Measurement of gamma production from a neutron beam on water

A background to neutrino-oxygen nuclear de-excitation gammas after neutral current quasielastic scattering

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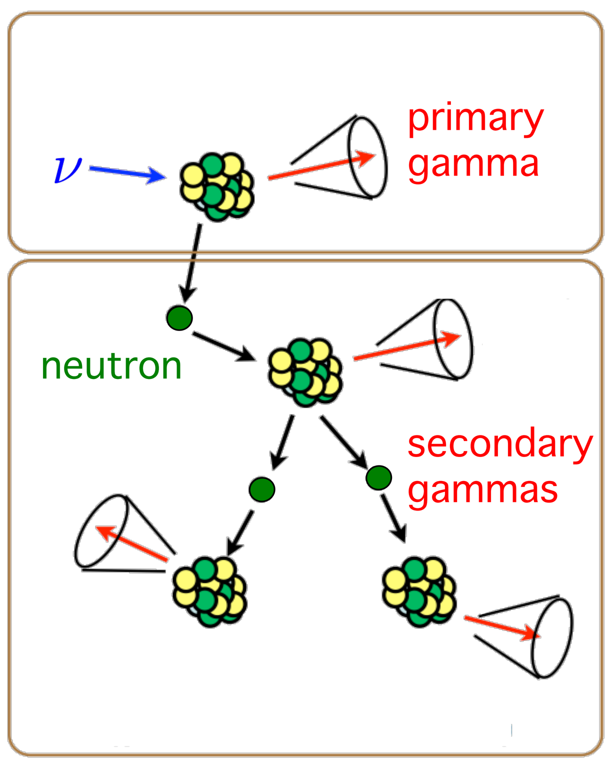
1. MOTIVATION



TO REDUCE SYSTEMATIC UNCERTAINTY IN T2K MEASUREMENT

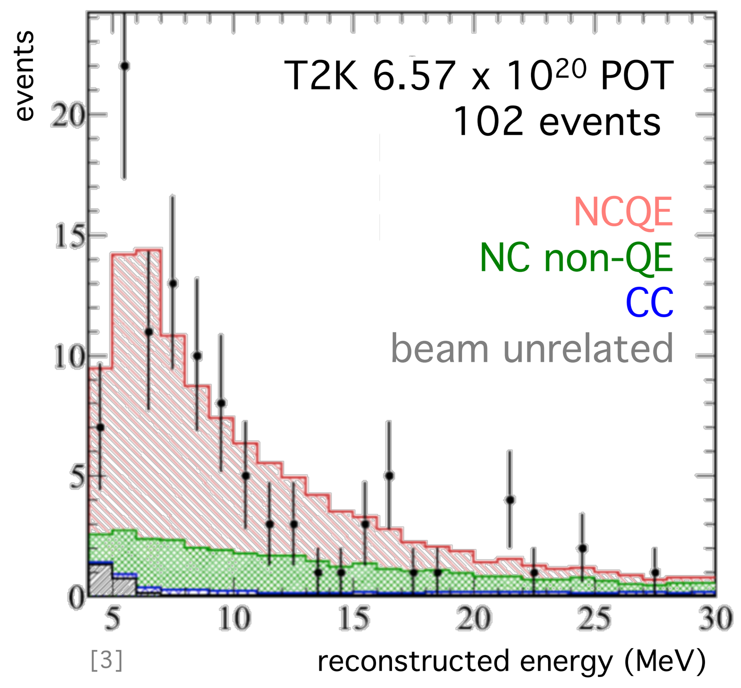
Incident particle excites ^{16}O, and Super-K (SK) detects gammas from the nucleus de-exciting

600 MeV neutrino beam
→ single nucleon emission dominant [1]

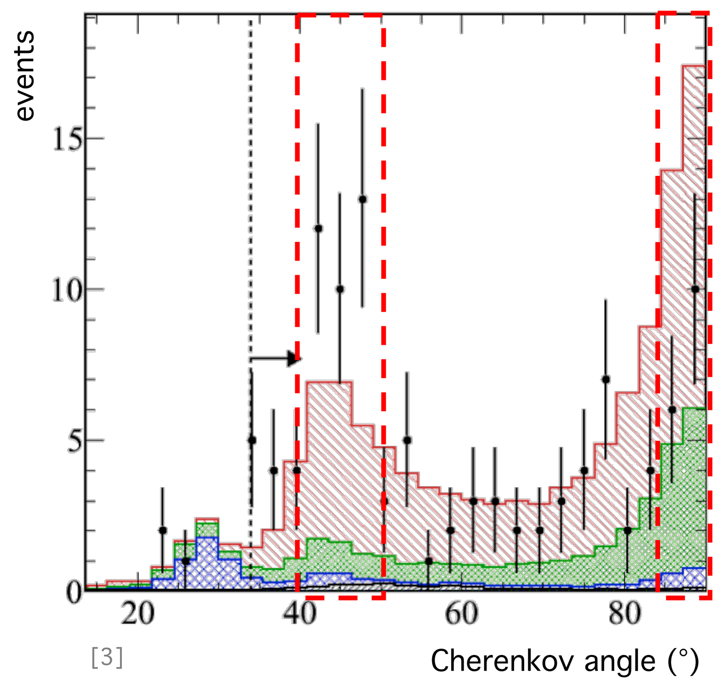
Contribution of $p_{3/2}$ overwhelming
6.18 MeV from $(p_{3/2})_n$
6.32 MeV from $(p_{3/2})_p$ [1]

POOR MODEL OF SECONDARY GAMMAS

MC simulations do not agree, compared currently used Geant3 GCALOR to Geant4 QBHP_BIC_HP, FLUKA, and PHITS
Based on various theoretical models, need data to establish reliable simulations



[3]



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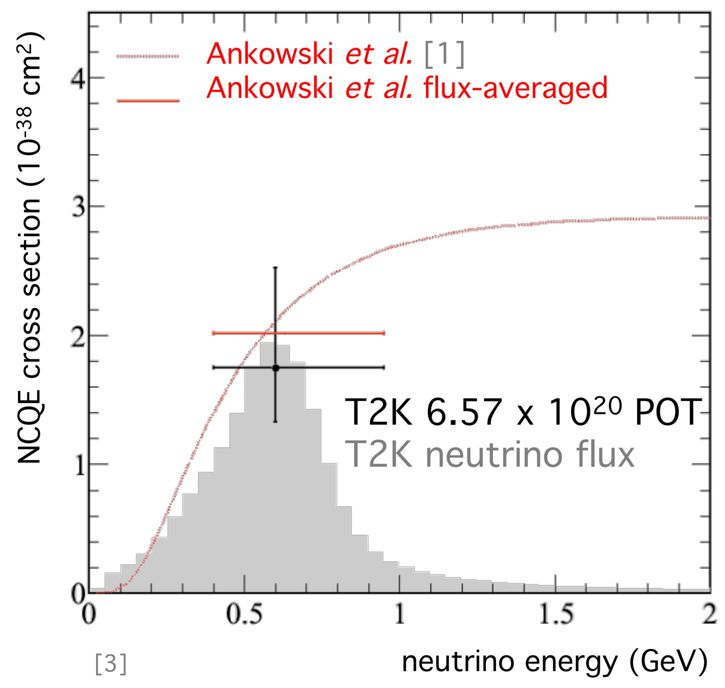
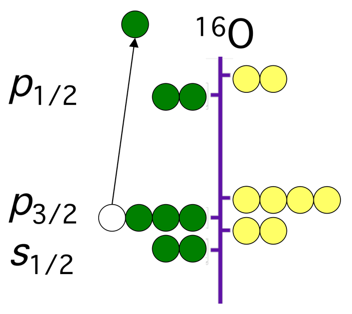


[3]

$(1.75 \pm 0.27\ (stat.)\ ^{+0.70}_{-0.36}\ (sys.)) \times 10^{-38}\ \mathrm{cm}^2$



NCQE (neutral current quasielastic) de-excitation gammas

T2K made first observation at this energy [2]

sterile neutrino and dark matter searches

T2K-SK neutrino-oxygen NCQE events

Selection cuts:
- 4–30 MeV reconstructed energy
- > 34° Cherenkov angle
- ±100 ns of beam timing
- fiducial volume
- reconstruction quality cuts

NEED TO UNDERSTAND SECONDARY GAMMA RAY PRODUCTION

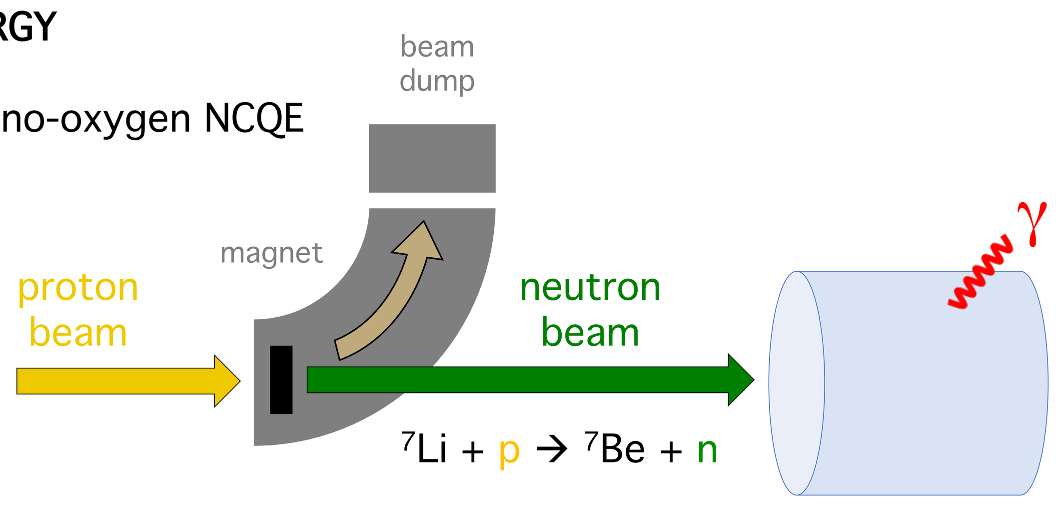
An emitted neutron can excite another ^{16}O nucleus
Cannot be easily separated by energy or timing

2. EXPERIMENT

NEUTRON BEAM ON WATER, MEASURE GAMMA ENERGY

30–300 MeV neutrons escape nucleus in T2K neutrino-oxygen NCQE

Run 1	80 MeV	January 2015	E361 parasite
Run 2	50 MeV	June 2015	E400 parasite
Run 3	80 MeV	June 2016	E465 pilot
Run 4	392 MeV	February 2017	E493 parasite
Run 5	80 MeV	March 2017	E487 pilot

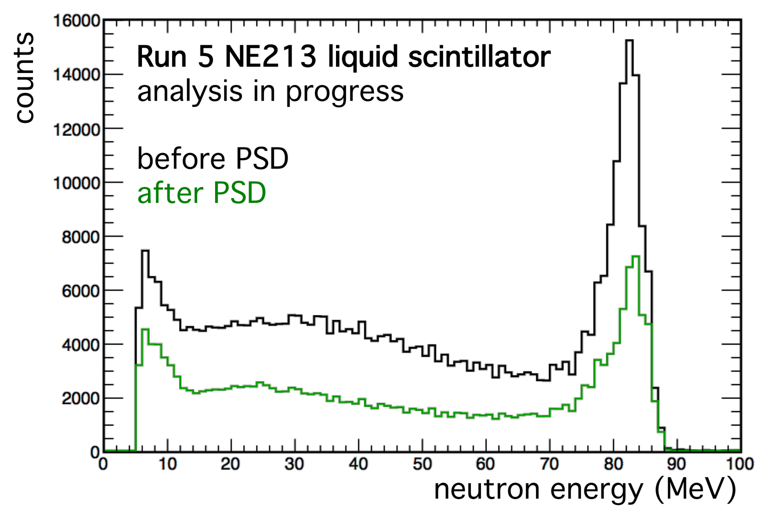


Osaka University's **RCNP**
(Research Center for Nuclear Physics)

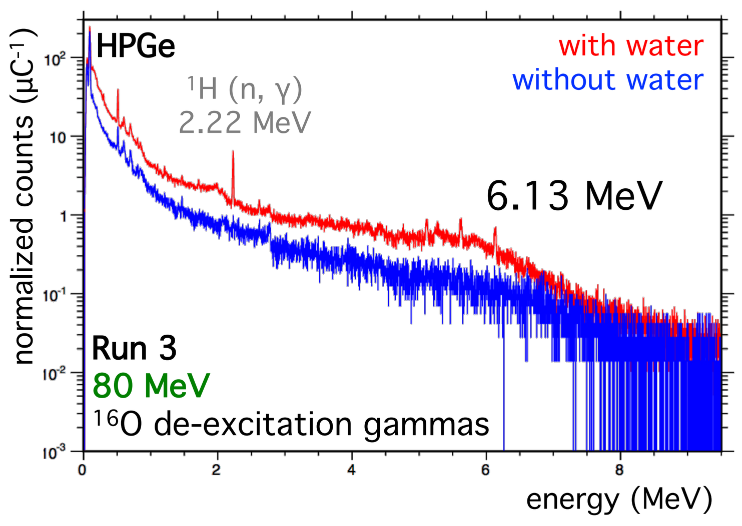
water filled acrylic container
(20 cm diameter, 25 cm length)

investigating several detectors:
HPGe, $LaBr_3$(Ce), CsI(Tl), and NaI(Tl)

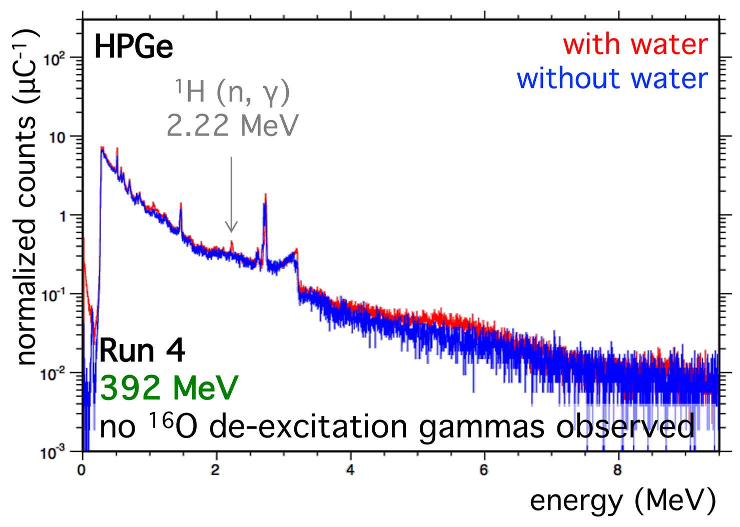
NE213 liquid scintillator for neutron flux [4]



3. ANALYSIS IN PROGRESS



pair production e⁺e⁻ annihilation
single (-m_e) and double (-2m_e) escape



higher energy did not result
in different de-excitation gammas

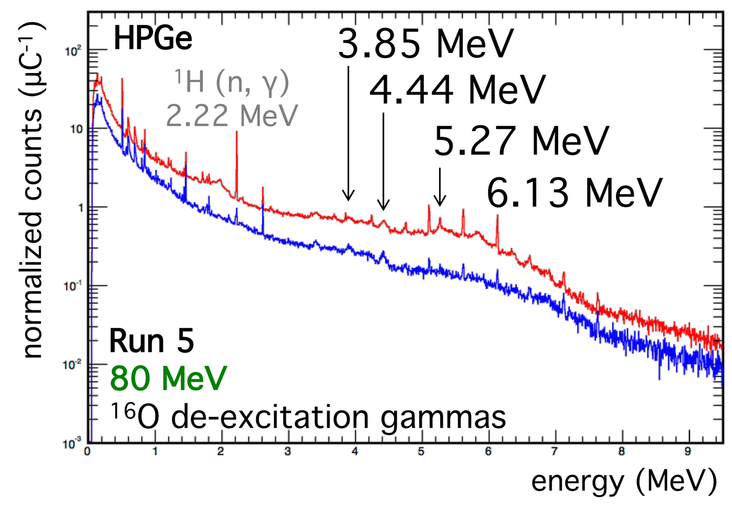
Run 1 & 2 were tests
both used NaI(Tl), which was found to have poor resolution
low statistics
→ no ^{16}O de-excitation gammas observed

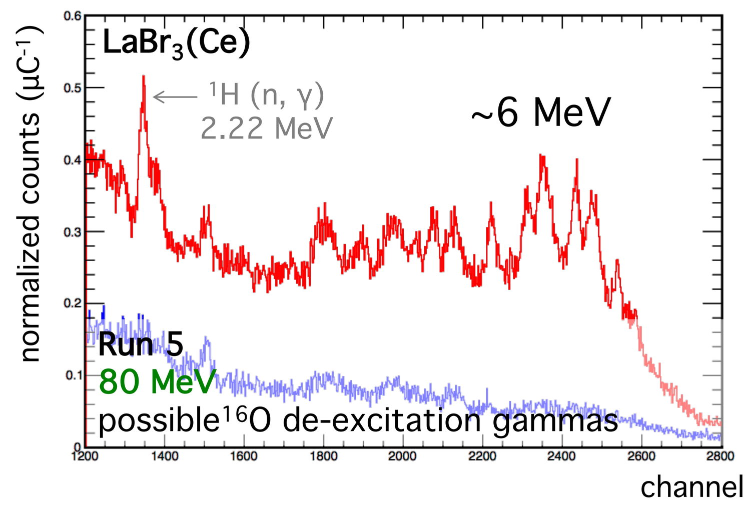
- HPGe has excellent resolution, yet expensive
- $LaBr_3$(Ce) has good resolution
- CsI(Tl) Pulse Shape Discrimination (PSD) to separate neutrons and gammas

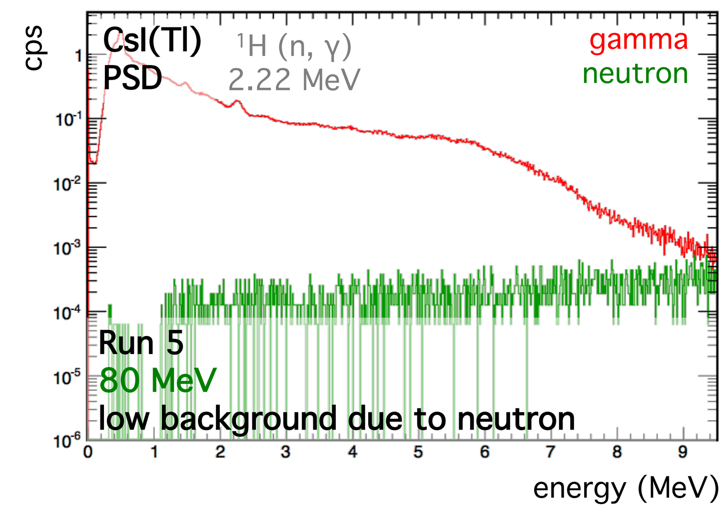
Run 5
analysis in progress

GAMMAS OBSERVED

3.85 MeV
4.44 MeV
5.27 MeV
6.13 MeV







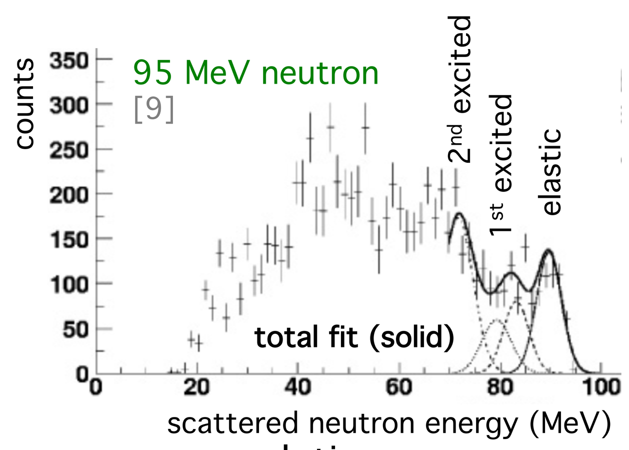
4. OVERVIEW OF NEUTRONS ON OXYGEN

GAMMAS OBSERVED

0.87 MeV	[5, 6]
1.09 MeV	[5, 6]
1.75 MeV	[7]
2.18 MeV	[5, 6]
2.74 MeV	[7, 8]
3.09 MeV	[7]
3.27 MeV	[5, 6]
3.68 MeV	[7, 8]
3.85 MeV	[7, 8]
4.19 MeV	[6]
4.44 MeV	[7]
6.13 MeV	[7, 8]
6.92 MeV	[7, 8]
7.12 MeV	[7, 8]

note that these used lower energy neutrons
thermal [5, 6]
6–17 MeV [7]
15 MeV [8]

SCATTERED NEUTRONS MEASURE ENERGY LEVELS



poor resolution

1st excited state:
6.13 MeV
6.92 MeV
7.12 MeV

2nd excited state:
9.84 MeV
10.34 MeV

6.05 MeV	[8, 9, 10]
6.13 MeV	[9, 10, 11, 12]
6.92 MeV	[9, 10, 11, 12]
7.12 MeV	[9, 10, 11, 12]
8.87 MeV	[10, 11]
9.84 MeV	[9, 11]
10.34 MeV	[9, 11]
11.1 MeV	[11]
11.52 MeV	[11]

besides 95 MeV [9]
lower energy neutrons
22 MeV [10]
24 MeV [11]
18–26 MeV [12]

de-excitation gammas possible for all of these energy levels

GAMMAS EXPLAINED BY EXCITED STATES OF ^{16}O, ^{17}O, ^{12}C, ^{13}C

6.13 MEV GAMMA FROM ^{16}O OBSERVED IN SEVERAL MEASUREMENTS

produced directly, in gamma cascades, or ^{16}O(n,p)^{16}N where ^{16}N → e⁻ + ^{16}O*

2.22 MeV ^{1}H(n,γ) IS WELL KNOWN

NO REFERENCE FOR 5.27 MeV, WHICH WE ATTRIBUTE TO ^{15}N

CROSS SECTION CALCULATIONS WILL BE COMPARED TO LITERATURE

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