SoLID EC Design

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SoLID Jlab Physics Division
Brainstorming Session
2012/01/06

Jefferson Lab

OUTLINE

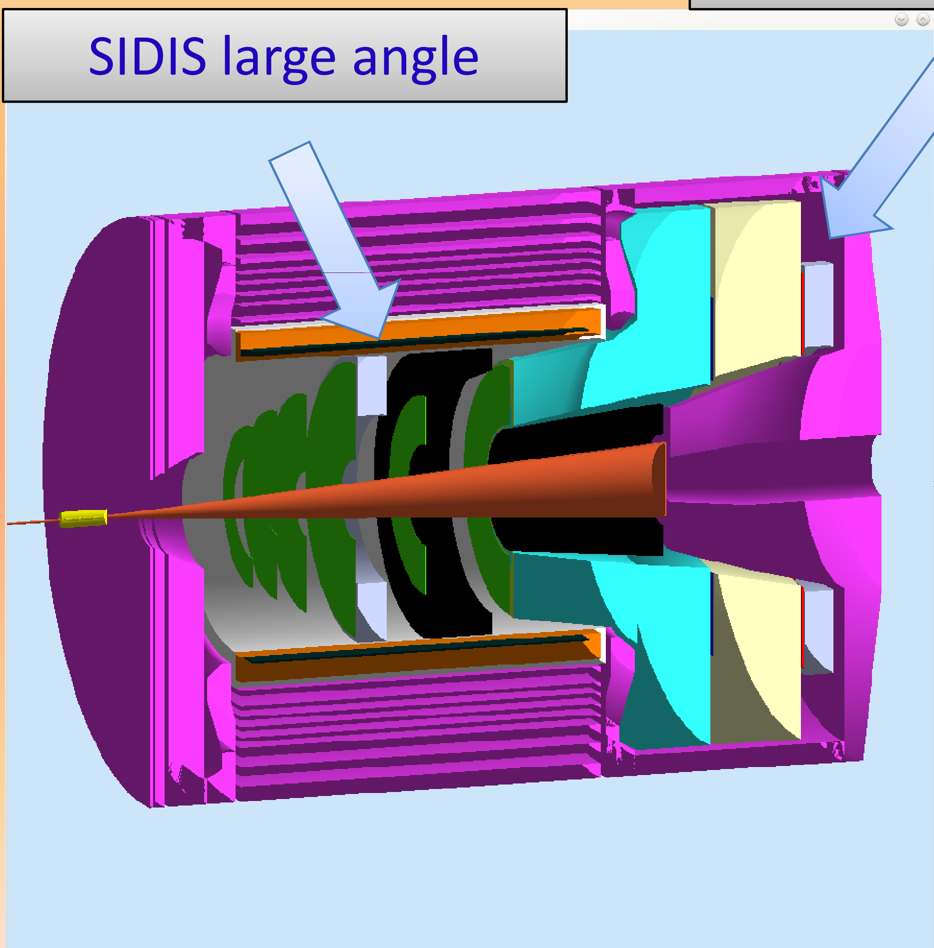
Requirement

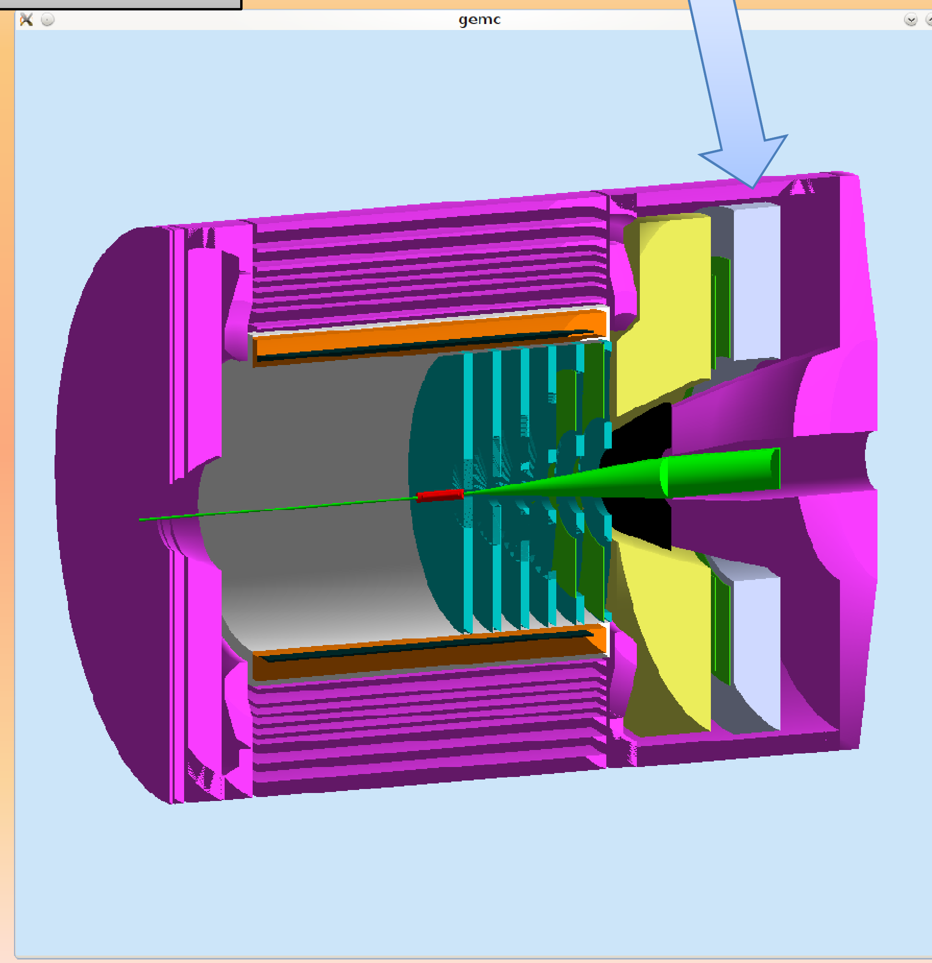
Design Progress

- Choosing Shashlyk
- Our Design
- Preshower/shower
- Fiber connection
- Background Simulation
- Beam test plan

Todo List

EC Configuration





Physics Requirement

- Electron-hadron separation
  - 100:1 pion rejection in electron sample
  - Energy resolution: $\sigma(E)/E \sim 5\%/\sqrt{E}$
- Provide shower Position
  - $\sigma \sim$ 1 cm, for tracking initial seed / suppress background
- Time response
  - $\sigma <\sim$ few hundreds ps
  - provide trigger/identify beam bunch (TOF PID)
- Radiation resistant
  - PVDIS forward angle
    - EM <=2k GeV/cm^2/s + pion (GeV/cm^2/s), total ~<60 krad/year
  - SIDIS forward angle
    - EM <=5k GeV/cm^2/s + pion , total, total ~<100 krad/year
  - SIDIS large angle
    - EM <=20k GeV/cm^2/s + pion, total, total ~<400 krad/year

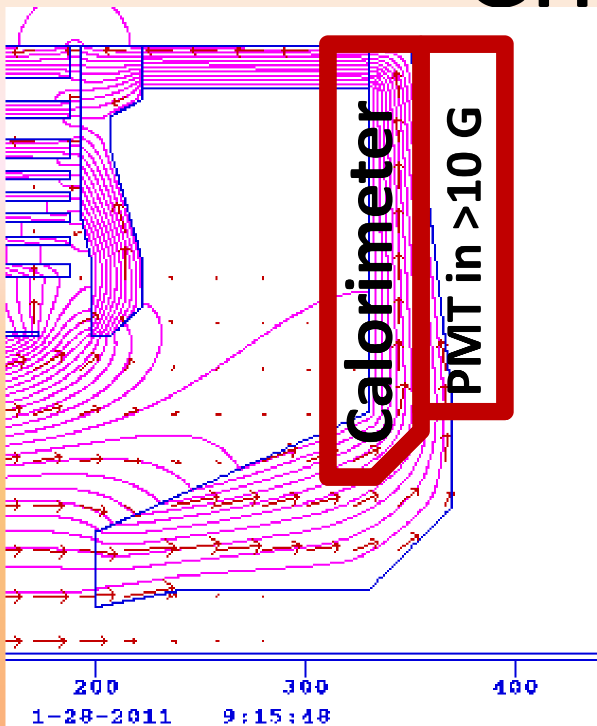
Other Requirement

- The Layout need to satisfy 2-fold rotation symmetry for SIDIS.
- Modules can be easily swapped and rearranged for different configuration.
- Photonsensors located outside of magnet yoke, fiber connection is one solution.
- A reasonable cost, strongly affected by the number of modules/channels, to cover the same acceptance area, we need the module transverse size not too small.

Choosing EC Type

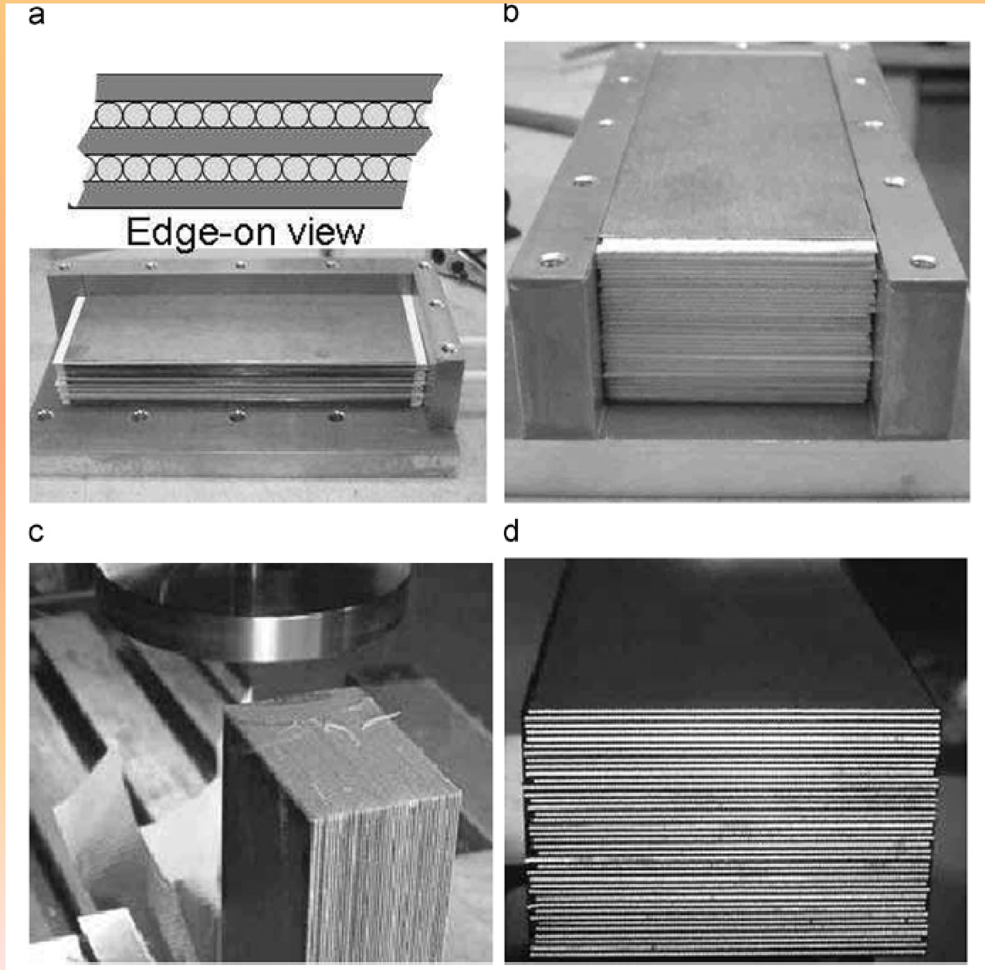
- PVDIS and SIDIS radiation level (400krad per year) is too high for lead glass and crystals (1krad), both Shashlyk or SPACAL/SciFi (0.5-1M rad) will work.
- Both Shashlyk and SciFi have good energy, position and time resolution.
- ***SciFi costs more***
  - SciFi needs about half volume being scintillation fibers for good energy resolution.
  - 1mm diameter fibers cost $1/m.
  - Forward angle EC (10m^2 area, 0.4m depth), Large angle EC (5m^2 area, 0.4m depth)
  - SciFi , total **$4M** for the ***fiber** alone.*
  - Shashlyk , total from **$1.5M to $2.2M** for **produced modules** of 10x10cm from IHEP.

Choosing EC design

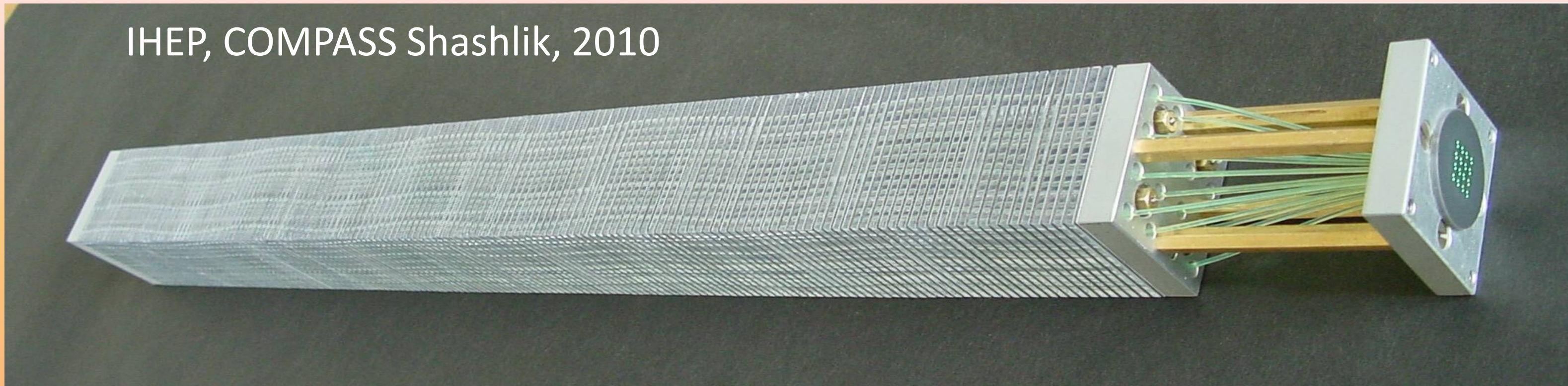


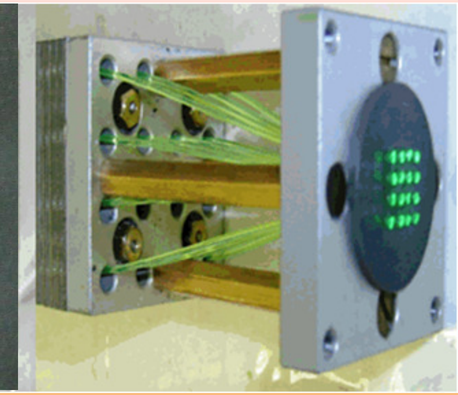
- Scifi/Fe combined with flux return
  - Simulation shows feasibility.
  - Need significant R&D effort.

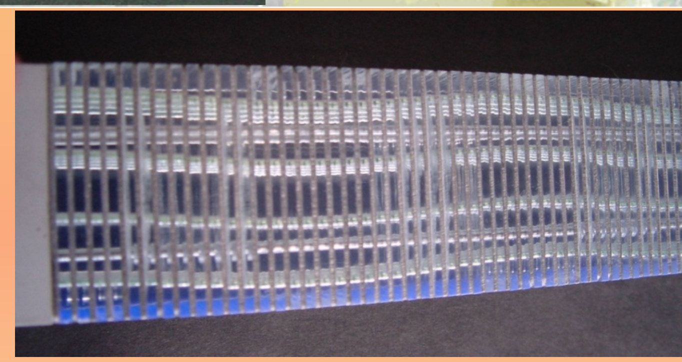
- Scifi/Pb standalone
  - 10M of scintillation fibers,connect to outside for readout by light guide.
- Shashlyk standalone
  - Mature production at IHEP@Russia
  - 150k of WLS fibers,connect to outside for readout by light guide or fiber connection.



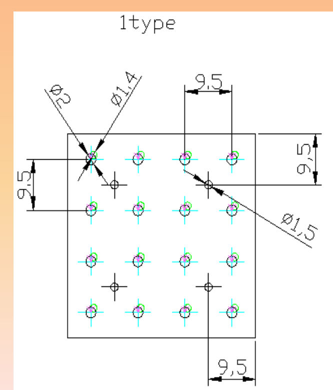
Best option:
Shashlyk Calorimeter







- Shashlyk calorimeter
  - Lead-scintillator sampling calorimeter
  - WLS Fiber collects and reads out light
- Satisfy the SoLID requirement
  - Good energy resolution (tunable)
  - transverse size can be customized
  - Radiation hardness ~ 500kRad (improvable)
- Easier to collect and read out the light
- Well developed technology, used by many experiments
- IHEP production rate about 200 per month



Basics Features of Preliminary Design

- Based on COMPASS Shashlyk module.

- 0.6mm lead/1.5mm scintillator, 200 layers, 42cm in length (20 X_0)
  - Balance between longitudinal size and pion rejection
  - ~100:1 pion rejection

- 10x10cm of transverse size in square shape
  - Balance between cost and resolution/background
  - 1000 modules for forward angle EC, 500 modules for large angle EC

- Splitting : ~4 X_0 for preshower and ~16 X_0 for shower
  - Maximizing e-pi separation
  - MIP energy deposition: ~60MeV (preshower)/300 MeV (TotalShower)

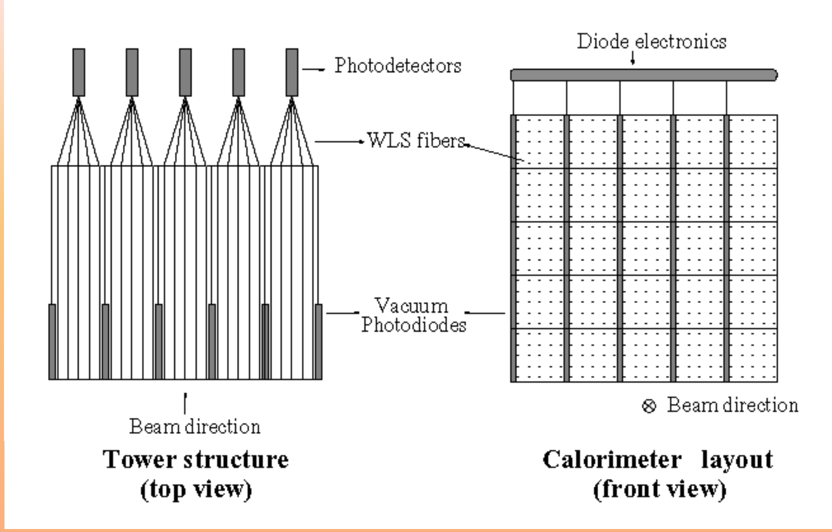
- ~100 WLS fibers/module (KURARAY Y11)
  - Same fiber density ($1/cm^2$) to sample the EM shower

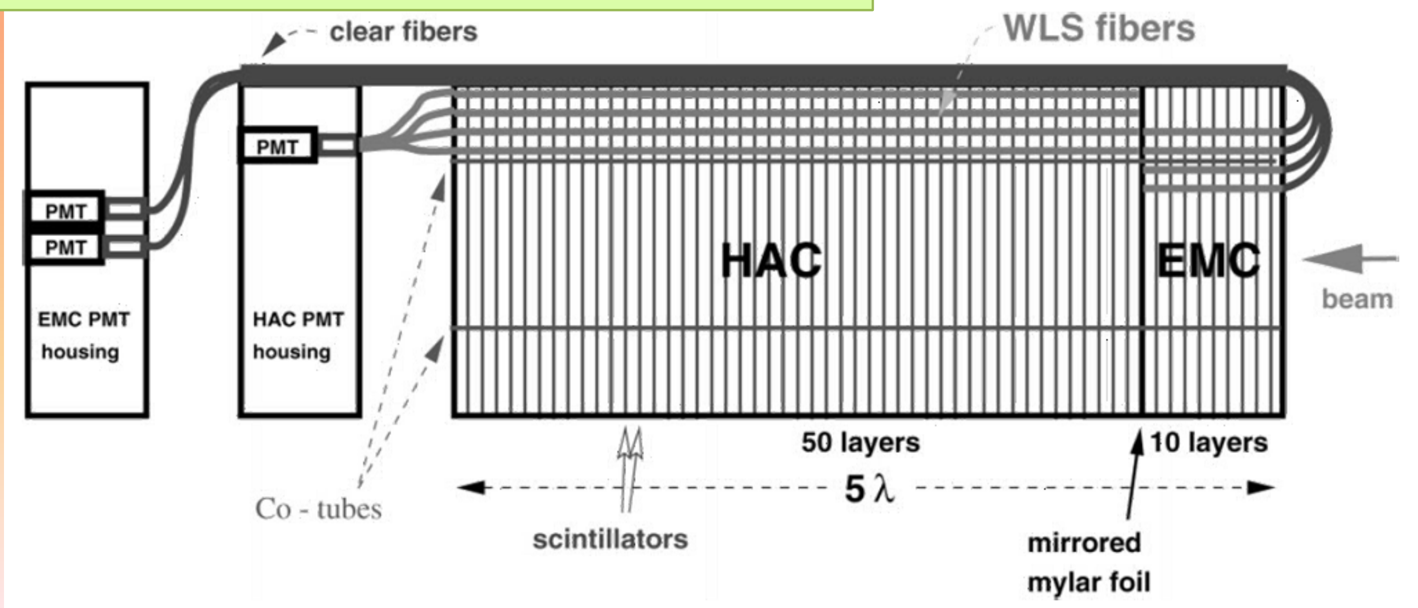
Preshower/shower

- Preshower-shower separation for better electron PID
- 4 RL as preshower, 16 RL as shower

Readout option 1, separate readout

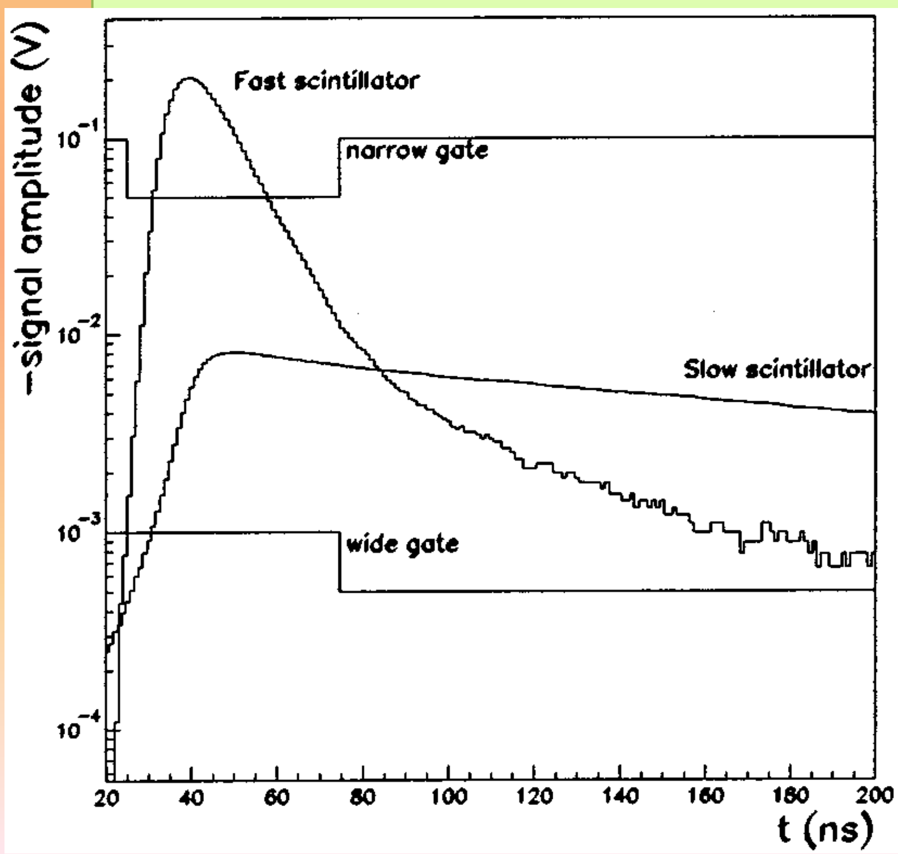
1. ***Run preshower fiber through shower part with light-protection***
2. Run preshower fiber (separately) to outside magnetic field
3. Curve fiber from front, ZEUS example below
4. Readout preshower by photodiode, example on right.



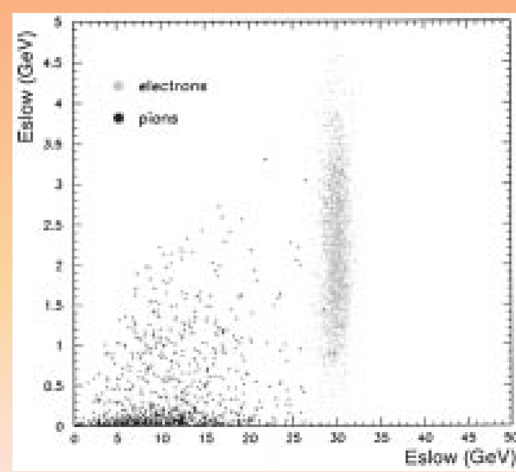


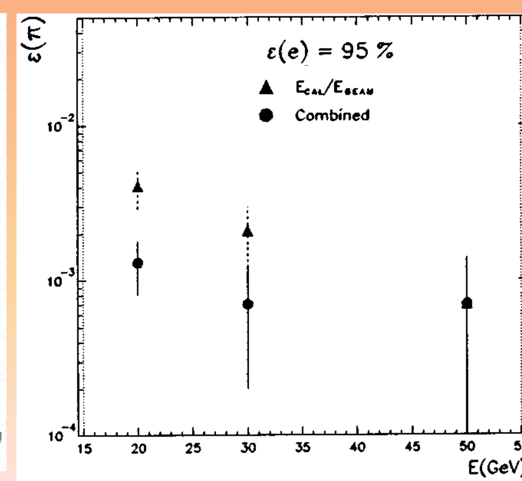
Preshower/shower

- Readout option 2, same readout
  - **•slow response scintillator for preshower and fast scintillator for shower.**
  - **•Use flashADC (4us) to fit line shape, could shorten the required time.**
  - **•Simple design and production, half number of fibers to connect, half number of channels for readout.**
  - **•High pion background may affect PID. SIDIS largeangle EC have low pion background**



CALEIDO has successfully built and tested prototype with traditional ADC



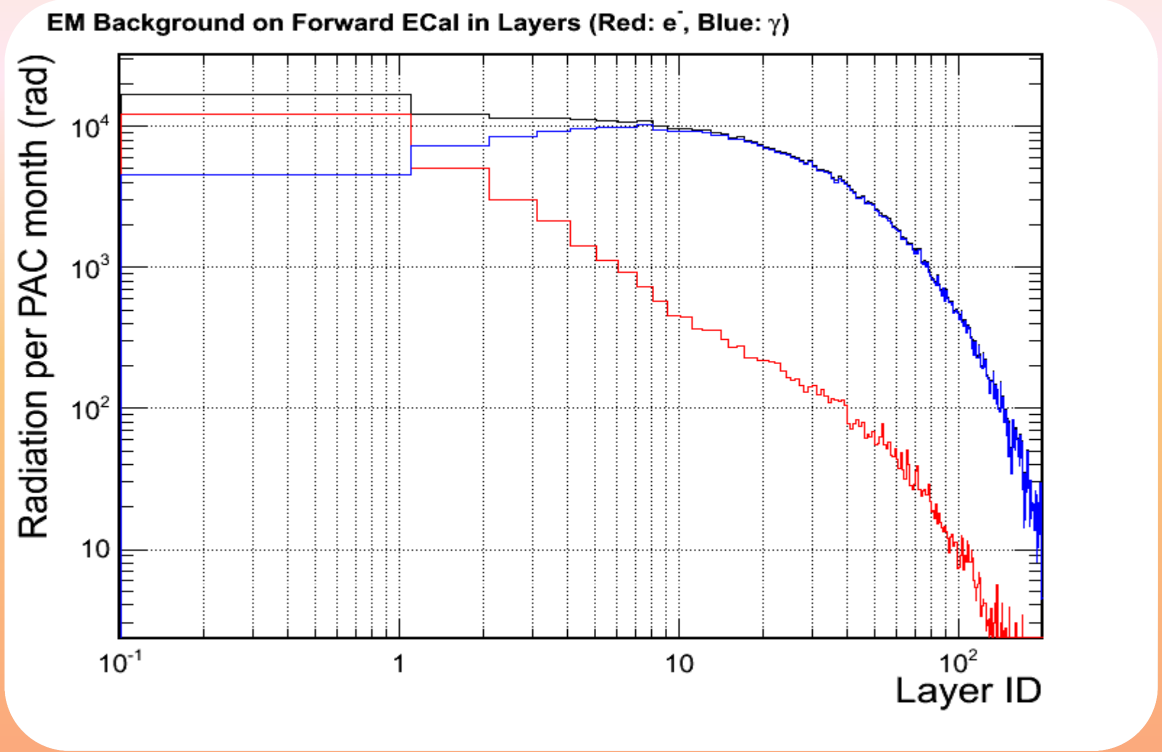


Calorimeter Design: Fibers

- **Fibers:**
  - Wave Length Shifting fibers (WLS): KURARAY Y11
  - Clear Fibers: KURARAY clear PS, Super Eska…,

- **Connectors**
  - One to one WLS/clear fiber connector, used in previous experiments (LHCb, Minos,…) light loss studies and design well documented
  - Lucite rod to couple the fibers option would reduce the cost, no information about the light loss
  - Fiber bunch diameter for one module 100 mm
    For 1500 modules, min. length of WLS: 150 km!
    Clear fiber length depends on the readout option ~500km?
  - Ongoing work: study of the fiber bundling design

Background Simulation

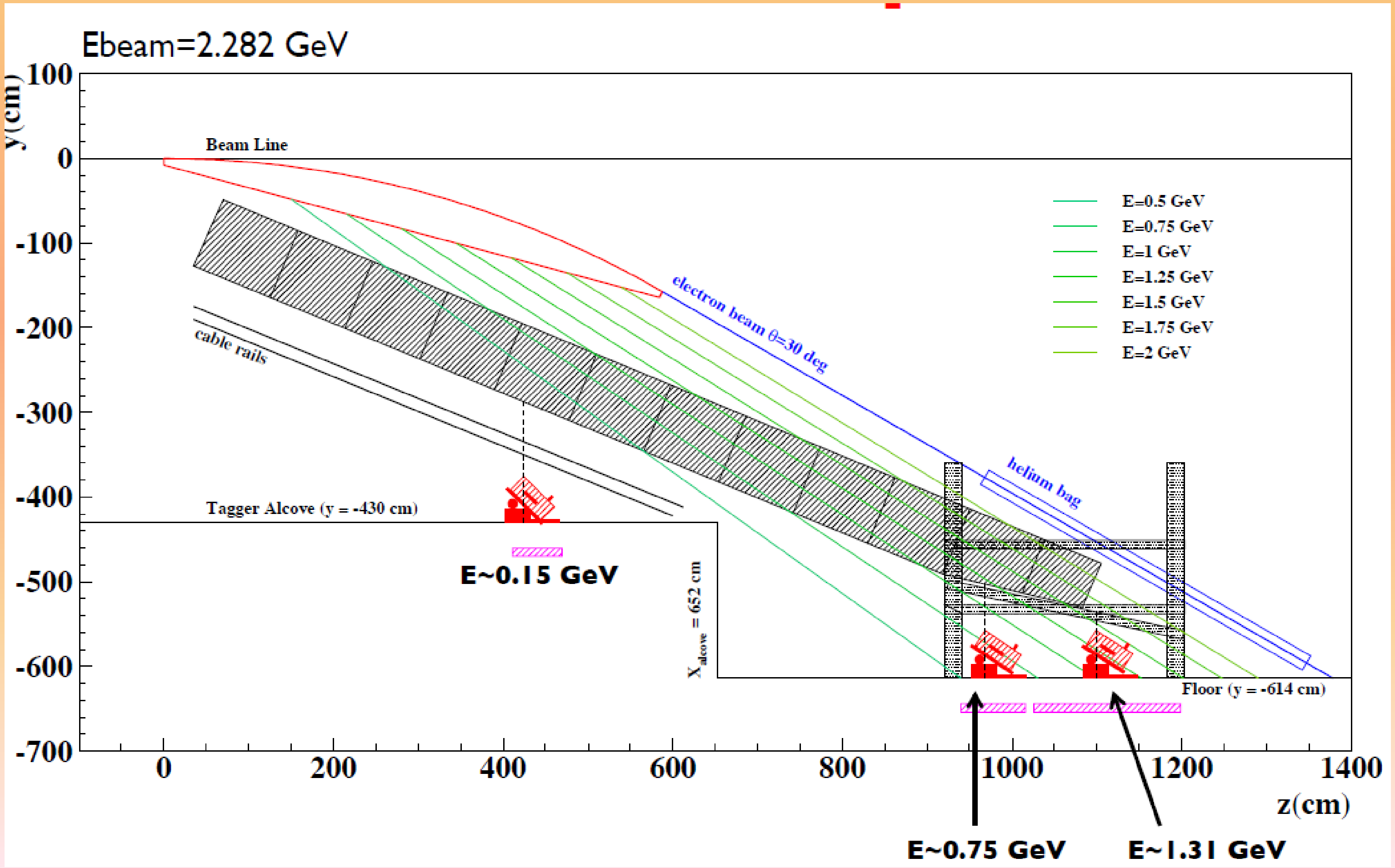


- The first 10 layers of scintillator have most of the radiation dose. Dominated by γ.
- Not much safety margin to radiation limit for some scintillator. Need to use radiation hard material.
- Can add a front shielding of 1~2mm lead (equivalent to 2~3 layers) to reduce the radiation in the first few layers.
- GEMC background model is being improved.

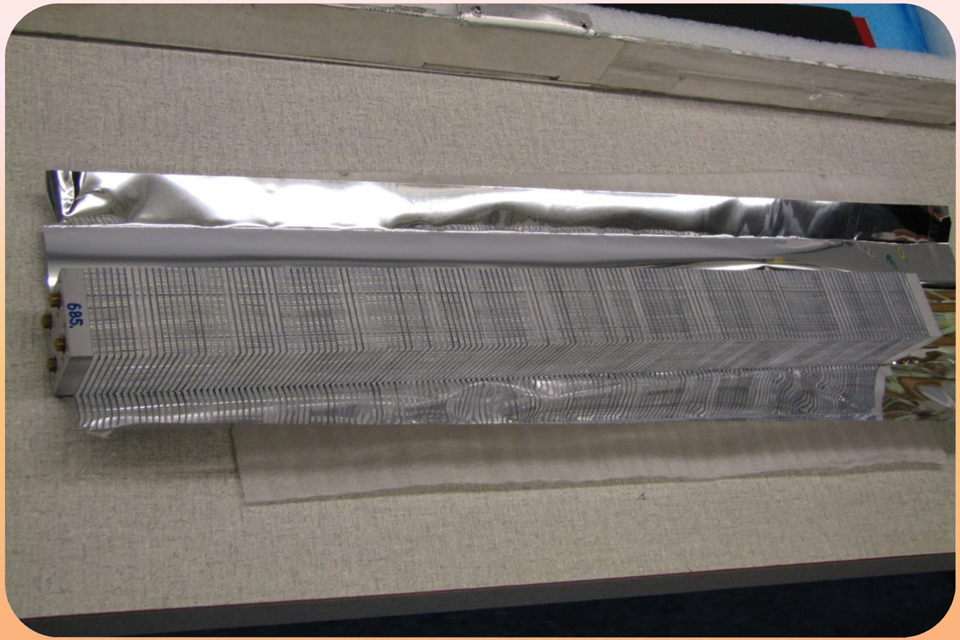
Beam test TPE caloriemeter

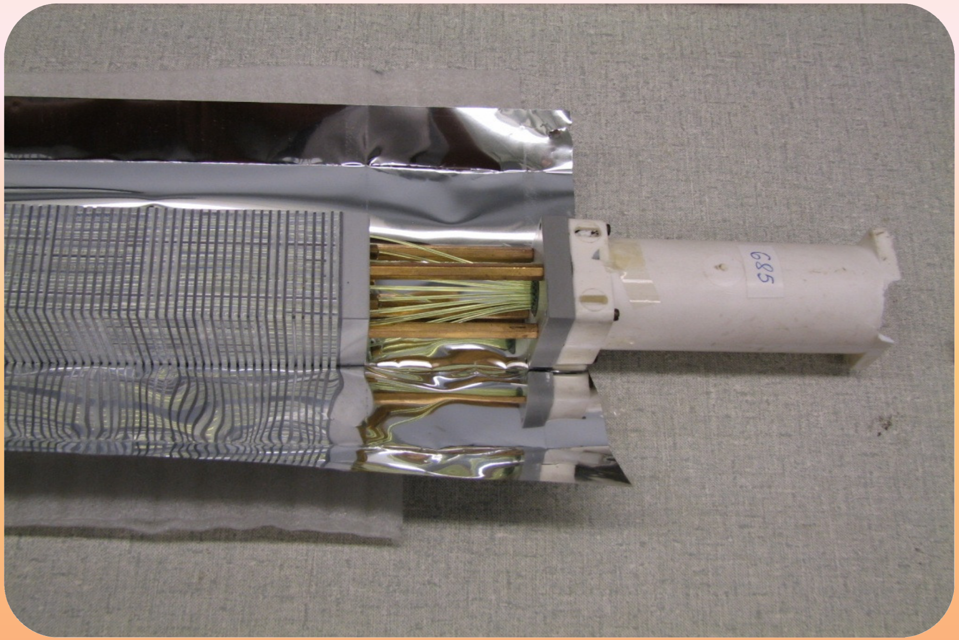
under CLAS tagger during g14 photon run

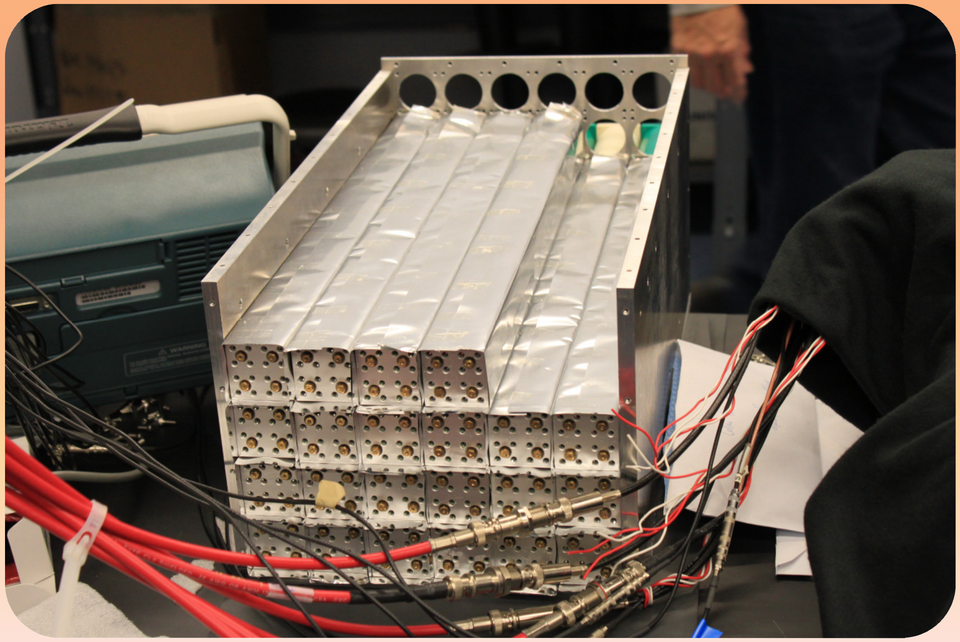
- Gain direct experience with the modules.
- Test energy, position, time resolution
- Study position resolution at different incoming angles.
- Use test results to anchor the simulation.

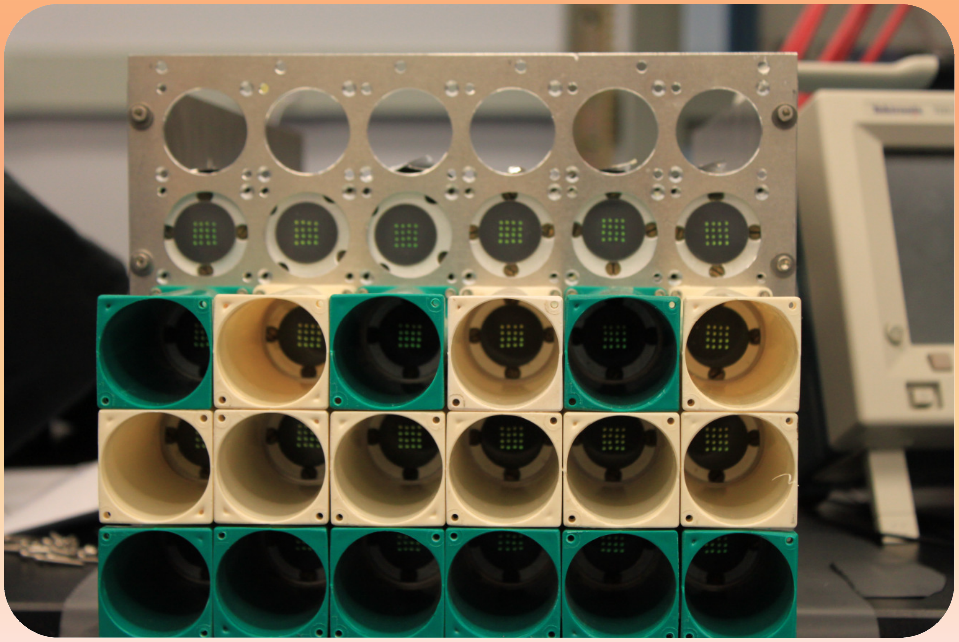


COMPASS modules used for TPE@CLAS









Todo List

- Beam test COMPASS modules
- Fine tuning simulation
- Prototyping module with preshower/shower and further test
- Further background study
- Fibers attenuation length and radiation hardness study
- Fiber connection study
- layout and engineering

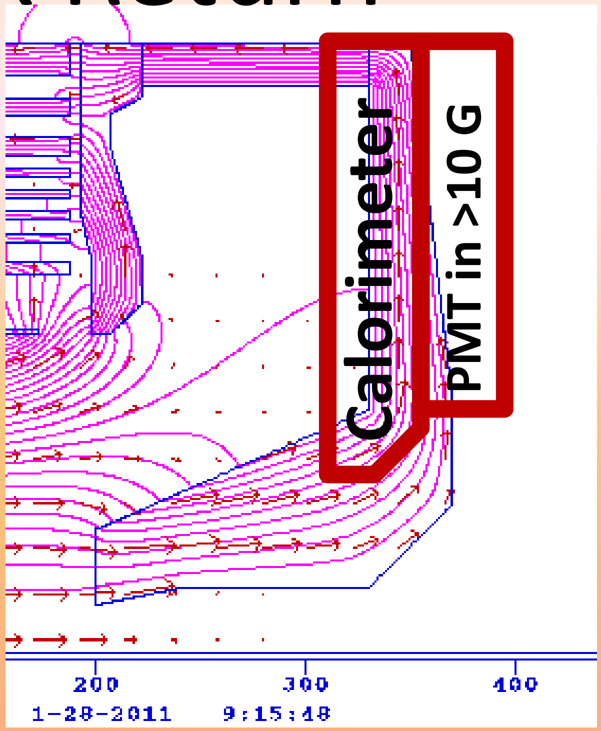
Backup

EM calorimeters with optical readout

Material	Density g/cm^3	X_0 cm	R_M cm	λ_I cm	Refr. index	τ ns	Peak λ nm	Light yield	$\frac{N_{p.e.}}{GeV}$	rad	$\frac{\sigma E}{E}$
Crystals											
NaI(Tl)**	3.67	2.59	4.5	41.4	1.85	250	410	1.00	10^6	10^2	$1.5\%/E^{1/4}$
CsI *	4.53	1.85	3.8	36.5	1.80	30	420	0.05	10^4	10^4	$2.0\%/E^{1/2}$
CsI(Tl)*	4.53	1.85	3.8	36.5	1.80	1200	550	0.40	10^6	10^3	$1.5\%/E^{1/2}$
BGO	7.13	1.12	2.4	22.0	2.20	300	480	0.15	10^5	10^3	$2.\%/E^{1/2}$
$PbWO_4$	8.28	0.89	2.2	22.4	2.30	5/39%	420	0.013	10^4	10^6	$2.0\%/E^{1/2}$
						15/60%	440				
						100/01%					
LSO	7.40	1.14	2.3		1.81	40	440	0.7	10^6	10^6	$1.5\%/E^{1/2}$
PbF_2	7.77	0.93	2.2		1.82	Cher	Cher	0.001	10^3	10^6	$3.5\%/E^{1/2}$
Lead glass											
TF1	3.86	2.74	4.7		1.647	Cher	Cher	0.001	10^3	10^3	$5.0\%/E^{1/2}$
SF-5	4.08	2.54	4.3	21.4	1.673	Cher	Cher	0.001	10^3	10^3	$5.0\%/E^{1/2}$
SF57	5.51	1.54	2.6		1.89	Cher	Cher	0.001	10^3	10^3	$5.0\%/E^{1/2}$
Sampling: lead/scintillator											
SPACAL	5.0	1.6				5	425	0.3	$2 \cdot 10^4$	10^6	$6.0\%/E^{1/2}$
Shashlyk	5.0	1.6				5	425	0.3	10^3	10^6	$10.\%/E^{1/2}$
Shashlyk(K)	2.8	3.5	6.0			5	425	0.3	$4 \cdot 10^5$	10^5	$3.5\%/E^{1/2}$

$*$ - hygroscopic

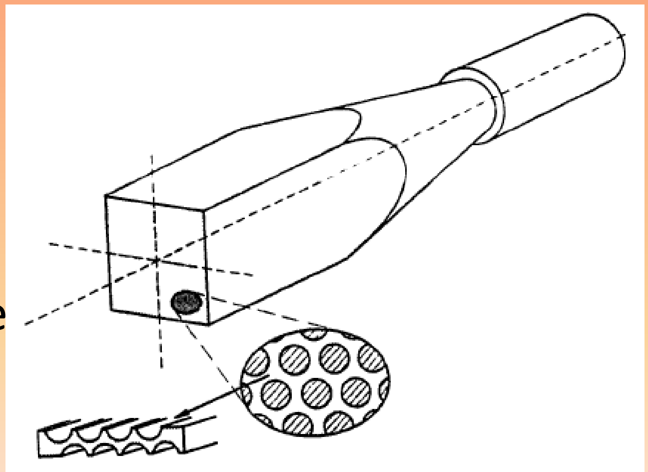
Calorimeter in Solenoid Flux Return



Open Questions:

- What does magnetic field do the shower?
  - My guess is that charged particles in the EM shower will curl up causing the shower to become shorter and wider
- How does magnetic field affect resolution in Energy and in space? Is this a strong function of field strength or direction?
- What resolution do we need? [Pb:SciFi at ~1:1 gives 4.5%/sqrt(E)]
- Is Iron dense enough?
- How does the fiber affect the Magnetic flux return?
  - My guess is that we use and "effective" µ which is about half that of Fe.

Require detailed MC; Have contacted D. Hertzog about simulations.



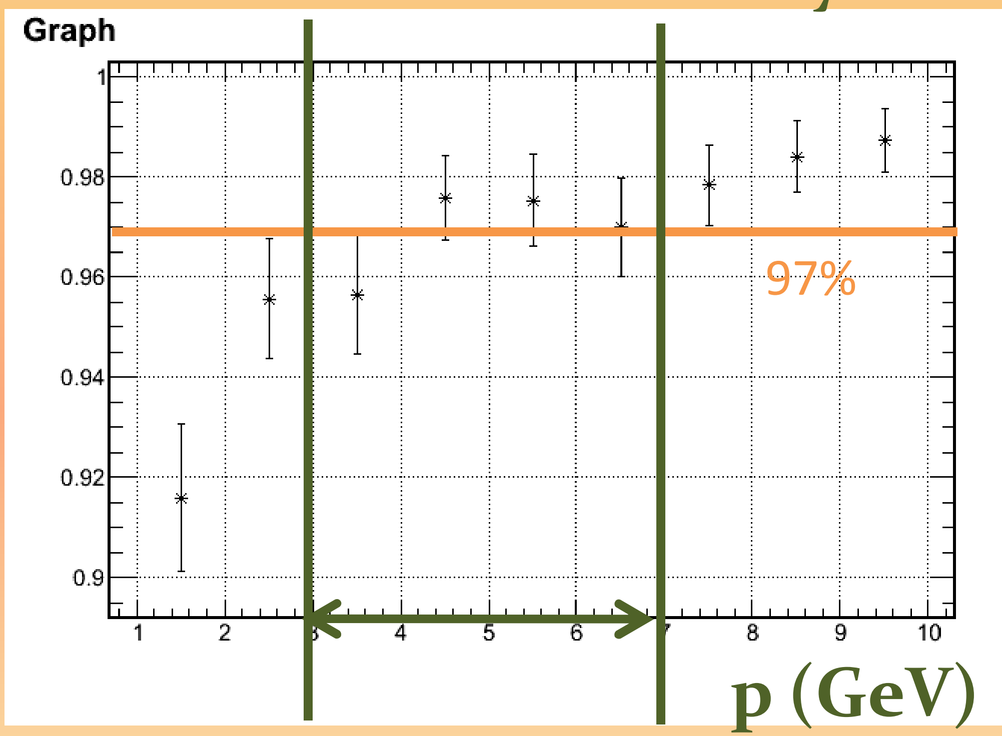
- How do we cost this?
  - D Hertzog—driving cost is amount of fiber—Fe less dense than Pb thus need more fiber.

Calorimeter Design: Lead/Sci Ratio

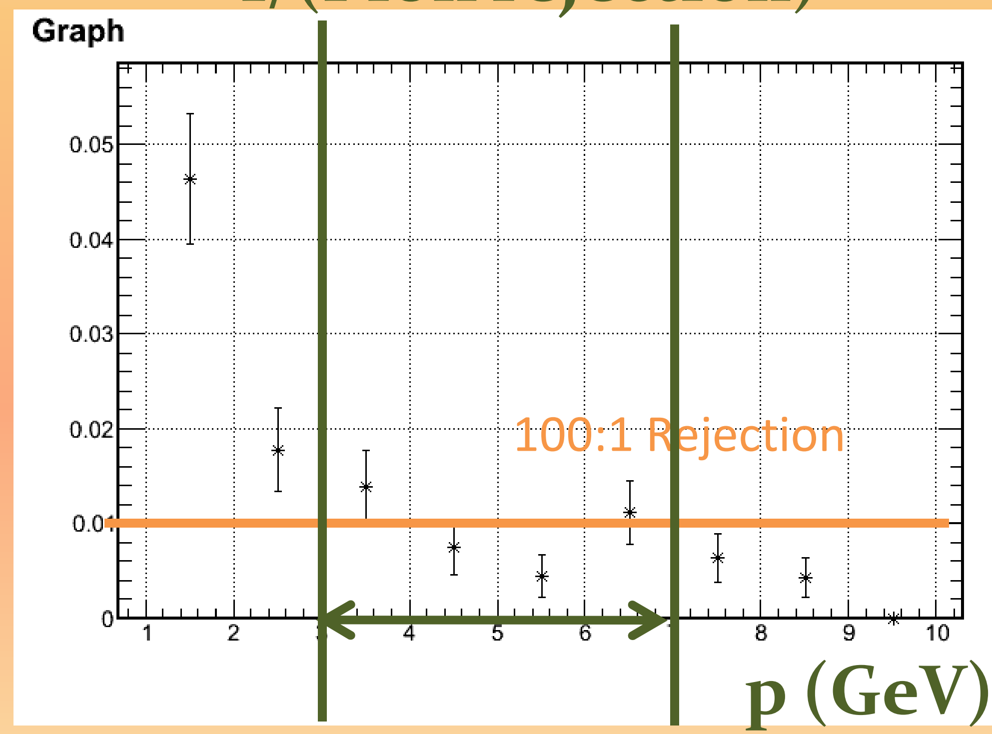
❖ Tuning of the ratio performed with a dedicated Geant 4 simulation.

↳ Can reach a pion rejection factor of 100/1 with Pb thick. = 0.6 mm /layer

Electron Efficiency



1/(Pion rejection)

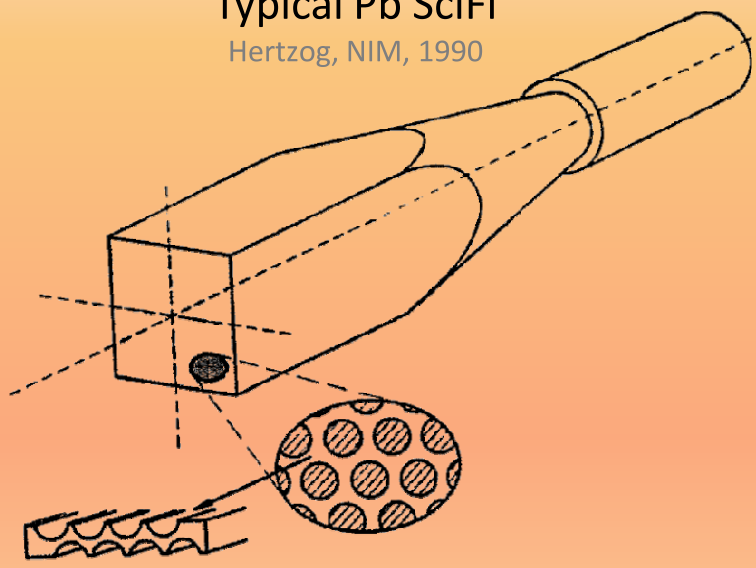


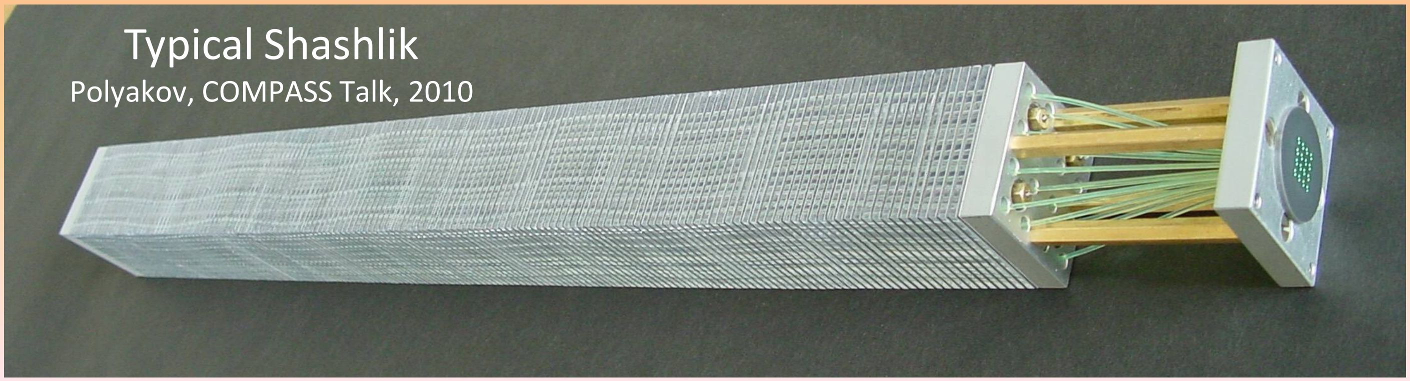
Range of interest: 3~7 GeV

Compare of calorimeter types

A. Shashlik calorimeter
B. SciFi calorimeter – Pb
C. SciFi calorimeter – Fe
   – Combined with end cap

Typical Pb SciFi
Hertzog, NIM, 1990





Typical Shashlik
Polyakov, COMPASS Talk, 2010

Compare option A & B

Shashlyk and SciFi-Pb

- Similarity
  - Pb-scintillator based sampling calorimeter
  - Similar in resolution and radiation hardness
  - Both fit the need of SoLID
- Choice : Shashlyk
  - Easier to read out light:
    Photon collection area 100 times smaller than SciFi
  - Matured production

Compare A & C for the forward Calo.
The choice - Shashlik

Reason of choosing Shashlik over Scifi/Fe in endcup

- Shashlik is cheaper.
  - It's production module cost cheaper or similar to SciFi fiber cost alone.
- Shashlik is more mature.
  - SciFi/Fe needs R&D
- Shashlik is easier.
  - several suppliers with good experience are available.

IHEP Scintillator Fasilities

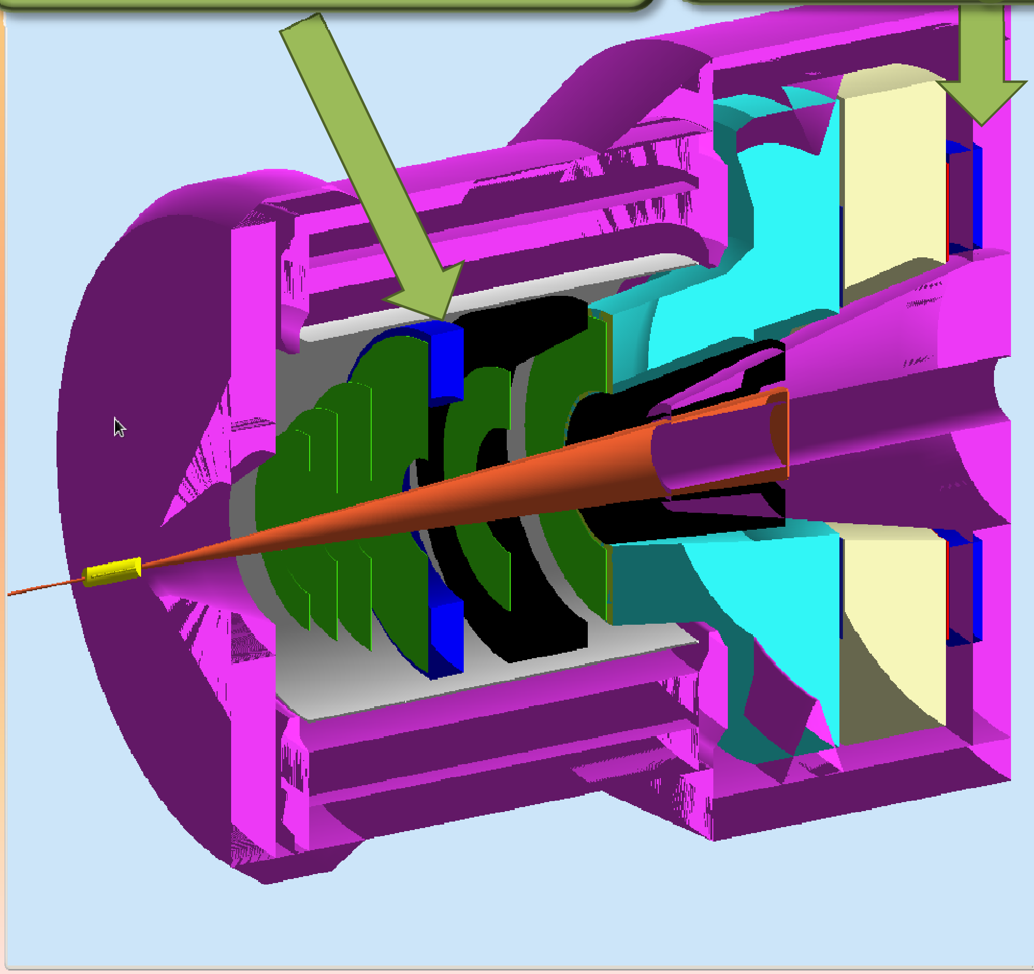
www.ihep.ru/scint/index-e.htm

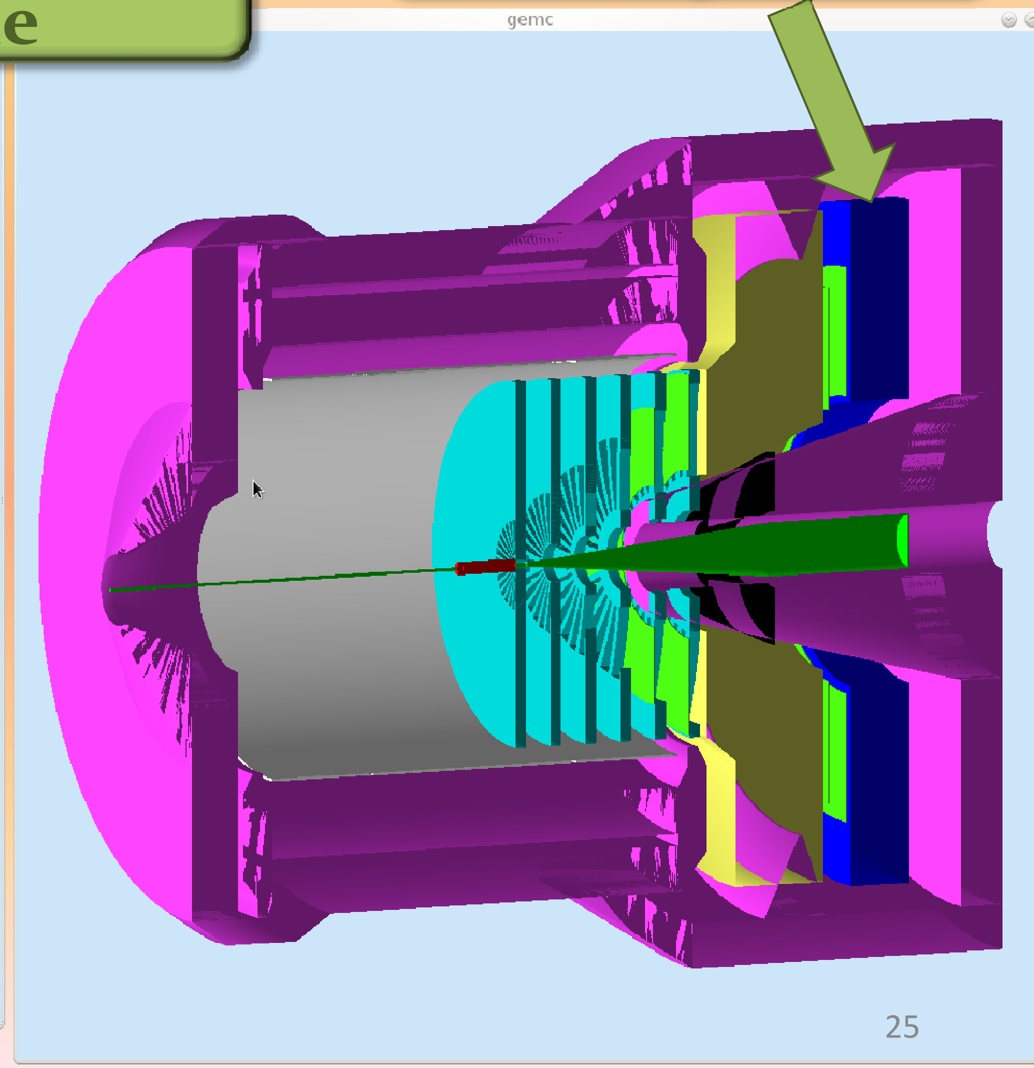
ECAL Configuration

SIDIS Large Angle

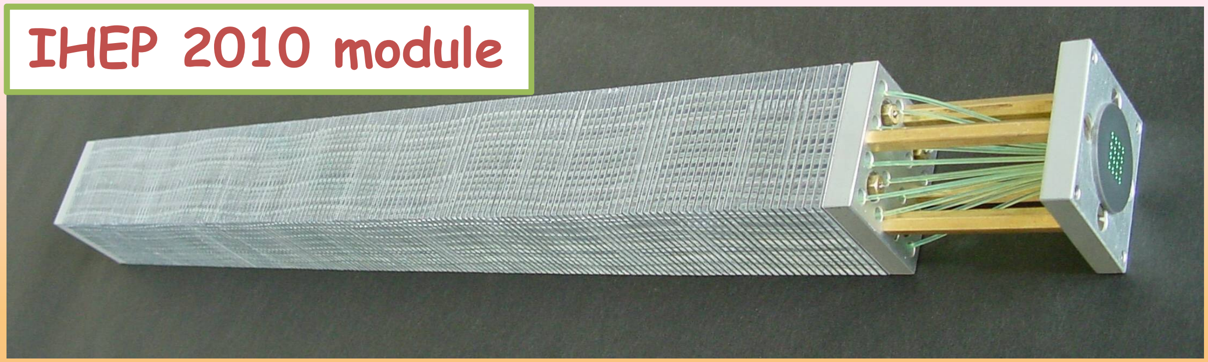
SIDIS Forward Angle

PVDIS Forward Angle





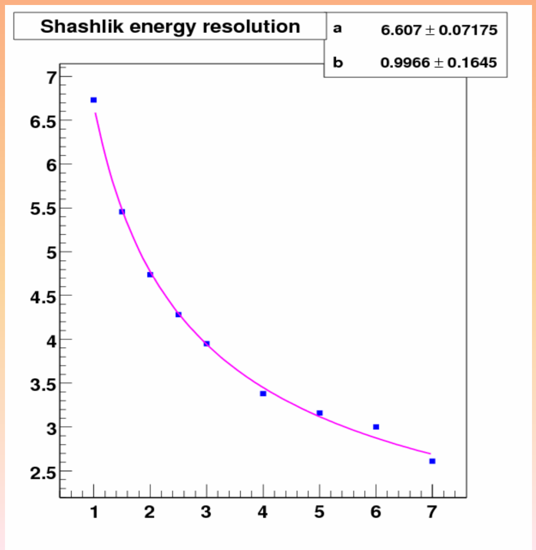
ECAL Choice

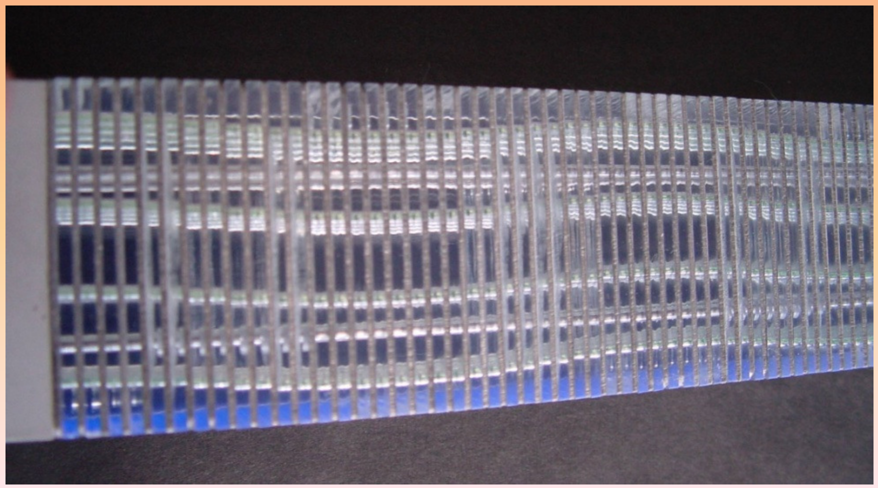


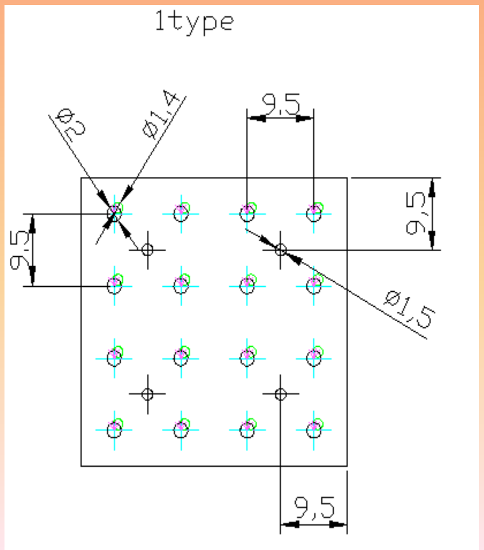
- Lead-Scintillator Sampling Calorimeter: Shashlyk Calorimeter
- Fibers collect and read out the light
- Great flexibility, tunable energy resolution: ~ 6%/√E is not a problem
- Good radiation Hardness: ~ 500 krad
- Well developed and mature technology: used previously in other experiments

ECAL Shashlik

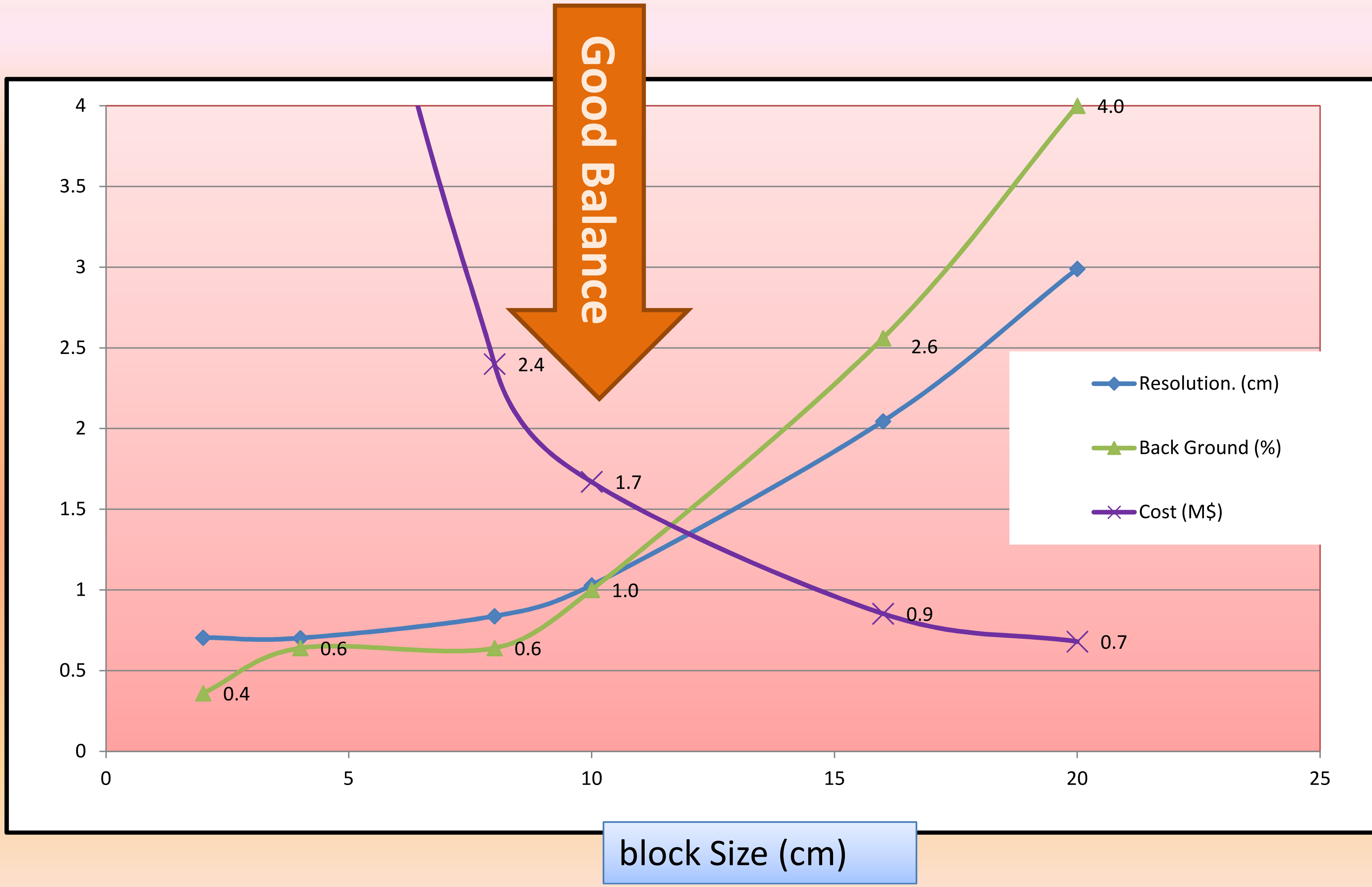
Dimensions	38.2×38.2 mm^2
Radiation length	17.5mm
Moliere radius	36mm
Radiation thickness	22.5 X_0
Scintillator thickness	1.5mm
Lead thickness	0.8mm
Radiation hardness	500 krad
Energy resolution	6.5%/√E 1%





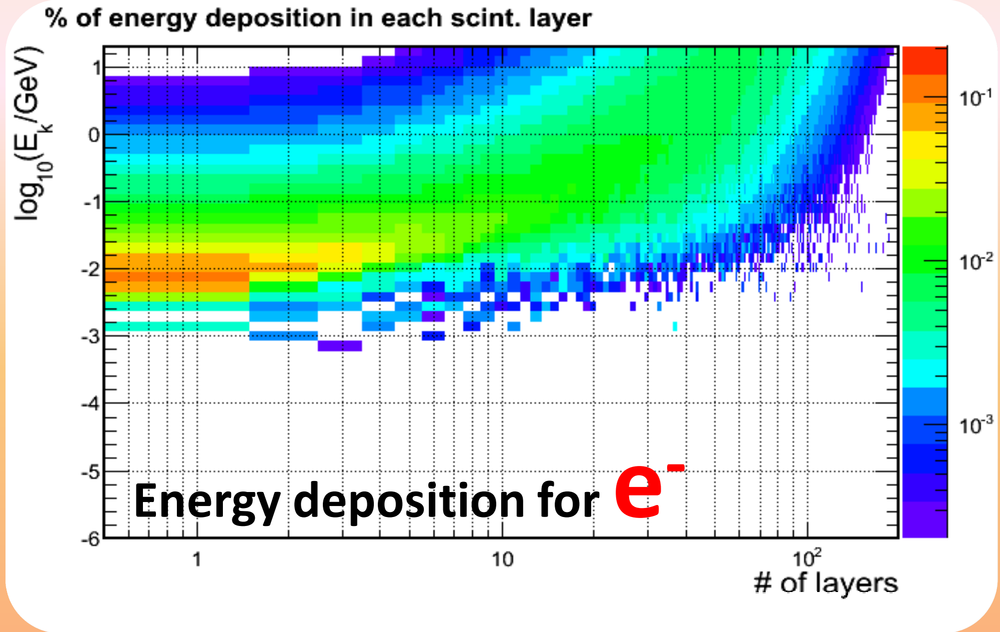


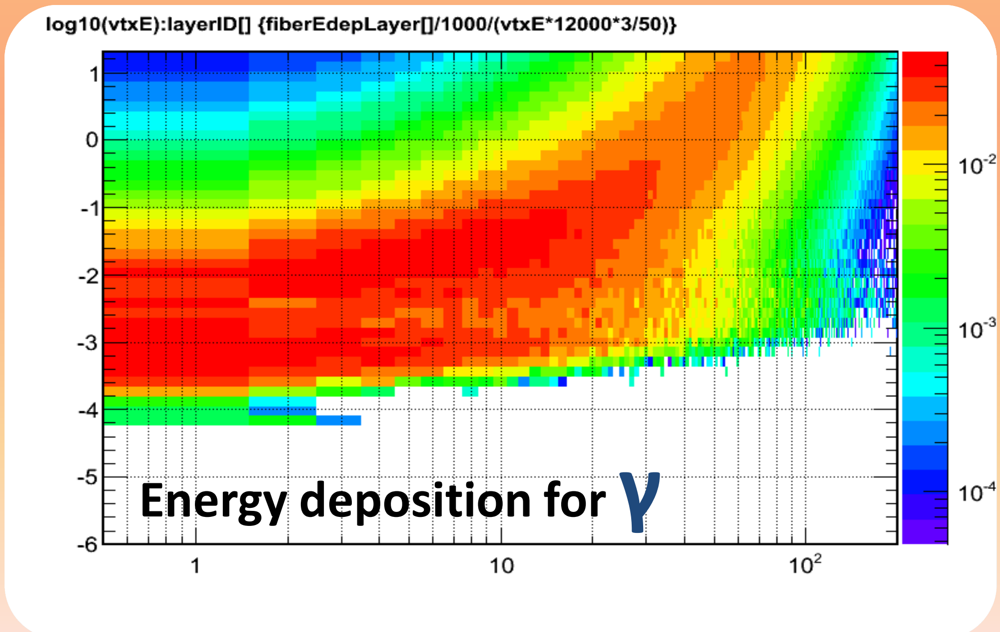
ECAL Design: Lateral Size



Background Simulation

- The radiation dose for scintillators is 100krad~2Mrad, material dependent.
- Doses on the fibers are similar to the doses on scintillator tiles (both are plastic based).
- Dose = (fraction energy deposition for each layer) *(energy flux)
- (energy flux) is generated by using GEMC and Babar model.
- (fraction energy deposition) is calculated using GEANT 4 simulation for each layer and different incoming particle kinematic energy.

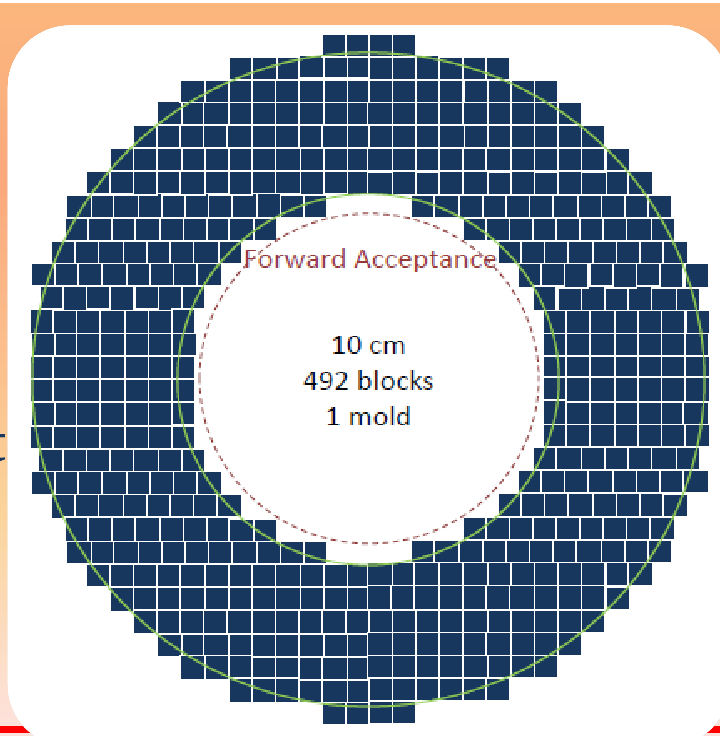


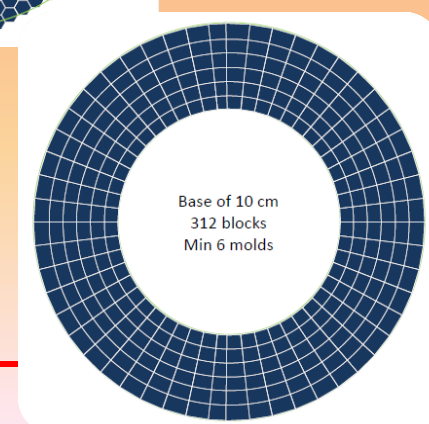


ECAL Design: Layout

	Hexagon		Square		Sector	
	Small	Large	Small	Large	Small	Large
Size (cm)	10	10	10	10	10.5	9.95
Blocks	912	486	908	492	576	312
Molds	Min 1	Min 1	Min 1	Min 1	Min 9	Min 6
Total	1398 blocks 1 mold ~ $1.4M		1400 blocks 1 mold ~ $1.4M		888 blocks 15 molds ~ $1.64M	

❖ Preferred Square
- Easy assembly
- Mature production
- Easier rearrangement





Calorimeter Design: Fibers

❖ **Fibers:**

➢ Wave Length Shifting fibers (WLS):

KURARAY Y11: - good attenuation length (3.5-4m),

- good radiation hardness : <30% loss of light output after a 693 krad irradiation.

- Recovery: few percents after 10 days

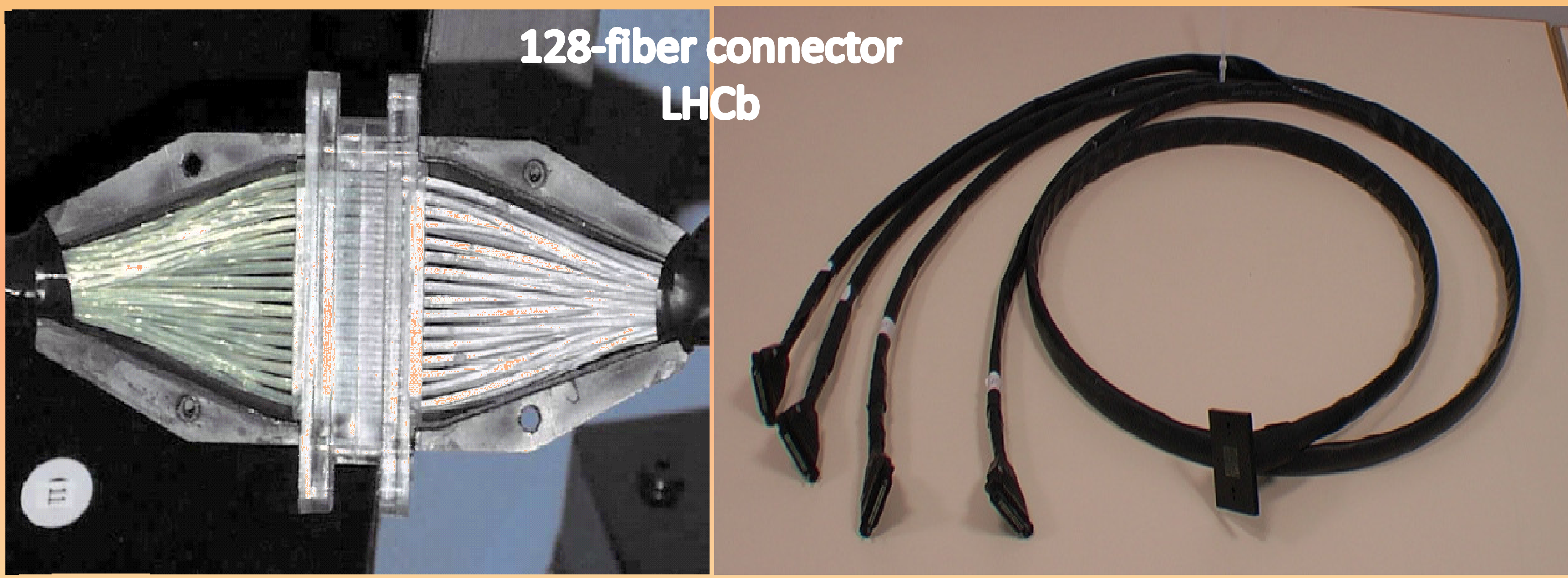
(M.J. Varanda et al. / NIM in Phys. Res. A 453 (2000) 255}258)

➢ **Clear Fibers:** KURARAY clear PS, Super Eska..., options under study.

Calorimeter Design: Connectors

❖ **Option 1:**

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

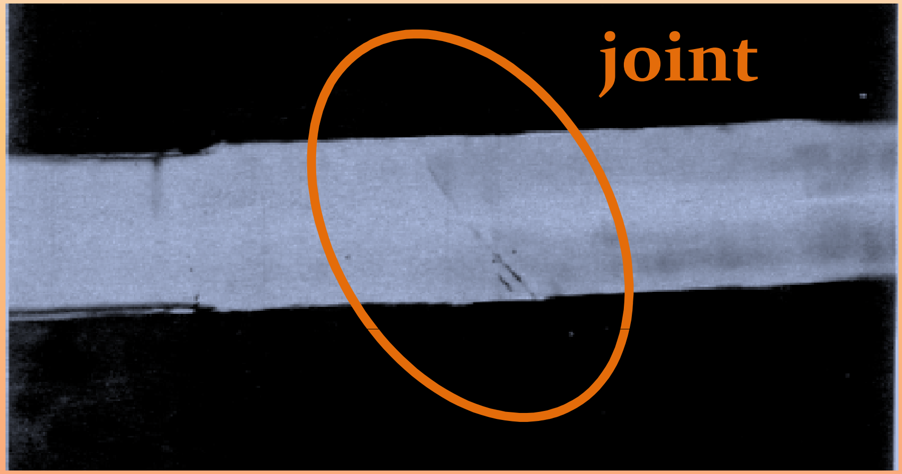


Calorimeter Design: Connectors

❖ **Option 2:**

Thermal fusion: splice the WLS and clear fiber.

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



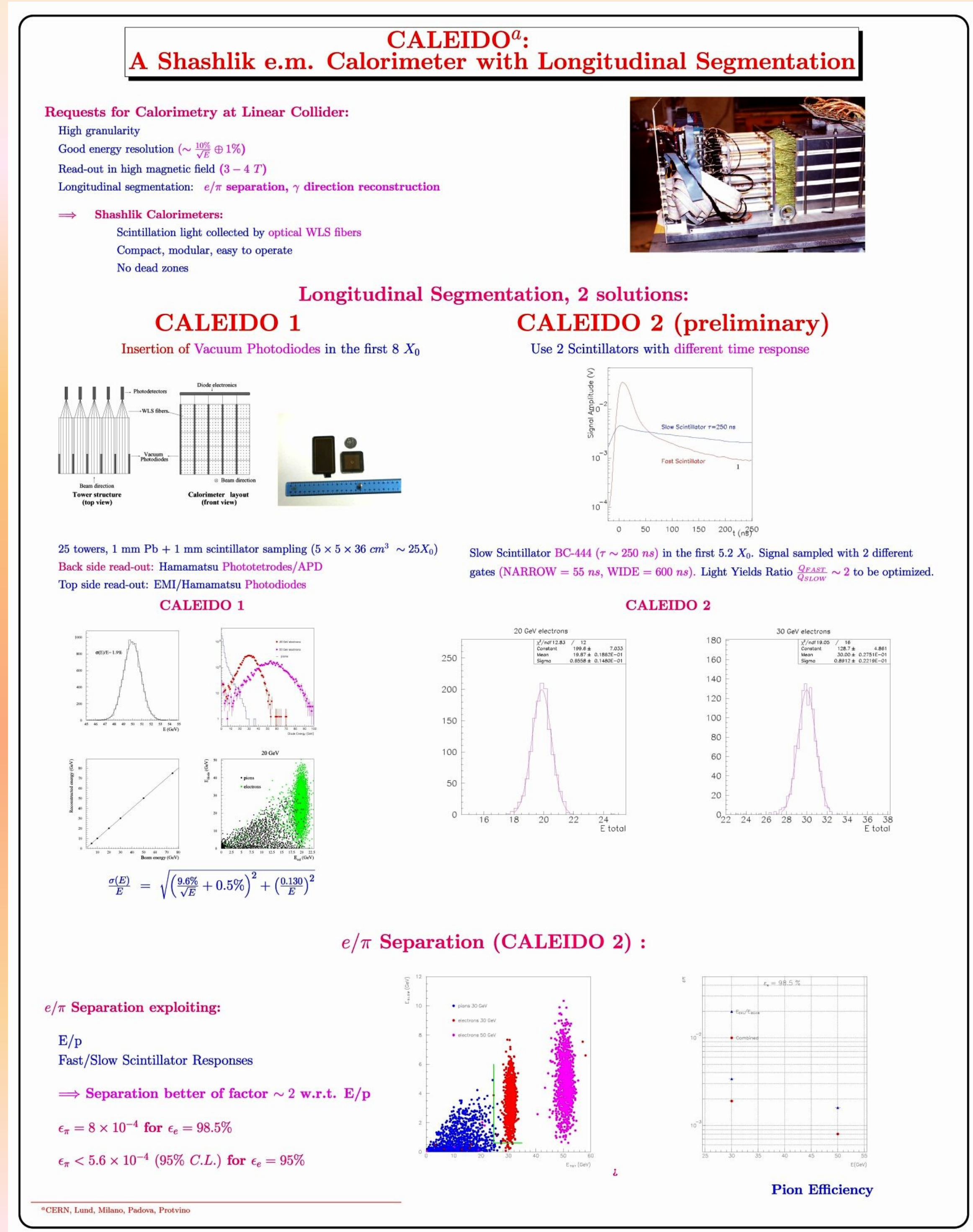
❖ **Option 3:**

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

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

https://hedberg.web.cern.ch/hedberg/home/caleido/caleido.html



PVDIS rate

Process	Geometry	
	Open	baffles
DIS total	2500 kHz	110 kHz
DIS $W > 2$ GeV, $X > 0.20$	1500 kHz	110 kHz
DIS $W > 2$ GeV, $X > 0.55$	35 kHz	12 kHz
DIS $W > 2$ GeV, $X > 0.65$	8 kHz	3 kHz
π^- $p > 0.3$ GeV	2300 MHz	140 MHz
π^- $p > 1.0$ GeV	460 MHz	70 MHz
π^- $p > 2.0$ GeV	26 MHz	8 MHz
DIS $X > 0.20$ $E_{CALOR} > E_{thr}(R)$	680 kHz	102 kHz
π^- $E_{CALOR} > E_{thr}(R)$	540 kHz	120 kHz
π^- $E_{CALOR} > E_{thr}(R)$ pileup	$\sim$10 kHz	$<$2 kHz

Table 3.3: Calculated DIS and pion rates in the spectrometer.

SIDIS rate

Process	Rate Forward angle 11 GeV	Rate Large angle 11 GeV	Rate Forward angle 8.8 GeV	Rate Large angle 8.8 GeV
$(e,e\pi^+)$	1467 Hz	192 Hz	810 Hz	117 Hz
$(e,e\pi^-)$	1010 Hz	120 Hz	554 Hz	73 Hz
single e^-	88.5 kHz	11.0 kHz	151 kHz	16.5 kHz
high energy photon	623 kHz	51.5 kHz	596 kHz	37 kHz
single π^+	2.90 MHz	20.2 kHz	2.5 MHz	13.4 kHz
single π^-	1.77 MHz	14.5 kHz	1.47 MHz	9.2 kHz
single K^+	226 kHz	5.9 kHz	185 kHz	4.1 kHz
single K^-	54.6 kHz	1.2 kHz	39.9 kHz	0.6 kHz
single proton	1.15 MHz	13.8 kHz	0.99 MHz	9.4 kHz
low energy photon	200 MHz	-	200 MHz	-