

单光子灵敏相机成像研究

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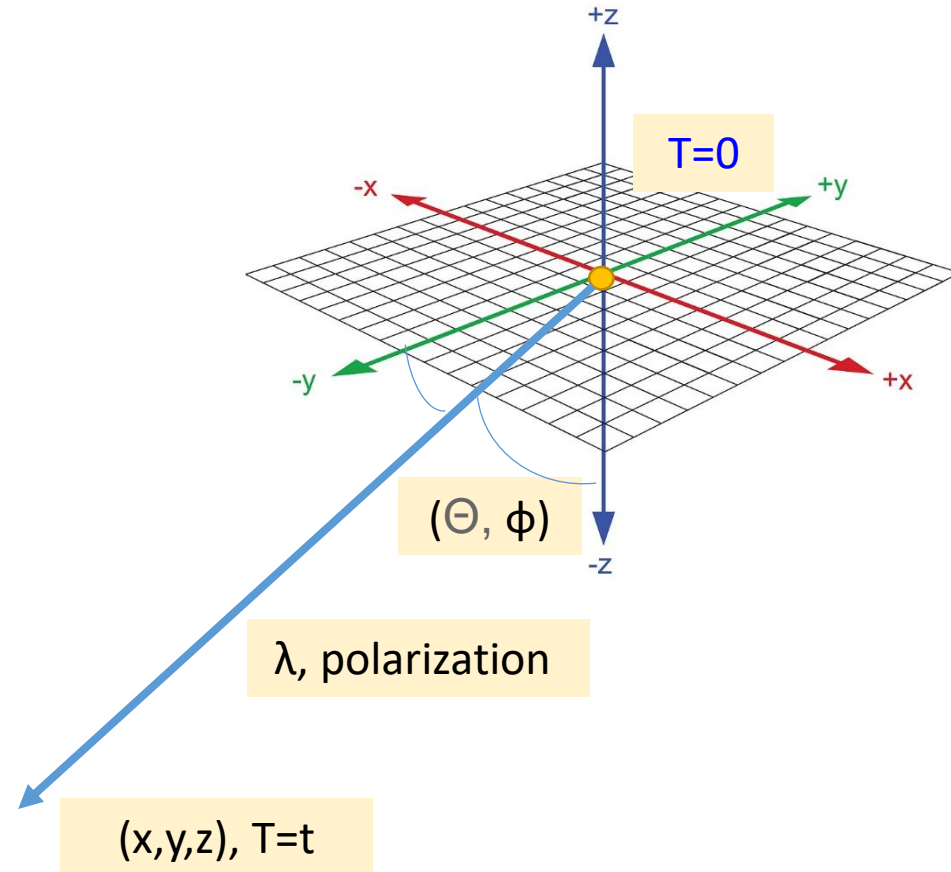
Outline

- Photon detection & Imaging
- Characteristic of camera
- Double-slit Young's interference
- Particle imaging with CsI(Tl) crystal

Parametrization of a single photon

- **Parameters:**

- Wavelength: λ
- Polarization
- Direction: (Θ, ϕ)
- **Hitting location: (x,y,z)**
- **Arriving time: t**



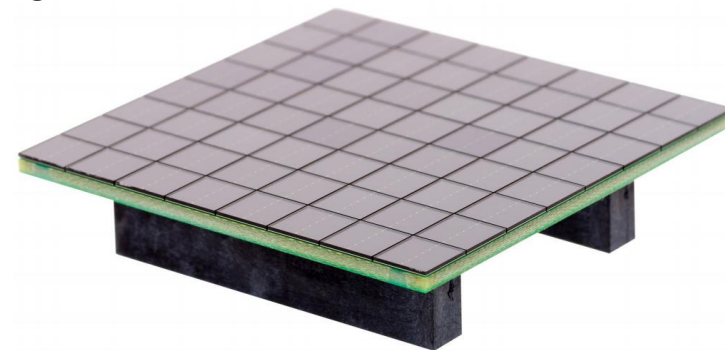
PMT/SiPM vs. imaging

- PMT/SiPM:
 - Roughly (x,y,z) , (cm,mm)
 - T (ns, ps)
- Imaging:
 - (x,y,z) (mm,um)
 - (Θ, ϕ)



https://www.hamamatsu.com/content/dam/hamamatsu-photonics/sites/documents/99_SALES_LIBRARY/etd/PMT_handbook_v3aE.pdf

SiPM

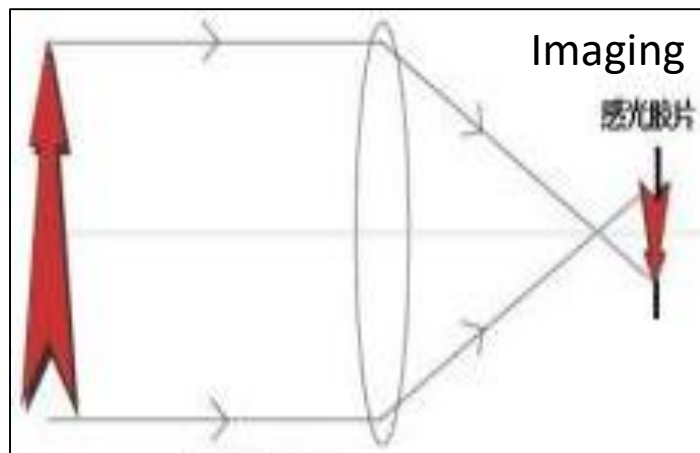
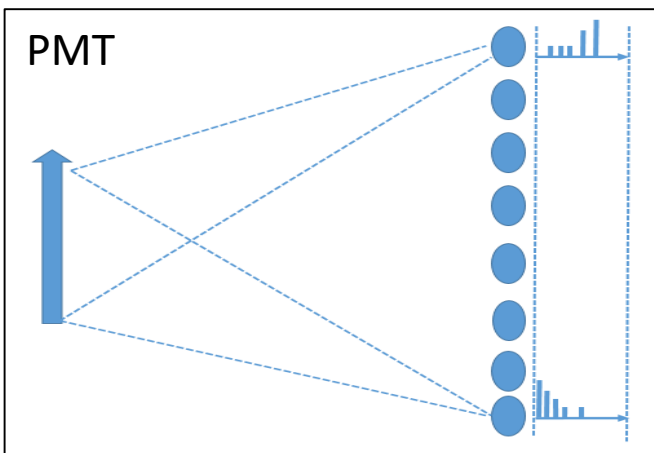


<https://www.onsemi.com/pdf/datasheet/arravi-series-d.pdf>

Film

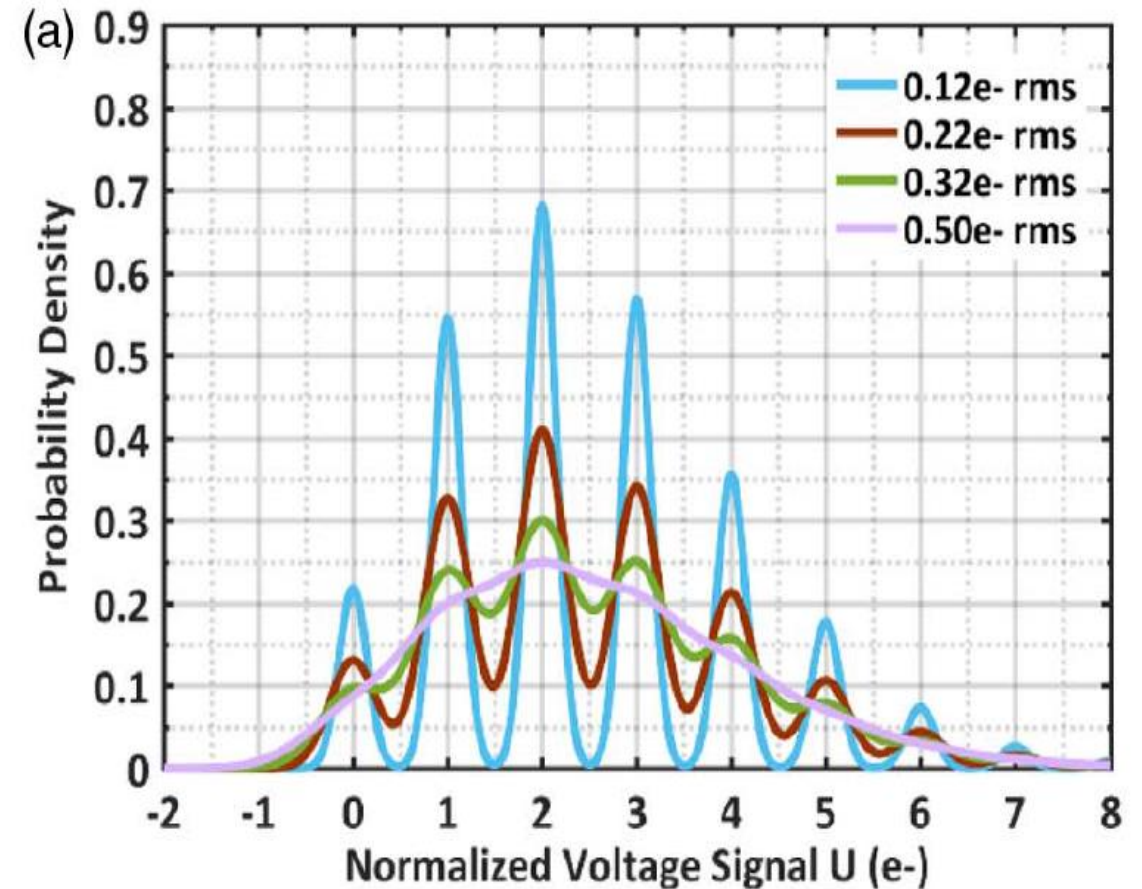


Camera

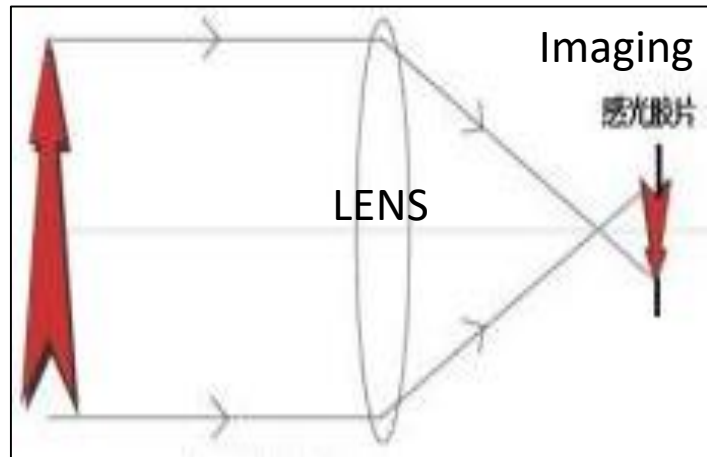


Noise vs. signal (signal-noise ratio)

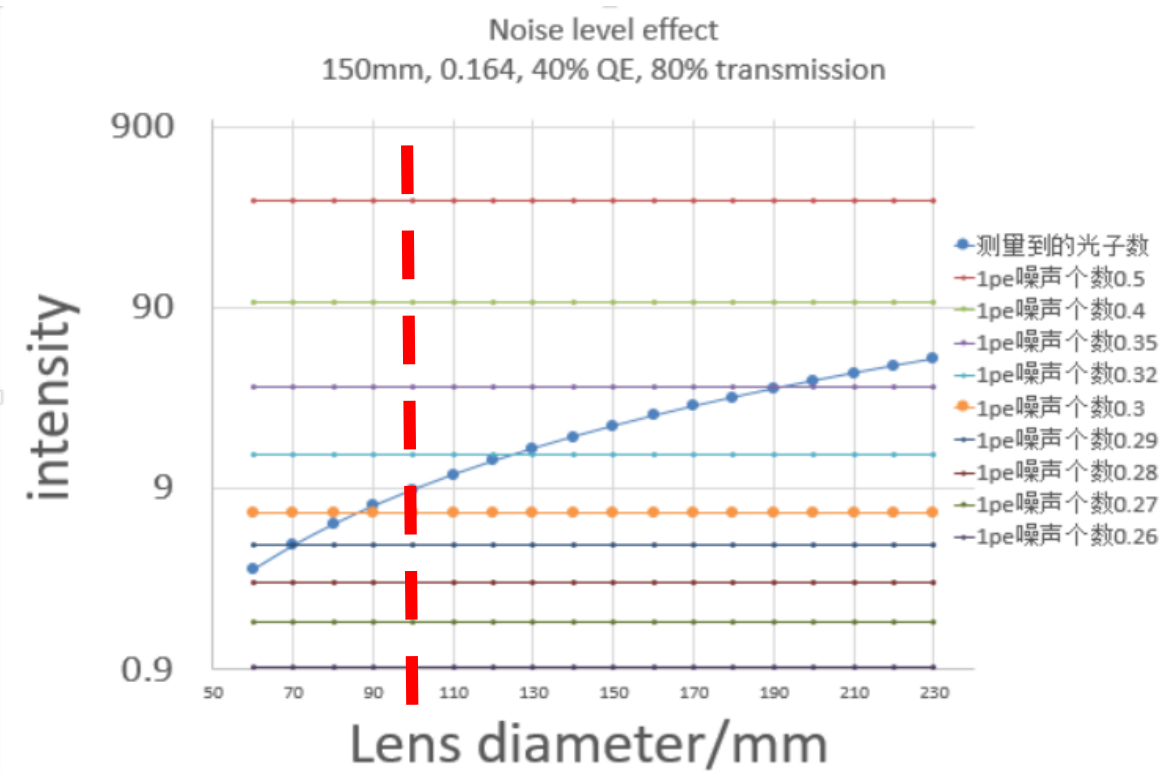
- Noise level/resolution @single photon level(SPE)
 - PMT: ~30% (0.3e-)
 - SiPM: 10%~20% (0.2e-)
 - Camera: 1~100e-
- Single photon counting
 - <40%@SPE



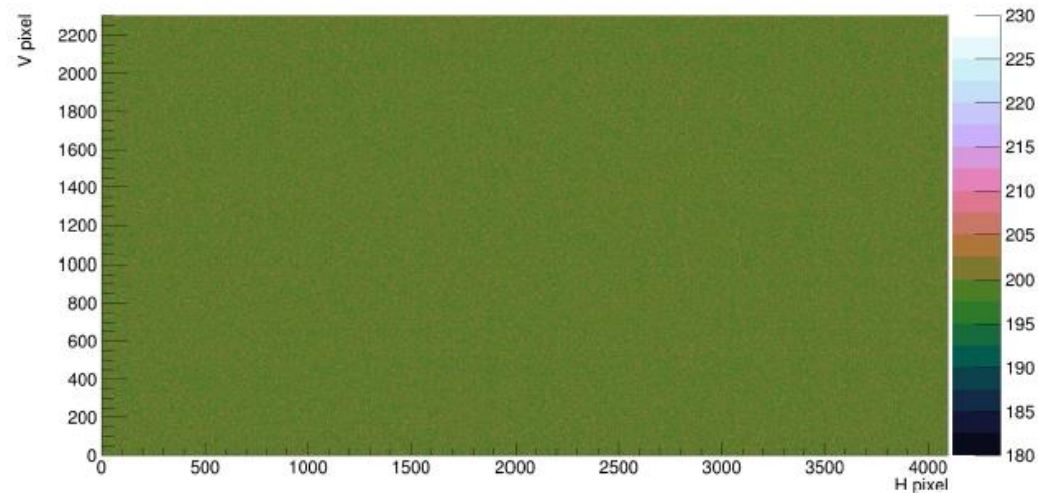
Noise vs. identification@imaging



- Possibility to identify a signal from noise
 - Signal intensity
 - Solid angle
 - Lens diameter
 - effective aperture
 - Distance
 - Noise level

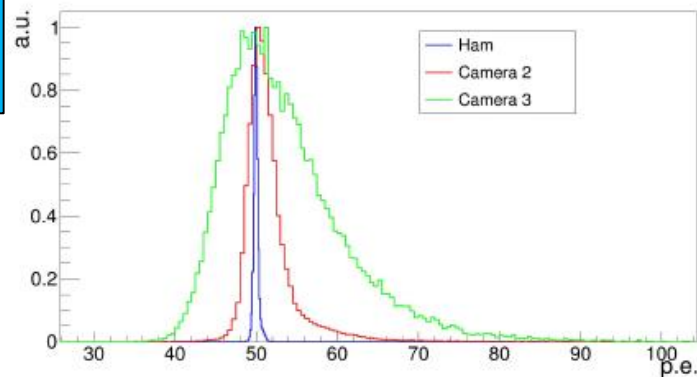


Single photon sensitive camera

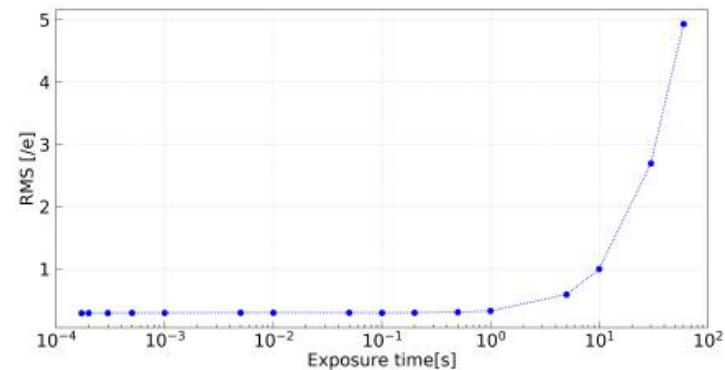


(a) 2-D image of the camera in dark w/ exposure 1 s

Noise level reaching
to $0.3e^-$



(b) 1-D plot of pixel noise in (a)



(c) Noise vs. exposure time

暗电流噪声
读出噪声

Cross check between PMT and camera

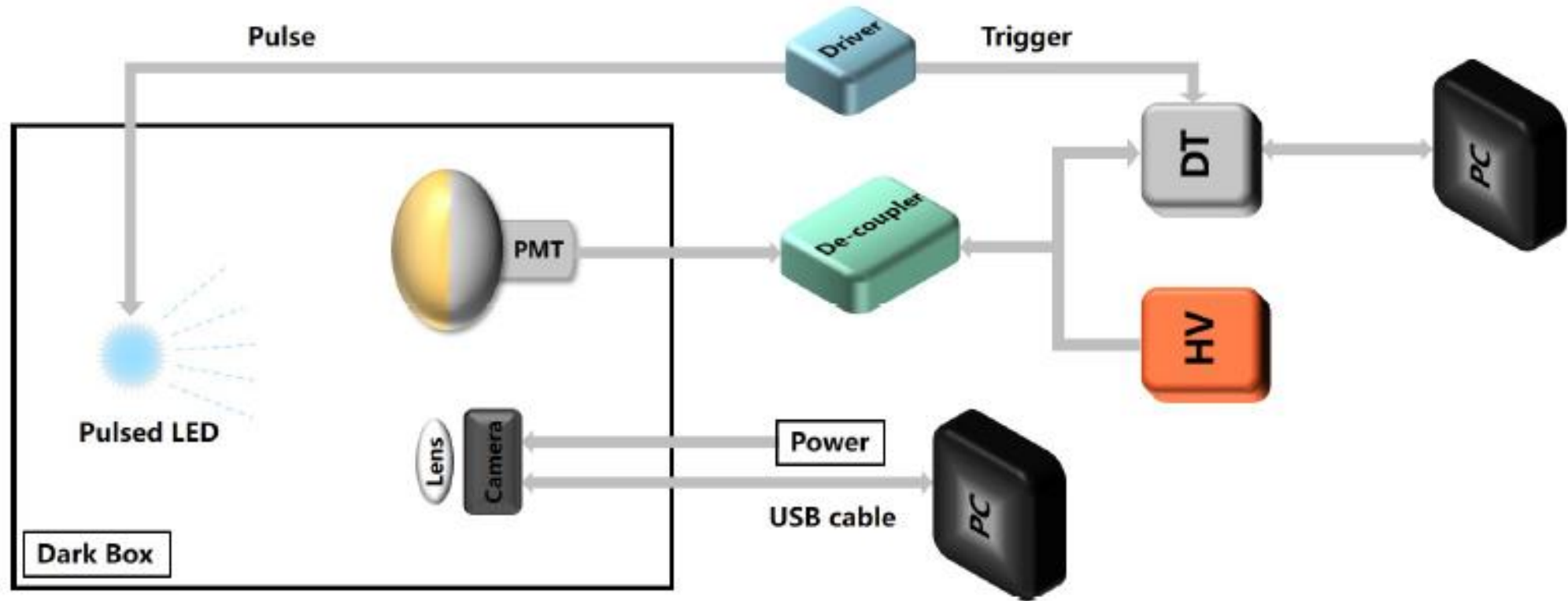
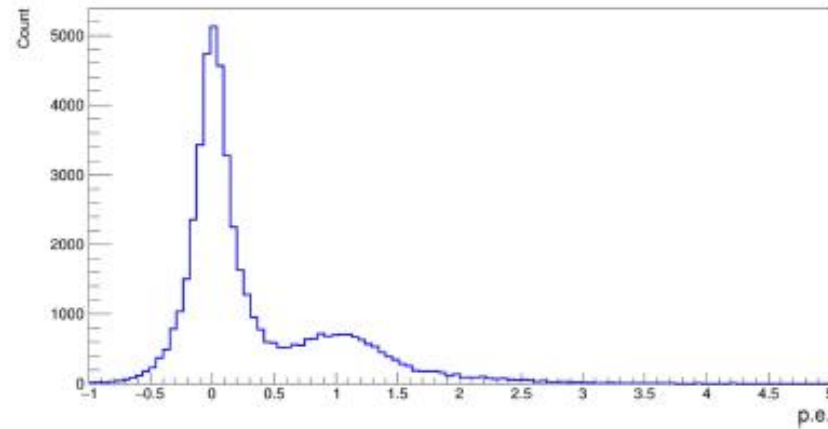


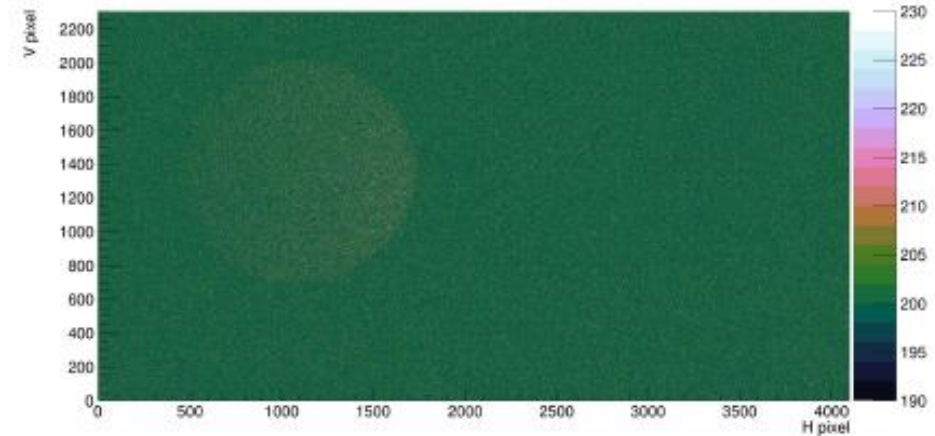
Fig. 1: Schema of LED testing system.

Single photon testing With light source

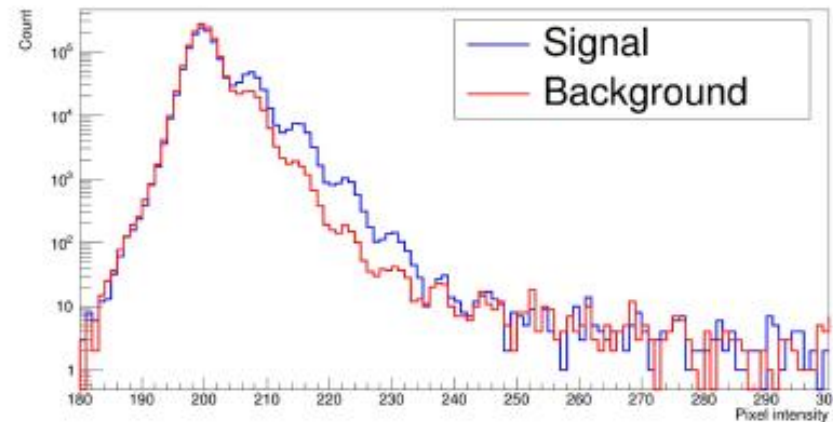
- Pulse light
- Single photon identified
- Light intensity



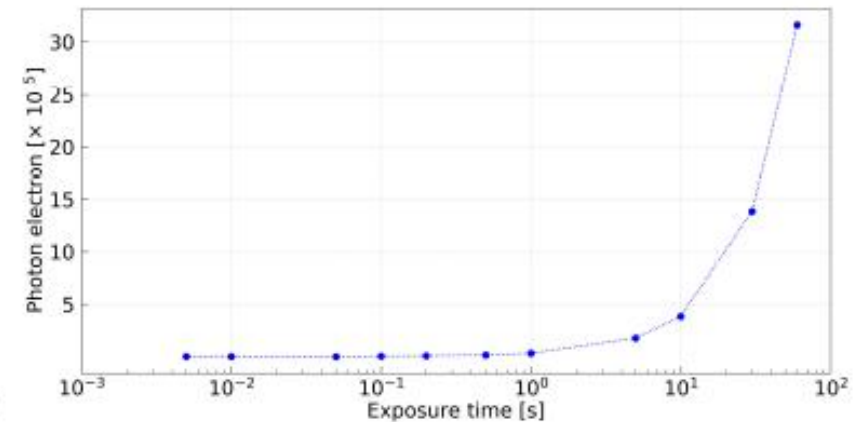
(a) Intensity viewed by PMT.



(b) 2-D image of LED



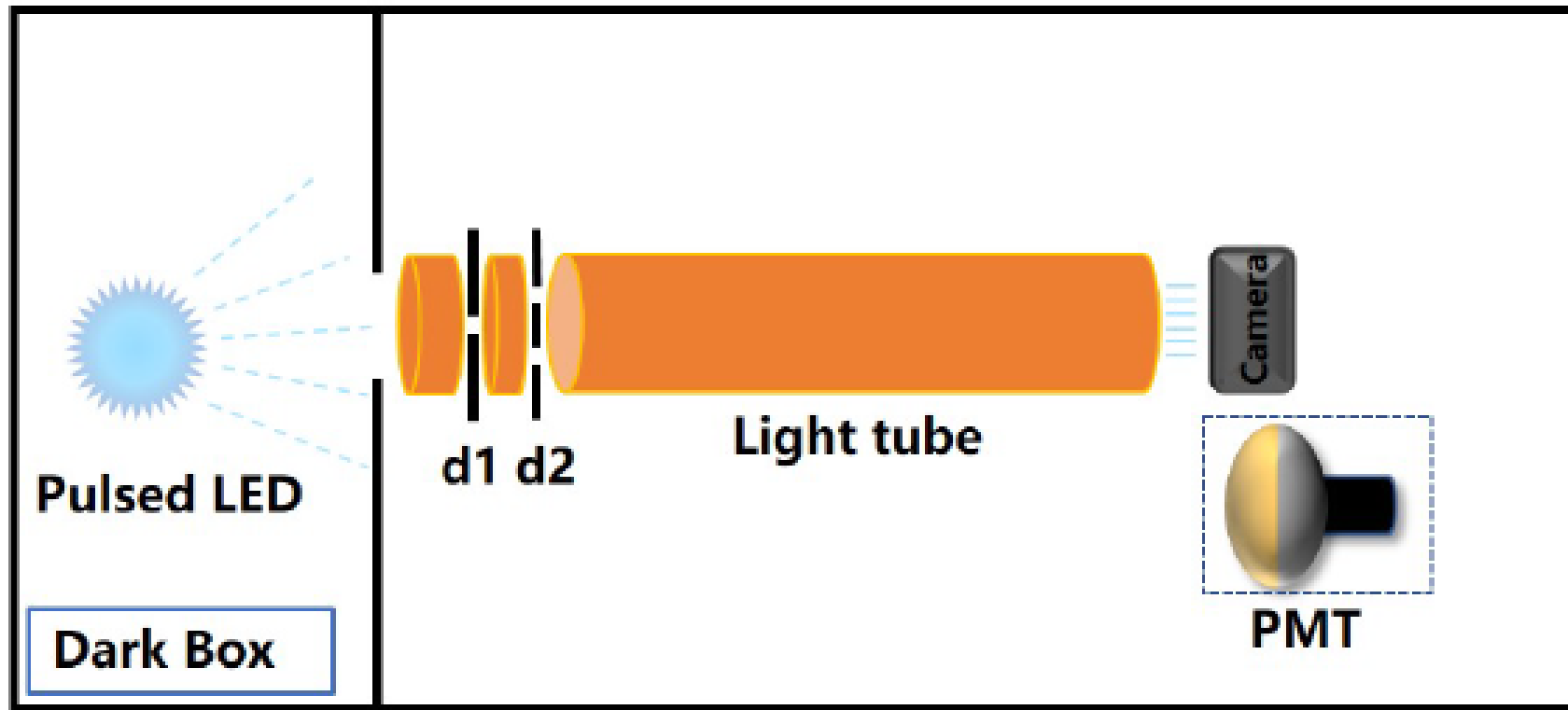
(c) 1-D plot of pixels intensity



(d) Intensity vs. exposure time.

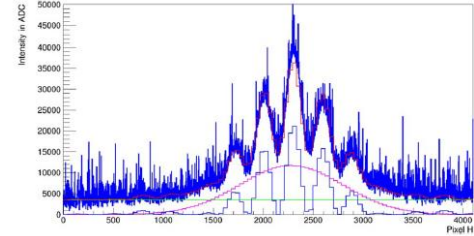
Single photon Double-slit Young's interference

Single photon in
space and time

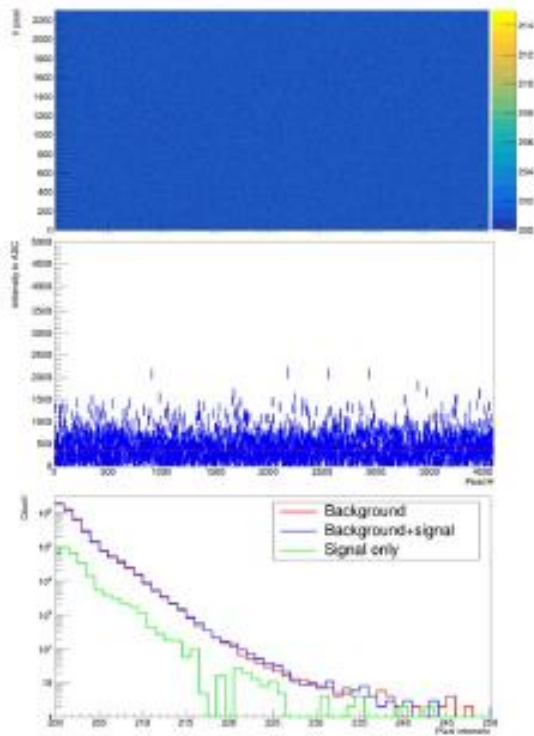


(a) Schema of Young's interference.

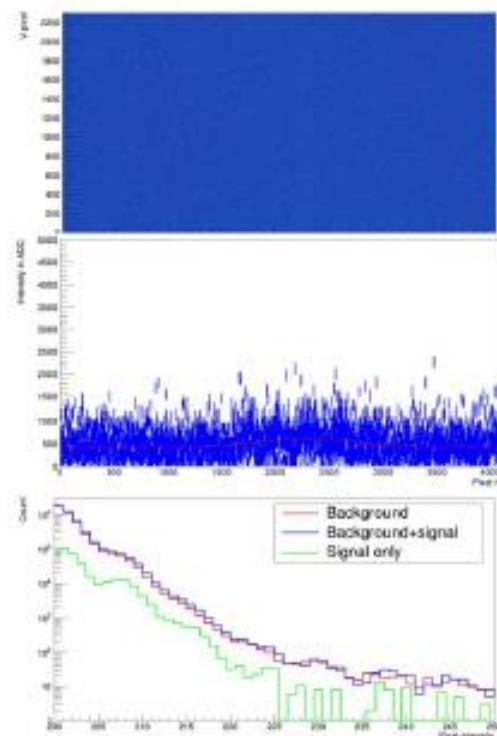
Double-slit Young's interference with single photon



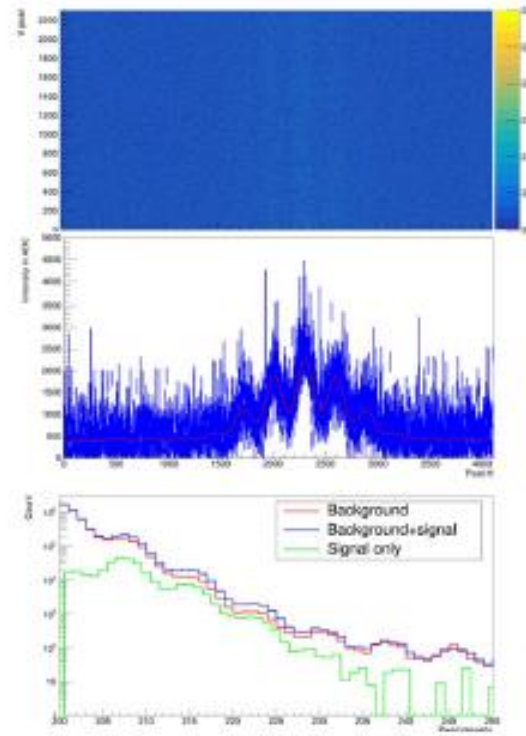
(a) 1-D plot fitting of the interference 60s



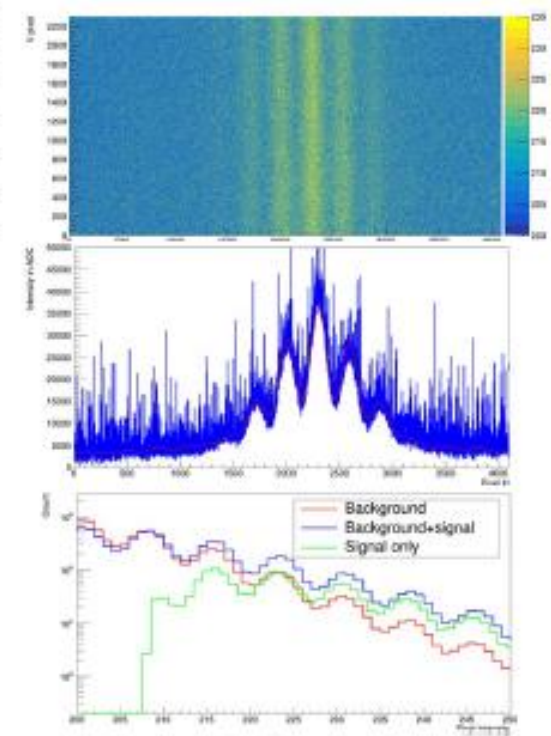
(a) 0.1 s



(b) 1 s

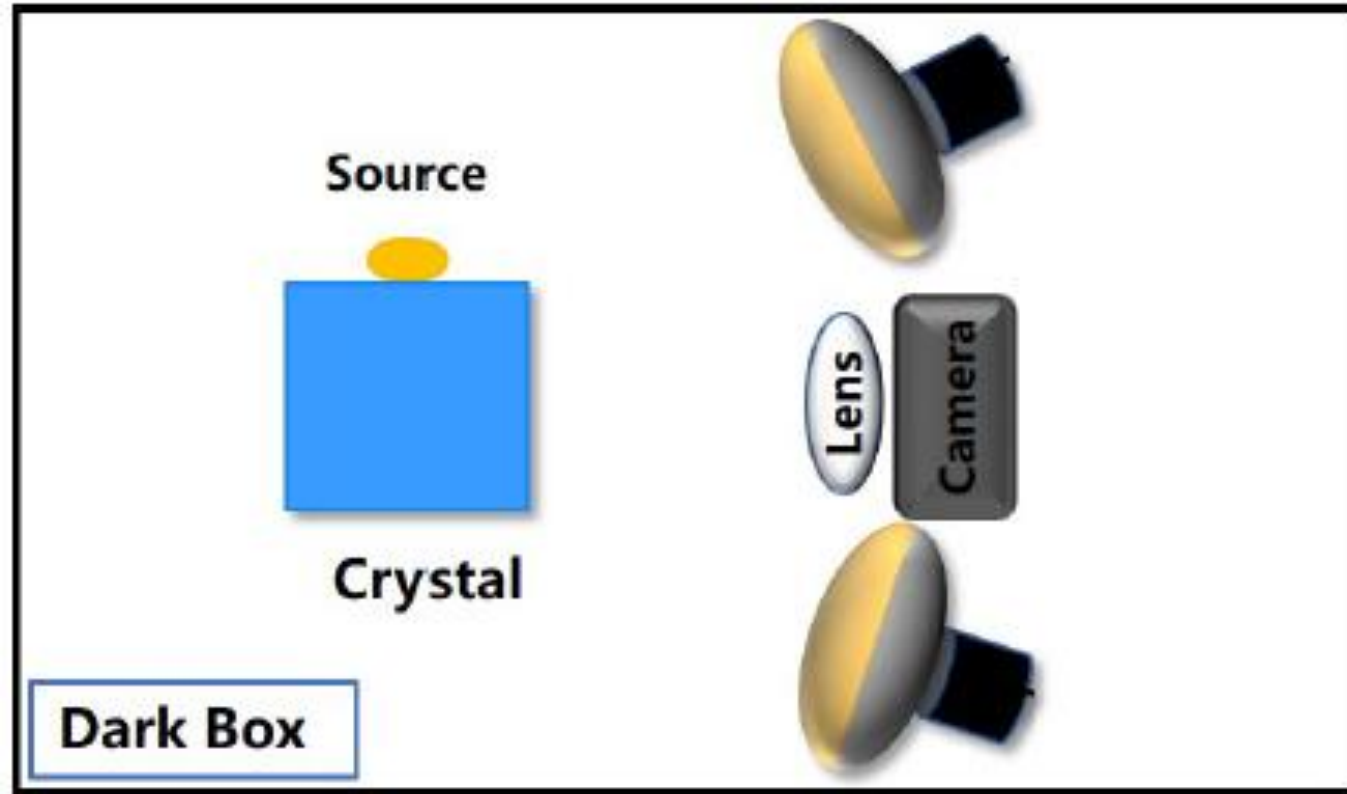


(c) 5 s



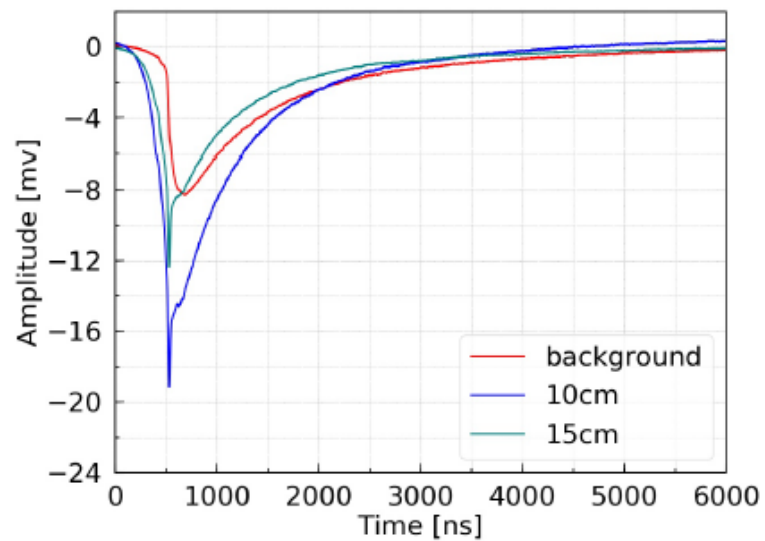
(d) 60 s

Particle imaging with CsI(Tl) crystal & ^{241}Am

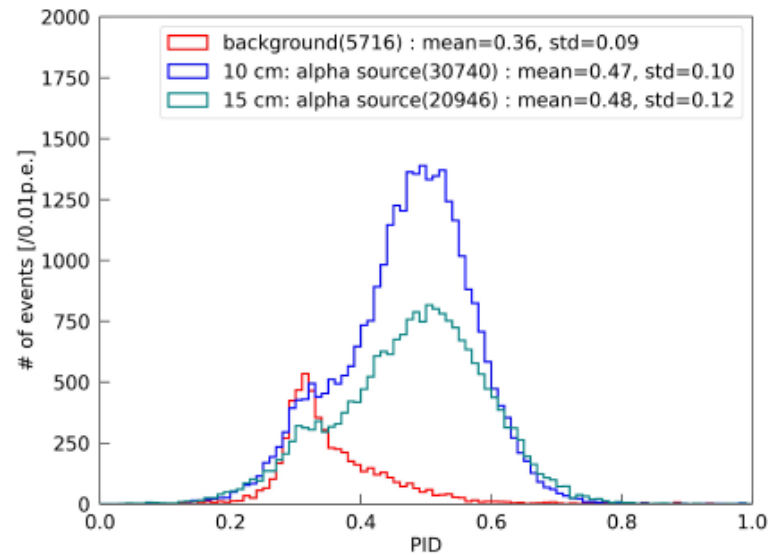


(b) Schema of crystal test.

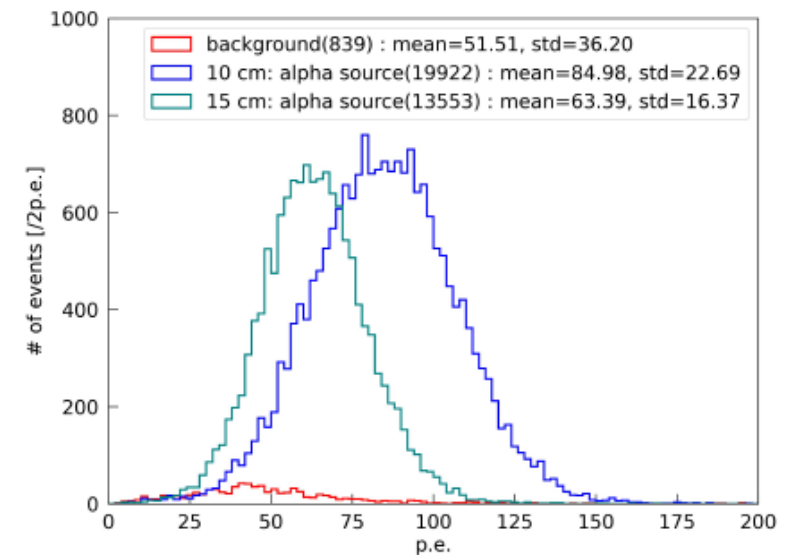
Selection of Alpha events (by PMT)



(a) Average waveform



(b) PID of crystal

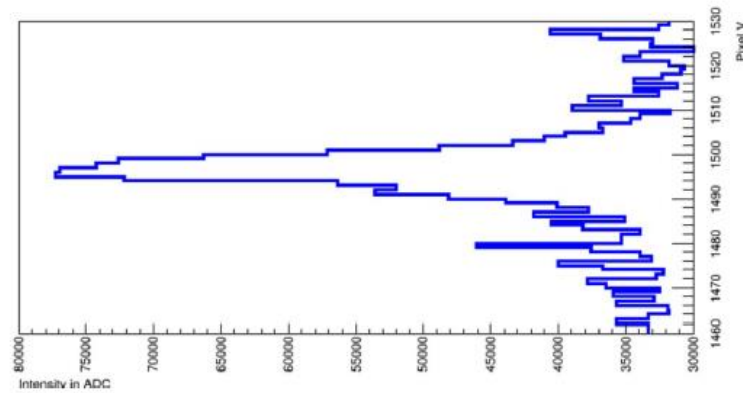


(c) Charge intensity

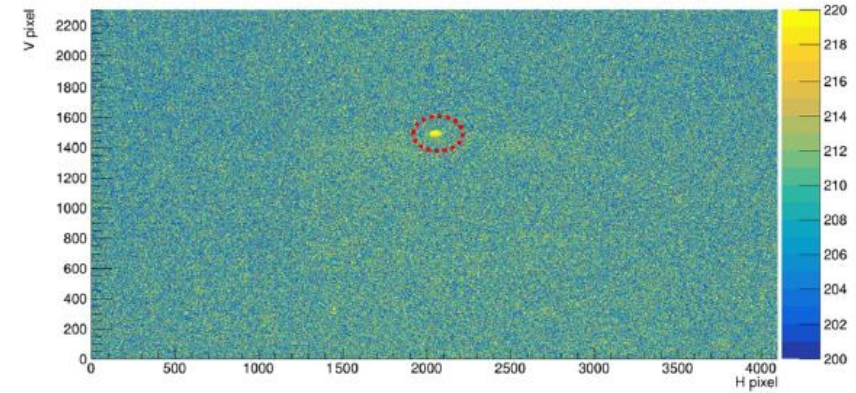
- ~100Hz
- ~80pe/alpha event@10cm

Imaging of ^{241}Am

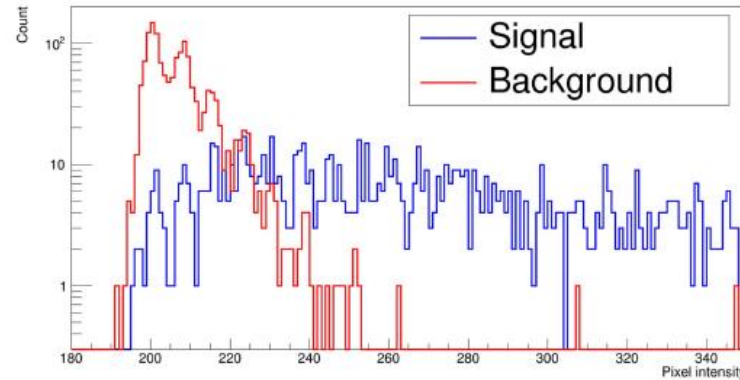
- Source location:
 - $\sim 0.1\text{mm}$
- Source intensity



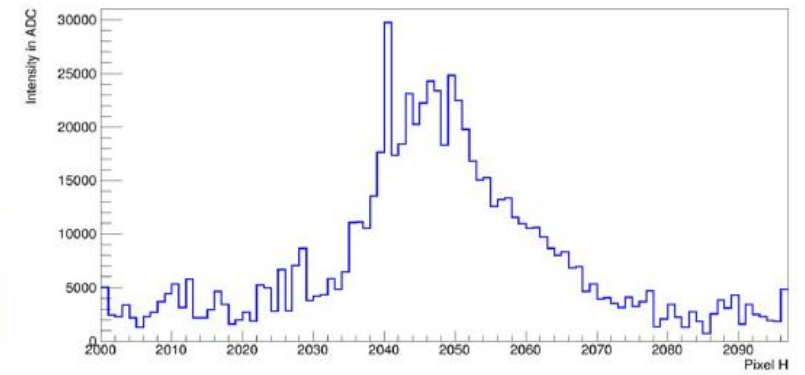
(a) 1-D intensity on vertical



(b) 2-D image of crystal w/ alpha

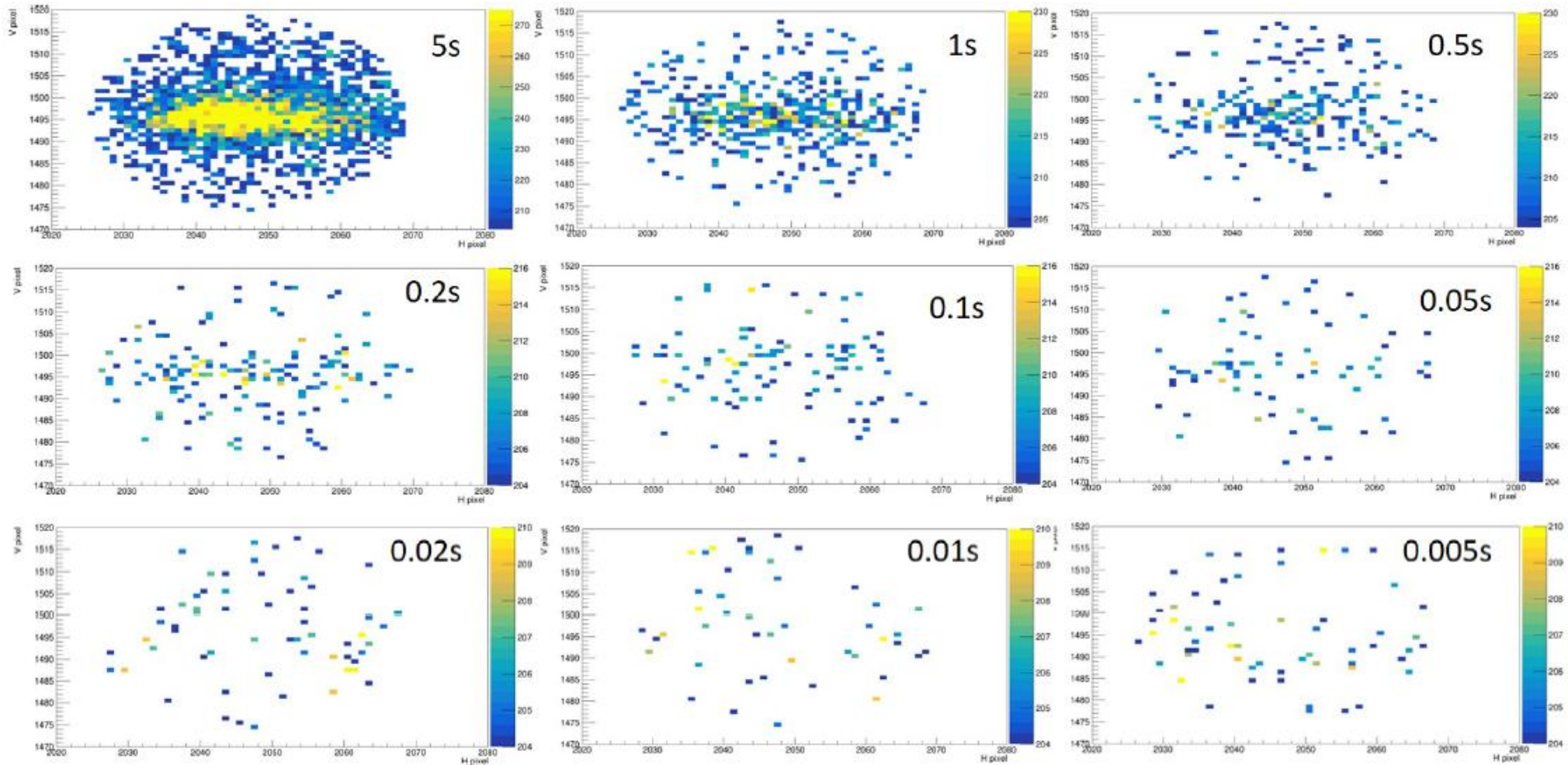


(c) Pixel intensity of source region



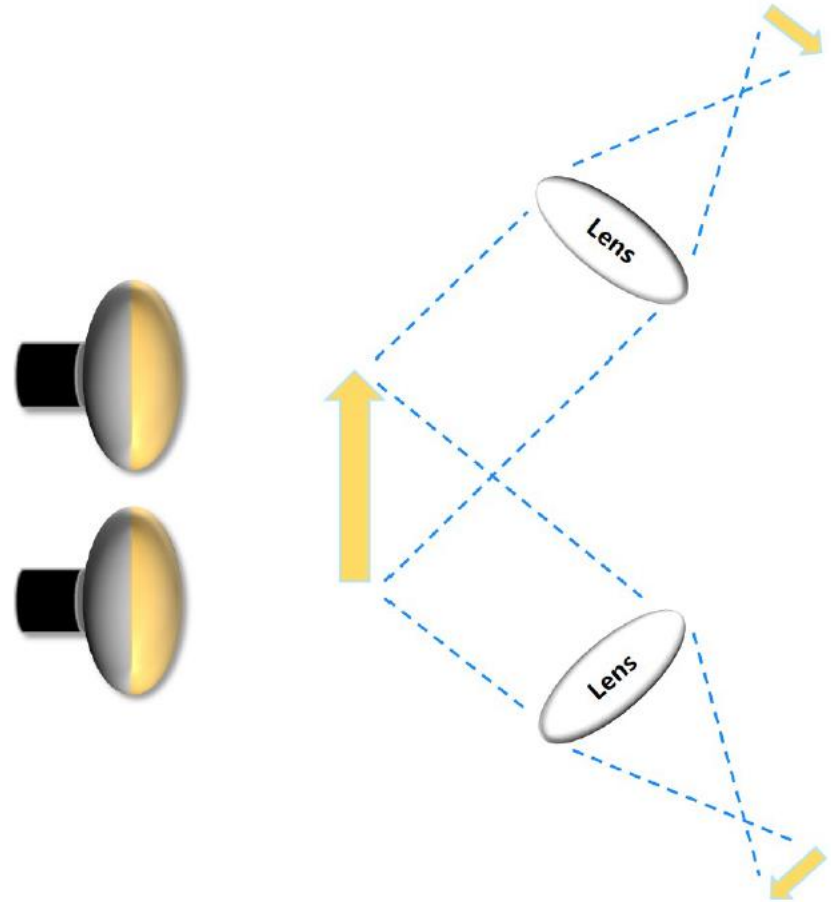
(d) 1-D intensity on horizontal

Aiming to a single particle: single event $\sim 8\text{pe}$

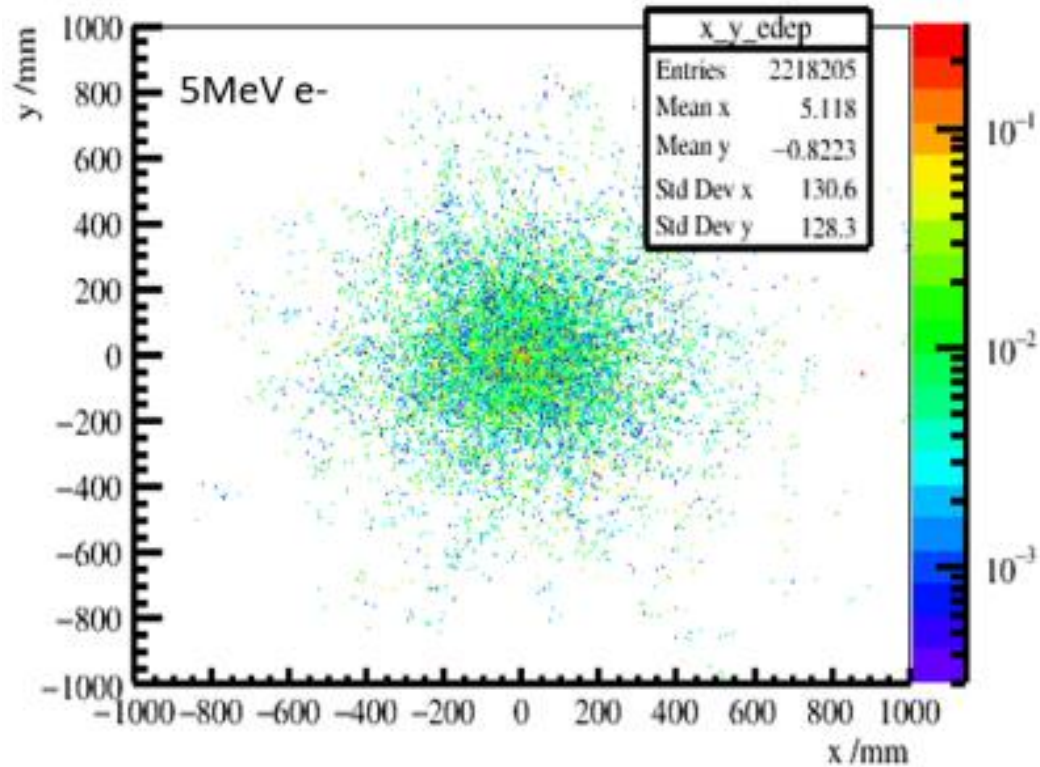


Proposal for further application

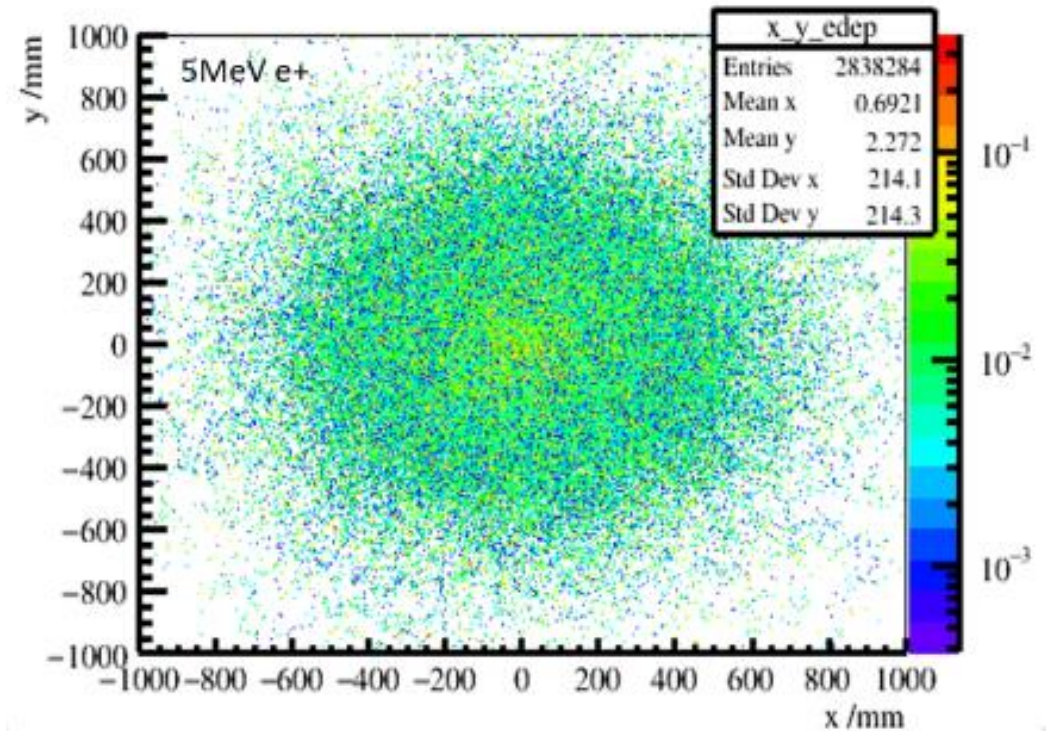
- Coincidence of Multi cameras
 - 3D vertex (x,y,z)
 - Noise suppression
- Additional to real time PMT/SiPM for
 - Precise vertex
 - Topology of energy deposition



Preliminary simulation of event pattern in LS

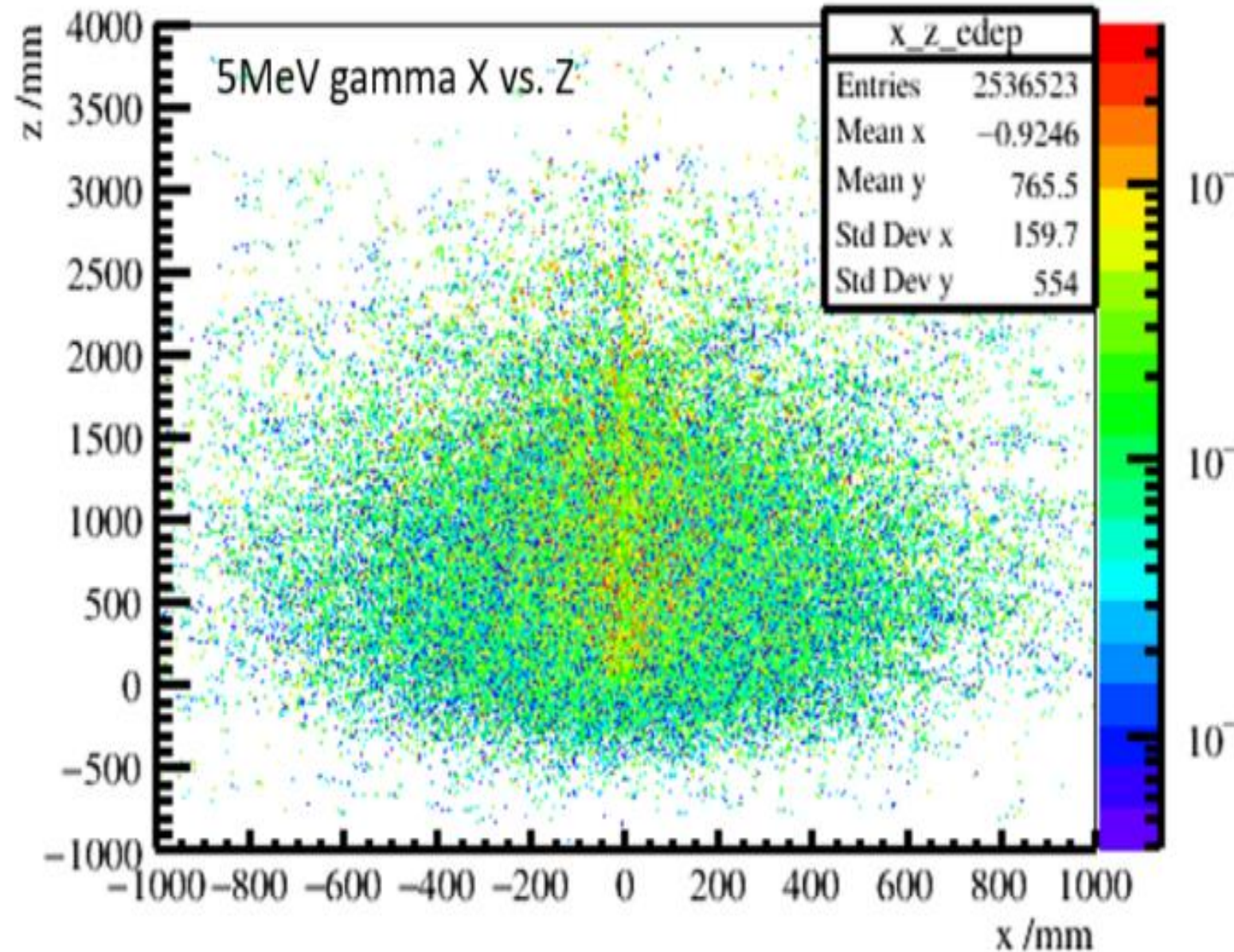
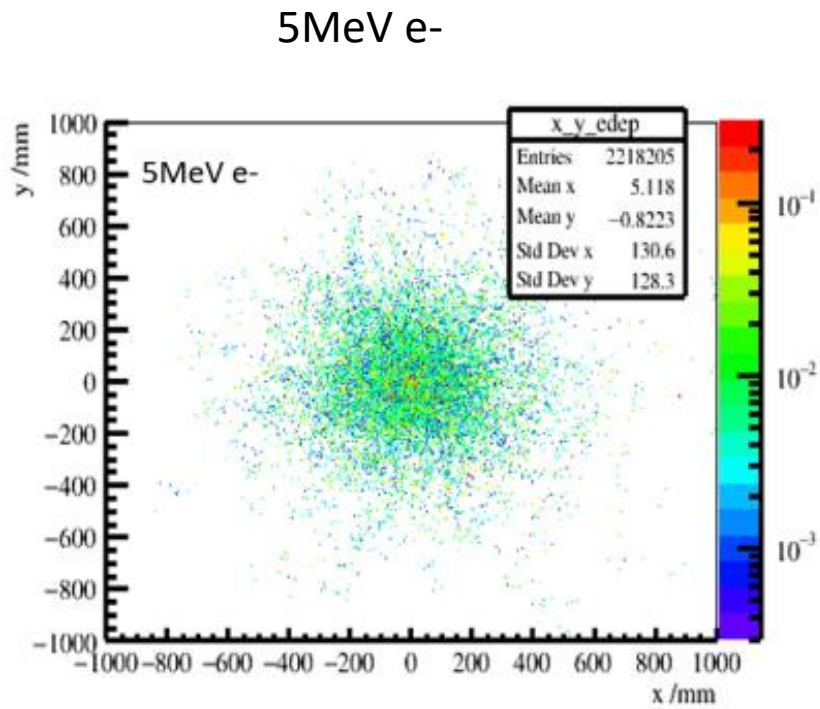


5MeV e-

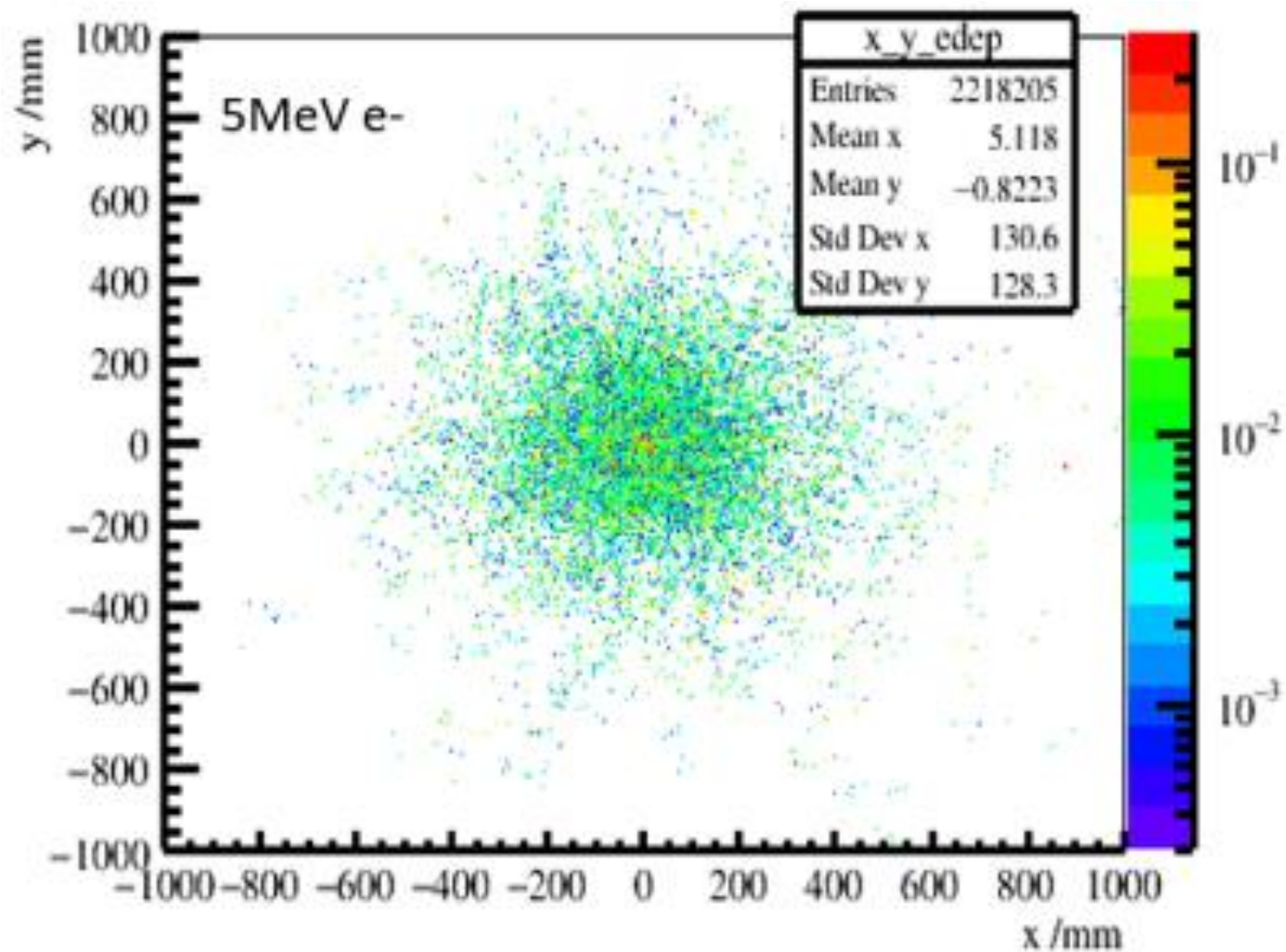


5MeV e+

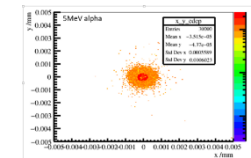
Preliminary simulation of event pattern in LS



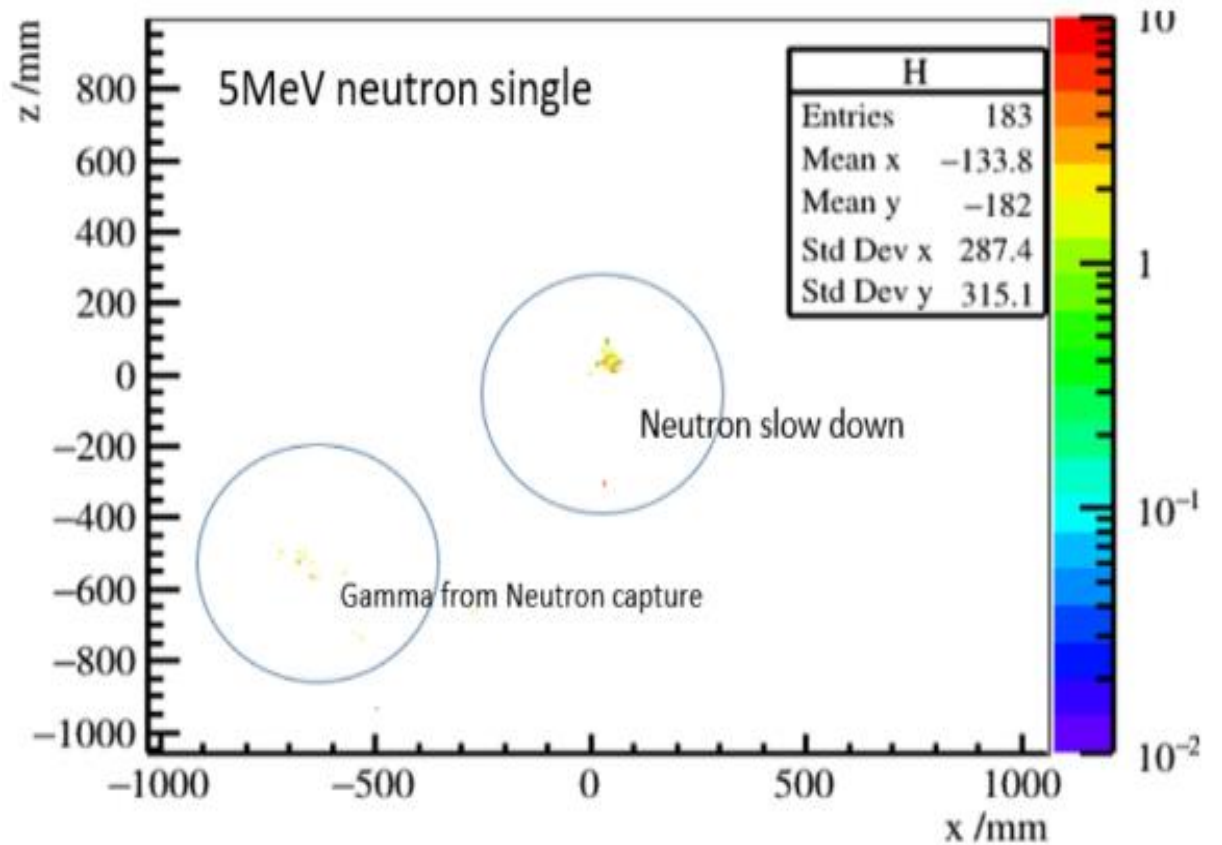
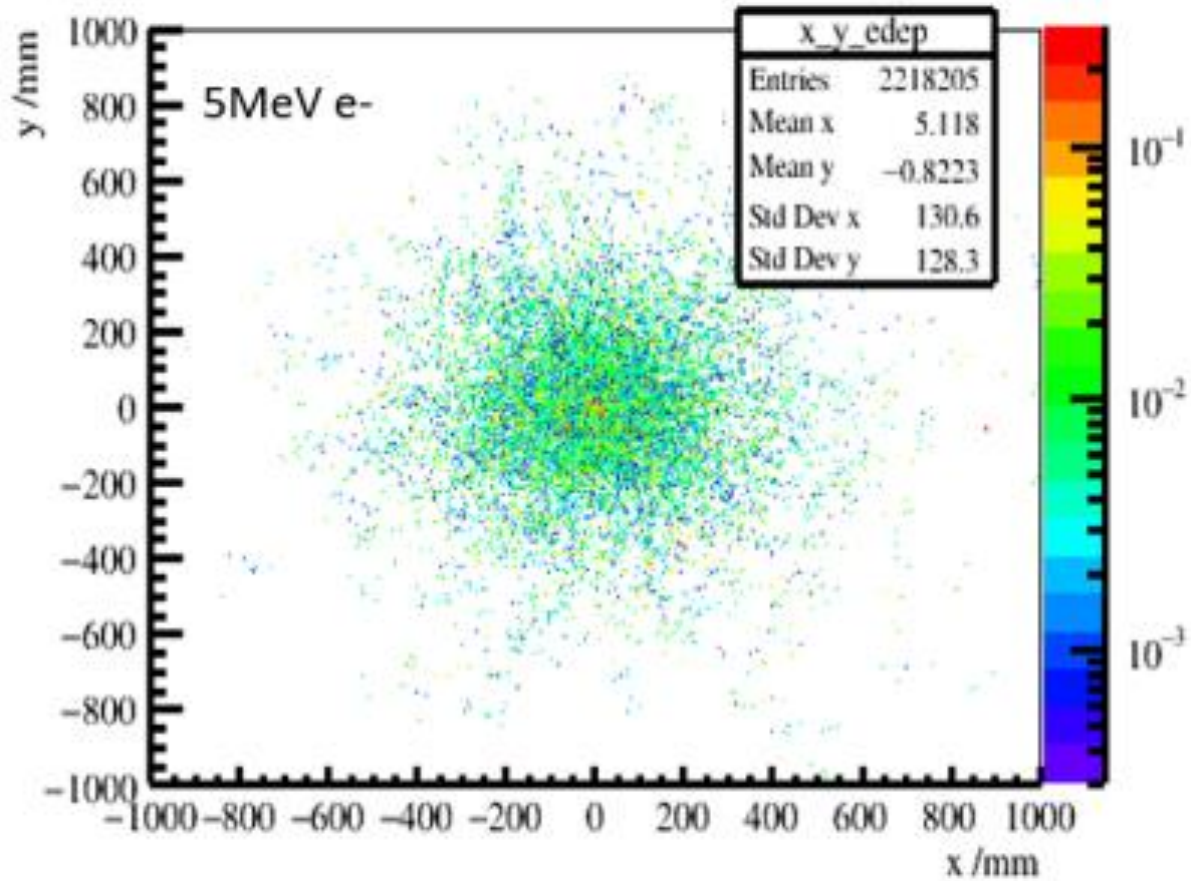
Preliminary simulation of event pattern in LS



5MeV alpha



Preliminary simulation of event pattern in LS



Summary

- Imaging of single particle with single photon level
 - Possible now!
- Noise of camera
 - $\sim 0.3e^-$
- PMT/SiPM+ Multi-cameras in scintillation detector
 - Noise suppression
 - Vertex, and topology identification
 - Imaging of single particle in crystal, LS
 - Simulation shows a good potential
- Proposal for many future applications
 - Welcome for more discussion

谢谢