# Light Gas Cherenkov Detector for SoLID

E. Kaczanowicz, Z.-E. Meziani,
M. Paolone, N. Sparveris

Temple University

SoLID Dry Run
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# Detector Configurations and Requirements

- The LGC is designed to accommodate two primary configurations:
  - SIDIS
  - PVDIS

- Each configuration has different:
  - incident particle angle / momentum ranges
  - luminosity
  - background profiles
  - space constraints

- Goal is to have each configuration provide a pion rejection above 99% *when combined with the calorimeter*.

# Detector Configurations and Requirements

- The LGC is designed to accommodate two primary configurations:
  - SIDIS
    - 1 to 5 GeV
    - ~7 to 15 deg
  - PVDIS
    - 2 to 4 GeV
    - 22 to 35 deg

- Each configuration has different:
  - **incident particle angle / momentum ranges**
  - luminosity
  - background profiles
  - space constraints

- Goal is to have each configuration provide a pion rejection above 99% when combined with the calorimeter.

# Detector Configurations and Requirements

- The LGC is designed to accommodate two primary configurations:
  - SIDIS
    - 15uA on $^3$He
  - PVDIS
    - 50uA on D / H

- Each configuration has different:
  - incident particle angle / momentum ranges
  - **luminosity**
  - background profiles
  - space constraints

- Goal is to have each configuration provide a pion rejection above 99% when combined with the calorimeter.

# Detector Configurations and Requirements

- The LGC is designed to accommodate two primary configurations:
  - SIDIS
    - Forward Calorimeter
    - Additional Gems
  - PVDIS
    - Baffles

- Each configuration has different:
  - incident particle angle / momentum ranges
  - luminosity
  - **background profiles**
  - space constraints

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# Detector Configurations and Requirements

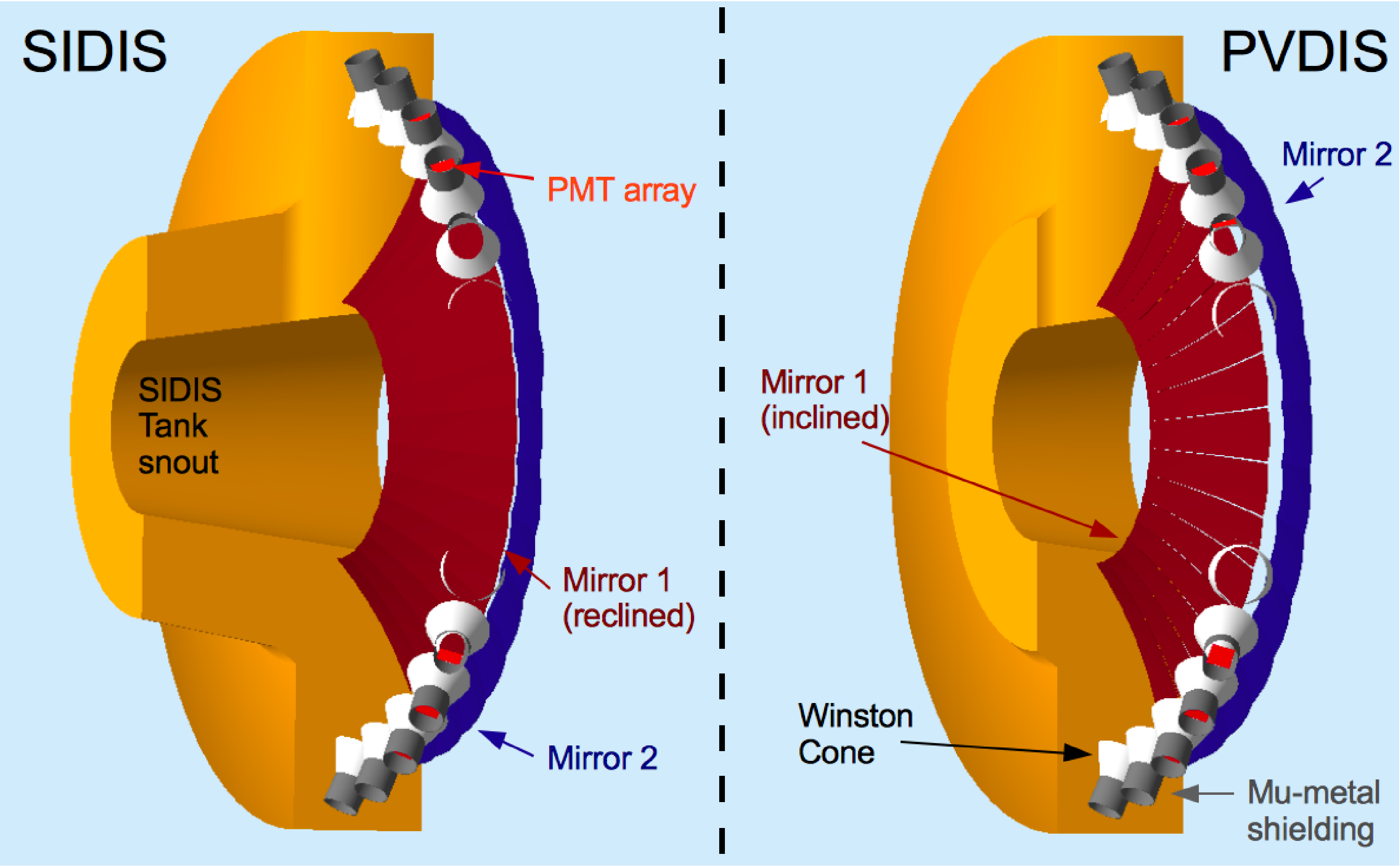
- The LGC is designed to accommodate two primary configurations:
  - SIDIS
  - PVDIS
    - Baffles

- Each configuration has different:
  - incident particle angle / momentum ranges
  - luminosity
  - background profiles
  - **space constraints**

- Goal is to have each configuration provide a pion rejection above 99% when combined with the calorimeter.

# LGC geometric / material characteristics

- Cherenkov is designed to maximize component use between the two configurations.

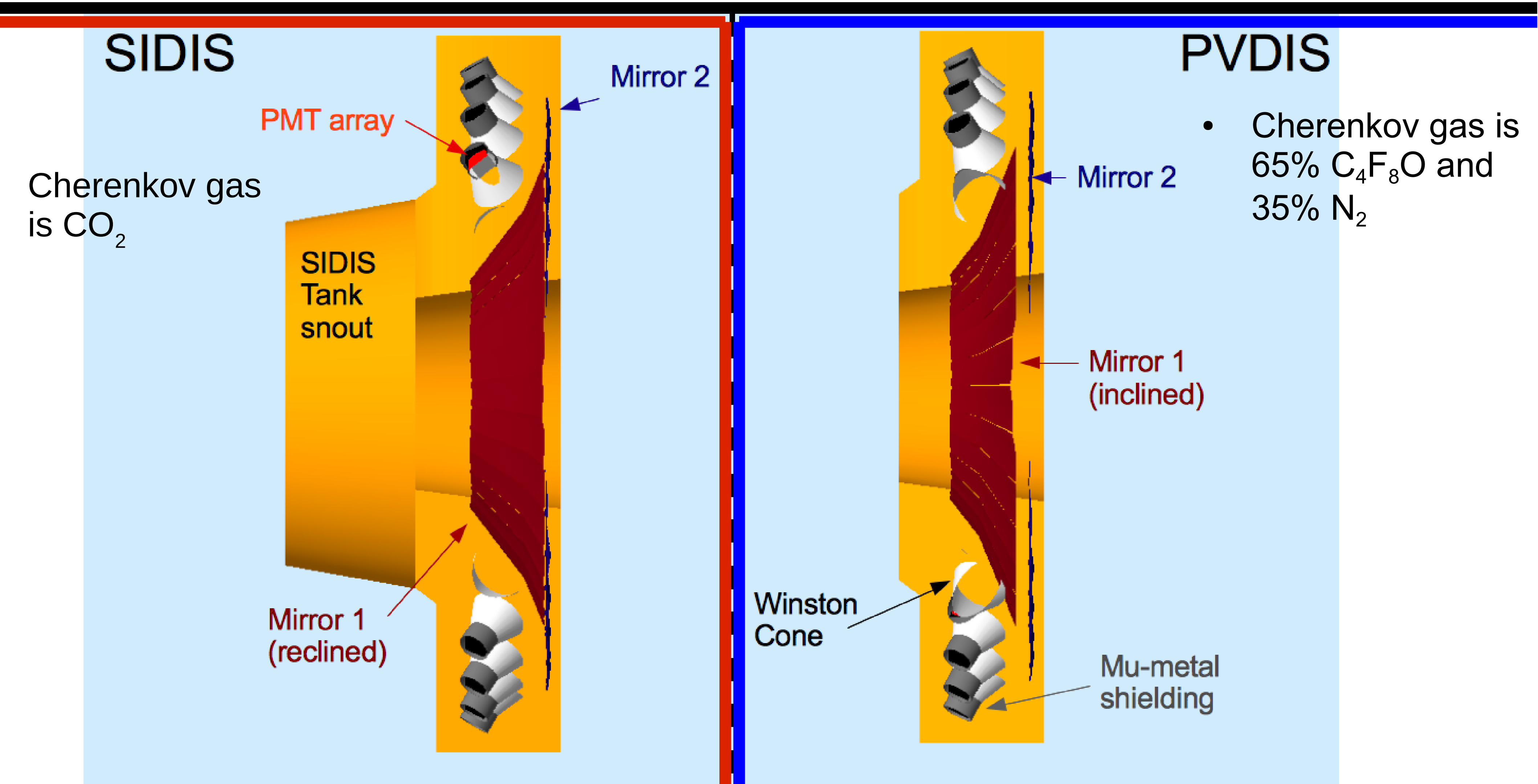


# Tank

- Primary tank toroidal shape:
  - 105 cm length
  - 71 to 85 cm inner radius
  - 265 cm outer radius

**Common**

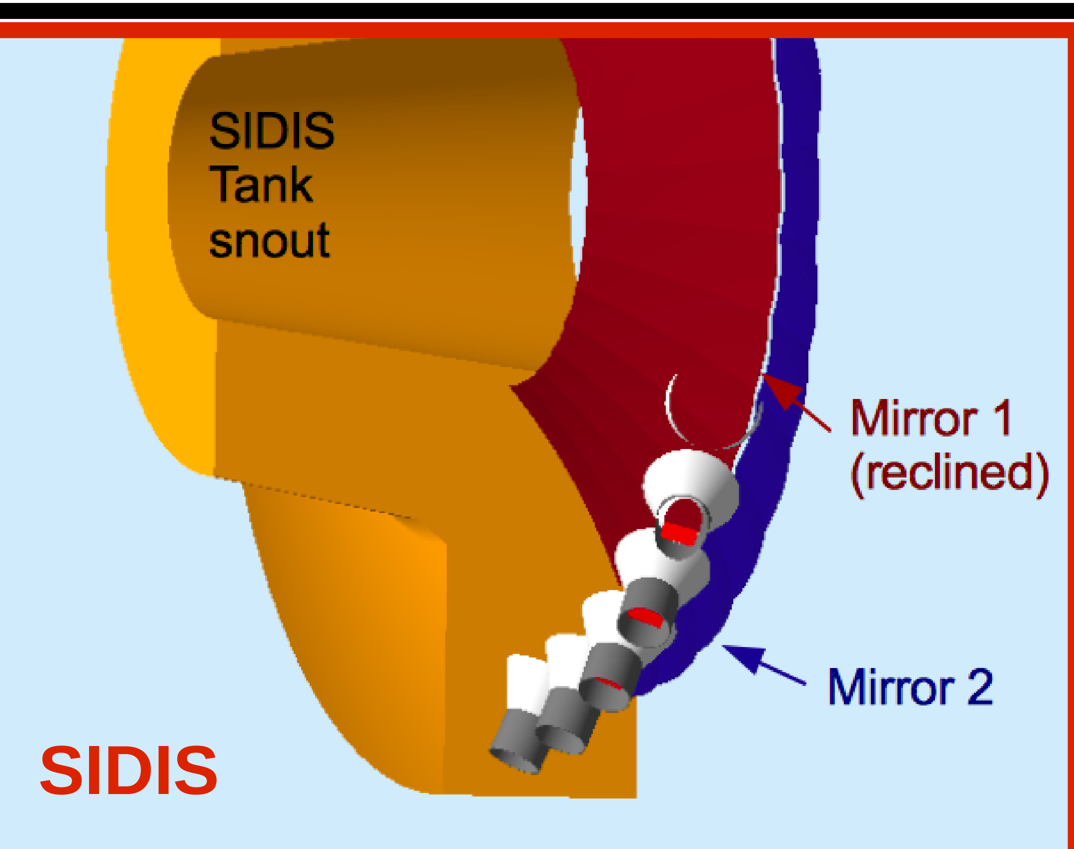
- Windows
  - Polyvinyl fluoride (Tedlar)
    - 1.45 g/mm³ density
  - 0.05 mm entrance window
  - 0.1 mm exit window

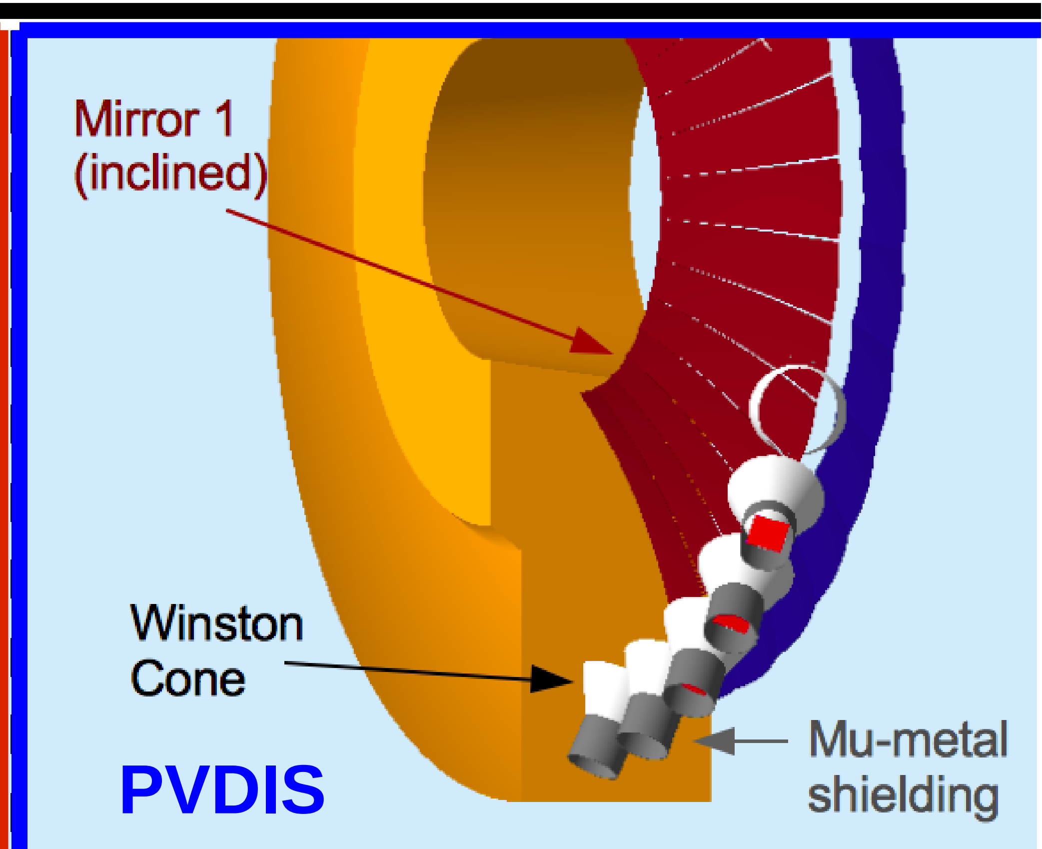


# Mirrors

- 30 sectors (defined by baffle segmentation)
  - 2 spherical mirrors per sector (60 mirrors total)
- Blanks are Carbon Fiber Reinforced Polymer [CFRP] (Same as LHCb RICH)
  - Areal density < 6 kg/m$^2$
  - Reflective coating provided by Stony Brook (Al / $MgF_2$ )
    - Total reflective area per mirror is roughly 0.3 m$^2$

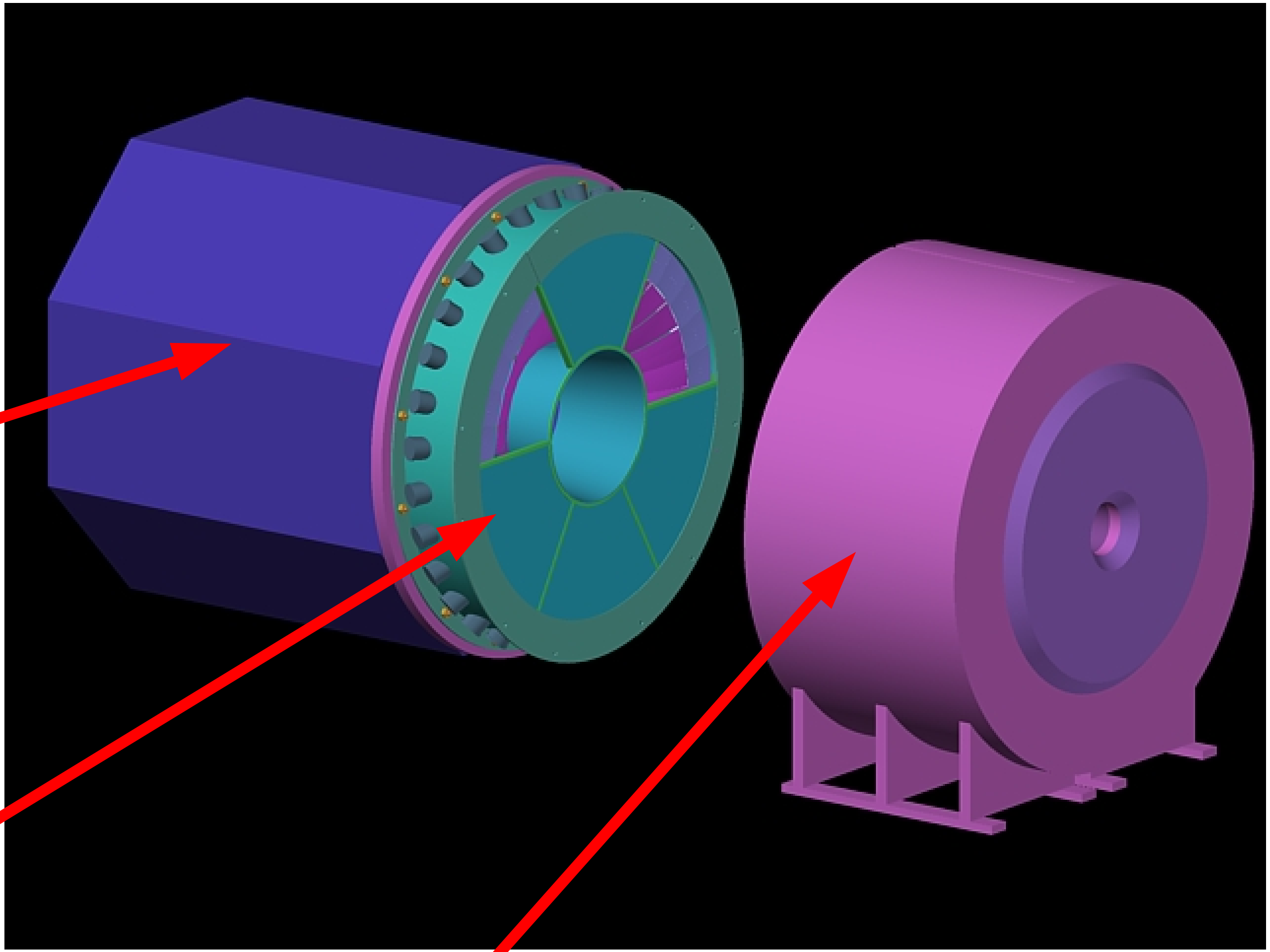
**Common**



# LGC Position and Mounting

- The LGC will be directly mounted to the back of the magnet support, and will not wheel-out with the snout assembly.



**Magnet housing**

**LGC**

**Snout Assembly**

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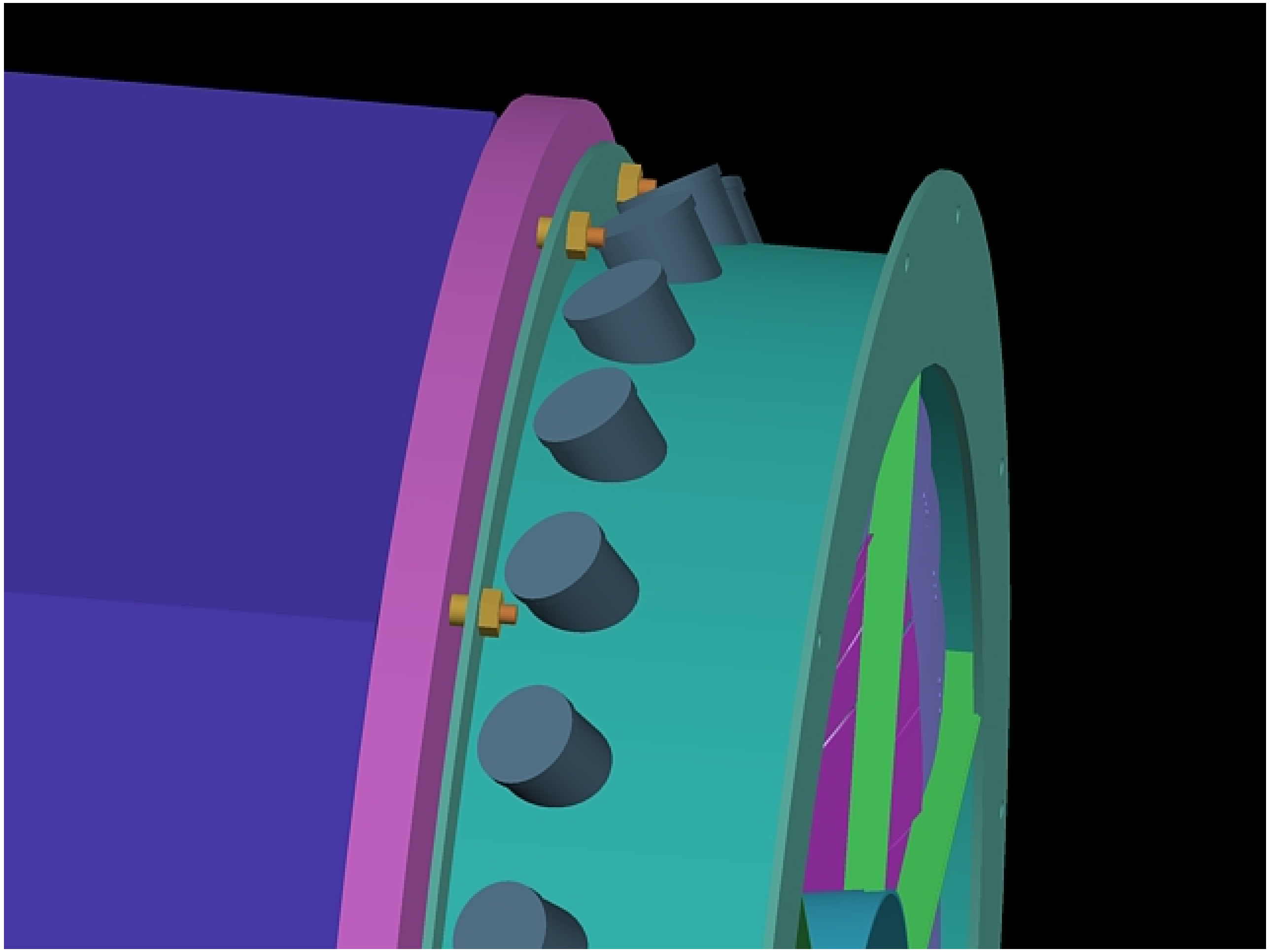

# LGC Position and Mounting

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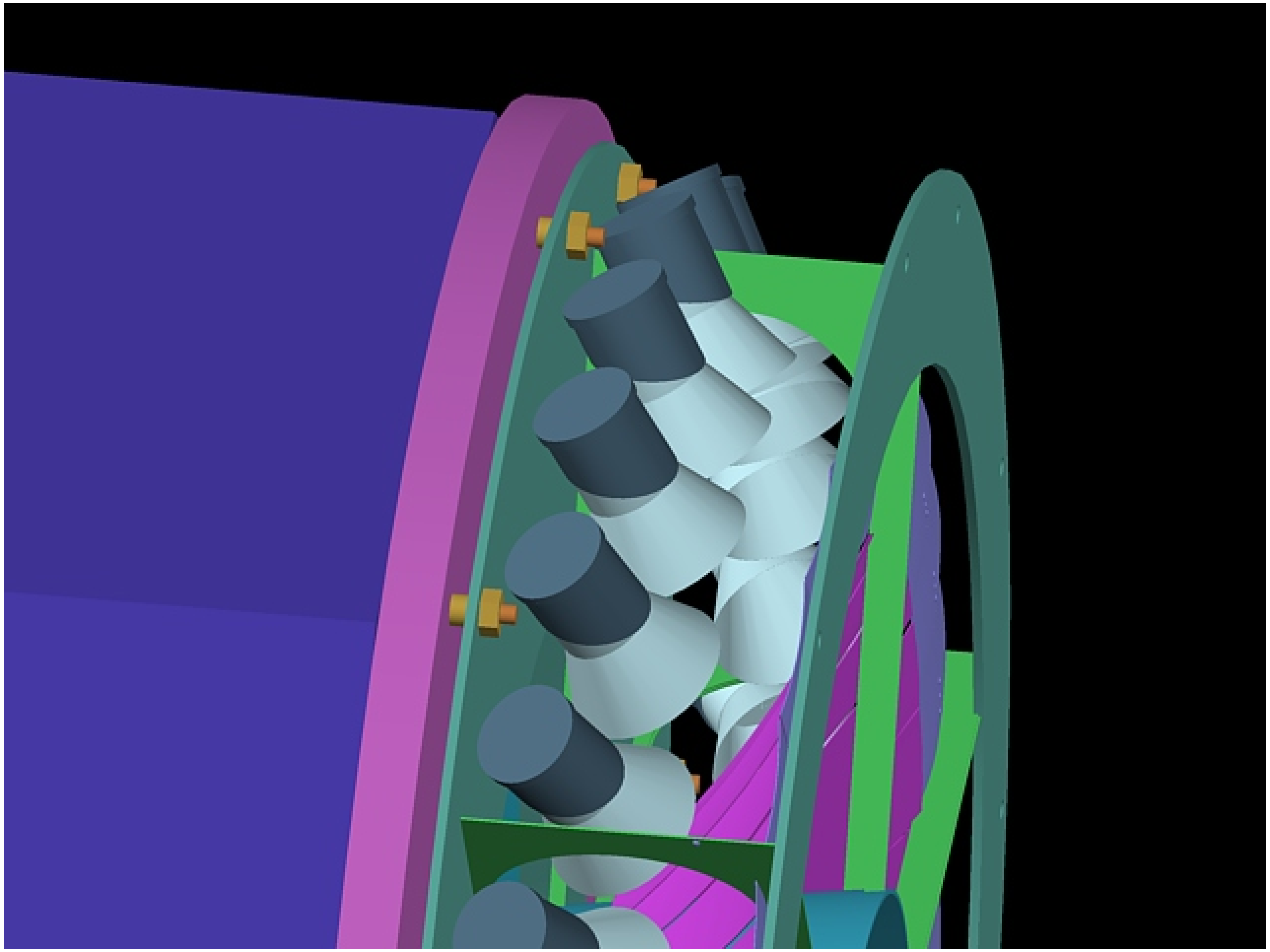
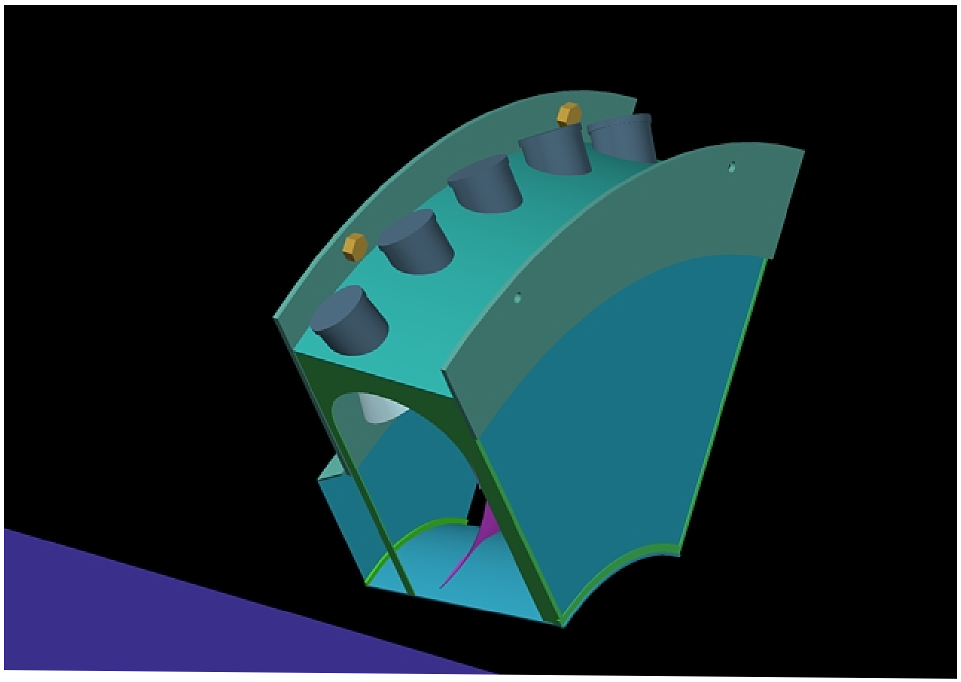
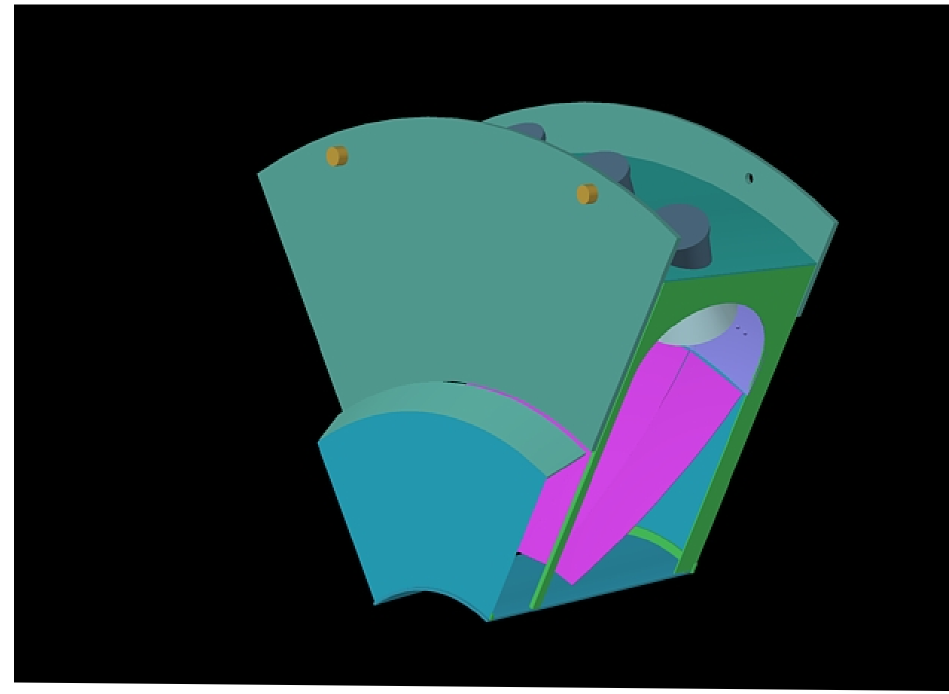
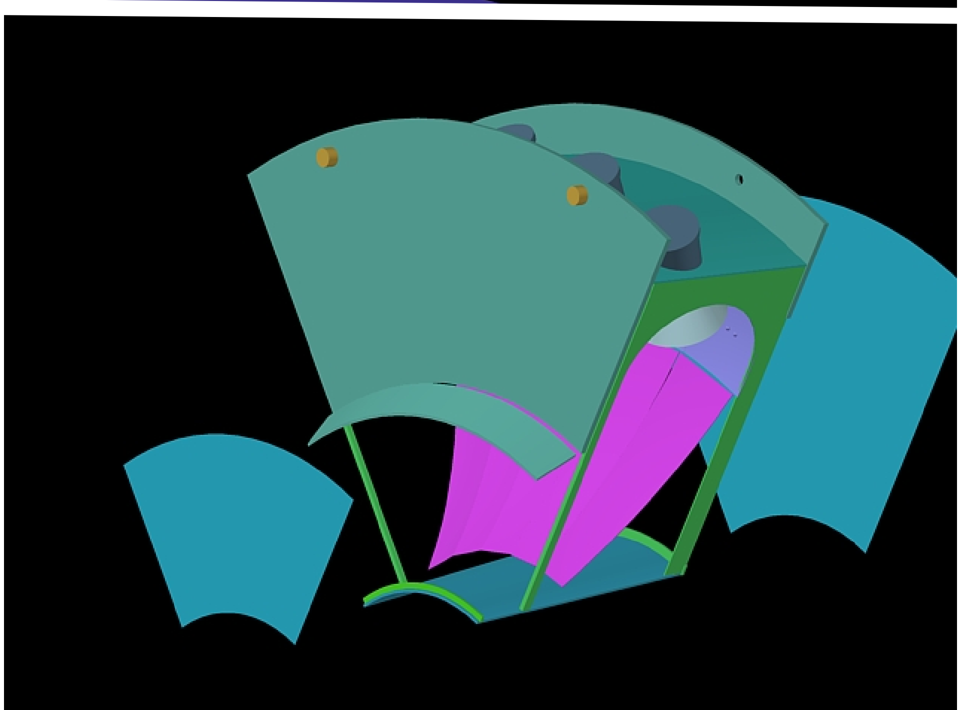
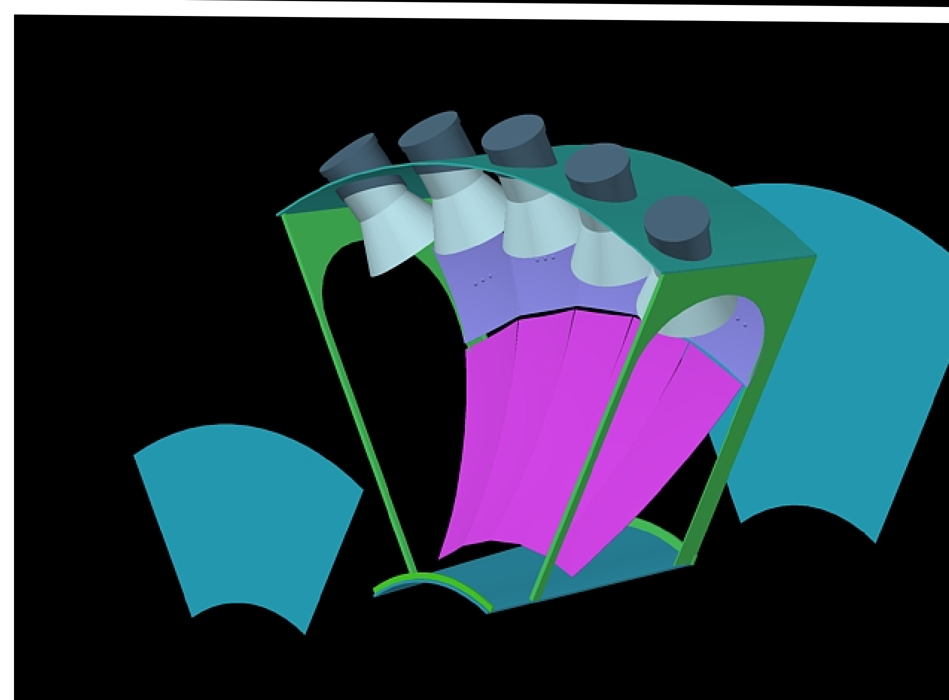
- Six total internal support struts are designed to avoid interference with optical photon collection.

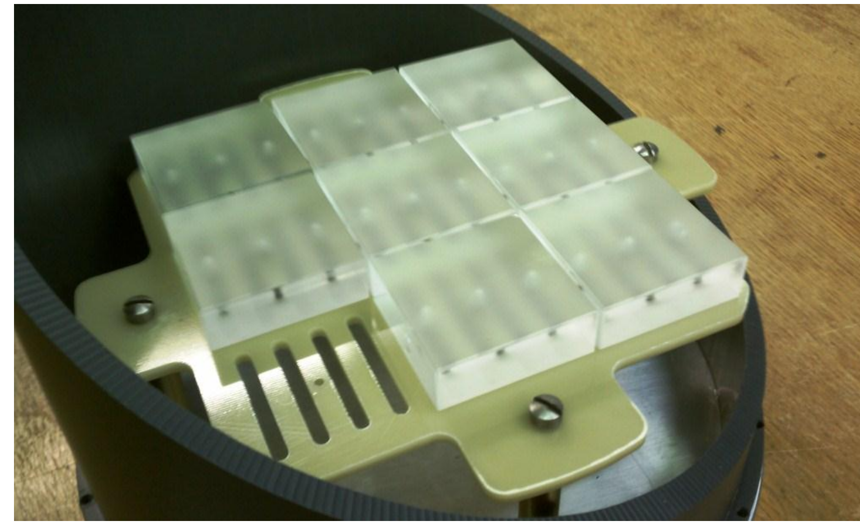


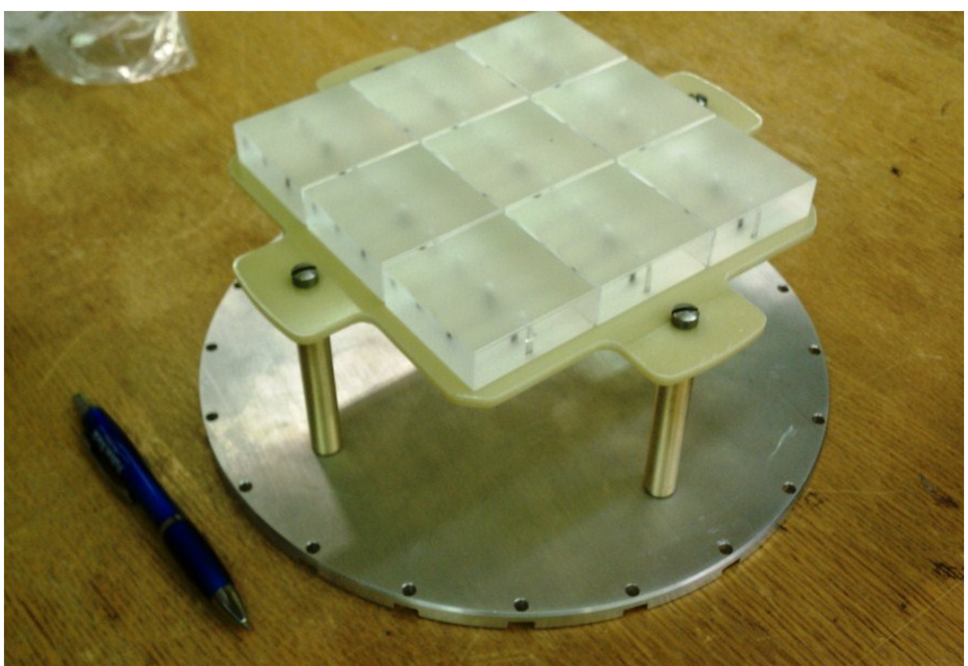
# LGC support and engineering

# PMT Assembly

- All components are common without adjustment between both configurations.
- PMT assembly is:
  - **3 x 3 array** of Hamamatsu H8500C-03 maPMTS
    - 64 pixel PMT array for each H8500C
    - Average QE ~ 15%
    - 2” by 2” per H8500C-03





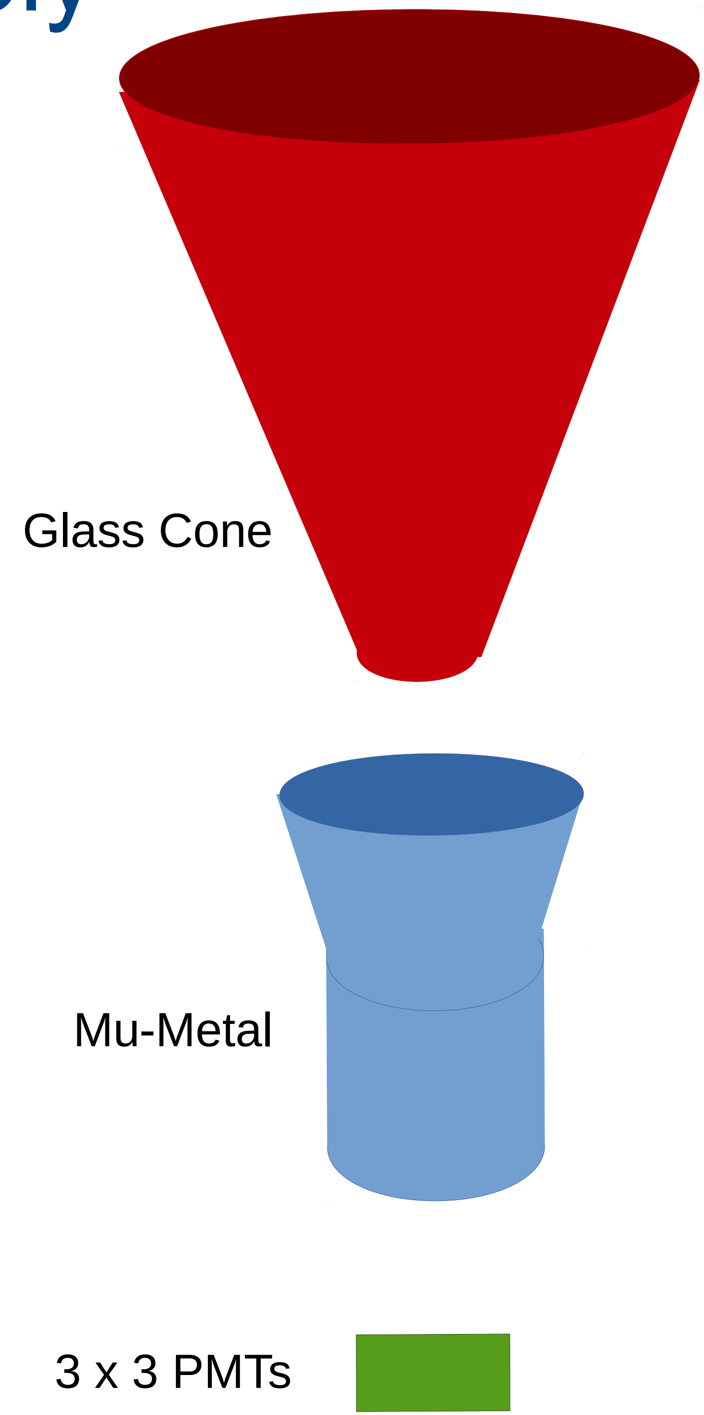
# PMT Assembly

- All components are common without adjustment between both configurations.
- PMT assembly is:
  - **3 x 3 array** of Hamamatsu H8500C-03 maPMTS
  - **Reflective cone**
    - Standard glass cone
    - 30cm tall, inner radius = 7.6cm, outer radius = 21cm, ~0.5cm thick.
    - polished and coated to maintain a reflectivity > 80%.

Model representation.
Approximate size of reflective cone

# PMT Assembly

- All components are common without adjustment between both configurations.
- PMT assembly is:
  - **3 x 3 array** of Hamamatsu H8500C-03 maPMTS
  - **Reflective cone**
  - **Mu-metal shielding.**
    - 0.04” thickness with 0.125” thick steel reinforcement
    - Reduce $B_T$ and $B_L$ from 95 and 135 gauss (respectively) to < 50 gauss.
      - Maintains at least 90% efficiency (see talk by M. Meziane)



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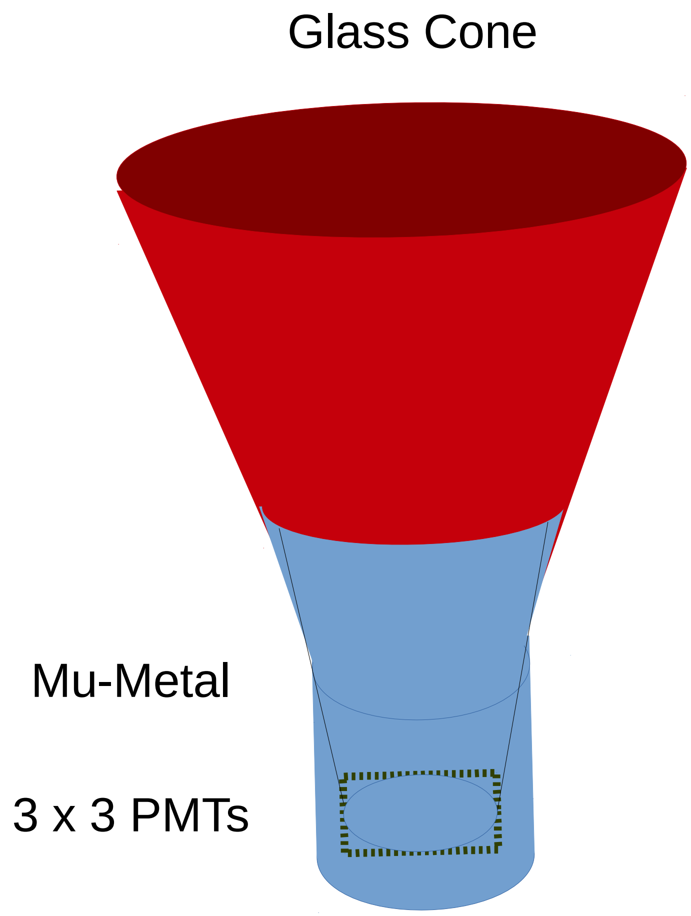
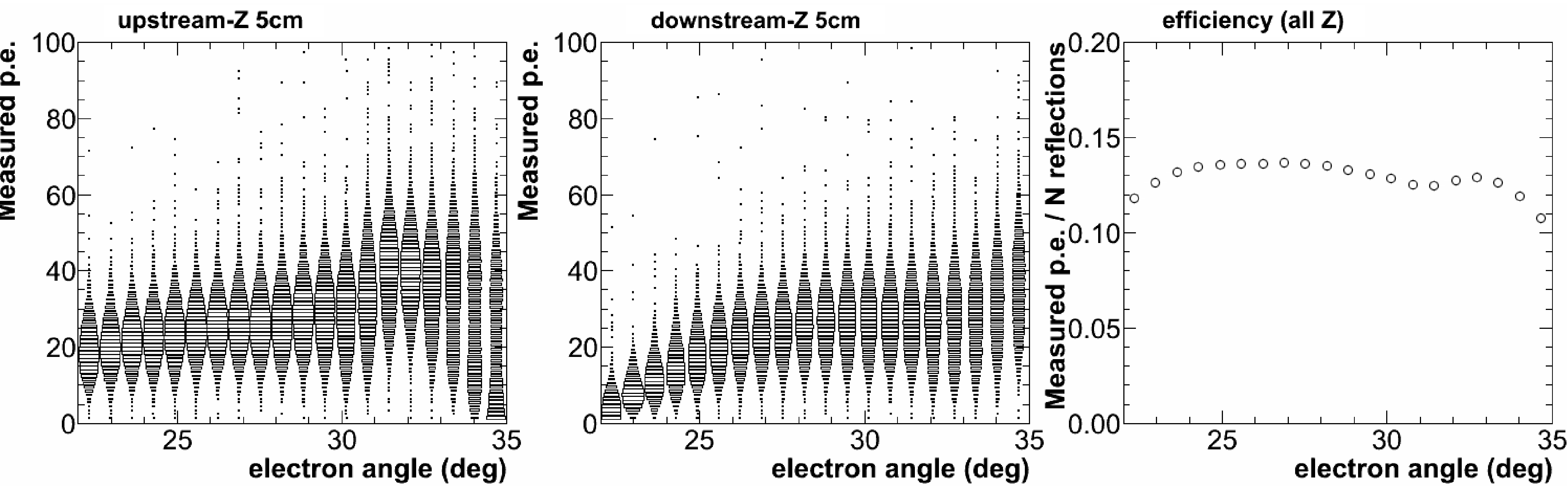


# Simulation for pi rejection

- Event generation:
  - Electrons from electron generator eicRate.
  - Pions from eicRate (Wiser)
  - Uniformly distributed along target length.
- Propagate tracks out of target to LGC window
  - All interactions are handled by GEMC / Geant4
  - All materials from SoLID design are included in the transport.
  - CLEO magnetic field map is used.
- Simulate Cherenkov radiation through gas and collect optical photons.
  - Collection is recorded at the PMT on a p.e. per pixel level.
  - QE as a function of photon energy is taken into account.
  - Pion triggers below Cherenkov threshold are primarily from delta rays.

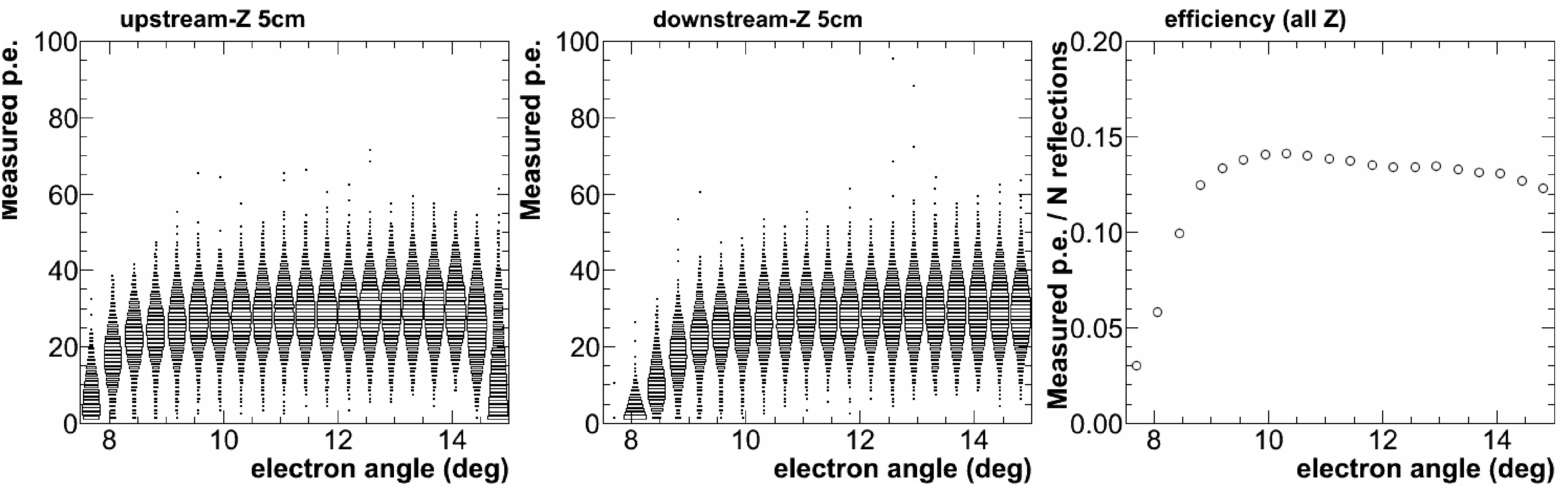
# Total Collection Efficiency for Electrons

- Calculated as # optical photons detected at PMT divided by # of reflections from spherical mirrors. Includes:
  - Reflection efficiencies
  - Quantum efficiency (dominant)
  - Geometrical acceptance


upstream-Z 5cm
downstream-Z 5cm
efficiency (all Z)
Measured p.e.
Measured p.e. / N reflections
electron angle (deg)

PVDIS

SIDIS

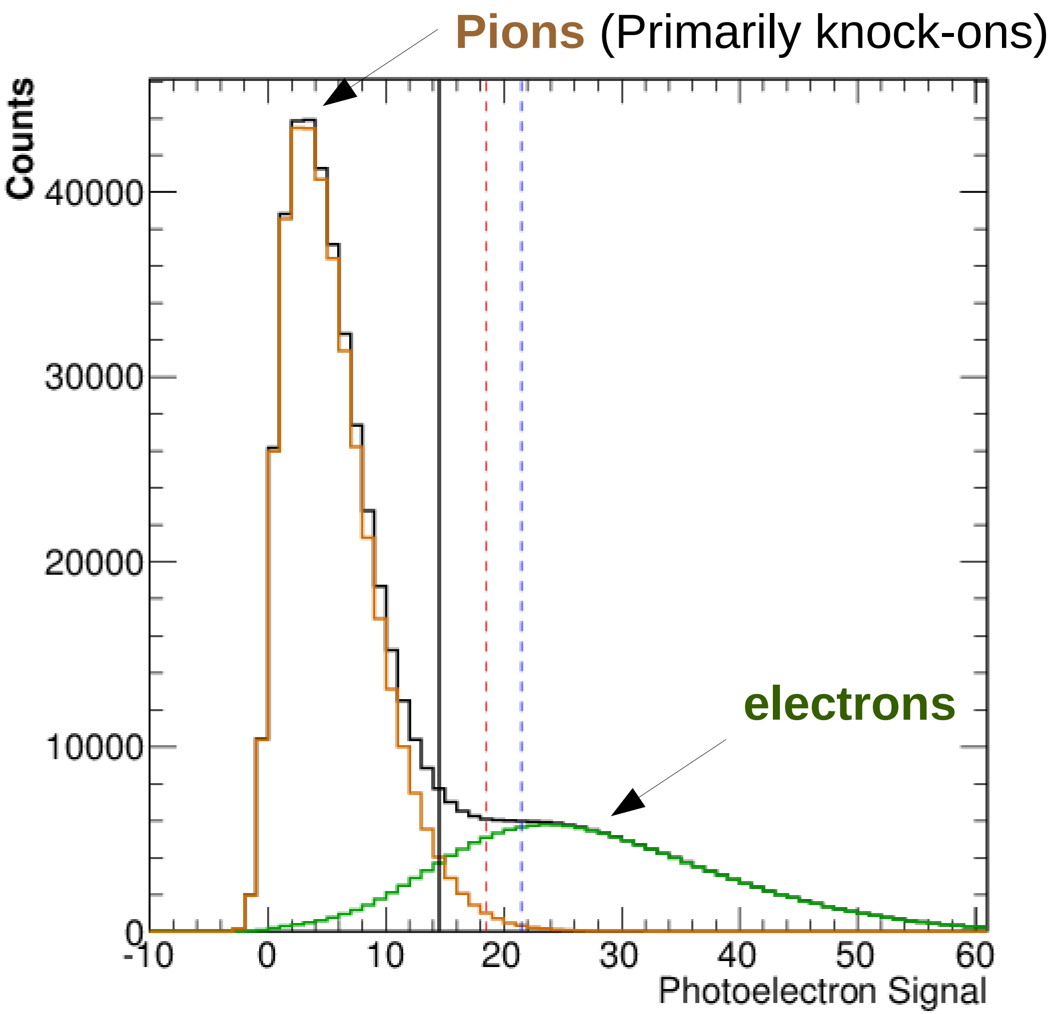

upstream-Z 5cm
downstream-Z 5cm
efficiency (all Z)
Measured p.e.
Measured p.e. / N reflections
electron angle (deg)

# Pion / electron signal

- Sample of collected PE signal:

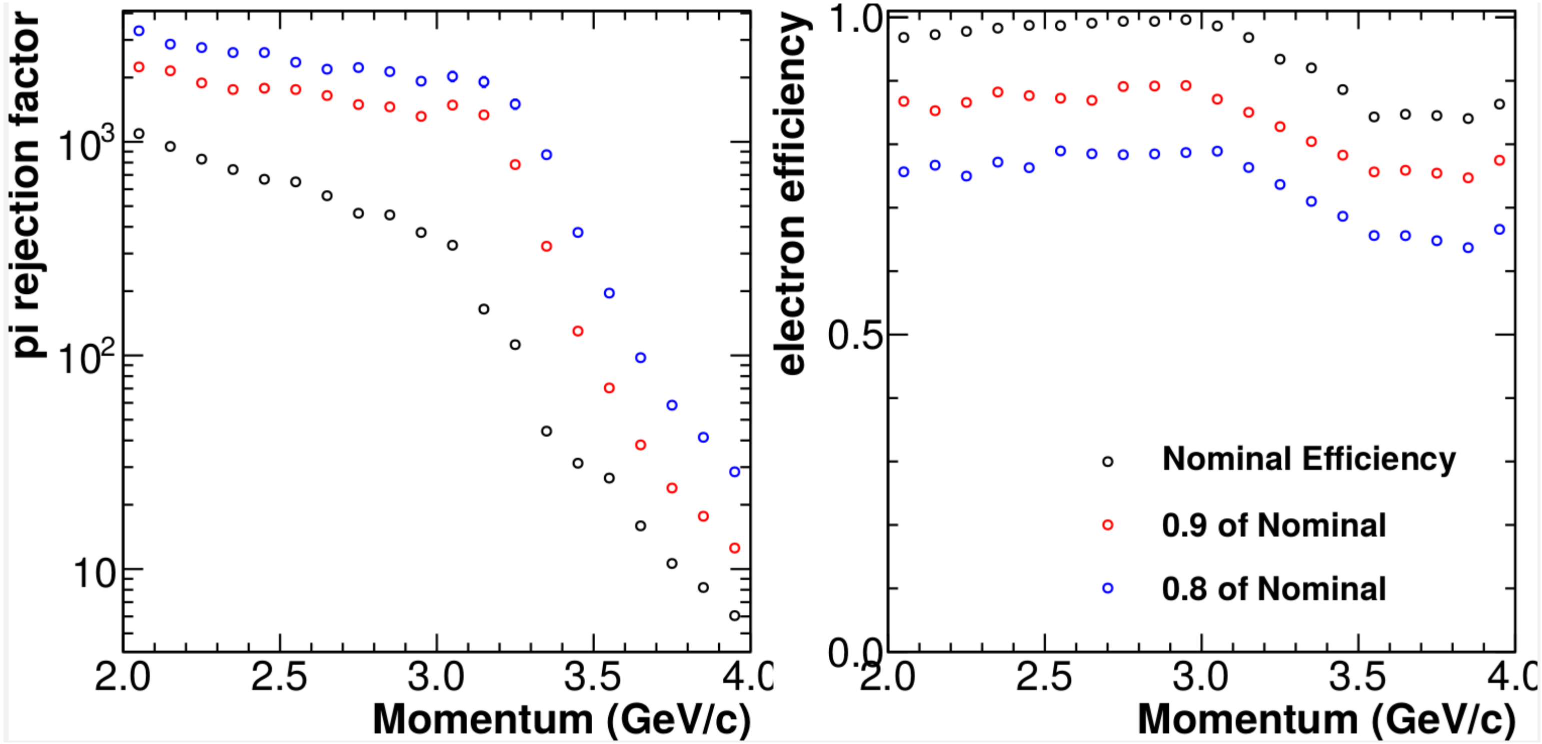
    (This MC is for track momentum below pion radiation threshold)

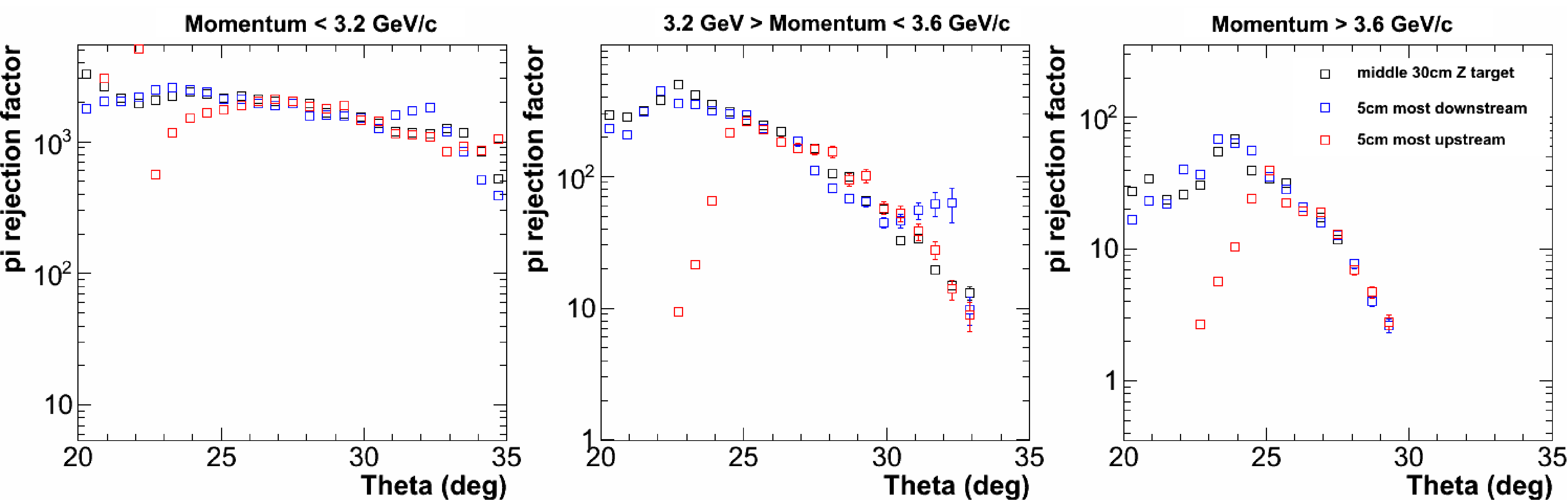
- Three settings possible pion rejection setting shown:
    - **Nominal**
        - Best compromise between electron efficiency and pion rejection.
    - **0.9 Nominal**
        - Electron efficiency now 90% of nominal above.
    - **0.8 Nominal**
        - Electron efficiency no 80% of nominal above



# PVDIS

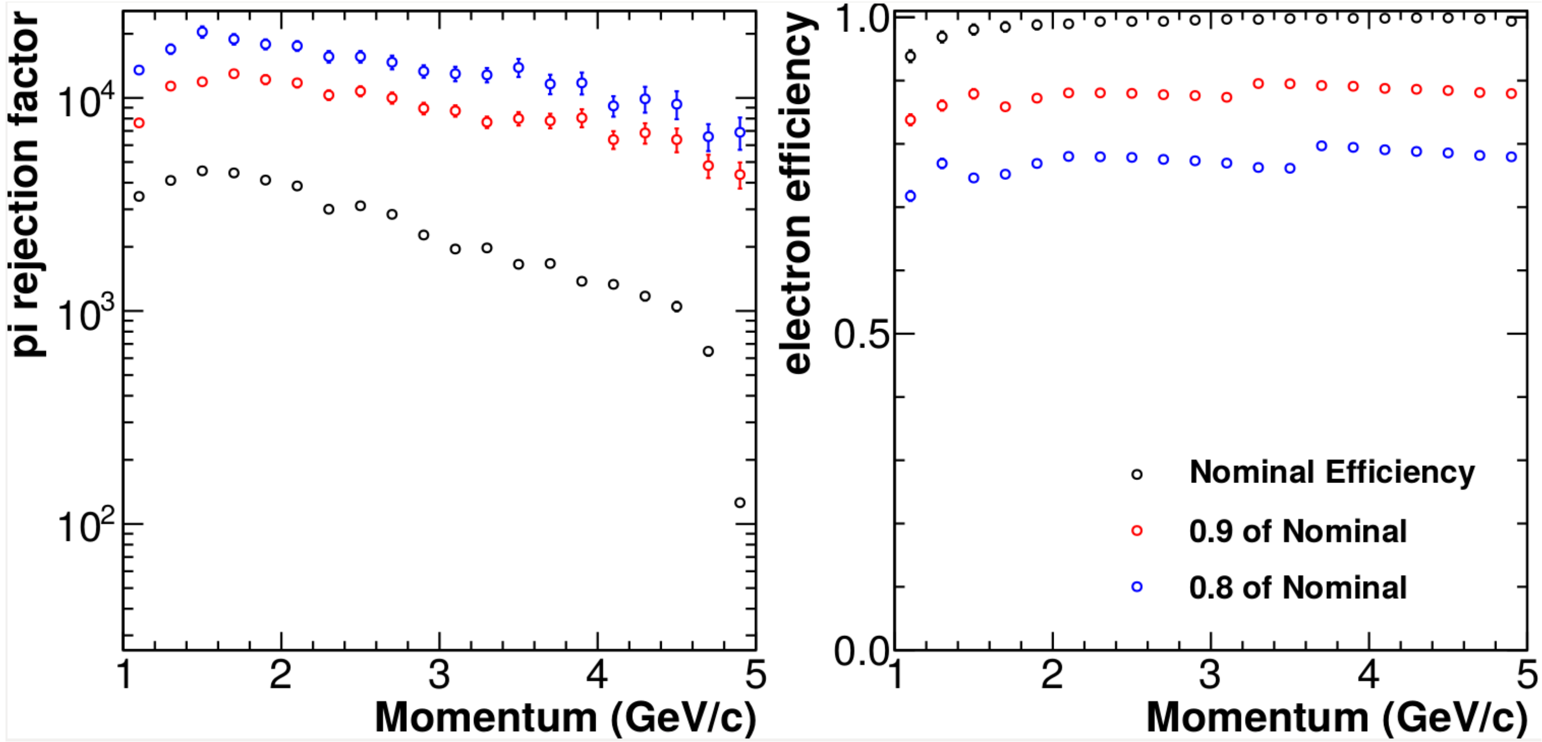
pi rejection factor is the inverse pi acceptance after selection cut.

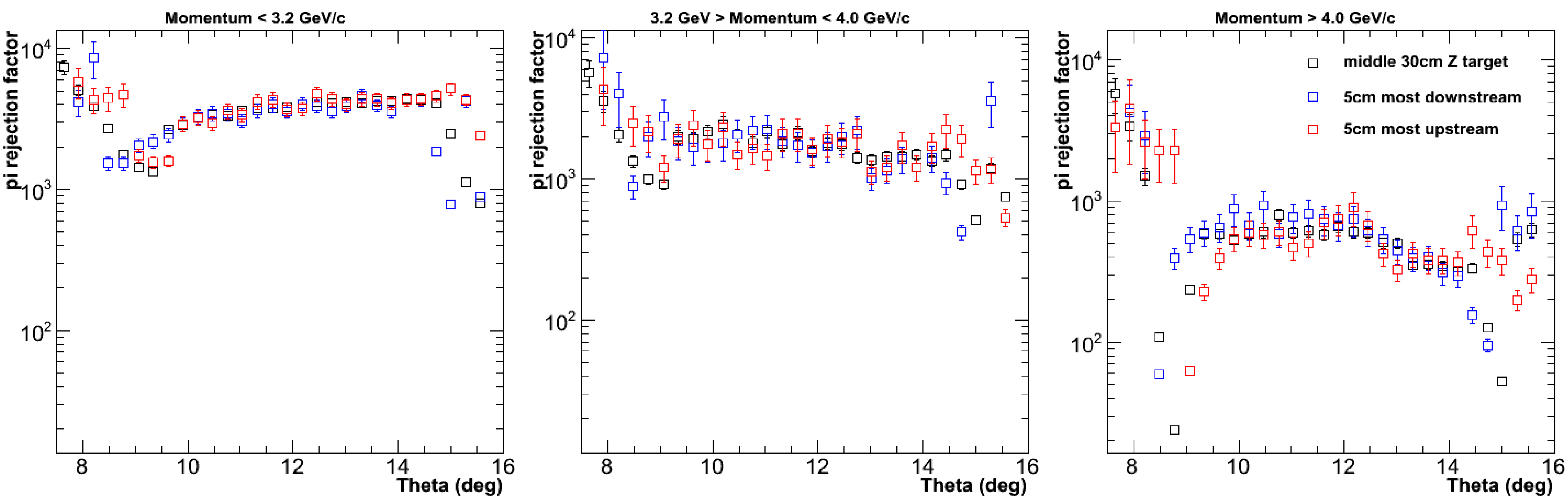


# SIDIS

pi rejection factor is the inverse pi acceptance after selection cut.



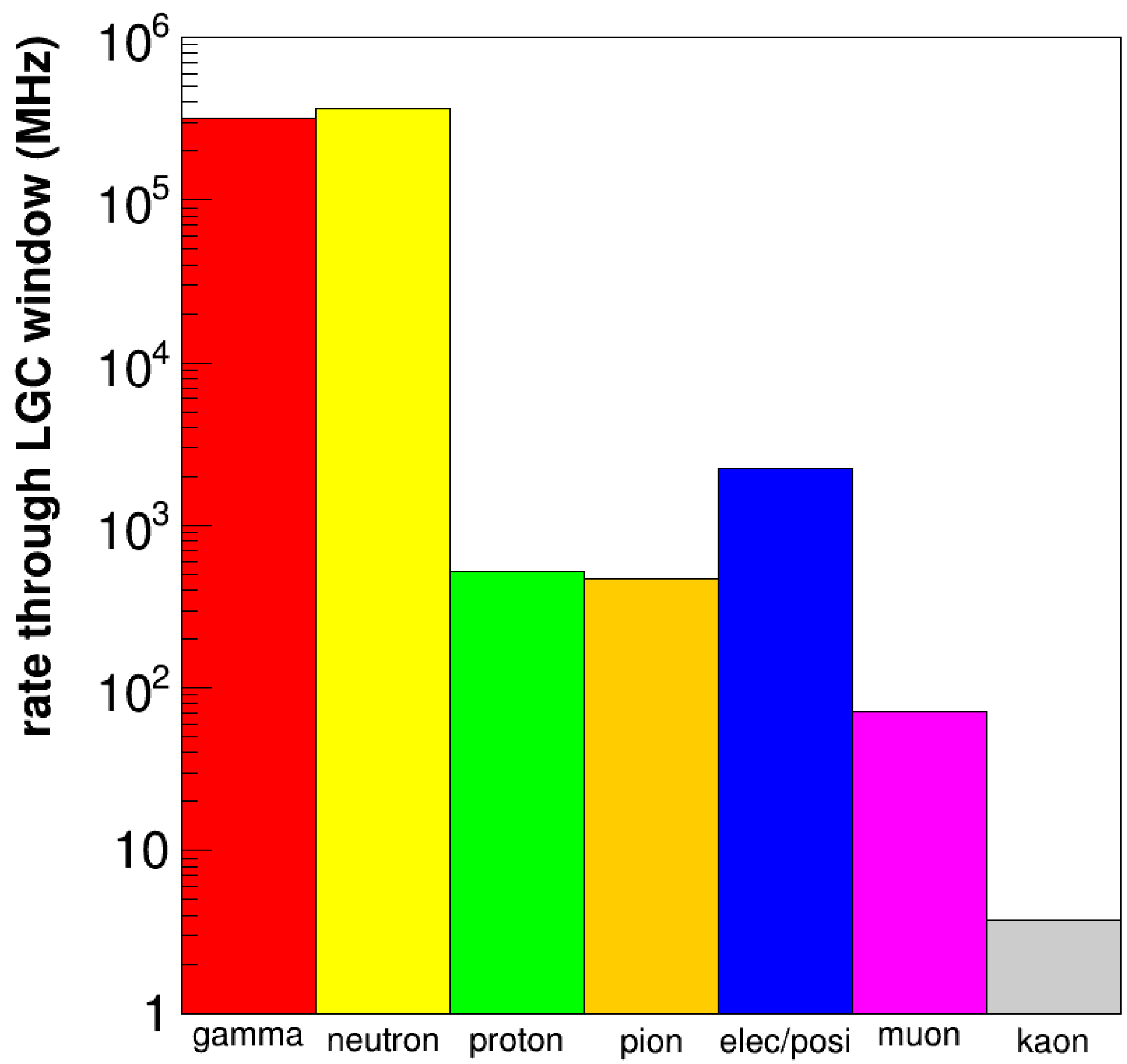



# Secondary backgrounds

- All pion rejection shown on previous slides only considers the primary source of pion contamination from **charged** pion production at the beam / target nucleon vertex (via Wiser)
- Other sources of background come from secondary particle production.
  - Secondary background simulation is done by putting an 11 GeV electron beam on target in GEMC / Geant4.
    - 200M events are simulated per “pass” on the ifarm.
      - This equates to 0.64 micro-seconds of beam.
    - Geant4 physics list QGSP_BERT controls all EM / hadronic reactions.

# Rate of particles through LGC entrance window (PVDIS)

- High luminosity + large acceptance = large rates
  - High rates can be handled, but care must be taken!
- Total rate through the LGC window for PVDIS.
  - Integrated over all momentums.



# Rate of particles through LGC entrance window

- Rate through the LGC window.
  - Only cherenkov radiation candidates.

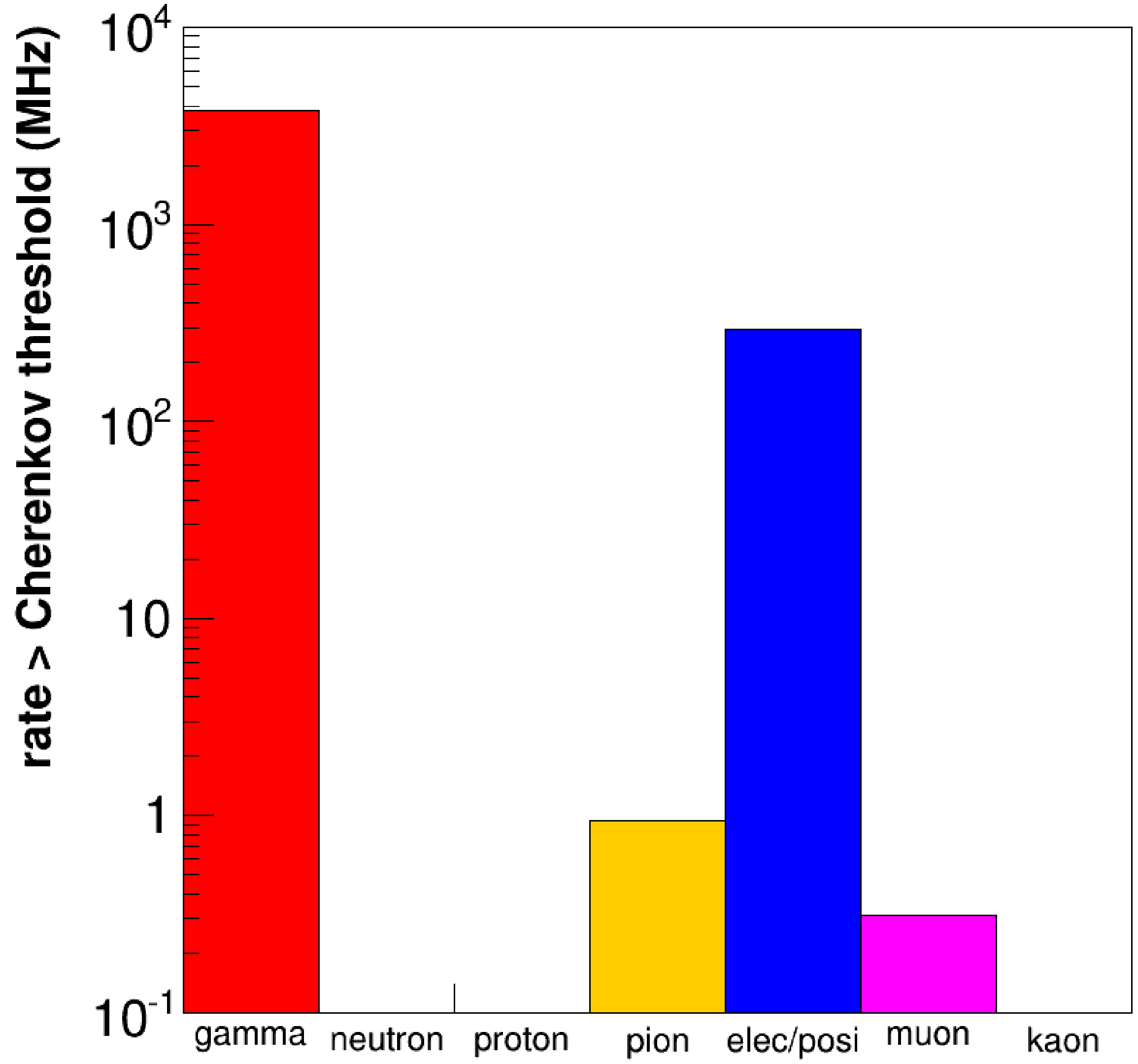
Energies > LGC threshold

(10 MeV **gamma**/**electrons**)

(3 GeV **pions**)

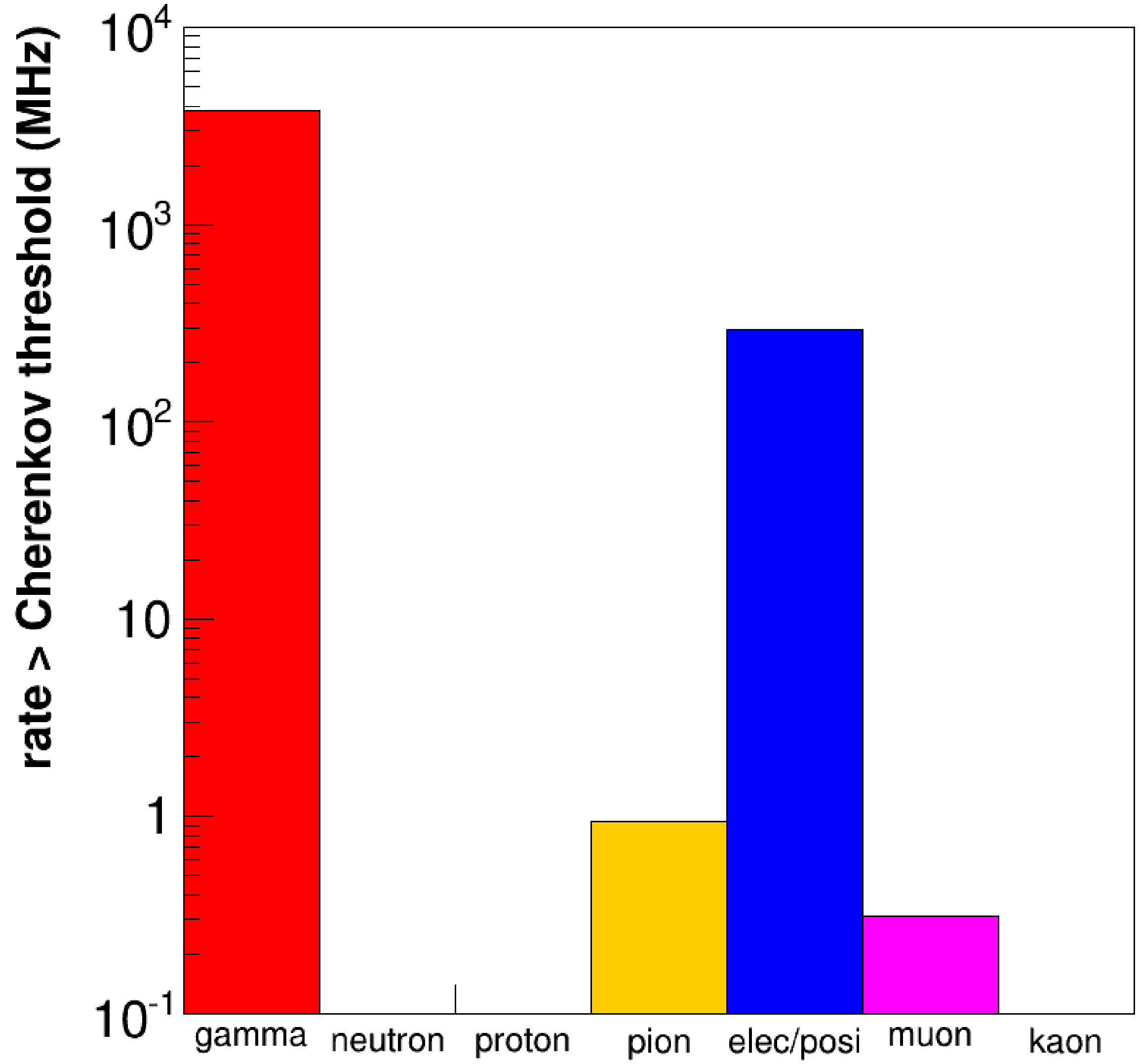
(2.4 GeV **muons**)

(11 GeV kaons)



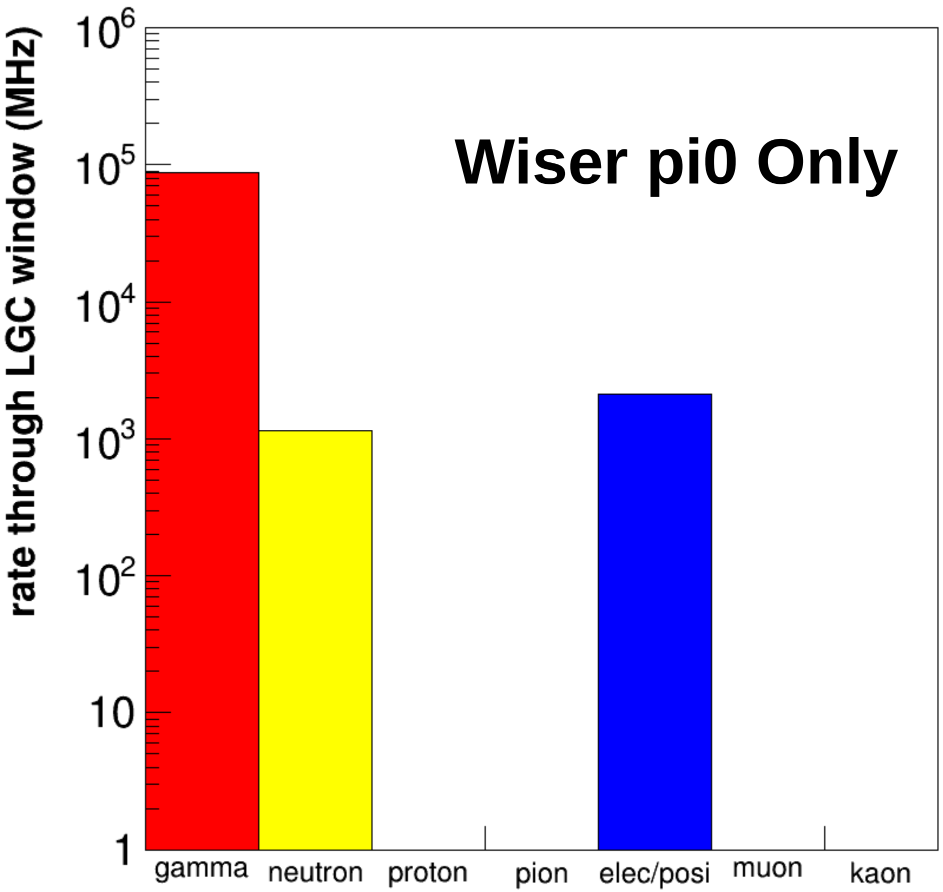
# Rate of particles through LGC entrance window

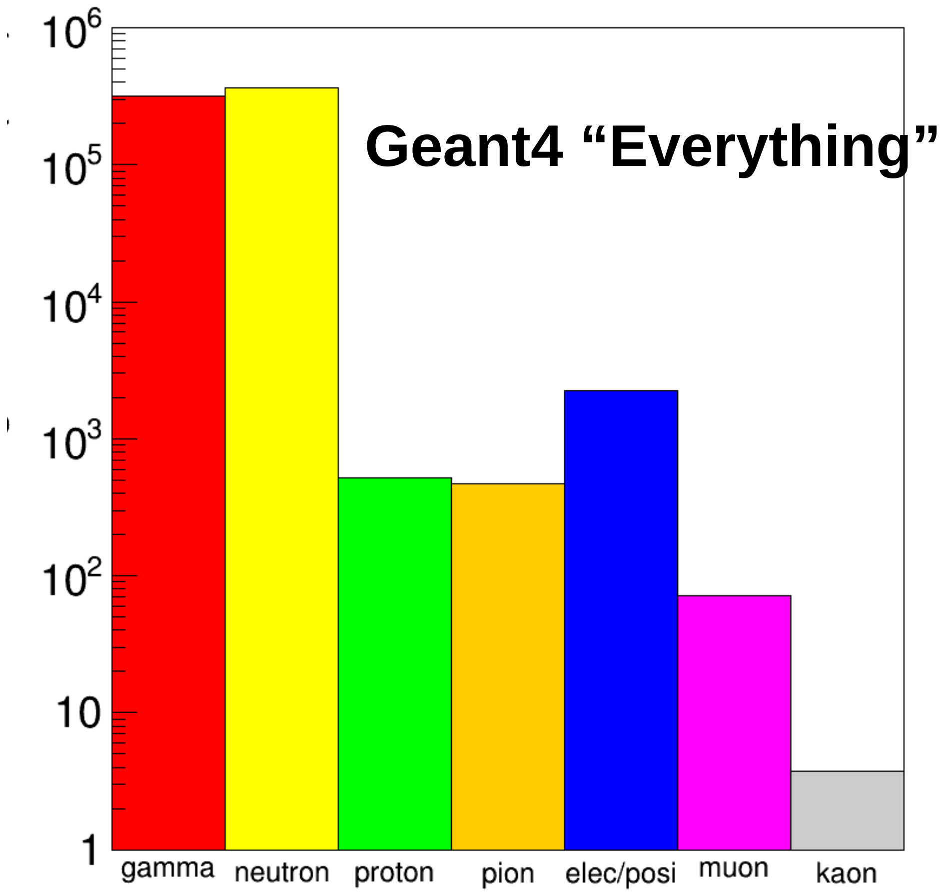
- Where does the majority of the electromagnetic radiation come from?:
  - pi0's!
  - Geant4 physics lists and Wiser predictions give very different rates of pi0 production at SoLID momentums and angles.



# Rate of particles through LGC entrance window

Comparison between Wiser and Geant4

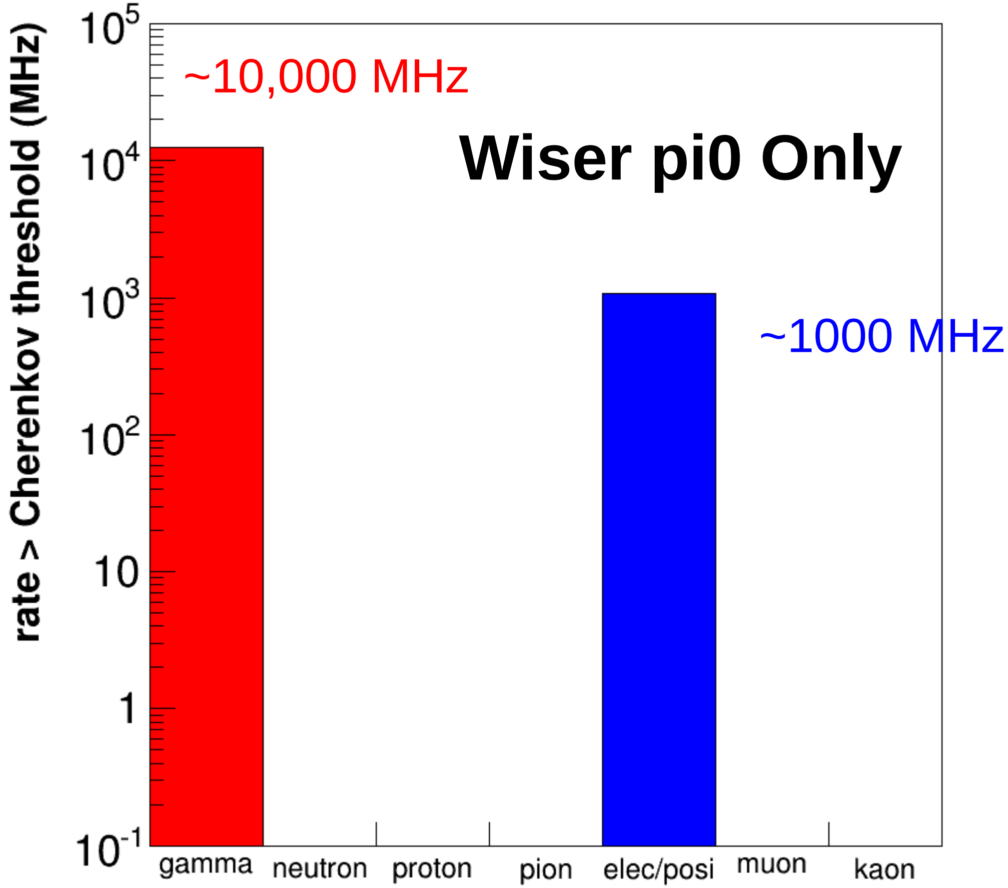


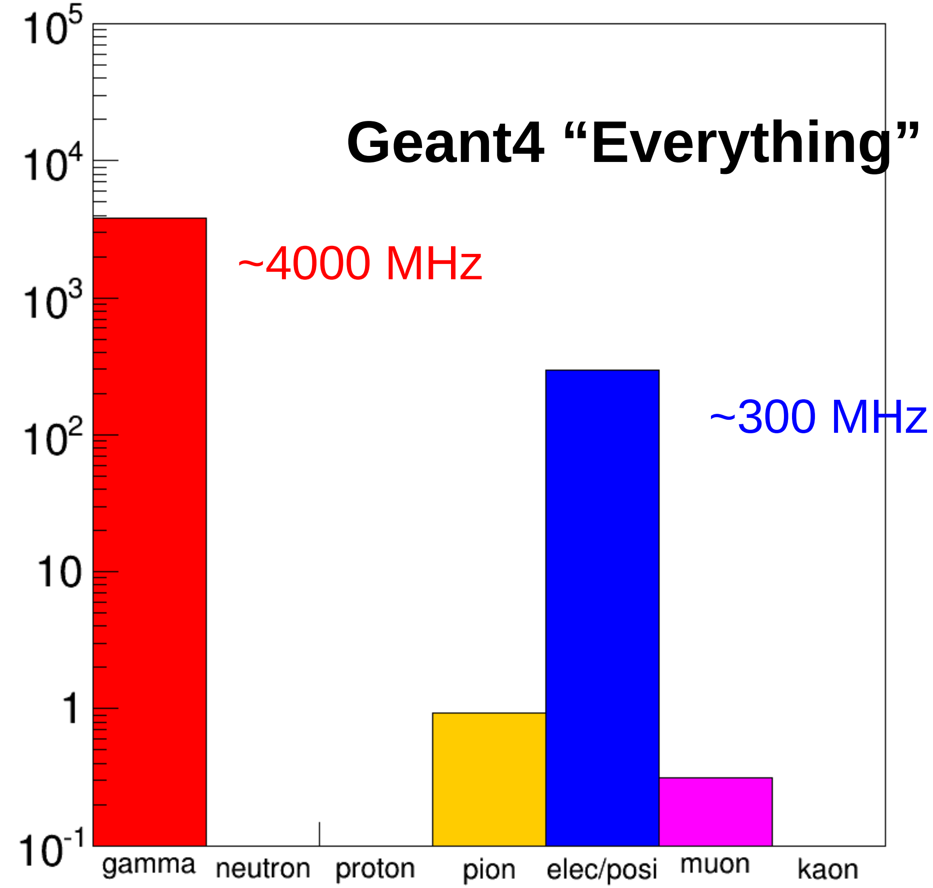




All momentums

# Rate of particles through LGC entrance window

Comparison between Wiser and Geant4




Momentums greater than radiation threshold

# What estimate to use?

- Which estimate is best?
  - Geant4 likely underestimates rate.
  - Wiser likely overestimates rate.
- Further testing (and comparison to experimental results) is needed.

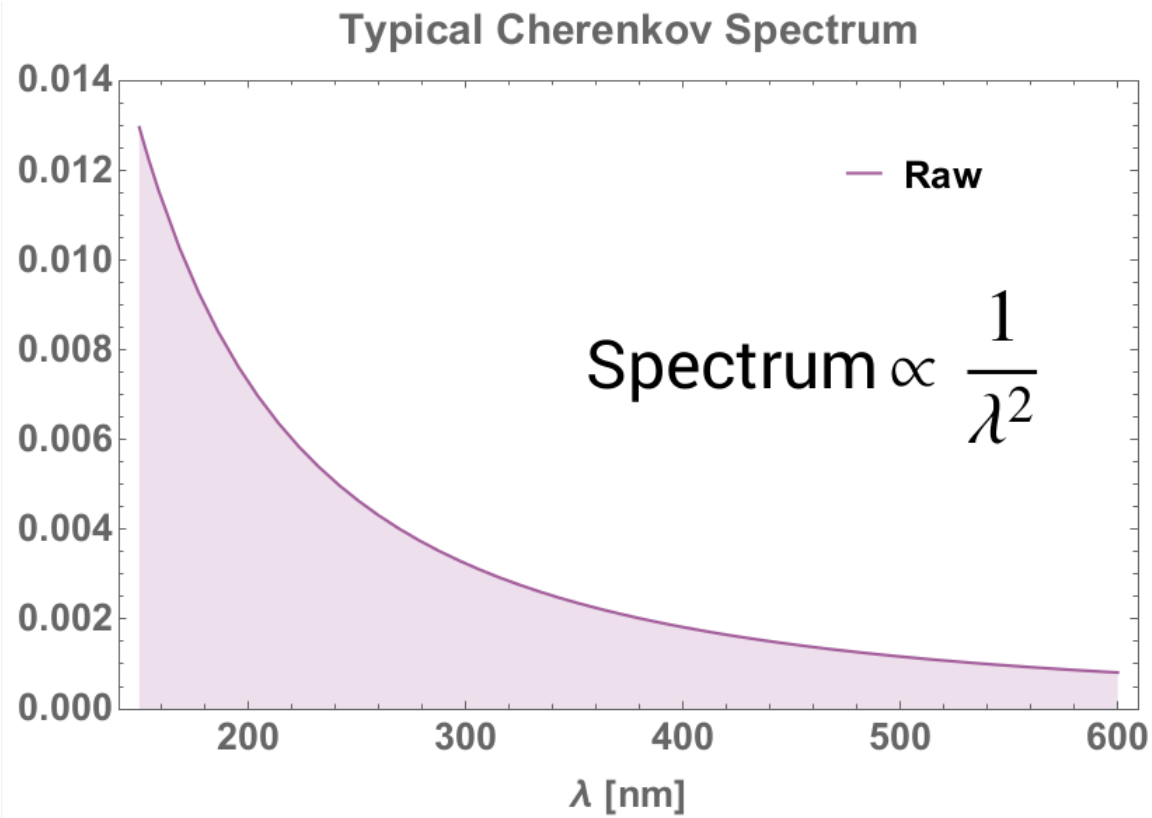
# What effect does this have on the LGC rate (PVDIS)?

- For a trigger with 2 photoelectrons in 2 different PMTs in a given sector:
  - Geant4 rate: ~ 1-2 Mhz/sector (Within DAQ capabilities)
  - Wiser rate: ~ 5-6 Mhz/sector (Pushing DAQ)

# What effect does this have on the LGC rate (SIDIS)?

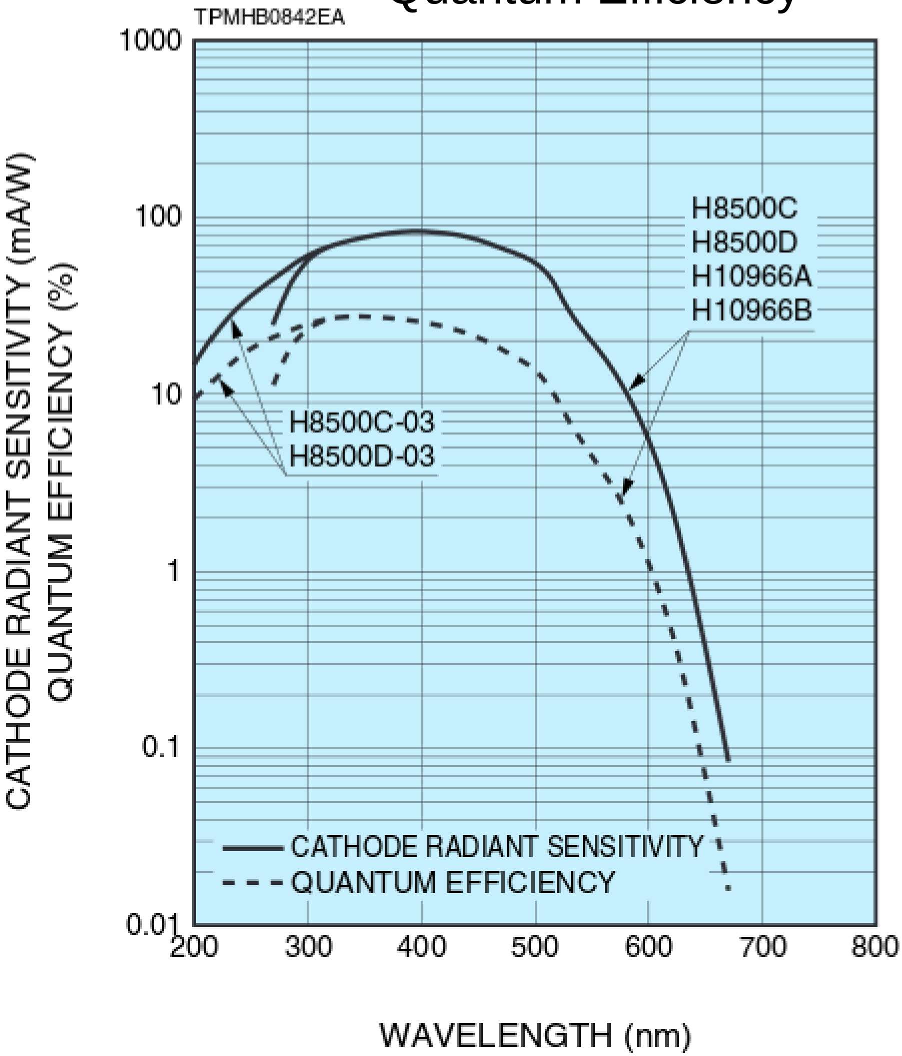
- The SIDIS rate is much more manageable:
  - Wiser rates are in the 10's of kHz/sector

# Continuing Improvements




$$\text{Spectrum} \propto \frac{1}{\lambda^2}$$

Quantum Efficiency



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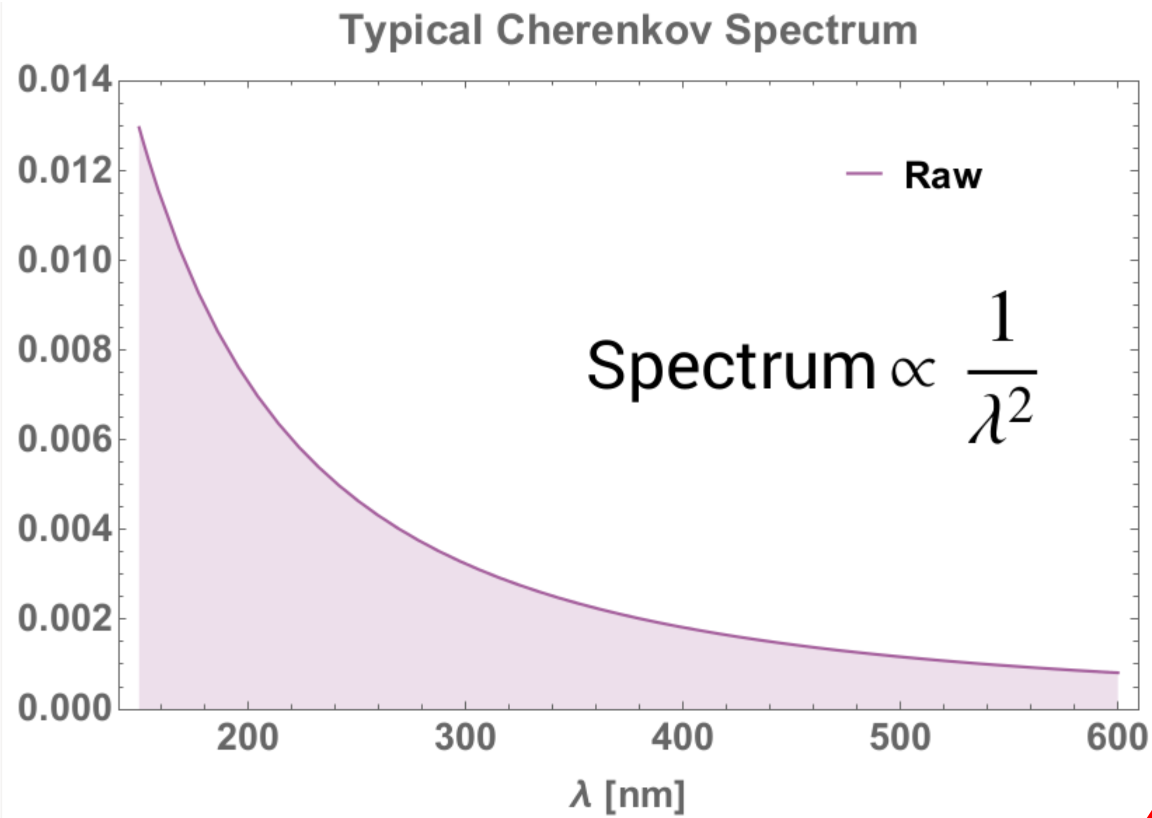


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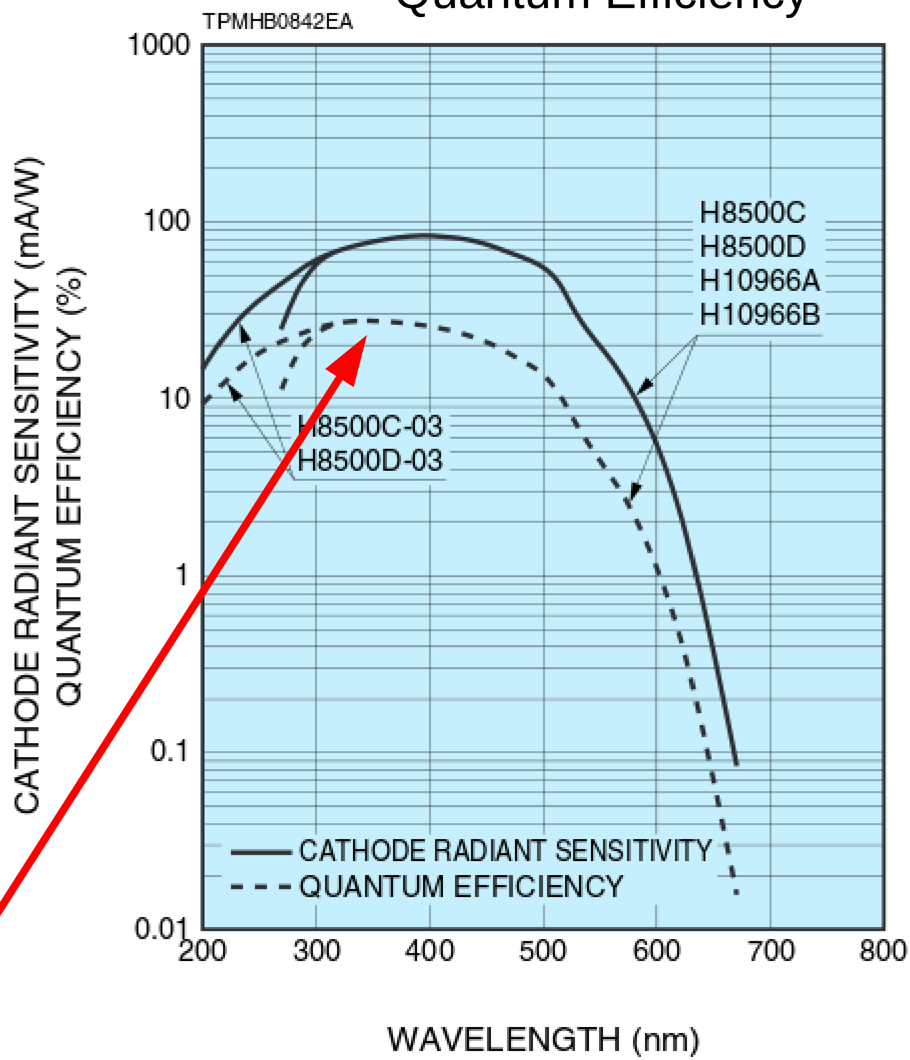
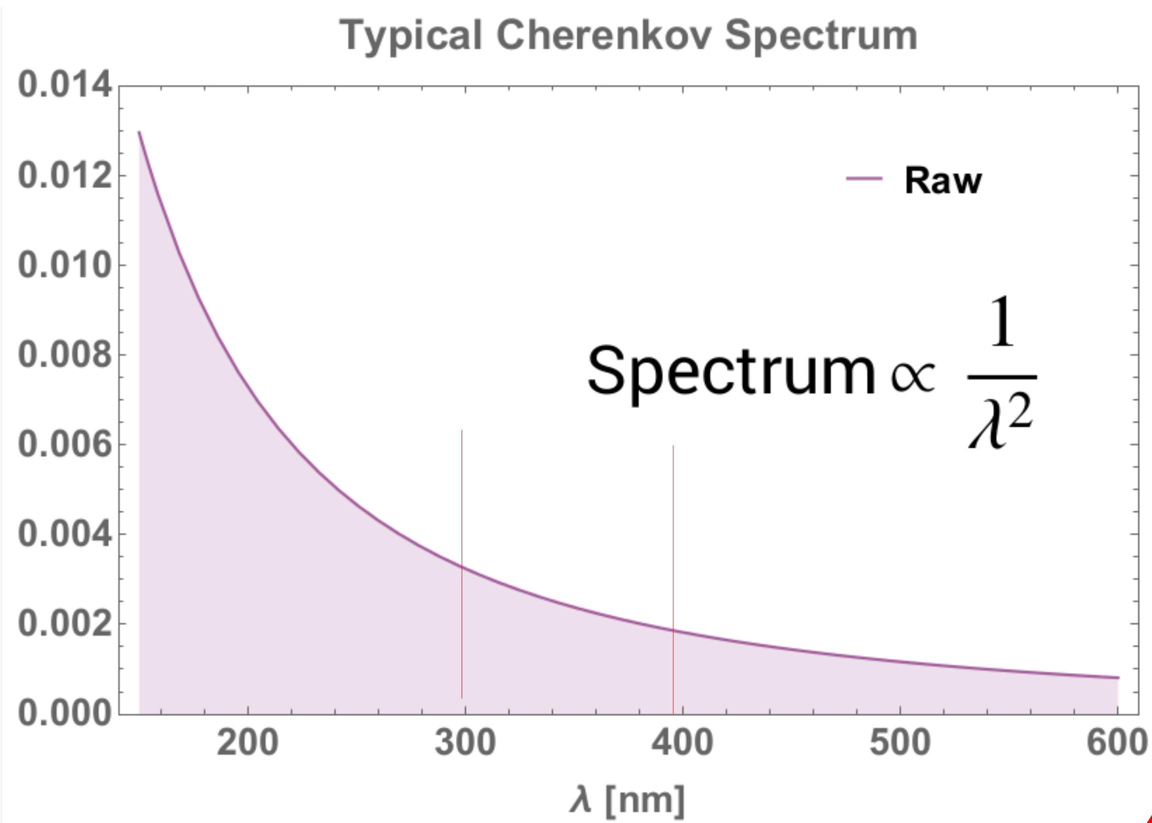



QE peaks between 300 to 400 nm at about 30%

# Continuing Improvements

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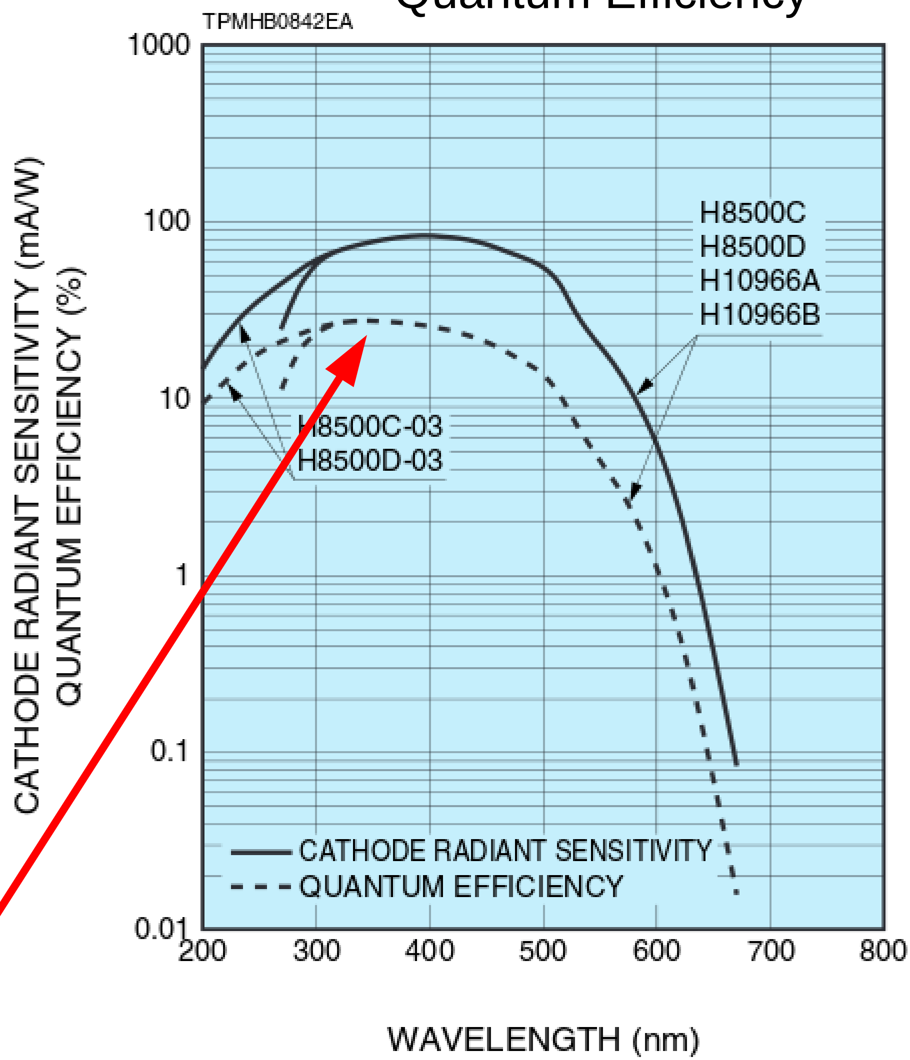
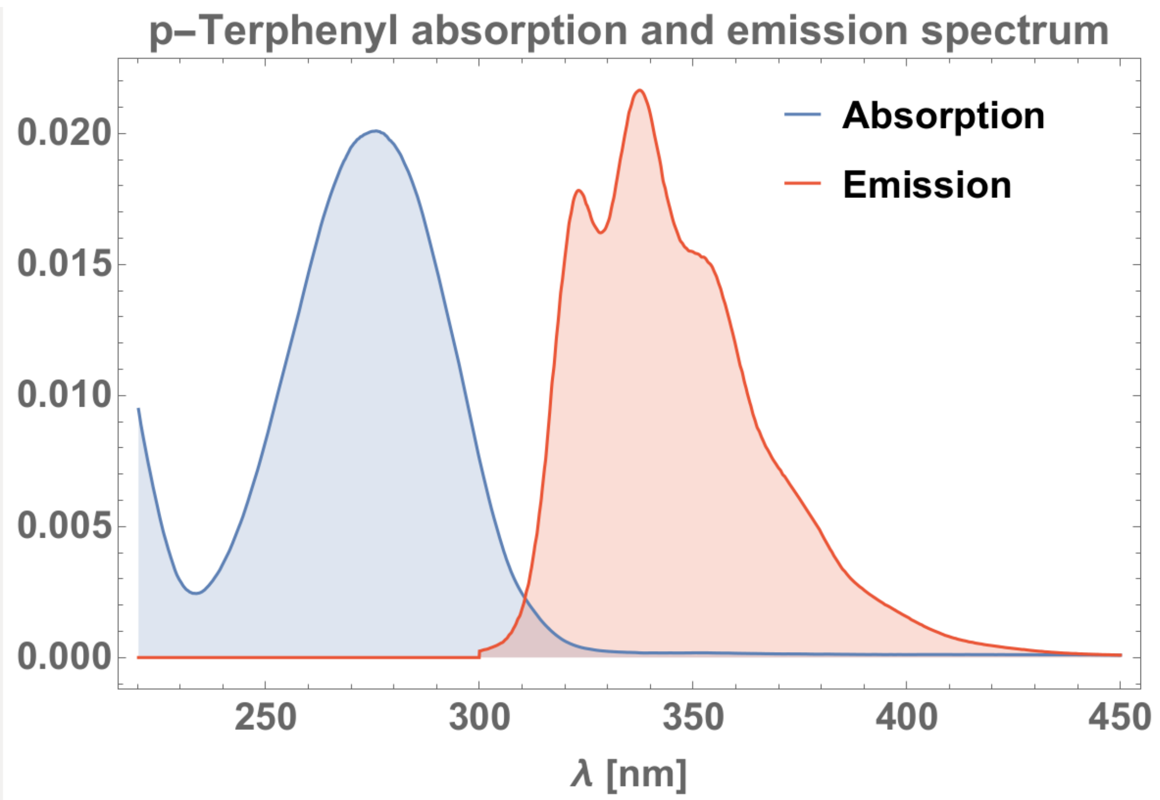


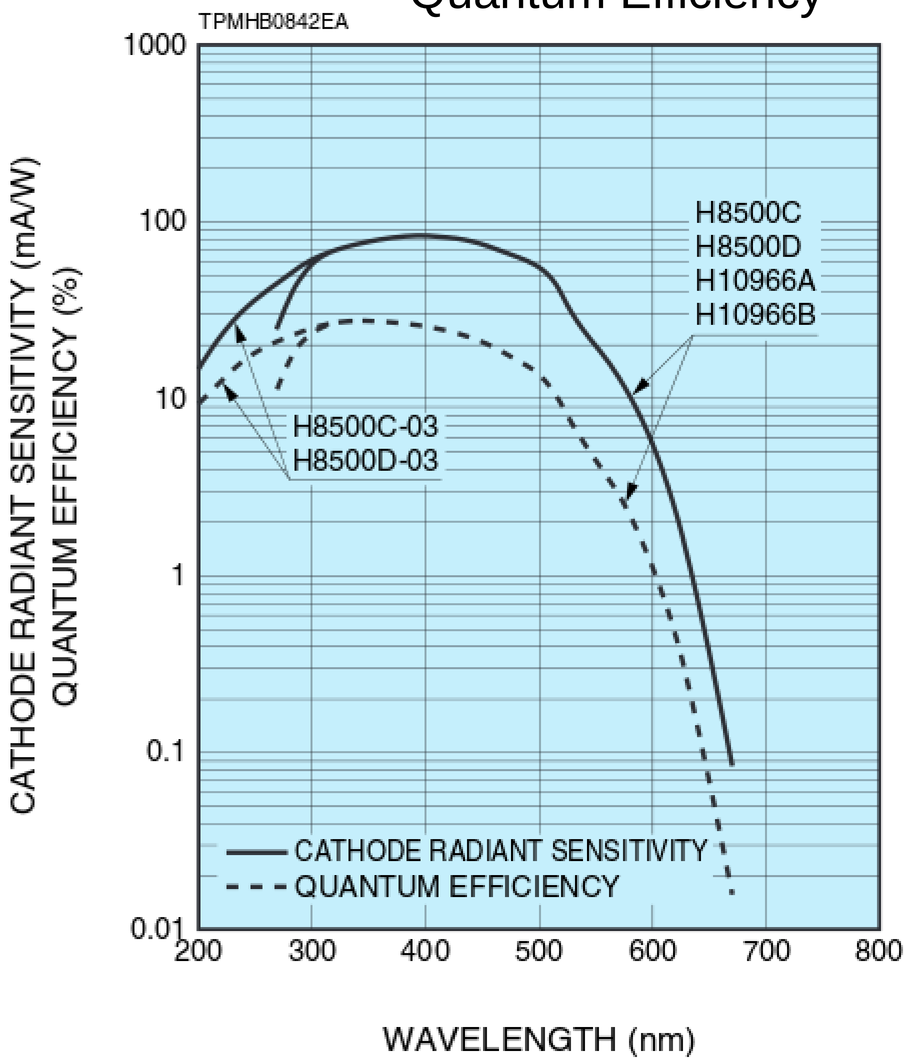

QE peaks between 300 to 400 nm at about 30%

# Continuing Improvements

## Wavelength Shifting!




Quantum Efficiency



# Continuing Improvements

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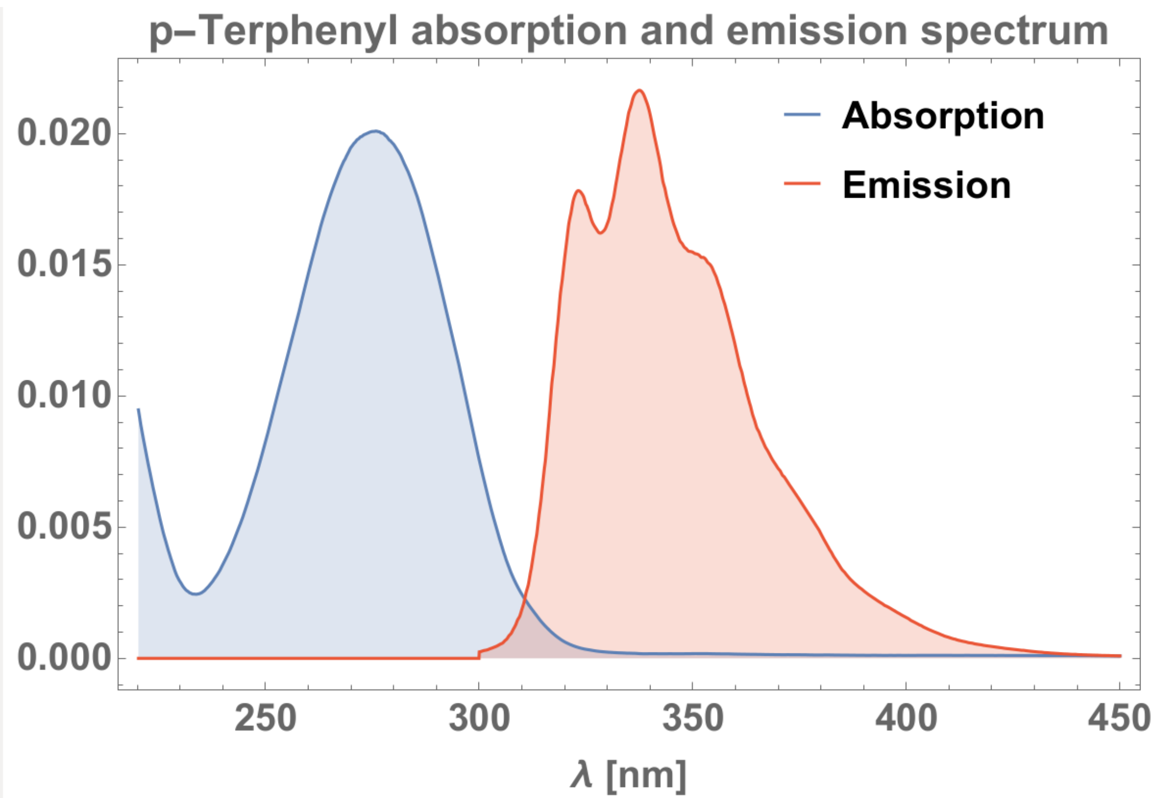
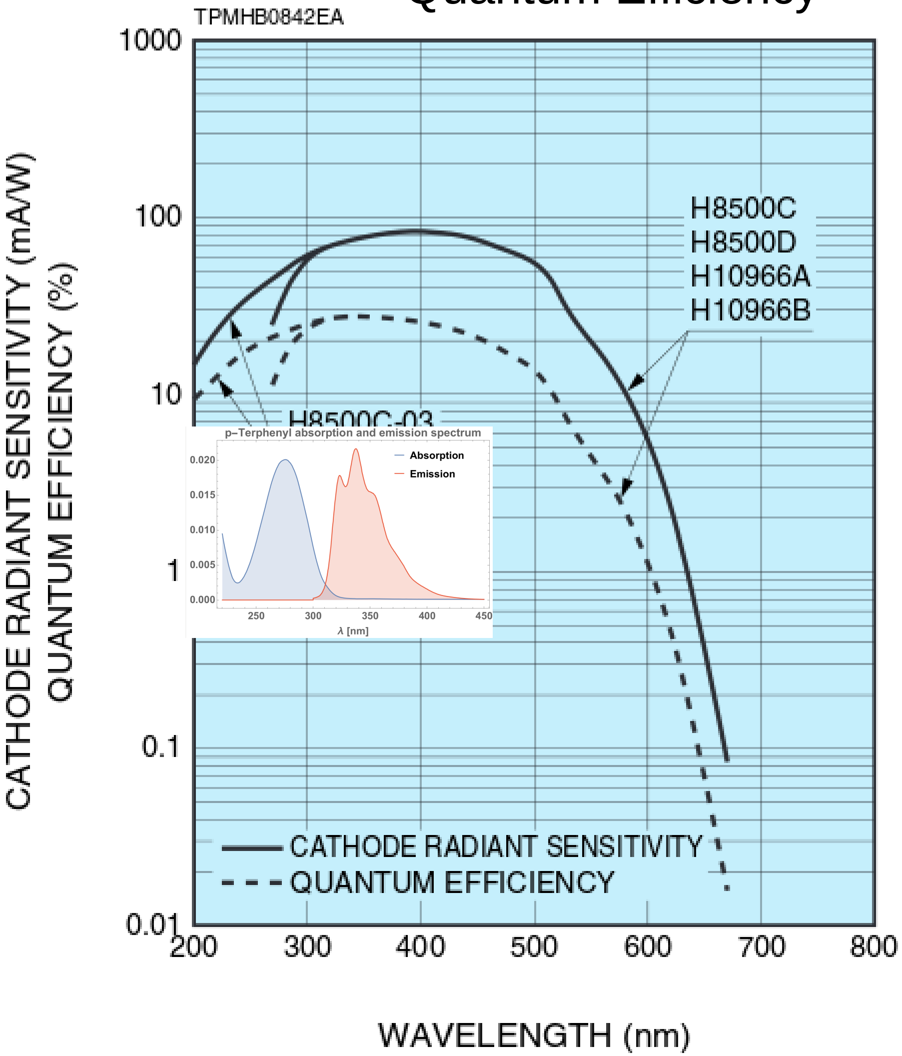
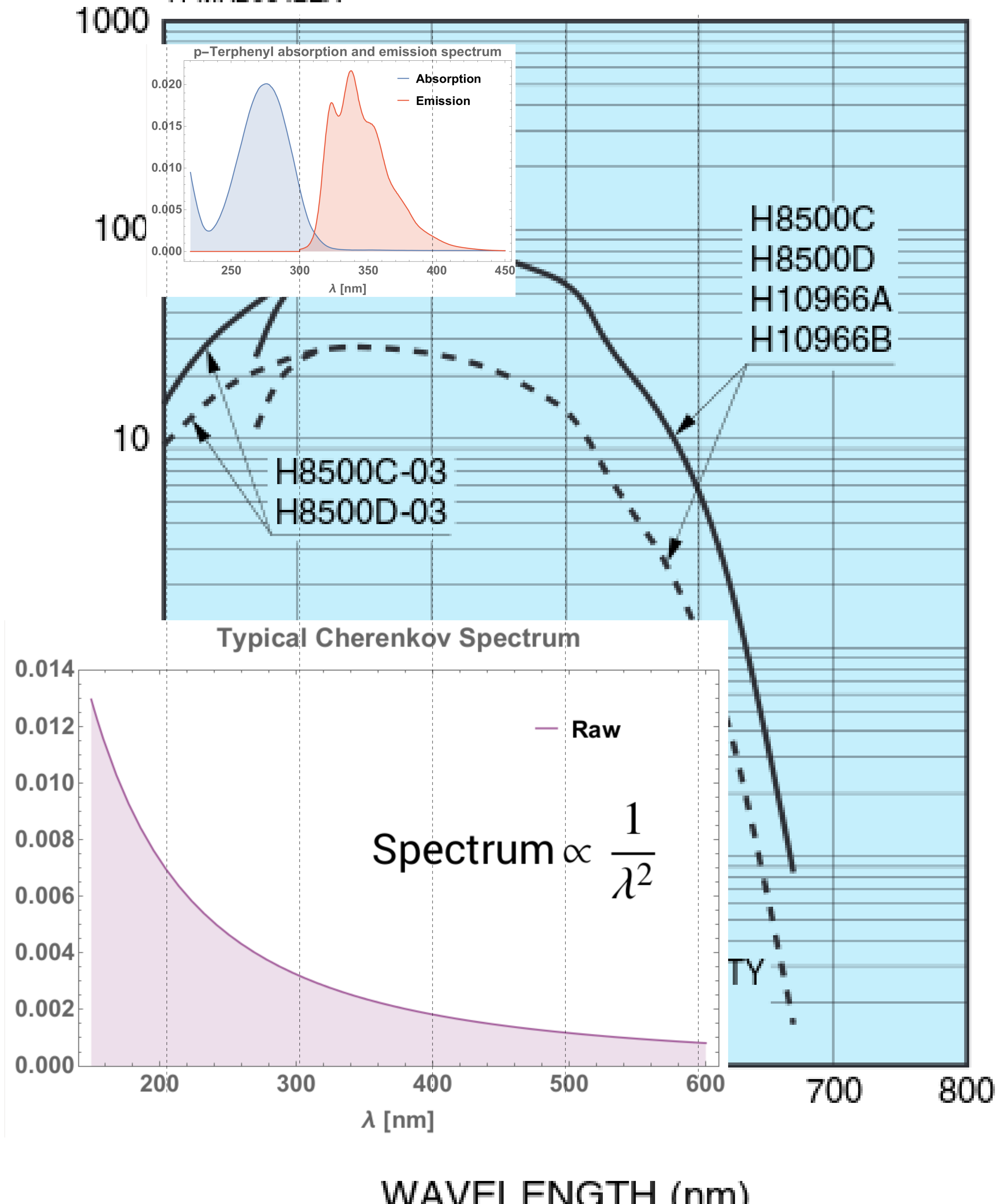



Quantum Efficiency



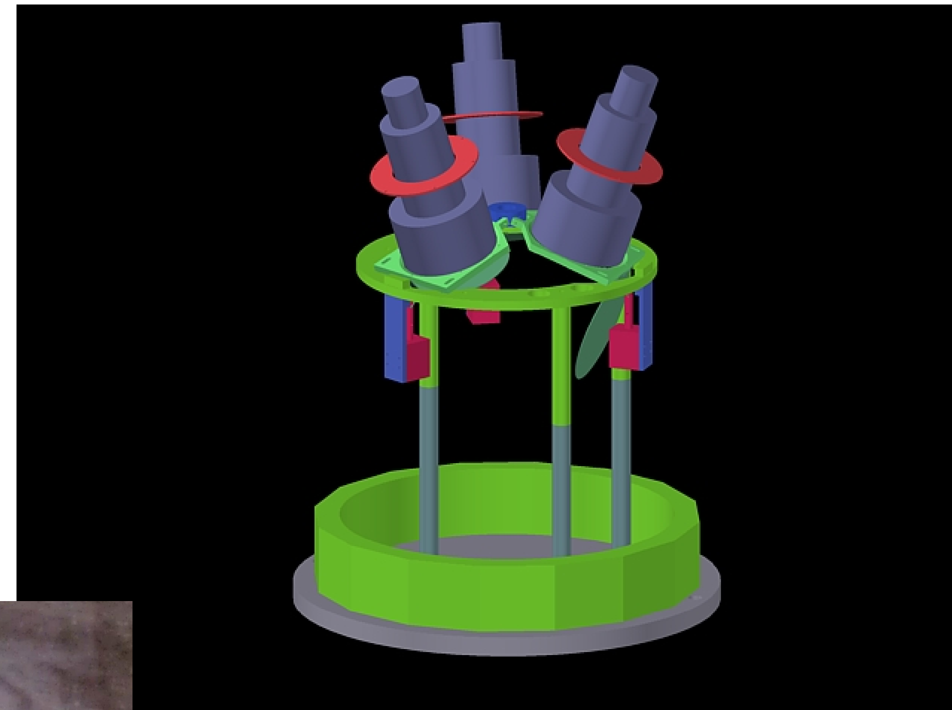


1000
100
10
p–Terphenyl absorption and emission spectrum
Absorption
Emission
0.020
0.015
0.010
0.005
0.000
250
300
350
400
450
λ [nm]
H8500C
H8500D
H10966A
H10966B
H8500C-03
H8500D-03
Typical Cherenkov Spectrum
Raw
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
200
300
400
500
600
λ [nm]
Spectrum $\propto \frac{1}{\lambda^2}$
TY
700
800
WAVELENGTH (nm)

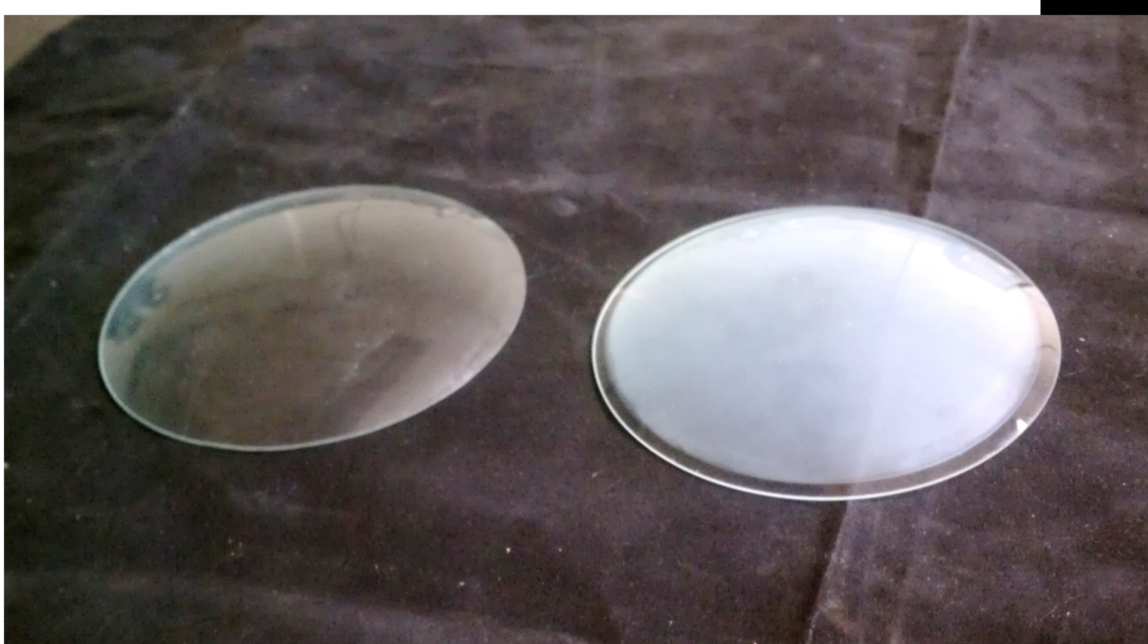
# Continuing Improvements

- Wavelength shifter for PMTs:
  - Temple is currently coating and testing the clas12 LGCC PMTs with p-Terphenyl.

    .

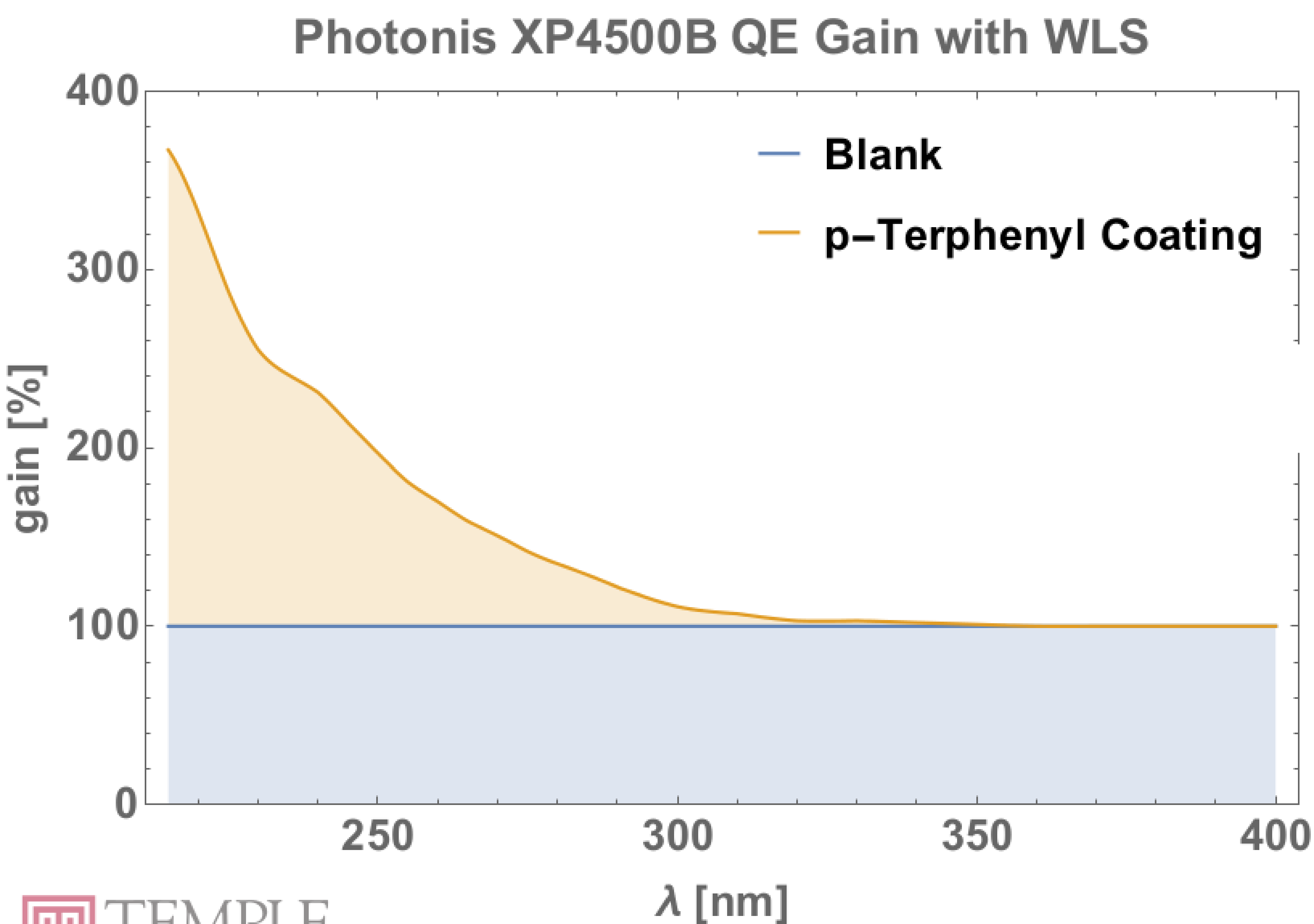


Coating apparatus

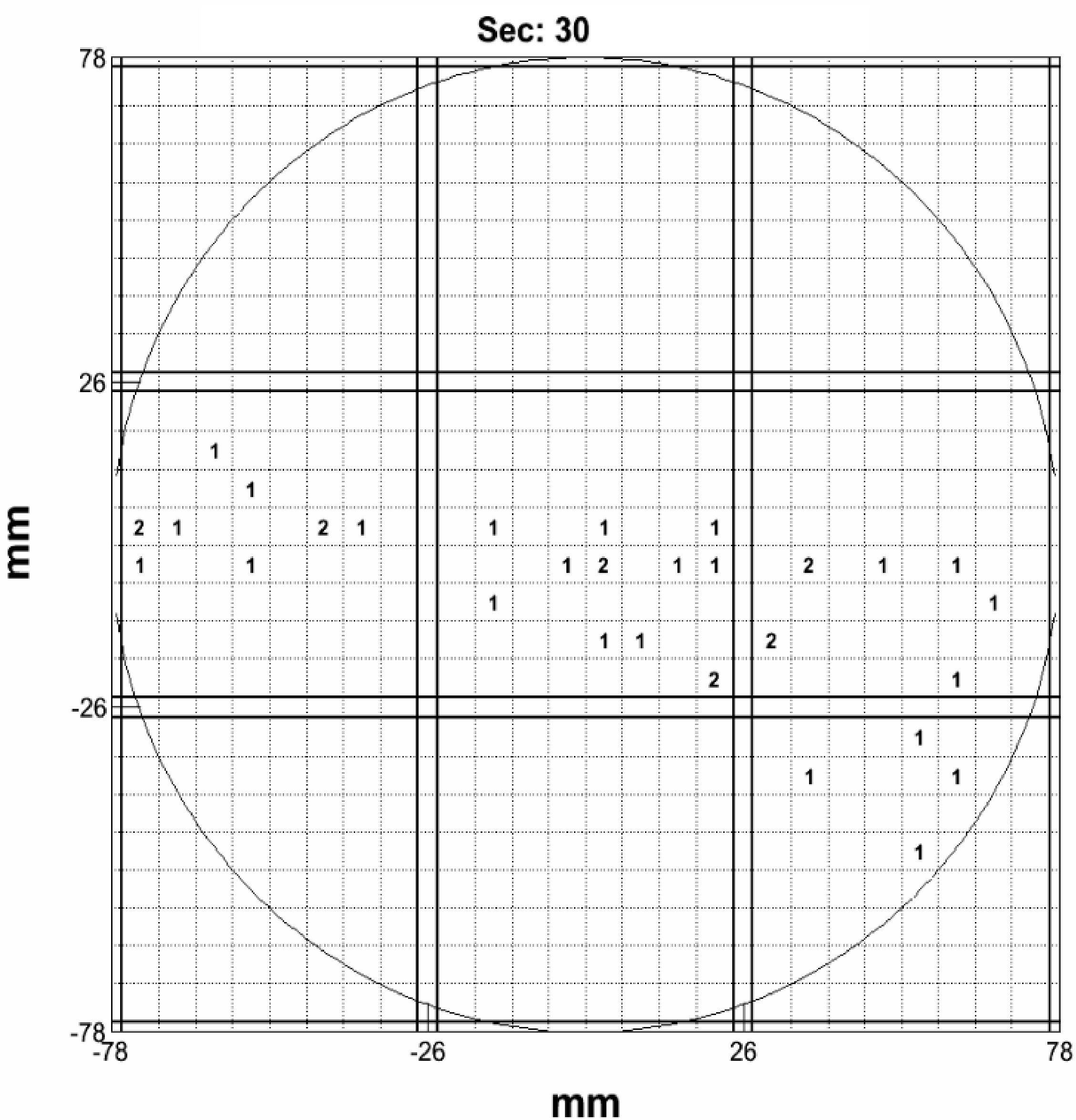


Face plate coating:
Before and after

# Wavelength shifting gains



# Continuing Improvements: PE pattern analysis

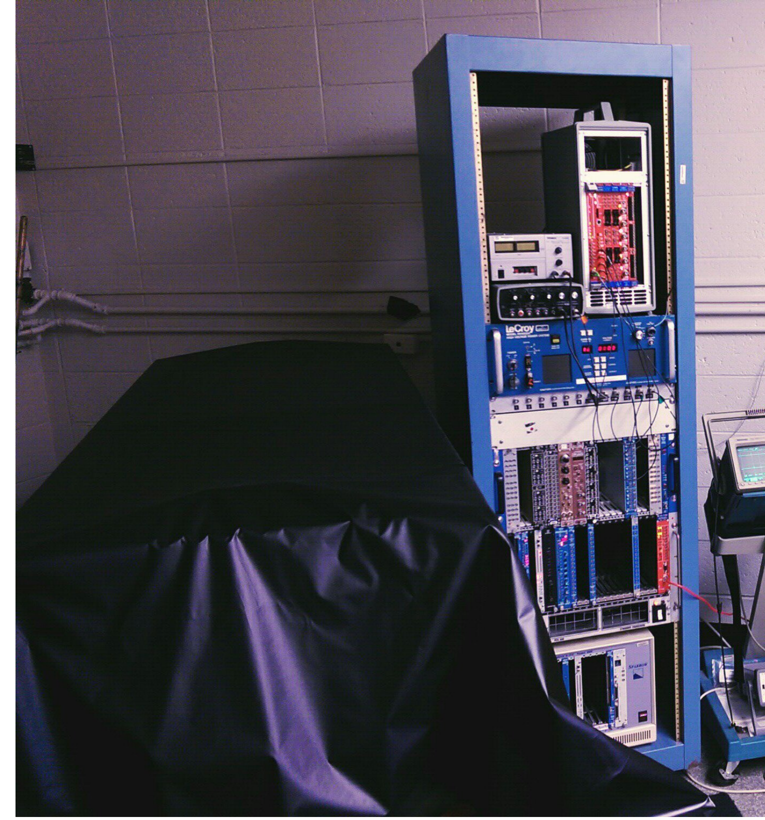



Example: Single triggered event

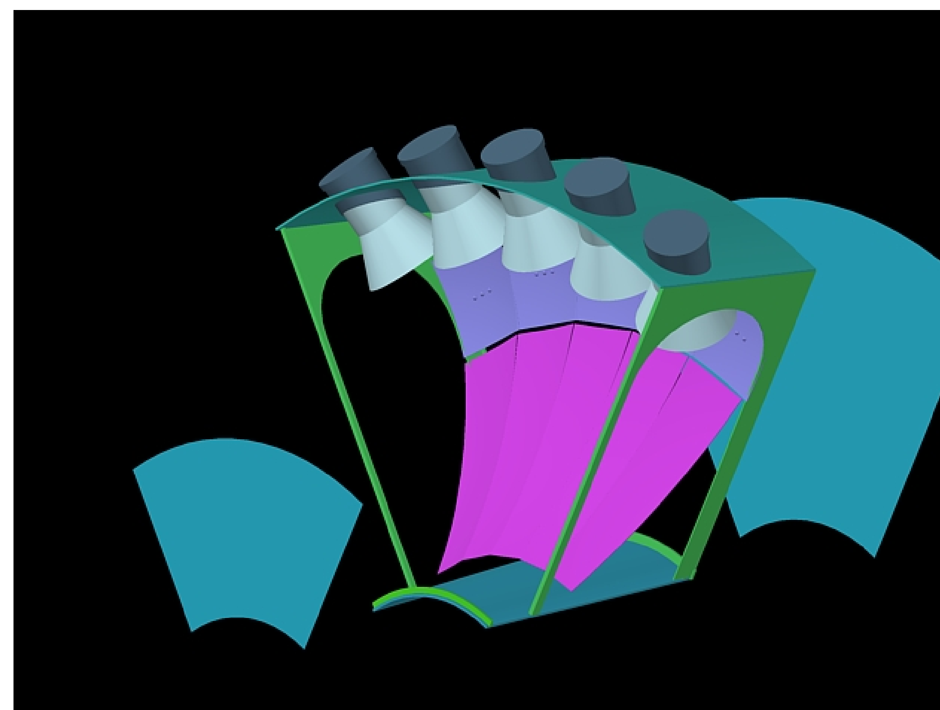
- Pattern of photoelectron signal could be recorded (binary signal per pixel) with a MAROC chip.
- Binary output together with pattern recognition could provide limited tracking information.
  - Possibly useful for background suppression or better pion rejection.

# Prototyping

- 1st stage (Pre-R&D)
  - maPMT / DAQ testing
  - small Cherenkov tank
  - With electron source → test more realistic PMT response.
  - Ideally with a single aluminized / polished CFRP mirror



- 2nd stage (1st – 2nd year DOE)
  - Construction of 1/6th of total SoLID detector.
    - 5 combined sectors → to be used in final detector.
    - Prototype 1/6th size tank.



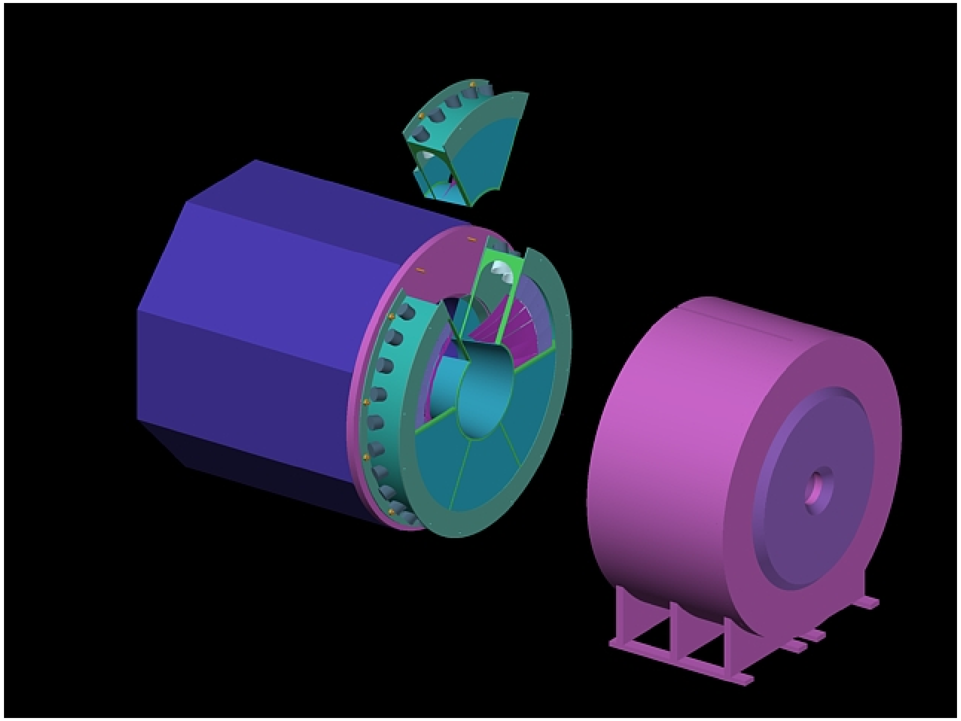
# Budget

# Conclusion

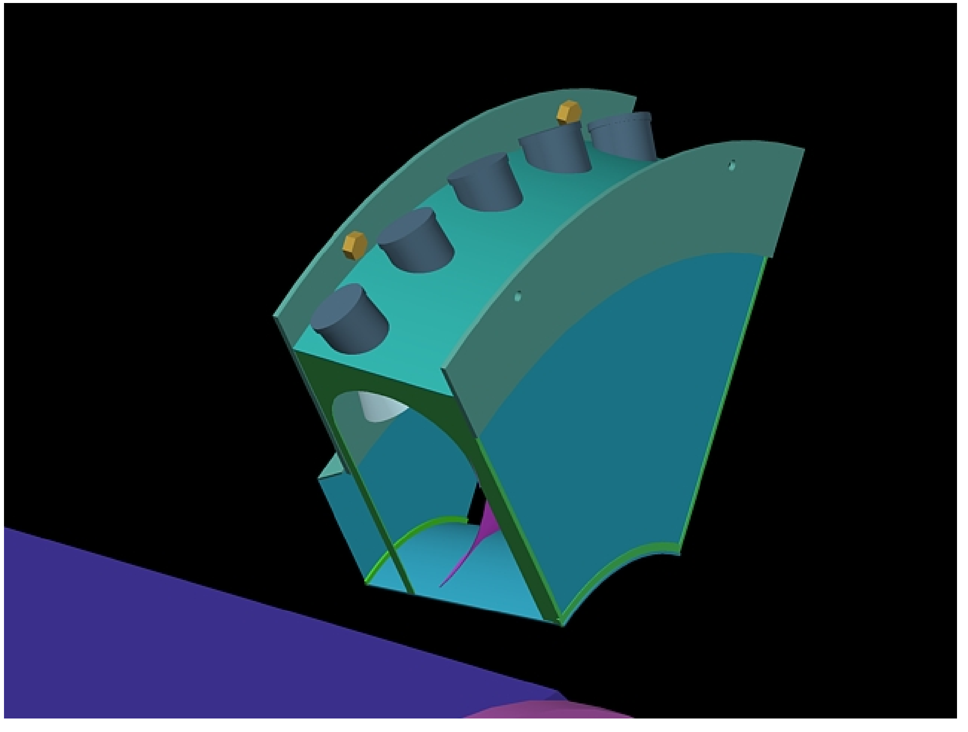
- The SoLID LGC is designed to meet the requirements of the SIDIS and PVDIS experimental programs while maximizing inter-component use (minimizing cost).
- Extensive GEMC / Geant4 simulations have been performed testing signal, backgrounds, and pion rejection.
- Continuing efforts to study (and reduce) simulated EM / hadronic backgrounds.
- Wavelength shifting and PMT pixel pattern analysis are being investigated and may lead to even better LGC performance.

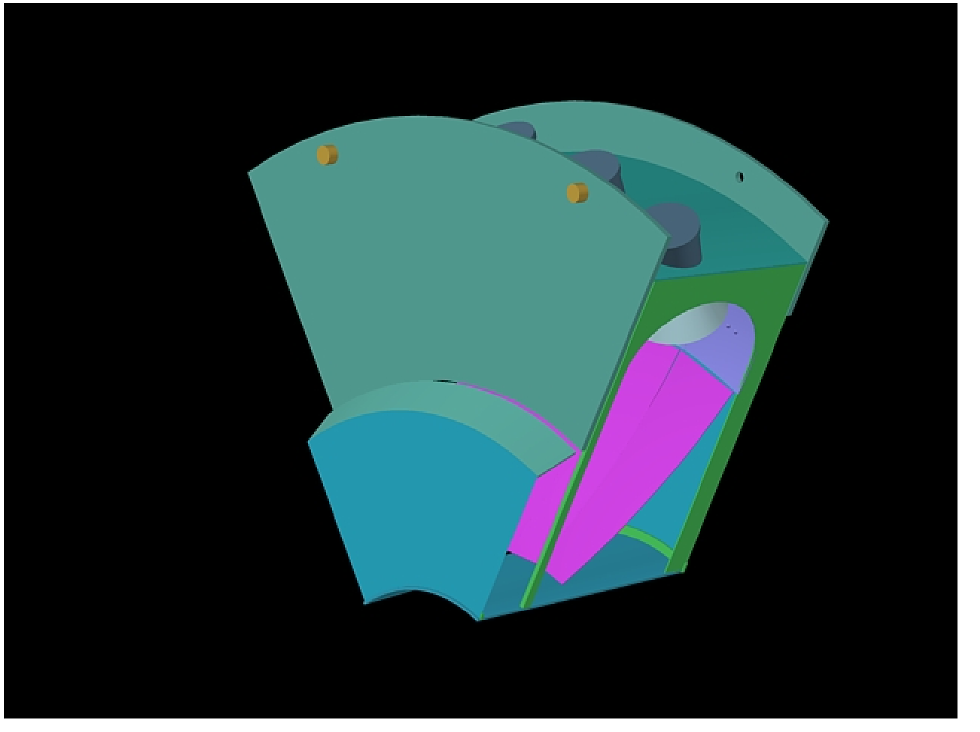
# Backups

# LGC support and engineering

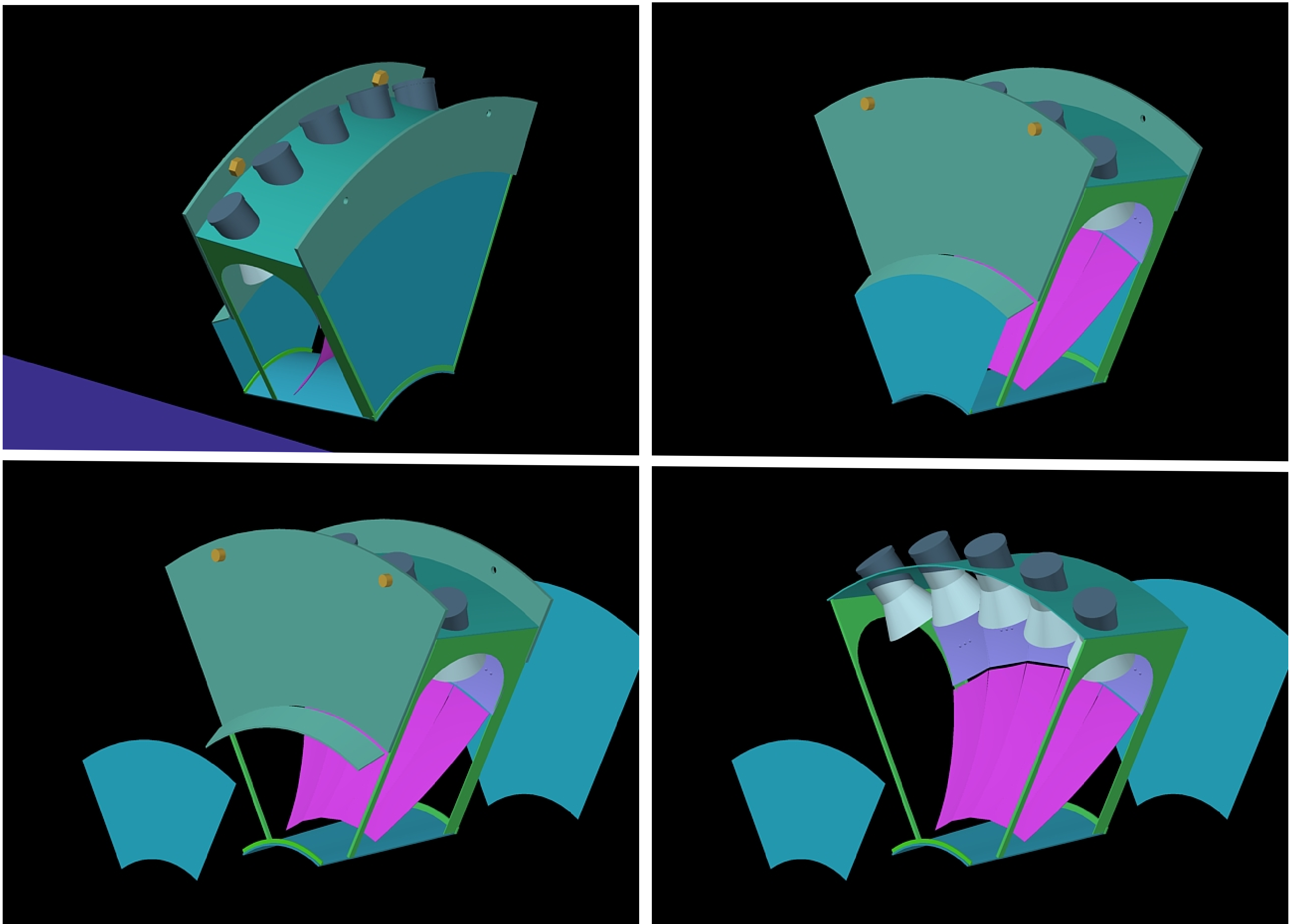


# LGC support and engineering

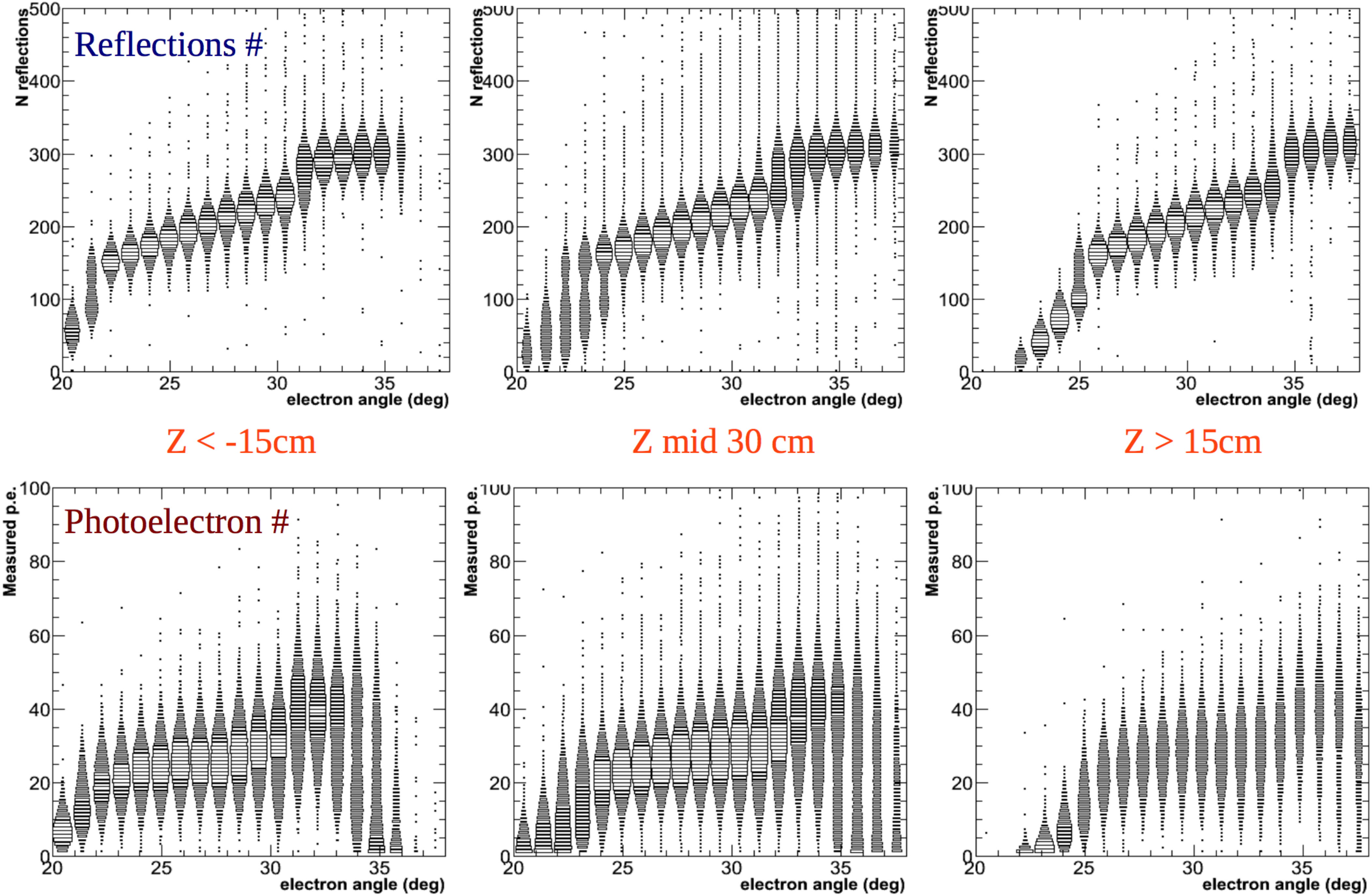




# LGC support and engineering

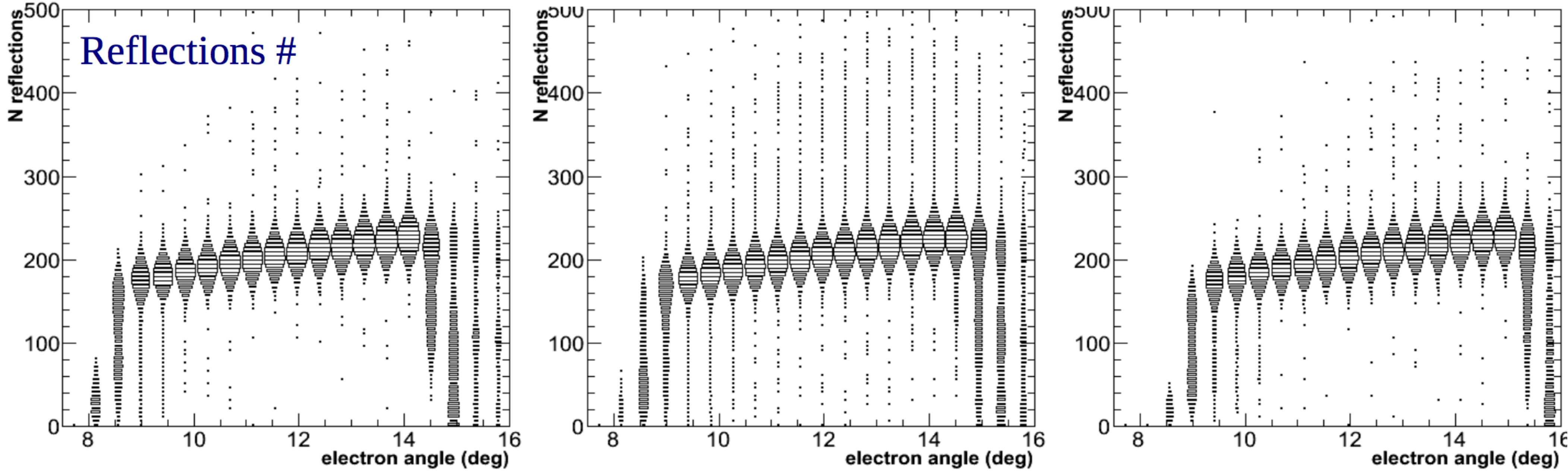


# PVDIS

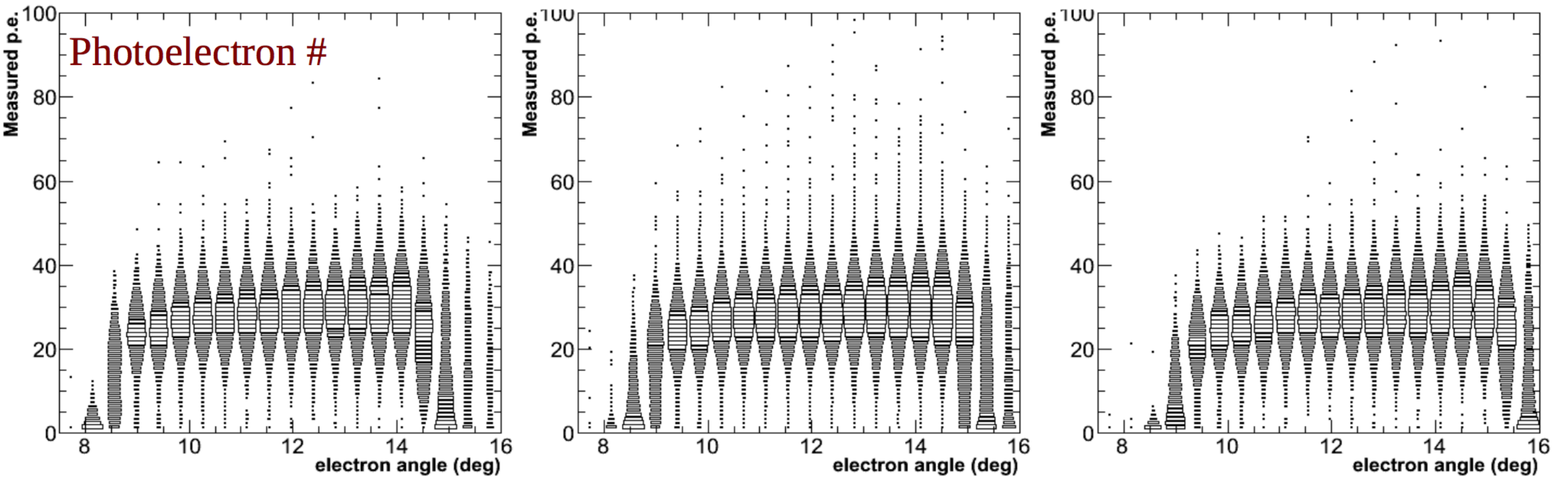


Reflections #
N reflections
electron angle (deg)
Z < -15cm
Z mid 30 cm
Z > 15cm
Photoelectron #
Measured p.e.
electron angle (deg)

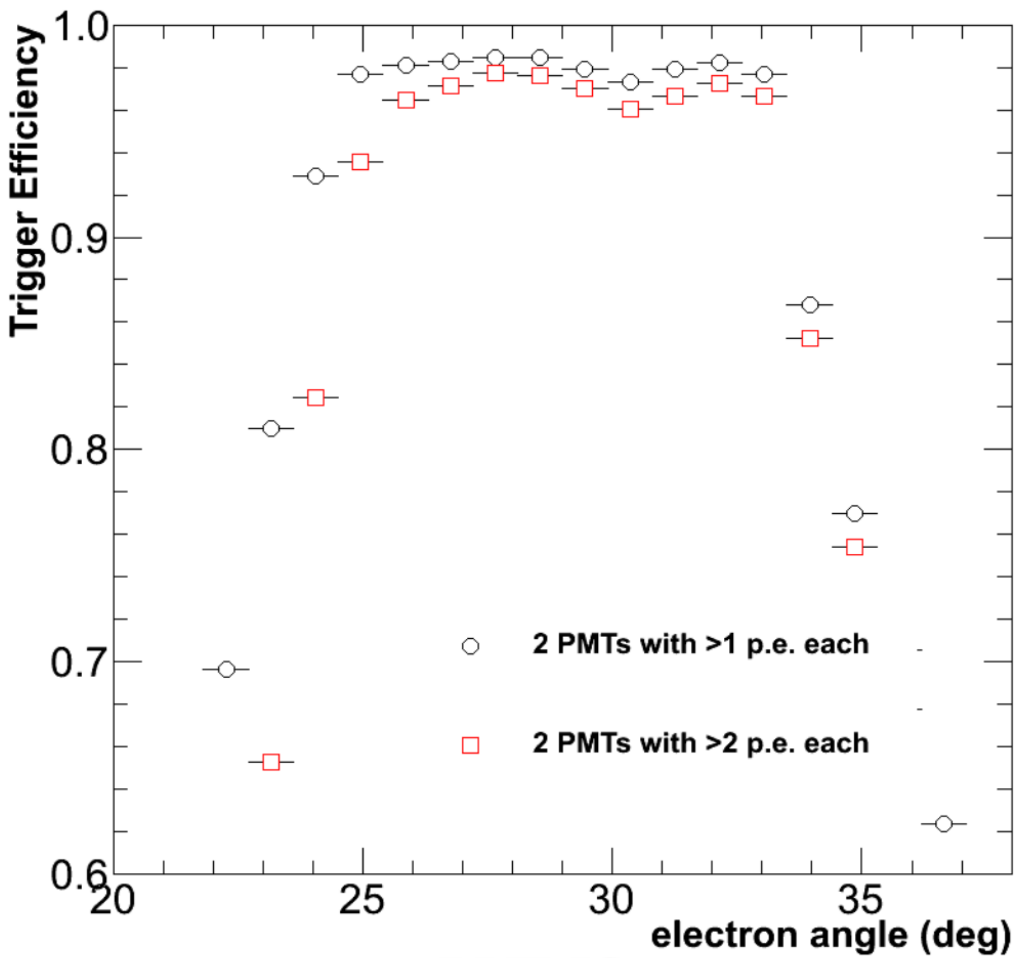
# SIDIS



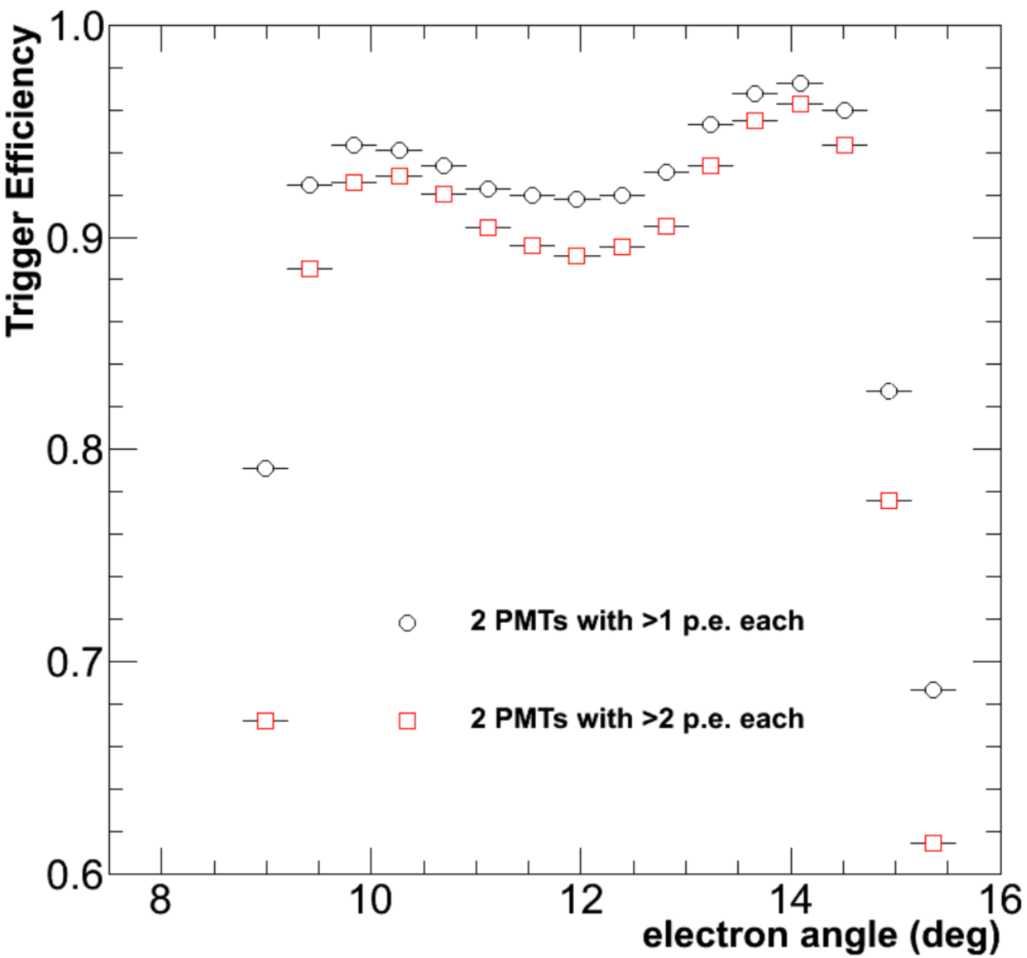

Z < -15cm | Z mid 30 cm | Z > 15cm



# Trigger Efficiencies

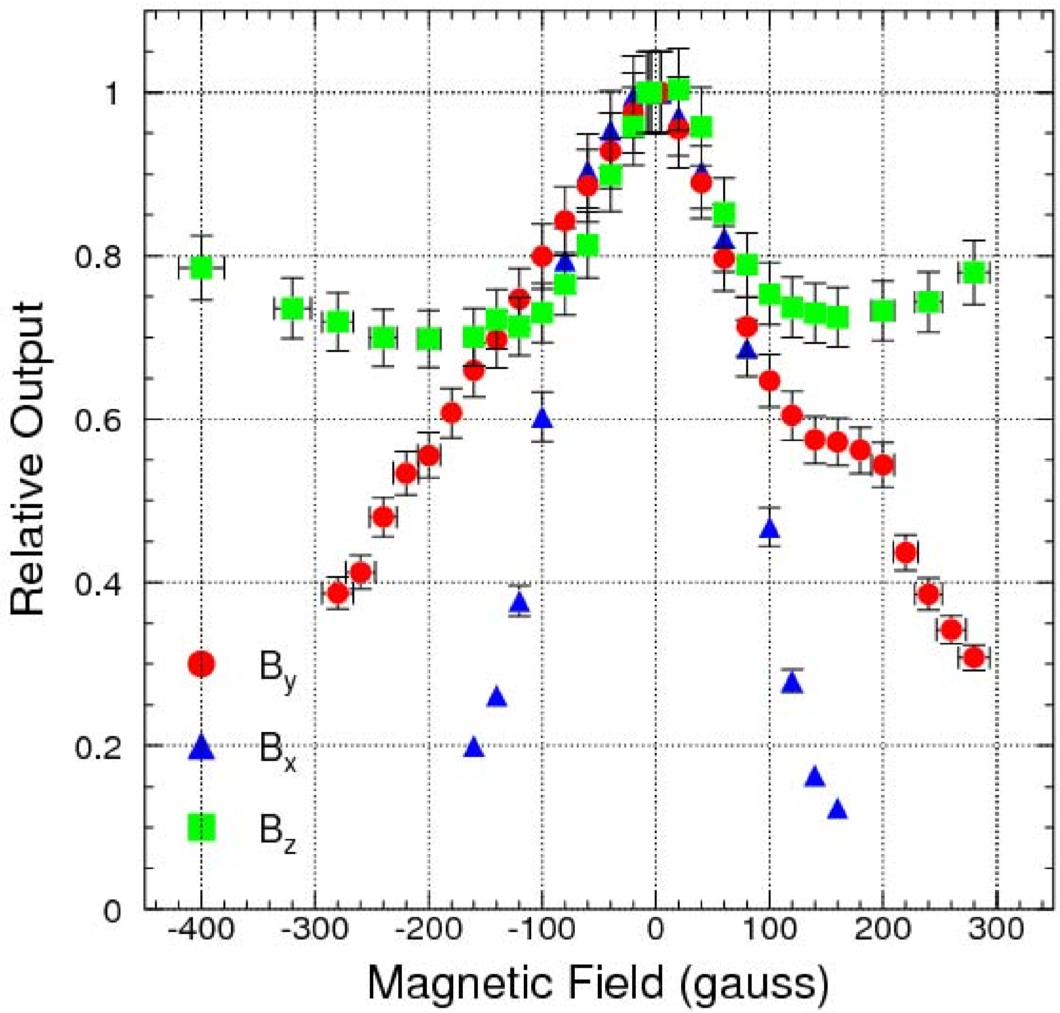



PVDIS



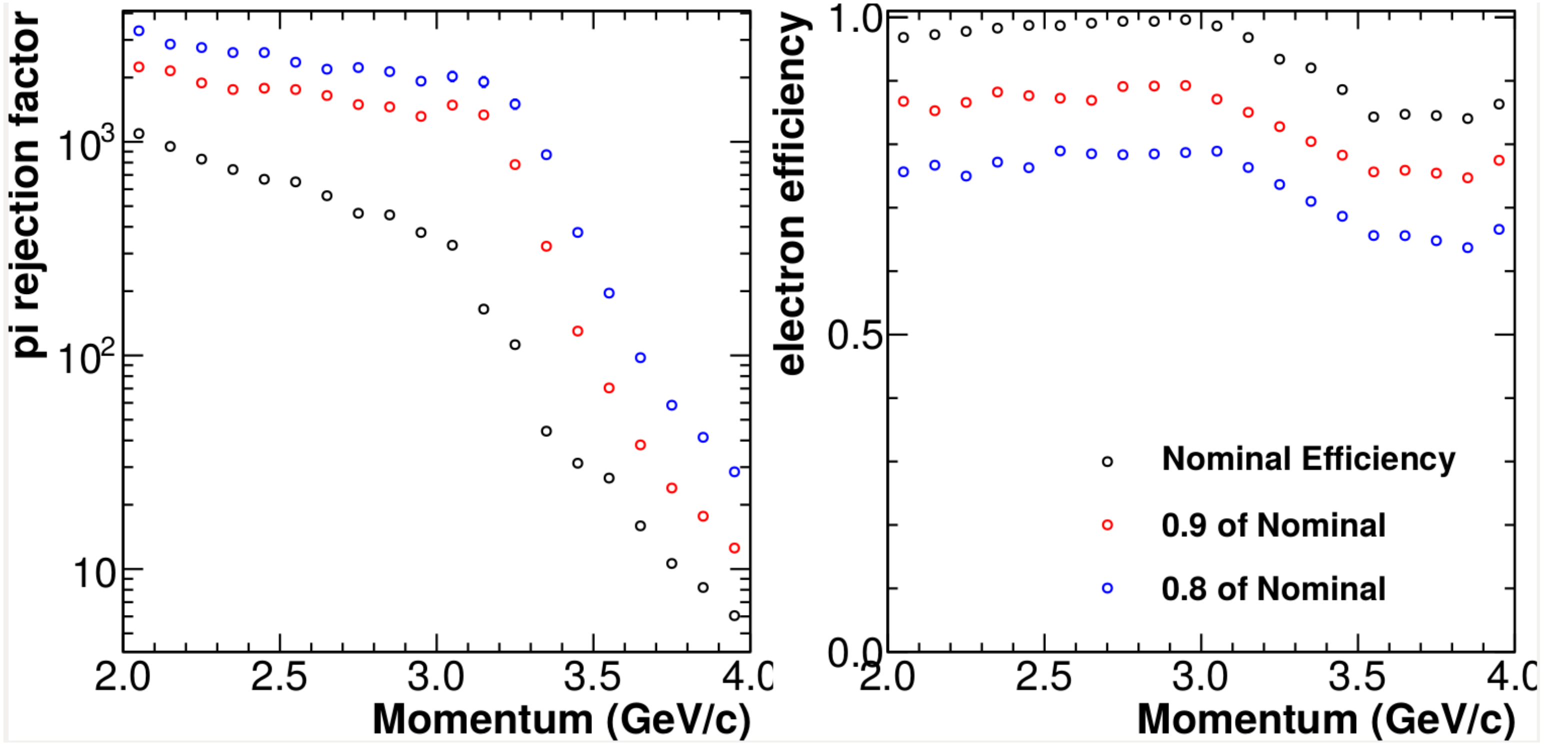

SIDIS

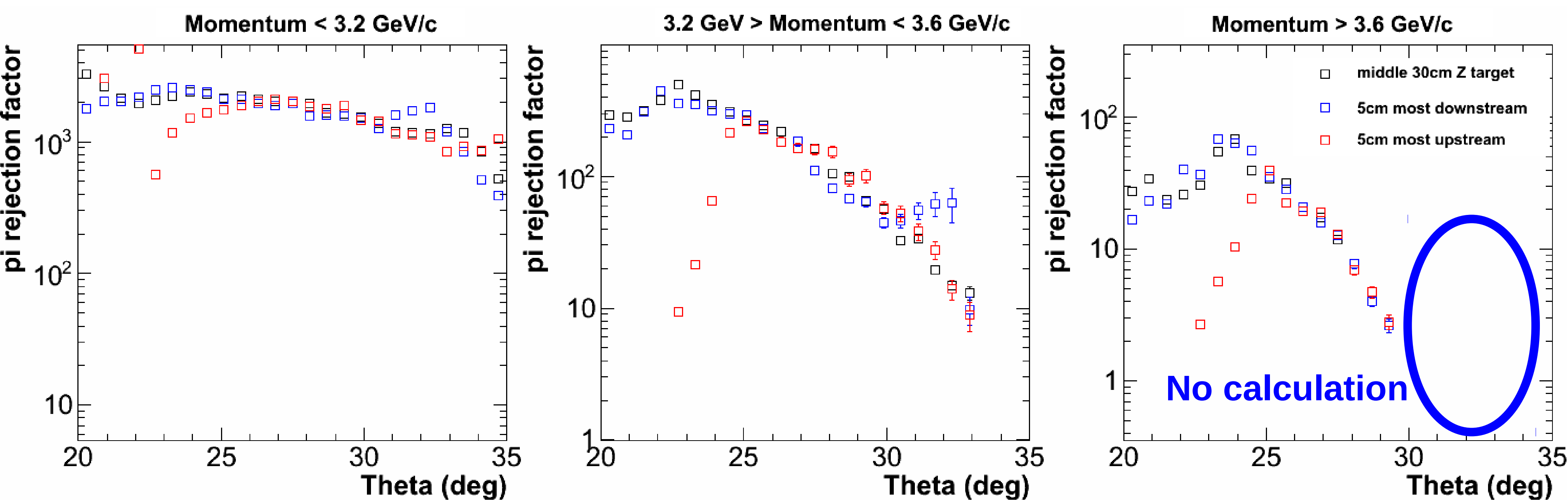
# PMT in Magnetic Field



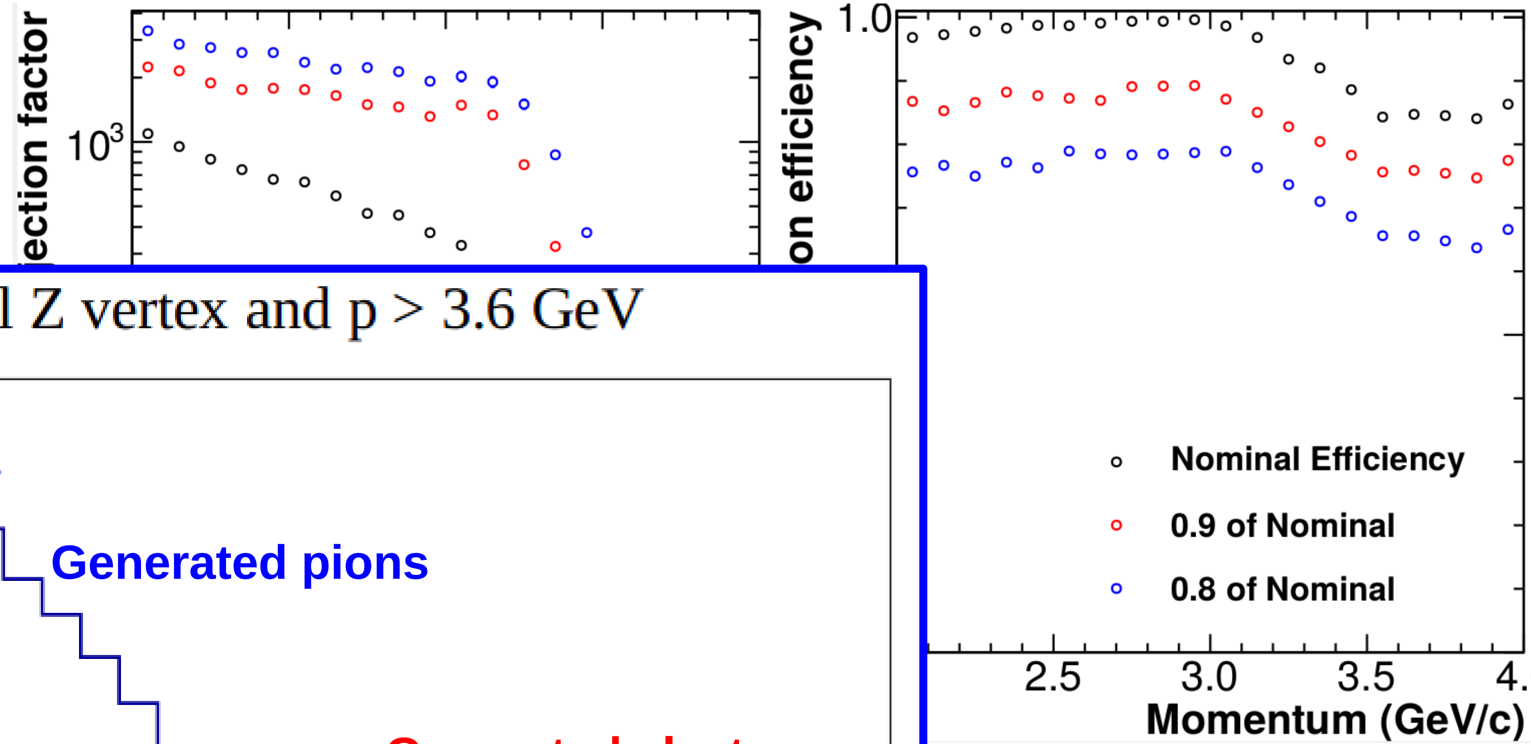
# PVDIS

pi rejection factor is the inverse pi acceptance after selection cut.

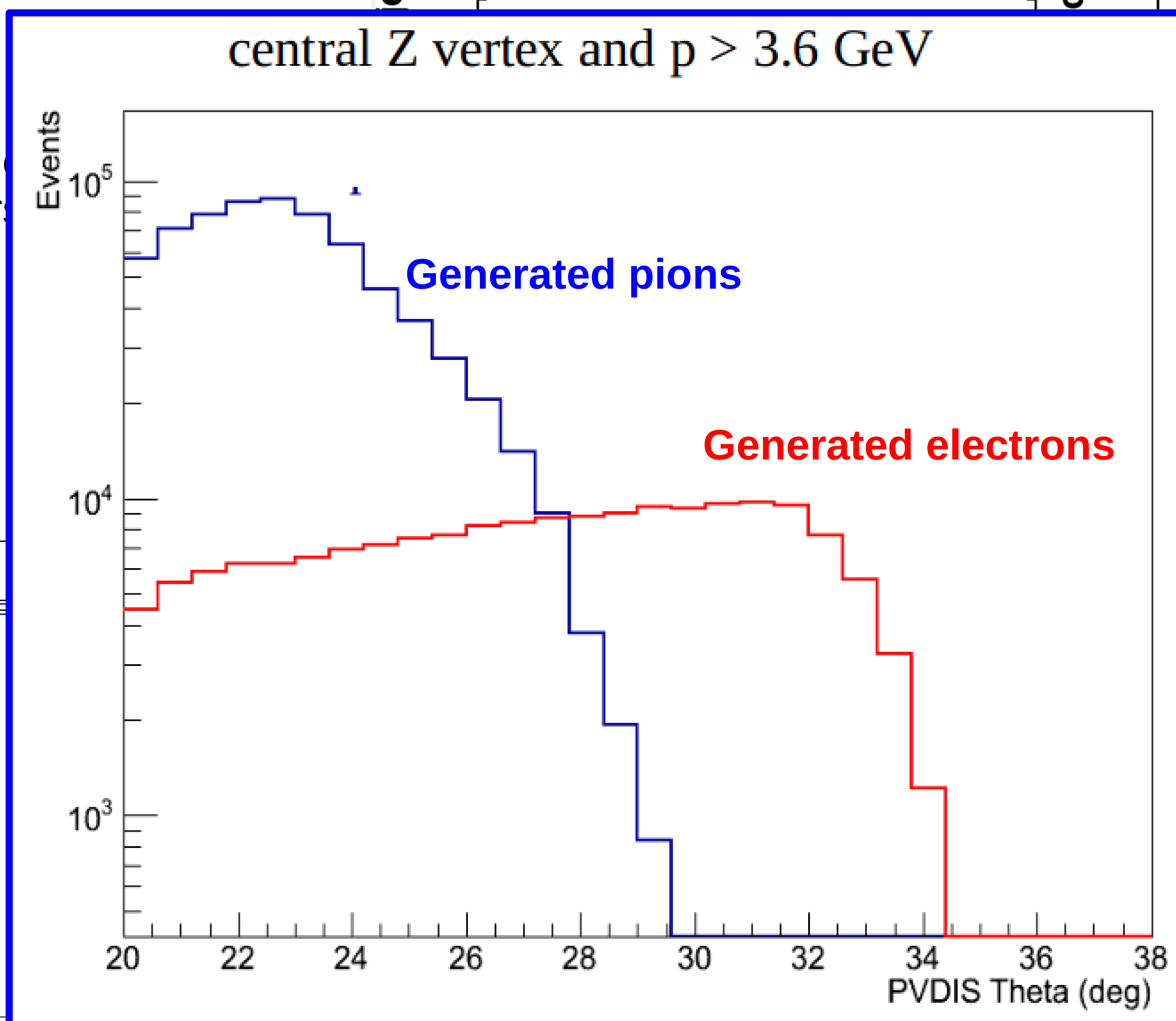


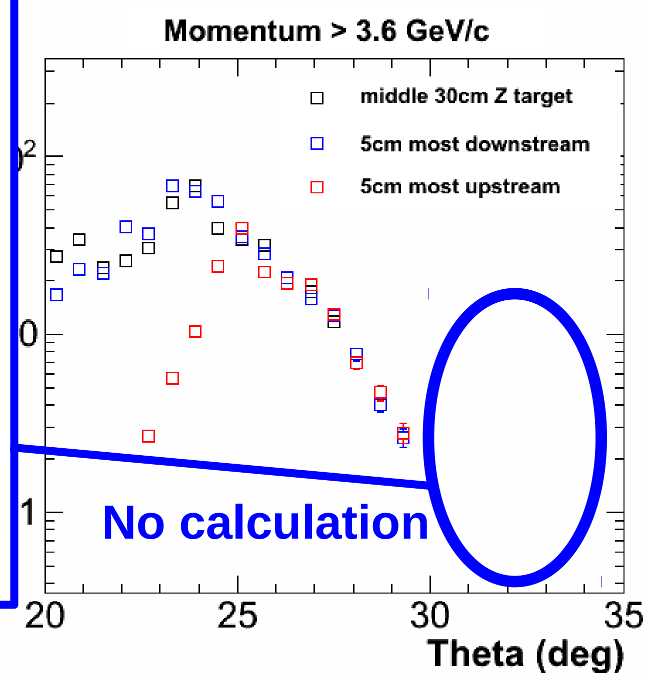



# PVDIS



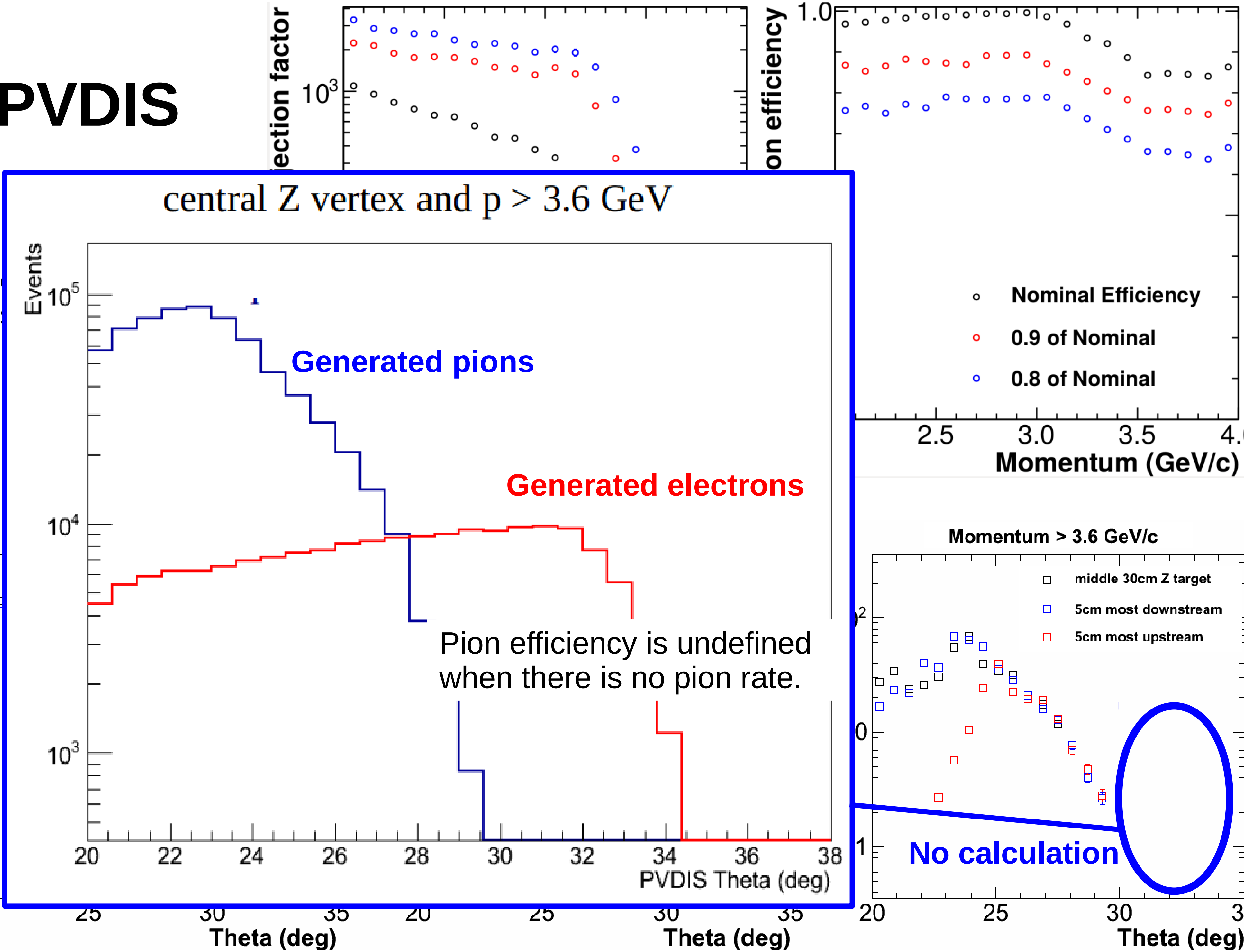

pi rej
invers
after

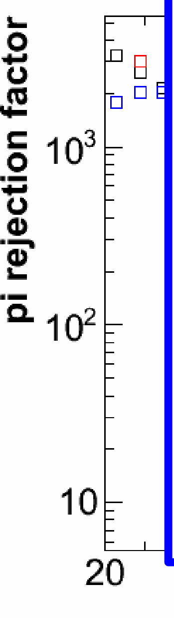


# PVDIS

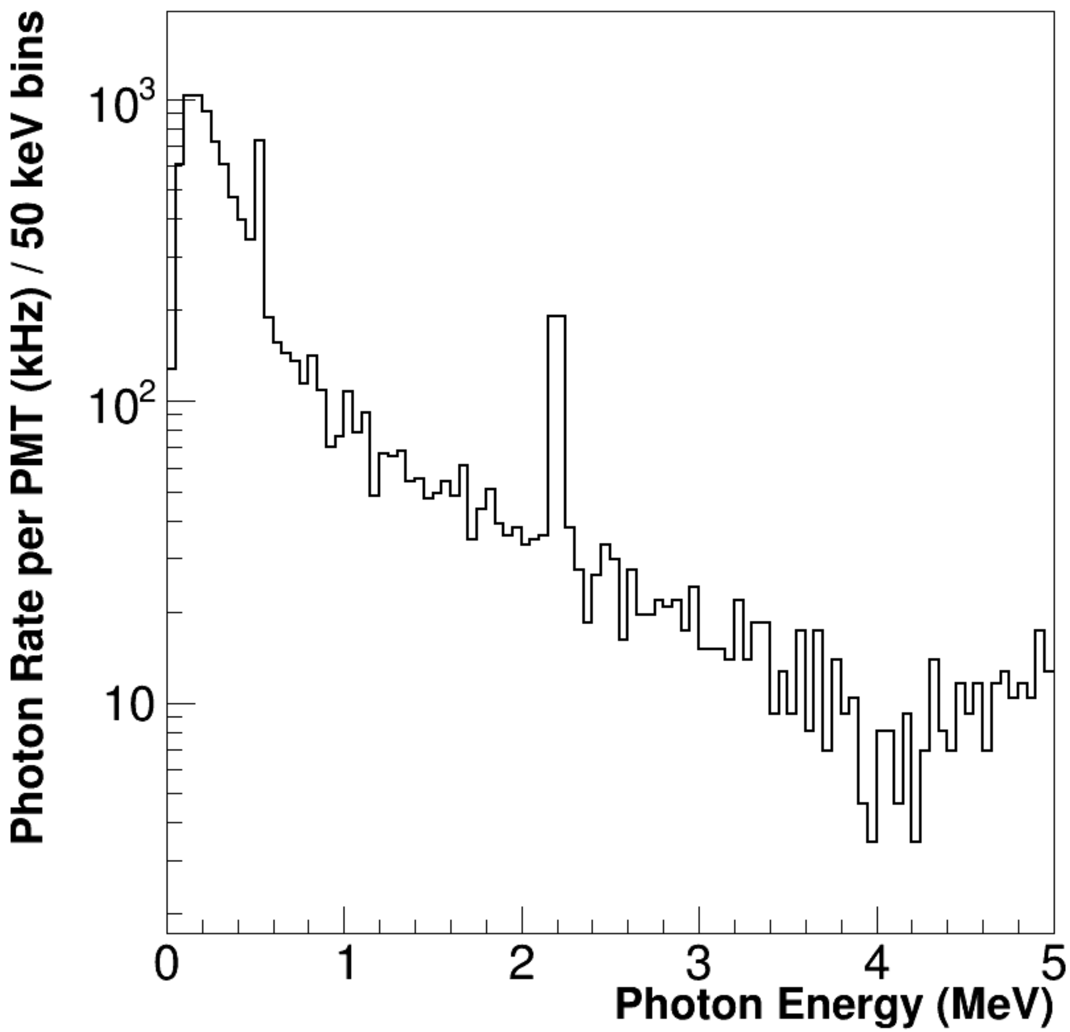
pi rej
invers
after



# Photons direct on PMTs

- Non-optical photons that interact with the maPMTs may also cause some background.
  - First step: Simulate the rate of these photons incident on the PMTs:
  - Two obvious peaks.
    - Neutron capture with hydrogen in carbon fiber mirrors.
    - e+ e- annihilation
  - Low energy photon rate still dominated by electron production.



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