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Study of Gamow-Teller strength from ^{132}Sn via the inverse kinematics (p,n) reaction

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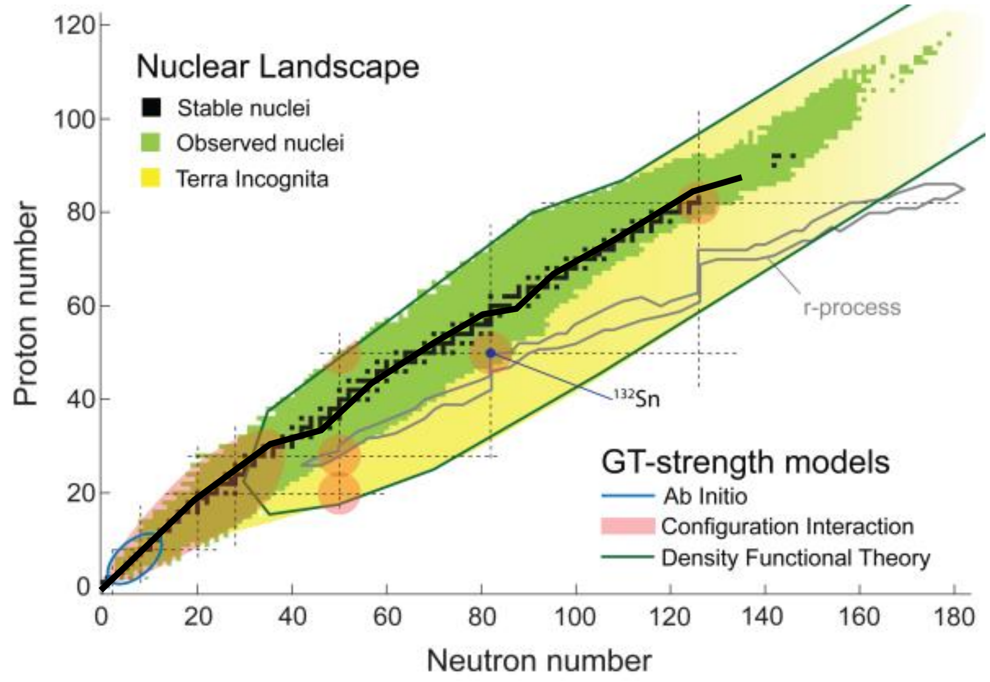
Motivation

- **Exotic property of unstable nuclei**
  - Neutron halo, skin (low density)

    <—> density saturation
  - Magic number breaking



- **Comprehensive nuclear models**
  - ▸ Nuclear EOS (equation of state)
  - ▸ r-process

➡ **Need many information of ground state & excitation state**

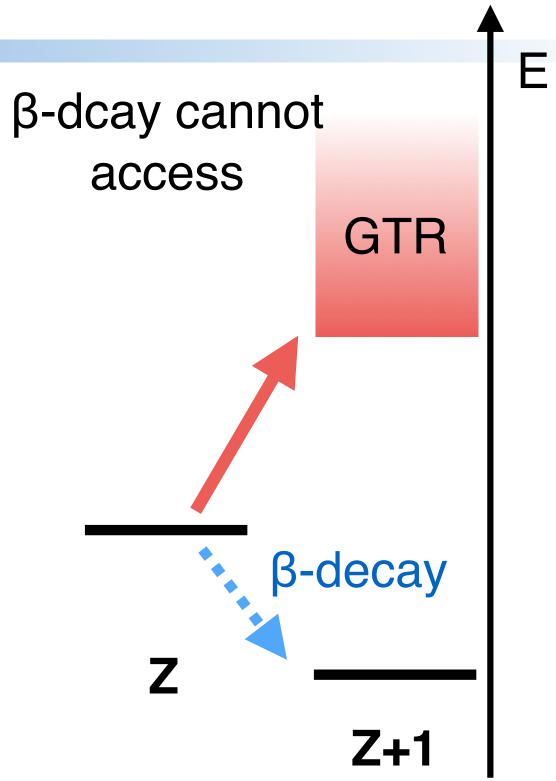
✳ **Lack of the knowledge of excitation state of unstable nuclei**

- Gamow-Teller resonance, Spin Dipole resonance, Giant Dipole resonance etc…

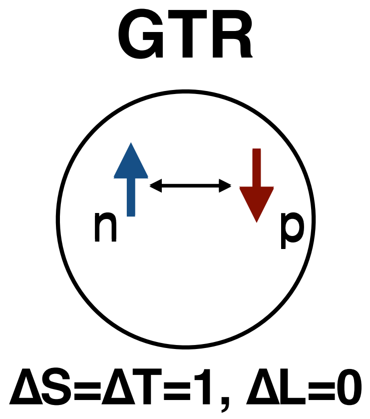
➡ **Measure spin-isospin excitation at any (A,Z)**

Gamow-Teller transition

- **Gamow-Teller (GT) transition**
  - **One of the most simplest mode of nuclear excitations**
    - Isospin-flip (ΔT=1), Spin-flip (ΔS=1)
    - No angular momentum transfer (ΔL=0)
      - Operator : $\beta^{\pm}_{GT} = \boldsymbol{\sigma}_{\mu}\boldsymbol{\tau}_{\pm}$
    - Strength : B(GT)
      - **Directly connect with a half life of β-decay**



- **GT Resonances (GTR) : High excitation mode**
  - Collective motion in spin-isospin space
  - **Cannot access by β-decay due to Q-value**



Charge Exchange (CE) reaction

- **CE reaction at intermediate energy**
  - **can access any Ex. energy**
    - β decay is limited by Q-window
  - **Selectivity to ΔT=1, ΔS=1**
    - Gamow-Teller (GT), Spin-Dipole (SD) etc..
  - **Proportionality**

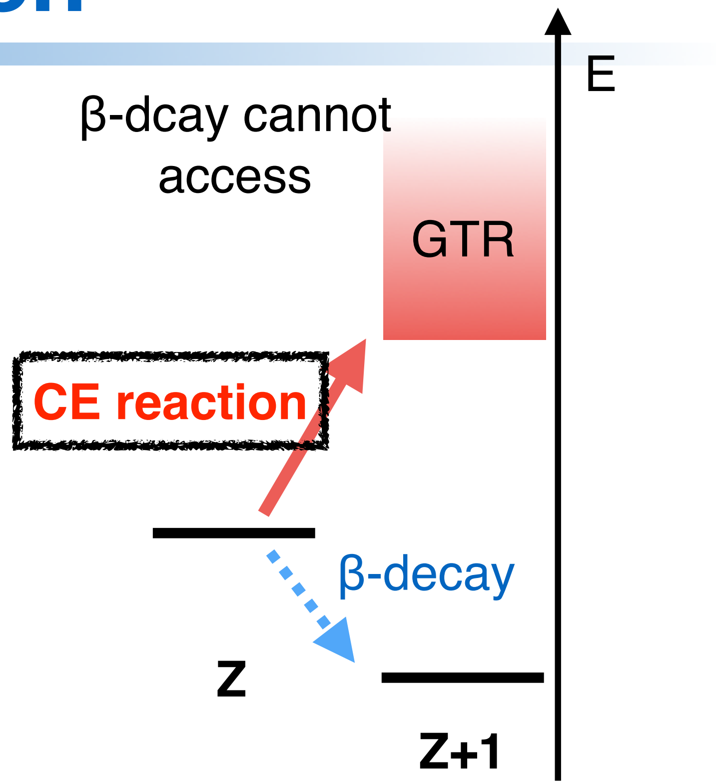
CE c.s.

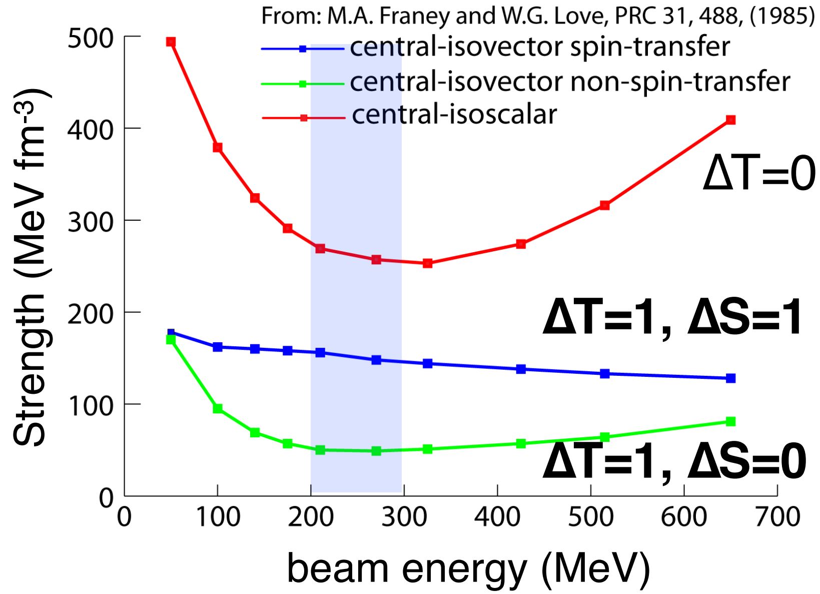
$$\frac{d\sigma}{d\Omega}(q=0) = \hat{\sigma} B(GT)$$

▶ **Powerful tool to study GTR**

- **Limited to stable, low-lying state in light unstable-nuclei**

➡CE reactions for RI beams are required





(p,n) CE reactions for RI beam

- **Missing mass spectroscopy with RI beam**
  - Detect recoil neutron, residual is used just tag for (p,n) reaction.

➡ **High statistics**

- RI beam (~10^6) x thick target (~100mg/cm^2) x large n-detector acceptance (FPL~1m)

  ~ Stable p-beam (160nA) x 100mg x acceptance (FPL~100m)

➡ **Simple kinematics**

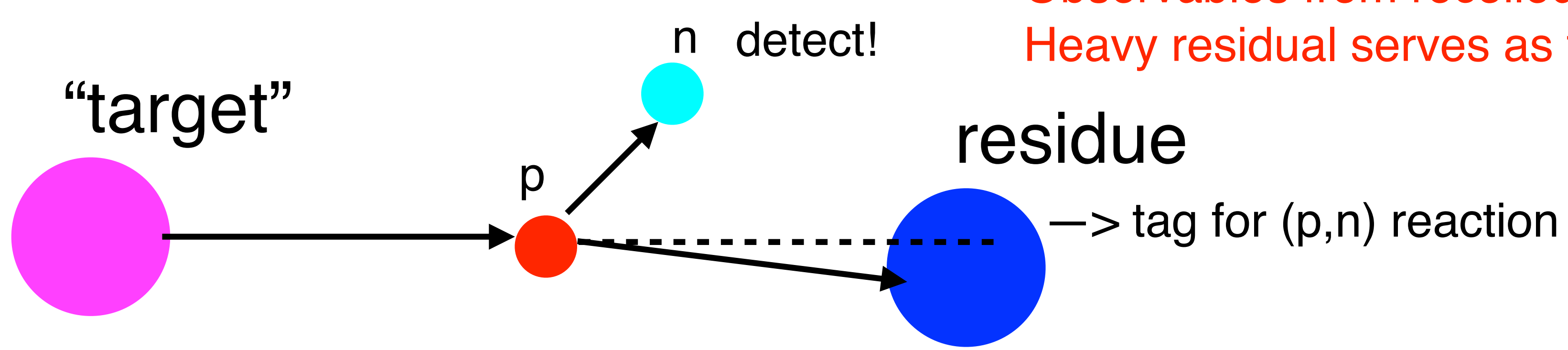
- all kinematics information from the measurement of neutron (2 body kinematics)

➡ **Extensive**

- can be applied to any mass region and to any excitation energy region

✳ improve S/N ratio by tagging of (p,n) reaction

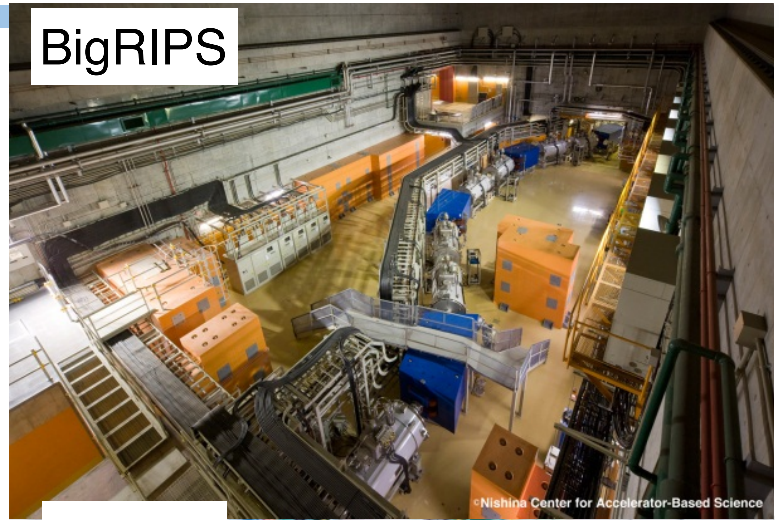
Observables from recoiled n only
Heavy residual serves as tag

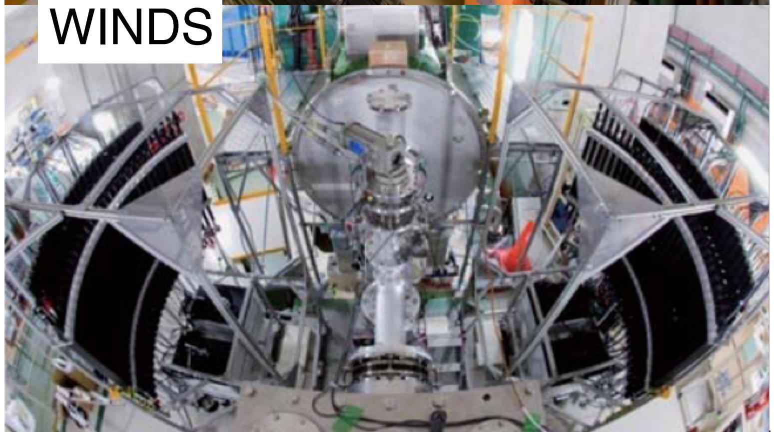


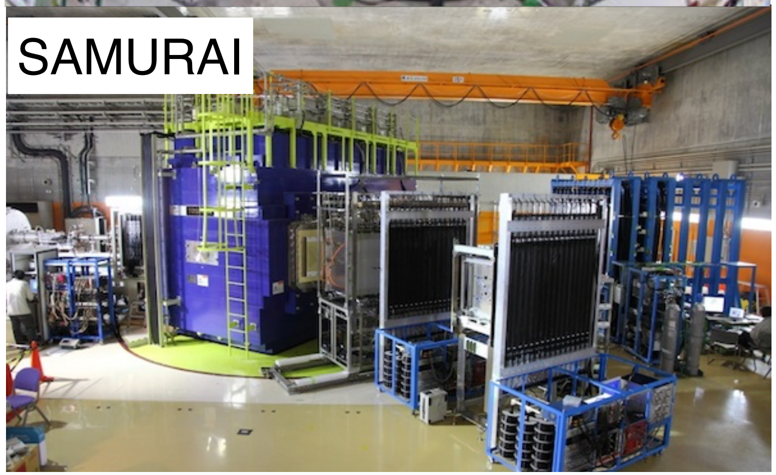
Efficient measurements can be performed even with RI beam

(p,n) measurement with WINDS + SAMURAI

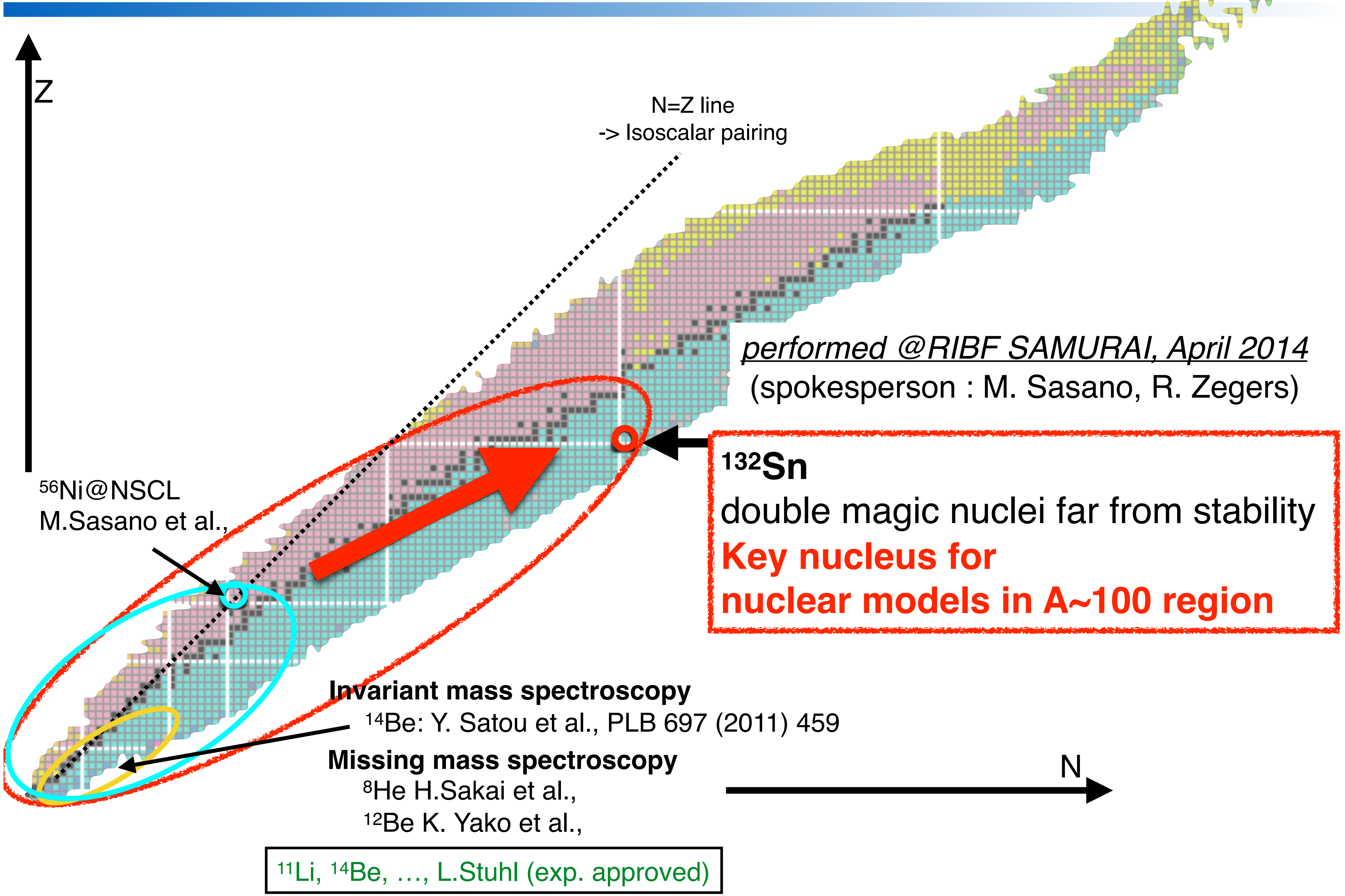
- **Beam**
  - High Intensity : >10^4 pps
  - Intermediate kinetic energy : 200~300 MeV/u
    - **can access to far from the stability line**
- **Neutron detection**
  - WINDS(Wide angle Inverse kinematics Neutron Detectors for SHARAQ) : 73 scintillators
    - **cover wide angular range**
- **Residue tag**
  - SAMURAI
  - Large acceptance
    - **measure all decay particle in one setting**



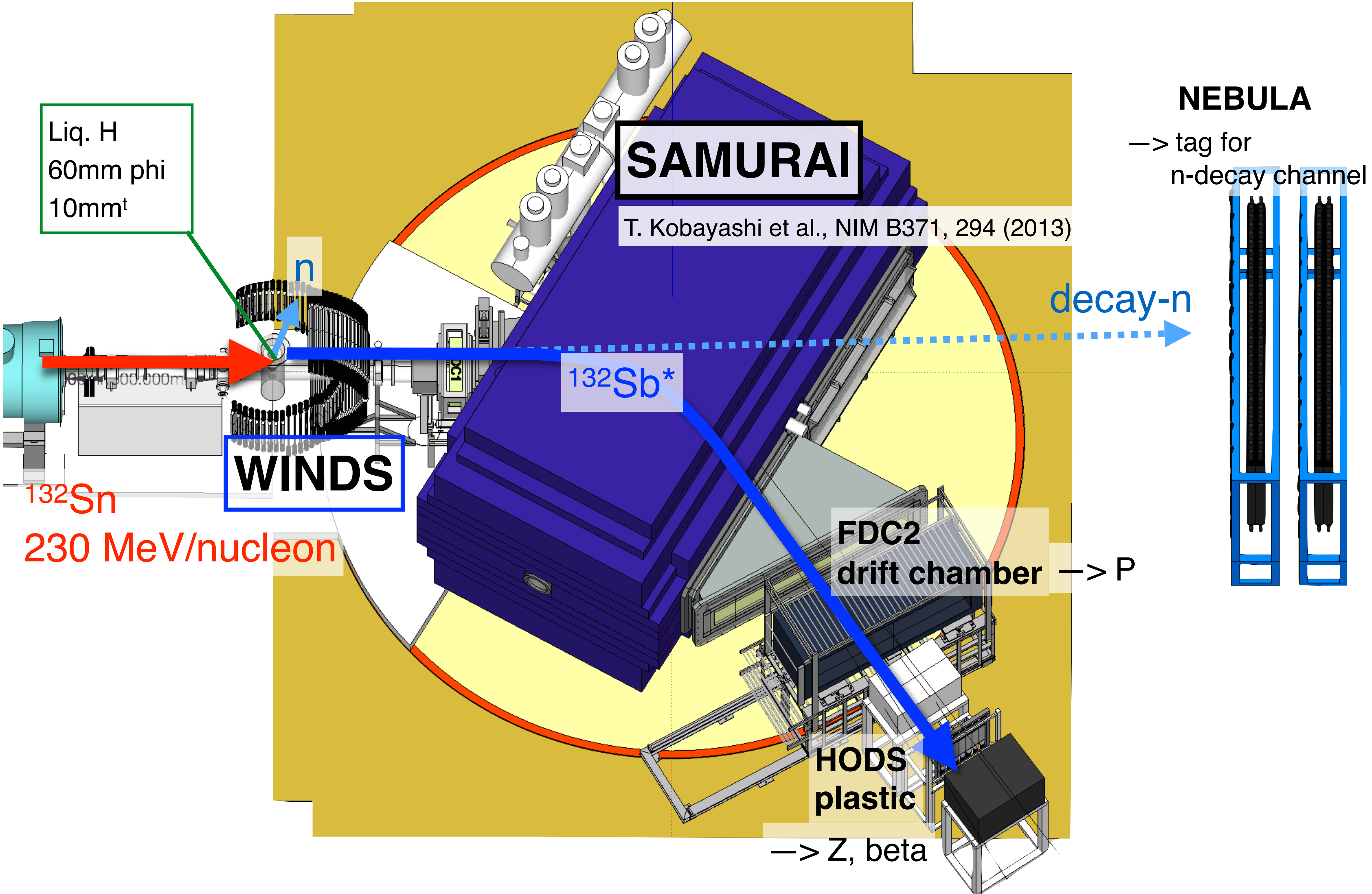




Overview of (p,n) studies for RI beam



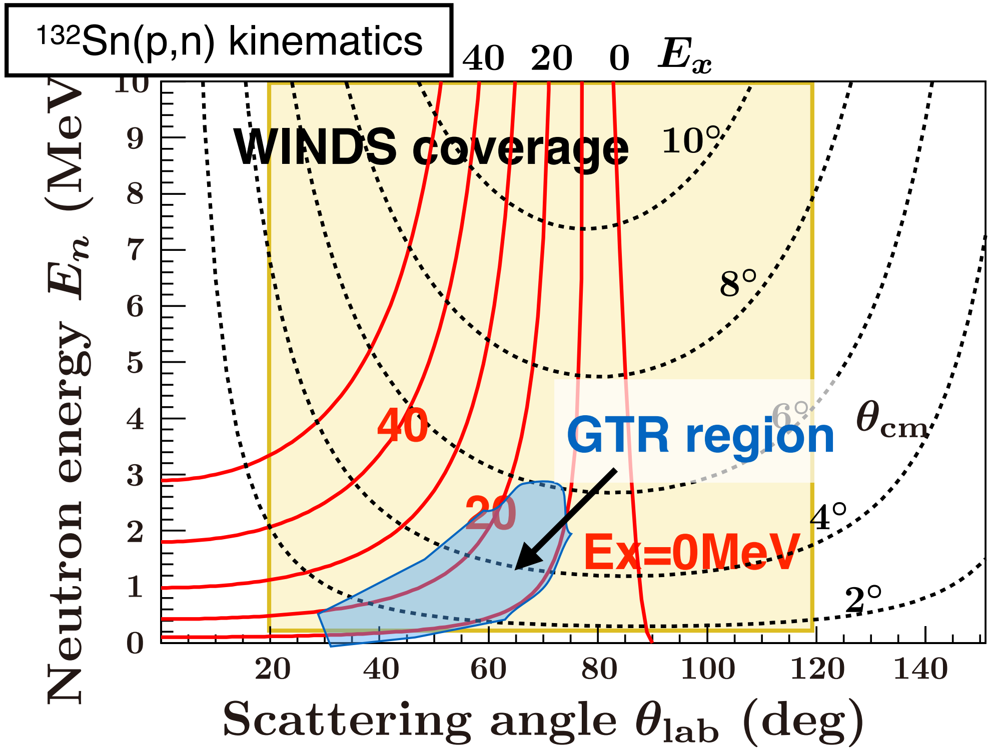
Experimental setup

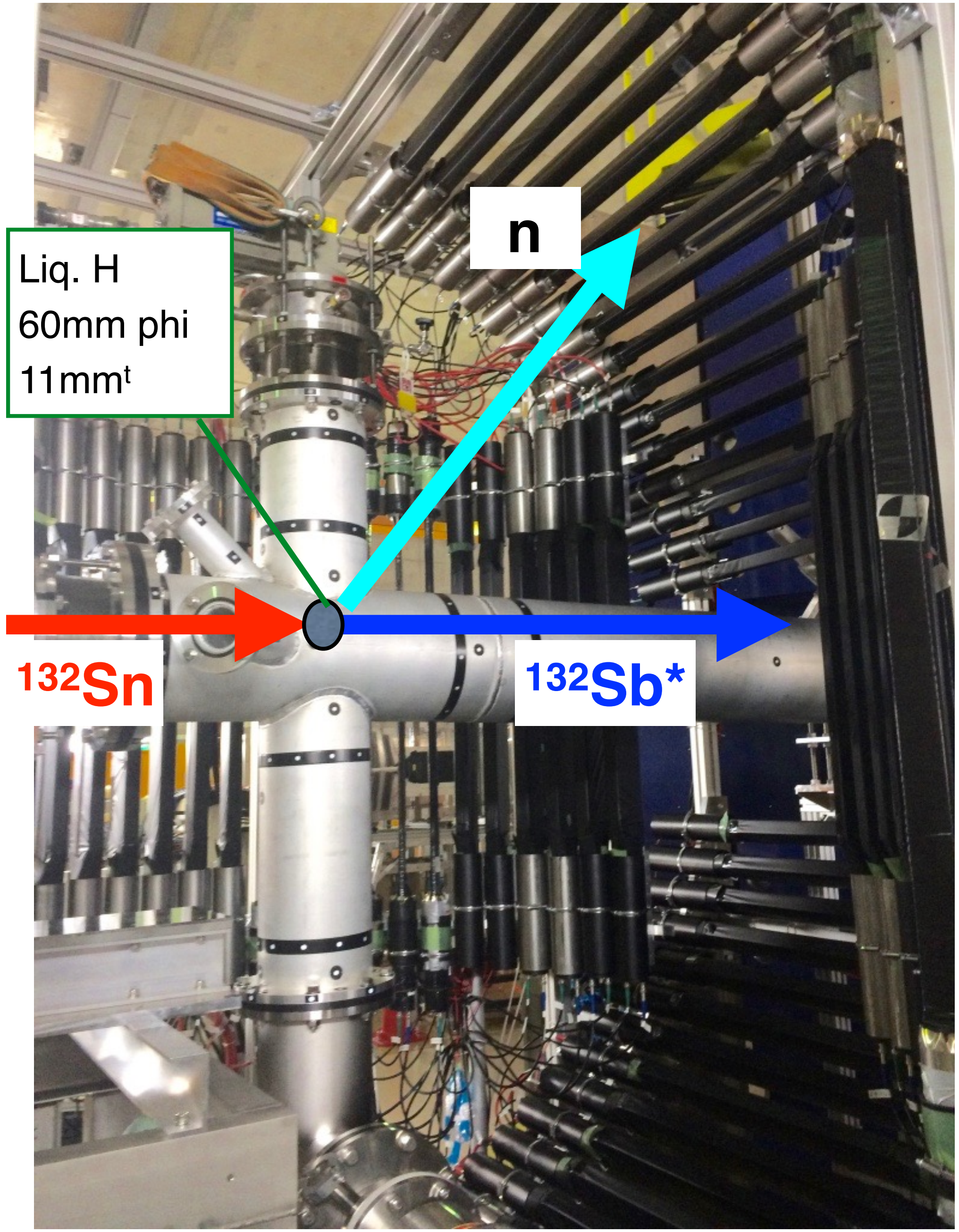


Slow neutron detector WINDS

- **Wide angular acceptance**
  - 73 plastic scintillation counter
  - ➡ θ_{lab} = 20 〜 120° , FPL = 900,1100mm
- **Energy range**
  - TOF : 20 〜 250 ns, Tn : 0.2 〜 10 MeV
- **Low threshold**
  - Threshold: 〜 40 keVee

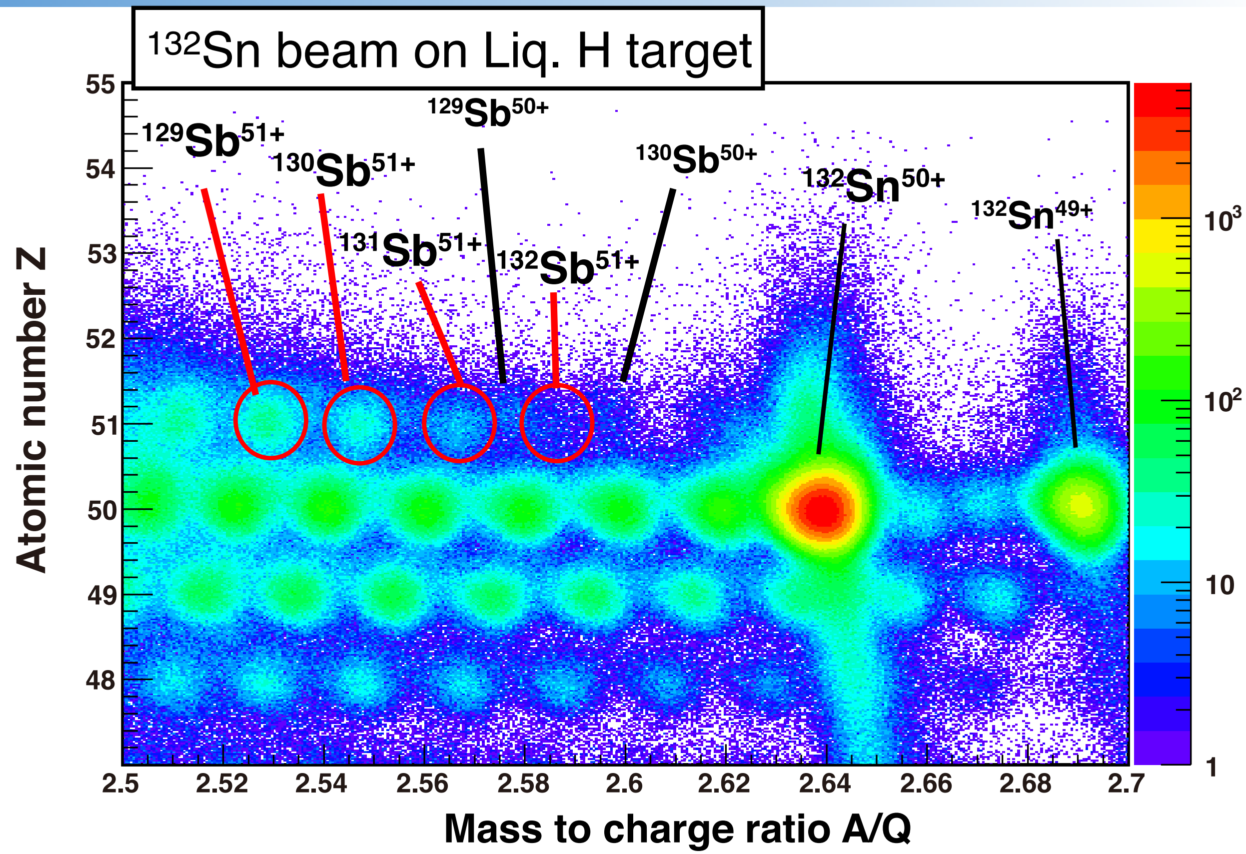
➡ **Overall Efficiency (include acceptance) : ~10% @θ_{cm}~2deg**





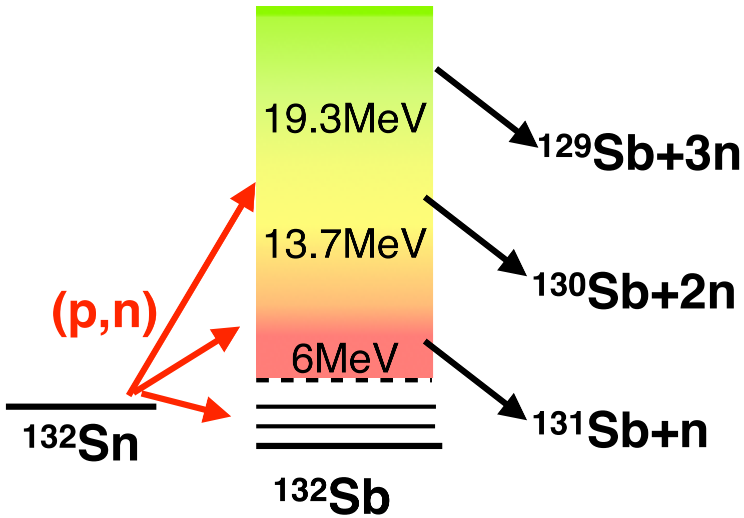
Result ～PID of heavy residues～

- **TOF**
  - plastic counter SBT1,2 and HODS
  - resolution : $\sigma_t \sim 60$ ps
- **ΔE**
  - plastic counter HODS (5mm)
  - resolution : $\sigma_{\Delta E}/\Delta E \sim 0.9$ %
- **Bρ**
  - drift chamber BDC1,2, FDC1,2
  - SAMURAI magnet : 2.56T
  - resolution : $P/\sigma_P \sim 1300$

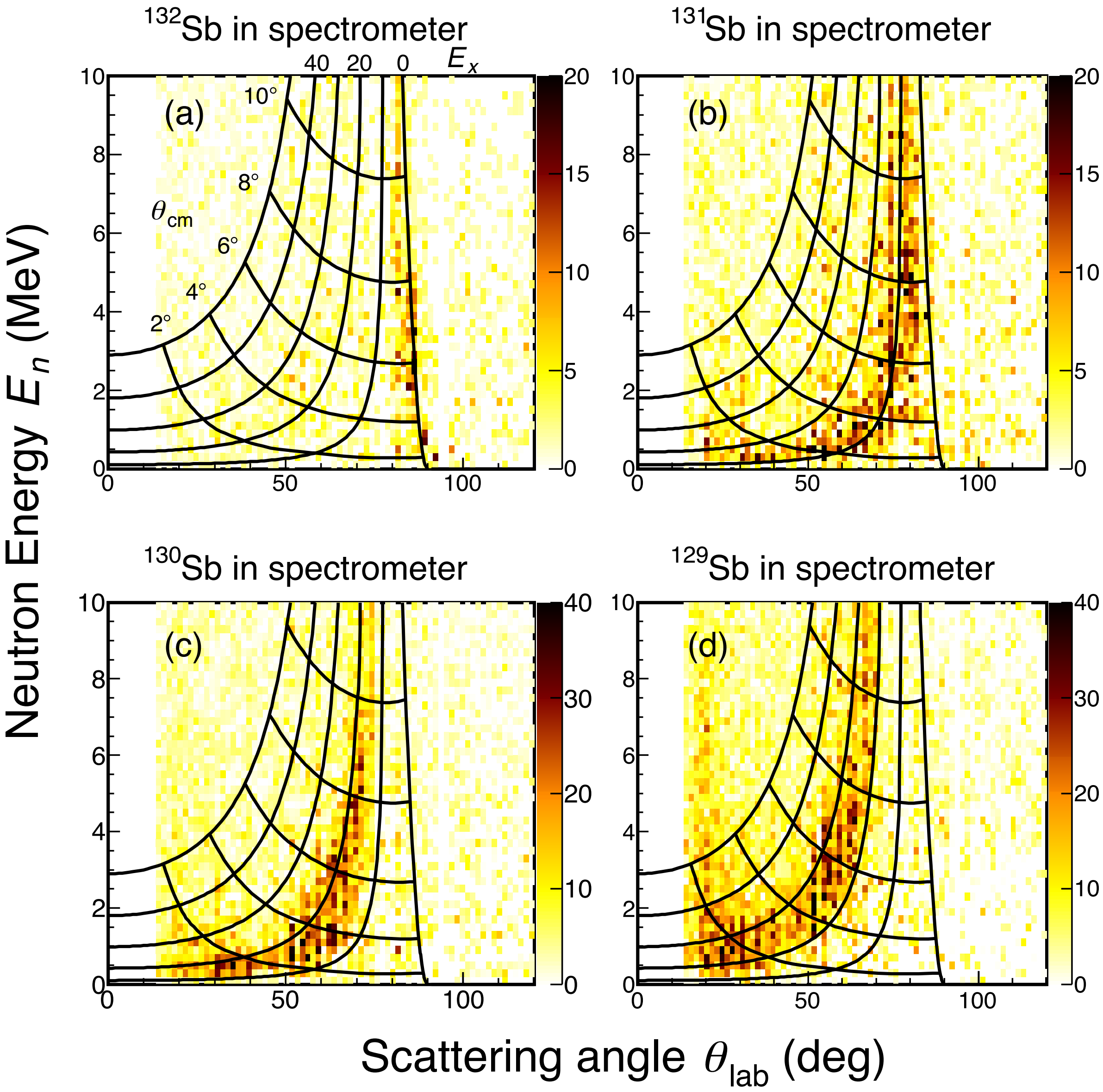


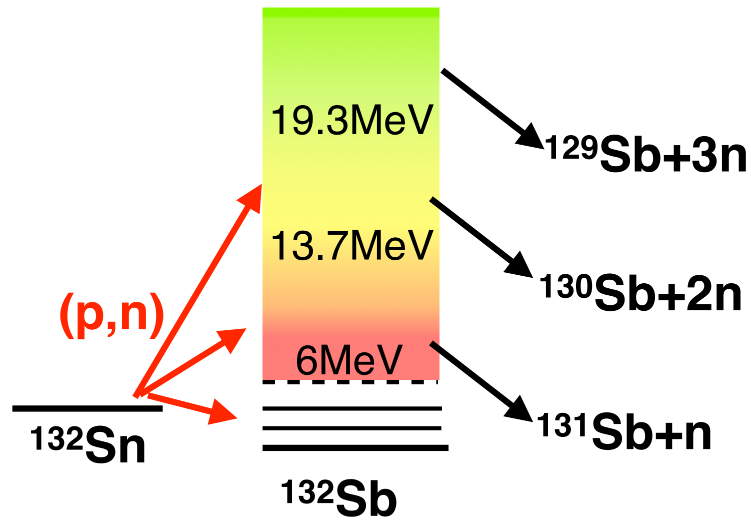
- $\sigma_A = 0.16$ **6.1σ separation**
- $\sigma_Z = 0.22$ **4.5σ separation**

Large acceptance
➡all decay channel was measured with good resolution



Kinetic locus

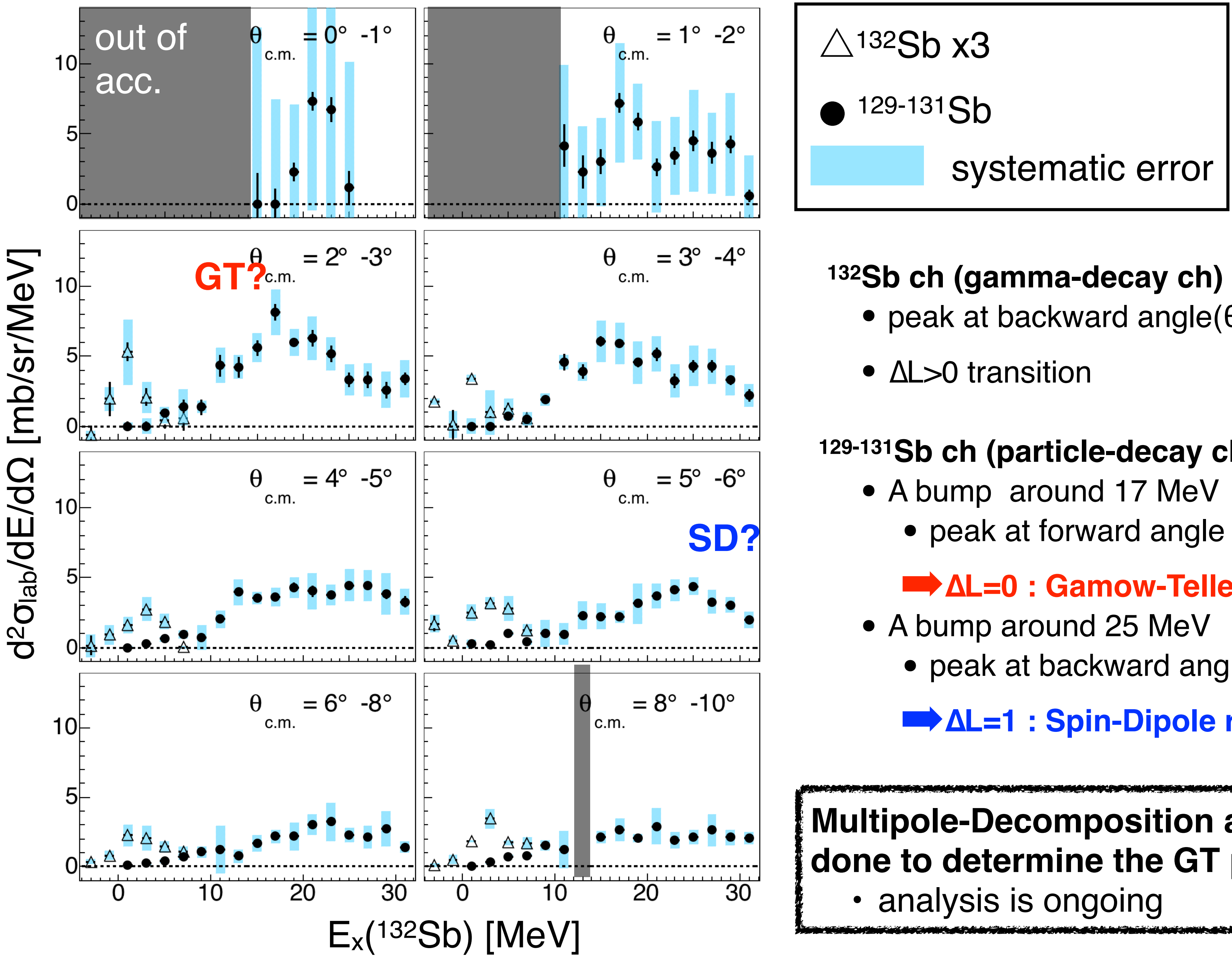




✔ kinematics correlation of (p,n) reaction was clearly seen

➡Successfully measure high Ex
Ex $\lesssim$ 30MeV

A preliminary result of excitation energy spectrum



^{132}Sb ch (gamma-decay ch)

- peak at backward angle(θcm ～ 6deg)
- ΔL>0 transition

$^{129-131}$Sb ch (particle-decay ch)

- A bump around 17 MeV
  - peak at forward angle (θcm ～ 2deg)

  ➡ **ΔL=0 : Gamow-Teller resonance**
- A bump around 25 MeV
  - peak at backward angle (θcm ～ 5deg)

  ➡ **ΔL=1 : Spin-Dipole resonance**

Multipole-Decomposition analysis will be done to determine the GT peak position

- analysis is ongoing

Summary

- **GTR study at any Ex & (A,Z)**

- **WINDS + SAMURAI setup for (p,n) reaction on unstable nuclei**
  - WINDS : wide angular coverage θ_{lab} 20— 120deg (4π configuration)
  - SAMURAI : Large acceptance

- **^{132}Sn(p,n) experiment was performed**
  - successfully measure all decay channel with good resolution σA ~0.16, σZ~0.24
  - can be access to high Ex energy ~30MeV
  - **(p,n) study can be extended to A~100 region**

- **Perspective**
  - 132Sn(p,n) study
    - MDA —> B(GT) distribution on 132Sn
  - (p,n) reactions on ^{11}Li, ^{24}O, ^{48}Cr, ^{64}Ge (N=Z)

Collaborators

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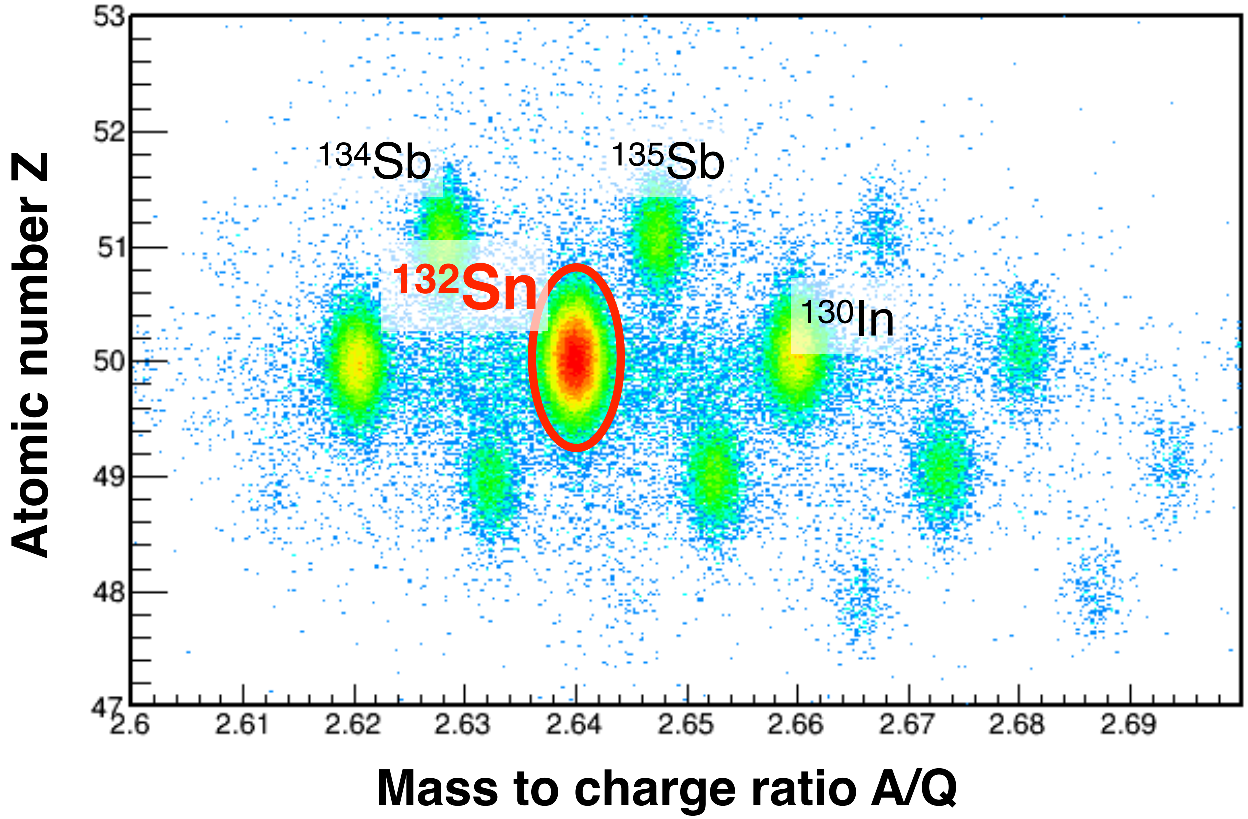
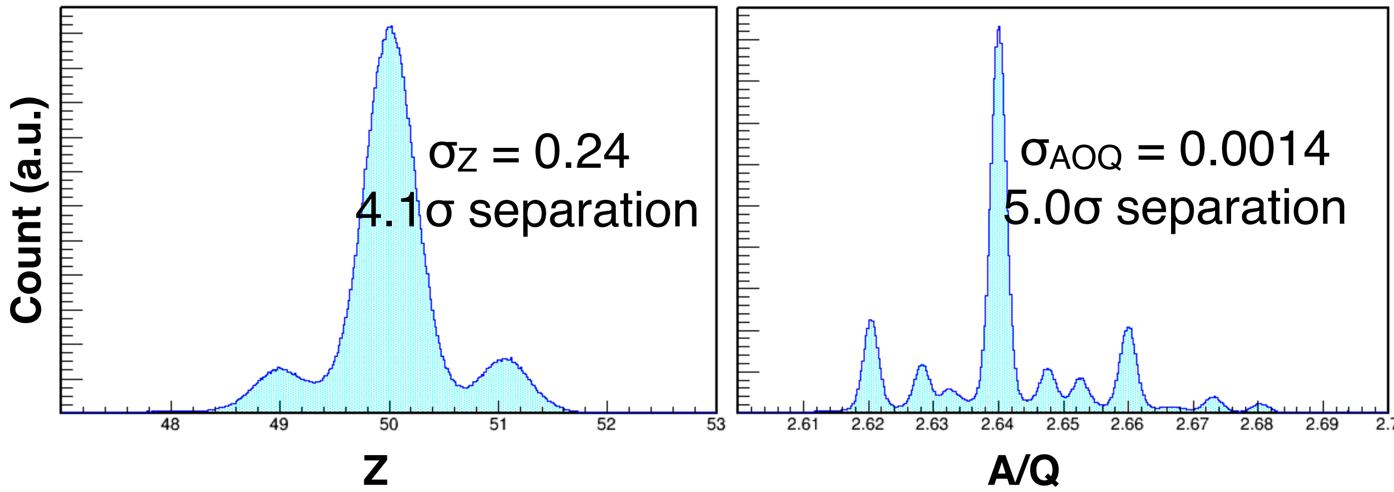
back up

^{132}Sn beam production

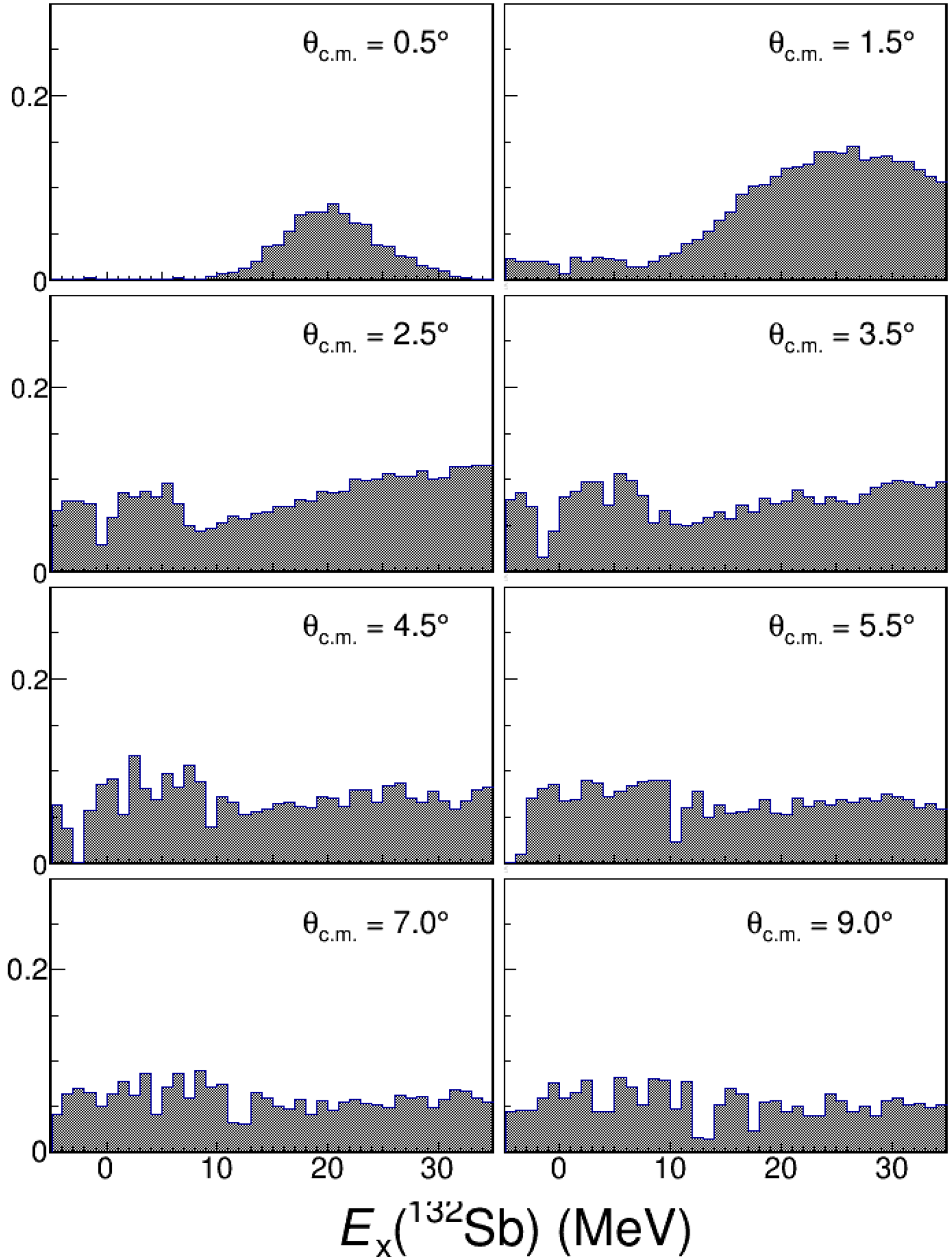
- **Total beam Intensity**
  - 1.4×10^4 pps
- **PID by BigRIPS**
  - $\sigma_Z = 0.24$
  - $\sigma_{A/Q} = 0.0014$
- **Purity**
  - ^{132}Sn : 40%

	purity [%]
132Sn	40.11
133Sn	9.47
131Sn	9.50
135Sb	3.88
134Sb	4.28
130in	3.24
129In	1.96





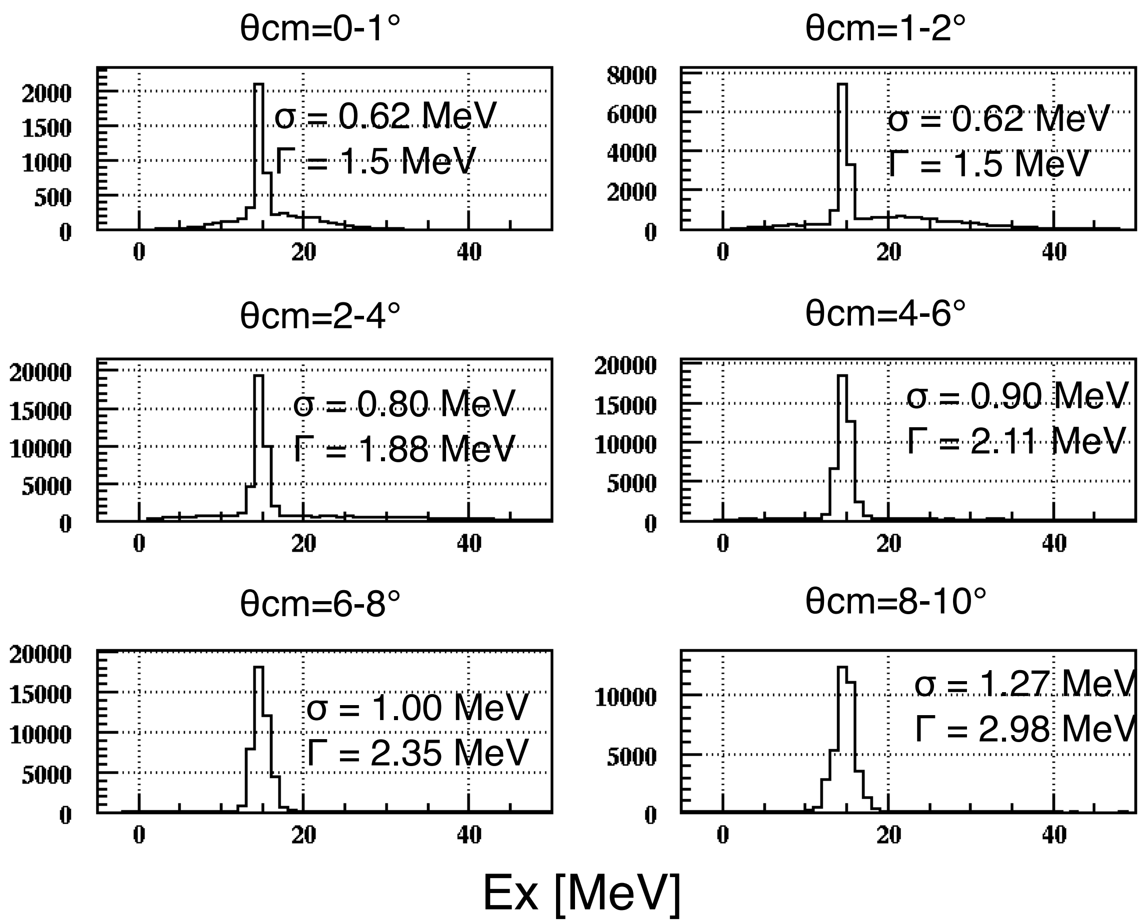
Overall Efficiency



WINDS excitation energy resolution

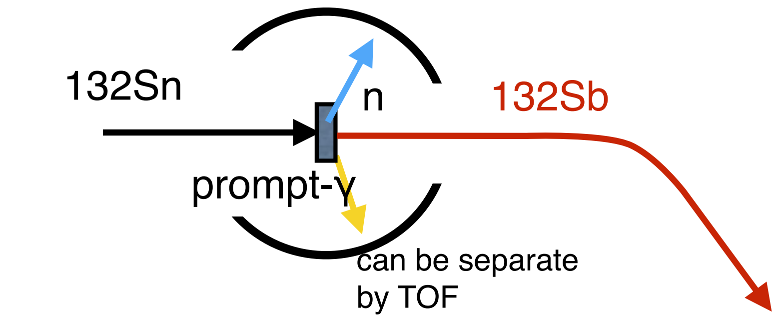
- **GEANT simulation**
  - intrinsic timing resolution WINDS : 500 ps
  - uncertainty for FPL : ΔL/L = 10%

➡ resolution for Ex : 1.5 ~ 3 MeV (FWHM)

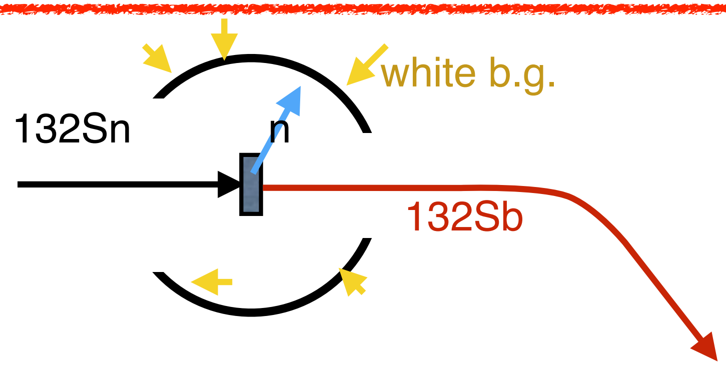


B.G. source

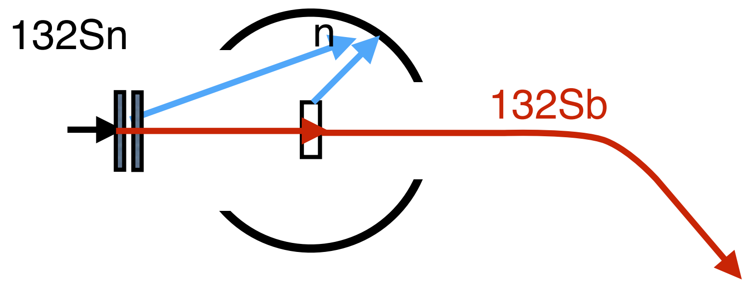
- **prompt-γ**
  - can be separate by TOF information
    - cut fast TOF event at Hardware & Software level



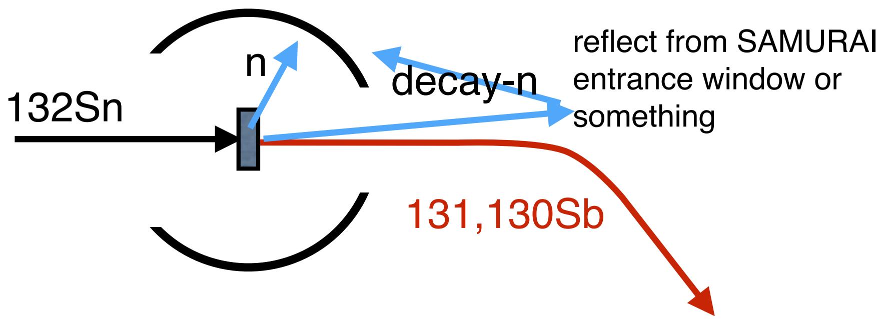
- **White b.g.**
  - 2 kHz for all WINDS bars
  - estimate by using beam channel 132Sn—>132Sn



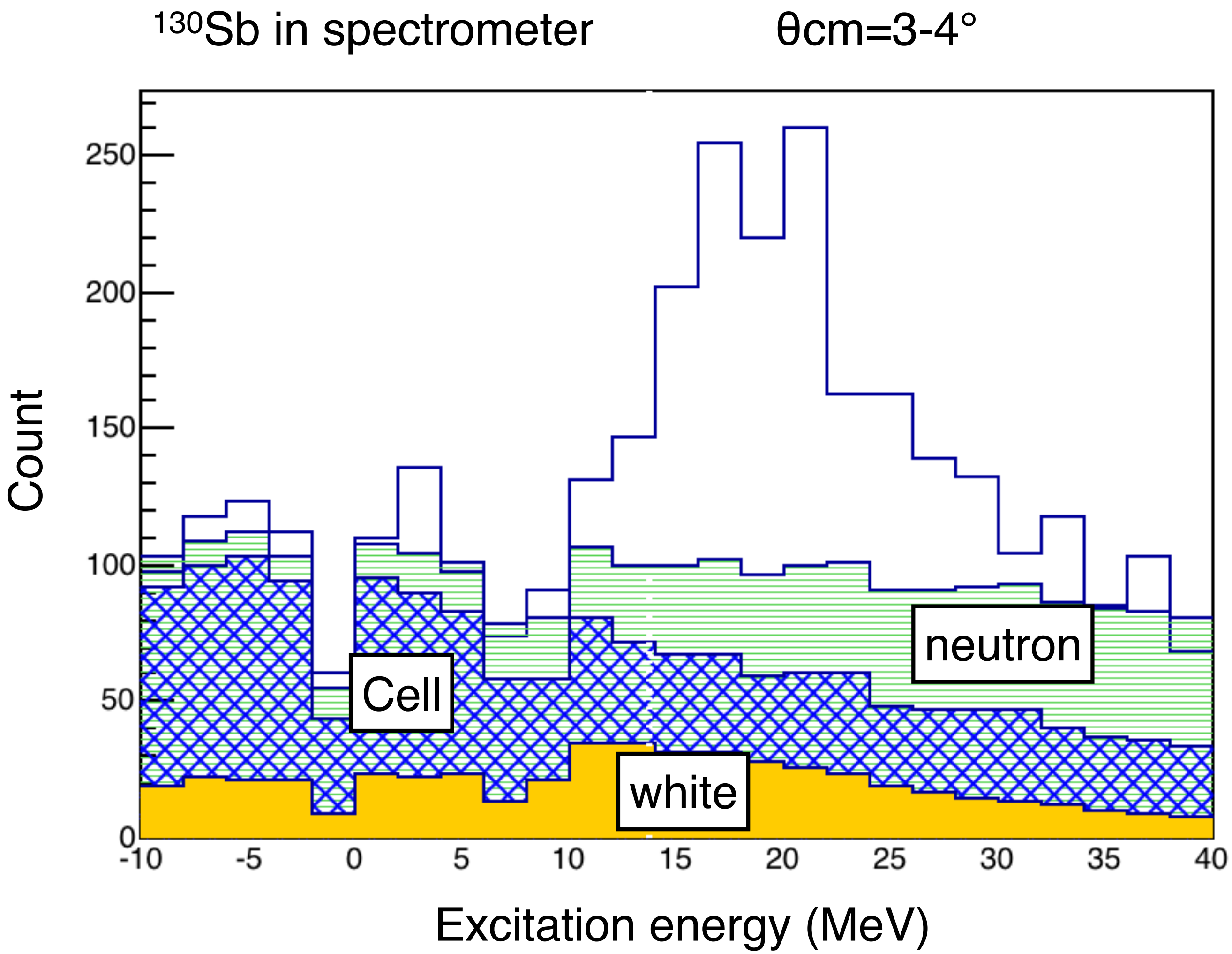
- **Neutron from SBT & cell**
  - SBT thickness (H10C9)
    - Density : ~1g/cm^3, Thickness :1.2mm
      - ~ 6 x 10^{21} /cm^3 for H in SBT
  - haver cell
    - Density 8.3 g/cm3, Thickness 19um
      - ~ 1.6 x 10^{20} /cm^3
  - Liq. H thickness
    - Density : ~70.85mg/cm^3, Thickness : 10mm
      - ~ 2 x 10^{22} /cm^3
  - estimate by Empty cell run



- **Decay neutron**
  - estimate by NEBULA On/Off



Back ground



^{130}Sb in spectrometer
θcm=3-4°
Count
Excitation energy (MeV)
250
200
150
100
50
0
-10
-5
0
5
10
15
20
25
30
35
40
Cell
neutron
white

TOF analysis

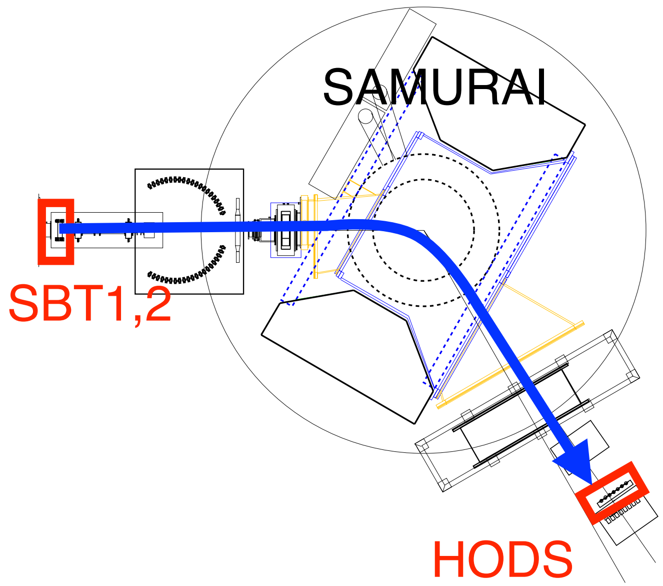
- **Plastic counter HODS & SBT1,2**
  - HODS : 6 plastic scintillation with size of 450 x 100 x 5 mm^3
  - SBT1,2 : 130 x 130 x 5 mm^3
  - FPL ~12.5 m
  - Resolution estimation
    - Empty cell & beam trigger

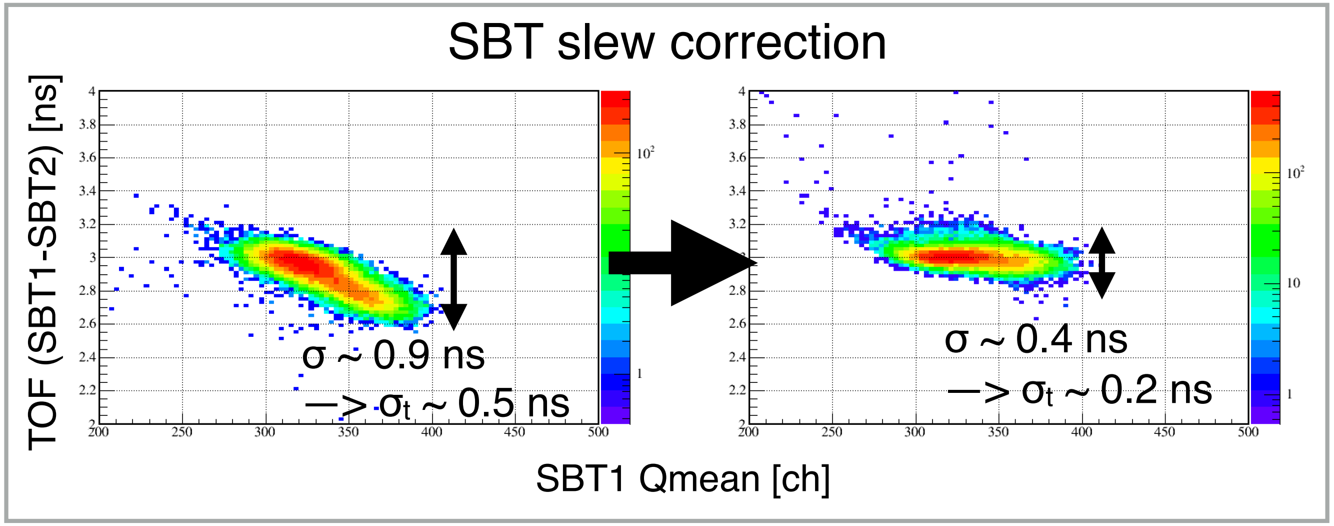
➡ SBT1,2 timing resolution (average of SBT1,2)

σ_t = 17ps (w/ slew correction)

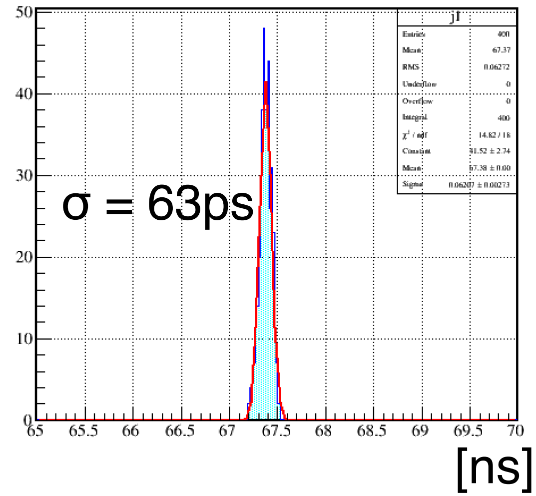
<—> σ_t = 46 ps (w/o slew correction)

➡ **TOF (SBT1,2-HODS) : σ = 63ps**





TOF(SBT1,2—HODS)
@ Empty cel & Beam trigger



Momentum analysis

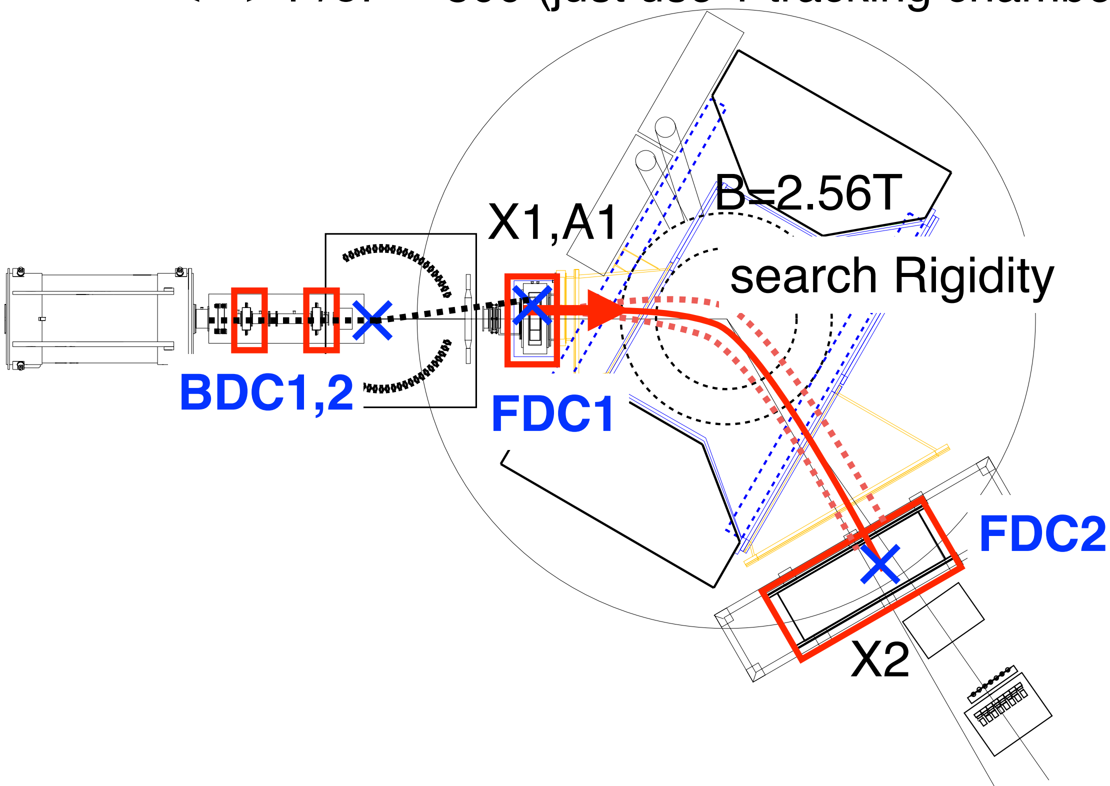
- **Input parameter**
  - Upstream vector (X1, A1), Magnetic Field, Downstream position (X2)
  - **A1 was derived by using 3 tracking detectors**

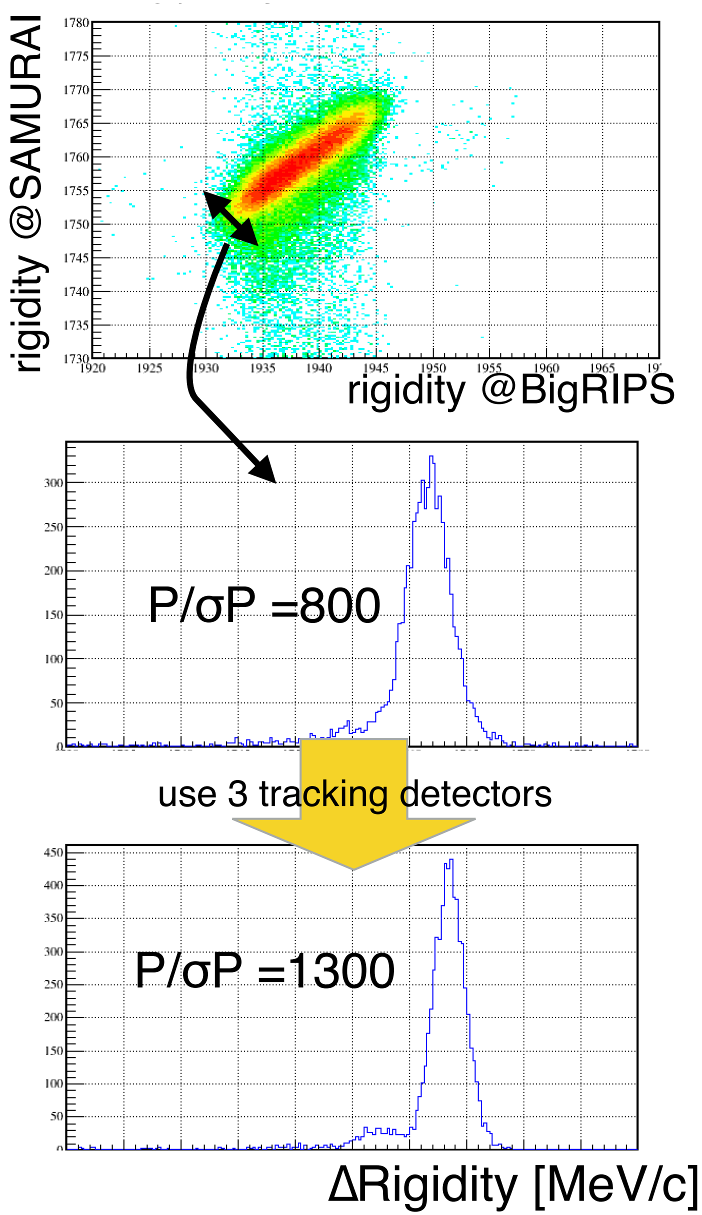
➡ High angular resolution σA ~0.3 mrad

<—> σA~0.8 mrad (just use 1 tracking chamber)

➡ **Resolution : P/σP = 1300**

<—> P/σP = 800 (just use 1 tracking chamber for ini. p)





ΔE analysis

- **Energy loss at plastic scintillator HODS**
  - HODS thickness : ~ 6 mm
    - Non-uniformity ~ 20%
    - Energy loss ~ 6000 MeV
  - Correct position dependence by using FDC2 tracking information

➡ Resolution : $\sigma_{\Delta E}/\Delta E$ = 0.9%