Test Results of HERD CALO prototype 2017

QUAN Zheng

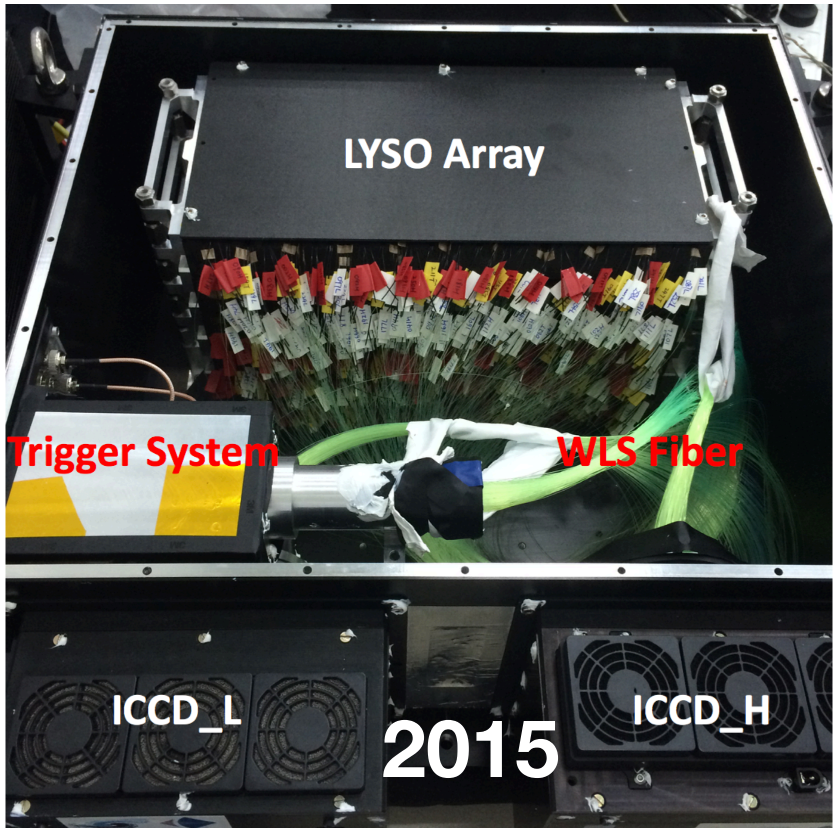
6th HERD Workshop
27 March, Beijing

中國科學院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

Outline

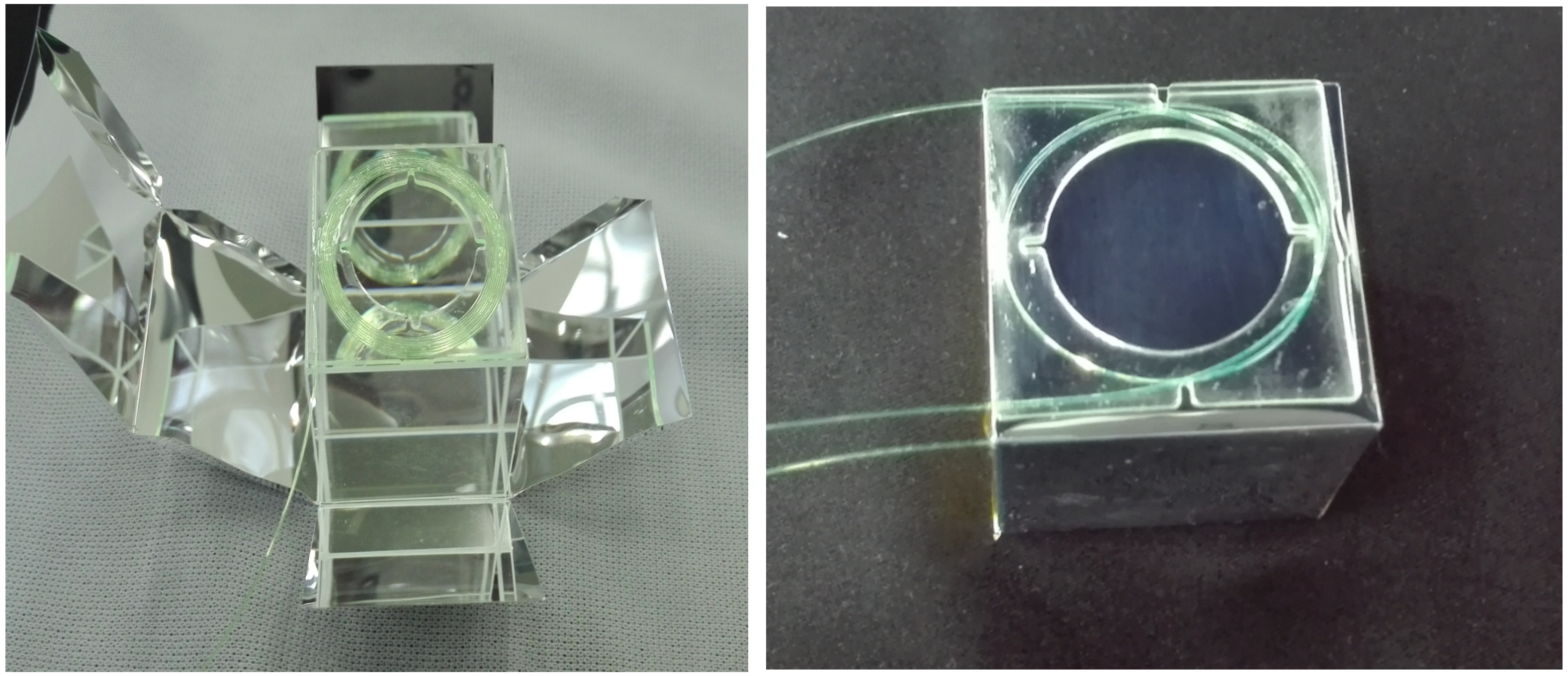
- Overview of HERD CALO prototype
- Results of beam test at CERN
- Troubleshooting
- Summary

HERD CALO prototype: 2015 vs 2017

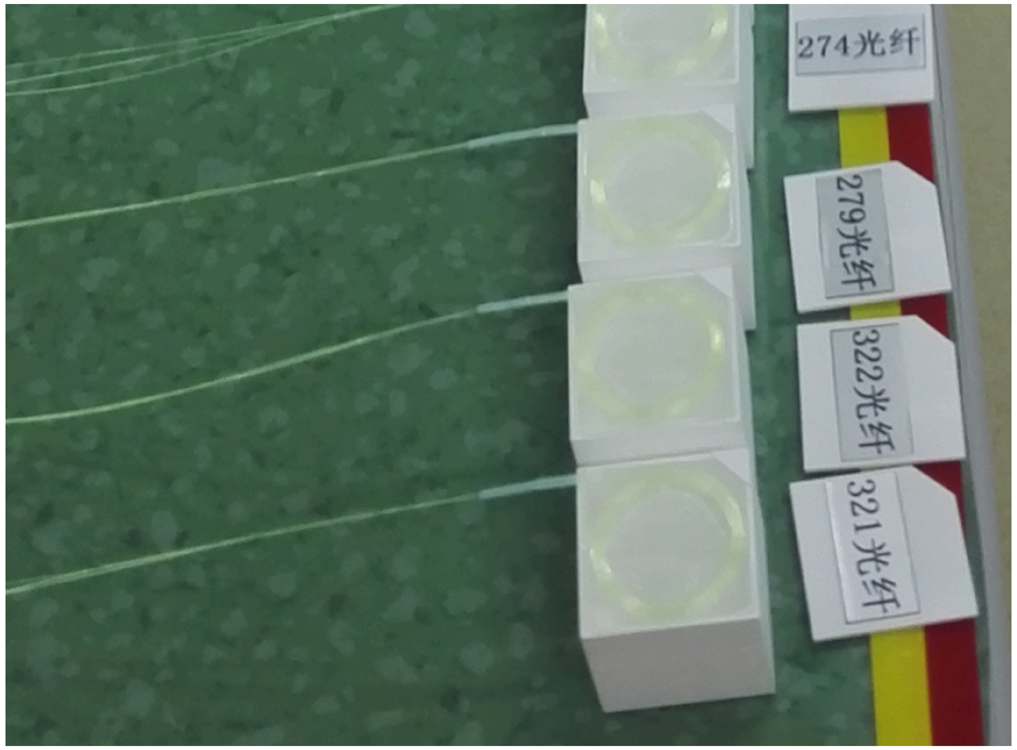


HERD CALO prototype		
	2015	2017
Scale	$5\times5\times10$, $26X_0$, $1.5\lambda_I$	
Readout	ICCD×2	ICCD_H is replaced by IsCMOS
Temperature Control	Fan	TEC+Fan
Crystal reflector	ESR	TiO_2
WLS Fibers	Spiral×2, Fiber×3	Spiral×1, Fiber×3
Fiber polishing	No	Yes
Energy Range Control	Reduce light output of fibers	Adjust I.I. gain of cameras
Reference LED	LED×2	0
Gating delay of I.I.	210 μs	7 μs

CALO Cell Design



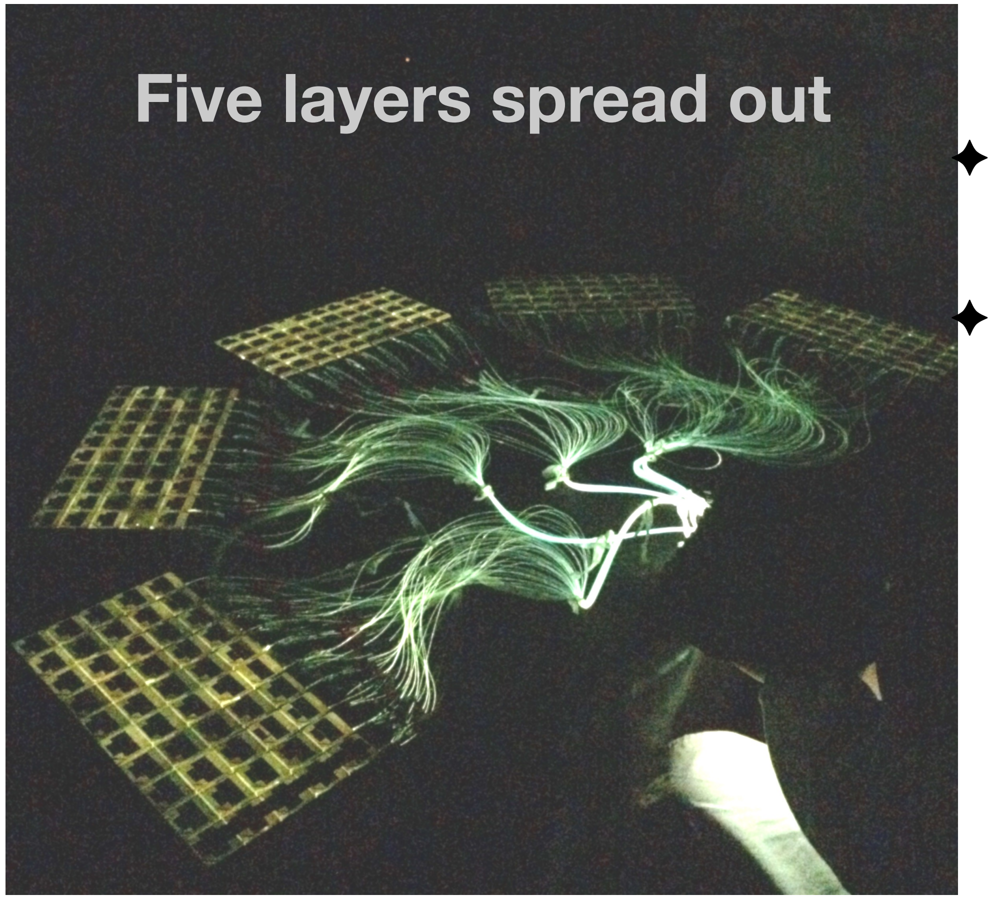
Prototype 2015:
- ESR coat;
- 1 fiber spiral for low energy range, 1 for high energy range and trigger system;
- Light output: H/L~1/40;



Prototype 2017:
- TiO_2 coat;
- 1 fiber spiral for low energy range, high energy range and trigger system;
- Light output: H/L~1;

Photon counting fluctuation is effectively reduced by improving CALO cell design.

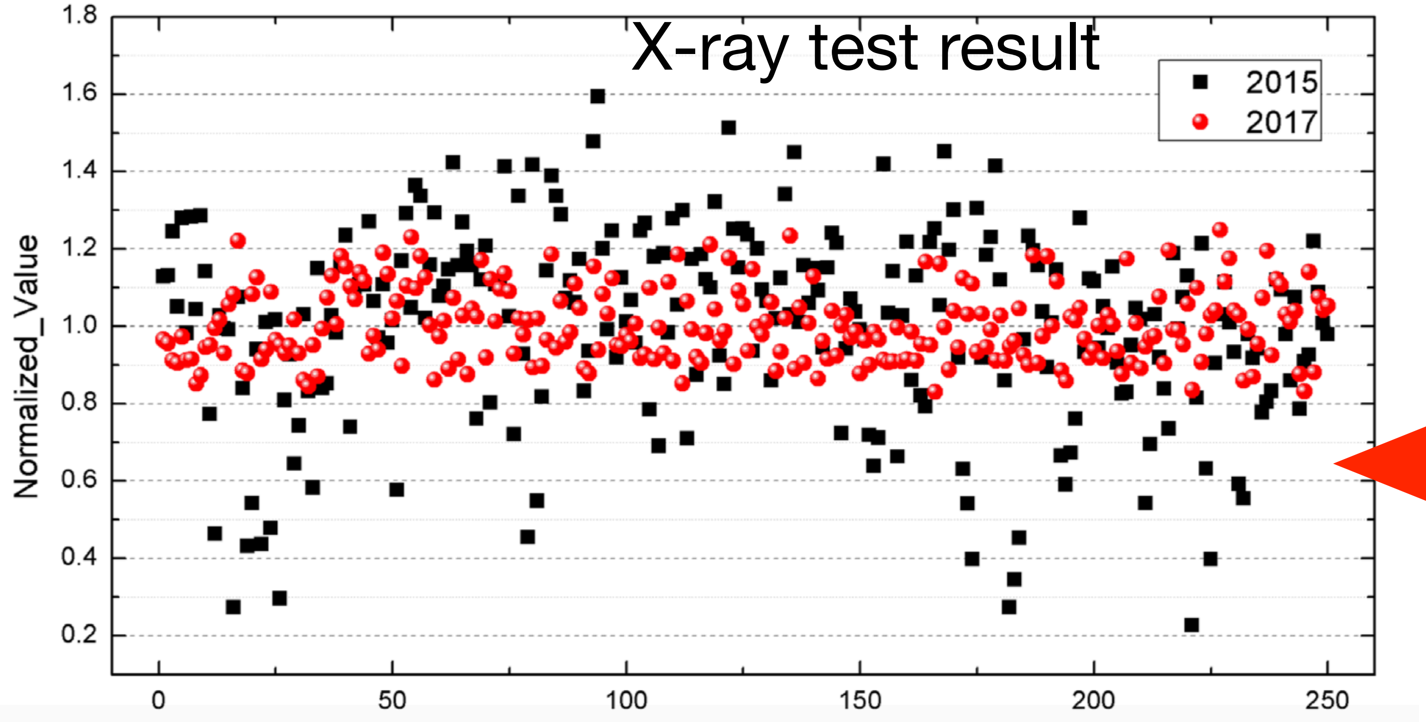
Crystal Array



Structure:

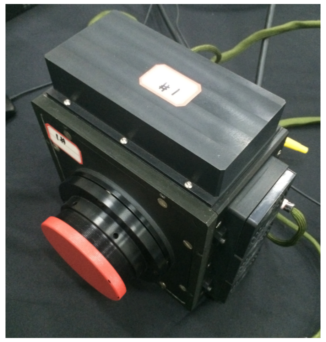
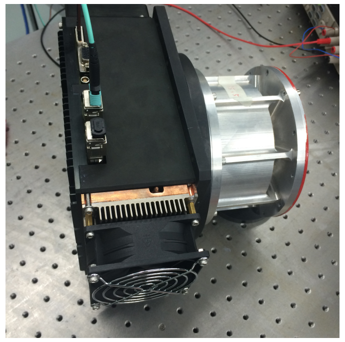
- ✦ Carbon fiber thickness: 1mm,
- ✦ Gaps: 5mm(X, vertical), 2mm(Y, horizontal), 3mm(Z, along the beam)

Fiber plate: make polishing after fiber installation

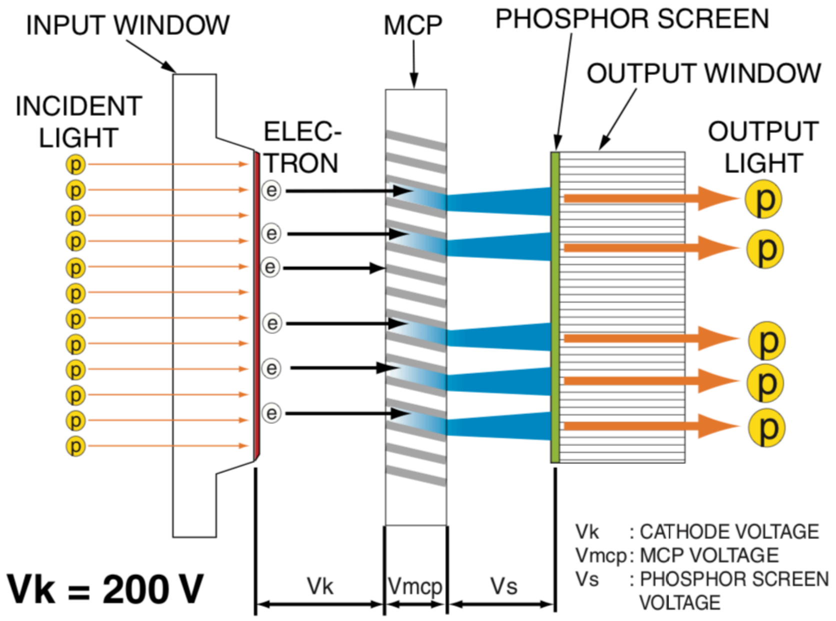

X-ray test result

Uniformity improved.

ICCD vs IsCMOS

	ICCD	IsCMOS
Picture		
Window Size	ϕ25 mm	ϕ40 mm
Phosphor screen	P20	
Phosphor Decay time	1 ms (to 1% of the maximum)	
Pixel size	$18\mu m \times 18\mu m$	$5.5\mu m \times 5.5\mu m$
Pixel number	300×400	2240×620
Maximum frame rate	300 fps	250 fps
MCP	Double-stage	Single-stage
Maximum gain	10^6	2×10^4
Demagnification ratio	3.3:1	3:1
Data size of on frame	0.23 MByte	2.7 MByte
Required data transfer rate	~70 MByte/s	~1 GByte/s
Electronic shutter	No	Yes

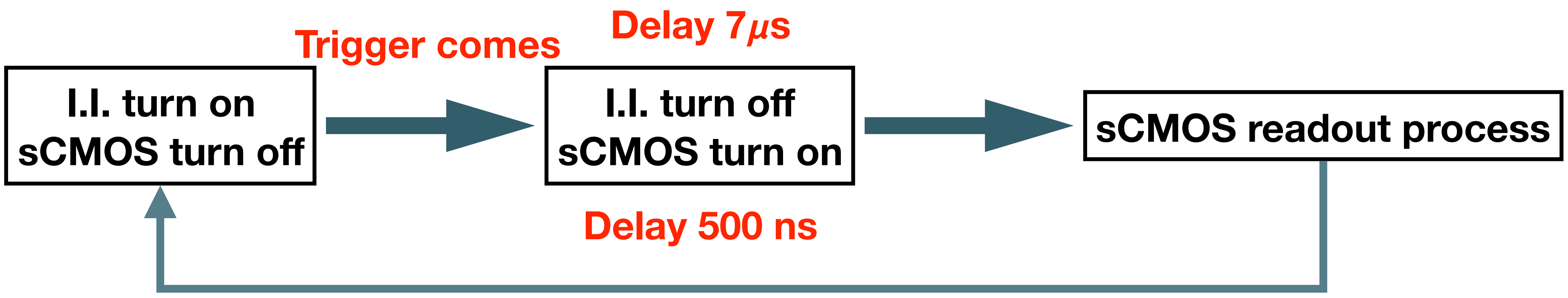
Working logic of ICCD and IsCMOS



By Hamamatsu

Image intensifier working sequence:
Input window converts photons into electrons
-> Accelerate electrons through electric field
-> Secondary cascades occur in MCP
-> Accelerate secondary electrons to hit a phosphor screen
-> Phosphor screen converts electrons to photons

ICCD and IsCMOS working sequence:



Trigger comes

Delay 7μs

I.I. turn on
sCMOS turn off

I.I. turn off
sCMOS turn on

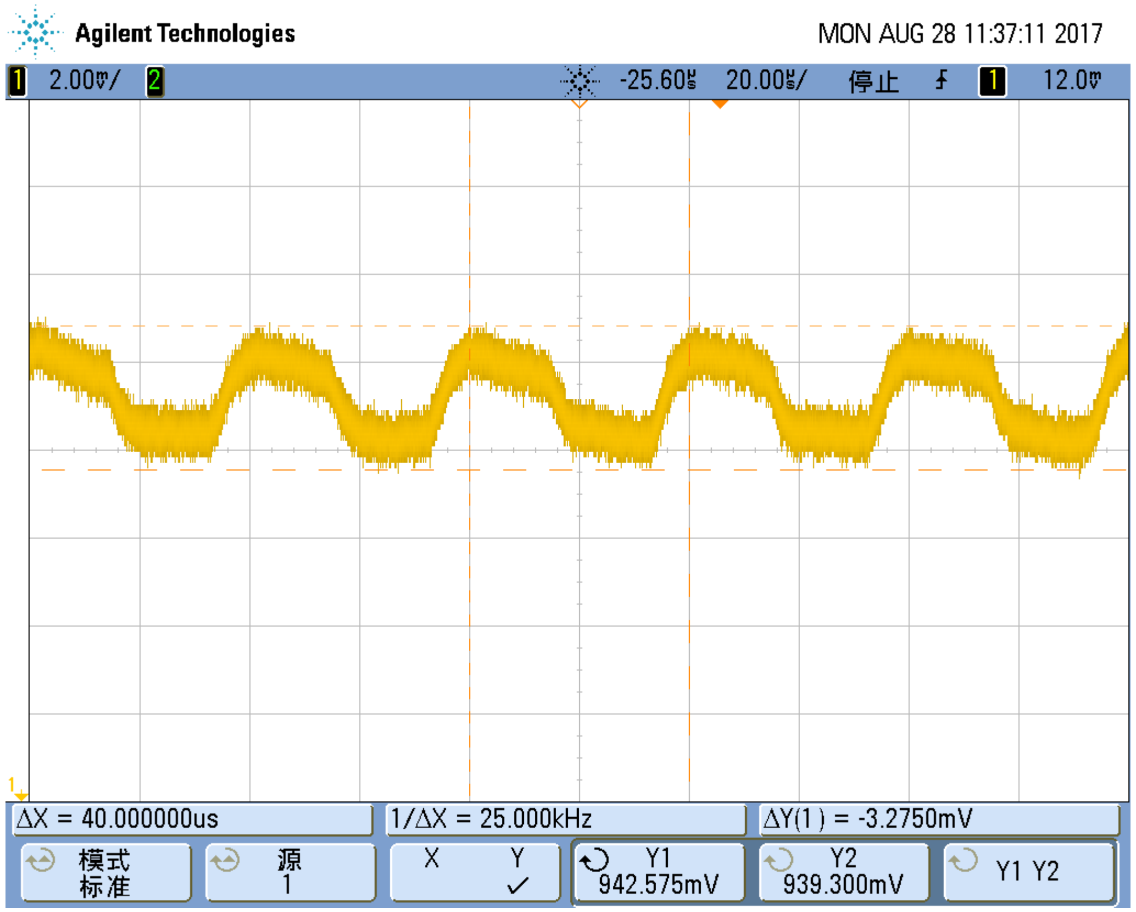
sCMOS readout process

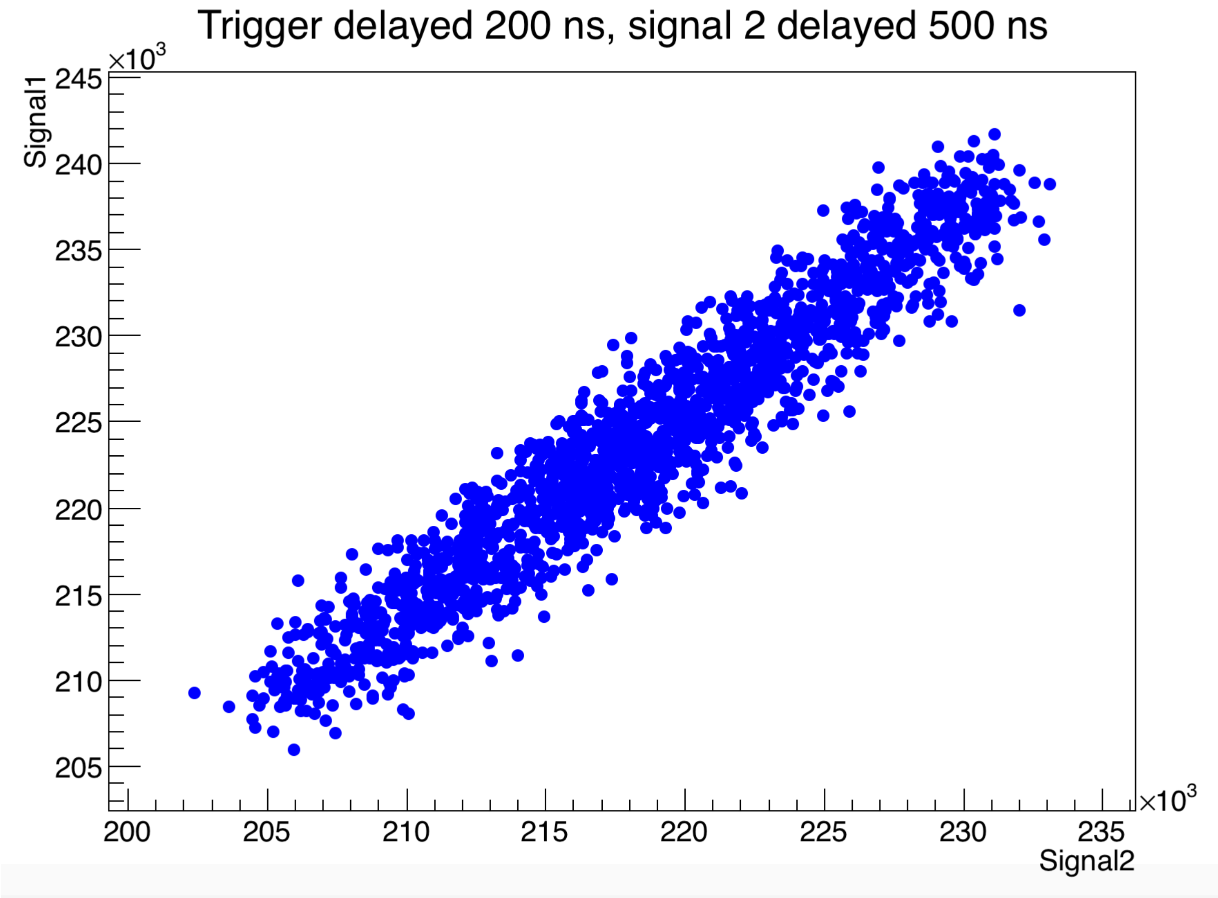
Delay 500 ns

Dead time = 3.2 ms

CCD does not have a electronic shutter, it’s never turned off but continuously doing charge transfer operation with a fixed period of 1.28μs. CCD will run at full speed at its “spare” time. That means a considerable power consumption and heat generation.

Common noise correction





✦Periodic fluctuation of MCP's high voltage is observed using an oscilloscope;

✦The period is about 40 us, while the reference LEDs delay about 200 ns, so the correction is feasible;

✦Strong linear relationship between two signals detected by ICCD or IsCMOS at the same time is observed, the common noise can be easily corrected by the equation:

$$L_{cor} = L_{ori} \cdot \frac{L_{ref}(mean)}{L_{ref}}$$

Energy reconstruction from ICCD and IsCMOS images

1. Merge pixels： calculate output (in grayscale) of all faculae on the image;

2. Correct crosstalk: calculate a crosstalk matrix for each event；

3. Calibrate ICCD for low energy range by using MIP events;

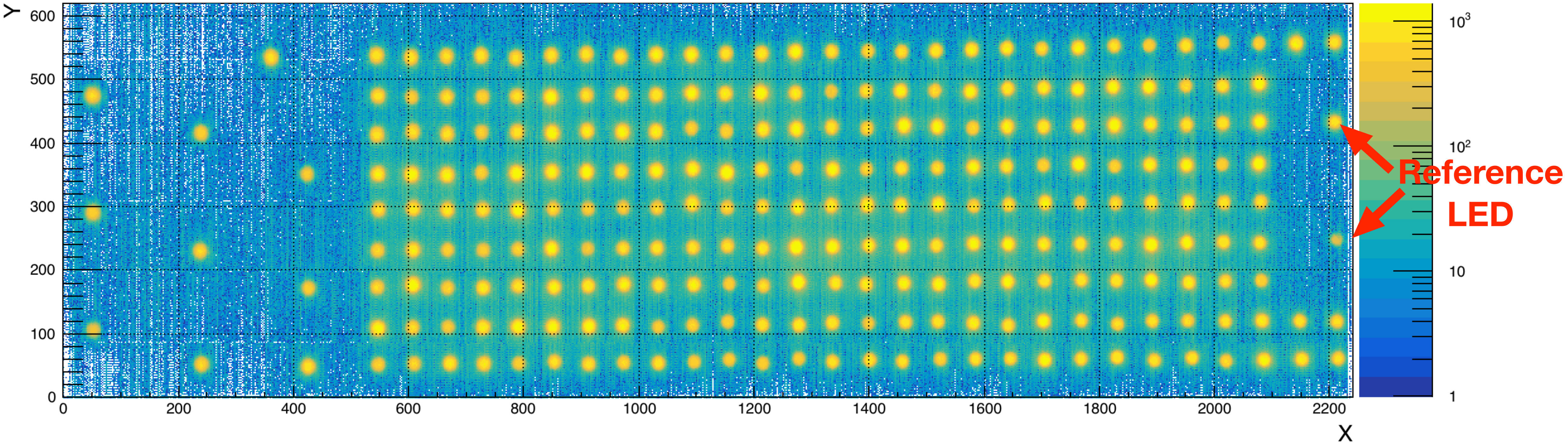
4. Calibrate IsCMOS for high energy range by using the overlap between the two ranges;

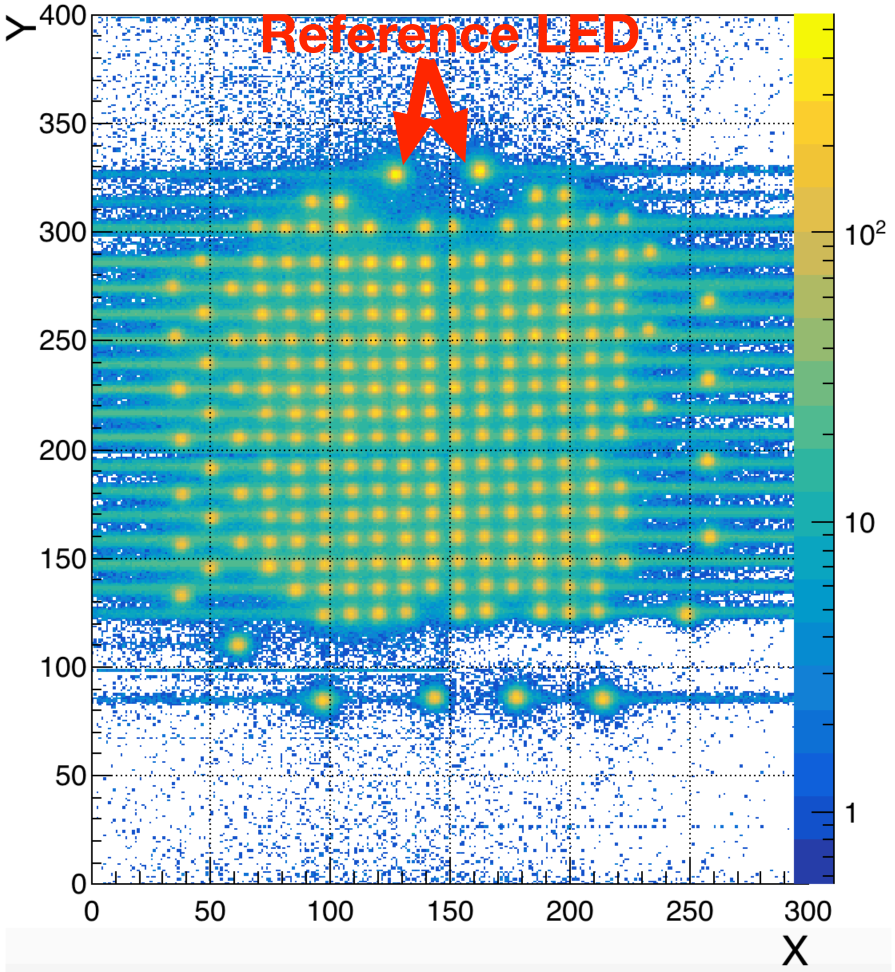
5. Correct saturation effect;

6. Remove pile-up events: using trigger system data;

7. Correct common noise: using reference LEDs.

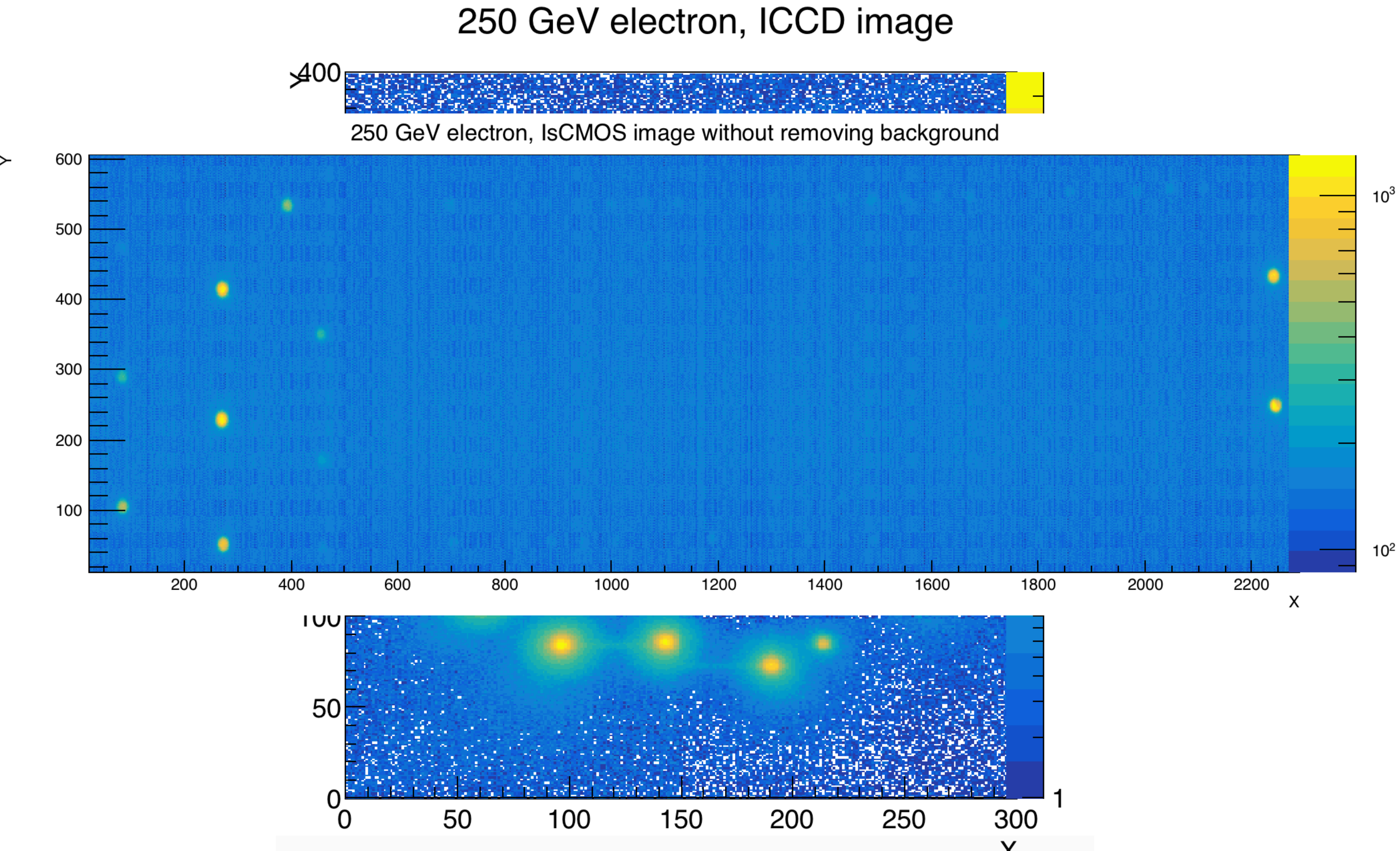
Images of ICCD and IsCMOS



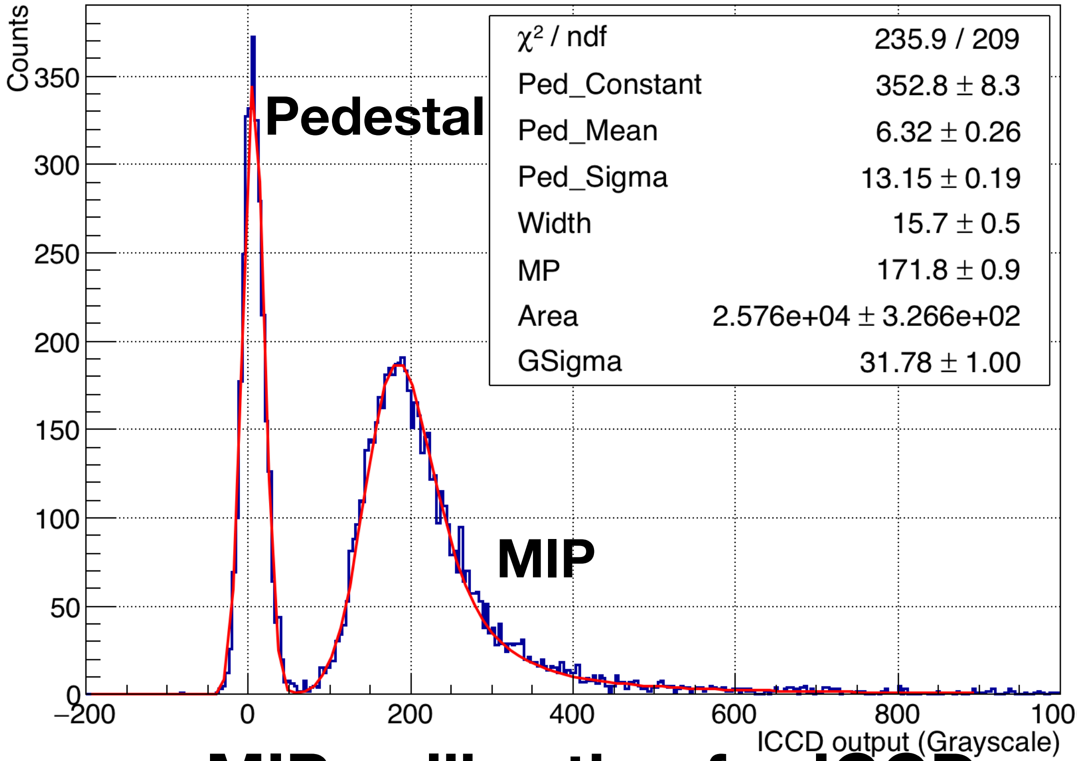


- 252 faculae on each frame;
- Center distance of two neighboring fibers: 1mm;
- One frame of ICCD:
  300×400 pixels, 1mm = 12 pixels on the input window;
- One frame of IsCMOS:
  2304×620 pixels, 1mm= 60 pixels on the input window.

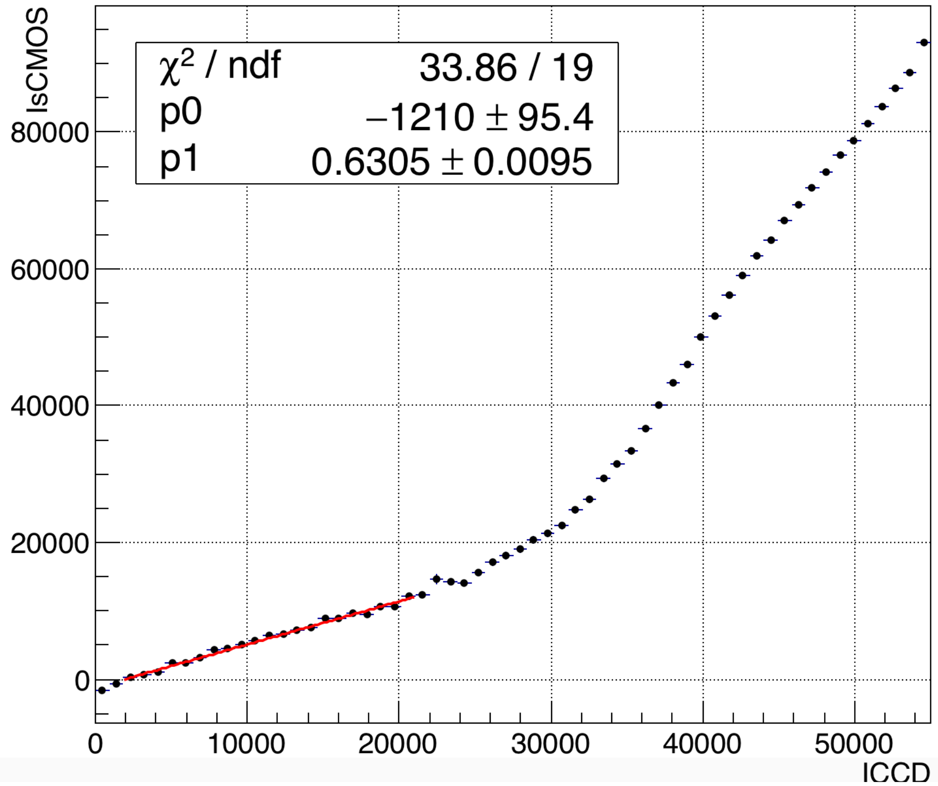
250 GeV electrons



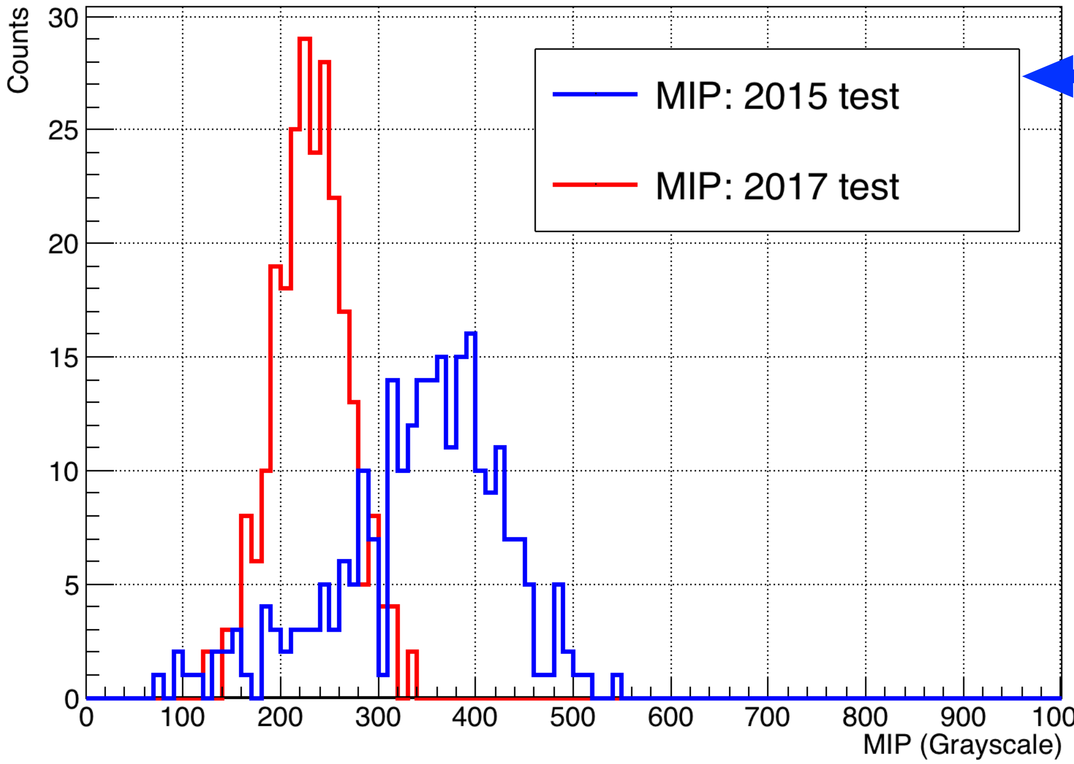
Calibration



MIP calibration for ICCD



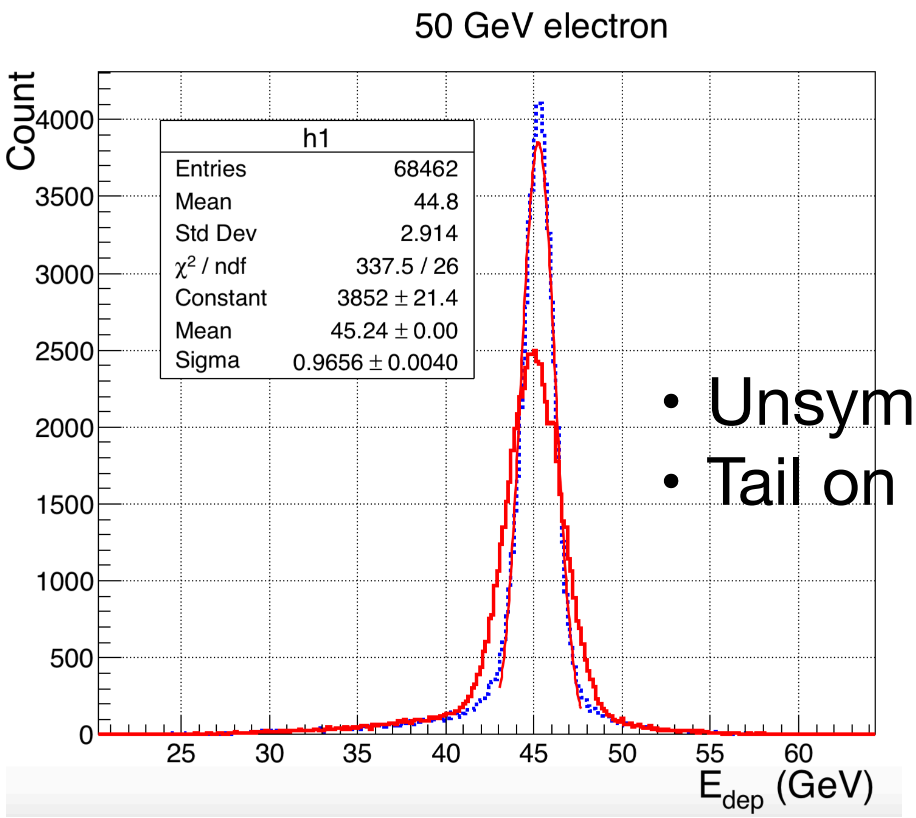
Cross-calibration for IsCMOS

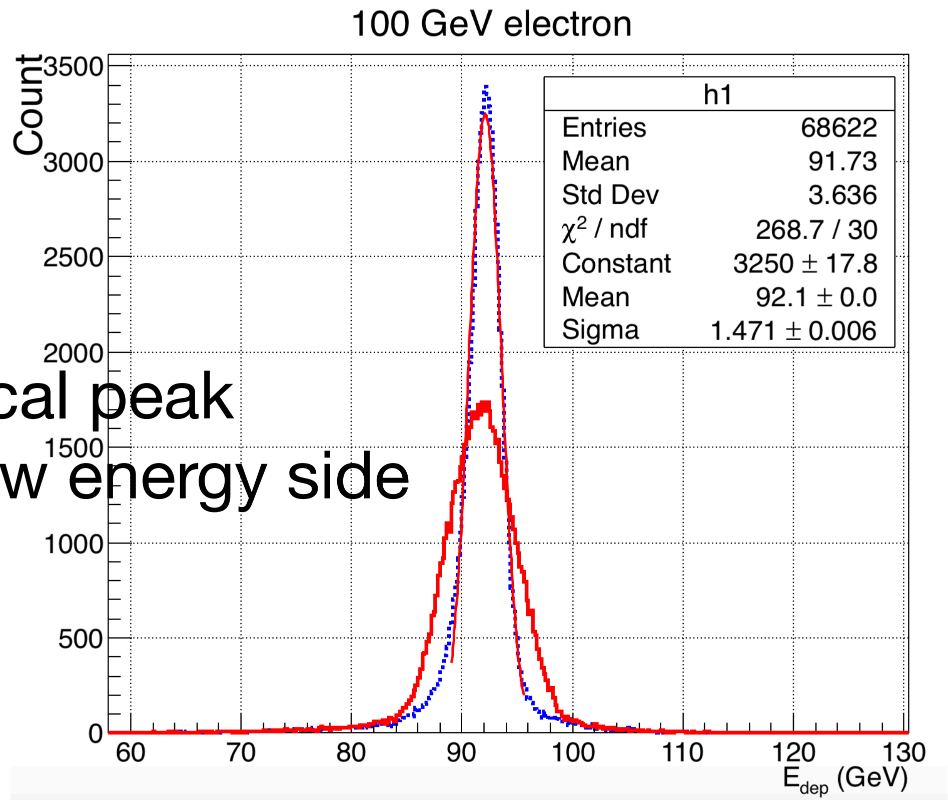


MIP distribution, 2015 VS 2017:

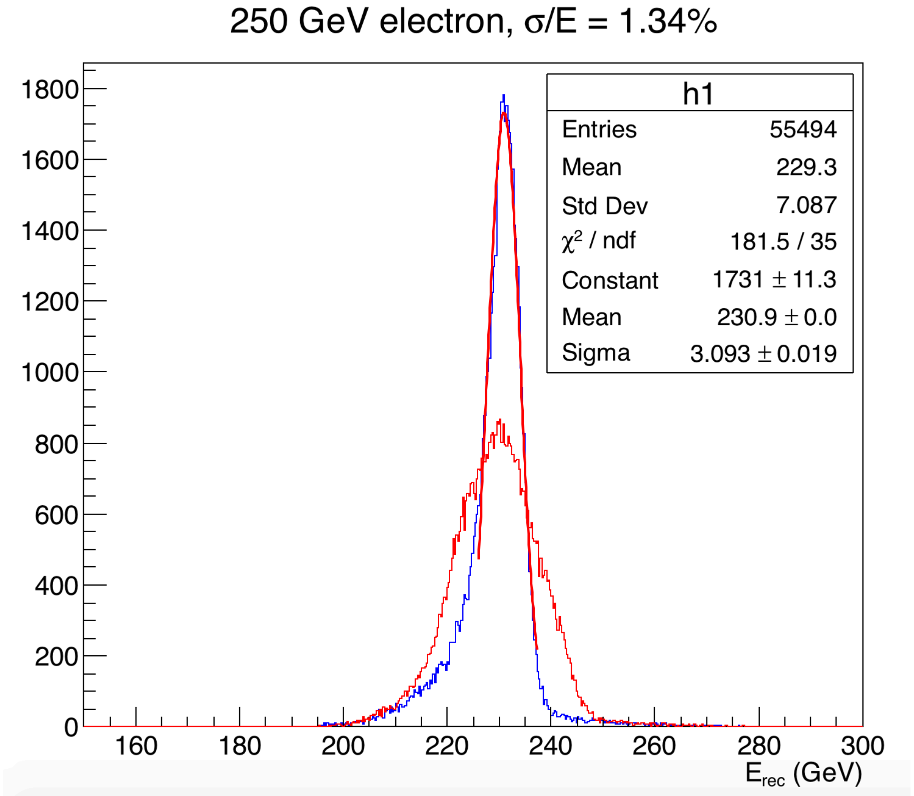
- The uniformity is significantly improved due to the strict selection criteria of fiber spirals and fine polishing;
- MIP signals decrease(~200 P.E. for 2015, ~100 P.E. for 2017) due to the change of reflector and decrease of photon collecting area.

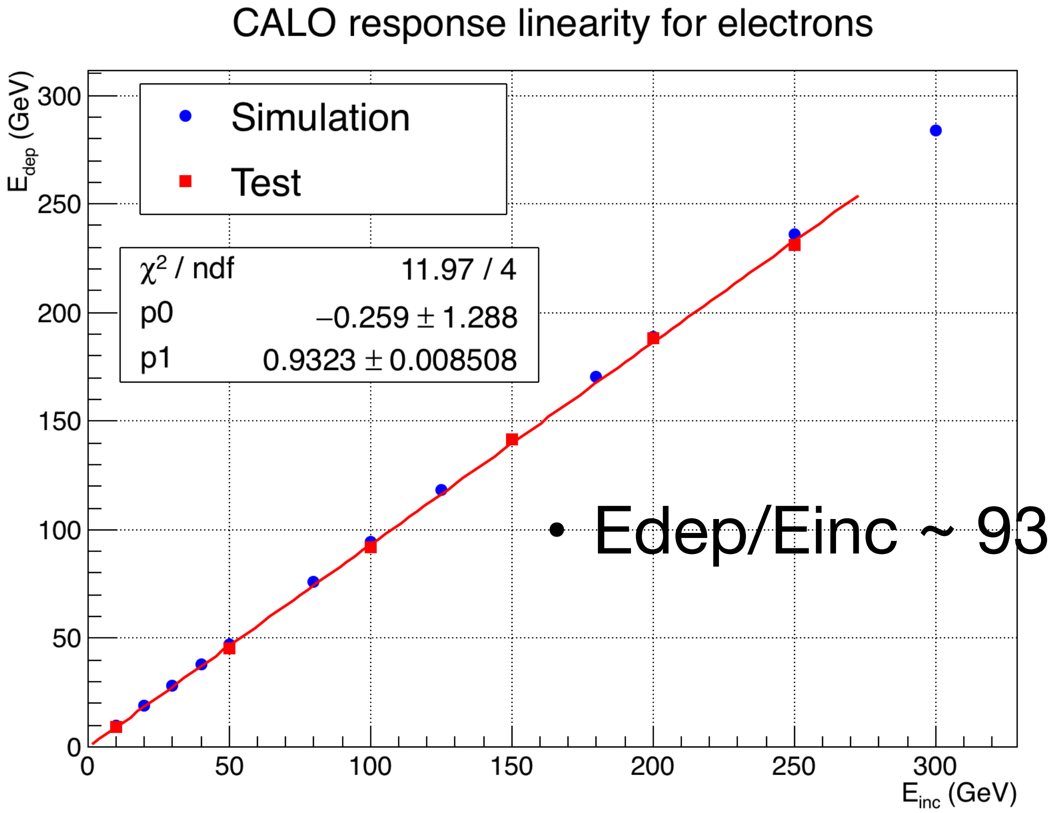
Energy spectrum of electrons





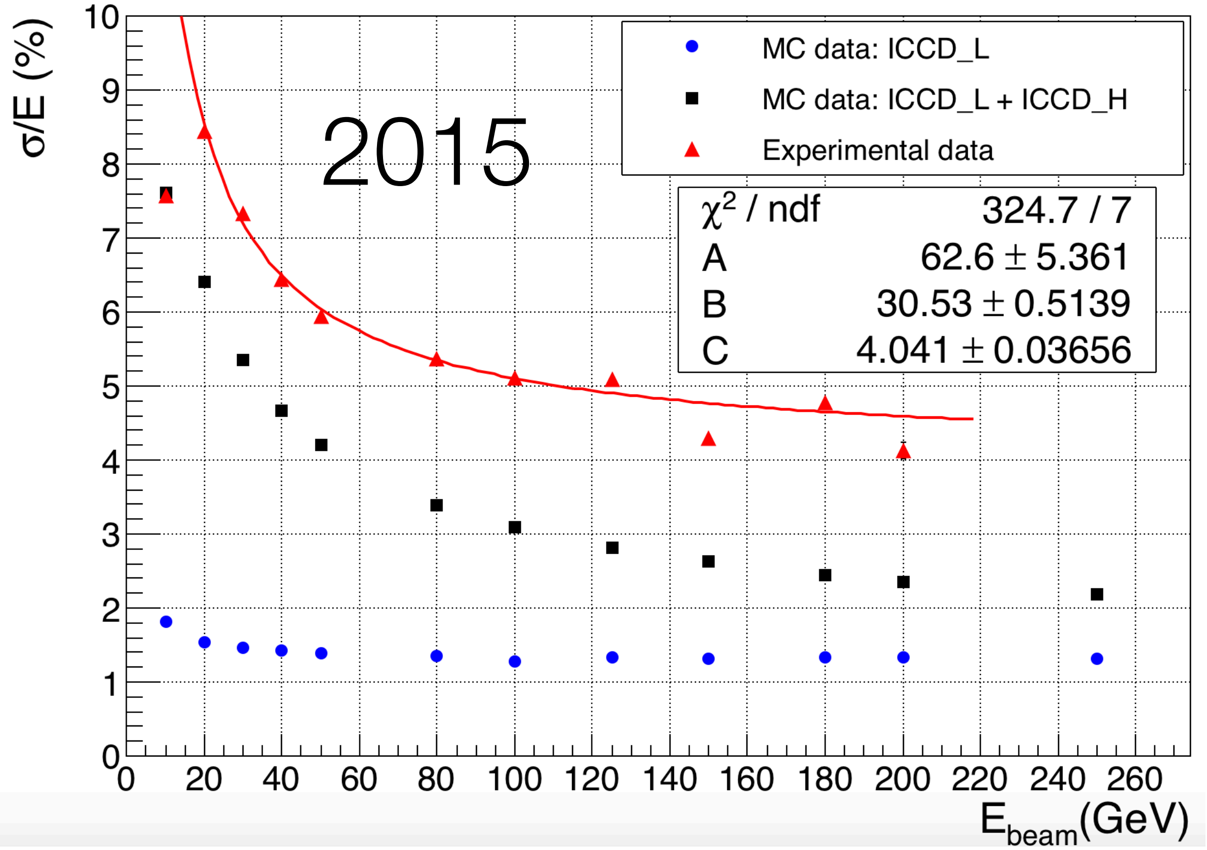
- Unsymmetrical peak
- Tail on the low energy side

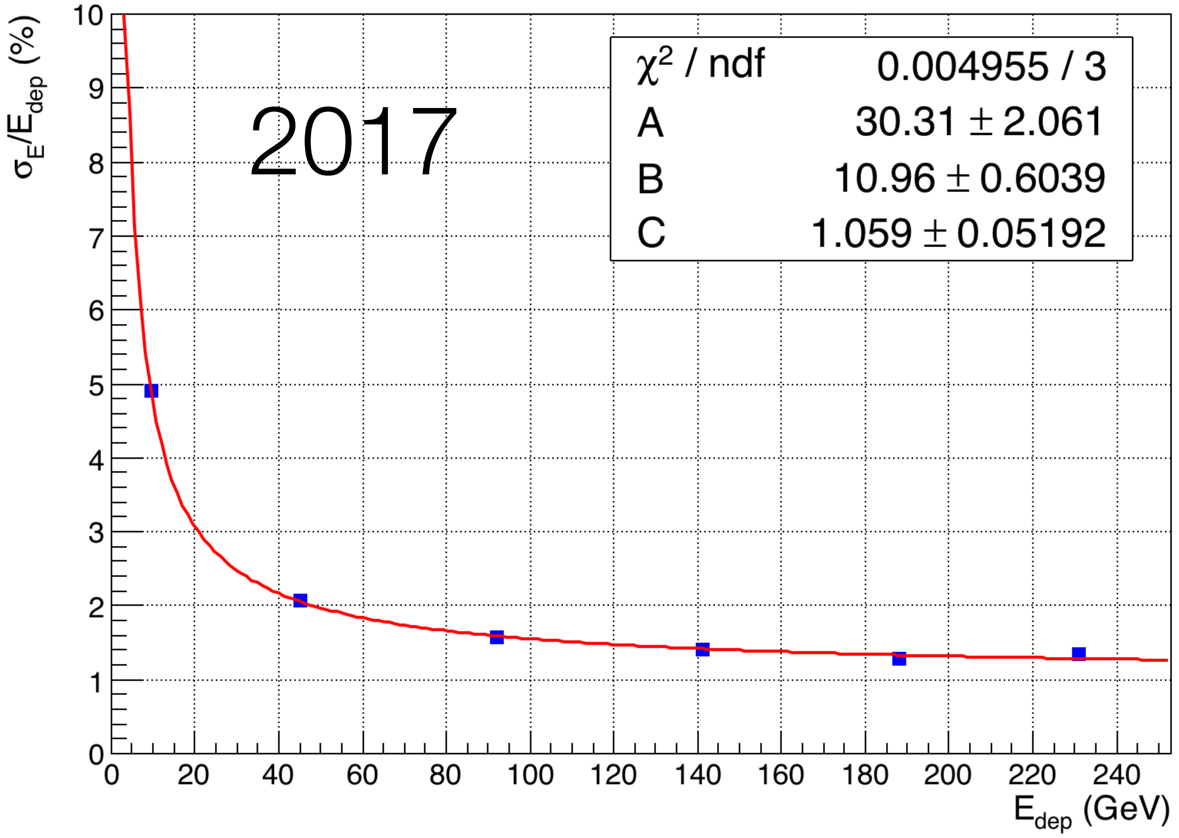




- Edep/Einc ~ 93%

Energy resolution for electrons

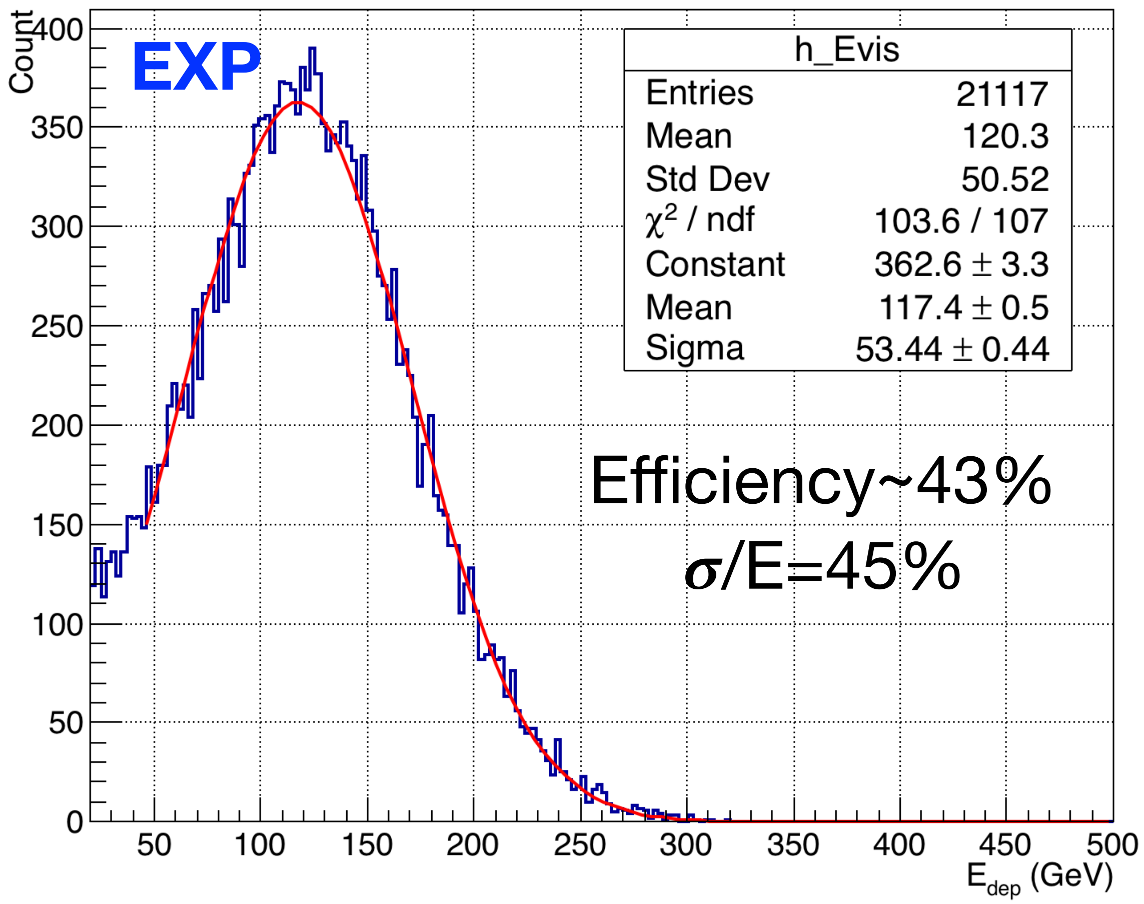




Electron energy resolution:

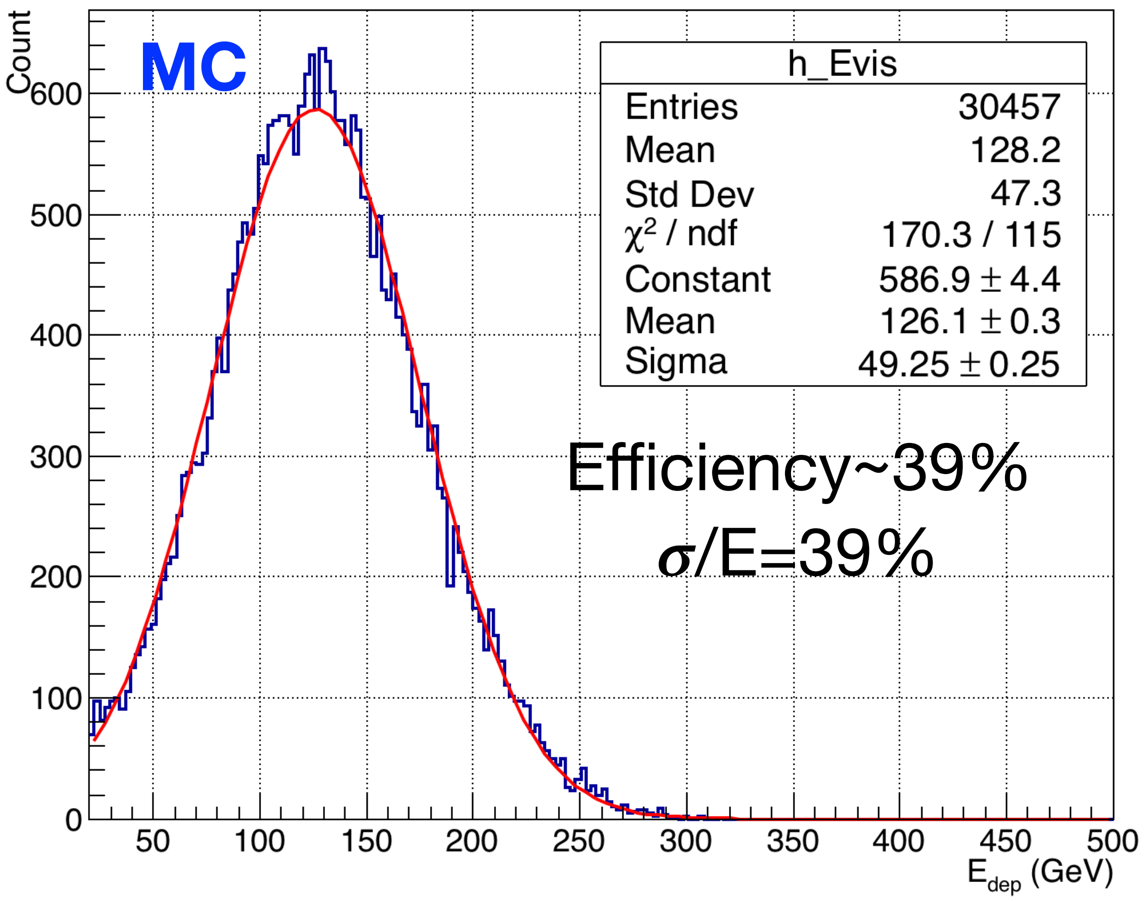
- 4.2%@200GeV for prototype 2015;
- 1.3%@200GeV for prototype 2017;
- Constant term is suppressed to nearly 1%, thanks to common noise correction.

Energy resolution for protons


350 GeV proton

Efficiency~43%

σ/E=45%


350 GeV Proton

Efficiency~39%

σ/E=39%

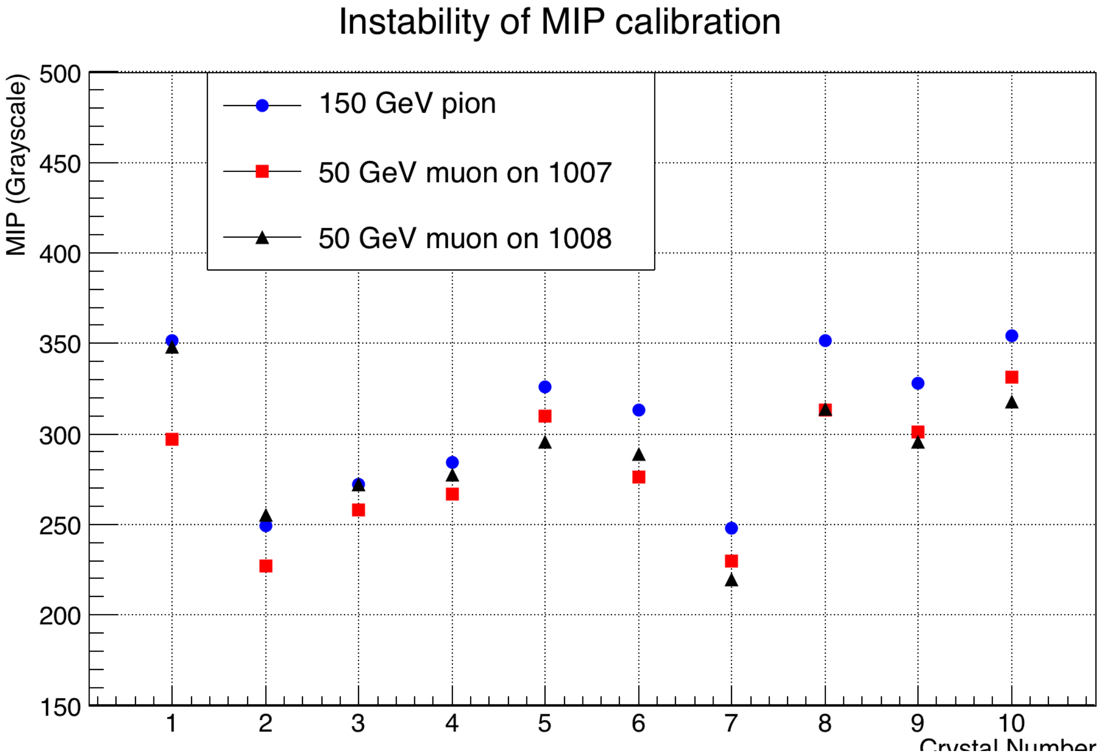
Selection:

1. the layer number of shower maximum $\in$ (2, 6);
2. E_{dep} of the whole CALO > 1 GeV.

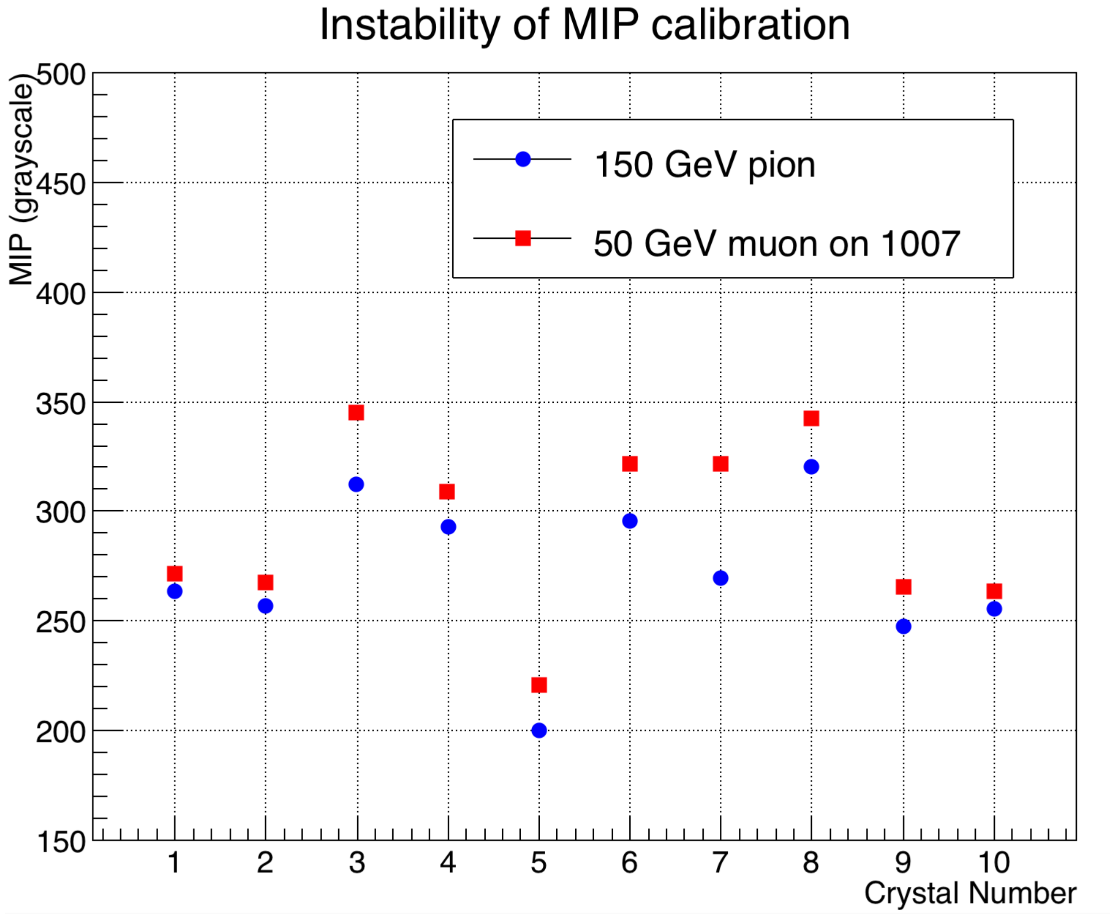
Test results: 2015 VS 2017

HERD CALO prototype		
	2015	**2017**
Energy resolution for electrons	4.1%@200GeV	1.3@200GeV
Energy resolution for protons	50%@350GeV	45%@350GeV
Angular resolution for electrons	1.2 deg @100 GeV	1.2 deg @100 GeV
e/p separation at $E_{dep} \in$ (85GeV, 110GeV)	0.999@90% signal efficiency	0.999@90% signal efficiency

Problems to solve: MIP instability

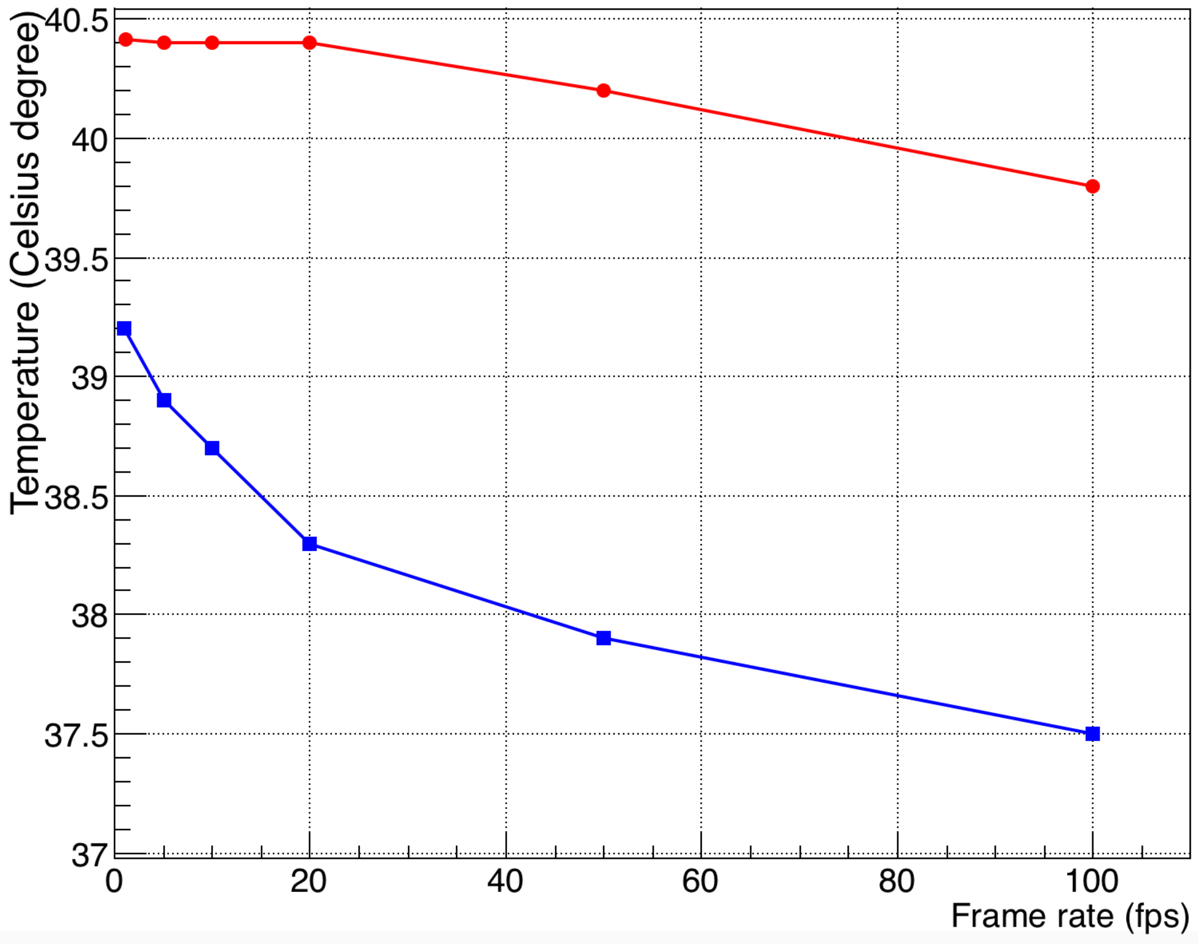


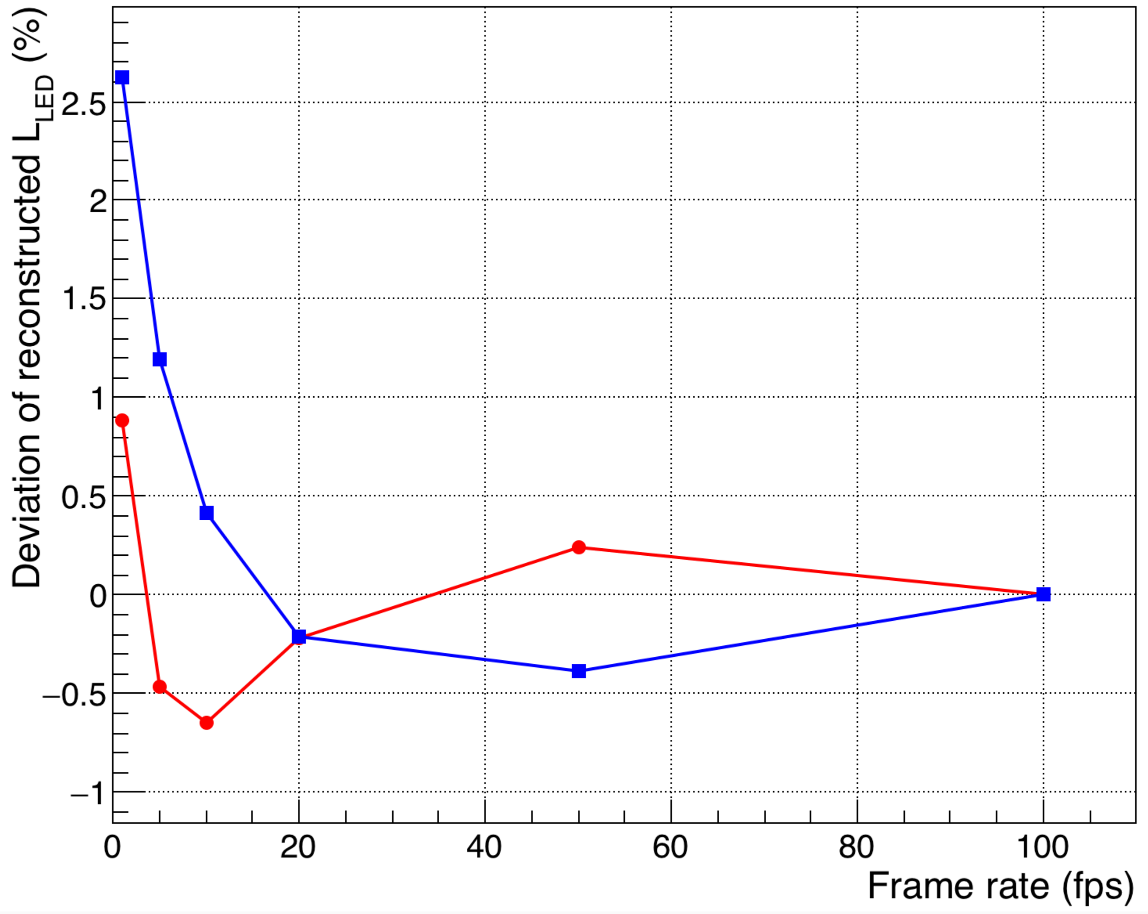
Crystal position: central line (C2X);
Deviations: up to 15%;
Env. temperature: from 35°C to 38°C



Crystal position: edge (A0X)
Deviations: up to 19%
Env. temperature: from 36°C to 38°C

Stability of ICCD





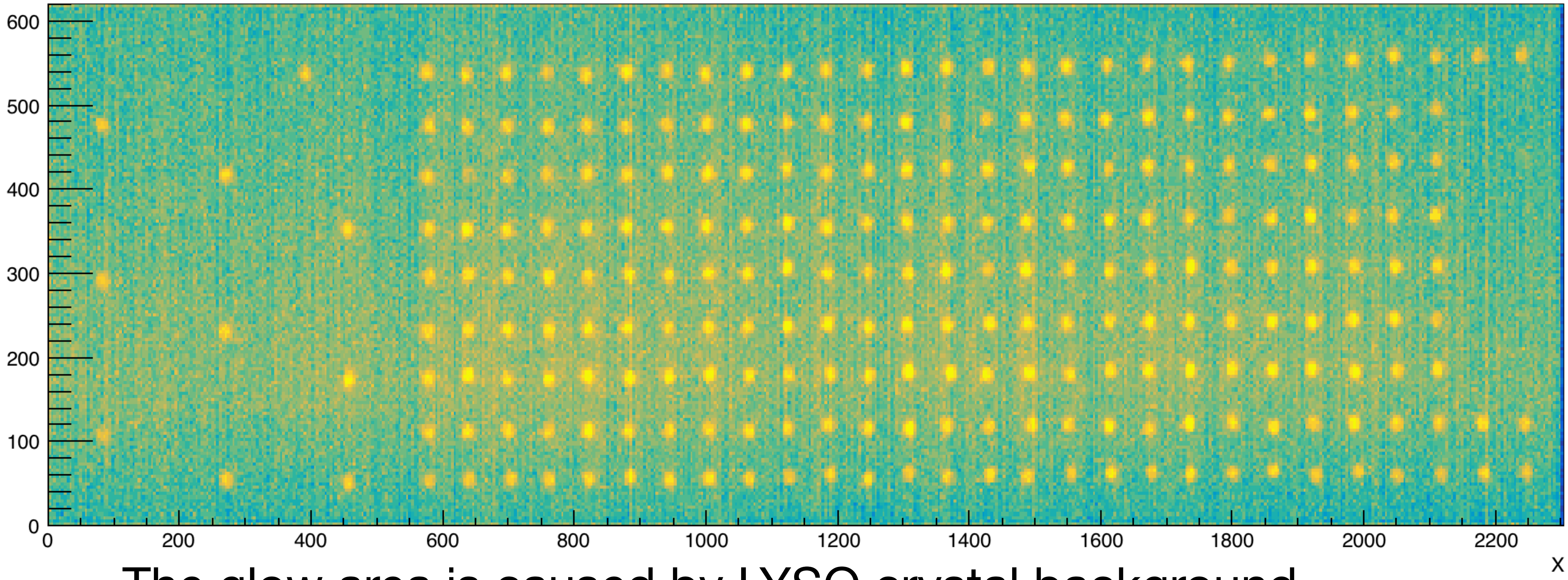
Test Setup: LED source, light output ~2MIP, measure the response of ICCD at different frame rates.

- Run 1 (Blue): adjust frame rates from 100fps to 1fps, along with temperature changing from 37.5°C to 39.2°C;
- Run 2 (Red): adjust frame rates from 1fps to 100fps, along with temperature changing from 40.4°C to 39.8°C;

The response of ICCD is temperature dependent.

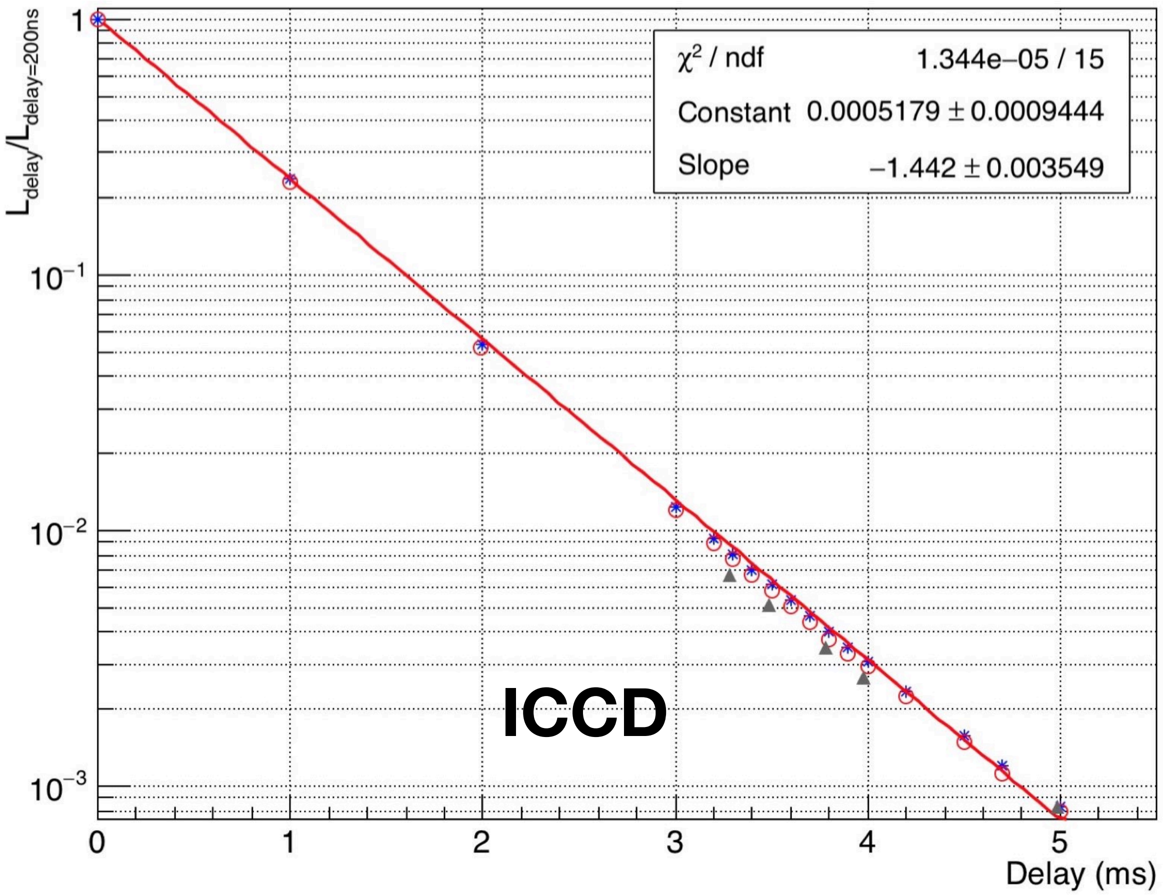
Problems to solve: pile-up

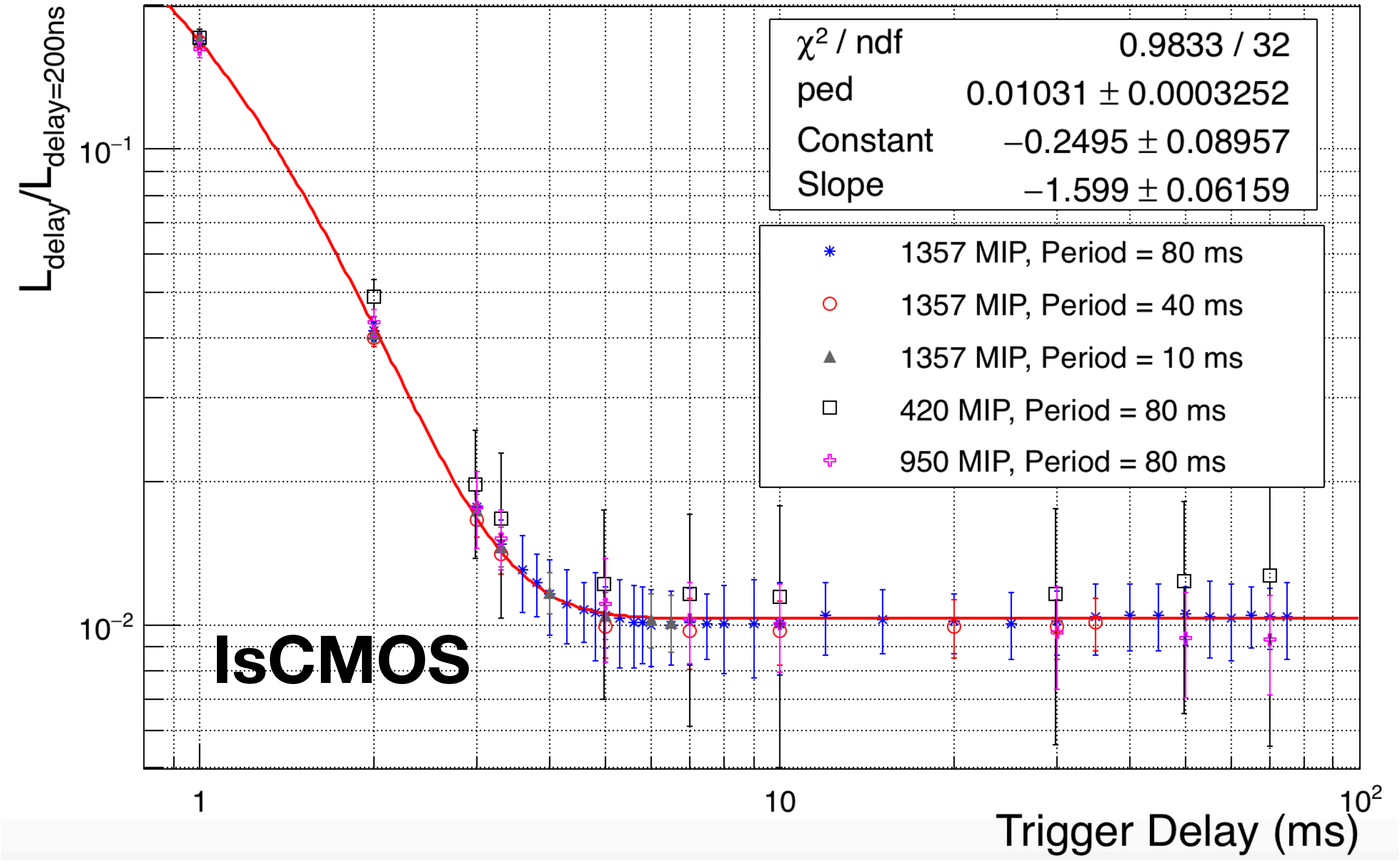
One dark frame recorded by IsCMOS at 0.3Hz



The glow area is caused by LYSO crystal background,
Photons from crystal are collected by IsCMOS.

Phosphor (P20) afterglow





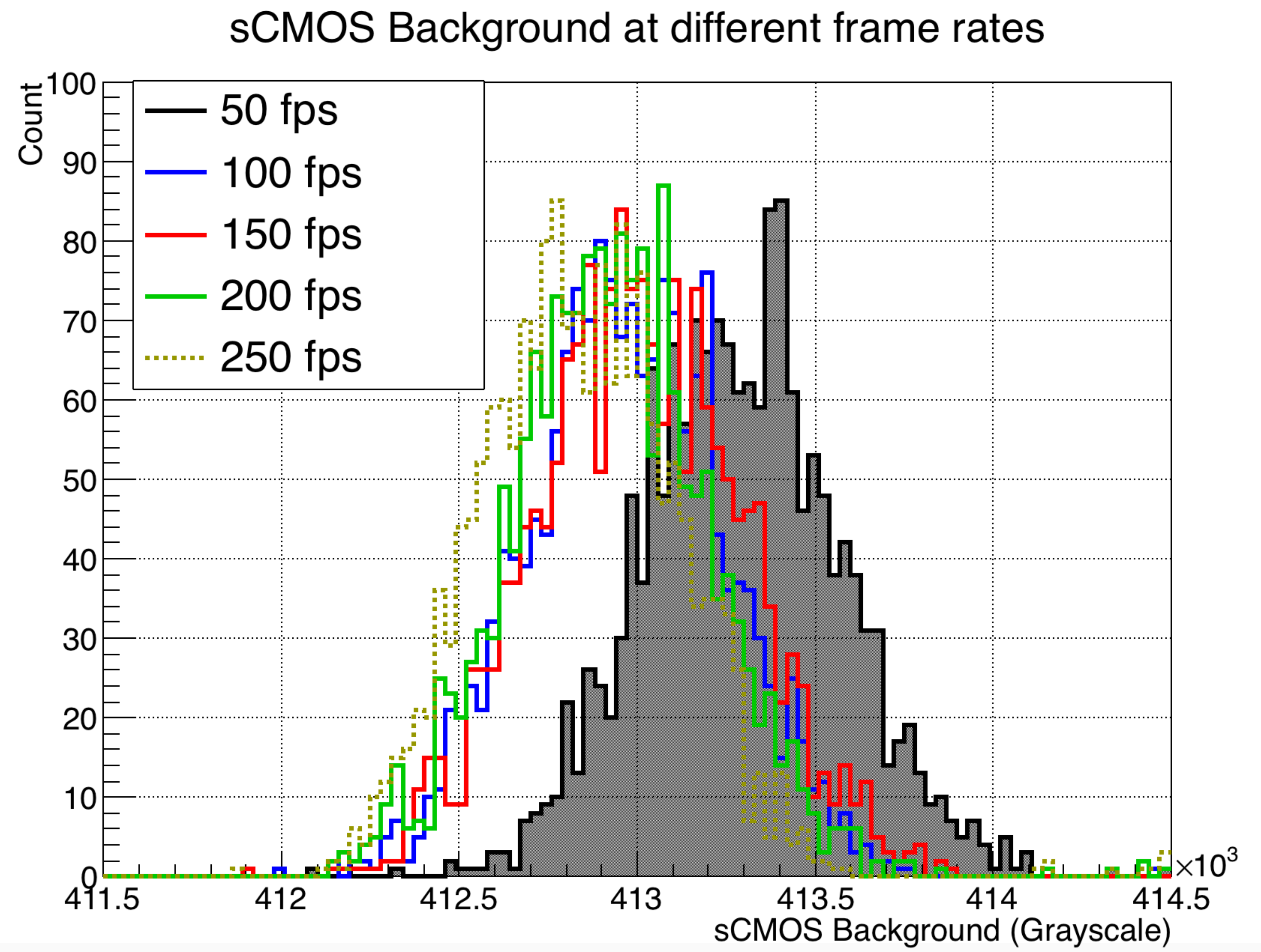
Both ICCD and IsCMOS use P20.

✦ICCD：3ms down to 1%, 5ms to 0.08%;

✦IsCMOS: 5ms down to 1%, with a long tail extended to 100ms.

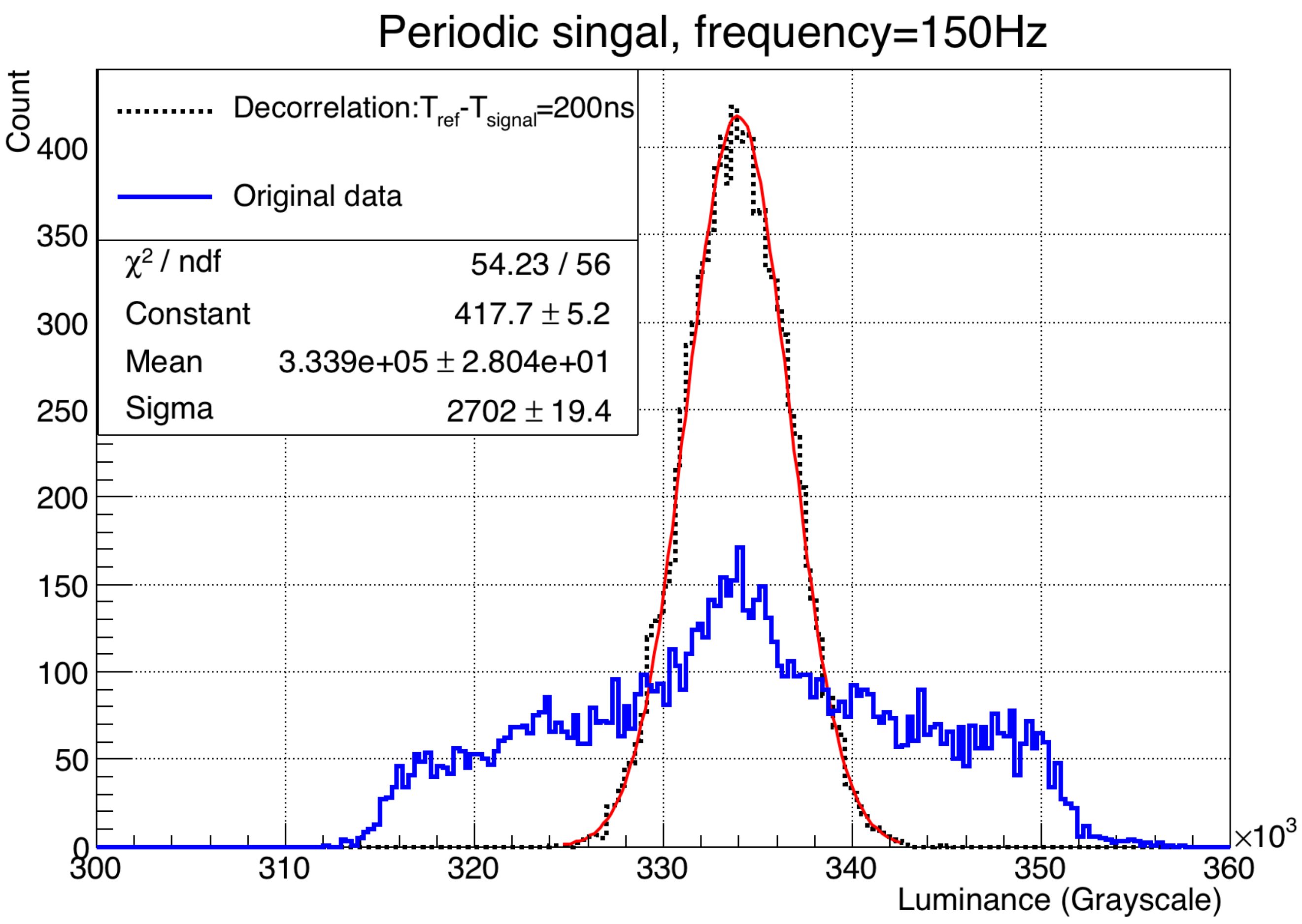
The afterglow of phosphor screen may cause pile-up.

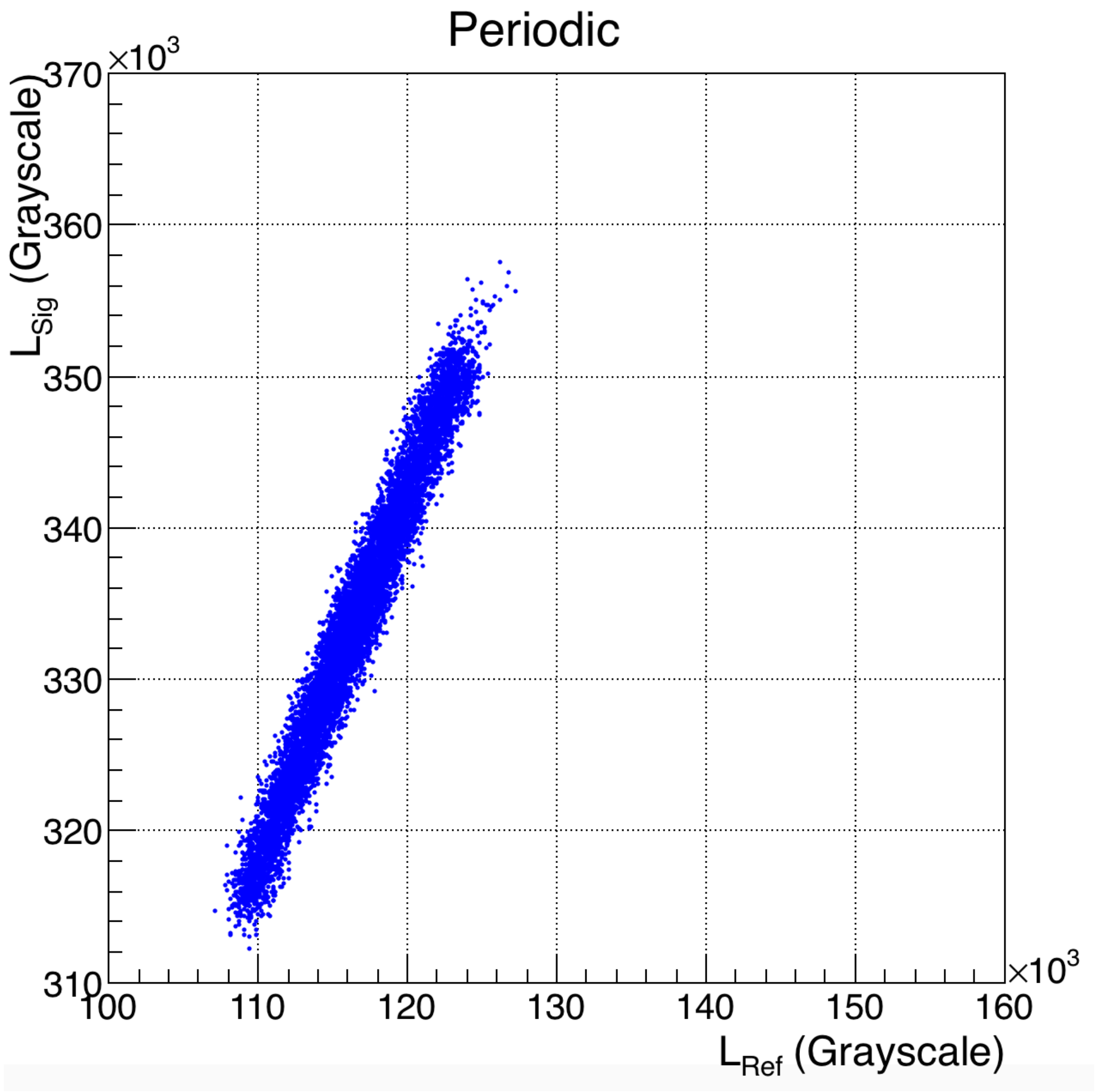
Background stability of sCMOS



Higher frame rates lead to larger backgrounds:
BKG(50fps)-BKG(250fps) = 464 grayscale,
while 1 MIP for CALO cell is on average 210 grayscale.

Common noise correction: Results of LED test with periodic signal

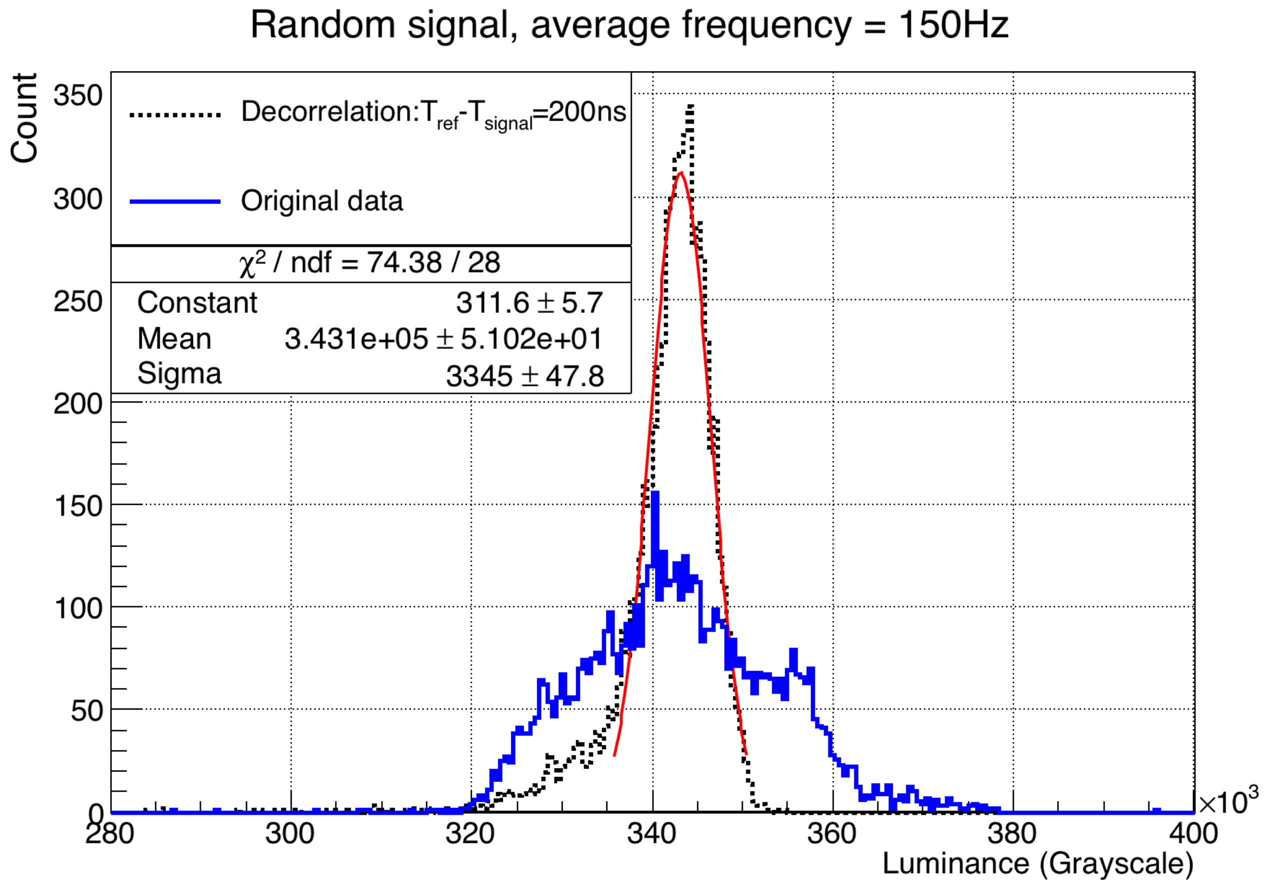


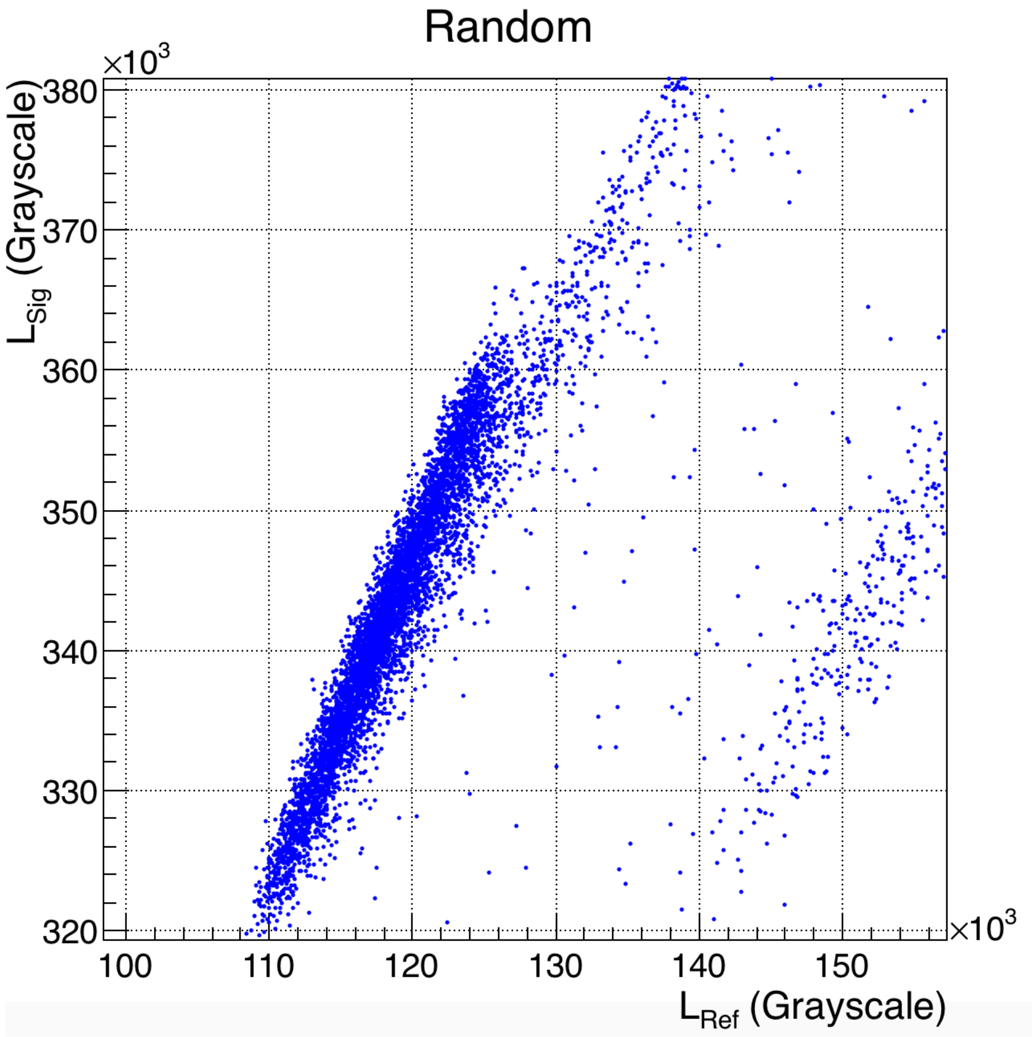


✓Correction results: energy resolution 2.8%->0.8%;

✓Symmetric gaussian peak;

Common noise correction:
Results of LED test with random signal





✓Correction results: energy resolution 2.9%->1.0%;

✓Long tail on the low energy side;

✓The deviation of peak value from periodic test results is 2.7%.

Common noise correction using reference LED has its own limitation: it does not work well at unfixed frame rates.

Troubleshooting

Phenomenon	Reason	Solution
Unstable MIP calibration	The response of ICCD is temperature dependent	Replace ICCD with IsCMOS
Dark frames detected by IsCMOS contain large signals at low frame rates (<1fps)	Phosphor afterglow	Replace P20 with a faster and non-afterglow phosphor screen (such as P24)
Different reconstructed MIP signals with different selections		
Common noise correction may cause unsymmetrical energy peak of electrons	The response of IsCMOS is frequency dependent, decorrelation does not work well at unfixed frame rates	Change the readout mode of IsCMOS to "Global Reset”
		Improve the power supply system of IsCMOS
		Remove of reduce common noise by improving the power supply system of I.I.

Summary

1. The new design of CALO prototype is proved effective by beam test at CERN in 2017.

2. The performance is significantly improved, especially energy resolution (1.3%@200 GeV) and channel uniformity (Max/Min<2).

3. Some design defects are found: bad energy resolution of prototype 2015 is caused by I.I. gain fluctuation; phosphor afterglow may cause pile-up; frequency dependence of IsCMOS may cause the failure of common noise correction.

4. We are making progress in solving these problems.

Thank you

e/p separation