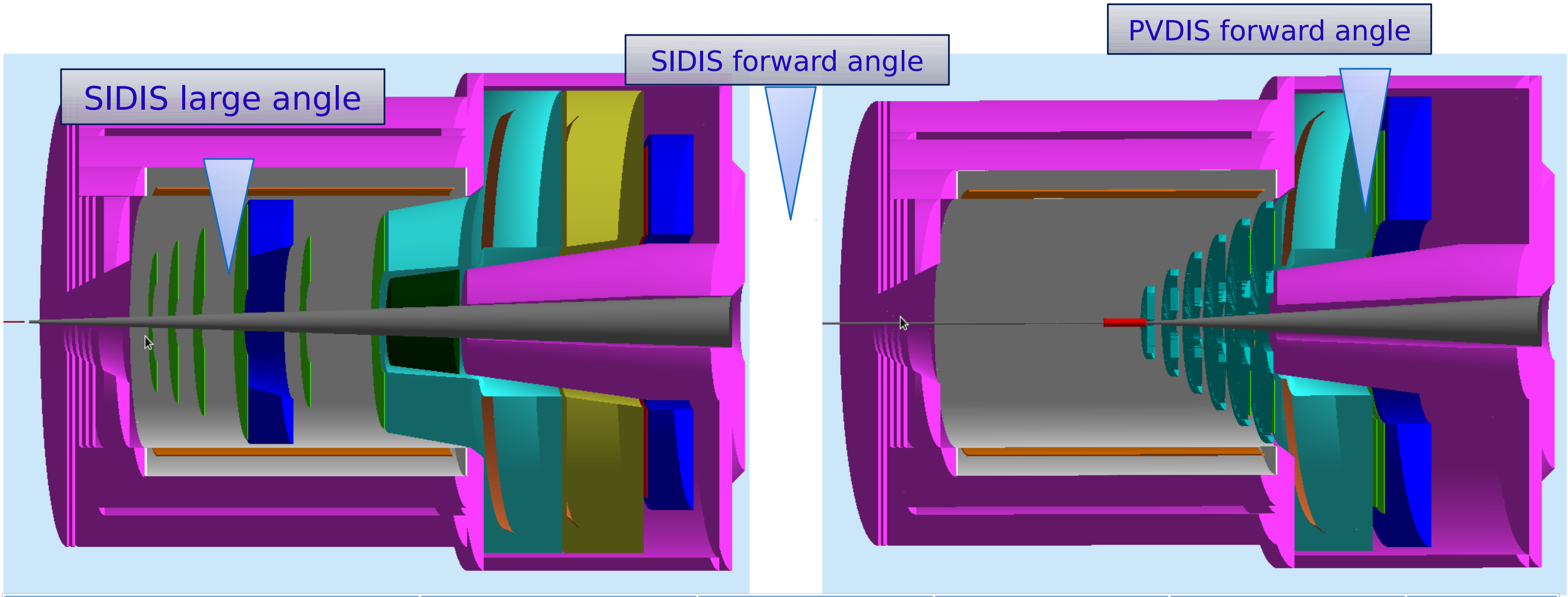
Update on EM Calorimeters

Calorimeter Group

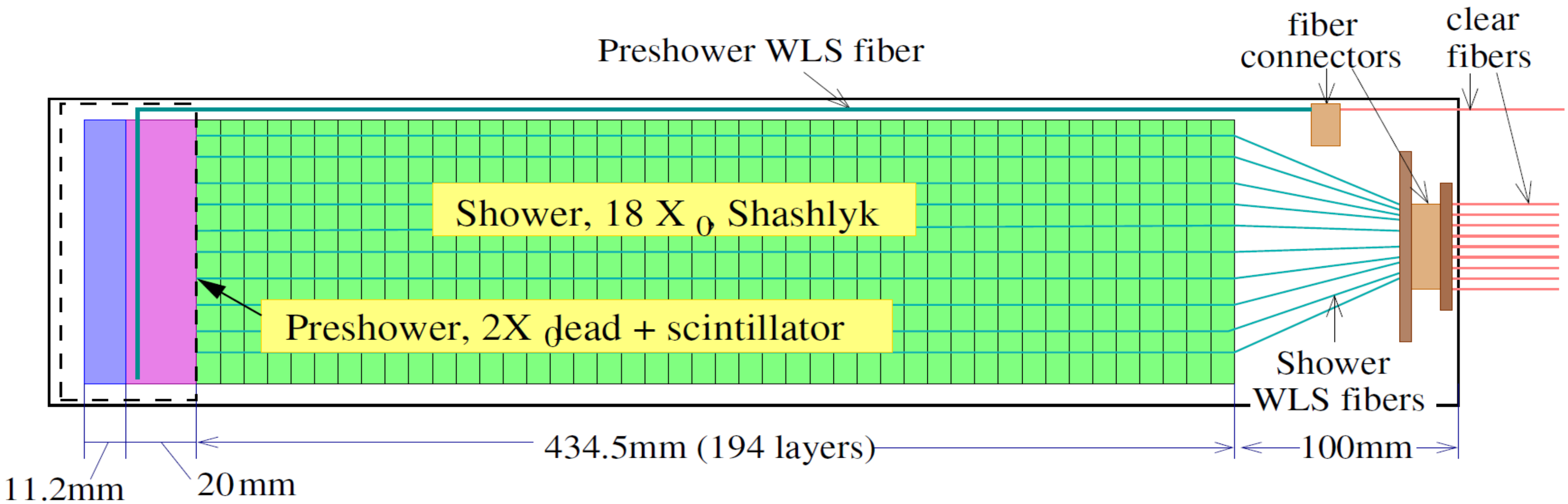
Jefferson Lab

SoLID EM Calorimeter Overview



SoLID EM Calorimeters	Polar Angle (degree)	P (GeV / c)	Max π / e	Cerenkov Coverage	Area (m²)
PVDIS Forward-Angle	22 - 35	2.3 – 6	~ 200	<3-4 GeV/c	~17
SIDIS Forward-Angle	8-15	1 -7	~ 200	<4.7 GeV/c	~11
SIDIS Large-Angle	17-24	3 - 6	~20	None	~5

Module Design @ last meeting

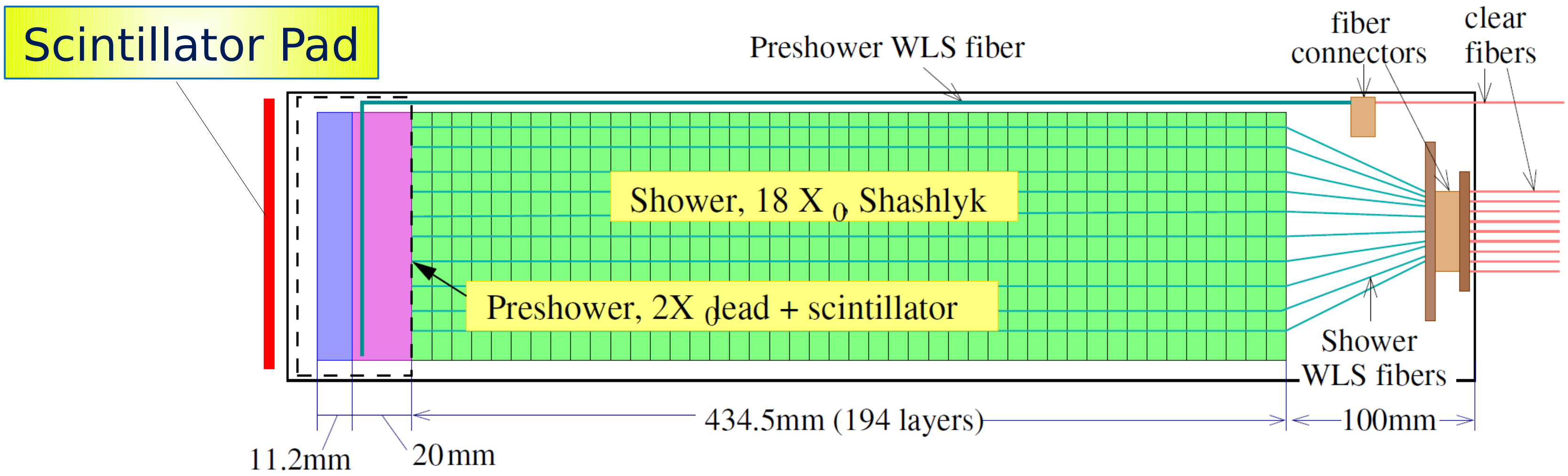


- Preshower (PS) – HERMES/LHCb style passive radiator + scintillator
  - 2 X_0 Pb radiator + 2 cm scintillator tile w/ WLS readout
- Shower – COMPASS style Shashlyk calorimeter design
  - Layer structure : 0.5 mm lead + 1.5 mm scintillator + 0.12 mm gap (x2); X_0 = 24cm, R_M ~ 5 cm, 194 layers, 43cm total in depth

Updates since last meeting

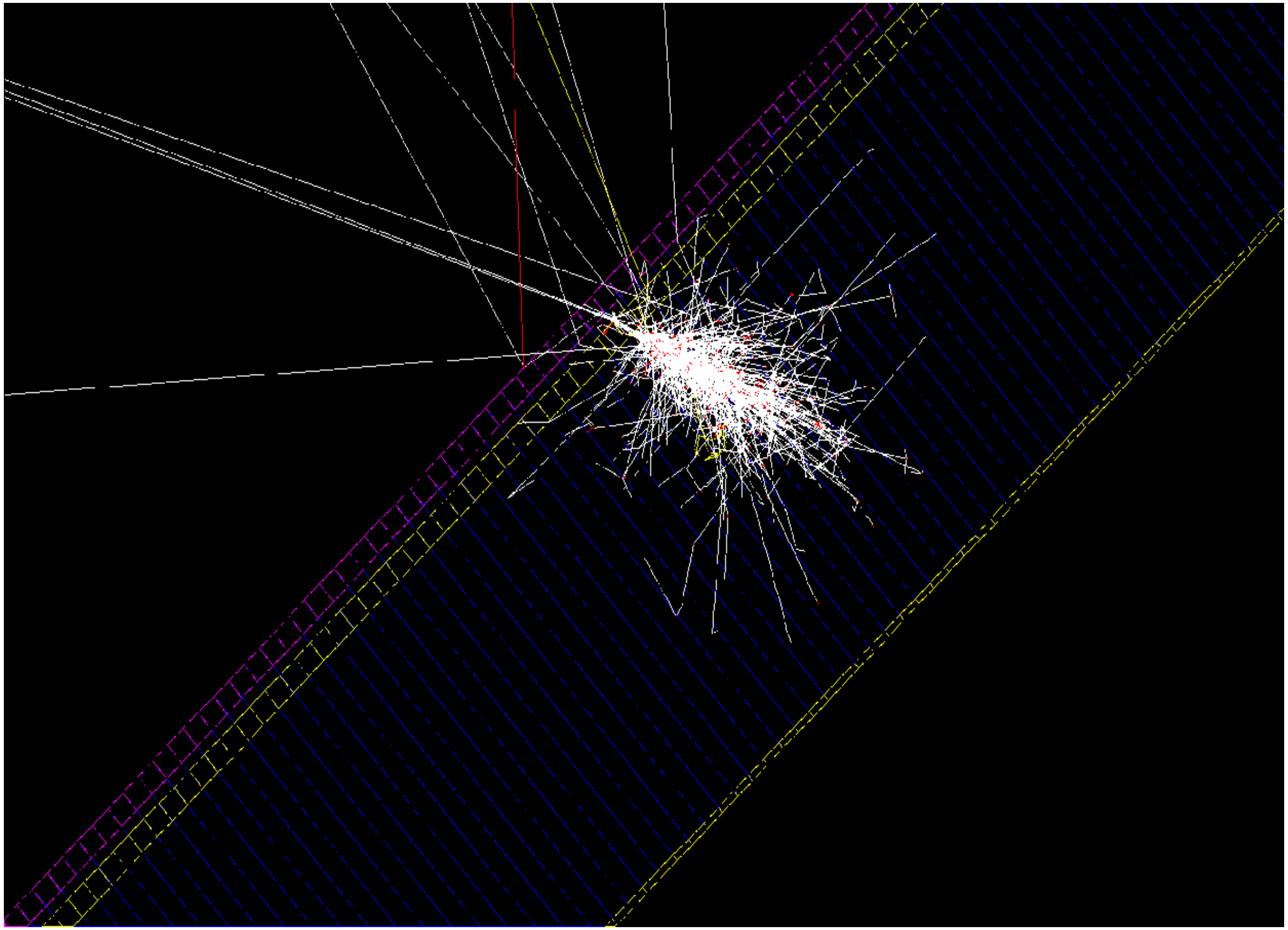
- Additional Scintillator pad before Preshower for photon background rejection – for FAEC, being discussed for LAEC.
- Module shape changed from $10x10cm^2$ square to $100cm^2$ hexagon (6.25cm/side) due to support design.
- Now include background in the PID and other performance simulation
  - today will report on SIDIS FAEC PID & Trigger;
  - work ongoing for SIDIS LAEC and PVDIS.
- Updates on fiber connection and total EC cost estimate

Photon-rejecting Scintillator Pad



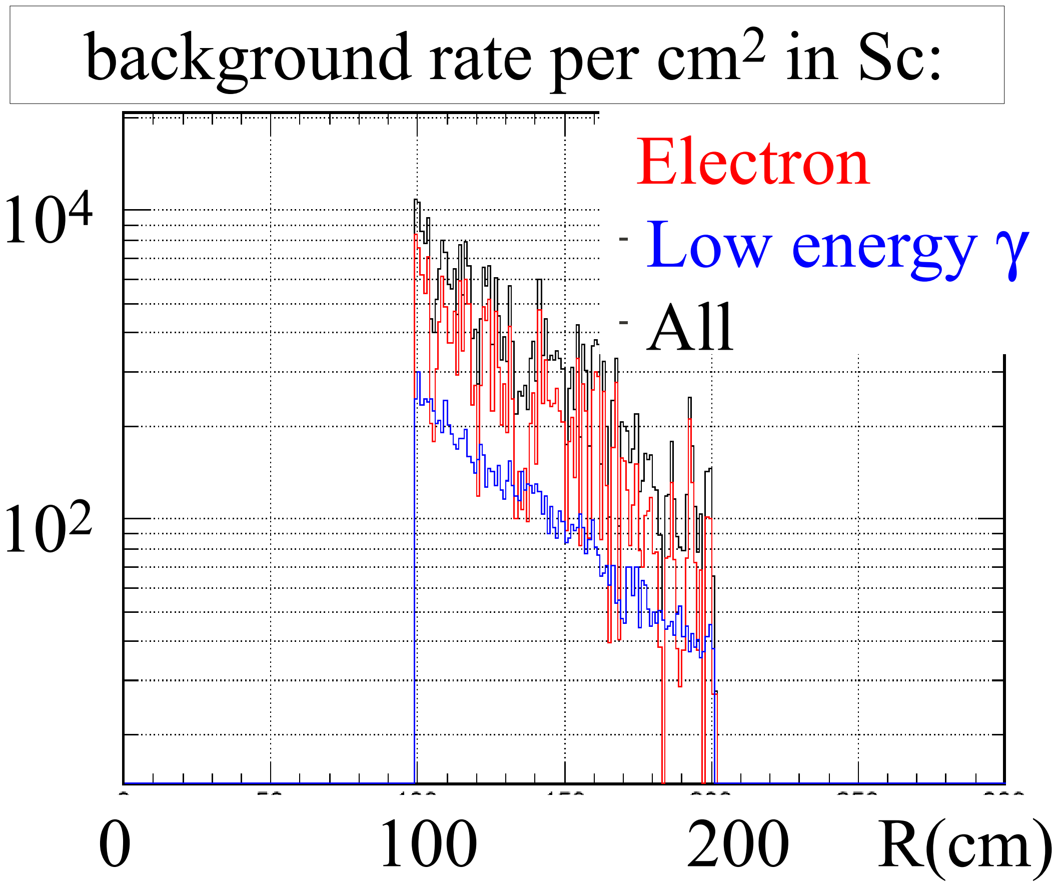
- Scintillator Pad (SPD): 0.5cm, reject high energy photons for electron trigger and hadron trigger at SIDIS forward angle.
- Less segmentation than PS, readout by WLS fiber → clear fiber → PMT.

Simulation



Thin scintillator pad to reject γ 's at trigger level

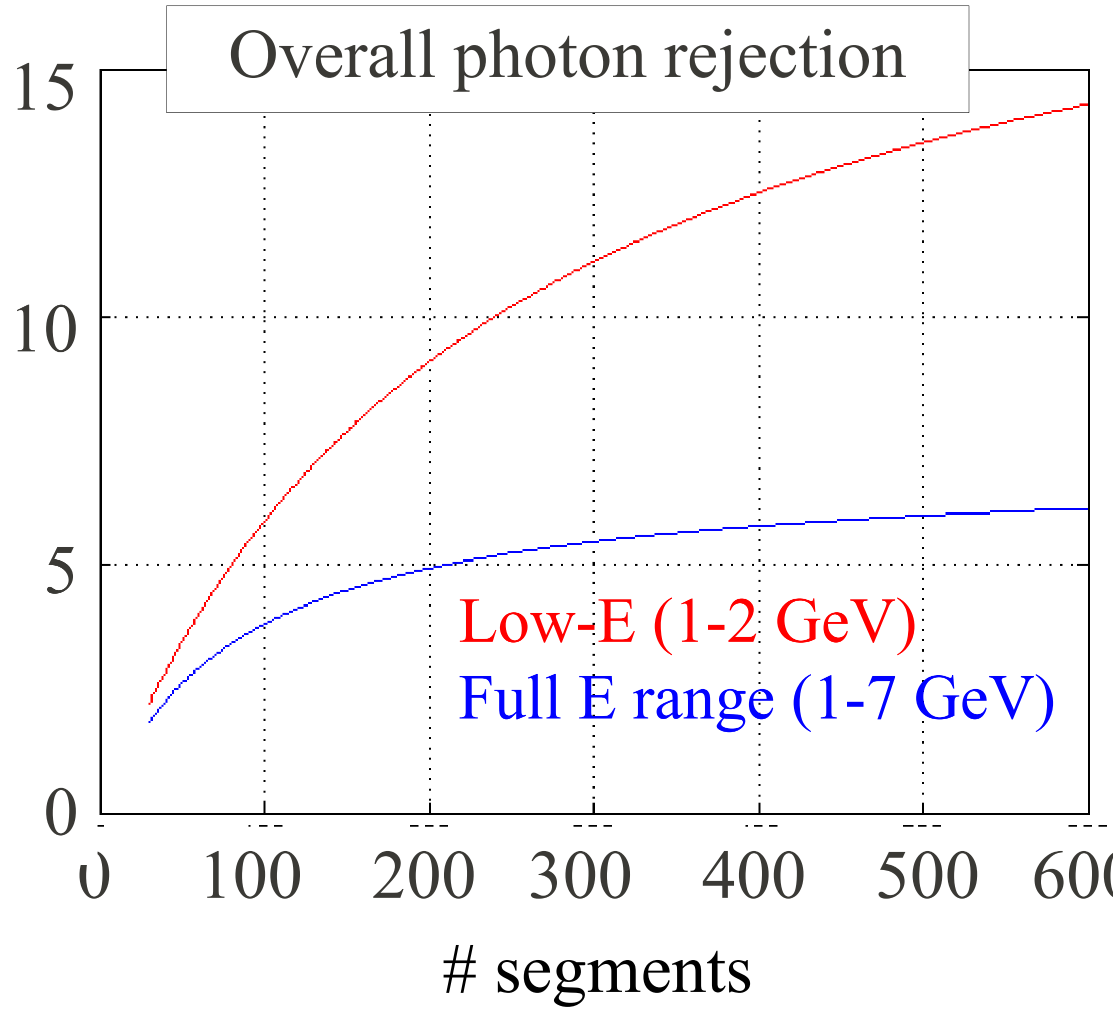
- 5mm Sc pad;
- Background dominated by low energy electrons: 20% from end cap of heavy GC, other from more upstream
- Have to be placed before MPRC (which has lots of material for conversion)!



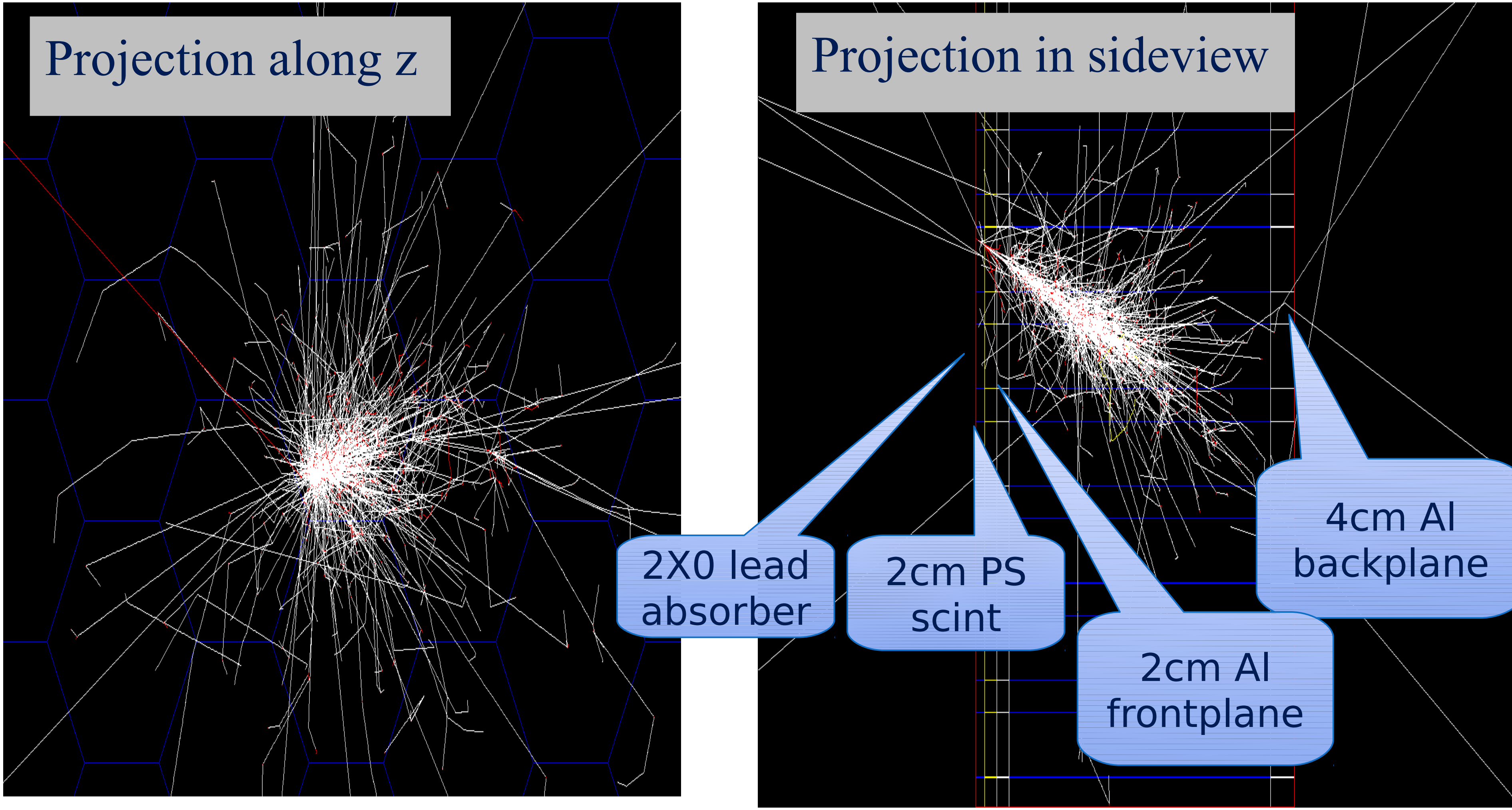
Optimizing # Segment

- Photon background dominated by 1-2 GeV.
- A 50ns coin window with corresponding calorimeter (Shower) assumed, will be better at FPGA level.

- Trigger require 5:1 rejection → 120 segments (could be 60 fans divided into 2 sections/fan) → 2MHz MIP rate/segment



Hexagon Calorimeter Simulation

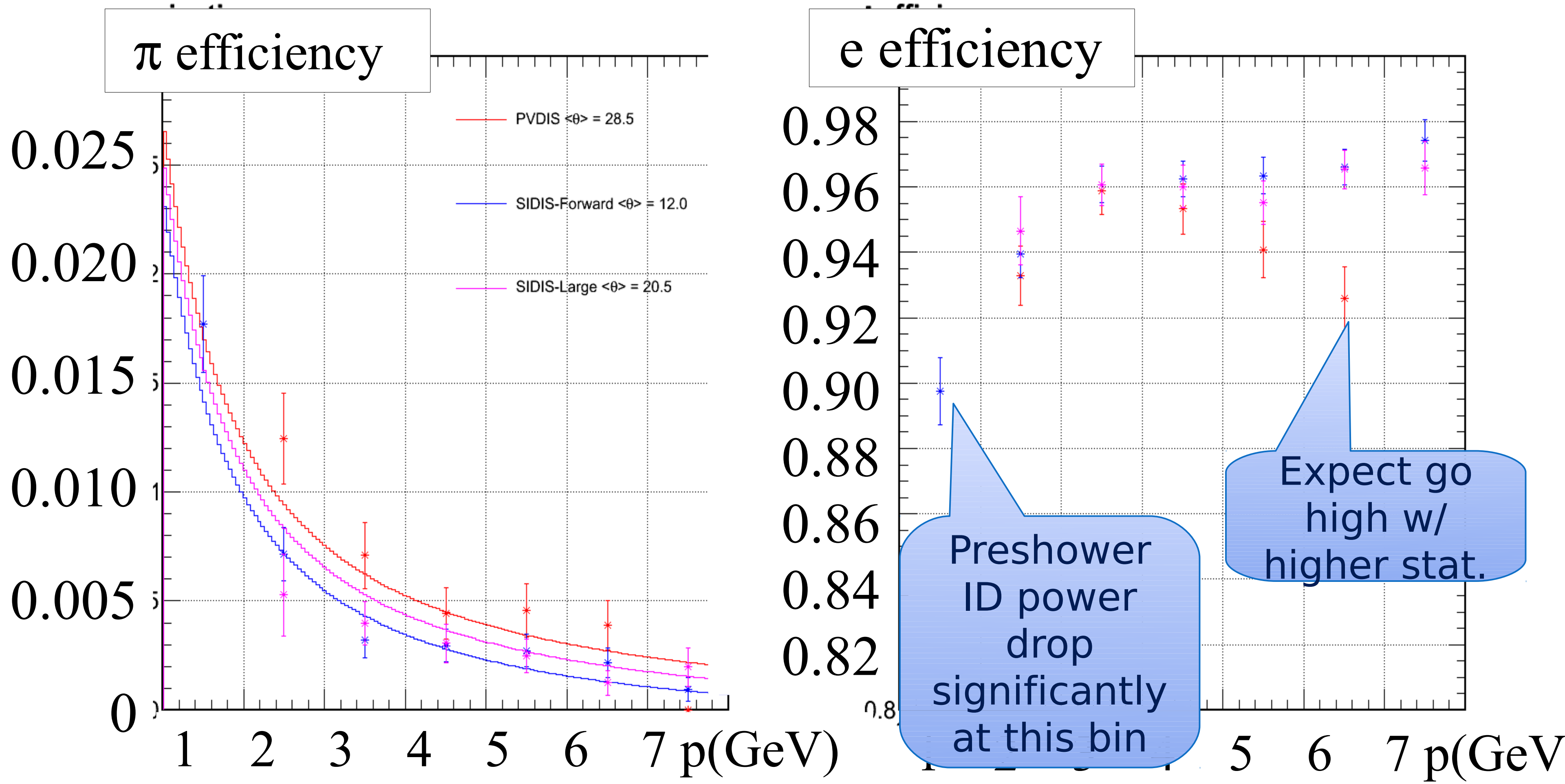


3GeV electron shower on hexagon calorimeter grid;
Support Al plates just added, not used in the results of following slides

PID with Hexagons

- Revised with hexagon, no big diff.
- No background yet included

(last meeting: square module 3x3 clustering 94% electron efficiency



Status of Background Simulation

3rd iteration of GEMC +
CaloSIM background study

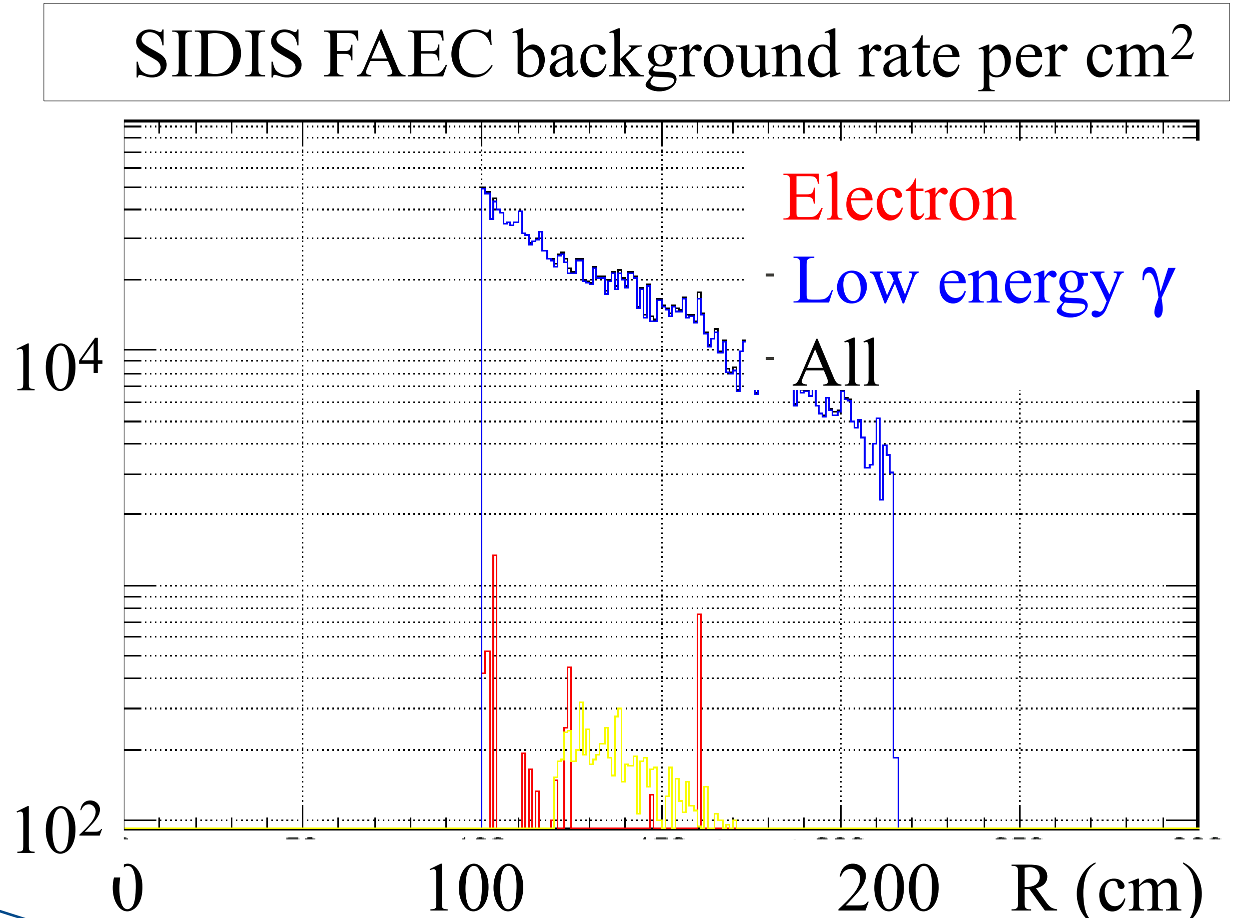
Calorimeter Background Simulation with GEMC + CaloSIM

- GEMC simulate background particles at the front surface of EC (Zhiwen);
- CaloSIM build calorimeter response;
- Combine above two and sum over all contributions (EM, DIS, pi0, pi+,pi-) stochastically within a 50ns coincidental window → background distribution at each trigger
- Embed background into signal simulation (high energy e, pi) and perform analysis (clustering, e/pi separation, etc.)

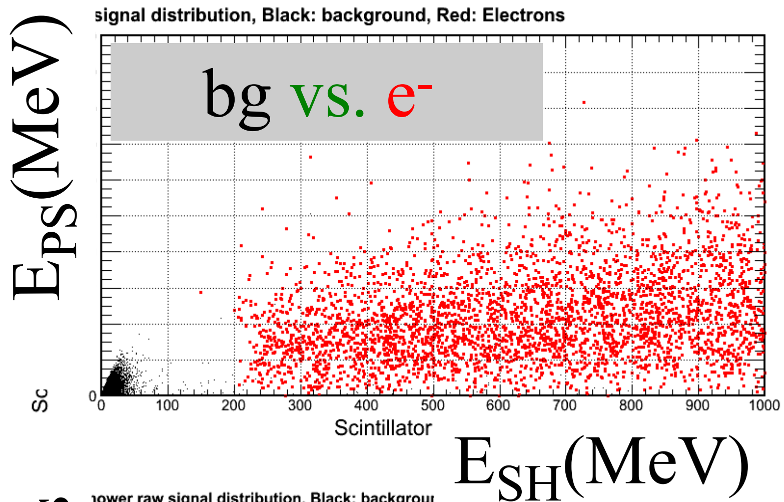
SIDIS FAEC Background

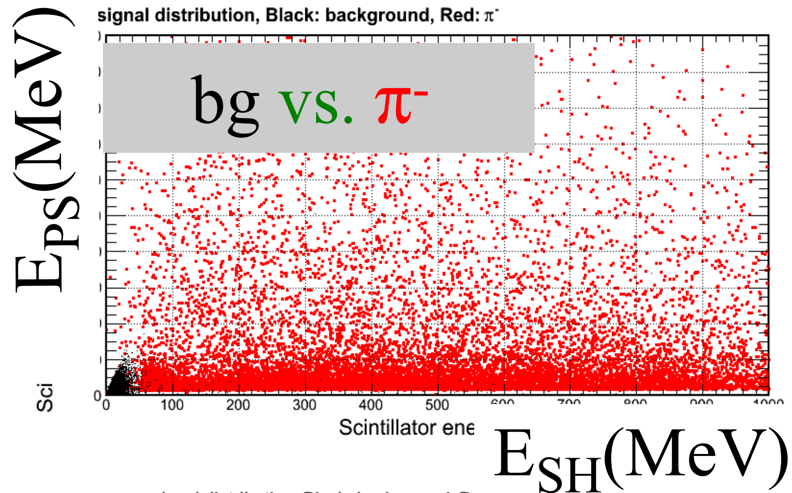
- $2X_0$ of Pb in preshower reduces photon background from 1GHz/cm^2 to 10kHz/cm^2 (MIP signal), still, 1-100MeV photons dominate.

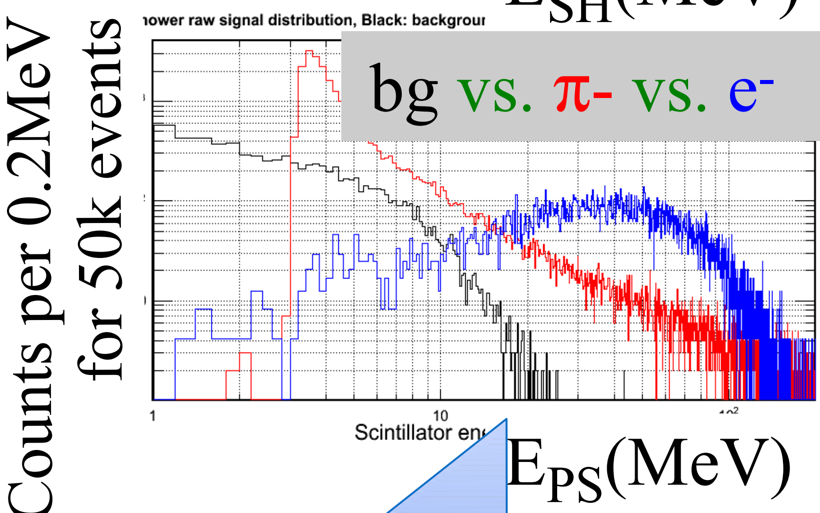
- 3MHz MIP rate / 100cm^2 PS at inner radius;
- 10x lower at outer radius, could bundle multiple modules for PMT readout.

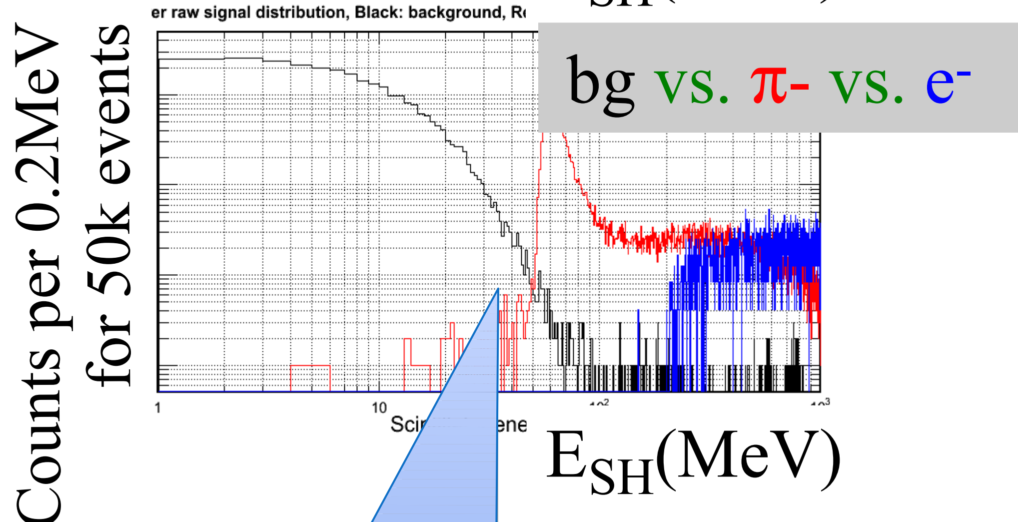


Background Energy deposit in Scintillators





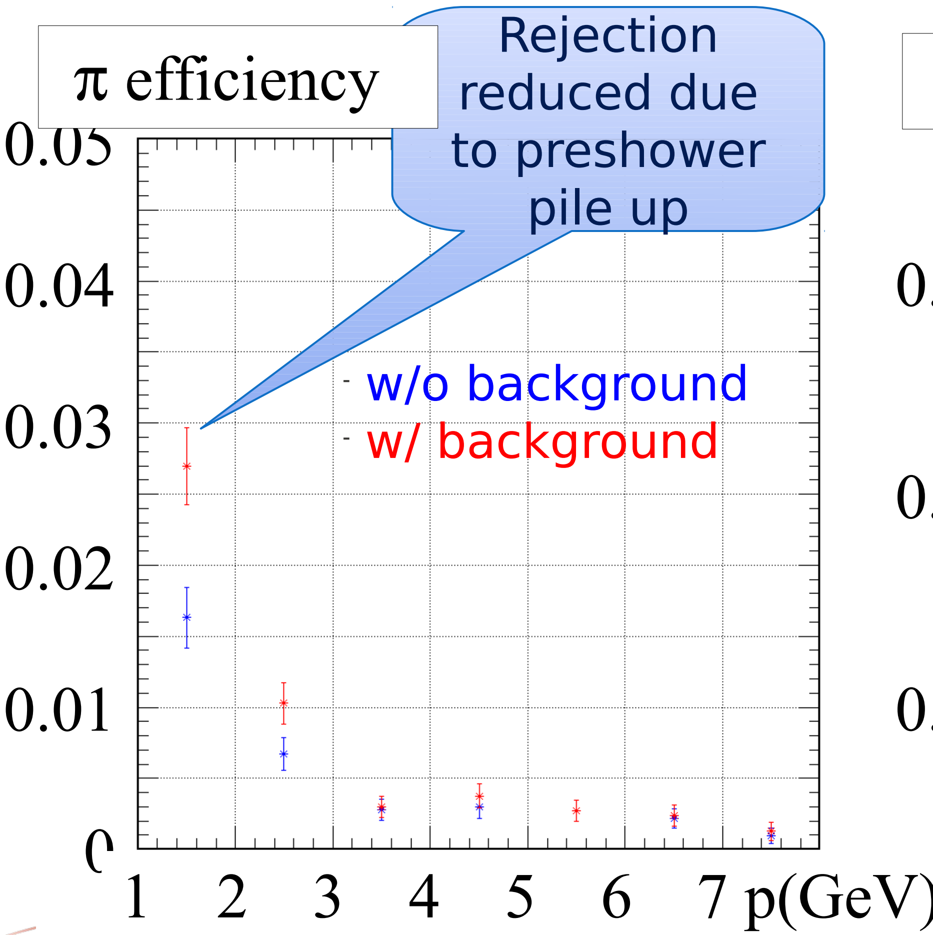


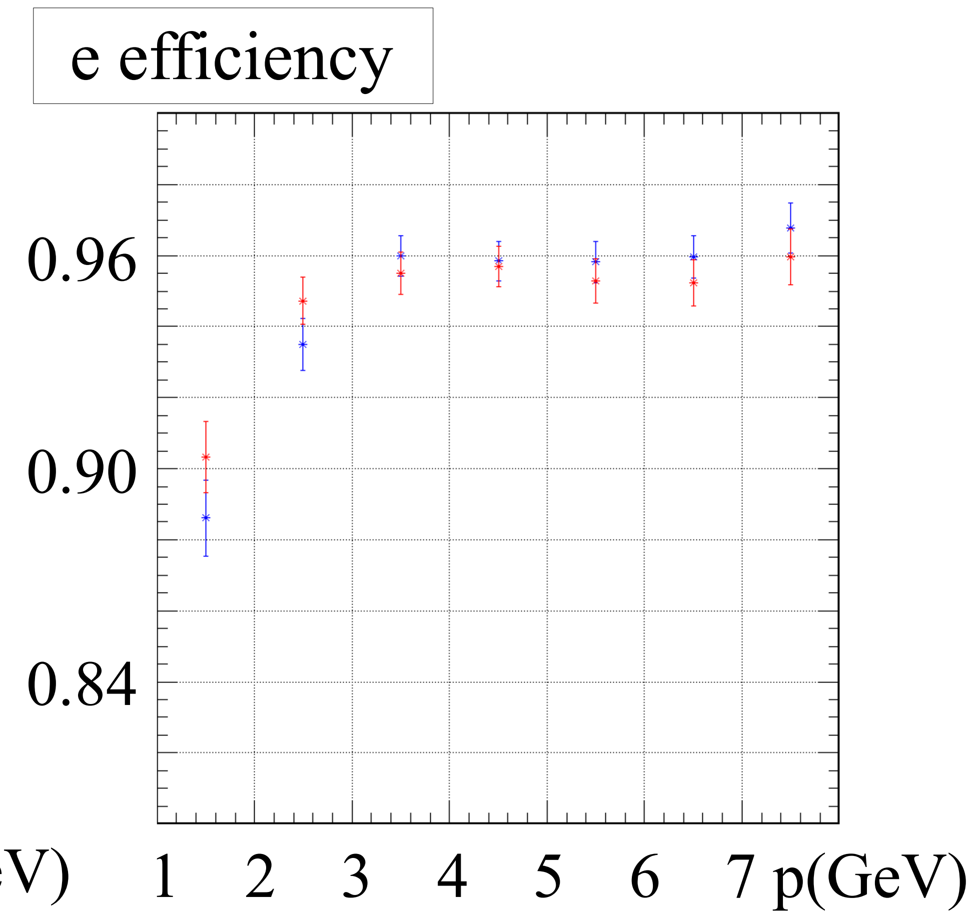


significant in preshower

less significant for shower

SIDIS FAEC PID w/ background: No change in eff., reduced rejection at low-p

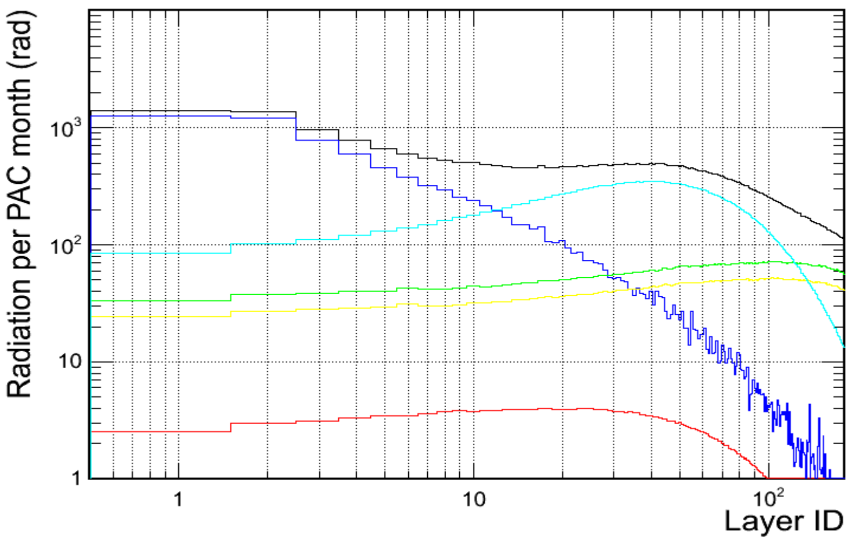




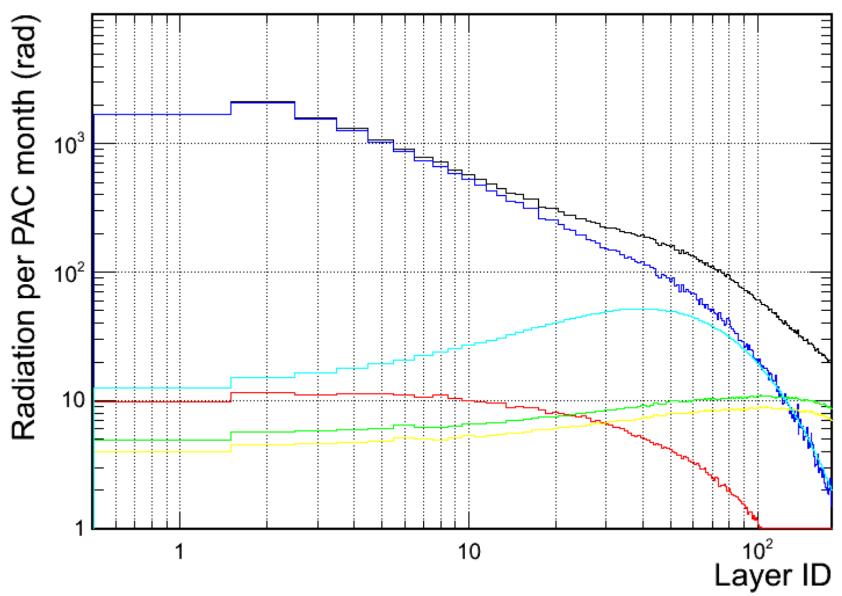
Radiation dose prediction now with background – remain stable

- Dose is not a problem for SIDIS configuration.
- Calorimeter design should stand 500krad, now expect 100krad – nice safety margin
- Still missing final PVDIS radiation dose, need final baffle w/o direct line of sight.

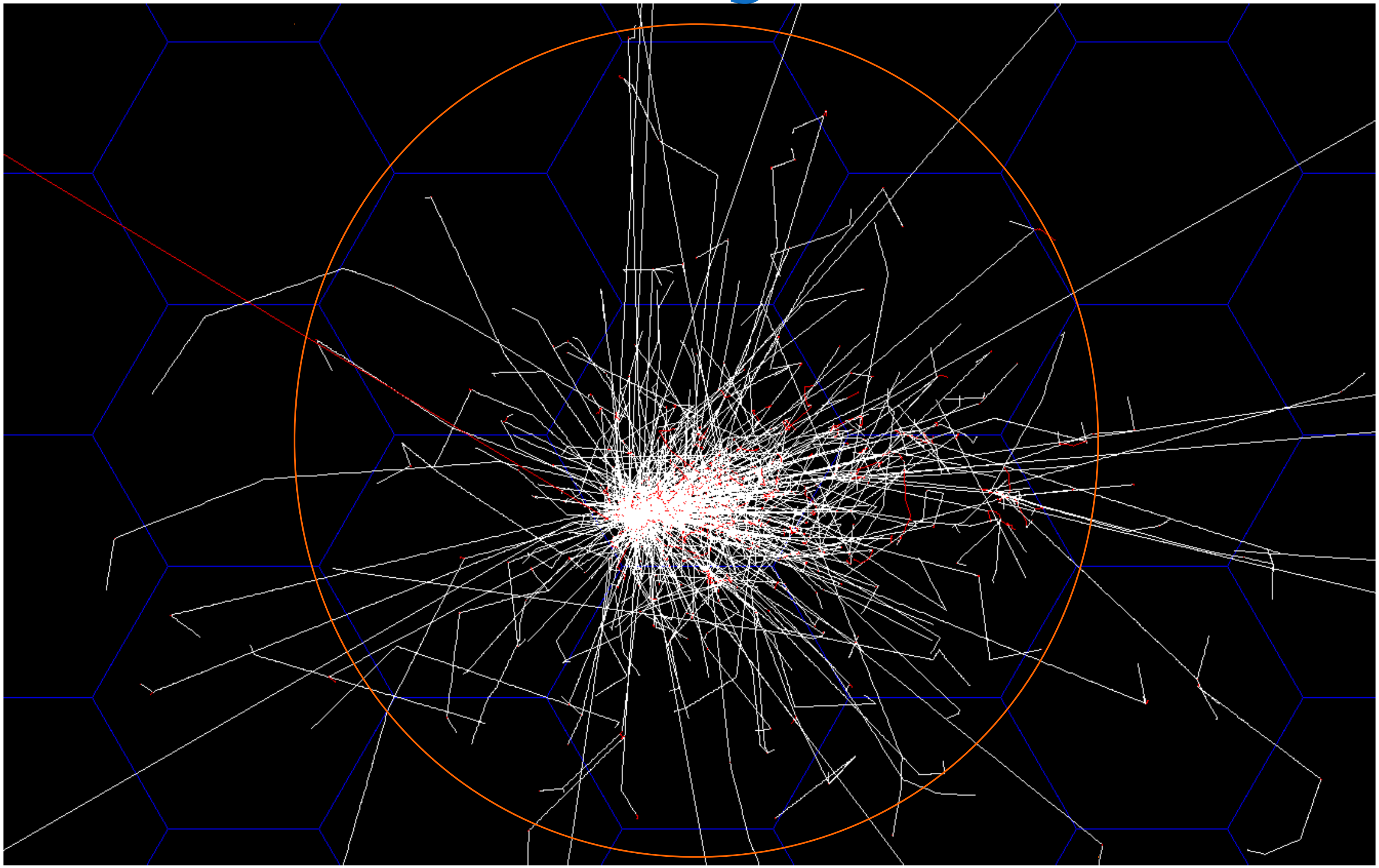
SIDIS – He3– Large Angle Calorimeter



SIDIS – He3– Forward Calorimeter



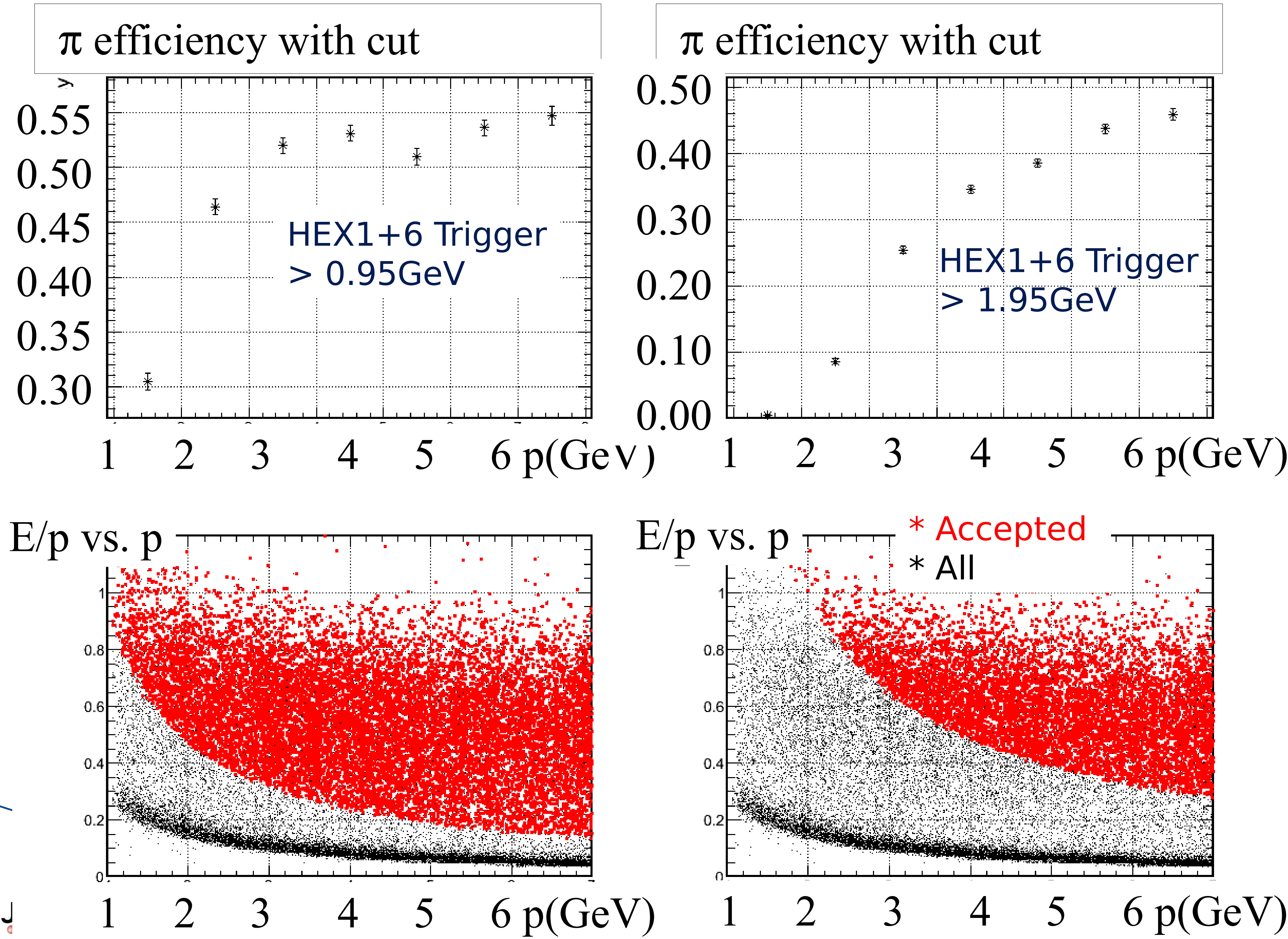
Hexagon Calorimeter Trigger with Full Background



6+1 cluster contains ~96% of shower energy

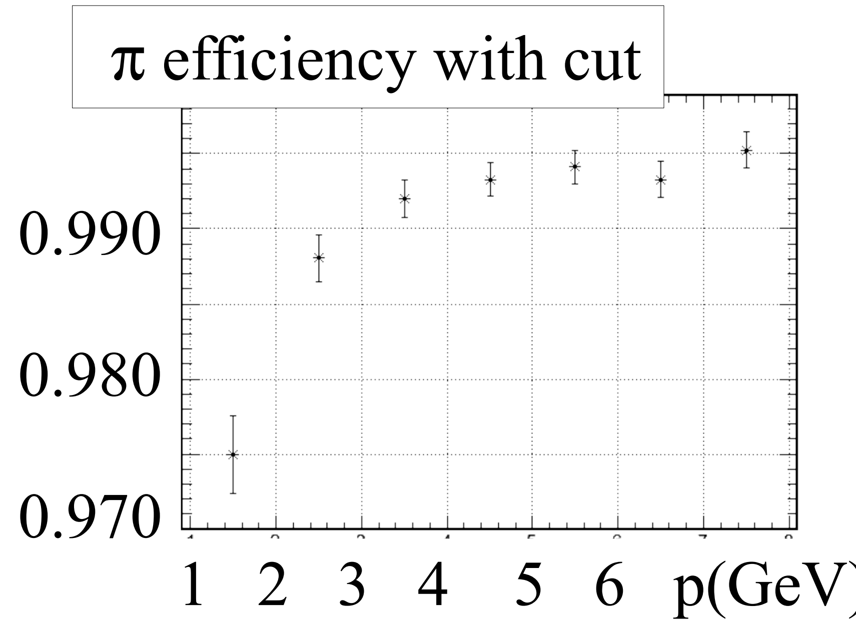
Hexagon Calorimeter Electron Trigger Using 6+1 cluster energy

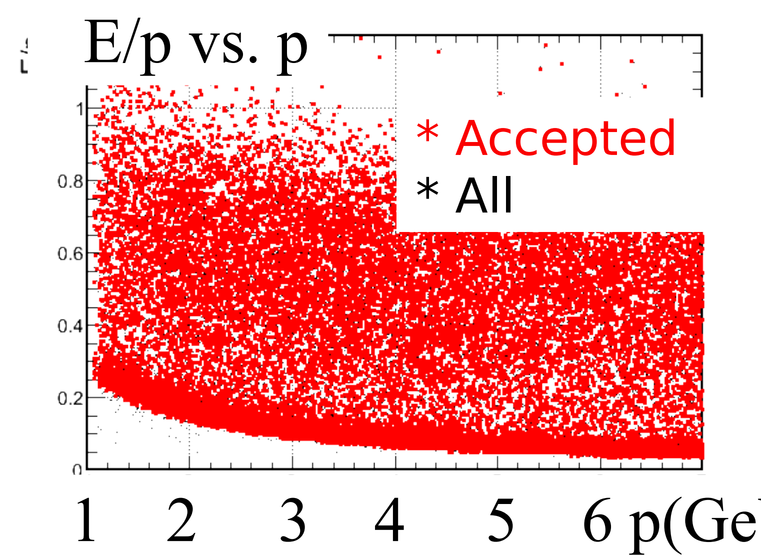
- Do observe very high electron efficiency in simulation
- However, shower cut must be low to accept low-p electrons. This limits the rejection for high-p pions. See next slide.
- Possible solution:
  - From DAQ group (Xin, Alex): use position dependent threshold,
  - consider including preshower trigger


π efficiency with cut
HEX1+6 Trigger
> 0.95GeV
0.55
0.50
0.45
0.40
0.35
0.30
1 2 3 4 5 6 p(GeV)
π efficiency with cut
HEX1+6 Trigger
> 1.95GeV
0.50
0.40
0.30
0.20
0.10
0.00
1 2 3 4 5 6 p(GeV)
E/p vs. p
1
0.8
0.6
0.4
0.2
0
1 2 3 4 5 6 p(GeV)
E/p vs. p
* Accepted
* All
1
0.8
0.6
0.4
0.2
0
1 2 3 4 5 6 p(GeV)

Hexagon Calorimeter Pion Trigger Efficiency

- Trigger cut: HEX1+6 trigger raw signal > 85% MIP (which is MIP – 2σ = 220MeV calibrated)
- Background passes this cut: rate ~20Mhz, dominated by photon.
- With a 5:1 photon suppression from scintillator, we get ~4MHz total trigger rate, which fit in the DAQ limit (PR12-10-006)
- Will join global DAQ study for final verification



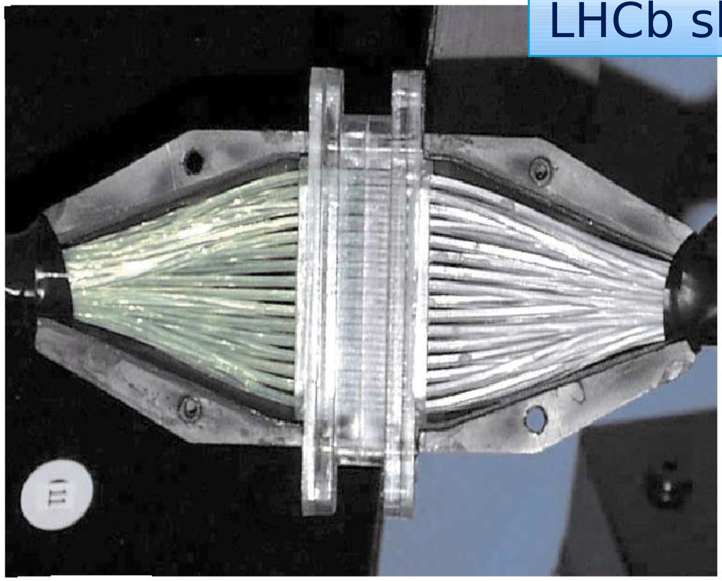


Design Updates – Fiber connectors

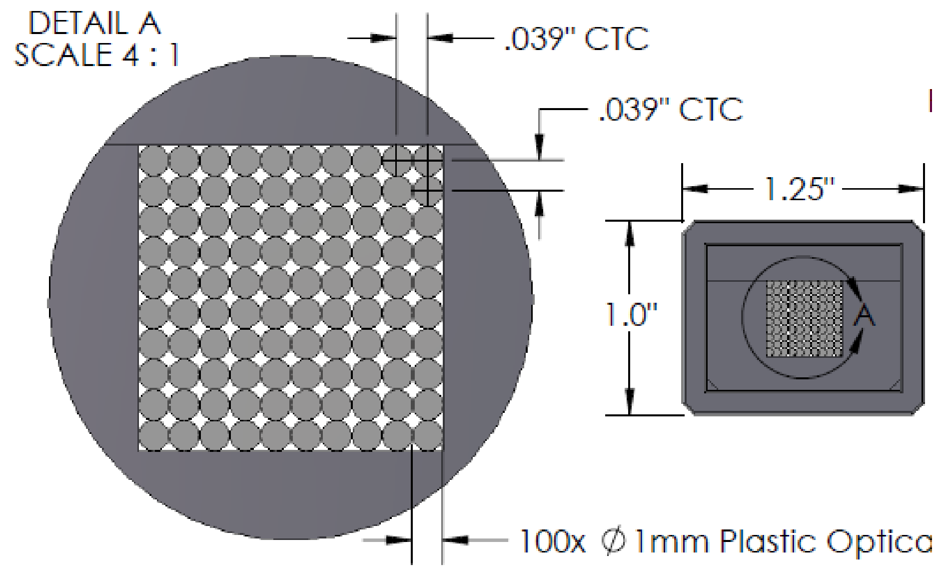
SoLID Collaboration

@ last meeting

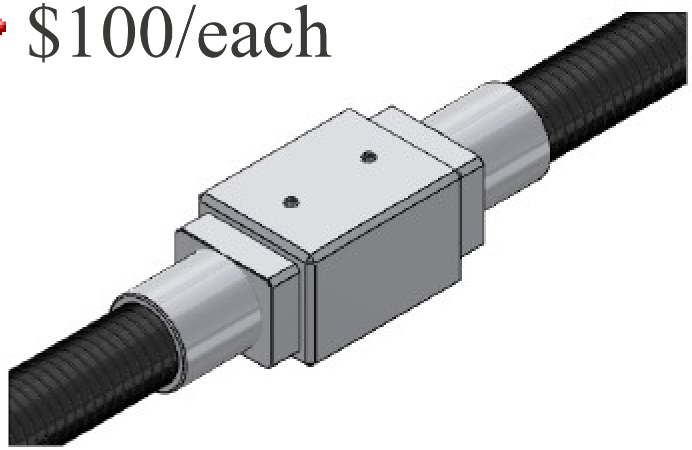
LHCb shower

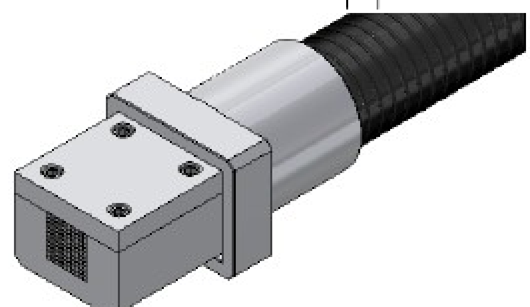


Now: Fiber connector conceptual design from LEONI Fiber



- 100 fibers/connector:
  - made of Al
  - 35% light loss at worst
  - $100/each





- fiber bundle to PMT connector, estimate $25/module (Leoni)
- 1-1 fiber for PS: $10 each (other companies)

Budget @ last meeting

	Per module cost ($)	All module cost (M$)
Module material	700(L)/250(S)	1.26
Module production	800(L)/500(S)	1.49
Clear fiber	260(L)/65(S)	0.46
Fiber connectors	150	0.27
PMTs	600*2	2.34
Labor	5 tech and 5 student years	1.3
Total		7.12
Total+30% contingency		9.26

5.8M, to be compared to next slide

- + Prototyping ~ 0.3 M$
- + Support ~

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Budget Update (no new Sc Pad yet)

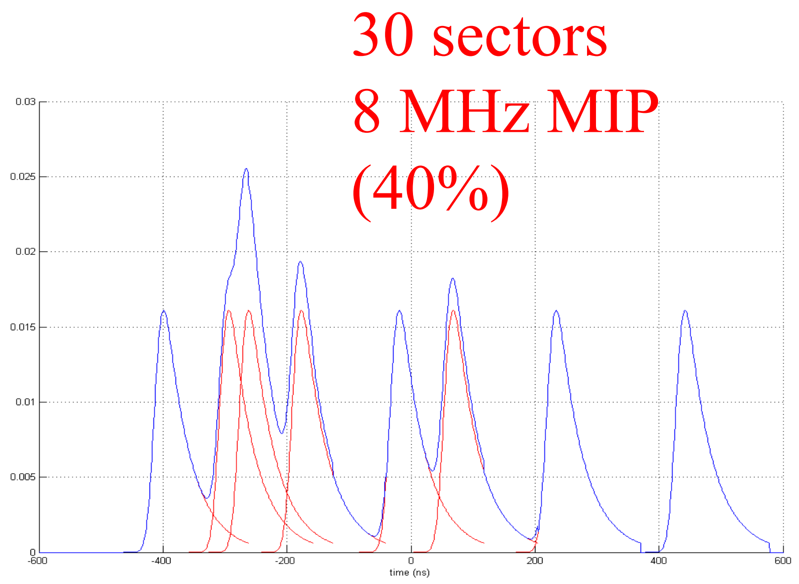
- IHEP (not including fibers) for 1700 PS+SH
  - Preshower: \$112k-\$120k
  - Shower: \$549k-\$651k
  - Structure+assembly: \$255k-\$340k
  - IHEP total: (\$1.22-\$1.51)M + 24% overhead (2012 rate) = (\$1.51-\$1.87)M
- Fiber connectors+tubing (Leoni+other): ~\$300k
- WLS+clear fibers(?): \$703k (S.G.) - \$2.47M (Kuraray)
- PMTs: \$600x2x(~1900)=\$2.28M
- Total from above (no contingency): **(\$4.8M-\$5.2M)** if using S.G.; \$(6.6-7.0)M if using Kuraray
- Labor? Shipping? Overhead? Contingency?

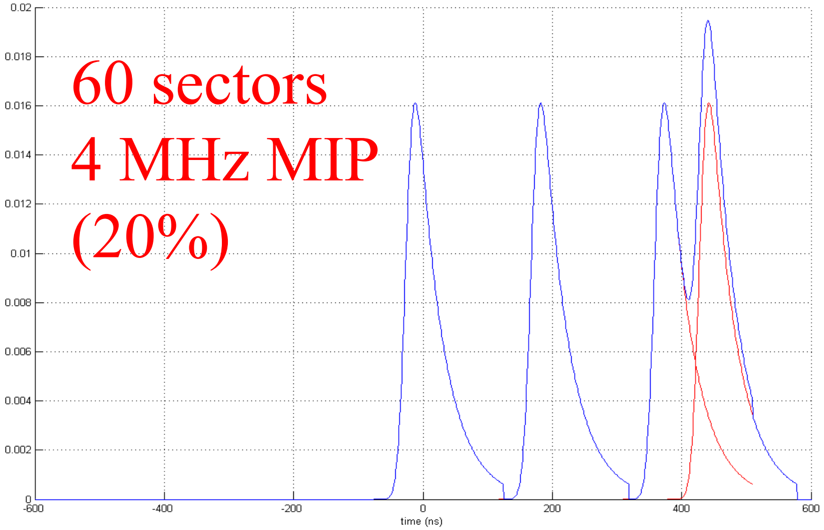
Plan

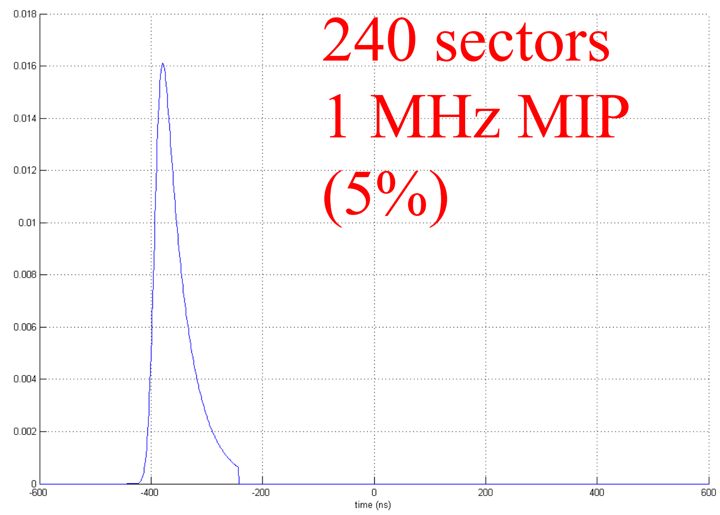
- PID and Trigger study with background for SIDIS LAEC and PVDIS;
- Discussing overlapping module readout with DAQ group;
- Ongoing studies to reduce PMT cost:
  - Multi-anode PMTs ($100/channel) to read out Preshower, but there are gain matching issues.
  - Smaller PMTs to read out Preshower
  - Need solid quotes for PMTs

backup

Simple illustration of timing pileup vs. # segments – using only 1MIP events







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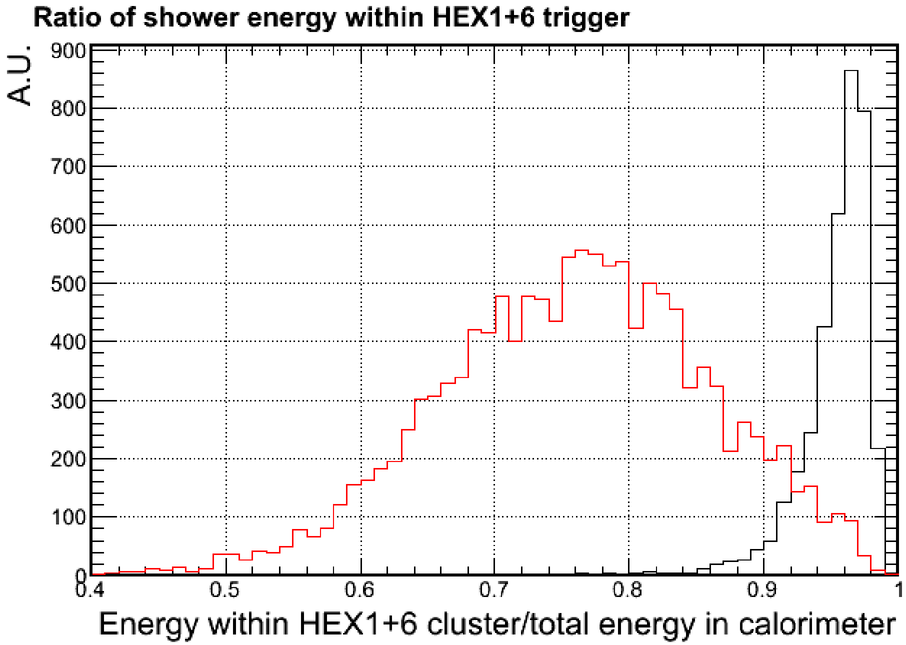
Online: Trigger with background

Hadronic shower which introduce a pion contamination, usually spread into larger area compared to EM shower

A localized trigger, e.g. HEX1+6 trigger can significantly suppress the hadron response, while maintaining high eff. for electrons

- Ratio of EM shower contained
- Ratio of Pion shower contained



Shower – quick review

Choice of technology

Shashlyk design was chosen based on advantage of radiation resistance + cost + ease of readout

Features

Pb/Scint ratio 1:3 (V) : chosen to reach <5%/√E energy resolution and ~100:1 pion rejection

Scintillator thickness of 1.5mm: based past designs to balance sampling fineness VS lateral light transmission loss

Total length of 20 X0 : contain 98% of shower and maximize pion-electron difference

→ MIP = 270 MeV (real) / 320 MeV (reconstructed)

Lateral size of 10x10 cm2: max size allowed (to reduce $$) before position resolution significantly deteriorates (σ~1 cm after cor.)

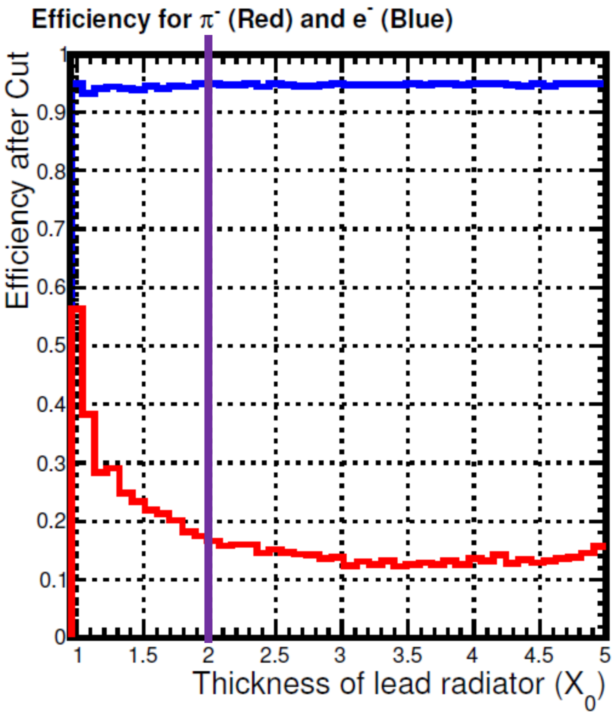
Preshower – quick review

Choice of technology
HERMES/LHCb style VS full Shashlyk design, former is much easier to readout and high in radiation resistance
Features
Absorber of 2 X0 lead :

- Thinner – loose preshower rejection
- Thicker – loose shower resolution
- Scanned for 1.5, 2 and 3 X0;
- 2 X0 serve SoLID best

Scintillator of 2 cm:

- MIP = 4 MeV, electron cut ~ 3 MIP



Simulation setup with hexagon calorimeter modules

SoLID Collaboration

Back up 1/2 for previous slides

Electron eff. for SIDIS large angle calorimeter

- All events
- Accepted events w/ 3D cut

Back up 2/2 for previous slides

Pion eff. for SIDIS large angle calorimeter

- All events
- Accepted events w/ 3D cut

Backup - Simulated efficiency & rejection

- Electron
- Pion
- Photon

Energy range: 1-7 GeV, flat phase space for SIDIS-forward

MIP peak

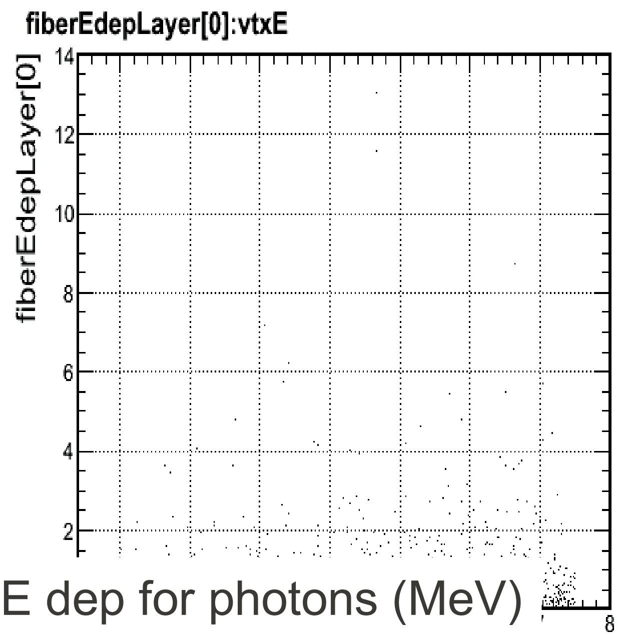
Efficiency

~1:7 γ-rej cut below MIP peak

Cut on energy dep.

Backup - Simulated efficiency & rejection

Most photon focus on lower energy side (π0 decay)
And lower energy photon produce less back scattering
Therefore, do the study again with 1<Eγ<2 GeV

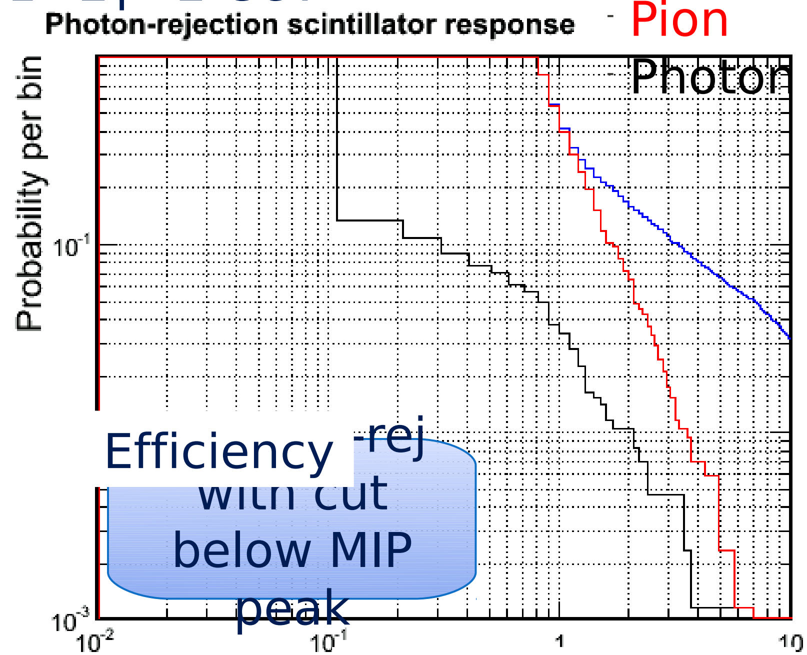


E dep for photons (MeV)

Eγ (GeV)

1<Eγ<2 GeV

Electron
Pion
Photon



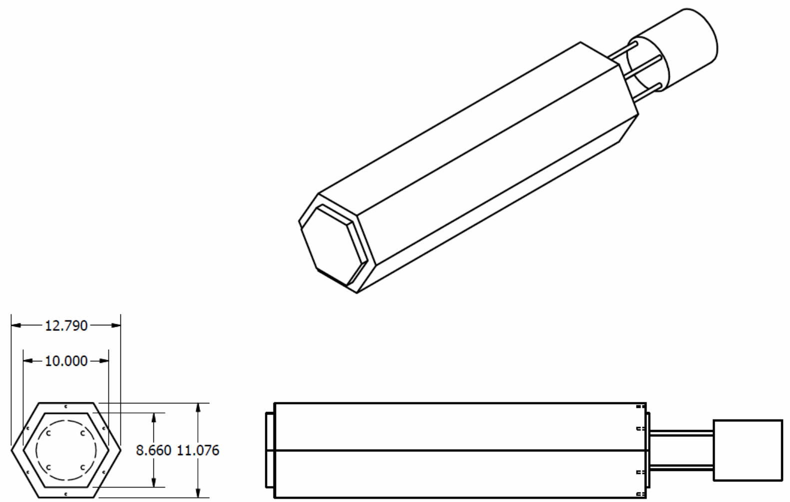
Efficiency -rej with cut below MIP peak

Cut on energy dep.

Design Updates - Shape

Change from square to hexagon

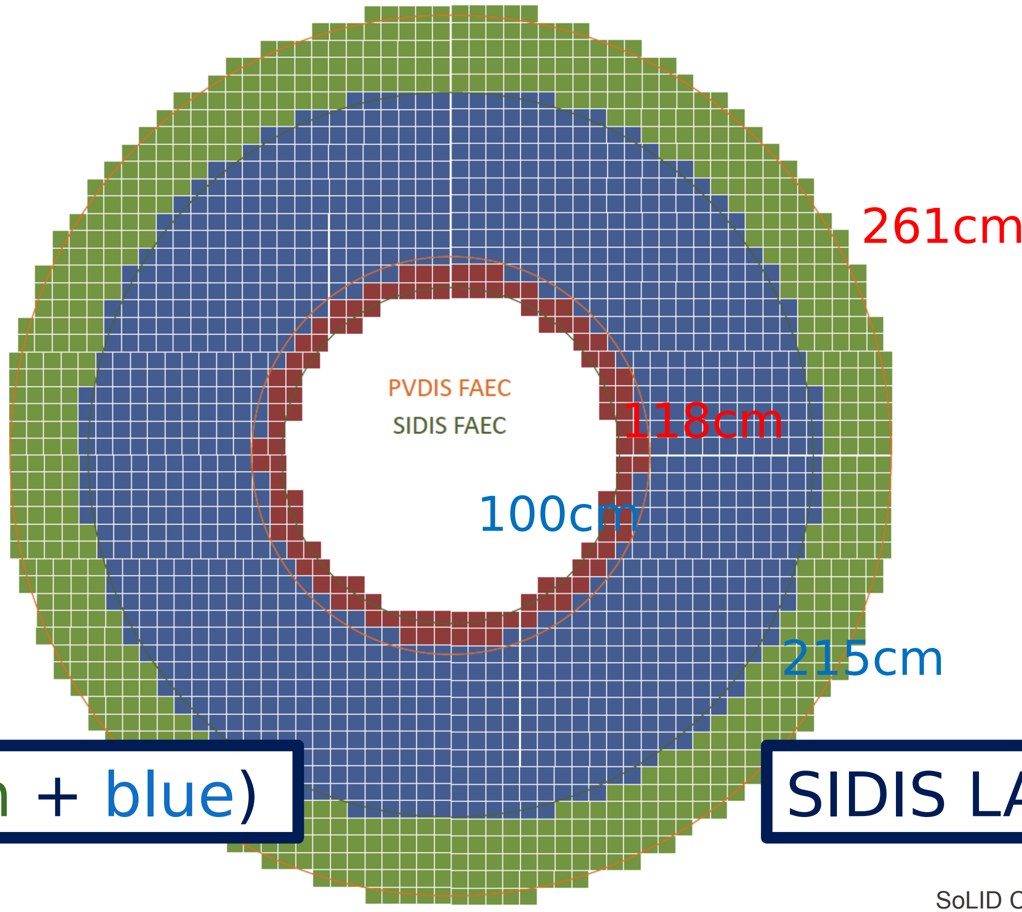
Main reason from supporting structure and layout (see Paul Reimer's talk)
Physics feature should be similar to square shape and we will go through test and prototyping



Design Updates
- Layout Update

SIDIS and PVDIS FAEC (beam view)

Both can share supporting structure, only need to move along beam direction to change configuration
Supporting structure needs to be made from 100cm to 261cm



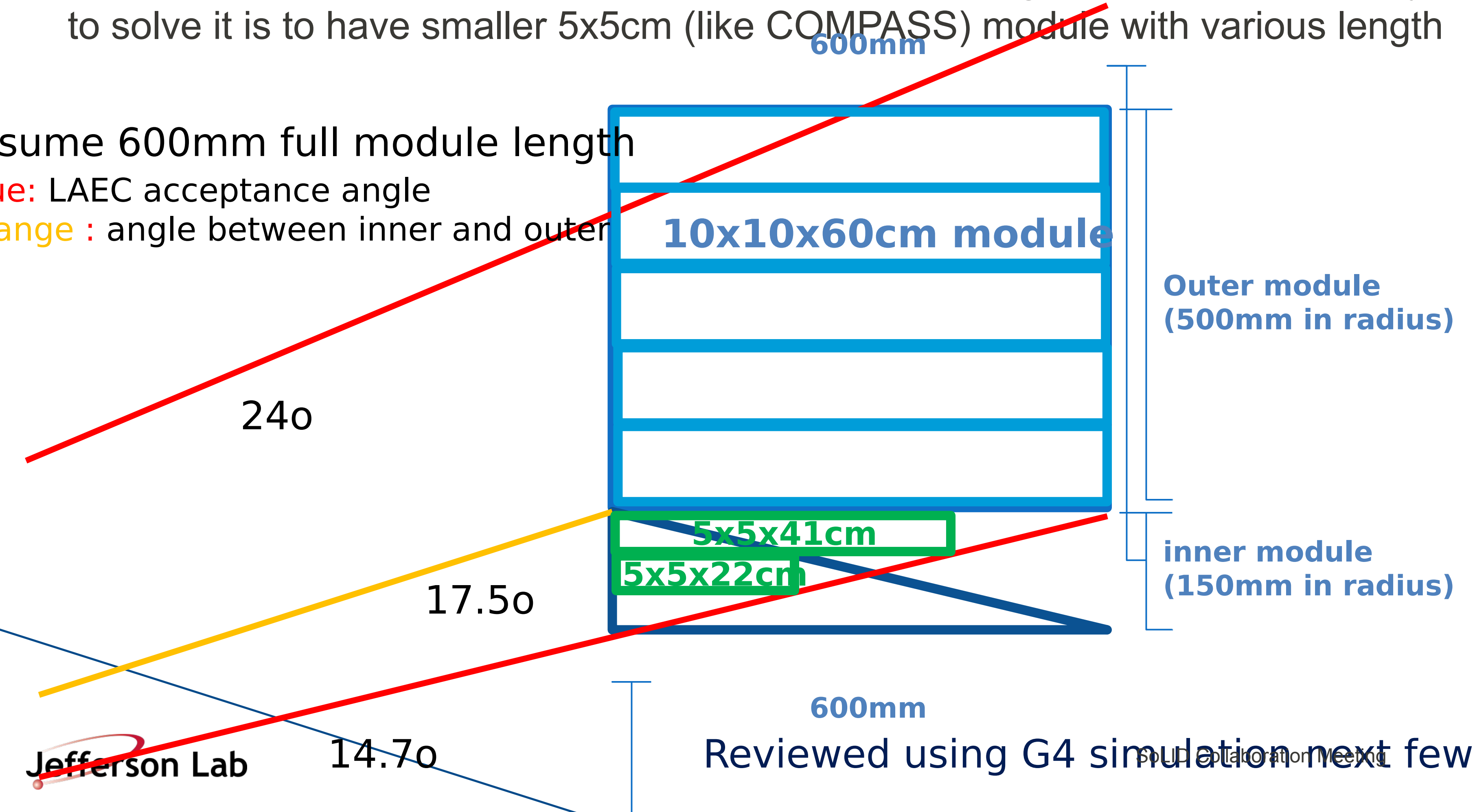
DIS FAEC (green + blue)

SIDIS LAEC (blue + red

Ideas to minimize SIDIS LAEC Acceptance gap

We want to cover full azimuthal angle and leave no gap between modules, so module can not be tilted and need to be along Z axis
Prefer having short outer module so that the outer module area can cover more and inner module area can cover less
Inner module need to be special shape to avoid blocking acceptance. One way to solve it is to have smaller 5x5cm (like COMPASS) module with various length

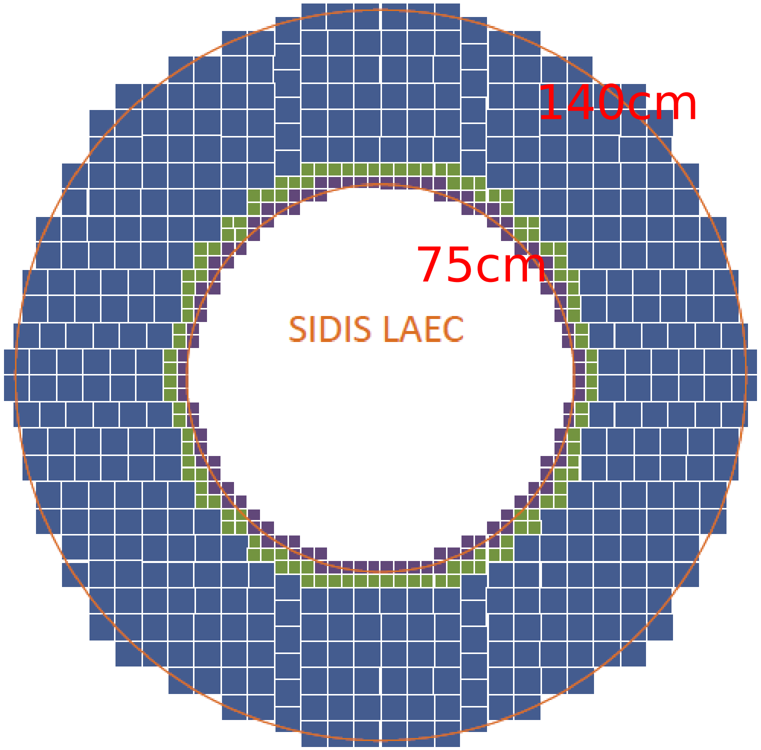
sume 600mm full module length
ue: LAEC acceptance angle
ange : angle between inner and outer



Reviewed using G4 simulation next few page

SIDIS LAEC (beam view)

Type I (10x10cm) module in blue, type II (5x5cm long) module in green, type III (5x5cm short) module in purple. Supporting structure needs to be made from 75cm to 140cm



Design Updates
- Edge effects for LAEC

LAEC layout in G4 Simulation

LAEC in full standalone G4 Simulation

Track transportation provided by GEMC, CLEO field

How much does inner modules help?

- LAEC catch 80% of shower
- Go freely to forward acceptance

Minor improvement

Design Updates
- Shower cluster size cut

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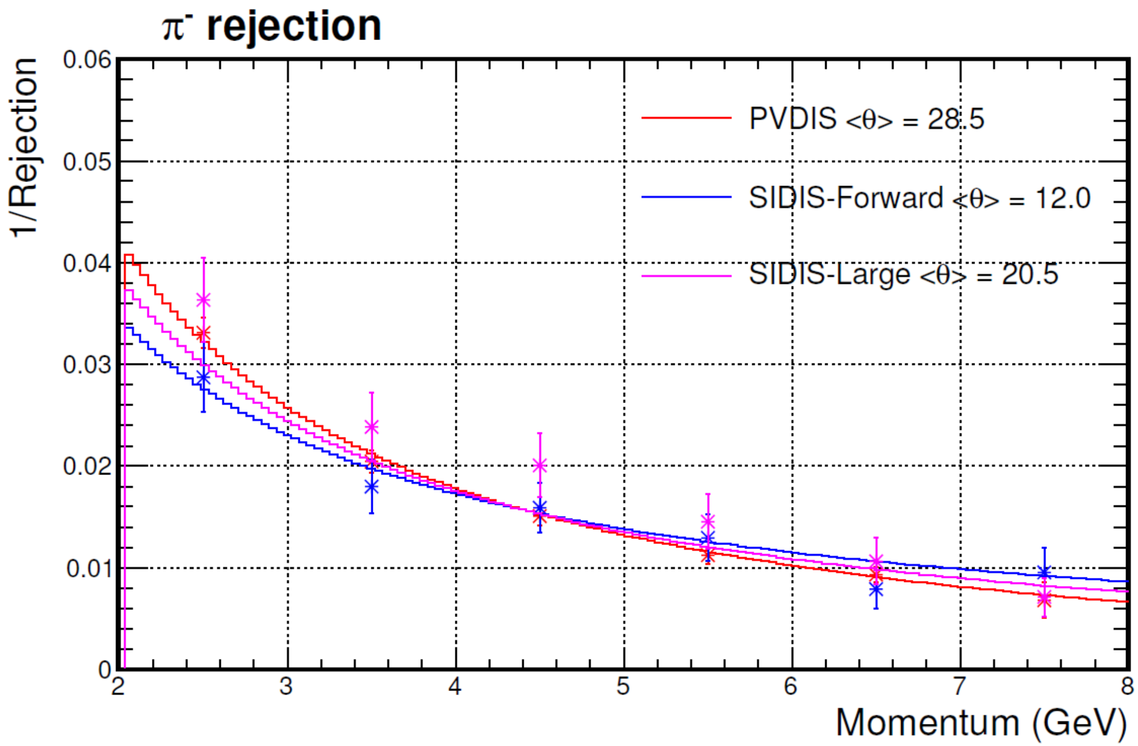
Previously showed pion rejection



94% electron eff.

PID selection used 3-D cut on PS, e/p and momentum
PS and e information come from sum signal in all non-zero modules
Enemy here is very specific: almost fully absorbed hadronic shower with high energy deposition

Shower area difference

Electron shower

Hadronic shower (e/p>80%)

R spread (mm)

Φ - spread (mm)

R spread (mm)

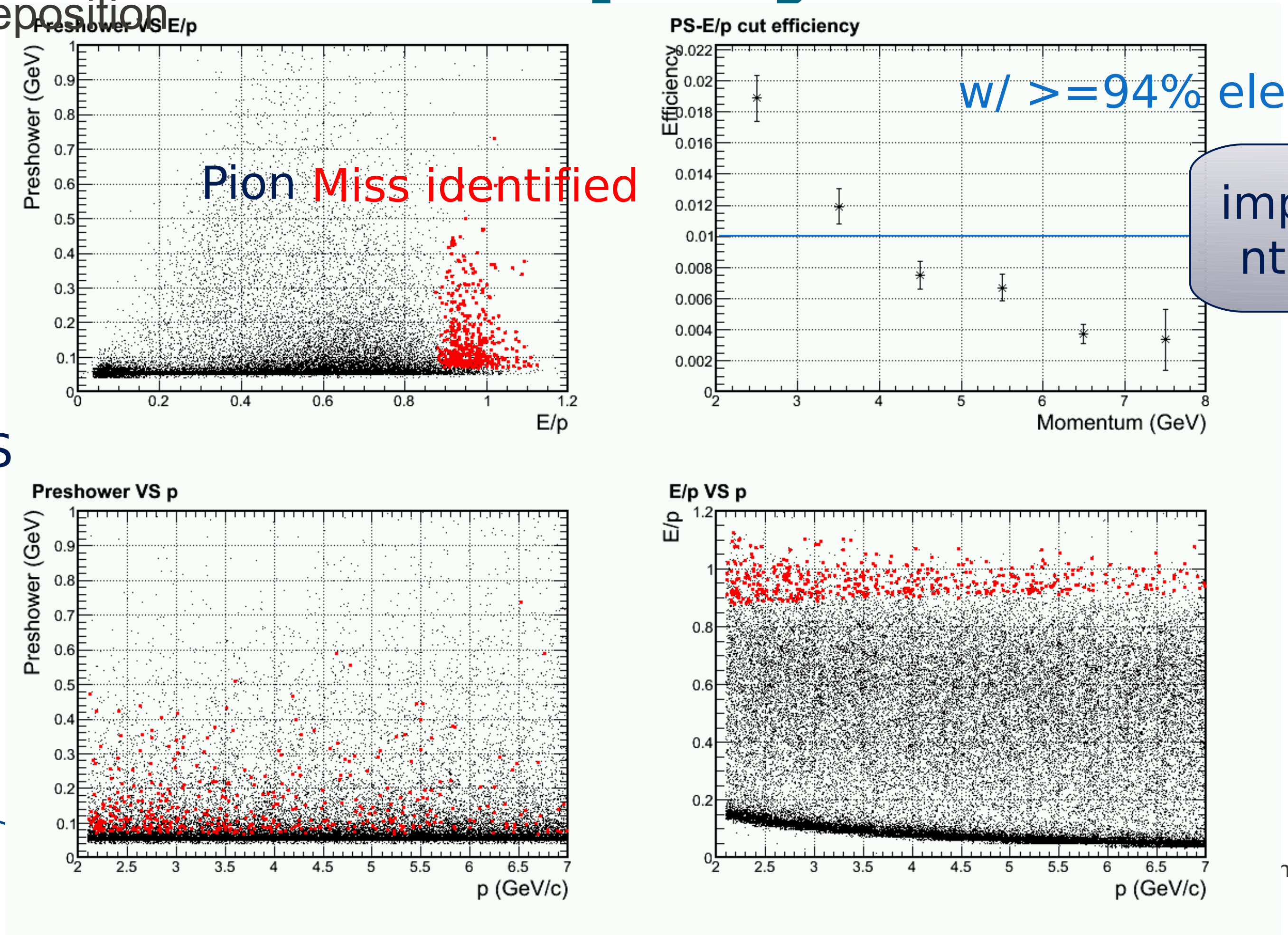
Φ - spread (mm)

Notice the difference in color scale

Apply additional cut to limit max size of cluster around track projection

Limit cluster to be not larger than 3x3 modules around track projection to shower central depth

Minor cut on EM shower but effectively removed hadronic showers of very high energy deposition

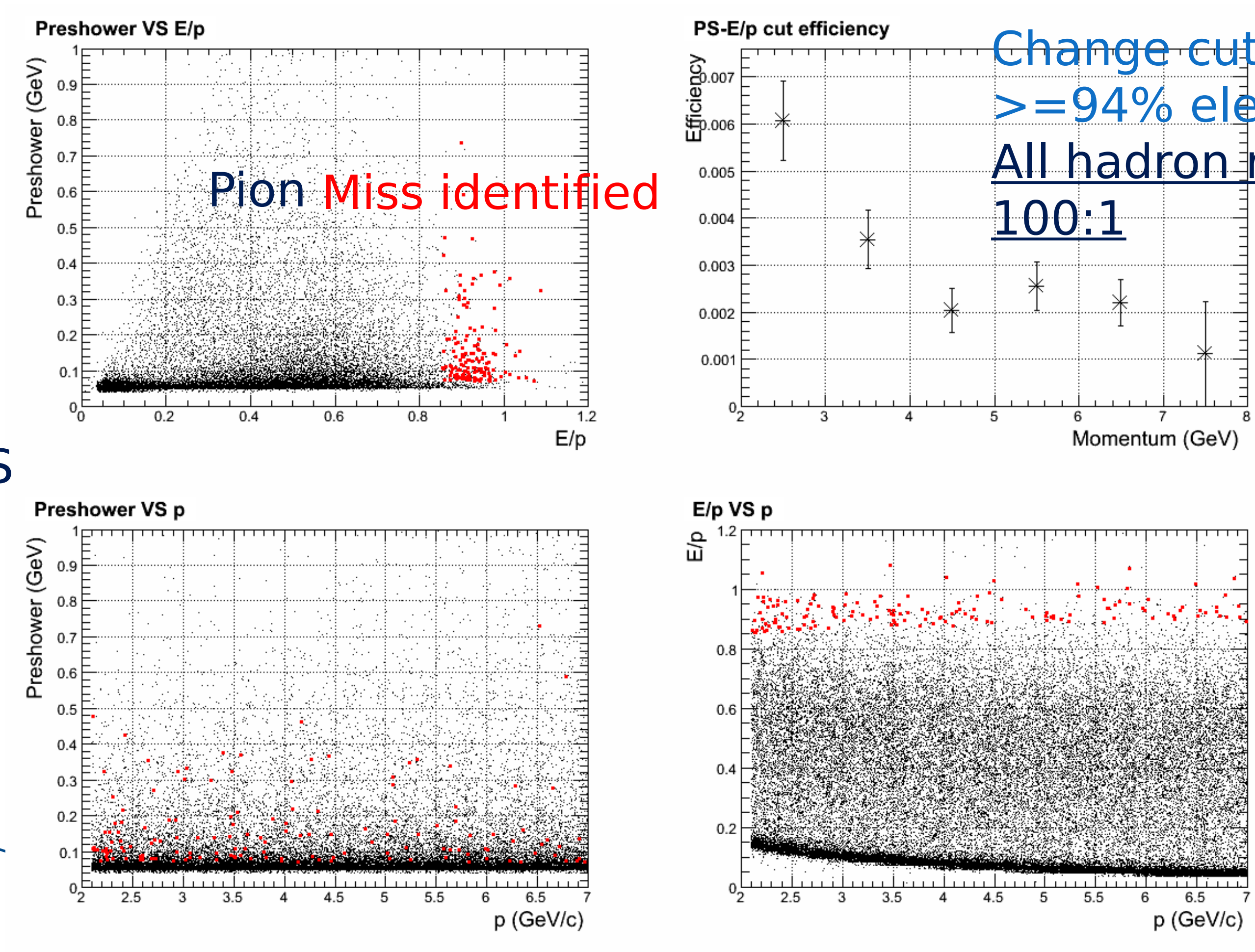


Flat phase space in PVDIS acceptance

Can it be further improved?

Further limit cluster to be not larger than 2x2 modules around track projection to shower central depth

Now loose ~5% of EM shower, but hadron shower cuts faster



Change cut and maintai
>=94% electron eff.
All hadron rej. better tha
100:1

Flat phase
space in PVDIS
acceptance

Design Updates
- Radiation dose

What's new

LHCb/HERMES preshower, instead full Shashlyk preshower

As shown before, the preshower scintillator receive most of the radiation, due to the low energy backgrounds

This part radiation dose are now absorbed in 2X0 absorber, and we just see its EM tail now

Especially, lead absorber effectively kill all low energy electron background

New background distribution updated by Zhiwen

SIDIS:

- With target collimator (suppress background by 4)
- First large angle simulation

PVDIS: have option to remove direct photon sight (expected to be removed in the final baffle design)

Dominating background, photons 1-10 MeV

After preshower, which attenuate them a lot, they still penetrate ~10 layers in Shashlyk

PVDIS – current baffle (with direct γ)

γ dominate
But attenuated quickly

Layer #1 is 2cm preshower scint

PVDIS – preview for a baffle w/o direct γ

γ get reduced by ~5

π- become important here

Layer #1 is 2cm preshower scint

SIDIS – Forward

γ dominate
But attenuated quickly

Layer #1 is 2cm preshower scint

SIDIS – Large-Angle

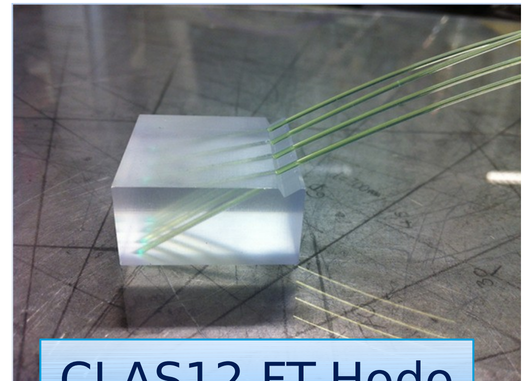
γ dominate
But attenuated quickly

Layer #1 is 2cm preshower scint.

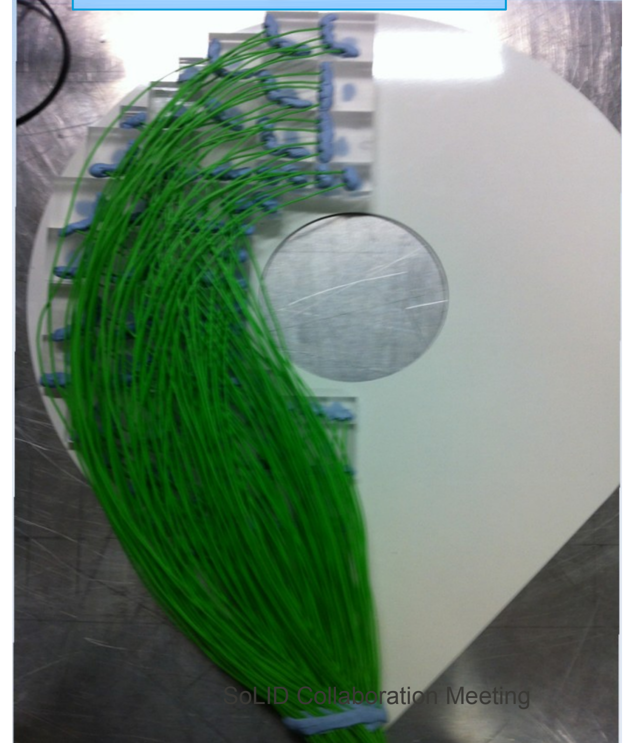
Light Readout

WLS fiber in scintillator pad

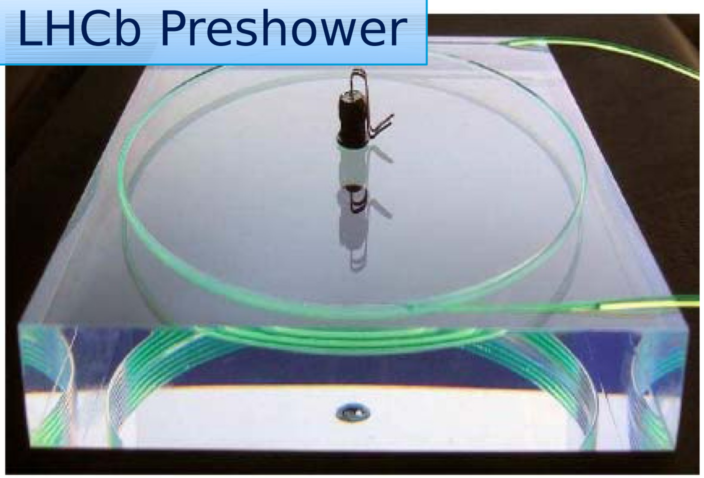
Drill on scintillator and glue WLS in
Used by LHCb etc.
Will use by CLAS12 FT-Hodo



CLAS12 FT-Hodo



LHCb Preshower



Fiber

WSL fiber in shower, 100/module
Bicron BCF-91A

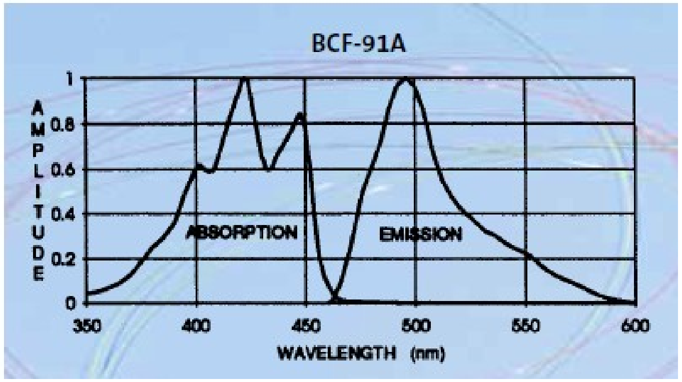
- multi-clad, 1/e length >3.5m
- 1mmD, bend 20cmD (?)
- $0.87/m
- less rad hard

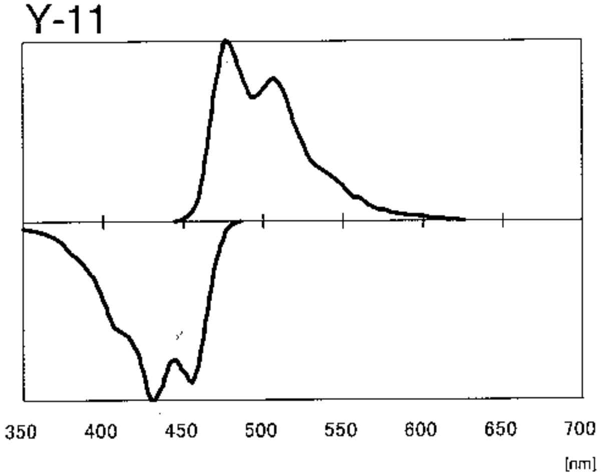
WLS fiber in preshower pad, 1-2/module
KURARAY Y-11(200)MS

- multi-clad, 1/e length >3.5m
- 0.5mmD, bend 5cmD
- $1/m
- more rad hard

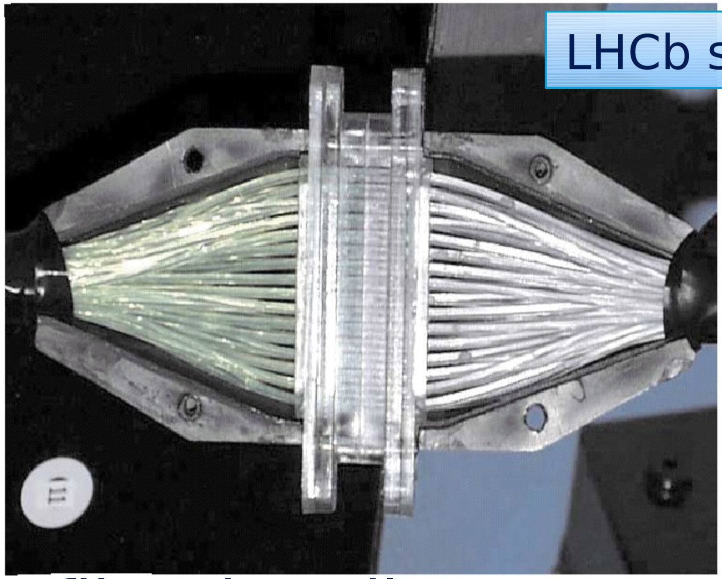
Clear fiber for both, 101-102/module
Bicron BCF-98

- $1/m





Fiber connection



LHCb shower

- fiber bundle to PMT connector, cost estimate $25/module

Readout

PMT option - Hamamatsu R3998-02
28mmD Bialkali Photocathode
$600 each
Used by CLAS TPE calorimeter which has COMPASS module
As our baseline design
APD/SiPM option
High resistance to magnetic field
Need to be careful due to high neutron background
Contacting vendor for high radiation resistance designs (sensor + amp.)
Estimating neutron background @ photon detectors

Budget Update

Budget table
– calorimeter group

	Per-module cost($)	All-module cost(M$)
Module material	700 (L)/250 (S)	1.26
Module production	800 (L)/500 (S)	1.49
Clear fibers	260 (L)/65 (S)	0.46
Fiber connectors	200	0.39
PMTs	600 x 2	2.34
Labor	5 tech years, 5 student years	0.75
Total	-	6.7
Total+ 30% contingency	-	8.7

+ Prototyping ~ 0.3 M$
Lab estimate : 5.7 (base)+3.8 (Labor)
JP : 6.2 (base) + 1.3 (Labor)

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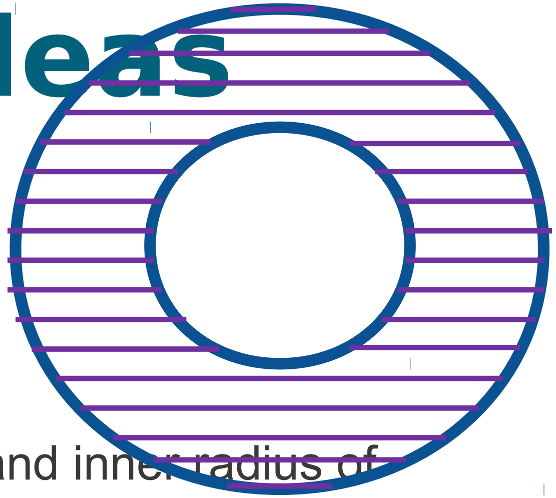
What we need

What we need

Engineering support (Zhiwen)
Support structure
How to do maintenance and install it back
Inquiries
IHEP (Xiaochao)
Fiber connection (Mehdi)
Photon detectors (Zhiwen)
Background effect (Jin)
Event mixing with signal and background simulation
Prototyping

Support structure ideas



Overview

One support for LAEC, one support
for FAEC

Only a few cm gap between outer radius of SIDIS LAEC and inner radius of cryo, is it enough?

Only a few cm gap between outer radius of FAEC and inner radius of nose cone, is it enough?

Need to consider the supporting with overall magnet cryo and yoke structure.

“super” Modules

Group 1-3 row of modules into supermodule

shift supermodule’s horizontal position to make layers

backup

WLS radiation hardness

Table 1
Optical properties of each type of WLS fibers before the irradiation. Average light output at 140 cm and RMS, average attenuation length (L_{att}) and RMS, for ten fibers of each type. The values are normalized to I_{140} of the Y11(200)MSJ fibers

Fiber type	I_{140}	RMS (%)	L_{att} (cm)	RMS (%)
BCF91A MC	0.98	9.6	280	9.5
Y11(200)MSJ	1.00	1.8	280	1.6
S250-100	0.81	5.7	230	5.6

Table 2
Relative light output at $x = 140$ cm, for total doses of 1.16 and 6.93 kGy

Fiber type	$\frac{R(140)}{R(30)}$ for 1.16 kGy			$\frac{R(140)}{R(30)}$ for 6.93 kGy		
	0 days	1 day	10 days	0 days	1 day	10 days
BCF91A MC	0.83	0.86	0.85	0.54	0.56	0.56
Y11(200)MSJ	0.87	0.92	0.91	0.71	0.72	0.74
S250-100	0.60	0.70	0.81	0.52	0.55	0.64

Fiber connection (Backup option)

Fiber splicing

Robust connection and excellent transmission (2%)
CLAS12 Forward Tagger Hodoscope will fuse WLS and clear fiber. Commercial vendor has been contacted and They are also developing their own method.
We will collaborate with them to examine the labor and cost requirement.