12 GeV Upgrade
Future Science at Jefferson Lab

EC and SPD Updates

The SoLID EC Working Group

SoLID Collaboration Meeting

June 7-8, 2018

Outline

1. Prototype shashlyk module overview, problem with PMT gain.
2. Cosmic test preliminary results on LASPD timing resolution
3. Progress on LASPD segmentation simulation
4. Progress on reproducing the Ecal PID simulation
5. Progress on beam test
6. Progress on testing clear fiber attenuation (Chendi/THU) and fiber reflective coating (Chendi/THU + Cunfeng+Ang/SDU)
7. Preparation for CD0, CD1?

Shashlyk prototype and light yield overview

Proto-type	scintillator	lead	reflective layer	WLS fiber	WLS fiber end	module side	cosmic vertical test Npe	cosmic horizontal test Npe	PMT gain method
SDU1	Kedi original	US	printer paper	BCF91A	none	Tyvek→ TiO2	224→ 254	48 → 50**	SPE/SDU
SDU2	Kedi new	CN	printer paper	BCF91A	CN silver-plating	Tyvek→ TiO2*	427 → 383*	83 → 75**	SPE/SDU
SDU3	Kedi new	US	printer paper	Y11	CN silver-plating	TiO2+glue (1/1)	$\boxed{491}$	107	SPE/SDU
THU1	Kedi original	CN	mirror mylar (reflective)	Y11	Italian silver shine	TiO2 (Kedi)	430-470	96	not measured
THU2	Kedi new	CN	powder paint (喷塑) (diffusive)	BCF91A	Italian silver shine	Tyvek wrapping (now)	748 680#	90-103	SK/SP (Hama-matsu)

* TiO2 side-paint was not as good as SDU1

** Could not finish before shipping to Jlab. Done in Jlab (see report on Feb 01,2018)

$\boxed{}$ Yields 500/200 layers for MIP → 1666 p.e./GeV electron, factor 2-3 lower than LHCb or ALICE → 833 p.e./GeV if using clear fibers → 3.5% in δE/E due to photoelectron statistics

\# Use SPE method (Feb 01,2018)

SDU is planning to construct SDU4, SDU5, Tsinghua to construct THU3.

PMT Gain Puzzles

PMT gain method:

1) SPE/SDU: SPE determined at high HV, then increase LED light so signal is high enough to see at low HV, then measure signal vs. HV and use signal to calculate gain for all HV values – should be the most reliable (SDU PMT also have manufacturer's SK/SP data but not sure what base was used).

2) THU SK/SP: measured at Beijing Hamamatsu with the SK/SP ratio, base changed but was told base is "identical to" the one used for testing at THU.

3) THU took their PMT to Beijing IHEP and measured the SPE at high HV=1000v and 1100v (with the same base),. Found gain to be 2/3 of the SK/SP method.

4) SDU took their PMTs to Beijing IHEP and test them using the same SPE method at HV=1050V, 1100V and 1200V. Found that the gains are within 5% from SDU's measurements, except one PMT is 15% different. (Later on found that PMTs are saturated at these HVs. SDU then did a scan of HV down to 800V.)

5) THU took one SDU PMT and mounted it to THU2 module. In the vertical setup test it gives similar result to that uses a THU's PMT.

6) Latest analysis from THU confirms that THU2 gives 680 NPE.

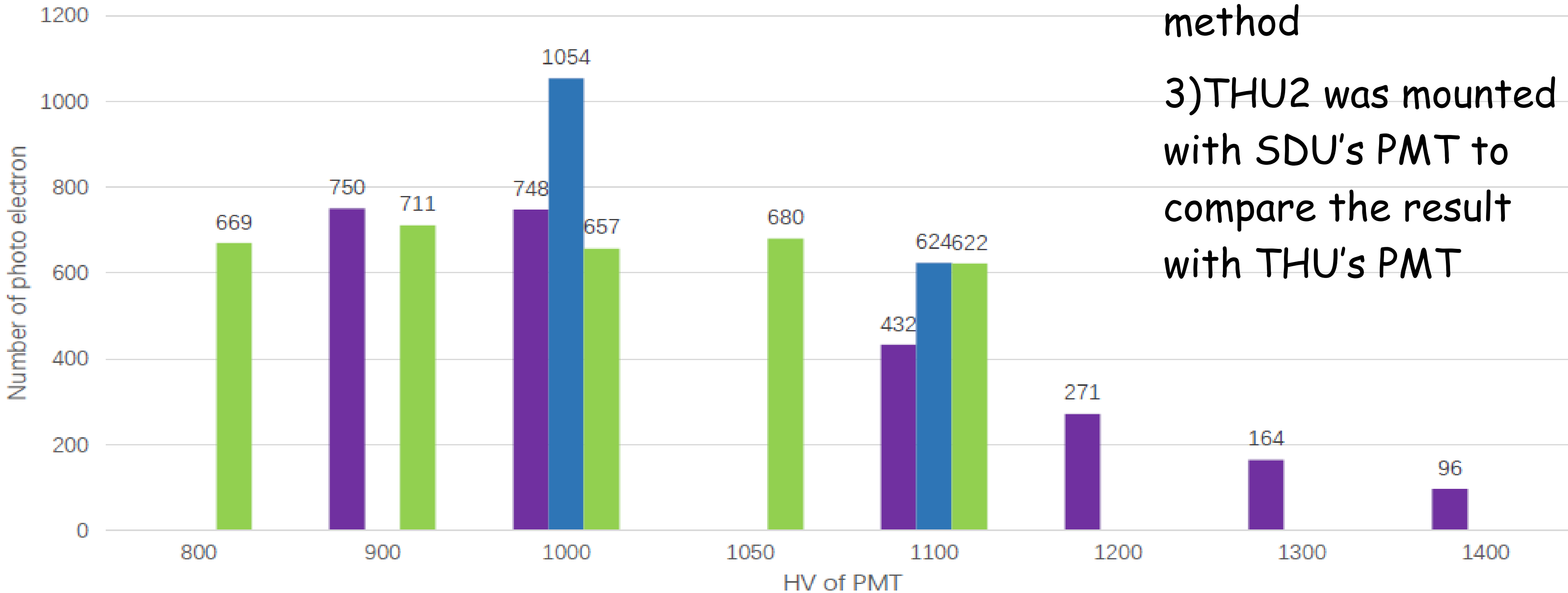
PMT Gain Puzzles (cont.)

	THU PMT		SDU PMT
HV	hamamatsu	IHEP	SDU
800			$0.527*10^6$
900	$1.3*10^6$		$1.295*10^6$
1000	$3.1*10^6$	$2.2*10^6$	$2.9*10^6$
1050			$4.11*10^6$
1100	$6.5*10^6$	$4.5*10^6$	$5.997*10^6$
1200	$13.3*10^6$		$11.227*10^6$
1300	$26.1*10^6$		

1) SDU PMT: HV=800,900 and 1000 were tested in SUD using SPE method;

2) SDU PMT: 1050,1100 and 1200 were tested in Beijing IHEP using SPE method

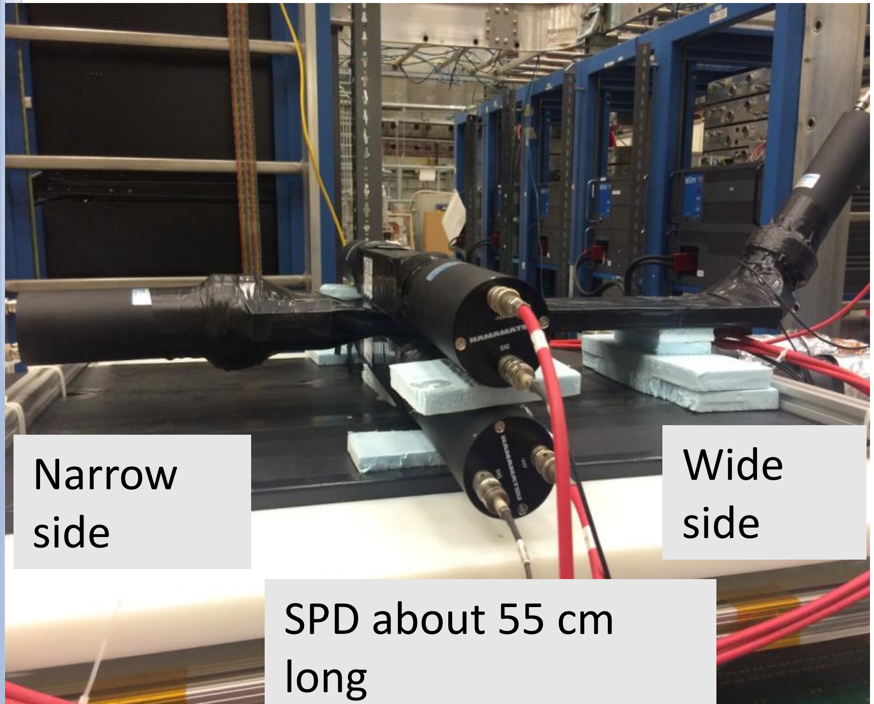
3)THU2 was mounted with SDU's PMT to compare the result with THU's PMT

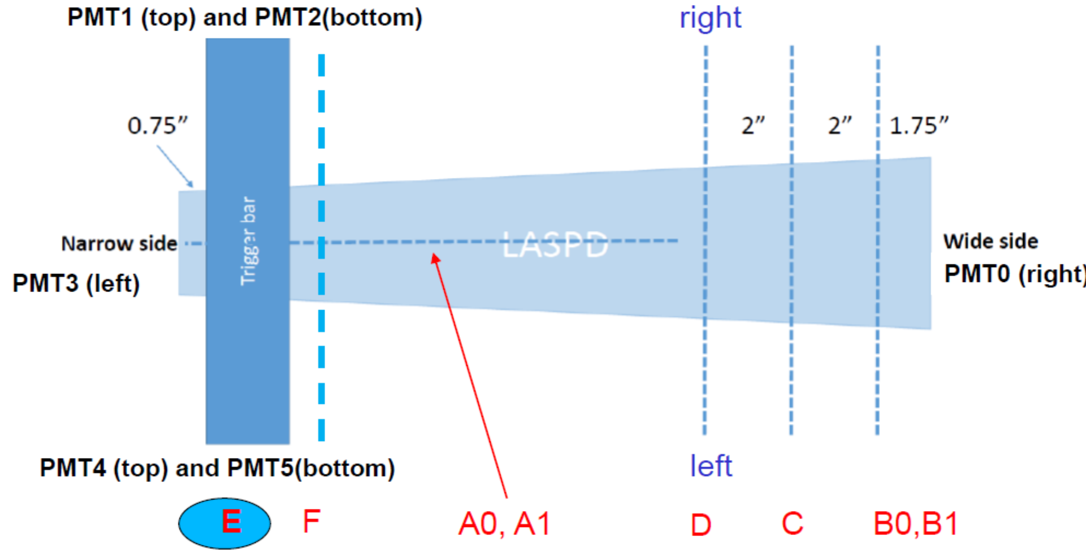


- SDU PMT is stable and the result is more reasonable, so Npe of THU2 is around 680.

JLab Test Lab Cosmic Runs (Ye Tian/SDU + Jixie/UVa)

LASPD time resolution test



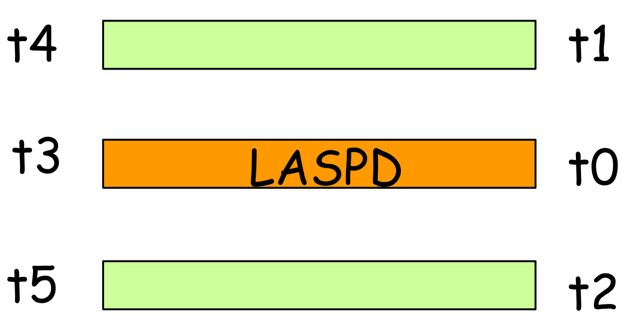


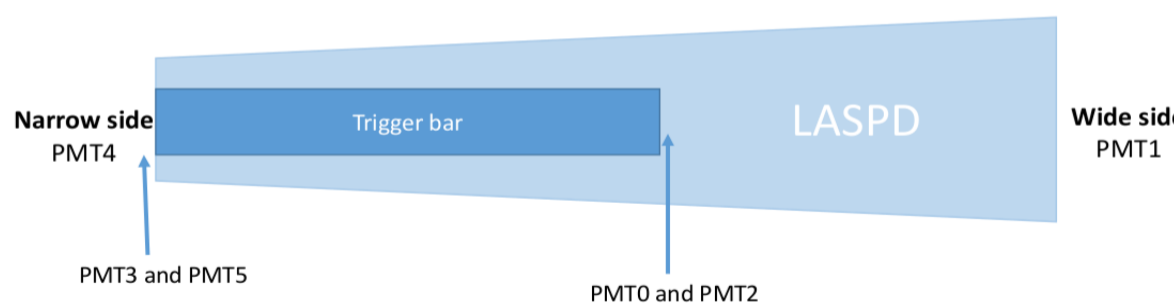
Low HV: A0, B0, C, D
High HV: A1, B1, E, F

Data set F uses only 2 GEM detectors.
All the others use 3 GEM detectors

Parallel test setup

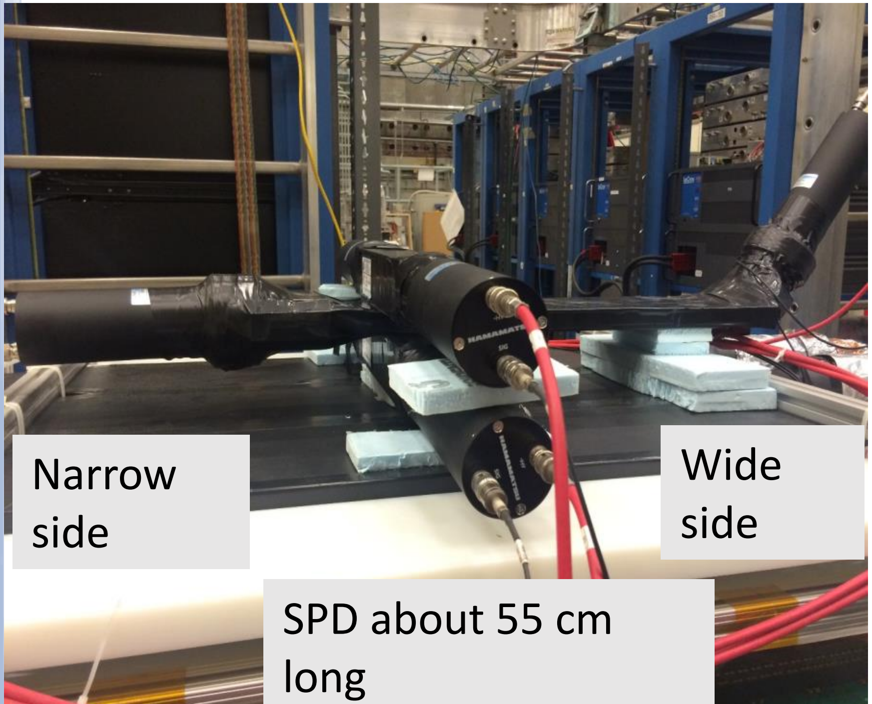
PMT labeling:

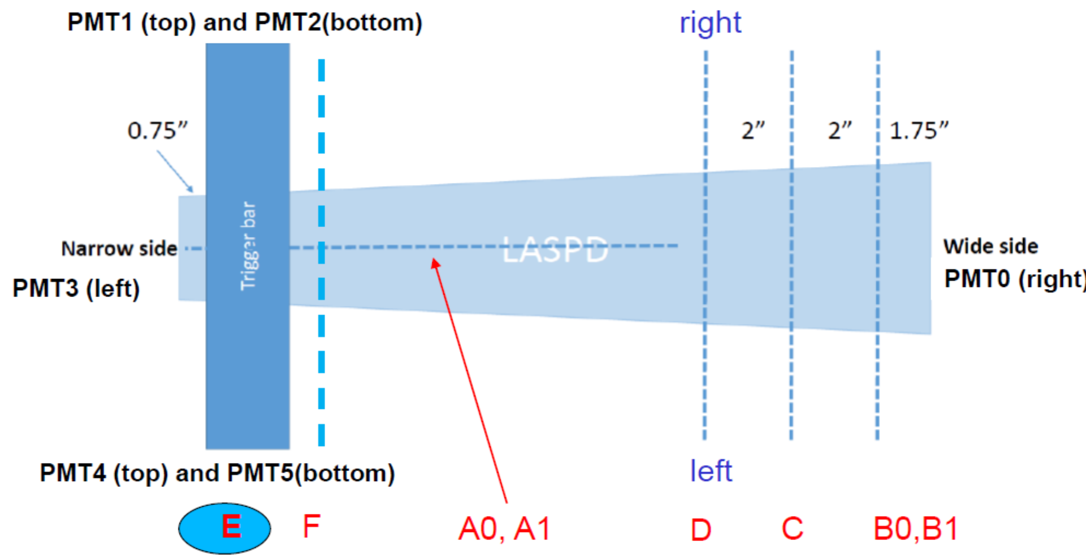




JLab Test Lab Cosmic Runs (Ye Tian/SDU + Jixie/UVa)

LASPD time resolution test





Low HV: A0, B0, C, D
High HV: A1, B1, E, F

Data set F uses only 2 GEM detectors.
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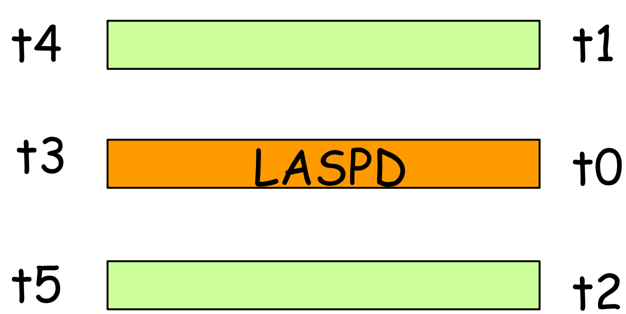
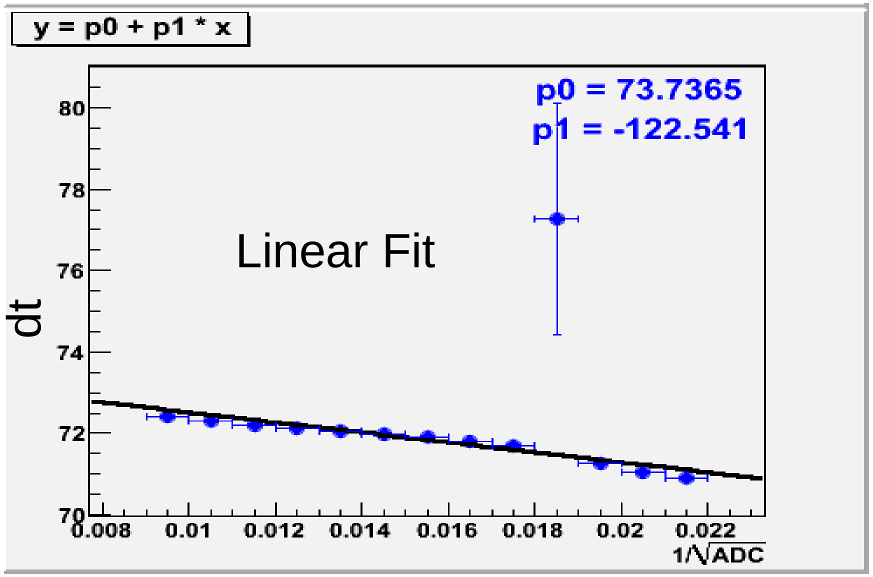
PMT labeling:

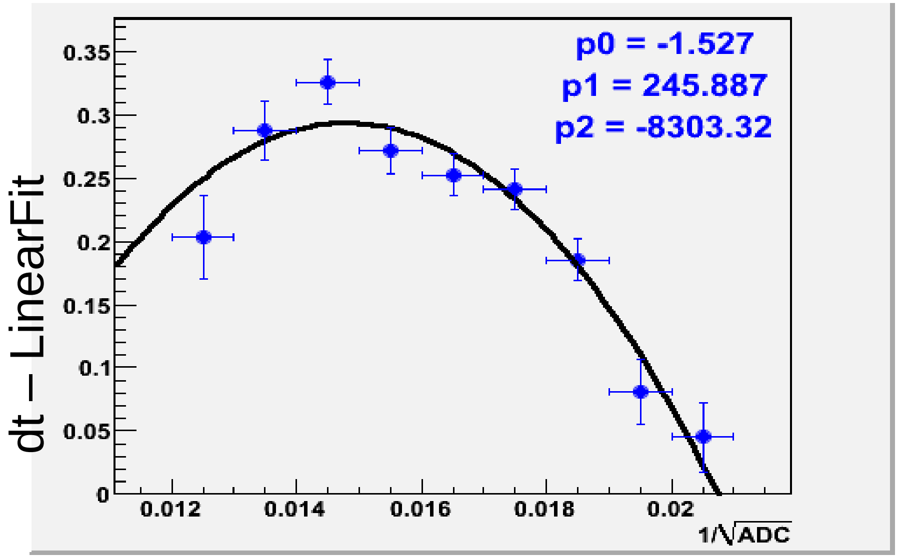


Data-set	A0+A1	B0+B1	C	D	E	F
Trigger#	363.1k	26.3k	33.0k	25.3k	28.6k	95.9k
+ADC	219.1k	16.7k	21.7k	17.0k	17.1k	53.9k
+GEM	55.8k	2828	3660	2859	2908	7770
#/cm^2	372	57	73	57	58	155

3-D Time Walk Calibration

Old Method:
2nd-order-fiiting to "dt vs 1/sqrt(ADC)"





New Method:
Use position x-y information, do
time walk calibration for x-y-ADC.

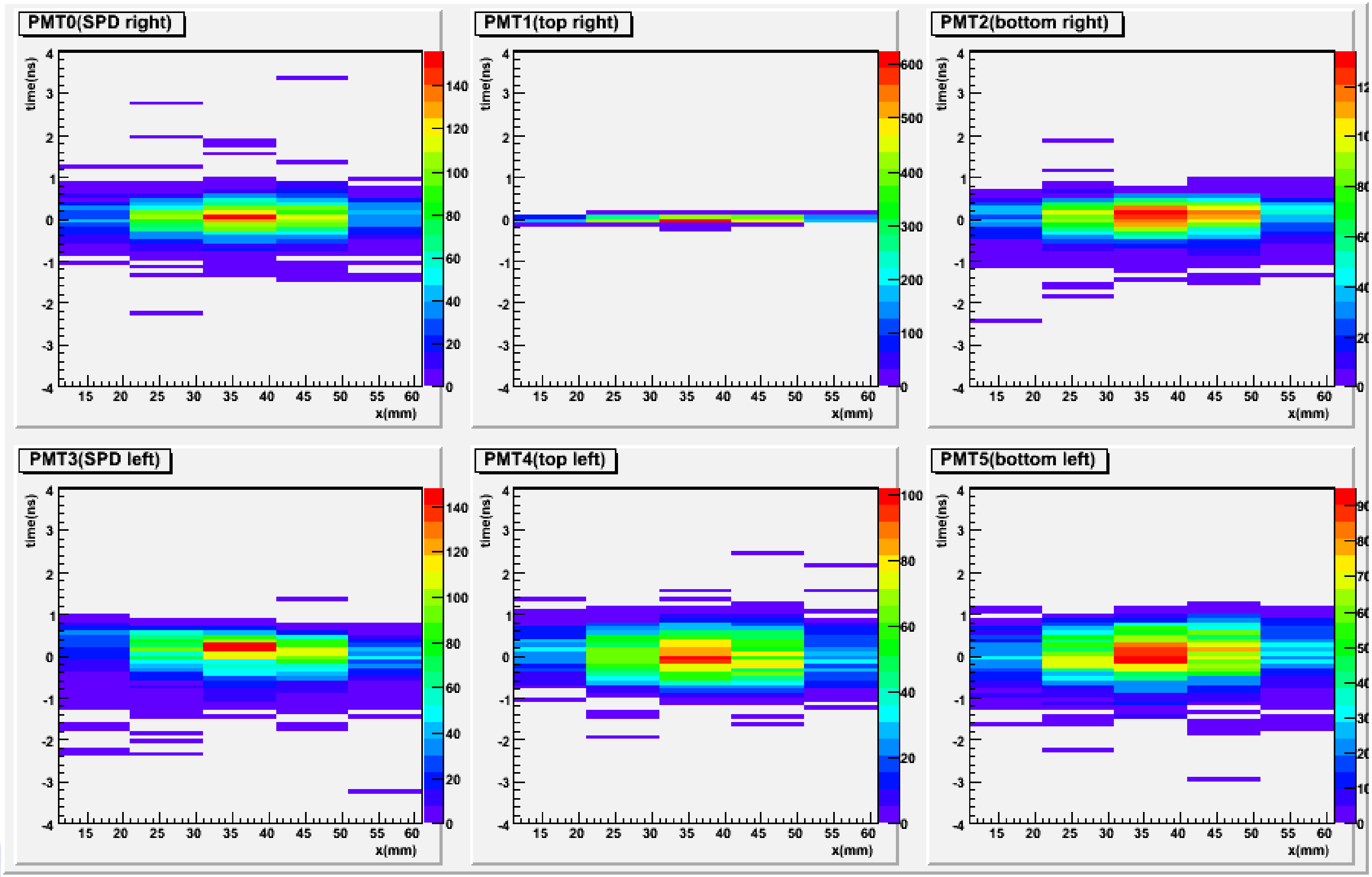
dt = Time_PMT – TriggerTime

Chi^2 = [dt – f(X,Y,ADC)]^2

f(X,Y,ADC) = p0*x + p1*x*x
+ p2*y + p3*y*y + p4*x*y
+ p5 + p6*pow(ADC,-0.5) + p7*pow(ADC,-1.0)

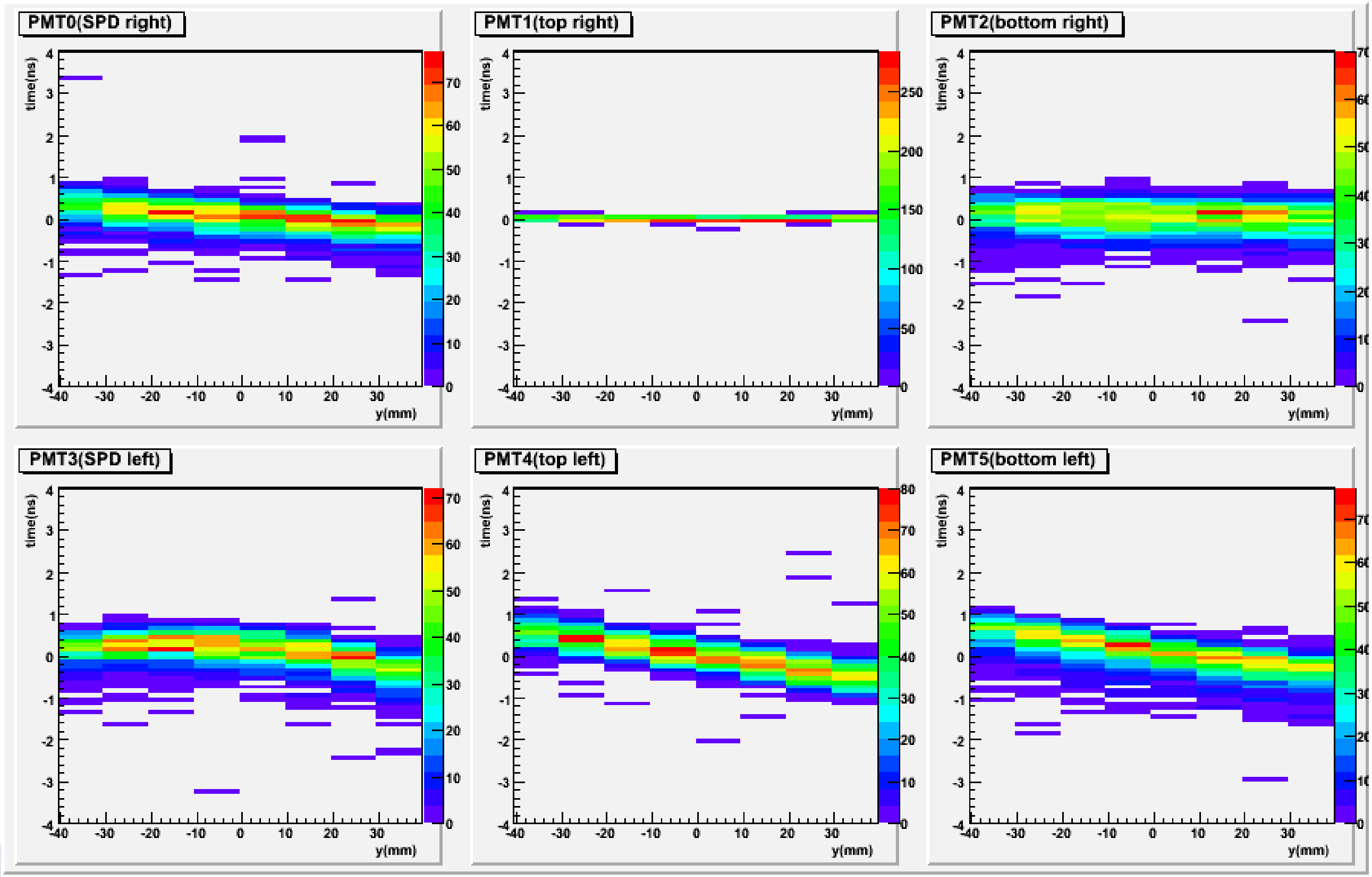
For each PMT, minimized the chi^2.
Problems: Very hard to fit. Need to give accurate initial values. I use the result of 2nd-order-fitting to set initial values of p5, p6, and p7, and set p0 – p4 to zero. Start from here, do several iterations. Each iteration manually set the previous result as new initial values.

Check 3-D Time Walk Calibration



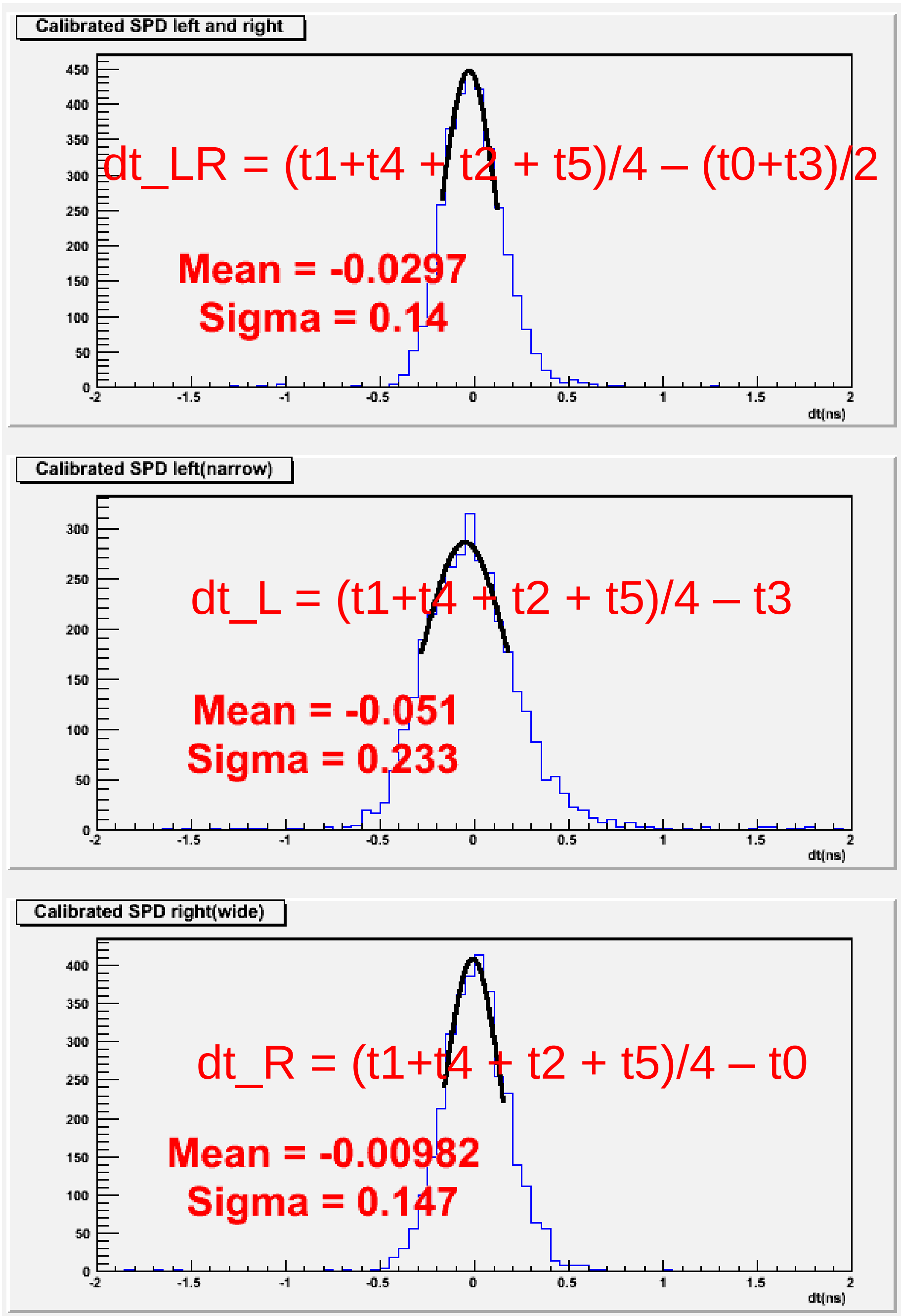
Calibrated TDC, X dependence seems fine.

Check 3-D Time Walk Calibration



Calibrated TDC, Y dependence is over fitted for some PMTs.
But it is very difficult to tune. Leave it as is for now.

Timing resolution of Data Set E

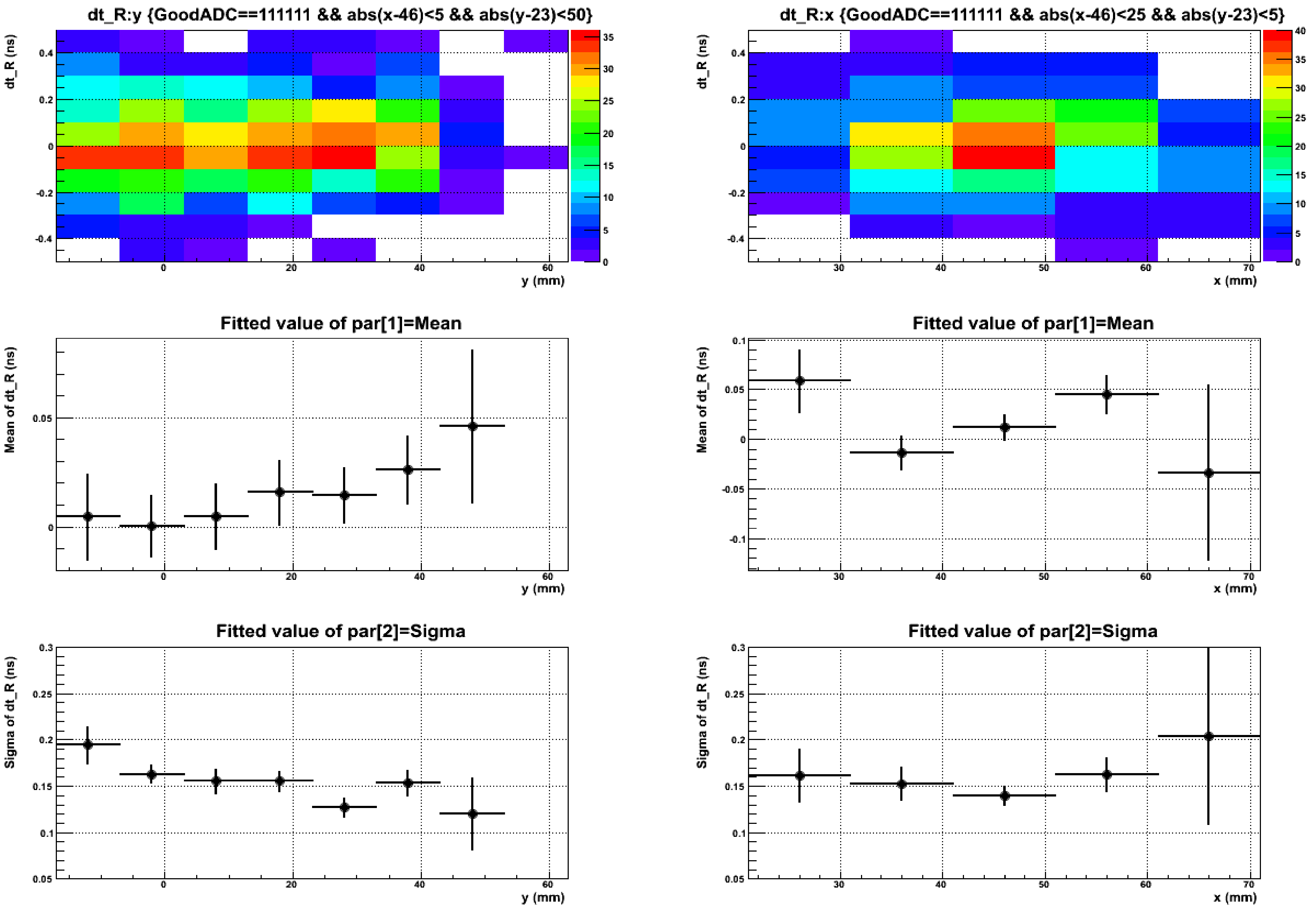


Mean: indicates how good is the calibration

Sigma: time resolution

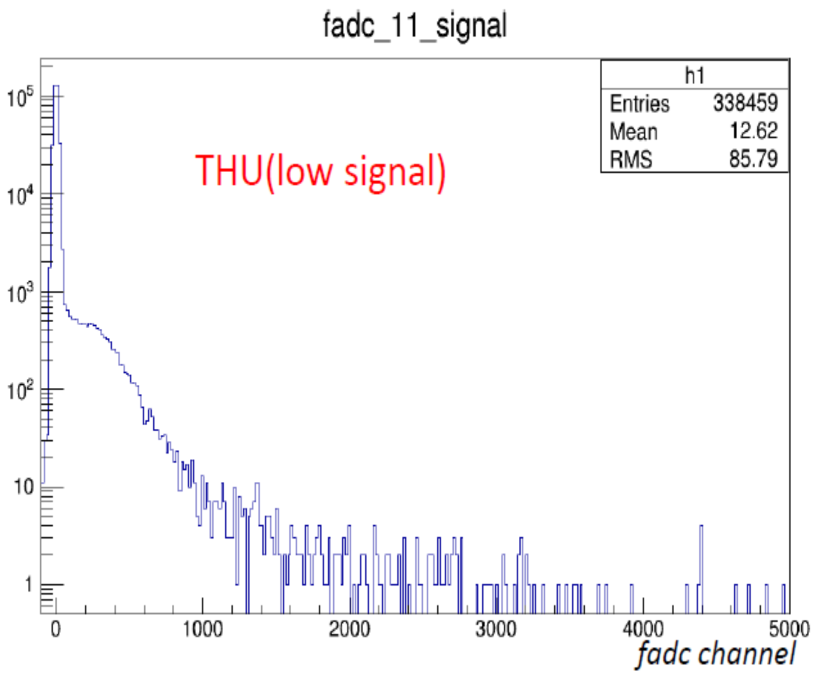
For the whole data set E

Timing resolution of Data Set E: 1x1 cm^2



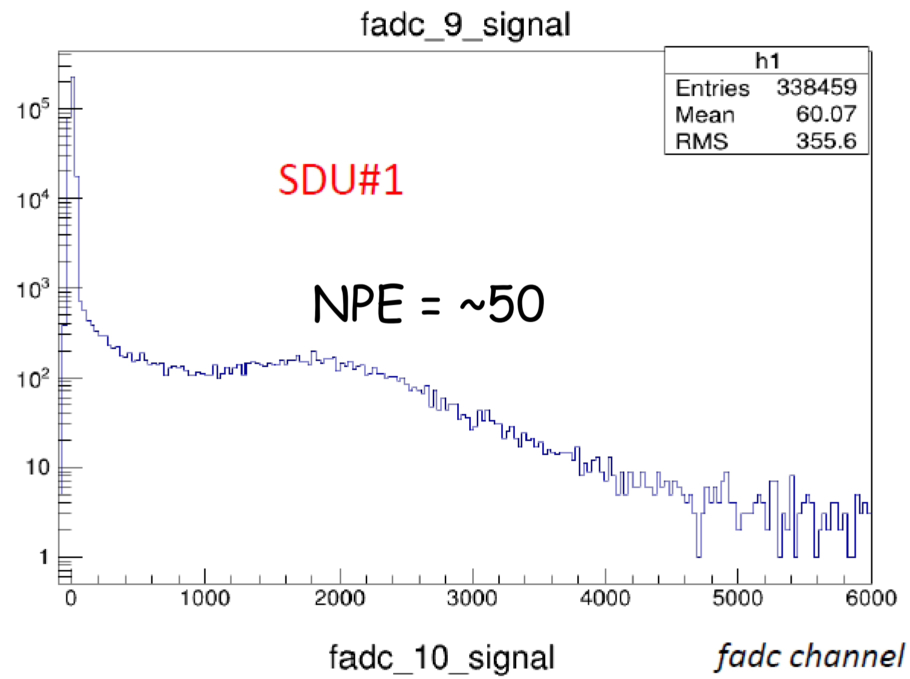
Shashlik cosmic test in Jlab (Ye Tian/SDU)

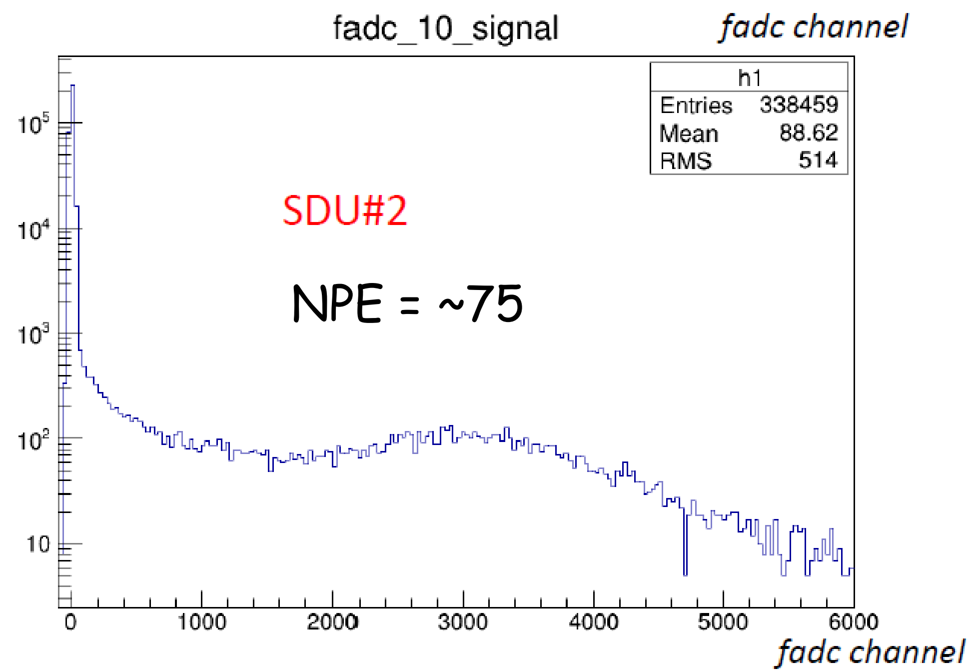
Shashlik Module	HV(start from run 1140)	Gain(10^6)
THU	1700	?
SDU#1	1453	5
SDU#2	1294	5



Modules are placed Horizontally.

Charge = peak *(1v/4000) *(50ohm) *4ns
NPE = charge/gain/e





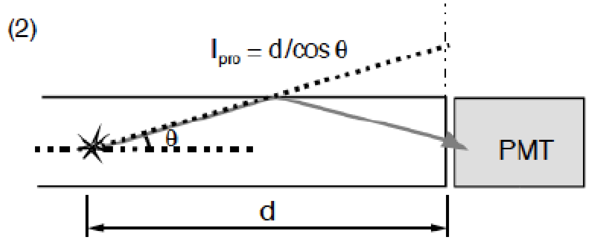
Summary of JLab Test Lab Cosmic Runs (Ye Tian/SDU + Jixie/UVa)

- The timing resolution for single PMT at wider side is 147ps. Eventually this dominates the TOF for the LA particles (since the other timing for the coincidence is from MRPC which has a 20-30ps resolution depending on the rate, and is still been improved on) – note: SIDIS requires 150ps.
- More Fine tuning of timing analysis at other data sets is still going on. I am trying to improve the stability of 3-D fitting.
- Shashlik modules cosmic test in Jlab: SDU1 gives 50 NPE and SDU2 gives 75 NPE. THU1 module still had problem (mounted with SDU PMT).
- THU1 has been shipped back to Tsinghua. Investigation on THU1 module is carrying on.
- Will be good to measure LASPD's light yield, but this also need to know the PMT gain and thus the SDU PMT.

LASPD Simulation (Sanghwa's work)

Post GEMC Simulation (Sanghwa)

- Using the hit information of the GEMC output
- Photons generated uniformly along the particle path and isotropic emission
- Number of generated photoelectrons is reduced by a couple factors:
  - Collection factor: assume the effective area of PMT to the scintillator end area as 0.6 (can be optimized later with a comparison to the data or simulation)
  - Assumed QE of 0.15
  - Attenuation: Simulated according to the probability of 1 - exp(-l_{pro}/λ_{pro})



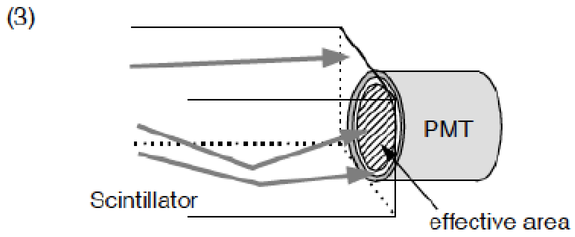


Fig. 7. Light propagation in a scintillator counter.

A detailed Monte Carlo simulation for the Belle TOF system
(NIM(A) 491 (2002) 54-58)

- **Time information:**
  - time = $t_{traj} + t_{emit} + t_{pro} + t_{TT}$

t_{traj} : time for the particle trajectory (currently using the average time information of the particle in the SPD)

t_{emit}: light emission time. Simulated using the emission time probability function

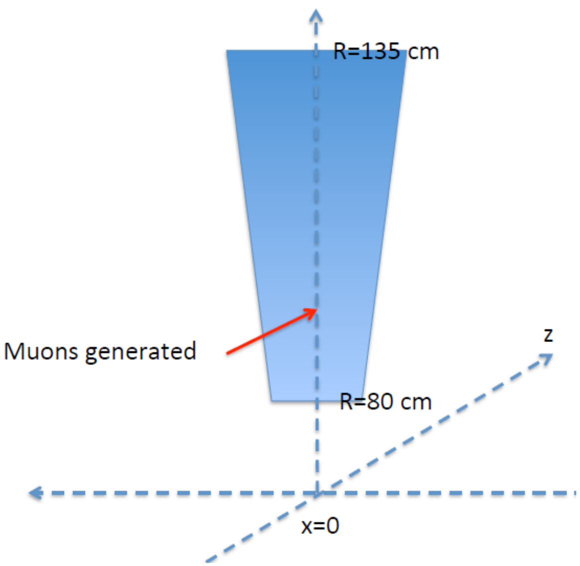
$$E(t_{emit}) = \frac{1}{1+R}\left(\frac{e^{-t_{emit}/\tau_2} - e^{-t_{emit}/\tau_1}}{\tau_2 - \tau_1} + \frac{R}{\tau_3} e^{-t_{emit}/\tau_3}\right)$$

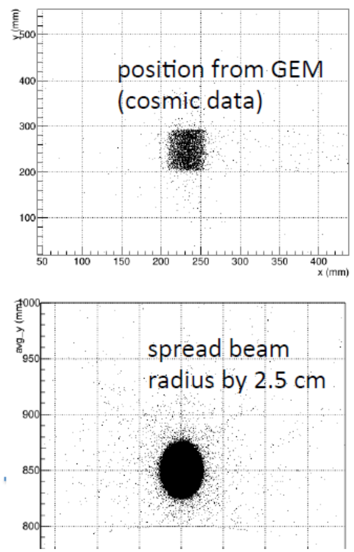
EJ200's refractive index is 1.58 → θ = 39.2°

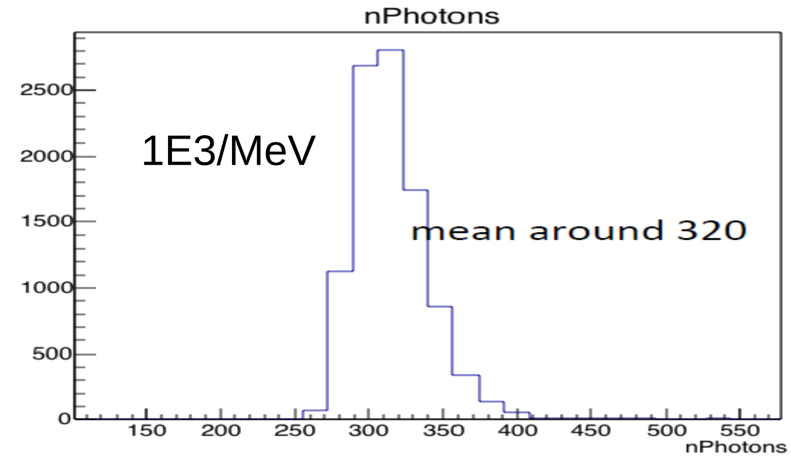
t_{pro} : light propagation time in the scintillator. tpro = n_{scin} * l_{pro} / c
t_{TT} : transit time of a single p.e in the PMT (Gaussian smearing with a mean of PMT transit time (TT) and rms transit time spread (TTS). For R9779, TT is 20 ns and TTS is 0.25.)

Post GEMC Simulation

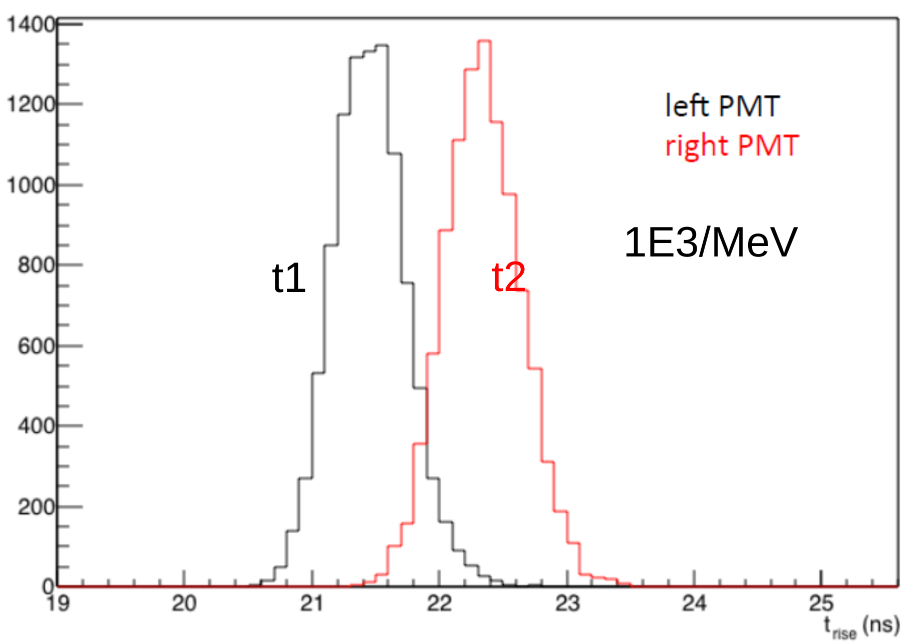
Single muon generation

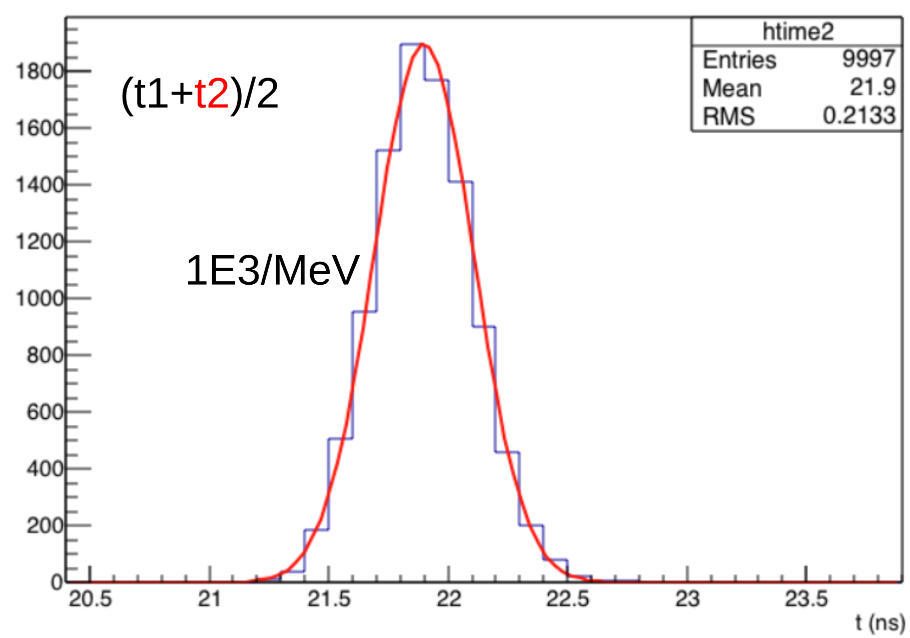




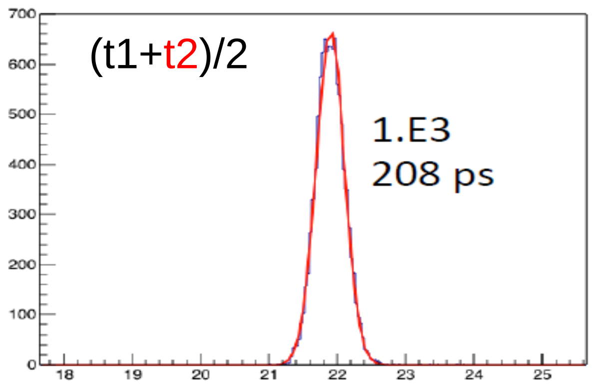


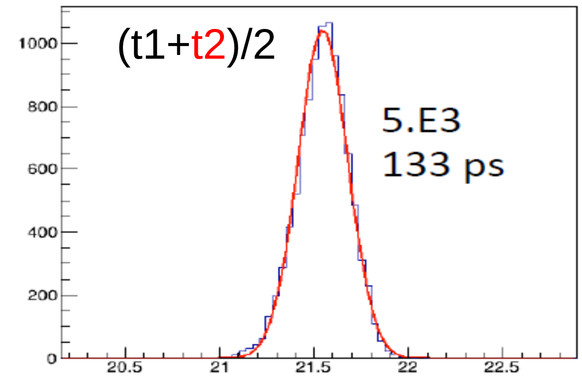
Average SPD time

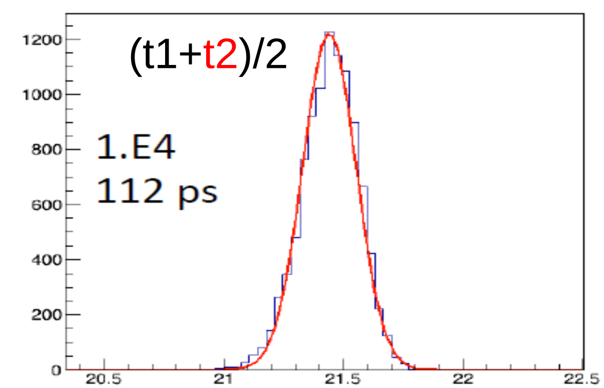




SPD Time Resolution in Simulation



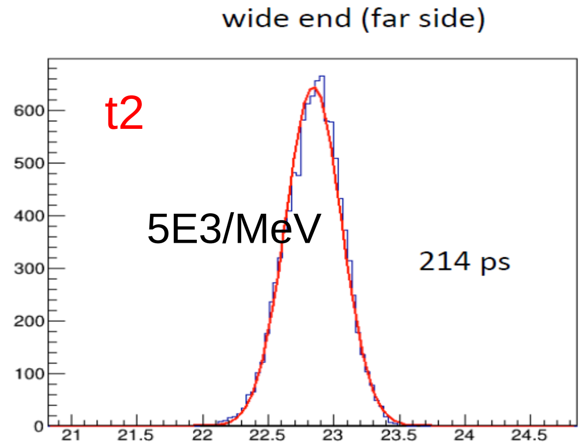


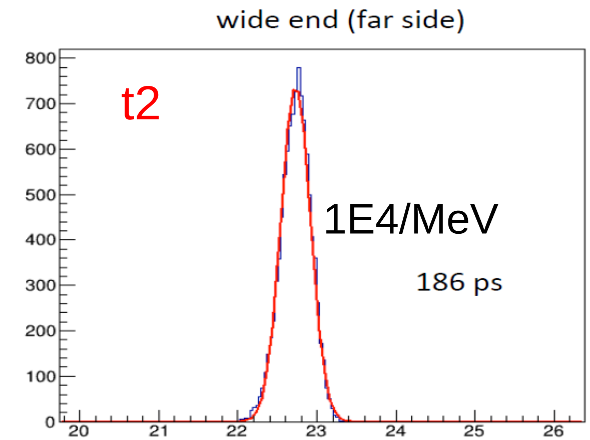


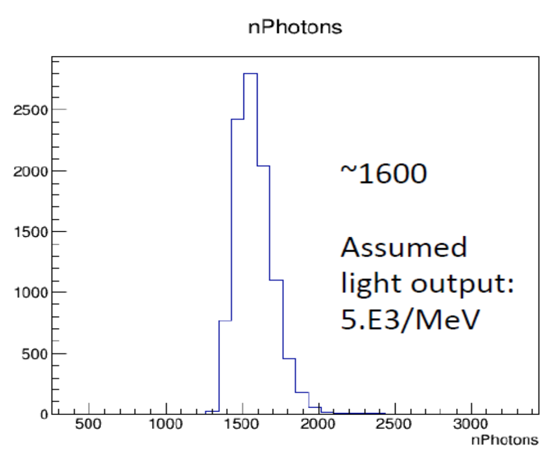
Summary:
Jixie's analysis show that two PMT can reach ~140ps resolution, wide side PMT can reach ~150ps if cut at 1x1 cm^2. This simulation is using 5cm diameter beam spot.

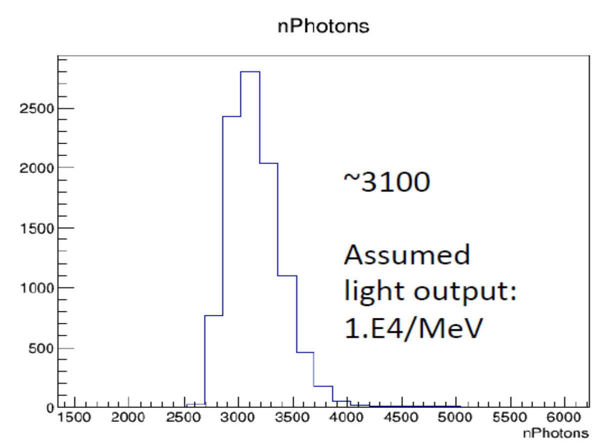
Need to measure NPE of SPD prototype to very this NPE result here.

#γ/MeV is a big uncertainty.





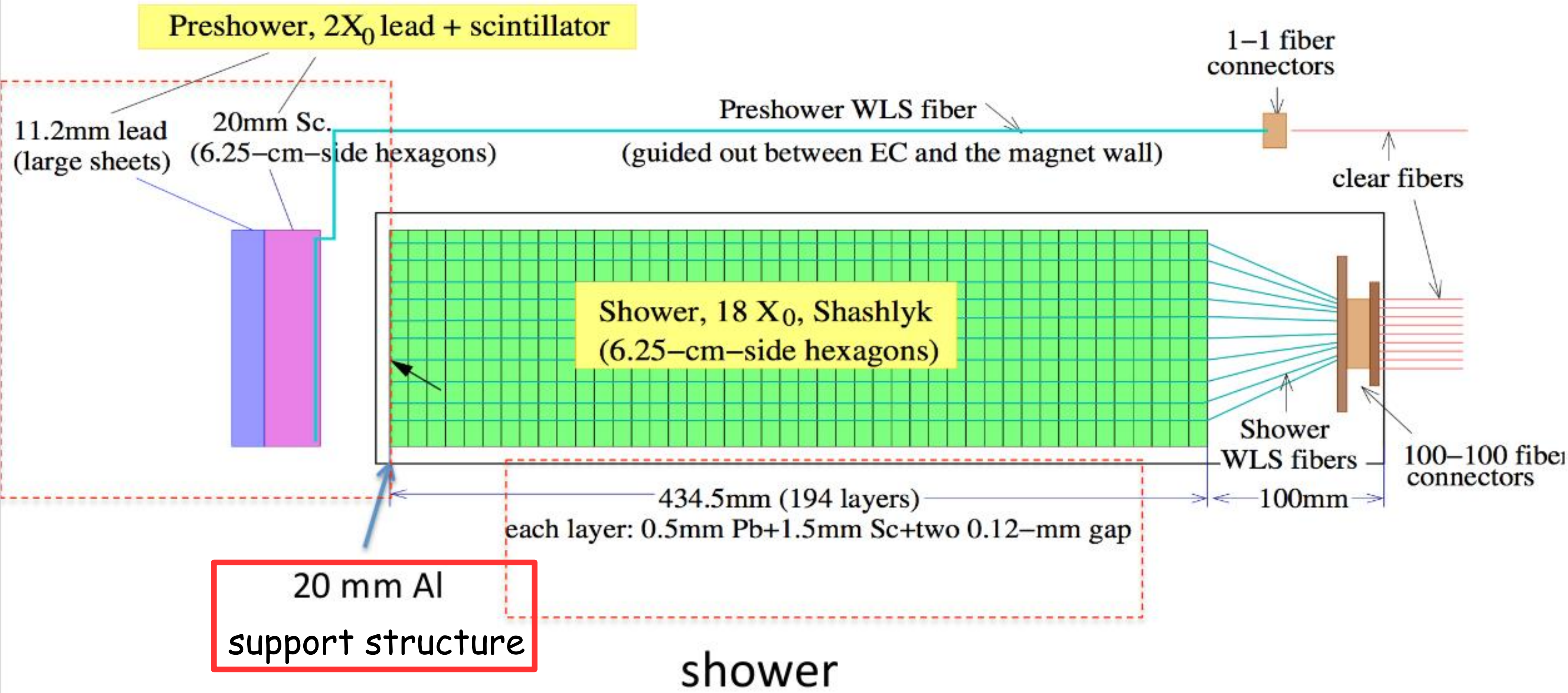




ECal Simulation (Ye Tian, Syracuse)

Ecal Simulation (Ye Tian/Syracuse)

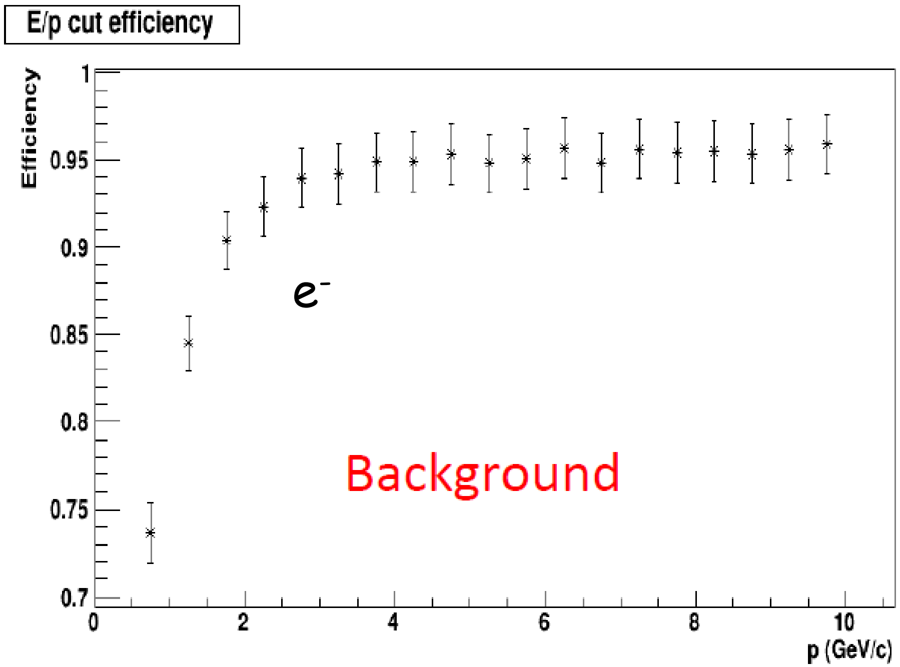
Preshower+ Al

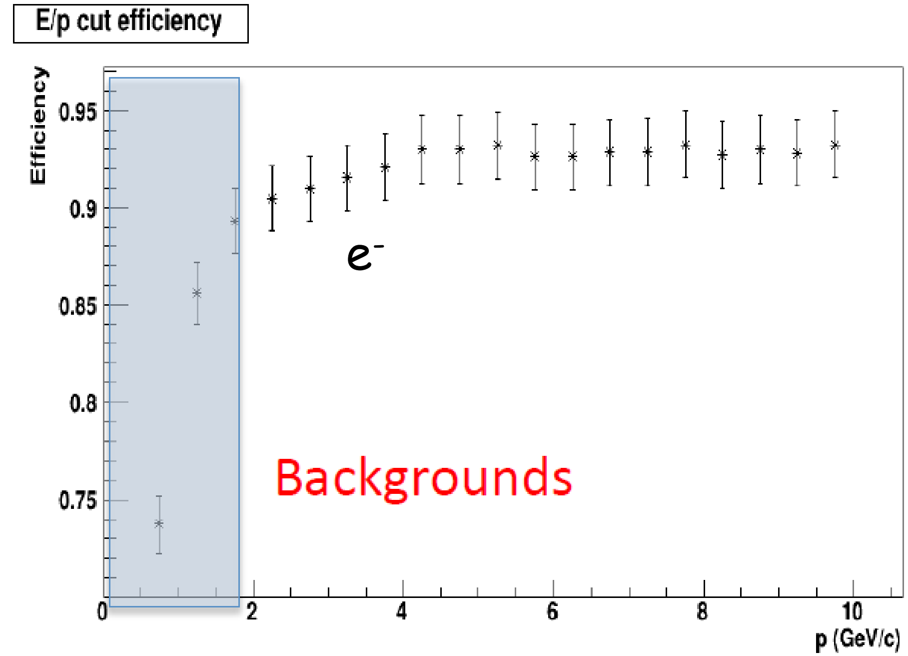


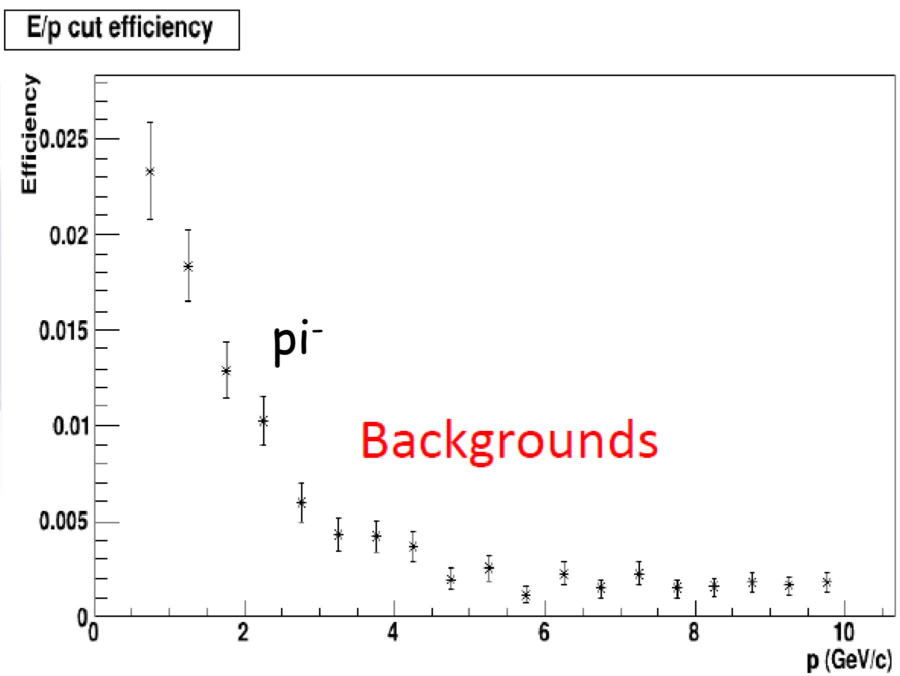
Ye is using the following function to fit simulation: $\frac{\delta E}{E} = \frac{p_0}{\sqrt{E}} \oplus p_1 \oplus \frac{p_2}{E}$

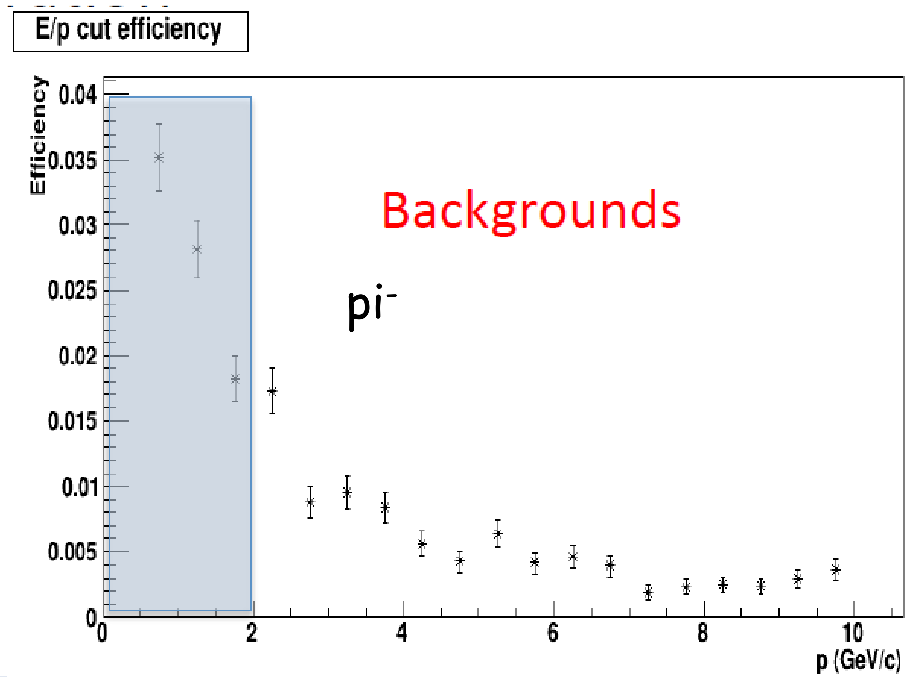
FAEC 2Xo prelead

LAEC 2Xo prelead

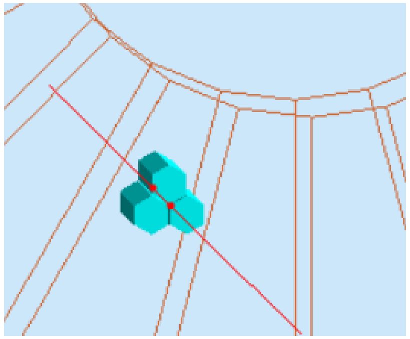








Beam test module simulation



1. 100 MeV/c, e+ and π+

2. 200 MeV/c, e+ and π+

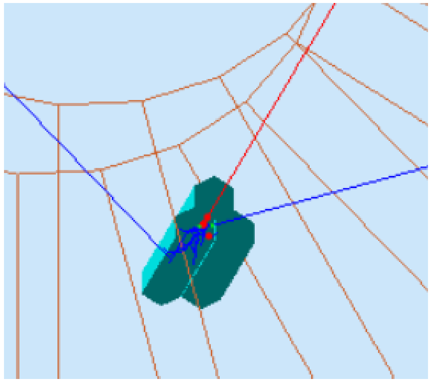
No field, straight hit the center module.

Beam size: 3cm radius

1) 1 module: Y= - 120.984cm, X= - 39.116cm;

2) 3 modules: Y= - 117.575-1cm, X= - 44.704+1cm;

3) 7 modules: Y= - 120.984cm, X= - 39.116cm;



Each above setup has 2 configurations:

a) Full ECAL without 2cm Al support structure

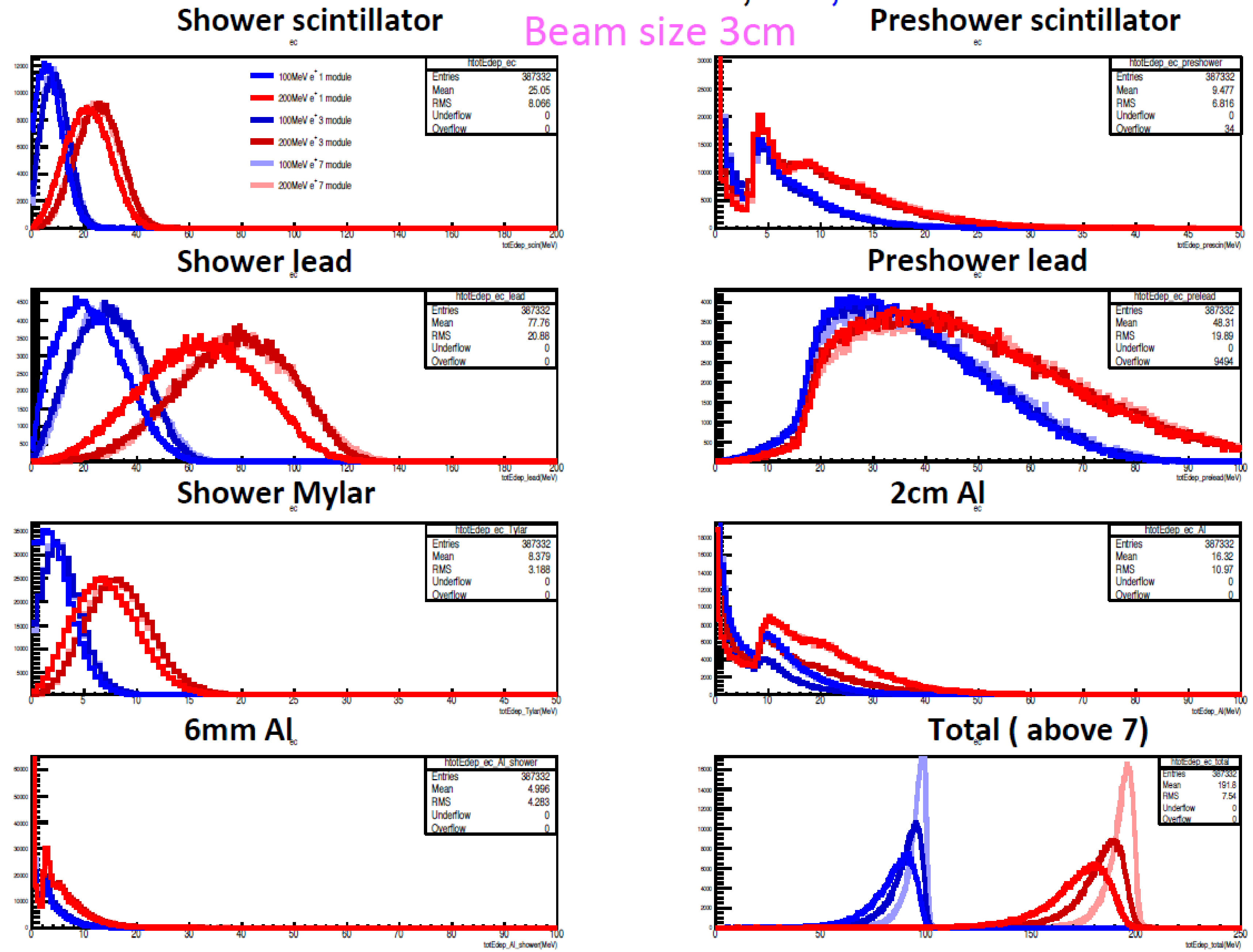
b) Full ECAL with 2cm Al support structure

Modified configurations:

1) Add 6mm Al at front of the shower

2) Replace 0.12mm Mylar to 0.07mm TIO_2 painting.

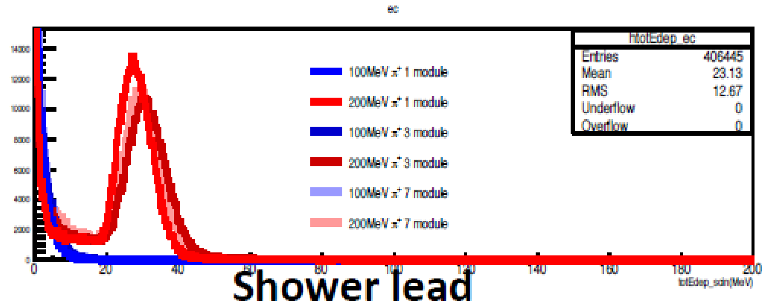
100 and 200 MeV/c, e+, ECAL



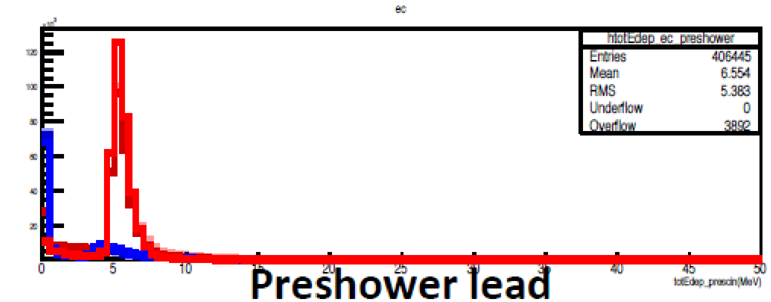
100 and 200 MeV/c, $\pi+$, ECAL

Beam size 3cm

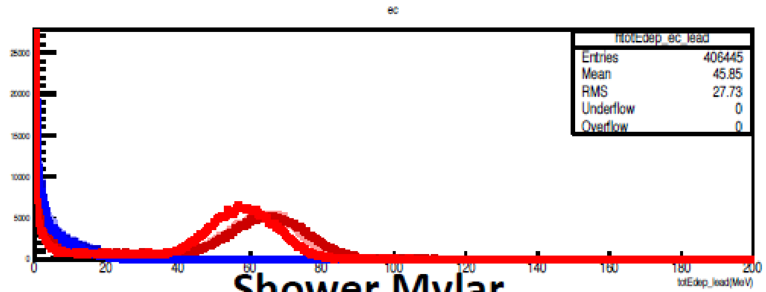
Shower scintillator



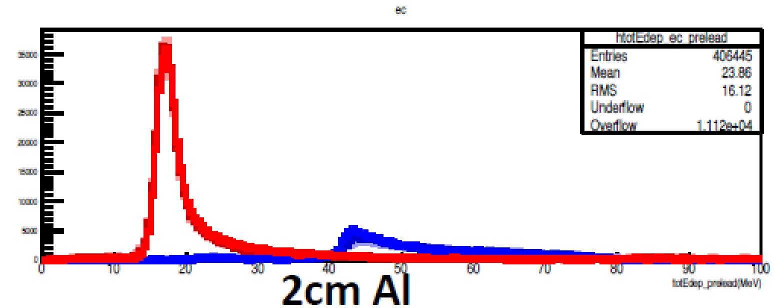
Preshower scintillator



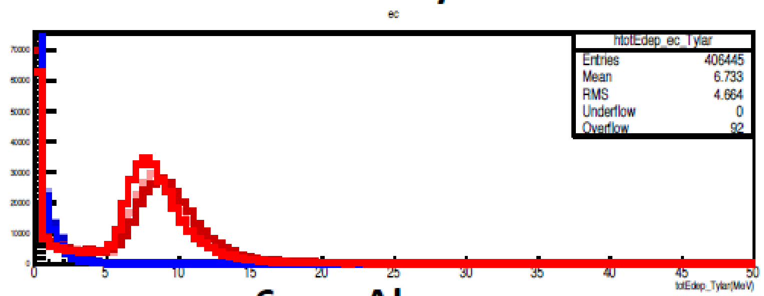
Shower lead



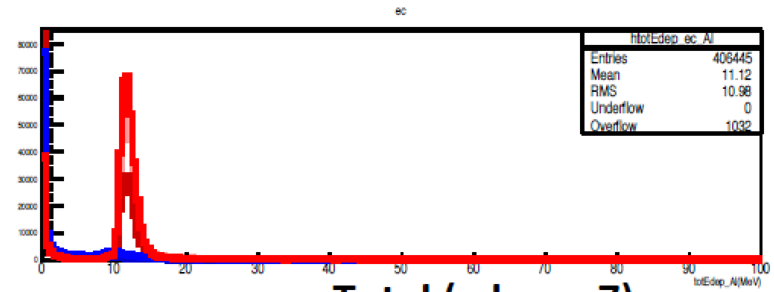
Preshower lead



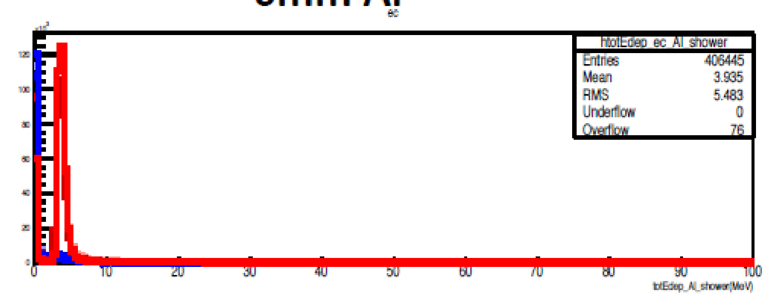
Shower Mylar



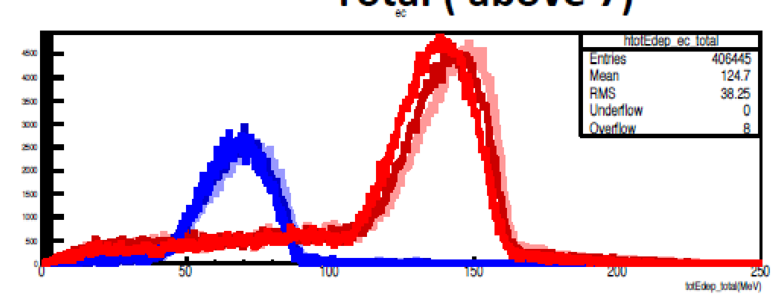
2cm Al



6mm Al



Total (above 7)



ECal Simulation Summary

1. Include SIDIS backgrounds, PID performance (e/pi seperaion) from both FAEC and LAEC are consistent with pCDR Results (Jing's result) by ignoring the edge effect.
2. For momentum less than 1 GeV, electron PID efficiency is 70-80%, and pion rejection efficiency is worse than pCDR.
3. still need to add Birk effect, Nphe statistics, etc. Will Birk effect improve pion PID?
4. Beam test simulation:
   A. beam size of 3cm radius does not show obvious difference comparing to spot beam.
   B. The energy deposited in 3-module or 7-module are very similar. 7-module setup is preferred, while 3-module setup is also acceptable.
   C. Expected energy resolution of Ecal is 15% for 100 MeV, and 10% for 200 MeV. Prefer to test with 200 MeV beam.

Beam Test

- Xiaochao provided a very detail parameters between Fermi Lab and Beijing IHEP. After very carefully comparison we decided to choose to do beam test in IHEP.
  A) Feimi lab provides very little support in detector. We have to bring our own SC array, shashlik detectors, electronics and DAQ.
  B) In Fermi lab, the only PID is TOF, Cherenkov Counter does not work at low energy (several GeV) which is out favorite energy range.
  C) IHEP provide superior detector conditions. The available beam energy is 100 MeV or 200 MeV. Ye Tian's simulation shows that this is do-able.
  D) IHEP beamline upgrade is expected to finish in June 2018. Need to follow this up to find out when the test can be carry on.

- Support structure is under design by Argon group. We also need one support frame to move modules in 2D plan during beam test.

- 7-modules is needed. THU2, SDU3 is available. Tsinghua is going to construct THU3, THU4(maybe), SDU is going to construct SDU4, SDU5. Should SDU1 and SDU2 be shipped back to China?

Other On-going Tests

1. Fiber-end reflectivity test is carried on recently in SDU.

   (clear <-> silver shine <->TiO2 painted)

   Need to do some more test to fully understand the result.

2. Powder paint reflectivity test:

   Older THU powder painted lead tile samples (used in THU2) are compared to the newer THU samples (will be used in SDU4). These two sets of samples have about the same performance, varying by ~10%.

3. New Kedi scintillator test:

   New Kedi scintillators samples are tested. These samples are the same formula as previous "Kedi improved" used in SDU2, SDU3 and THU1, but were produced just now.

   The test results show 10-20% variation. However, these tests are using different PMTs.

   Tests between different samples from the same batch but use this same PMT show that the scintillators in the same batch could have 10% variation.

Preparation for CDO

1. Continue shashlyk prototyping (SDU, THU), figure out the gain puzzle. If 1000 → Okay. If 500 → not okay and we need to figure out how to reach the light yield of LHCb.
2. Finalize LASPD timing data; determine light yield of LASPD; (might give up determining relative yield of THU1 module)
3. Continue LASPD simulation, if confirming more segmentation is needed, need to test new prototype and/or more simulation for a second LASPD.
4. Continue clear fiber test and TiO2 powder reflectivity test – previously only THU, but SDU will also start.

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5. Continue simulation on triggering, then proceed to other aspects (Birk effect, photon statistics, photon collection, etc.).
6. Need to fully understand shashlyk data from Hall A test. Plan for a full-cluster beam test in IHEP.
7. Continue support structure design.
8. (From March meeting: LHCb will dismount their preshower in 2019, (in Dec 2016) asked us if we are interested.)

ECal + SPD cost estimate (June 2017)

Item	2014	2017
Shashlyk	$2,997,657 (1800 modules Russian IHEP)	China using 0.1454USD/Y: $3,460,567 (1800 modules); $3,630,323 (5% extra) +US $40k lead (material only)
Preshower	$280,800 (1800 modules Russian IHEP)	
SPD (Eljen)	FA: $54,900; LA: $34,680	FA: $58,620 LA: $37,440
HV/CAEN	$1,026,624	$365,015 (newer, lower cost modules)
PMT/Hamamatsu	$885,600 (5% spare incl., MAPMT overestimated); FMPMT not quoted; plus MAPMT base/preamp	$797,510 (5% spare included), plus 128 units of MAPMT base/preamp at $200 each(?) → $825k?
Fiber (Saint Gobain)	$700k (~$1/m, 200kmWLS, 520km clear)	$996.5k ($1.8/m WLS 192km, $1.25m clear 520km)
Fiber (Kuraray)	$64k ($2/m 23.5km clear, $3.2/m 6800m WLS)	$82,281 ($4.67/m WLS 6.8km; $2.15/m clear 23.5km)
Fiber connectors	$365k	$420k (incl. 5% spare)
Total	$6,411k	$6,455k