Update on Calorimeters

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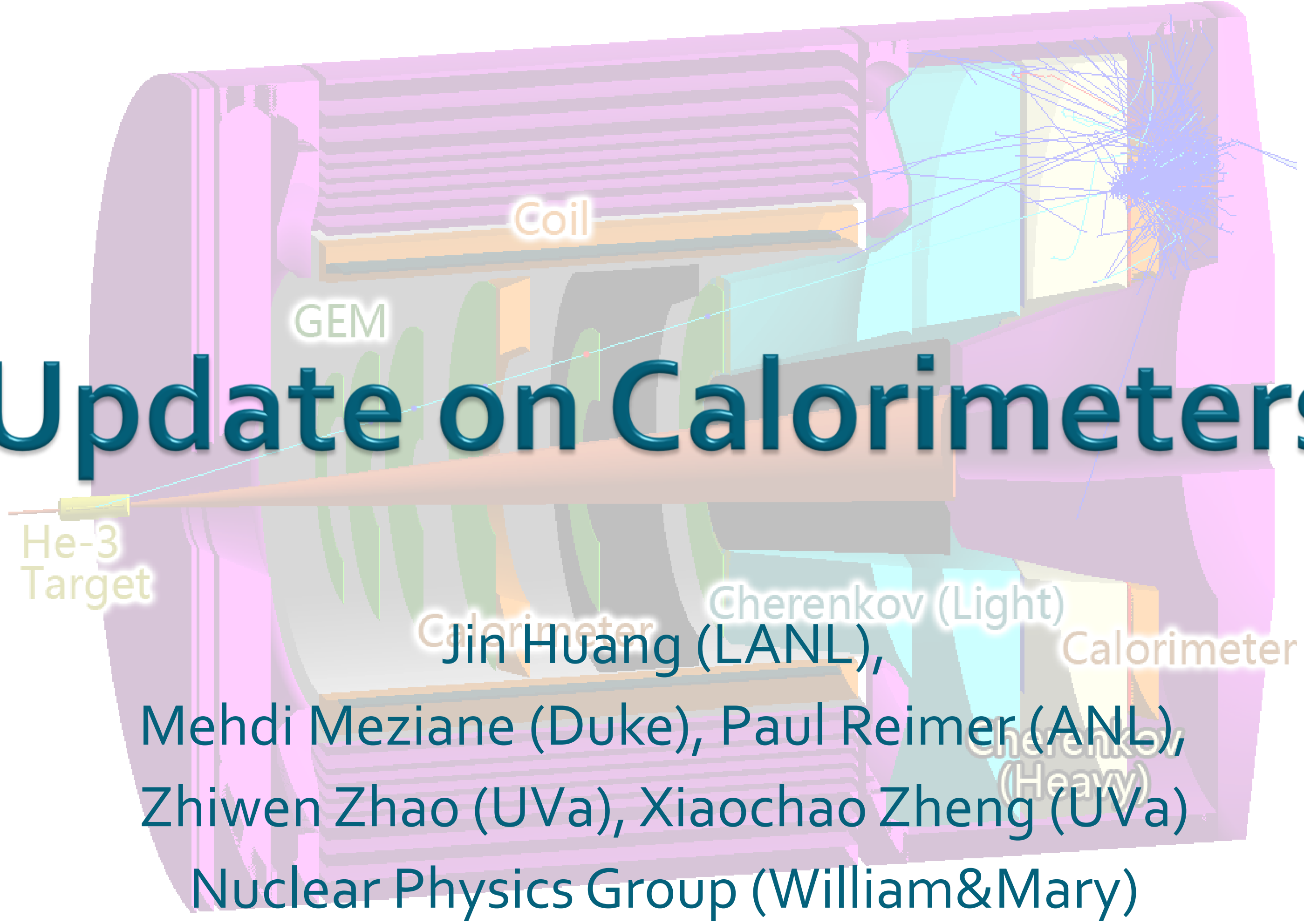

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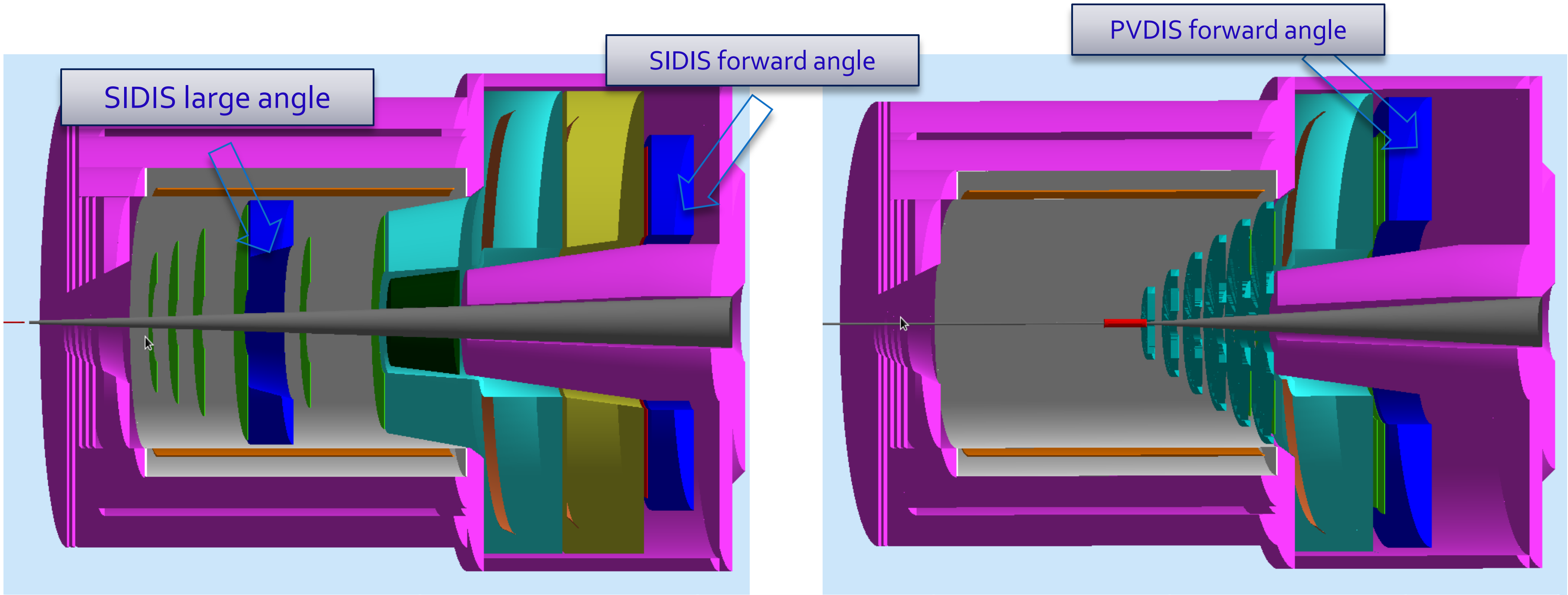
SoLID Calorimeter Overview



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

Summary of design

Based on COMPASS Shashlyk module design.

- 0.5 mm Pb/1.5 mm scintillator, 240 layers
- 48cm long (20 X_0), 4X_0 preshower, 16X_0 shower.
  - Balance between longitudinal size and pion rejection
  - 20:1 - 100:1 pion rejection with 95% electron efficiency (depending on momentum)
- 10x10 cm^2 square shape modules ← balance between cost and position resolution/background
- 100 WLS fibers per module (1 cm^{-2})
- Total 1600(SIDIS) ~ 1700(PVDIS) modules
- Fiber connection still being studied

Main comments received since last review

- Design
  - Ed: reduce the electron efficiency to improve hadron rejection
  - Ed: explore scintillator pad at the end of calorimeter for hadron-rejection
  - Paul S. & Zhiwen : passive-radiator preshower (HERMES-LHCb type)
- Readout
  - Ed: explore preshower readout options
    - Wave length shifting pad readout
    - Additional fiber group for readout
  - Ed: evaluate the feasibility of using APD or other field insensitive photon-detector instead of fiber-connector option
- Background – comparing background simulation between GEANT4 & FLUKA
- Budget - improved budget required

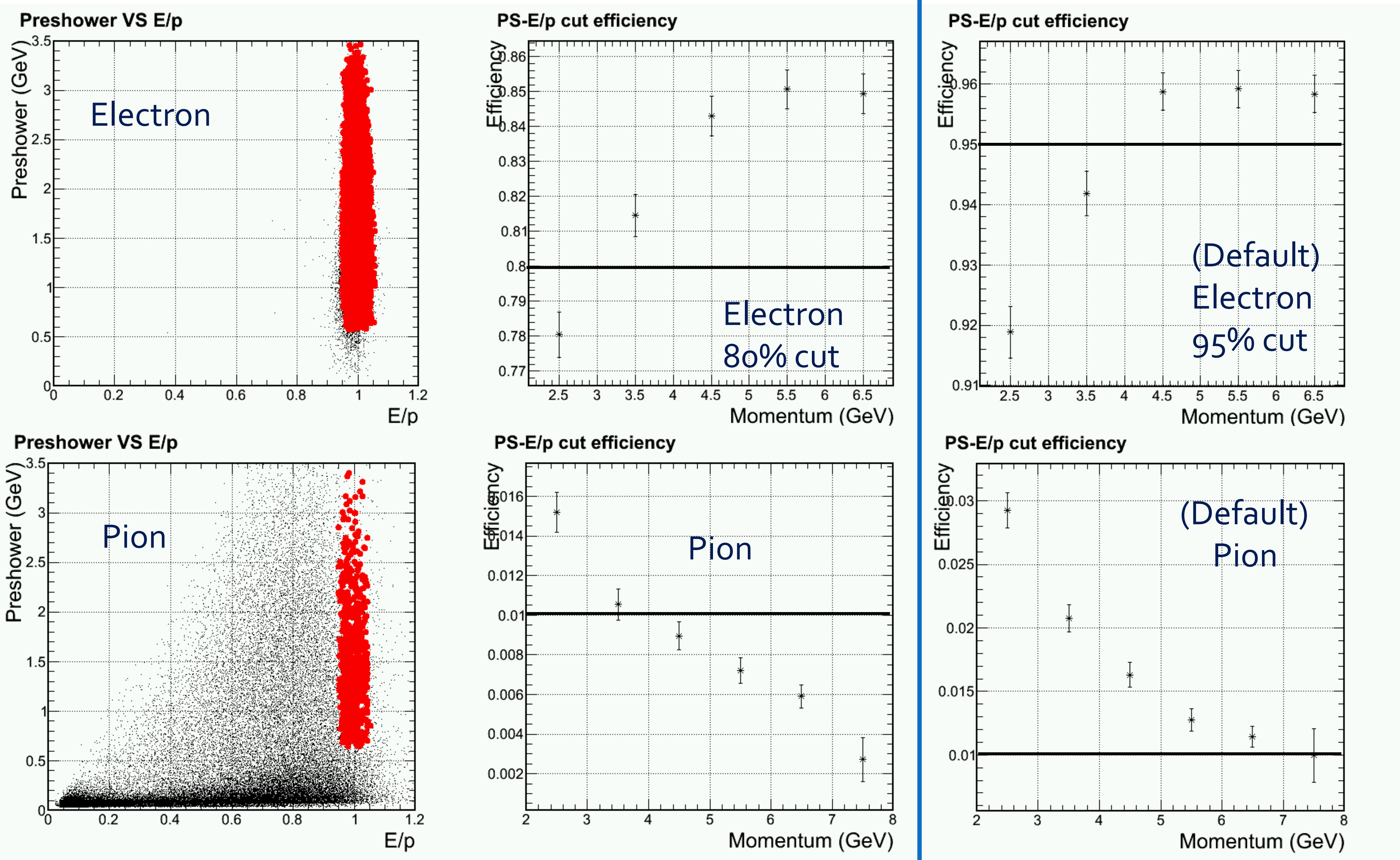
Design Updates

- Ed: Reduce the electron efficiency to improve hadron rejection

The idea

- Sacrifice efficiency to trade for pion rejection
  - The idea came from Ed
  - He concerns that we quote too high efficiency which might degrade due to practical reasons (noise, background, …) and push us to the corner to achieve high pion rejection too
  - He suggests that we lower efficiency to ~80%, which may be more realistic and make rejection easier
- We probably want to do so for low-P region
  - Low-P region has larger cross section which can sacrifice some efficiency
  - Low-P region has larger pion/e ratio
  - Low-P region has smaller pion rejection

It is an effective way to enhance rejection



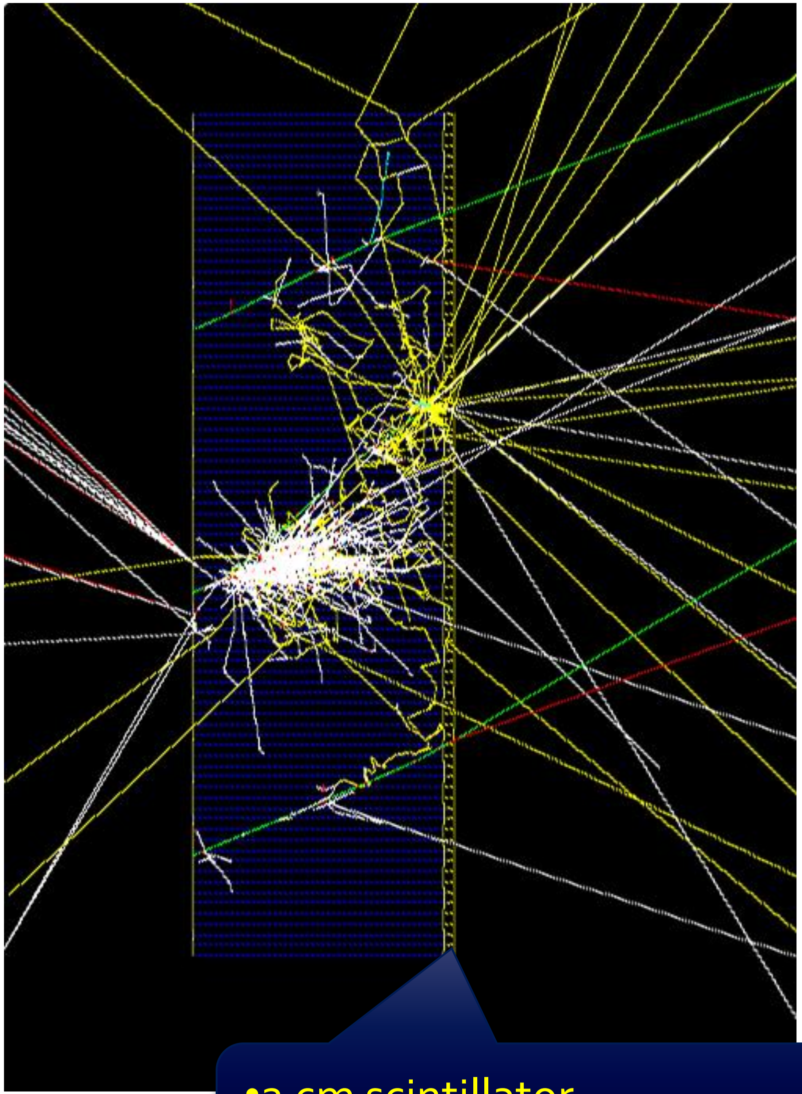
Jin Huang, et. al.

Design Updates

- Ed: explore scintillator pad at the end of calorimeter for hadron-rejection

The idea

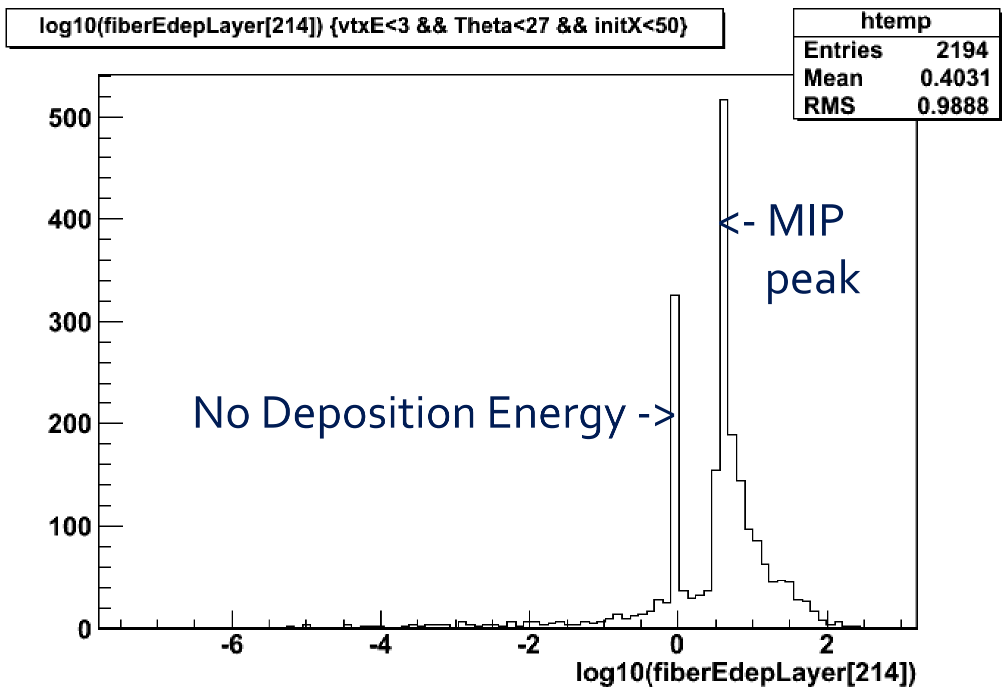
- 2 cm of scintillator at the end of 20 Xo Shashlyk detector
- Expect hadronic shower to leak to this scintillator , while EM shower is fully absorbed
- Indenting angle of 22^{o}-27^{o} simulated



- 2 cm scintillator
- Three 3GeV pion track shown

Turn out that low energy pion can not punch through too …

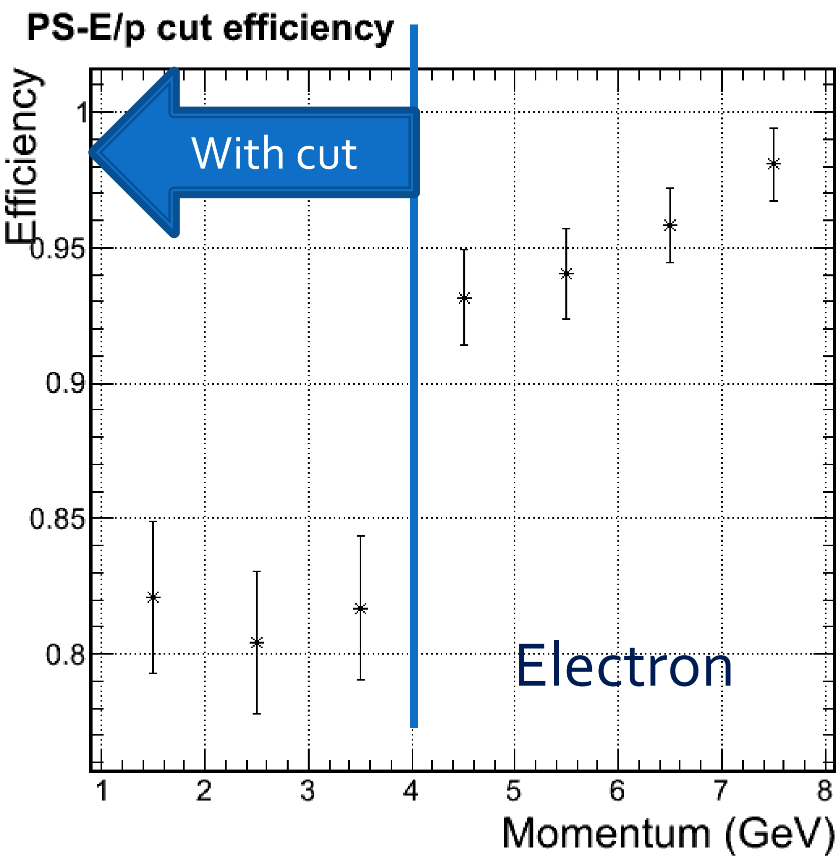
- 1/3 lower energy pions do not reach this layer
  - Absorbed or track significantly deflected

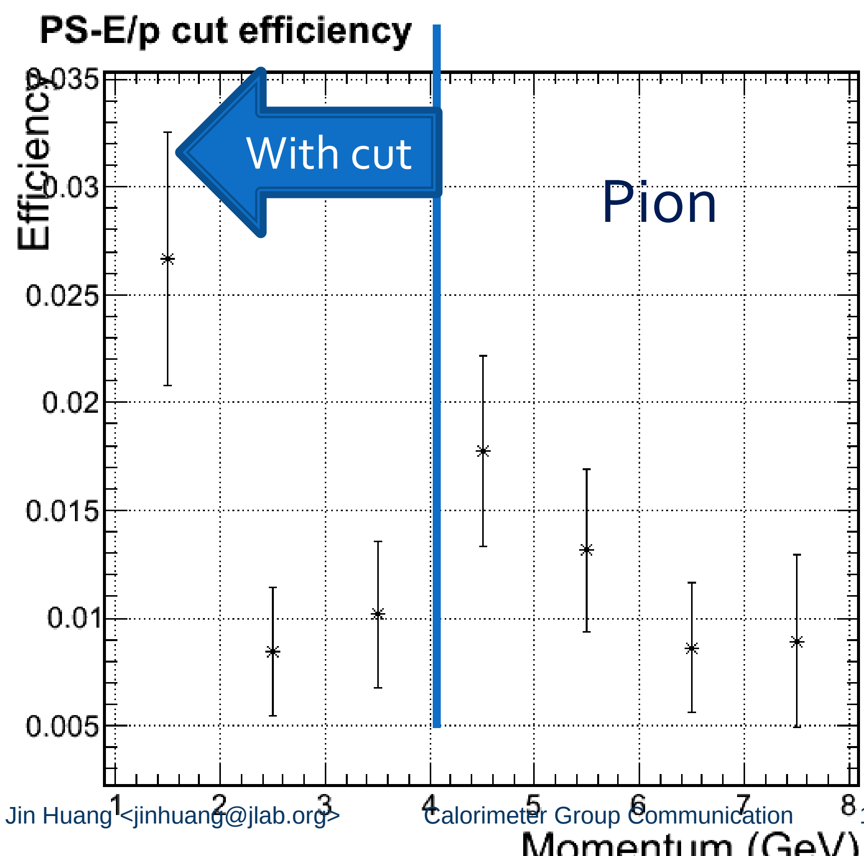


Log 10 of energy deposition

Try to use this pad to help pion rejection at lower energy (p < 4 GeV)

- Can help reject some low energy hadron but left with ~80% electron efficiency
- Similar improvement in pion rejection can be achived with lower the threshold, but this mothod go through trouble of hardware construction. Not suitable for SoLID.



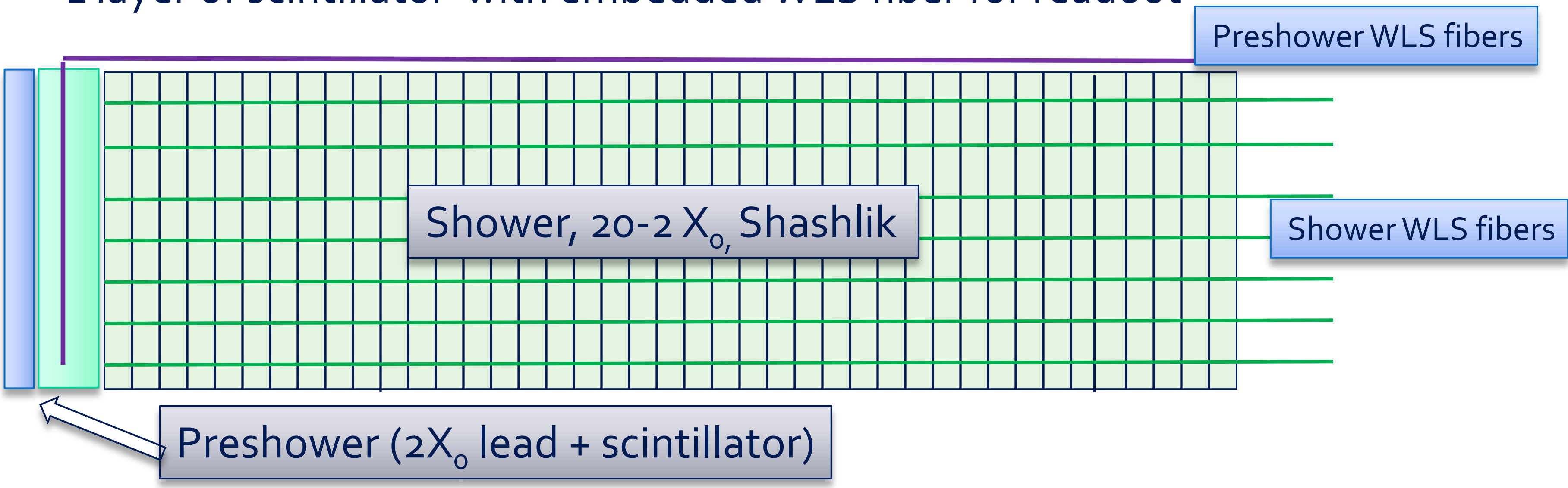


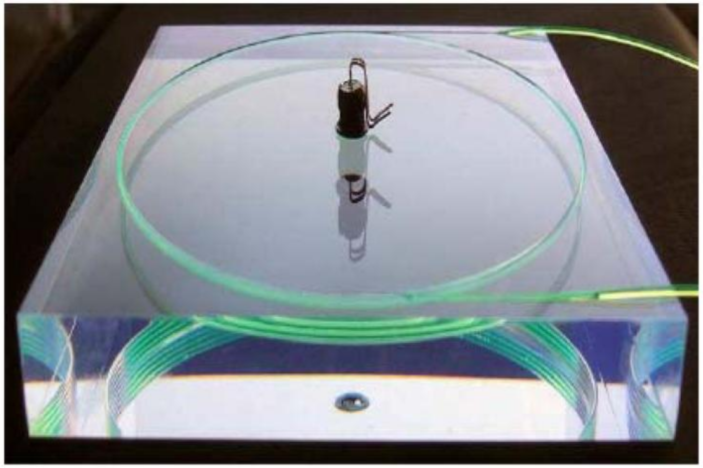
Design Updates

- Paul S. & Zhiwen : passive radiator preshower (HERMES-LHCb type)

Testing a new preshower configuration Passive-radiation and Scintillator-Pad

Preshower has 1 layer of $2X_0$ lead as passive radiator and
1 layer of scintillator with embedded WLS fiber for readout

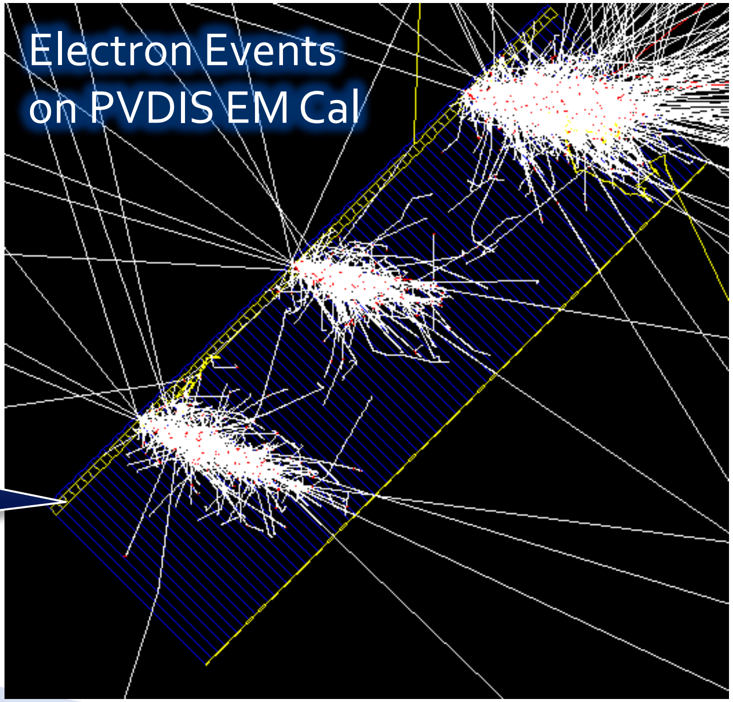




- Used by LHCb and Hermes
- Good hadron rejection
- Simple design with no change to Shashlyk module prodution
- Preshower work as radiation shielding
- Reduce number of fiber significantly for readout in preshower

Simulation studies

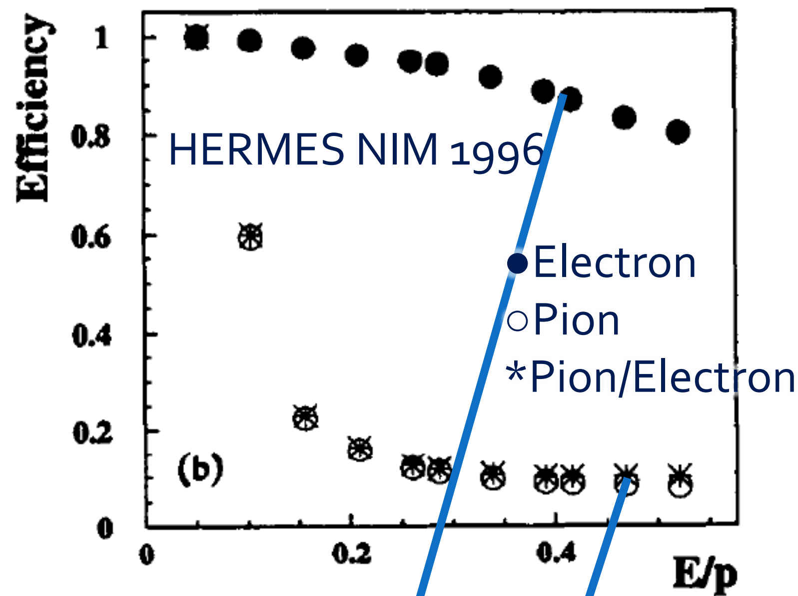
- A 2-radiation length thick Pb plate and 2 cm thick scintillator plate were added to the default Shashlik calorimeter (1.5 mm scint + 0.5 mm Pb per layer)
- Shashlik calorimeters have a single readout, serve as shower detector
- Shower length = (20 – 2) Xo with 1.5mm Scint – 0.5mm Pb sandwiches
  1/Sqrt(E) energy resolution : ΔE/E ~5%/√ (E)
  compared with pure shashlik conf. with 4%/√ (E)

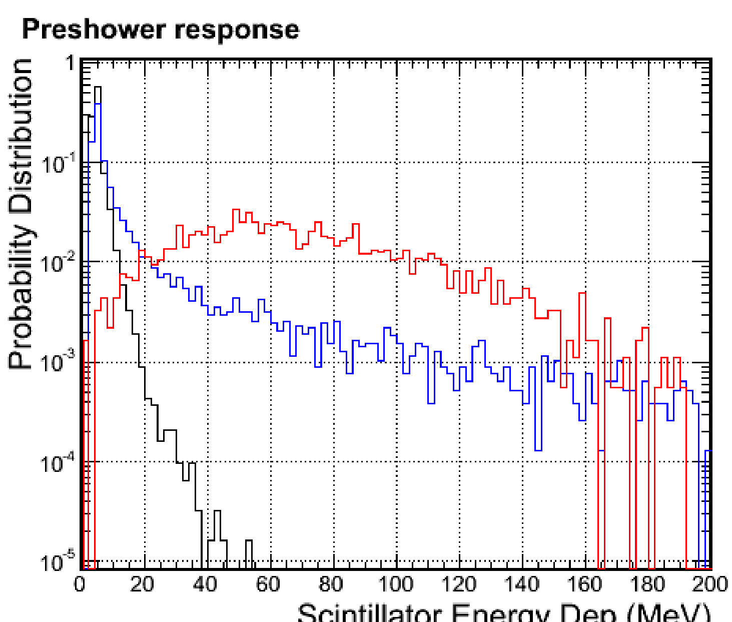


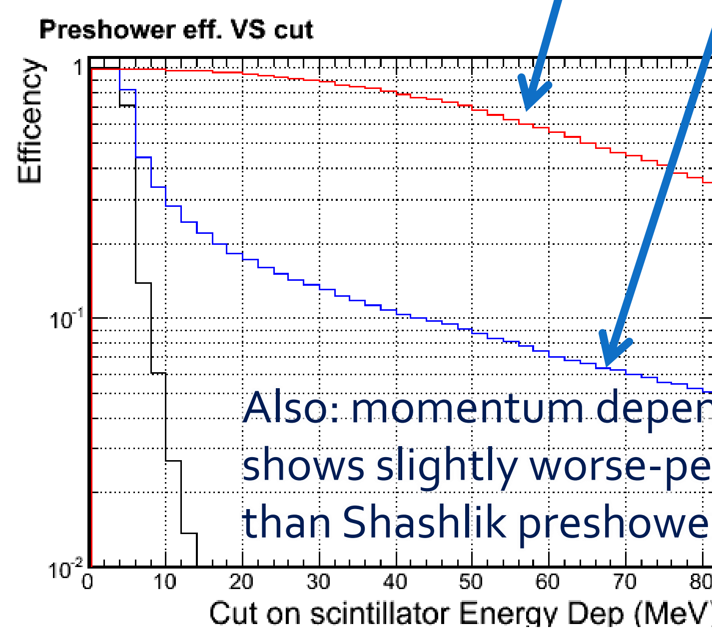
- 2 Xo Lead (HERMES - LHCb)
- 2 cm scintillator

Preshower response

- Preshower alone, cut eff.
  ~15% (pion) VS ~95% (electron)
- Similar performance for Shashlik preshower
- Legend : Electron; Pion; Muon



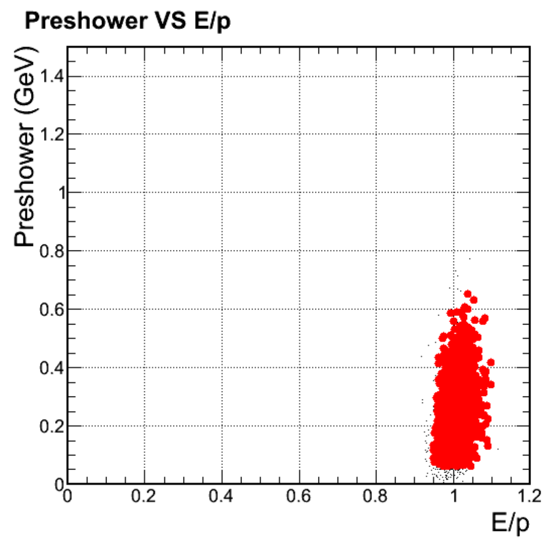


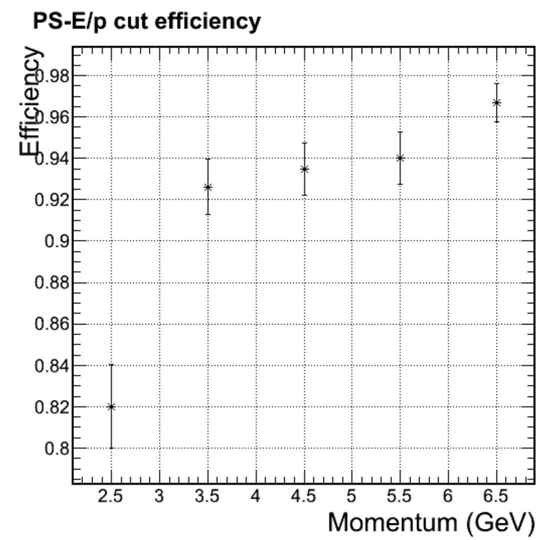


Also: momentum dependent cut shows slightly worse-performance than Shashlik preshower

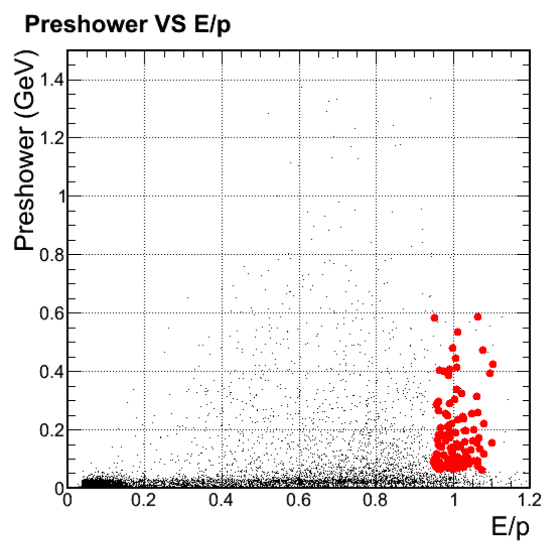
Preshower + shower rejection - not better but close-to full Shashlik design

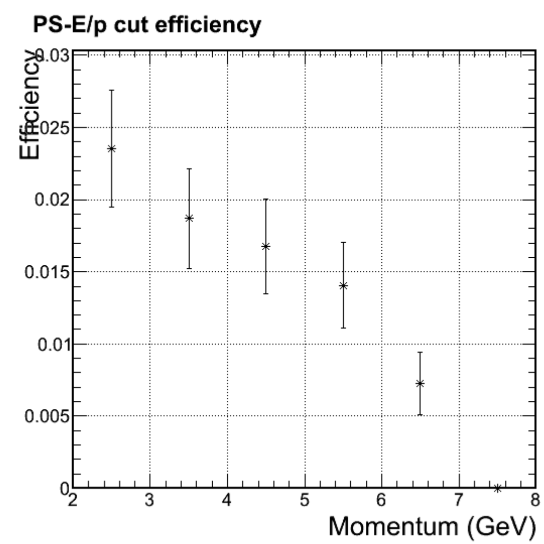
Electron





Pion

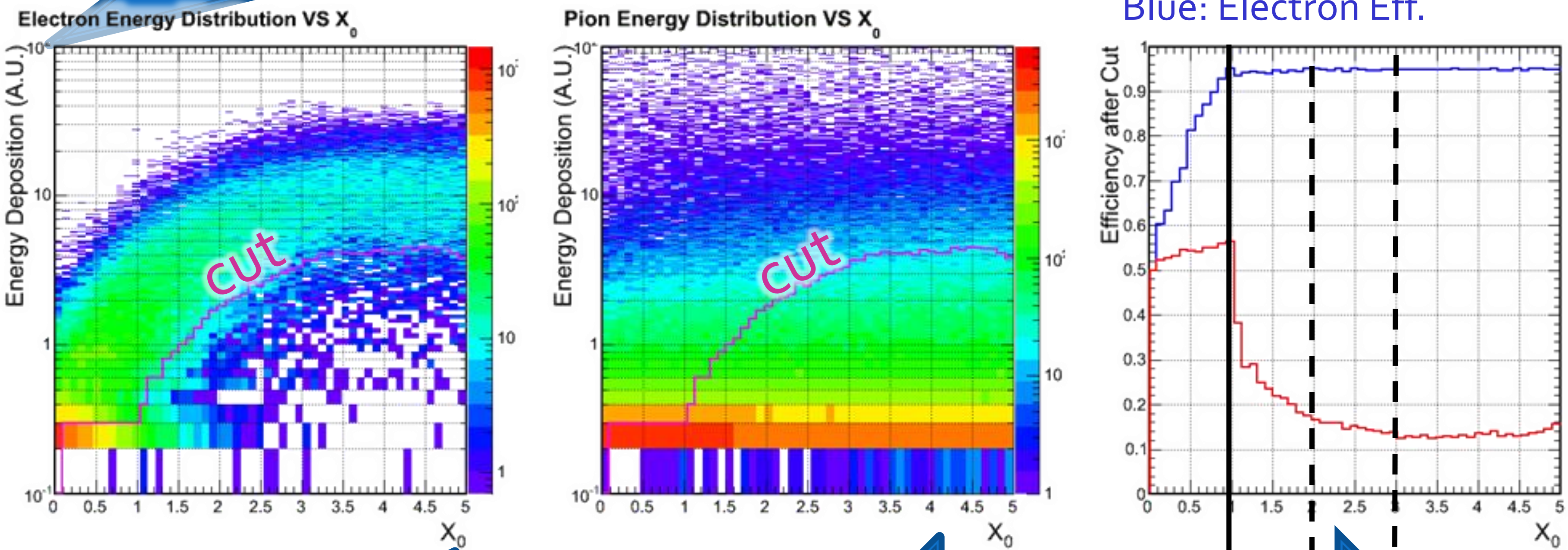




Other choice? Radiator thickness scan

Energy deposition in scintillator pad

Red : Pion Eff.
Blue: Electron Eff.



Thickness of passive radiator

Cut on MIP Peak

95% e

HERMES

Give Another Try

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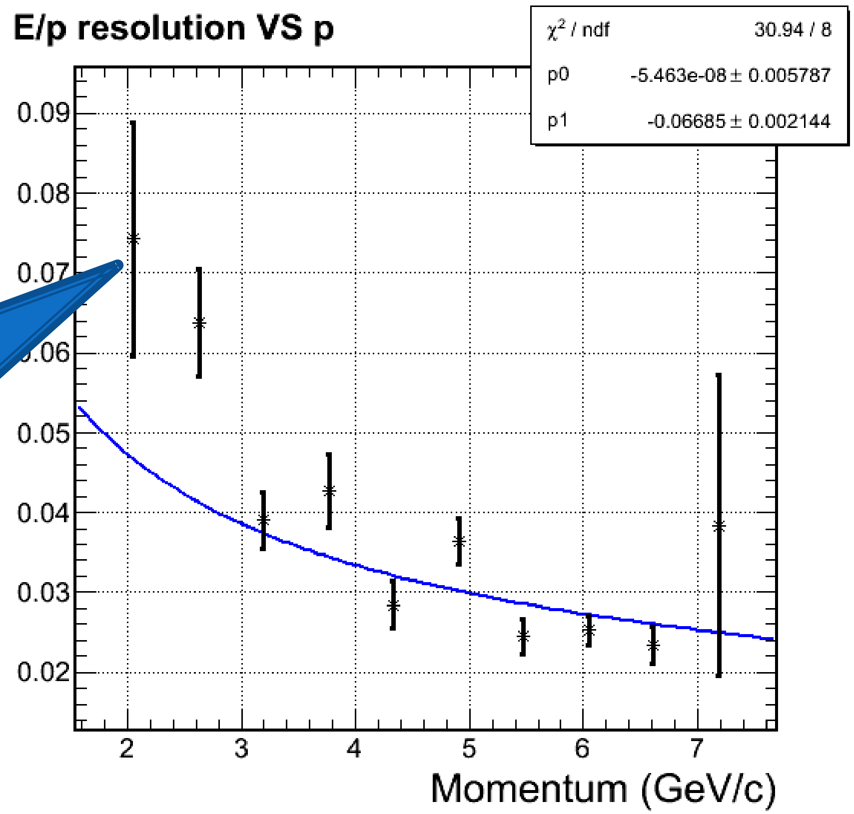
Give another try: radiator = 3 X_0 Lead

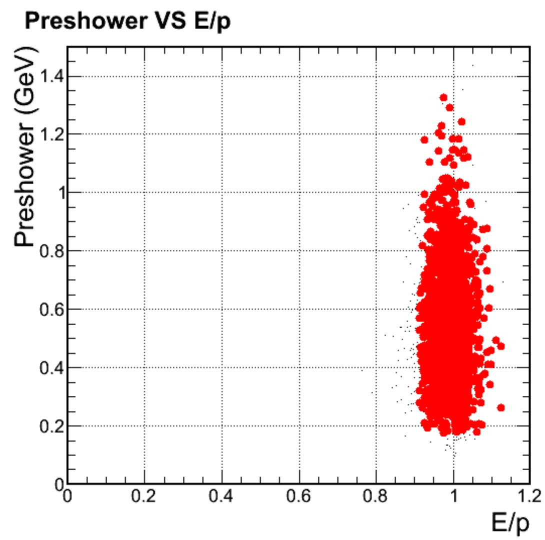
- Resolution is significantly degraded with 3X_0 passive radiator

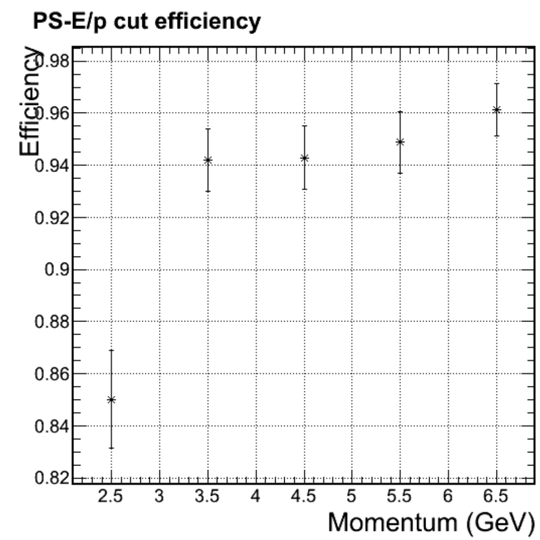


Significant contribution of 1/E term (~10%/E)

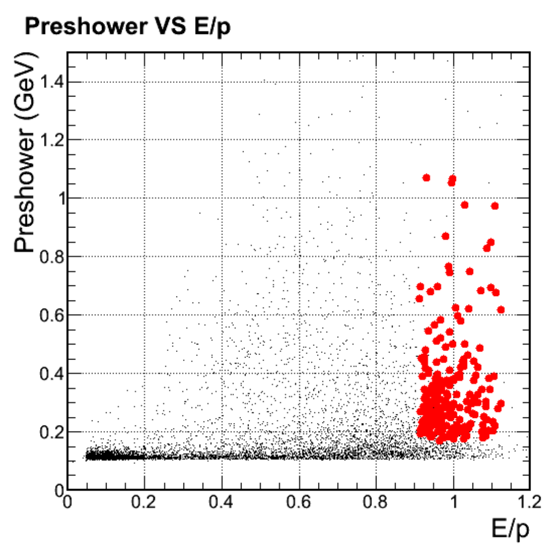
Preshower ($3X_0$) + shower rejection - worse than the HERMES design

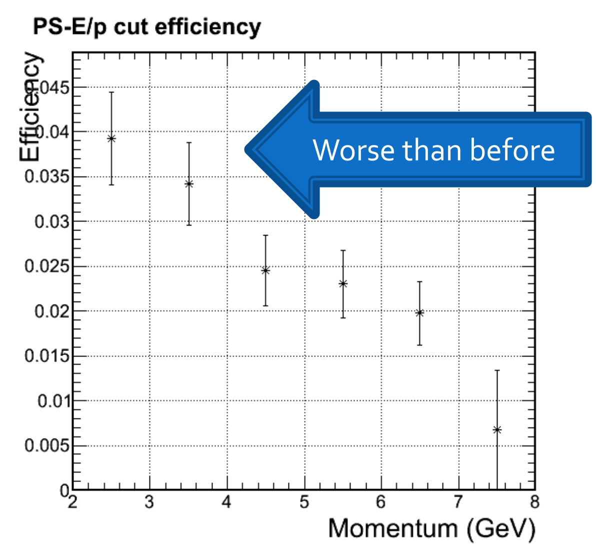
Electron





Pion





Conclusion - passive radiator preshower

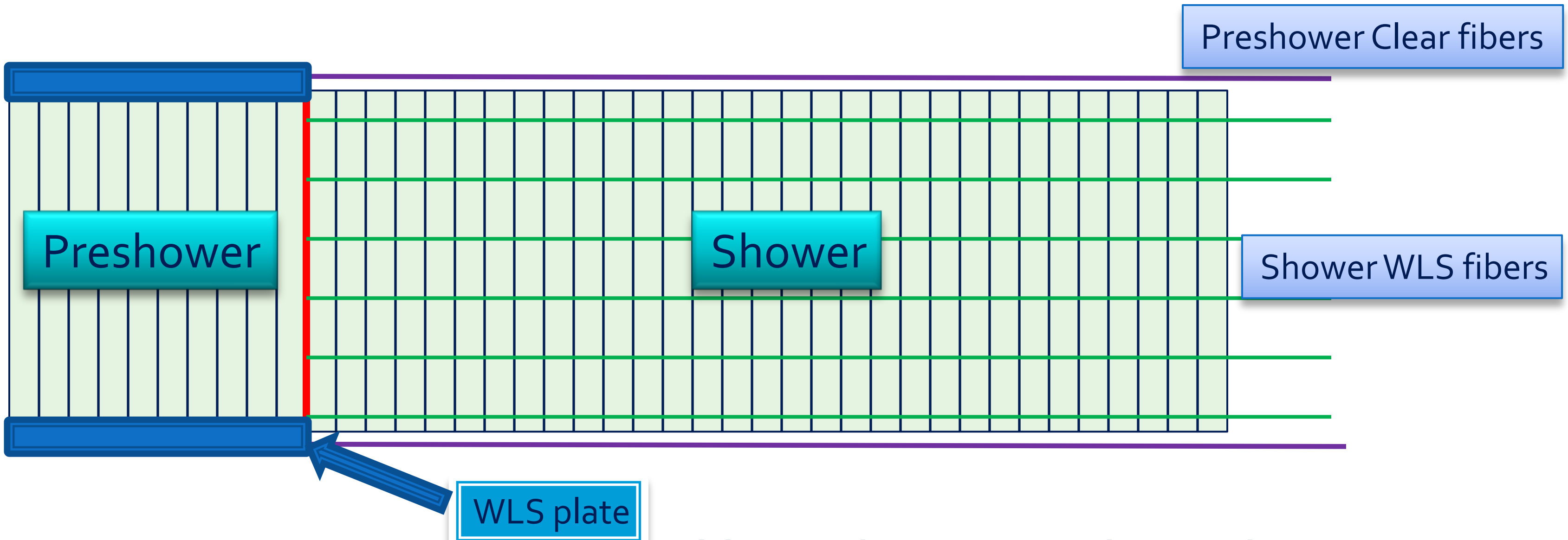
- Do not provide improved performance than our default design (Shashlik calorimeter)
- However, considering its advantage in construction and readout, makes this option is attractive
- $2X_0$ passive radiator as used in HERMES and LHCb is still suitable for SoLID

Readout Updates

- Ed: explore preshower readout options
  - Wave length shifting pad readout
  - Additional fiber group for readout

Pad readout

Preshower has thin WLS plate for readout and use embedded clear fibers to send signal at back. Shower has WLS for readout.



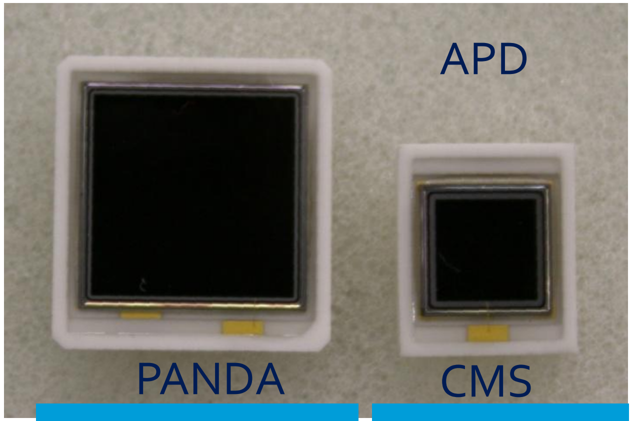
- WLS plates are available and have been used in other calorimeters.
- Problem, the 1.5mm thickness of scintillation layers won't allow enough lights to be collected by pad on the side.
  --> Light cannot go beyond ~few cm

Readout Updates

- Ed: evaluate the feasibility of using APD or other field insensitive photon-detector instead of fiber-connector option

Field Insensitive photon-detector

- APD
  - Pro: not sensitive to field, large QE
  - Con: radiation sensitive, low gain 50-1000, bias V sensitive, noise
- SiPM
  - Pro: not sensitive to field
  - Con: radiation sensitive (much worse than APD), bias V sensitive, noise
- VPT (Vacuum Phototriode)
  - Pro: radiation hard, high rate capability, not very sensitive to field within certain angle
  - Con: low gain 10-40
- Finemesh PMT
  - Pro: not very sensitive to field within certain angle
  - Con: expensive ($1600?)
- All are being investigated



$10x10mm^2$ $5x5mm^2$

Current progress

- Study of field Insensitive photon-detector is still ongoing.
  - In contact with Hamamatsu
- Ongoing study of fiber and connectors
  - Waiting for quotes from Moritex and Avantes for light concentrating lenses/ optical connectors
  - Waiting for quotes from Leoni fibers for multi-furcated fibers option.
  - Received quotes from Saint Gobain and Kuraray.
- Evaluating other ideas from Ed on improving preshower readouts

Budget

- Improved budget required

Cost estimate
- default Shashlyk design

Number of Module: 1700
Number of clear fibers per module: 10
Number of fiber connectors per module: 10

- cost not included
  - Supporting structure Robin included in magnet budget
  - DAQ Alex included in DAQ budget

	Per-module cost($)	Total cost($M)
Module material	500	0.85
Module production	1000	1.7
Clear fibers	240	0.41
Fiber connector	120	0.2
PMT	600 x 2	2.0
Labor	5 Tech year 5 Student year	0.75
TOTAL		**~ 5.9**
TOTAL + 30% contingency		**~ 7.7**

Cost for R&D prototyping : $0.2M

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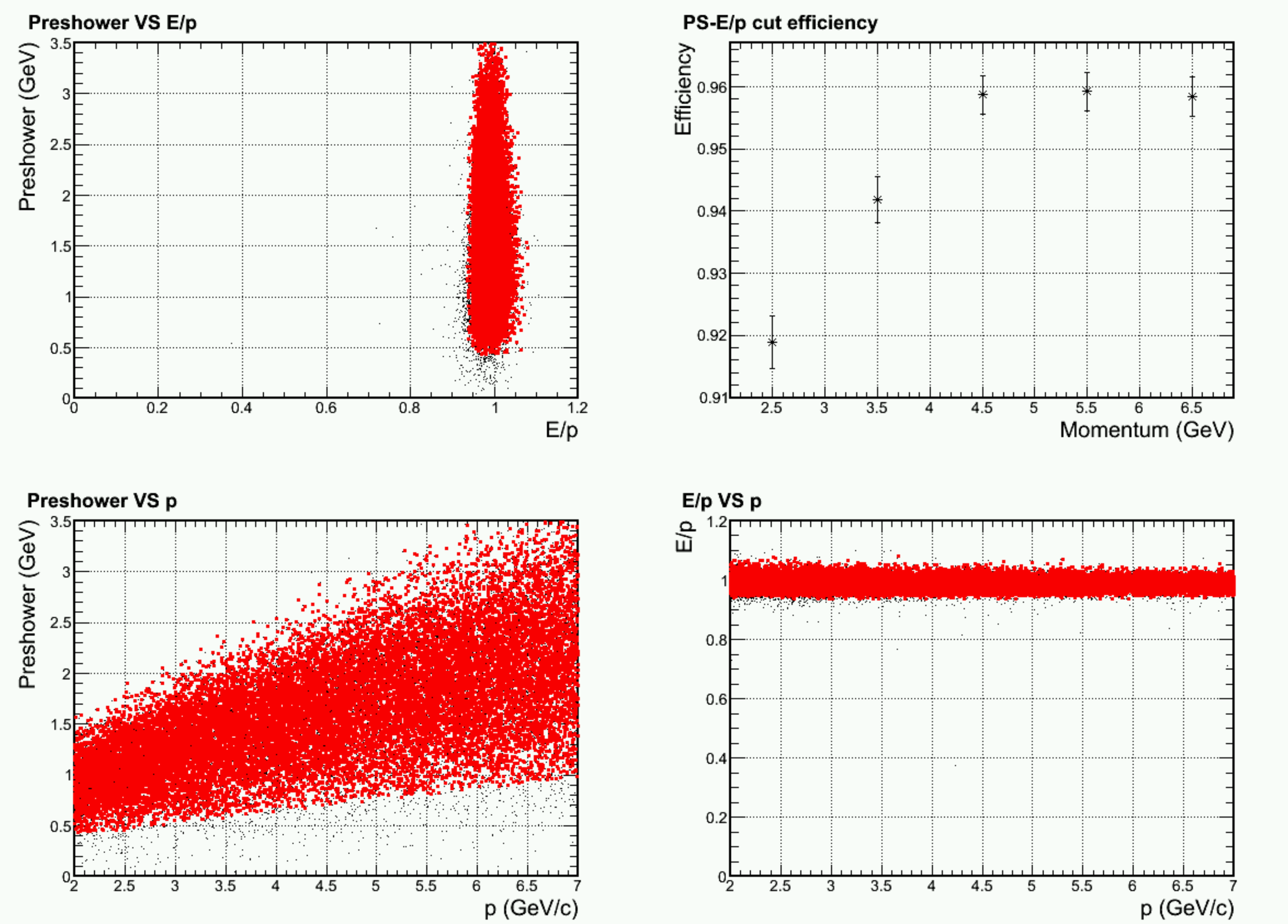
Conclusion

- Design
  - Ed: reduce the electron efficiency to improve hadron rejection
    Very effective to improve rejection
  - Ed: explore scintillator pad at the end of calorimeter for hadron-rejection
    Pad's information is correlated with shower, not much help
  - Paul S. & Zhiwen : passive-radiator preshower (HERMES-LHCb type)
    Useful in simplifying the construction
- Readout
  - Ed: explore preshower readout options
    - Wave length shifting pad readout - Do not work for scintillator
    - Additional fiber group for readout - May work, under investigation
  - Ed: evaluate the feasibility of using field insensitive photon-detector
    - under investigation
- Background – Solved, see Lorenzo's talk
- Budget - Updated

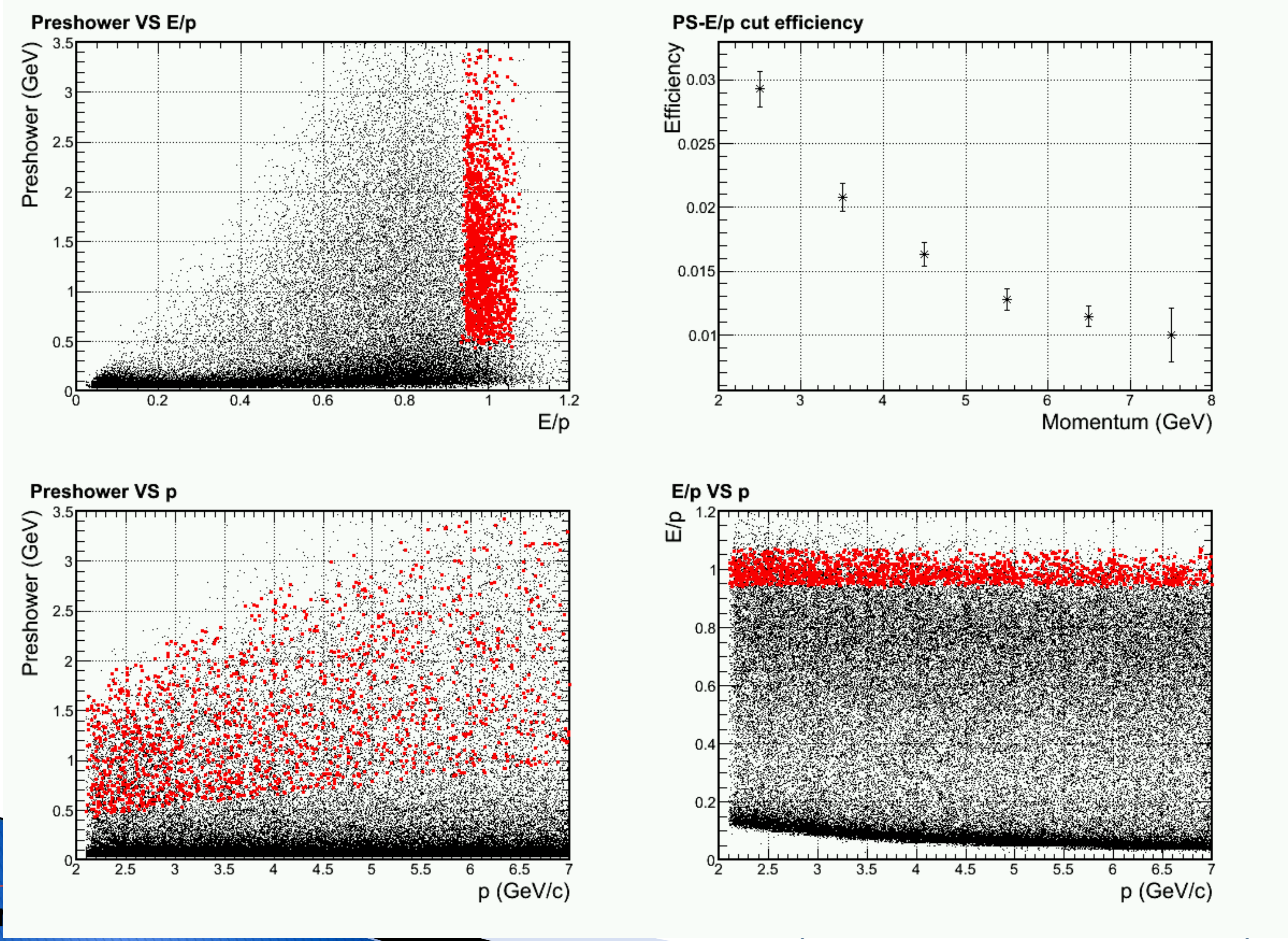
Backup Slides

More details on cuts

3-D cuts Electron (~95% eff. cut)



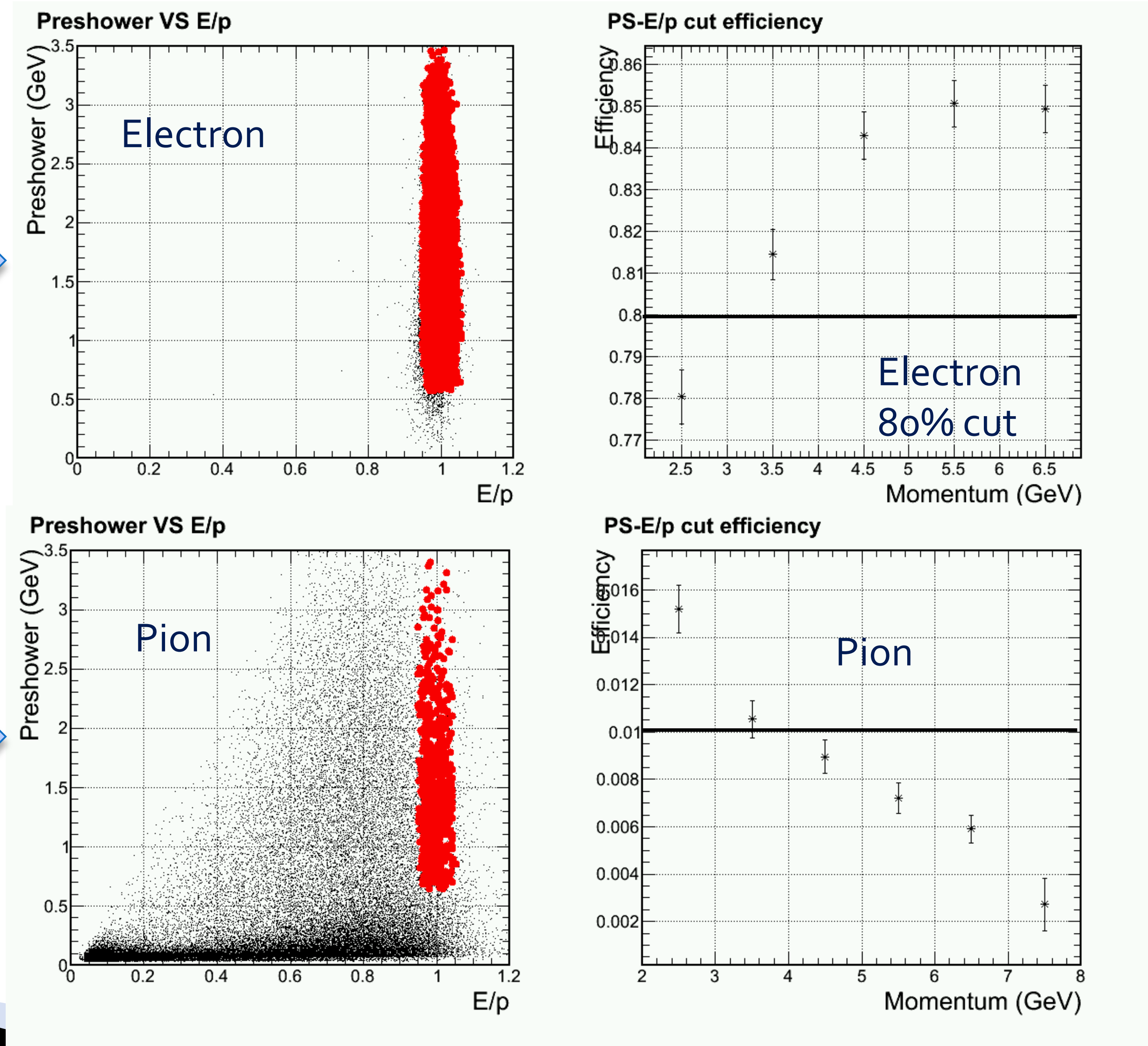
3-D cuts Pions (~95% electron eff. cut)



High statistics

Electron

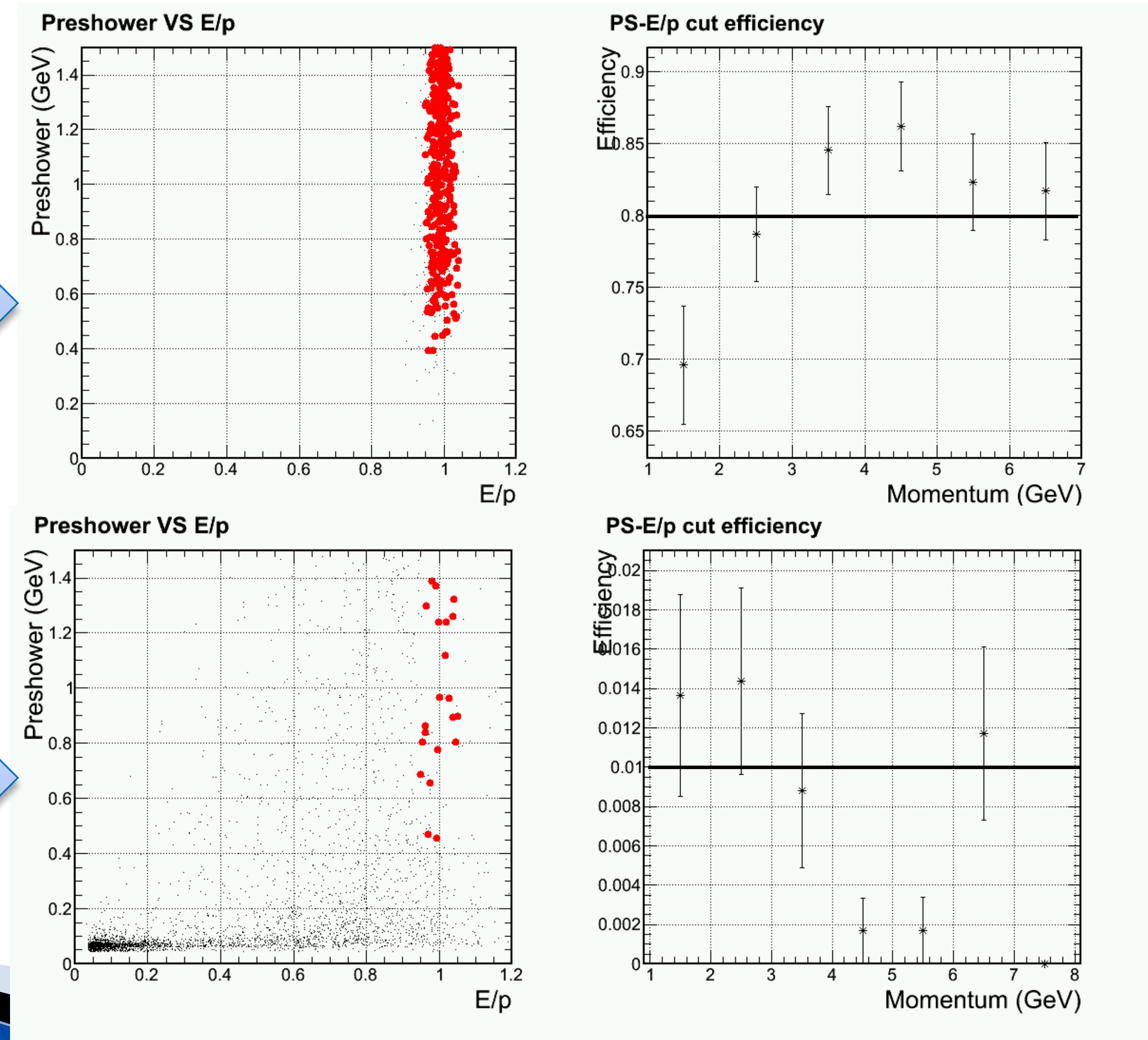
Pion



Same cut / What if lower statistics

Electron

Pion



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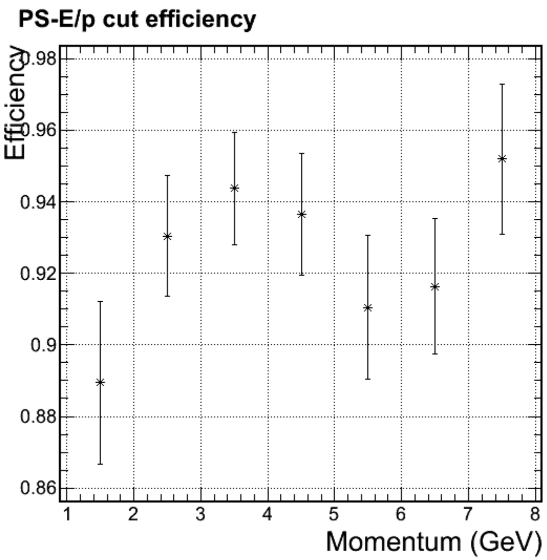
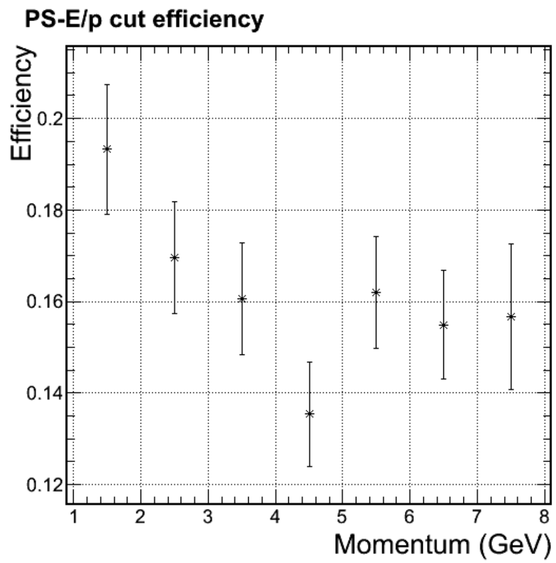
Momentum dependent cuts and eff. Preshower cut only

Shown in last meeting, which is consistent level compared with Shashlyk preshower

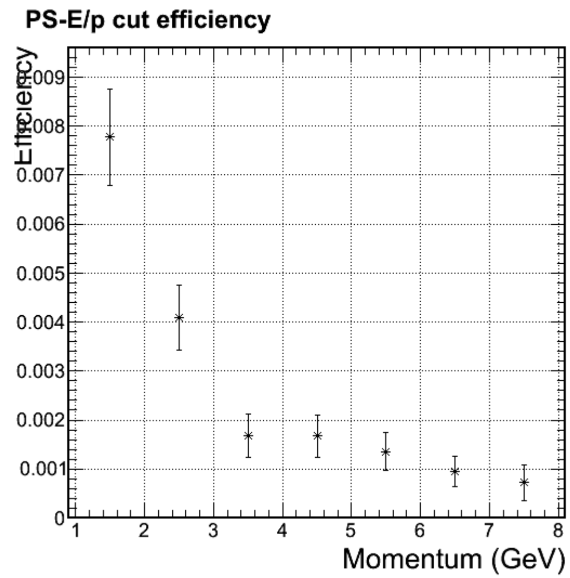
Electron



Pion



Muon



SoLID EC cost estimate

- Module total $2.55M
  - Number of module 1700 (SIDIS large angle 450, SIDIS forward angle 1150, PVDIS forward angle 1700)
  - Module cost $1500 (30% material, 70% production)
- Readout option 1 (clear fiber and common PMT) total $2.31M ???
  - Clear fiber total $0.41M, cone total $0.2M???
    - Each module has 100 WLS fibers to 10 2mmD clear fibers with factor 2.5 reduction winston cone
    - 2mmD unit cost $4/m (saint-gobain), $10/m(Kuraray)
    - average 3 meters on both preshower and shower
  - PMT total $1.7M???
    - Unit price 500
- Readout option 2 (field insensitive photonsensor) total $5.5M???
  - finemeshPMT unit cost $1600, total $5.5M ???
  - Vacuum Phototriode (VPT) unit cost ???
  - APD unit cost ???
- Labor total $0.75M???
  - 5 technician years (100k/year) + 5 student years (50k/year)

Total cost with readout option 1: 5.6M , after 30% contingency $7.3M ???

Total cost with readout option 2: 8.8M , after 30% contingency $11.5M ???

Cost for R&D prototyping : $0.2M ???

- cost not included
  - Supporting structure Robin gives total 0.5M estimated for all detector support, included in magnet budget
  - DAQ Alex included in DAQ budget

Panda APD

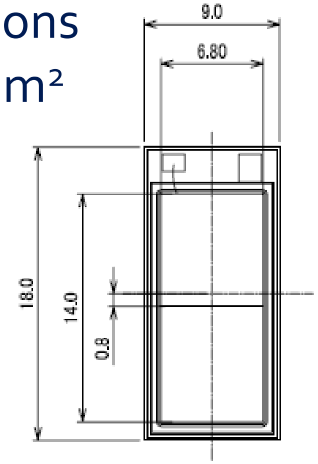
- excellent performance
  at RT and T = –25°C
- radiation resistent
  up to 10^{13} protons
  in particular at T = -25°C

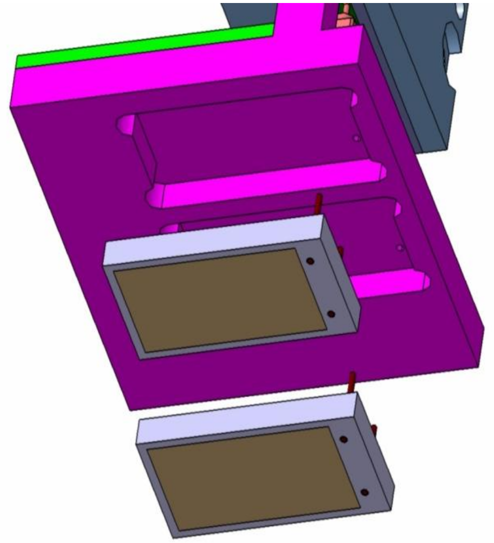
10x10mm²

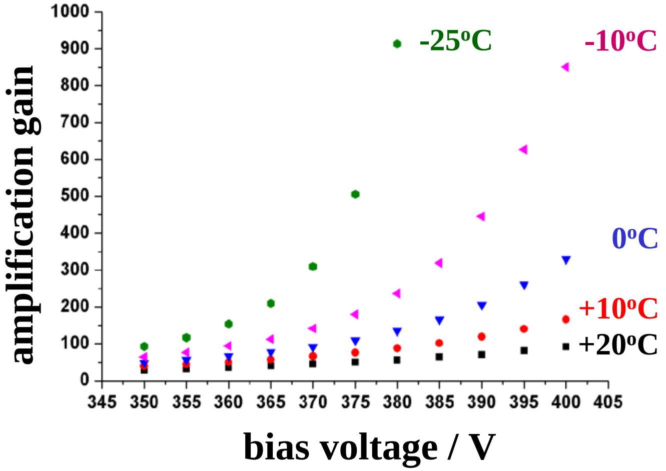
5x5mm²

final concept: 2 LAAPDs/crystal, separately readout

dimensions
7 x 14 mm²

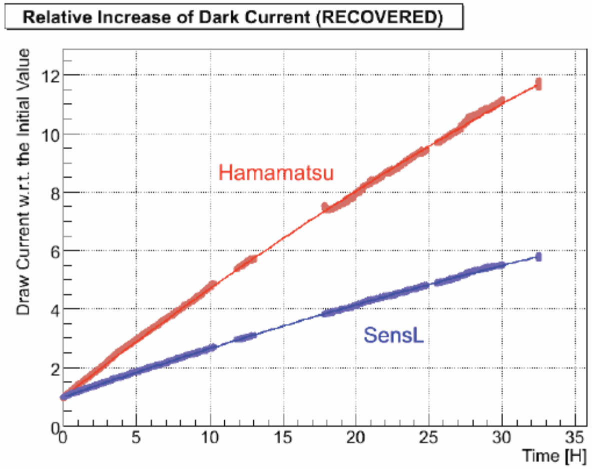






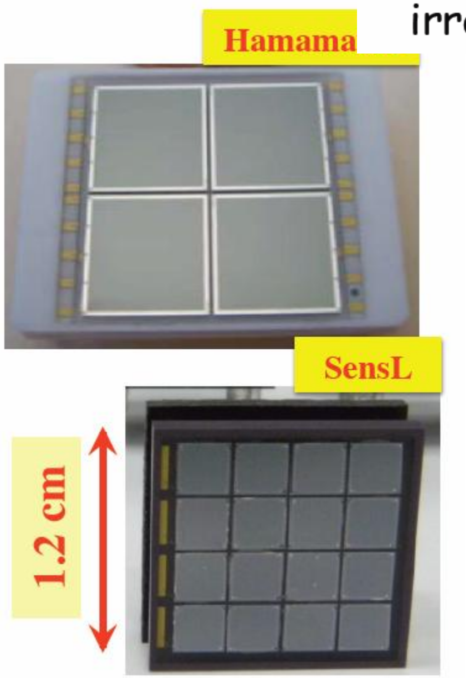
HallD BCAL SiPM

- Dark rate increase by factor of 10 for 10e9 eq 1MeV neutron



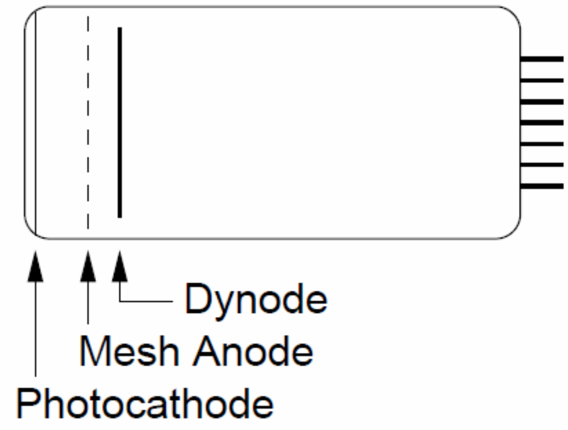
Dark rate increase during irradiation at 3.1 rem/hr

	SensL	Hamamatsu
Pixel size (μm)	35	50
N_{pixels} / cell	3640	3600
PDE	10-20%	> 20%
Fill Factor	59%	61.5%
Dark Rate (per cell)	8Mhz	5-6 Mhz
V_{op}	30 V	70 V
Gain	$> 10^6$	$> 10^6$
Eff. Area	75%	89%



VPT

- Field insensitive within 30 degree at 1.8T
- Preamiplifier needs to be close to VPT



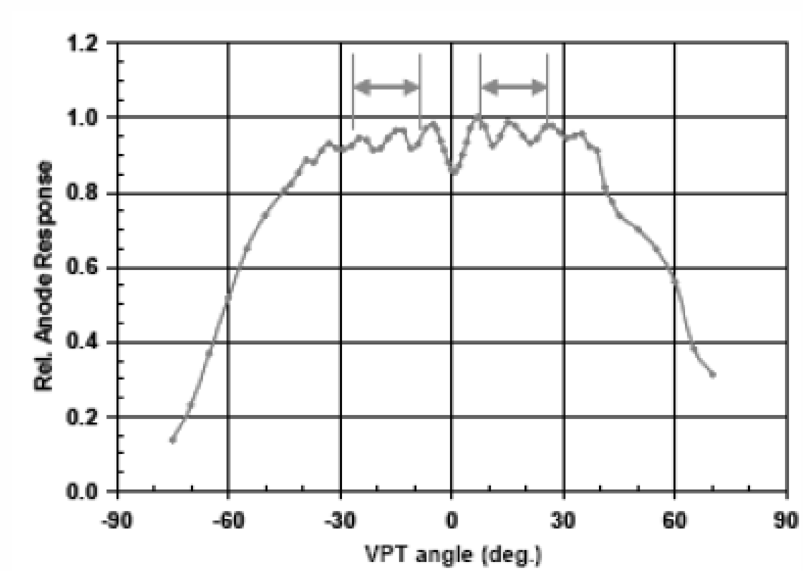


Figure 5.32: Variation of anode response for constant pulsed LED illumination as a function of the VPT angle to the axial field of 1.8 T for the CMS type VPT [17].

Hamamatsu R2148MOD
especially made for $\overline{\text{P}}$ANDA, $\varnothing < 24$ mm

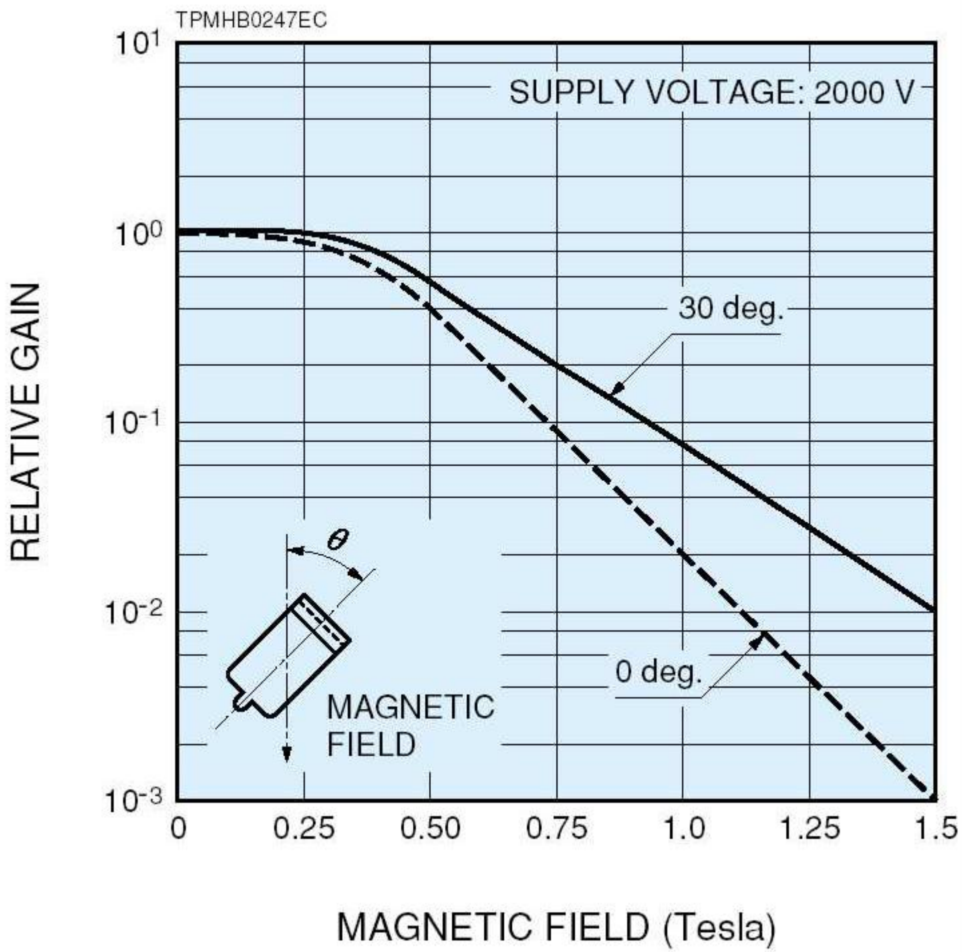
- $\varnothing = 23.7$ mm
  $\ell = 30$ mm
- $U_A = 750$ V
  $U_D = 500$ V
- G = 9.3
- QE = 32 %
  (at 420 nm)

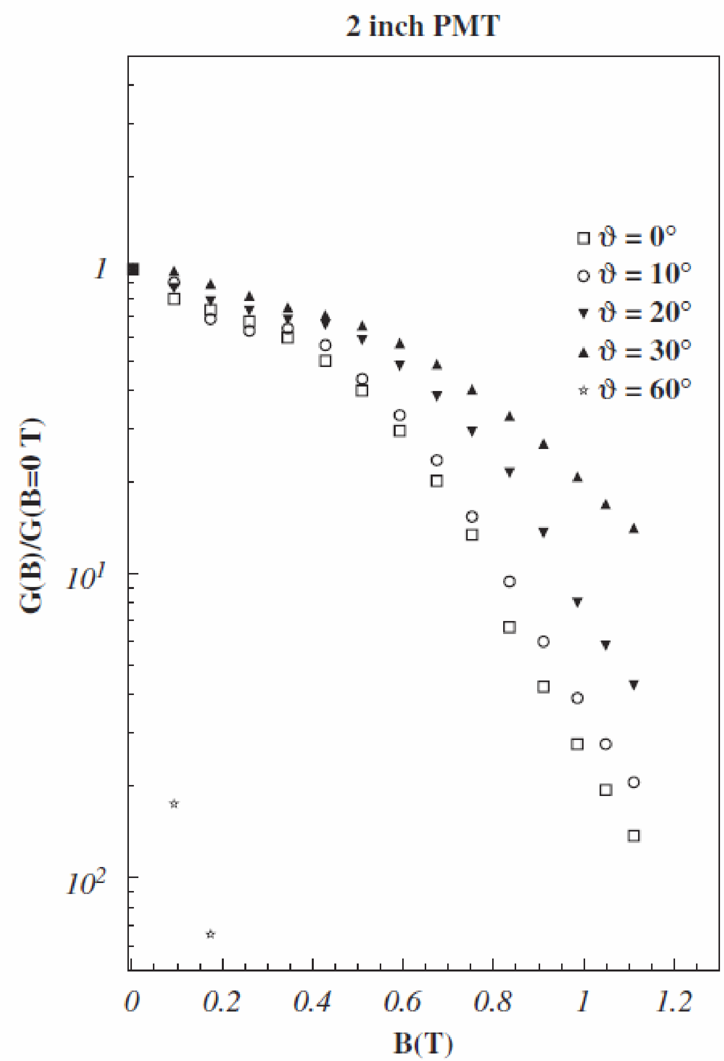
RIE St. Petersburg, Russia

- Tetrode (photo cathode, 2 dynodes, anode)
- G = 24 – 45
- QE = 14 – 20%

Finemesh PMT

- Has closely spaced mesh dynodes
- Need to be around 30 degree to work with 1.5T





Readout Updates

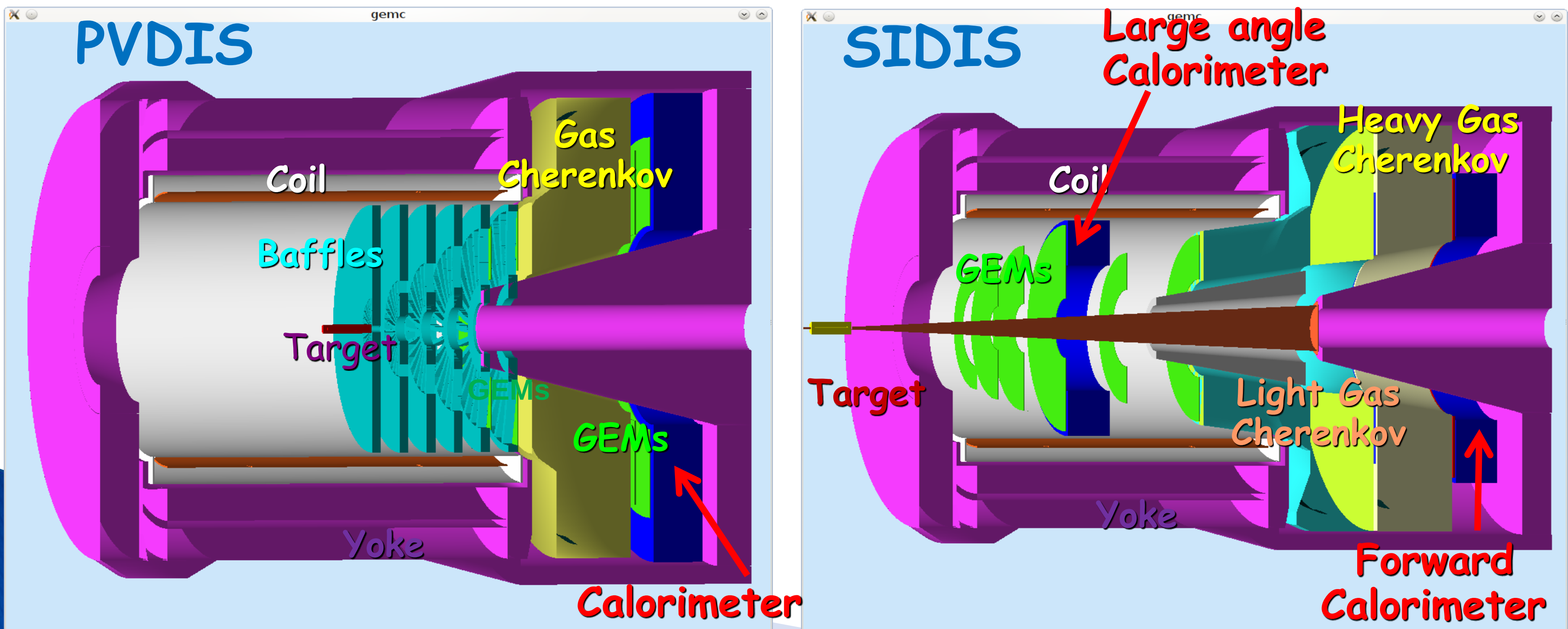
- Generic updates

Generic Updates

- Waiting for quotes from Moritex and Avantes for light concentrating lenses/ optical connectors
- Waiting for quotes from Leoni fibers for multi-furcated fibers option.
- Received quotes from Saint Gobain and Kuraray.

SoLID EC configuration

Provide key e/p separation, modules shared between PVDIS & SIDIS



EC Design Requirements

1. Electron- hadron separation:
   - 20:1 - 100:1 pion rejection within p= 1 – 7GeV/c
   - Energy resolution:
2. Time response: provide trigger, identify beam bunch for PID through coincidence TOF (SIDIS only);
   - σ <~ a few hundreds ps (CEBAF beam bunch ~2ns)
3. Provide shower position to help tracking/suppress background
   - $\sigma \sim 1$ cm
4. Radiation resistance: 5×10^5 rad for one PAC year
5. Magnetic field 1.5 T for SIDIS large angle EC: Silicon based photon-sensors (field-resistant) can't survive high neutron environment and expensive; PMTs work but need to be away from high magnetic field.
6. Modules easily swapped and rearranged for PVDIS ↔ SIDIS
7. SIDIS needs 2-fold rotation (180°) symmetry

Choosing EC Type

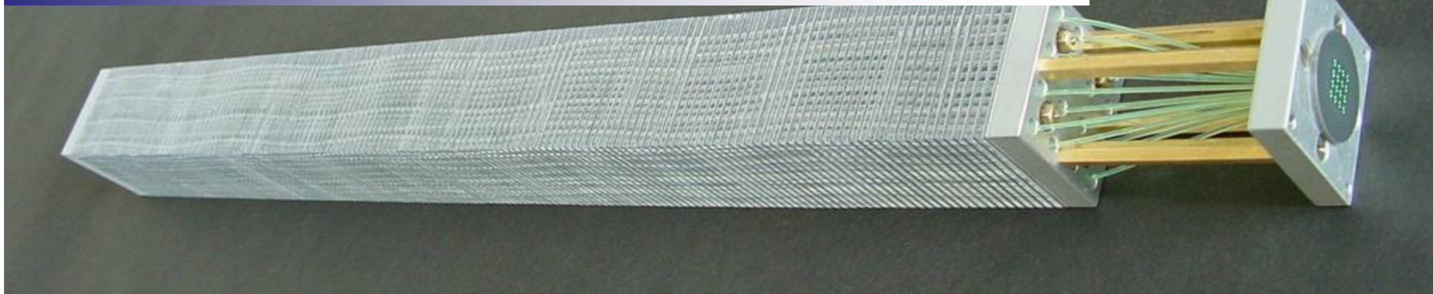
- PVDIS and SIDIS radiation level (~400 krad per year) is too high for leadglass and CSI-like crystals (typically 1krad).
- Our ECs are large: Forward angle EC ($10m^2$x0.4m depth), Large angle EC ($5m^2$x0.4m), or PVDIS EC ($20m^2$x0.4m) → Total 6-$8m^3$
- Crystals like $PbWO_4$ (\$10/cc) and LSO (\$40/cc) can stand 10^6 rad, but too expensive: Total ~$3m^3$→ \$30M or \$120M .
- Both Shashlyk or SPACAL/SciFi (0.5-1Mrad) have enough radiation hardness and good energy, position and time resolution.

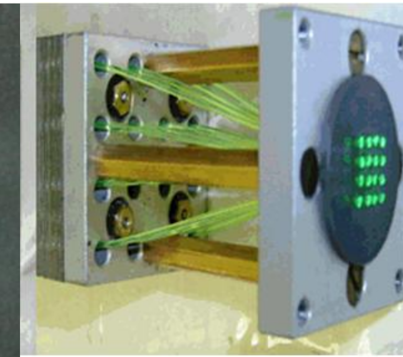
SciFi vs. Shashlyk:

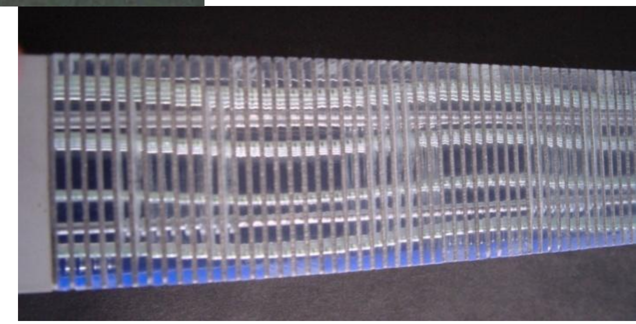
- SciFi needs about half volume being scintillation fibers to reach good energy resolution, 1mm-diameter fibers cost \$1/m: Total $6m^3$ → **\$4M** for fiber alone.
- Compare to Shashlyk: total module cost from <**\$3M** from IHEP.
- Two orders of magnitude fibers than Shashlyk, hard to read out.

Shashlyk EC

IHEP, COMPASS Shashlik, 2010



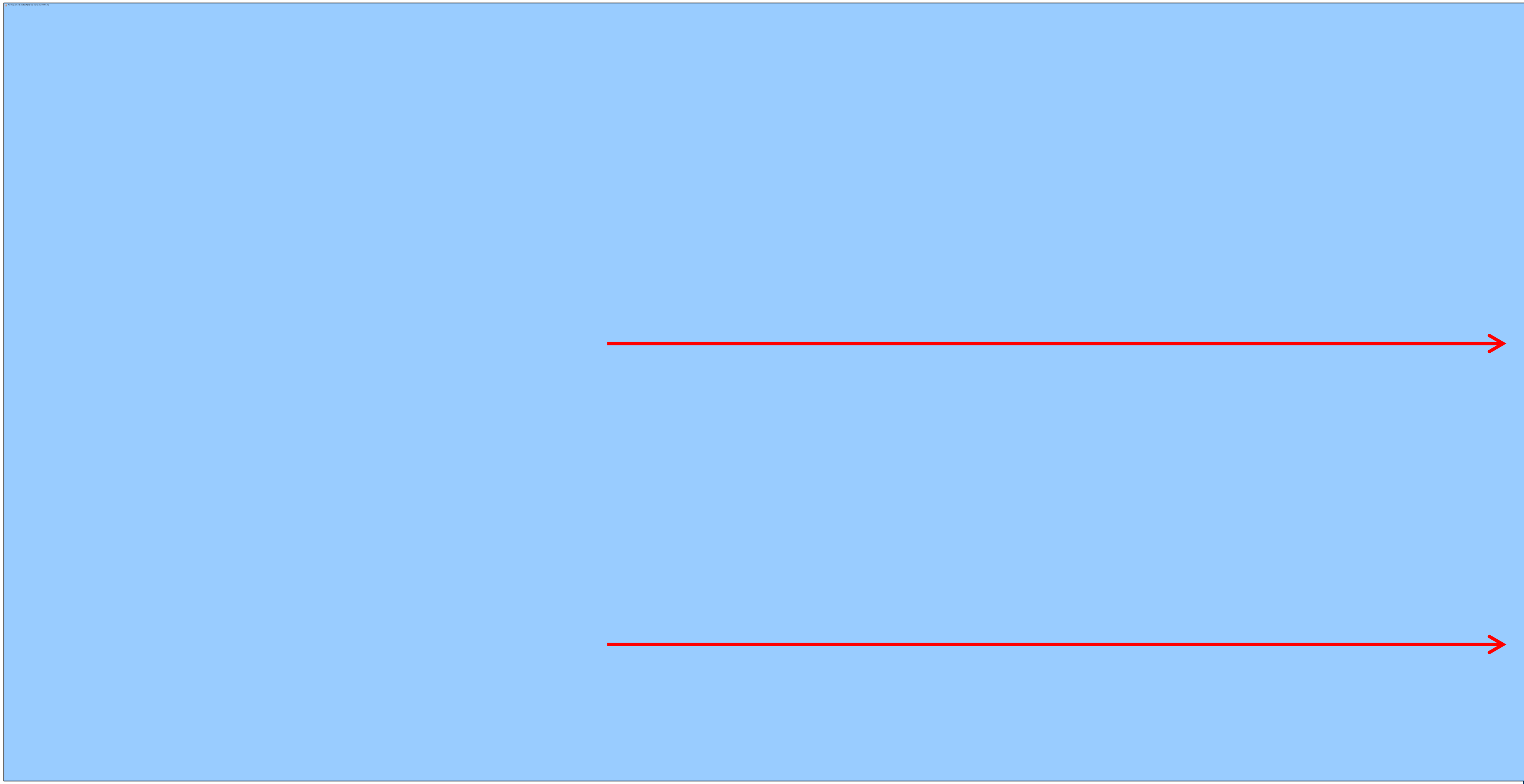




- Lead-scintillator sampling calorimeter
- WLS fibers [$1/(9.5\text{mm})^2$] collect and guide out light → one PMT per module.
- Good and tunable energy resolution
- Radiation hardness: ~ 500 krad tested by IHEP
- transverse size can be customized
- Light collection and readout straightforward
- Well developed technology, used by many experiments, IHEP production rate about 200/month

IHEP Scintillator Facilities
www.ihep.ru/scint/index-e.htm

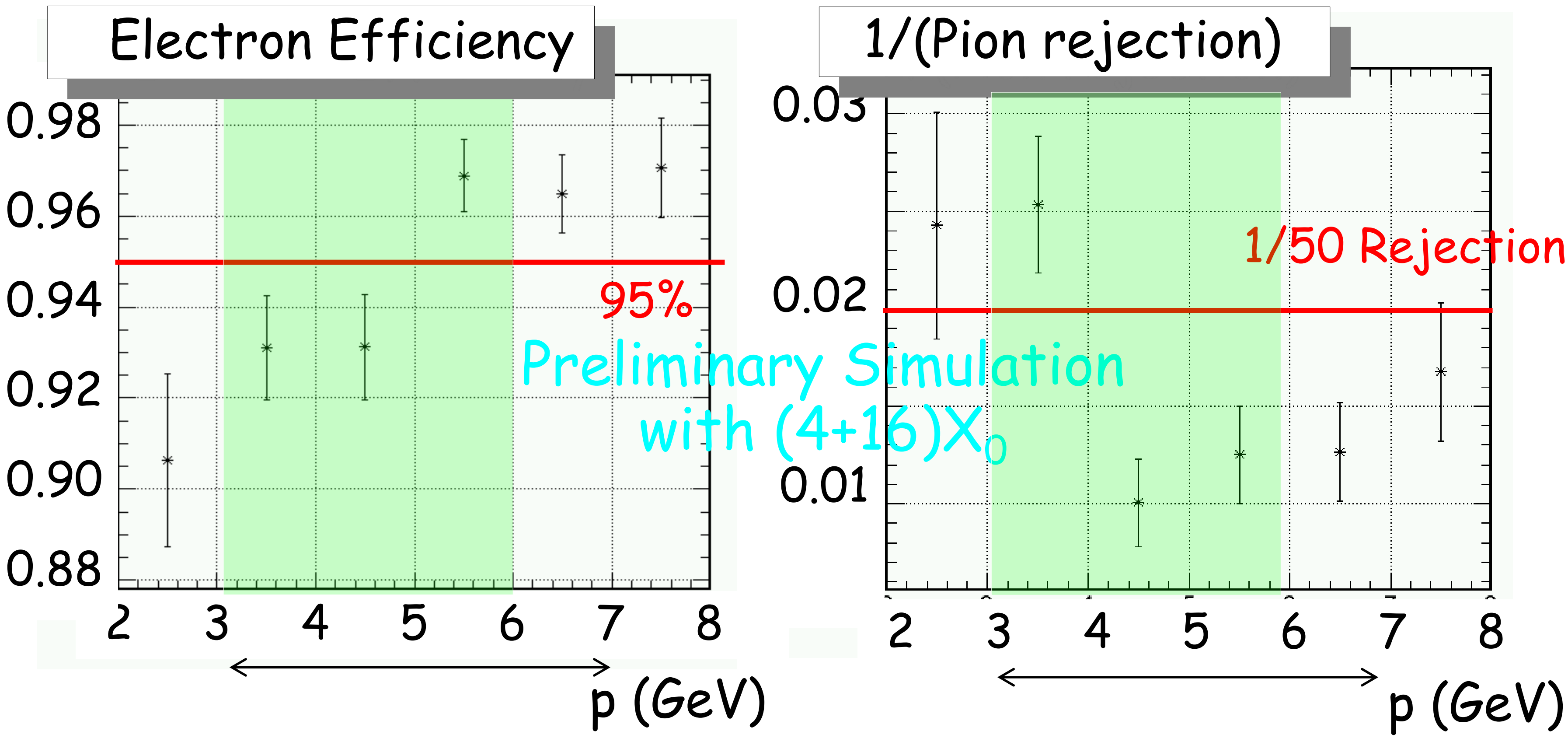
Design Consideration 1: Pb/scintillator ratio



- Thinner Pb layers give better energy resolution, but requires more layers → Balancing between energy resolution and module length

Design Consideration 1: Pb/scintillator ratio

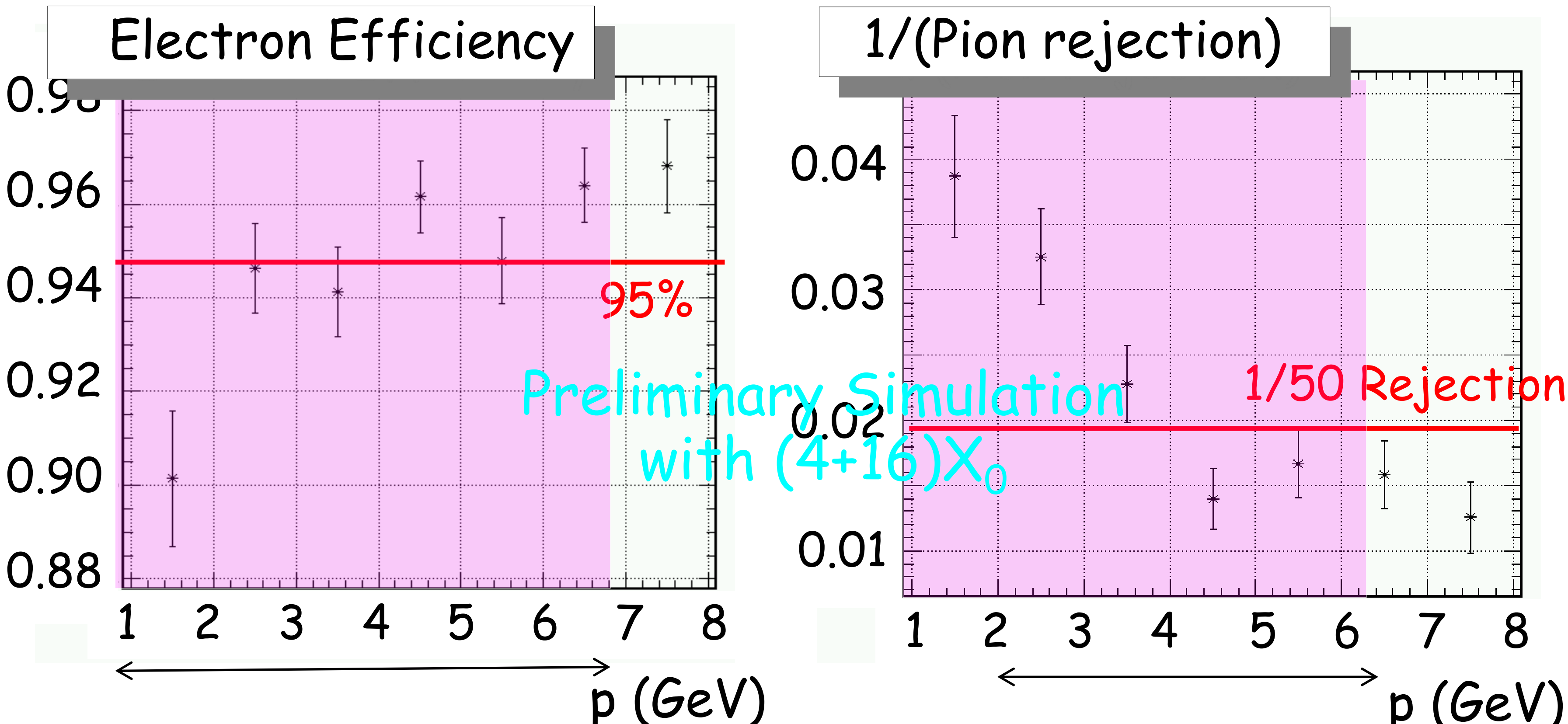
- Minimize scintillator ratio while reaching 100:1 pion rejection → 0.5mm Pb/1.5 mm Scint. (BASF143E) per layer.



SIDIS large angle: p=3~6 GeV

Design Consideration 1: Pb/scintillator ratio

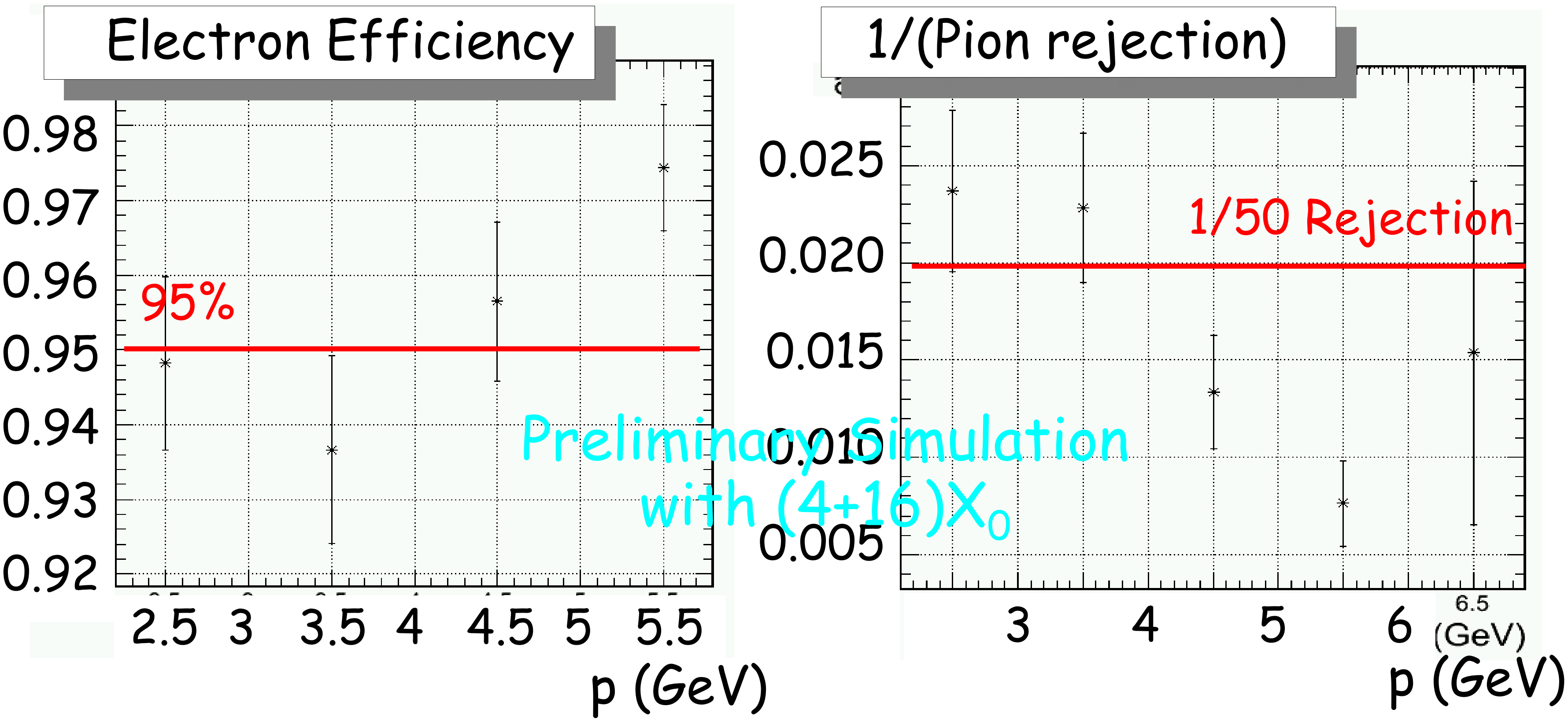
- Minimize scintillator ratio while reaching 100:1 pion rejection → 0.5mm Pb/1.5 mm Scint. (BASF143E) per layer.



SIDIS forward angle: p=1~7 GeV

Design Consideration 1: Pb/scintillator ratio

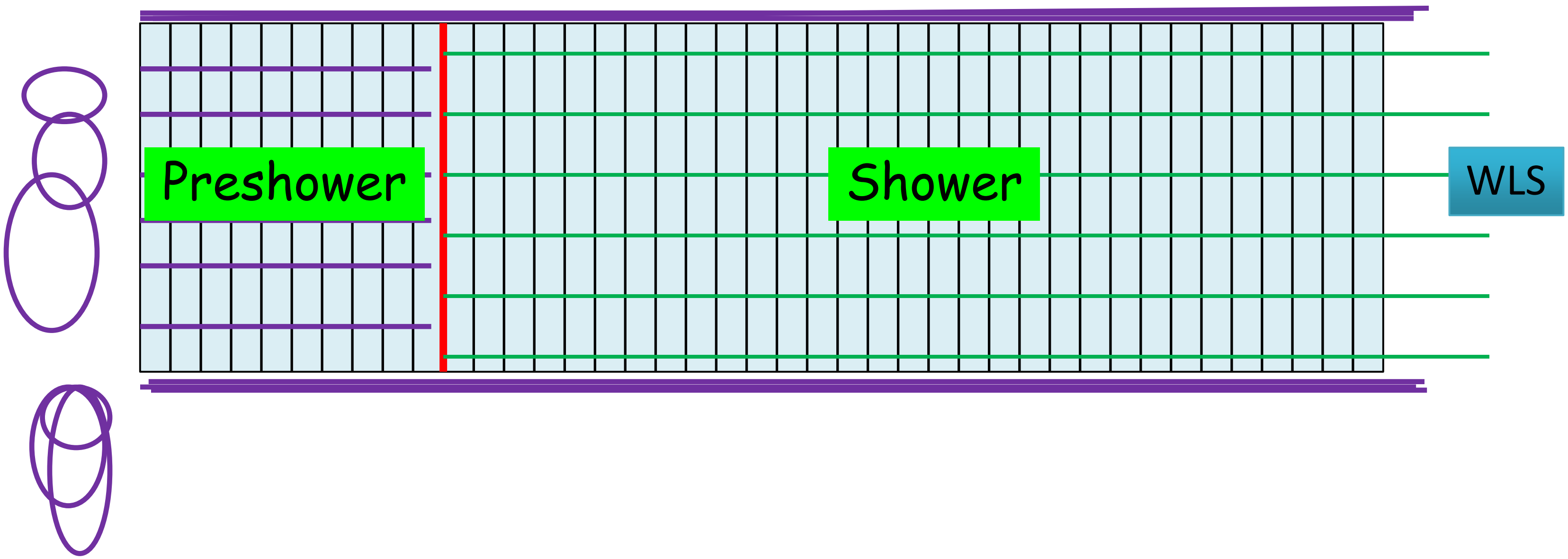
- Minimize scintillator ratio while reaching 100:1 pion rejection → 0.5mm Pb/1.5 mm Scint. (BASF143E) per layer.



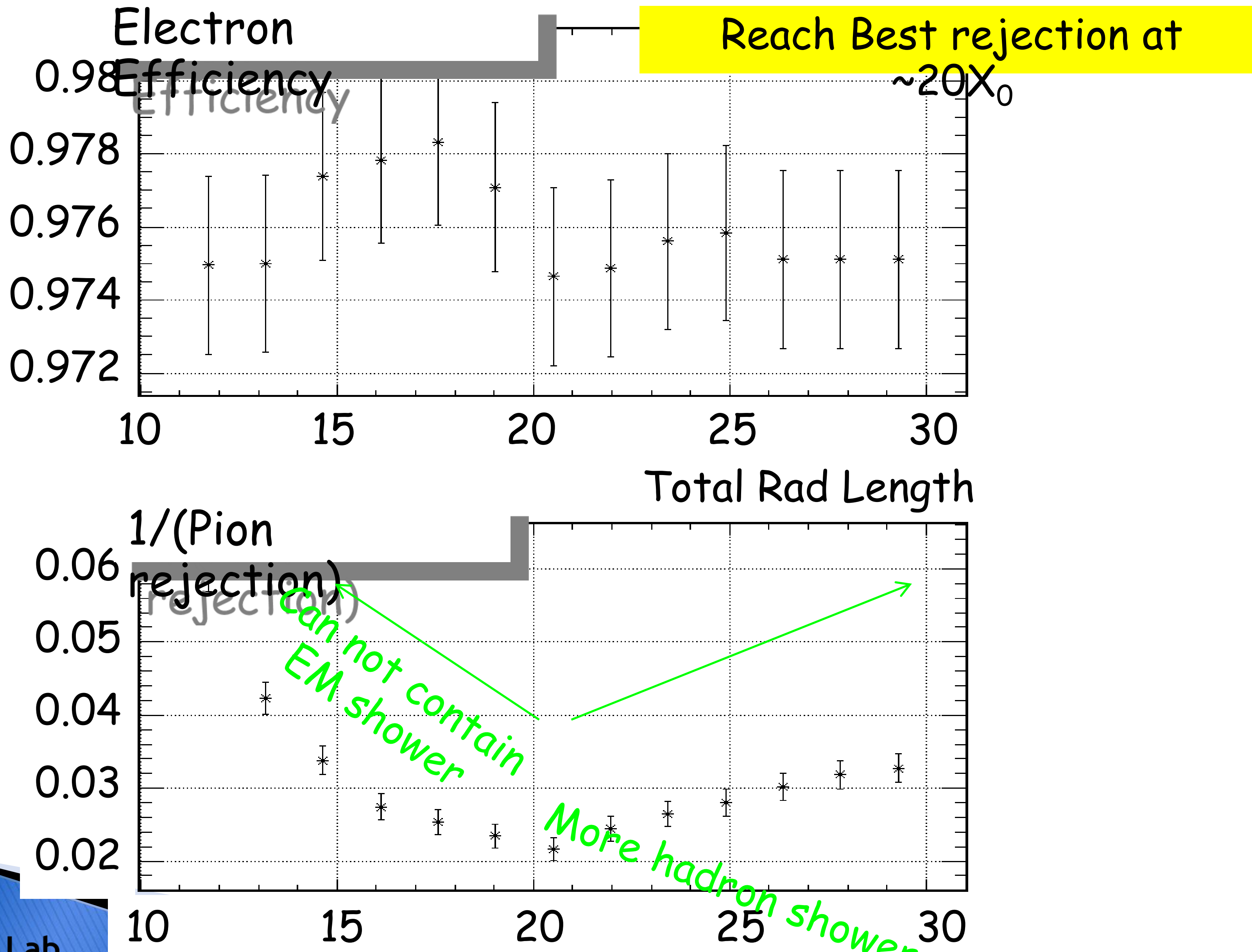
PVDIS (forward angle): p=2.3~6 GeV

Design Consideration 2.0: Preshower/Shower

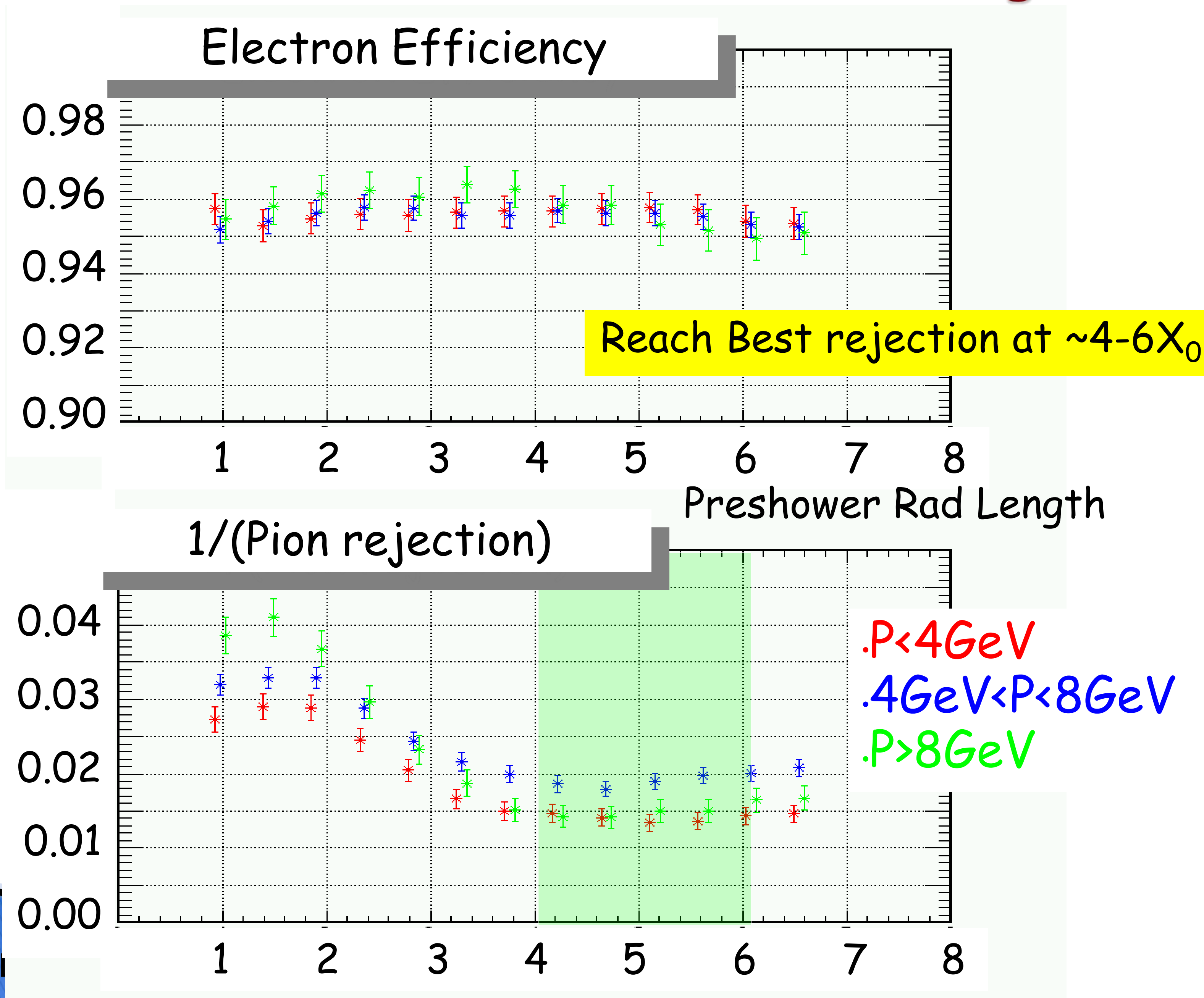
Preshower and shower have separate WLS readout in the current design:



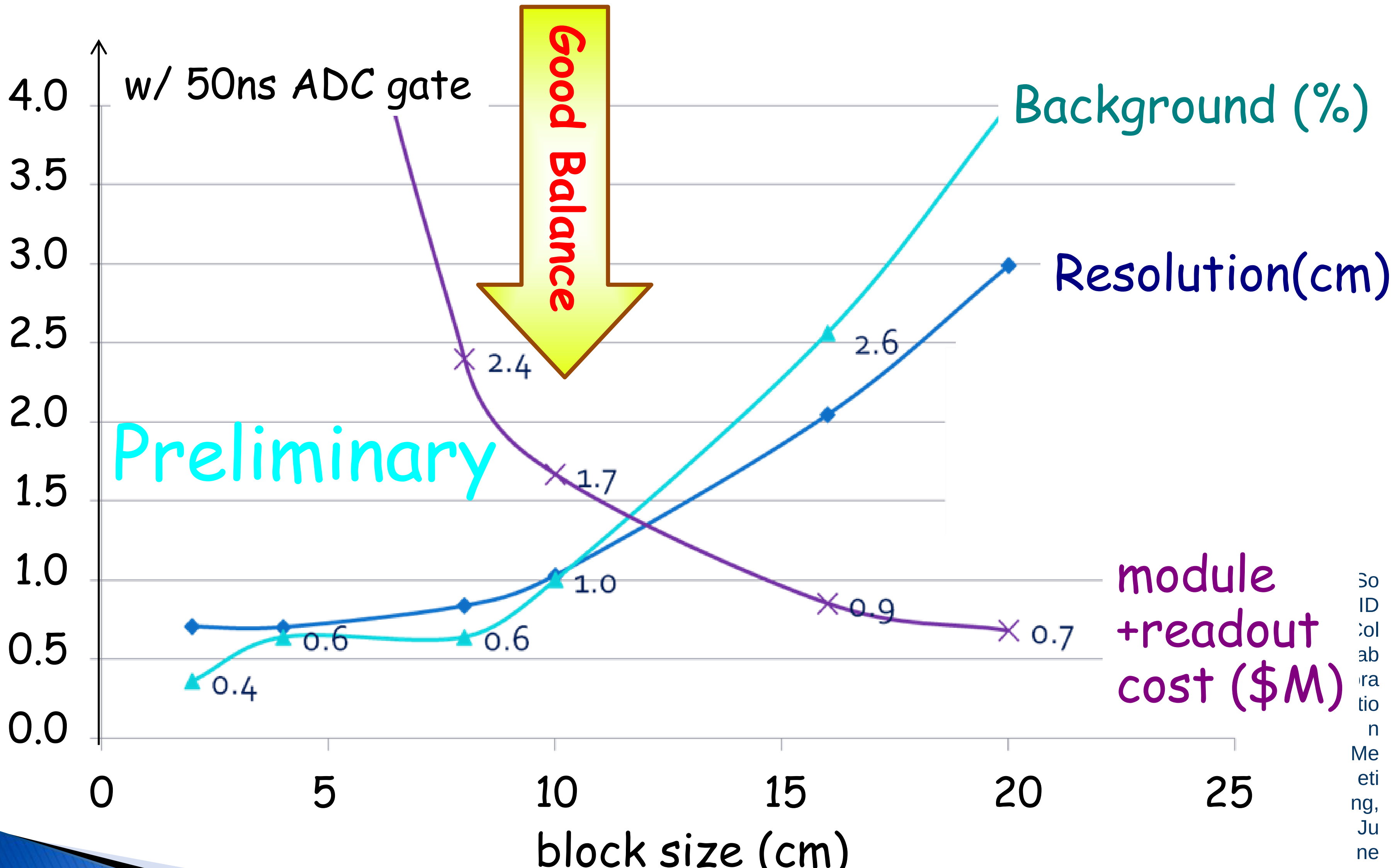
Design Consideration 2.1: Total Length



Design Consideration 2.2: Preshower Length

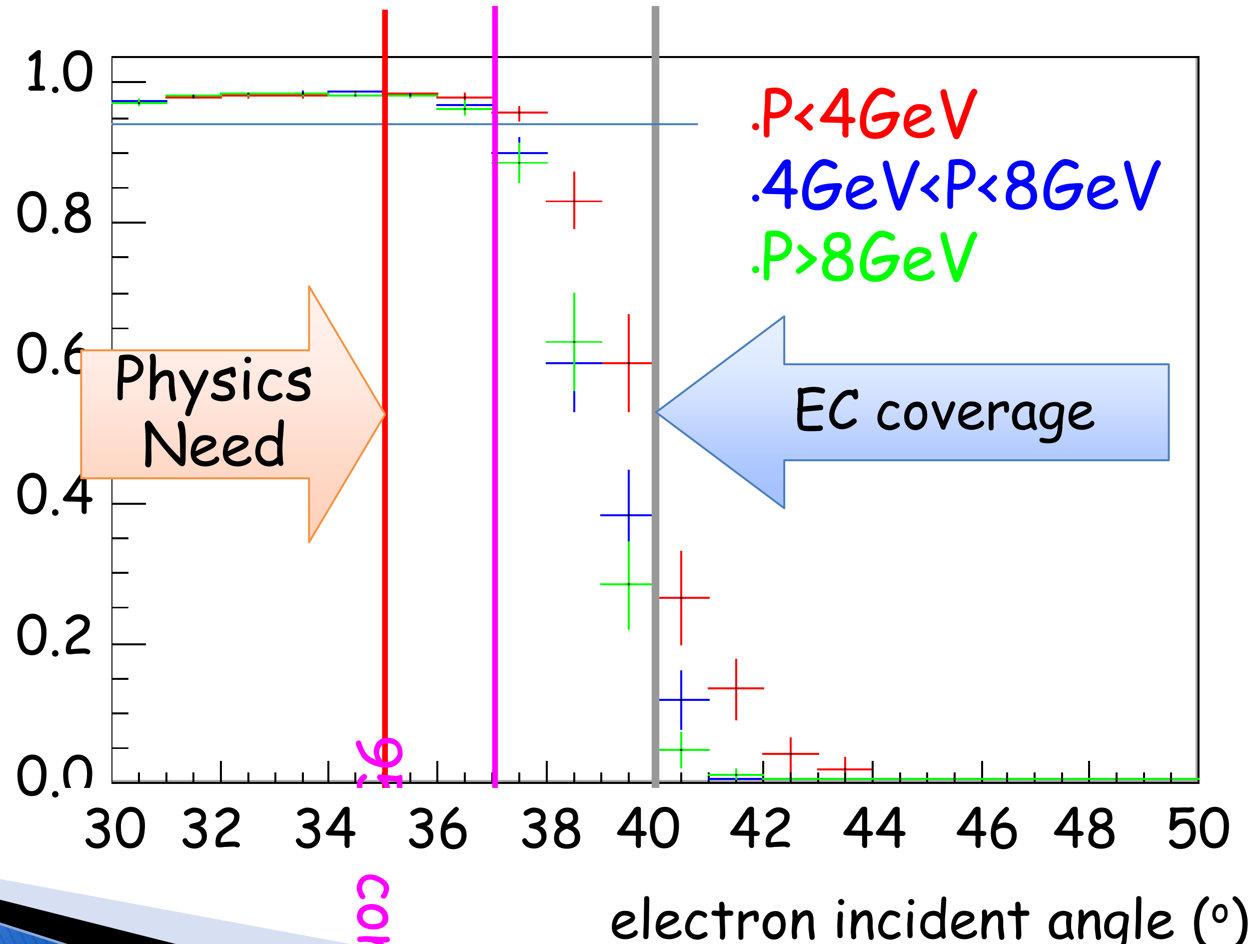


Design Consideration 3: Lateral Size

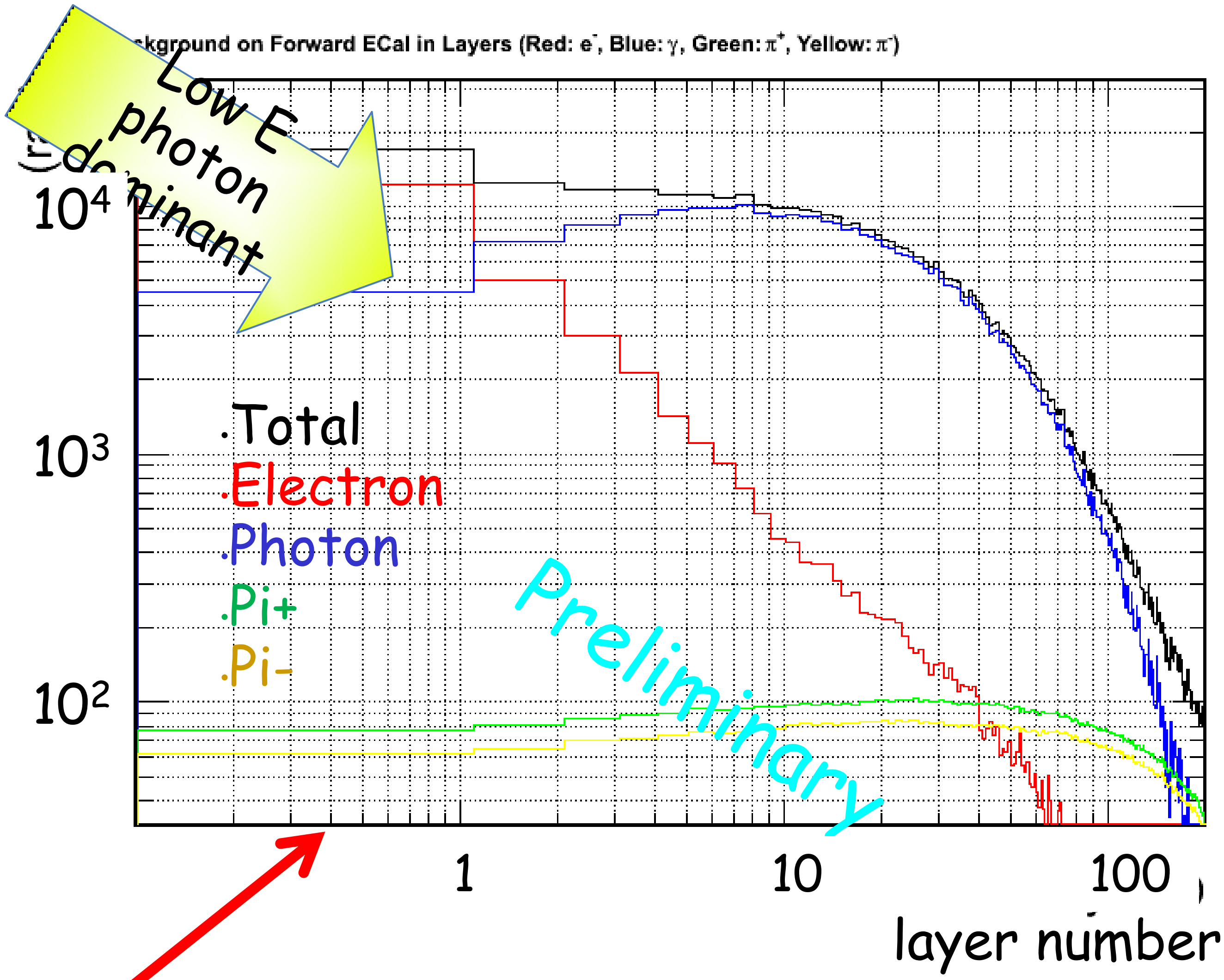


Design Consideration 4: Edge Effect

PVDIS physics requires the largest incident angle (35° from target center, 37° from downstream target); Calorimeter covers up to ~40°.



Design Consideration 5: Radiation Dose



Can be shielded with 2mm Pb; Effect on energy resolution ~0.1%/sqrt(E) worse, no obvious effect on pion rejection (EM shower not yet developed in the first few layers)

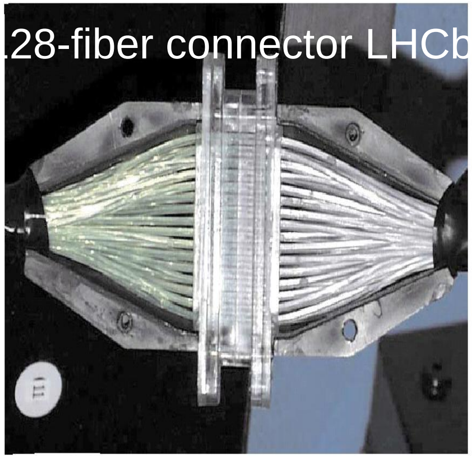
Design Consideration 6: Fibers & Connectors

Fibers:

- Wave Length Shifting fibers: KURARAY Y11
  - Radiation hardness: 13% light loss at 0.1Mrad, 30% light loss at 0.7Mrad (manageable with scintillator BASF143E)
  - Attenuation length ~3m, okay for PVDIS or SIDIS forward angle, but not for SIDIS large angle
  - Difference between PVDIS and SIDIS large angle complicates re-arrangement.
- Clear Fibers (3-5m from SIDIS large angle to readouts): KURARAY, clear PS, Super Eska;

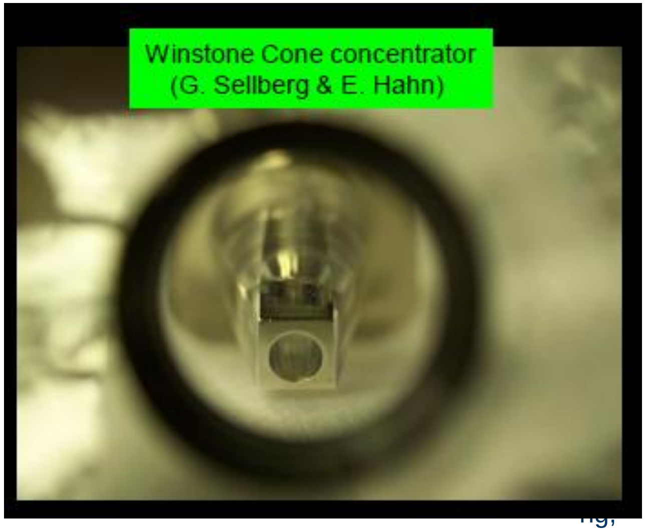
Design Consideration 6: Fibers & Connectors

Fiber connector options:



- One to one WLS/clear fiber connector: used in previous experiments (LHCb, Minos,…), light loss studies and design well documented, but costly and must run 2x50000 fibers to readouts for SIDIS large angle alone;

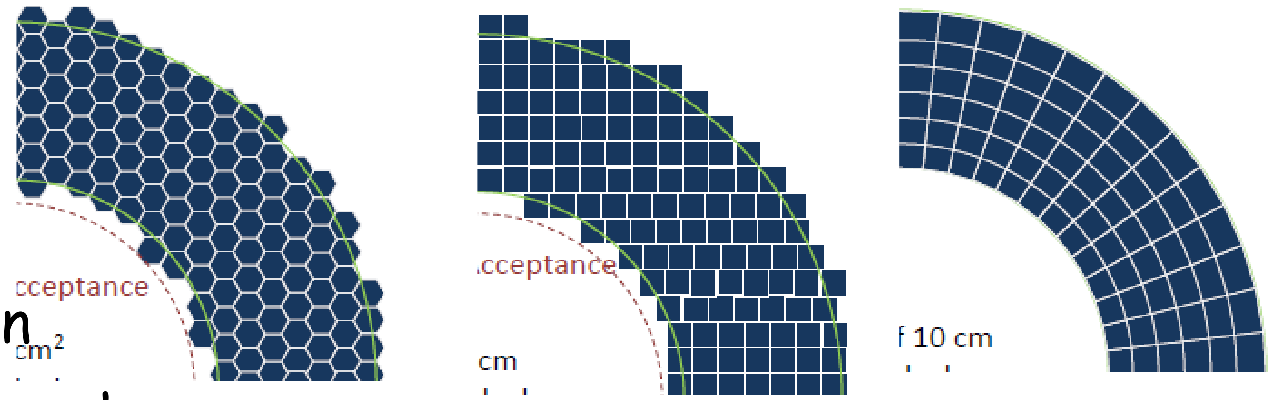
- Lucite rod would reduce the cost, but rigid and no information on light loss.



- Winstone cone concentrator from Fermi Lab (~20 fibers to f3-mm, read out by 9 clear fibers): need 5000 cones + clear fibers (SIDIS large angle alone); larger clear fibers?

- Searching for other fiber bundle to bundle connection.

Design Consideration 7: Shape & Layout



Prefer Square

- easy assembly
- mature production
- easier rearrangement

Cost Estimation

Total ~ $5M
+ clear fiber

- Based on module $1500EA, PMT~$500EA;
- Table not including clear fibers and connectors, and DAQ.

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Overview of Current Design

Based on COMPASS Shashlyk module design.

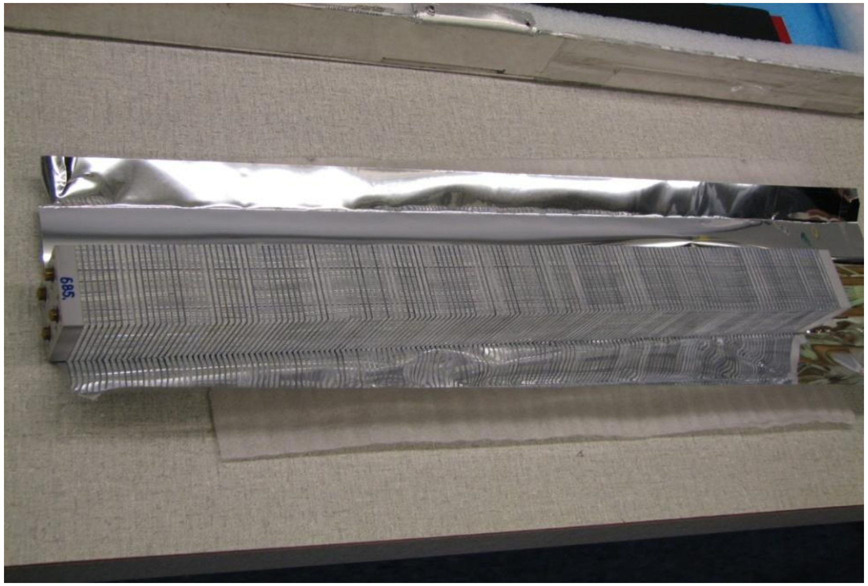
- 0.5mm Pb/1.5mm scintillator, 240 layers
- 48cm long (20 X_0), $4X_0$ preshower, $16X_0$ shower.
  - Balance between longitudinal size and pion rejection
  - 20:1 - 100:1 pion rejection with 95% electron efficiency (depending on momentum)
- 10x10cm^2 square shape modules ← balance between cost and position resolution/background
- 100 WLS fibers per module (1/cm^2, KURARAY Y11)
- Total 1500(SIDIS) ~ 2000(PVDIS) modules
- Fiber connection still being studied

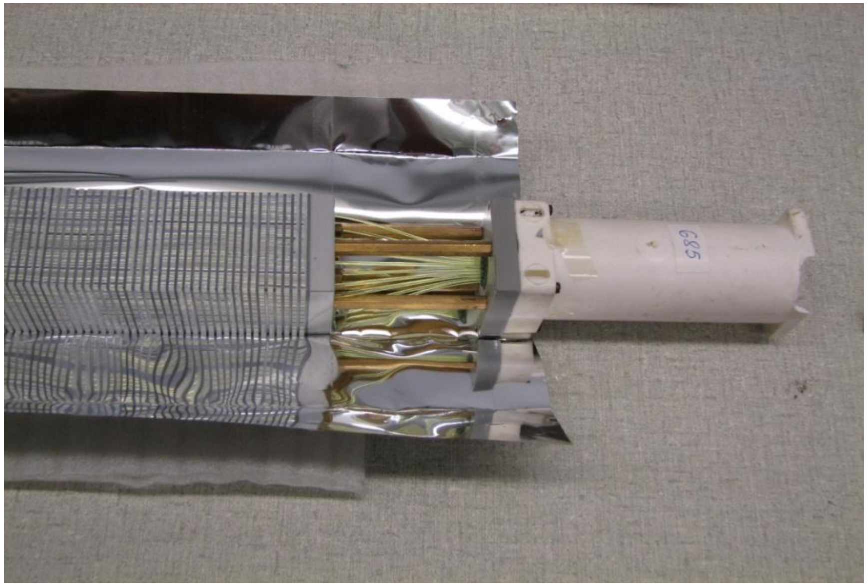
Summary

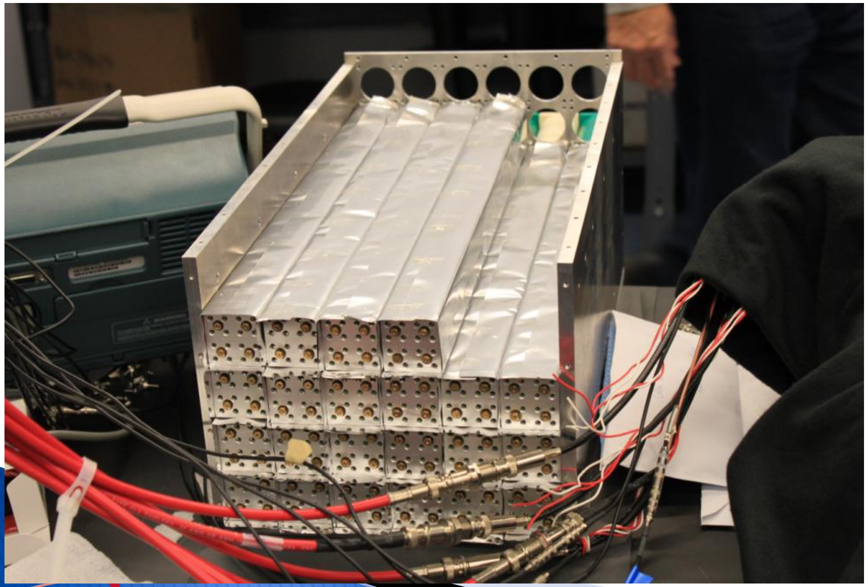
- EC is the key detector for electron-hadron separation in SoLID.
- The challenges:
  - reach good pion rejection
  - operate in high radiation environment
  - and strong magnetic field.
- Preliminary design is on-going.
- We will collaborate with IHEP on prototyping and production.

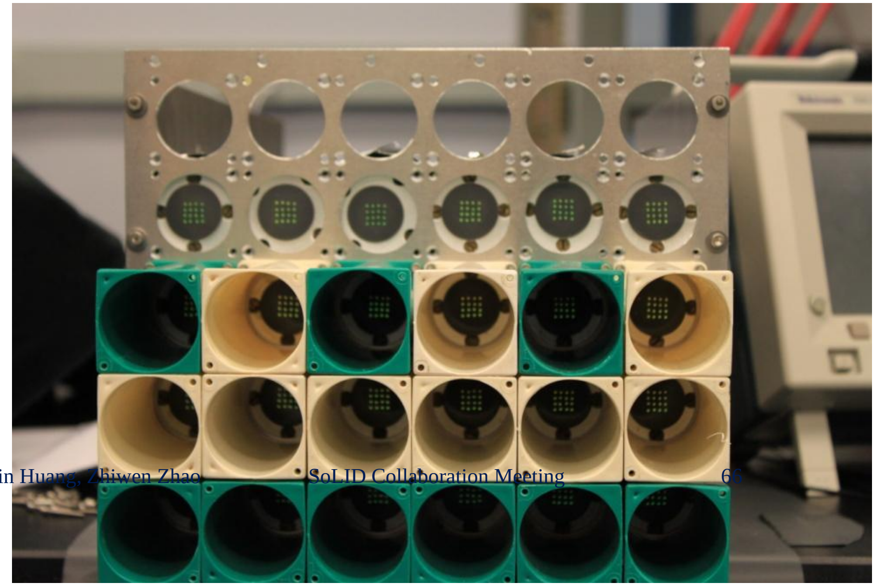
Backup for beam test in Hall B

COMPASS modules used for TPE@CLAS





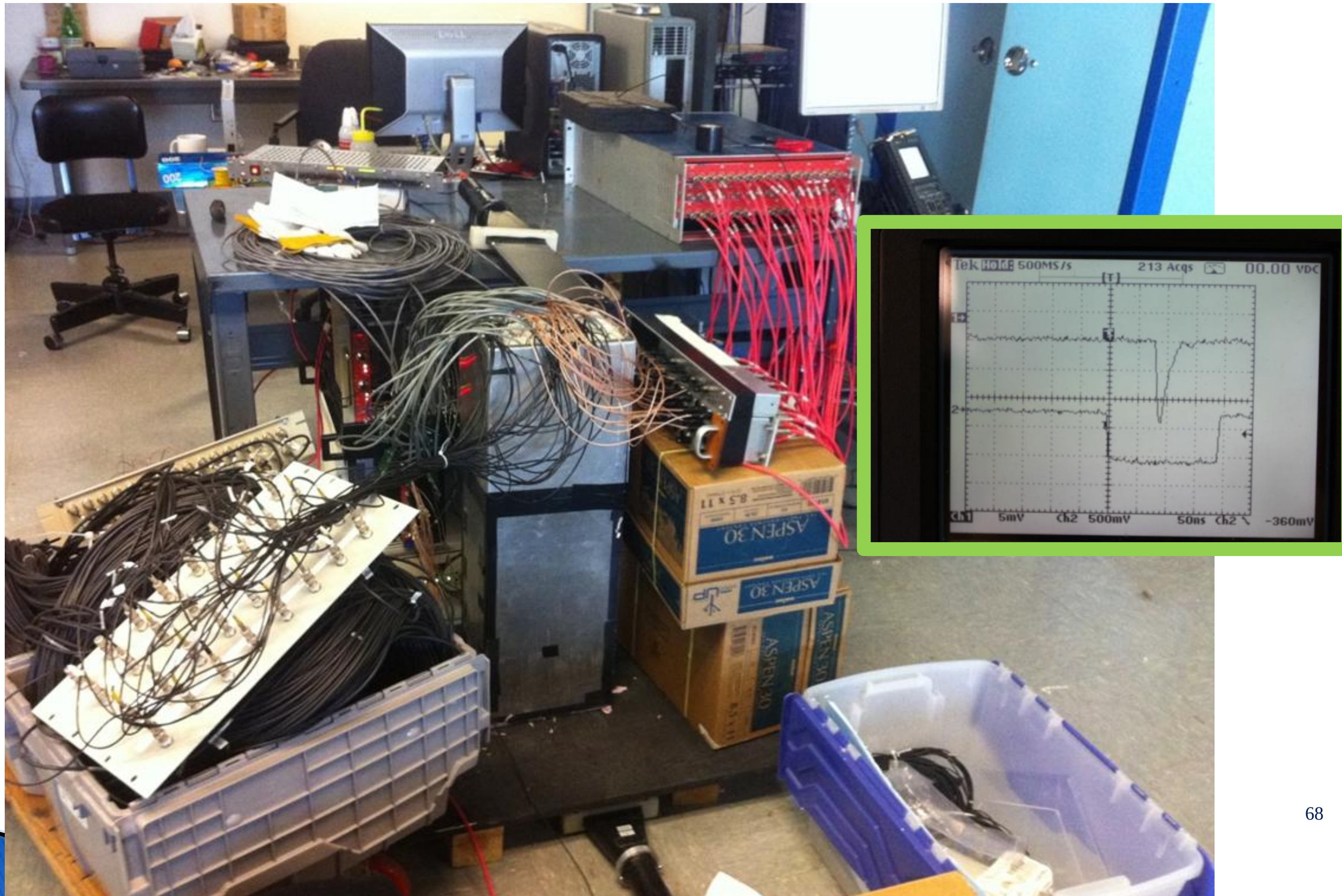




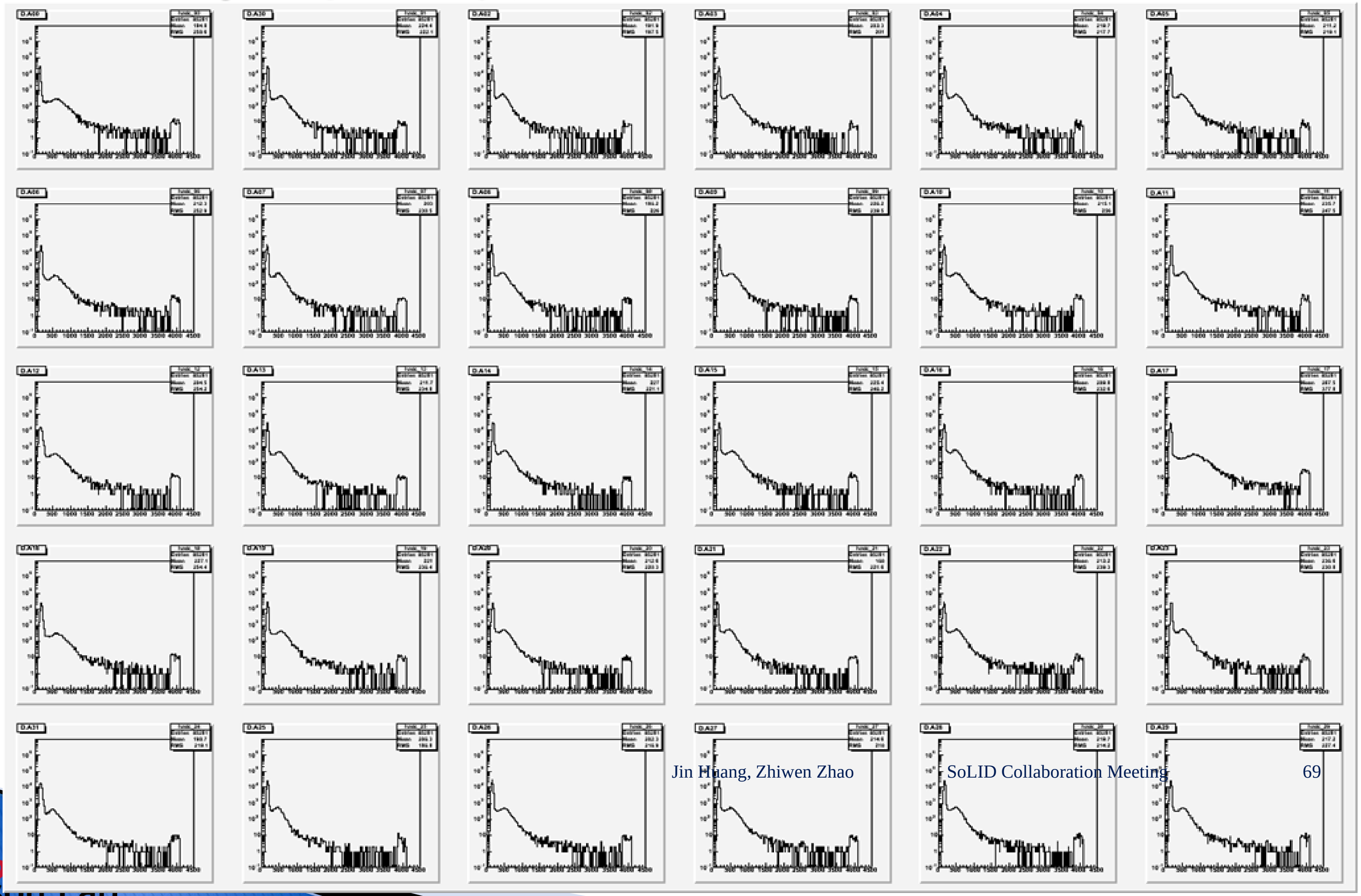
EC 4/2012 beam test: Modules and readout

- Module is in TPE frame with original PMT removed. 30 of 3.8x3.8cm modules in 6x5 array.
- Readout: 1.1"D Photonis
- XP2972 PMTs, used in HallA
- DVCS proton array.

Cosmic ray test (vertical setup) on 2nd floor counting house

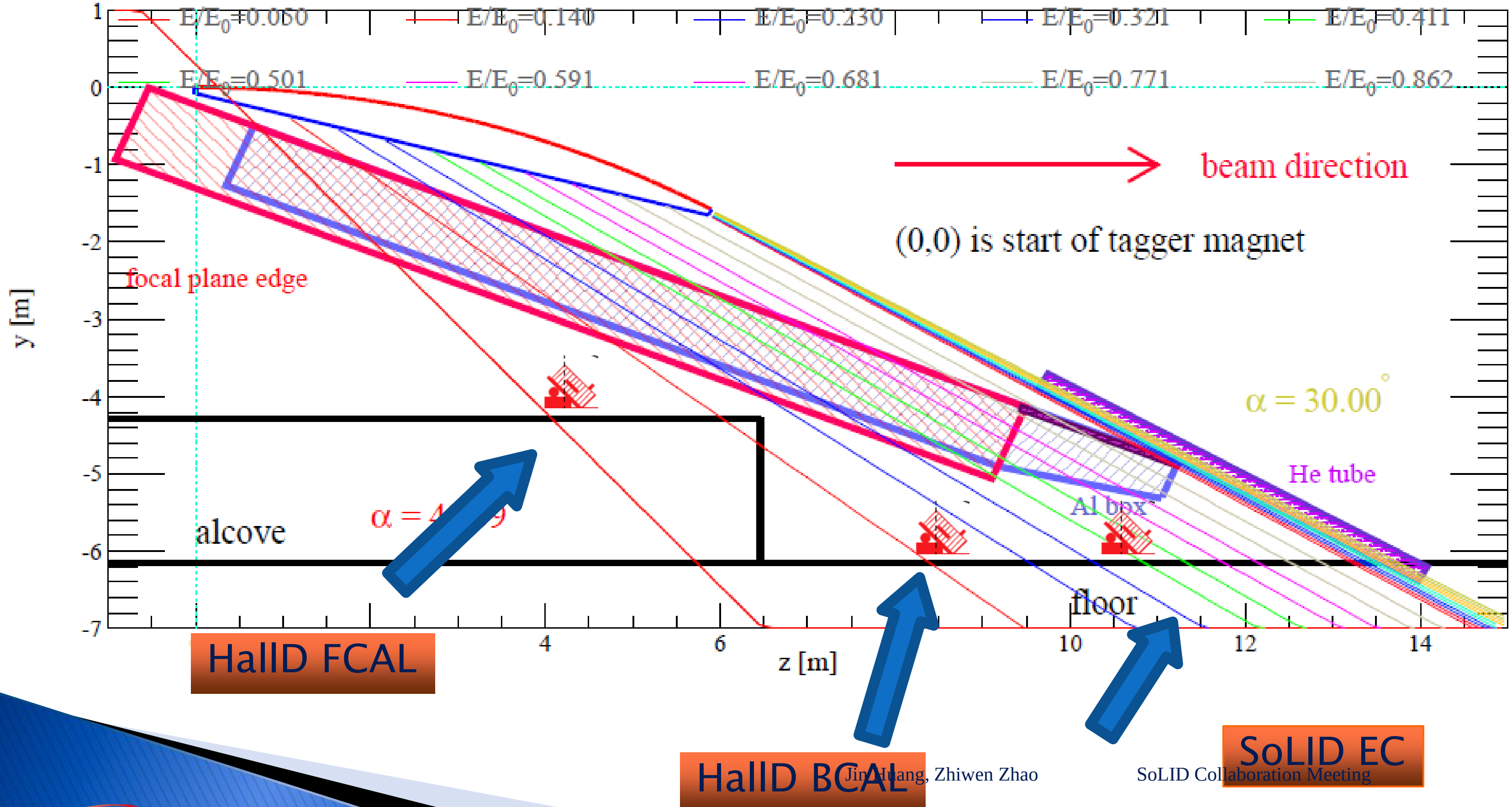


Cosmic ray gain match
after matching, most signals are within factor of 0.7-1.5



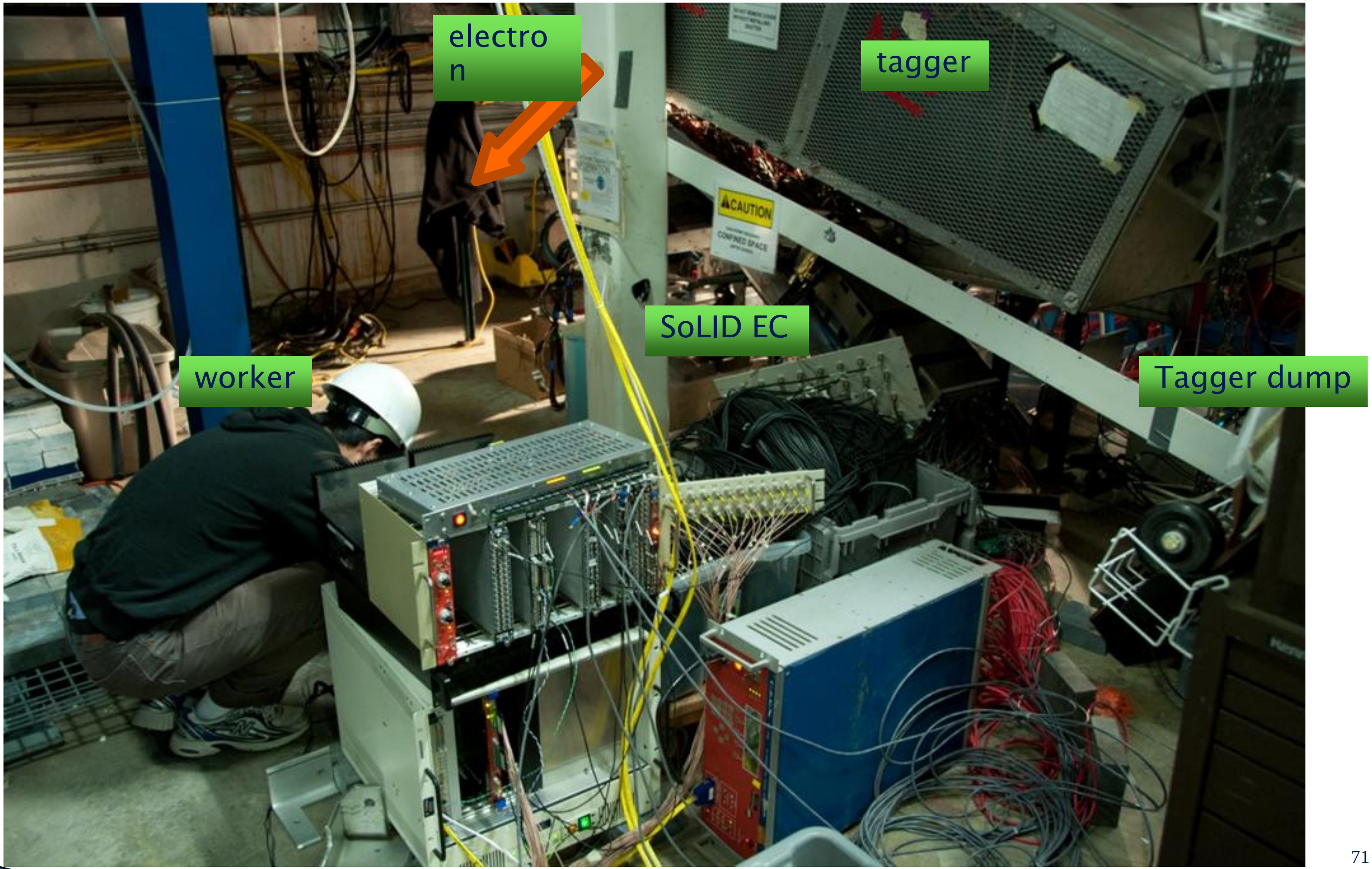
4/2012 Test under CLAS photon tagger

- Electron with known energy and impact angle
- Possibility to use Hall B DAQ resources



Jefferson Lab

In HallB, under Photon Tagger



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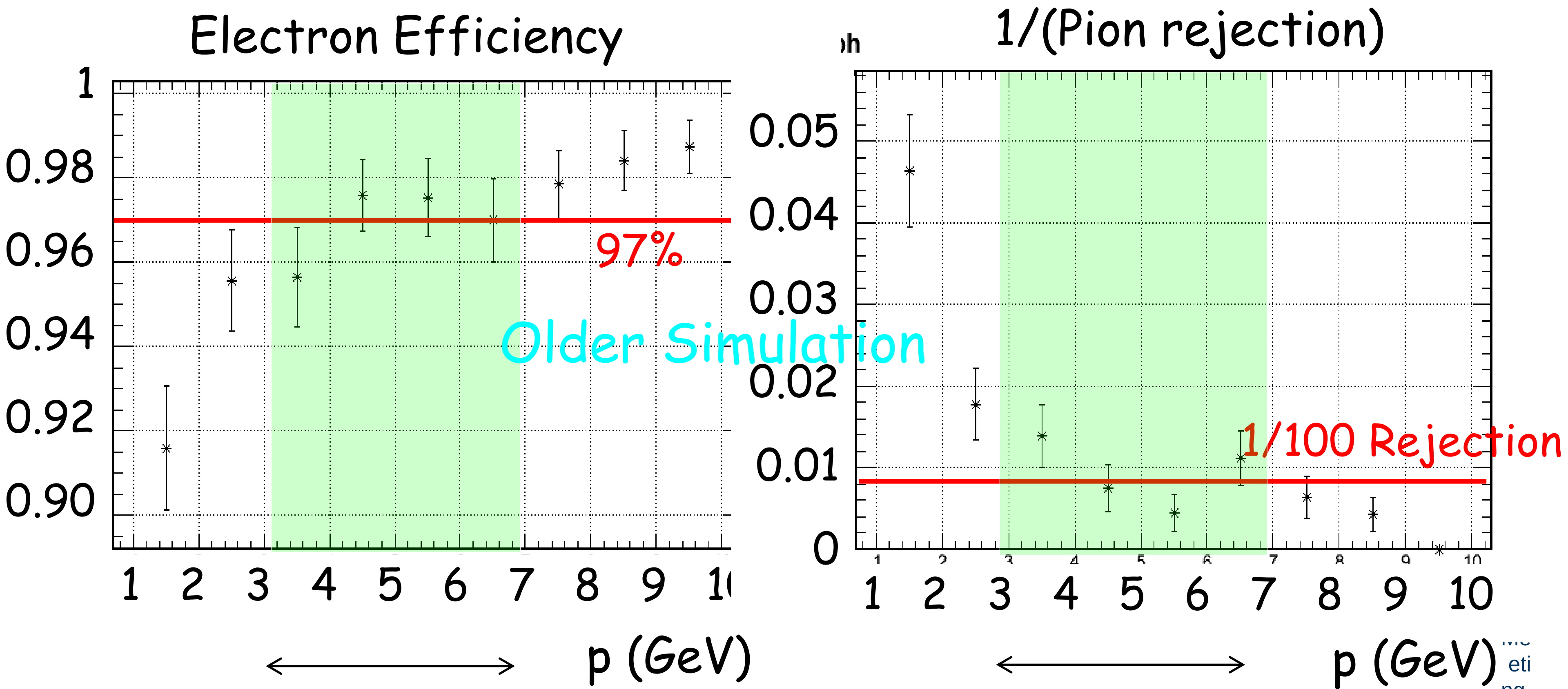
Backup

Clear/Extension fiber cost

- One-one connection:
- SIDIS forward WLS: 2x1000 modules x 100 fibers/module x 1m x $1.5/m = $800k
- SIDIS large angle clear: 2x 500 modules x 100 fibers/module x 4m x $2/m = $300k
- PVDIS: +1000 modules in forward → $800k+$800k (changing fibers) or $800k+$400k+$300k (keep clear fibers)
- Total: $1.6M + 200,000(?) connectors
- Winstone cone:
- # fibers reduce by factor 2.2 (or more) → $0.73M (or less) +10,000 Winstone cones.

Design Consideration 1: Pb/scintillator ratio

- Minimize scintillator ratio while reaching 100:1 pion rejection → 0.6mm Pb/1.5 mm Scint. (BASF143E) per layer.

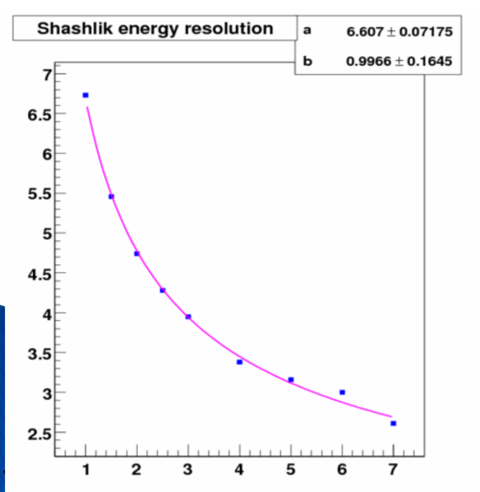


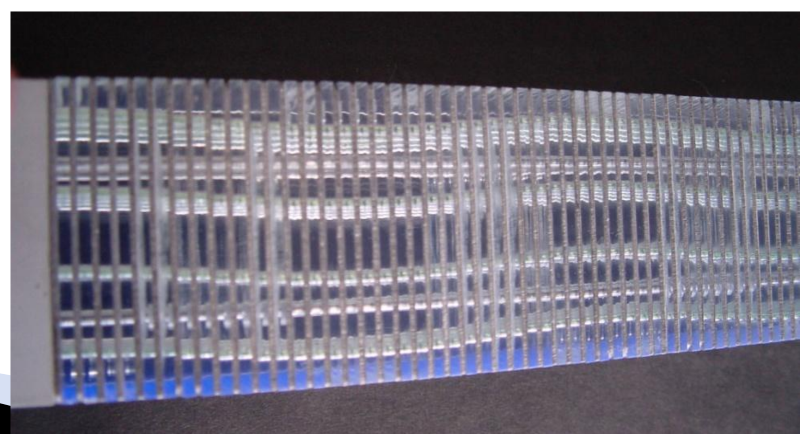
SIDIS large angle: 3~7 GeV

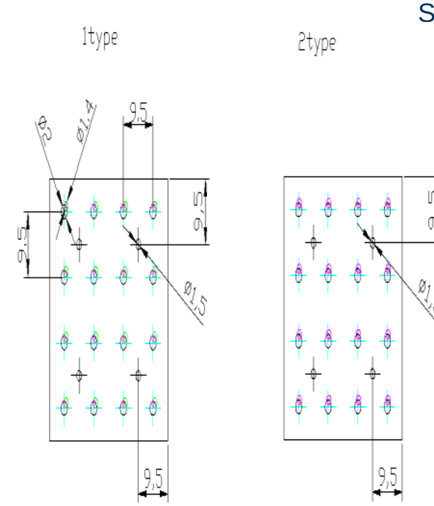
ECAL Shashlik

- Dimensions 38.2x38.2 mm2
- Radiation length 17.5mm
- Moliere radius 36mm
- Radiation thickness 22.5 X0
- Scintillator thickness 1.5mm
- Lead thickness 0.8mm
- Radiation hardness 500 krad
- Energy resolution 6.5%/√E 1%

So







Radiation on preshower

Reaching radiation limit (30% reduction in light output) for current approved experiments (about 300 PAC days)

A few possible solutions

Swapping modules between large R-inner R

- Radiation dose varies by factor of ~10

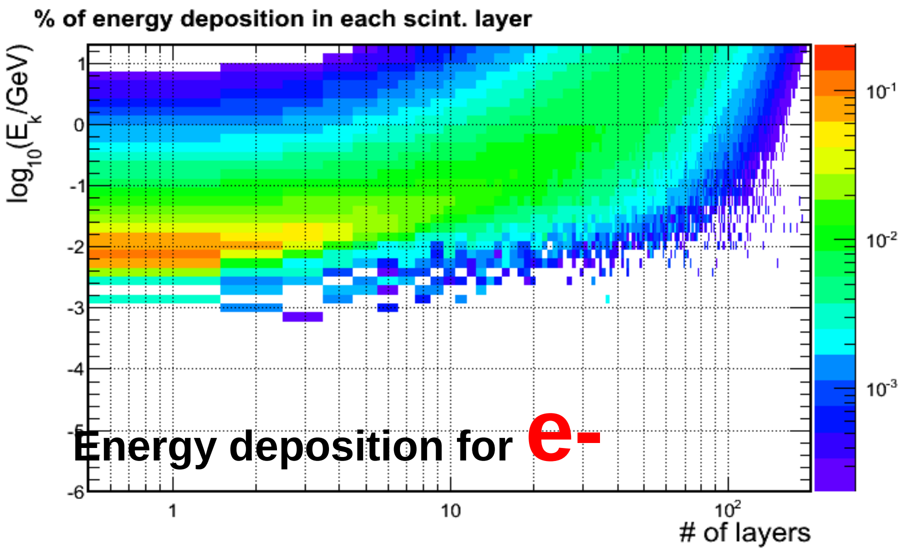
Keep searching for high radiation-resistant fiber/scintillator

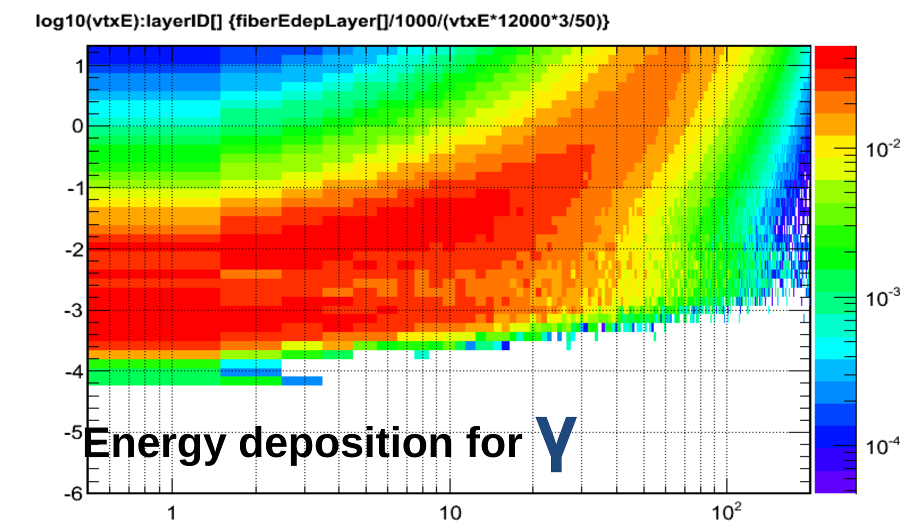
Replacing the preshower part of calorimeter

Redesign preshower with PbWO4/LYSO crystal with wavelength shifting fiber read out

Simulate the radiation level

- Overall dose close the calorimeter limit
  ->
  inspect radiation inside calo.
- The radiation dose for scintillators is 100krad~2Mrad (material dependent)
- Use Geant3/Wiser tools to simulate radiation background
- Use Geant4 simulate energy deposition in each layer for various background





Positioning calorimeter for PVDIS

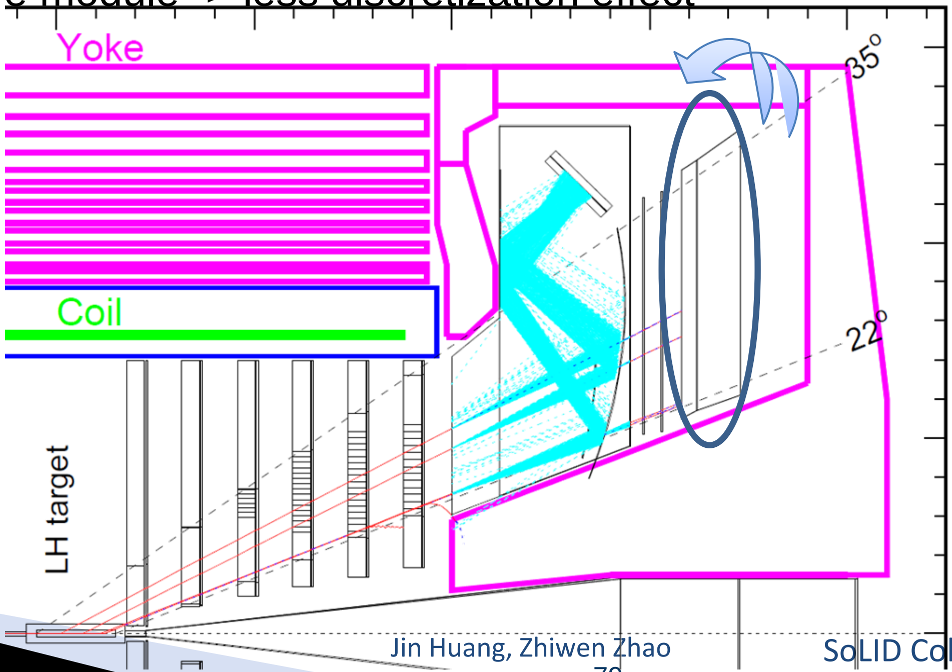
PVDIS calorimeter have largest polar angle

22 – 35 degree

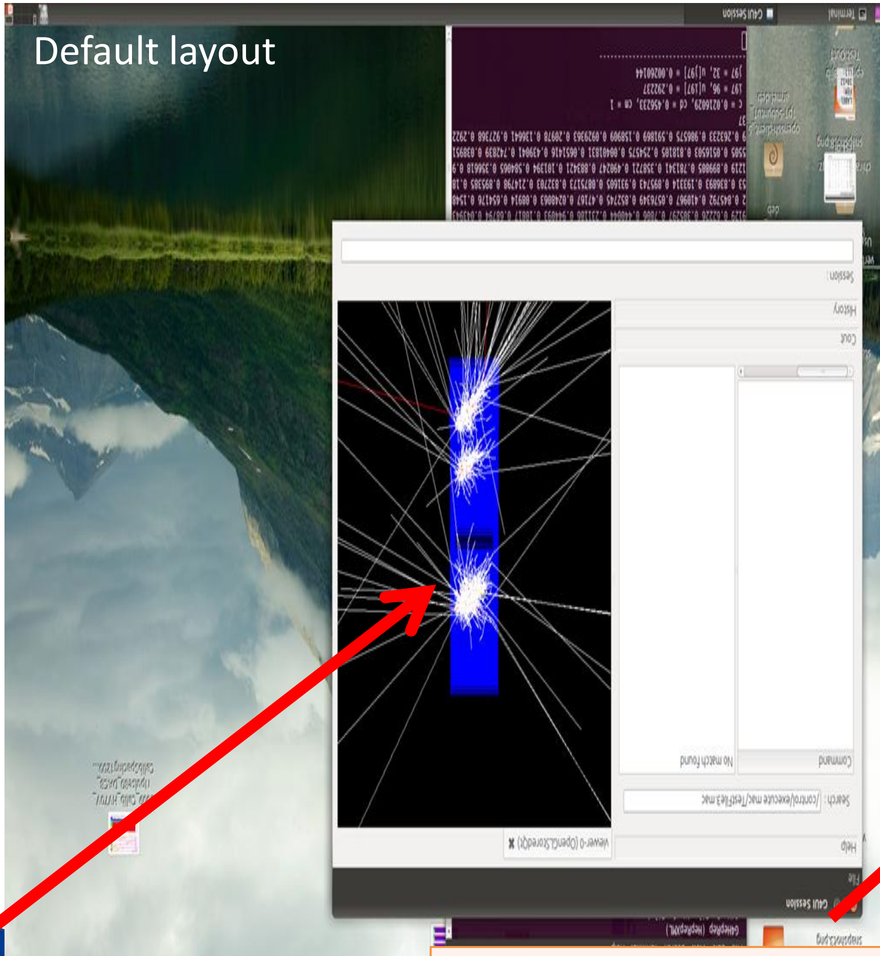
Not full azimuthal coverage, possible to rotate

Two main factor relates resolution with larger indenting angle

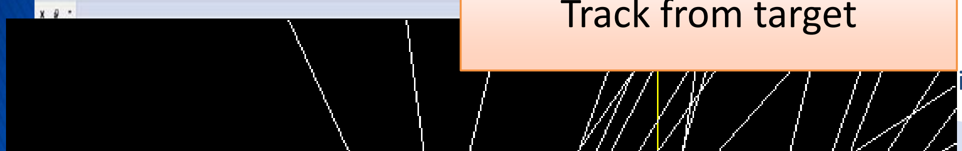
1. Variation in shower position along track translates into transvesre position
2. Spread charge into more module -> less discretization effect



Tested in specialized Geant4 simulation with SIMC inputs of realistic tracks



Track from target



Corrections

Shower location at predefined plane of nominal max shower =

Center of gravity

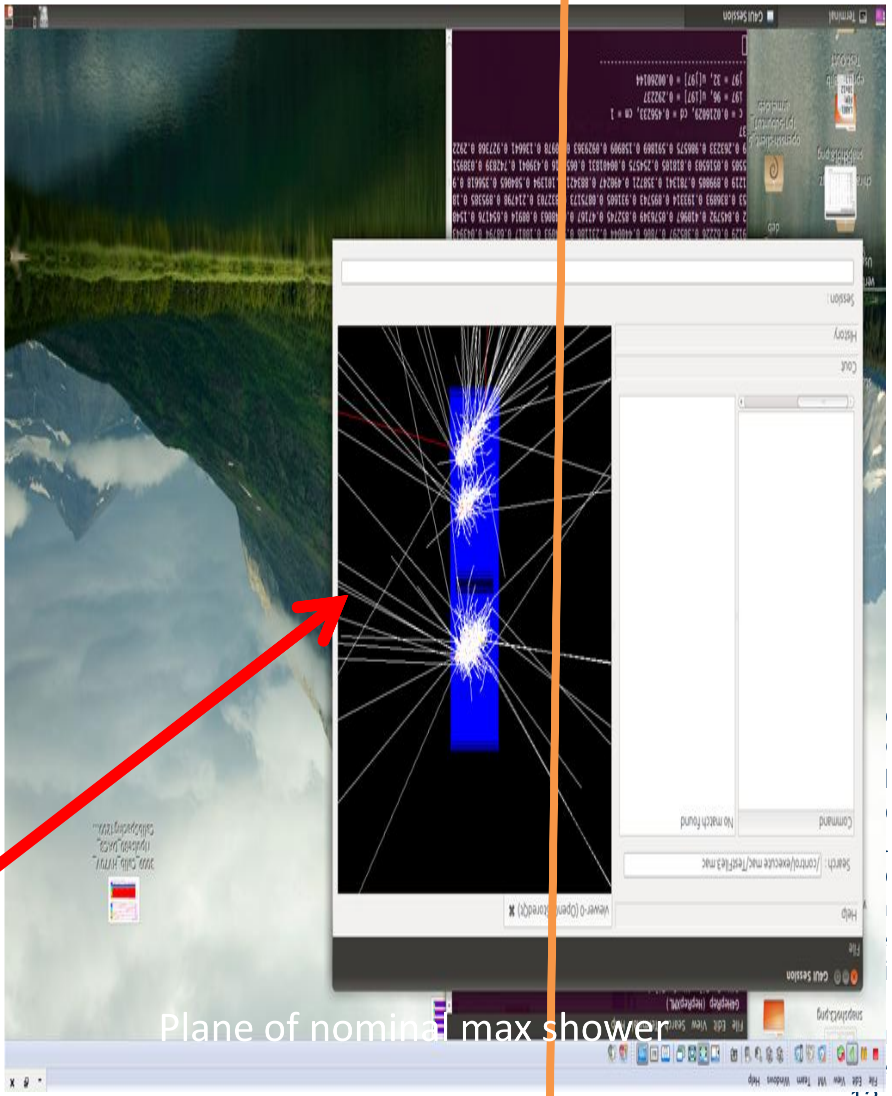
- Average position with energy weighting

Energy/slope correction

- Shifting of shower center with energy, fitted from simulation
- Information available from calorimeter only

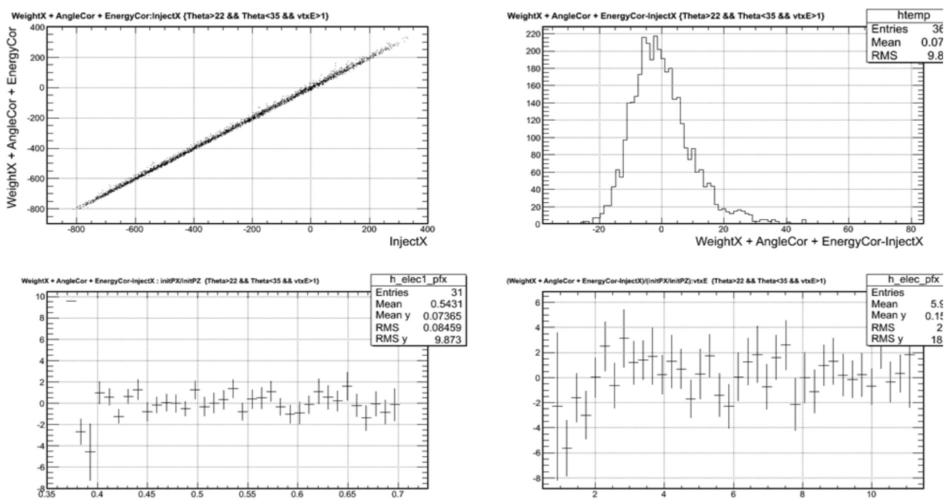
Discretization correction

- Position readout discredited to center of each module
- Can be corrected to some extent (see later slides)



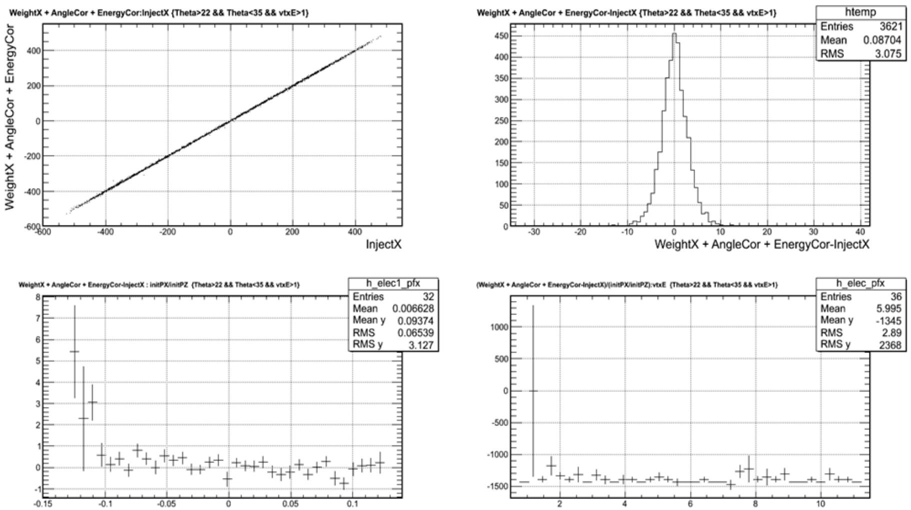
Effect 1: Probing shower longitudinal size effect w/ very fine segmentation

Nominal layout



Residual for corrected shower position (mm)

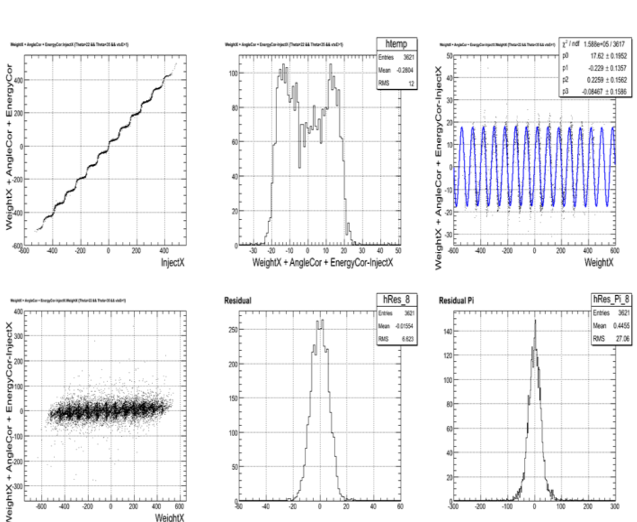
Facing track



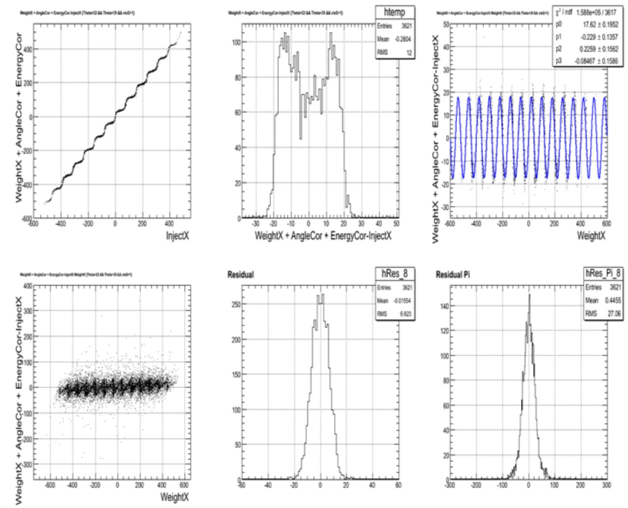
Residual for corrected shower position (mm)

- At nominal of 28 degree, variation of shower translate to 1 cm of uncertainty from the detector intrinsic best ~0.3 cm

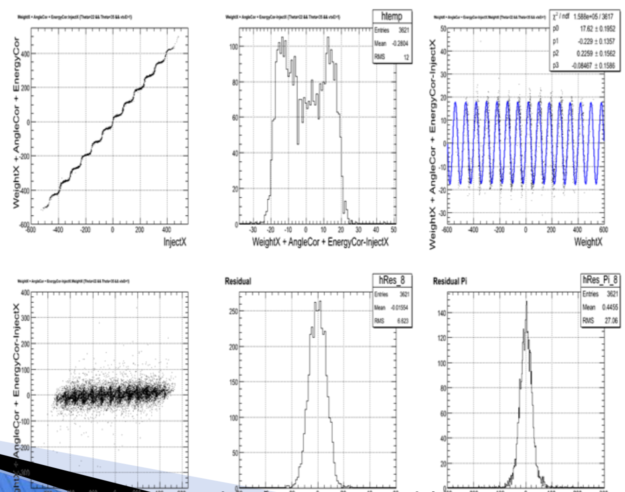
Effect 2: Probing shower longitudinal size effect w/ very fine segmentation



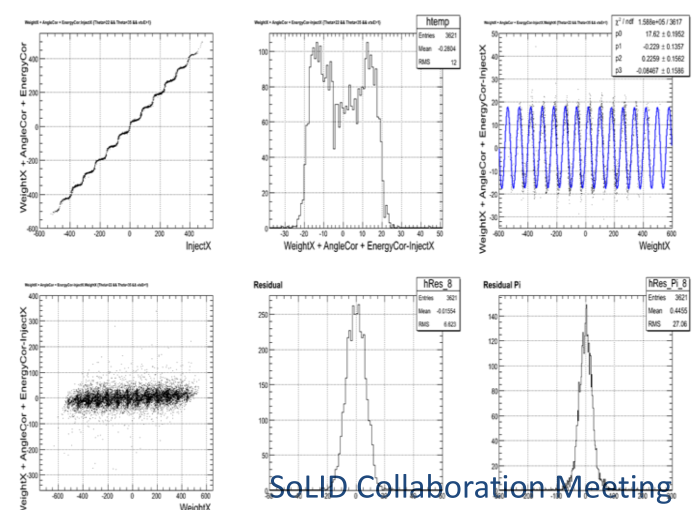
Residual (mm) of center of of gravity
for 8x8 cm module = 12 mm



Reconstructed location
VS track projection



Corrected residual, improved by 2

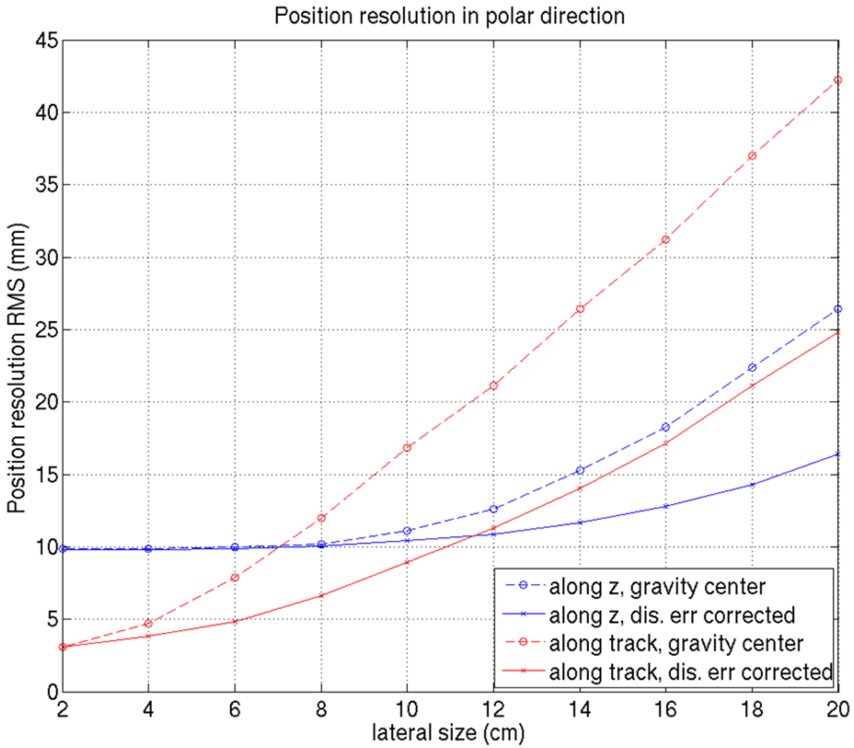


Fit and correct discretization effect
(Based on calorimeter response only)

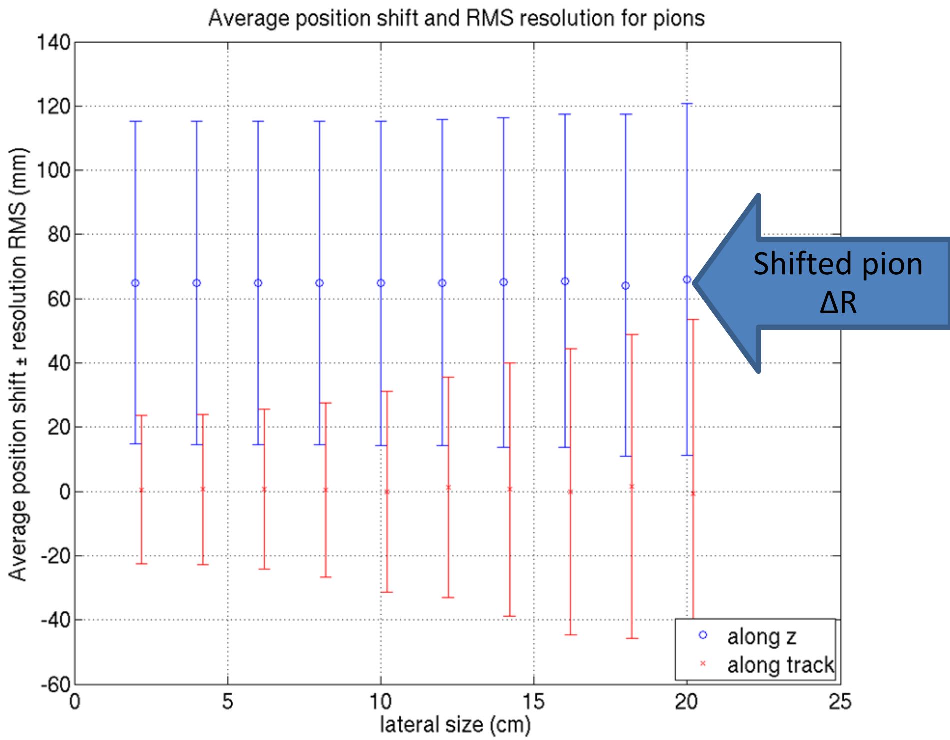
Position resolution VS lateral size

- Blue: calorimeter modules along z axis
- Red: calorimeter modules along central track

Electron



Hadron



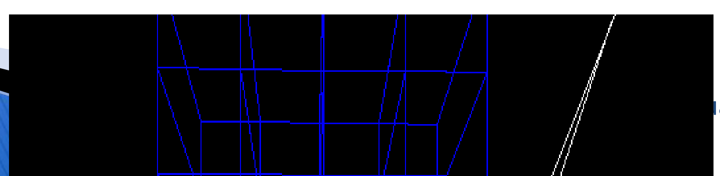
Comparison between two choise

- No show stopper in either case

Nominal layout (along z)	Rotated to face track
Simple to support Less discretization error	Better resolution after correction Better pion reconstruction Smaller size in R Personal preferable

Simulate edge effect

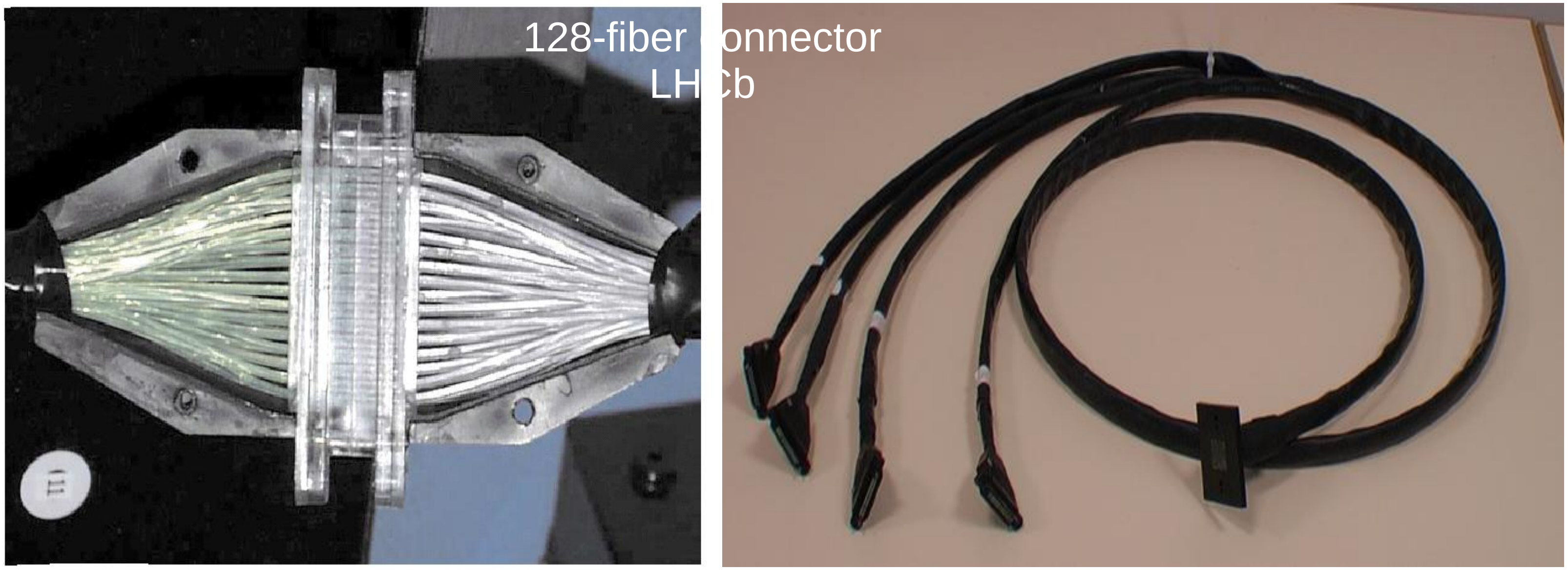
- Calorimeter module laid long z direction
- Particle impacts to calorimeter with an angle to normal direction
- Edge event can not be fully contained in calorimeter
- How wide is this edge region?



Calorimeter Design: Connectors

❖ Option 1:

One to one WLS/clear fiber connector, used in previous experiments (LHCb, Minos)

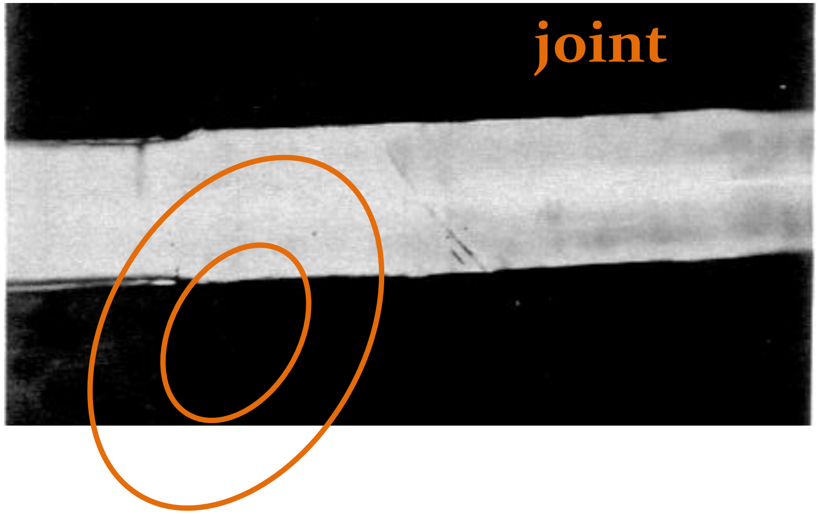


Calorimeter Design: Connectors

- **Option 2:**

  Thermal fusion: splice the WLS and clear fiber.

  Giorgio Apollinari et al NIM in Phys. Research. A311 (1992) 5211-528



- **Option 3:**

  Glue the WLS fibers to a lucite disk coupled to a lucite Rod with optical grease or Si gel "cookie".

  Would reduce the cost significantly

d more R&D to decide what is the best option.