PMT Optical Simulation Update

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Outline

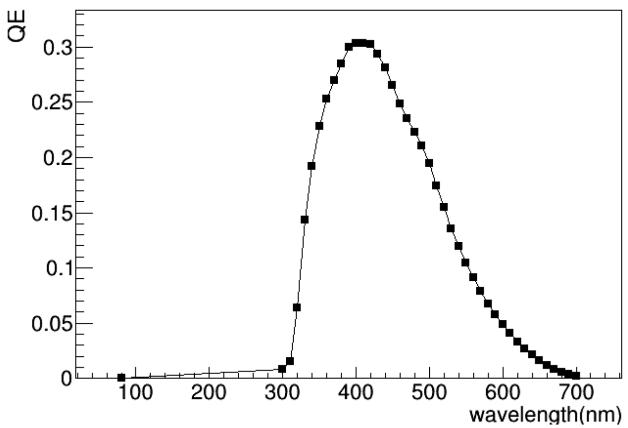
- Comparison of two PMT models
- Introduction of the new model
- Input parameters needed
- Usage of the new model in offline software
- Future plan

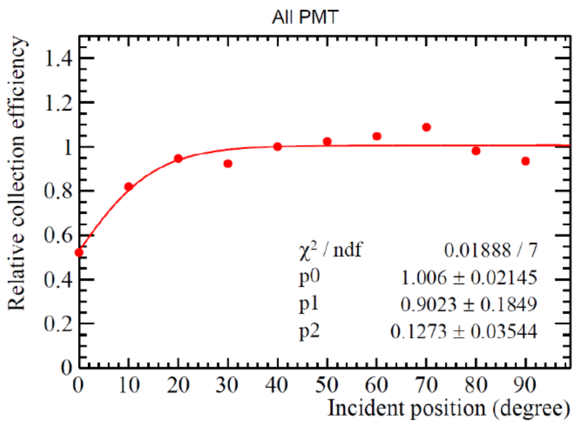
Current PMT optical model

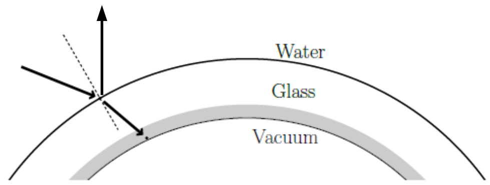
➢Simulation procedure

Ref: ihepjuno-doc-469-v1

- Optical photon goes from water to glass, reflection and refraction happens here
- Photon reaches the photocathode, which is an optical surface between glass and vacuum. The reflectivity of the surface is zero so that the photon will be detected or absorbed
- Depending on Q.E., the photon is detected or absorbed
- If the photon is detected, the C.E. is applied in sensitive detector
- If it is collected, a hit is generated







The new model

- Photons hitting on photocathode may undergo three processes:
  - Absorbed by photocathode, with probability $A(\lambda, \theta)$
    - If a photon is absorbed, a p.e. will be generated, the probability of it to escape from photocathode is related to a escape factor: $\rho(\lambda)$

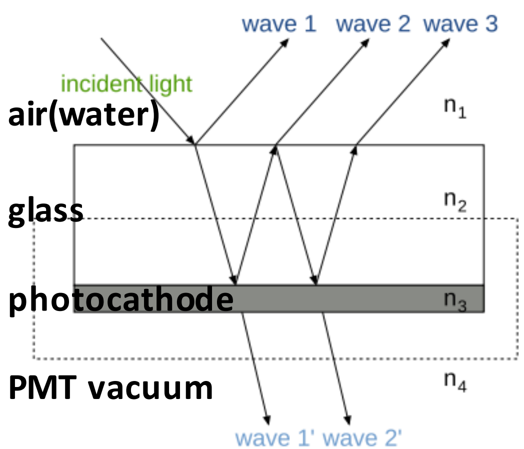
$$QE(\lambda, \theta) = A(\lambda, \theta) \times \rho(\lambda)$$

  - Reflected by photocathode, with probability $R(\lambda, \theta)$
  - Transmitted into the PMT, with probability $T(\lambda, \theta)$
    - Photons may be reflected by Al film on bottom surface, and absorbed by photocathode again

Ref: NIMA 539(2005)217-235, Doc1595, Doc1811

A, R, T can be calculated with **Snell's Law** and **Fresnel equations.**
Photocathode have complex refraction index

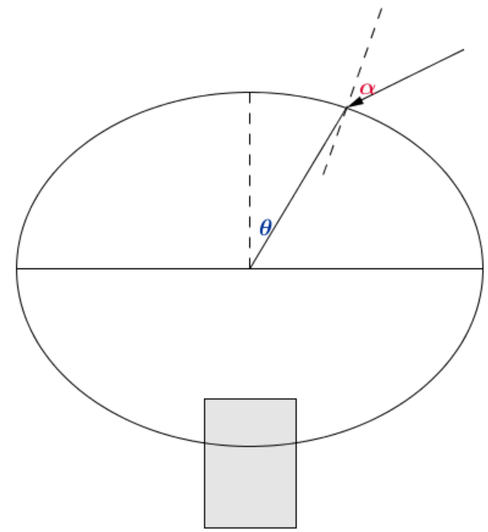
$$\tilde{\boldsymbol{n}} = \boldsymbol{n} + \boldsymbol{ik}$$

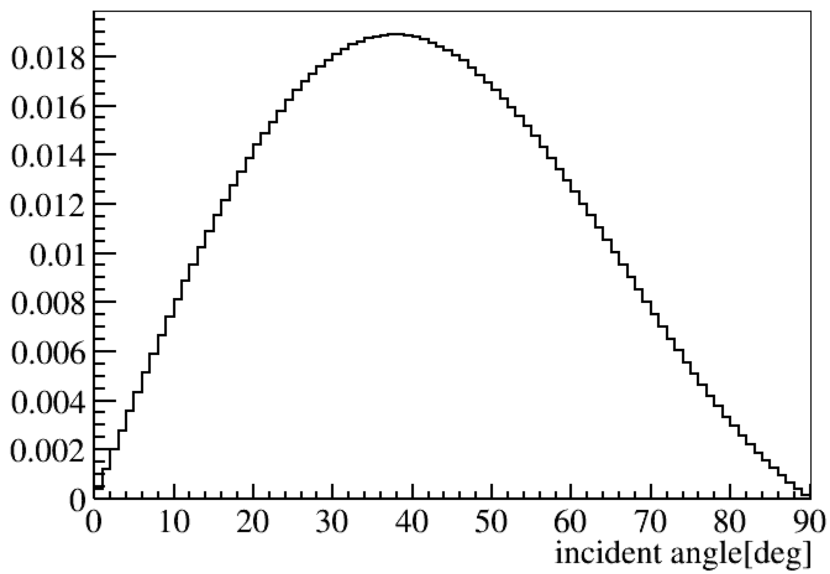


Multi-layered medium system

Angle response

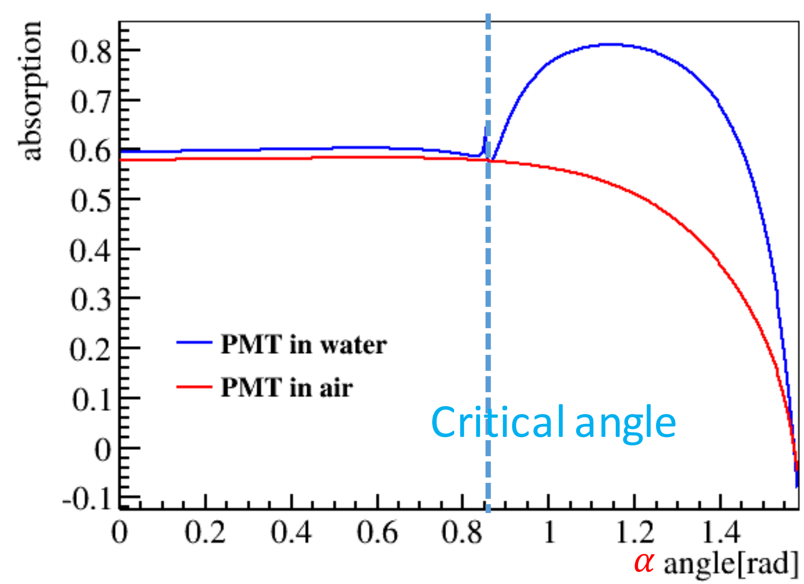
- Total internal reflection between photocathode and PMT vacuum leads to different angle responses if we put PMT in water
- Maximum of α distribution is around 40°, angle response may not be negligible
- The old model gives nearly the same result in these two conditions





α distribution in JUNO detector

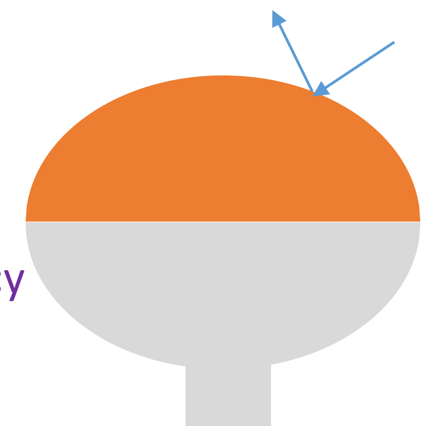
wavelength@410nm



Simulation method (1)

- Photons hitting on PMT surface may undergo three processes:
  - Reflection
  - **Absorption, photoelectron may escape from photocathode, and collected by dynode or mcp**
  - Transmission

Reflection of Al film is not considered here



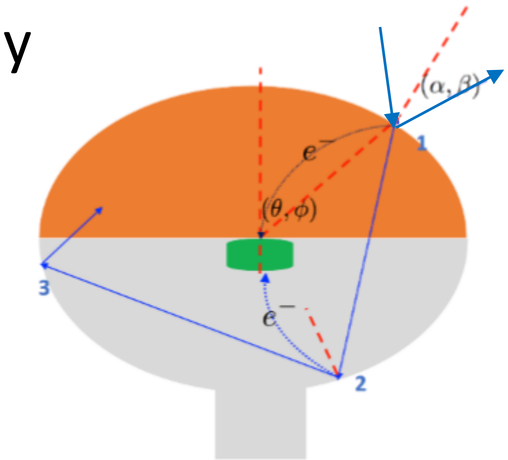
- DE can be denoted as:

$$DE(\lambda,\theta) = \underbrace{A(\lambda,\theta)}_{\text{absorption}} * \underbrace{\rho(\lambda)}_{\text{escape probability}} * \underbrace{CE(\lambda)}_{\text{collection efficiency}}$$

Absorption can be given by simulation, $\rho * CE$ can be got from scanning station measurement.

- Simulation based on Geant4

Simulation method (2)



- DE measured in scanning station is contributed by different points due to reflection:

$$DE = \sum_{i=1}^{n} A_i * \boxed{\rho_i * CE_i} = \sum_{i=1}^{n} A_i * F_i$$

- From scanning station data, we can solve the equation set to get F:

From experiment

$$\boxed{\begin{pmatrix} DE_1 \\ DE_2 \\ \vdots \\ DE_n \end{pmatrix}} = \boxed{\begin{pmatrix} A_{11} & \cdots & A_{1n} \\ \vdots & \ddots & \vdots \\ A_{n1} & \cdots & A_{nn} \end{pmatrix}} \begin{pmatrix} F_1 \\ F_2 \\ \vdots \\ F_n \end{pmatrix}$$

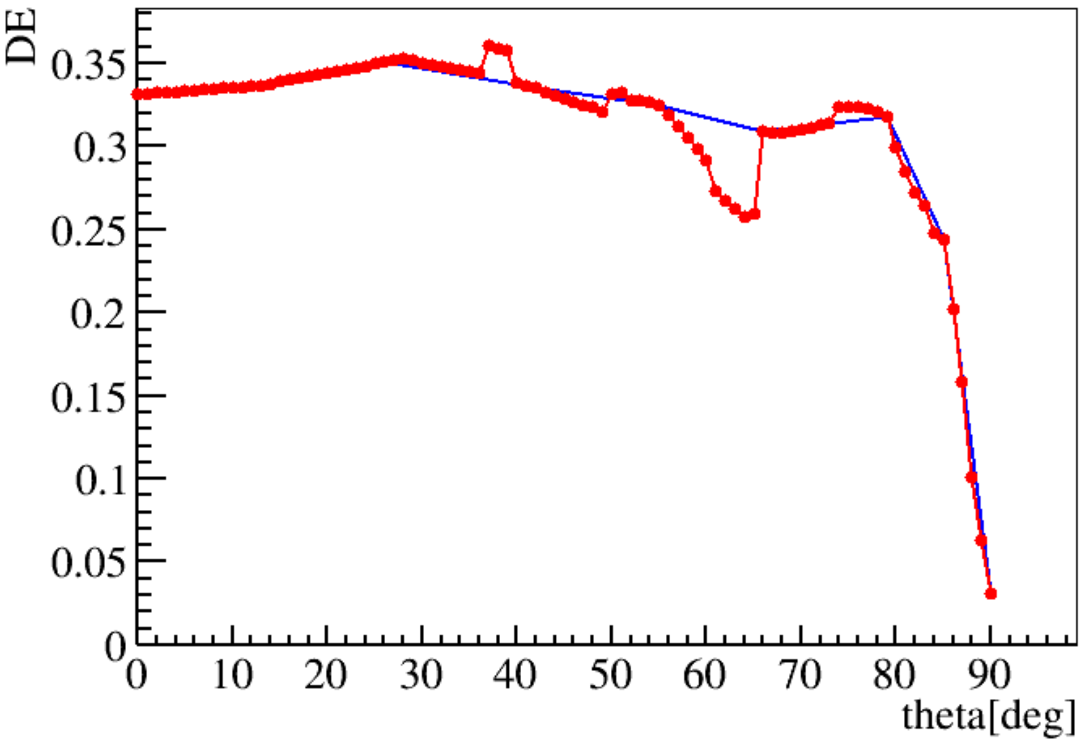
From simulation

- Putting the F map solved into simulation enables us to simulate the Al film reflection

Note: escape probability ρ is assumed the same for transmission photocathode and reflection photocathode

Problem of method 2

- DE curve from simulation is not continuous caused by reflection, more data are needed to constrain reflection contribution.
- Method 1 is now applied in simulation, more study on method 2 will be done



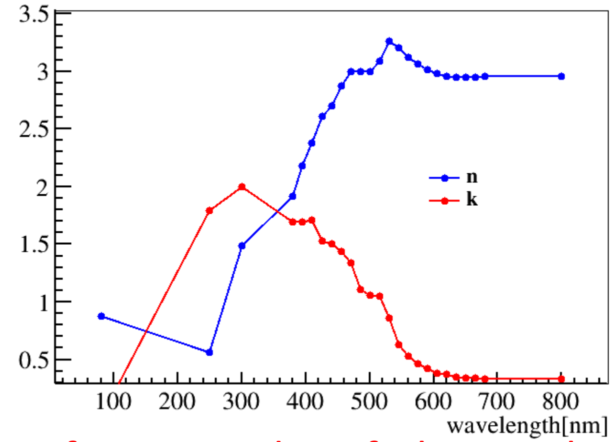
Blue: input DE curve

Red: DE curve from simulation

Input parameters

- Refraction index and thickness of photocathode (necessary)
  - Measurement of PMT reflectivity vs incident angle will be done to constrain them
  - If n, k, d of photocathode has been measured, the absorption of it can be determined immediately

Ref: NIMA 539(2005)217-235



refraction index of photocathode

- QE and CE (Option 1)
  - We can get escape factor with QE and absorption

$$\rho = \frac{QE}{A}$$

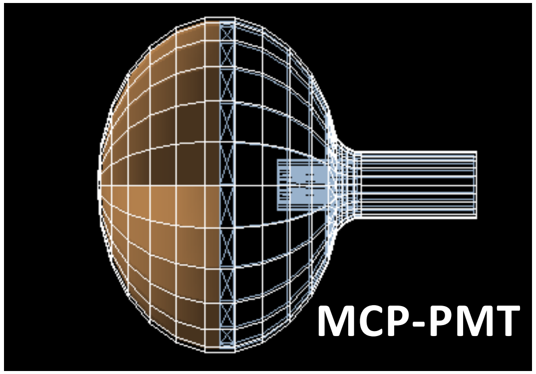
- DE (Option 2)
  - DE map has been measured in scanning station, with DE and absorption, we can get the $F - parameter$,

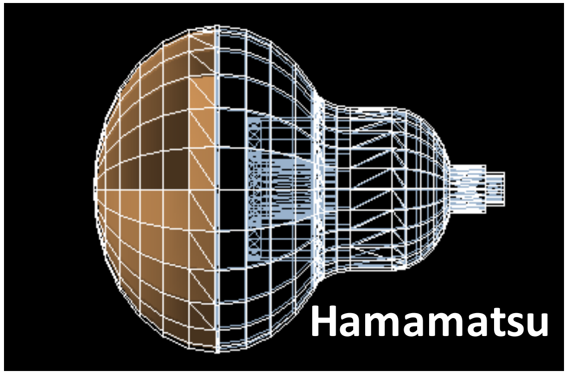
$$F = \rho * CE = \frac{DE}{A}$$

  - In this case, we do not need the CE curve

Offline software update

- Geometry: $PMTSIMROOT
  - MCP-PMT: **NNVTMCPPMTManager→MCPNewModel**
  - Hamamatsu: **HamamatsuR12860PMTManager →R12860NewModel**





- Physics: $PHYSISIMROOT
  - New class for film interference effect calculation: DsG4OpticalMembrane
  - Interference effect added into optical boundary process: DsG4OpBoundaryProcess
- Options: $DETSIMOPTION/src/LSExpDetectorConstruction.cc
  - **Hamamatsu:** R12860NewModel
  - **Hamamatsu+Mask:** R12860MaskNewModel
  - **MCP-PMT:** MCPNewModel
  - **MCP-PMT+Mask:** MCPMaskNewModel

Usage of the new model

- Simulation with MCP-PMT + Mask

```
python tut_detsim.py --evtmax 100 --pmt20inch-name MCPMaskNewModel
hepevt --exe IBD --volume pTarget
```

- The new model has not been submitted to svn, more check will be done
- Anyone interested in it can source /junofs/users/wangyg/NewOffline/bashrc

Conclusion and furture plan

- The new PMT optical model gives a more accurate angle response, especially when put PMT in water
- The new model has been added to JUNO offline software, more check will be done
- PMT reflectivity measurement is in the plan to get the parameters of photocathode