Shashlik style ECal R&D for the SoLID project

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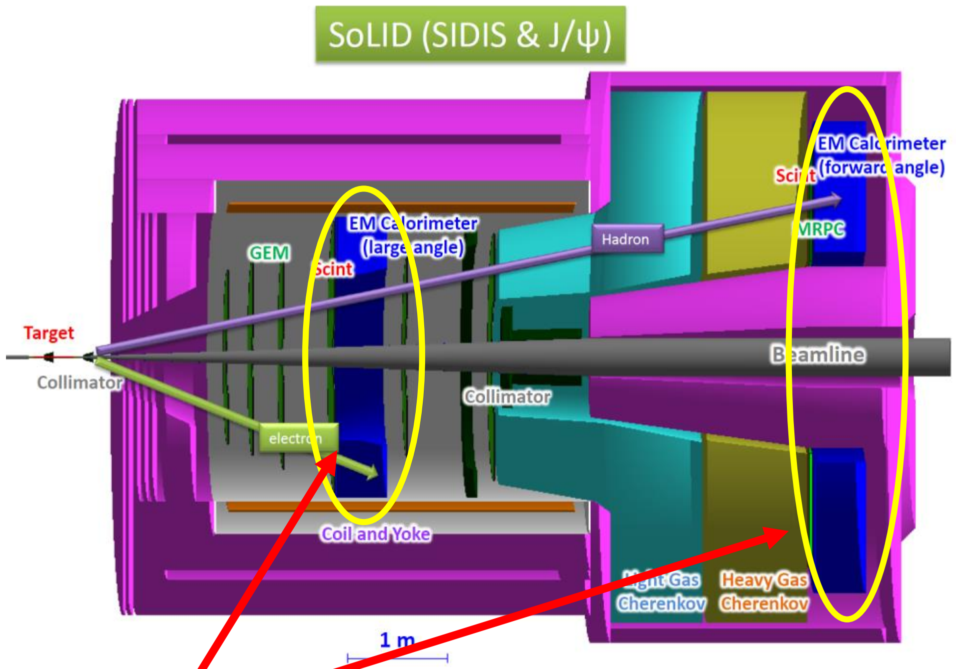
Outline

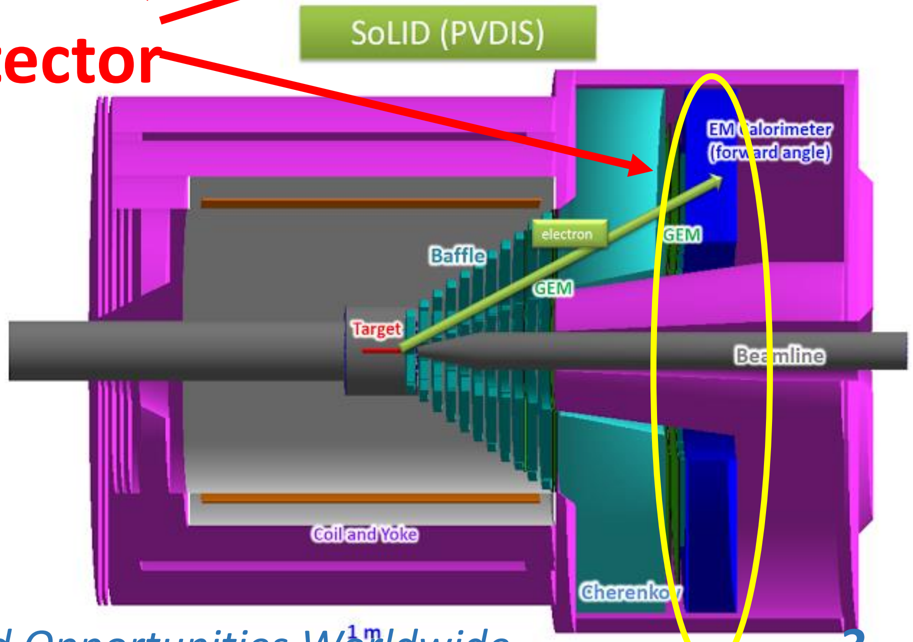
1. SoLID Shashlik style EC Introduction
2. Material optimization and test
3. Prototype cosmic ray test
4. Prototype beam test plan

SoLID project and EM calorimeter
(Solenoidal Large Intensity Device)

- 12GeV detector upgrade in HallA
- Including two detector configurations: the "SIDIS" (Semi-Inclusive Deep Inelastic Scattering) and the "PVDIS" (Parity-Violating Deep Inelastic Scattering).
- Three main programs: SIDIS, PVDIS and J/ψ
- Work includes preshower, shower detector and SPD(single pad detector)



ECal detector



SoLID ECal coverage

	PVDIS FAEC	SIDIS FAEC	SIDIS LAEC
z (cm)	(320, 380)	(415, 475)	(-65, -5)
Polar angle (degrees)	(22,35)	(7.5,14.85)	(16.3, 24)
Azimuthal angle	Full coverage		
Radius (cm)	(110, 265)	(98, 230)	(83, 140)
Coverage area (m^2)	18.3	13.6	4.0

ECal Design Requirements

Basical ECal functions and requirements(preCDR):

- Electron- hadron separation: >100:1 π rejection above Cherenkov threshold
- Energy resolution better than $10\%/\sqrt{E}$(GeV)
- Provide trigger: Shower signal coincidence with cherenkov, suppress background
- Time resolution of LASPD less than 150ps

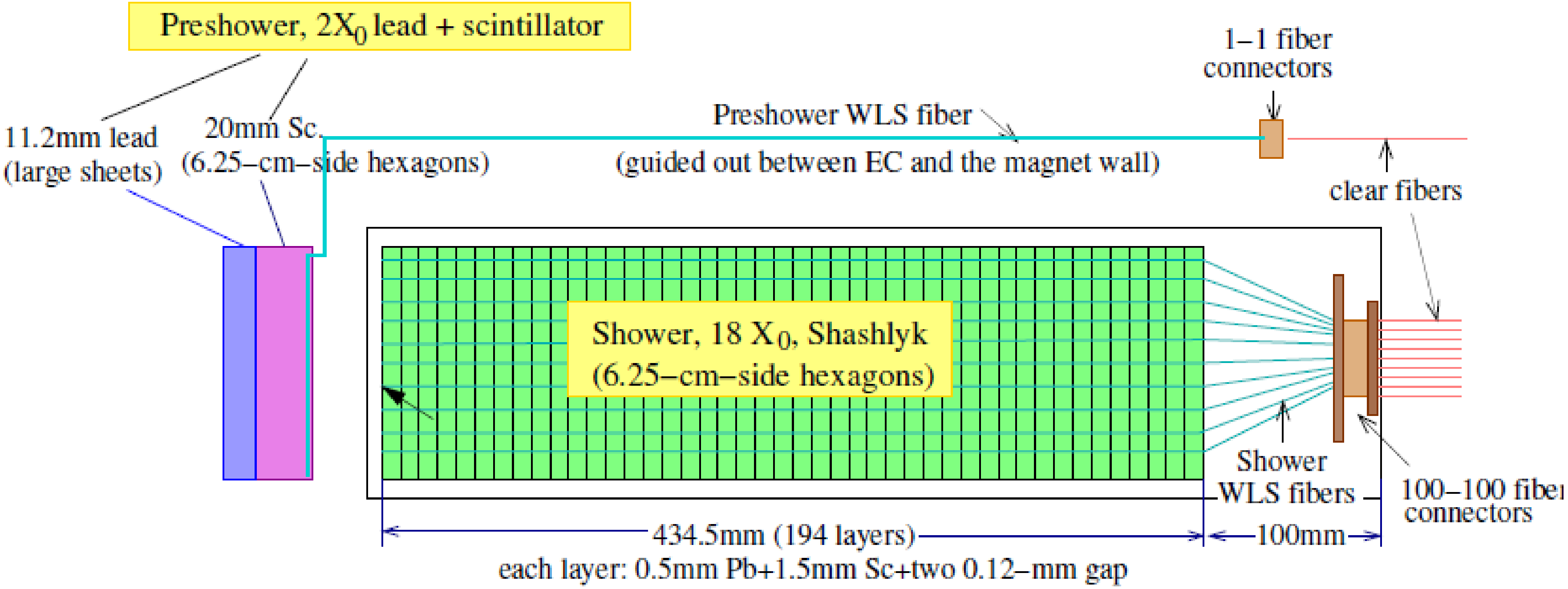
Special ECal challenge for SoLID:

- Radiation resistance: > (4-5)x10^5 rad (crystal ECal worse with time)
- High magnetic field B~1.5 T (ordinary PMT not work)
- Modules easily swapped and rearranged for PVDIS ↔ SIDIS;

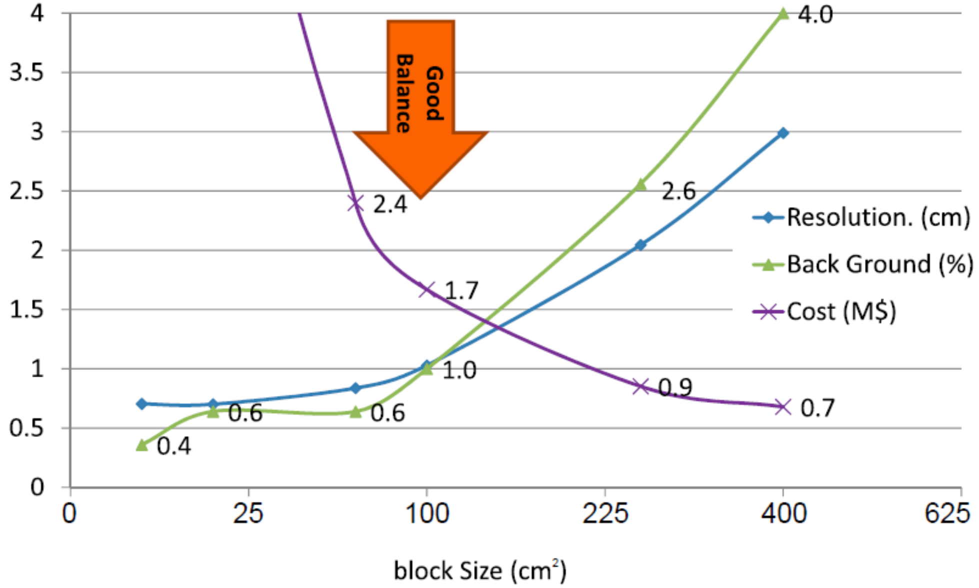
A shashlik style sampling EC is designed to satisfy the requirement.

Shashlik ECal Longitudinal design

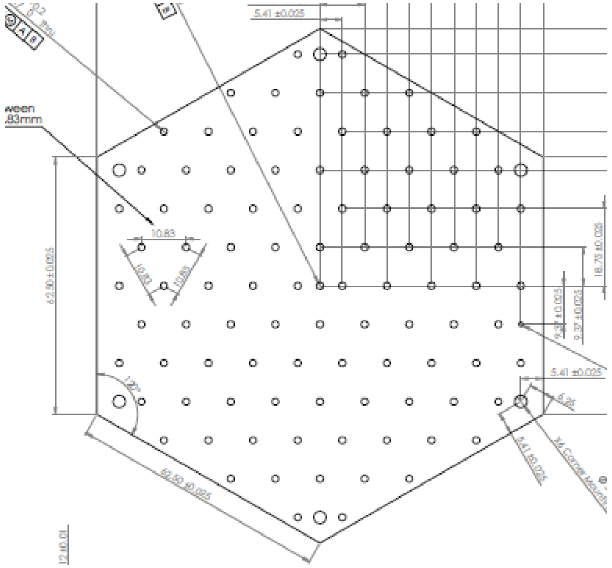
- Preshower: 2 X_0 lead + 20 mm plastic scintillator, WLS(wavelength shift) fiber embedded in scintillator. Designed for additional cut of pion rejection.
- Shower: shashlik module (0.5mm lead + 1.5mm scintillator + 0.1mm reflector×2) ×194, WLS fiber×96 penetrating layers longitudinally.
- Overall: 20 X_0(<2% leakage), balance between electron detection and hadron rejection



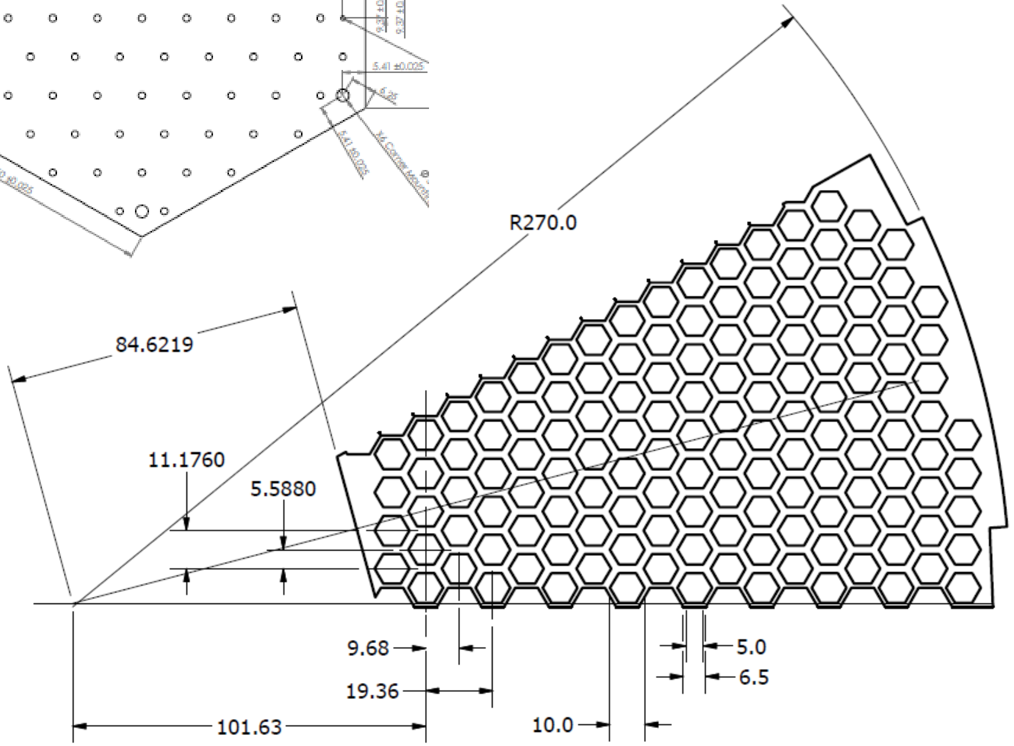
Shashlik EC Lateral design



Good balance between cost and position resolution/background(simulation) for 100cm^2 block size.



- 100 cm2 of hexagon shape with 6.25cm side length
- 1600+(SIDIS) and 1700+(PVDIS) modules in total



PVDIS FAEC (portion) viewing along the beam direction

Preshower detector design

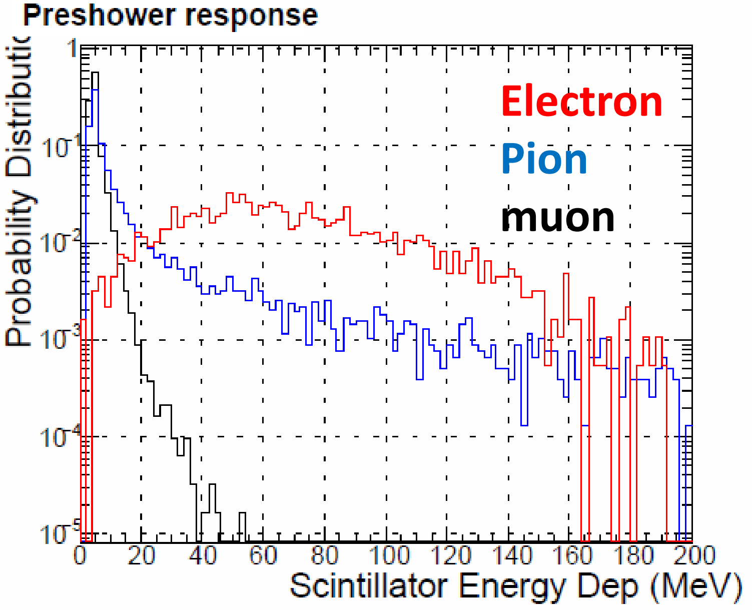
- Offer additional pion rejection
- Simulation shows 3.5 X_0 has best efficiency, However, increased thickness of the absorber degrades the overall energy resolution. Optimized to 2 X_0 for the SoLID application.

Actual design of preshower scintillator:

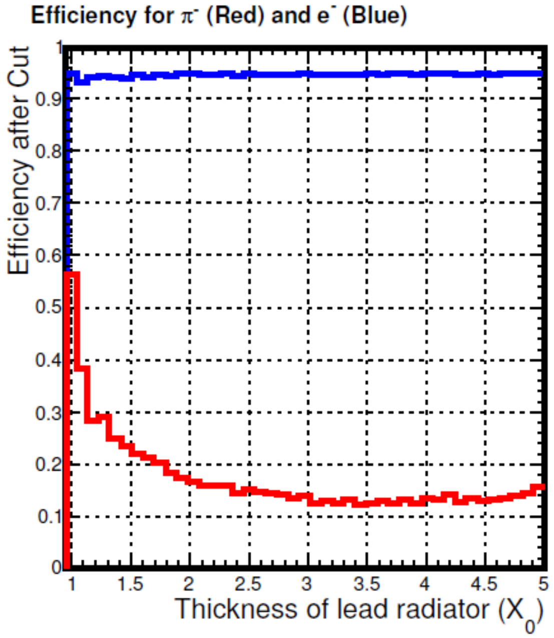
- 2 cm thickness
- Fiber routing: optimized to two ϕ-1mm Y11 double cladding fiber, 2.5 turns of 9cm diameter each, wrapped by Tyvek
- Readout by 16-ch MAPMT

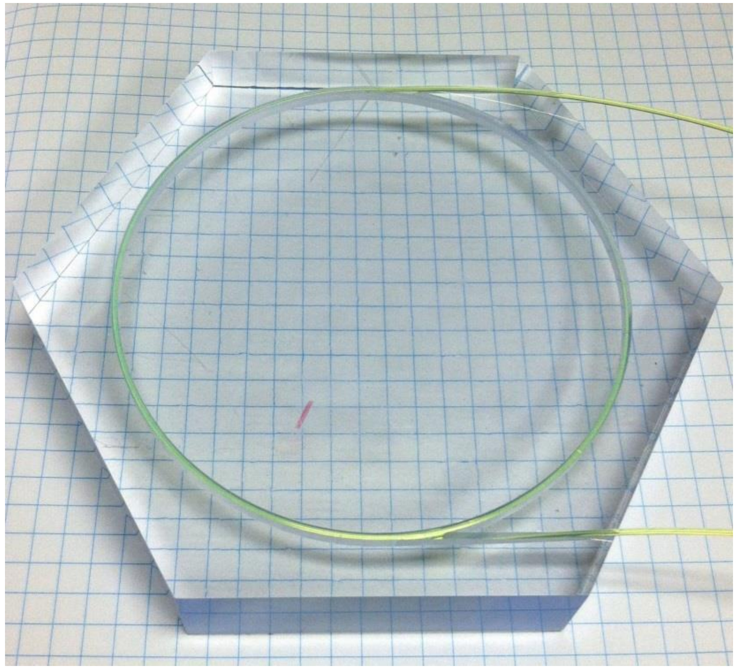
Test results: **~80 p.e.** for all samples

Energy deposition distribution in scintillator



Detector efficiency as the function of radiator thickness

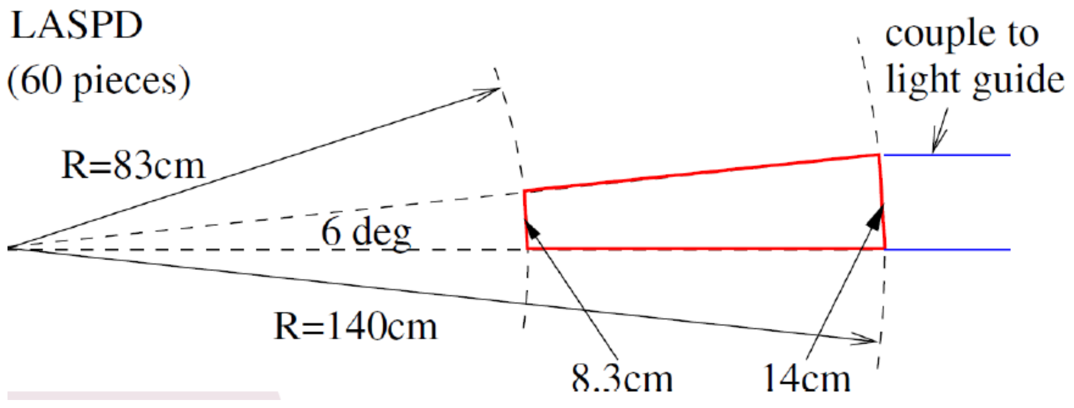


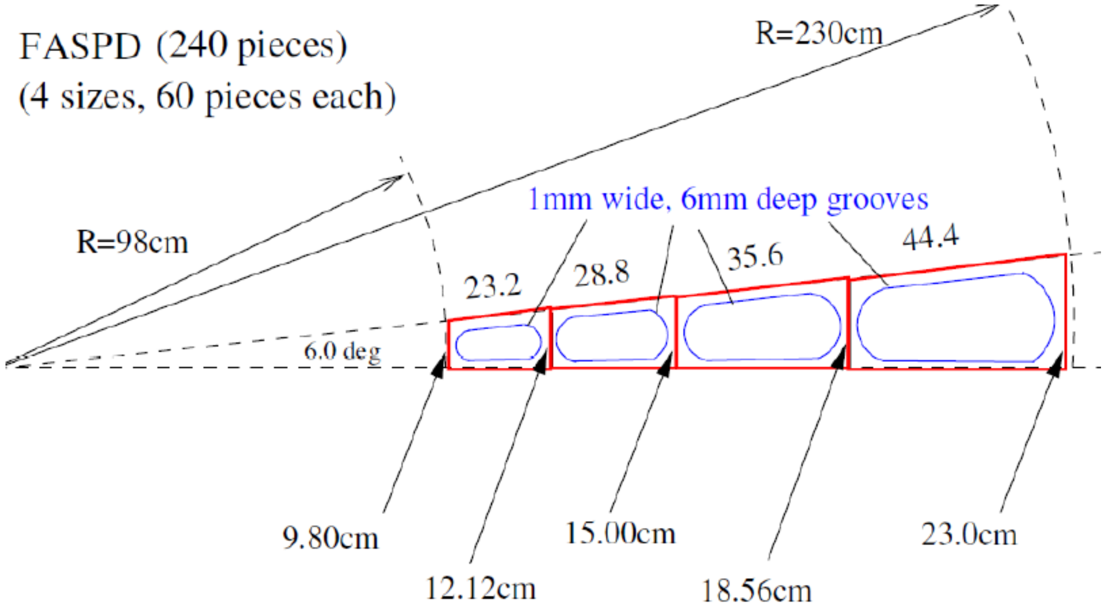


SPD: scintillator pad detector

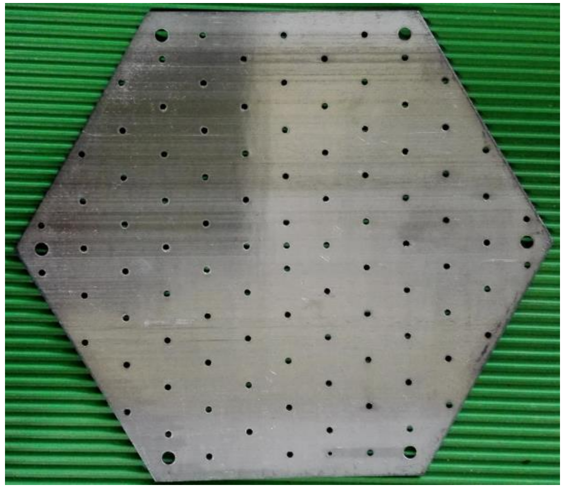
Main purpose: offer time information and suppress photon trigger

- Only exist in SIDIS, include Large angle SPD (LASPD), and forward angle SPD (FASPD)
- LASPD is the main time decision detector of large angle, and 2cm thickness is balanced between photon rejection and time resolution. 150ps time resolution is required for single side readout.

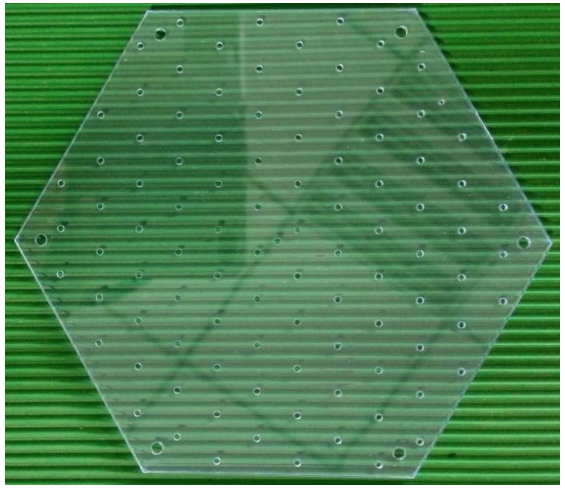




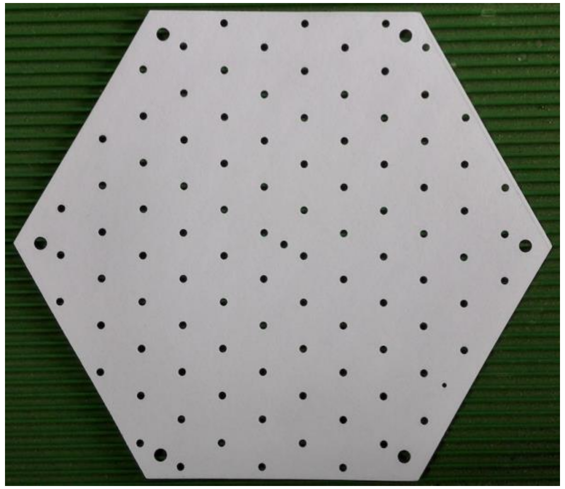
Main materials in Shashlik ECal detector



Lead plate



Scintillator tile



Reflector layer (paper)

1mm diameter WLS fiber

The geometry and machining quality of scintillator tiles, lead plates and reflection layers are all fine.

- Lead Plate: pure lead plate with punching hole
- Scintillator Tile: made by Kedi Company in China with special mould, formular enhaced as reguirement, which match the absorption spectrum of WLS fiber.
- Reflection Layer: print paper /powder painting/tyvek
- WLS Fiber: BCF91A(Saint-Gobain, US) Y11(Kuraray, Japan)

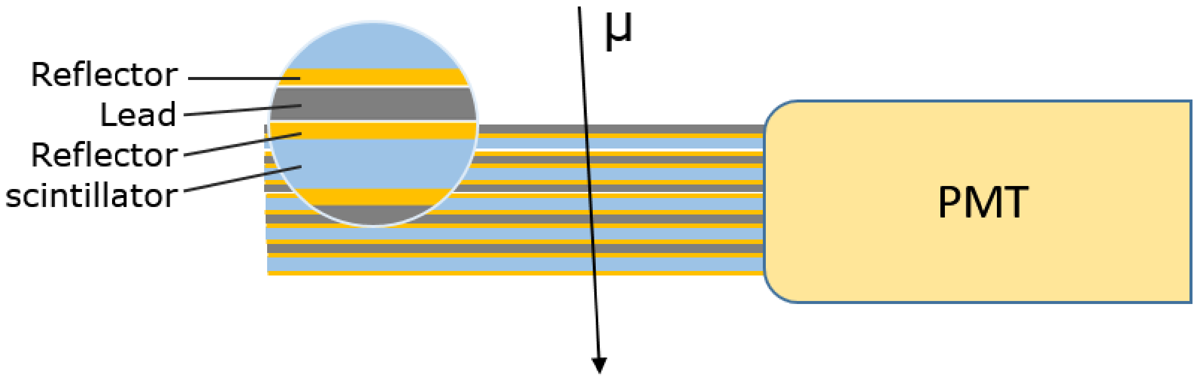
Design and construction requirement: good quality and get as high as light yield !!!

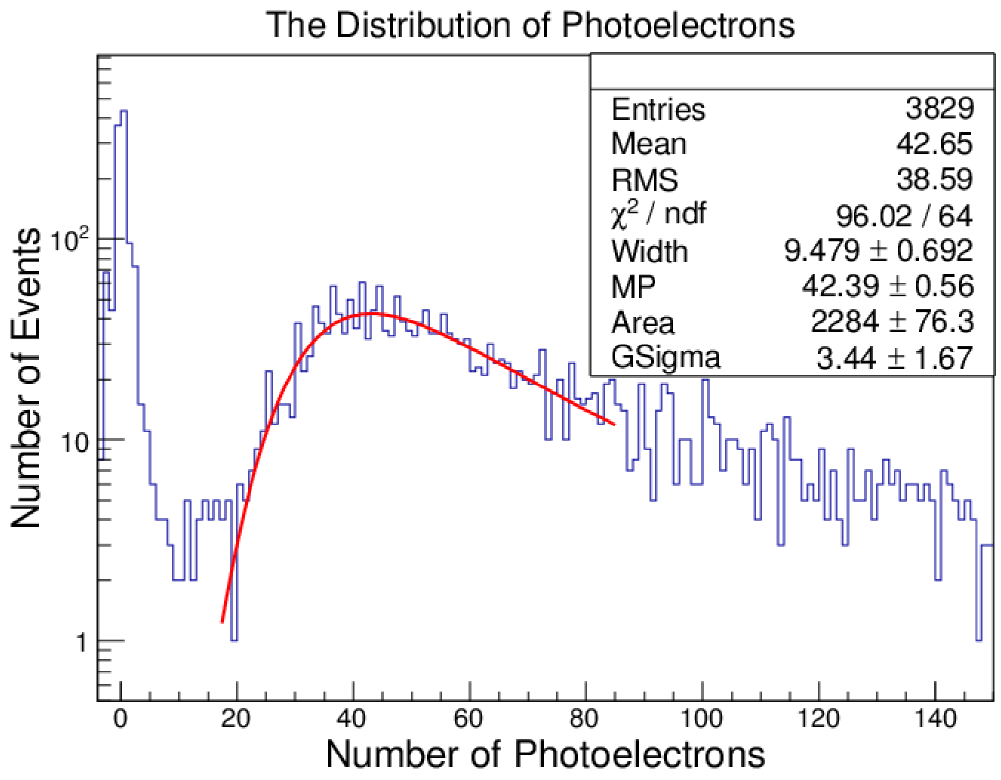
Reflective layer selection

Even small reflectivity difference will cause large influence on light yield with several reflections in thin scintillator layer.

Several materials performed in test, including both diffuse and specular reflection material.

SDU cosmic ray test setup: 5 layers of shashlik





Typical number of photoelectrons distribution

Reflector layer test result

Reflector material	Relative light yield
Lead with metal plating	1
Print Paper	1.24
Aluminum foil	1.14
Tyvek(100 μm)	1.89
TiO_2 Powder painting(70 μm)	2.02

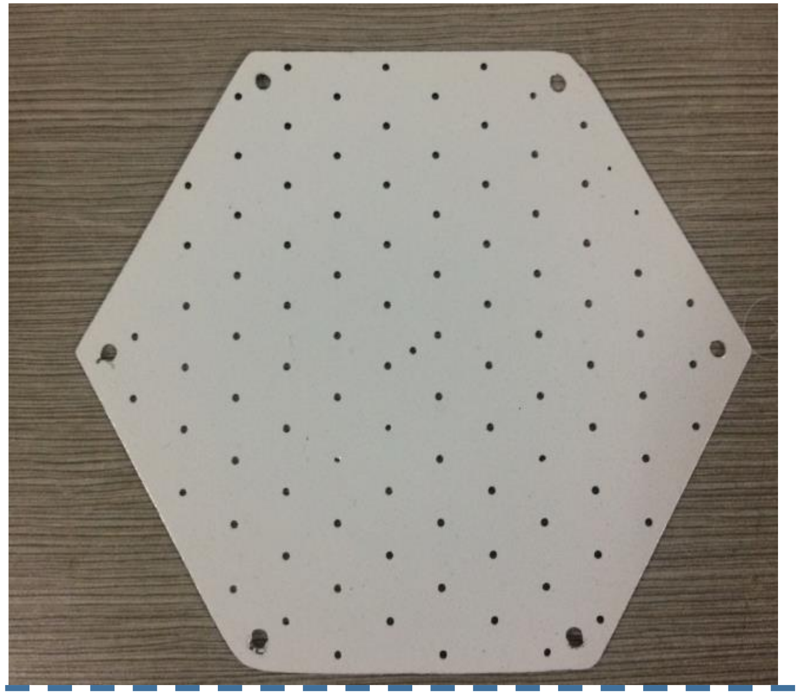
- The thicker reflector layer improve light yield.
- Real module test result shows 70 μm powder painting has 18% higher light yield than 100 μm Tyvek.
- The powder painting method will be optimized and applied in the future module construction.

Powder painting

TiO_2 *painting with* bonding/glue material, painted directly on lead.

Pro:

- ✓ *High reflectivity*
- ✓ *Thin thickness(could reach 50 μm)*
- ✓ *Good quality*
- ✓ *Easy to assemble module*
- ✓ *Lead protection*



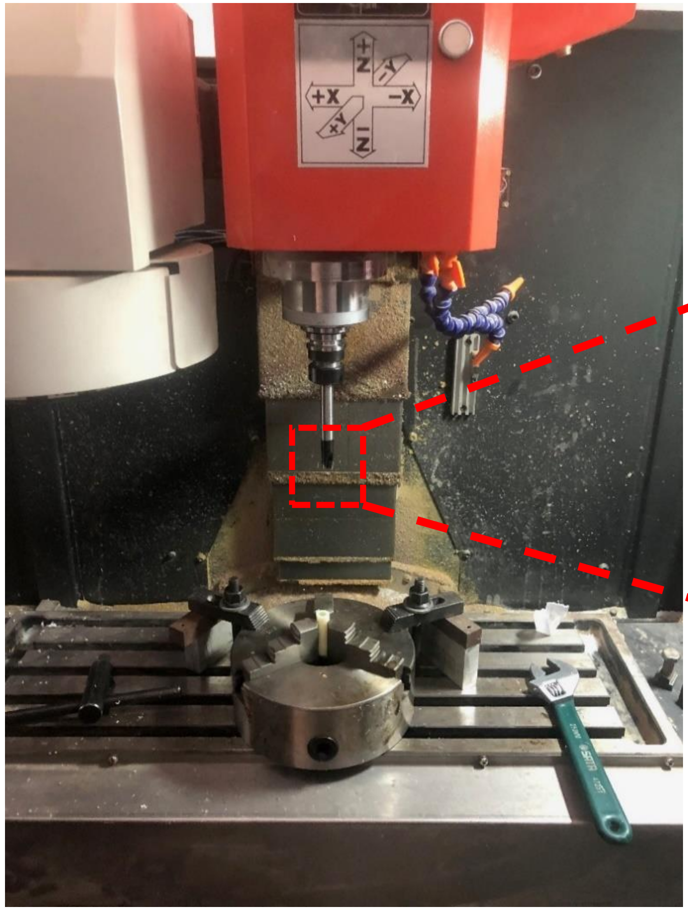
WLS and clear Fiber selection *(data from product brochure)*

Fiber type	WLS fiber		Clear fiber
	Kuraray Y11(200)	**Saint Gobain BCF91A**	**Saint Gobain BCF98**
Wavelength shift	~430 → 476nm	~420 → 494nm	
Attenuation length(1/e)	>3.5 m		>8m from brochure (test shows worse result)
Radiation hardness	13% light loss at 100k rad (30% at 700k rad)	15% light loss at 100k rad (50% at 700k rad)	
Mechanical property	Less bending loss		
Light yield		10% less than Y11 without bending	
Cladding	Single cladding / Double cladding Double cladding **50%-60%** better light collection yield than single		Should match the cladding type of WLS fiber
Price	High	Low	

Y11 will be good choice in preshower and BCF91A in shower, and both with double cladding .

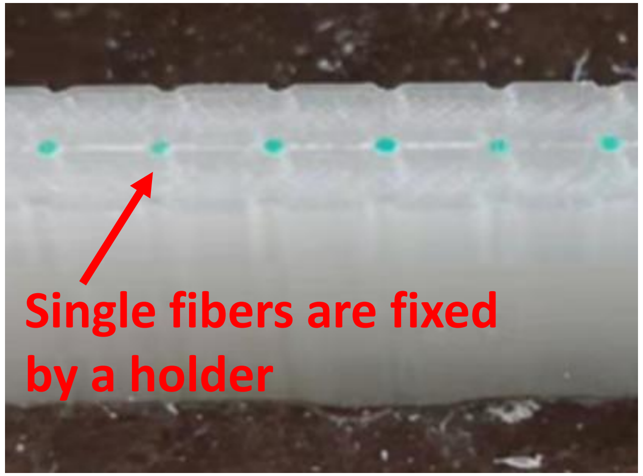
Fiber polishing

Fiber is polished in bundle or as single by a diamond milling cutter in SDU. This method shows good efficiency and quality.

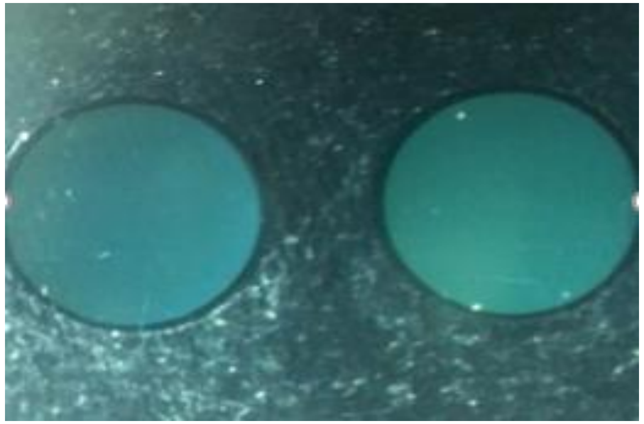


Polishing Machine tool

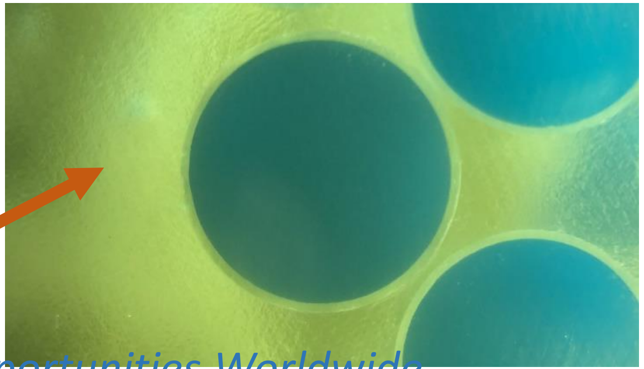
Diamond milling cutter



Loose single fiber (unglued)



Single fiber in connector



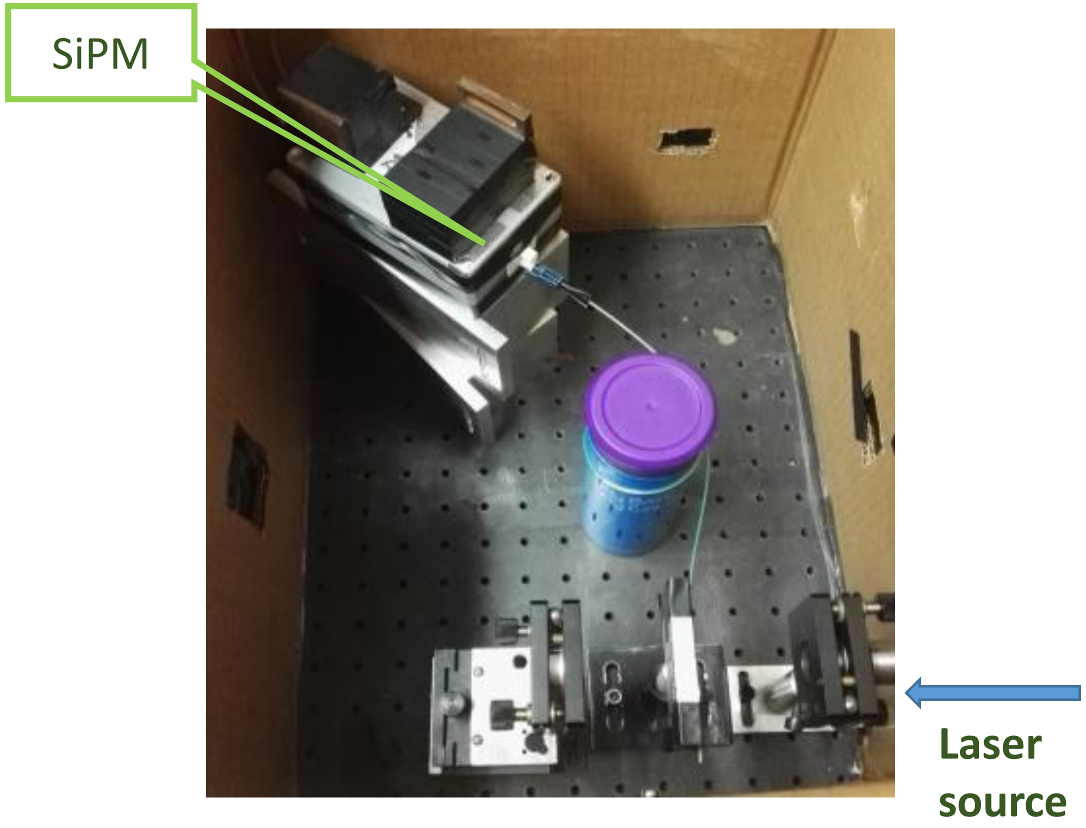
Fiber in bundle

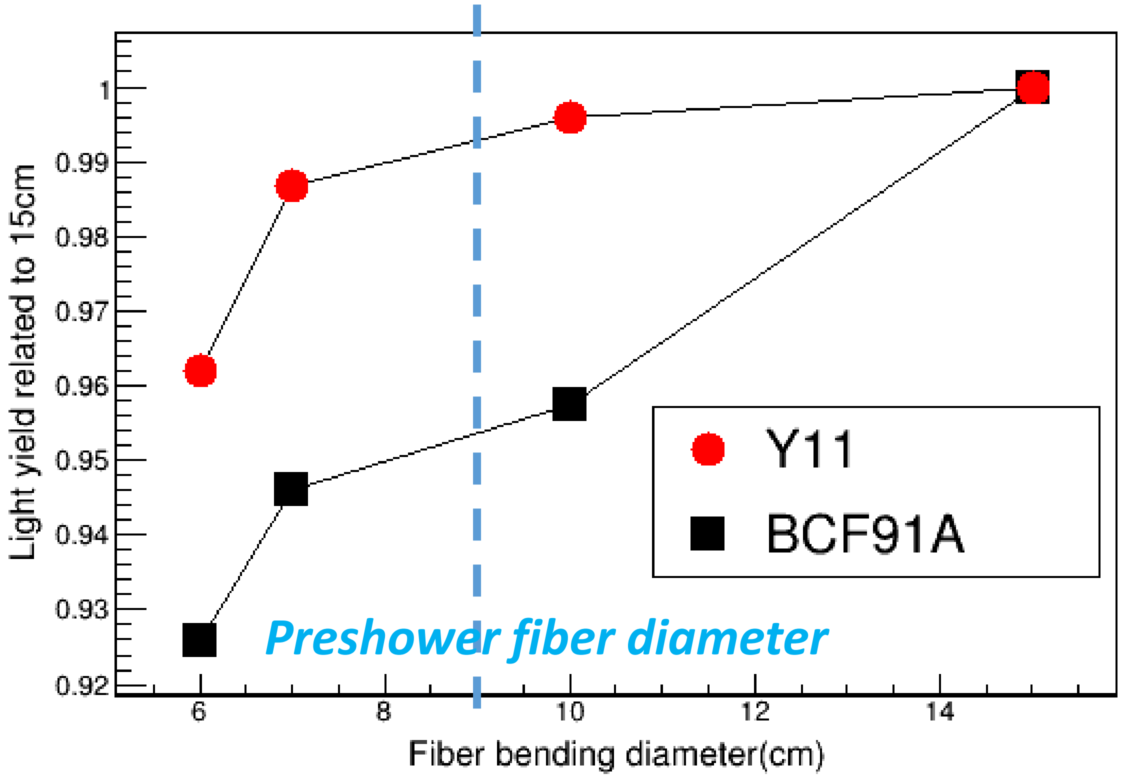
Optical glue

WLS fiber Y11 and BCF91A comparison

Bending light loss test

WLS fiber test in THU



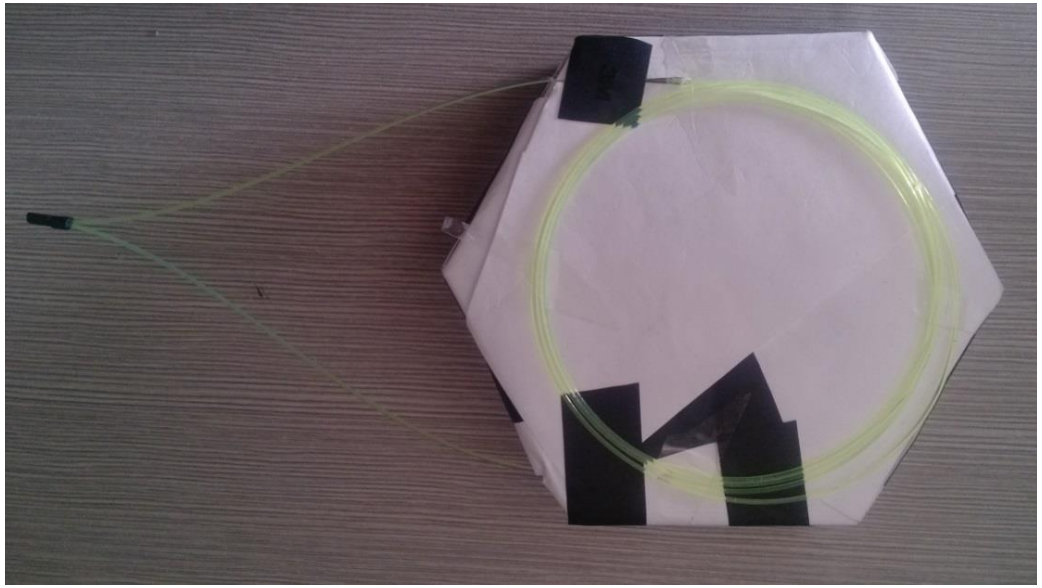


BCF91A lose more light than Y11 with same bending diameter, but the difference is not too much.

WLS fiber Y11 and BCF91A comparison

Preshower light yield test

- We only have single-cladding BCF91A and double-cladding Y11 in SDU.
- This test include the both influences of bending loss and fiber difference.
- Only one fiber with 2.5 turns in groove.

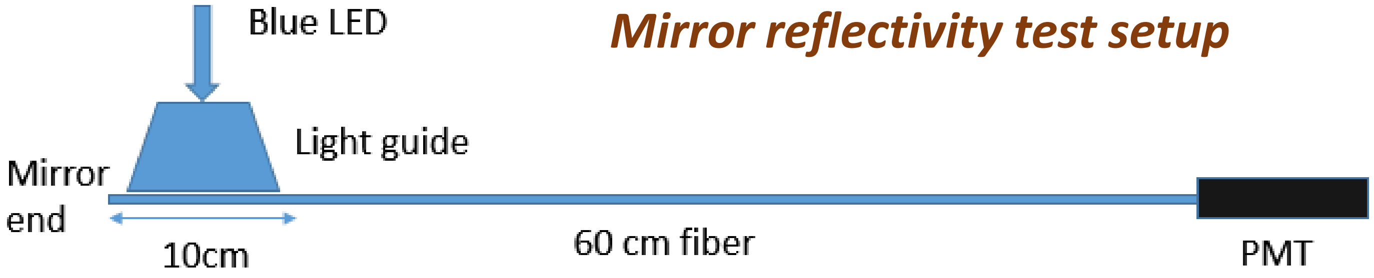


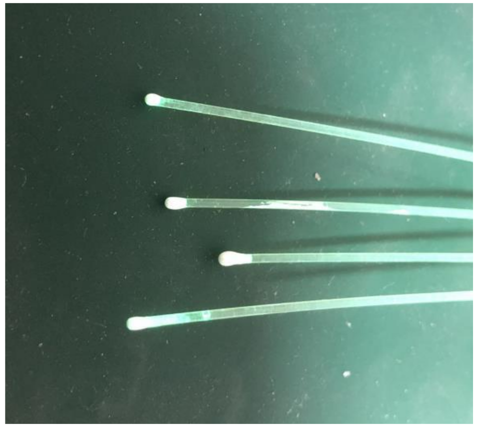
	Scintillator group 1	Scintillator group 2
BCF91A (single-cladding)	27.8	24.8
Y11 (double-cladding)	42.8	39.2
Difference	**54%**	**58%**

Fiber mirror reflector

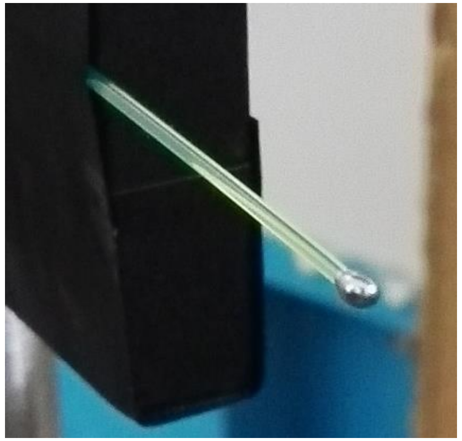
Photon is collected only by one end of fibers, which coupled to PMT in bundle. Half of generated photons will go to other end, collection of these photons is necessary. To collect more photon, for the other end, adding specular reflection mirror is applied.

Mirror reflectivity test setup

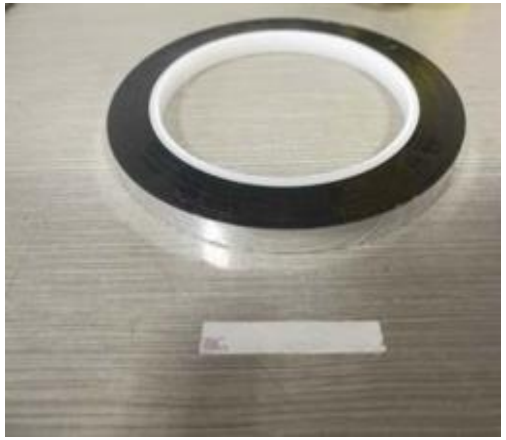




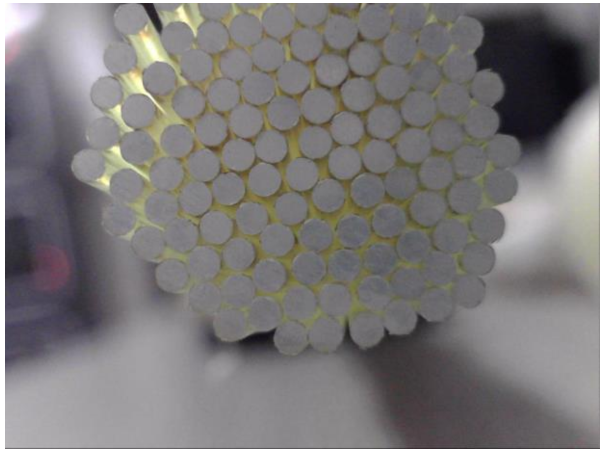
TiO2 + epoxy resin



Silver shining



Silver reflective tape



Silver mirror by plating

Fiber mirror reflector test result and comparison

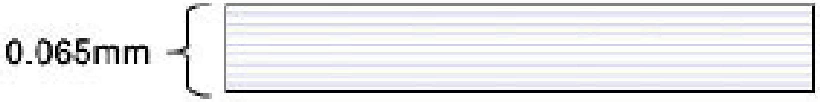
Type of reflector	Light yield improvement
TiO_2 + *Epoxy Resin*	20%(SDU), 40%(THU)
Sliver shining ink	20% - 30%
Silver tape	60%
Silver mirror	60% - 90%, depend on technique and quality
ESR	80%
ESR + black layer	80%

Silver mirror could reach highest light improvement, and flexible to insert fiber. However, the price is much higher than others, and the mirror layer could shed, may have aging problem.

The ESR reflector has very good performance, only challenge is pasting to fiber end because its smooth surface.

3M™ Enhanced Specular Reflector (3M ESR)

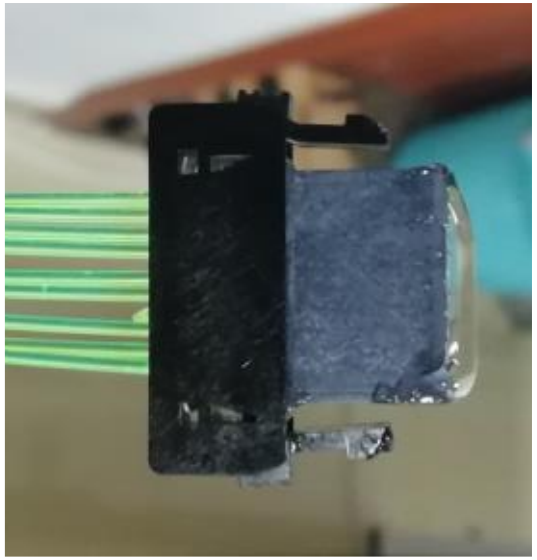
Mirror reflector, more than 98% reflectivity
A high-performance, non-metallic, color-neutral reflector.

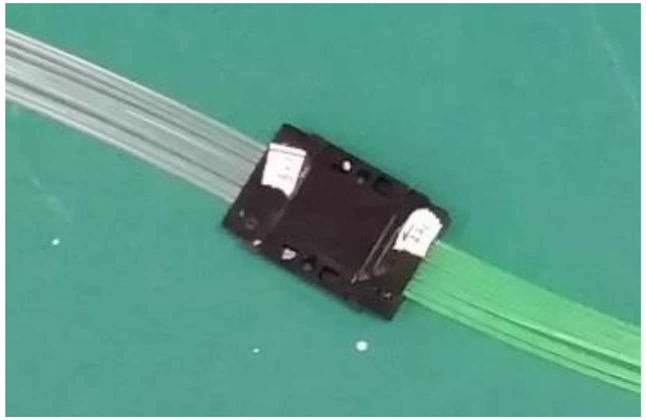


More than 1000 layers

WLS fiber to clear fiber connector

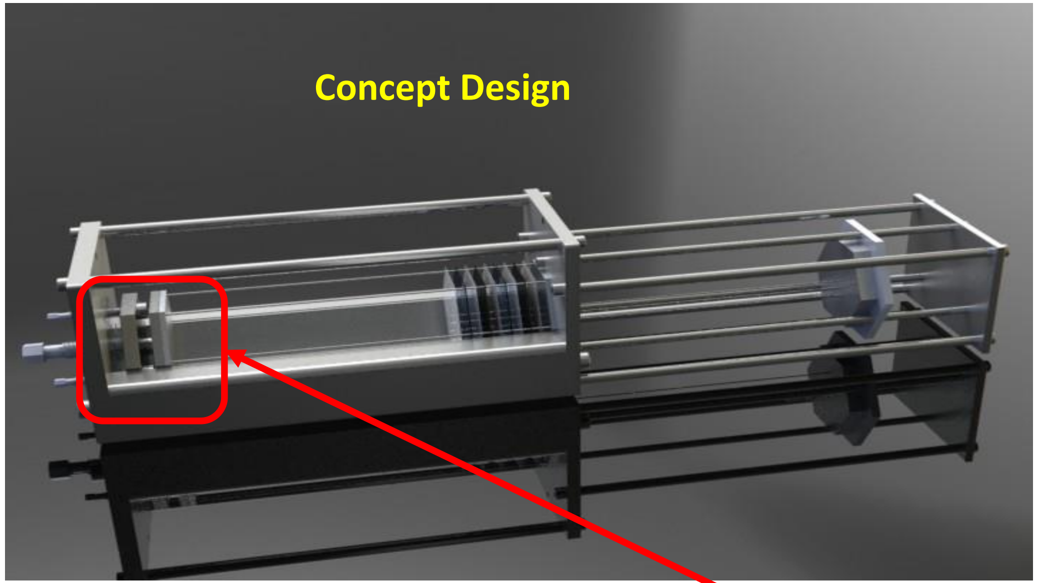
The attenuation length of clear fiber is short, which highly contribute to light loss in transportation. To reduce light loss in transportation, a connector is applied to send photon from WLS fiber to clear fiber, which has long attenuation length.

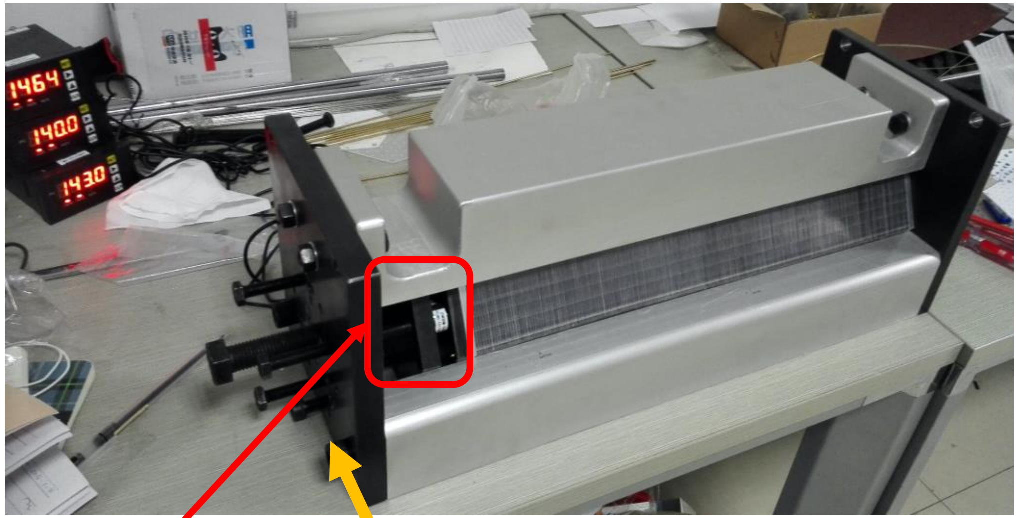


Results shows air gap coupling reach to around 20%, adding silicone grease will get around 15%.

Assembly tool





Sensors for compression

Force is exerted by pushing several screws.

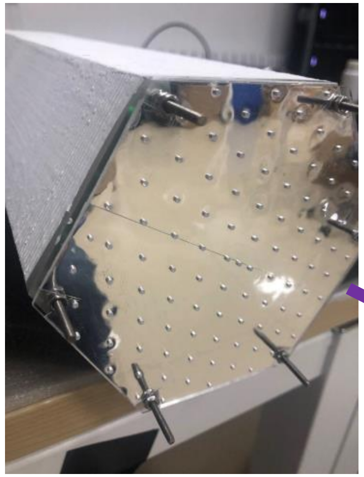
- Stack all the scintillator tiles, lead plates, and reflectors together
- Compress the module stack with 5000N force, release 2000N to the six rods in module
- Force will be monitored for several days, until the pressure is stable

Prototype modules

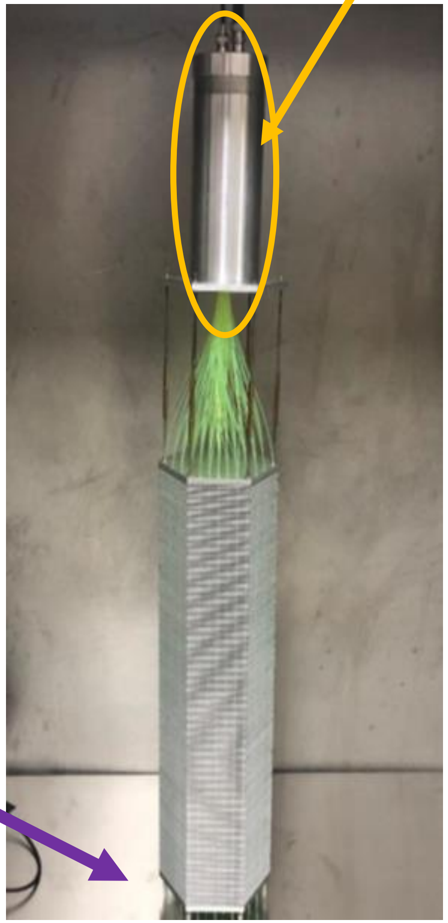
- SDU: 4 finished +1 in process
- THU: 2 finished +1 in process
- The module built later with improved material and technology, could get more light yield.
- Total 7 good modules needed for the future beam test

TiO2 coating

Paste a whole layer of ESR reflector at fiber end



PMT: Hamamatsu R11102



SDU #4

Light tight tape

THU #1

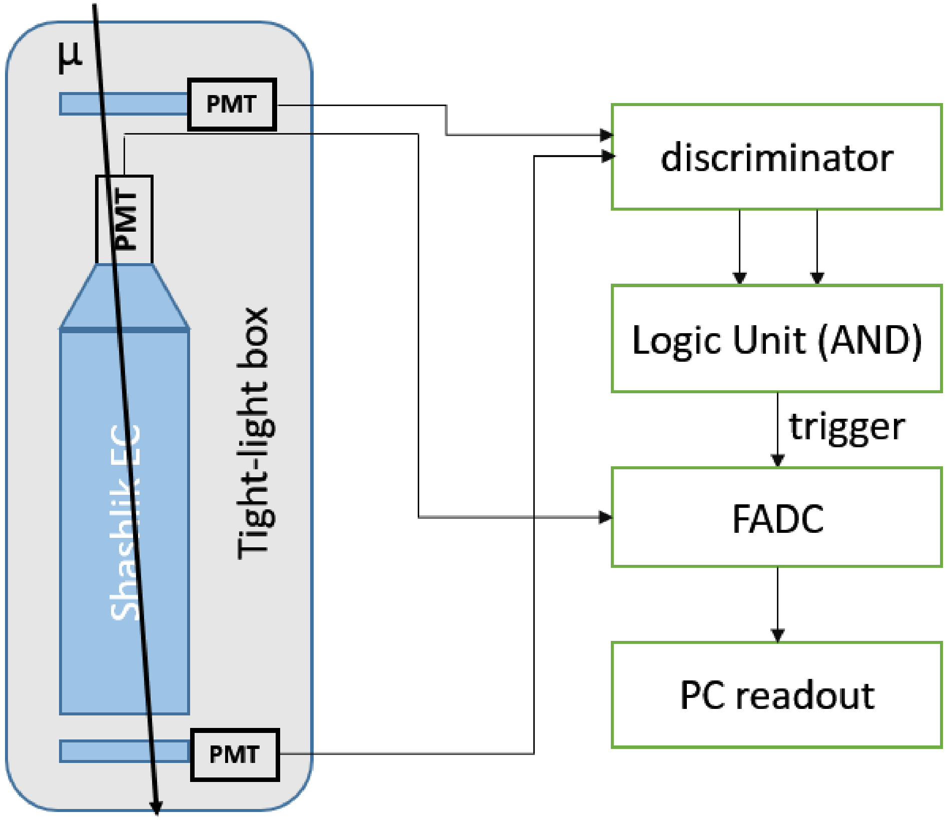
Shashlik ECal module material list

Module No.	WLS fiber	Scintillator	Reflector layer	Fiber reflector	Module Coating
SDU #1	BCF91A	Kedi	Print paper	No reflector	TiO2+glue
SDU #2	BCF91A	Kedi(enhanced)	Print paper	Silver mirror	TiO2+glue
SDU #3	Y11	Kedi(enhanced)	Print paper	Silver mirror	TiO2+glue (1:1)
SDU #4	BCF91A	Kedi(enhanced)	Powder paint	ESR film	TiO2+glue
SDU #6 **(in progress)**	**Y11**	**Kedi(enhanced)**	**Powder paint**	**ESR film**	**TiO2+glue**
THU #1	Y11	Kedi	mirror mylar	silver shine ink	TiO2(Kedi) painted
THU #2	BCF91A	Kedi(enhanced)	Powder paint	silver shine ink	Tyvek
THU #3 **(in progress)**		Kedi(enhanced)	Powder paint		

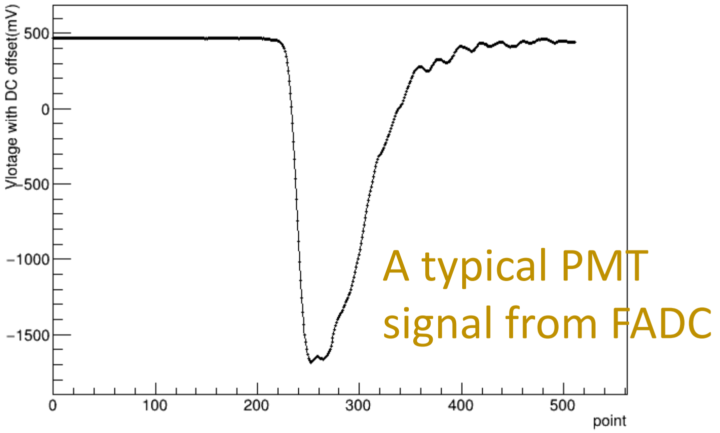
Shashlik cosmic ray test

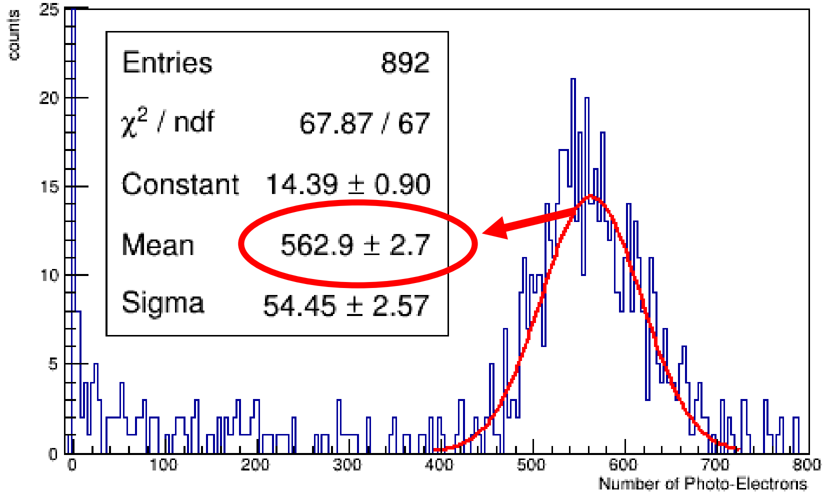
Purpose: Evaluate the light yield of prototype.

Most of cosmic rays are mouns, and deposit energy through ionization(MIP), which could offer a reference light yield to the signal of electron shower.



Vertical test setup





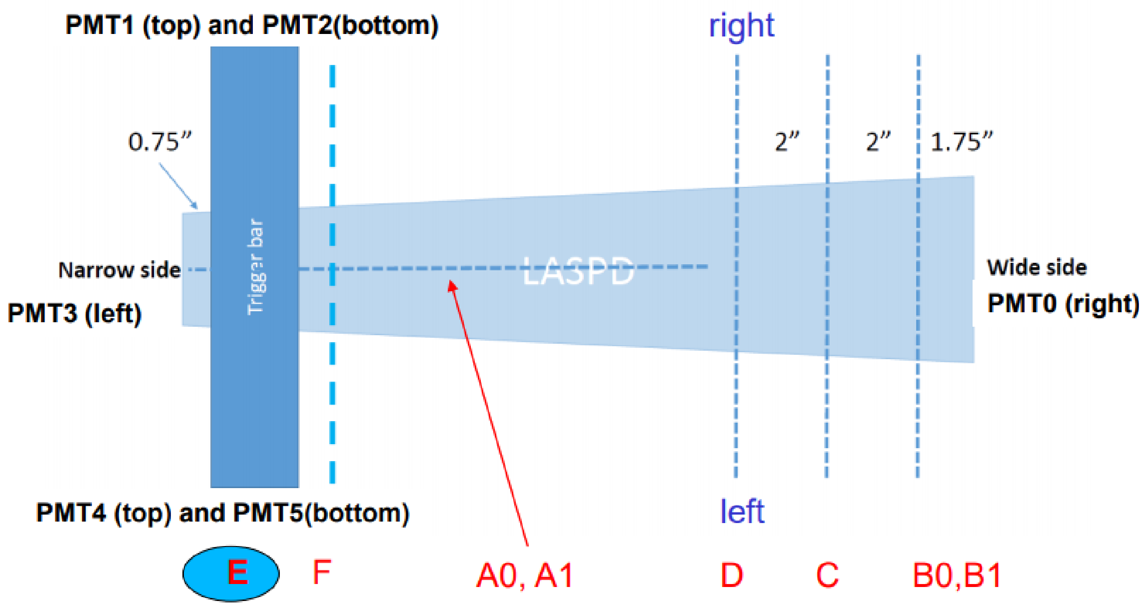
Cosmic ray test result

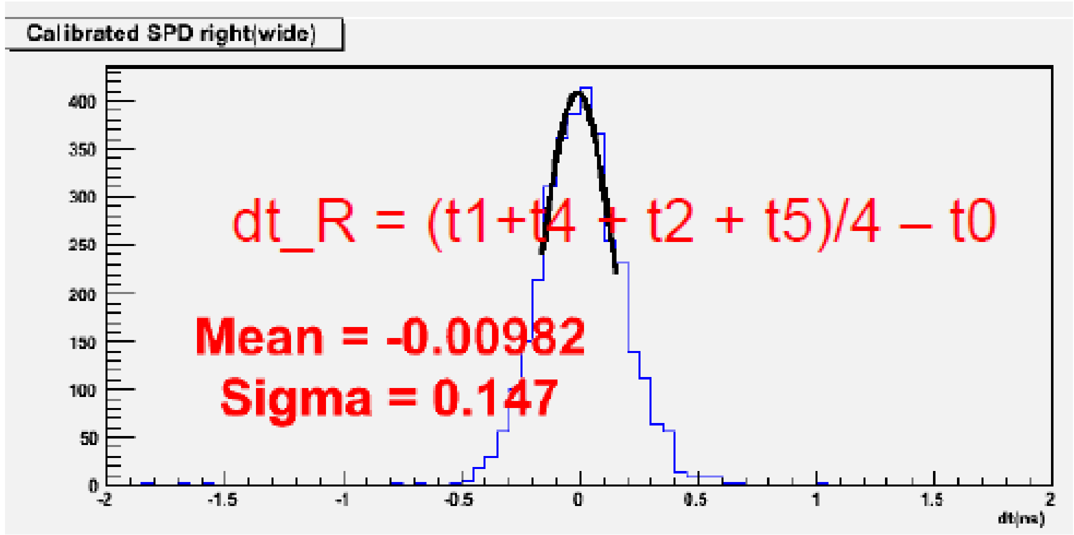
Module No.	Vertical (NPE)	WLS fiber	Scintillator	Fiber reflector	Painting	Reflector layer
SDU #1	212.5	BCF91A	Kedi	No reflector	TiO2+glue	Print paper
SDU #2	413.8	BCF91A	Kedi(enhanced)	Silver mirror	TiO2+glue	Print paper
SDU #3	484.5	Y11	Kedi(enhanced)	Silver mirror	TiO2+glue(1:1)	Print paper
SDU #4	563.2	BCF91A	Kedi(enhanced)	ESR film	TiO2+glue	Powder painting
THU #1	425	Y11	Kedi	silver shine ink	TiO2(Kedi) painted	mylar mirror
THU #2	657	BCF91A	Kedi(enhanced)	silver shine ink	Tyvek	Powder paint

- Enhanced scintillator and fiber mirror increase light yield significantly
- Coating with TiO2: increase about 40% comparing without coating by test.
- THU #2 achieve the max light yield up to now
- Future module that replace fiber to Y11 and use better fiber reflector will achieve much higher light yield
- For initial plan, 900 p.e. from moun is good enough to get 3% statastic error, which responding to 2% error regarding 1GeV electron.

SPD time resolution test

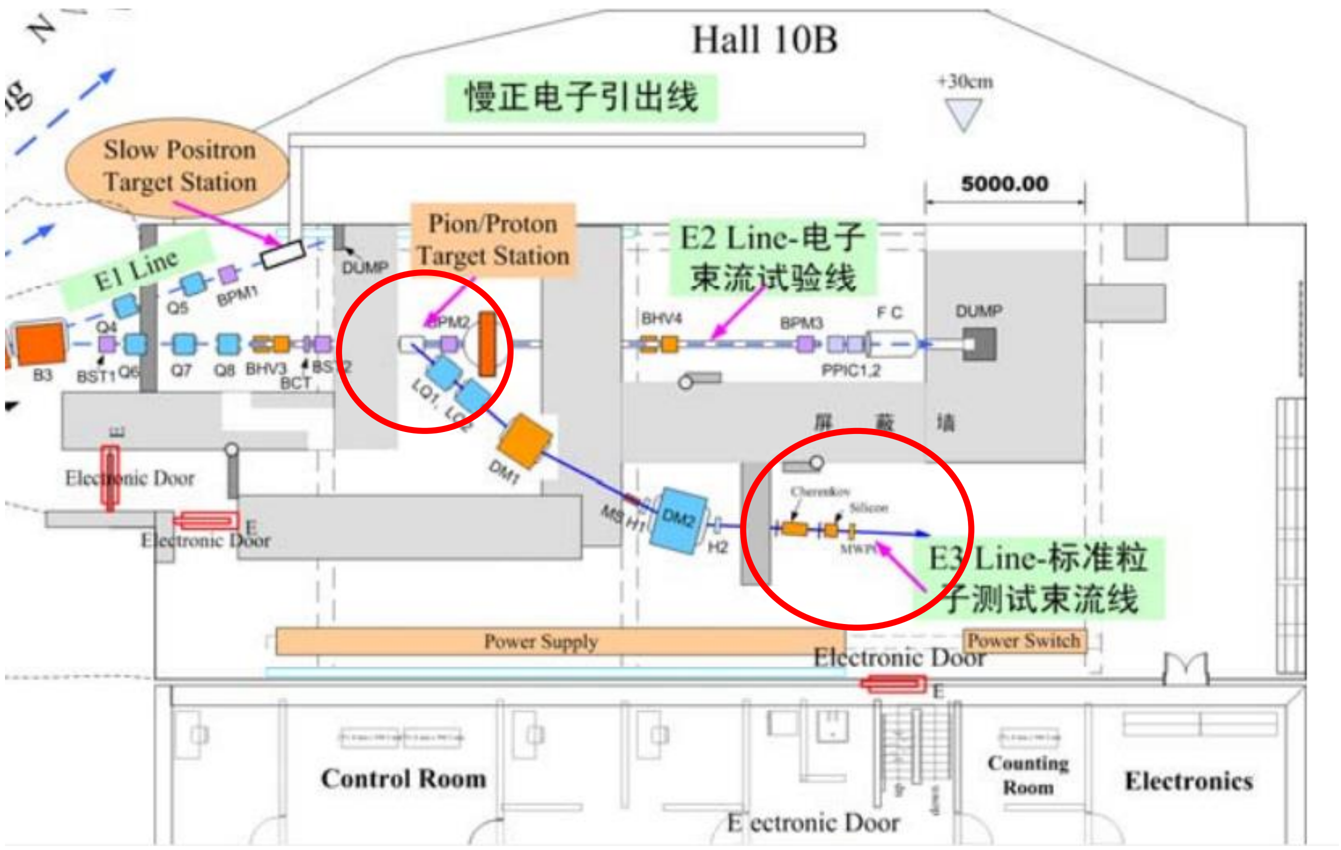
- Cosmic ray test
- Use three bars method
- With tracking information from GEM
- Achieve 147ps for single side readout





Possible beam test chance in IHEP

covenience and practical chance to perform beam test



Beijing-BTF Hall 10, IHEP

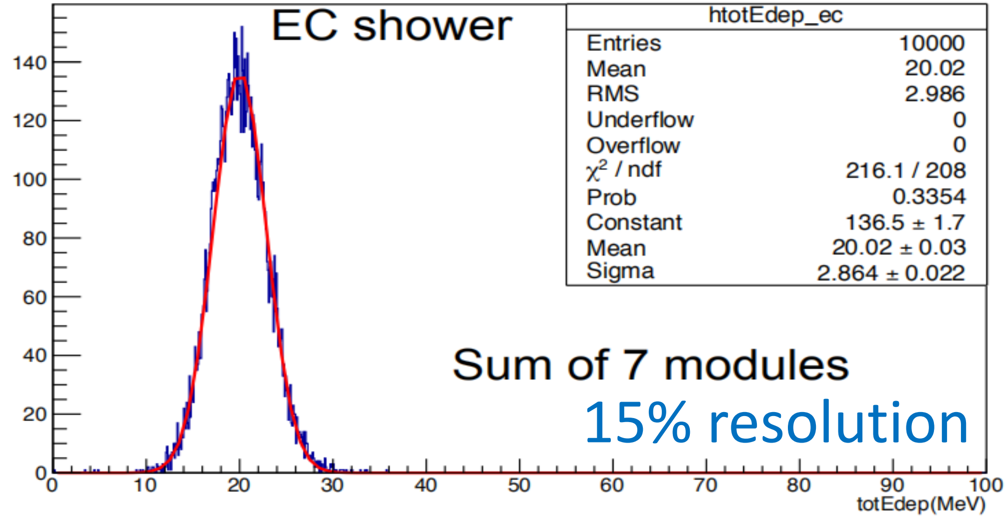
- e+/e- energy: 100MeV/c, 200 MeV/c
- rates at Hz level but depend on target thickness
- Own tracking, e/π saperation(cherenkov) and trigger detector

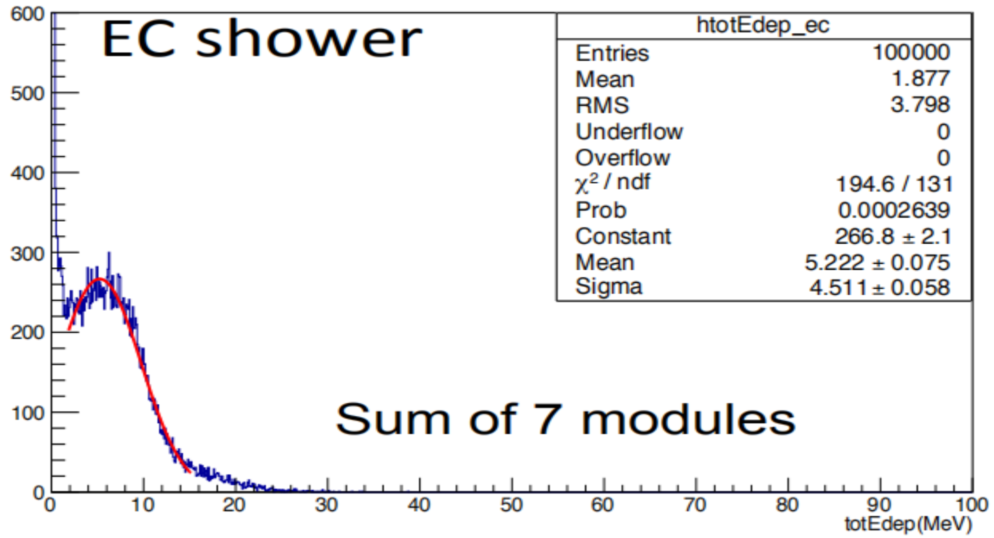
Other laboratorys with good electron beam are also in our consideration.

Shower simulation result (energy deposit)

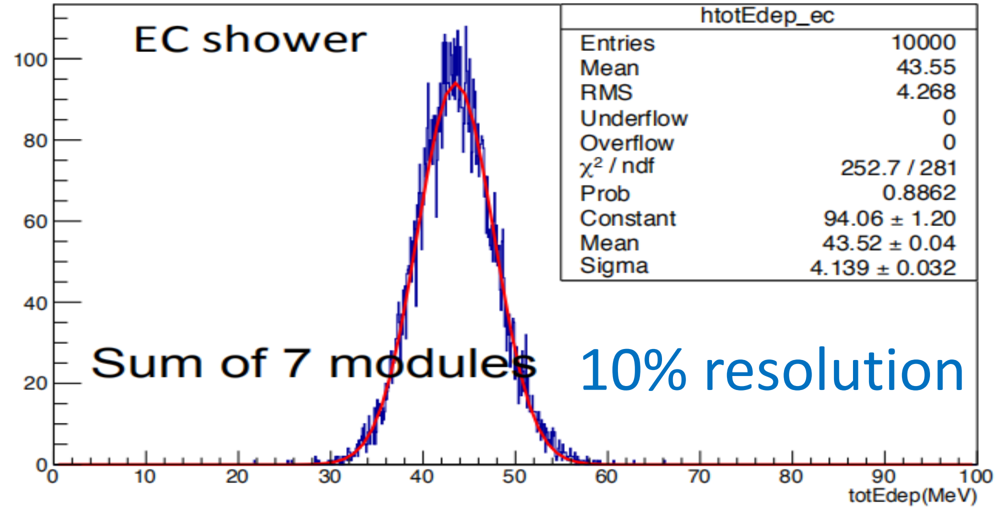
e+ π+

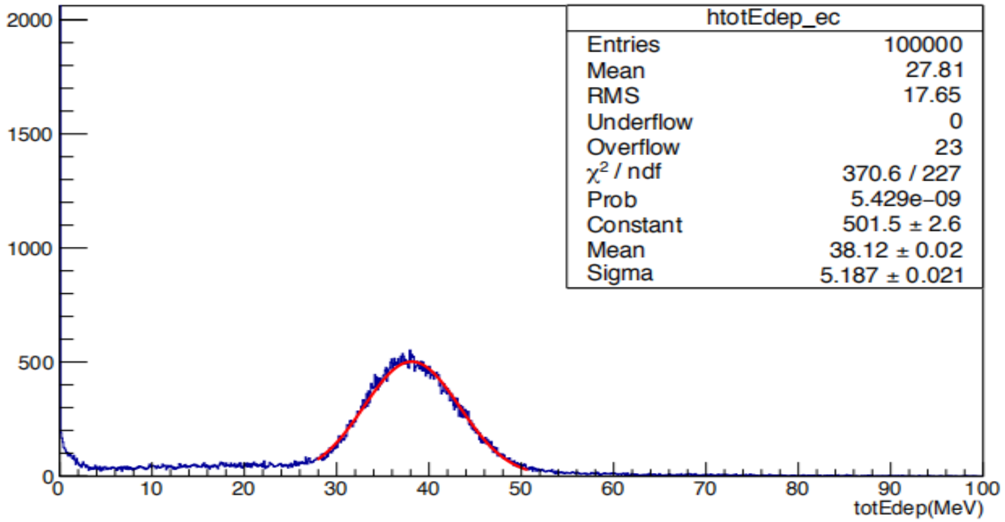
100MeV





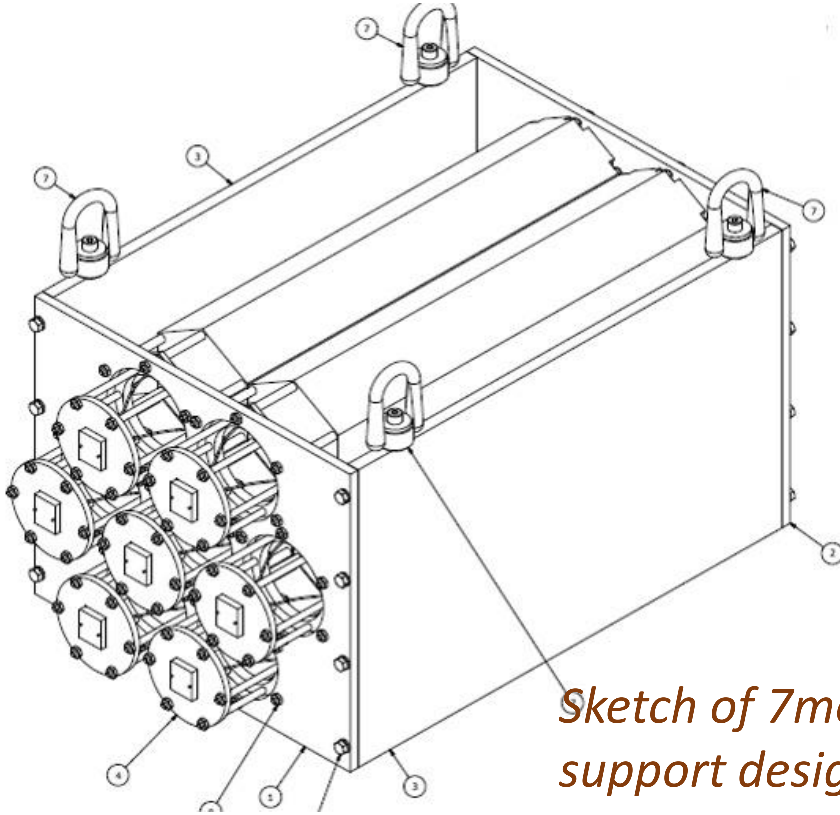
200MeV





Support structure design of beam test

- Support structure for beam test is design by engineer in Argonne National Lab, and built in SDU.
- Provide experience and reference for supporting and mounting large amount of shashlik EC
- Both designs of shashlik detector and support structure need to be optimized to match each other.



Sketch of 7modules support design

Shashlik module built as the design in support structure, which will be applied in future module.

Summary and outlook

- Shashlik ECal prototypes are constructed in very good quality as the design of simulation.
- The best light yield of module THU#2 is 657 p.e. now
- New module in progress will get more light yield, especially to apply double cladding fiber
- IHEP beam test is still significative according to simulation result, even if the beam energy is low.

Work for future:

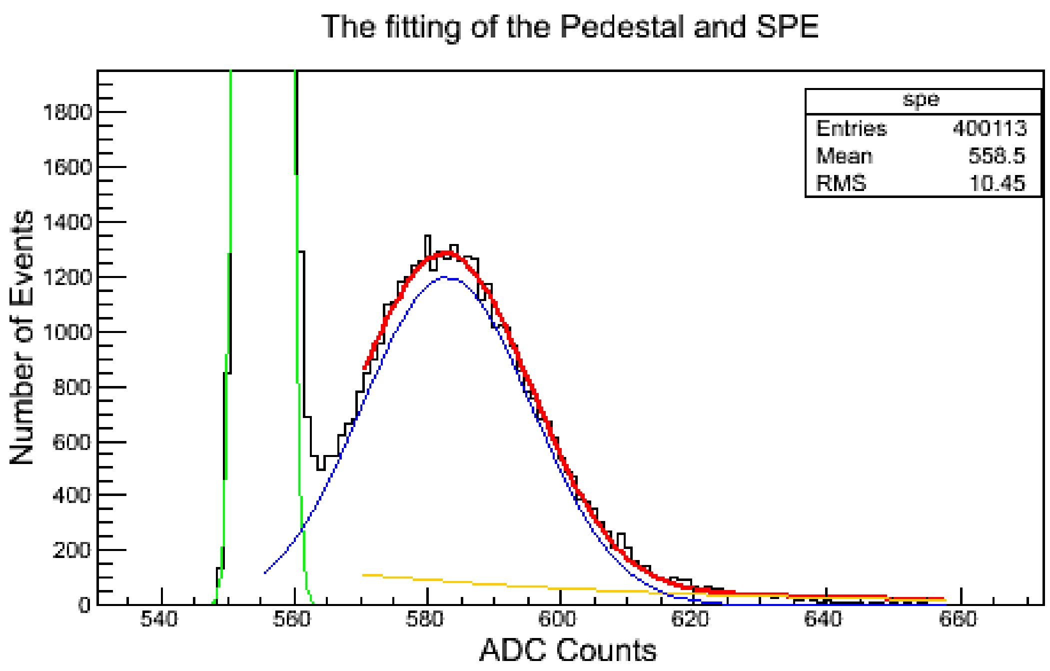
- Continue to improve the material and processing technology to achieve higher light yield.
- As proposal, 900 p.e. from cosmic ray test is our first goal with good statistics to achieve acceptable energy resolution
- Prepare for possible beam test chance both in IHEP and other Lab that has good electron beam.
- Beam test is necessary and crucial way to determine the quality

Thank You

BACKUP

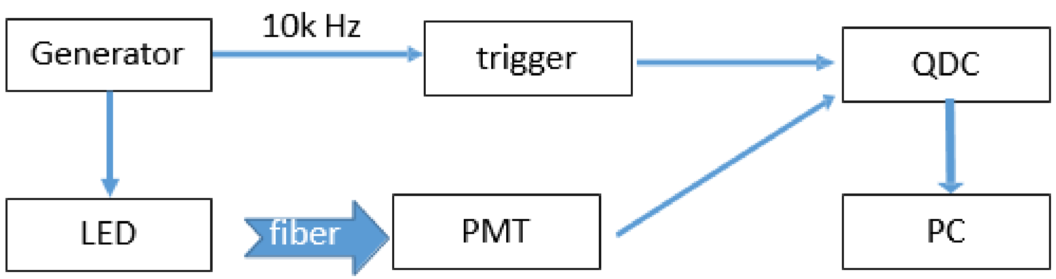
PMT absolute gain test

- The Npe(number of photoelectron) is calculated based on the “gain” of single photon: *NPE=Q/(e×Gain)*
- *The NPE is only determined by the light yield of detector, not influenced by HV of PMT*
- Detecte SPE(single photon spectrum) to acquire the gain
- Test performed in SDU PMT test Lab



Gain=(ADC_{signal}-$ADC_{pedestal}$)×0.029pC/e

SPE test setup schematic in SDU



Beam test module simulation

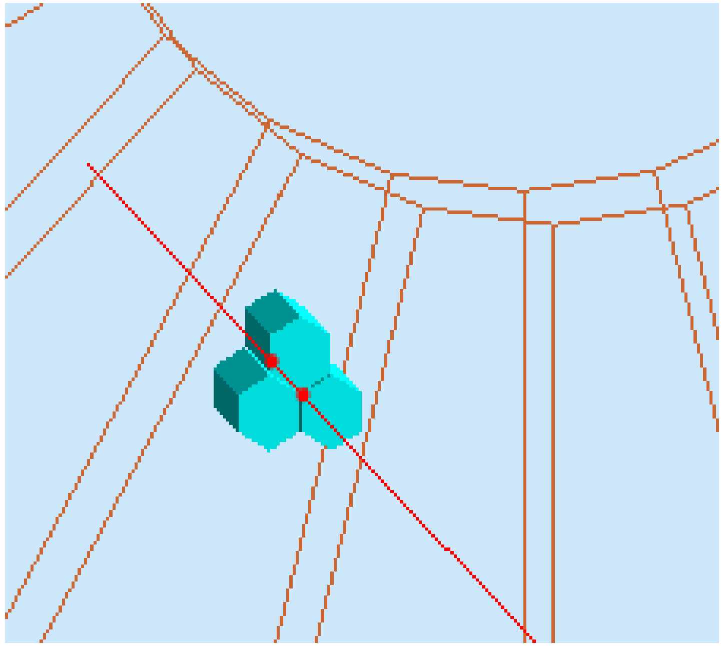
Simulation *work finished by Ye Tian(**Syracuse)***

The simulation is performed follow the real situation in IHEP

1. 100 MeV/c and 200MeV/c
2. e+ and π+
3. 1 module, 3 modules, 7 modules

- Beam size: 3cm radius
- No field, straight hit the center module.

The simulation is finished without fiber, and contain all other part of shower shashlik: shower scintillator and lead, TiO2 reflector layer and aluminum plate for supporting.



3 modules sketch

Preshower+ shower simulation result (energy deposit)

100MeV

200MeV

e+ π+

Shower scintillator

Preshower scintillator

Total energy Deposit in shashlik