SoLID Simulation Update

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(SoLID Collaboration)

➢ Background challenge for FY26 beam test
➢ Magnetic field study and shielding optimization
➢ Radiation evaluation at 18 deg
➢ Statistics improvement for pion simulation
➢ Summary and Outlook

FY22 Detector Beam Test

☐ The best GEM quadrants worked reasonably with the tracks based on the detection efficiency < 50%, and the other quadrants are much worse.

☐ For setting GEM detectors properly, it requires low-rate conditions to do the alignment and the APV gain checking.
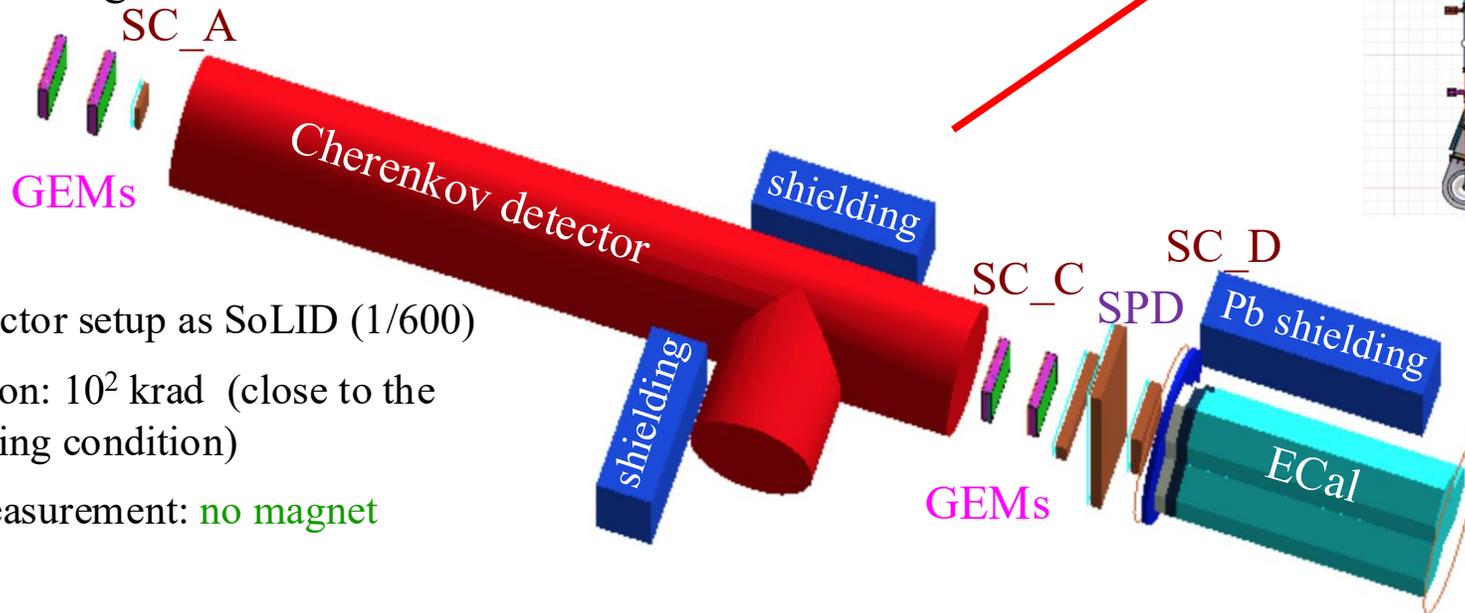
High Momentum Spectrometer (HMS)

~22m away from target

SC_A

GEMs

Cherenkov detector

shielding
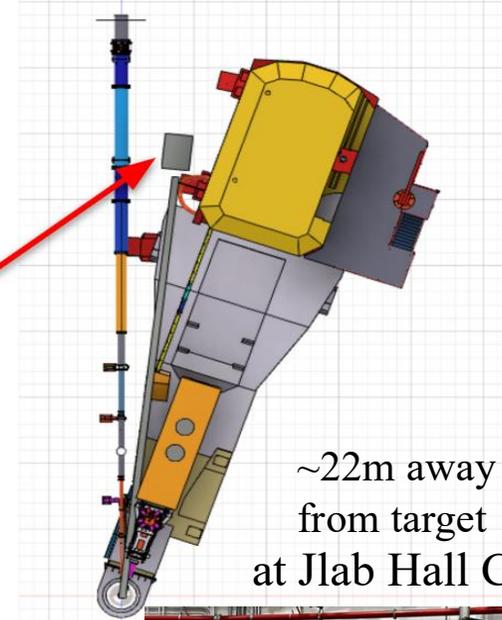
~22m away from target at Jlab Hall C

SC_D

SC_C

SPD

Pb shielding
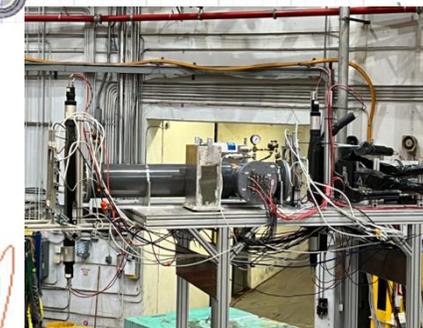
- Similar detector setup as SoLID (1/600)

- High radiation: 10^2 krad (close to the SoLID running condition)
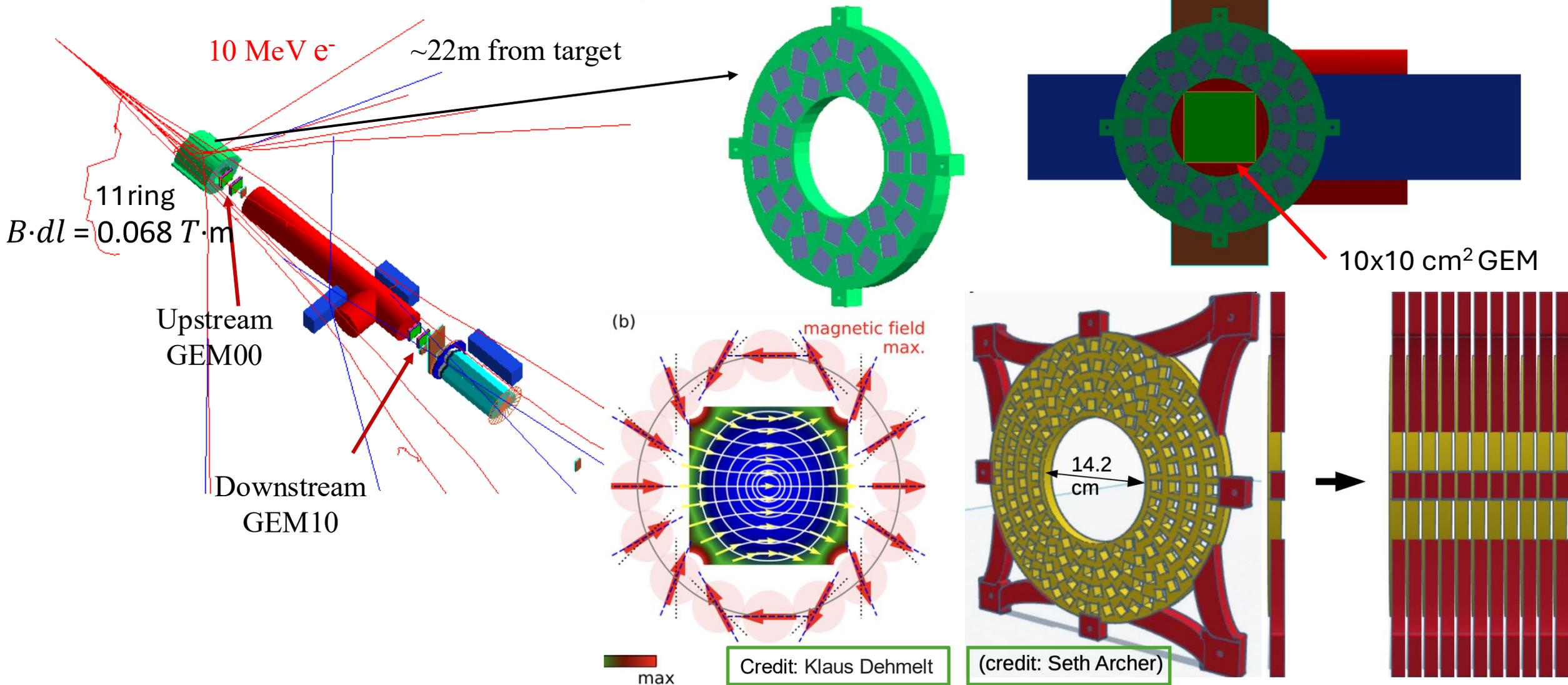
- Parasitic measurement: no magnet

shielding

GEMs

ECal

SC_B

This motivates background suppression

Reducing soft background: material shielding or magnetic field?

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

10 MeV e⁻   ~22m from target

11ring

$B \cdot dl = 0.068\ T \cdot m$

Upstream
GEM00

Downstream
GEM10

Reducing soft background: material shielding or magnetic field?

- soft Møller electrons (~10MeV @ $\theta = 18$ deg) in front of upstream GEMs and SCs

10 MeV e⁻

~22m from target

11 ring

$B \cdot dl = 0.068 \ T \cdot m$

Upstream GEM00

Downstream GEM10

10x10 cm² GEM

(b)

magnetic field max.

max

Credit: Klaus Dehmelt

14.2 cm

(credit: Seth Archer)

Depends strongly on the energy of the electrons

➢ **E < 5 MeV**:
   1. These low-energy electrons stop in 1 inch of polyethylene placed directly in front of the GEMs.
   2. Dominant source of background.

➢ **E > 30 MeV**:
   1. The magnetic field becomes essential for deflection.
   2. Shifting the magnet 33 cm upstream improves background rejection.
   3. A front collimator is recommended to stop these high-energy electrons. It may need to be large enough to also prevent punch-through from scattered electrons reaching the GEMs.

➢ **5 MeV < E < 30 MeV**:
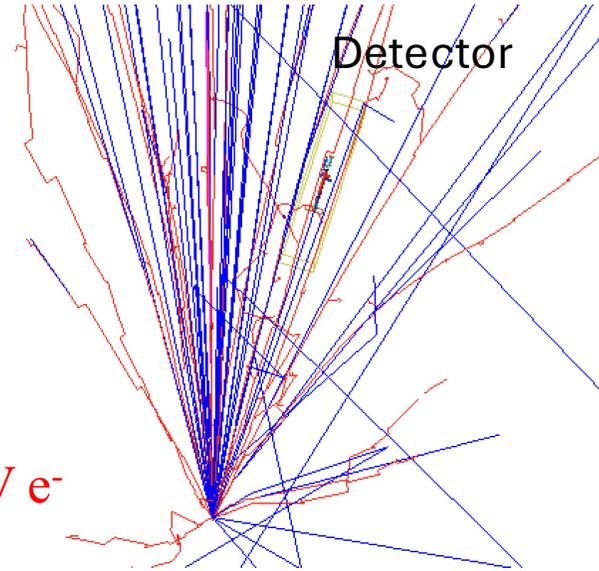   These intermediate-energy electrons can be effectively stopped with the help of the magnet.

Detector

strong angular spread at low momentum
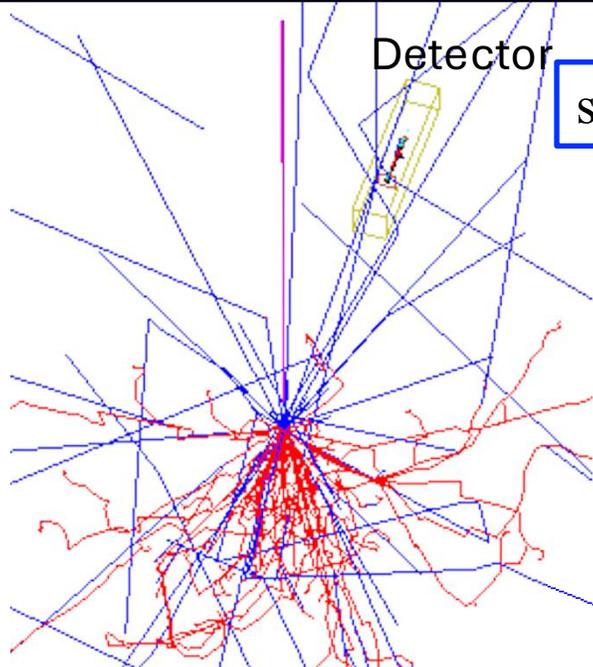
50 MeV e⁻

10 MeV e⁻ from target

Detector

Detector
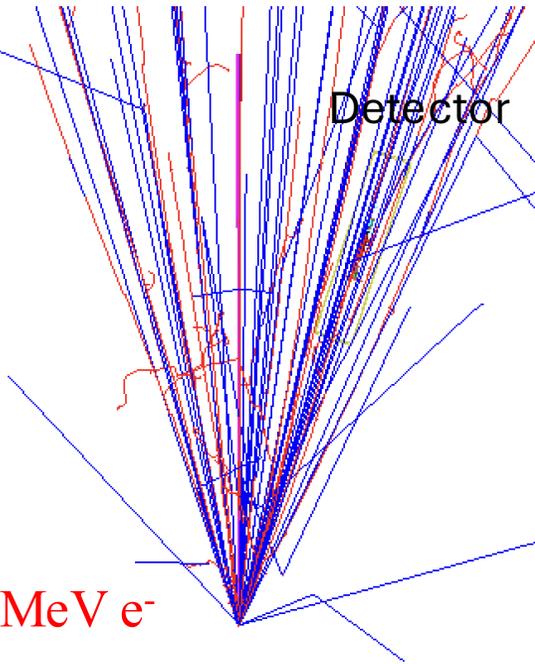
100 MeV e⁻

Multiple scattering: L_Rad= 30m, L=20m; sqrt(L/L_Rad ≈0.67):

$$\theta_0 = 13.6 \text{ MeV}/p * \text{sqrt(L/L\_Rad)} = \frac{11.1\ MeV}{p} \text{ radians.}$$

Momentum p MeV	θ_0 (radians)	θ_0 (deg)
10	1.11	63.6
20	0.555	31.8
50	0.222	12.7
100	0.111	6.4

100cm

36 cm

33 cm

Virtual with R=7.1cm, z= 32.8cm

E

magnet

1st GEM

4 3 2 1

**100x100cm² virtual planes:** **Guides collimator sizing**
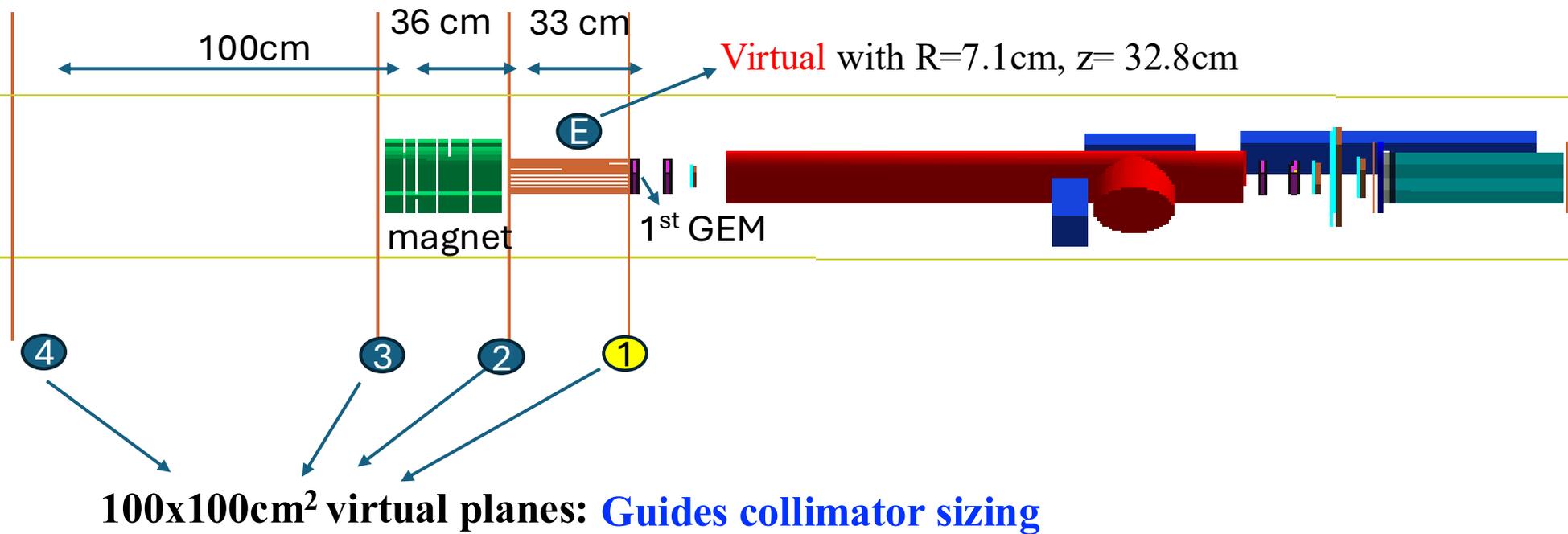
- 100x100 cm² virtual planes are used to study the background profile for shielding design.
- Virtual E is a cylindrical virtual plane, which is used to study the backgrounds E_k and ϕ distributions before the first GEM
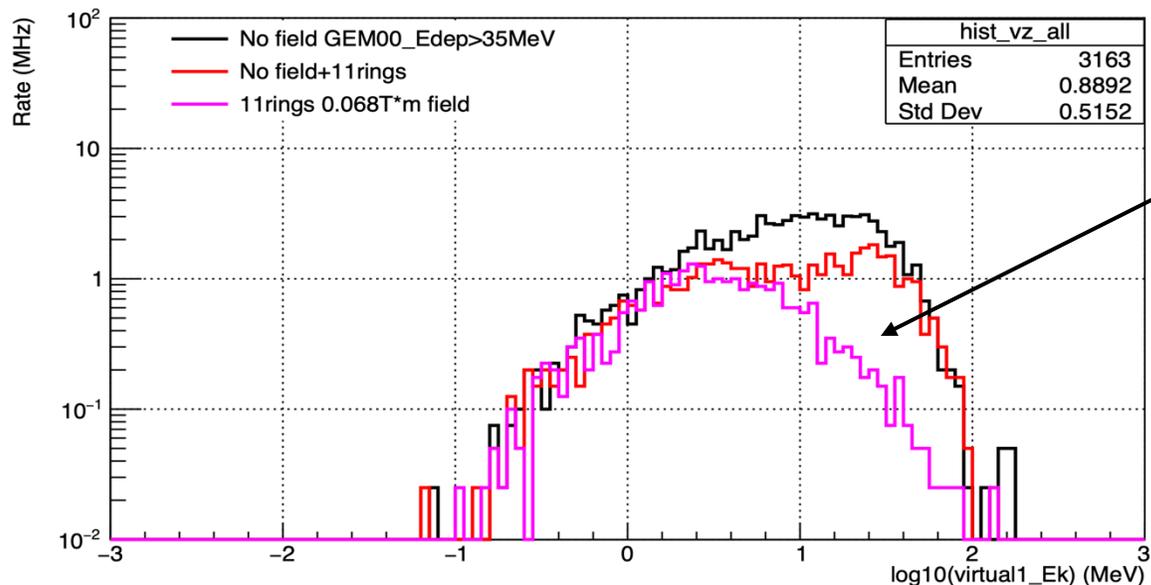
- **High-energy electrons** are strongly bent by Bx field
- Field alone not sufficient

- **Low-energy electrons** are weakly affected by the field and can enter through side openings. **Side shielding is needed.**
- Infinite collimator studies show these electrons can be strongly suppressed.
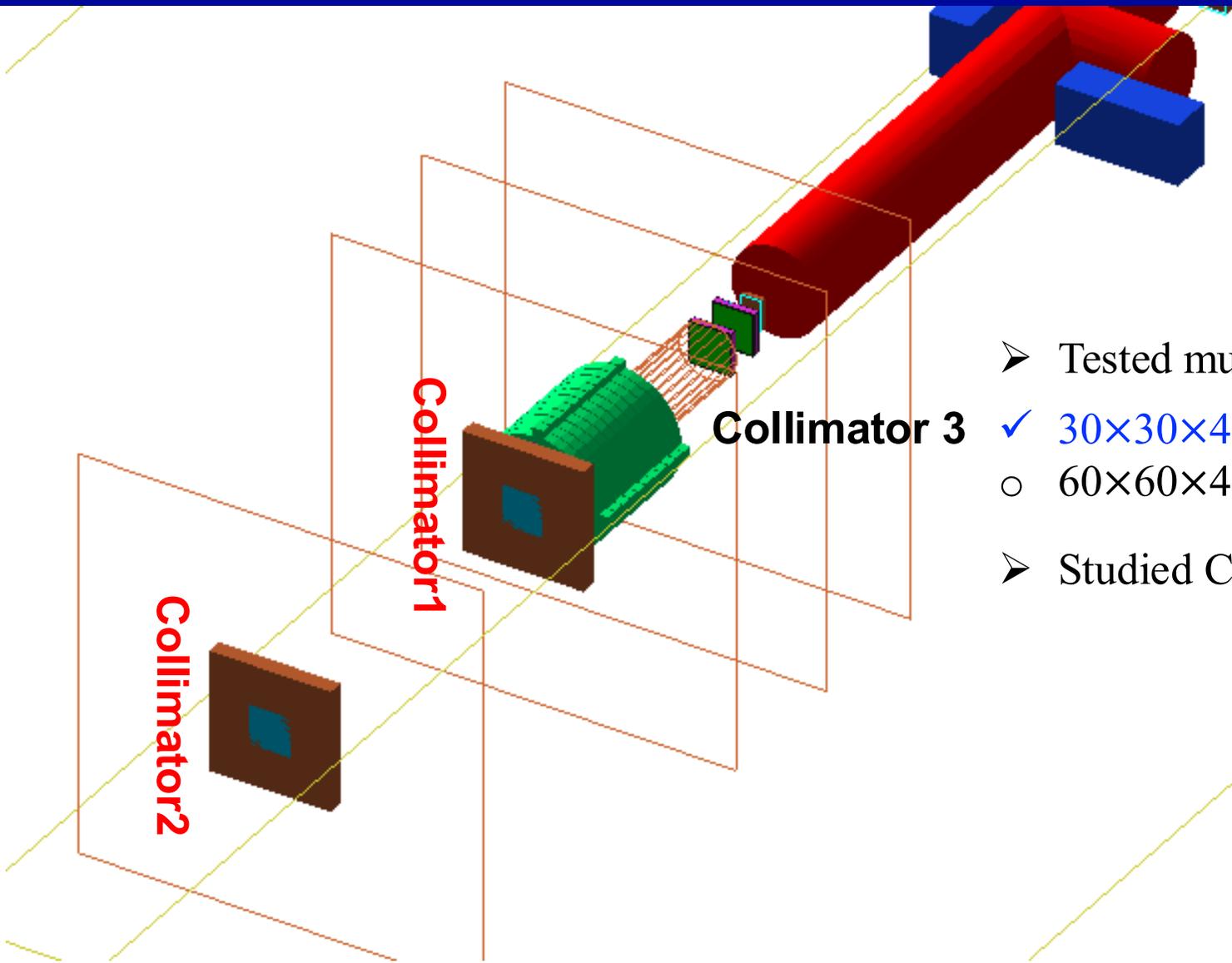- Virtual-plane cuts help determine realistic collimator sizes.
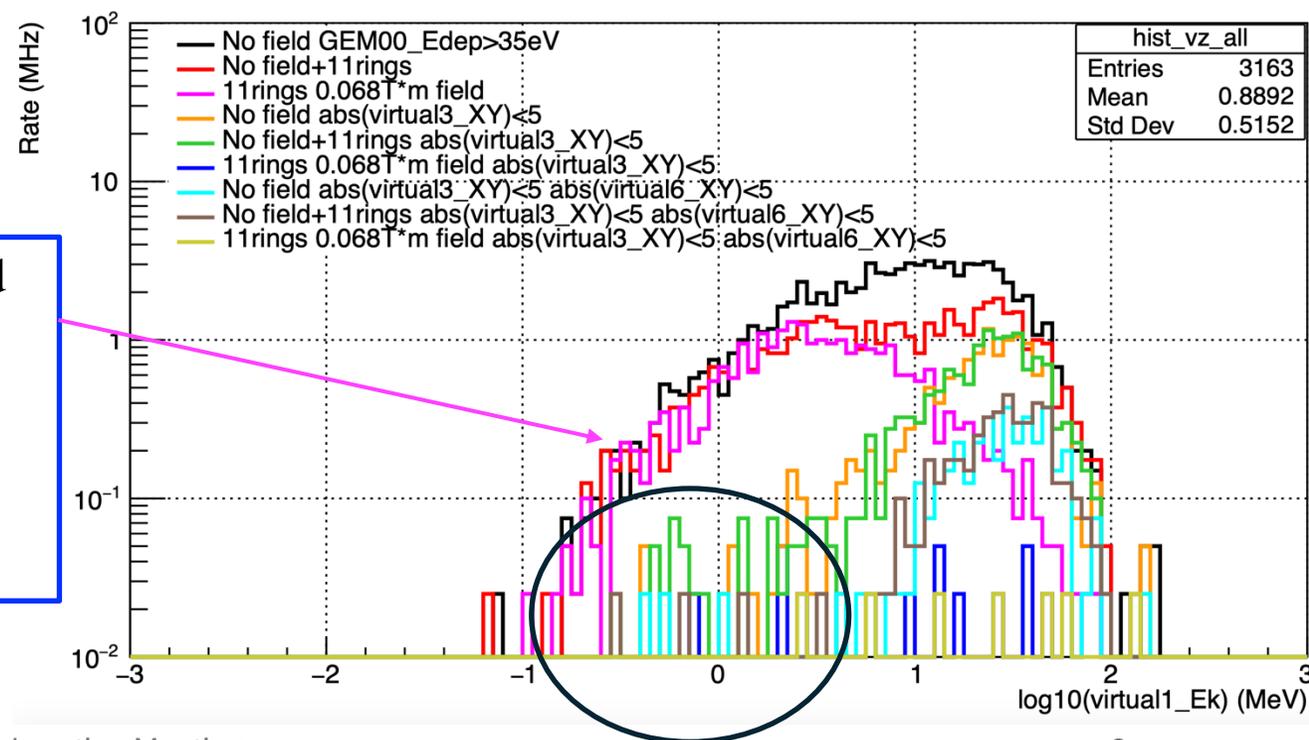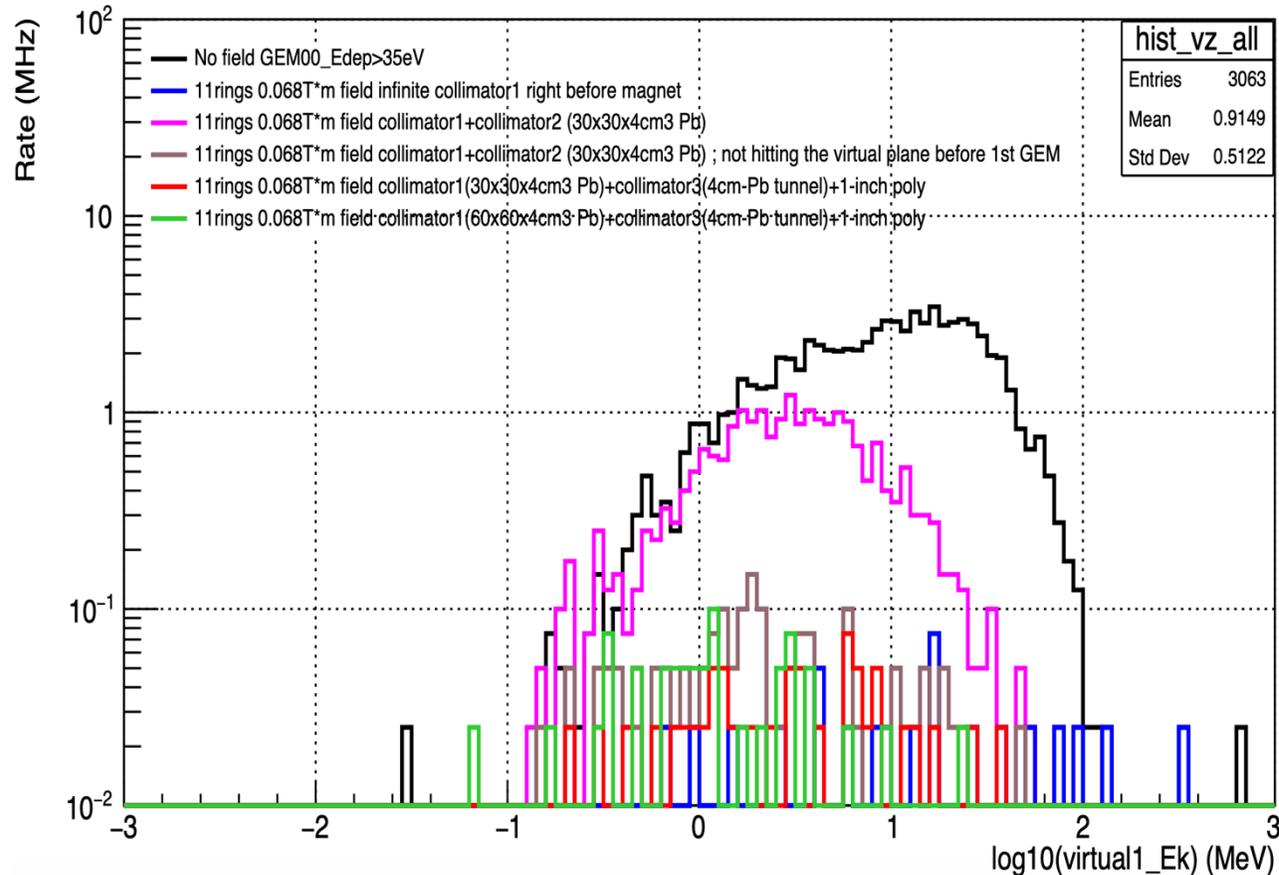
Virtual Plane Hit Map

No Field

75 MHz

11-ring 0.068 T·m

22 MHz
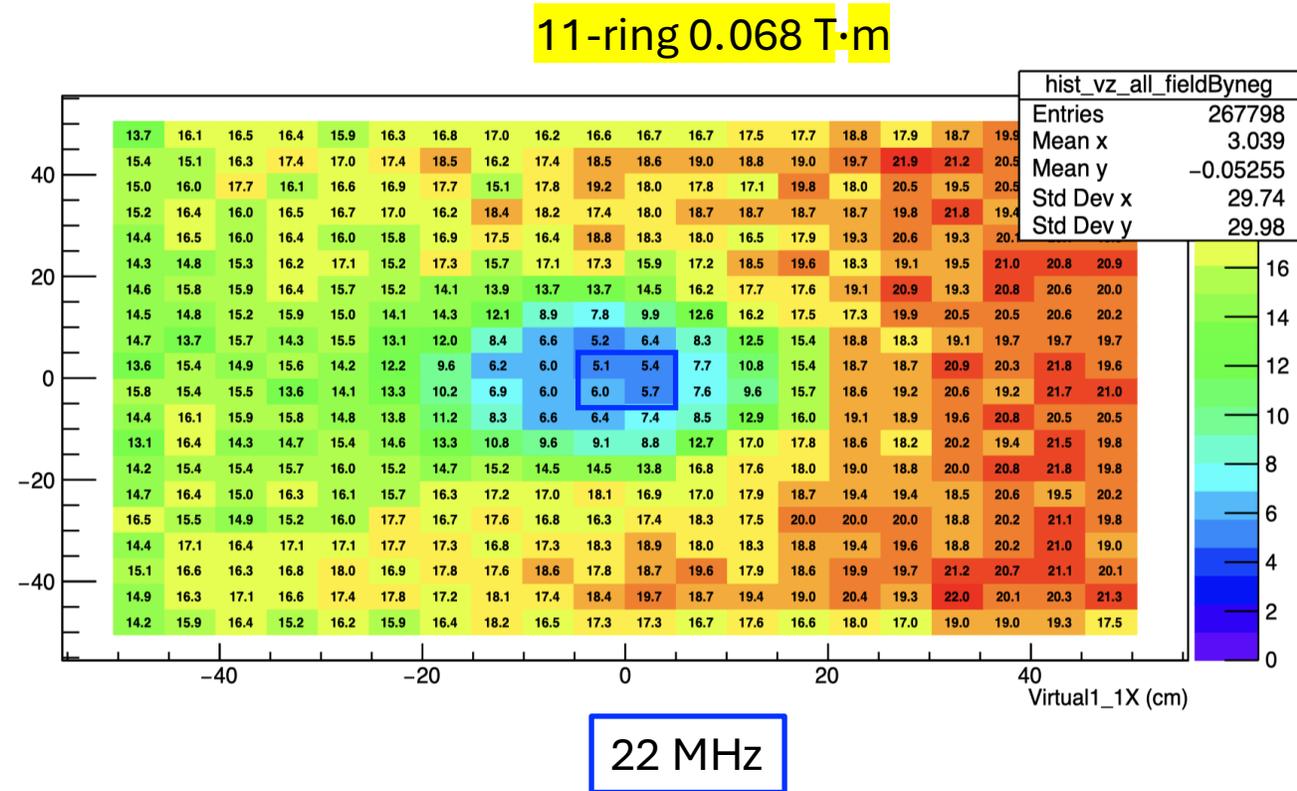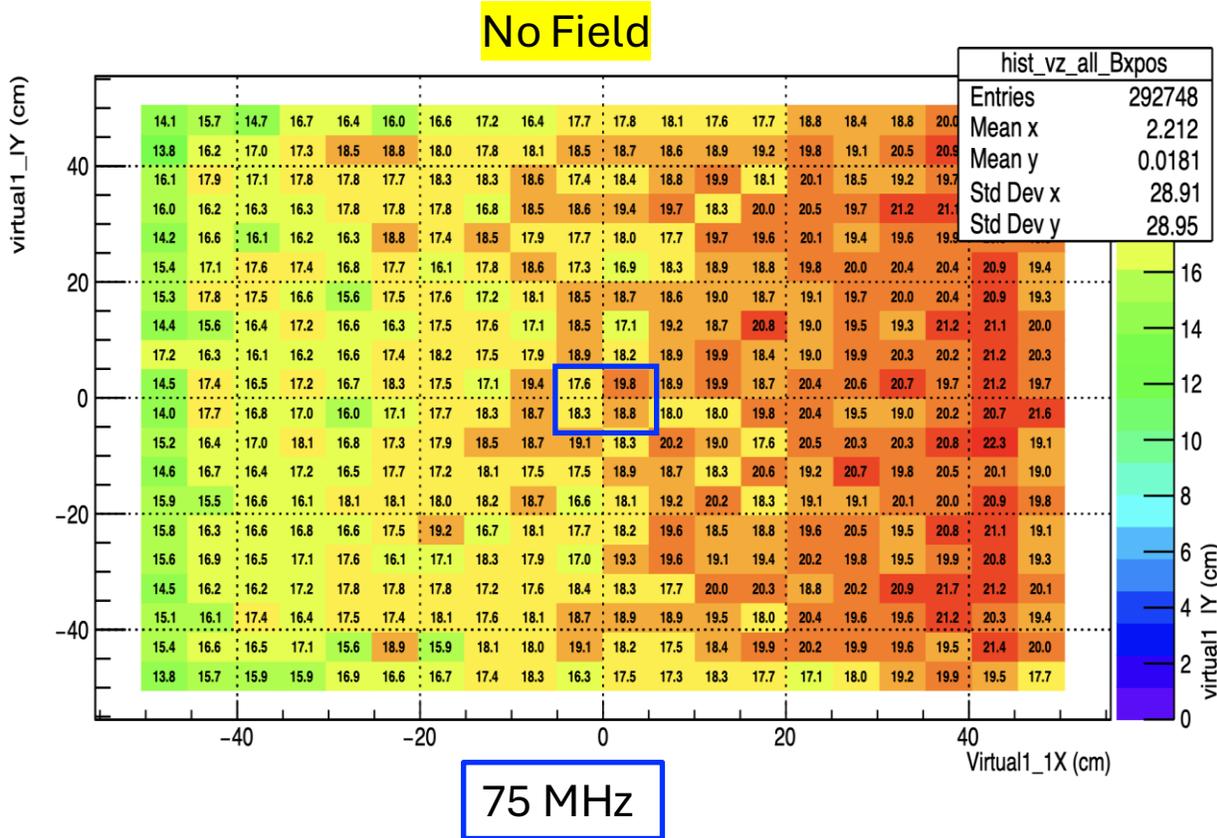
- The field alone provides only a **factor-3 reduction**
- Collimators are needed.

Collimator1

Collimator2

Collimator 3

➢ Tested multiple Pb collimator sizes.

✓ 30×30×4 cm^3 Pb collimators with a 10× 10×4 cm^3 hole

○ 60×60×4 cm^3 Pb collimators with a 10× 10×4 cm^3 hole

➢ Studied Collimator 1, 2, 3 configurations

- No field
- Collimator 1 + Collimator 2
- Collimator 1 + Collimator 2 + Collimator 3 cut (cylinder with a r=7.1cm hole)
- 30x30cm^2 Collimator 1 + Collimator 3 (4cm thickness Pb tunnel)
- 60x60cm^2 Collimator 1 + Collimator 3 (4cm thickness Pb tunnel)

- Collimator 3 (between the magnet and the 1st GEM) provides significant background reduction.
- Collimator 1 (upstream of the magnet) is required.
- Collimator 2 (1 m upstream of Collimator 1) is not required.

local ϕ vs Ek distribution on the cylindrical virtual plane
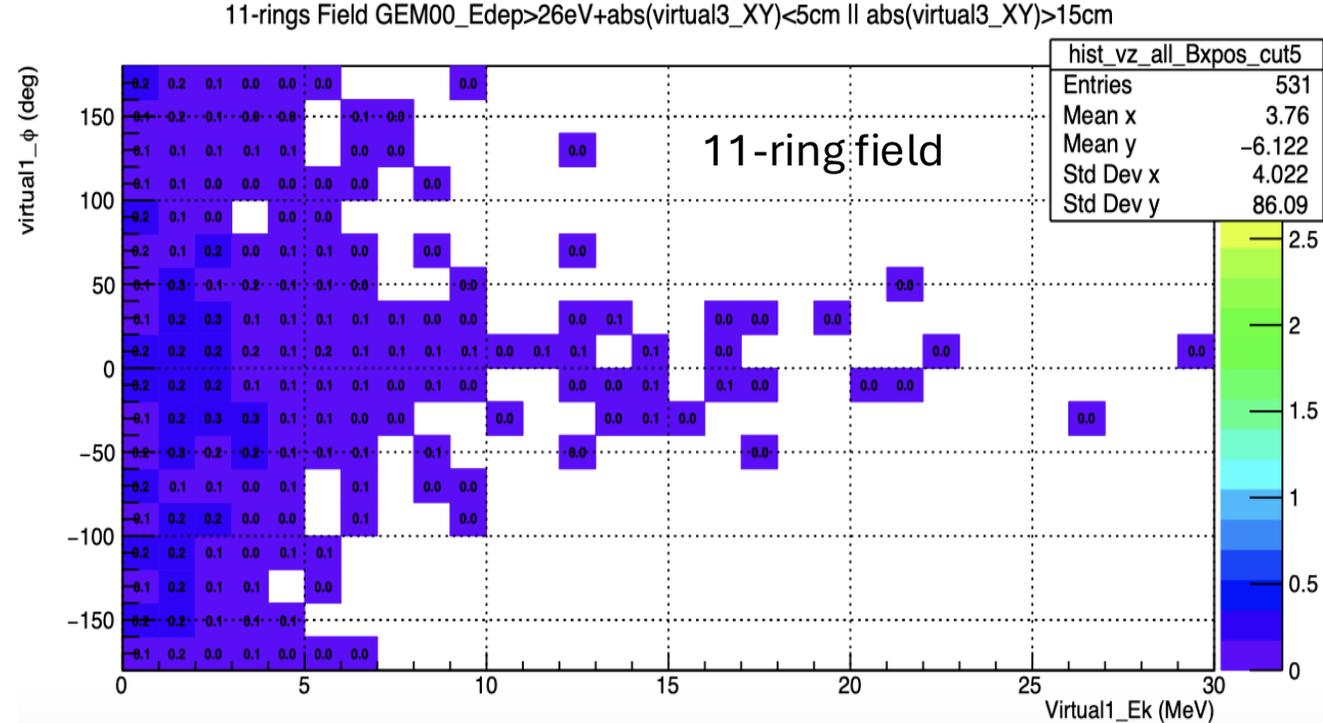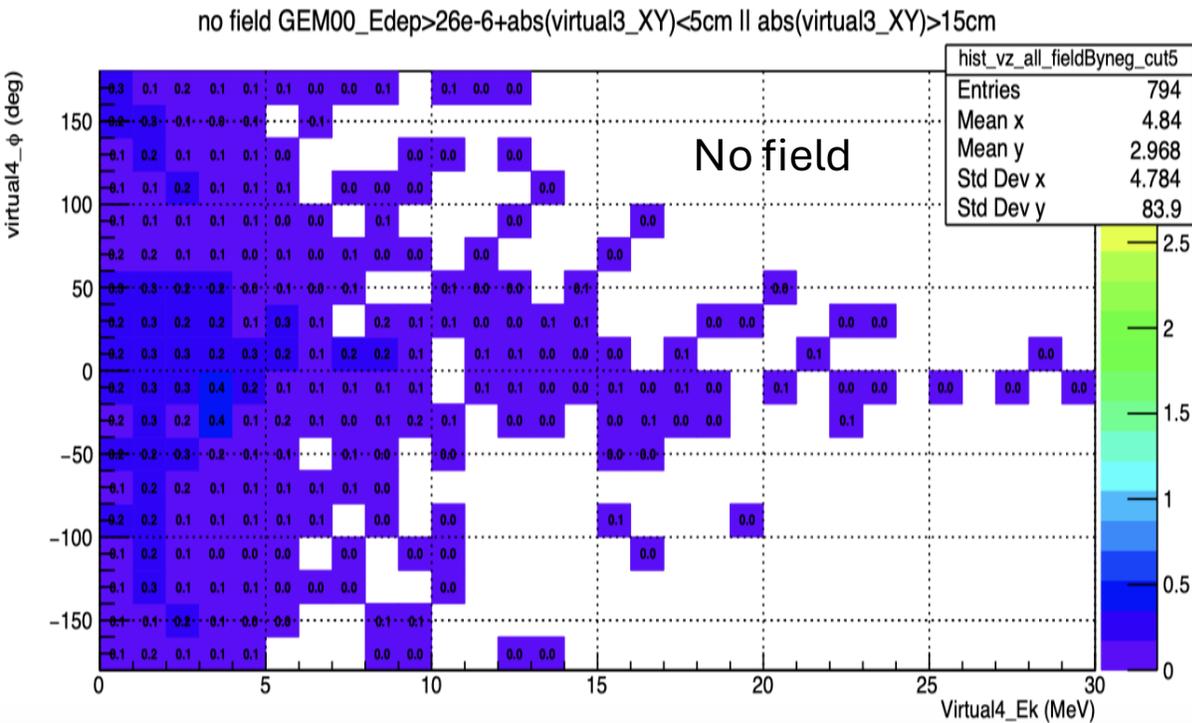
11-rings field GEM00_Edep> 26 eV, Collimator_1 ±15 cm cuts, -180 deg<ϕ<180 deg

The field reduces high-energy backgrounds reaching the GEM

- With 0.0508 cm target chamber Al window

11-ring magnet $B \cdot dl$ = **0.068T· m**

Collimator3

11-ring magnet $B \cdot dl$ = **0.068T· m**

Collimator3

4cm thickness Pb
With 10x10x4cm³ hole

Collimator1

Collimator1

- Collimator 3 optimization
  - Pb or poly
  - Length

33-ring magnet $B \cdot dl$ = **0.2T· m**

Collimator1

- Magnet field optimization
  - 6 ring
  - **11 ring**
  - 16 ring
  - 33 ring

Best compromise: 11-ring + optimized collimators
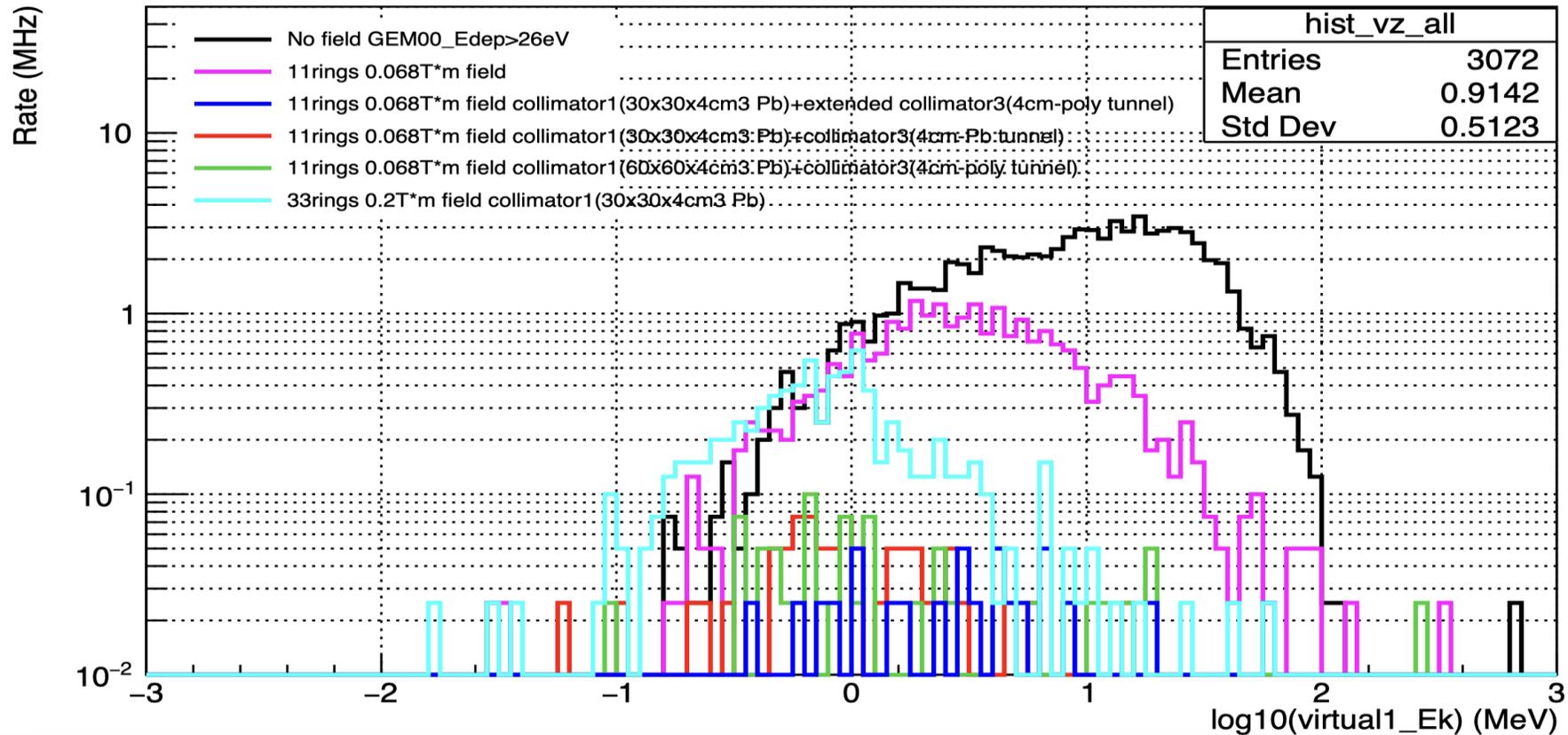
- No field
- 11-rings field
- Collimator 1 (30x30x4cm^3 Pb)+Collimator 3 (4cm thickness **Pb** tunnel)
- Collimator 1 (60x60x4cm^3 Pb)+Collimator 3 (4cm thickness **Poly** tunnel)
- Collimator 1 (60x60x4cm^3 Pb)+Collimator 3 (4cm thickness **extended Poly** tunnel)
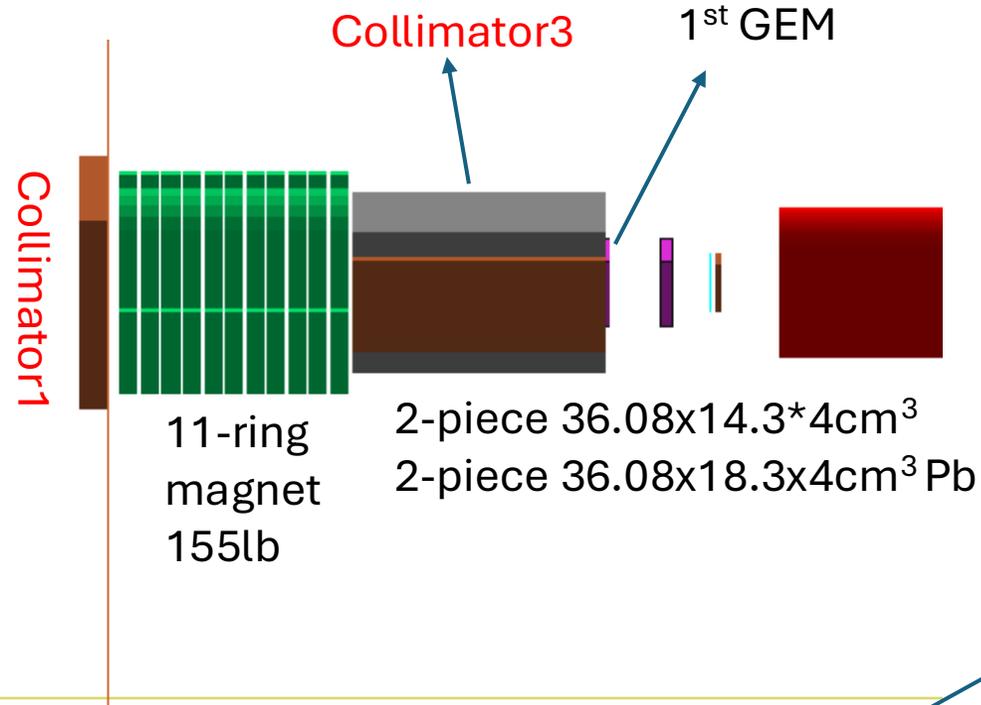- 33-rings field Collimator 1 (30x30x4cm^3 Pb)

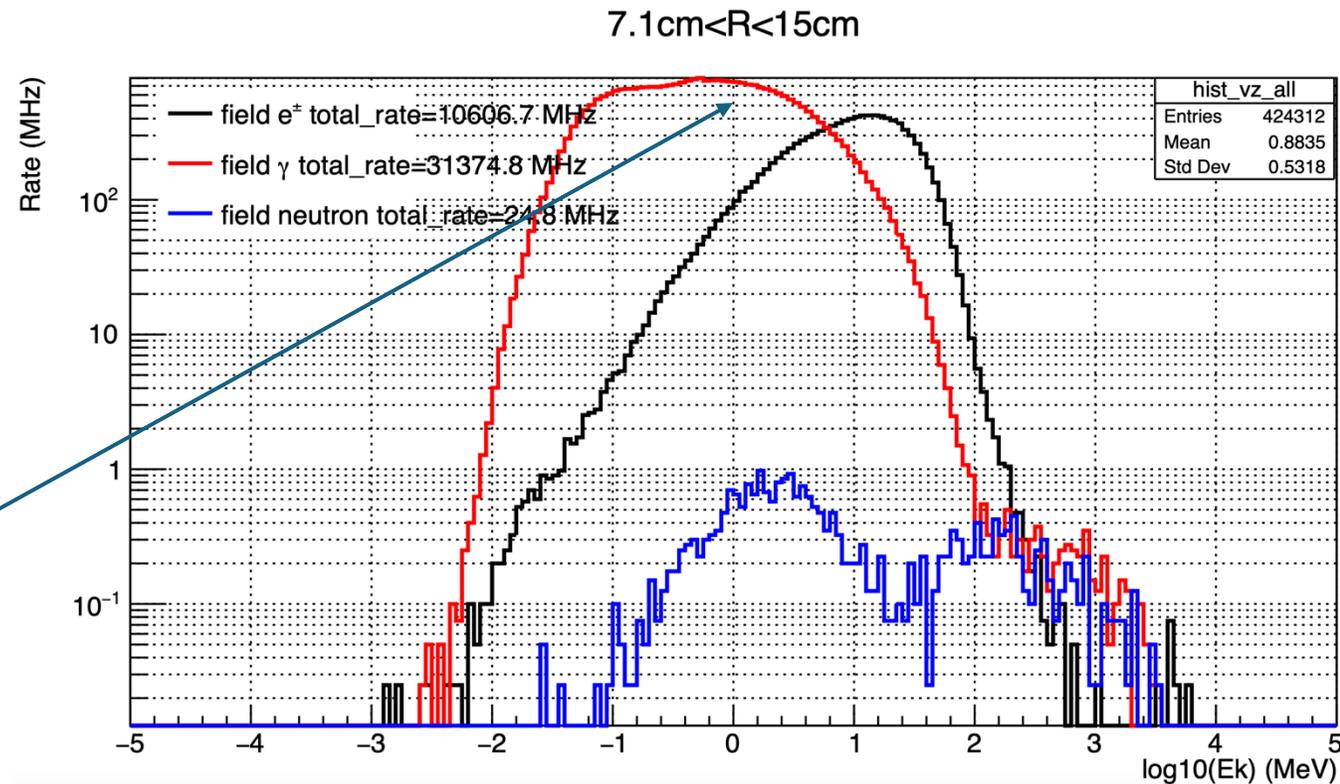# Background Rate on the 1st GEM

Requirement < 0.1 MHz/strip satisfied

Rate on 1st GEM Rate (MHz/strip) 40μA 10cm LD2 target		All Edep>26eV		e⁻ Edep> 26 eV	
no field		0.40		0.32	
Field (Bx+0.068 T·m) 11-rings	Field only	0.14		0.11	
	+ Collimator _ +**36cm** Collimator_3 **Pb**	0.0084		0.006	
	+Collimator_1+**18cm** Collimator_3 **Pb**	0.0288		0.022	
	+Collimator_1+**18cm** Collimator_3 **poly**	0.029		0.022	
	+Collimator_1+**36cm** Collimator_3 **poly**	0.011		0.007	
	+Collimator_1+**38.6cm** Collimator_3 **poly**	**0.0096**	**42**	**0.007**	**46**
Field (Bx+0.2 T·m) 33-rings	+Collimator_1	0.084		0.065	

Collimator_1: 30x30x4cm³-Pb with a 10x10x4cm³ hole   Collimator_3 tunnel: 2*36.08x14.3*4cm³+2*36.08x18.3x4cm³

Collimator3   1st GEM

Collimator1

11-ring
magnet
155lb

2-piece 36.08x14.3*4cm^3
2-piece 36.08x18.3x4cm^3 Pb

Energy distribution at virtual plane right before the magnet

7.1cm<R<15cm

hist_vz_all	
Entries	424312
Mean	0.8835
Std Dev	0.5318

field e$^{\pm}$ total_rate=10606.7 MHz
field γ total_rate=31374.8 MHz
field neutron total_rate=24.8 MHz

Assuming full energy deposition in the magnet

- e$^{\pm}$ rate = 10606.7 MHz = 1.06067×10^{10} /s
- mean energy ≈ 7.6 MeV

1.06e10MeV/s*(30*24*60*60)s/(70kg)
= **6.3 krad/PAC month**

Collimator3

1st GEM

Collimator1

11-ring magnet 155lb

2-piece 36.08x14.3*4cm^3
2-piece 36.08x18.3x4cm^3 Pb
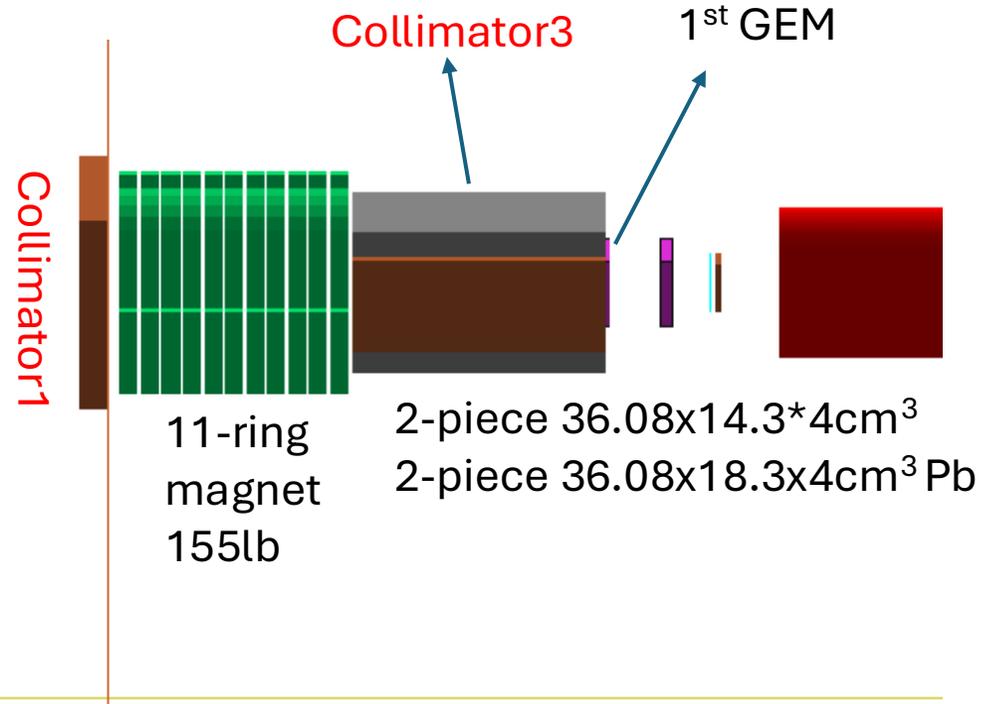
Compared to known Radiation Damage on Neodymium Magnets (Nd–Fe–B)

- 9% flux loss at **2.6 MGy** from **17 MeV electrons**
- 14% remanence loss at **450 Mrad** from bremsstrahlung (**85 MeV**)
- Severe demagnetization (>85%) reported at about **50 Mrad** in a mixed field produced by **2.5 GeV electrons**
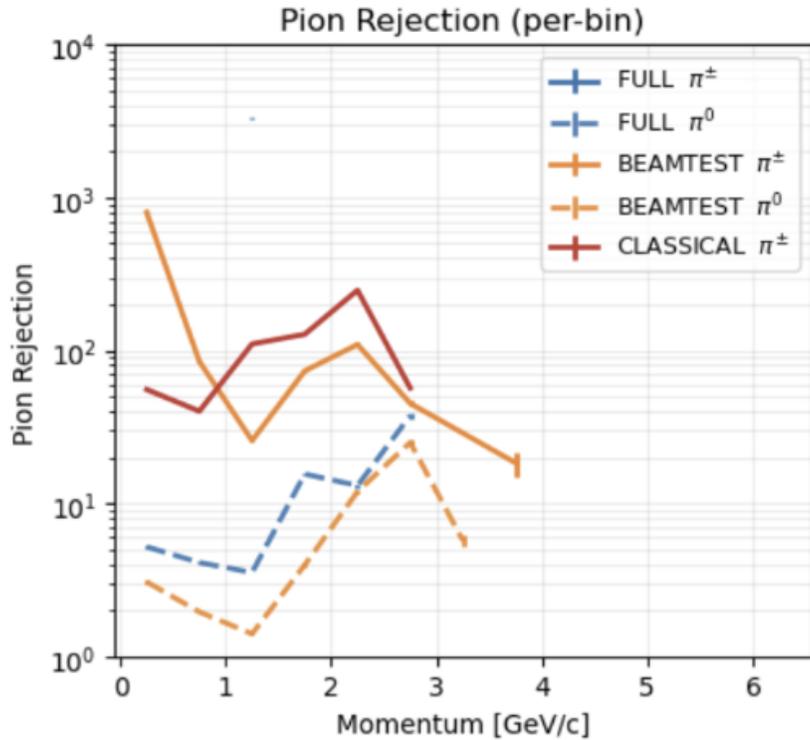
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- mean energy ≈ **7.6 MeV**

1.06e10MeV/s*(30*24*60*60)s/(70kg)
= **6.3 krad/PAC month**

From Xiaochao's group

FY22 beam test

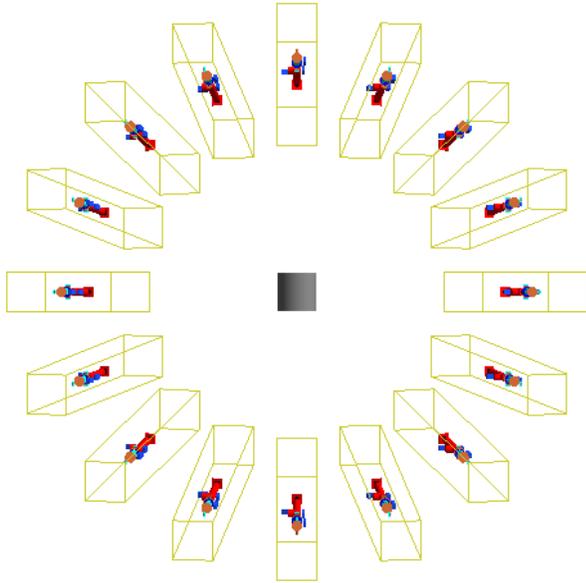Need more statistics

> ML pion rejection degrades at higher momenta.
> More statistics are needed to pinpoint the cause.
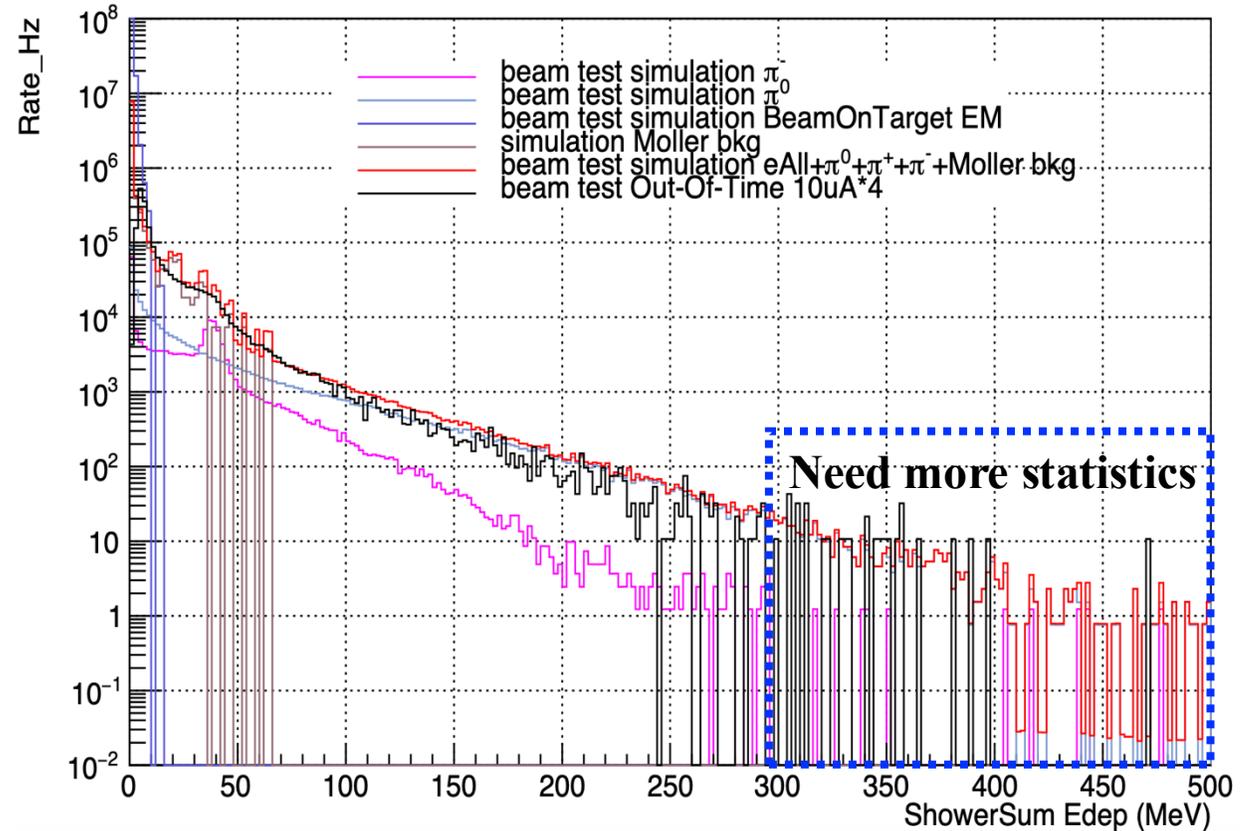
Red: simulated eAll+ $\pi^0 + \pi^- + \pi^+ +$ **Moller**
Black: beam test data

EM background

1e⁹ generated BeamOnTarget events No field: 16copy/16.

1e¹⁰ generated BeamOnTarget events No field: no copy

Integral()/Integral() = 0.94

hist1: Entries 300418, Mean 0.2126, Std Dev 0.7368

ShowerSum {rate}

P_gen>1.5 GeV

Everything from π^0

16copy/16.
no copy

Integral()/Integral() = 0.97

hist1: Entries 370, Mean 41.18, Std Dev 61.7

Everything from π^+

16copy/16.
no copy

Integral()/Integral() = 0.99

hist1: Entries 258, Mean 15, Std Dev 29.64
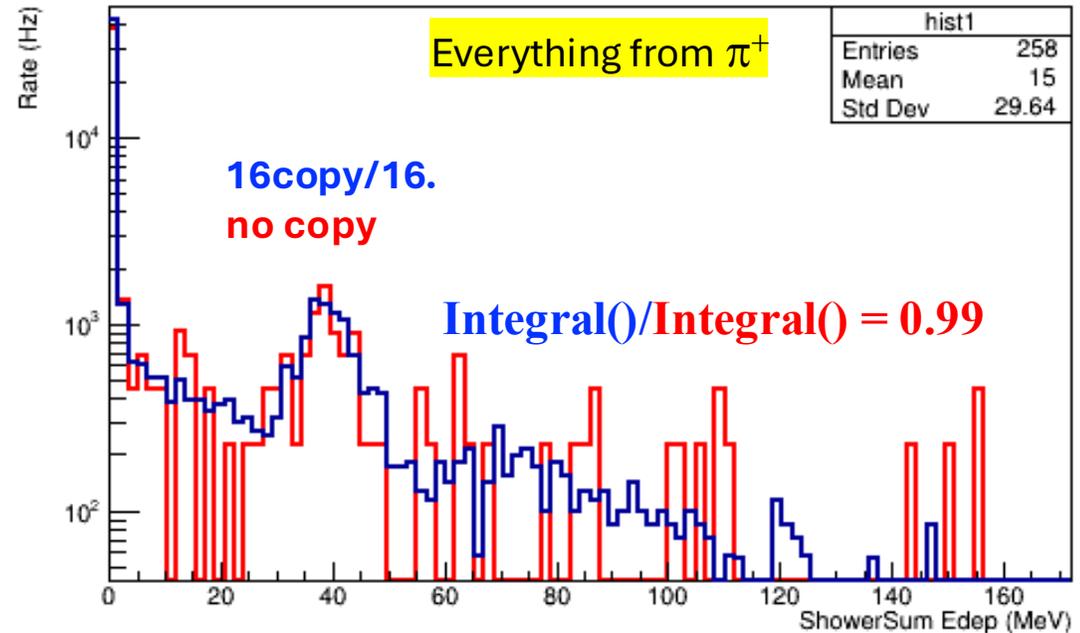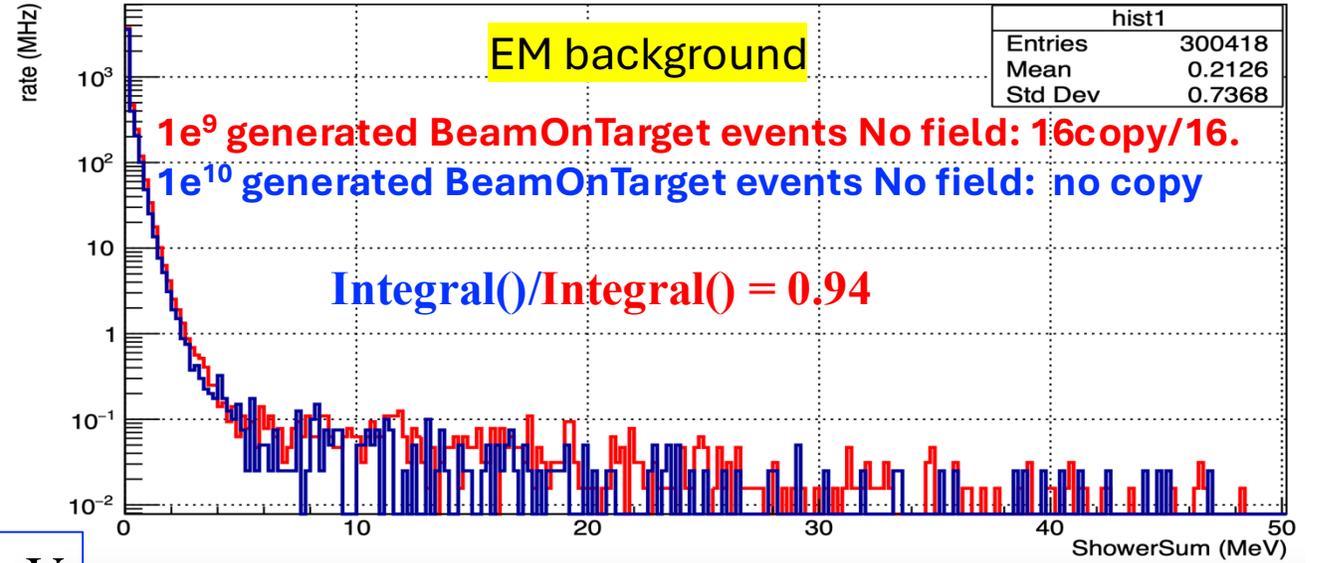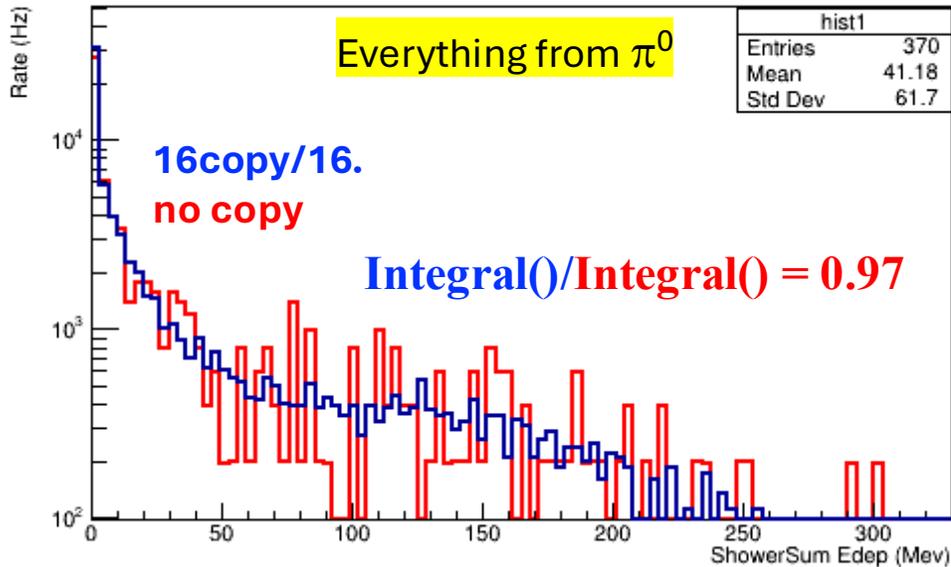
- Magnetic field and collimator optimization significantly reduce GEM background (field: ×3; combined design: ~×40).

- Preliminary estimates indicate that magnet radiation risk is negligible for the FY26 beam test.

- The 16-copy method is validated for improving pion statistics.

- Next steps: implement the updated tracking detector in the simulation and evaluate large-angle rates for FY26 beam test commissioning.
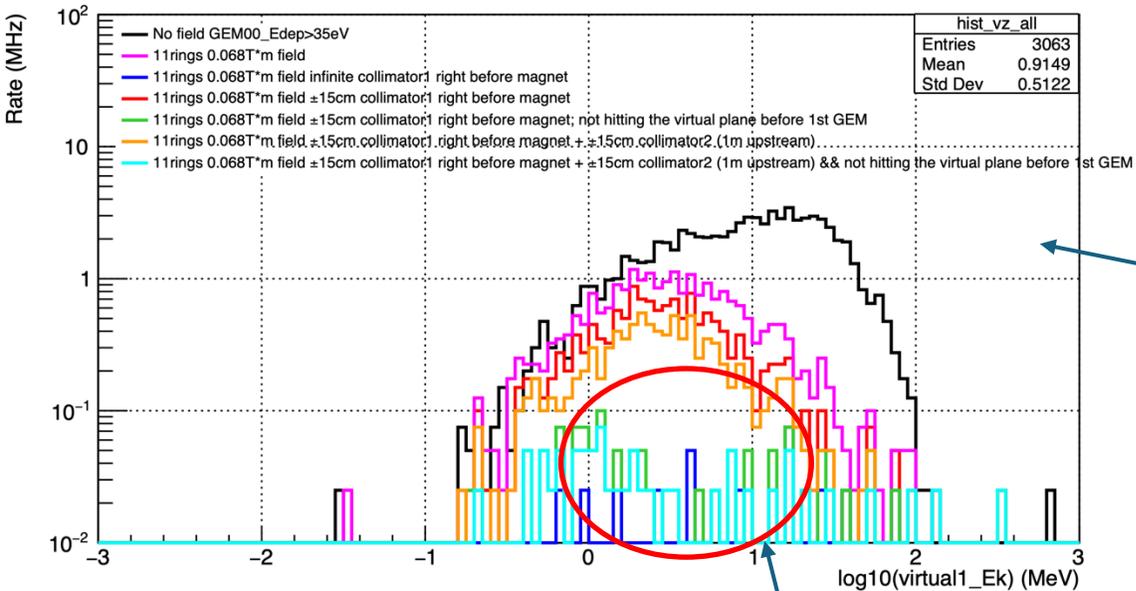
Acknowledgements

- Thanks to **Zhiwen** for assistance with simulation file preparation and job submission
- Thanks to **Paul**, **Jian-Ping**, and the beam test group for valuable discussions and feedback

Backup

SoLID Collaboration Meeting

Collimator Size Optimization

log10(Ek) comparison

- Collimator 1 ($\pm$15cm plate with a $\pm 5cm$ hole)
- Collimator 1 ($\pm$15cm plate with a $\pm 5cm$ hole)+ Collimator 2 ($\pm$15cm plate with a $\pm 5cm$ hole)
- Collimator 1 ($\pm$15cm plate with a $\pm 5cm$ hole)+Collimator 3 (cylinder with a r=7.1cm hole)
- Collimator 1 ($\pm$15cm plate with a $\pm 5cm$ hole)+ Collimator 2 ($\pm$15cm plate with a $\pm 5cm$ hole)+Collimator 3 (cylinder with a r=7.1cm hole)

From outside of the collimator

- Collimator 2 ($\pm$15cm plate with a $\pm 5cm$ hole)
- Collimator 2 ($\pm$15cm plate with a $\pm 5cm$ hole)+Collimator 3 (cylinder with a r=7.1cm hole)
- Collimator 3 cylinder (cylinder with a r=7.1cm hole)

- **$\pm$15cm collimator plate**
- Preliminary result: Collimator 1 + Collimator 3 suppress most backgrounds.
- Collimator 2 is not necessary.