

Modified photo of a charged kaon decay  
chain captured in a bubble chamber

# The Effect of Charged Hadrons in ECL Reconstruction at Belle II

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Supervised by Dr. Steven Robertson

McGill University

CAP 2023 University of New Brunswick



**McGill**

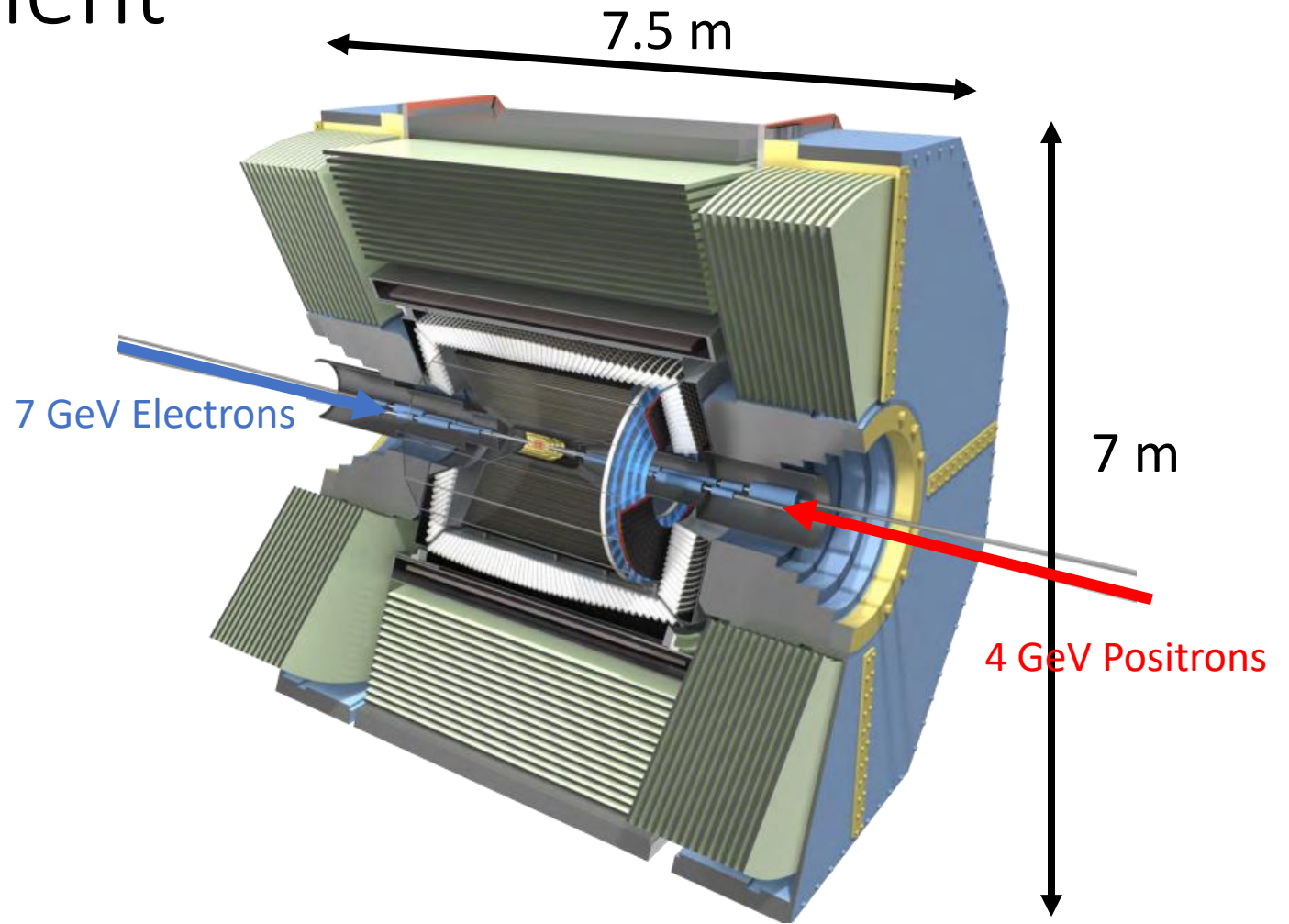
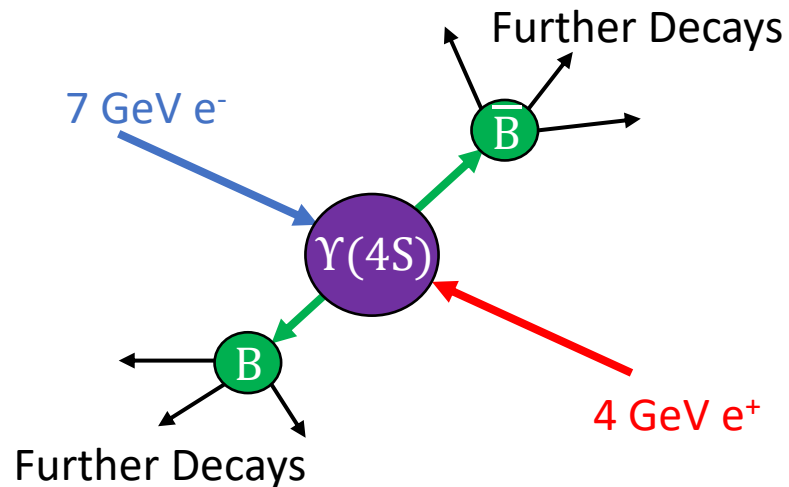


# Introduction to Belle II

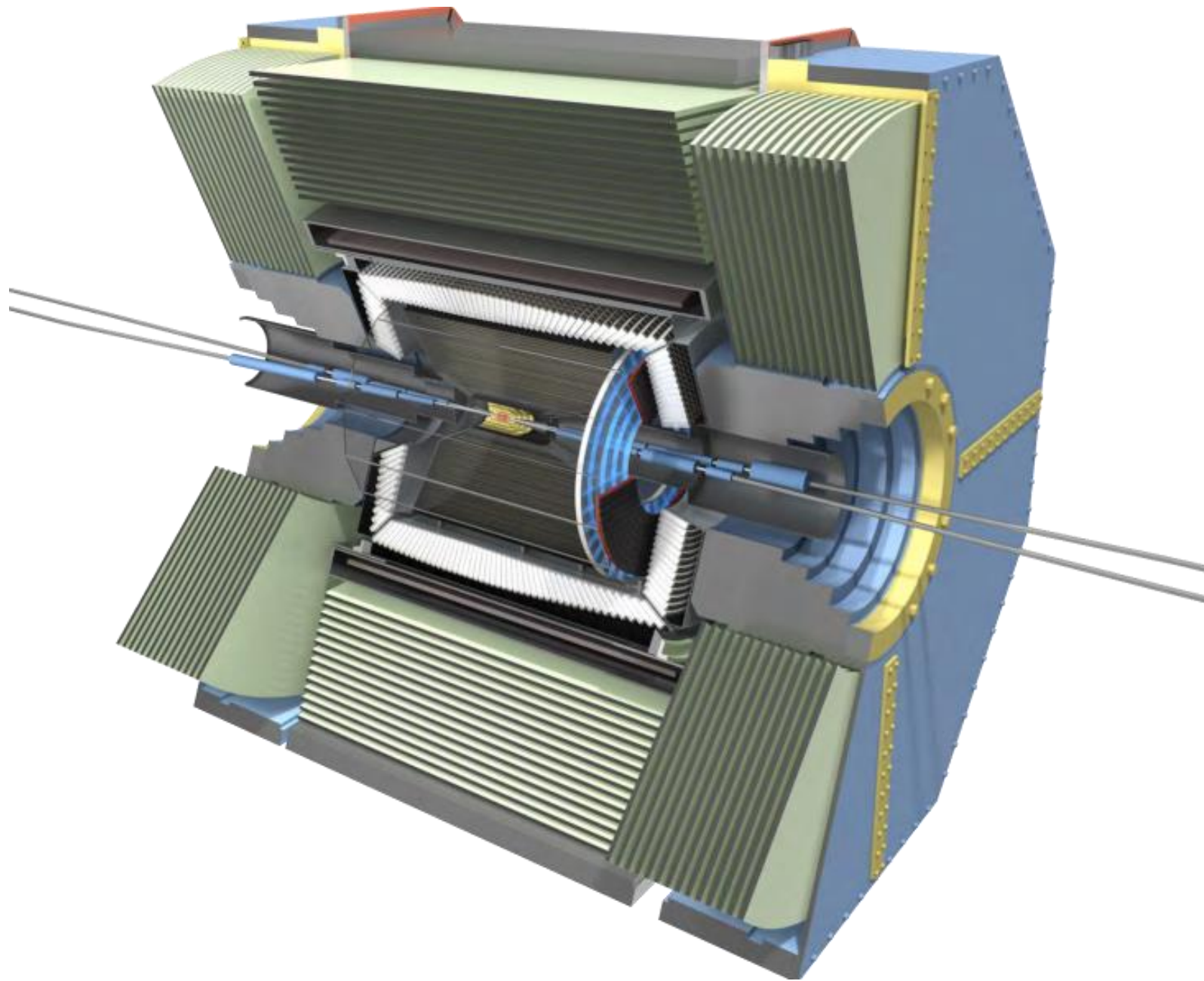
The basics

# The Belle II Experiment

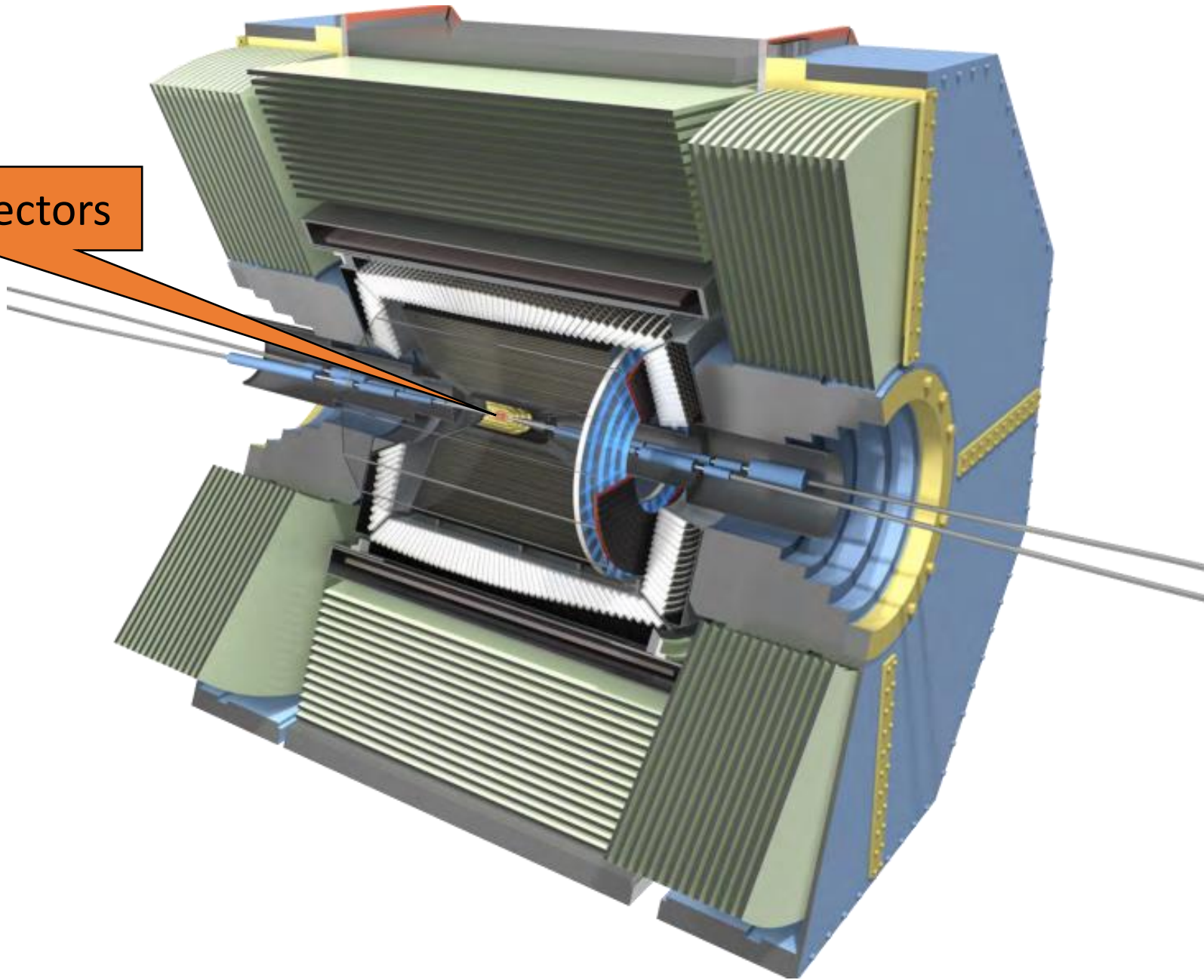
- $e^+e^-$  collider B-factory
- Luminosity frontier
  - Sensitive to rare decays and BSM physics

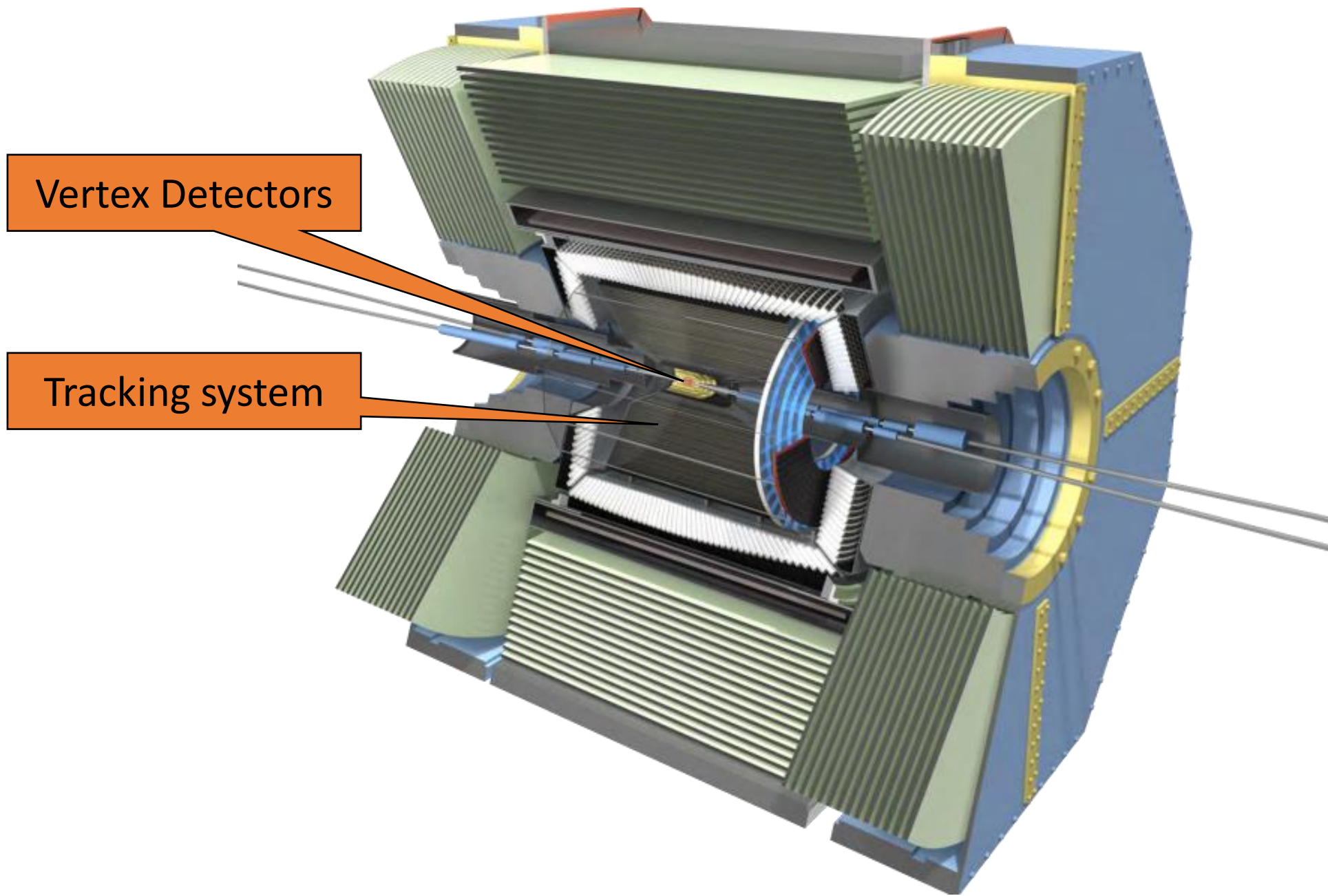


The Belle-II Detector



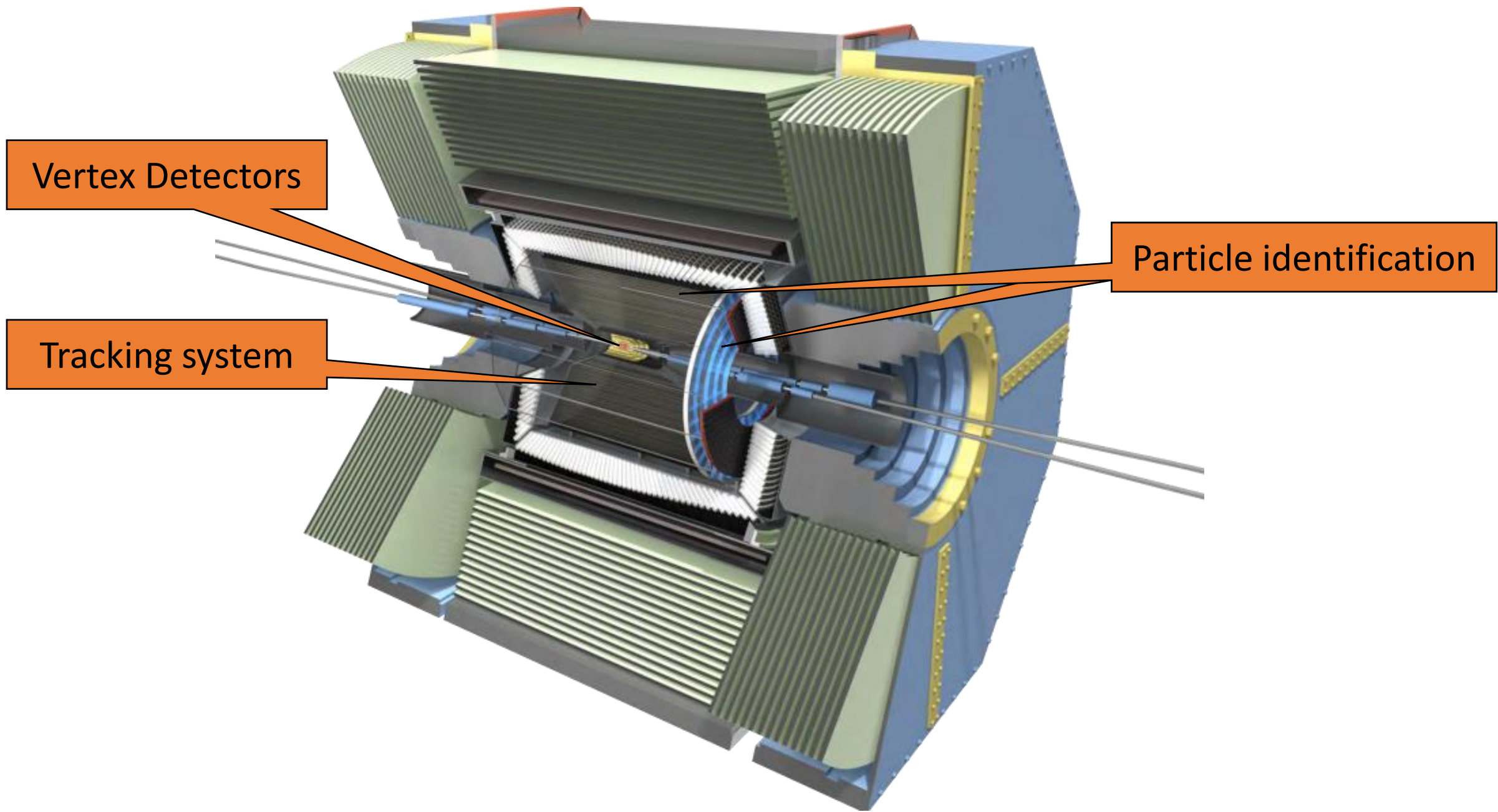
Vertex Detectors

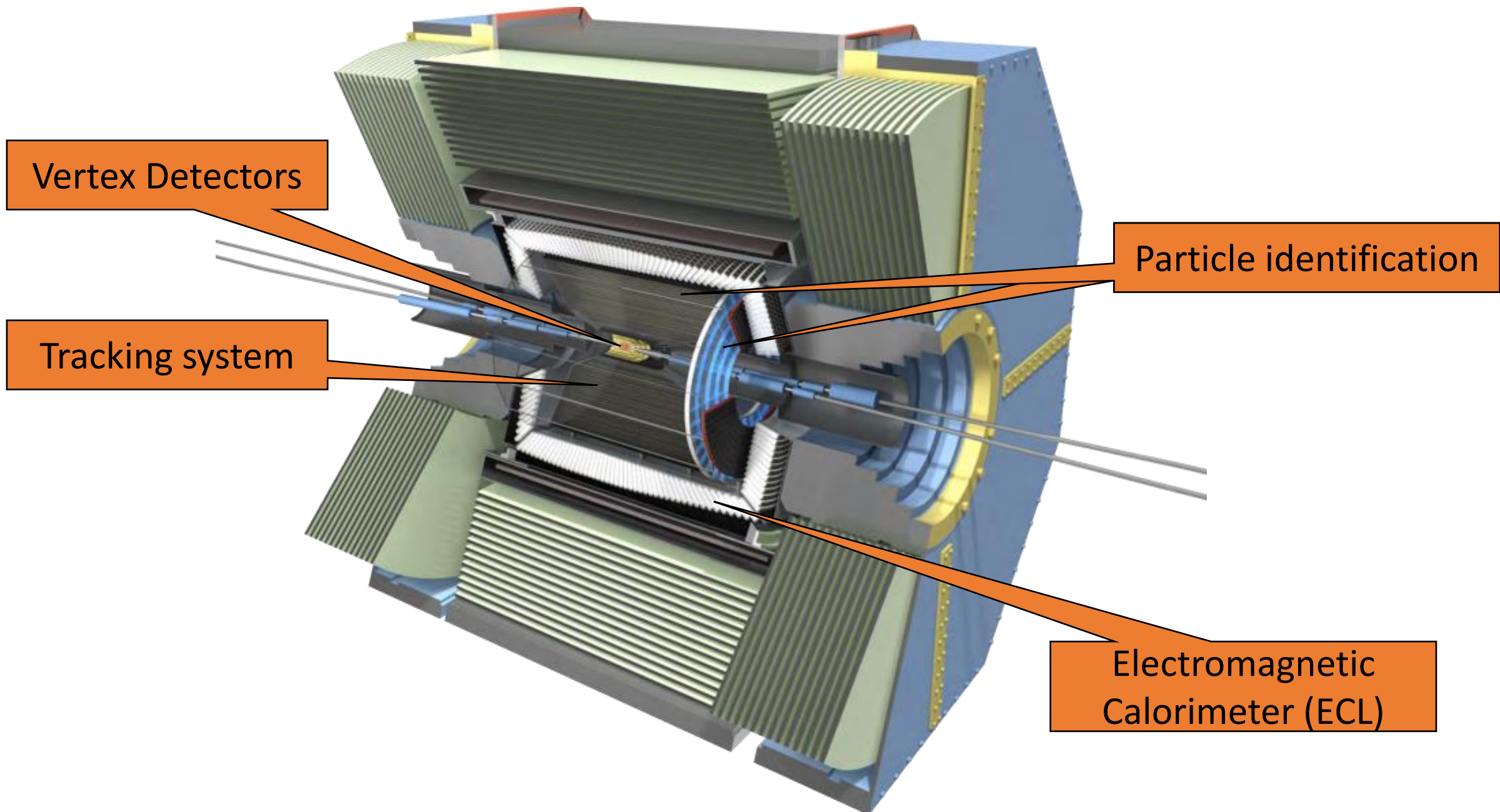




Vertex Detectors

Tracking system





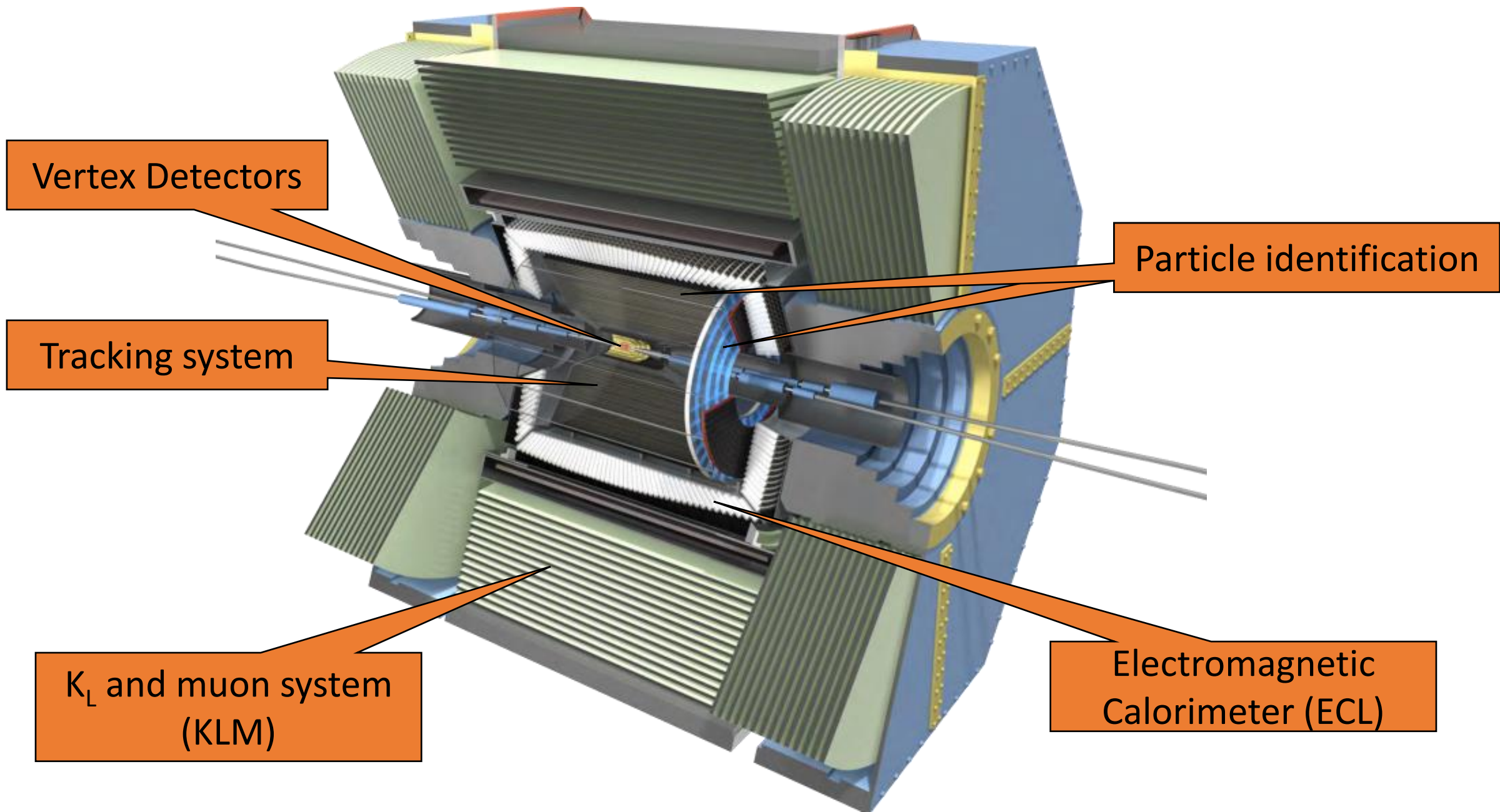
Vertex Detectors

Tracking system

Particle identification

Electromagnetic Calorimeter (ECL)





Vertex Detectors

Tracking system

$K_L$  and muon system  
(KLM)

Particle identification

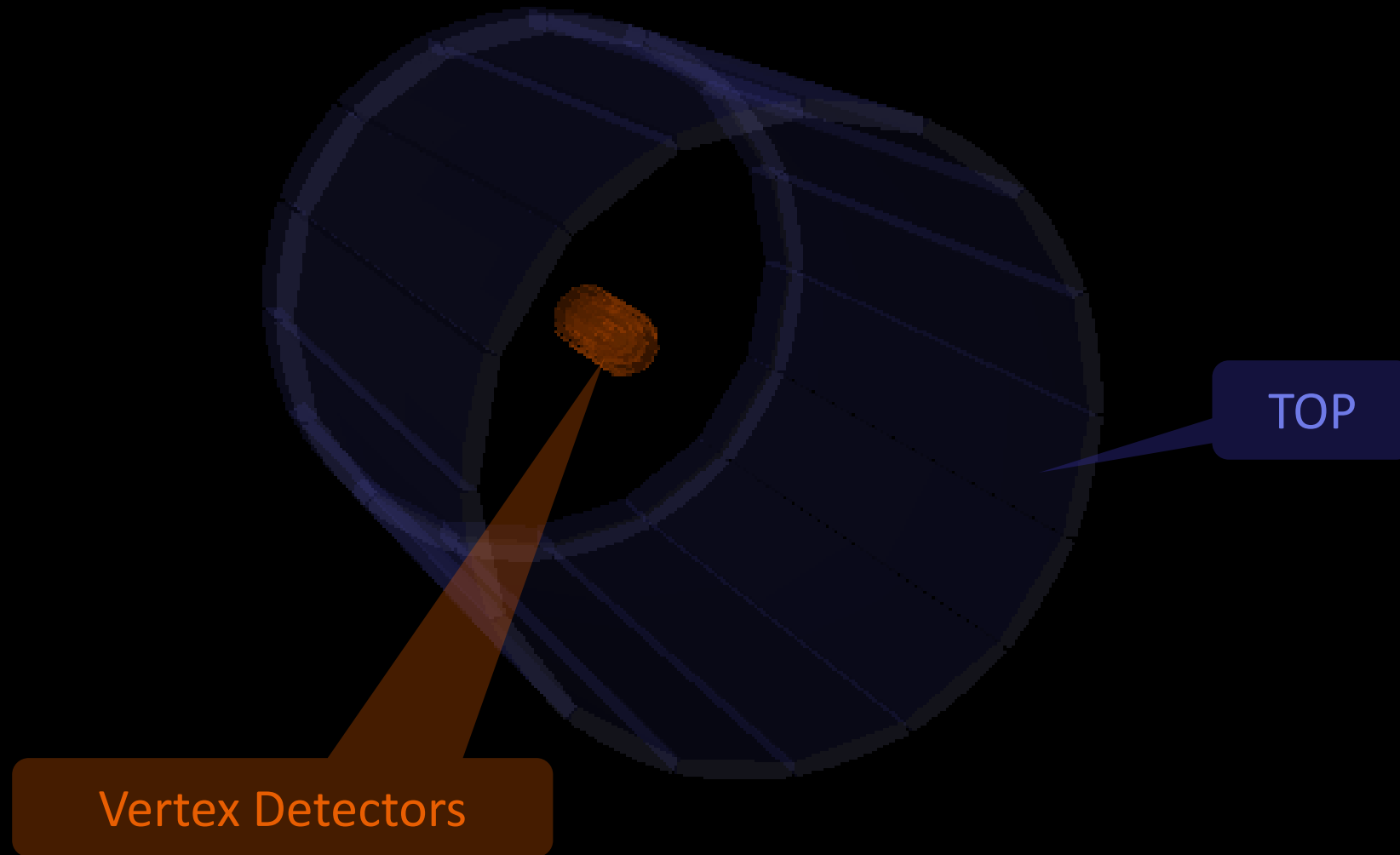
Electromagnetic  
Calorimeter (ECL)

A complex visualization of particle detector reconstruction. It features a large, semi-transparent blue circle overlaid on a dense network of blue lines and nodes, representing a detector's internal structure or event reconstruction. The background is a light blue gradient with faint, repeating patterns of the detector's geometry. The text is positioned on the left side of the image.

# Reconstruction

Event interpretation and ECL  
reconstruction

# Event Reconstruction

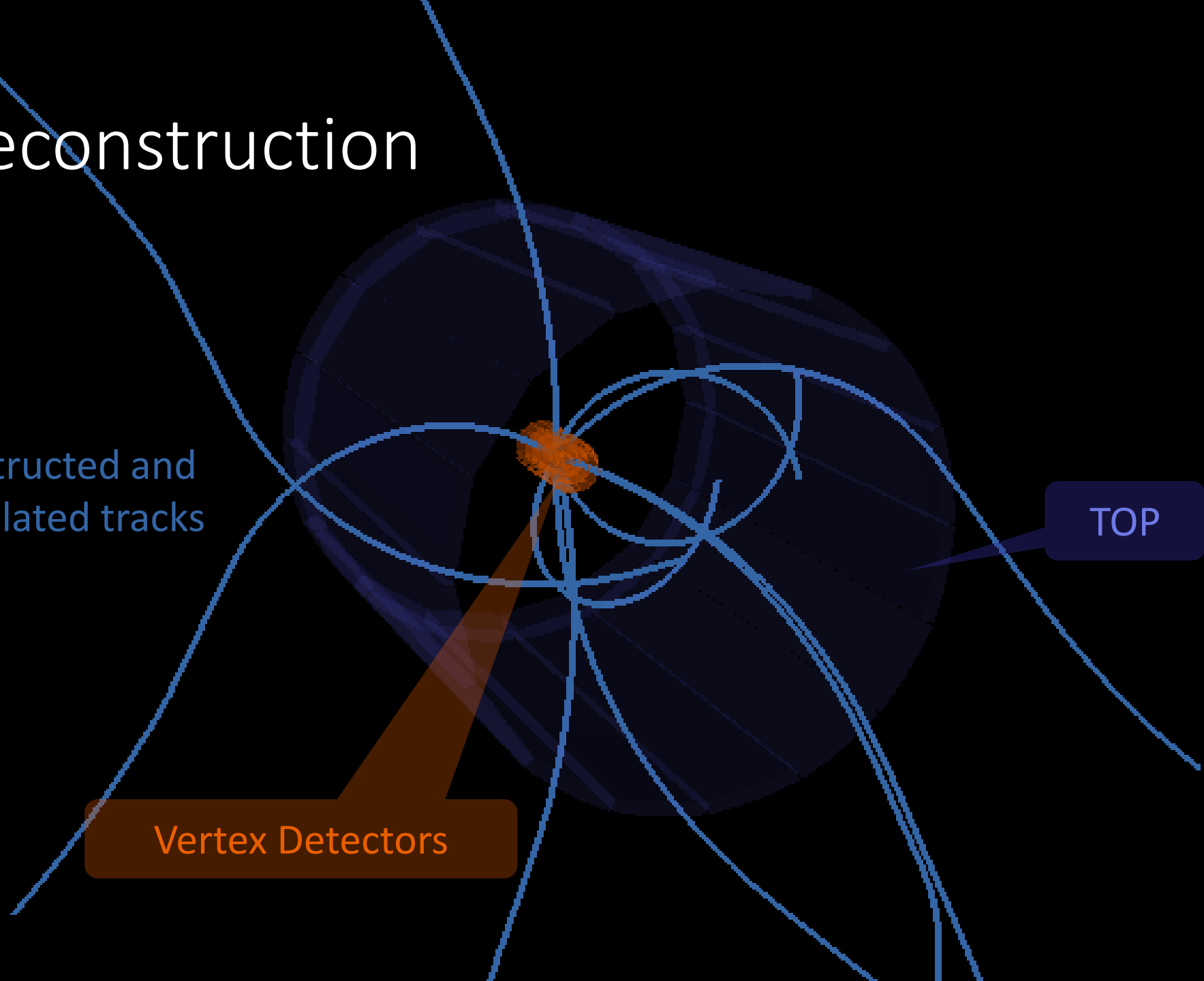


# Event Reconstruction

Reconstructed and  
extrapolated tracks

Vertex Detectors

TOP



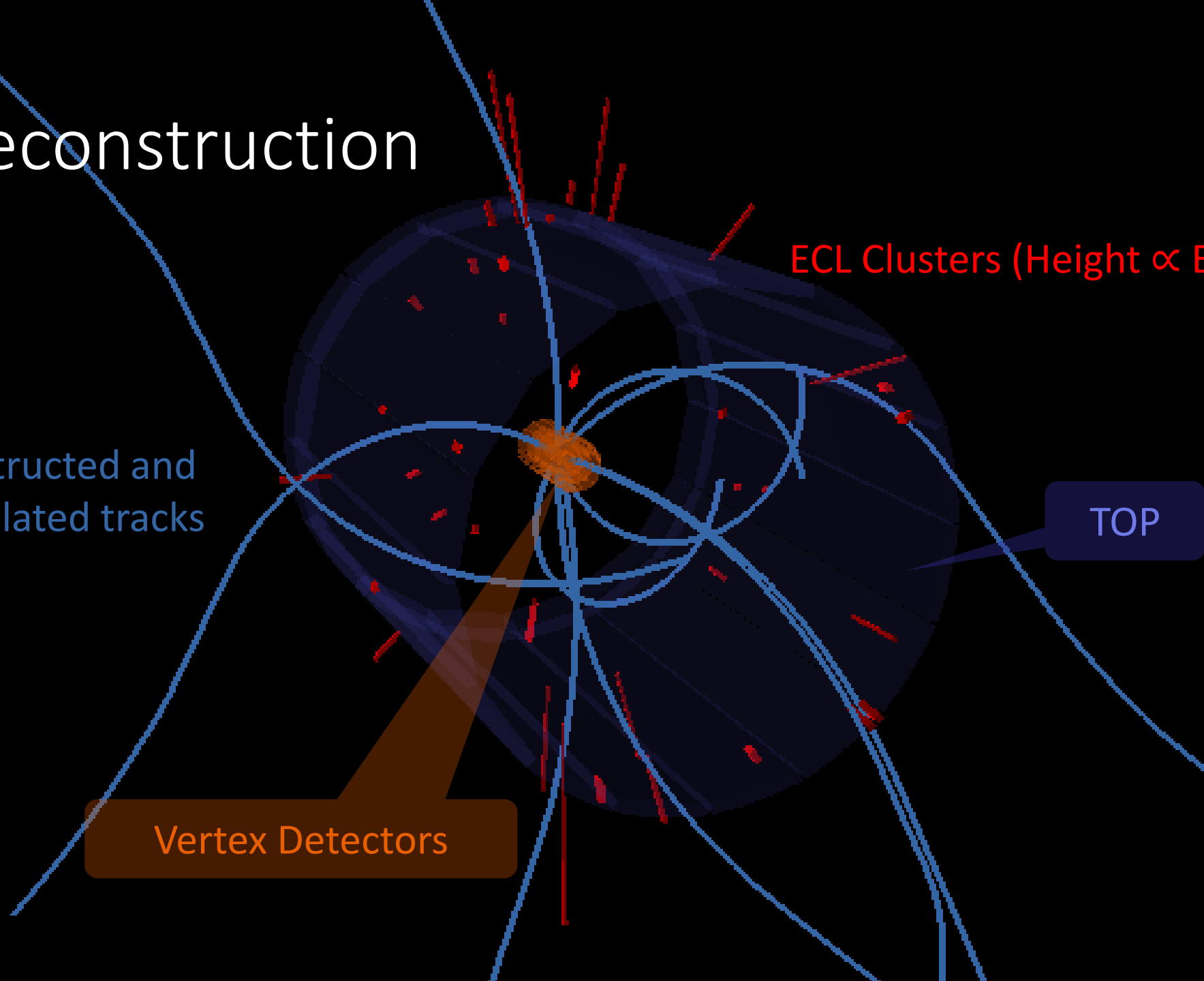
# Event Reconstruction

Reconstructed and  
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ECL Clusters ( $\text{Height} \propto \text{Energy}$ )

TOP

Vertex Detectors



# Event Reconstruction

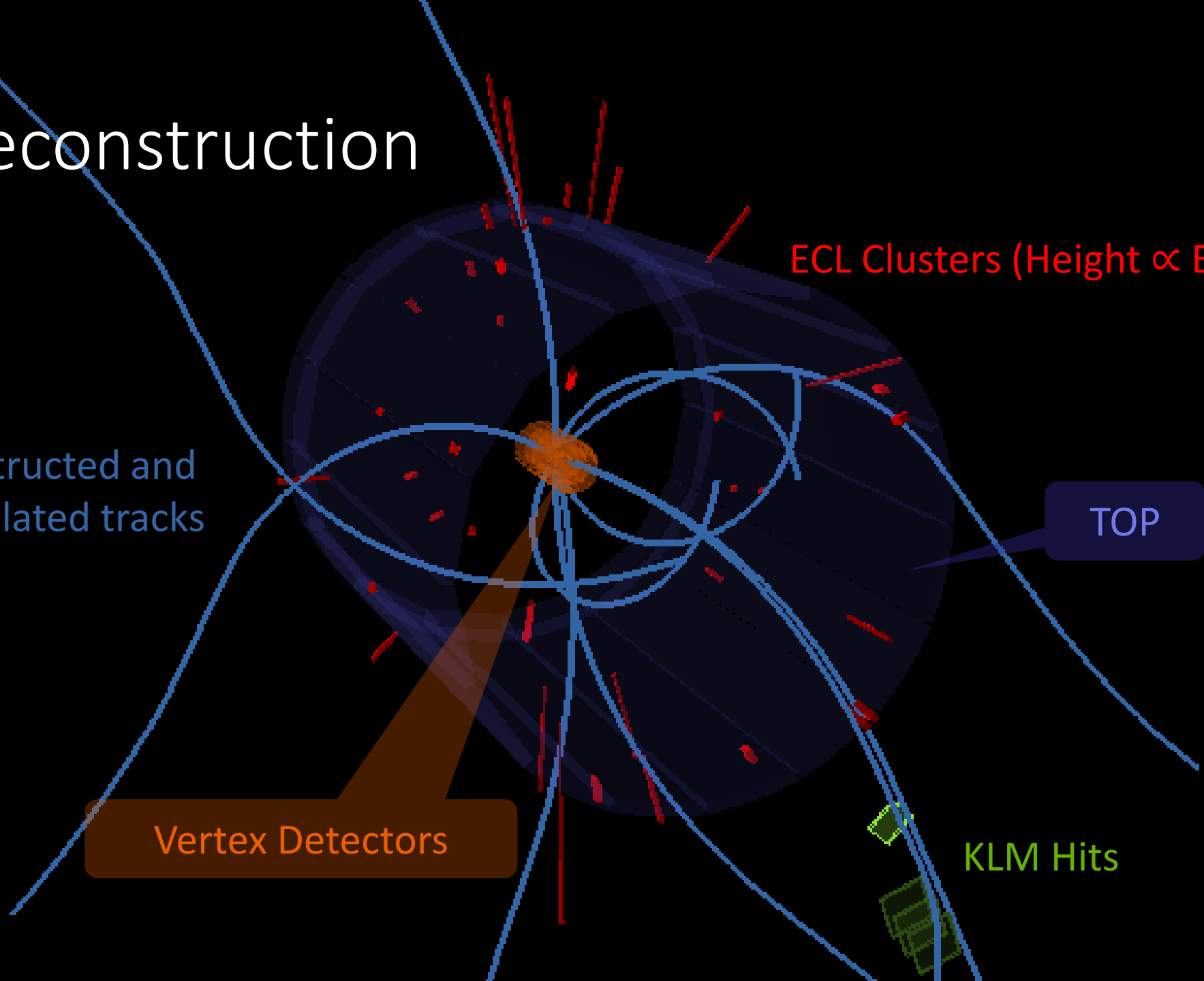
Reconstructed and  
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ECL Clusters ( $\text{Height} \propto \text{Energy}$ )

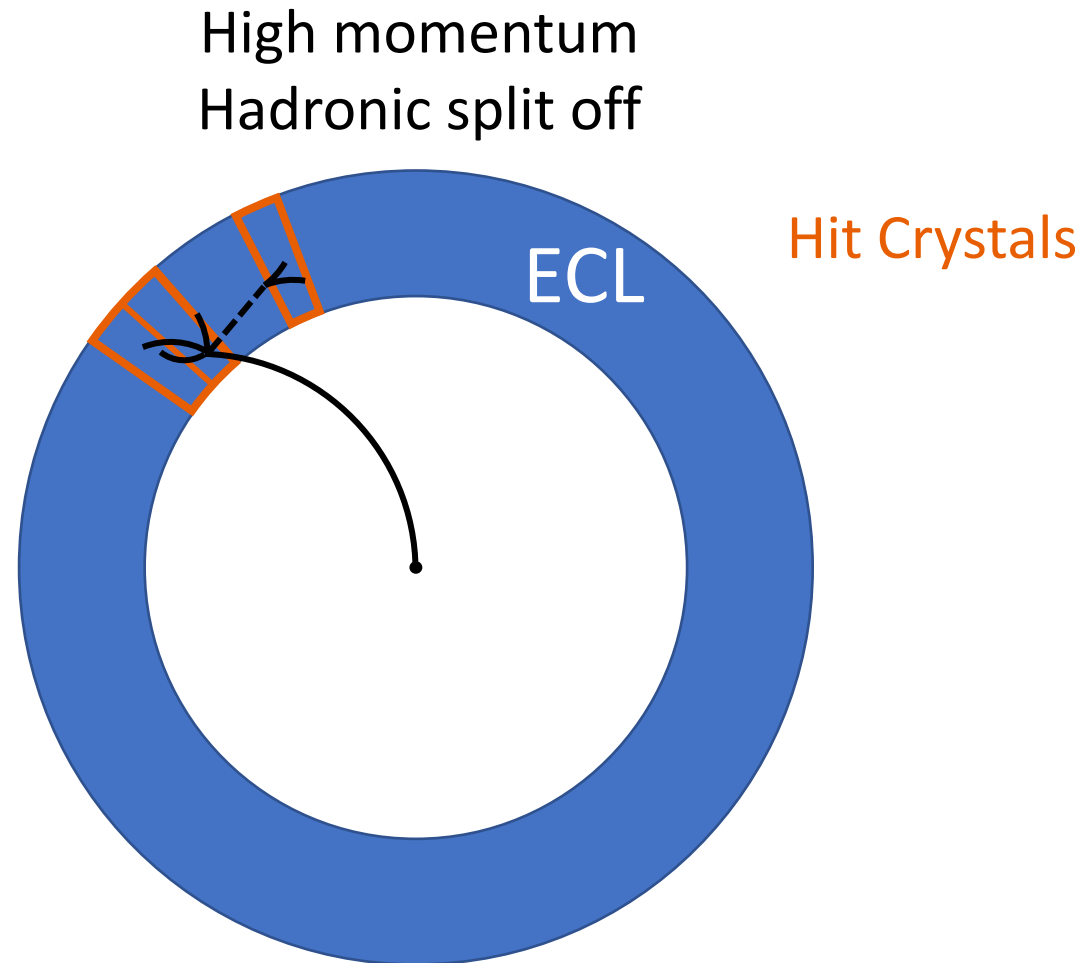
TOP

Vertex Detectors

KLM Hits

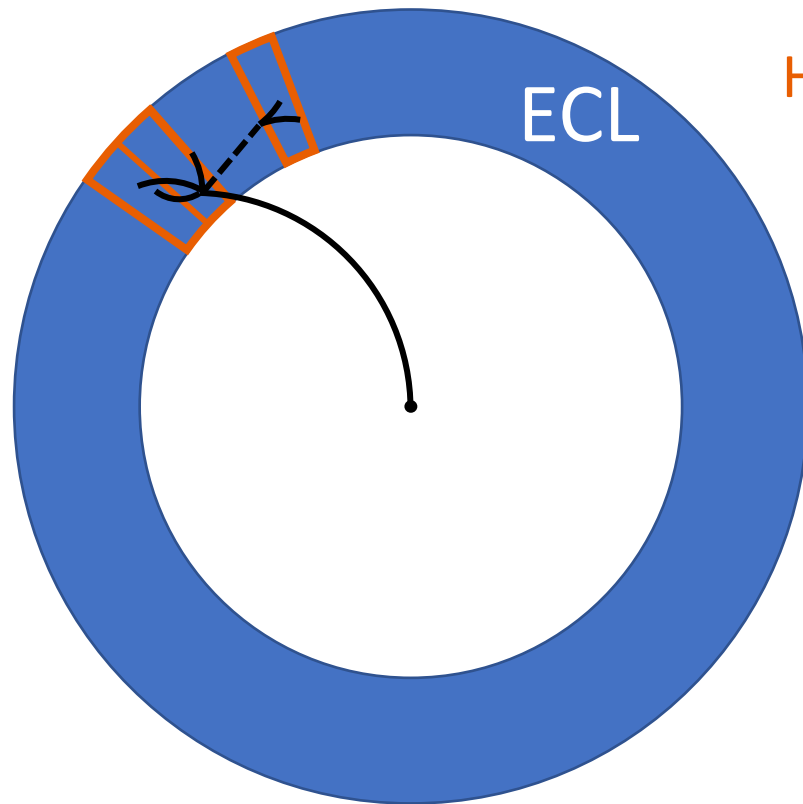


# Challenges in ECL Reconstruction



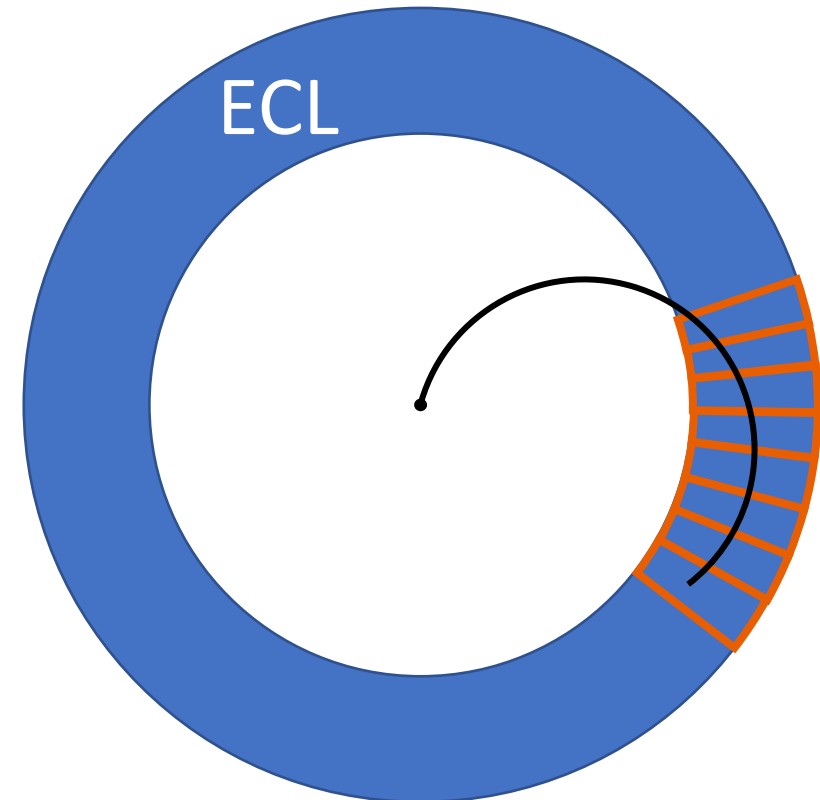
# Challenges in ECL Reconstruction

High momentum  
Hadronic split off



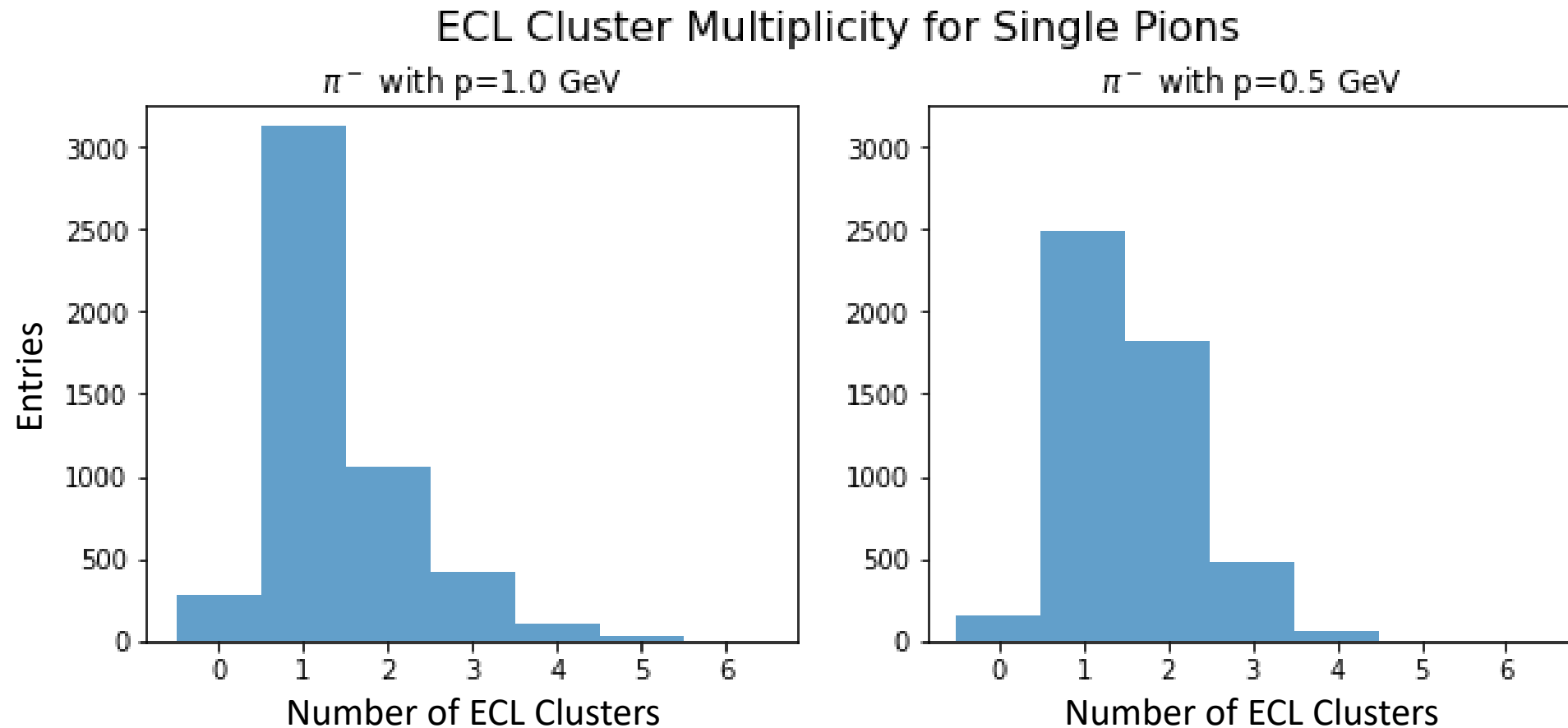
Hit Crystals

Low momentum  
Long trails of ionization





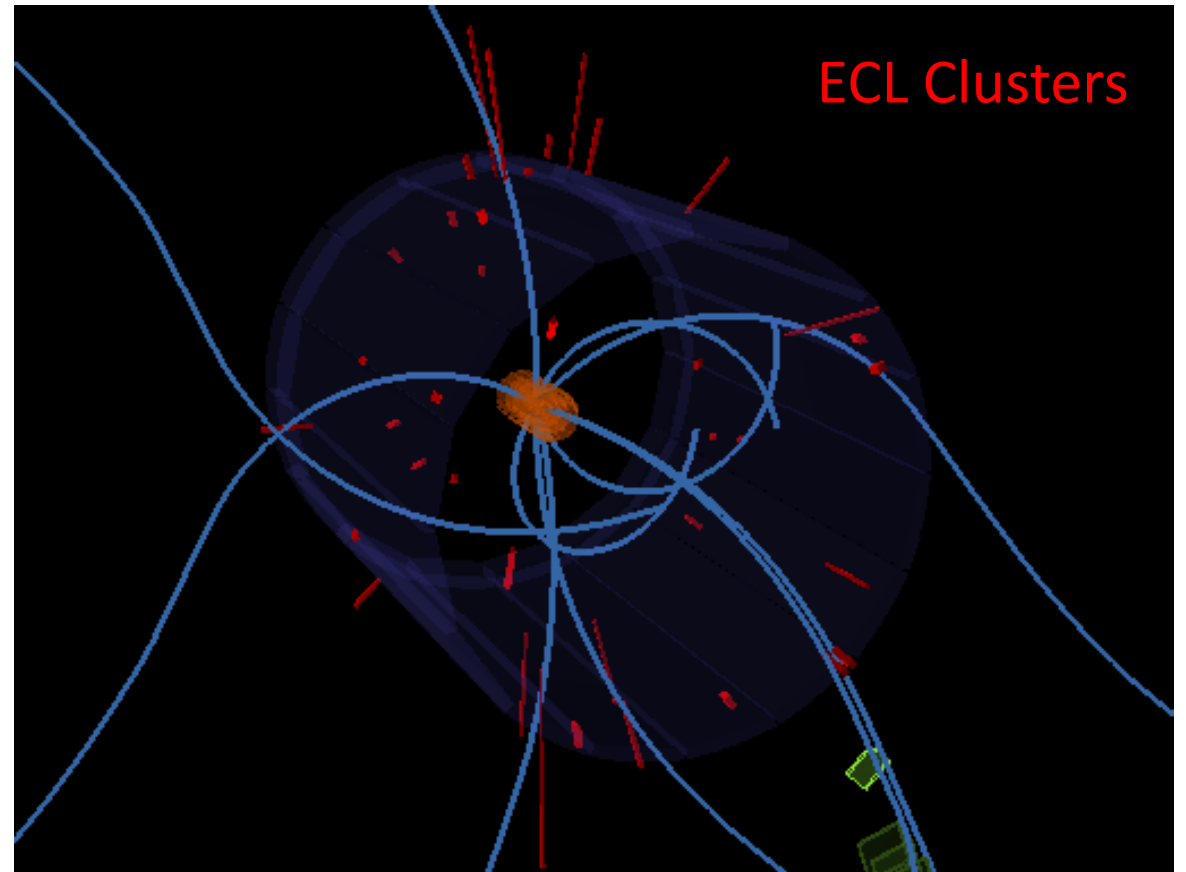
# Number of Clusters from Single Pions



From a sample of 5000 simulated pions each

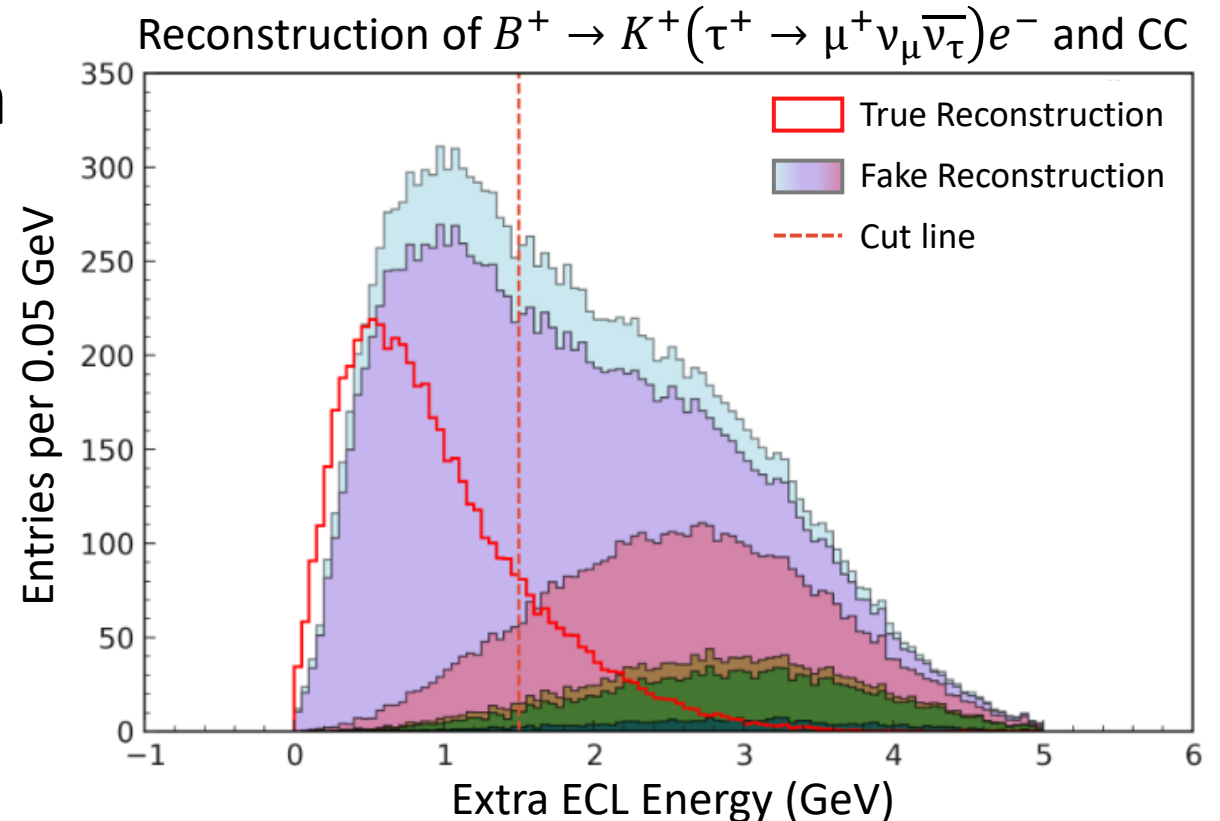
# Problems with ECL Reconstruction Backgrounds

- Neutral pion reconstruction
  - Difficult with high ECL cluster multiplicity



# Problems with ECL Reconstruction Backgrounds

- Neutral pion reconstruction
  - Difficult with high ECL cluster multiplicity
- Evaluation of event interpretation
  - Left over ECL clusters indicate a misinterpreted event



From Trevor Shillington's MSc Thesis

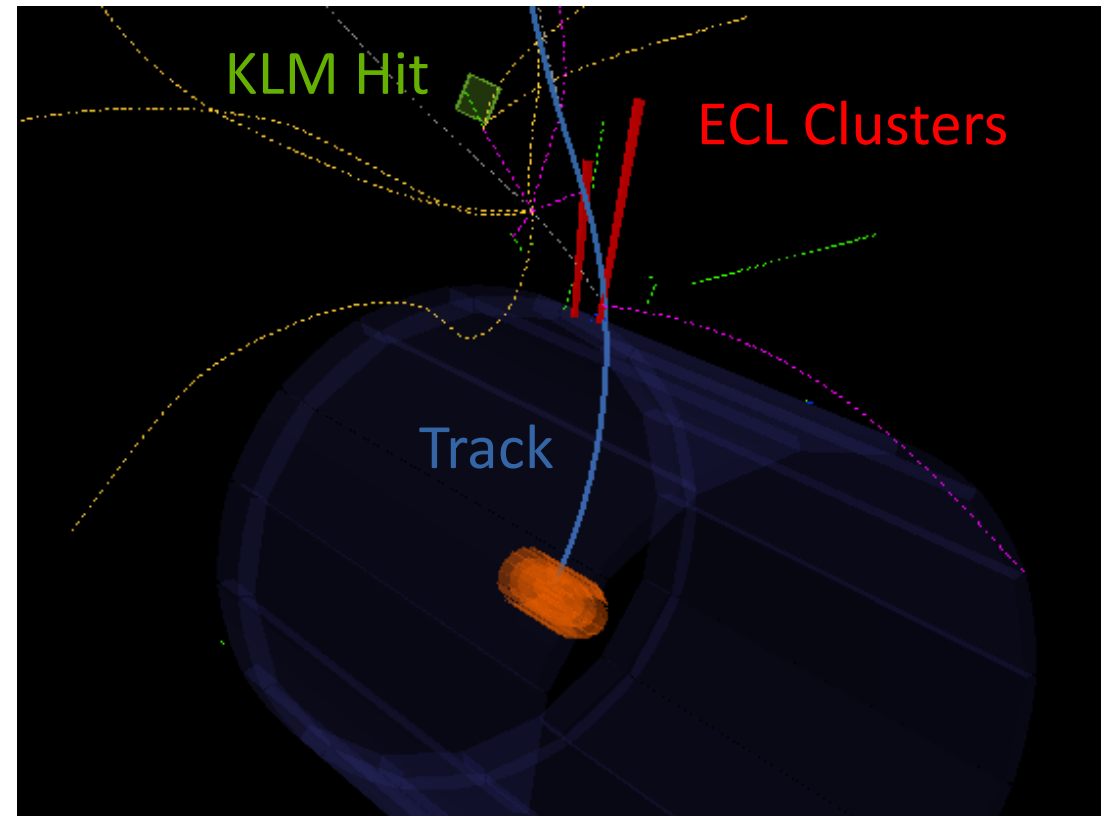
The background of the slide is a complex simulation of a particle detector, likely a calorimeter or tracking chamber. It features a dense network of blue lines representing particle tracks, with several prominent circular patterns that resemble spiral patterns or concentric rings, possibly indicating particle showers or specific detector components. The overall color scheme is light blue and white, with darker blue accents for the tracks and patterns.

# Charged Hadron Reconstruction

Based on simulation studies

# Simulation Details

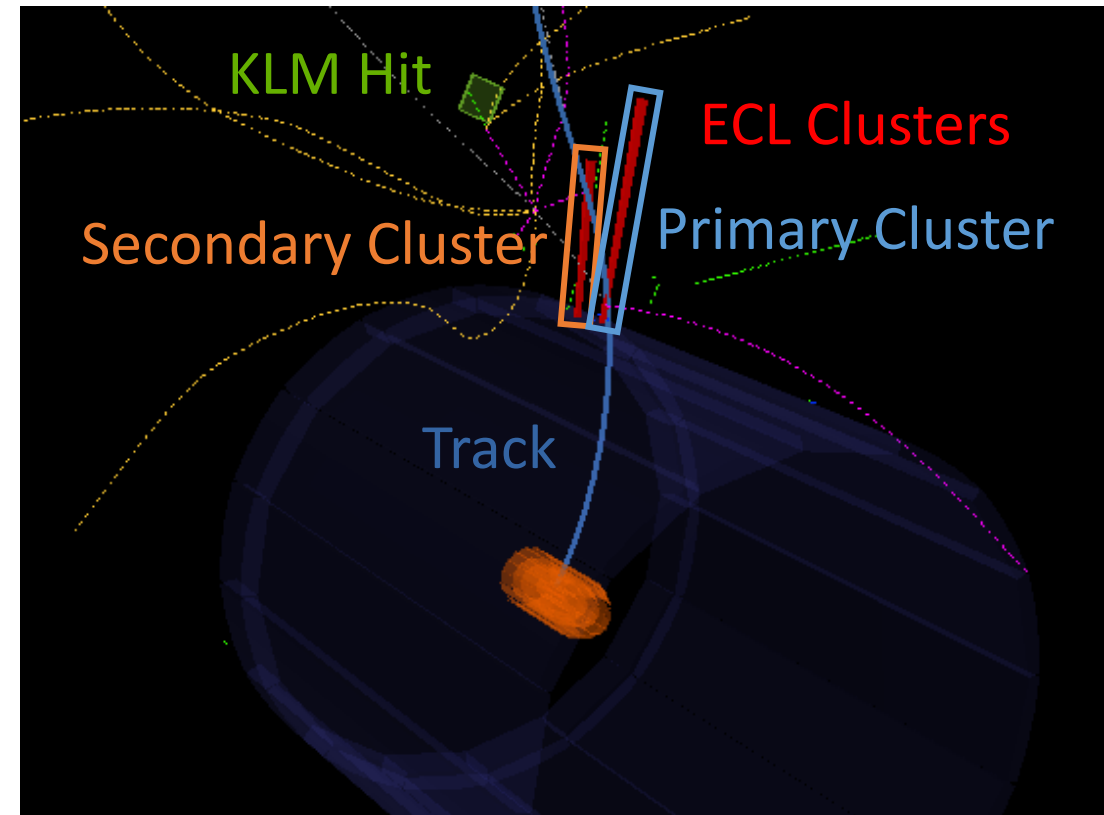
- Single particles coming from interaction point
- 5000 for each particle and momentum
- Direction of initial momentum:  $\phi = 60$ ,  $\theta = 90$



Instance of hadronic split off. Dotted lines are simulated particles.

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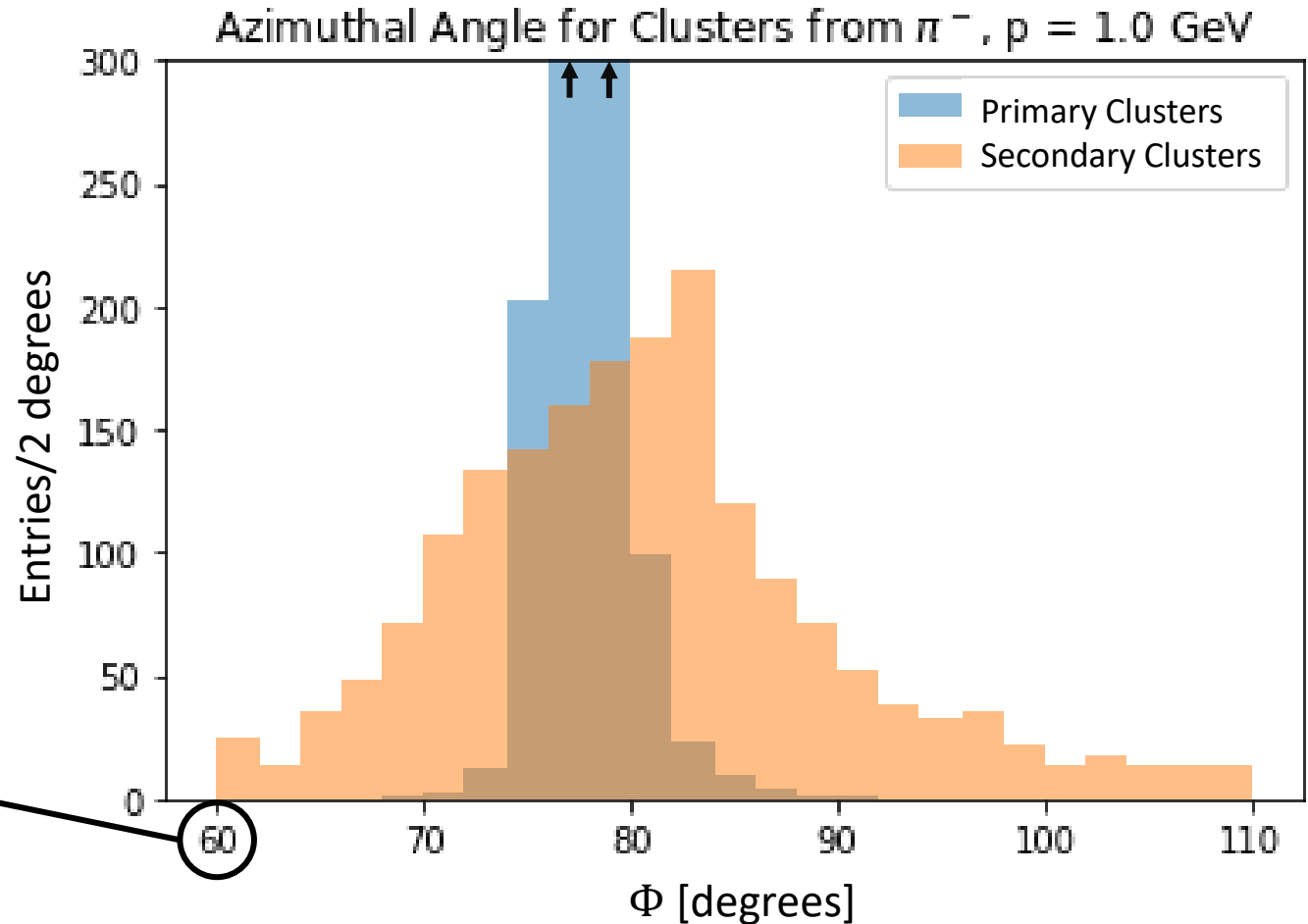


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# Directionality

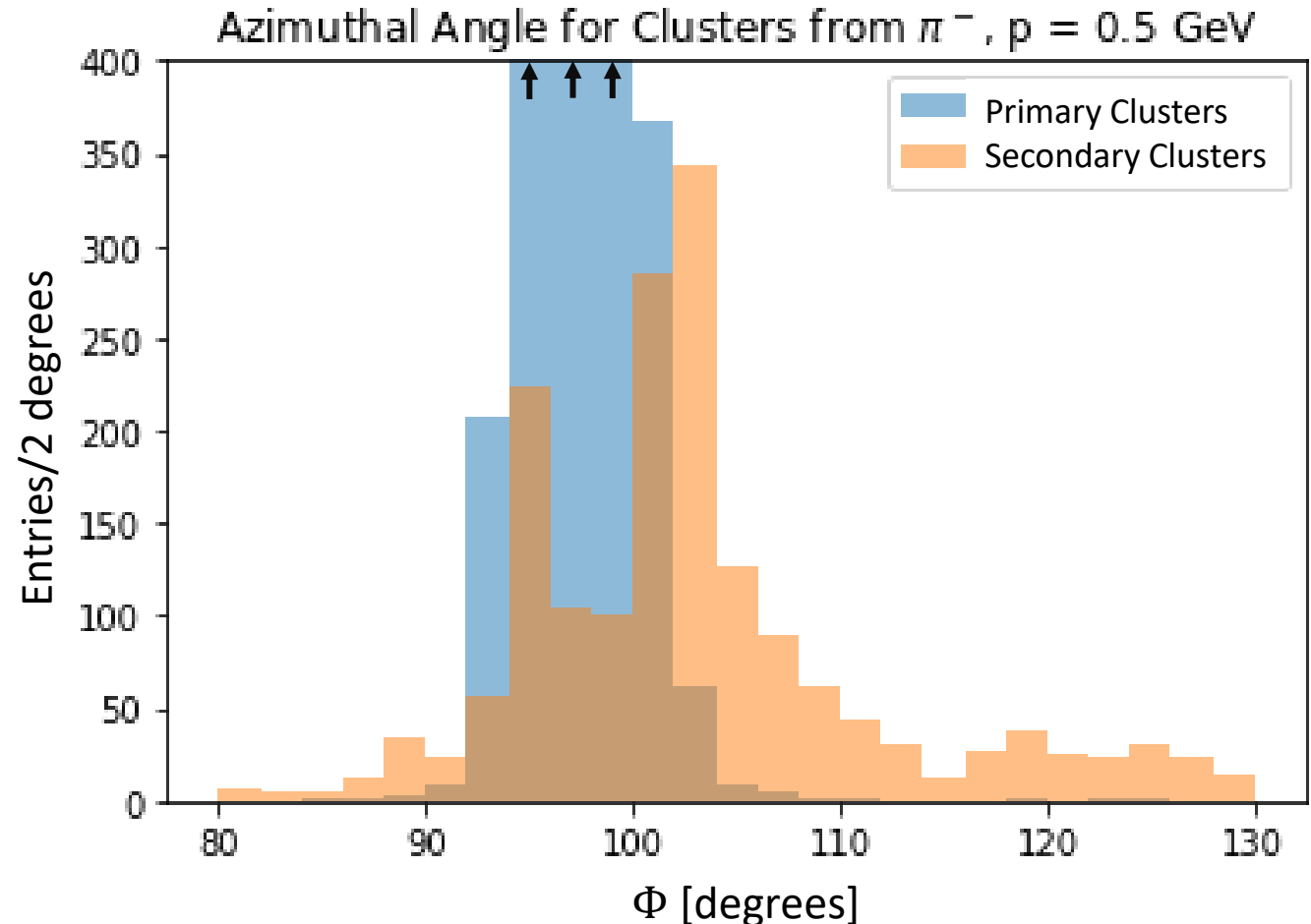
- Split offs continue in direction of particle bend
- Due to momentum conservation

Angle of initial pion momentum



# Directionality at Lower Momentum

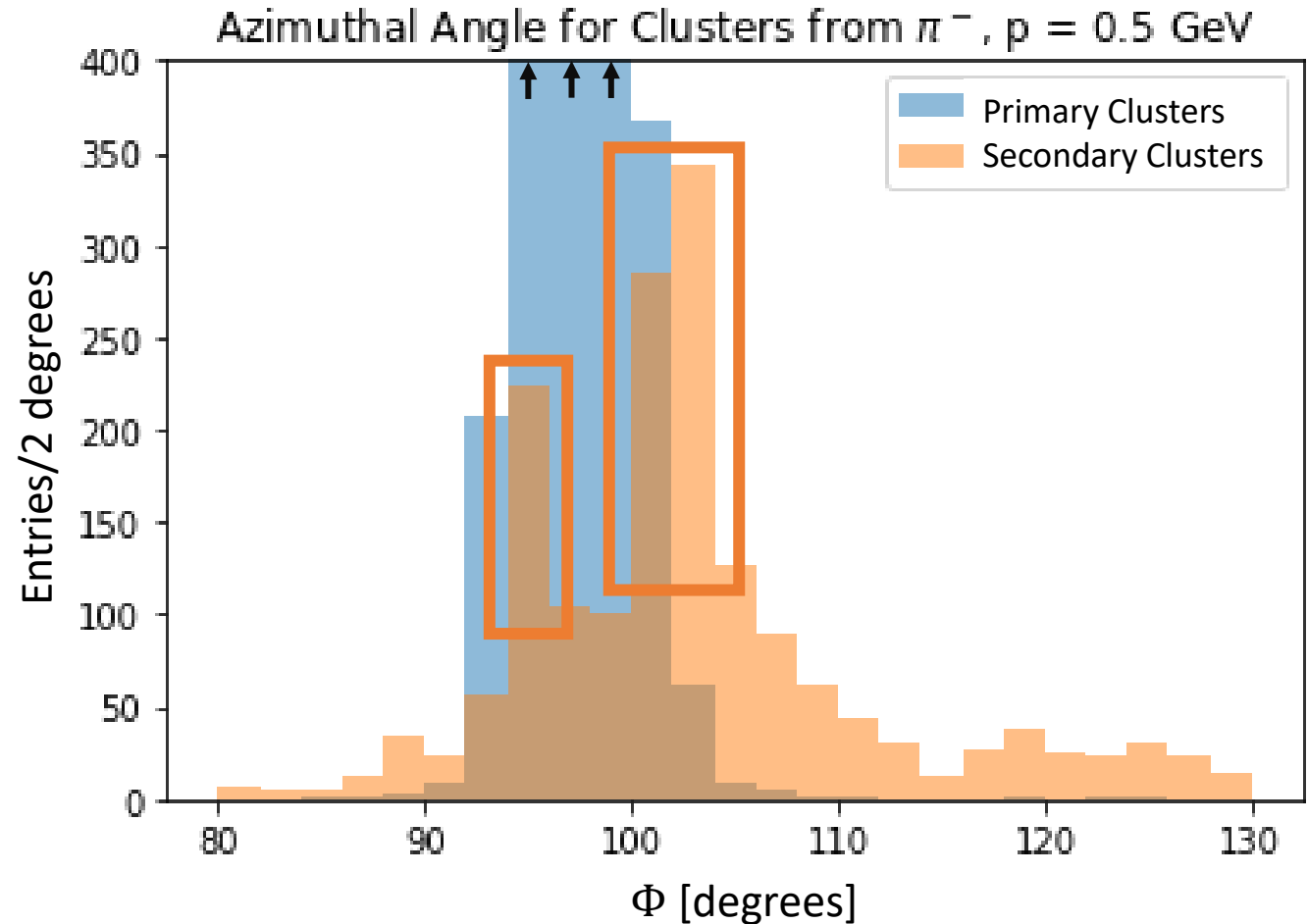
- At lower momenta, there is a stronger correlation with direction
- Due to low transverse momentum clustering





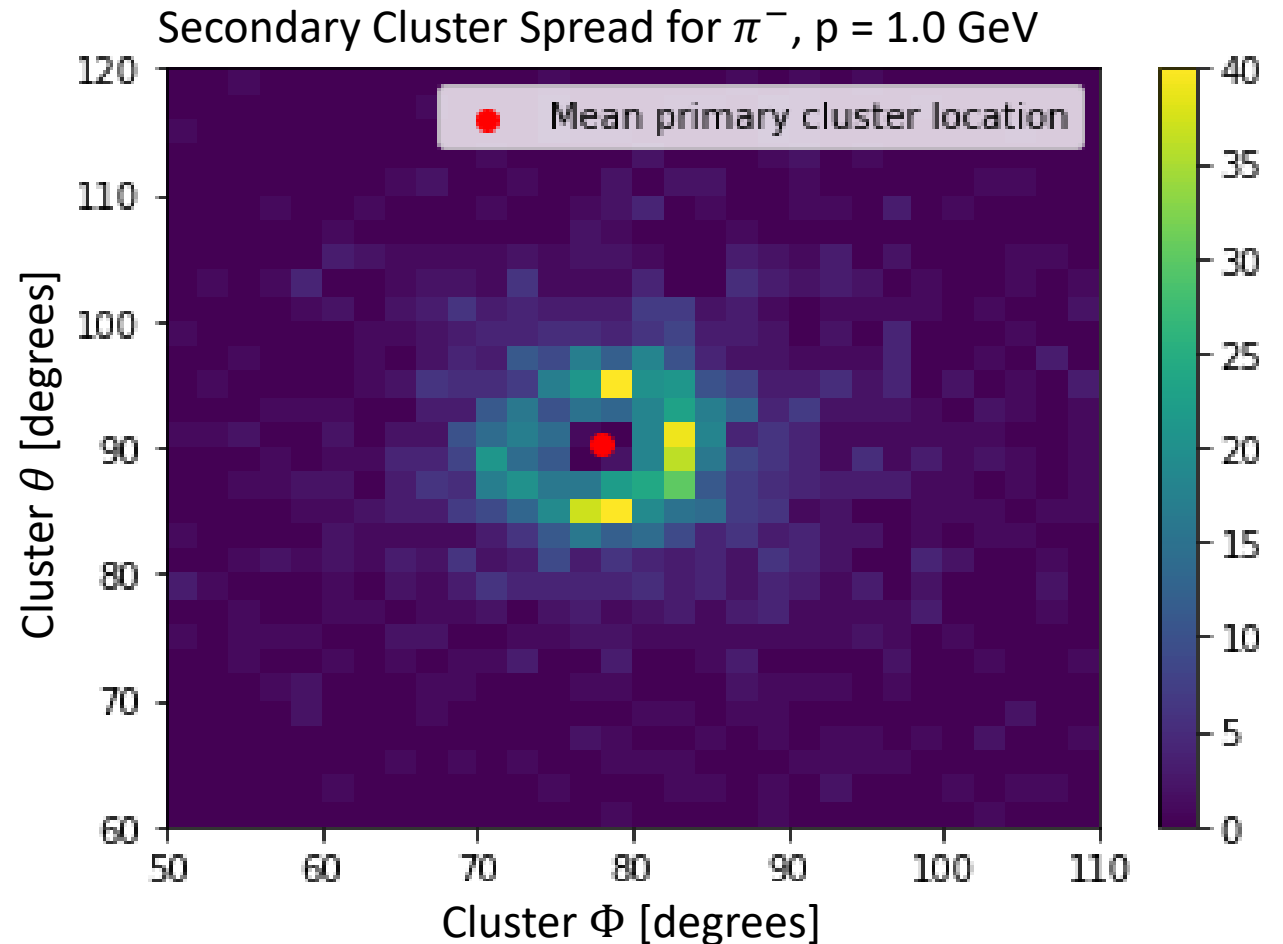
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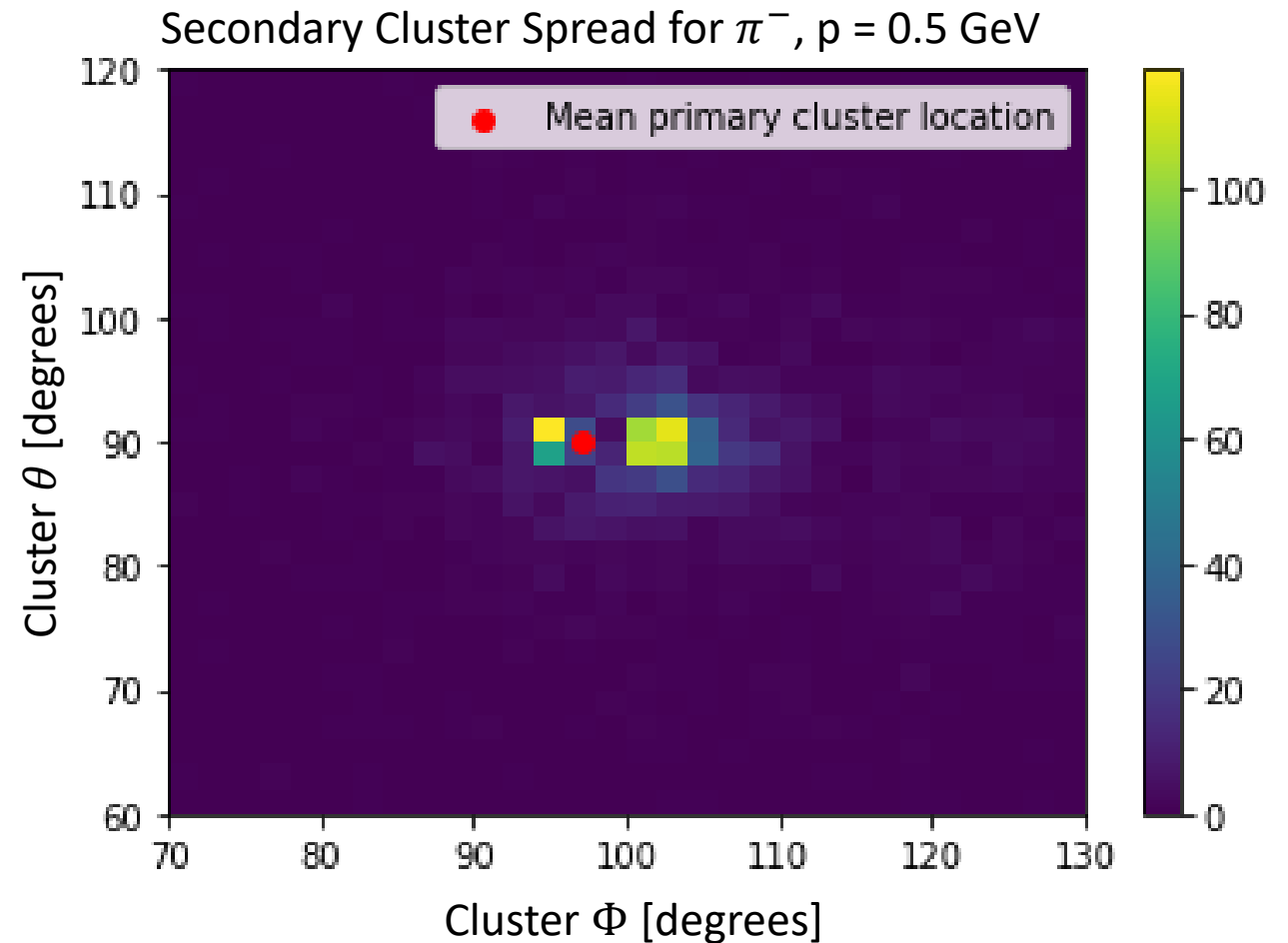
# Directionality Including Polar Angle

- Visible ring around primary clusters at high momentum at high momentum

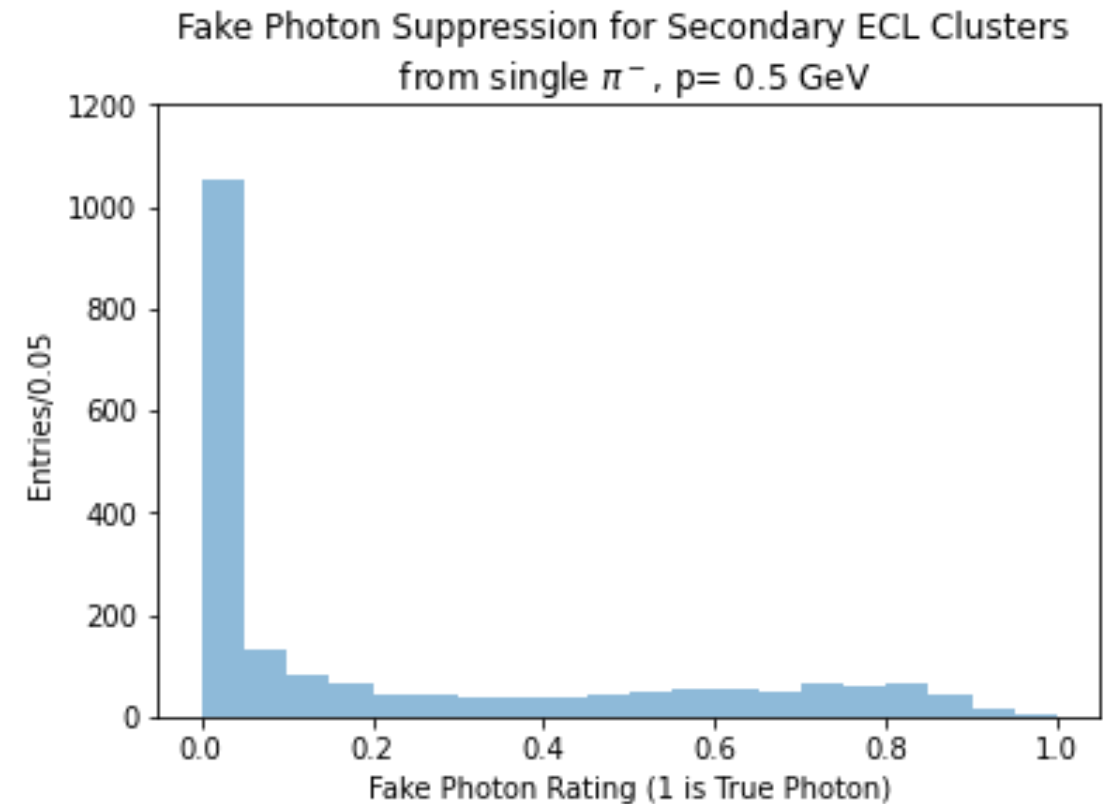
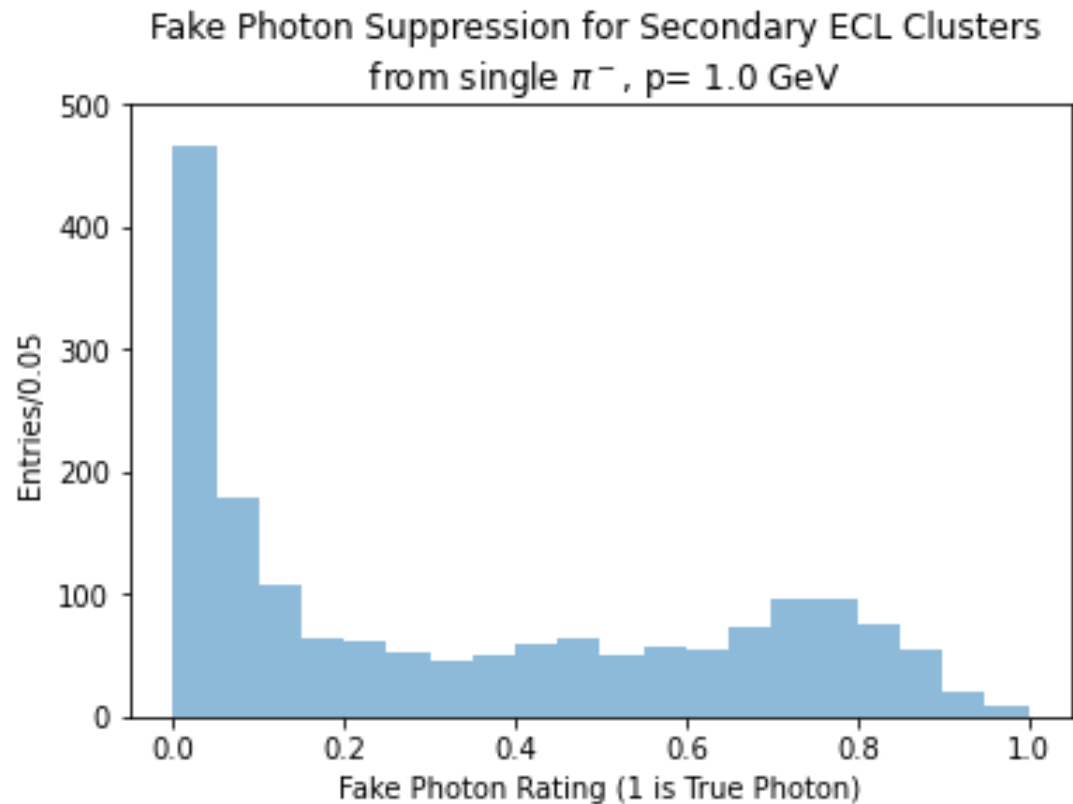


# Directionality Including Polar Angle

- Visible ring around primary clusters at high momentum at high momentum
- No ring at low momentum
  - Closer in theta



# Methods For Suppressing Secondary Clusters



# Summary & Conclusion

- **Multiplicity** in ECL reconstruction is important for neutral pion reconstruction and evaluation of event reconstruction

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- **High multiplicity** in ECL reconstruction is caused by charged hadrons when they:
  - Cause long trails of ionization at **low momentum**
  - Cause hadronic split off at **high momentum**
- **Parameters of hadronic tracks** may be used to **discriminate secondary clusters** in the ECL

# Acknowledgments

I would like to thank the following people for their help in this research and presentation

Steven Robertson

Trevor Shillington

Andreas Warburton

Savino Longo

Hannah Wakeling

Raynette van Tonder

Andrea Fodor

Ahmad Mahmood



McGill



Thanks for  
listening!

Questions are welcome.

# Summary & Conclusion

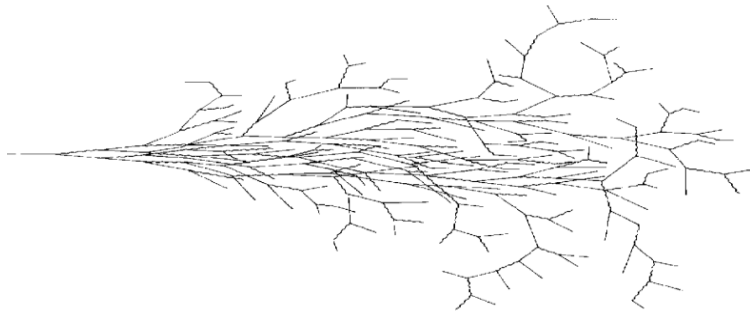
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# Extra Slides

# Basics of EM and Hadronic Showers

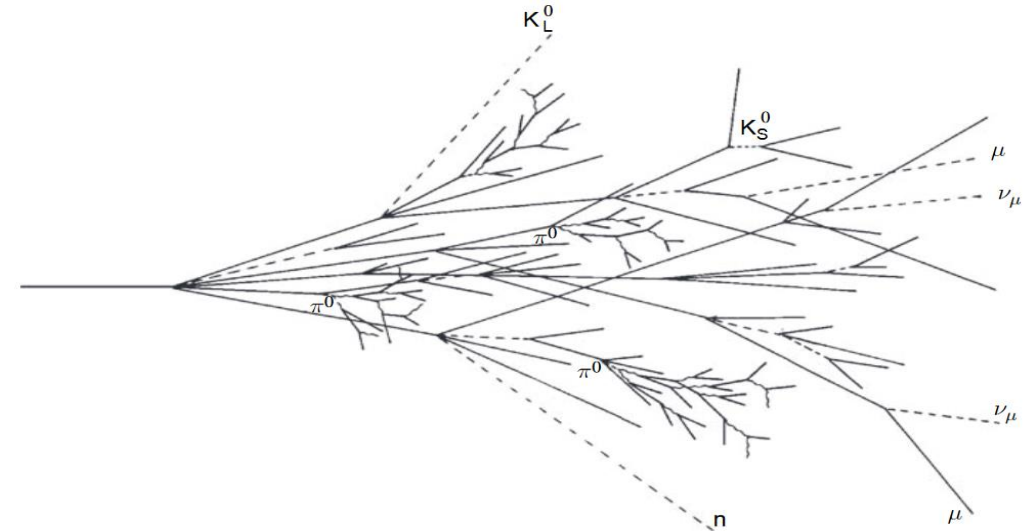
## EM Showers

- Develop via pair production and bremsstrahlung



## Hadronic Showers

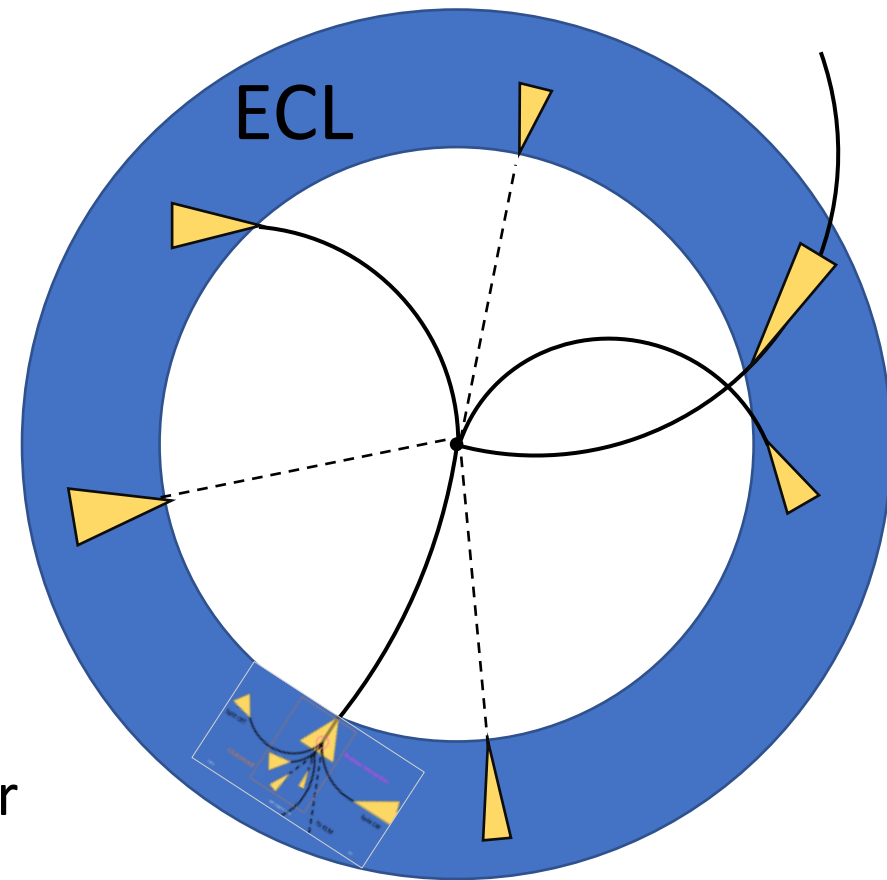
- Develop via nuclear interactions, particle decays, and EM showers



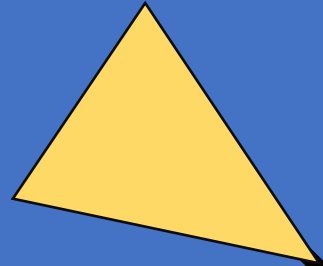
# Hadronic showers in Belle II

- Hadrons are common in Belle II events
- They have ~60% chance of nuclear interaction in ECL
  - Otherwise, will interact with KLM

▼ = EM shower

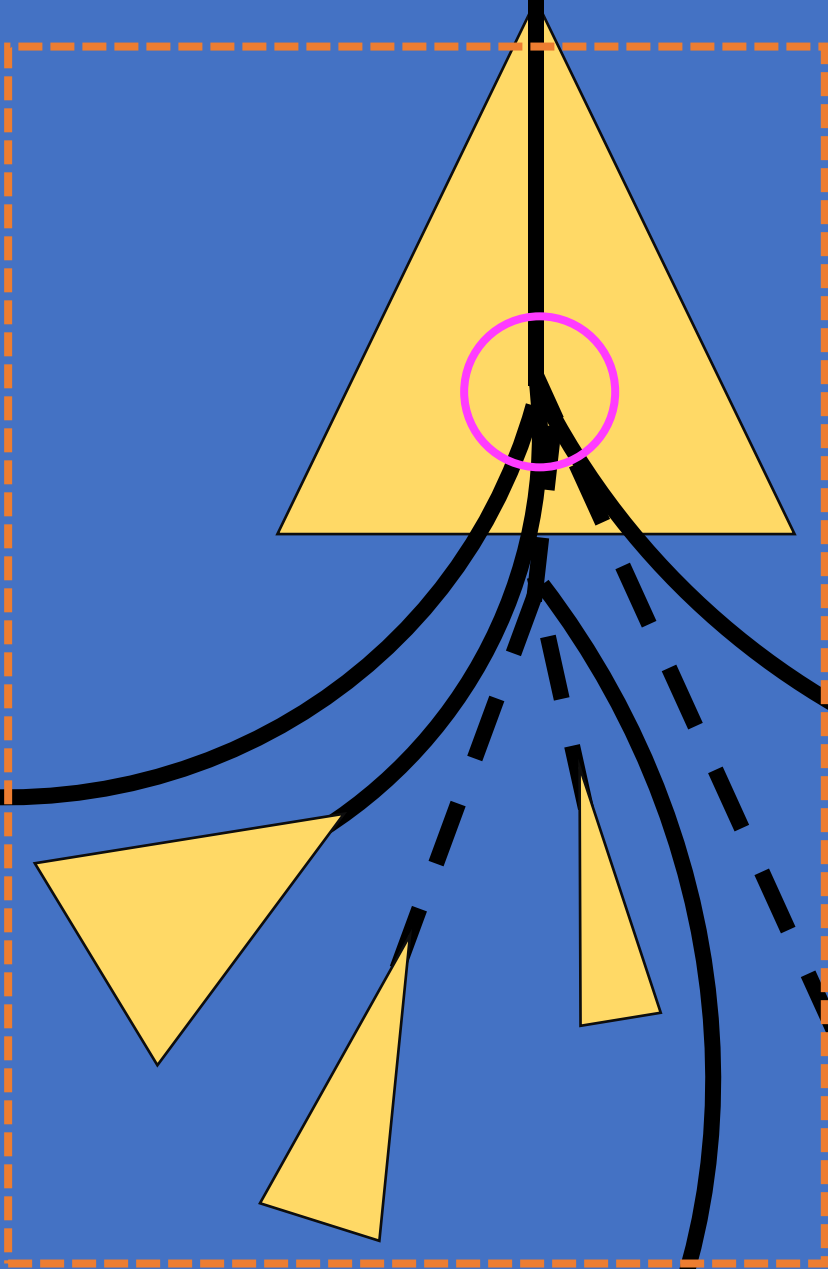


Simplified Event (Beam Perspective)



Split Off

Clusterized



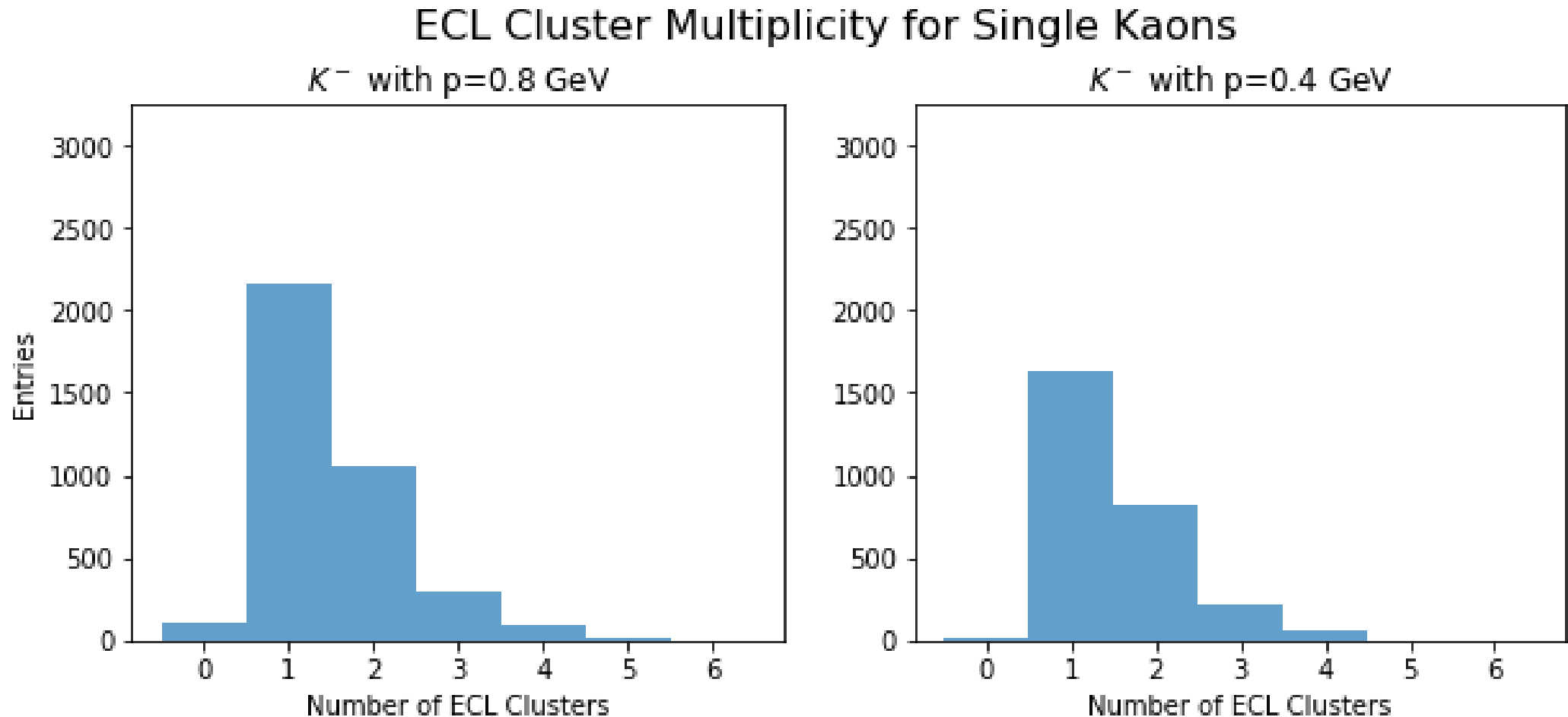
Nuclear interaction

Split Off

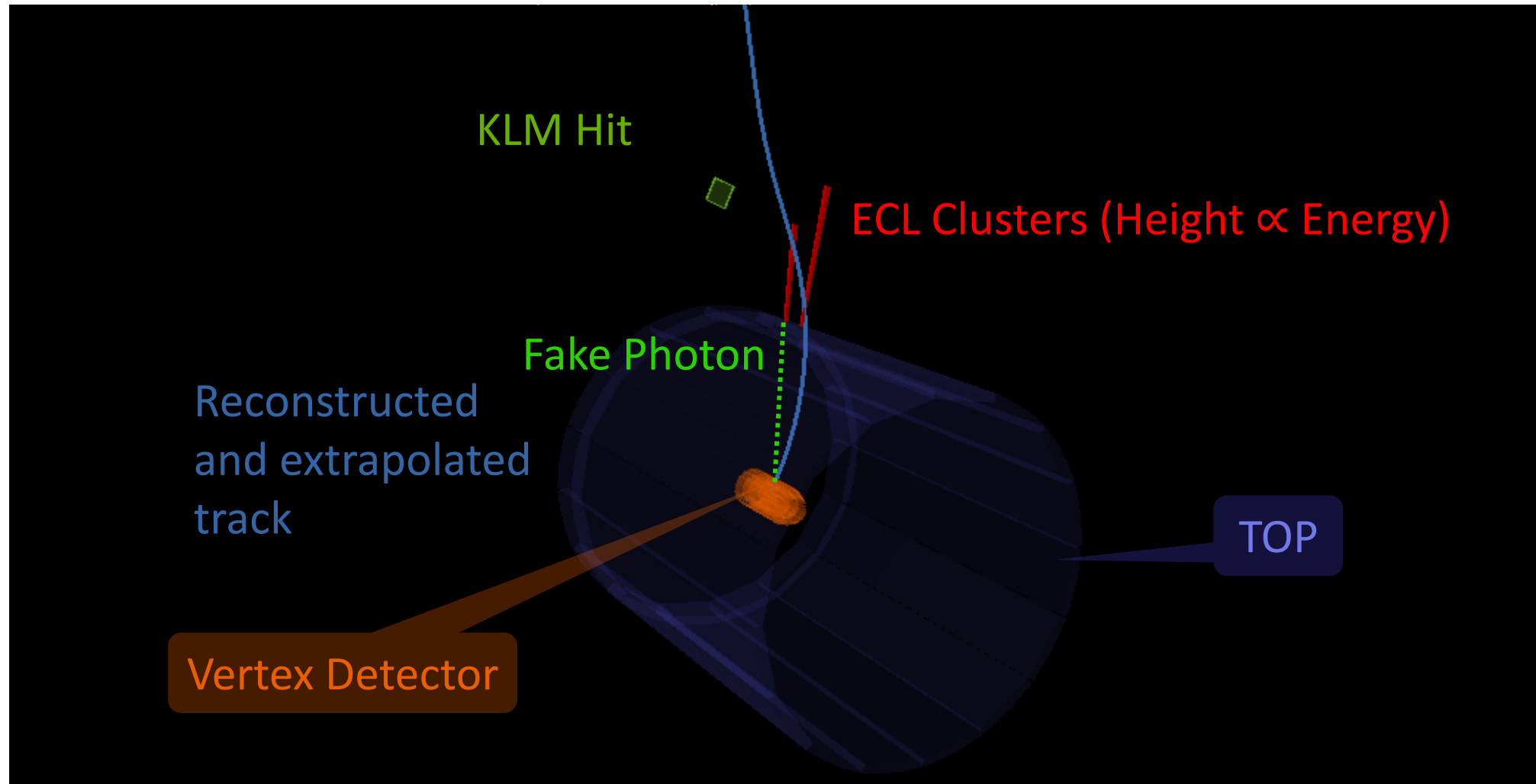
To KLM



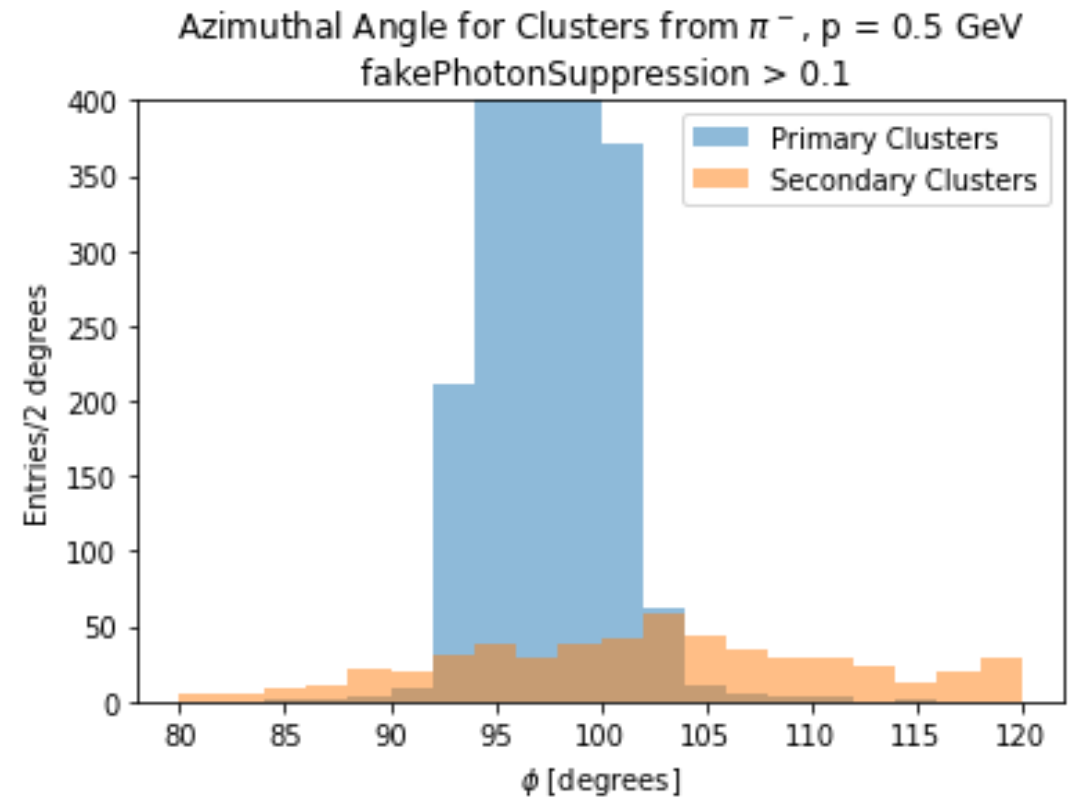
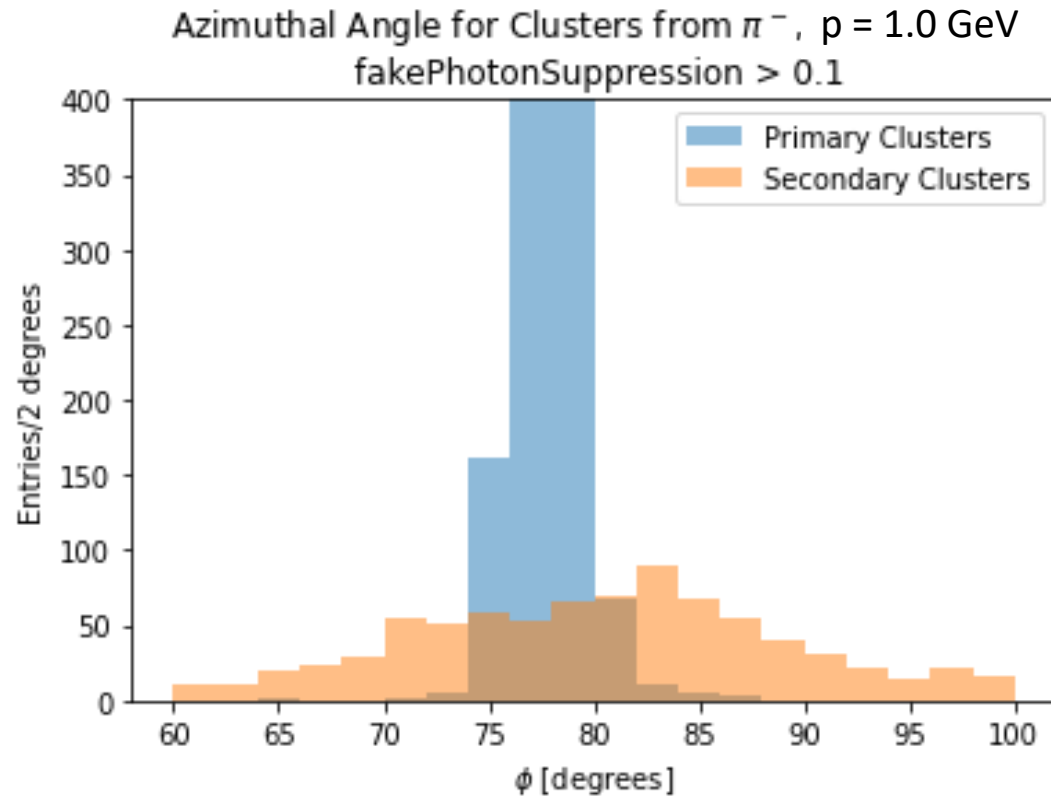
# ECL Cluster Multiplicity for Kaons



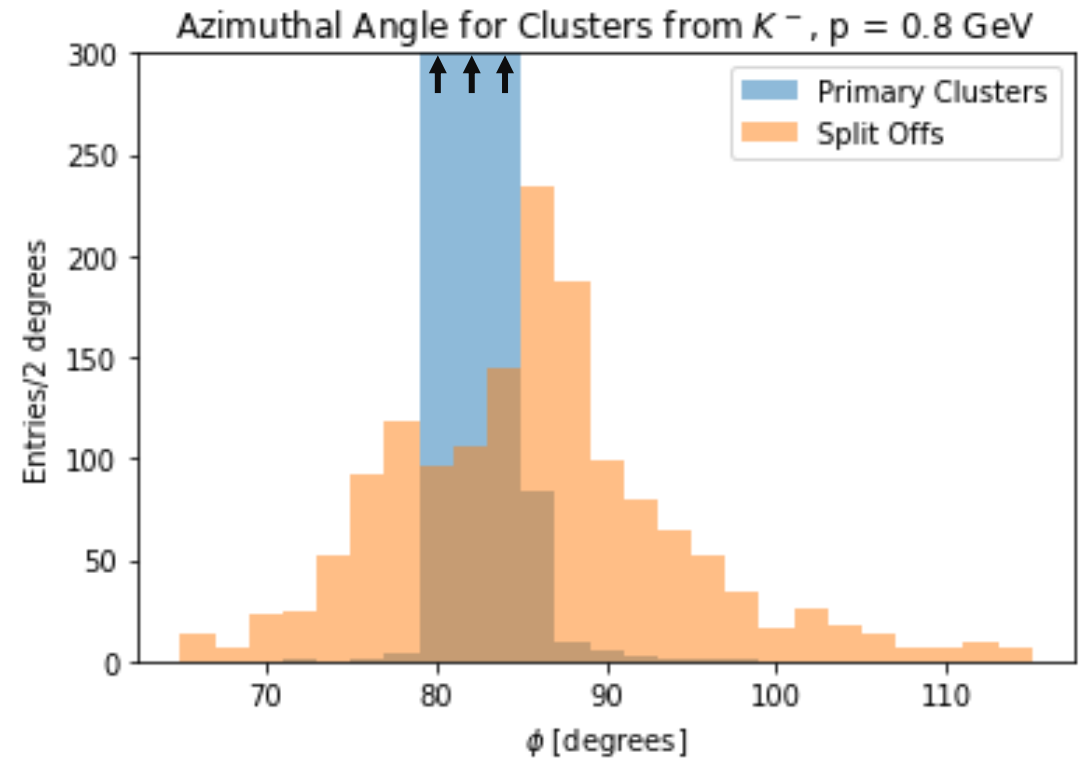
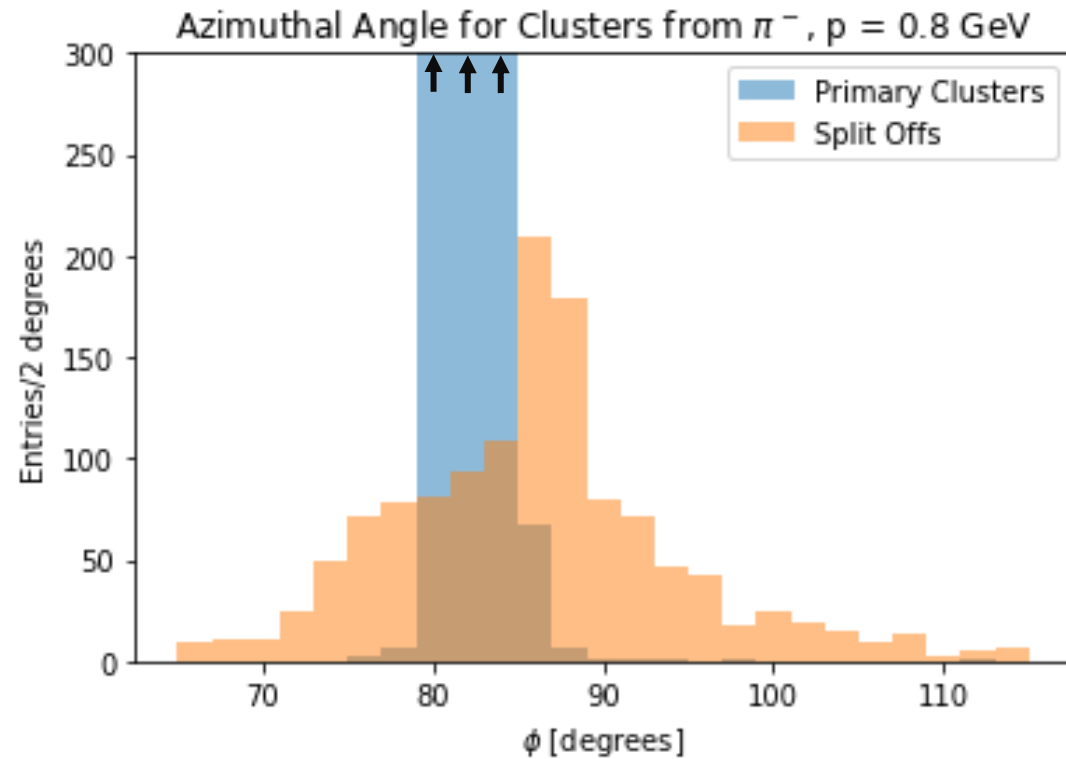
# Split Off from Single Pion



# Split Off from Single Pion



# Particle Type



# KLM Multiplicity

## KLM Cluster Multiplicity for Single Pions

