Calibration studies at the Coherent CAPTAIN-Mills Experiment Using Cosmogenic Muons and Michel Electrons

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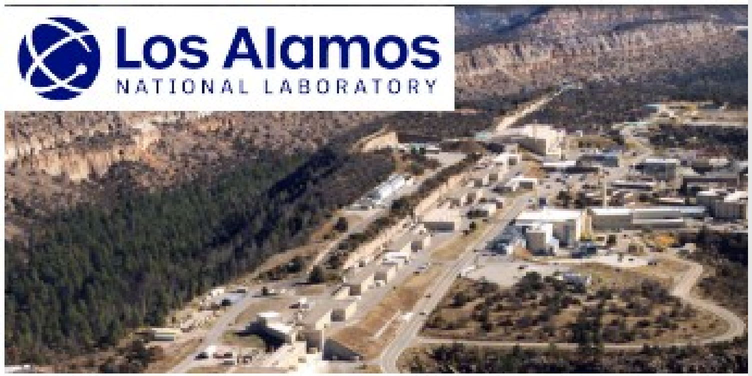

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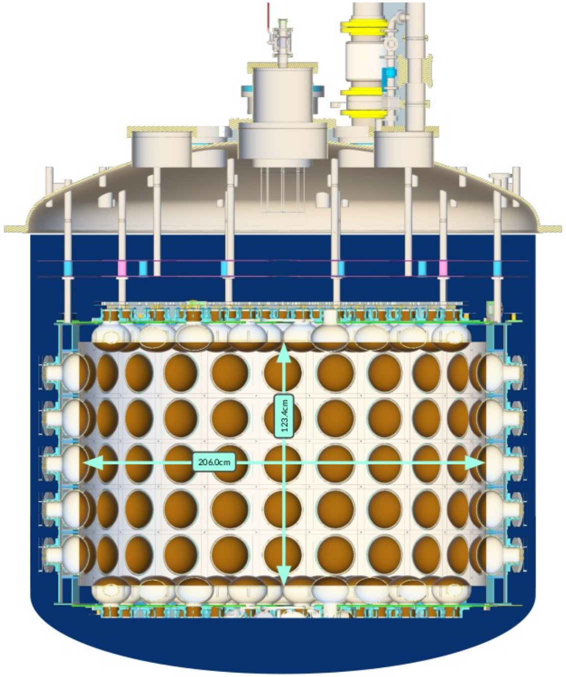
Outline

- Coherent CAPTAIN-Mills (CCM) detector.
- Physics at CCM.
- Energy Calibration: Cosmogenic muons and Michel electrons.
- Prospects.
- Summary.

Coherent CAPTAIN-Mills (CCM) Detector

- Located at Los Alamos National Lab.
- Detector of 7 ton fiducial LAr volume.
  - Covered by 200 8” PMTs
- 3 ton LAr active veto region
  - surround fiducial volume with 40 1” PMTs.
- Sensitive between ~ 10 KeV and ~ 600 MeV.



Physics at CCM

- Proton beam hits a tungsten target.
  - CCM is 90° off axis from the beam.

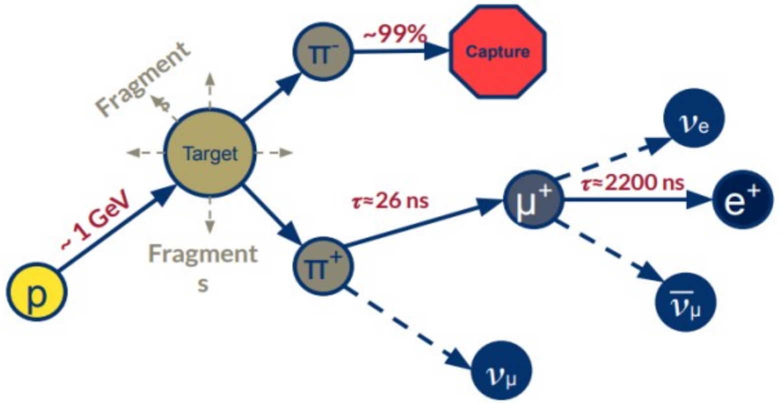
- An intense flux of: pions, gammas, muons, neutrinos and neutrons is formed.

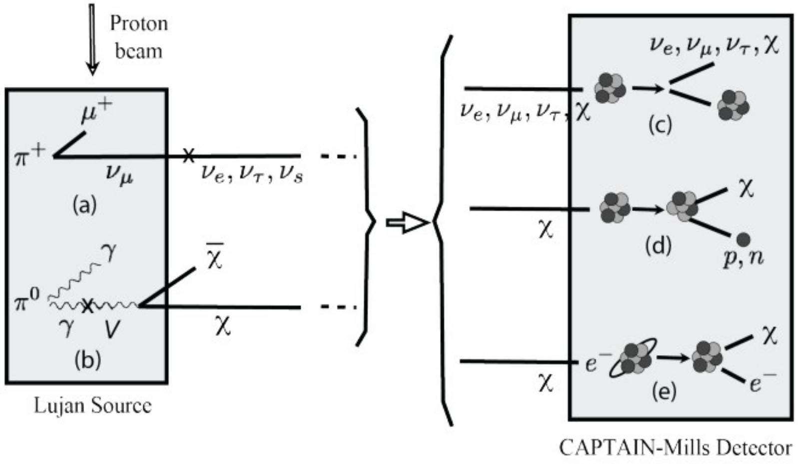
- Ideal for dark-sector searches:

  - Axion-Like- Particles and MeV scale QCD axion (arXiv:2112.09979).
  - Light-dark-matter (arXiv:2105.14020).
  - Search for dark photons .
  - Leptophobic MeV-scale dark matter (arXiv:2109.14146).

- Optimal to CC and NC cross section measurements on Argon (see Marisol Chávez's talk this afternoon).

- Relevant energy scale 0-10 MeV.

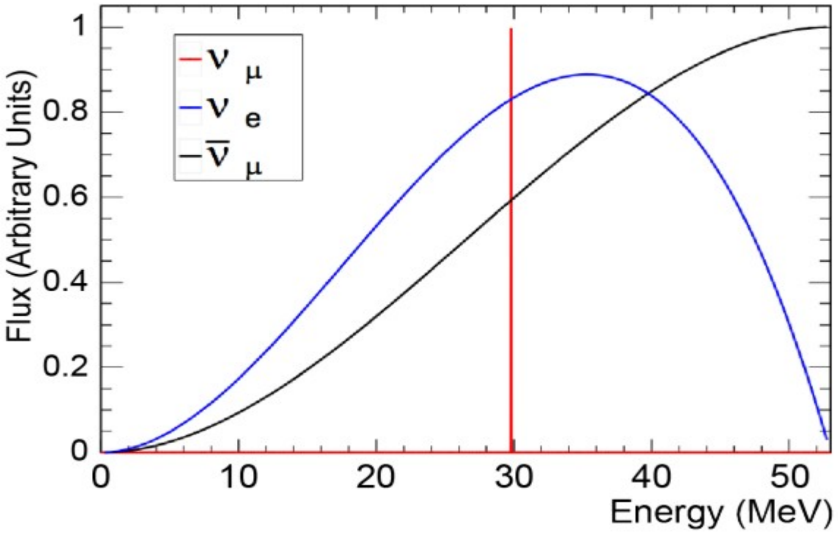




Physics at CCM (Cont)

Calibration in the region of E < 60 MeV is relevant for:

- ν Argon cross sections $E_\nu < 52.8$ MeV
- Dark sector searches (E_{dep} < 1MeV)
- ALP search (1-10 MeV)

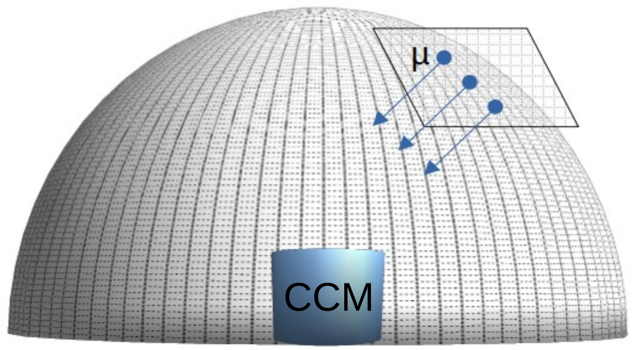


Energy spectra for individual neutrino species resulting from π^+ and μ^+.

Cosmogenic Muon Simulation

- Injection of Muons.
- Energies depositions in fiducial volume.
- Michels simulation.
- CCM Simulation.

Injection of Muons



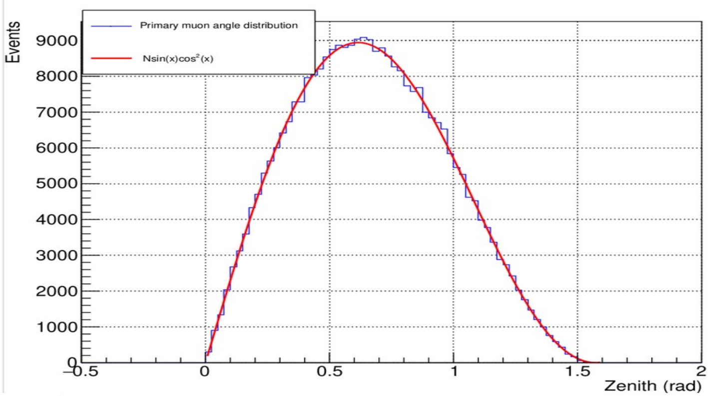
- Simulation based on Geant4.

- Generator contain the following features:

- Muon Initial position based on a geometrical construction

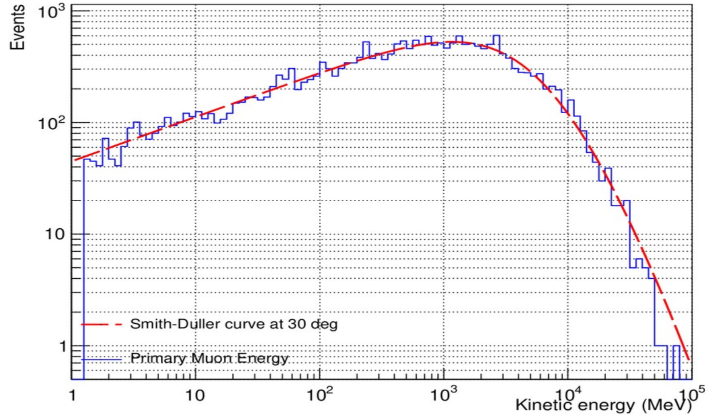
- Monoenergetic intensity profile

$$\frac{dN}{dAdtd\Omega} = I_0 \cos^2(\theta)$$

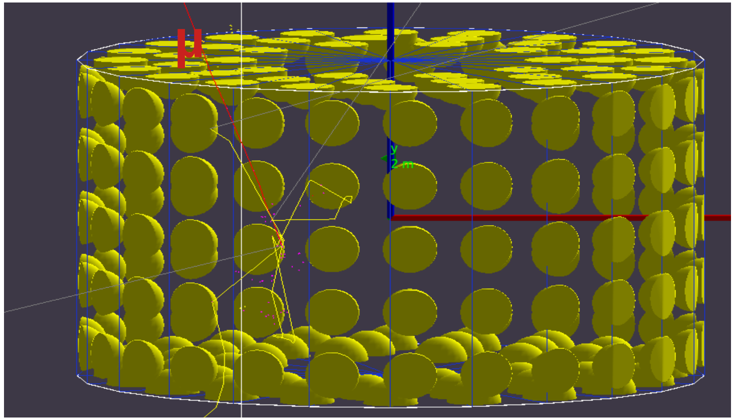


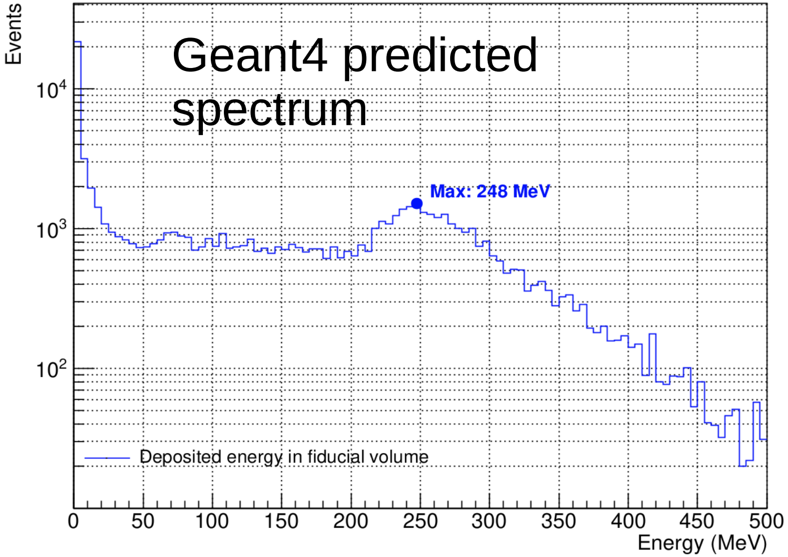
- Energy sampling following Smith-Duller parametrization.

$$\frac{dN}{dAd\Omega dtdE_\mu}(E_\mu, \theta) = \frac{AE_\pi^{-k} P_\mu \lambda_\mu b j_\pi}{E_\pi \cos(\theta) + b j_\pi}$$



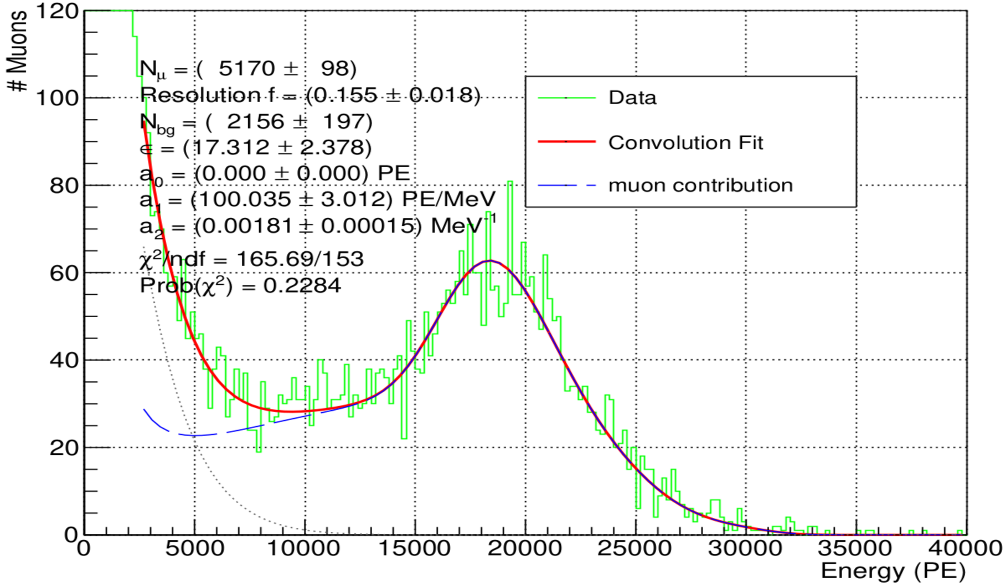
Energy depositions in fiducial volume





- Energy reconstruction using the Geant4 predicted energy deposition.

- 2021 data taking by looking Pre-Beam window (background measurements).



- Fit to experimental spectrum involving:
  - Effects on random fluctuations (in average).
  - non-linearity response.

- Expected rate at Los Alamos: ~ 105 $m^{-2}s^{-1}sr^{-1}$.

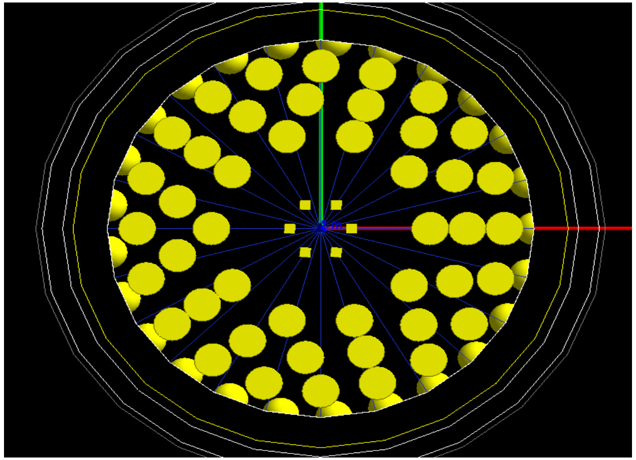
Michels Simulation ($\mu \rightarrow e + \nu_e + \nu_\mu$)

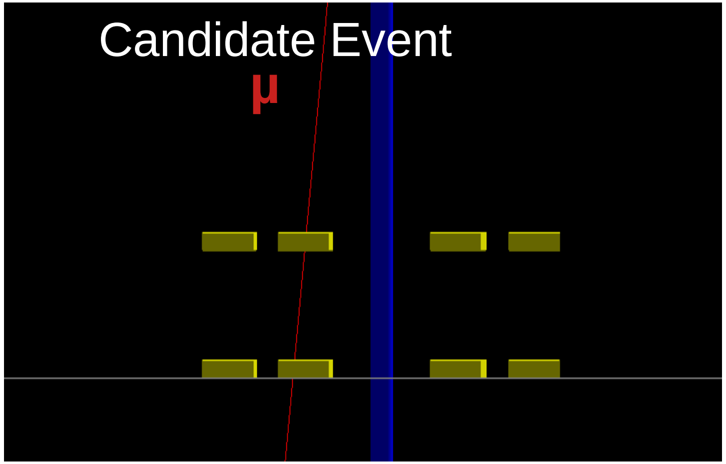
- Signal by electron (or positron) in the range of ~ [0, 60] MeV.

- Approach of the simulation:

  - Selecting cosmic muons that activate the pair of cosmic watcher detectors (developed by MIT team).

  - Expected 0.0926 Michels per Muons tagged by CWs.





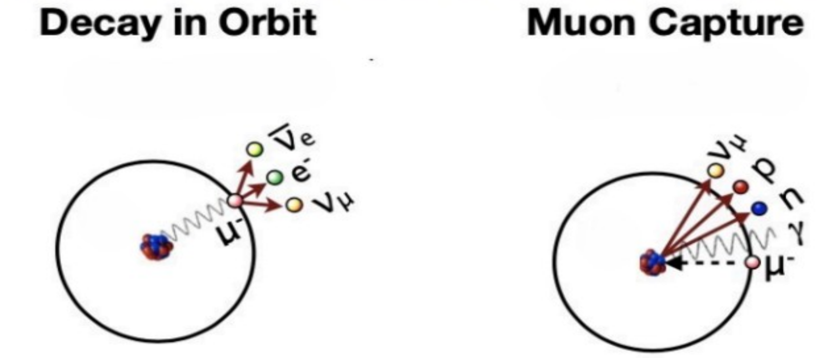
Michels Simulation (Cont)

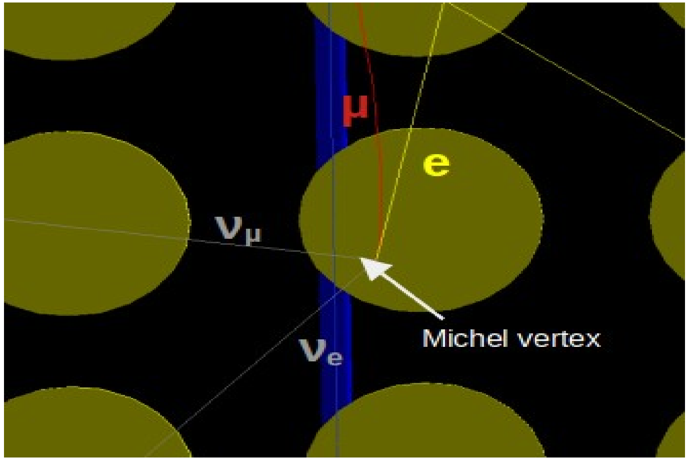
- Activating the physical processes in Geant4 that handle the decay of μ^+ or μ^-.

- Michel creation in LAr:

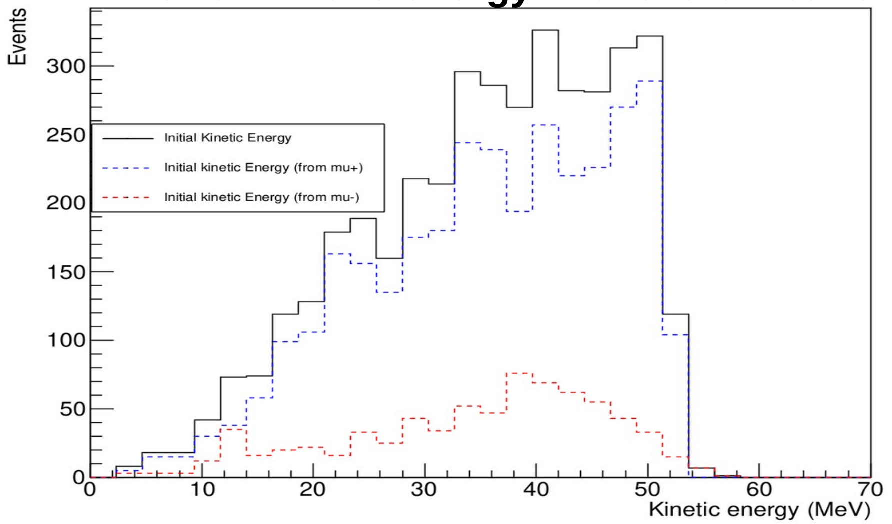
  - 100% decay in free of μ^+

  - About 25% decay in orbit of μ^- (75% muon nuclear capture, no electron signal).



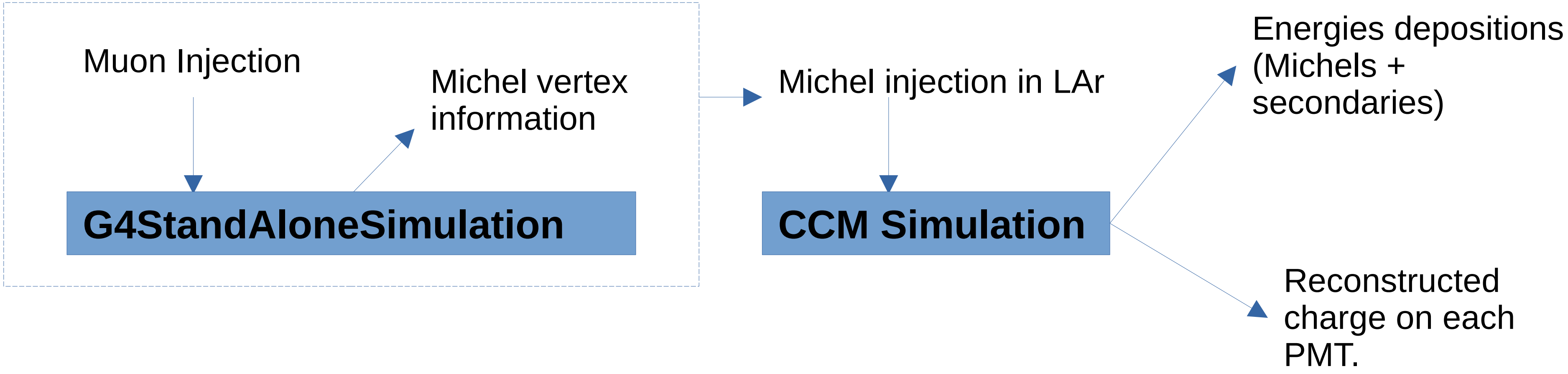


Vertex kinetic energy Michel distribution



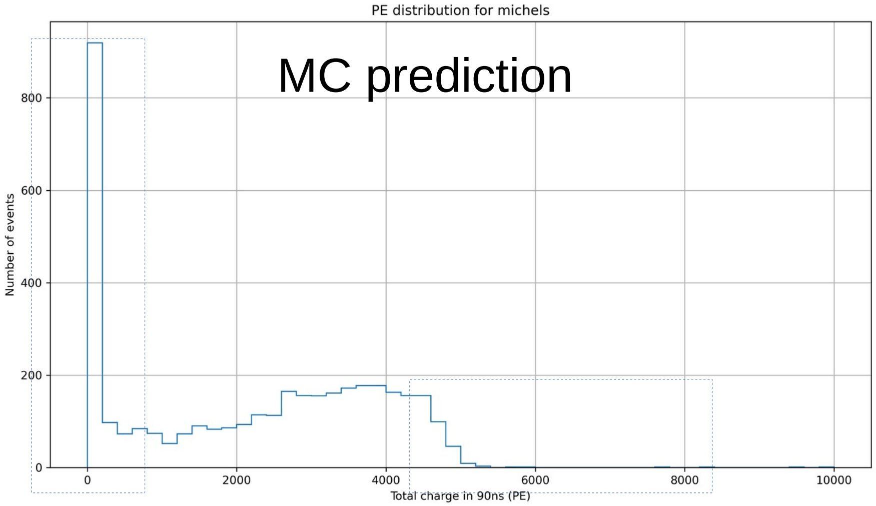
CCM Simulation

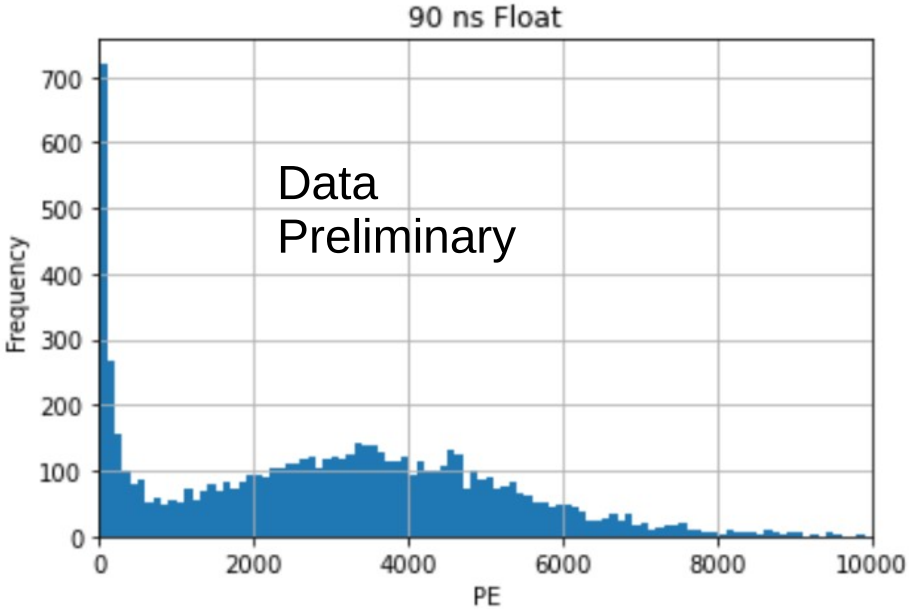
- Use IceTray software.
- CCM has been developing a Geant4-based simulation with detailed photon propagation in LAr.
- So far, we have connected the information of “StandAloneMuon” simulation with CCM framework.



CCM Simulation (Cont)

- Preliminary results show good qualitative agreement with data. Discrepancies under investigation.
- CCM simulation scaled to match low energy peak features.





- High energy missing events, possible reconstruction effects.
- Low energy peak mainly due to Michels created in the veto region.

Prospects

- Include more general injectors of Cosmogenic particles (MCEq, CRY).
- Process recent cosmic muon data, monitor high energy [100-600] MeV calibration and rate.
- Implementing the complete version of Michel simulation in the CCM framework.
- Perform bump searches in Michel and cosmic muon regions.

Summary

- Implementing a simple model for the injection of cosmogenic muons we can predict the spectrum in the pre-beam region of CCM data, considering a model that involve Gaussian fluctuations and non-linearity detector response.

- A Geant4 simulation based on the characterization of Michels electrons show a good correspondence to the observed PE spectrum.

- Prospects for a more precise Monte Carlo implementation is still in progress.

Thank you for listening

Backup

Energy reconstruction

$$F(E_a) = \frac{1}{dE_a/dE_v} \int_0^{E_{max}} N_\mu F_\mu(E_d) \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(E_v - E_d)^2}{2\sigma^2}}$$

$$\sigma = f\sqrt{E_0 E_v}$$

Gaussian response

$$E_a = a_0 + \frac{a_1 E_v}{1 + a_2 E_v}$$

Non-linearity response

Muon Minus Decay in Orbit

$$\lambda_{LAr}^{\mu^-} = \lambda_{DIO} + \lambda_{capt}$$

$$B_{DIO} = \frac{\lambda_{DIO}}{\lambda_{LAr}^{\mu^-}} \qquad \text{Branching Ratio}$$

$$\lambda_{DIO} = R_H \lambda_{Free}, \qquad R_H \approx 1 - (\alpha Z)^2$$

- In LAr $R_H \approx 0.99$ by theoretical predictions given 25% probability of DIO.
- Independent tests in Geant4 show good correspondence with deviations around ~ 1%.

Fit to Michel Spectrum