Constraining “Dirt” Backgrounds for the MicroBooNE Single Photon Low Energy Excess Search

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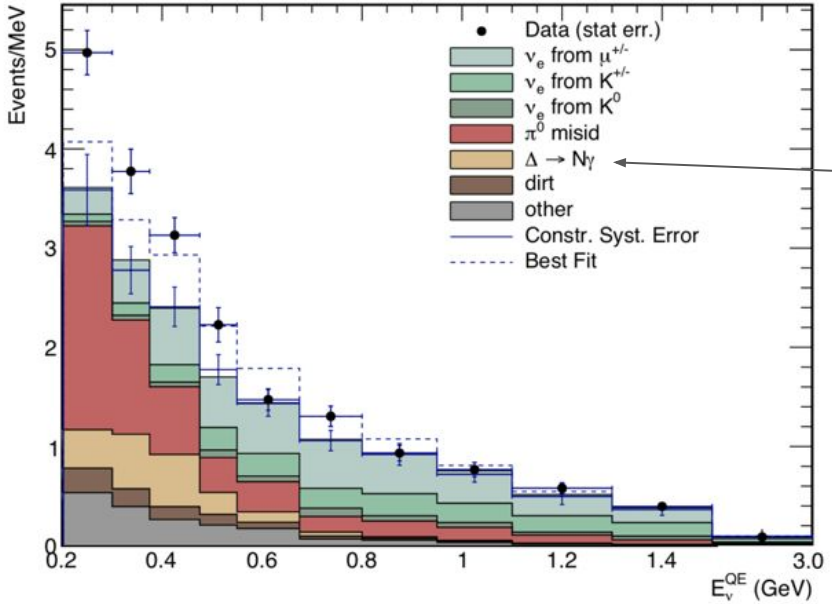
Los Alamos National Lab
(formerly, Columbia University)

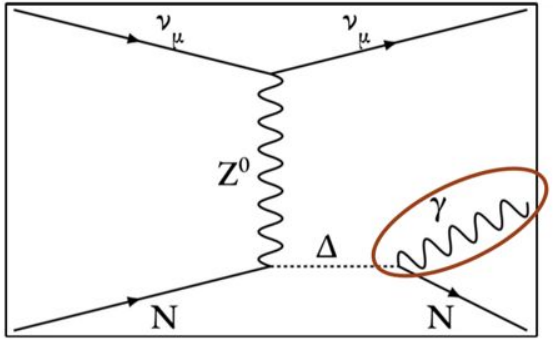
New Perspective 2.0
August 2020

MiniBooNE MicroBooNE

Low Energy Excess interpreted via Single Photon



The MiniBooNE Low Energy Excess (LEE)
(https://arxiv.org/abs/1805.12028)

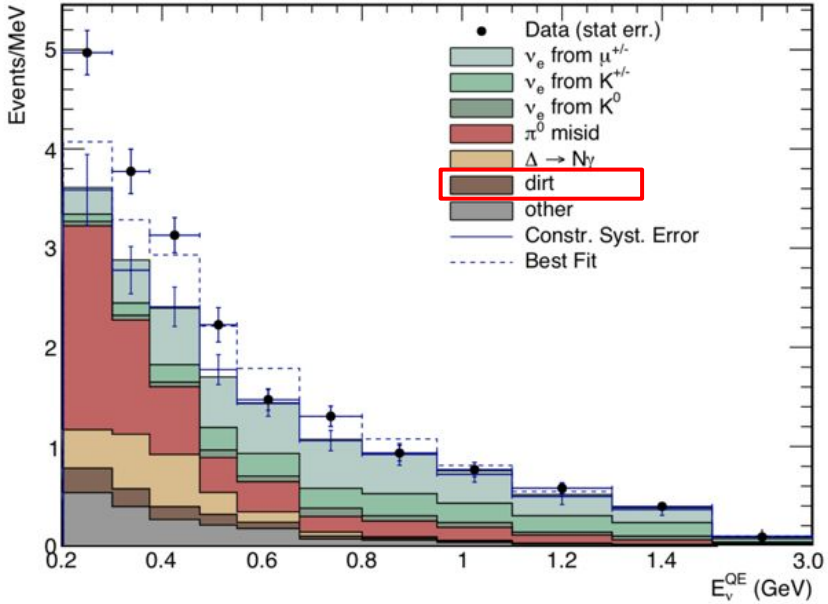


Neutral Current (NC) Δ production followed by radiative decay.

- A standard model source of **single photons**.

MicroBooNE is searching for **single photons** as evidence of an enhanced delta production rate, which is one of the **candidate explanations** of the MiniBooNE LEE.

Develop Methods to Constrain Dirt Backgrounds



The MiniBooNE Low Energy Excess (LEE)
(https://arxiv.org/abs/1805.12028)

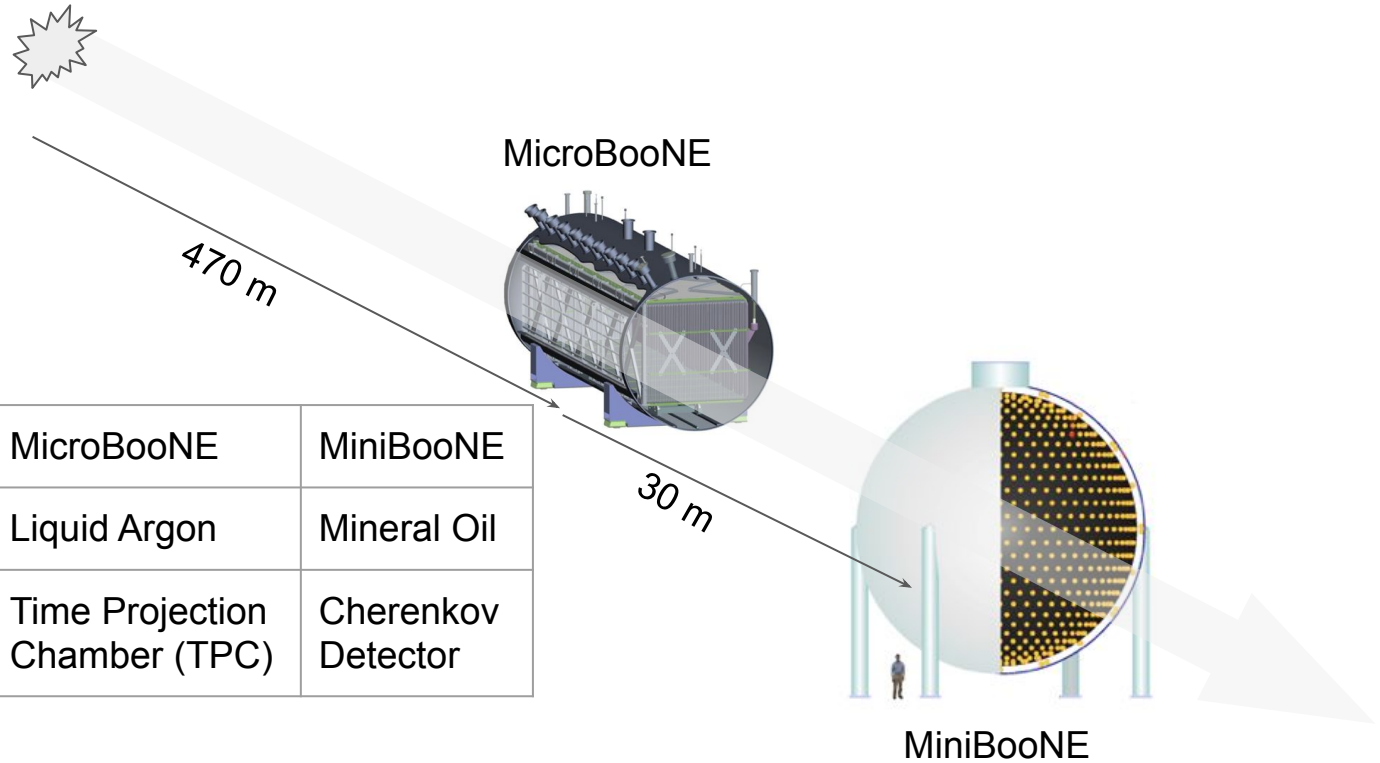
Two purposes:

1. **Reduce dirt** as a background to the MicroBooNE single photon search.

2. **Assess the dirt prediction model** in MicroBooNE through a **dirt-enhanced** sample (a selected sample with high dirt purity with minimal single photon signal events).

MicroBooNE Investigates what MiniBooNE Has Seen

Muon Neutrinos from the Booster Neutrino Beam (**BNB**) at Fermilab



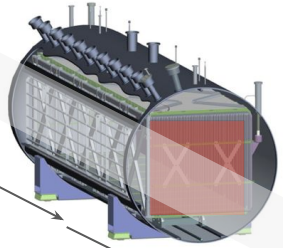
Experiment	MicroBooNE	MiniBooNE
What's inside	Liquid Argon	Mineral Oil
Technique	Time Projection Chamber (TPC)	Cherenkov Detector

MicroBooNE Investigates what MiniBooNE Has Seen

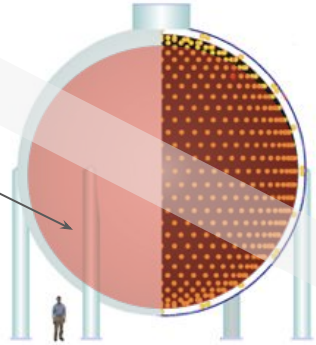
Muon Neutrinos Source

470 m

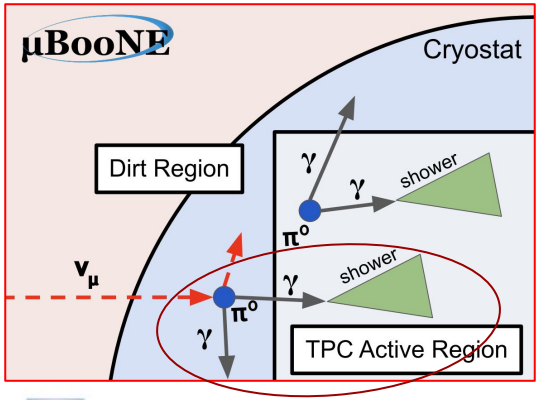
MicroBooNE



30 m



MiniBooNE



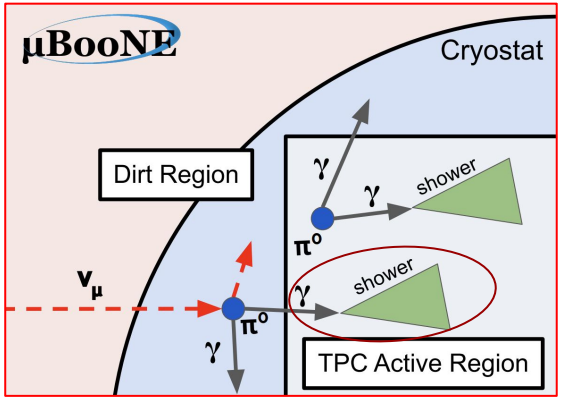
This dirt looks like a single photon signal event.

Dirt are events that

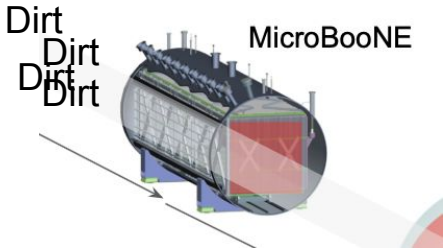
- **originate outside** the active detector (labeled in red),
- but produce a **detectable state inside**.

Features of Dirt

- Dirt backgrounds are usually with reconstructed objects (as tracks or showers, identified by MicroBooNE) **close to the boundary** and **pointing toward the center** of the detector.



- They are **mostly generated upstream** of the detector in the Booster Neutrino Beam (BNB).



Features of Dirt

MicroBooNE single photon simulation overlays with some off-beam data to reflect the reality of the detection, so the identified dirt backgrounds could be:

- **truly simulated**;
- or coming from **the overlay part** of the sample.

A spoiler (the detailed composition will be shown in the end of this talk):

- Dirt are not just **pions**,
- they could also be **Cosmic overlay events**;
- or beam-induced **Michel electrons** (with energy less than O(10) MeV);
- and some others..

Goal: Obtain and Inspect a Dirt-enhanced Sample

- Develop topological/calorimetric variables targeting dirt backgrounds;
- Use 1D/2D-histograms to determine **optimal selection cuts** to select dirt backgrounds, i.e. a dirt-enhanced sample.

- Assess the dirt prediction by checking dirt-enhanced Monte Carlo (MC) prediction against **an open partial data set** and look for **data-MC agreement**.
    - The data-MC agreement will provide confidence that MicroBooNE has the proper prediction on dirt backgrounds.

Obtaining a Dirt-enhanced Sample

Focus on the comparison of two samples:

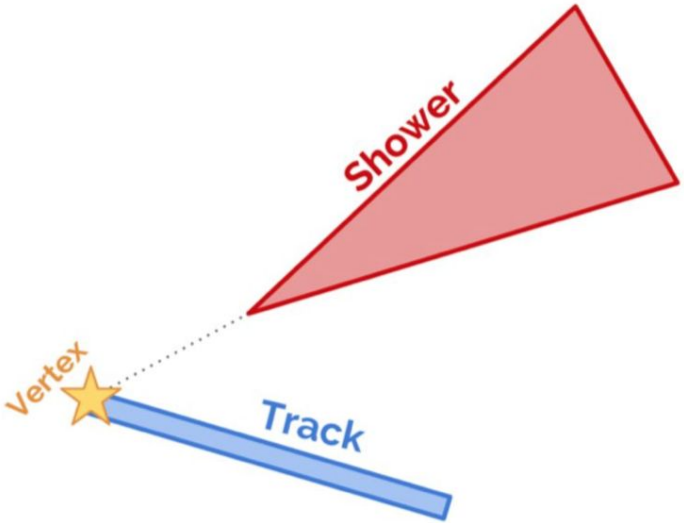
- the generated **dirt sample**;
- the generated **NC delta radiative sample** (single photon signal events);

Use histograms constructed with:

1. Topological variables
    a. Geometry and kinematics
    b. Inner products with **specially-designed directional vectors**
2. Calorimetric variables (reconstructed energy)

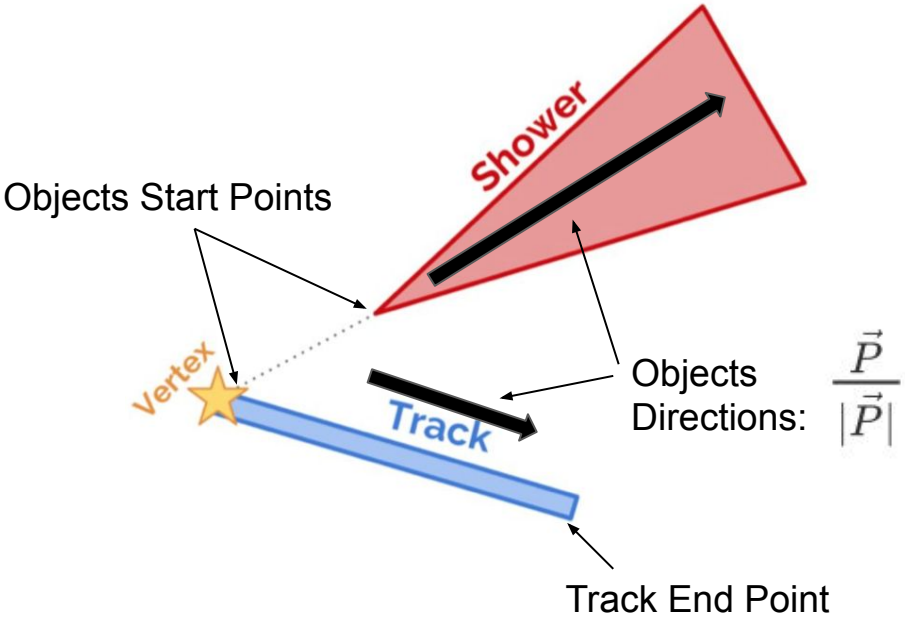
Obtaining a Dirt-enhanced Sample

1. Topological variables
    a. Geometry and kinematics



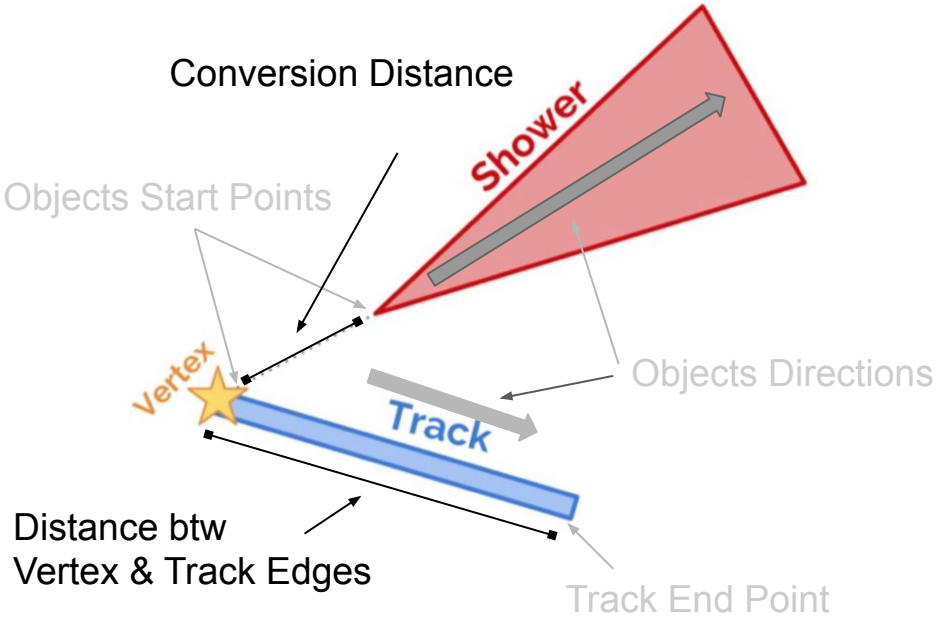
Obtaining a Dirt-enhanced Sample

1. Topological variables
   a. Geometry and kinematics



Obtaining a Dirt-enhanced Sample

1. Topological variables
   a. Geometry and kinematics



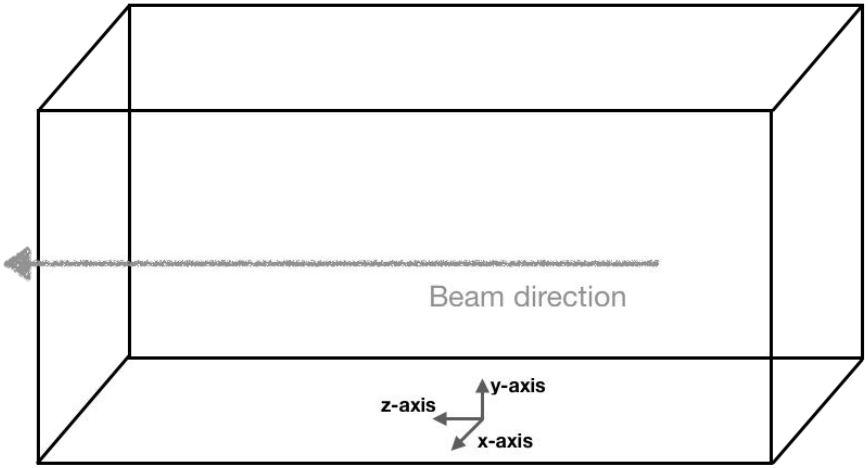


Figure of the MicroBooNE active detector

Obtaining a Dirt-enhanced Sample

1. Topological variables
   a. Geometry and kinematics
   b. **Inner products** with specially-designed directional vectors:

VX: Vector parallel to **x-axis**
(pointing at the central yz plane)

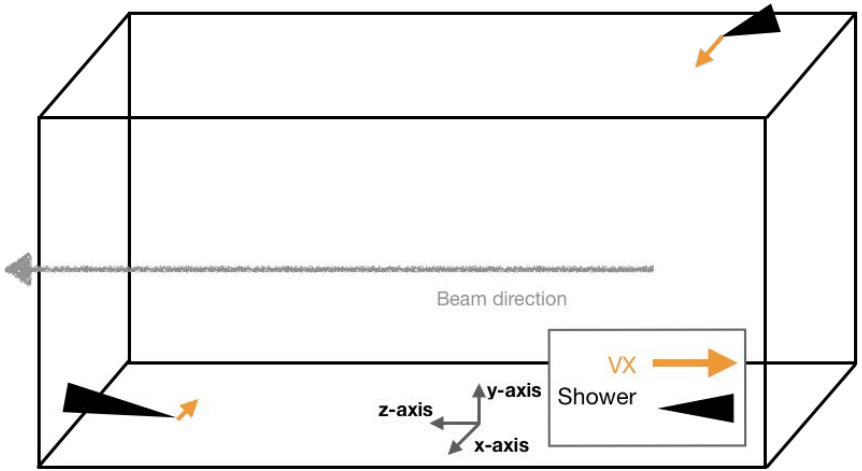


Figure of the MicroBooNE active detector
(an example of two scenarios of a single shower)

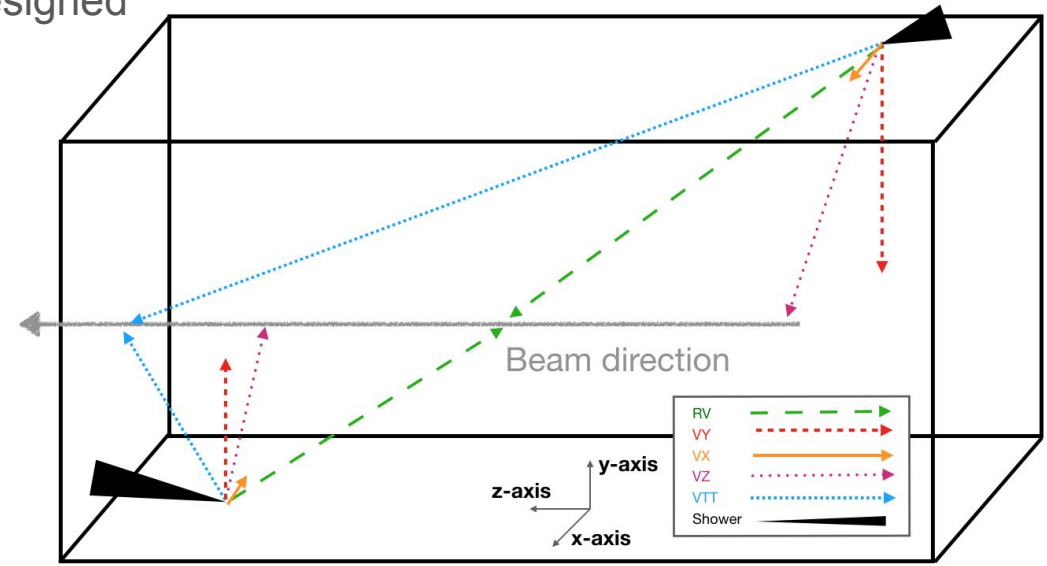
An inner product of an **object's direction** (shower/track) and a **designed vector** compress an object's <u>position</u> and <u>direction</u> into an one dimensional variable.

(These characterize dirt backgrounds' features.)

Obtaining a Dirt-enhanced Sample

1. Topological variables
   a. Geometry and kinematics
   b. **Inner products** with specially-designed directional vectors:

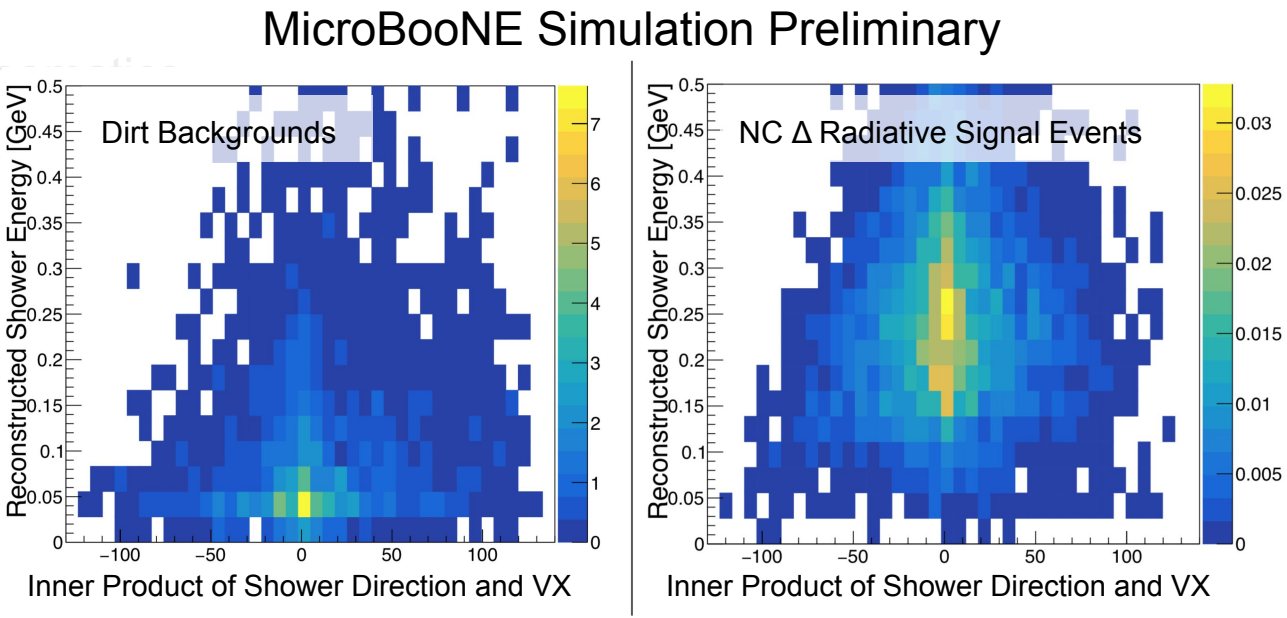
More **designed directional vectors** pointing at different spots of the detector are useful!



*See backup slides and the public note.

Obtaining a Dirt-enhanced Sample

1. Topological variables
   - Geometry and kin
   - **Inner products** wit
   directional vectors
2. **Calorimetric** variables:
   - Shower energy
   - Track energy



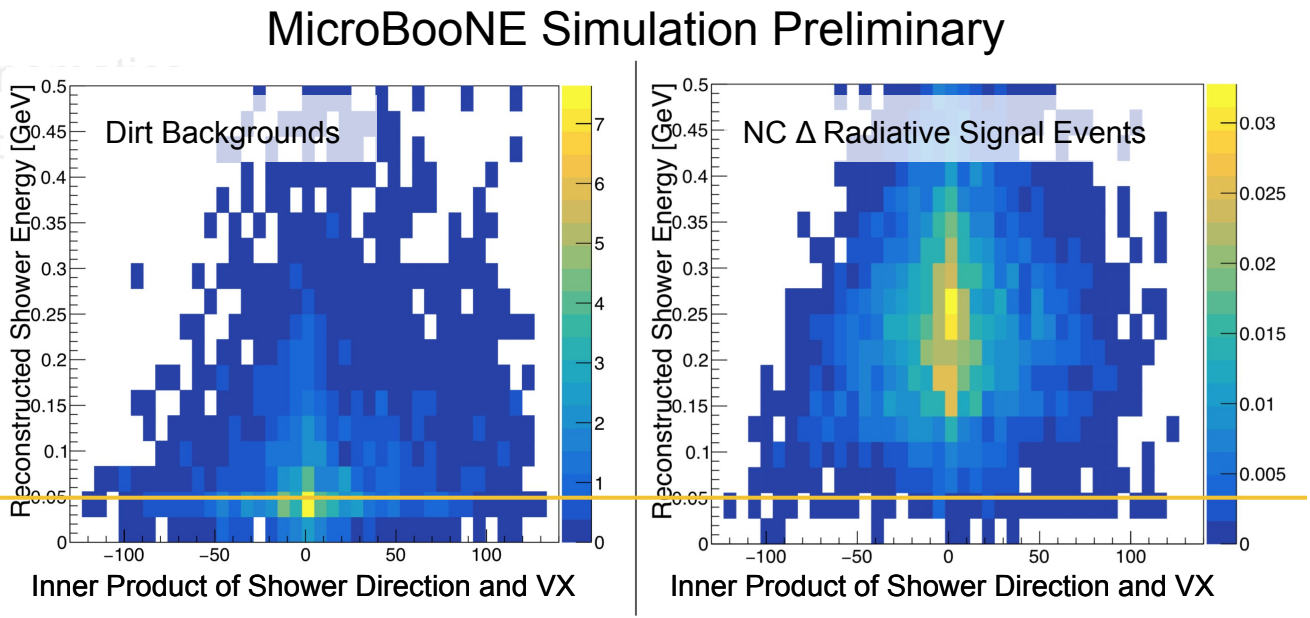
x-axis: $\frac{\vec{P}_{\text{Shower}}}{|\vec{P}_{\text{Shower}}|} \cdot \overrightarrow{VX}$

Obtaining a Dirt-enhanced Sample

1. Topological variables
   - Geometry and kin
   - **Inner products** wit
     directional vectors
2. **Calorimetric** variables:
   - Shower energy
   - Track energy

Signal-enhanced

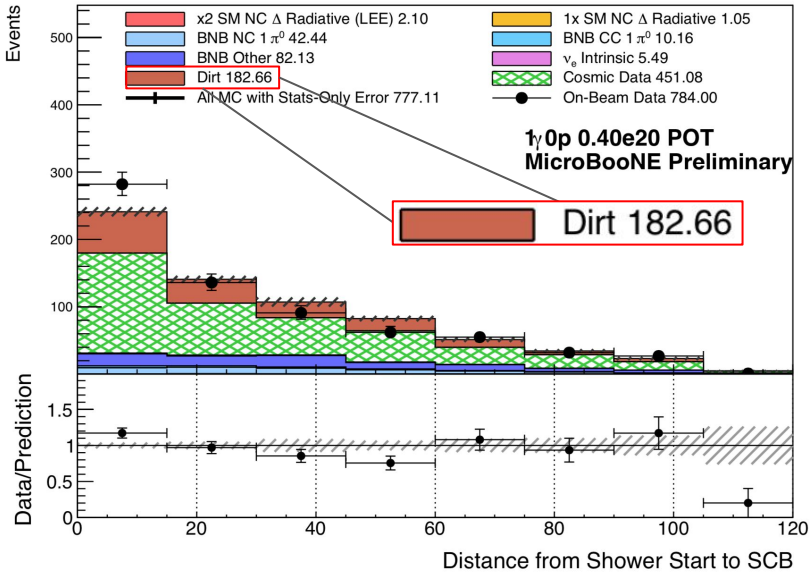
Dirt-enhanced



Optimal selection cuts are determined through comparing many histograms.

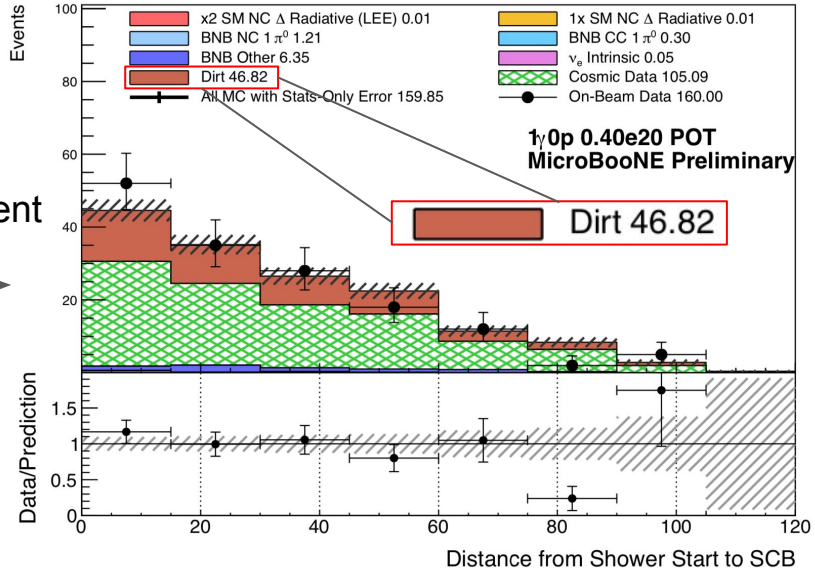
Inspect a Dirt-enhanced Sample:

1γ0p (only one photon shower reconstructed)



(Data/MC: 1.01) (KS: 0.038) (χ^2/n*DOF*: 15.68/8) (χ^2 P^{val}: 0.047)

Dirt Enhancement



(Data/MC: 1.00) (KS: 0.810) (χ^2/n*DOF*: 7.57/8) (χ^2 P^{val}: 0.476)

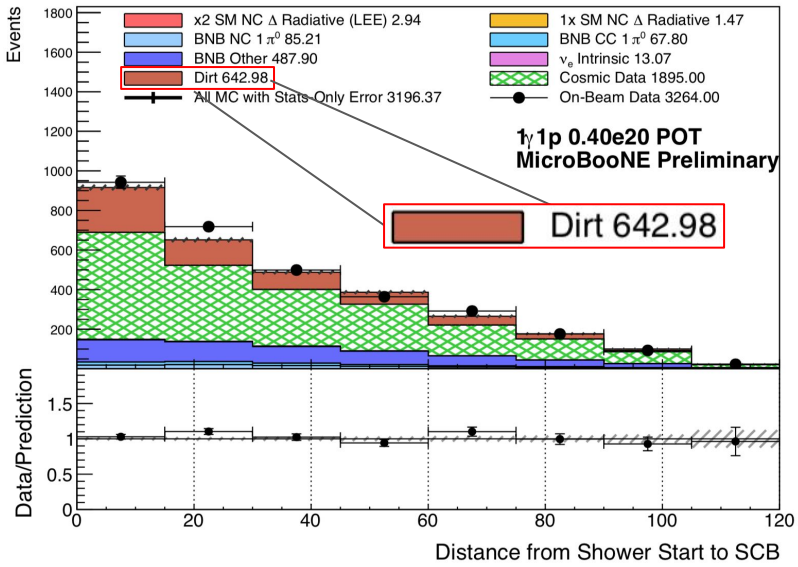
Dirt purity: 56% ----> **85.4%**, with good data-MC agreement.
(Note that here ONLY include statistical errors, no ~~systematics~~.)

*SCB: Space Charge Boundary, close to the detector boundary.

*Purity calculation excludes Cosmic Data.

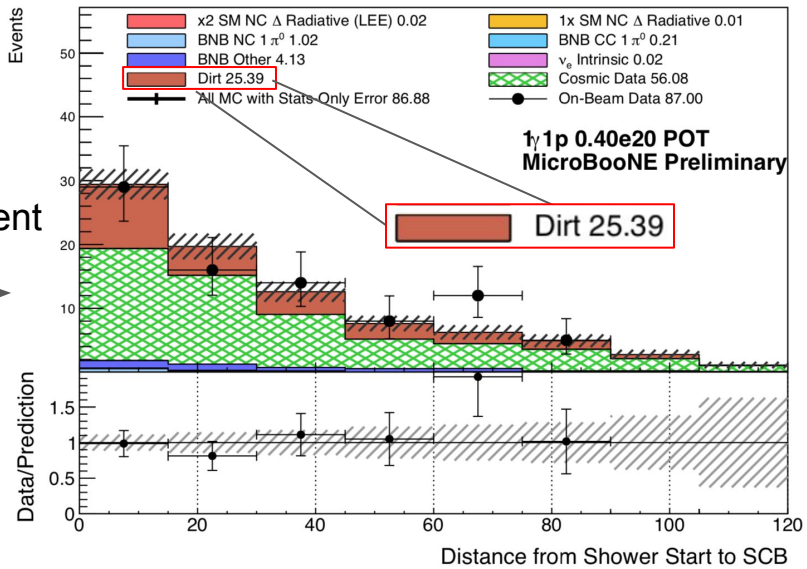
Inspect a Dirt-enhanced Sample:

1γ1p (one photon shower and one proton track reconstructed)



(Data/MC: 1.02) (KS: 0.734) (χ^2/n*DOF*: 10.43/8) (χ^2 P^{val}: 0.236)

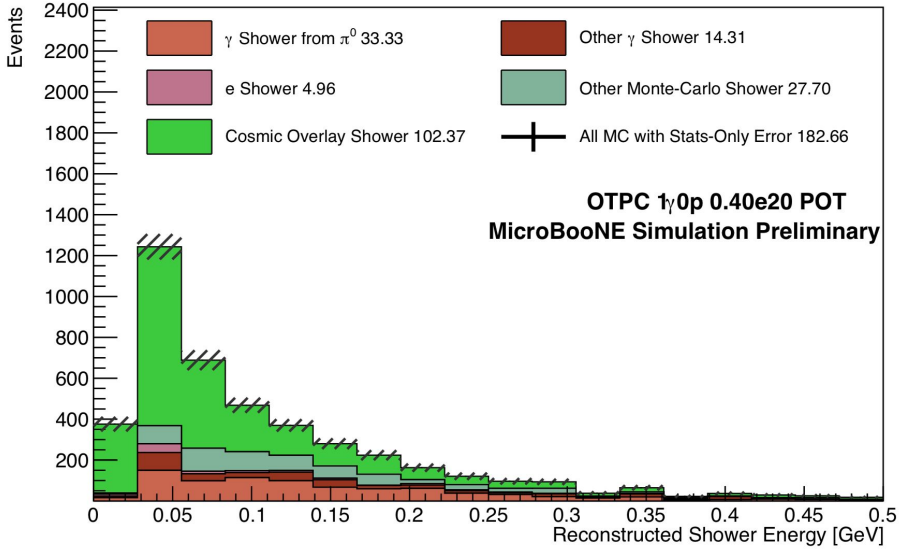
Dirt Enhancement

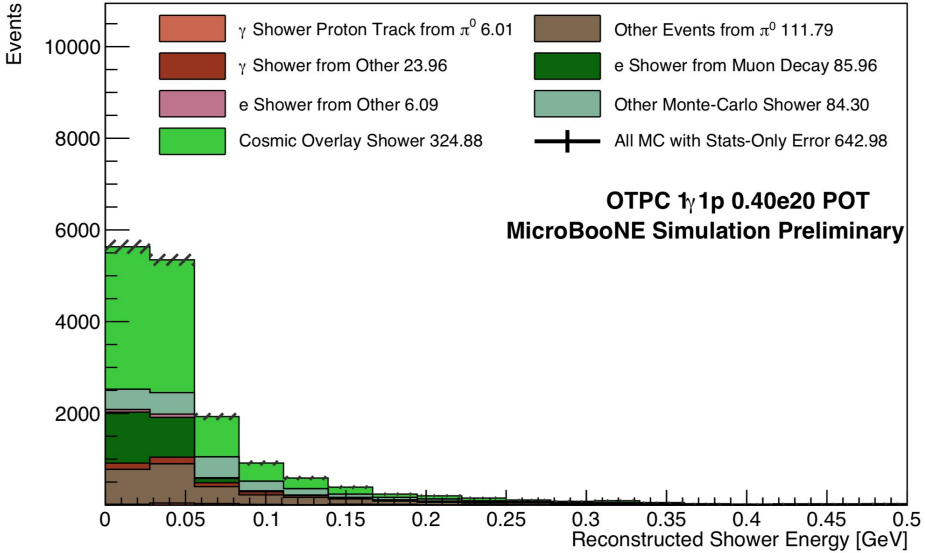


(Data/MC: 1.00) (KS: 0.998) (χ^2/n*DOF*: 8.39/8) (χ^2 P^{val}: 0.397)

Dirt purity: 49.5% ----> **82.4%**, with good data-MC agreement.
(Note that here ONLY include statistical errors, no ~~systematics~~.)

Origin of the Dirt Backgrounds





Data-MC agreement provides confidence that **dirt backgrounds are properly predicted**:

1. **Overlay** events are the majority.
2. **Michel electrons** are identified with low energy.
3. **Pions** span through the spectra.
   (They are the bottom bins.)

Summary

MicroBooNE investigates the MiniBooNE observed Low Energy Excess (LEE), searching for NC $\Delta \rightarrow N\gamma$ as one of the interpretations of the LEE (K. Sutton has introduced the most recent result at NP Jul. 2020).

This presentation has introduced effective methods for dirt backgrounds constraint/selection, which allow MicroBooNE to select dirt backgrounds in the single photon samples with **> 80% purity**.

The data-MC agreement are observed in the dirt-enhanced sample, providing confidence that the MicroBooNE Monte Carlo simulation has **properly predicted dirt backgrounds**.

Thanks!!

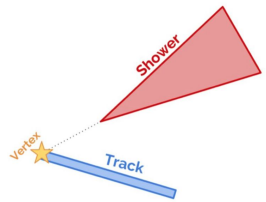
Find more detail in the supporting public note:

MICROBOONE-NOTE-1087-PUB

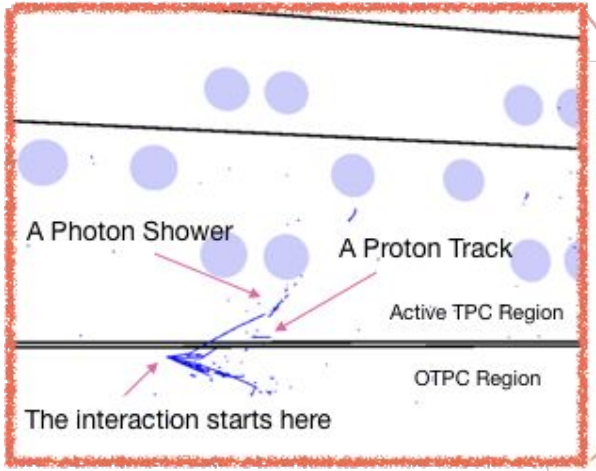
Backup Slides

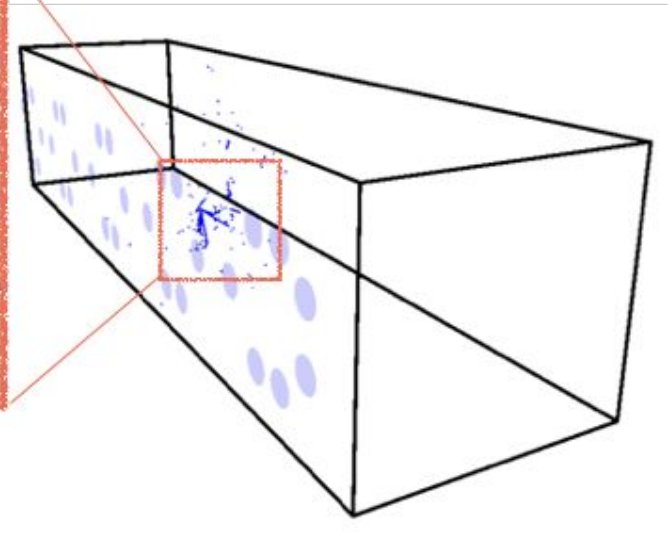
- Example of a Dirt Monte Carlo Event
- Single Photon Selection Results
- More about Designed Directional Vectors

Example of a Dirt Monte Carlo Event:



A reconstructed shower & a reconstructed track



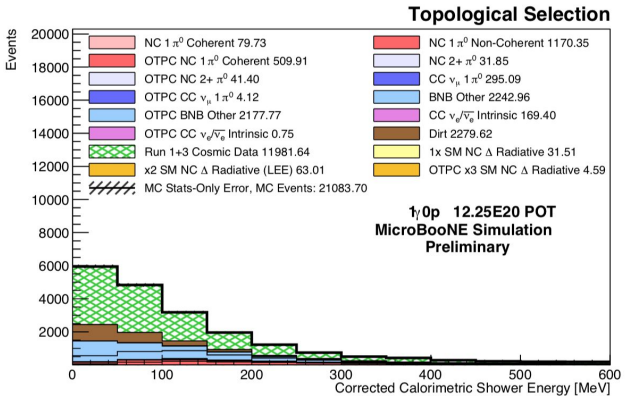


*__OTPC__: Outside of the active TPC

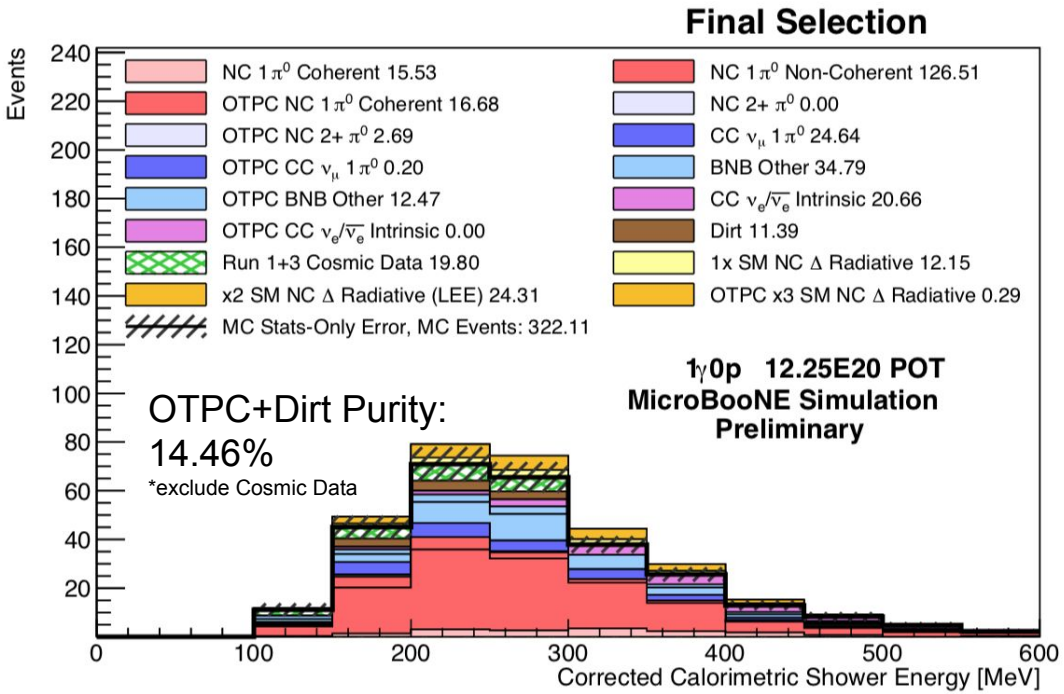
- The blue lines label the dirt Monte Carlo event, which is partially reconstructed as a shower and a track.
- This event (with photon shower) looks like our **single photon signal events.**

$1\gamma 0p$ Selection Before Dirt Removal

* OTPC: Events generated out of the active TPC; they satisfy the dirt definition.

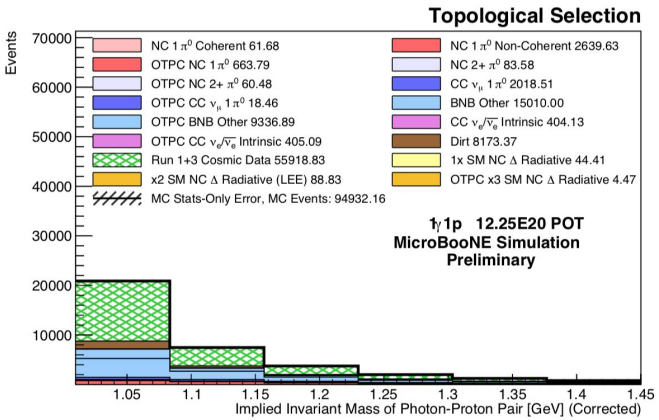


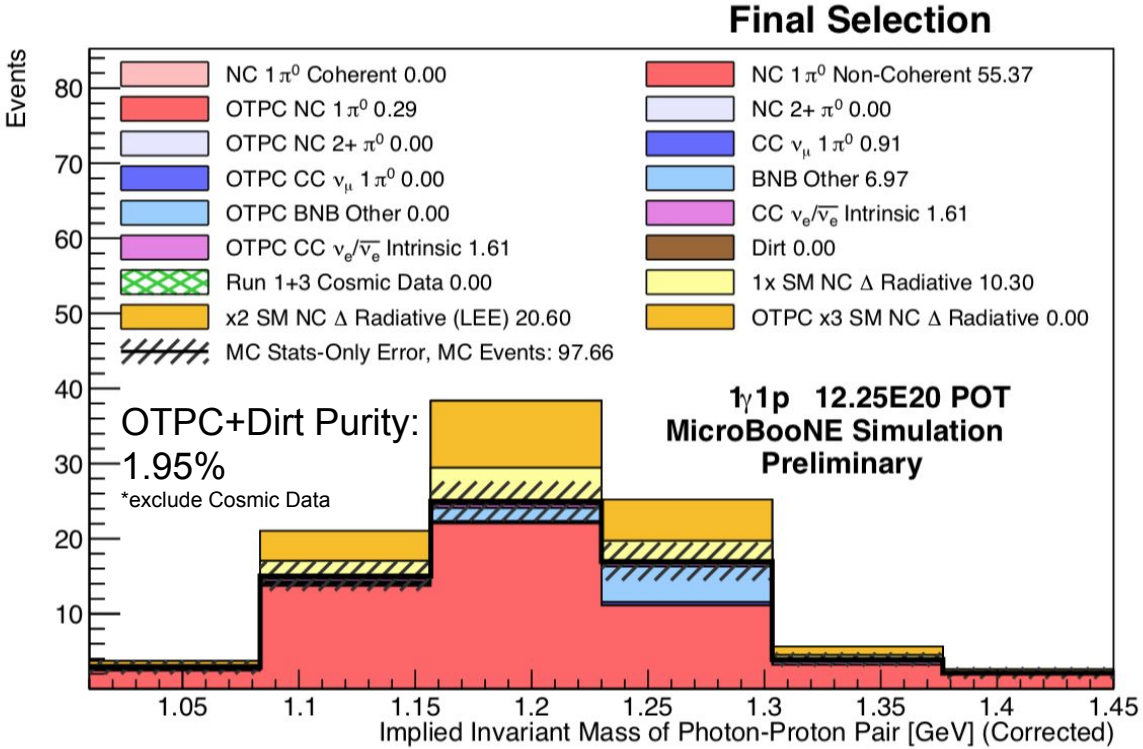
Our default BDT (Boosted Decision Tree) selection can properly handle the Dirt Backgrounds as background such that not much of them survive the final selection.



*Note that OTPC+dirt here is equivalent to the dirt discussed previously.

$1\gamma 1p$ Selection Before Dirt Removal





Our default BDT (Boosted Decision Tree) selection can properly handle the Dirt Backgrounds as background such that not much of them survive the final selection.

More about Designed Directional Vectors

Inner products with:

A. Radial vector pointing to the **center** of TPC. (RV)

B. Vector parallel to **y-axis** (pointing at y=0). (VY)

C. Vector parallel to **x-axis** (pointing at x=128.165cm). (VX)

D. Vector pointing to the **beam center** (parallel to the z-axis). (VZ)

E. Vector pointing to the **Tip of the TPC**. (VTT) (downstream of the BNB)

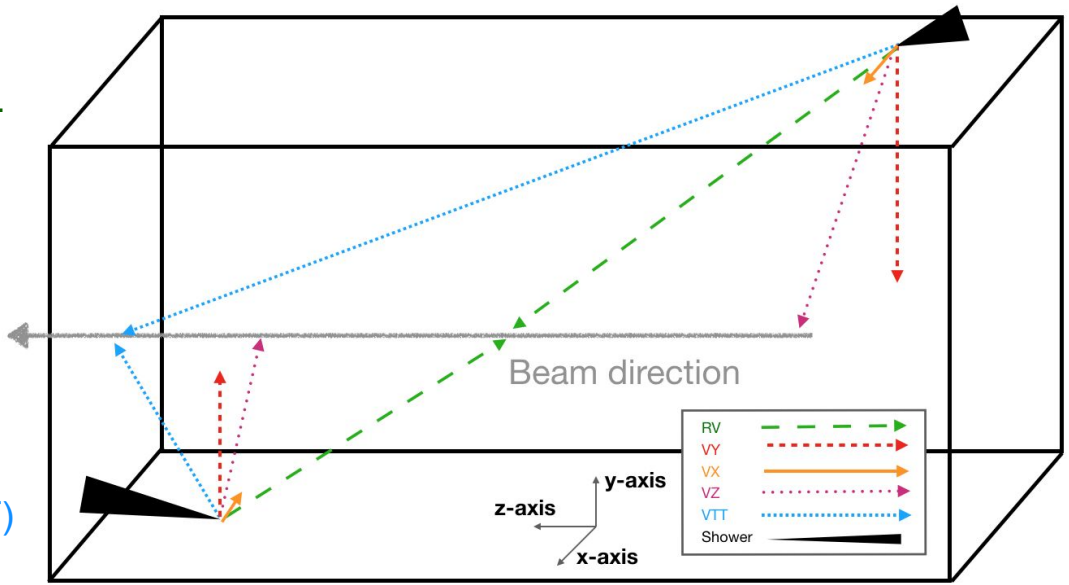


Figure of the MicroBooNE active detector