The ratio of γ/π^0 production rates in neutrino-nucleus interactions at the Δ resonance mass region

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$$R \equiv \frac{\sigma_{(\nu+\mathtt{target}\to\gamma+X)}}{\sigma_{(\nu+\mathtt{target}\to\pi^0+X)}} \quad (1)$$

All SBN program experiments (SBND, MicroBooNE, ICARUS) have already extracted (planned) the π^0 production rates from the data (CC and NC interactions).
For the argon target, in all cases (NC or CC interactions, for neutrino or antineutrino beams), we estimate

$$R^{\mathtt{Ar}} = \frac{\sigma_\gamma}{\sigma_{\pi^0}} = R^{\mathtt{Ar}}_{\mathtt{NC}} = R^{\mathtt{Ar}}_{\mathtt{CC}} = \bar{R}^{\mathtt{Ar}}_{\mathtt{CC}} = 3.1\% \quad (2)$$

People from SBND, MicroBooNE, and ICARUS, please also measure the CC one-photon production rate.

Importance:

- Calibration tool for T2K, Hyper-K, and the second maxima at DUNE.
- MiniBooNE

On a free nucleon (PDG)

$$R^0 \equiv \frac{\Gamma^{\gamma}(\Delta^{+/0})}{\Gamma^{\pi^0}(\Delta^{+/0})} \simeq 9 \cdot 10^{-3}. \tag{3}$$

$$R \equiv \frac{\sigma_{(\nu+\mathtt{target}\to\gamma+X)}}{\sigma_{(\nu+\mathtt{target}\to\pi^0+X)}} = \frac{\sigma_\gamma^\Delta + \delta\sigma_\gamma}{\sigma_{\pi^0}^\Delta + \delta\sigma_{\pi^0}} \tag{4}$$

$\delta\sigma_\gamma, \delta\sigma_{\pi^0} =$ non-resonance, coherent, higher resonances...
$\delta\sigma_{\pi^0} \ll \sigma_{\pi^0}^\Delta, \quad \delta\sigma_\gamma \ll \sigma_\gamma^\Delta$

$$R \simeq \frac{\sigma_\gamma^\Delta}{\sigma_{\pi^0}^\Delta} \cdot \left(1 + \frac{\delta\sigma_\gamma}{\sigma_\gamma^\Delta} - \frac{\delta\sigma_{\pi^0}}{\sigma_{\pi^0}^\Delta}\right) \simeq \frac{\sigma_\gamma^\Delta}{\sigma_{\pi^0}^\Delta} \tag{5}$$

target$=$ H_2O, CH_2, Ar

$$R > R_0 \tag{6}$$

π^0s have difficulties in escaping the nucleus $A^{-2/3}$

MiniBooNE
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The $\Delta \to N + \gamma$ background is determined from the NC π^0 event sample [30], which has contributions from Δ production in ^{12}C (52.2%), Δ production in H_2 (15.1%), coherent scattering on ^{12}C (12.5%), coherent scattering on H_2 (3.1%), higher-mass resonances (12.9%), and nonresonant background (4.2%). The fraction of Δ decays to π^0 is 2/3 from the Clebsch-Gordon coefficients, and the probability of pion escape from the ^{12}C nucleus is estimated to be 62.5%. The Δ radiative branching fraction is 0.60% for ^{12}C and 0.68% for H_2 after integration over all the invariant mass range, where the single gamma production branching ratio increases below the pion production threshold. With these values, the ratio of single gamma events to NC π^0 events, R, can be estimated to be

$$R = 0.151 \times 0.0068 \times 1.5 + 0.522 \times 0.0060 \times 1.5/0.625 = 0.0091.$$

Note that single gamma events are assumed to come entirely from Δ radiative decay. The total uncertainty on this ratio is 14.0% (15.6%) in neutrino (antineutrino) mode.

Shert Baseline Neutrino program experiments at FNAL
For the argon target, in all cases (NC or CC interactions, for neutrino or antineutrino beams), we expect

$$R^{\mathtt{Ar}} = \frac{\sigma_\gamma}{\sigma_{\pi^0}} = R^{\mathtt{Ar}}_{\mathtt{NC}} = R^{\mathtt{Ar}}_{\mathtt{CC}} = \bar{R}^{\mathtt{Ar}}_{\mathtt{CC}} = 40^{\frac{1}{3}} R^0 = 3.42 R^0 = 3.1\% \quad (7)$$

People from SBND, MicroBooNE, and ICARUS, please also measure the CC one-photon production rate.

- It can help to understand the MiniBooNE anomaly.
- We'll obtain a strong calibration tool for T2K, Hyper-K, and the second maxima of DUNE

Thank you