Missing Mass Spectroscopy with Inverse kinematics

2006 RIBF Users Meeting

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- Contents
  - Nuclear physics with unstable nuclei
  - Experimental Method for unstable nuclei

    Missing mass spectroscopy

    + inverse kinematics
  - Investigation of ISGMR with

    the inelastic (p,p') scattering
  - Summary

Nuclear physics with unstable nuclei

- Orthodox nuclear physics study... but on the Play Ground of the Large or All (N,Z) region

➡ Exodus from bondage around stable nuclei

- ? What are interesting ?
  - Shape : charge/matter distribution
  - Collective motion
  - Single particle/hole structure
  - Statistic properties ...

➡ Same approach for investigations (or break through?)

- ? Methods

  ➡ inverse kinematics ← normal kinematics

  ➡ missing mass spectroscopy ⇔ invariant mass sp.

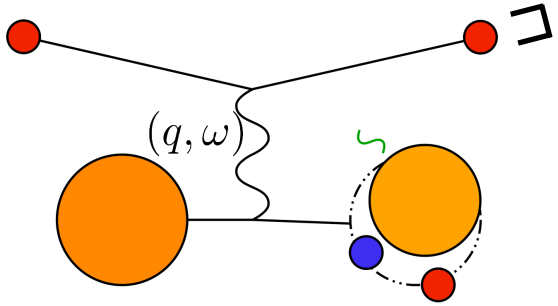
Method for spectroscopy and Kinematics

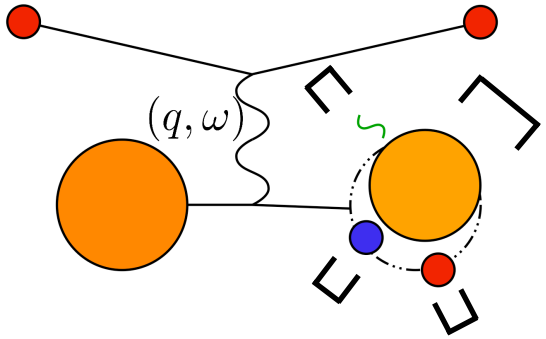
spectroscopy

Missing mass | Invariant mass

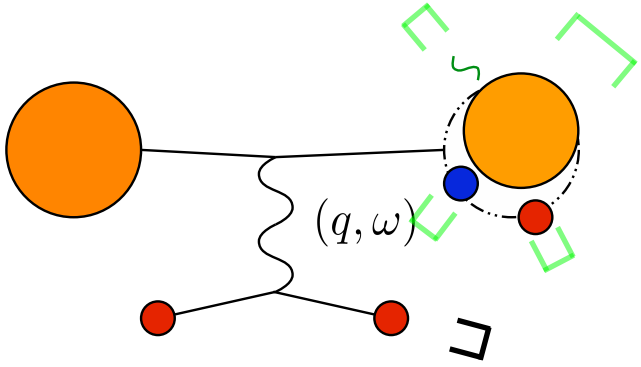
kinematics

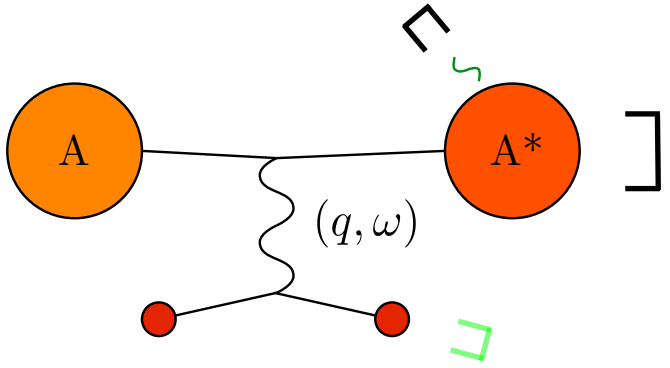
normal





inverse





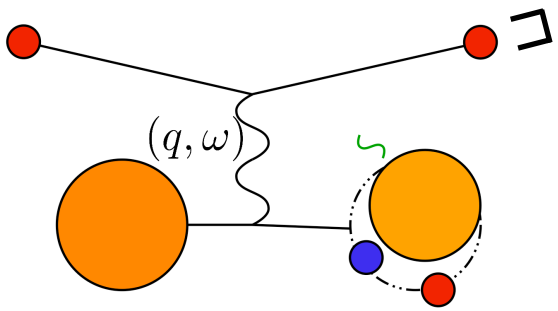
Method for spectroscopy and Kinematics

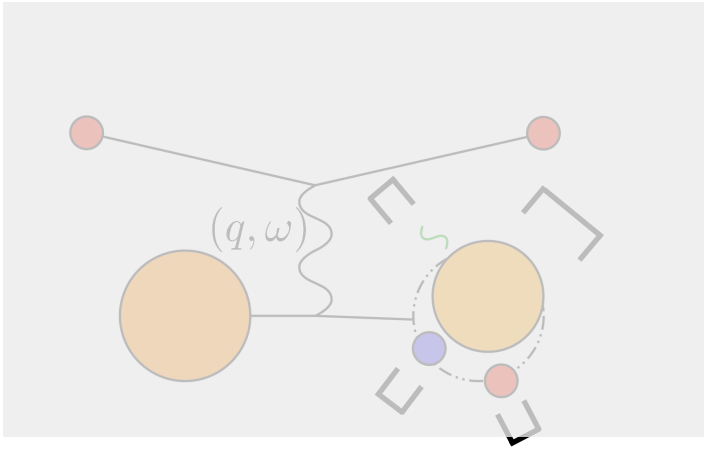
spectroscopy

Missing mass | Invariant mass

kinematics

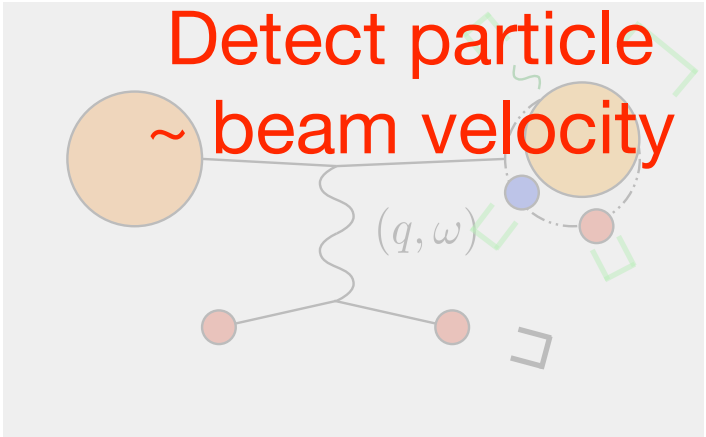
normal

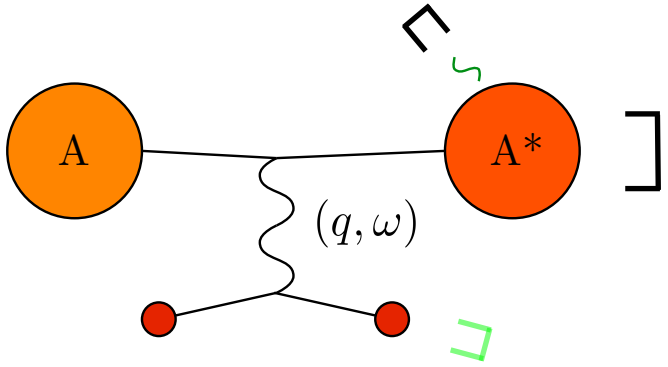




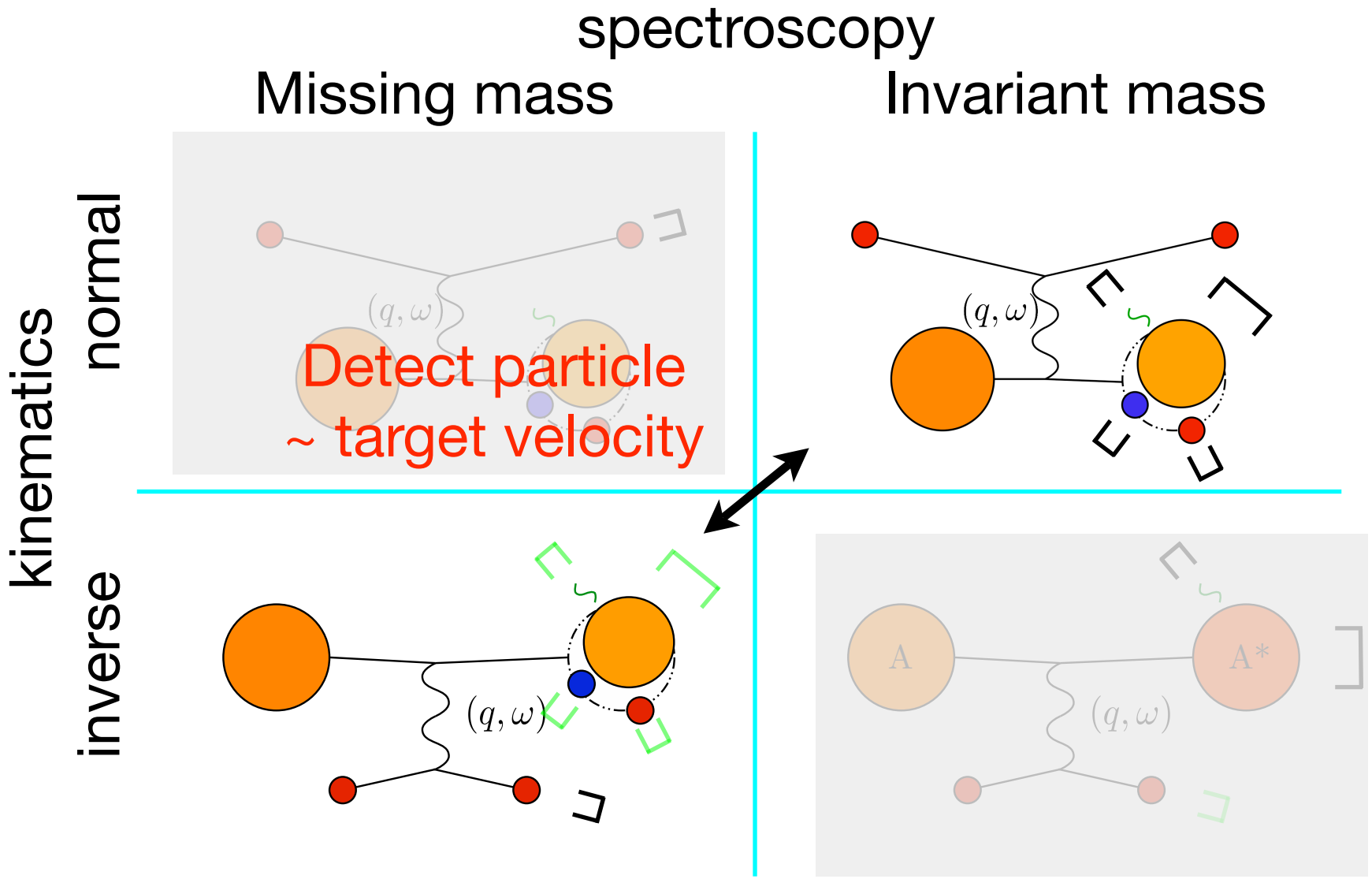
inverse

Detect particle
~ beam velocity



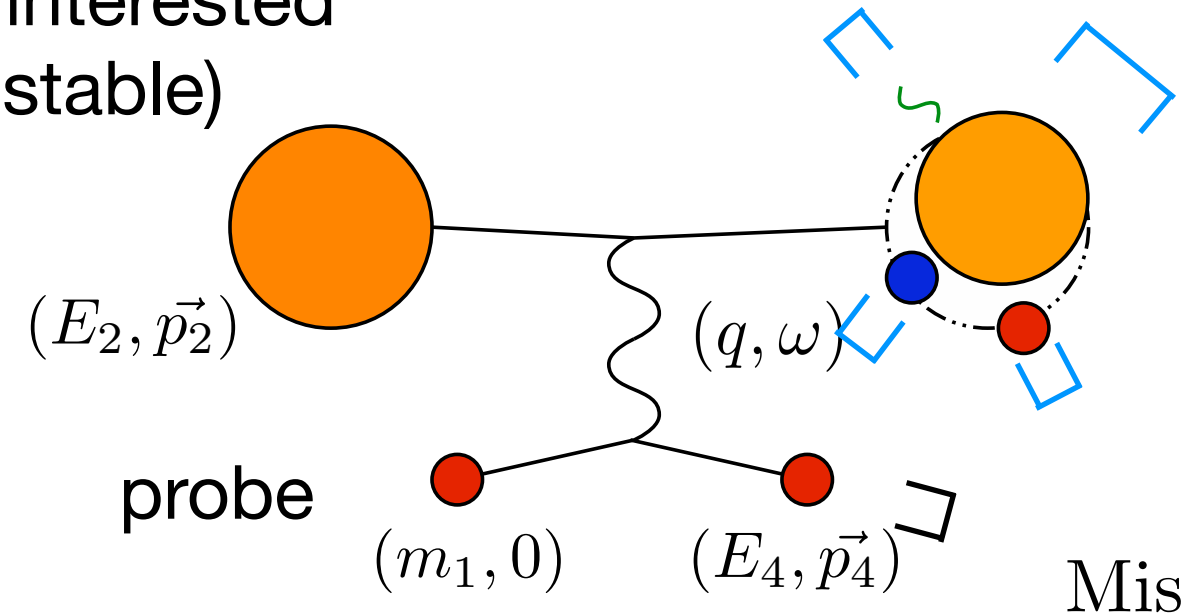


Method for spectroscopy and Kinematics



Missing mass spectroscopy

nuclei interested
(unstable)



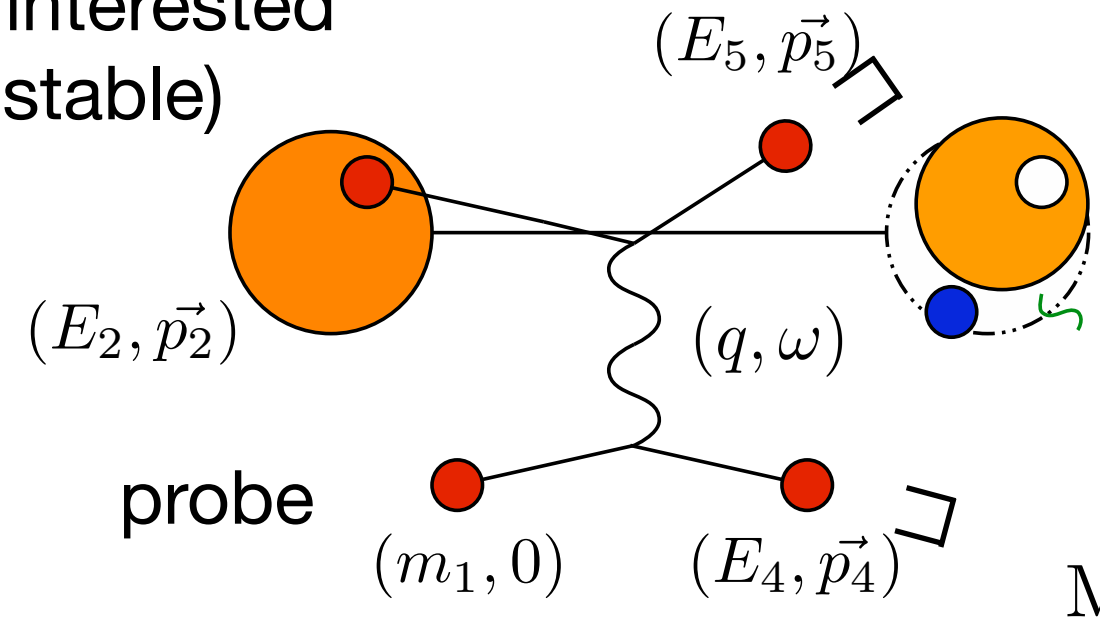
$E_x \uparrow$
$\gg S_n, S_p$

Missing mass
E_x
+Decay modes

- ◯ no bias @ High E_x above threshold
  independent of decay mode
- ◯ good θ resolution
- ▼ recoil particle : far from beam velocity
  @ small q transfer

(Exclusive) knockout reaction

nuclei interested
(unstable)



$E_x \uparrow$
$\gg S_n, S_p$

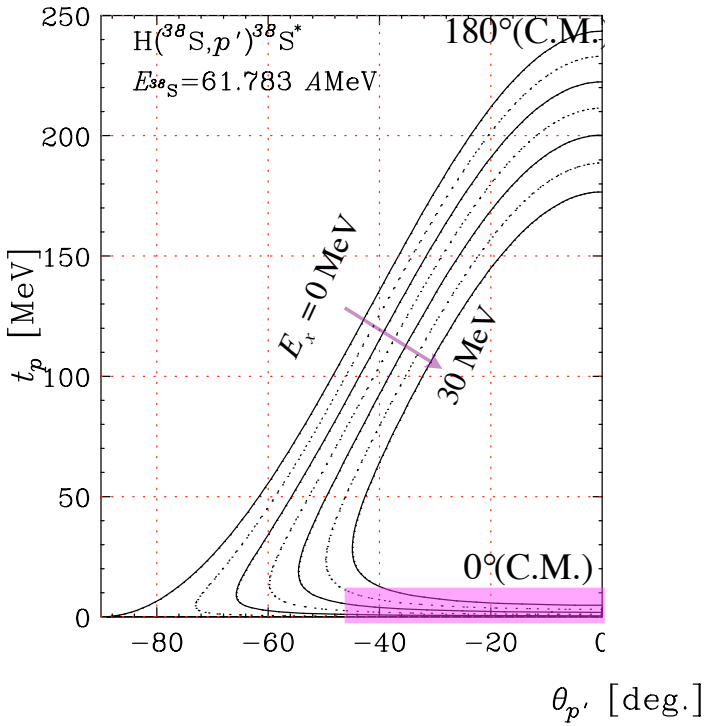
Missing mass
E_x
+Decay modes

Exclusive knockout reaction
belongs to missing mass spectroscopy

△ recoil particles : half of beam velocity
@ largest q transfer

Experimental difficulty

Most severe case : small q on (N,N'), (aN,aN')



Difficulty for (p,p') or (α,α')

T_4 (extremely) small as :

$$\hat{t}_4(0°) = \frac{E_x^2}{4A_4\hat{t}_1}$$

$\sigma(E_x)$ not so good relative to γ Spectroscopy

Experimental difficulty

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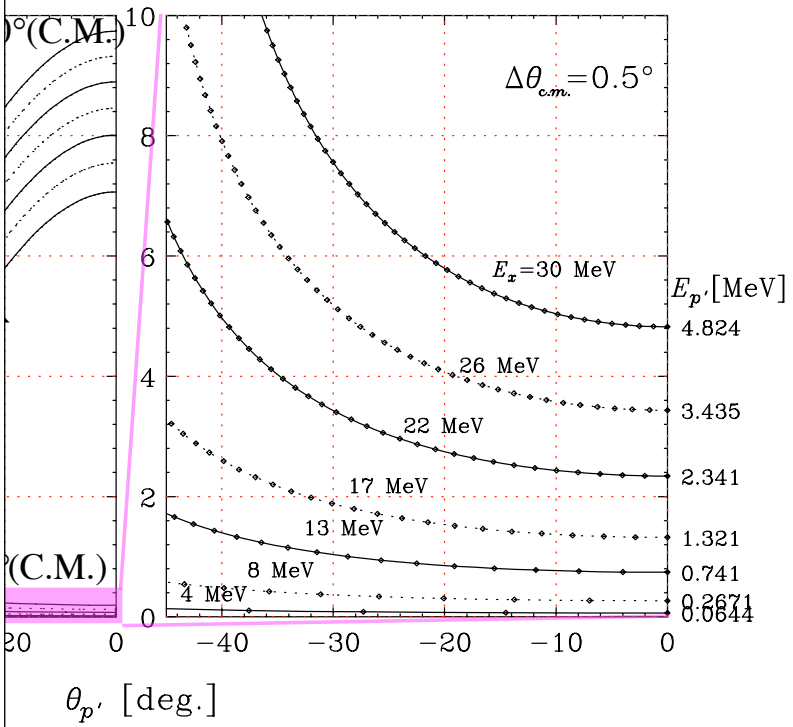

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Proposed/Planned experiments in RIBF

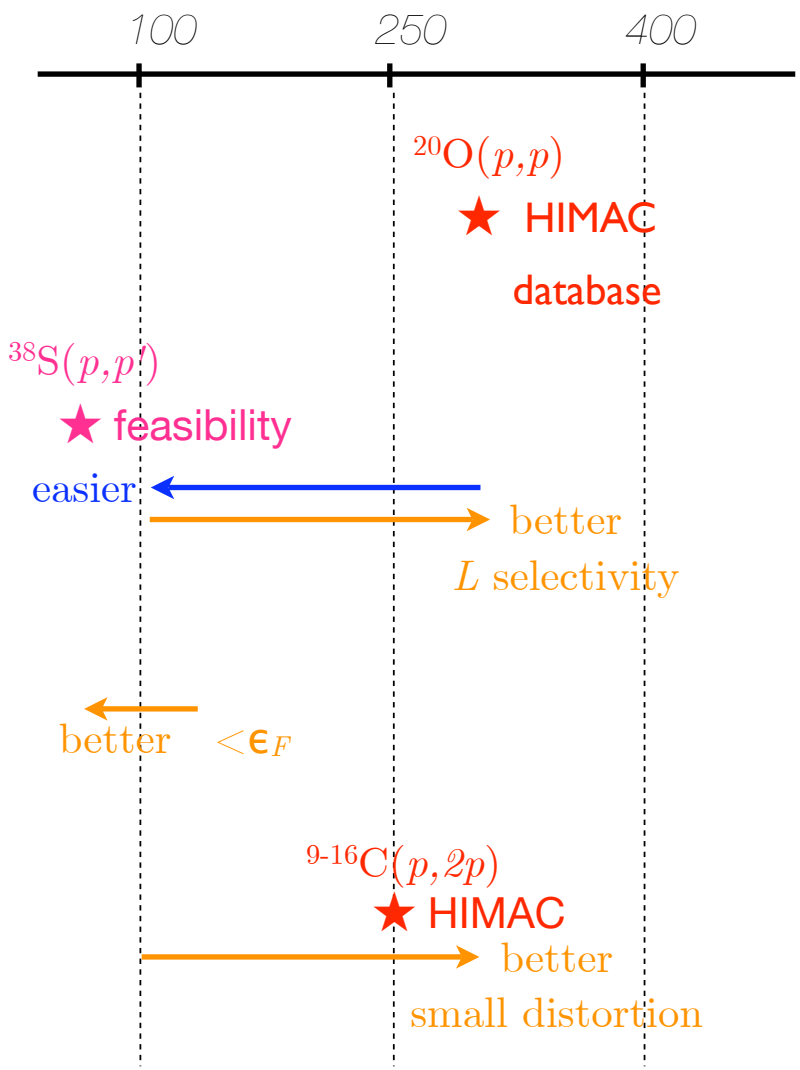
reaction	aim	spokesperson
(p,p)	Matter Density	H. Takeda
(p,p')	ISGMR	Otsu
$(p,2p),(p,pn)$	p-,n- single hole beyond n-, p- drip line	T. Kobayashi
$(d,{}^3\mathrm{He})$	beyond n- drip line	K. Alexey
(d,dp)	high q knockout	Otsu
CX w/HI	(GT),SDR	T. Ichihara
(e,e)	Charge Density	T. Suda
$(d,{}^3\mathrm{He})$	deeply bound π nuclei	K. Itahashi
$(\vec{p},p)$,$(\vec{p},2p)$	$A_y \rightarrow J^\pi$ of single particle	S. Sakaguchi

Proposed/Planned exp. in other facilities

reaction	aim	Collaboration
(p,t)	$2n$ correlation	H. Iwasaki in Ganil
@<100 AMeV		(approved)
(d,d')	ISGMR, GQR	MAYA in Ganil
@ 50 AMeV		(done)
(α,α')	ISGMR	EXL in GSI/FAIR
@>400 AMeV		(proposed)
(p,n)	(GT),SDR	MSU
@~100 AMeV		(planned)

Experiments and Incident energy

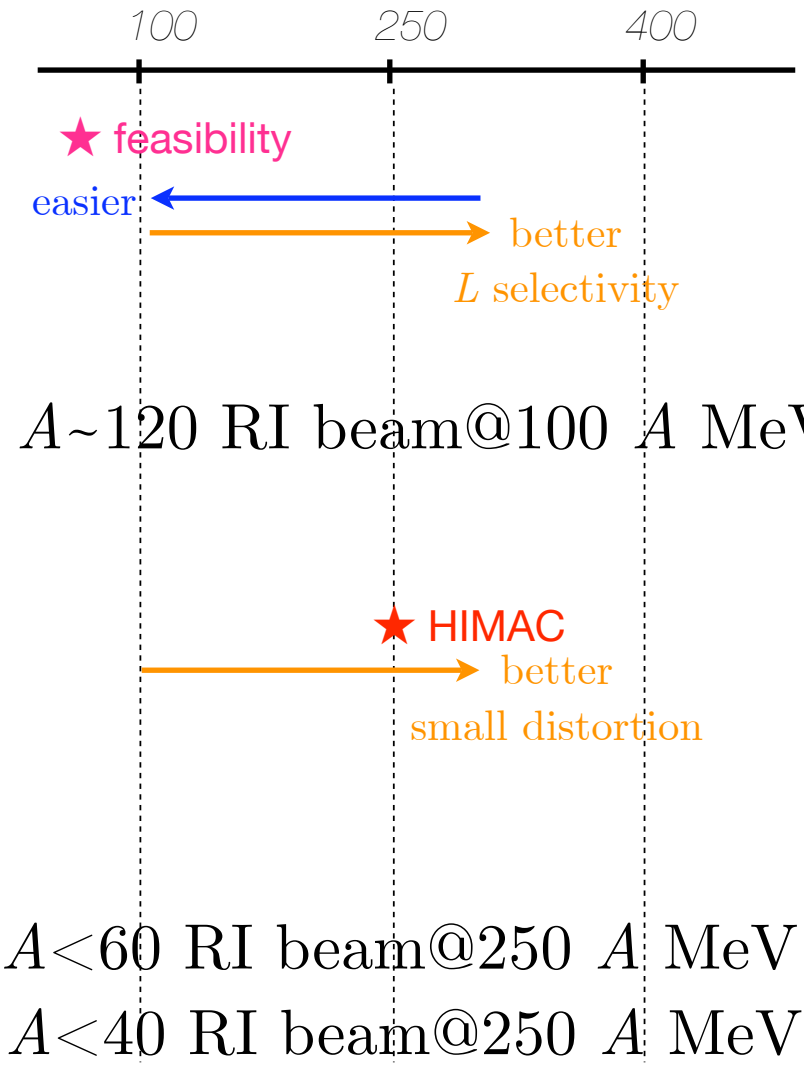
type	reaction
elastic	$(p,p),(e,e)$
inelastic/CX	$(p,p'),(p,n),$ $(d,d'),(\alpha,\alpha')$
transfer/strip	$(d,{}^3\mathrm{He}),(p,d),$ $(d,p),(p,t)$
knock out	$(p,2p),(p,pn),$ (d,dp)



Missing mass spectroscopy

Day-0 experiment in RIBF

type	reaction
inelastic/CX	(p,p')
knock out	$(p,2p),(p,pn),$ (d,dp)



^{136}Xe 200 A MeV 100 pnA → A~120 RI beam@100 A MeV

^{84}Kr 300 A MeV 400 pnA → A<60 RI beam@250 A MeV

^{48}Ca 400 A MeV 1 pμA → A<40 RI beam@250 A MeV

Investigation of ISGMR on
unstable nuclei

→ ^{38}S(p,p') measurement
at forwarding angle

Physical motivation

^{38}S(p,p') 0°

- Unstable nuclei → Asymmetric matter

  static (+basic) property : n-halo, n-skin (Shape)

$$k_F(n) \neq k_F(p) \qquad \langle r_p^{\,2} \rangle \neq \langle r_n^{\,2} \rangle$$

- The first moment of the Shape ?

$$K_{n.m.} = k_F^2 \frac{d^2}{dk^2}\left(\frac{E}{A}\right)_{k=k_F}$$

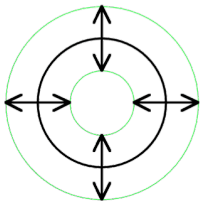
  →E0 : Incompressibility

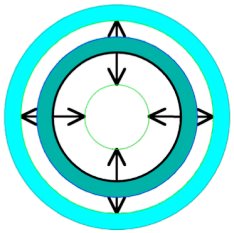
neutron matter EOS

g.s.

$$| R_p - R_n | \mapsto 0.4 \approx 0.8 \text{ fm}$$

E0 resonance





not measured

- Systematics@stable, A>90

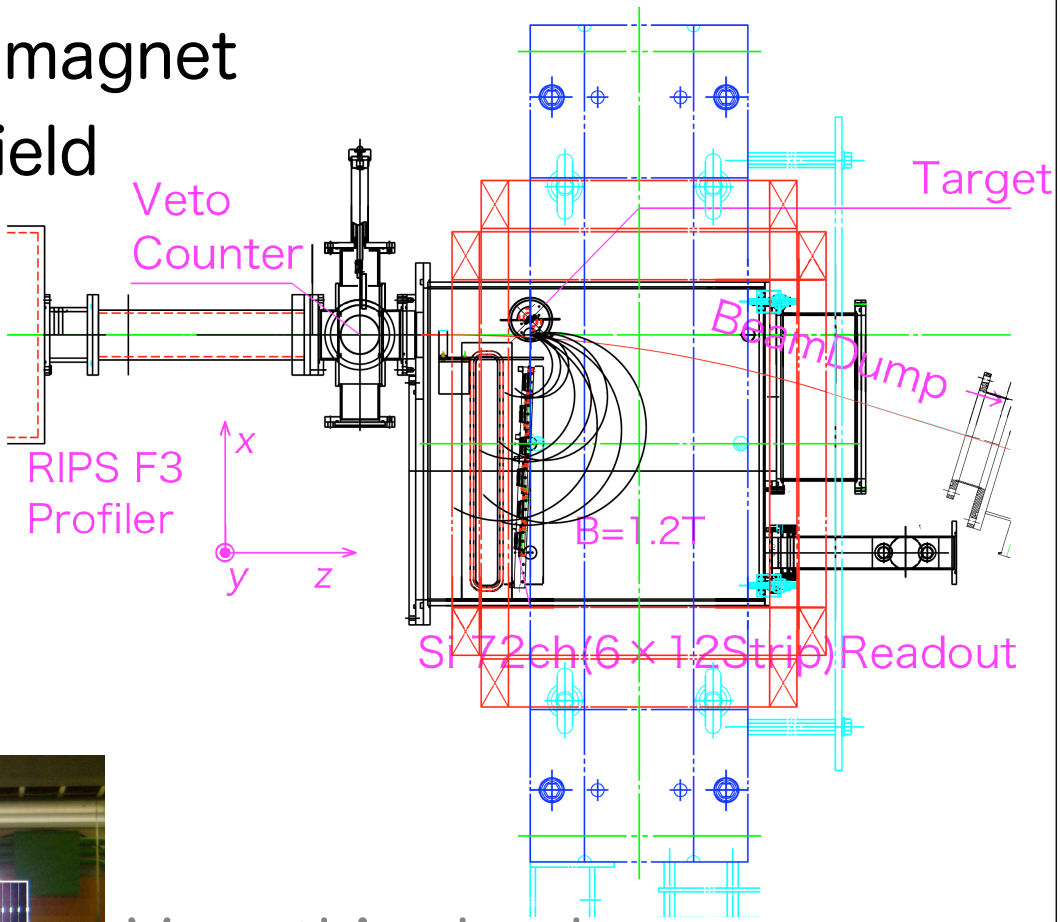
$$\bar{E}_x = 78A^{-1/3} = \frac{94}{r_A}$$

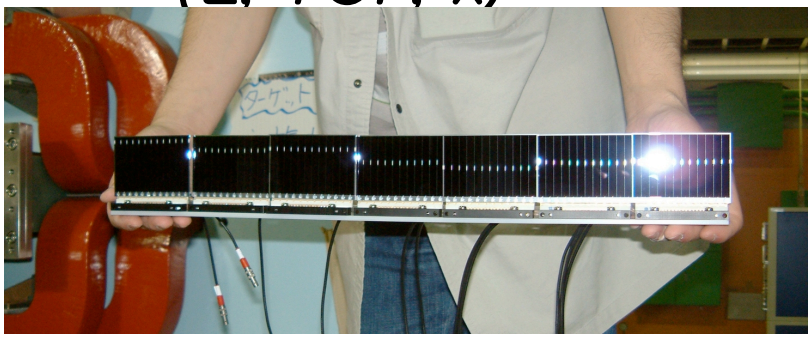
$^{38}S(p,p')\ 0^{\circ}$

Construction

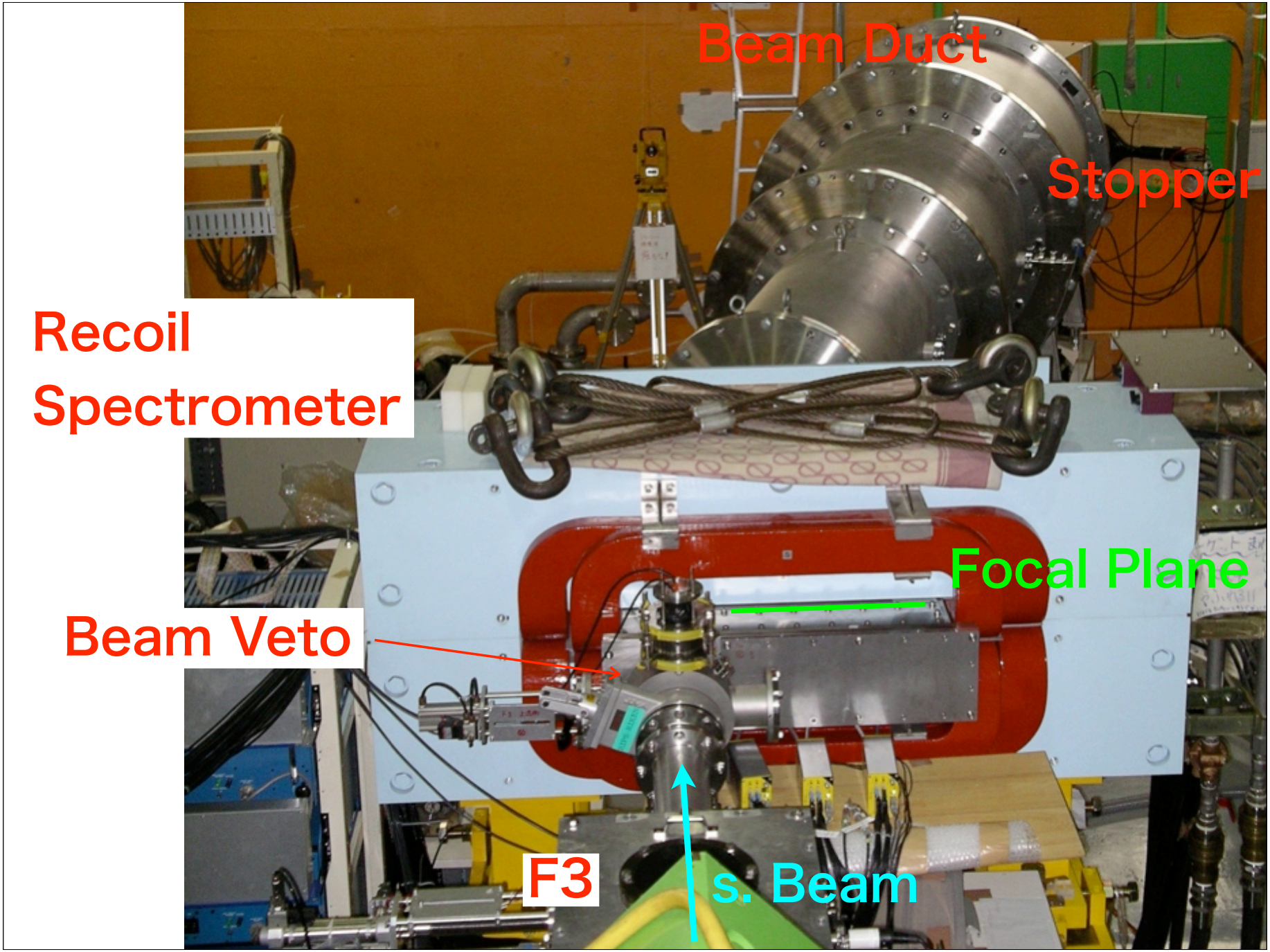
- Recoil Spectrometer magnet
  By=1.2T : Uniform Field

- Si detector array
  at 180 degree F.P.
  12 strip(72 mm) × 6
  $E_p < 4.5MeV(0^{\circ})$
  → (E, *TOF*, x)





Very thin dead area
along x(momentum) axis


Beam Duct
Stopper
Recoil
Spectrometer
Focal Plane
Beam Veto
F3
s. Beam

Experimental Condition

^{38}S(p,p') 0°

- RIKEN/RIPS(E6) facility
- ^{38}S 62AMeV well separated 2nd-beam
- CH_2-C @ 0.4 mg/cm^2

  ➡ $E_{p'}$ -ΔE_{DET} > 0.25 MeV @trigger threshold
- I_B ~ 0.6 MHz (typ.)

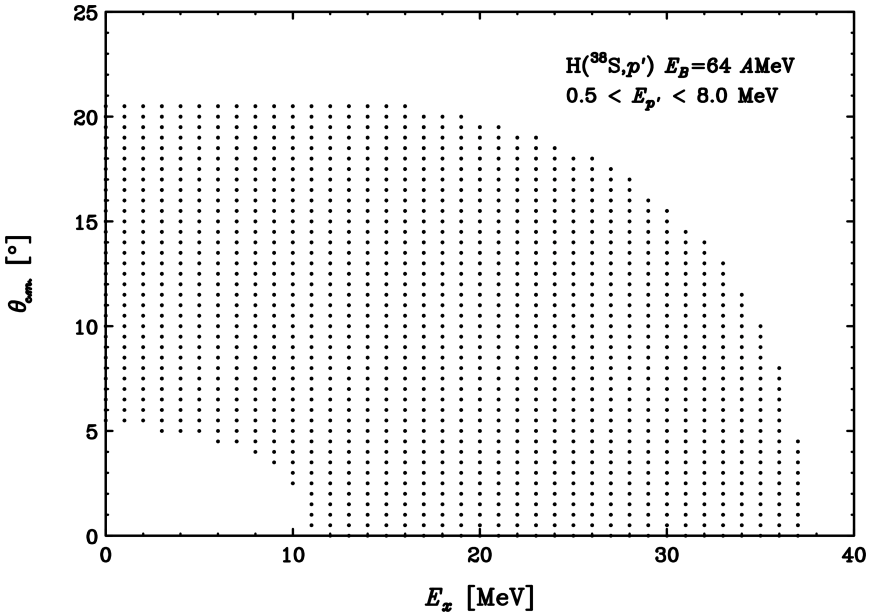
  ➡ N_T =3.4e19/cm^2 :small for 2nd-beam exp.

1-path

- Acceptance

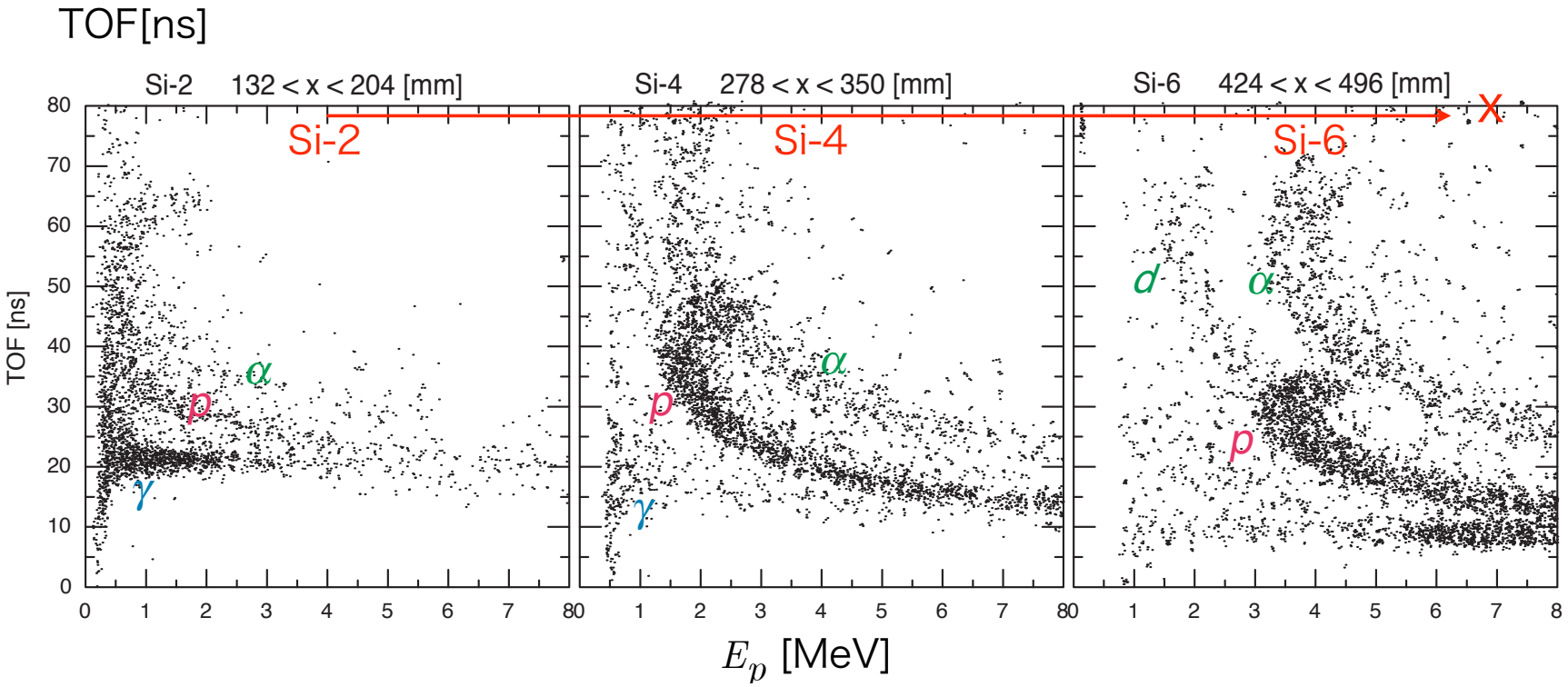
  limited by $E_{p'}$

  ※$\phi_{C.M.}$<1°



Data Analysis: Particle Identification

^{38}S(p,p') 0°

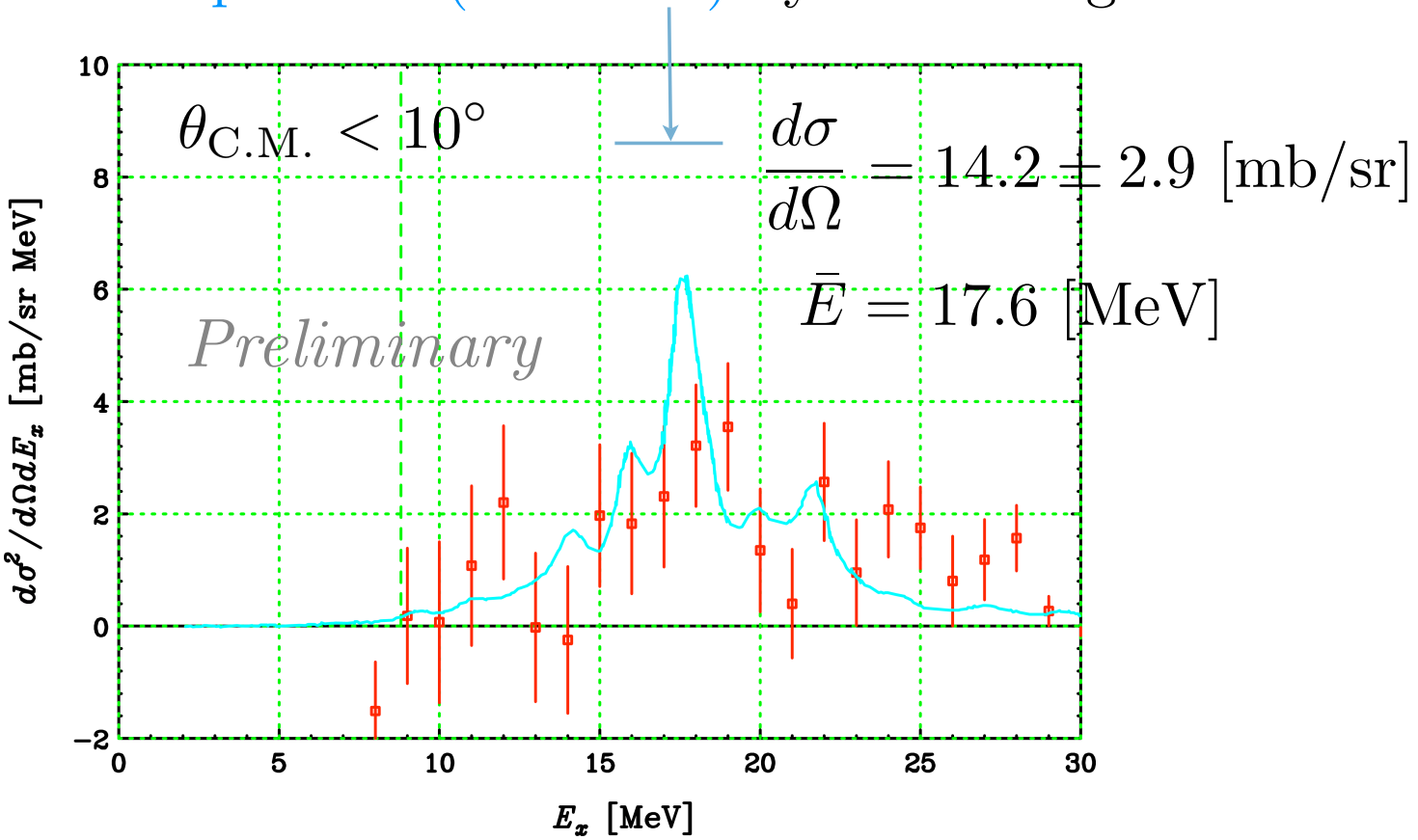


- Position, E_p, TOF → PID(p'), E_x, $\theta_{\mathrm{C.M.}}$
- p' well identified
- BG γ well isolated

Results: cross section ^{38}S(p,p') 0°

- peak at E_x=12 MeV
- bump around E_x=17 MeV

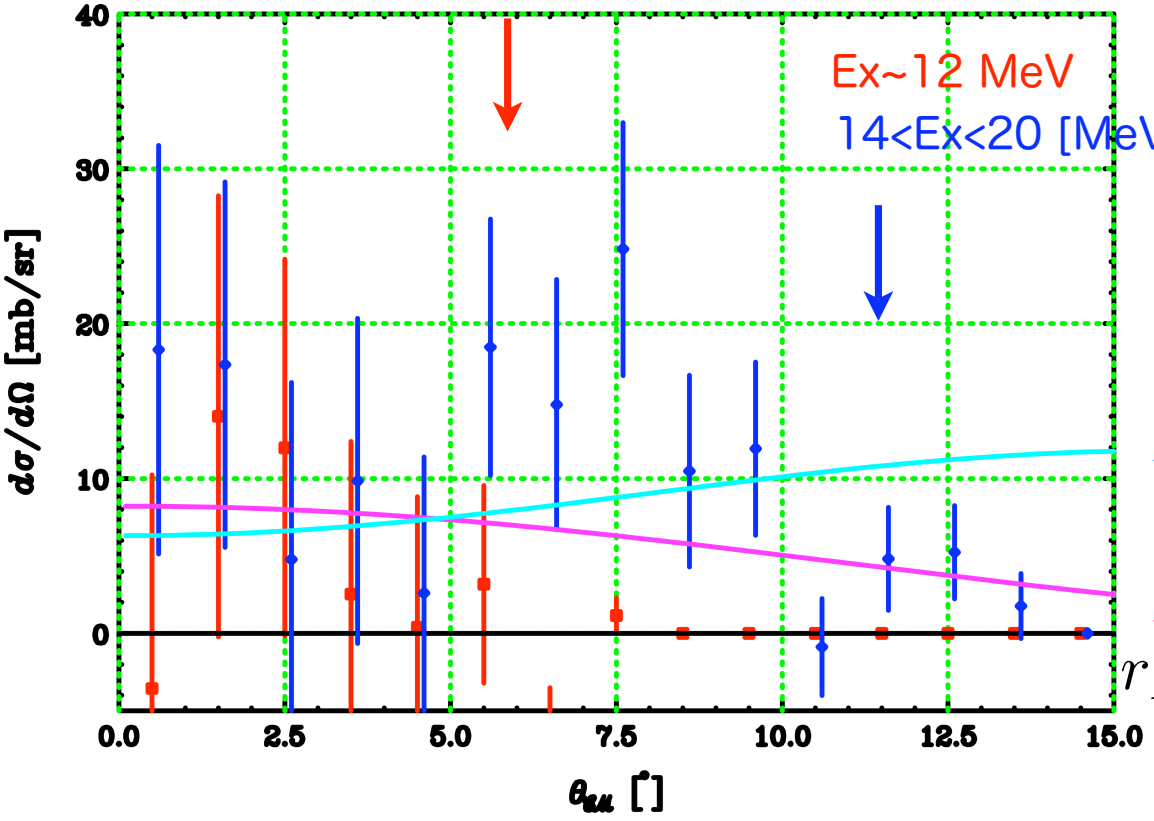
IVGDR SkM* spherical (arb. unit) by M. Yamagami



Results: Angular Distributions ^{38}S(p,p') 0°

- $14 < E_x < 20$ [MeV] :
- E_x~12 MeV :

➡ L selection from this dataset : difficult



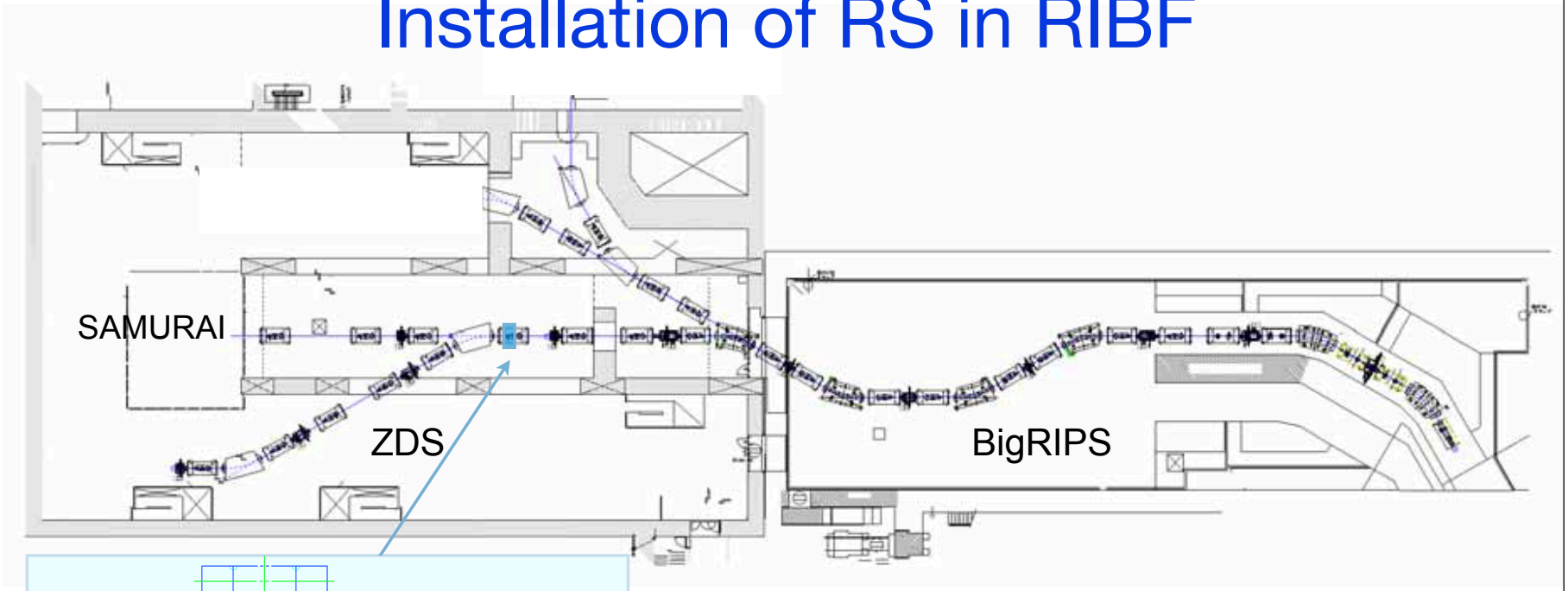
$L=1$

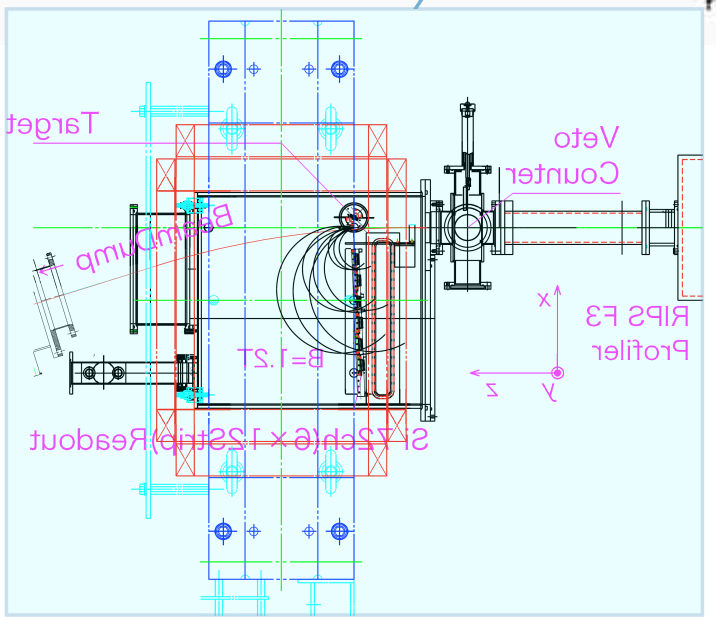
$L=0$

$r_A = 4.0$[fm]

Installation of RS in RIBF

(*p*,*p*') 0° at RIBF





- Tagged n/p decay channel from GR by ZDS

Summary

- Missing mass spectroscopy in RIBF

  → no-biased information will be derived

  even in high E_x region

- Variety of experiments have been proposed for RIBF.
- inelastic (p,p') scattering : collective motion

  ^{38}S(p,p')@62 AMeV experiment : feasible enough

  Primary Beam~200 AMeV → 100AMeV RI at A~100

  Big RIPS + RS (+ ZDS for decay products)

Measurement of the H(^{38}S,p') reaction at forward angles including 0 degree

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Collaboration:

Tohoku Univ.

Hideaki Otsu ※

Toshio Kobayashi

Yohei Matsuda (D3)

Kiyohiko Inafuku(M2)

※move to RIKEN on 2005/10

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Tsukuba Univ.

Akira Ozawa