Shashlik style ECal R&D for the SoLID project

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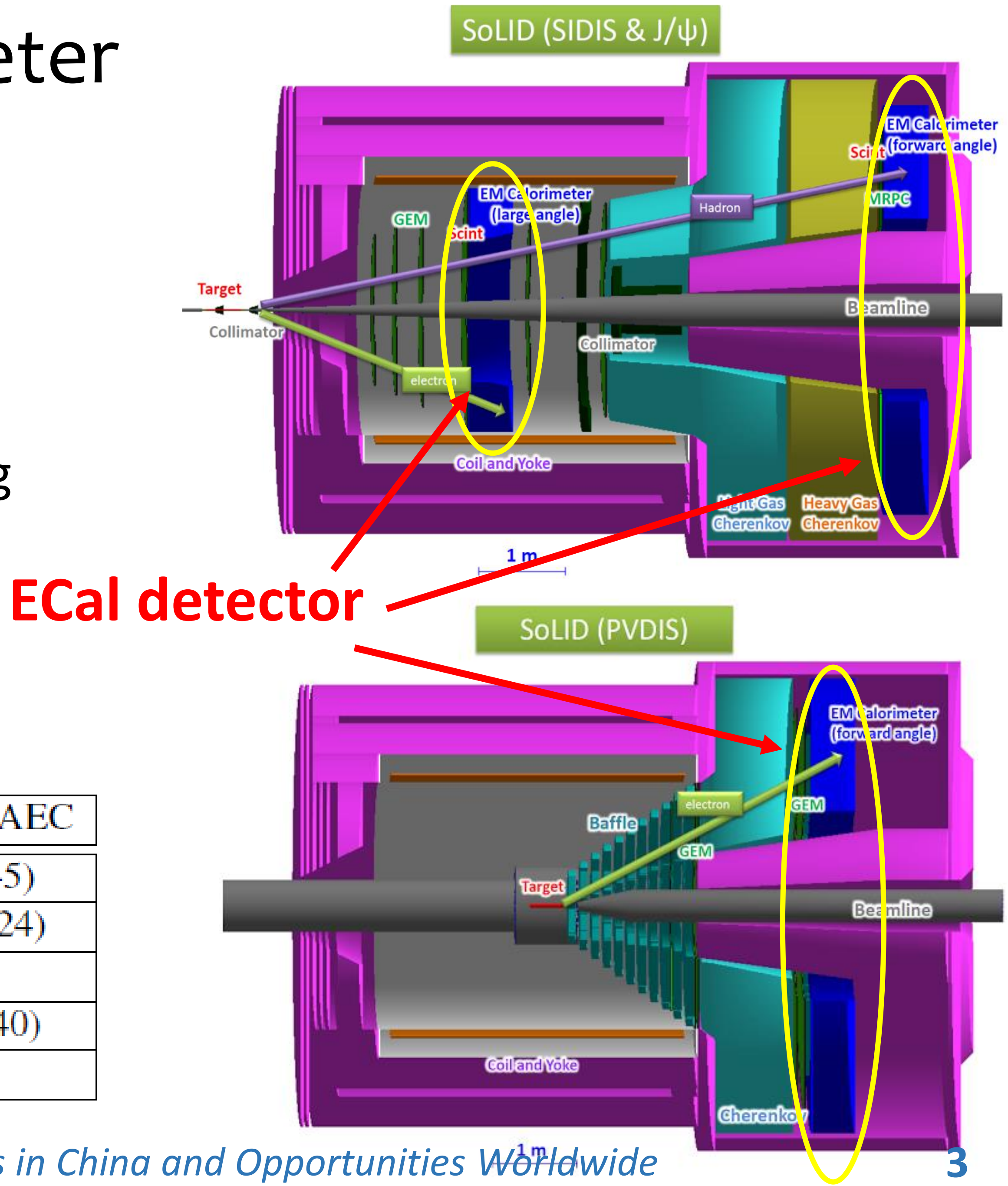
Outline

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



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 (~4) to 7GeV/c;
- Energy resolution less than $10\%/\sqrt{E}$(GeV)
- Provide trigger: Shower signal coincidence with cherenkov, suppress background

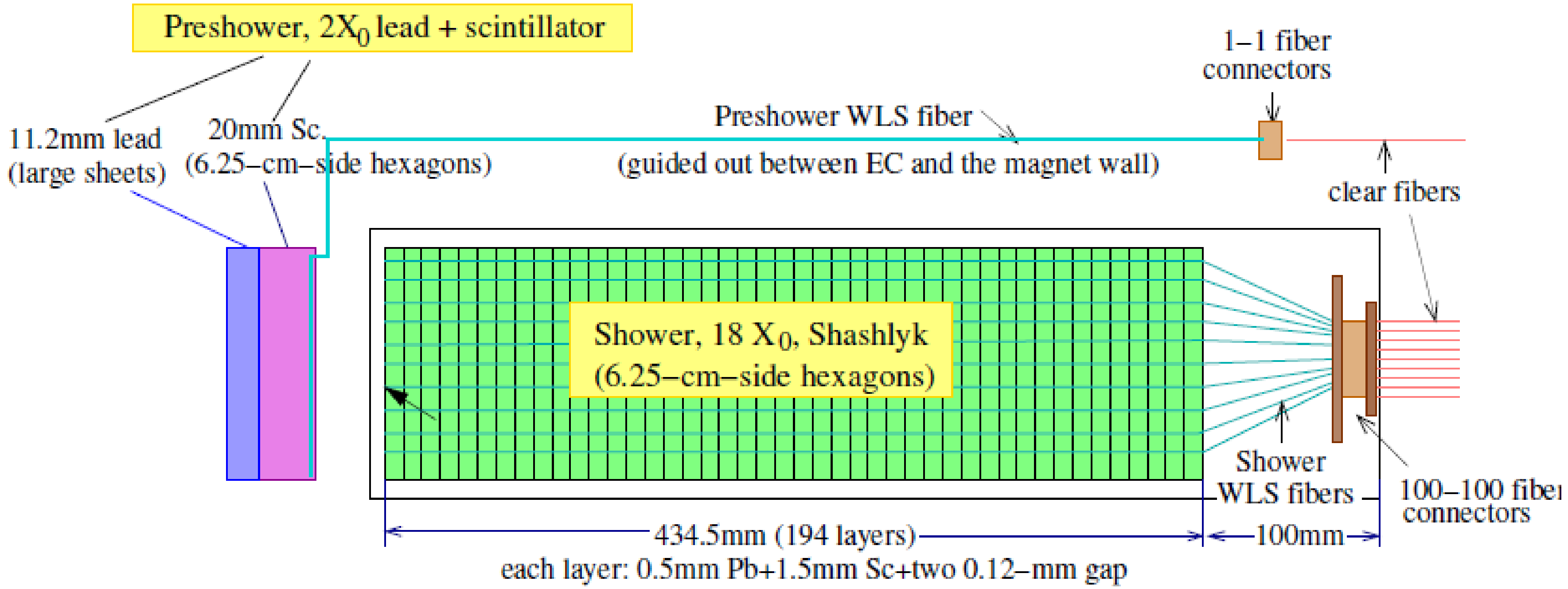
Special ECal challenge for SoLID:

- 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;

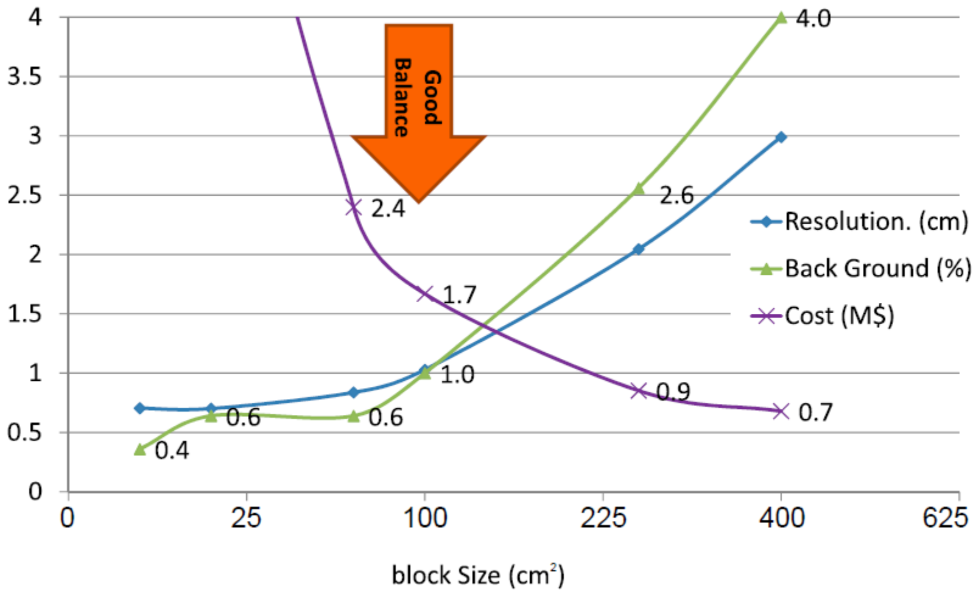
A shashlik style sampling EC is designed to satisfy the requirement.

Shashlik ECal Longitudinal design

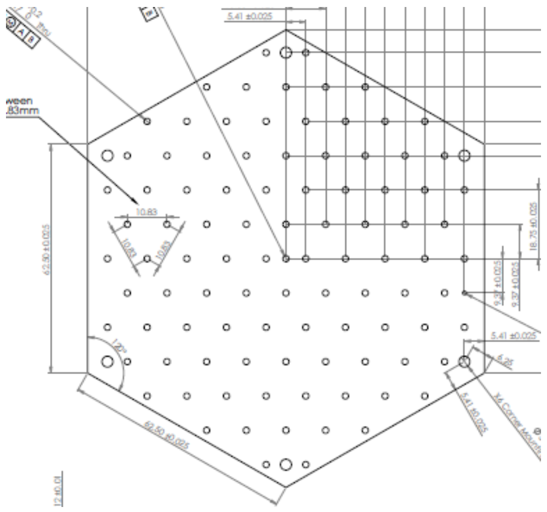
- Preshower: 2 X_0 lead + 20 mm plastic scintillator, WLS fiber embedded in scintillator. Designed for pion rejection.
- Shower: shashlik module (0.5mm lead + 1.5mm scintillator + 0.1mm reflector×2) ×194, WLS fiber×96 penetrating layers longitudinally.
- Overall: 20 X_0(<2% leakage)



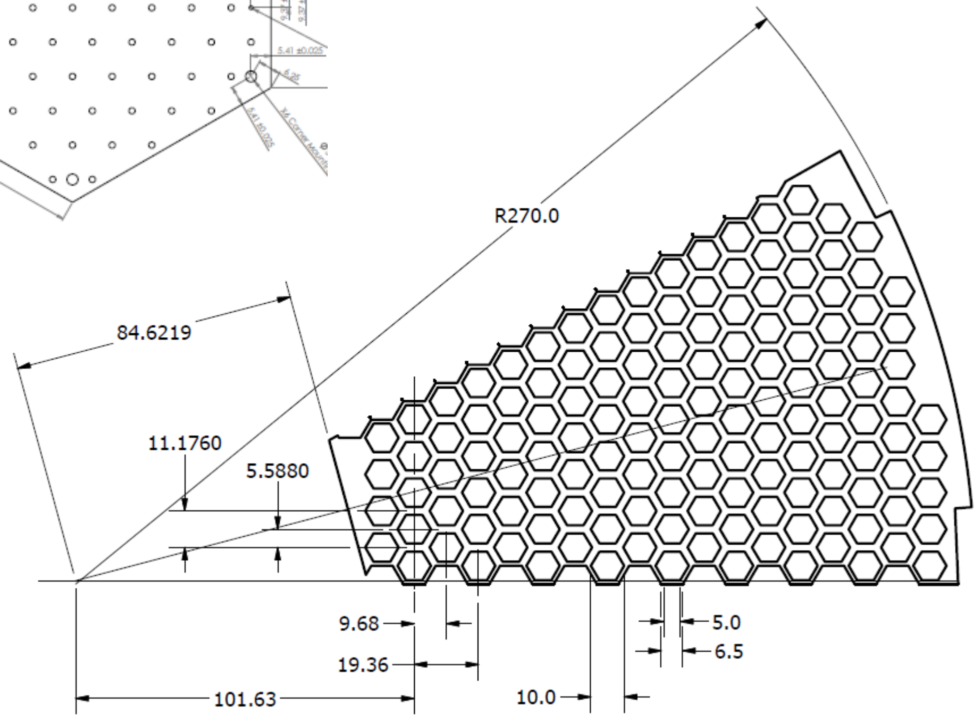
Shashlik EC Lateral design



Good balance between resolution, background and cost(simulation) for 100cm² block size.

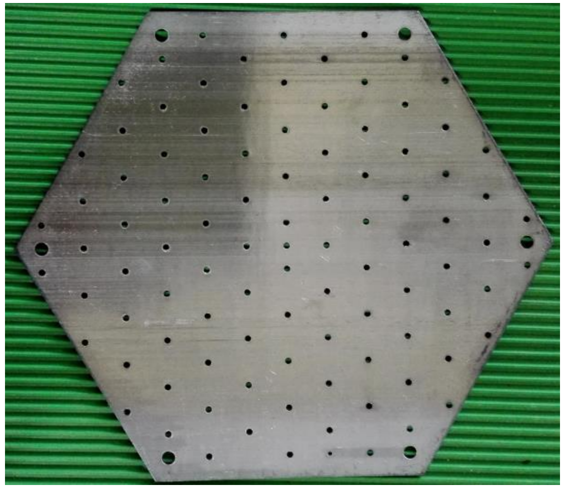


- 100 cm2 of hexagon shape with 6.25cm side length
- About 1800 modules in total

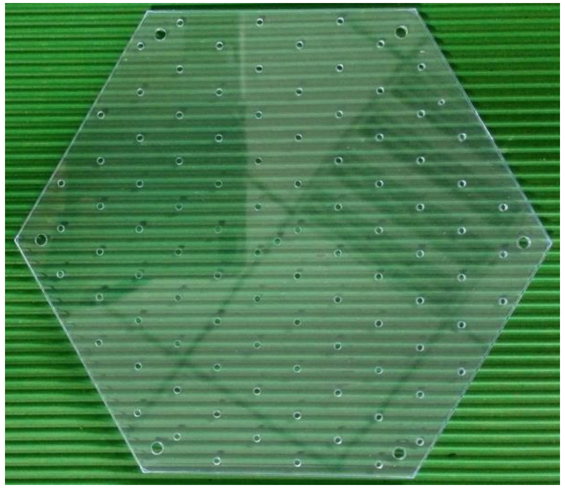


PVDIS FAEC (portion) viewing along the beam direction

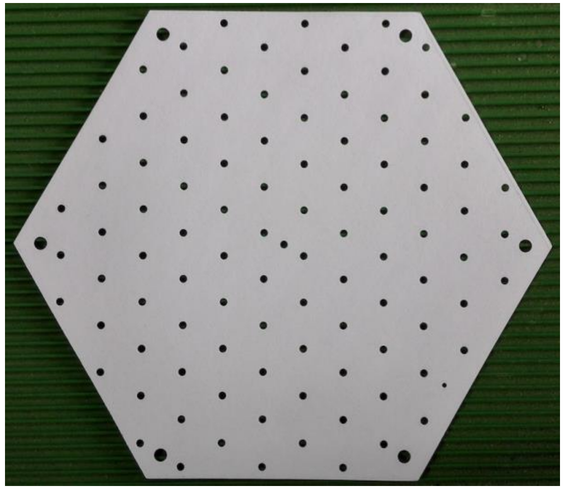
Main materials in Shashlik ECal detector



Lead plate



Scintillator tile



Reflector layer (paper)

1mm WLS fiber

The geometry and machining quality of scintillator tiles, lead plates and reflection papers 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)

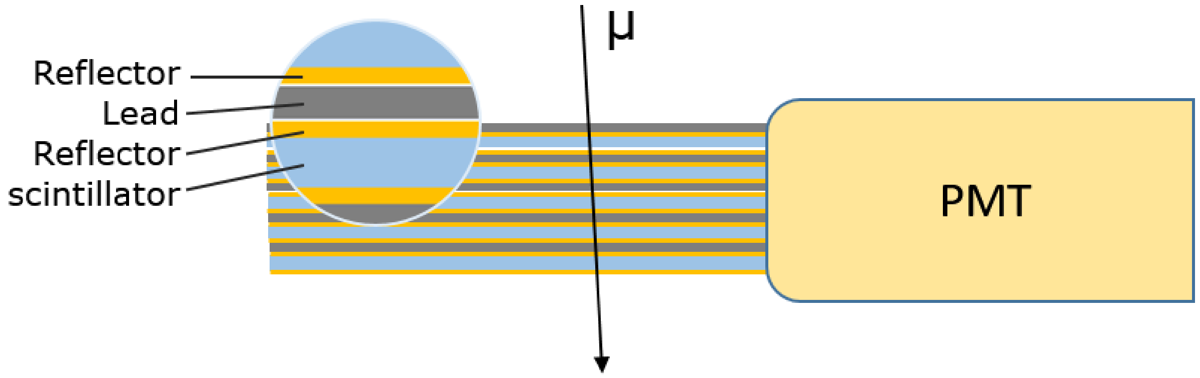
Purpose: good module quality and enough light yield

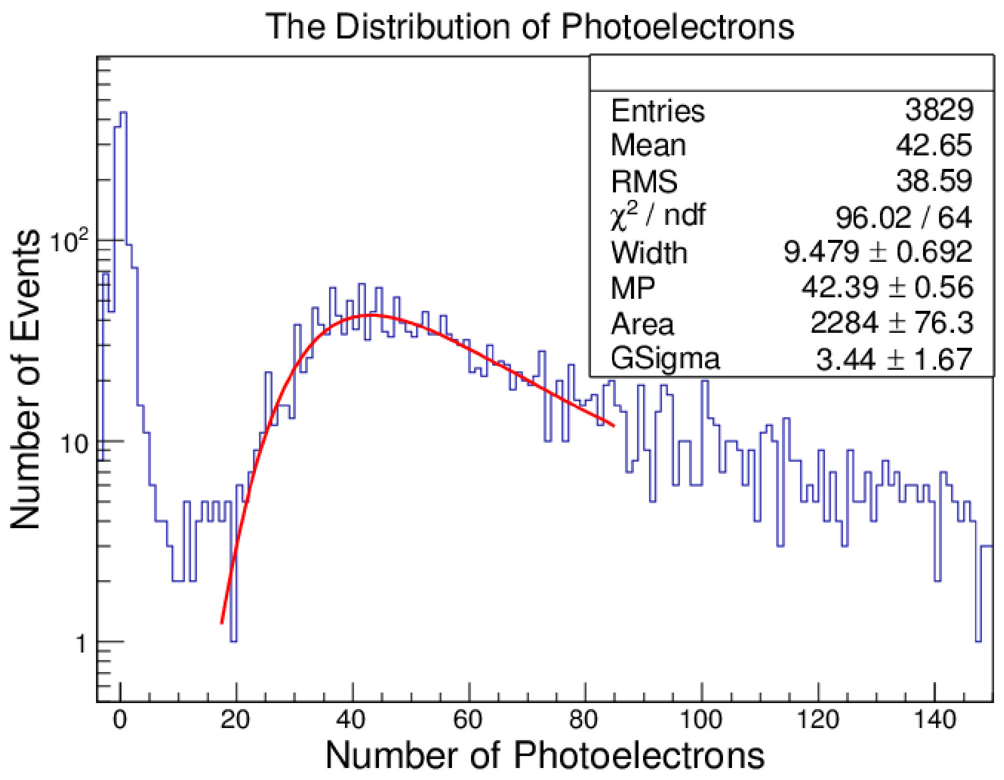
Reflective layer selection

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





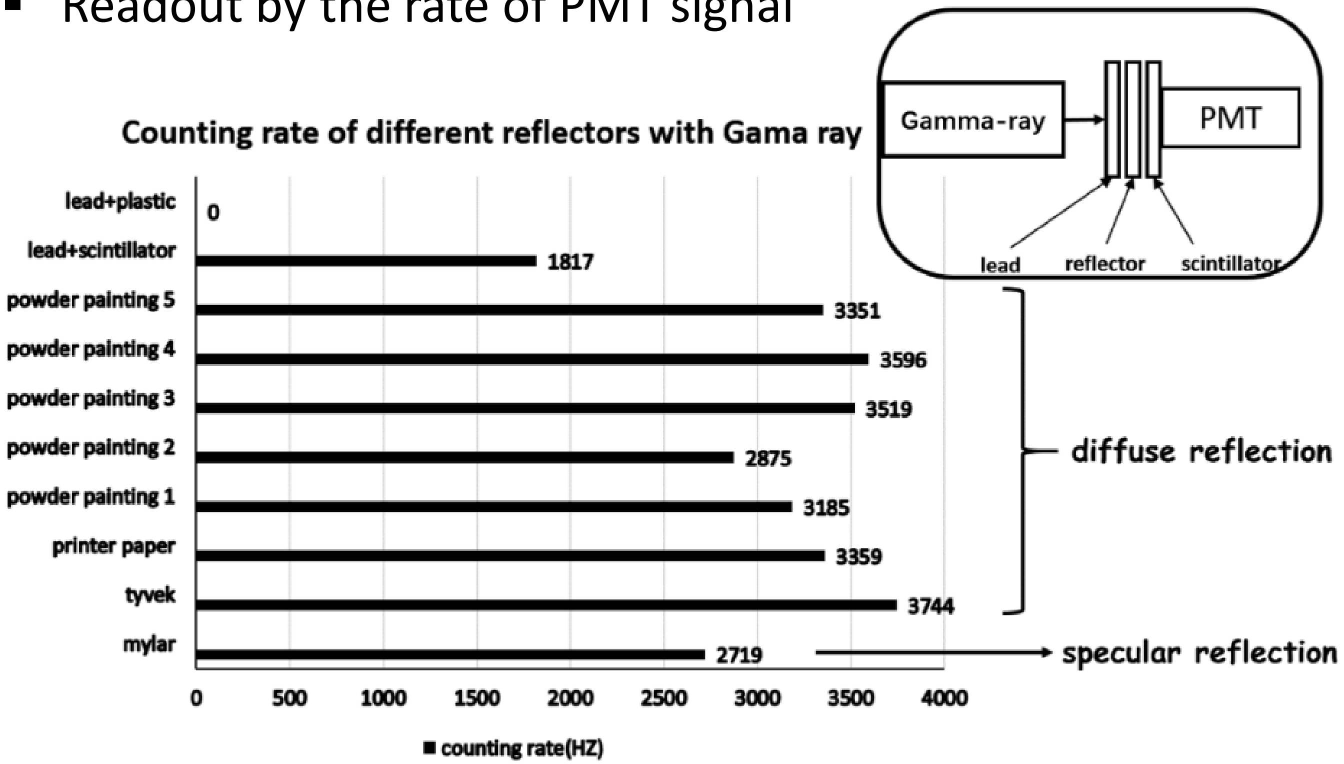
Typical number of photoelectrons distribution

Reflector layer test result

Reflector material	No reflector	Print Paper	Aluminum foil	Tyvek paper	MCPET
Relative light yield	0.85±0.02	1.06±0.06	0.97±0.08	1.61±0.16	1.24±0.05

THU group refelction material test

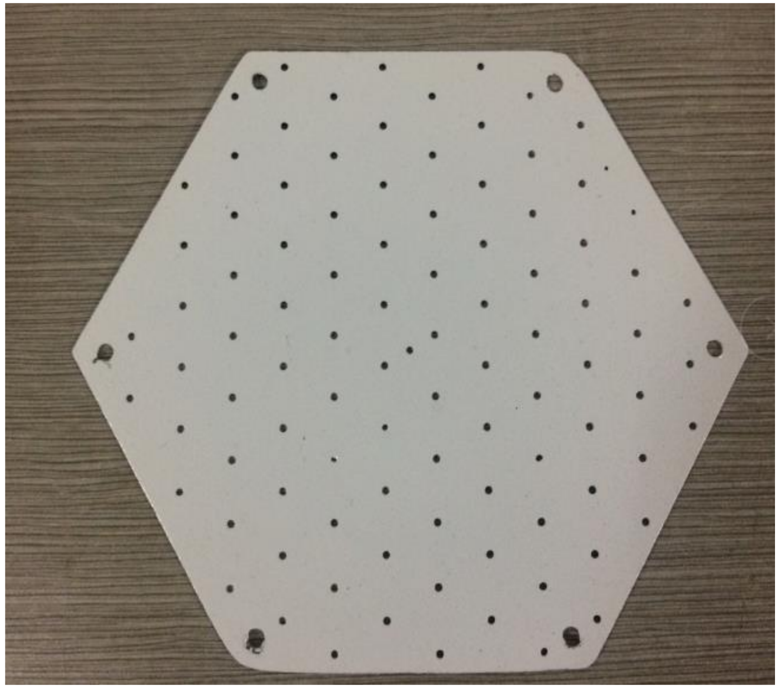
- Gamma-ray source
- Lead-reflector-scintillator layer
- Readout by the rate of PMT signal



Result shows the tyvek own the best reflection property, but aslo depende on the thickness of tyvek.

Powder painting

Special painting on lead with thin thickness and good guality



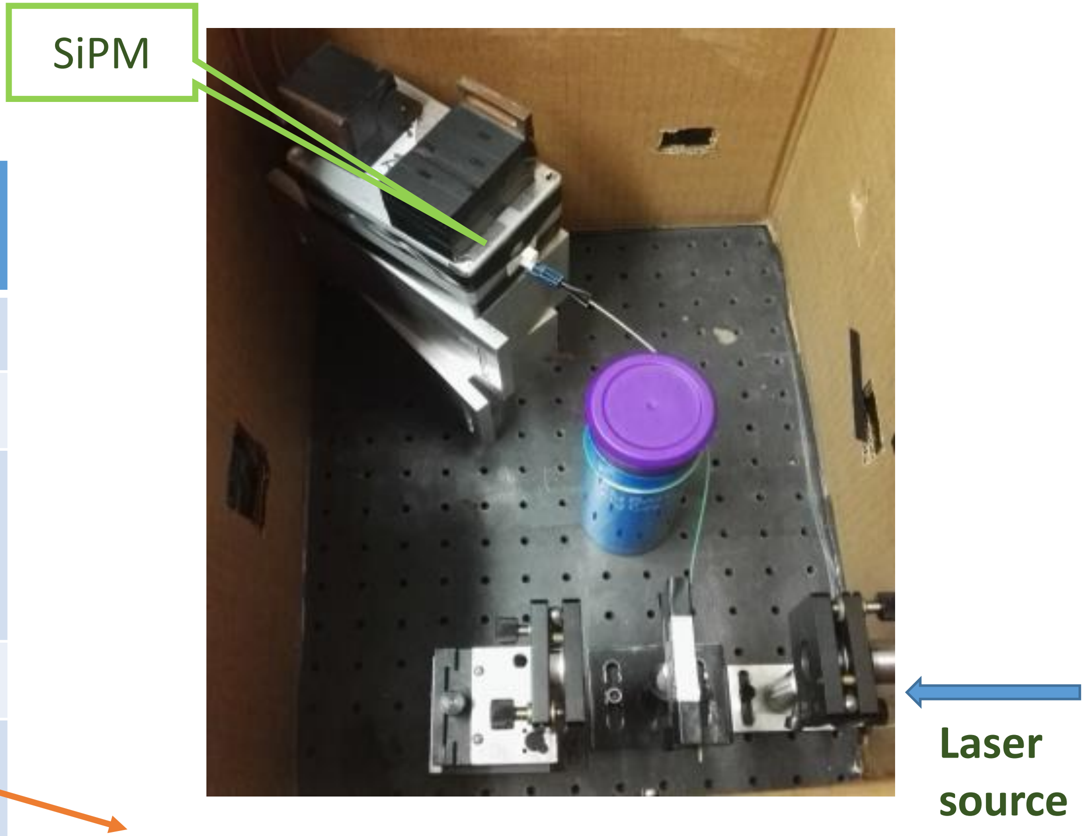
Recent test result of 5 layers shashlik test shows half thickness comparing with tyvek create 40% more light yield.
And this painting method will be applied to new module to check the property.

WLS Fiber selection

WLS Fiber	Kuraray Y11	Saint Gobain BCF91A
Wavelength shift	~420 → 494nm	~430 → 476nm
Attenuation length(1/e)	>3.5 m	
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	Double cladding	
Price	High	Low

Y11 will be good choice in preshower and BCF91A in shower.

WLS fiber test in THU

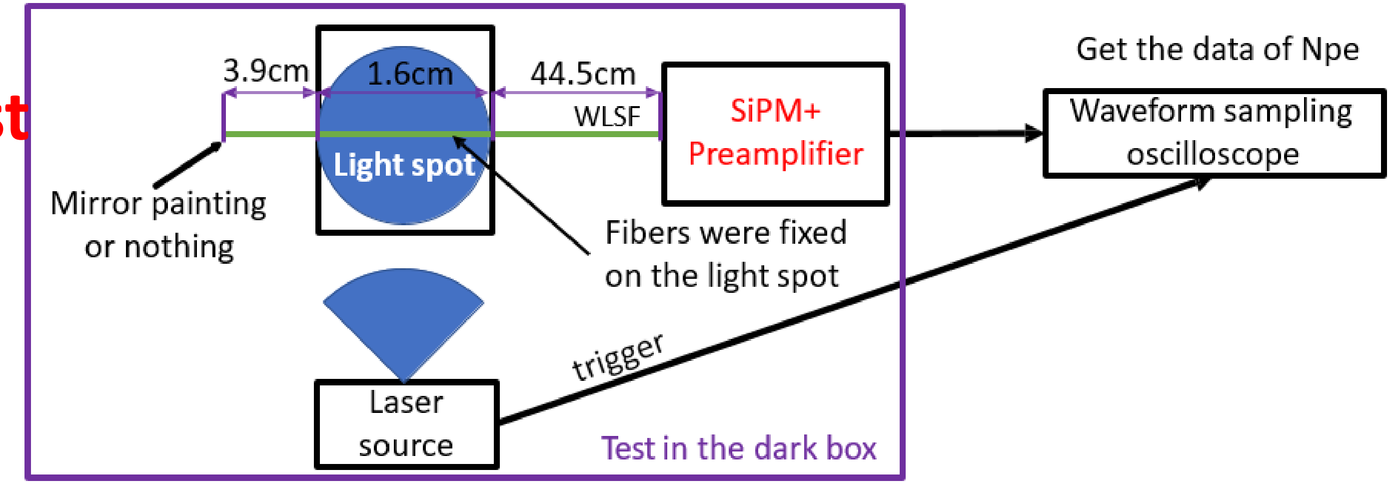


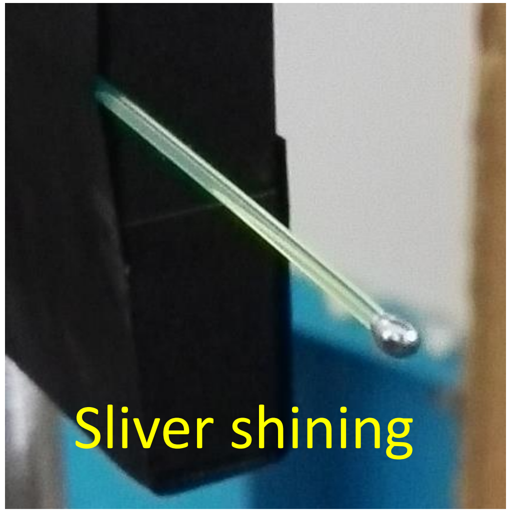
	BCF91A	Y11
No mirror painting	14	13
Bending (ϕ6)	4 (-71%)	11 (-15%)

Fiber mirror reflector

Photon is collected only by one end of fibers, which coupled to PMT in bundle. To collect more photon, for the other end, plating mirror is applied as reflector.

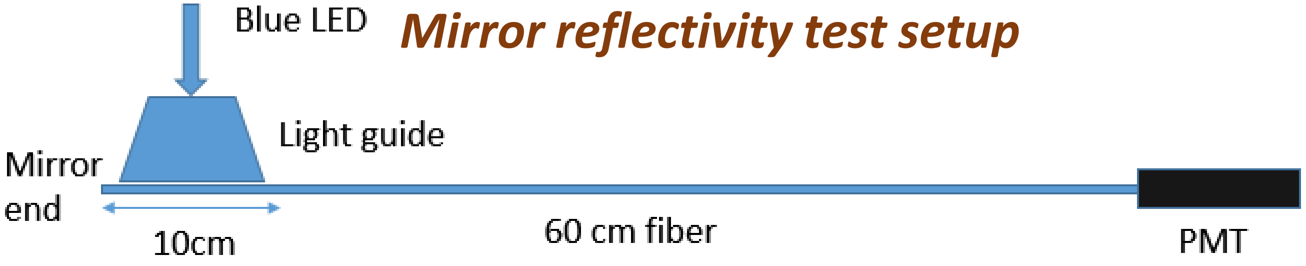
THU test

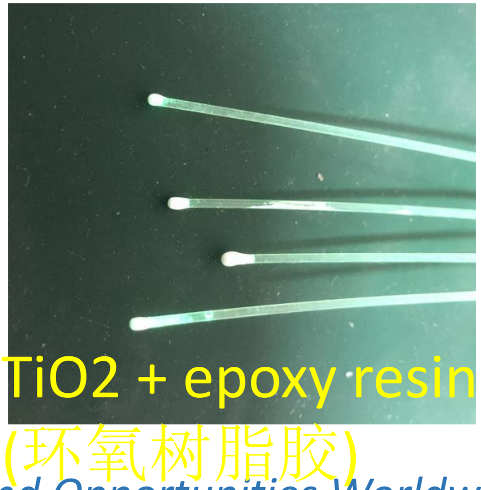




SDU test

Mirror reflectivity test setup





Fiber mirror reflector test result

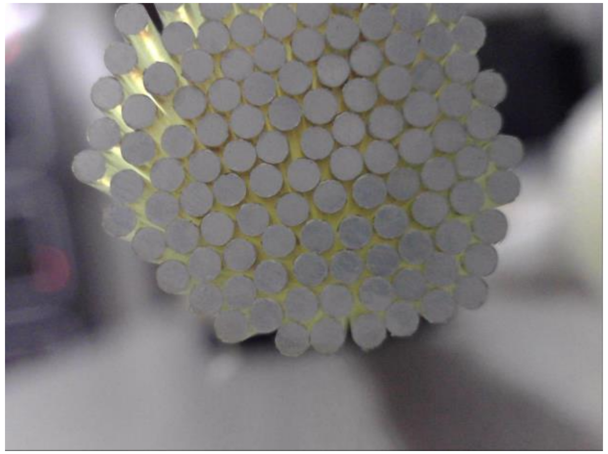
	Laser source		γ source
	BCF91A Npe	Y11 Npe	BCF91A Voltage (mV)
No mirror painting	24	25	640
Silver 415001	34	33	890
improvement	41.67%	32%	39%

	No mirror	With mirror	improvement
Tape	1096	1460	33%
Tape	1623	2223	37%
TiO2	426	514	20%

Diffuse reflector may cause more light leak than mirror reflector.

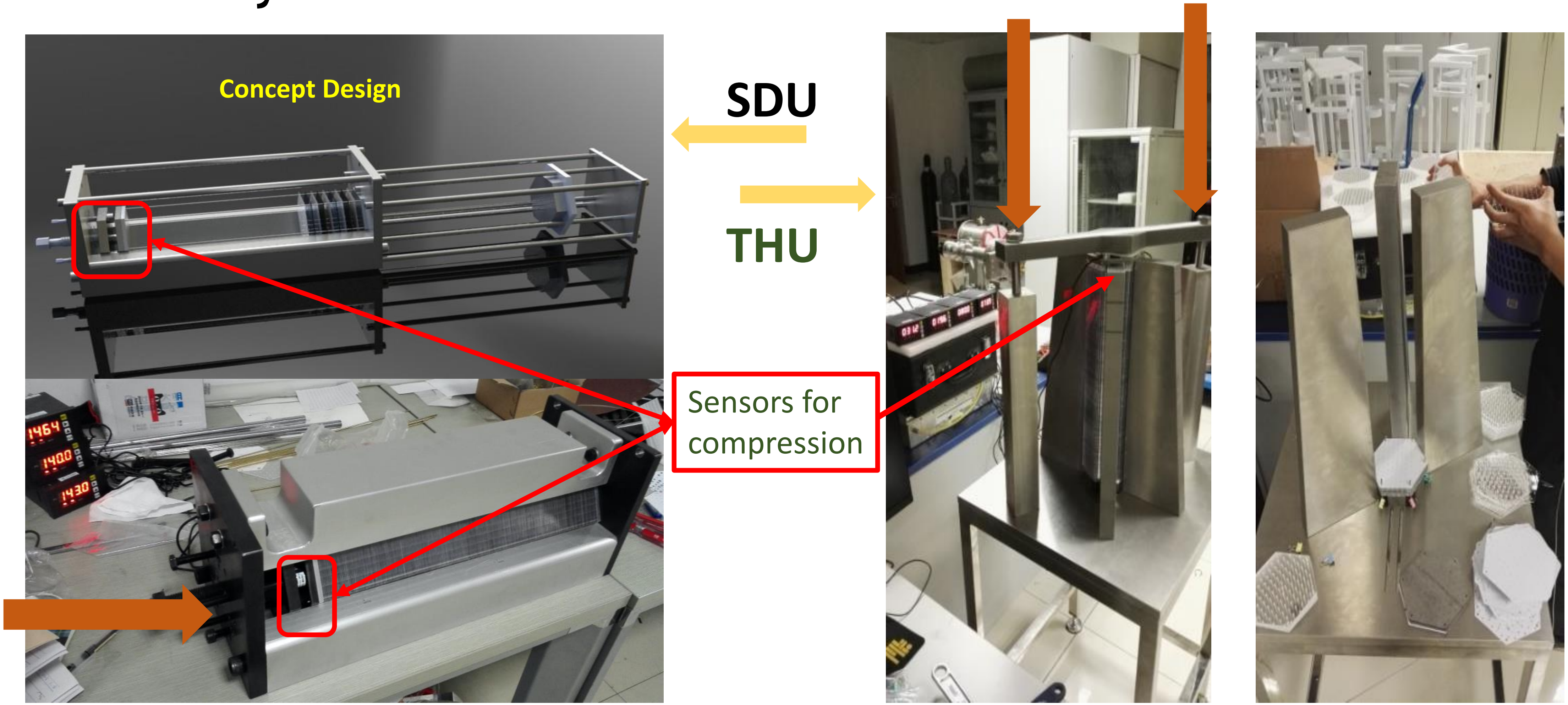
Silver mirror

Used in ALICE, easy to mount fiber, good refelectivty but also shed easily.



Good silver mirror quality with applying magnetron sputtering technique, try to test and apply in future.

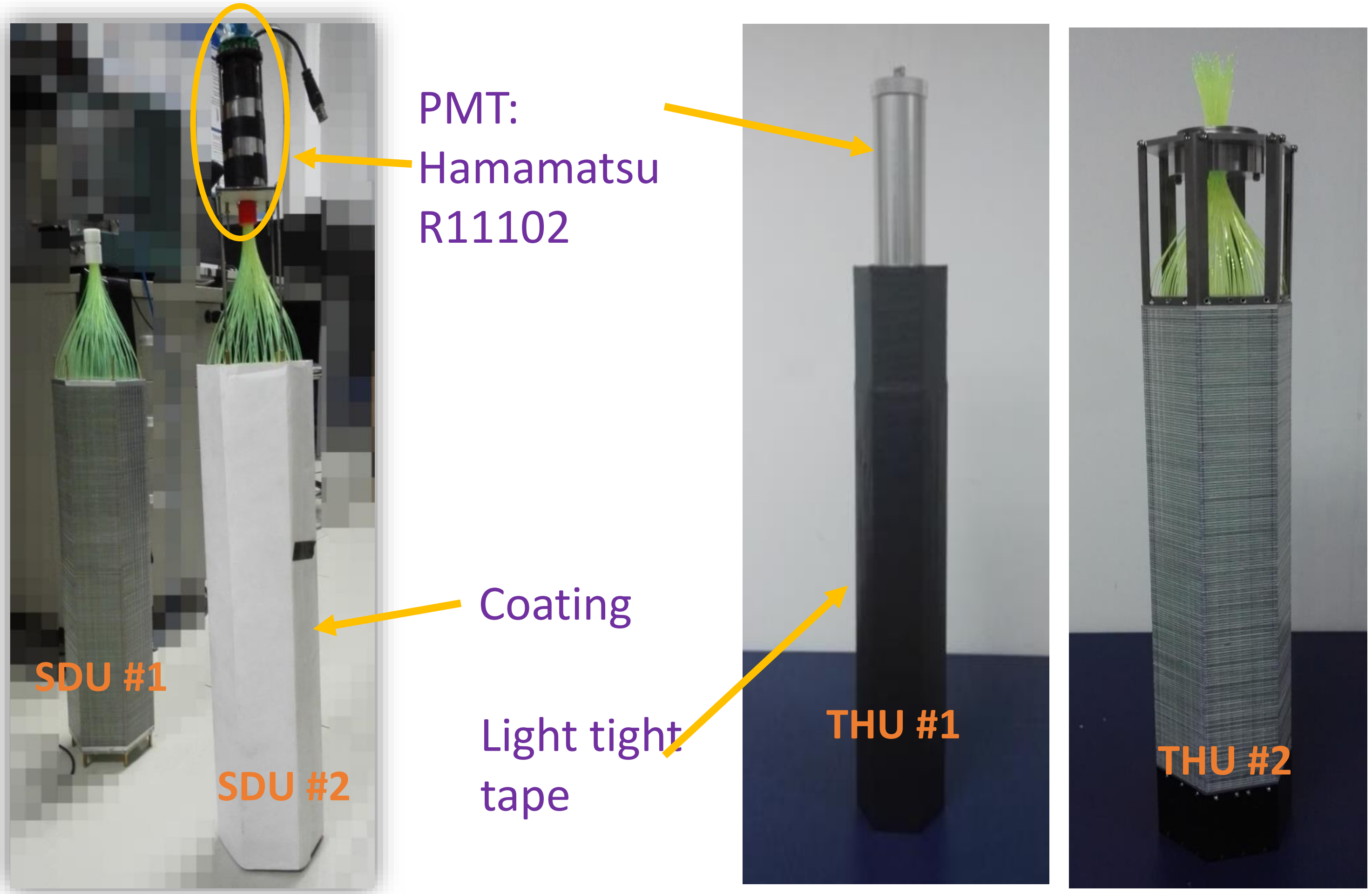
Assembly tool



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

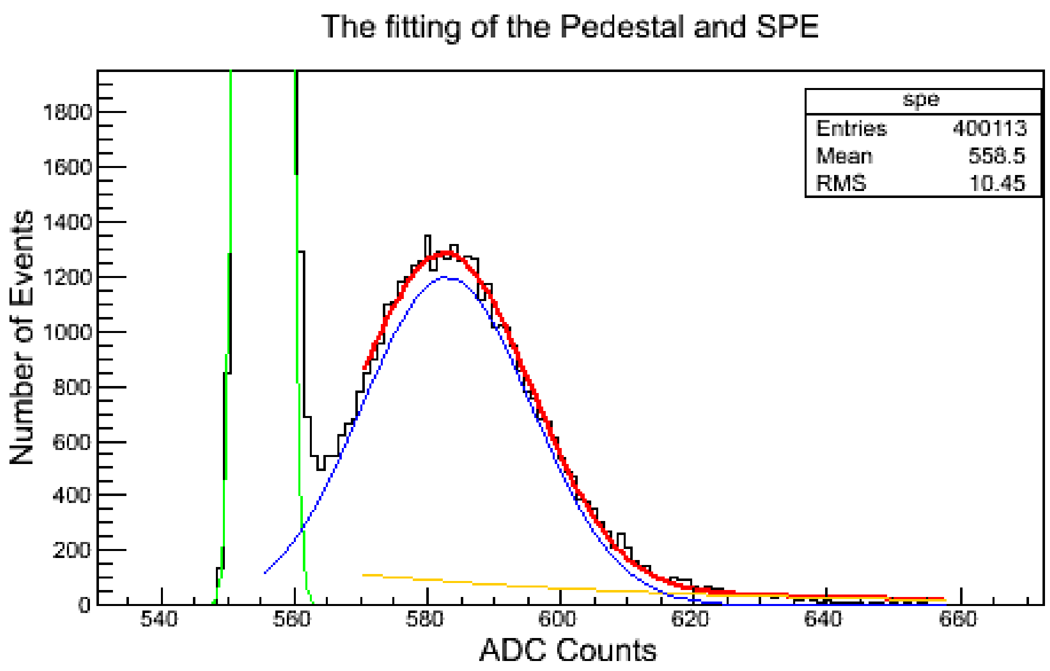


Shashlik ECal module material list

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 (in progress)	BCF91A	Kedi(enhanced)	Powder paint		
SDU #5 (in progress)	BCF91A	Kedi(enhanced)	Tyvek		
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)	BCF91A	Kedi(enhanced)	Powder paint		

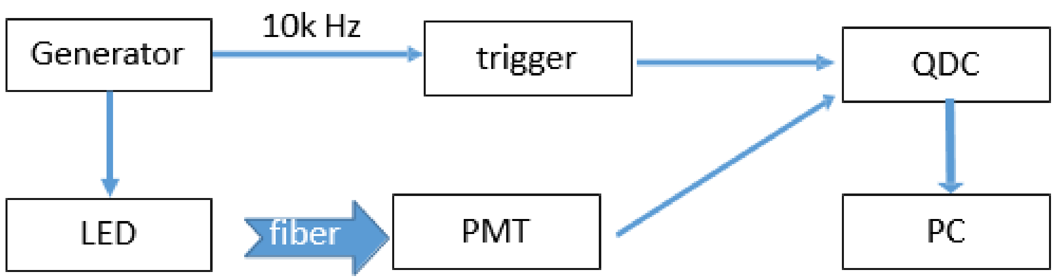
PMT absolute gain test

- The Npe(number of photoelectron) is calculated based on the "gain" of single photon: *NPE=Q/(e×Gain)*
- Detecte SPE(single photon spectrum) to acquire the gain
- Test performed in SDU PMT test Lab
- Similiar gain test performed at JUNO PMT group in IHEP, the difference of gain is below 5%



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

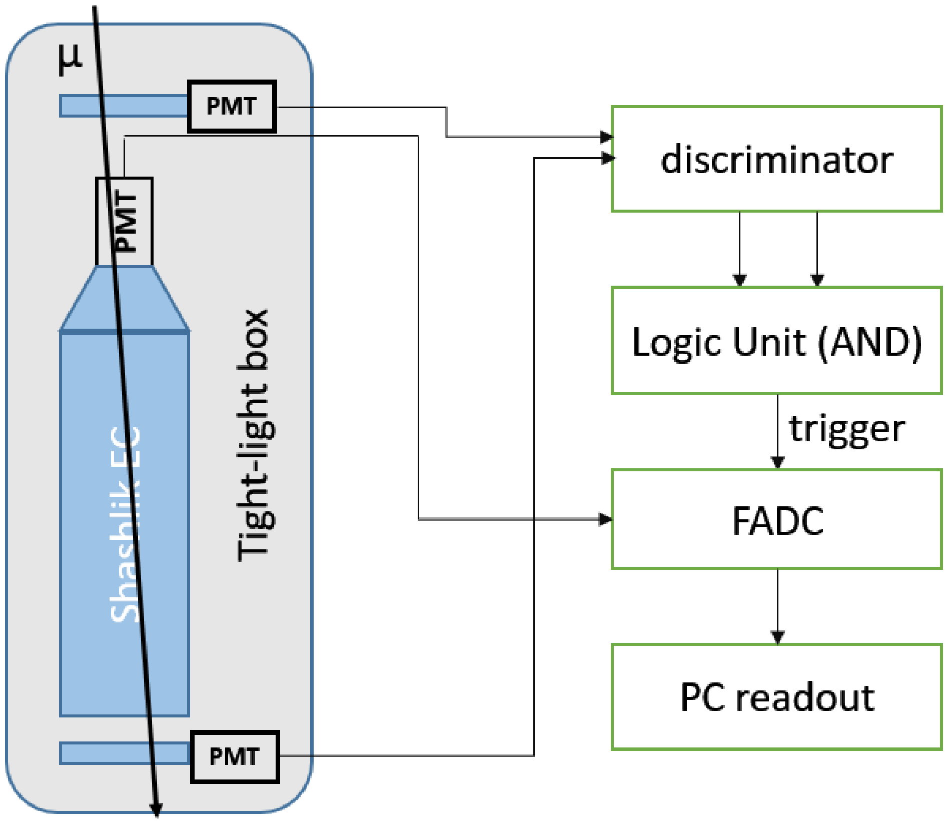
SPE test setup schematic in SDU



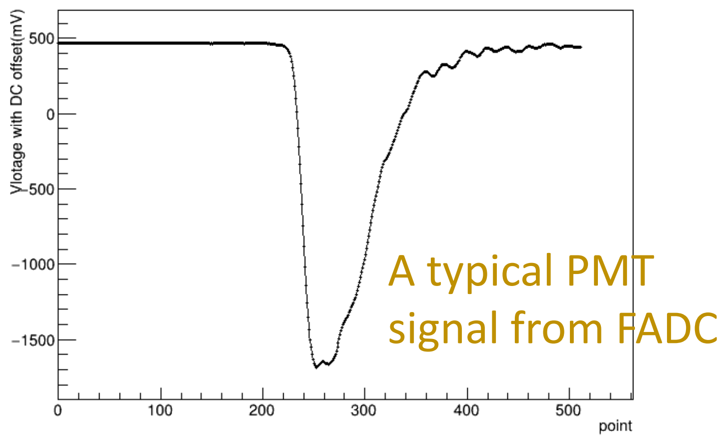
Shashlik cosmic ray test in SDU

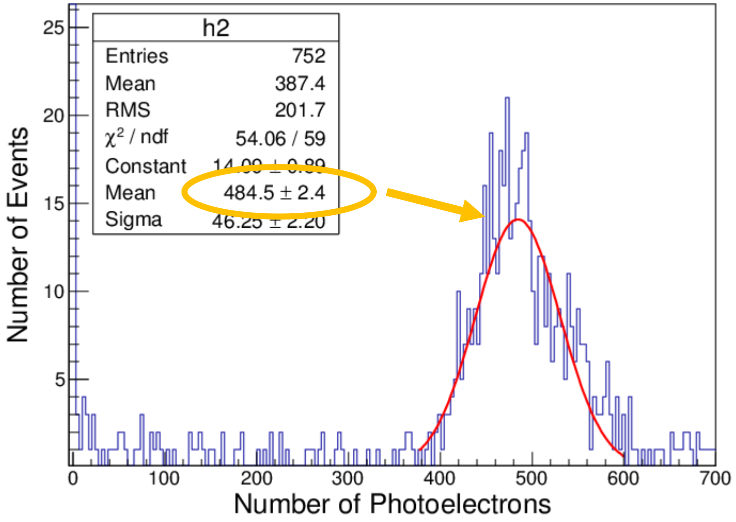
Purpose: Check the light yield of prototype.

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



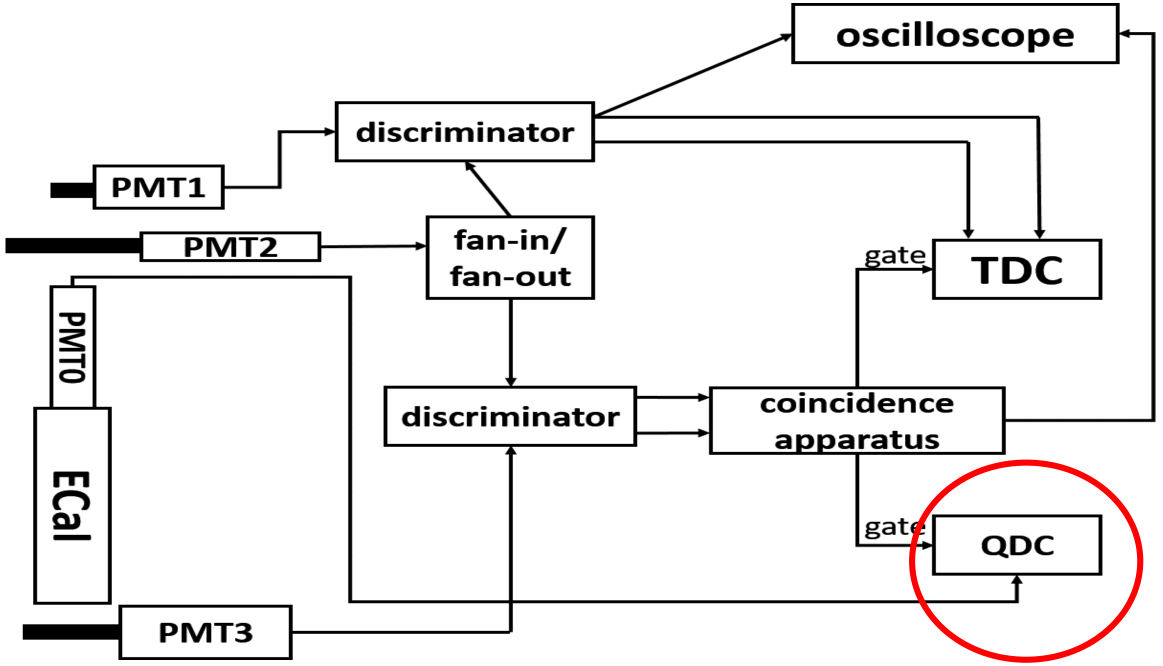
Vertical test setup



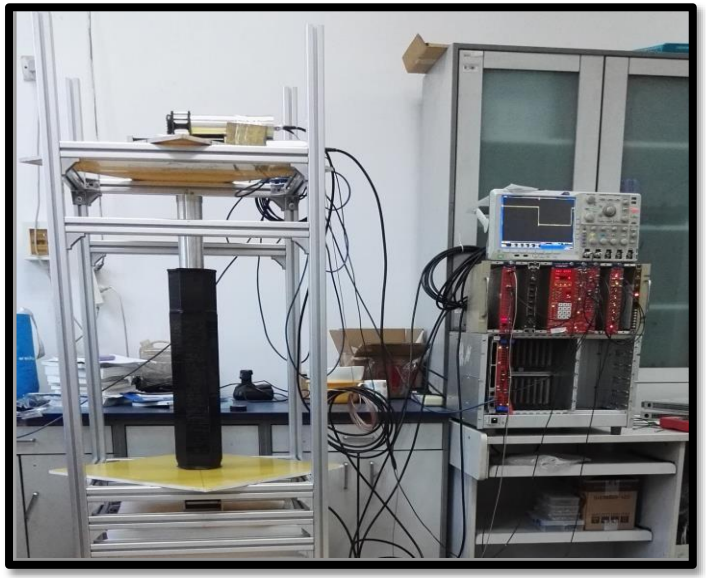


Shashlik cosmic ray test in THU

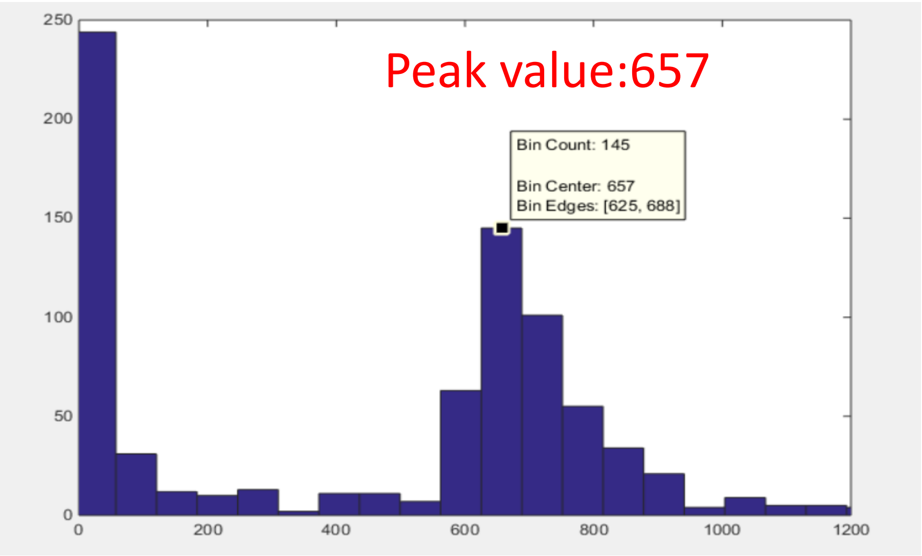
- Similar testup as SDU
- Shashlik EC signal is readout from QDC



Schematic diagram of vertical cosmic ray experiment setup



First Ecal mudule in THU (Sep 2016)



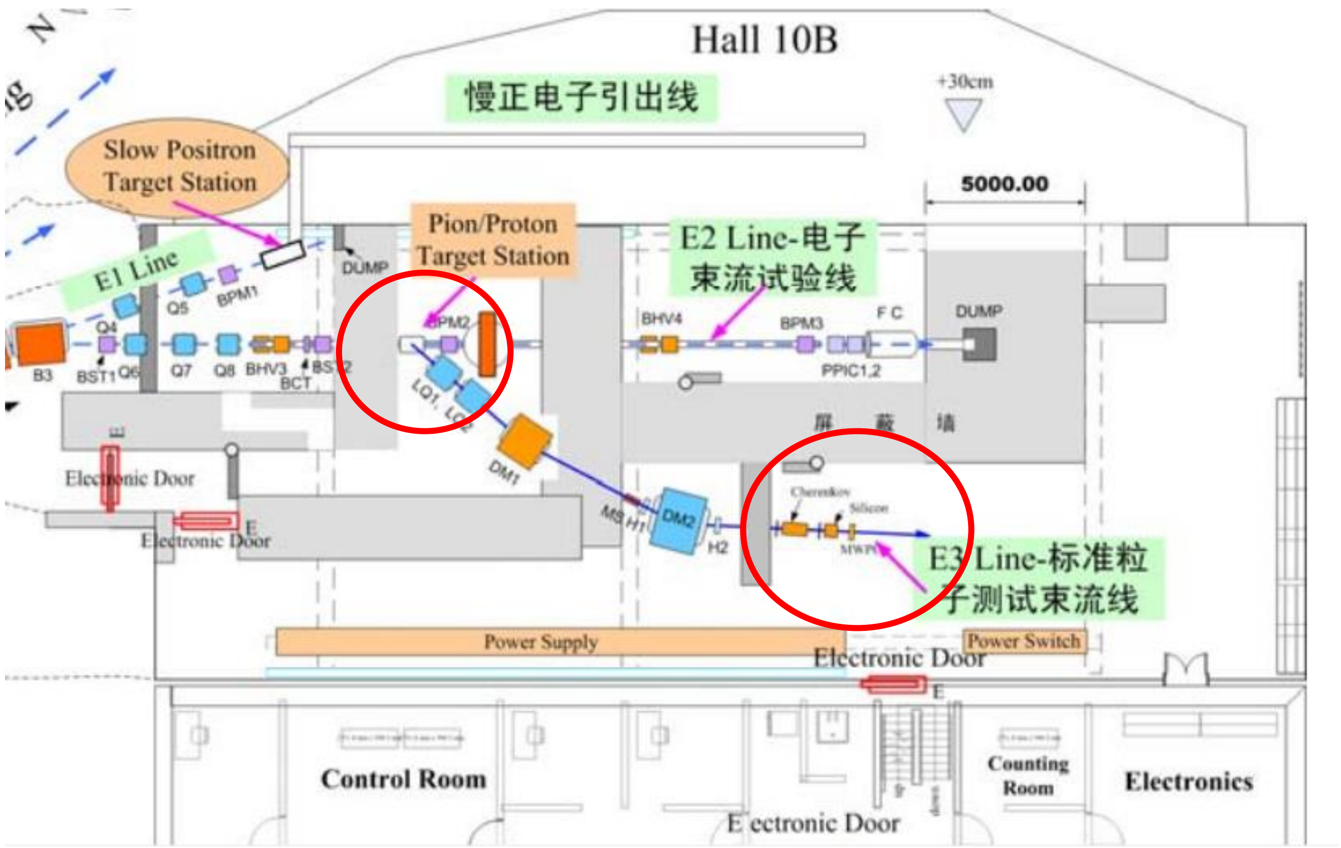
Cosmic ray test result

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
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 25% by test.
- THU #2 achieve the max light yield up to now
- New module(SDU#4, SDU#5, THU#2) with improved material will achieve 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.

Possible beam test chance in IHEP

covenience and practical chance to perform beam test



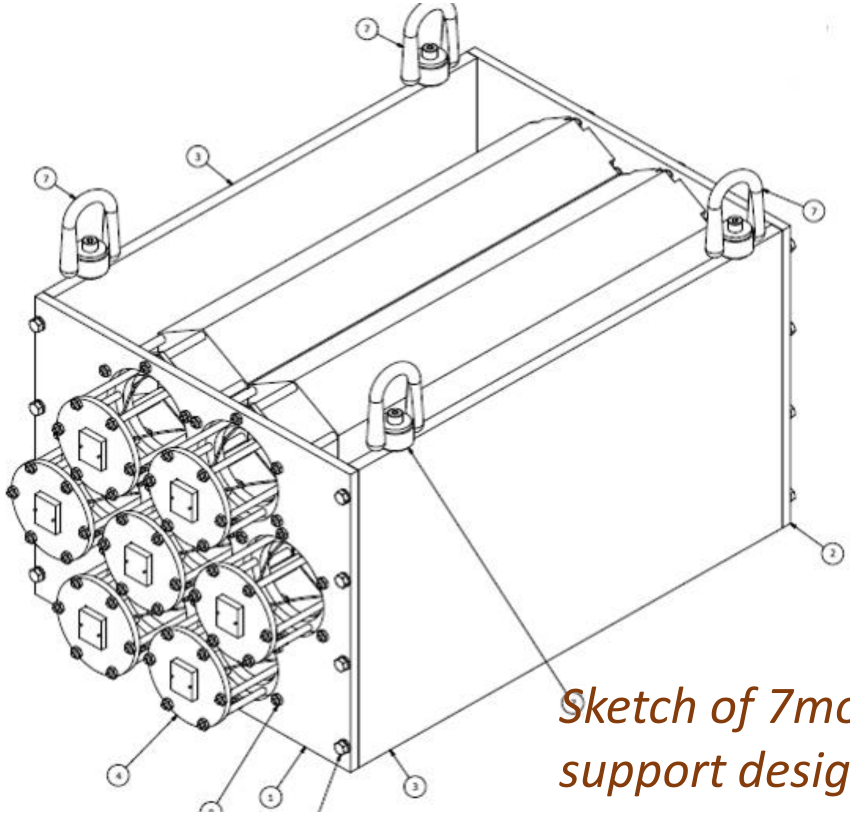
Beijing-BTF Hall 10, IHEP

- 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

Fermi Lab would be other choice with ideal beam energy, but need more work including lack of other detectors.

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.

Beam test module simulation

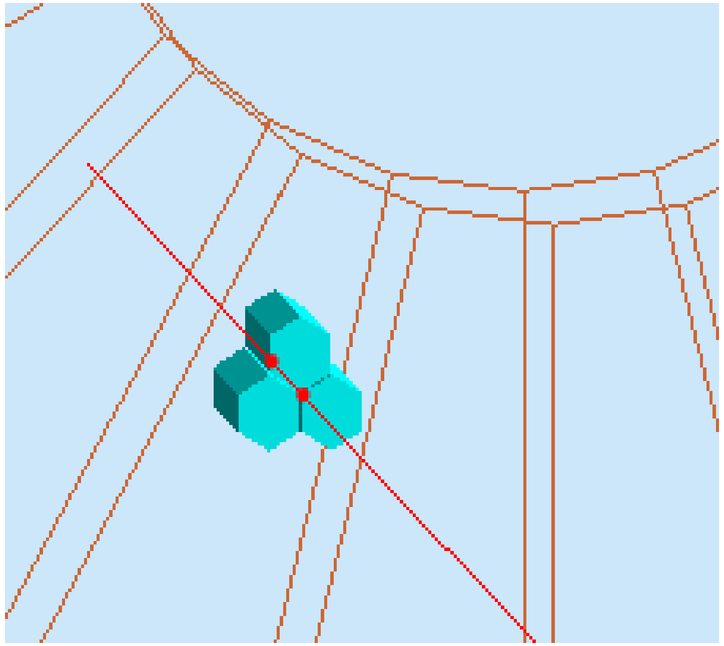
Simulation *work finished by Ye Tian(Syracuse)*

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.

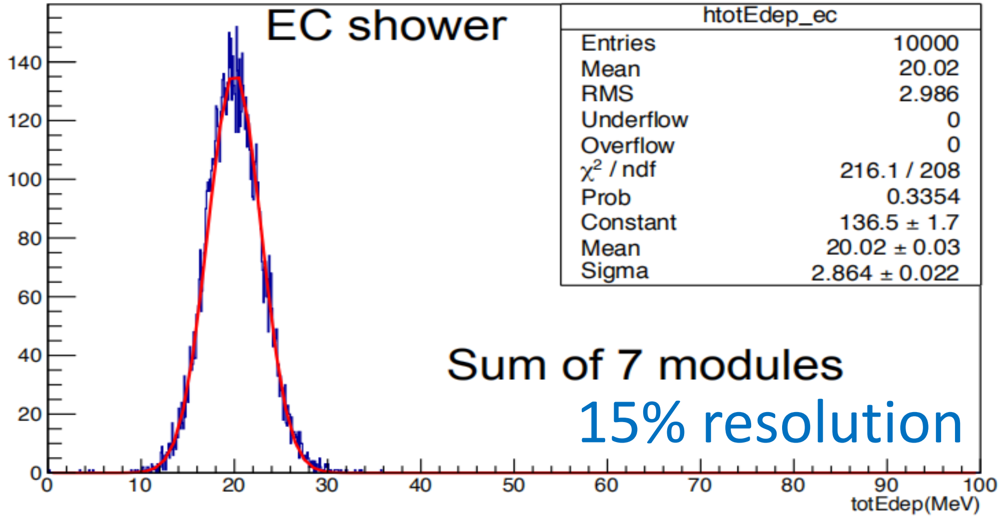


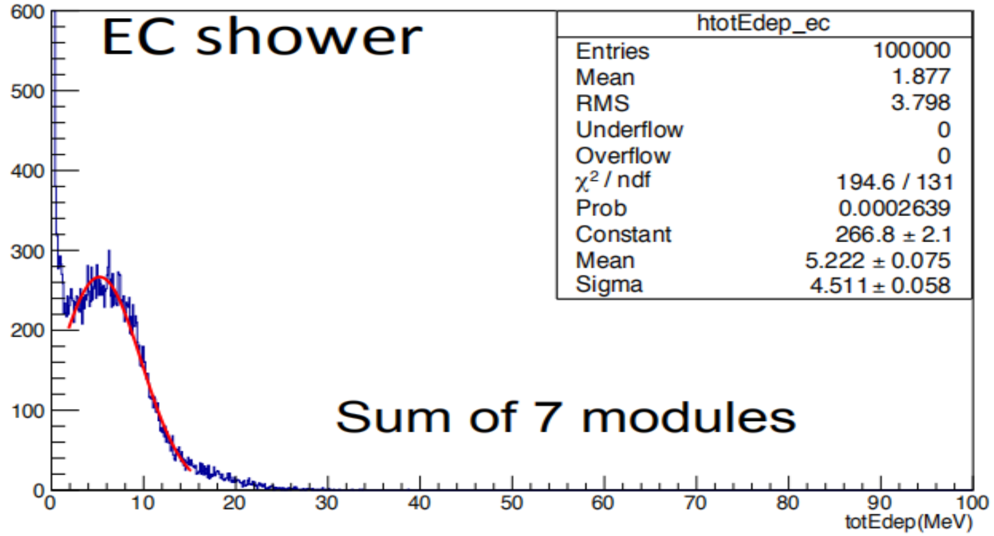
3 modules sketch

Shower simulation result (energy deposit)

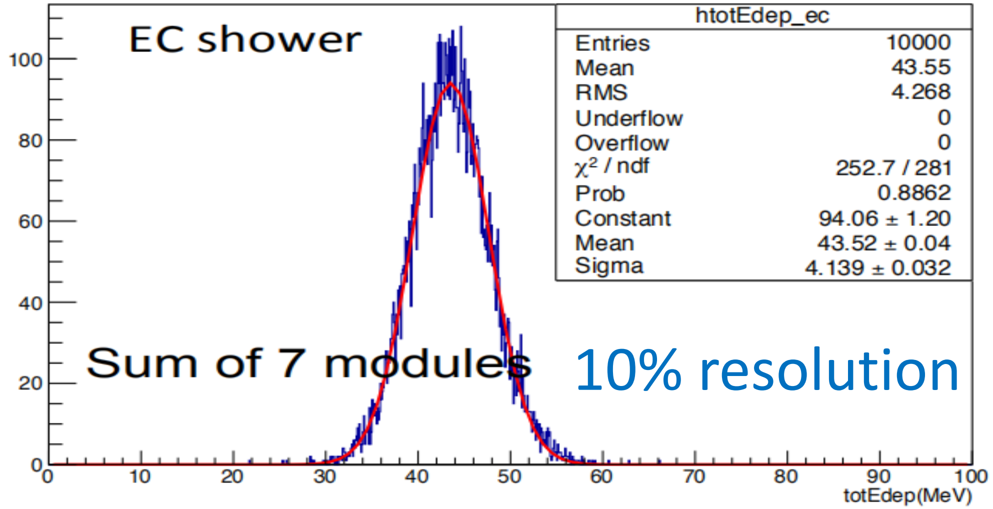
e+ **π+**

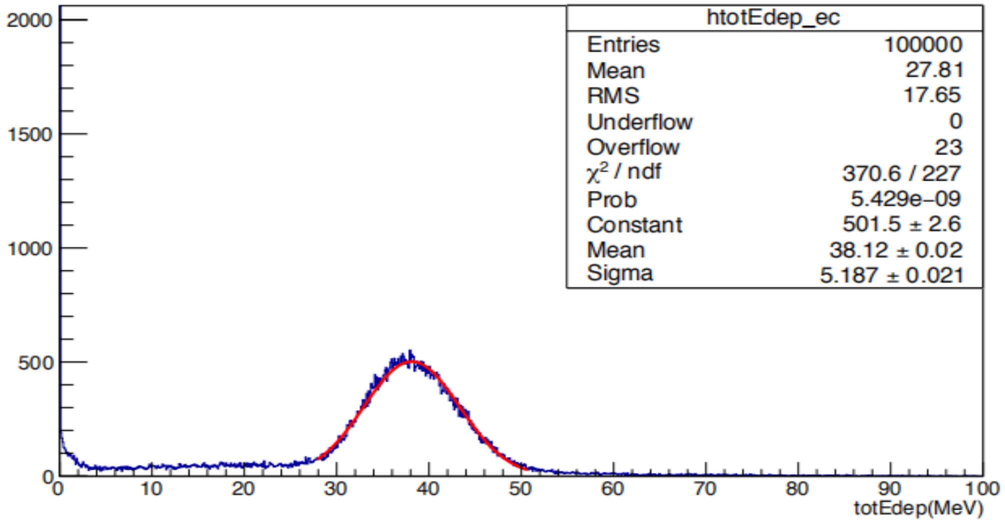
100MeV





200MeV



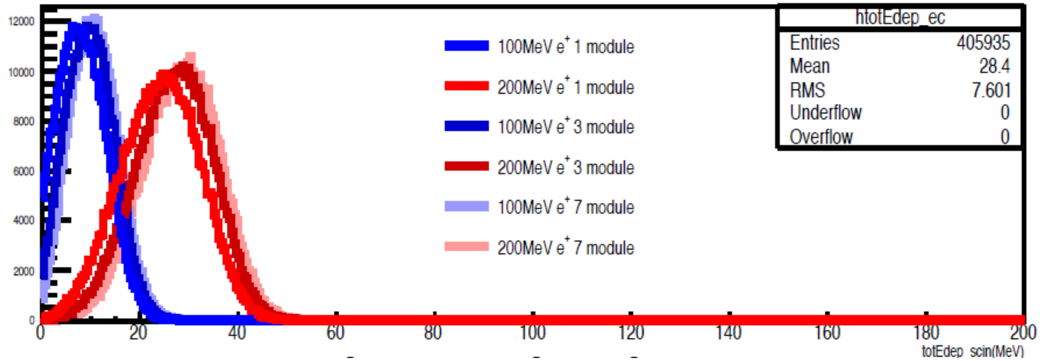


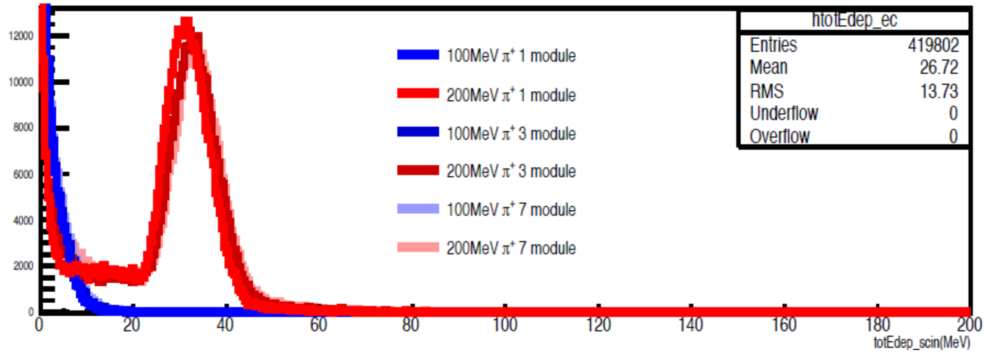
Preshower+ shower simulation result (energy deposit)

100MeV
200MeV

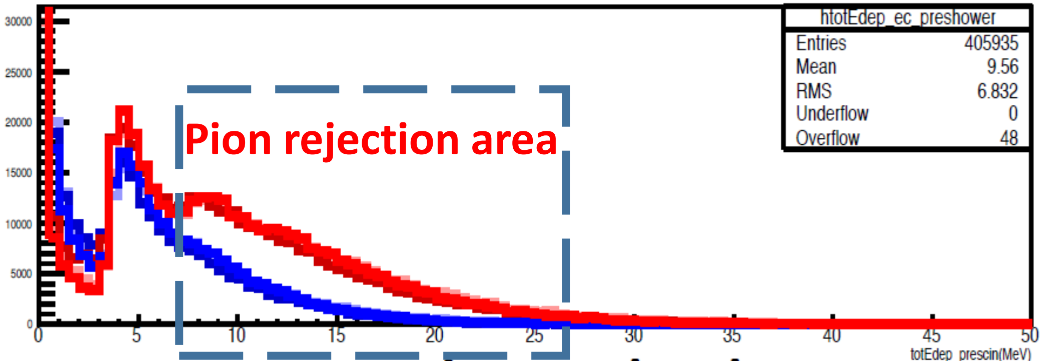
e+ π+

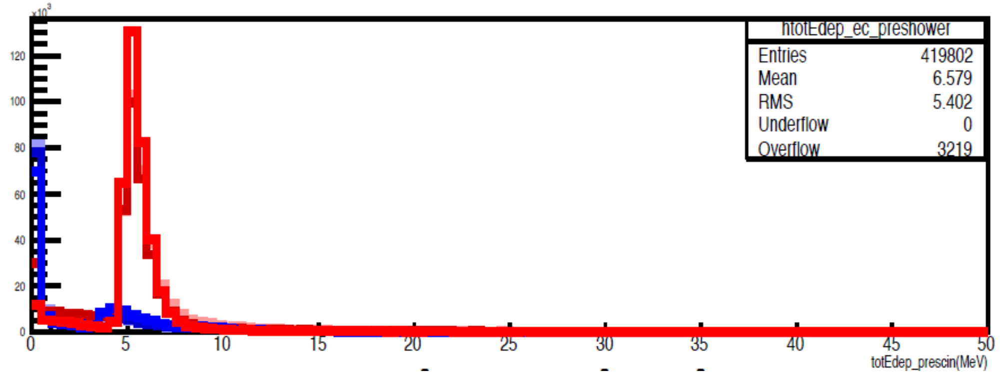
Shower scintillator



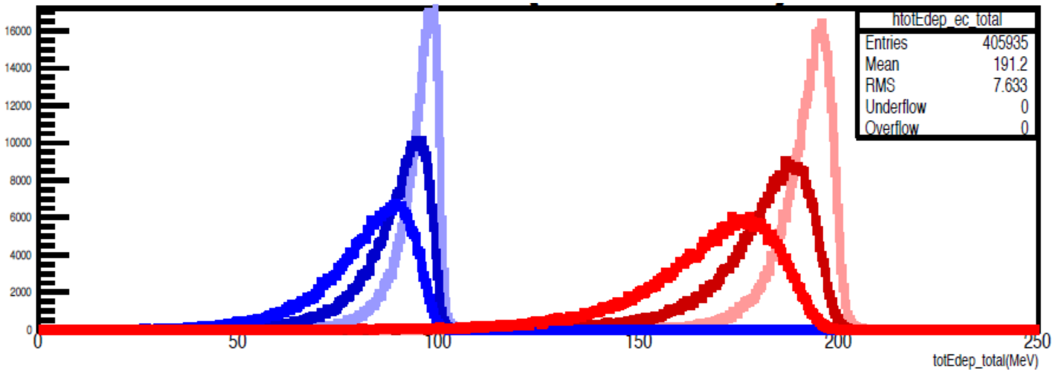


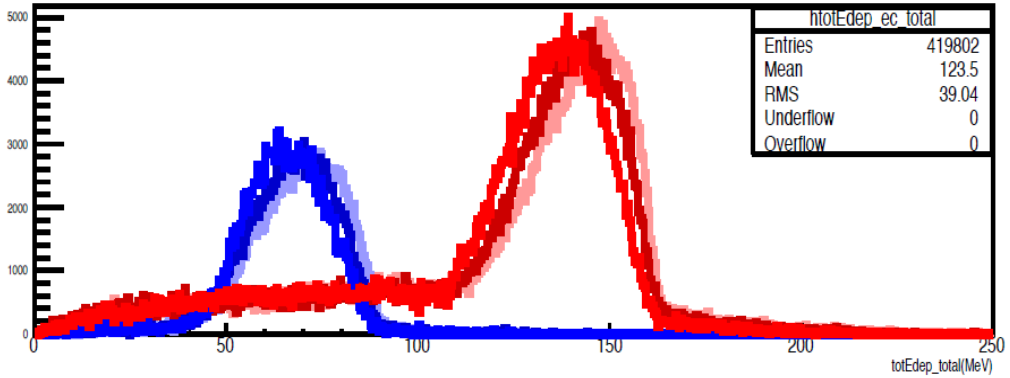
Preshower scintillator





Total energy Deposit in shashlik





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. with improving material and technolody.
- New module in progress will get more light yield.
- 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 Fermi Lab.
- Beam test is necessary and crucial way to determine the quality

Thank You