Simulation, Reconstruction and R&D for the STCF EMC

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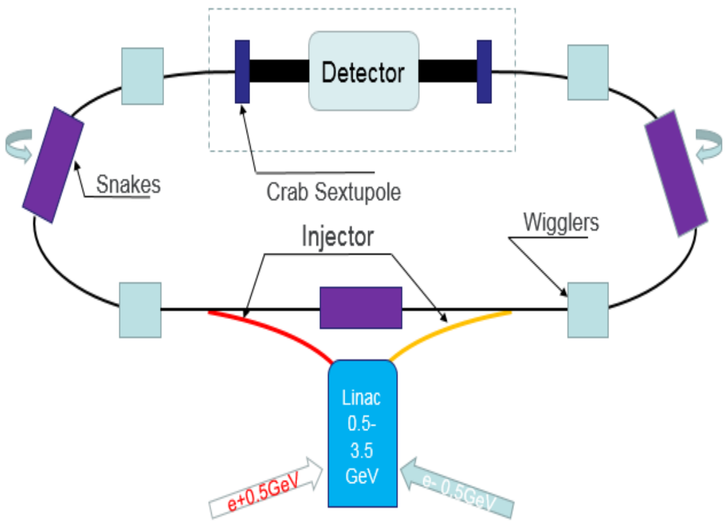
On behalf of STCF Calorimeter working group

Outline

- Motivation
- STCF EMC
  - Conceptual Design
  - EMC performance
  - Electronics design
  - Some test results
- Summary

What kind of Calorimeter do we need

- **Super T-C Facility (STCF)**
  - $E_{cm} \approx 2 - 7$ GeV, luminosity $\sim 1 \times 10^{35}$ $cm^{-2}s^{-1}$ at 4 GeV
  - ~600 m double ring



- STCF EMC Requirements
  - High Event Rate
    - About MHZ background event rate
  - Precise Energy Resolution
    - Better than 2.5% @ 1GeV
  - Good Time Resolution
    - 300 ps @ 1 GeV

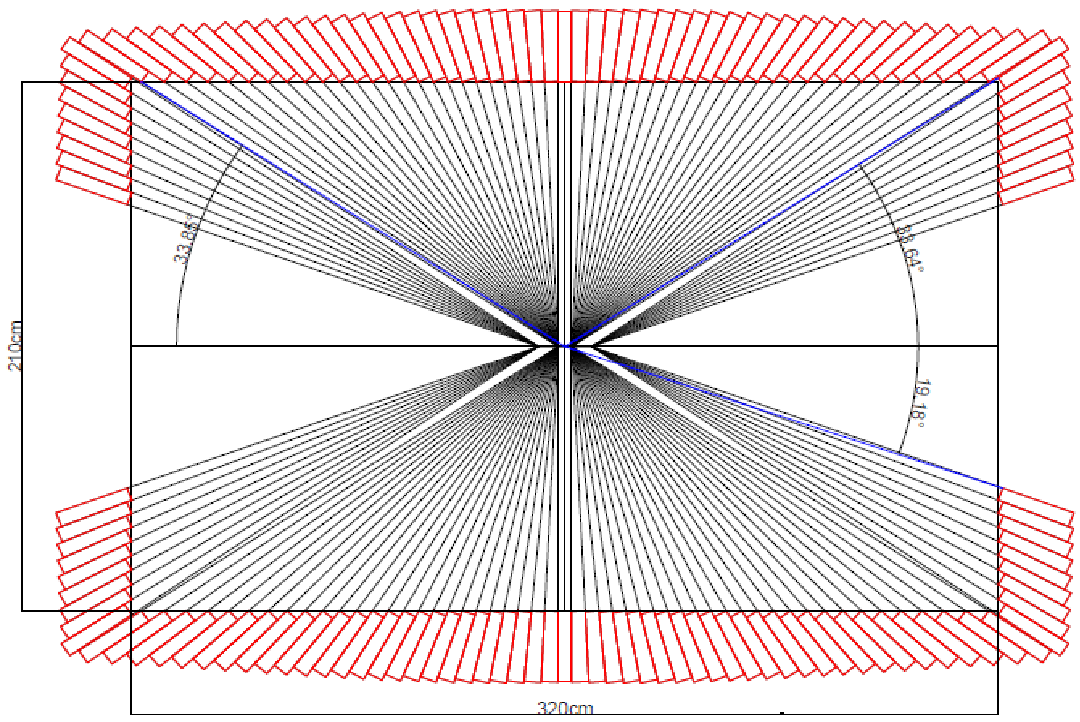
EMC Design — Crystal Selection

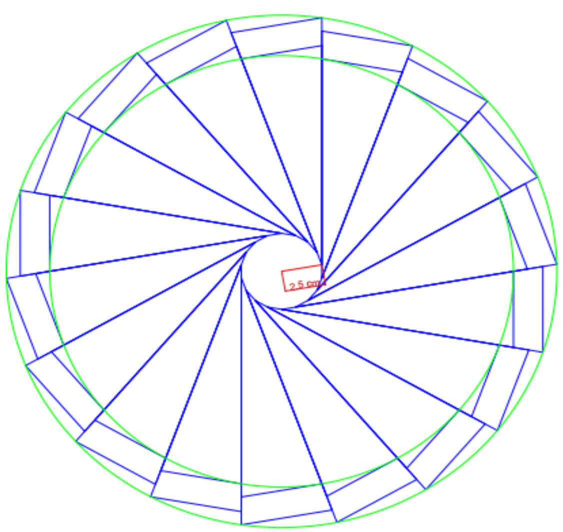
- Total absorption calorimeter
  - pCsI crystal + APD photo-device

Crystal	Pure CsI	LYSO	GSO	YAP	PWO	BaF:Y
Density (g/cm^3)	4.51	7.40	6.71	5.37	8.30	4.89
Melting Point (°C)	621	2050	1950	1872	1123	1280
Radiation Length (cm)	1.86	1.14	1.38	2.70	0.89	2.03
Moliere Radius (cm)	3.57	2.07	2.23	4.50	2.00	3.10
Refractive index	1.95	1.82	1.85	1.95	2.20	1.50
Hygroscopicity	Slight	No	No	No	No	No
Luminescence (nm)	310	402	430	370	425 420	300 220
Decay time (ns)	30 6	40	60	30	30 10	600 1.2
Light yield (%)	3.6 1.1	85	20	65	0.3 0.1	1.7 4.8
Dose rate dependent	No	No	TBA	TBA	Yes	No
D(LY)/dT (%/°C)	-1.4	-0.2	-0.4	TBA	-2.5	TBA
Experiment	KTeV Mu2e				CMS ALICE PANDA	

EMC Design

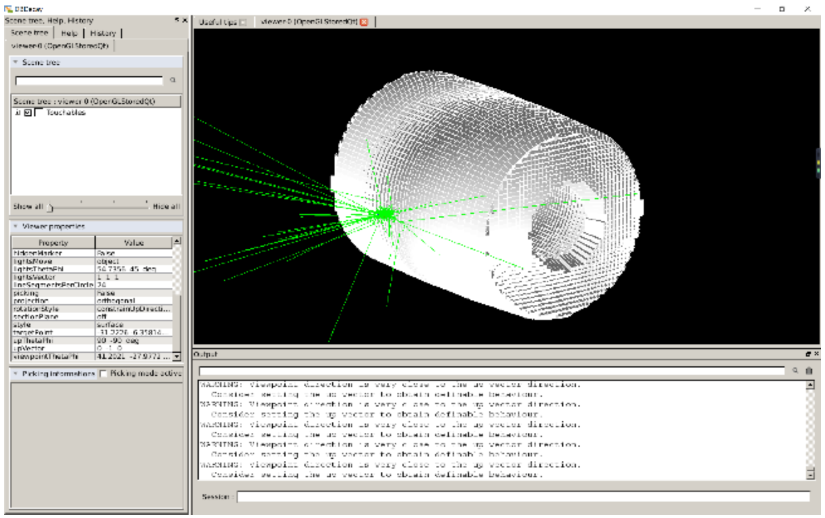
- Barrel has 6732 crystals, which are arranged in 51 circles with 132 bars in each circle.
- Each endcap has 969 crystals

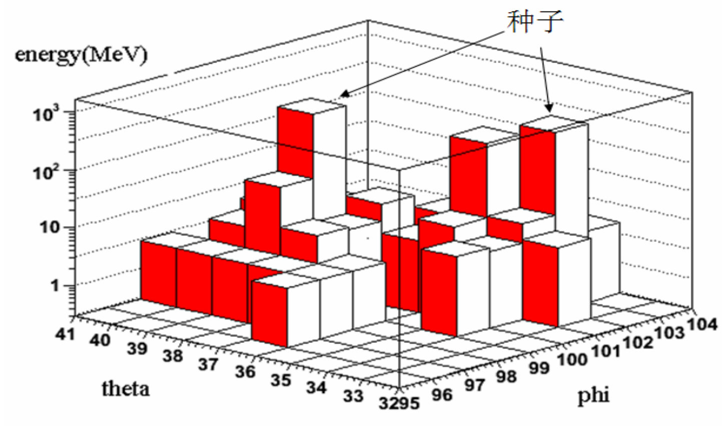




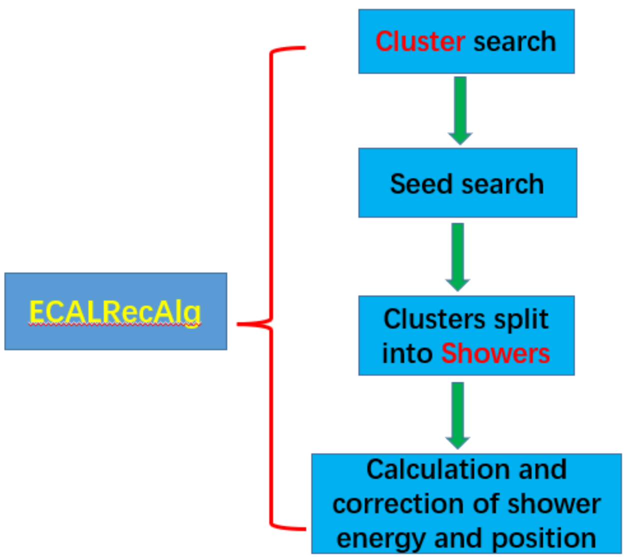
Defcous design

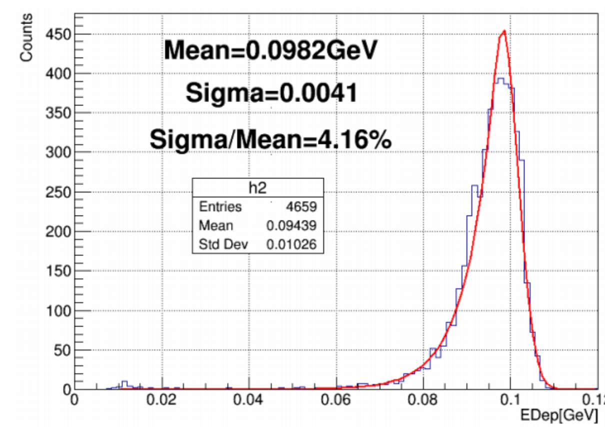
EMC Performance study using OSCAR





π^0 cluster (two photons)

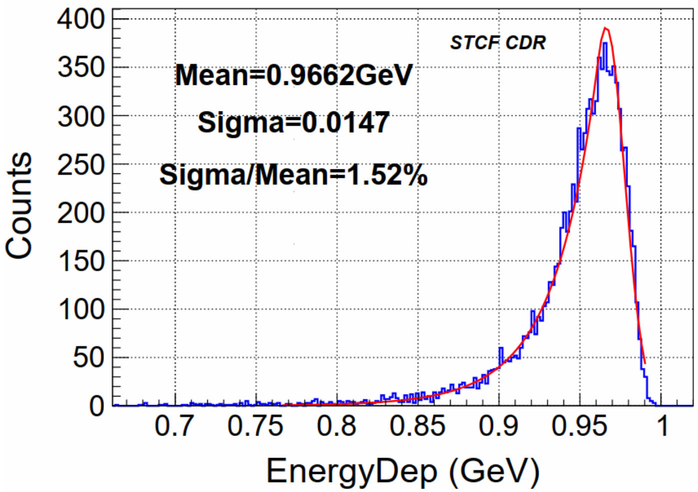




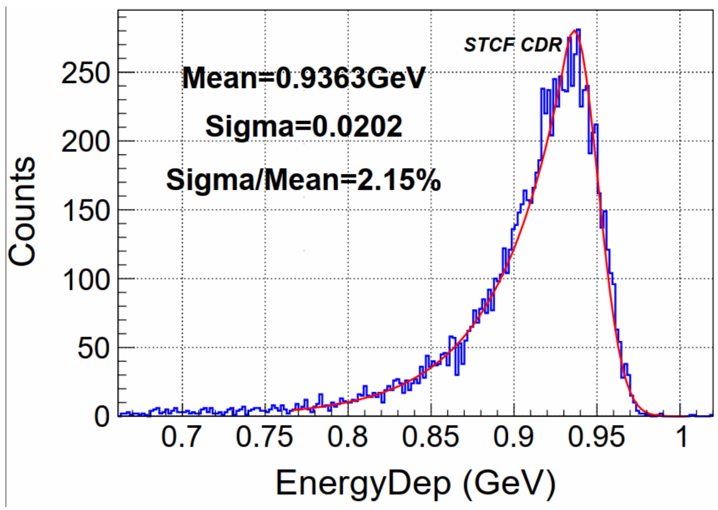
0.1 GeV γ energy reconstruction

EMC Energy Response

- Energy Resolution
  - Light yield: 100 pe/MeV
  - Support materials: carbon fiber: 200 um
  - Crystal light collection uniformity: ±5%
  - Energy deposition of Secondary particles incident on APD
  - Electronics noise: 1 MeV



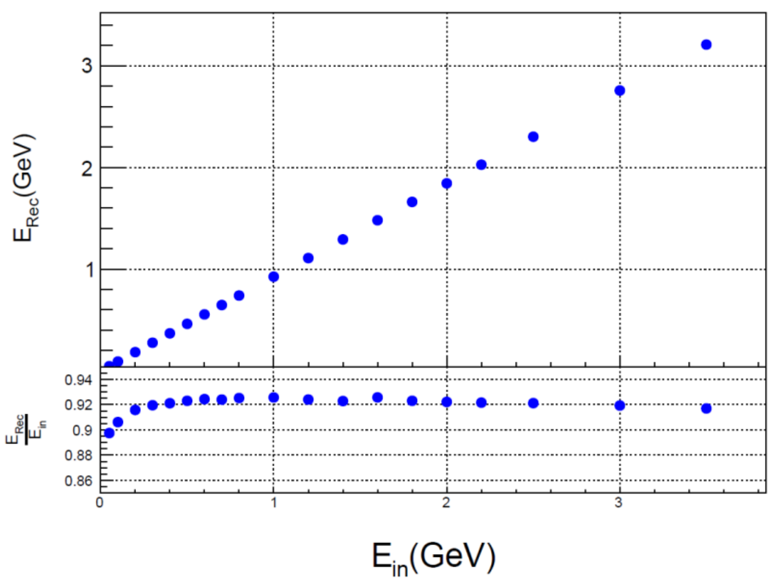
LY: 100 pe/MeV



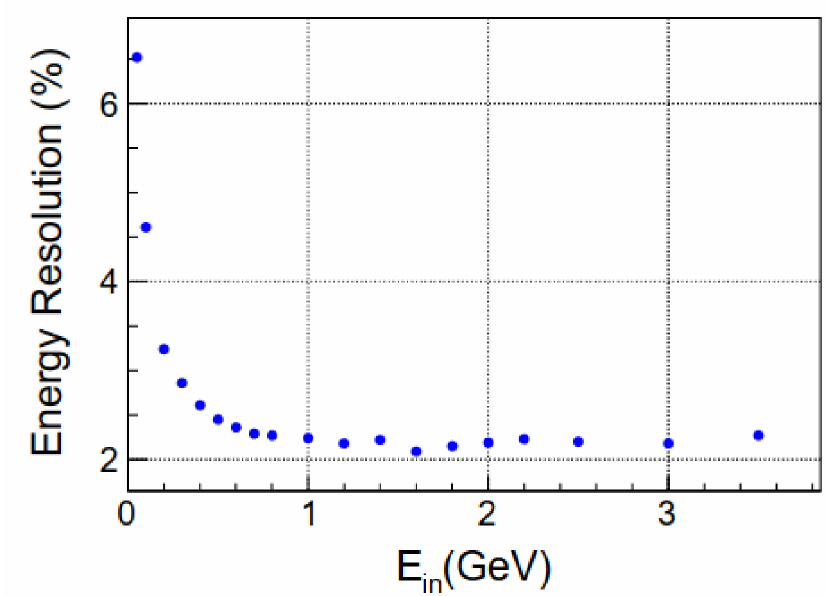
All the items were considered

EMC Linearity and Resolution

- The energy linearity is good from 50 MeV to 3.5 GeV without correction, the energy leakage is not obvious after 2.5 GeV
- The energy resolution is about 7.0% @ 50 MeV, and 2.2%@1GeV. At about 1GeV, the energy resolution began to enter the plateau area. After 2GeV, it seemed to become worse, but it was not significant.



Energy linearity

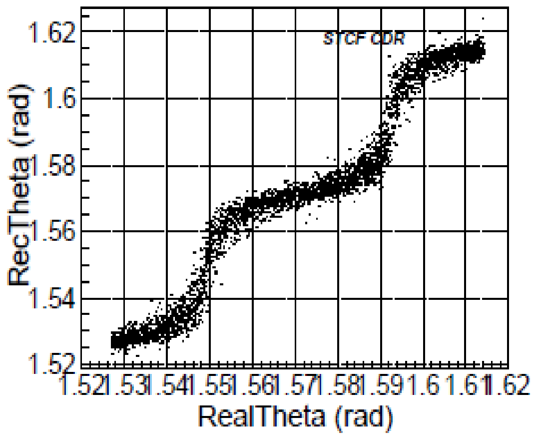


Energy resolution

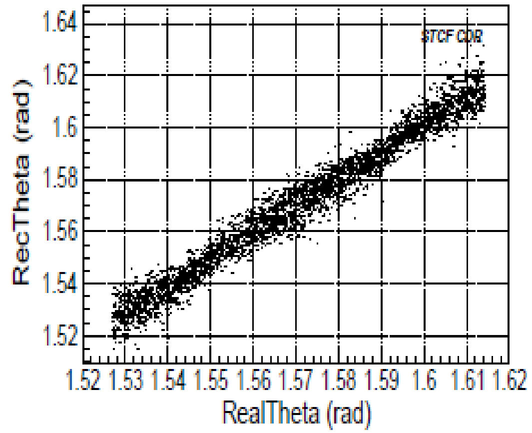
EMC Position Resolution

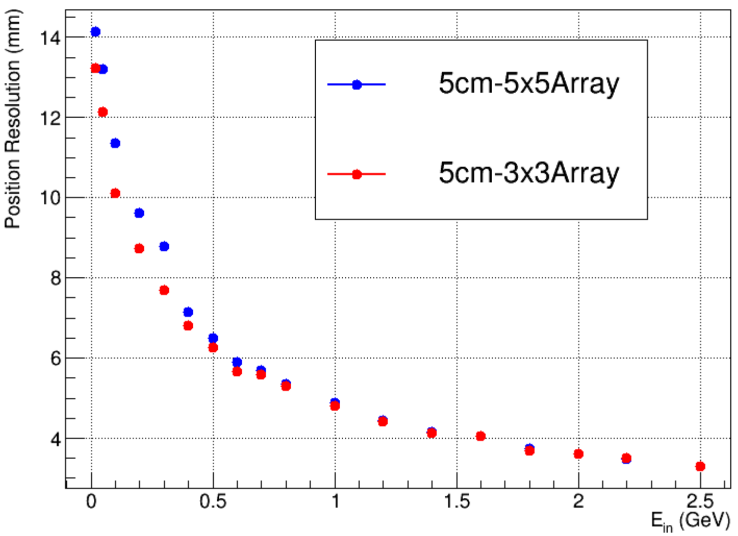
- Position Resolution
  - Barycenter method was used to reconstruct the incident position
  - Two different weights were compared, the position resolutions are very close
    - Linear weight, Log weight
  - The position resolution is about 5mm @ 1GeV while the crystal end size is about 50 mm.

Linear-Weight

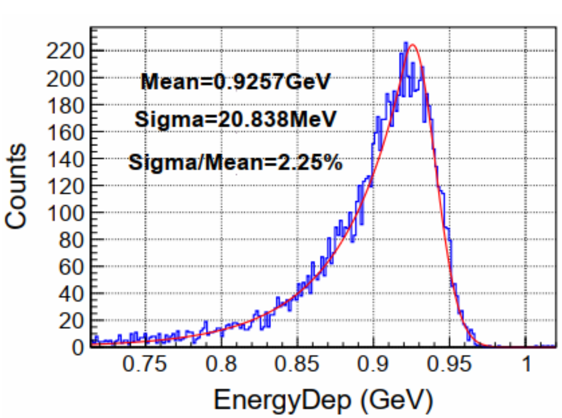


Log-Weight

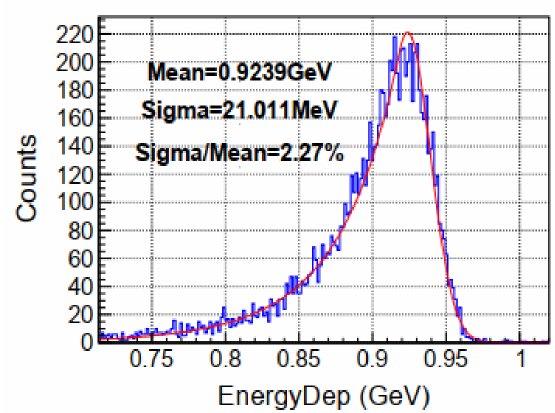




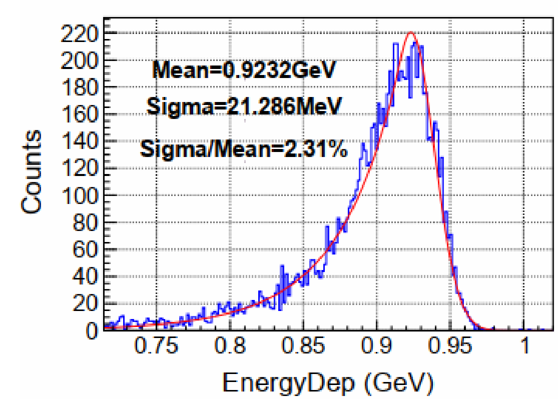
- upstream materials will affect the performance of the EMC
  - Compared the effects of different upstream mass on energy resolution
  - With the increase of material quality, the energy resolution gradually becomes worse
  - When the material mass exceeds 30% X_0, the resolution is larger than 2.3%,



23% X_0



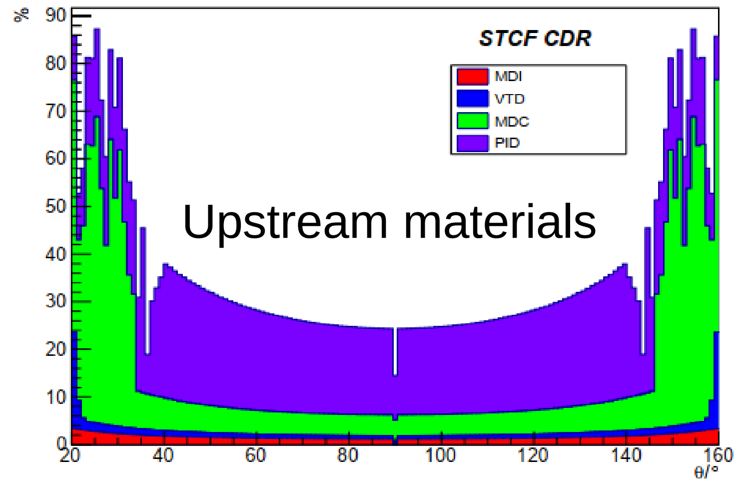
27% X_0



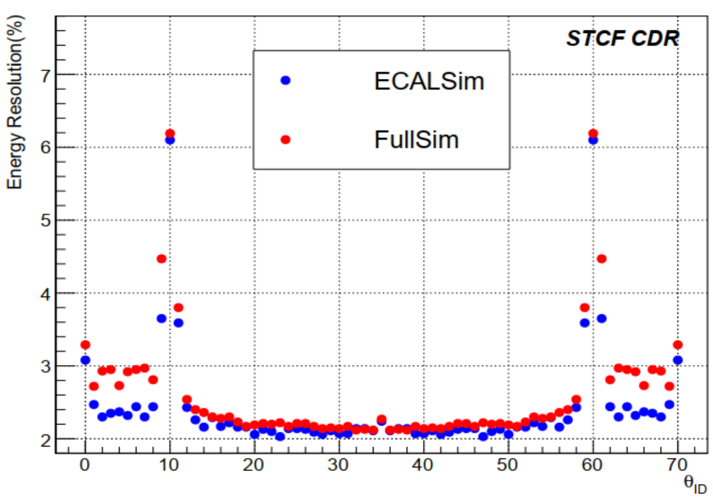
31% X_0

Upstream Material Influence

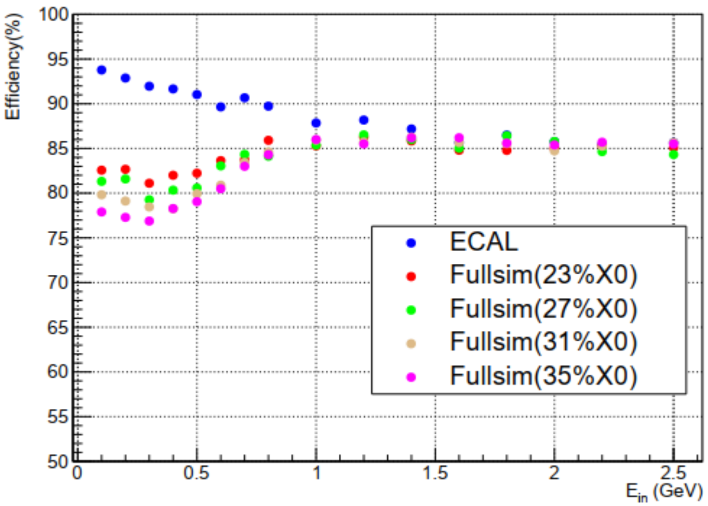
- In STCF baseline geometry, the EMC upstream mass is set to 30% X_0 (barrel), mainly from PID detector, and is about 80% X_0 in endcap, mainly due to MDC



Upstream materials



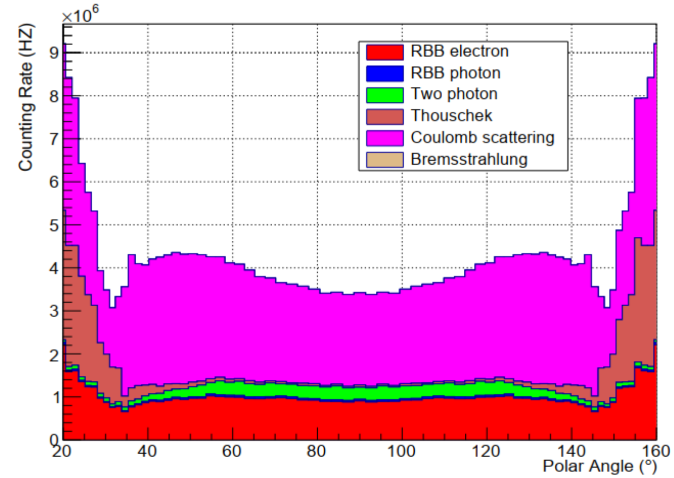
Energy resolution

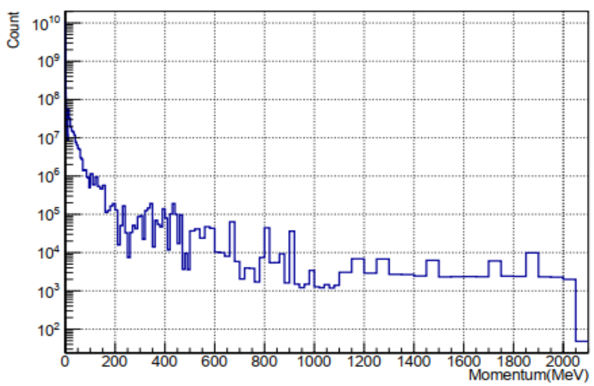


Detection efficiency

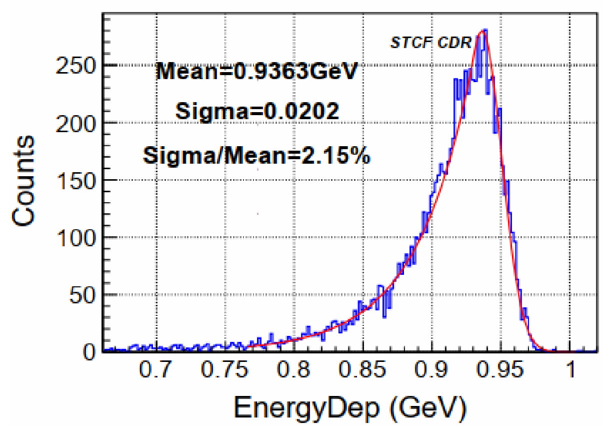
Pileup study

- High luminosity introduces high background, which will cause pileup and affect energy reconstruction
- The background rate is about several MHz in the position of EMC
- Most of the energy is less than 10 MeV

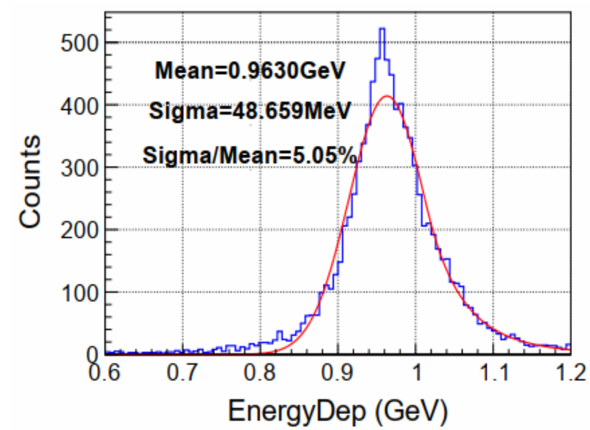




Background energy



Without background



With background

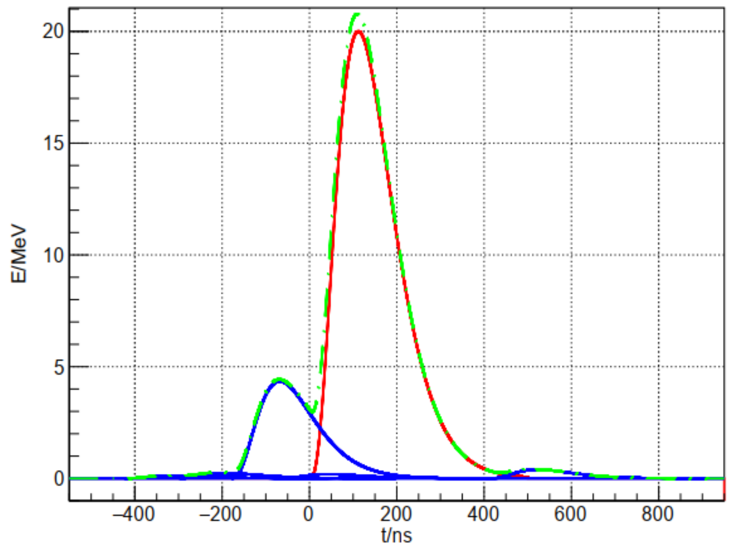
Multi-wave fitting

- The fit minimizes the χ^2 defined as:

$$\chi^2 = \left(\sum_{j=1}^{N} A_j \vec{p_j} - \vec{S}\right)^T C^{-1} \left(\sum_{j=1}^{N} A_j \vec{p_j} - \vec{S}\right)$$

Where:

the vector $\vec{S}$ comprise the 40 readout samples;
the vector $\vec{p_j}$ are the pulse templates;
the A_j are the pulse amplitudes
the covariance matrix **C** is currently only associated with the electronics noise.

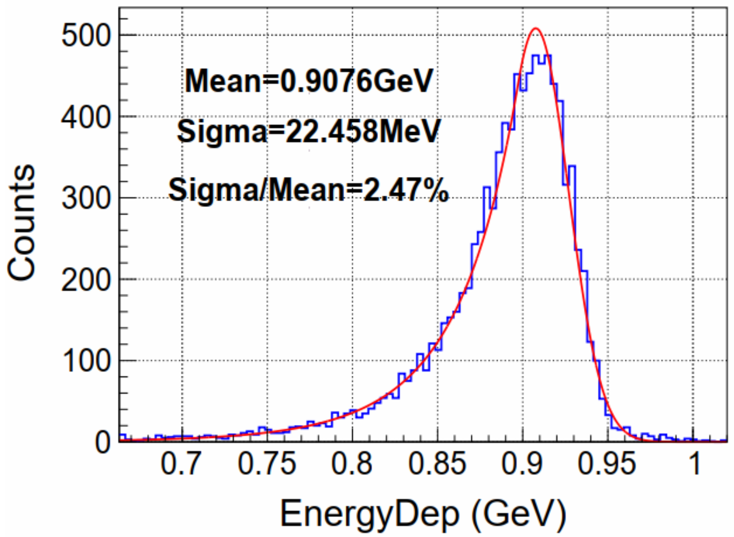


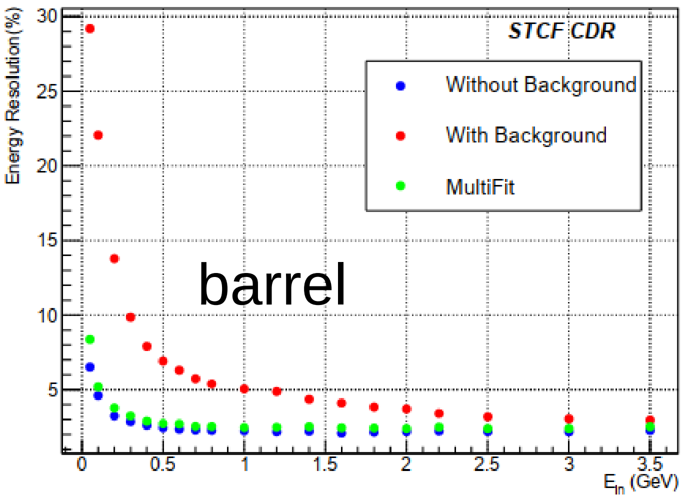
The technique of nonnegative least square is used to minimize the χ^2, with the constraint that the fitted amplitudes A_j are all nonnegative.

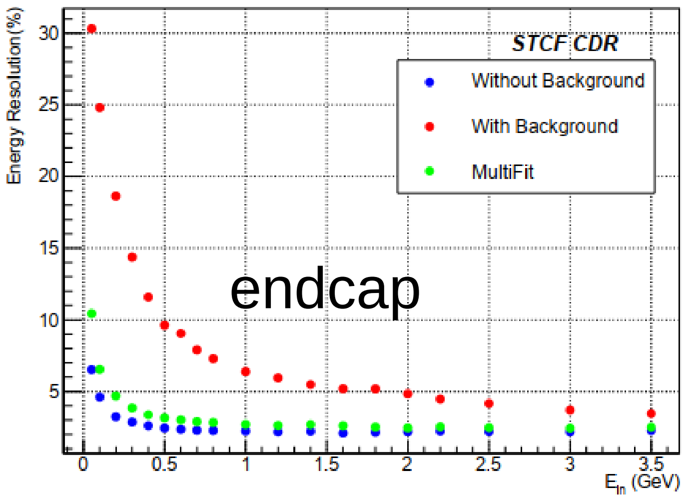
Noise: 0 MeV
Data: Signal: 20 MeV, Start Time: 0 ns
Background: 1 MeV, Start Time: 50 ns
Fit Result: Signal: 20 MeV, Start Time: 0 ns
Background: 1 MeV, Start Time: 50 ns

Multi-wave fitting

- The energy resolution becomes 2.47% after multi-wave fitting, which is greatly improved compared with the previous 5.05%
  - Without background: 2.15%
  - With background: 5.05%
  - Multi-wave fitting: 2.47%

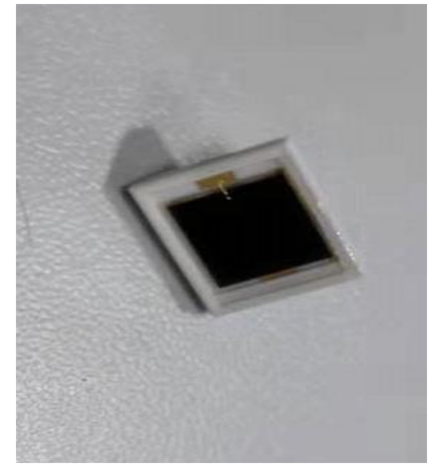


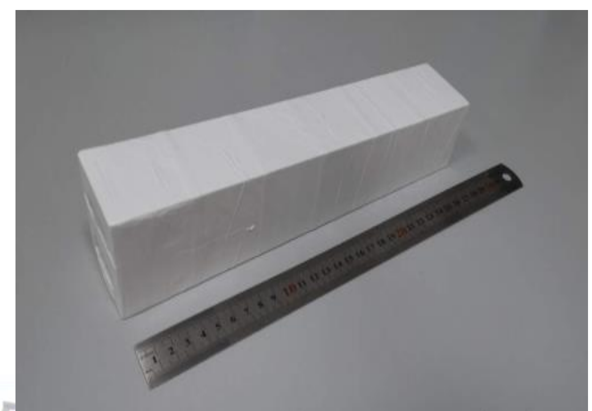


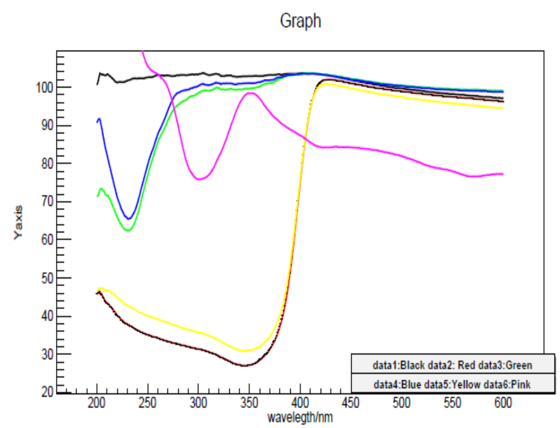


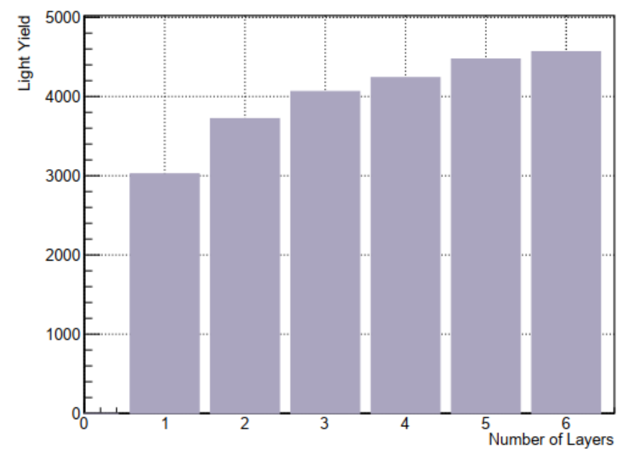
Detector element

- pCsI crystal
  - The fluorescence main peak is at about 310 nm
  - The transmission is about 40% @ 310 nm
- The reflection coefficient of reflective film
  - Teflon material is close to 100% @ 310 nm
- APD type
  - HAMAMATSU, S8664-55 vs. S8664-1010



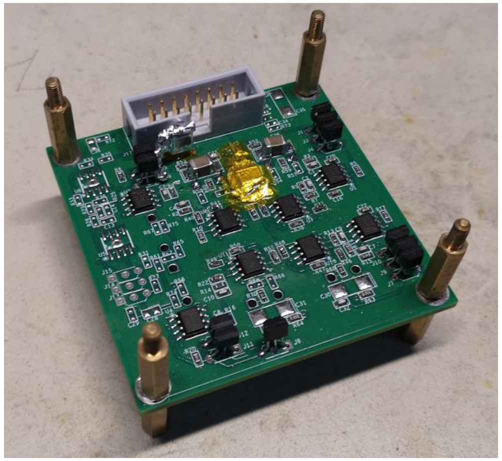




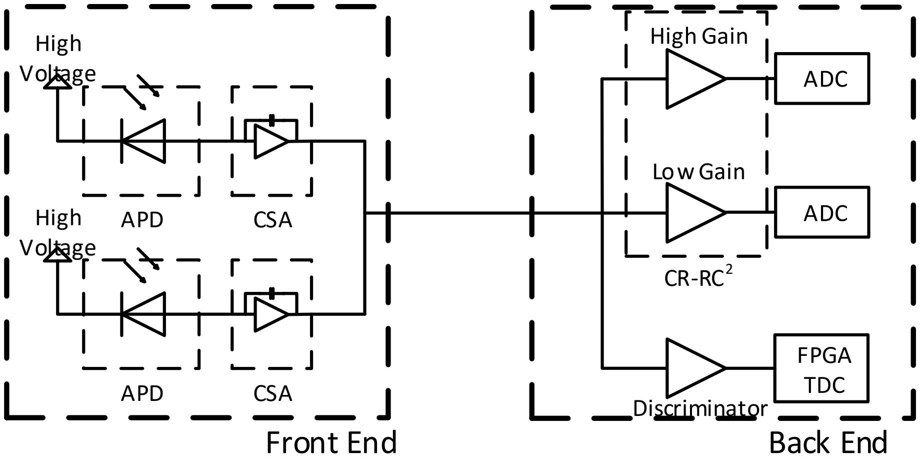


Electronics

- High precise energy measurement
  - CSA-based readout design
- High dynamic range
  - dual gain readout
- Time measurement
  - Leading edge and waveform fitting



Front end board

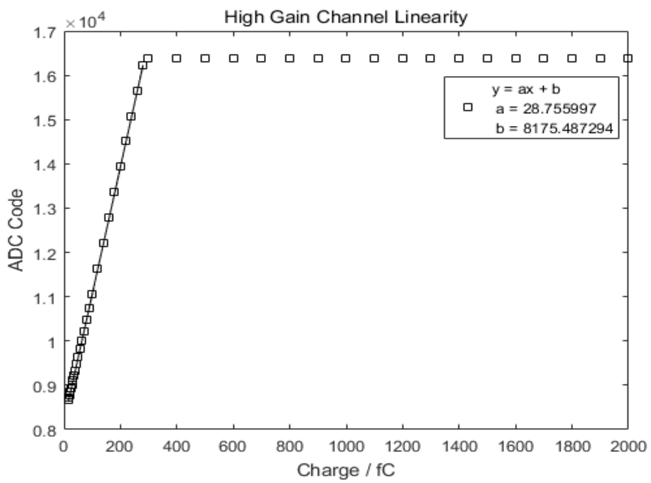


Electronics design

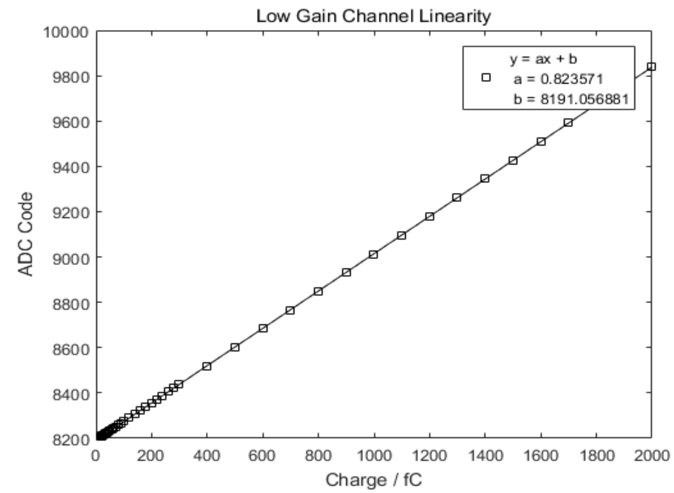
Back end board

Electronics test – linearity I

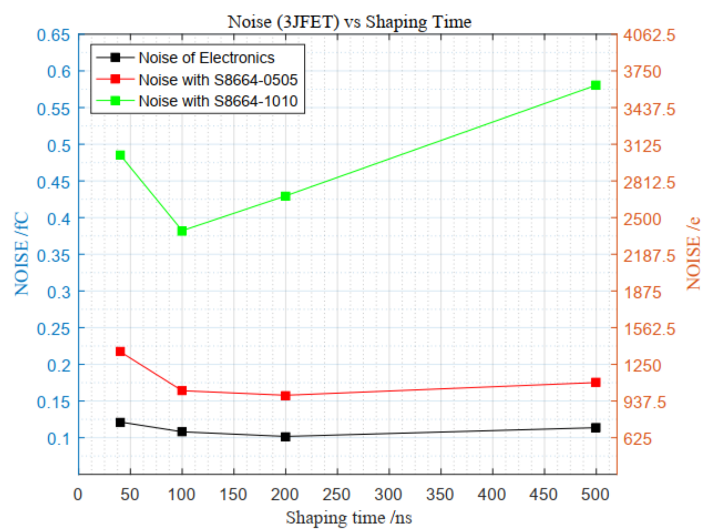
High gain linearity



Low gain linearity

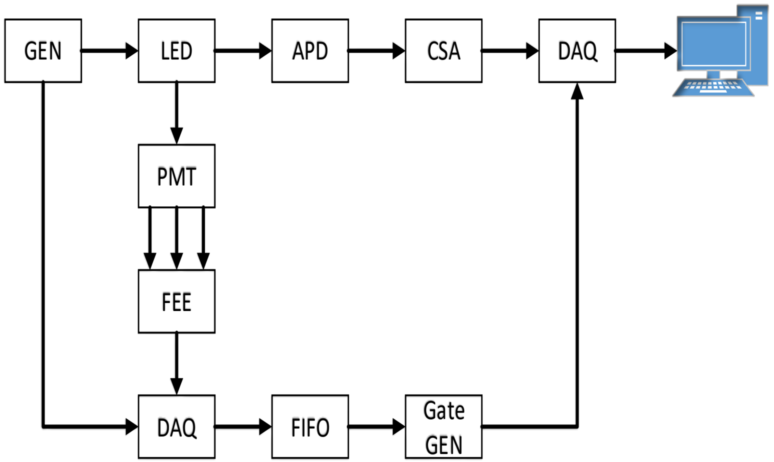


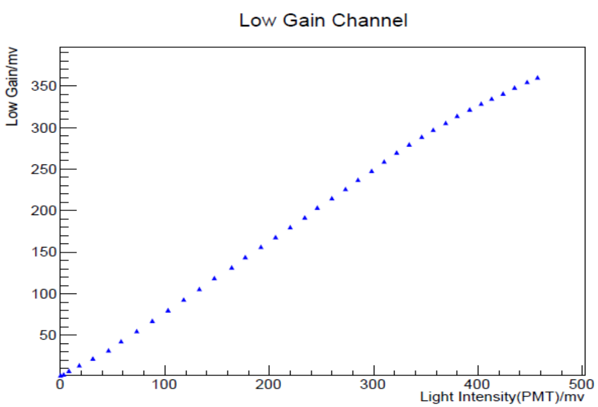
- High gain: 28.76 Code/fC, Low gain: 0.82 Code/fC
- Dynamic range：~2000 fC
- Noise
  - 0.16 fC (5*5 APD),
  - 0.38 fC (10*10 APD)



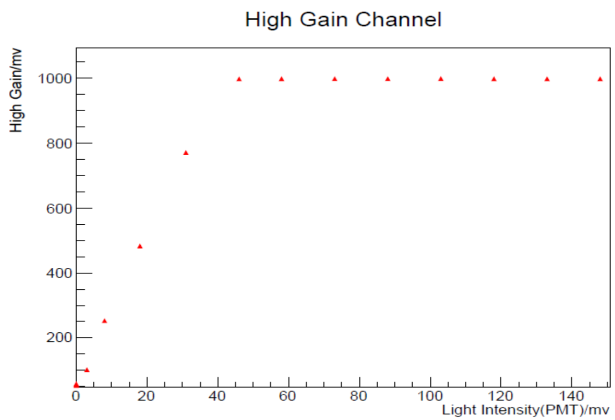
APD Response – Linearity II

- An LED test system was used to calibrate the linearity of APD
- The results show that APD can respond linearly to the upper limit of low gain electronics

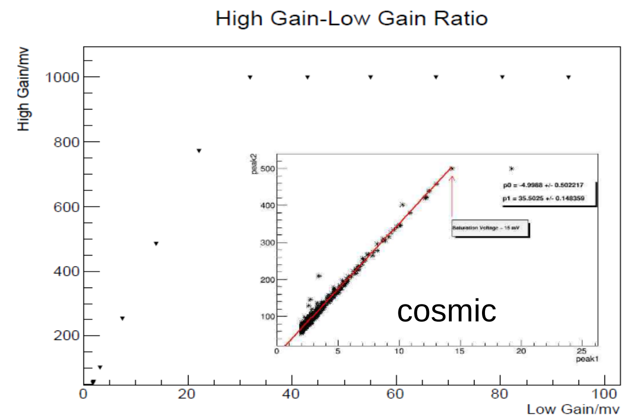




Low gain linearity



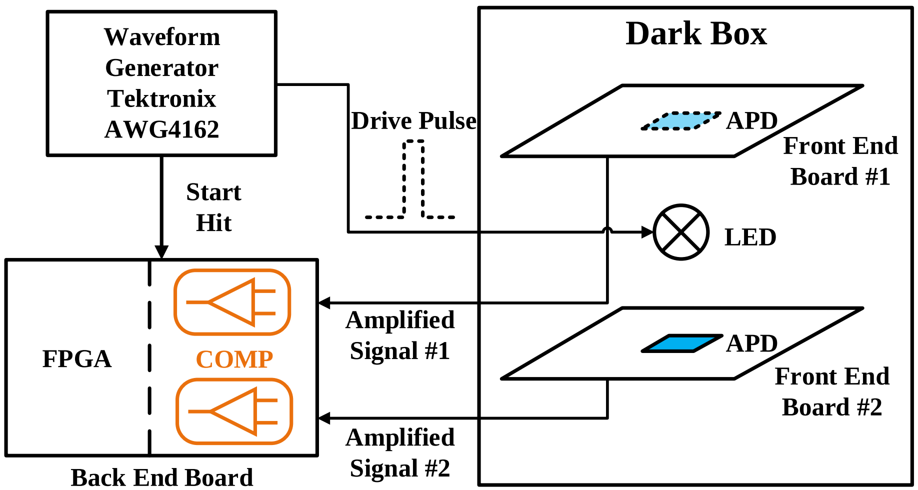
high gain linearity



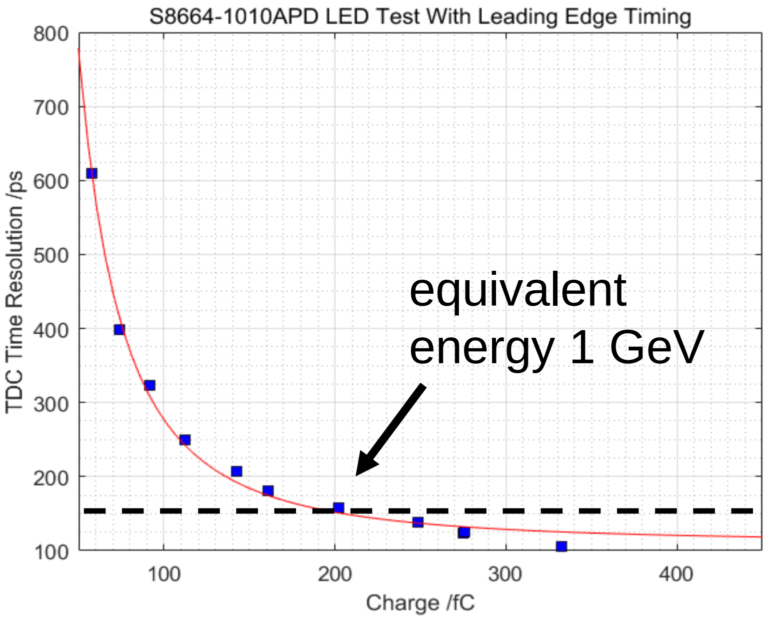
Low/High gain ratio

CSA-Time Measurement I

- Leading edge time measurement
  - An LED test system was used to test the time resolution
- APD type: 1010
- The time resolution is about 150 ps @ 1 GeV equivalent energy



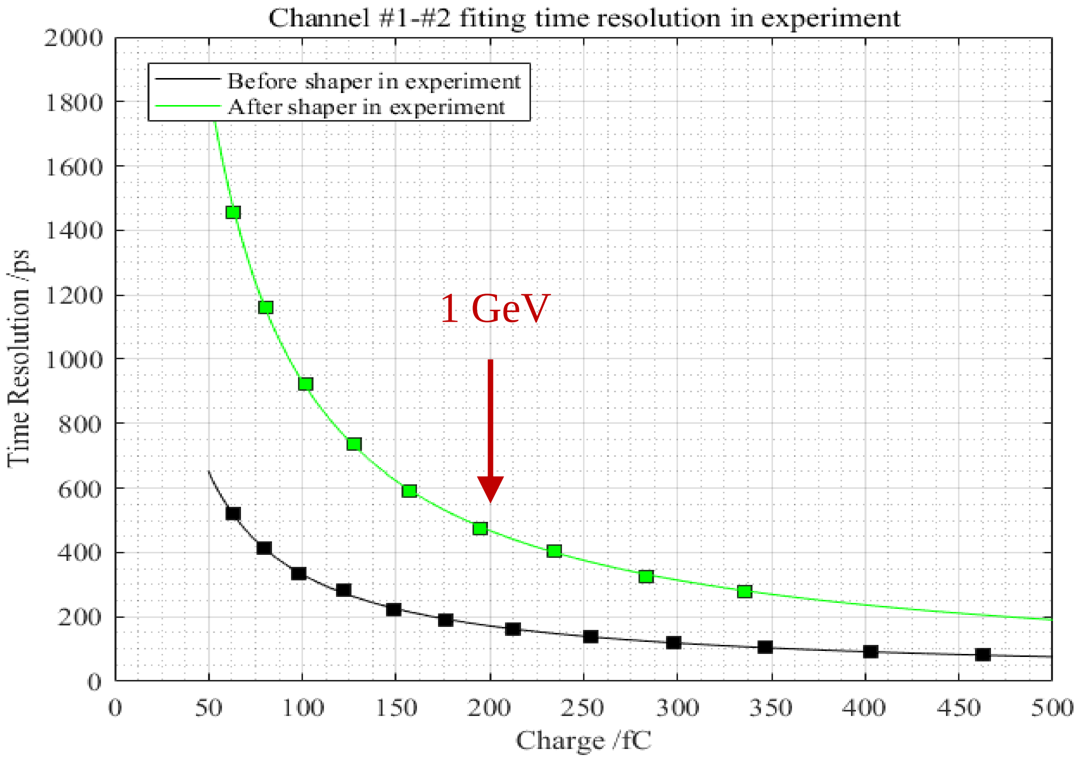
LED test system



Time resolution

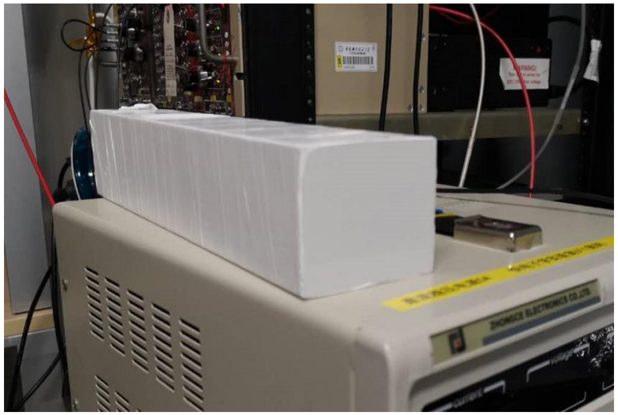
CSA-Time Measurement II

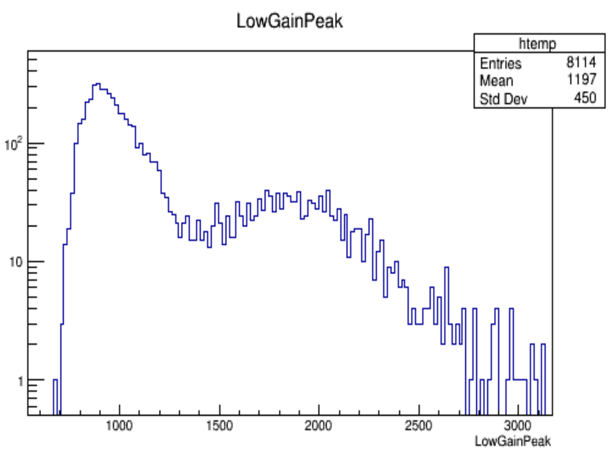
- FPGA waveform fitting method was also studied
- fit the waveforms before and after forming, and the resolutions are 171 ps and 496 ps @ 1 GeV respectively

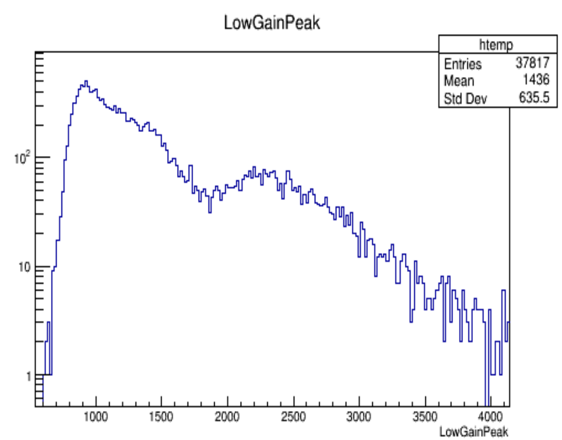


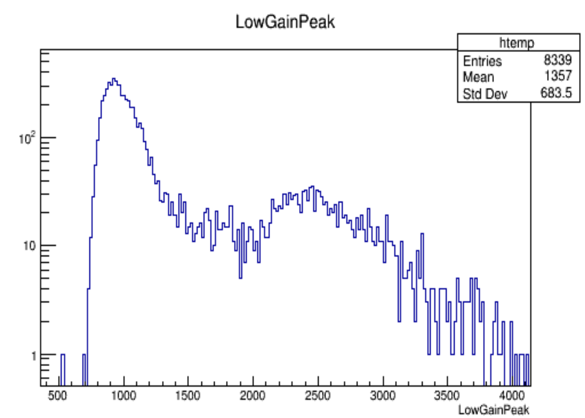
Cosmic Test I

- Silicone coupling between pCsI 4 APDs (S8664-0505)









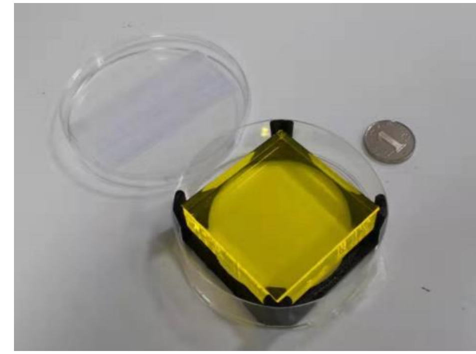
~34 p.e/MeV

~47 p.e/MeV

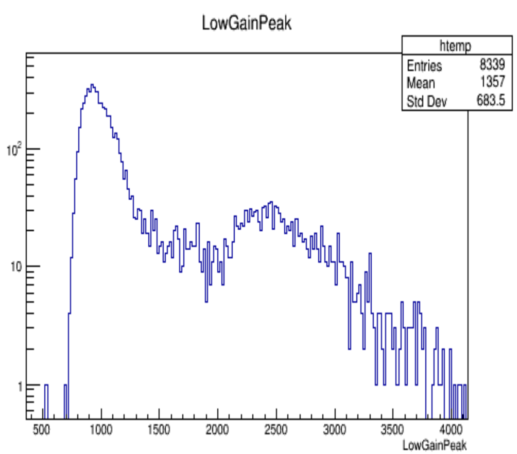
~54 p.e/MeV

Cosmic Test II

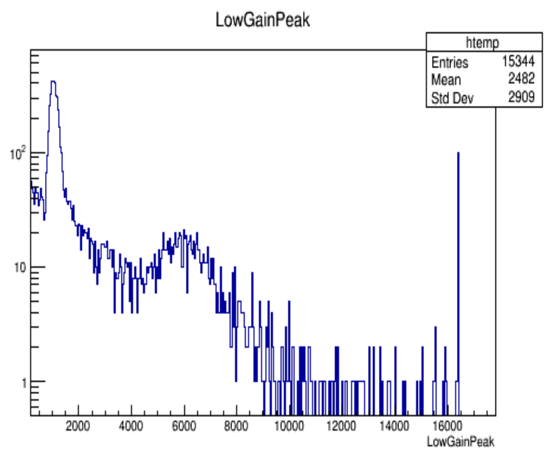
- S8664-55 vs. S8664-1010
- The light yield of 1010 APD is about 3 times as much as 0505
- With NOL-9 WLS material, the light could reach 220 pe/MeV



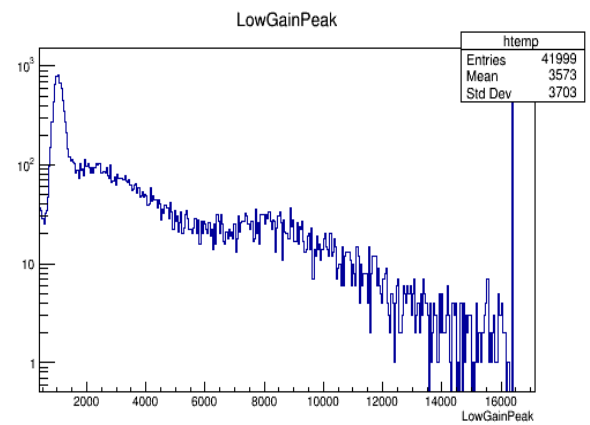
NOL-9 WLS



~54 p.e/MeV



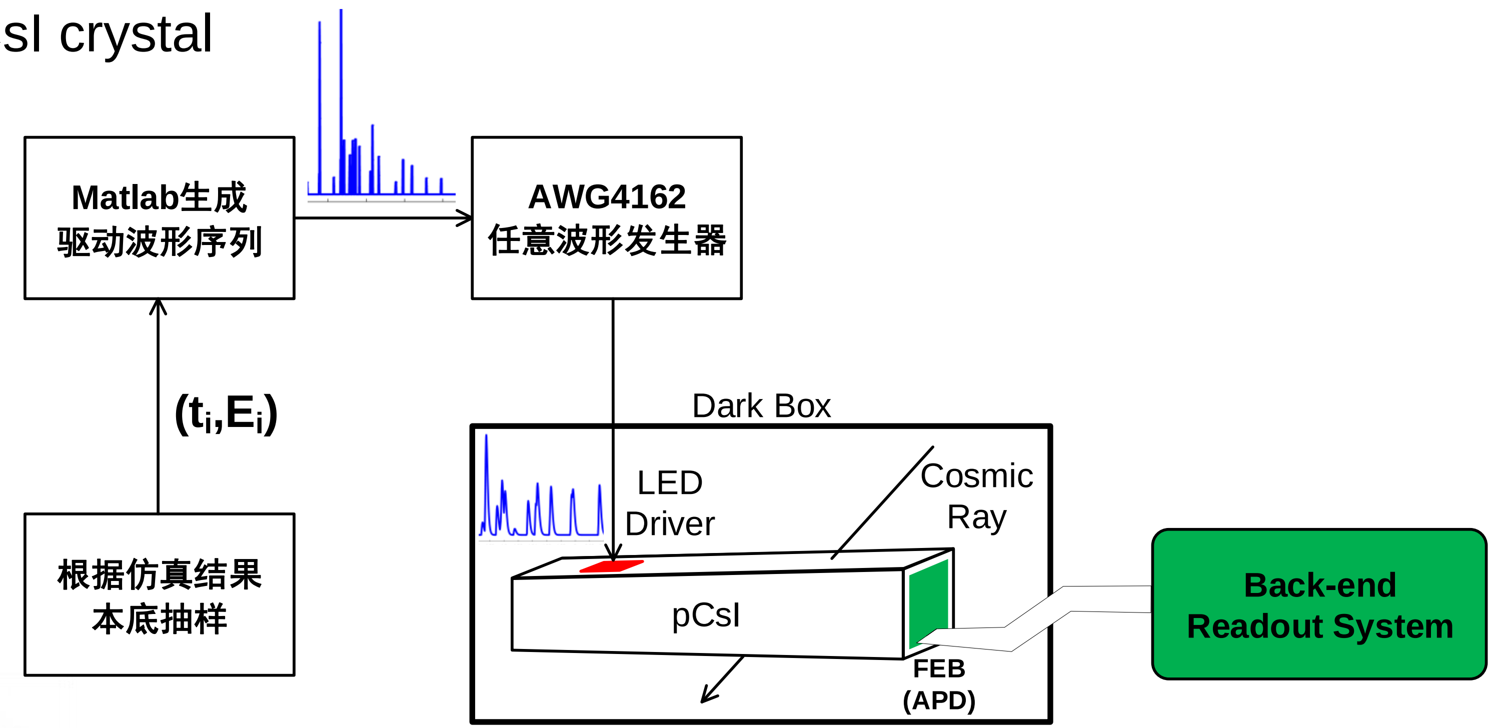
~156 p.e/MeV



~220 p.e/MeV

How to evaluate high background in laboratory

- The background particles are simulated by LED
- The background information is sampled according to the simulation
- Using MATLAB to generate the driving files
- Input to the pulse generator, and generate the driving pulse
- excite the led to emit light, which is transmitted to the APD coupled with pCsI crystal



Summary

- We illustrate the design of EMC detector for the future STCF program.
  - High luminosity, precise energy resolution, good time resolution..
- The baseline design of the EMC was done
  - pCsI + APD + CSA electronics
  - The preliminary MC results show that this design could meet STCF requirements
- Readout electronics is designed for pcsI + APD unit
  - The equivalent noise is about 1 MeV (100 pe/MeV)
  - Time resolution could reach 150 ps @ 1 GeV (without crystal)
- The cosmic results show the L.Y could reach ~ 220 pe/MeV
- The pileup study in laboratory will continue

THANKS

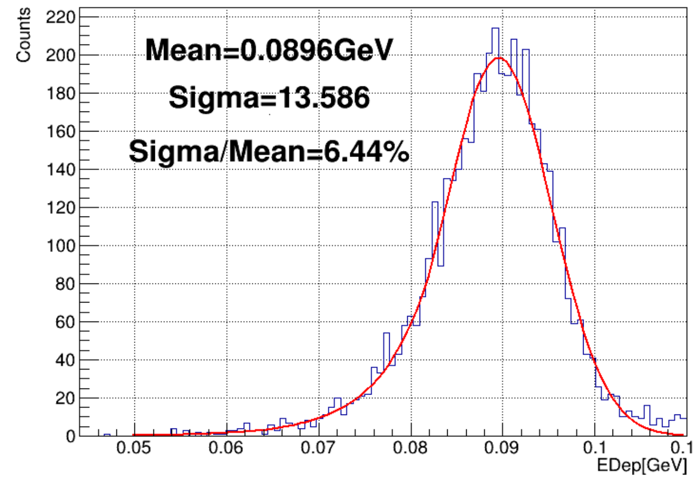
backup

- The fit minimizes the χ^2 defined as:

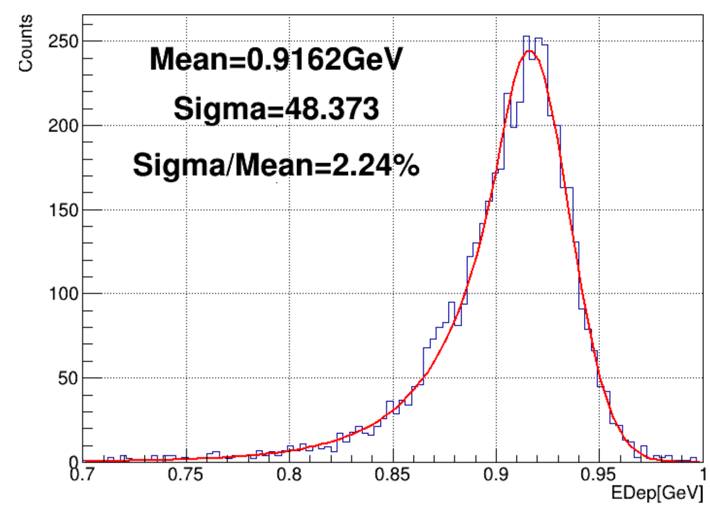
$$\chi^2 = \left(A \cdot \vec{p}(t-\tau) - \vec{S}\right)^T C^{-1} \left(A \cdot \vec{p}(t-\tau) - \vec{S}\right)$$

Where:

the vector $\vec{S}$ comprise readout samples;
the vector $\vec{p}$ are the pulse template;
the A is the pulse amplitudes;
the τ is the time offset between template and real waveform;
the **C** is the noise correlation matrix.



OnePulseFit Result **(100 MeV γ)**



OnePulseFit Result **(1 GeV γ)**

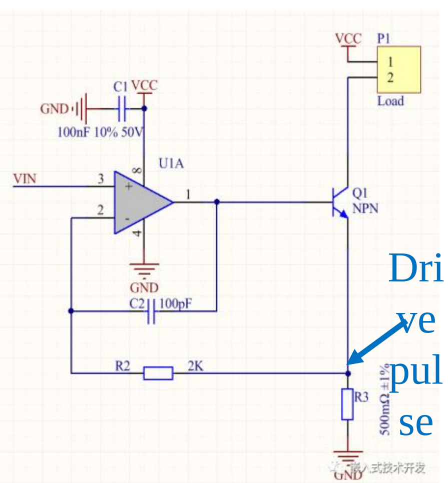
Compared with MultiFit:

- No huge computing power is required
- No accurate trigger is required
- A possible timing technical route

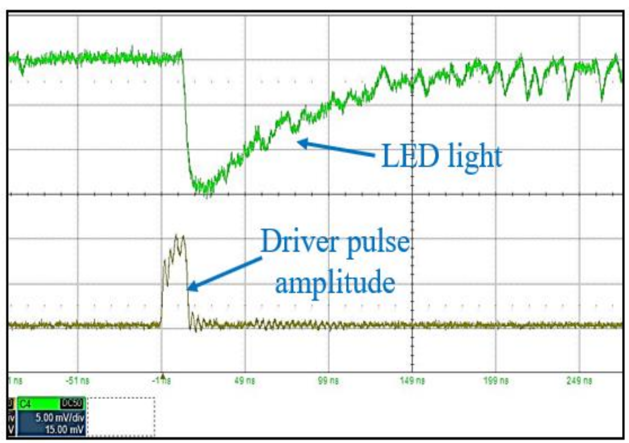
How to evaluate high background in laboratory

- The background particles are simulated by LED
- The event rate and amplitude of the background are sampled by the distribution obtained by simulation
- LED driver
  - The LED light waveform is controlled consistent with pCsI crystal

LED driver



LED light



LED light intensity