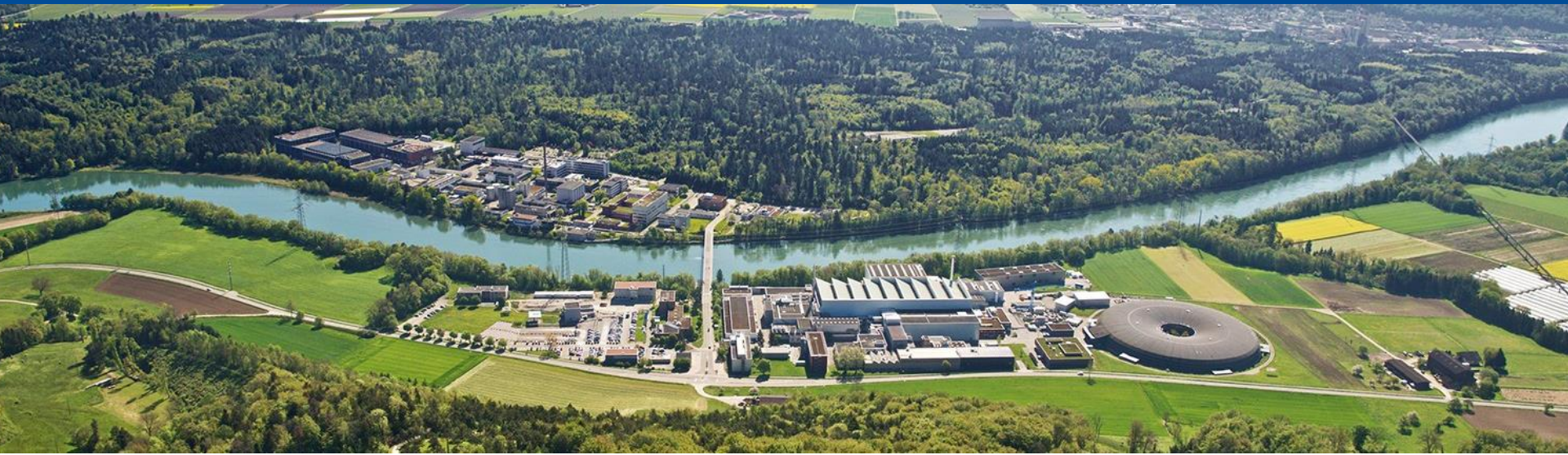


Role of a Tracker in the PIONEER Experiment

Josh LaBounty and Jaydeep Datta

PIONEER Collaboration Meeting

6/19/2024

What is the purpose of the tracker?

Trigger

(see Peter's talk)

triggers	prescale	range	rate	CALO			ATAR digitizer			ATAR high thres	
		TR(ns)	(kHz)	ΔT(ns)	chan	MB/s	ΔT(ns)	chan	MB/s	chan	MB/s
PI	1000	-300,700	0.3	200	1000	120	30	66	2.4	20	0.012
CaloH	1	-300,700	0.1	200	1000	40	30	66	0.8	20	0.004
TRACK	50	-300,700	3.4	200	1000	1360	30	66	27	20	0.014
PROMPT	1	2,32	5	200	1000	2000	30	66	40	20	0.2

TABLE III – Main triggers: time range TR and trigger rates. For detector systems readout island length ΔT, average number of channels and required readout bandwidth are given.

1. PI: This is a minimum bias trigger, with the PI signal prescaled by about k=1000.
2. CaloH: Selection of high energy ($E_{tot} \gtrsim 58$ MeV) events detected by the CALO within a time range TR=[-300,700] ns relative to PI.
3. TRACK: All events with TRACKER hit within time range TR relative to PI, prescaled by about k=50. We note that the probability to observe a $\pi \to \mu \to e$ positron in TR is 0.19, while the probably for detecting an old muon positron is 0.3, thus accidentals are a significant part of this trigger.
4. PROMPT: Selected prompt events with a TRACKER hit in time range [2,32] ns relative to PI, potentially prescaling required.

https://arxiv.org/abs/2203.01981

Physics

- Join ATAR information to CALO hits
- Provide information about pileup in calorimeter
  - Disambiguate multiple pulses when combined with ATAR information
- Provide information about charged particle content in an event
  - radiative decays
  - appropriate dead material energy estimation for scattering events

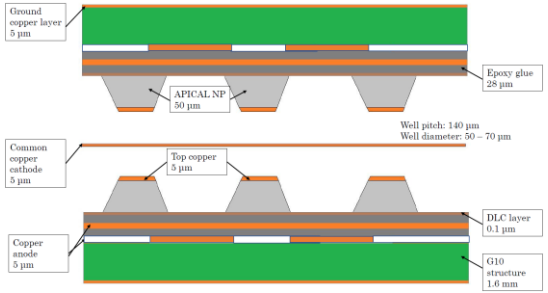
What does the tracker need to fulfill that purpose?

Fast response (~ns)

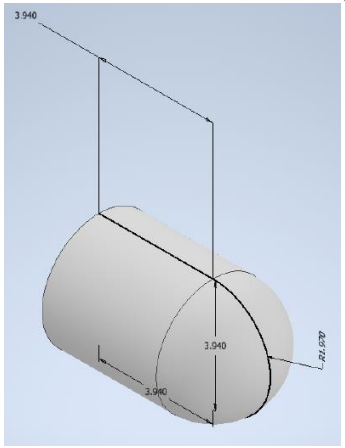
Good position resolution
Good pileup resolution
High efficiency/layer

Minimal dead material

Tracker Designs



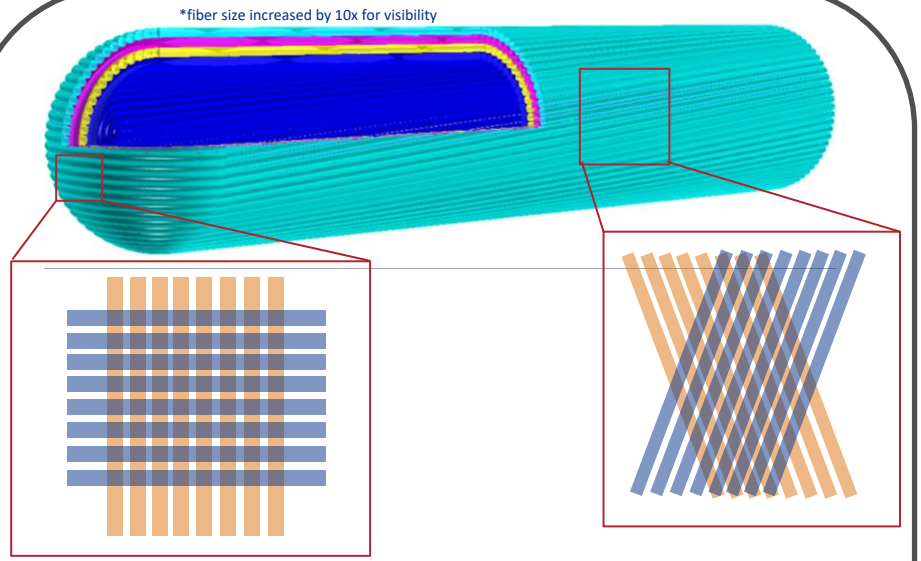
Common cathode Micro-RWELL Technology



CAD drawing

μRWELL | Primary technology choice

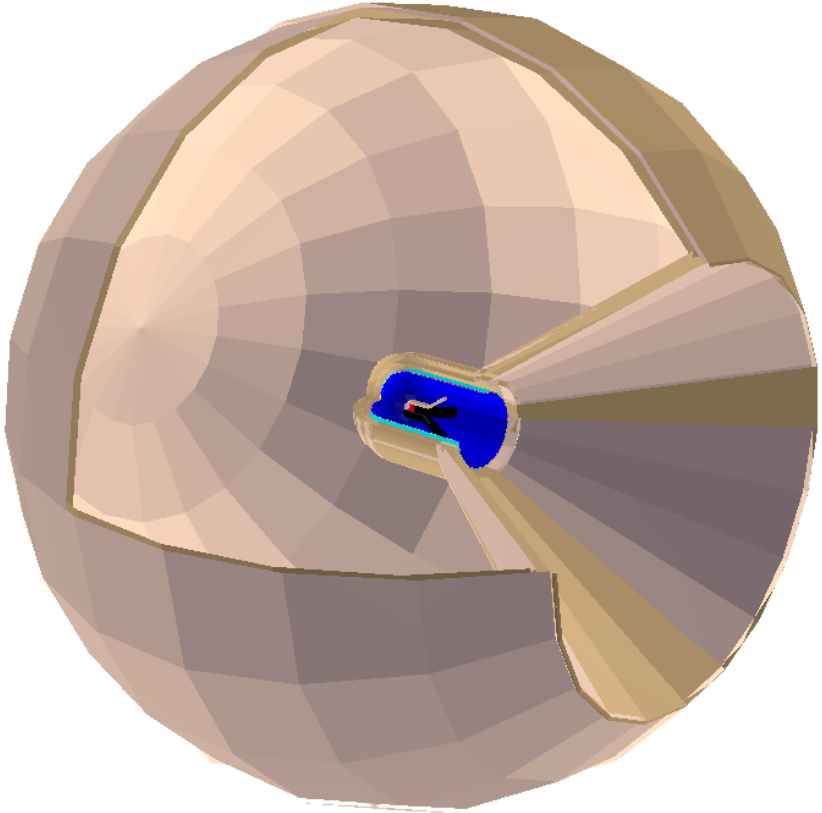
- 5.7 ns time resolution
- Spatial resolution: $\mathcal{O}(50\ \mu m)$
- Efficiency $\approx 97\%$
- More details from Jaydeep in the sessions tomorrow

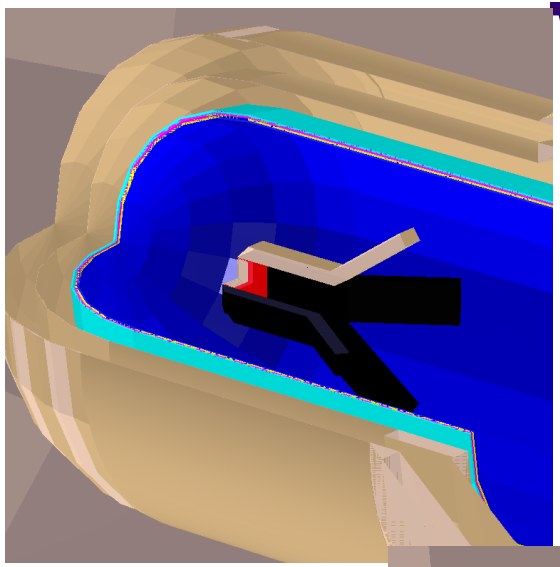


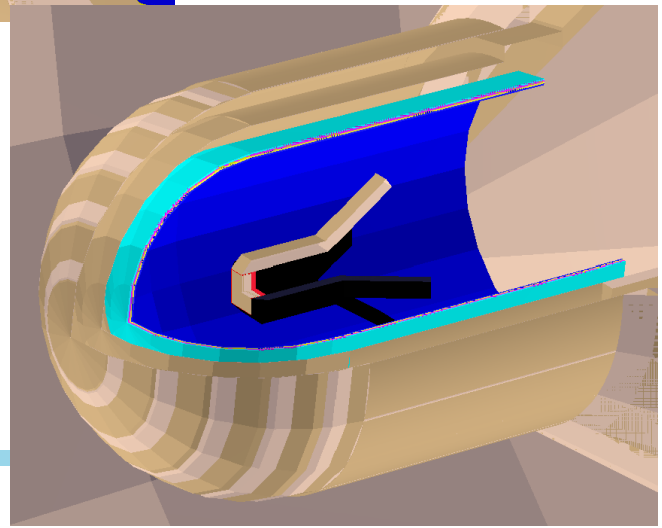
Scintillating fiber planes | Alternative technology

- 2-3 ns time resolution
- Preliminary studies suggest $\delta\theta, \delta\phi < 0.2$ rad
- Design challenges (fiber bending, etc.)
- Reconstructed positions challenging to disentangle

Generic Tracker Simulation







Some Specific Studies: Setup

Simulation of a LXe calorimeter

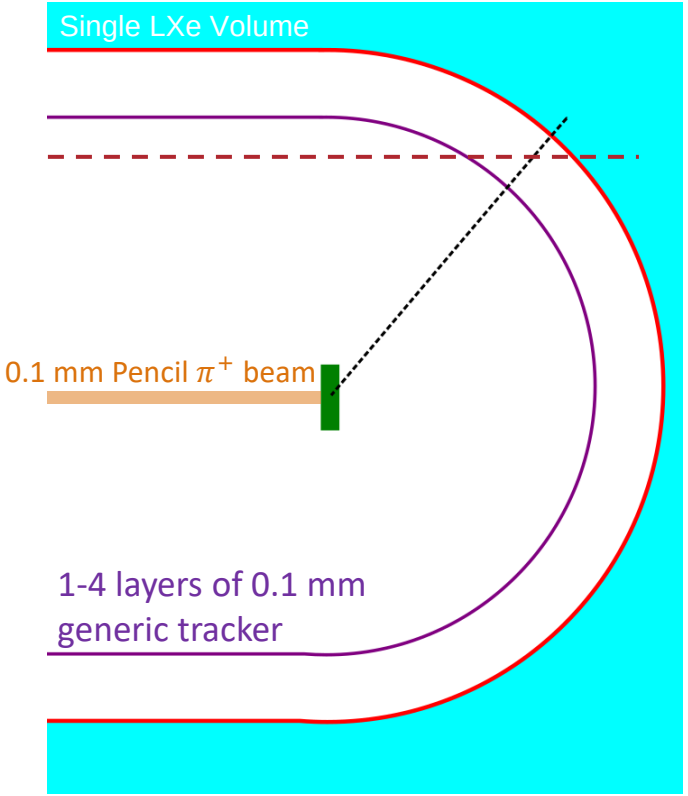
- **10ns time resolution.**
- **Single volume: No position resolution.**
- **“Worst case” pileup → Segmentation would make all these plots better (see Omar’s talk)**

Implemented cuts from Patricks ‘standard analysis’:

- **`BOX`: π^+ stop within ATAR**
- **`FID`: Positron exits ATAR within the calorimeter fiducial volume of 120°**
- **ATAR pattern and calo hits are matched**

Generating “unbiased” sample of decays to examine the effect of the tracker on the data

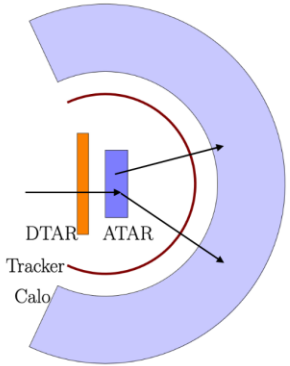
- **Event mixing rate: 1e6**
- **Tracker event mixing optimized to not assume time ordered steps in Geant4**



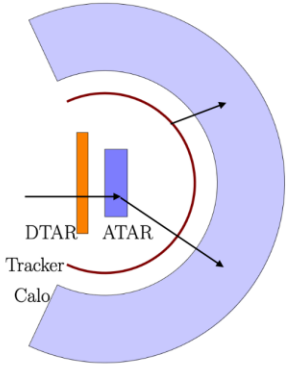
Types of Pileup

Caveats piling up

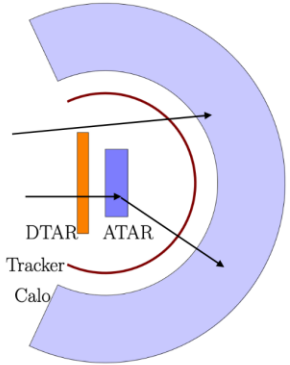
Only a fraction of possibilities has been covered so far …



Classic old muon:
Old muon decays on target. clearly identifiable by two pattern structure. The only case where the current dataset is suitable for. Either fit it or use ATAR for suppression



Stray old muon:
Old muon decays somewhere in dead material. The emitted positron may be seen by tracker or calo only. Their abundance will increase with future implementation of Cables and Supporting Structures.



Beam Pileup:
Some beam particles bypasses all our structures and hits the calo. Potential candidates are recent beam muons as suggested by Stefan. These require all support structures and cables as well as a dedicated simulation with a more realistic beam.

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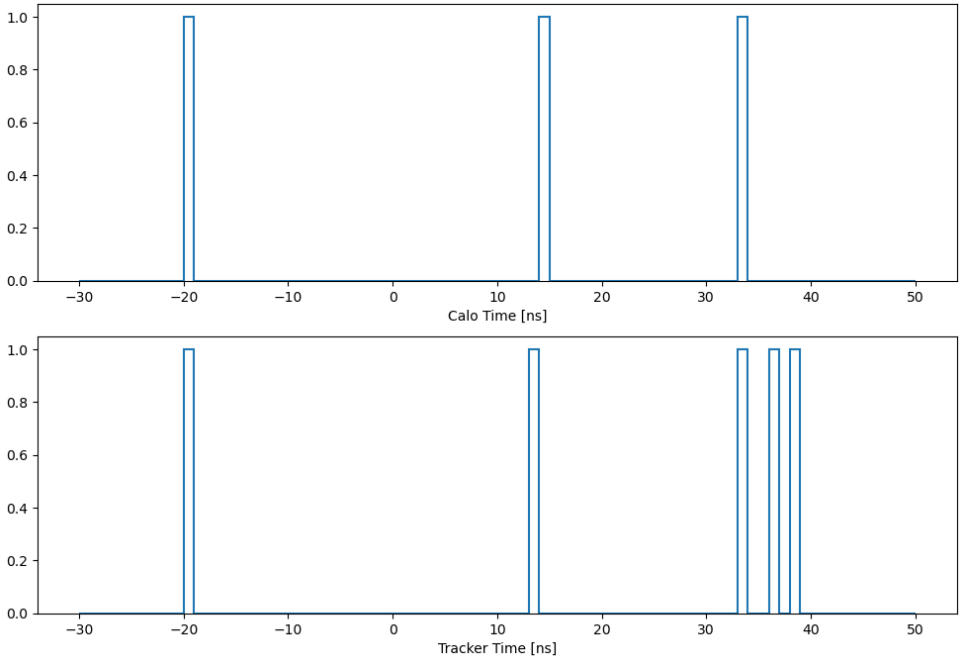
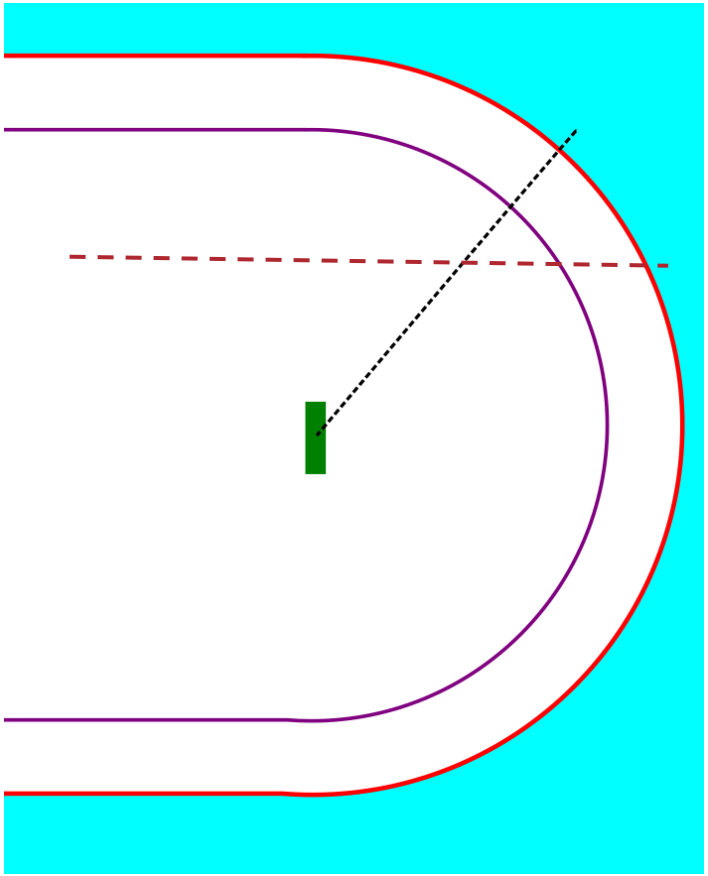
[Patrick's talk from last year]

Basic Tracker Analysis

$$\text{Score} = \frac{N_{hit}-1}{N_{layers}}$$





Basic Tracker Analysis

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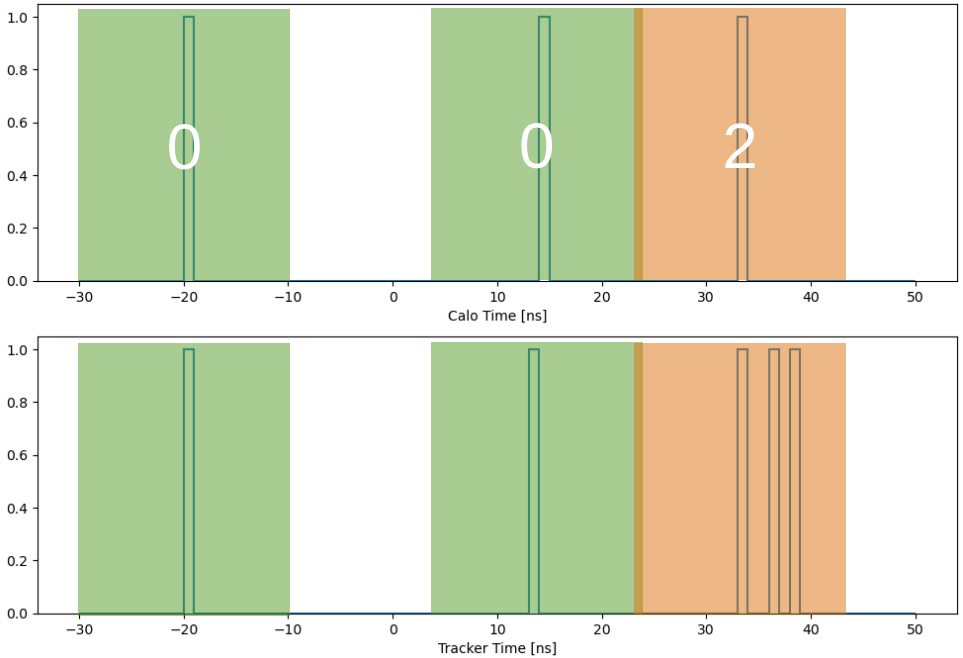

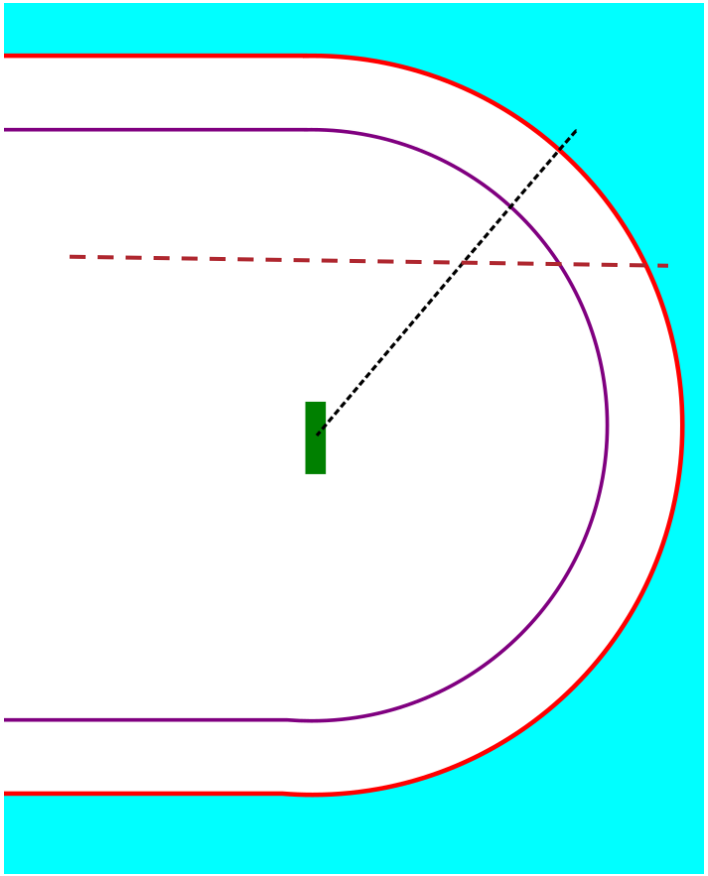

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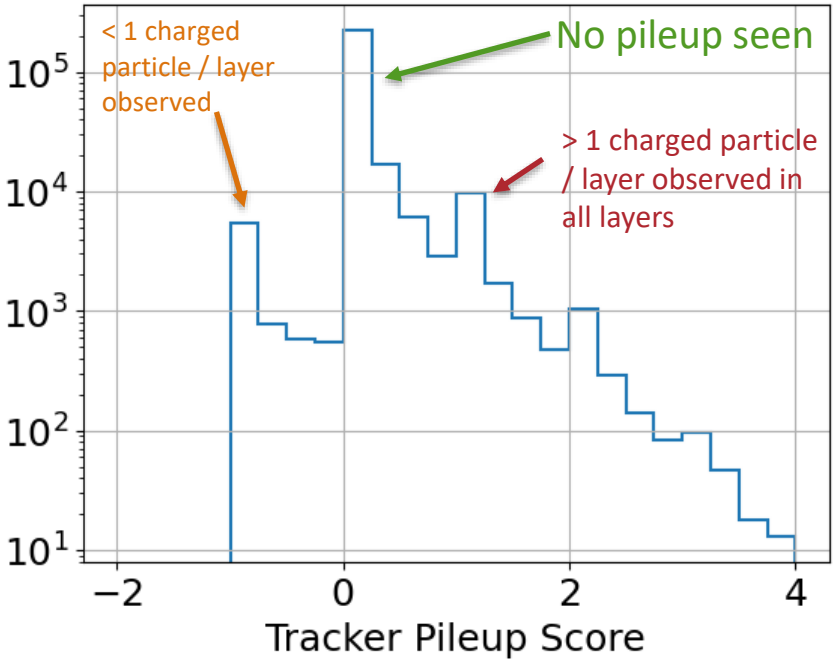

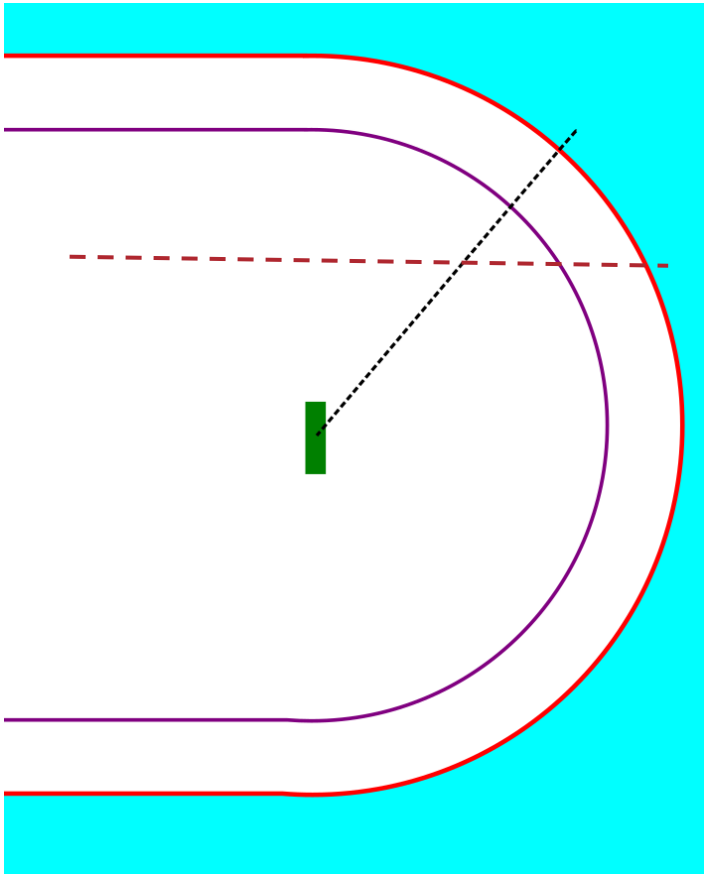

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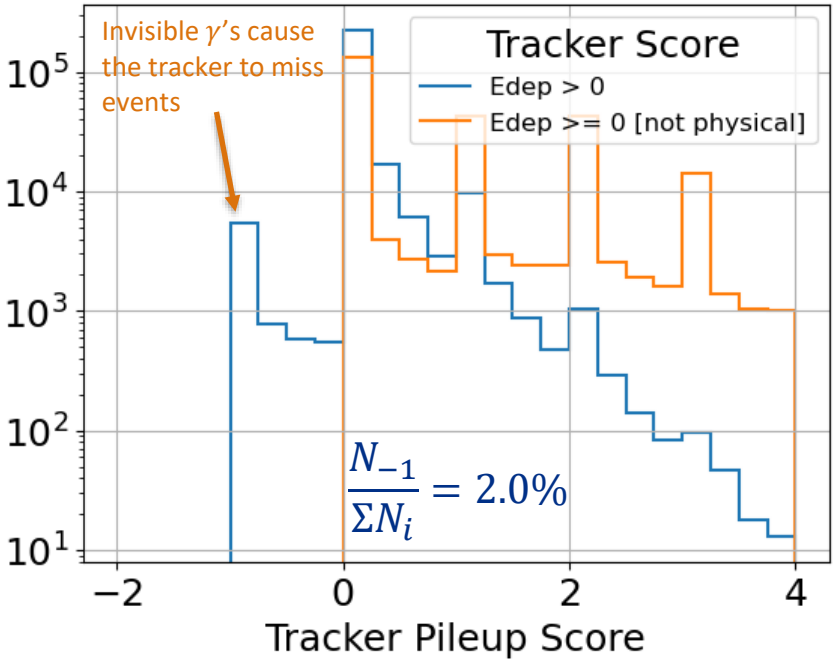
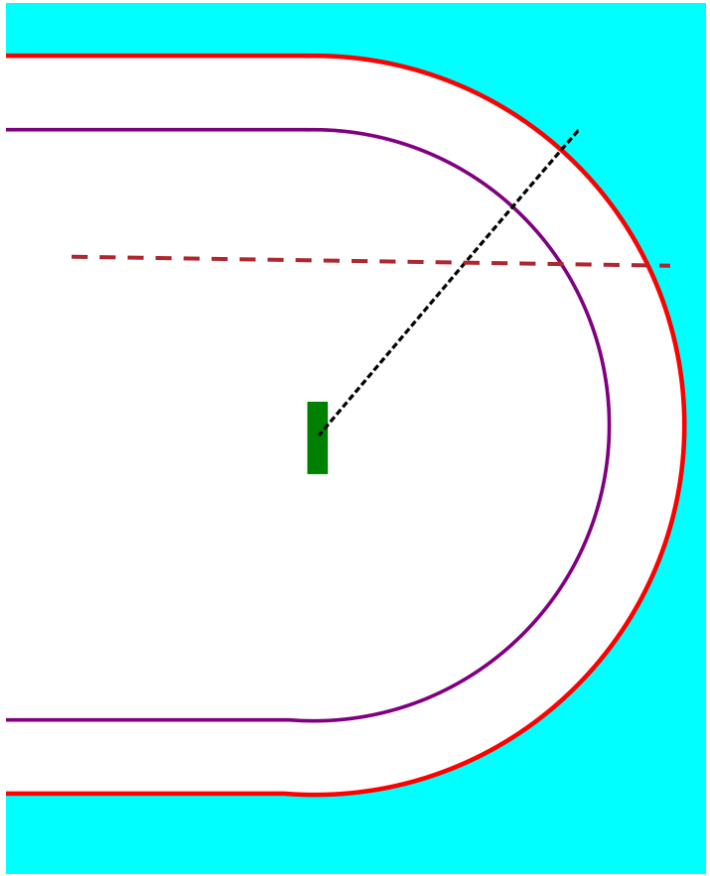
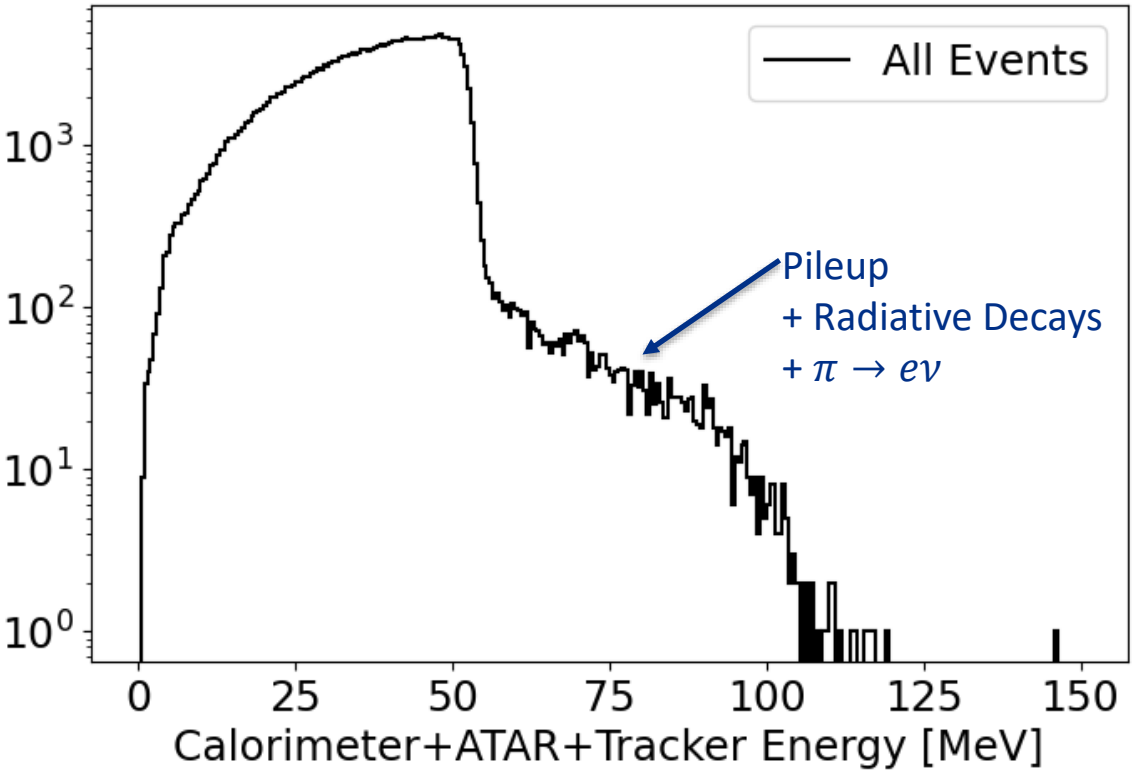
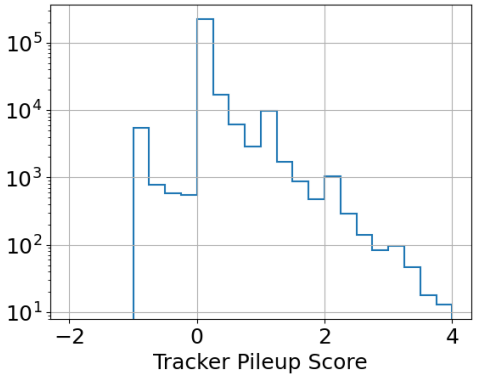


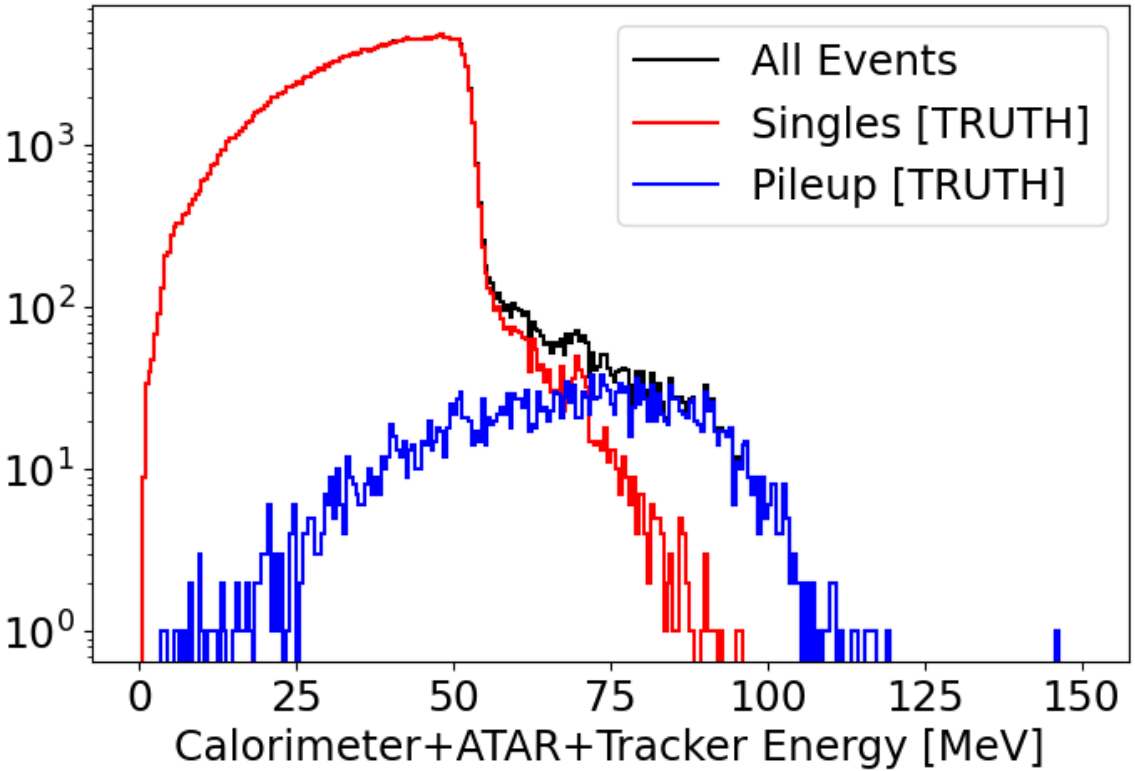


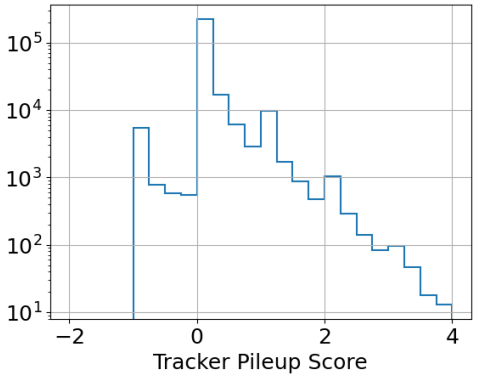
Tagging Event Types





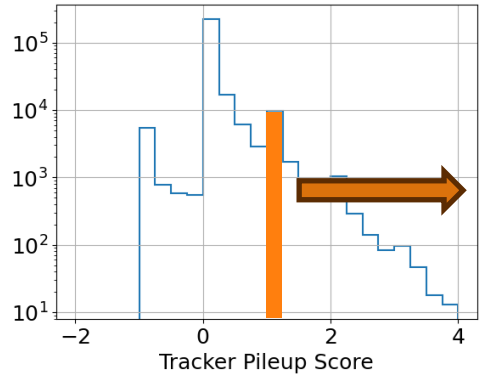
Tagging Event Types

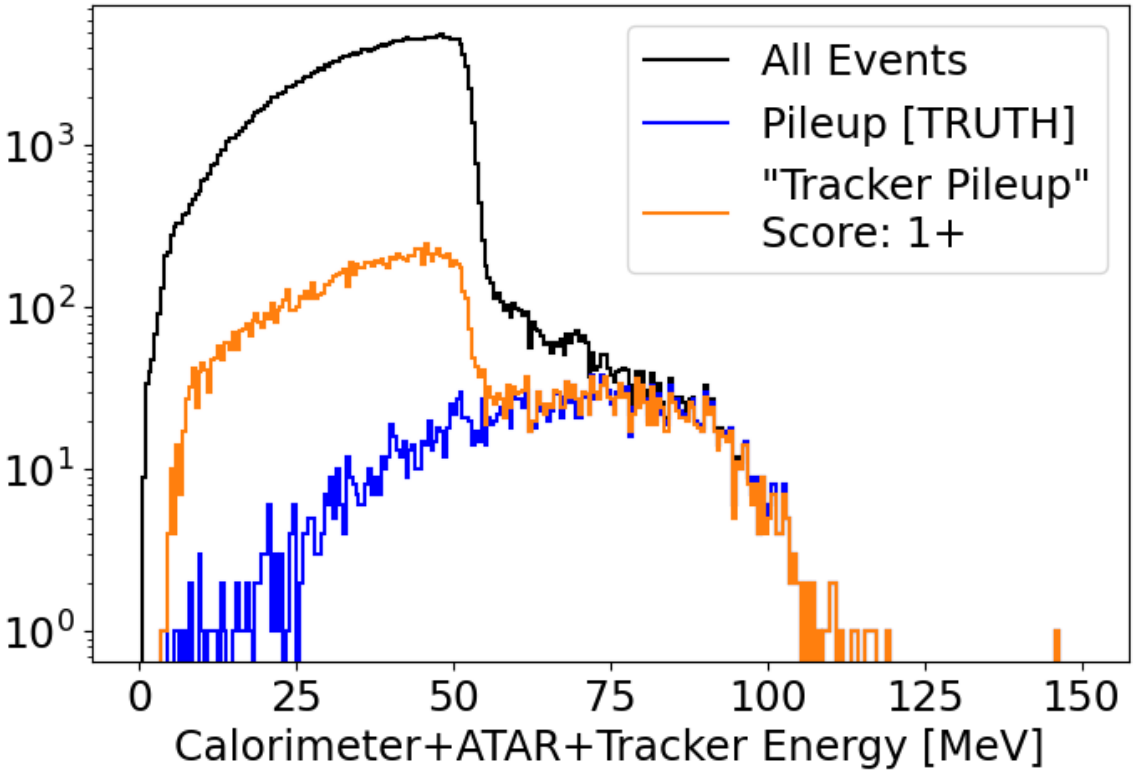




Tagging Event Types

$$\delta t = 1\ ns$$
$$\delta x = 20\ mm$$



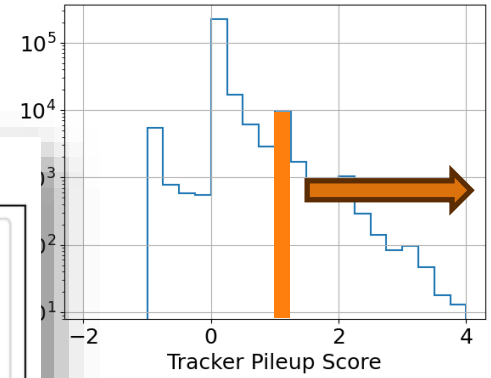


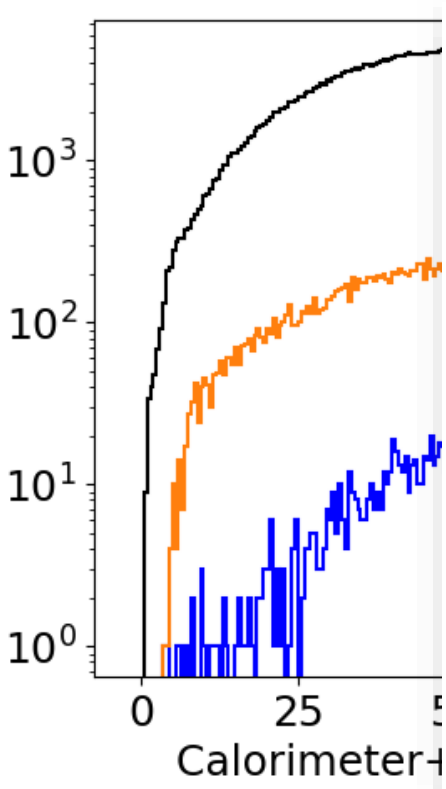
High energy pileup can be tagged with good efficiency.

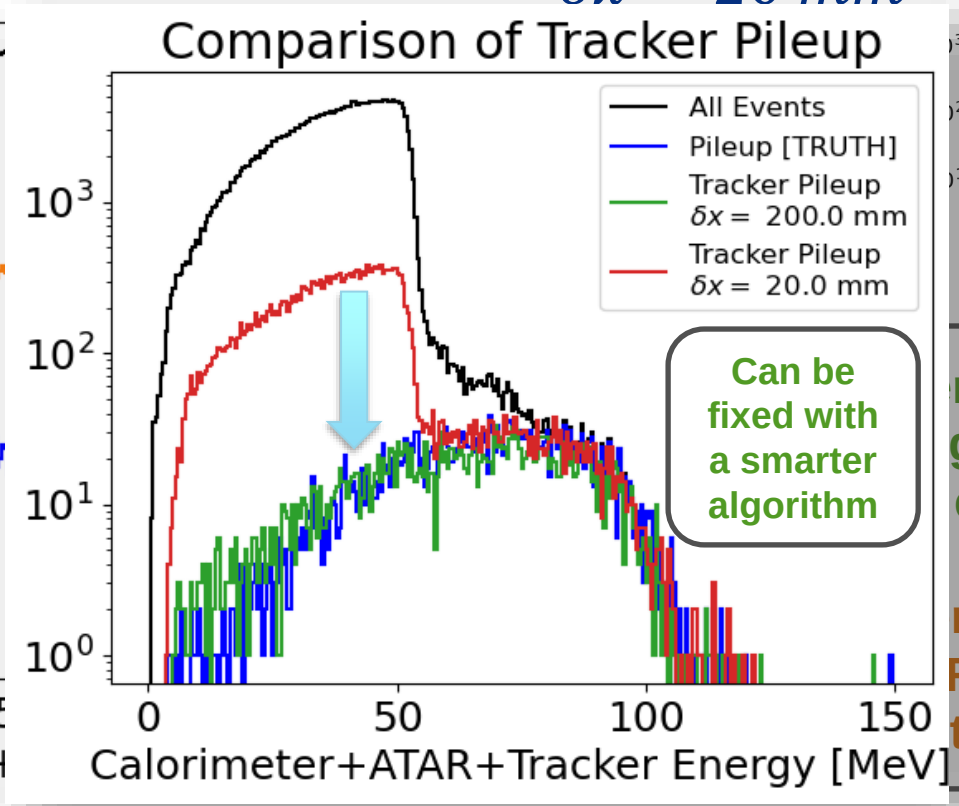
Low energy scattering in ATAR/cables appears in the tracker as pileup

Tagging Event Types

$$\delta t = 1\ ns$$
$$\delta x = 20\ mm$$







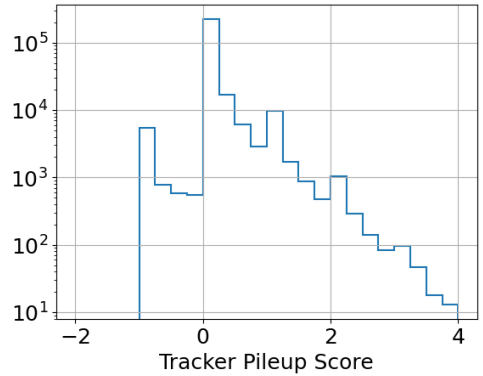
Can be fixed with a smarter algorithm

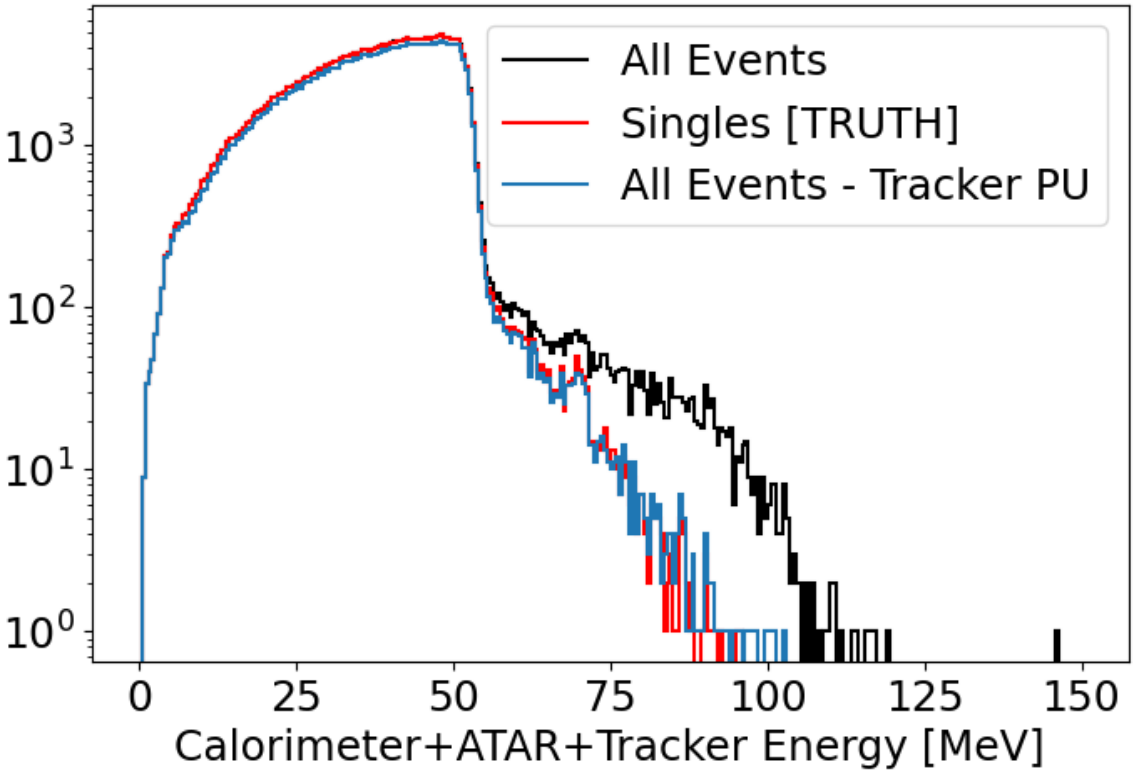
nergy pileup can gged with good efficiency.

nergy scattering R/cables appears tracker as pileup

Tagging Event Types

$$\delta t = 1\ ns$$
$$\delta x = 20\ mm$$



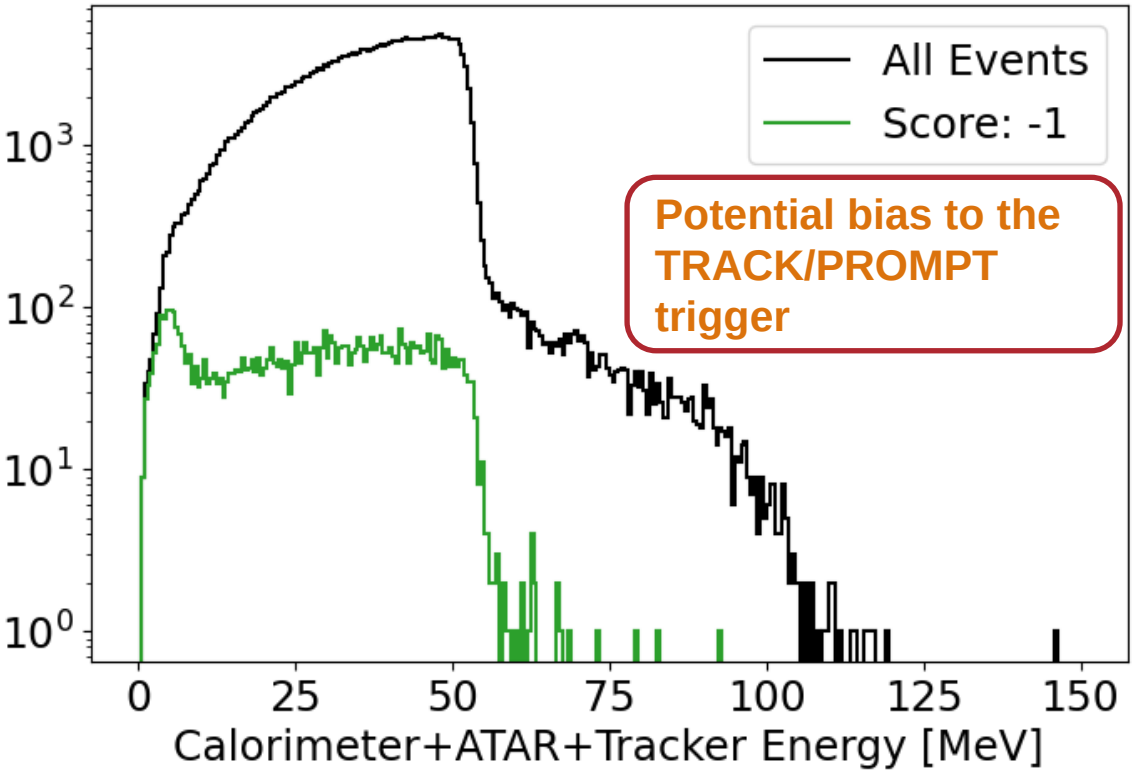


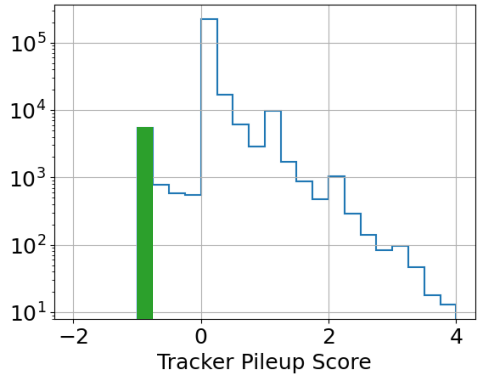
High energy pileup can be tagged with good efficiency.

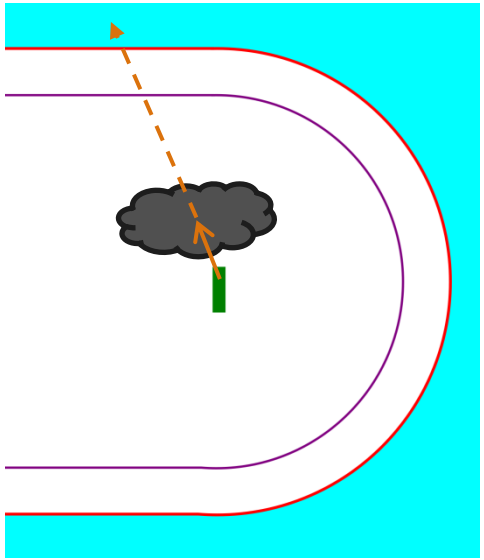
Low energy scattering in ATAR/cables appears in the tracker as pileup (but can be recovered)

Tagging Event Types

$$\delta t = 1\ ns$$
$$\delta x = 20\ mm$$







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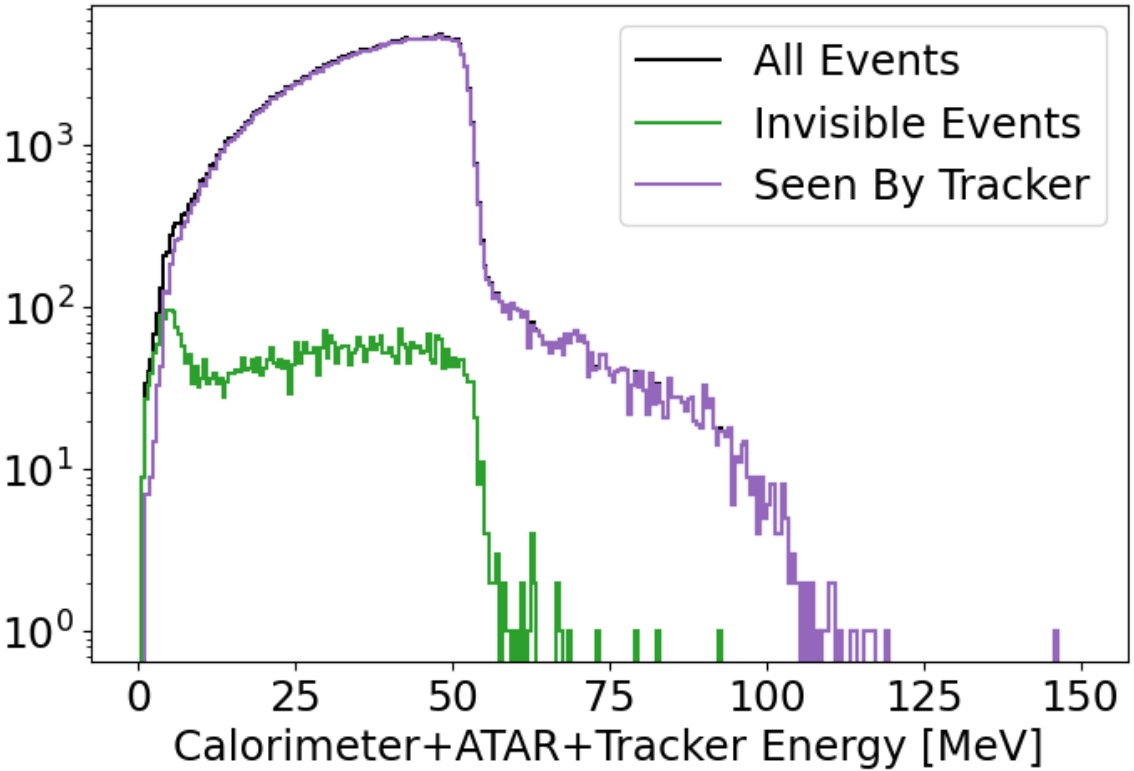
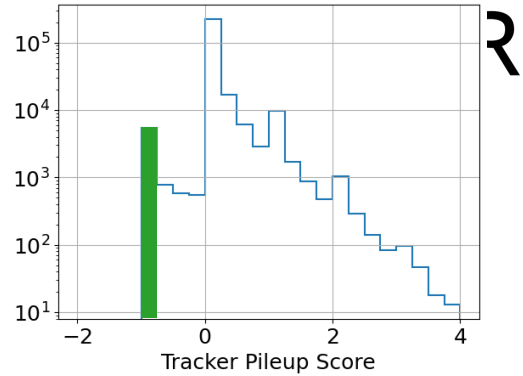
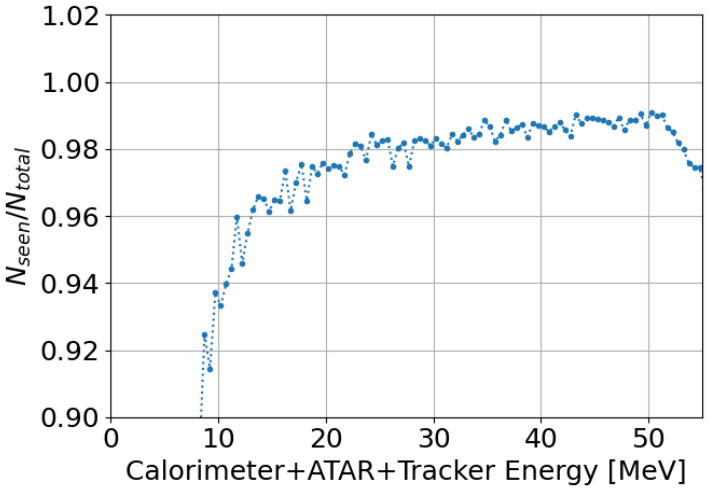
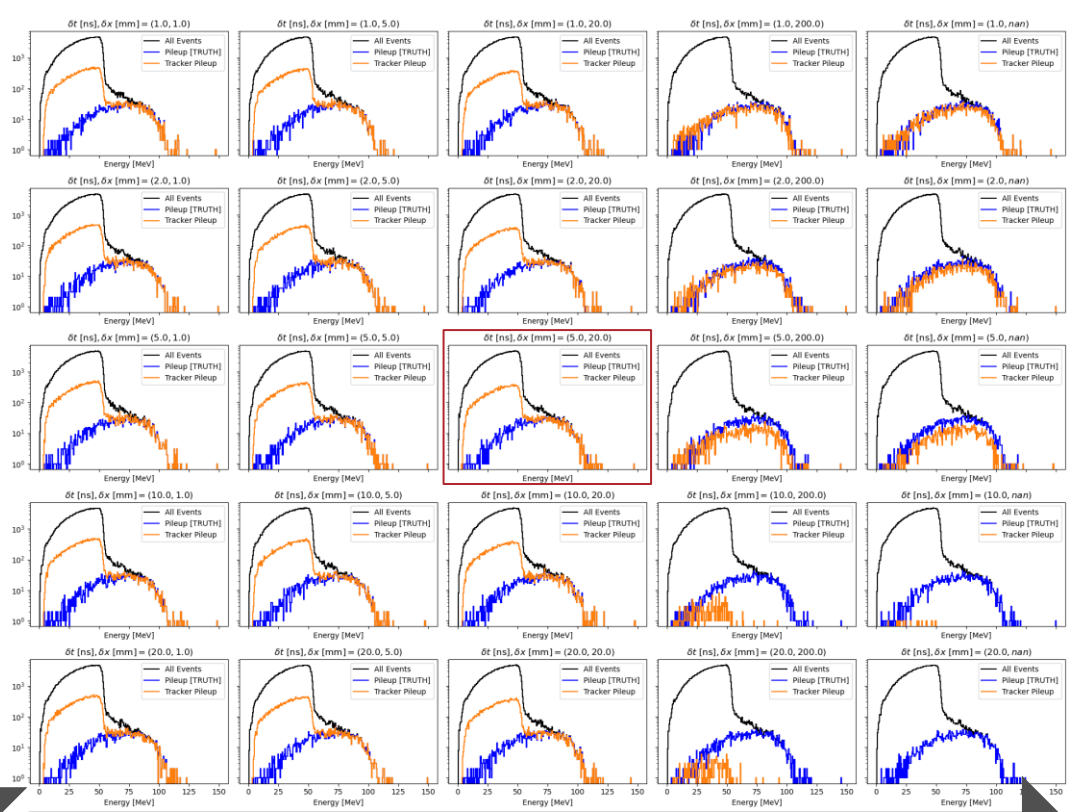
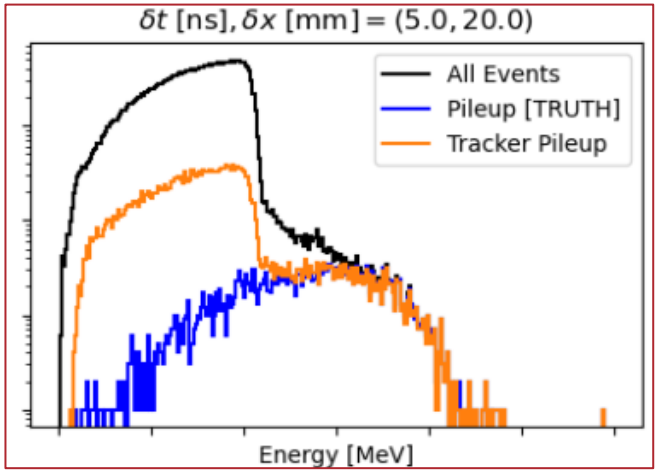






Pileup Tagging: Time vs. Spatial Resolution

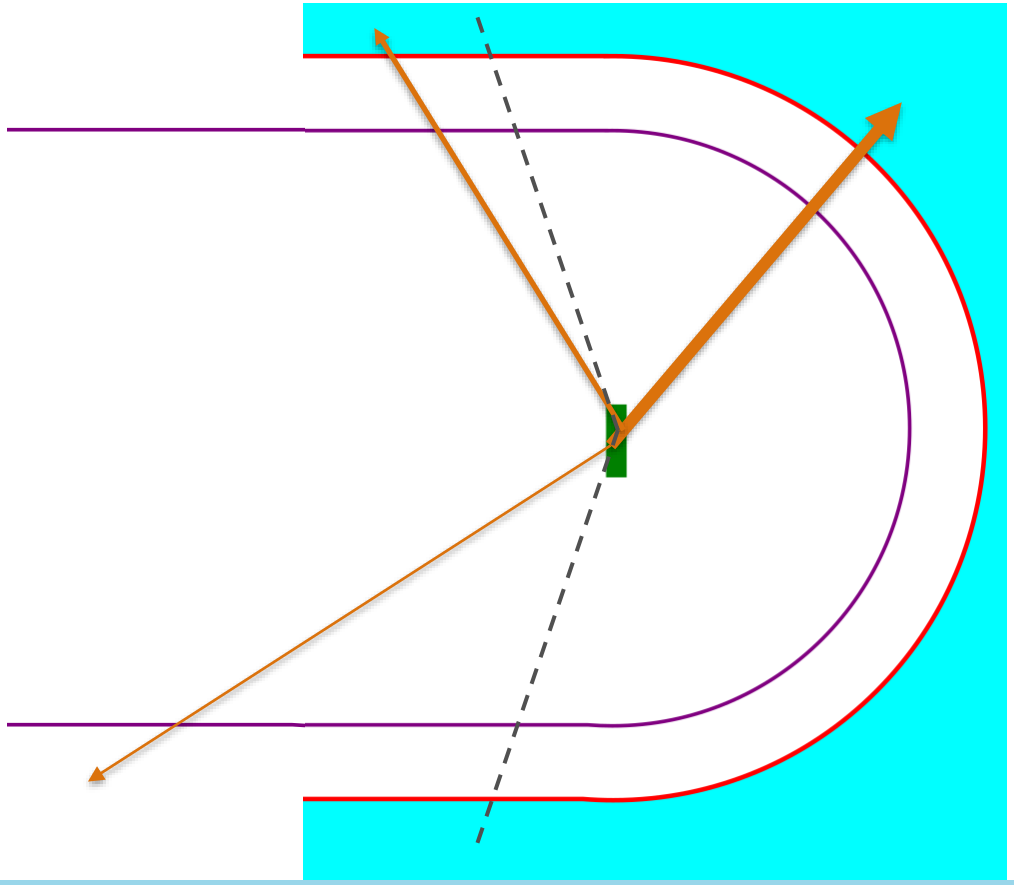


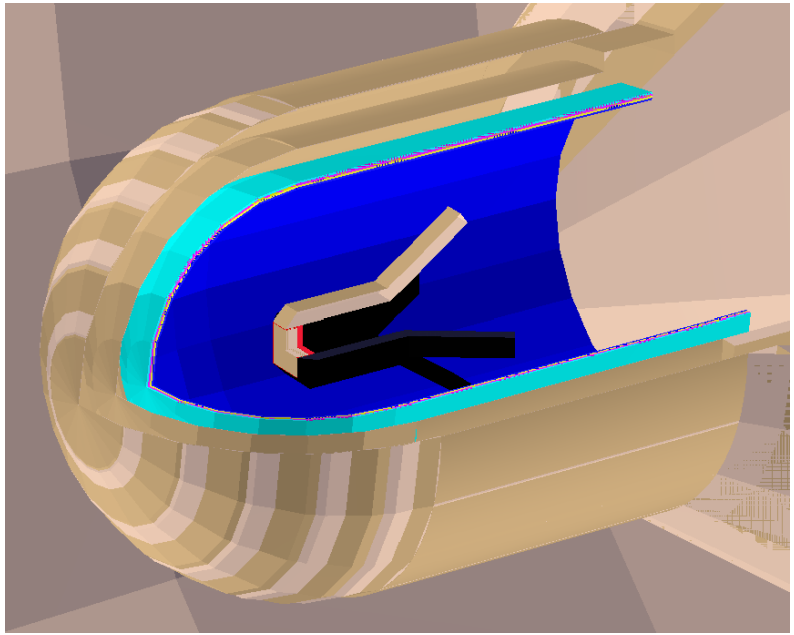


5 ns δt and 20 mm position resolution are sufficient to resolve Bhabha and pileup events

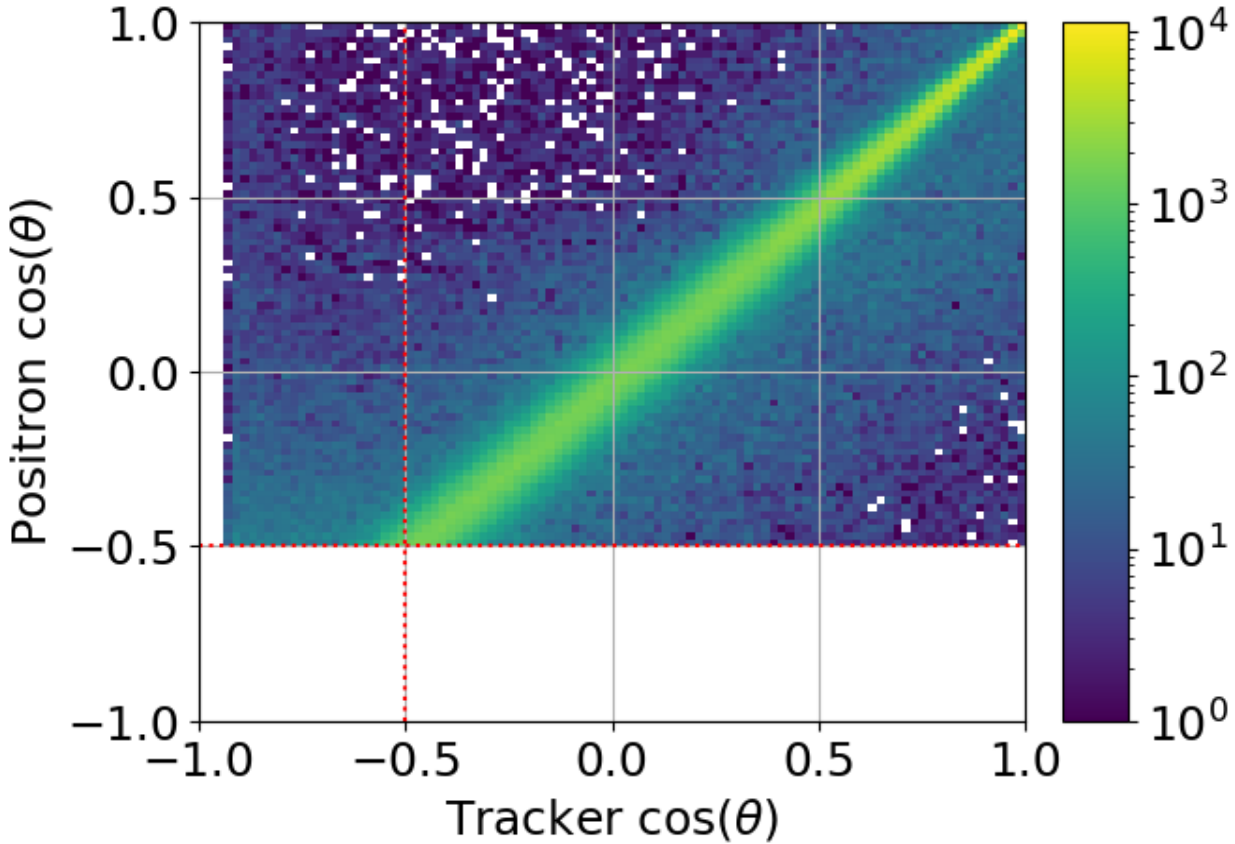
Both technologies are viable

Tagging Scattering Outside Fiducial Region

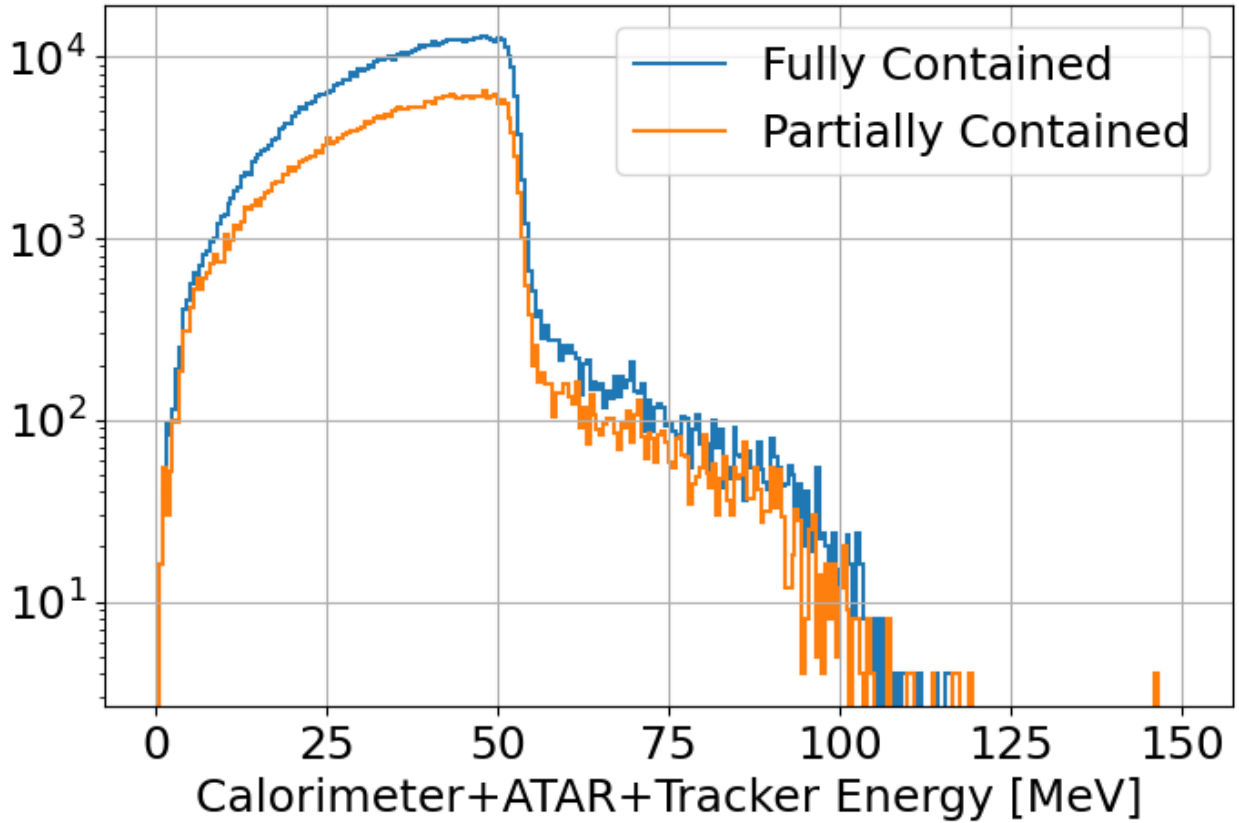




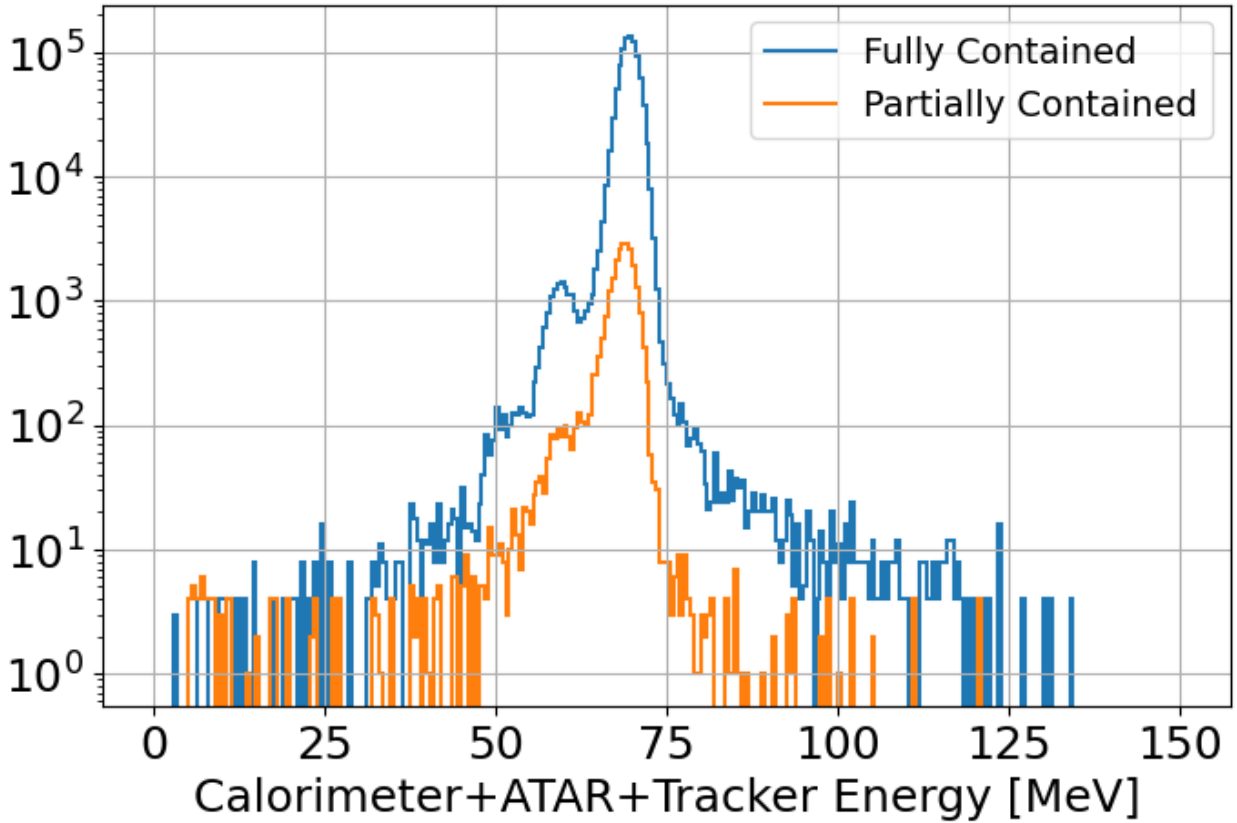
Tagging Scattering Outside Fiducial Volume



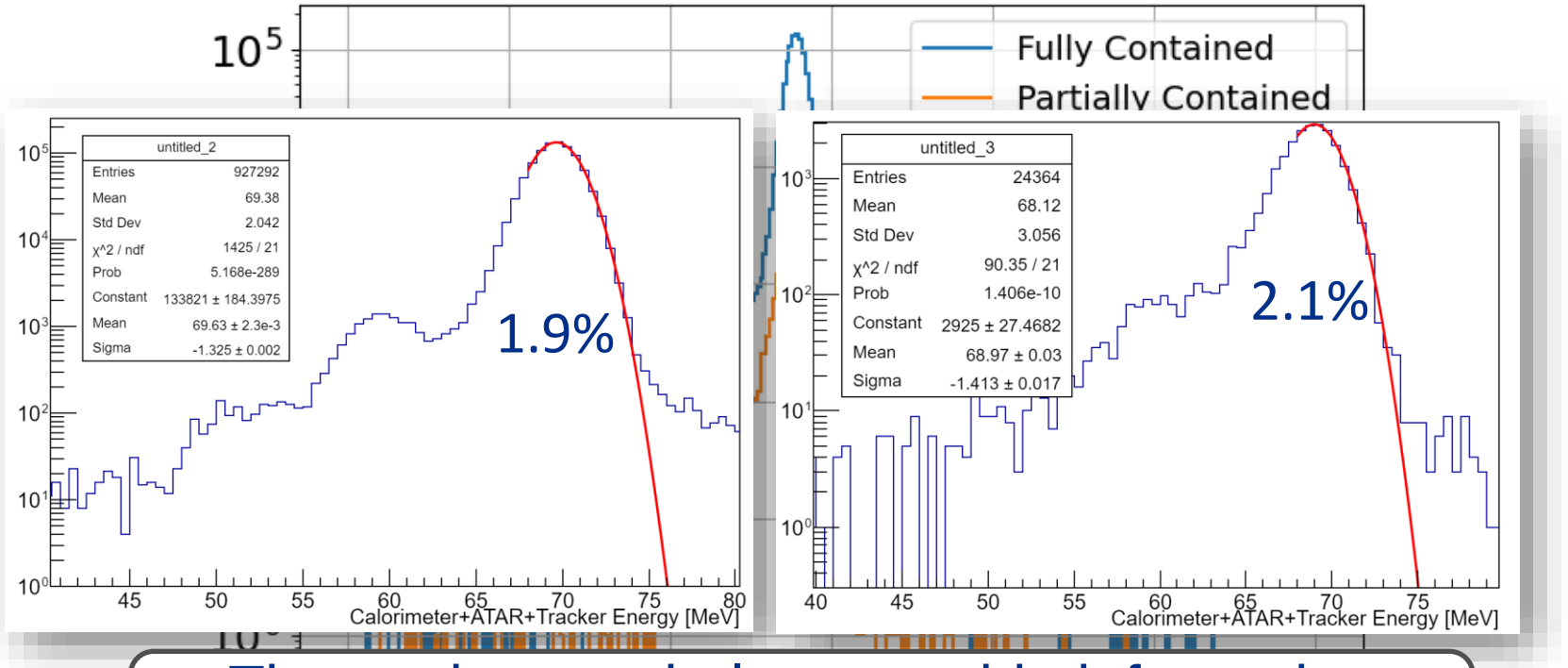
Tagging Scattering Outside Fiducial Volume



Tagging Scattering Outside Fiducial Volume



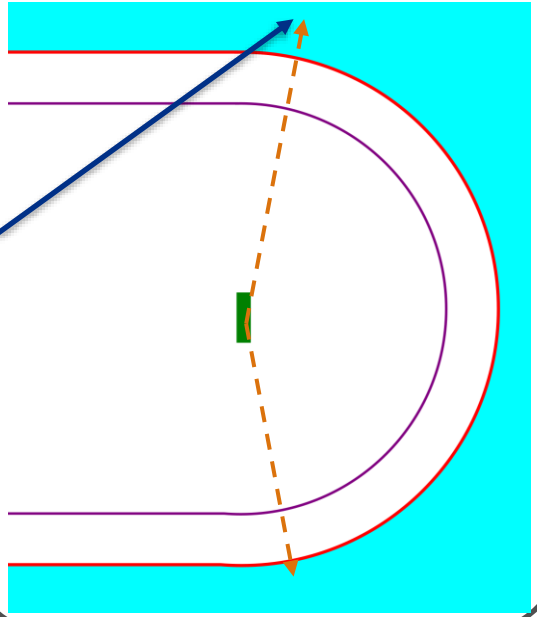
Tagging Scattering Outside Fiducial Volume



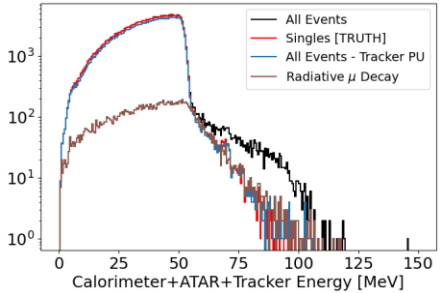
The tracker can help to provide information about energy leakage

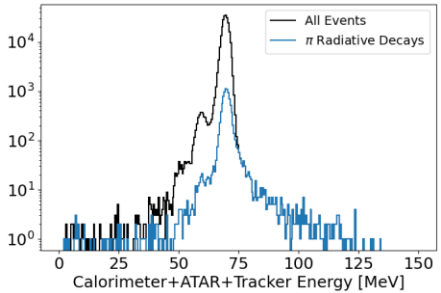
Additional Roles

Charged particle tagging for $\pi\beta$

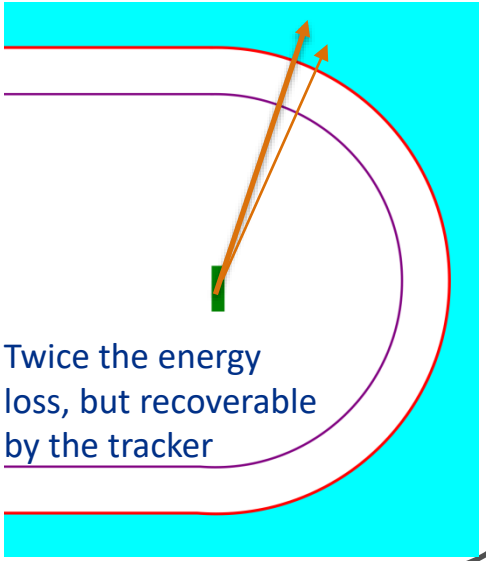


Radiative Decay Measurements





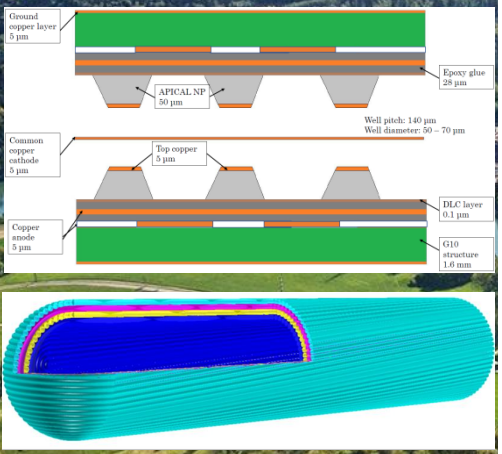
Dead material estimation for Bhabha events

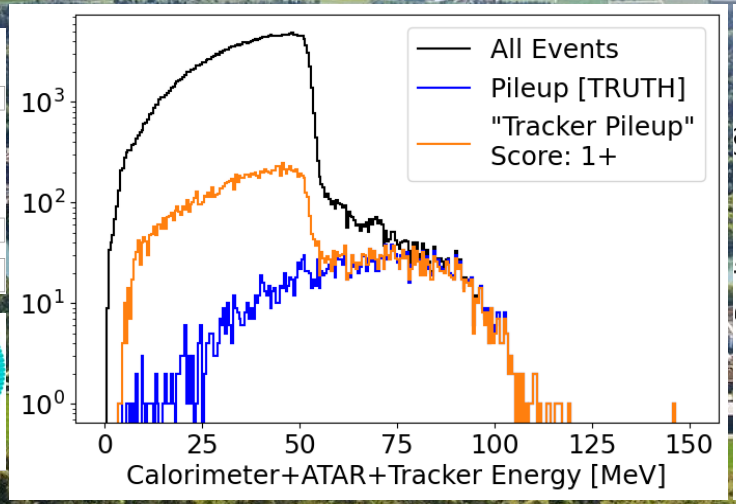


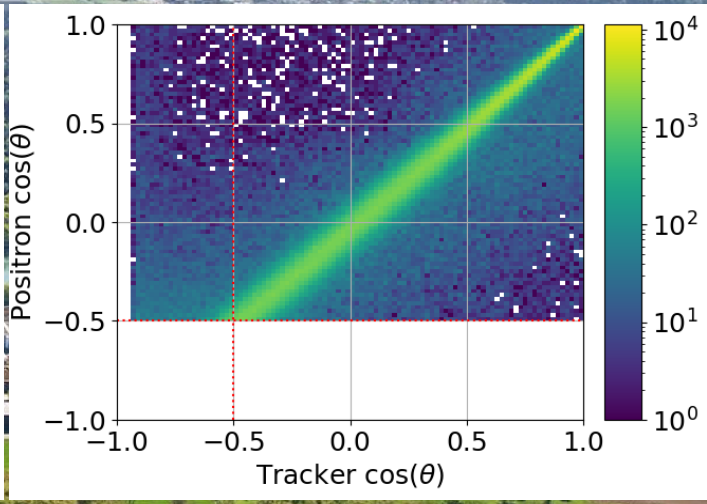
Twice the energy loss, but recoverable by the tracker

Conclusions

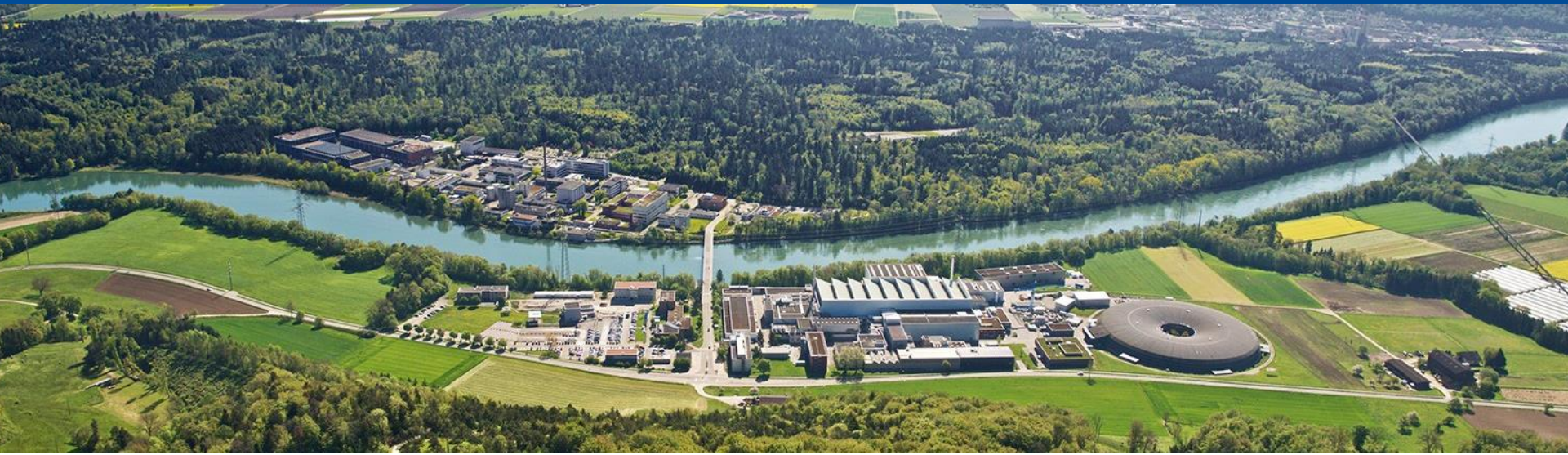
- The tracker has two important roles in the experiment:
  - Trigger
    - The bias to a potential trigger due to annihilation in flight (percent level contribution to all events) must be quantified and understood
  - Physics Analysis
    - A tracker with ‘reasonable’ timing and position resolution provides a great view into high energy pileup and scattering.
    - Studies are underway to quantify the needs of the tracker for all phases experiment
      - Timing resolution cuts may not be as stringent as imagined because of spatial resolution
- Integrating tracker information into the SPA pipeline is in its infancy, but is crucial to understanding the entire picture of the experiment.
  - Details of the hardware will be discussed in the sessions tomorrow
  - Integration of this detector into the proto-analysis chain is a goal for the software workshop
    - These studies can then be repeated with high statistics to get an understanding of higher order effects and bias to the final energy/timing spectrum


Ground copper layer 5 μm
Epoxy glue 28 μm
APICAL NF 50 μm
Well pitch: 140 μm
Well diameter: 50 – 70 μm
Common copper cathode 5 μm
Top copper 5 μm
DLC layer 0.1 μm
Copper anode 5 μm
G10 structure 1.6 mm


All Events
Pileup [TRUTH]
"Tracker Pileup"
Score: 1+
10^3
10^2
10^1
10^0
0
25
50
75
100
125
150
Calorimeter+ATAR+Tracker Energy [MeV]

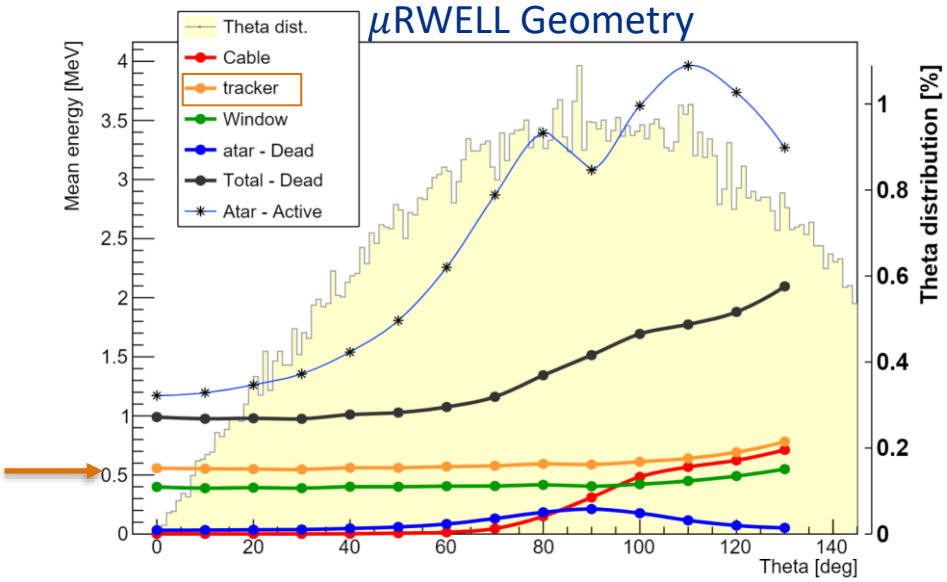

1.0
0.5
0.0
−0.5
−1.0
Positron cos(θ)
−1.0
−0.5
0.0
0.5
1.0
Tracker cos(θ)
10^4
10^3
10^2
10^1
10^0

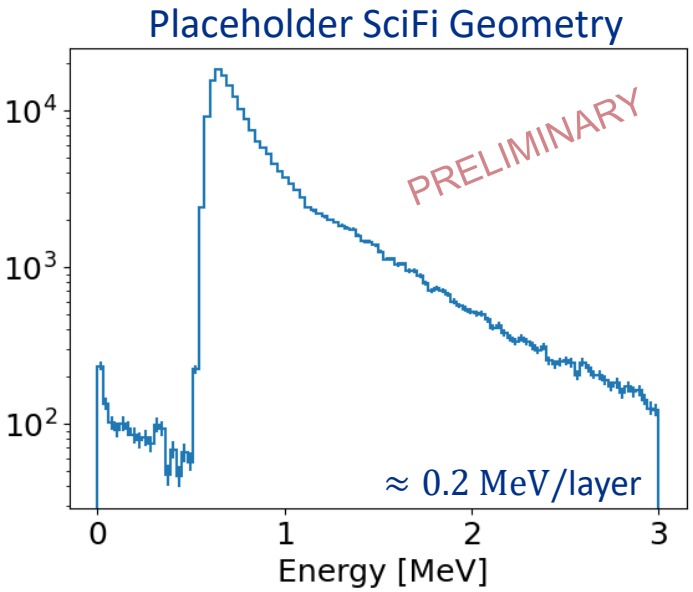
Questions?



Backup

Tracker Cost: Dead Material

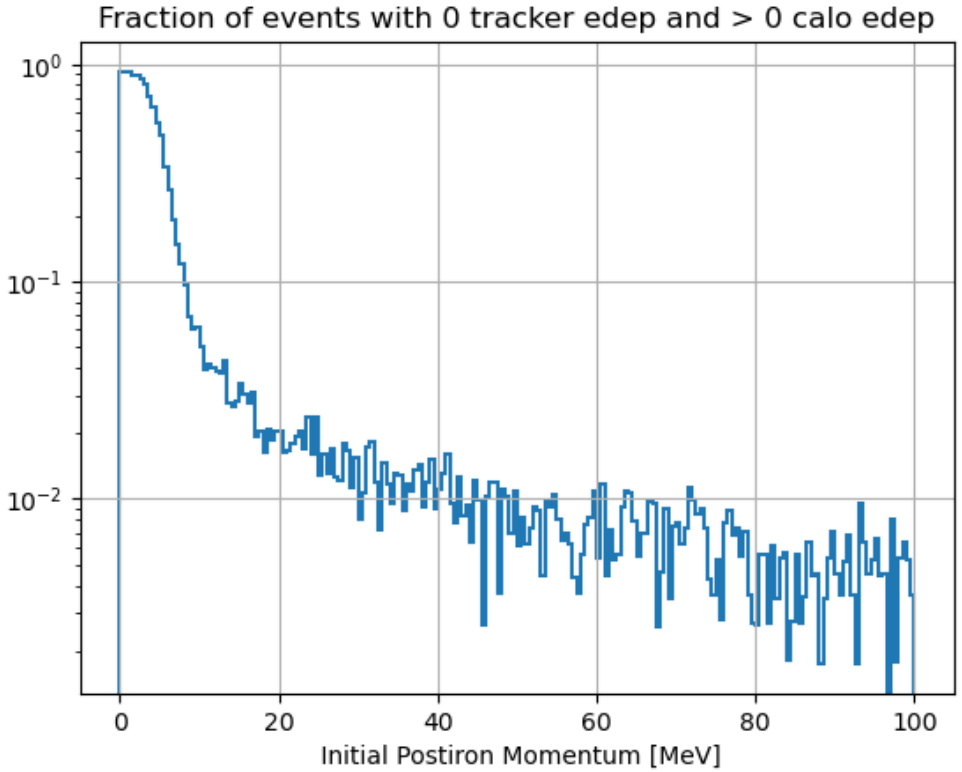




Energy deposition in either set of trackers is $\mathcal{O}(0.6\ \mathrm{MeV})$.
In principle, completely recoverable with a $\sigma \sim 0.15\ \mathrm{MeV}$.

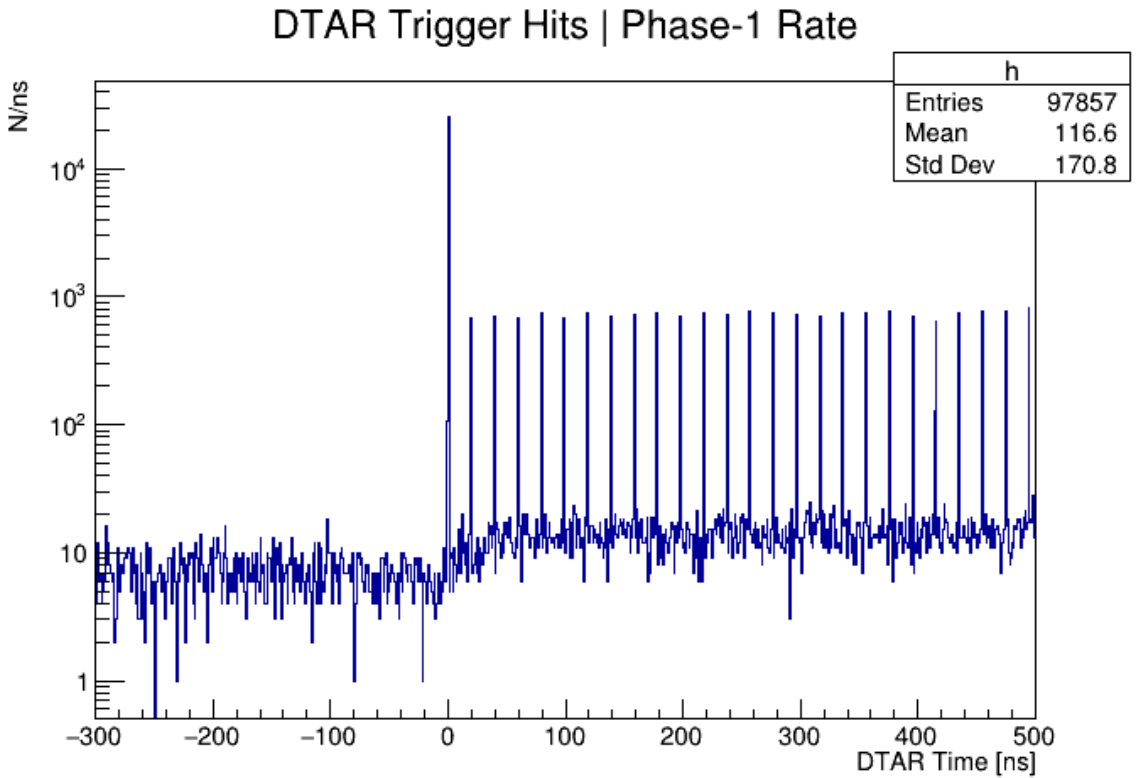
Left: Jessie Yang | See more in her talk here

e^+ Annihilation in Flight vs. Energy



Fiducial cut
Positrons generated in center of ATAR

Role: Pileup from Particles Outside ATAR



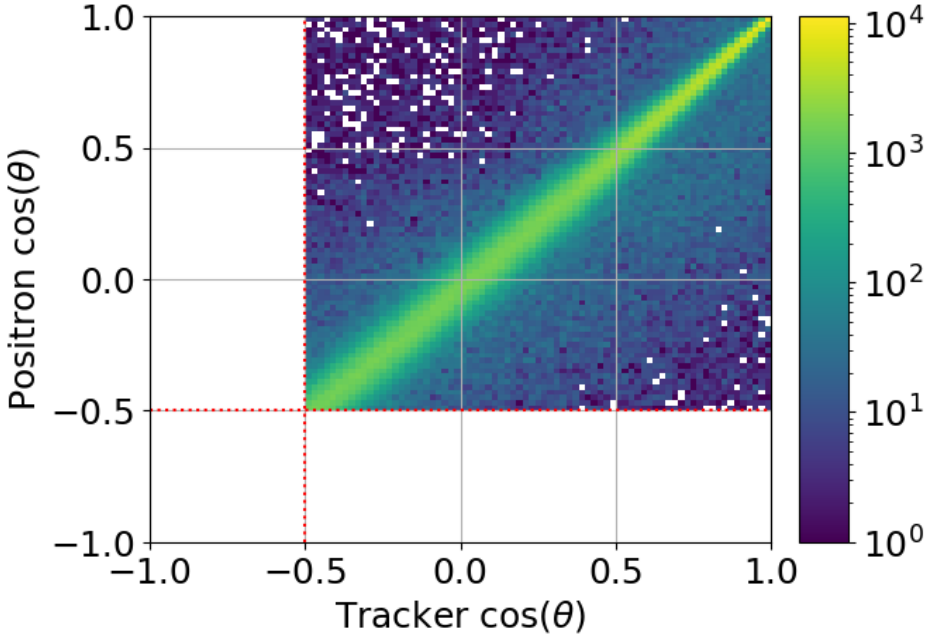
Role: Trigger

triggers	prescale	range	rate	CALO			ATAR digitizer			ATAR high thres	
		TR(ns)	(kHz)	ΔT(ns)	chan	MB/s	ΔT(ns)	chan	MB/s	chan	MB/s
PI	1000	-300,700	0.3	200	1000	120	30	66	2.4	20	0.012
CaloH	1	-300,700	0.1	200	1000	40	30	66	0.8	20	0.004
TRACK	50	-300,700	3.4	200	1000	1360	30	66	27	20	0.014
PROMPT	1	2,32	5	200	1000	2000	30	66	40	20	0.2

TABLE III – Main triggers: time range TR and trigger rates. For detector systems readout island length ΔT, average number of channels and required readout bandwidth are given.

Tagging Scattering Outside Fiducial Volume

All Contained



Partially Contained