TRIUMF

ATLAS EXPERIMENT

UBC THE UNIVERSITY OF BRITISH COLUMBIA

Efficiency study of the displaced muon reconstruction for dark photon search with ATLAS detector

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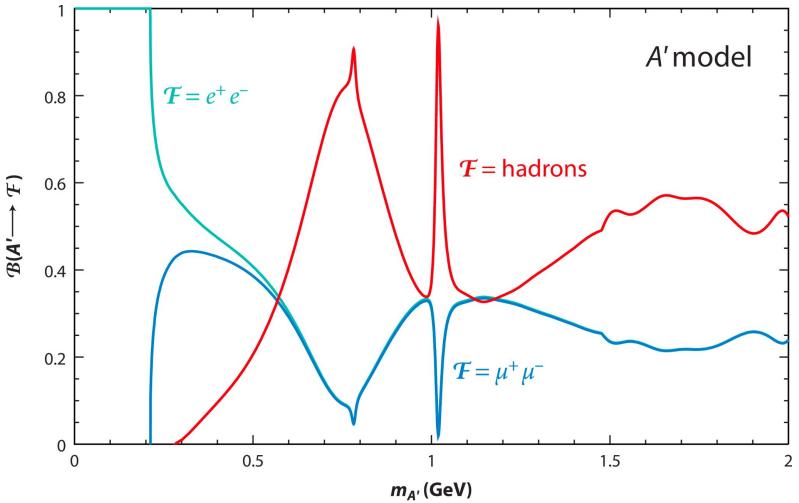
Winter Nuclear and Particle Physics Conference (WNPPC) 2025

Dark photon - a mediator to the dark sector

- One of the simplest mediators in the dark sector
- Complementary to directly detecting DM particles

Massive visible dark photon models

- Naturally long-lived with small coupling and low mass.
- A generic and versatile dark sector benchmark model.



Retrieved from https://arxiv.org/pdf/1801.04847

$$\tau_{A'} \propto \frac{1}{\varepsilon^2 m_{A'}}$$

where , A' denotes the dark photon, m_A is the dark photon mass, and ε^2 is the kinetic mixing strength

Retrieved from https://arxiv.org/pdf/1801.04847

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A mediator to the dark sector

Direct production (minimal model)

Production rate is suppressed by kinetic mixing.

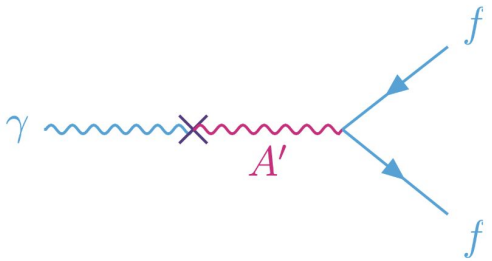


Figure 2: Feynman Diagram created by Kehang Bai

Exotic Higgs Production (HAHM)

Production rate is protected by Higgs cross section.

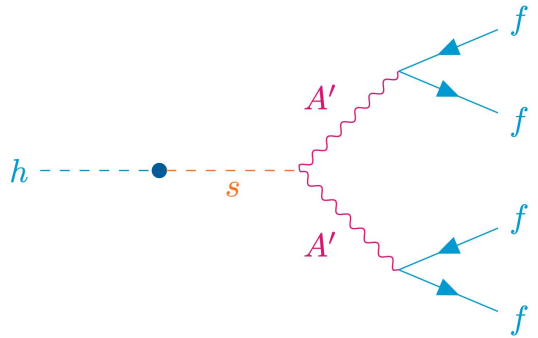


Figure 3: Feynman Diagram created by Kehang Bai

Definitions

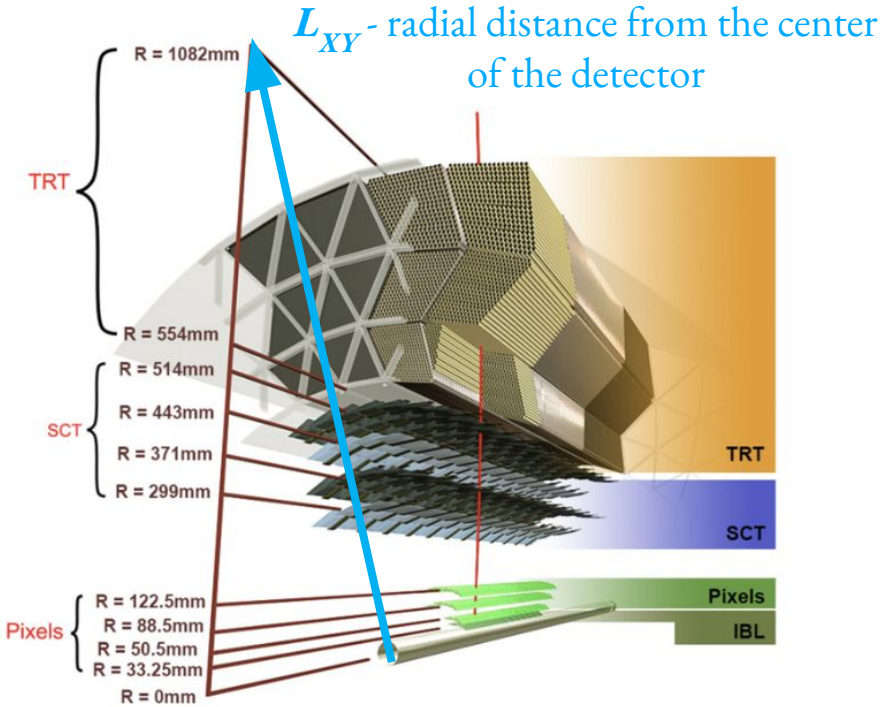


Figure 5: The structure of the ATLAS Inner Detector, ATLAS Collaboration,1

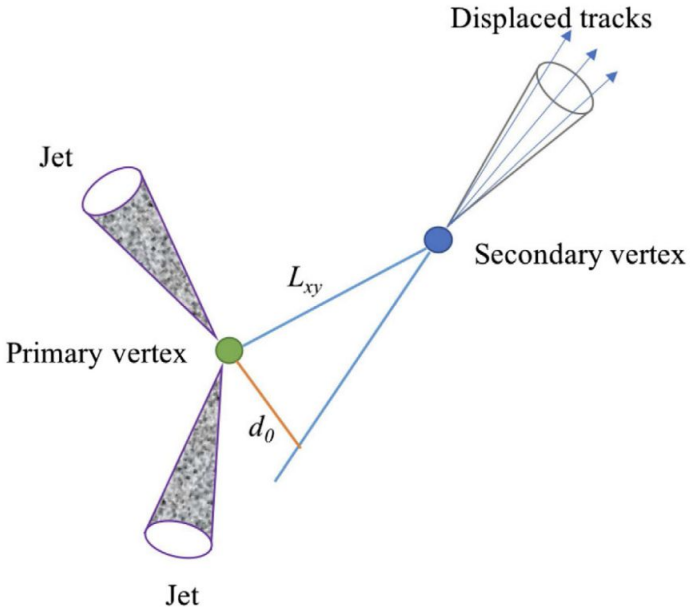
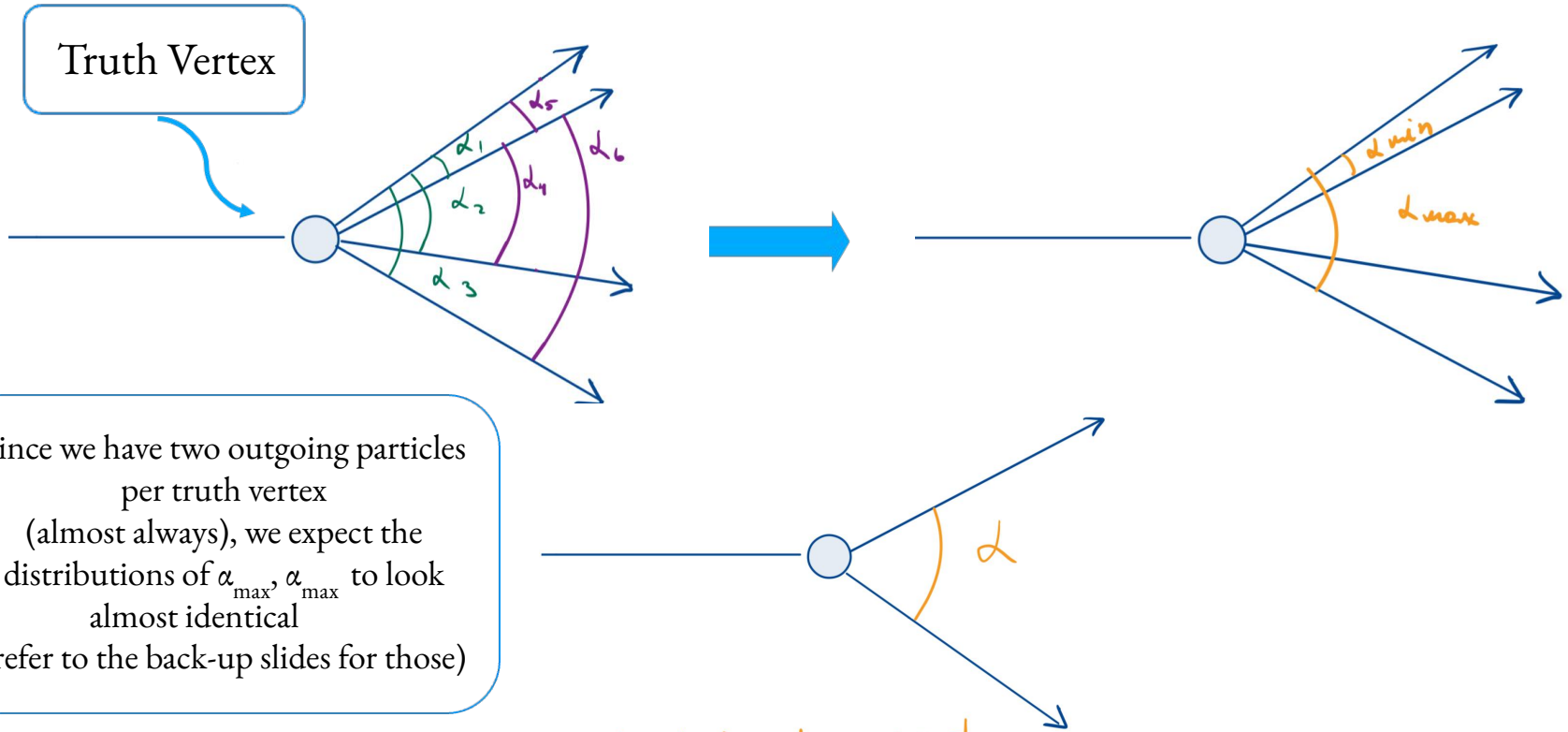


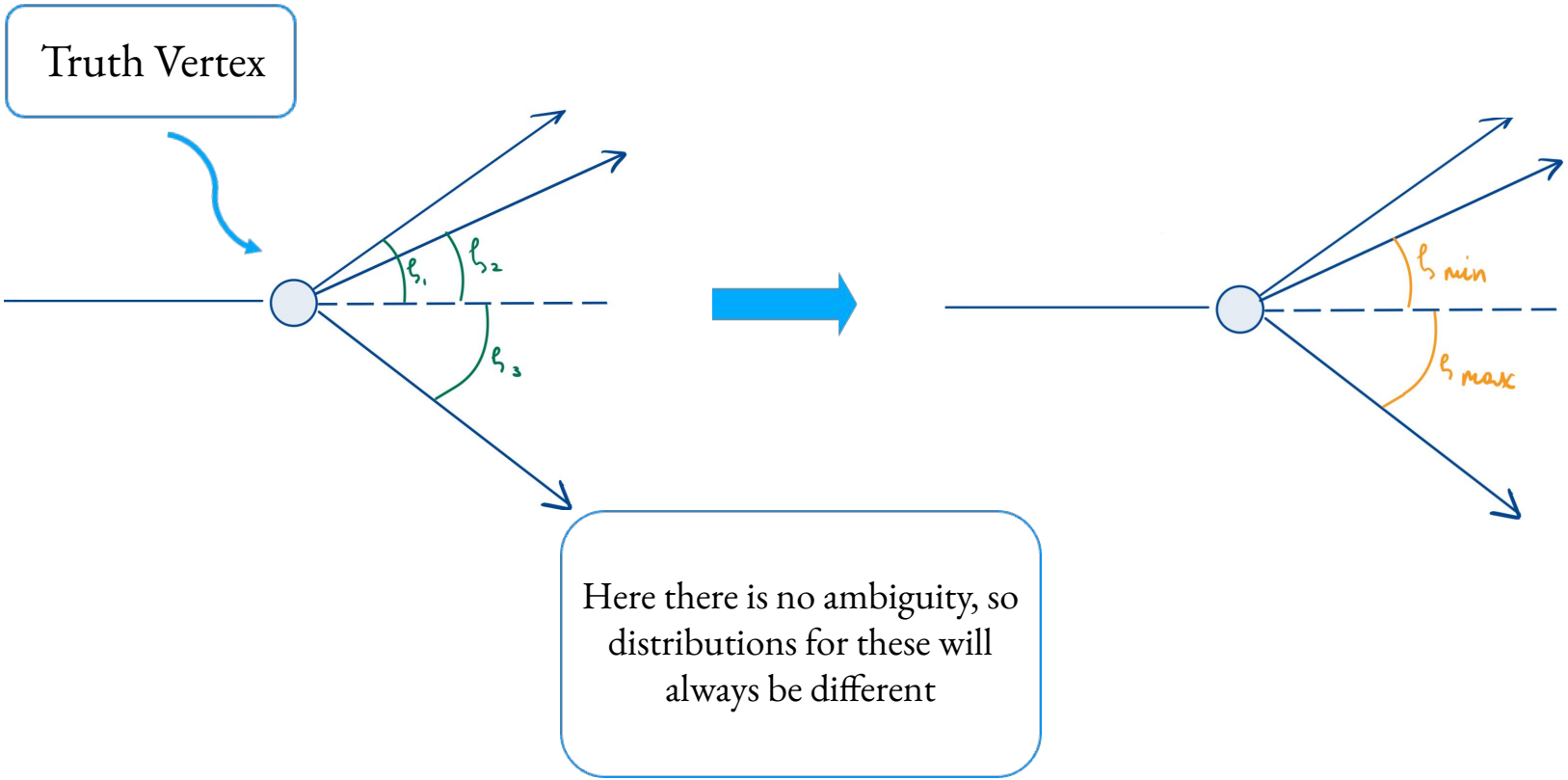
Figure 6: Schematic diagram for the LLP displaced vertex, retrieved from Abdallah et al. (2018), 2

Schematic Definitions of Observables α_{max}, α_{min}



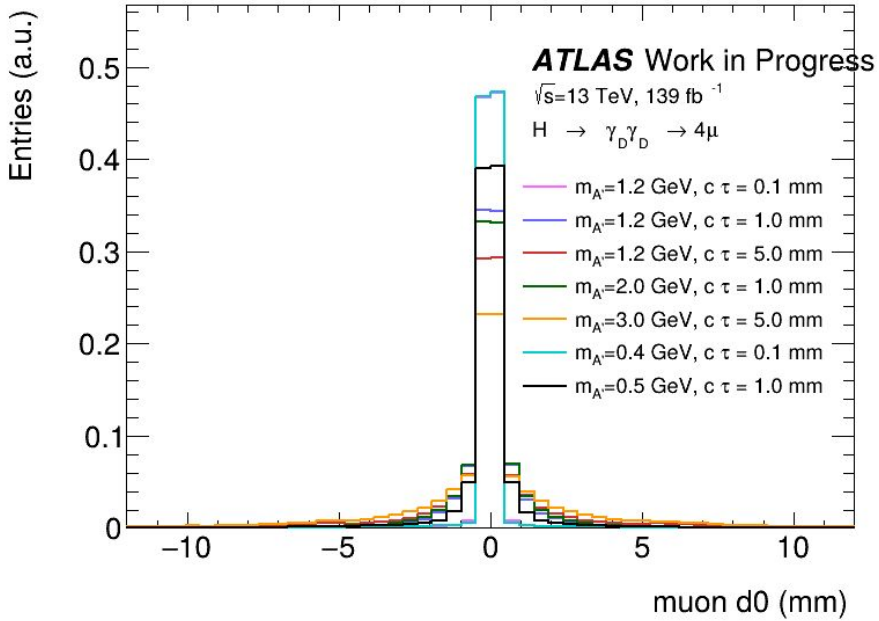
Since we have two outgoing particles per truth vertex (almost always), we expect the distributions of α_{max}, α_{max} to look almost identical (refer to the back-up slides for those)

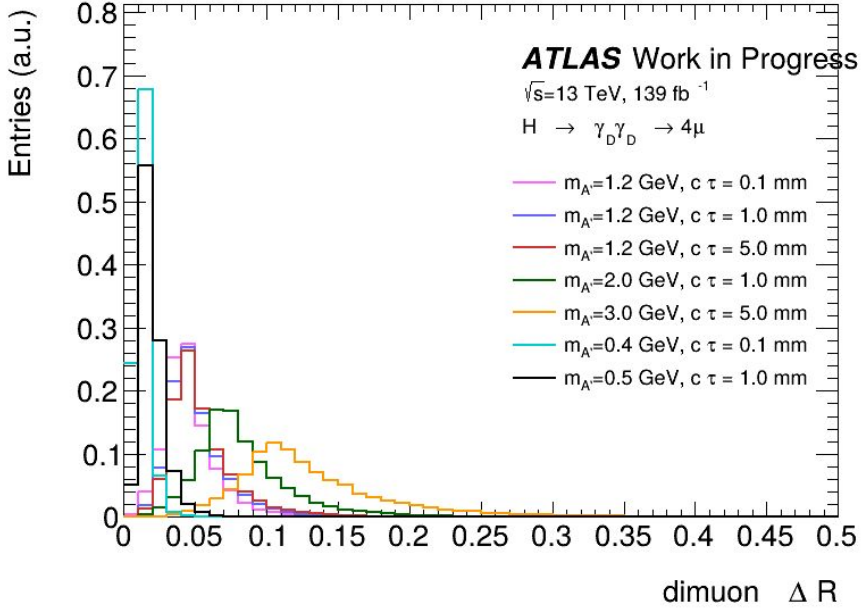
Schematic Definitions of Observables ζ_{max}, ζ_{min}



Our signature

- ➔ Muons are boosted and collimated, with small d0.
- ➔ Vertex displacement within Lxy $\in$ [1, 300] mm.
- ➔ Use prompt + LRT single-muon OR di-muon triggers.

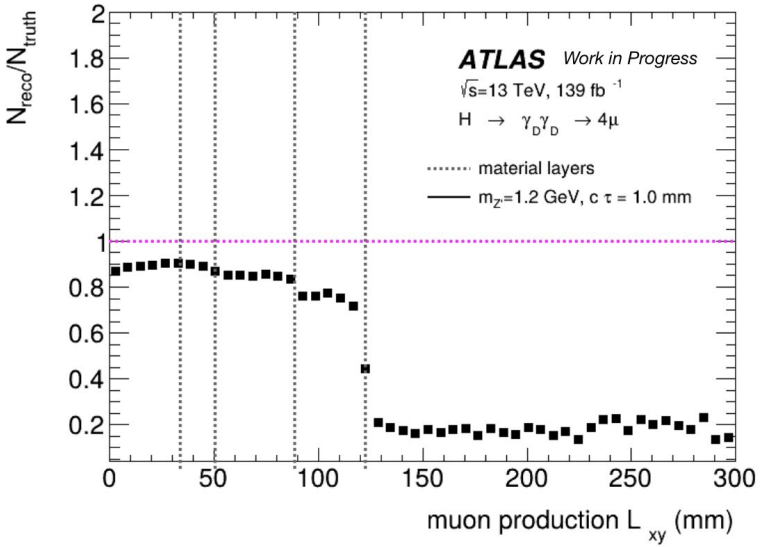




Muon Reconstruction Challenge 1

Low muon reco efficiency past the last pixel layer

- Standard combined muon reconstruction requires at least 1 pixel hit.
- Muons with small d0 are not reconstructed as Large Radius Tracking (LRT) muons.
  - Hence, we get hit by this efficiency problem.

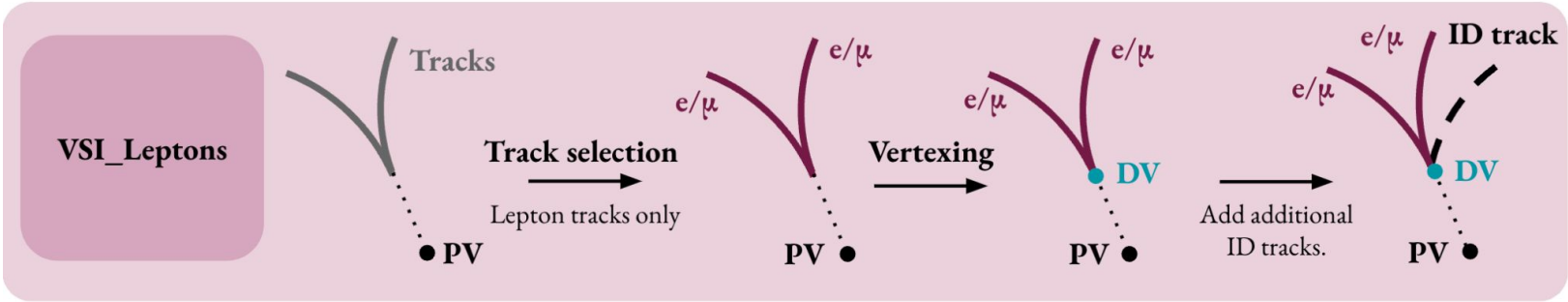


Plot by Kehang Bai

Muon Reconstruction Challenge 2

Existing Vertex Secondary Inclusive (VSI) Algorithm configurations are not applicable for low-d0 tracks

- Our signal requires a relaxed 2-track-forming d0 cut (now set to 0).
- Need other additional selections on muons and Displaced Vertices (DV) to reject prompt vertices.
- Potentially recover zero-pixel-hit muons, and add other features.



VrtSecInclusive_SecondaryVertices_Leptons

Figure 4: VSI_Lepton Flow Diagram by Kehang Bai

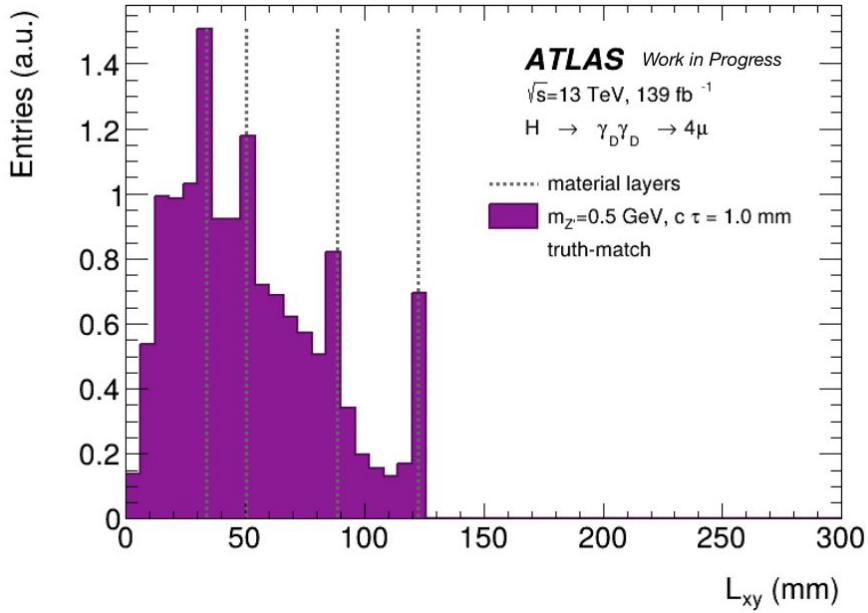
Muon Reconstruction Challenge 3

Vertex position uncertainty is larger in the direction of the track trajectory.

- Collimated tracks will have shared hits when their vertex forms right before a pixel layer

  → has a tendency to pull the DV towards that layer.

- Large signal loss if naively apply material veto. Need a customized configuration based on VSI_Leptons.



Plot by Kehang Bai

Efficiency Studies

To study efficiency of muon reconstruction, we proceeded by

- Defining the types of truth reconstructed muons we store
- Identifying relevant kinematic distributions of the truth muons
- Defining total tracking and vertex efficiencies as the following ratios

$$\epsilon_{\text{tracking}} = O^{\text{Reconstructed}}/O^{\text{Reconstructable}},$$

$$\epsilon_{\text{vertexing}} = O^{\text{Reconstructed}}/O^{\text{Accepted}}$$

where O is a kinematic observable

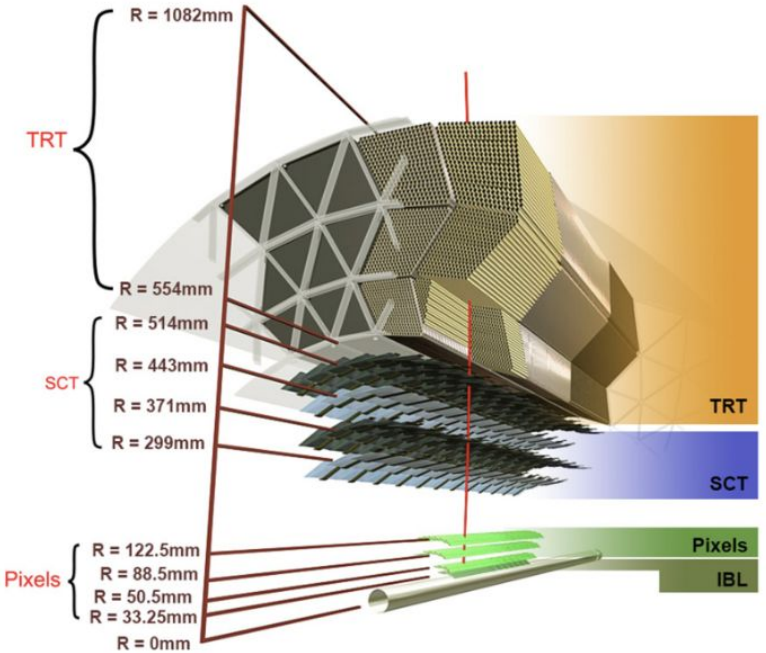


Figure 5: The structure of the ATLAS Inner Detector, ATLAS Collaboration,1

Vertex Definitions

Vertex Definition	Requirements
Inclusive	All vertices
Reconstructible	Fiducial cuts, ≥ 2 charged daughters
Accepted	Reconstructible and ≥ 2 reconstructed tracks
Reconstructed	Reconstructed and matching to the reconstructed vertex

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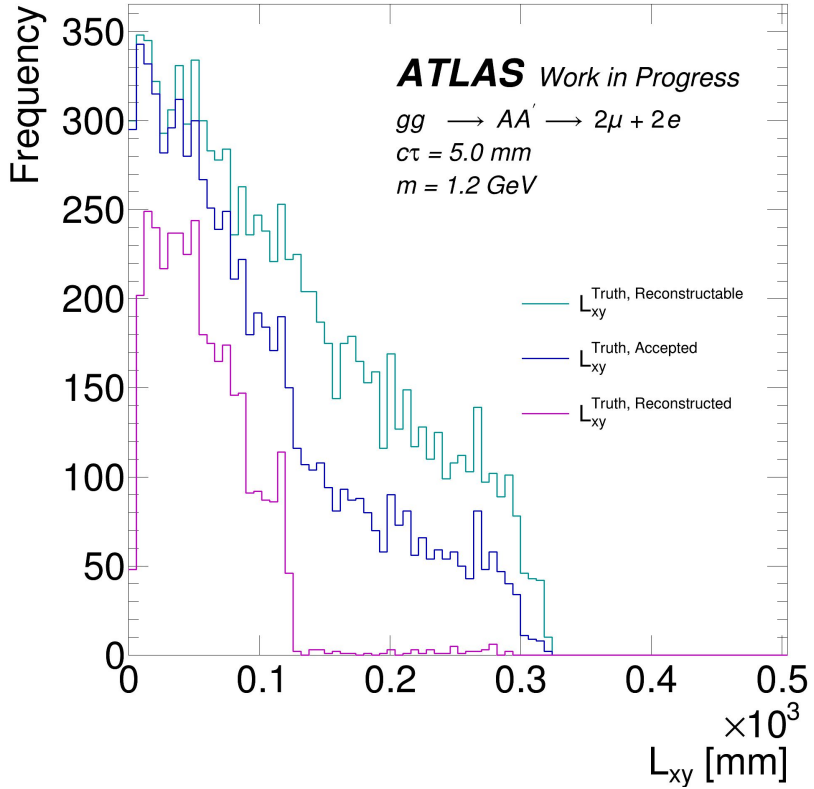
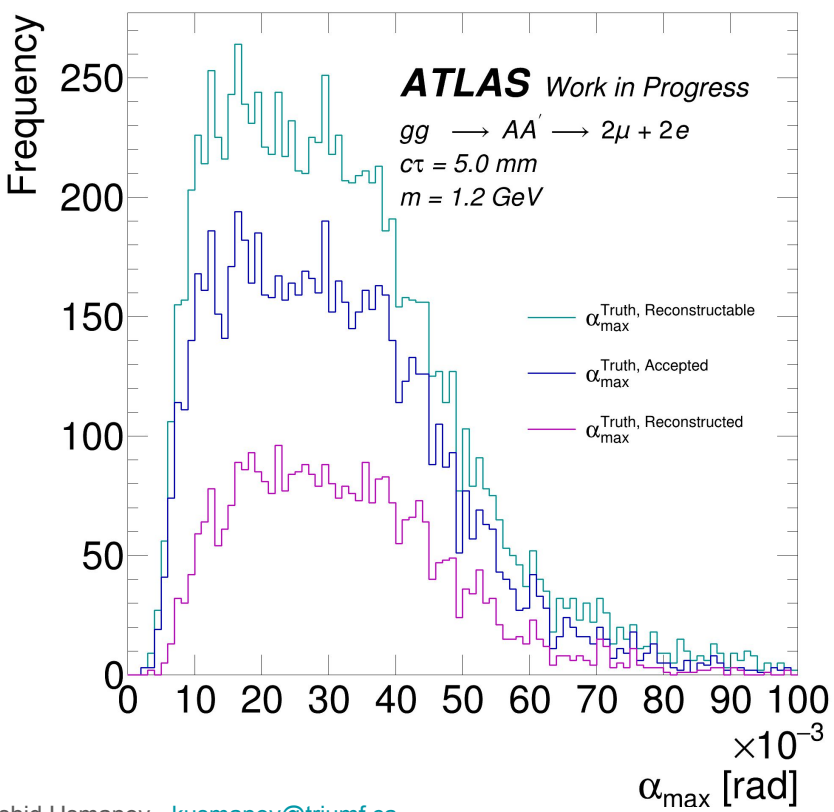
Distributions for L_{XY}

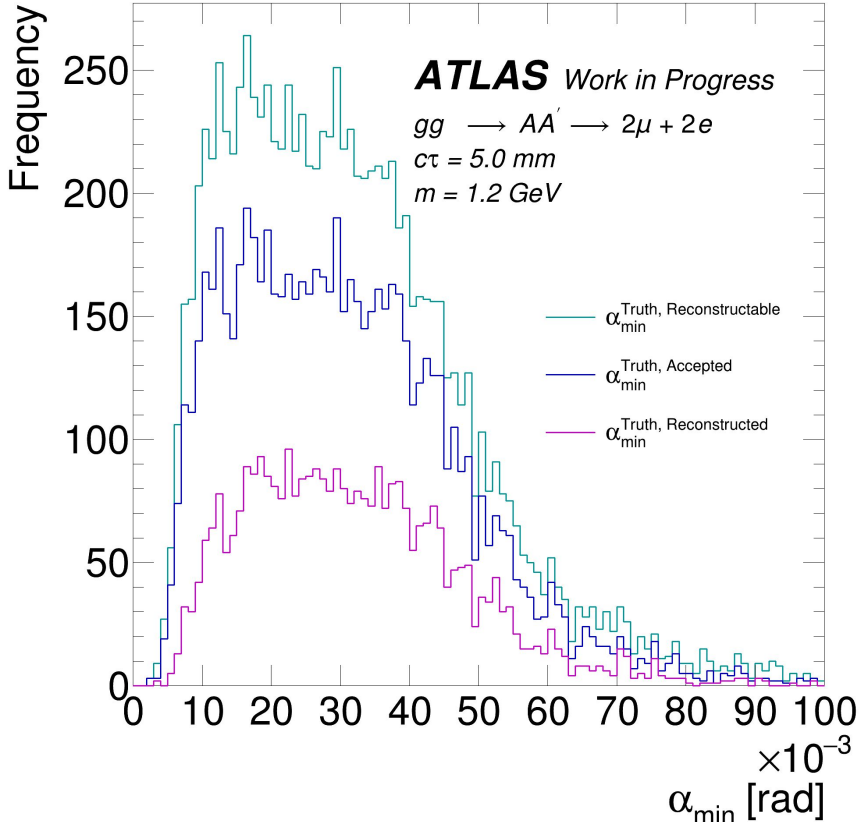
Plotting distributions of types of truth reconstructed muons as a function of L_{XY}, we can confirm once again:

- The distribution truth reconstructed muons falls off at 122.5 mm (the last pixel layer)
- While truth reconstructible and truth accepted distributions fall around 322 mm (the SCT)



Distributions for α





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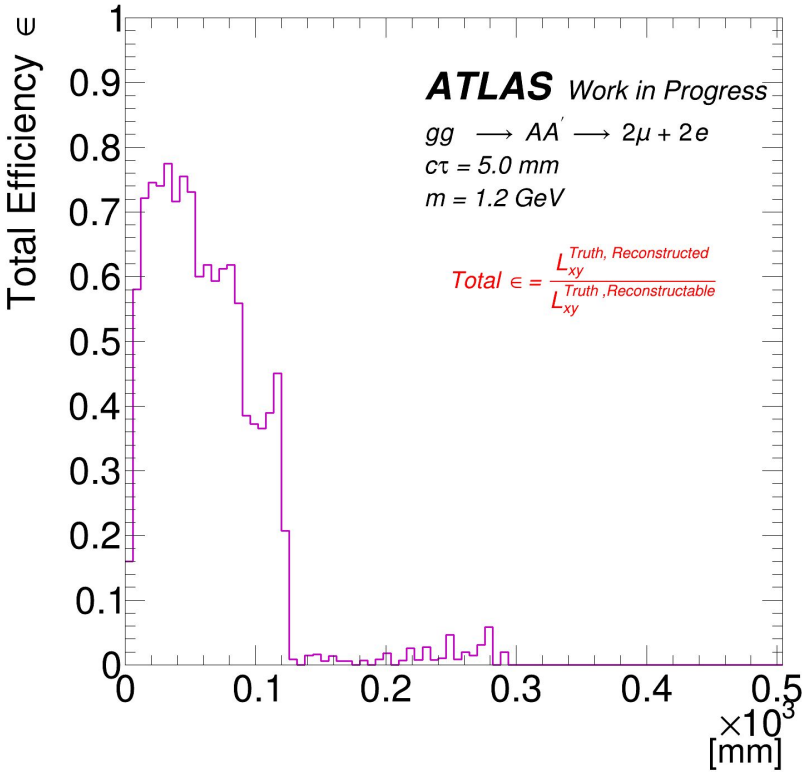
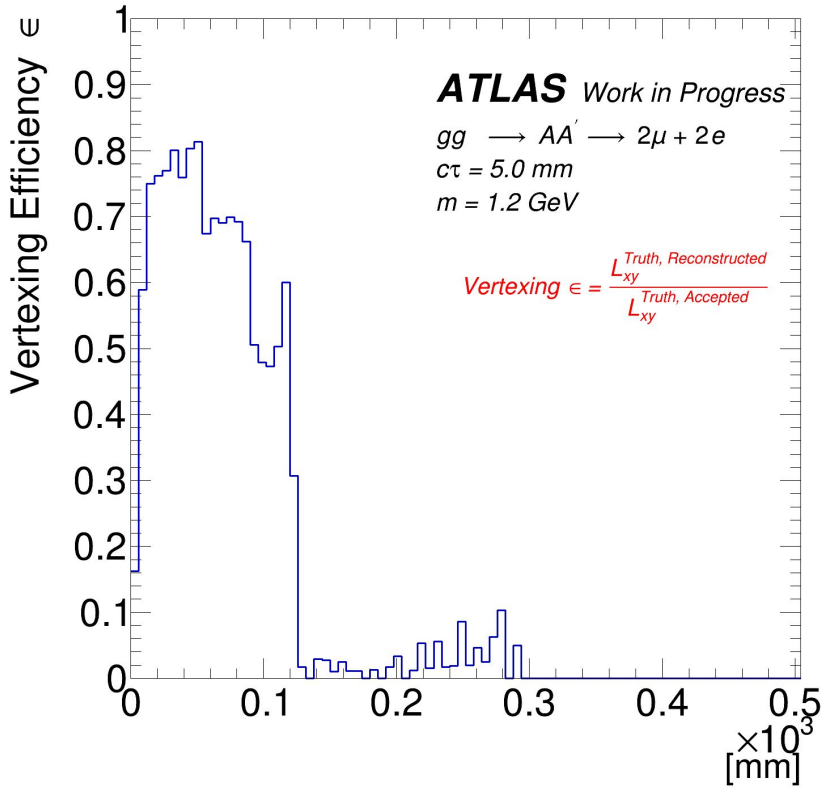
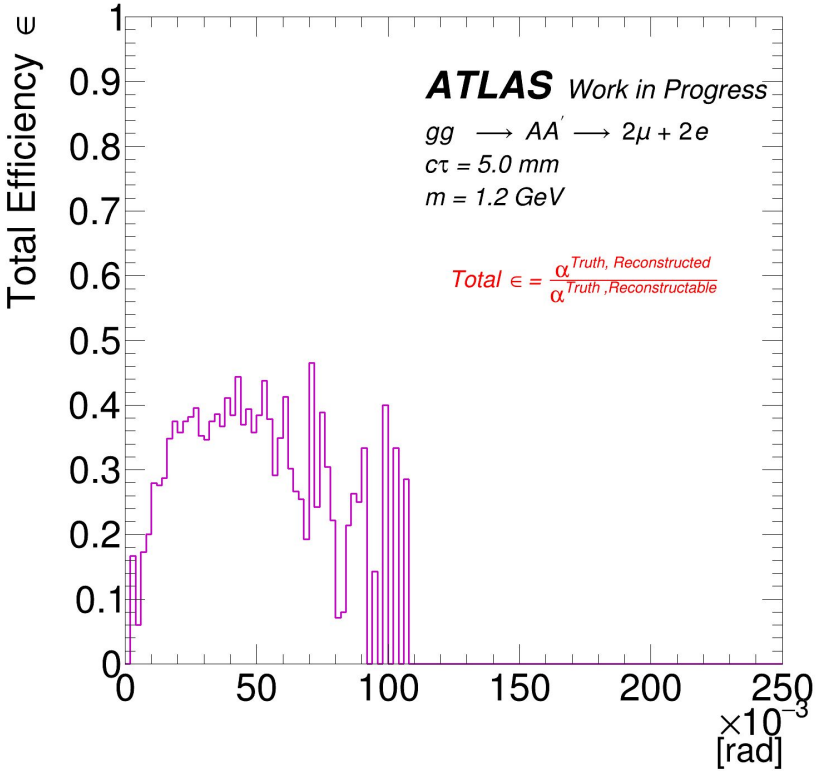
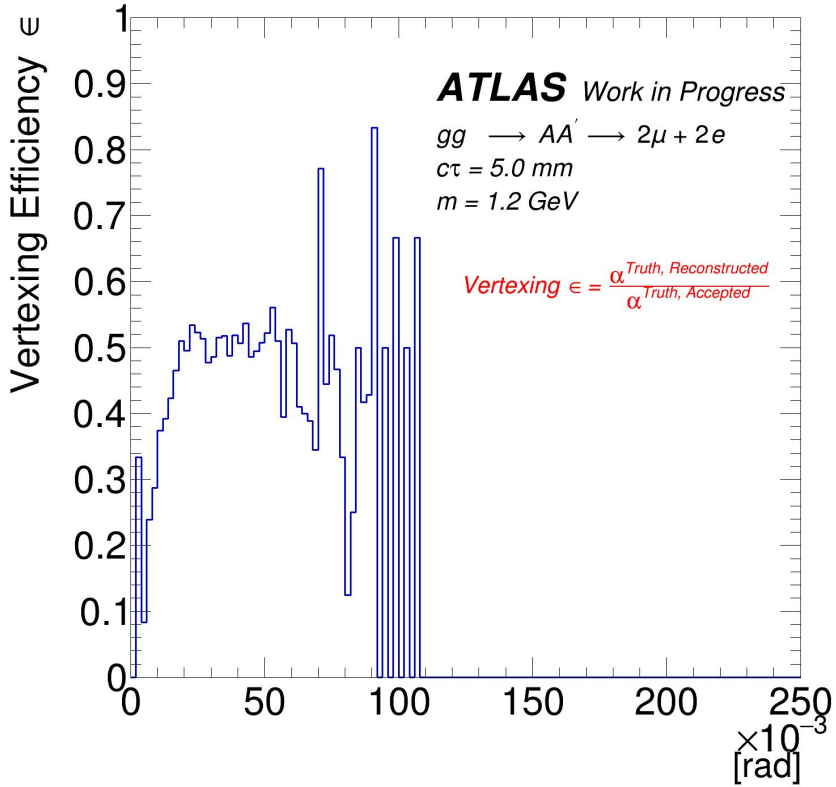
Efficiency Plots for L_{XY}



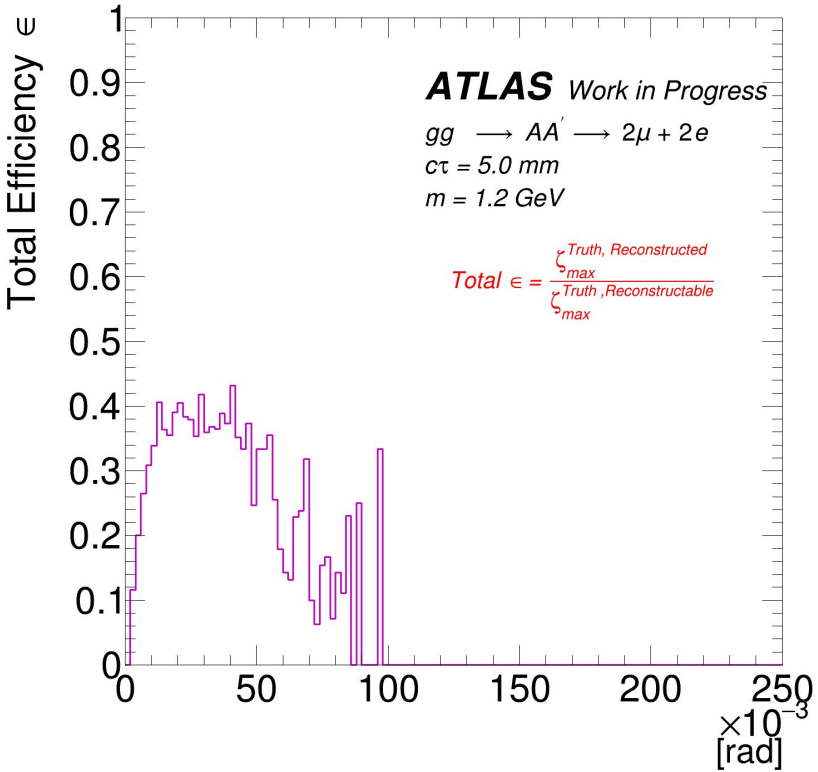


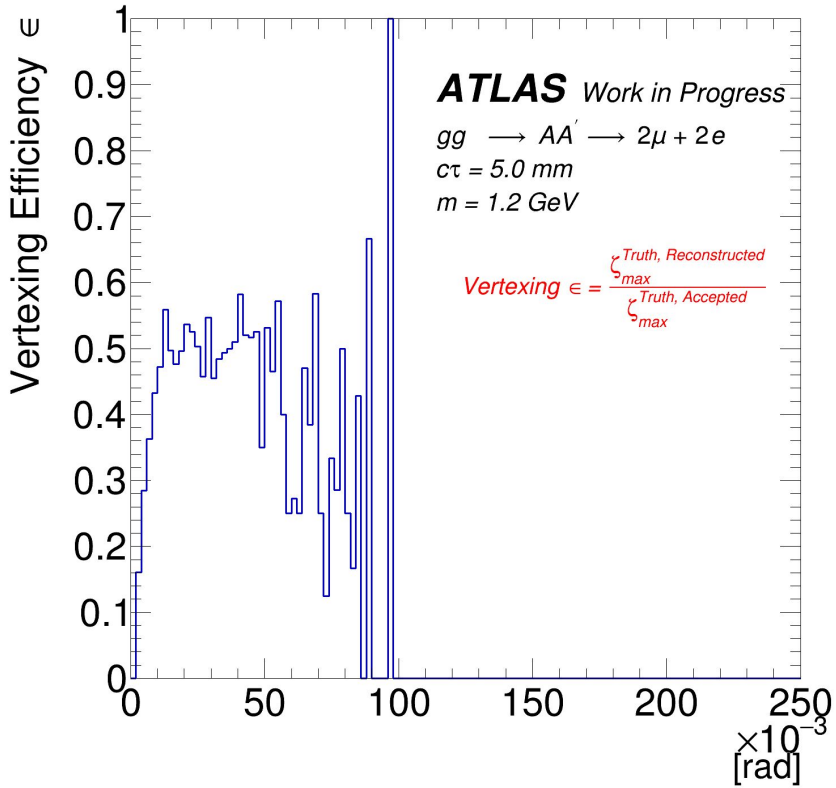
Efficiency Plots for α (opening angle)



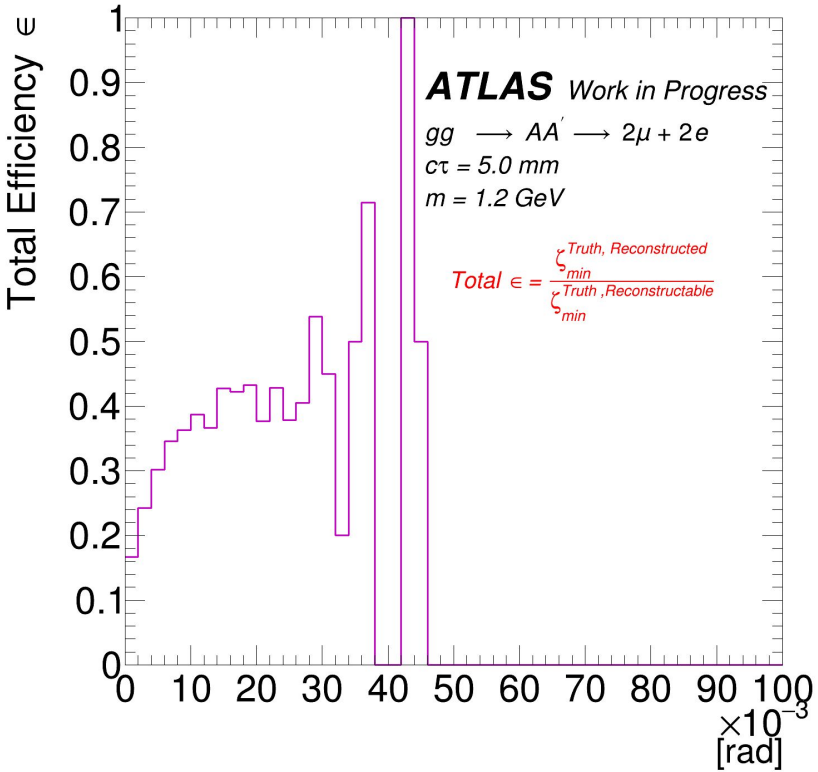


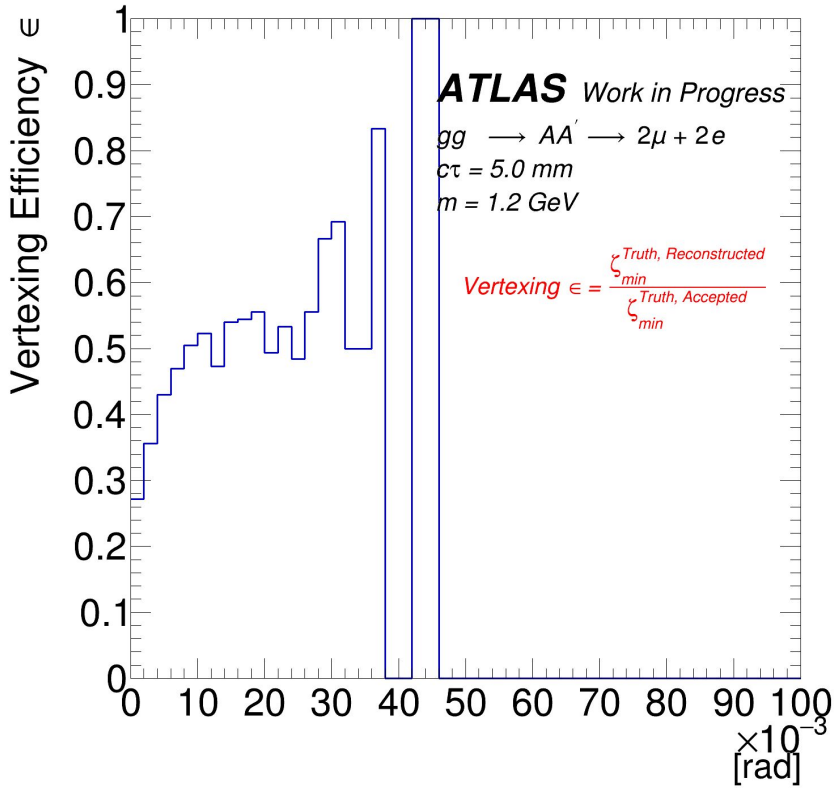
Efficiency Plots for ζ_{max}





Efficiency Plots for ζ_{min}





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Conclusion

We have unique challenges that affect the muon reconstruction past the last pixel layer which demonstrate a falling efficiency. Hence the next steps in our study are:

- ➔ Expand vertex definitions (slide 11) and as a result store larger collection of truth muons
- ➔ Come up with more kinematic variables as a function of the efficiency

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Thank you!

Khurshid Usmanov supervised by Colin Gay and Katherine Pachal

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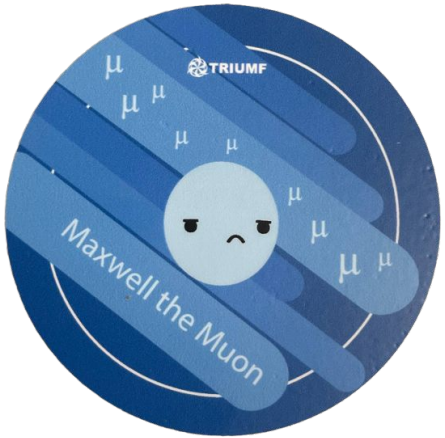
References

1. *ATLAS schematics Structure of the ATLAS Inner Detector*. (n.d.). ATLAS Experiment at CERN. https://atlas.cern/Resources/Schematics
2. Abdallah, W., Hammad, A., Kasem, A., & Khalil, S. (2018). Long-lived B−L symmetric SSM particles at the LHC. *Physical Review. D/Physical Review. D.*, *98*(9). https://doi.org/10.1103/physrevd.98.095019
3. *ATLAS schematics Structure of the ATLAS Detector*. (n.d.). ATLAS Experiment at CERN. https://atlas.cern/Resources/Schematics

Questions?



This Muon looks happy...

Backup Slides

ATLAS Detector

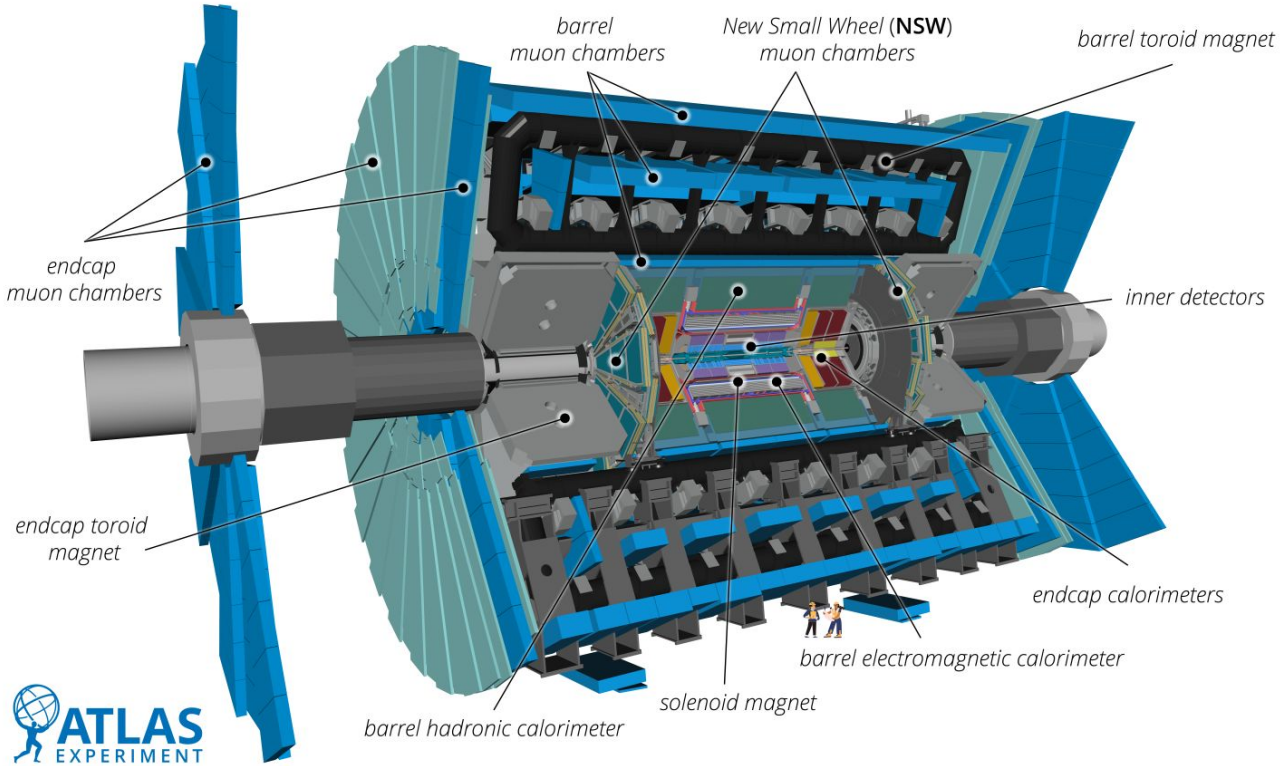
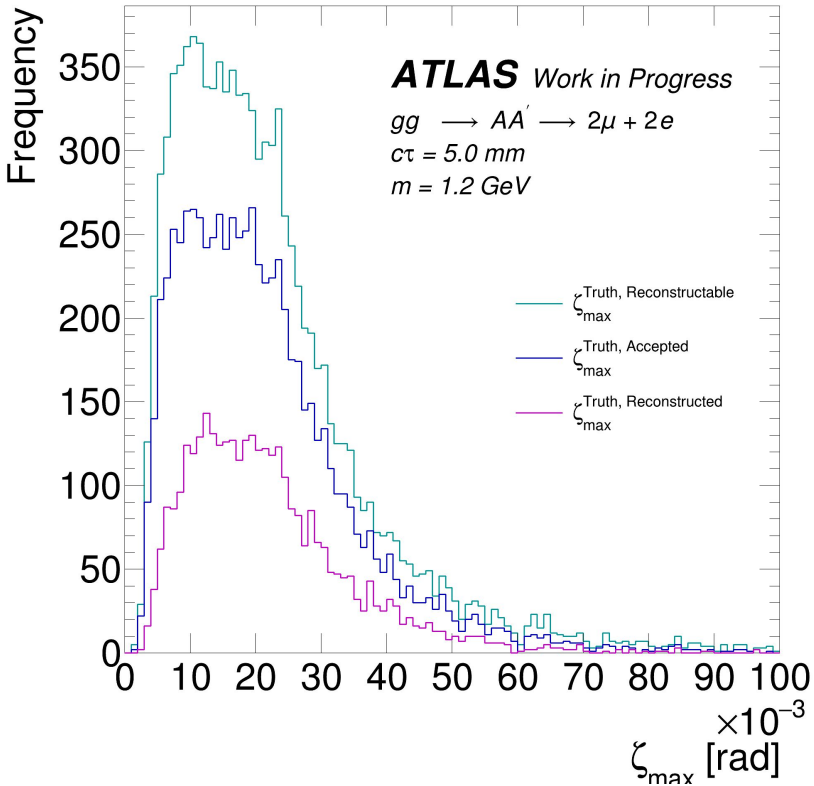
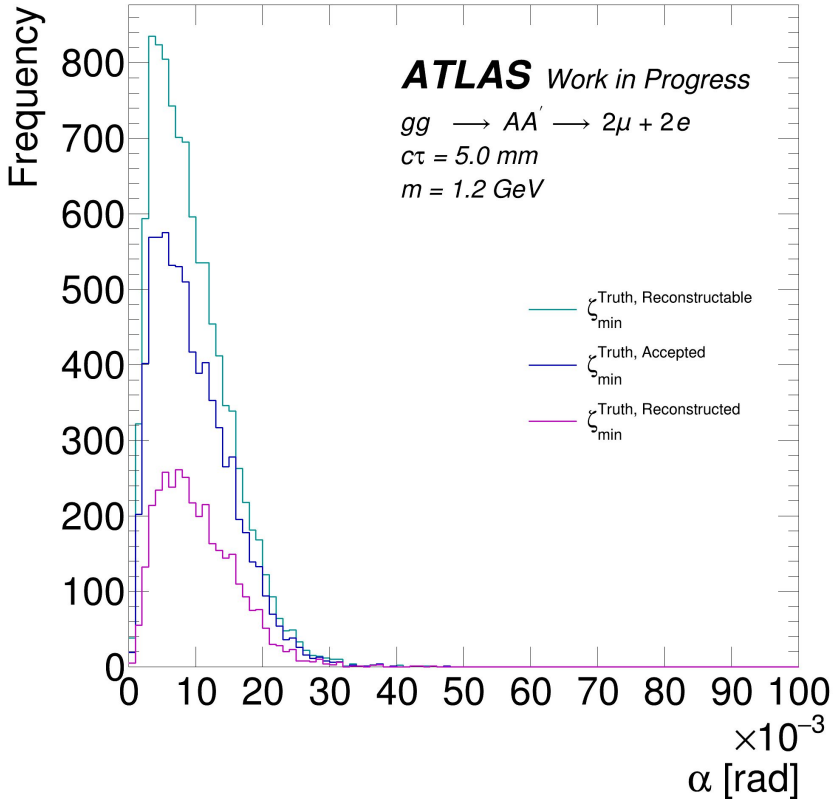


Figure 6: The structure of the ATLAS Detector, ATLAS Collaboration, 2

Distributions for ζ_{max} , ζ_{min}





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