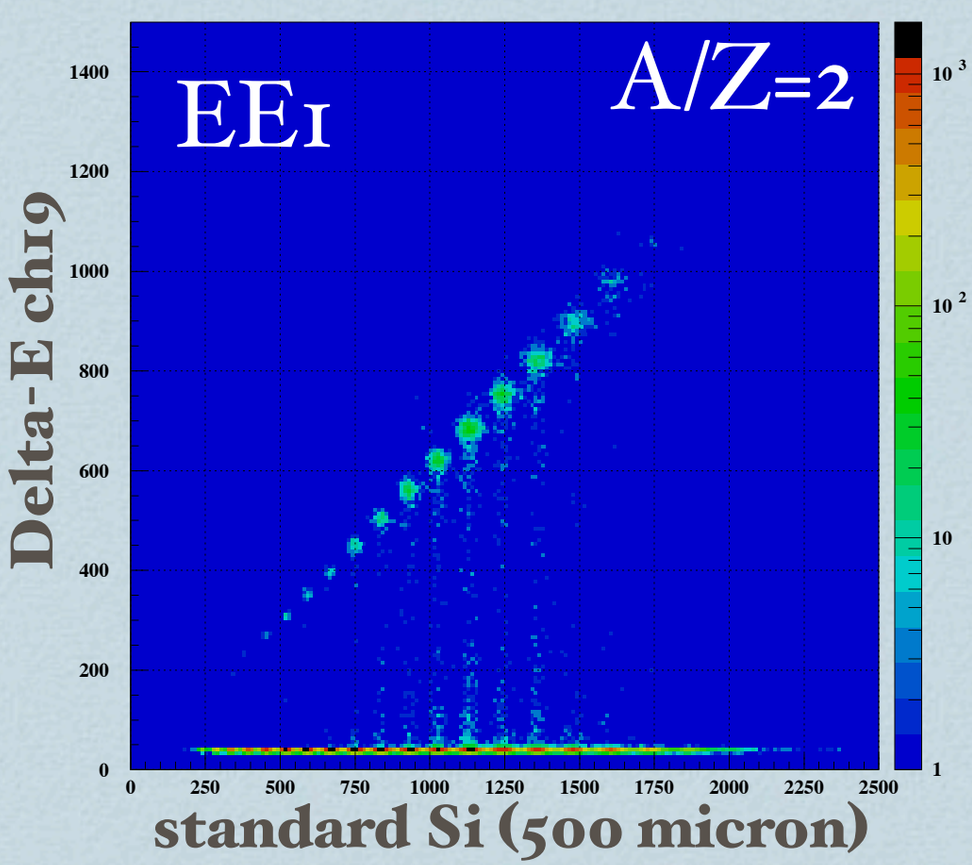
single side

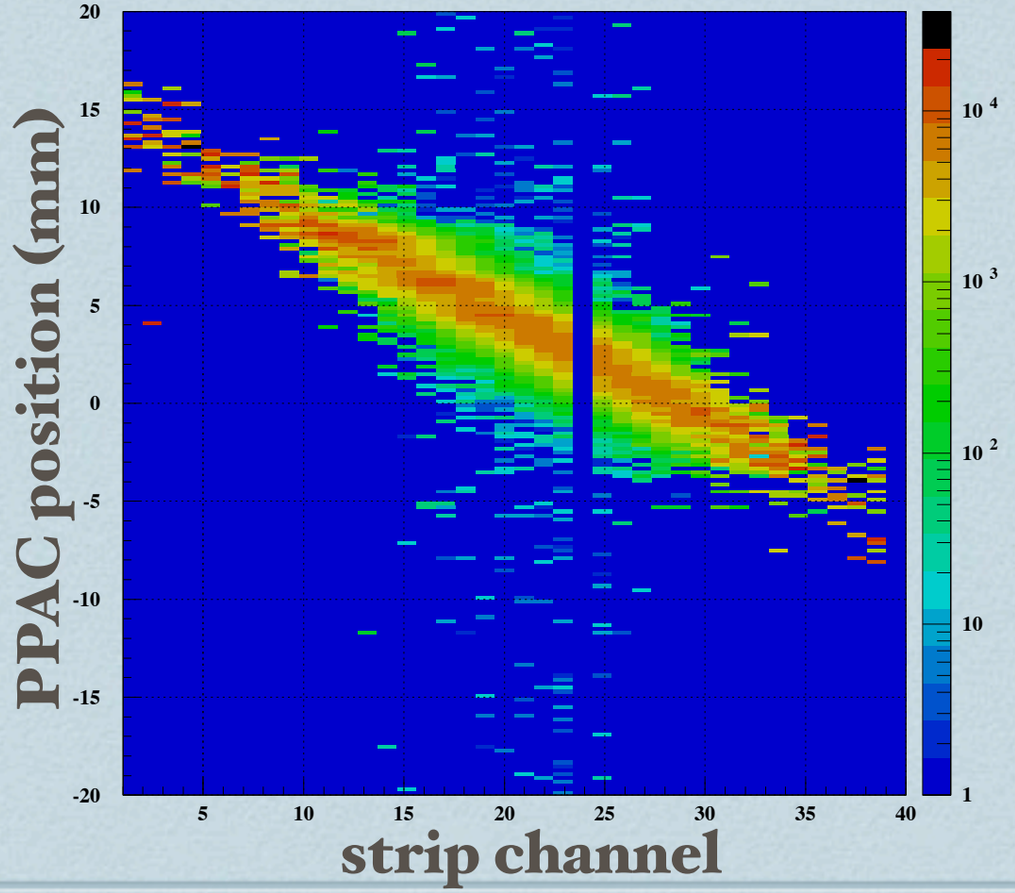
DESIGN	**EE1**	**EE2**
EXPERIMENT	FRASCATI	ALEPH
ACTIVE AREA	12.5 cm^2	10 cm^2
ACTIVE DIMENSION	62.4 x 2 mm^2	50 x 20 mm^2
Nº CHANNELS	96	40
ELEMENT LENGTH	20 mm	50 mm
ELEMENT PITCH	650µm	500µm



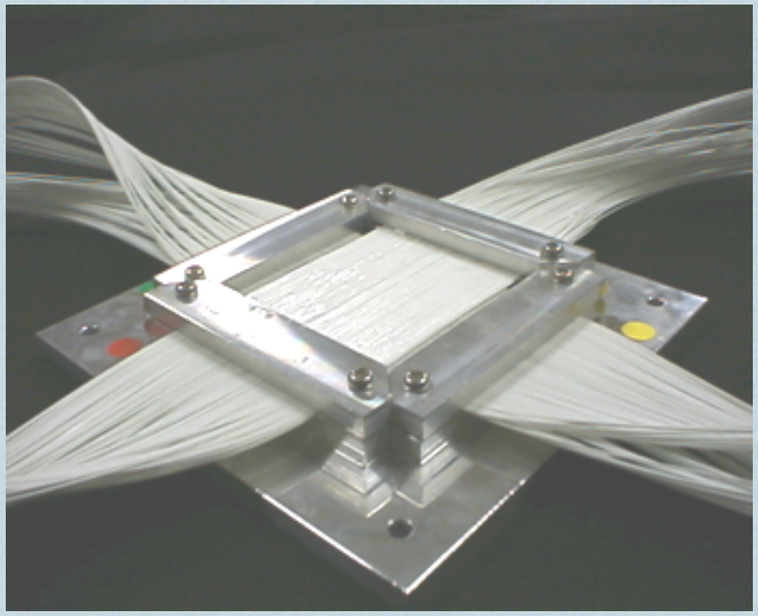
^{56}Fe 500MeV/u







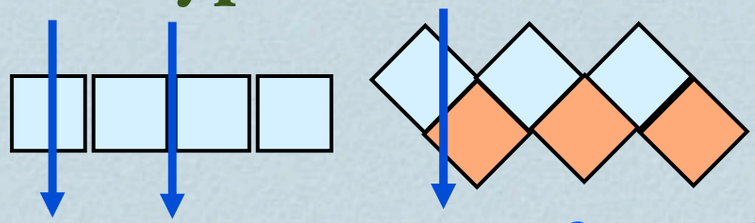
Fiber scintillation counter



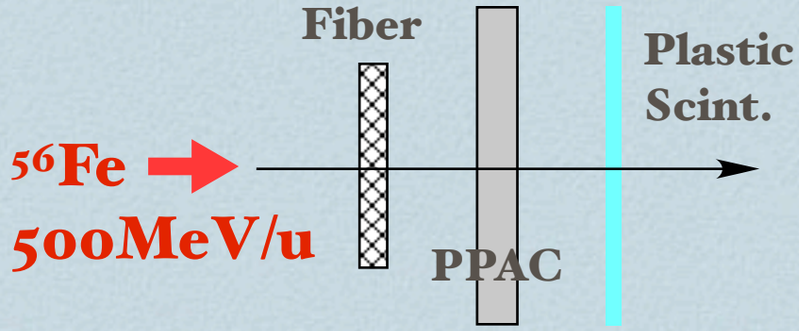
position counter

- high efficiency
- high resolution
- high rate

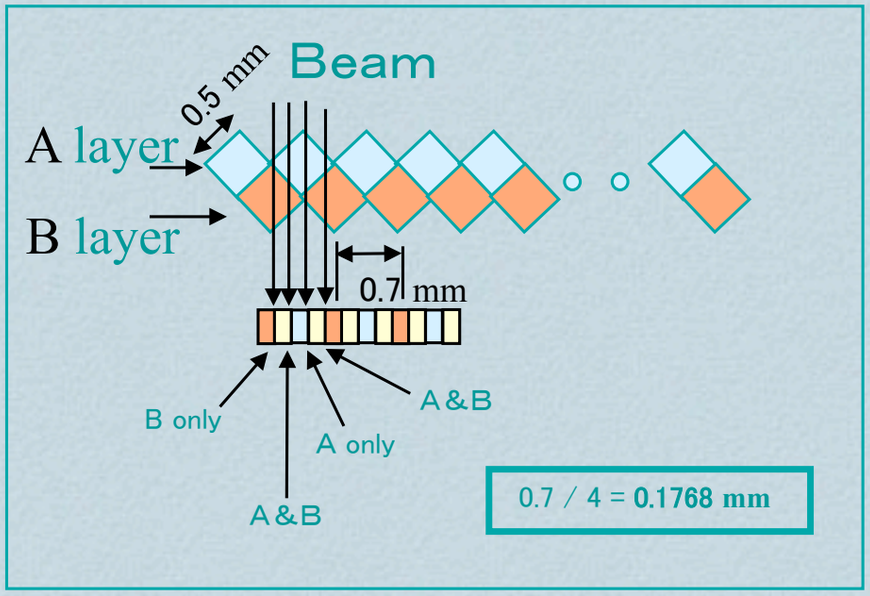
usual type

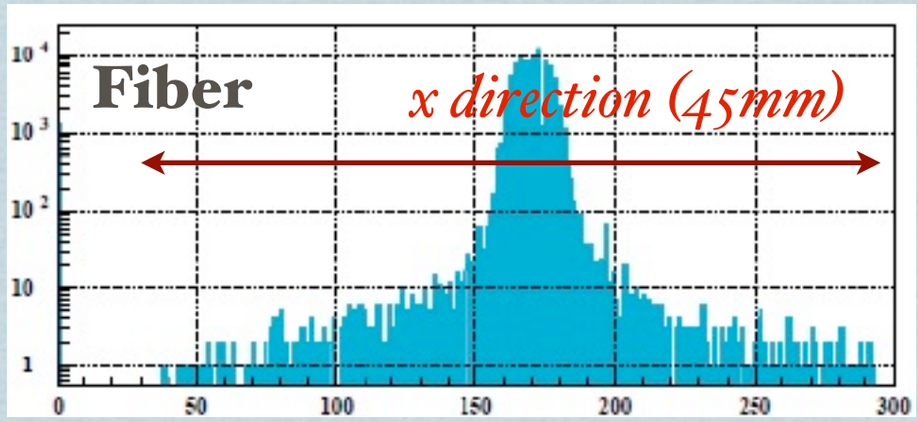


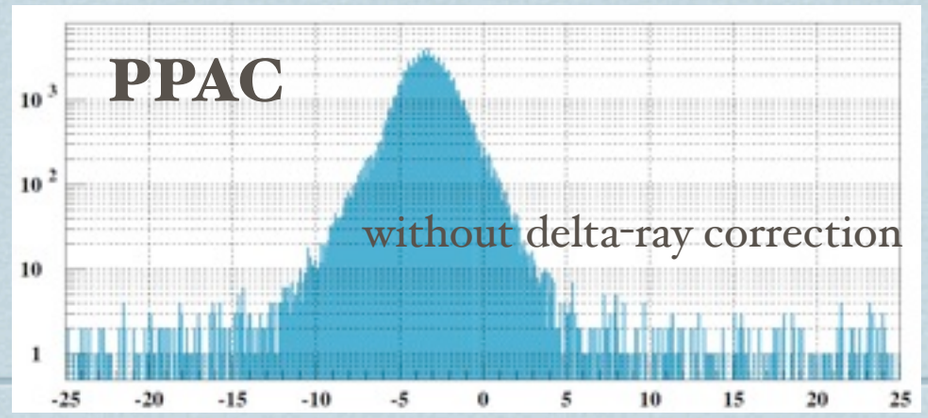
New configuration



eff. = 96-99 %







K. Morimoto and F. Tokanai

Conclusion

- *Several possible/new experiments can be proposed :*
  - *mass and lifetimes will be an extension of the ESR activities.*
  - *reaction experiments are possible ...*
    - *nucleon removal study with the Schottky resonator*

- *Detector developments are ongoing for future in-ring decay and reaction experiments.*
  - ✓ *Si strip detectors for position and energy-loss*
  - ✓ *Fiber scintillation counter for position and timing*