XEMIS2 simulation summary

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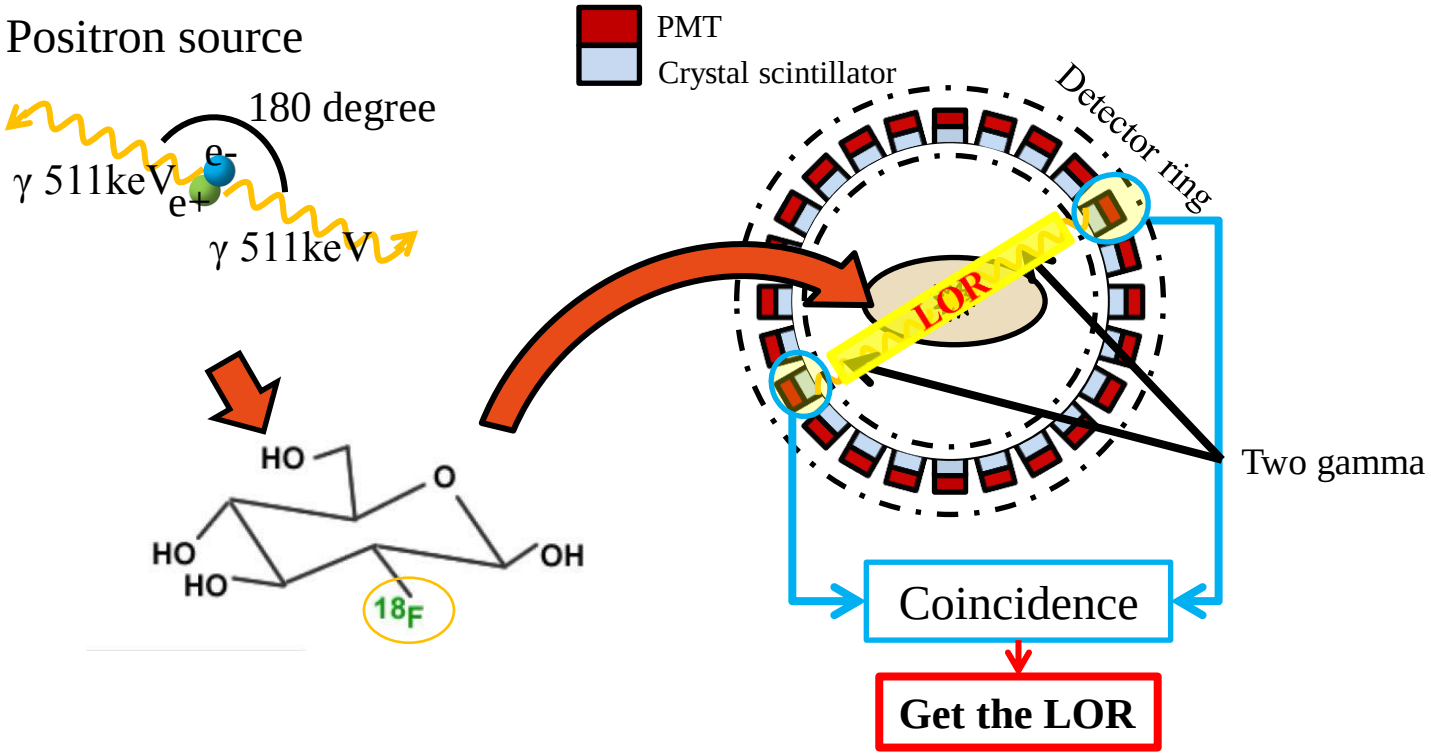
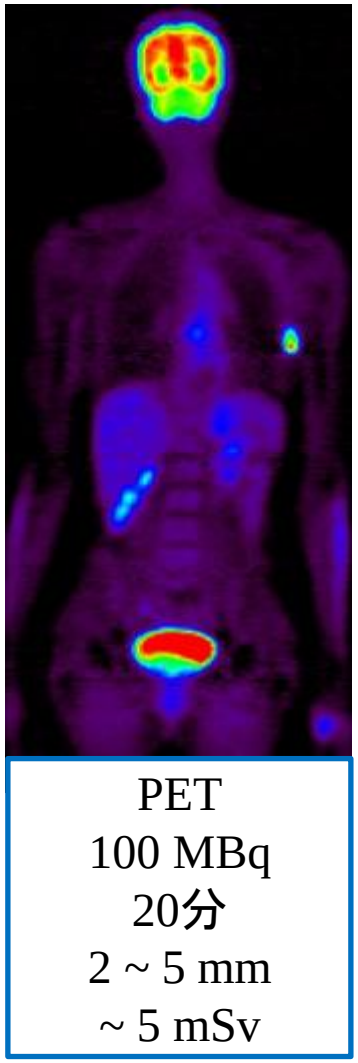
Introduction

- PET

  (Positron Emission Tomography)

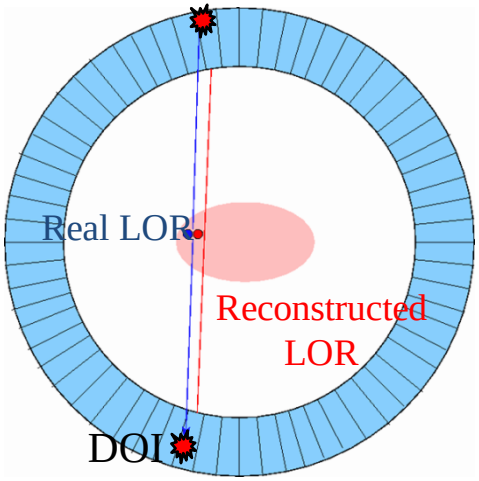




PET
100 MBq
20分
2 ~ 5 mm
~ 5 mSv

Introduction

- Problem of the prior technique
  - Deviation of the LOR due to crystal size
  - Increase in costs due to fragmentation of the crystal
  - Degradation and variations of sensitivity due to reflector between the crystals

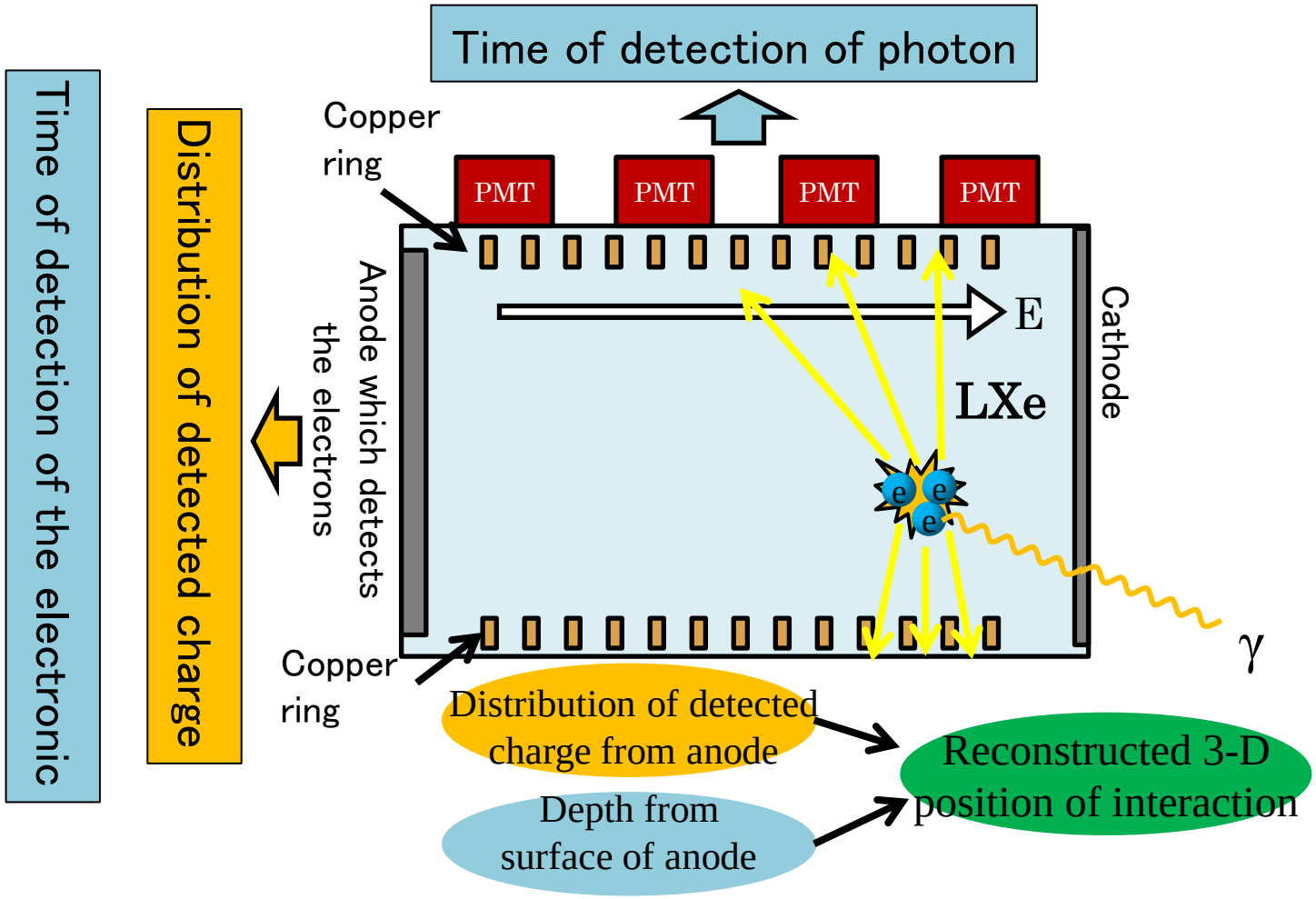


Reconstruct the interaction point regardless of the crystal size

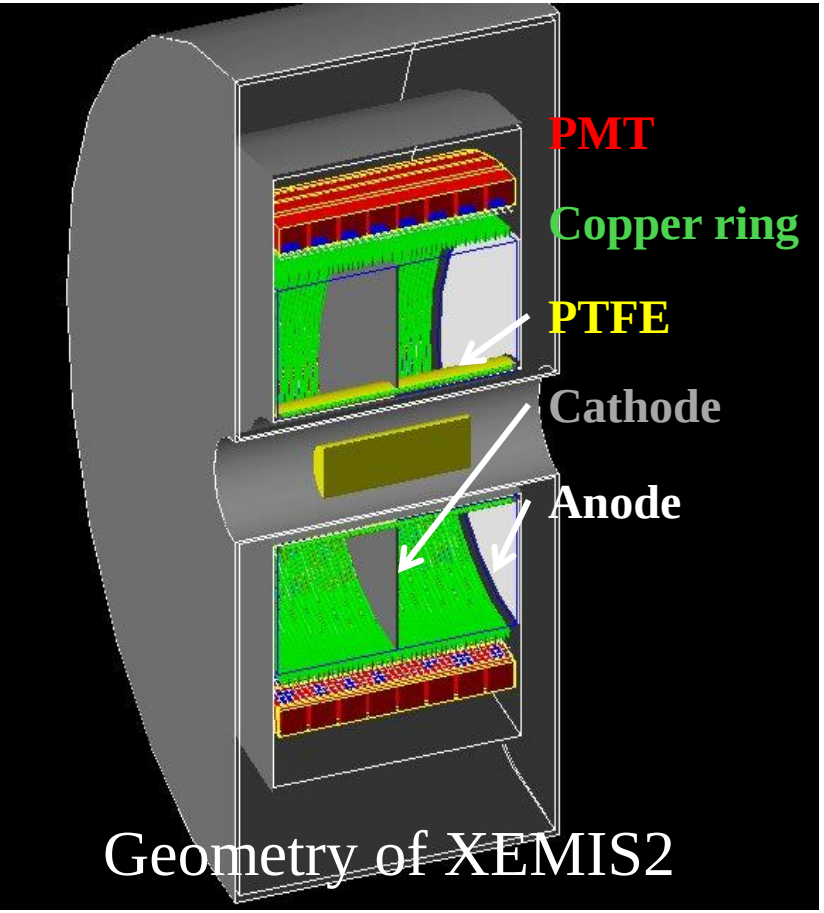
Develop new PET which has LXe-TPC

LXe-TPC

- Gamma detector for 3-D information



XEMIS2



Geometry of XEMIS2

XEMIS2

Full liquid xenon cylindrical camera for small animal imaging (~ 130 kg LXe)

- radial $7 < r < 19$ cm
- axial (z) Length 2×12 cm
- Electric Field in z direction 2 kV/cm
- PMT system 4 x 24 (R10551)
  or 8 x 48 (R7600)
- Micromegas ionization read-out
- FEE Idef-X, pixels 3.175x3.175 mm^2 (~25k channels)
- Electronic noise ~100 e-
- Source ^{44}Sc (20kBq)

XEMIS2

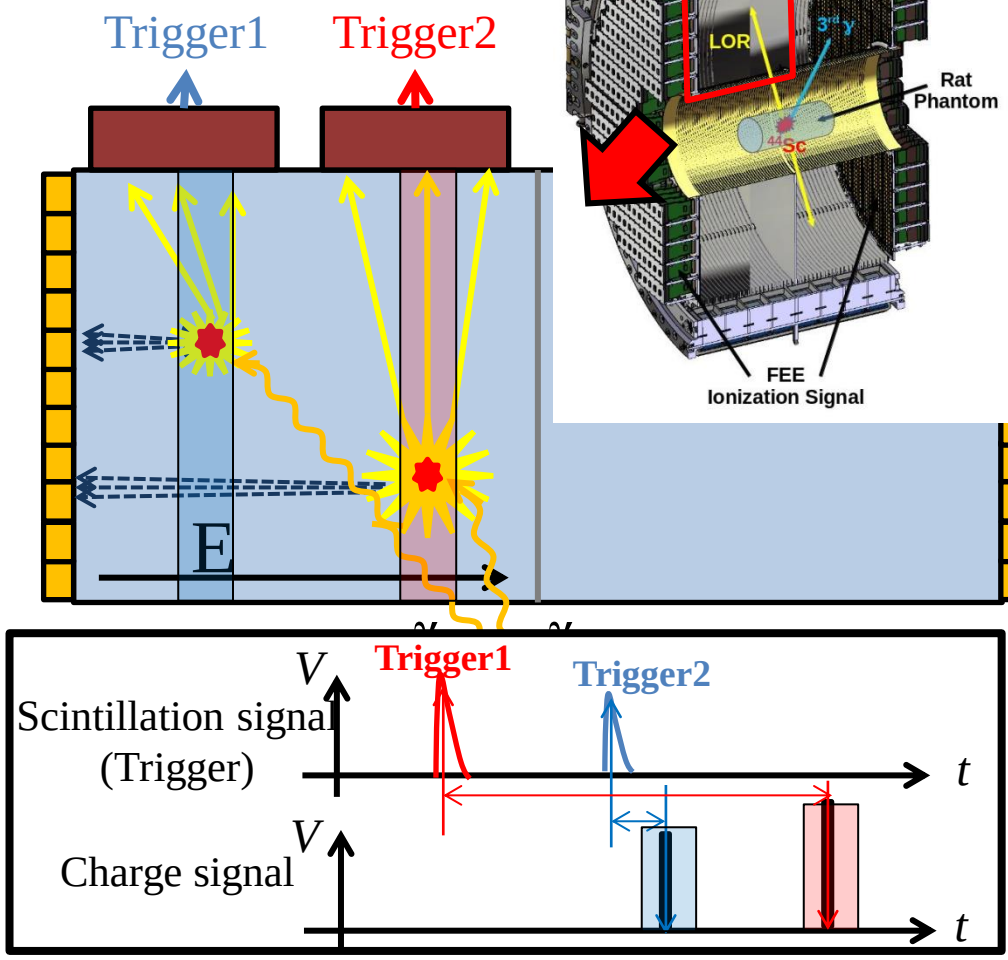
- Proposal

Problem

If γ-rays is incident within a short time, trigger signal overlap. In this case, the charge signal corresponding to the trigger can not be obtained.

Proposal

Mutual complement of charge signal and scintillation signal which has good response about time



Simulation

Simulation1

Simulate the trigger

Simulation2

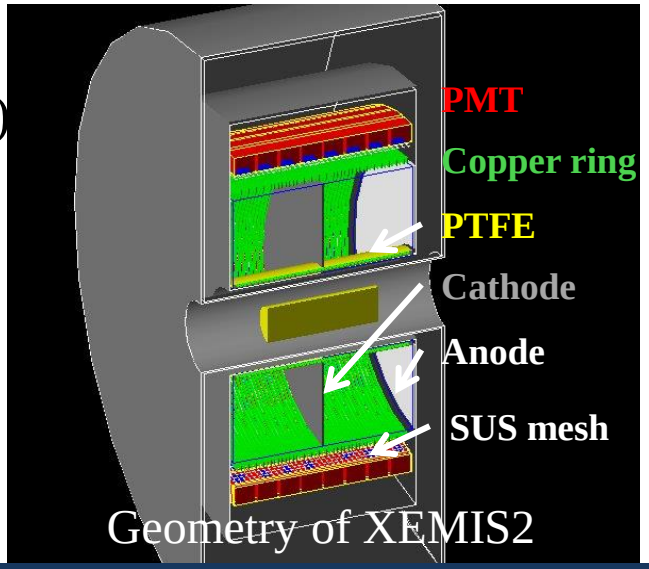
Evaluate resolution of reconstruction of the interaction point with scintillation signal

- GATE (Developed by 21 laboratories in France)

  (Geant4 Application for Emission Tomography)

  - Based on Geant4
  - More easily defined geometry
  - Description by easy macro languages

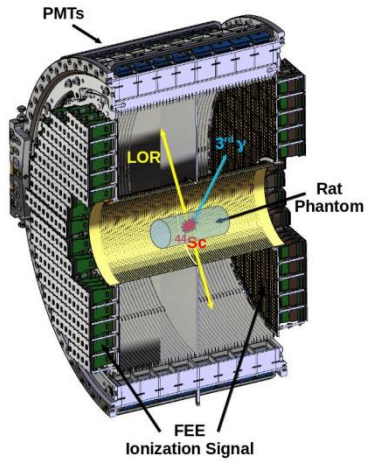
- Efficiency of R&D for radiation medical devices

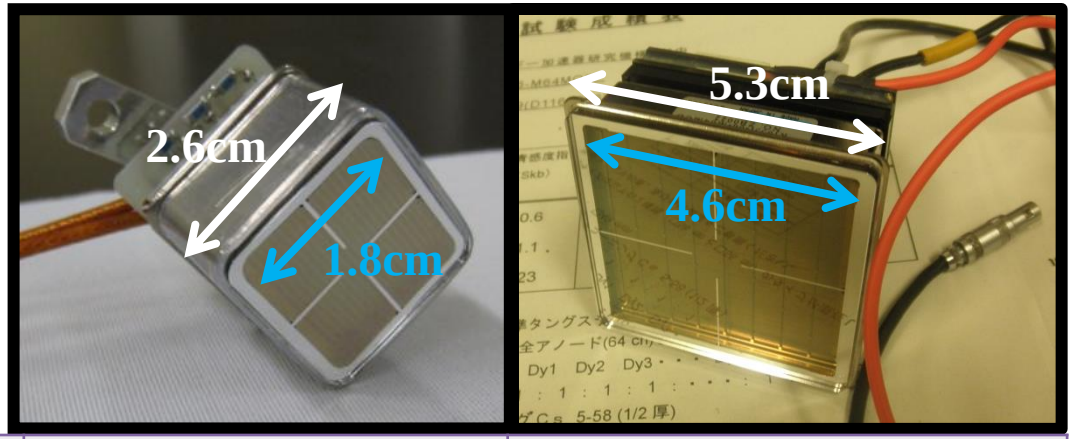


Geometry of XEMIS2

Simulation

- PMT (PhotoMultiplier Tube)

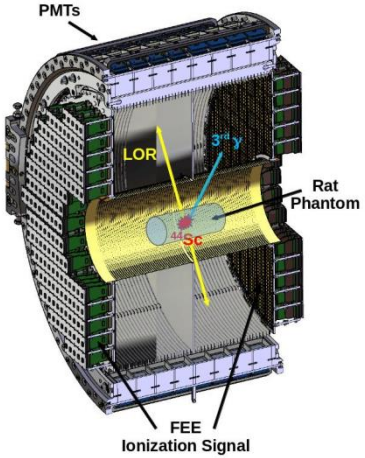


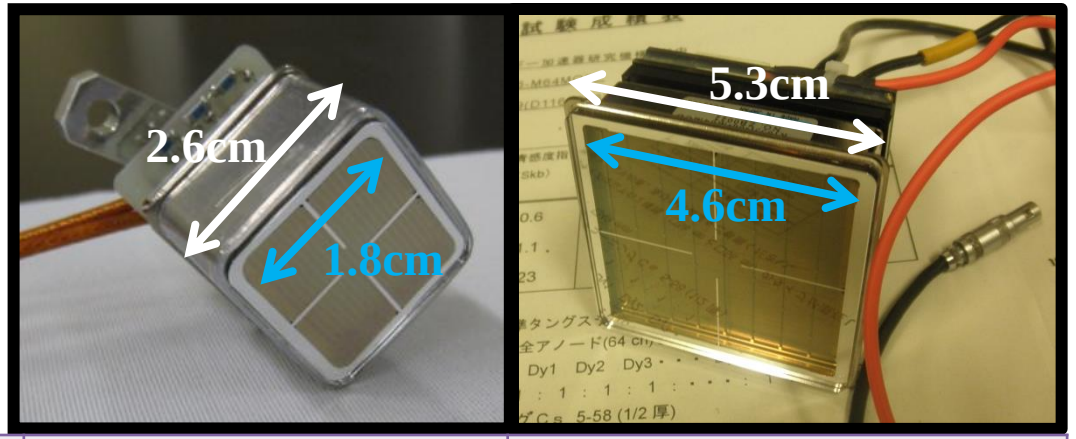


	R7600-06-AL	R10551-06-M64MOD
Quantum efficiency(@178nm)	30 %	34.82 %
Read out	1	8 x 8
Number	8 x 48 (384)	4 x 24 (96)
Size of photo cathode	1.8 x 1.8 cm^2	4.6 x 4.6 cm^2
	First proposal	New development

Simulation

- PMT (PhotoMultiplier Tube)





	R7600-06-AL	R10551-06-M64MOD
Quantum efficiency(@178nm)		%
Read out		
Number	8 x	96)
Size of photo cathode	1.8	cm^2

Compare R10551 with R7600
Total coverage : x 1.65
Quantum efficiency : x 1.16
x 1.92

First proposal | New development

Simulation

- Number of photoelectrons
  - GATE can not simulate the electric field and the material of 2” PMT photocathode is not known in detail.

    (Patent of HAMAMATSU)
  - Scintillation yield includes these effect to simulate how many number of photoelectrons are detected by PMTs

(It does not include some fluctuation, e.g. electric noise.)

2” PMT (1” PMT)

$$\frac{1.0\times10^{6}}{21.6}\times 0.3482(0.3)\times 0.3 \cong 4836(4167)[/\,MeV]$$

Scintillation yield of Xe　Q.E.　Electric field　Scintillation yield for simulation

Simulation

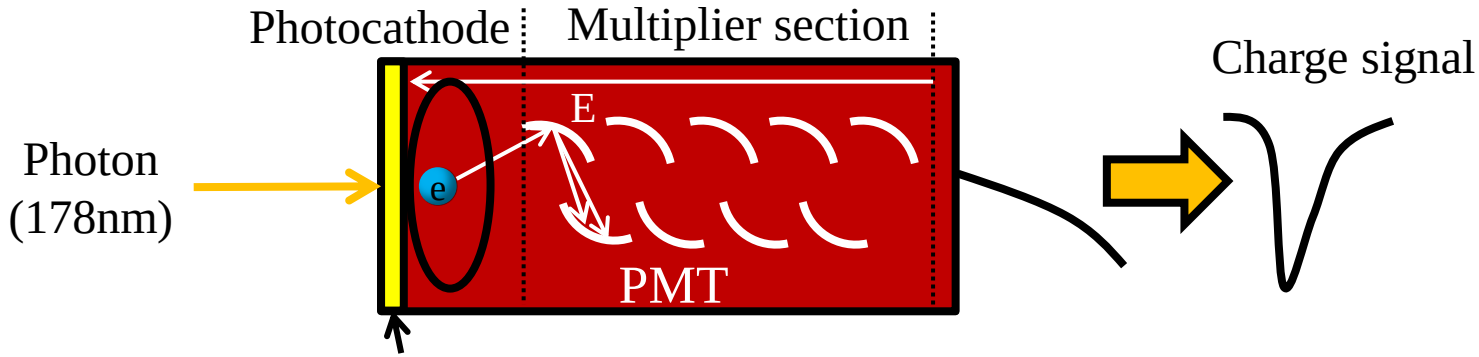
- Parameter of reflection
  - Teflon
    - Reflectance : 95 [%]
    - Component : Diffuse
  - SUS304
    - Reflectance : 6.5 [%]
      - Calculated
    - Component : Specular lobe
  - Copper
    - Reflectance : 23 [%]
      - reference : http://www-sk.icrr.u-tokyo.ac.jp/xmass/prelist/2004AutumnTomita.pdf
    - Component : Specular lobe

$$\left(\frac{n_a - n_b}{n_a + n_b}\right)^2$$

n_a = 2.36 (RINDEX of SUS304)
n_b = 1.615 (RINDEX of LXe)

Simulation 1

- Simulate the trigger



Photoelectrons are generated by Photo-electric

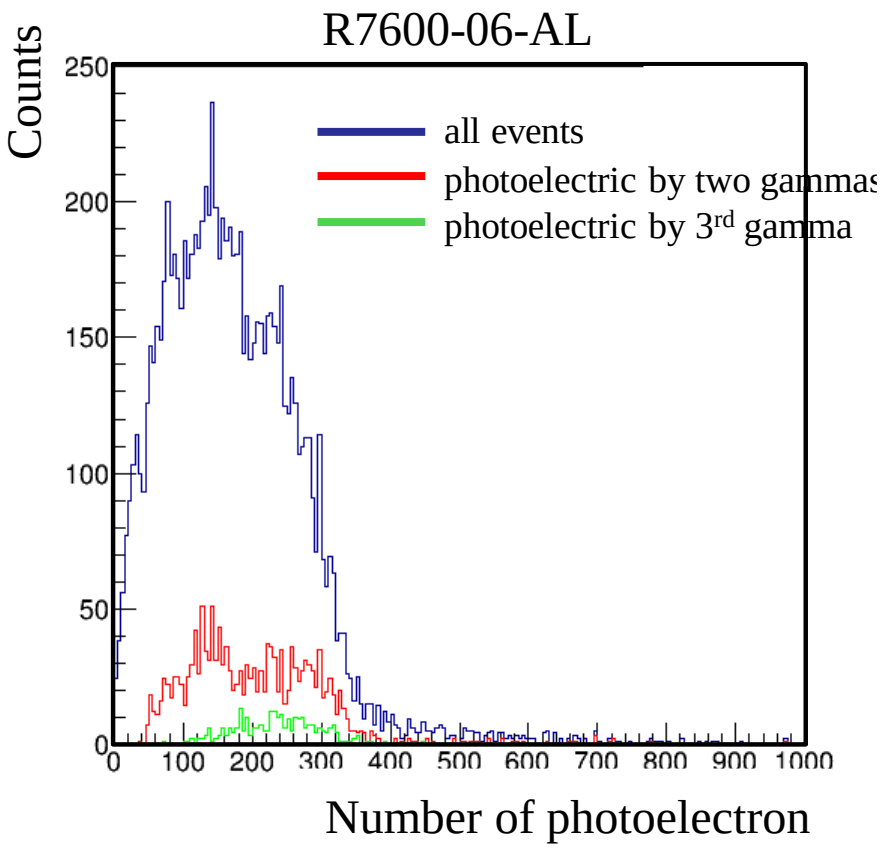
One Decay of ^{44}Sc is one event.
Get the number of photoelectrons in each events,

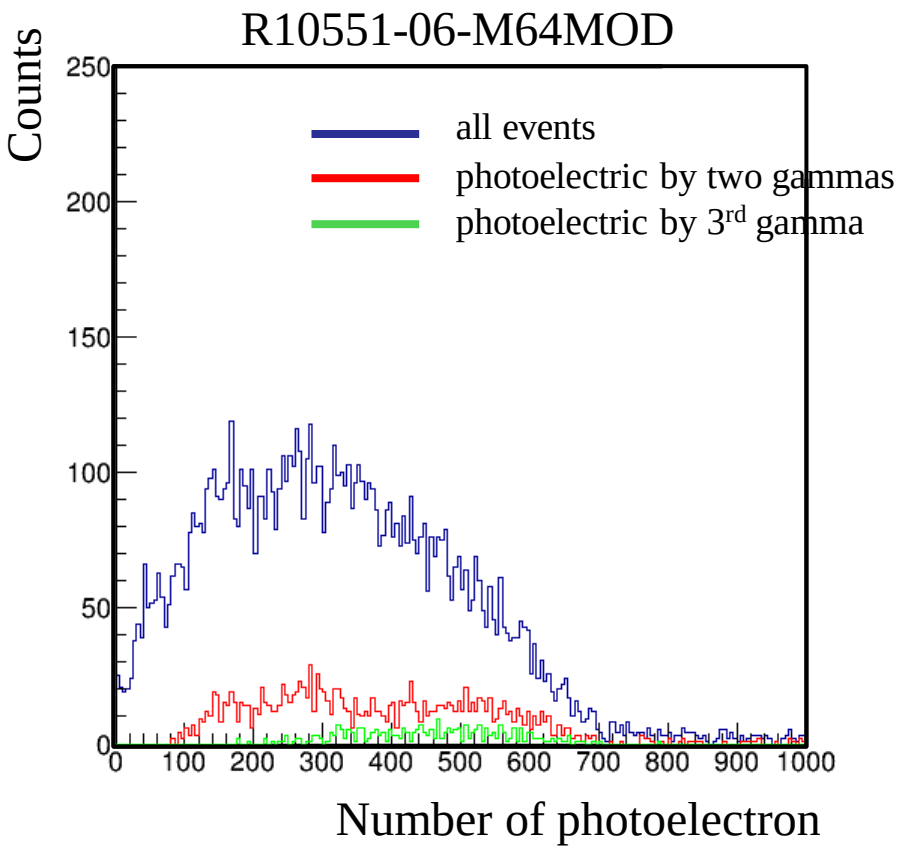
Condition

Source	^{44}Sc, 20kBq
Number of events	約10,000

Simulation 1

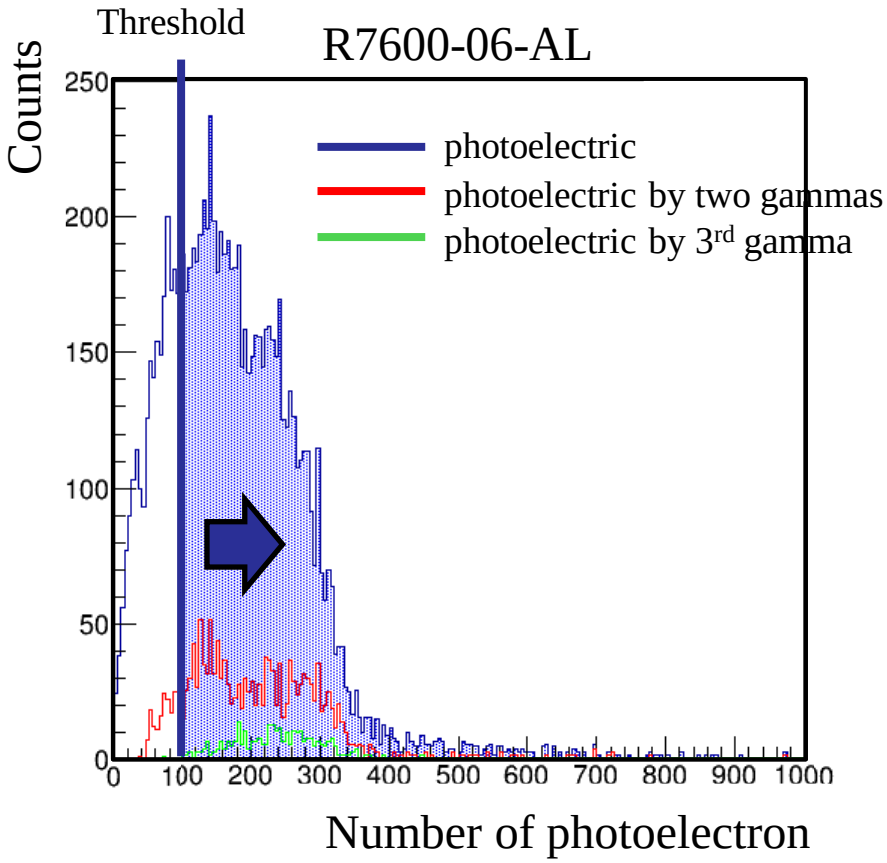
- Simulate the trigger

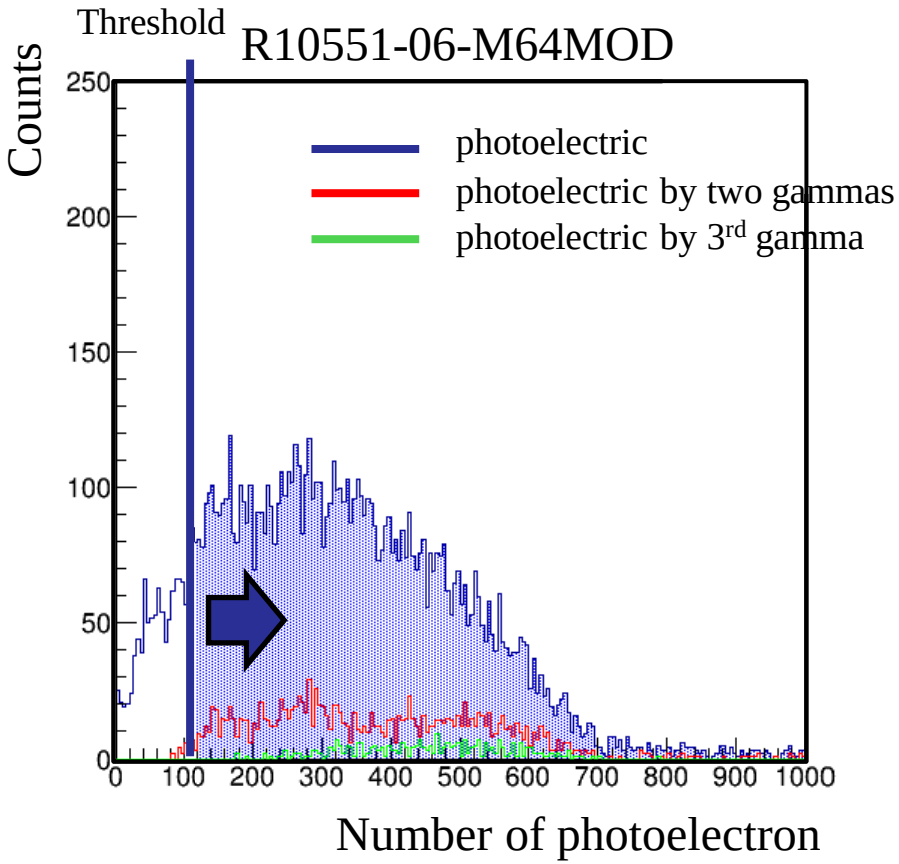




Simulation 1

- Simulate the trigger
  - Set threshold

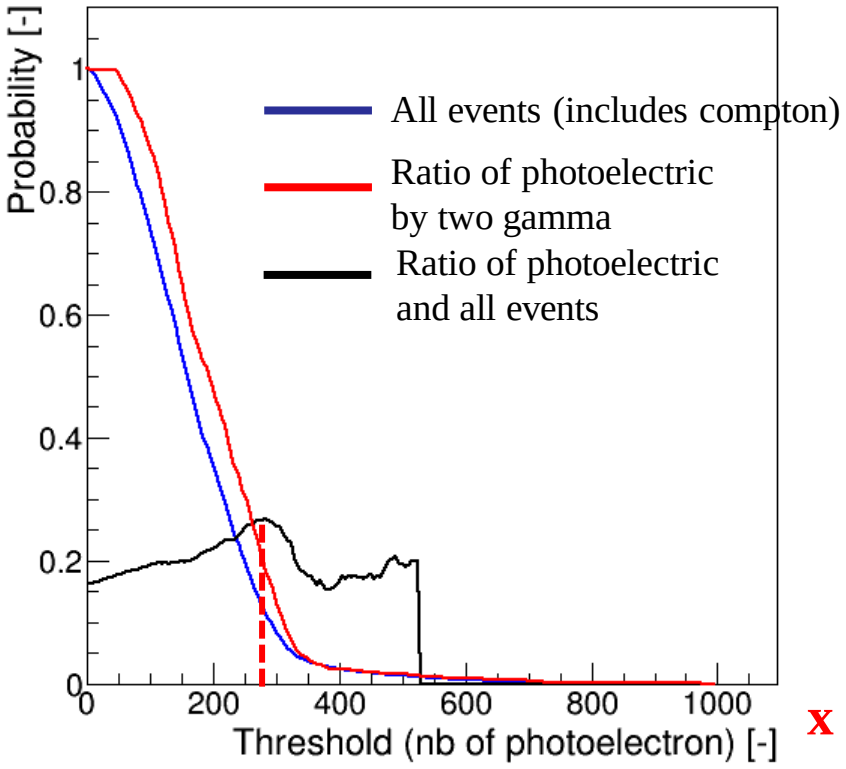




Simulation 1

- Simulate the trigger

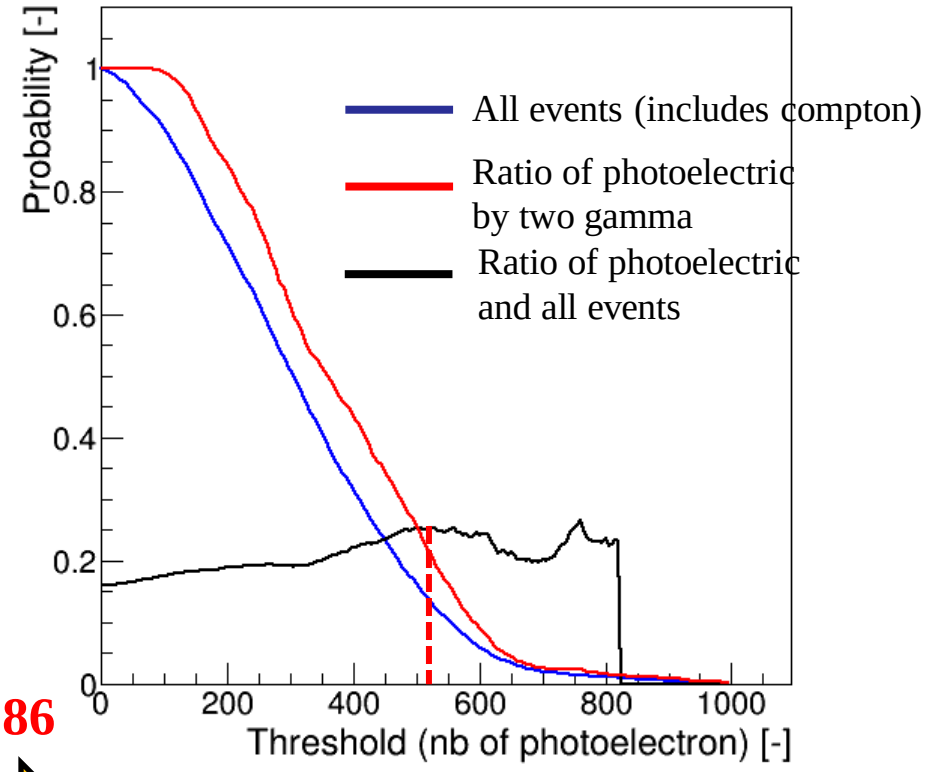
R7600-06-AL



280 photoelectron

x 1.86

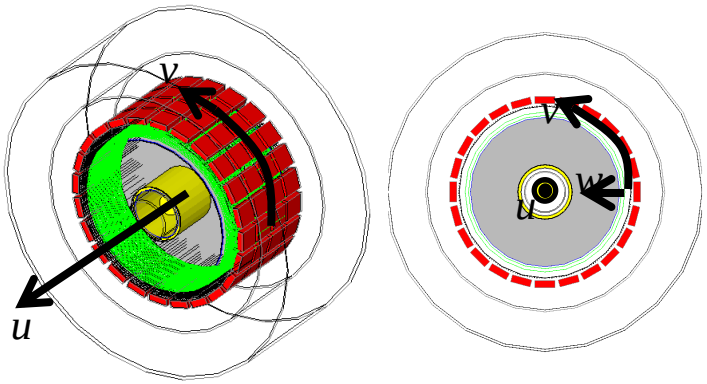
R10551-06-M64MOD



520 photoelectron

Simulation 2

- Evaluate the resolution of reconstruction of the interaction point with scintillation signal
  - Get the detection position based on the IDs assigned to each photocathode
  - Express 2-D coordinate (u, v)
  - Calculate the mean of distribution by center of gravity method

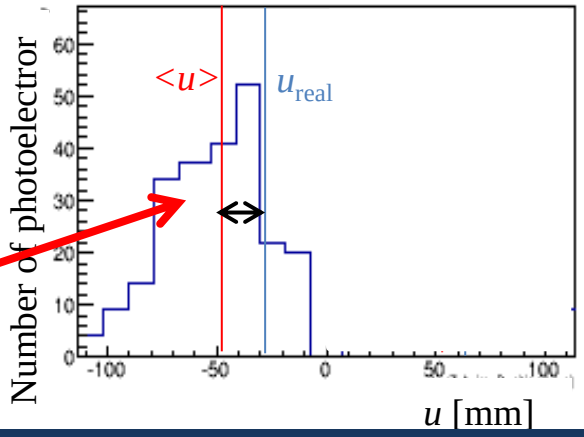


$$< u >= \frac{\sum_i q_i \cdot u_i}{\sum_i q_i} \qquad < v >= \frac{\sum_j q_j \cdot v_j}{\sum_j q_j}$$

i,j : ID of photocathode
$q_{i,j}$: Number of photoelectron

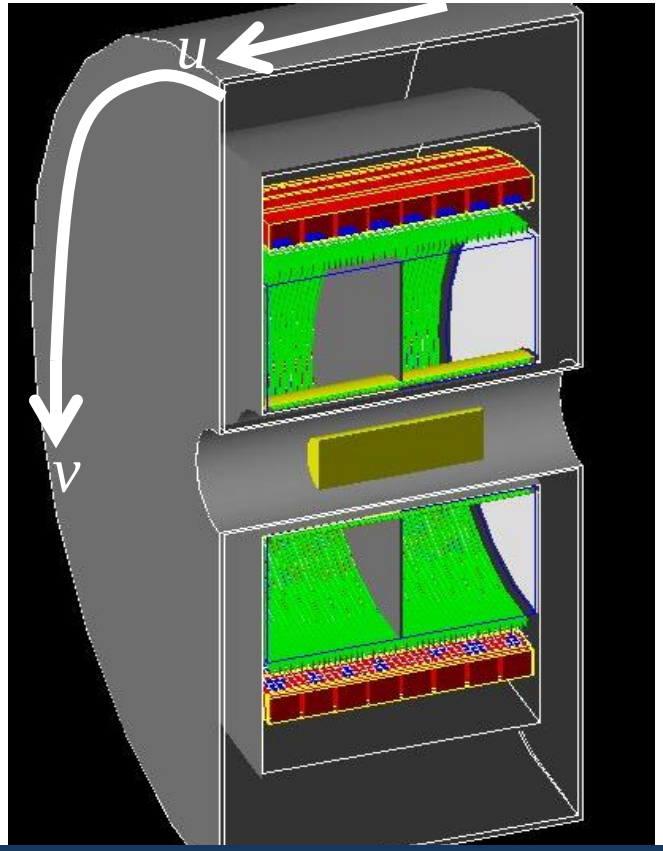
  - Compare the mean with real interaction point per event

$$(<u> - u_{\mathrm{real}}, <v> - v_{\mathrm{real}})$$



Simulation 2

- Evaluate the resolution of reconstruction of the interaction point with scintillation signal



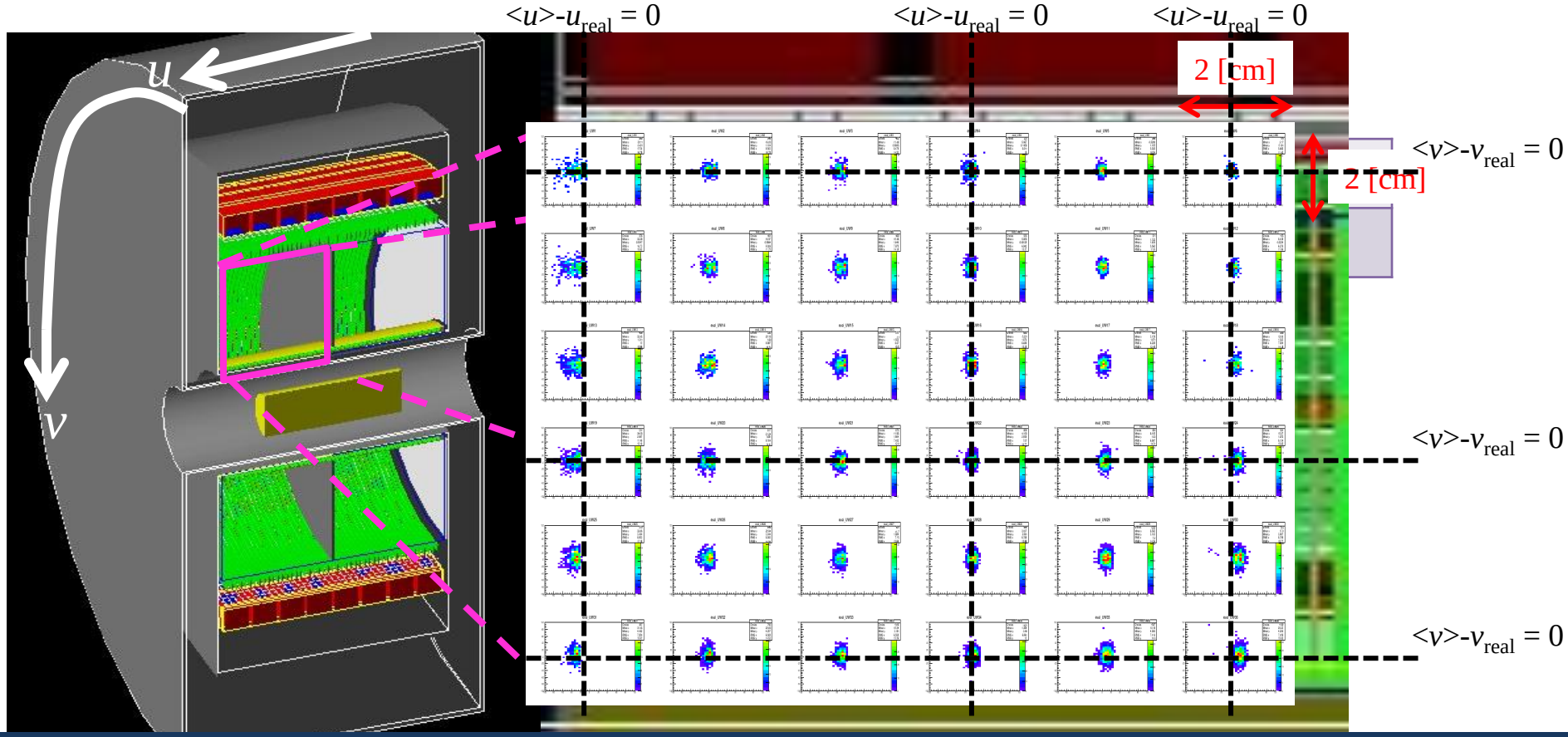
Condition of simulation

γ	Only two gammas, 20kBq
Time	5.0s

Interaction was only photoelectric

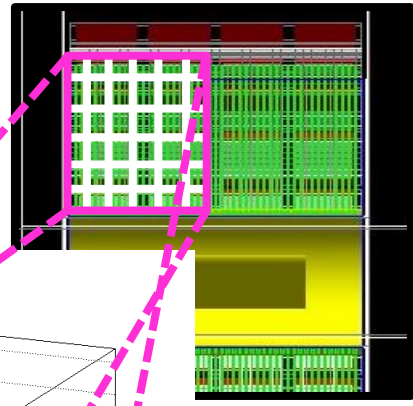
Simulation 2

- Evaluate the resolution of reconstruction of the interaction point with scintillation signal

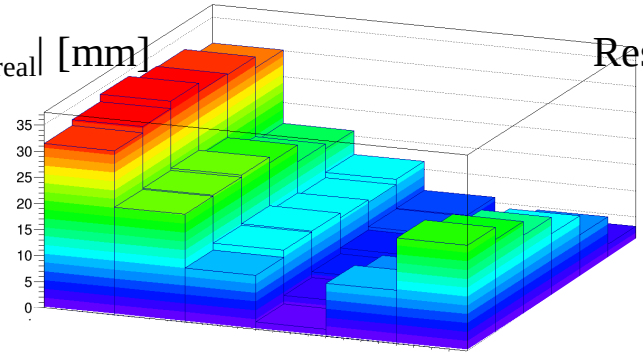


Simulation 2

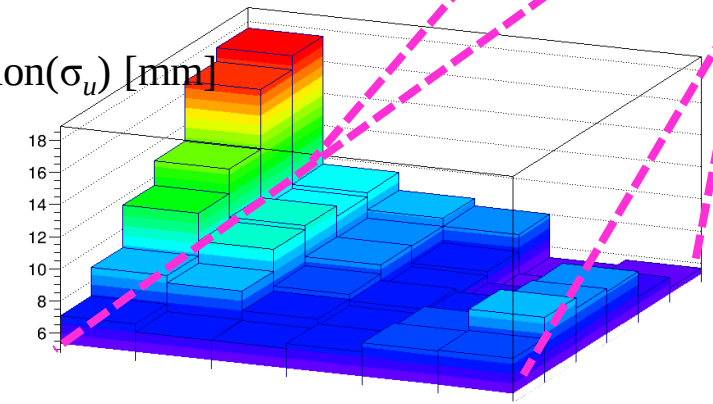
- Evaluate the resolution of reconstruction of the interaction point with scintillation signal
  - Evaluate each area



$|\langle u \rangle - u_{real}|$ [mm]

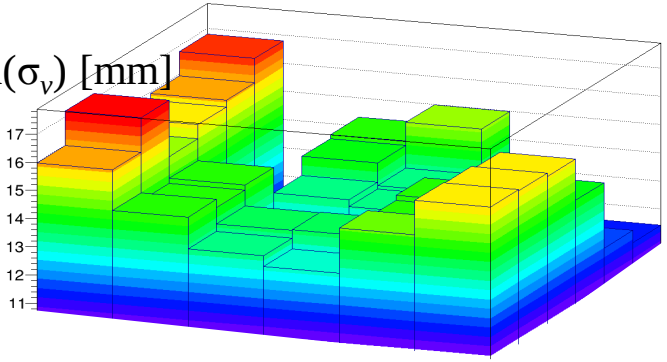


Resolution(σ_u) [mm]



- v

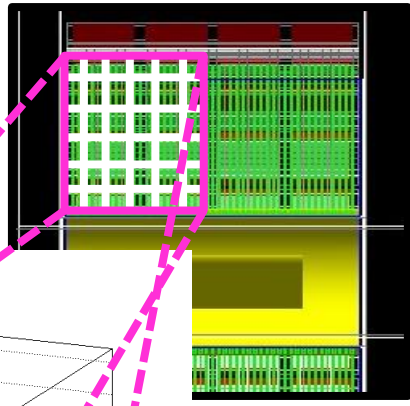
Resolution(σ_v) [mm]



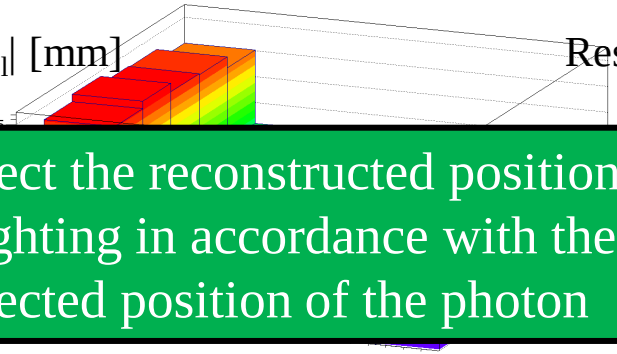
	R10551	R7600
Average σ_u	8.32±0.26mm	8.12±0.26mm
Average σ_v	14.24±0.42mm	18.89±0.58mm
σ_u x σ_v	118.5±5.09mm^2	153.3±6.81mm^2

Simulation 2

- Evaluate the resolution of reconstruction of the interaction point with scintillation signal
  - Evaluate each area

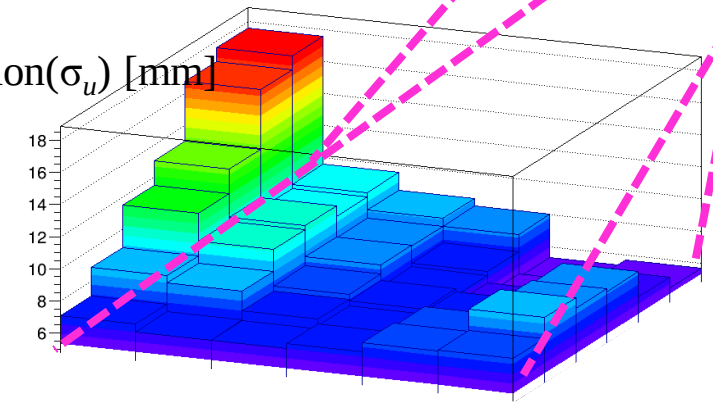


$|\langle u \rangle - u_{real}|$ [mm]



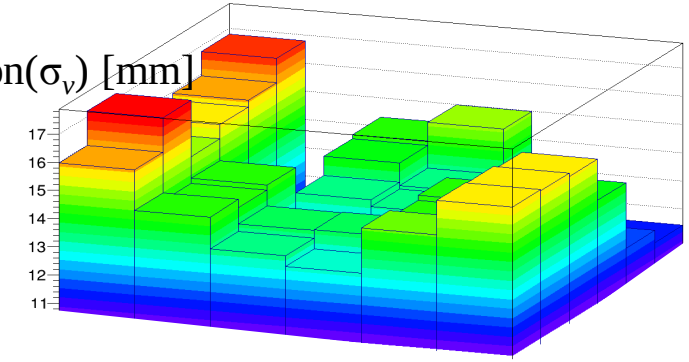
Correct the reconstructed position
Weighting in accordance with the detected position of the photon

Resolution(σ_u) [mm]



- v

Resolution(σ_v) [mm]



	R10551	R7600
Average σ_u	8.32±0.26mm	8.12±0.26mm
Average σ_v	14.24±0.42mm	18.89±0.58mm
σ_u x σ_v	118.5±5.09mm^2	153.3±6.81mm^2

Simulation 2

- $3\sigma_u$ x $3\sigma_v$ (about 10.66cm^2)…..

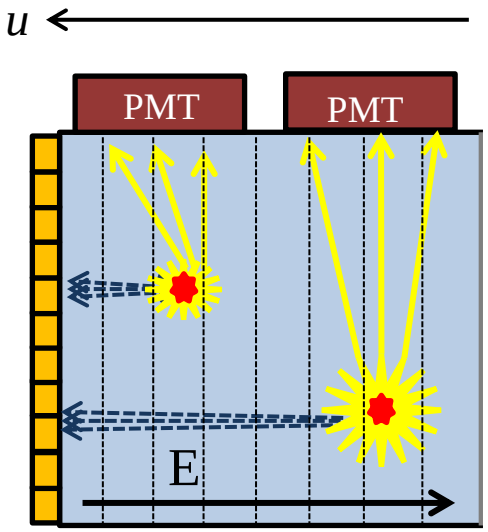
Scintillation signal will be used as only trigger.

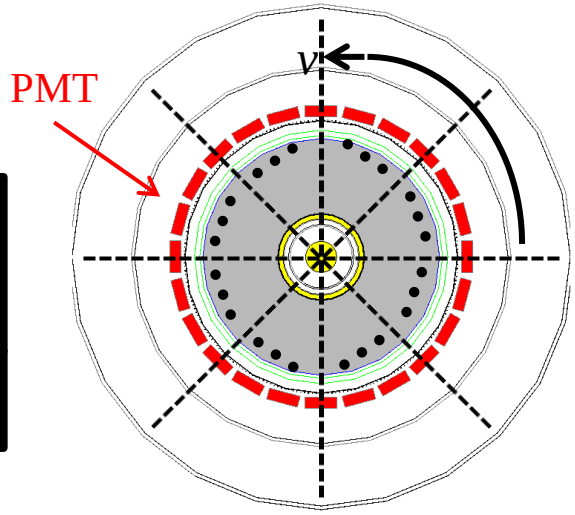
Signals more than 20kHz will be piled up.

improve?

Surface of photocathode (includes space) can be divided by 160 areas.

Signals less than 3.2MHz can be distinguished



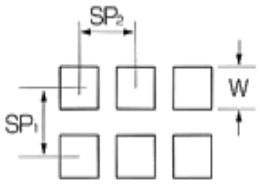


Simulation 2

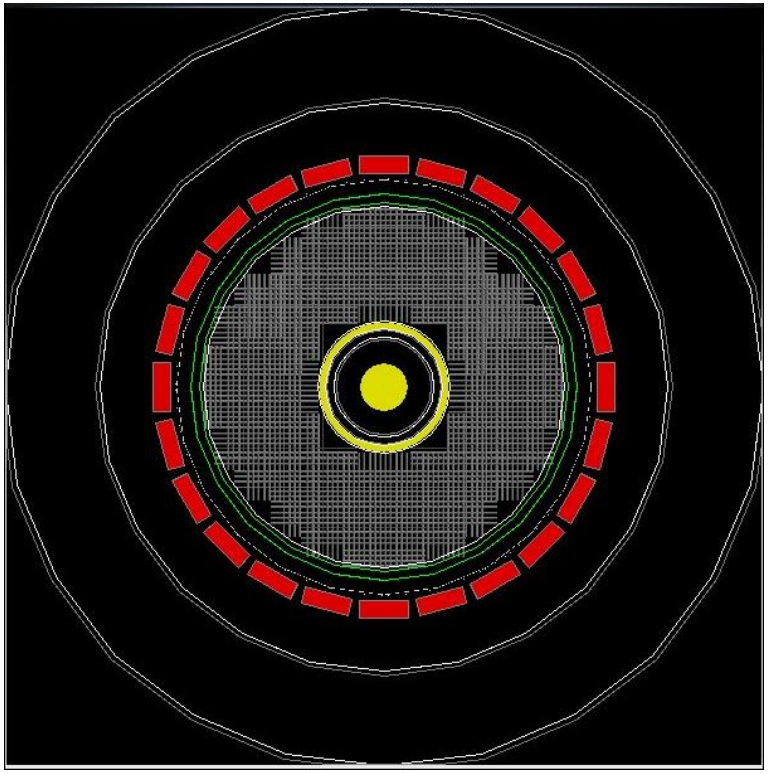
- Evaluate the resolution of reconstruction of the interaction point with scintillation signal
  - Evaluate mesh cathode
    - Aperture ratio (A.R.) :
      19% and 57%

Example

A.R. [%] $= \frac{W^2}{SP_1 \times SP_2} \times 100$

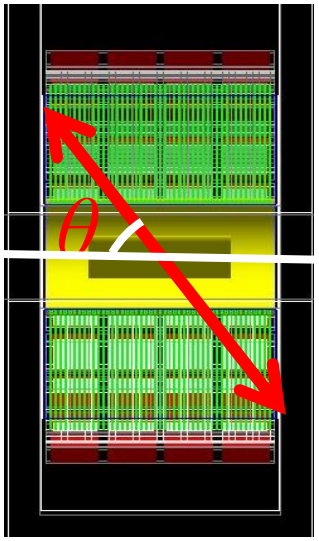


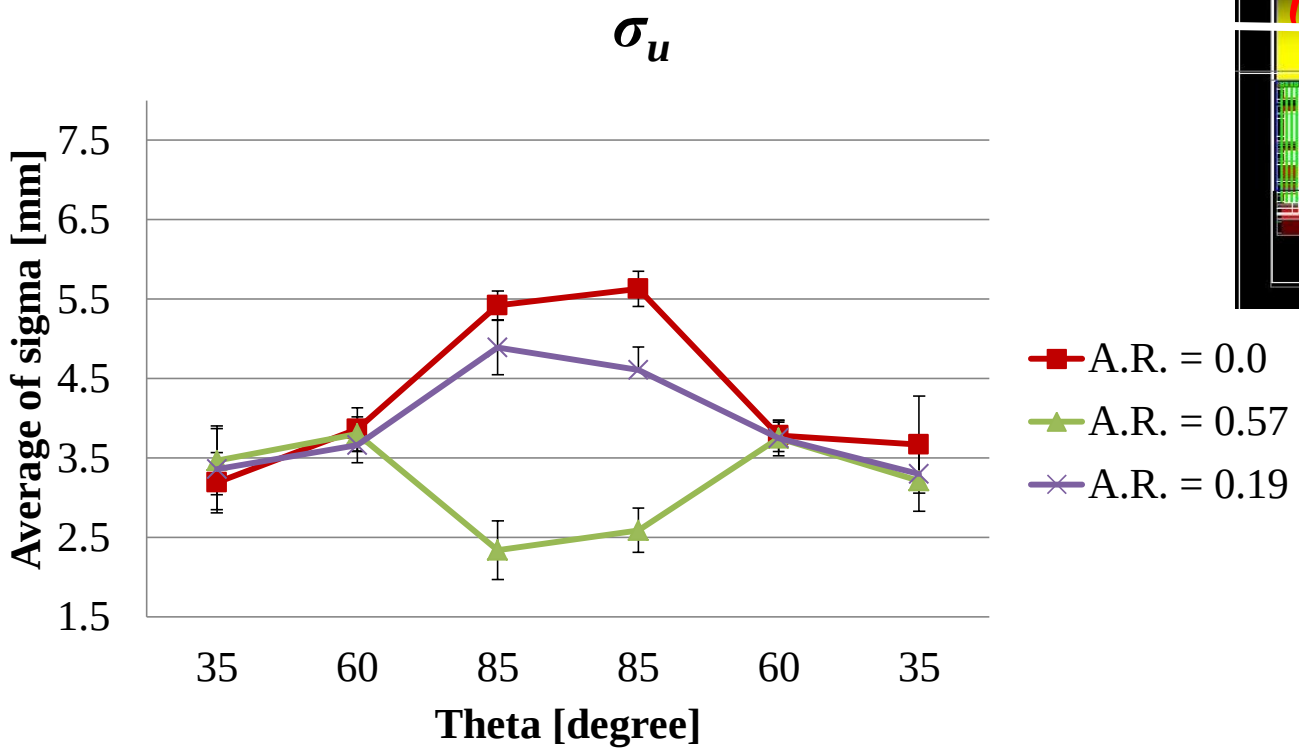
W	0.31
SP 1	0.41
SP 2	0.41
A.R.	57.2



Simulation 2

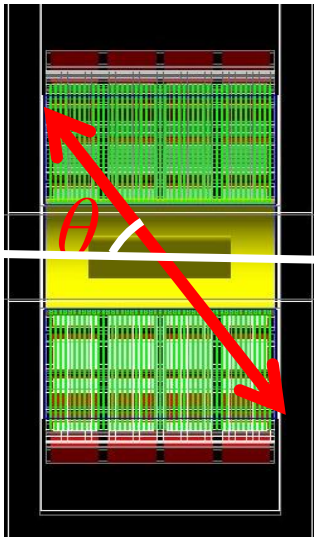
- Evaluate the resolution of reconstruction of the interaction point with scintillation signal
  - Evaluate the *u* resolution per angle of gamma

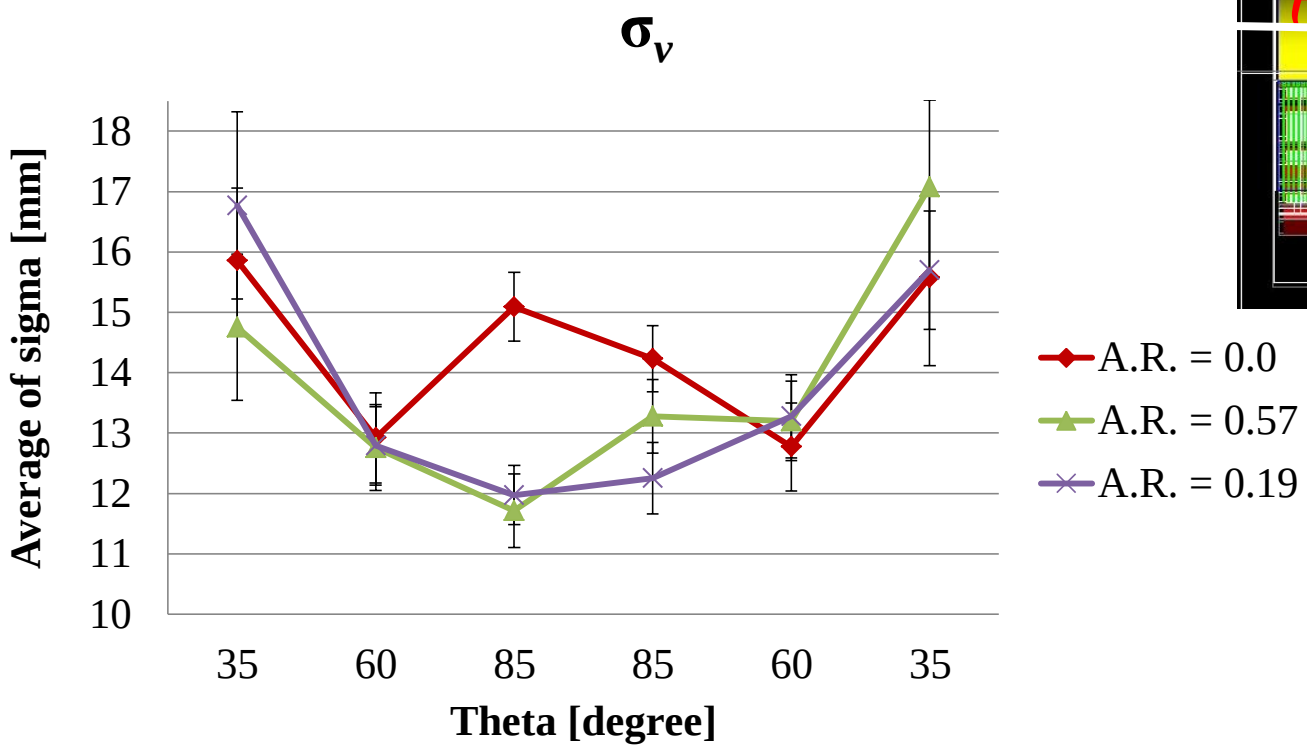




Simulation 2

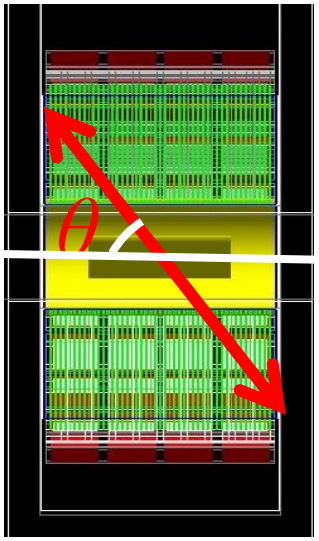
- Evaluate the resolution of reconstruction of the interaction point with scintillation signal
  - Evaluate the *v* resolution per angle of gamma

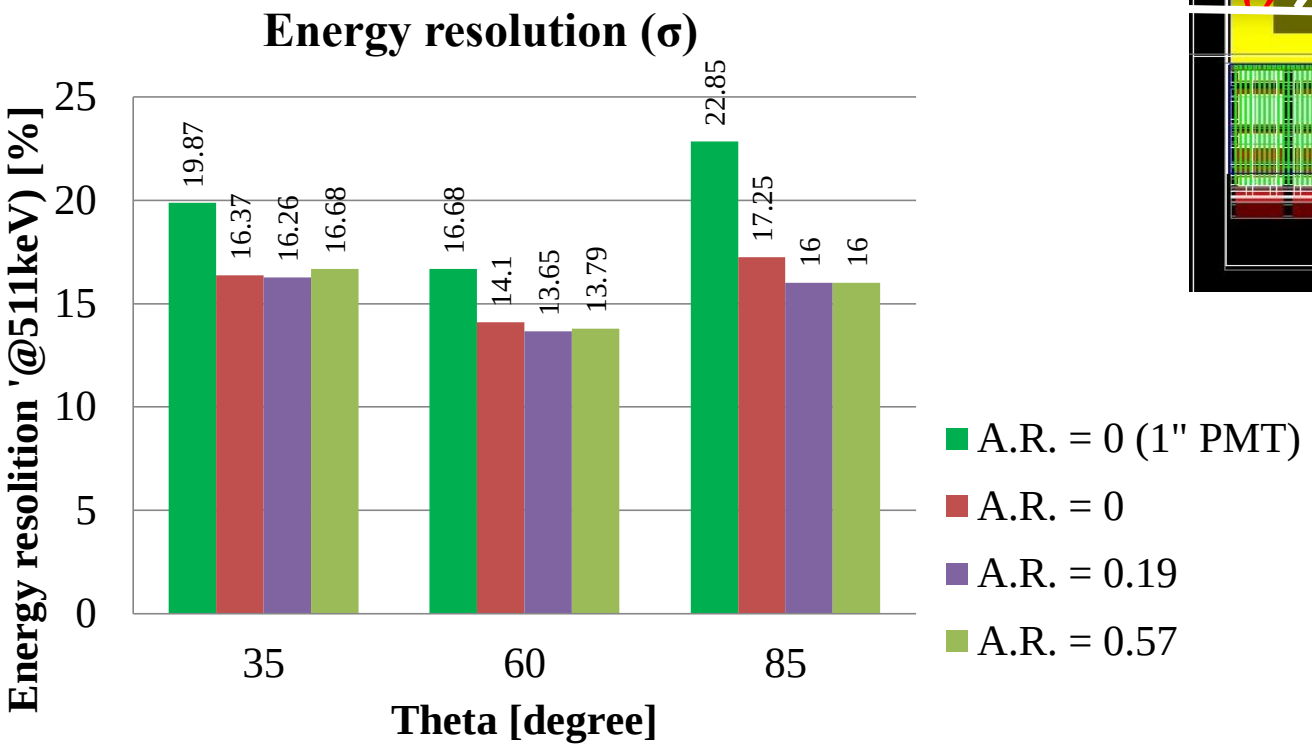




Simulation 2

- Evaluate the resolution of reconstruction of the interaction point with scintillation signal
  - Evaluate the energy resolution per angle of gamma



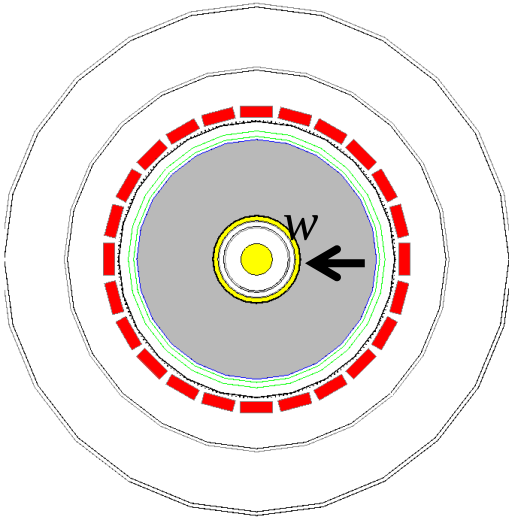


Conclusion

- We have developed a small animal PET which has full cylindrical LXe-TPC.
- In order to operate the XEMIS2 in higher count rate, I studied the photon collection system.
    - Simulate the trigger
        - Increase the number of photoelectron by using 2'PMT (x 1.84)
    - Evaluate the resolution of reconstruction of the interaction point with scintillation signal
        - σ_u=8.32mm, σ_v=14.24mm (2'PMT system)
        - Shift of *u* showed dependent on the interaction position
        - Good resolution of energy and position with mesh cathode

Future

- Weighting in accordance with the detected position of the photon
- Study w which express the depth of interaction from photocathode surface
- Change the division of photocathode



Thank you.

液体キセノンTPC

- Lquid Xenon
  - character for scintillation

Atomic number	54	Emission peak (nm)	178
Density (g/cm^3)	2.98	Boil point (K)	165.1
Decay time (ns)	2.2, 27	Melt point (K)	161.4
Scintillation yield (/511keV)	24000		

  - character for charge

Charge yield (/511keV)	30000
Attenuation (m/ppb)	2.1
Drift velocity (mm/μs)	**2.3**