12 GeV Upgrade
Future Science at Jefferson Lab

Electromagnetic Calorimeters (EC) for SoLID

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On behalf of the SoLID EC Working Group

Contents:

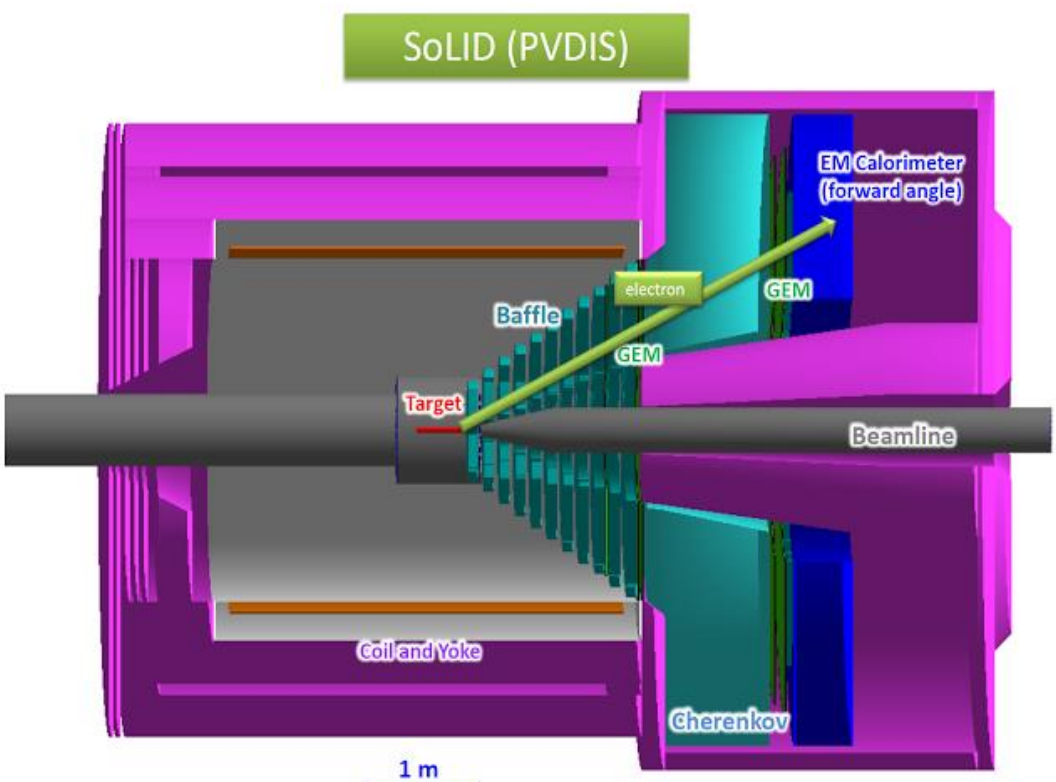
- Structure of EM Cal.
- Simulation performance
- Prototype study

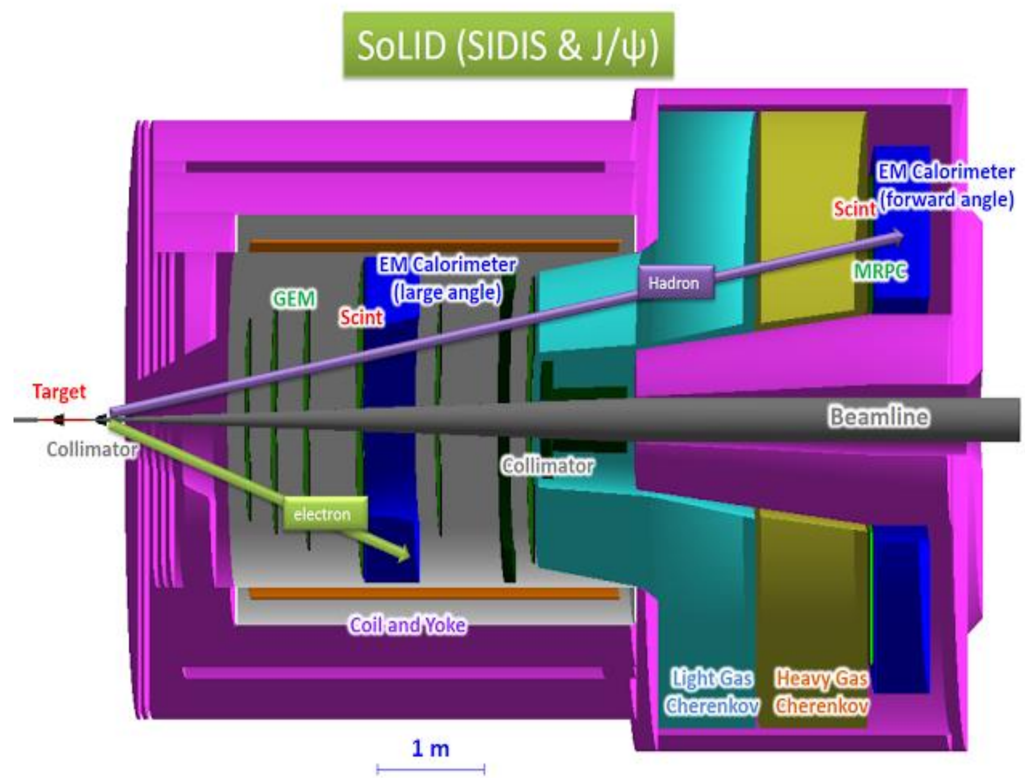
Hadron 2015, Duke Kunshan University
August 3-7,2015

SoLID EC Coverage

Play multiple roles, provide key e/π separation and triggering

	θ(deg)	z (cm)	R(cm)	P (GeV/c)	Max π/e	Area (m^2)
PVDIS FAEC	22 - 35	(320,380)	(110,265)	2.3 - 6	~200	~ 18.3
SIDIS FAEC	8 – 14.8	(417,475)	(105,230)	1 - 7	~200	~ 13.6
SIDIS LAEC	16.3 - 24	(-65,-5)	(83,140)	3-6	~20	~ 4.0



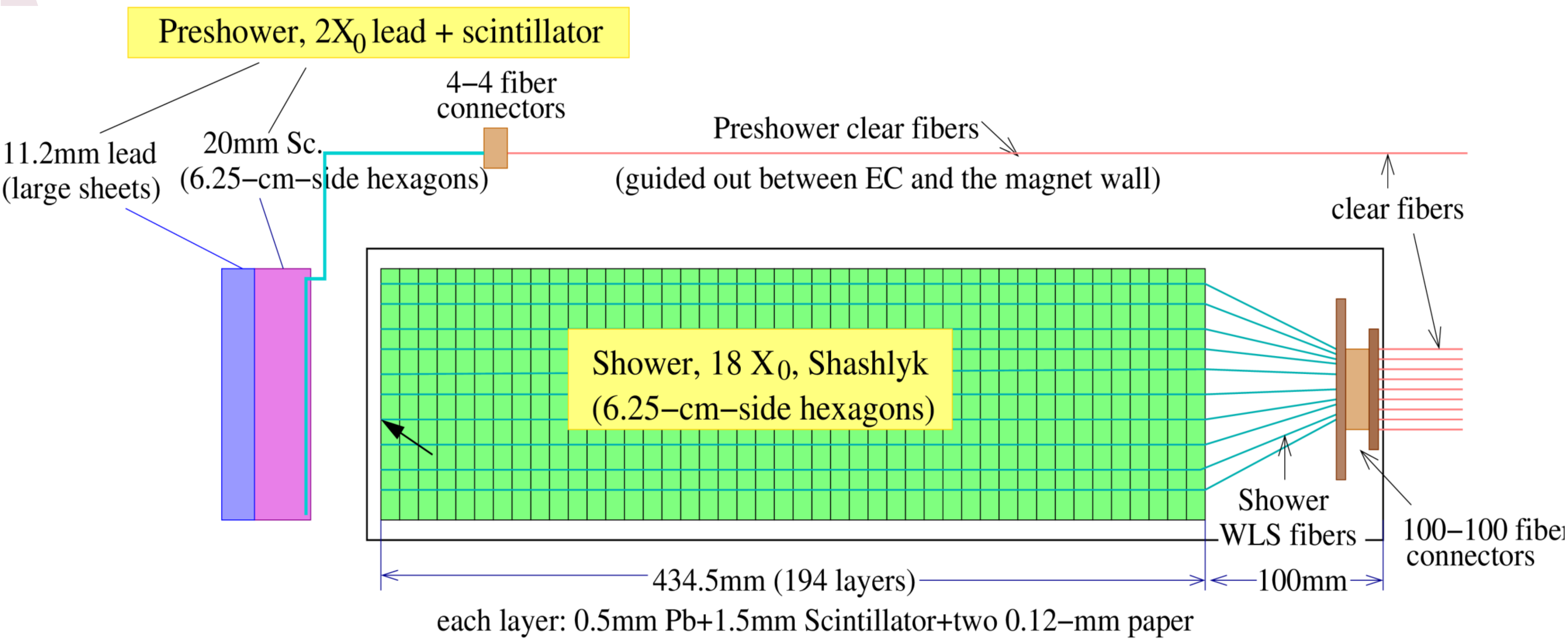


EC Design Requirements

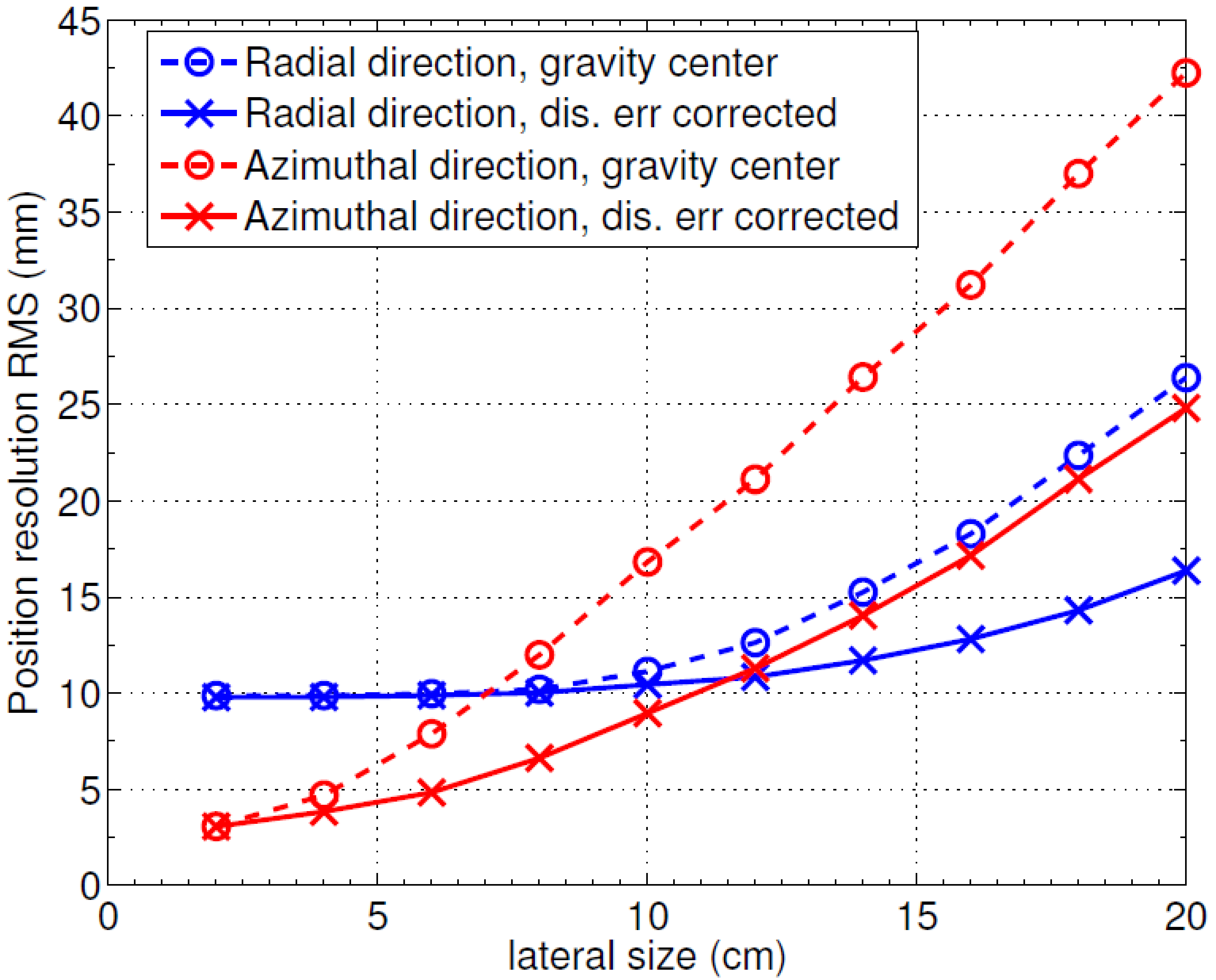
1. Provide trigger: Shower portion coincidence with LGCC, suppress background
2. Electron- hadron separation:
   - >50:1 π rejection above Cherenkov threshold (~4) to 7GeV/c;
   - Electron efficiency > 95%;
3. Provide shower position to help tracking/suppress background
   - σ ~ 1 cm
4. Radiation resistance: > (4-5)x10^5 rad
5. B~1.5 T
6. high neutron background
7. Modules easily swapped and rearranged for PVDIS ↔ SIDIS;

Design Consideration 1: Longitudinal

- Preshower: $2X_0$ lead + 20mm scintillator
- Shower: 0.5 mm Pb/1.5mm scintillator sampling
- Total length: $20X_0$ (<2% leakage)

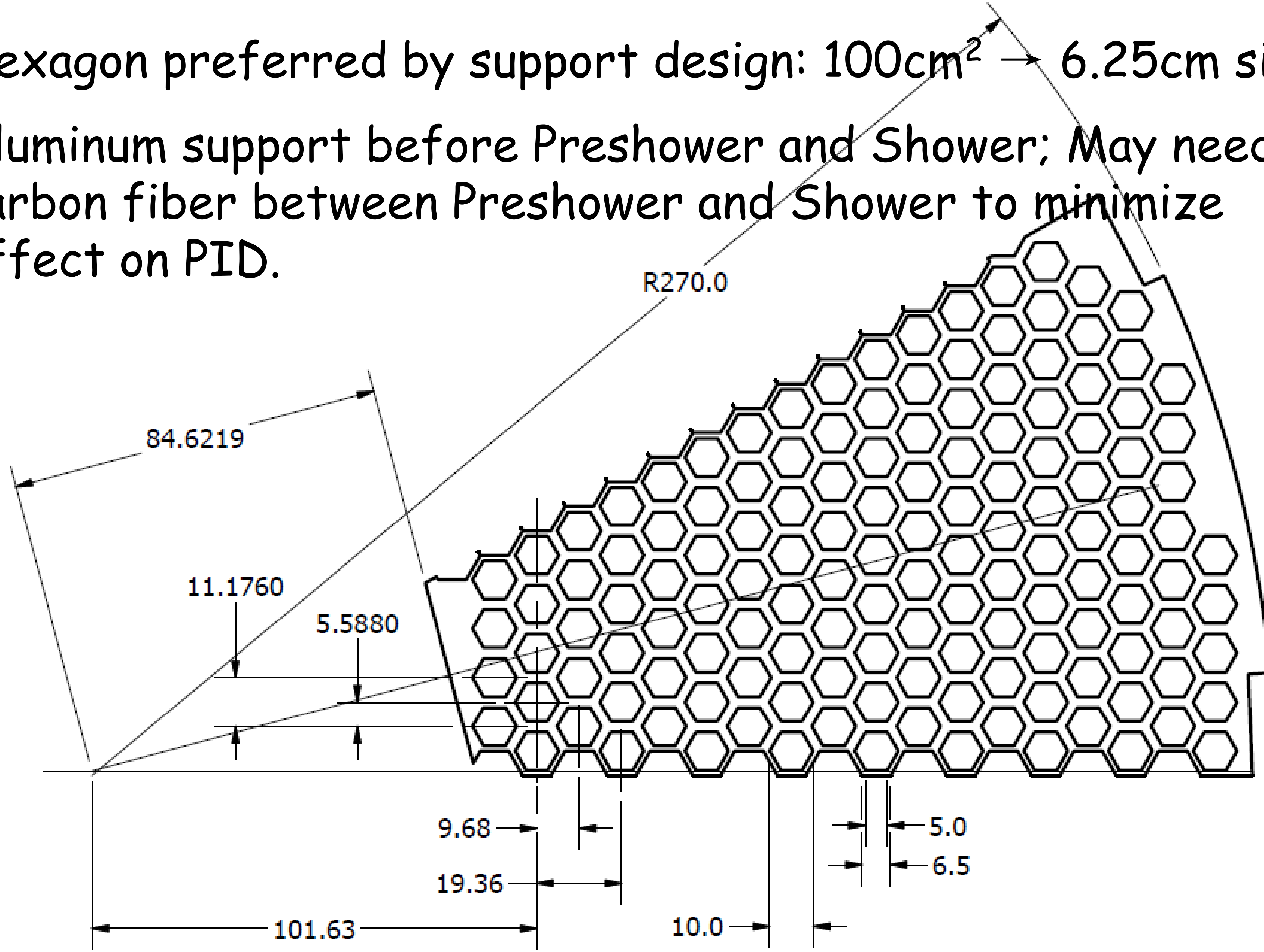


Design Consideration 2: Lateral

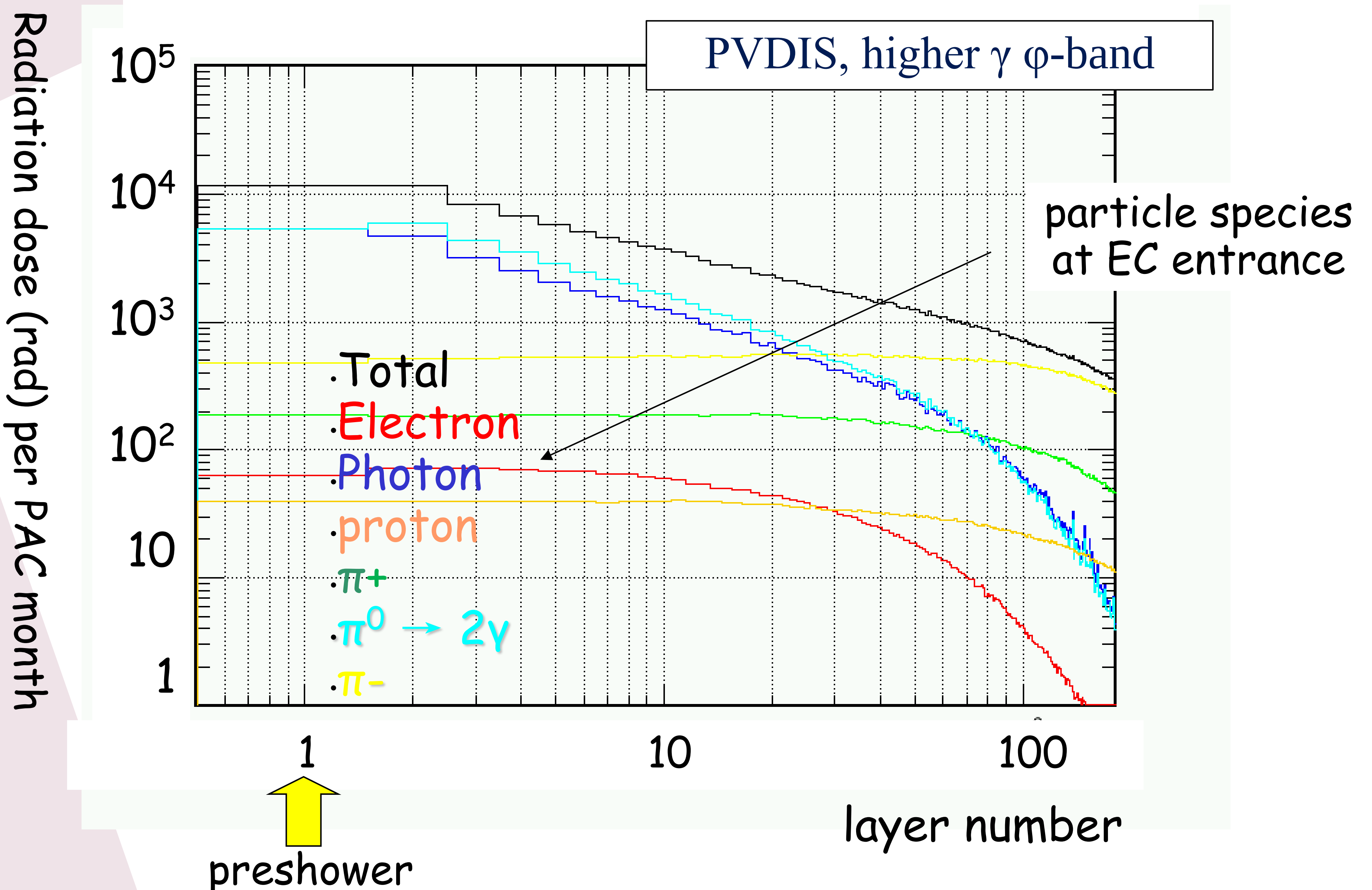


Design Consideration 2: Lateral

- Hexagon preferred by support design: 100cm^2 → 6.25cm side
- Aluminum support before Preshower and Shower; May need carbon fiber between Preshower and Shower to minimize effect on PID.



Design Consideration 3: Radiation Dose



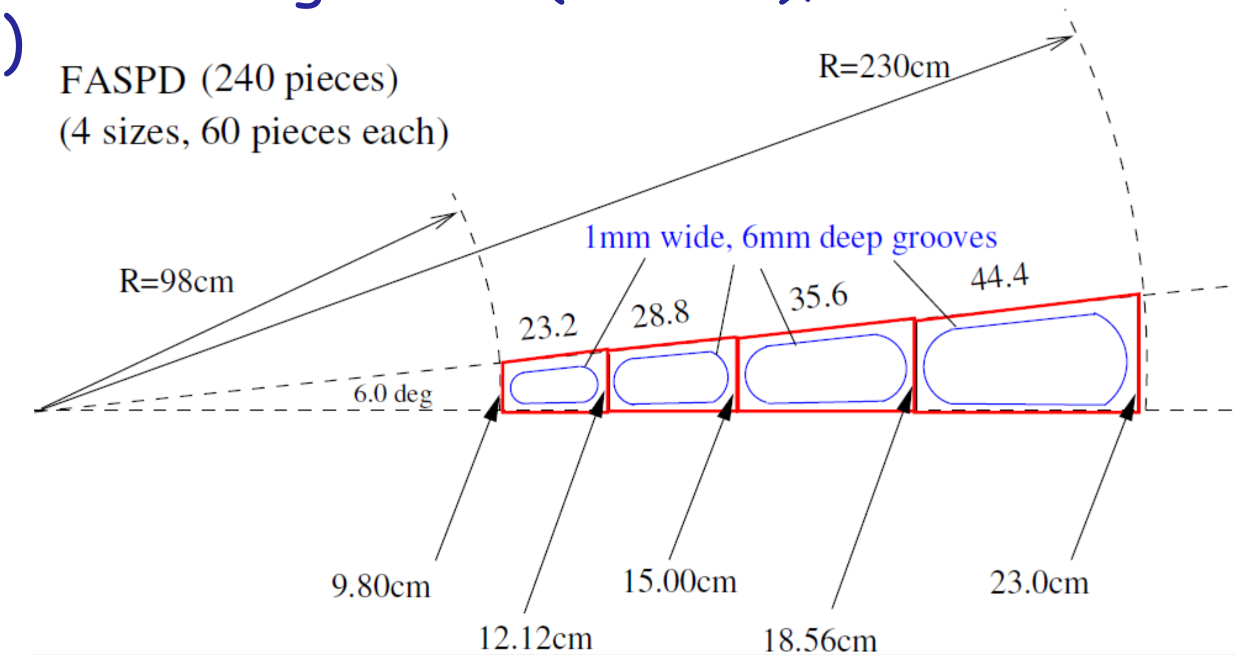
Design Consideration 4: Fiber Choice

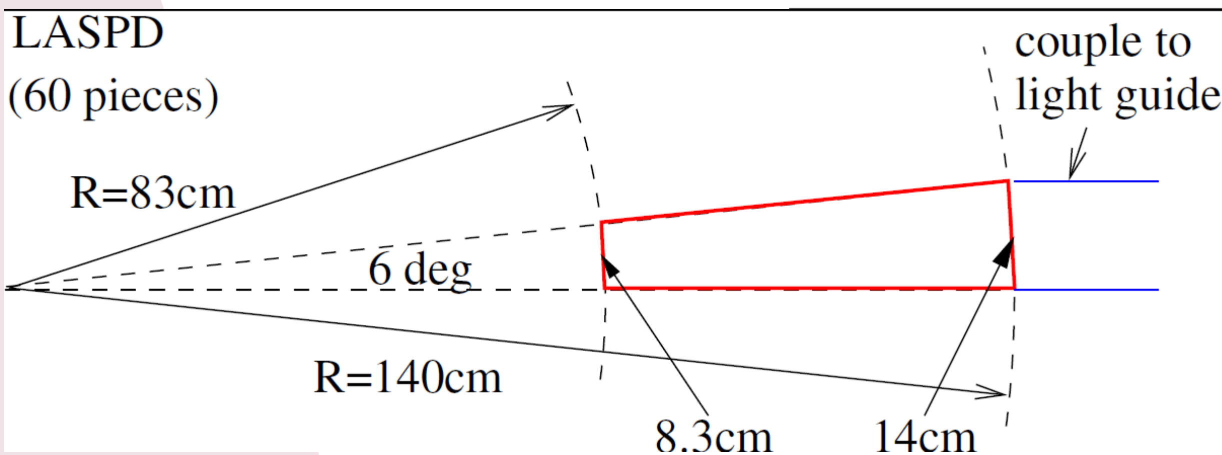
WLS fibers	Kuraray Y11	Saint Gobain BCF91A, BCF92 (faster)
wavelength	~420 → 494nm	~430 → 476nm
1/e length	>3.5m	>3.5m
mechanical property	less bending loss	
radiation hardness	13% light loss at 100krad (30% at 700krad)	15% light loss at 100krad (50% at 700krad)
light yield		2-3 times less than Y11
Clear fibers	Kuraray clear-PSM	Saint Gobain BCF98

Will use Y11 for Preshower and FASPD, BCF91A for Shower; Clear fiber yet to be tested.

SPD: scintillator pad detector

- ✓ SPD help to reduce calorimeter based trigger rates for high energy charged particles
- ✓ Only in SIDIS, include forward angle SPD (FASPD), and Large argle SPD (LASPD)

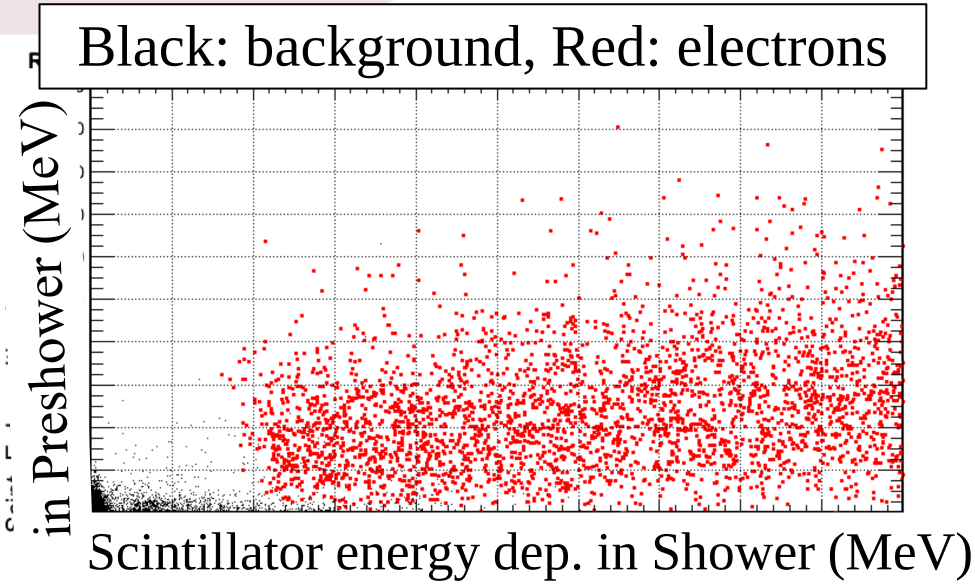


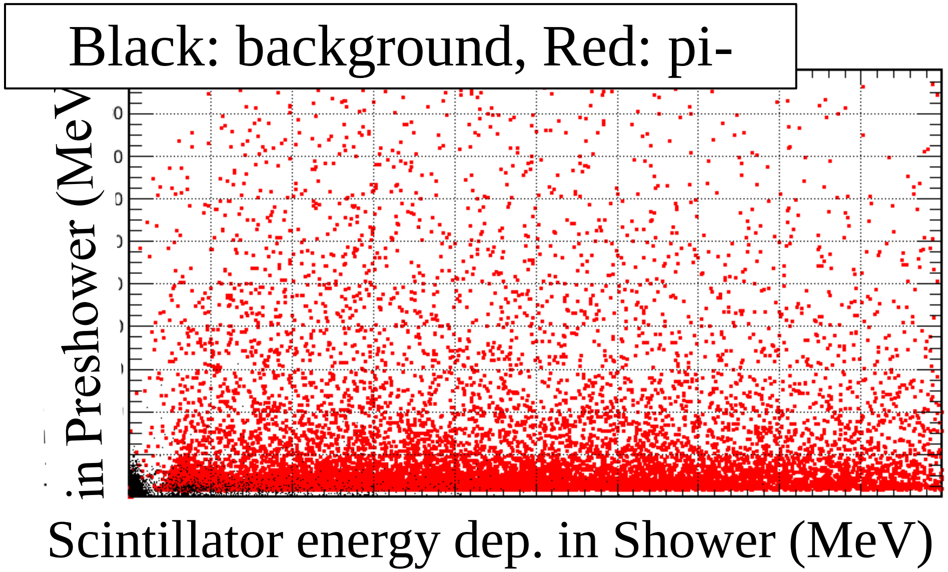


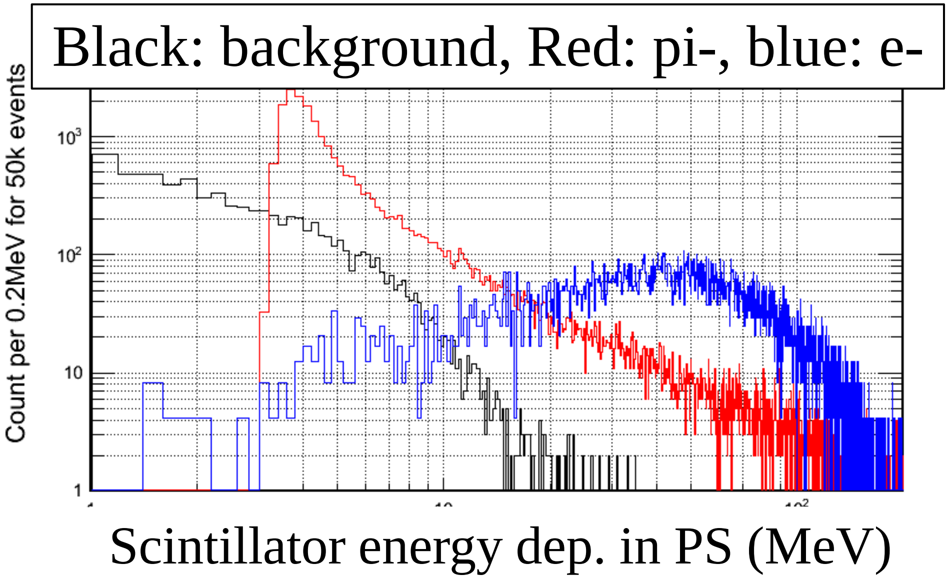
Performance Simulation — Offline PID

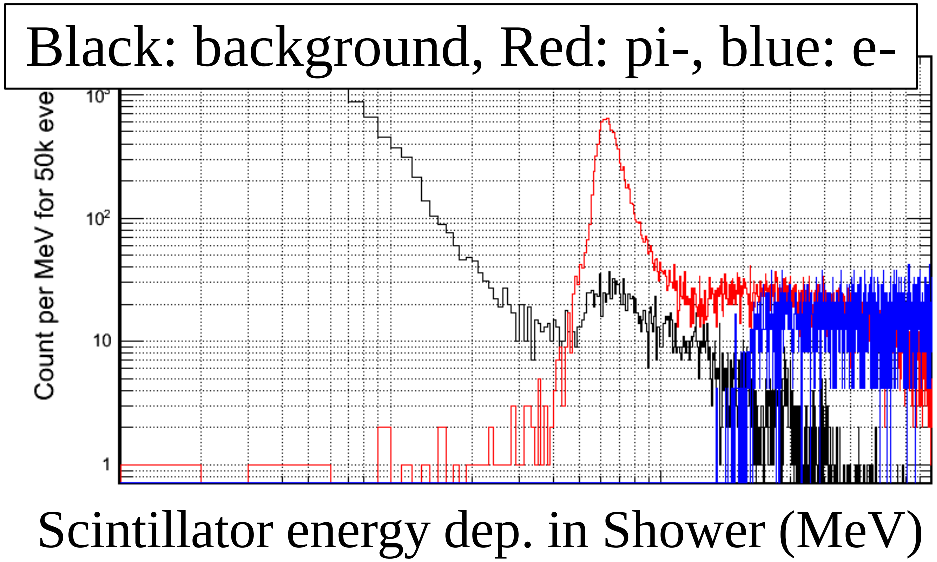
Performance Simulation — PID, SIDIS LAEC

- Background







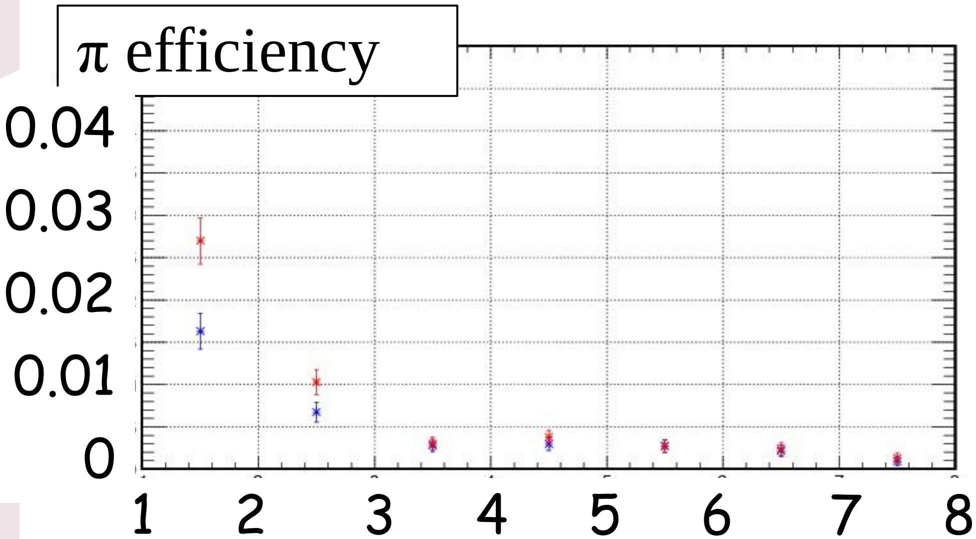


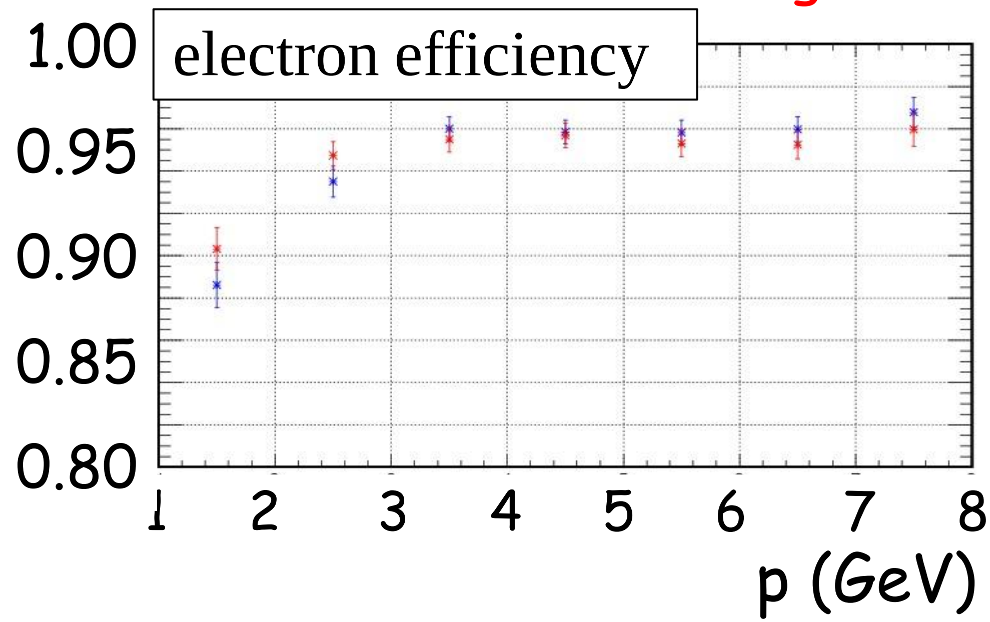
Performance — PID, SIDIS

Most inner radius region shown – worse case situation

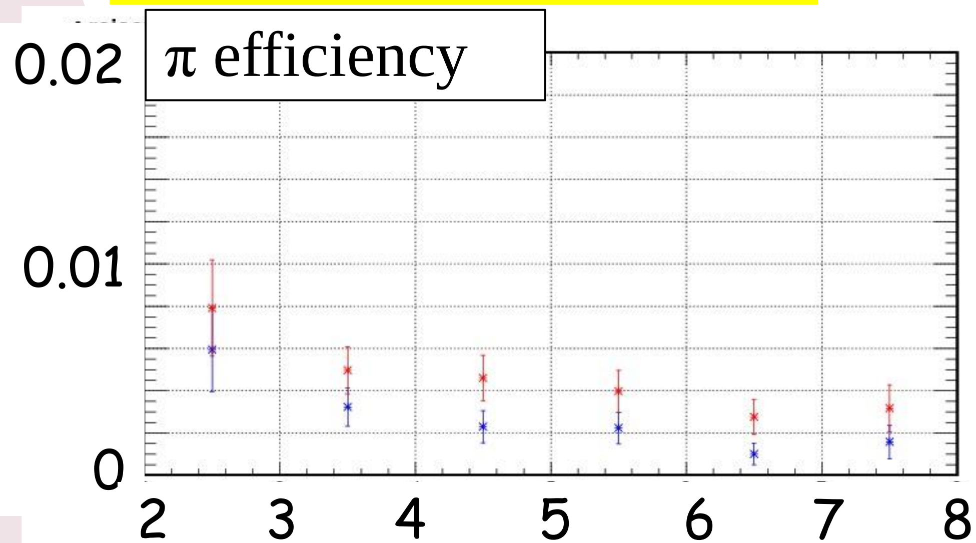
* Intrinsic
* W/ Background

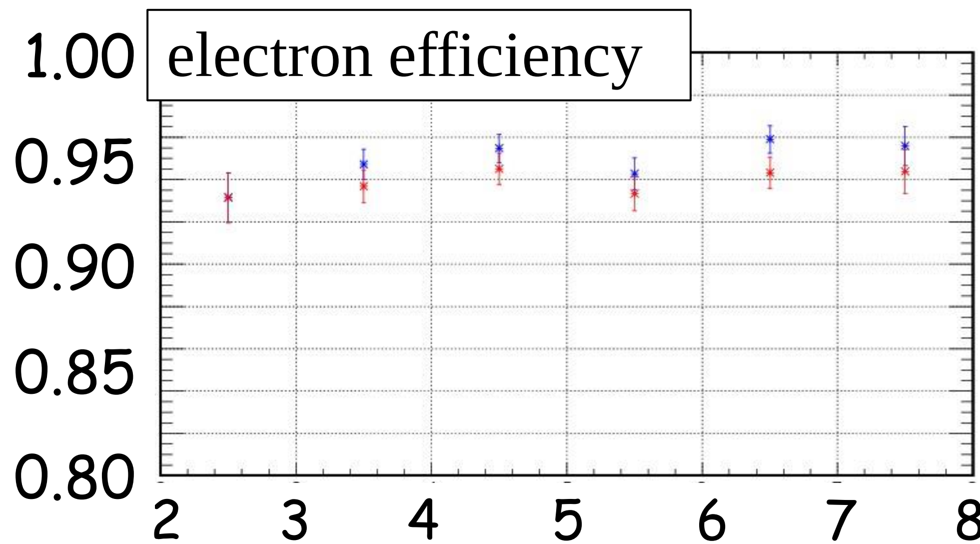
Forward Calorimeter





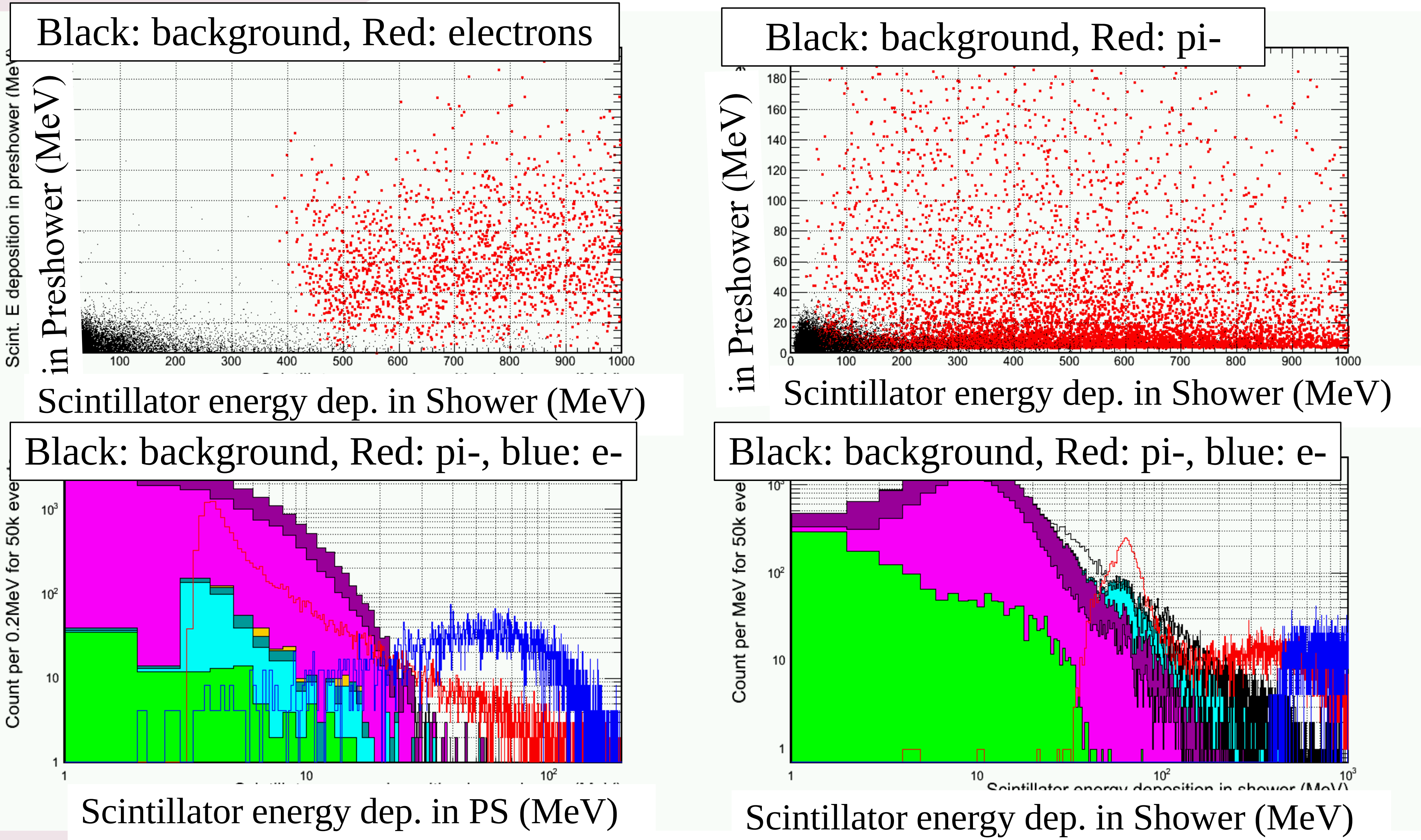
Large-Angle Calorimeter





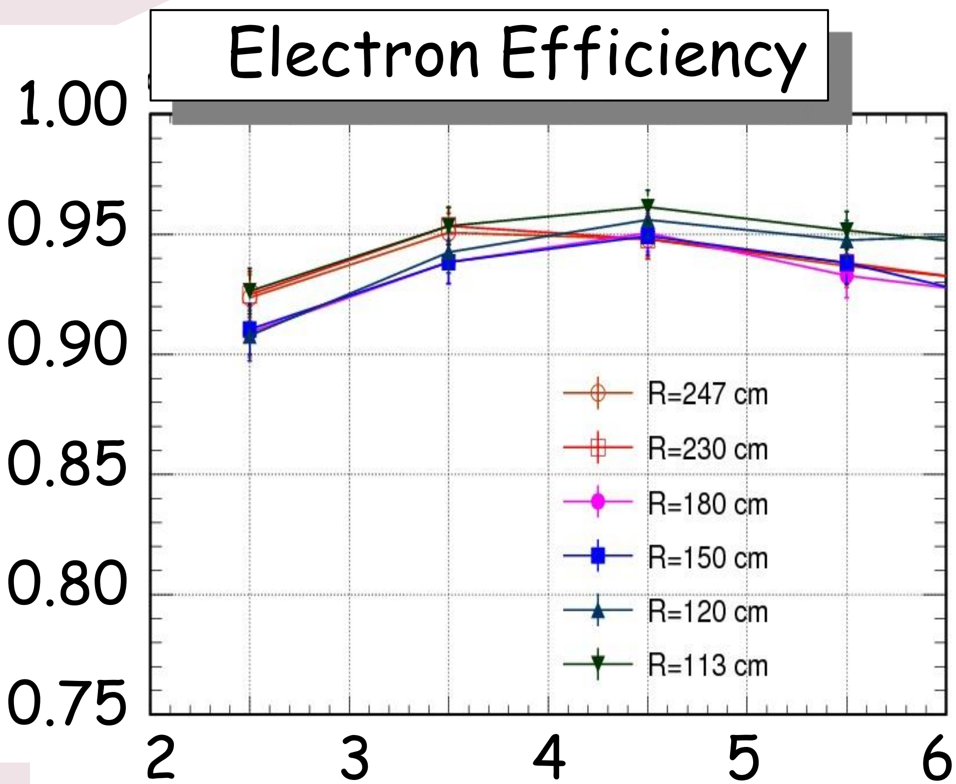
Performance — PID, PVDIS

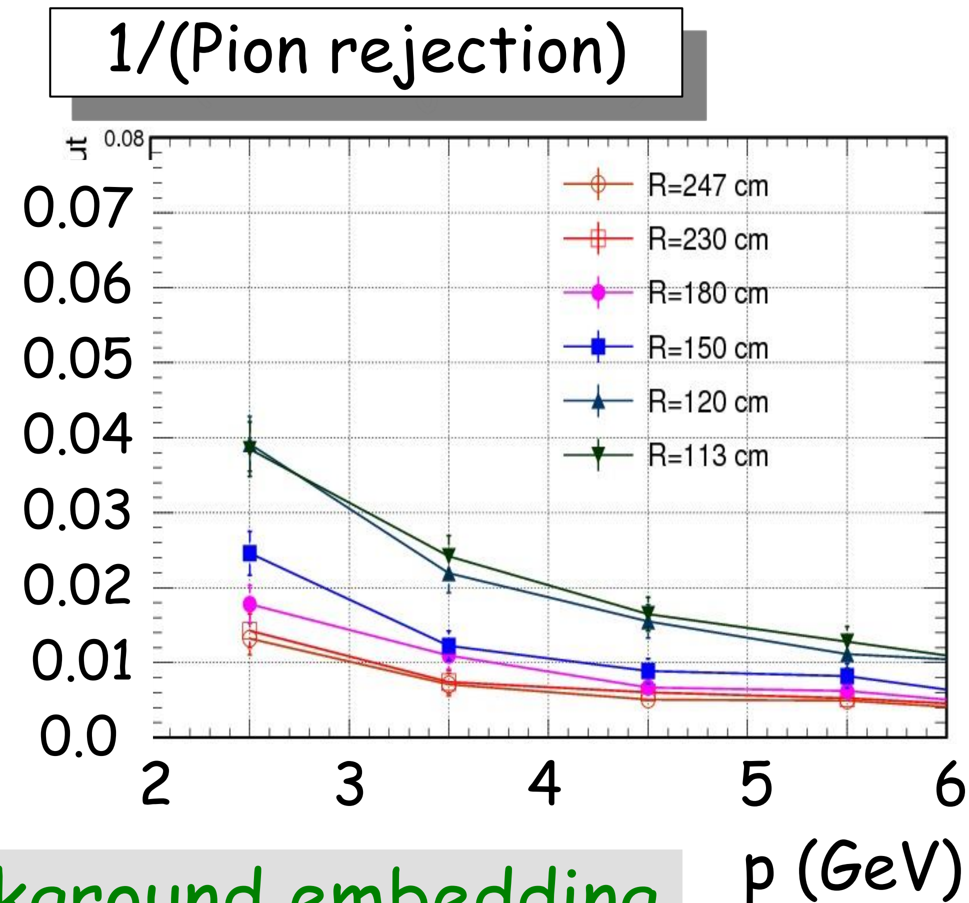
- Background rate significantly higher



Performance — PID, PVDIS (high γ)

- Background worsens PID. Will require full waveform recording if better PID is desired.





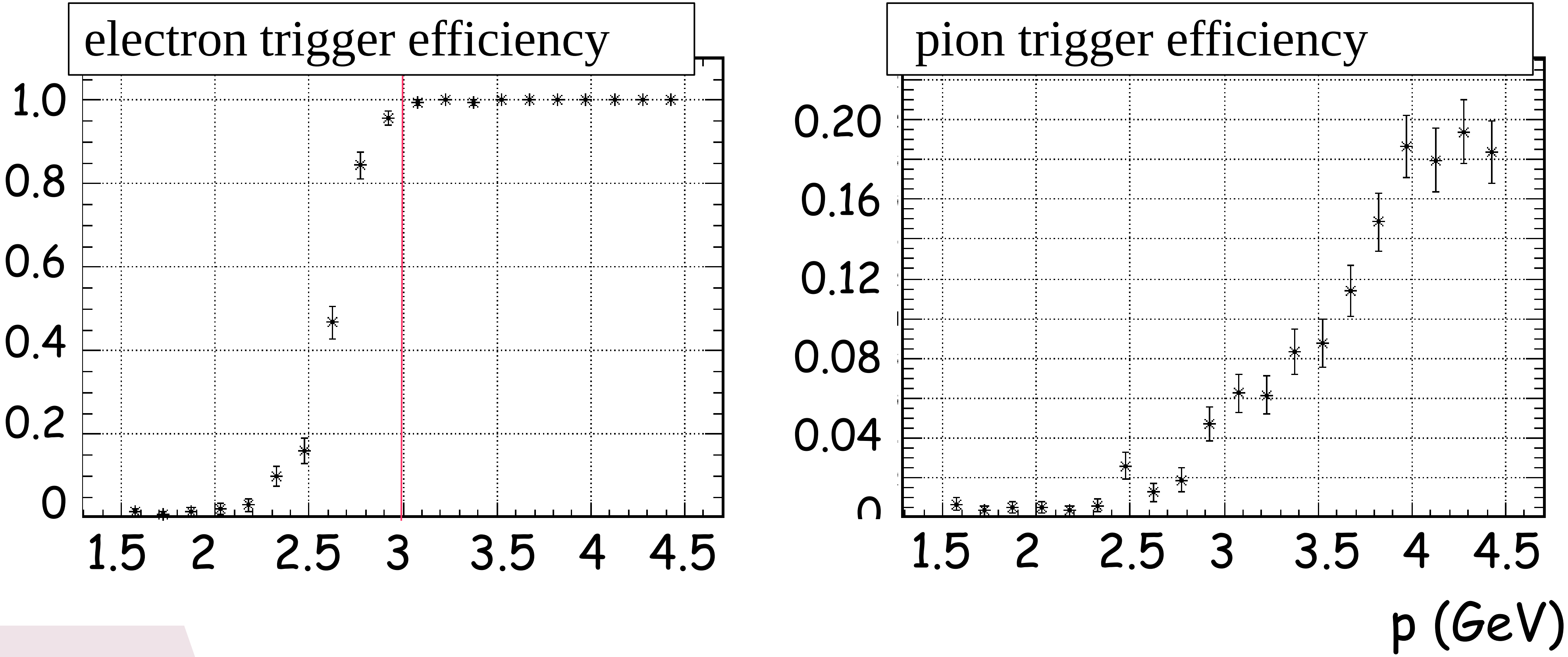
2D-cut PID, with latest background embedding

PVDIS: p=2.3~6 GeV

Performance Simulation
—
Online Triggering

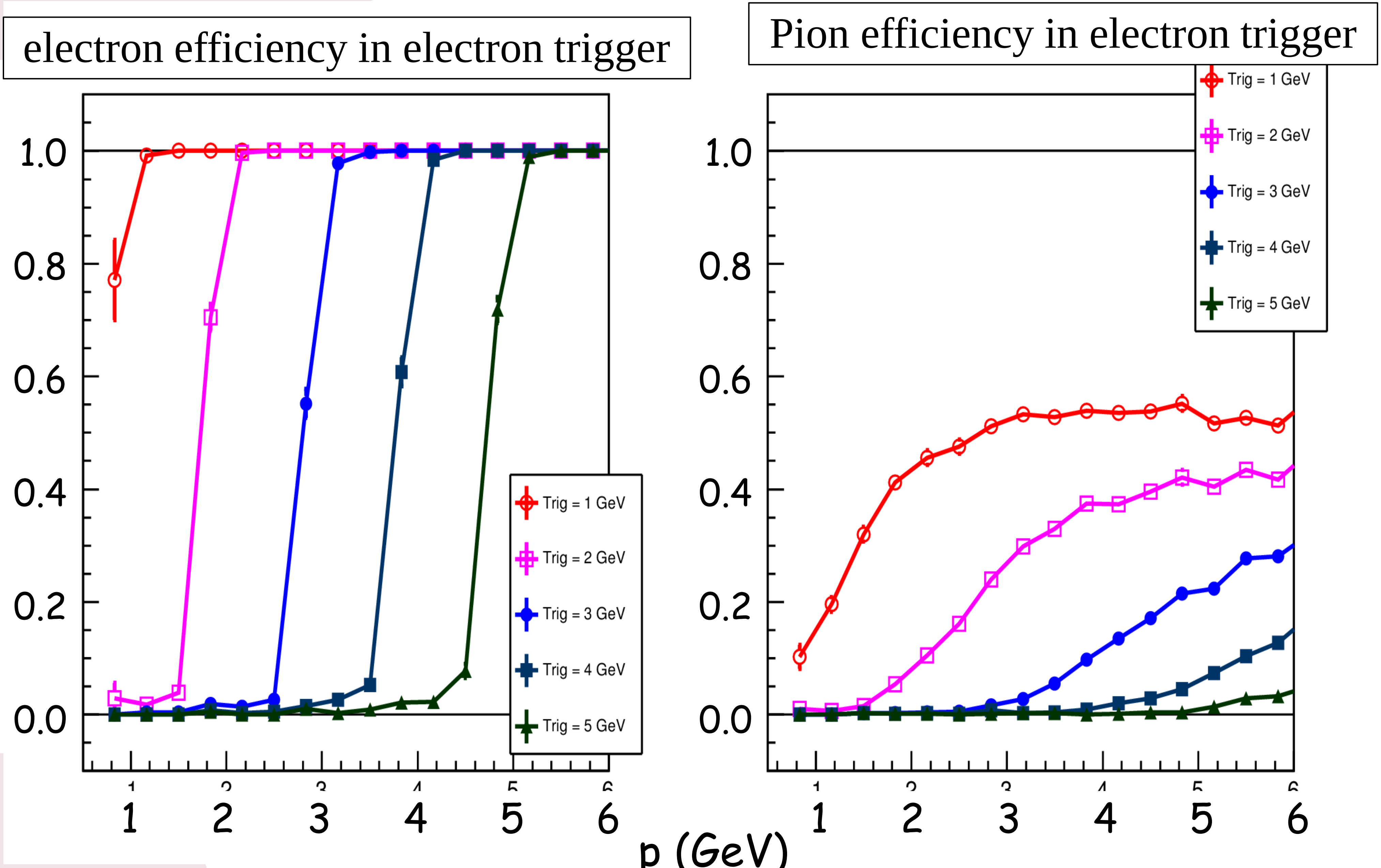
Performance — Triggering
SIDIS, LAEC, electron trigger

Most inner radius region shown - worse case situation



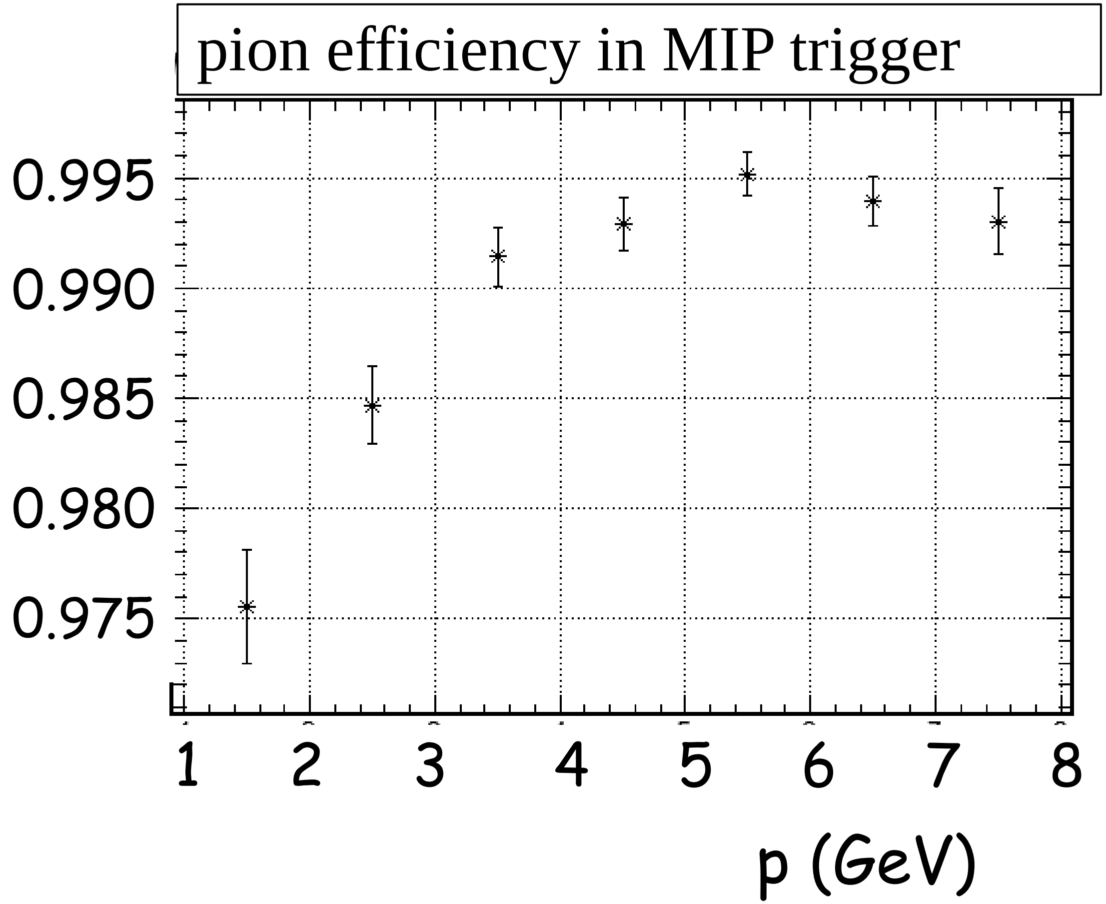
threshold: 2.6 GeV → 3 GeV momentum

Performance — Triggering SIDIS, FAEC



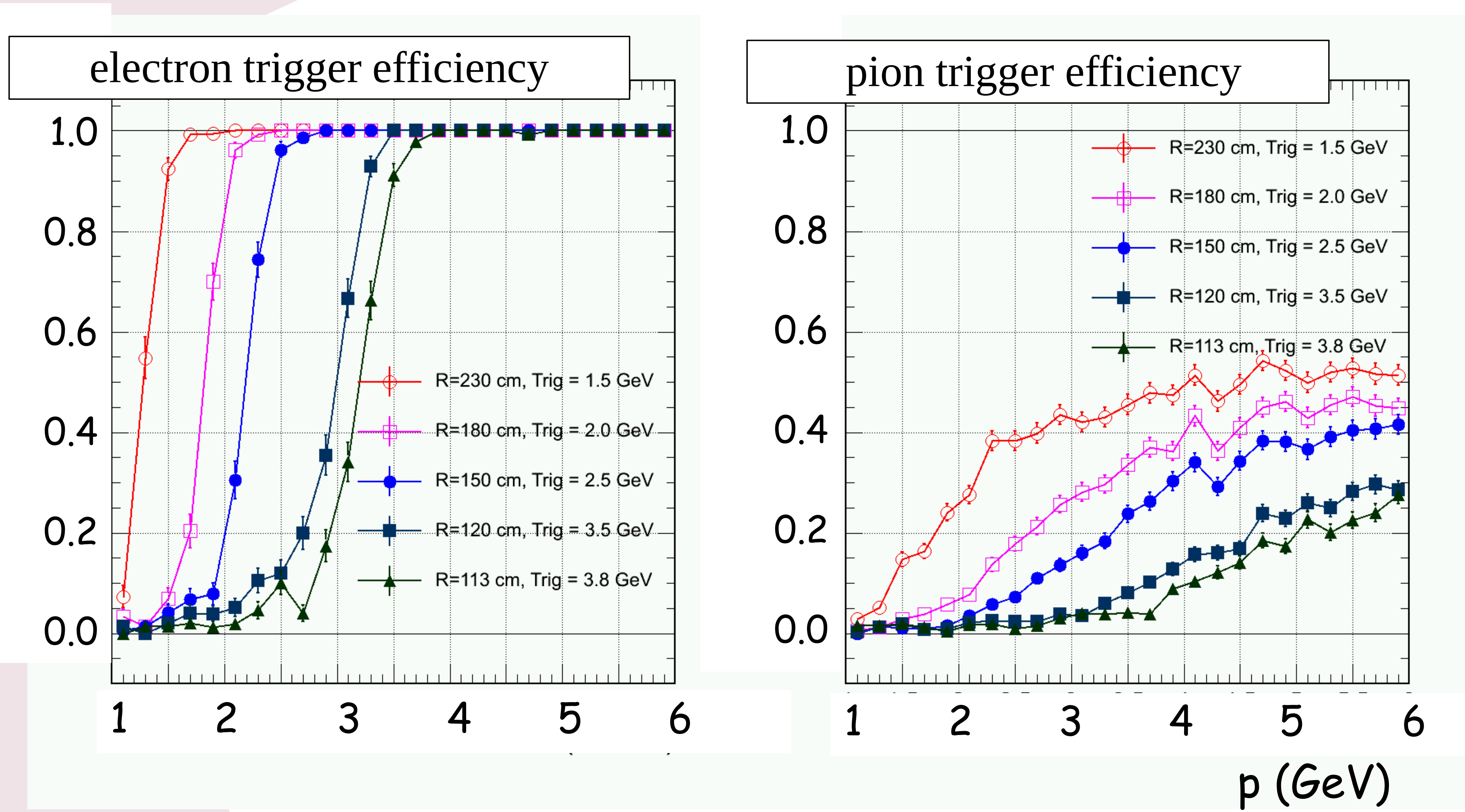
Performance — Triggering
SIDIS, FAEC MIP trigger

Pion trigger: 2-sigma below MIP
Coincidence with SPD to suppress bkg trigger rate



Performance — Triggering

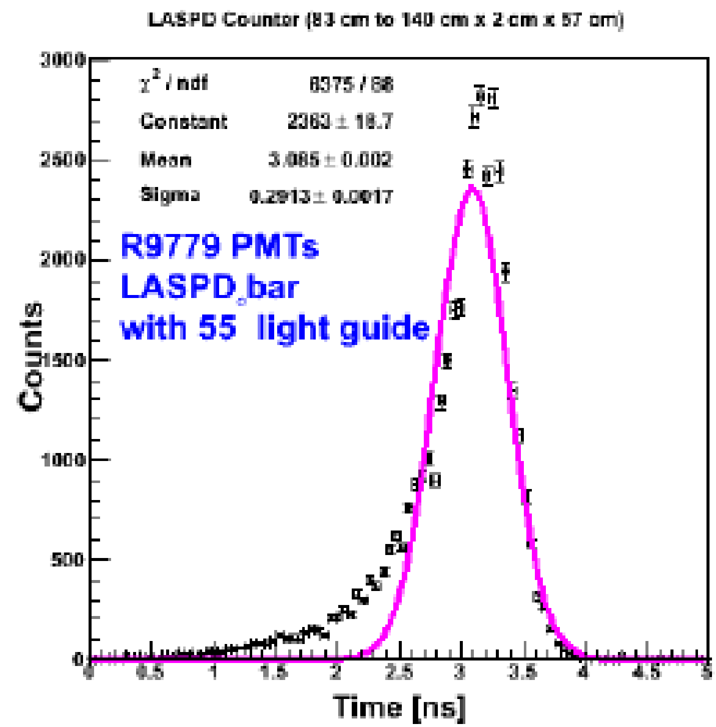
PVDIS, higher photon background region



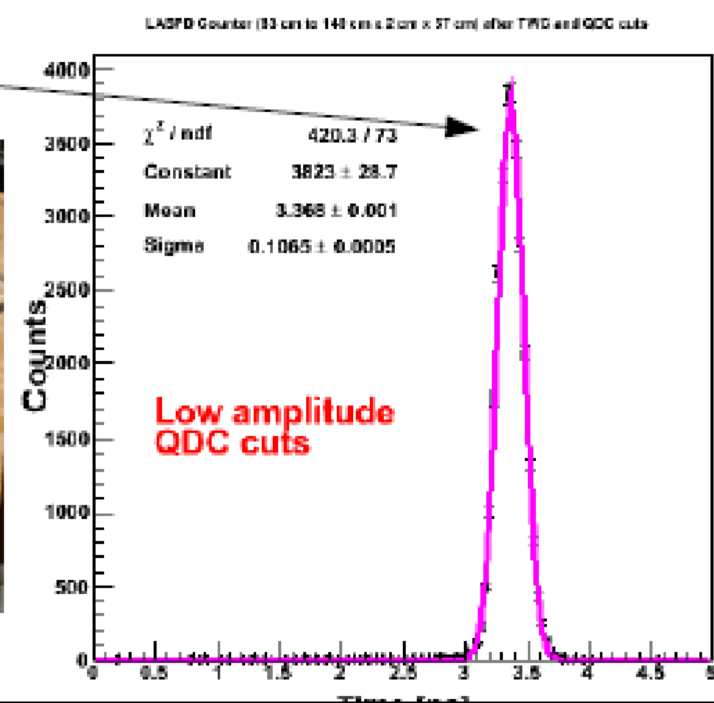
Pre-R&D: Prototyping

Pre-R&D: LASPD prototype testing

- Setup: "3-bar" setting (Ref FTOF12 testing), 5x5x30cm EJ200 reference bars, PMT R9779
- Results: 58ps for reference bars, 98ps for 2-cm LASPD (two-side readout). [Single-side readout expected to be ~(84-170)ps, looking for further testing with tracking.]



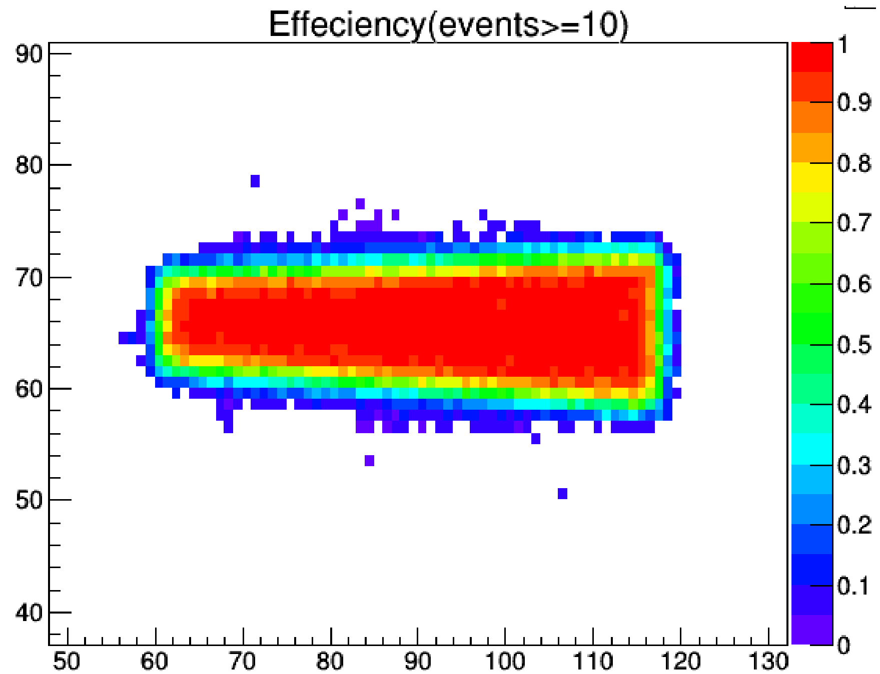
$(t_{left}+t_{right})/2-t_{event,ref}$



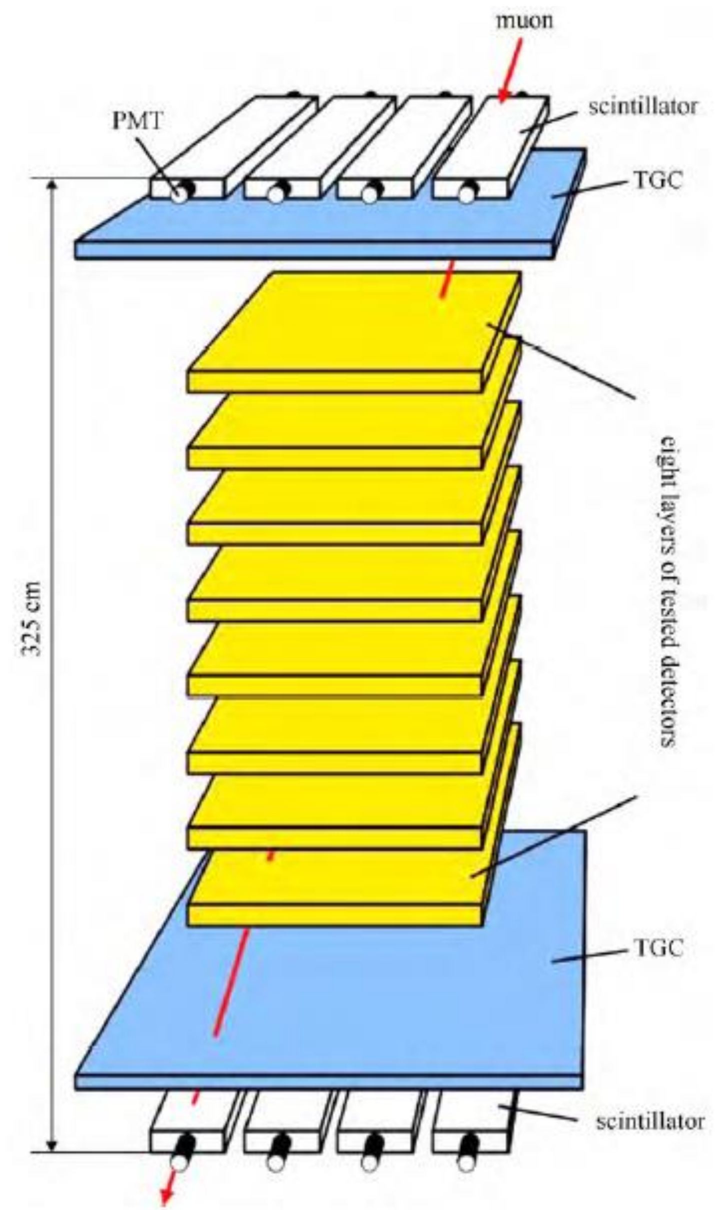
LASPD with 55 degree fishtail light guide

LASPD prototype test in SDU

LASPD(Kedi) couple to PMT directly.

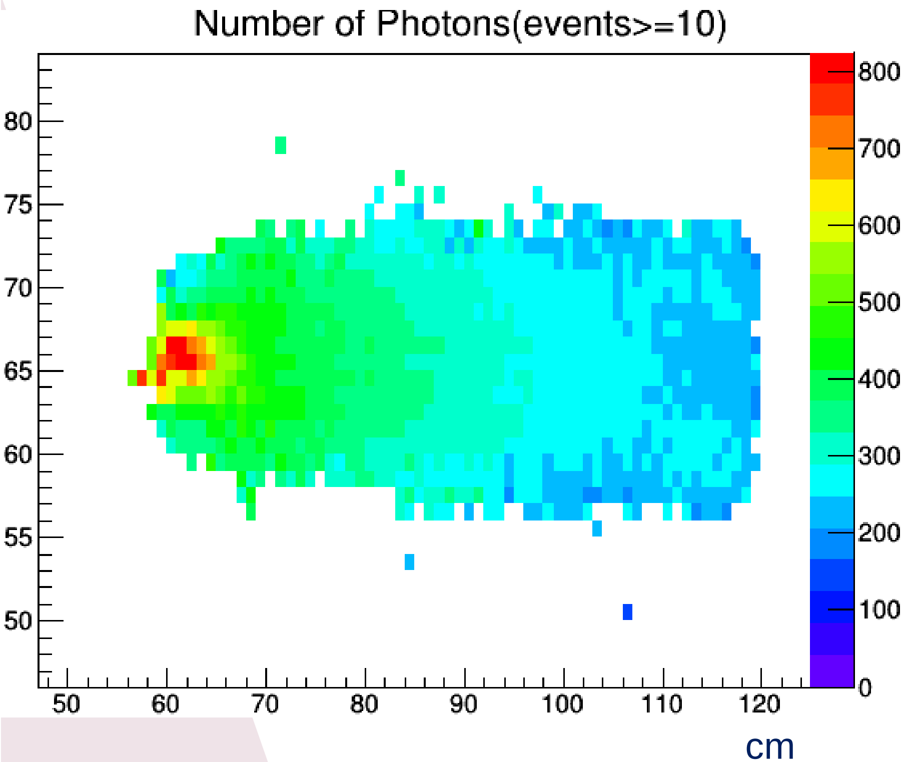


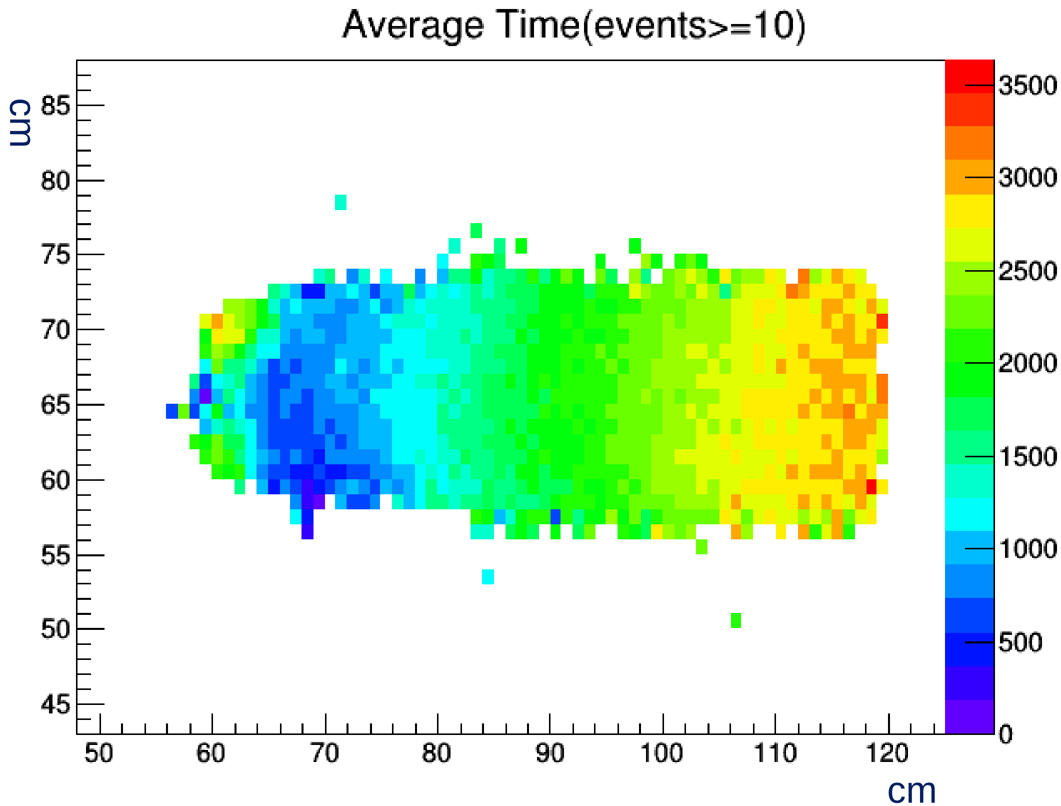
Detector efficiency



Cosmic ray telescope in SDU

LASPD prototype test in SDU





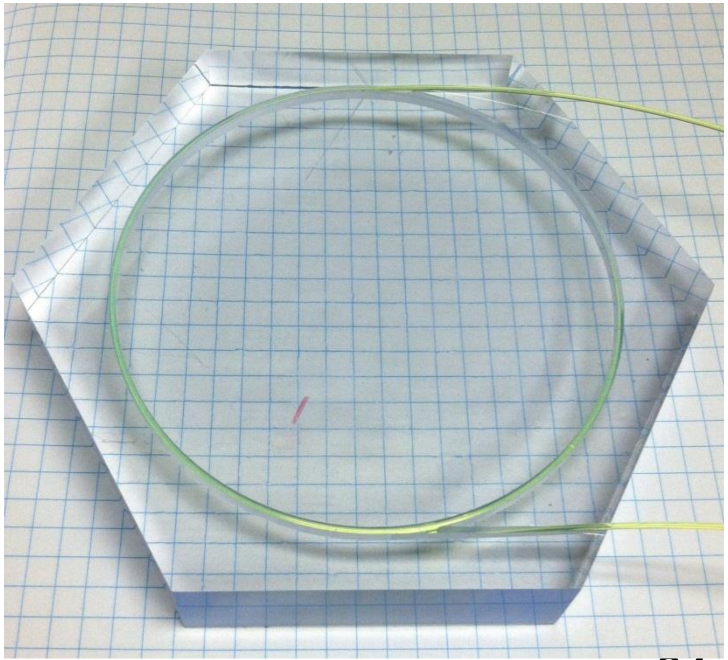
Number of photon electron for MIP (each bin size 1cm*1cm). Signal read from left.

Relative response time. Signal read from left.
Time delay found in the left up and down corner due to multiple reflection.

Pre-R&D: preshower prototype testing

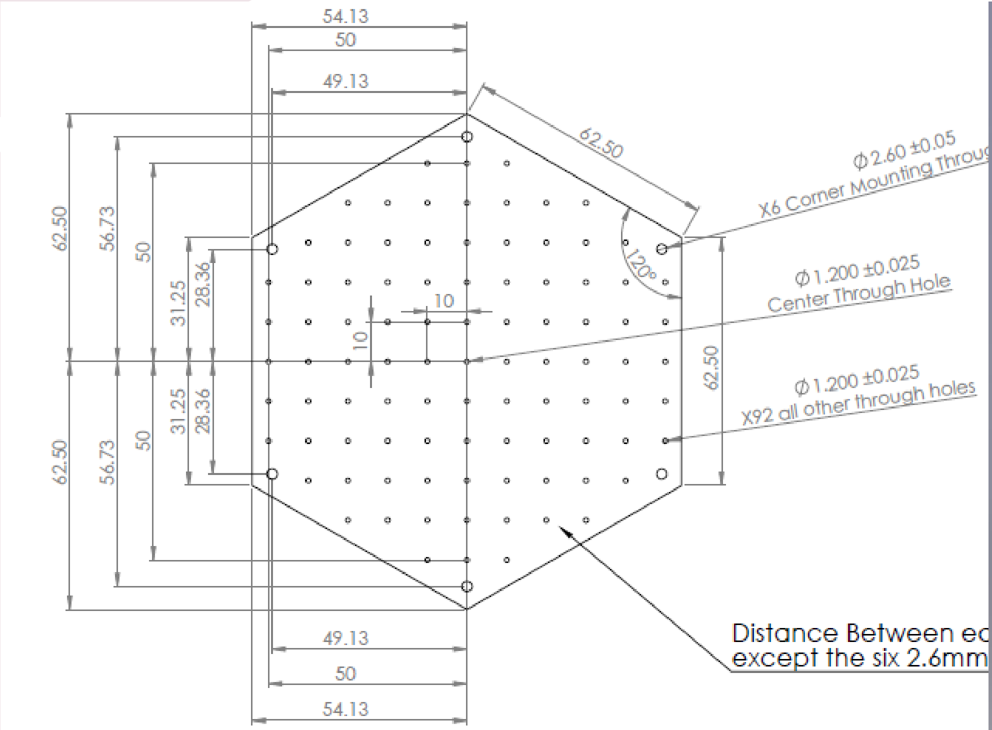
- Tested: IHEP, Beijing Kedi, CNCS (similar yield)
- WLS fiber: Y11, BCF91A(55% relative), BCF92(35% relative)
- wrapping: printer paper, Tyvek 1055B(10% higher), Al-mylar (17% higher)
- Fiber routing: optimized to double φ-1mm fiber, 2.5 turns each
- Test results (printer paper, Y11, 2x 2.5-turn): ~80 p.e. for all samples

- To do:
- fiber connector design;
- PID simulation with 40 p.e. (after fiber connector and 2-m long clear fiber)

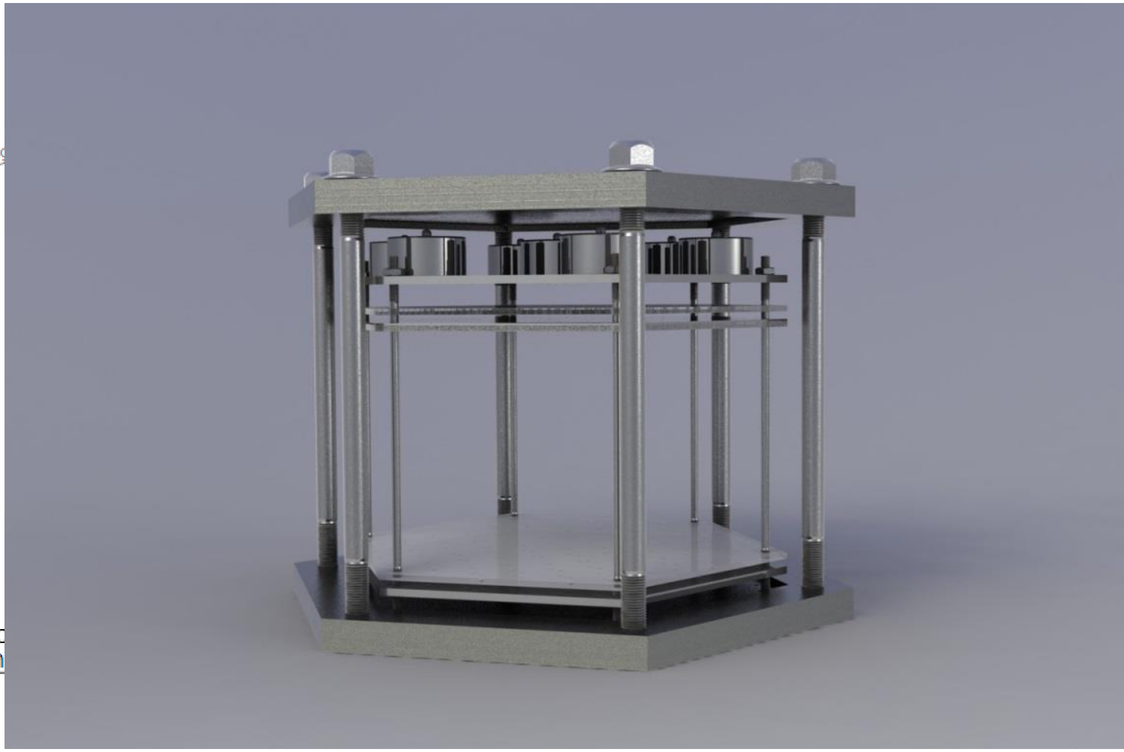


Pre-R&D: Shashlyk Prototyping

- "Physicist's design": use 6x 2.5-mm dia brass or stainless steel rods to support all layers, fix to 6mm-thick Al endcaps using hex nuts.



Skeleton of Shashlyk tile.



Primary idea for pressure testing.
The shashlyk module is inside the pressure module.
The endcap plate of the pressure module is little big, six φ 6mm rods will provide the pressure.
Seven pressure meters on the top of shashlyk to monitor the pressure.

SDU has provided initial funding for 4 shashlyk prototypes.

scintillator Production

Vendor	polymer base	light yield anthracene	Price for preshower mass production (20mm)
Russia IHEP	polysterene	40% from CERN data	$216k tot + 30%, or $156 each
高能科迪科技有限公司(Kedi)	unknown (but looks the same as CNCS)	40% from UVa data	($100)*1800=$180k, or $100 each w/o overhead
中核控制系统工程有限公司 (CNCS)	ST401 phenylethene	40%	($100)*1800=$180k, or $100 each w/o overhead
Eljen Technology	EJ200 polyvinyltoluene	64%	[$77 (no groove)/$204 (grooved)] *1800; or $204 each
Saint Gobain Crystal	BC408 polyvinyltoluene	64%	$430x2 no groove

Workshop of Kedi（科迪） company

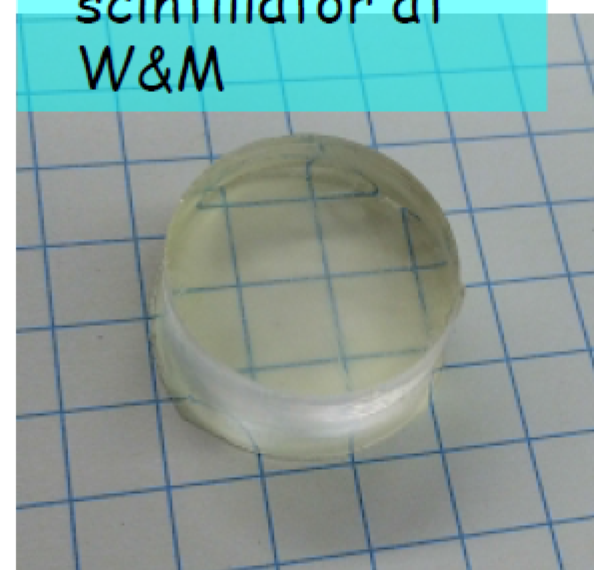
Can provide 400k pieces (for all modules) shashlyk scintillators within 5 months by using molds.

The "New" Component — 3D Printing

- Three existing 3D printing methods:
  - FDM
  - Resin-printing (polyjet)
  - metal sintering

- We have already experimented with Polyjet-printing scintillators [G. Ron (Hebrew U.), W. Deconinck (W&M)]
  - Published results show plausible light yield (30% of commercial polysterene-based scintillators, currently improving compound design, comparable to commercial, need more study)
  - Need mechanical data to see if they are suitable for shashlyk Ecal construction

http://arxiv.org/abs/1406.4817



3D-printed scintillator at W&M

Potentials of 3D Printing

- fast and cost-effective prototyping;
- "easy" construction of projective shape modules;
- may provide better layer thickness uniformity (~10-20 μm, better than injection molding) → better energy resolution;
- possible simplification of assembly process.

Construction plan

- SDU(China): Preshower+FASPD construction/testing, PMT testing, possibly Shower construction
- UVa: LASPD, and Preshower+FASPD construction/testing, possibly Shower construction, general installation
- W&M: MAPMT testing, general construction and installation
- LANL: general construction and installation

Welcome more man power join us !

Summary

- SoLID EM calorimeter has been well defined
- EM calorimeter has the capability to provide PID, trigger and position
- Prototype study have started

Thanks for your attention!

Backup Slides

Performance — Triggering

SIDIS, trigger rates (whole EC)

region	FAEC	LAEC
rate entering the EC (kHz)		
e^-	93.4	18.7
π^-	5.36×10^3	1.55×10^4
π^+	5.96×10^3	1.66×10^4
$\gamma(\pi^0)$	1.52×10^5	2.43×10^5
$e(\pi^0)$	6.52×10^3	2.04×10^3
p	1.86×10^3	6.16×10^3
electron trigger rate (kHz)		
e^-	74.2	11.68
π^-	500	5.16
π^+	548	5.12
$\gamma(\pi^0)$	896	12.5
$e(\pi^0)$	43	0.14
p	109	2.15
sum	2170	36.75
MIP trigger rate (kHz)		
e^-	93.4	
π^-	5240	
π^+	5800	
$\gamma(\pi^0)$	6760	
$e(\pi^0)$	772	
p	1732	
sum	2×10^4	

Performance — Triggering

PVDIS, trigger rates (whole EC)

region	full	high	low
rate entering the EC (kHz)			
e^- (DIS)	413	148	265
π^-	5.1×10^5	2.7×10^5	2.4×10^5
π^+	2.1×10^5	1.0×10^5	1.2×10^5
$\gamma(\pi^0)$	8.4×10^7	4.2×10^7	4.3×10^7
p	5.5×10^4	2.4×10^4	3.1×10^4
sum	8.5×10^7	4.2×10^7	4.3×10^7
trigger rate for $p > 1$ GeV (kHz)			
e^- (DIS)	321	80	231
π^-	4.8×10^3	3.4×10^3	1.4×10^3
π^+	0.28×10^3	0.11×10^3	0.17×10^3
$\gamma(\pi^0)$	4	4	0
p	0.18×10^3	0.10×10^3	0.08×10^3
sum	5.6×10^3	3.7×10^3	1.9×10^3
trigger rate for $p < 1$ GeV (kHz)			
sum	$(3.1 \pm 0.7) \times 10^3$	$(1.6 \pm 0.4) \times 10^3$	$(1.5 \pm 0.4) \times 10^3$
Total trigger rate (kHz)			
total	$(8.7 \pm 0.7) \times 10^3$	$(5.3 \pm 0.4) \times 10^3$	$(3.4 \pm 0.4) \times 10^3$

Shashlyk Production (IHEP)

- Mold: $30k x 2 (scintillator), $15k (lead); plus
- $1270 per module, see below
- Same prototyping and mass production
- Not including 30% overhead

Component	Cost per module
Scintillator	$200
Lead	$240
flanges, nuts	$230
assembly	$320
add fiber mirror, testing	$110

Prototyping (8 modules): $55k+30%, plus fiber ($2,961)

Mass production: $2,361k + 30% = $3,069k, plus fiber

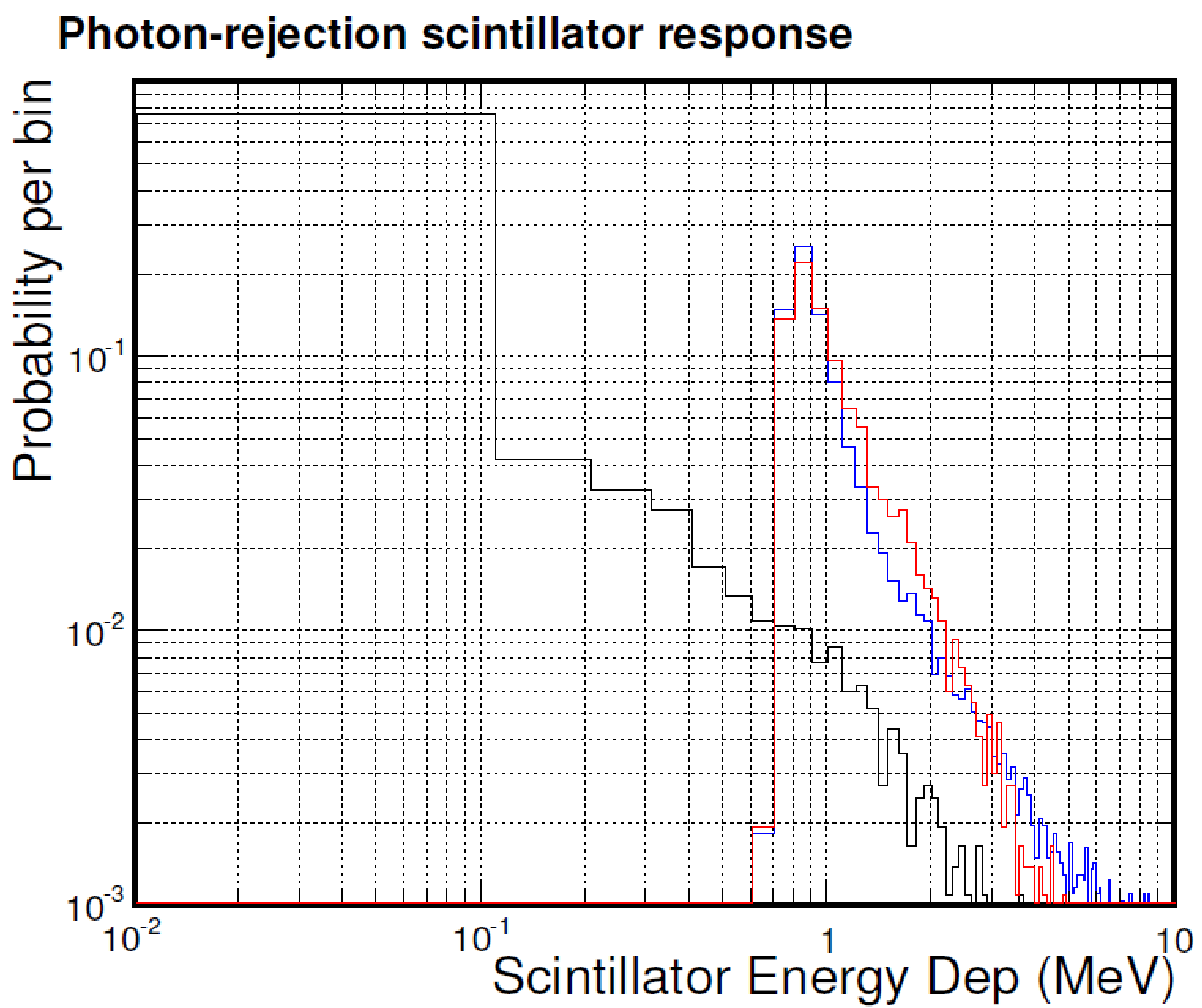
Shashlyk Production (Alternate)

Component	3 modules	8 modules	1800 modules
scintillator (Kedi)	$10k	$27k	$1kx1800=$1.8M
lead (Kolgashield)	$7,776	$17k	$488k
paper (Kolgashield)	$1,152	$2.5k	$130k
flanges, nuts, rods	$600	$1.6k	$150x1800=$270k
fiber mirror, testing	?		
Total w/o assembly	$19.5k	$48.1k	$2,688k

Chinese vendors: only Kedi can do injection molding

Total: $2.7M + overhead (20% for SDU, varies for US manpower only)+ assembly + fiber

Forward

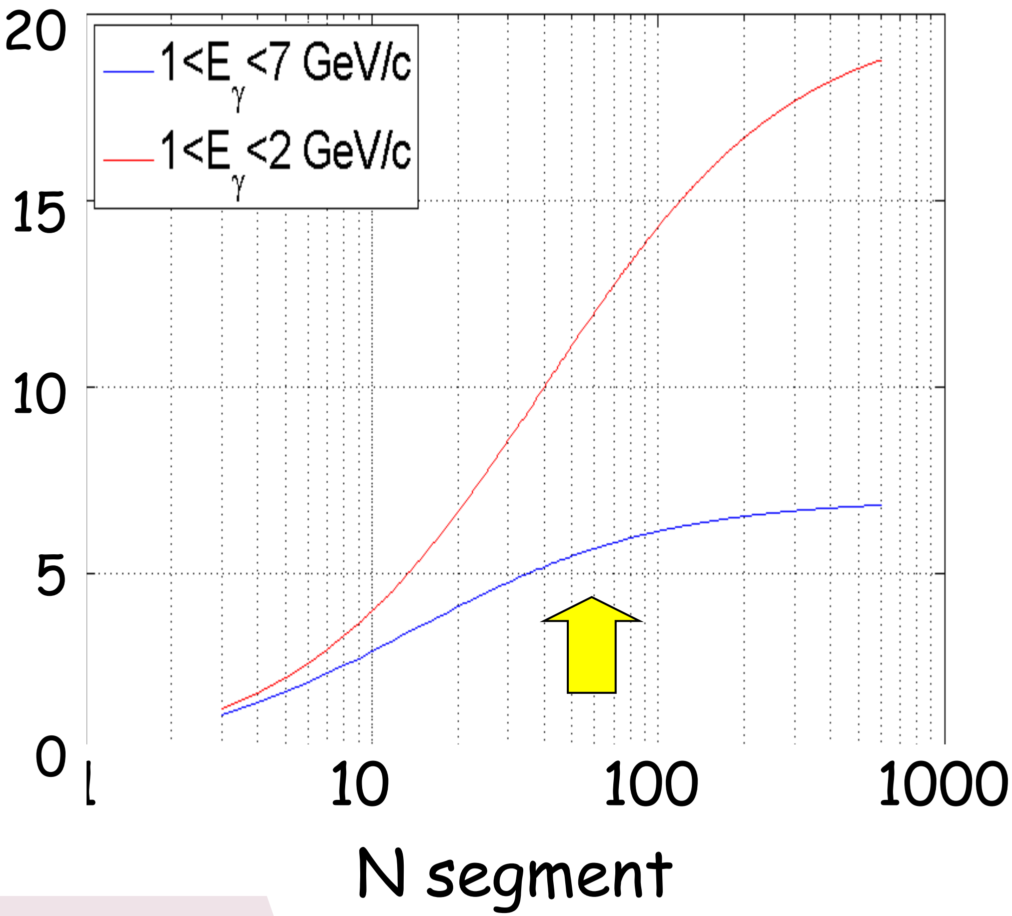


Photon-rejection scintillator response
Probability per bin
10^{-1}
10^{-2}
10^{-3}
10^{-2}
10^{-1}
1
10
Scintillator Energy Dep (MeV)

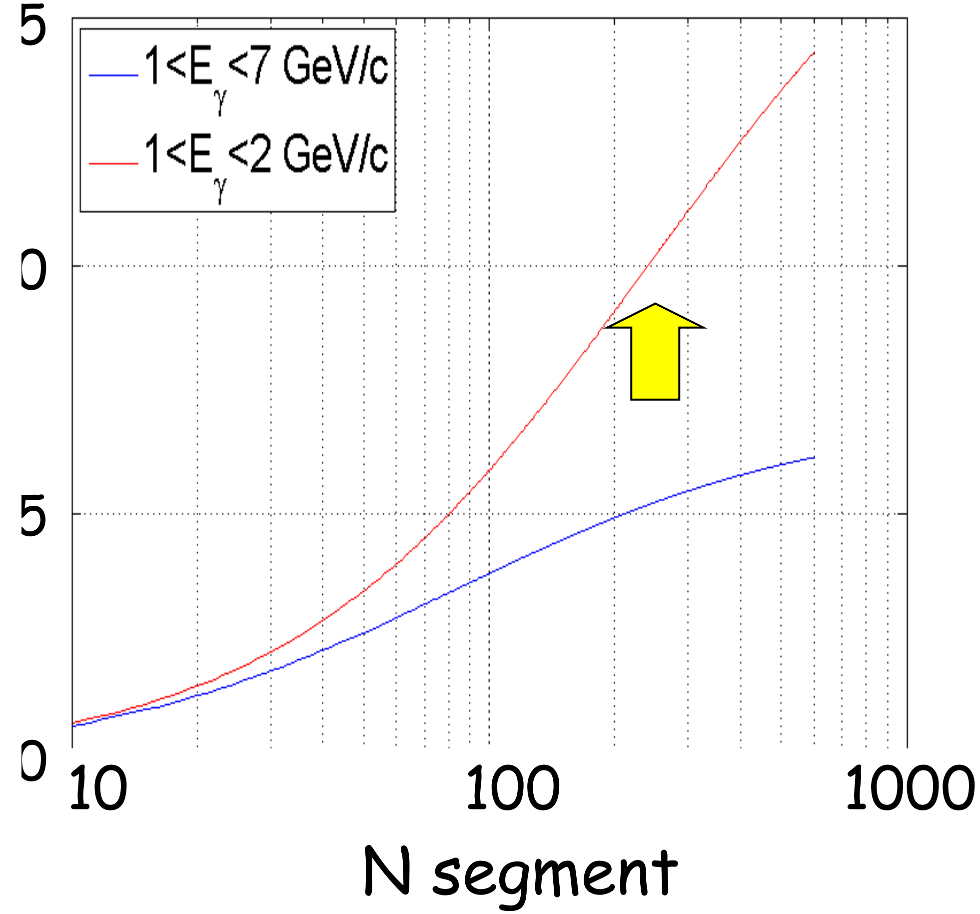
SPD Segmentation

- Starting point: 60 azimuthal segments for LASPD to provide the required 10:1 photon rej; 60 azimuthal x 4 radial for FASPD to provide 5:1;

Large-Angle photon rejection



Forward photon rejection



EC PMT Choice

- Guide light to low-B region to be read by PMTs
  - Shower: 100xφ 1mm fibers → φ-1in PMT (good area match), Hamamatsu R11102, custom divider with x5 preamp, 3E4 PMT gain, dynamic range 45mV(MIP) – 1.5V(e- max)
  - Preshower: (4)x φ 1mm fiber → 16-ch MAPMT, Hamamatsu R11265-100-M16, 8E3 PMT gain limited by anode current (1/10 of max), require x50 preamp, range 9mV(MIP) – 260mV(e- max)
- Working with JLab detector group on PMT base/preamp design