GATE Simulation study

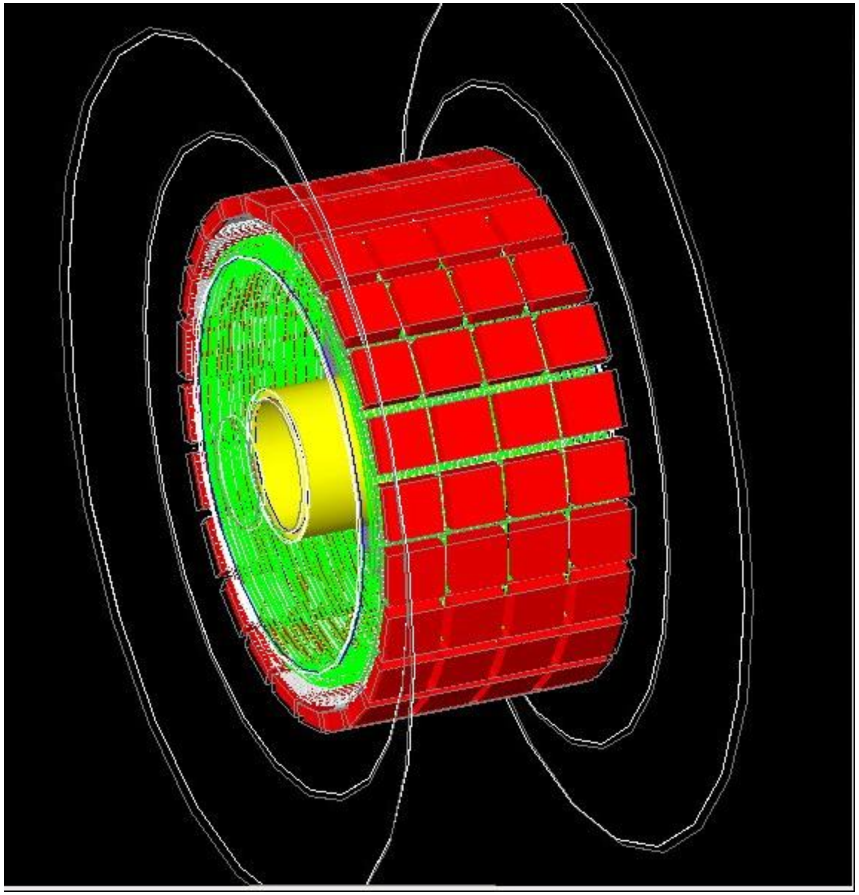
@Subatech

19 / Dec. / 2014

Ryo Hamanishi

Contents

- Purpose of stay
- Modify GATE code
- New geometry
- Define surface
- Simulation
- Analysis
- Result
- Conclusion
- Future

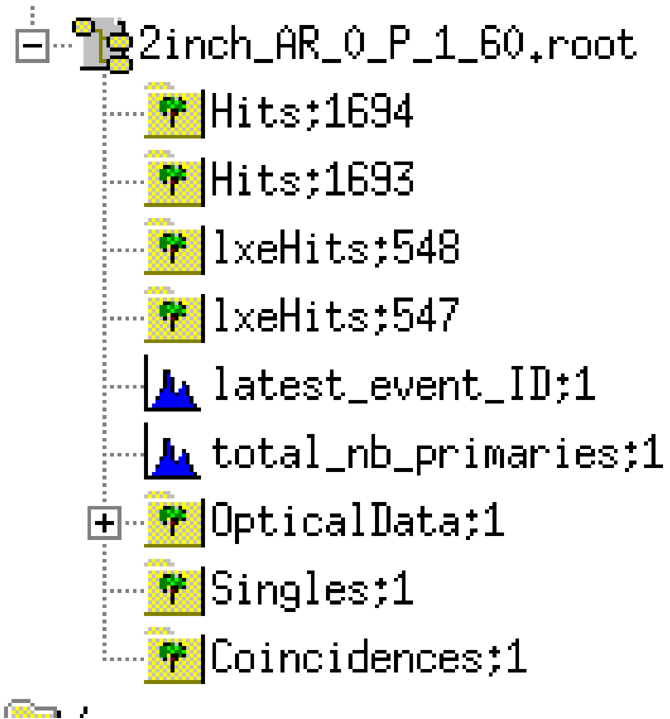


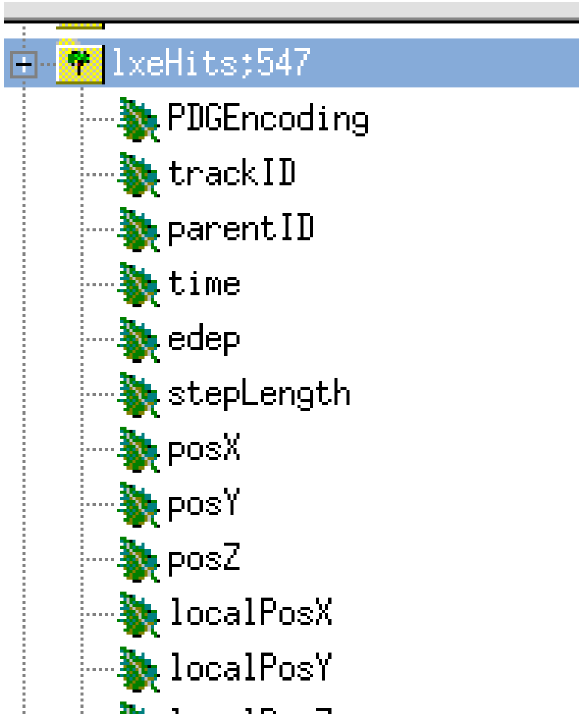
Purpose of stay

1. Modify GATE code to record hit information in LXe
2. Change the geometry to new one designed in Subatech (1” PMT case and 2” PMT case)
3. Analyze the results of new set up by previous method and hit information in LXe
4. Study the case angle of γ is uniform
5. Study compton event
6. Study two γ (back-to-back) and 3rd γ event (Future)

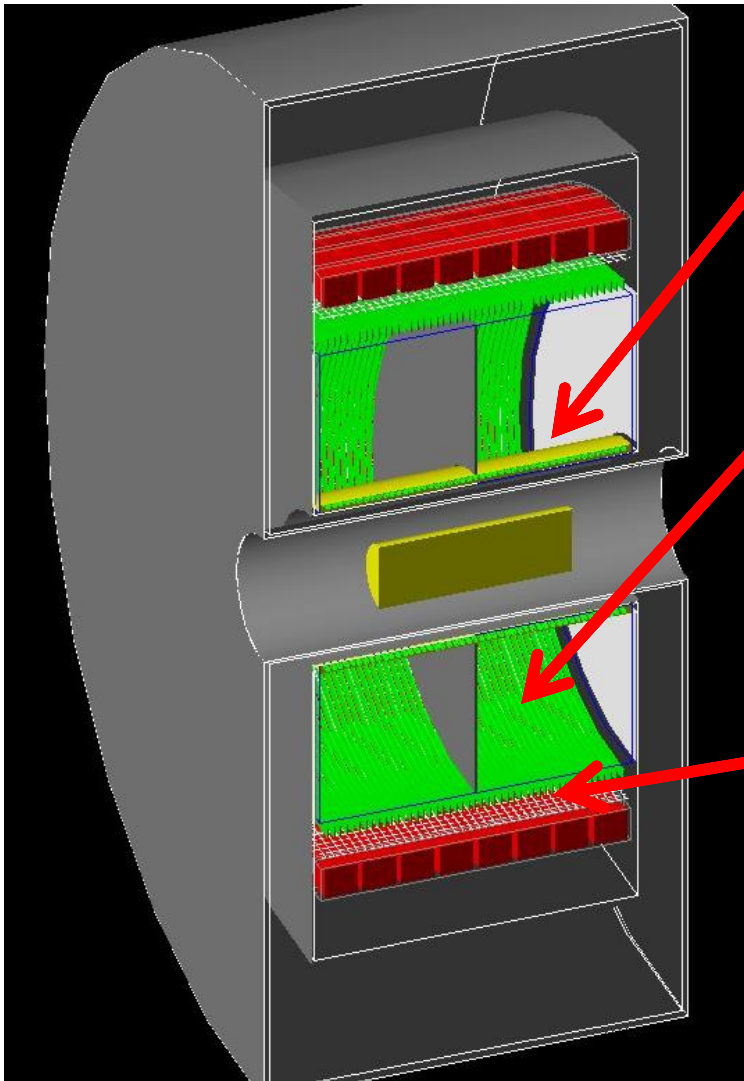
Modify GATE code

- In order to record the hit information in liquid Xenon, I made "lxeHits" Tree. (version 7.0 (newest) was modified)
  - register the liquid xenon to sensitive detector as "LXeSD"
  - includes many "Branch"(histogram) e.g. posX, posY, posZ, eventID..

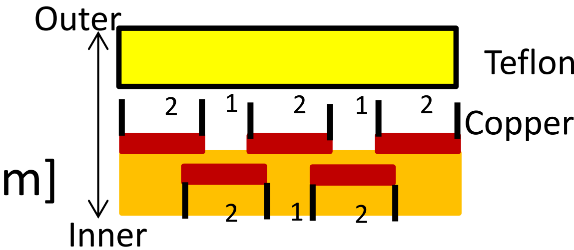


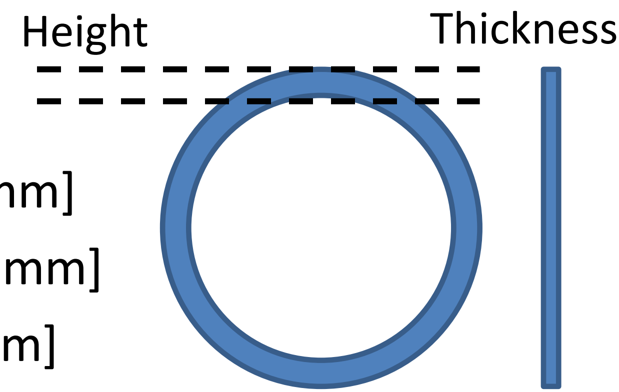


New geometry



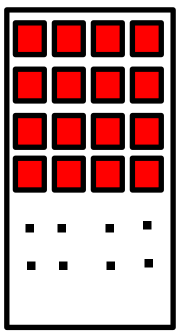
- Teflon cylinder
  - Thickness : 7 [mm]
- Copper ring
  - Height : 8.5 [mm]
  - Thickness : 1 [mm]
  - Interval : 5 [mm]
- SUS mesh
  - Space : 6.3 x 6.3 [mm]
  - wire : 0.71 [mm]
  - A.R. = 80.8[%]



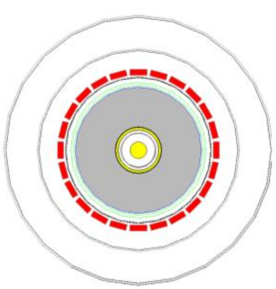


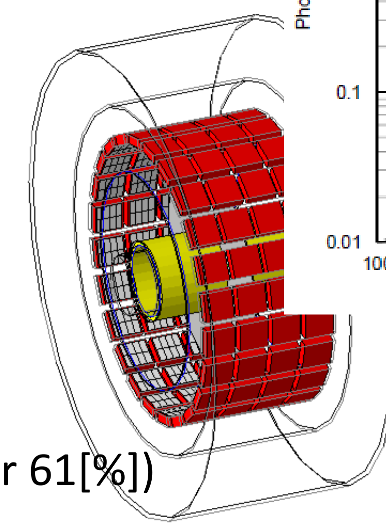
New geometry

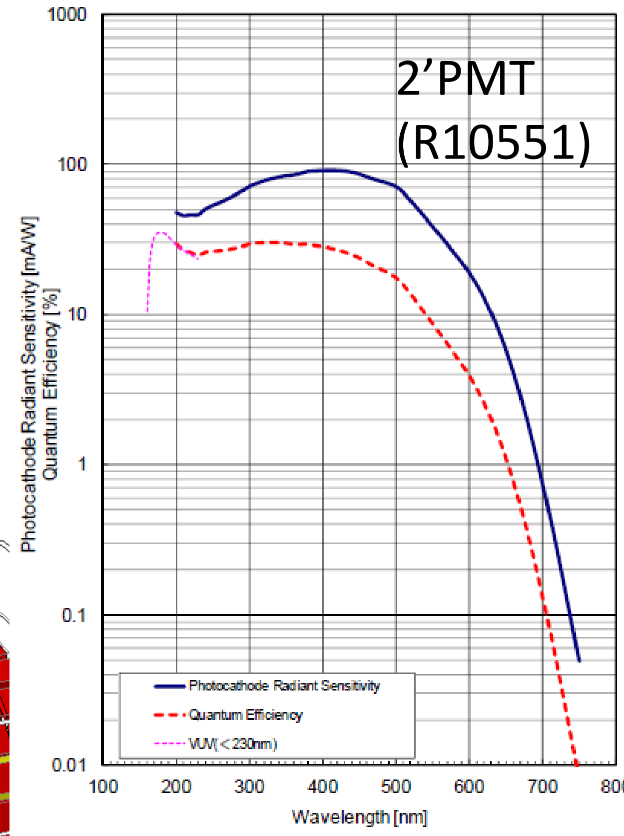
- Parameter
  - 1’PMT
    - Quantum efficiency : 30[%]
      - Nb of photon : 4167 [/MeV] (explained at next page)
    - Number : 8 x 48 = 384
    - Detecting area : 1244[cm^2] (cover 37[%])



  - 2’PMT
    - Quantum efficiency : 34.82 [%]
      - Nb of photon : 4836 [/MeV] (explained at next page)
    - Number : 4 x 24 = 96
    - PhotoCathode : 2(v) x 4(u)
    - Detecting area : 2053 [cm^2] (cover 61[%])







New geometry

- Nb of Photon
  - 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.)

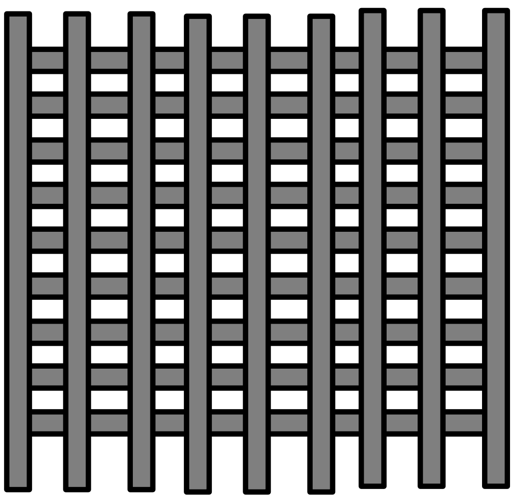
2” PMT (1” PMT)

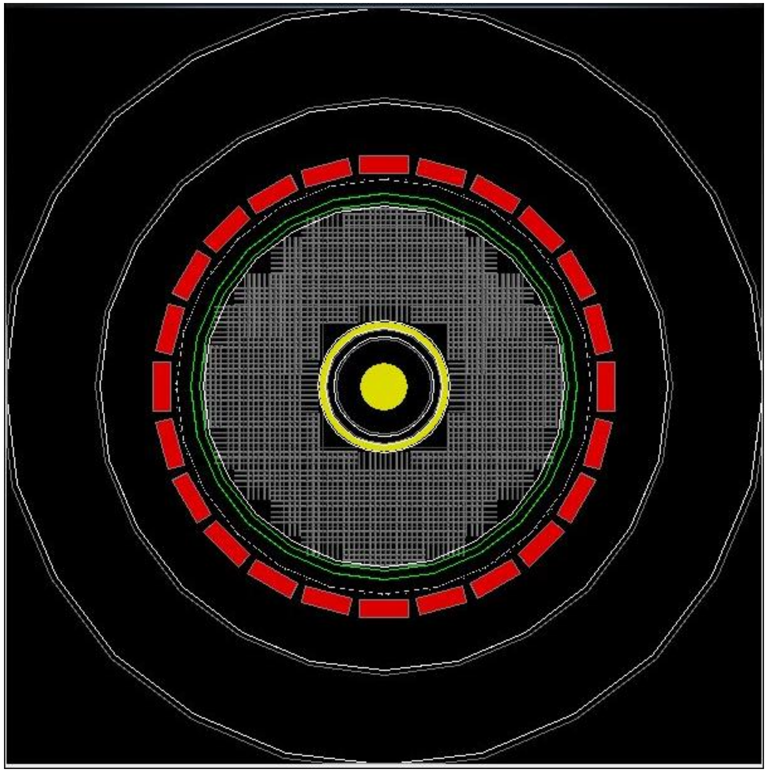
$$\frac{1.0\times10^{6}}{21.6}\times0.3482(0.3)\times0.3\cong4836(4167)[/MeV]$$

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

New geometry

- Mesh cathode
  - Repeat the wire along x and y axis





  - Divide the repeaters to 18 areas to approximate the shape to circle

Define surface

- Parameter of reflection
  - Teflon
    - Reflectance : 95 [%]
    - Component : Diffuse
  - SUS304
    - Reflectance : 6.5 [%]
      - Calculated

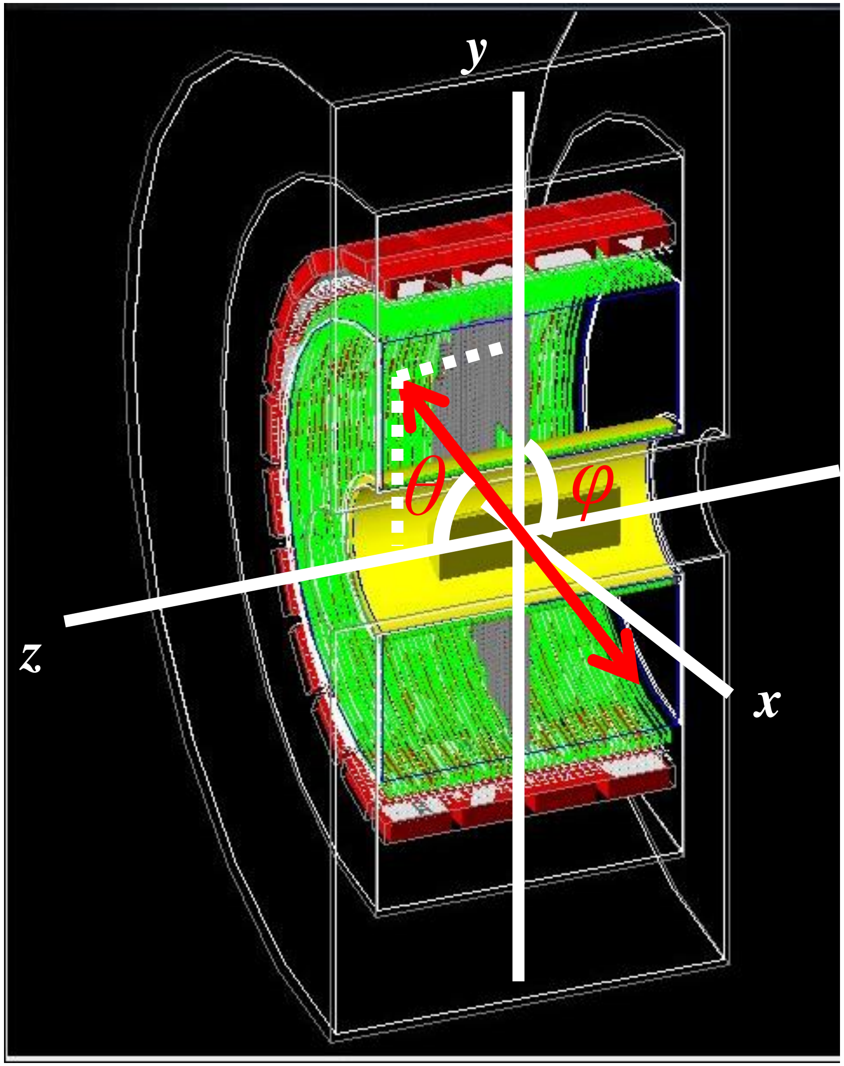
$$\left(\frac{n_a - n_b}{n_a + n_b}\right)^2$$

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

    - Component : Specular lobe
  - Copper
    - Reflectance : 23 [%]
      - reference : http://www-sk.icrr.u-tokyo.ac.jp/xmass/prelist/2004AutumnTomita.pdf
    - Component : Specular lobe

Simulation

- Simulation 1
  - θ = 35, 60, 85 [degree]
  - ϕ = 90 [degree]
  - Point source (sphere r = 0.5 [cm])
  - 20 kBq x 0.5[s] = 10000 [event]
  - Only photoeletric event
- Simulation 2
  - θ = 35 - 85 [degree] (isolated)
  - ϕ = 90 [degree]
  - Point source (sphere r = 0.5 [cm])
  - 20 kBq x 5.0 [s] = 100000 [event]
  - Only photoeletric event



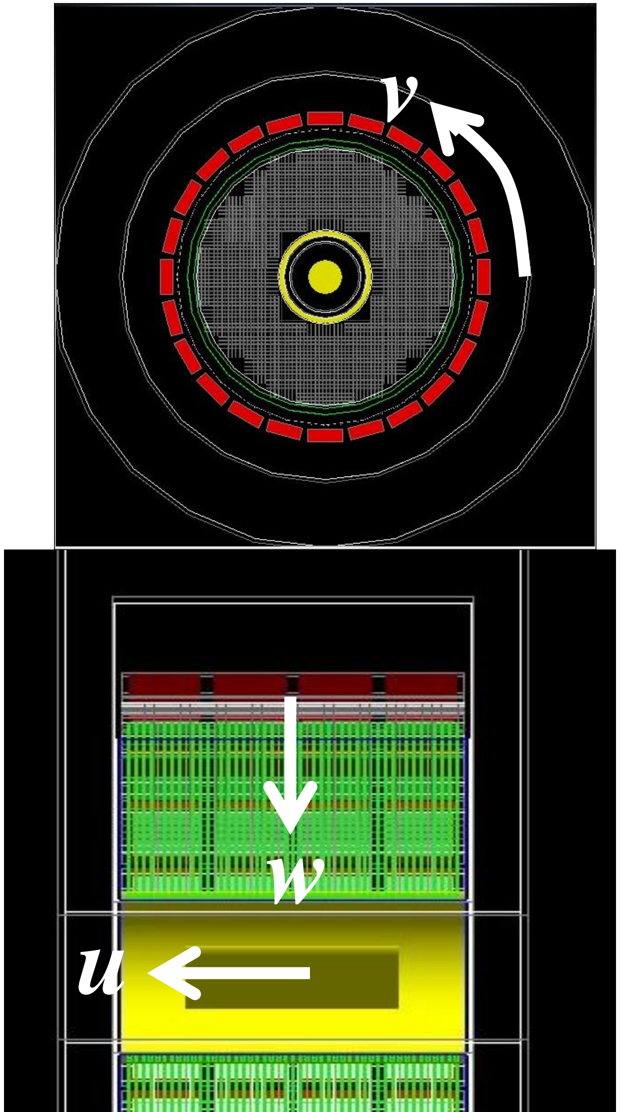
Analysis

- Coordinate
  - R is radius of photocathode surface
  - R = 225 [mm]

$$u = z$$

$$v = R \times \arctan\left(\frac{y}{x}\right)$$

$$w = R - \sqrt{x^2 + y^2}$$



Analysis

- Analysis 1 (previous method) for simulation 1
  - Calculate the mean of u and v by center of gravity method

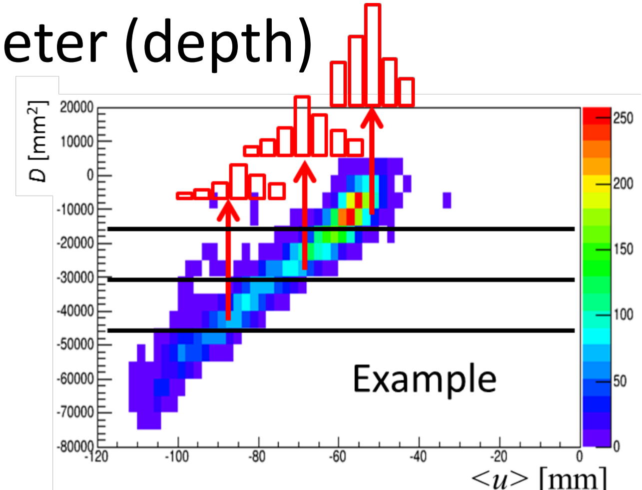
$$<u> = \frac{\sum_i q_i \cdot u_i}{q} \qquad <v> = \frac{\sum_i q_i \cdot v_i}{q}$$

q_i : nb of photoelectron detected by PMT(i)

$$q = \sum_i q_i$$

  - Calculate $\sigma_{<u>}$ and $\sigma_{<v>}$ in each D parameter (depth)

$$D = \frac{\sum_i q_i \cdot u_i^2 + \sum_j q_j \cdot v_j^2}{q} - \left(\frac{\sum_i q_i \cdot u_i + \sum_j q_j \cdot v_j}{q} \right)^2$$



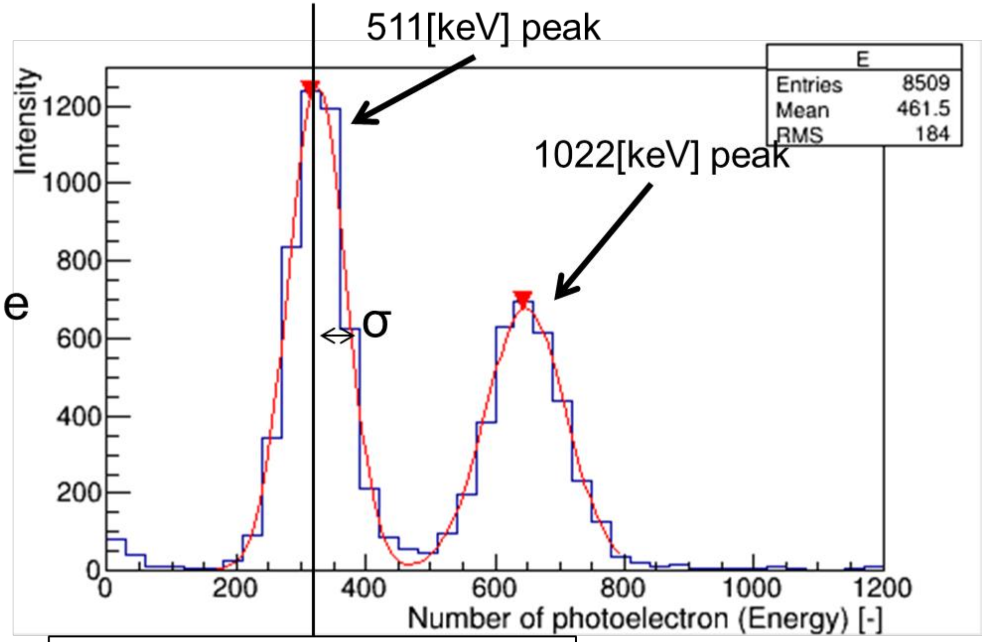
θ = 60 [degree]

  - Get the average sigma of above σ in each θ

Analysis

- Analysis 1 (previous method) for simulation 1
  - Get the number of photoelectron generated 511 [keV] and energy resolution at 511 [keV]

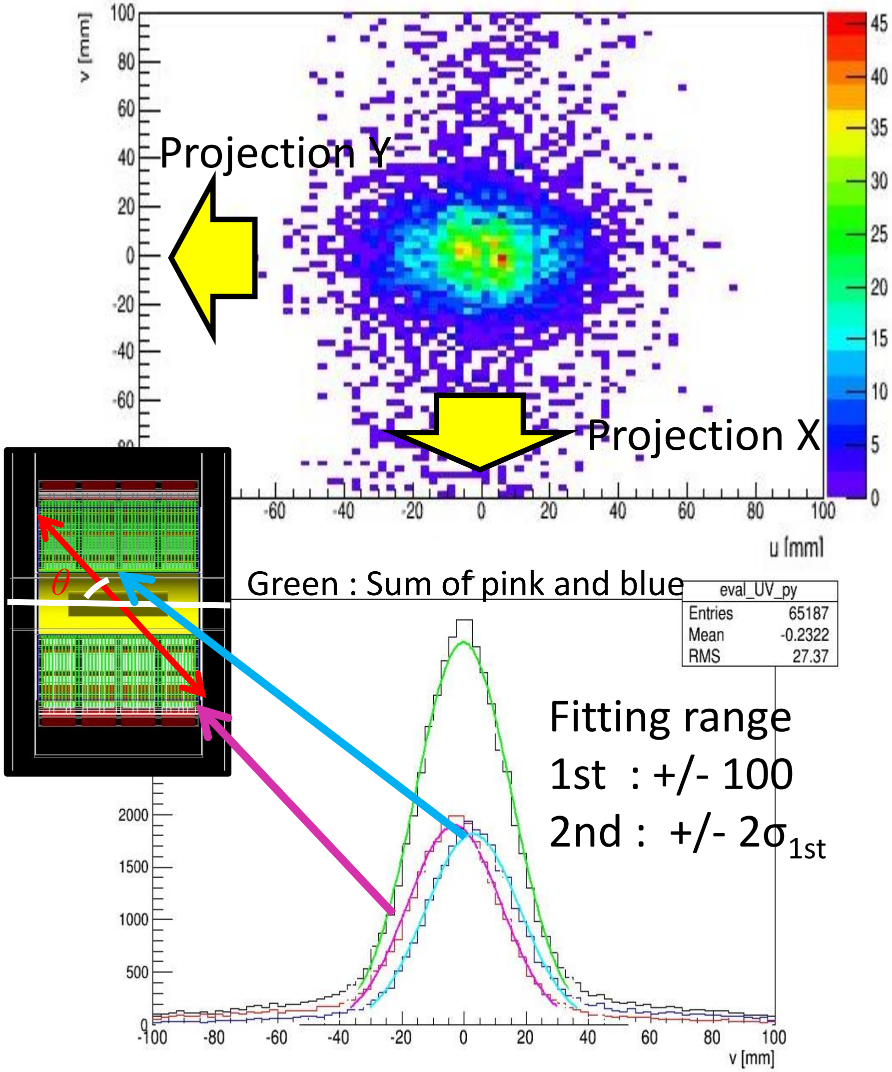
Example



Number of photoelectron detected by PMT in one event

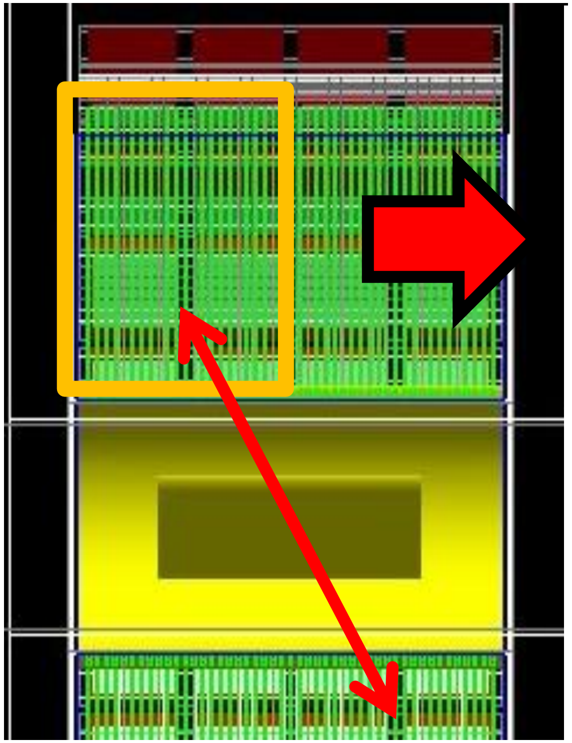
Analysis

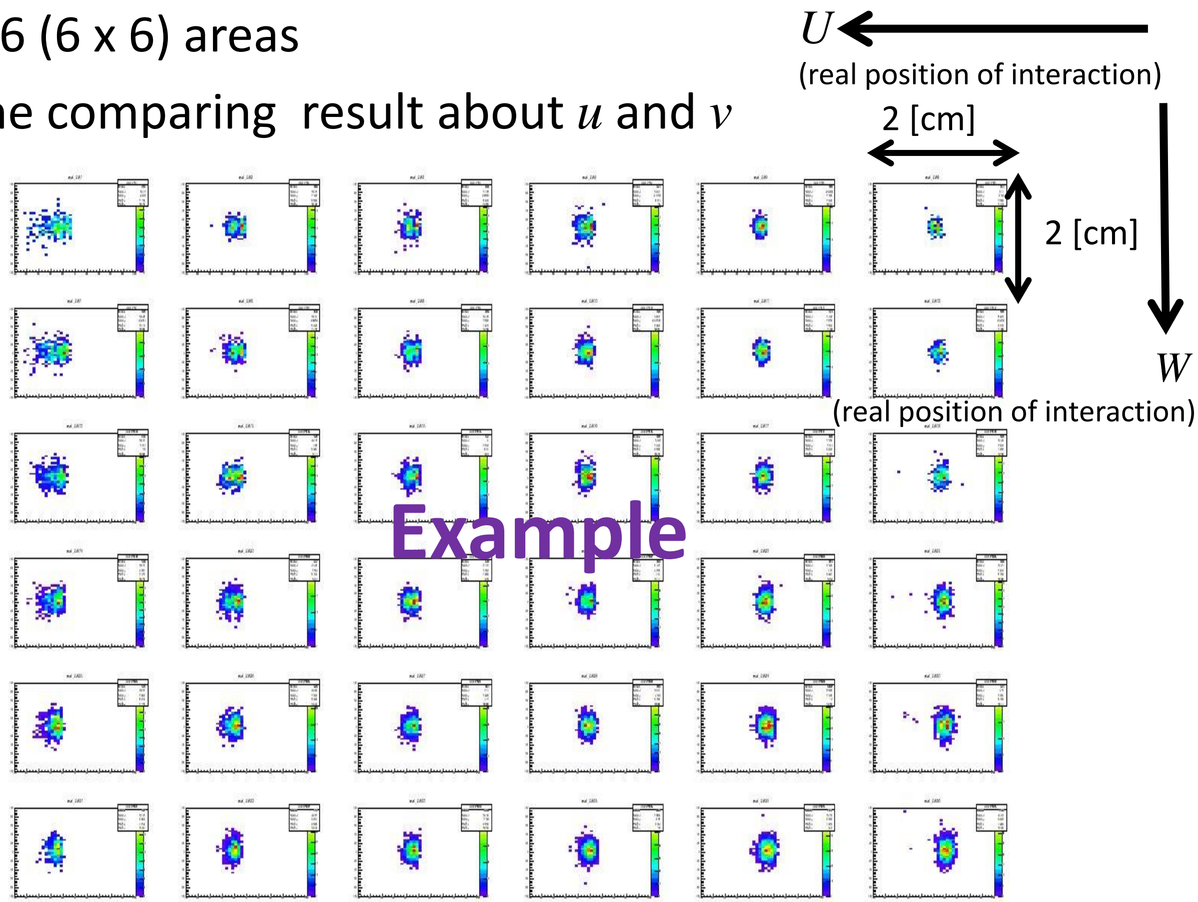
- Analysis 2 for simulation 2
  - Get the real position of interaction from “LXeHits”
  - Get the reconstructed position by center of gravity method
  - Plot the difference of u and v
  - Project 2D histogram to X and Y
  - Calculate the σ by twice gauss fitting



Analysis

- Analysis 3 for simulation 2
  - Divided volume by 36 (6 x 6) areas
  - Histograms shows the comparing result about u and v





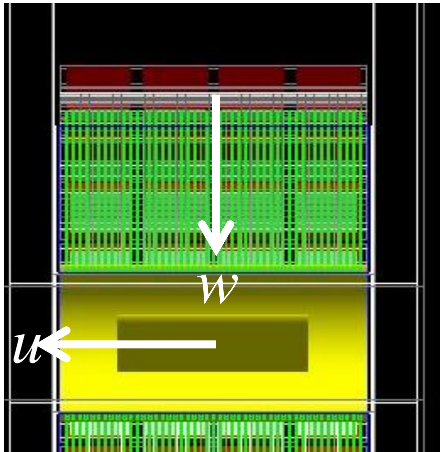
Analysis

- Analysis 3 for simulation 2
  - Calculate the mean and sigma of each areas by GetMean() and GetRMS() of ROOT function

$$\sigma = RMS = \sqrt{\frac{\sum_i q_i x^2}{q} - \left(\frac{\sum_i q_i x}{q}\right)^2}$$

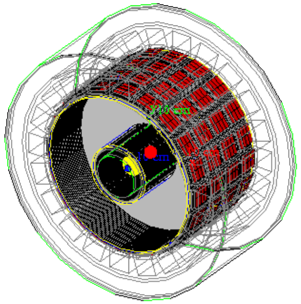
$$Mean = \frac{\sum_i q_i x}{q}$$

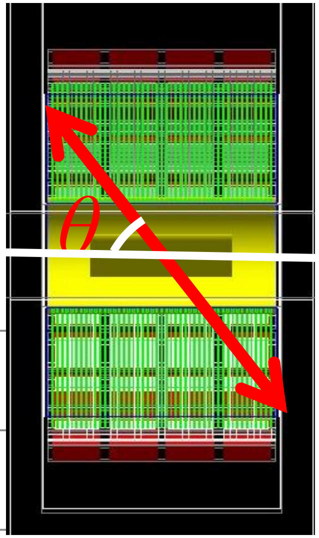
  - Plot sigma and mean of each area
  - Evaluate the volume and compare the result of each other

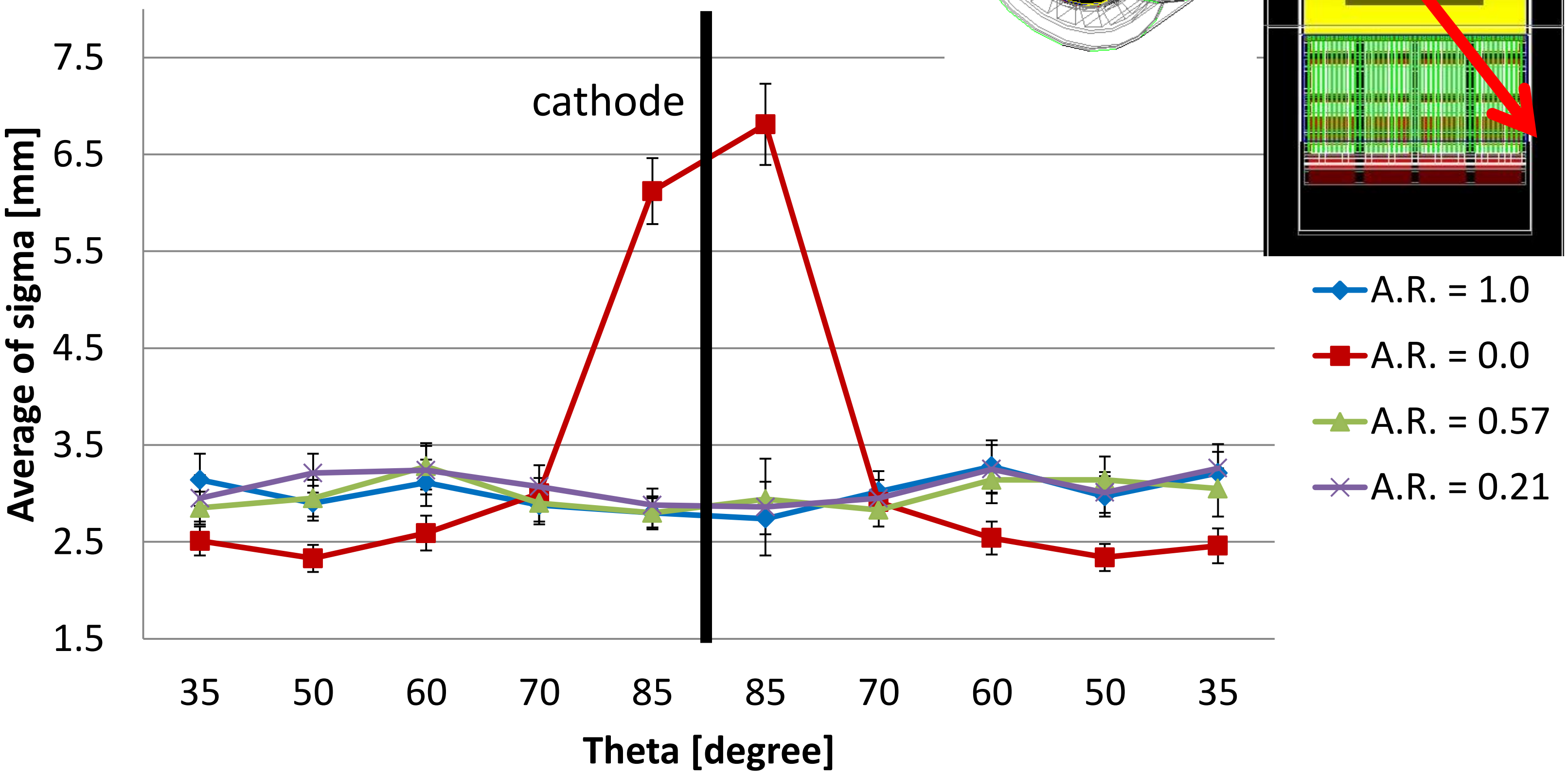


Result

- Analysis 1
  - old geometry



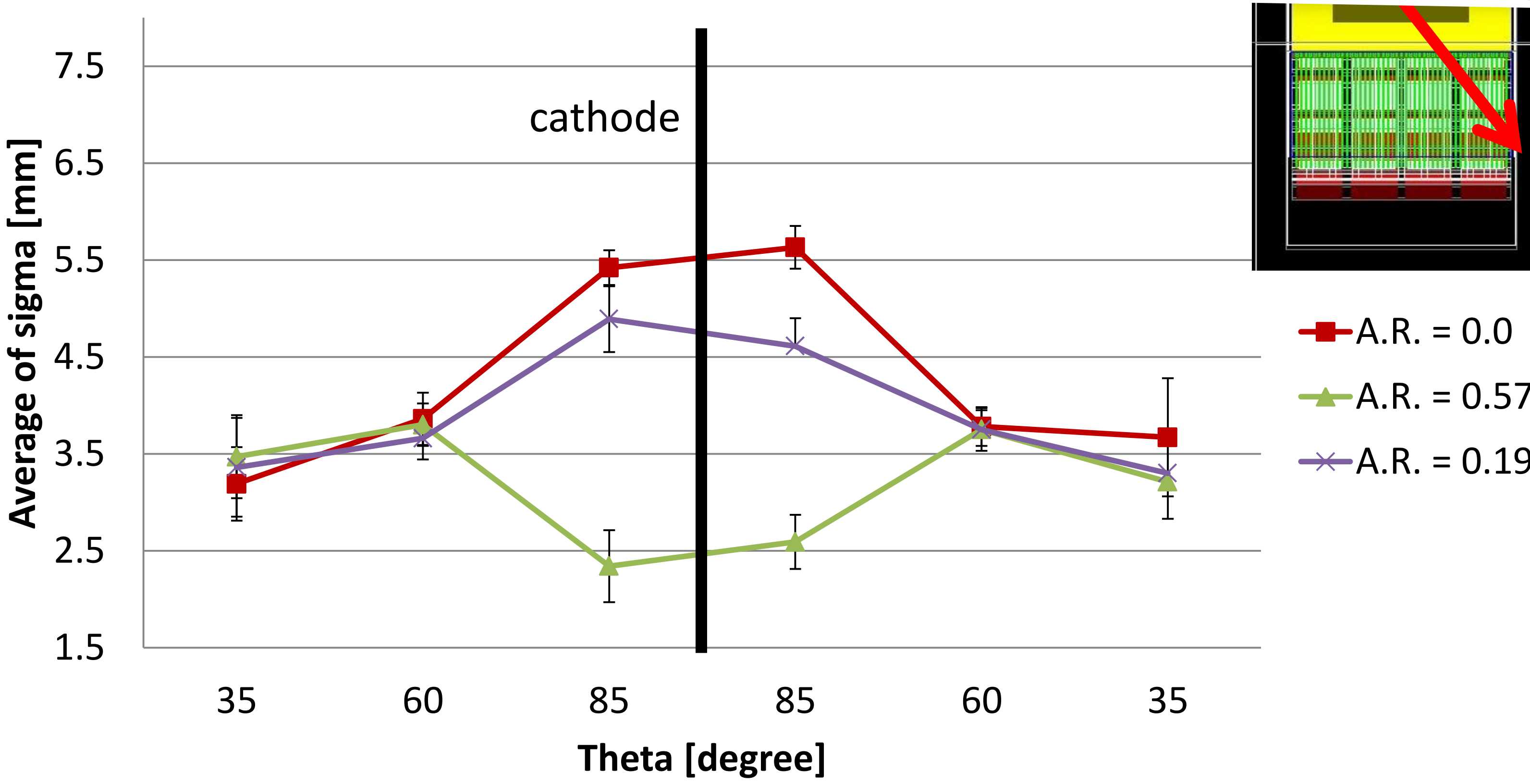


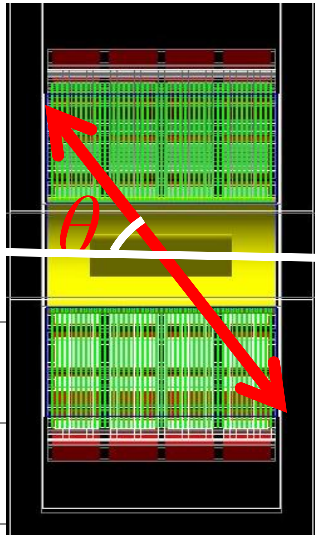


Result

- Analysis 1
  - new geometry

σ_u

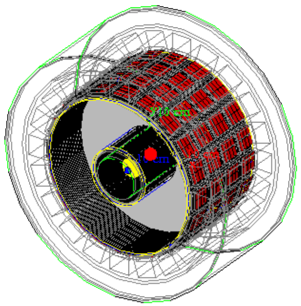


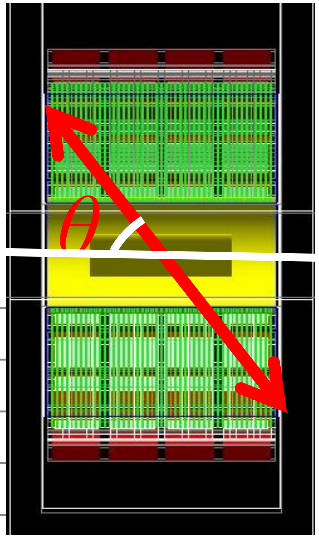


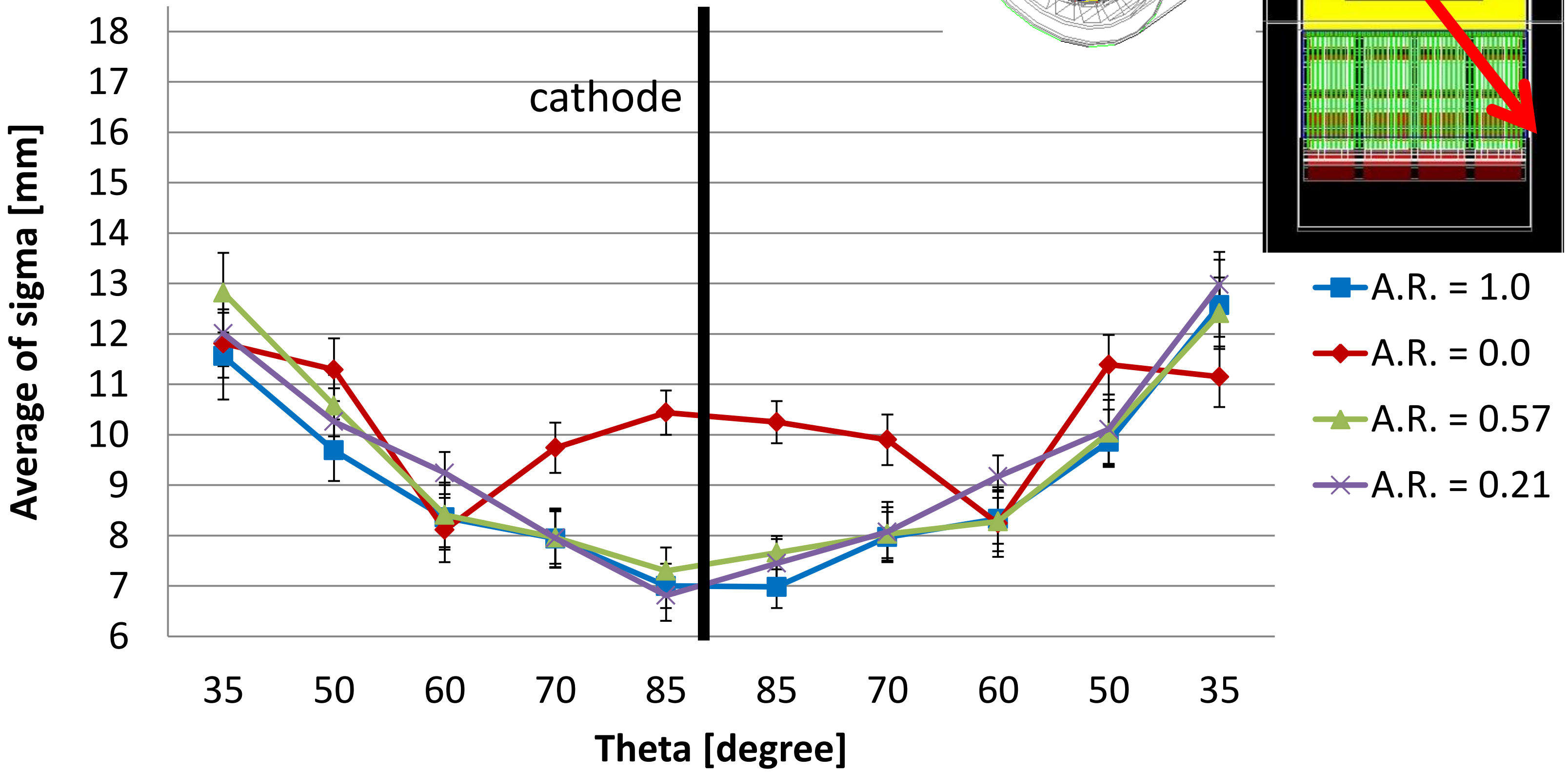
Result

- Analysis 1
  - old geometry

σ_v

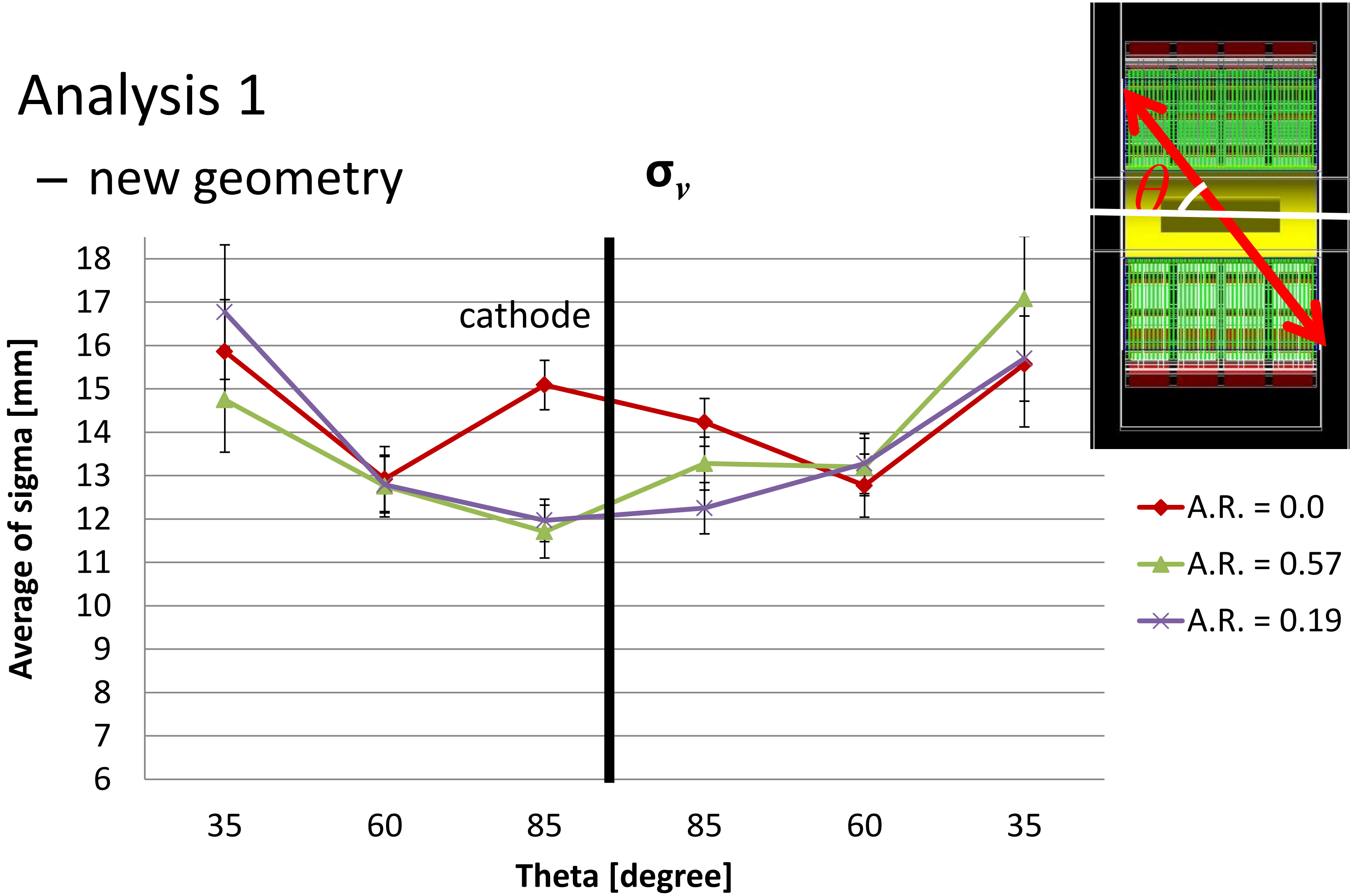






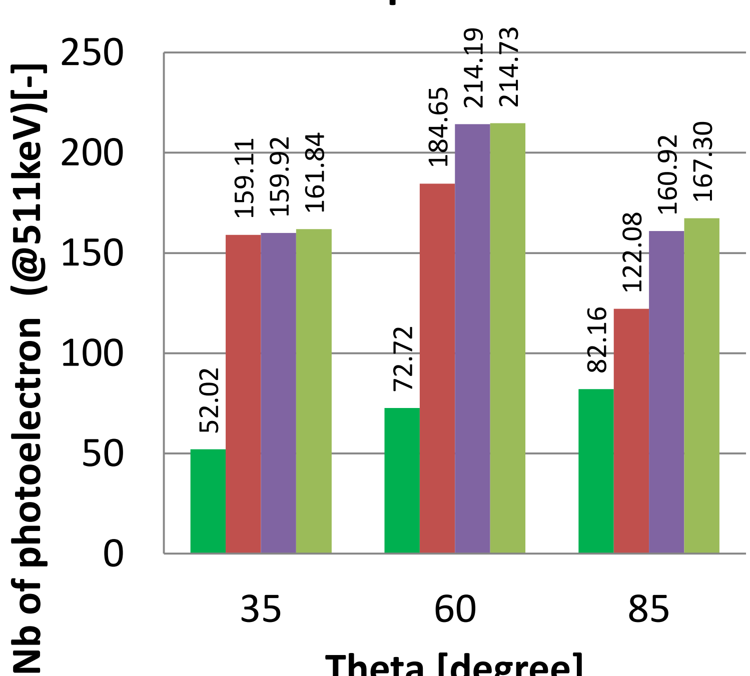
Result

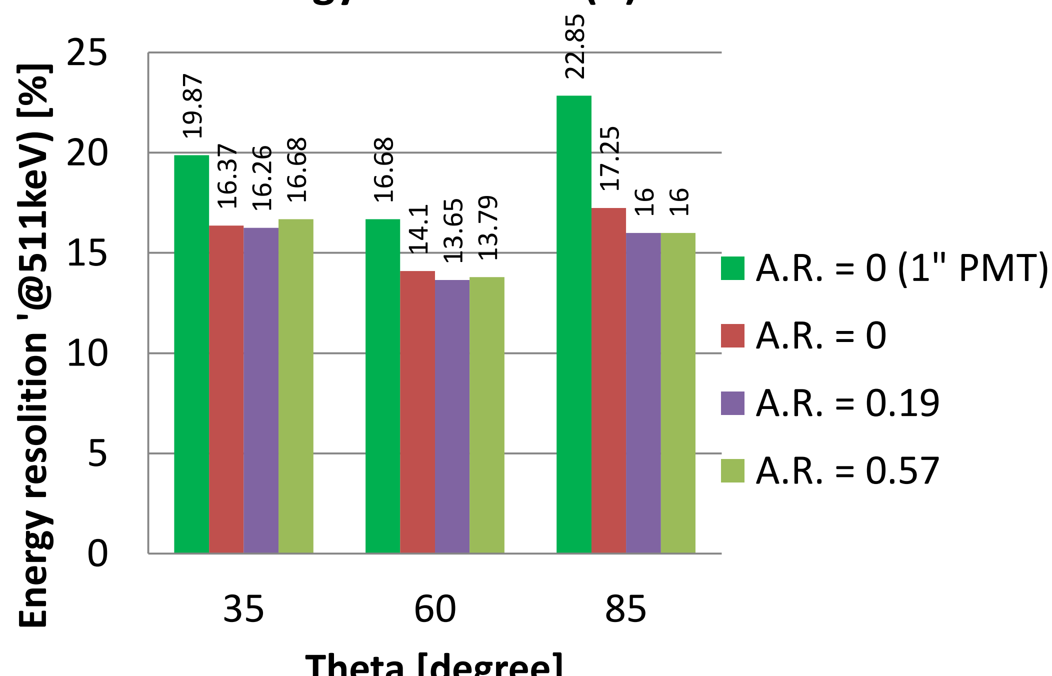
- Analysis 1
  - new geometry



Result

- Analysis 1
  - Number of photoelectron and energy resolution
  - each aperture ratio and PMT



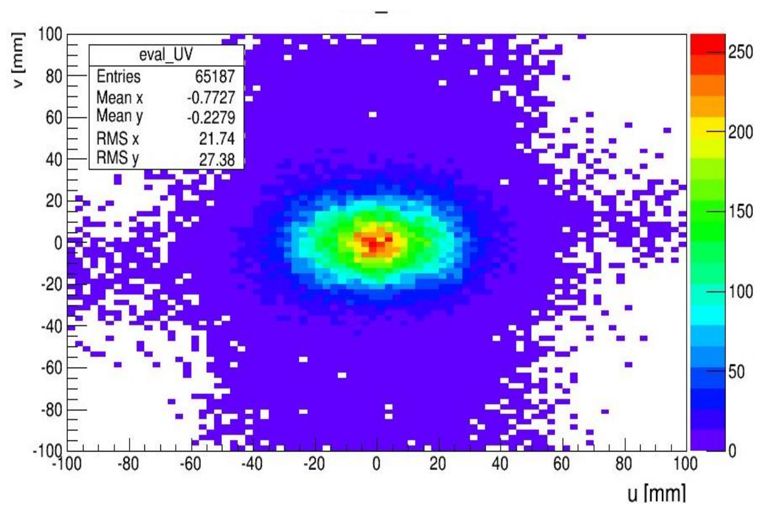


Result

- Analysis 1 conclusion
  - Both σ of u and v became worse than old geometry
    - Decrease the Number of photoelectron (less than half)
  - Especially u, σ has better value in case A.R. has a larger value
  - Got the 1.5 - 3 times number of photoelectron in 2” PMT geometry, comparing with one of 1”PMT
    - 2” PMT has better quantum efficiency (1.16 times) and larger detecting area (1.65 times) than 1” PMT
  - Little improvement in mesh cathode case
  - Energy resolution was improved 2-7% in 2”PMT and mesh cathode case

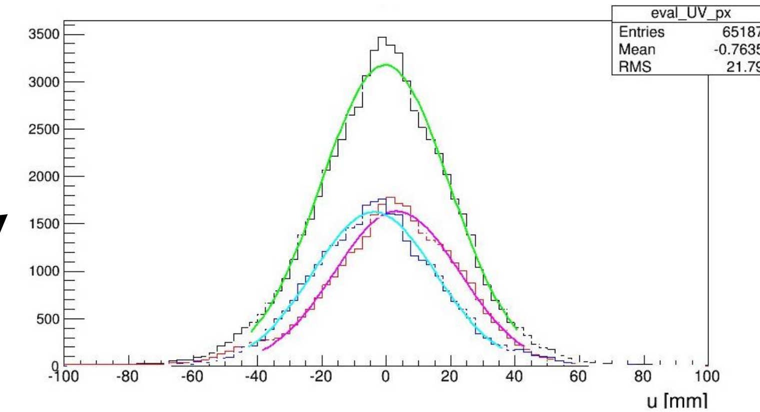
Result

- Analysis 2
  - 2” PMT, A.R. = 0 model
  - all volume



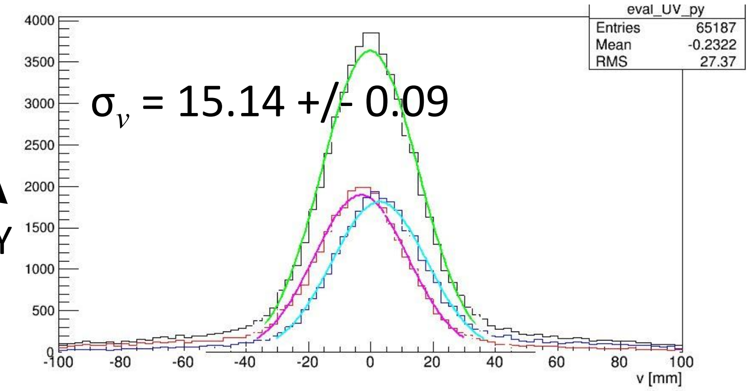
ProjectionX

σu=19.27 +/- 0.12 [mm]



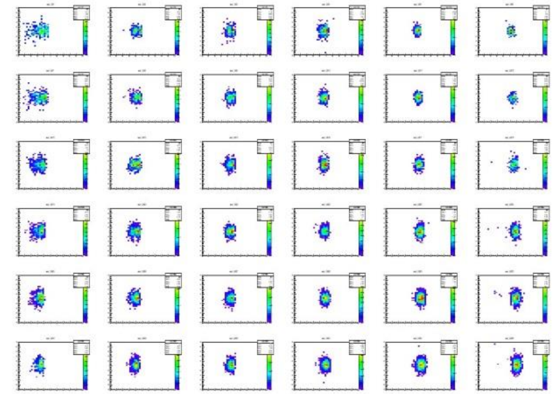
ProjectionY

σ_v = 15.14 +/- 0.09

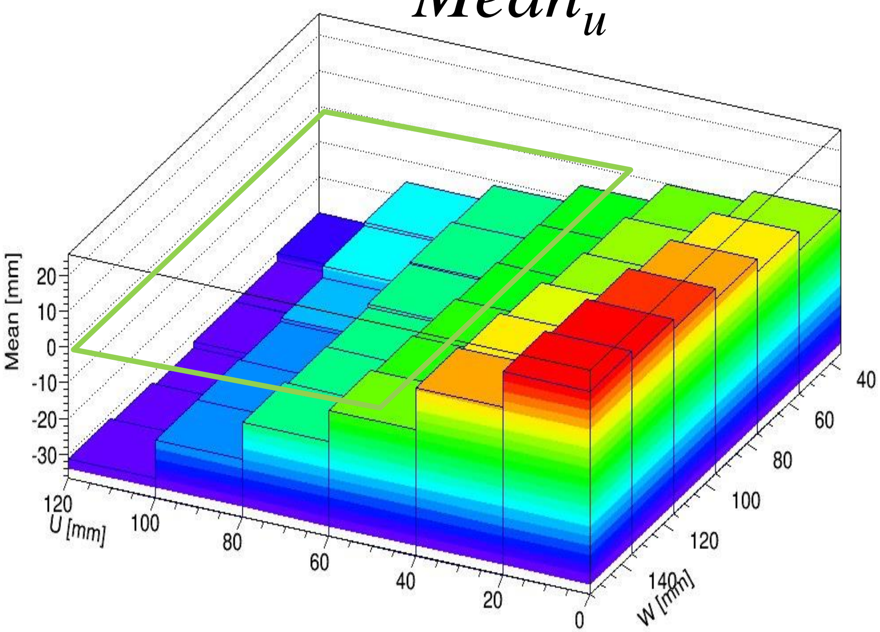


Result

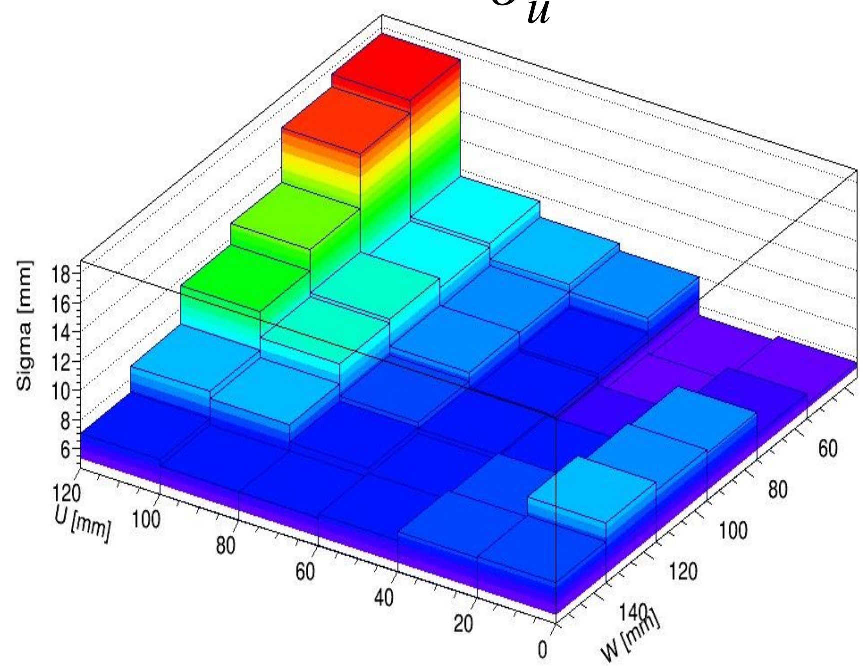
- Analysis 3
  - 2” PMT, A.R. = 0 model
  - U and W means real position of interaction



$Mean_u$

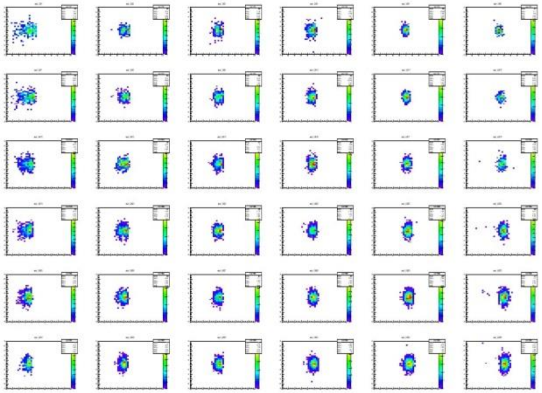


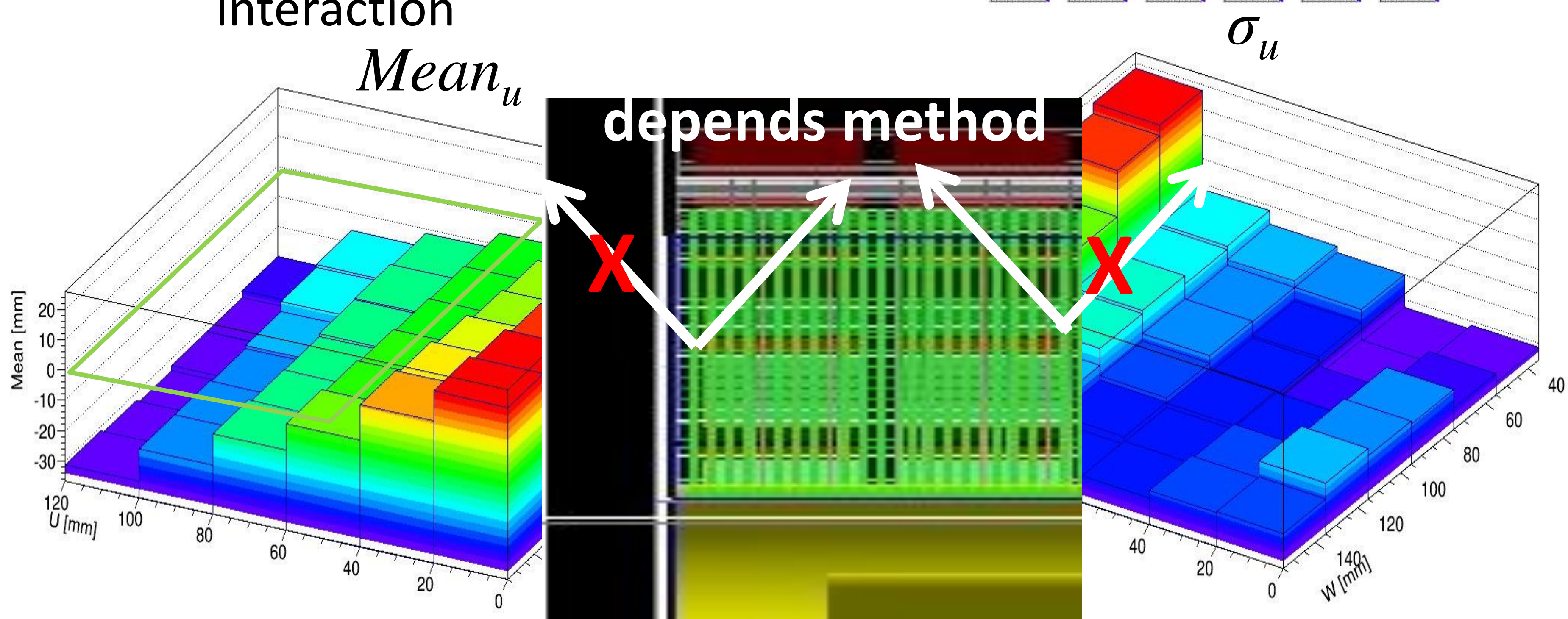
σ_u



Result

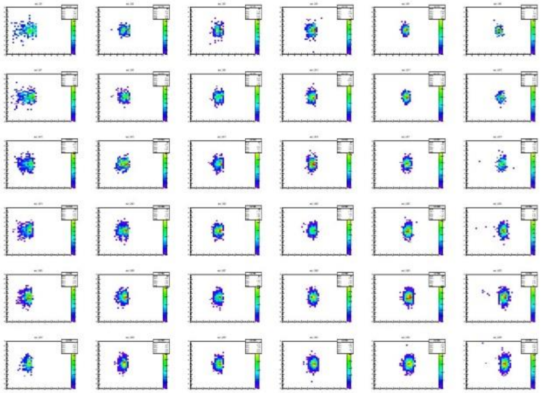
- Analysis 3
  - 2” PMT, A.R. = 0 model
  - U and W means real position of interaction



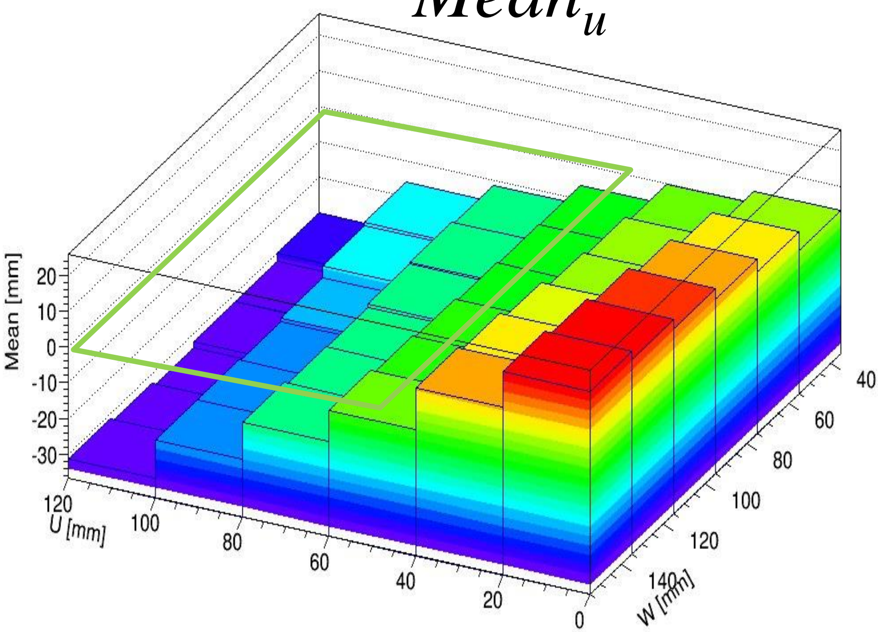


Result

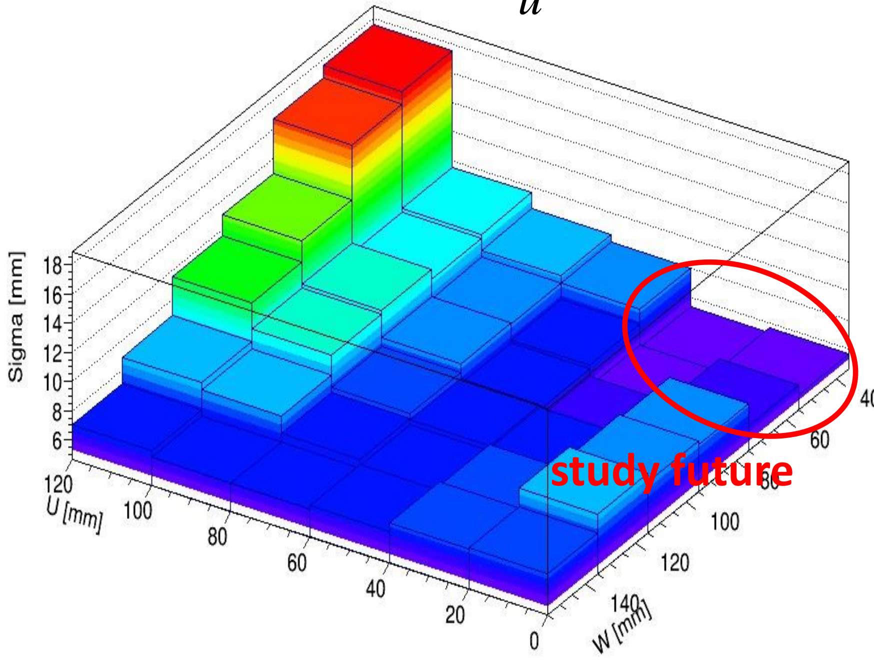
- Analysis 3
  - 2” PMT, A.R. = 0 model
  - U and W means real position of interaction



$Mean_u$

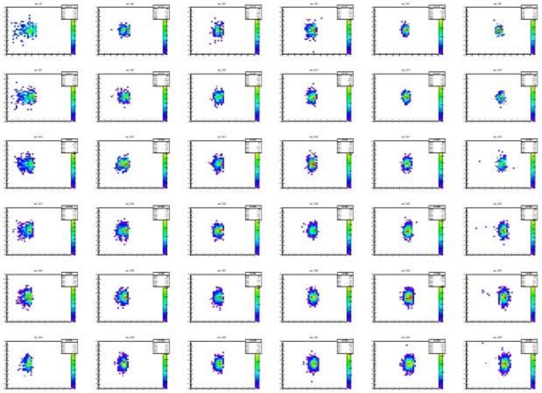


σ_u

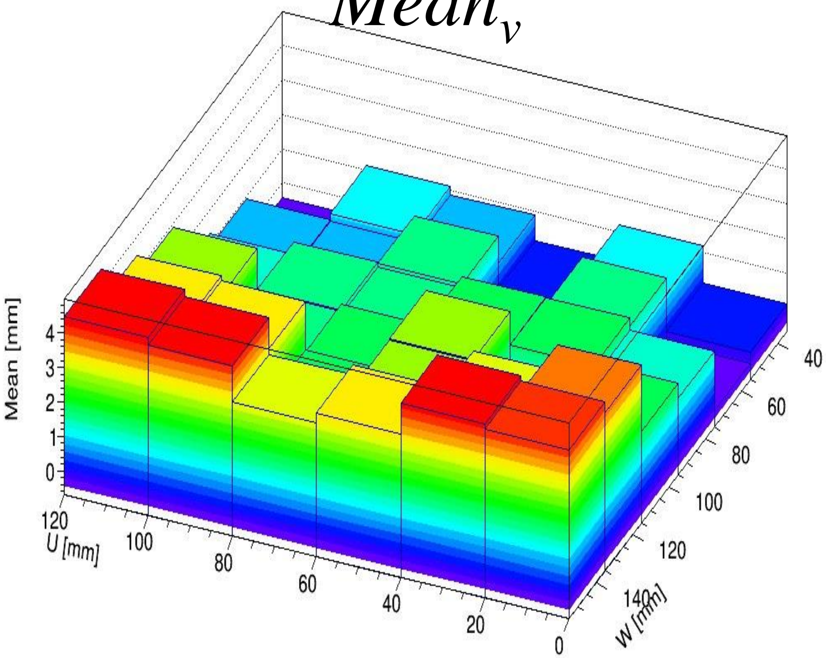


Result

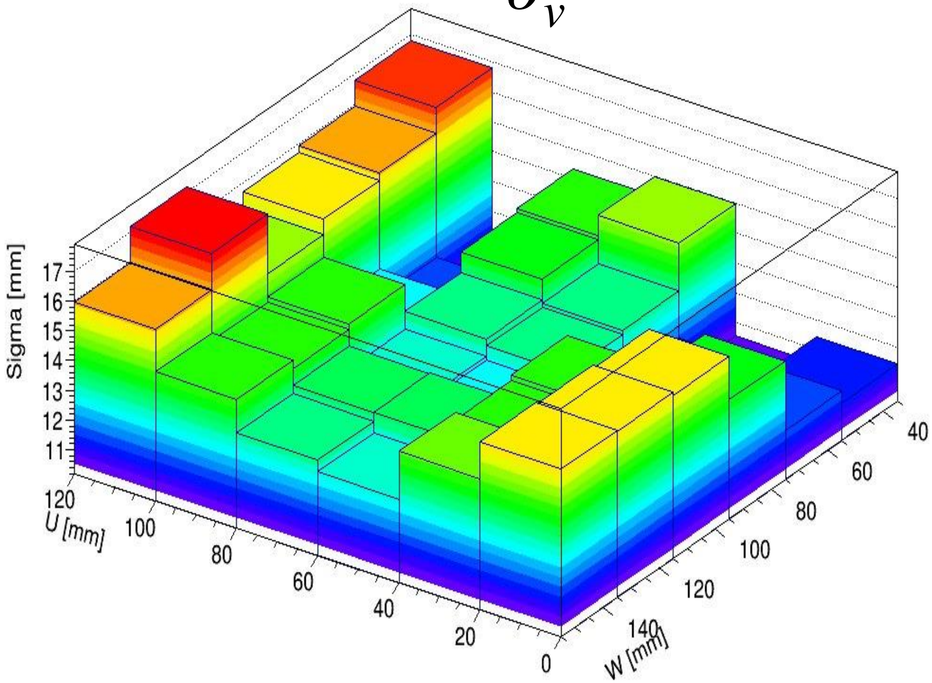
- Analysis 3
  - 2” PMT, A.R. = 0 model
  - U and W means real position of interaction



$Mean_v$

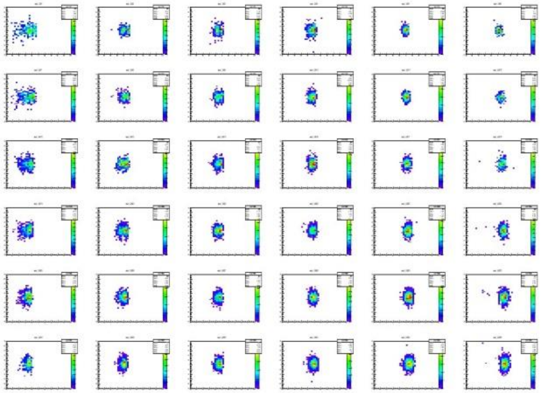


σ_v

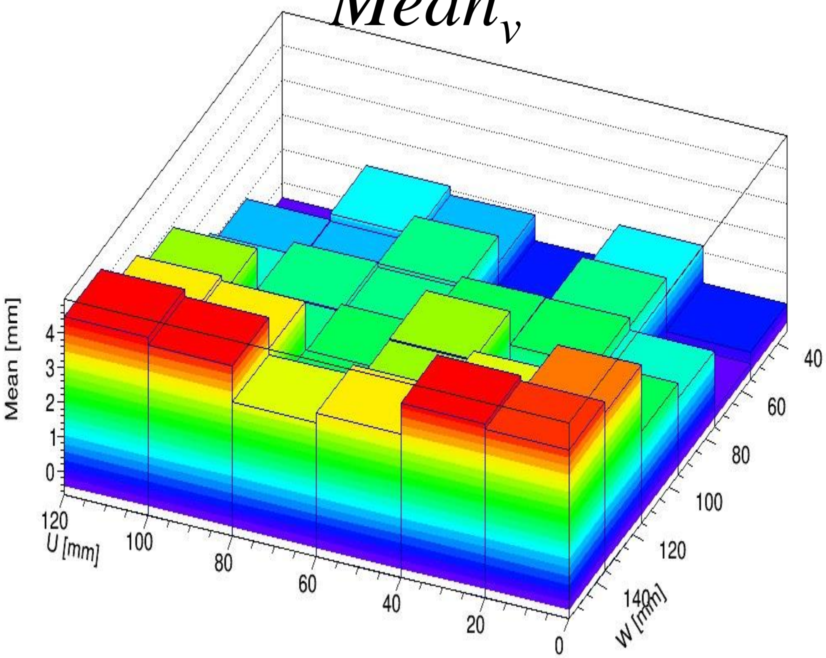


Result

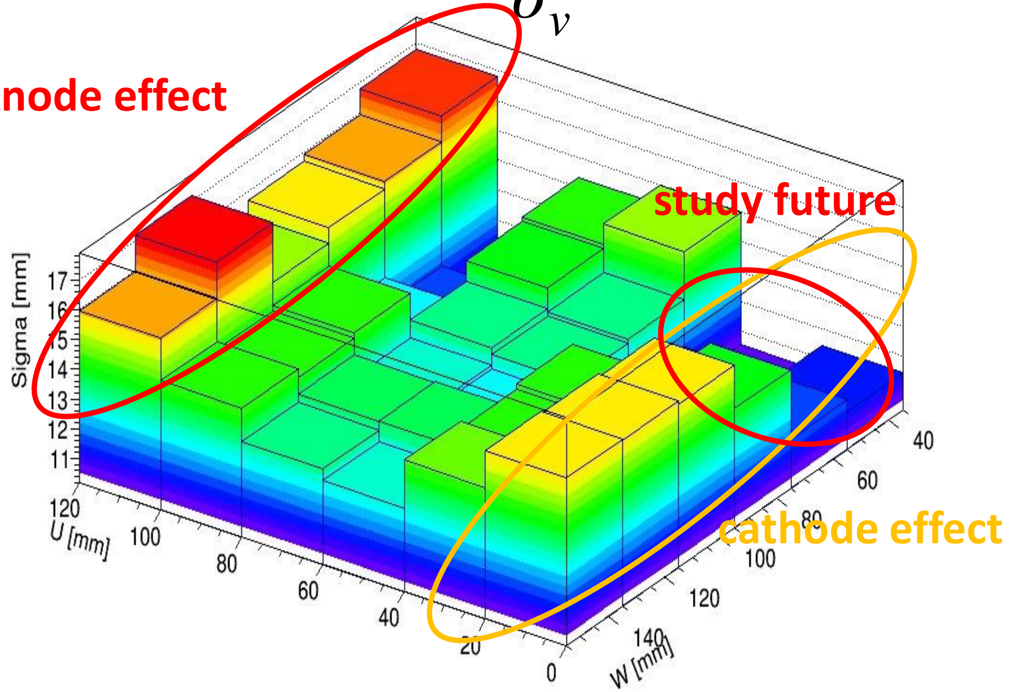
- Analysis 3
  - 2” PMT, A.R. = 0 model



$Mean_v$



σ_v



Result

- Analysis 2 and 3 conclusion
  - Average σ$_u$ and σ$_v$ of one event
    - σ$_u$ = 19.27 +/- 0.12 [mm], σ$_v$ = 15.14 +/- 0.09[mm]
  - Mean value depends the interaction position
    - Center of gravity method should be modified or need calibration
  - Need more statistics
  - Need more study for fluctuation of sigma

Conclusion

- Modified GATE code to record hit information in LXe
- Updated some macros of GATE and the geometry of XEMIS2
- Made the program which compares reconstructed position with real position and analyzes σ and mean in each area
  - Need the other method to calculate the mean of u and v

Future

- Instead of v, test ϕ resolution (angle resolution)
- Study the fluctuation of volume
- Study the relation between D and w
- Simulate the case other materials are used for cathode or electrode

Merci beaucoup.