Research and development of Hadronic Calorimeter for DarkSHINE Experiment

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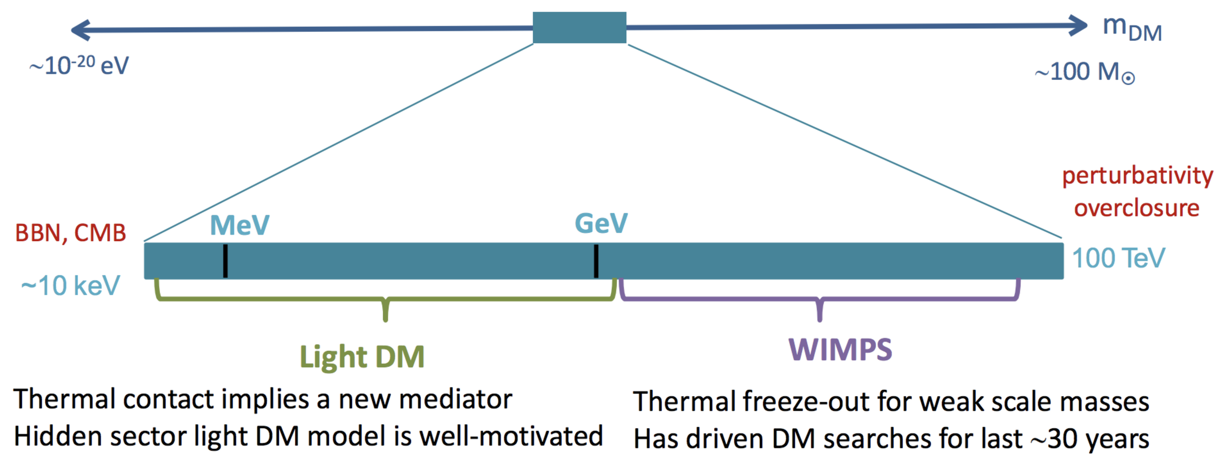
Introduction

The recently proposed DarkSHINE experiment is a fixed-target experiment designed to search for dark photon by utilizing electron beam from the SHINE (Shanghai High Repetition-Rate XFEL and Extreme Light Facility). Dark photon is introduced to mediate the interaction between dark matter and Standard Model (SM) particles in the Light Dark Matter (LDM) model through the mixing with photon. The hadronic calorimeter (HCAL) is one of the three sub-detectors within the DarkSHINE setup, providing veto capability against backgrounds, which include muons and neutral hadrons. The optimized design of HCAL and its hardware testing are presented.

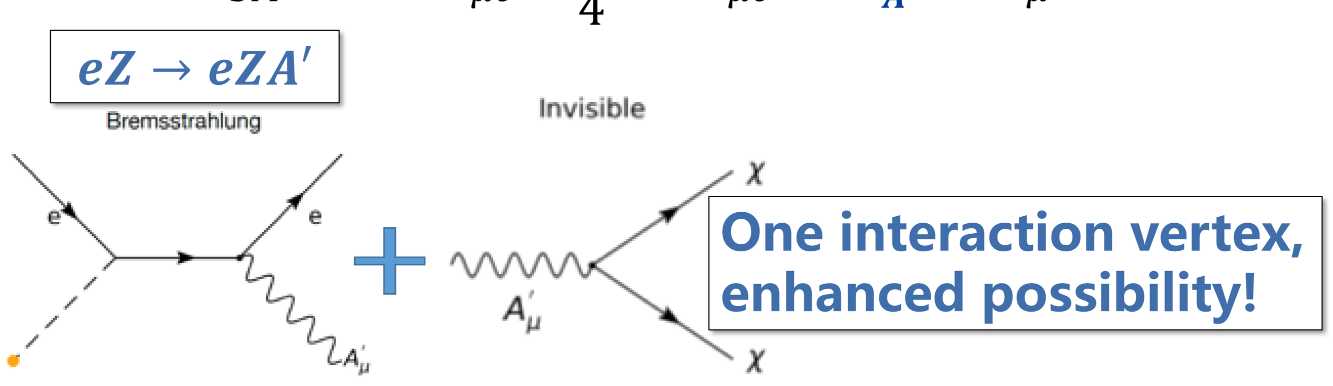
DarkSHINE experiment

- Various theories predict a broad mass range for Dark Matter.
- The freeze-out, being one of the prominent mechanisms, permits the possibility of DM within the MeV to 10 TeV range.

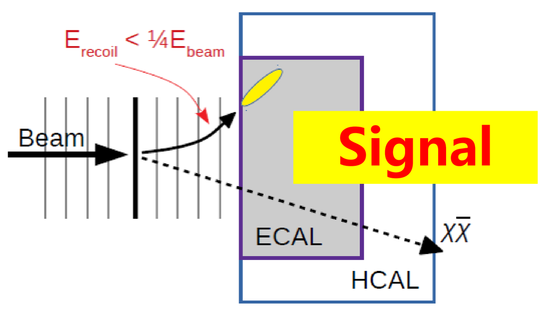


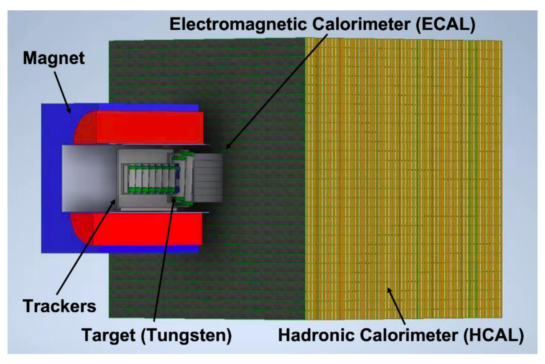
- WIMPs has been extensively studied, but the sub-GeV LDM remains to be explored. Dark Photon (A') serves as an important portal between DM and SM particles.

$$L = L_{SM} + \varepsilon F^{\mu\nu}F'_{\mu\nu} + \frac{1}{4}F'^{\mu\nu}F'_{\mu\nu} + m_{A'}^2 A'^{\mu}A'_{\mu}$$

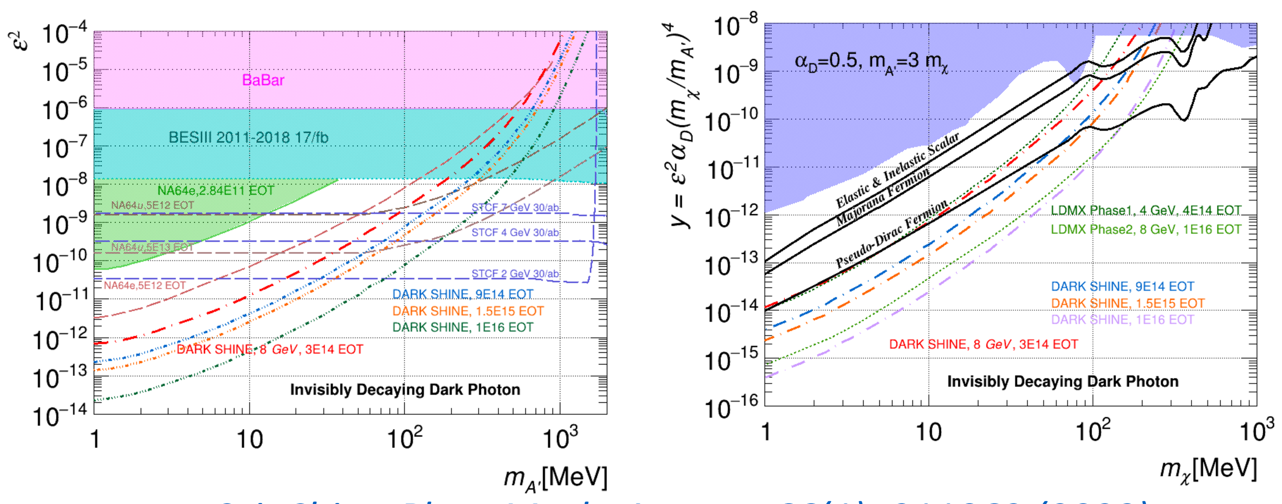


- DarkSHINE: electron-on-target, **8 GeV** single-electron beam from SHINE, **3e14 EOT/year**
- Search for A' in $[m_{A'}, \varepsilon]$ parameter space





- **Competitive sensitivity**



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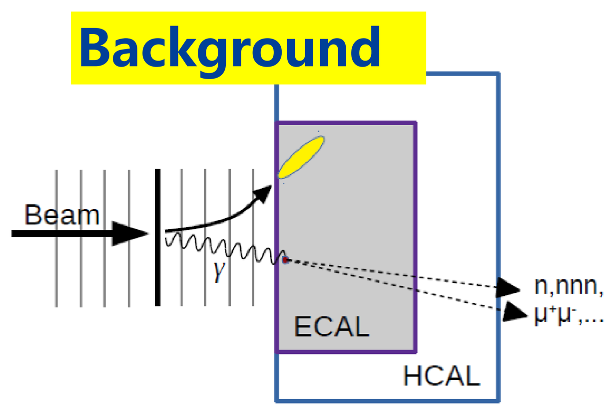
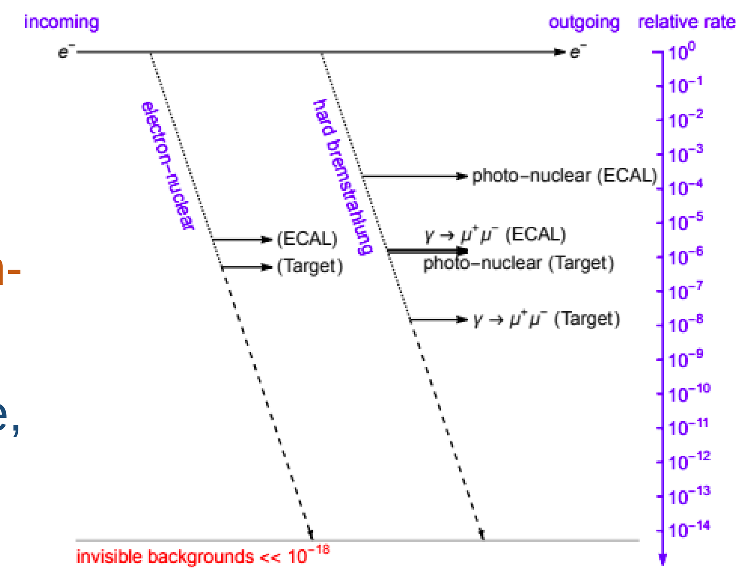
HCAL Design optimization

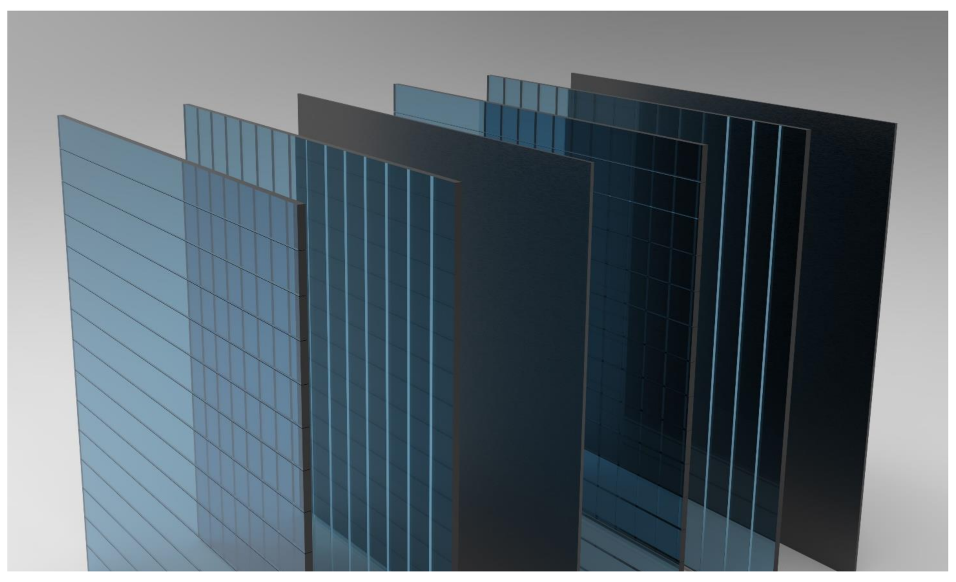
- HCAL provides veto functionality against backgrounds, which encompass muons and neutral hadrons and have same performance to signal process.



- Leading background: γ bremsstrahlung
- Rare processes include: electron-nuclear, photon-nuclear, γ→μμ
- Neutrino production is irreducible, but negligible



- 1.5 m × 1.5 m (perpendicular to the beam), ~10 λ (~160 cm iron, parallel to the beam), sensitive layers (Plastic scintillator + Wavelength shift fiber) + iron absorber layers
- Split to 4 modules, 75 cm × 75 cm each
- Iron absorber: 10 mm/50 mm thick, 75 cm × 75 cm
- Plastic scintillator: 10 mm thick, 75 cm × 5 cm, 15 bars per layer per module
- 90 degree rotation between 2 adjacent layers

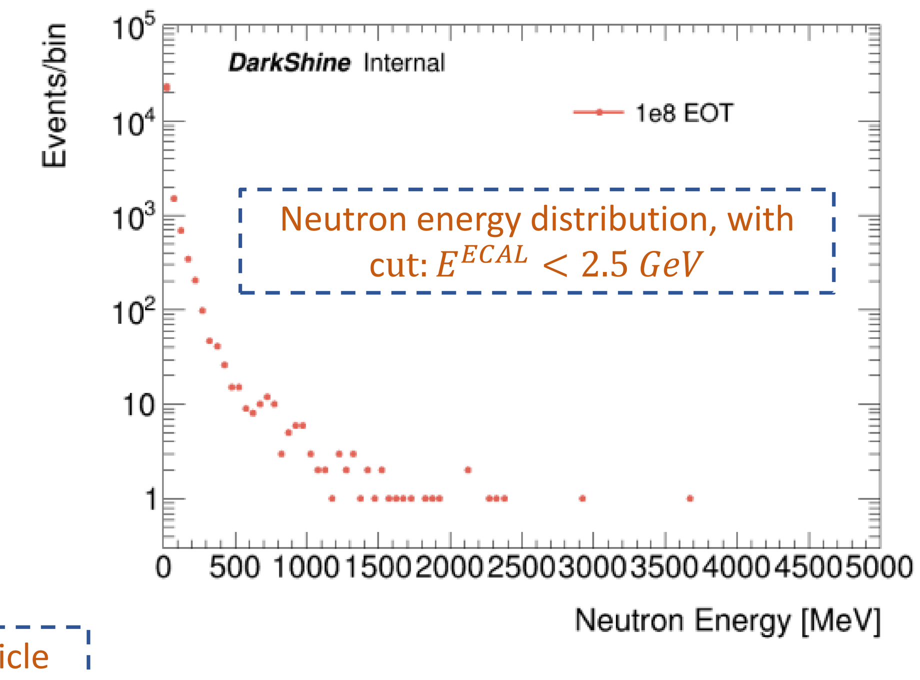


Process	Neutron	Proton	Pion	Kaon
Electron-Nuclear	73.42%	21.52%	4.64%	0.42%
Photon-Nuclear	64.95%	18.56%	14.43%	2.06%

Particle types and frequencies from electron-nuclear and photon-nuclear process and its ratio.

- The muons are expected to deposit a quantifiable amount of energy, with the performance of neutral hadron rejection being employed as the metric for the optimization of geometric design.

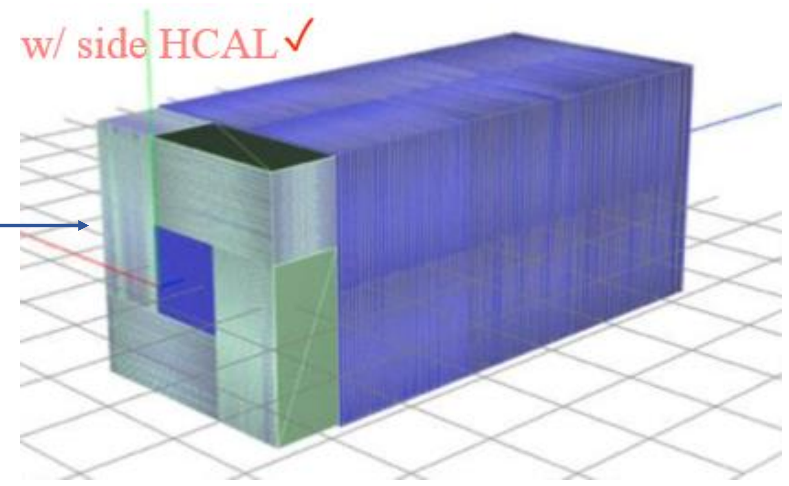
- Define veto inefficiency: ratio of hadrons/events that can not be rejected by HCAL cuts:
- $E_{Total}^{HCAL} < 30\ MeV\ \&\&\ E_{Max-cell}^{HCAL} < 0.1\ MeV$
- High p_T neutron: Veto inEff $< 1 \times 10^{-5}$ can suppress backgrounds to unit level in 3×10^{-14} EOT
- Low p_T neutron: multi-neutrons in one event, Veto inEff $\sim 1 \times 10^{-3}$ is enough



Energy[MeV] \ Particle	n	k^0	π^0	p
100	1.17E-03	3.16E-02	7.30E-06	3.07E-02
500	1.84E-05	3.30E-06	1.00E-07	8.04E-06
1000	3.70E-06	4.30E-06	1.00E-07	1.00E-07
2000	2.70E-06	1.15E-05	1.00E-07	1.00E-07

Neutral particle veto inefficiency

- Side HCAL: encircling the ECAL



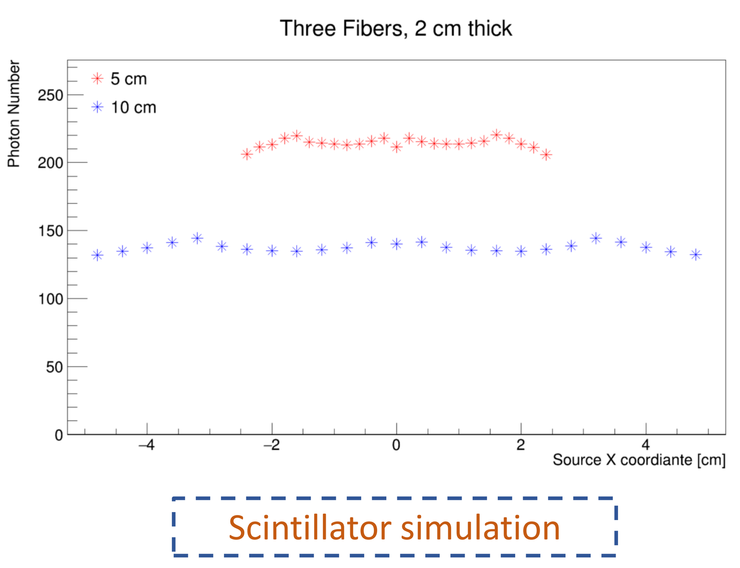
Structure \ Process	EN-target	EN-ECAL	PN-target	PN-ECAL
x-abs-y-noside	2.68E-02	3.94E-02	9.29E-02	1.24E-01
x-abs-y-side	1.04E-03	1.09E-02	1.94E-03	3.58E-02

Rare process events veto inefficiency

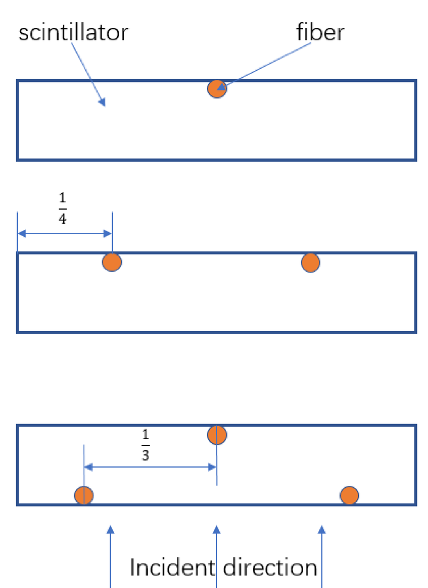
arXiv:2311.01780

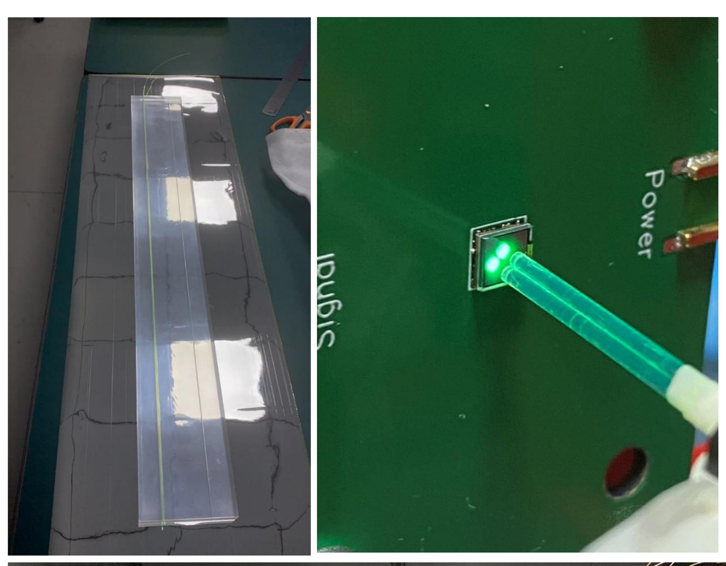
Scintillator test

- Scintillator size : 5/10 cm × 75 cm × 1 cm/2 cm
- Fiber size : 0.5 mm radius with clad
- Incident e^-, 100 MeV
- Incident position : -2.4/-4.8 cm to 2.4/4.8 cm per 0.2/0.4 cm

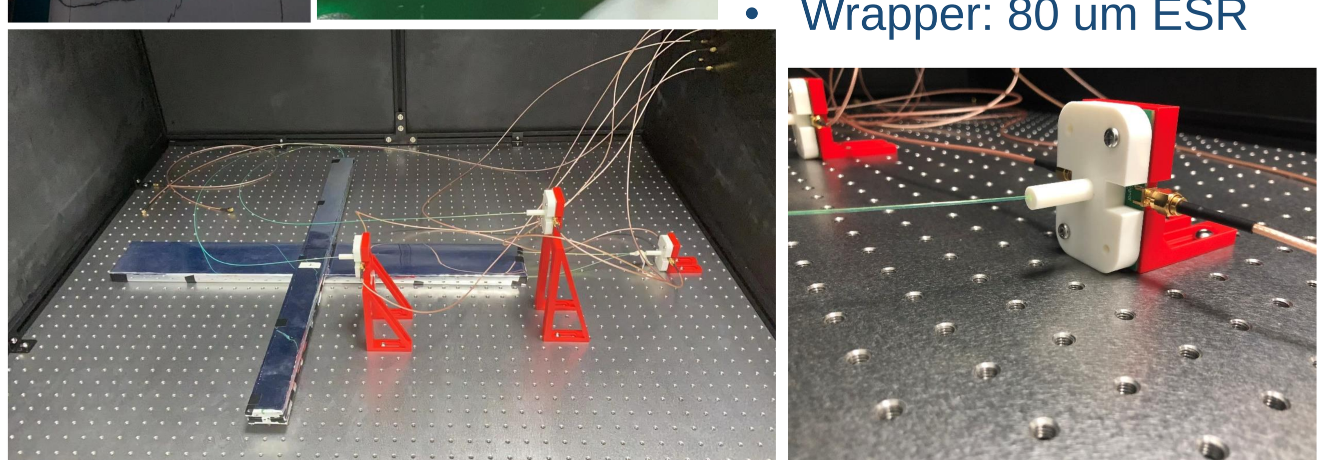


Scintillator simulation

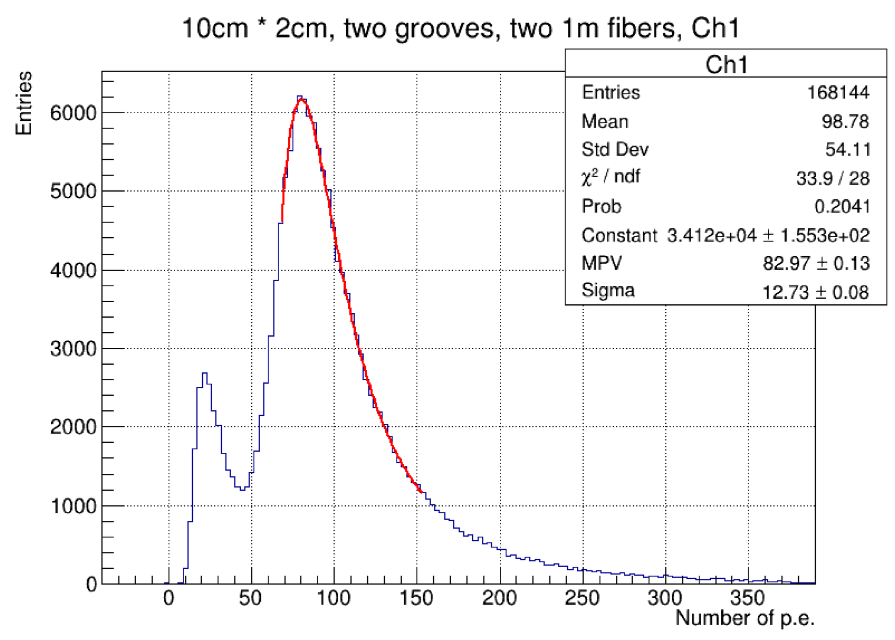




- Scintillator: HND-S2 (高能科迪) polystyrene
- Width/thickness/grooves are varied
- WLS: Kurary, d = 1 mm, reflector on one side
- SiPM: EQR15 11-3030D-S, 3.0 mm × 3.0 mm, 40000 microcell
- Wrapper: 80 um ESR



- Uniformity test is done by utilizing radioactive source.
- Evaluation of the photon yield from various scintillators is currently underway.



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