Gamow-Teller transitions from ^{56}Ni

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Charge-Exchange (CE) reactions:
a tool for studying Gamow-Teller strengths

Gamow-Teller transition

ΔT=1, ΔS=1, ΔL=0

induced by $\sigma\ t\downarrow\pm$

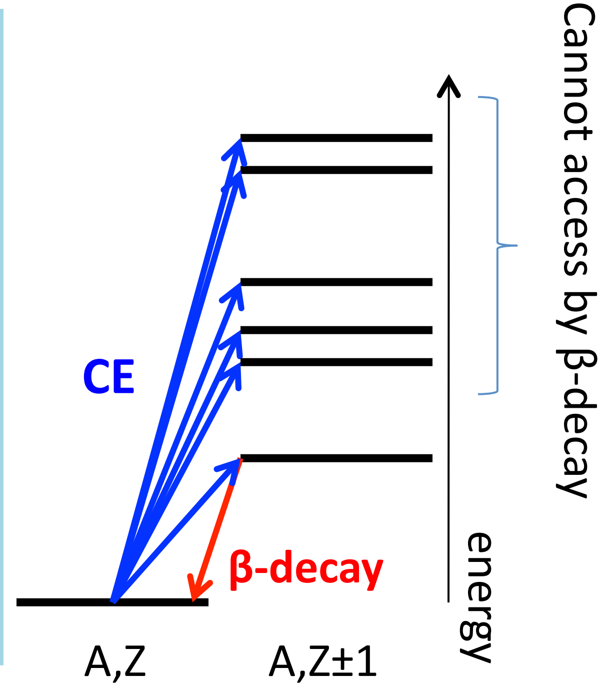
strength : **B(GT)**

→ allowed β-decay

CE reactions at 100-300 MeV

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

β^- type	β^+ type
(p,n), (^{3}He,t) …	(n,p), (t,^{3}He), (d,^{2}He), (^{7}Li,^{7}Be+γ)



Very powerful probe

→ Many successful studies on stable nuclei

GT studies on stable nuclei via CE reactions

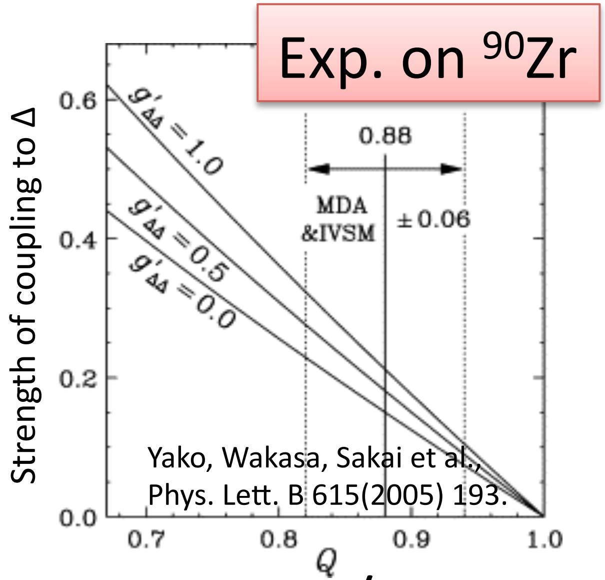
- Fundamental

  GT quenching ←→ non-nucleonic (Δ)
- Nuclear astrophysics

→ Weak processes in Type Ia、II supernovae
- Deeper understanding of nuclear structures and its applications

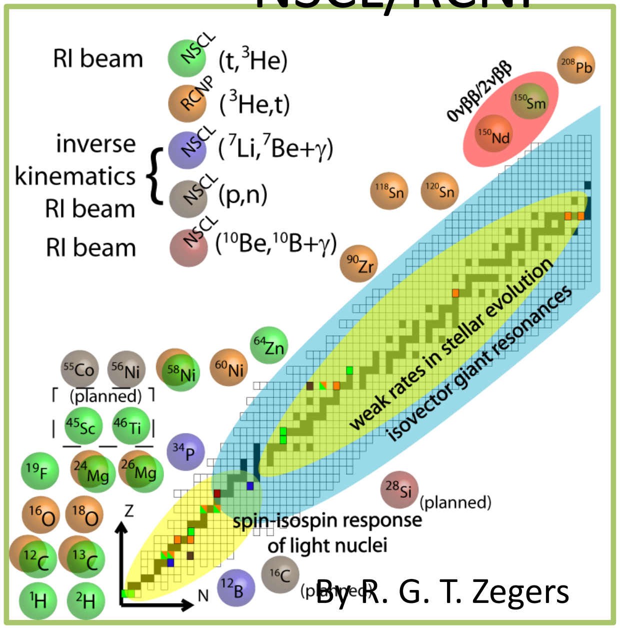
→ e.g., nuclear matrix elements in double beta decay

Exp. on ^{90}Zr

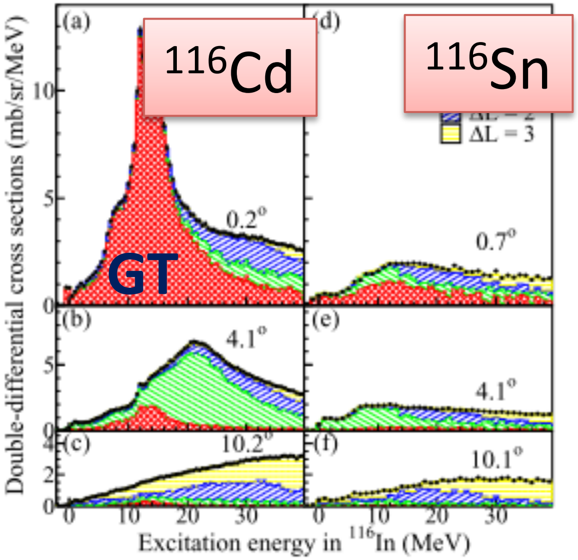


Yako, Wakasa, Sakai et al., Phys. Lett. B 615(2005) 193.

NSCL/RCNP



By R. G. T. Zegers



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

Why unstable nuclei?

- spin isospin collectivity

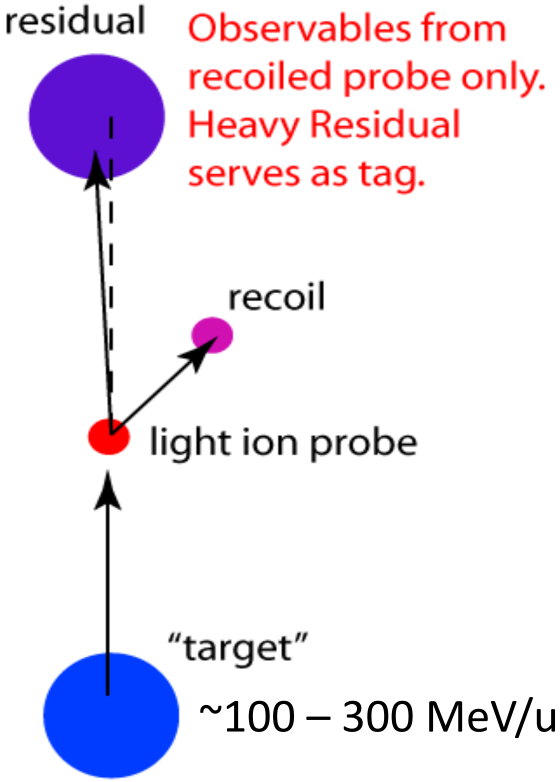
in terms of

  - Ratio of neutron and proton numbers
  - p-h vs. p-p
  - density (neutron skin, neutron halo)
  - double magicity far from the stability line

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

How?

The (p,n) reaction in inverse kinematics



Observables from recoiled probe only. Heavy Residual serves as tag.

Missing mass with recoil neutron detection

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!

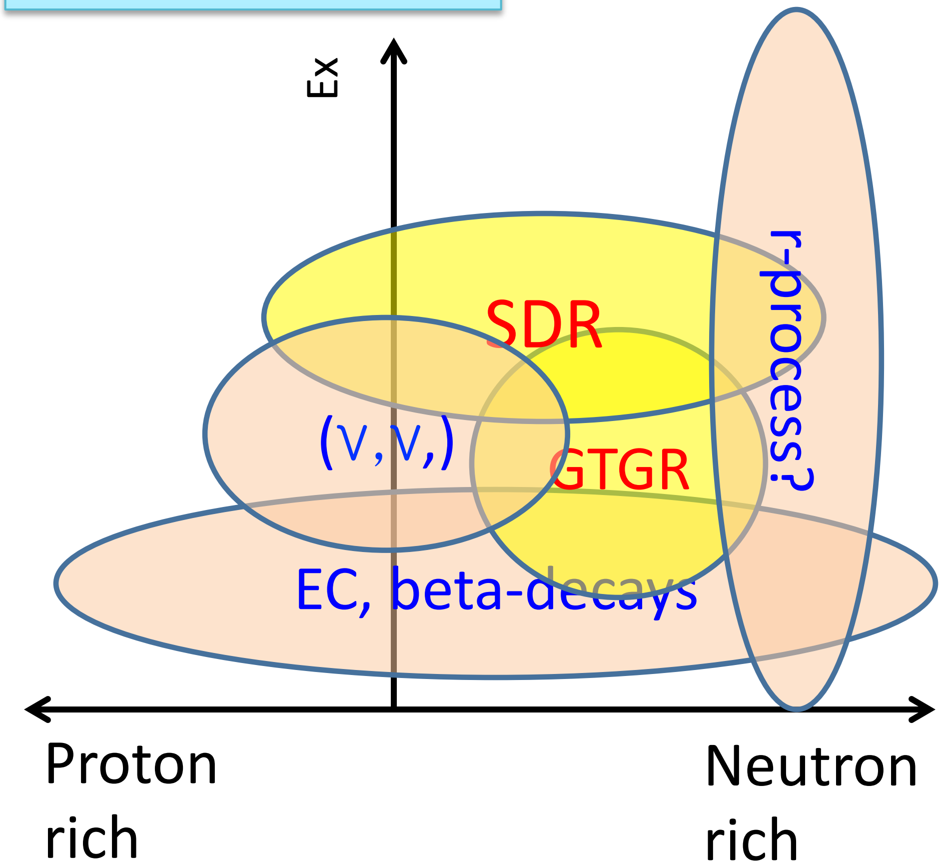
All kinematic information
from measurement of the neutron
(two-body kinematics)

Extensive!

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

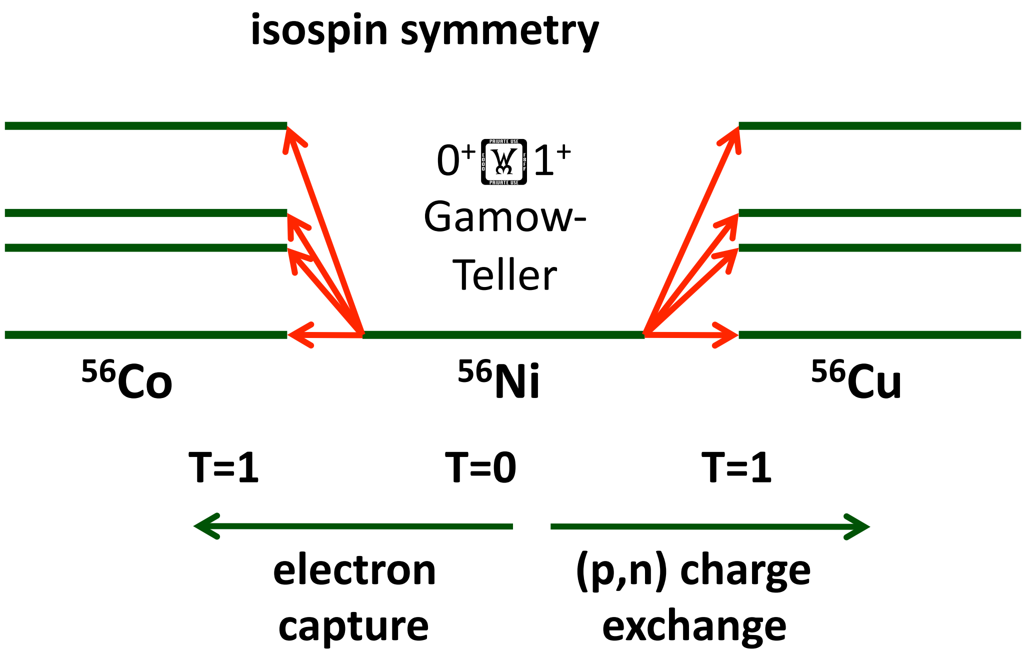
Applications

Possible to probe
any Ex on any A/Z
(beam intensity 10$^{4-5}$ pps)



^{6}He, ^{11}Li, ^{14}Be,
^{70,72}Ni, ^{132}Sn
at RIKEN RIBF

^{56}Ni



isospin symmetry

0^+ □ 1^+
Gamow-
Teller

^{56}Co
^{56}Ni
^{56}Cu

T=1
T=0
T=1

electron capture

(p,n) charge exchange

One of the important cases
in core collapse super novae of massive stars
(Phys. Rev. Lett. 86, 1678 (2001))

^{56}Ni is a key nucleus in Fe region

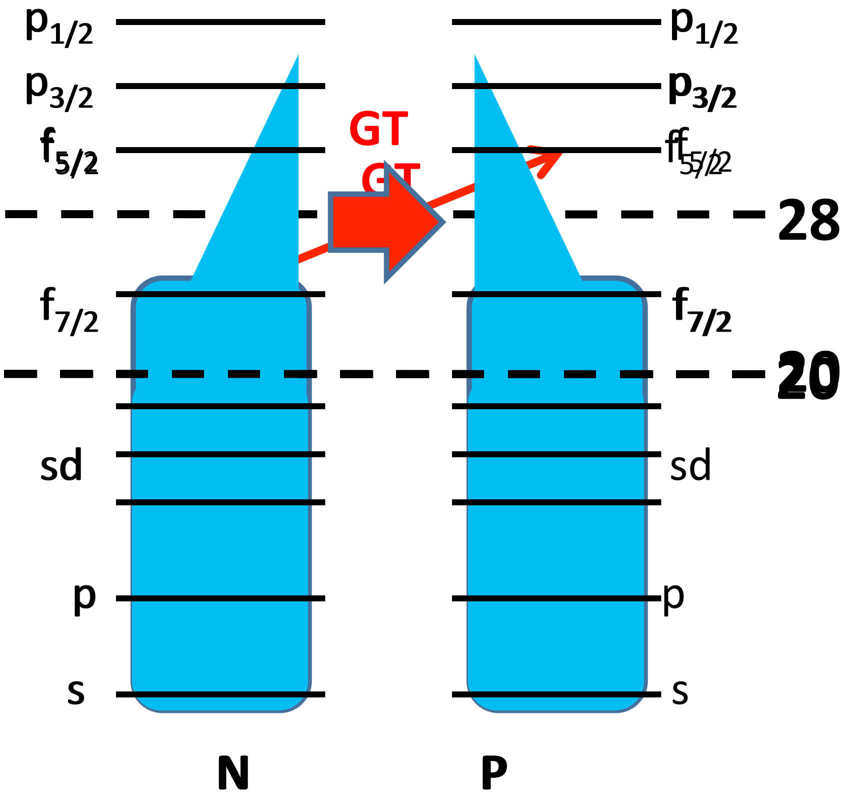
^{56}Ni (Z=N=28)

- independent particle model

  → ^{56}Ni is doubly magic

- Large p-n residual interaction

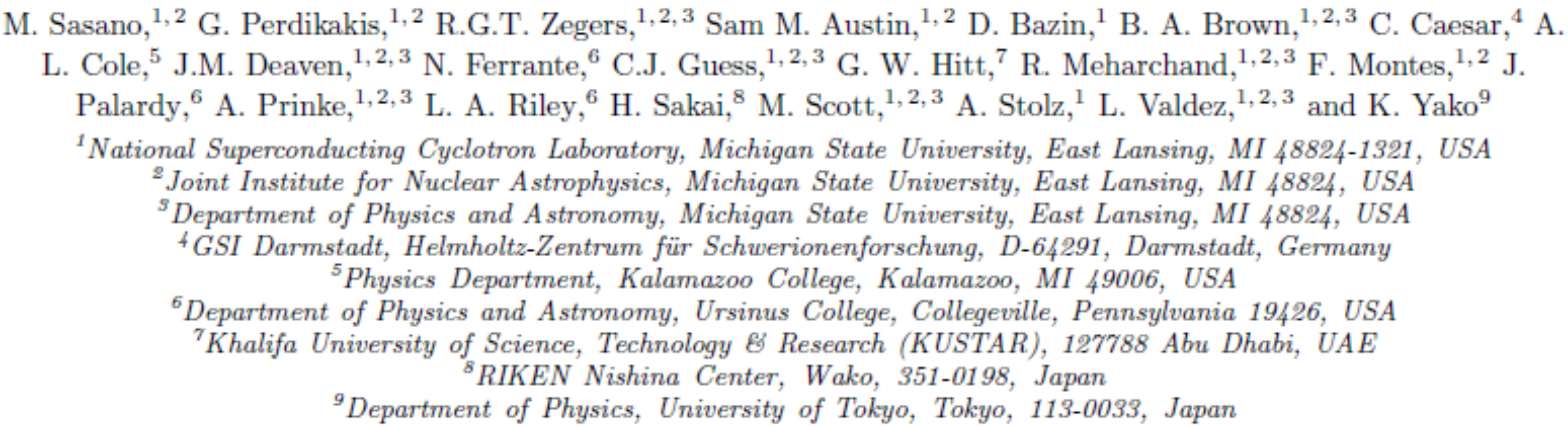
  → ^{56}Ni is not magic



f7/2 70% in ^{56}Ni (GXPF1A, KB3G)

(e.g., Honma et al., Phys. Rev. C 69, 034335 (2004))

Collaborators for the ^{56}Ni(p,n) measurement



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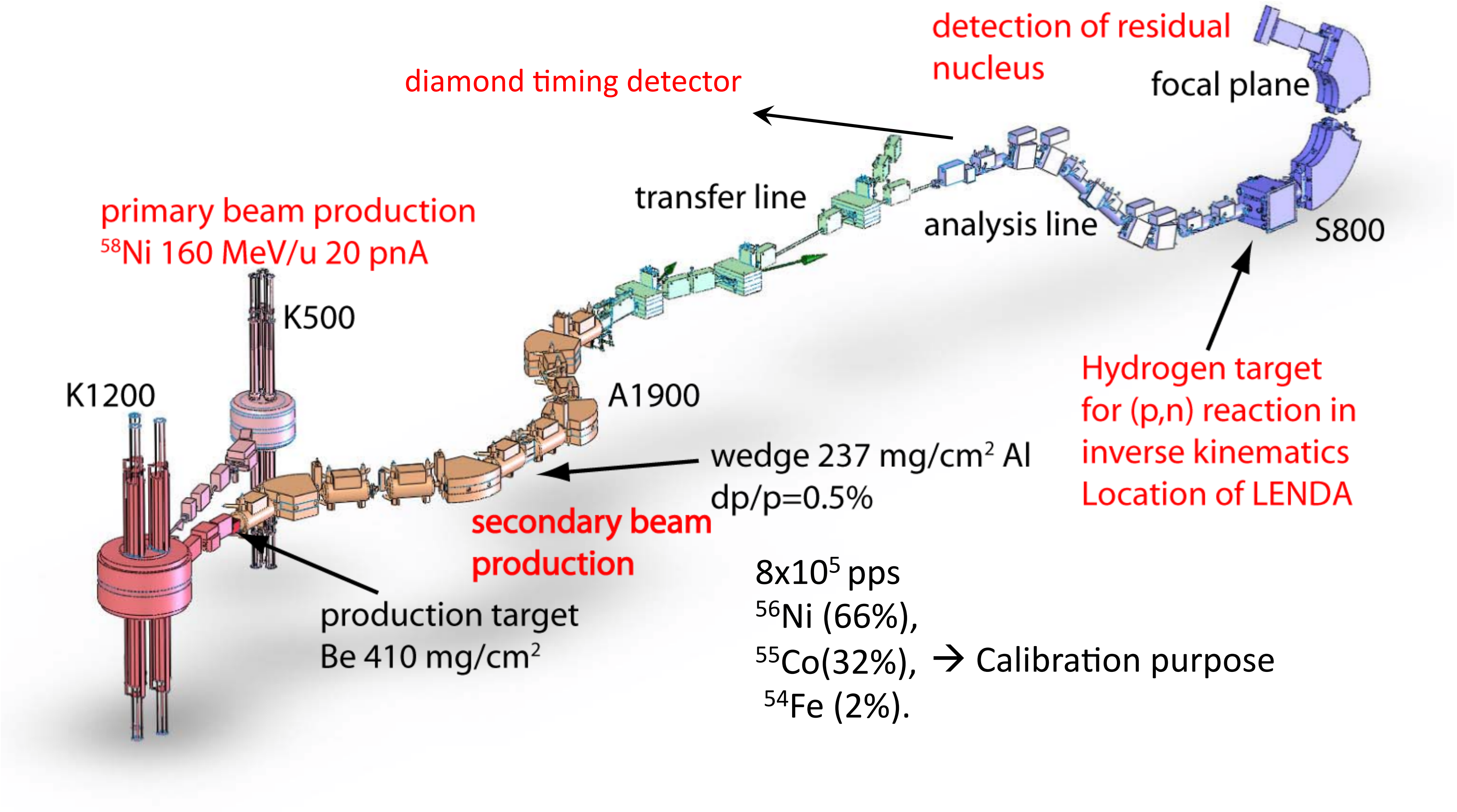
^{56}Ni beam production and experiment overview



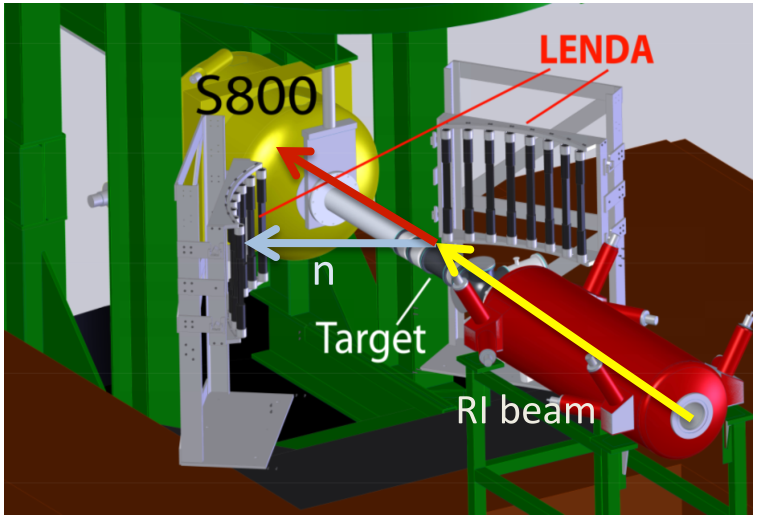
primary beam production
^{58}Ni 160 MeV/u 20 pnA

wedge 237 mg/cm^2 Al
dp/p=0.5%

production target
Be 410 mg/cm^2

8x10^5 pps
^{56}Ni (66%),
^{55}Co(32%), → Calibration purpose
^{54}Fe (2%).

Set up of LENDA



Low Energy Neutron Detector Array (LENDA)

neutron detection

Plastic scintillator

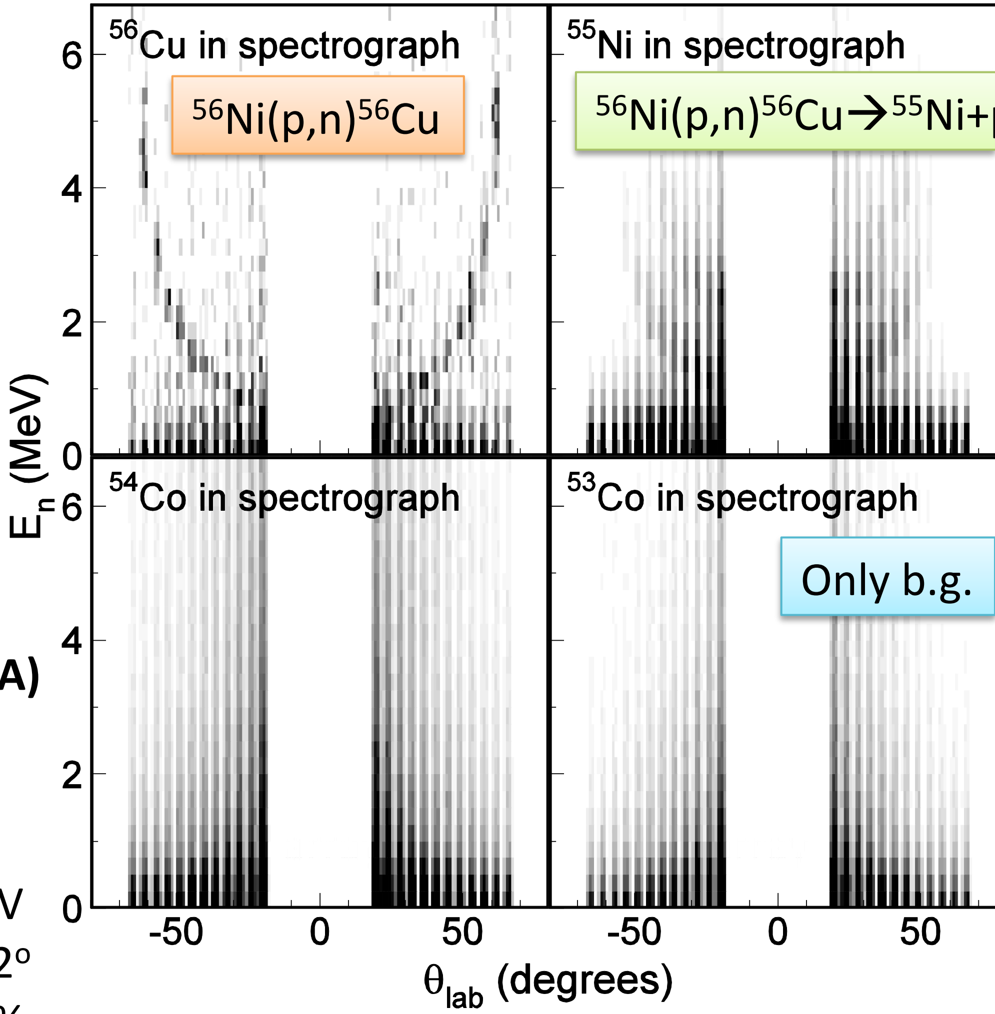
24 bars 2.5x4.5x30cm

150 keV < E_n < 10 MeV

□E_n ~ 5%   □□$_n$ < 2°

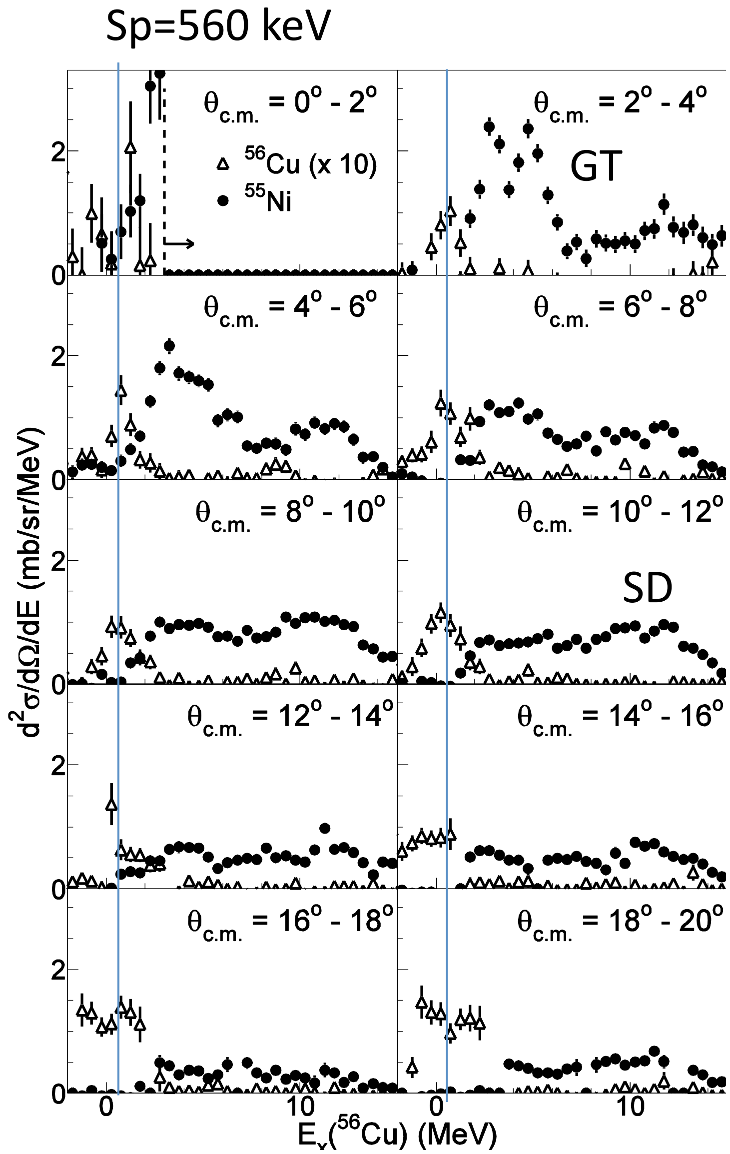
efficiency 15-40%

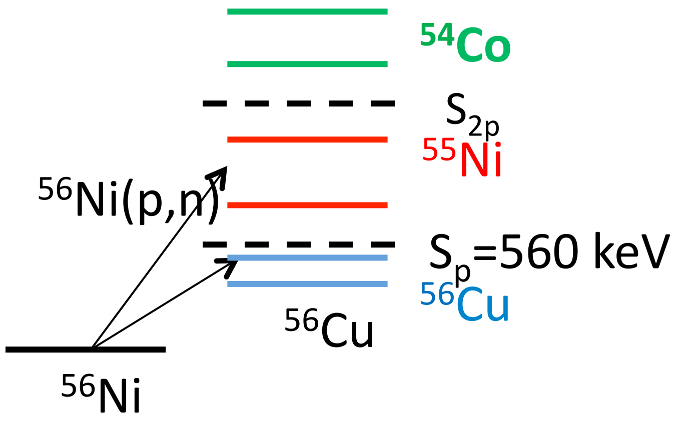
Flight path : 1 m



Perdikakis et al, NIM.

Double differential cross sections





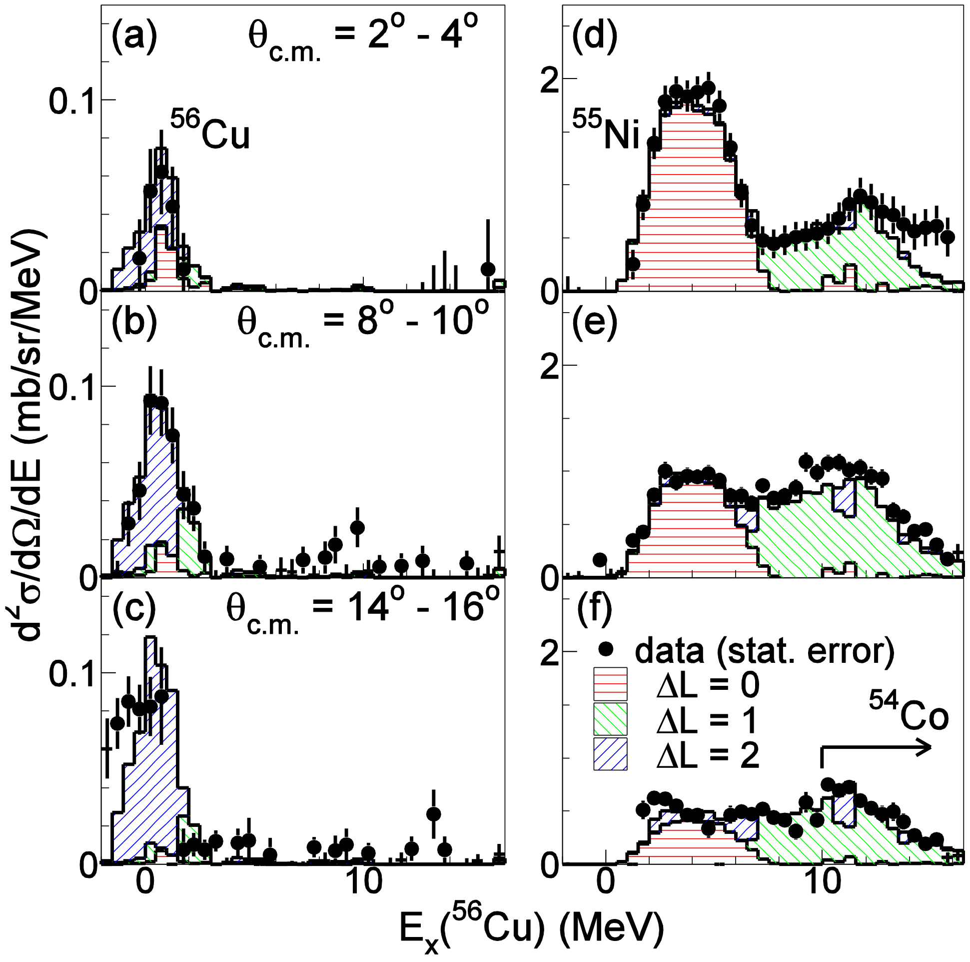
Two bumps at 3 and 5 MeV
with forward angle peaks (GT:ΔL=0)

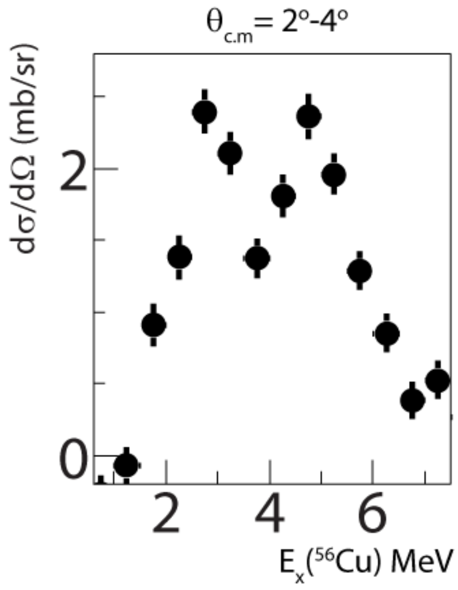
A bump around 12 MeV
→ Peak around 10-12 degrees
→ Spin dipole (ΔL=1)

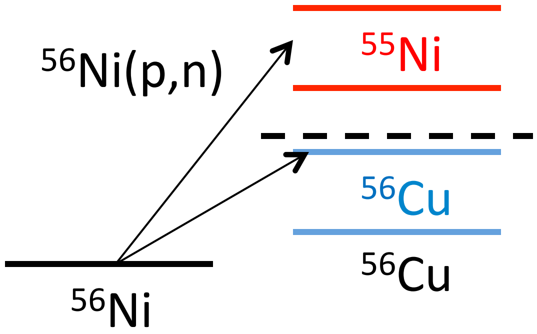
States without proton emission
→ Peak at most backward angle
→ Higher multipoles (ΔL>1)

To extract GT component quantitatively
→ Multipole decomposition

Results of MDA





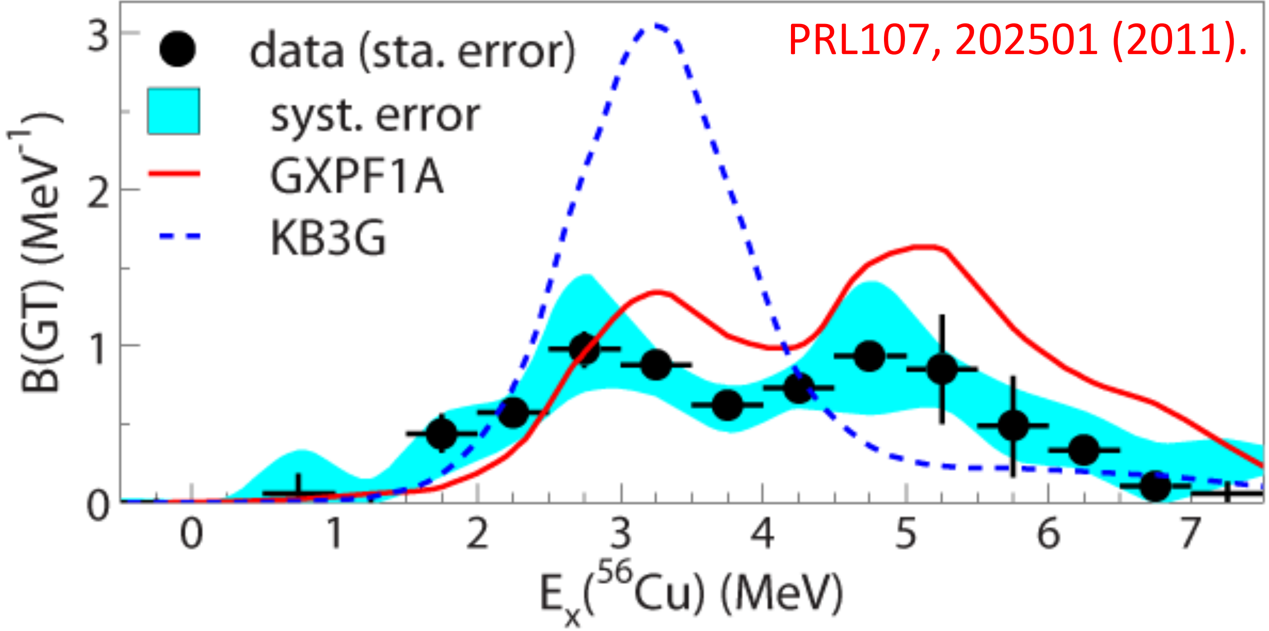


GT component dominates the region below 8 MeV.

→ Scale the spectrum before smearing

GT strengths from ^{56}Ni(p,n) at 110 MeV/u

- Use the extracted ΔL=0 component in combination with unit cross section to extract Gamow-Teller strength [B(GT)].
- Compare with large-scale shell-model calculations



PRL107, 202501 (2011).

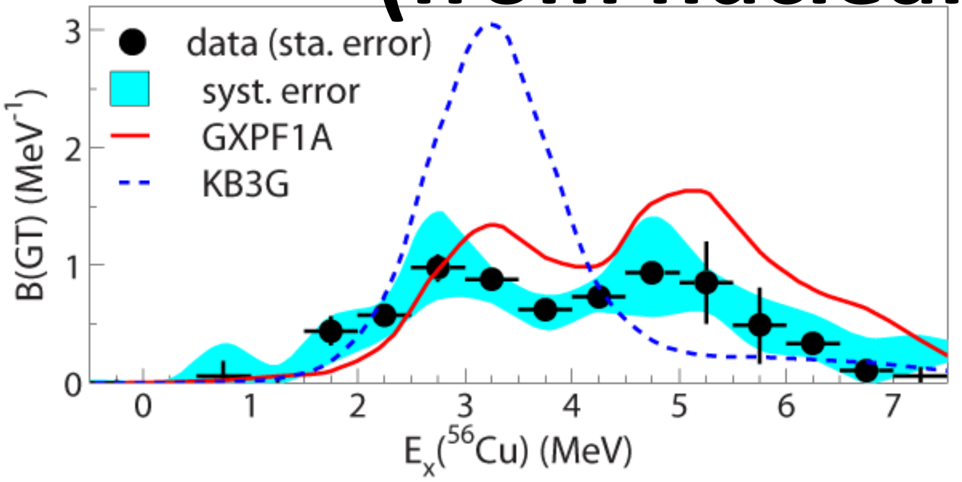
GXPF1A: Honma et al. : constrained by data in full pf-shell

KB3G: Poves et al. : less constraints – used in database for weak rates for astrophysical purposes.

Difference between KB3G and GXPF1A:

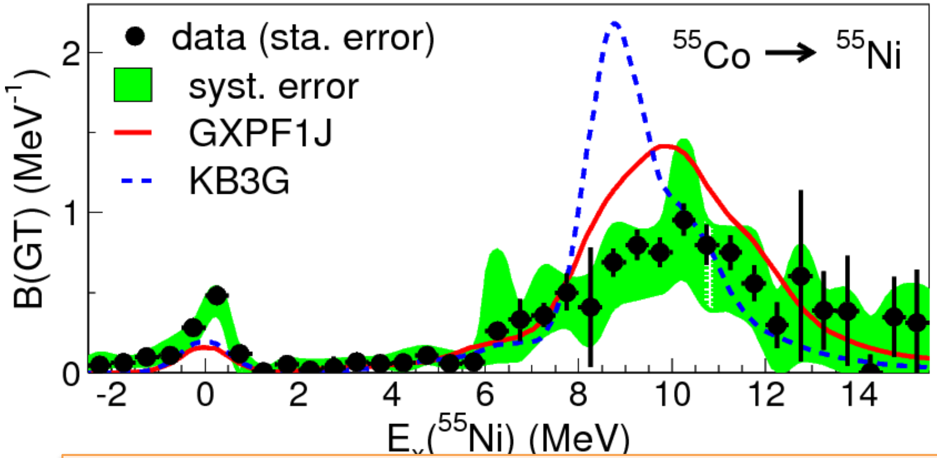
- KB3G weaker spin-orbit and pn-residual interactions
- KB3G lower level density

A question (from nuclear structure)



Two prominent peaks exist
Large difference between KB3G and GXPF1

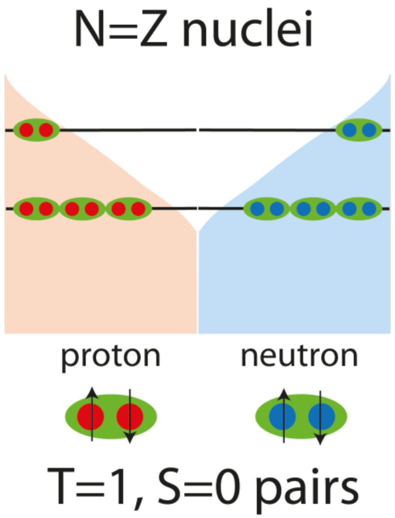
Remove one neutron
from parent & daughter



Two peaks disappear
Small difference between KB3G and GXPF1

Point:
Along N=Z, B(GT) is sensitive to some part of interaction and showing two peaks.
Question:
What picture can **intuitively** explain the origin of the two peaks?

A new picture of GT resonance



<u>Initial ground state</u>

Filled with pp/nn (isovector) pair

<u>GT transition</u>

breaking a pair

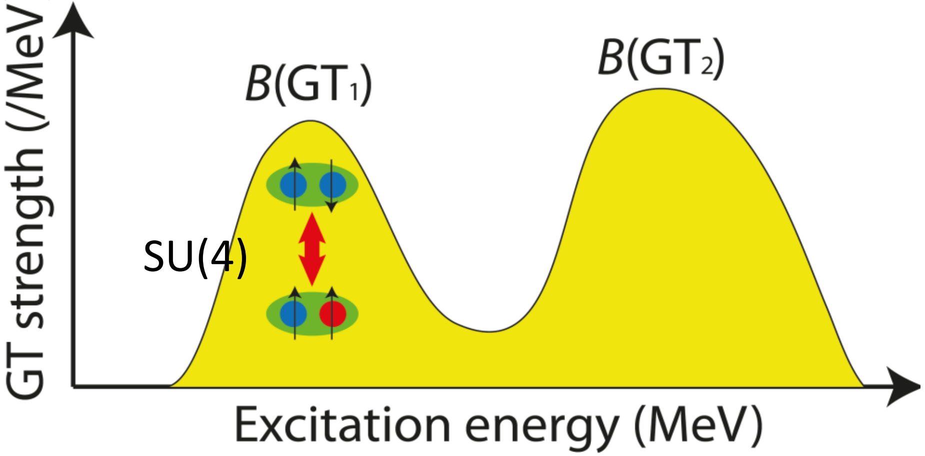
<u>Final state</u>

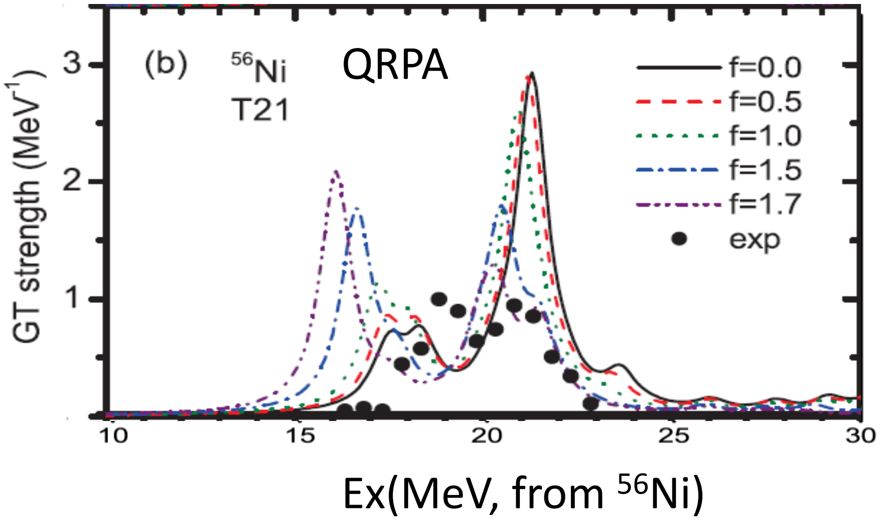
- **particle-hole**: repulsive
  → pushed up to higher energy
  (well studied in stable nuclei)
- **particle-particle (pn)**: attractive
  → pushed down to lower energy

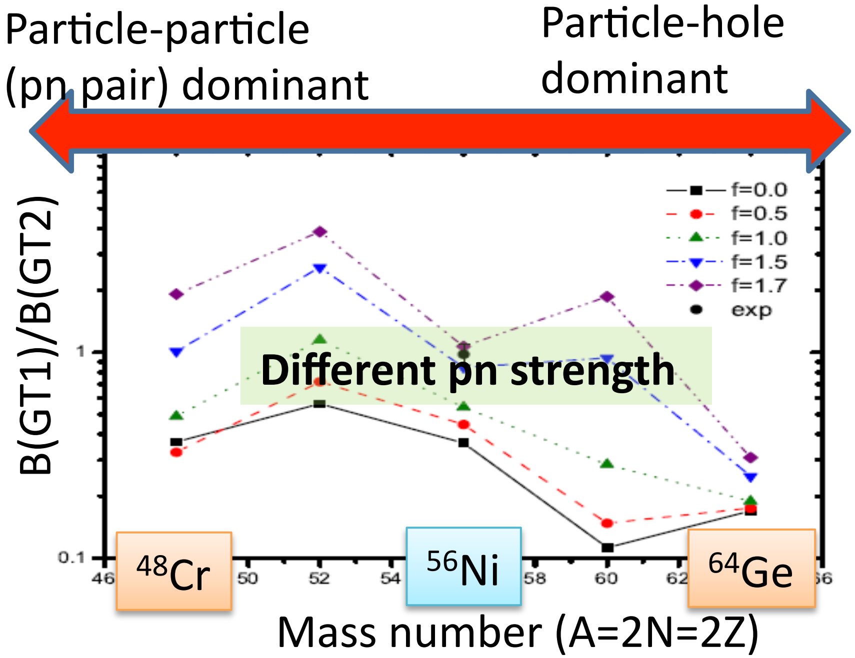
The states in the lower peak is expected to form a T=0, S=1 pair (identical proton and neutron orbits)

pn (T=0) effect along N=Z

Bai, Sagawa, et al.,
C. L. Bai, H. Sagawa, et al., Phys. Lett. B 719 (2013).







^{48}Cr and ^{64}Ge at RIKEN RIBF

(4 neutrons and protons away from^{56}Ni)
for a wide (0-20 MeV) Ex region
→

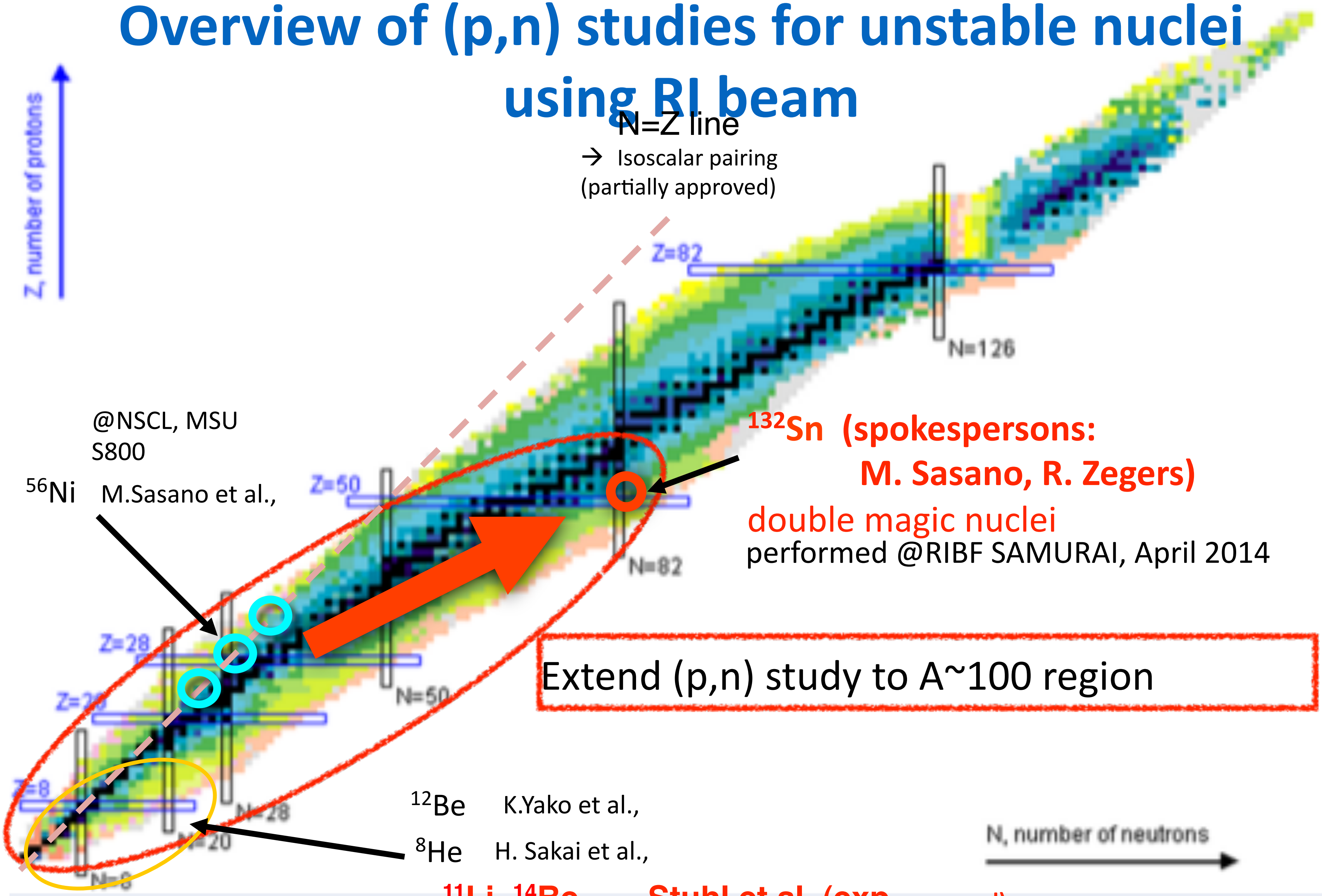
- **Confirm the picture;**
  (nn → pn vibration)
- **Determine the strength of the pn pairing**

Take-home messages

From a key nucleus (^{56}Ni), we learned a lot that was not so easy to extract from a wide range of experiments

Pinning down key parameters of nuclear models
Spin isospin collectivity hidden in stable nuclei

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



N=Z line

→ Isoscalar pairing
(partially approved)

@NSCL, MSU
S800

^{56}Ni M.Sasano et al.,

^{132}Sn (spokespersons:
M. Sasano, R. Zegers)

double magic nuclei

performed @RIBF SAMURAI, April 2014

Extend (p,n) study to A~100 region

^{12}Be K.Yako et al.,

^{8}He H. Sakai et al.,

^{11}Li, ^{14}Be, …, Stuhl et al. (exp. approved)

132Sn(p,n) exp. collaboration

R. G. T. Zegers, S. Noji, M. Scott, C. Sullivan, S. Lipschutz, D. Bazin, S. Austin, A. Brown, E. Litvinova, D-L. Fang (NSCL, MSU), T. Uesaka, J. Zenihiro, M. Dozono, T. Motobayashi, K. Yoneda, H. Sato, Y. Shimizu, H. Otsu, H. Baba, M. Nishimura, H. Sagawa, H. Sakai, N. Inabe, H. Hiroshi, N. Fukuda, T. Kubo, Zhenyu Xu (RIKEN Nishina Center) ,

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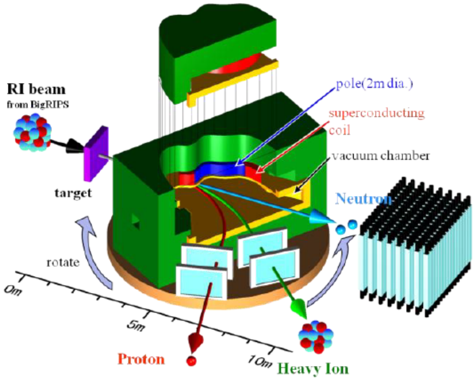
K. Yako, S. Shimoura, S. Ota, S. Kawase, Y. Kubota, M. Takaki, S. Michimasa, K. Kisamori, C. Lee, H. Tokieda (CNS, University of Tokyo), R. G. T. Zegers, S. Noji (NSCL, Michigan State University),

J. Yasuda, T. Wakasa (Kyushu University)

A. Krasznahorkay, Laszlo Stuhl (ATOMKI)



Summary & perspective

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

- **The first case is done on 56Ni at NSCL (A1900xLENDAxS800)**

  GXPF1A ○、 KB3G X

  Key (sometimes, unstable) nuclei

→ pin down key parameters in nuclear model

  collectivity hidden in stable nuclei

- **Perspective**

  Expanding rapidly…

  - N=Z nuclei, ^{48}Cr and ^{64}Ge
  - ^{132}Sn(p,n) study at RIBF
  - (p,n) reactions on halo nuclei