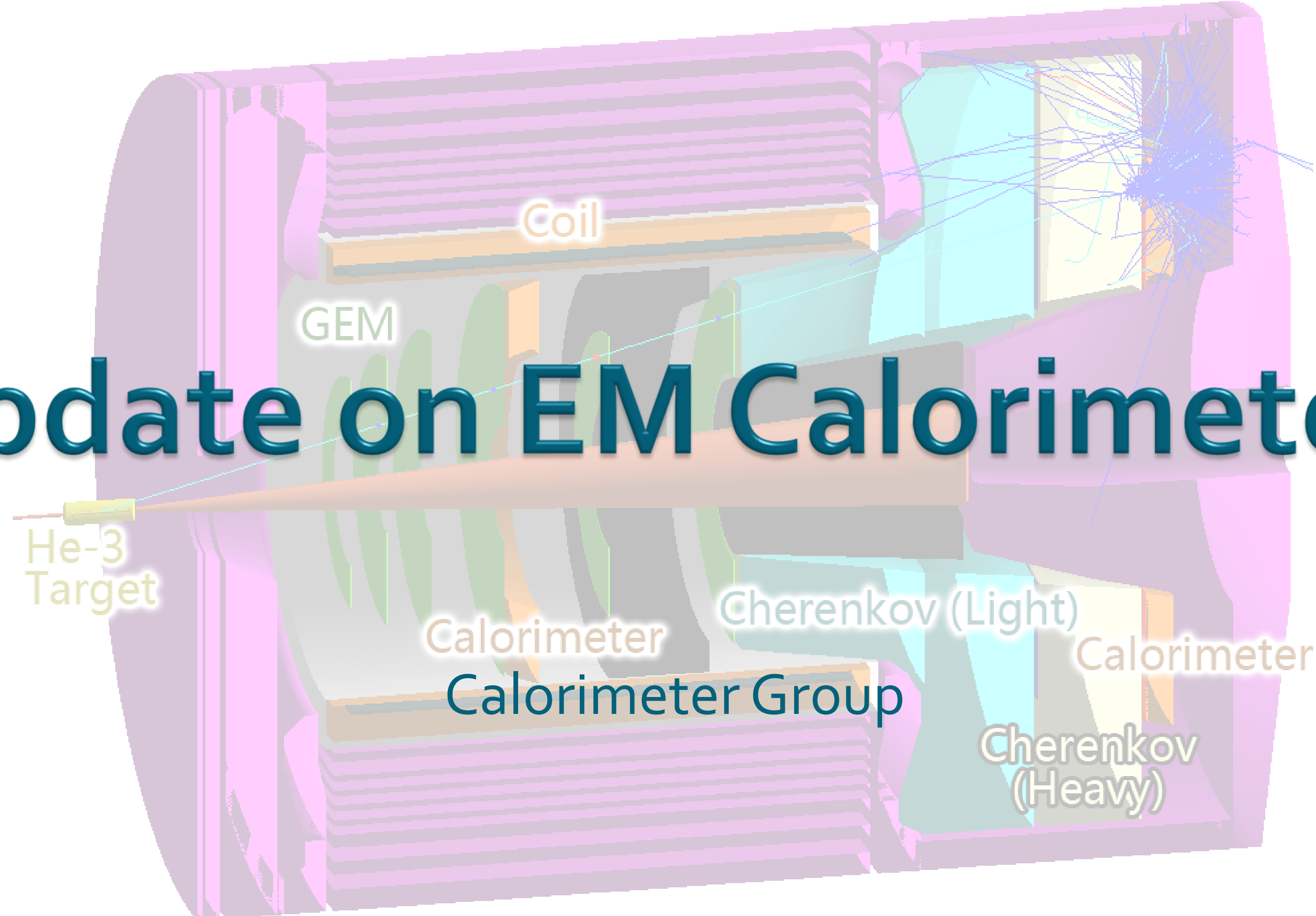
Update on EM Calorimeters

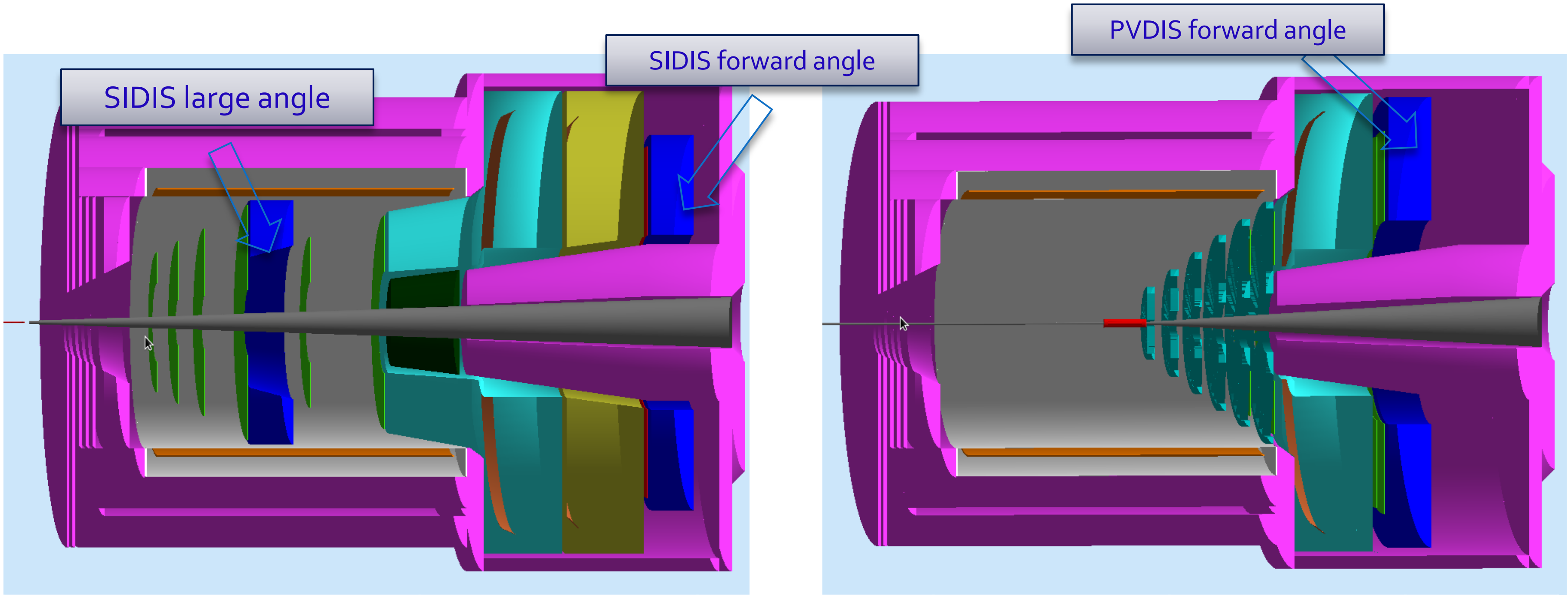


Calorimeter Group

Jefferson Lab

Overview

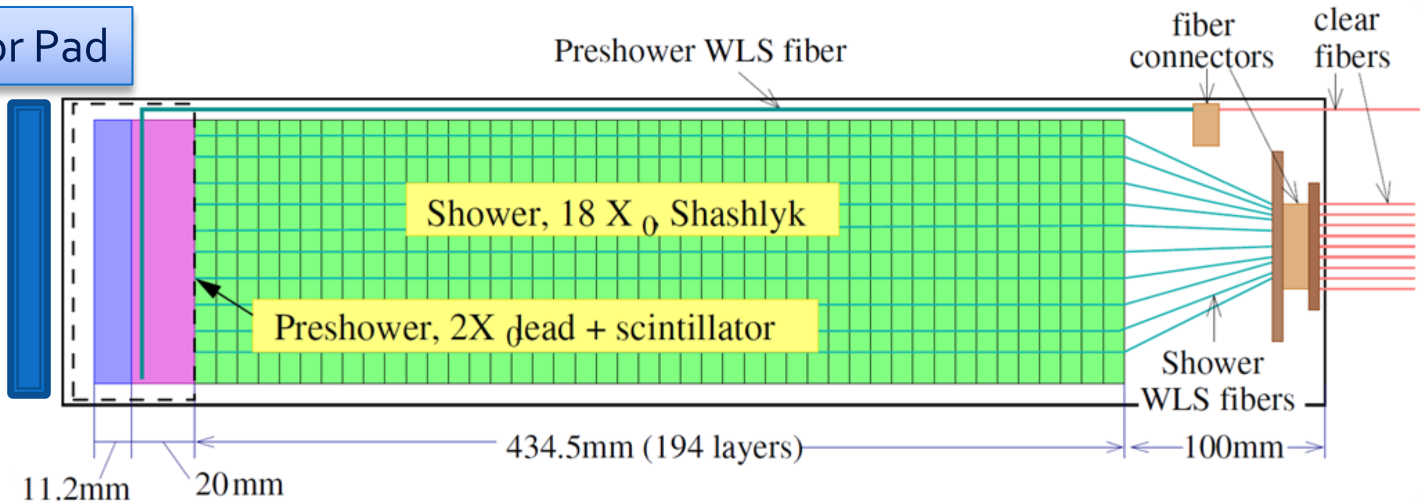
SoLID EM Calorimeter Overview



SoLID EM Calorimeters	Polar Angle (degree)	P (GeV / c)	Max π / e	Cerenkov Coverage	Area (m^2)
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

Default design for calorimeter modules

Scintillator Pad



- Scintillator Pad (SPD)
  - Reject high energy photons for electron trigger and hadron trigger at SIDIS forward angle
- Preshower (PS)
  – HERMES/LHCb style passive radiator + scintillator design
  - 2 Xo lead 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 x 2
  - X_0 = 24cm, R_M ~ 5 cm, 194 layers, 43 cm in depth

Requirement/Parameters	SIDIS LAEC	SIDIS FAEC	PVDIS FAEC	note	
(Zmin, Zmax) (cm)	(-65,-5)	(405,465	(320-380)		
Polar angle (deg)	15.7-24	7.5-14.85	21-36		
Momentum (GeV)	3-7 (SIDIS) 2-8 (Jpsi)	1-7 (SIDIS) 0.6-2 (Jpsi)	1.5-5		
Area (m2)	4.5	12	17		
pi rejection	10	100	100		
e- efficiency	95%	95%	95%		
Radiation hardness (krad/year)	500	500	500	Based on PAC year	
Position resolution (cm)	1cm	1cm	1cm	Related to tracking	
Energy resolution	5%/sqrt(E)	5%/sqrt(E)	5%/sqrt(E)	Related to pi rejection	
Time resolution (ps)	300	300	300		

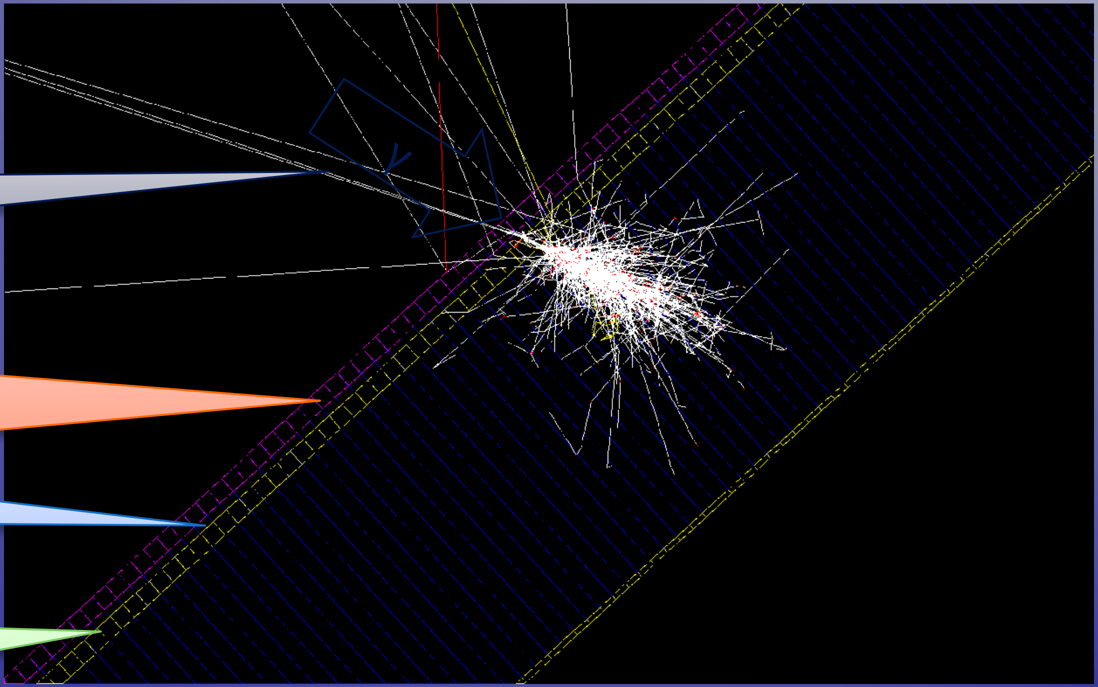
Scintillator for rejecting background photon

back scattering for high-E γ

Scintillator Thickness = 5 mm (thicker version shown)

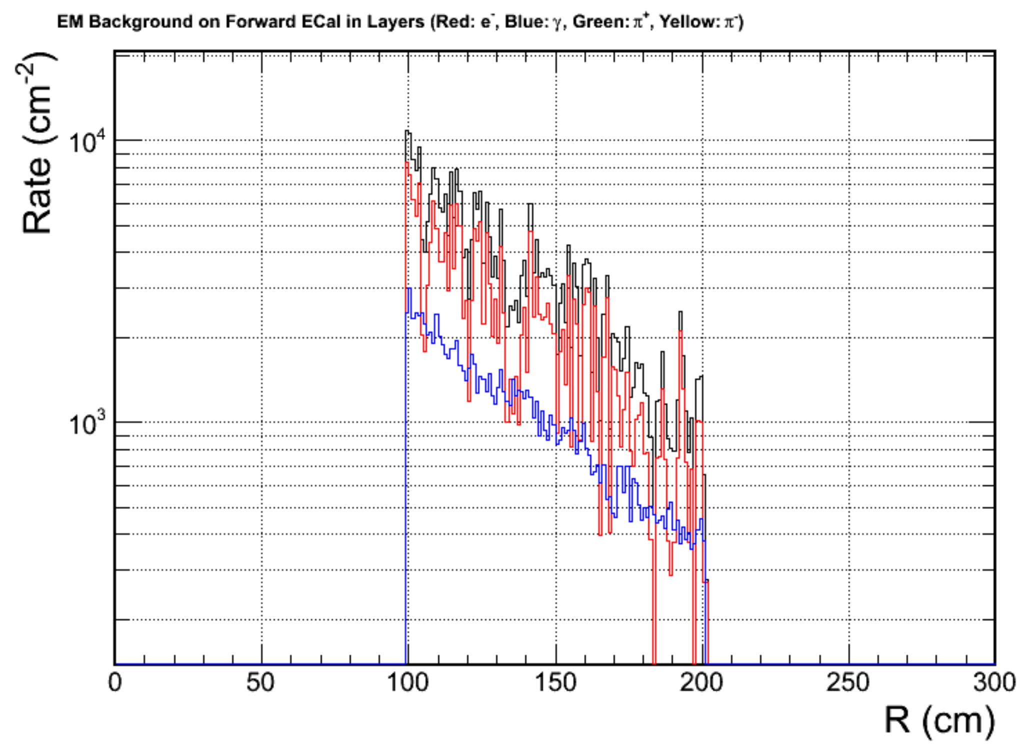
Preshower Pb

Preshower Scint



Thin scintillator pad to reject photons at trigger level

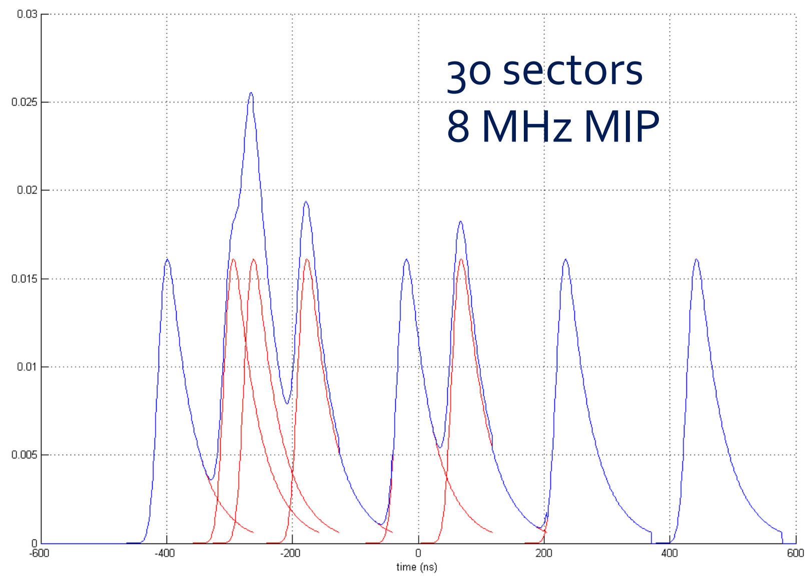
- Features
  - Scintillator thickness of 5mm: simulation shows 2.3% of photons from SIDIS pio would deposit energy, the rejection factor estimated at least 20
  - Segment into fan shape for readout by WSL fiber or PMT directly
- Background is important: dominated by low energy electrons
- Source of low energy electrons
  - 20% from end cap of heavy gas Cerenkov, other from more upstream
  - Have to be placed before MPRC, which have lots of material for conversion!
- Rate: if 120 segment take 2MHz MIP per segment

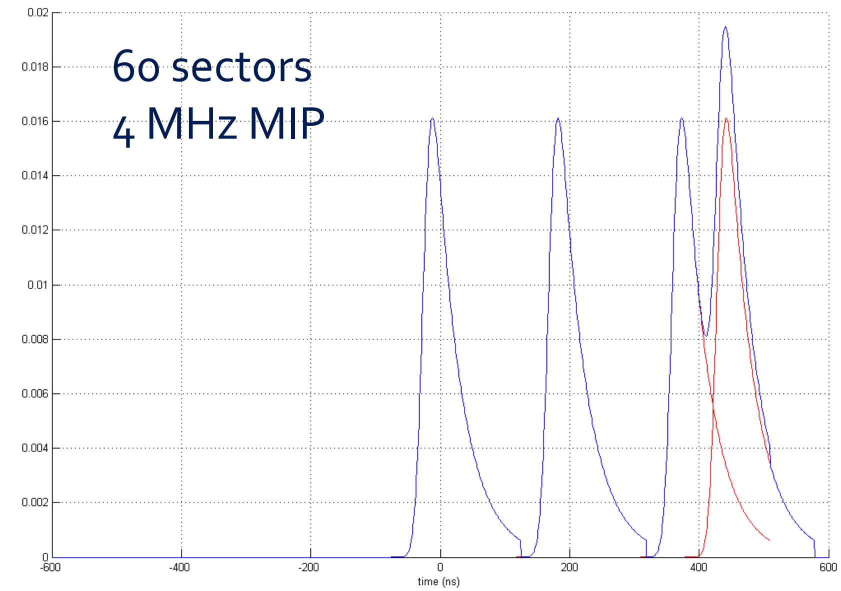


Particle species at front surface:

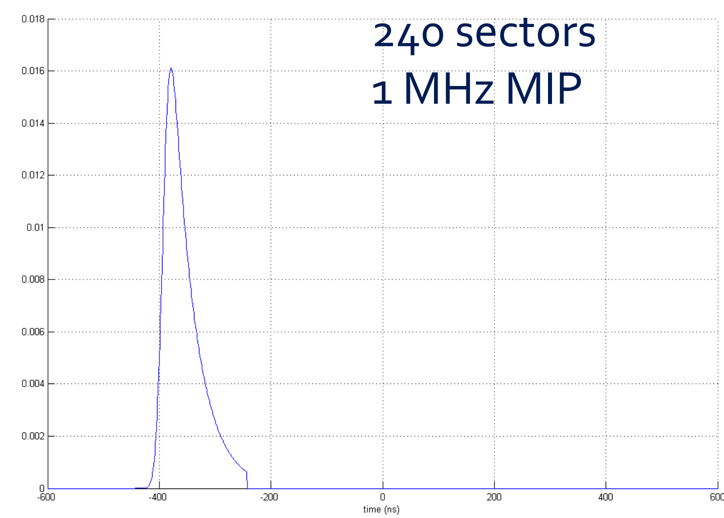
- Electron
- Low energy gamma
- All

How signal looks like



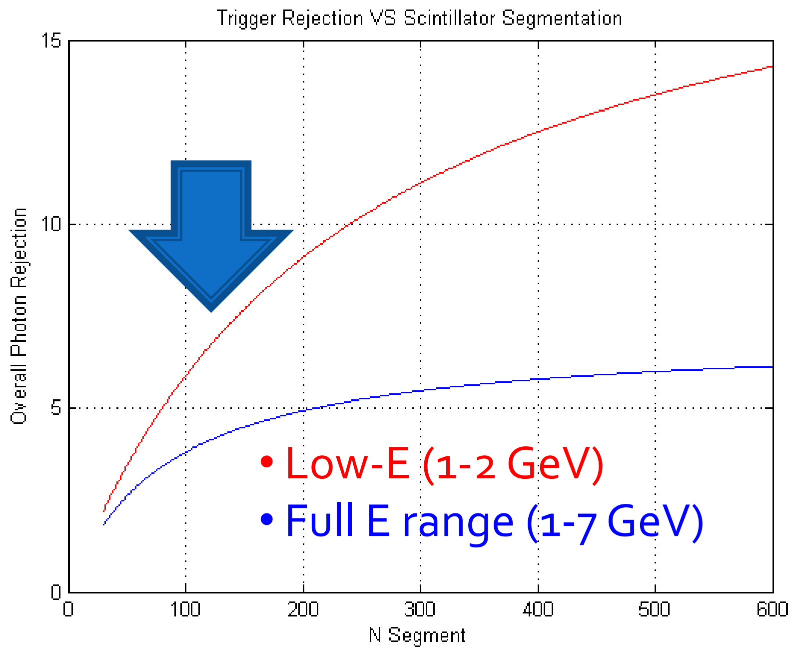


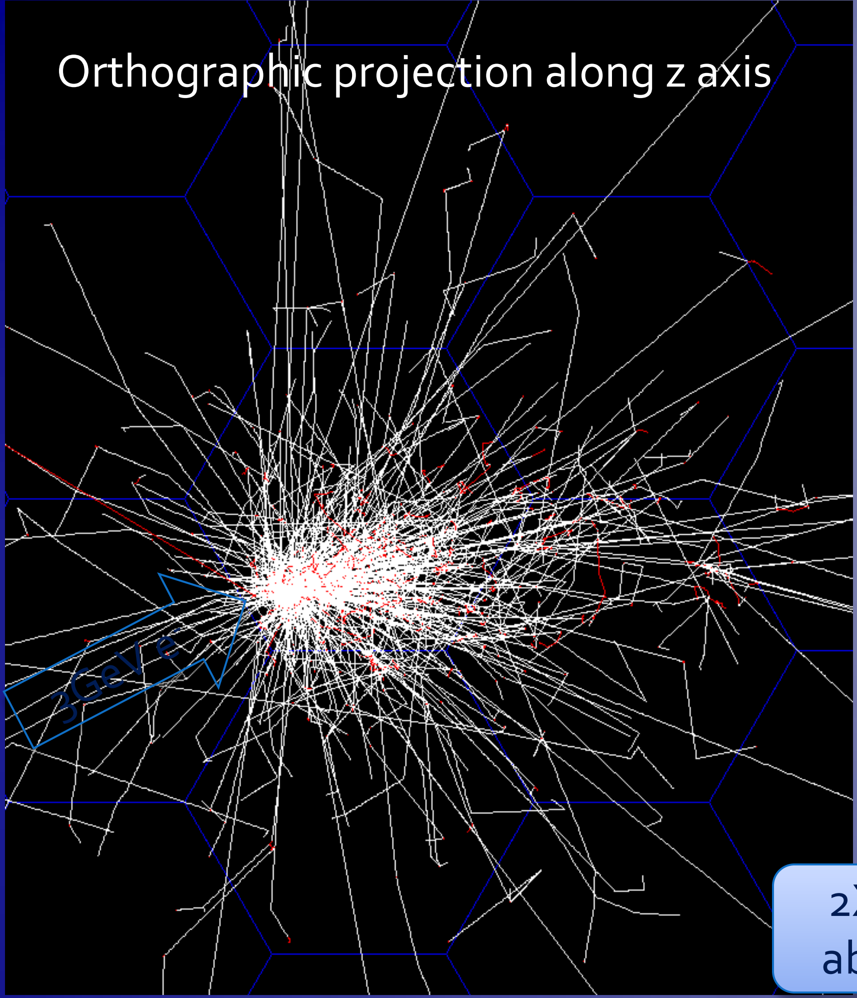
- Signal of each MIP hit
  (amp. variation not included)
- Sum of all signals

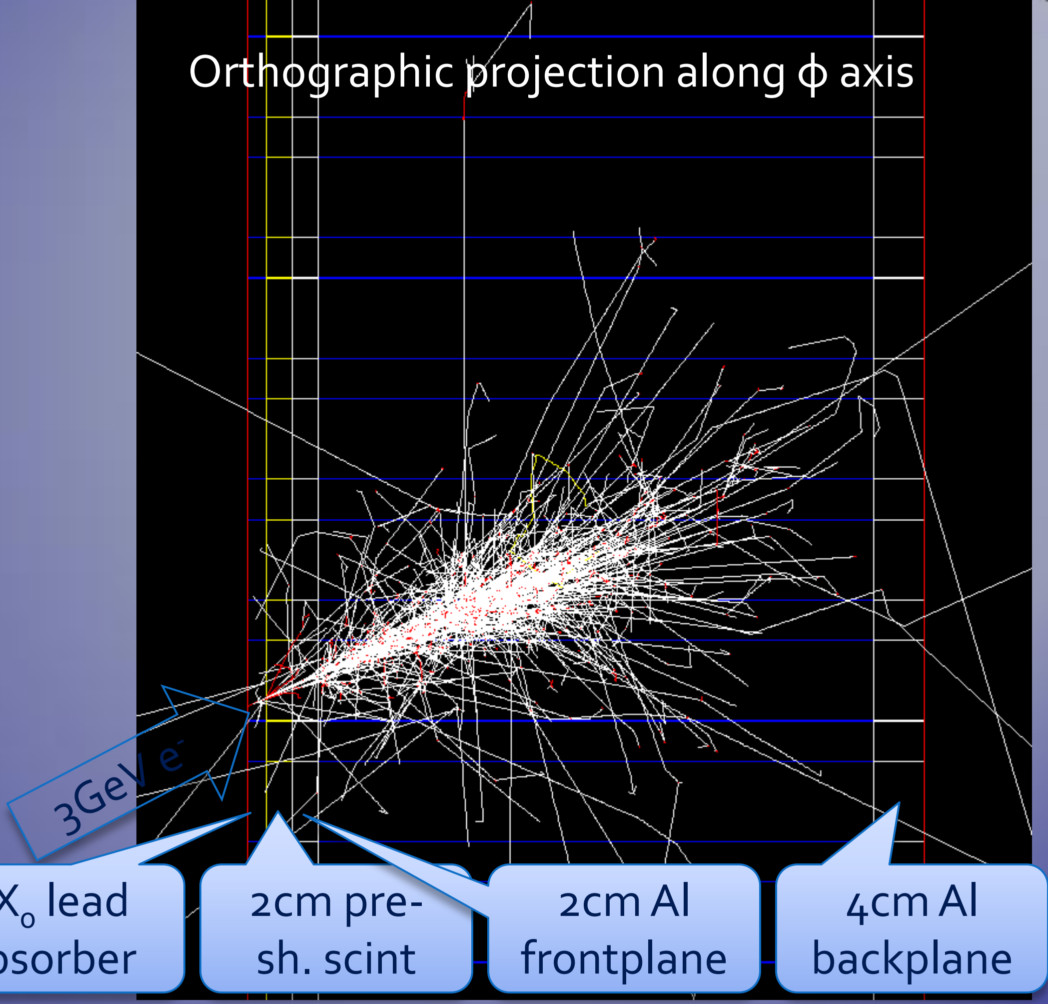


Optimizing the segment

- Lower energy photon (1-2 GeV) are dominant, which we have higher rejection
- Trigger require 5:1 rejection. Satisfied with margin at a 120 segments
- A 50ns coincidental window with calorimeter assumed. Expect improvement in FPGA level







Hexagon Calorimeter Simulation

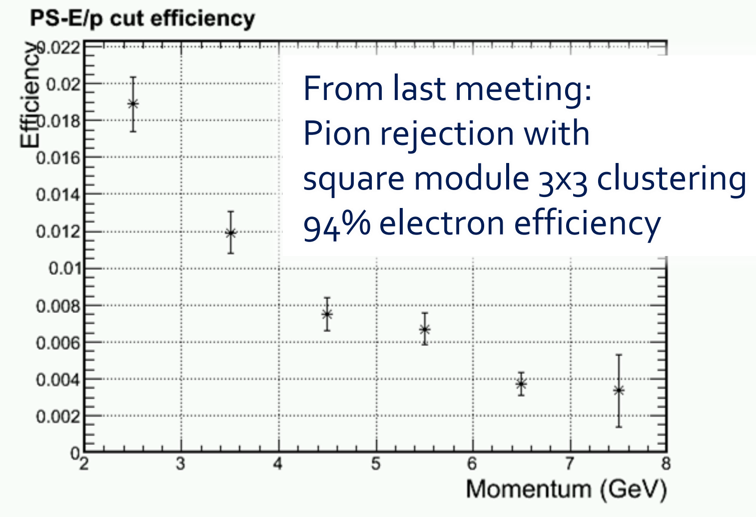
3GeV electron shower

On hexagon calorimeter grid

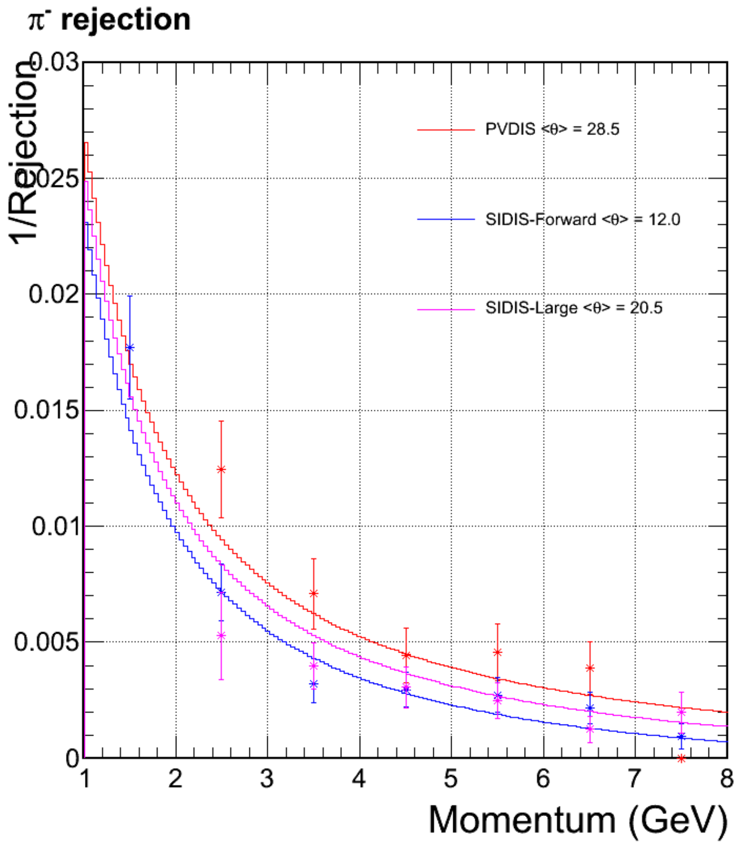
- The support Al plate was just added, not used in this study

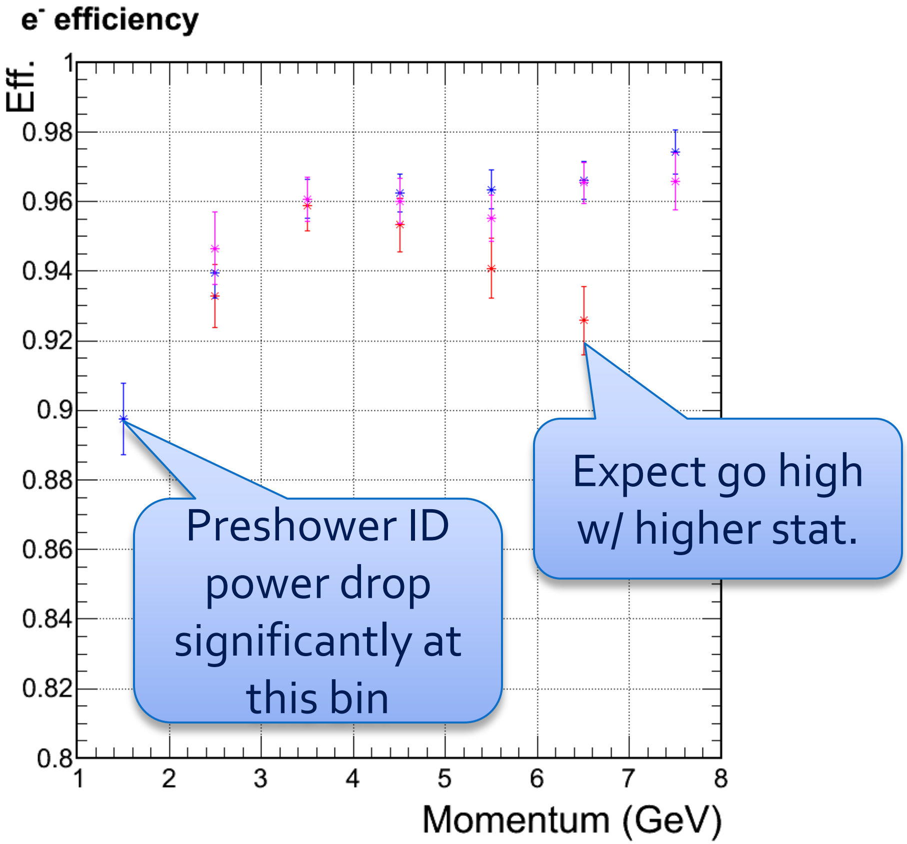
All rejection/efficiency reviewed with hexagon-shape calorimeter modules

- No background yet assumed at this step



From last meeting:
Pion rejection with
square module 3x3 clustering
94% electron efficiency





Review of Background Simulation

- 3rd iteration of GEMC + CaloSIM background study

Calorimeter background simulation with GEMC + CaloSIM

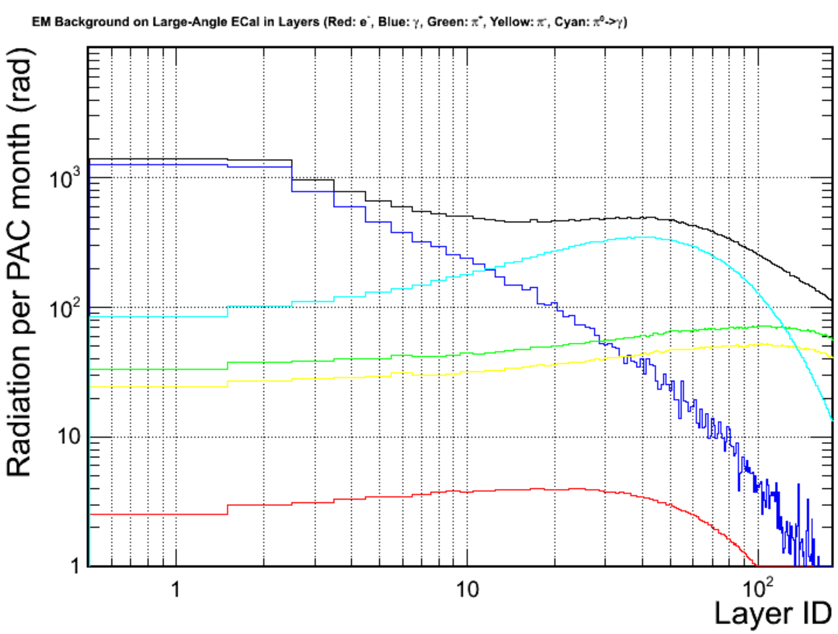
1. GEMC simulate spectrum and rate of background particle at the front surface of calorimeter (Zhiwen)
2. CaloSIM (standalone calorimeter simulation, on SoLID SVN) build calorimeter response from a wide range of incoming particle species and energy range
3. Combine above two and sum over all contributions (EM, DIS, pio, pi+,pi-) stochastically within a 50ns coincidental window (assumed at this moment)
   -> background distribution at each trigger
4. Imbed background into the signal simulation (high energy e, pi) and perform analysis (clutering, e/pi separation, etc.)

Radiation dose prediction remain stable

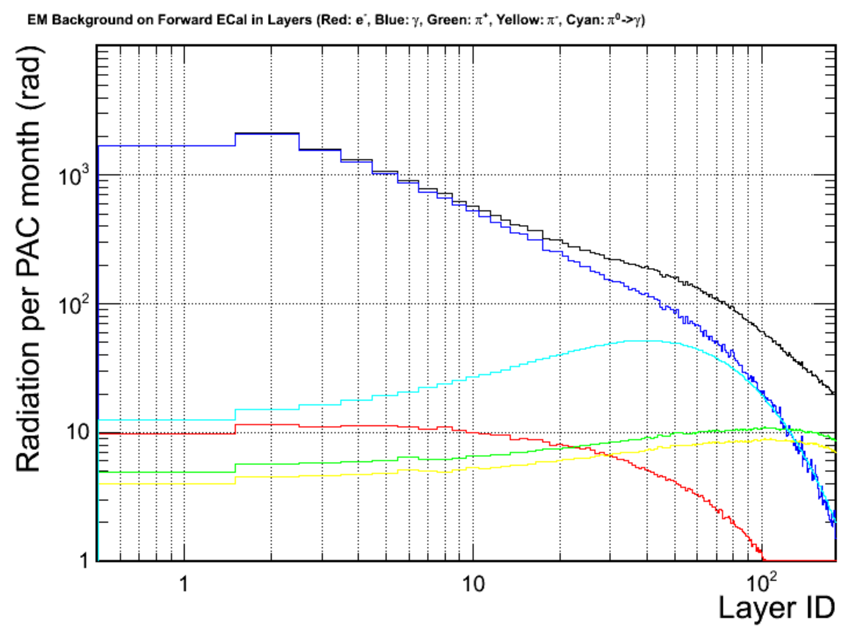
- Dose is not a problem for SIDIS configuration.
  - Calorimeter design to stand >10^5 radiation dose
  - Important to have this safty margin
- Still missing final PVDIS radiation dose, need final baffle w/o direct line of sight

Particle species at front surface:
- Electron
- Low energy gamma
- Pi- / pi+
- pi^0 -> gamma

SIDIS – He3– Large Angle Calorimeter



SIDIS – He3– Forward Calorimeter

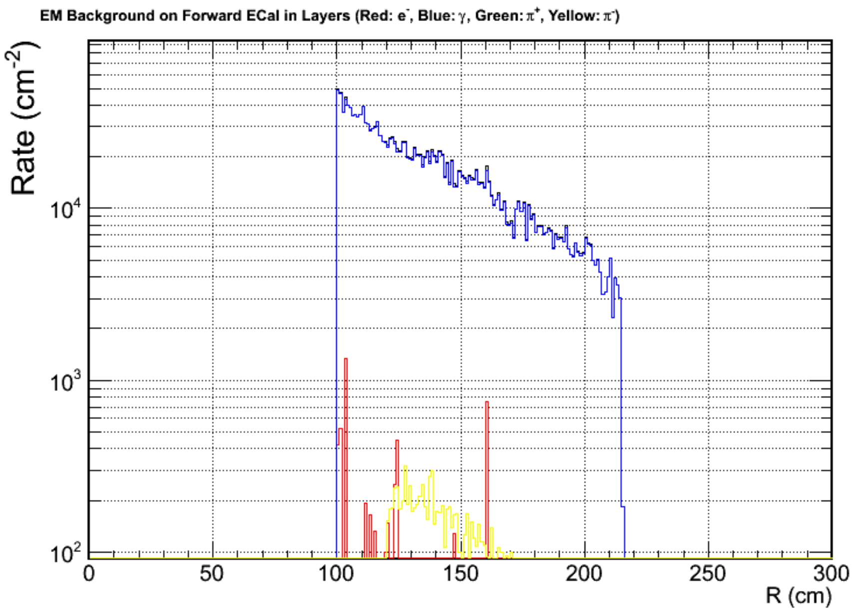


Full background simulation For SIDIS Forward Calorimeter

SIDIS forward background

- We have good “shielding” with 2Xo preshower, save us from 1GHz/cm2 photon background
- Dominated background: low energy photon 1-100 MeV, which lead to 10kHz/cm² MIP signal on preshower
- The background on shower is small
- Used in this study:
  - Most inner side (highest rate)
  - 100 cm² segmented preshower - 3 MHz MIP rate
  - For outer radius, rate is 10x lower, less segmentation can be used there

preshower MIP rate categorized with its source



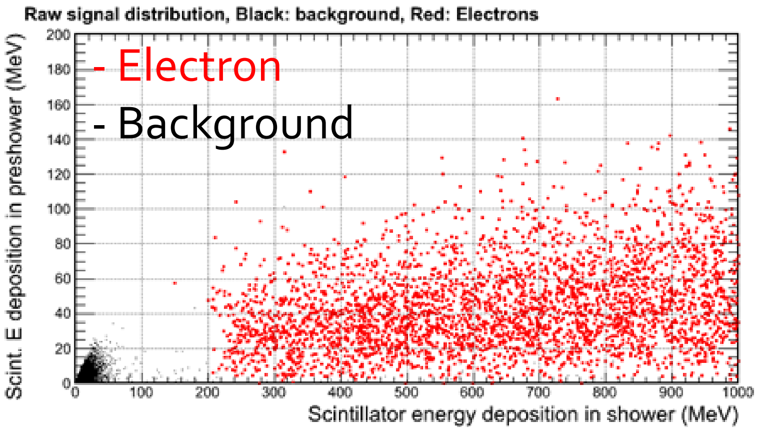
Particle species at front surface:

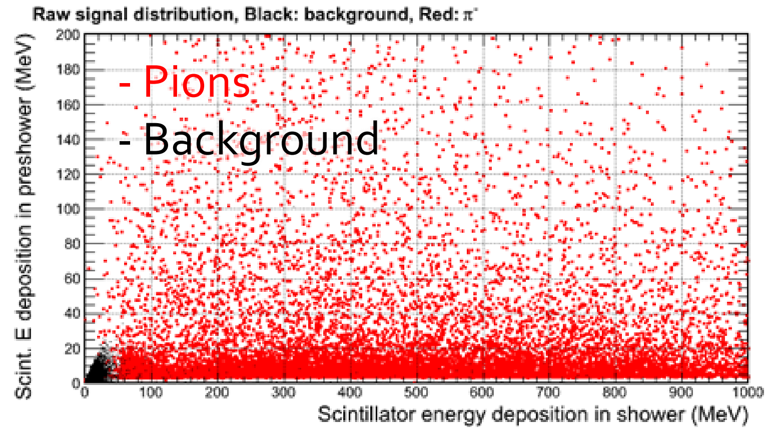
- Electron

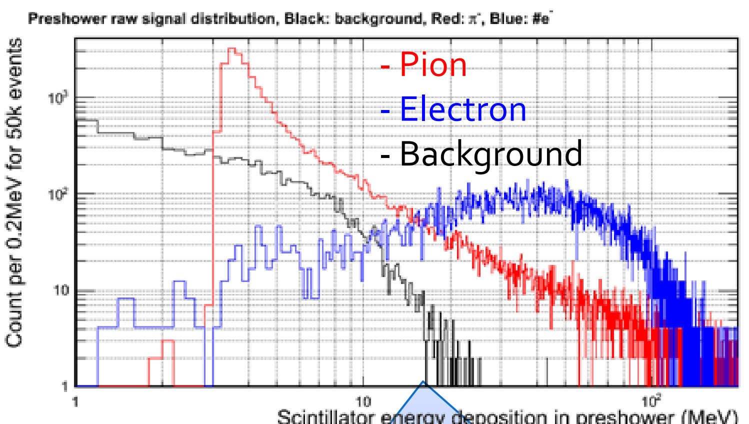
- Low energy gamma

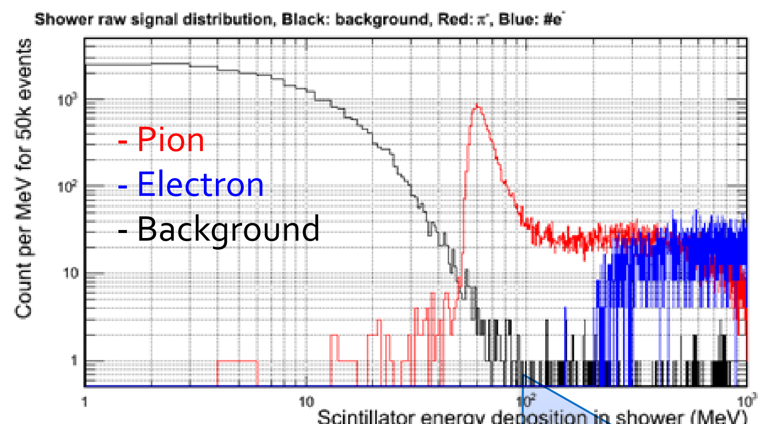
- Pi-

Compare background to signal





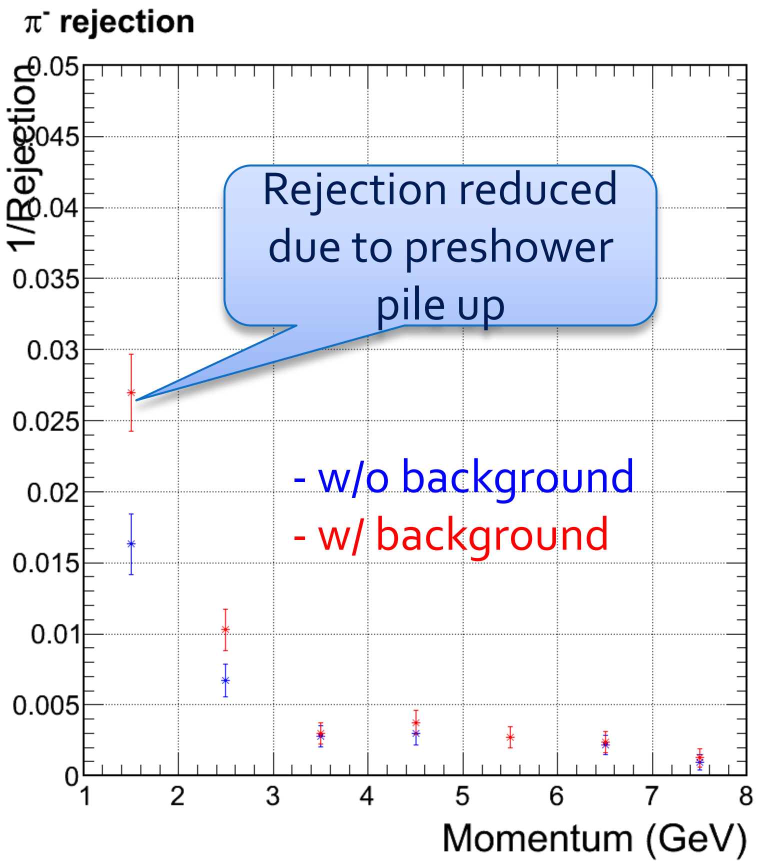


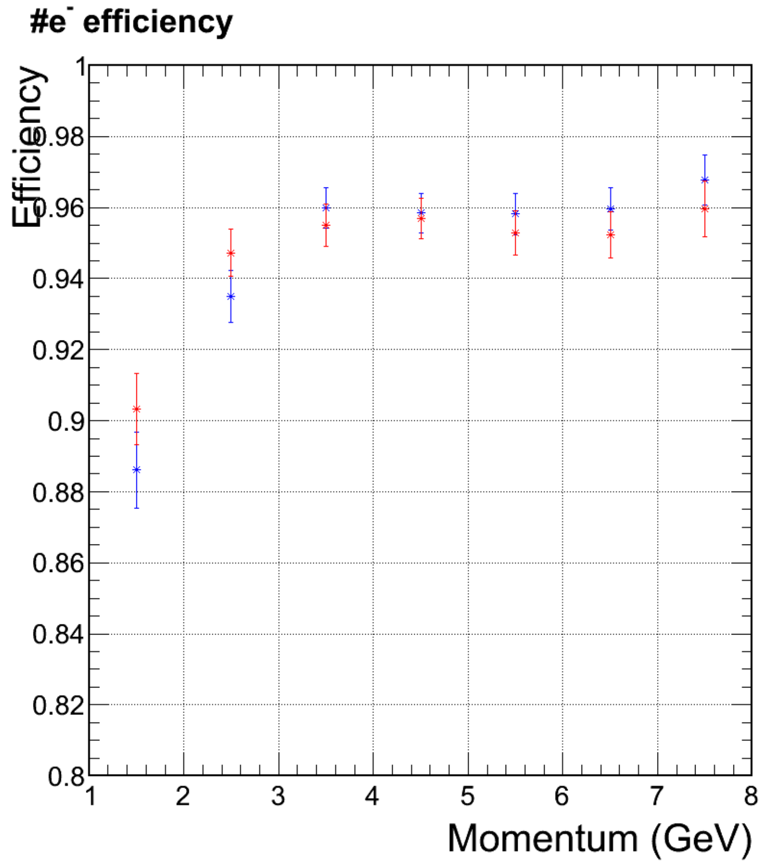


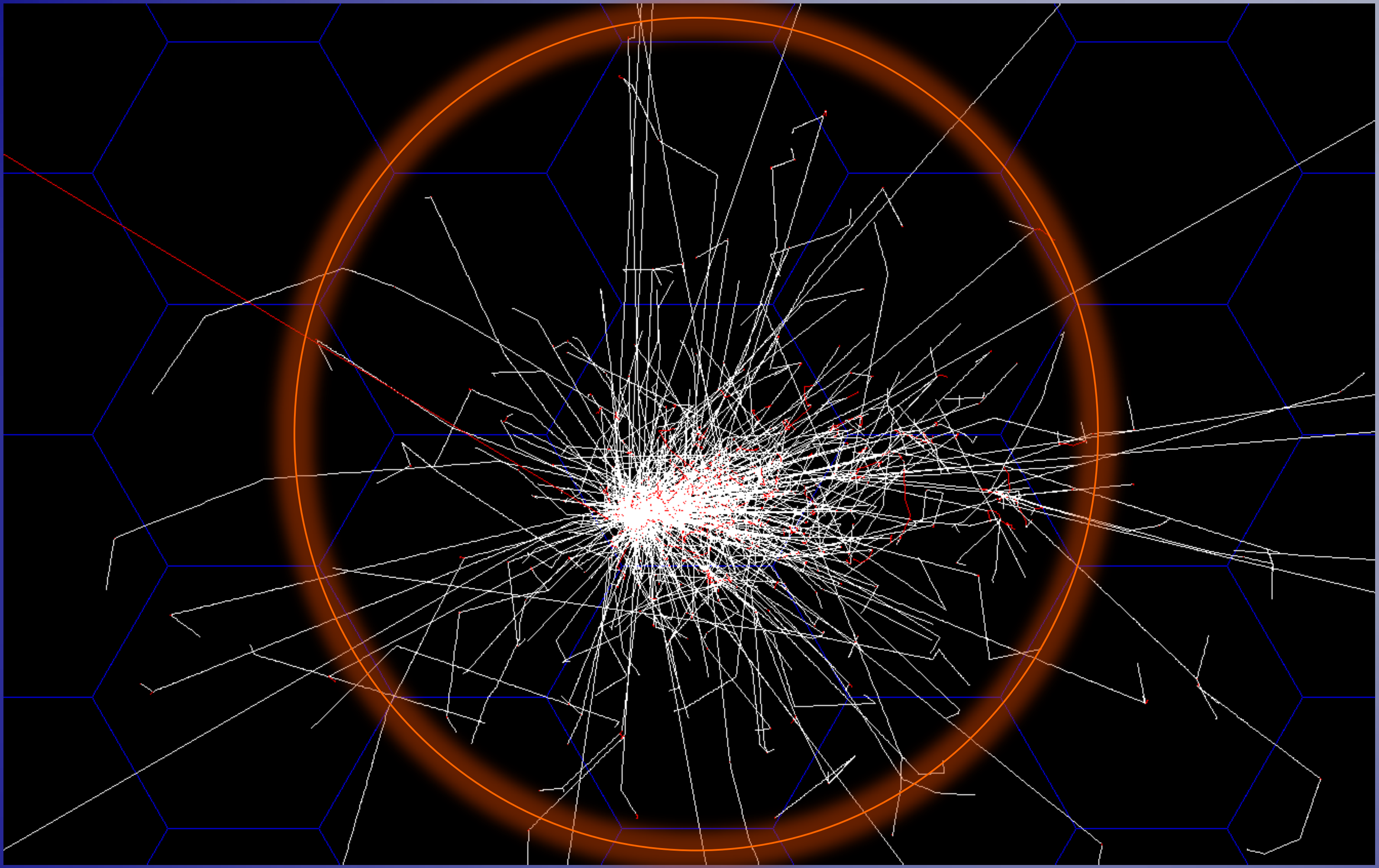
MIP Background is significant in preshower

Background is much less significant for shower

Offline: No change in eff., reduce rejection at low-p end







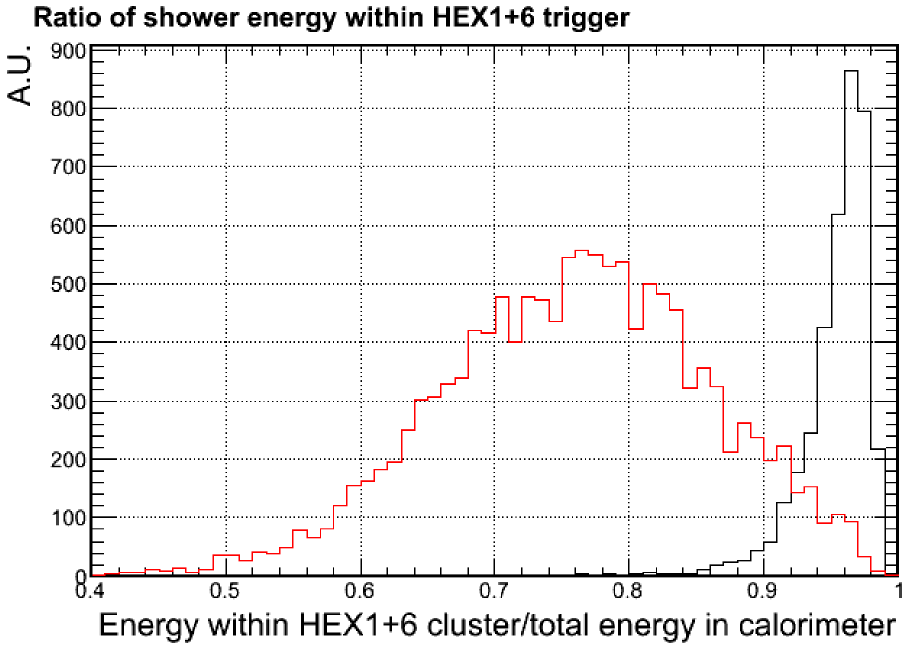
Hexagon Calorimeter Trigger

- Hexagon Provide nice shower area cuts – can be used in both online and 1^{st}-order offline analysis
  - clustering – contains ~96% of shower energy
  - FPGA-based pattern trigger (HEX 1+6 trigger)

Online: Trigger with background

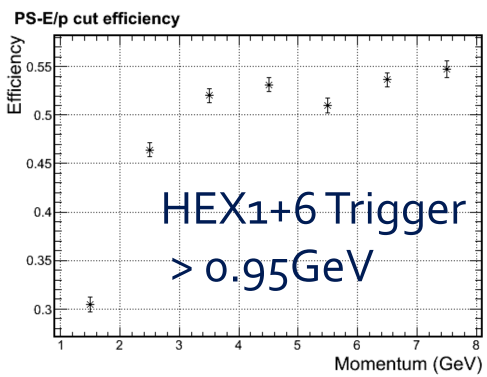
- Hadronic shower which introduce a pion contamination, usually spread into larger area compared to EM shower
- A localized trigger, e.g. HEX1+6 trigger can significantly suppress the hadron response, while maintaining high eff. for electrons

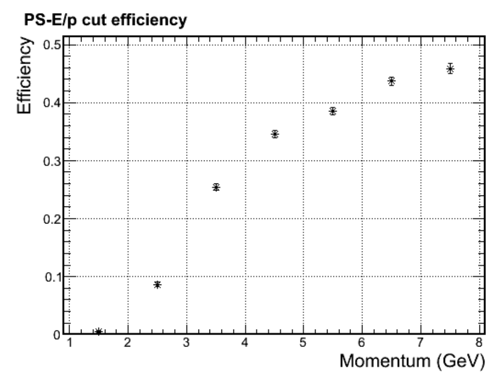
- Ratio of EM shower contained
- Ratio of Pion shower contained



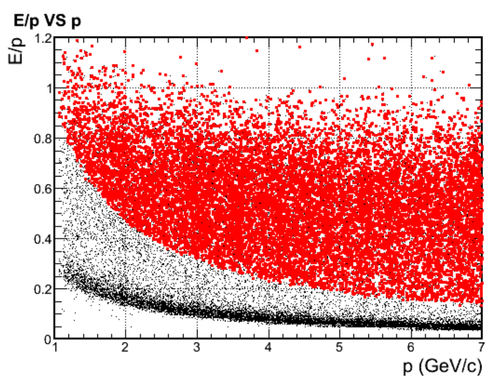
If we only trigger on total EM energy

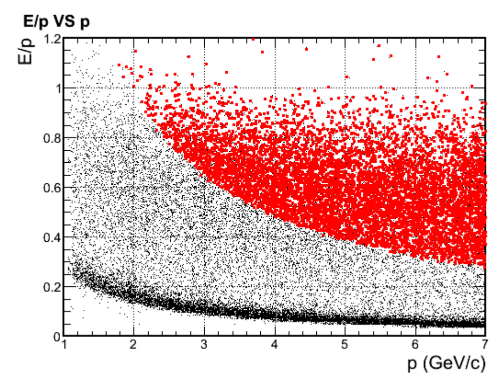
- Do receive very high electron efficiency in simulation
- However, for SoLID, wide momentum range is used.
  - Therefore to accept lowest momentum electrons, the shower cut have to be low.
  - the rejection for high momentum pion will be very limited
- From DAQ group (Xin, Alex): use position dependent threshold, consider plus preshower trigger
- Simulated with background imbedding. The pion response is shown below:





HEX1+6 Trigger
> 1.95GeV



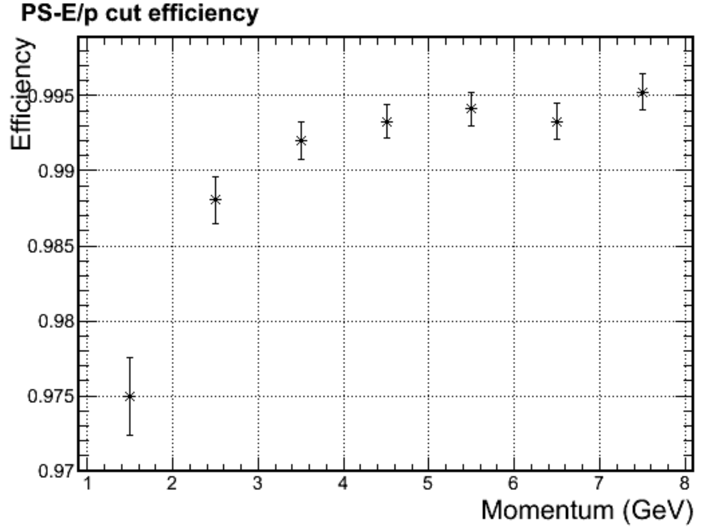


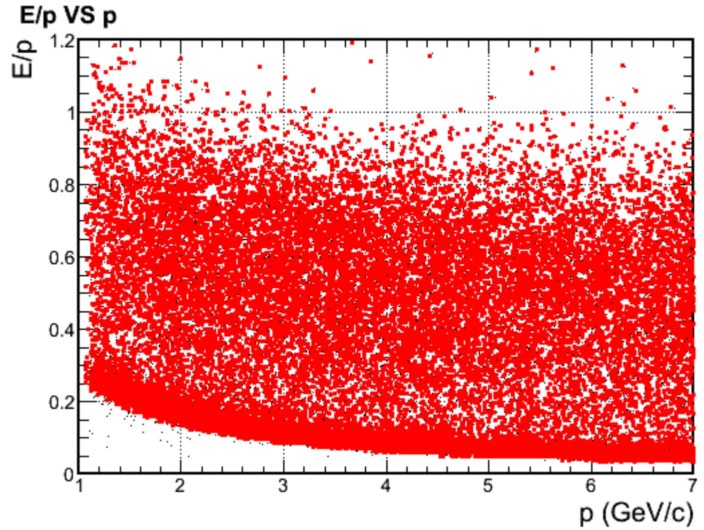
* Accepted
* All

Charged Particle (Pion) trigger efficiency

- Full background simulation for pion efficiency shown on the right.
- Trigger cut is HEX1+6 trigger raw signal is larger than 85% MIP (which is MIP – 2σ = 220MeV calibrated)
- The background which pass this cut
  - rate ~20Mhz
  - is dominated by photon.
  - With an additional 1/5 suppression from scintillator, we get ~4MHz trigger rate, which fit in the DAQ limit (PR12-10-006)
  - Will join global DAQ study for final verification

Pion trigger response
* Accepted
* All

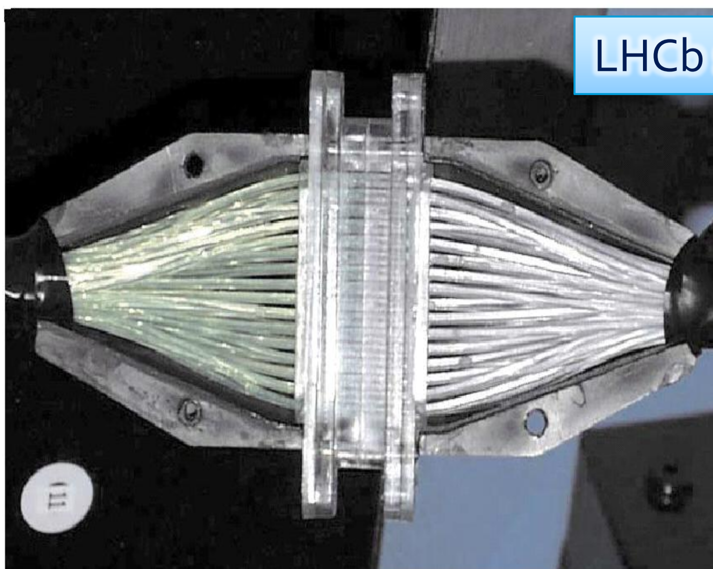




Design Updates
- Fiber connector

Fiber connection

- Shower will use 1-1 bundle fiber connector.
  Used in previous experiments (LHCb, Minos)
  custom made fiber connector, quote by LEONI (see next slide)
- Preshower will use comercial 1-1 single fiber connector, a few $ each.

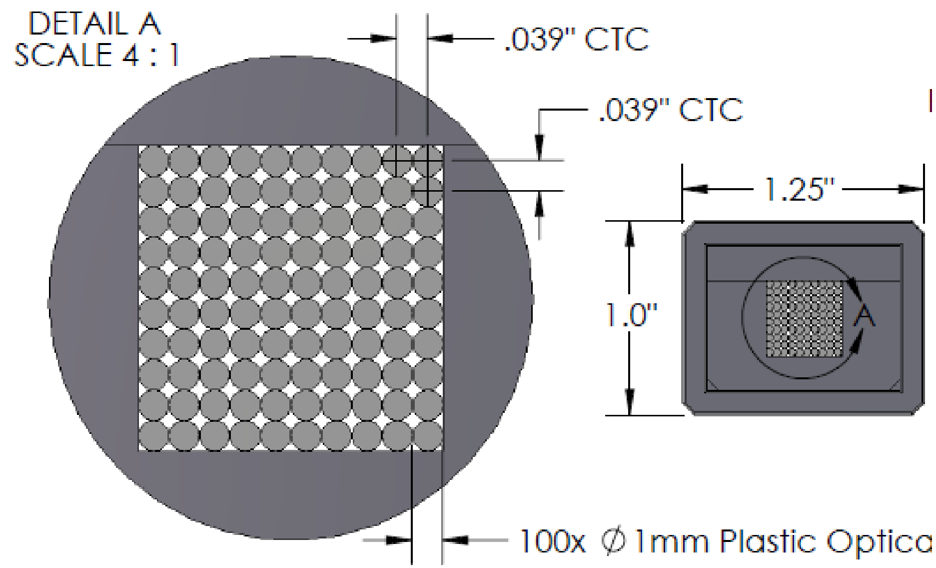


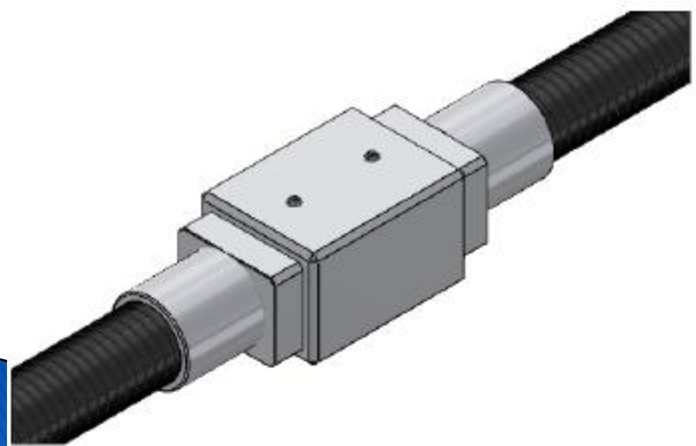
LHCb shower

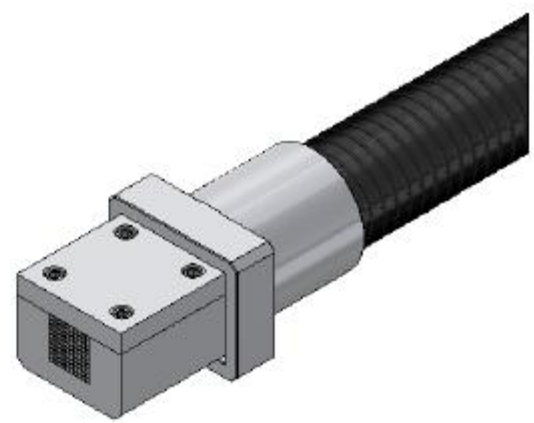
- fiber bundle to PMT connector, cost estimate $25/module

Fiber connector
Concept design from LEONI

- 1 connector for 100 fiber pairing
- made of Al
- 35% worst light loss
- $100/each







Budget Update

Budget

	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

- + Prototyping ~ 0.3 M$
- + Support ~

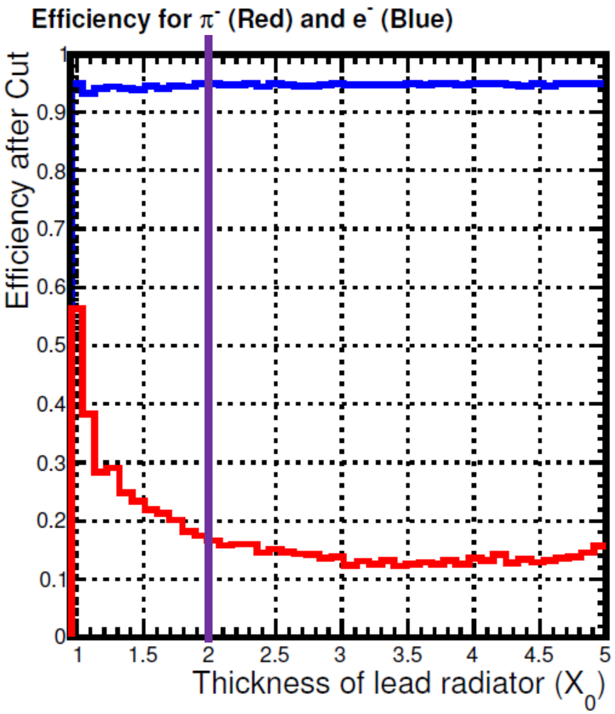
backup

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 X_0 : contain 98% of shower and maximize pion-electron difference
    → MIP = 270 MeV (real) / 320 MeV (reconstructed)
  - Lateral size of 10x10 cm^2: 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 X_0 lead :
    - Thinner – loose preshower rejection
    - Thicker – loose shower resolution
    - Scanned for 1.5, 2 and 3 X_0; 2 X_0 serve SoLID best
  - Scintillator of 2 cm:
    - MIP = 4 MeV, electron cut ~ 3 MIP

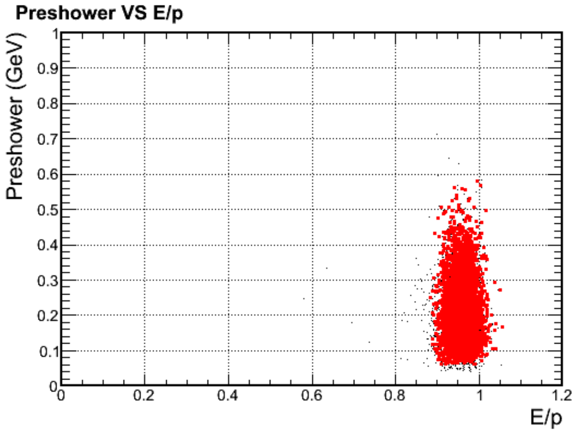


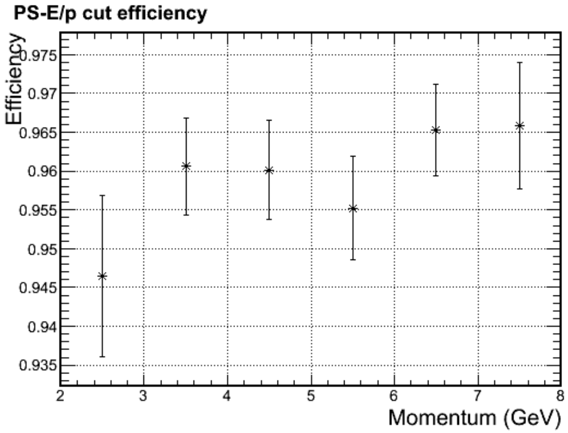
Simulation setup with hexagon calorimeter modules

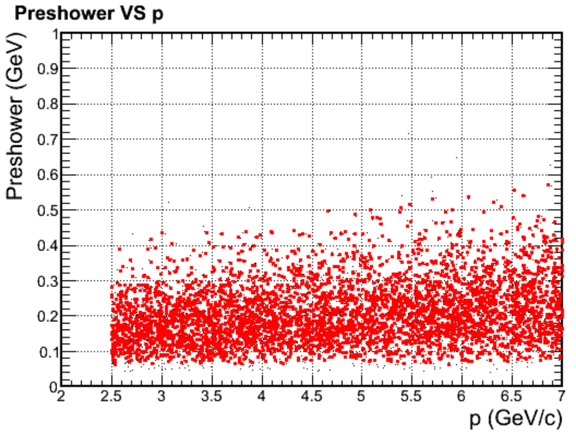
Back up 1/2 for previous slides

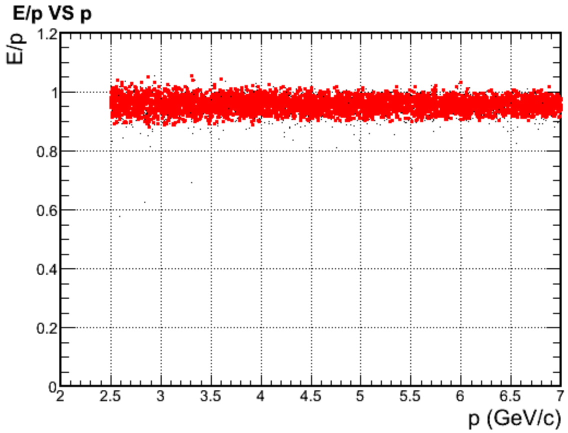
Electron eff. for SIDIS large angle calorimeter

- All events
- Accepted events w/ 3D cut





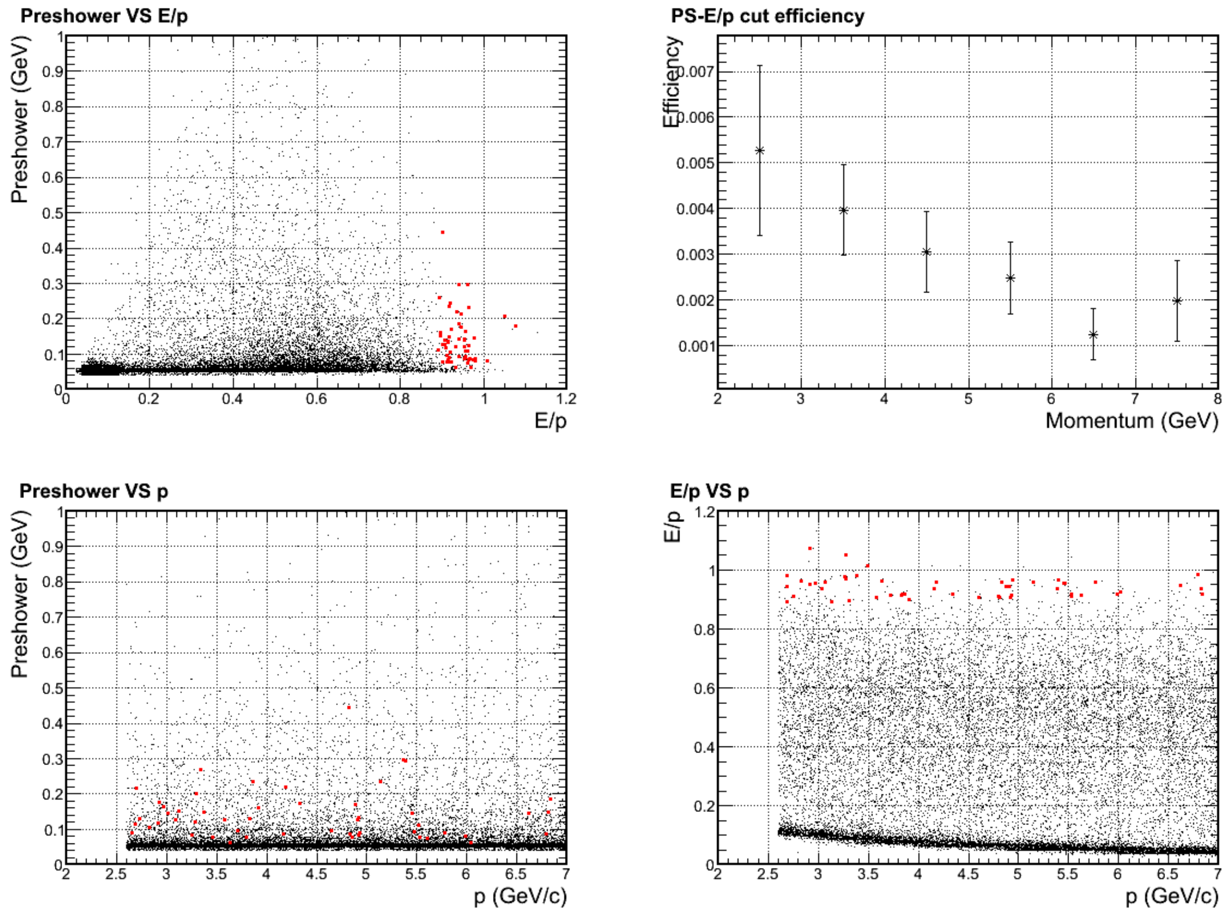




Back up 2/2 for previous slides

Pion eff. for SIDIS large angle calorimeter

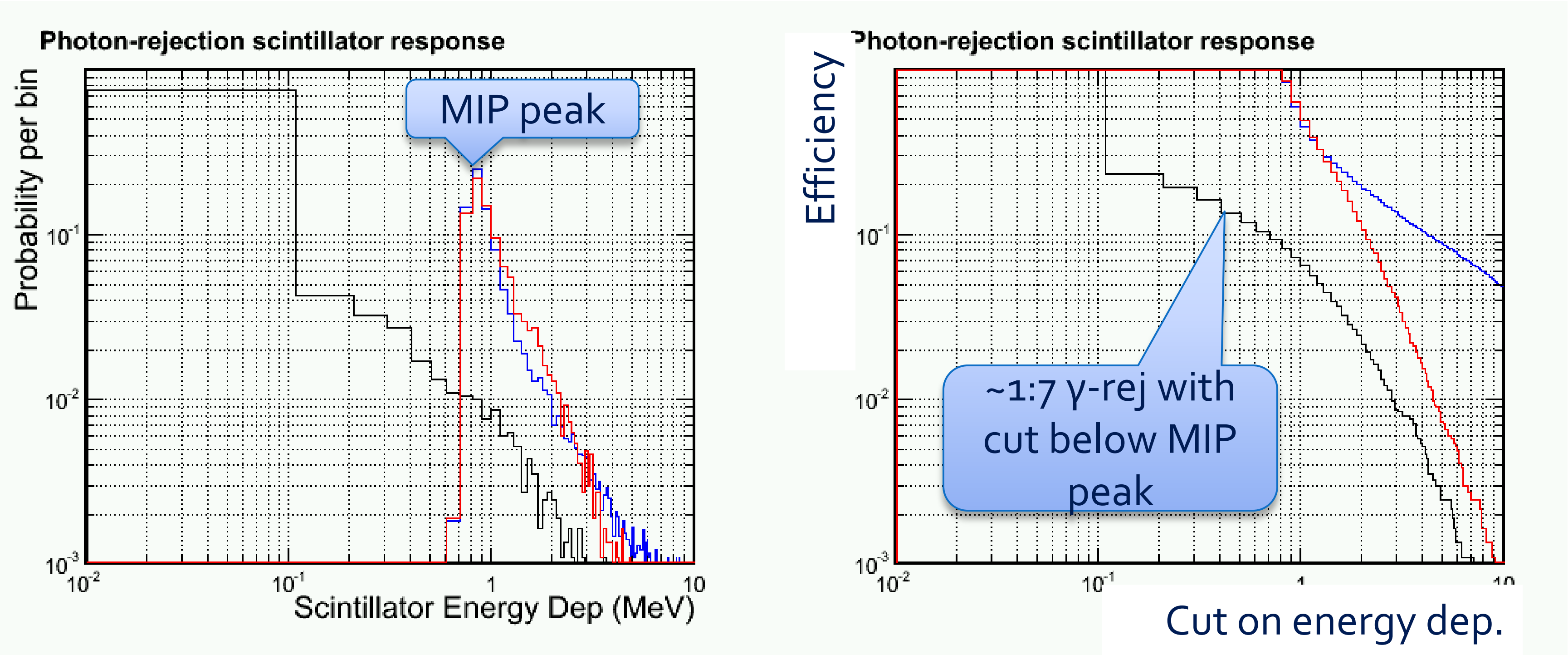
- All events
- Accepted events w/ 3D cut



Backup - Simulated efficiency & rejection

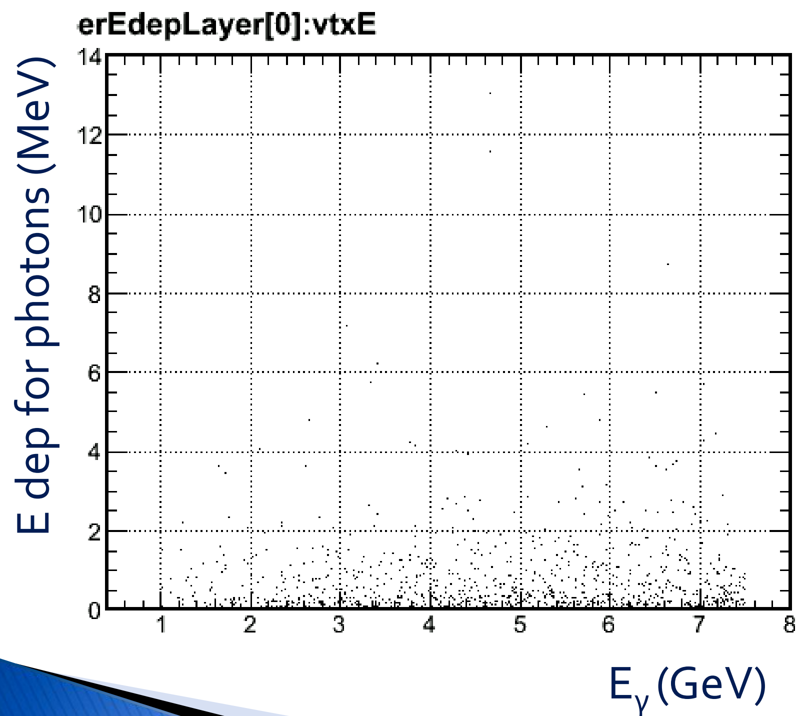
- Electron
- Pion
- Photon

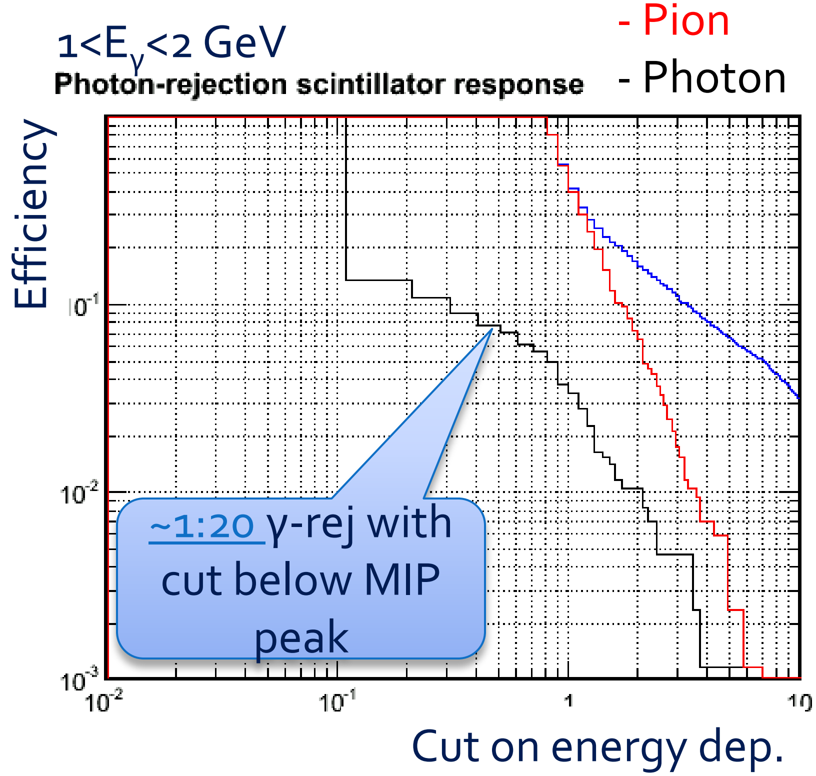
Energy range: 1-7 GeV, flat phase space for SIDIS-forward



Backup - Simulated efficiency & rejection

- Most photon focus on lower energy side (π_o decay)
- And lower energy photon produce less back scattering
- Therefore, do the study again with $1<E_\gamma<2$ GeV

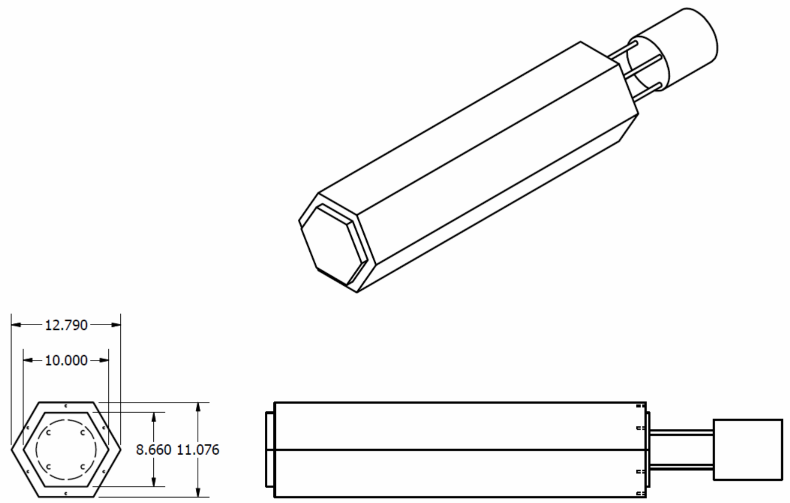




Design Updates
- Shape

Change from square to hexagon

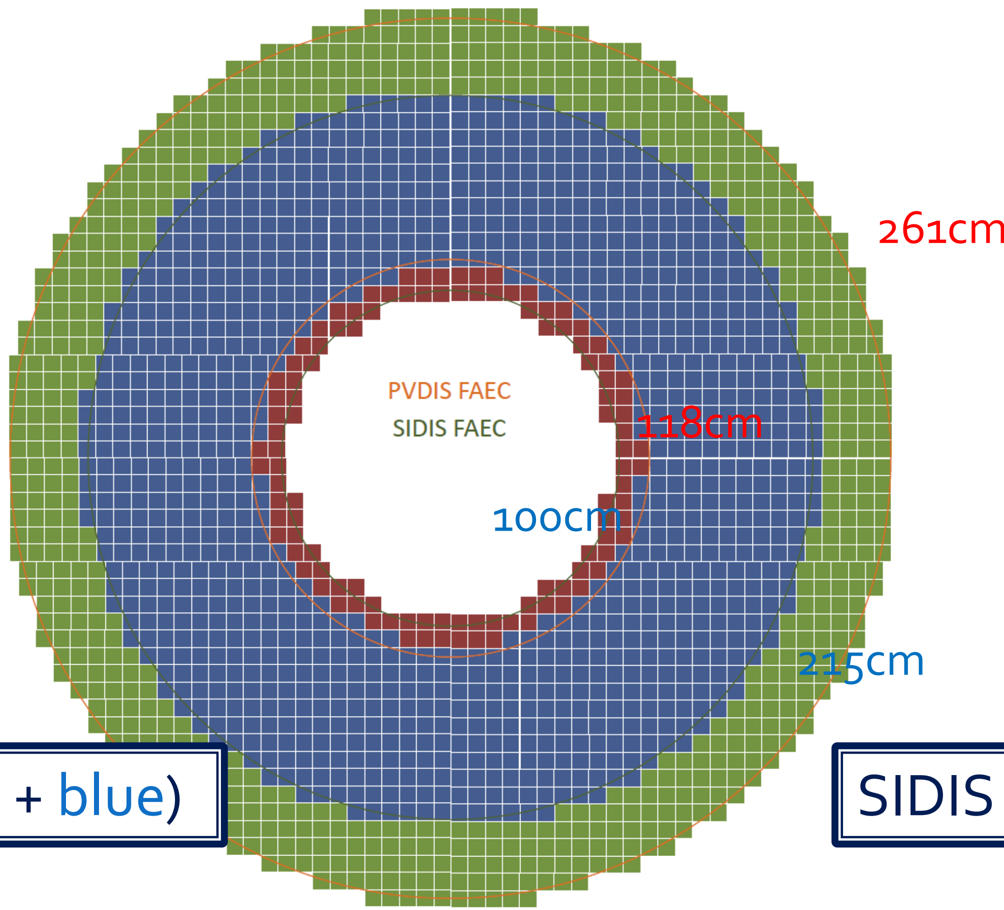
- Main reason from supporting structure and layout (see Paul Reimer's talk)
- Physics feature should be similar to square shape and we will go through test and prototyping



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



PVDIS FAEC (green + blue)

SIDIS LAEC (blue + red)

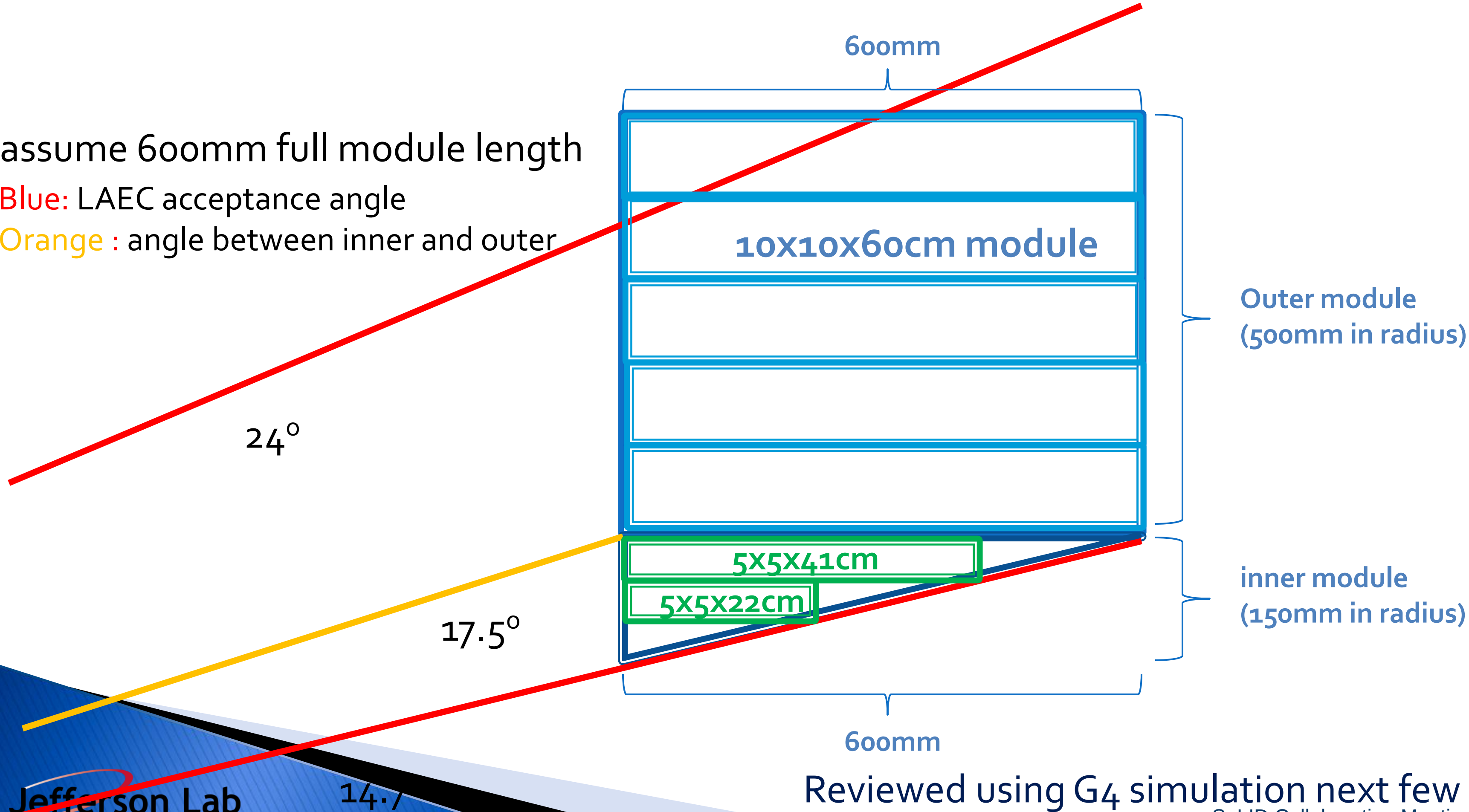
Ideas to minimize SIDIS LAEC Acceptance gap

- 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

assume 600mm full module length

Blue: LAEC acceptance angle

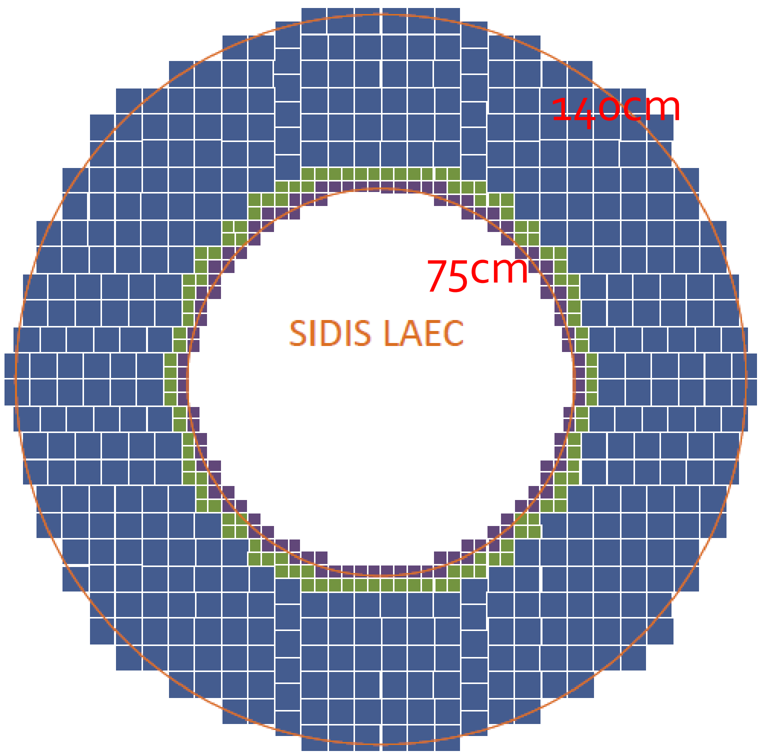
Orange : angle between inner and outer



Reviewed using G4 simulation next few pages

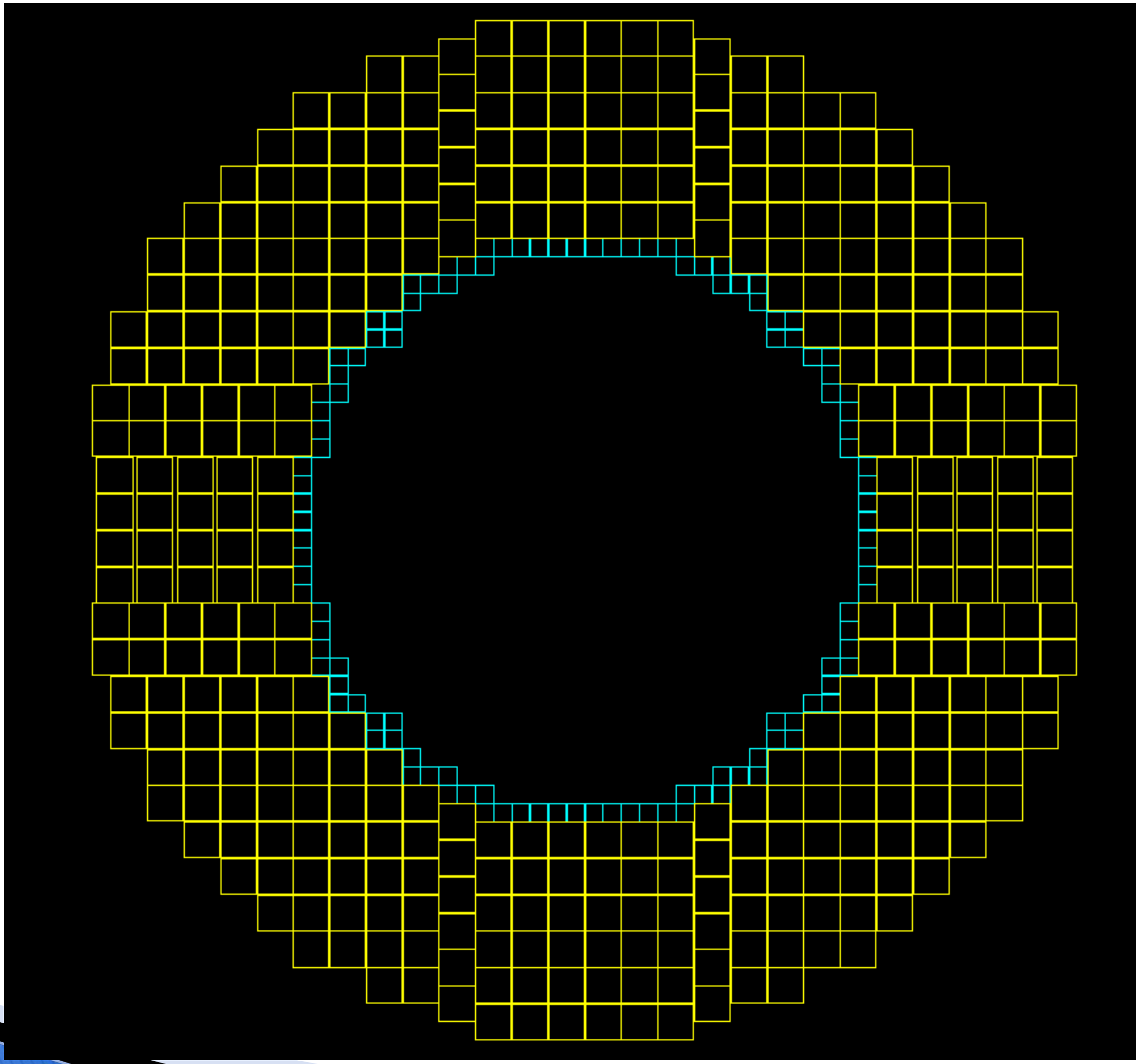
SIDIS LAEC (beam view)

- 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



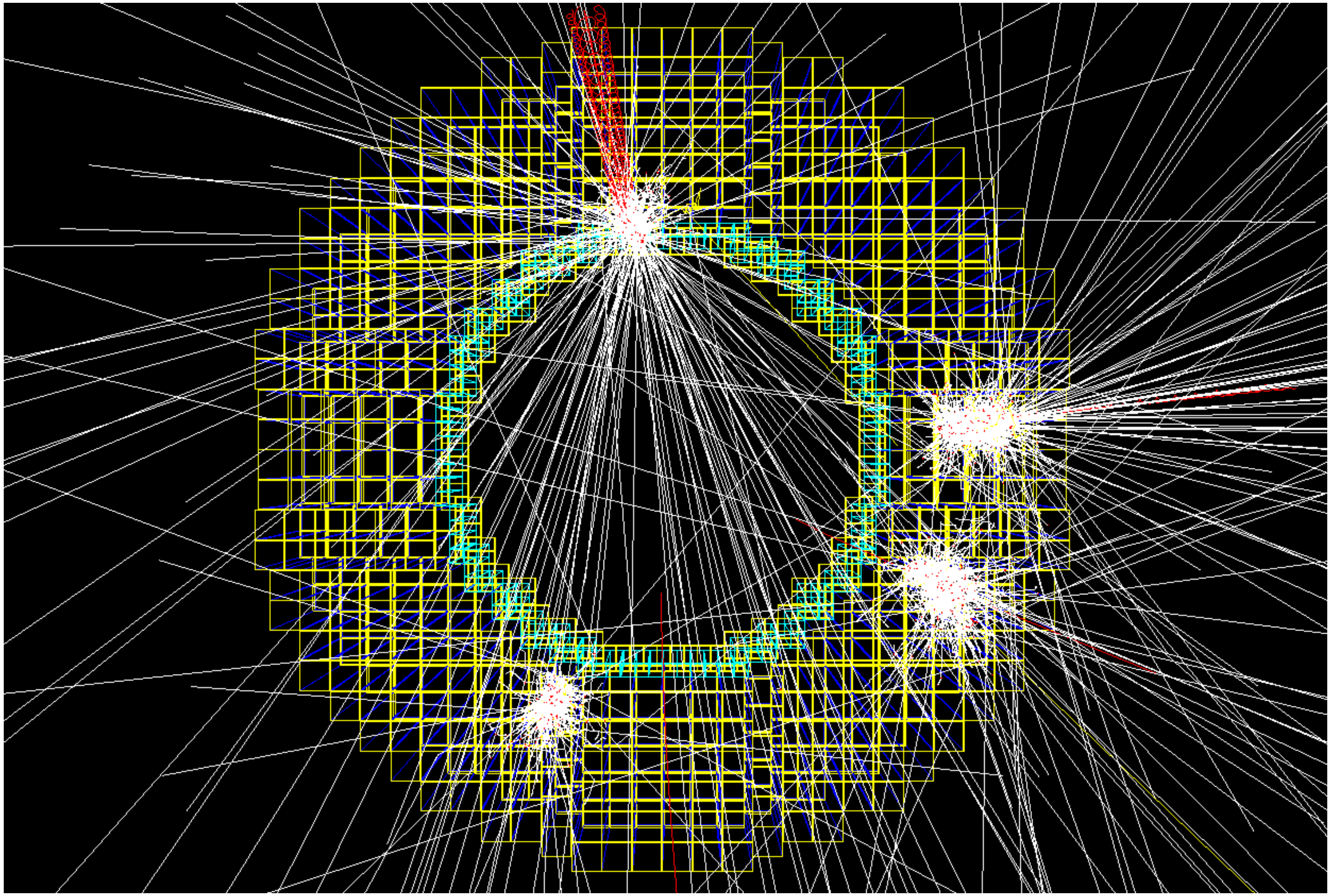
Design Updates
- Edge effects for LAEC

LAEC layout in G4 Simulation



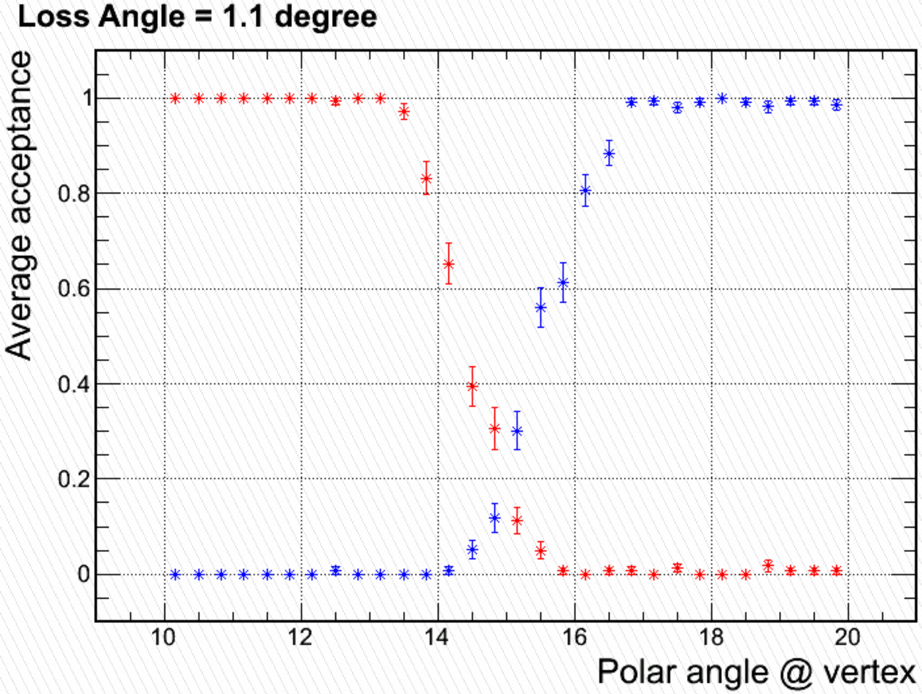
LAEC in full standalone G4 Simulation

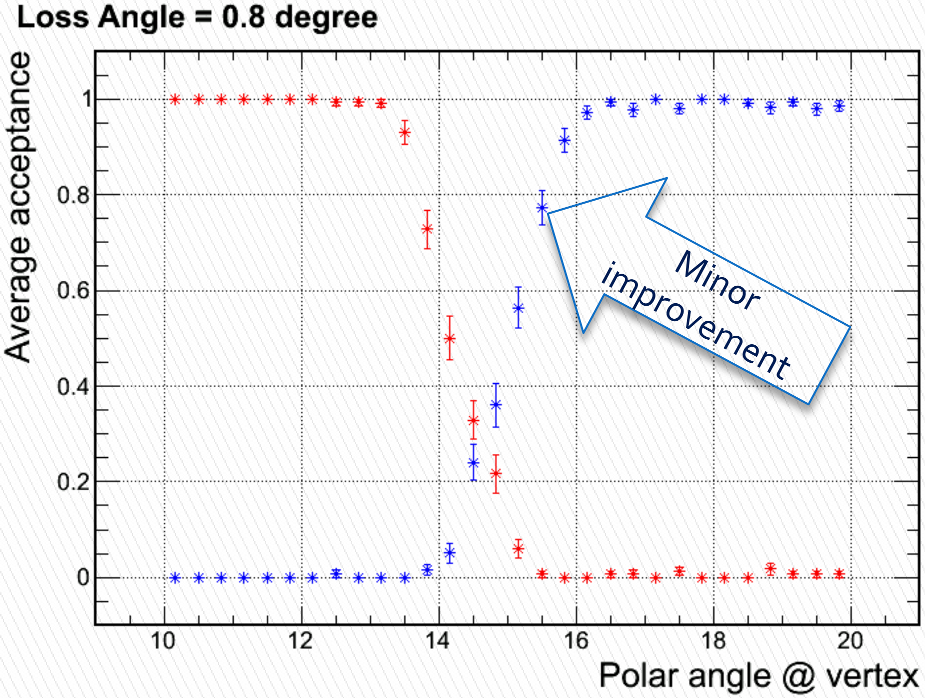
Track transportation provided by GEMC, CLEO field



How much does inner modules help?

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



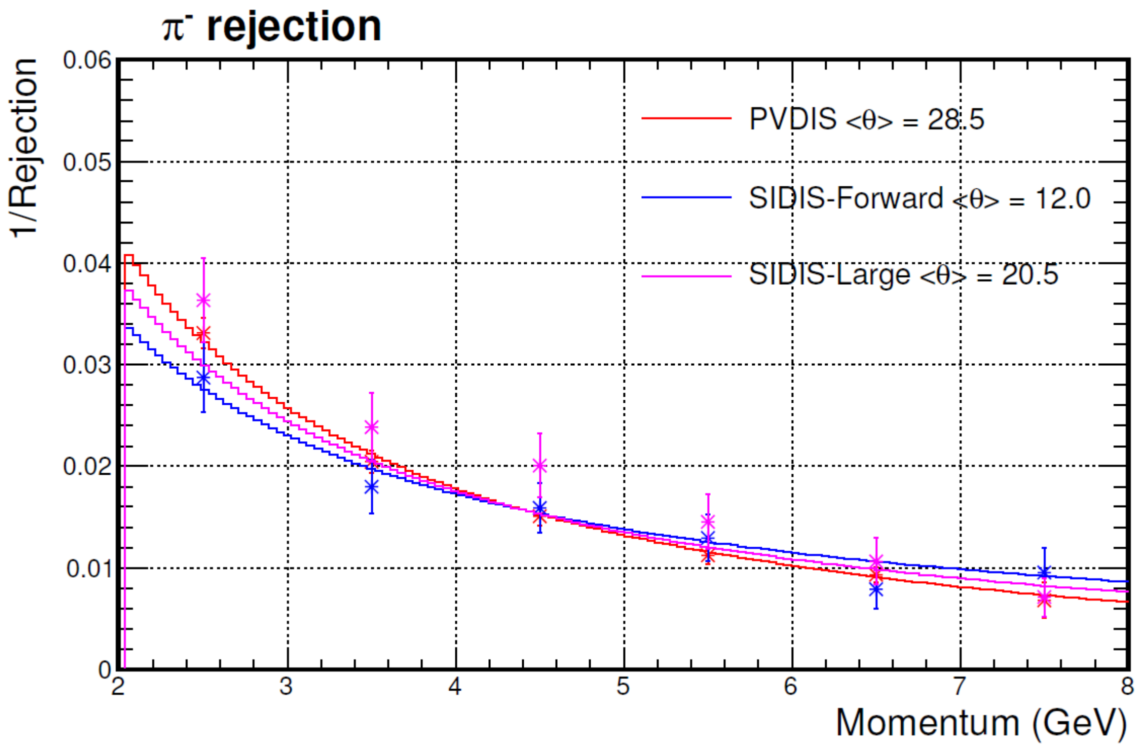


Stand conf. 404 10x10 cm² modules

+ 116 5x5 cm² inner modules

Design Updates
- Shower cluster size cut

Previously showed pion rejection

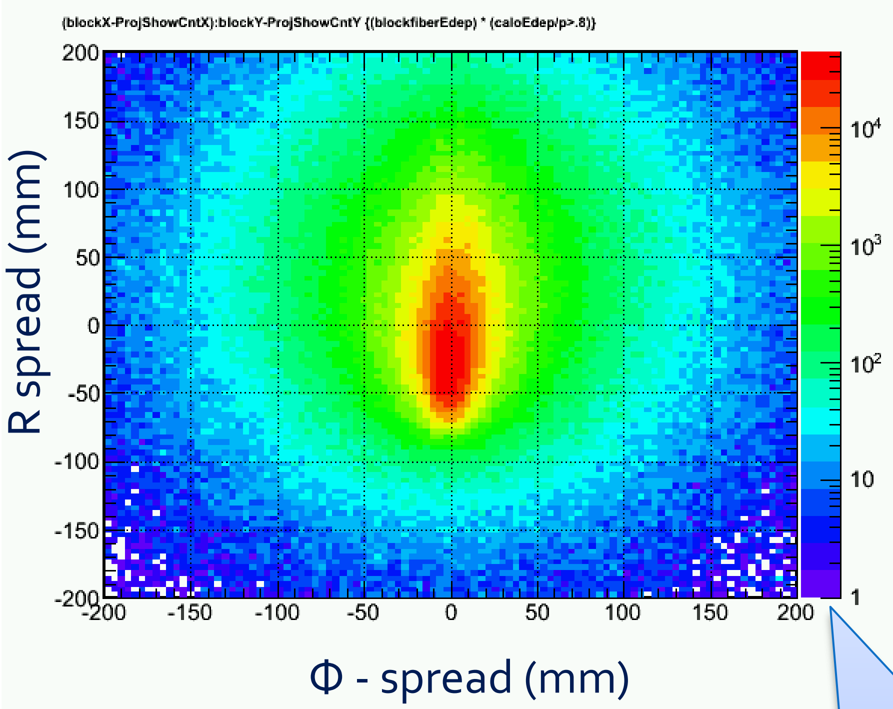


94% electron eff.

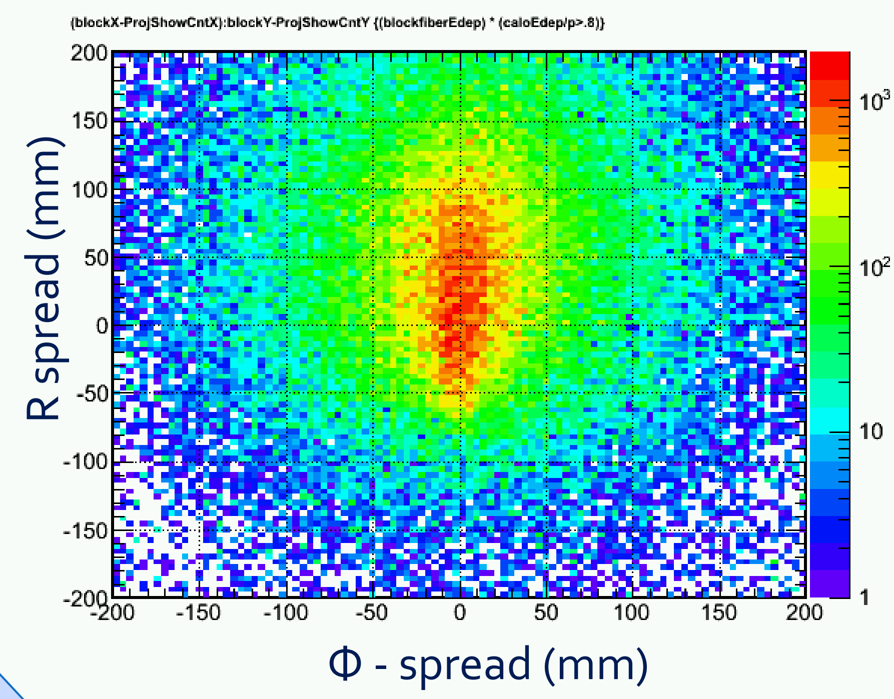
- PID selection used 3-D cut on PS, e/p and momentum
- PS and e information come from sum signal in all non-zero modules
- Enemy here is very specific: almost fully absorbed hadronic shower with high energy deposition

Shower area difference

Electron shower



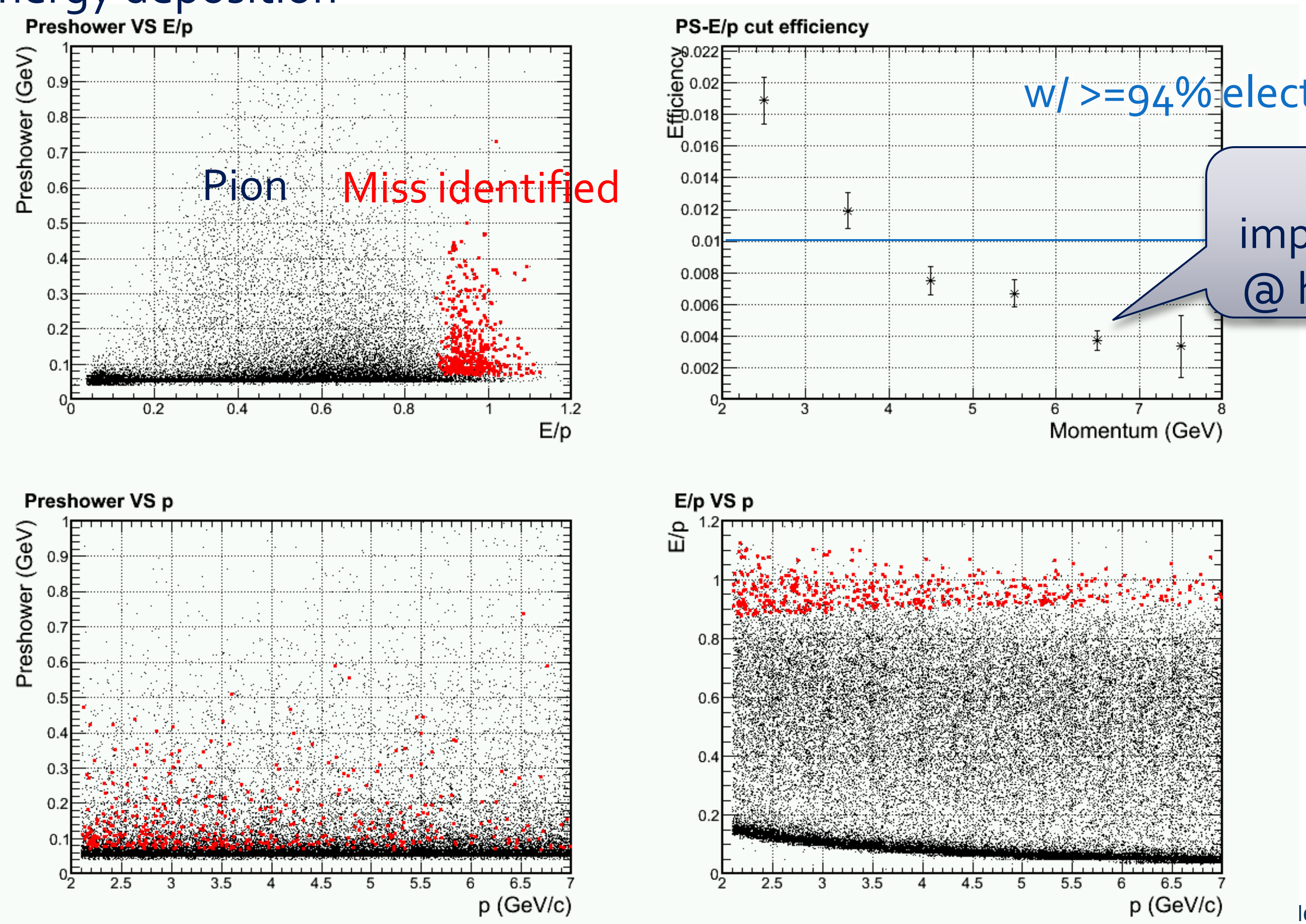
Hadronic shower (e/p>80%)



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

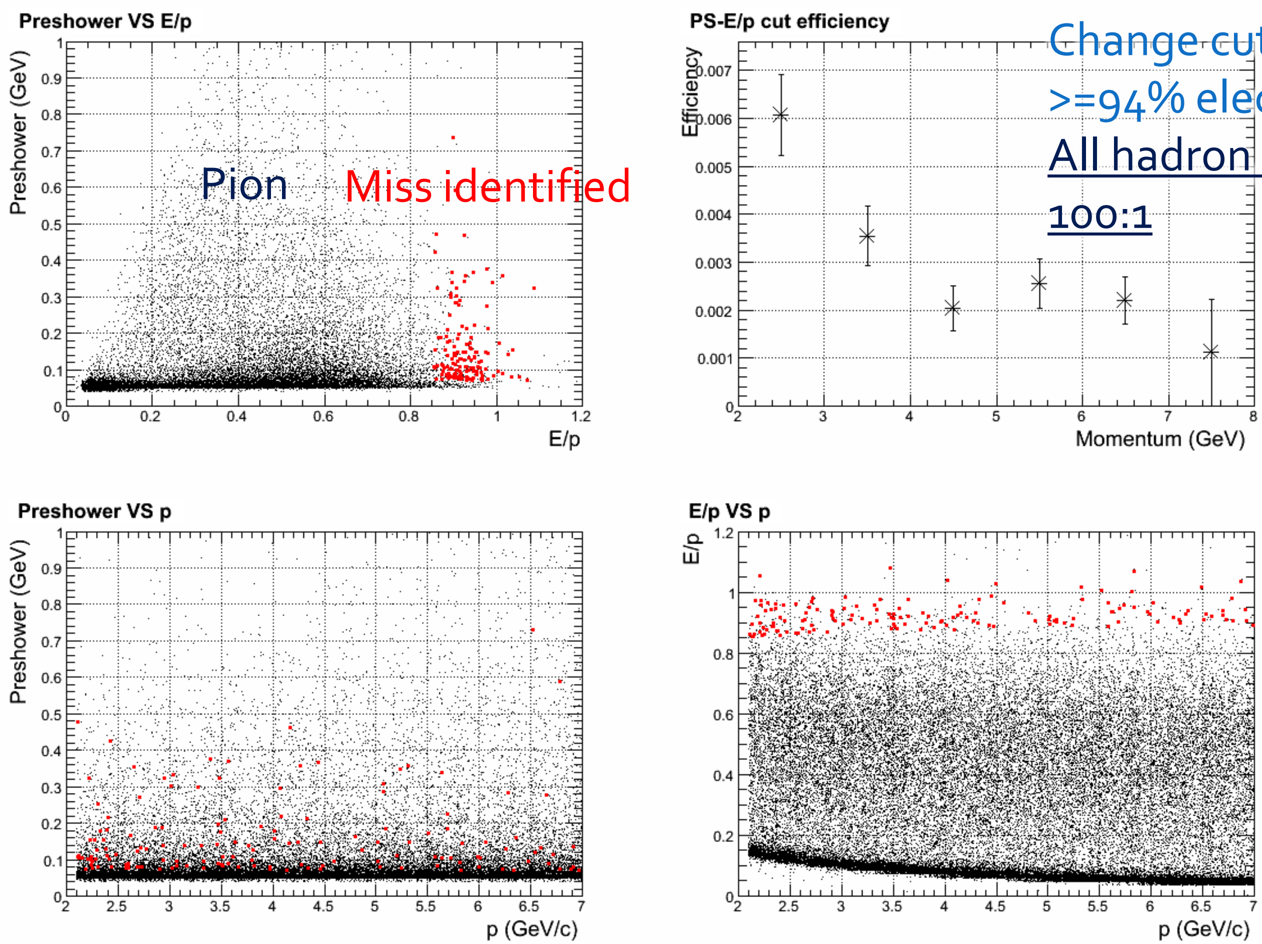
Can it be further improved?

- 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 maintain >=94% electron eff.

<u>All hadron rej. better than 100:1</u>

Flat phase space in PVDIS acceptance



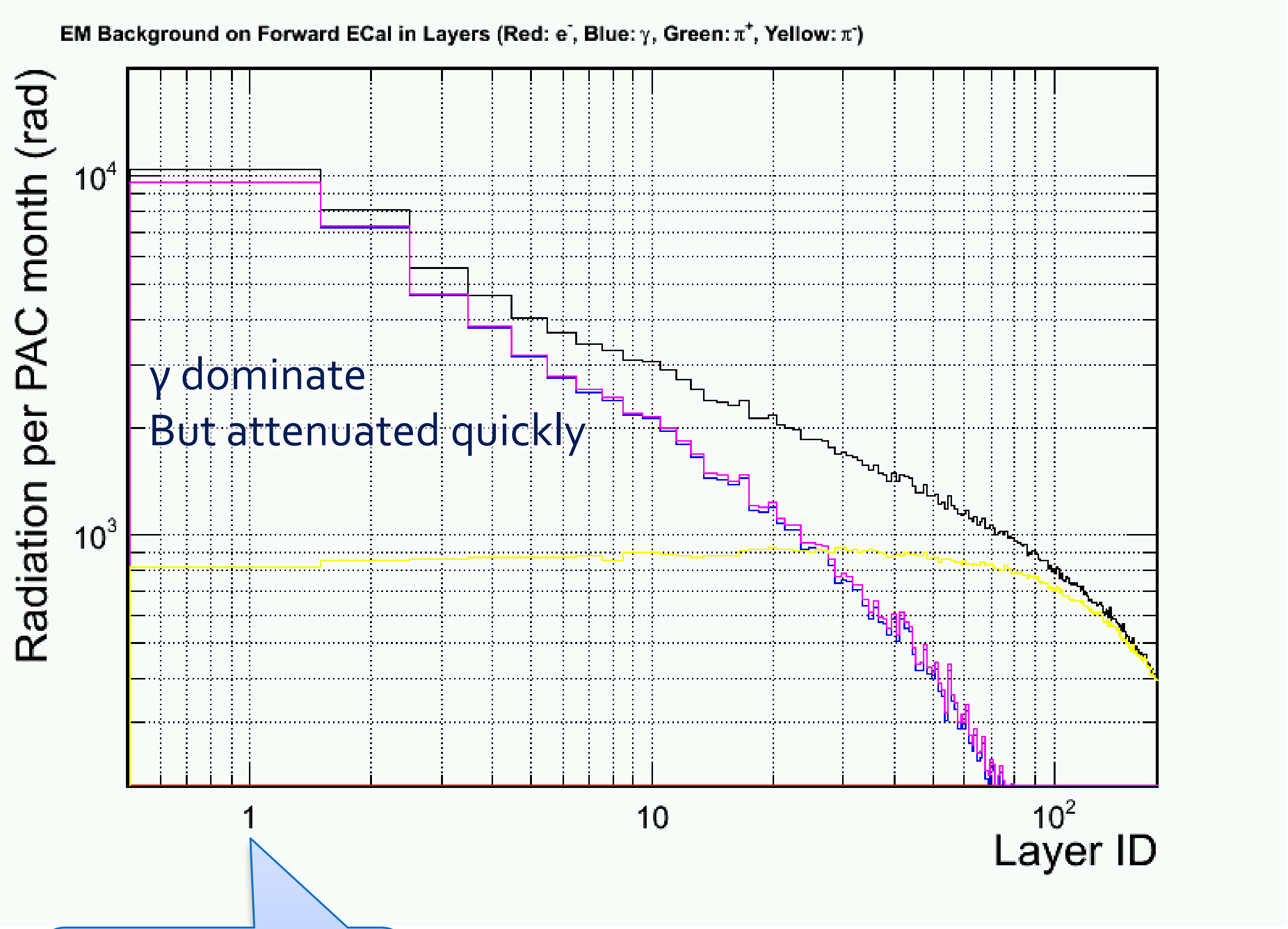
Jefferson Lab

Design Updates
- Radiation dose

What's new

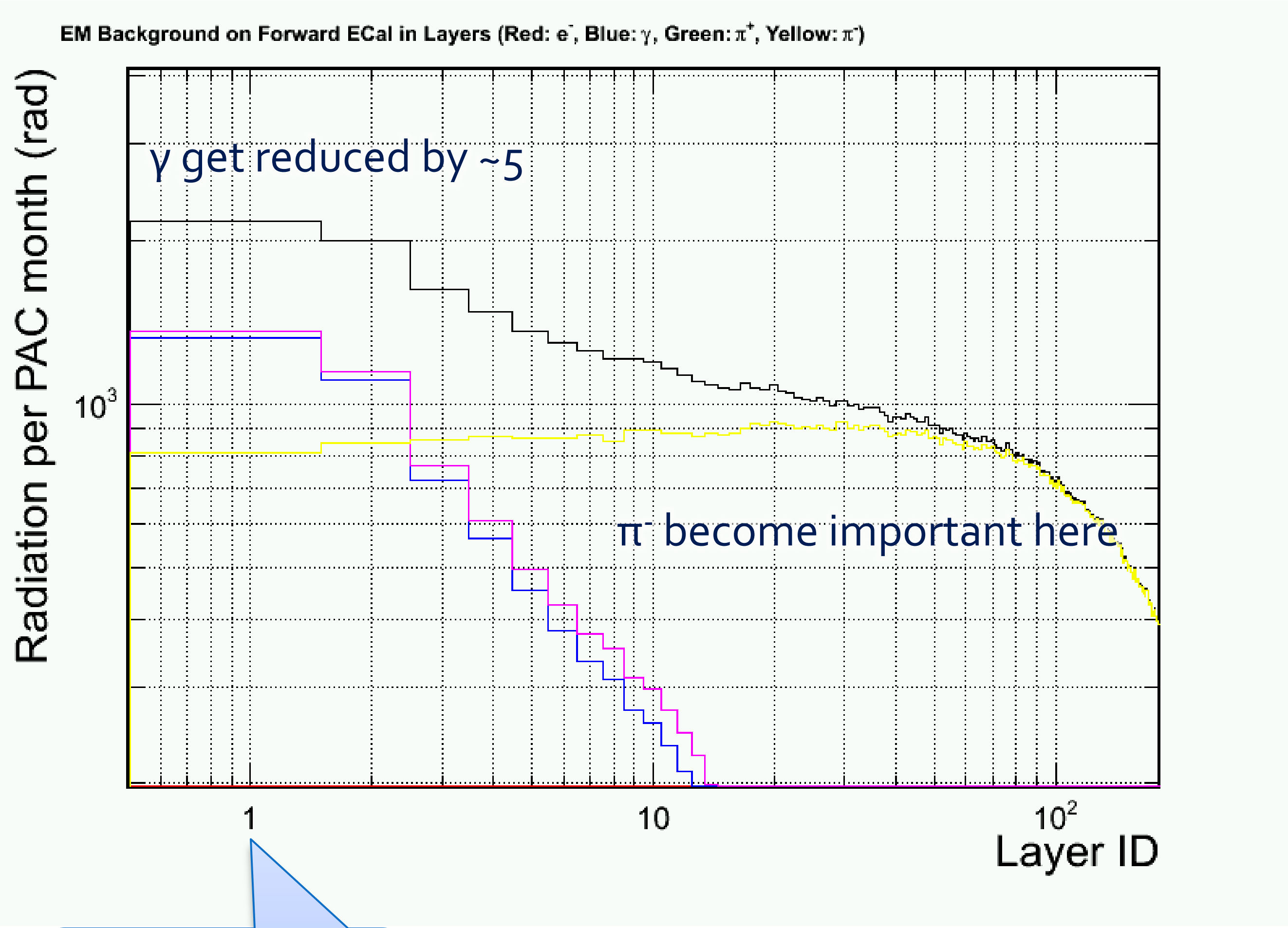
- LHCb/HERMES preshower, instead full Shashlyk preshower
  - As shown before, the preshower scintillator receive most of the radiation, due to the low energy backgrounds
  - This part radiation dose are now absorbed in 2Xo absorber, and we just see its EM tail now
  - Especially, lead absorber effectively 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)



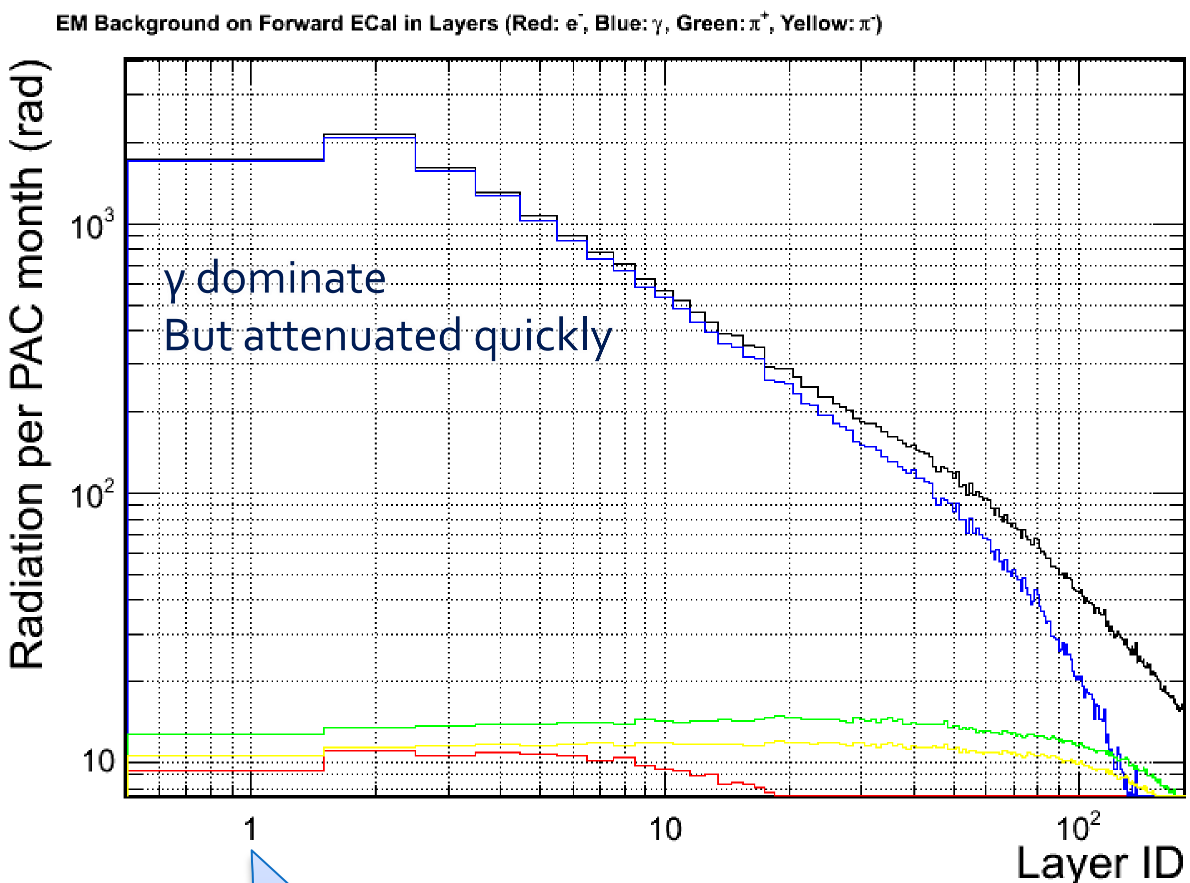
Layer #1 is 2cm preshower scint.

PVDIS – preview for a baffle w/o direct γ



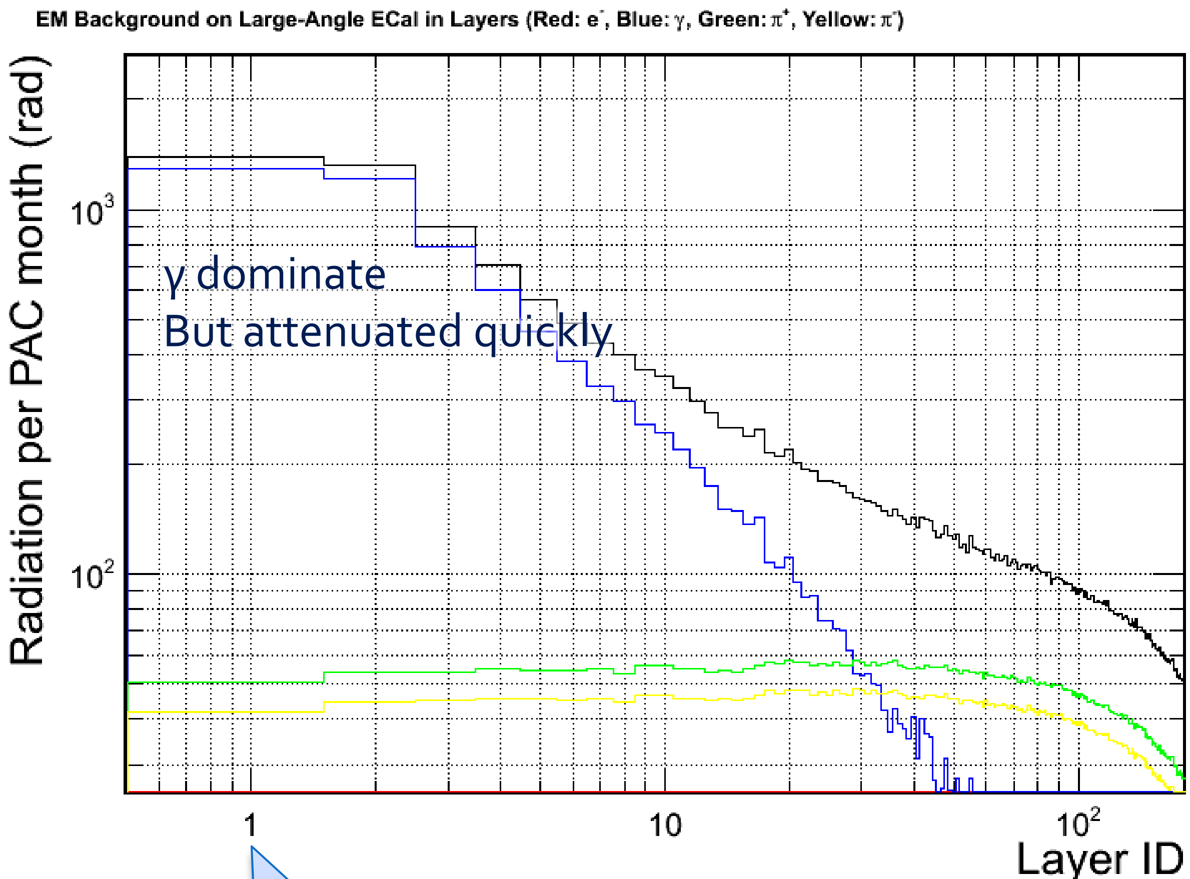
Layer #1 is 2cm preshower scint.

SIDIS – Forward



Layer #1 is 2cm preshower scint.

SIDIS – Large-Angle

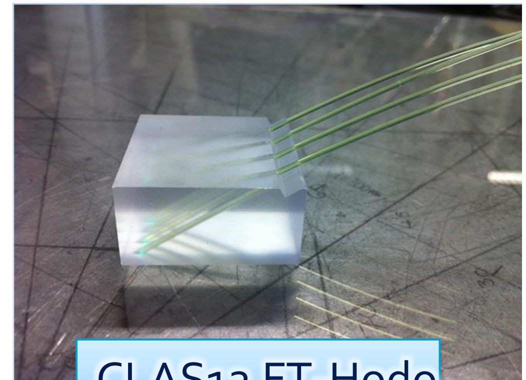


Layer #1 is 2cm preshower scint.

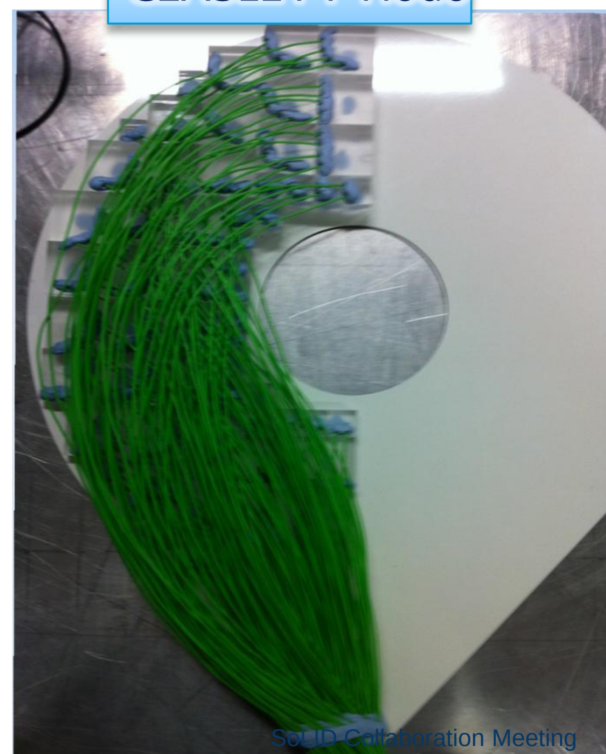
Light Readout

WLS fiber in scintillator pad

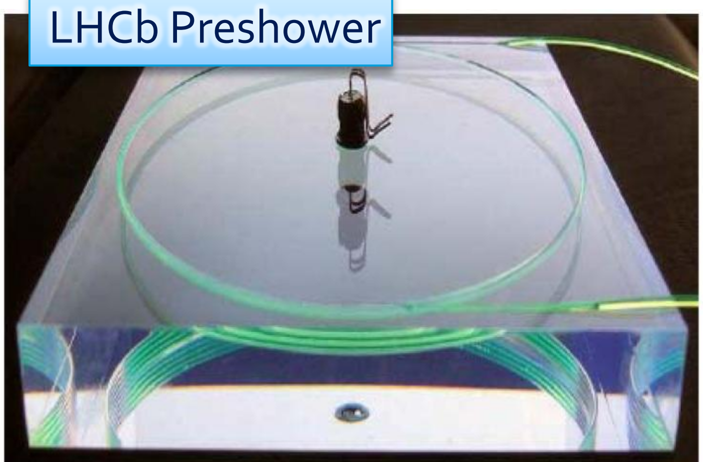
- Drill on scintillator and glue WLS in
- Used by LHCb etc.
- Will use by CLAS12 FT-Hodo



CLAS12 FT-Hodo

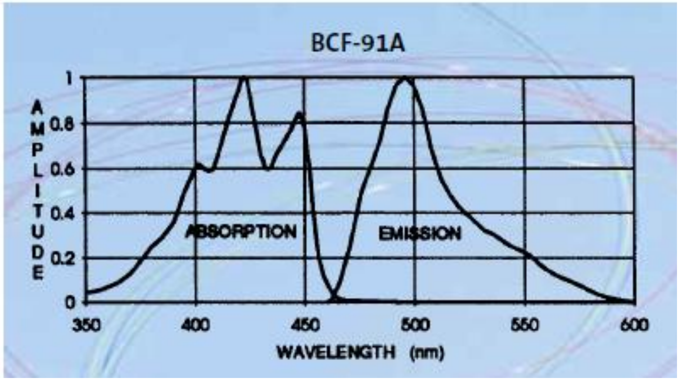


LHCb Preshower

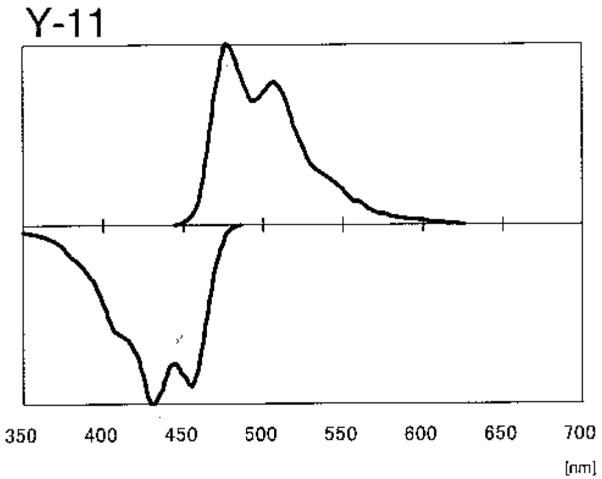


Fiber

- 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



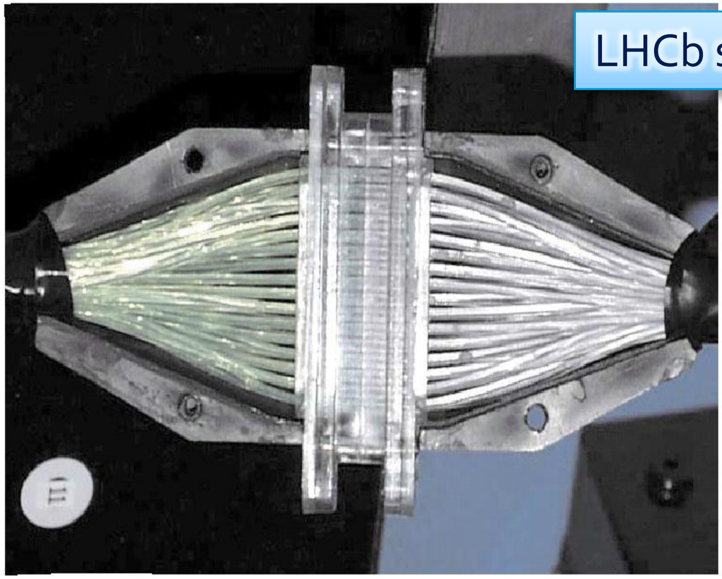
- Clear fiber for both, 101-102/module
  - Bicron BCF-98
    - $1/m

Jefferson Lab

Fiber connection

- Shower will use 1-1 bundle fiber connector.
  Used in previous experiments (LHCb, Minos)
  custom made fiber connector $175/module, quote by LEONI
- Preshower will use comercial 1-1 single fiber connector, a few $ each.

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 version

	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)

Budget Update

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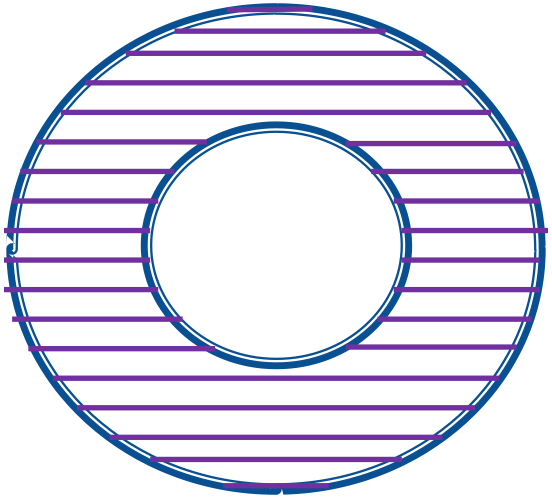
What we need

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.