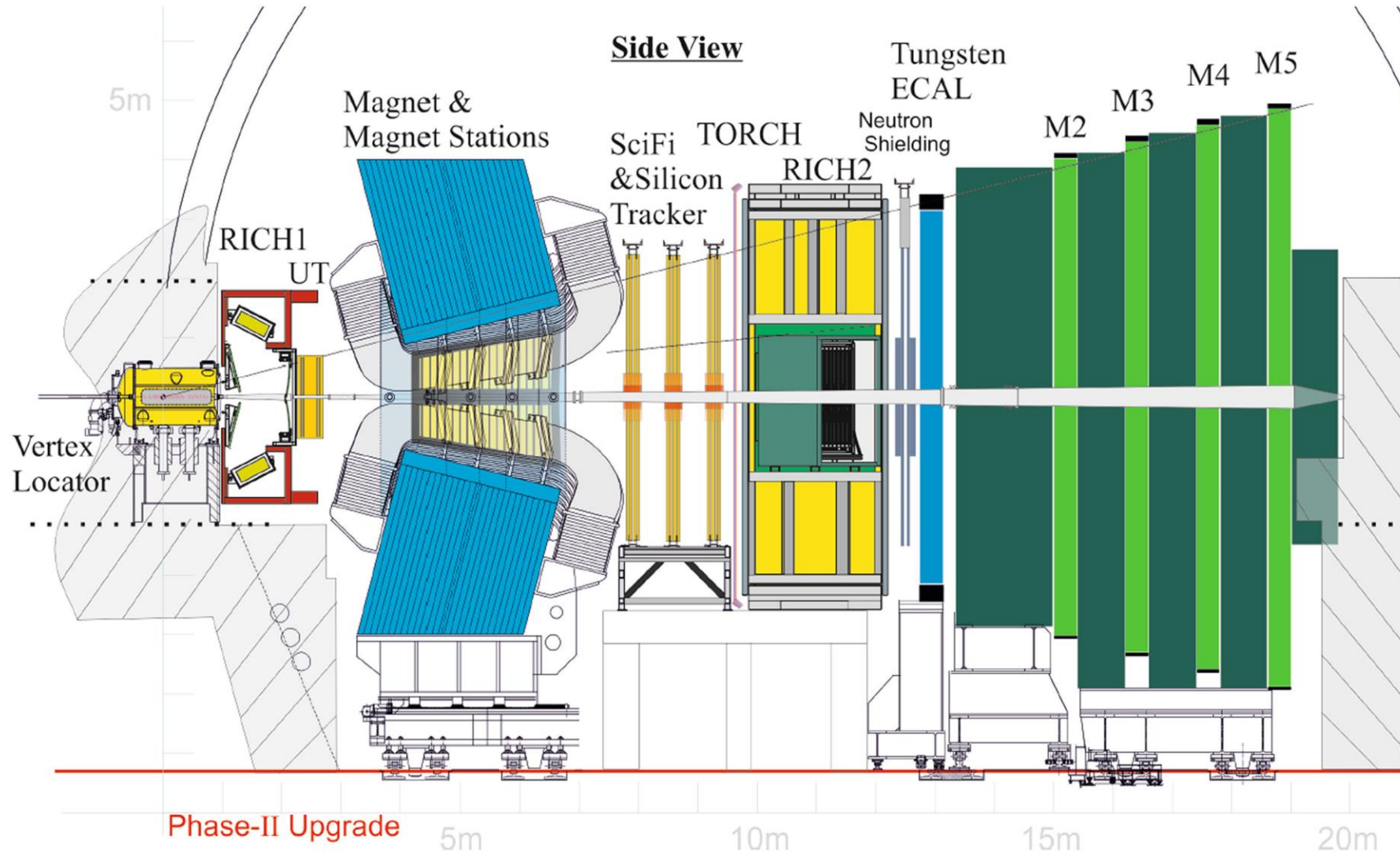




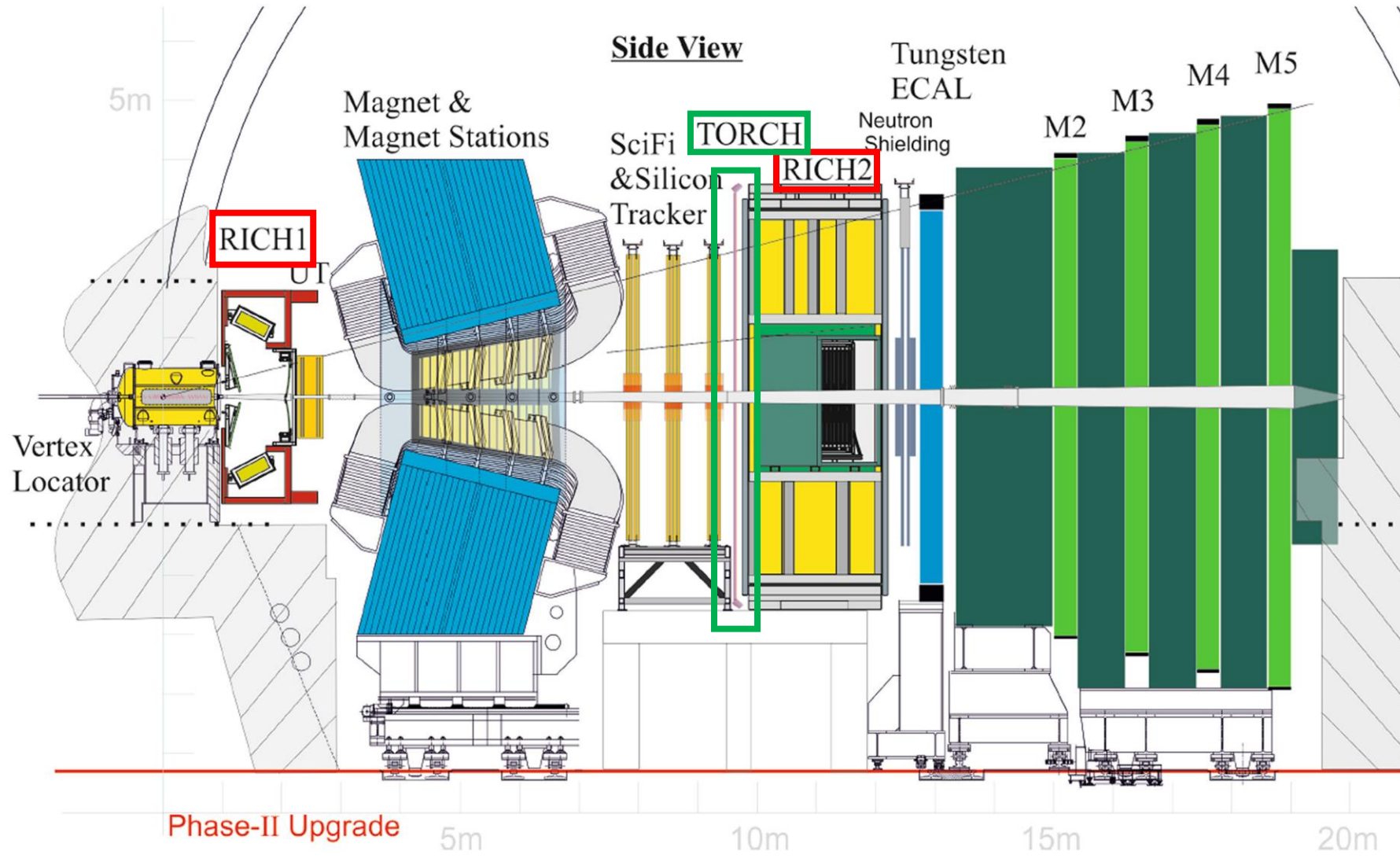
# TORCH: A Time-of-Flight particle identification system

**High Energy Seminar - Matteo Da Valle**

# LHCb – Phase II Upgrade



# LHCb – Phase II Upgrade



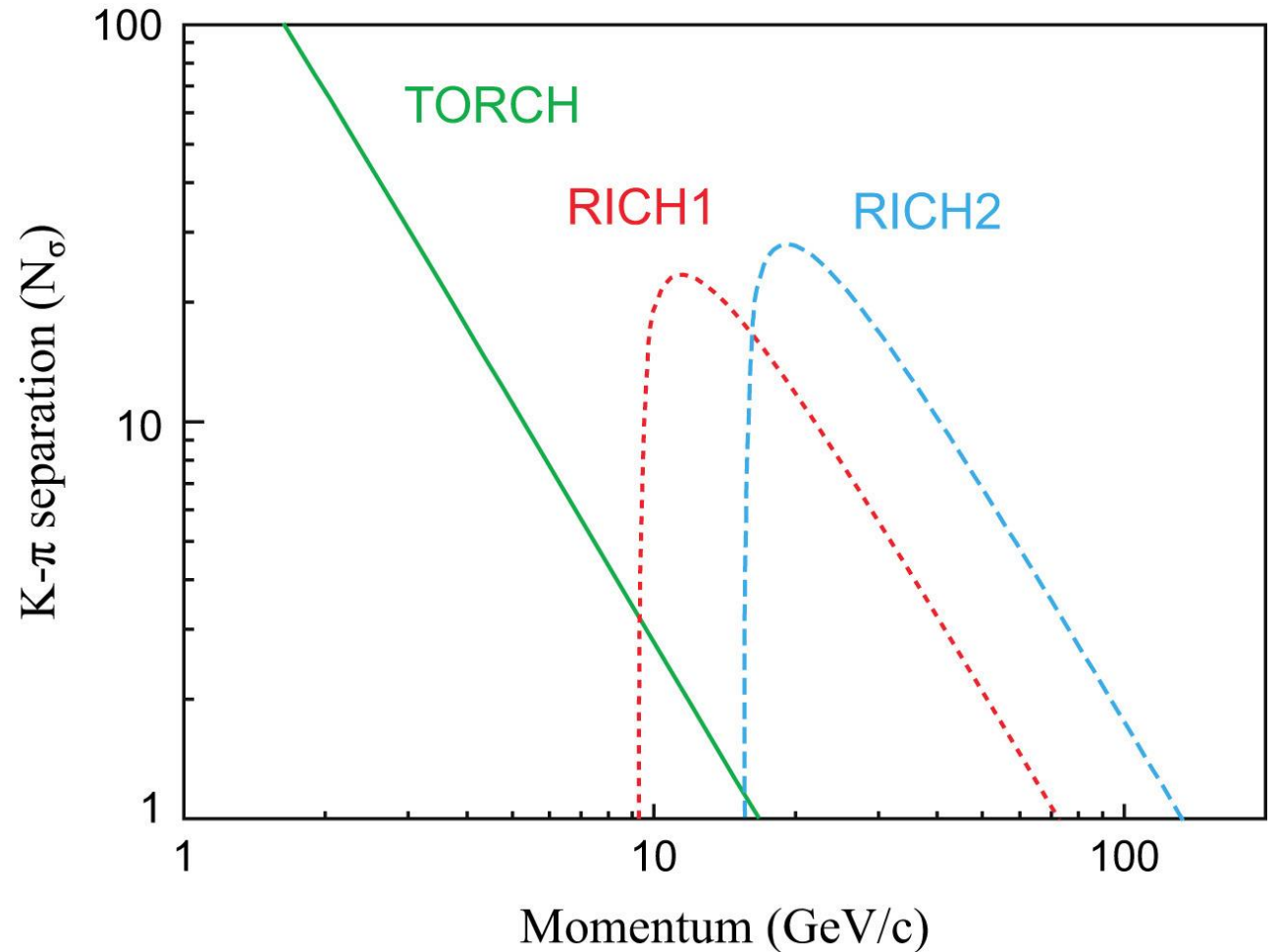
# TORCH GOAL

Low momentum particle identification (PID) system:

- $\pi/K/p$  distinction
- Particle momentum between  $2\text{GeV}/c$  and  $10\text{GeV}/c$  (below RICH1 threshold)
- $3\sigma$  of accuracy in PID



**Time-of-Flight based  
PID system**

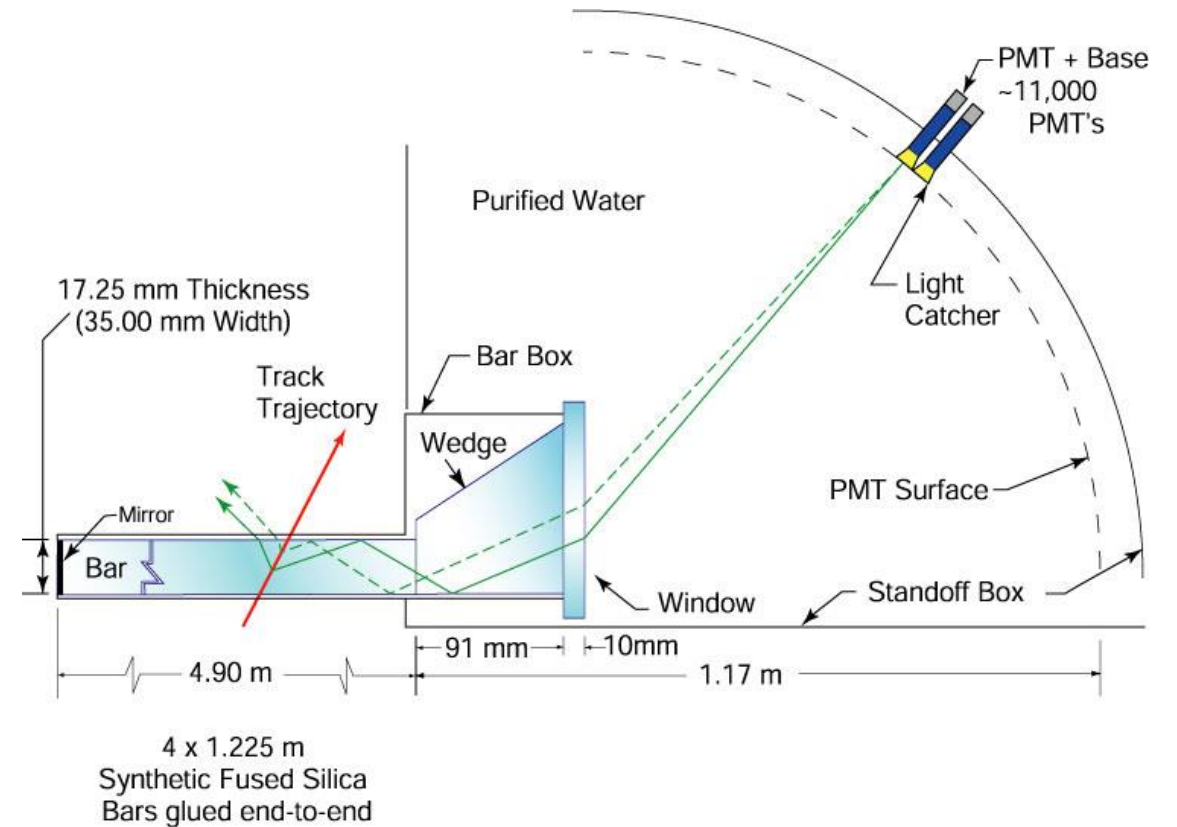


# TORCH

Time **O**f internally **R**eflected **C**herenkov light for charged particle identification

Time of Flight PID

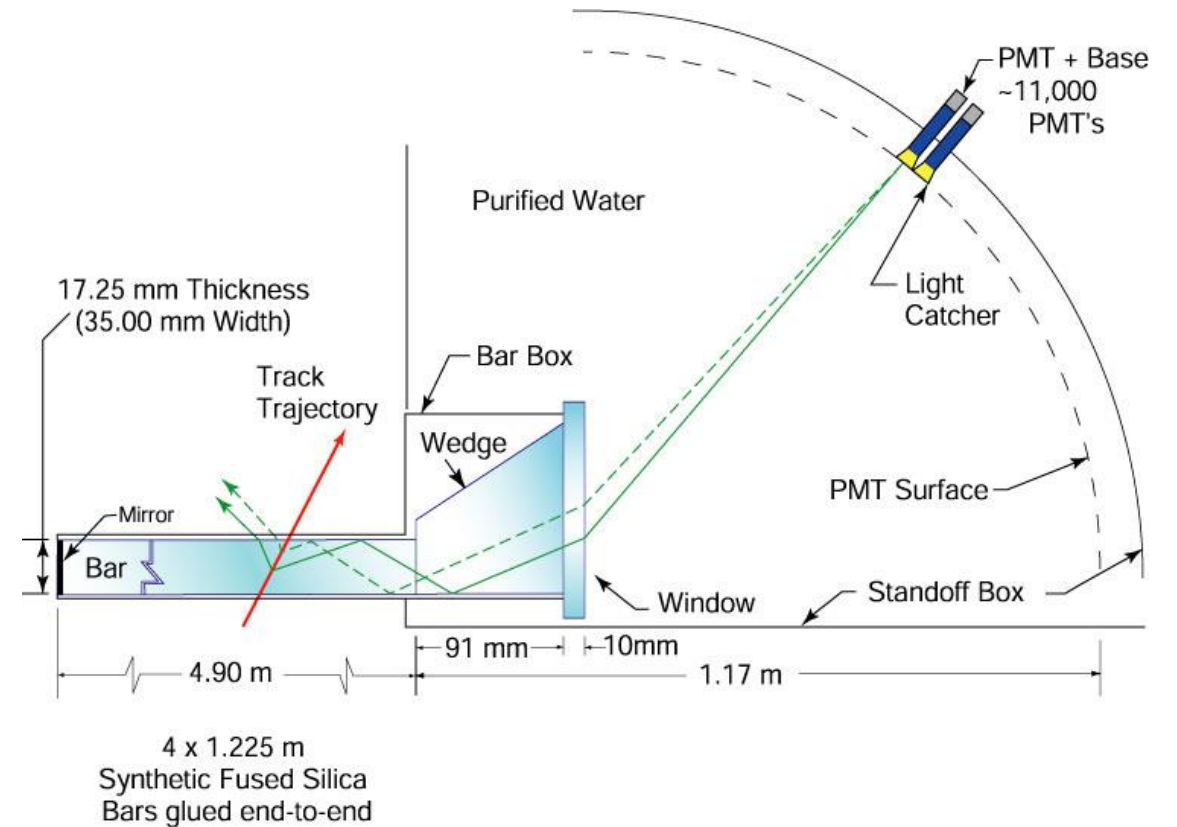
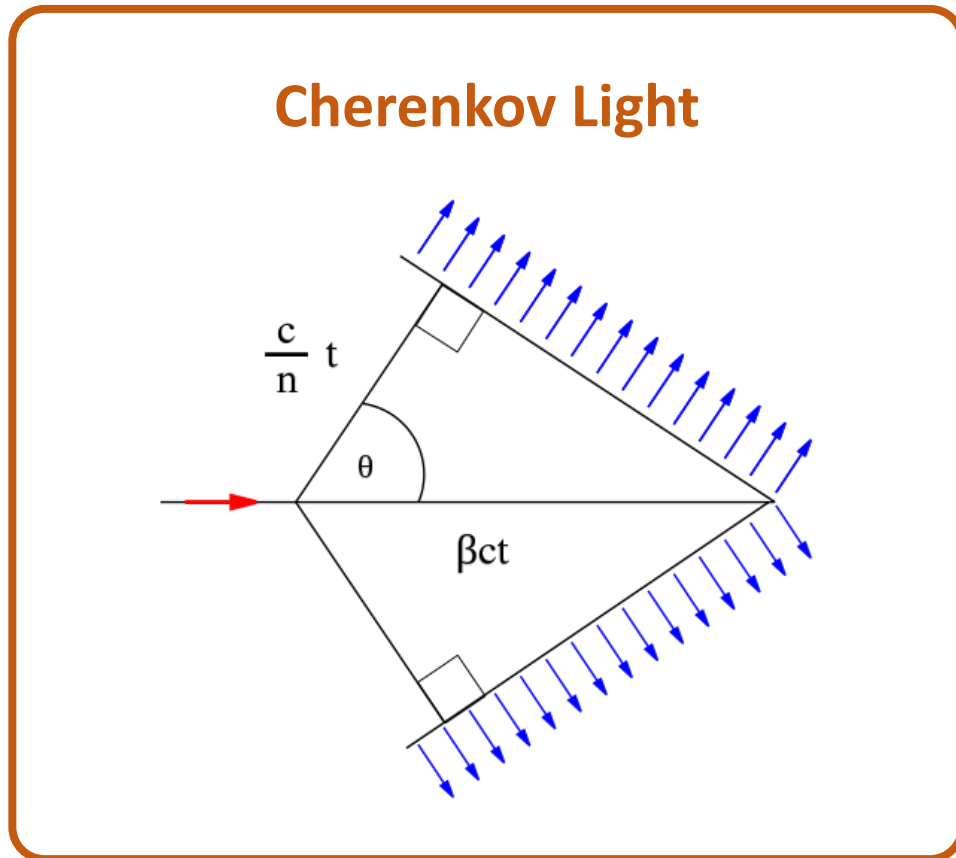
Cherenkov Light



*DIRC PID system*

# TORCH

Time **O**f internally **R**eflected **C**herenkov light for charged particle identification



# TORCH

Time **O**f internally **R**eflected **C**herenkov light for charged particle identification

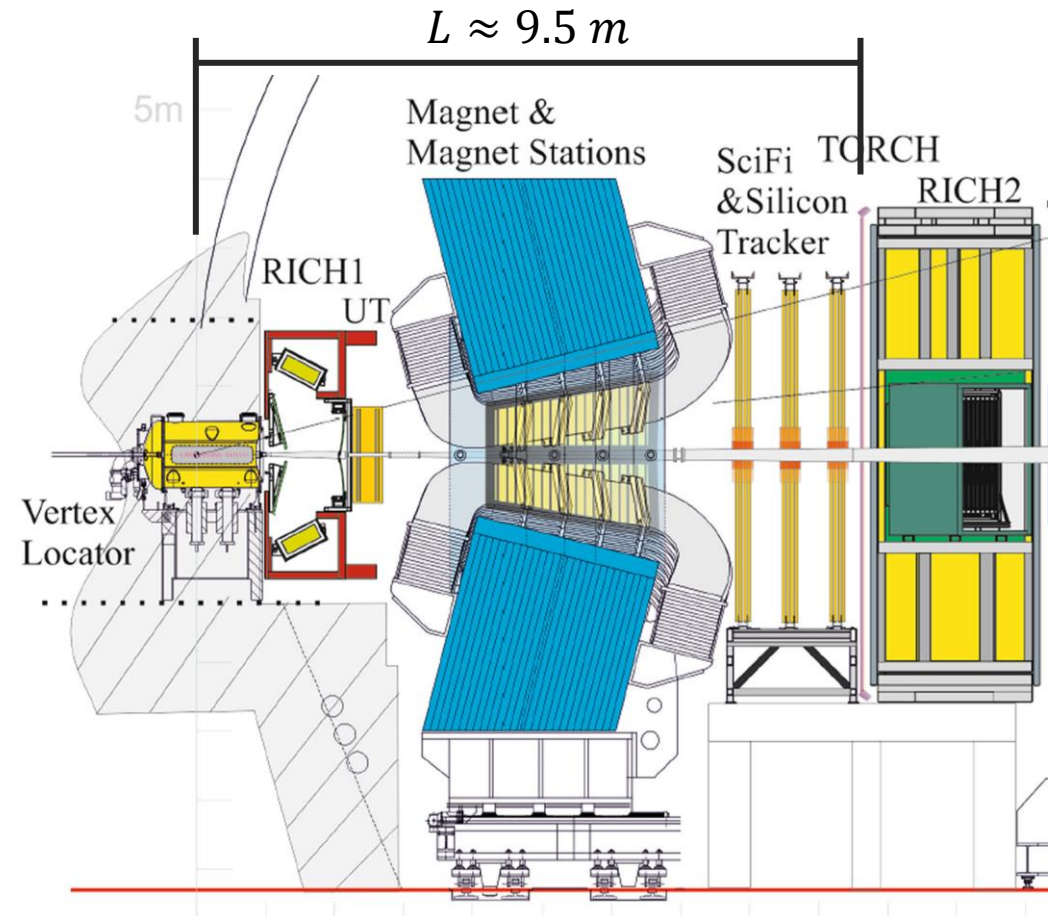
## Time of Flight PID

$$t_{ToF} = \frac{L}{c} \sqrt{1 + \left(\frac{m}{p}\right)^2}$$

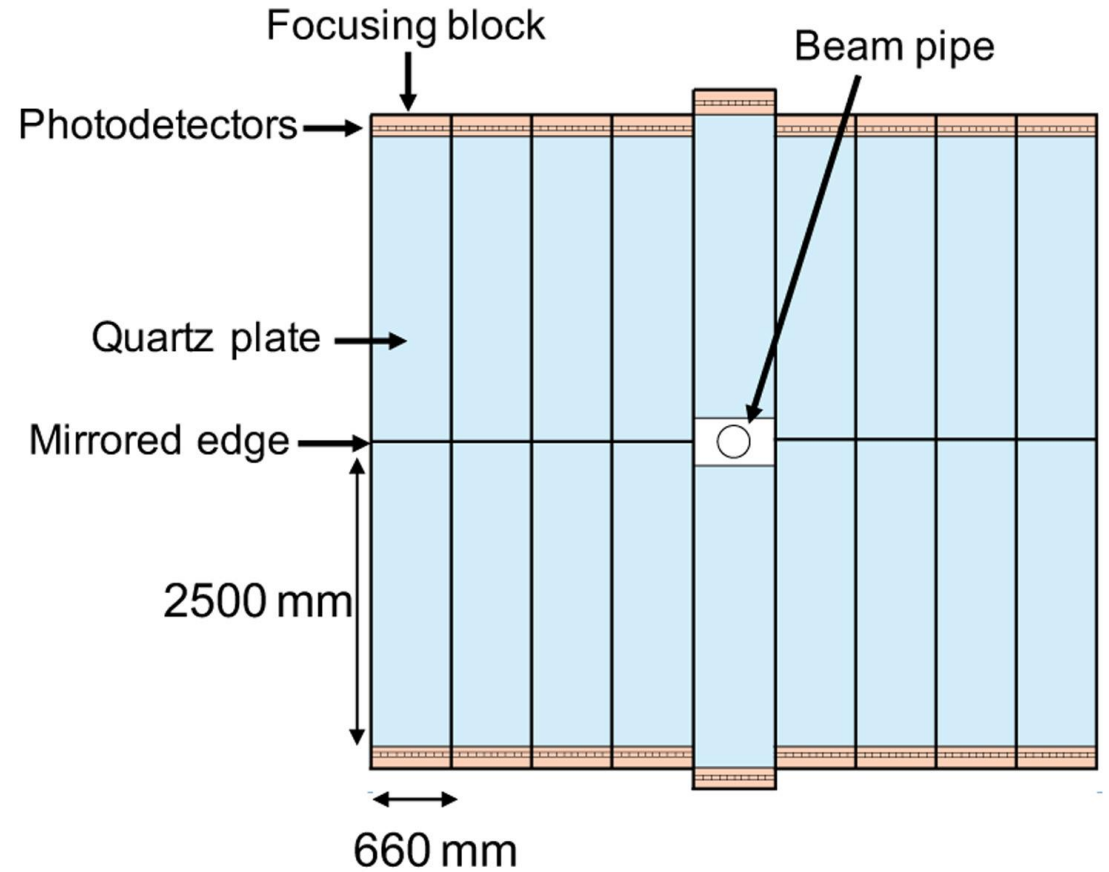
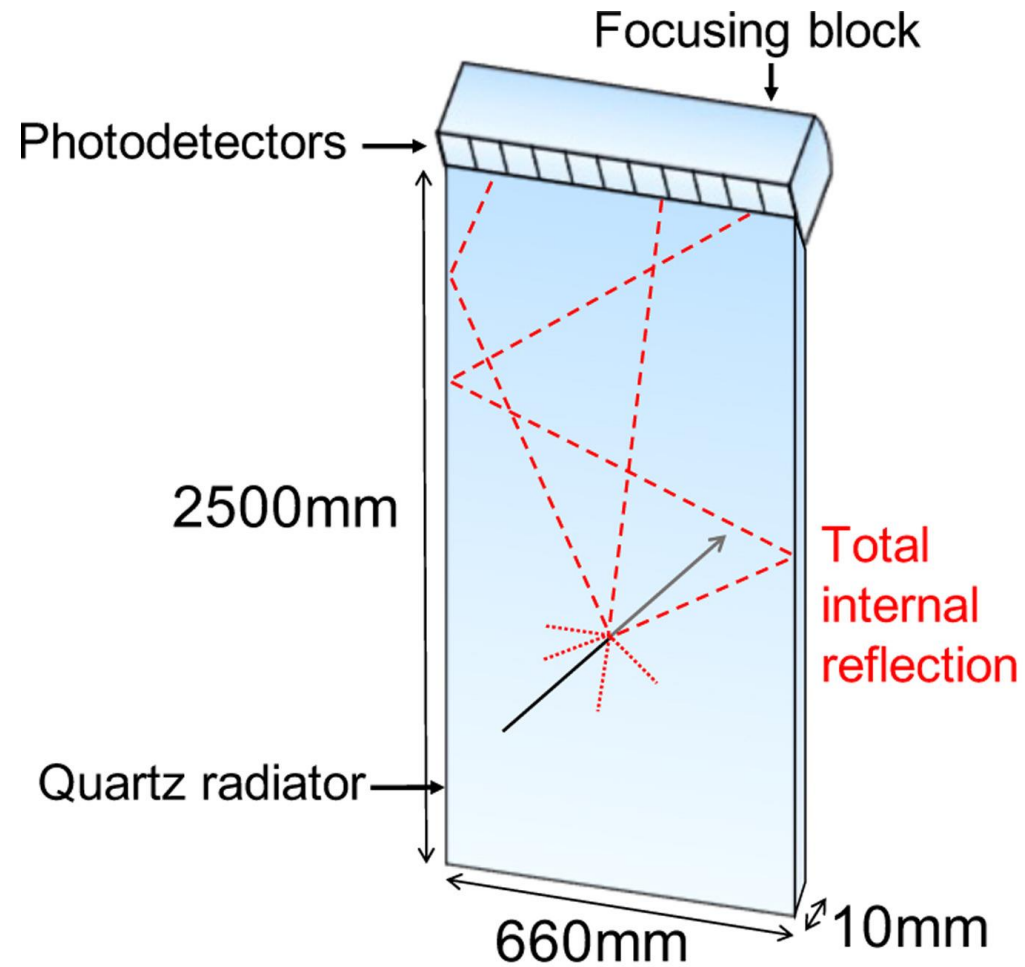
$$\Delta t_{ToF} \approx \frac{L}{2c} \frac{(m_1^2 - m_2^2)}{p^2}$$

$3\sigma$  accuracy:

$$\sigma_t \leq \frac{L}{6c} \frac{(m_1^2 - m_2^2)}{p^2} \approx 10 \div 15 \text{ ps}$$



# TORCH



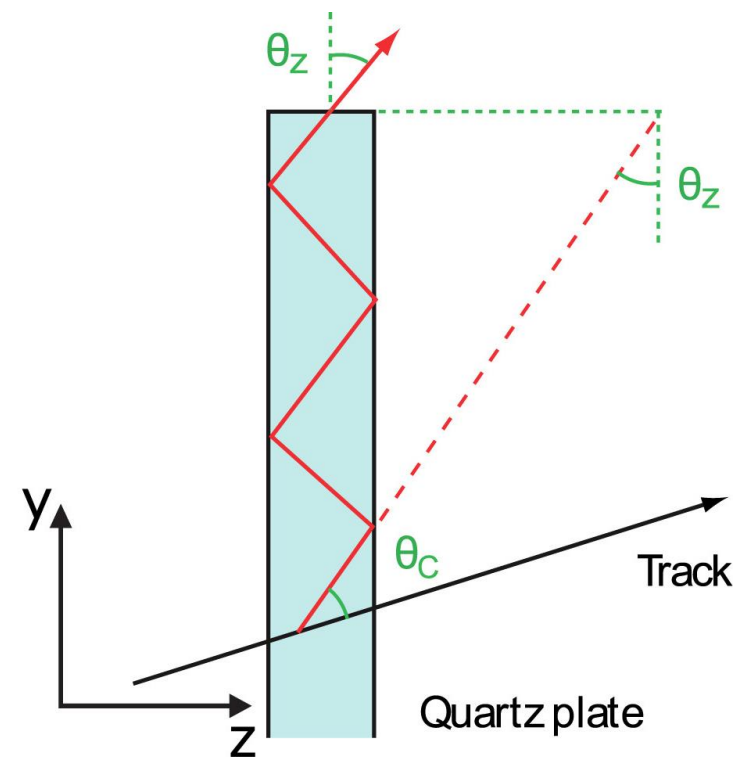
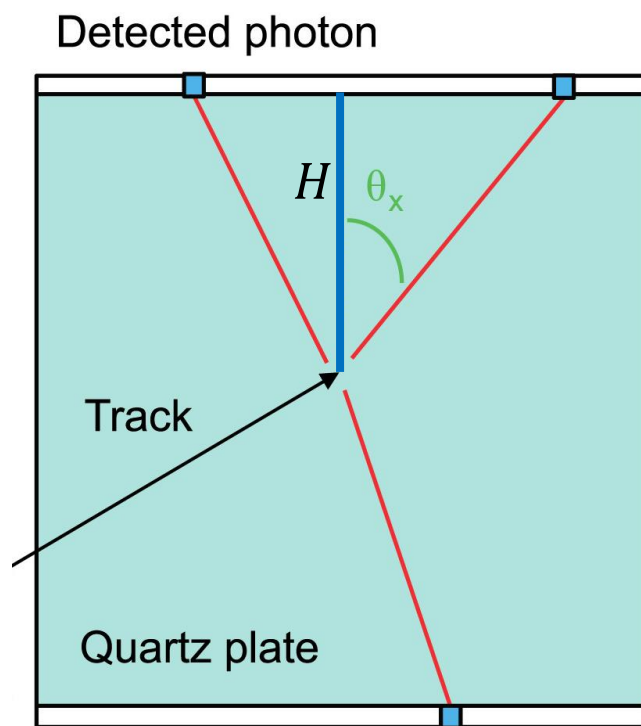


# Working Principle

Propagation time of photons

$$\tau_\gamma = \frac{n_g(E)L_\gamma(\theta_x, \theta_z)}{c}$$

$$L_\gamma(\theta_x, \theta_z) = H \sqrt{\frac{1}{\cos^2(\theta_x)} + \frac{1}{\cos^2(\theta_z)} - 1}$$



# Working Principle

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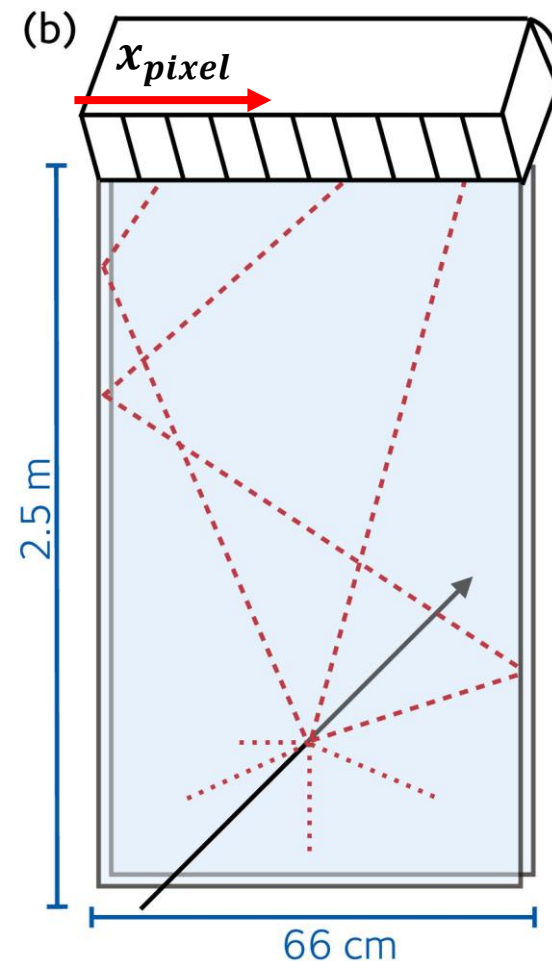
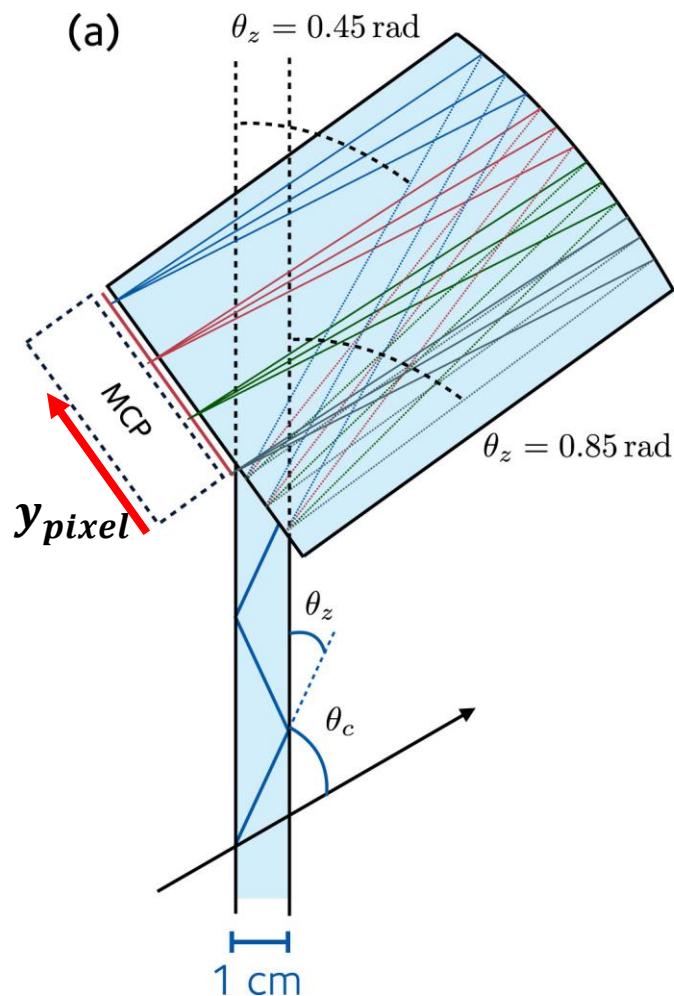
## Measurements

$H$ : particle trajectory

$$\theta_x = \theta_x(x_{pixel})$$

$$\theta_z = \theta_z(y_{pixel})$$

➔  $t_{ToF}$

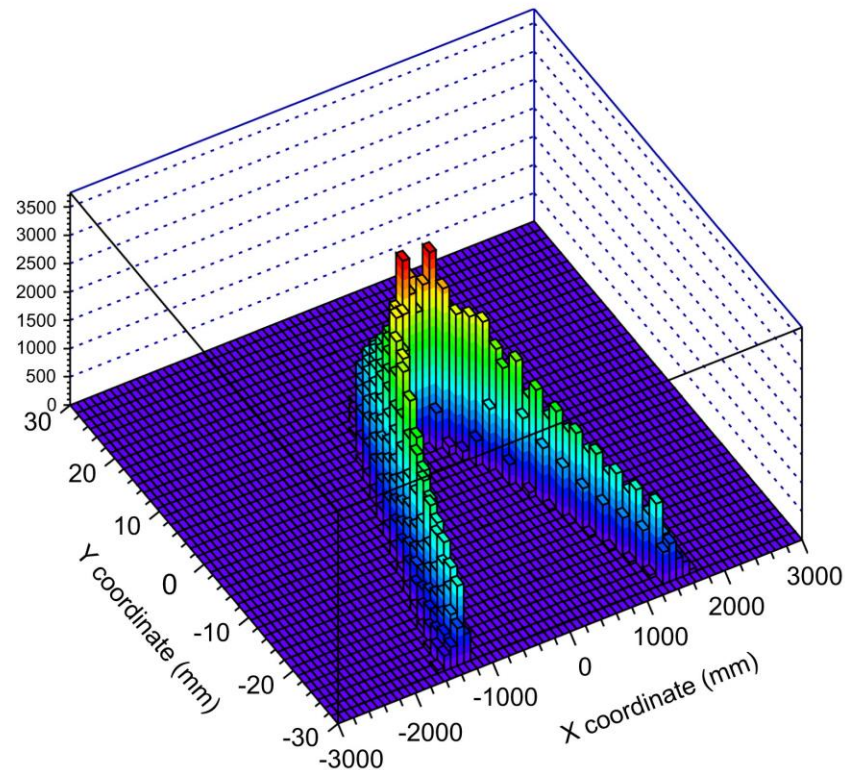


# Working Principle

Additional issues for reconstruction:

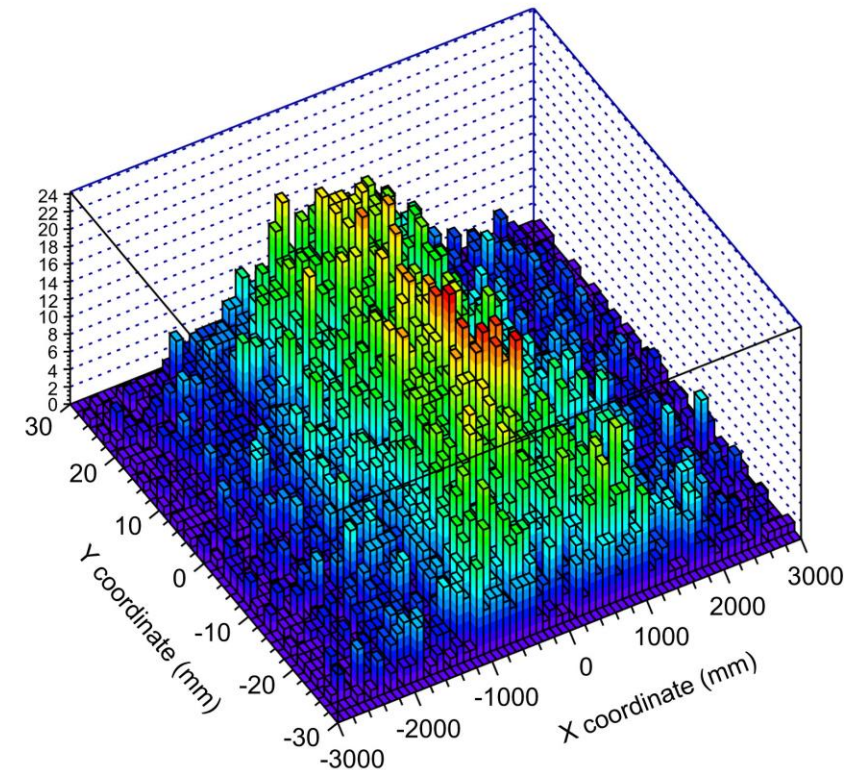
1. **Secondary particles**
2. Chromatic dispersion

Photons from primary track



**No correlation  
in y-direction**

Photons from secondary tracks

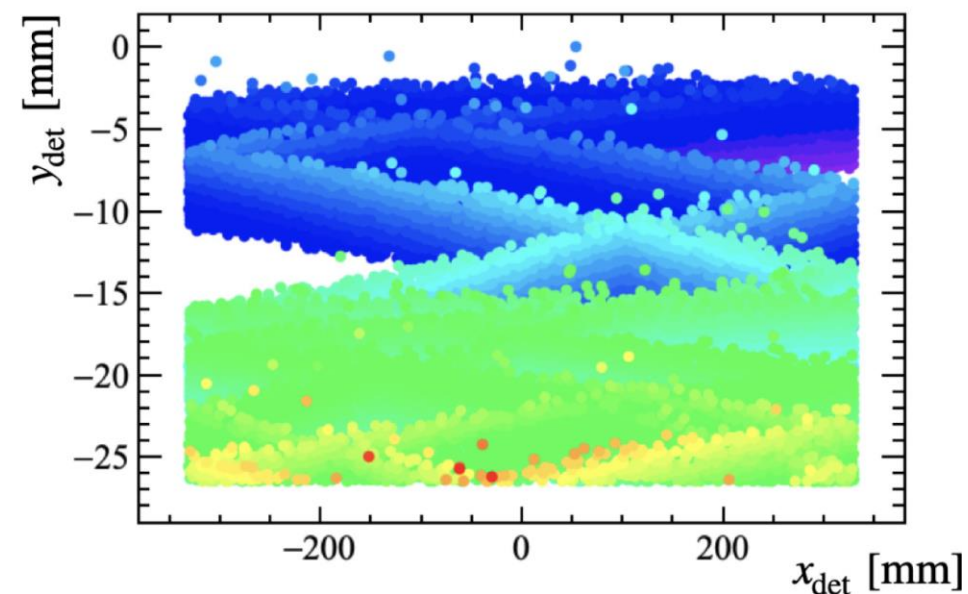
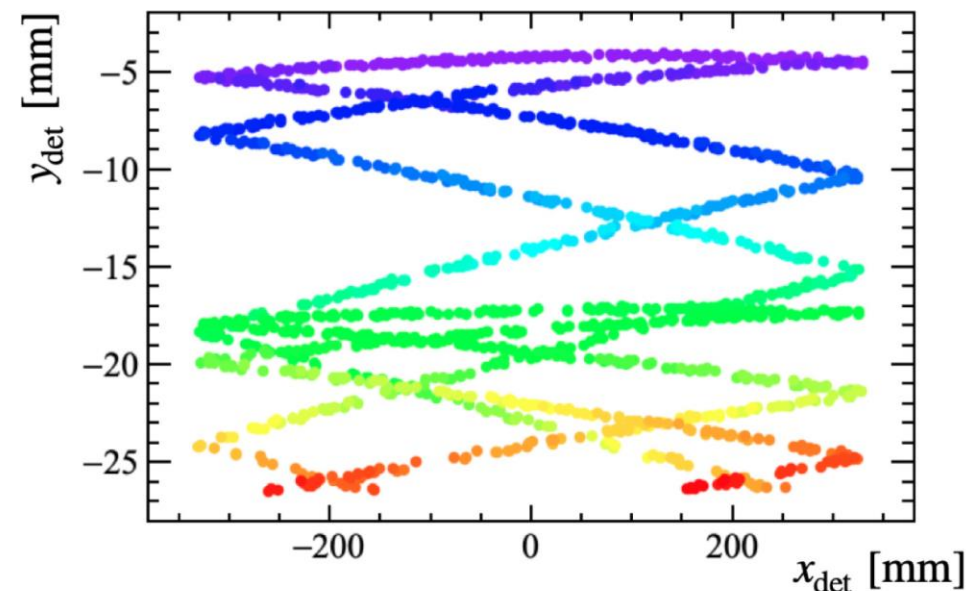
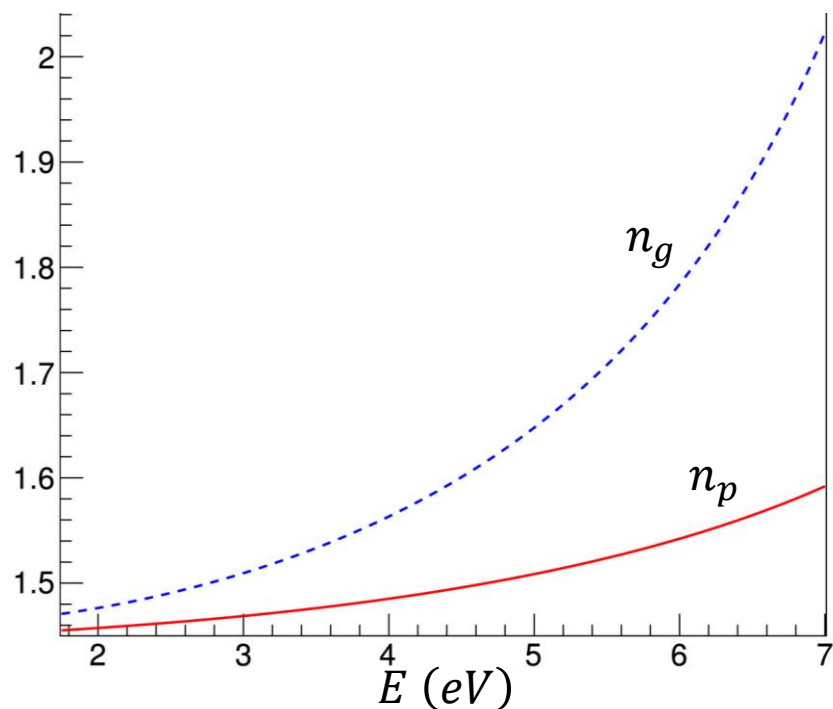


# Working Principle

Additional issues for reconstruction:

1. Secondary particles

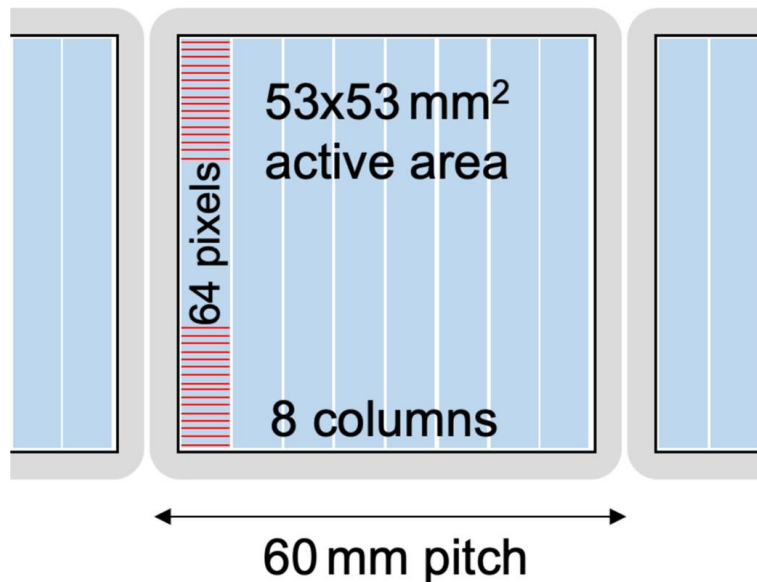
2. Chromatic dispersion  $n_g(E) = n_p(E) + E \frac{dn_p}{dE}$



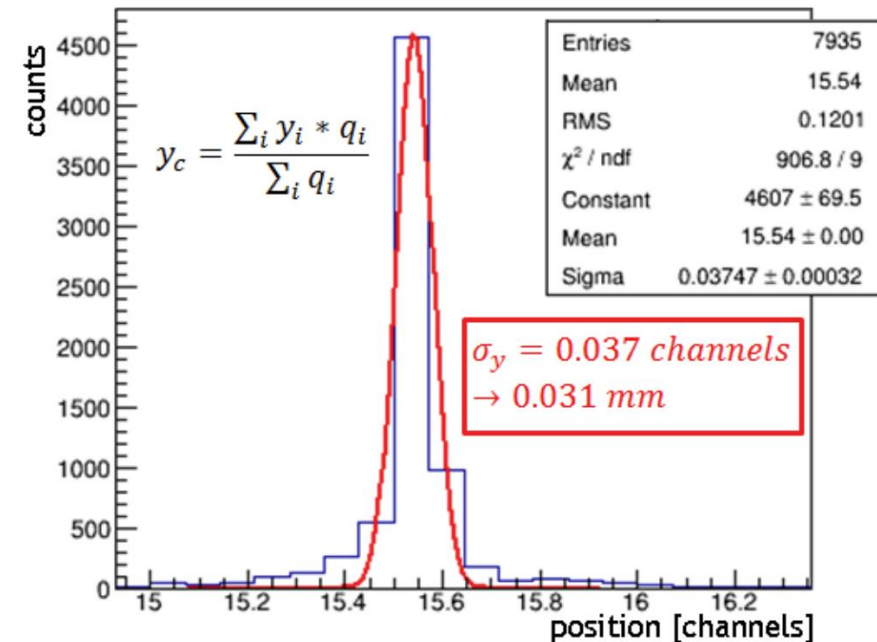
# TORCH: Detectors

Main Challenges:

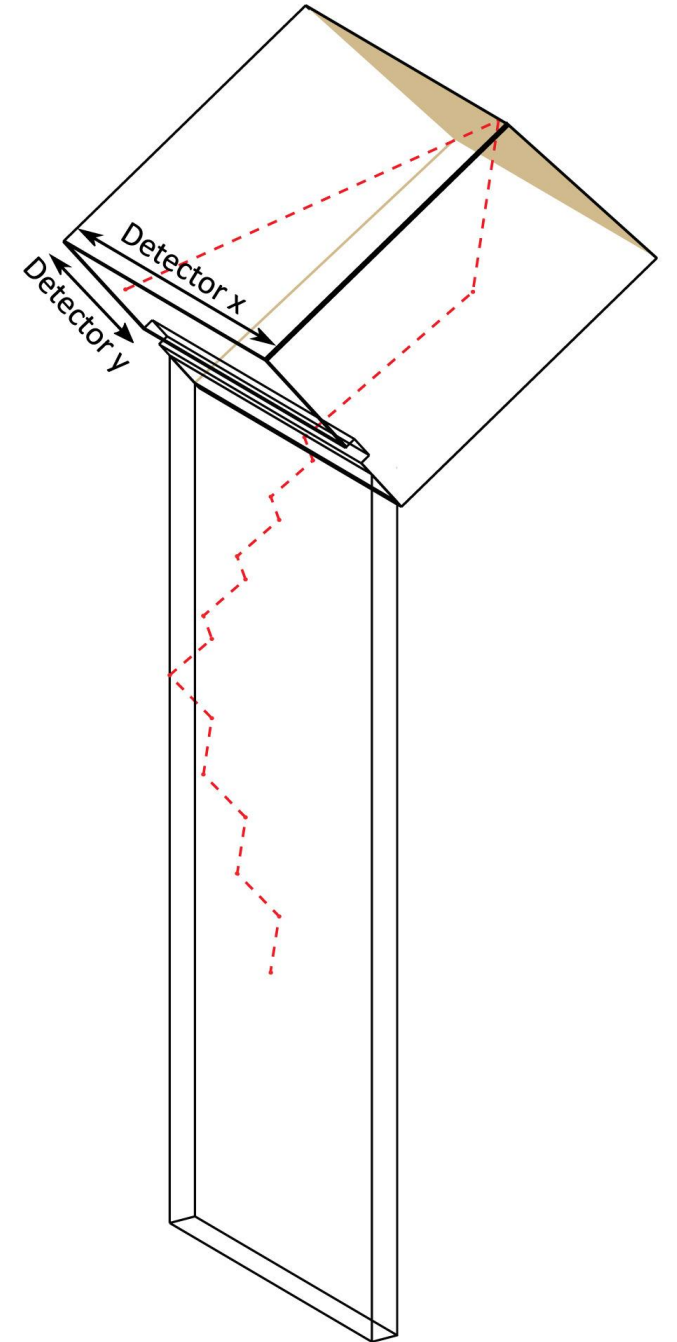
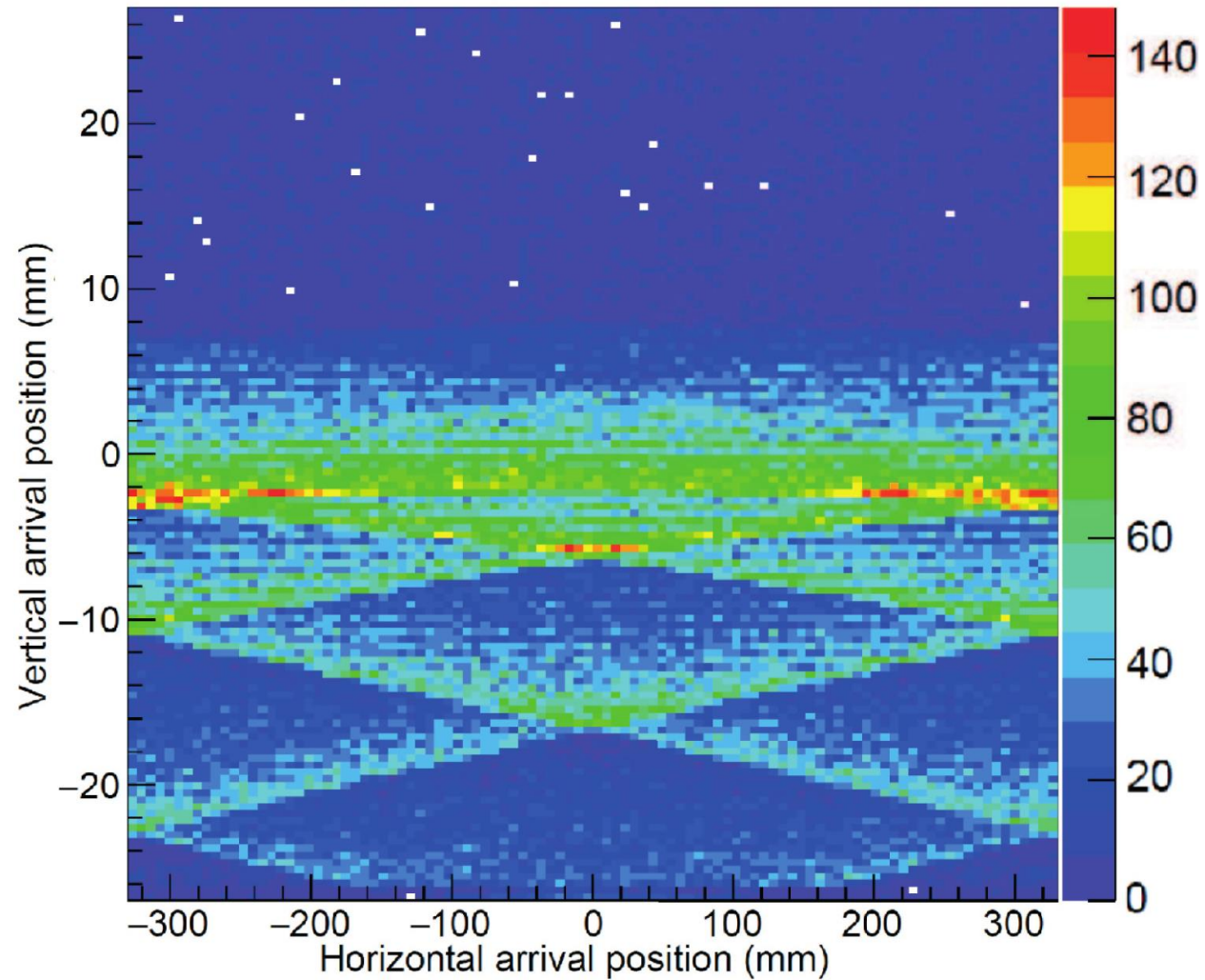
- Single-photon time resolution:  $\sigma_{ph} = 70 \text{ ps} \rightarrow \sigma_{ToF} \approx \frac{70 \text{ ps}}{\sqrt{30}} = \mathbf{12.8 \text{ ps}}$
- Accuracy in  $\theta_x$  and  $\theta_z$  better than mrad



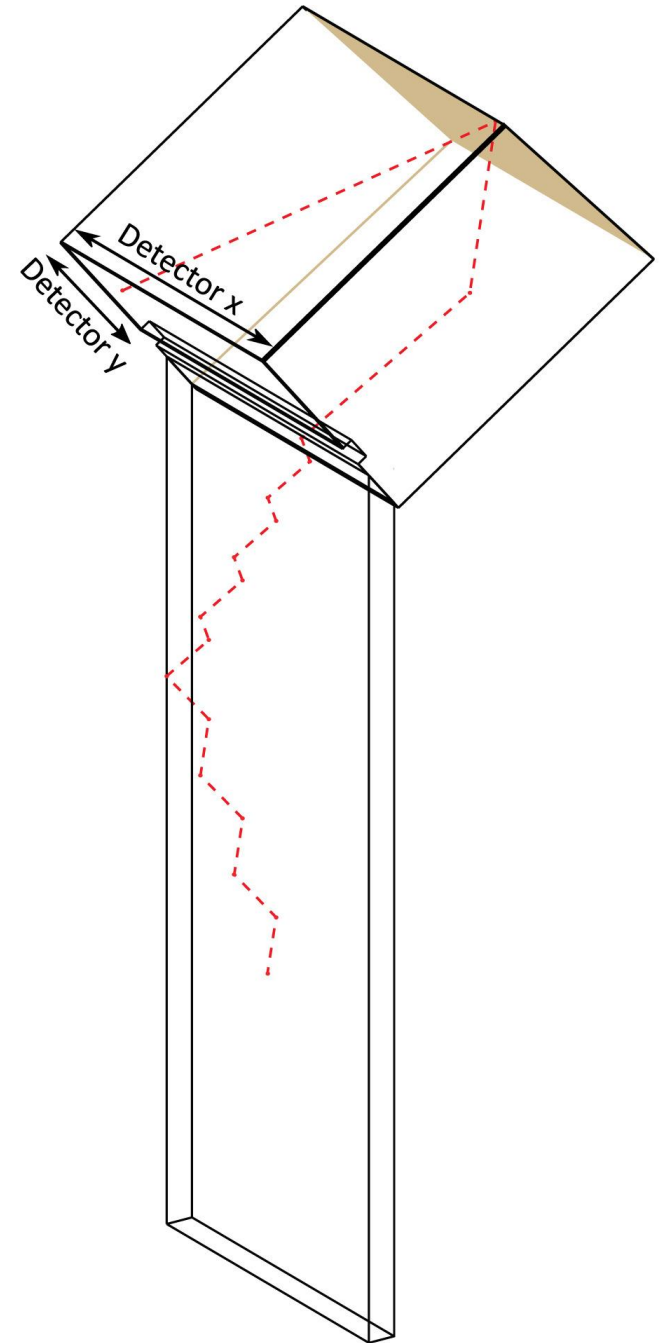
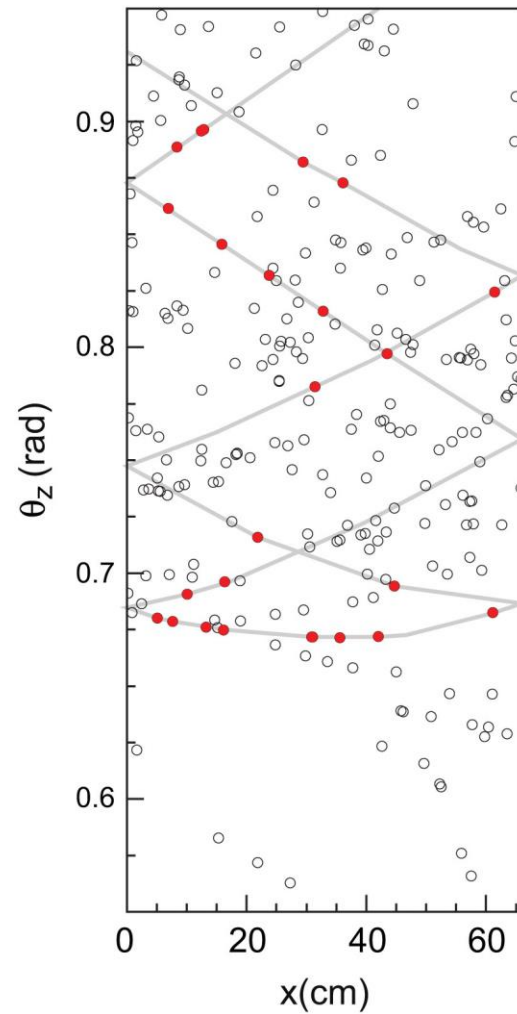
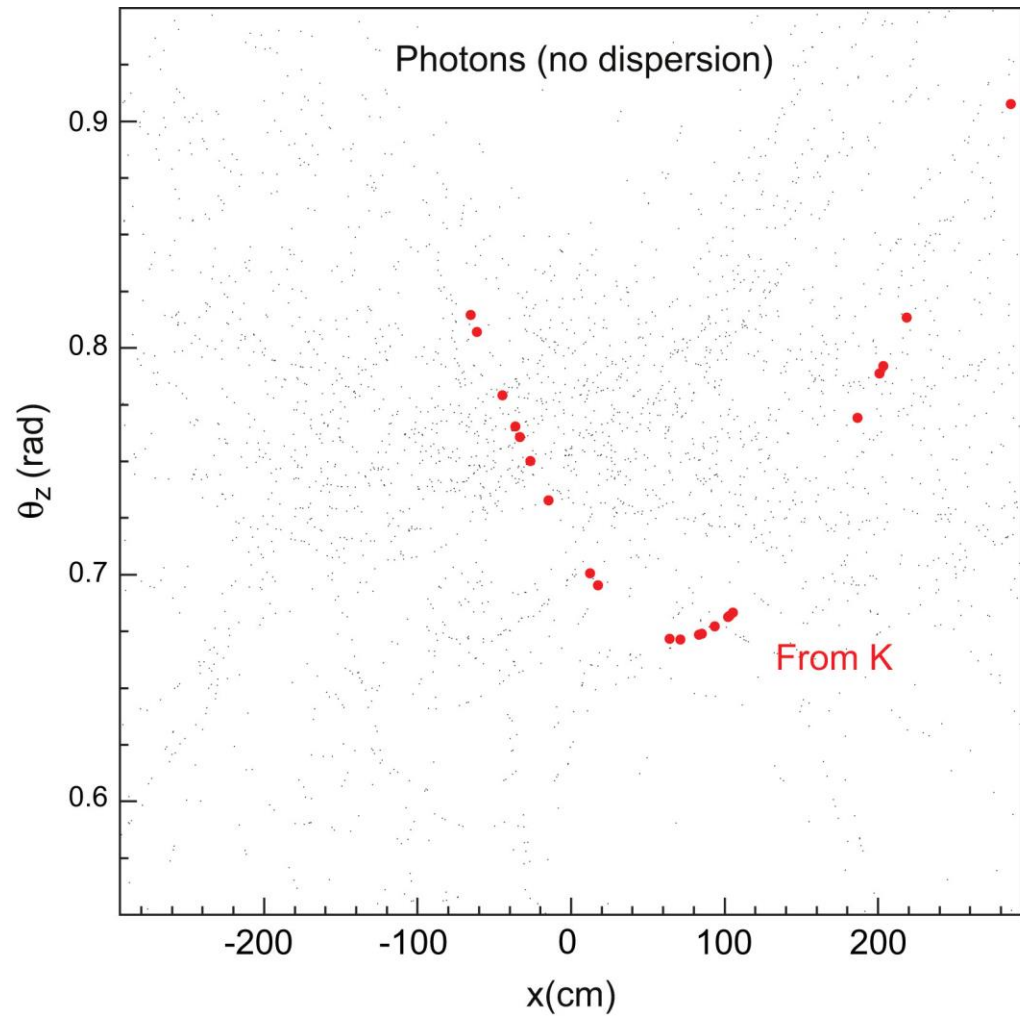
Clustering algorithm



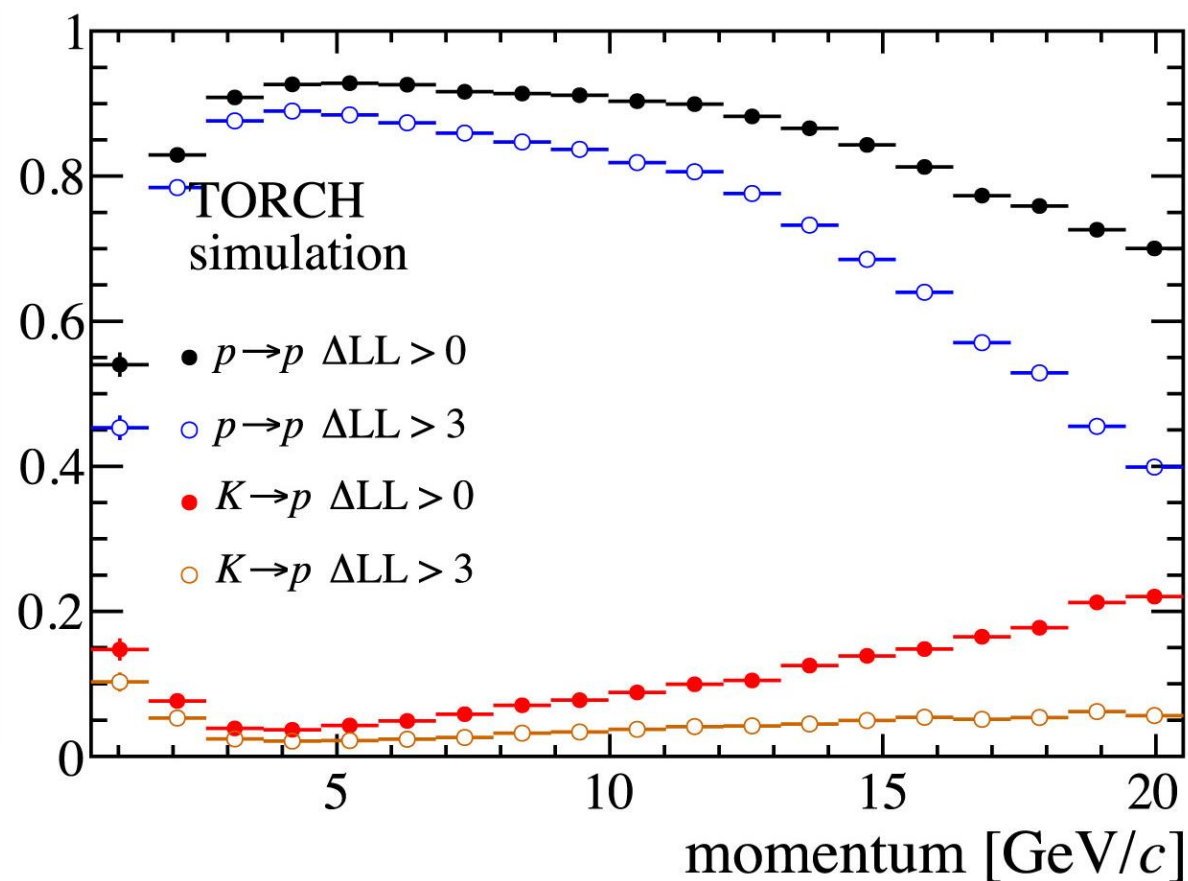
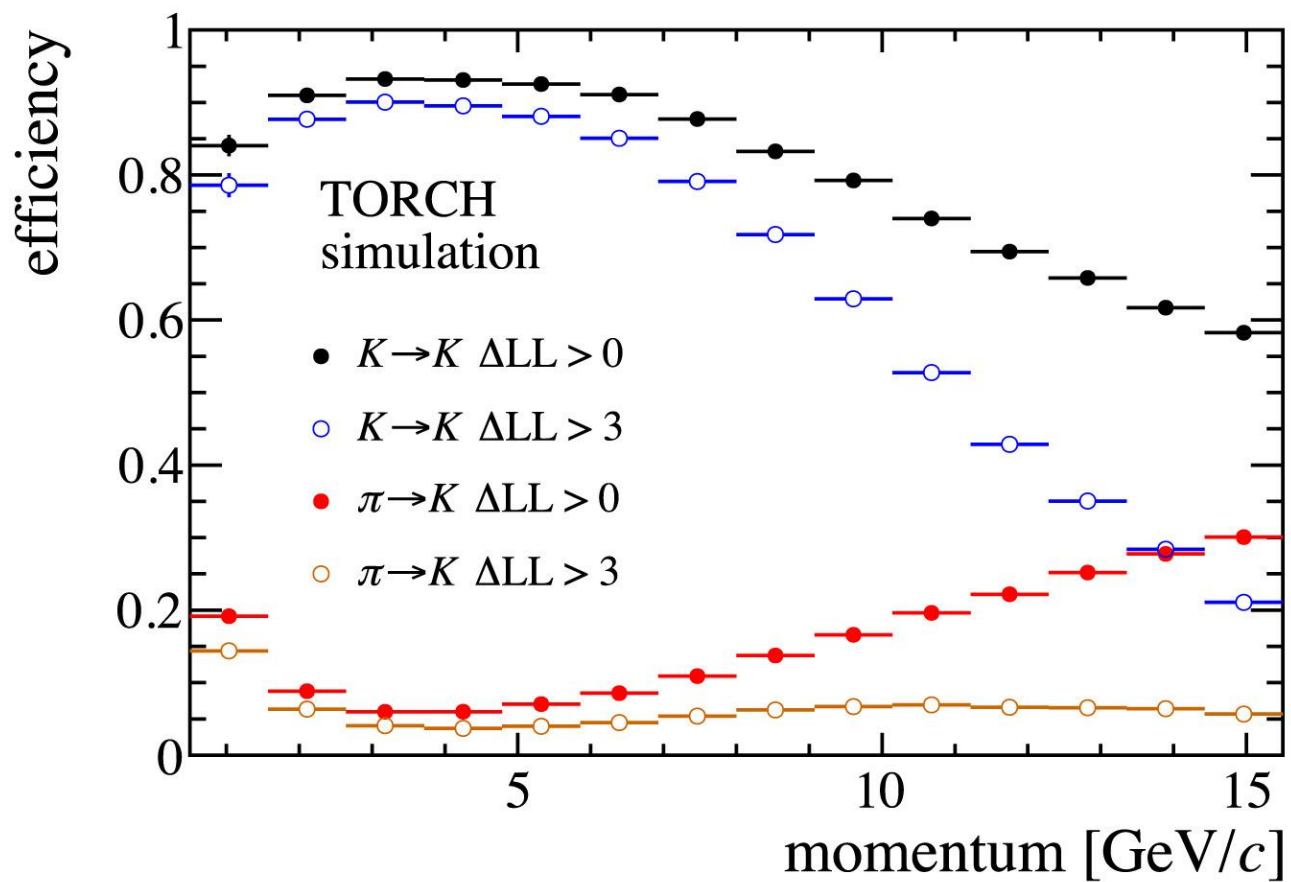
# GEANT4 Simulations



# GEANT4 Simulations

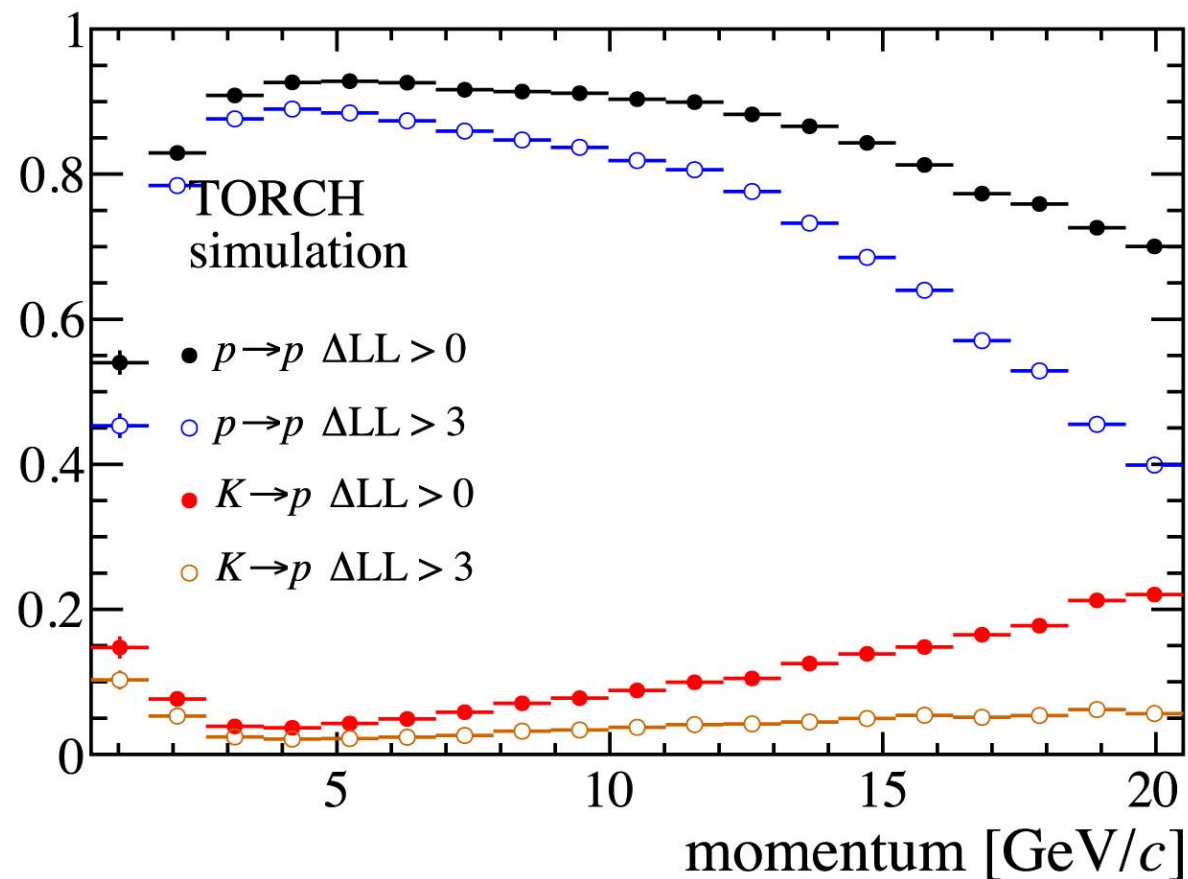
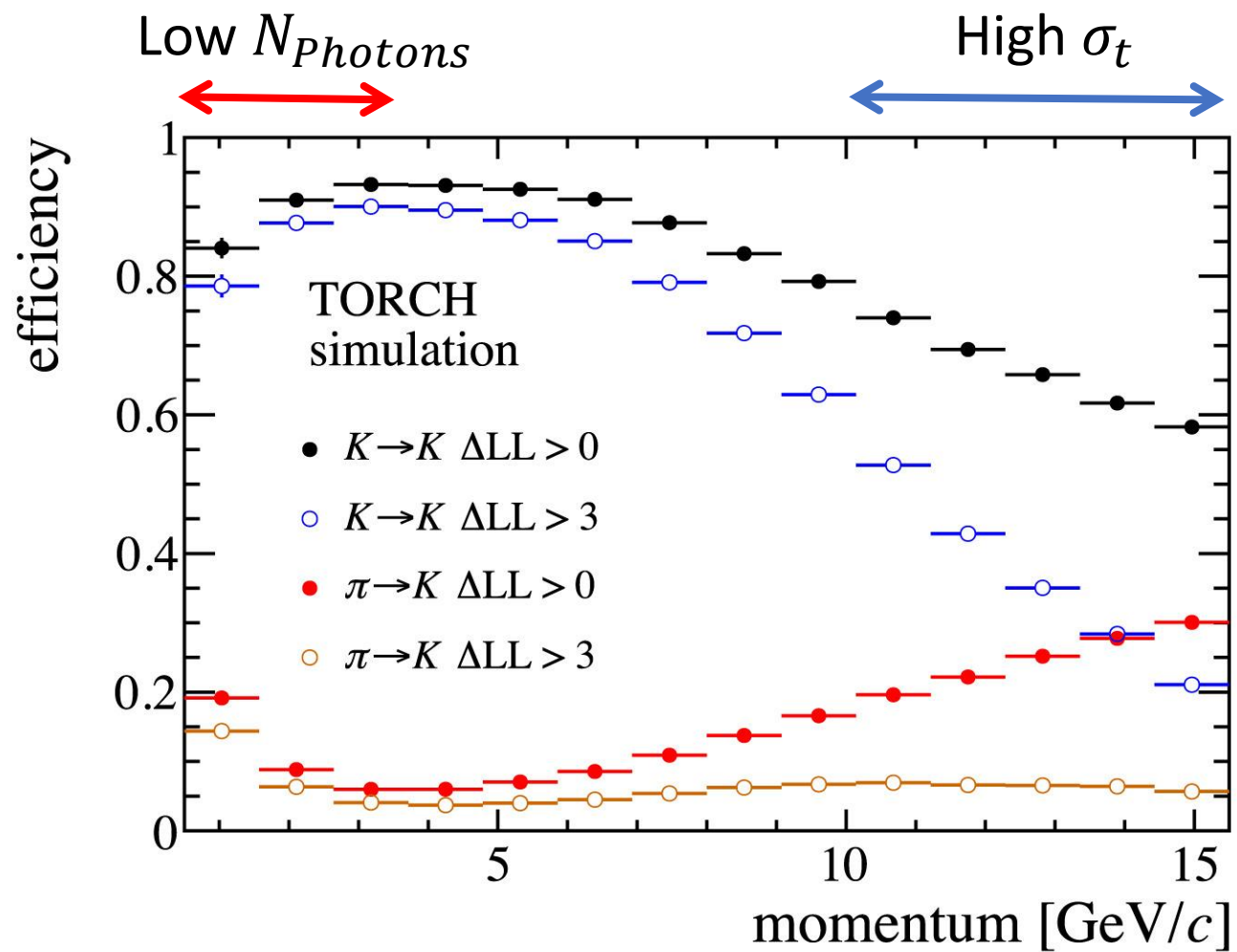


# GEANT4 Simulations





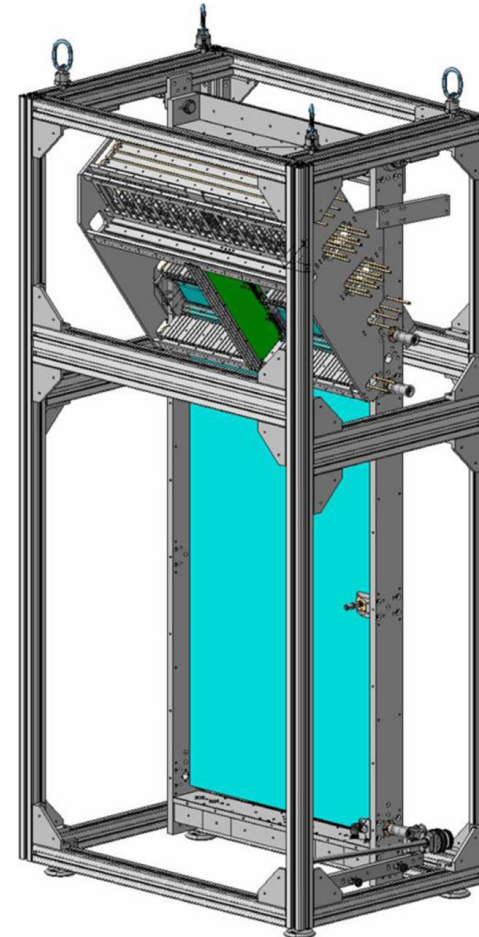
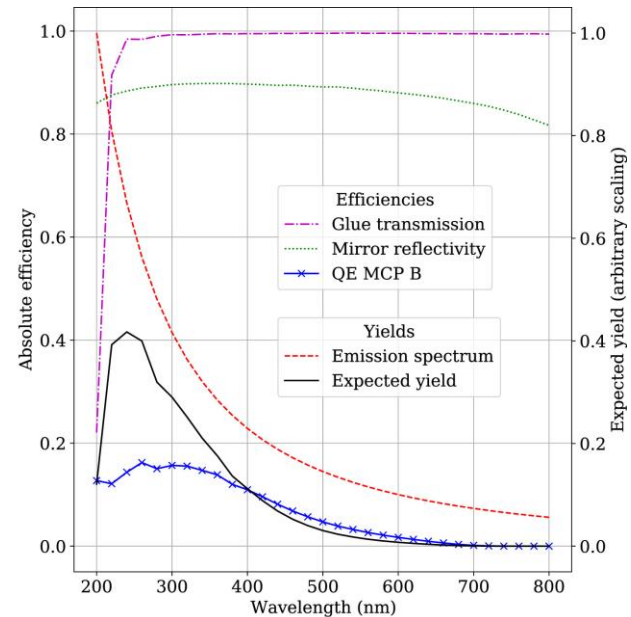
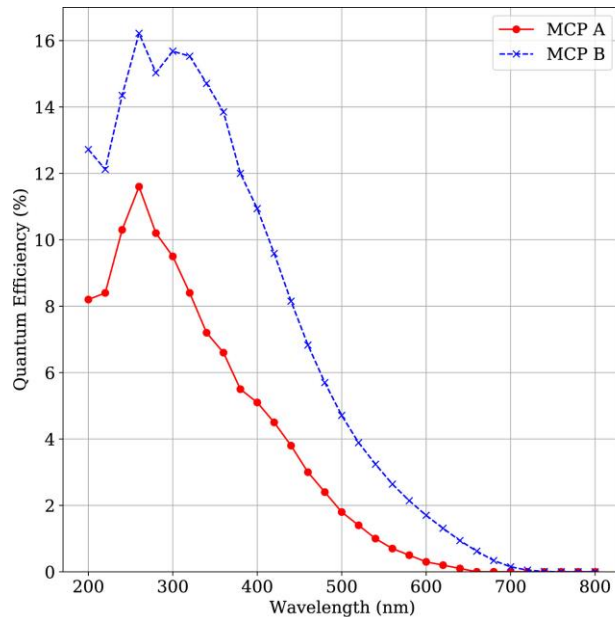
# GEANT4 Simulations



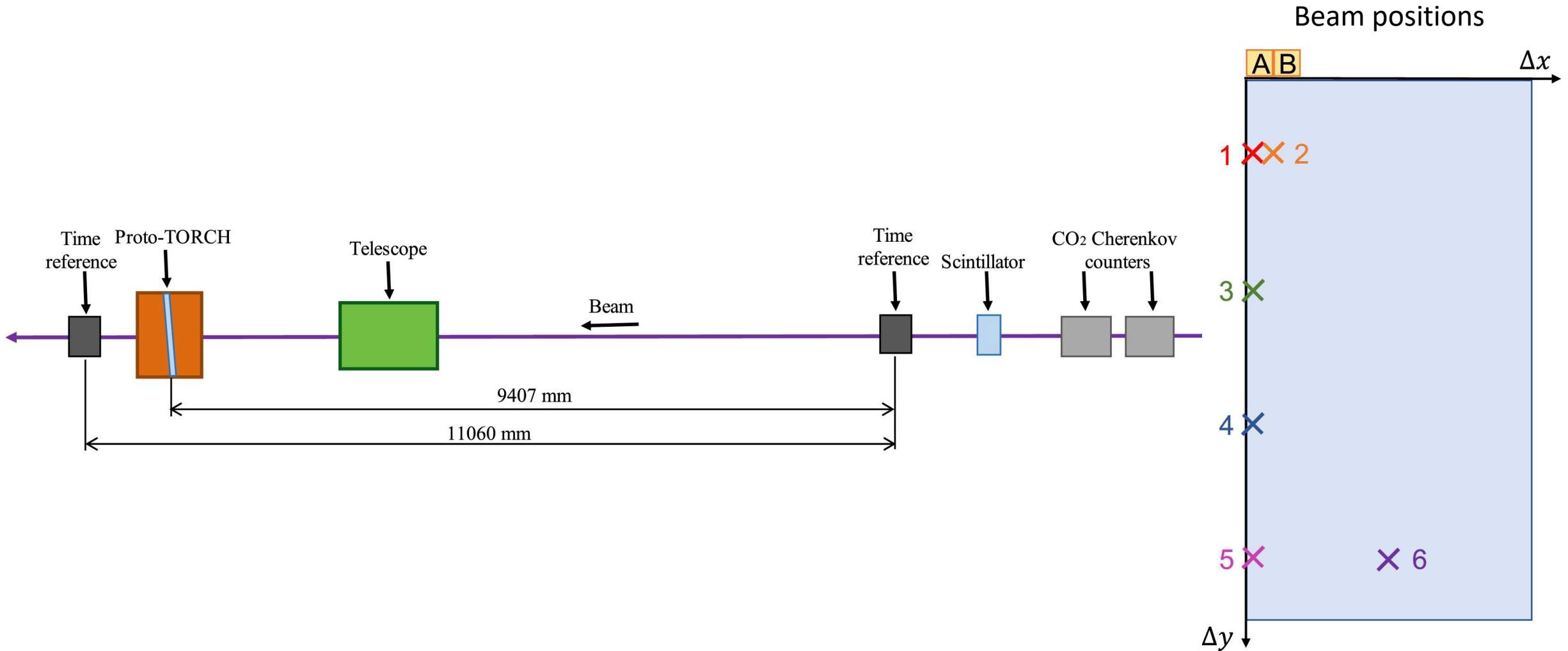
# Proto-TORCH

Main differences w.r.t. TORCH:

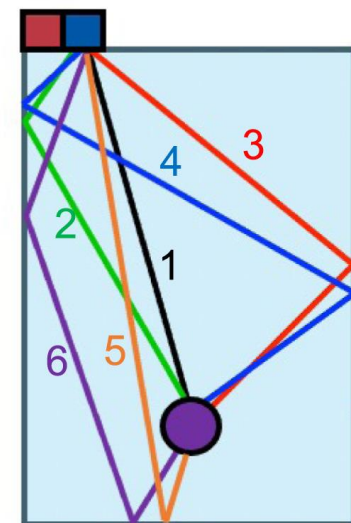
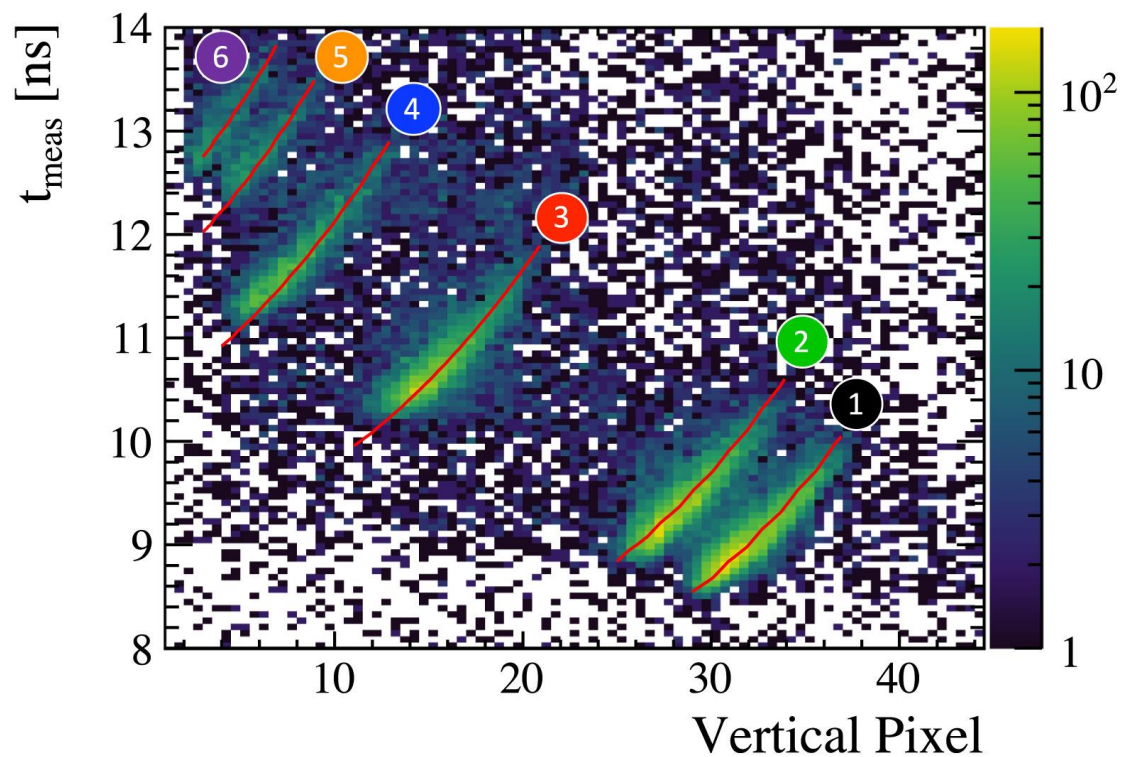
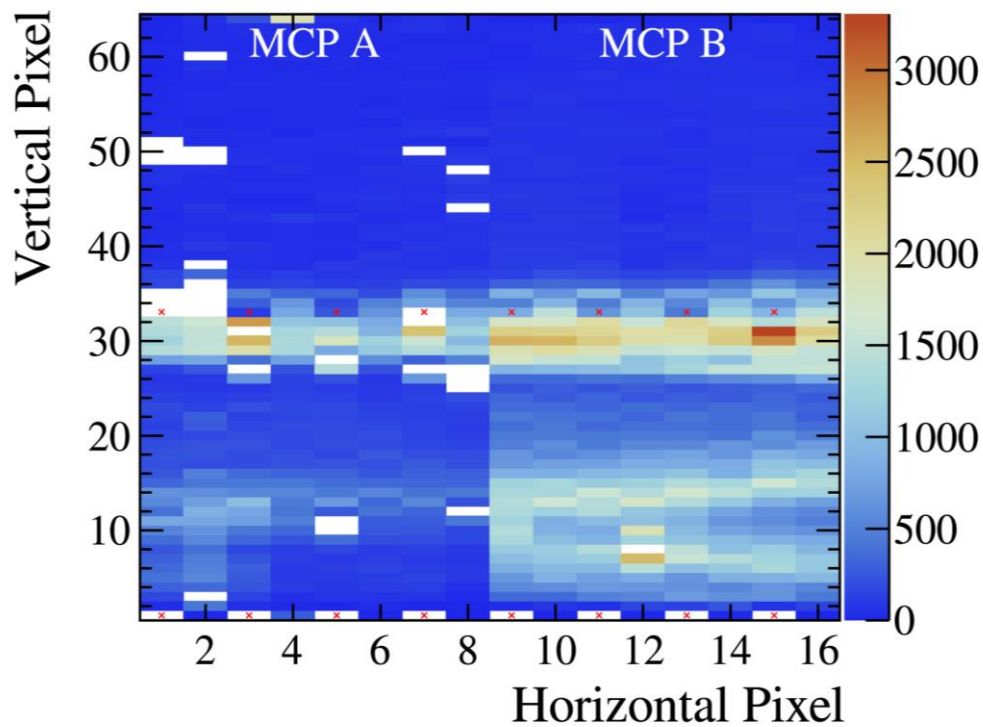
- One half-height, full-width panel
- Two MCP-PMTs positioned adjacent to the upper corner of the radiator plate



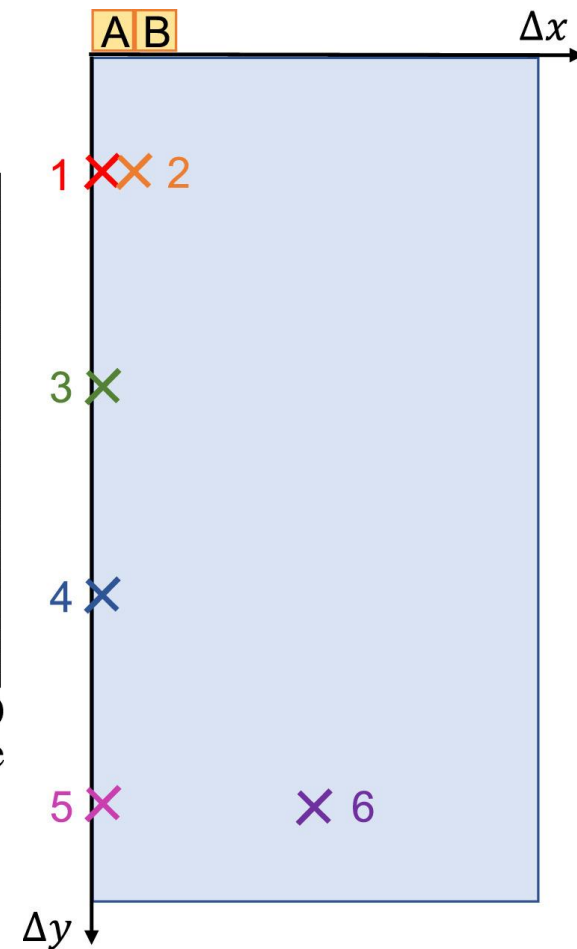
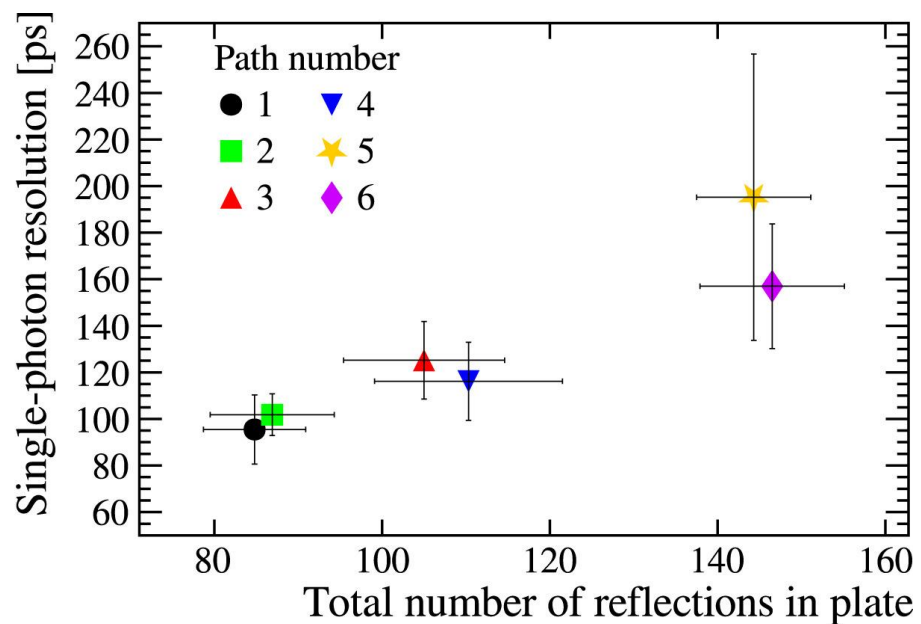
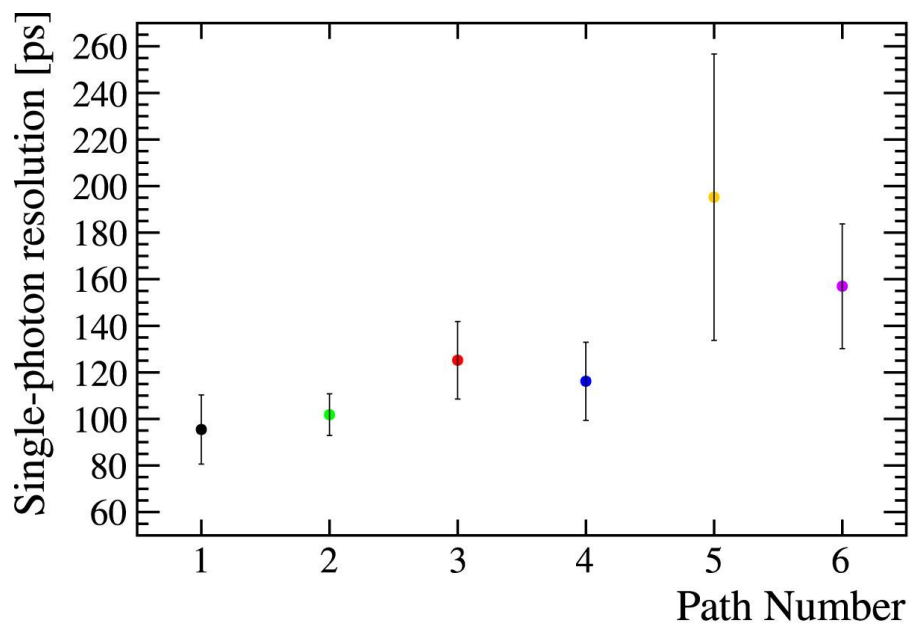
# Proto-TORCH: Test Layout



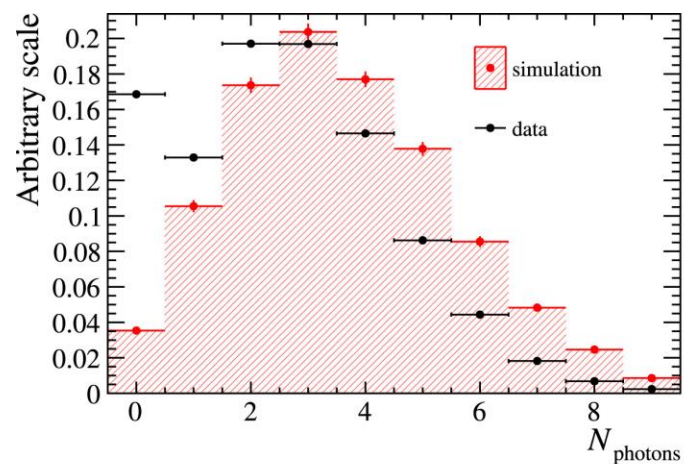
# Proto-TORCH: Analysis and Results



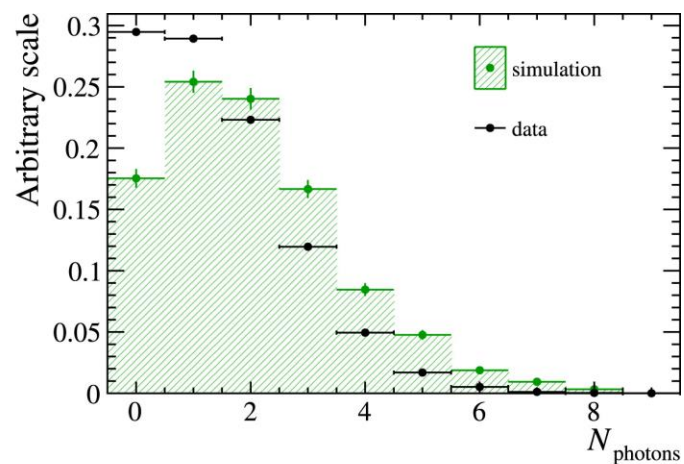
# Proto-TORCH: Analysis and Results



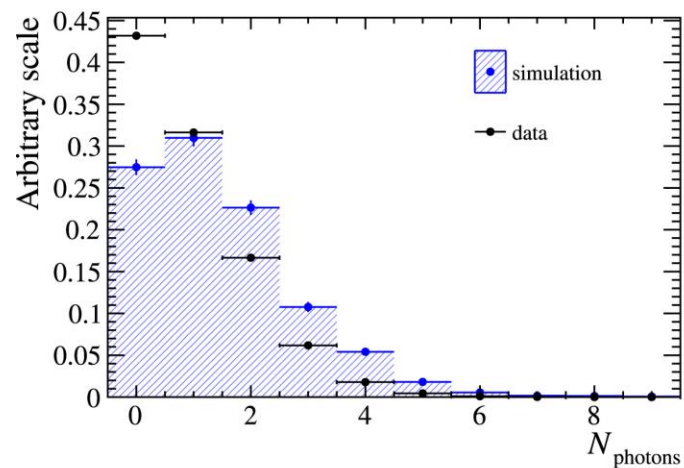
# Proto-TORCH: Analysis and Results



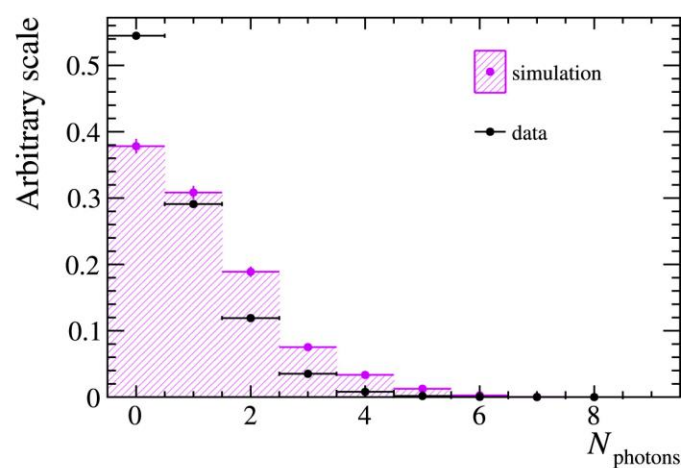
(a) Position 1



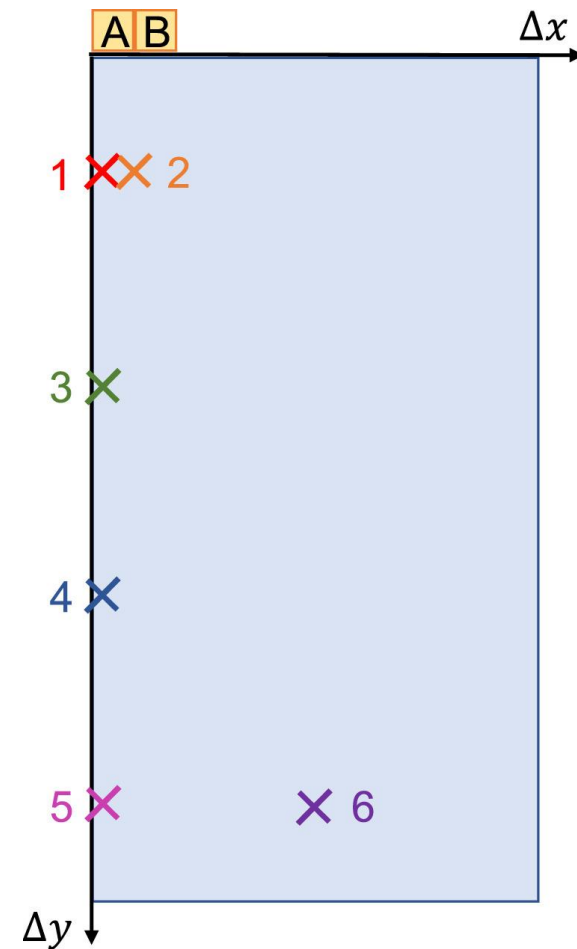
(b) Position 3



(c) Position 4

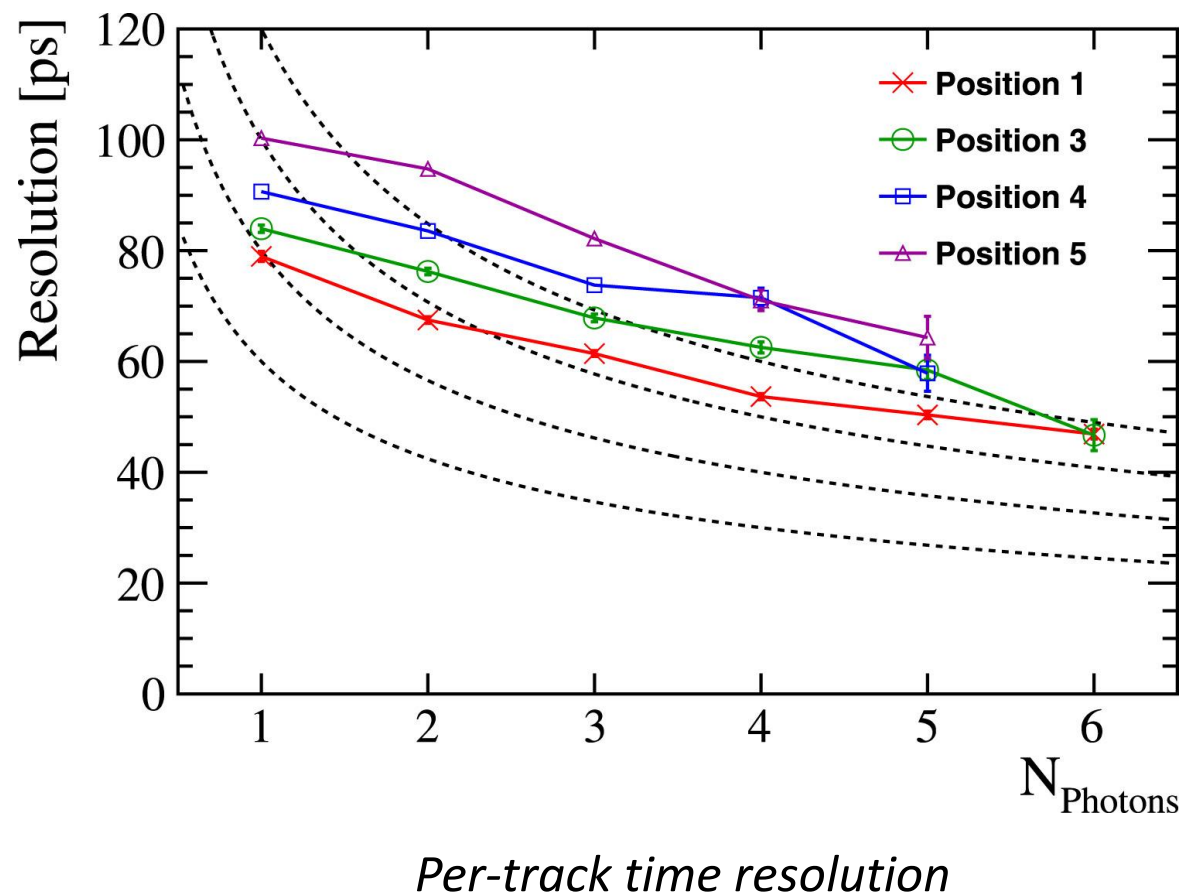


(d) Position 5



# Conclusions and Future Works

- Strong agreement between Geant4 simulation and Proto-TORCH results for photon yields
- Requirement in single photon time resolution respected for paths 1 and 2
- Necessity of better path and travel time reconstruction for long photon paths
- Required further analysis of the correlation of closely spaced hits of photons on the detectors



# Bibliography

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- Garcia Martin, L.M., et al. "TORCH Pattern Recognition and Particle Identification Performance." (2023)
- Bhasin, S., et al. "Performance of a Prototype TORCH Time-of-flight Detector." (2023)