DEEP UNDERGROUND NEUTRINO EXPERIMENT

BROOKHAVEN NATIONAL LABORATORY

CRT studies: upstream CRTs in-line

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Outline

- ⇒ The Space Charge Effect (SCE) is the build-up of slow-moving positive ions in a detector, leading to a distortion of the electric field within the detector
- ⇒ It is anticipated that the space charge distortions in ProtoDUNE maybe as large as 20 cm
- ⇒ As a part of a plan to produce a MC-based demonstration of the space charge calibration, reconstructed TPC tracks need to be matched to Cosmic Ray Tagger (CRT) hits
- ⇒ However, matching is not trivial:
  - Only cosmics that fall within the readout window will be reconstructed
  - We will not know their true time; and hence the true position in the drift direction x

Method

- ⇒ Performs matching using CRT hit position and time (x, y, z, t)
- ⇒ Matching is done with
  - **Front or Back CRT**
  - **Front and Back CRT**

Cosmic Ray Tagger (CRT)

Toy model CRTs used in this study covers the active TPC volume in :

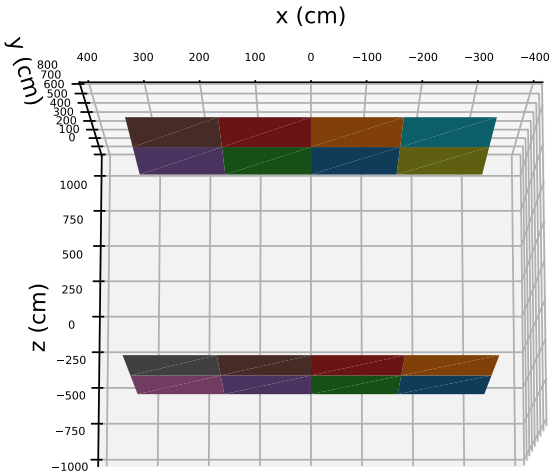
⇒ -340 cm $< x <$ 340 cm and 0 cm $< y <$680 cm

⇒ $z = 1000$ cm: $\sim$**1 m downstream** from the cryostat

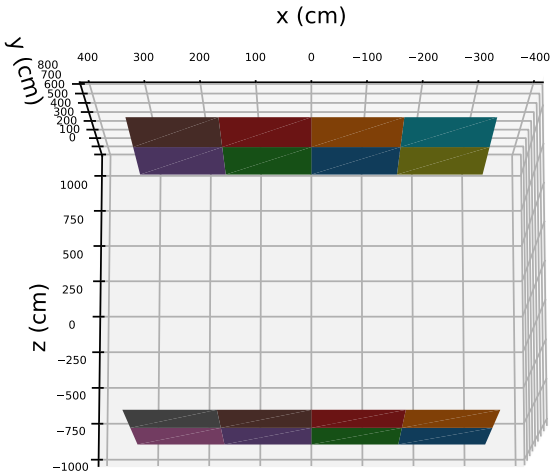
⇒ **Default in-line**: Both Jura side and Saleve side at $\sim$**3.5 m upstream** from the cryostat **or**

⇒ **New in-line**: Both Jura side and Saleve side at $\sim$**7 m upstream** from the cryostat

Default in-line



New in-line



⇒ This study is performed with MCC-10: 4 GeV beam (which includes muon halo) + Cosmics

⇒ In this study, we are interested in the rate and coverage of the matched tracks for two different CRT configuration: **Default and new in-line upstream positions**. We will look at these quantities separated for cosmics and muon halo and for matching done with both **Front or Back** and **Front and Back** CRTs.

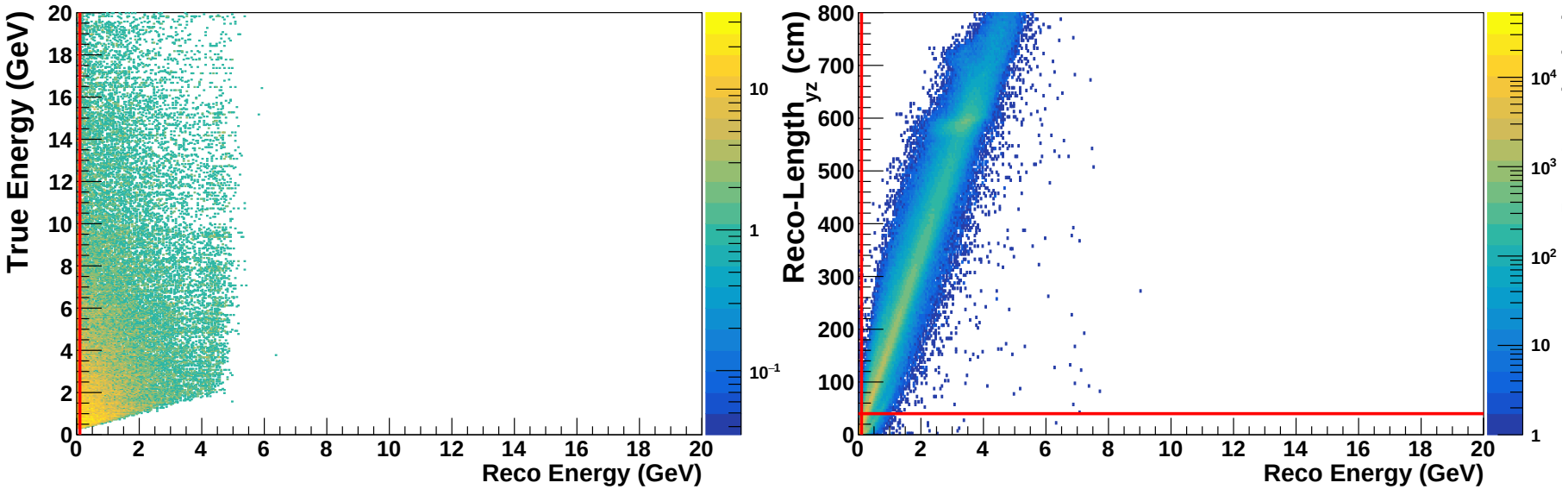
Cosmic Ray Tagger (CRT)

CRT hits are dummied up from truth information and are defined as:

- ⇒ Intersection point between any of the CRT plane and primary muon in the readout window; CRT hit time is primary muon T at the intersection point
- ⇒ Each of two dimensions within the CRT plane is individually smeared by a random uniform distribution on the interval ± 2.5 cm (expected CRT position resolution)
- ⇒ CRT hit time is smeared by a random uniform distribution on the interval ± 16 ns (expected CRT timing resolution as each module is expected to require a 62.5 MHz clock)

Reconstructed tracks

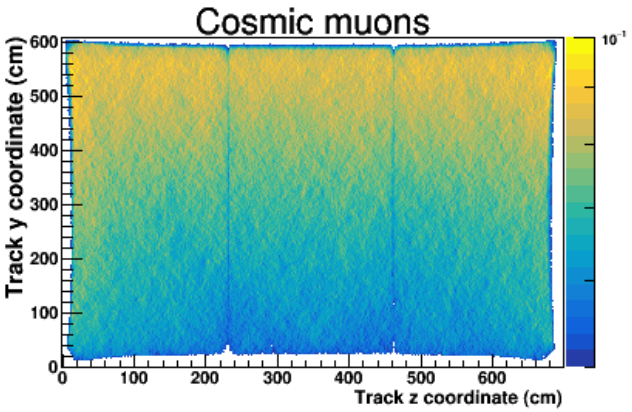
- ⇒ Using **pmtrack Module** to access reconstructed tracks
- ⇒ **Energy** deposited by the track is calculated by summing energy from hits associated with the track
- ⇒ **TrackID** of the track is assigned same as the Geant4 supplied TrackID of the particle contributing the maximum energy

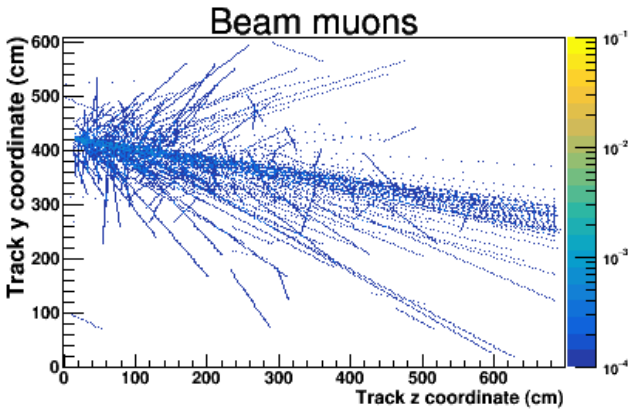


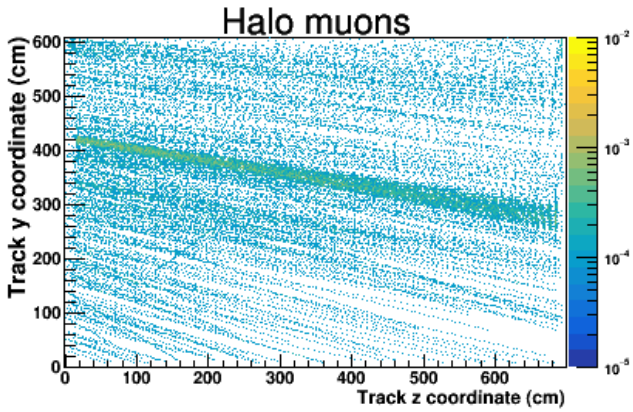
Track selection

- ⇒ Track-Energy > 0.1 GeV (loose cuts as we don't know true track energy)
- ⇒ Track-Length$_{yz} > 40$ cm (as we will work first on the y-z plane, this is needed to ensure reasonable track selection)

Reconstructed tracks





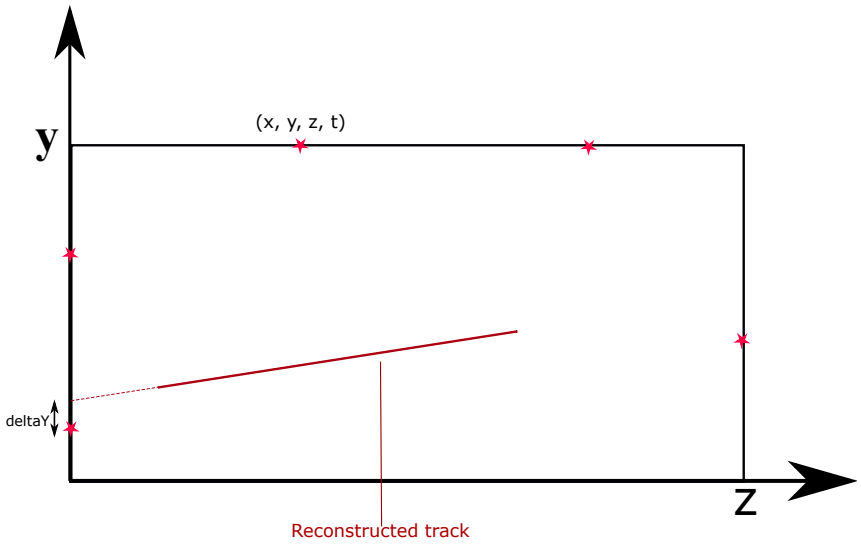


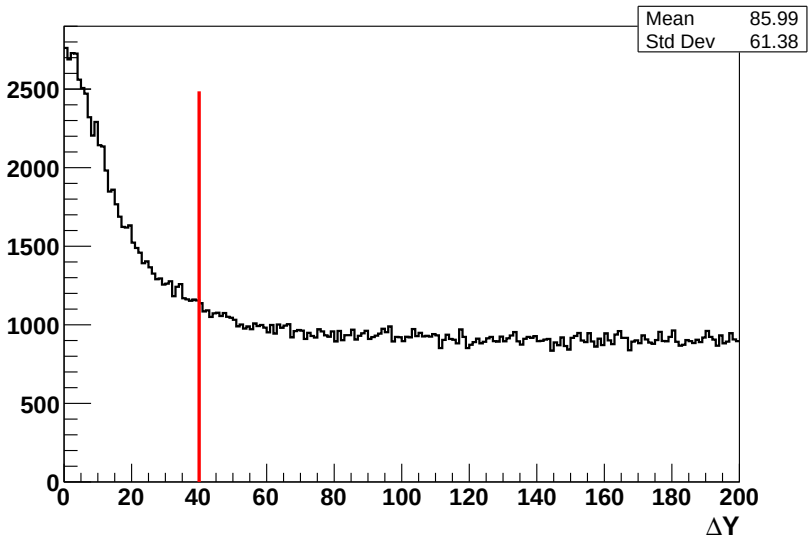
- ⇒ Using BackTracker to check the origin of reconstructed tracks
- ⇒ Plots are normalized by the total number of events
- ⇒ On average, 63.2 reconstructed tracks per event; out of which, 61.5 (∼97%) are from cosmic muons, 0.04 are from beam muons and 0.1 from halo muons
- ⇒ **Note**: Sometimes muon which is not exactly **muon halo** but the **muon beam particle** can also get tagged as **muon halo**

Matching

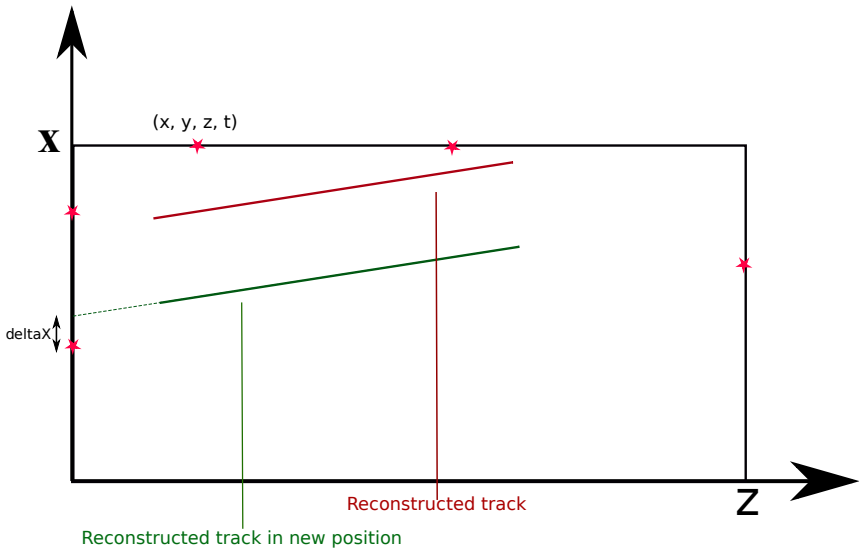
Pair each reco tracks with CRT hit if:

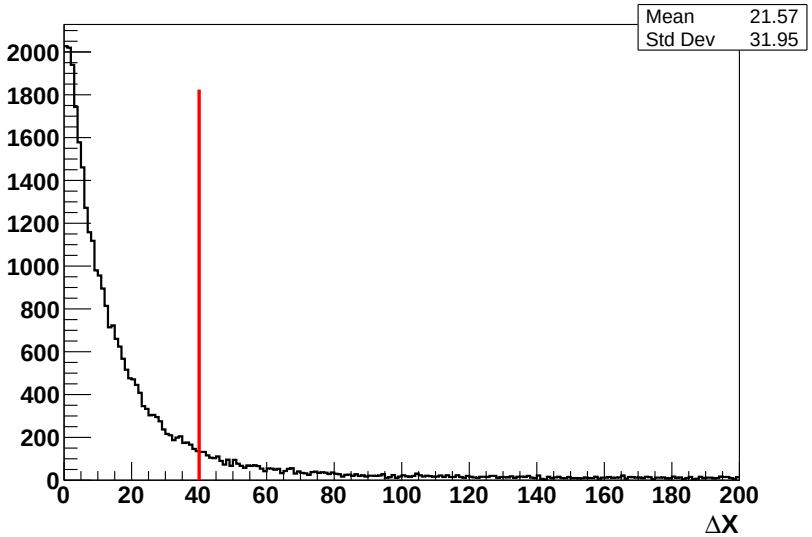
⇒ $|$**predictedHitPositionY - HitPositionY**$| <$ **40 cm**
→ ensures that the reco track and the CRT hit are close in y-direction





- ⇒ Use T_0 from CRT hit to calculate new start and end track position in x
- ⇒ Make sure the new start and end track position (x, y, z) is inside the TPC
- ⇒ Calculate Δ**X** = |**predictedHitPositionX** - **HitPositionX**|



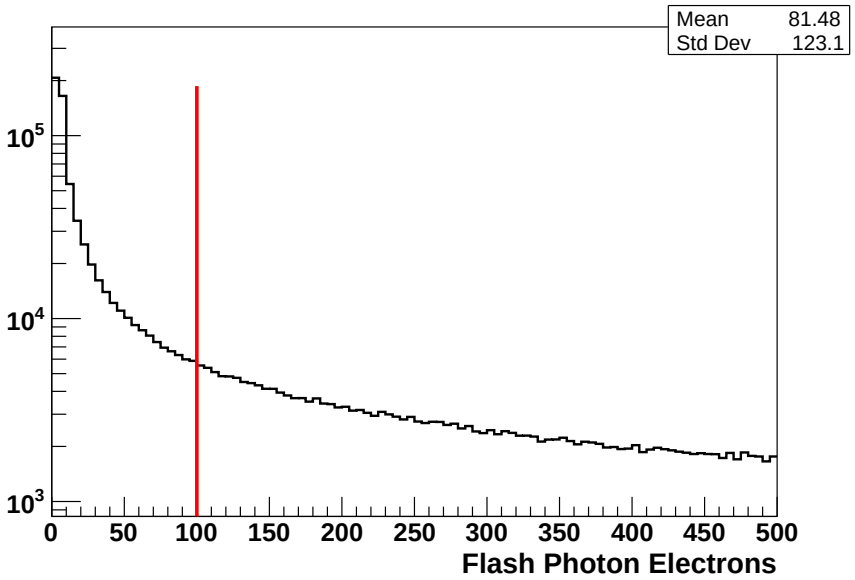


Ensure one-to-one matching:

- ⇒ Give priority to pair with smallest ΔX
- ⇒ Reco track can't be used twice, CRT hit can't be used twice
- ⇒ Only pairs with $\Delta X < 40$ cm are considered to be matched (ensures physically reasonable matching)
- ⇒ Tag tracks that match to both front and back hits- avoid double counting
- ⇒ Keep track if $-0.20 < \Delta T < 0.10$ μs (ΔT is defined in next two slides)

Flash information addition

- ⇒ Using flash information to increase the purity
- ⇒ Using **opflash Module** to access photon signal
- ⇒ **PE**: The amount of light, in units of photo electrons, observed in the hit
- ⇒ How much light we see is a strong function of where we are in the geometry; in practise we expect $\sim$ 1 PE/MeV
- ⇒ **PeakTime**: The time the hit occurred

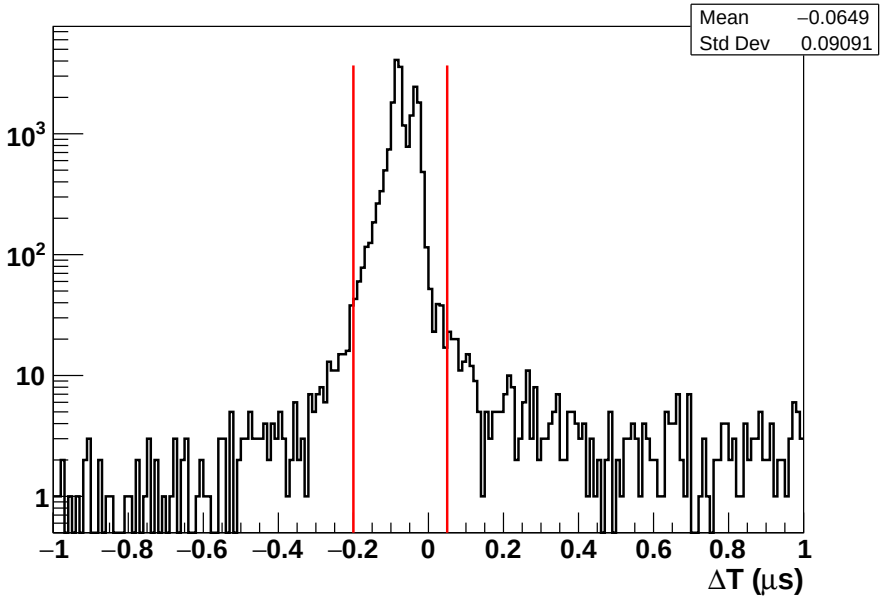


Flash selection

- ⇒ PE $>$ 100

Track-Flash association

⇒ **ΔT**: Minimum (PeakTime - Track T_0)



Track selection

⇒ Keep matched track if -0.20 $<$ ΔT $<$ 0.05 μs

⇒ Currently, there is no one-to-one association; so, a flash can be associated with two or more tracks

Matching Efficiency and Purity

Matching Efficiency

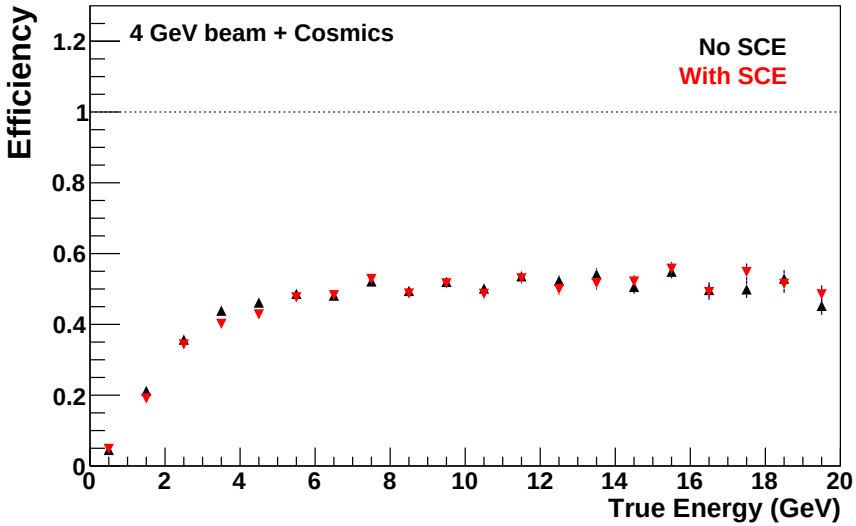
- ⇒ Matching Efficiency = (no. of reco tracks with good match)/(no. of primary muon with one CRT hits (two CRT hits))
- ⇒ Good match means reco track have the same **TrackId** as CRT hit/hits

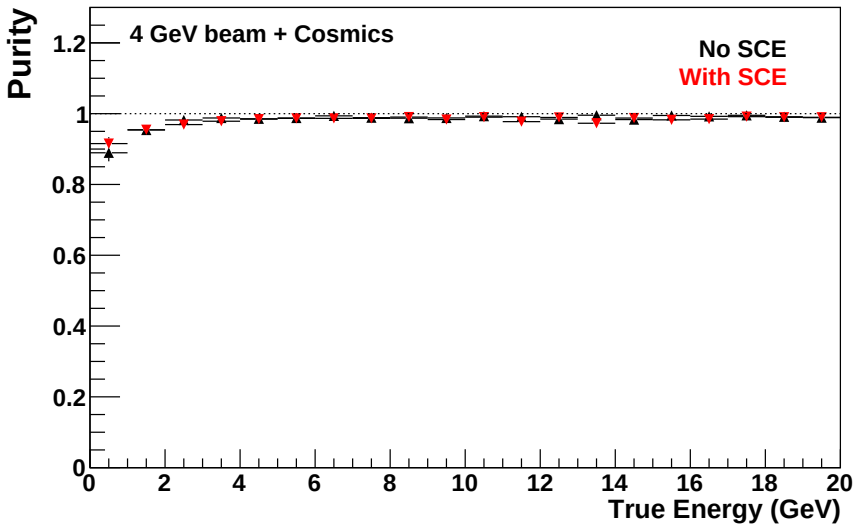
Purity

- ⇒ Purity = (no. of reco tracks with good match)/(no. of reco tracks that match with one CRT hit (two CRT hits))
- ⇒ Good match means reco track have the same **TrackId** as CRT hit/hits

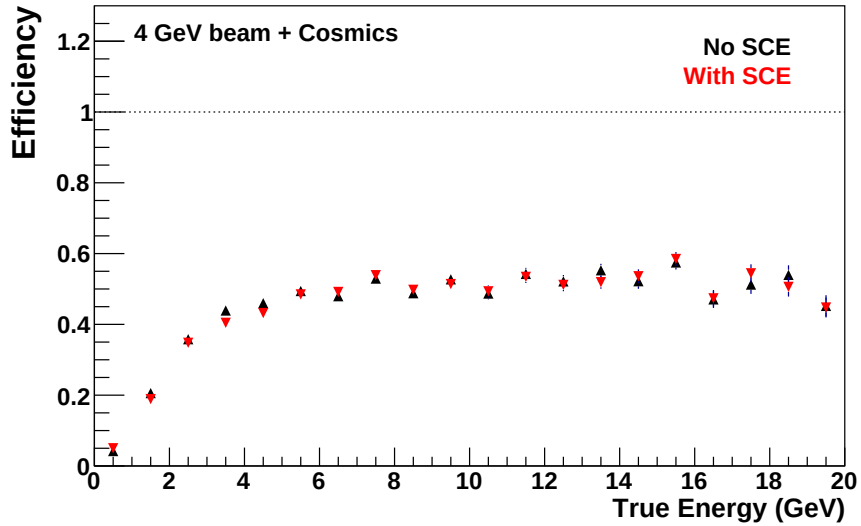
All: Front or Back

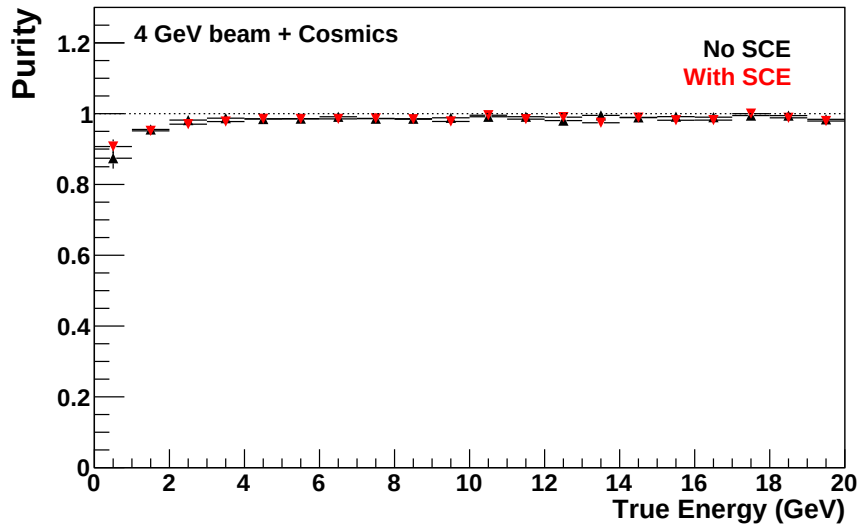
Upstream z = default in-line





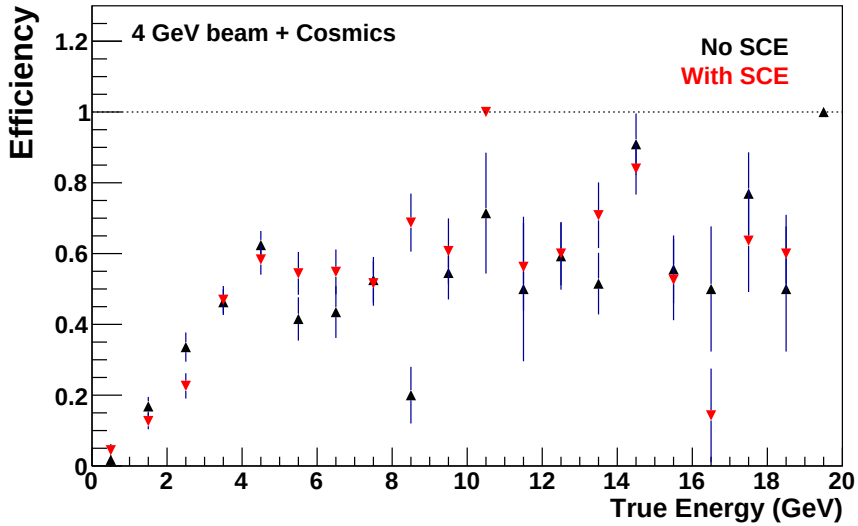
Upstream z = new in-line

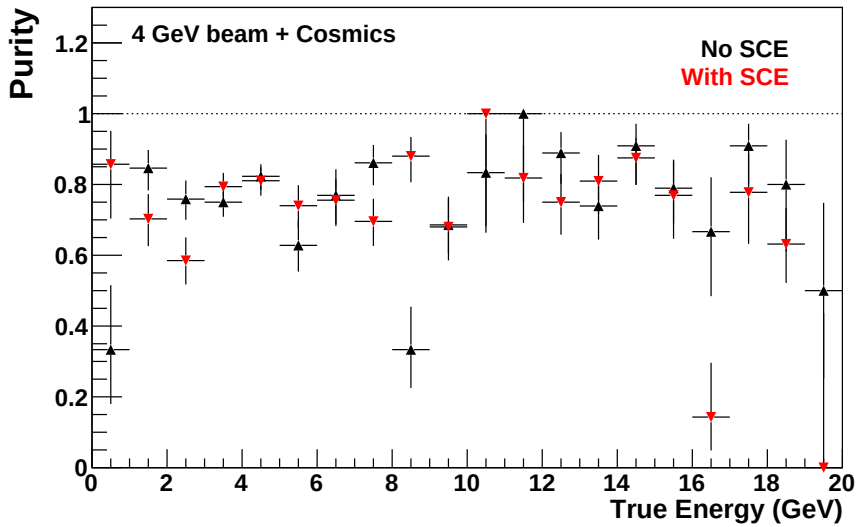




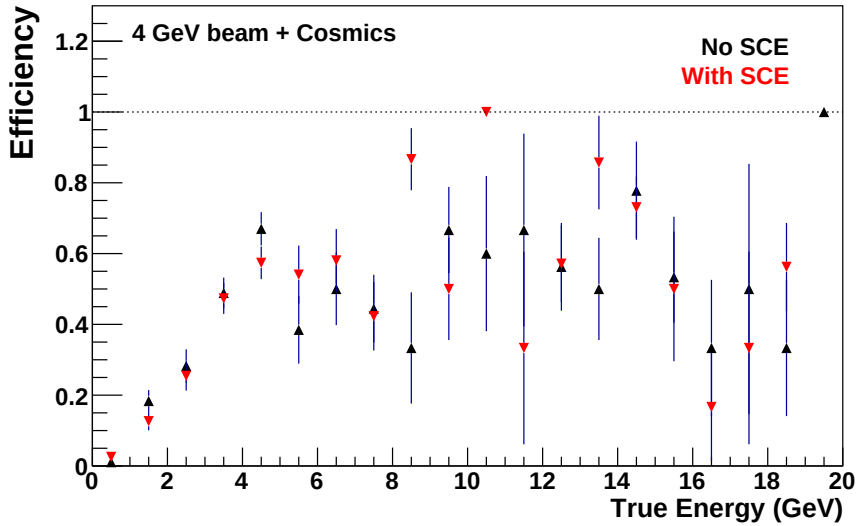
All: Front and Back

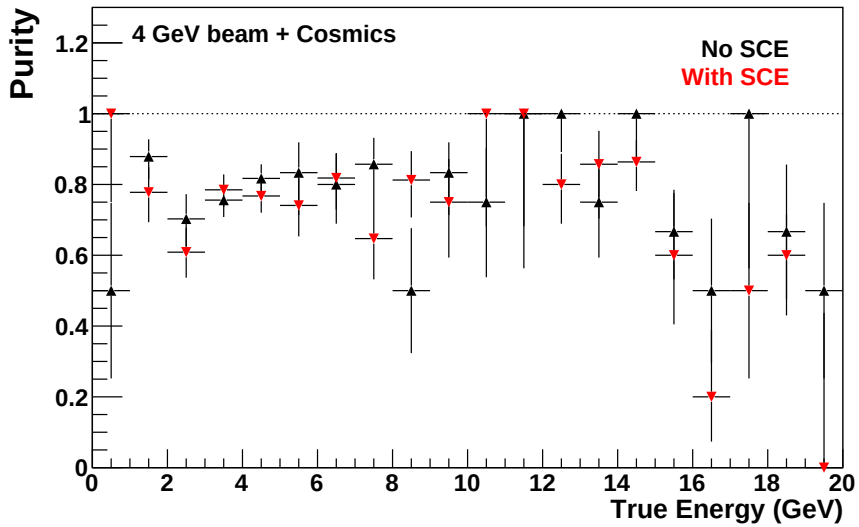
Upstream z = default in-line





Upstream z = new in-line





Front or Back

	No. of matched tracks per event (with SCE)	
	Upstream z = default in-line	**Upstream z = new in-line**
All	2.03	1.68
Cosmics	2.01	1.66 (17% decrease)
Halo	0.015	0.014 (7% decrease)
Beam	negligible	negligible

Front and Back

	No. of matched tracks per event (with SCE)	
	Upstream z = default in-line	**Upstream z = new in-line**
All	0.080	0.046
Cosmics	0.048	0.020 ($\sim$58% decrease)
Halo	0.031	0.026 ($\sim$16% decrease)
Beam	negligible	negligible

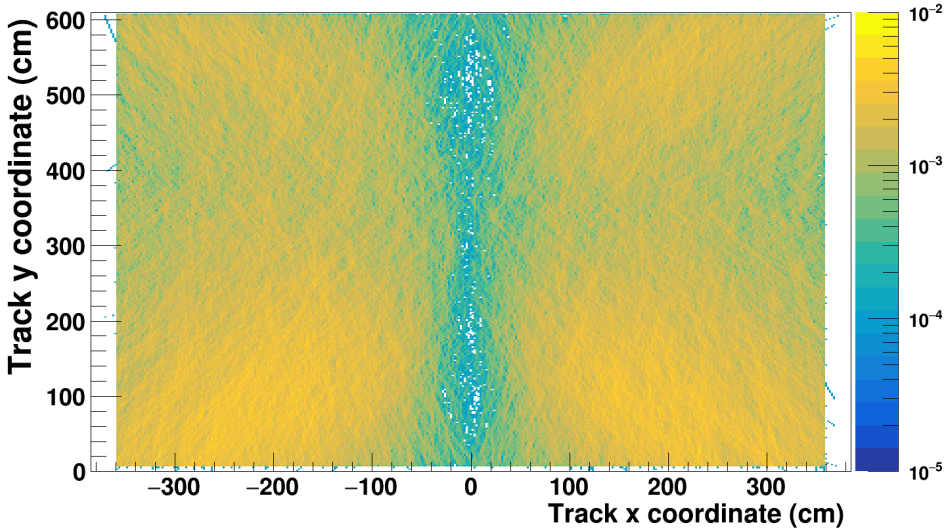
Coverage

Coverage

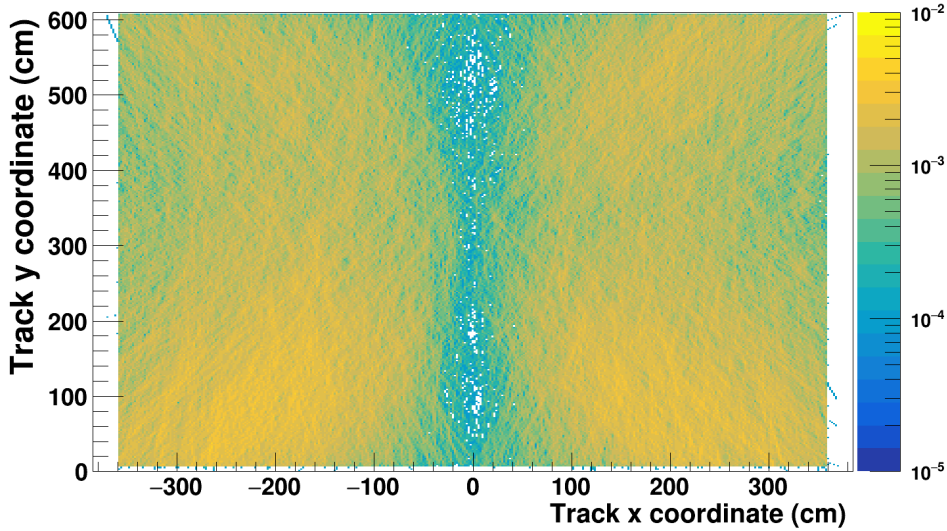
- ⇒ Coverage maps include SCE
- ⇒ Coverage maps show which area of the TPC have the highest concentration of tagged tracks
- ⇒ Plots are normalized by the total number of events
- ⇒ x is the corrected x-coordinate

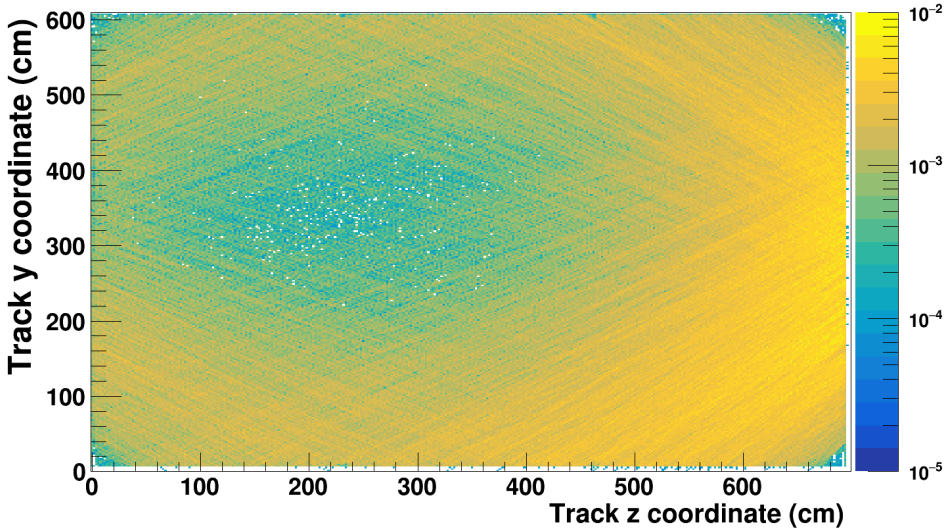
All: Front or Back

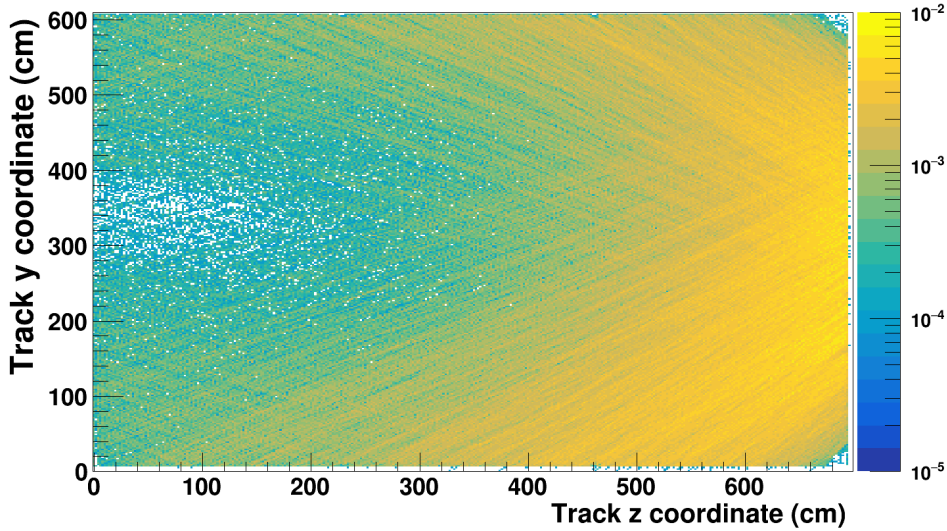
Upstream z = default in-line



Upstream z = new in-line

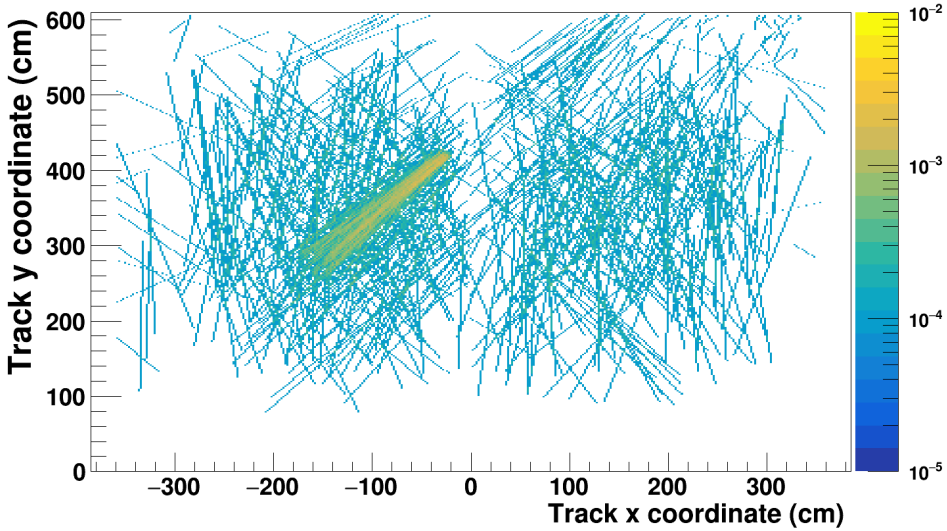




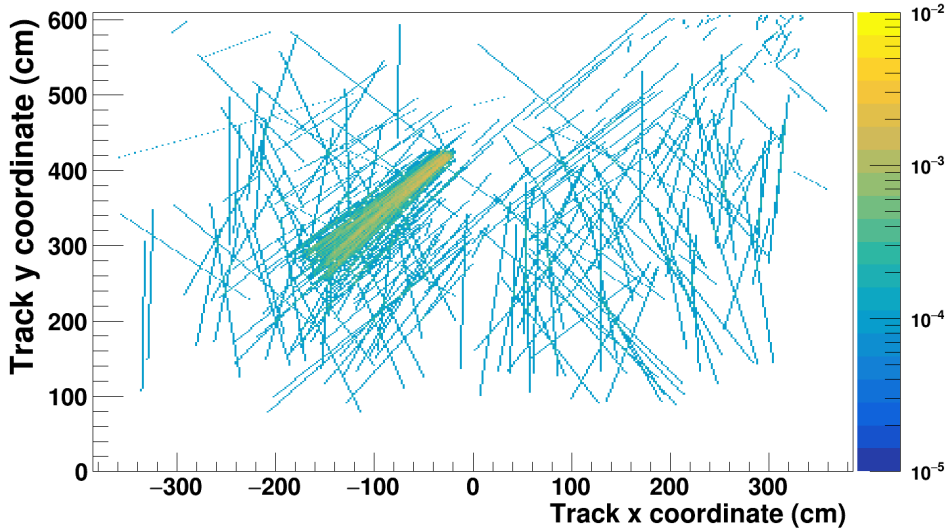


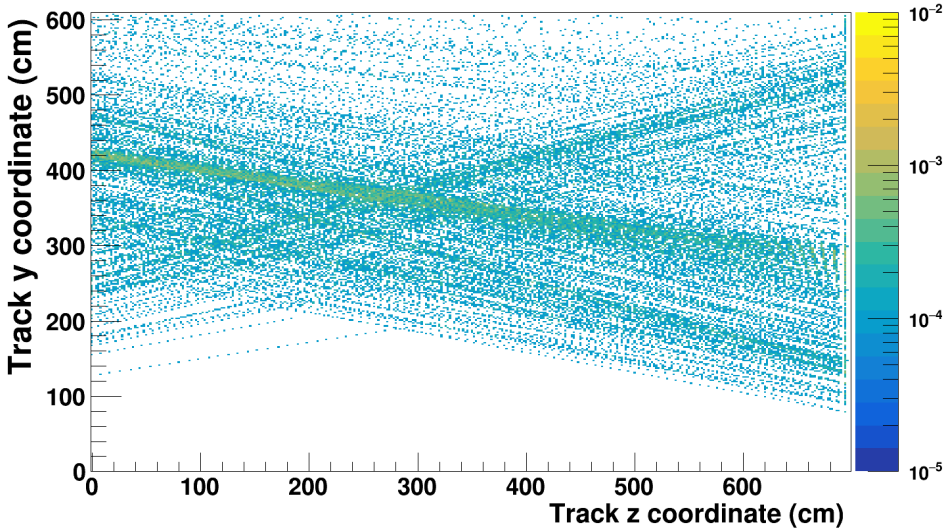
All: Front and Back

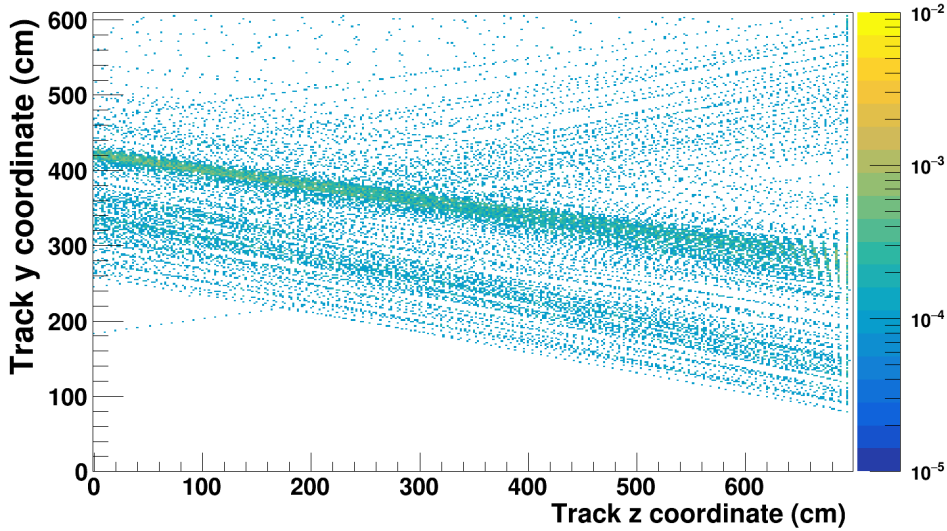
Upstream z = default in-line



Upstream z = new in-line

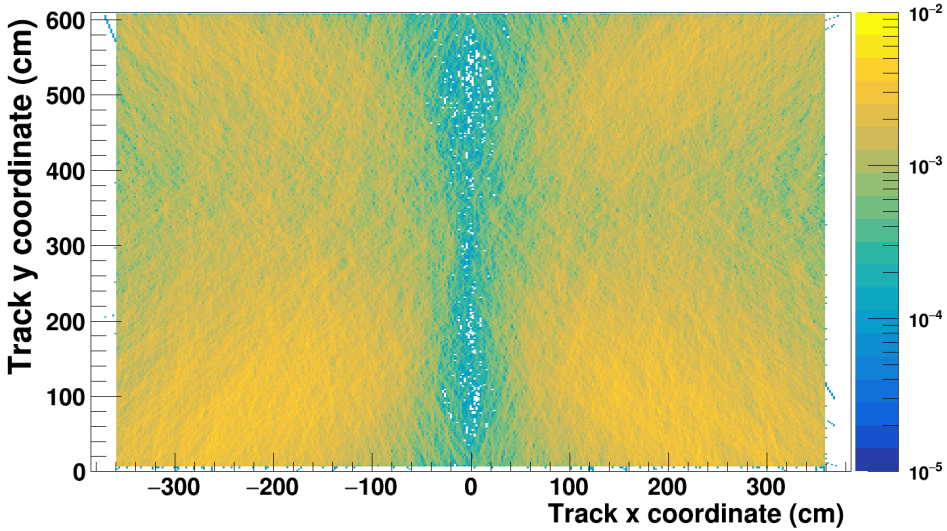




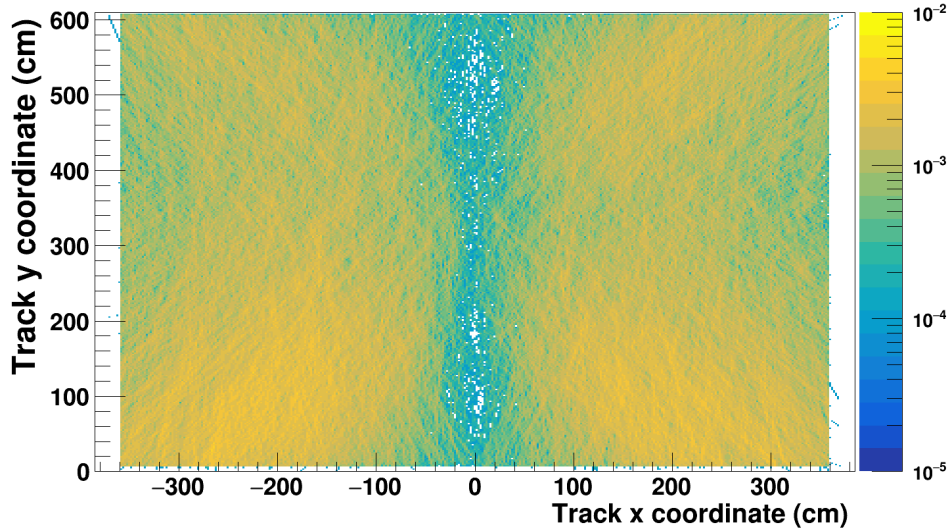


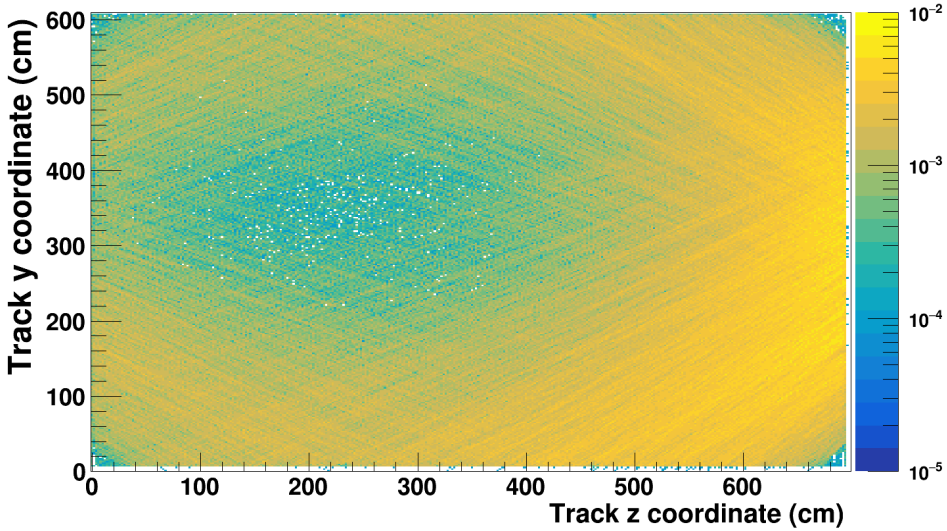
Cosmics: Front or Back

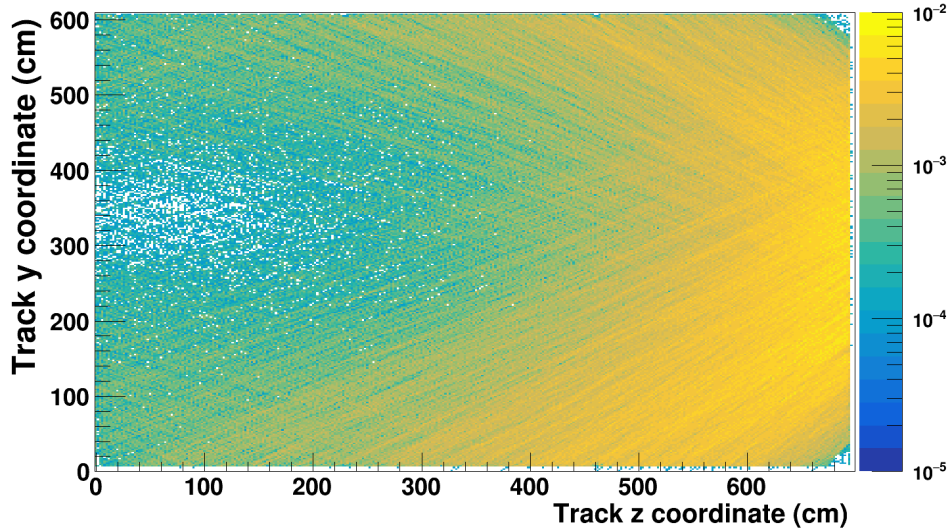
Upstream z = default in-line



Upstream z = new in-line

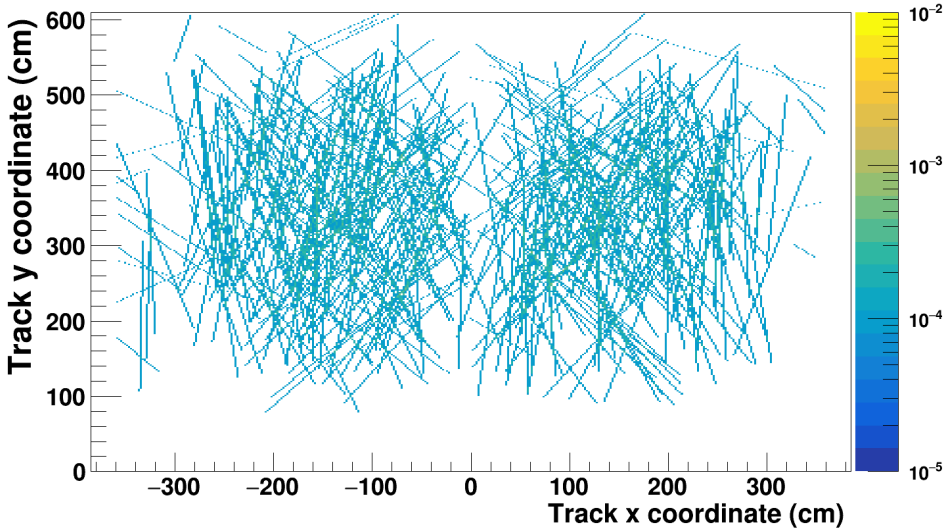




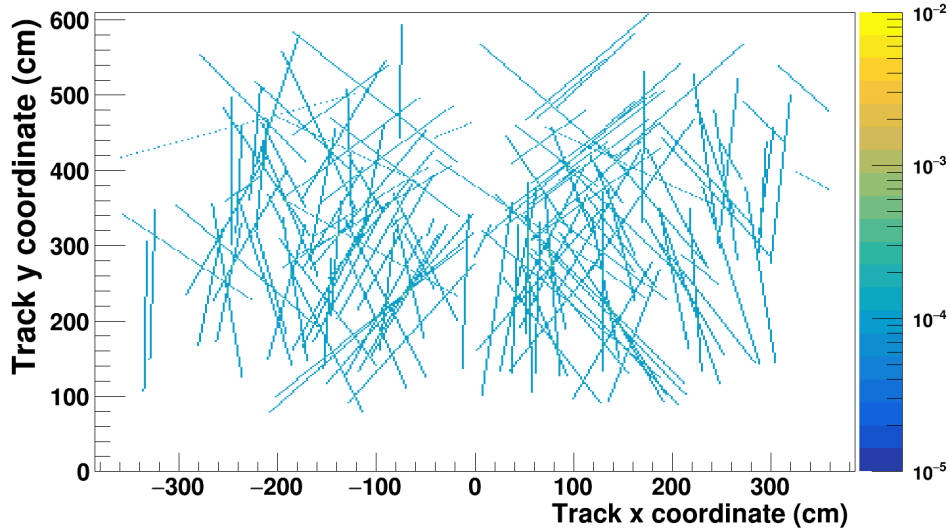


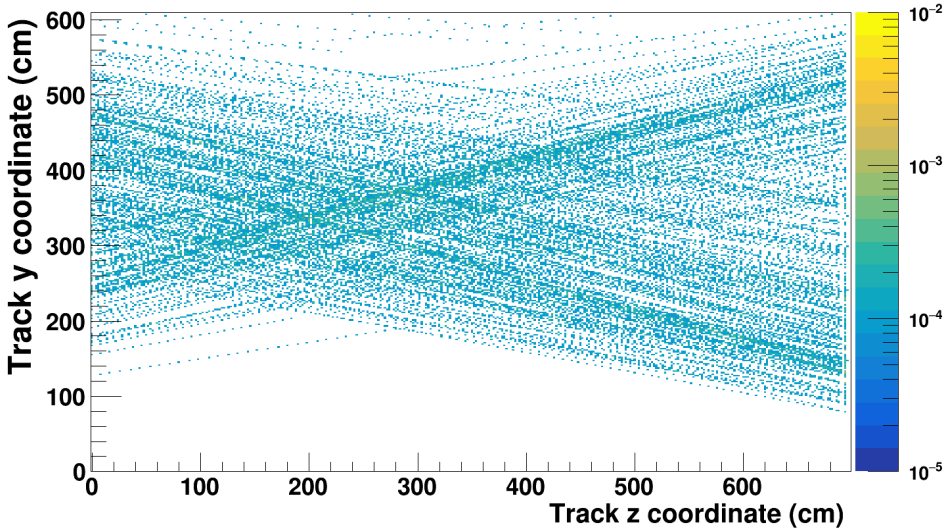
Cosmics: Front and Back

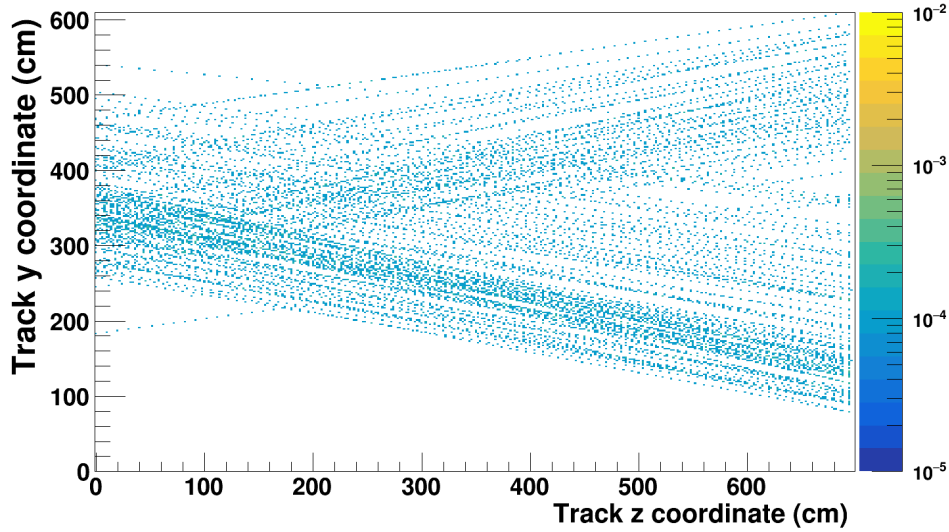
Upstream z = default in-line



Upstream z = new in-line

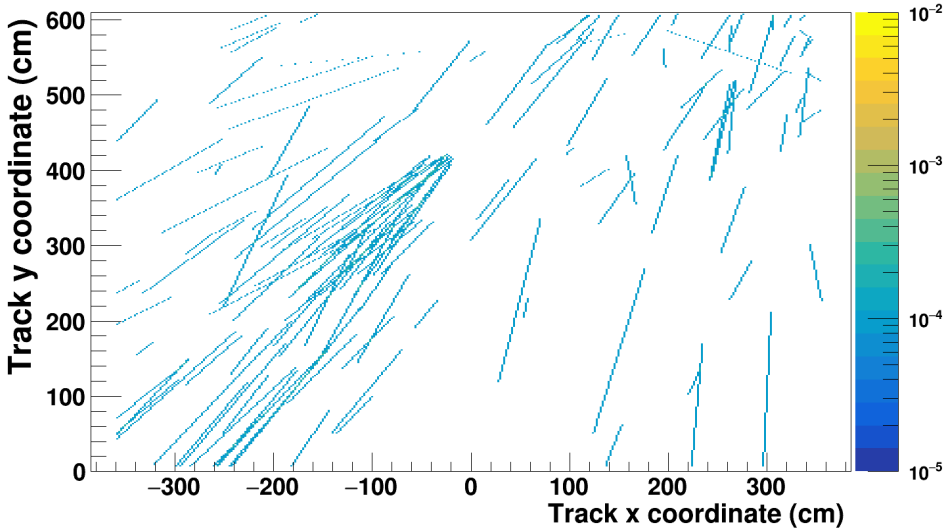




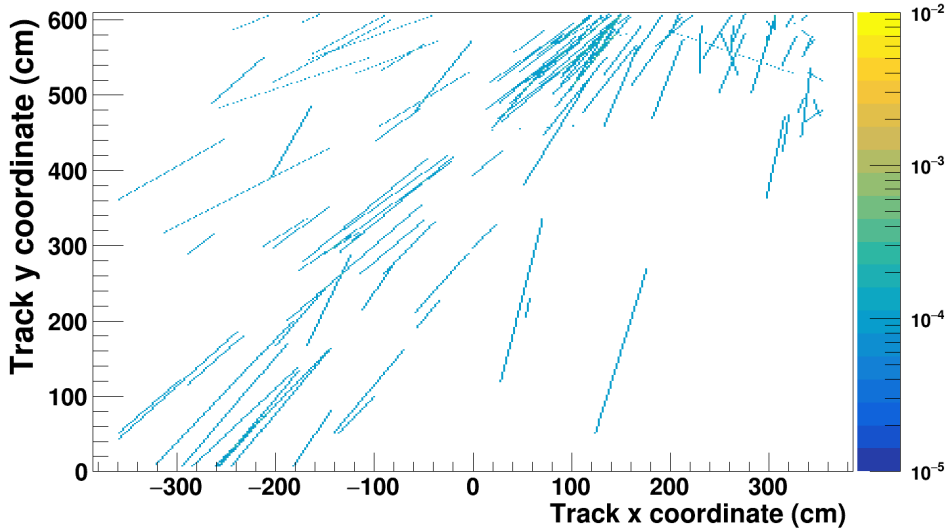


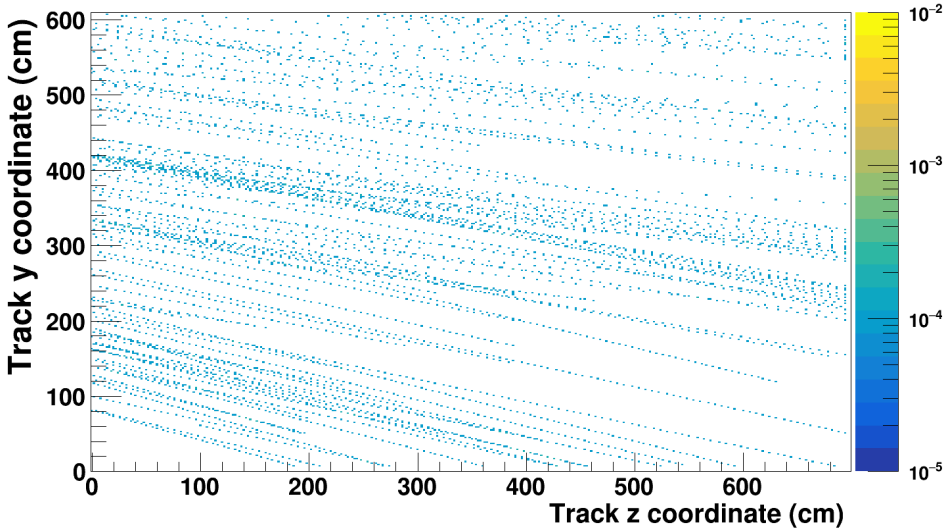
Halo: Front or Back

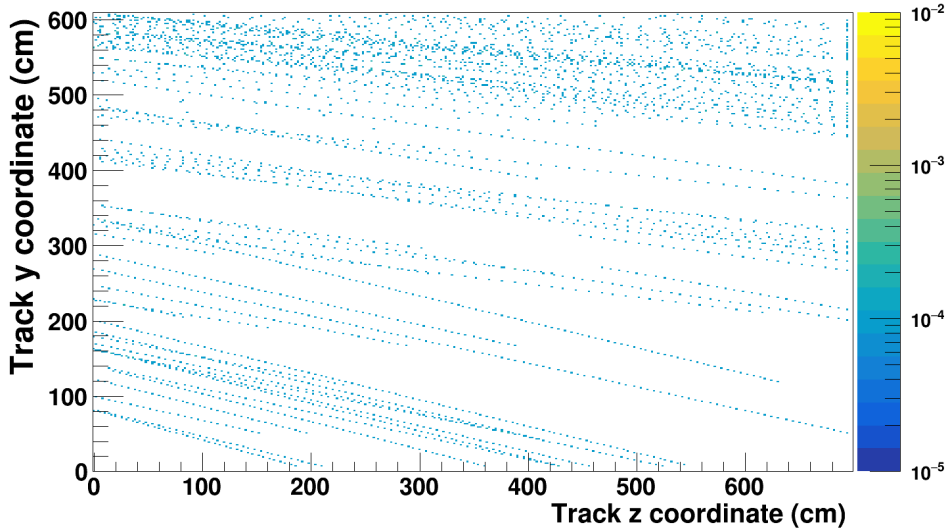
Upstream z = default in-line



Upstream z = new in-line

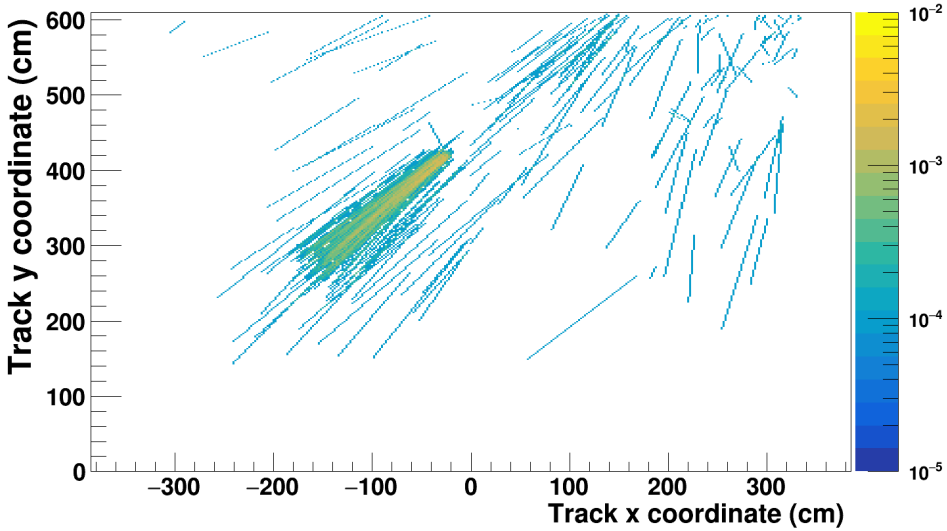




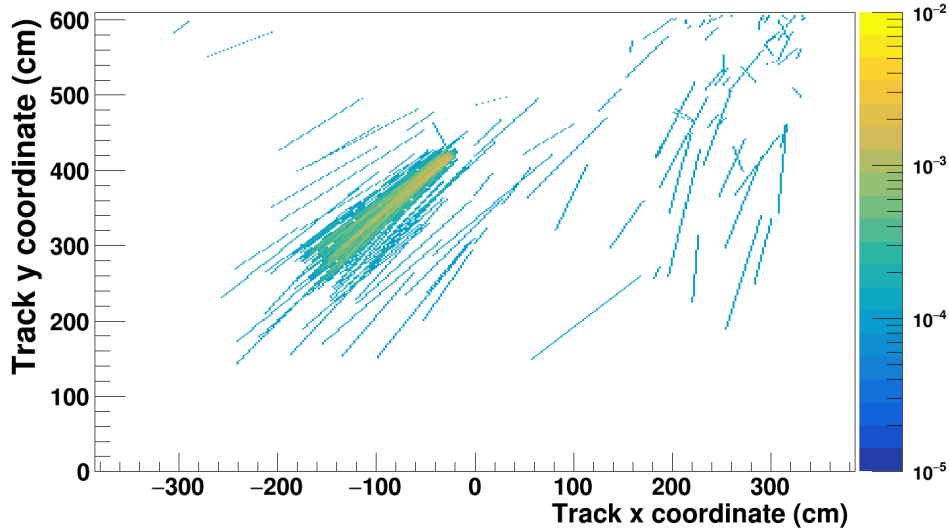


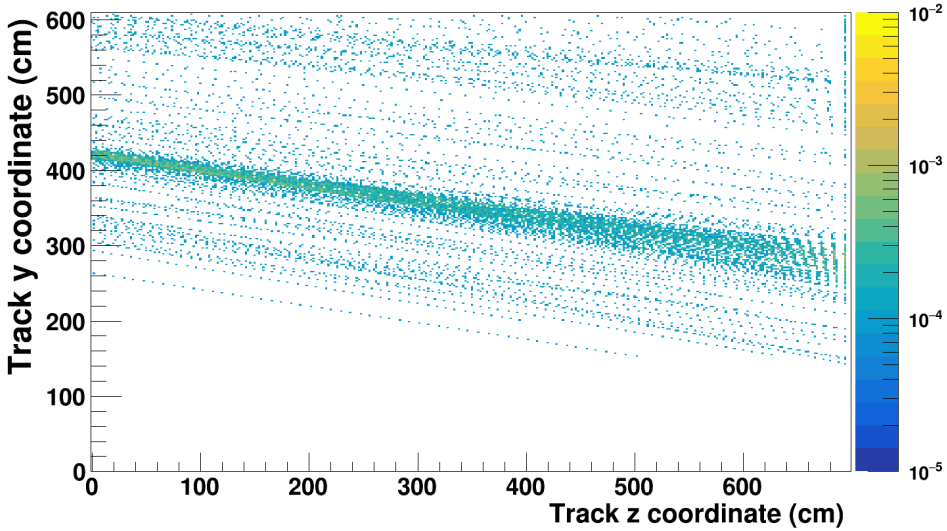
Halo: Front and Back

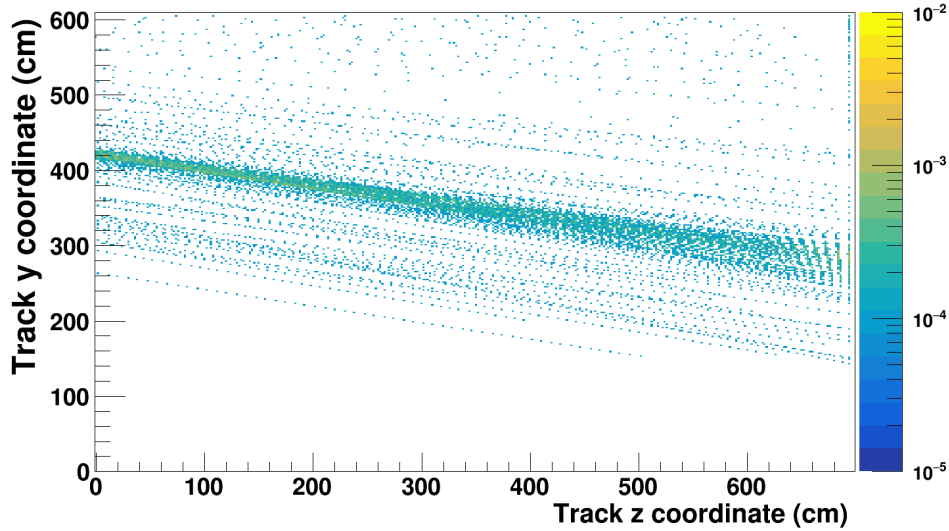
Upstream z = default in-line



Upstream z = new in-line



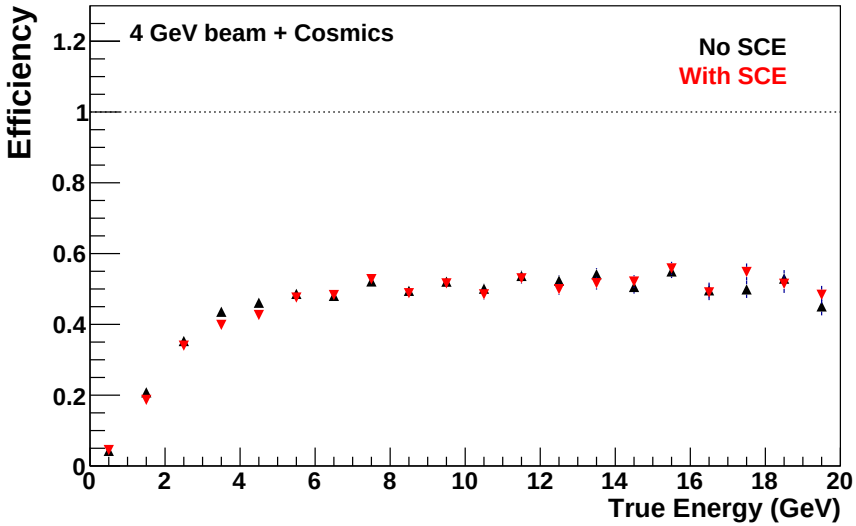


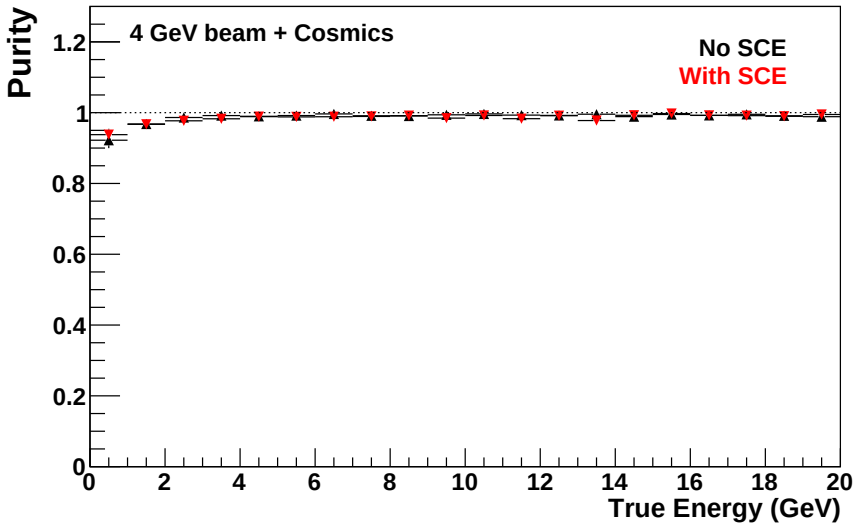


Backup

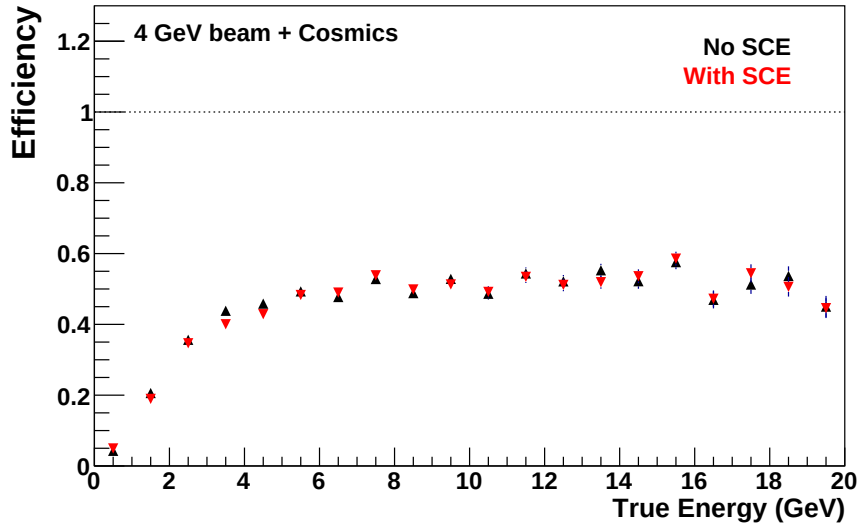
Cosmics: Front or Back

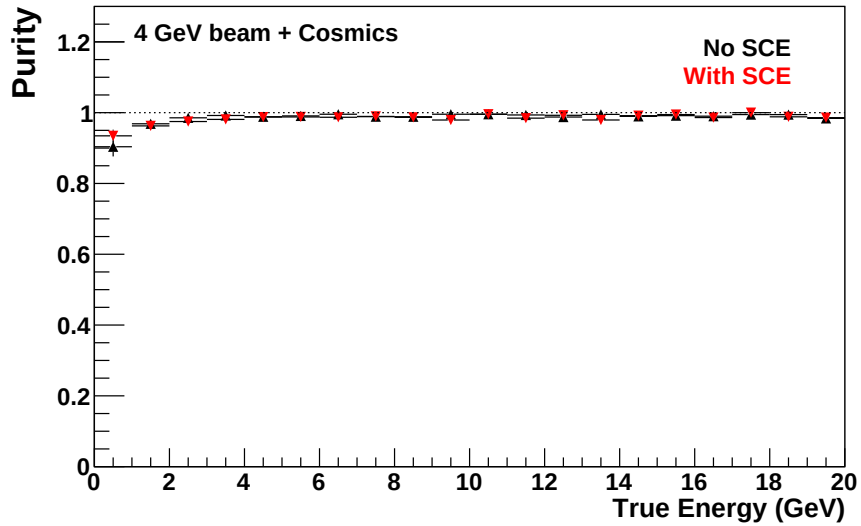
Upstream z = default in-line





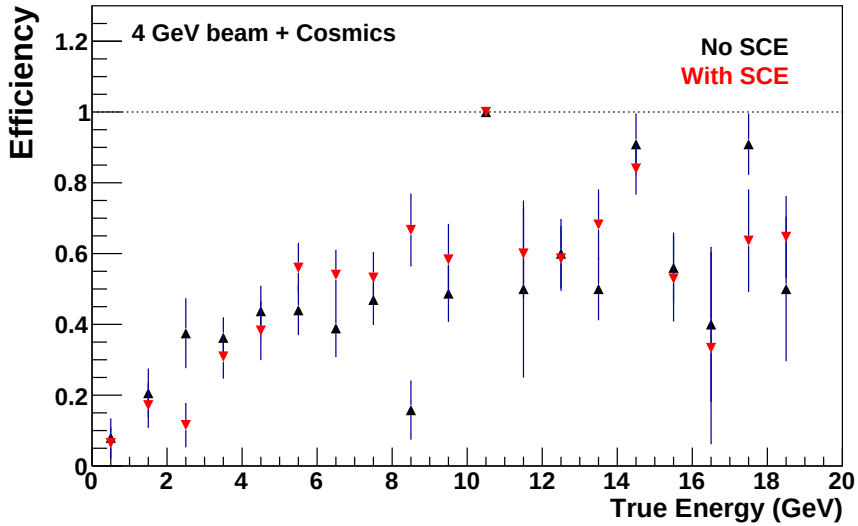
Upstream z = new in-line

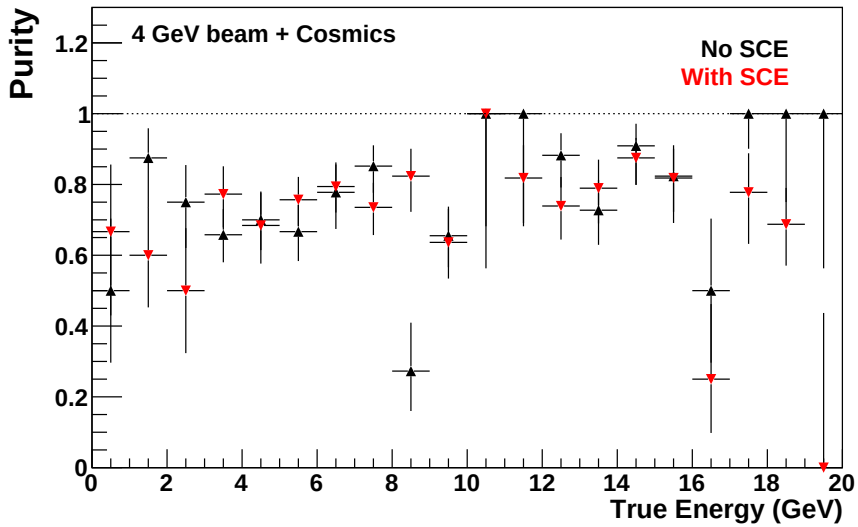




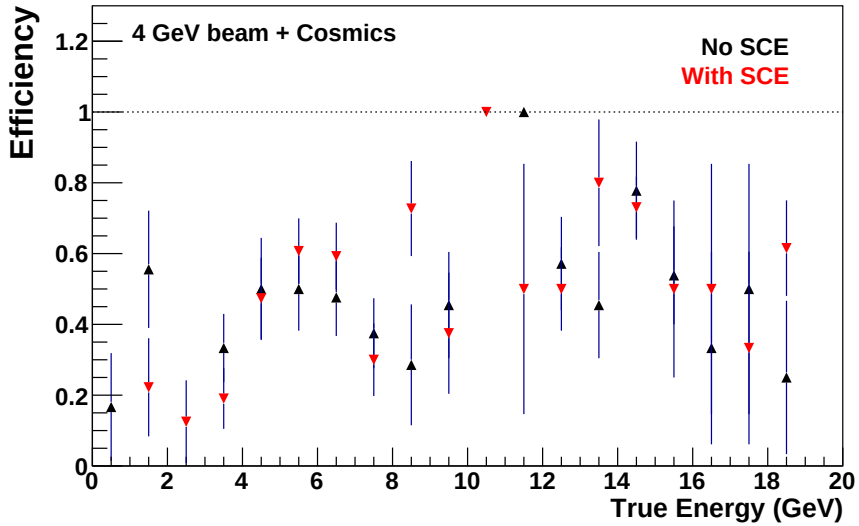
Cosmics: Front and Back

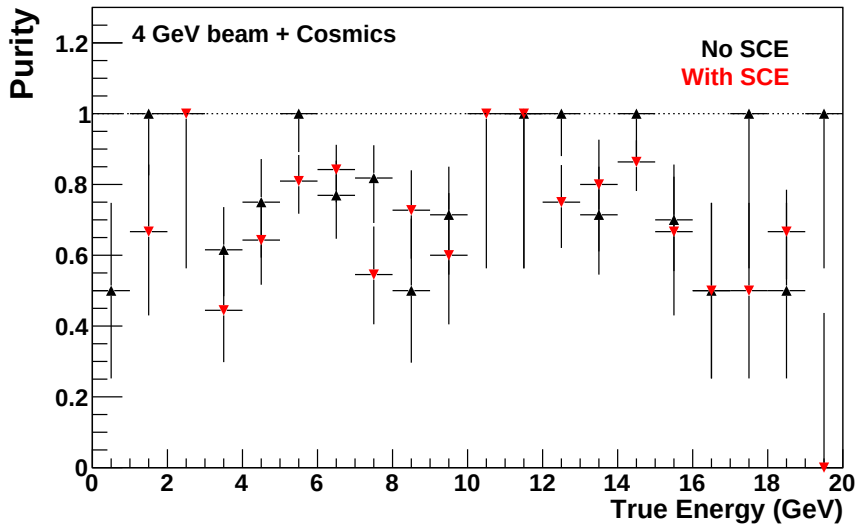
Upstream z = default in-line





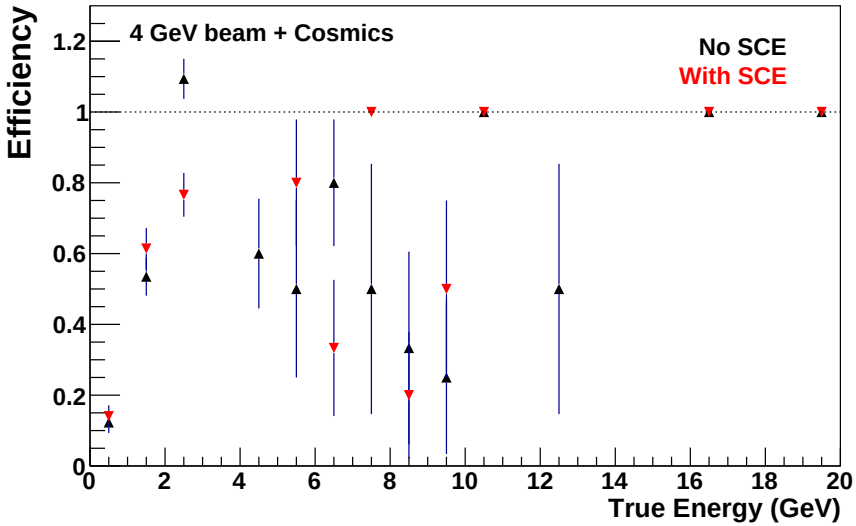
Upstream z = new in-line

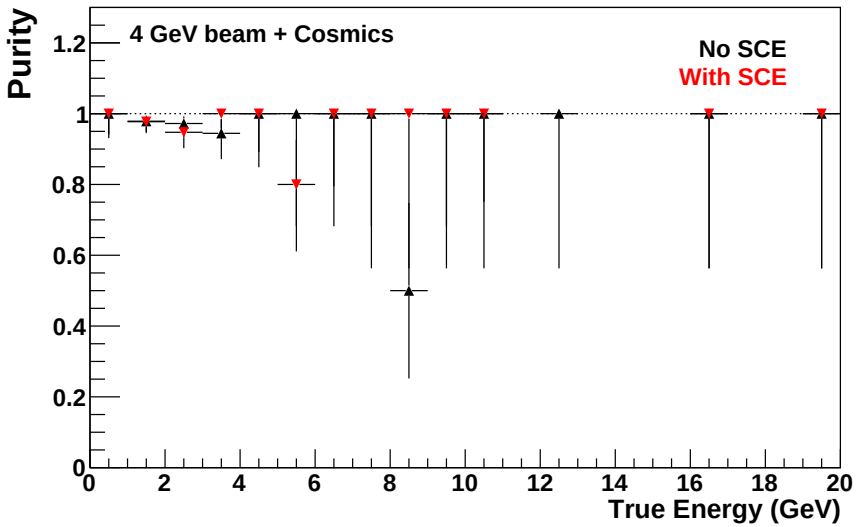




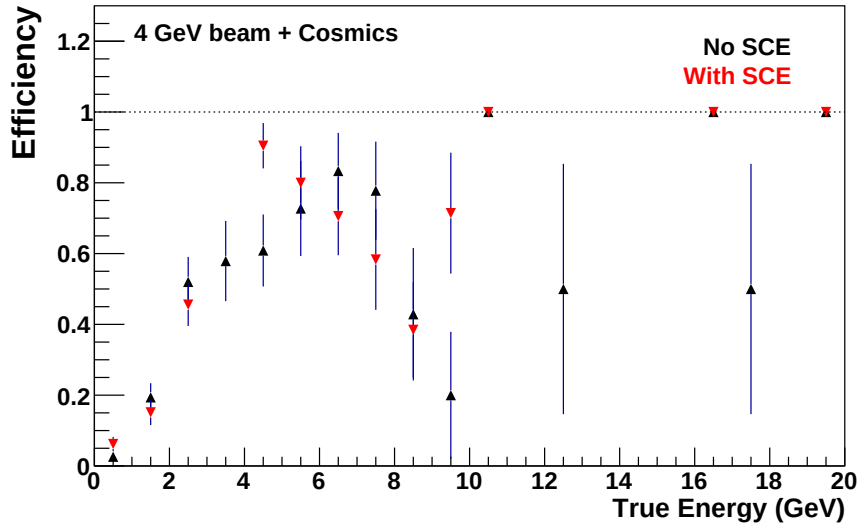
Halo: Front or Back

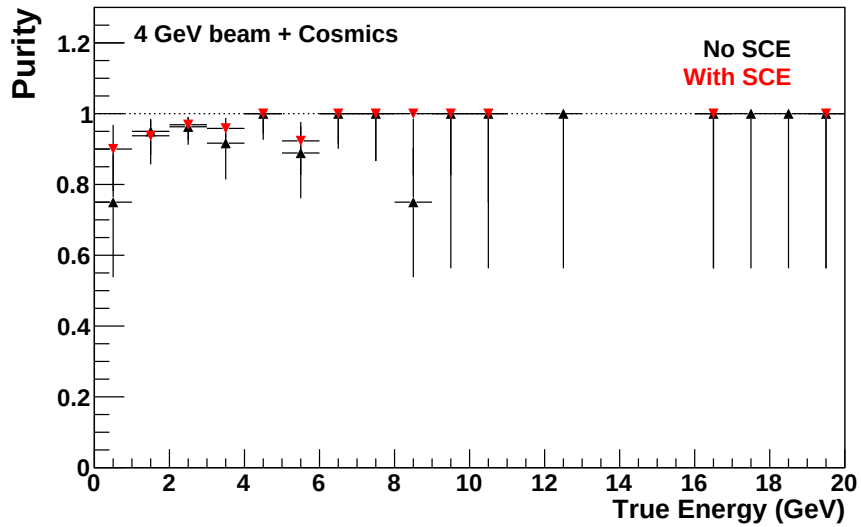
Upstream z = default in-line





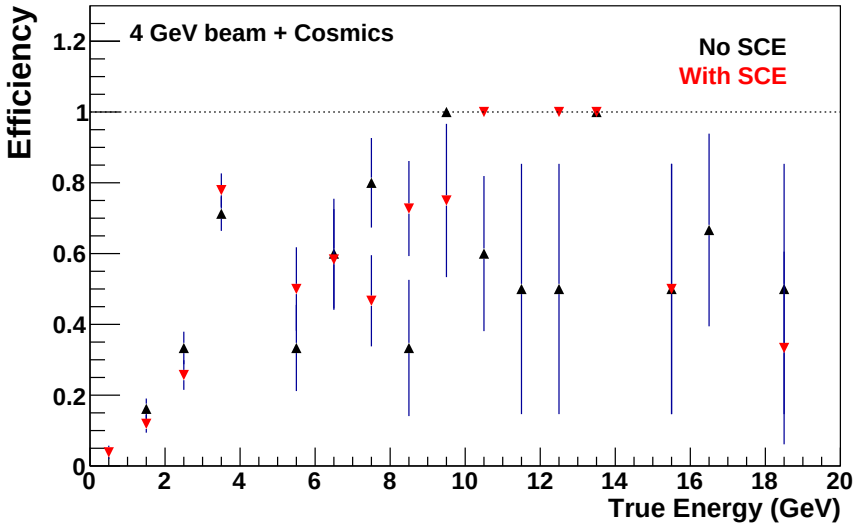
Upstream z = new in-line

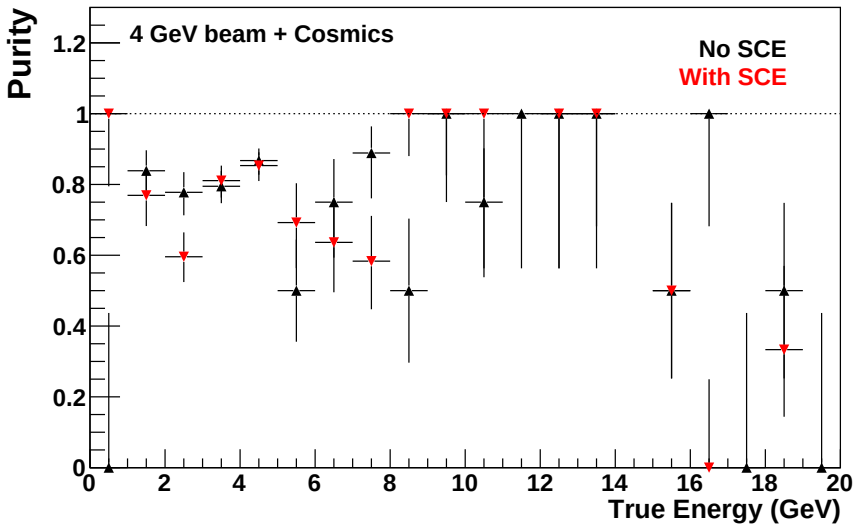




Halo: Front and Back

Upstream z = default in-line





Upstream z = new in-line