SoLID Simulation Update

Radiation Dose Comparison and Magnetic Field Study for the FY26 Beam Test

Ye Tian

Work conducted at Syracuse University

- PreShower and Shower radiation dose comparison
- Magnetic field study for the FY26 beam test
- Summary

PVDIS Simulation Comparison

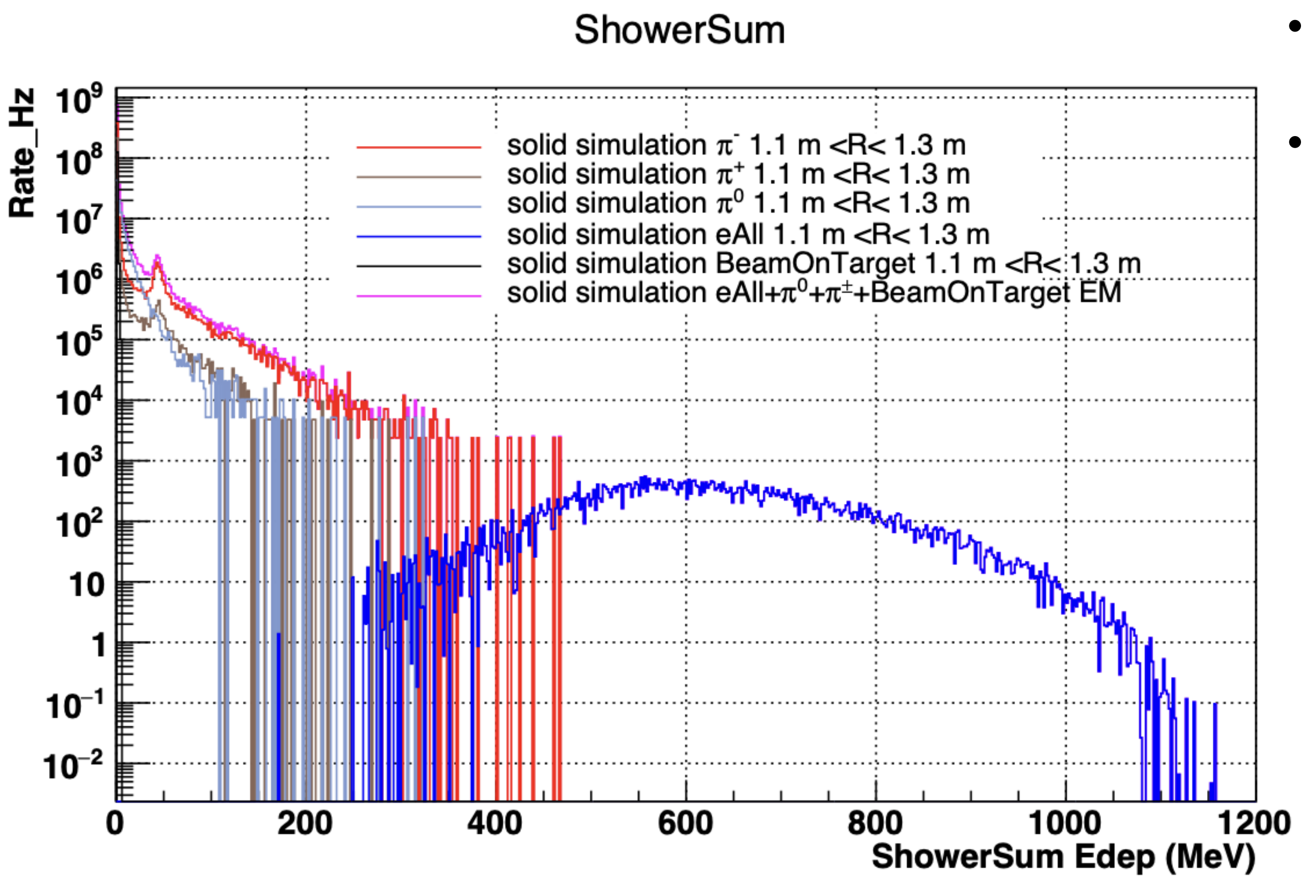
PreCDR Simulation: more than a decade old includes two step simulation
Current Simulation: latest generator, geometry, field map, G4 and G4 physics list

❑ Configurations:
- preCDR: shorter endcap with babarmore1 baffle (**lead baffle and kryptonite for everything else)**
- Babarmore1: longer endcap with babarmore1 baffle
- Moved: longer endcap with "CLEO2" baffle

❑ Generator:
- Wiser: pions
- eDIS: electron
- Bggen: pions
- eAll: electron

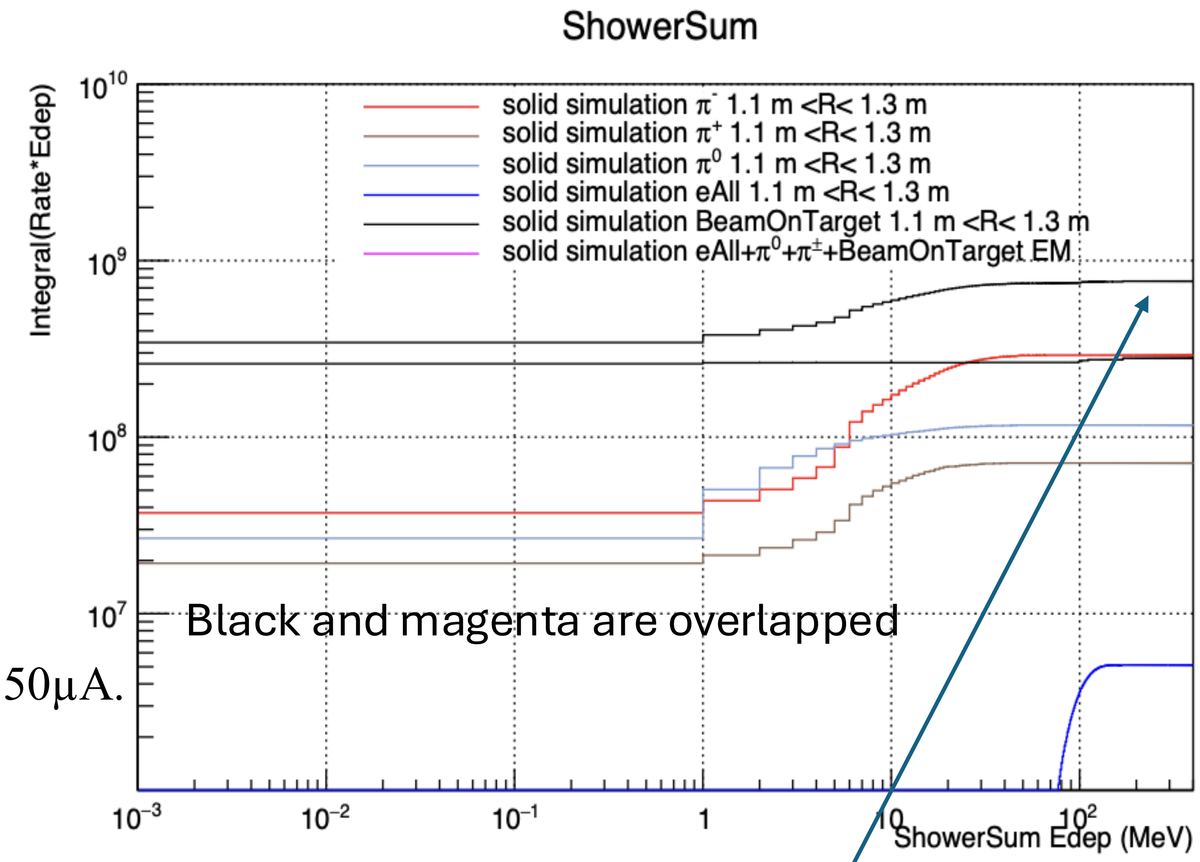
❑ Geant4: BeamOnTarget EM
- gemc2.9+geant4.10.7.p03

How to Get Radiation Dose



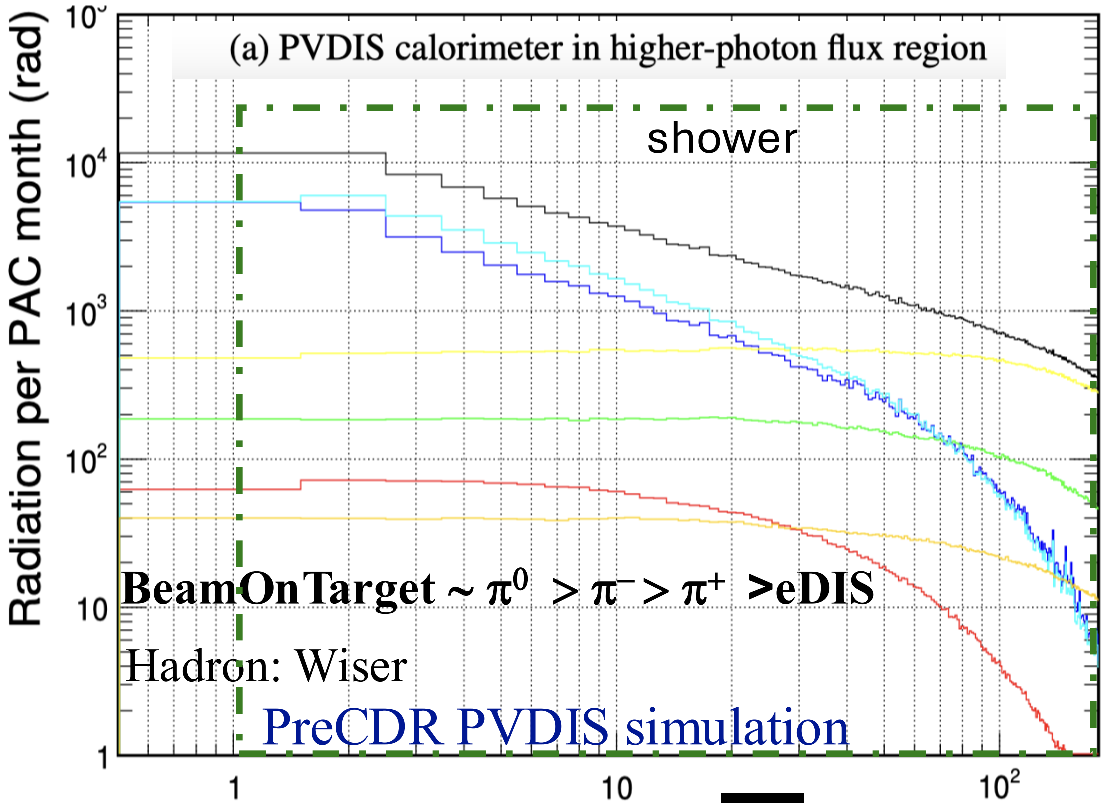
The Shower 6p1 distributions of solid simulation with 40cm LD2 at 50μA.

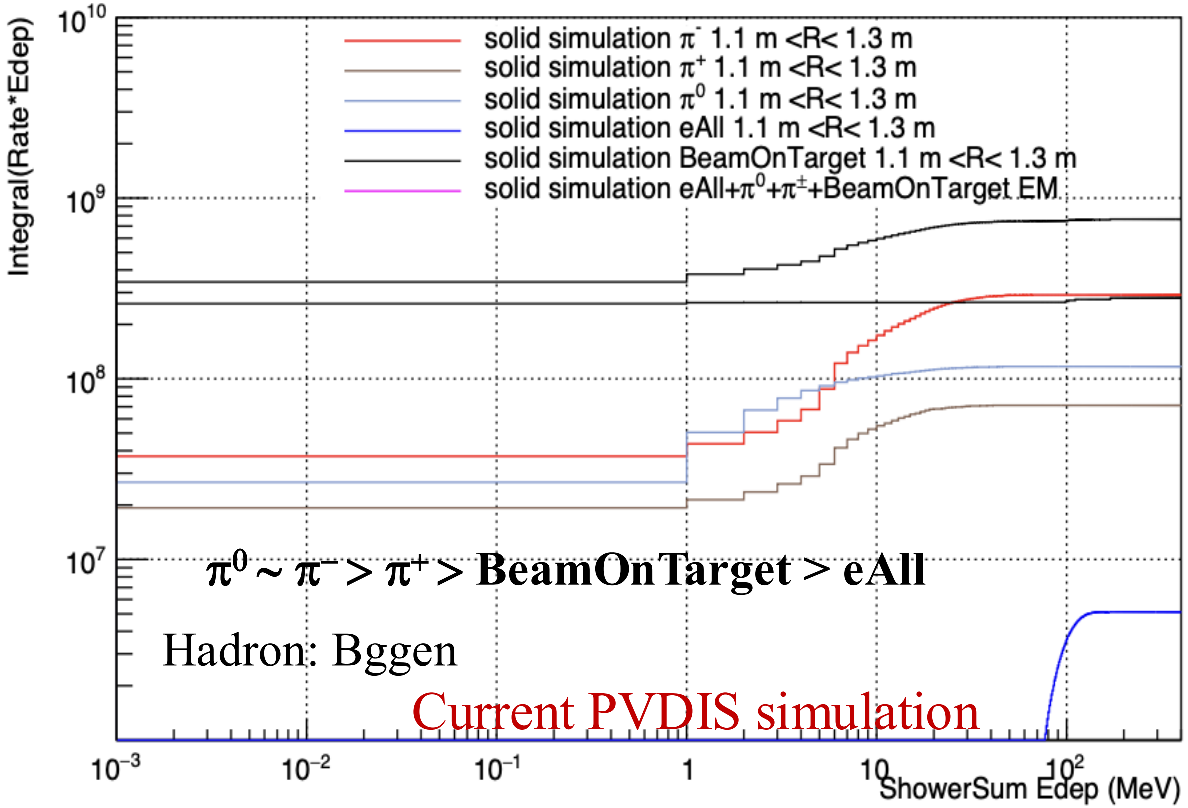
- Create a new histogram using: (bin center) × (bin content)
- Integrate the resulting values up to each bin to produce a cumulative (rate*Edep)



Use to calculate the total radiation dose

Radiation Dose Comparison at Shower



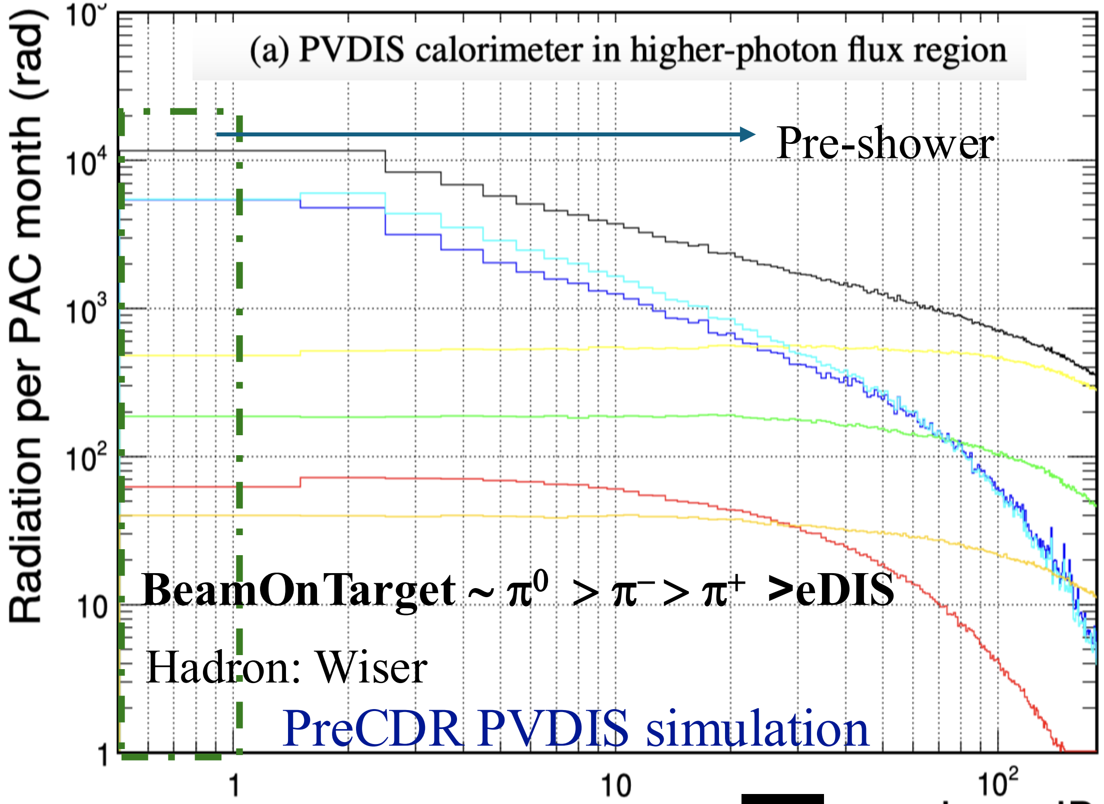


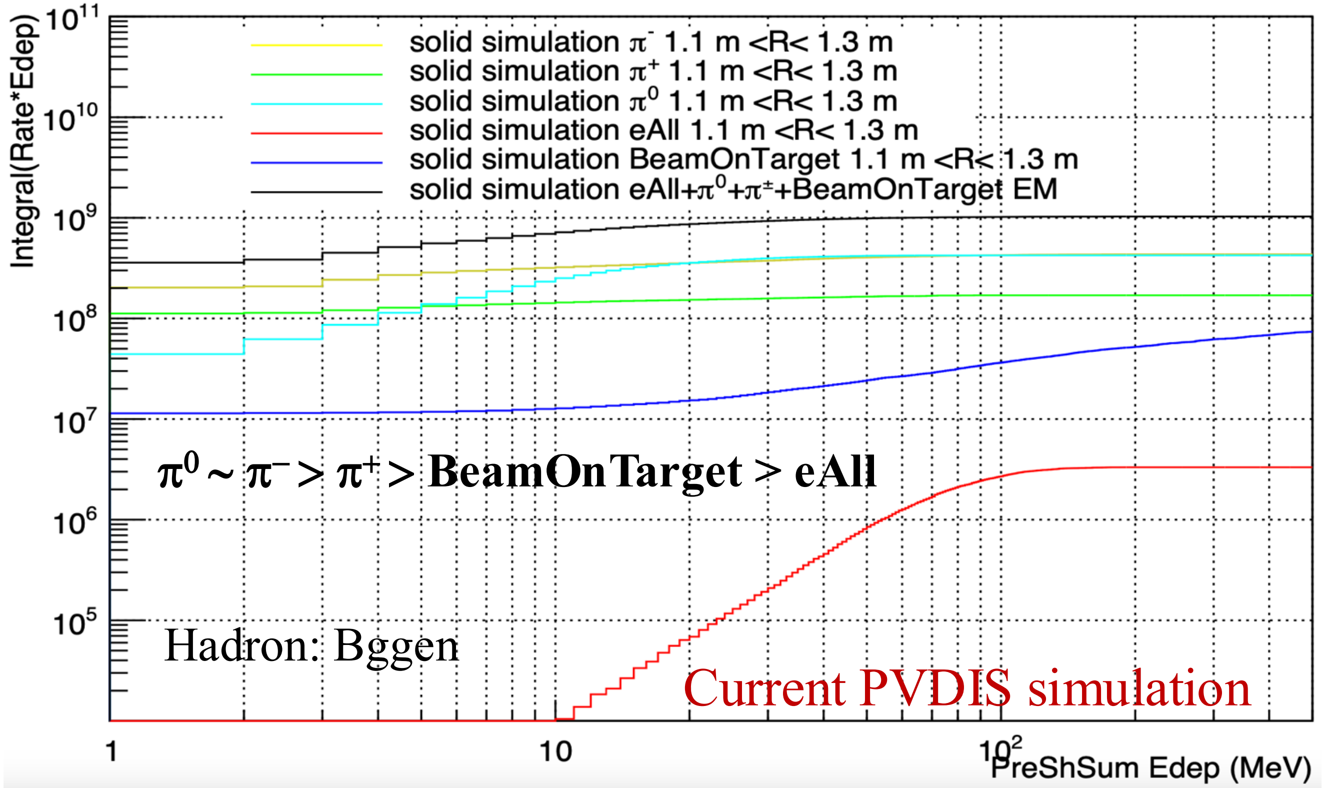
- Electrons, photons , EM total, π+, π −, and protons. The overall dose is shown by the black curve.

Current PVDIS:
7.4e8MeV/s*(30*24*60*60)s/(101.3*30cm^3*1g/cm^3)
= **10 krad /PAC month**

The radiation dose on the shower from the latest PVDIS simulation (10 krad/month) is comparable to that from the PreCDR PVDIS simulation

Radiation Dose Comparison at Pre-shower





- Electrons, photons , EM total, π+, π −, and protons. The overall dose is shown by the black curve.

PreCDR PVDIS: 10 krad/PAC month

Current PVDIS:
$1.03e9 MeV/s*(30*24*60*60)s/(7*101.3*2cm^3*1g/cm^3)$
=**30 krad /PAC month**

The radiation dose on the pre-shower from the latest PVDIS simulation (30 krad/month) is approximately three times higher than that from the PreCDR PVDIS simulation (10 krad/month)

Radiation Dose Comparison at Pre-shower

PreCDR document:

- The maximum integrated radiation level for the active material reaches **100 kRad for the PVDIS** experiment and 20 kRad in the SIDIS and J/ ψ experiments, which leads to a total radiation dose of less than **200 kRad** for all approved experiments.
- Experience from **LHCb shows light yield of their pre-showers reduce by factor two at 200 kRad and factor five at 2 Mrad**.
- Our own irradiation tests of pre-shower prototypes showed similar results at 200 kRad. **While we are confident the current design will last 200 kRad**, studies of the effect on the detector performance with reduced light yield is on-going.

➢ Latest PVDIS simulation shows a total pre-shower radiation dose of ~300 krad

➢ This is a significant increase compared to the PreCDR estimate (~100 krad)

➢ Higher accumulated radiation dose may degrade pre-shower detector performance, prompting a potential redesign of the readout system

Pre-shower Radiation per PAC Month

() indicate radiation contributed from Prime particles tid==1, () from γ from π^0

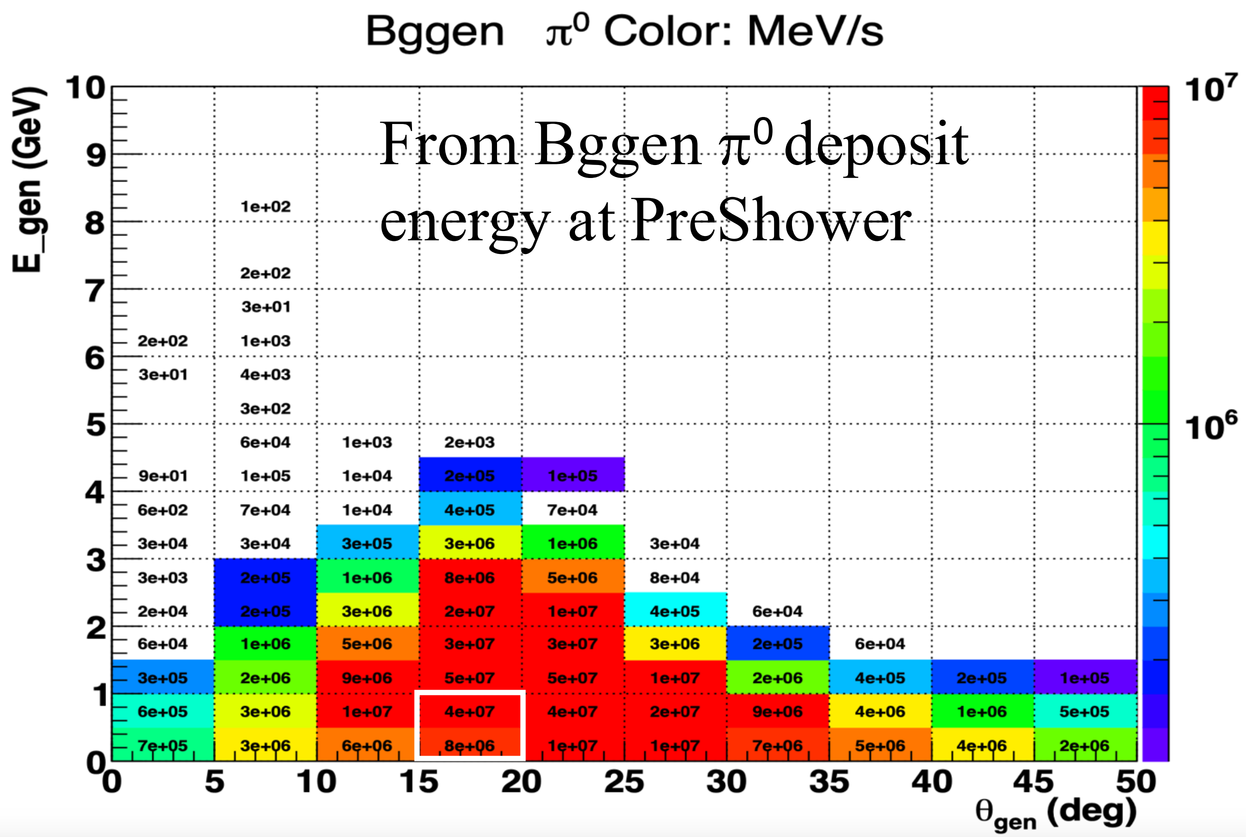
<table>
<tr><th colspan="3">Edep</th><th>π^-
krad/month</th><th>π^+
Krad/month</th><th>π^0
Krad/month</th><th>BeamOnTargetEM
Geant4
Krad/month</th></tr>
<tr><td rowspan="3">shorter endcap with "babarmore1" baffle</td><td rowspan="2">Wiser</td><td>preC DR</td><td>0.5</td><td>0.2</td><td>5.5</td><td>5.5</td></tr>
<tr><td>latest study</td><td>PreSh:29.1(8.6)</td><td>PreSh:15.8(2.7)</td><td>PreSh:48.9(0.77)</td><td rowspan="2">2.7</td></tr>
<tr><td colspan="2">Bggen</td><td>PreSh:19.6(7.1)</td><td>PreSh:4.8(0.75)</td><td>PreSh:13.2(0.23)</td></tr>
<tr><td>longer endcap with "babarmore1" baffle</td><td colspan="2">Bggen</td><td>PreSh: 23.6 (7.3)</td><td>PreSh:5.7(0.78)</td><td>PreSh:11.1(0.012)</td><td>2.5</td></tr>
<tr><td>longer endcap with "CLEO2" baffle</td><td colspan="2">Bggen</td><td>PreSh:17.3(6.3)</td><td>PreSh:3.8(0.62)</td><td>PreSh:12.8(0.22)</td><td>1.9</td></tr>
</table>

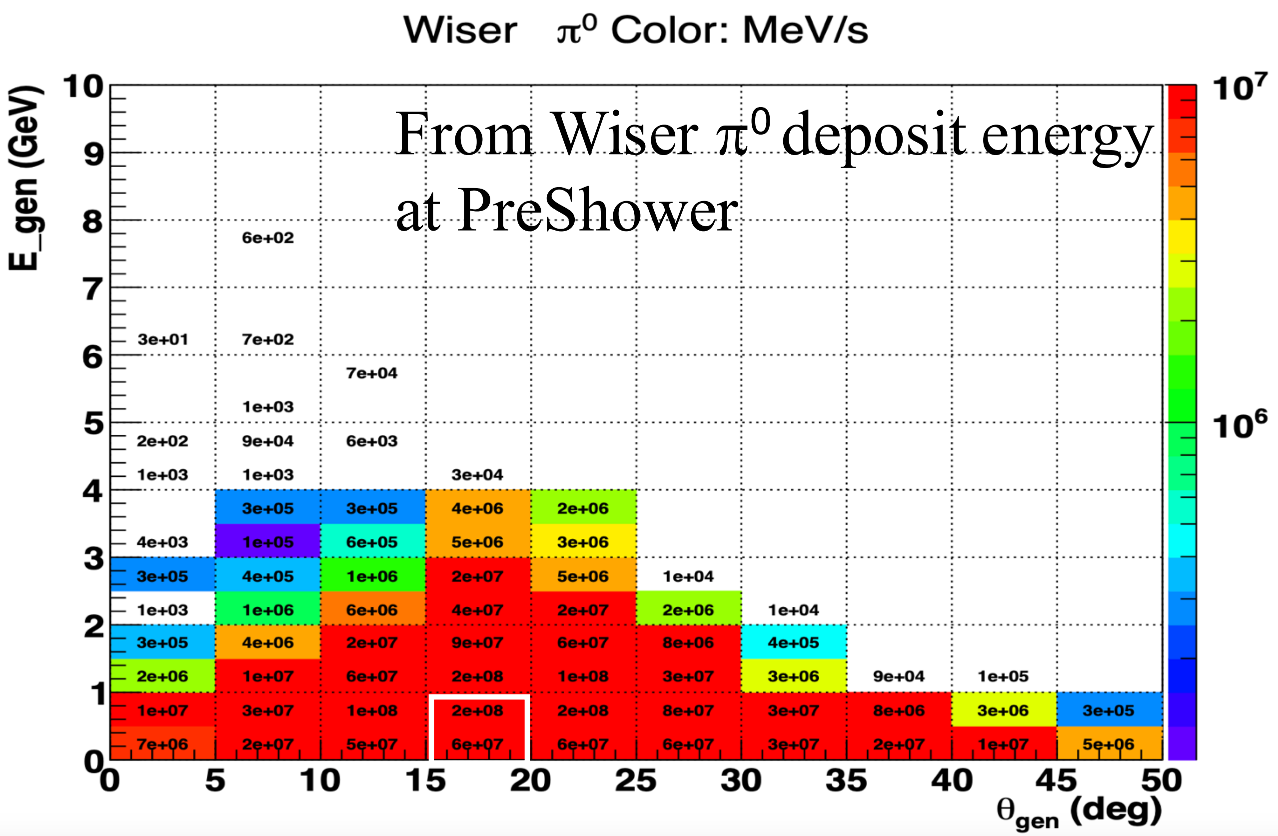
The Wiser event generator predicts significantly higher radiation dose in the pre-shower than Bggen.

Which estimate is more reliable?

Bggen vs Wiser for π^0

- Which generated events cause the most damage?

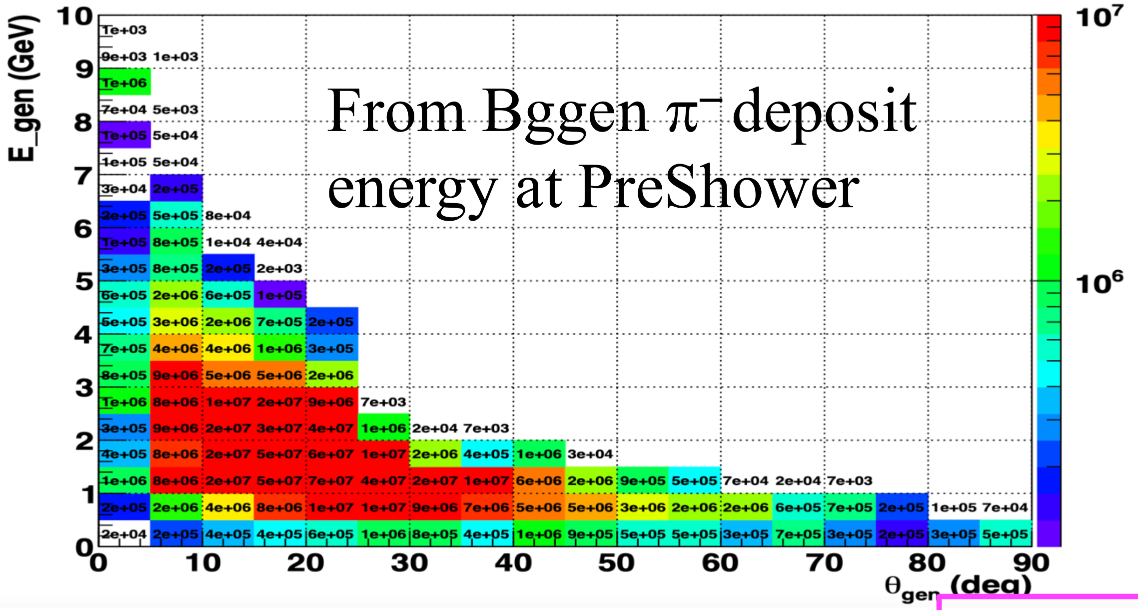


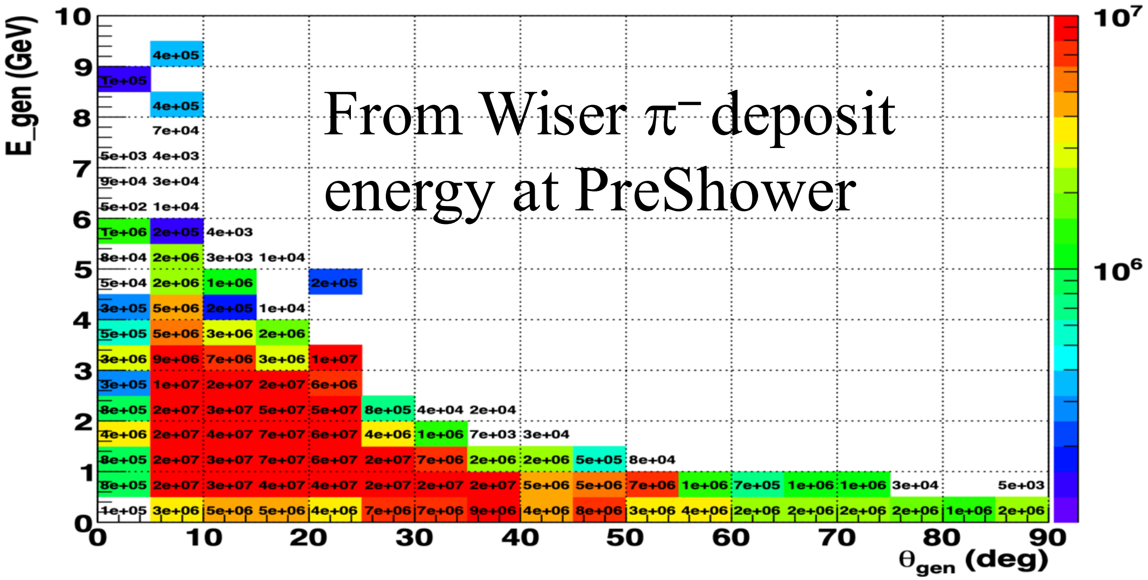


Color: rate*Edep_preshower (MeV/s)

- For the Wiser generator, most of the radiation damage comes from low energy and low angle π^0.
- For low energy and low energy π^0, the Wiser and Bggen codes predict very different contributions.
- **Wiser overestimates low-energy π^0**

Bggen vs Wiser for $\pi^{\pm}$





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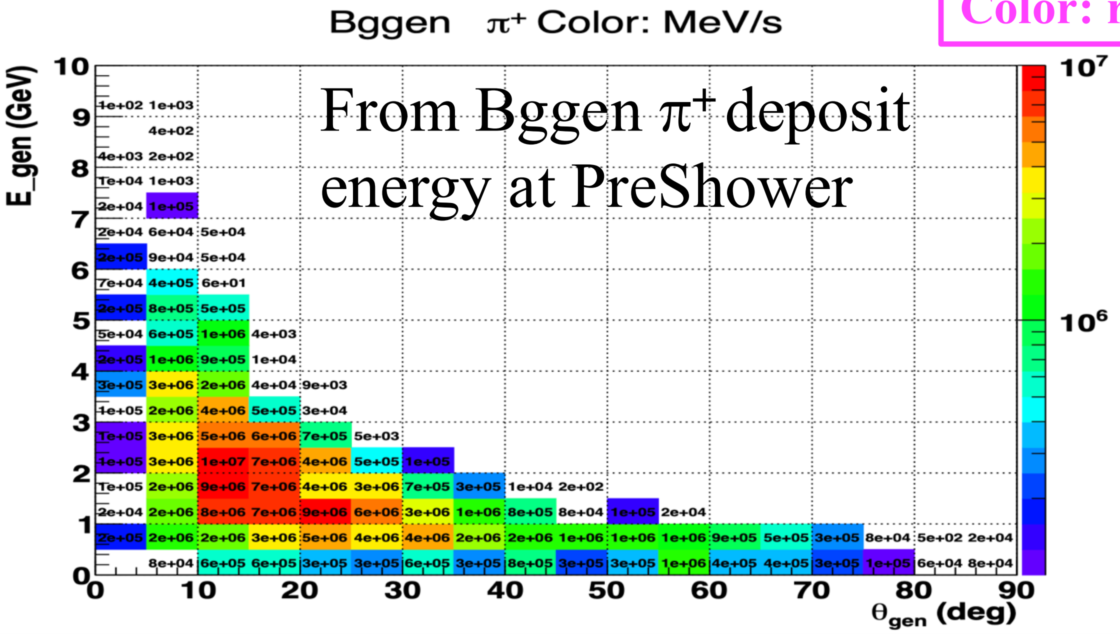

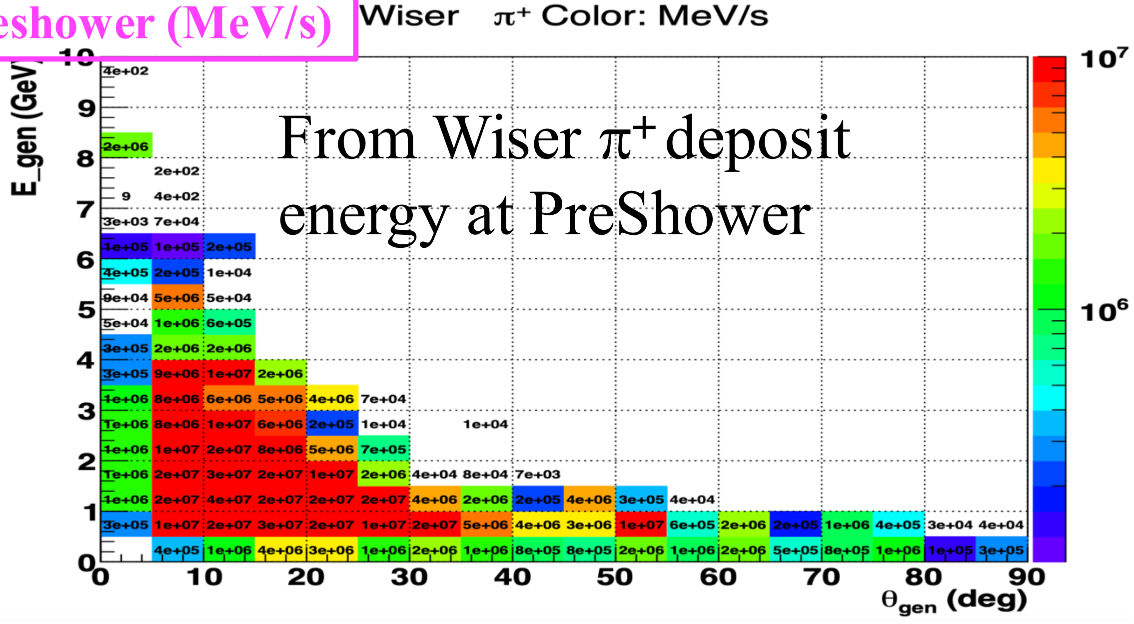

Pre-shower Radiation per PAC Month with Different E_gen Cuts

() indicate radiation contributed from Prime particles tid==1, () from γ from π^0

Edep No cut			π^- krad/month	π^+ Krad/month	π^0 Krad/month
shorter endcap with "babarmore1" baffle	Wiser	latest study	PreSh:29.1(8.6)	PreSh:15.8(2.7)	PreSh:48.9(0.77)
	Bggen		PreSh:19.6(7.1)	PreSh:4.8(0.75)	PreSh:13.2(0.23)
Edep E_gen>1 GeV			π^- krad/month	π^+ Krad/month	π^0 Krad/month
shorter endcap with "babarmore1" baffle	Wiser	latest study	PreSh: 20.8 (7.5)	PreSh: 10.9 (1.7)	PreSh:19.9(0.26)
	Bggen		PreSh:17.0 (6.6)	PreSh: 3.7 (0.58)	PreSh:7.6(0.088)
Edep E_gen>2 GeV			π^- krad/month	π^+ Krad/month	π^0 Krad/month
shorter endcap with "babarmore1" baffle	Wiser	latest study	PreSh: 8.0(3.07)	PreSh: 4.0 (0.18)	PreSh: 2.9 (0.019)
	Bggen		PreSh: 5.7(2.22)	PreSh: 1.8 (0.19)	PreSh:1.6 (0.019)

Checking preCDR Wiser Result

() indicate radiation contributed from Prime particles tid==1, () from γ from π^0

<table>
<tr><th colspan="3">Edep</th><th>π^- krad/month</th><th>π^+ Krad/month</th><th>π^0 Krad/month</th><th>BeamOnTargetEM Geant4 Krad/month</th></tr>
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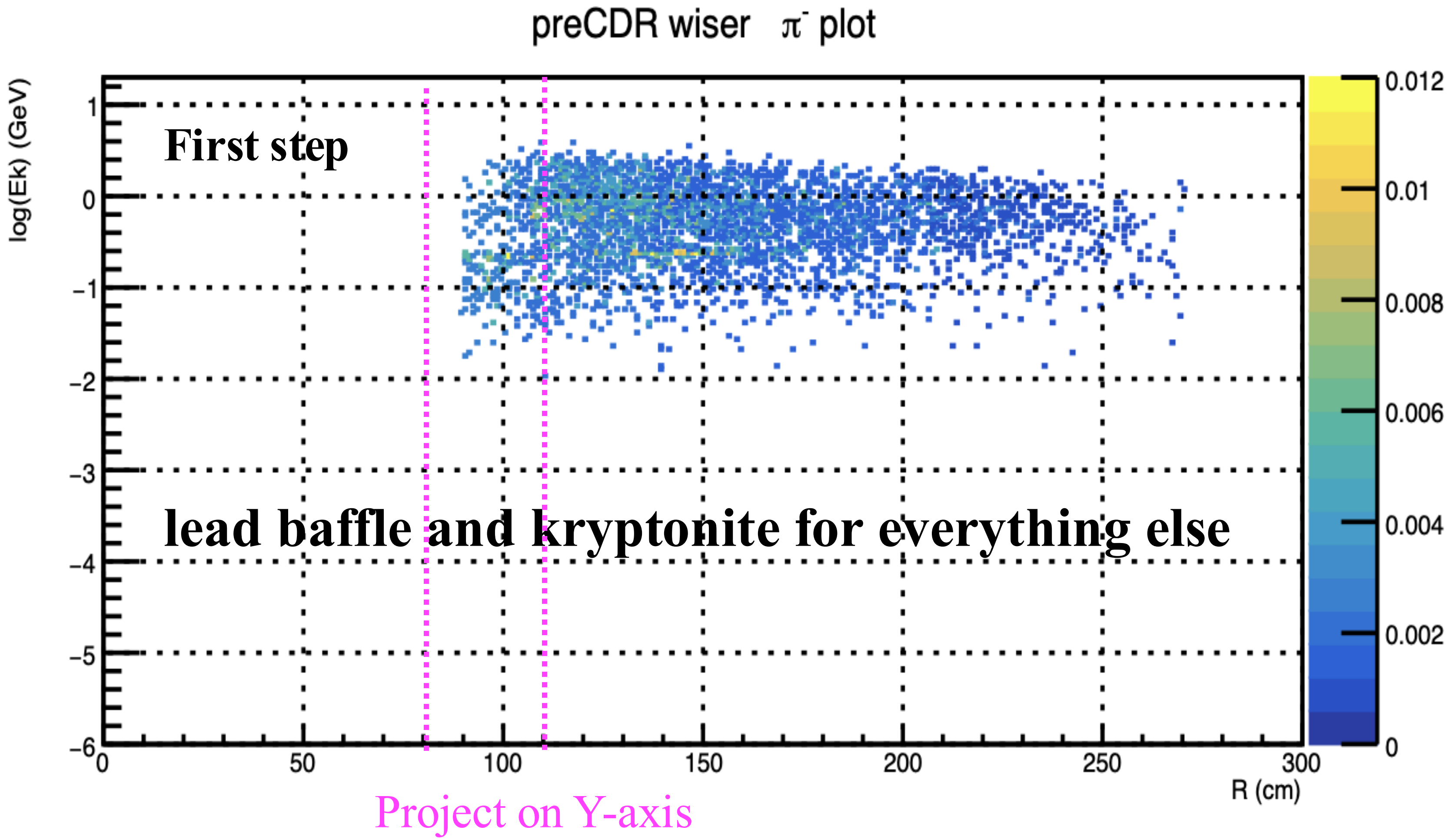
Checking preCDR Wiser Result



At FAEC front

pid=

0 photon+electron+positron

1 photon

2 electron + positron

3 neutron

4 proton

5 pip

6 pim

7 Kp

8 Km

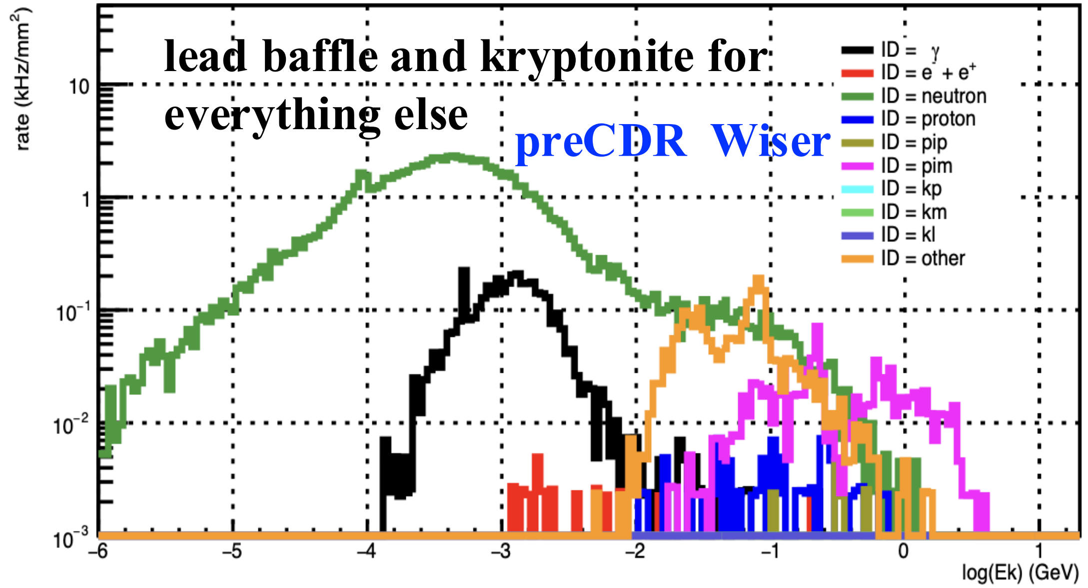
9 Kl

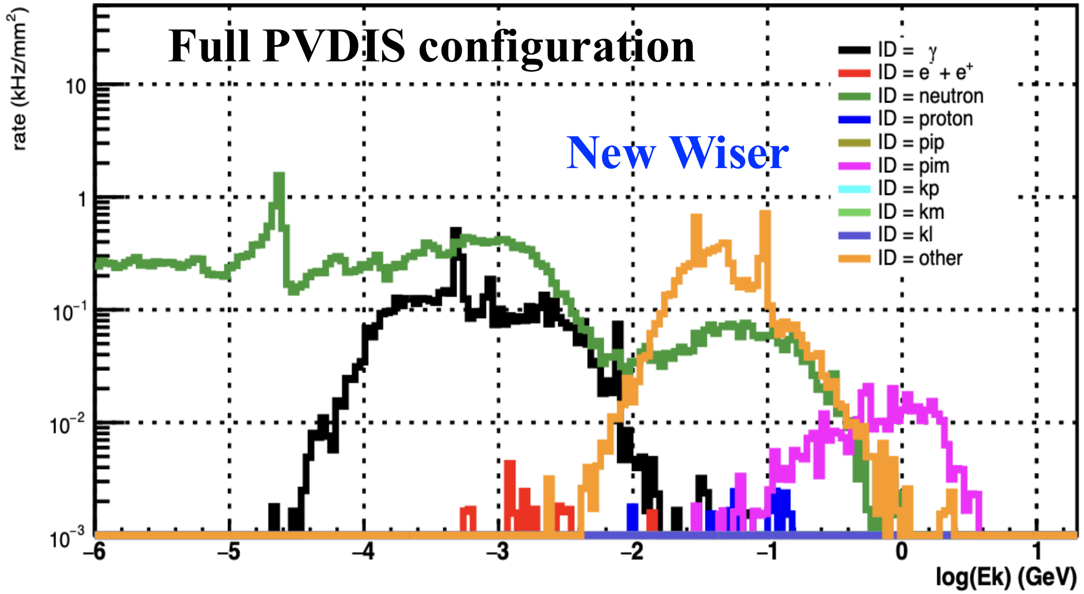
10 other

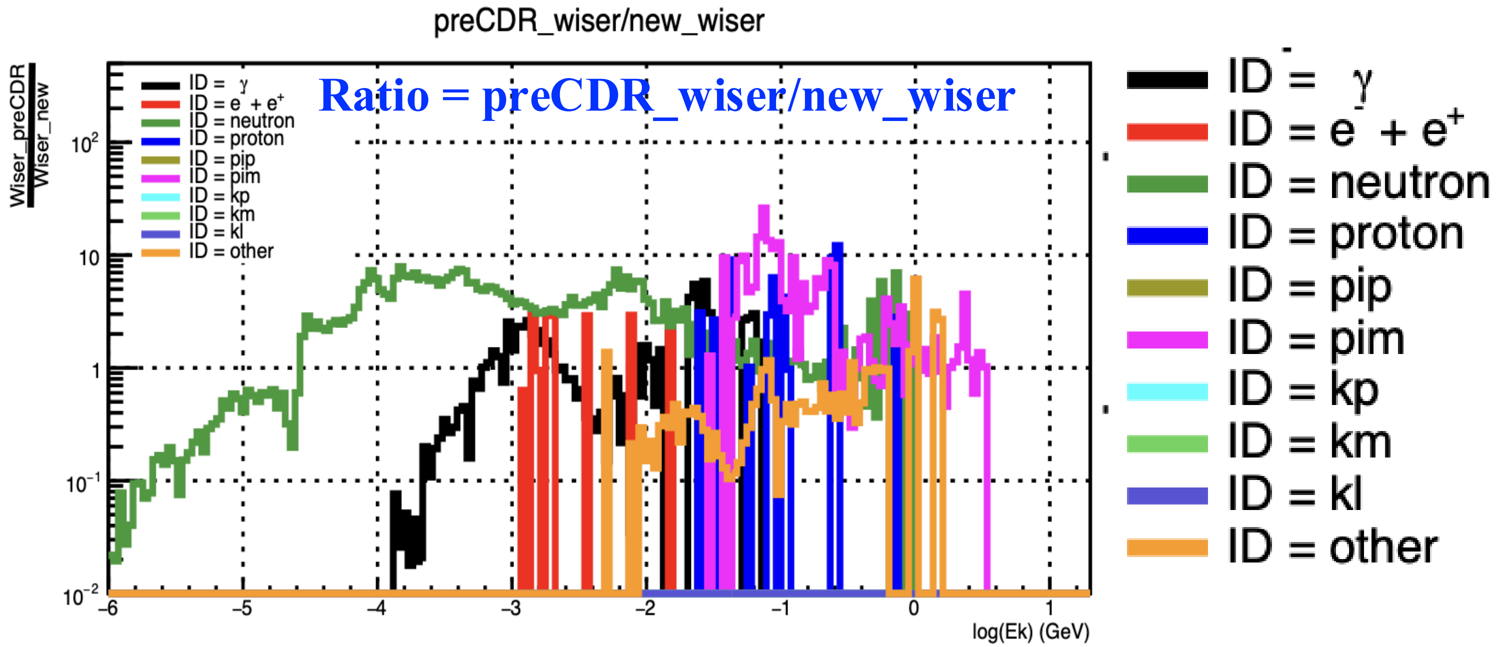
- **PID = π^-**
- **Z-axis is rate (kHz/mm2)**

- /lustre24/expphy/cache/halla/solid/sim/solid_gemc/PVDIS_LD2_run1/baffle_babarbafflemore1_block/background_solid_CLEO_PVDIS_LD2_real_pi*_1e6_output.root

Checking preCDR Generated Wiser π^-

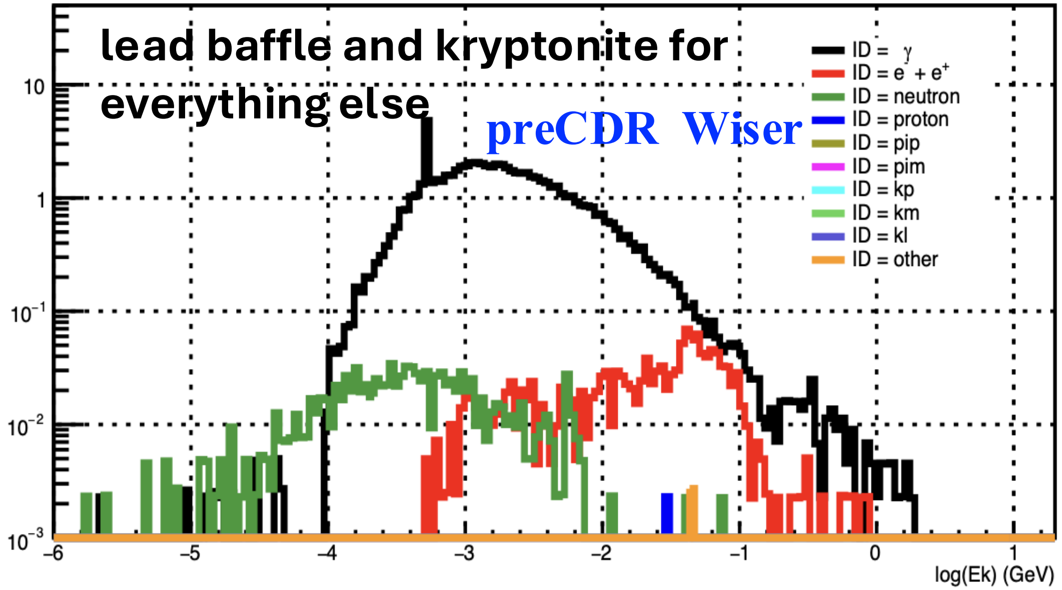


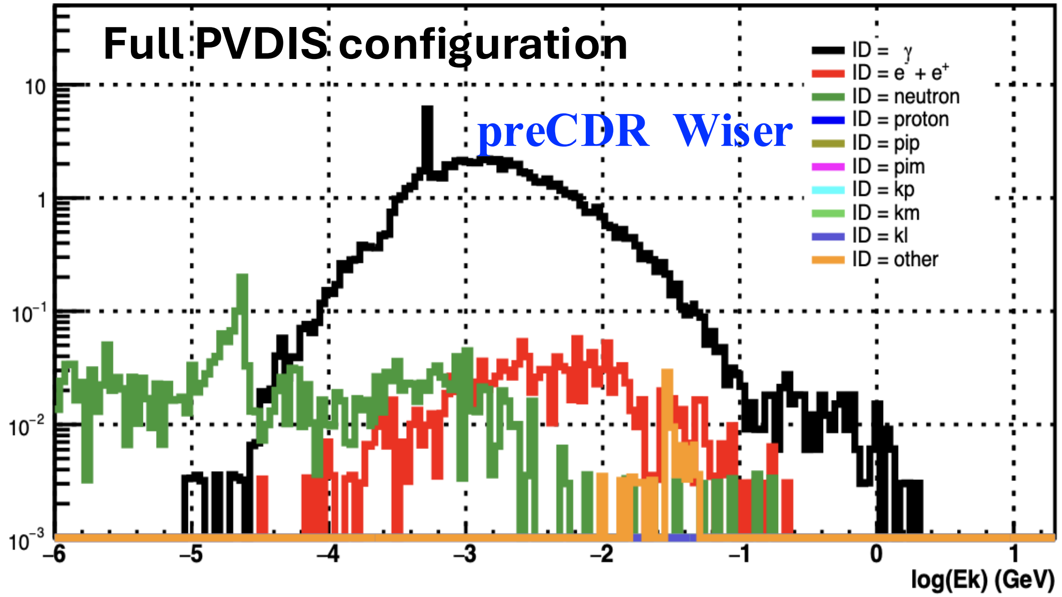


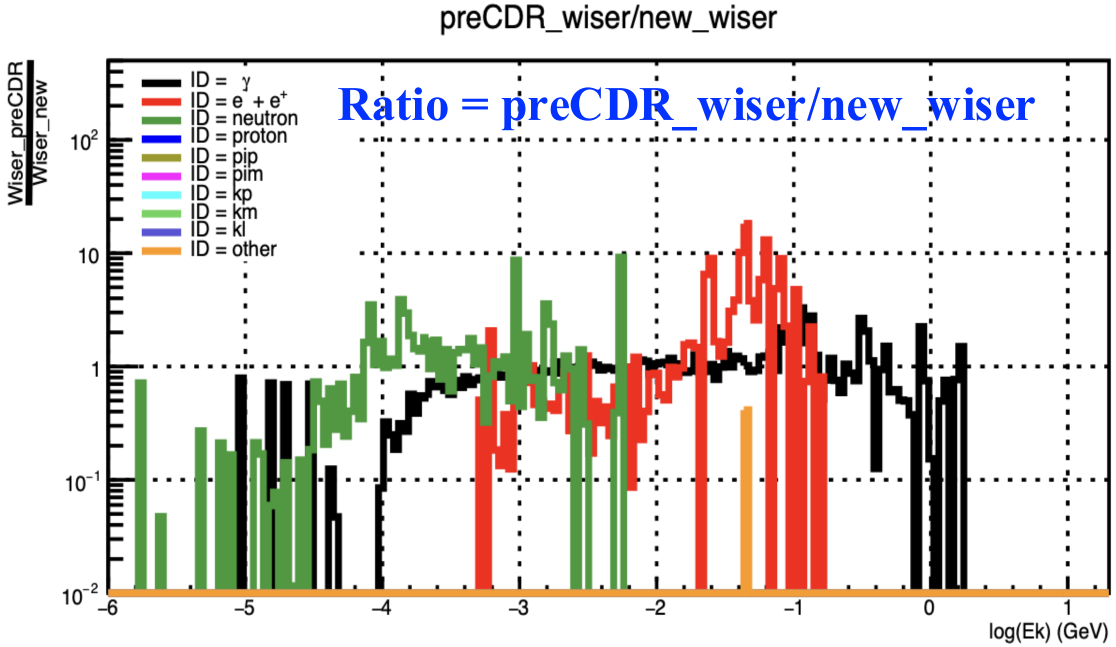


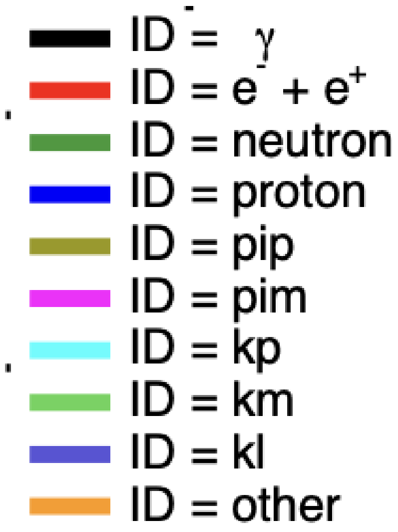
- 80 cm <R<110 cm
- Everything from π^-
- Y-axis is rate (kHz/mm2)
- X-axis is log (Ek) in front of prelead

Checking preCDR Generated Wiser π^0









- 80 cm <R<110 cm
- Everything from π^0
- Y-axis is rate (kHz/mm2)
- X-axis is log (Ek) in front of prelead

PreShower Radiation Dose Study Summary

- ❑ The shower radiation dose from the latest PVDIS simulation matches the PreCDR value when using a shower module length of 30 cm (1.5×200 cm).

- ❑ The Pre-shower radiation dose from the latest PVDIS simulation is three times higher than the PreCDR value.

- ❑ The Wiser generator is inadequate for the radiation background study because it lacks accurate treatment of low-energy processes, which are the main contributors to SoLID PVDIS radiation.

- ❑ Energy Profile of Radiation Backgrounds at pre-shower:
  - Most background is punch-through from the baffles, and the particles have low energy.
  - High-energy π^- are within acceptance, but not dominant in radiation damage
  - Low-energy π^0 are more relevant for dose near sensitive regions

Next Steps:

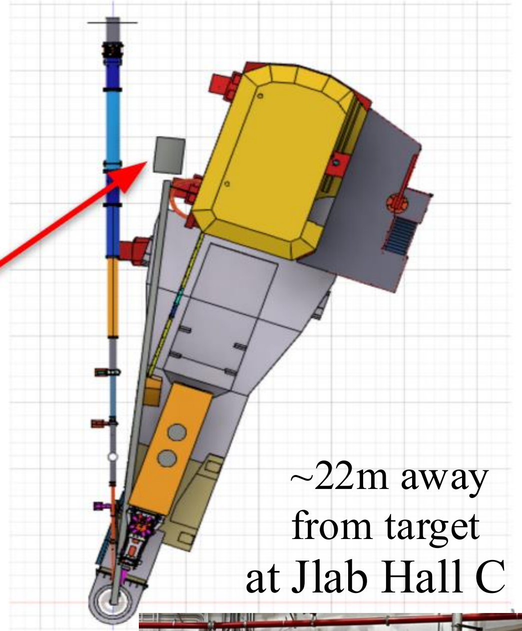
- ❑ Compare the results form Jin's old ECAL standalone code with the current calculation ---Zhiwen and Ye

- ❑ To update the design to get the radiation on the pre-shower with FLUKA--- Lorentzo?

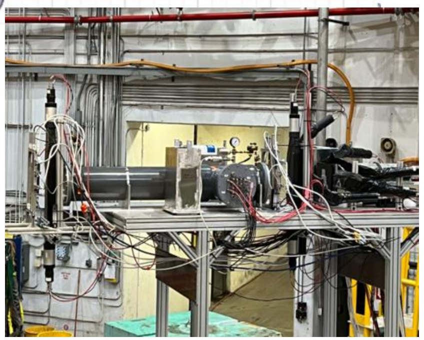
Latest pre-R&D – Detector Beam Test

- ❑ The best GEM quadrants works reasonable with the tracks based on the detection efficiency < 50%, and the other quadrants are much worse. Due to the reason of not setting GEMs properly, it is not worth to do further analysis at this point.
- ❑ For setting GEM detectors properly, it requires low-rate condition to do the alignment and the APV gain checking.

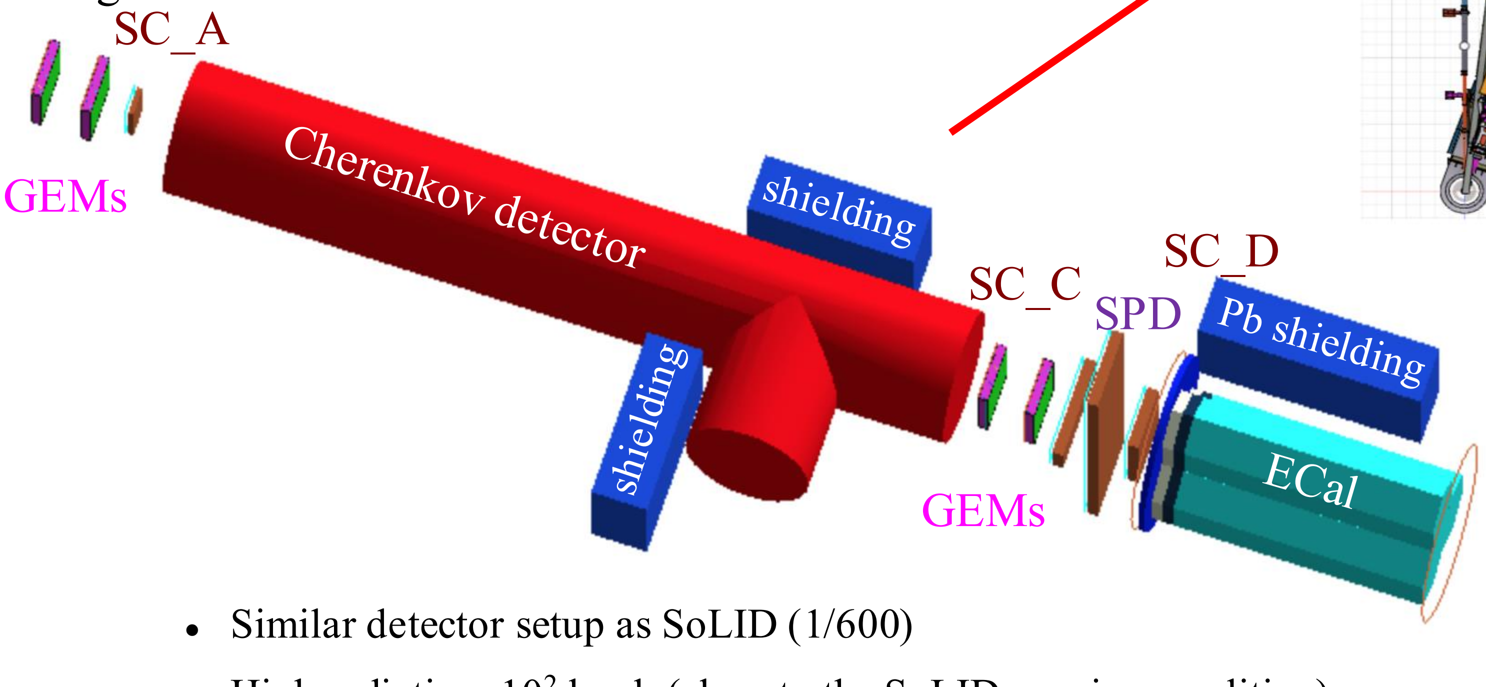
High Momentum Spectrometer (HMS)



~22m away from target at Jlab Hall C



~22m away from target

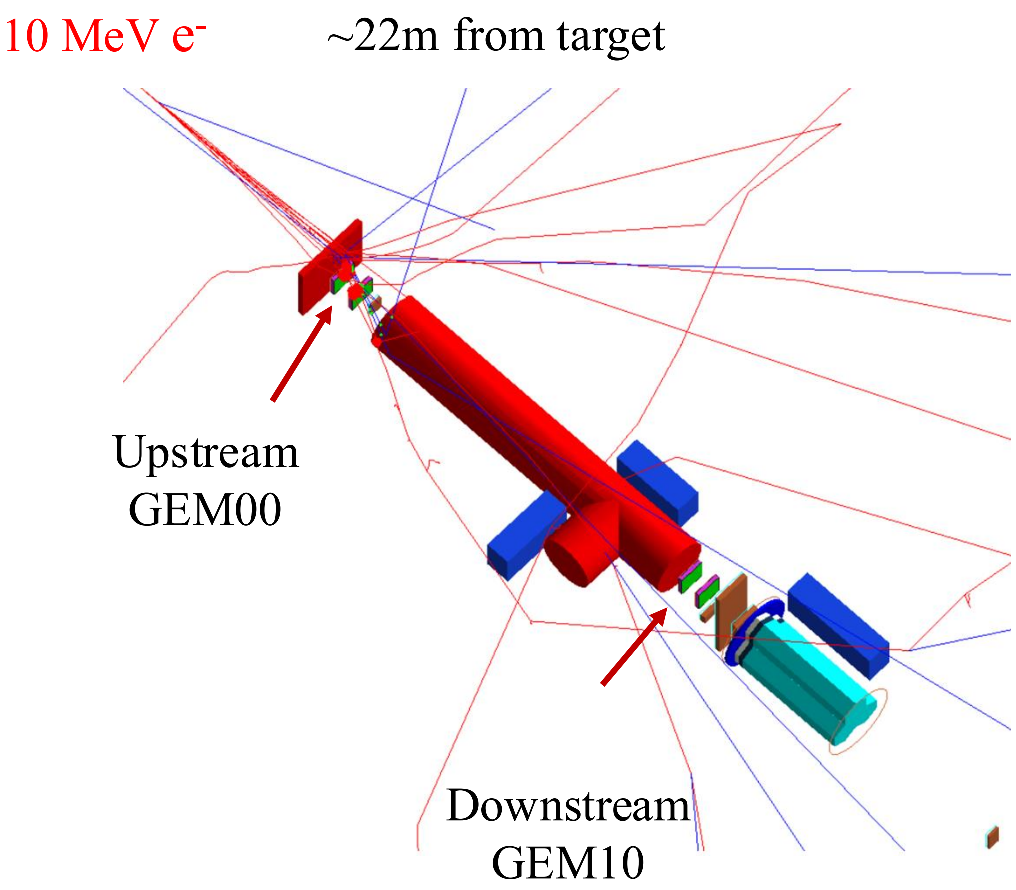


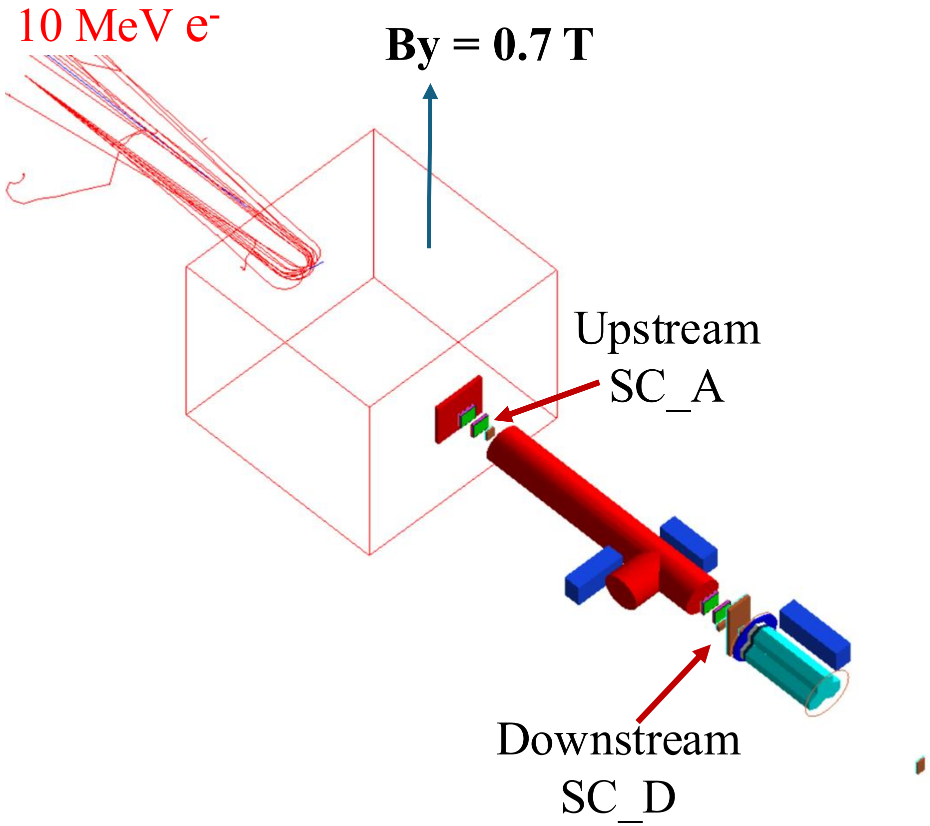
- Similar detector setup as SoLID (1/600)
- High radiation: 10^2 krad (close to the SoLID running condition)
- Parasitic measurement: no magnet

Magnetic Field Study for the FY26 Beam Test

Reducing soft background - soft Moller electrons (~10MeV @ θ=18deg) in front of upstream GEMs and SCs:

- Material or magnetic field?





Magnetic Field Study for the FY26 Beam Test

Rate MHz/cm2	Edep>0.5MIP	Edep>0.5MIP e^-	Edep>0.5MIP γ
SC_A	0.96	0.71	0.15
SC_A with field	0.096	0.024 (**3.4% left**)	0.066
SC_D	0.41	0.20	0.17
SC_D with field	0.30	0.12 (**60% left**)	0.14

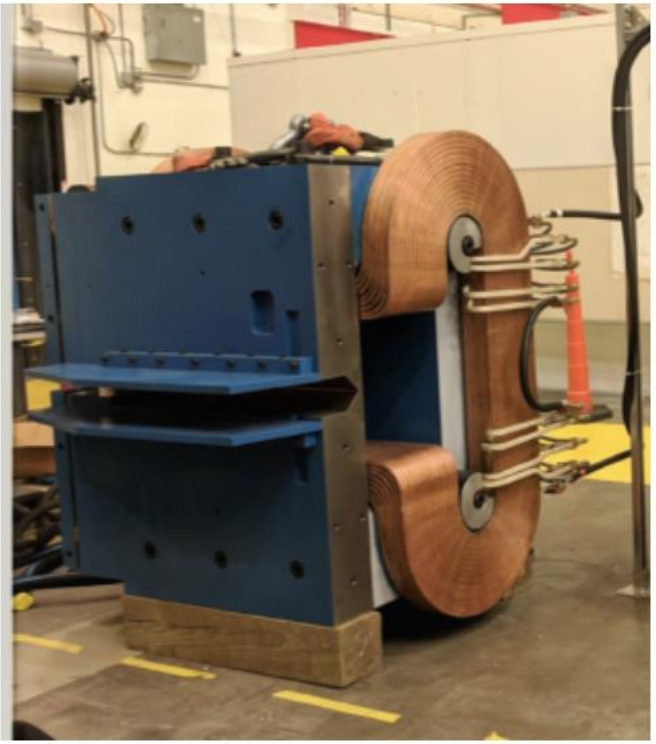
Rate MHz/cm2	Edep>35e-6	Edep>35 eV + e^-			Edep>35 eV + γ	
		all	from target	from poly	all	from poly
GEM00	0.18	0.14	0.079	0.004	0.009	0.002
GEM00 with field	0.0015	0.0004 (**<1% left**)	0	0	0.009	0
GEM10	0.09	0.06	0.022	0.0009	0.01	0
GEM10 with field	0.027	0.013 (**22% left**)	0.002	0	0.01	0

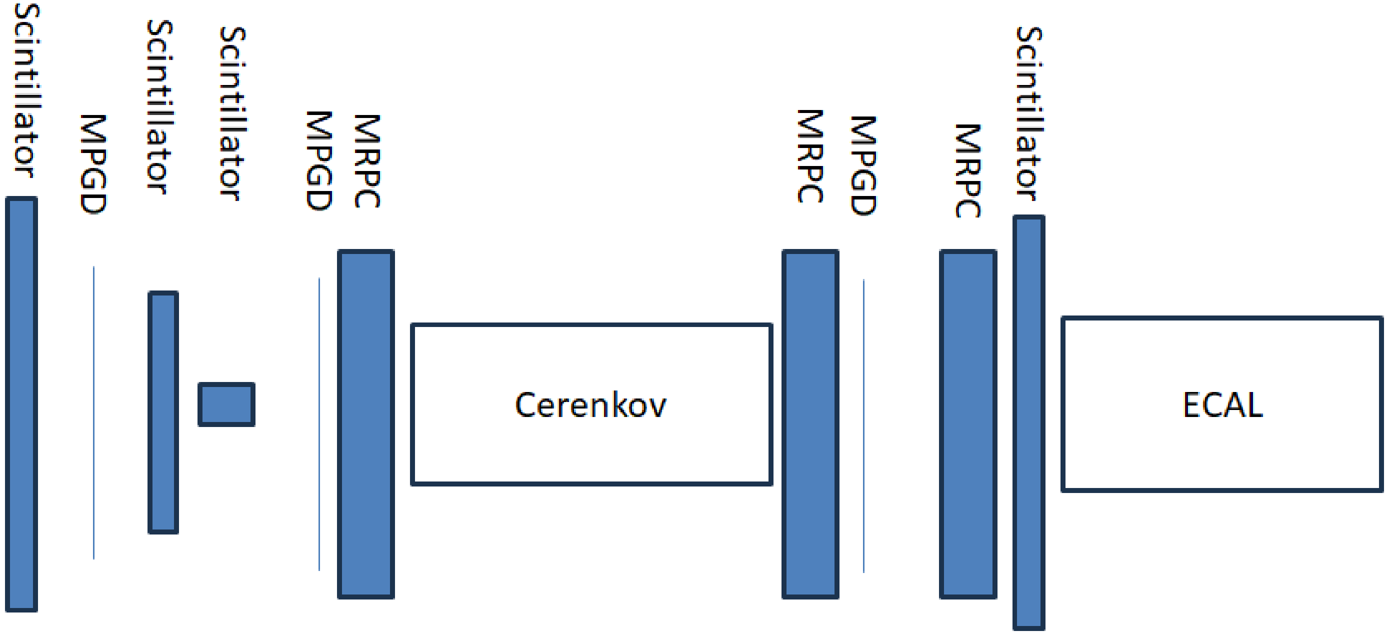
- Magnetic field reduces soft background on GEMs and SCs.
- Poly is not needed if magnetic field is used.

Magnetic Field Study for the FY26 Beam Test

- NPS sweeping magnet and its operating parameters
- Placement of the magnet requires a dedicated simulation study to optimize position and performance

NPS Magnet main coil	
Maximum current, Amp	990
Resistance @ 20°C, Ohm	0.11
Voltage drop at max current, Volt	110
Total water flow, gallon per minute	14
Max operational pressure, psi	130
Cooling medium	LCW
Max temperature rise, °C	30





Magnetic Field Study for the FY26 Beam Test Summary

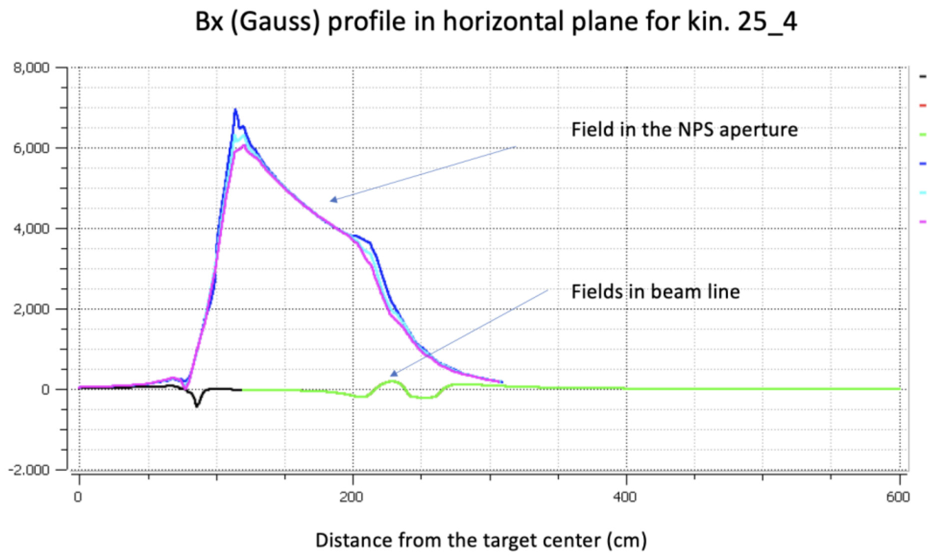
- ❑ Previous beam tests (Cherenkov and ECal) did not include a sweeping magnet
  → Resulted in dominant low-energy backgrounds (e.g., Møller electrons)
  → Made GEM tracking difficult, unlike expected SoLID conditions

- ❑ Applying a uniform 0.7 T magnetic field significantly reduces soft background on GEMs and SCs

- ❑ Applied NPS sweeping magnet field map to ECal test setup at 18° configuration

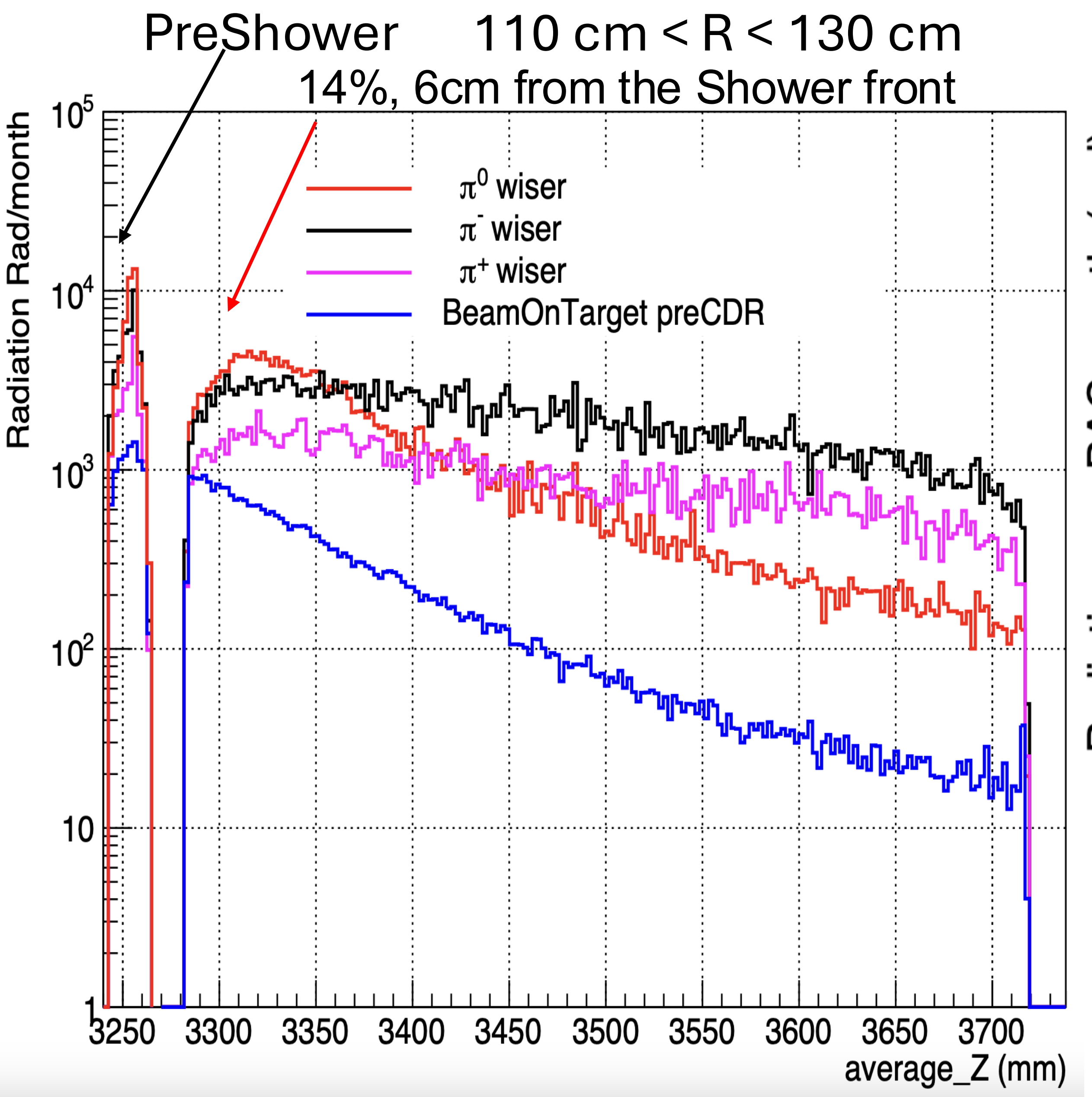
Next Steps:

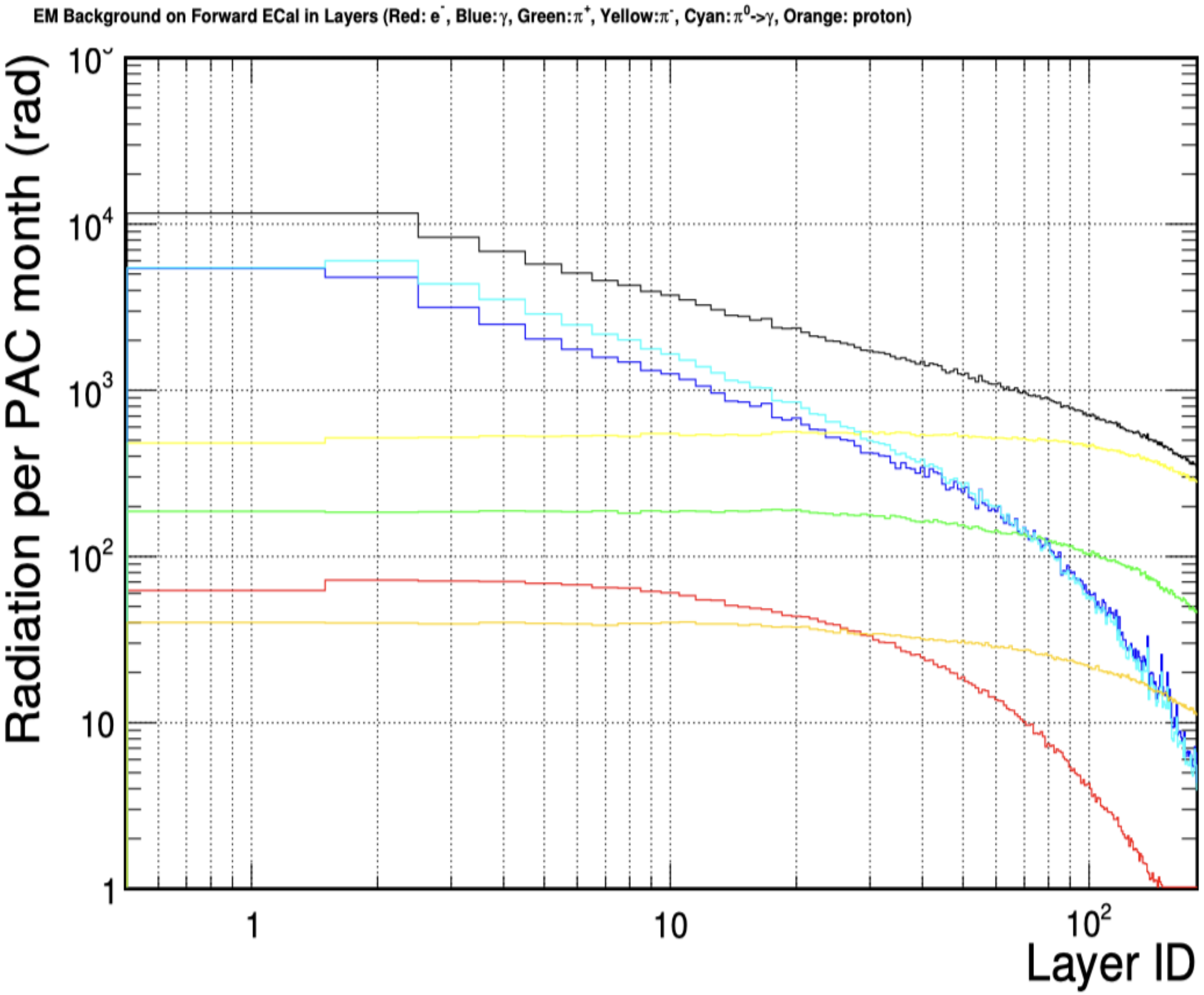
- ❑ Placement of the magnet requires a detailed simulation study to optimize:
  → Position, direction, and field performance

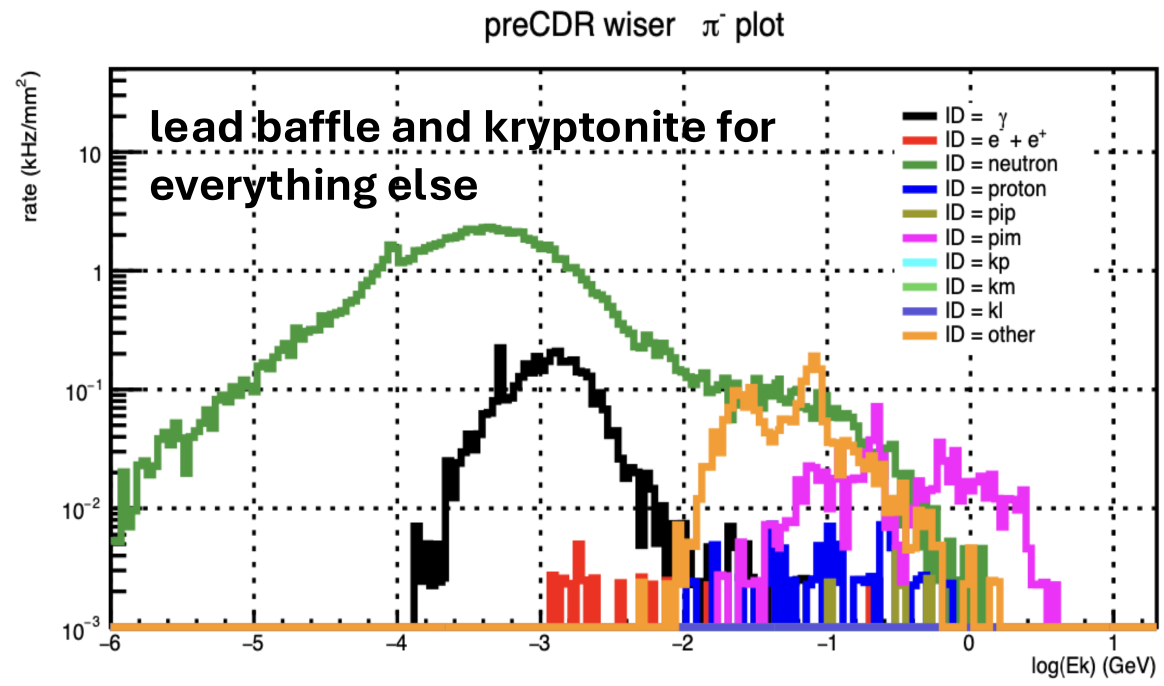


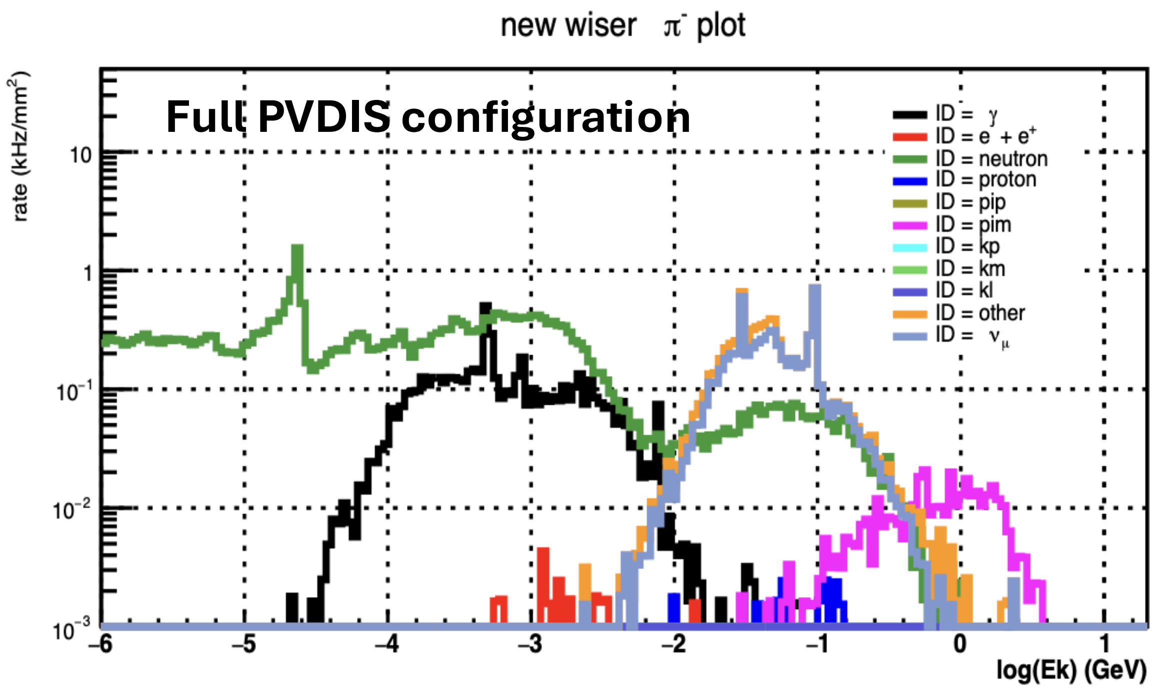
Backup

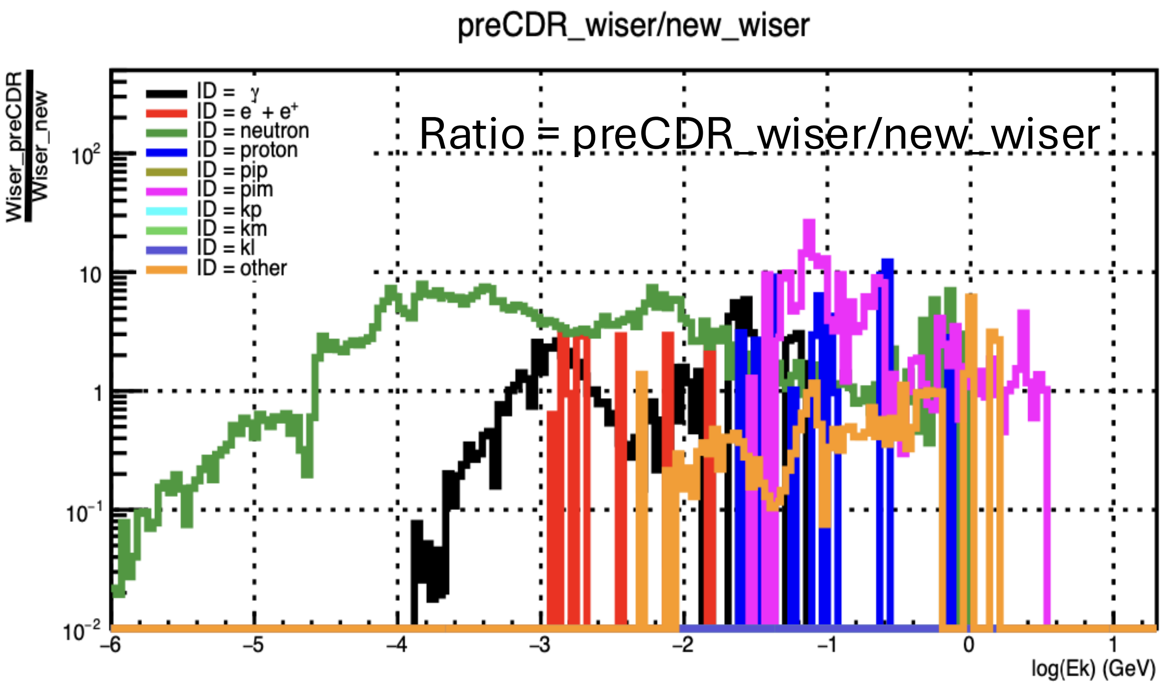
shorter endcap with "babarmore1" baffle











- 80 cm <R<110 cm
- Everything from π^-
- Y-axis is rate (kHz/mm2)
- X-axis is log (Ek) in front of prelead

- Wiser: $\sigma(A)_{\pi^0} = 2 * (\sigma_{\pi^+} + \sigma_{\pi^-})$

  $\sigma(A)_{\pi^0} = 0.5 * (\sigma_{\pi^+} + \sigma_{\pi^-})$

- Bggen: $\sigma(A)_{\pi^0} = Z \cdot \sigma_{\pi^0} + N \cdot \sigma_{\pi^0}$

From Ye Tian (SDU PhD thesis)

π^0 Bggen and data comparison