Recent Results of (^{3}He,*t*+n) and (^{3}He,*t*+p) reactions

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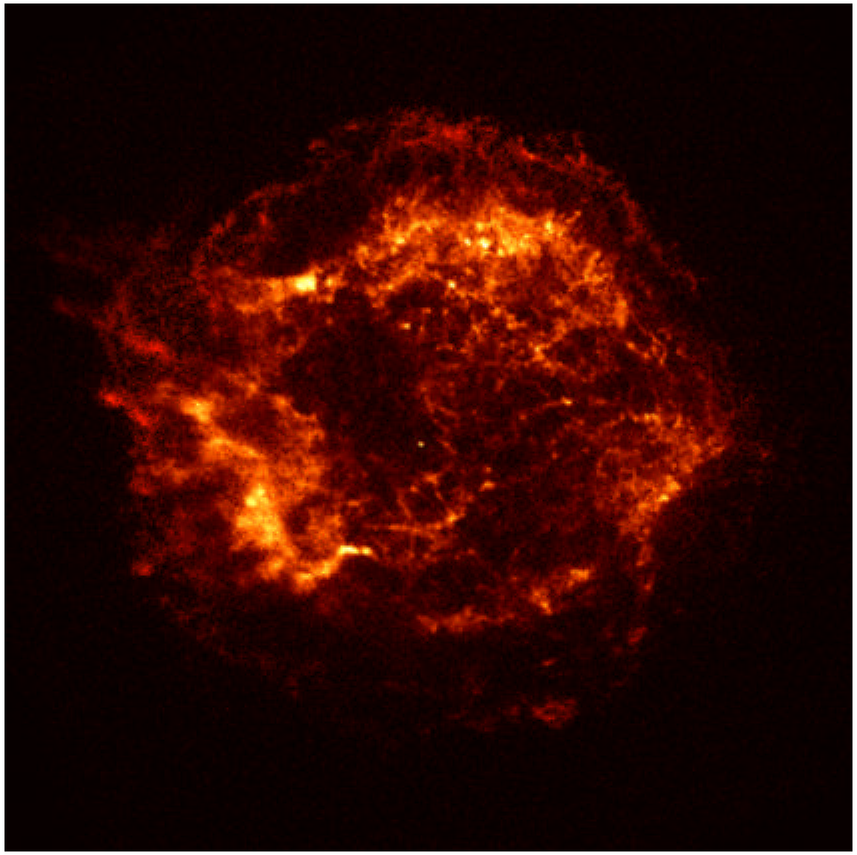
(^{3}He,*t*+n) reaction

- Supernova explosion and neutrinos
- Neutrino detection using lead
- Neutron decay measurement from excited ^{208}Bi

(^{3}He,*t*+p) reaction

- Giant monopole resonance
- Proton decay coincidence



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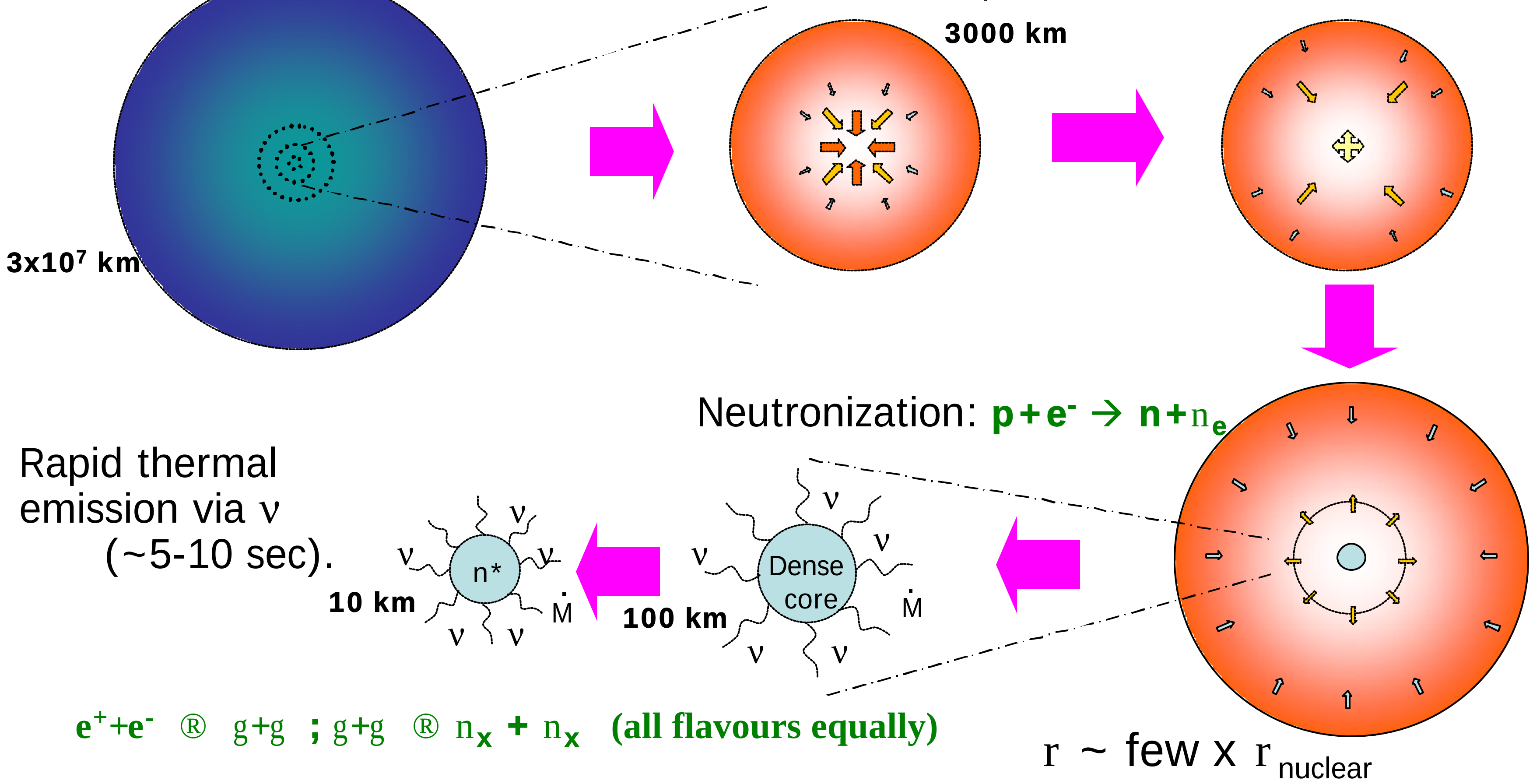
Type-II Supernova

Mass >8 $M_\odot$ Life time ~10^7 yr

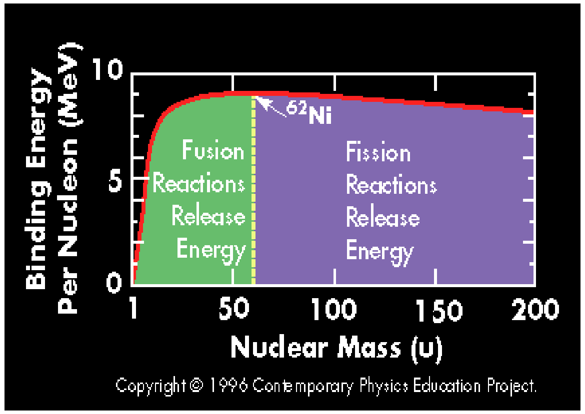
Nucleus are decomposed to protons, neutrons and a's by photo-nuclear reaction in high-temperature environment.

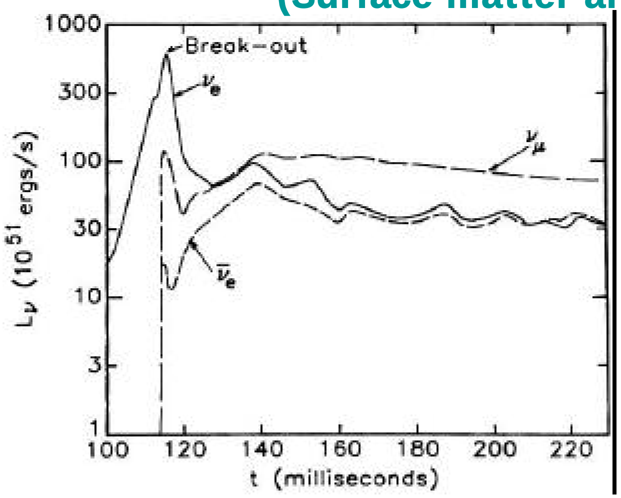


- Happens in 10-30 years interval in the galaxy
- The total energies are transported in
  - about 0. 1% as light
  - about 1% as matter
  - remaining 99% as neutrino's.

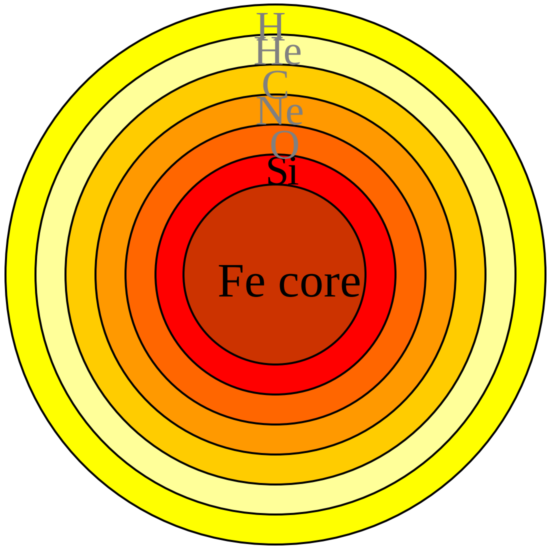
Before and Just after Explosion

Status	T (K)	Remnant	Carrying time
H burning	2×10^{7}	He	few $\times 10^{6}$ yrs
He	2×10^{8}	C, O	few $\times 10^{4}$ yrs
C	8×10^{8}	Ne, O	~600 yrs
Ne	1.4×10^{9}	O, Mg	~1 yr..
O	2×10^{9}	Si, S	~6 mo..
Si	3.5×10^{9}	Fe, Ni	~1 day
Collapse	$\sim40\times10^{9}$	90%n	~few ms
		10%p +diffusion	
		(Surface matter and heavy element)	





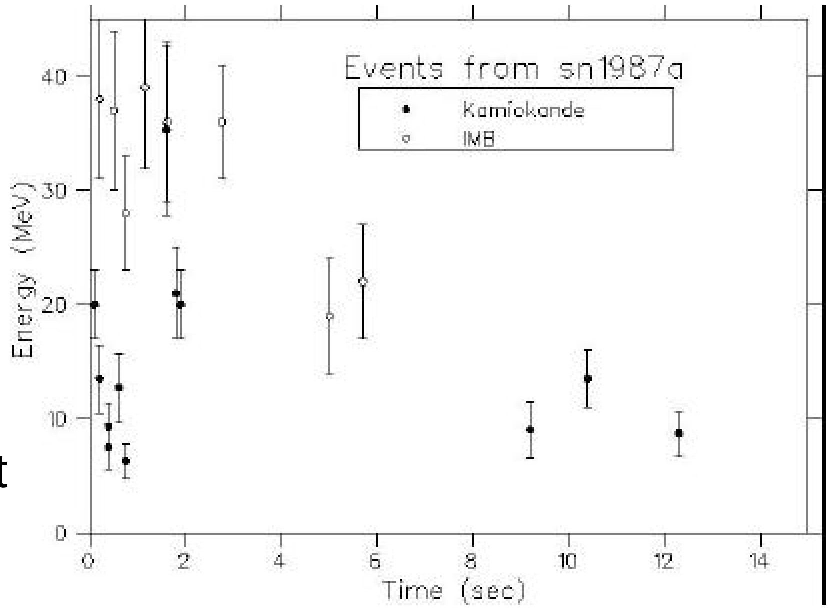
Burrows ARNPS 1990



SN1987A

Anglo Australian Observatory

- About 50 kpc distance from the earth
- Neutrinos were detected about 2 hrs later than the optical observation.



- ~20 events were confirmed at Kamiokande and IMB
- First (and only so far) neutrino detection from outside of the solar system
- Because of water Cerenkov method, almost all the neutrinos were $\overline{n}_{e}$:

$$?_e + p \rightarrow n + e^+$$

The importance of neutrinos in the Core Collapses

- Neutrinos promote supernova explosion.
  - Photo-nuclear reaction prevents early explosion.
  - Core is ‘opaque’ to neutriono due to extreme high density.
  - The interaction between neutrinos to core has defference depending on energy and neutrino spicies.
- Almost all energies are transported via neutrions.
  - The transparency is higher than any other matters and the amount of emitance is much.
  - Supernova is cooled down via neutrinos.
- The interaction between neutrinos and matters before explosion is greatly related to the core collapse.

  ? The flux, energies and time distribution give a lot of information about the mechanism of supernova explosions.
- No computer simulations have been succeeded in the core collapse.
  - It seems rotation, strong magnetic field, and so on have involved.

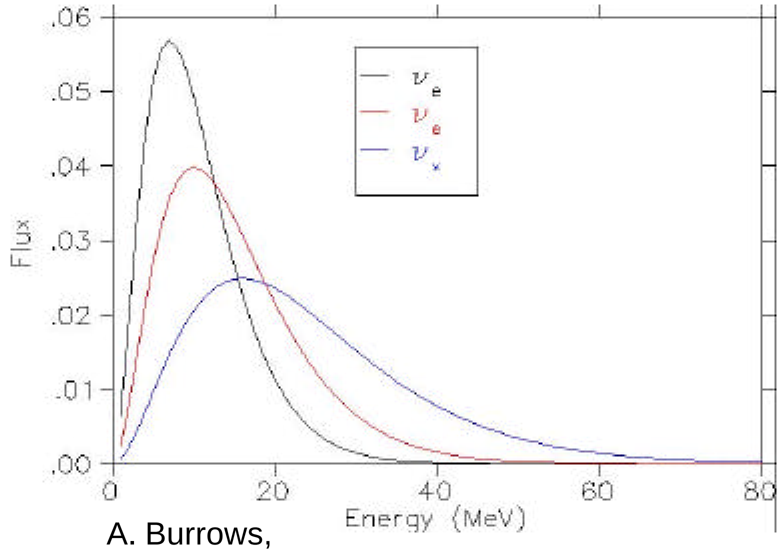
Neutrino Flavors and Energy Distributions

- Cross Section: Coupling constant of weak interaction → σ ~10^{-42} cm^2
  - ~10^{15} Smaller than cross sections in ordinary nuclear reaction
  - More neutrons than plotons at core → $?_e + n \rightarrow p + e^-$ > $\bar{?}_e + p \rightarrow n + e^+$
  - **CC** reactions (n↔p exchange) are easy to happen.
- **The radii of 'Neutrino sphere' are different in flavors.**
- Prediction of neutrino energy distribution

<E(n_e)> = 11 MeV
<E($\bar{n}_e$)> = 16 MeV
<E(n_x)> = 25 MeV

Average energies depend on supernovae explosion model.

The first purpose is to measure energy distributions.
→ Equation of neutrino state and transimissivity can be known.

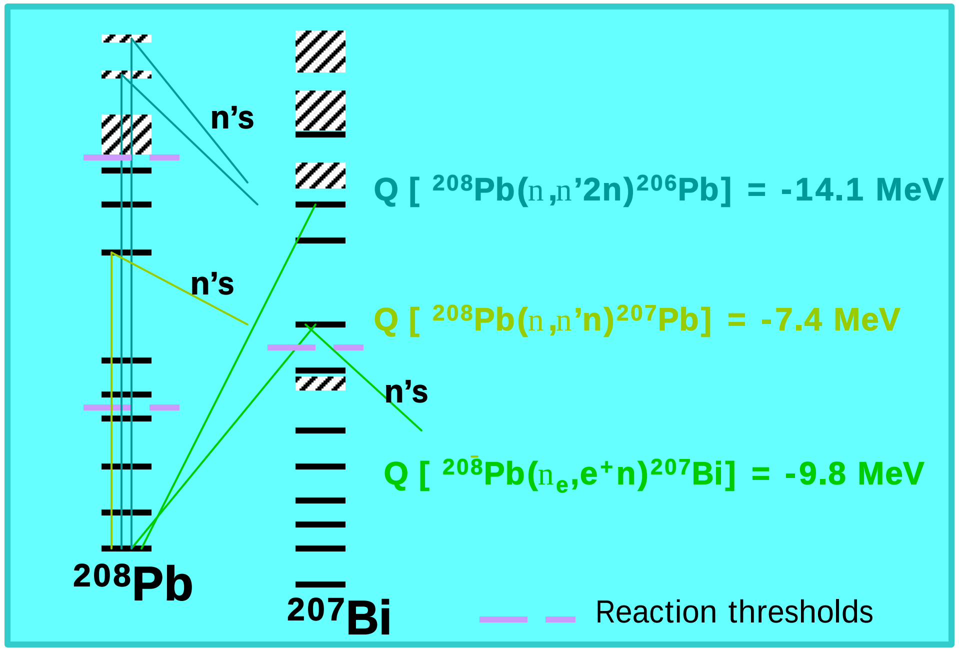


A. Burrows,
Annu. Rev. Nucl. Part. Sci **40**, 181 (1990).

Neutrino Detection via ^{208}Pb

CC & NC reaction can be measured by matter with low neutron decay threshold and many electrons. Cross section is relatively higher.

Abailable to measure n_m & n_t
Playing as *'Flavor Filter'*.



- <u>Neutral Current (NC) reaction</u>

$$n_i + {}^{208}\text{Pb} \rightarrow n'_i + {}^{208}\text{Pb}^* \rightarrow {}^{208}\text{Pb} + g \;\; or \;\; {}^{207}\text{Pb} + \text{n} \;\; or \;\; {}^{206}\text{Pb} + 2\text{n}$$

$$(i = e, m, t)$$

$$n_e + p \rightarrow n'_e + p'$$

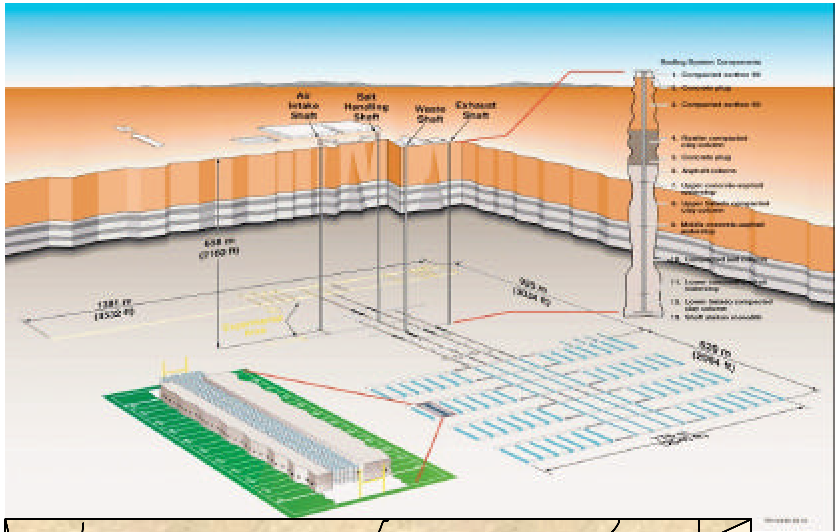
- <u>Charged-Current (CC) reaction</u>

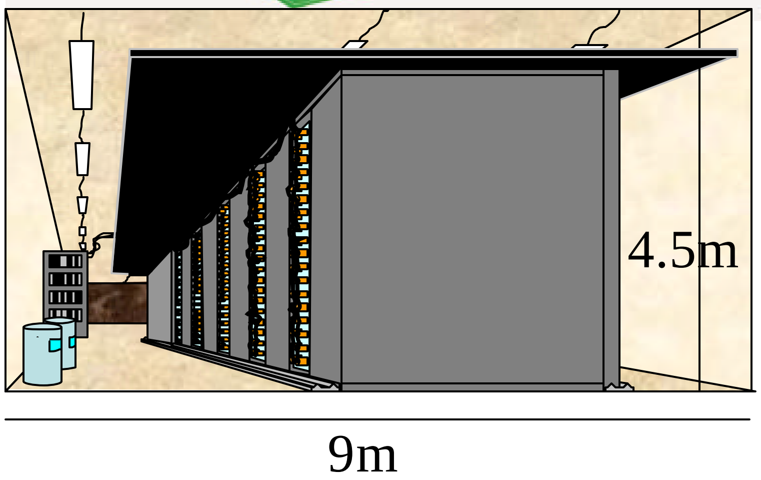
$$n_e + {}^{208}\text{Pb} \rightarrow e^- + {}^{208}\text{Bi}^* \rightarrow {}^{207}\text{Bi} + \text{n} \;\; or \;\; {}^{206}\text{Bi} + 2\text{n}$$

$$\overline{n}_e + p \rightarrow e^+ + n$$

- **1-2 decay neutrons from excited neuclei become neutrino signal.**
- **Charged particles from the reaction with protons (hydrogen nucleui) are the key to flavor identification.**

OMNIS (The Observatory for Multiflavor NeutrInos from Supernovae)





@ NM, USA

- Lead detector
  - Lead slab   2000 t
  - Lead-doped liquid scintillator ($Pb[ClO_4]_2$) 1000 t
- Feature:
  - Large volume
  - More efficient than other materials
  - Possible to identify events against background
  - Signals are first
  - Low price

Expected events

8 kpc, 2 kT	n_e	$\bar{n}_e$	n_x
No osc’	60	24	430
n_m « n_e	2450	24	340

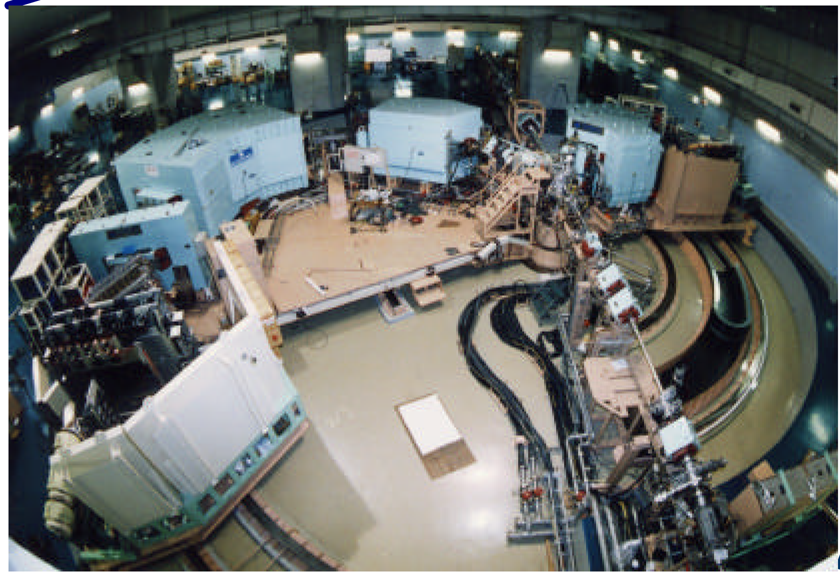
Decay Neutron Measurement from ^{208}Bi

- Energy distribution of decay neutrons as a function of excited energy of residual nuclei is necessary to be known for measuring supernova neutrinos.
- The prediction is difficult because of nuclear giant resonance, resonance width and nuclear structures.
  - ? **Need to confirm experimentaly**

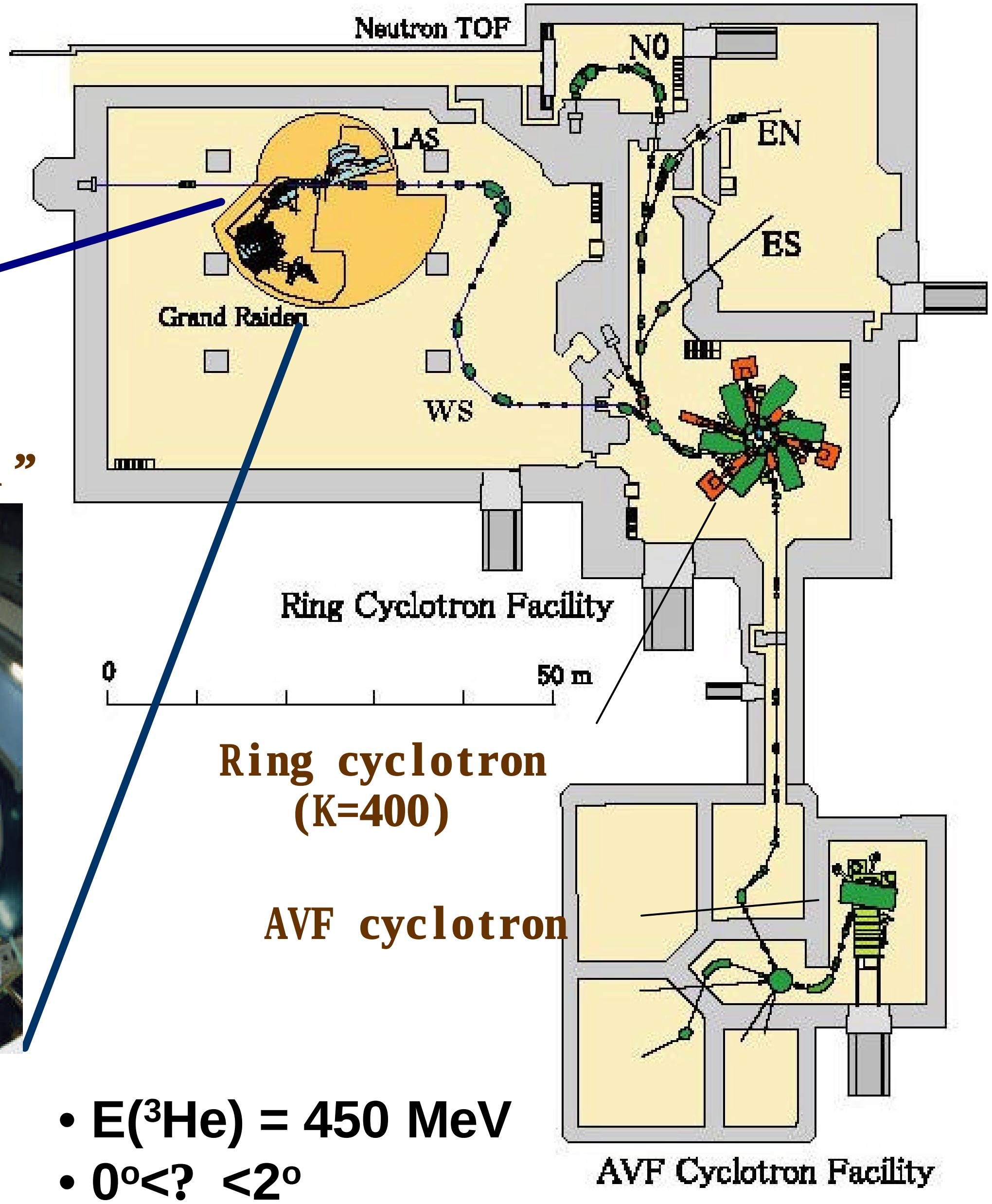
- Measuring energy distribution of decay neutron from excited ^{208}Bi via $^{208}Pb(^{3}He,t)$ reaction.
- Seeking energy distribution and neutron decay multiplicity as a function of excitation energy.

RCNP
beam course

Spectrometer
“Grand Raiden”



M. Fujiwara et al., NIM A422, 484 (1999)

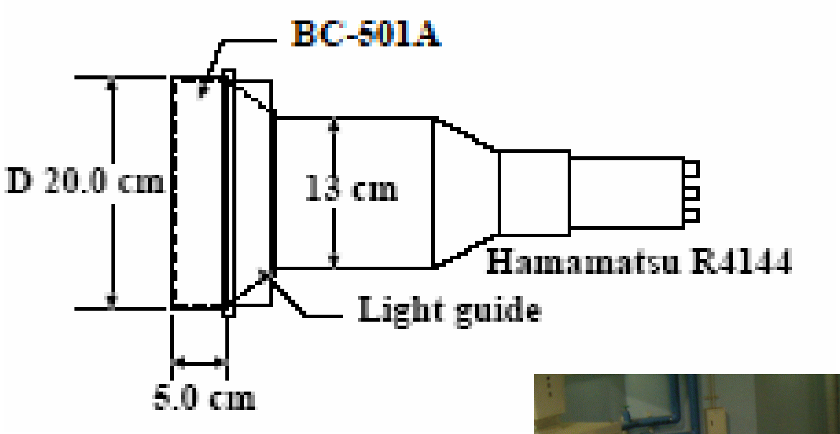


Ring cyclotron
(K=400)

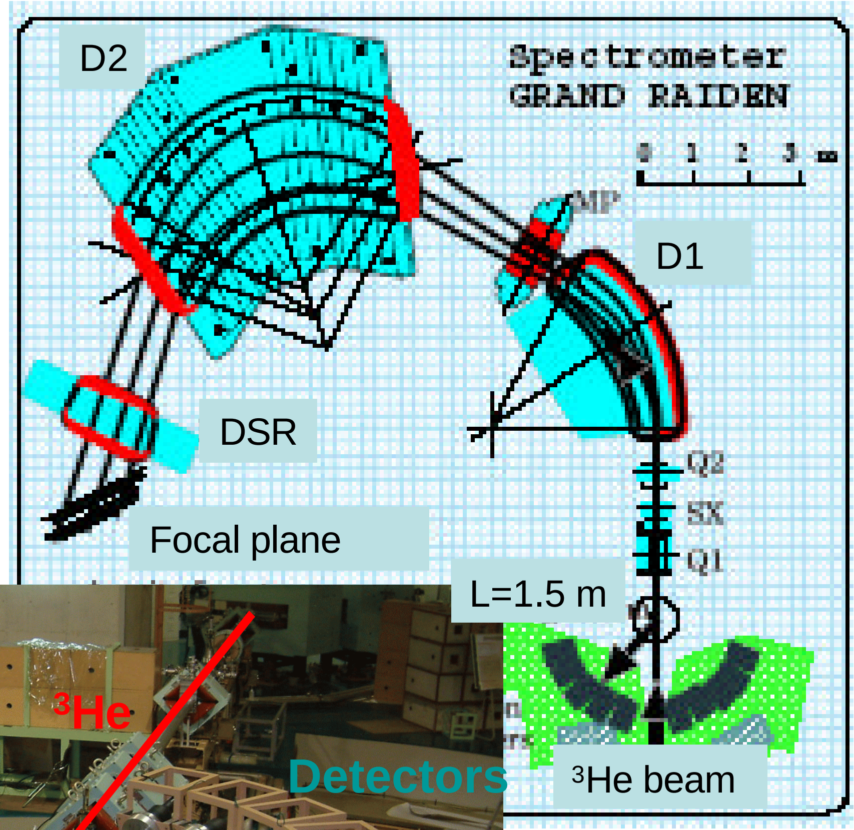
AVF cyclotron

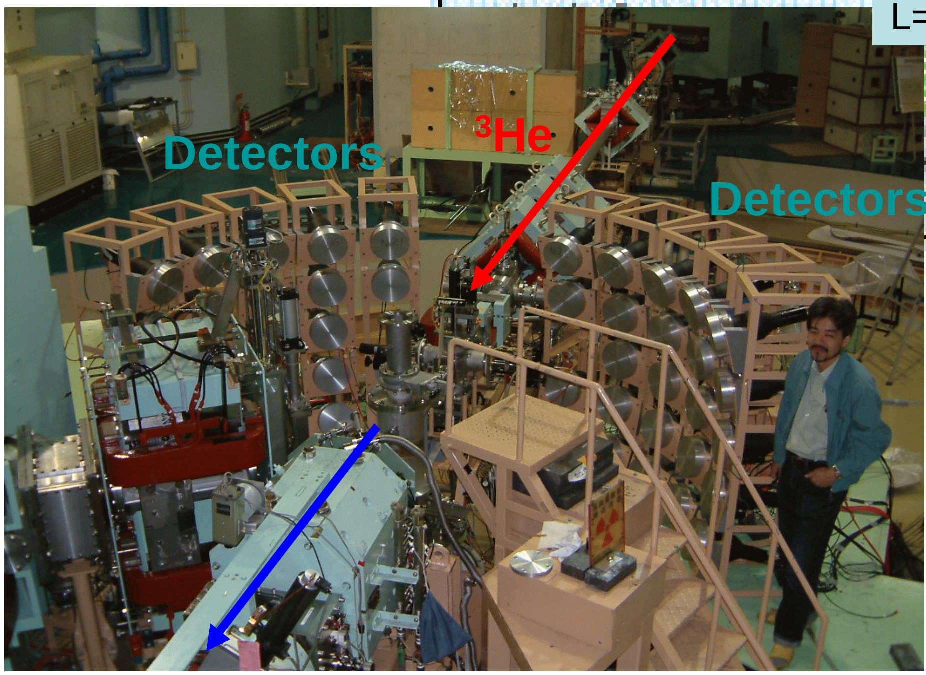
- E(^{3}He) = 450 MeV
- 0^o<? <2^o
- -5 < Ex < 32 MeV

Neutron Counter



48 Liquid
scintillators were used.





Excitation Energy Spectra

A) Singles measurement

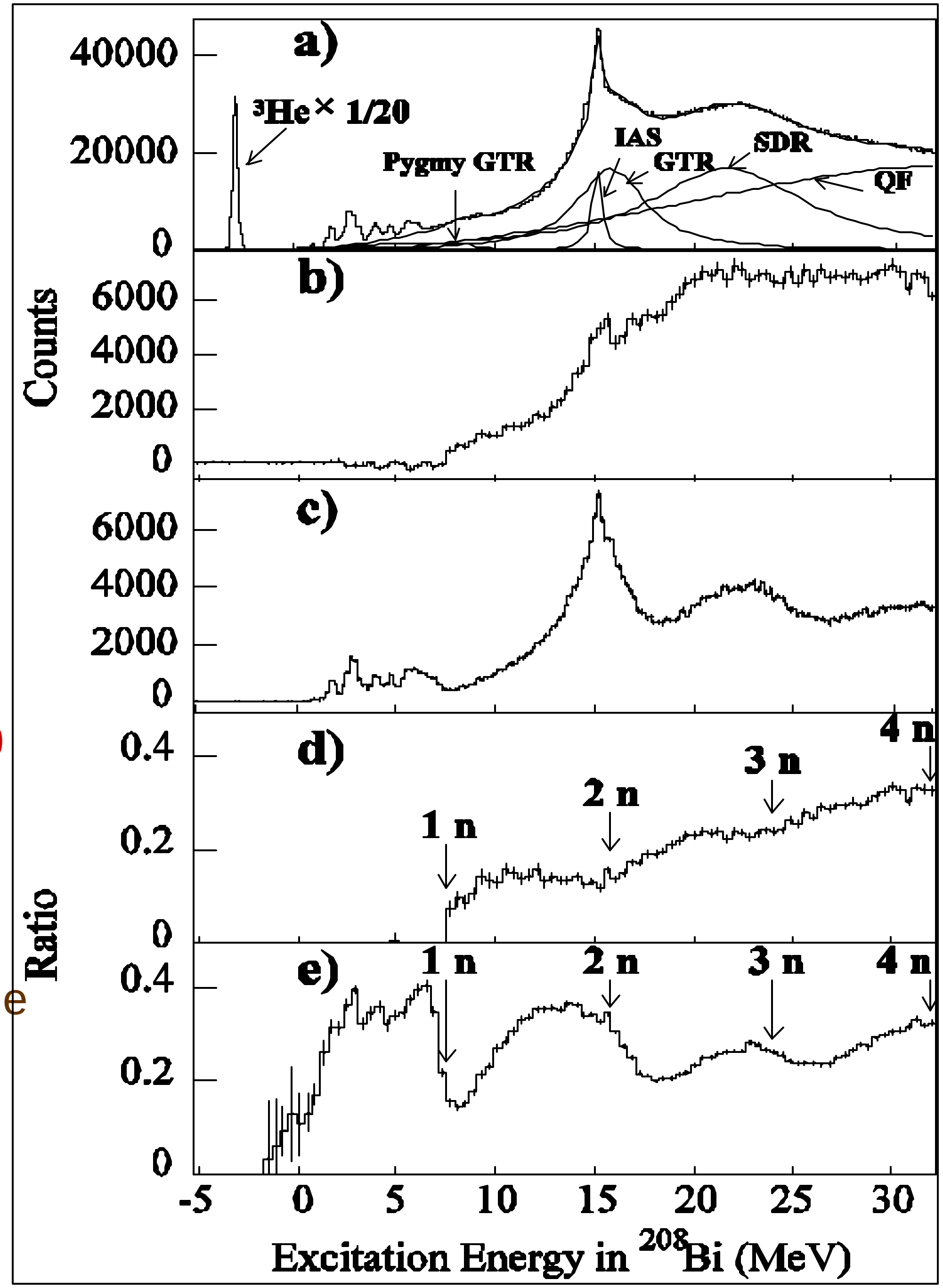
B) Neutron coincidence

C) γ-ray coincidence

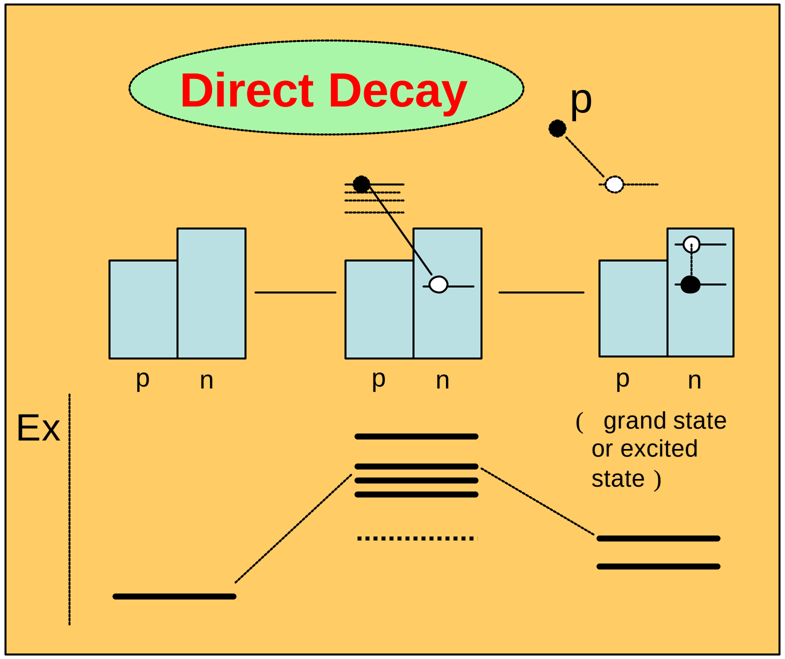
D) Decay neutron ratio

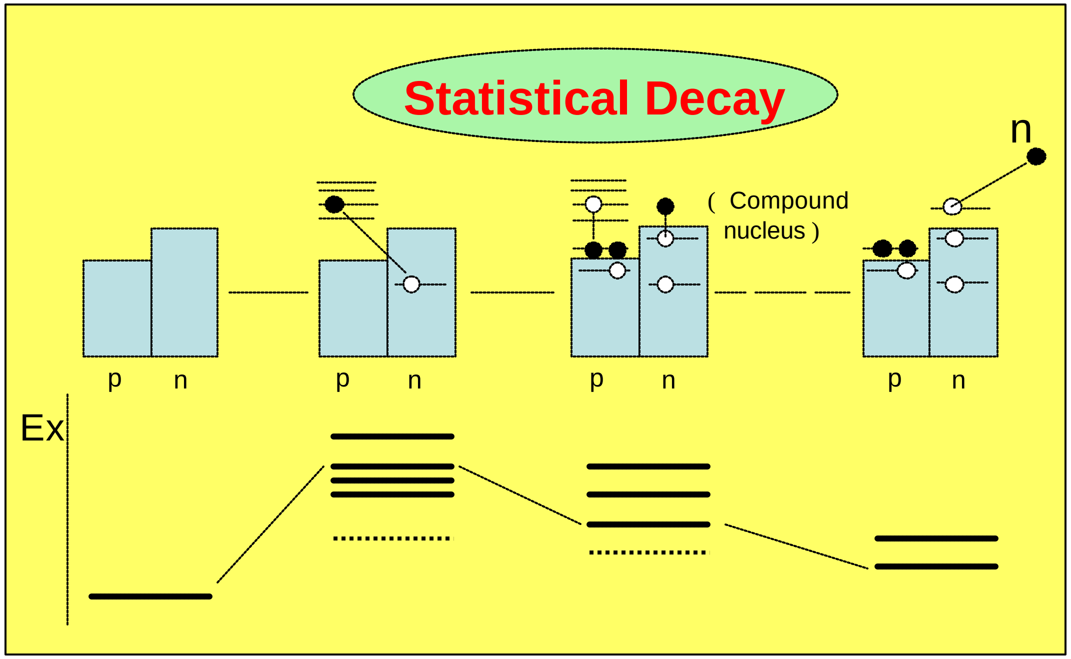
E) Decay γ-ray ratio

(Scattering angle
0º<? <2º)

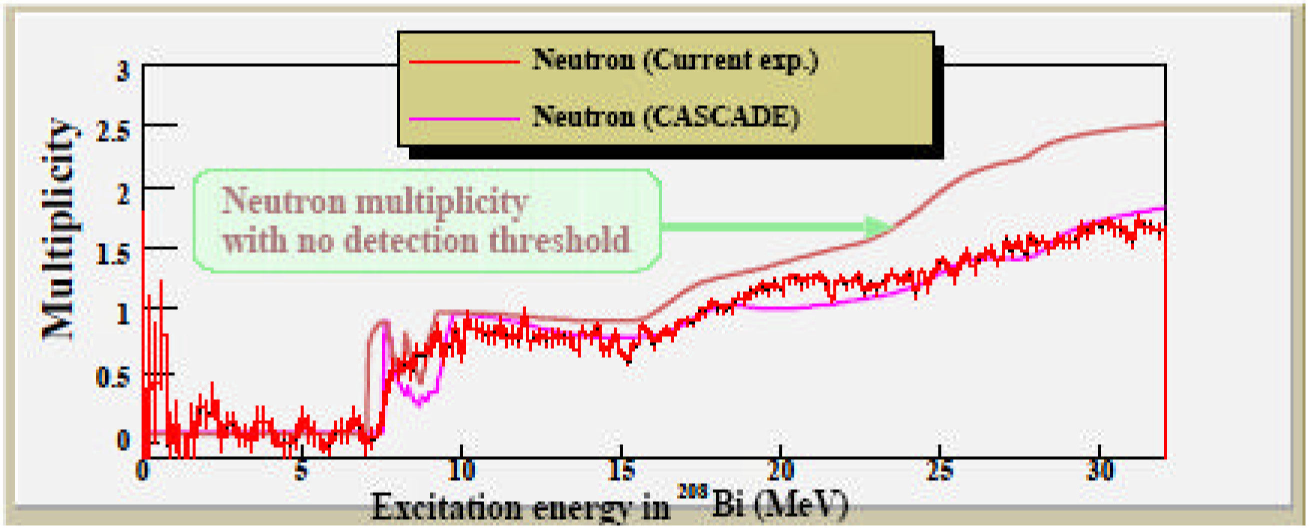


Statistical Decay and Model Calculation





- Comparison of statistical-model calculation and measurement



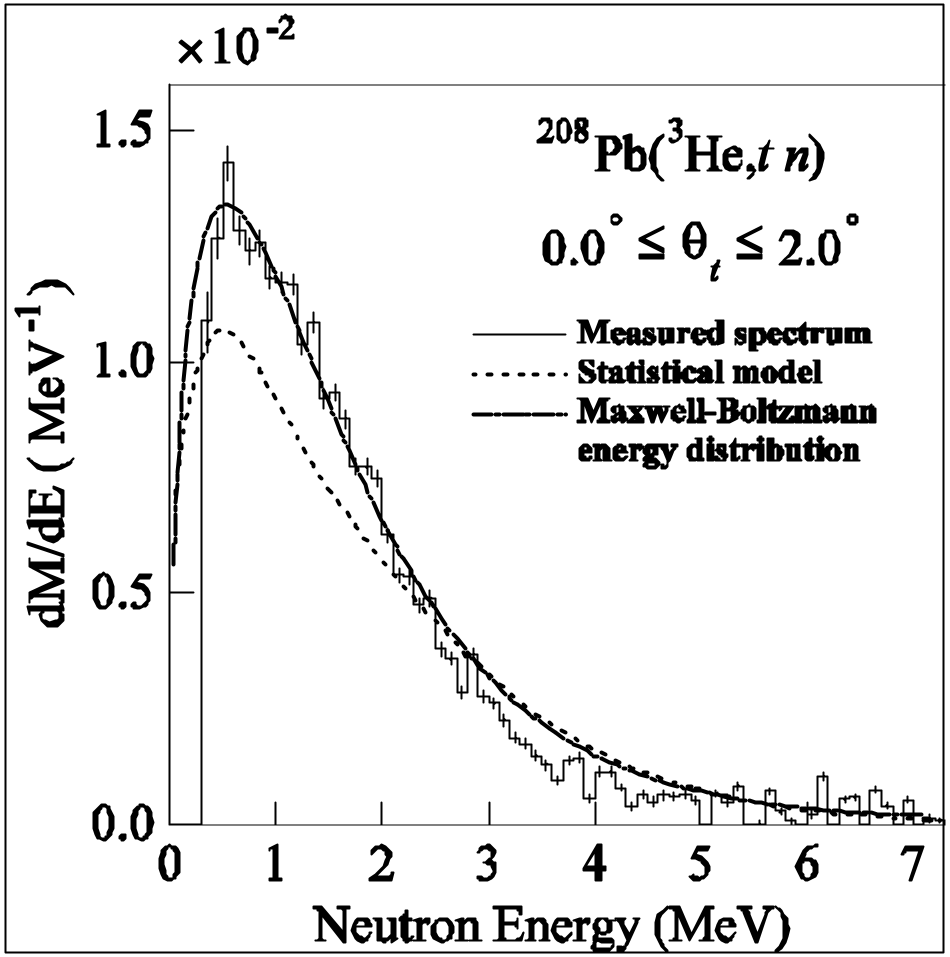
Energy Distribution of Decay Neutron

- Energy distribution has a global agreement with statistical-model calculation.
- As fitting by using Maxwell-Boltzmann distribution function in nucleus,

$$f(E) \propto E \exp(-aE)$$

the center energy became

1.0 $\pm$ 0.1 MeV.

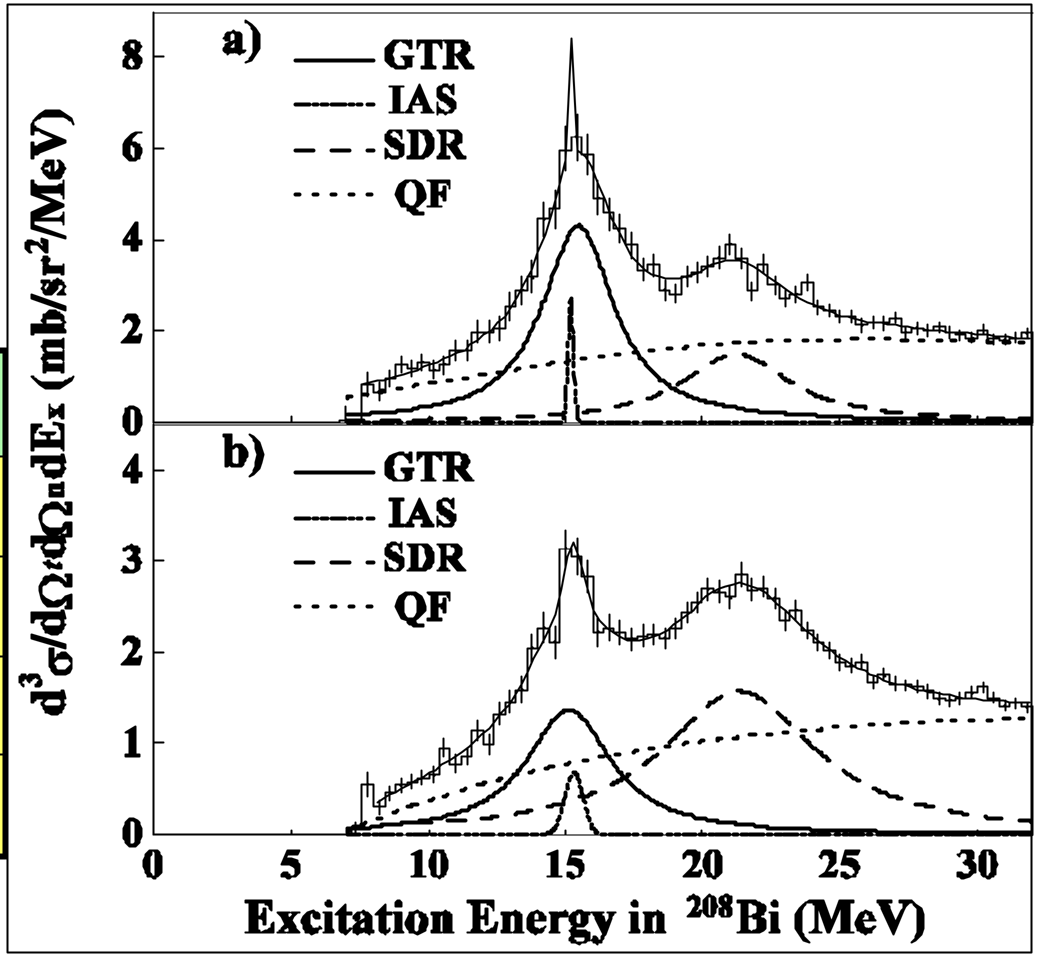


Coincidence Spectra

A) Scattering angle
   0º<? <1º

B) Scattering angle
   1º<? <2º

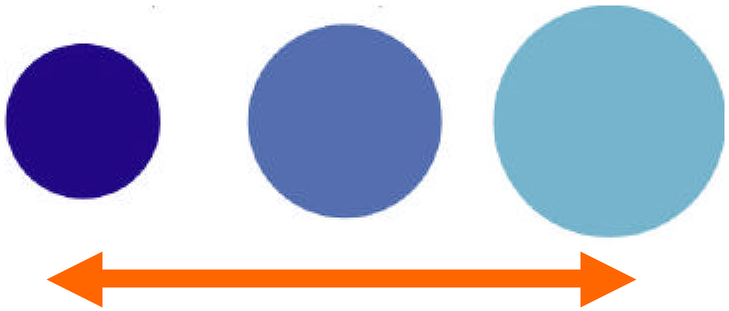
resonance	E_0 (MeV)	CS (mb/sr² /MeV)	G? (MeV)
GTR 0º -1º	15.3 ± 0.1	18.9 ± 1.6	3.3 ± 0.5
GTR 1º -2º		7.7 ± 0.7	3.6 ± 0.7
SDR 0º -1º	21.3 ± 0.2	10.9 ± 0.8	4.8 ± 0.9
SDR 1º -2º		16.8 ± 1.2	6.8 ± 0.7



Conclusion

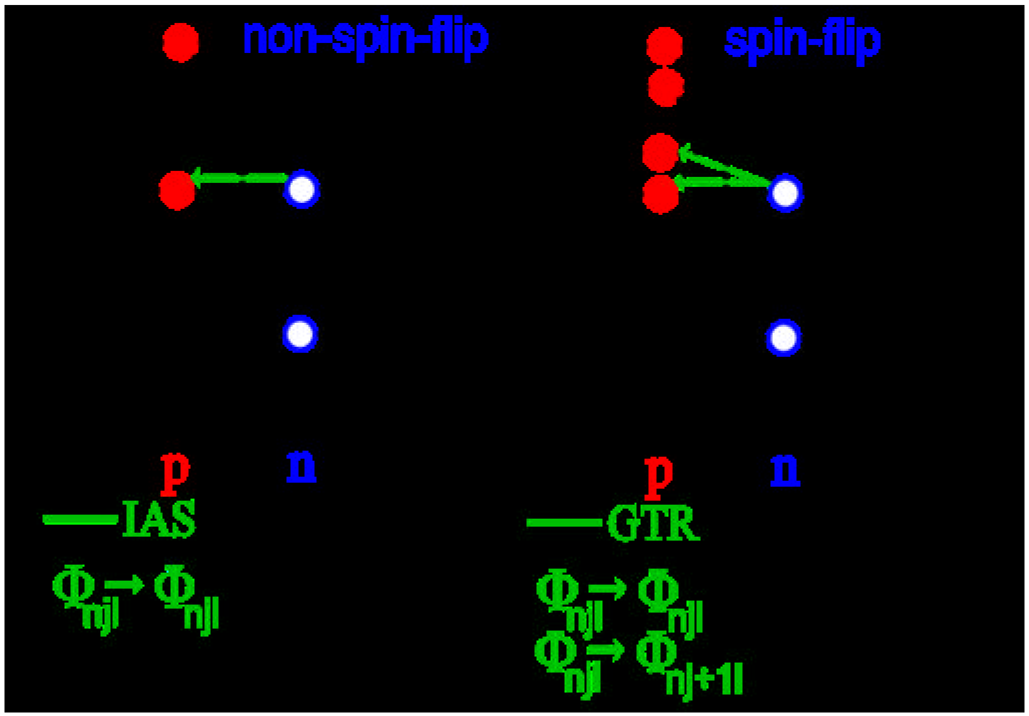
- Measured the energy spectrum of excited ^{208}Bi, decay neutron and decay γ-ray coincidence caused by charge-exchange reaction in intermediate energy.
- Particle decay thresholds and energy distribution of decay neutrons had good agreement with statistical-model calculation. The average energy of neutrons were 1.0 ± 0.1 MeV.
- Obtained neutron decay cross section from giant resonances.
- The energy distributions of neutron are managed as input parameters for neutrino observation facility to deduce neutrino energy distributions, flaxes and time expansion.

Giant Monopole Resonances (GMR)



Kinds of nuclear giant resonance
with ΔL=0

They are classified to ISGMR (ΔS=0 ΔT=0)
IVGMR (ΔS=0 ΔT=1)
IVSGMR (ΔS=1 ΔT=1)



$$\hat{O} = r^{l}[s \otimes Y_L]_J t_z$$

IVGMR : l=2 L=0 J=0

IVSGMR : l=2 L=0 J=1

Current Status of IV(S)GMR research

IVGMR

- (p^-, p^o) Erell *et al.* PRL 52,2134
  Irom *et al.* PRC 34,1822
- ^{60}Ni(^{7}Li,^{7}Be) Nakayama *et al.*
  PRL 83,690
- (p^+, p^o) Erell *et al.* PRL 52,2134
  Irom *et al.* PRC 34,1822
- ^{90}Zr(n,p) Ford *et al.* PLB 195,311
- (^{13}C,^{13}N) Bérat *et al.* NPA 555,455
  Lhenry *et al.* NPA 599,245c
  Von Oertzen NPA 482,357c
- ^{124}Sn(^{3}He,*tn*) Zegers *et al.*
  PRC 61, 054602

IVSGMR

- ^{208}Pb(^{3}He,tp) 410 MeV
  Zegers *et al.* PRL 90, 202501.
- Pb(^{3}He,*tp*) 177 MeV
  Zegers *et al.* PRL 84,3779/PRC 63, 034613 (IVGMR?? No final state info)
- ^{90}Zr(^{3}He,t) 600/900 MeV
  Ellegaard *et al.* PRL 50, 1745
  Auerbach *et al.* PLB 219, 184
- $(\bar{p},\bar{n})$ at 200/800 MeV
  D.L. Prout *et al.* PRC 63, 014603
- ^{60}Ni(^{7}Li,^{7}Be) Nakayama *et al.*
  PRL 83,690

Legend:
- (red) evidence found
- (magenta) ambiguous
- (blue) no evidence

$^{90}Zr(^{3}He,t+p)$ experiment

Following to $^{208}Pb(^{3}He,t+p)$ experiment

Aim：

Obtaining more systematic view of IVSGMR through the measurement in ^{90}Nb via $^{90}Zr(^{3}He,t+p)$ coincidence experiment.

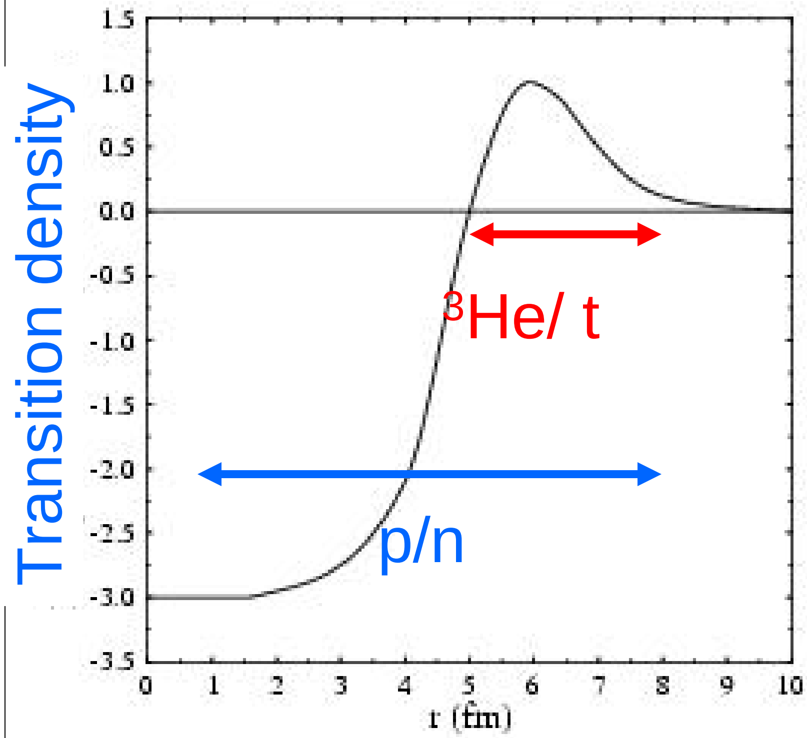
- The measurement for ^{90}Zr target enables us to deduce the direct relationship of the Gamow-Teller (GT) strength shifted to high excited states.
- Deep-hole states in the final spectrum in $^{208}Pb(^{3}He,t+p)^{207}Pb$ were confirmed.

Verifying whether the same phenomenon is seen in ^{90}Zr target.

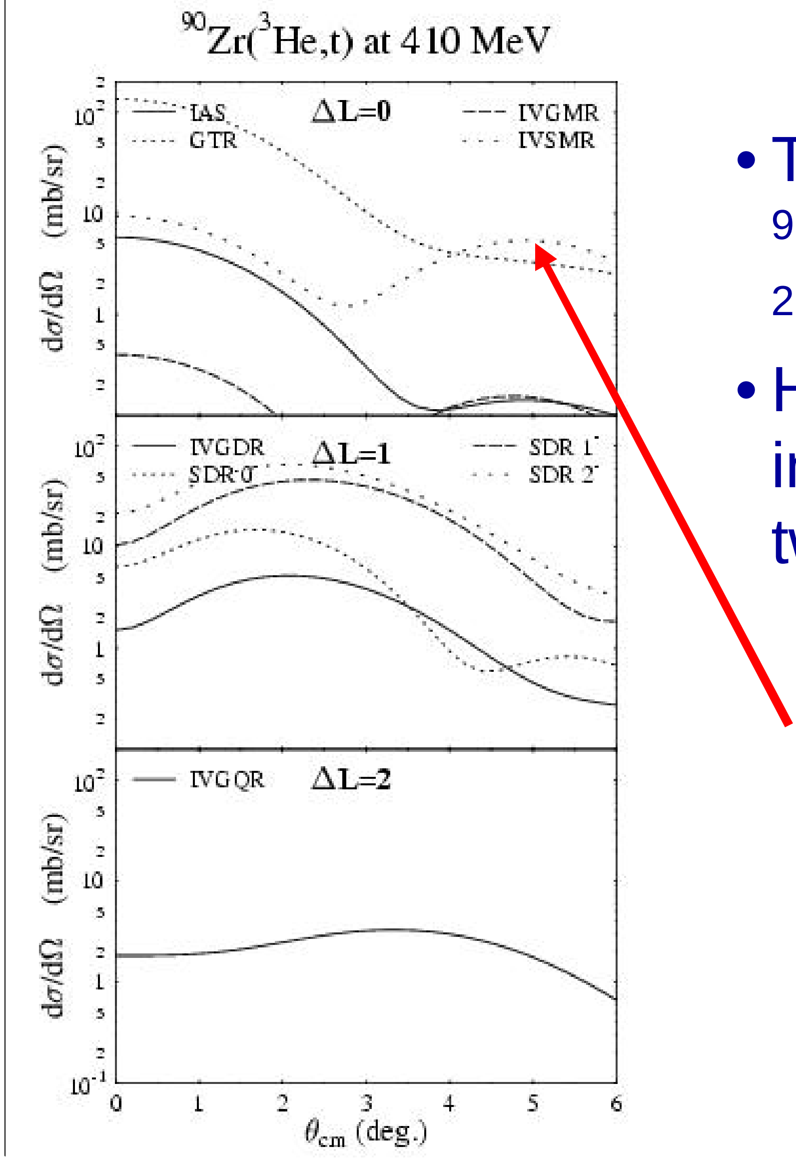
(^{3}He,t)/(t,^{3}He) reaction is more effective than (p,n)/(n,p) reaction to excite IVSGMR

- ^{3}He & t become the probe near the surface of nuclei.

- p & n cause the reaction in whole volume: Strength cancellation



Cross Section (DW81)

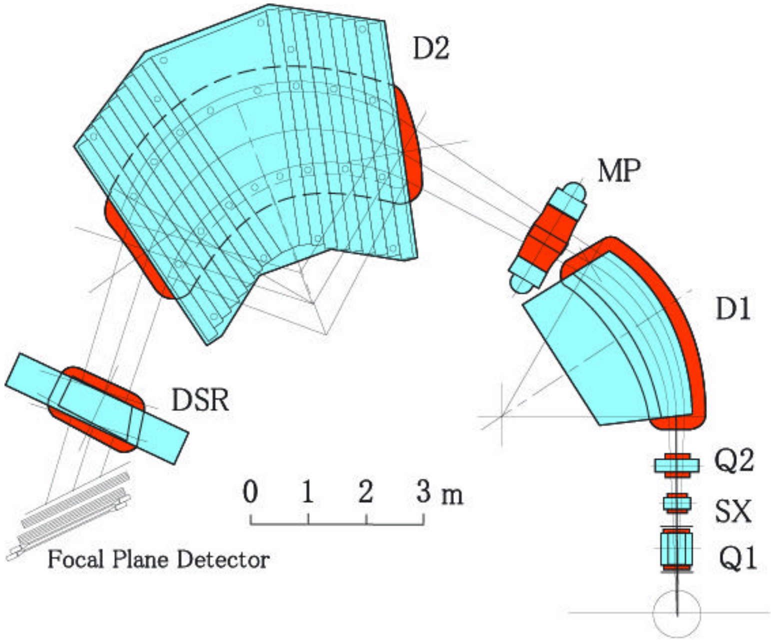


- The cross section of IVSGMR in ^{90}Nb is about 50% compared to ^{208}Bi.
- However, the number of nucleus in unit thickness is more than twice to ^{208}Bi.

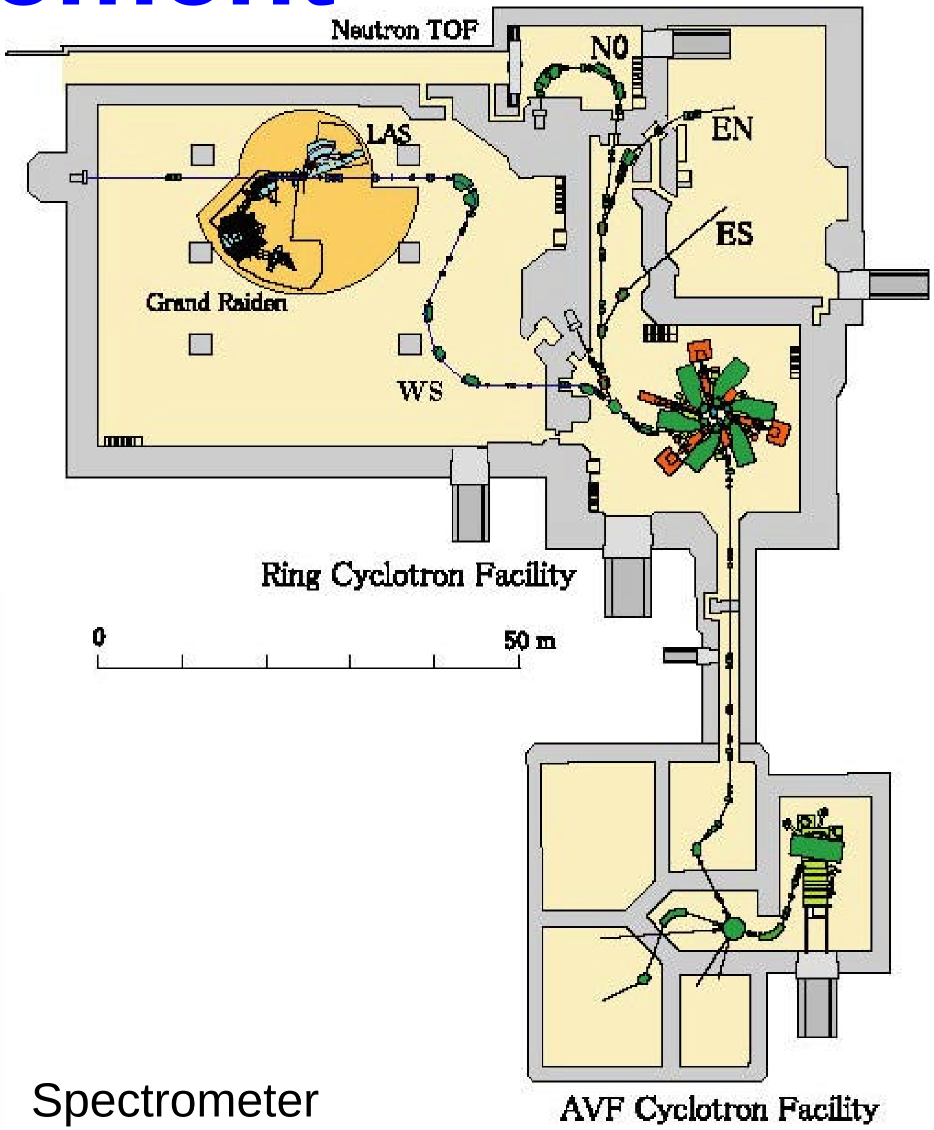
High second maximum

Experiement

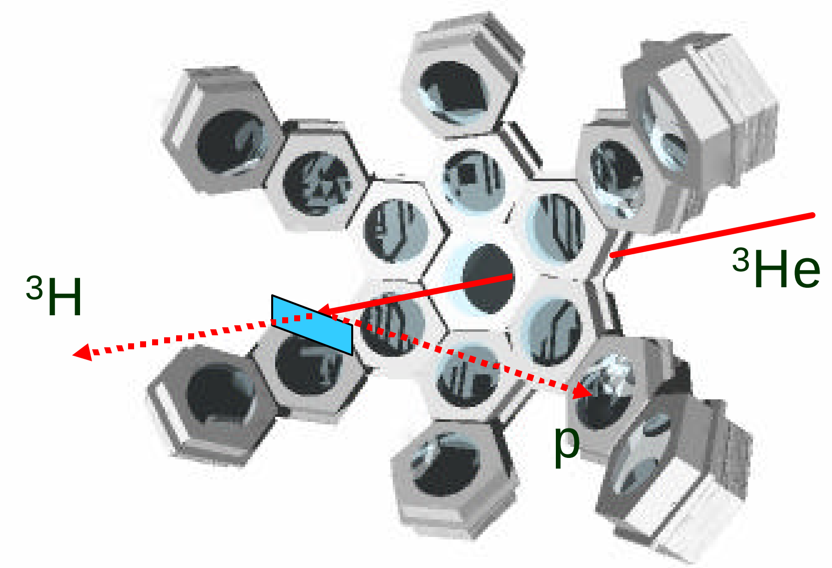
- Cyclotron facility, RCNP
  K=400 MeV Ring cyclotron
  Grand Raiden spectrometer
- Beam：
  $^{3}He^{++}$, 420 MeV
- Target:
  ^{90}Zr 7.3 mg/cm



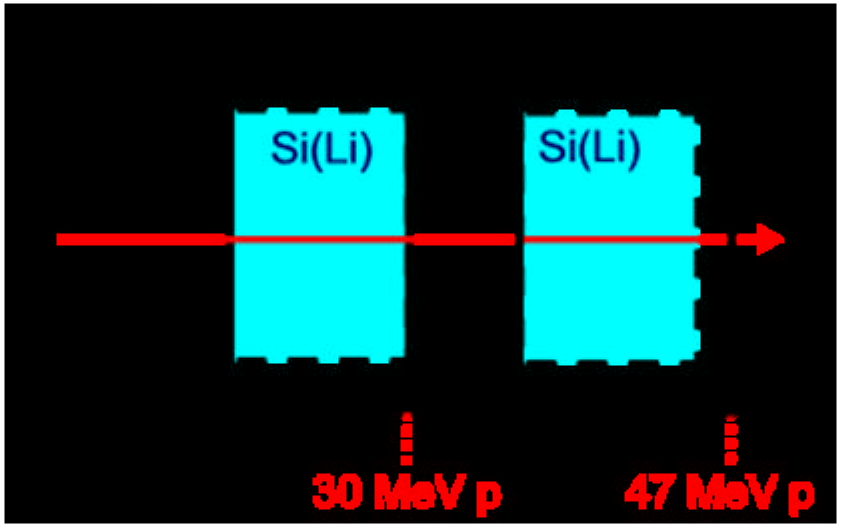
Spectrometer
Grand Raiden



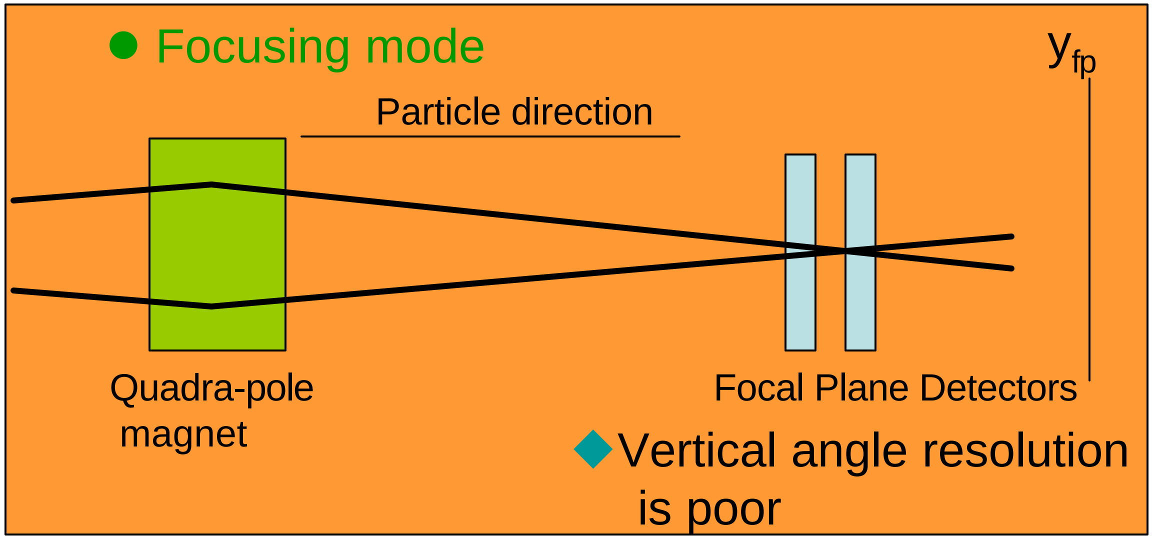
Decay Proton Detector:
Particle energy measurement over 30 MeV

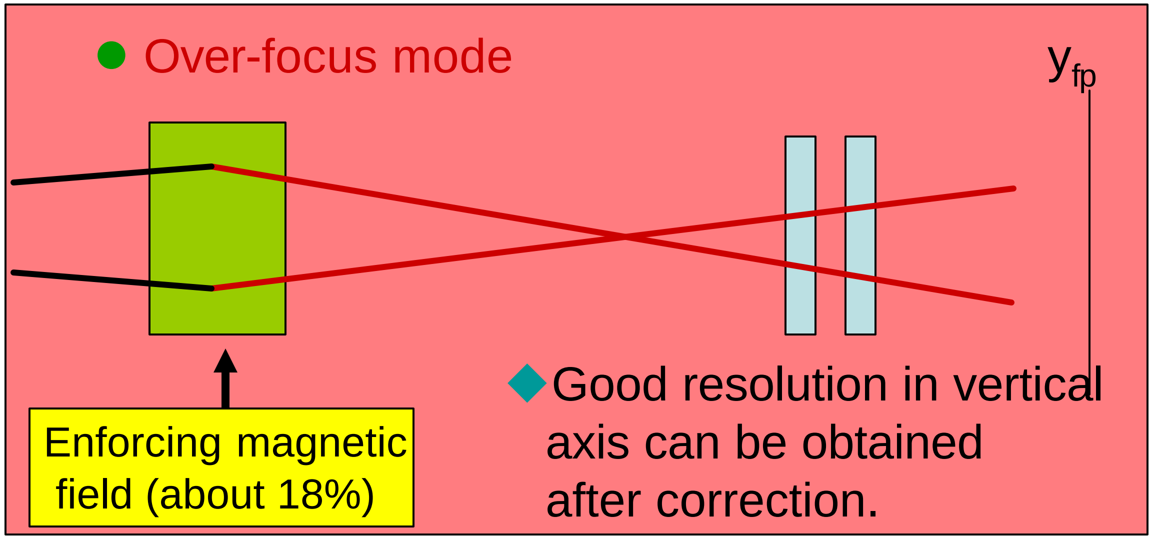


- 8 DE-E telescopes

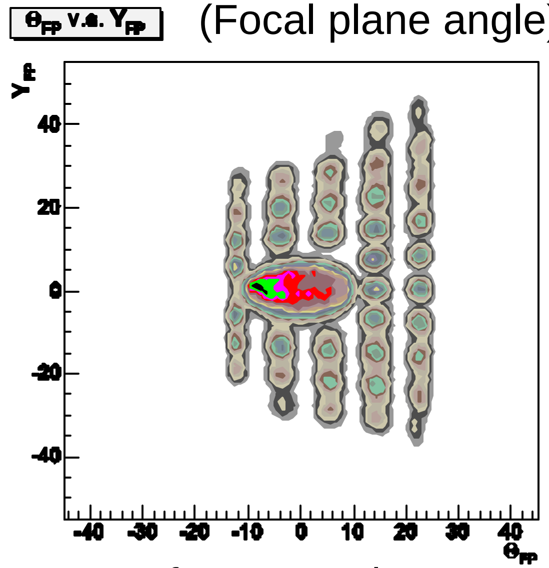


Over-focus mode

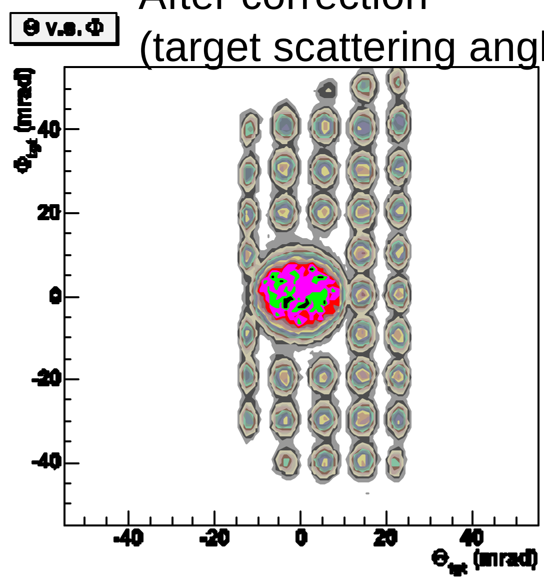




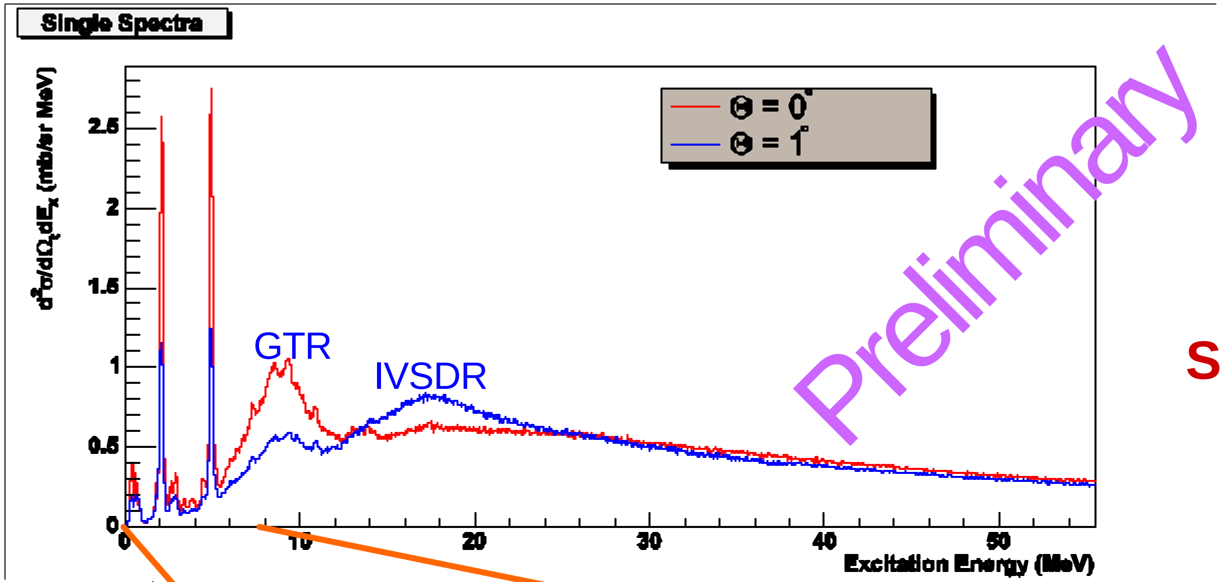
Before correction
(Focal plane angle)

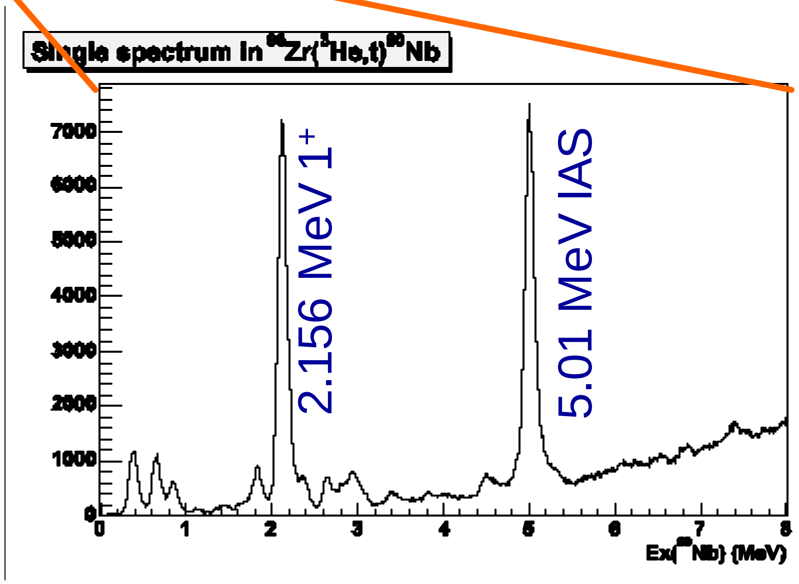


After correction
(target scattering angle)



Singles Spectra





Singles

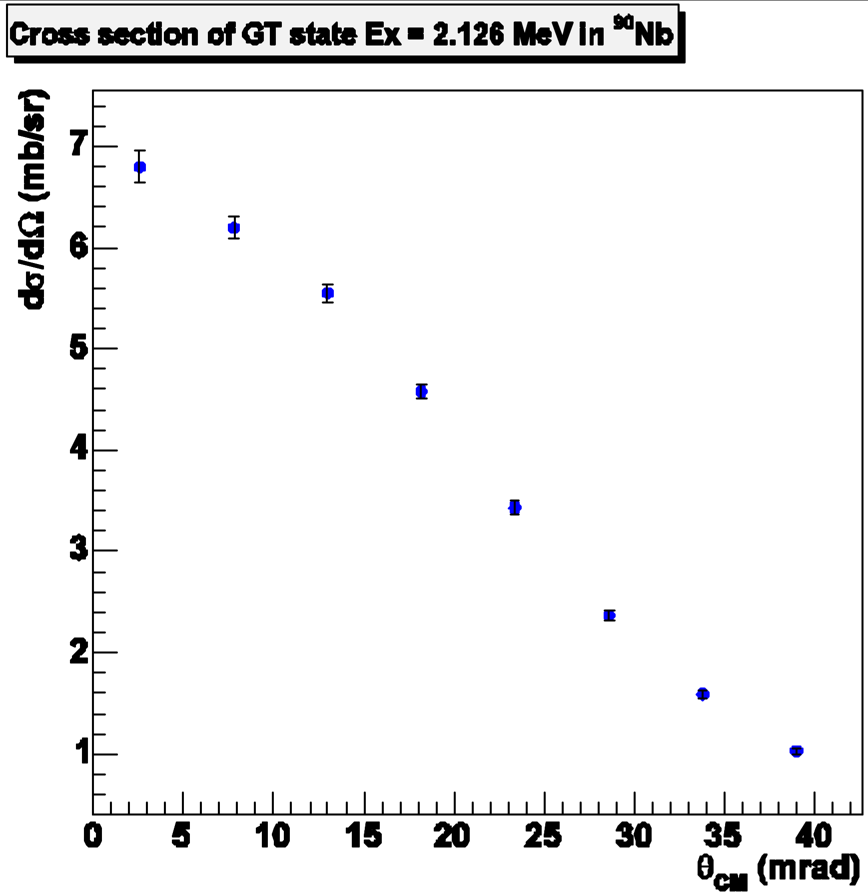
Two distinguished peaks

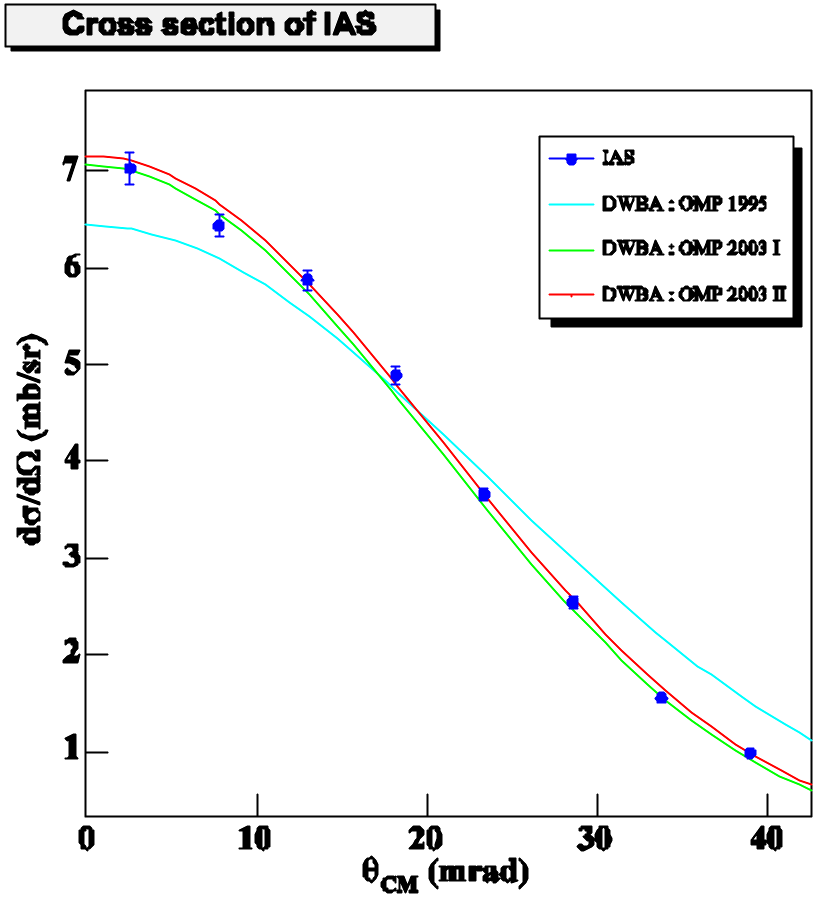
GTstate (J^p =1⁺ Ex=2.156 MeV)

and

IAS (J^p =0⁺ Ex=5.01 MeV)

Angular Distribution of IAS and GT state





Optical model potential : T. Yamagata *et al.* (1995).

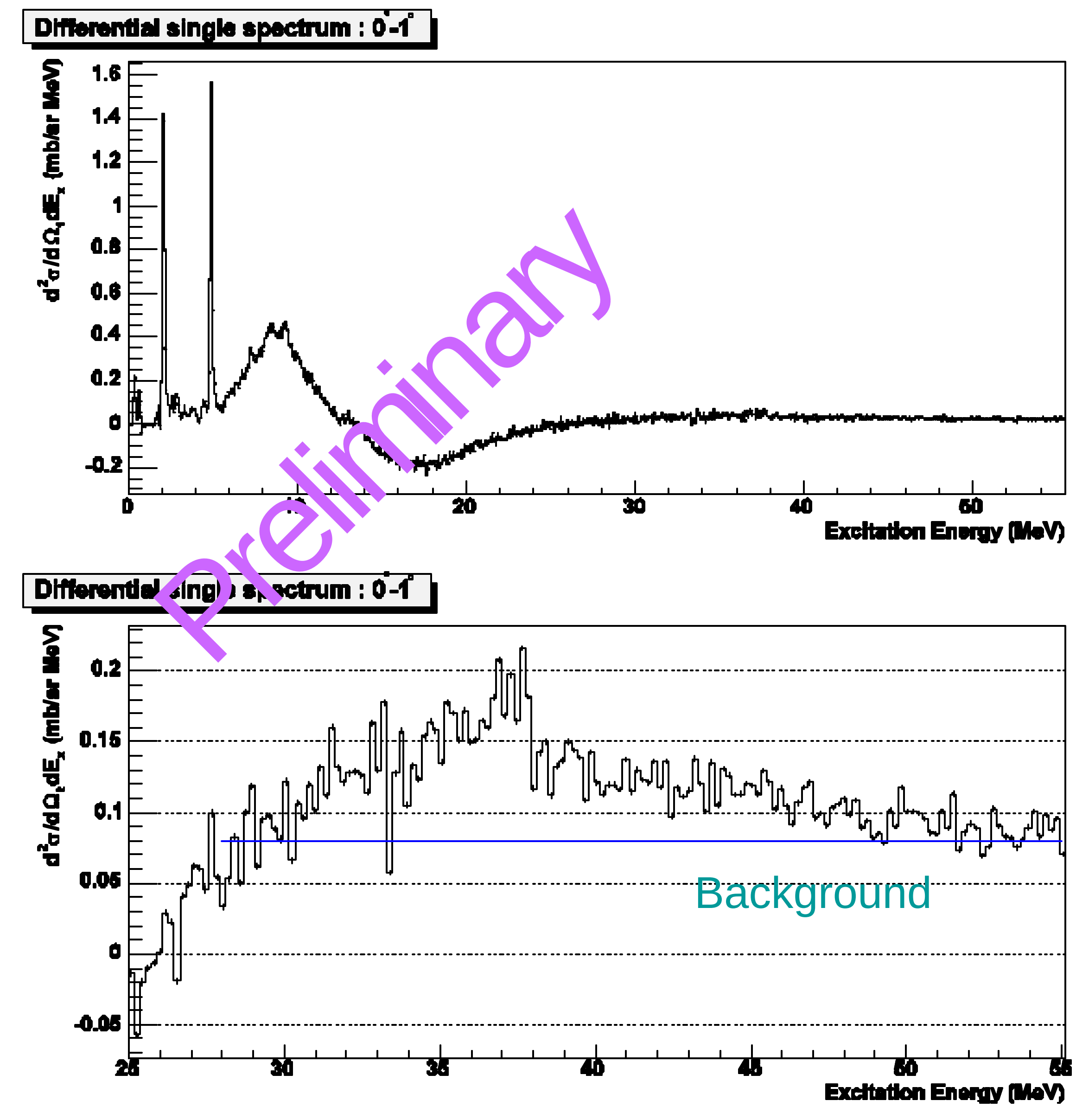
J. Kamiya *et al.* (2003).

Shell-model calculation : Model space SLGT (only $2p_{1/2}$ and $1g_{9/2}$)

Interaction SLGT0

(Herndl and Brown, NPA627, 35 (1997))

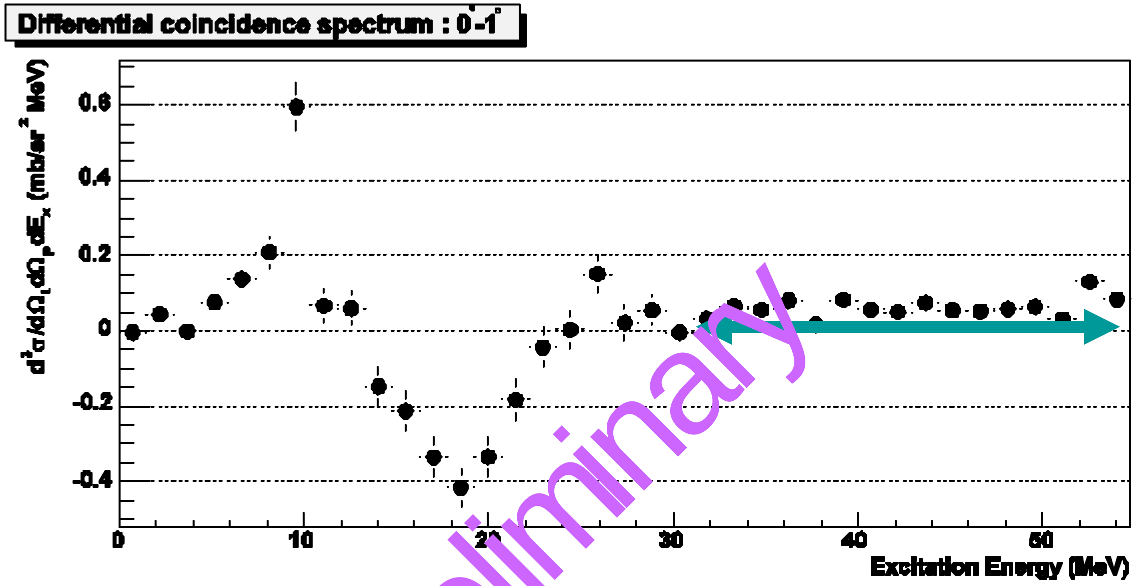
The singles differencial spectrum between forward and backward scattering



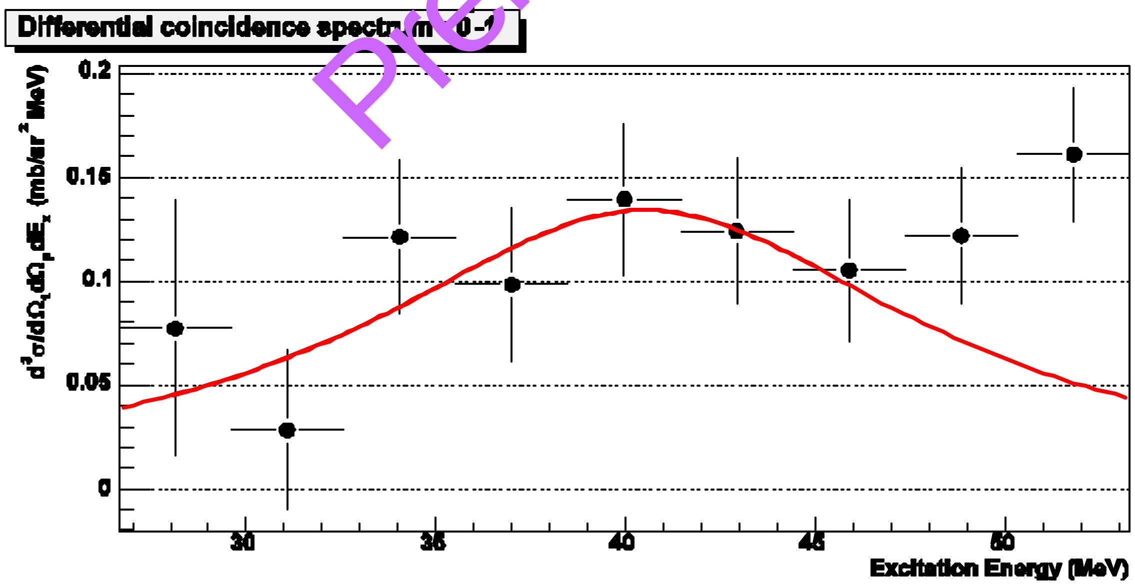
The difference between
Θ = 0 ° and 1 ° singles spectra

Wide peak around
Ex = 30 - 50 MeV

The coincidence differential spectrum between forward and backward scattering



The difference between θ= 0 ° and 1 ° coincidence spectra.
A forward peak around 40 MeV
Appeared additionally to GTR and SDR.



? Expansion

Ex ~ 40 MeV

Conclusion

- Measured excitation spectrum of ^{90}Nb and proton decay coincidence by using ^{90}Zr(^{3}He,*t*) reaction if E(^{3}He) = 140 MeV/u.
- Over-focusing method in the spectrometer was performed to obtain better resolution in vertical direction at aroud 0 degree measurements.
- The angular distribution of IAS and GT state (Ex=2.156 MeV) were obtained and DWBA calculation had good agreement with IAS distribution.
- The IVSGMR is likely to exist in ^{90}Nb. The detail results are under analysis.