SBN Proposal: Backgrounds and Mitigation

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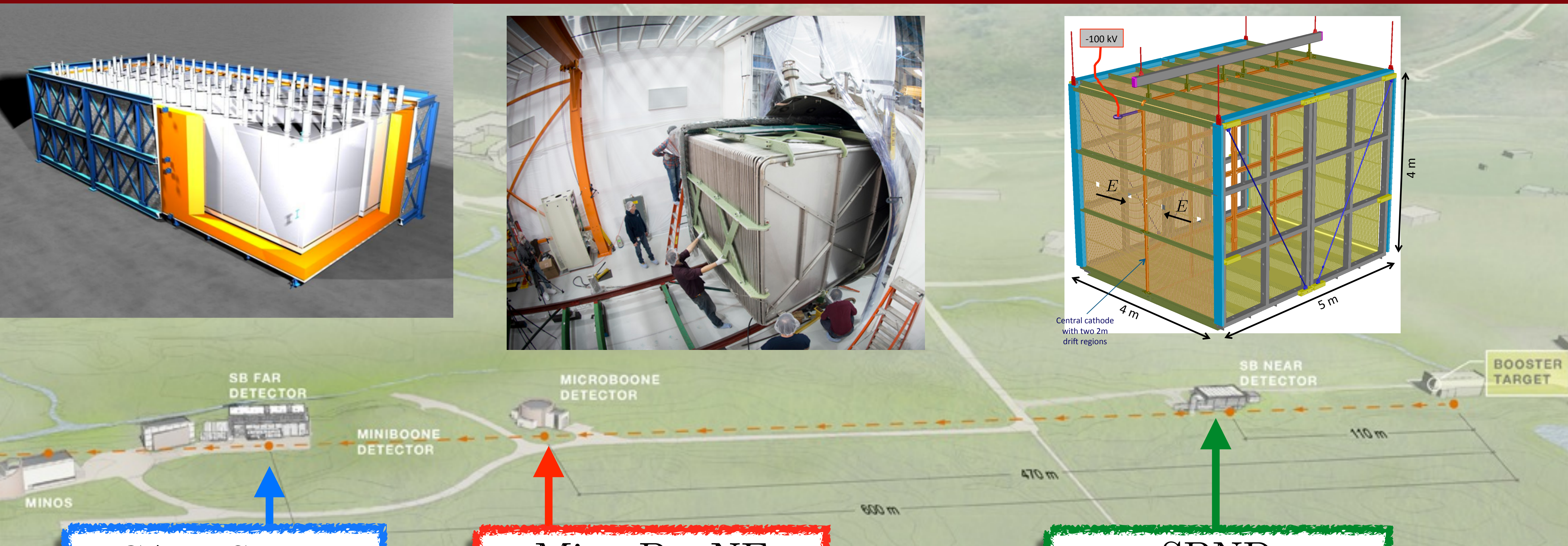
on behalf of the SBND, MicroBooNE, and ICARUS Collaborations

PITT PACC SBN Physics Workshop
University of Pittsburgh
January 27th, 2016

Short-Baseline Neutrino Program



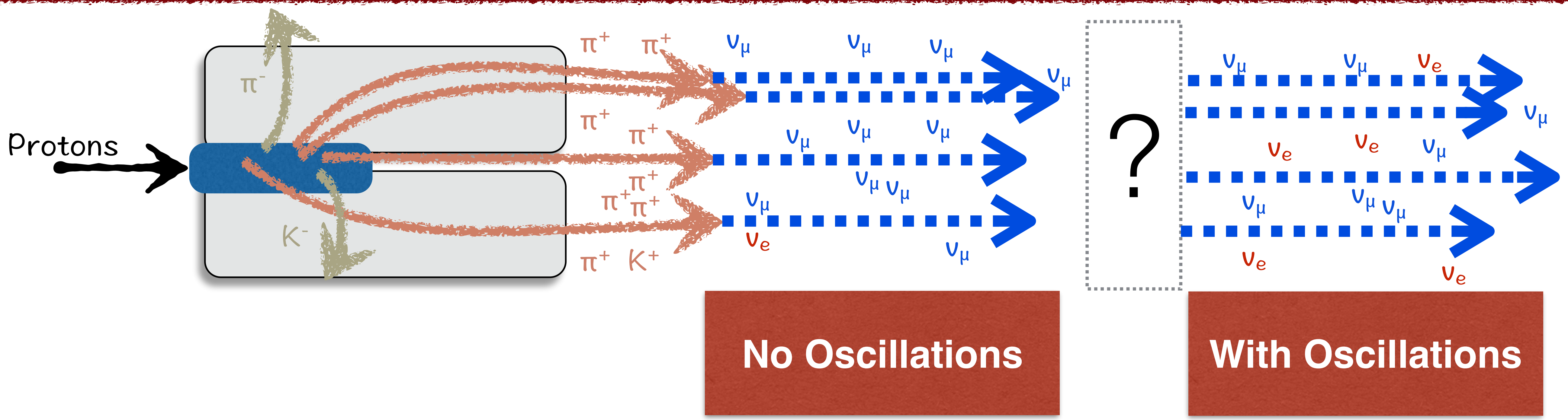
ICARUS T600
476t Active Mass
600m Baseline

MicroBooNE
89t Active Mass
470m Baseline

SBND
112t Active Mass
110m Baseline

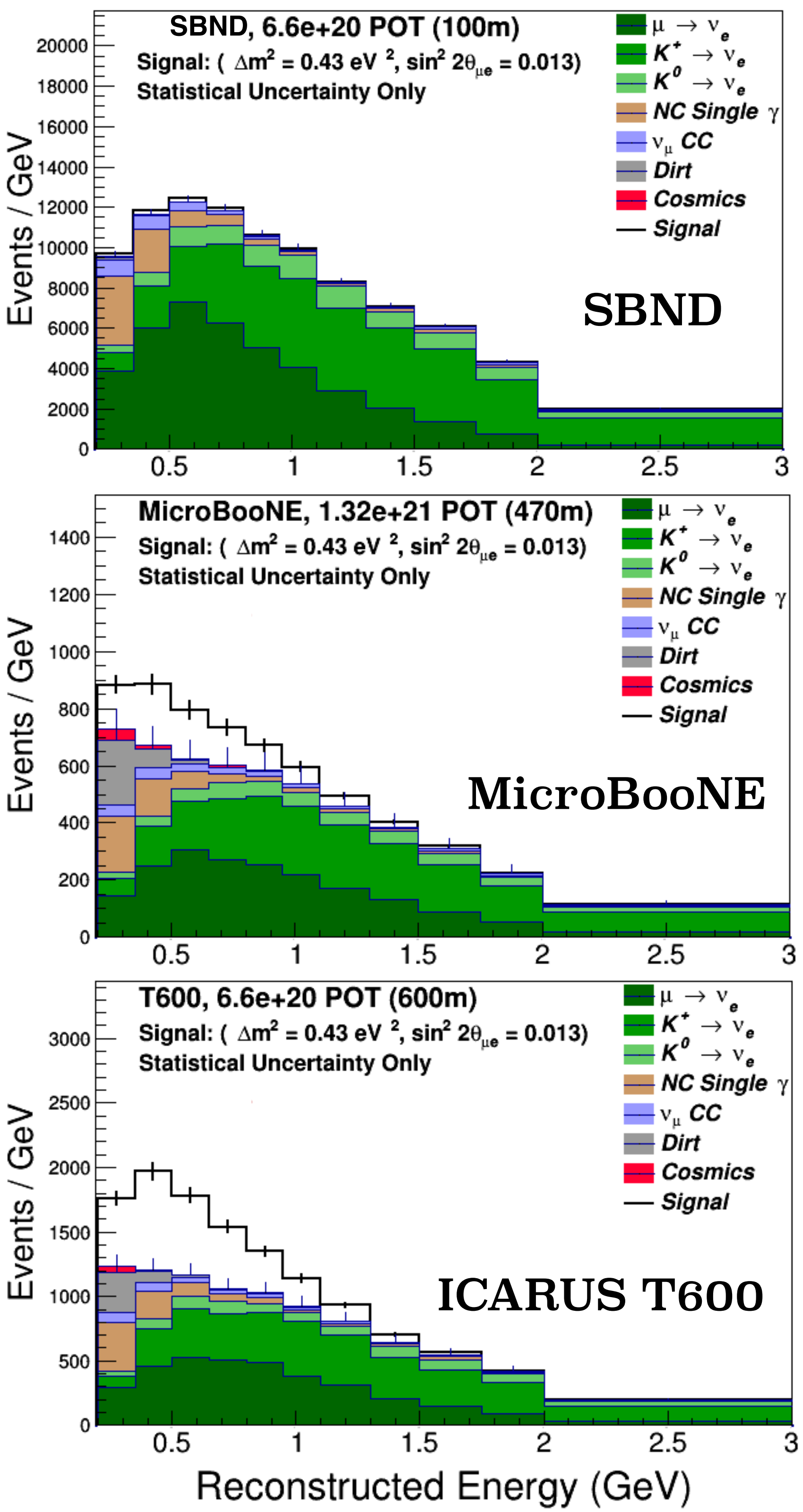
- Program is composed of three functionally identical detectors
- Slight difference between them can translate into different background sizes and compositions

Focus on Electron Appearance



- This talk will focus on the backgrounds associated with the electron appearance analysis
- This search is the most sensitive to the sterile neutrino hints from LSND
  - Traditionally backgrounds have hampered other appearance searches

Background Types



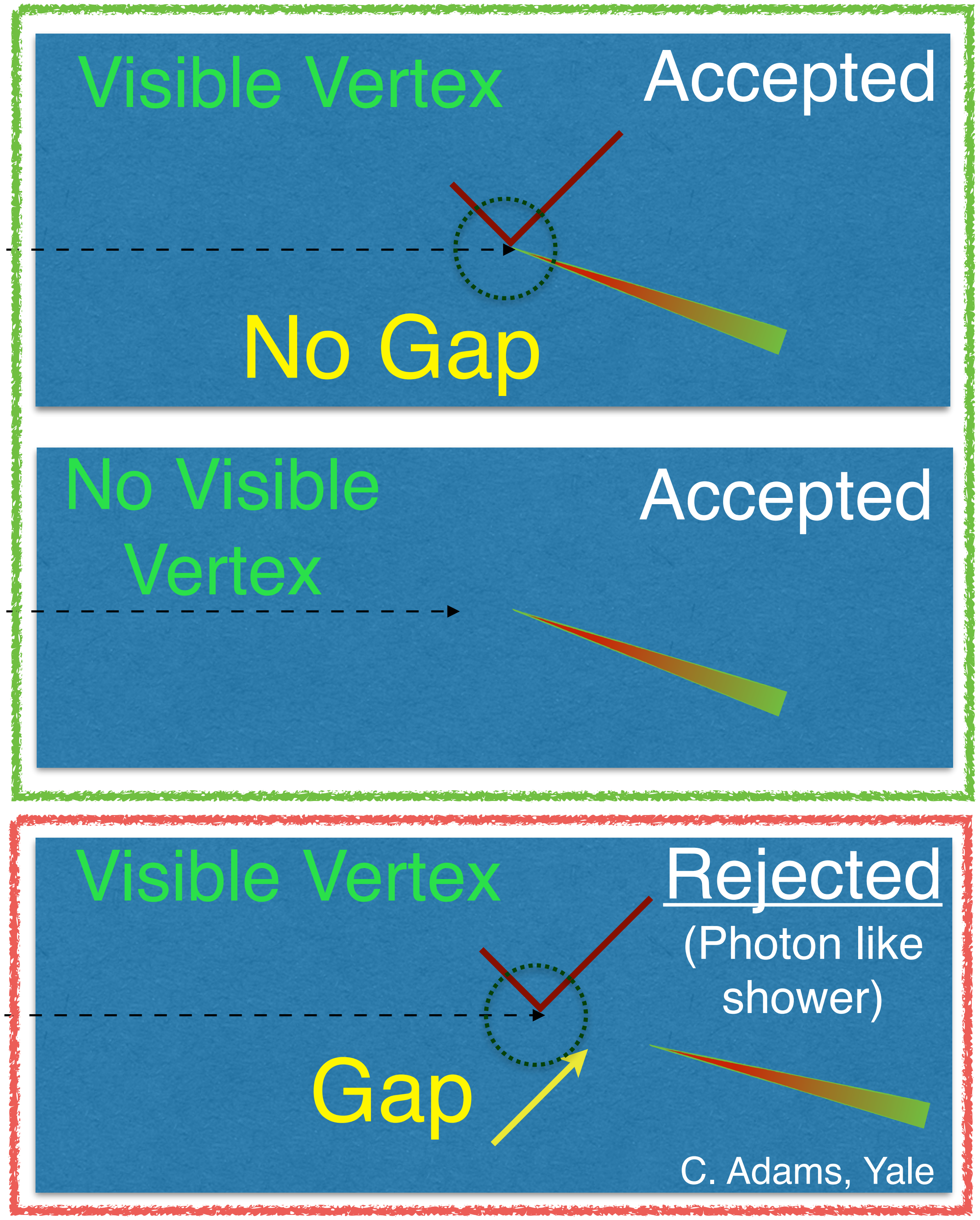
- Electron neutrino CC interactions
  - $\pi \rightarrow \mu \rightarrow \nu_e$
  - $K^+ \rightarrow \nu_e$
  - $K^0 \rightarrow \nu_e$
  - Sample appearance signal

Intrinsic beam ν_e

- Photon-induced backgrounds
  - NC misIDs
  - ν_μ CC misIDs
  - "Dirt" Backgrounds: beam-related but out-of-detector interactions
  - Cosmogenic photon sources

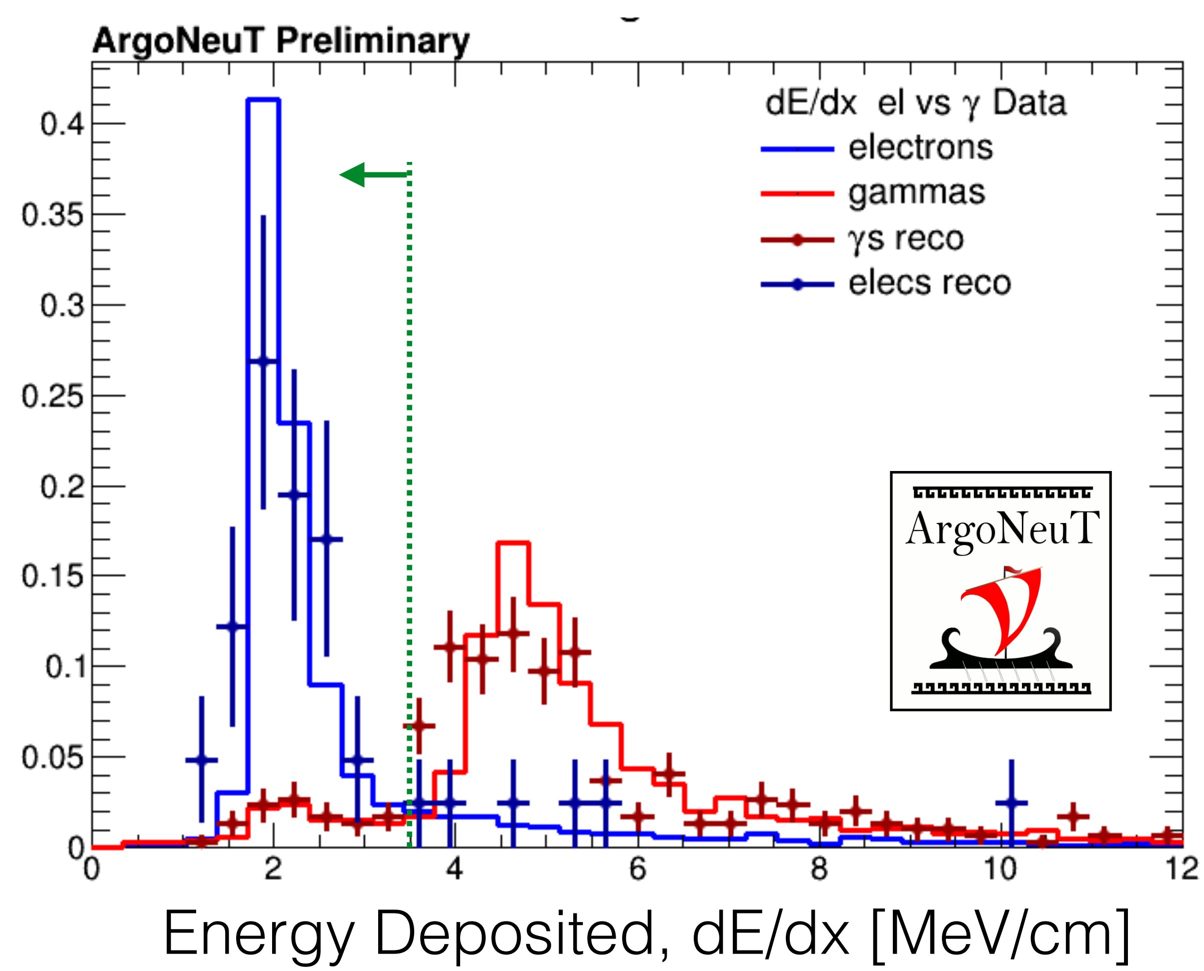
Electron Neutrino Event Selection

- We require that the event occurs away from the detector boundaries and that there is no gap between the shower and an energetic vertex
  - To be detected **vertices** must have **>50MeV** and the **shower must be <3cm away**
  - We require that the selected **shower** have an **energy >200MeV**



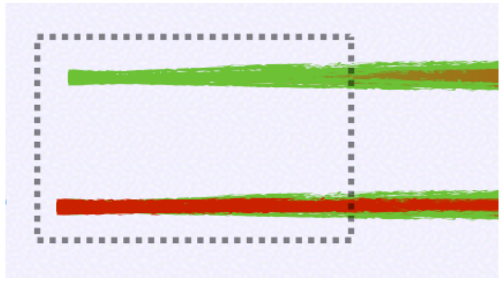
Calorimetric Photon Rejection

- By leveraging the LArTPC technology for the SBN program we have a second handle on photon like backgrounds, calorimetry
- By placing a **cut at 3.5 MeV/cm** we are able to **suppress the pair-produced photons by 94%**



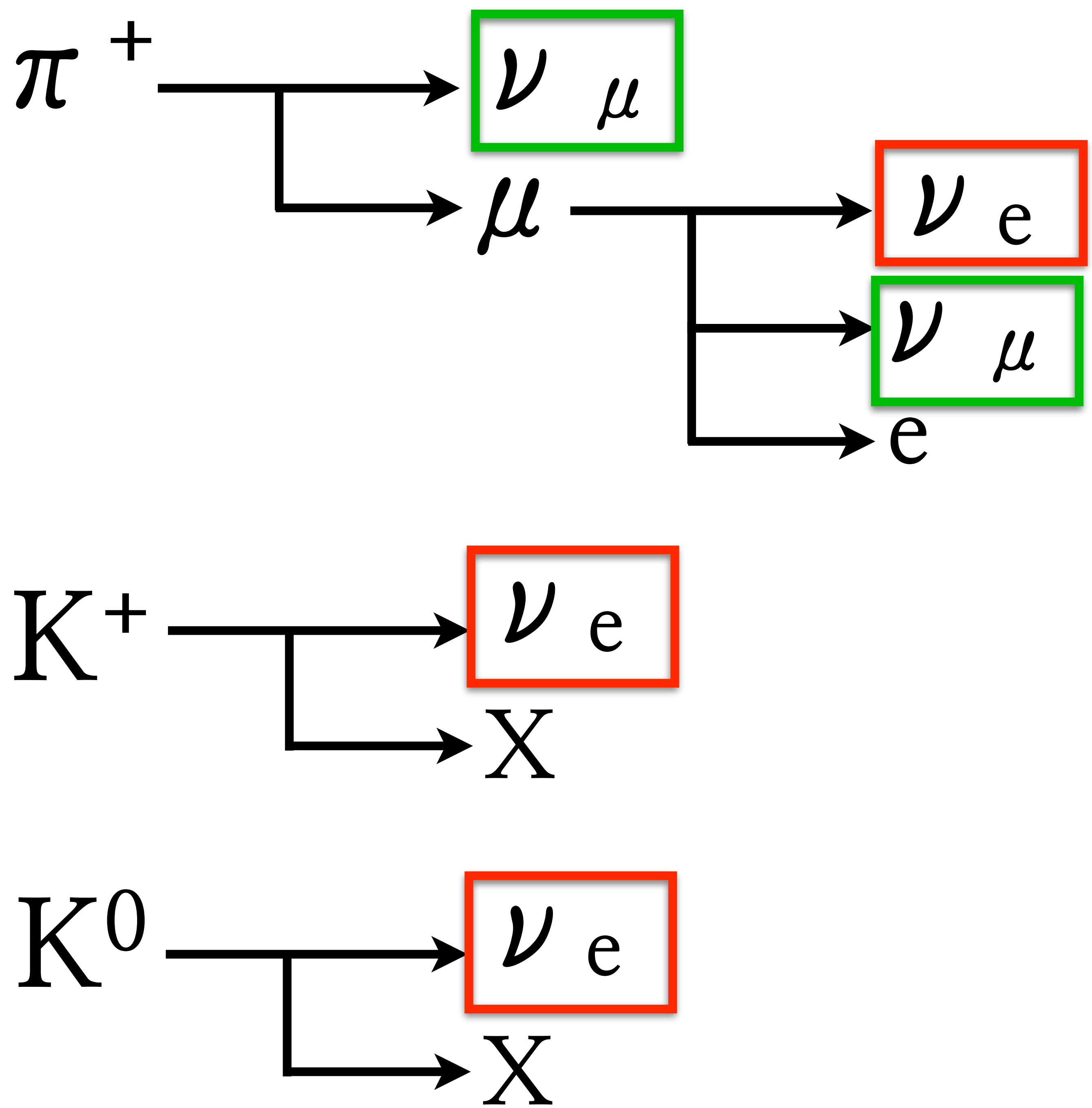
$e^{\pm}$

$\gamma \rightarrow e^{+} + e^{-}$



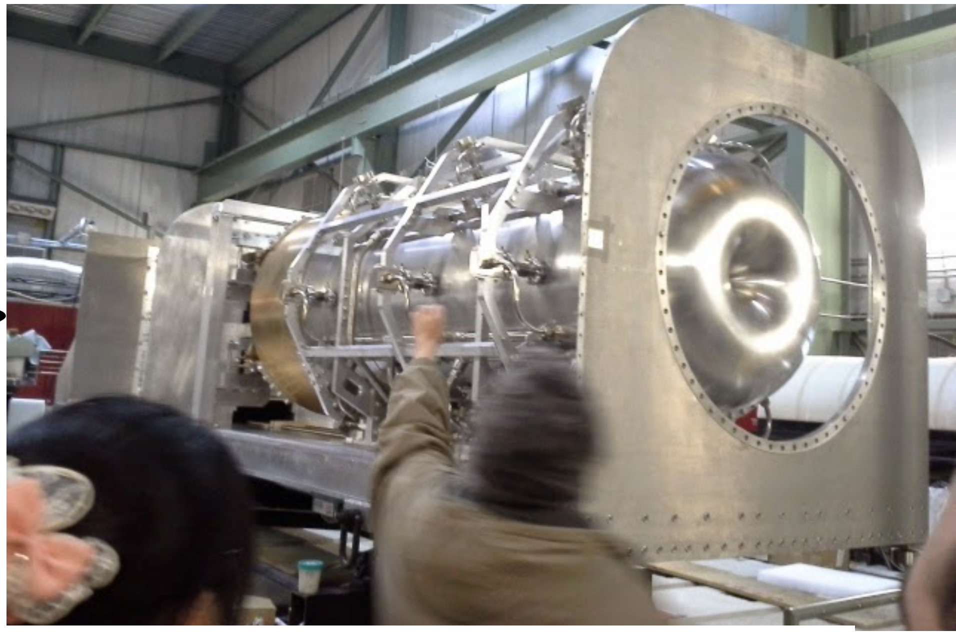
Beam Intrinsic Electron Neutrino Candidates

- Since we are searching for the appearance of electron neutrinos, we must understand precisely the beam's initial electron neutrino content

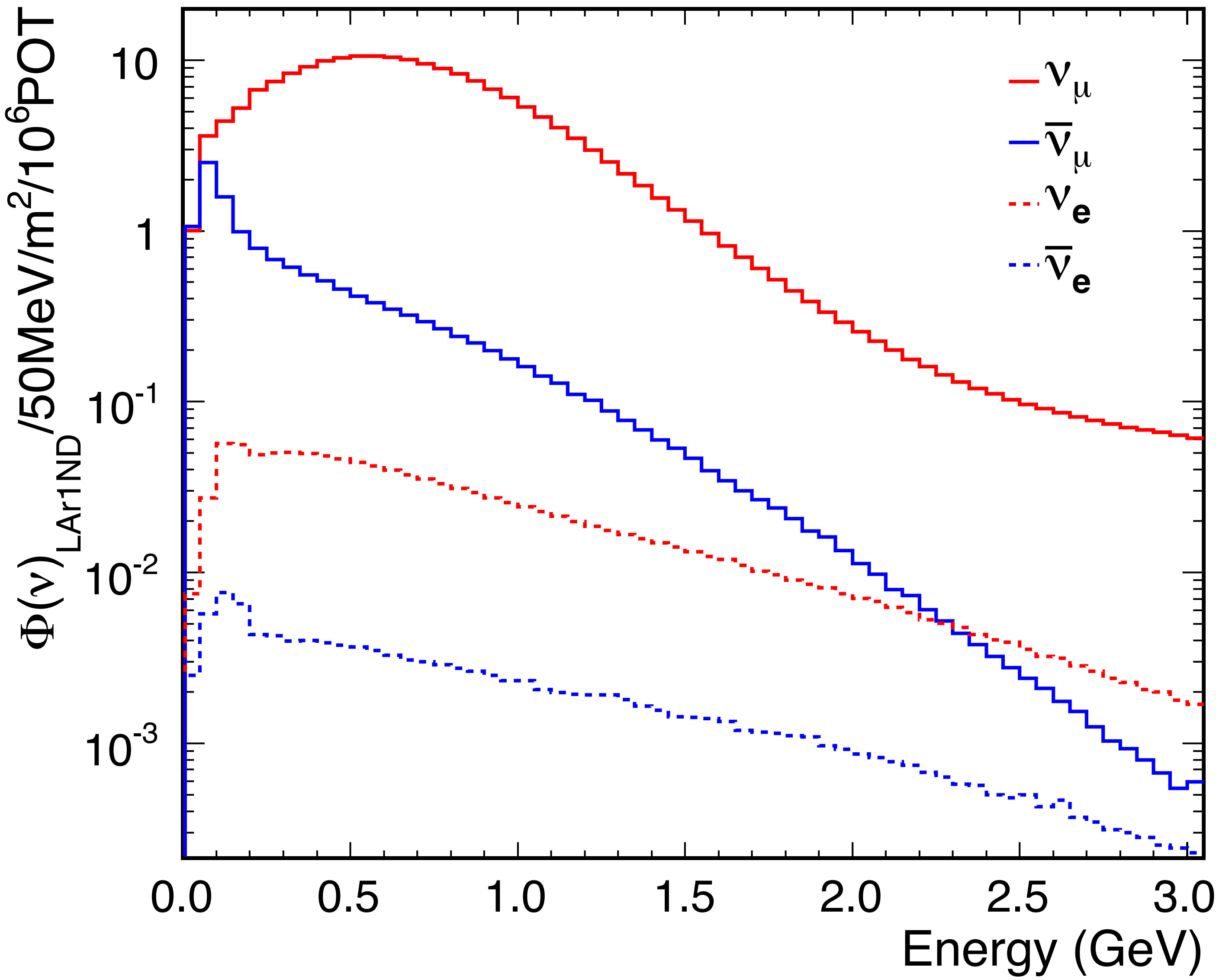


Beam Intrinsic Electron Neutrino Candidates

8GeV Protons on Beryllium



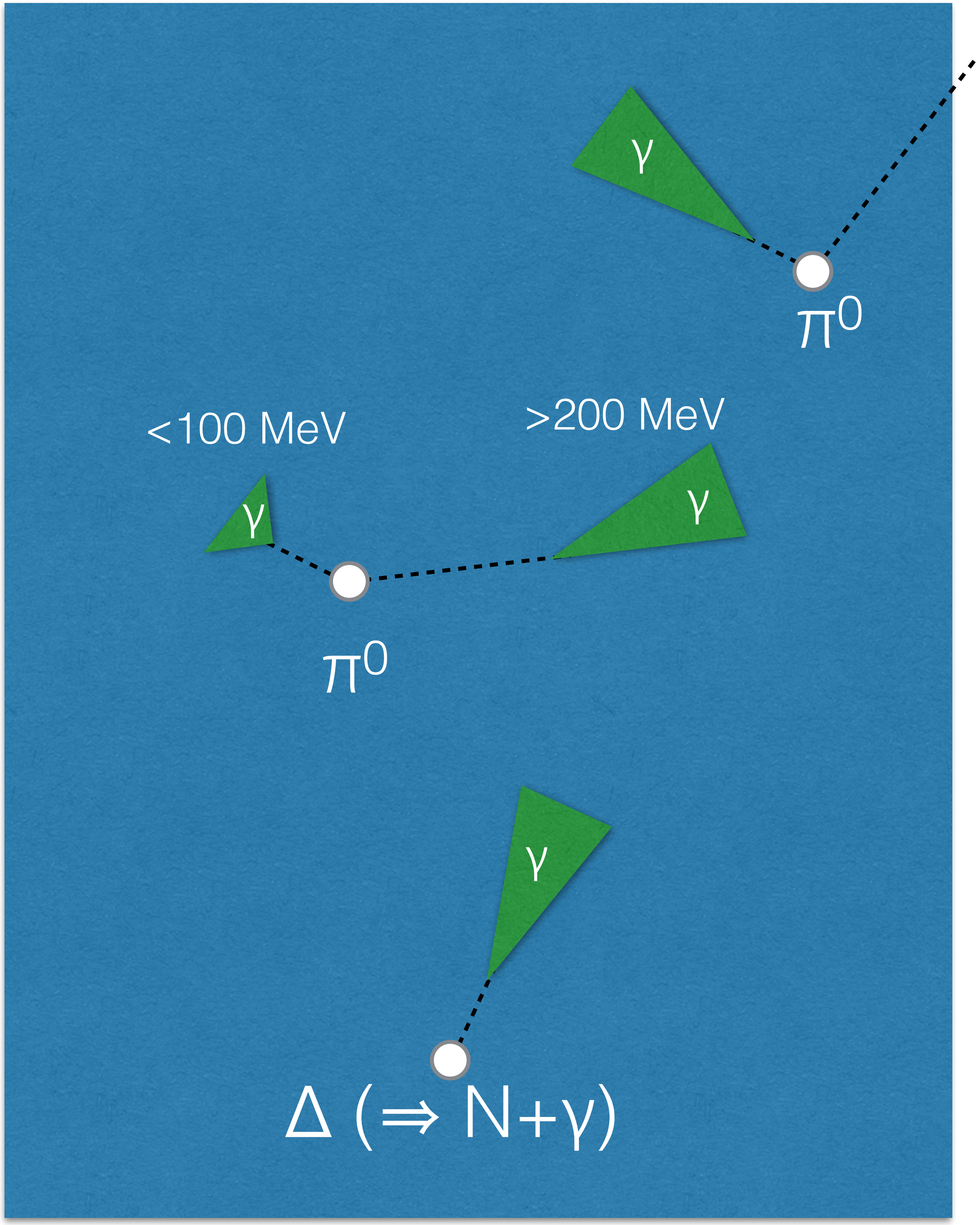
- The Booster Neutrino Beam is that it is a very pure source of muon neutrinos
  - Only a 0.5% contamination from electron neutrinos



Neutral Current Single Photons

- While there is a strong suppression of the neutral current photon production by the topological and calorimetric constraints we can also reject events with two photons

- There are instances where only one photon is observed
  - Photon exits the detector
  - Photon is below detection threshold (taken as **100 MeV**)
  - Radiative Δ decays



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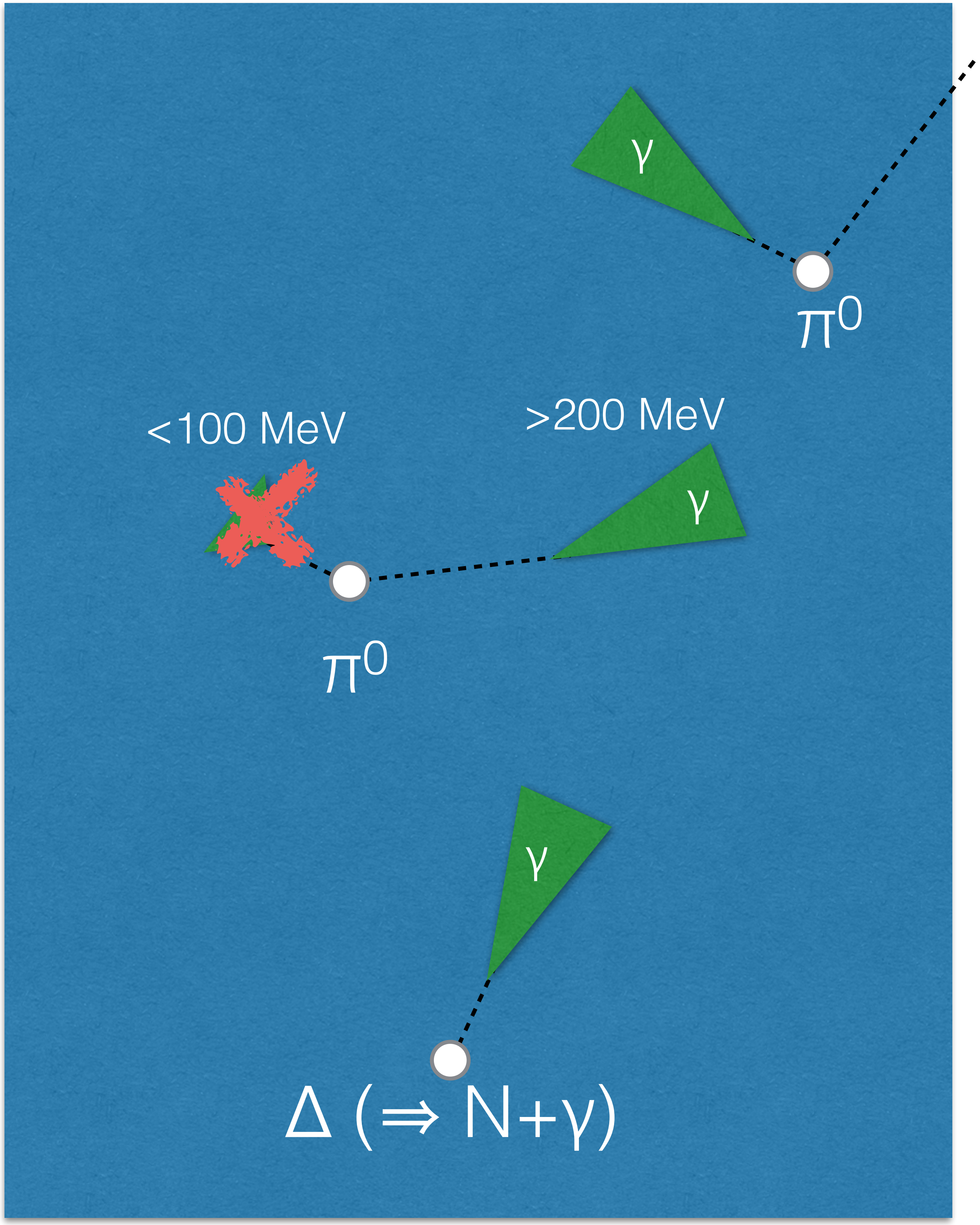
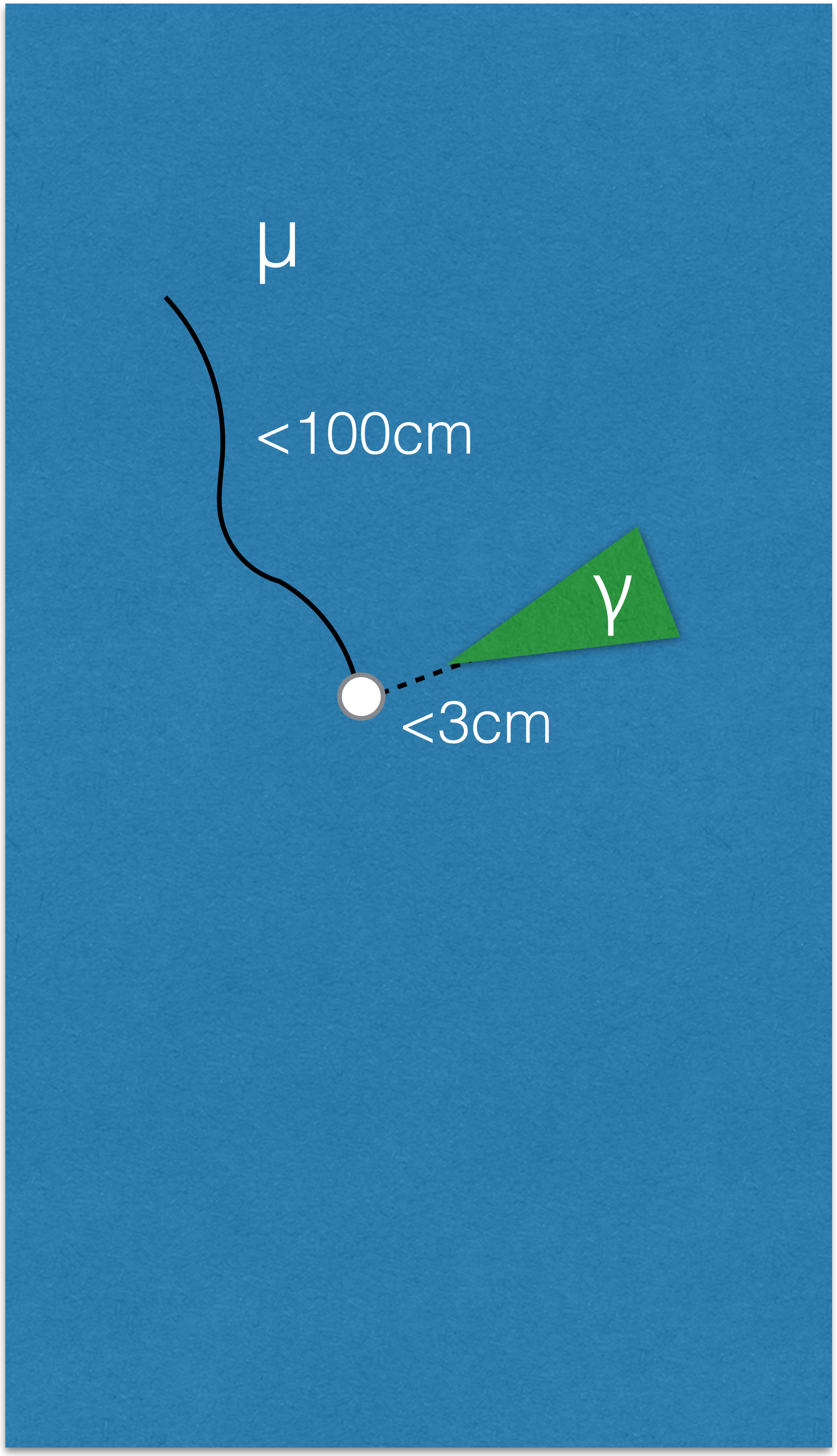


ν_μ Charged Current Mis-ID

- Background is dominated by:
  - ν_μ CC+γ looking like ν_e CC+$\pi^\pm$
- This comes about when the muon fails a muon-pion identification cut, we used a **length cut of 100cm** and the photon is attached to the vertex and fails the **calorimetric cut**



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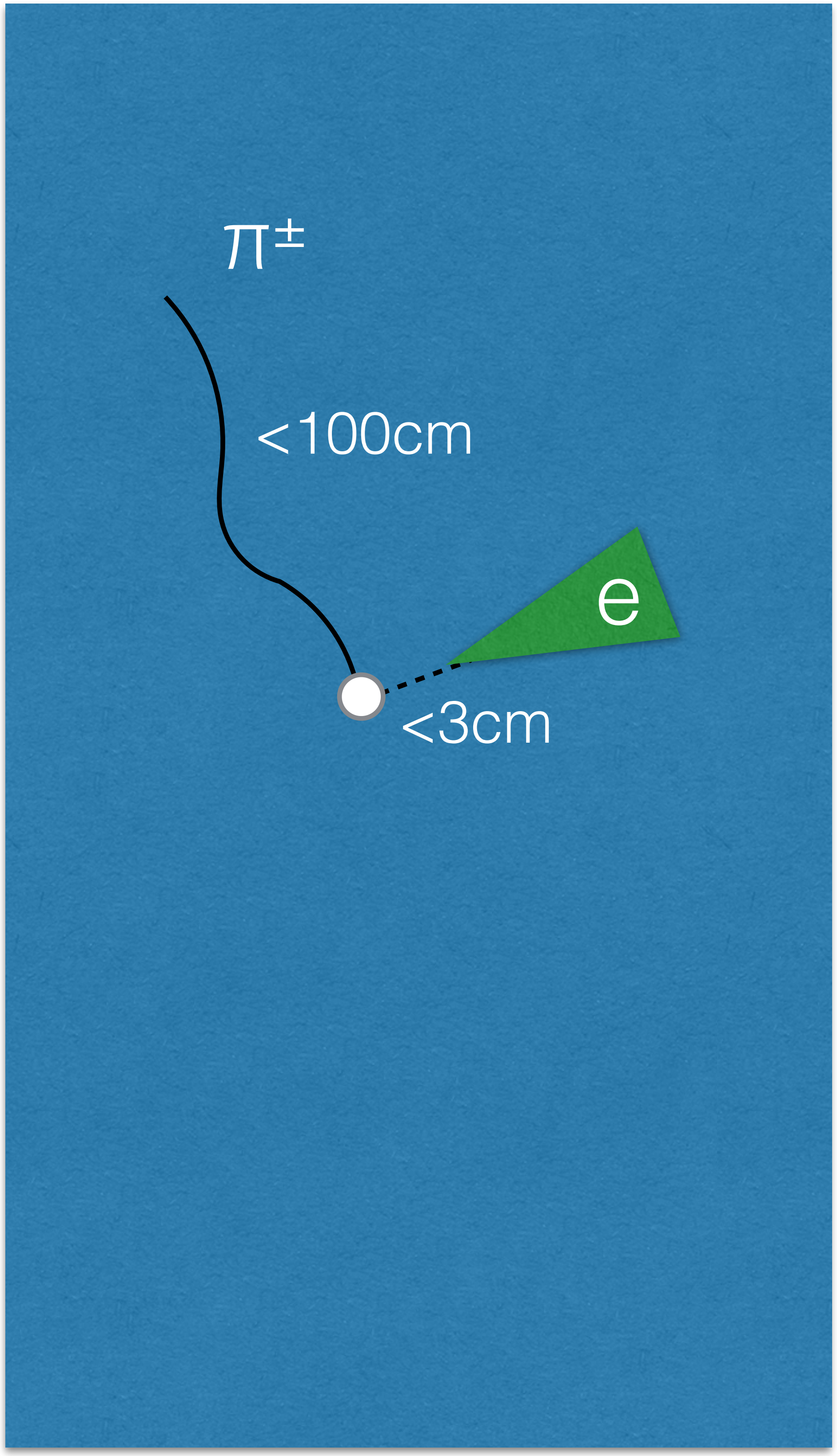
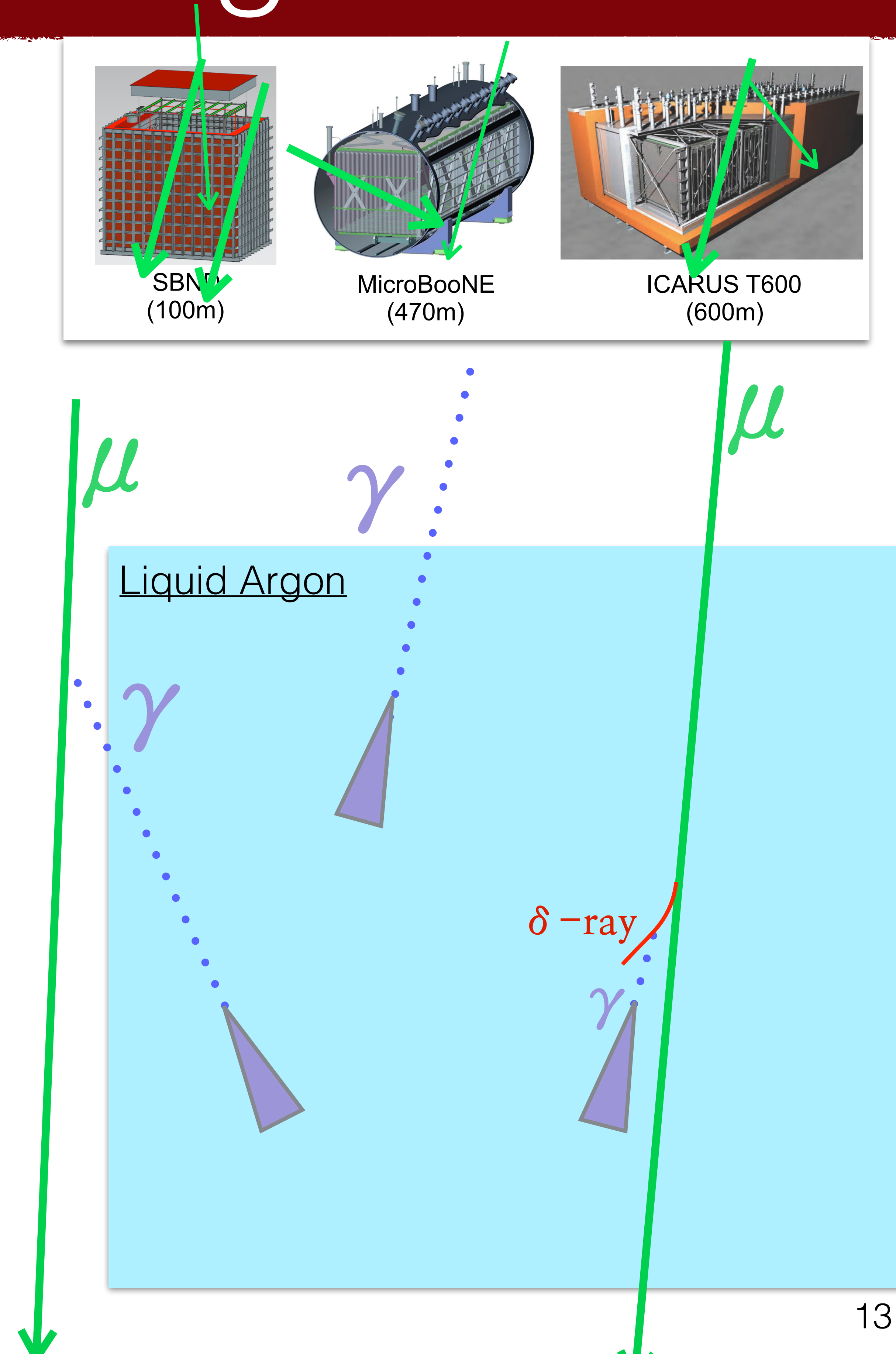


Cosmogenic Backgrounds

- Cosmics can deposit photons into the detector which form backgrounds
  - The photons can also **Compton scatter** which will maximally **fail the calorimetric cuts**

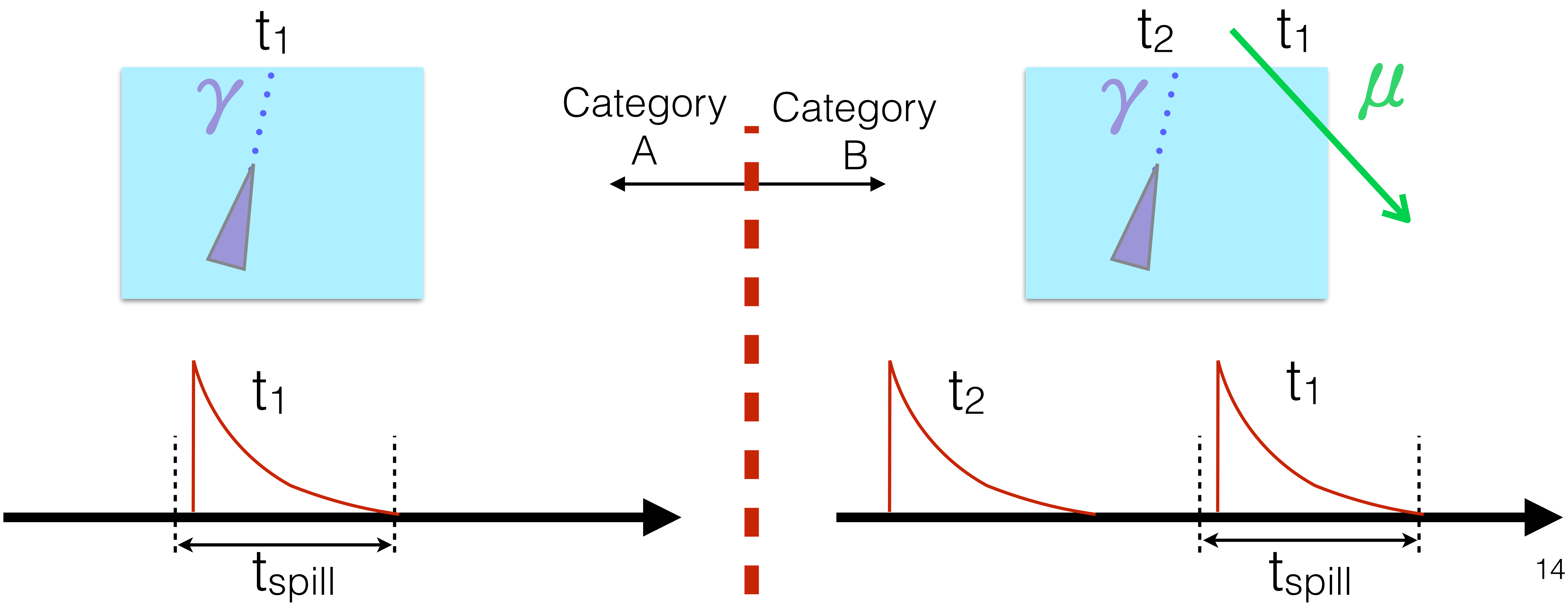
- The size of these backgrounds depend strongly of the detector geometry and drift lengths
  - SBND, 1.28 ms
  - MicroBooNE, 1.6 ms
  - ICARUS, 0.96 ms



Cosmogenic Topologies

- **Timing Categories**
  A. Cosmic produces a flash coincident with the spill
  - Measure backgrounds in 211sec exposure, N_A

  B. Cosmic photon interacts in the same drift window as another cosmic produces a flash coincident with the spill
  - Estimate background as, $N_B = P^{drift}_{\gamma} P^{spill}_{\mu} = N_A N^{drift}_{\mu}$



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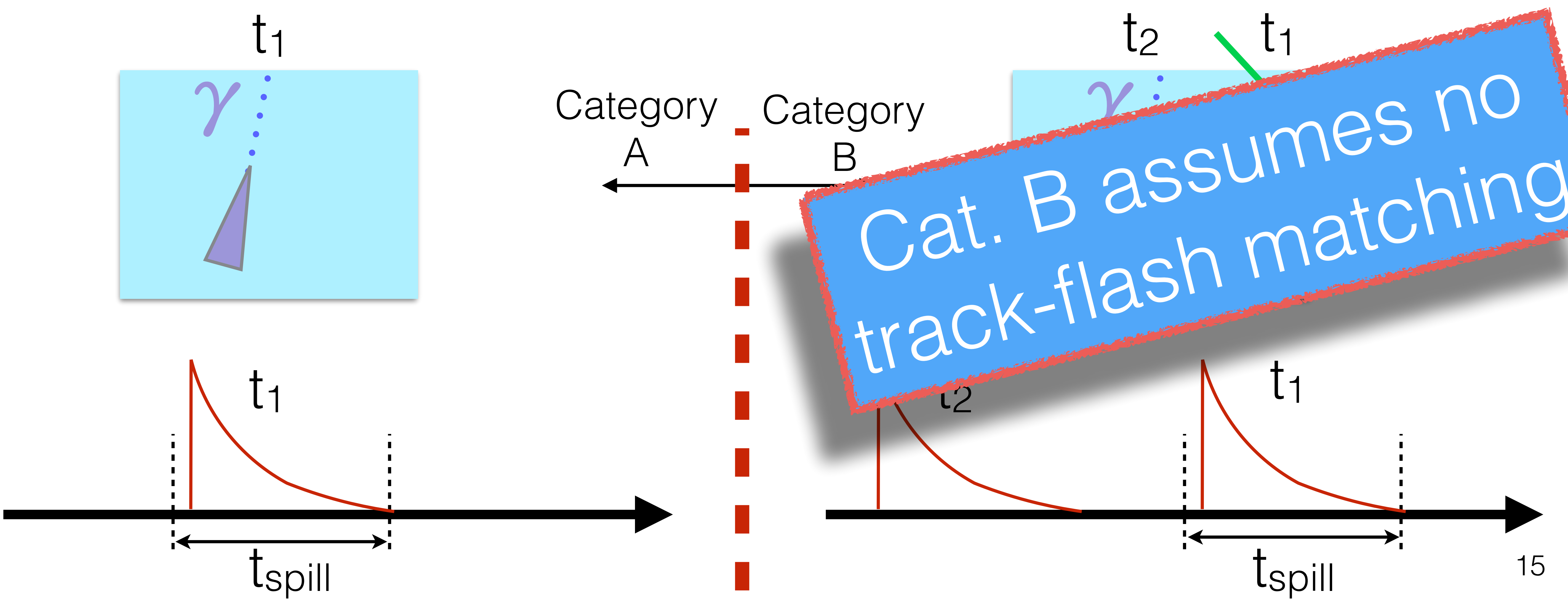
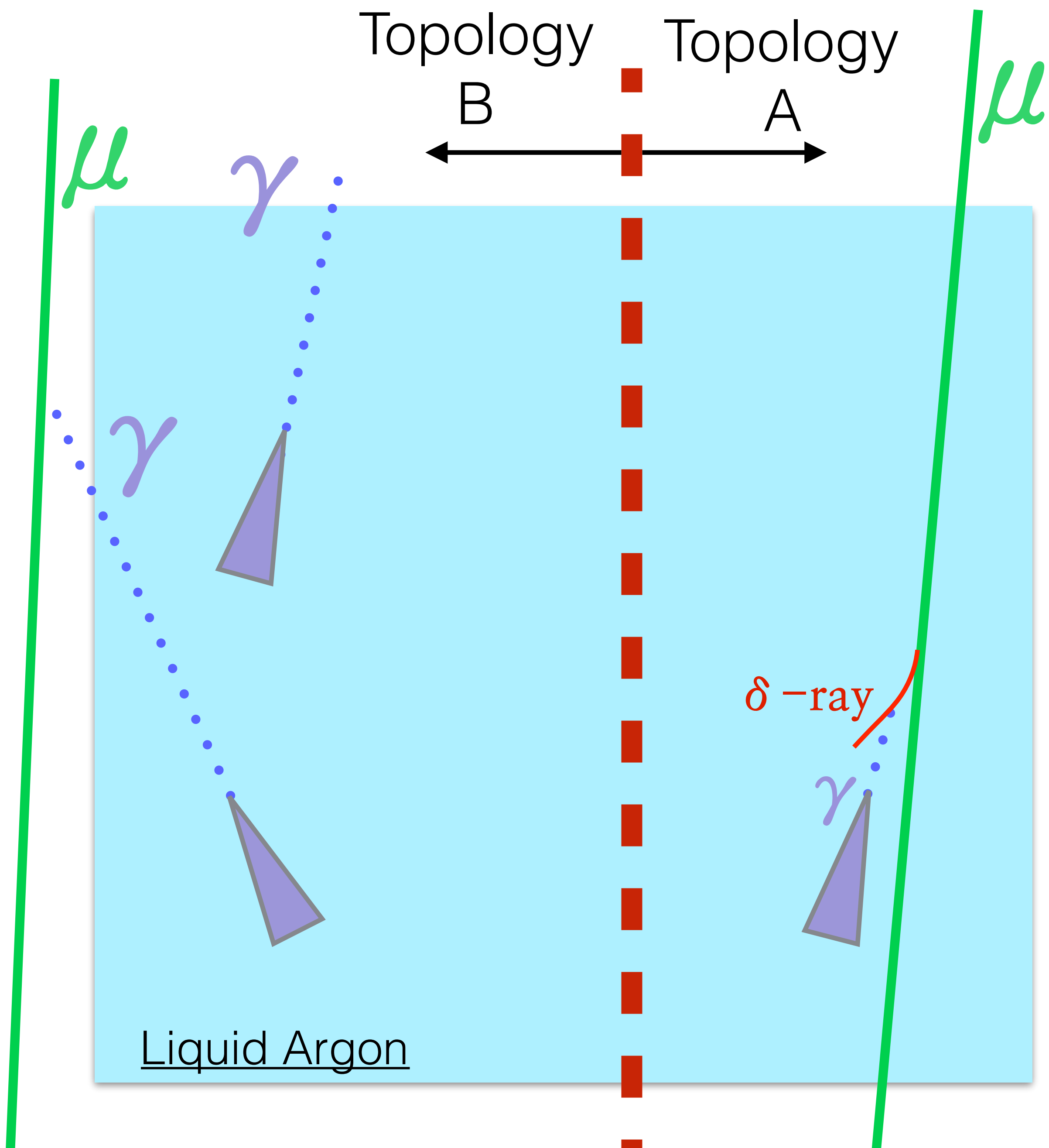
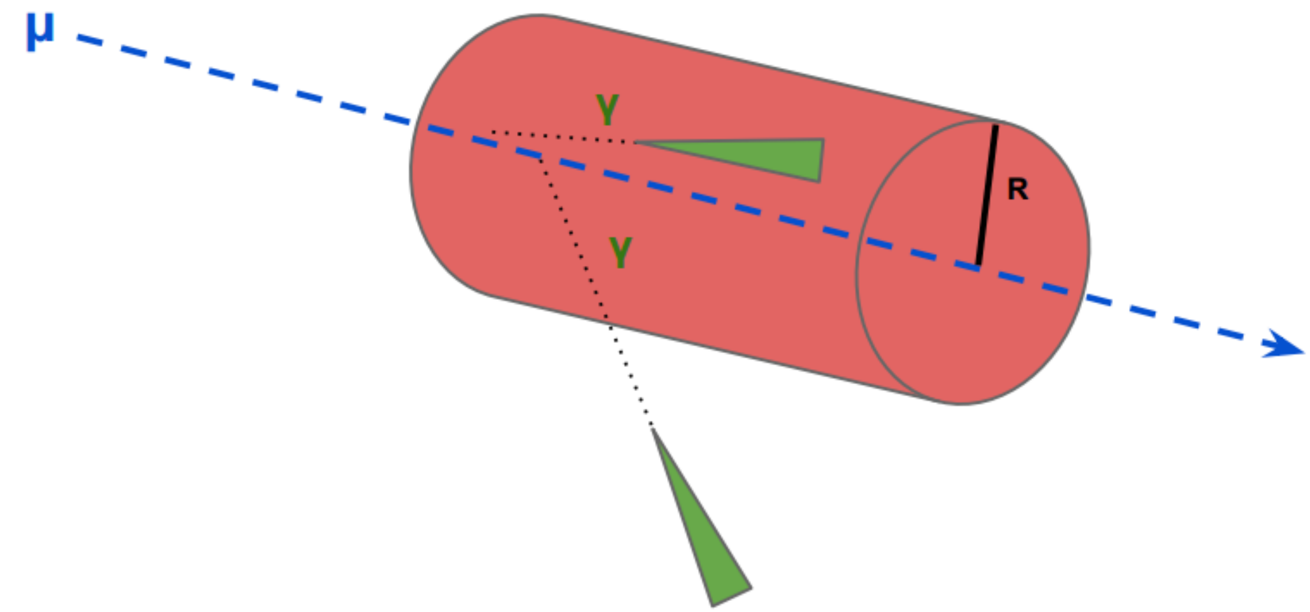


Cosmogenic Topologies

- **Topological Categories**
  A. Photon is born of a muon which interacts inside of the detector
  B. Cosmogenic photon has no parent muon, or it doesn't interact in the detector

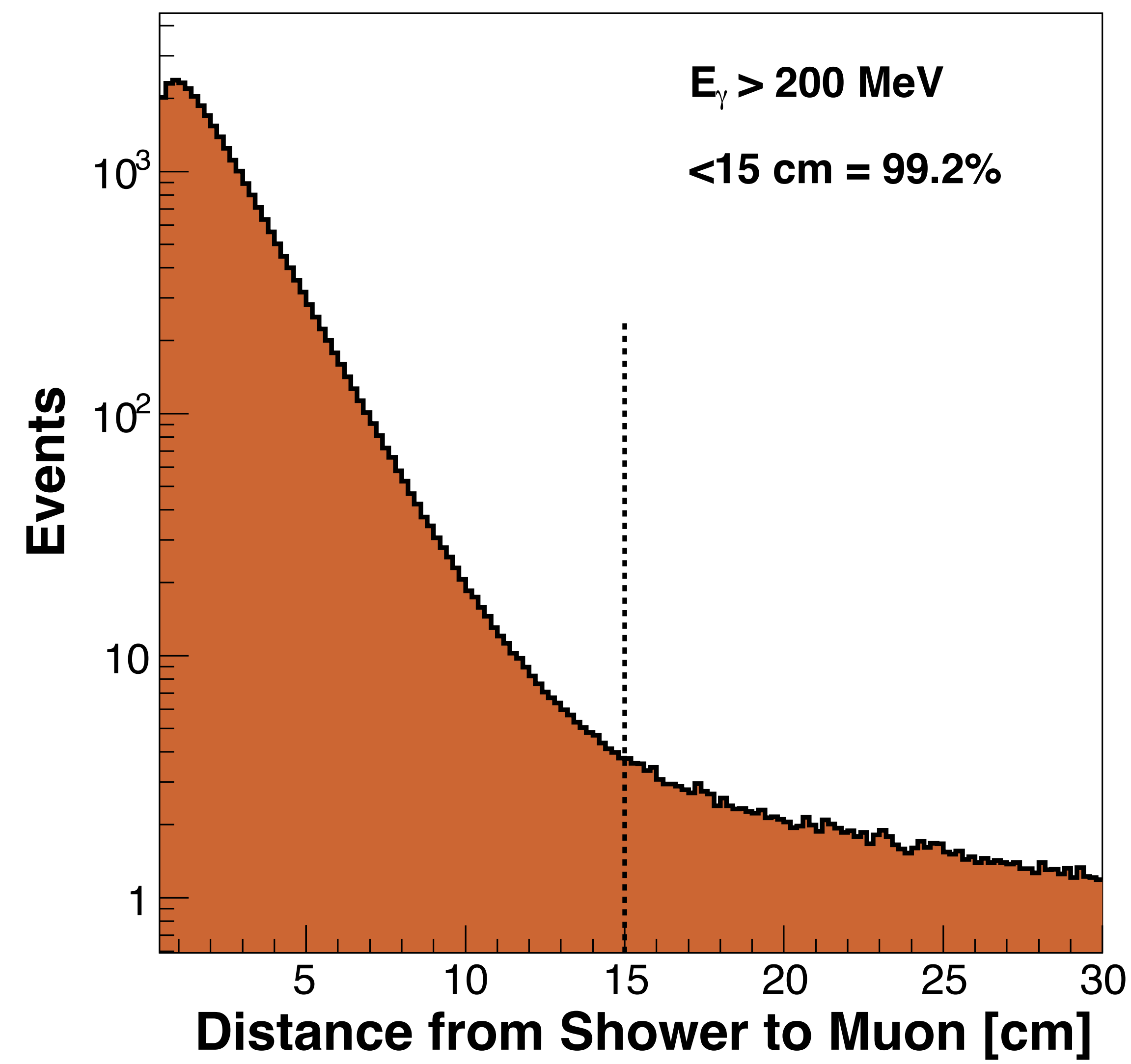


Mitigation: Muon Proximity



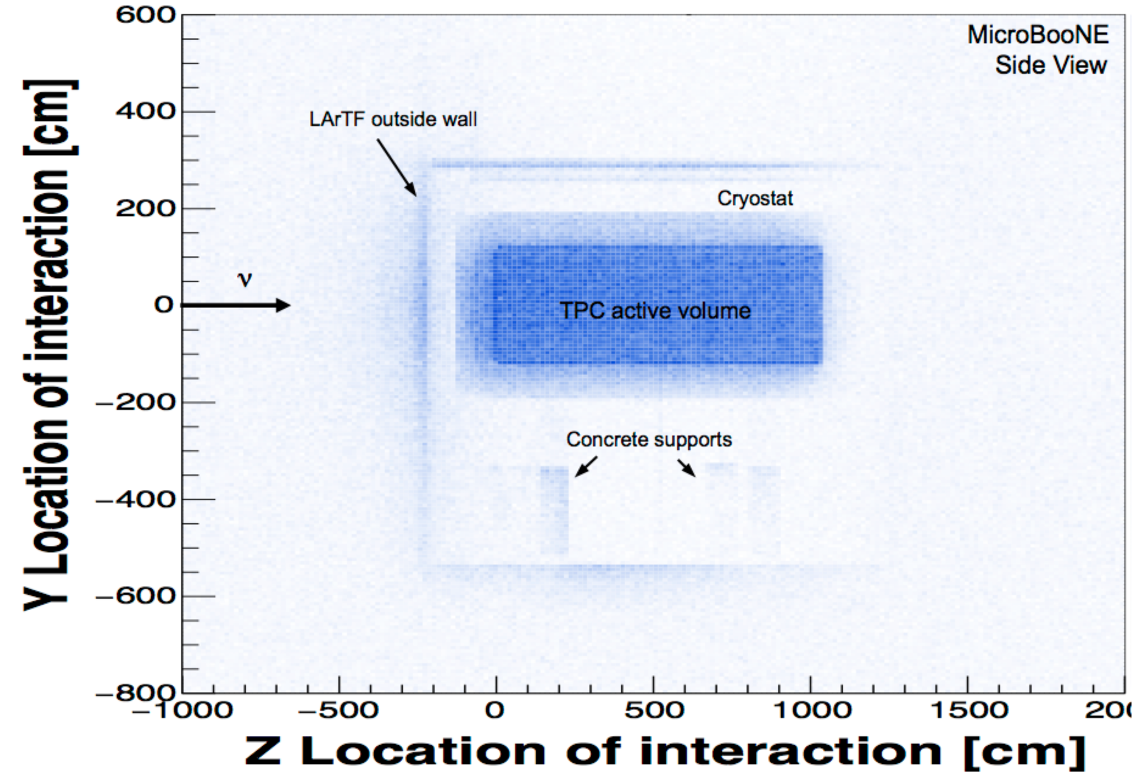
- One of the most powerful mitigation cuts we found for cosmics was relying on the correlation between the shower and muon from which it originated

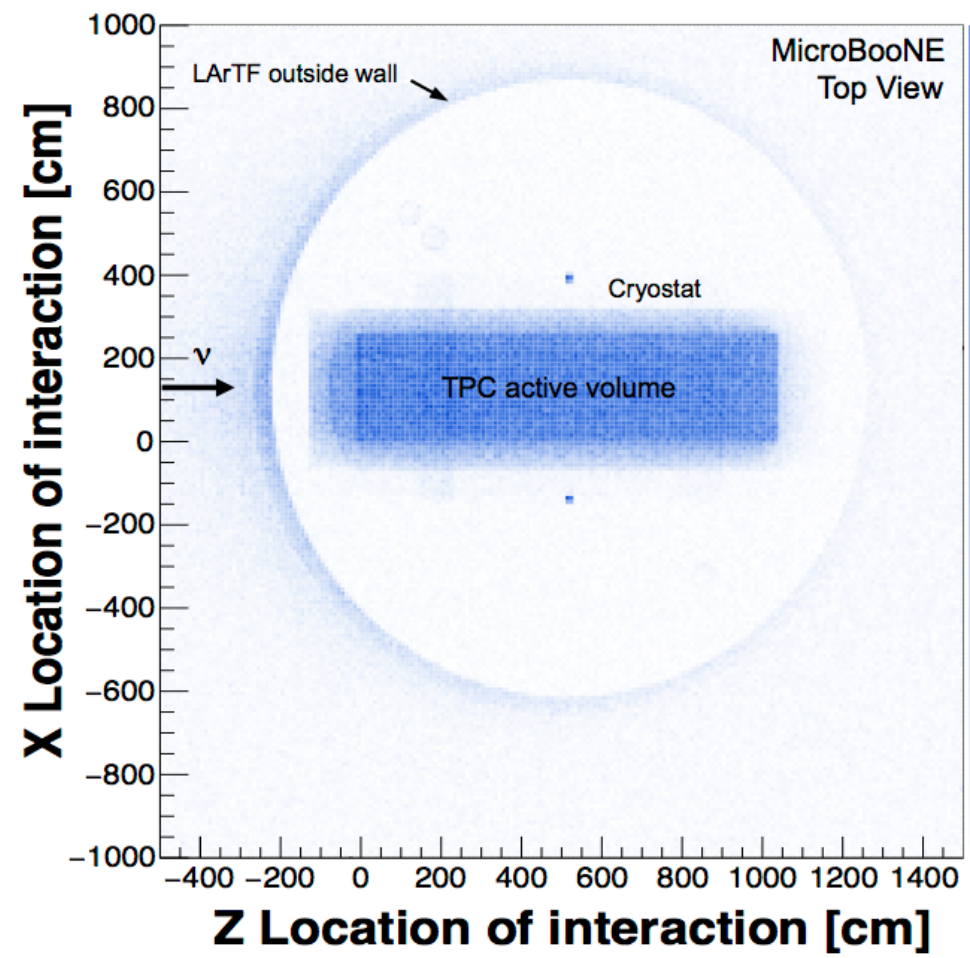
- By **rejecting showers within 15cm of a crossing muon** we are able to reject **99.2%** of cosmics while only **sacrificing ~1% of the fiducial volume**



Beam-Induced TPC-External Events

- Neutrino interactions in the material surrounding the detector can radiate activity into the TPC
- Such backgrounds depend strongly on the detector geometry and neutrino flux
- Photon radiation length of 14cm in LAr helps isolate the detector from photons traveling large distances in the TPC



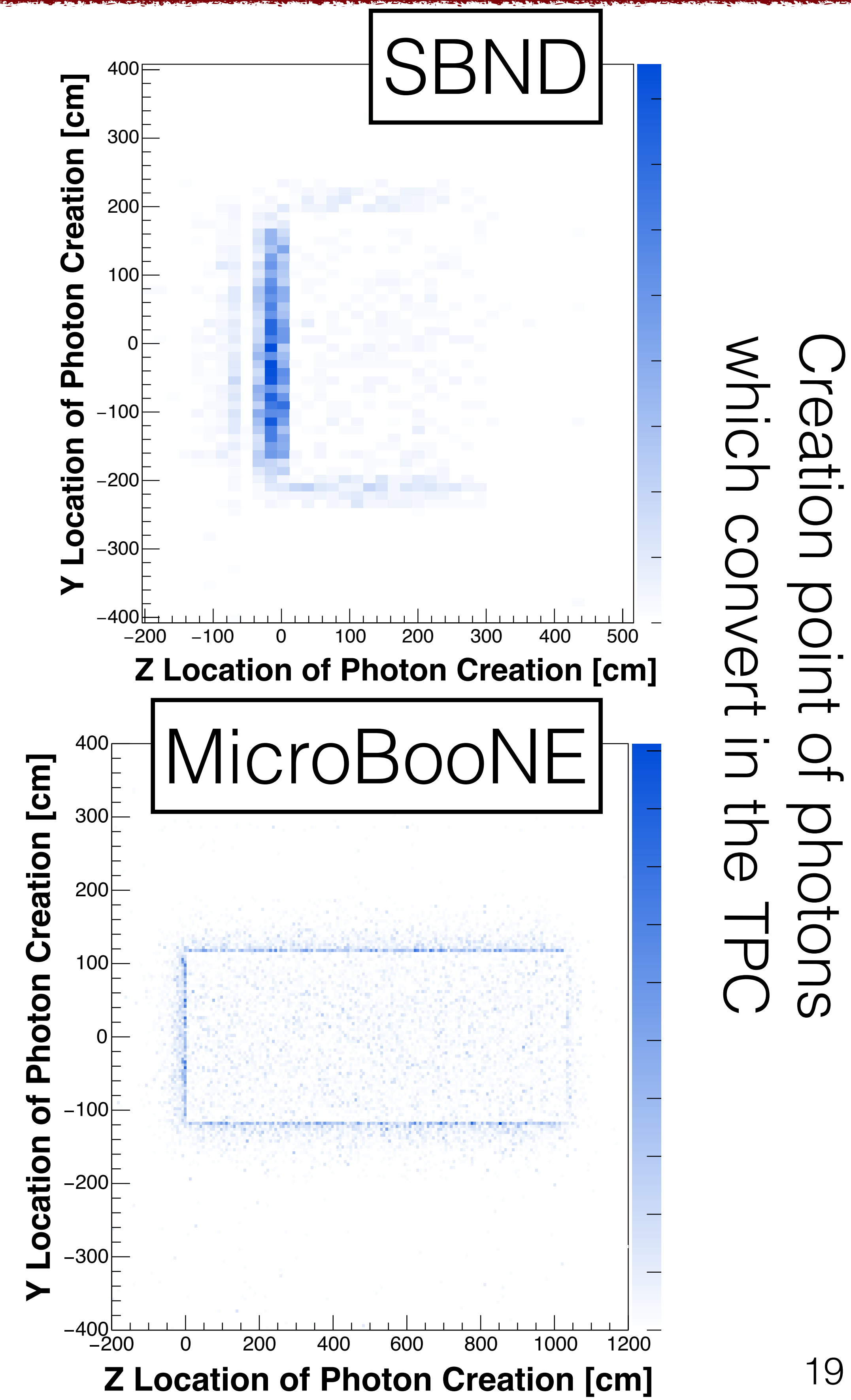


Location of neutrino interactions that leave energy in the TPC

Estimates in SBND and MicroBooNE

- If we study where photons which convert inside the TPC originate from we find that they predominantly originate in the inactive argon surrounding the TPC

- We also see that in SBND these tend to originate from the front face of the detector while at MicroBooNE these tend to populate evenly around the outside
  - This was traced back to the difference in the flux



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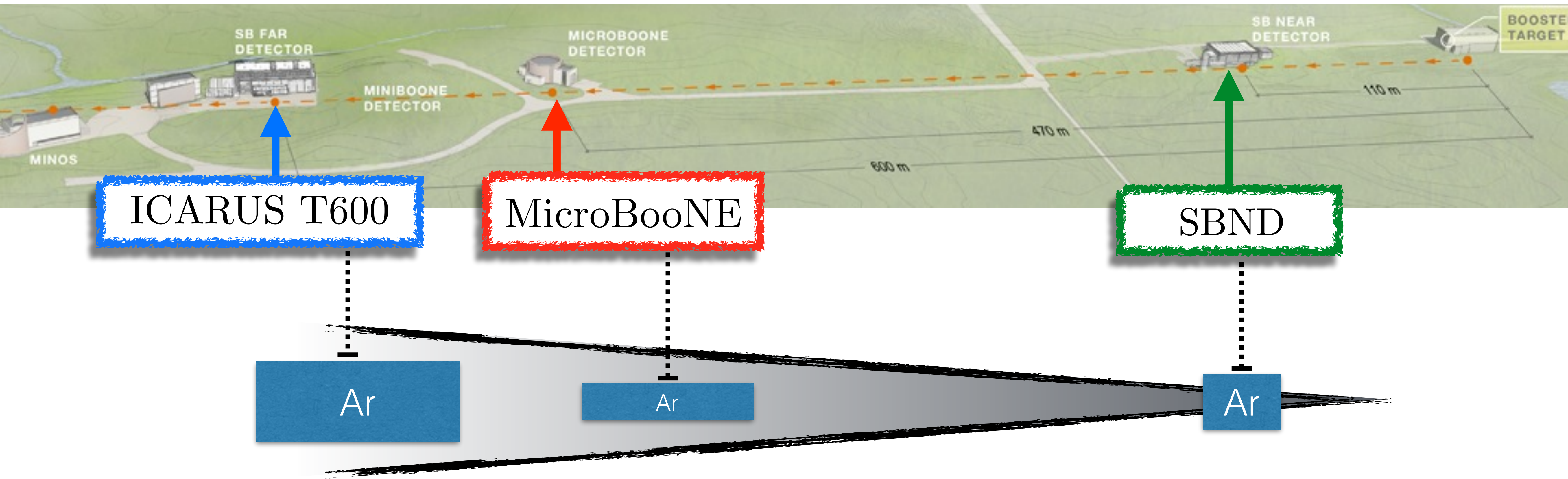
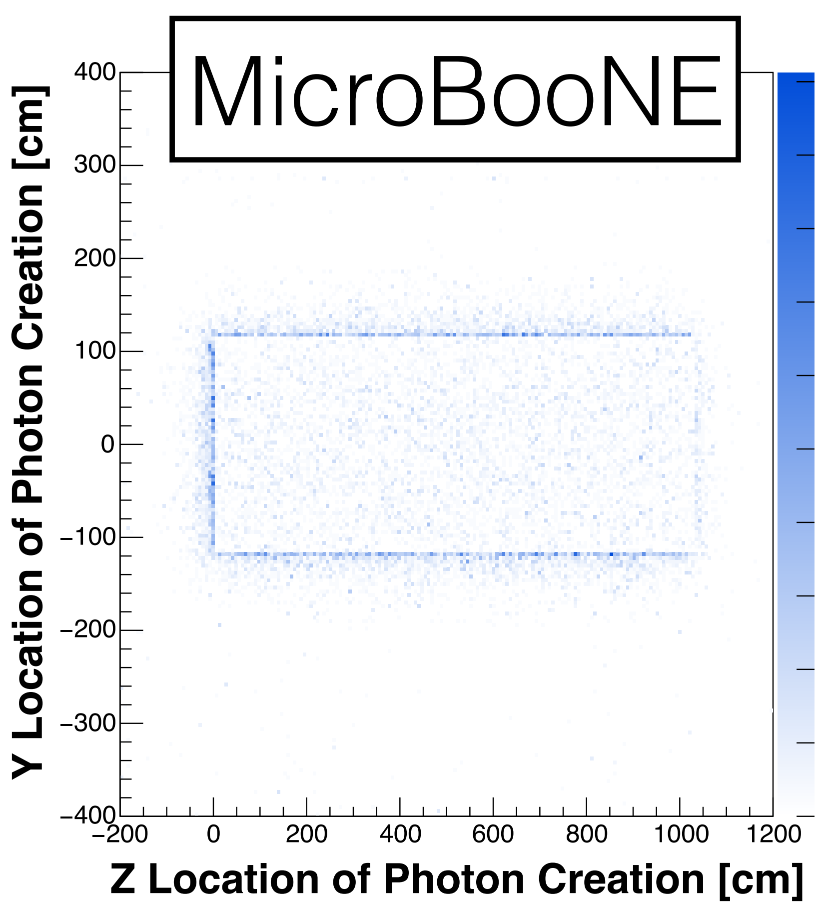
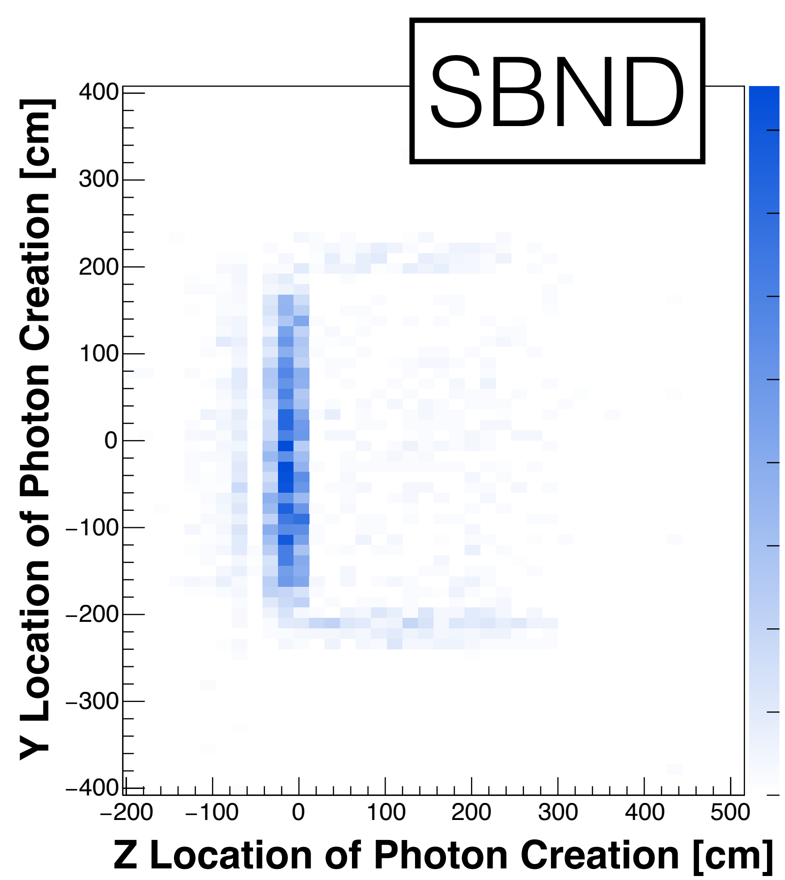
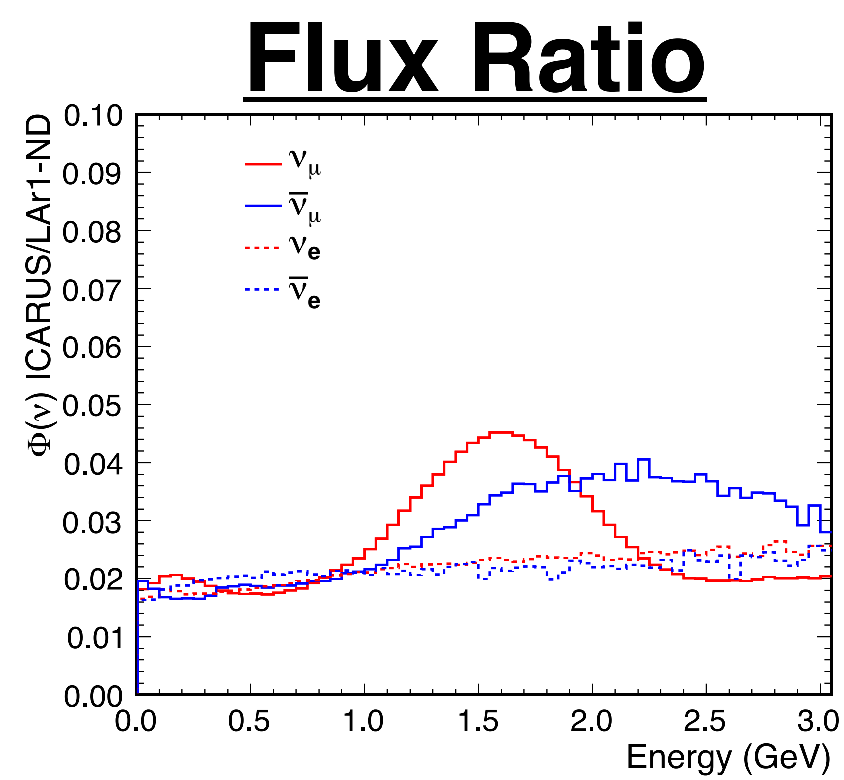






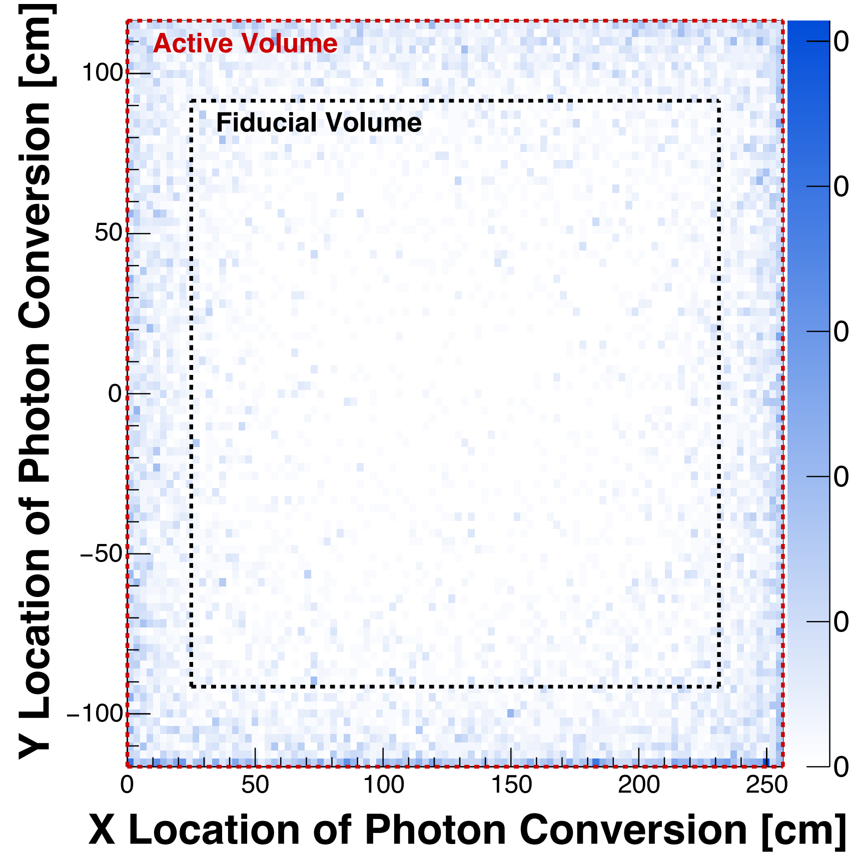


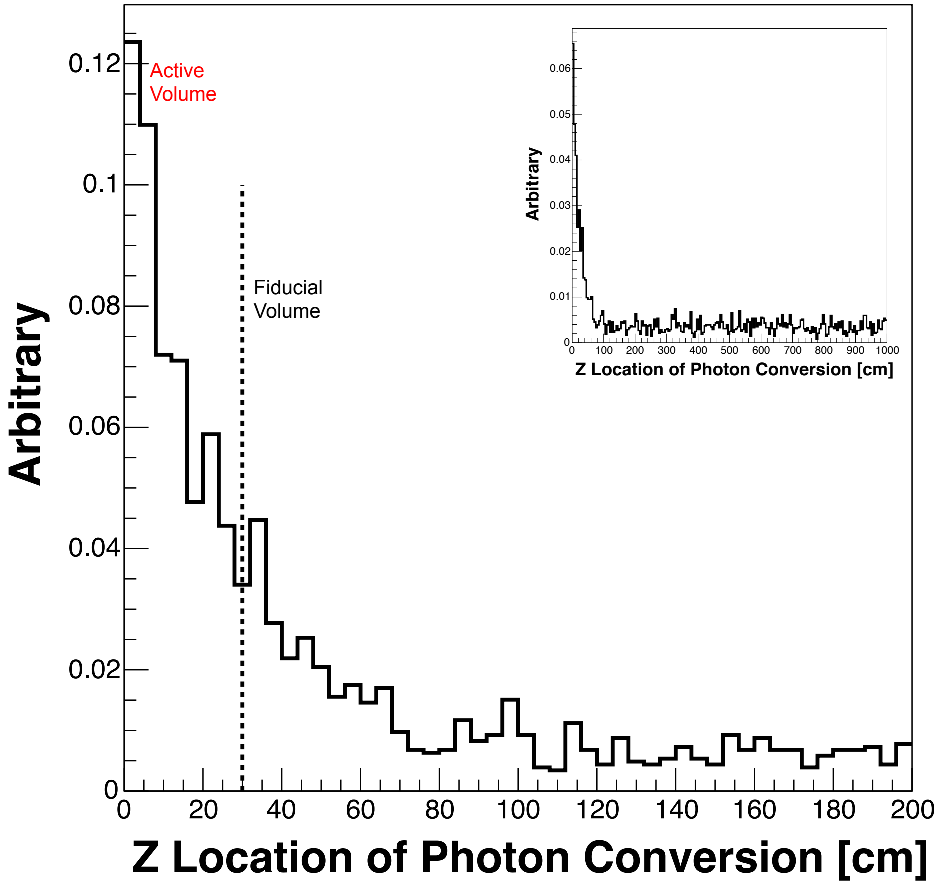
Mitigation: Fiducial Volume

- When mitigating these backgrounds we are again helped by the short radiation length in LAr

- By applying a tight fiducial volume cut we are able to highly suppress this background

- Taking **25cm from the sides and 30cm from the front face** leads to an 80% reduction in background





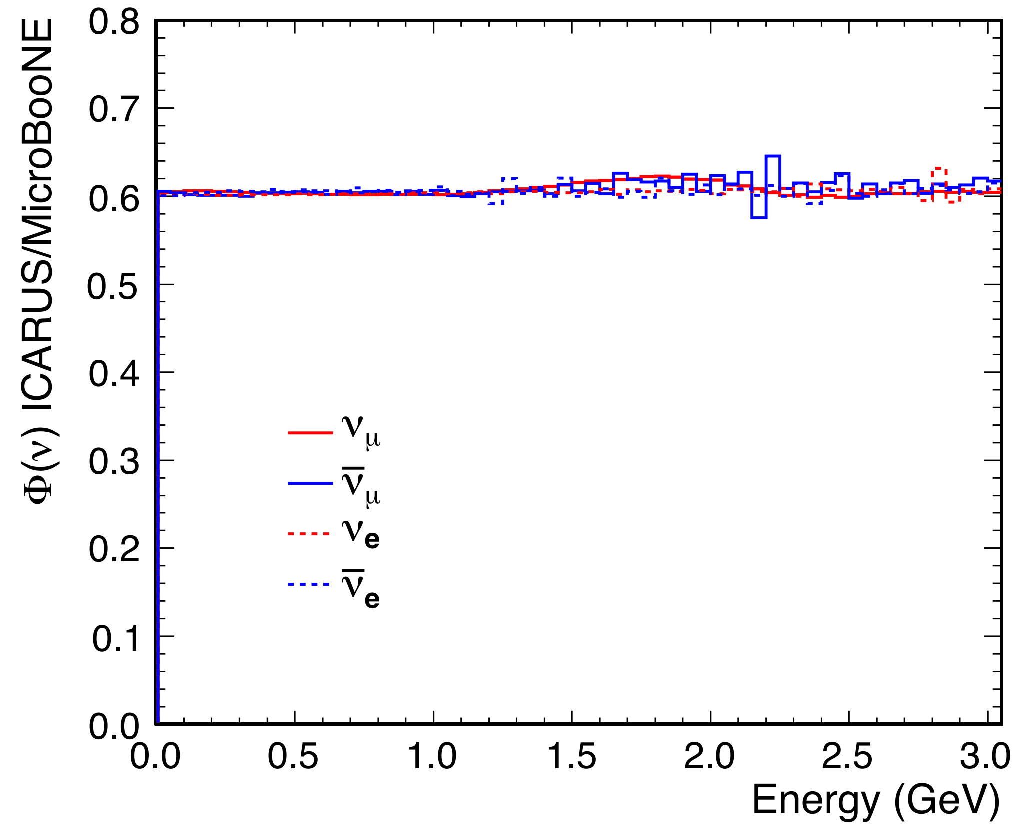
Conversion point of externally produced photons

Scaling to ICARUS

$$N_{\text{dirt}}^{\text{T600}} = \frac{470^2}{600^2} \times 2 \times \left(\frac{\text{Front Area T300}}{\text{Front Area } \mu\text{BooNE}} N_{\text{dirt}}^{\mu B}(z \leq 50 \text{ cm}) + \frac{\text{Side Area T300}}{\text{Side Area } \mu\text{BooNE}} N_{\text{dirt}}^{\mu B}(z > 50 \text{ cm}) \right)$$

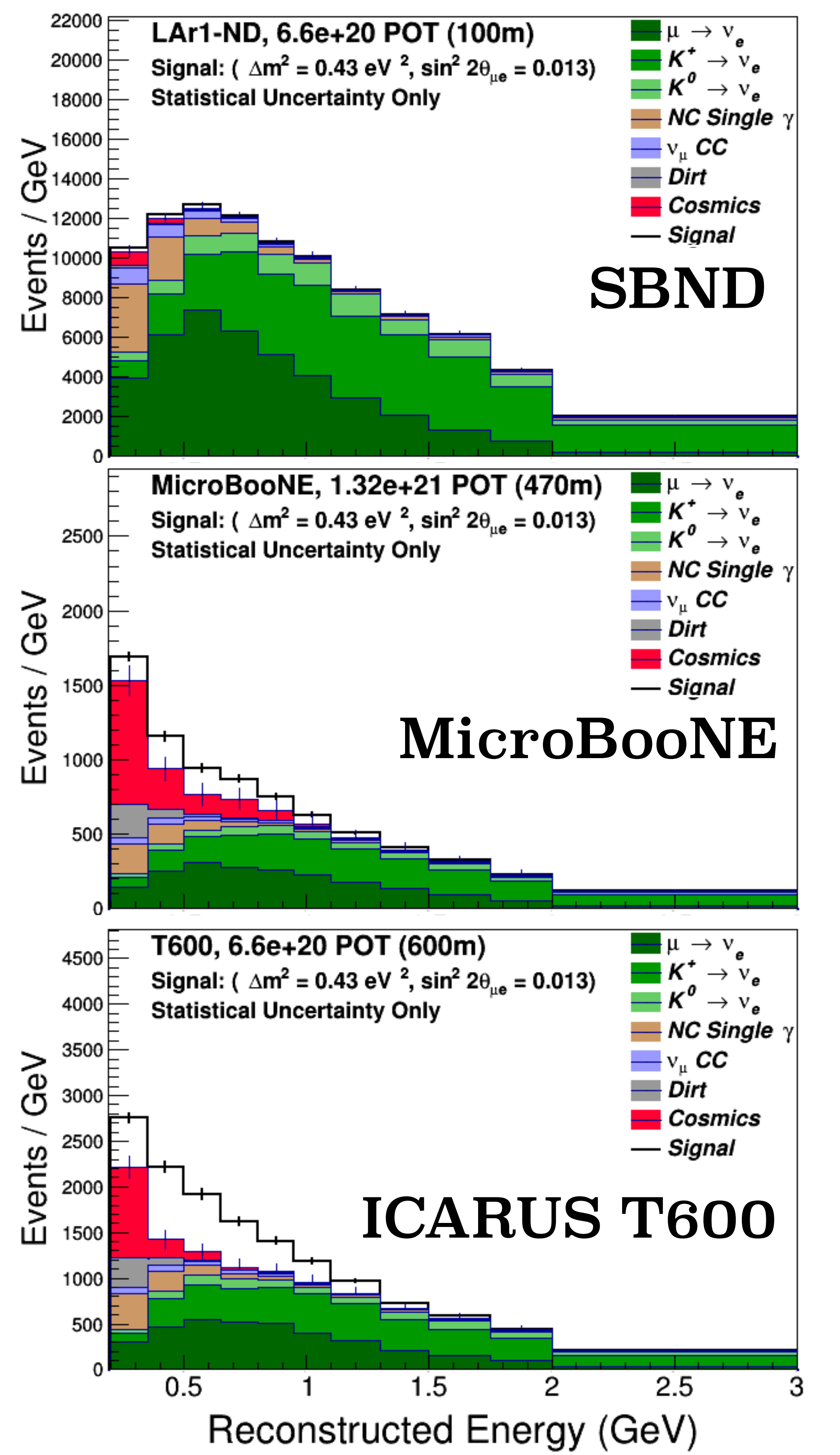
- At the time of the proposal MicroBooNE had the most mature detector geometry
- While SBND and MicroBooNE external event predictions disagreed due to differences in the flux, MicroBooNE and ICARUS see very similar fluxes
- Scaled based on $1/r^2$ for the flux and based on the surface area of the detectors

Flux Ratio



Bringing it all together!

- By applying all these mitigation cuts and fiducial volume reductions we then can study the impact of the final event totals our how well we can observe a signal
- The largest background comes from the irreducible beam intrinsic electron neutrinos
- The size of the other backgrounds depend of the various detector, especially the cosmic backgrounds

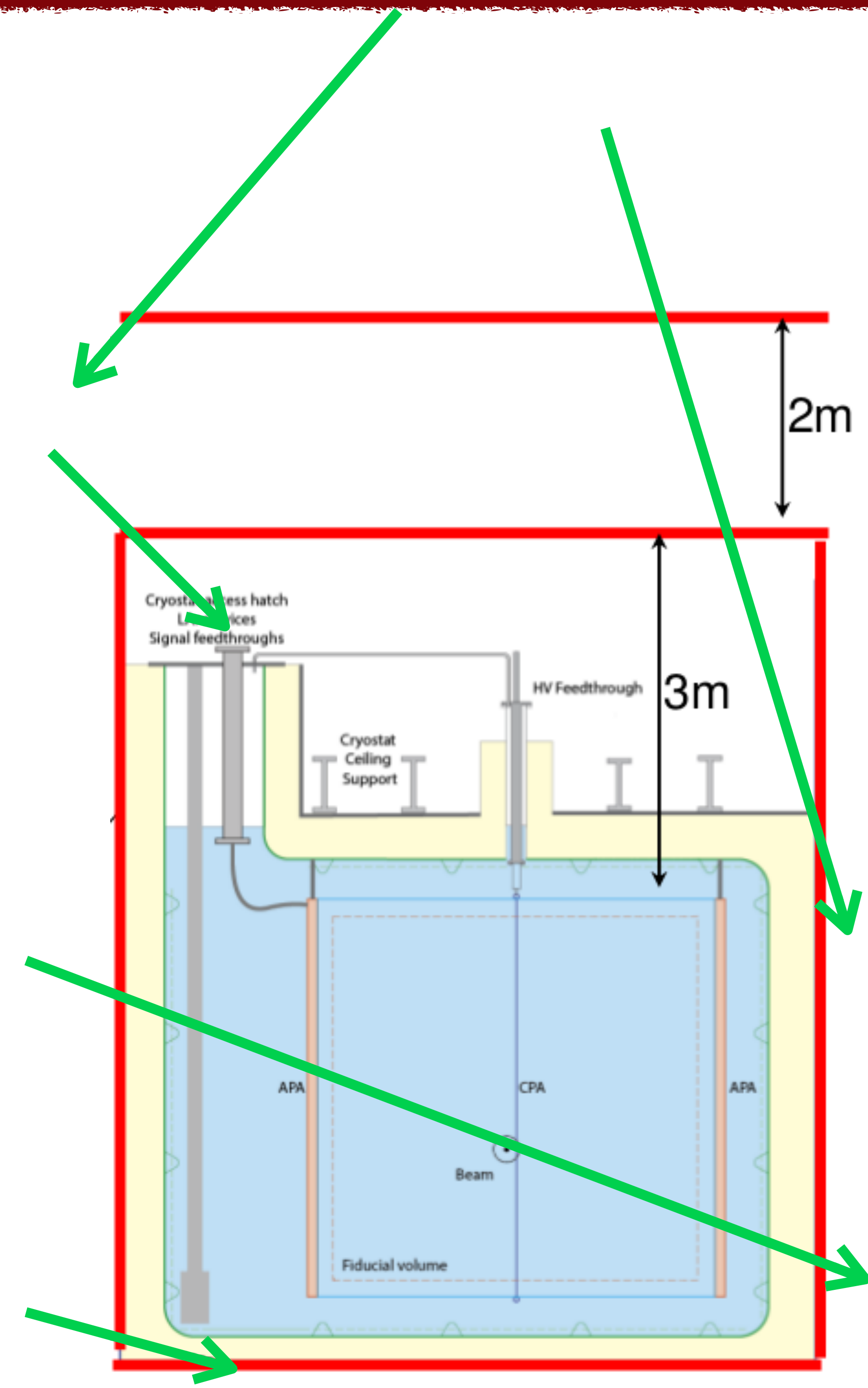


Addition of Tagger and PMT System Cuts

- Due to the size of the cosmic backgrounds and impact at the lowest energies we investigated the impact of including a 95% efficient cosmic tagging system and PMT system for all the SBN detectors

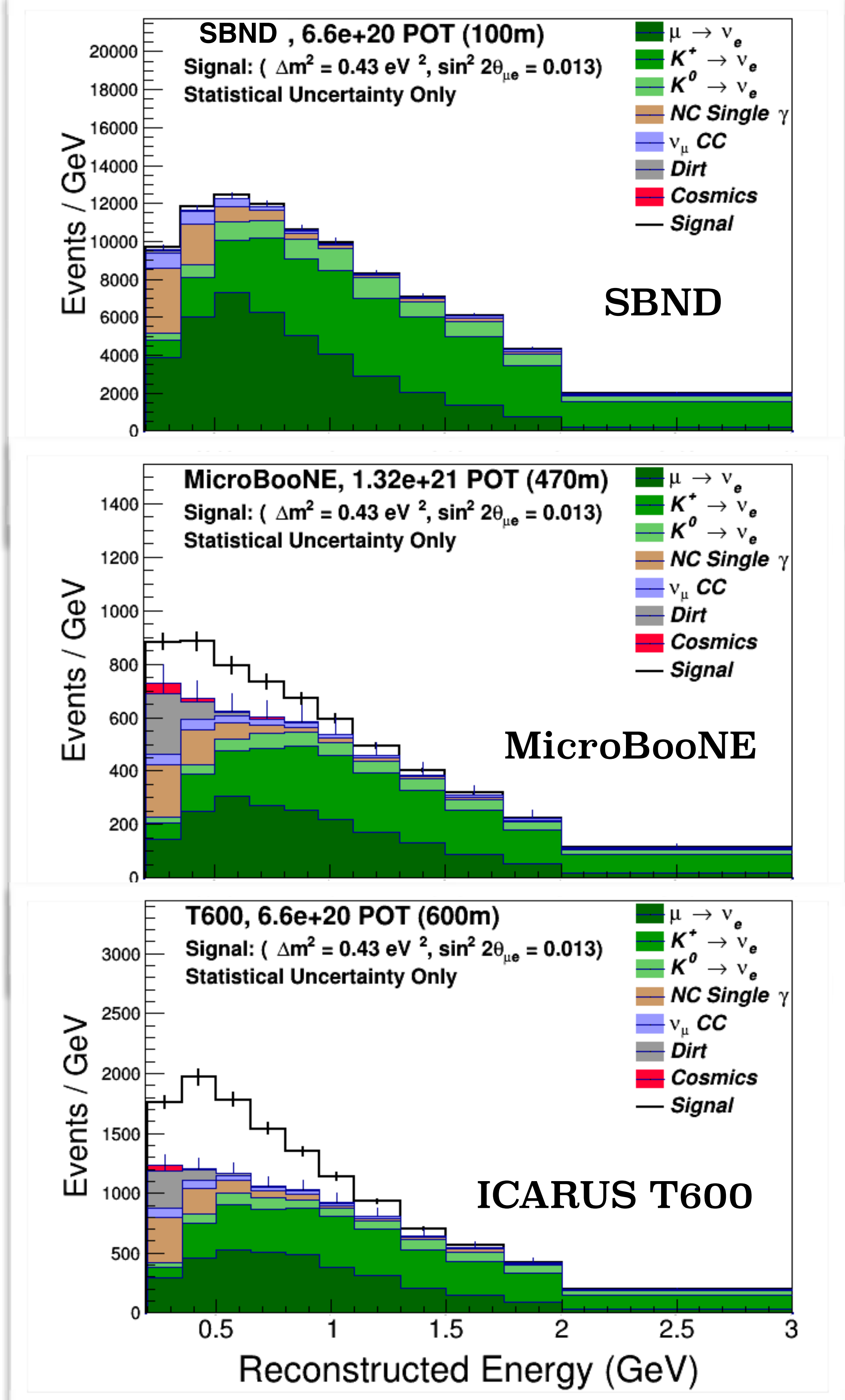
- These would allow us to reject triggers that also had a coincident tagger hit

- This also leads to a ~2% reduction in the accepted signals, leading to less signal



Final Event Distributions

- This tagger system has the impact in removing most of the cosmics and removes comparatively little signal
- These formed the final event distributions of the SBN Proposal
- Using these we can investigate our sensitivity to sterile neutrino mixing covering a large parameter space



Turning this into a Sensitivity

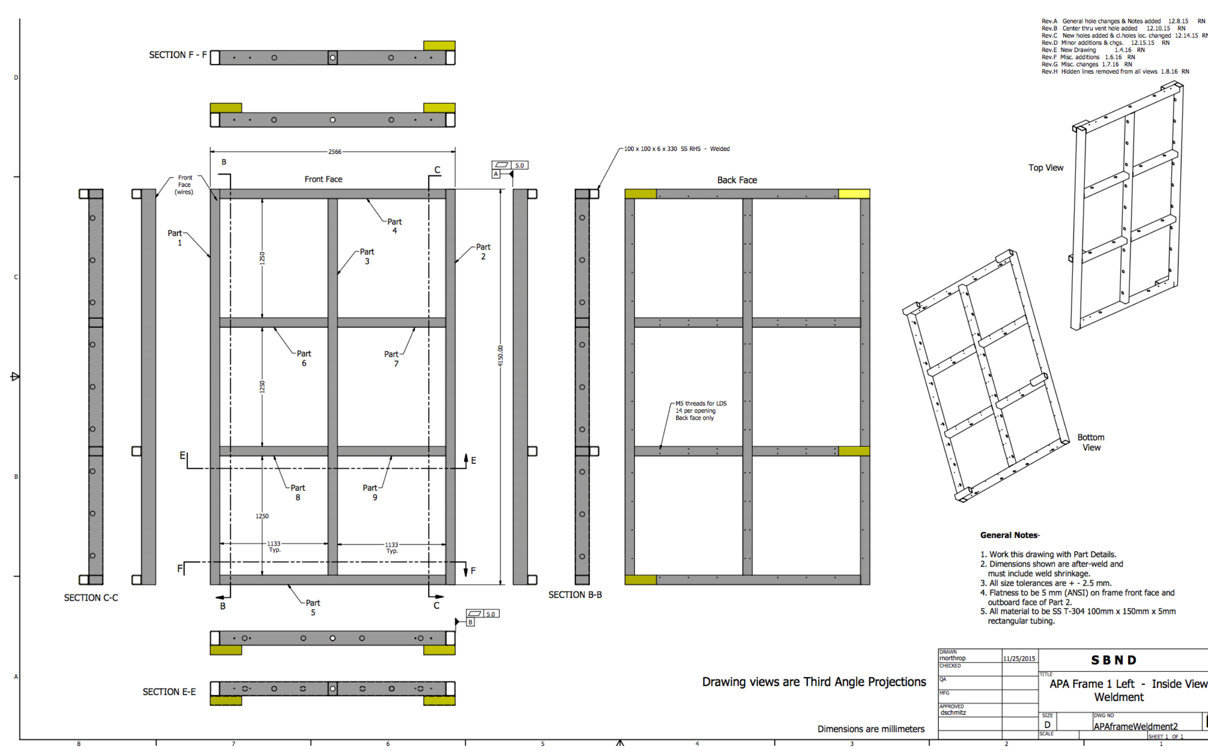
- Before we can accurately gauge our ability to interpret and observed any signal as sterile neutrino oscillations we need to carefully take into account the systematic uncertainties and their correlations between the various detectors
  - This will be covered in the next talk by Corey
- These event distributions were the culmination of countless hours of work by members of each SBN collaboration and I thank them for their dedication

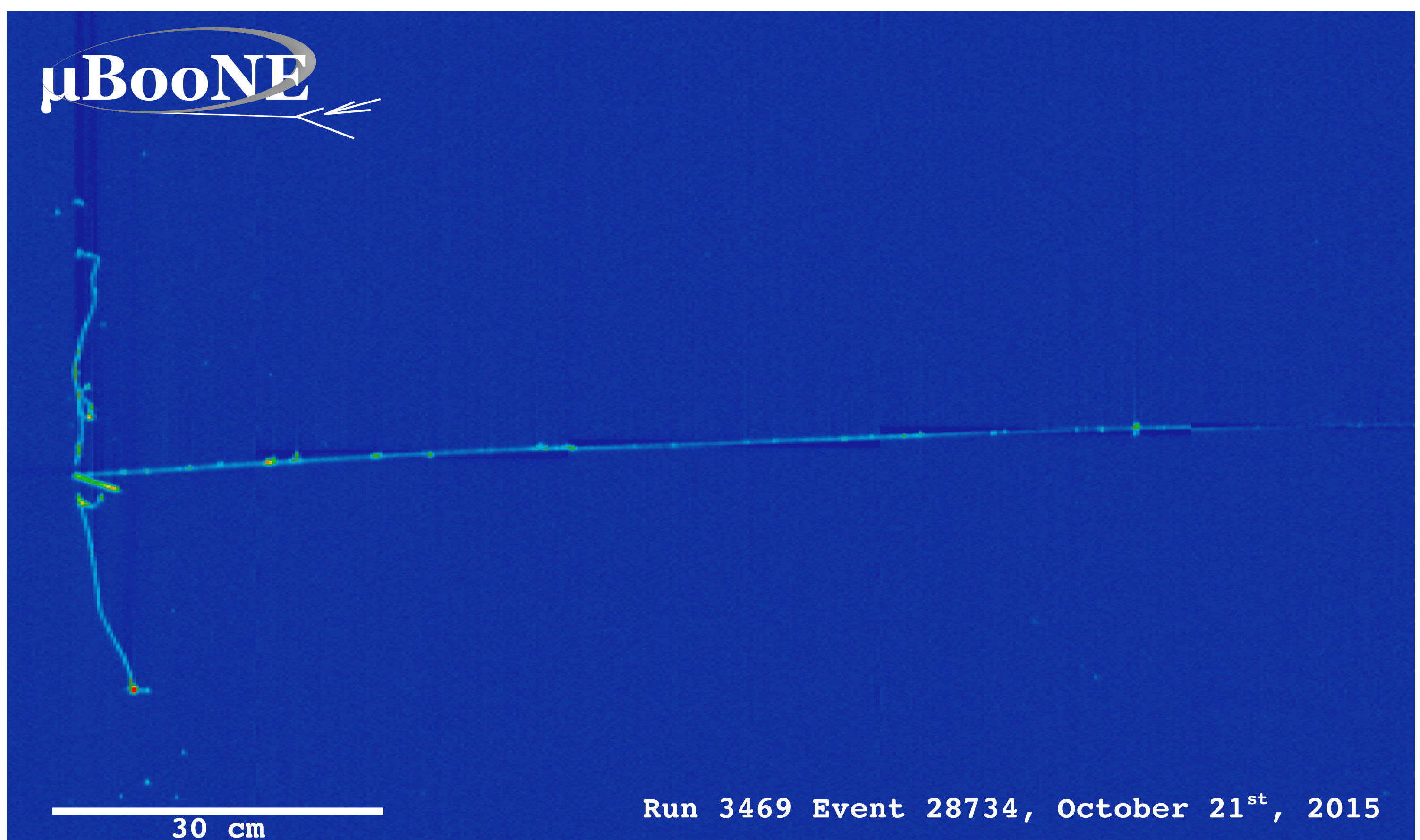
Improvements Beyond

- The SBN mitigation choices were purposely conservative and there are improvements that we can expect
  - A powerful cosmic mitigation cut will be the association of ionization tracks with the photon signatures
  - There are a variety of cuts to help us constrain the "entering" backgrounds
    - Backwards-distance-to-wall, etc.
  - Better track based particle ID can suppress backgrounds
  - etc.

- These analysis tools are being built within the MicroBooNE analyses now, **so stay tuned!**

The SBN is on its way!





Backups

Cosmic Simulation Methods

- ICARUS - Fluka, **with 3m overburden**
  - N^{drift}_{μ} =2.5, per TPC
- SBND - MuFlux and decedent photons, **thus simulated perfectly efficient overburden**
  - N^{drift}_{μ} =1.7, per TPC
- MicroBooNE - CRY (with a fully developed geometry), **no overburden**
  - N^{drift}_{μ} = 5

Table of Event Totals

	LAr1-ND 6.6×10^{20} p.o.t.	MicroBooNE 13.2×10^{20} p.o.t.	ICARUS-T600 6.6×10^{20} p.o.t.
$\mu \to \nu_e$	6,712	338	607
$K^+ \to \nu_e$	7,333	396	706
$K^0 \to \nu_e$	1,786	94	180
NC $\pi^0 \to \gamma\gamma$	1,356	81	149
NC $\Delta \to \gamma$	87	5	9
ν_μ CC	484	35	51
Dirt events	44	47	67
Cosmogenic events[a]	170 (9)	220 (11)	204 (10)
Signal ($\Delta m^2 = 0.43$ eV^2, $\sin^2 2\theta = 0.013$) [41]	114	136	498

[a]These predictions exclude a small correction from the case where an unidentified neutrino interaction provides the scintillation trigger, as discussed in Section II G.

Flash Match Math (1D)

No Flash Match

$$t_{\text{exposure}} = (211\ \text{sec}) \times (1 + N^{\mu}_{\text{drift}})$$

With Opaque Cathodes

	Muons Per Drift	Time of Exposure [sec]
LAr1-ND	1.70	570
MicroBooNE	5.00	1,266
T600	2.50	739

With Flash Match

$$t_{\text{exposure}} = (211\ \text{sec}) \times \left[1 + N^{\mu}_{\text{drift} \times (1 - P_{\text{CosTag}})}\right]$$

$$t_{\text{exposure}} = (211\ \text{sec}) \times \left[1 + N^{\mu}_{\text{drift}} \times \left(1 - \left(1 - \frac{2\sigma_L}{Z_i}\right)^{N^{\mu}_{\text{drift}}}\right)\right]$$

With Opaque Cathodes

	Muons Per Drift	Detector Length [cm]	Light System Resolution [cm]	Time of Exposure [sec]	% Reduction in Exposure
LAr1-ND	1.70	500.00	50.00	324	43.1
MicroBooNE	5.00	1,036.00	50.00	631	50.2
T600	2.50	1,795.00	100.00	346	53.2