Study of Gamow-Teller transitions in unstable nuclei

Masaki Sasano

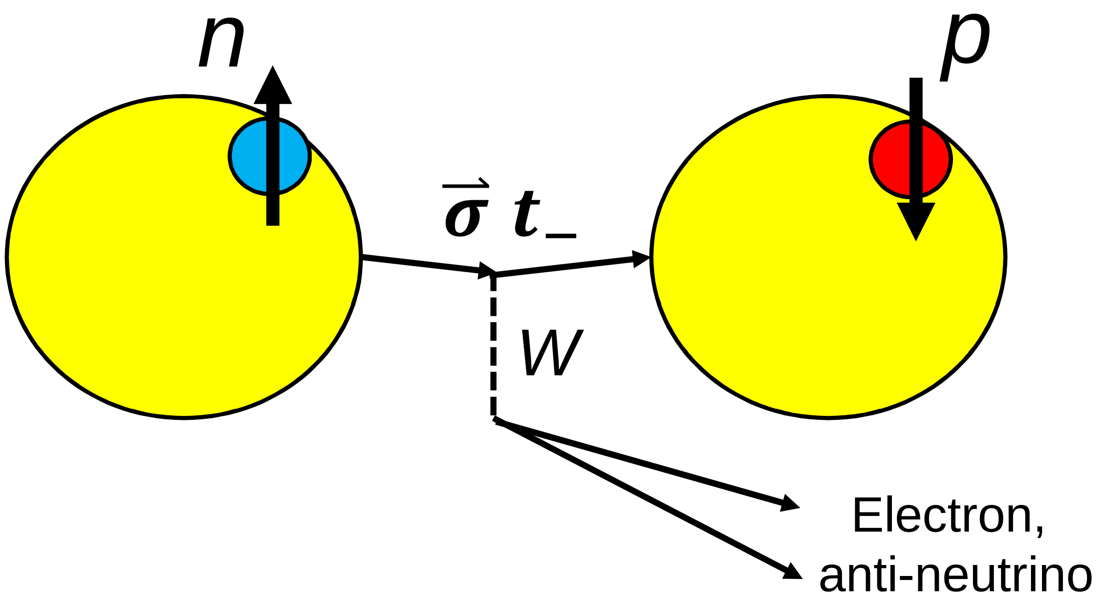
Gamow-Teller transition

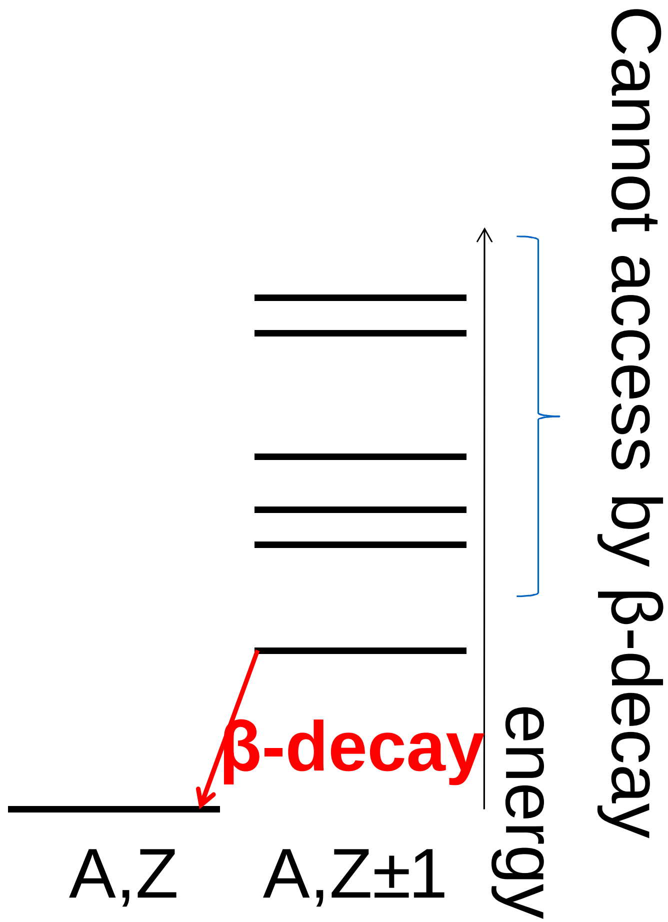
<u>The simplest isovector spin responses</u>

$\Delta T=1,\ \Delta S=1, \Delta L=0$

induced by $\vec{\sigma}\, t_{\pm}$

strength : **B(GT)**



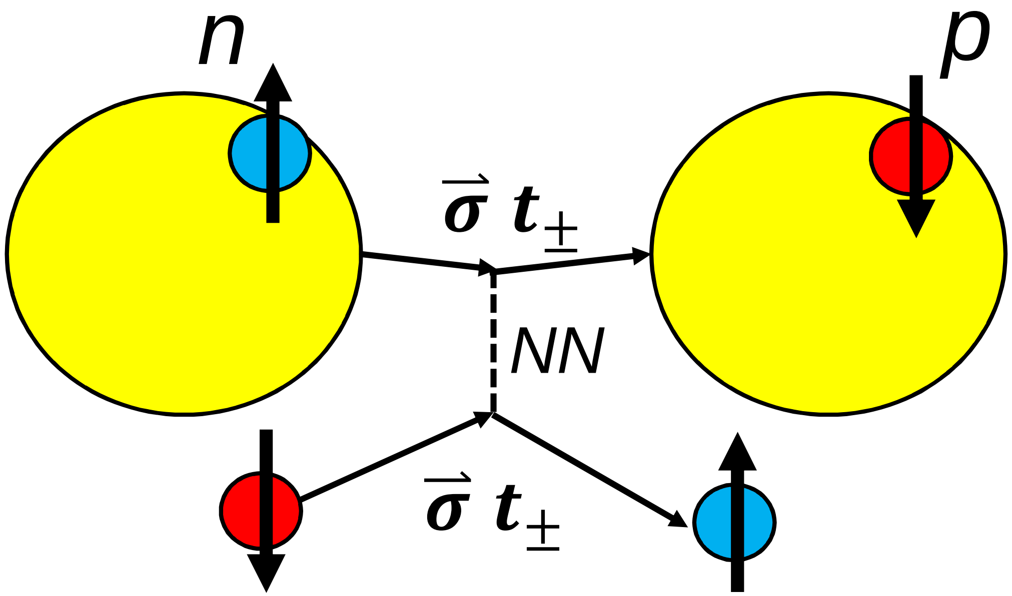


<u>The simplest isovector spin responses.</u>

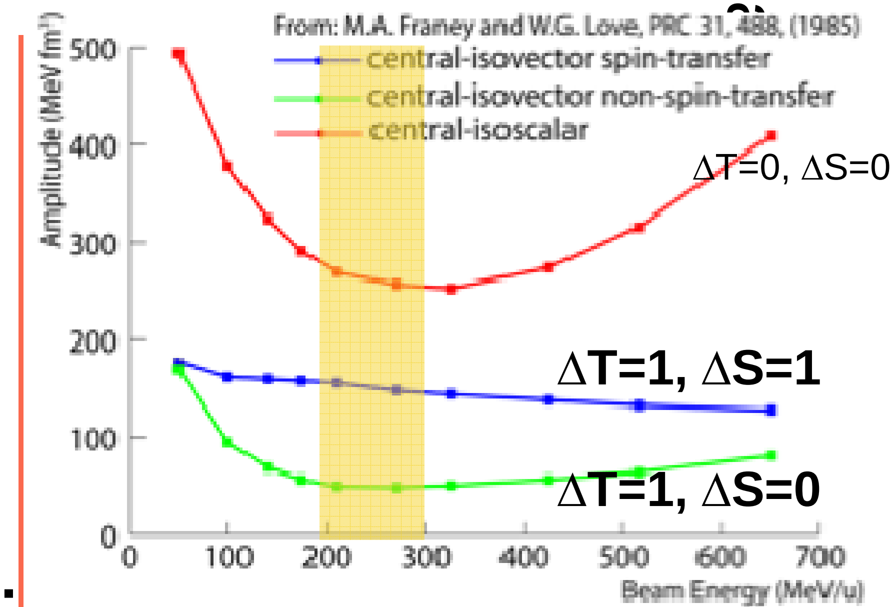
Experimental source: half life of allowed beta decay

Restricted by the Q-value window

Charge-Exchange (CE) reactions at 100-300 MeV



(p, n), (^{3}He, t), (n, p), (t, ^{3}He), …



100 – 300 MeV
→ Isovector spin-flip >> Isovector nonspin-flip
& DWIA good

$$\left(\frac{d\sigma}{d\Omega}(q=0)\right)_{(p,n)} = \hat{\sigma}\, B(GT)$$

→ *Any (0-50 MeV) Ex!*

GT studies on stable nuclei via CE reactions

- Fundamental

  GT quenching ←→ non-nucleonic (Δ)

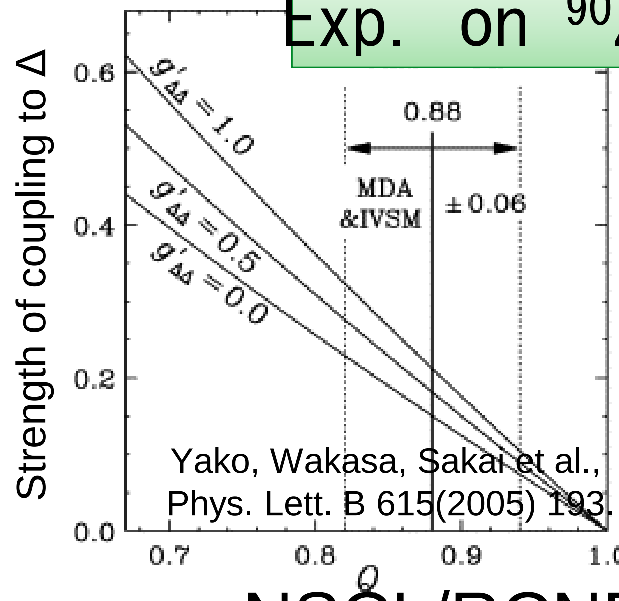
- Nuclear astrophysics

→ Weak processes in Type Ia 、II supernovae

- Deeper understanding of nuclear structures and its applications

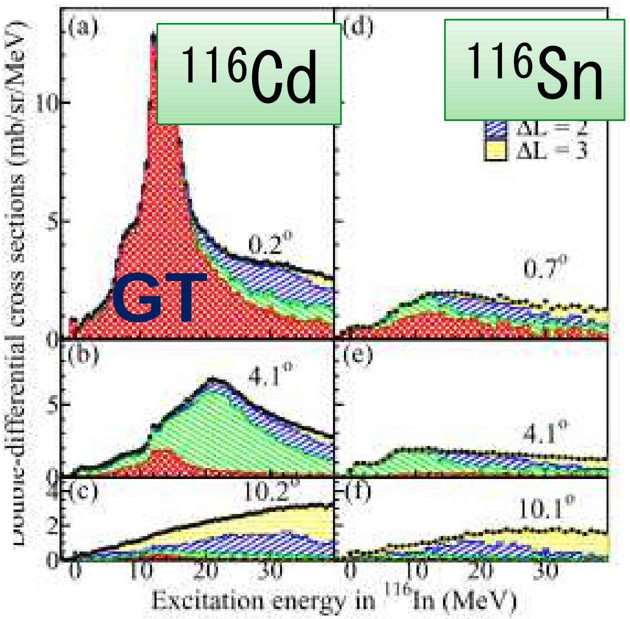
→ e.g., nuclear matrix elements in double beta decay

Exp. on ^{90}Zr

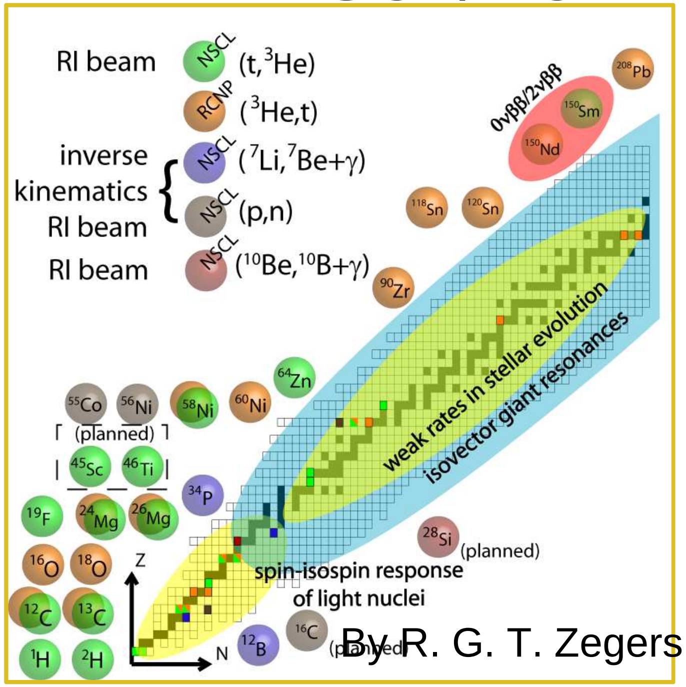


Yako, Wakasa, Sakai et al., Phys. Lett. B 615(2005) 193.

NSCL/RCNP



Sasano et al., Phys. Rev. C **85**, 061301



By R. G. T. Zegers

Why unstable nuclei

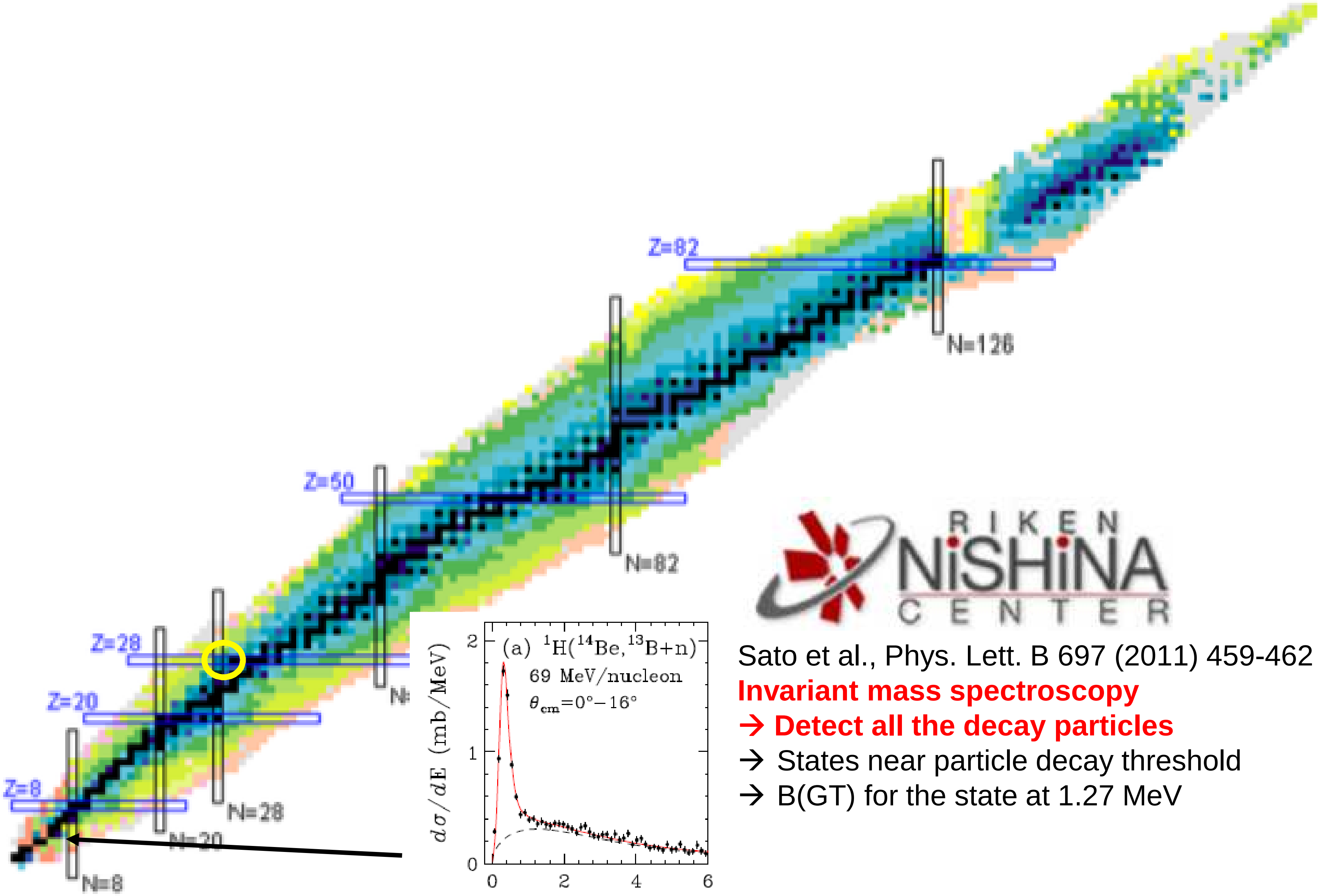
- **spin isospin collectivity**

in terms of

  - **Ratio of neutron and proton numbers**
  - **p-h vs. p-p**
  - **restoration of SU(4) (spin x isospin) symmetry?**
  - **density (neutron skin, neutron halo)**
  - **double magicity far from the stability line**

- **Nuclei of astrophysical interests (electron captures, neutrino responses, …)**

GT strength via (p, n) on unstable nuclei



Sato et al., Phys. Lett. B 697 (2011) 459-462

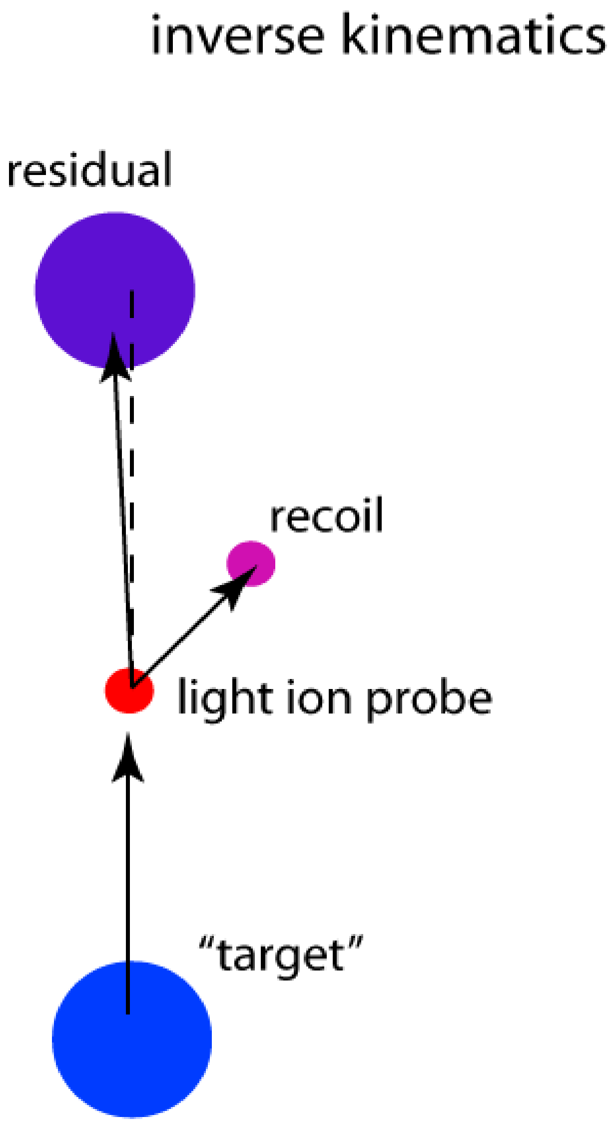
Invariant mass spectroscopy

→ Detect all the decay particles

→ States near particle decay threshold

→ B(GT) for the state at 1.27 MeV

Existing CE studies using RI beams



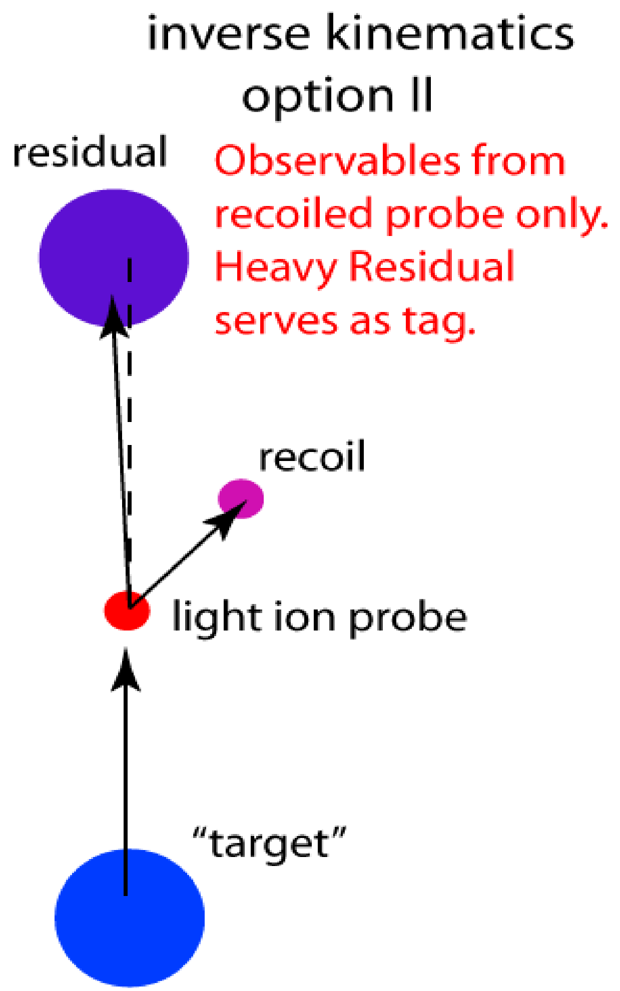
^{34}P(^{7}Li,^{7}Be+gamma)
(Zegers et al., Phys. Rev. Lett. 104, 212504 (2010)
^{12}B(^{7}Li,^{7}Be+gamma)^{12}Be
(Meharchand et al., Phys. Rev. Lett. 108, 122501 (2012))

→ beam residue analyzed by S800
→ excitation energy is limited by particle decay threshold

^{1}H(^{14}Be,^{13}B+**n**)n
(Satou et al., Phys. Lett. B 697 (2011) 459-462.

→ Invariant mass method with single neutron detection + gammas **from residue**
→ Only low-lying states
→ For high-lying states, multi nucleons

Our experimental method for (p,n) in inverse kinematics



Missing mass spectroscopy by the detection of the recoil neutron

Advantages

Efficient!

RI beam (10 ^6 pps) + Liq. H (100mg/cm^2)
~ stable p beam (160 nA) + 100 mg/cm^2 (A~100)
(after taking account detection eff. and acc.)

Simple!

All kinematic information
from measurement of the neutron
(two-body kinematics)

Extensive!

Can be applied to any mass region and to any excitation energy

New!

Branching ratio of the particle decay
(Heavy fragments as tag for each decay branch)

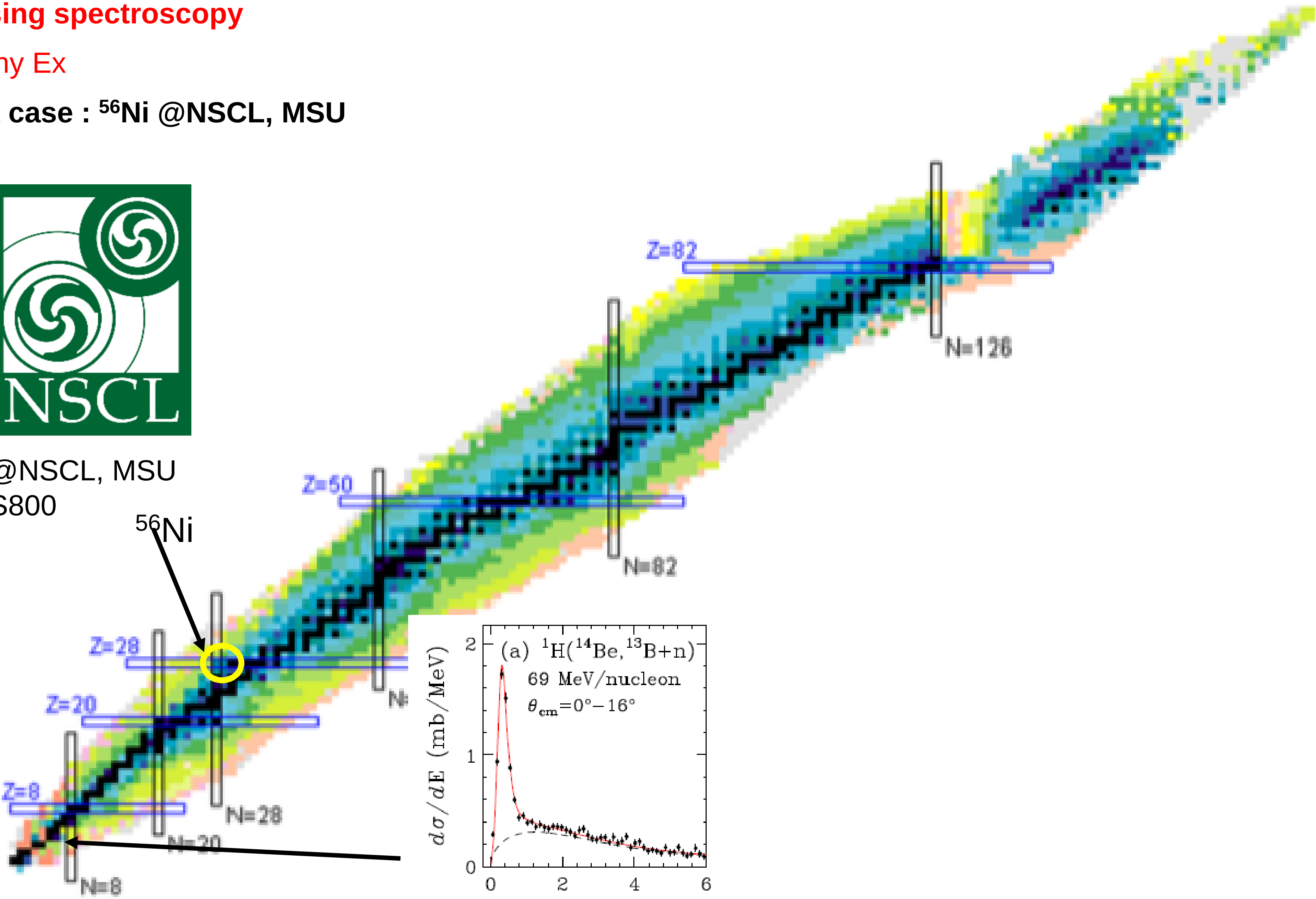
GT strength on unstable nuclei

Missing spectroscopy

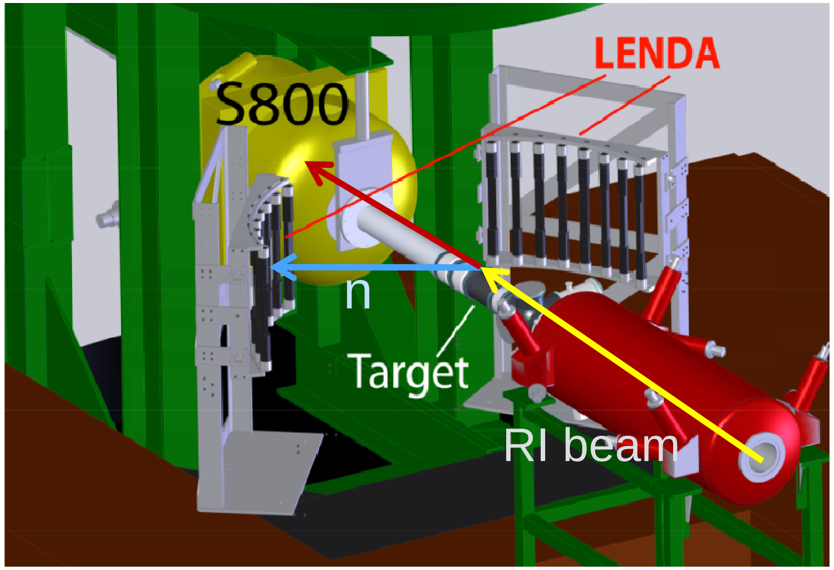
→ Any Ex

First case : ^{56}Ni @NSCL, MSU

@NSCL, MSU
S800



Set up



Low Energy Neutron Detector Array (LENDA)

neutron detection

Plastic scintillator

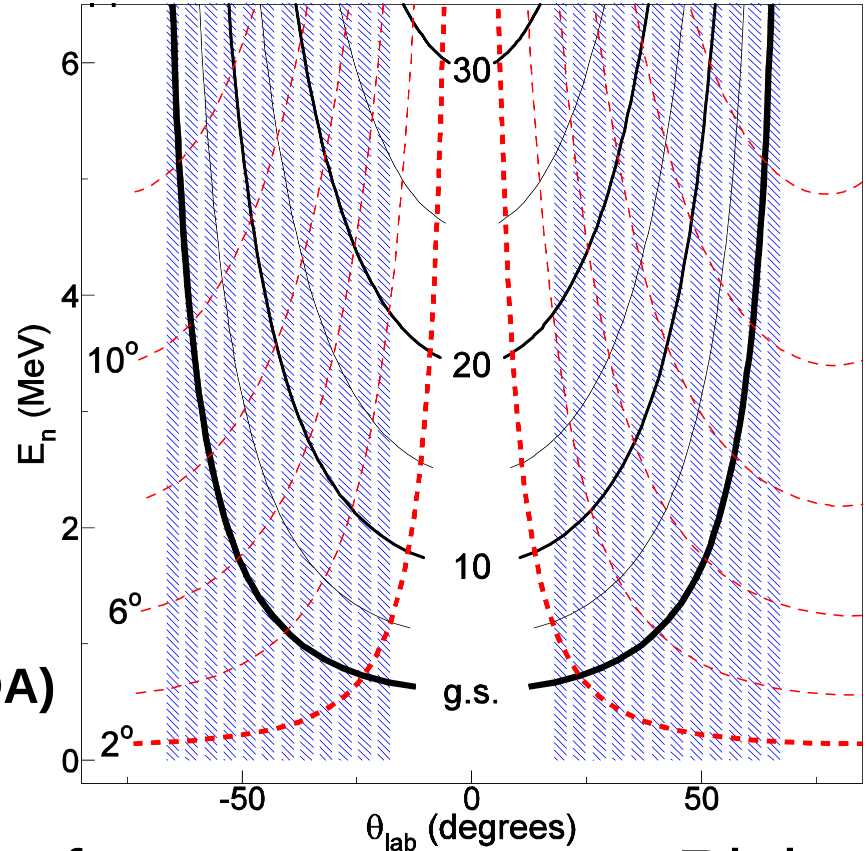
24 bars 2.5x4.5x30cm

150 keV < E_n < 10 MeV

$\Delta E_n \sim 5\%$ $\Delta\theta_n < 2^o$

efficiency 15-40%

Flight path : 1 m

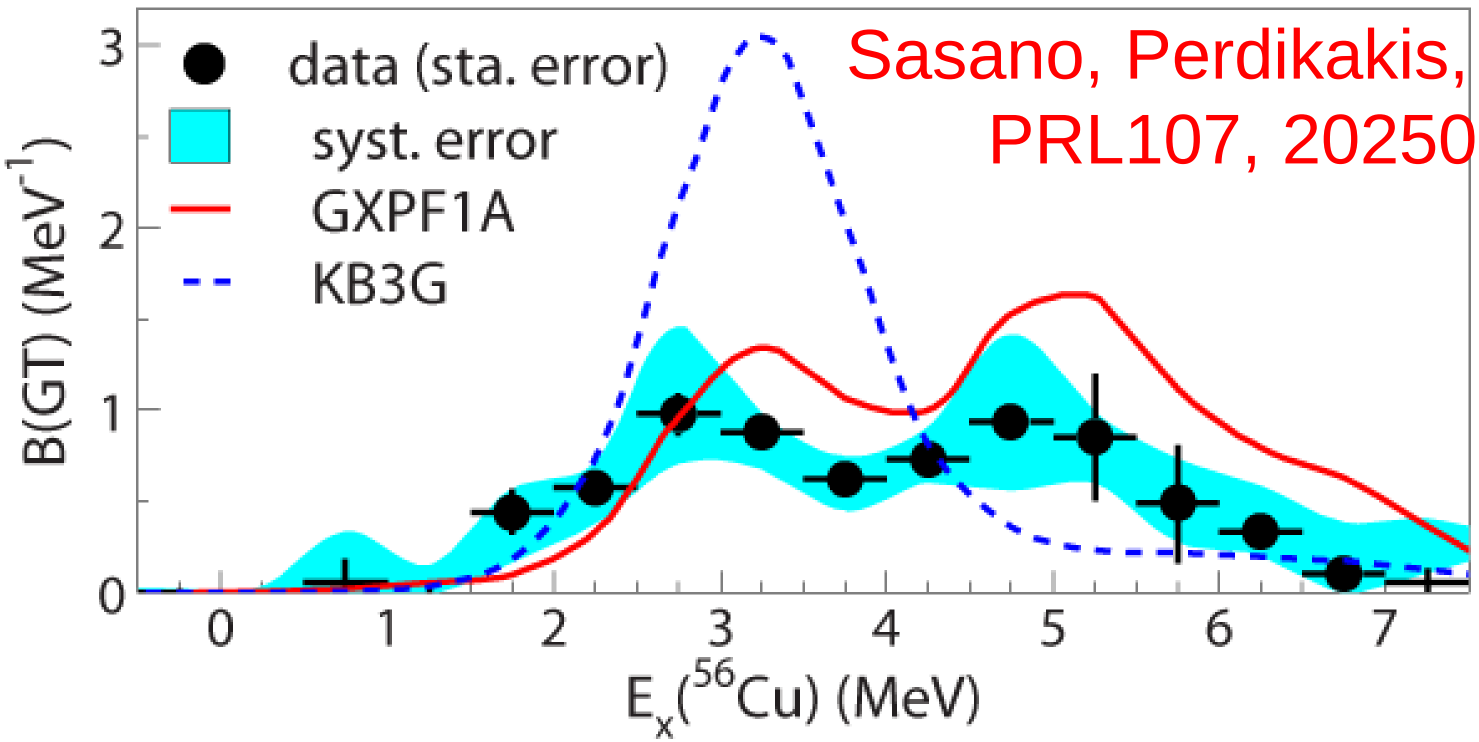


Left array

Right array

Perdikakis et al, NIM.

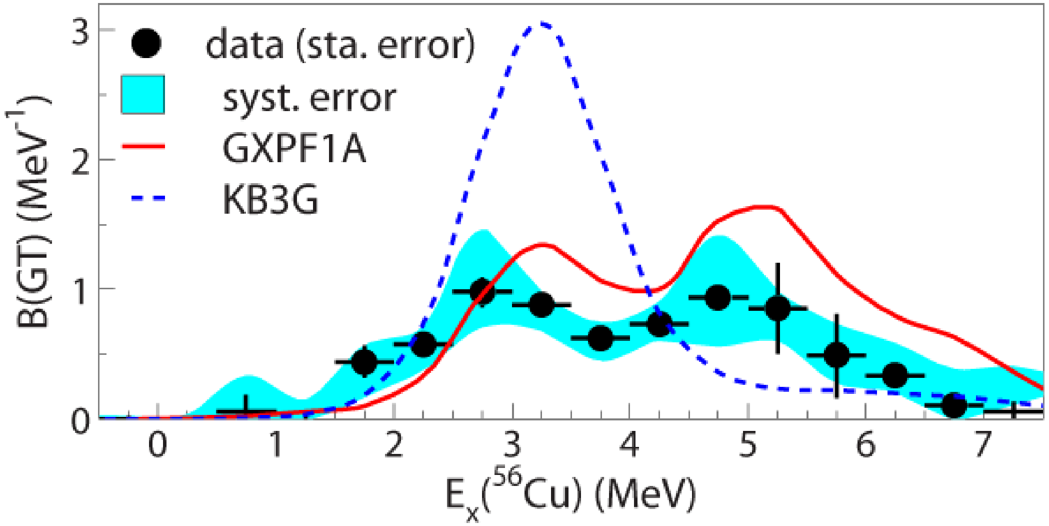
Benchmarking nuclear models…



Sasano, Perdikakis, Zegers et al., PRL107, 202501 (2011).

GXPF1A & KB3G
→ similar ground state prop.:
f7/2 70% in ^{56}Ni, but large diff. in B(GT) of N=Z nuclei

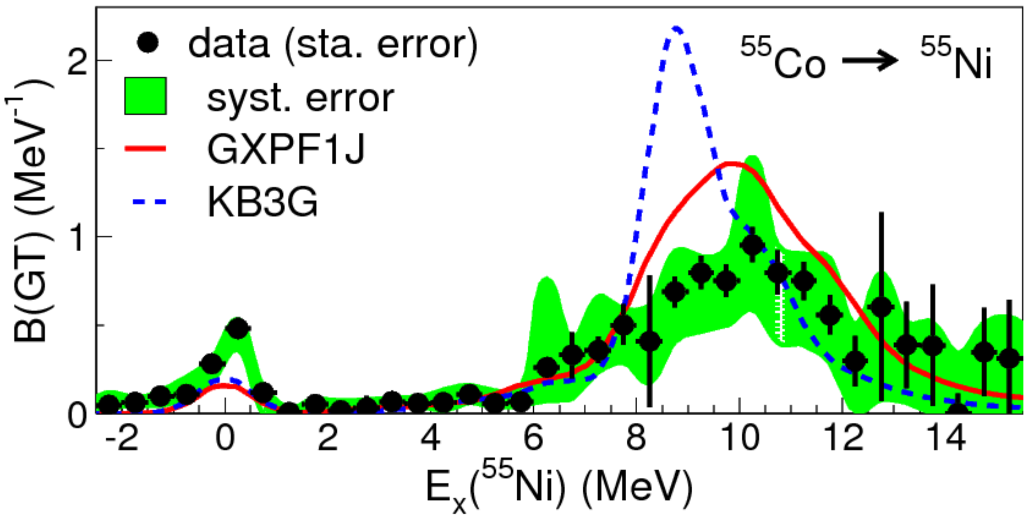
Why two peaks?



Two prominent peaks exist
Large difference between KB3G and GXPF1

Sum of B(GT) 3.8 ± 0.2(stat.) ± 0.8(syst.)

Remove one neutron from parent & daughter



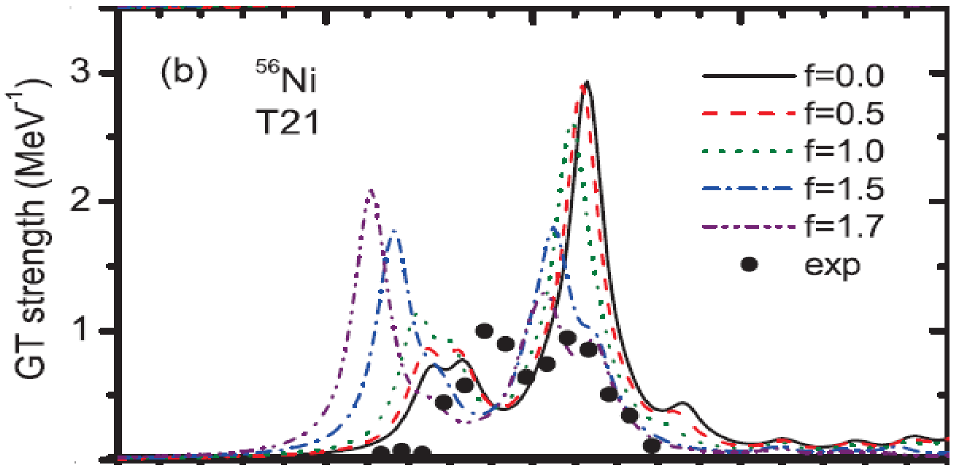
Two peaks disappear
Small difference between KB3G and GXPF1

5. 3 ± 0. 5(stat.)+2.5/−1.5(syst.)

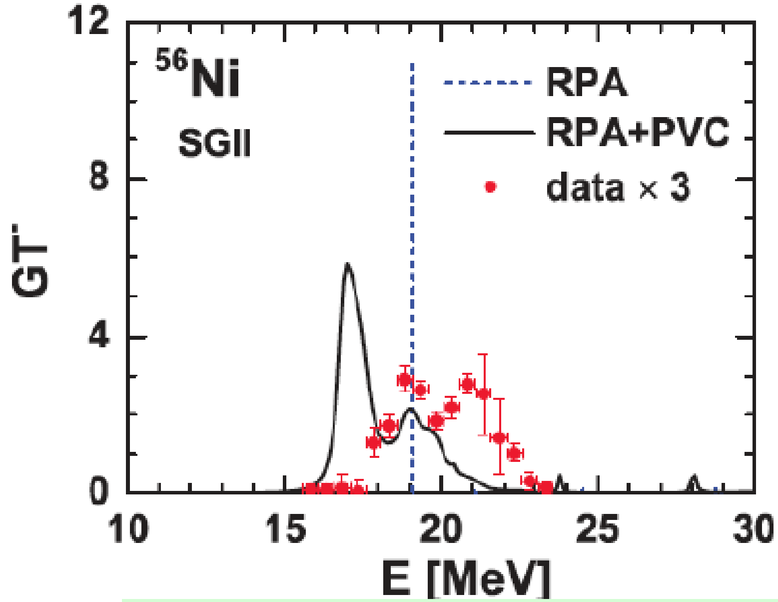
What picture can **intuitively** explain the origin of the two peaks?

Particle-particle *pn* (T=0) effect along N=Z?

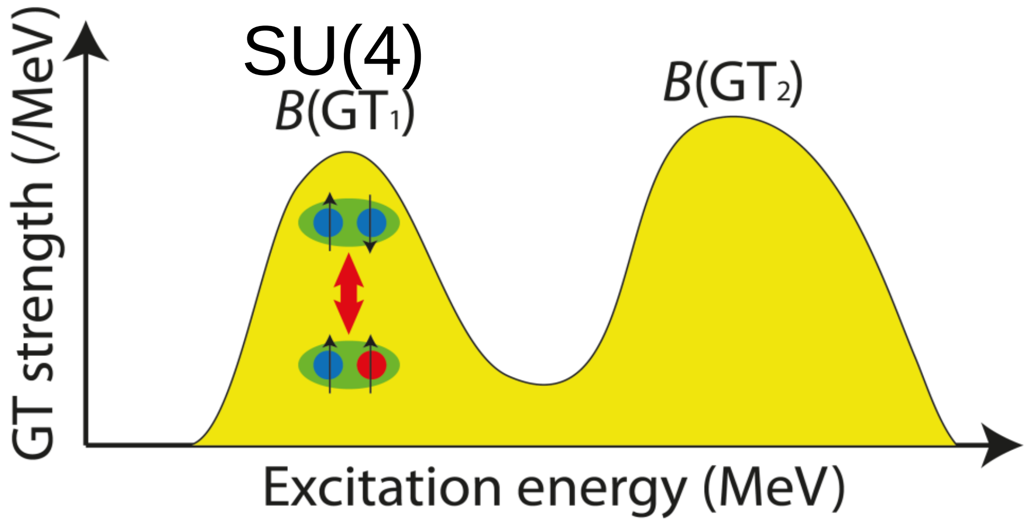
Bai, Sagawa, Phys. Lett. B719, 116- - 121 (2013).



Several theoretical models ….

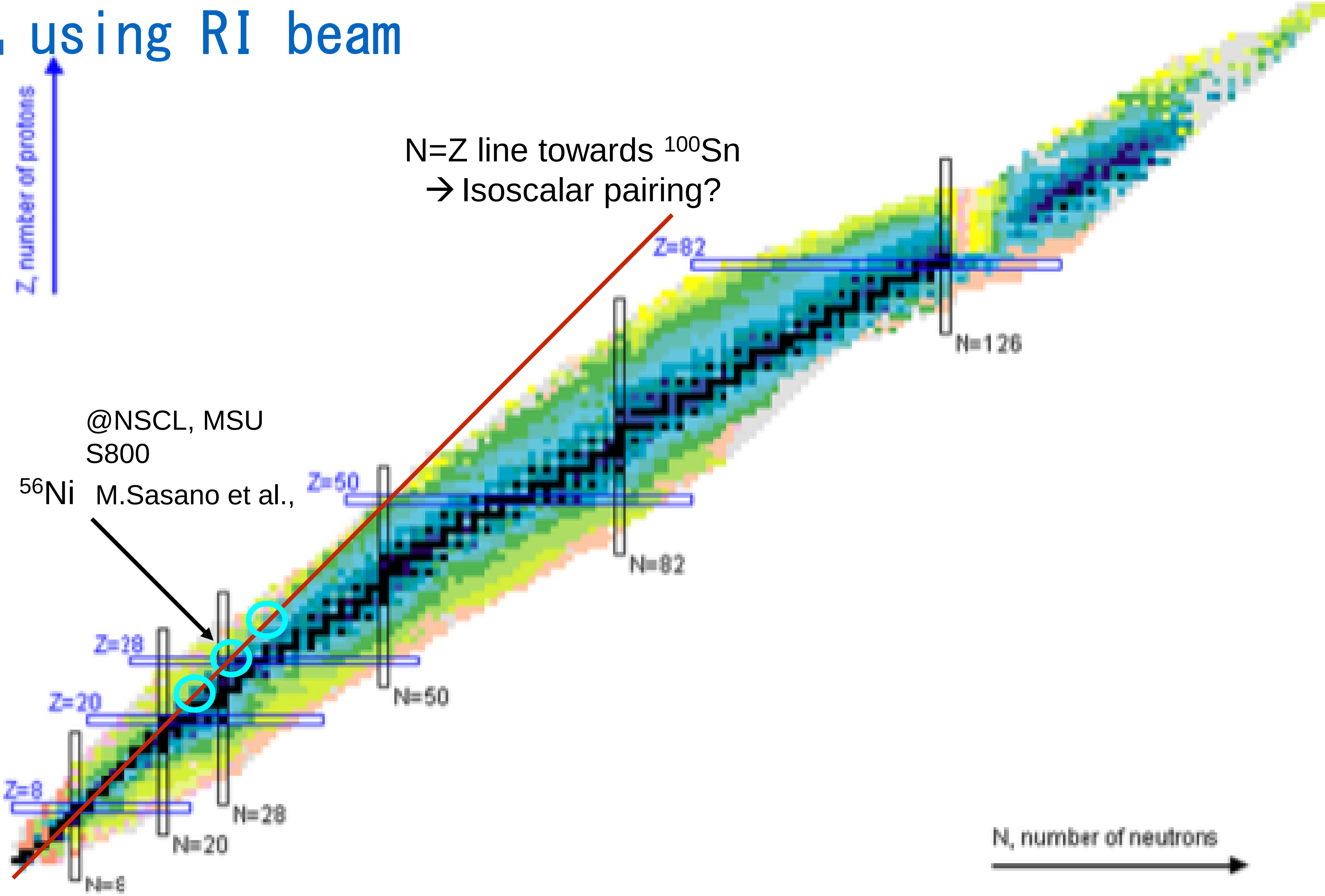


Beyond mean field effect:
Niu et al., PRC85, 034314(2012)

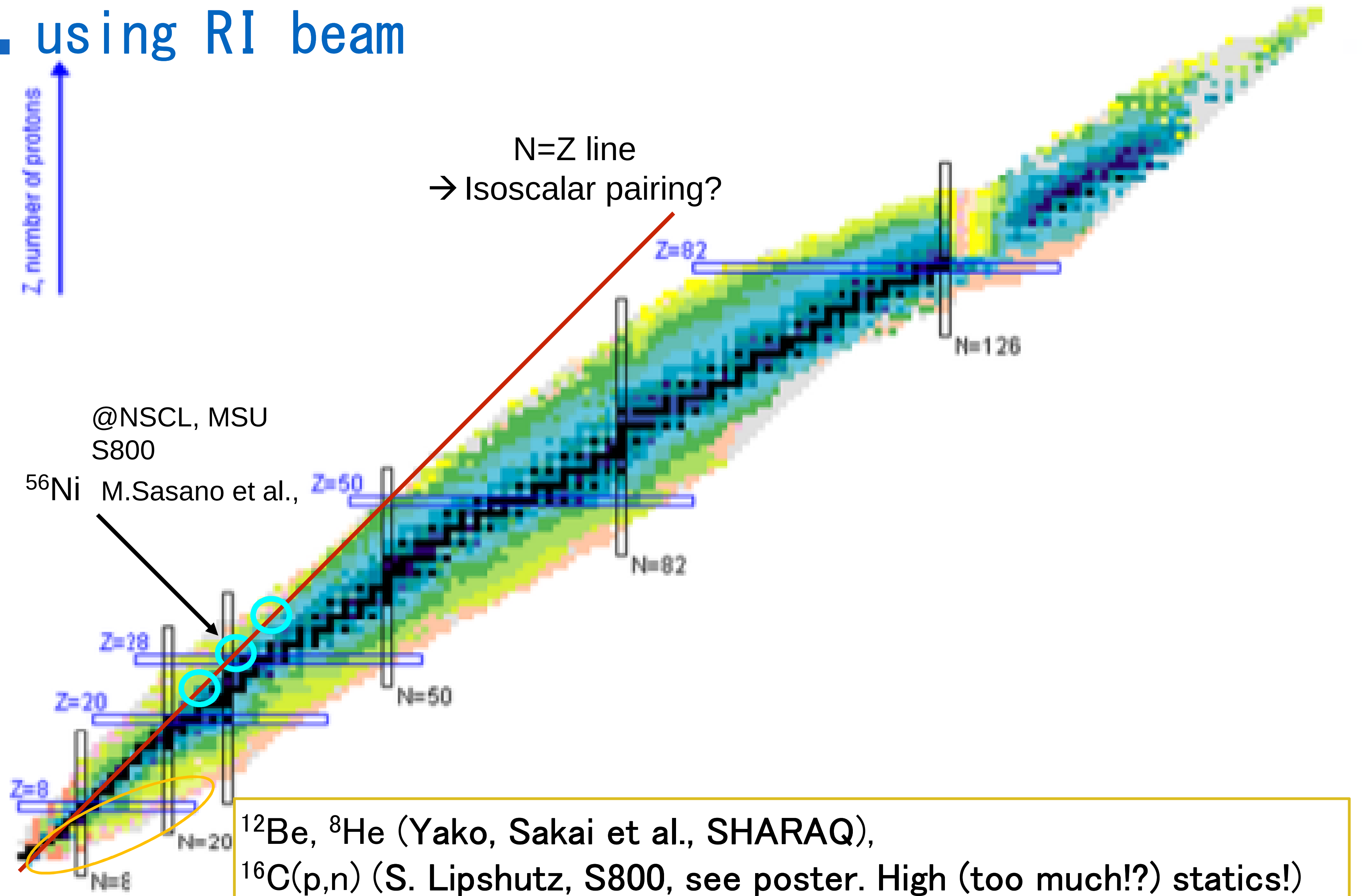


^{48}Cr, ^{64}Ge measurements at RIKEN RIBF

Overview of (p,n) studies for unstable nuclei using RI beam



Overview of (p,n) studies for unstable nuclei using RI beam



^{12}Be, ^{8}He (Yako, Sakai et al., SHARAQ),
^{16}C(p,n) (S. Lipshutz, S800, see poster. High (too much!?) statics!)
^{11}Li, ^{14}Be (L. Stuhl, SAMURAI, see poster, waiting for beam time…)

Spin-isospin residual interaction

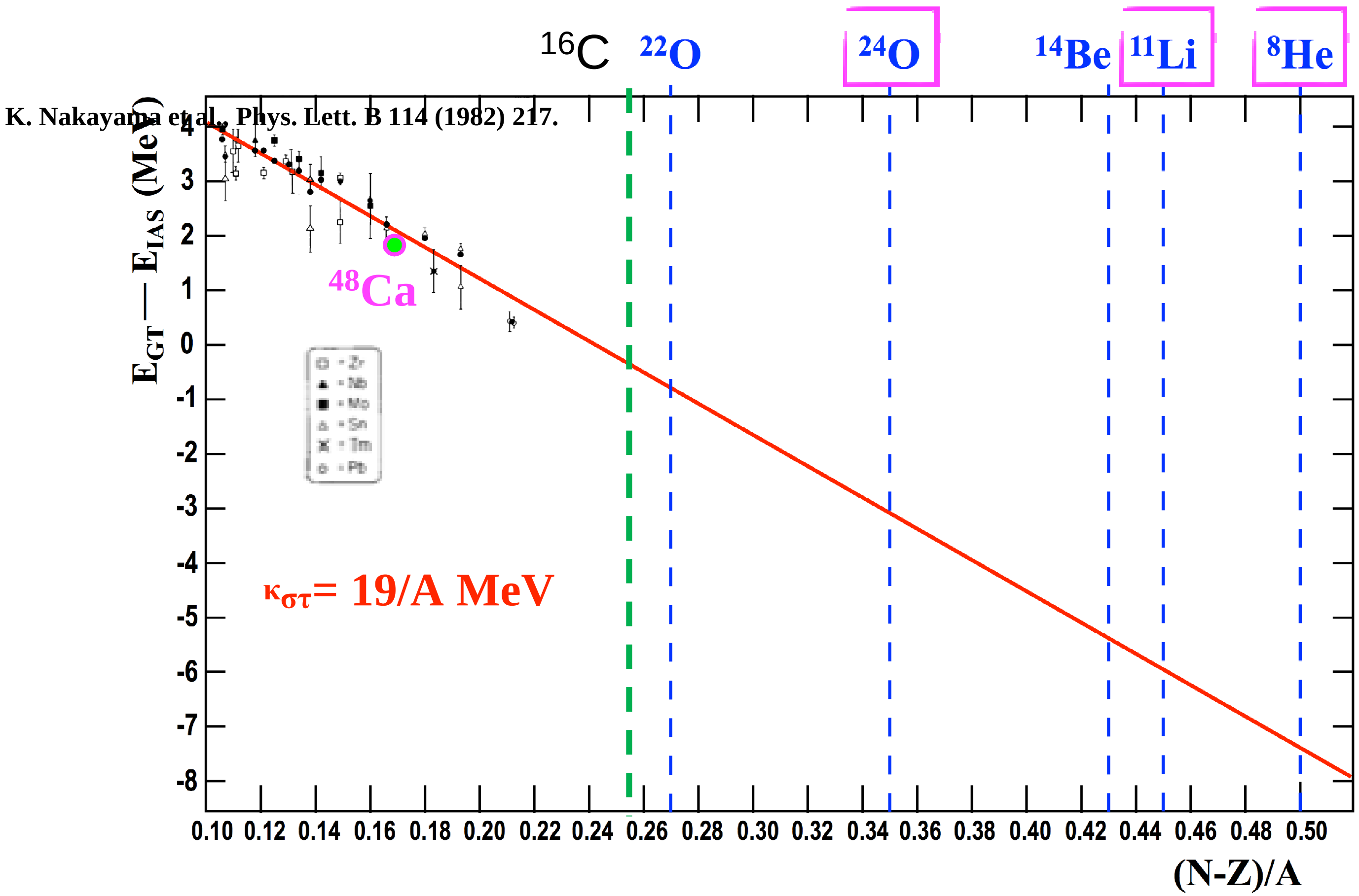
$$\langle E_{GT} \rangle - \langle E_{IAS} \rangle = \Delta E_{ls} + 2(\tilde{\kappa}_{\sigma\tau} - \tilde{\kappa}_{\tau}) \frac{N-Z}{A}$$

Can be large

well-known
for stable nuclei

The energy difference represents the spin-isospin residual interaction.
Is it different in case of large (N-Z)/A?

Spin-isospin coupling strength



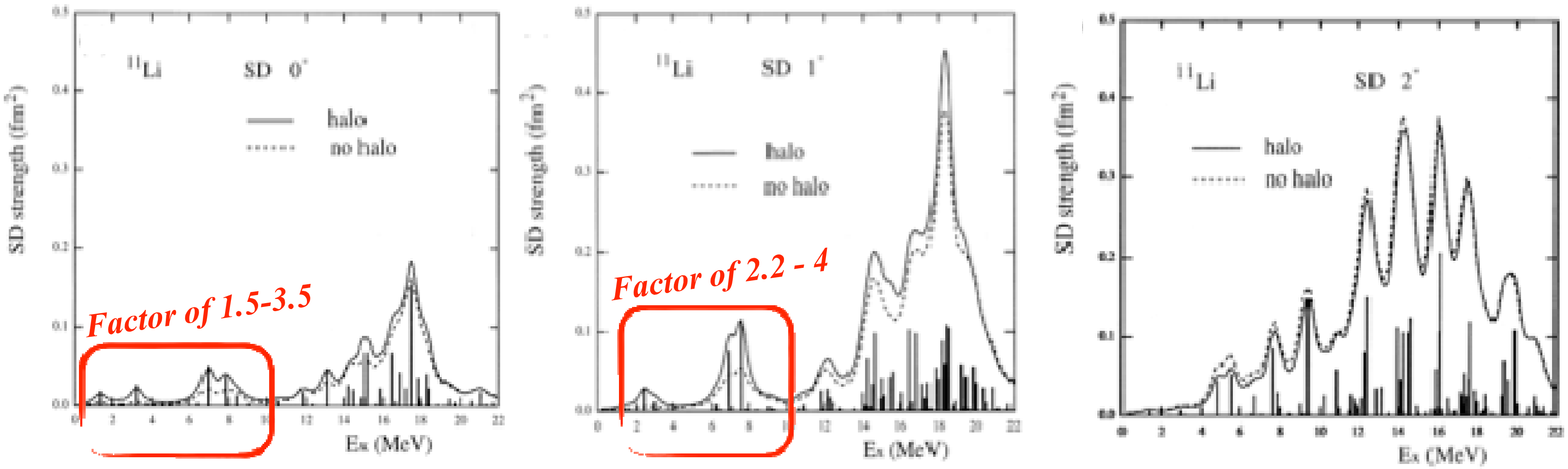
In the courtesy of K. Yako and H. Sakai

Study of spin-dipole strengths

transition operator: r[σY]τ

⇩

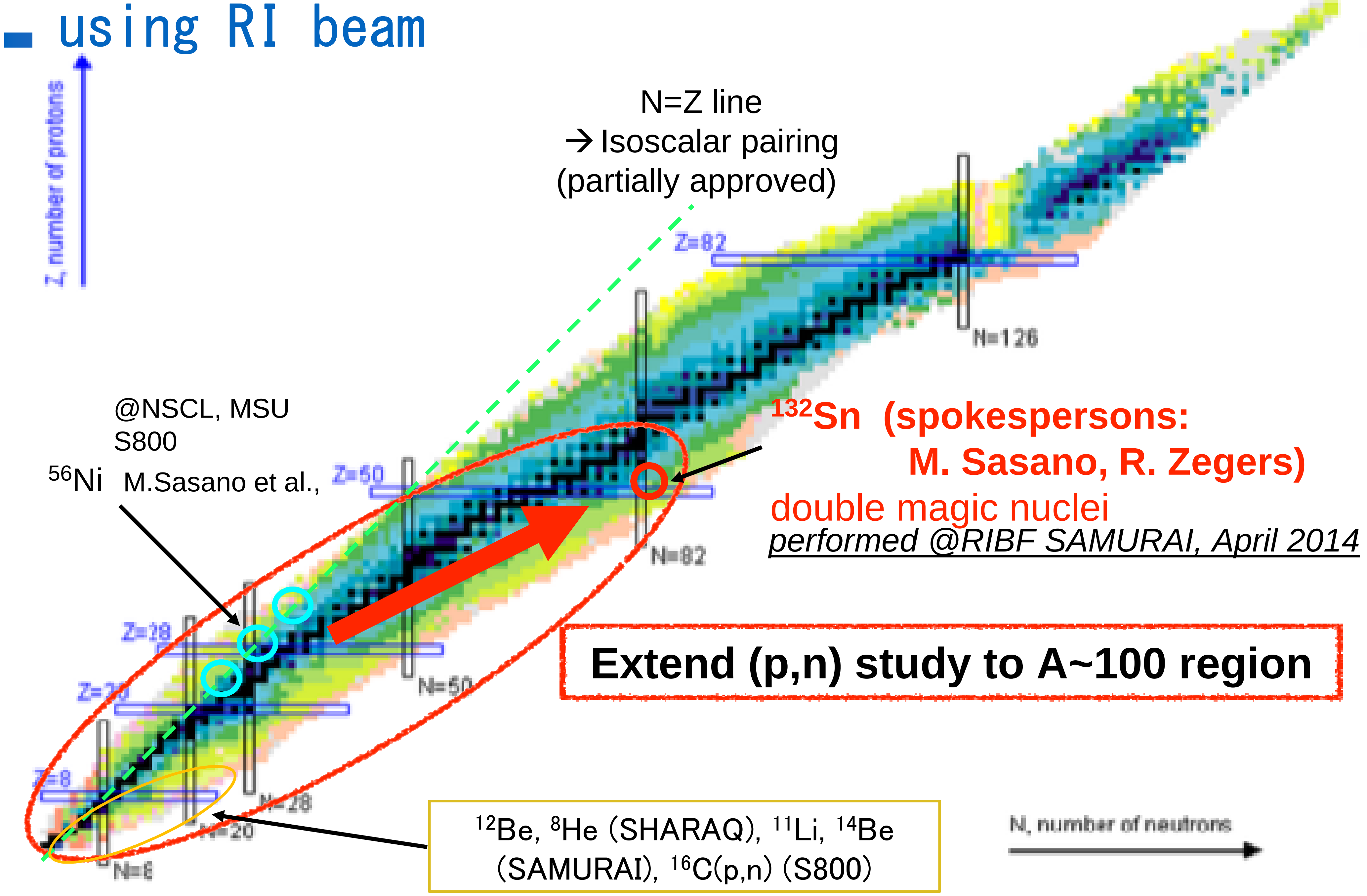
sensitivity to neutron halo



T. Suzuki et al., Nucl. Phys. A 662 (2000) 282.

Enhancement of low-lying SDR?

Overview of (p,n) studies for unstable nuclei using RI beam



Collaborators

M. Sasano, H. Baba, W. Chao, M. Dozono, N. Fukuda, N. Inabe, T. Isobe, D. Kamaeda,
T. Kubo, M. Kurata-Nishimura, E. Milman, T. Motobayashi, H. Otsu, V. Panin, W. Powell, M. Sako,
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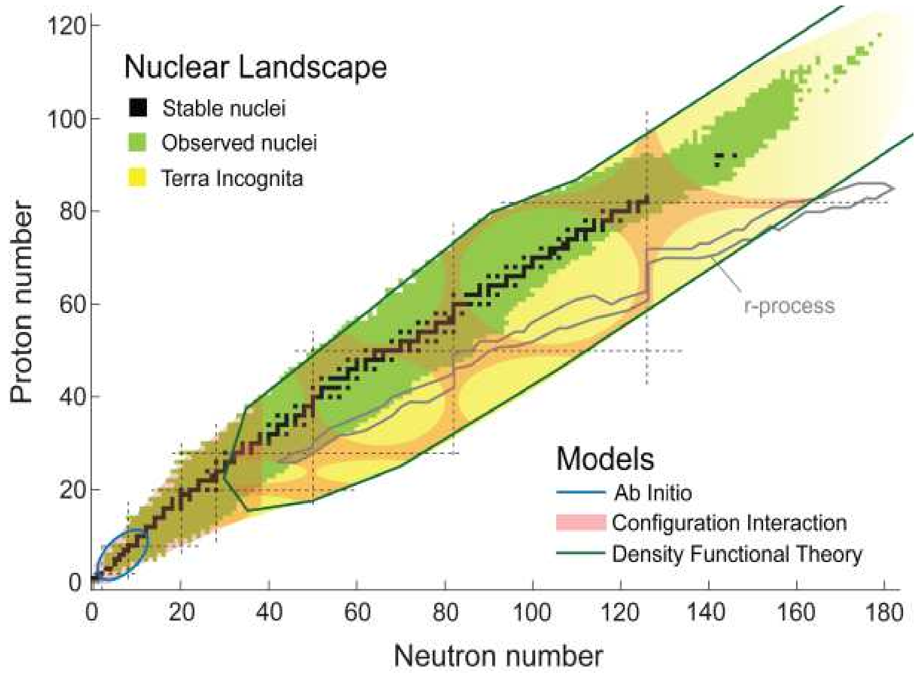
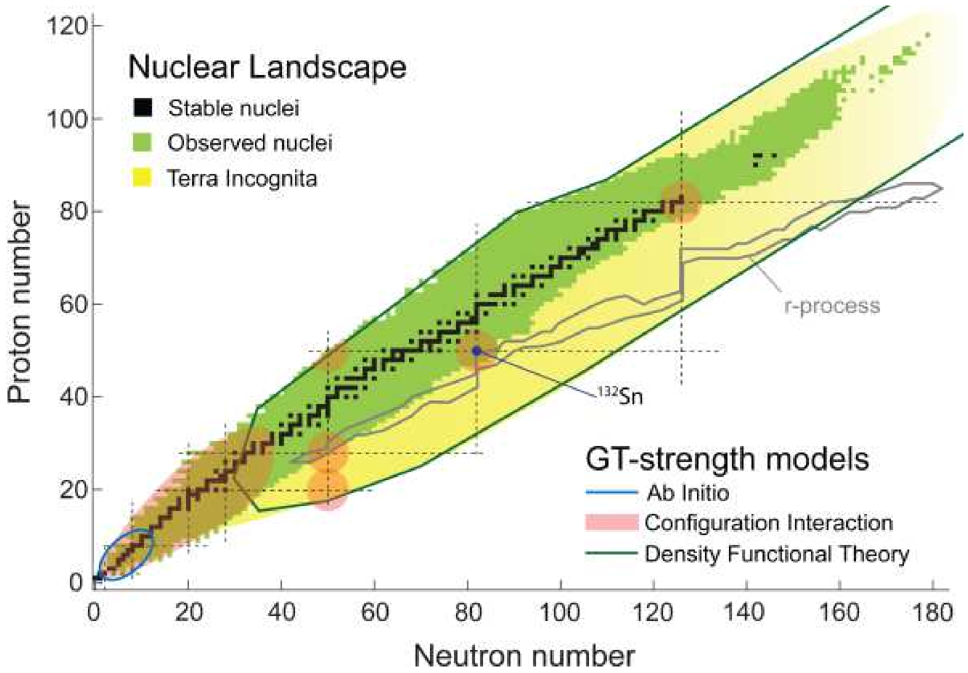
Why ^{132}Sn?



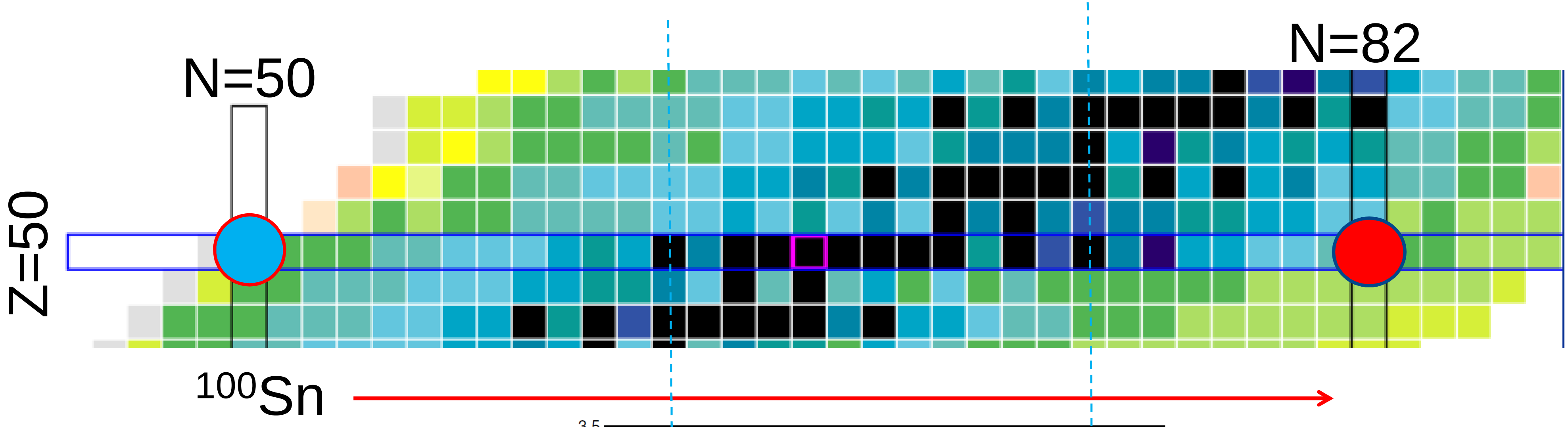


^{132}Sn is the benchmarking nucleus
for nuclear models in medium heavy region

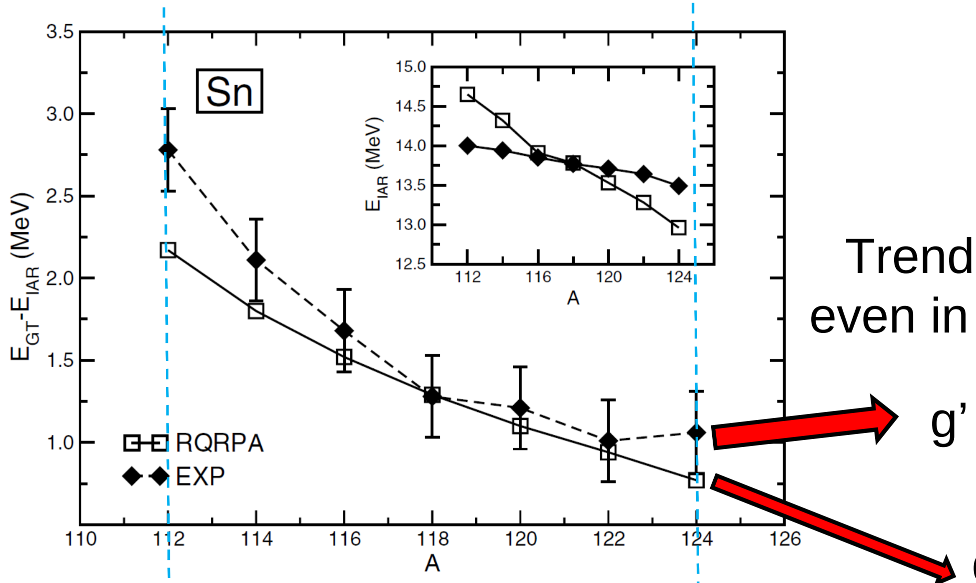
Spin isospin collectivity along Sn isotope chain

$$F^{ph}(\boldsymbol{r}_1,\boldsymbol{r}_2) = C(f_0' \boldsymbol{\tau}_1 \cdot \boldsymbol{\tau}_2 + g_0' \boldsymbol{\tau}_1 \cdot \boldsymbol{\tau}_2\, \boldsymbol{\sigma}_1 \cdot \boldsymbol{\sigma}_2)\, \delta(\boldsymbol{r}_1 - \boldsymbol{r}_2),$$

Zero-range Migdal force



Beta decay study
Hinke et al., Nature (2012).



Trend is different even in stable region

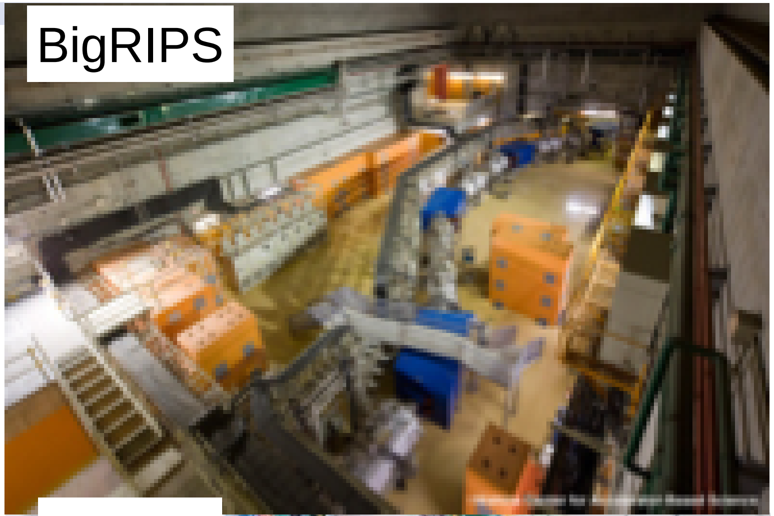
g' (↑) / f'(↓)

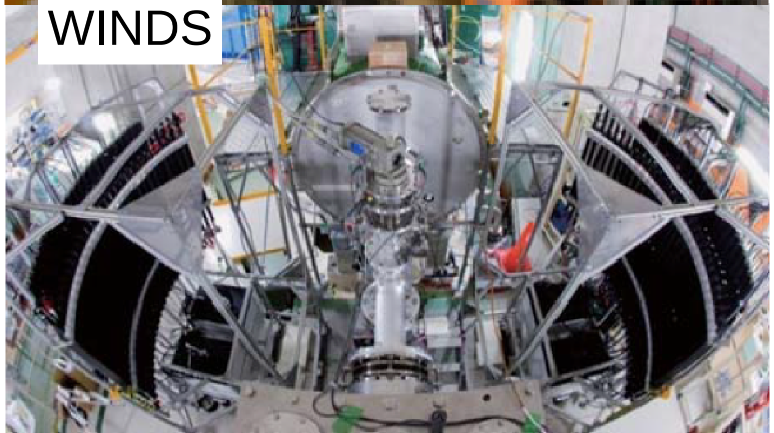
g' (↓) / f'(↑)

Vretenar et al., PRL91 (2003) 262502.

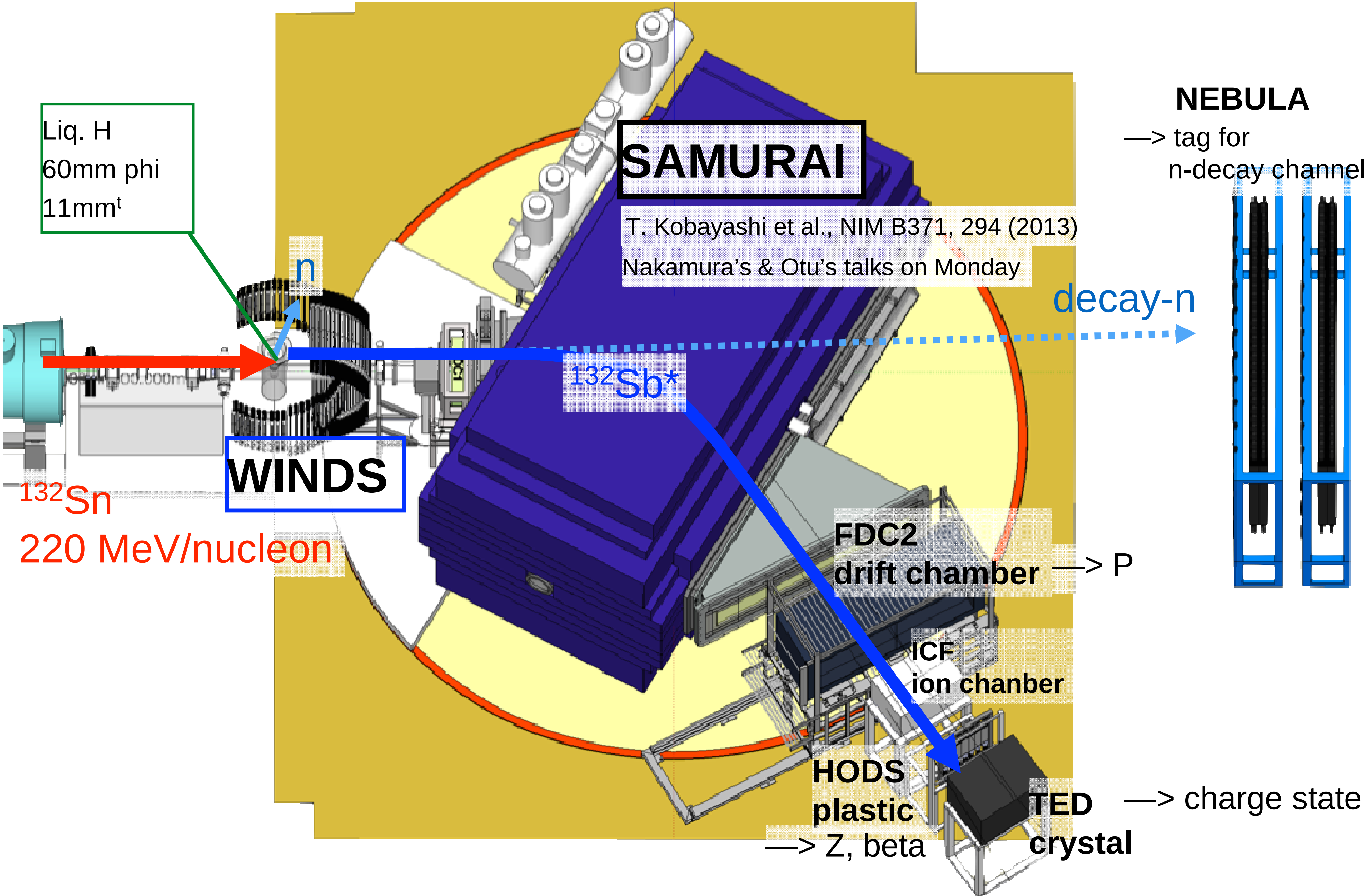
(p,n) measurement with WINDS + SAMURAI

- **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**





Experimental setup



Slow neutron detection with WINDS

- **Wide angular coverage**
  - 61 plastic scintillators (600x100x30mm^3) : 1°resolution

  ＋ 12 ELENS bars (1000x45x10mm^3) : 0.3°resolution

  L. Stuhl et al., NIMA 736, 1 (2014)

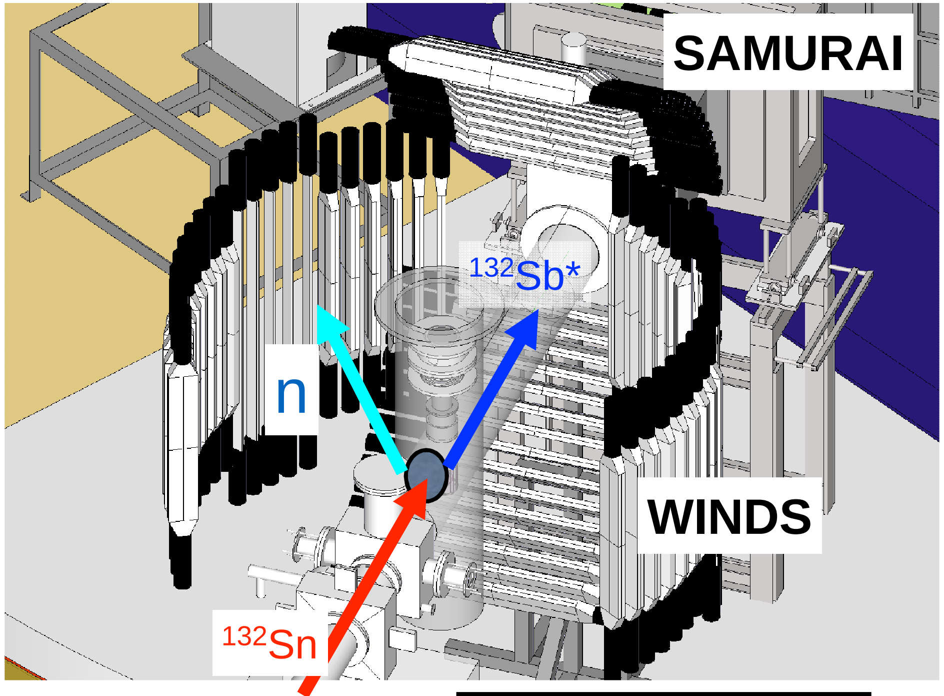
  → θlab = 20 — 120° , FPL = 900,1100mm

- **Energy coverage**
  - TOF : 20 — 250 ns   ※cut fast component
  - Neutron energy : 0.2 — 15 MeV

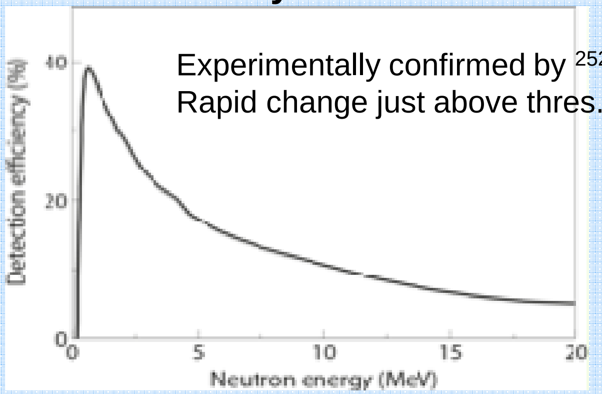
- **Low threshold**
  - Threshold was set to ~30 keVee

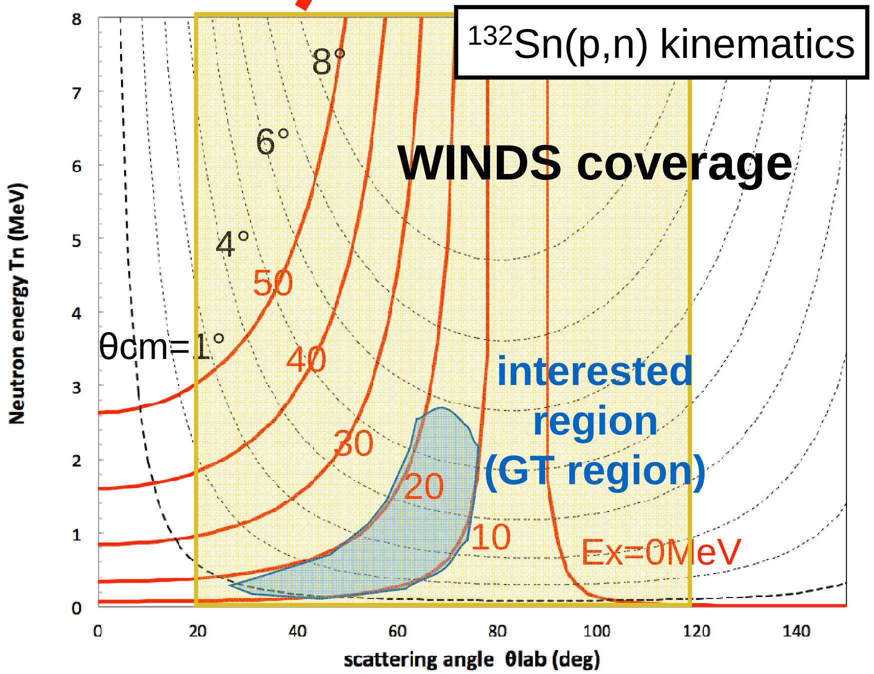
  → ε = 20—40% for 200 keV neutron energy

→ Overall efficiency : 10-15% at forward angle



Intrinsic efficiency for each neutron detector:

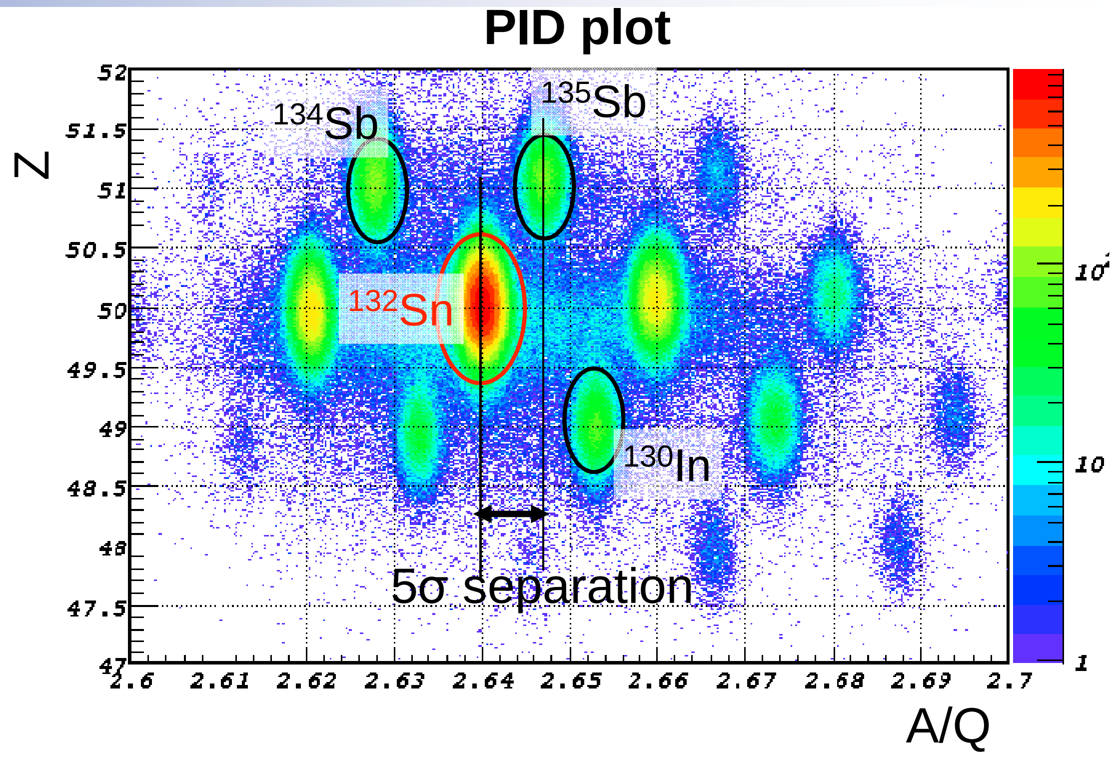


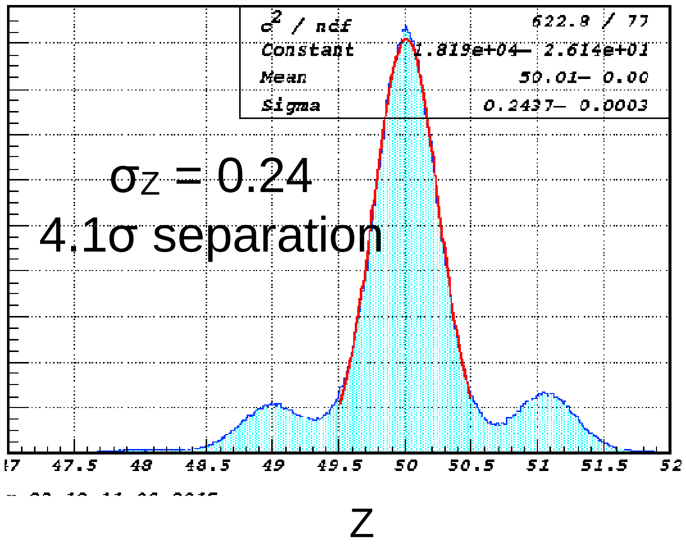


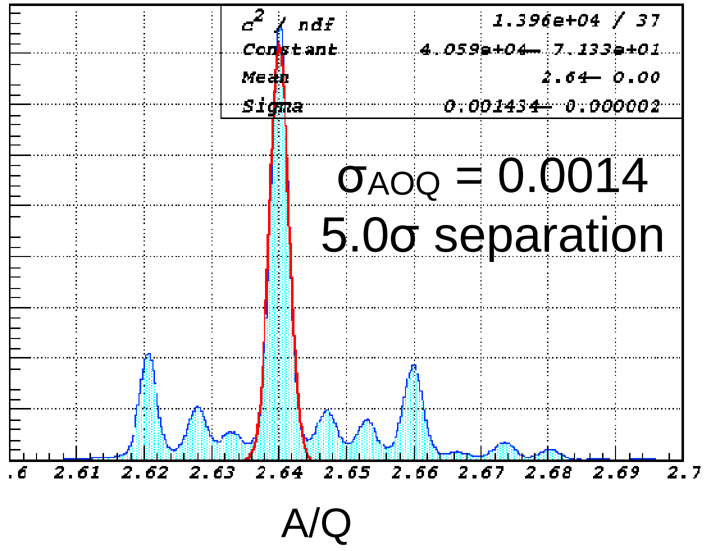
132Sn beam production

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

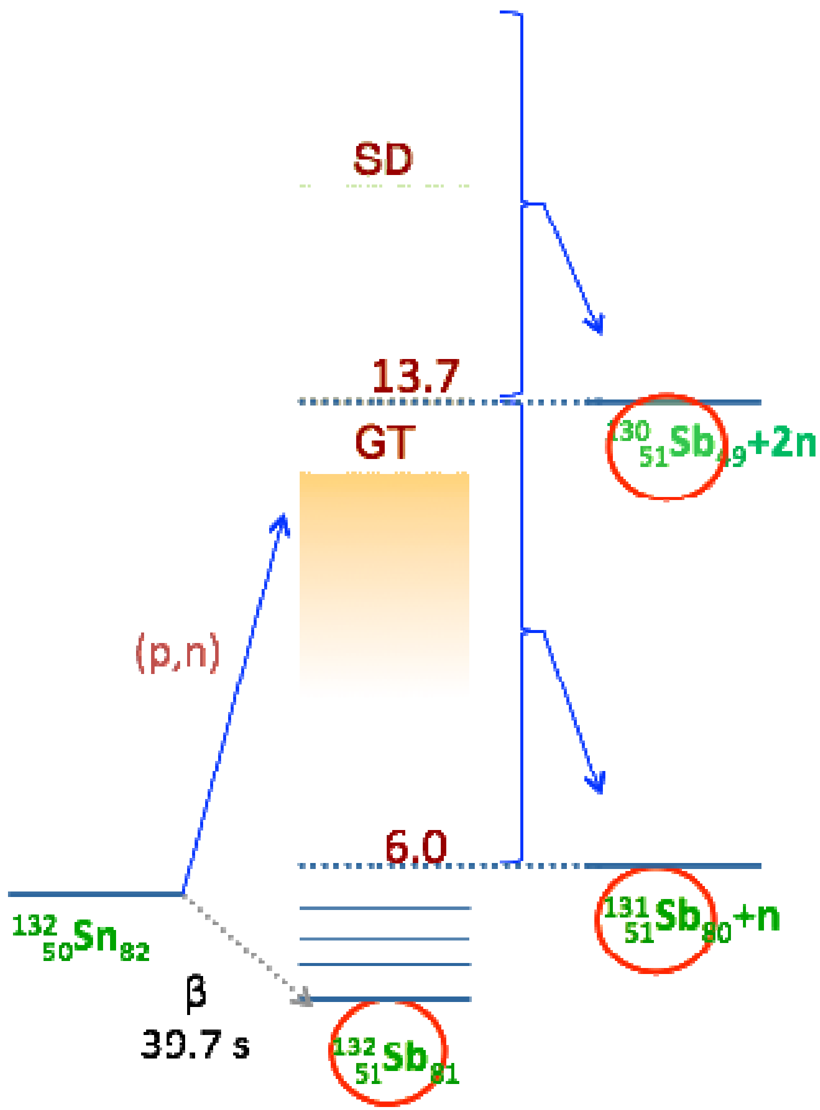
	purity [%]
132Sn	40.11
133Sn	9.47
131Sn	9.50
135Sb	3.88
134Sb	4.28
130in	3.24
129In	1.96





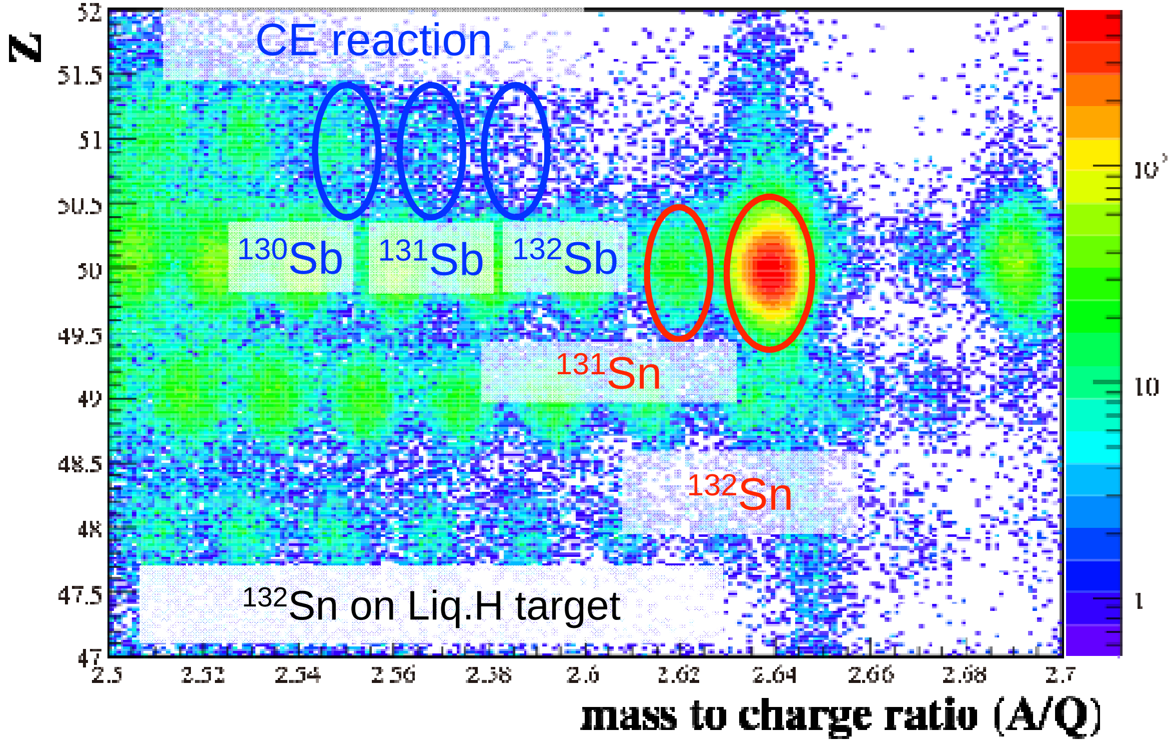


Reaction residue after the (p,n) reaction



PID for heavy residues with SAMURAI

- **TOF**
  - plastic counter SBT1,2 and HODS
  - resolution : σ_t ~ 60 ps
- **ΔE**
  - plastic counter HODS (5mm)
  - resolution : $\sigma_{\Delta E/\Delta}E$ ~ 0.4 %
- **Bρ**
  - drift chamber BDC1,2, FDC1,2
  - SAMURAI magnet : 2.56T
  - resolution : P/σ_P ~ 1300



- **σ_A = 0.16 6.1σ separation**
- **σ_Z = 0.22 4.5σ separation**

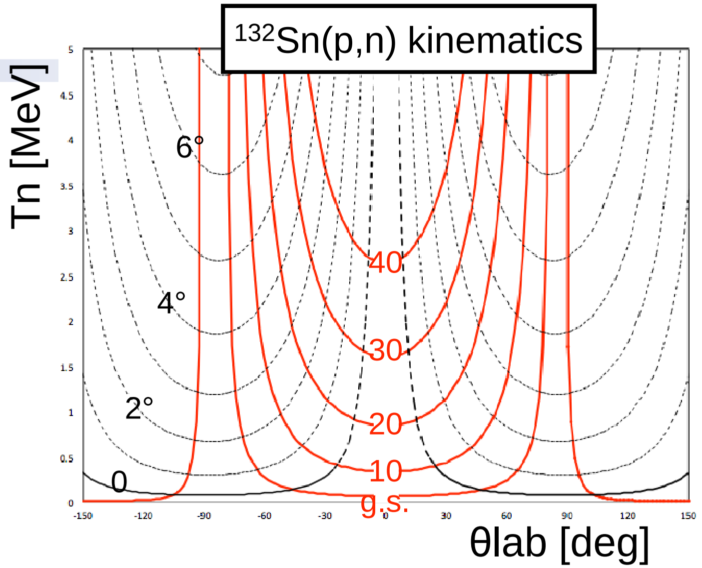
Charge Exchange (CE)reaction
$^{132}Sn(p,n)^{132}Sb$

Decay channel
Ex>6.0MeV : ^{132}Sb—> ^{131}Sb+n
Ex>9.8MeV : ^{132}Sb —> ^{131}Sn+p
Ex>13.7MeV : ^{132}Sb —> ^{130}Sb +2n

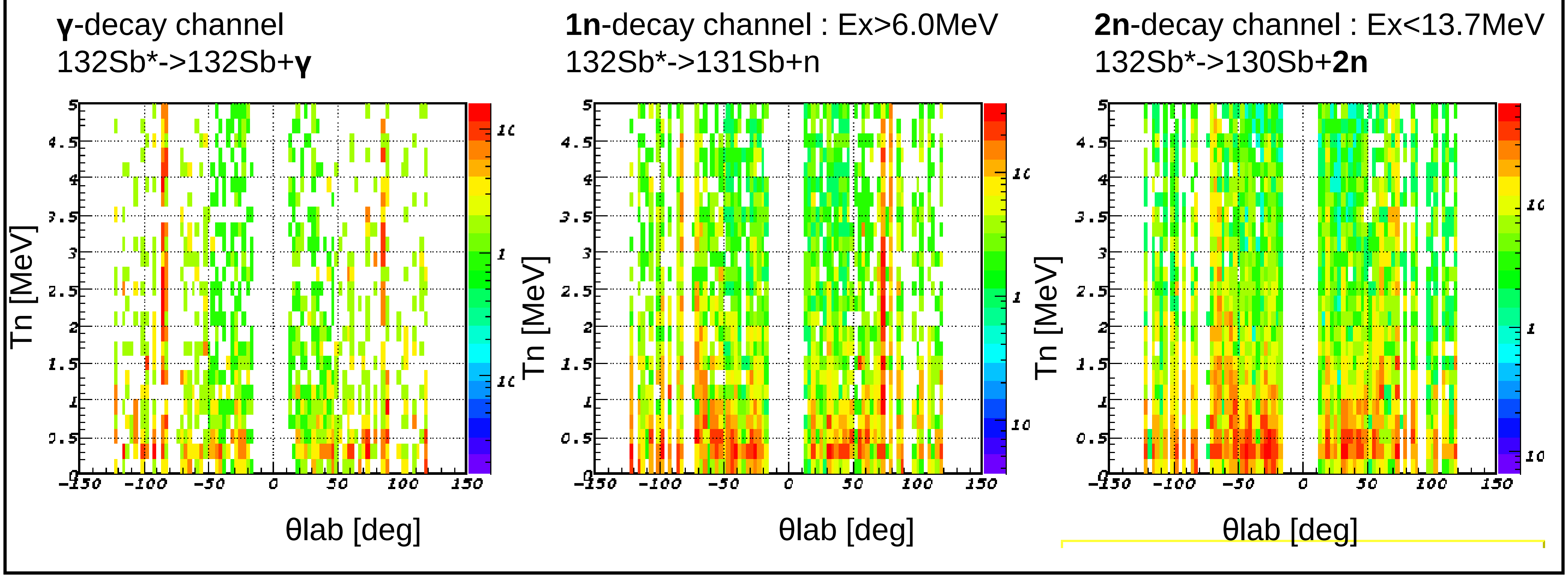
Large acceptance of SAMURAI
—> all decay channel was measured with good resolution

Kinetic curves

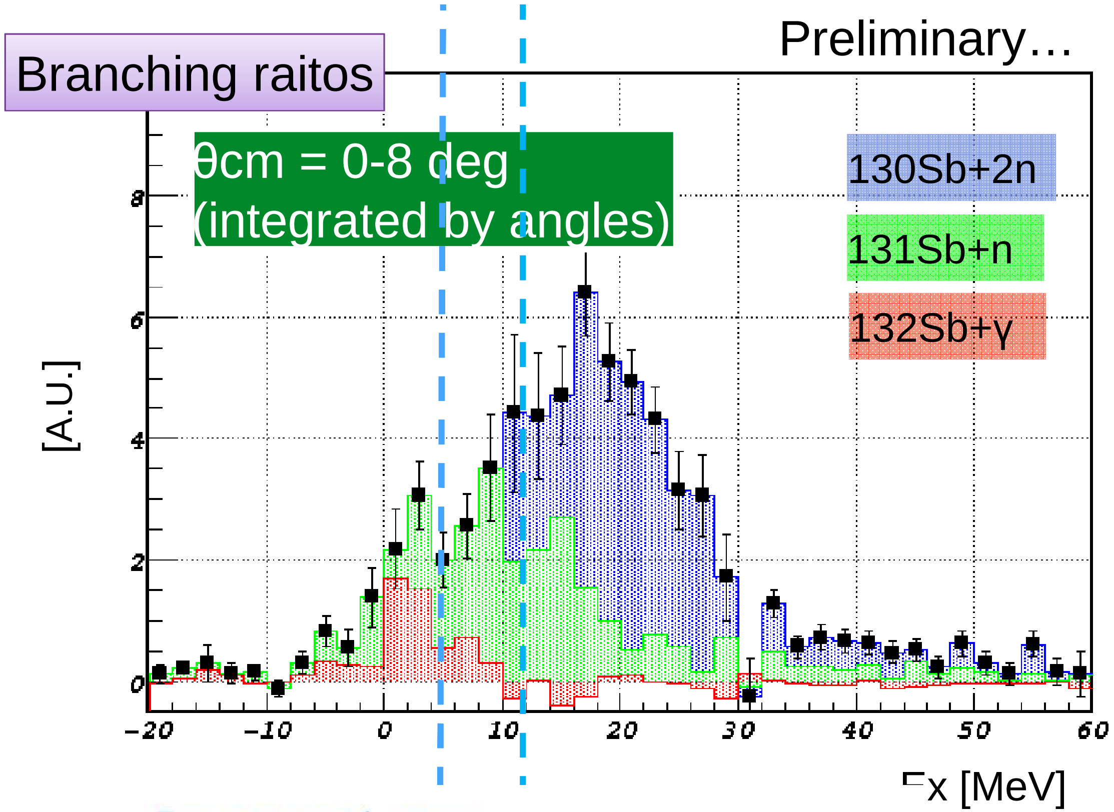
- **Neutron energy T_n vs Scattering angle θ_{lab}**
  - ✓ kinematics correlation of (p,n) reaction was clearly seen

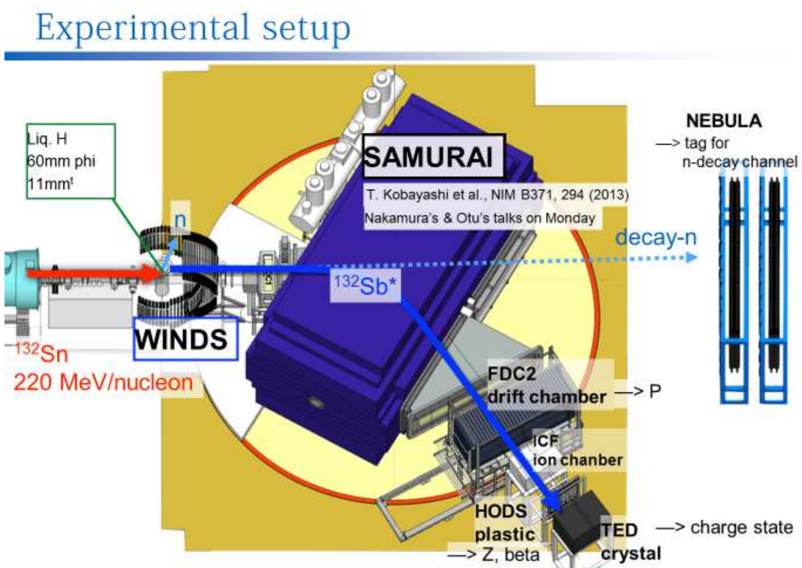


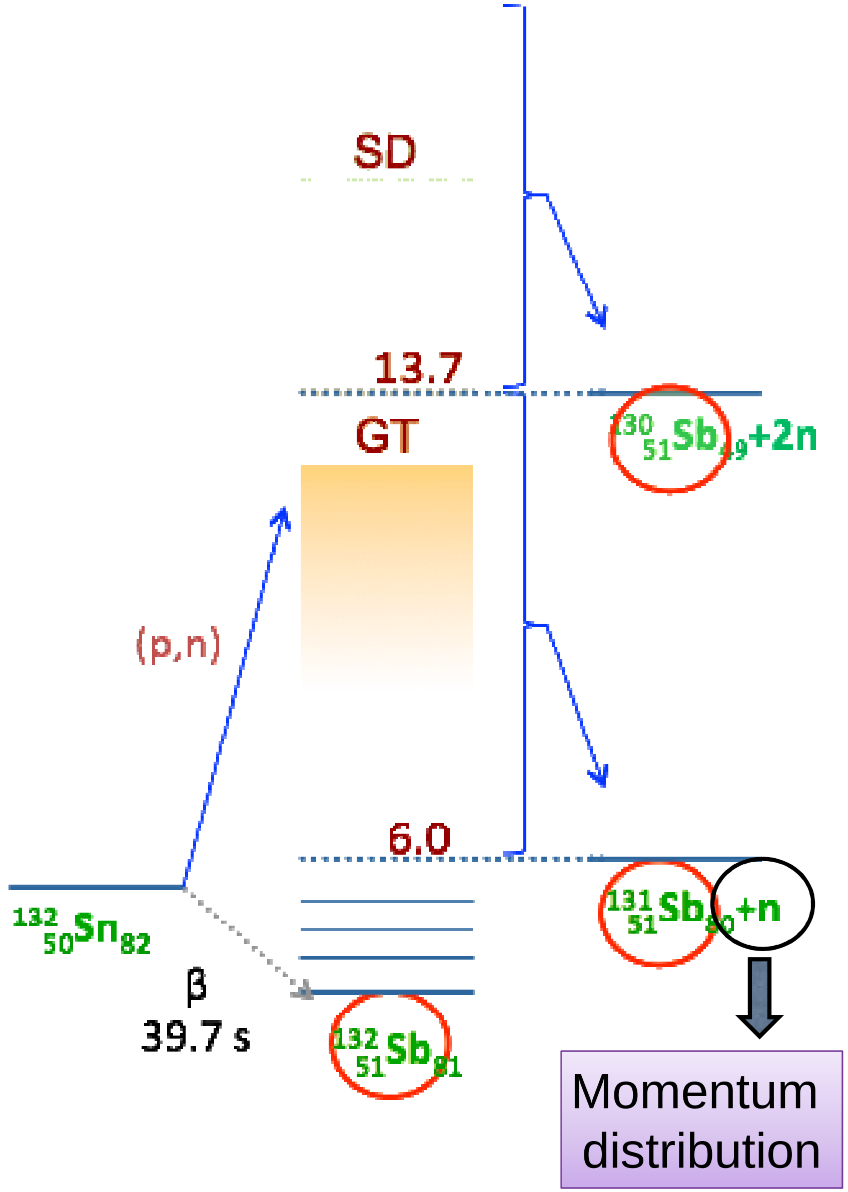
132Sn(p,n)132Sb*



Inverse kinematics → Decay properties







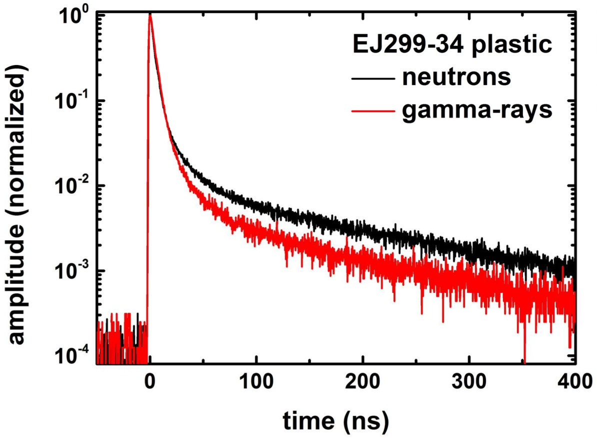
Upgrade of WINDS detector (Laszlo Stuhl & Jumpei Yasuda)

Problem:

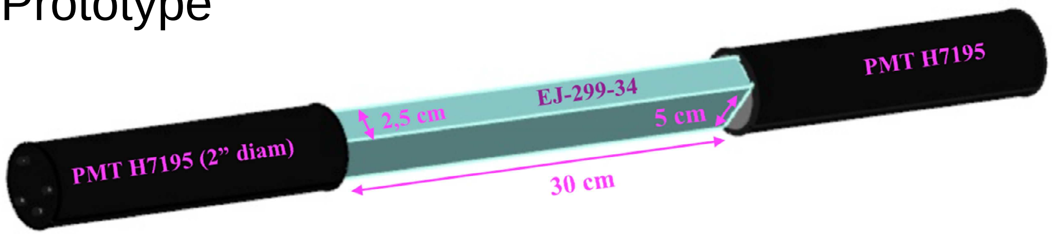
Charge-exchange experiments suffer by the high γ-ray background (~1kHz).

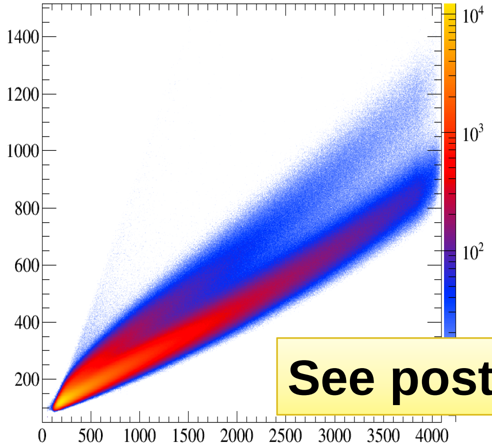
Solution:

The EJ-299-34 plastic scintillator enables the online separation of gamma and neutron signal



Prototype





252Cf source

See poster by L. Stuhl

Summary & perspective

- **Gamow-Teller study at any Ex & (A,Z)**
- **BigRIPS x WINDS x SAMURAI setup for (p,n) reaction on unstable nuclei**
  - BigRIPS : high intensity beam
  - WINDS : wide angular coverage θ_{lab} 20— 120deg (4π configuration)
  - SAMURAI : Large acceptance

- **^{132}Sn(p,n) performed**
  - **(p,n) study can be extended to A~100 region**

- **Perspective**
  - 132Sn(p,n) study
    - angular distribution —> B(GT) distribution on 132Sn
  - (p,n) reactions on two extreme isospin: (N-Z)/A = 0 or very large