The γ production from Giant Resonances of Carbon/Oxygen at Low Energy (10-100MeV) and Importance to Supernova Physics

Makoto Sakuda (Okayama) @EILH 2016

5 November, 2016

Outline

1. Introduction and SK-Gd Project
2. Feature of Neutral-Current (NC) ν-O,C γ-production
3. Neutral-Current (NC) ν-O,C γ-production
4. RCNP E398 C,O(p,p') experiment
5. Summary
6. A Few Photos of Prof. Singh working on NuInt/NuSTEC Collaboration (2001-)

1. Key Words from Prof. Kajita's talk

- Neutrino Oscillation Experiments and Neutrino Astrophysics need more "Precision" to enjoy the further discoveries.

- Precision in Interaction of Neutrino and Hadrons (= Neutrino-Nucleus Interactions).

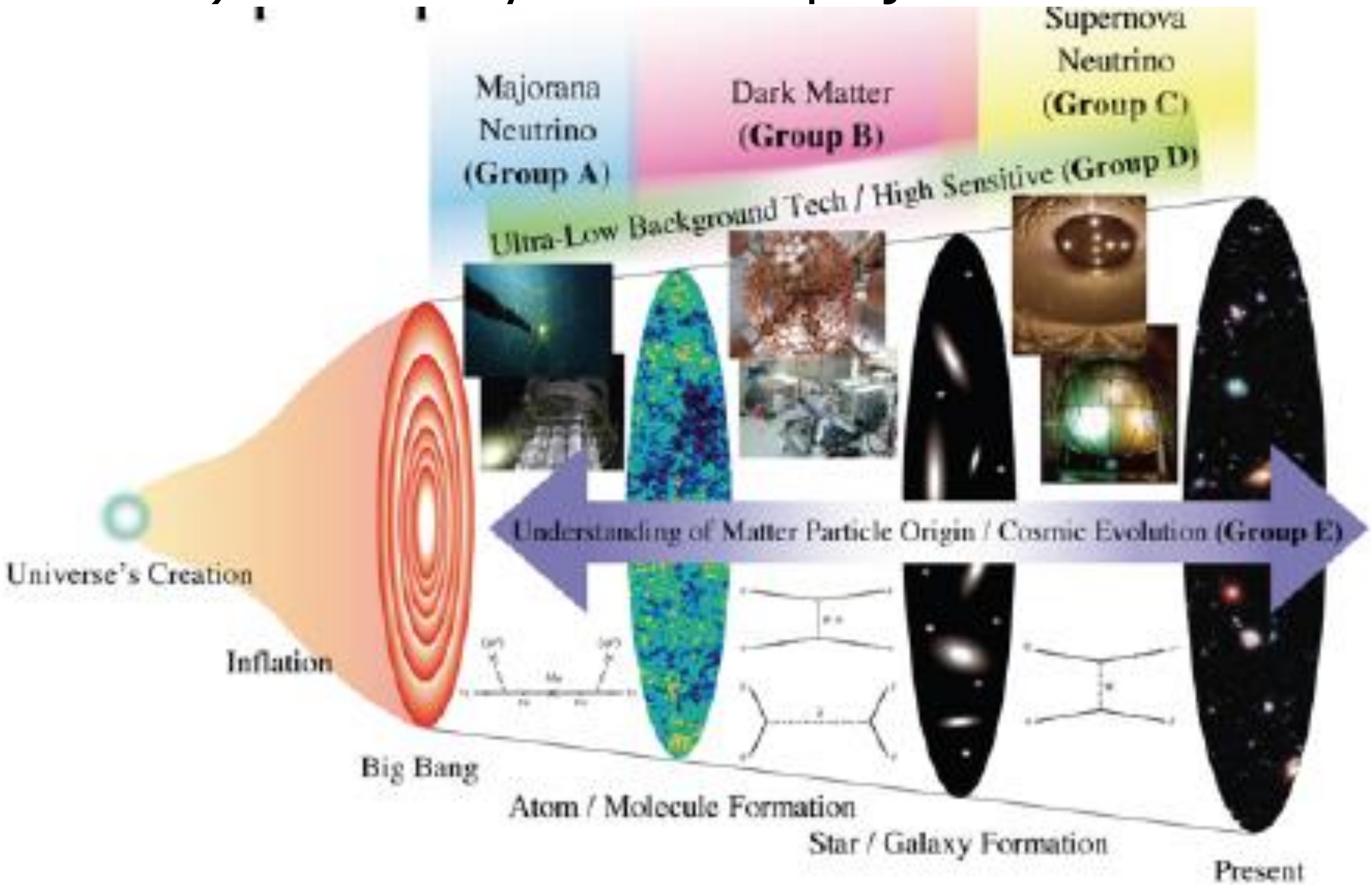
- Since Many previous speakers already discussed about the importance of Precision of neutrino-nucleus interactions to neutrino oscillation experiments, mainly the discovery of CPV and IH/NH,

I will present a part of the activities on neutrino-nucleus interactions, relavant to Supernova Neutrino Detection.

2. SK-Gd Project

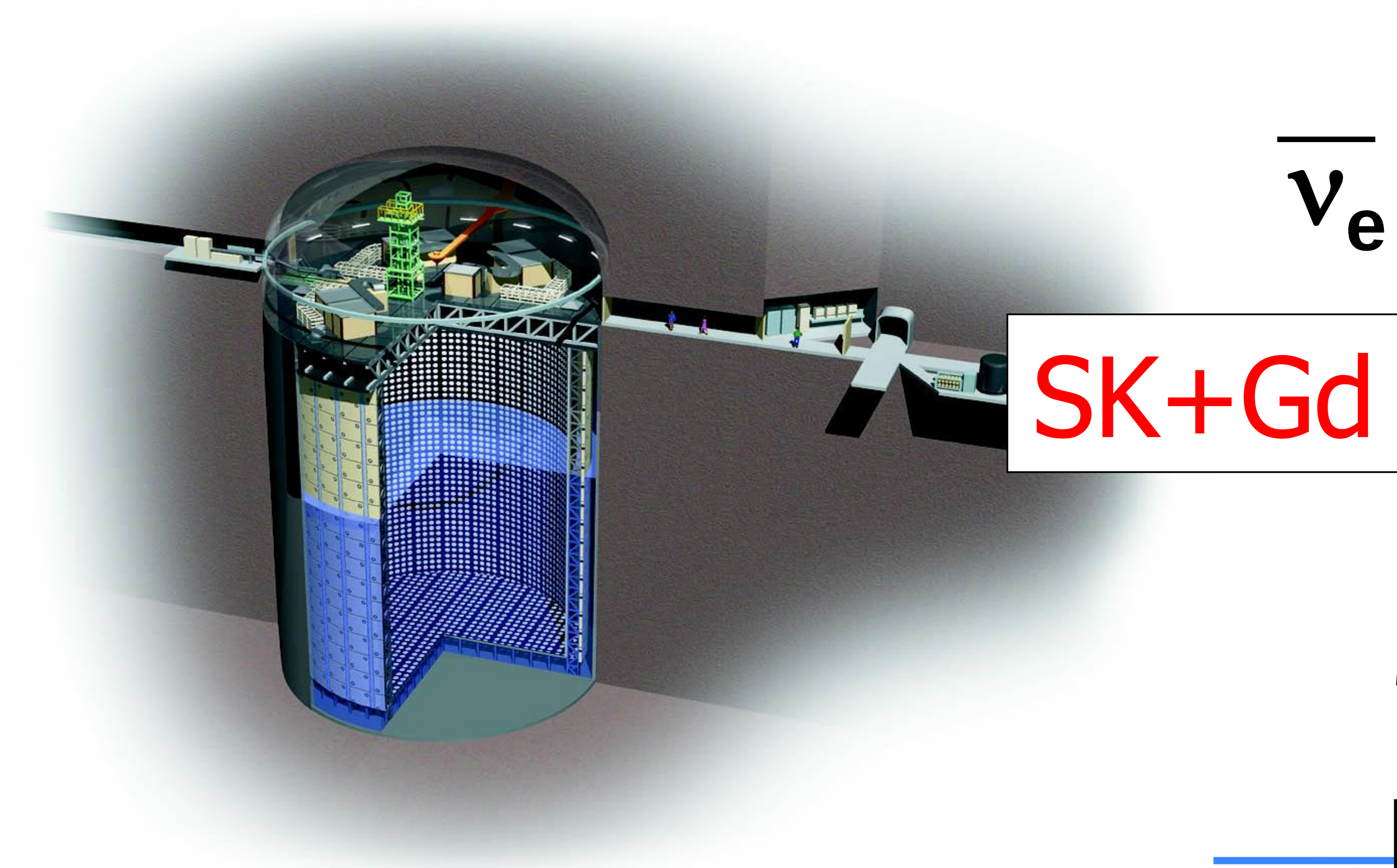
→For Recent Progress, please refer to H.Sekiya @ Neutrino2016.

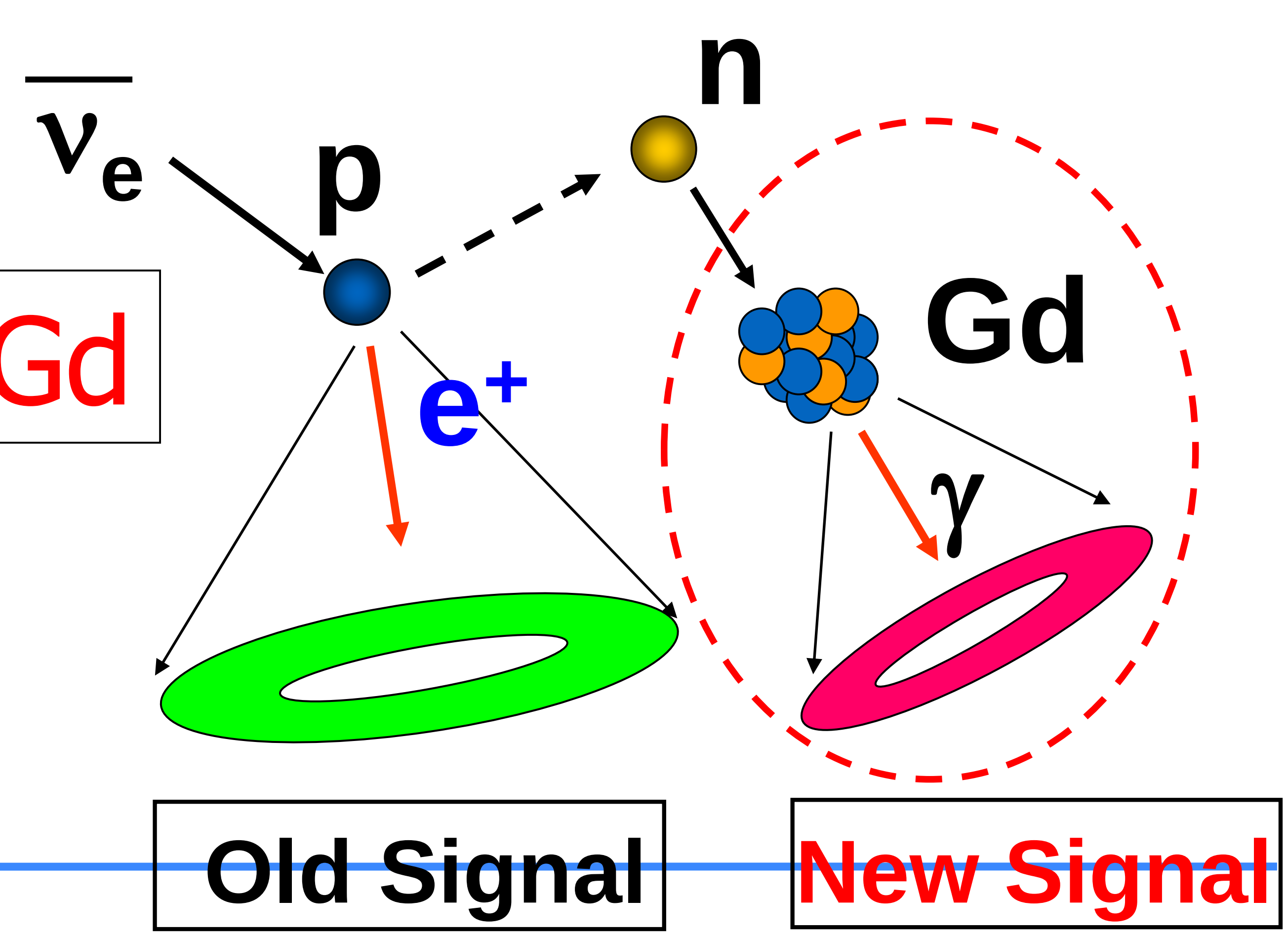
- All KAMIOKA Underground Experiments (KamLAND, Candles, XMASS, Newage, SK-Gd) work together to "Reveal The History of The Universe with Underground Particle and Nuclear Research" (JSPS Grant-In-Aid, Innovative Area, 2014-2018, PI Prof. K.Inoue (Tohoku)).
- SK-Gd Project is supported by JSPS Specially Promoted Research (2015-2019, PI Prof.M.Nakahata) and also by the above project.



SK-Gd Project
To Observe Supernova Relic Neutrinos (SRN)

- SRN Rate：0.8～5 events (Ee=10-30MeV),
  0.3 -1.9 events (Ee=18-30MeV)
- The project approved by Super-K Collaboration





H.Sekiya @ Neutrino 2016

SK & T2K Joint Statement on "SK-Gd"

- Jan.30, 2016

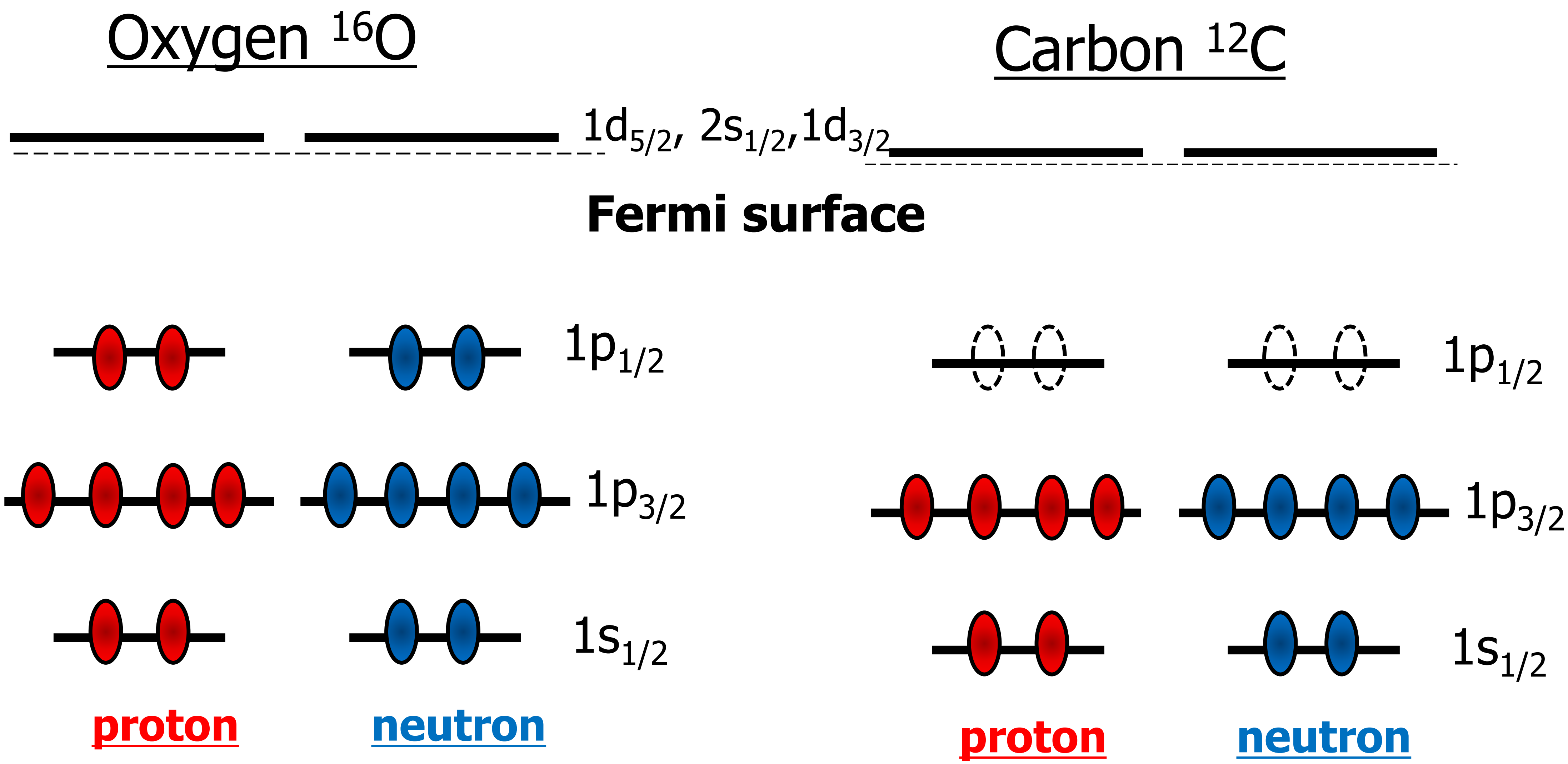
On June 27, 2015, the Super-Kamiokande collaboration approved the SK-Gd project which will enhance neutrino detectability by dissolving gadolinium in the Super-K water.
T2K and SK will jointly develop a protocol to make the decision about when to trigger the SK-Gd project, taking into account the needs of both experiments, including preparation for the refurbishment of the SK tank and readiness of the SK-Gd project, and the T2K schedule including the J-PARC MR power upgrade. Given the currently anticipated schedules, the expected time of the refurbishment is 2018.

Do you know oxygen or carbon?

- Shell Model
- Spectral Function Approach
- Collective Excitation (Giant Resonance)

Oxygen and Carbon (Shell Structure)

- You learn a single particle model or a shell model in nuclear physics.
- Shell structure of ^{16}O and ^{12}C.



Spectral Function S(p,E) for ^{16}O

O.Benhar et al., PRD72,053005,2005.

S(p,E) : Probability of removing a nucleon of momentum (p) from ground state leaving the residual nucleus with excitation energy (E).

O(e,e'p)

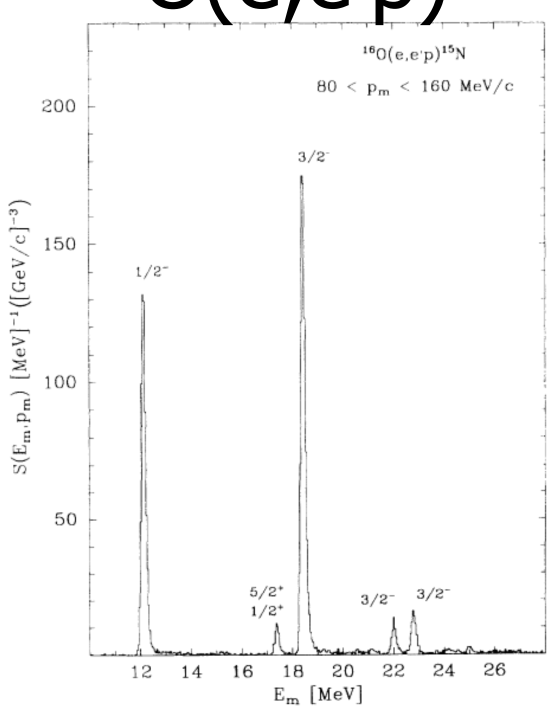
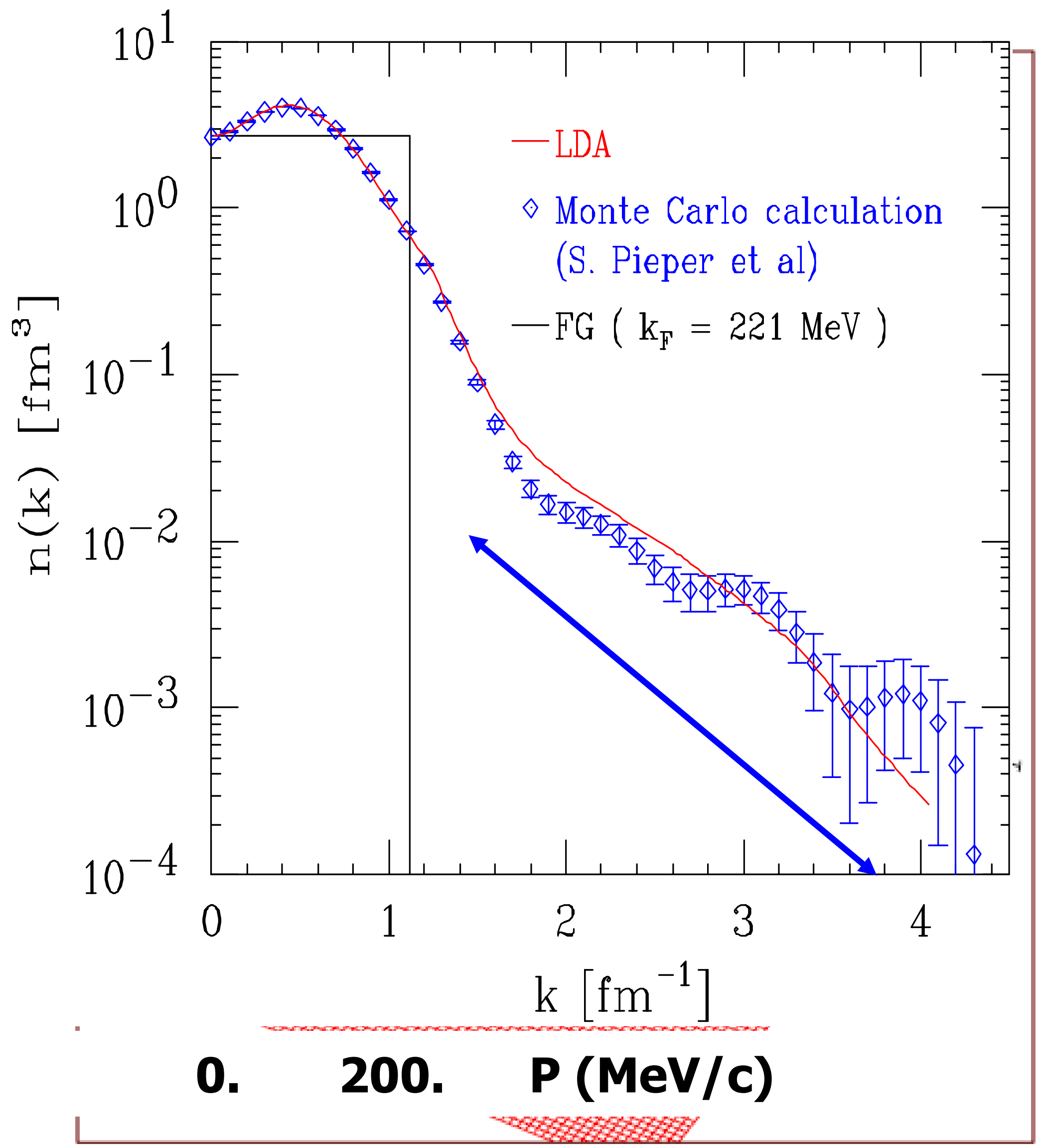
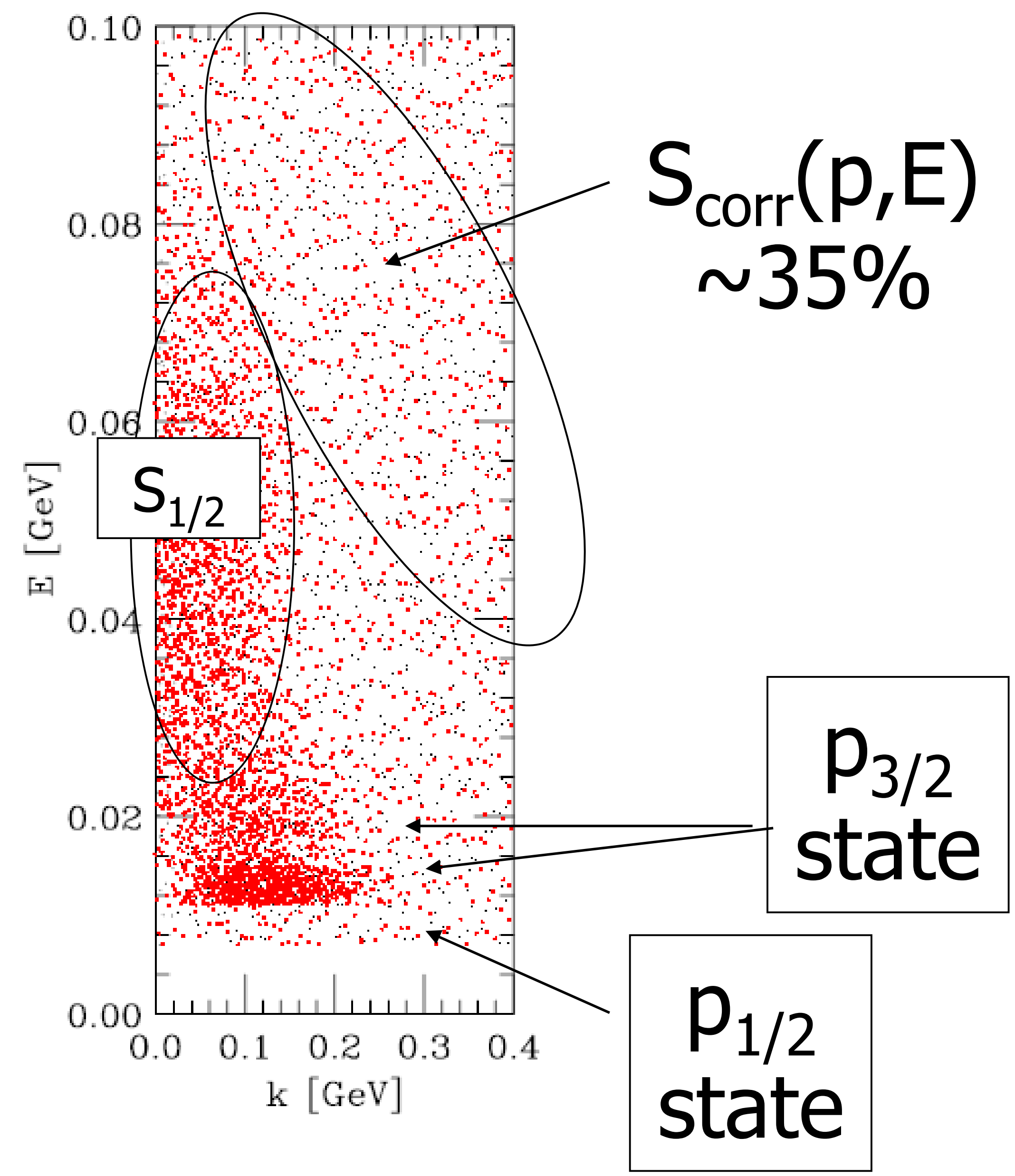


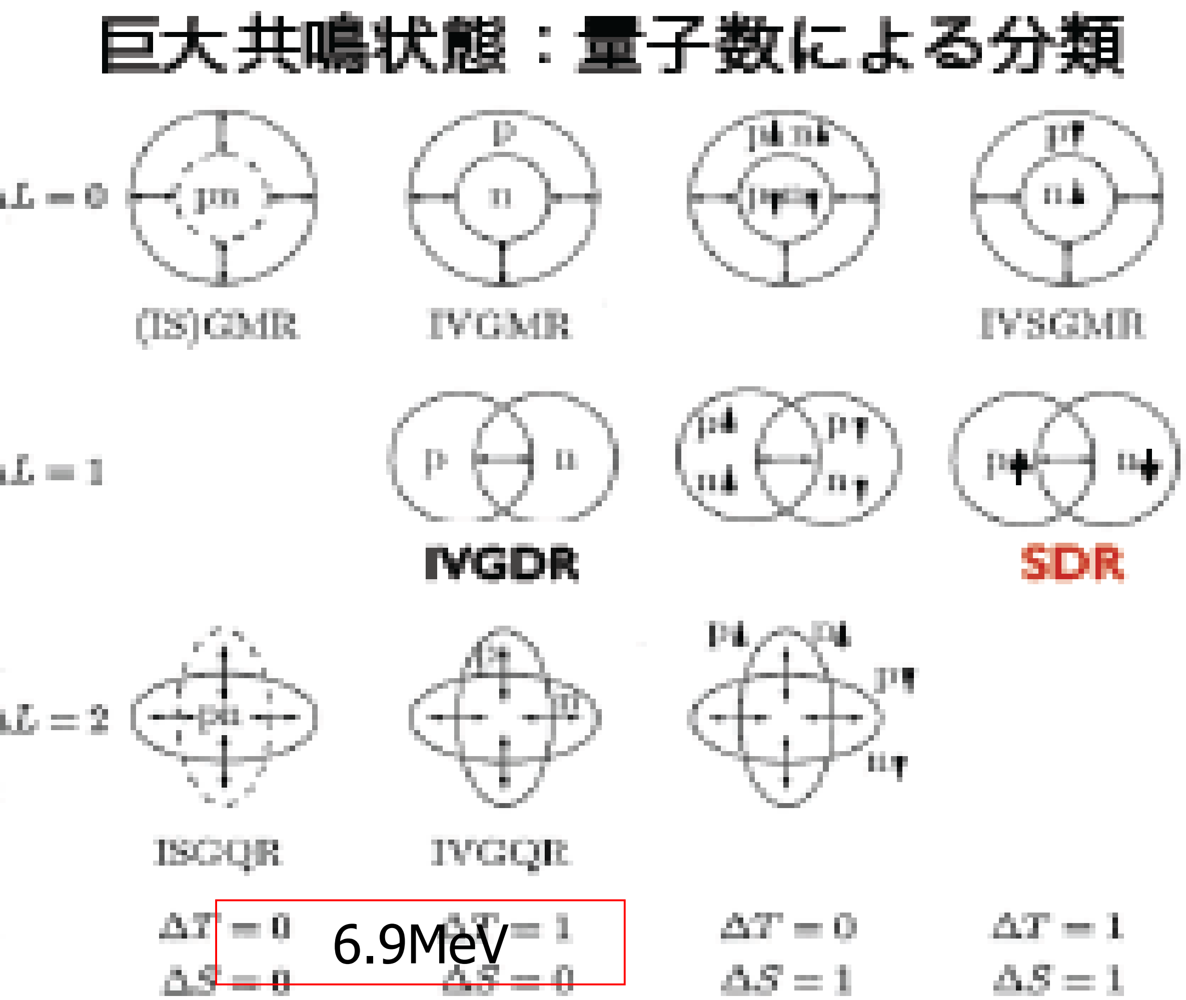
FIG. 1. $^{16}O(e,e'p)^{15}N$ missing energy spectrum for the kine-atics centered about $p_m = 120$ MeV/c.

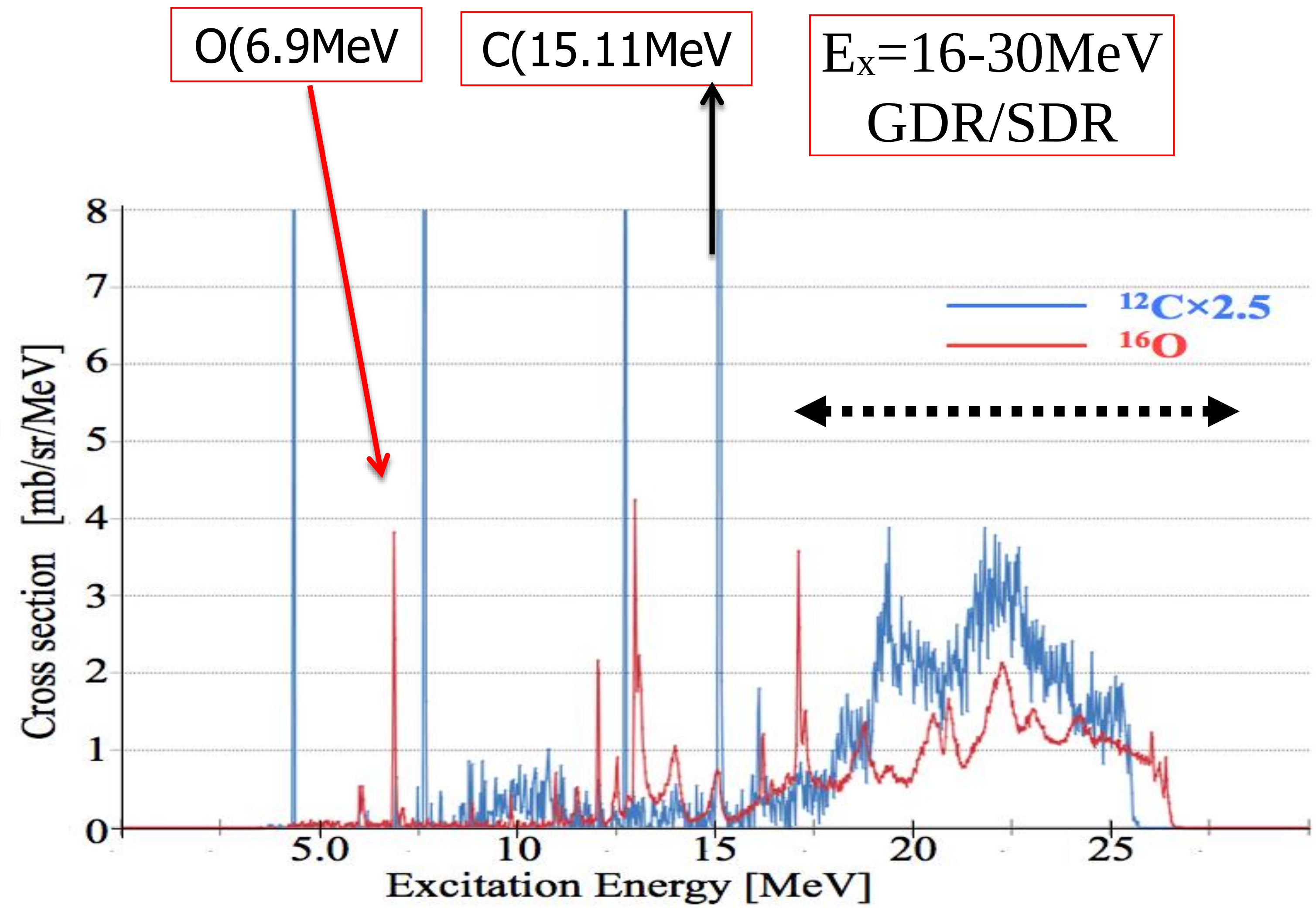




Three-dimensional plot (left panel) and scatter plot (right panel) of the oxygen spectral function obtained using
n described in the text.

Emergence of Giant Resonances (Ex>16MeV) [Our E398 data]

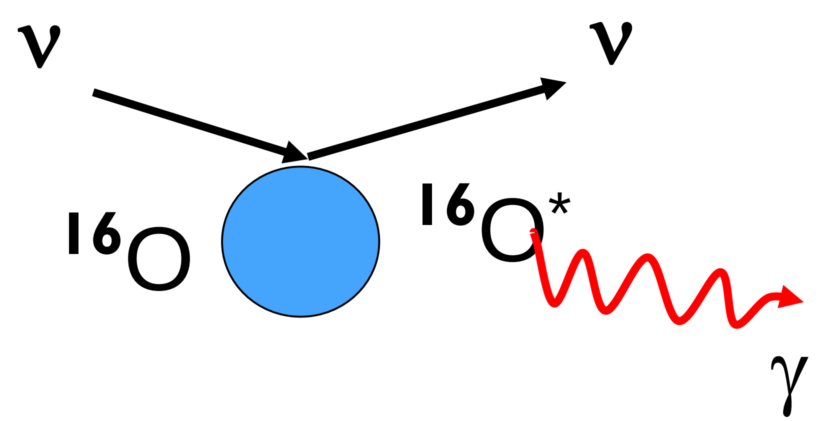




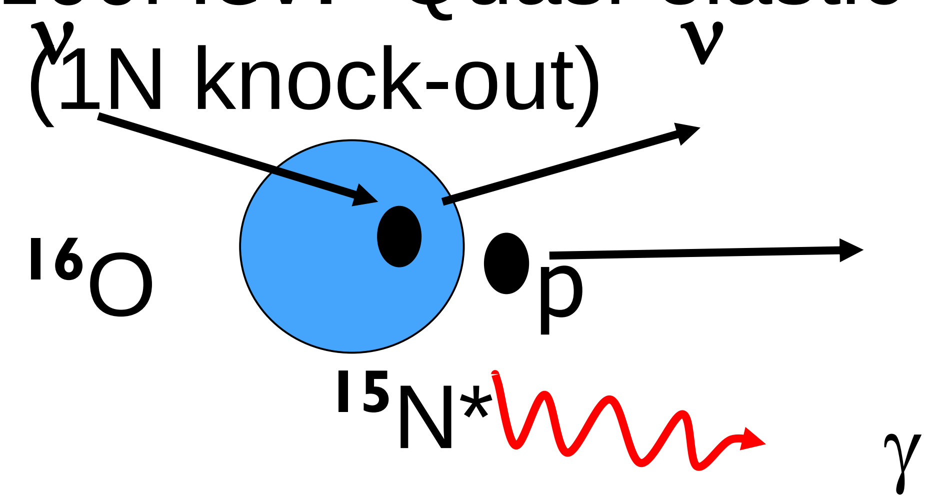
- At low energy (E_ν=10-100MeV) where E=10-40MeV is not negligible, we must consider those excitations.
- Cf.Discovery of Giant Resonance (1947, 48): A collective excitation of a nucleus in which the bulk of protons move in one direction while the neutrons move in the opposite direction.
- Shell Model (Nobel Prize 1963), Connection bet.Collective Motion and Particle Motion (Nobel Prize 1975)

2. Status of γ-ray production in NC ν-O (-C) reactions

1) E_ν<100MeV: Elastic and Inelastic



2) E_ν>100MeV: Quasi-elastic (1N knock-out)



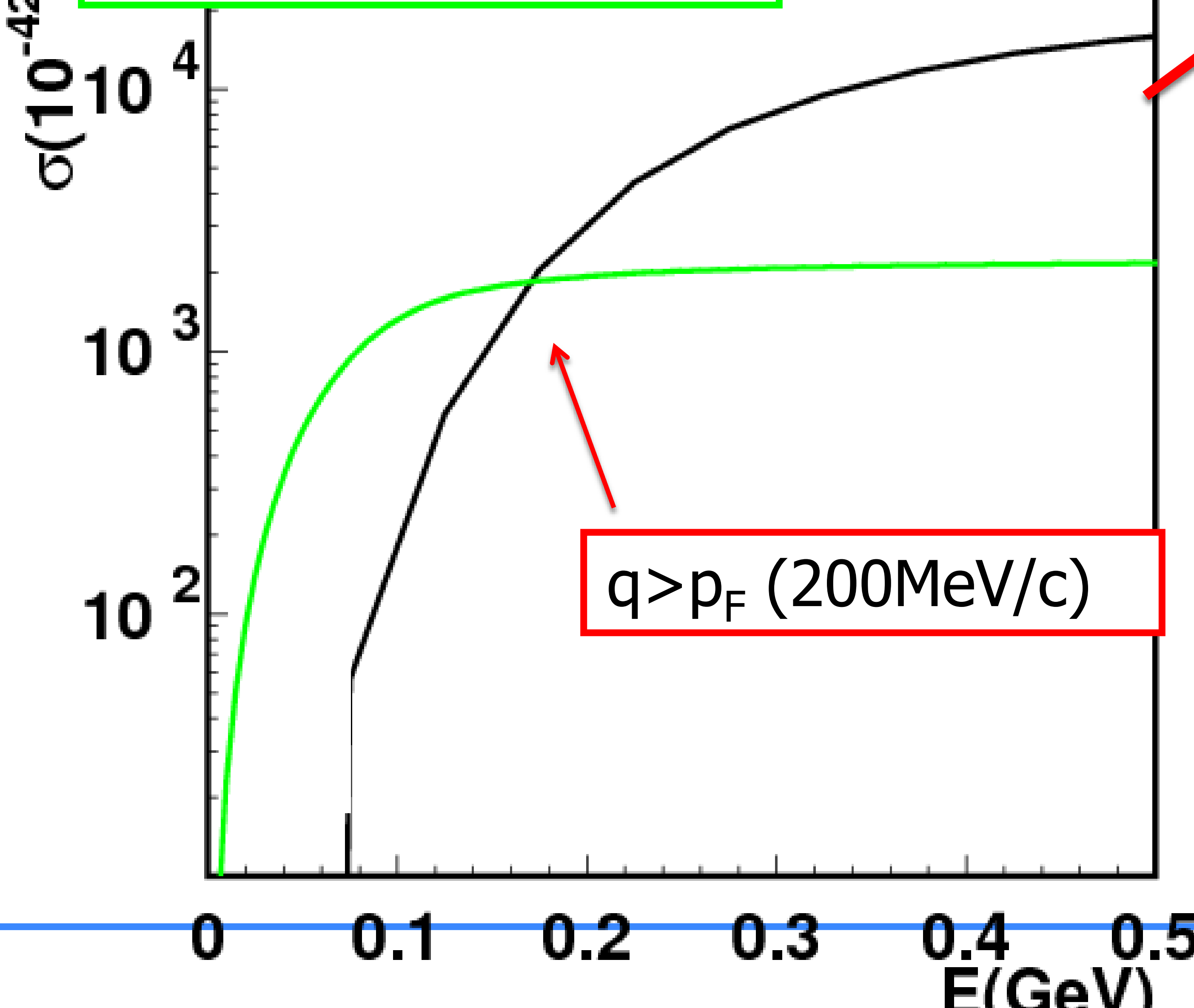
- Theoretical Calculations
  1) E_ν<100MeV: Langanke et al., *Phys.Rev.Lett.* **76**(1996).
     - Inelastic scattering (Giant resonances): $\nu O \rightarrow \nu O^* \rightarrow \gamma$
  2) E_ν>100MeV: Ankowski, Benhar, Mori, Yamaguchi and MS, *Phys.Rev.Lett.* **108**(2012)052505
     - Nucleon knockout: $\nu O \rightarrow \nu + p/n + {}^{15}N^*/{}^{15}O^*$ (Excitation of residual nucleus)
- Experiments
  1) E_ν<100MeV: Karmen for C*(15.1MeV) only. No experiments exists for Oxygen. → RCNP E398
  2) E_ν>100MeV: T2K →K.Abe et al.(T2K),PRD90,072012 (2014)

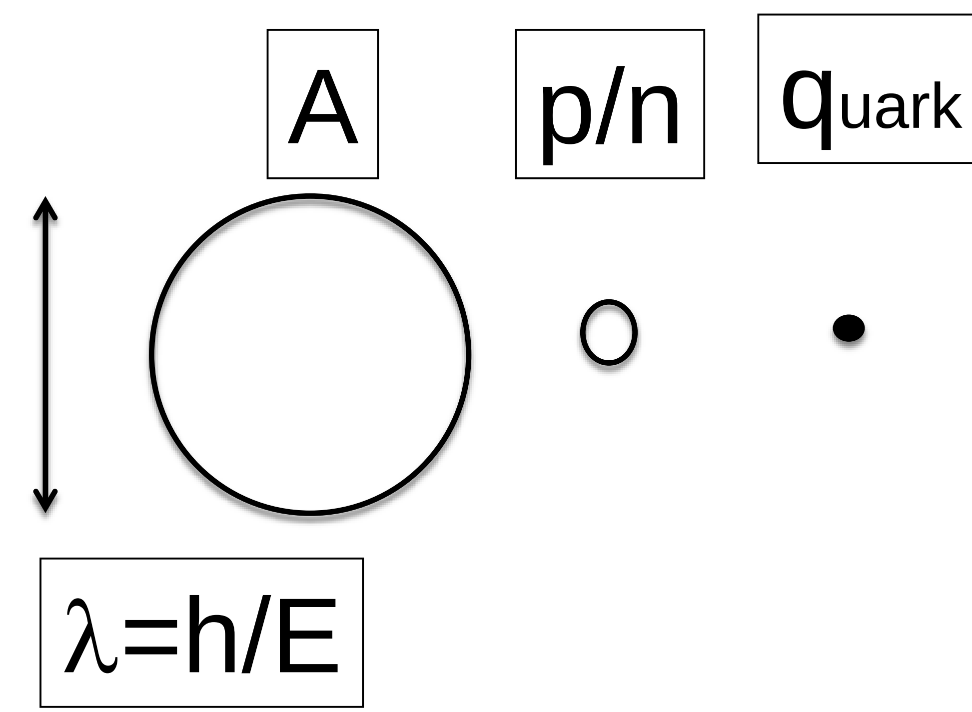
Overall Picture of the ν-A cross section

NC: Elastic(Coherent)
$\nu + {}^{16}O \rightarrow \nu + {}^{16}O$
Inelastic
$\nu + {}^{16}O \rightarrow \nu + {}^{16}O^*$
CC:
$\nu + {}^{16}O \rightarrow e + {}^{16}F / {}^{16}N$

NC quasi-elastic (QE)
$\nu + {}^{16}O \rightarrow \nu + p/n + X$
CC QE
$\nu + {}^{16}O \rightarrow e + p/n + X$

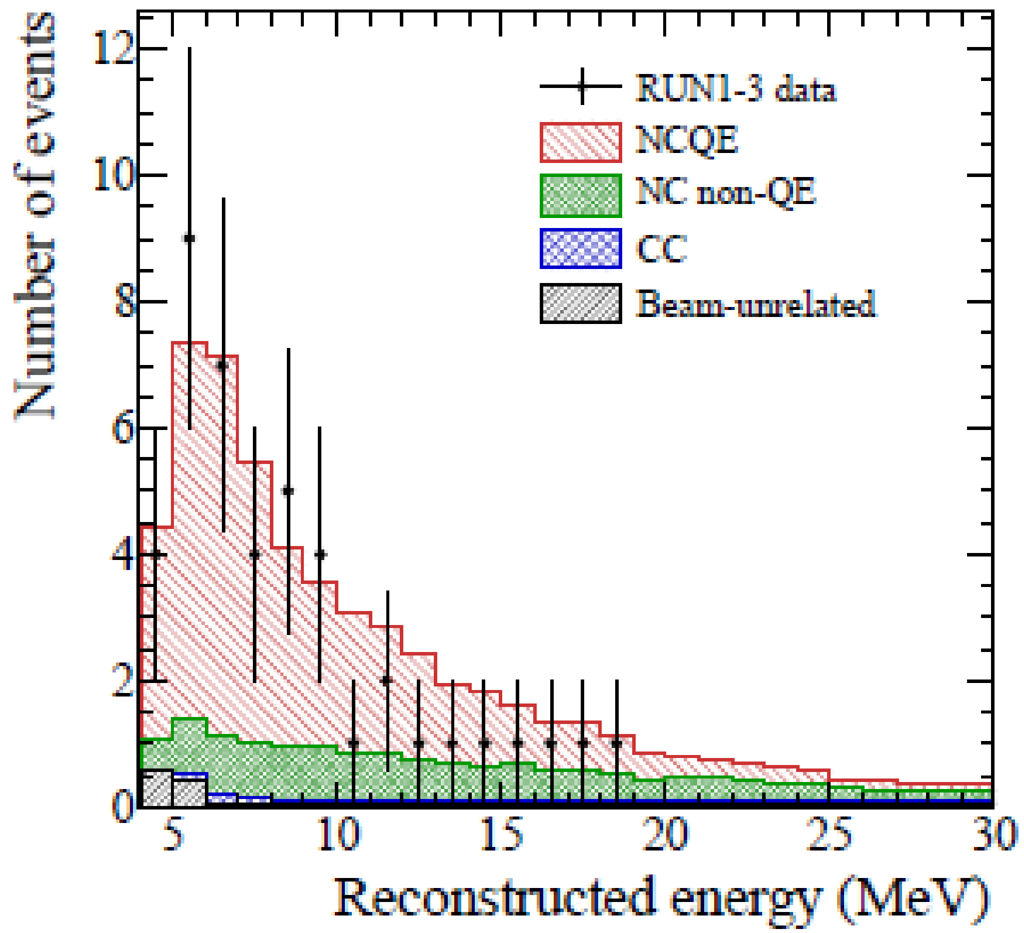
π-production and DIS



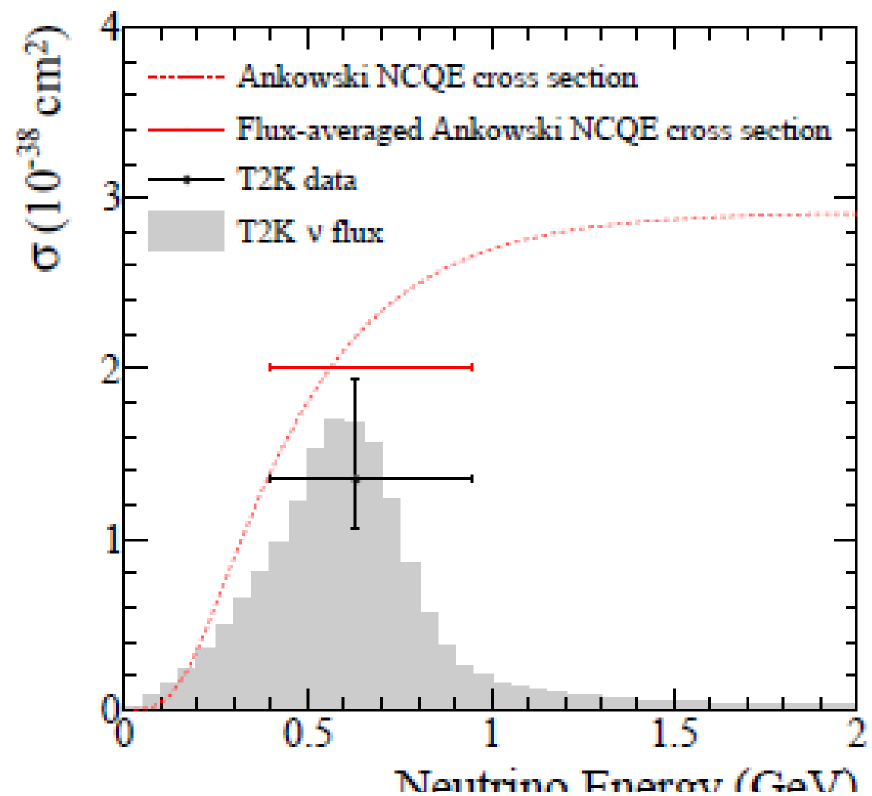


Experiments: T2K NC γ production and Karmen NC γ production

T2K 6MeV γ from $^{15}N/^{15}O$



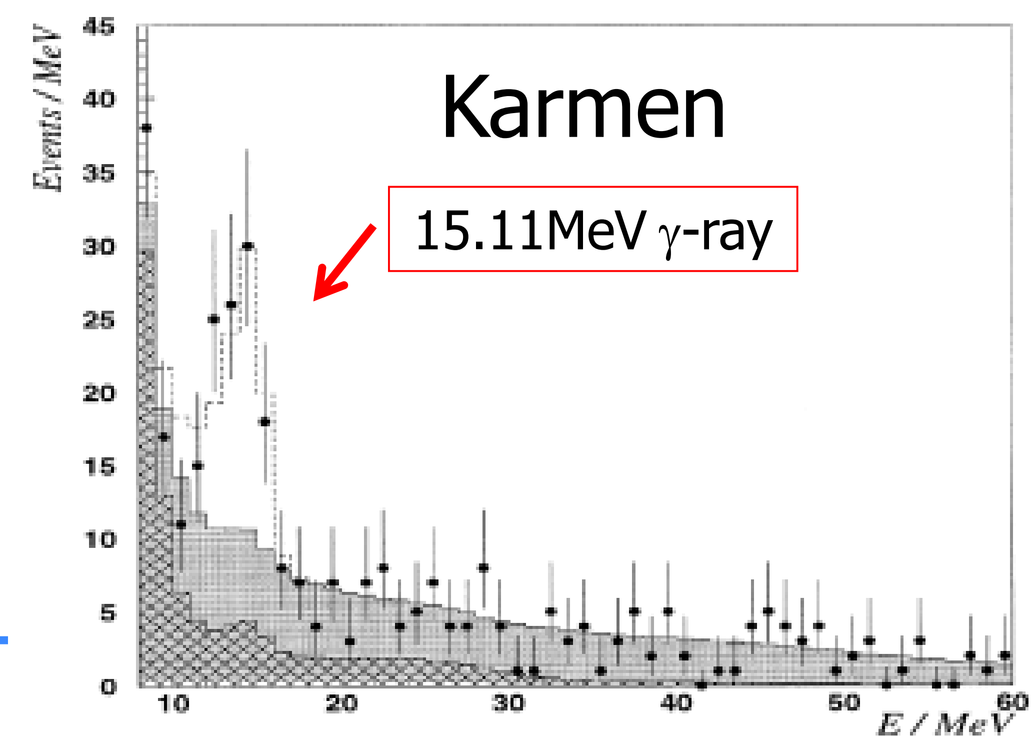
T2K and Ankowski et al, PRL108



•T2K data is consistent with Ankowski et al.

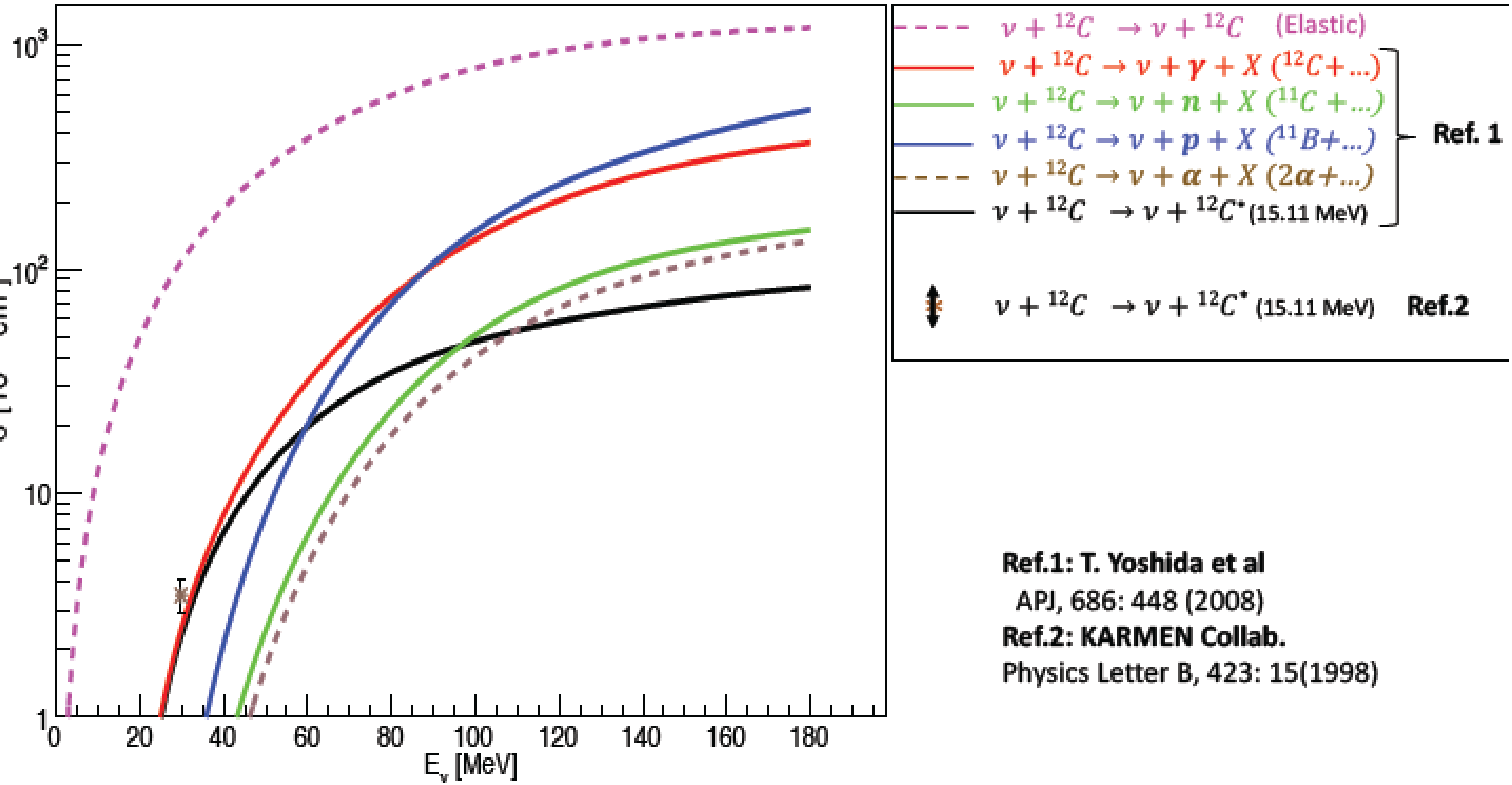
•KARMEN @E_ν=29.8MeV
 $(3.2\pm0.5\pm0.4)\times10^{-42}cm^2$
 In good agreement with the calculation,
 $2.8\times10^{-42}cm^2$.

•.



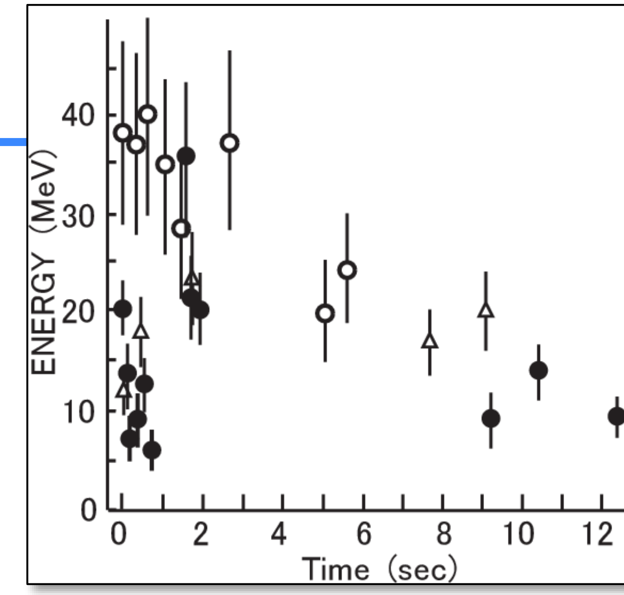
NC neutrino carbon interactions at low energy

-Cf.T.Yoshida et al., APJ, 2008 -



Ref.1: T. Yoshida et al
APJ, 686: 448 (2008)
Ref.2: KARMEN Collab.
Physics Letter B, 423: 15(1998)

1987A: First Observation of Supernova Explosion by Neutrinos from LMC (50kpc)



- Total Energy Reliesed＝2.5±1.2 ×10^{53} erg
- Equilibrium Temperature (Average Neutrino Energy)
  T=5.2±1.2 ×10^{10} K
- Neutrios: Reliesed during 12 seconds

- Though Prof.Koshiba won Nobel Prize in Physics in 2002. detailed mechanism of the explosion is still unknown.

天体物理学に対するパイオニア的貢献.

1. How to Study Neutrinos from Supernova (SN) Explosion

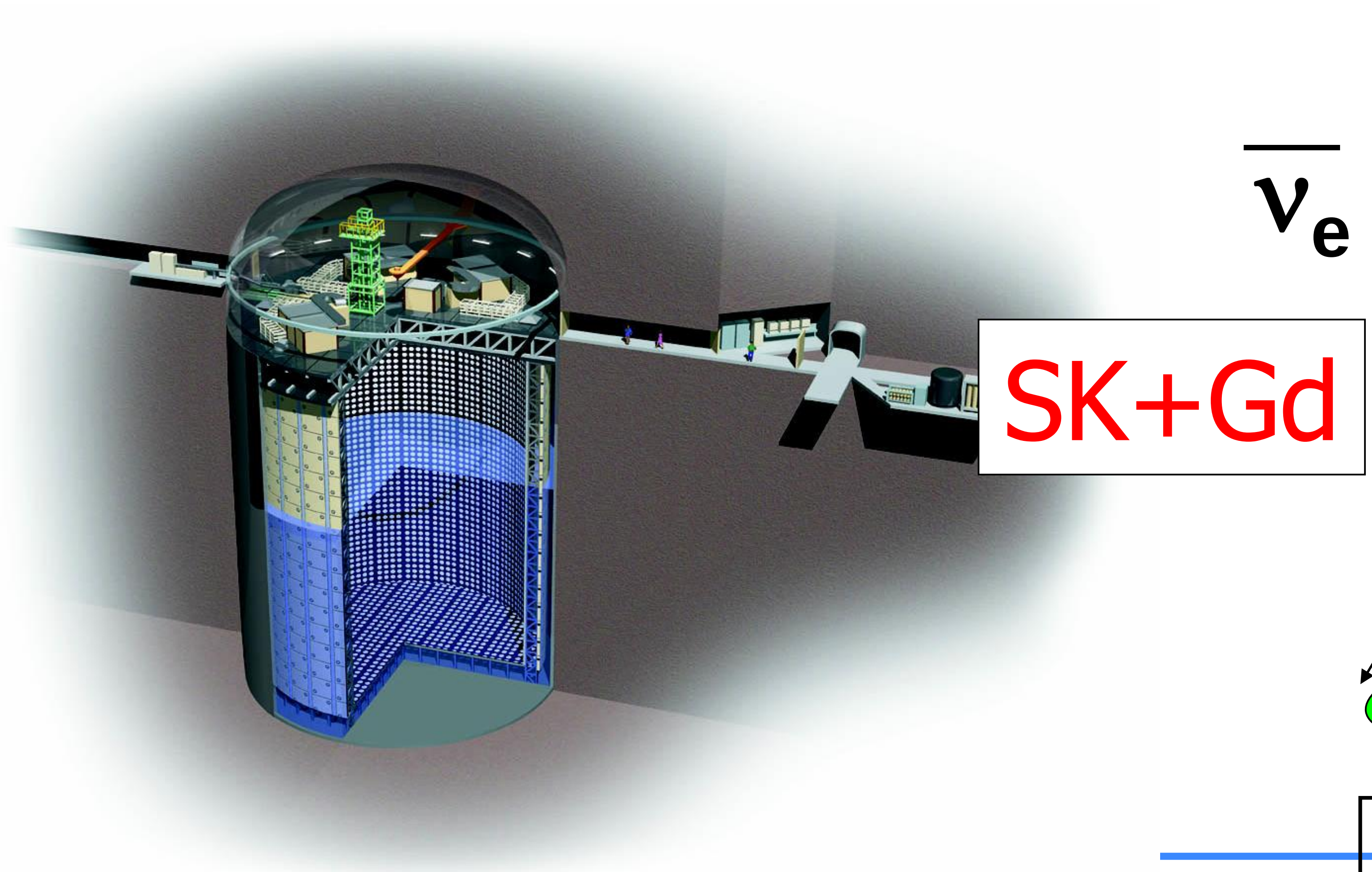
There are 10^{20} stars in the universe（10^9 Galaxies、10^{11} Stars/galaxy). About 0.3% of Stars are heavy enough to result in Gravitational Collapse and SN explosion.
The rate of SN explosion since the birth of the Universe (1st Star) is about 1 SN explosion/sec. 99% of the energy during SN explosion is carried away by neutrinos.
Our Strategy to study SN neutrinos:

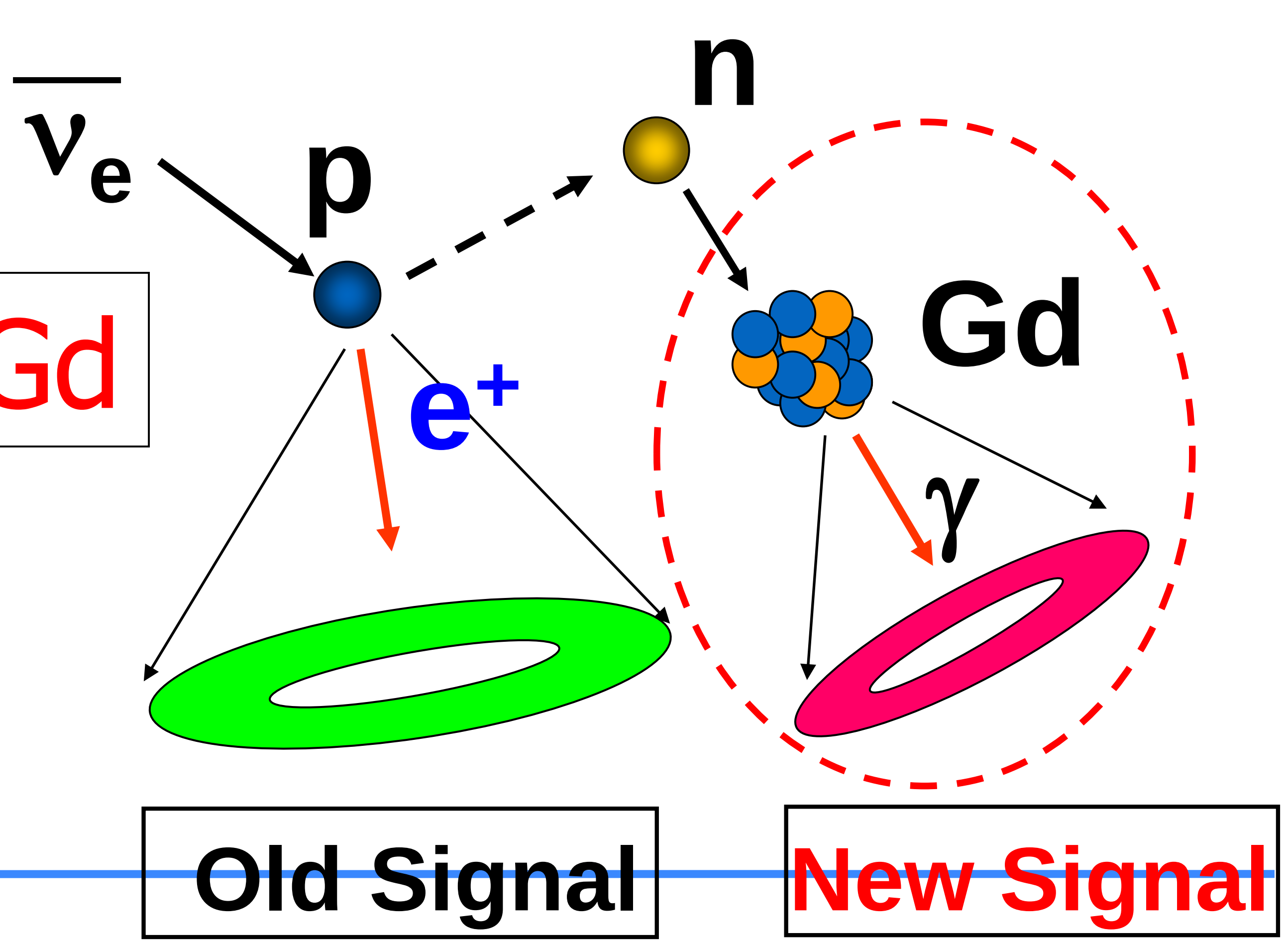
1. Steady way: Supernova Relic Neutrinos (SRN), which were produced from the past SN explosions (1 SN explosion/sec). We do not have to wait, the expected rate at SK is 0.8～5 events (Ee=10-30MeV), →SK-Gd Project

2. If we ar Lucky: We expect about 8000 neutrino events at Super-K if SN explosion happens at 10kpc in our Galaxy. Neutrino detector can observe every msec of the explosion process; we expect to clarify the mechanism of SN explosion. But, the chance is low, ~1 SN/20-50years.

SK-Gd Project
To Observe Supernova Relic Neutrinos (SRN)

SRN Rate：0.8～5 events (Ee=10-30MeV),
0.3 -1.9 events (Ee=18-30MeV)
The project approved by Super-K Collaboration



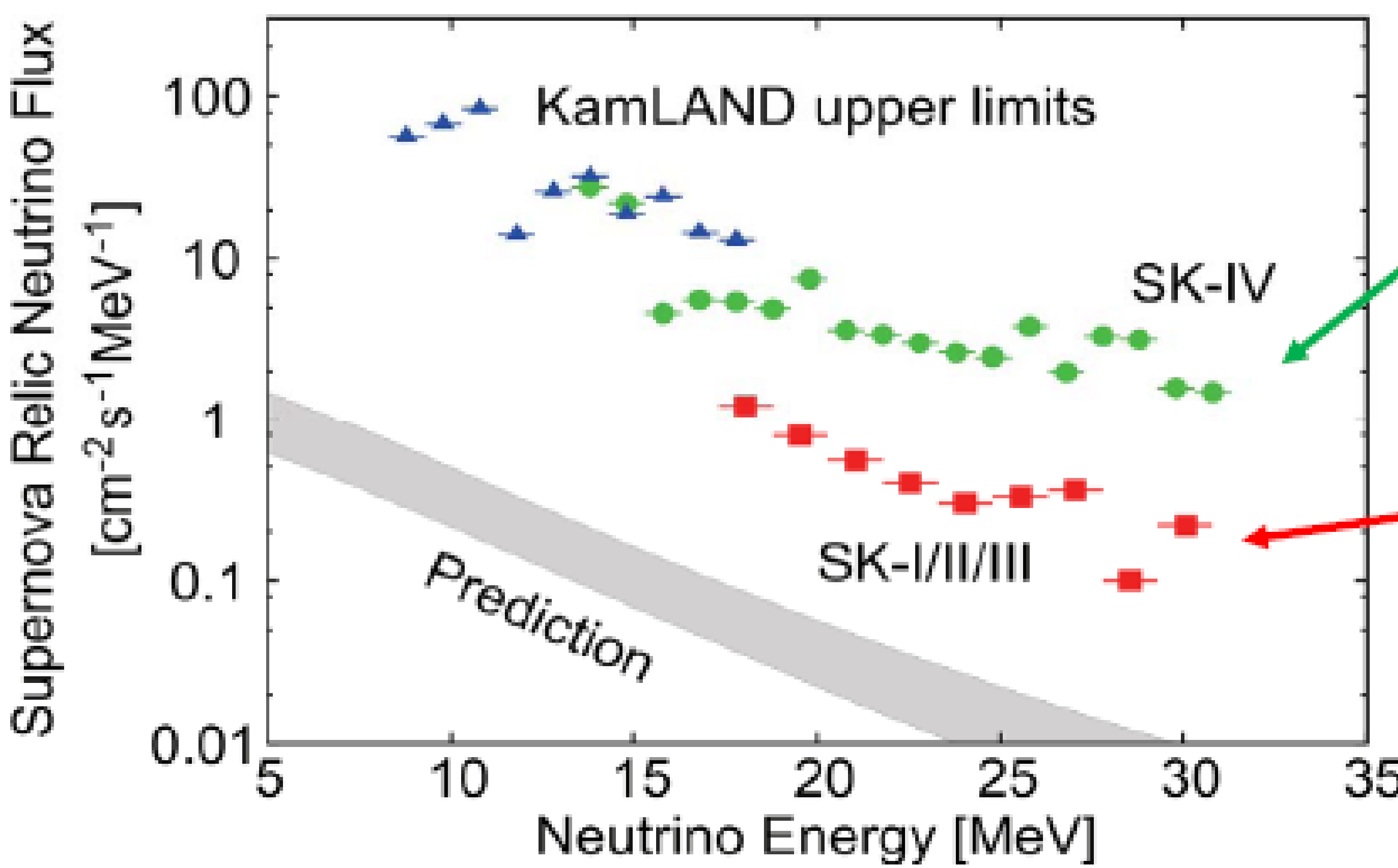


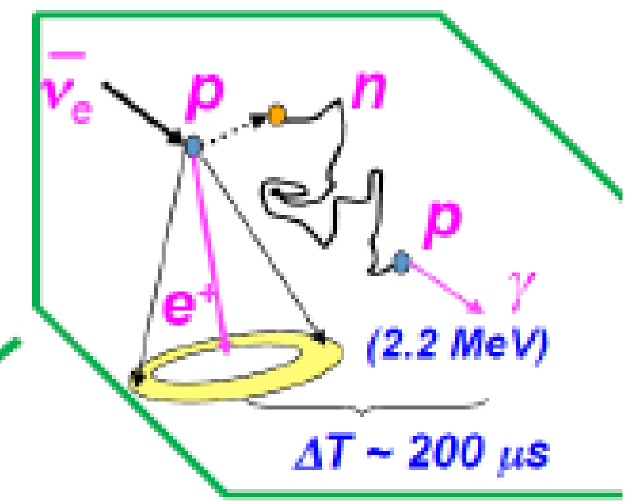
SRN search at SK: Best Sensitivity to SRN

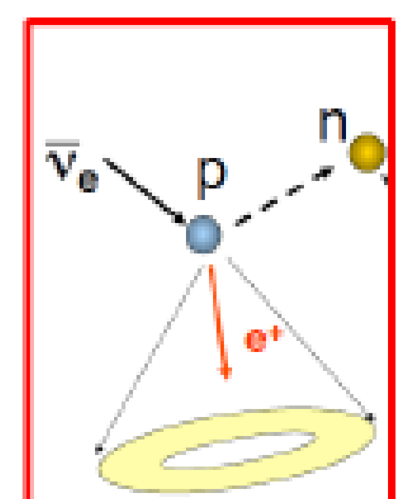
-H.Sekiya @ neutrino2016

Further Background suppression >10 is needed.

- Search window for SRN at SK : From 10MeV to 30MeV
- Limited by BG. More than 1 order reduction is needed.
  - n tagging efficiency (by proton) is low…





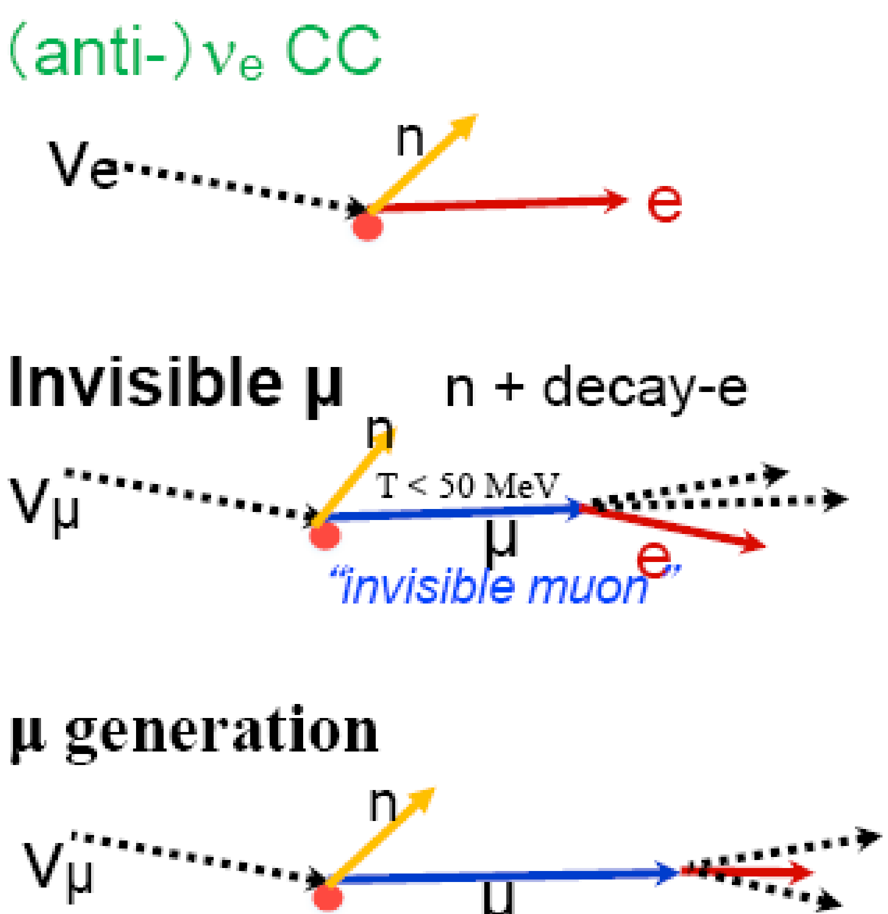


(1) γ-ray production in NC QE ν-O reactions
--Important Background to SRN --

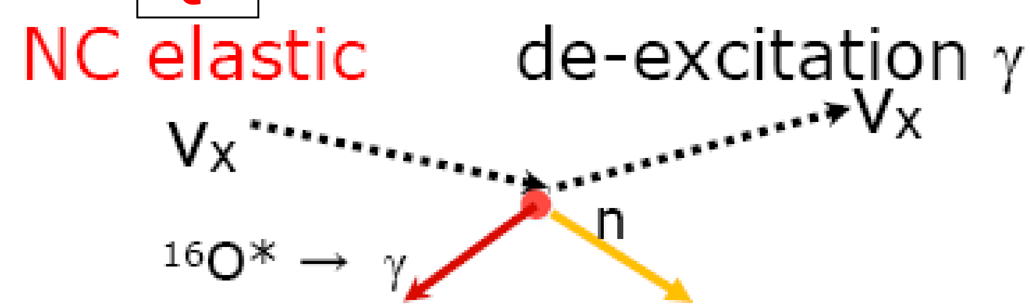
BG source: atmospheric neutrino

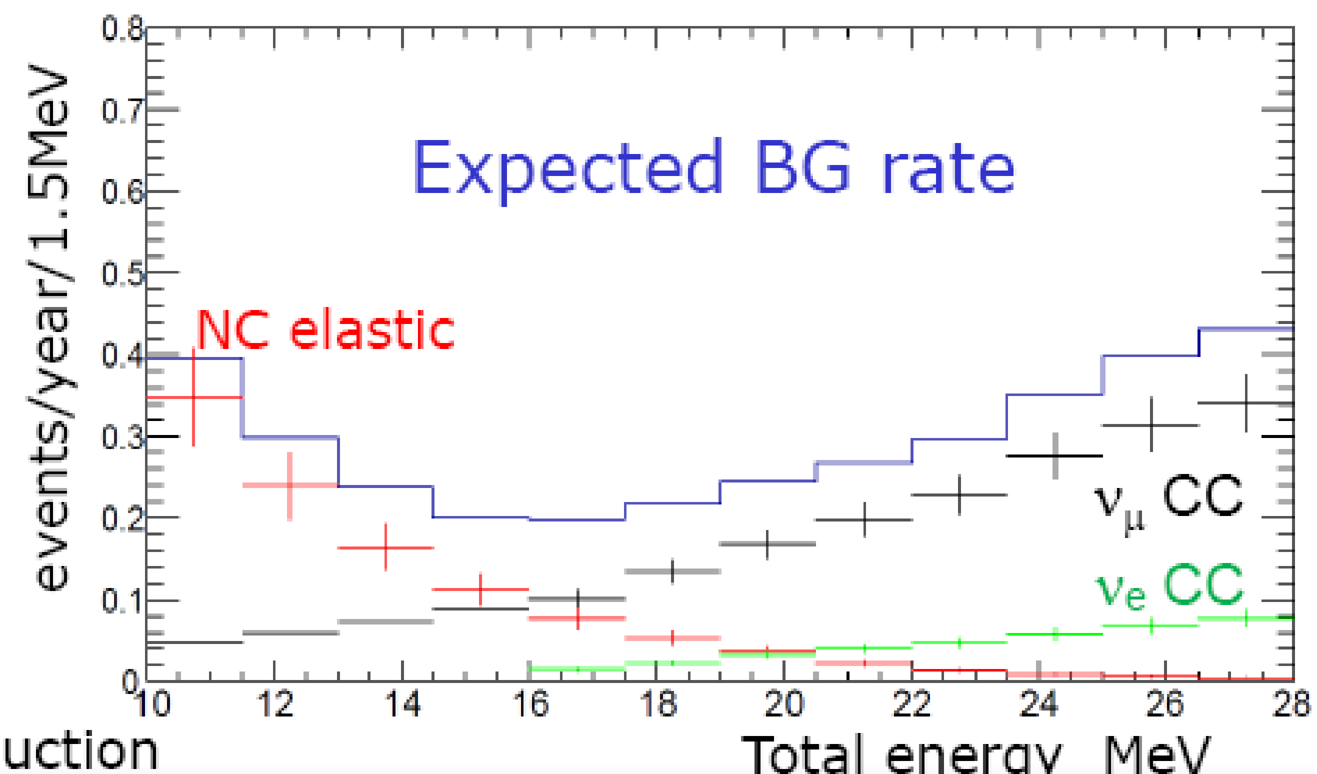
–H.Sekiya@Neutrino2016

- CC



- NC QE





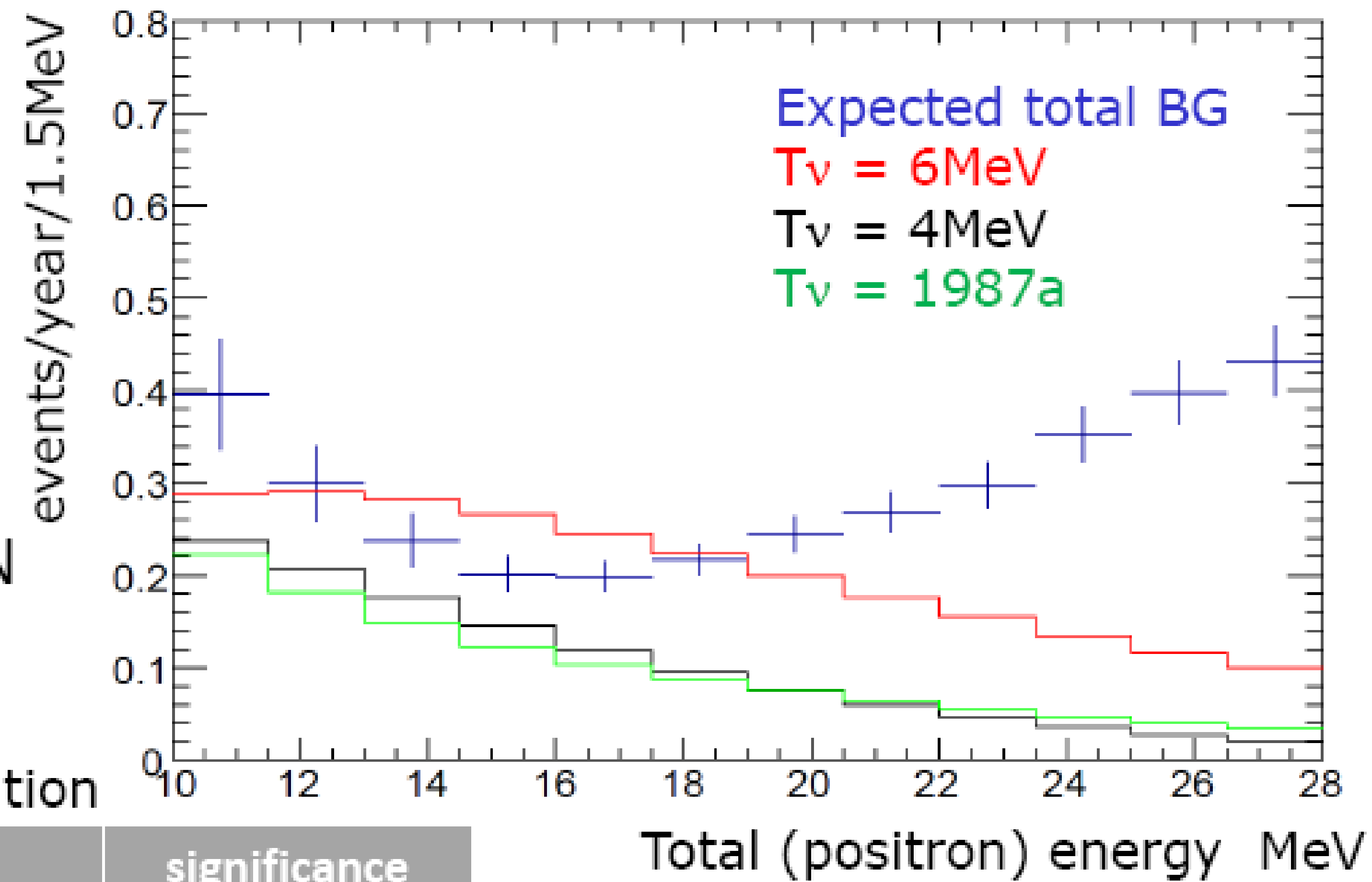
N.B. Vertex information gives further BG reduction

SRN Signal and Background -H.Sekiya @ Neutrino2016

Expected signal

DSNB flux:
Horiuchi, Beacom and Dwek,
PRD, 79, 083013 (2009)

- It depends on typical/actual SN emission spectrum

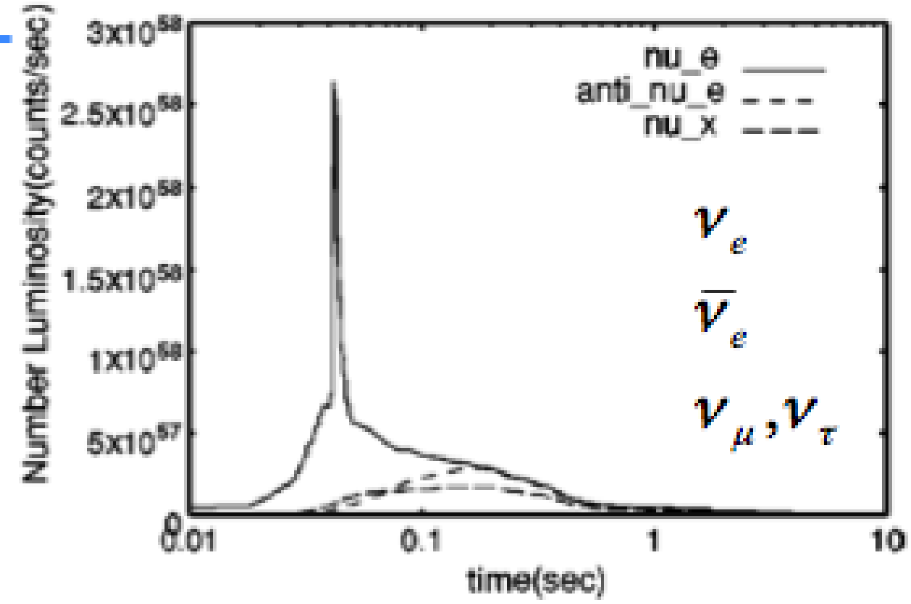


DSNB events number with 10 years observation

HBD models	10-16MeV (evts/10yrs)	16-28MeV (evts/10yrs)	Total (10-28MeV)	significance (2 energy bin)
T_{eff} 8MeV	11.3	19.9	31.2	5.3 σ
T_{eff} 6MeV	11.3	13.5	24.8	4.3 σ
T_{eff} 4MeV	7.7	4.8	12.5	2.5 σ
T_{eff} SN1987a	5.1	6.8	11.9	2.1 σ
BG	10	24	34	----

- First observation is within SK-Gd's reach!

: (2) Measuring Neutrino Bursts from SN explosion@10kpc
-NC γ production is important



■ The number of events observed in the detectors

□ Super Kamiokande (H_2**O**

$$\bar{\nu}_e + p \rightarrow e^+ + n$$ ~8000 events

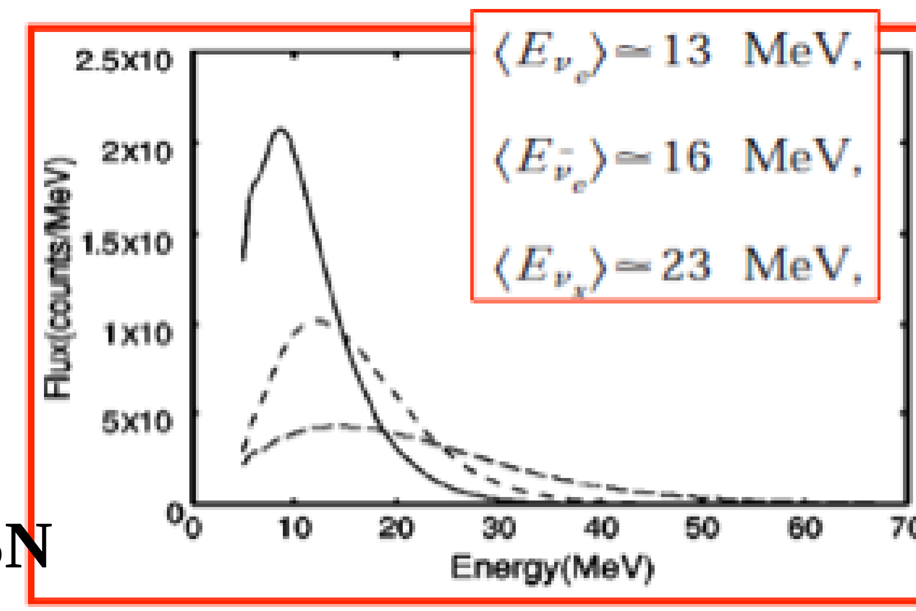
$$NC: \nu_x + {}^{16}O \rightarrow \nu_x + X + \gamma \ (\nu_x = \nu_\mu, \nu_\tau)$$ 400~600? events

□ KamLAND (**C**H)

$$\bar{\nu}_e + p \rightarrow e^+ + n$$ ~300

$$NC: \nu_x + {}^{12}C \rightarrow \nu_x + X + \gamma \ (15.1 MeV)$$ ~60

$$NC: \nu_x + {}^{12}C \rightarrow \nu_x + X + \gamma \ (E_X > 16 MeV \text{の巨大共鳴})$$ (~50??)



■ **Importance of Neutral-Current events**

✓ **The 2nd larget reaction and no one has measured them in SN bursts**

✓ **μ,τ –type neutrino-induced events dominate NC reactions since energy (Temperature) is higher than e-type.**

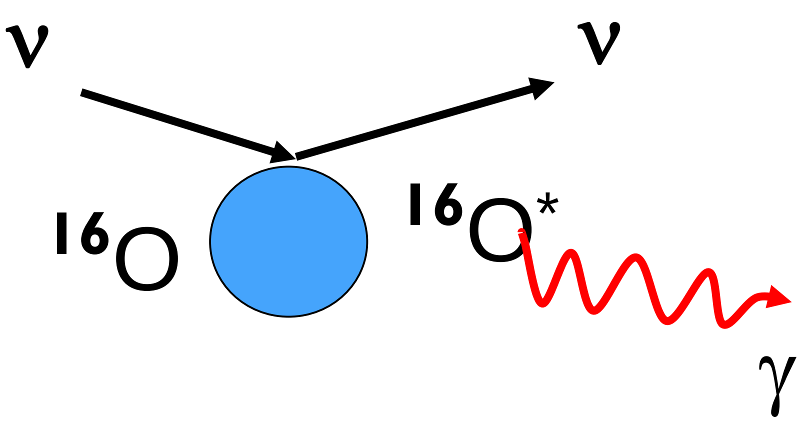
✓ **Independent of neutrino oscillations**

□ It is important to mesure both main CC signals and NC γ events.
Note:A.B.McDonald, Nobel Prize 2015 on Solar Neutrino Oscillations)

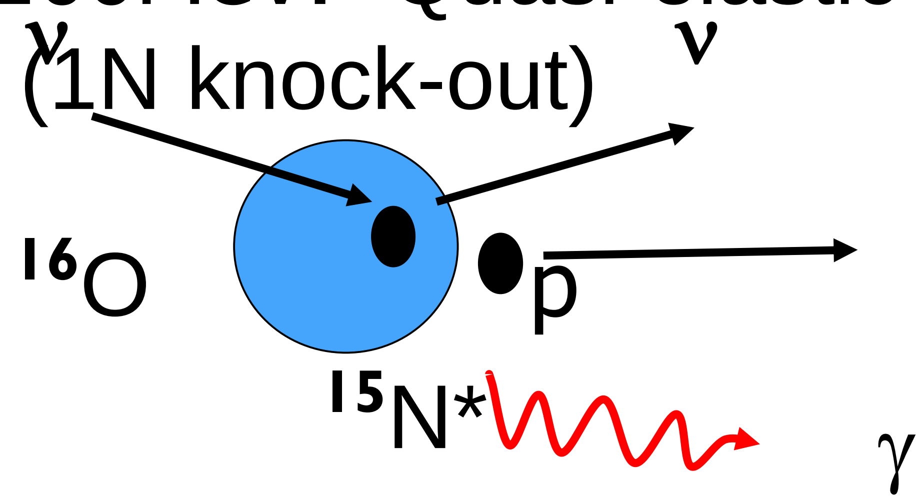
‣ We Do need to Measure Br(C*,O*→γ) = **Γγ/Γ (E_x).** --- Purpose of RCNP E398.

2. Status of γ-ray production in NC ν-O (-C) reactions

1）E_ν<100MeV: Elastic and Inelastic



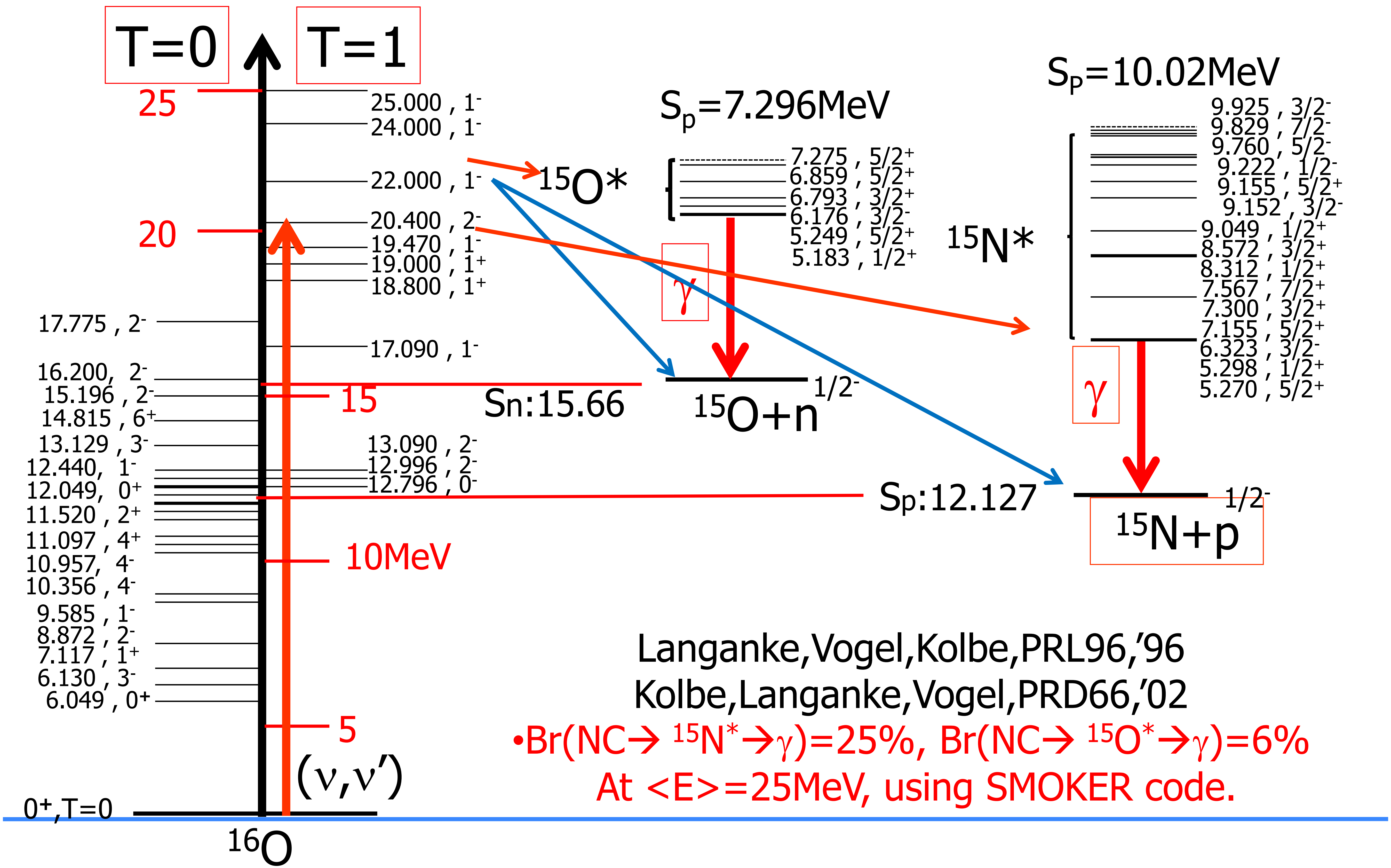
2）E_ν>100MeV: Quasi-elastic (1N knock-out)



- Theoretical Calculations
  1) E_ν<100MeV: Langanke et al., *Phys.Rev.Lett.***76**(1996).
     - Inelastic scattering (Giant resonances): νO→νO* , O*→γ
  2) E_ν>100MeV: Ankowski,Benhar,Mori,Yamaguchi and MS, *Phys.Rev.Lett.***108**(2012)052505
     - Nucleon knockout: νO→ν+p/n+$^{15}N^*$/$^{15}O^*$(Excitation of residual nucleus)
- Experiments
  1) E_ν<100MeV: No experiments exists for Oxygen. Karmen for C*(15.1MeV) only → RCNP E398
  2) E_ν>100MeV: T2K →K.Abe et al.(T2K),PRD90,072012 (2014)

NC ν-O γ-production (E<100MeV, Inelastic)

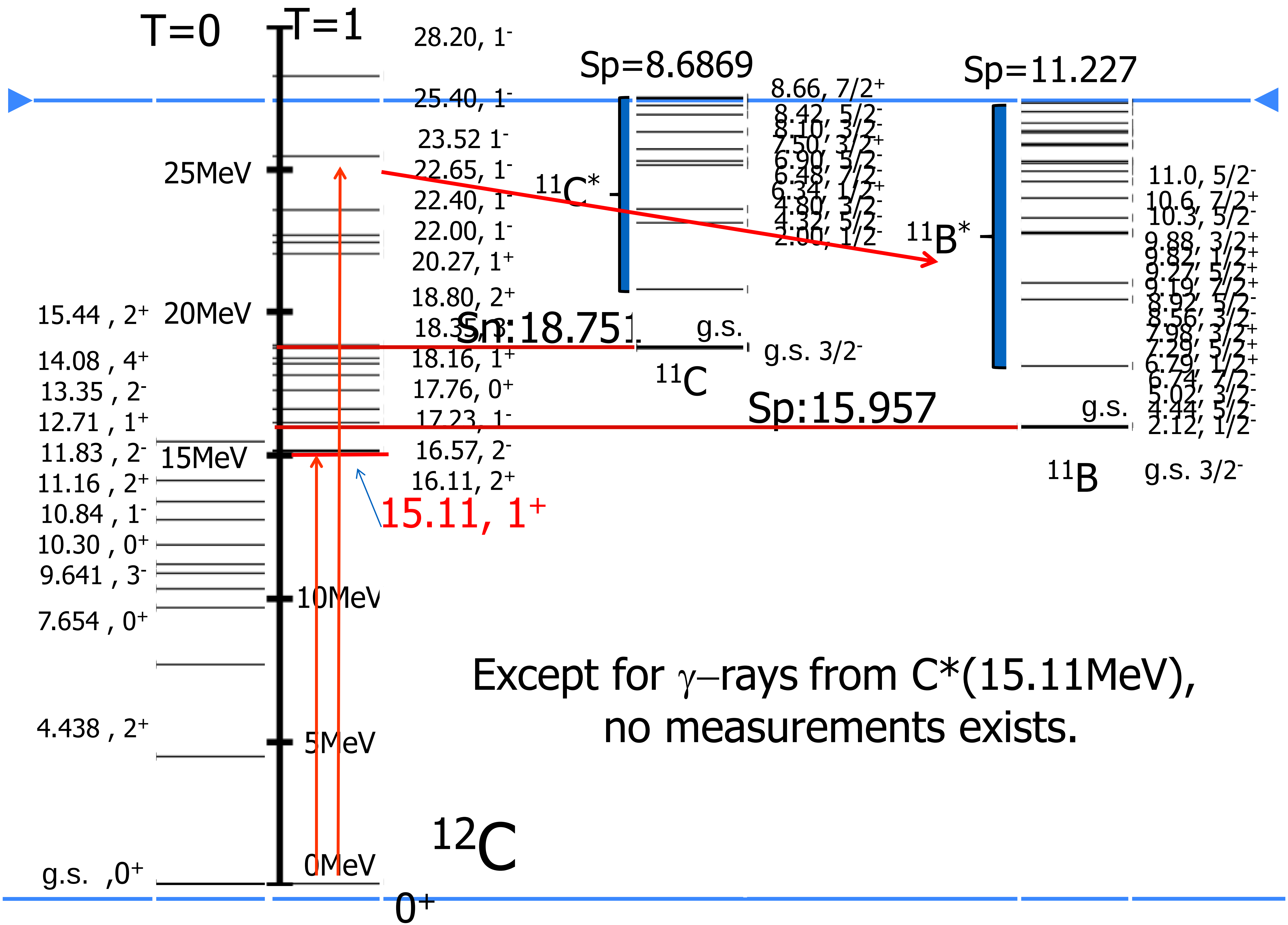
$\nu_x + {}^{16}O \rightarrow \nu_x + {}^{16}O^*$; ${}^{16}O^* \rightarrow {}^{15}N^* + p$, ${}^{15}O^* + n$; ${}^{15}N^*$, ${}^{15}O^* \rightarrow \gamma$



Langanke,Vogel,Kolbe,PRL96,'96
Kolbe,Langanke,Vogel,PRD66,'02

- Br(NC→ ${}^{15}N^* \rightarrow \gamma$)=25%, Br(NC→ ${}^{15}O^* \rightarrow \gamma$)=6%

At <E>=25MeV, using SMOKER code.



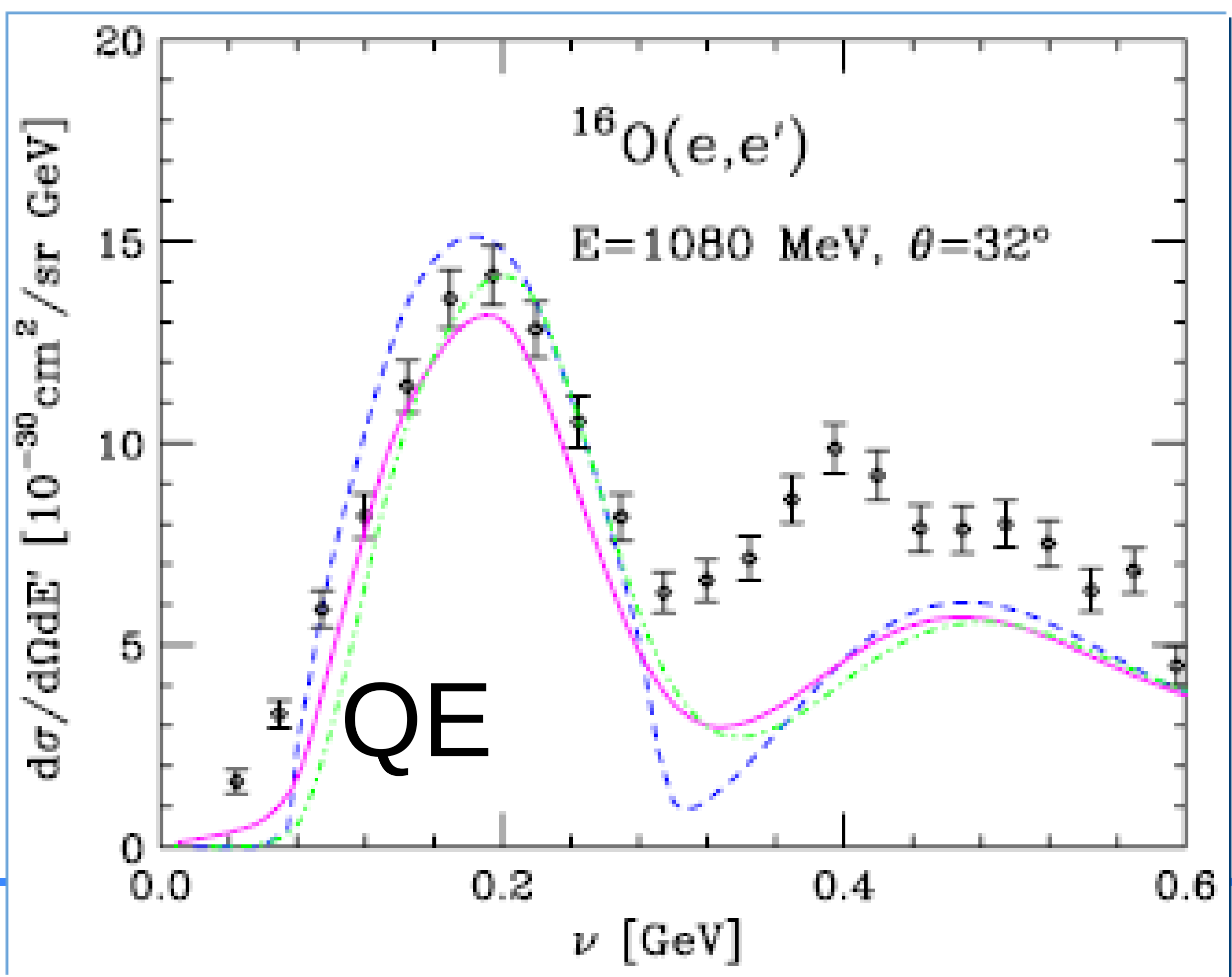
Except for γ–rays from C*(15.11MeV), no measurements exists.

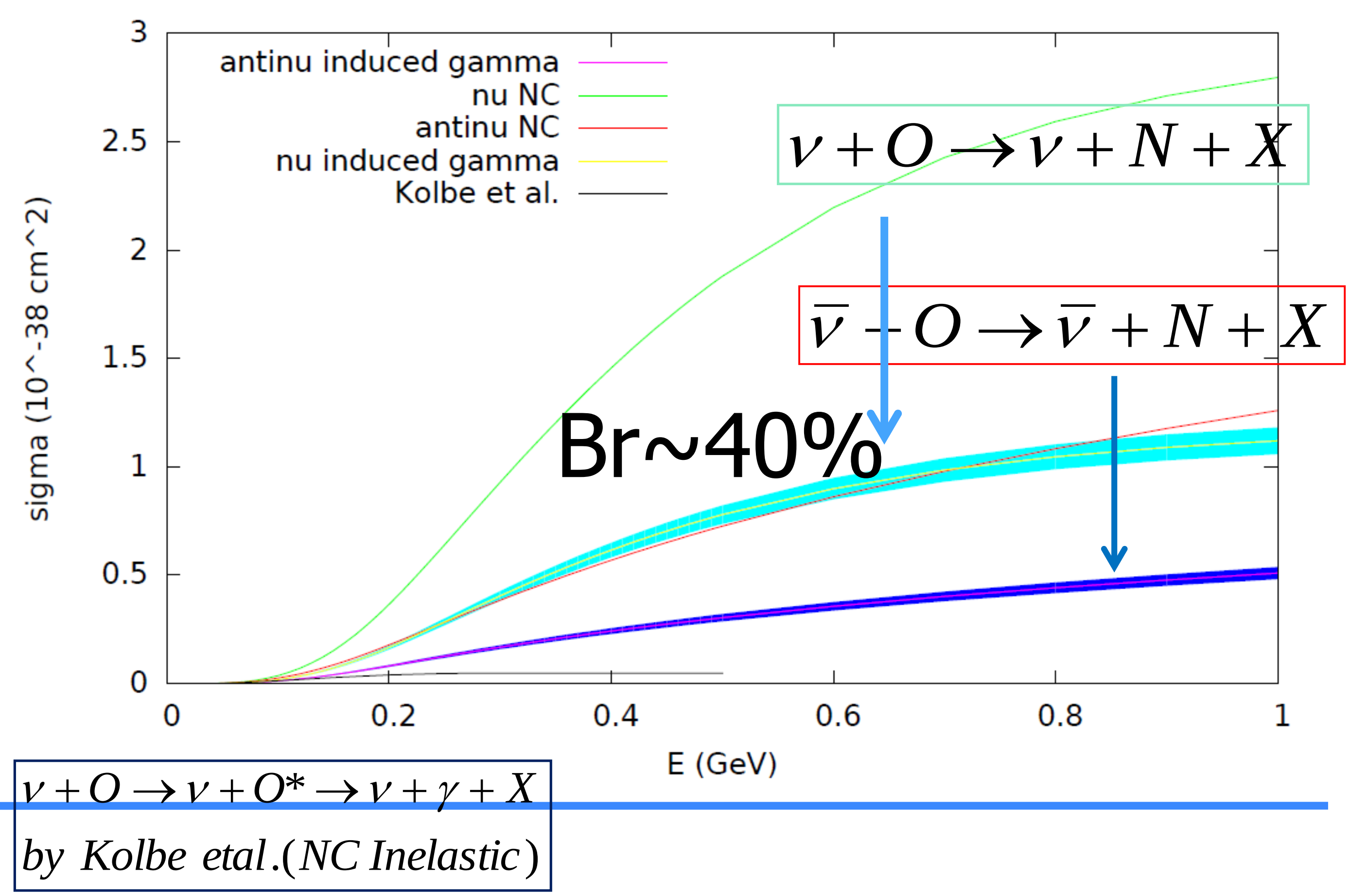
(1) How to Calculate NC QE γ Production

- We use Impulse Approximation approach with Spectral Function plus FSI to describe QE.

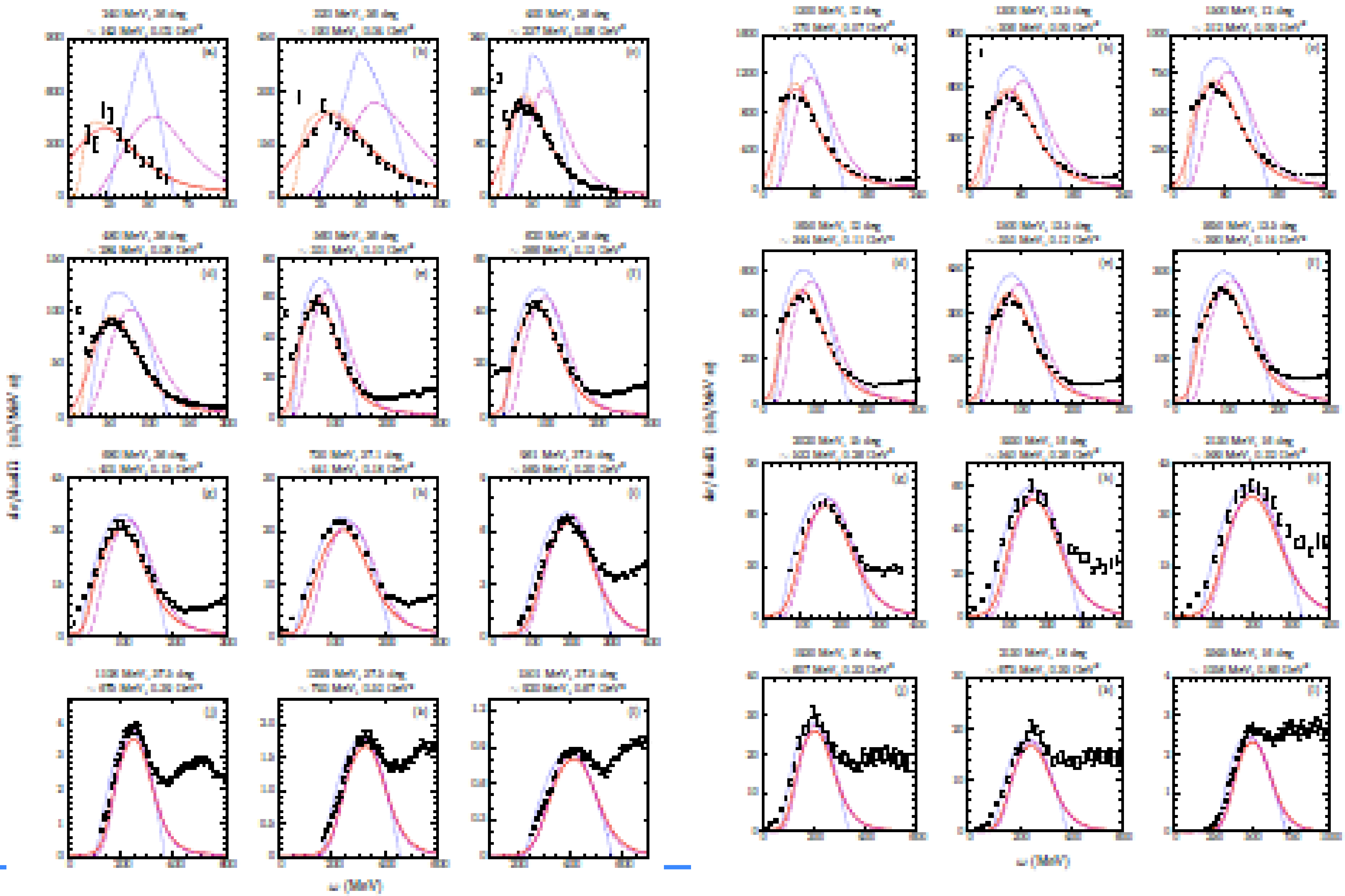
*Benhar,MS et al., PRD72,053005, '05; Ankowski,Benhar,MS:PRD91,033005,'15.

- Production of γ-rays (>5MeV) in NC/CC QE is significant (Br~ 40% for O). *Ankowski,MS et al, PRL 108,052505(2012).





We compare our calculations with all existing C(e,e’) data E=240-2000MeV Ankowski, Benhar, MS,PRD91,033005,’15.



3. RCNP E398 experiment

Measurement of γ −rays ($\Gamma\gamma/\Gamma$) from O(p,p′) and C(p,p′) (P29

E398: I. Ou, Y. Yamada, D.Fukuda, T.Shirahige, T. Yano, T. Mori, Y. Koshio, M. Sakuda, (Okayama), A. Tamii, N.Aoi , M.Yosoi, E. Ideguchi, T. Suzuki, T. Hashimoto, C. Iwamoto, K. Miki, T. Ito, T. Yamamoto (RCNP), H. Akimune (Konan), T.Kawabata (Kyoto)

[Goal]: We measure the γ-decay probability($\Gamma\gamma/\Gamma$) (E_γ>5 MeV) from giant resonances of ^{16}O and ^{12}C, at ±1% stat. accuracy, as the functions of excitation energy (E_x).

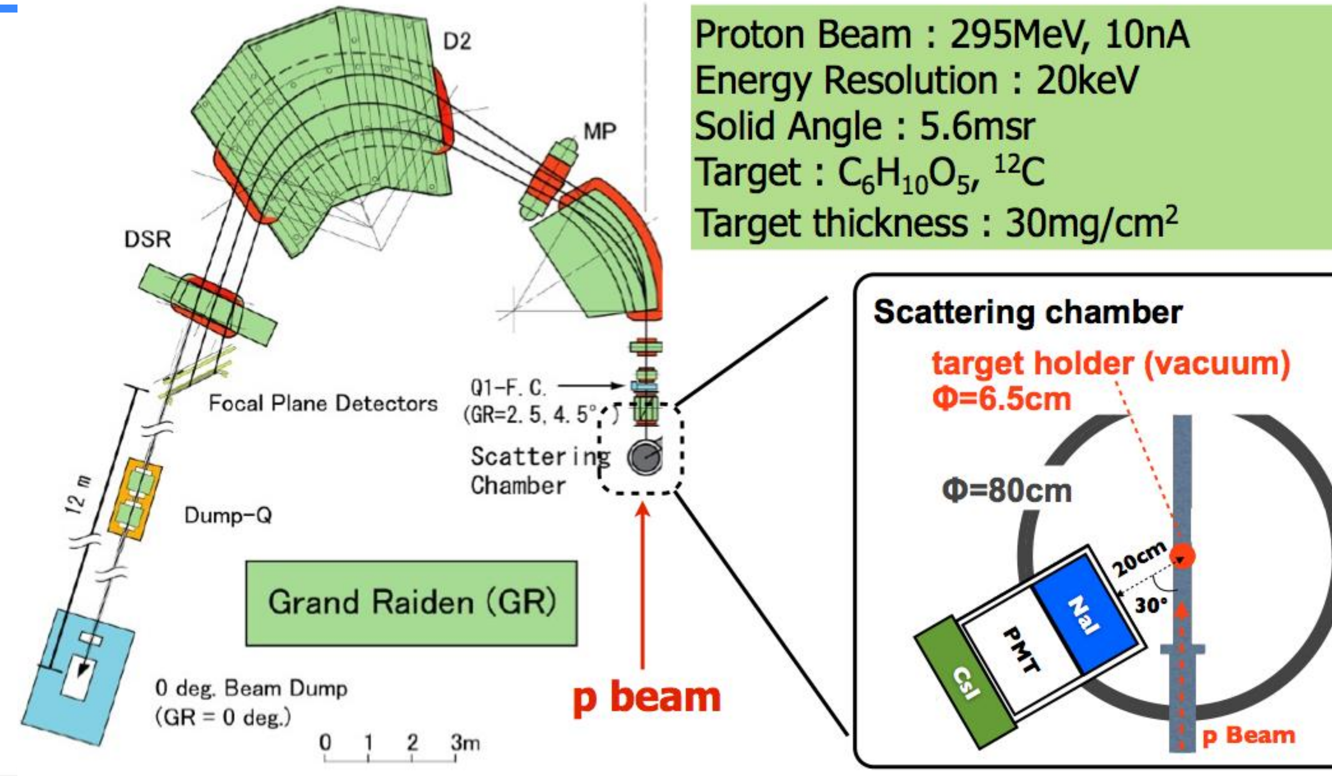
Definition: The γ-decay probability ($\Gamma\gamma/\Gamma$)(E_γ>5MeV)=
(Number of γ-rays observed for E_γ>5 MeV)/(Number of events excited in the range Ex=15-30 MeV, each Ex bin) →Fig.

[Importance]: Data for νO→νO*→γ and νC→νC*→γ do not exist and they are very important to neutrino physics. RCNP Grand-Raiden is the best place for this experiment.

-Proposal was approved in March, 2013 and Experiment was finished in May, 2014.

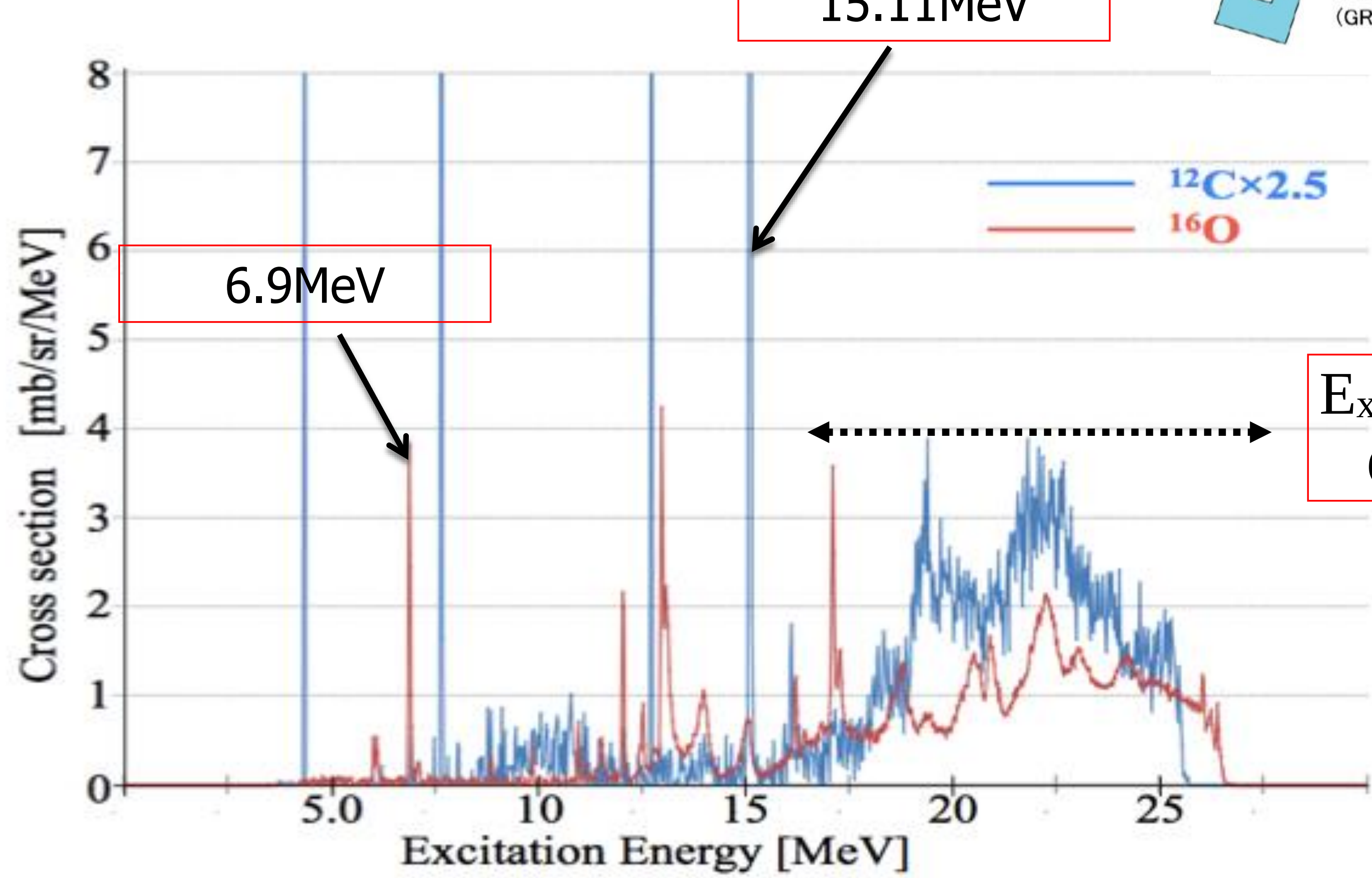
RCNP Grand-Raiden Spectrometer O,C(p,p')

See excellent Energy Resolution
Ex=Ep-Ep', ΔEx~20keV



Proton Beam : 295MeV, 10nA
Energy Resolution : 20keV
Solid Angle : 5.6msr
Target : $C_6H_{10}O_5$, ^{12}C
Target thickness : 30mg/cm^2

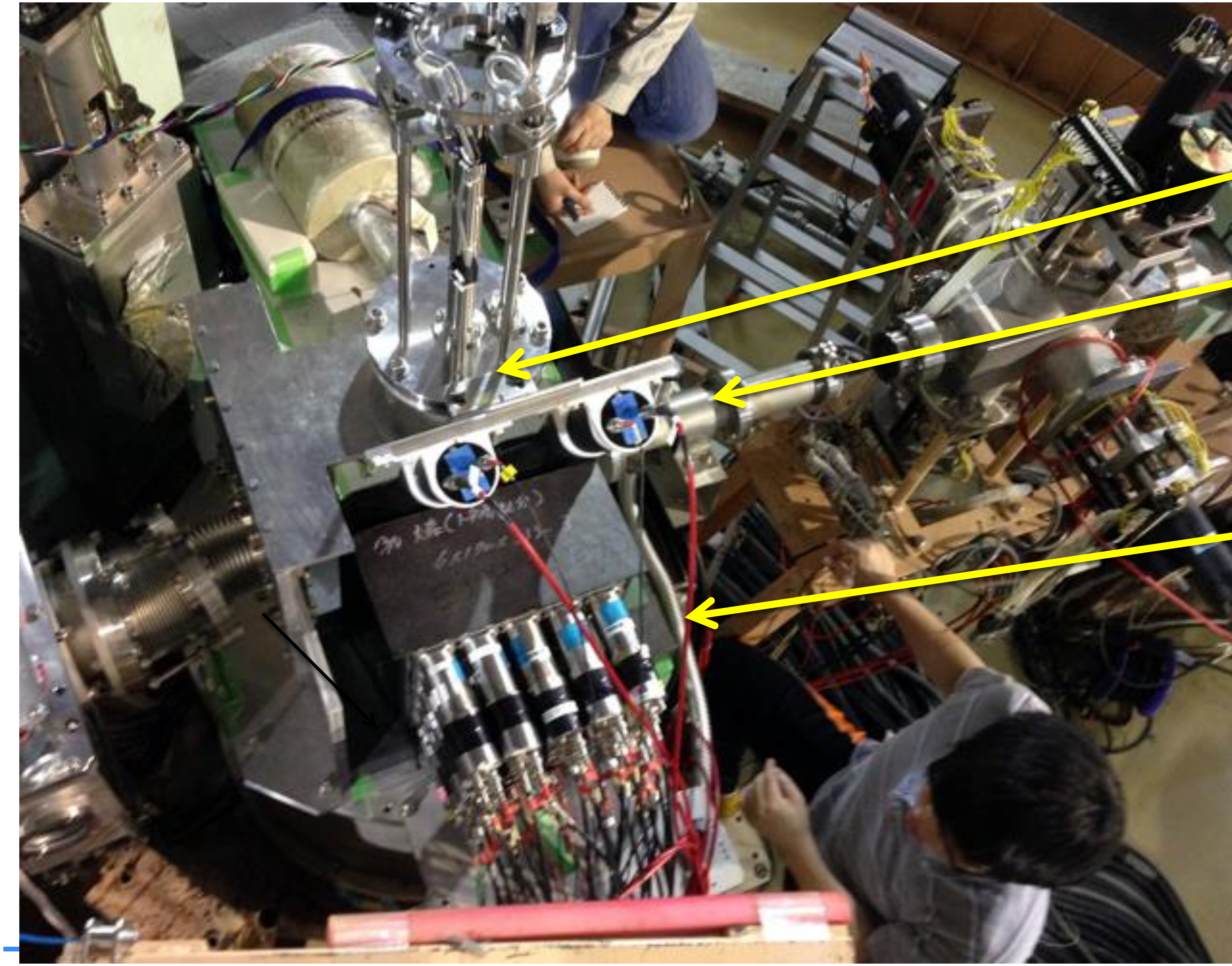
^{16}O,^{12}C(p,p') Rate at θ=0.4 deg. Ep=295MeV



E_x=16-30MeV
GDR/SDR

Ref. A. Tamii, H. Matsubara, et al.RCNP E249 & E299 Collaboration, 5-JAN-2011.

E398 (May 16-27, 2014)



Target(C,O)

Proton Beam
295MeV

NaI 5x5 array

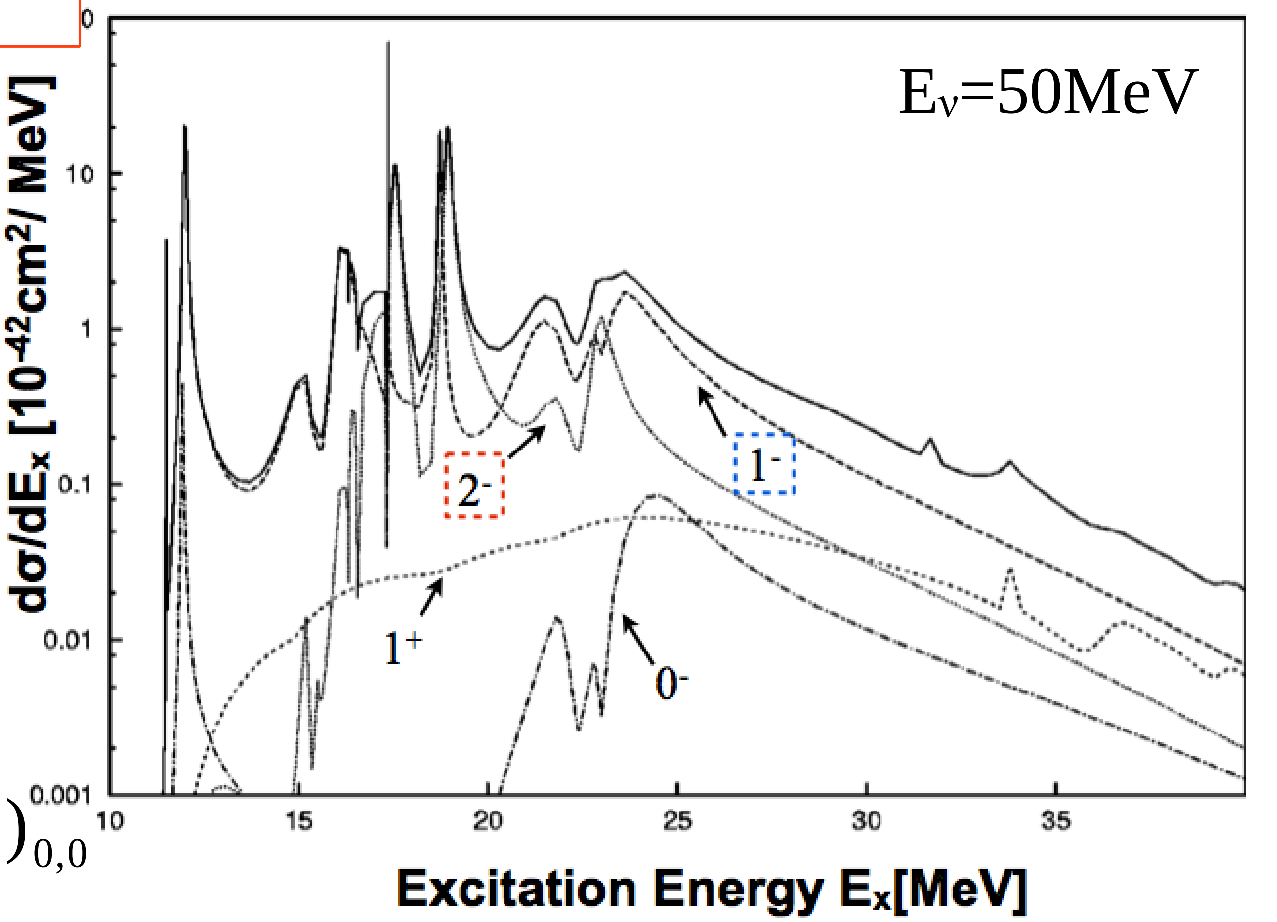
NC ν-^{16}O,^{12}C reaction

Ref. Jachowicz et al .,PRC59('99), Botrugno, Co', NPA761('05)

Axial Current Dominant:

Especially, Spin Dipole Resoance : J^P =2$^-$,1$^-$(T=1) Domiant. (1$^+$,15.1MeV for C)

^{16}O(ν,ν') Cross Section



✦NC Neutrino-Nucleus Cross Section :

ν+A→**ν**+A' : Nuclear Matrix Element

✦

$$J^{\mu}_{em} = (J^{\mu}_{V})_{1,0} + (J^{\mu}_{V})_{0,0}$$

$$J^{\mu}_{CC} = (J^{\mu}_{V})_{1,\pm1} + (J^{\mu}_{A})_{1,\pm1}$$

$$J^{\mu}_{NC} = \beta^{1}_{V}(J^{\mu}_{V})_{1,0} + \beta^{1}_{A}(J^{\mu}_{A})_{1,0} + \beta^{0}_{V}(J^{\mu}_{V})_{0,0} + \beta^{0}_{A}(J^{\mu}_{A})_{0,0}$$

$$= (J^{\mu}_{V})_{1,0} + (J^{\mu}_{A})_{1,0} - 2\sin^2\theta_W J^{\mu}_{em} \quad [+(J^{\mu}_{A})_{0,0}]$$

✦GDR (J^p=1$^-$,ΔT=1,ΔS=0,ΔL=1): $f_1(r)Y_1^m\tau_3$

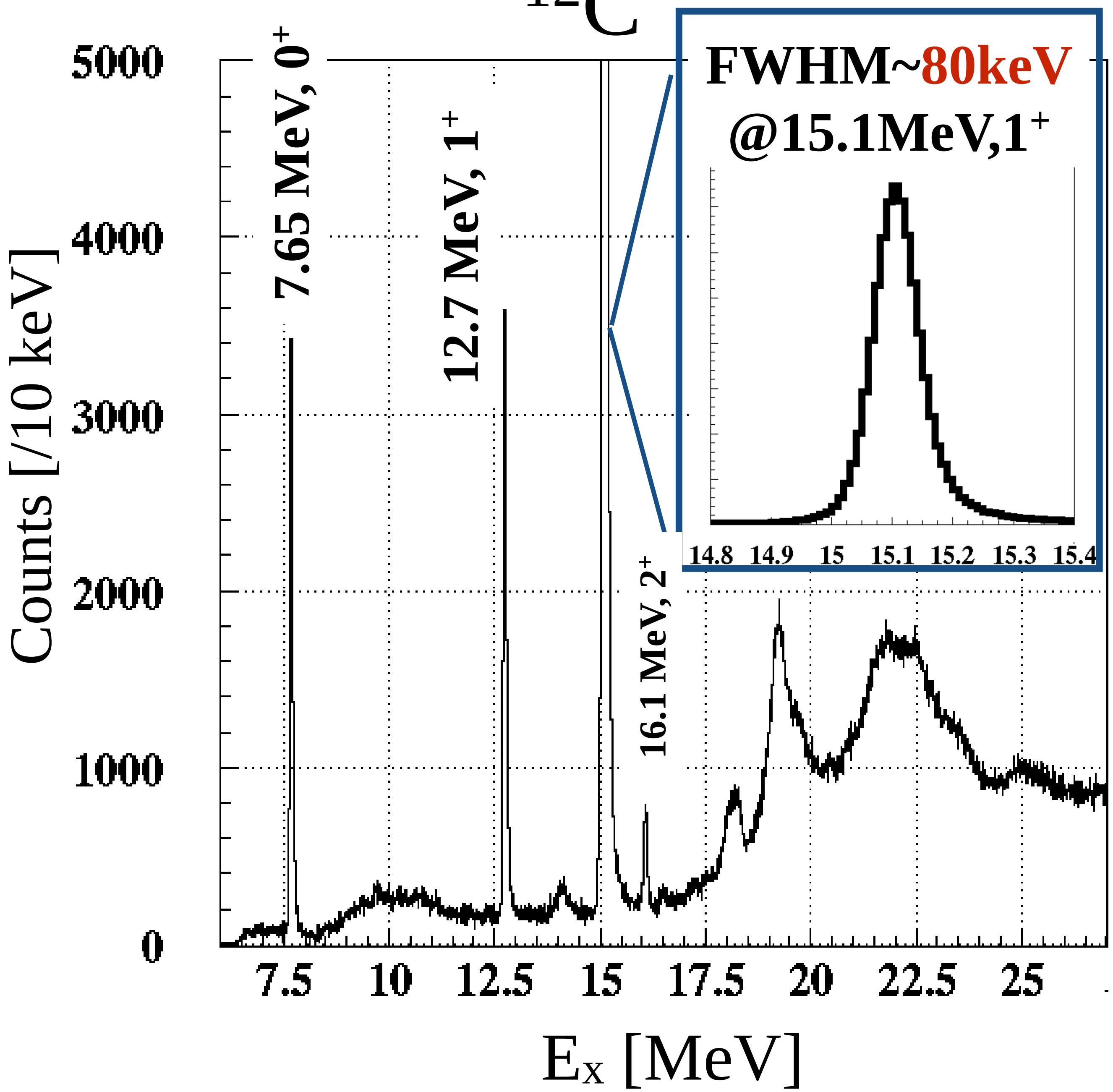
Spin Dipole R (J^p=0$^-$,1$^-$,2$^-$, ΔT=1,ΔS=1,ΔL=1): $\vec{\sigma} f_1(r)Y_1^m\tau_3$

M1 (J^p=1$^+$,ΔT=1,ΔS=1,ΔL=0): $\vec{\sigma} f_0(r)\tau_3$

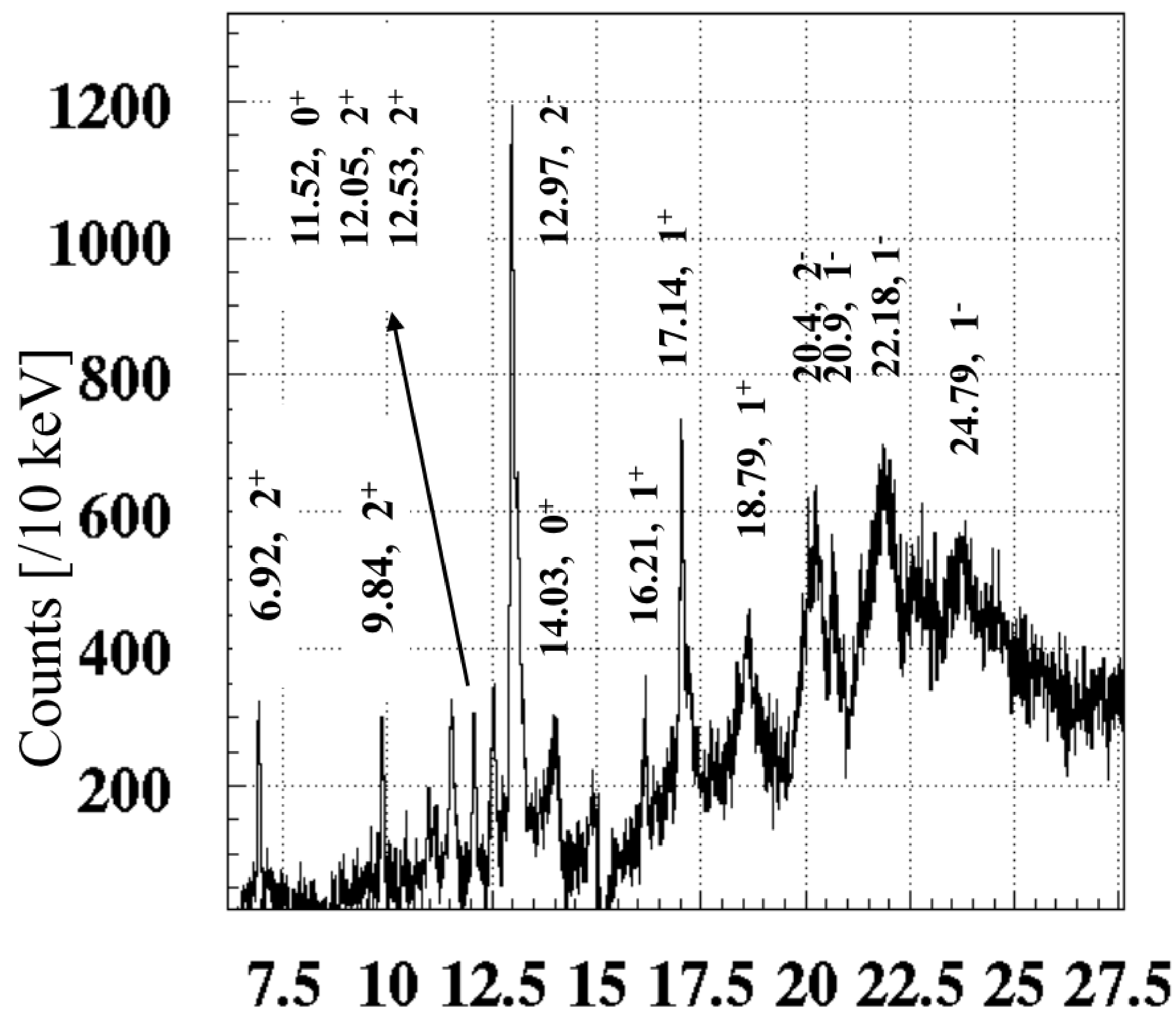
3. Results: (1) Excited States ($E_x=E_p-E_{p'}$) (C and O)

Each observed peak is consistent with existing data (Table of Isotopes, 8th ed**).**

^{12}C



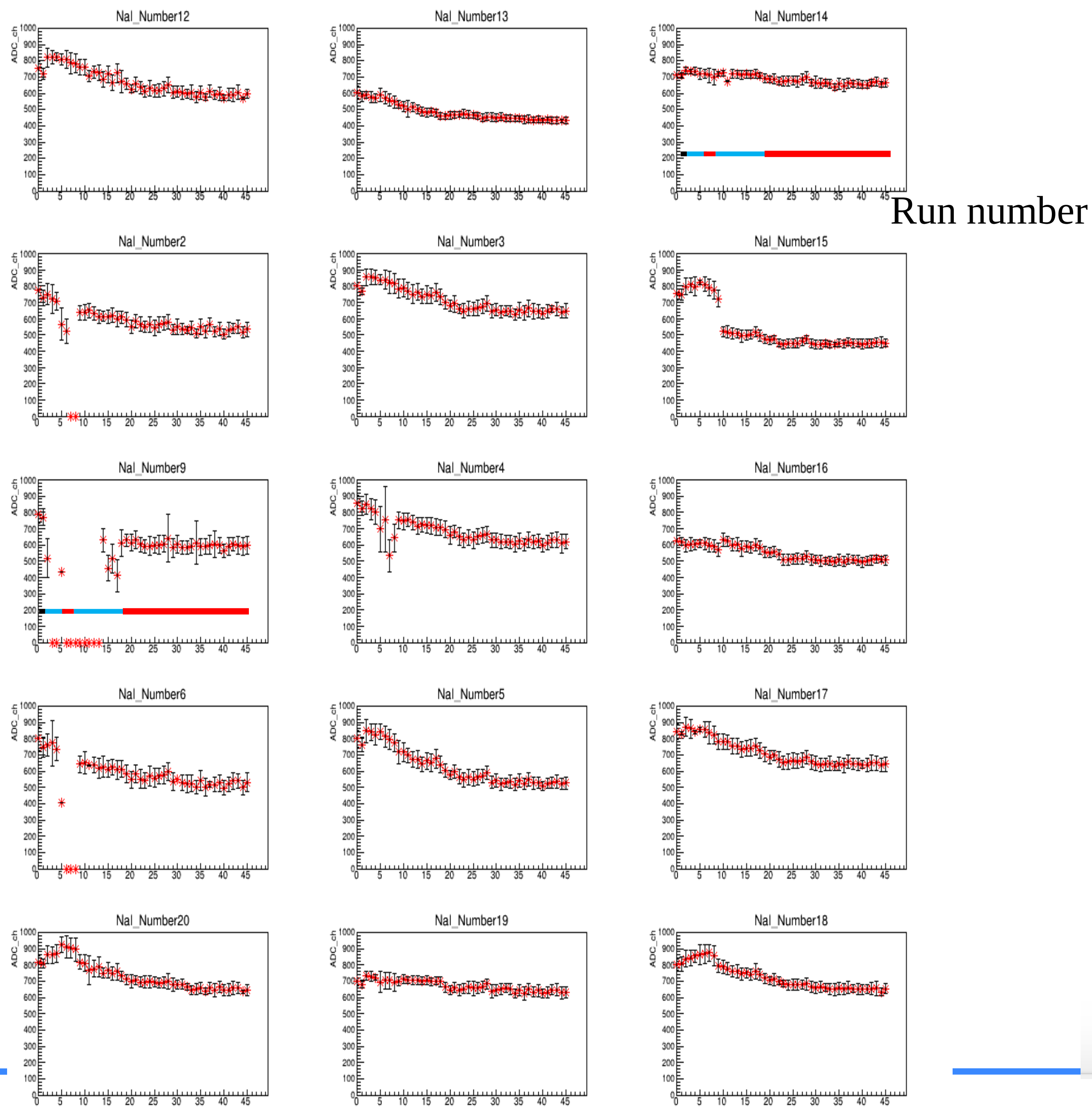
^{16}O

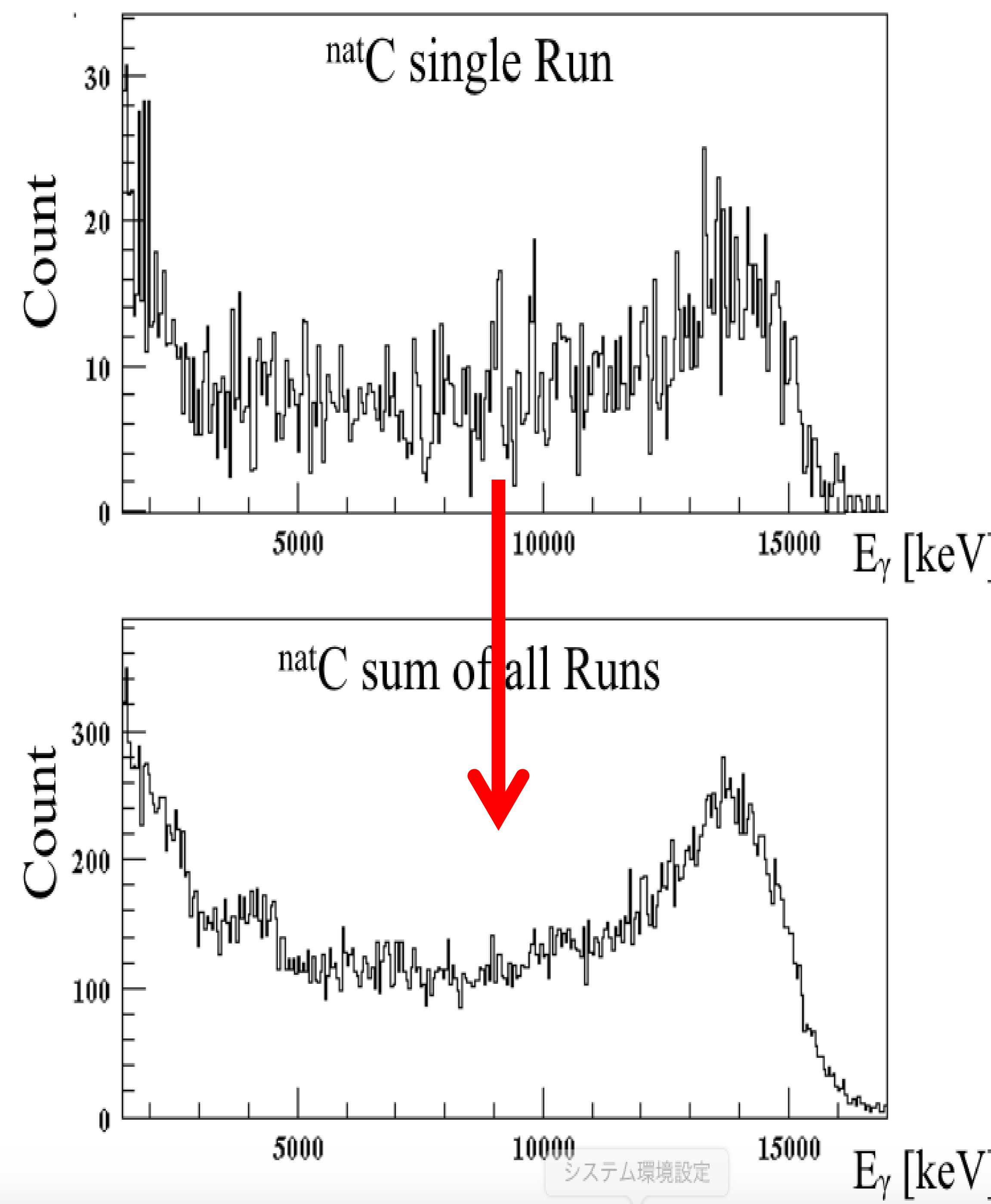


Data :C target, 0.5nA, 2hrs & $C_6H_{10}O_5$ target, 0.5nA, 2hrs

In-situ Gain Calibration using C(15.1MeV) during the experiment (May 16-27, 2014)

The pulse-height of NaI counters decreased during the experiment. We corrected it on run-by-run basis so that the





Results: Gamma Spectrum (I.Ou (E398), presented at NuInt15)

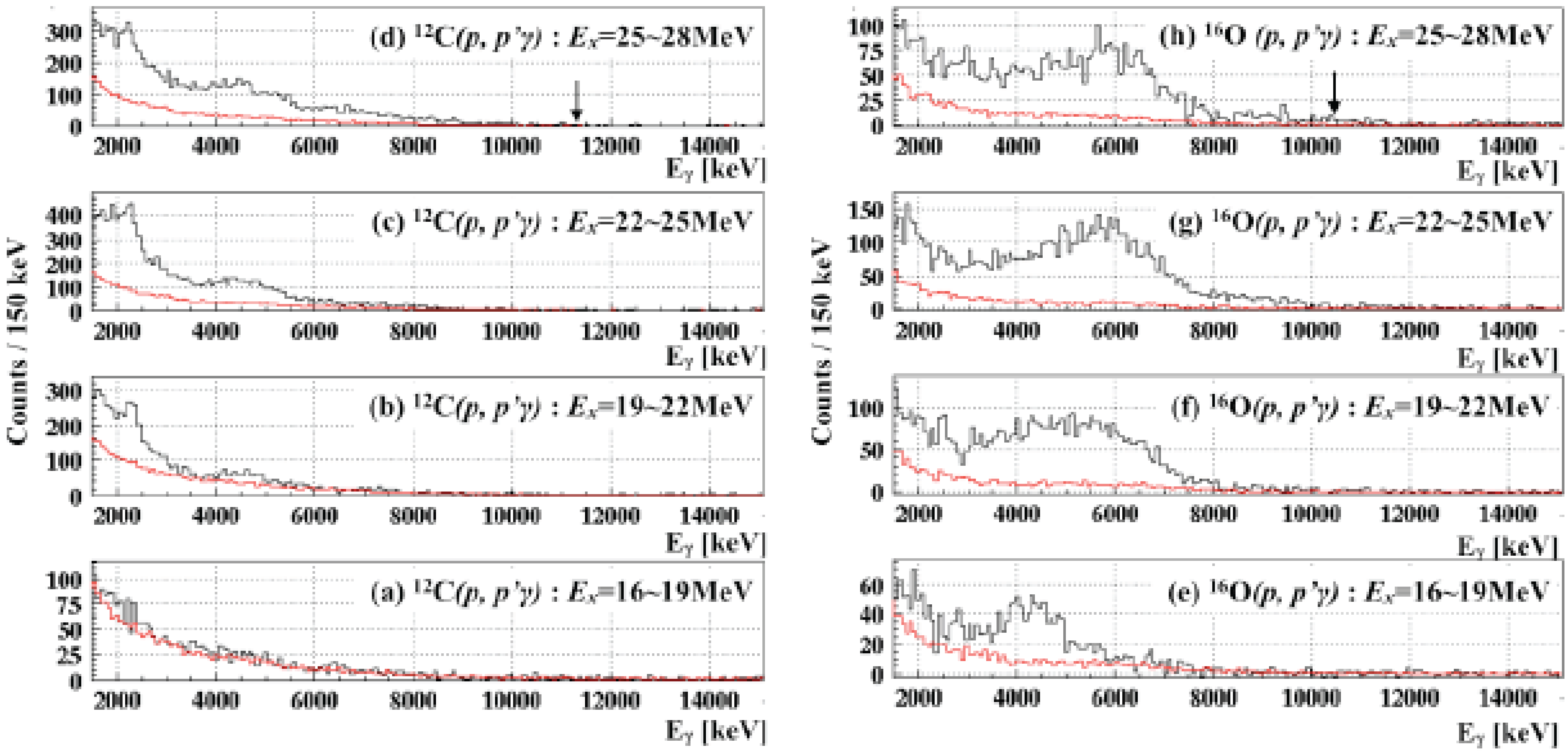
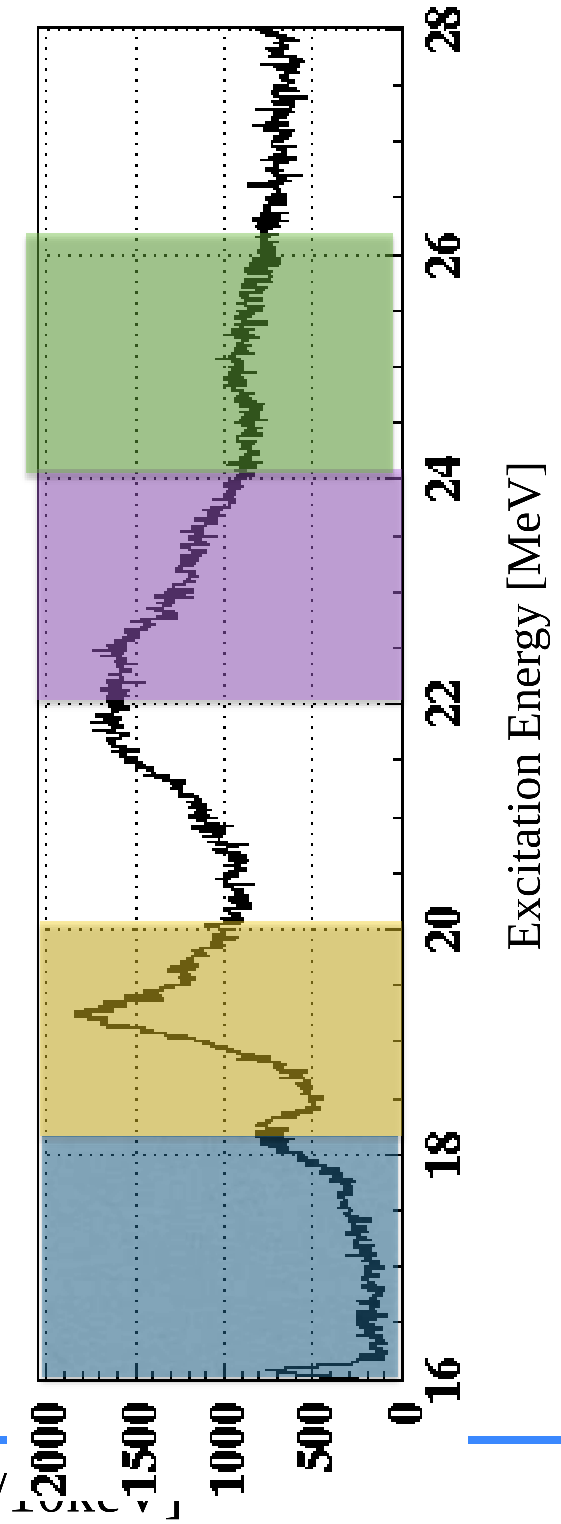
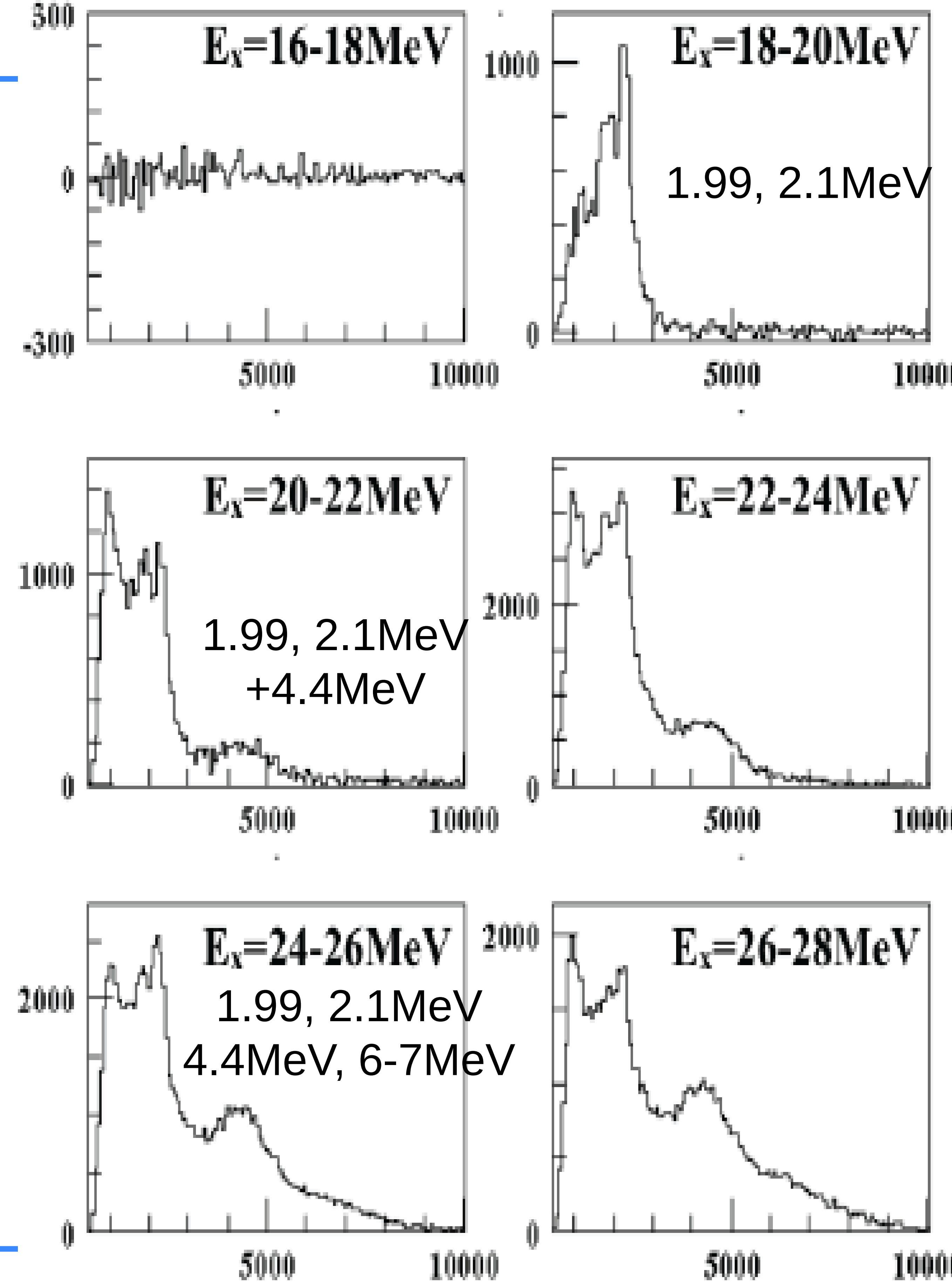


Figure 4. Coincidence γ-ray spectra (black line) with the 3 × 5 NaI array from giant resonances of ^{12}C (left) and ^{16}O (right) for different excitation energy region along with accidental coincidence γ-ray spectra (red line). Allows denote the separation energies of daughter nuclei.

γ-ray from giant resonance: ^{12}C (Using all data corrected for the gain shift.) (P20

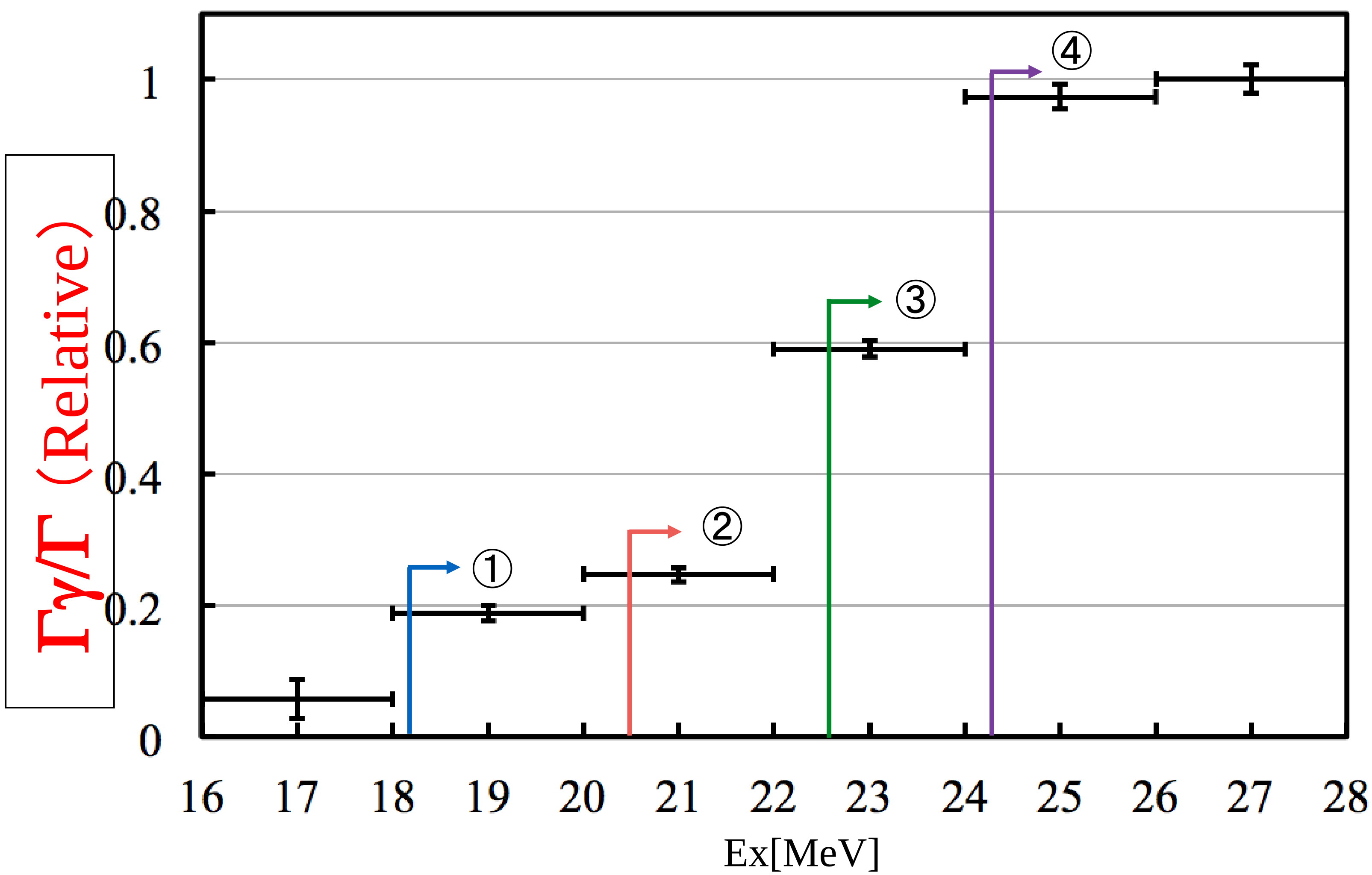
- Left：Excitaion energy of ^{12}C (Ex)
- Right：r-ray specrum for each Ex bin.

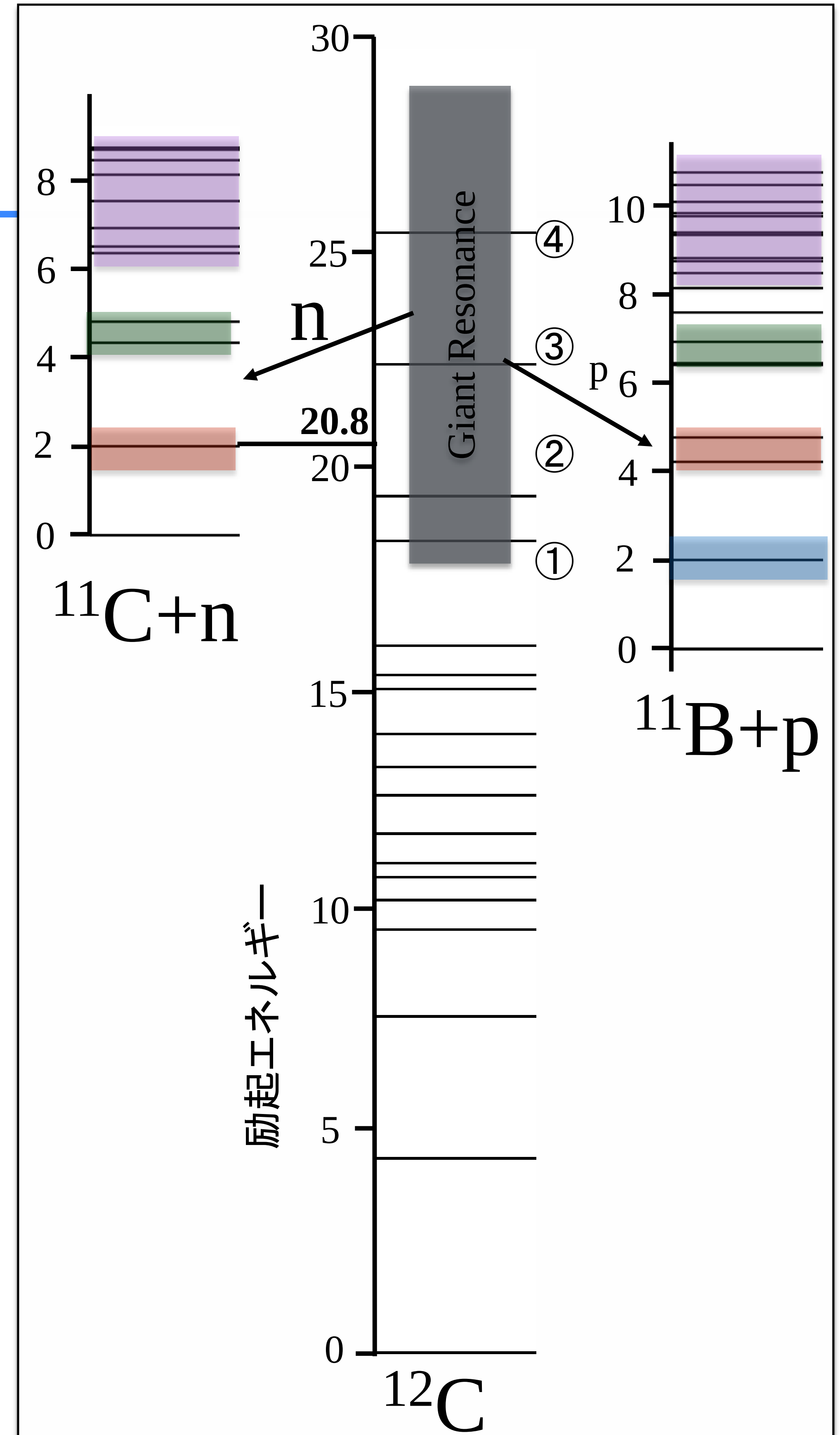




4. ^{12}C γ-decay probability (Γγ/Γ)

$$\Gamma\gamma/\Gamma = \frac{\text{Number of }\gamma\text{-rays detected}(1.5\,\text{MeV}<E\gamma<12\,\text{MeV})}{\text{Number of excited states (Ex)}}$$



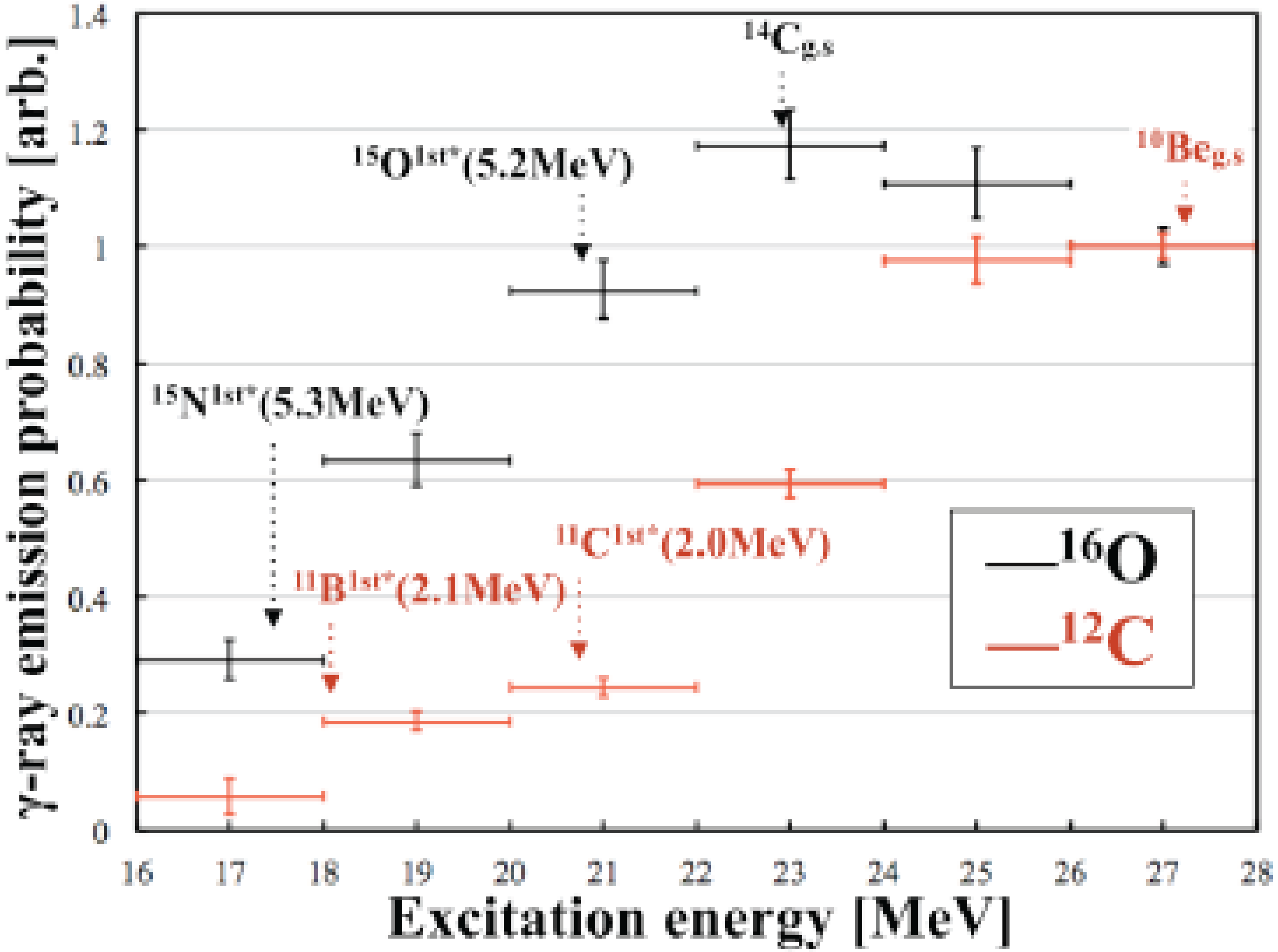


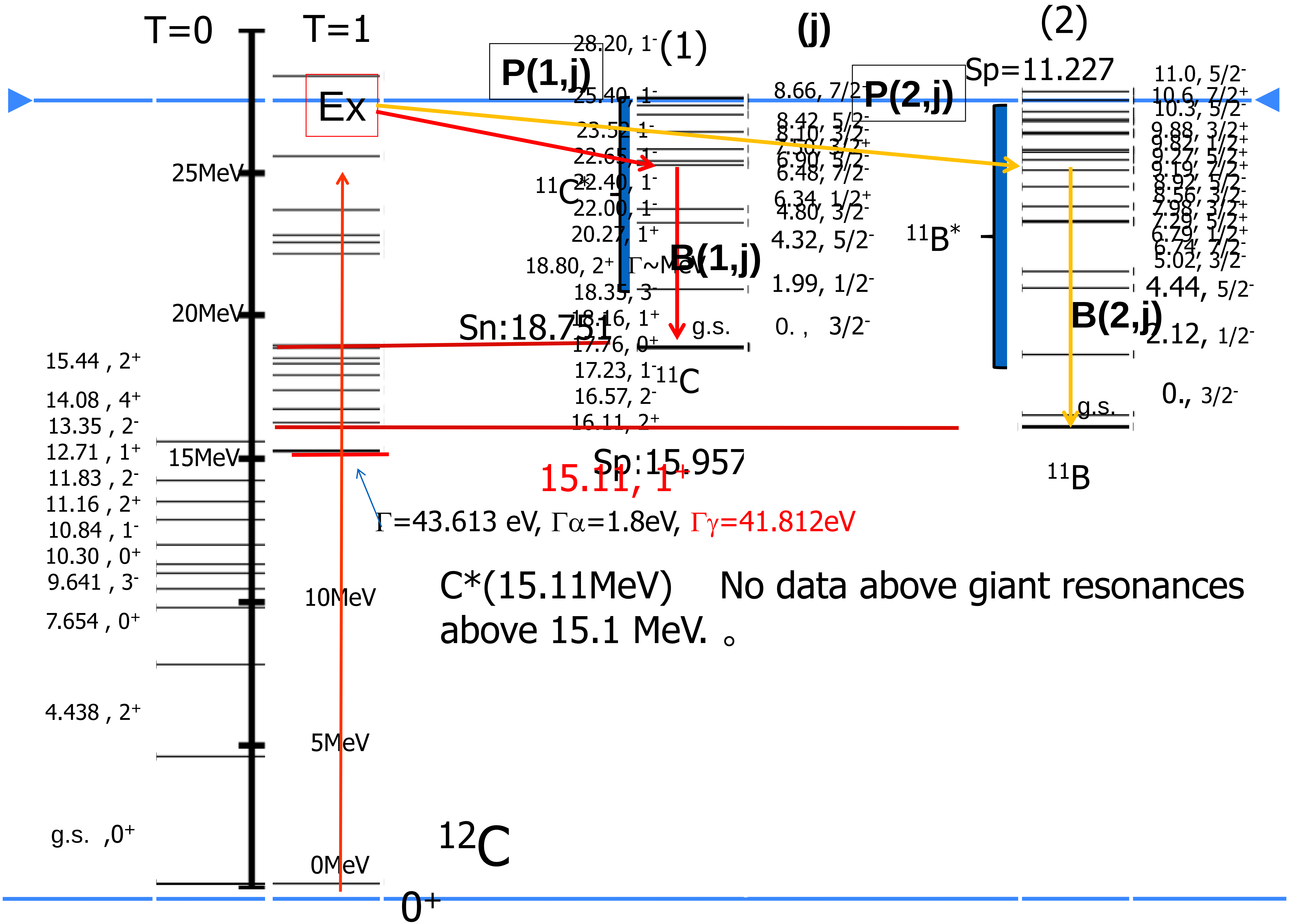
The observed rate is consistent with Langanke's prediction qualitatively. We will determine the decay probability (20%) after we estimate the γ-ray detection efficiency.

^{12}C and ^{16}O: γ-decay probability ($\Gamma\gamma/\Gamma$)

(I.Ou (E398), presented at NuInt15)

The observed rate is consistent with Langanke's prediction qualitatively.





C*(15.11MeV) No data above giant resonances above 15.1 MeV. 。

CASCADE

CASCADE Code (Puhlhofer('77), Harakeh('87))

- Decay: nucleus-1 (E_1, J_1)→x + nucleus-2 (E_2, J_2)

x=p,n,d,α,t

$$R_x d\varepsilon_x = \frac{1}{\hbar}\Gamma_x(\varepsilon_x) = \frac{1}{2\pi\hbar}\frac{\rho_2(E_2,J_2,\pi_2)}{\rho_1(E_1,J_1,\pi_1)}\sum_{S=|J_2-S_x|}^{J_2+S_x}\sum_{L=|J_1-S|}^{J_1+S} T_L^x(\varepsilon_x)d\varepsilon_x$$

$\varepsilon x = E_1 - E_2$ -Separation Energy, $S = J_2 + S_x$, is the channel spin

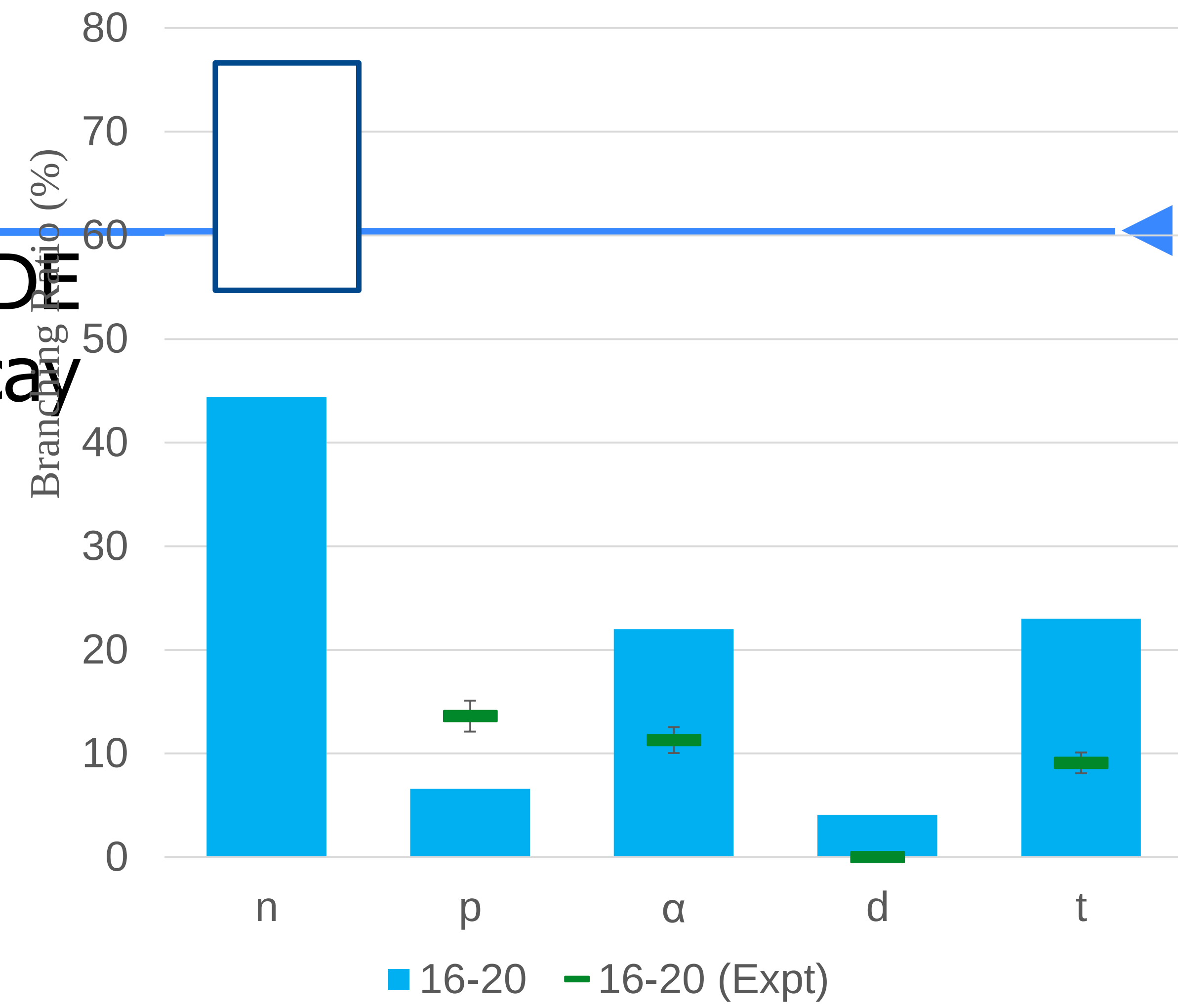
CASCADE calculations

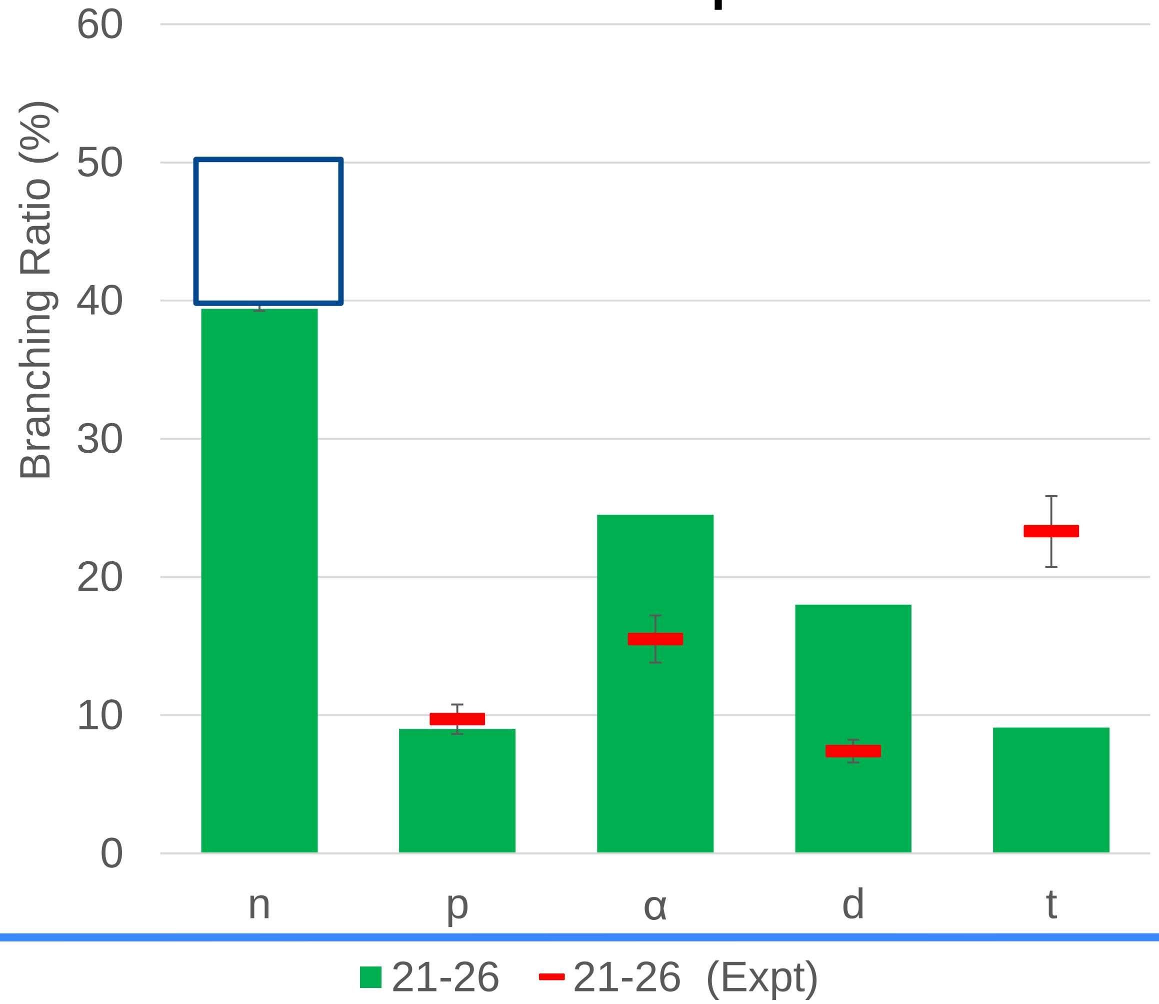
- We need to verify our CASCADE calculations with already measured decay rates of ^{11}B [M.Yosoi *PhdD Thesis*].
- Histograms (Cascade) vs

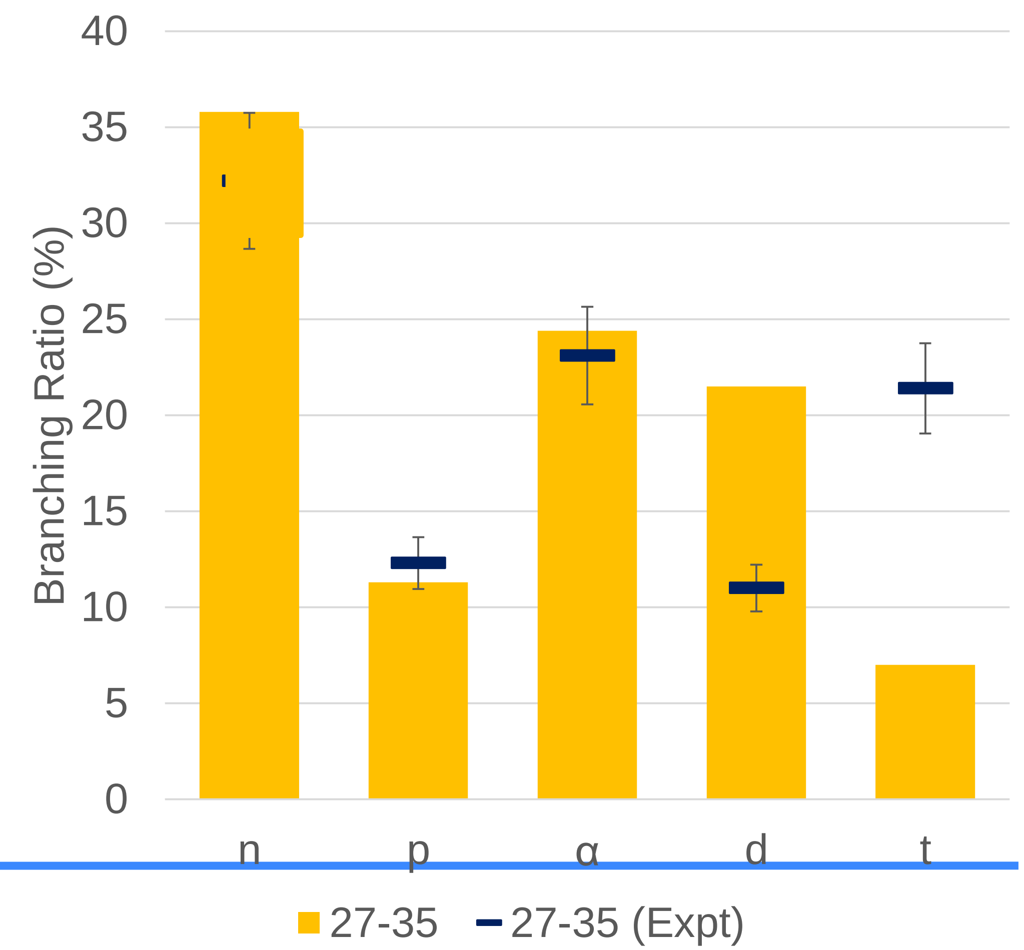
Data of ^{11}B Branching Ratios (%).

Ex=16-20MeV, 21-26MeV, 27-35MeV

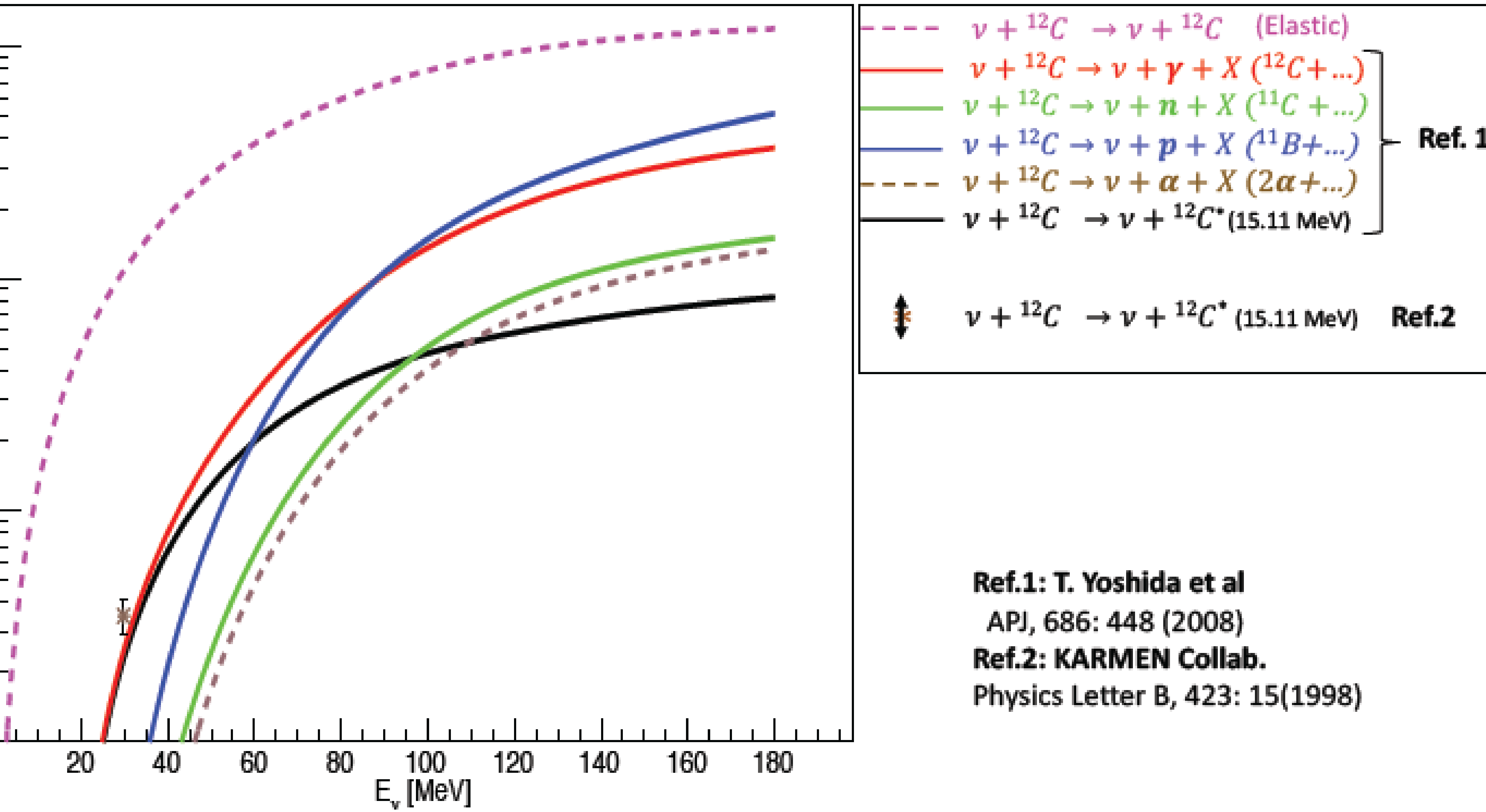
→Our calculations will improve.







neutrino interactions with carbon



Ref.1: T. Yoshida et al
APJ, 686: 448 (2008)
Ref.2: KARMEN Collab.
Physics Letter B, 423: 15(1998)

Summary

- We took data of the excitation energy and γ-ray energy spectrum from giant resonances in C, O(p,p’) reactions in 2014.
- Data are qualitatively consistent with Langanke et al.’s prediction in which the giant resonances above particle threshold decay to the ground state or excited states of daughter nuclei, and the latter emits γ-rays.]
- Hope to obtain the first measurements of Br(C,O, Ex=16-30MeV →γ) at 10-20% level.
- Need to calculate NC ν+O,C (1-,2-,1+) and combine Br(C*,O*→γ) , and finally obtain NC γ production cross section in the SN region.
- GR Forward Beamline has been improved. It accepts scattered protons at larger angles >4deg.
- After finishing off the first results, we like to propose an extension of the experiment to RCNP.

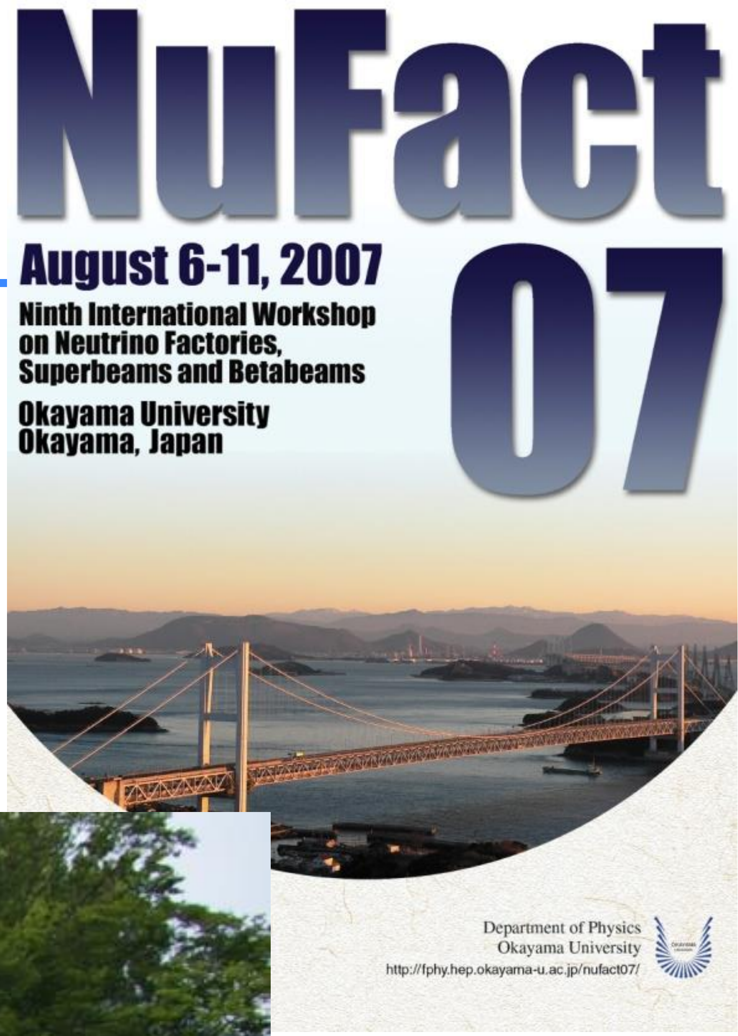
Workshop on Neutrino-Nucleus Interactions in the Few-GeV Region (NuInt01, KEK, Dec.13-16,2016)

- NuInt01 was organized just when K2K (the first long baseline neutrino oscillation experiment, PI K.Nishikawa) started producing new data on neutrino-nucleus interactions. MiniBooNE, MINOS about to start.
- J.Morfin and I hosted. Prof.Singh →

NuInt05 (Okayama, Sep.26-29, 2005)

JSPS Joint Seminar (India-Japan) at Okayama (NuFact07 Workshop) 2007 August 8-11

S.K.Singh (AMU) was there too.



Prof.Singh lecturing at Nustec-15 School at Okayama (Nov.8-14, 2015)

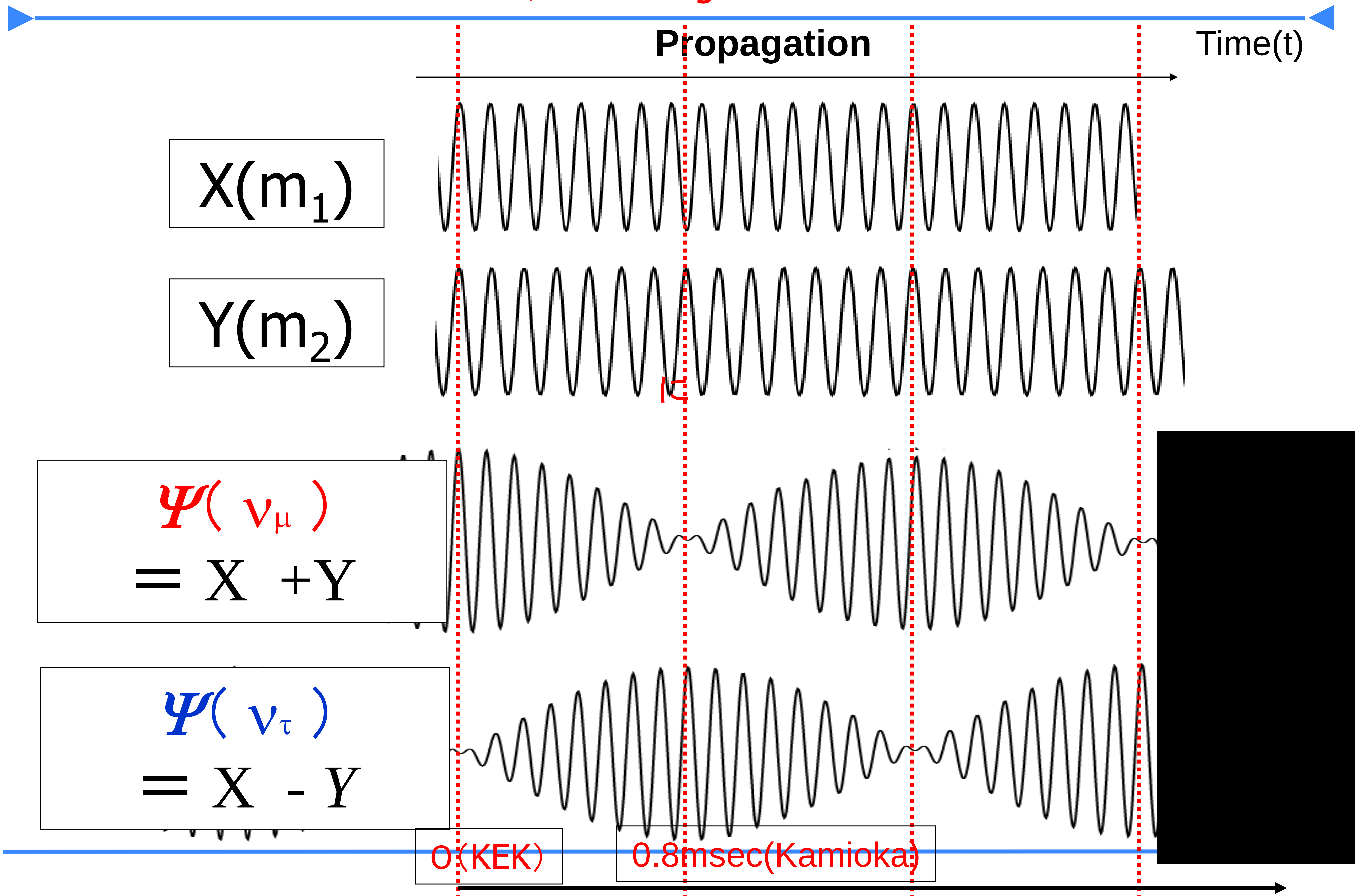
Prof. Athar also lectured at NuSTEC-15

Neut

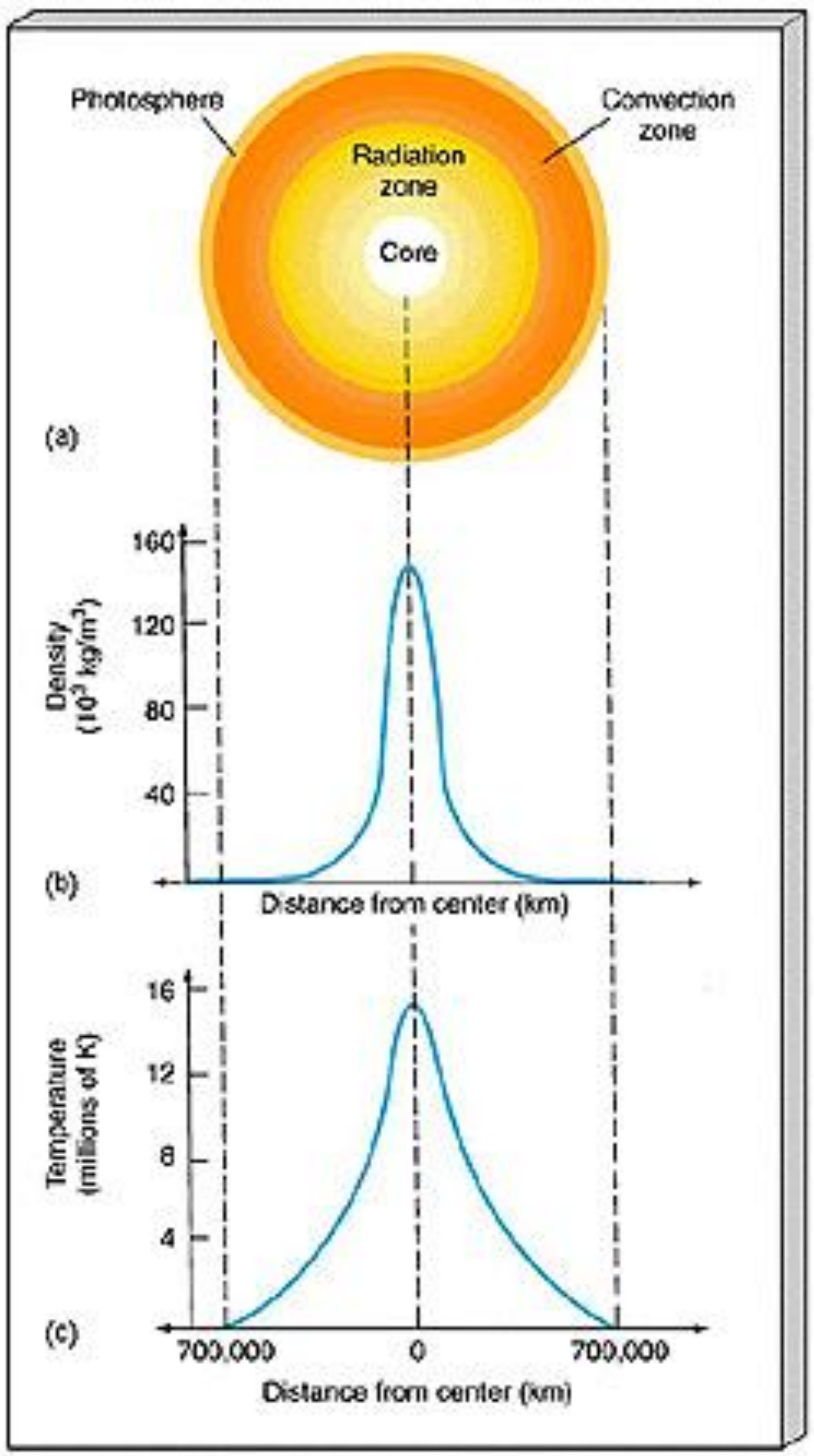
Neutrino Oscillation and Coupled Pendulum
(1) $\nu_\mu - \nu_\tau$ oscilllations (Prof.Kajita) and (2) Solar Neutrino Oscillations (Prof.MacDonald)

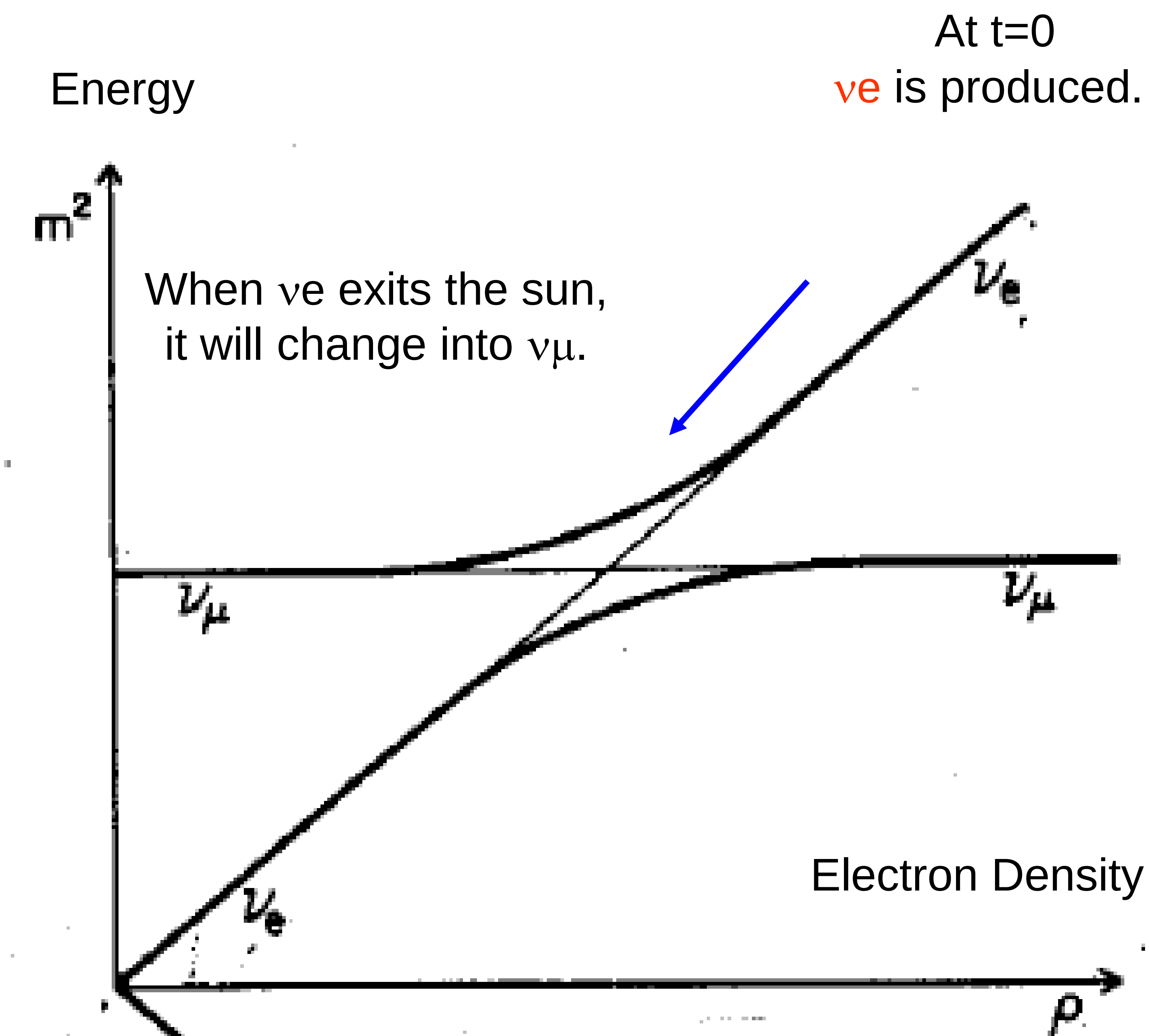
Small mass difference will makes an interference(beat).

ν_μ will change into ν_τ.



Matter oscillation in the Sun (or in SuperNova)

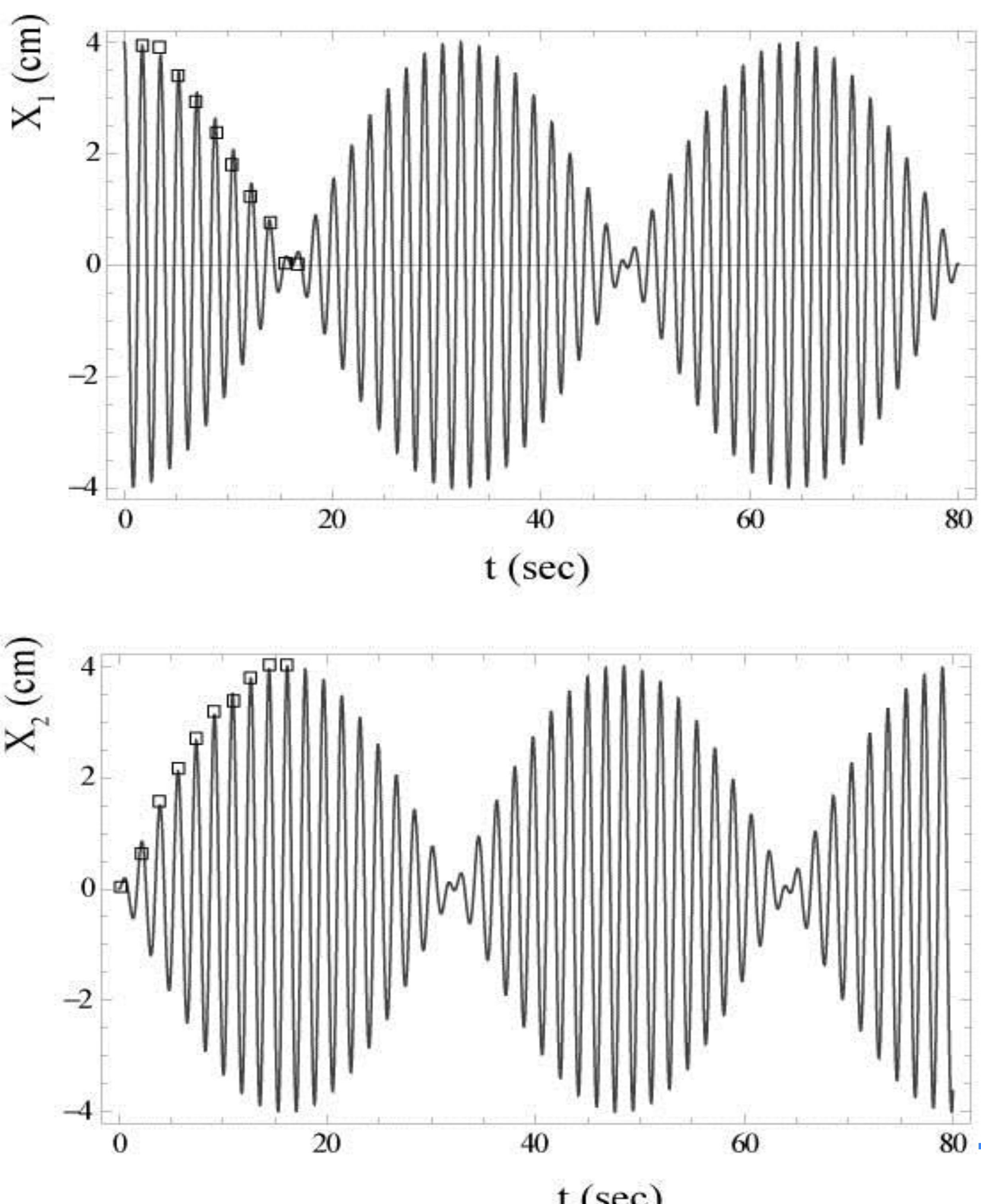


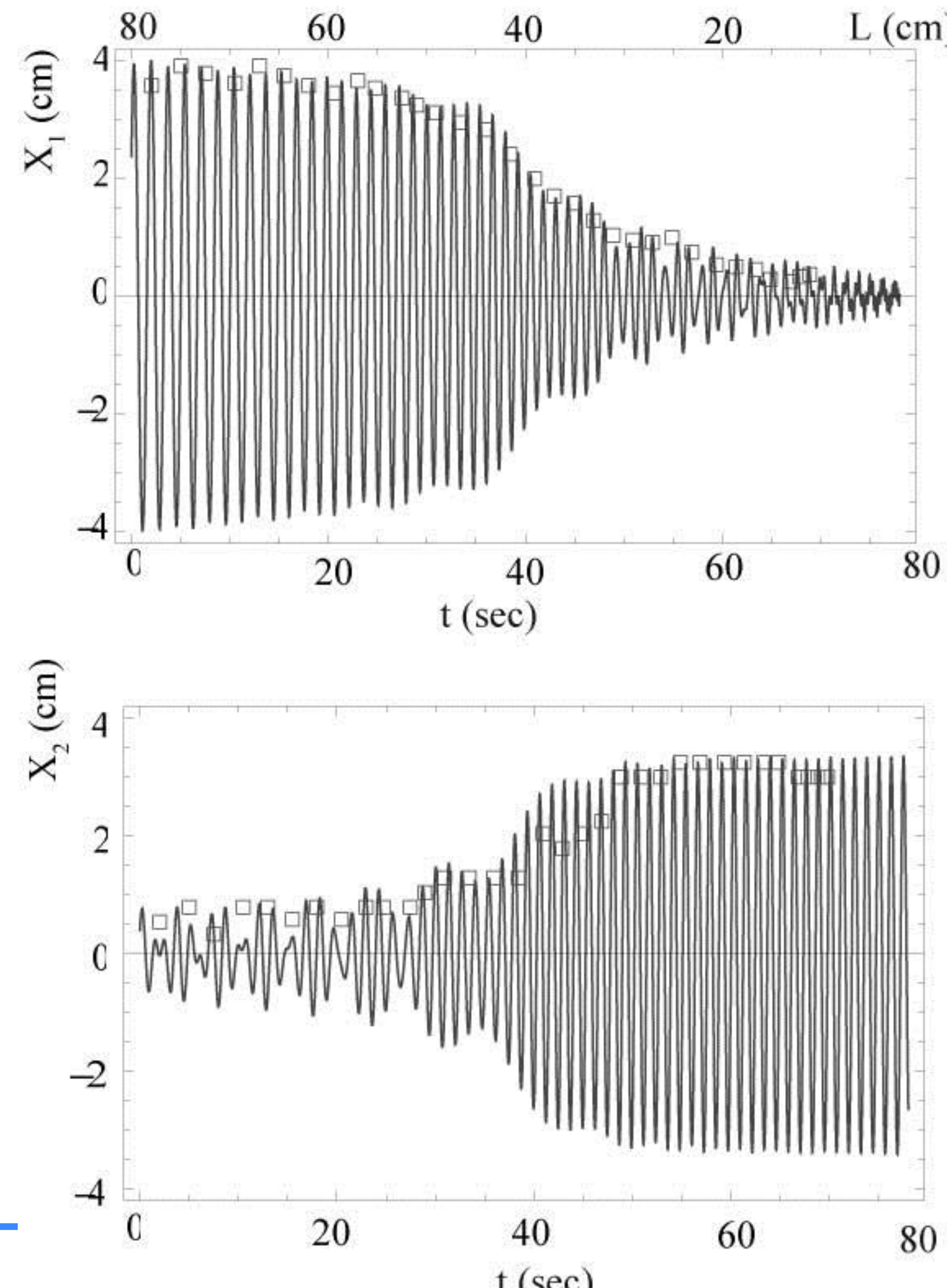


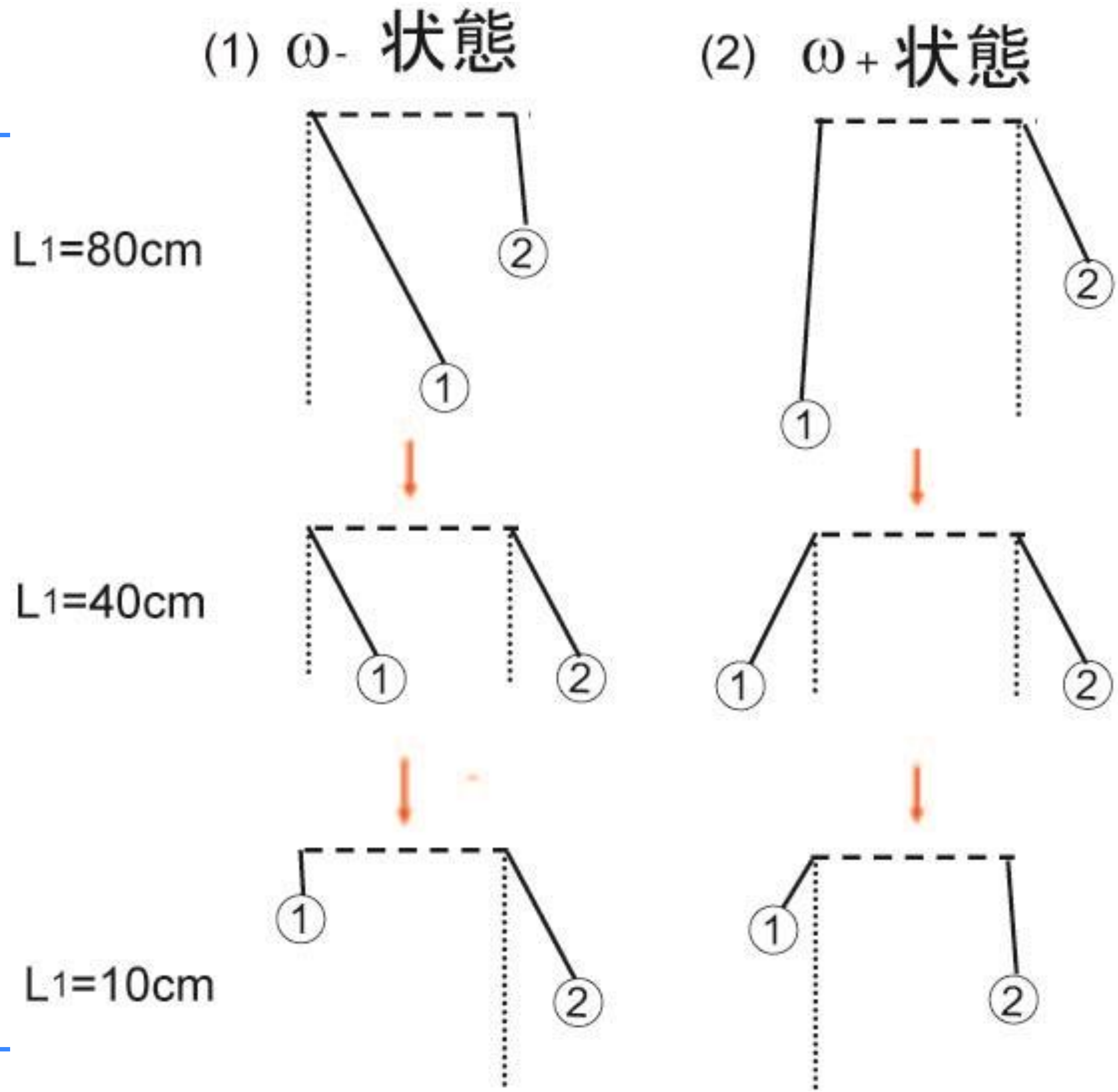
1．うなり　　2．断熱遷移

Coupled pendulum

1) Vacuum oscillation (beat)   2) Matter Oscillation



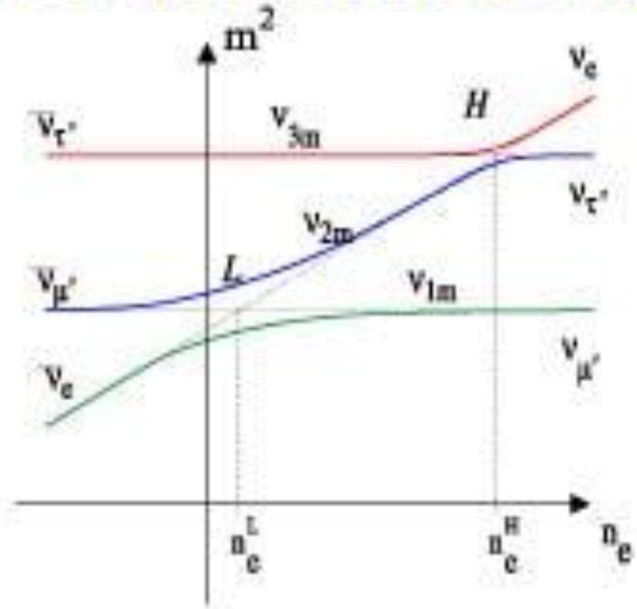



(1) ω- 状態
(2) ω+ 状態
L1=80cm
L1=40cm
L1=10cm
①
②

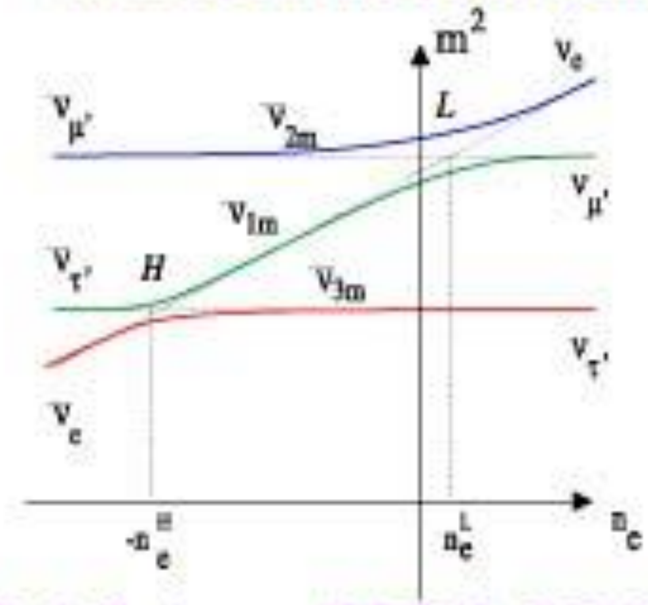
Dighe @Neutrino08

MSW Resonances inside a SN

Normal mass ordering



Inverted mass ordering



AD, A.Smirnov, PRD62, 033007 (2000)

H resonance: $(\Delta m^2_{atm}, \theta_{13})$, $\rho \sim 10^3$–10^4 g/cc

- In ν ($\bar{\nu}$) for normal (inverted) hierarchy
- Adiabatic (non-adiabatic) for $\sin^2\theta_{13} \gtrsim 10^{-3}$ ($\lesssim 10^{-5}$)

L resonance: $(\Delta m^2_{\odot}, \theta_{\odot})$, $\rho \sim 10$–100 g/cc

- Always adiabatic, always in ν

Δ production and N→Δ transition form factors

$$< \Delta(p')| J^{\alpha} | N(p) > = < \Delta(p')| V^{\alpha} | N(p) > - < \Delta(p')| A^{\alpha} | N(p) >$$

$$< \Delta(p')| V^{\alpha} | N(p) >$$

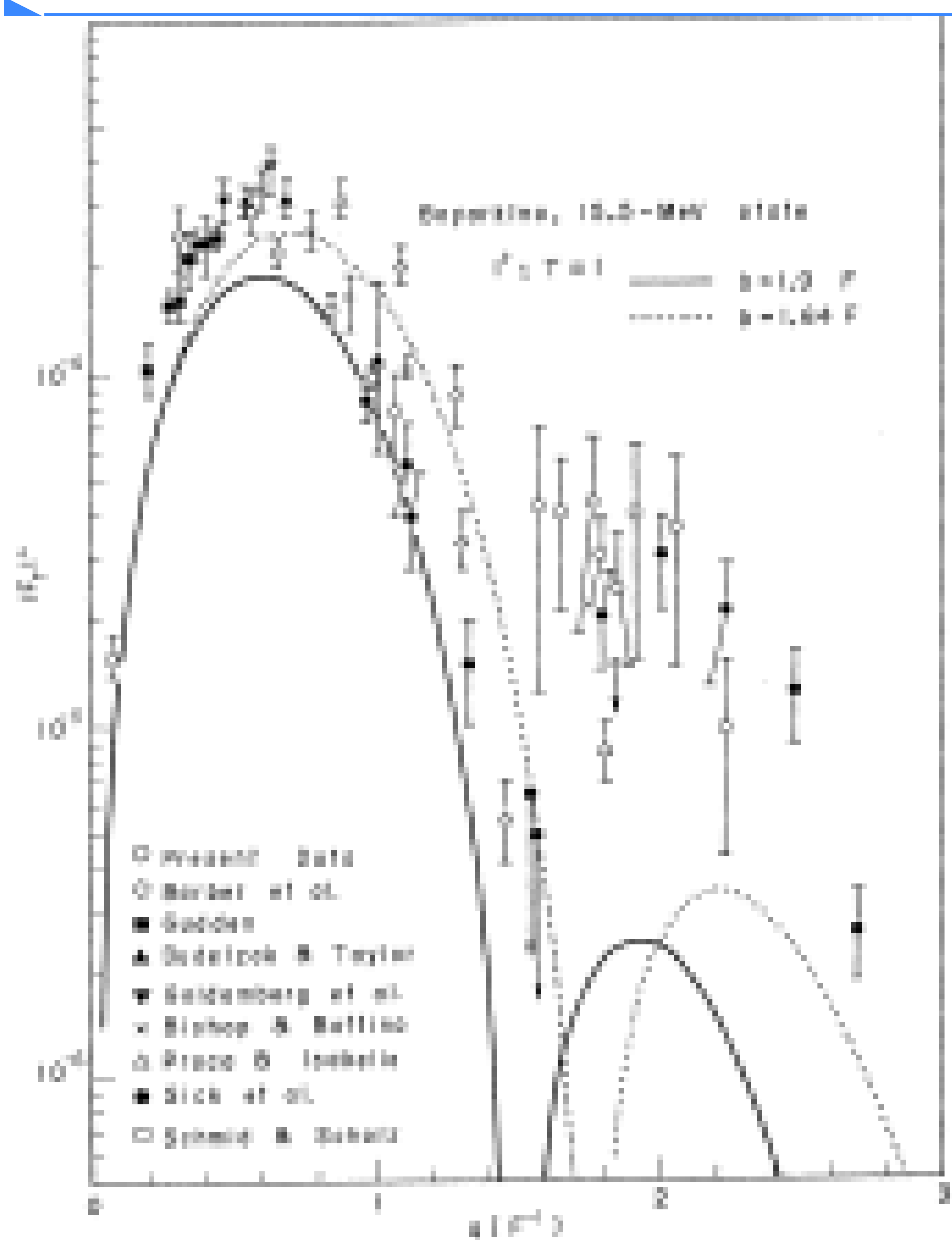
$$= \overline{\Psi}_{\mu}(p')\left[\frac{C_3^V(Q^2)}{M}(g^{\mu\alpha}\not{q} - q^{\mu}\gamma^{\alpha}) + \frac{C_4^V(Q^2)}{M^2}(g^{\mu\alpha}q\cdot p' - q^{\mu}p'^{\alpha}) + \frac{C_5^V(Q^2)}{M^2}(g^{\mu\alpha}q\cdot p - q^{\mu}p^{\alpha}) + C_6^V(Q^2)q^{\mu}q^{\alpha}\right]\gamma_5\Psi(p)$$

$$< \Delta(p')| A^{\alpha} | N(p) >$$

$$= \overline{\Psi}_{\mu}(p')\left[\frac{C_3^V(Q^2)}{M}(g^{\mu\alpha}\not{q} - q^{\mu}\gamma^{\alpha}) + \frac{C_4^V(Q^2)}{M^2}(g^{\mu\alpha}q\cdot p' - q^{\mu}p'^{\alpha}) + C_5^V(Q^2)g^{\mu\alpha} + \frac{C_6^V(Q^2)}{M^2}q^{\mu}q^{\alpha}\right]\gamma_5\Psi(p)$$

Congraturations on Prof. Shri K. Singh for the 70^{th} birthday! And on Prof. M.S. Athar for a great success and good organization of the Workshop.

Form Factors for Giant Resonances ^{12}C



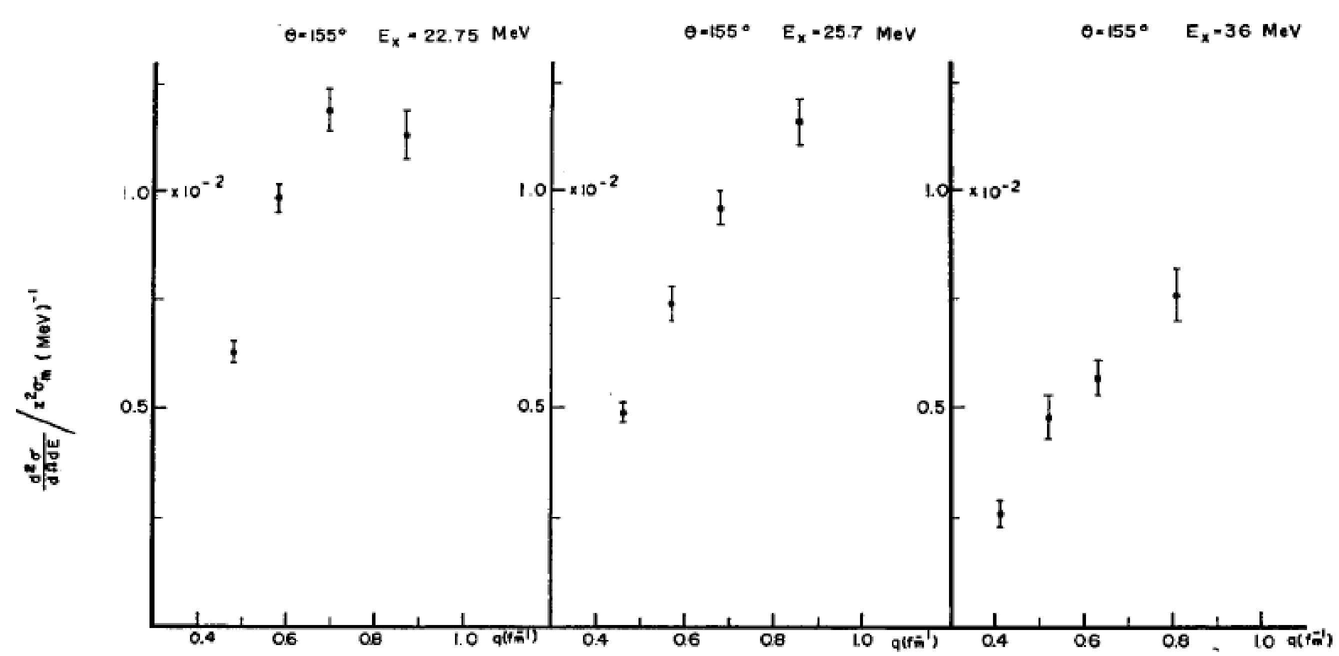
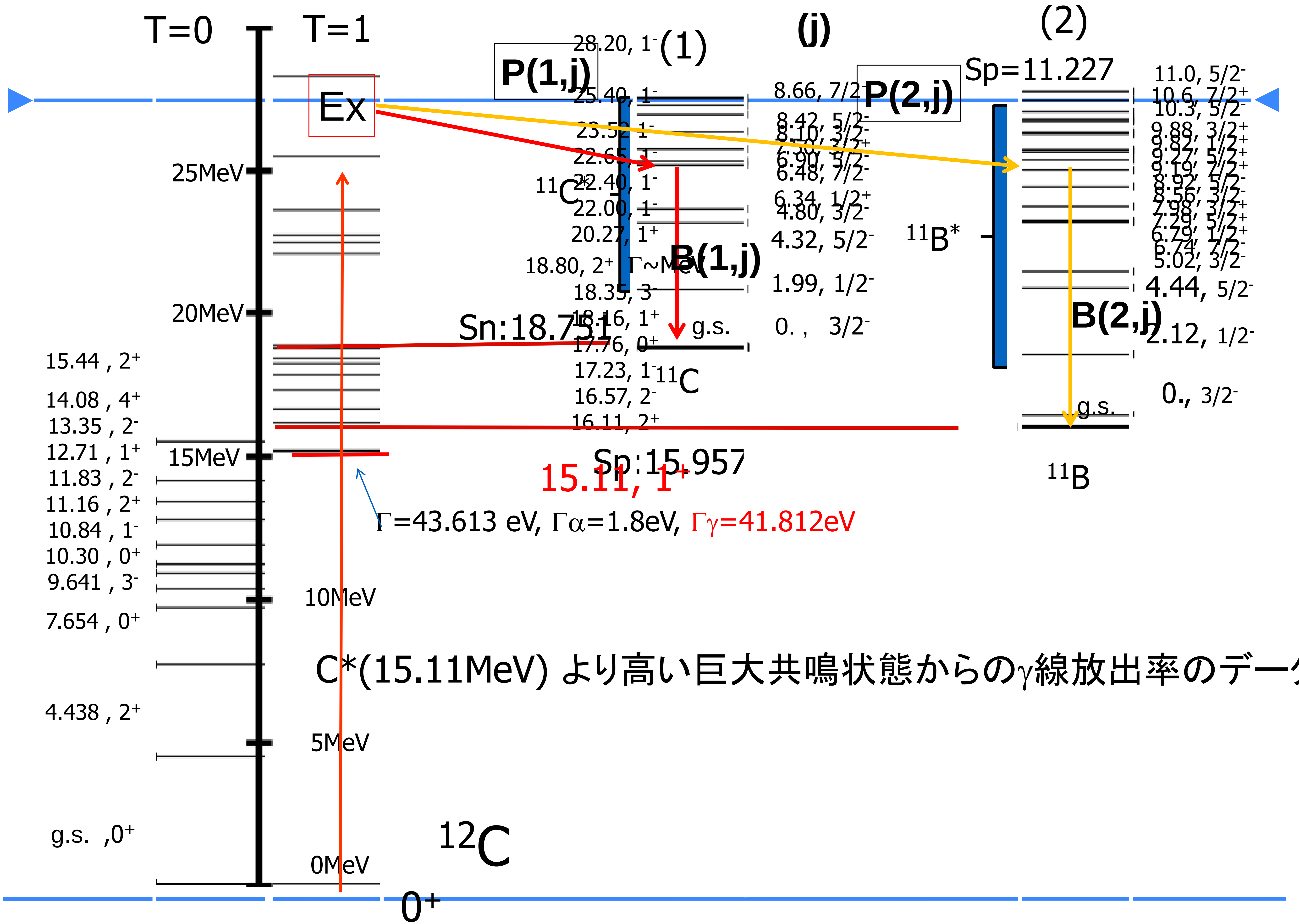


Fig. 8. Form factors per MeV at excitation energy E_x and $\theta = 155°$ as a function of the momentum transfer.

Table 2

Single particle energies in MeV for protons (p) and neutrons (n) states. The label WS indicates the theoretical results. The experimental energies have been deduced from the level schemes of the neighboring nuclei [21]. The horizontal lines indicate the Fermi surface. This is the discrete part of the configuration space used in the CRPA calculations

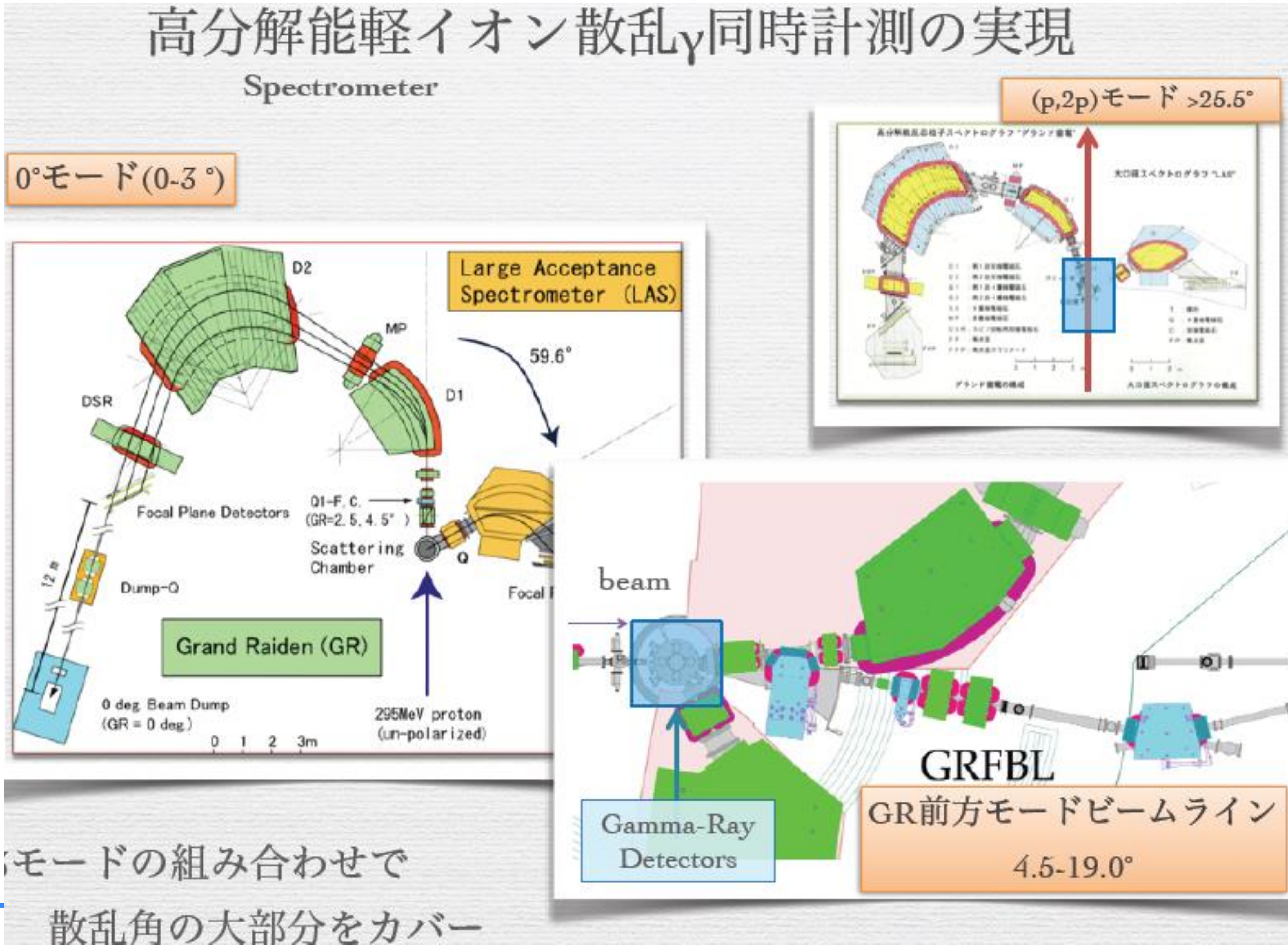
		^{12}C		^{16}O	
		WS	exp	WS	exp
p	1s1/2	−30.90		−29.90	
	1p3/2	−15.76	−15.96	−16.92	−18.44
	1p1/2	−12.95	−1.94	−12.74	−12.11
	1d5/2	2.0		−3.76	−0.60
	2s1/2			−0.89	−0.10
n	1s1/2	−34.04		−33.98	
	1p3/2	−18.92	−18.72	−20.52	−21.81
	1p1/2	−15.06	−4.96	−16.63	−15.65
	1d5/2	−3.88	−1.10	−6.84	−4.14
	2s1/2	−1.96	−1.86	−3.90	−3.27
	1d3/2	1.6		−3.90	−3.27



T=0
T=1
Ex
25MeV
20MeV
15MeV
10MeV
5MeV
0MeV
15.44 , 2+
14.08 , 4+
13.35 , 2-
12.71 , 1+
11.83 , 2-
11.16 , 2+
10.84 , 1-
10.30 , 0+
9.641 , 3-
7.654 , 0+
4.438 , 2+
g.s. ,0+
12C
0+
P(1,j)
(1)
28.20, 1-
25.40, 1-
23.52, 1-
22.65, 1-
22.40, 1-
22.00, 1-
20.27, 1+
18.80, 2+
18.35, 3-
18.16, 1+
17.76, 0+
17.23, 1-
16.57, 2-
16.11, 2+
11C*
Γ~MeV
B(1,j)
g.s.
11C
Sn:18.751
Sp:15.957
15.11, 1+
Γ=43.613 eV, Γα=1.8eV, Γγ=41.812eV
(j)
8.66, 7/2-
8.42, 5/2-
8.10, 3/2-
6.90, 5/2-
6.48, 7/2-
6.34, 1/2+
4.80, 3/2-
4.32, 5/2-
1.99, 1/2-
0. , 3/2-
P(2,j)
(2)
Sp=11.227
11B*
11.0, 5/2-
10.6, 7/2+
10.3, 5/2-
9.88, 3/2+
5.02, 3/2-
4.44, 5/2-
2.12, 1/2-
0., 3/2-
B(2,j)
g.s.
11B
C*(15.11MeV) より高い巨大共鳴状態からのγ線放出率のデー

GRFBL (Grand-Raiden Forward Beam Line, RCNP, Osaka)

- Almost complete; operational this Spring- -A.Tamii (GRFBL workshop, Nov.28-29,2013)

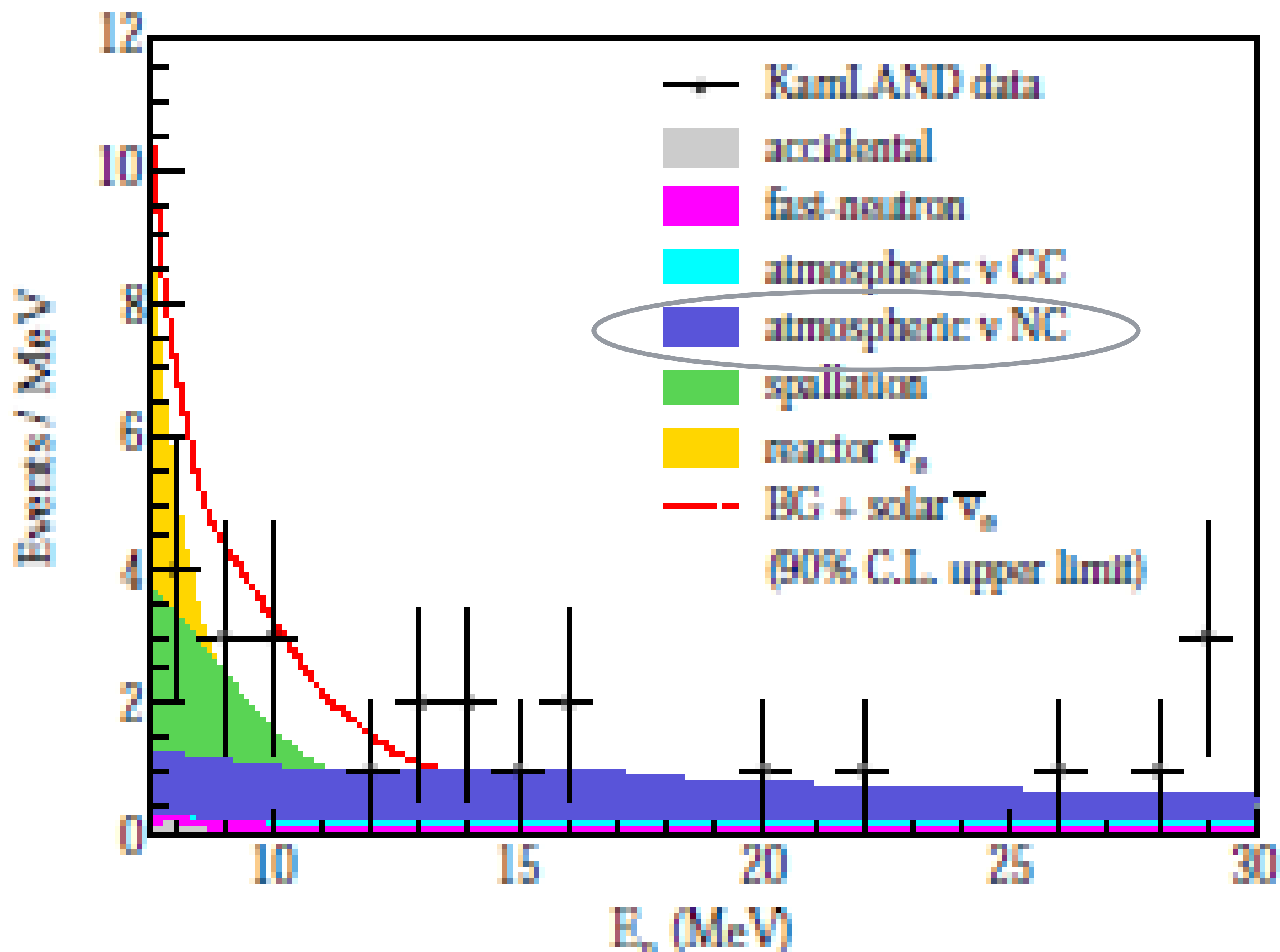


KamLAND's 25 $\overline{\nu}_e$ *Candidates* and MC estimation

A.Gando et al.,arXiv:1105.3516.

"Atmospheric ν NC background will be a challenge for future Large Liq.Scintillator detectors". KamLAND 論文からの引用。

Background	Number of events
Random coincidences	0.22 ± 0.01
Reactor $\overline{\nu}_e$	2.2 ± 0.7
^{9}Li	4.0 ± 0.3
Atmospheric ν (CC)	0.9 ± 0.2
Atmospheric ν (NC)	16.4 ± 4.7
Fast-neutron	3.2 ± 3.2
Total	26.9 ± 5.7



B. Spectral Function(IA)+FSI Model

(Benhar et al.,PRD72,2005 + Ankowski,Benhar,MS,arXiv:1404.5687)

- At NuInt12 and NuInt14, we mainly discussed about the contribution of 2p-2h/MEC to Quai-Elastic (QE) interactions, while the effect of Spectral Function S(p,E) to QE is agreed on, which is mainly 1p-1h (with initial SRC being taken into account). Now, almost all ν-exp's (SK, MINOS, Mirerva etc) use SF.
  In addition to a problem of 1p-1h/1p-2h/MEC, FSI is a key question.
- How quantitatively do we understand C,O(e,e') QE data with any models?? There are 2 important questions relevant to neutrino experiments:

1) How well we predict the peak of the QE cross section $d\sigma/dE_{e'}d(\cos\theta)$?? Equivalently, How well can we reconstruct the neutrino energy E_ν from (E_μ, $\cos\theta_\mu$) in ν-experiments??

-Ankowski1404.5687 (FSI) shows that the models without FSI cannot tell the peak, ie E_ν, within 10-15 MeV.

2) How good is the SFIA/FSI QE model at low energy, ie E<100MeV??
   - ✓ Is the model valid at E_ν <100 MeV??
   - ✓ Does the CC or NC QE process contributes to the SN neutrino detection, while it is considered as un-important at E_ν=20-50 MeV before??

-Ankowski1404.5687 (FSI) suggests YES!

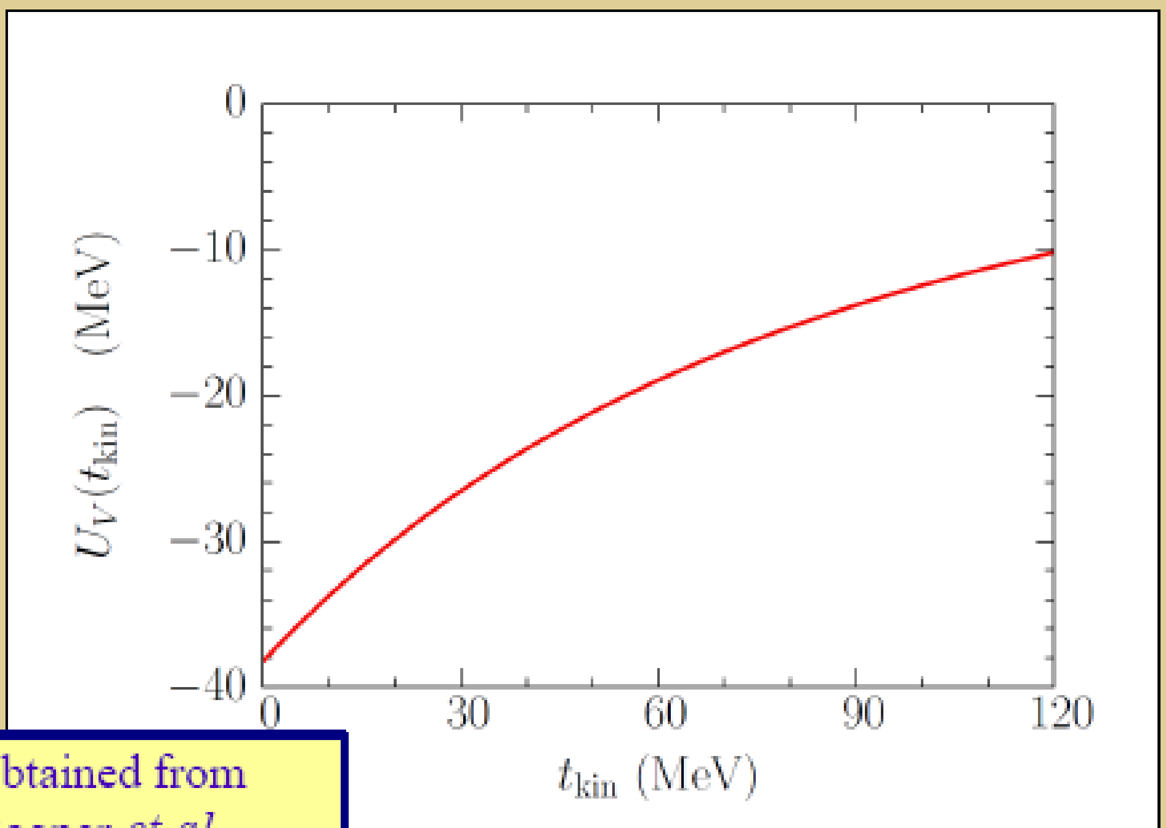
C(p,p') is well described by the optical potential model.

We included the result of optical potential in C(e,e').

e+"p"→e+"p"

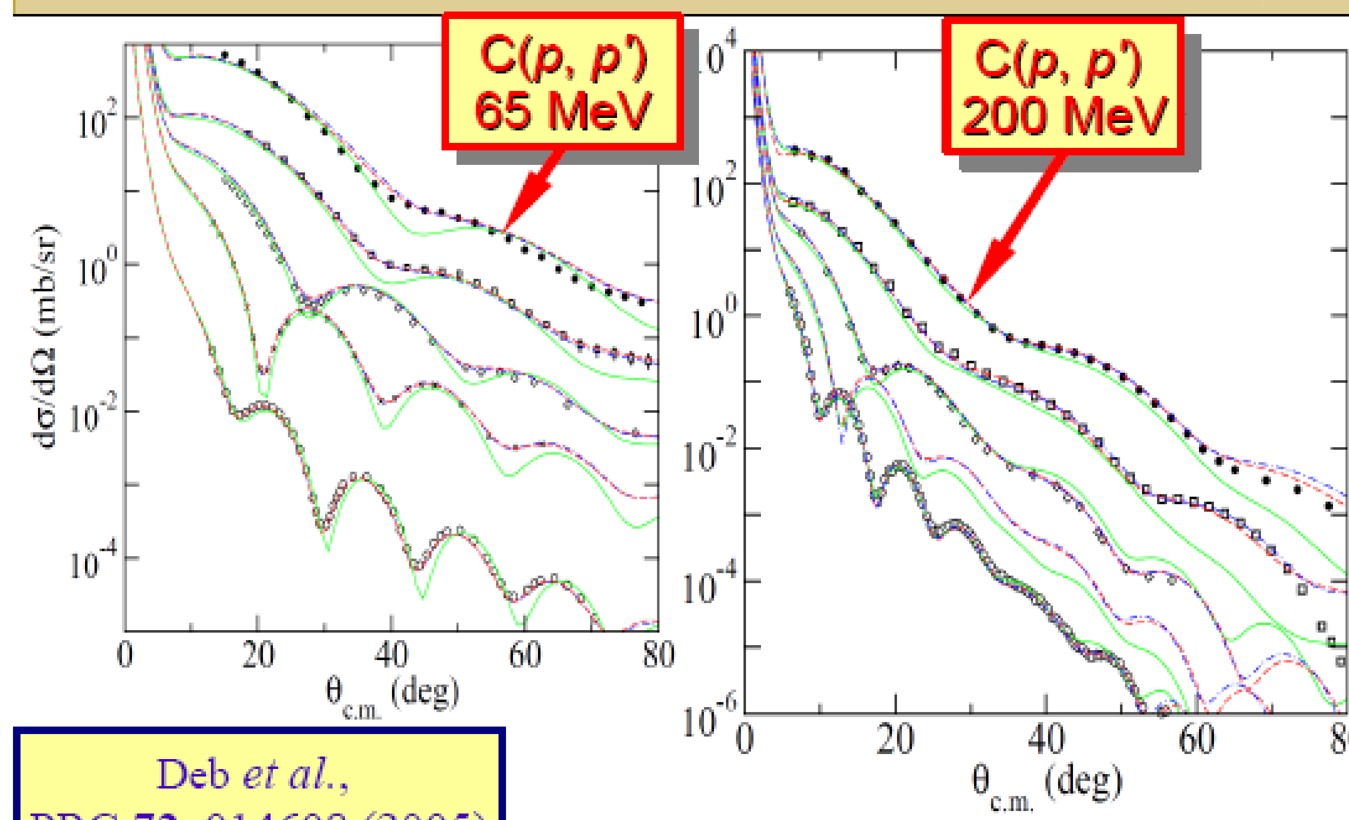
$$E_e + M - \varepsilon = E_{e'} + (E_{p'} + U_v)$$

Real part of the optical potential



obtained from Cooper *et al.*, PRC 47, 297 (1993)

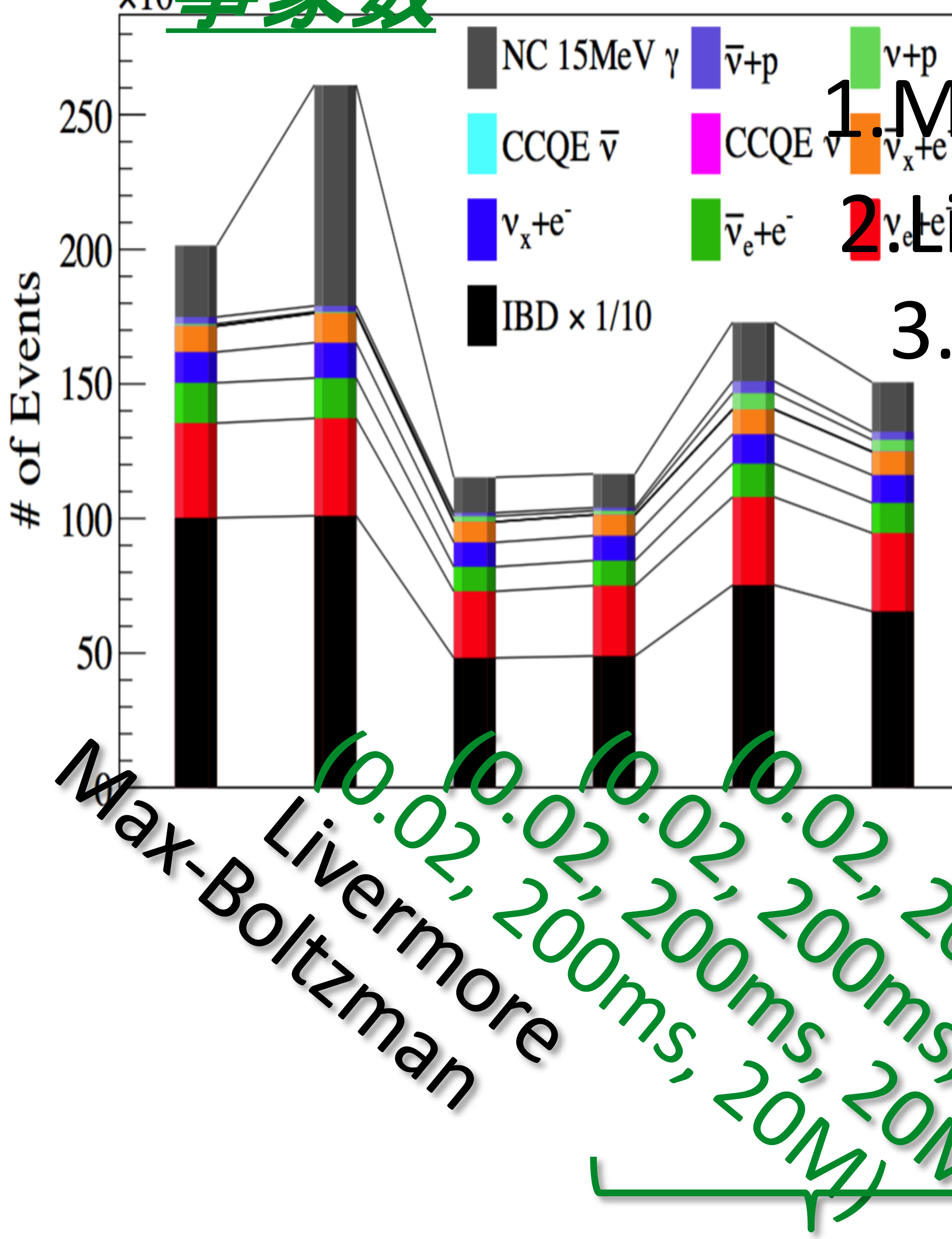
Optical potential by Cooper *et al.*



Deb *et al.*, PRC **72**, 014608 (2005)

SN理論モデルによる違い

事象数



Nakazato (Z, T_{rev}, M)

用いたSNνモデル

1. Maxwell-Boltzman Model (Fermi-Dira
2. Livermore Model *APJ 496, 216 (1998*
3. Nakazato Model *APJ 205, 2 (2013)*
   - 3つのパラメータを選択できる
     - Z: Metallicity
     - T_{rev}: Shock revival time
     - M: 質量

エネルギー分布