Coherent Pion Production induced by neutrino and hadron beam

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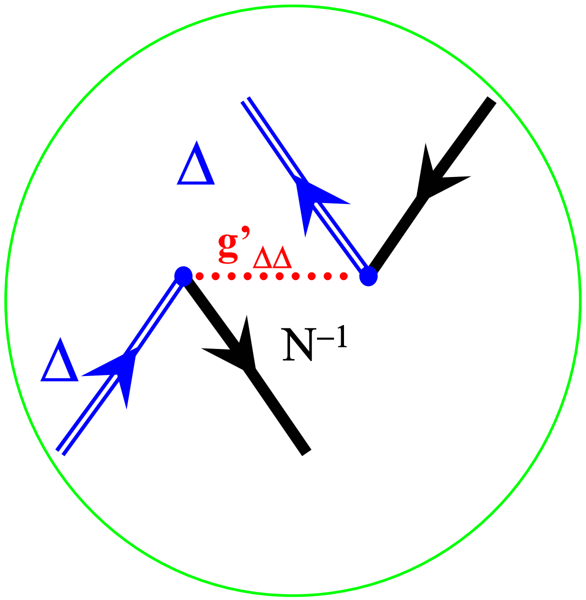
Contents

- Physics motivation
- Coherent Pion Production
- Proton induced CPP at RCNP
- Neutrino beam at J-PARC
- Summary

ΔΔ interaction in the nuclear medium
~ short range correlation of Δ-hole: $g'_{\Delta\Delta}$



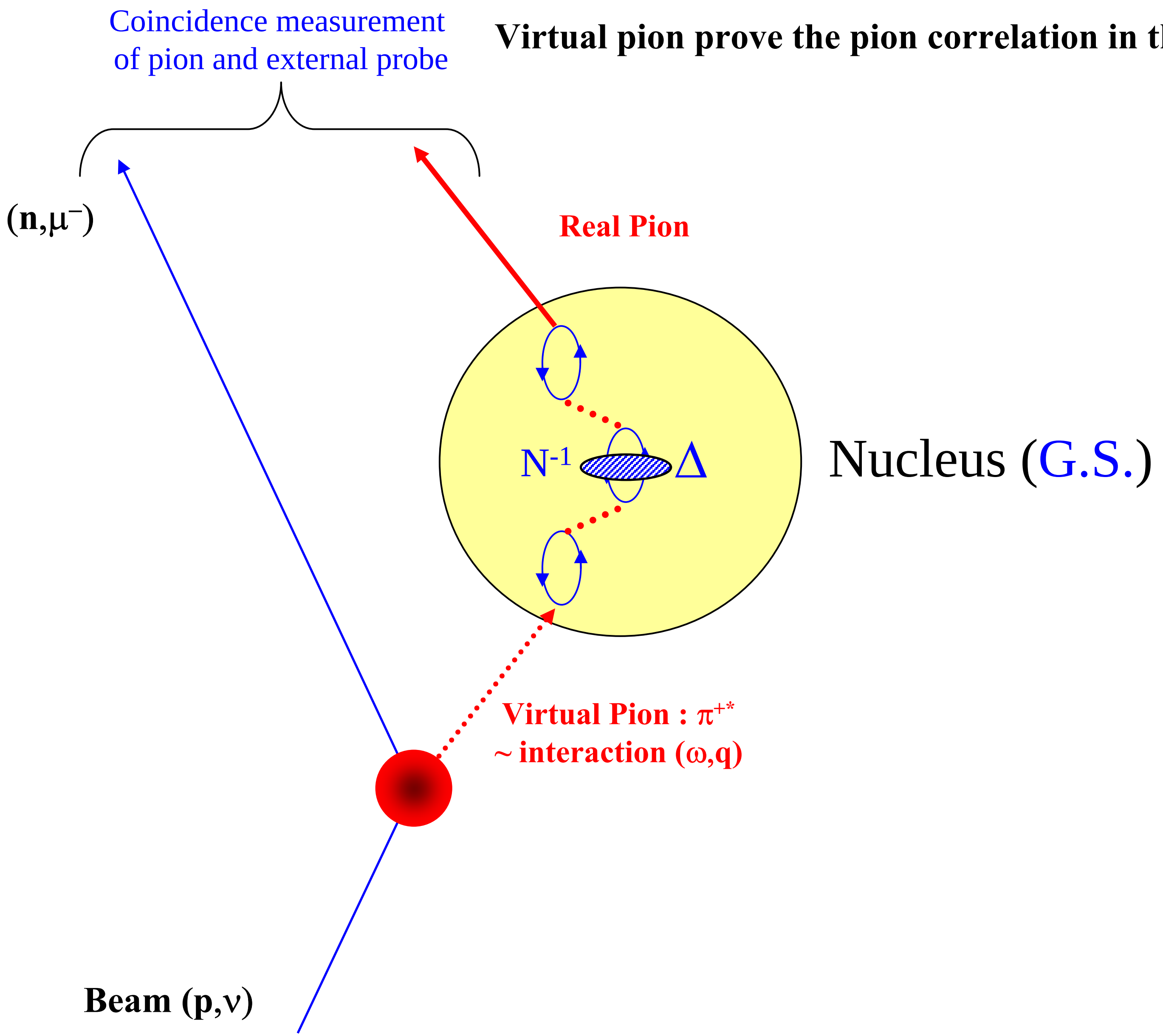
Hadron beam ~ Low density

Neutrino beam ~ Saturated density

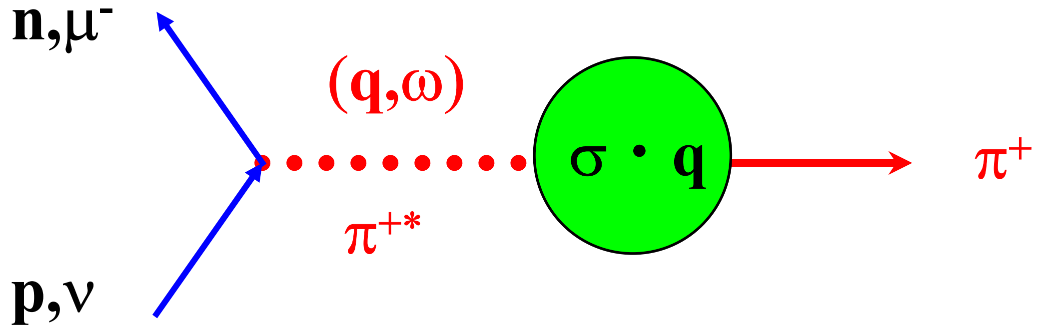
Density dependence of $g'_{\Delta\Delta}(\rho)$
ΔΔ interaction in high density

Coherent Pion Production

Virtual pion prove the pion correlation in the nucleus

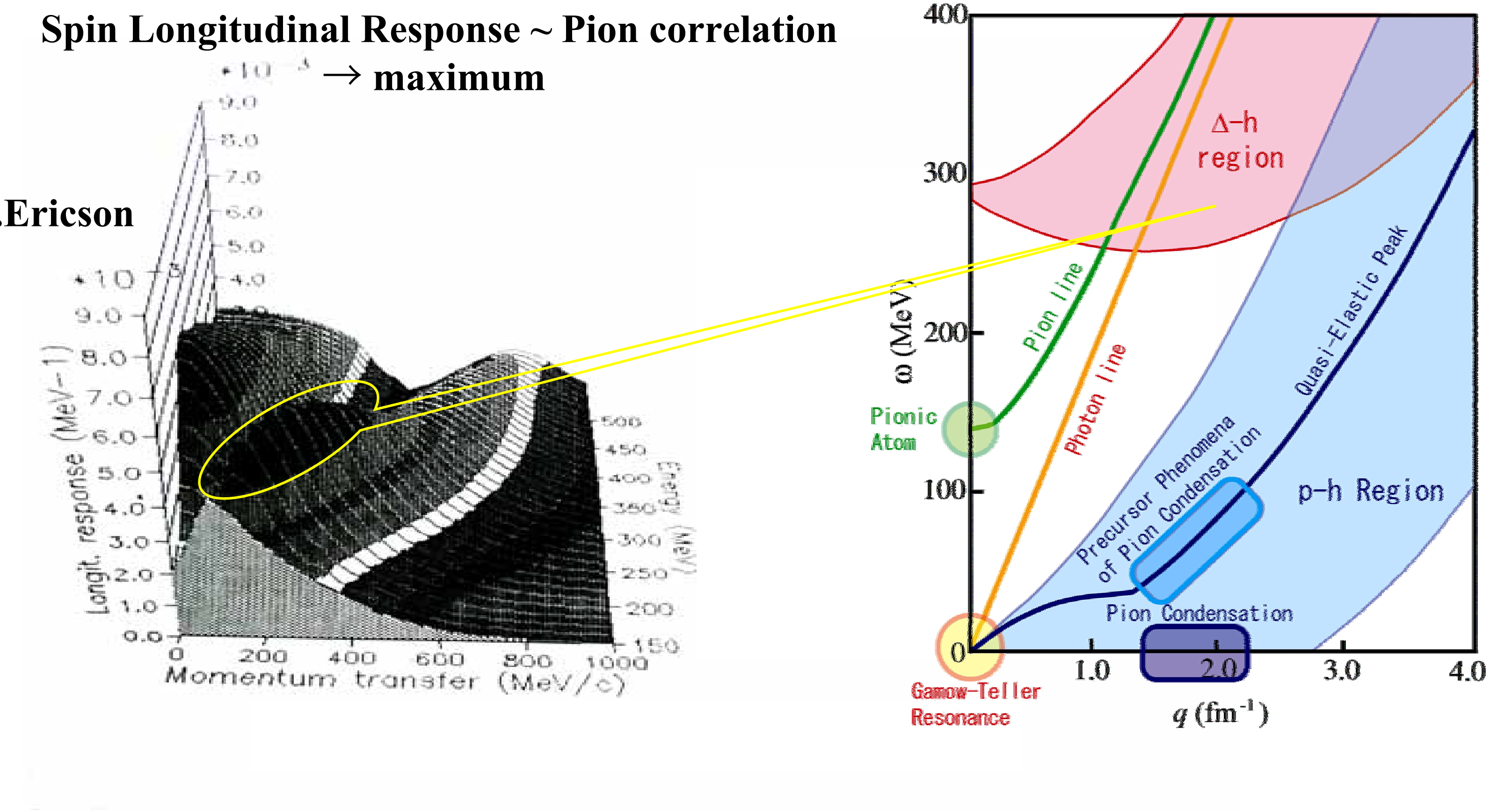


Spin Response in Nuclei



Spin Longitudinal Response ~ Pion correlation
→ maximum

M.Ericson



Longitudinal Response

- Longitudinal Response ~ Enhancement and Softening

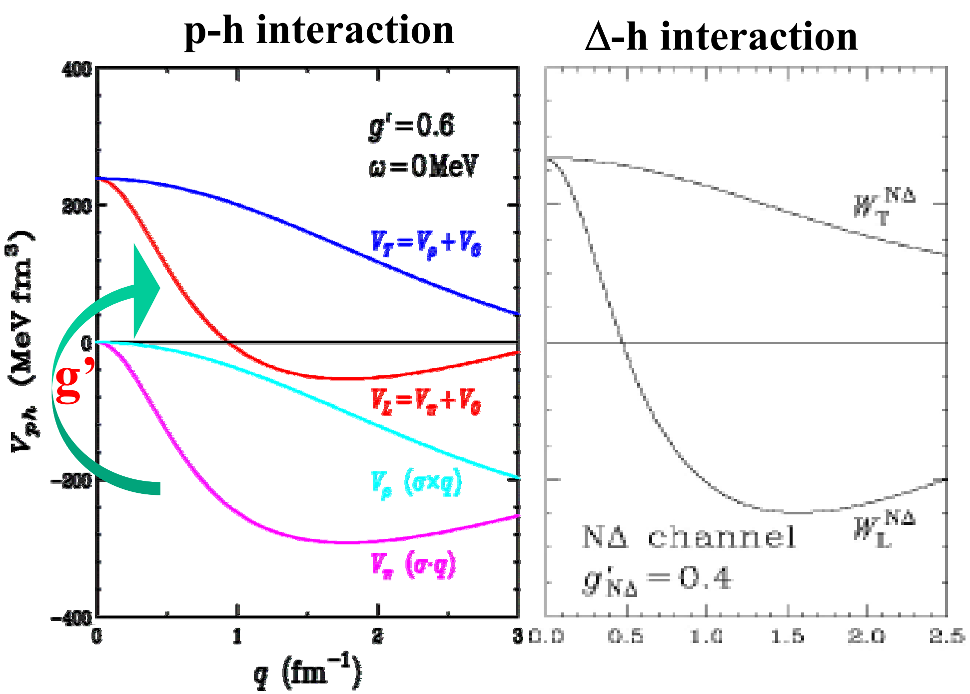
$$R_L \propto \left| \langle n | \sigma \cdot \mathbf{q} | 0 \rangle \right|^2$$

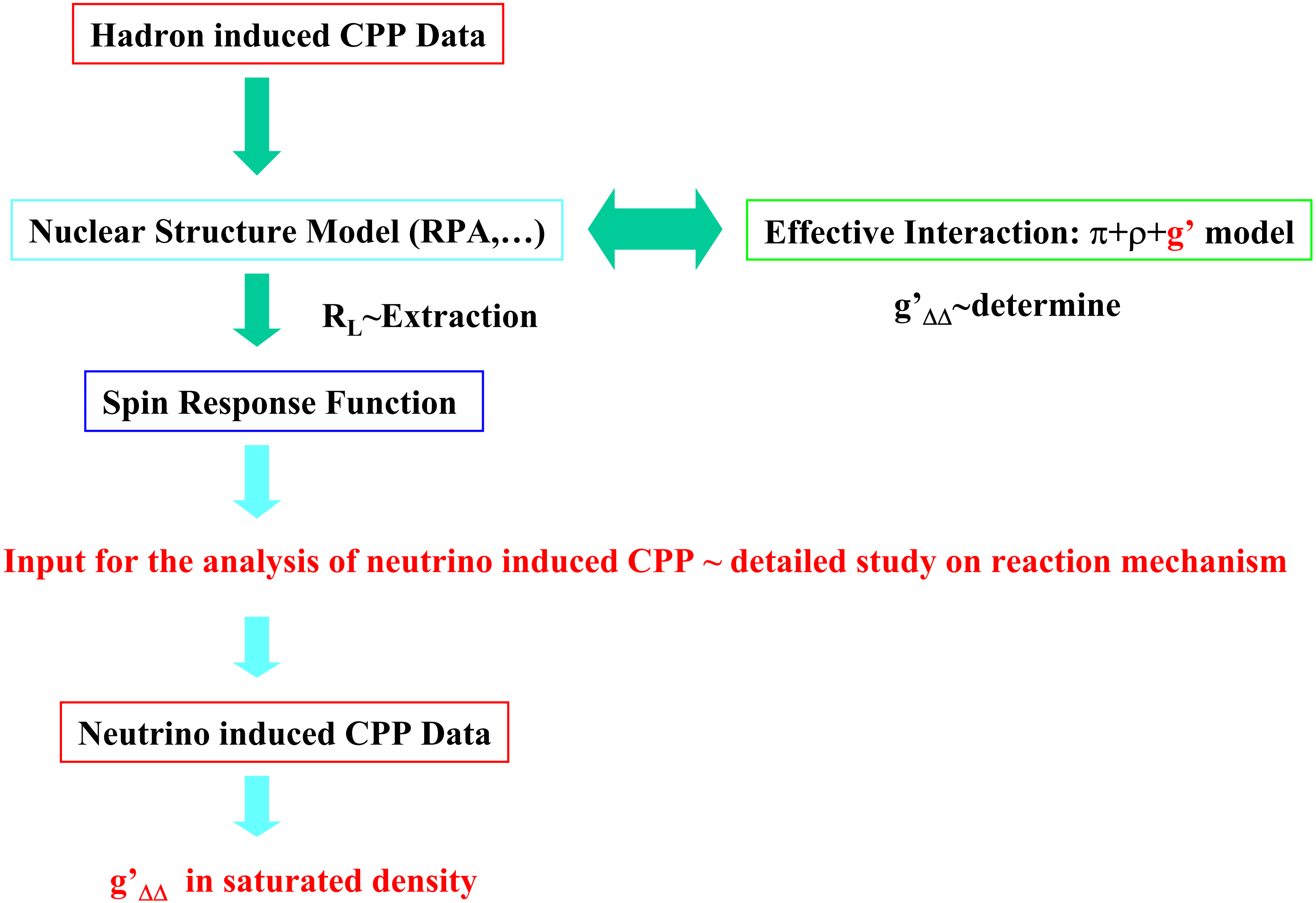
→ **Representing πNN and πNΔ couplings**

- Transverse Response ~ Quenching and Hardening

$$R_T \propto \left| \langle n | \sigma \times \mathbf{q} | 0 \rangle \right|^2$$

p-h and Δ-h attractive force from OPE
~ origin of the pion correlation




Hadron induced CPP Data
Nuclear Structure Model (RPA,…)
Effective Interaction: π+ρ+g’ model
R$_L$~Extraction
g’$_{\Delta\Delta}$~determine
Spin Response Function
Input for the analysis of neutrino induced CPP ~ detailed study on reaction mechanism
Neutrino induced CPP Data
g’$_{\Delta\Delta}$ in saturated density

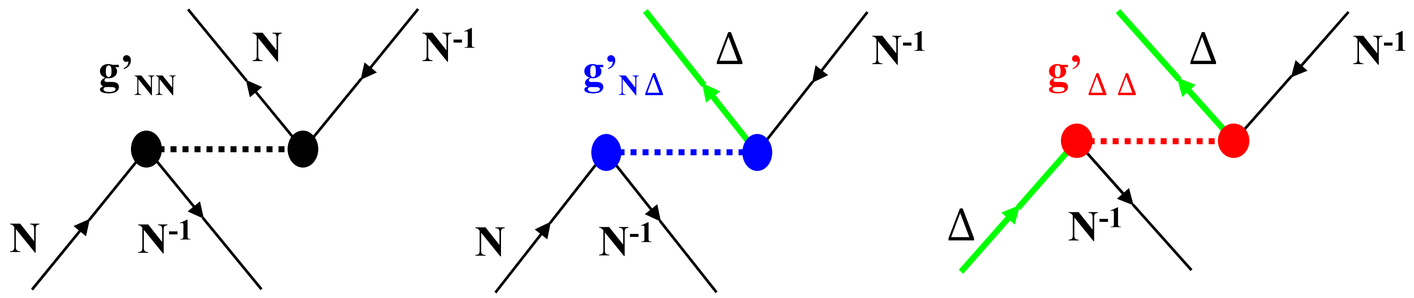
Effective Interaction

π+ρ+g' model

- $V_{eff}(q,\omega) = V_{LM} + V_{\pi}(q,\omega) + V_{\rho}(q,\omega)$
- Landau-Migdal parameters ~ short range correlation

$$
\begin{aligned}
V_{LM} = \frac{f_{\pi NN}{}^{2}}{m_{\pi}{}^{2}} \Big\{ & g'_{NN} (\sigma_1 \cdot \sigma_2)(\tau_1 \cdot \tau_2) \\
& + \frac{f_{\pi N\Delta}}{f_{\pi NN}} g'_{N\Delta} \left[\left((\tau_1 \cdot T_2)(\sigma_1 \cdot S_2) + (\tau_1 \cdot T_2)(\sigma_1 \cdot S_2) \right) + h.c. \right] \\
& + \left(\frac{f_{\pi\Delta\Delta}}{f_{\pi NN}} \right)^2 g'_{\Delta\Delta} \left[\left((T_1 \cdot T_2)(S_1 \cdot S_2) + (T_1 \cdot T_2)(S_1 \cdot S_2) \right) + h.c. \right] \Big\} \delta(r_1 - r_2)
\end{aligned}
$$

$g'_{NN}\, \sigma_1 \cdot \sigma_2 \tau_1 \cdot \tau_2$ | $g'_{N\Delta}\, \sigma_1 \cdot S_2 \tau_1 \cdot T_2$ | $g'_{\Delta\Delta}\, S_1 \cdot S_2 T_1 \cdot T_2$



Well known from Gamow-Teller resonance | **Known from Quasi-free scattering** | **Unknown**

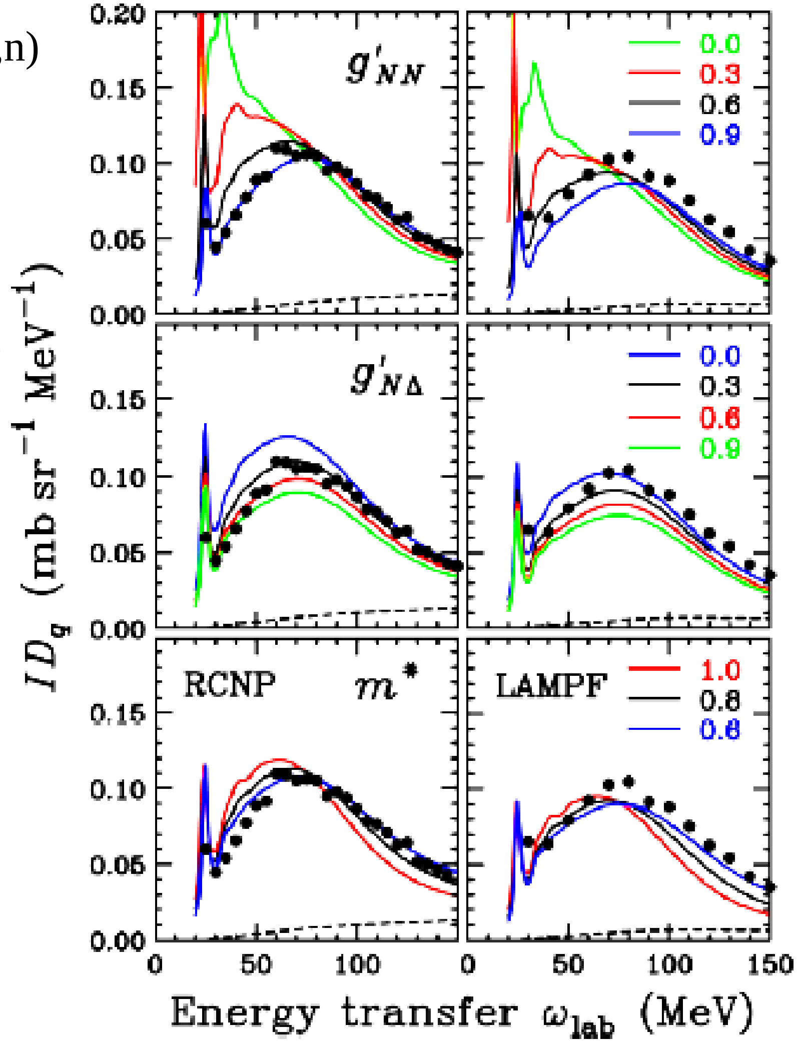
g’$_{NN}$ and g’$_{N\Delta}$

Polarization transfer experiment : Quasi-free ^{12}C(p,n)

RCNP: Tp=346 MeV
T.Wakasa et al., Phys.Rev.C69, 054609 (2004)

LAMPF: Tp=494 MeV
T.N.Taddeucci et al., Phys.Rev.Lett.73,3516 (1994)

g’$_{NN}$~0.7, g’$_{N\Delta}$~0.3



g’$_{N\Delta}$=0.3
m*=0.7m

g’$_{NN}$=0.7
m*=0.7m

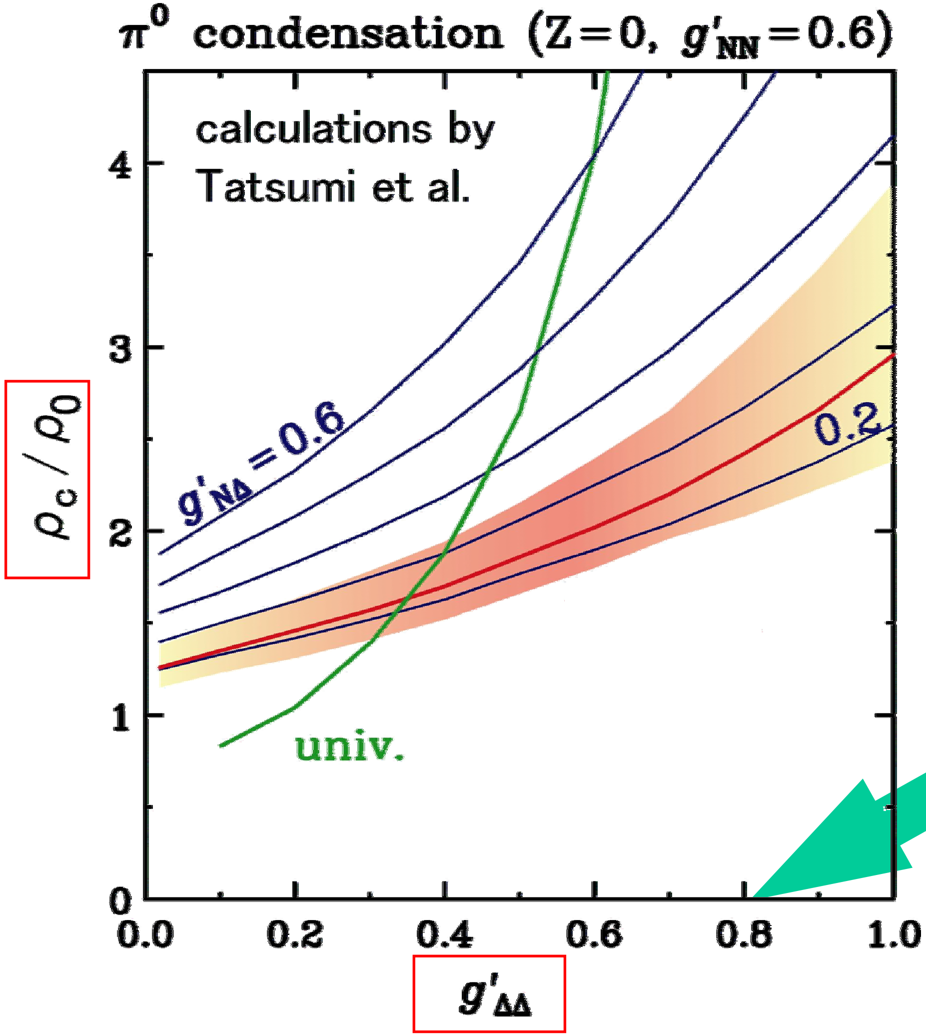
g’$_{NN}$=0.7
g’$_{N\Delta}$=0.3

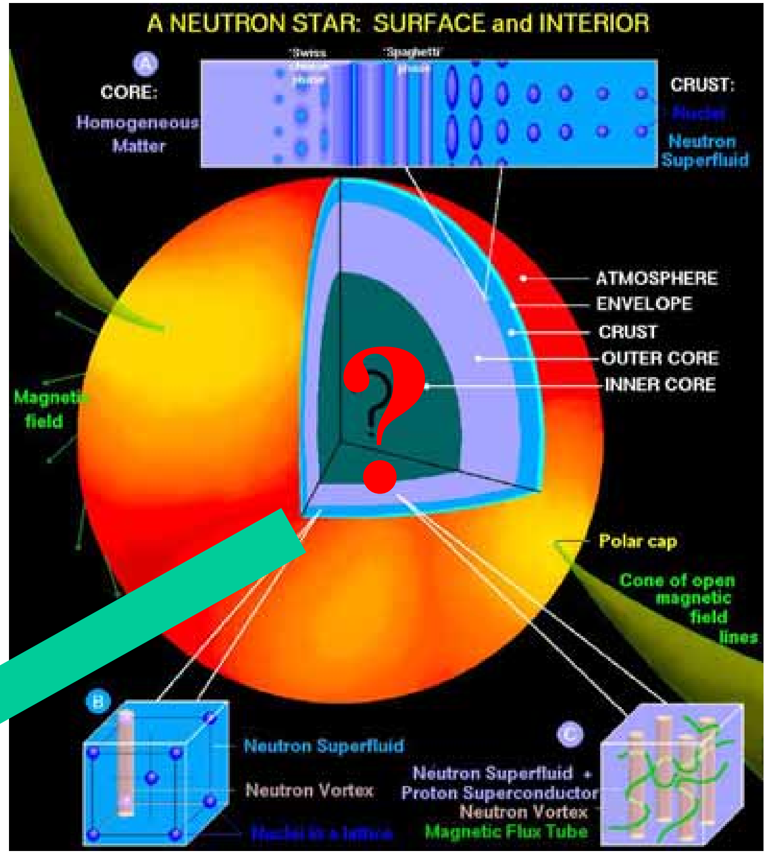
$g'_{\Delta\Delta}$ and pion condensation

$g'_{\Delta\Delta}$ ~ No experimental information

$g'_{\Delta\Delta}$ ~ Sensitive to
- **Critical density of pion condensation**
- **Cooling mechanism of neutron star**

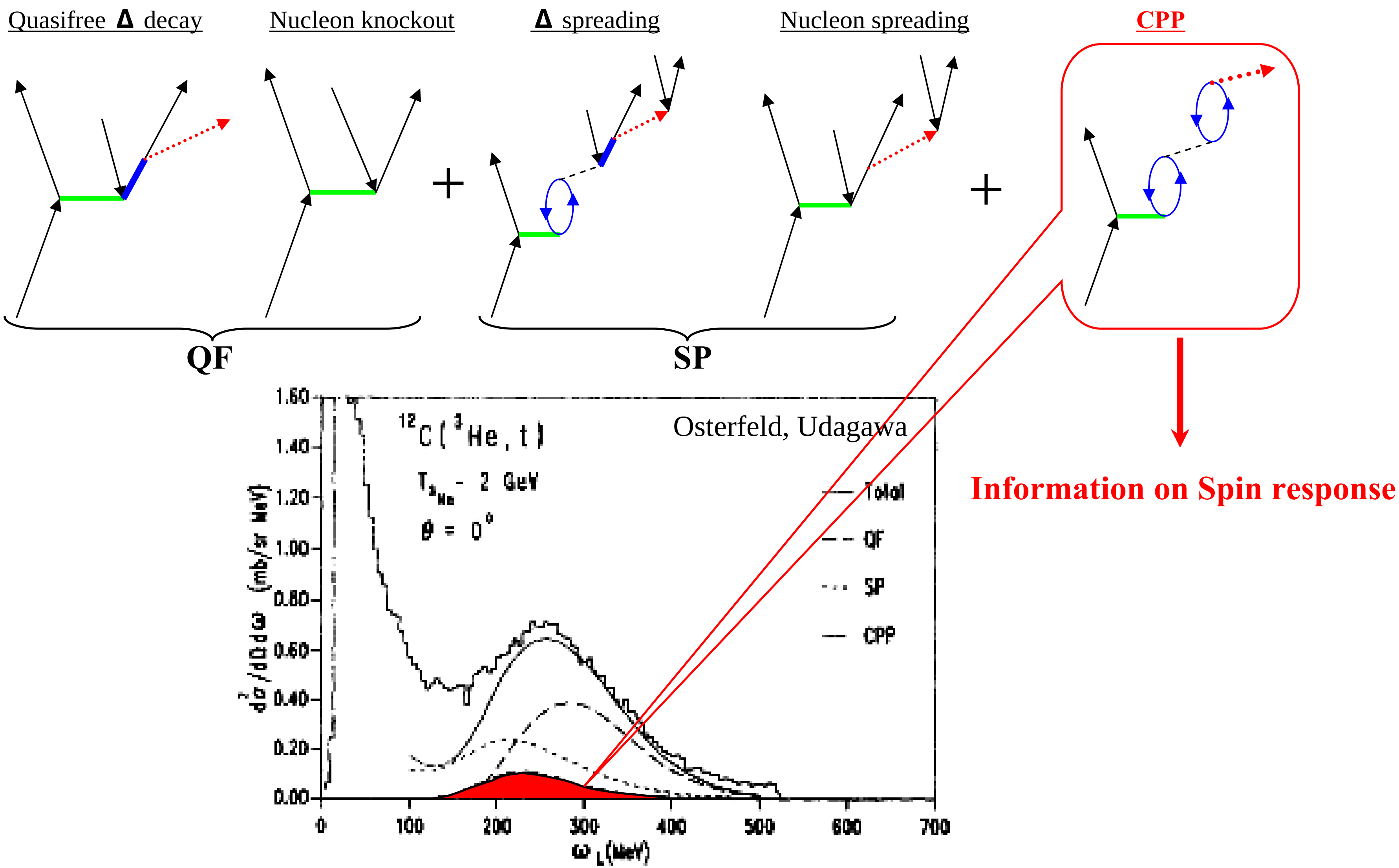
⇒ Δ propagation in the high density matter





Inclusive process

- Proton/^{3}He induced CPP : $p(^3He)+A \rightarrow n(t)+\pi^+ + A_{g.s.}$
- Neutrino induced CPP : $\nu+A \rightarrow \mu^- + \pi^+ + A_{g.s.}$

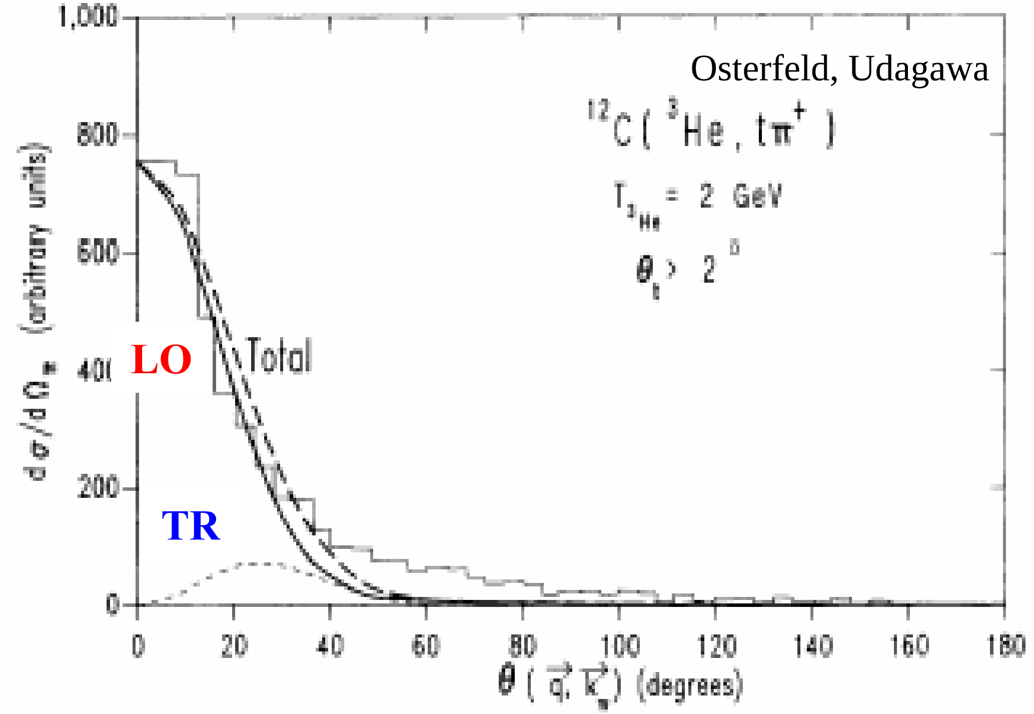


Spin longitudinal response

CPP ~ forward peaked :
Amplitude ~
$(S^\dagger \cdot q)(S \cdot k_\pi) \sim q k_\pi \cos\theta_\pi$

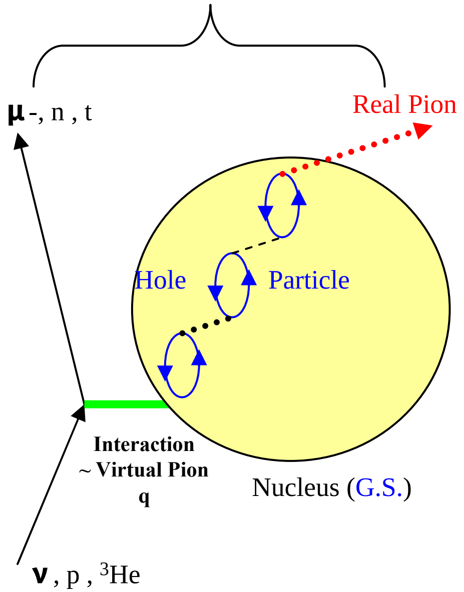
$\theta_\pi = 0$ degree
~ cross section : maximum
~ Spin longitudinal component
→ Dominant

0 degree measurement



g'$_{\Delta\Delta}$ extraction from CPP

Coincidence measurement of neutron and pion



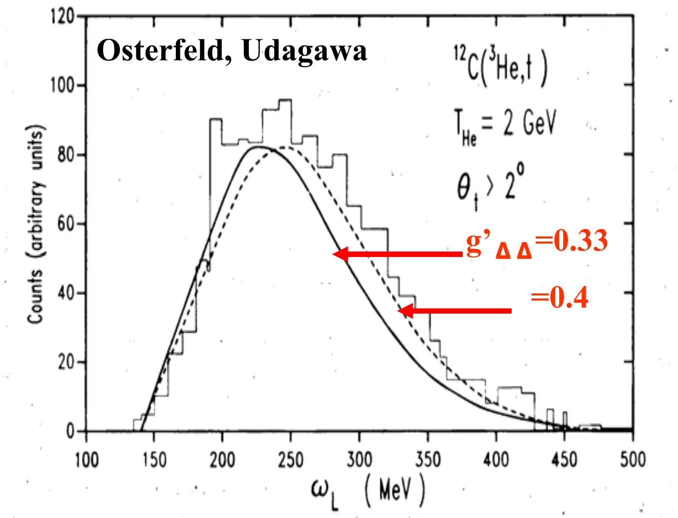
Observables

- **Cross section**
- **Spectrum shape**
- **Peak position :**

$$\Delta E \approx \Delta g'_{\Delta\Delta} \frac{hcf_{\pi N\Delta}}{m_\pi^2} \rho_0$$

↓

Depend on g' $_{\Delta\Delta}$



CPP experiments

Hadron probe

•Saclay (^{3}He,t π^+) ~ **resolution : not enough to separate ground state**

•LAMPF (p,n π^+) ~ **test experiment : shutdown**

•RCNP (p,n π^+) (^{3}He,t π^+) ~ **in progress**

⇒ **study residual interaction with high resolution measurement**

Neutrino

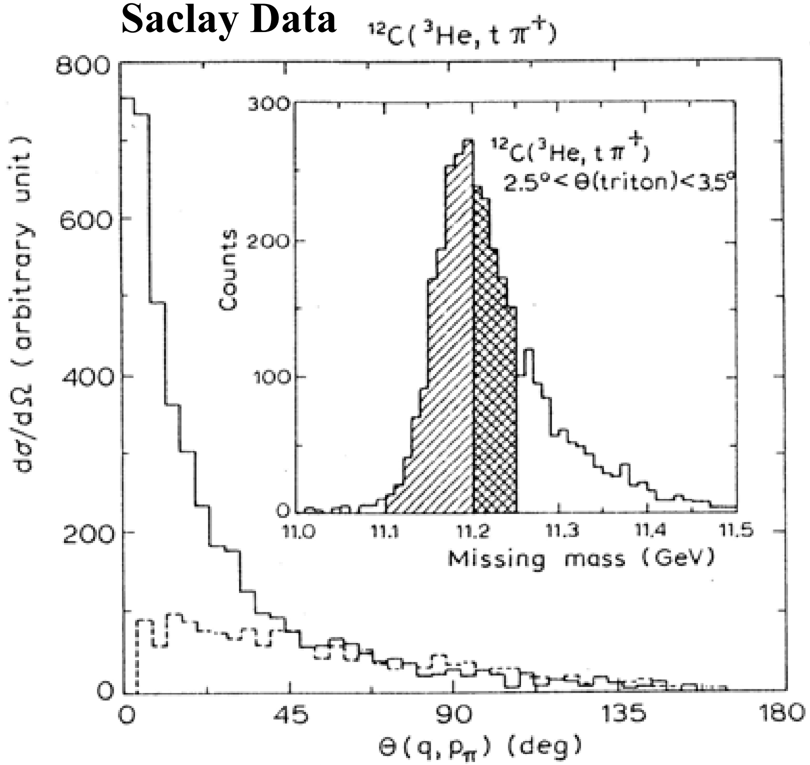
A(ν, μ^- π^+)A

→ a few GeV region ~ Data : poor

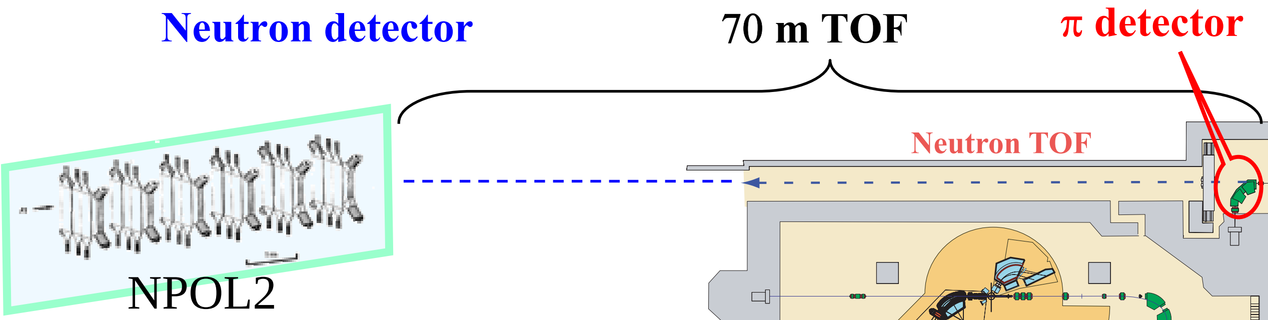
➢K2K ~ first data at <1.3 GeV>

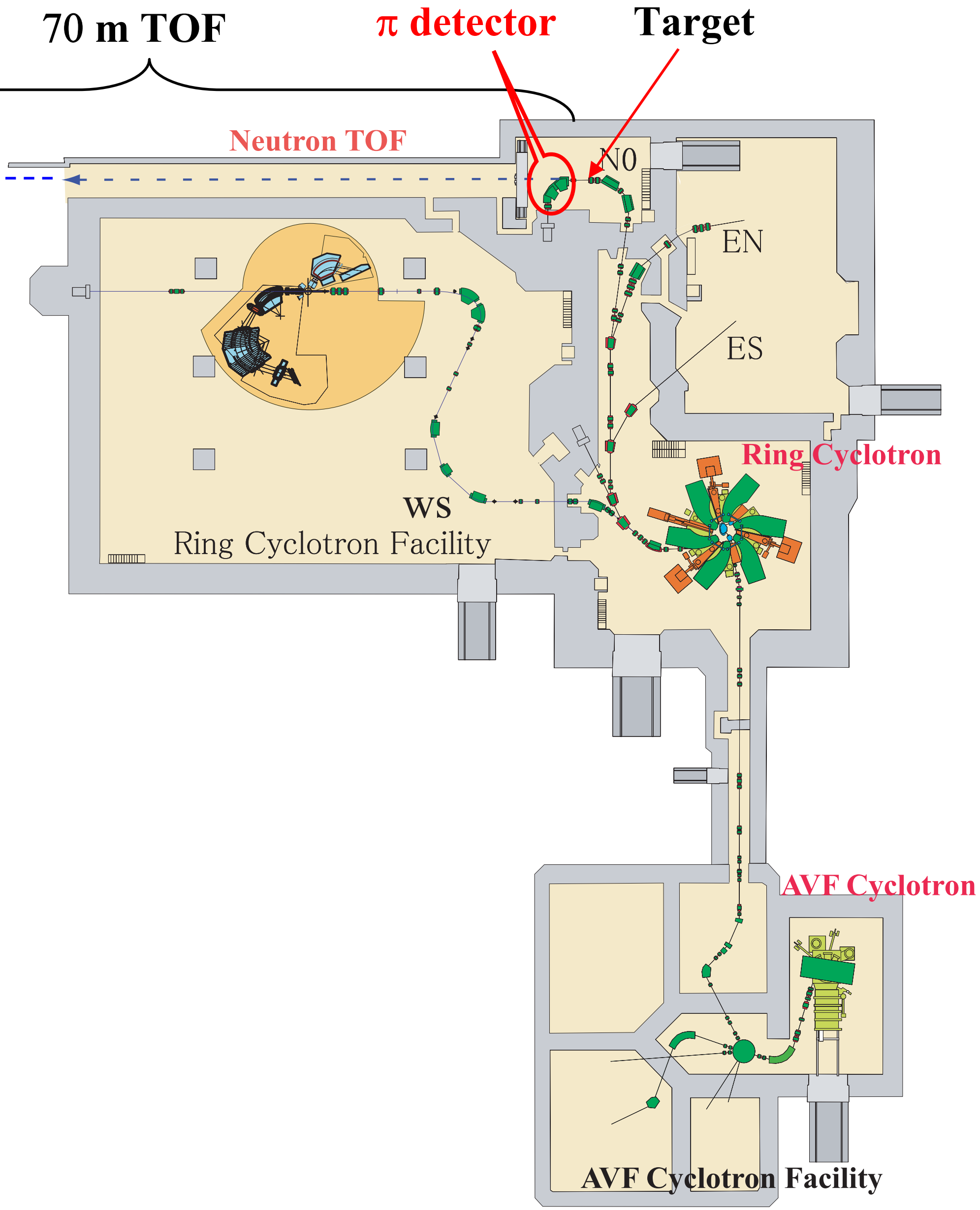
➢J-PARC !

Saclay Data



Proton induced CPP at RCNP



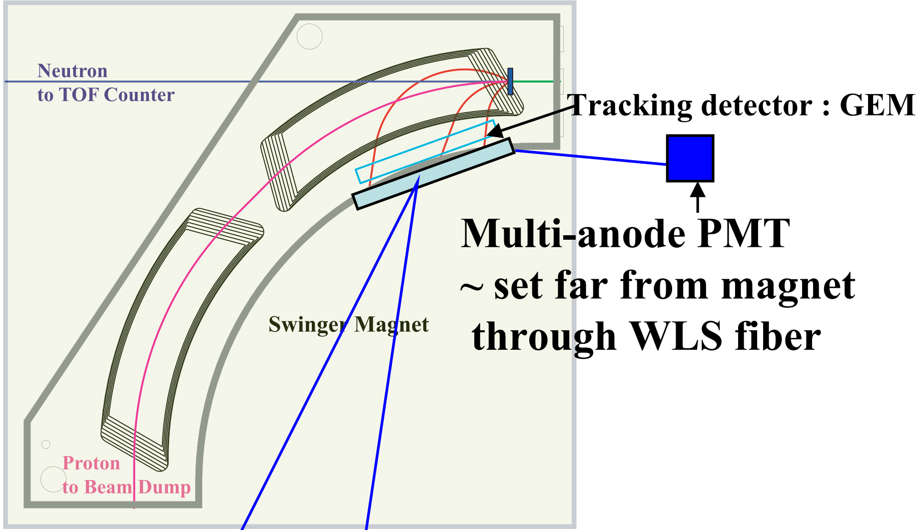


Experiment

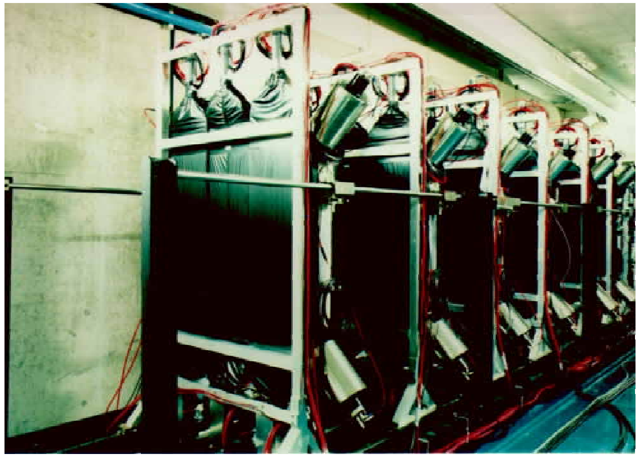
- $^{12}C(p,n\pi^{+})^{12}C$(g.s.)
- Beam ~ proton 400MeV
- Beam energy resolution ~ ΔE~100keV
- Current ~ 1 nA
- Target ~ ^{12}C (100mg/cm^2)
- Detector
  - Netron detector ~ ΔE~300 keV
  - π detector ~ ΔE~1 MeV
- Identification of CPP
  - select the ground state of residual nucleus

Experimental setup

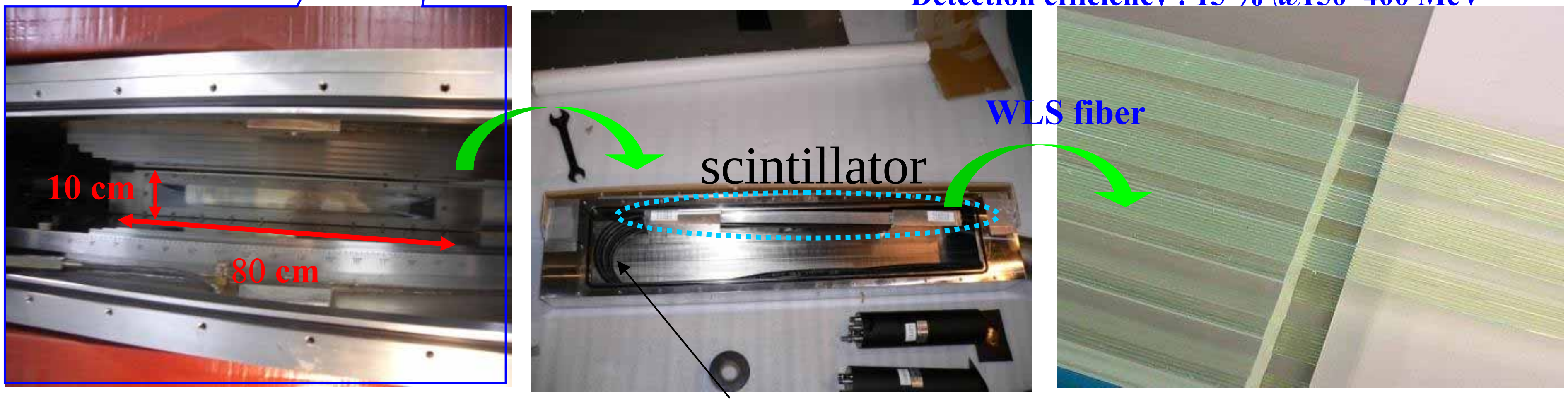
Charged particle detector in the sweeping magnet



Neutron Counter

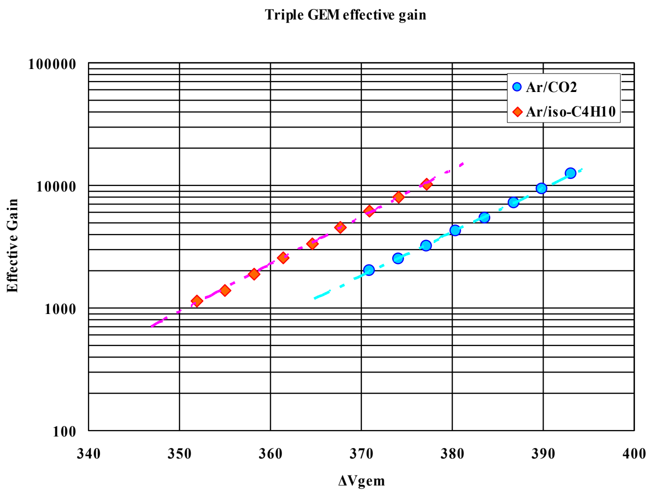


Position sensitive Neutron Counter (liq Sci.)
TOF length ~ 70 m
Energy resolution : 300 keV
Detection efficiency : 15 % @150~400 MeV

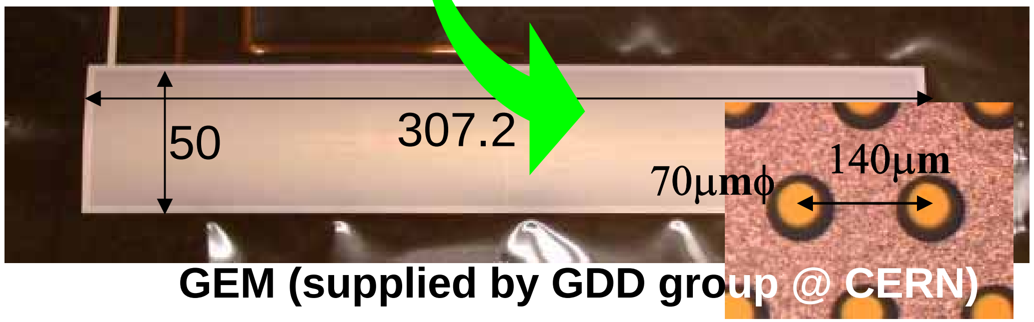


Tracking Detector

1. Gas Electron Multiplier detector (GEM)
2. Charged particle (π..) detection in the magnet
3. Detector components
   - Three layers of GEM foil ~ high gain
   - 2dimentional Readout board ~ high resolution
4. Specification
   - high position resolution~ 100mm
   - Effective area~ 300x50 mm
   - radiation tolerance
5. Readout ~ high speed with parallel processing : SpaceWire
6. Installation ~ completed in the spring of 2006.



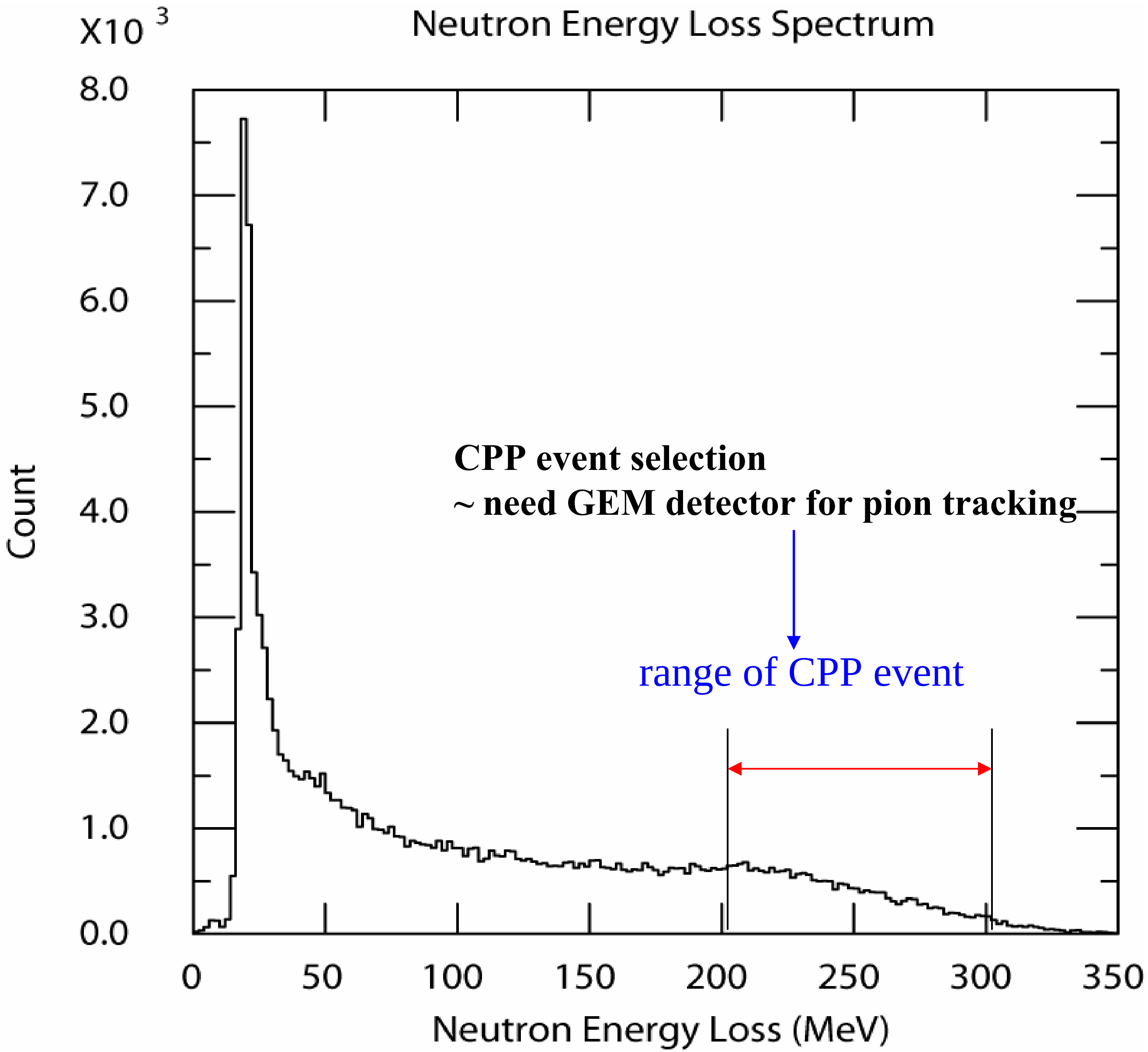
gain as a function of biased voltage to GEM

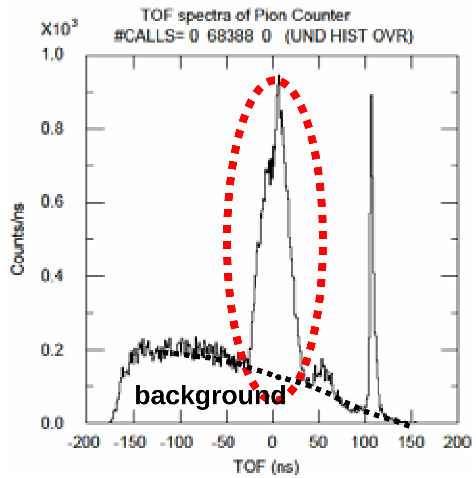


GEM (supplied by GDD group @ CERN)

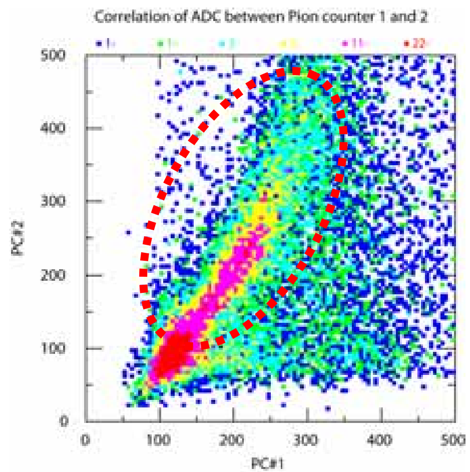
2 dimensional Readout Board

Test Experiment



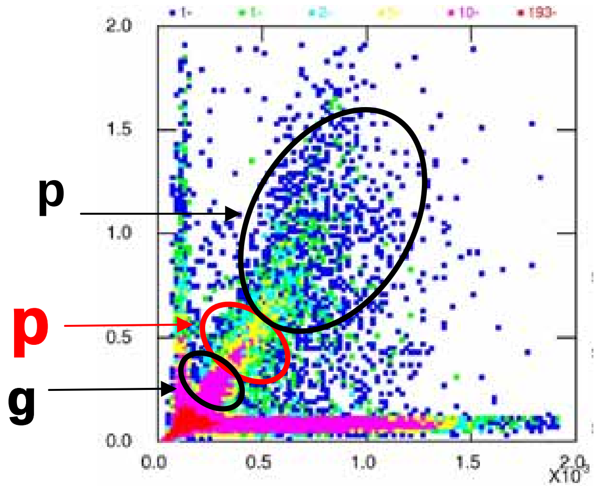


TOF spectrum of pion counter



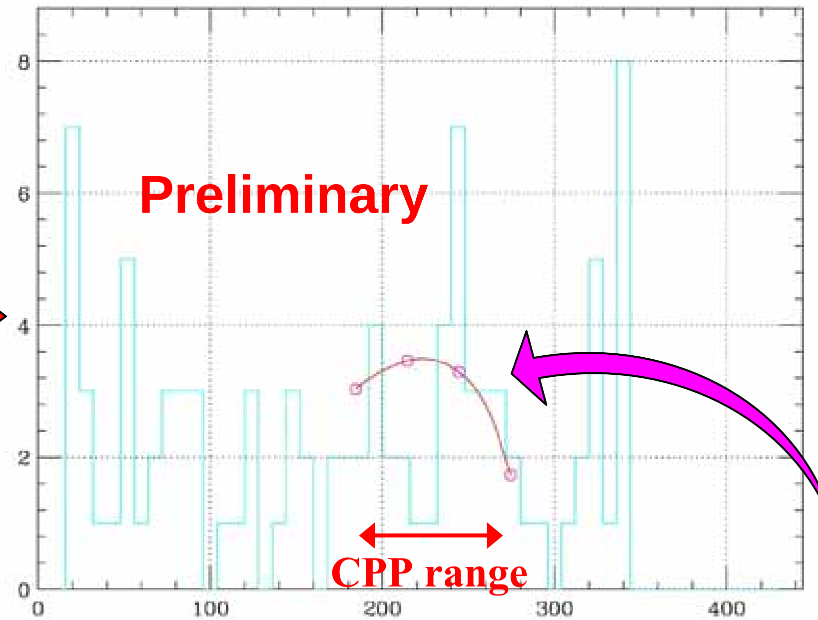
Energy loss of two sci.

Present status



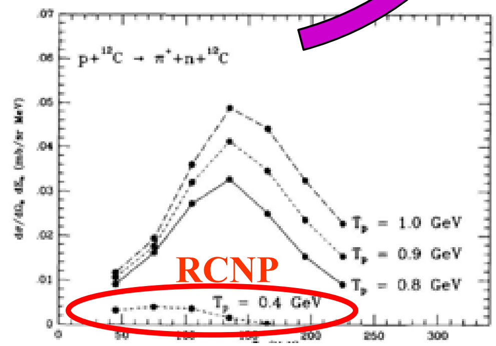
DE-DE 2

Cut
E/TOF



neutron energy loss (MeV)

theoretical calculation



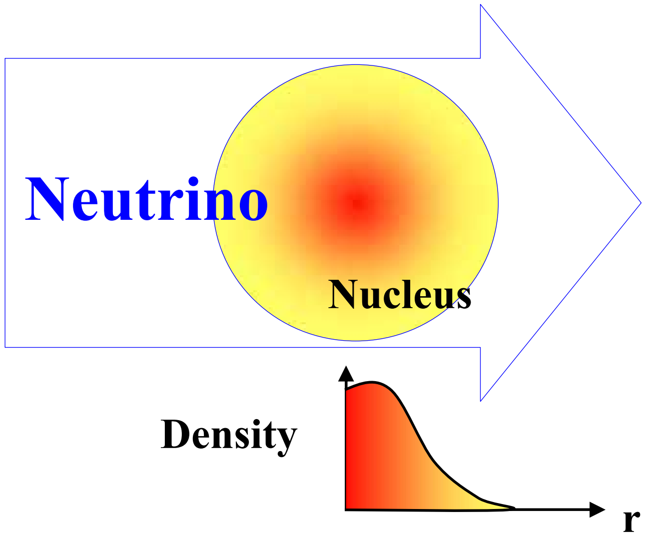
coherent pion cross section

E. Oset, Nucl. Phys. A 592 (1995) 472.

- Neutron energy spectrum
  - **CPP region ~ enhancement ? ~ detailed analysis continued**
  - **need much more statistics to confirm CPP**
- Background ~ study in progress
  - beam halo
  - Transmission efficiency of the primary beam ~ bad
  - beam optics tuning ~ considered now
- To identify CPP
  - Separate ground state of residual nucleus by missing mass spectrum

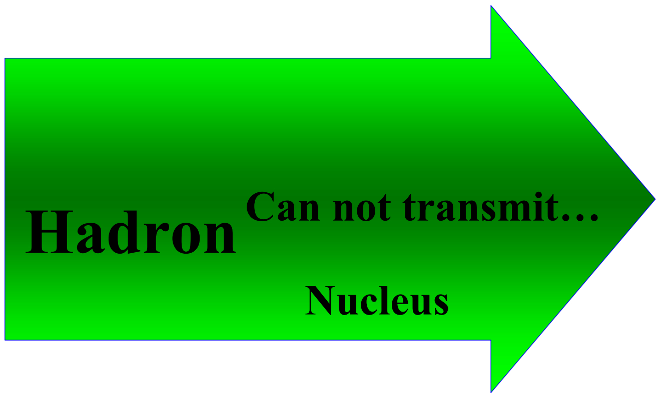
    ↓
  - Tracking information ~ GEM detector is needed next step

Neutrino Beam



- Weak interaction
- Can prove the interior of nucleus
- Cross section ~ behave volume like
- No distortion/absorption
- Adler's theorem : M~T(π (q)+N$\rightarrow$X)

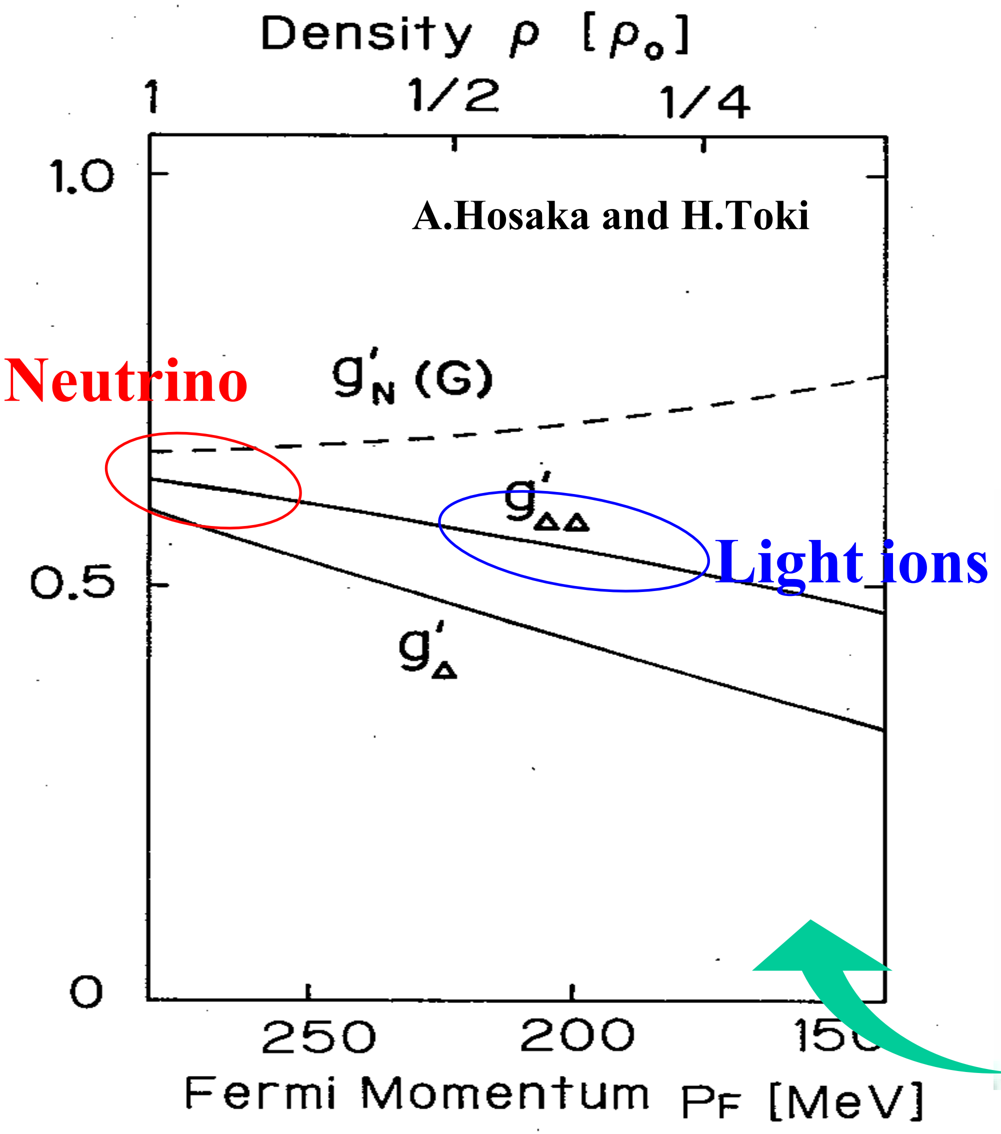
Neutrino
$\rightarrow$ Good Probe to study the interior of the nucleus
$\Rightarrow$ keep the information of nuclear interior



- Strong interaction
- Reaction ~ peripheral
- Sensitive to nuclear surface
- Distortion/Absorption effects

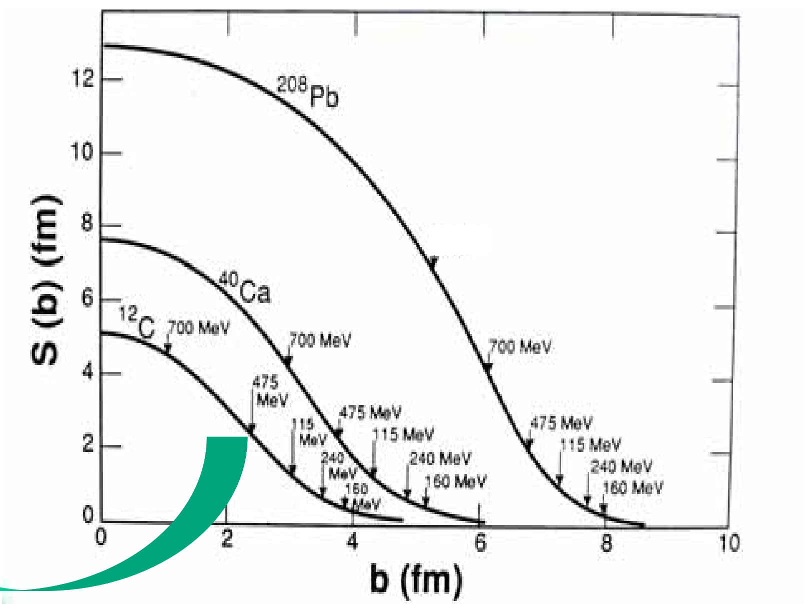
$\Rightarrow$can investigate residual interaction and response function with high accuracy

Density dependence of g'



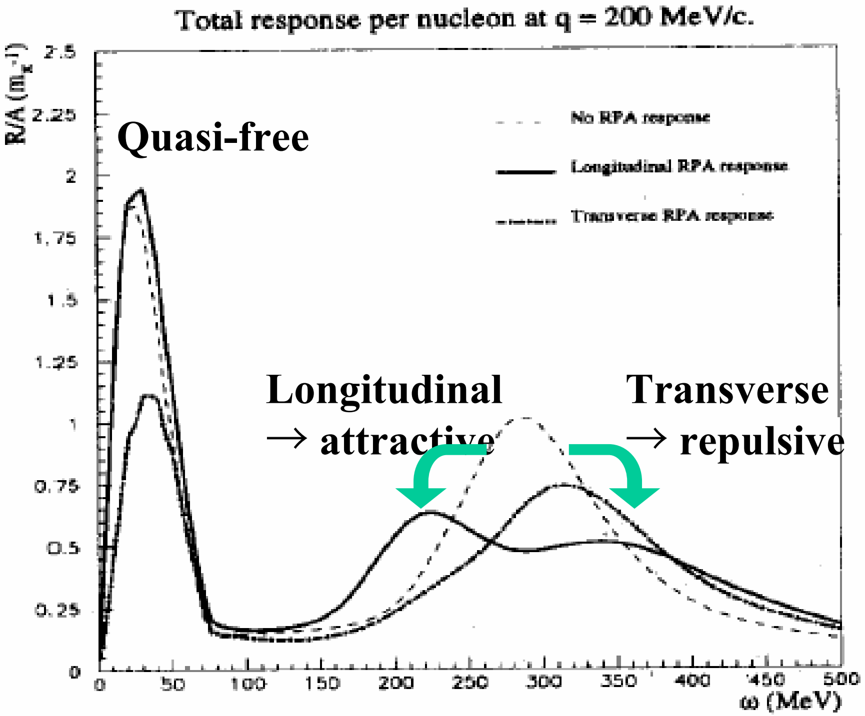
profile function ~ one mean free path

$S(b) \sim \lambda \sim (A\rho\sigma)^{-1}$

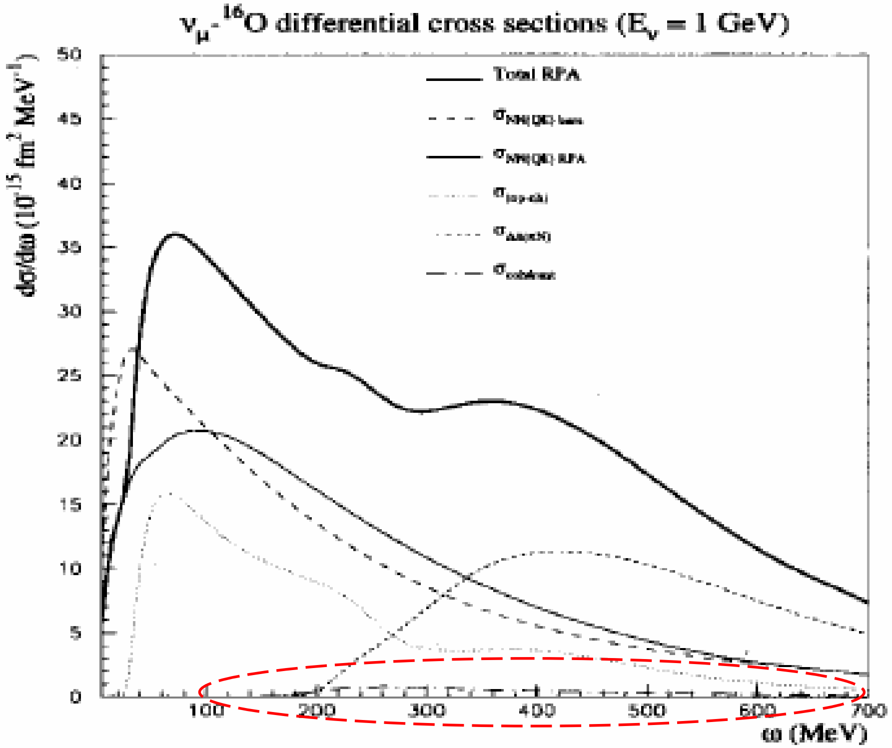


Neutrino induced CPP

J.Marteau



g'_{NN}=0.7, $g'_{N\Delta}$=0.5, $g'_{\Delta\Delta}$=0.5



● **Peak** $\Rightarrow$ **g'**$_{\Delta\Delta}$
● **Strength** $\Rightarrow$ **response function**

Search for coherent charged pion production in neutrino-carbon interactions

M. Hasegawa,[12] E. Aliu,[1] S. Andringa,[1] S. Aoki,[10] J. Argyriades,[3] K. Asakura,[10] R. Ashie,[30] H. Berns,[33] H. Bhang,[20] A. Blondel,[26] S. Borghi,[26] J. Bouchez,[3] J. Burguet-Castell,[32] D. Casper,[28] C. Cavata,[3] A. Cervera,[26] S. M. Chen,[25] K. O. Cho,[4] J. H. Choi,[4] U. Dore,[19] X. Espinal,[1] M. Fechner,[3] E. Fernandez,[1] Y. Fukuda,[15] J. Gomez-Cadenas,[32] R. Gran,[33] T. Hara,[10] T. Hasegawa,[22] K. Hayashi,[12] Y. Hayato,[7] R. L. Helmer,[25] J. Hill,[23] K. Hiraide,[12] J. Hosaka,[30] A. K. Ichikawa,[7] M. Iinuma,[8] A. Ikeda,[17] T. Inagaki,[12] T. Ishida,[7] K. Ishihara,[30] T. Ishii,[7] M. Ishitsuka,[31] Y. Itow,[30] T. Iwashita,[7] H. I. Jang,[4] E. J. Jeon,[20] I. S. Jeong,[4] K. Joo,[20] G. Jover,[1] C. K. Jung,[23] T. Kajita,[31] J. Kameda,[30] K. Kaneyuki,[31] I. Kato,[25] E. Kearns,[2] D. Kerr,[23] C. O. Kim,[11] M. Khabibullin,[9] A. Khotjantsev,[9] D. Kielczewska,[34,21] J. Y. Kim,[4] S. Kim,[20] P. Kitching,[25] K. Kobayashi,[23] T. Kobayashi,[7] A. Konaka,[25] Y. Koshio,[30] W. Kropp,[28] J. Kubota,[12] Yu. Kudenko,[9] Y. Kuno,[18] T. Kutter,[13,27] J. Learned,[29] S. Likhoded,[2] I. T. Lim,[4] P. F. Loverre,[19] L. Ludovici,[19] H. Maesaka,[12] J. Mallet,[3] C. Mariani,[19] T. Maruyama,[7] S. Matsuno,[29] V. Matveev,[9] C. Mauger,[23] K. McConnel,[14] C. McGrew,[23] S. Mikheyev,[9] A. Minamino,[30] S. Mine,[28] O. Mineev,[9] C. Mitsuda,[30] M. Miura,[30] Y. Moriguchi,[10] T. Morita,[12] S. Moriyama,[30] T. Nakadaira,[12,7] M. Nakahata,[30] K. Nakamura,[7] I. Nakano,[17] T. Nakaya,[12] S. Nakayama,[31] T. Namba,[30] R. Nambu,[30] S. Nawang,[8] K. Nishikawa,[12] K. Nitta,[7] F. Nova,[1] P. Novella,[32] Y. Obayashi,[30] A. Okada,[31] K. Okumura,[31] S. M. Oser,[27] Y. Oyama,[7] M. Y. Pac,[5] F. Pierre,[3] A. Rodriguez,[1] C. Saji,[31] M. Sakuda,[7,17] F. Sanchez,[1] A. Sarrat,[23] T. Sasaki,[12] H. Sato,[12] K. Scholberg,[6,14] R. Schroeter,[26] M. Sekiguchi,[10] E. Sharkey,[23] M. Shiozawa,[30] K. Shiraishi,[33] G. Sitjes,[32] M. Smy,[28] H. Sobel,[28] J. Stone,[2] L. Sulak,[2] A. Suzuki,[10] Y. Suzuki,[30] T. Takahashi,[8] Y. Takenaga,[31] Y. Takeuchi,[30] K. Taki,[30] Y. Takubo,[18] N. Tamura,[16] M. Tanaka,[7] R. Terri,[23] S. T'Jampens,[3] A. Tornero-Lopez,[32] Y. Totsuka,[7] S. Ueda,[12] M. Vagins,[28] L. Whitehead,[23] C.W. Walter,[6] W. Wang,[2] R.J. Wilkes,[33] S. Yamada,[30] S. Yamamoto,[12] C. Yanagisawa,[23] N. Yershov,[9] H. Yokoyama,[24] M. Yokoyama,[12] J. Yoo,[20] M. Yoshida,[18] and J. Zalipska[21]
(The K2K Collaboration)

2

(Dated: June 4, 2005)

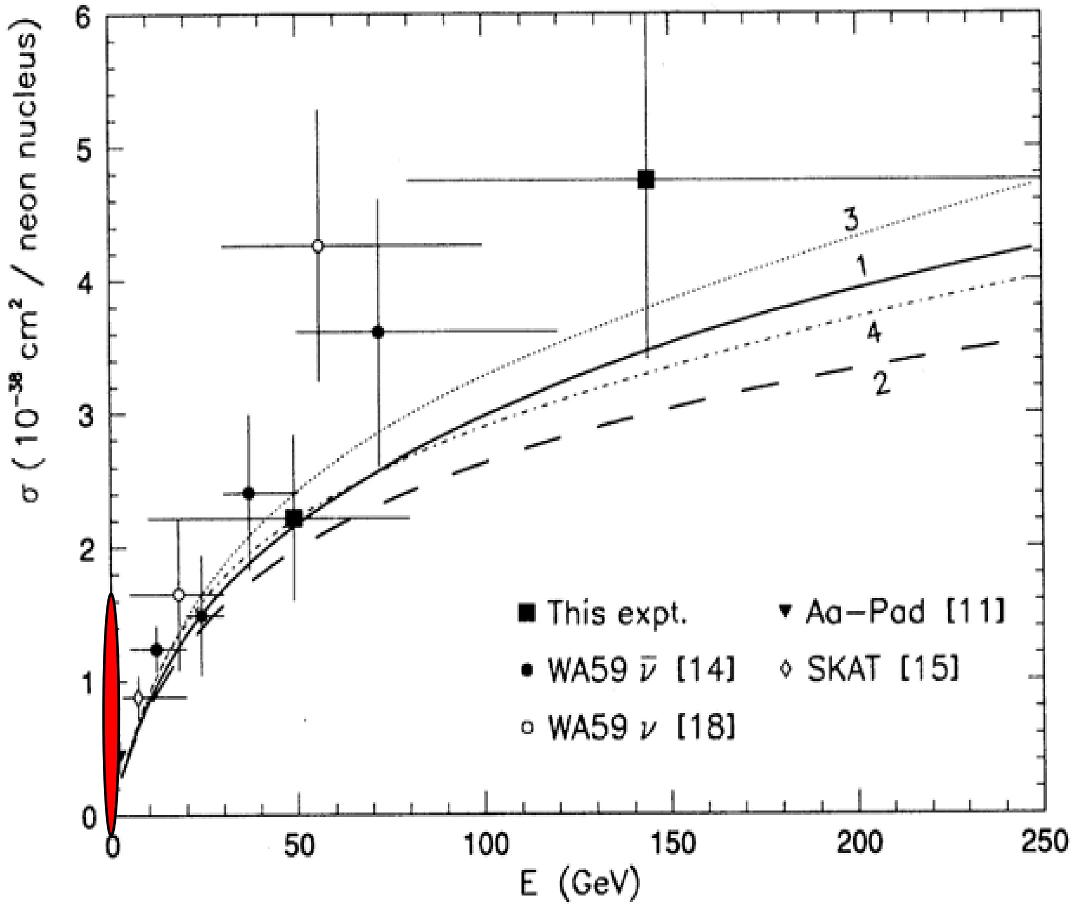
We report the result from a search for charged-current coherent pion production induced by muon neutrinos with a mean energy of 1.3 GeV. The data are collected with a fully active scintillator detector in the K2K long-baseline neutrino oscillation experiment. No evidence for coherent pion production is observed and an upper limit of 0.60×10^{-2} is set on the cross section ratio of coherent pion production to the total charged-current interaction at 90% confidence level. This is the first experimental limit for coherent charged pion production in the energy region of a few GeV.

PACS numbers: 13.15.+g,25.30.Pt,95.55.Vj

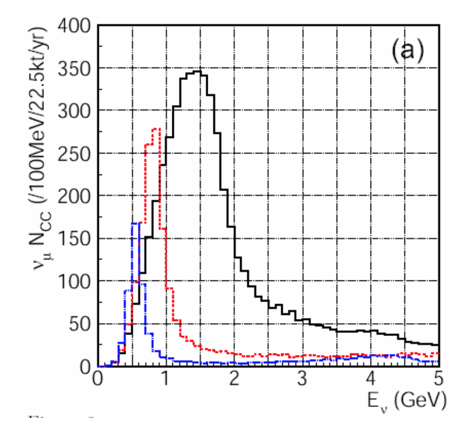
Neutrino induced CPP

Coherent Pion Production data ~ not so much data

First data from K2K ~ GeV energy region ⇒ NO evidence of CPP

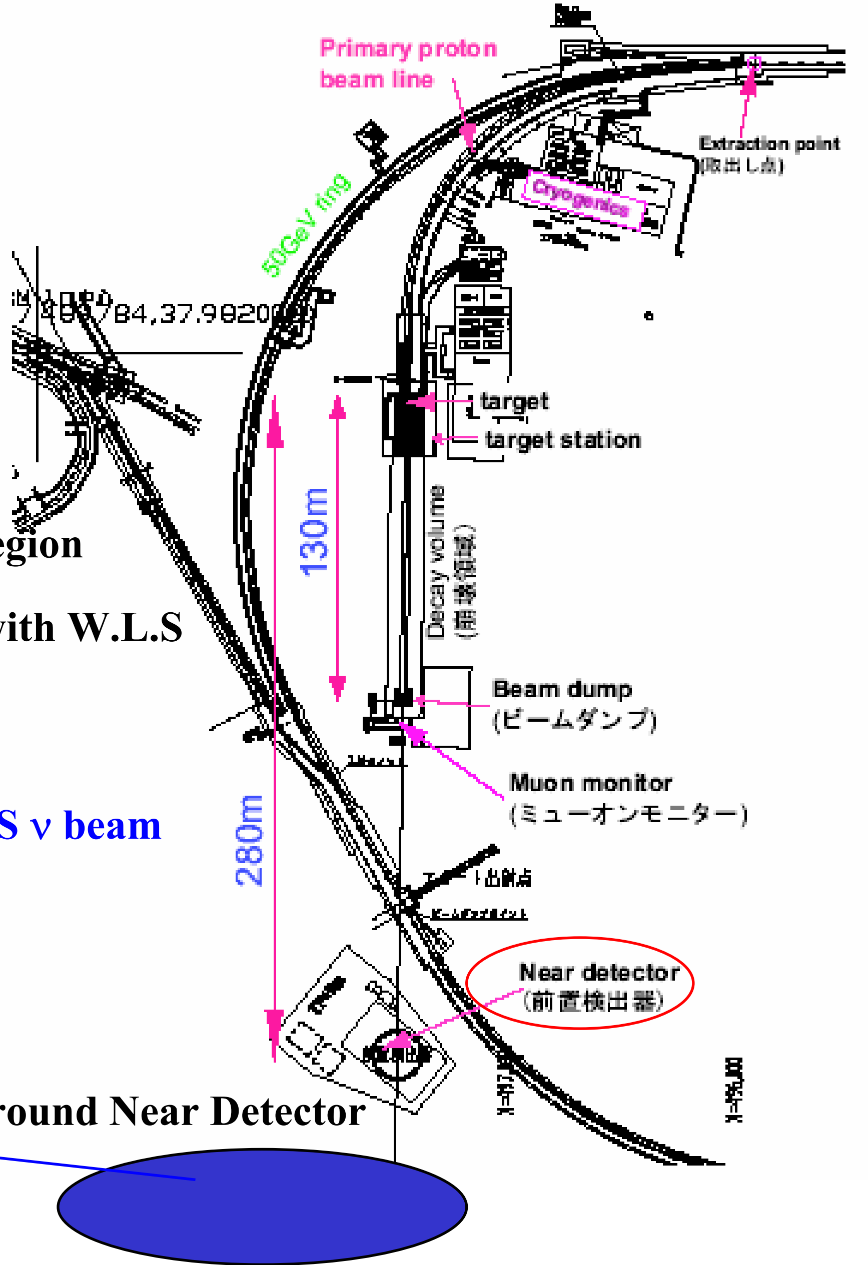


Neutrino Beam at J-PARC

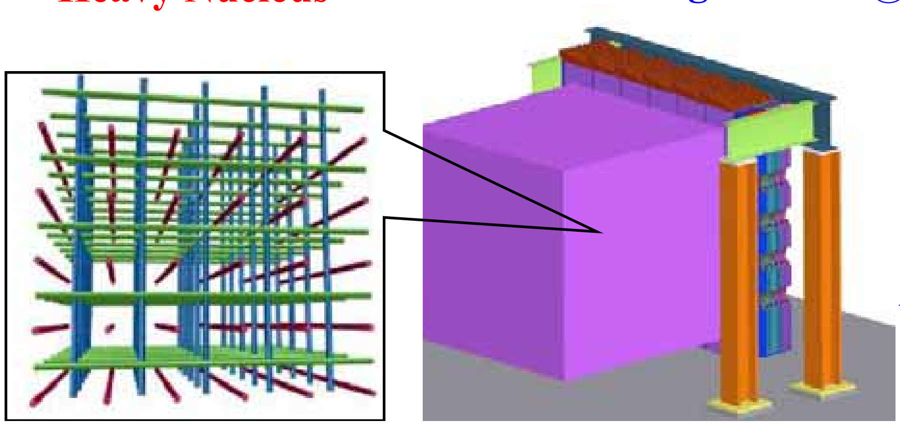


Beam energy ~ 1 GeV
→ suitable for Nuclear Physics in the Δ resonance region

Detector ~ LOI(AGS neutrino beam) ~ Liquid Sci. with W.L.S
Target
- **Proton**
- **Carbon !**
- **Heavy Nucleus**



Detector design in LOI@AGS ν beam



Around Near Detector

Neutrino induced CPP

E~1 GeV → Δ resonance region ~ ΔΔ interaction in the nuclear medium
~ π,Δ propagation in the interior of nucleus

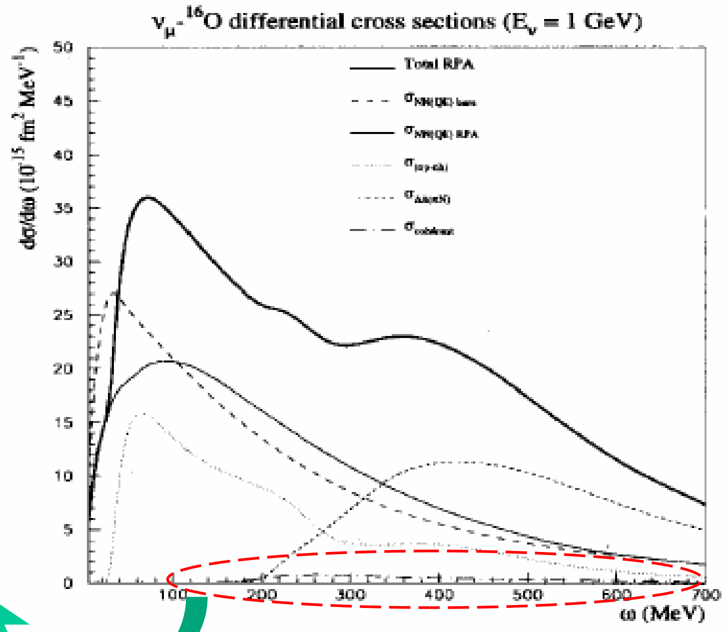
LOI (AGS neutrino beam)

ΔS physics: NC EL

Nuclear physics ~ ΔΔ interaction: CC coh π^+, NC coh π^0

ν interaction type	ν_μ 10^{20} POT 1 ton	$\overline{\nu_\mu}$ 10^{20} POT 1 ton	$\nu_e + \overline{\nu_e}$ 10^{20} POT 1 ton
CC QE, $\nu_\mu n \to \mu^- p$	11,395	184	56
NC EL, $\nu_\mu N \to \nu_\mu N$	4,993	86	22
CC π^+, $\nu_\mu p \to \mu^- p \pi^+$	3,293	24	24
CC π^0, $\nu_\mu n \to \mu^- p \pi^0$	725	11	6
CC π^+, $\nu_\mu n \to \mu^- n \pi^+$	646	10	6
NC π^0, $\nu_\mu p \to \nu_\mu p \pi^0$	606	10	5
NC π^+, $\nu_\mu p \to \nu_\mu n \pi^+$	370	6	3
NC π^0, $\nu_\mu n \to \nu_\mu n \pi^0$	454	8	3
NC π^-, $\nu_\mu n \to \nu_\mu p \pi^-$	290	5	2
CC DIS, $\nu_\mu N \to \mu^- X$	176	0	1
NC DIS, $\nu_\mu N \to \nu_\mu X$	64	0	0
CC coh π^+, $\nu_\mu A \to \mu^- A \pi^+$	539	22	3
NC coh π^0, $\nu_\mu A \to \nu_\mu A \pi^0$	349	14	2
other	464	14	1
total	24,364	394	134

Table 3.1: *Number of events expected at 50 m with a 25 m decay length for* 1×10^{20} *POT per ton detector. These predictions do not include final state effects and assume* 100% *detection/reconstruction efficiency.*



Summary

Nuclear physics with Coherent Pion Production

- **$\Delta\Delta$ interaction in the nuclear medium**
- **Short range correlation : $g'_{\Delta\Delta}$**
- **Spin longitudinal response function : R_L**

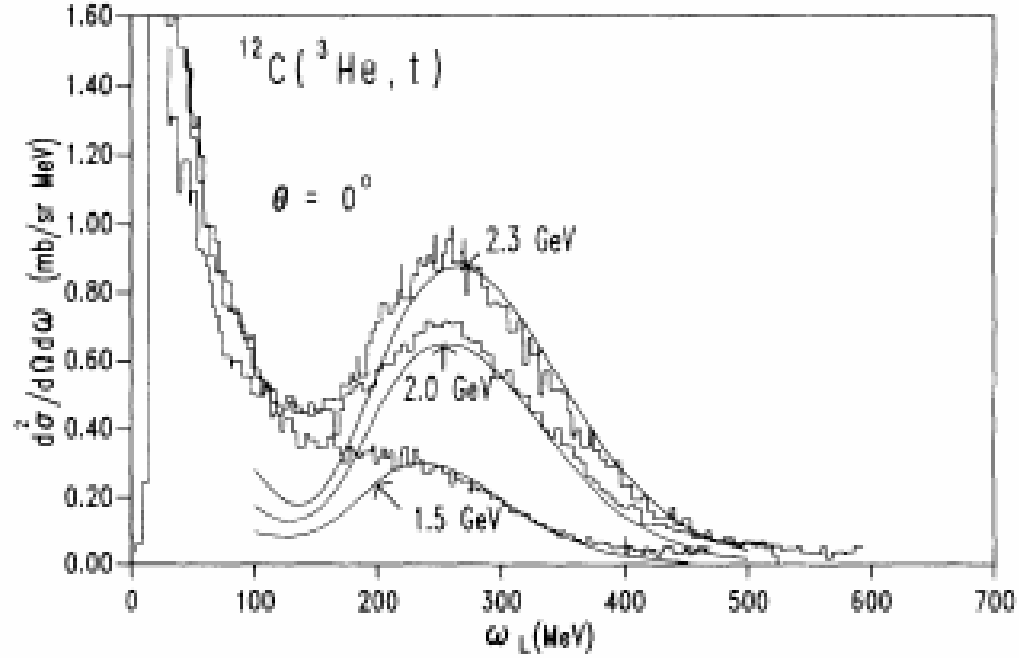
- **Hadron(Proton/3He) Beam ~ Prove the surface, low density region**
  - Detailed study of reaction mechanism, response function
  - Input for the accurate analysis of neutrino induced CPP data
  - proton induced CPP experiment @RCNP ~ test experiment ~ done
- **Neutrino Beam ~ Probe the interior of the nucleus**
  - J-PARC neutrino beam ~ 1 GeV ~ suitable for the ν-nucleus physics

- CPP ~ important to know neutrino detector response ~ RICH Particle ID
- Physics discussion, Detector design ~ needed

Strange Quark Content in the Nucleon
by T.-A. Shibata, N.Saito, Y.Miyachi

Nuclear Physics ~ $\Delta\Delta$ interaction in the nuclear matter
~ pion condensation, cooling mechanism of neutron star

Neutrino Beam



$^{12}C(^{3}He,t)$
$\theta = 0°$
2.3 GeV
2.0 GeV
1.5 GeV
$d^2\sigma/d\Omega d\omega$ (mb/sr MeV)
ω_L(MeV)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
0
100
200
300
400
500
600
700

Electron/Photon induced CPP

Suggested by Prof. M. Sakuda

- Longitudinal Response

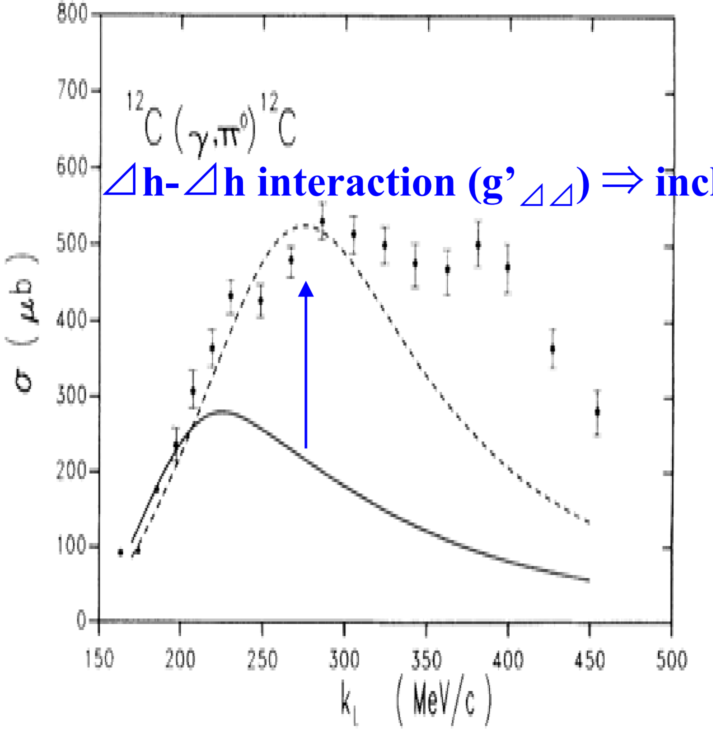
$$R_L \propto \left| \langle n | \sigma \cdot \mathbf{q} | 0 \rangle \right|^2$$

  - Enhancement and Softening

- Transverse Response

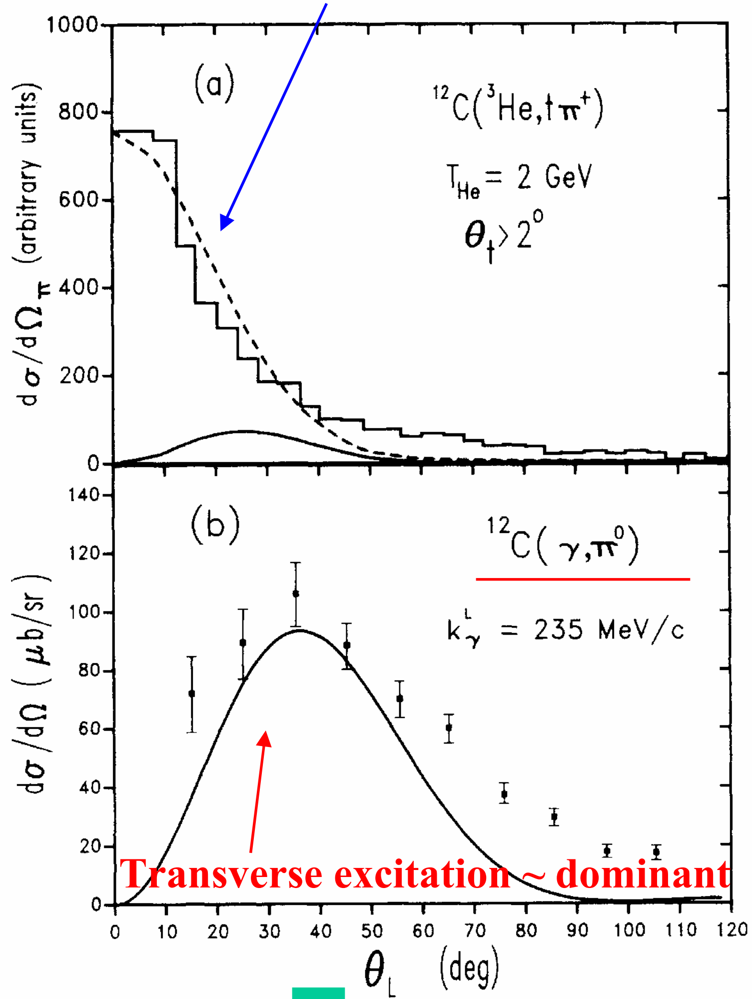
$$R_T \propto \left| \langle n | \sigma \times \mathbf{q} | 0 \rangle \right|^2$$

  - Quenching and Hardening



⊿h-⊿h interaction (g'$_{⊿⊿}$) ⇒ include

Mixture of longitudinal and transverse responses



Transverse excitation ~ dominant

Can extract Longitudinal response strength by reducing the Transverse component measured by e/ γ induced CPP

Tracking Detector: Gas Electron Multiplier