Coincidence Measurement of the Weak Decay of $^{12}_{\Lambda}C$ Hypernucleus and the Three-body Weak Interaction Process

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KEK
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I. Objects of the Experiment.

II. Decay Counter:
- Up-to-date setup
- Target energy loss correction,
- Yield Estimation and Beam time request.

III. Yield Characteristics and How to extract 2N-NMWD.

IV. Summary

I. Physics Motivation and Previous Searches

$$\Gamma_{tot}(=1/\tau) \begin{cases} \Gamma_m & \begin{cases} \Gamma_{\pi^-}\ (\Lambda \rightarrow p\pi^-) \\ \Gamma_{\pi^o}\ (\Lambda \rightarrow n\pi^o) \end{cases} \\ \Gamma_{nm} & \begin{cases} \Gamma_p\ (\Lambda p \rightarrow np) \\ \Gamma_n\ (\Lambda n \rightarrow nn) \\ \Gamma_{2N}\ (\Lambda NN \rightarrow nNN) \end{cases} \end{cases}$$

Mesonic

q~ 100 MeV/c

(1N)

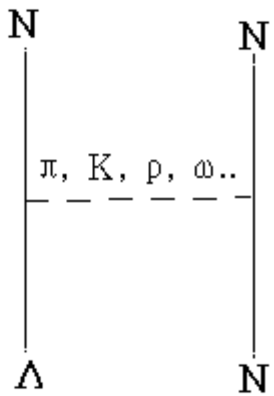
(2N)

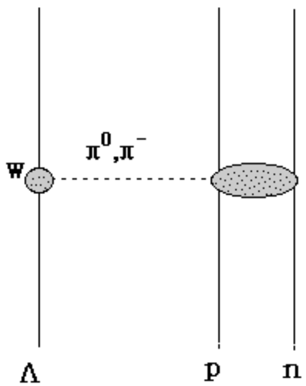
Nonmesonic

q~ 400 MeV/c

Previous Searches;
$\Gamma n/\Gamma p$ puzzle

3-Body Process





(3-Body)

Status of NMWD of Λ hypernuclei

I. **Main Issue** ; **B-B Weak Interaction** ;

Λ + N -> N + N (ΔS=1 B-B Weak Interaction)

- Γ_n/Γ_p (≡np ratio) and **Ay have been mainly studied so far.**

II. urgent Issues to be solved ;

- ΔI=1/2 rule
- 3-body process of Weak Decay;

  Is there really such processes?

  How much contribution?

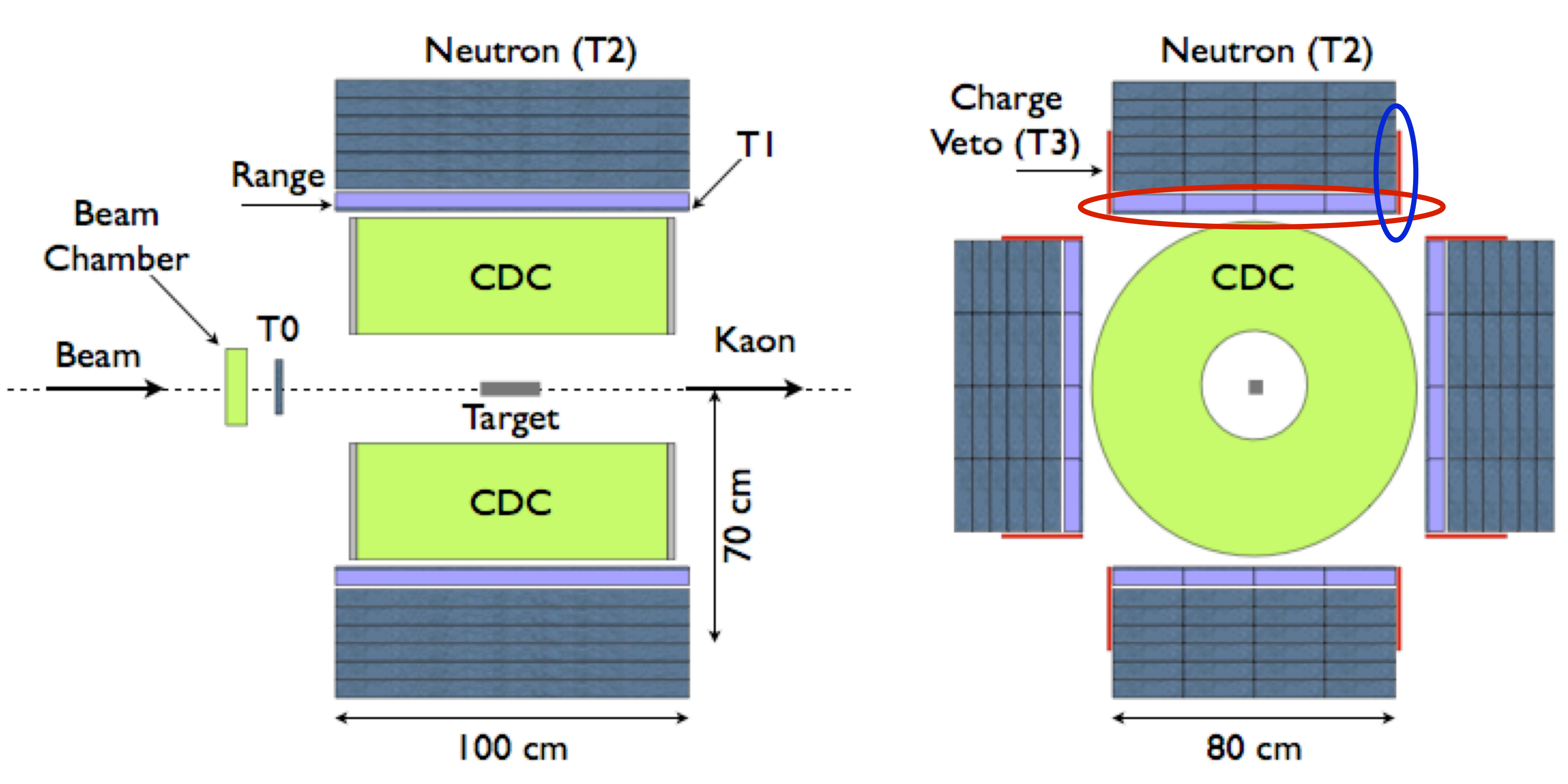
  Why 3-body effect is so strong that it is comparabe to 2-body effect?

- Branching ratios of NMWD; It has been so long, but accurate branching ratios are not available yet.

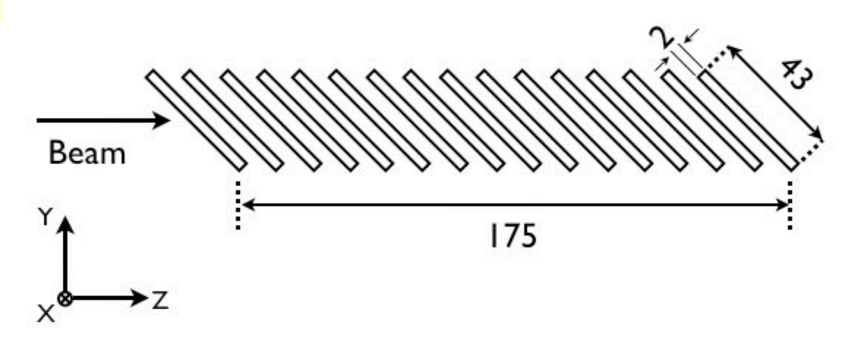
II. Decay Counter Setup

We modified the decay counter setup so as to share the same setup as that of P10.

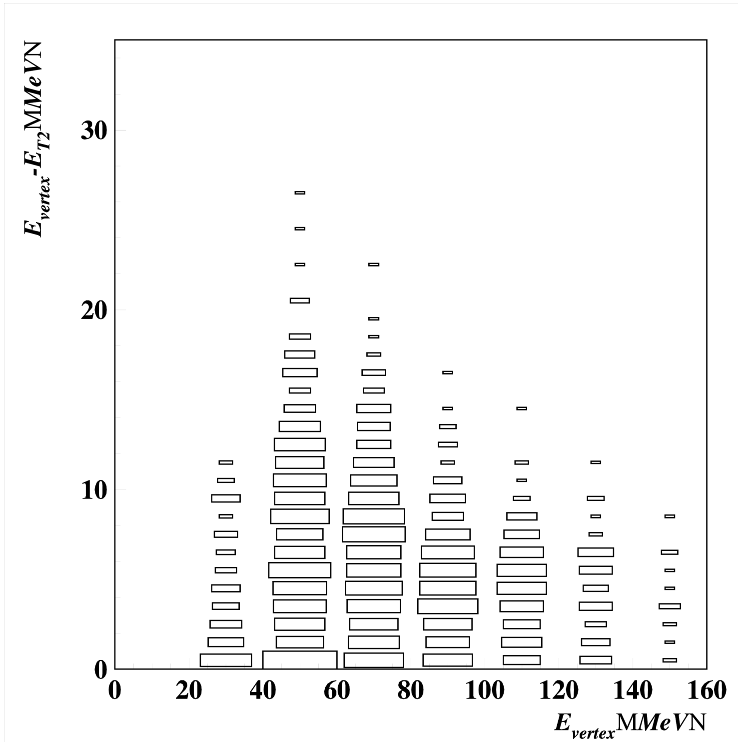
- CDC adopted
- Range counters for LE charge particles
- Side veto to reject passing through ptls



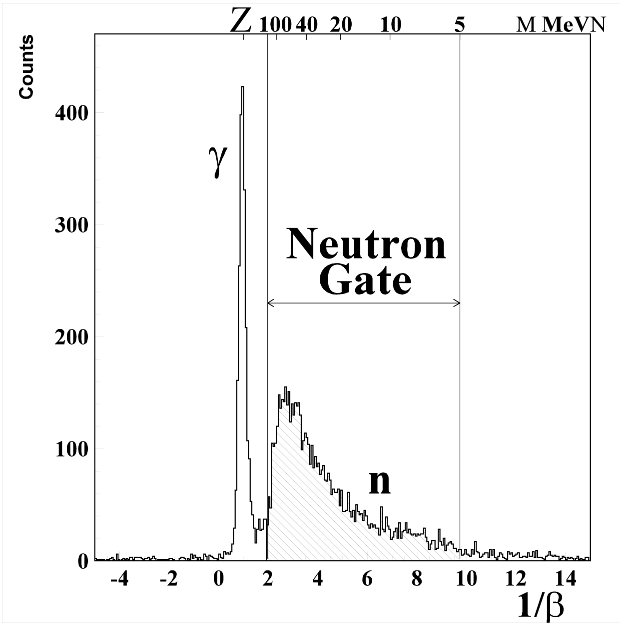
Target Energy Loss Correction and Vertex resolutions.

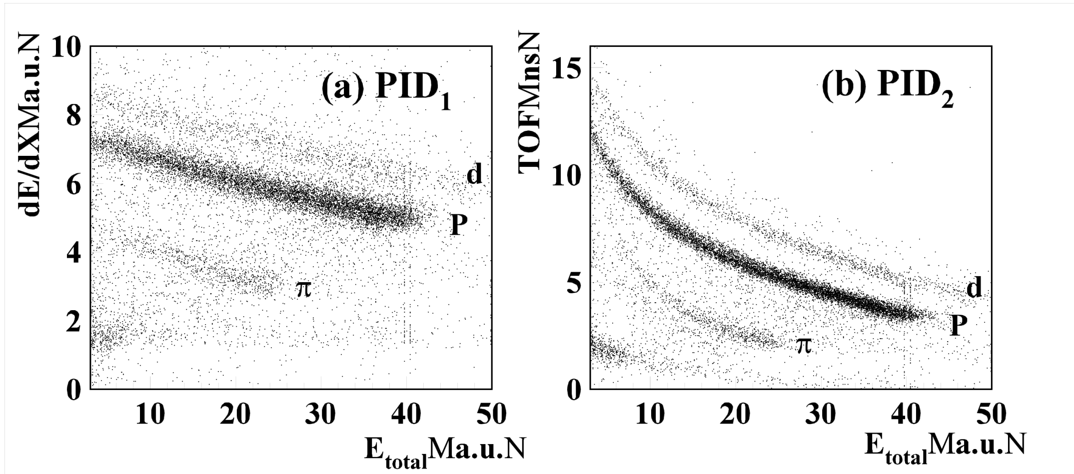


- Vertex resolutions (E508);
  σ_x = 0.4 mm,
  σ_y = 2.4 mm,
  σ_z = 2.56 cm
- Energy resolution,
  $\sigma_E(p)$ = 2-3 MeV, $\sigma_E(n)$ = 7-8 MeV.
- Depth resolution;
  – σ=2.4mm ↔ 3 cm target depth.
  - ΔE in target will be mostly less than 10(5) MeV.
    → gives σ_E~ 1-2 MeV



PID for neutral and charged particles





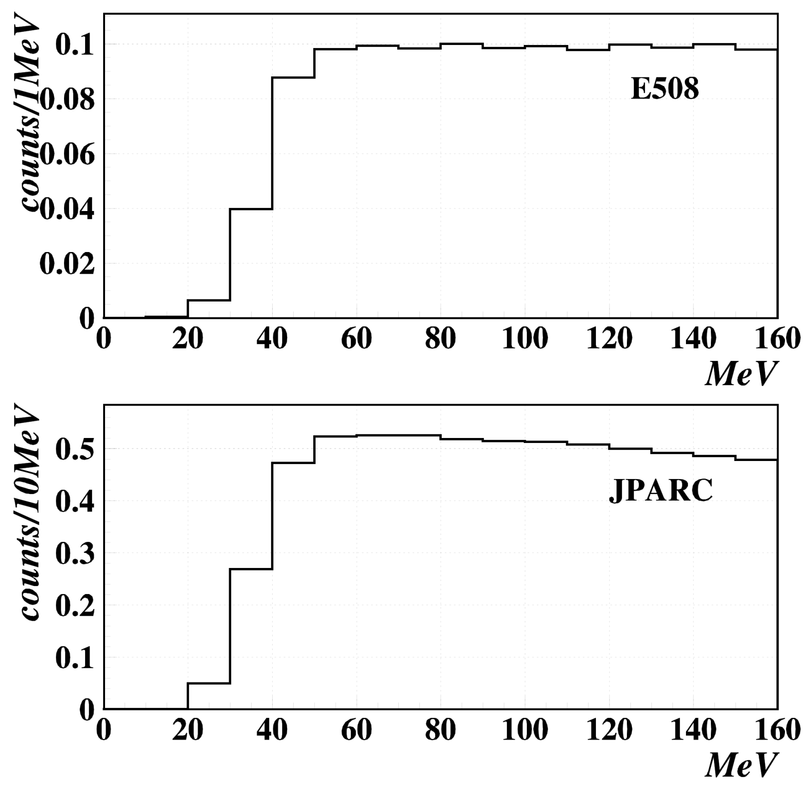
Essentially same as E508

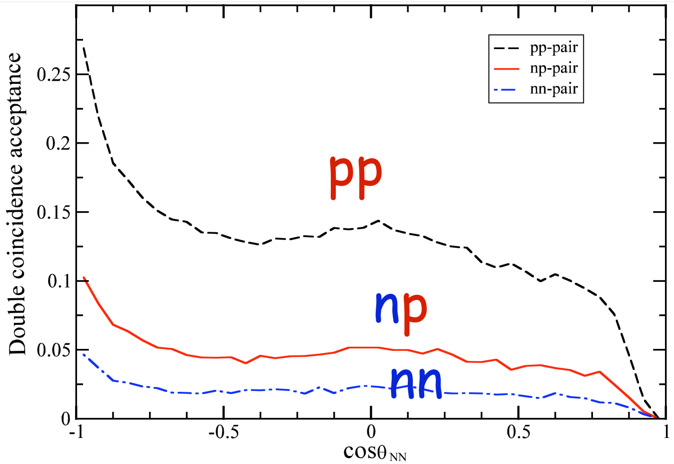
Charged particle PID will be improved than that of E508

Expected Yields

	E508	P18
N_π	2×10^{12}	5×10^{12}
dN_π/dt	4×10^{6}/spill	10^{7}/spill
T(arget)	$4.3g/cm^2$	$4.3g/cm^2$
N_{HY}(g.s.)	~62K	2.5*62K
Y_{bb} (np)	116	~1160
Y_{bb} (nn)	43	~430
Y_{bb} (pp)	8	~90
Y_{nbb} (np)	12	~375
Y_{nbb} (nn)	23	~300
Y_{nnn}	3	(~45)
Y_{nnp}	2	(~80)
$\sigma_{stat}(\Gamma_n/\Gamma_p)$	28%	~10%
$\sigma_{stat}(\Gamma_{2N})$		~10%

bb: back-to-back
nbb: non-back-to-back





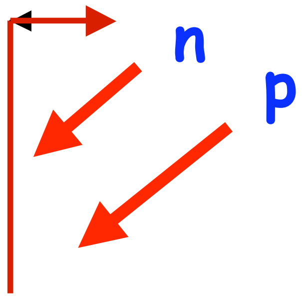
III. Yield Characteristics & How to extract 2N-NMWD.

1. Singles Yields.

- Similar shapes for n and p at E>50
- HE region ; Nn/Np=2; Maintain the same ratio for all HE region.

  → n, p experiences similar FSI.
- LE region ; Spectral shapes at LE ar e different.

\- Γ_n/Γ_p puzzle was resolved as soon as both n and p spectra are compared.



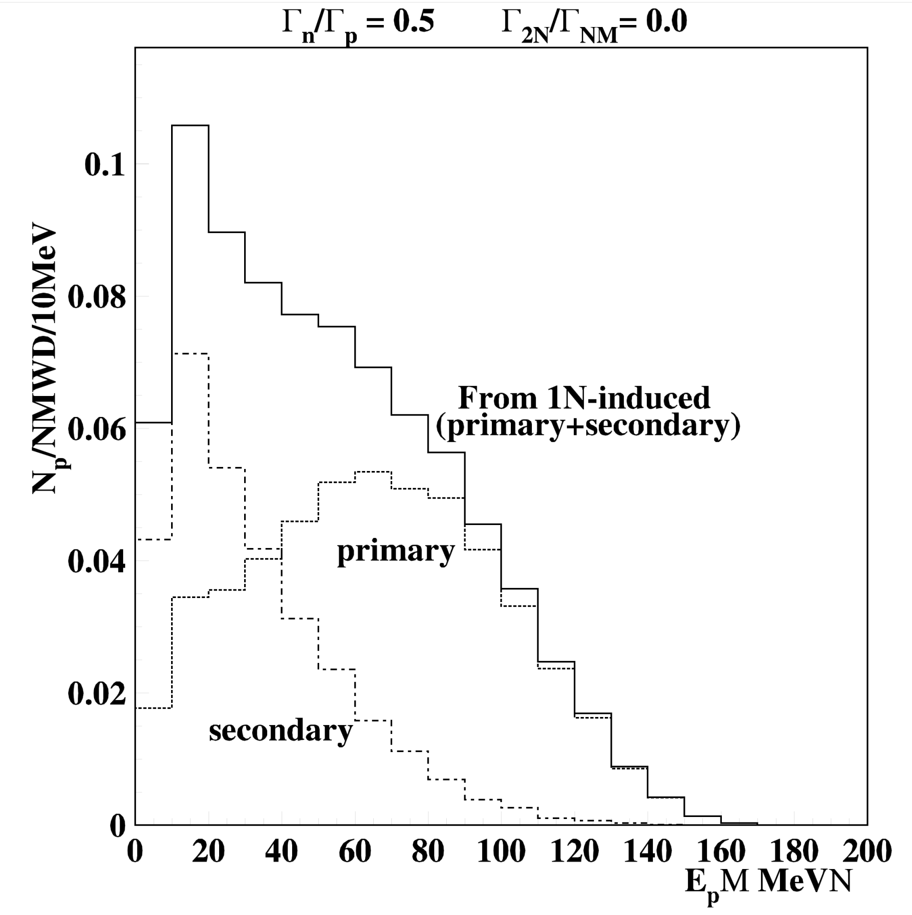
$N_n/N_p \sim 2$

2. Cross-Over(CO) contributions

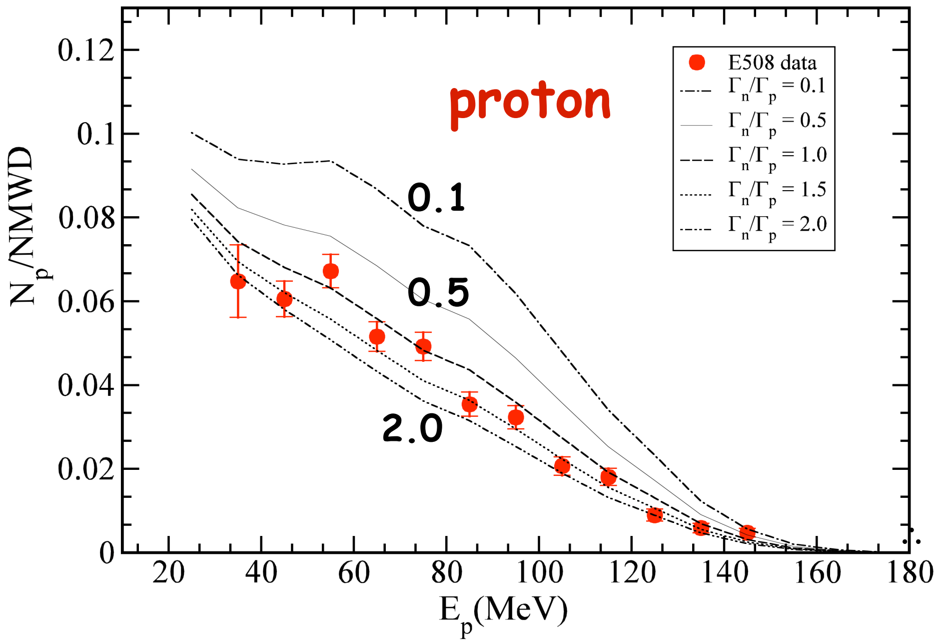
- p(n) recoil from n(p) projectile.
- Since 3 times more CO in p spec, N_p increases fast as $E_p \rightarrow 0$ while N_n does slowly.
- What observed are rather opposi te;

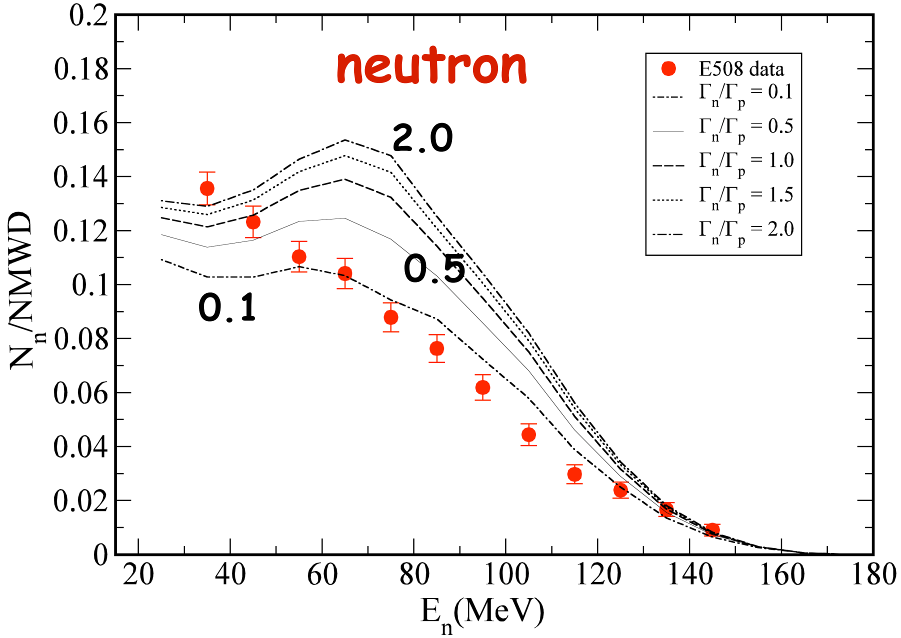
  → i) FSI not so strong!

  ii) LE behavior can not be expl ained well by FSI.
- There seems a LE neutron genera tion mechanism!!.



3. Comparison to INC spectra.



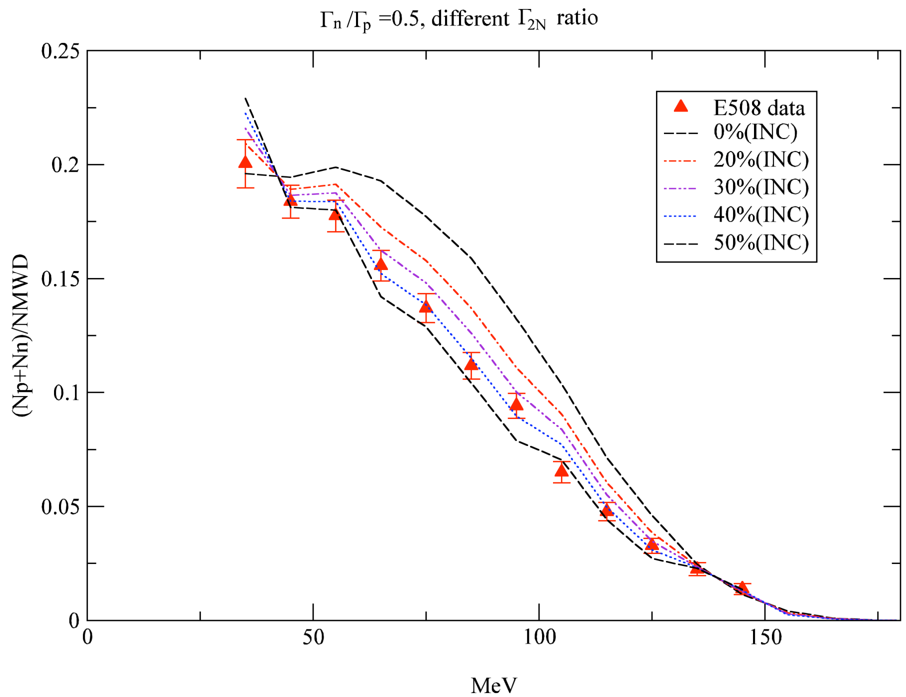


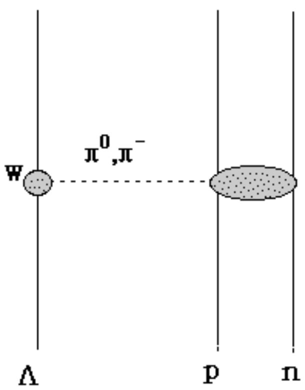
1. From the p spectrum, we get Γ_n/Γ_p value larger than unity, while n spectrum gives it much smaller than unity. → No consistent Γ_n/Γ_p value.
2. p and n both Yields are strongly quenched from those of INC over all ene rgy region above 50 MeV.
3. Could it be due to strong FSI? If so, we should observe faster increase of proton in LE. Instead we observe the fast increase of n yields at LE.

   → Such Quenching can not be explained by FSI.
4. Then what's the reason of this strong quenching??

n

p

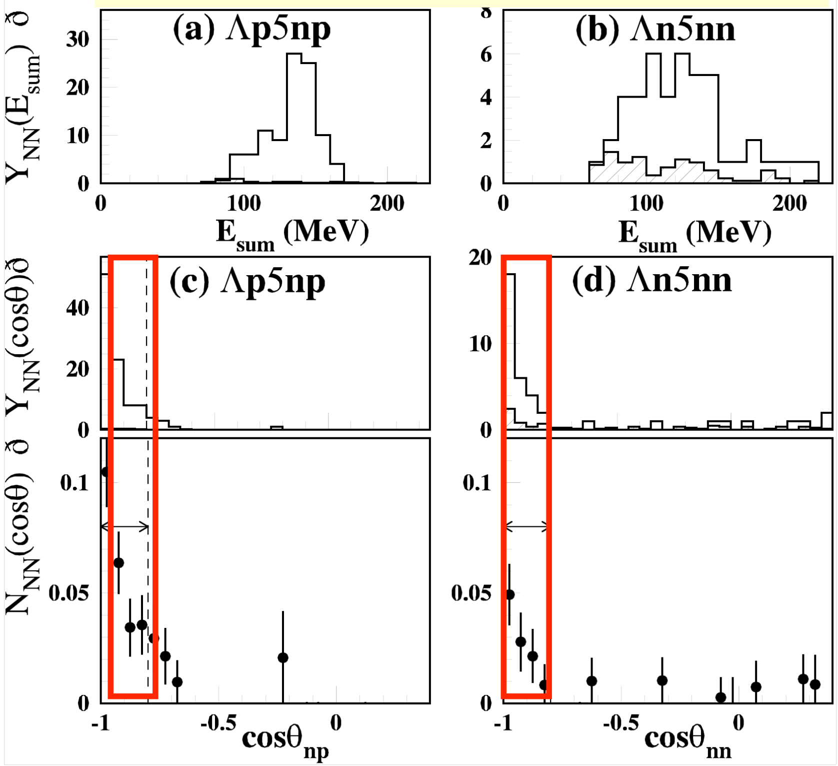


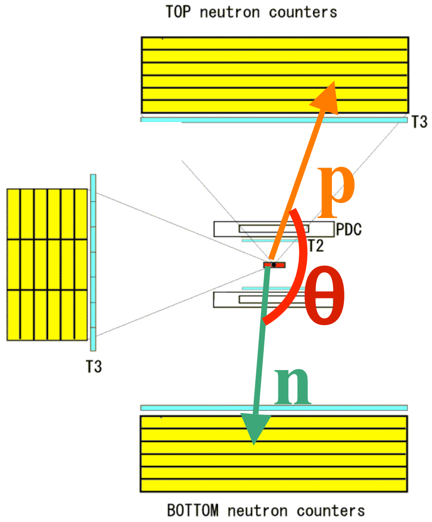


- For 2N NMWD, the 3-body final state with equal phase space sharing Dalitz kinematics was assumed.
- Nn+Np is compared to those of INC with different contributions of 2N.
- Quenching of Singles Yields is clearly shown.
- Singles yields can be well explained only with a significant contribution of 2N. Here, Γ_{2N}~0.4 Γ_{NM}.

5. Coincidence Yields ($^5_\Lambda He$)

Pair Energy Sum Spectum





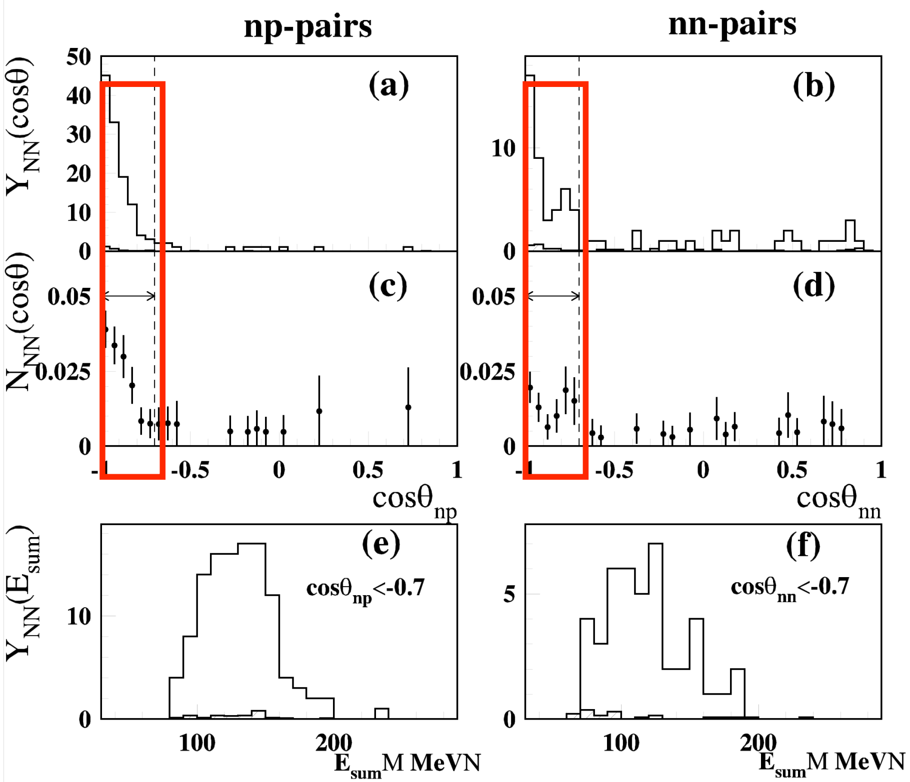
Angular Correlation of a pair nuc.

$$N_{np} \equiv Y_{np}/(Y_{nm} \cdot \epsilon_{np})$$

: Pair no. per NMWD (for full eff. and Ω).

1. Sharp peak in Y_{np}(He) at Q value.
   → FSI not severe in He.
2. ∃Broad spec in Y_{nn}(He).
   FSI? No.
   π^- absorption or 2N?
   π^- can not make it broad.
   ∴ Seems 3B phase space dist!!
3. bb dominance
4. $N_{bb}(nn)/N_{bb}(np) \approx \Gamma_n/\Gamma_p$

Coincidence Yields (NN correlations) ; $^{12}{}_{\Lambda}C$



1. No more sharp peak at Q value($\Lambda p \rightarrow np$).
   → FSI significant in C.
2. $Y_{nn}(C)$: Even further degraded.
   → 3B phase space?
3. bb dominance in np pairs.
4. N_{nbb}/N_{bb} is much enhanced in nn pair over that of np
   → 2N NMWD

Enhancement of nn pair yields in the nbb region ($^{12}_{\Lambda}C$)

1. Enhancement of N_{nn} in nbb, over that of N_{np}, by a factor, Rnn/Rnp~(2.3±0.93).

   → Assign it to Γ_{2N}.

2. Just Rough Estimation;

   1) N_{np}(nbb) → all FSI eff.

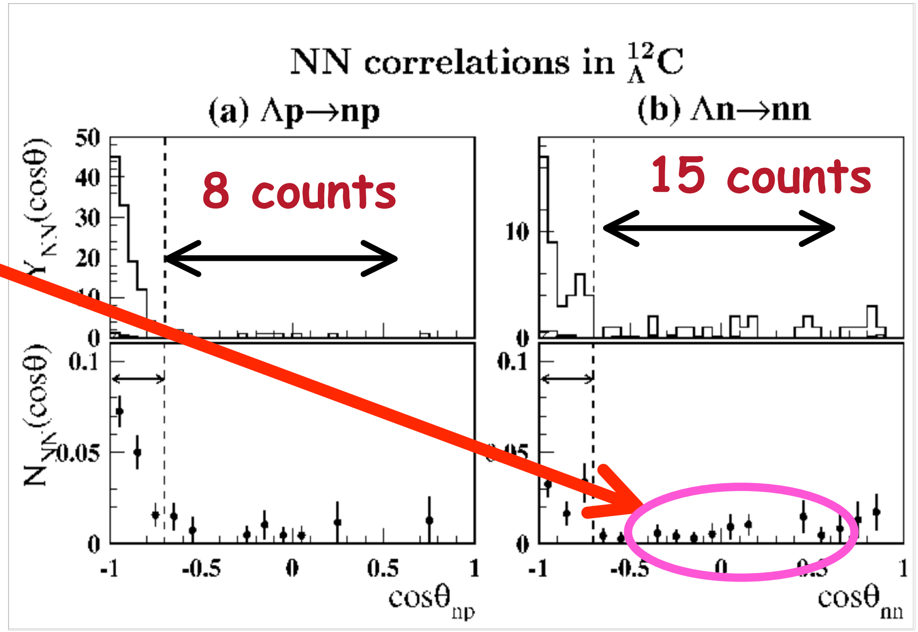
      → Same FSI on N_{nn}

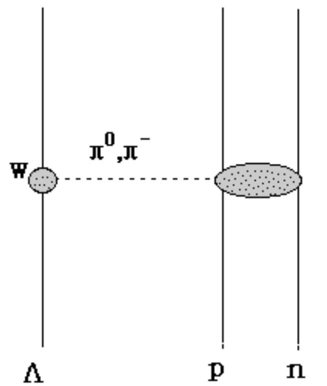
      → Γ_{2N} ~ The residual N_{nn} after FSI sub.

   → Γ_{2N} / Γ_{NM} ~0.15±0.09±

   2) Similarly, but using INC for FSI

   → Γ_{2N} / Γ_{NM} ~0.27±0.12

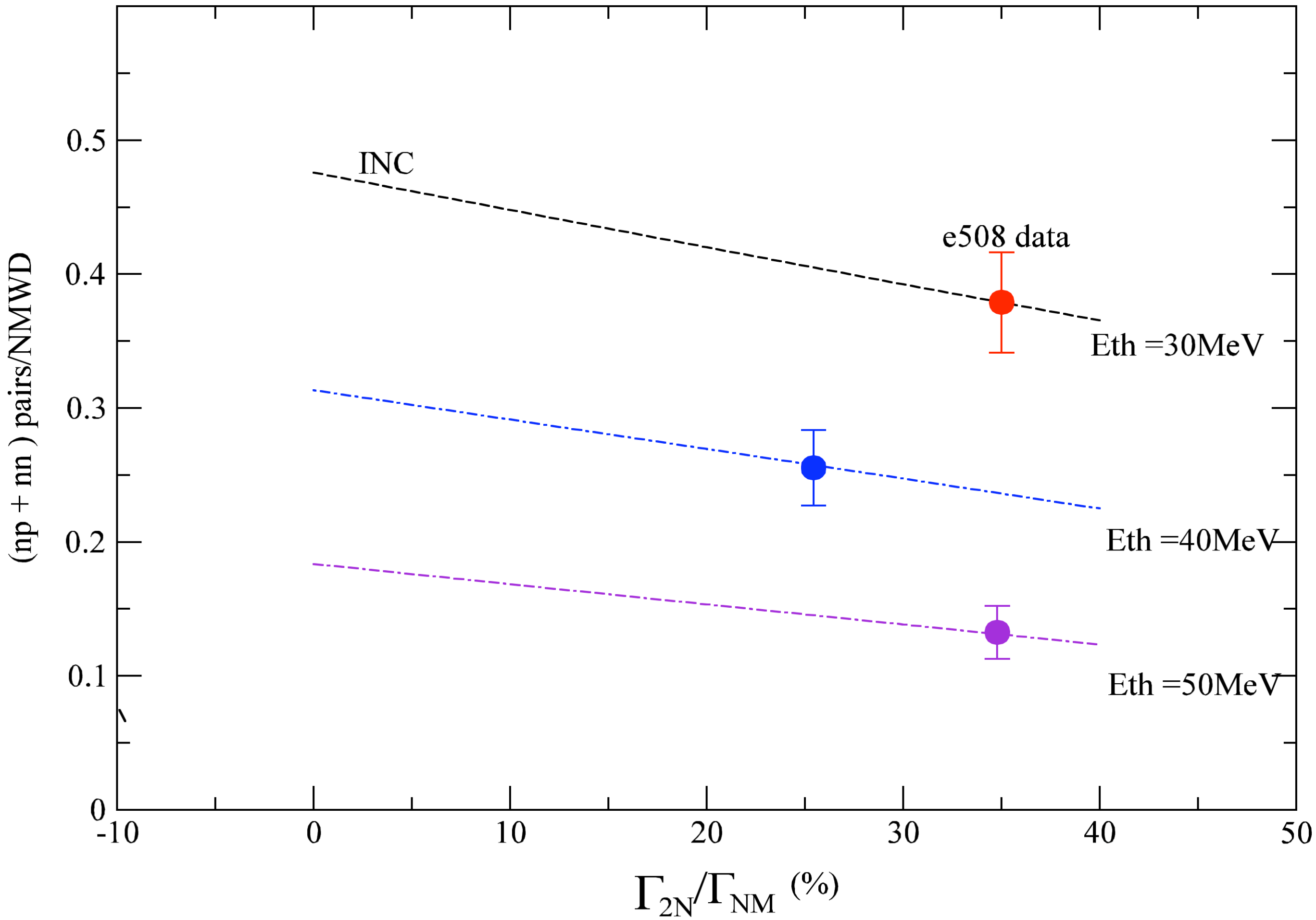




$R_{NN}=N_{NN}(nbb)/N_{NN}(bb)$;

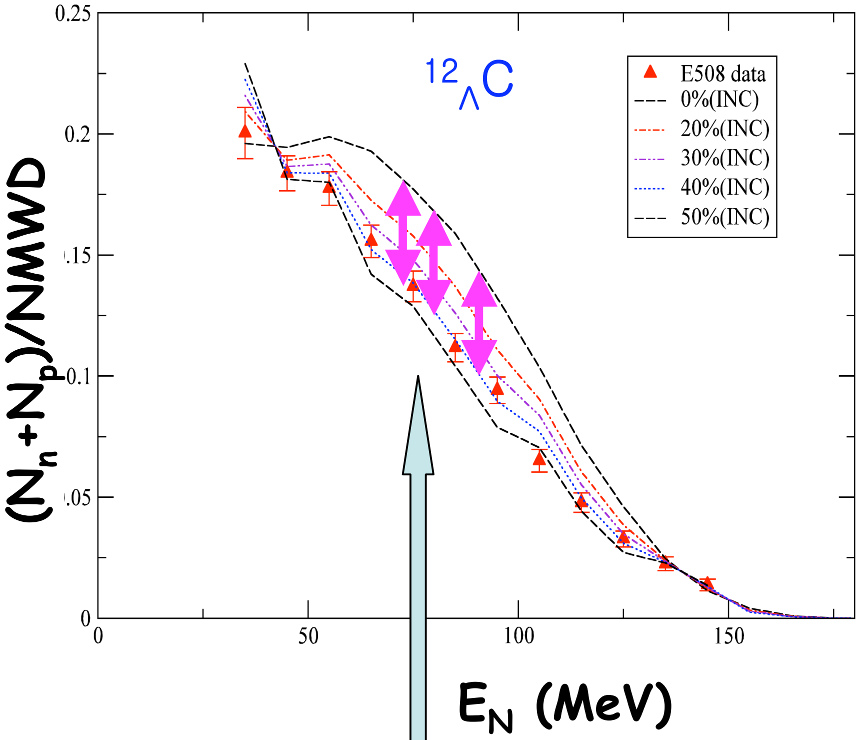
Ratio of N(nbb) to N(bb)

Quenching of Pair Sum, $N_{nn}+N_{np}$, compared to that of INC

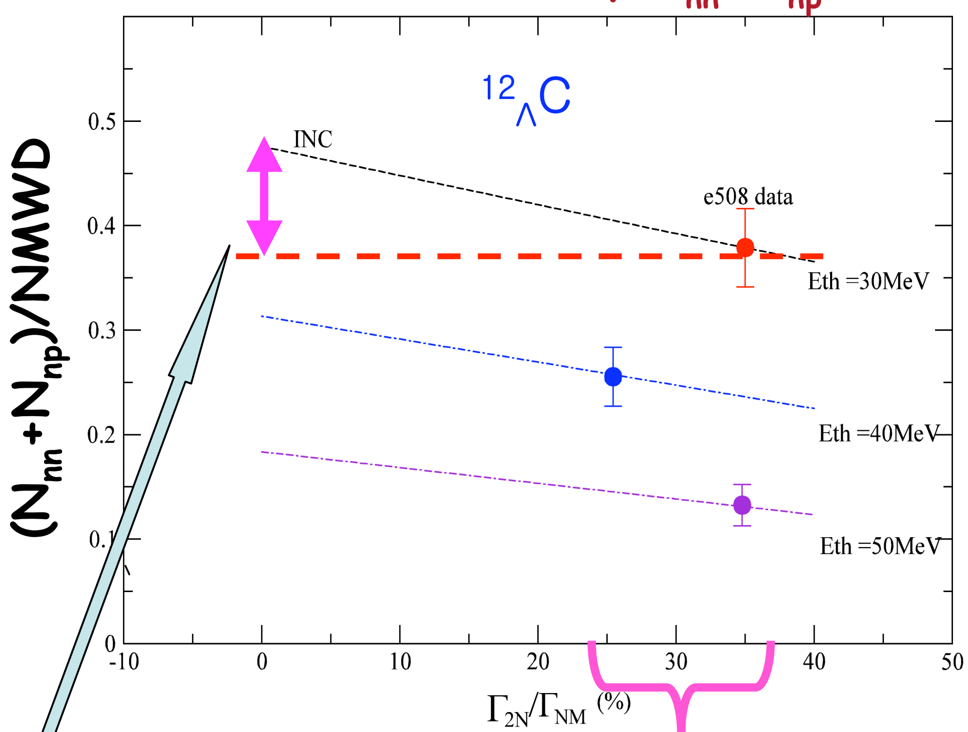


2. Quenching of Singles and Coincidence yields.

Singles Yield Sum, N_n+N_p



Coin. Pair Yield Sum, $N_{nn}+N_{np}$



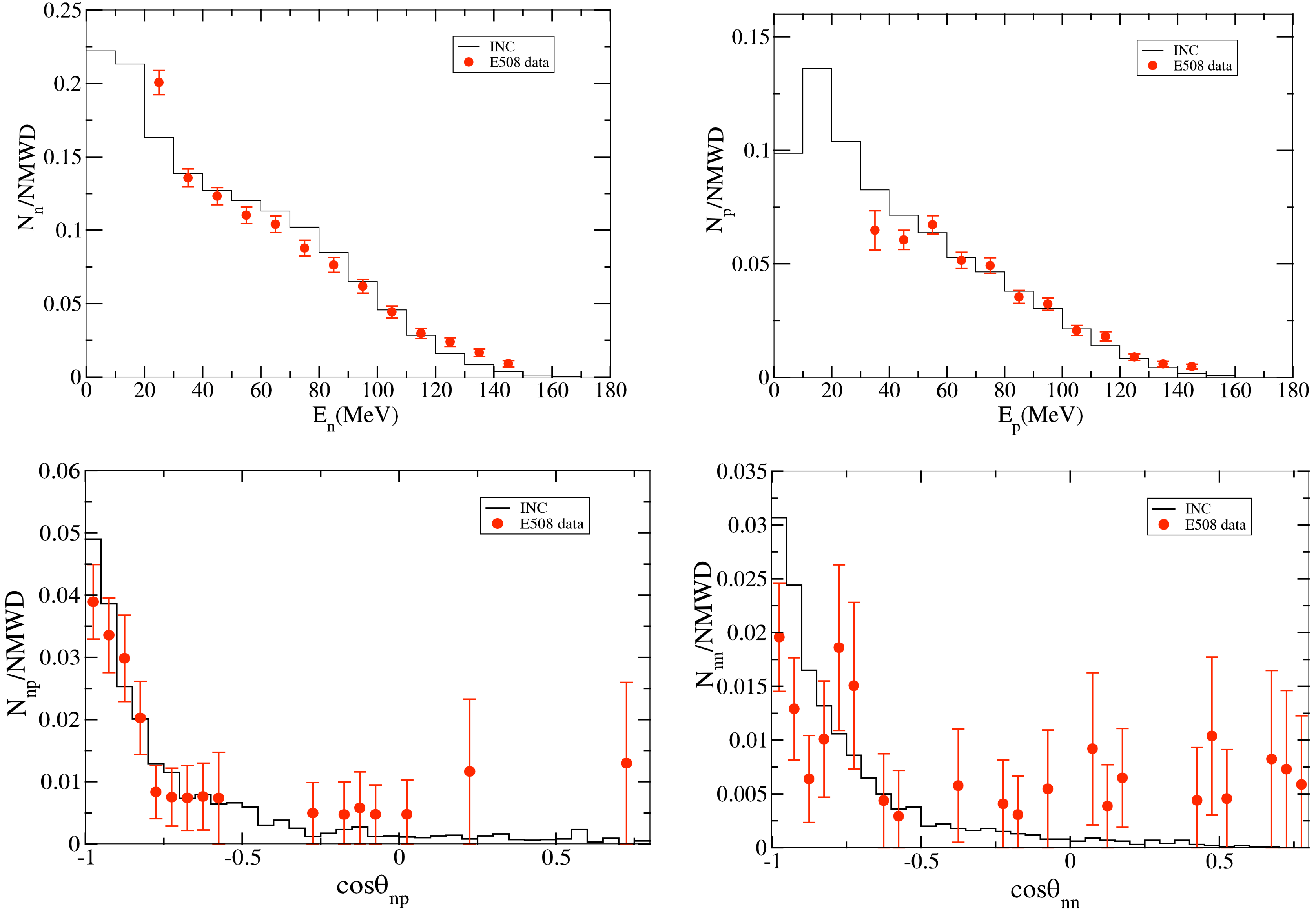
$\Gamma_{2N} \sim 0.32\Gamma_{nm}$

Quenching of N_n+N_p and $N_{nn}+N_{np}$ can not be explained without Γ_{2N}.!!

In this INC comparison, we need Γ_{2N}~$0.4\Gamma_{NM}$ to explain the nucleon quenching.

Singles and Coin. Yields Reproduction with INC.

$\Gamma_{2N}=0.4\Gamma_{nm}$



pp events and FSI.

- pp events are possible only via FSI.
- Their energy sum and angular correlation would give valuable information on FSI.
- We got 8 events at E508 due to the very limited solid angle for pp.
- We expect ~ 100 pp events which would give us another leverage to extract 2N out of FSI events.
- Additional side veto counters are to increase the proton efficiency.

IV. Summary

1. In the series of KEK-PS experiments, Γ_n/Γ_p and α_{nm} of NMWD have been clearly measured recently.
2. The signatures of (2N)-NMWD processes were found both in the si ngles and coincidence data. Quenching of the yields and the Energy spectra can be understood simultaneously only with a significant 2N contribution, $\Gamma_{2N} \sim \Gamma_{1N}$.
3. The signatures of 2N NMWD are abundant and in everywhere. 2N and FSI can not be seperated from each other kinematiclly, but th eir yield characteristics are quite different.
4. Our method to extract 2N NMWD is 1) to use N. yield characteris tics, and 2) PP events for the experimental FSI information.
5. We still do not have accurate partial decay widths of NMWD. It is because ot the large Γ_{2N} and its large error bar.
6. Need a conclusive experiment → at JPARC to determine

   1) Γ_{2N} : The strength of 3-body decay process
   2) Γ_n, Γ_p .

Proposal

- Main Objects, along with other observables,
  - To measure the 3-body decay process, Γ_{2N}, in 10% error level.
  - To measure all decay widths of NMWD in 10% error level.
- $^{12}C(\pi^+,K^+)$ for $5\times10^{12}\pi$ of $10^7\pi$/spill.
- - SKS spectrometer; ~100 mSr.

  - Coincidence Detectors; ~2π Sr
- For 80 shifts;
  - $N_{nbb}(np)$ ~ 375 (12), $N_{nbb}(nn)$ ~ 300 (23), $N_{bb}(pp)$ ~ 80 (8),
  - N(NNN) ~ (100) (5).
- Ideal to run at the initial stage;

  - Beam intensity requiremenht ; minimal

  - Counters ; Mostly funded already (Same counter as that of P10).

  - Solid experience with the system from previous experiments.
- Back-to-back Beam Time arrangement with P10, when approved, would be d esirable.

Collaboration

KEK, RIKEN, Seoul N. Univ., GSI, KRISS,
Kyungbuk N. Univ., Tohoku Univ., Pusan N. Univ.,
Univ. Tokyo, Osaka Elec. Comm. Univ.,
Tokyo Inst. Tech.

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EXTRA

II. New Setup

- CDC adopted
- Range counters for LE charge particles
- Side veto to reject passing through ptls increasing the proton a cceptance
- Acceptance for nn, np and pp

III. Yield Characteristics & How to extract 2N-NMWD.

- Quenching of Singles Yields.
- Quenching of back-to-back nucleon pair Yields.
- Enhancements of nn pair in non-bb region.
- The pp pair provides the energy and angular characteristics of FSI events so that it can be compared to those of 2N-NMWD.

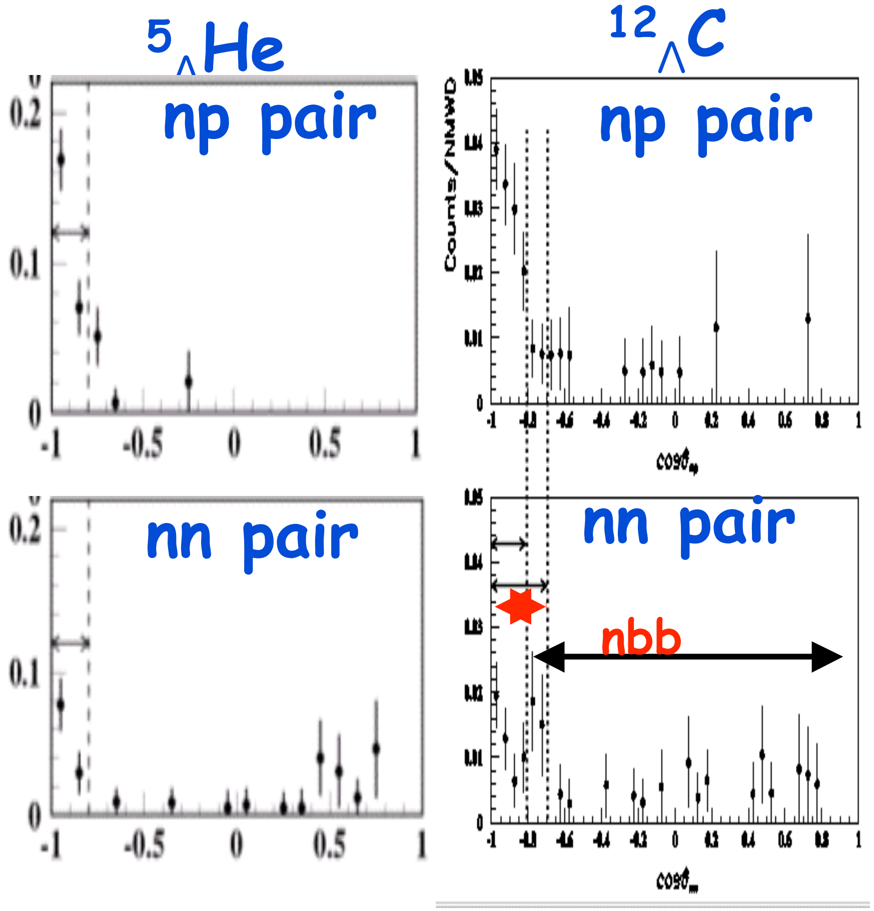
Quenching of Total Pair Yields

Total pair yields, N_T:

If Γ_{2N}=0, E_{th} =0 and FSI=0, N_T=1.

If Γ_{2N}=0, E_{th} =0 and FSI≠0, N_T=1+ α.

If Γ_{2N} ≠ 0 and Eth ≠ 0, N_T=?.



N_T = 0.38

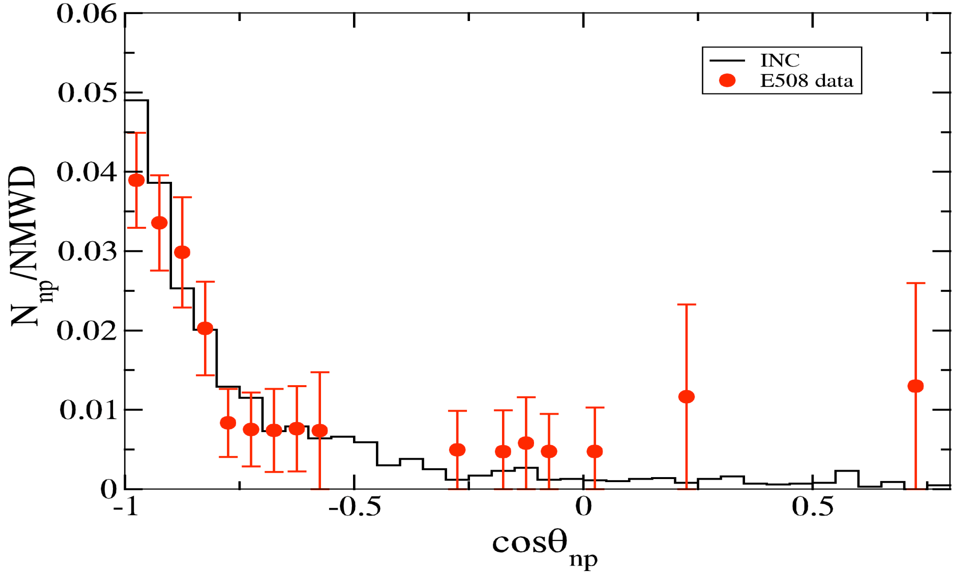
Signatures of Three Body Process in Weak Decay

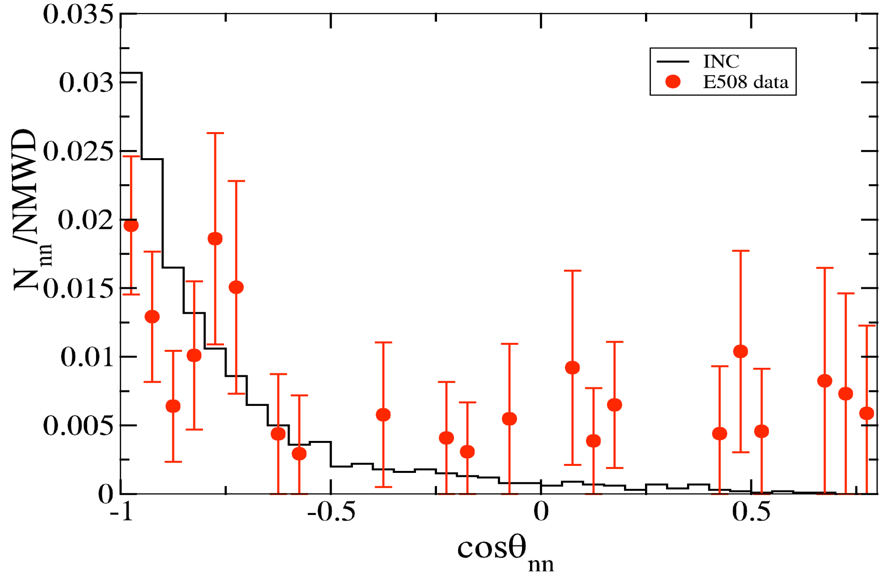
1. **Quenching of Singles yields ;**
2. **Energy sum spectrum ;**
3. **Quenching of Total pair yields ;**
4. **Enhancement of nn pair yields in the non-back-to-back angular kinematic region**
5. **The difference of Γ_n/Γ_p values derived from singles yield s and coincidence pair numbers.**

So many places !!

In every places !!

NN angular correlations compared to those of INC.



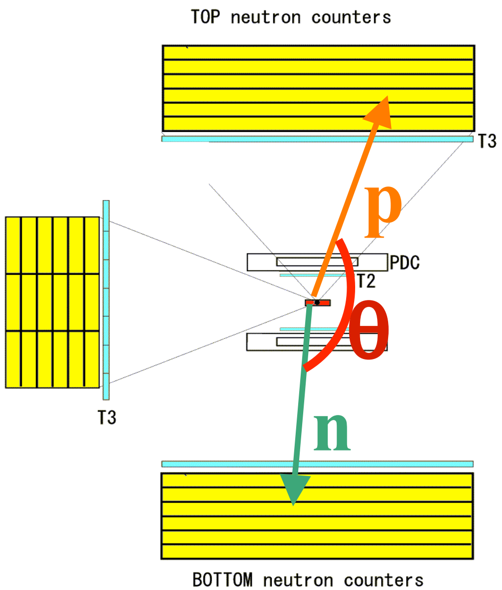


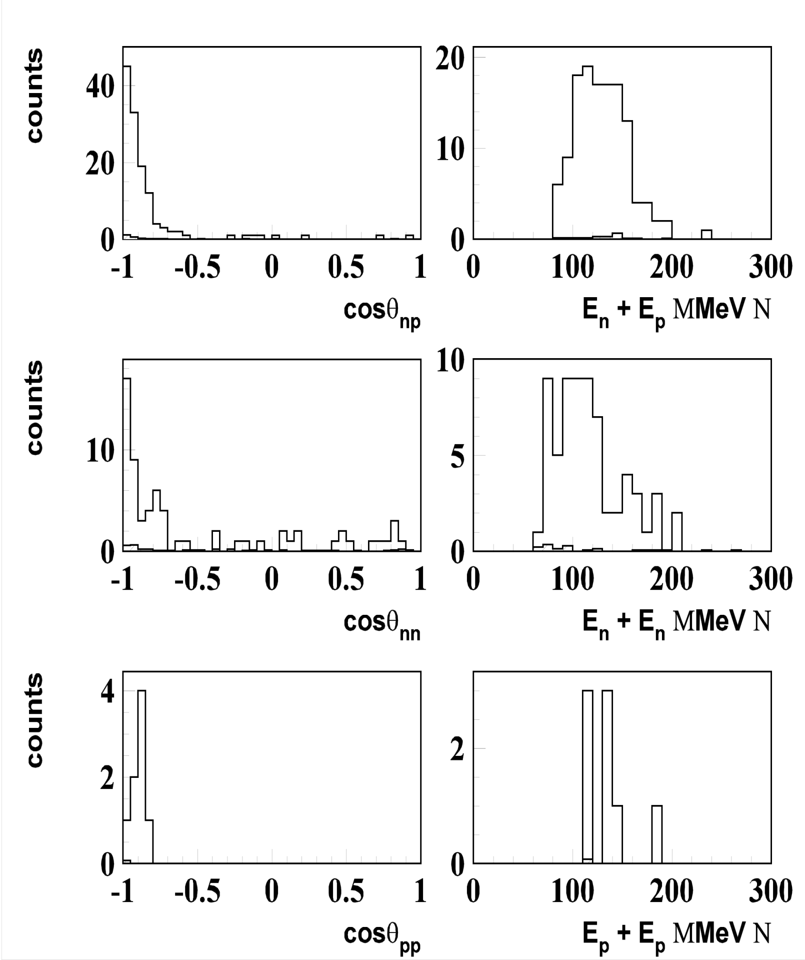
5. Coincidence Decay Observables.

1. Energy sum spectrum of a pair nucleons; Right side

   E_p+E_n, E_n+E_n

2. Raw Opening angle distribution of a pair nucleons; Left side





Angular Correlation of a pair nucleons;

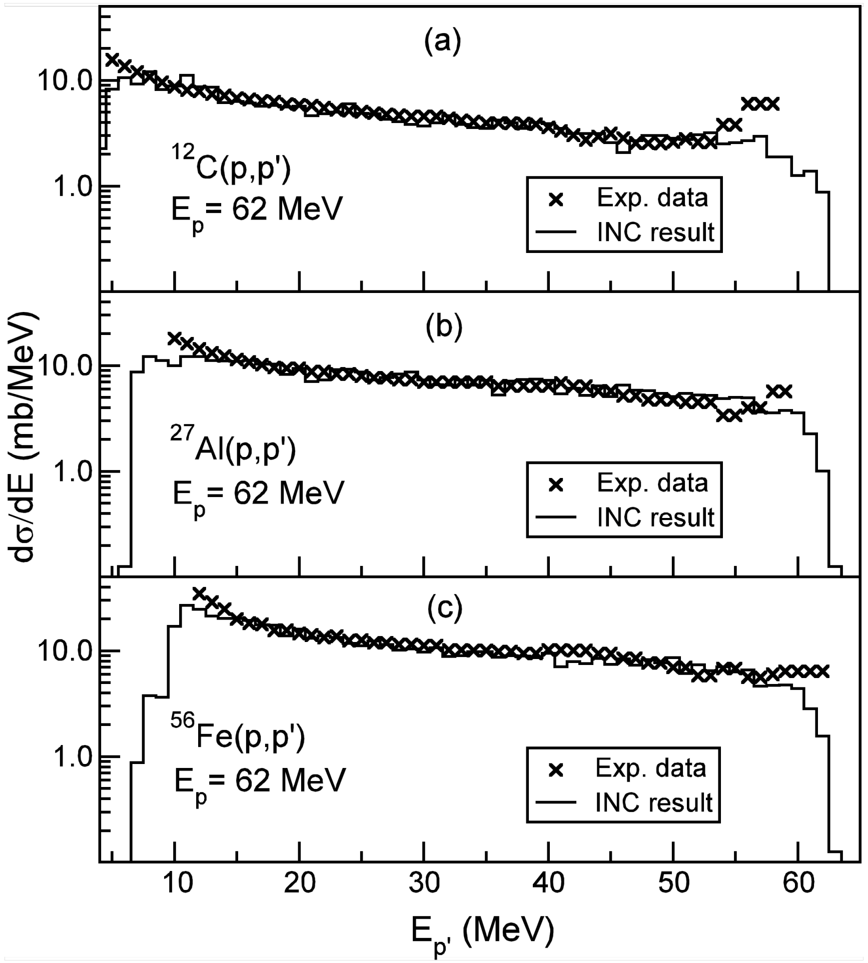
$$N_{np} \equiv Y_{np}/(Y_{nm} \cdot \epsilon_{np})$$

; Pair no. per NMWD for full eff. and Ω.

INC (IntraNuclear Cascade) calculation

- A nucleus as a Fermi gas.
- $\rho(x) \rightarrow V(x)$
- FSI is simulated as a cascade free NN scattering along with Fermi blocking imposed.
- Density geometry parameters are adopted from the reactions, (p, p') and (p,n) data with which Mass and Energy dependence were checked
- These parameters are fixed for the decay INC calc.

Mass Dependence



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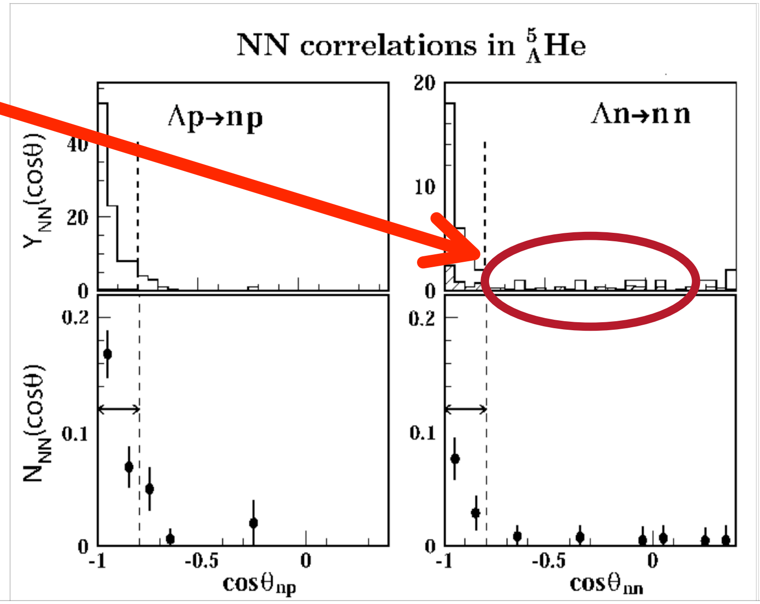
Enhancement of nn in nbb region

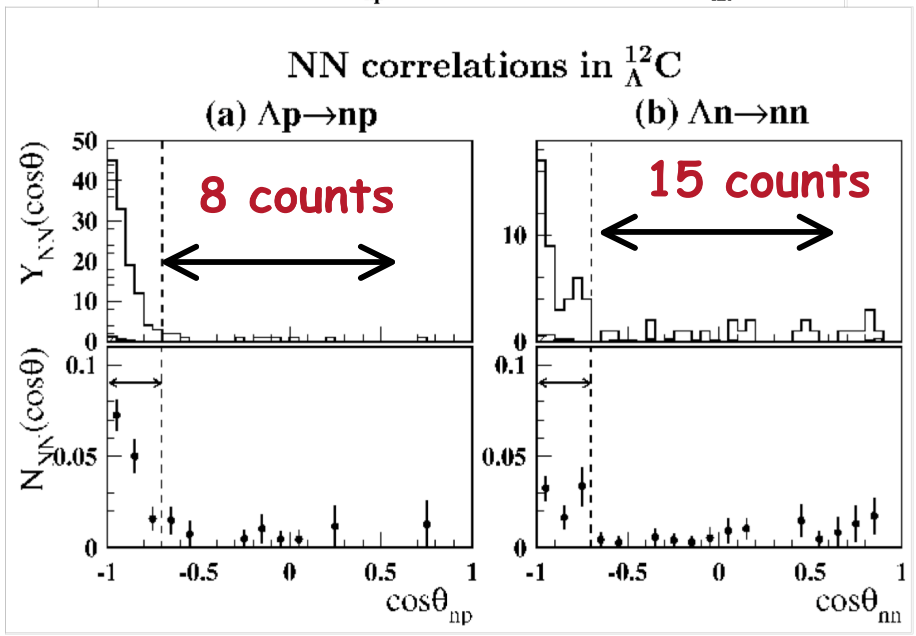
- We know that FSI(He) not strong.

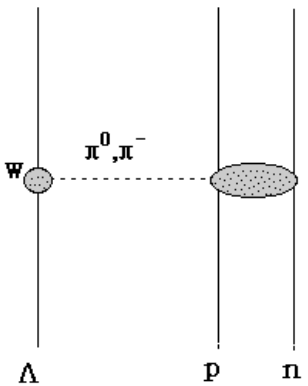
  Then what are those in Y_{nn}^{nbb}(He)?
- R(np) enhancement in C over He.

  → FSI
- R(nn) enhancement over R(np) both i n He and C

  → 2N?   where $R=N_{bb}/N_{nbb}$







This model tends to produce 2 HE neutron and one LE proton. Then p rotons are often cut off at the th reshold.

5. Coincidence Observables

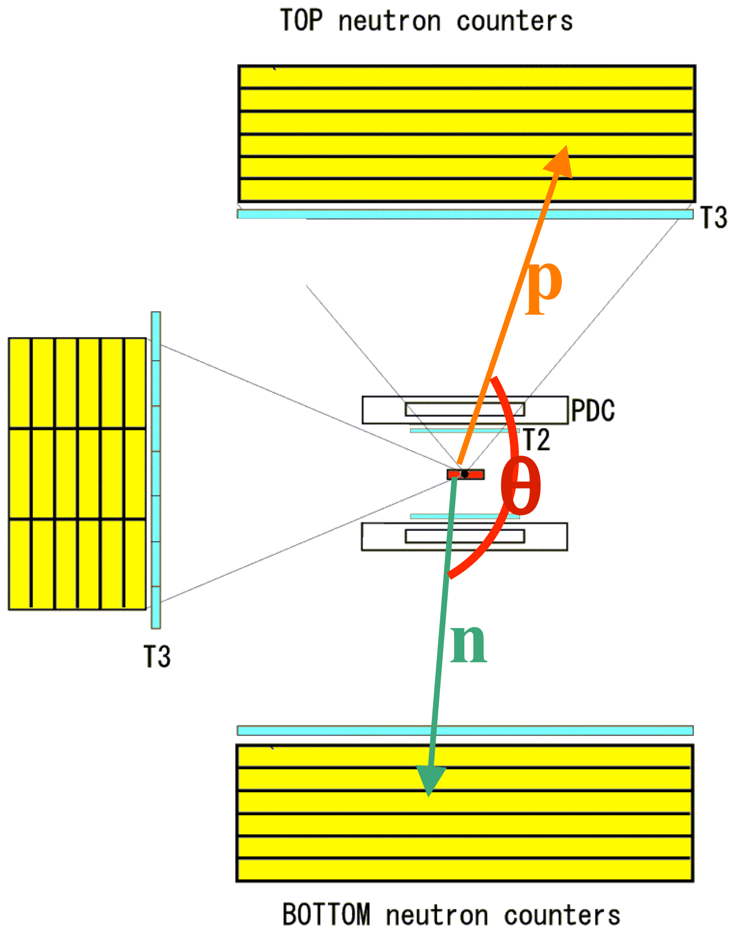
1. Nucleon Energy sum spectrum;

   E_p+E_n, E_n+E_n

2. Pair number per N MWD;

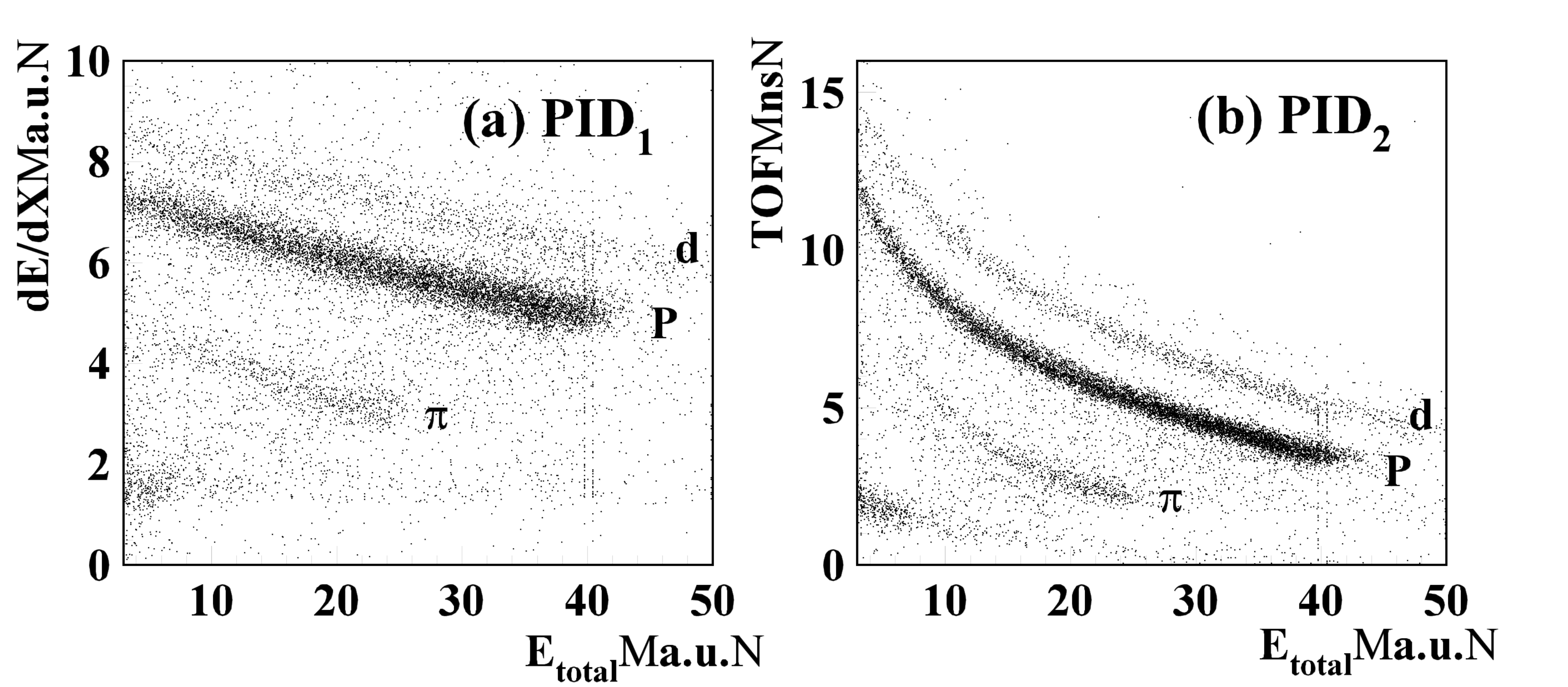
   $N_{np}(\cos\theta)$,

   $N_{nn}(\cos\theta)$



$N_{np} \equiv Y_{np}/(Y_{nm} \cdot \epsilon_{np})$

; Pair no. per NMWD for full eff. and Ω.



(a) PID1
dE/dXMa.u.N
ETotalMa.u.N
d
P
π
(b) PID2
TOFMnsN
ETotalMa.u.N
d
P
π

INC (IntraNuclear Cascade) calculation

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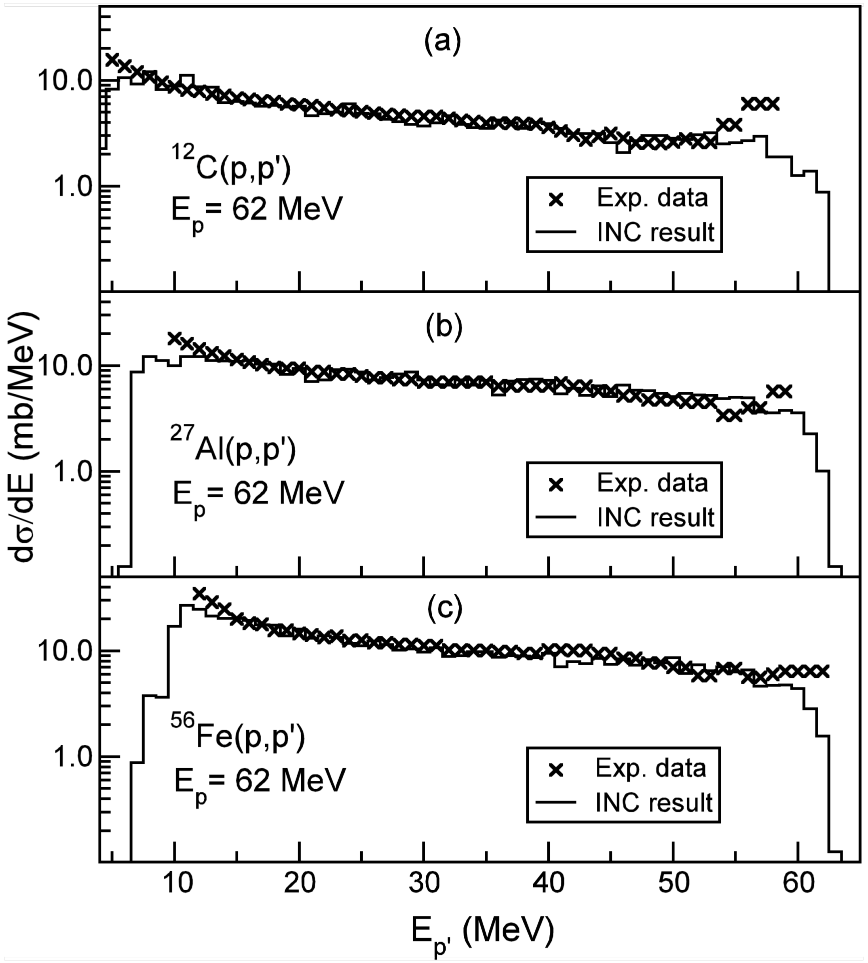
Mass Dependence



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Efficiency for singles and coincidence events.