Overview of HERD CALO beam test results

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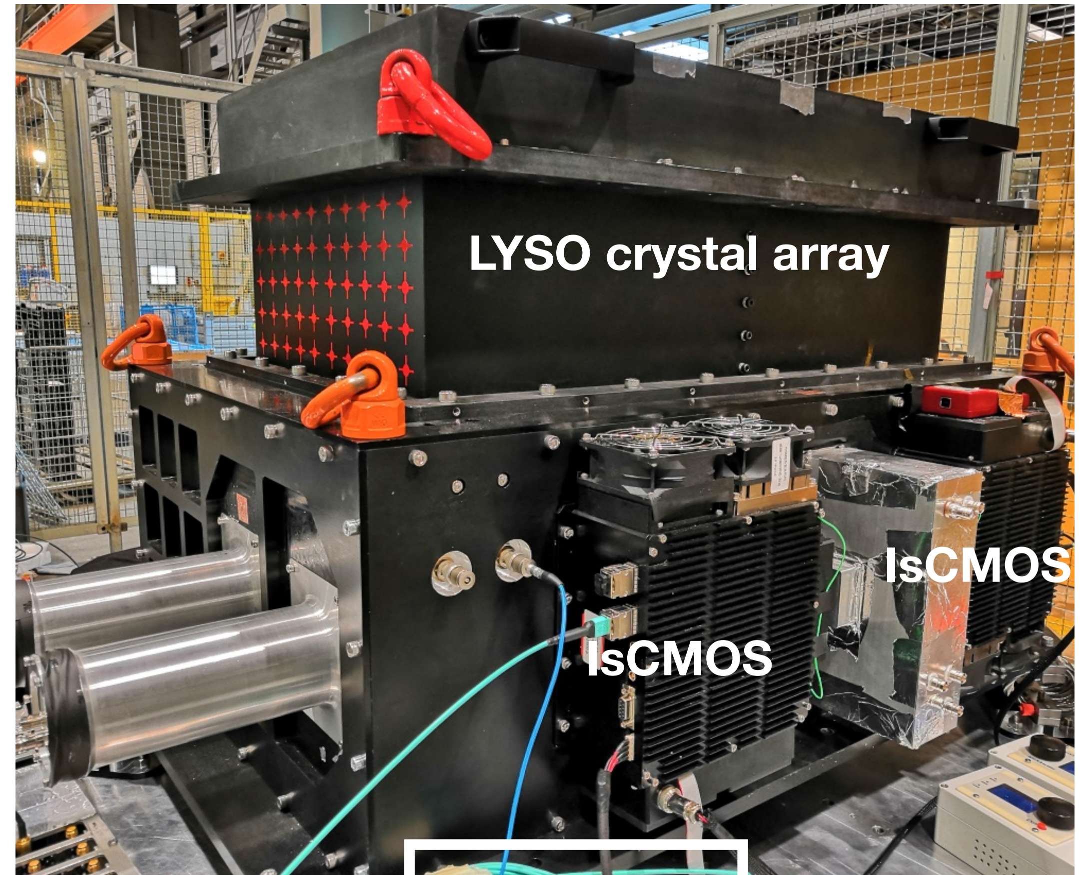
Objectives of three tests

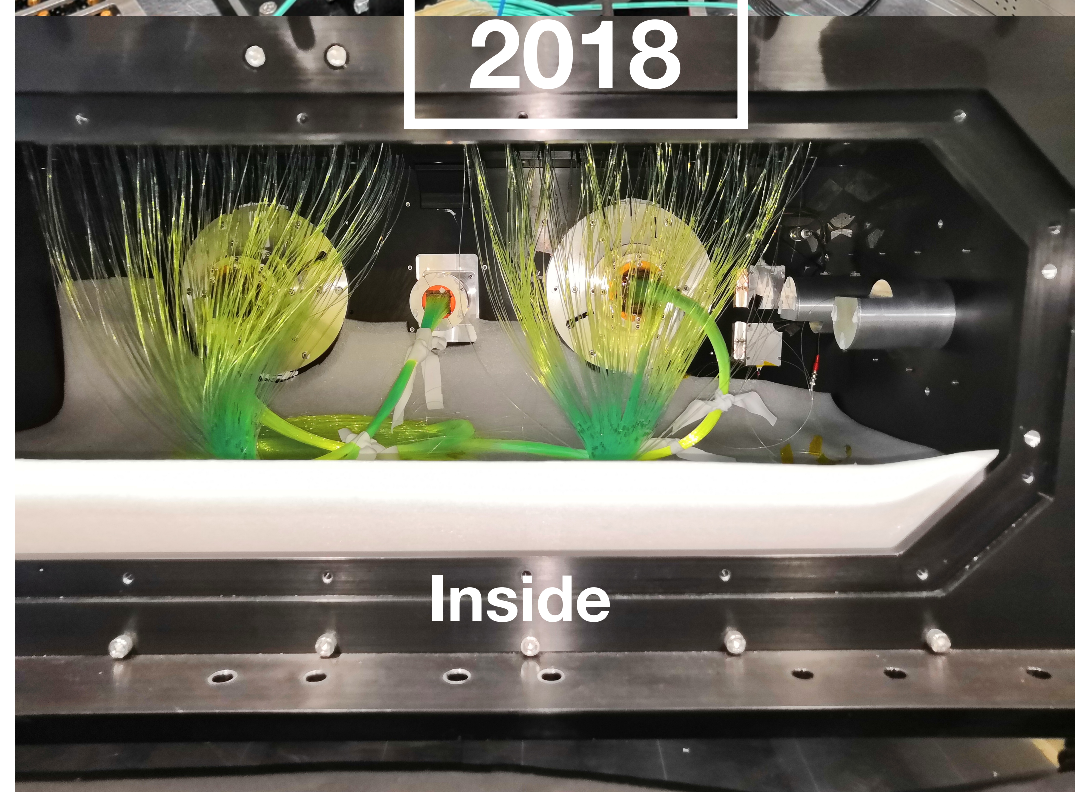
❖2015: Verification of the LYSO+WLSF+ICCD design, study the performance of CALO for high energy electrons and protons measurement;

❖2017: Use new IsCMOS; improve energy resolution;

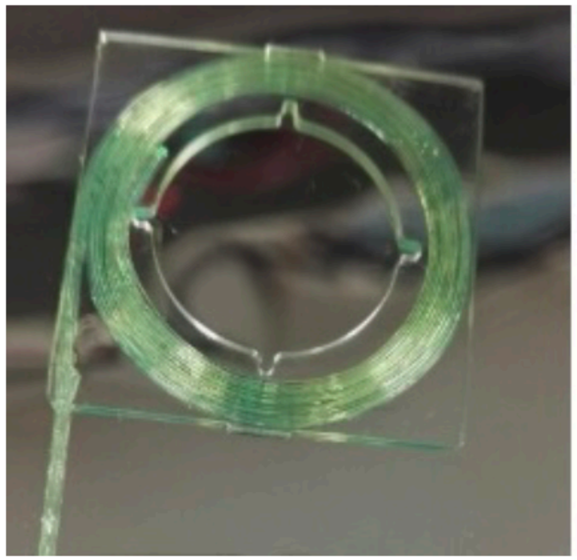
❖2018: Extend the longitudinal depth of CALO to the full scale (3 λ_I) and verify proton energy resolution and e/p separation power, verification of 2-taper design of IsCMOS;

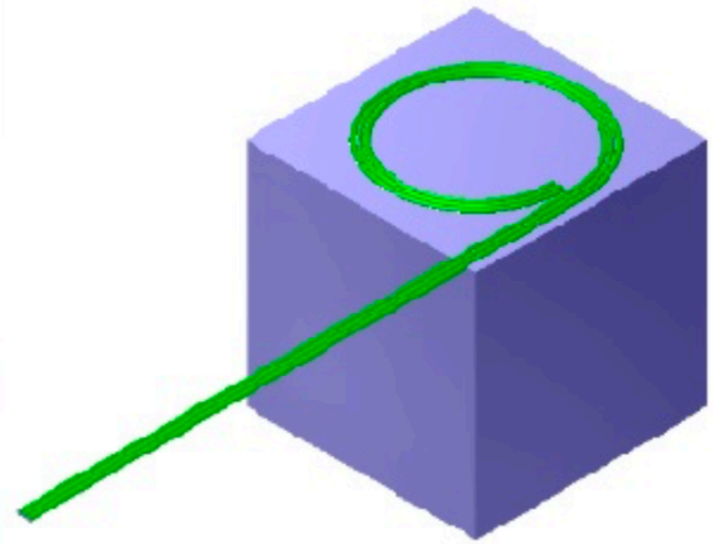
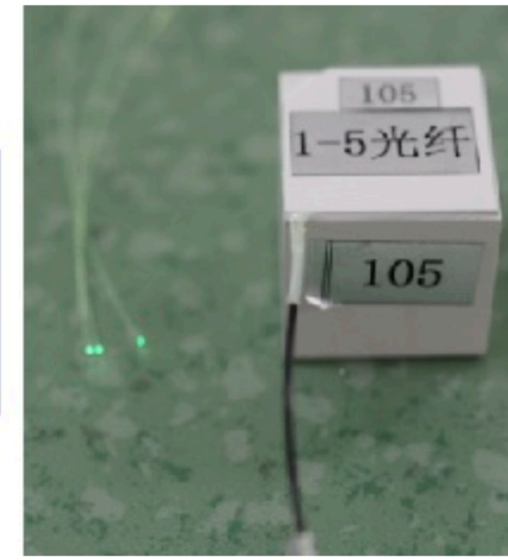
Three prototypes

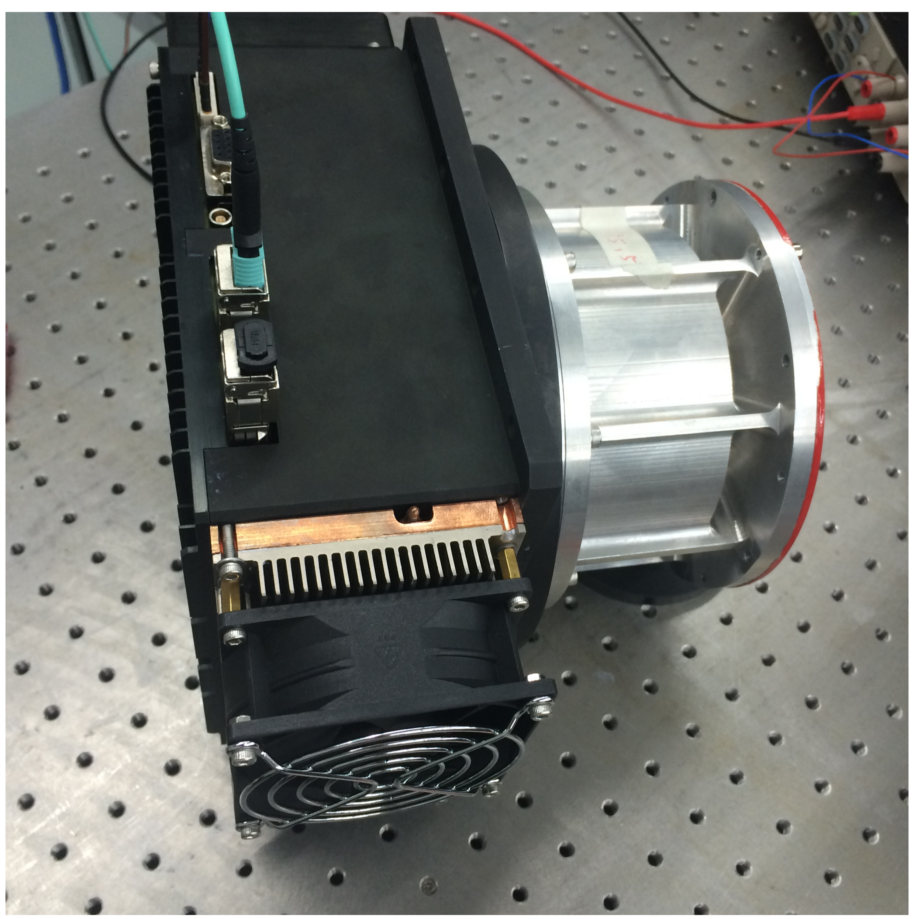




CALO Readout system: WLS fiber + ICCD/ IsCMOS





- Three fibers are reshaped into spirals to get the largest contact area, two for energy detection, one for triggering;
- Attached onto one surface;
- The crystal and fibers are coated with reflectors to increase light output;
- 1 MIP = 200 P.E. observed by PMT XP2020;
- All 7497 fibers attached to one IsCMOS camera.

Image intensified sCMOS

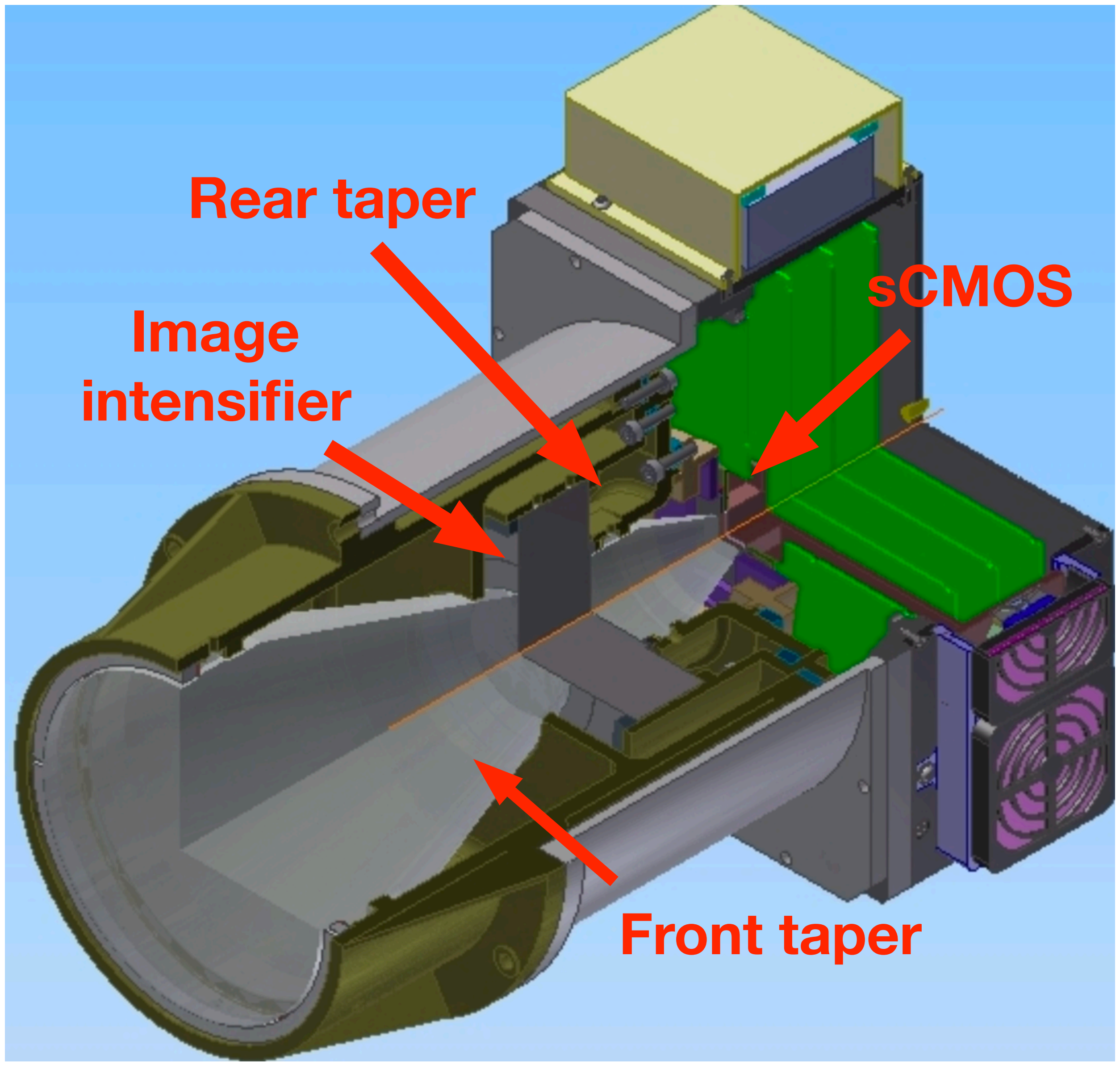
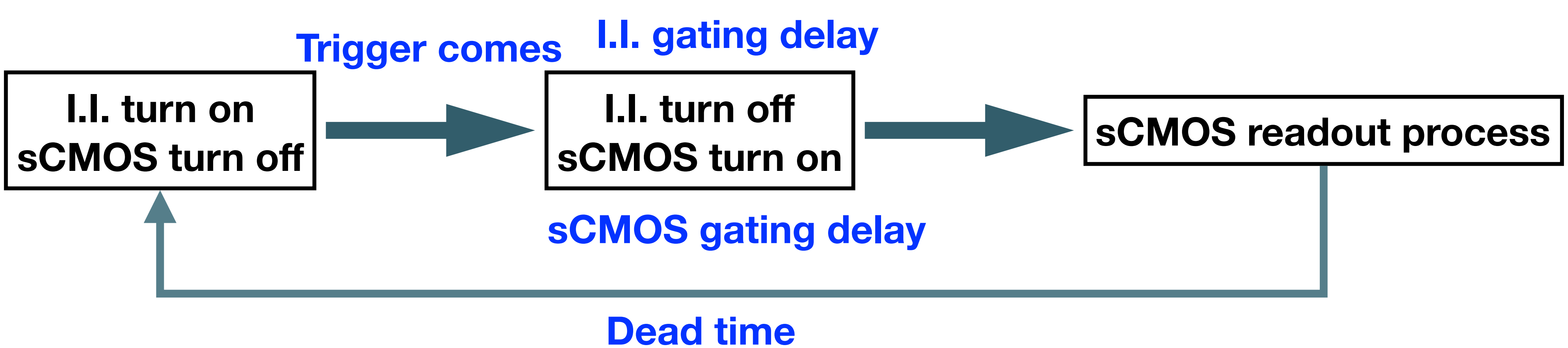


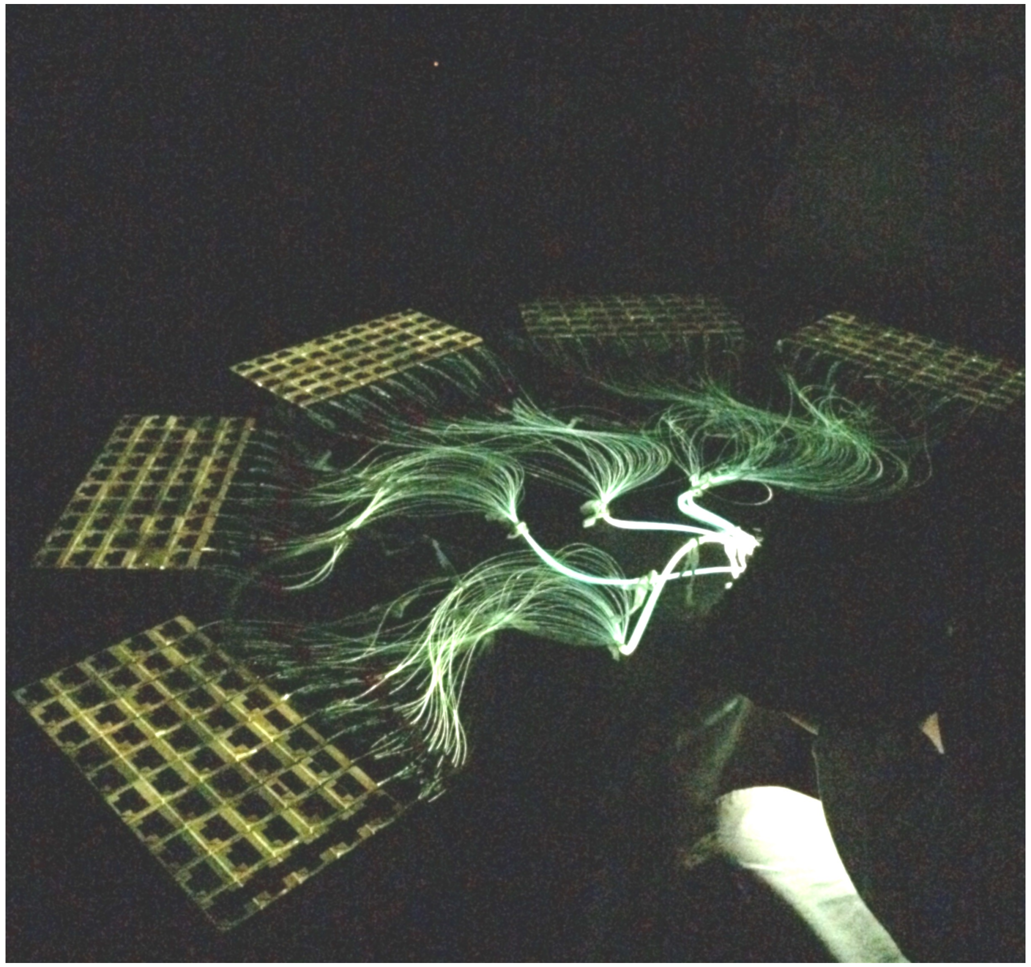
Image intensifier working sequence:
Input window converts photons into electrons
-> Accelerate electrons through electric field
-> Secondary cascades occur in MCP
-> Accelerate secondary electrons to hit a phosphor screen
-> Phosphor screen converts electrons to photons (1ms decay time for P20)



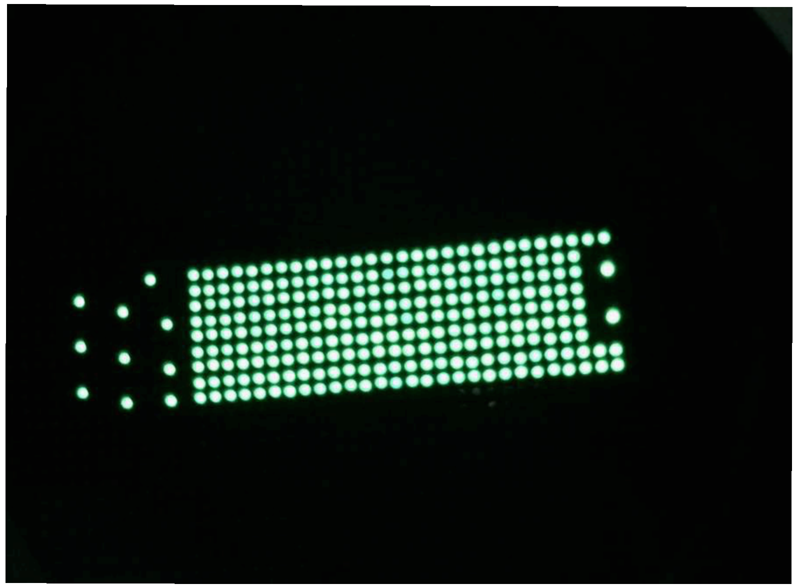
Properties of IsCMOS used in prototypes

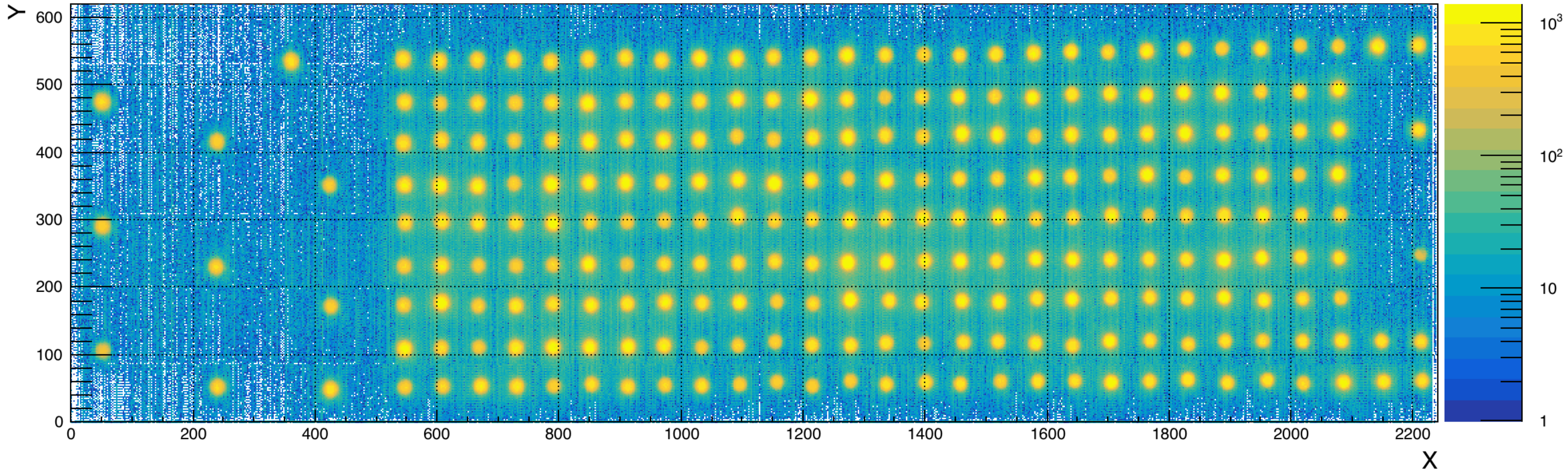
Window size of I.I.	ϕ40mm
Spectral range of I.I.	200nm – 900nm
Maximum gain of I.I.	14000
MCP type	Single stage
Quantum efficiency of I. I.	12%@500nm
Phosphor screen type	P20
Phosphor decay time	1ms down to 1%
sCMOS size	768×620 pixels
Pixel size	5.5μm×5.5μm
Maximum frame rate	430 fps
sCMOS cooling system	TEC + Fan (stable within 10~25°C)
Demagnification ratio	9:1
Gating delay of I.I.	1μs
Gating delay of sCMOS	500ns
Data size of one frame	0.9 MByte

HERD prototypes

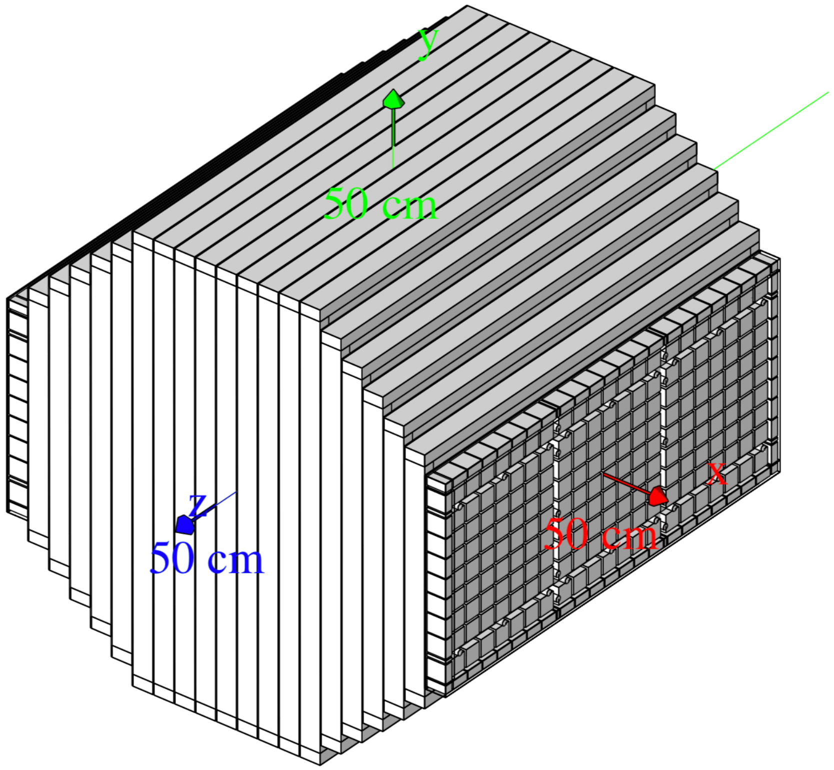


- Smaller scale, 5×5×10 crystals (2015 and 2017), 5×5×20 crystals (2018);
- 10 layers corresponding 26X_0 and 1.5λ_I ;
- 1mm center to center distance between two neighboring fibers.

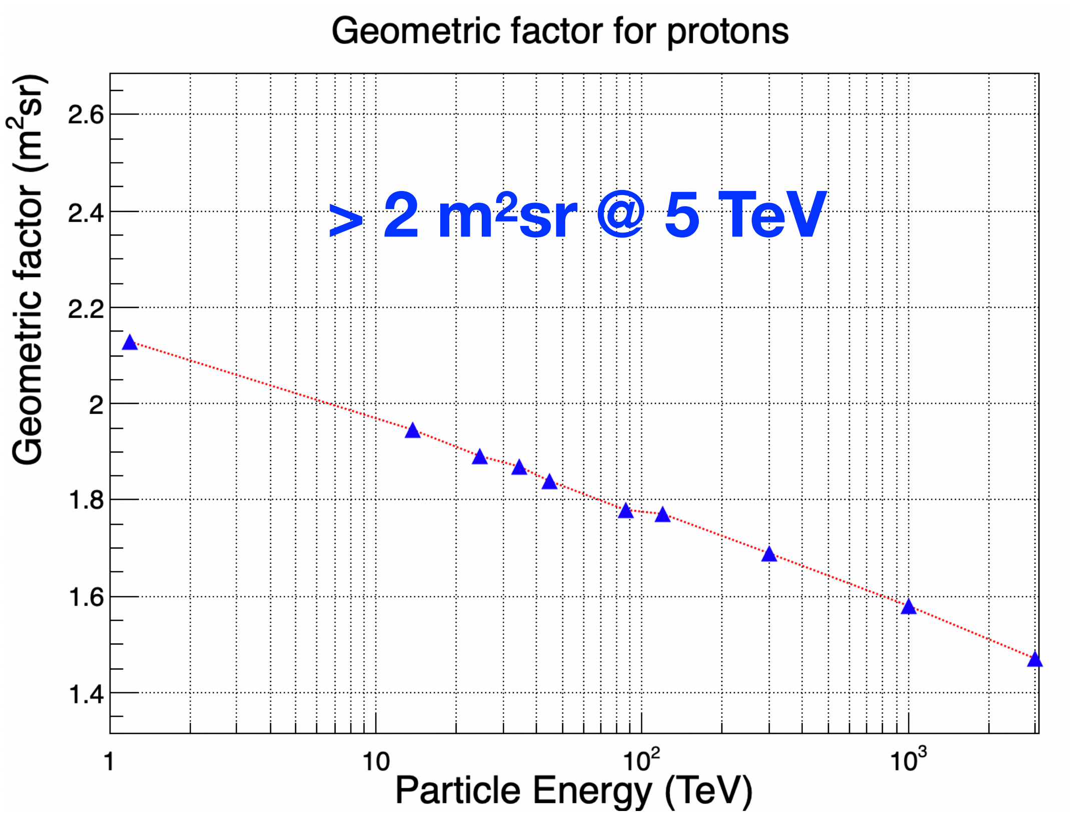


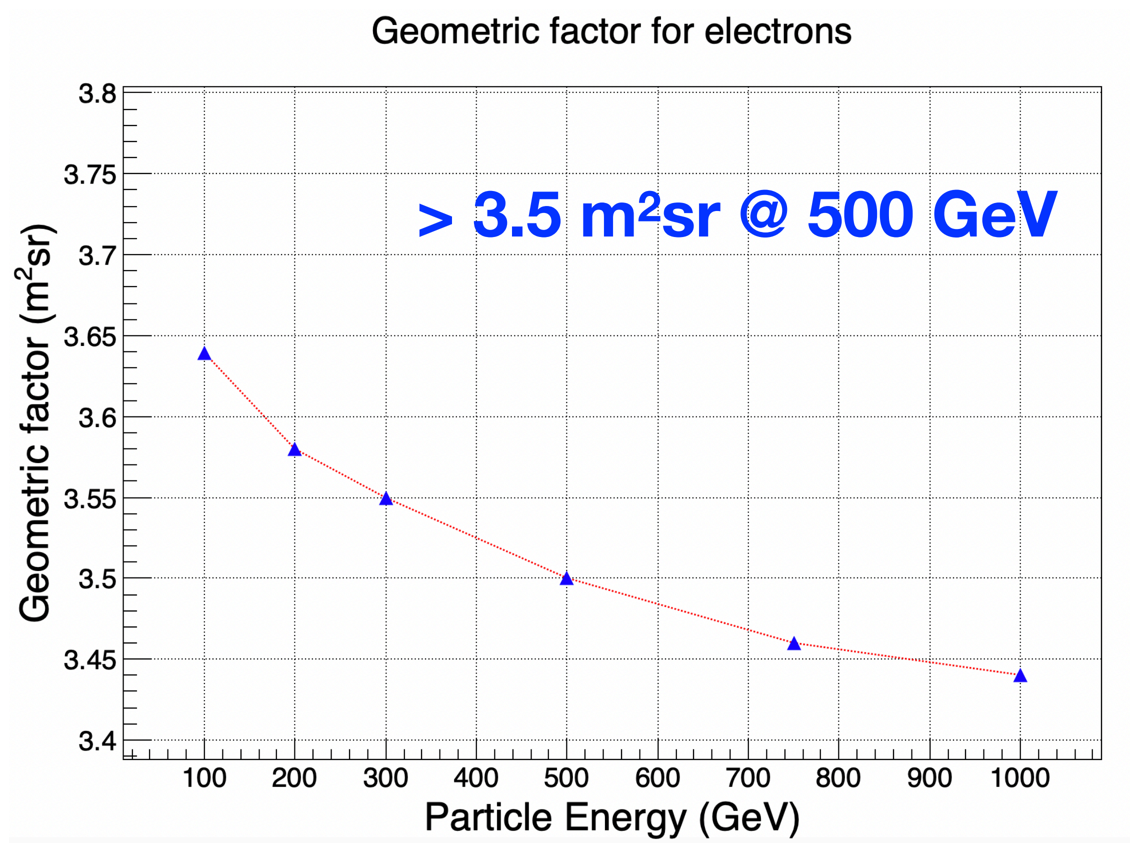


Full scale HERD CALO



- Homogeneous;
- Octagonal prism;
- Capable of accepting particles incident on its top face and four lateral faces;
- 7497 cells made of cubic LYSO crystals ($3\times3\times3$ cm^3), high granularity for shower imaging, 2 mm carbon fiber structure;
- $55X_0$, $3\lambda_I$.





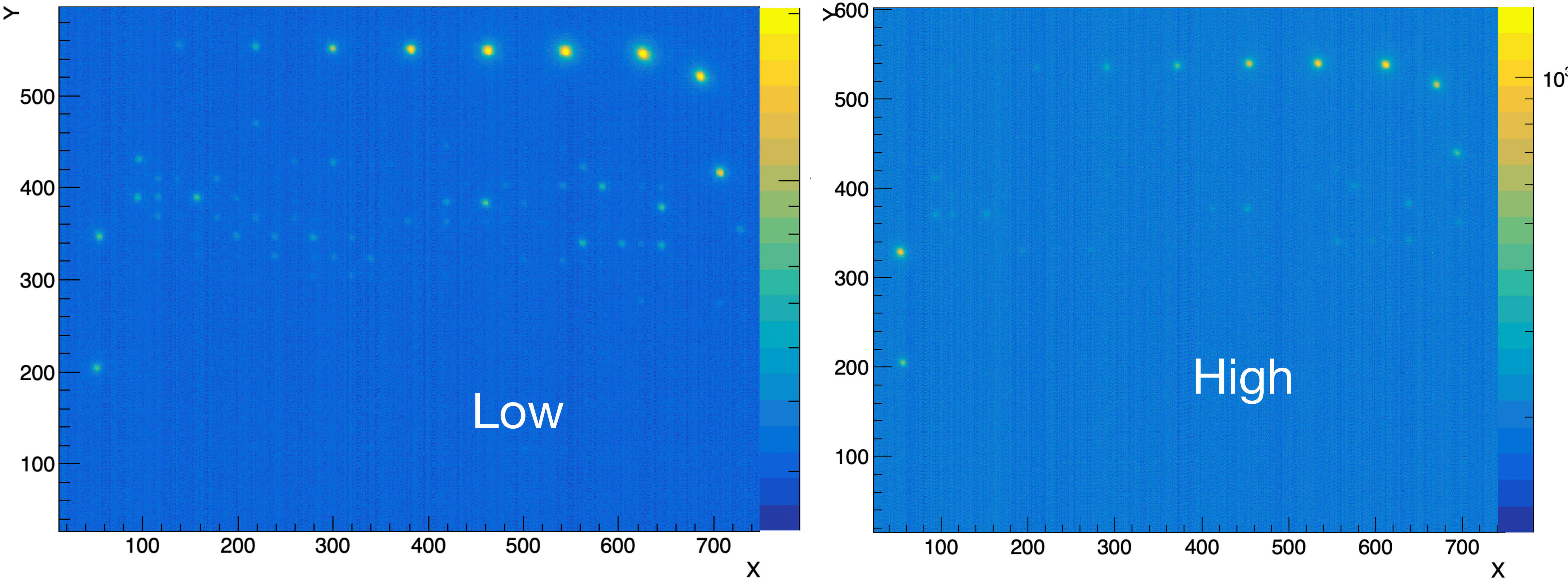
HERD CALO prototype: 2015 vs 2017 vs 2018

HERD CALO prototype			
	2015	2017	2018
Scale	5×5×10, $26X_0$, $1.5\lambda_I$		5×5×20, $52X_0$, $3\lambda_I$
Readout	ICCD×2	ICCD_H is replaced by IsCMOS(1 taper)	IsCMOS (2 tapers)×2
Temperature Control	Fan (37°C)	TEC+Fan (25°C)	TEC+Fan (14°C)
Crystal reflector	ESR	TiO_2	ESR (5 frosted surfaces)
WLS Fibers	Spiral×2, Fiber×3	Spiral×1, Fiber×3	Spiral×1, Fiber×3
Fiber polishing	No	Yes	Yes
Energy Range Control	Reduce light output of fibers	Adjust I.I. gain	Adjust I.I. gain
Reference LED	0	LED×2	LD×2
Gating delay of I.I.	210 μs	7 μs	<1 μs
Gating delay of sCMOS	1.28 μs	7 μs	< 500 ns

Test Beam

- CERN SPS H2 and H4;
- 350 GeV and 400 GeV protons;
- 10 GeV - 250 GeV electrons;
- Use PSD for triggering;
- Use silicon tracker for tracking and charge measurement;
- Use muons, pions and protons to calibrate MIP response of all cells.

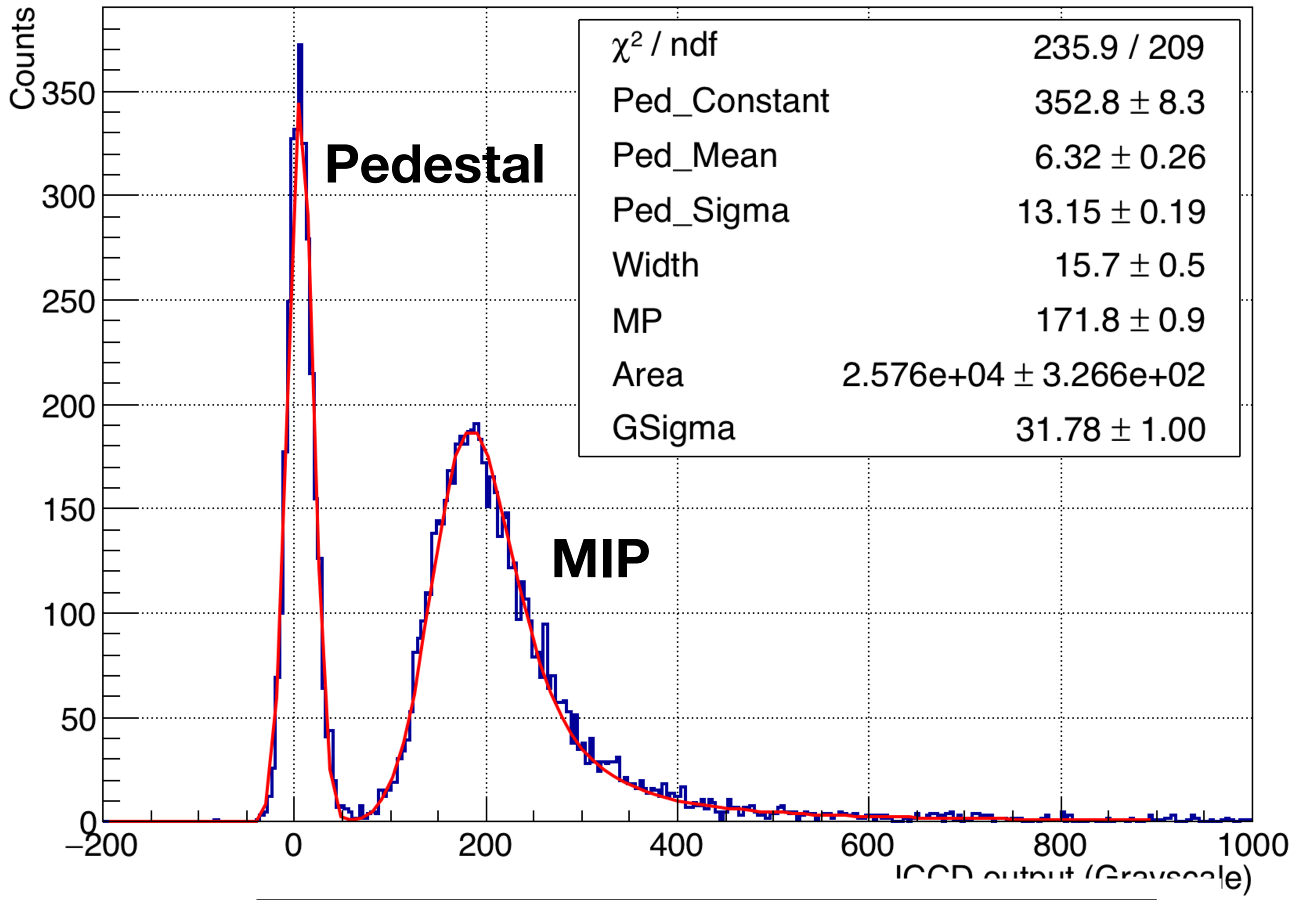
Reconstruction

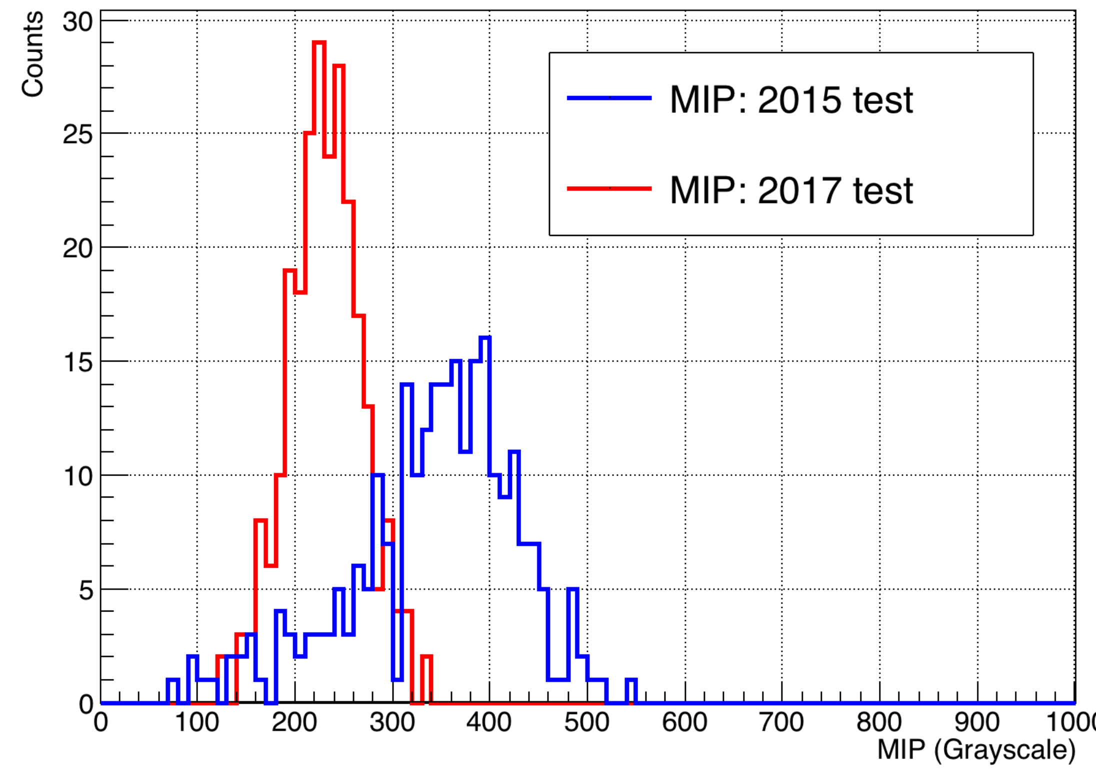


Typical outputs of two IsCMOS for 200 GeV electrons

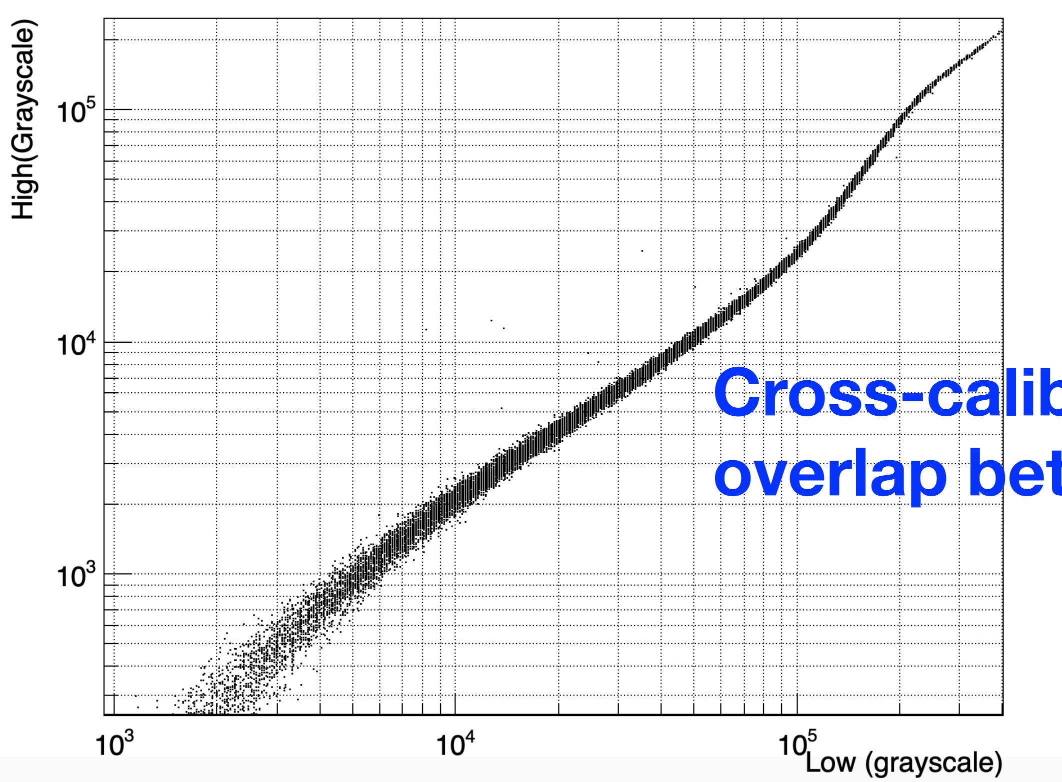
- First step: pixel merge, calculate output (in grayscale) of all faculae on the image.
- How about 2-D fitting? CPU-consuming, unstable, not always successful.

Calibration



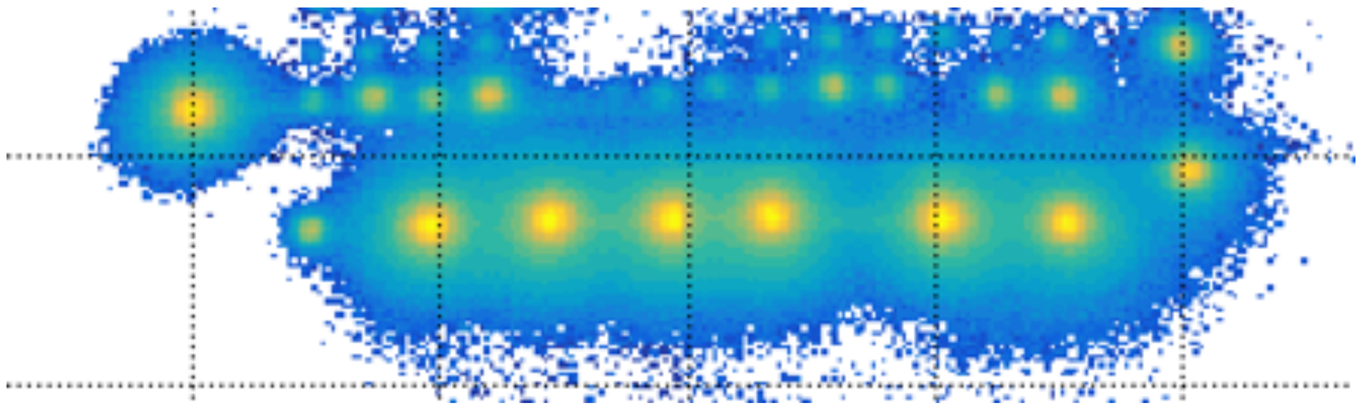


MIP distribution, 2015 VS 2017, significantly improved

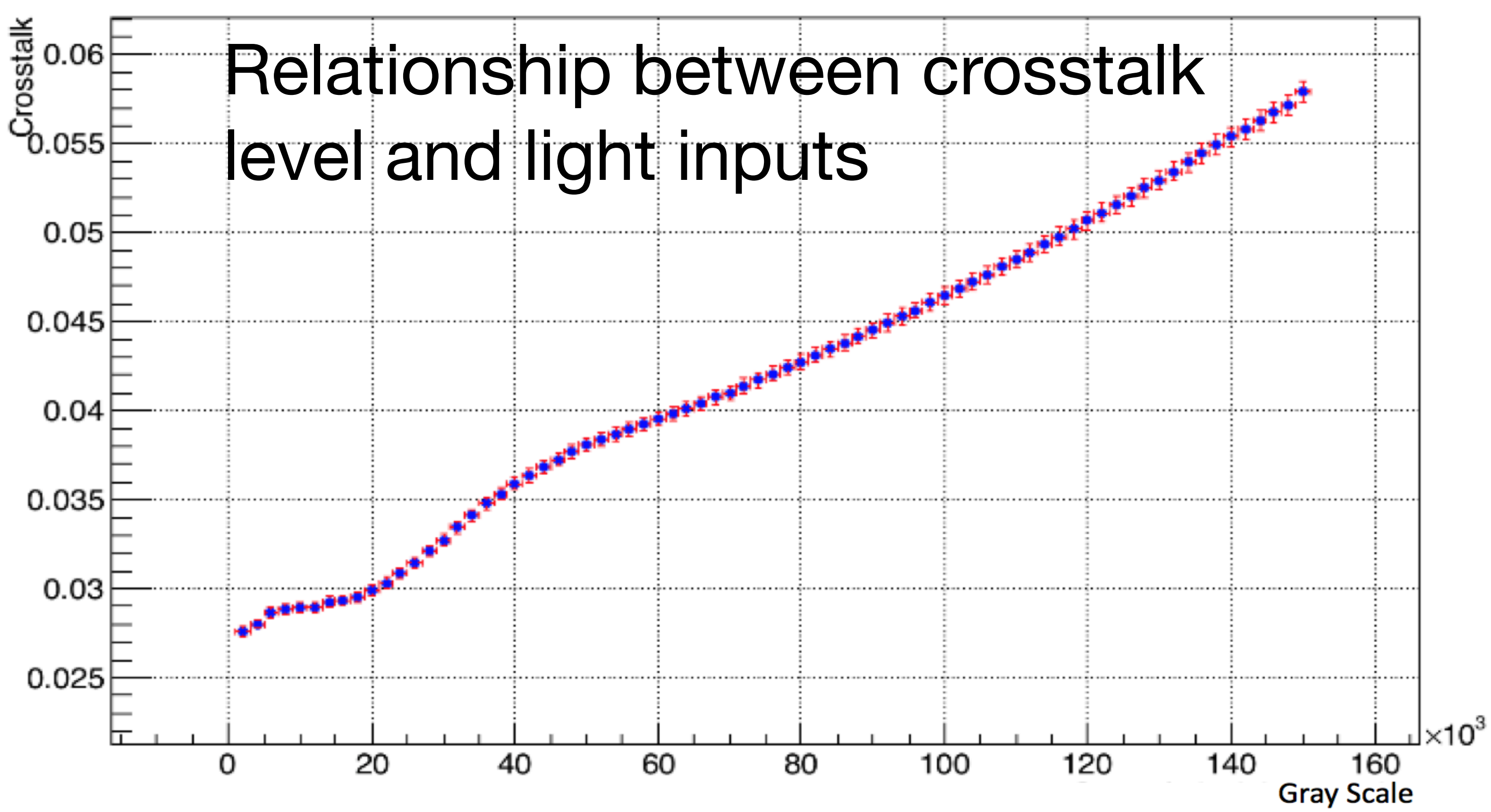


Cross-calibration by using the overlap between the two ranges

Crosstalk correction



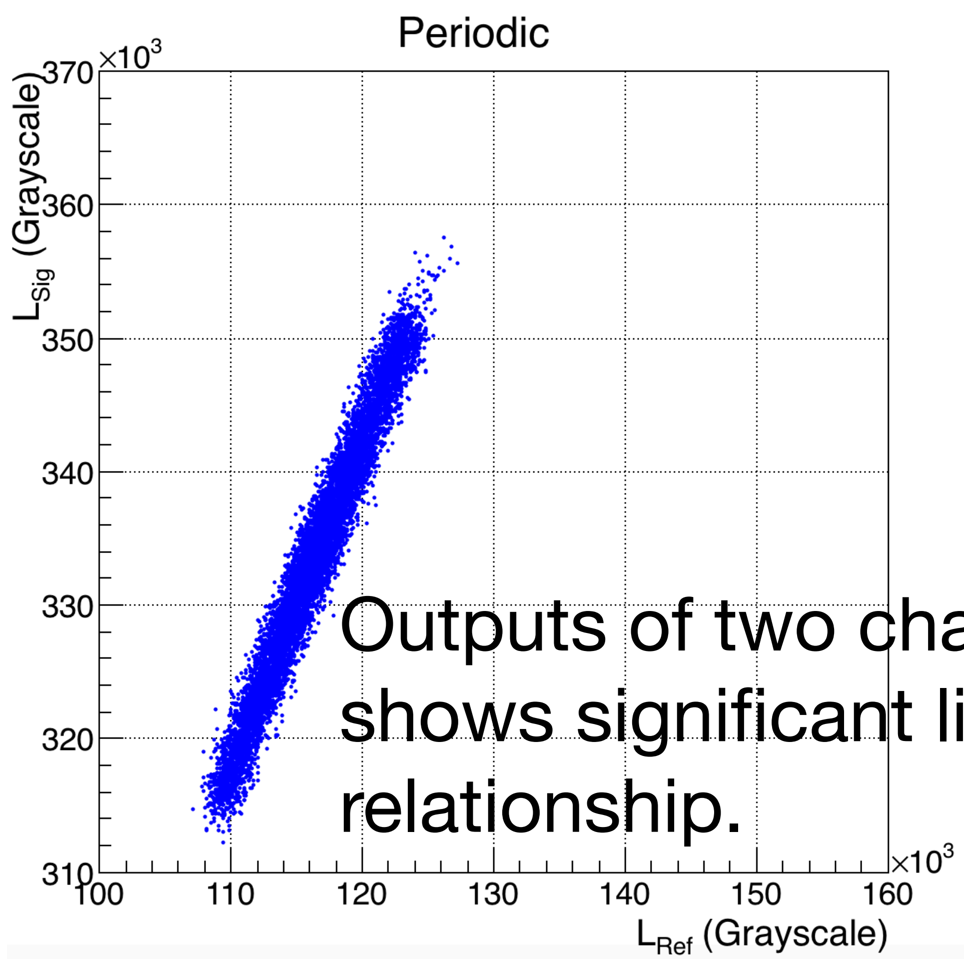
Overlapping with nearby faculae



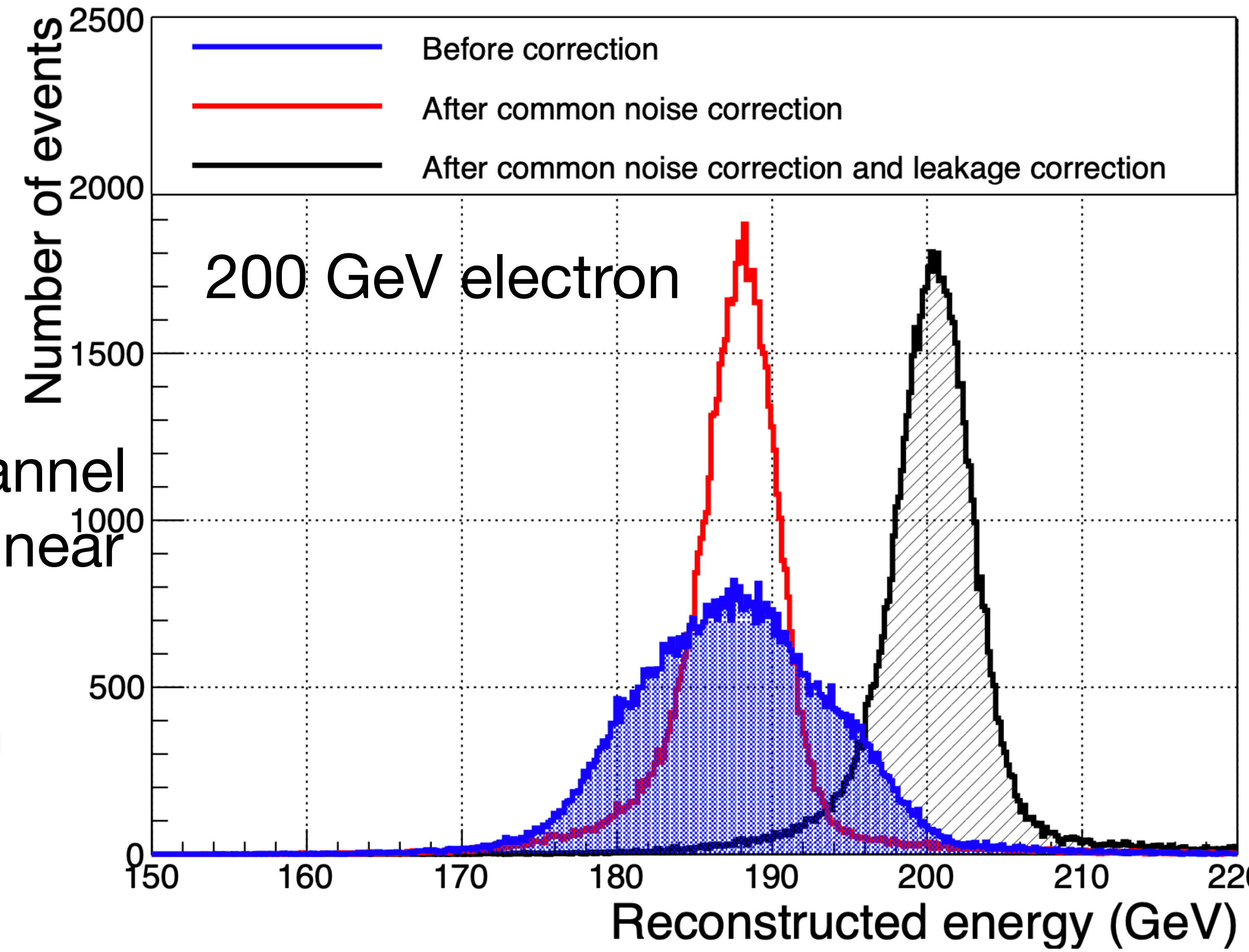
Correction:

- ✦Obtain crosstalk data by using a LED or LD to irradiate WLSF fibers one by one;
- ✦Use the data to calculate a crosstalk matrix and use the matrix to correct the output in grayscale.

Common noise correction

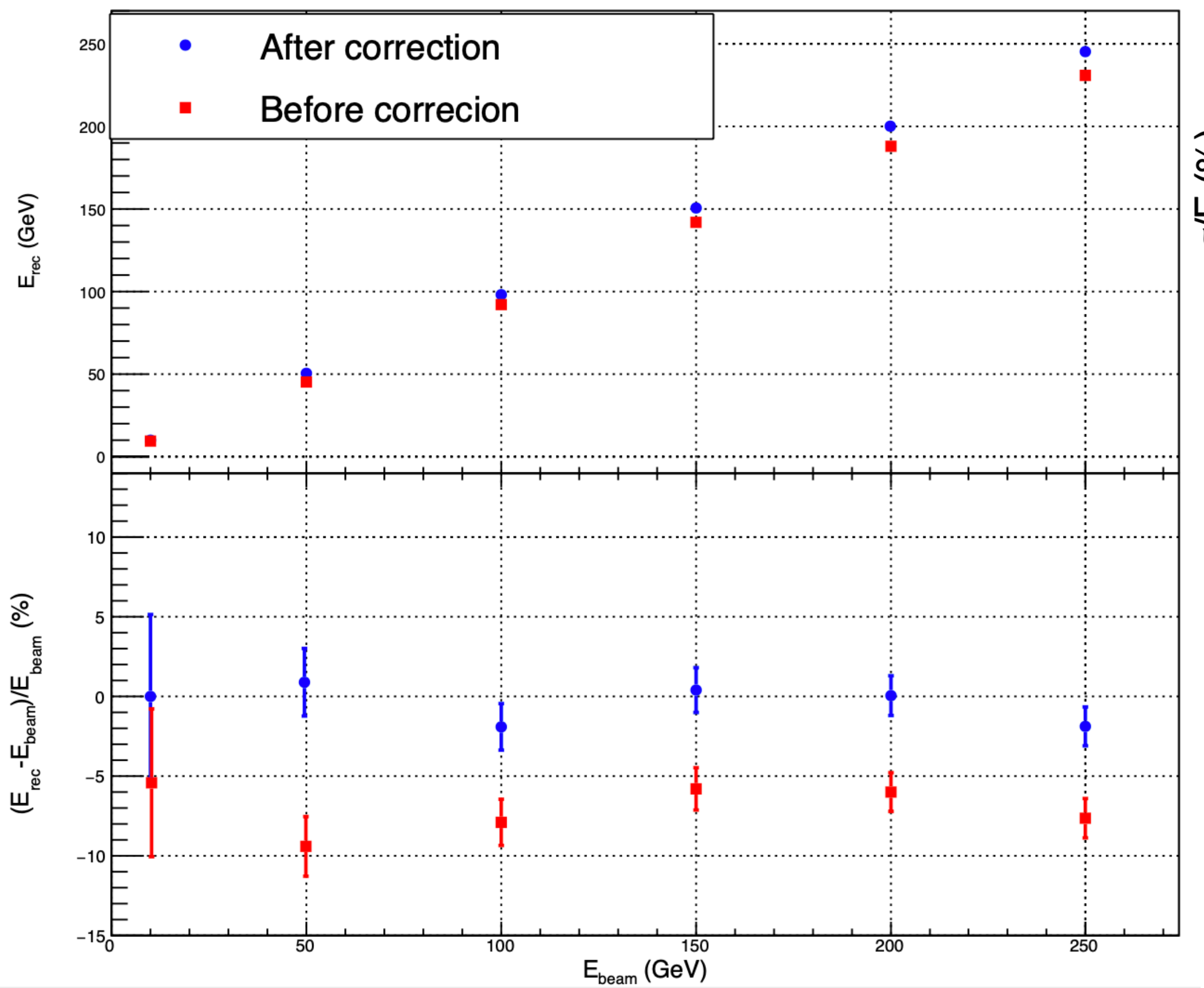


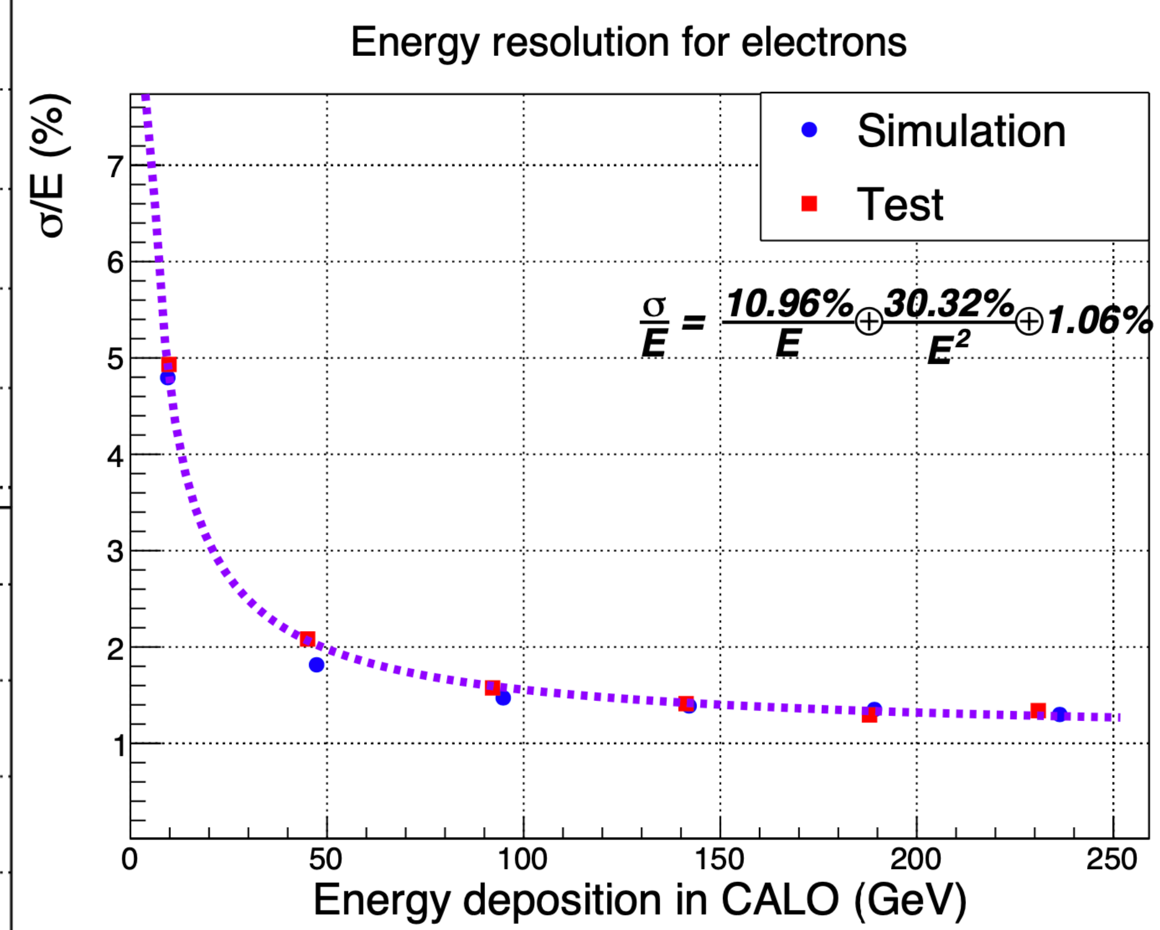
Outputs of two channel shows significant linear relationship.



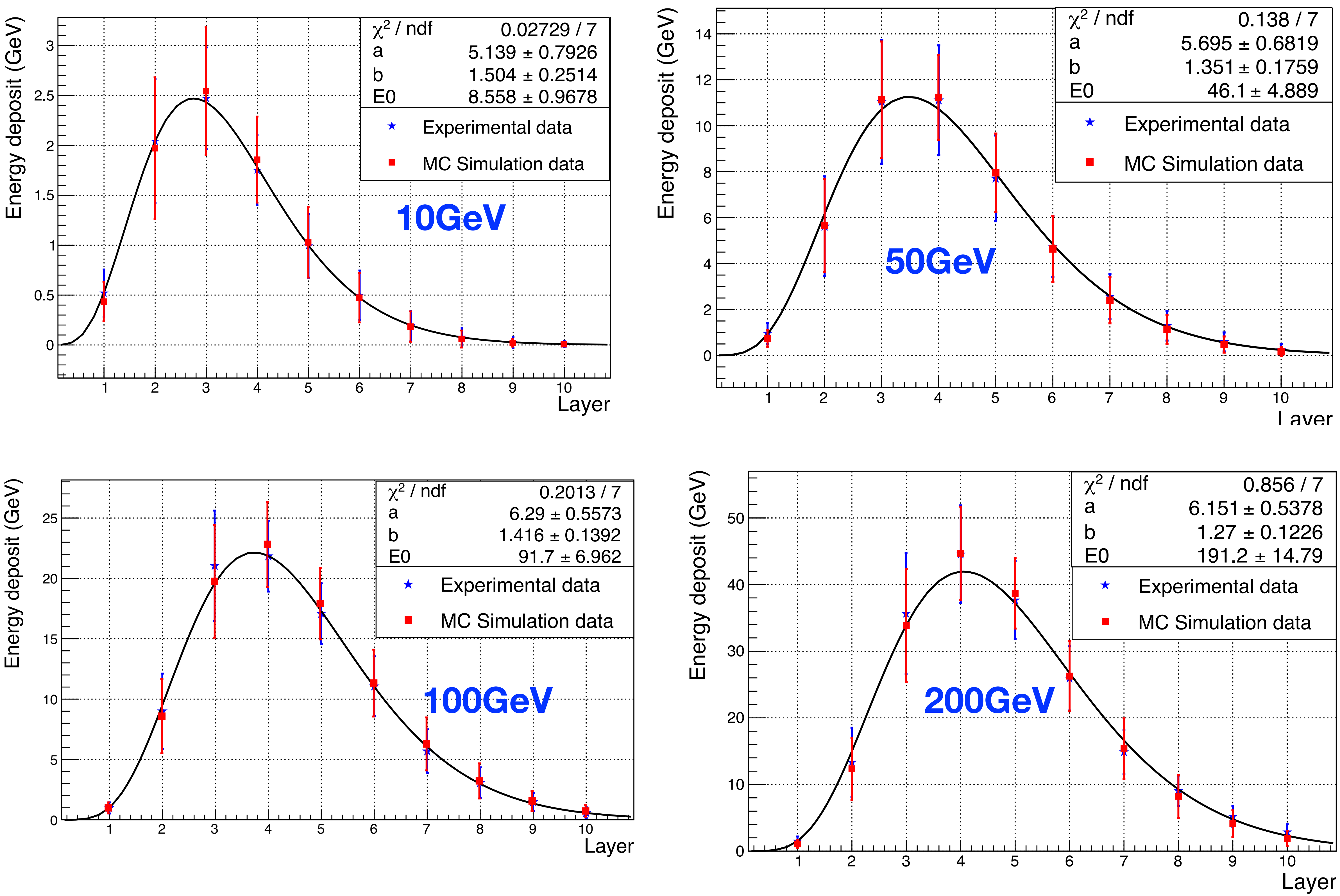
- ✦ All the channels share a same amplifier (I.I.);
- ✦ The fluctuation of I.I. contributes to the constant term of energy resolution;
- ✦ Use a stable LED to monitoring the fluctuation of I.I. and correct the common noise (decorrelation).

Test results: electrons

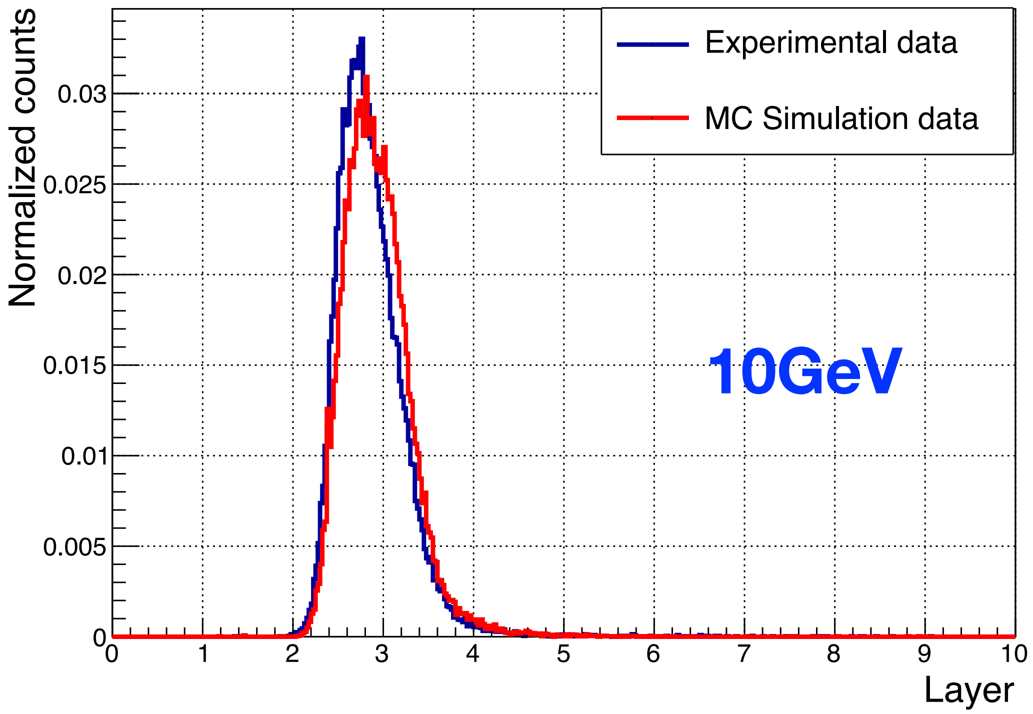


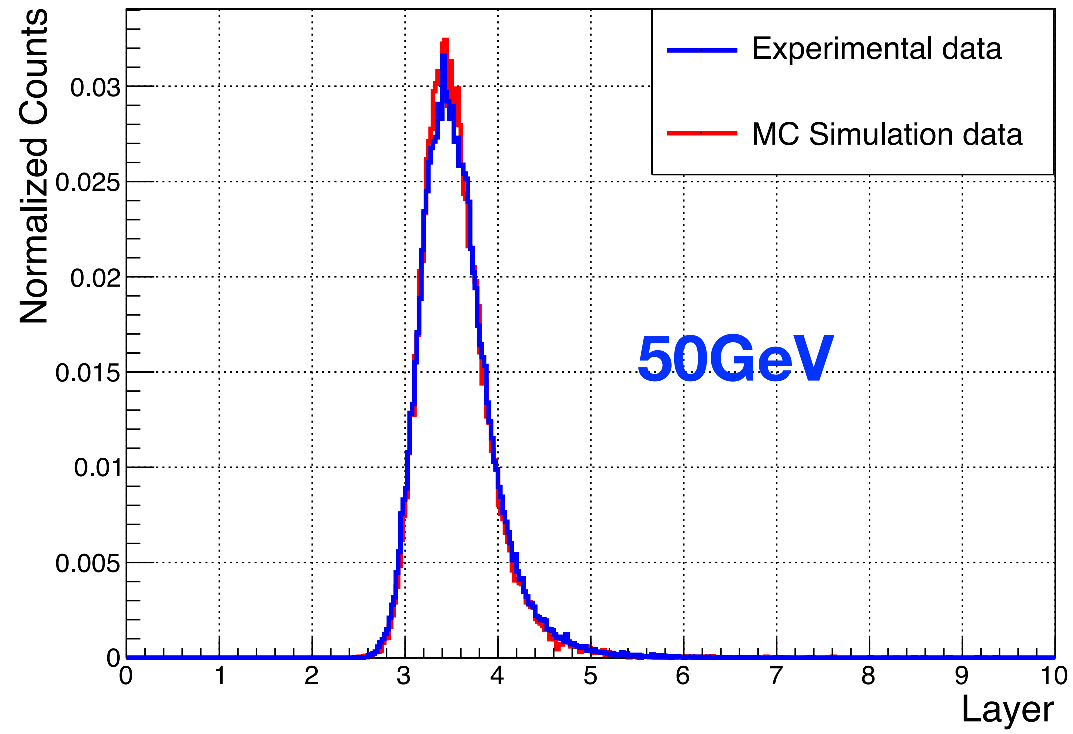


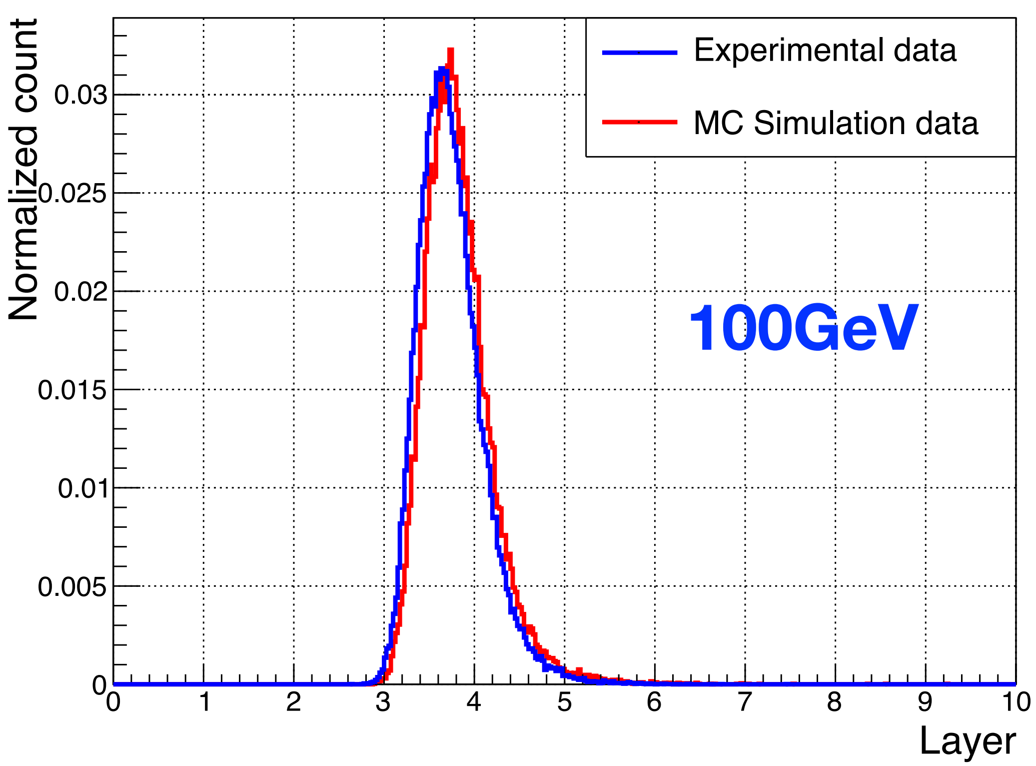
Longitudinal shower profile

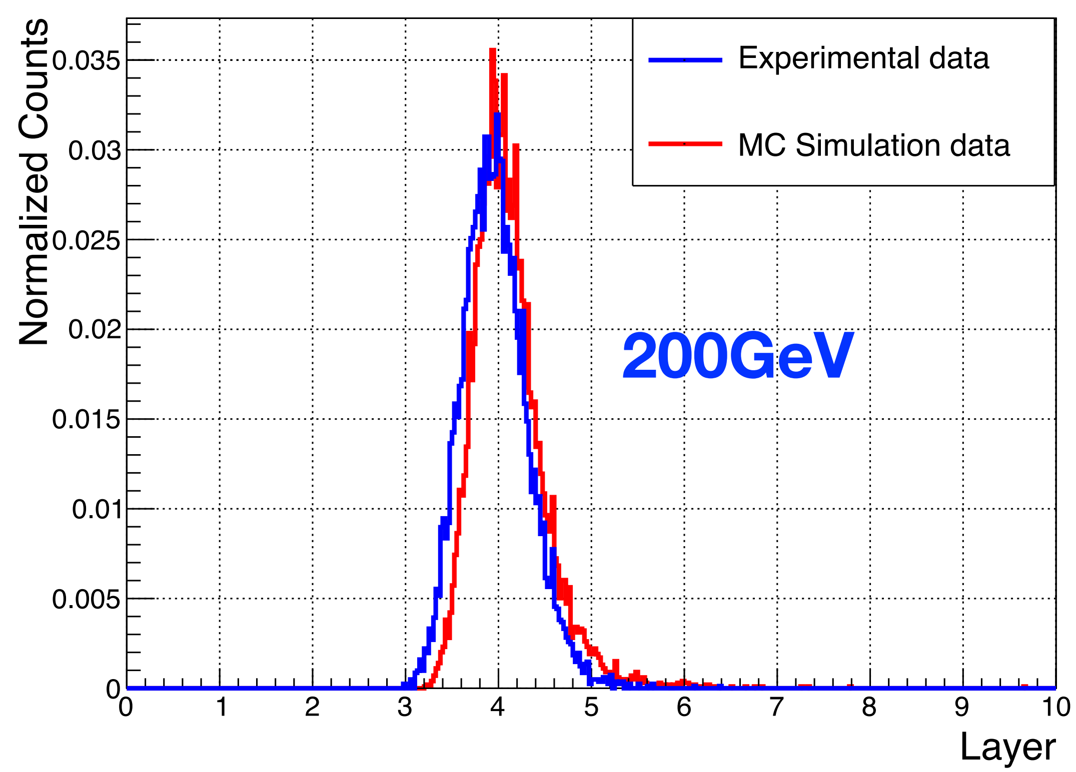


Shower maximum

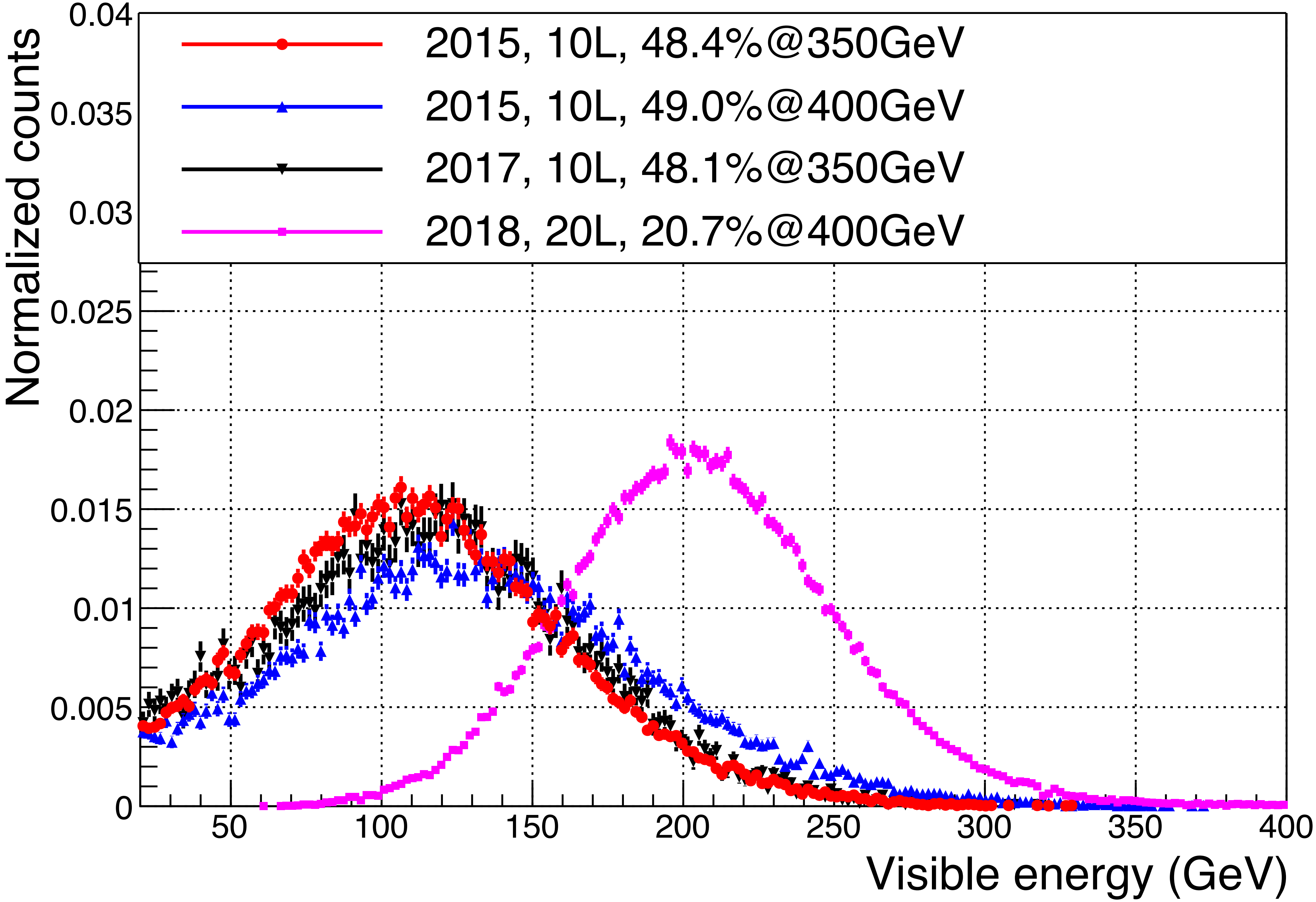




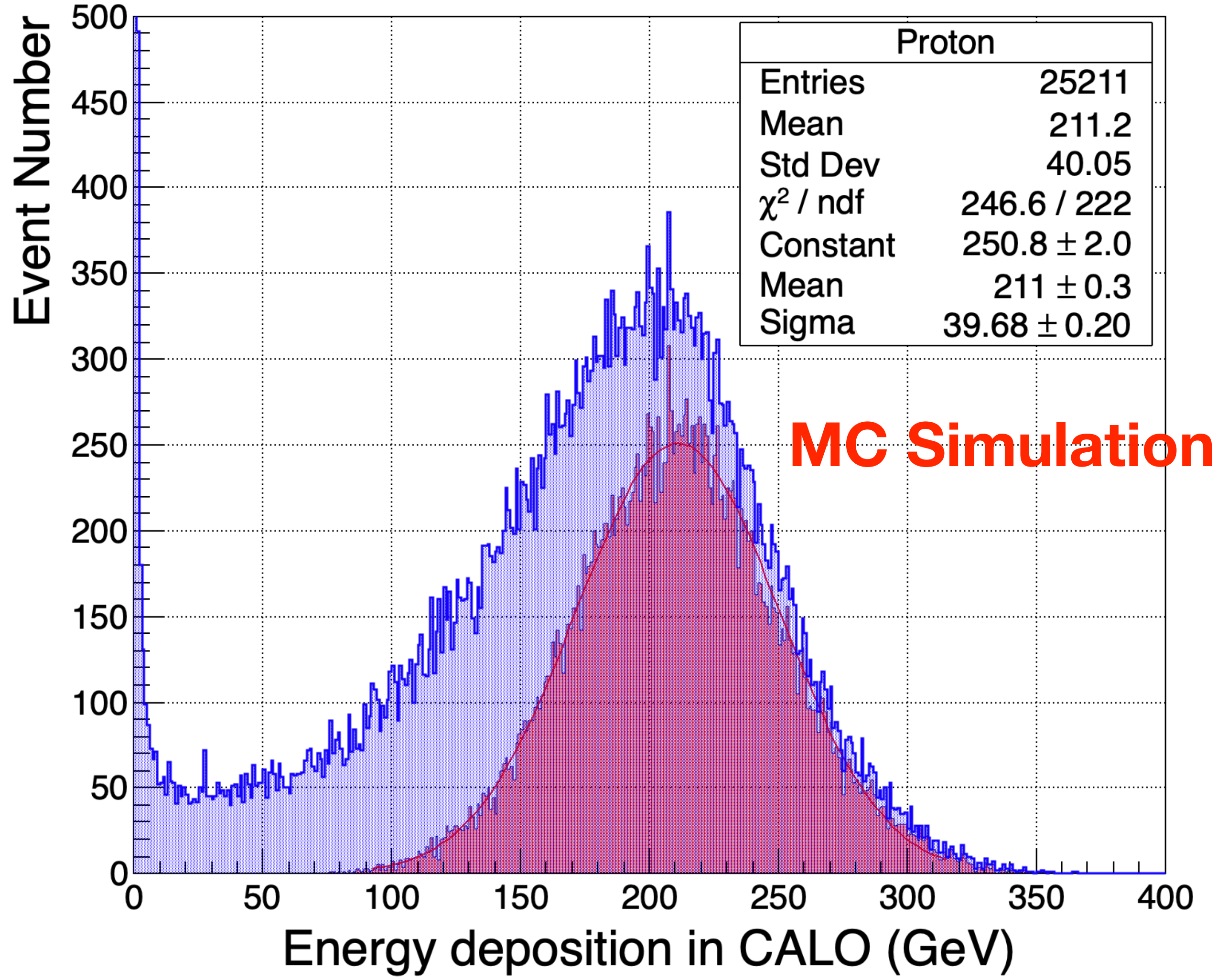


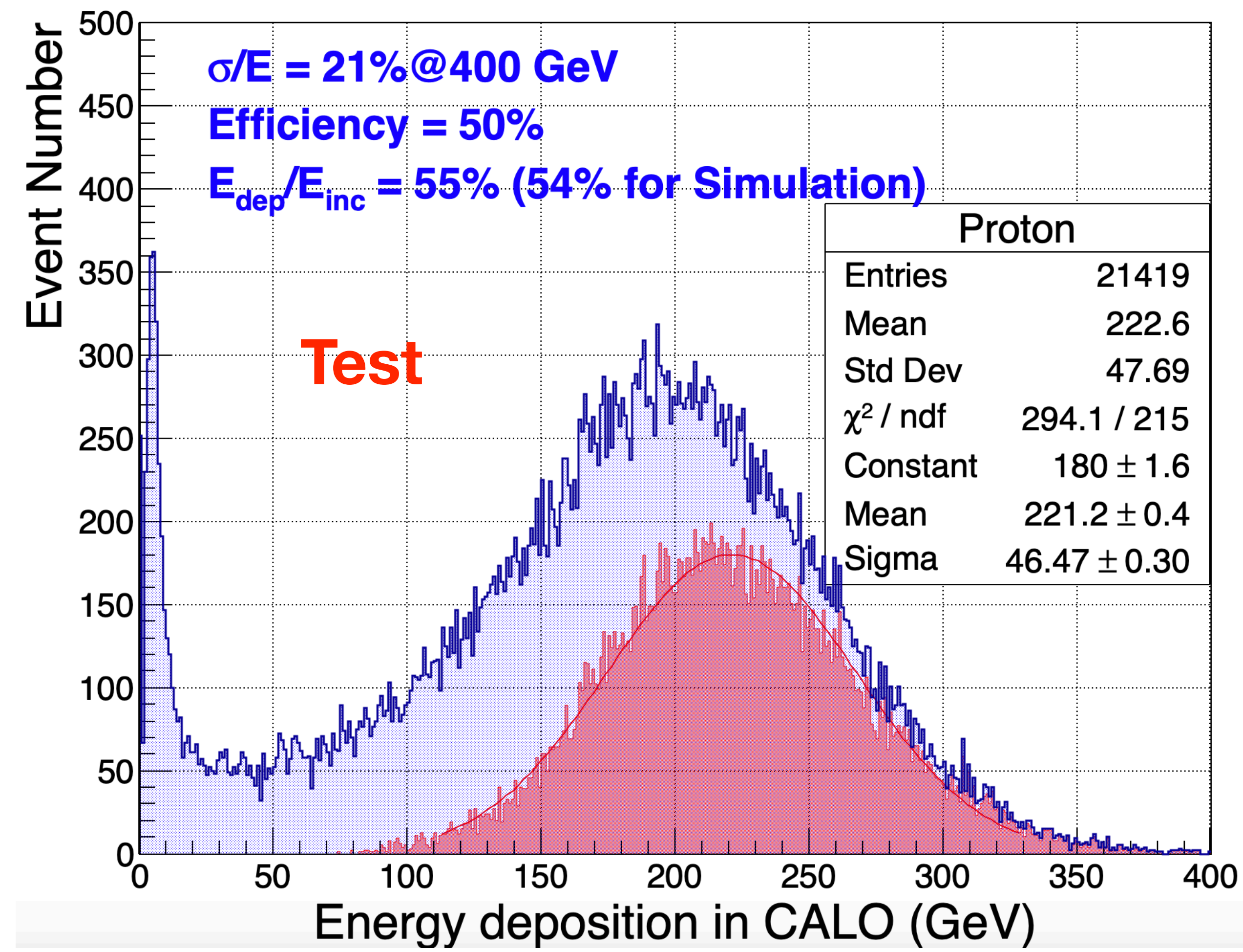


Protons: 10 layers VS 20 layers



Protons: 20 layers

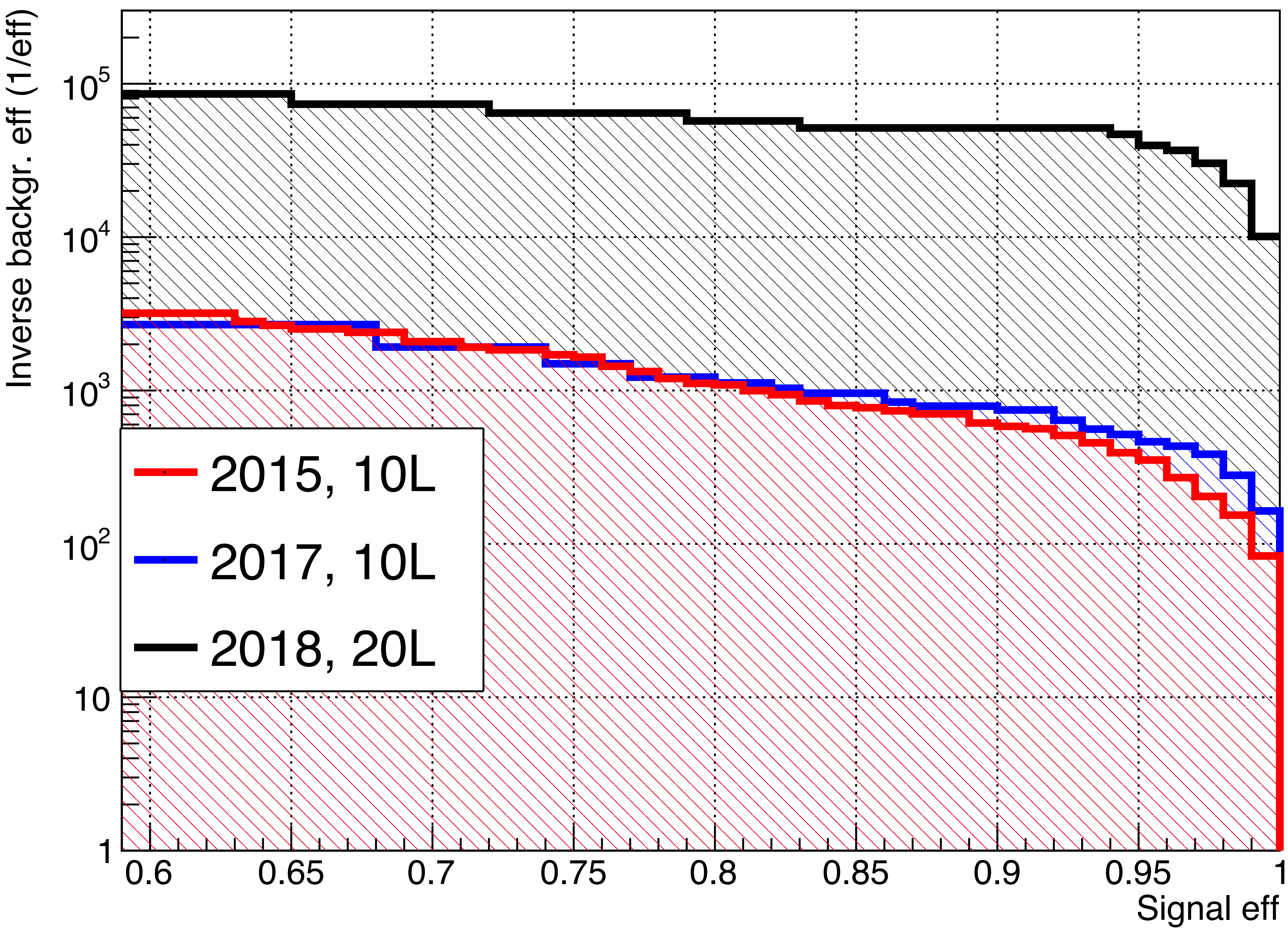




- **Selection: CALO contains shower max.**
- **MC Simulation: 19%@50% efficiency, peak value = 211 GeV;**
- **Test: 21%@50% efficiency, peak value = 221 GeV;**
- **Reason of differences: test data cannot be well described by the parameterized model used in digitization.**

e/p separation: BDT, TMVA

Using 200 GeV electrons and 400 GeV Protons for training and testing



Summary and prospect

- Energy resolution is 1.3%@200GeV for electrons, and 21%@400GeV for protons. Response linearity is better than 2%.
- The design of highly segmented 3-D calorimeter with WLS Fibers + IsCMOS readout is proved to be feasible for broad-band observation with good energy resolution.
- The next full-scale calorimeter prototype will use faster IsCMOS, maximum supported event rate is up to 800 cps: faster phosphor (P24), large-pixel sCMOS, low-impedance I.I. for a large linear range up to 5000 times.
- Study of digitization of MC simulation data, IsCMOS modeling.
- Study of the IsCMOS performance when the input signal is higher than 20000MIP(600GeV).

Thank you