Search for Missing Materials in LHCb Run3 Simulation

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Supervisor: Mengzhen Wang, Menglin Xu

Outline

- Motivation
- Warm Up
  - Data vs. MC with $J/\psi \rightarrow \mu\mu$
- Tomography
  - Downstream tracks
  - T tracks
- Other Contributions
- Conclusion

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Motivation

- MC of LHCb **Run3** have some potential **misdescriptions**
  - Too idealized
  - ……
  - Missing materials
- Precise **material description** is vital to
  - Lowering uncertainty for m_Z measurement [arXiv:2505.15582]
  - Reducing background in searches for **LLP**s [PRL.**116.**251803]
  - Identifying jets from B & C quarks [JINST 10(2015)P06013]
  - ……
- We need to probe this missing materials in **Run3 simulation**!

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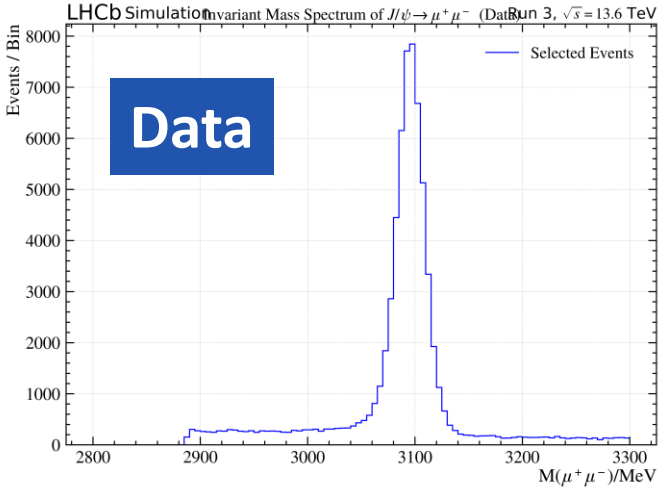
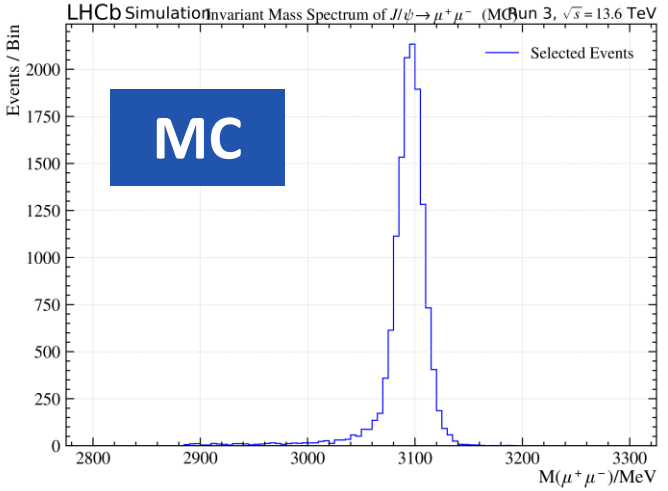
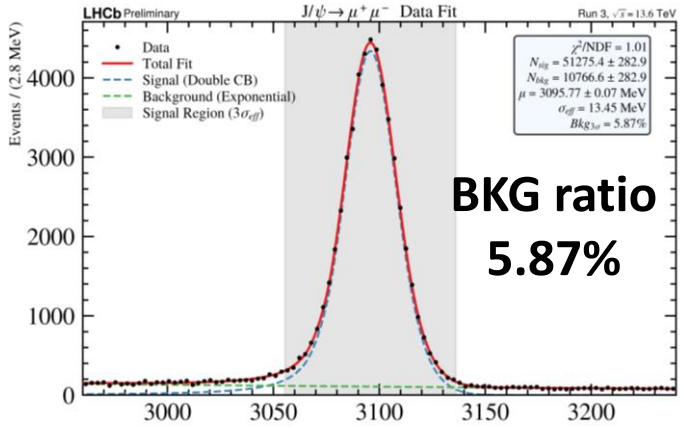
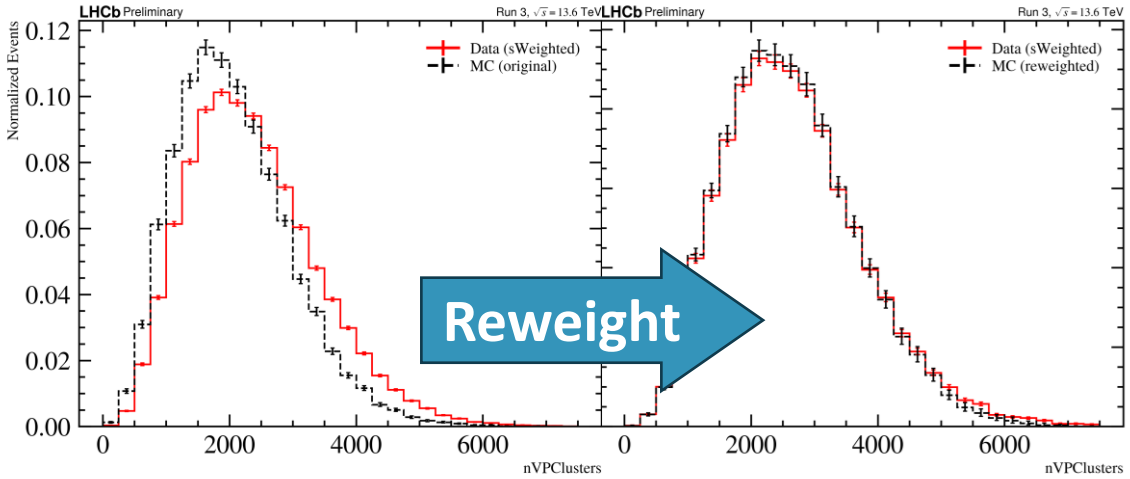




Selection & Fit of $J/\psi \to \mu\mu$

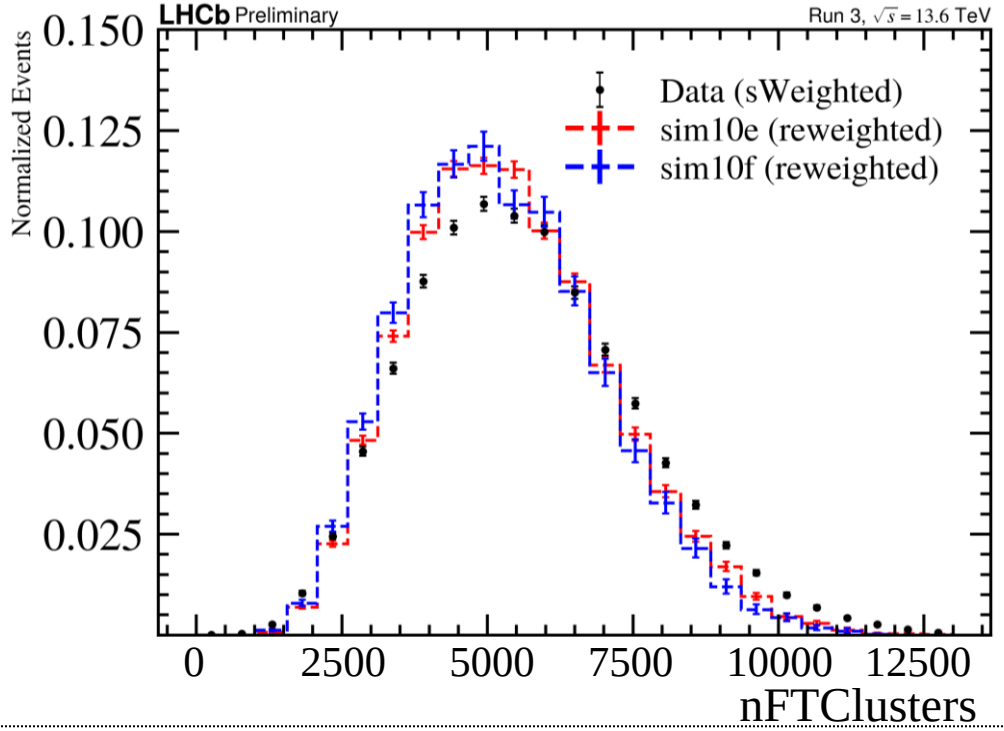
- **Selection**
  - cut are applied to **select signal** and **reduce BKG noise**
- **Fit**
  - Signal ~ Double Crystal Ball
  - BKG ~ Exponential
- **Reweight**
  - $p_T(J/\psi)$, $\eta(J/\psi)$, **nVPClusters**
  - 1st order correction at generator

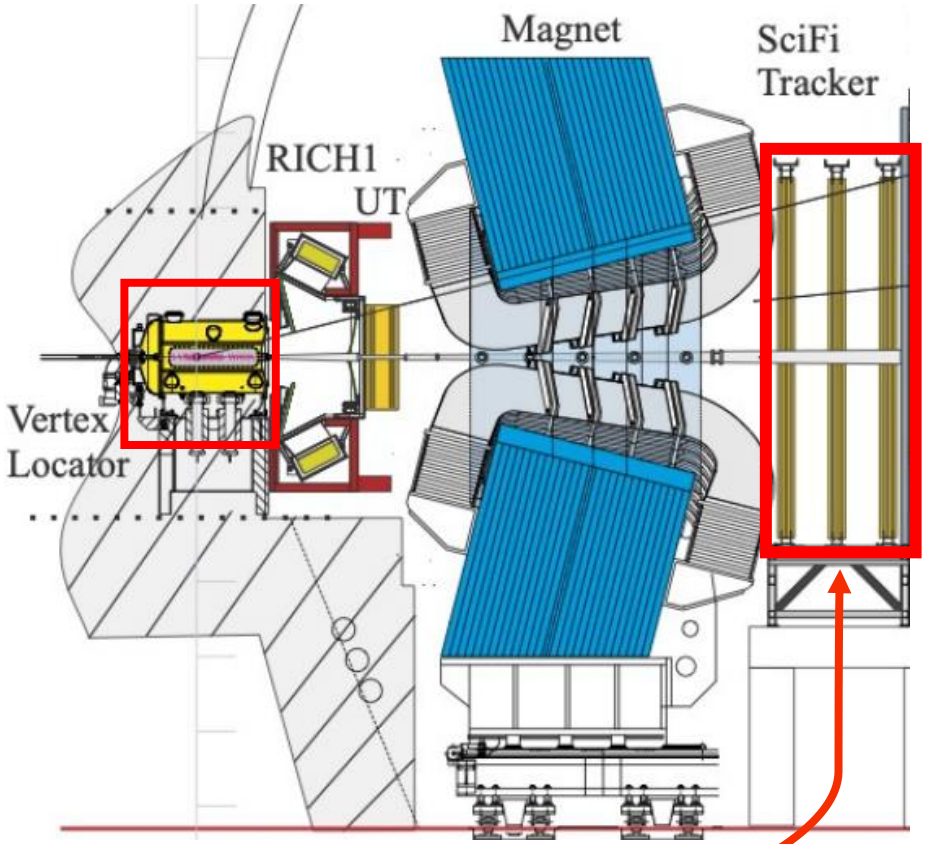




SciFi Clusters

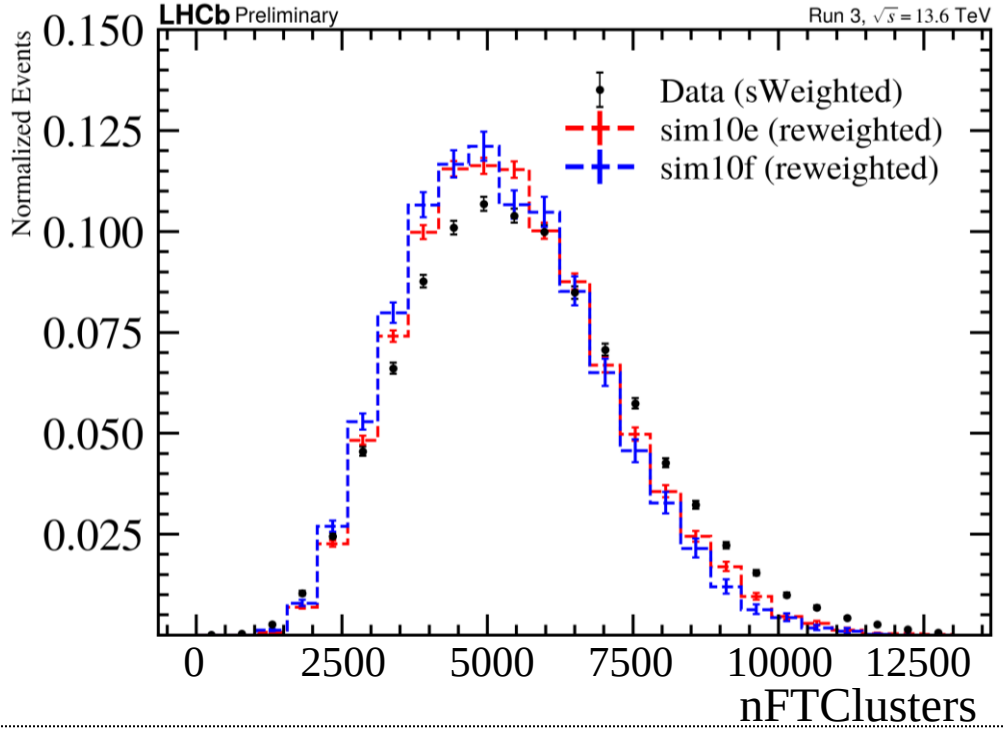
- Cluster Number of **Velo**
  - Already reweighted
- Cluster Number of **SciFi**
  - Data is busier than MC

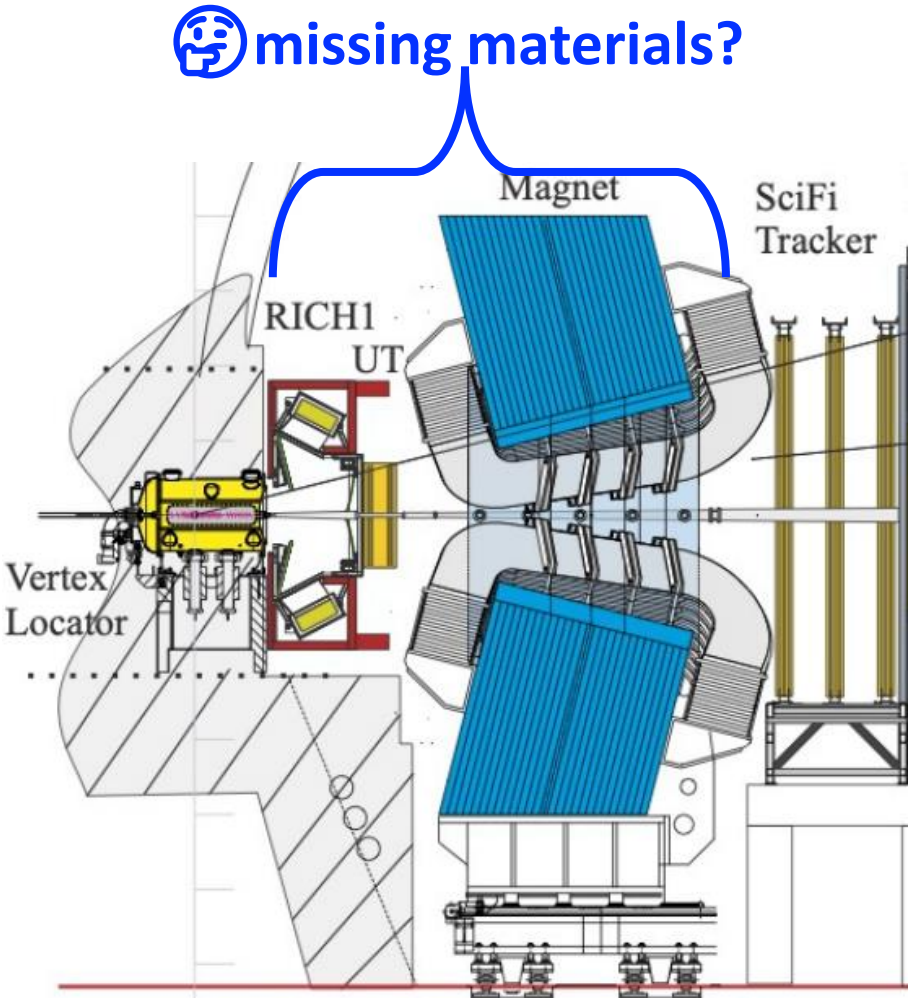




SciFi Clusters

- Cluster Number of **Velo**
  - Already reweighted
- Cluster Number of **SciFi**
  - Data is busier than MC
- **Hint of missing materials between Velo~SciFi**





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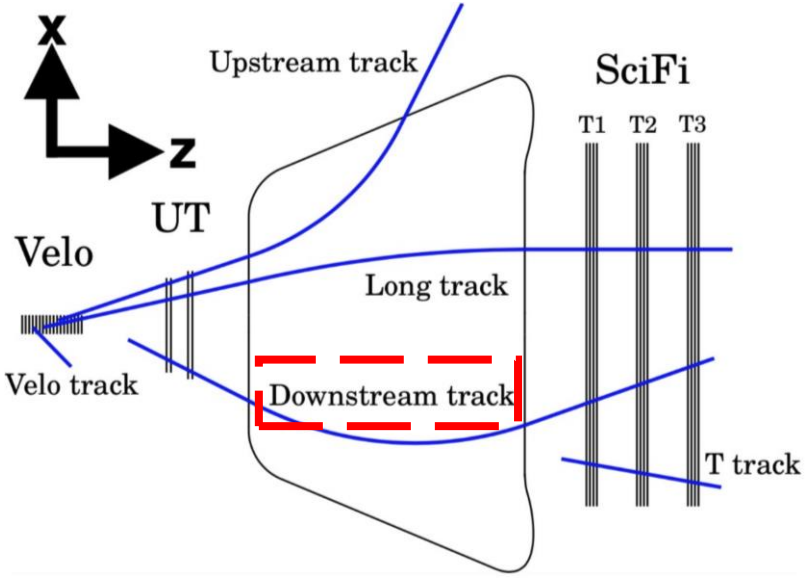
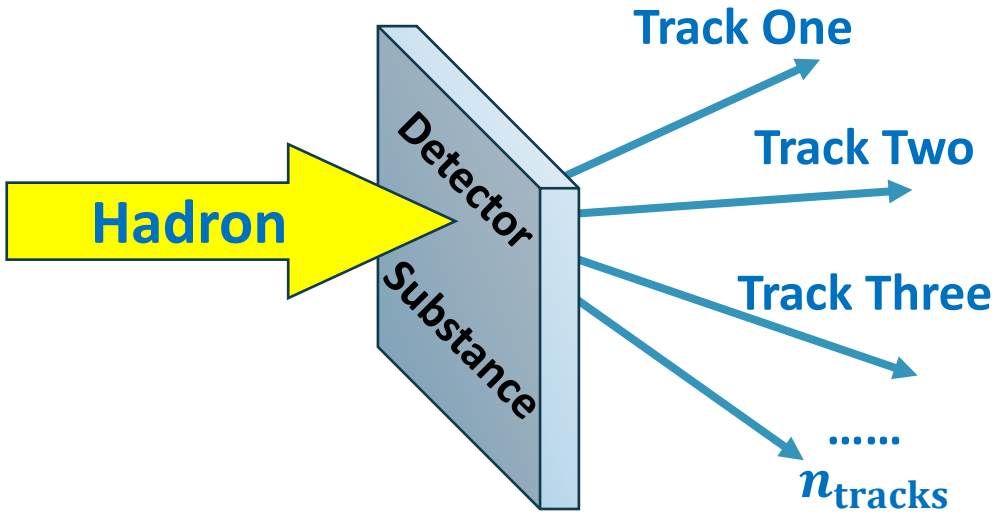
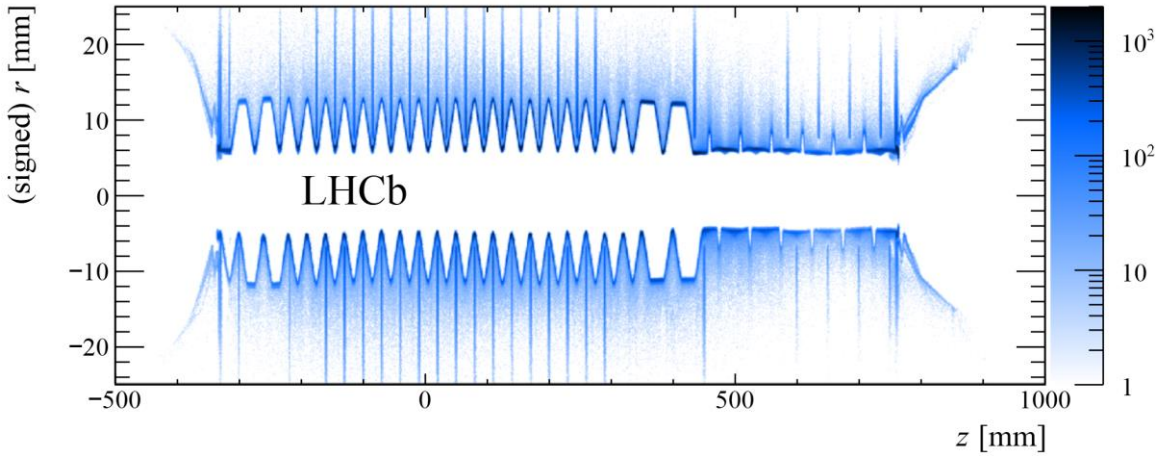


Tomography

- **Tomography:** A data-driven method to map the detector
  - Reconstruct **hadronic interaction** vertices to create a map of material distribution.



Secondary hadronic interactions



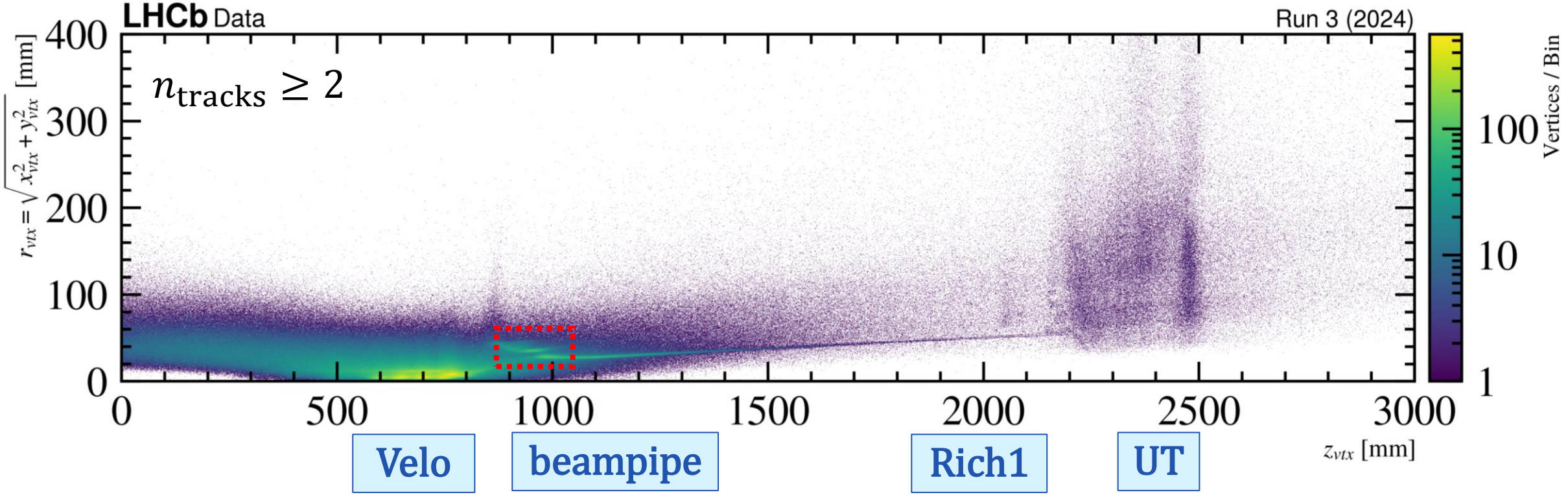
Tomography of VELO[JINST 10(2018)P06008]

Tomography with Downstream Tracks

- **Tomography:** A data-driven method to map the detector
  - Reconstruct **hadronic interaction** vertices to create a map of material distribution.

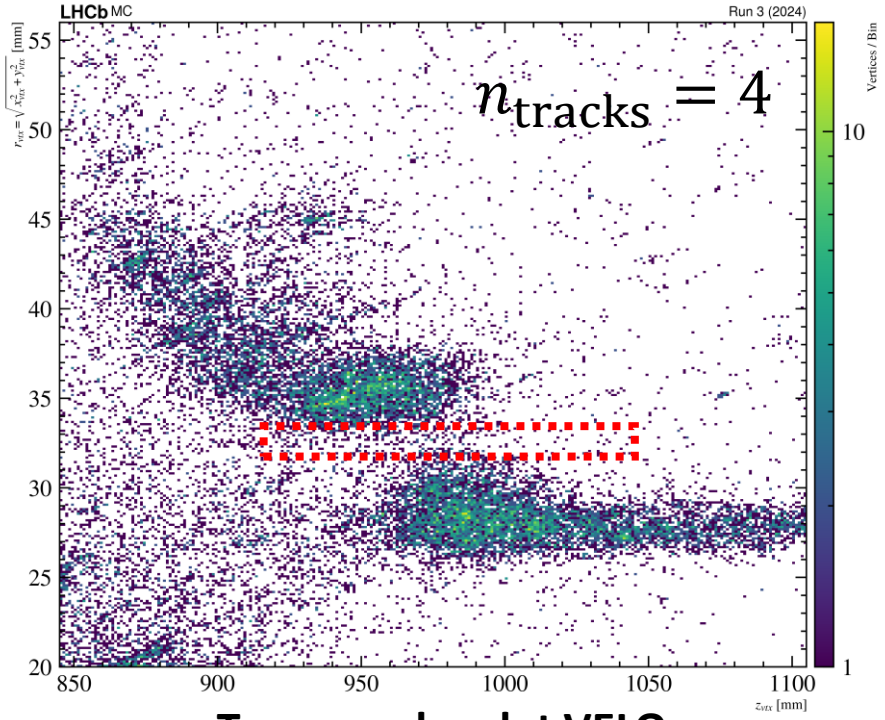
- **In our study**:
- $\mathrm{K_s} \rightarrow \underbrace{\pi + \pi + \cdots + \pi}(\text{Hadronic Interaction})$
  - $2 \leq n_{\text{tracks}} \leq 7,\ < n_{\text{tracks}} > = 2.6$.
  - First study of the **downstream tracks**
  - Combination with ***Davinci framework*: [Production]**
    - **Carefully selected** cut is applied to increase N_{sig}/N_{bkg}
    - e.g.: $n_{\text{tracks}} = 4,\ \sigma_r = 0.9\text{mm},\ \sigma_z = 11\text{mm},\ N_{sig}/N_{bkg} = 100\%$

Tomography Plot

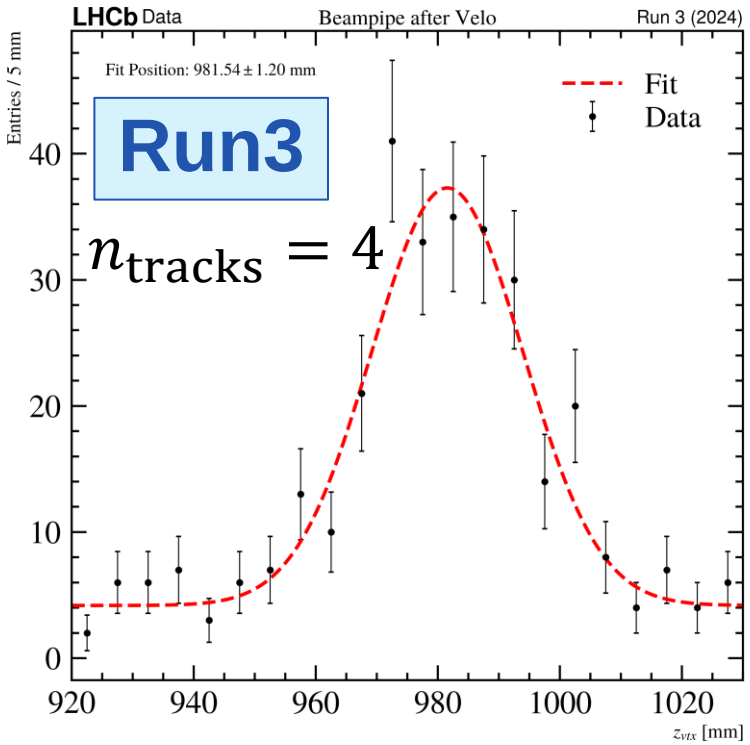


- **Velo, beampipe** distinguishably seen
- **UT, Rich1** can be seen but unclear

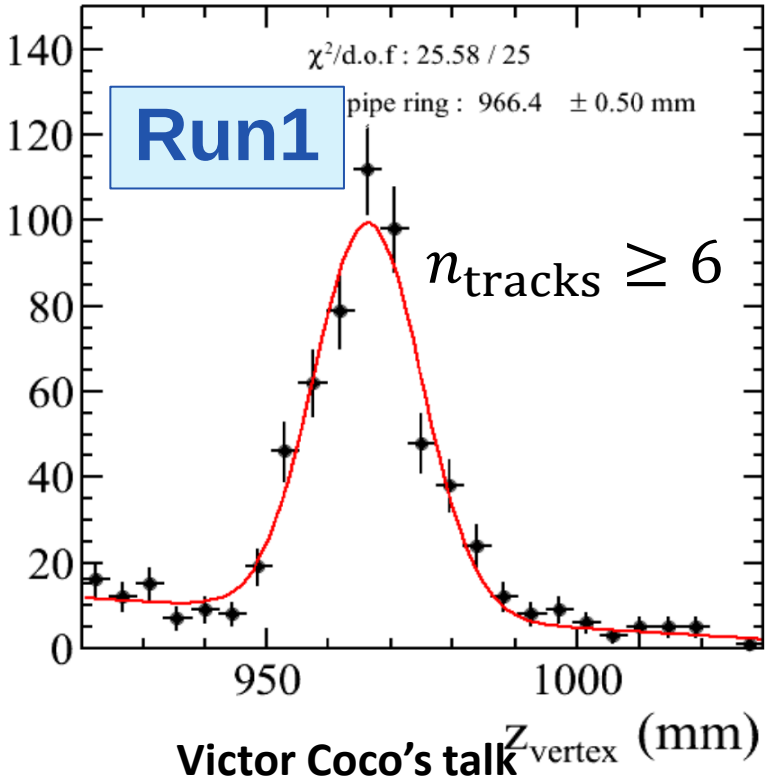
Tomography Plot: Velo



Tomography plot VELO



this study

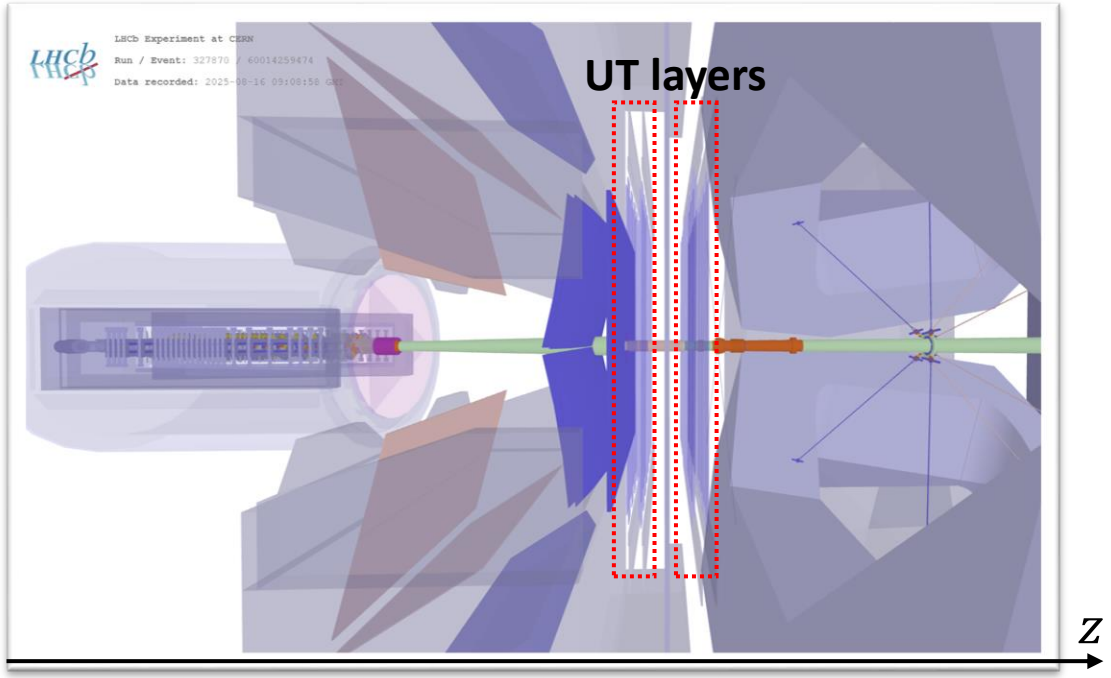


Victor Coco's talk [2012.10]

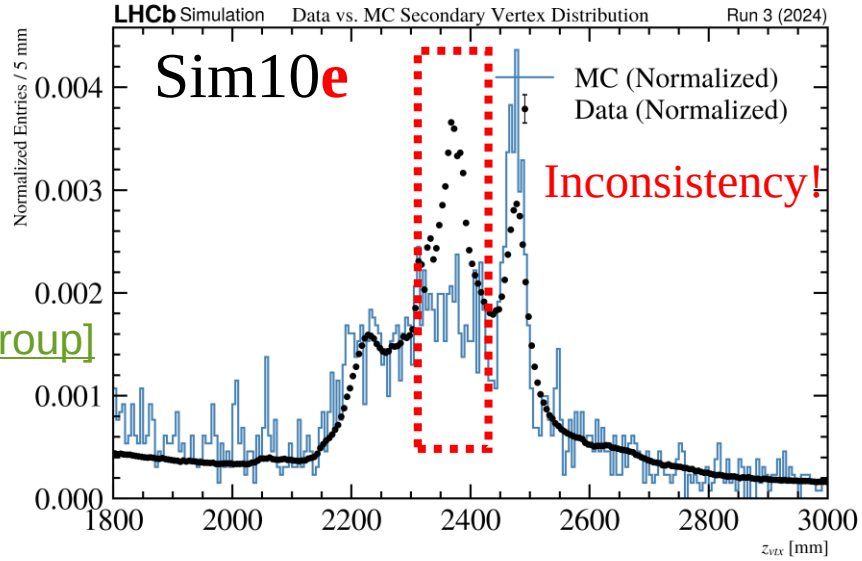
- **Beampipe ring** after exit window of the Velo
  - **Run3:** 981.5 ± 12.4 mm ~ good resolution
  - **Run1:** 966.4 mm

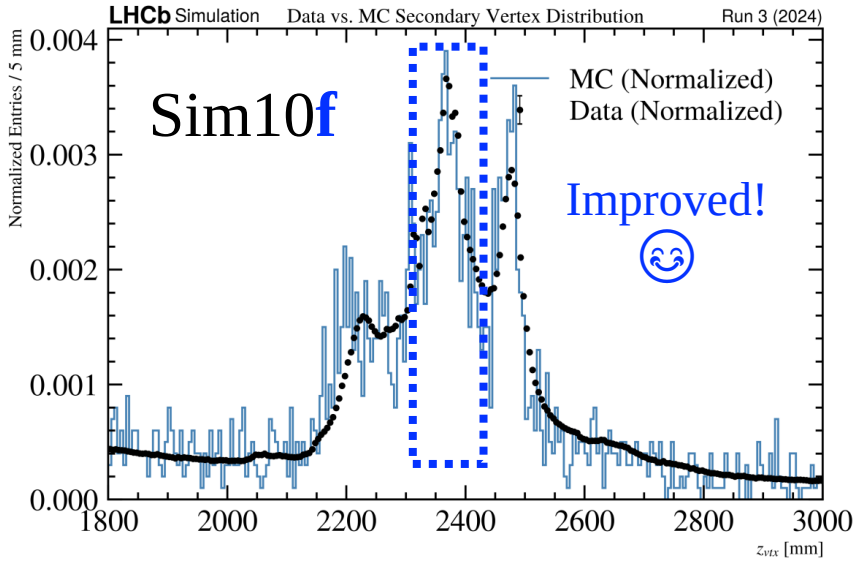
Material distribution comparison

- Vertex number ~ Material budget
- Sim10d → Sim10f
  - z_{vtx}: 2300~2450mm => **UT fibers aLayer**
  - Sim10f UT material description improved [MR UT group]



UT aLayer(left part) in Run3





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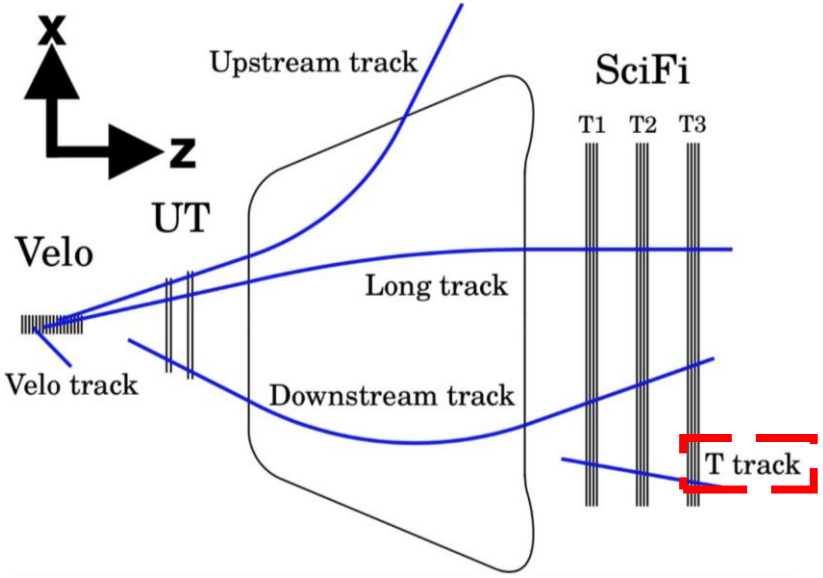


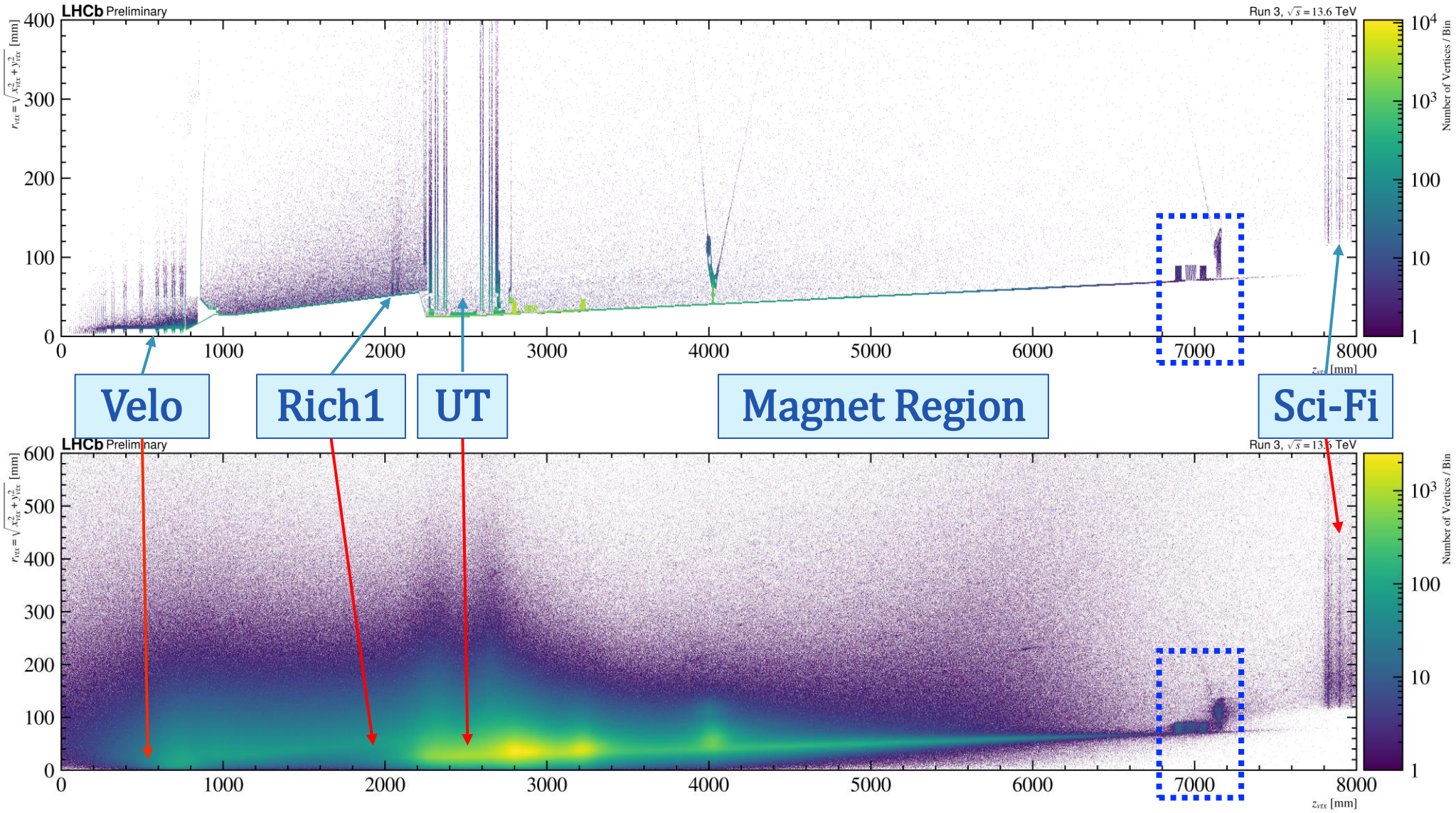
Tomography with Ttracks

- $\mathrm{K_s} \rightarrow \underbrace{\pi + \pi + \cdots + \pi}$ (Hadronic Interaction)
  - $2 \leq n_{\mathrm{tracks}} \leq 4.$
  - First study of the **Ttracks**
  - Combination with ***Davinci framework*: [Production]**
    - RK extrapolation from Javier's talk [Indico]

- Working in progress to improve N_{sig}/N_{bkg} in real data
  - Selection cut on vertices nPVs, χ^2/DOF, …
  - Selection cut on tracks p_{T}, χ^2, …

- Tomography with Ttrack **pure MC signal**

Tomography with Ttracks



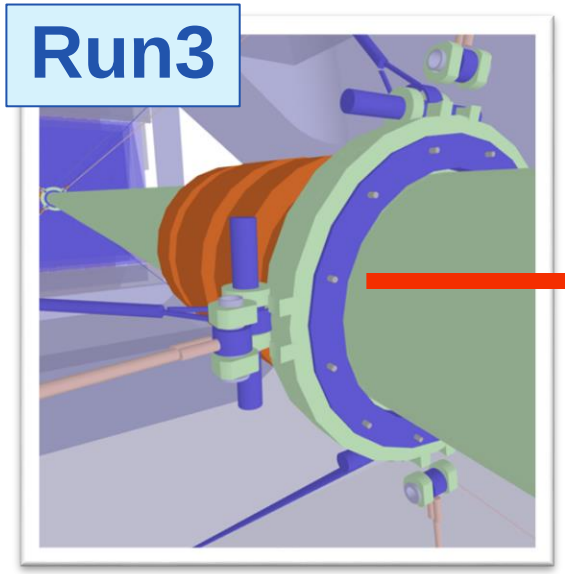
True vertex location

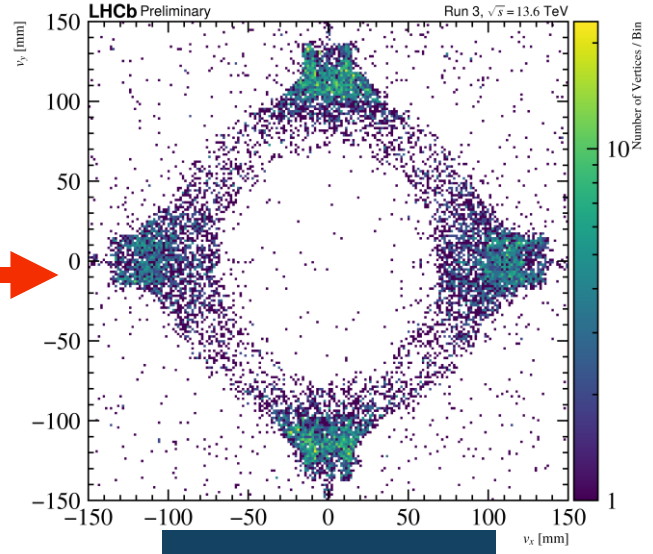
Pure MC Signal

Reconstructed location

Reconstructed - beampipe

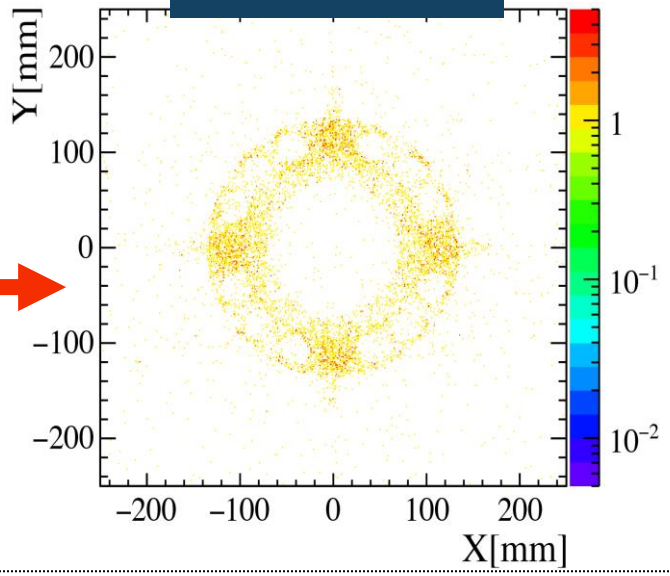
Run3





MC

Run1



- **Beampipe** tomography Ttrack
- **Migration of beampipe geometry** [dddb-20150703] **visible** in Ttrack tomography!

Mengzhen's summer student report supervised by Jibo [indico]

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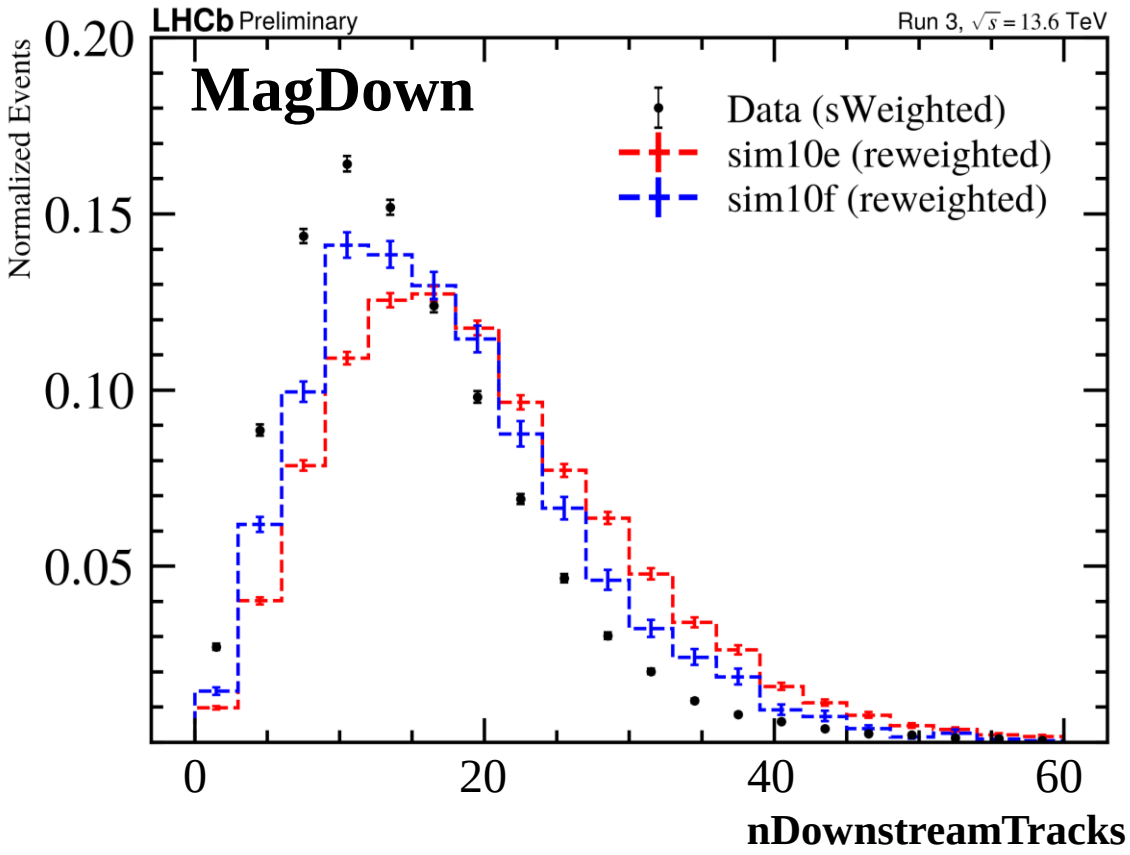
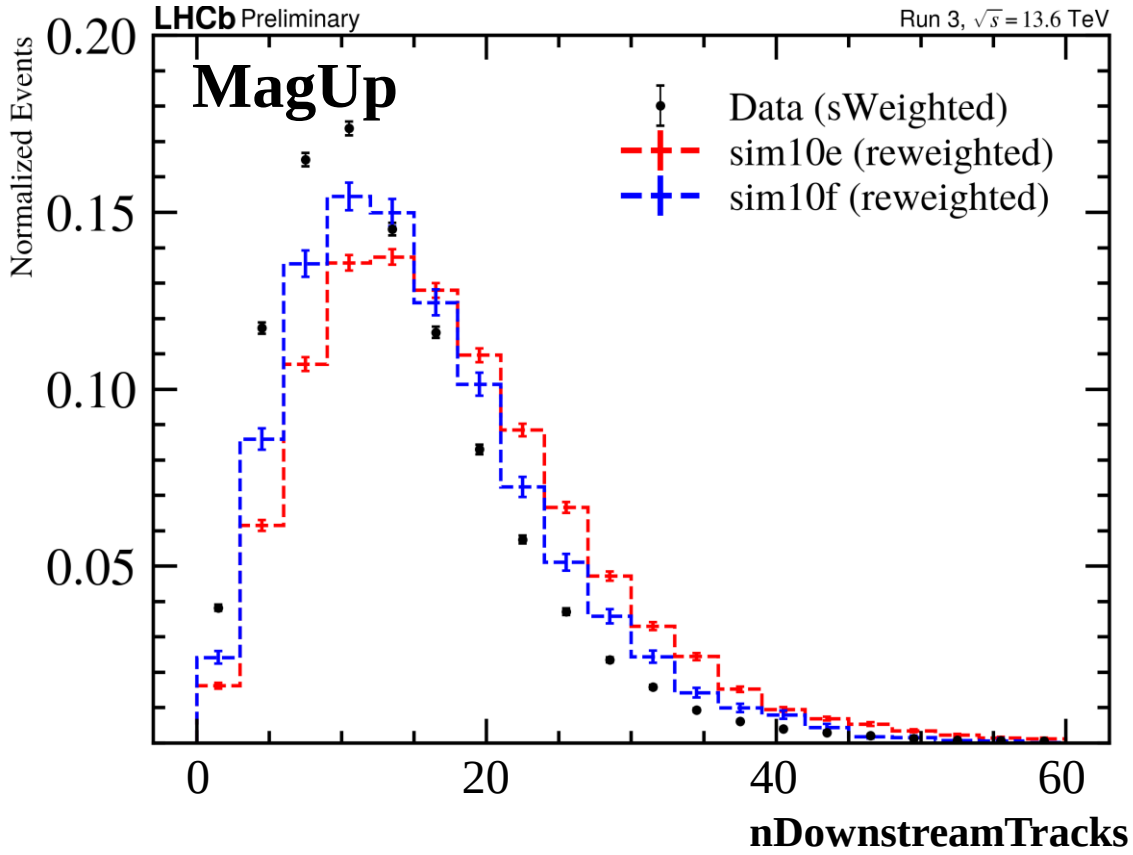
First feedback of Sim10f





Sim10f consistency improved 😊

- 22nd Jul. **Simulation meeting** [Indico].
- **UT efficiency** description improved in Sim10e→f [MR].

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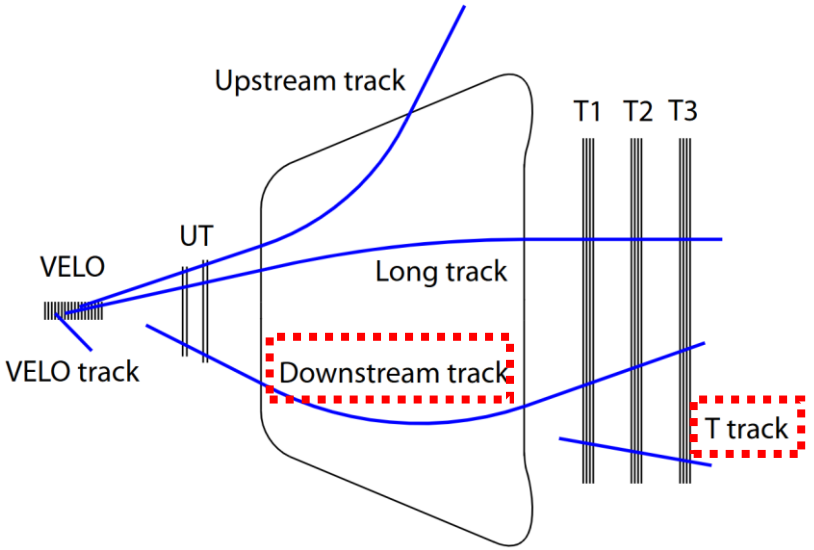
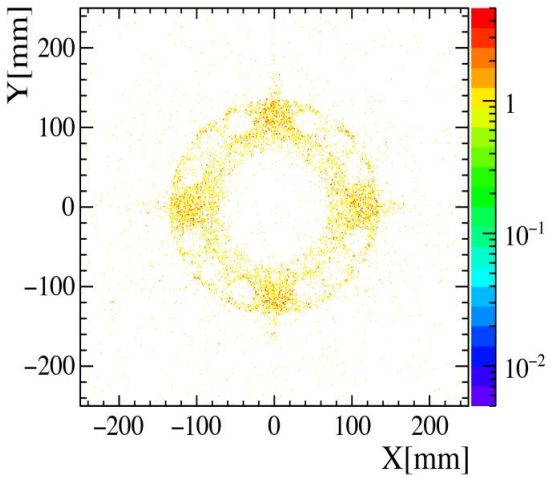
Conclusion & Outlook

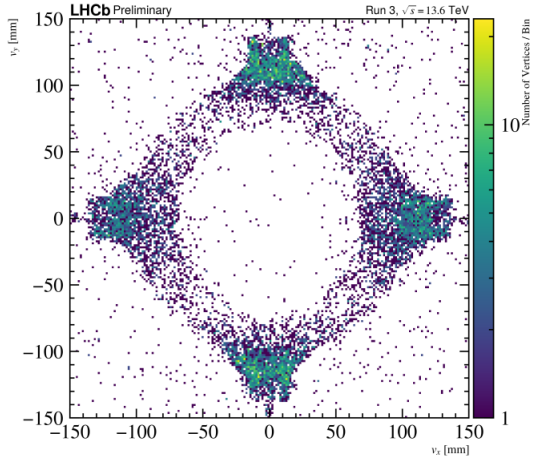
- **Run3 simulation shows missing materials between Velo& SciFi [Indico]**
- **Tomography - Downstream Tracks**
  - **Decent σ, SNR** with multi-track combination
  - Probed the **UT**'s material variation in Sim10e→f
- **Tomography - Ttrack**
  - Pure signal: **good resolution** for downstream structure



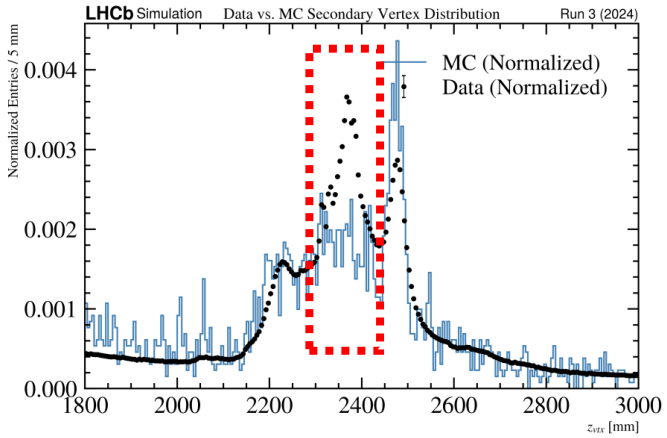
Conclusion & Outlook



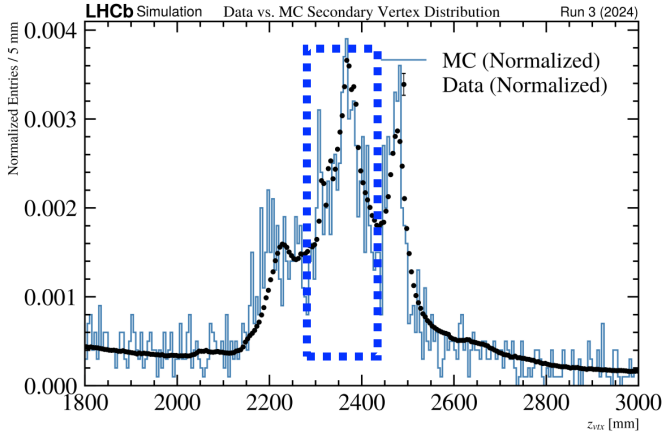
Run1



Run3



Sim10e



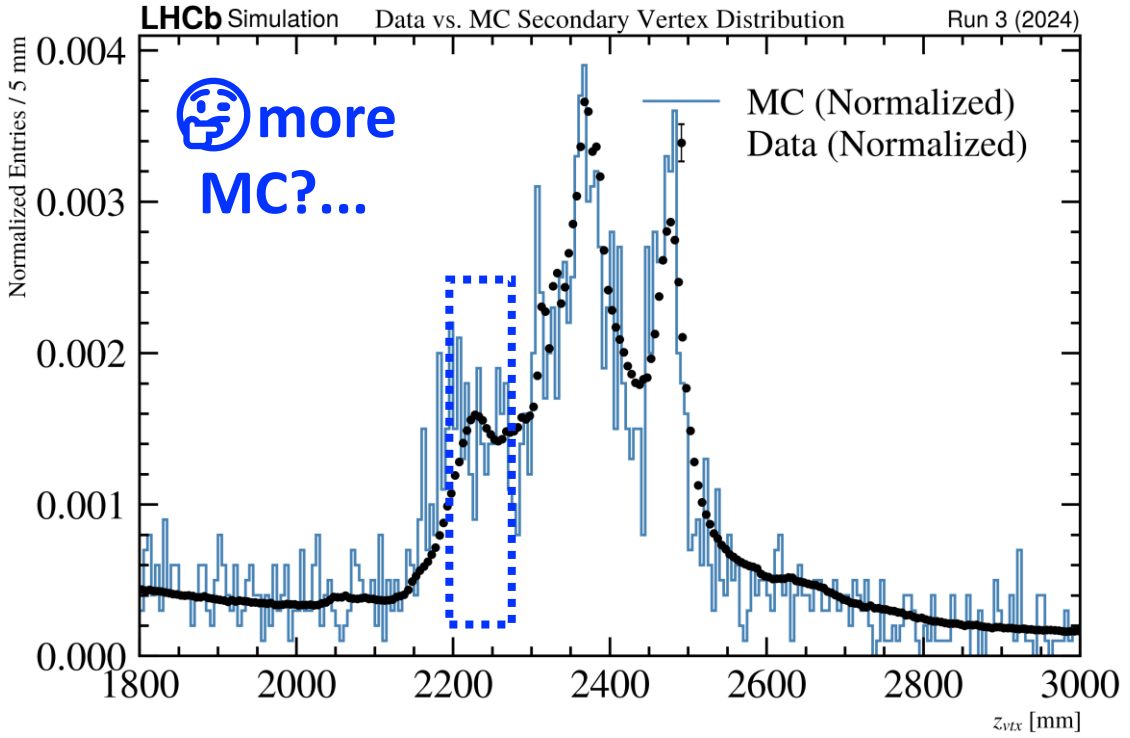
Sim10f

- All these variances crosscheck by documentations
- **Tomography (Data vs. MC) in LHCb Run3 is a promising method to search for missing materials!**

Conclusion & Outlook

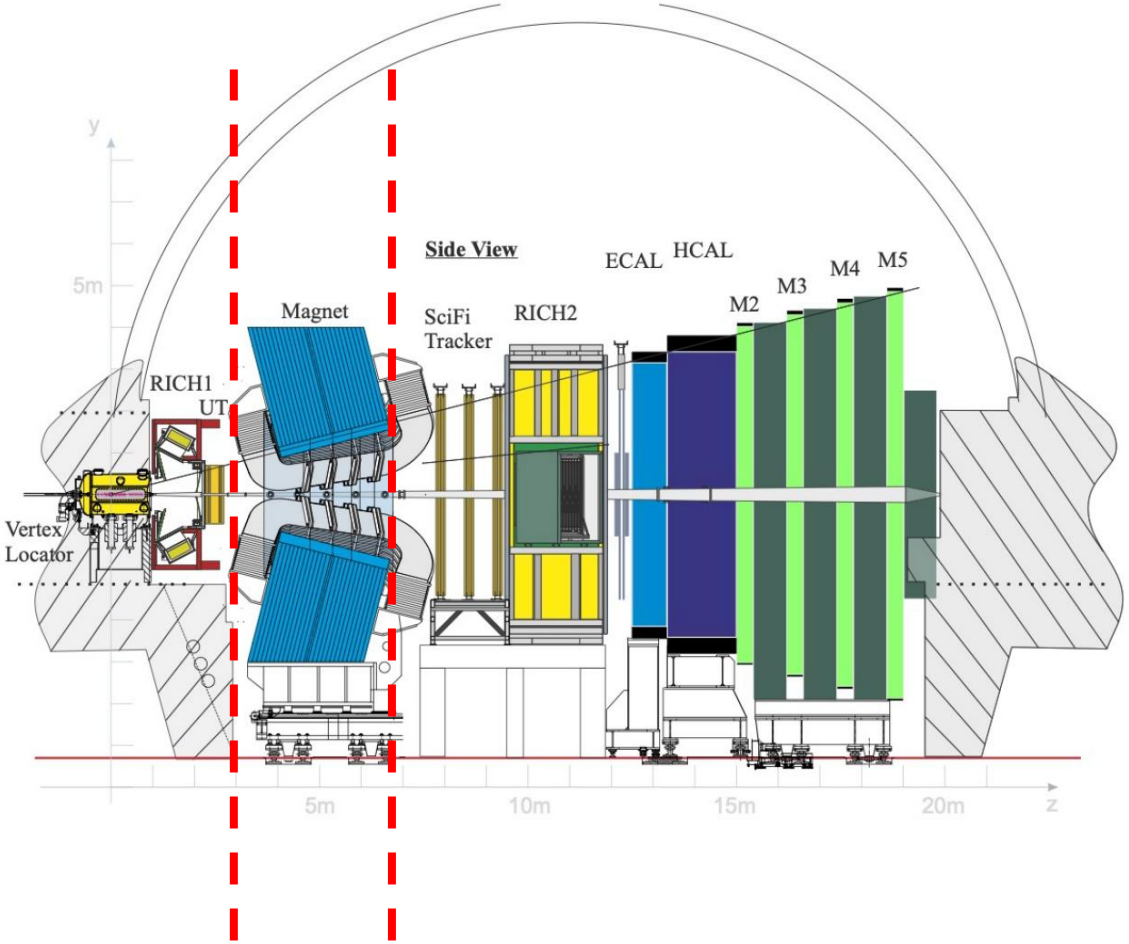
- **Outlook** of this study
  - **More MC** to reduce statistical error
  - Further optimization of the combination strategy
  - Cut to reduce BKG in **Ttrack** …

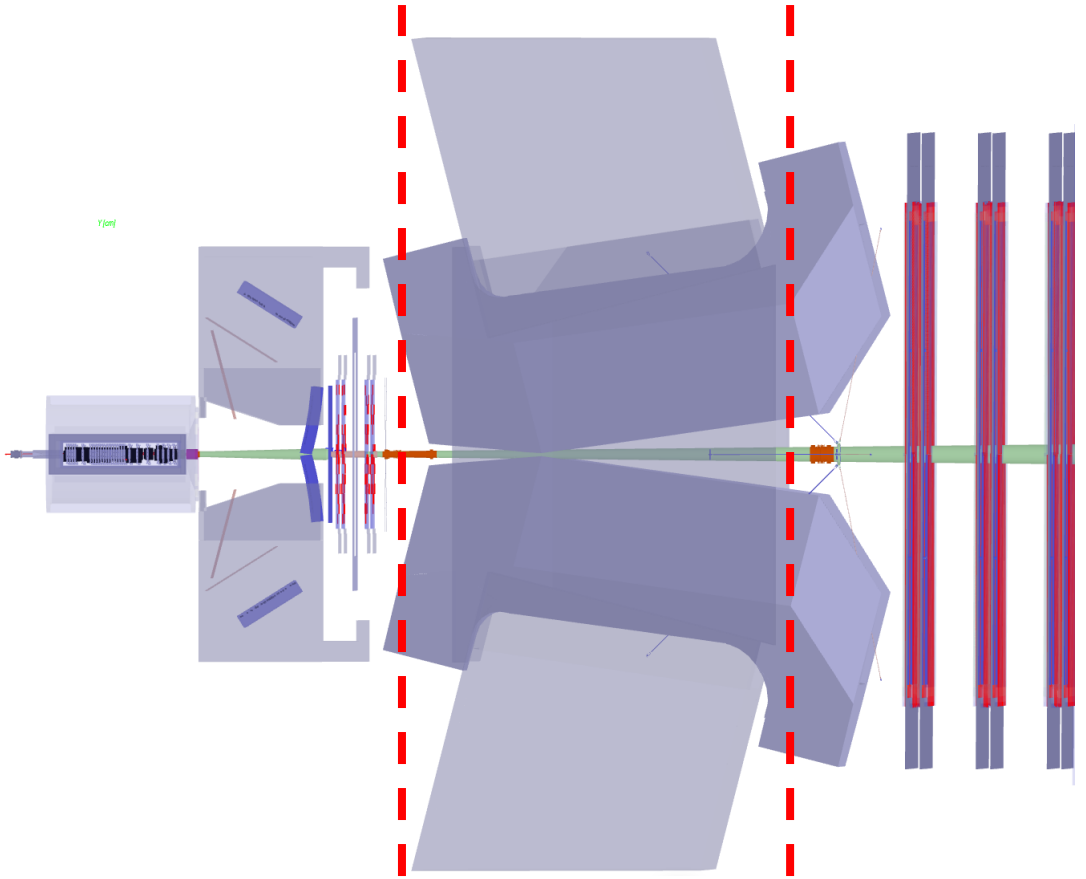
Thanks for your listening!



Back Up

LHCb detector





Dataset: $J/\psi \to \mu^+\mu^-$

- **Real Data tuple**
  - 2024 Run3 $J/\psi \to \mu^+\mu^-$
    - Block7 (MagDown) production link
    - Block8 (MagUp) production link

- **Monte Carlo sample**
    - Block7 (MagDown)
      - Sim10e production link
      - Sim10f production link
    - Block8 (MagUp)
      - Sim10e production link
      - Sim10f production link

Dataset: Tomography

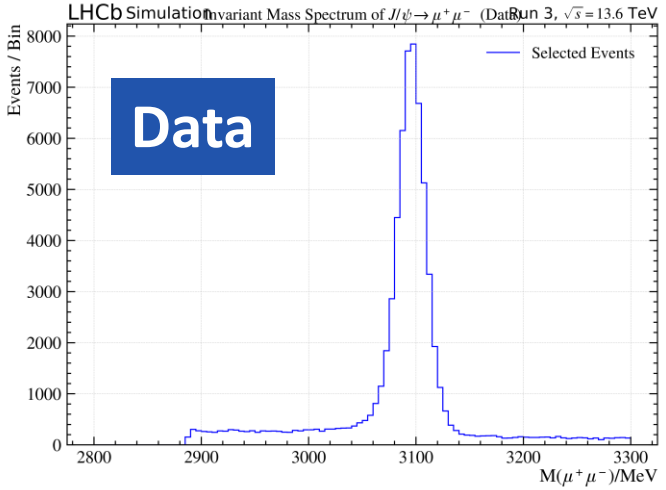
- **Hardonic Interaction**

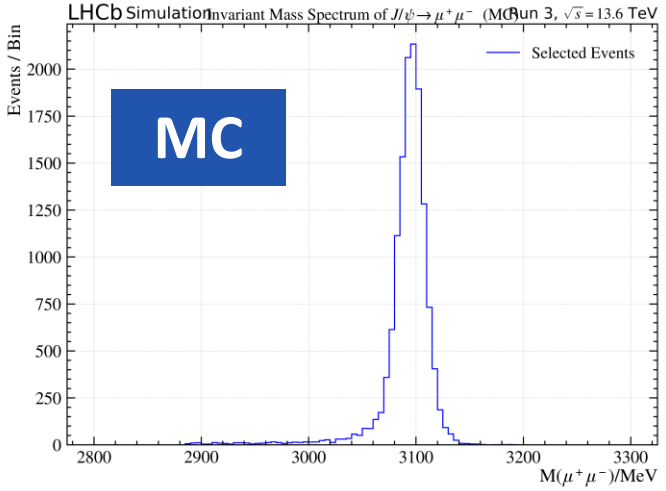
- **Downstream Track**
  - **2~7-body vertex**
  - **Sim10d** MagUp production link

- **TTrack**
  - **2~4-body vertex**
  - **Sim10f** MagDown production link

Selection

- Selection cut are applied to **select signal** and **reduce BKG noise**
  - **General cut for Data/MC**
    - $p_{\mathrm{T}}(\mathrm{J}/\psi) > 2000$ MeV, $p_{\mathrm{T}}(\mu^{\pm}) > 700$ MeV
    - DLS $(\mathrm{J}/\psi) > 4$ (focused on detached J/ψ)
    - $\mathrm{PID}_{\mu}(\mu) > 5$
    - $\chi^2_{\mathrm{IP}_{\mathrm{min}}}(\mu^{\pm}) > 9$
    - $\frac{\chi^2_{VTX}}{\mathrm{DOF}}(\mathrm{J}/\psi) < 9$
    - $\mathrm{TOS}_{\mathbf{Hlt1},\mathrm{DiMuon}}(\mathrm{J}/\psi) = 1$
  - **Cut for MC exclusively**
    - PDG true ID for μ^+, μ^-, J/ψ



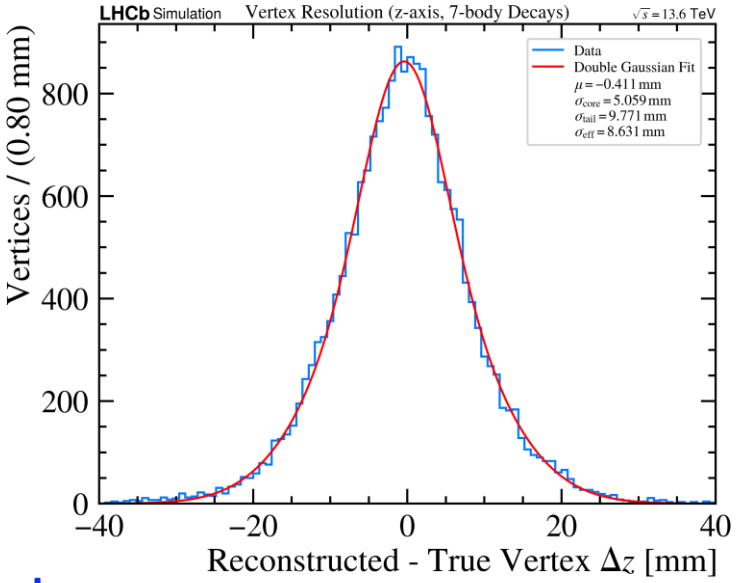


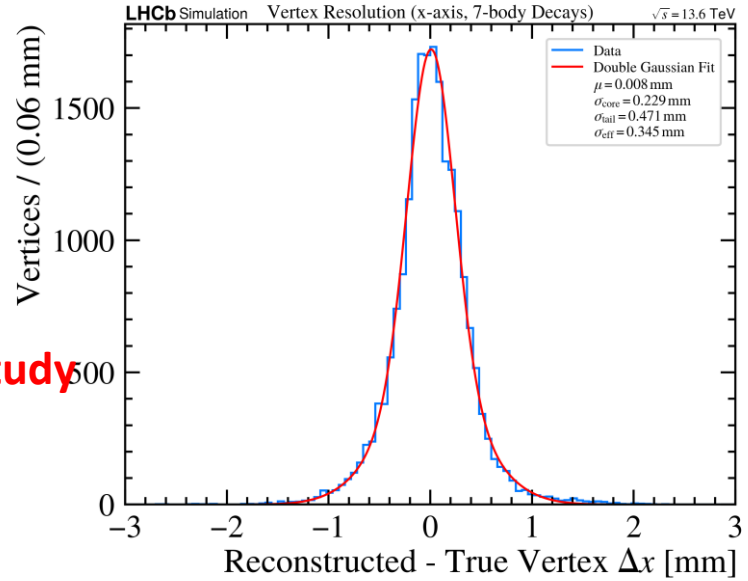
Tomography with Downstream Tracks

- $B^+ \rightarrow J/\psi + K_s$, with ***Davinci framework***
- $J/\psi \rightarrow \mu\mu$, $K_s \rightarrow \underbrace{\pi \ldots \pi}$ (Hadronic Interaction)
  - $< n_{\text{tracks}} > = 2.6$, **selected cut applied**

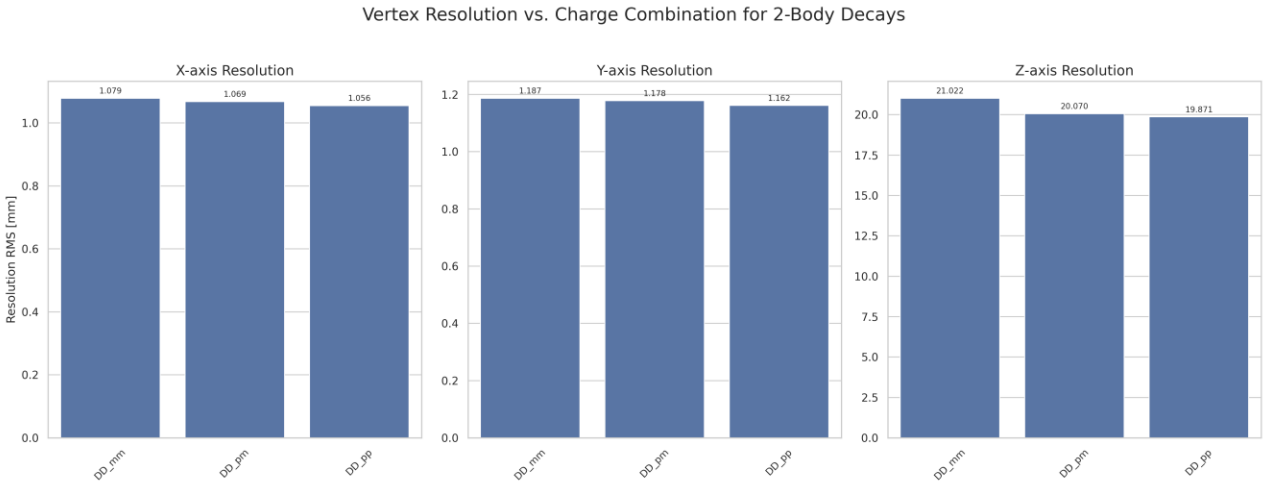
n_{tracks}	σ_x/mm	σ_y/mm	σ_z/mm	Signal/BKG	
2	1.1	1.3	21.0	33%	Run3's study
3	0.7	1.0	14.0	42%	
4	0.5	0.7	11.0	43%	
5	0.4	0.6	9.6	45%	
6	0.4	0.5	9.0	44%	
7	0.3	0.5	8.6	17%	
2	2	2	25	10%	Run1's study

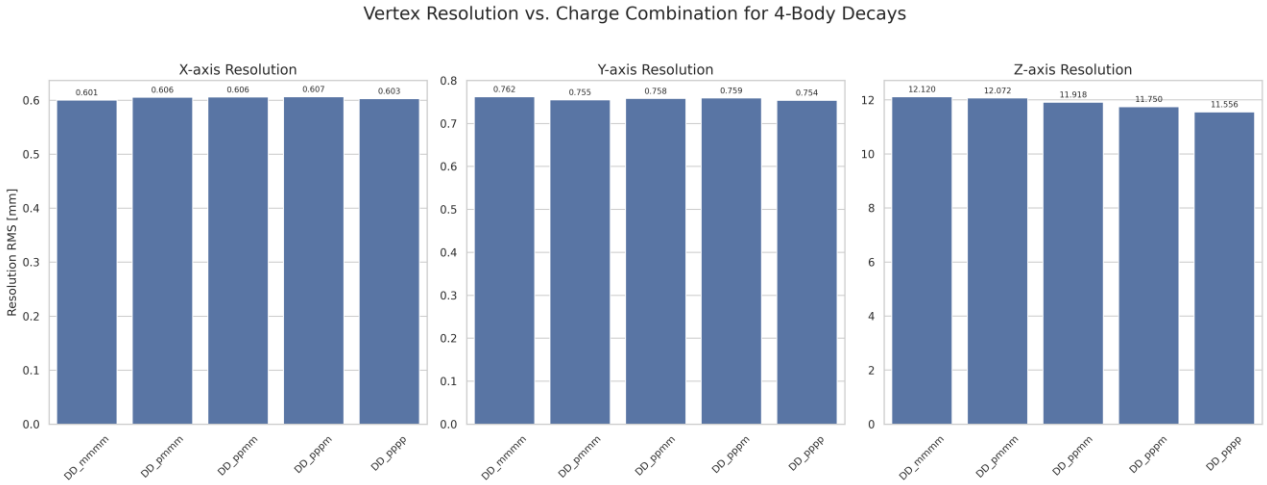
- σ, SNR significantly enhanced compared to Run1's study.

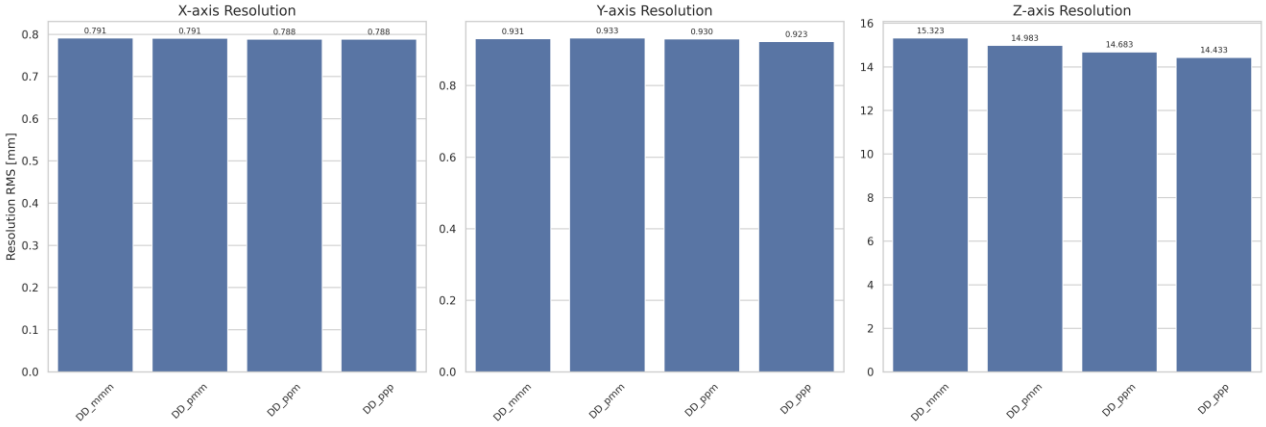


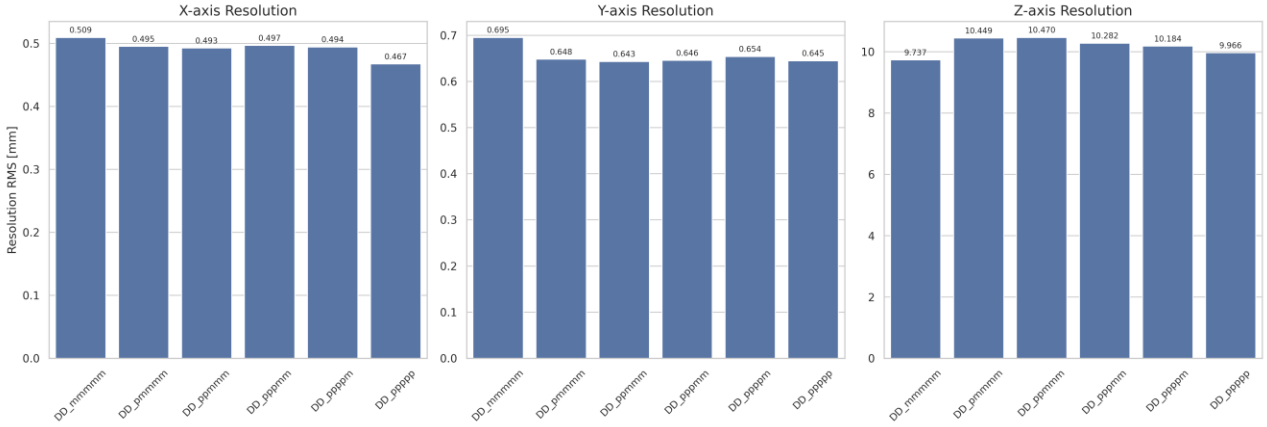


Resolution by charge comb



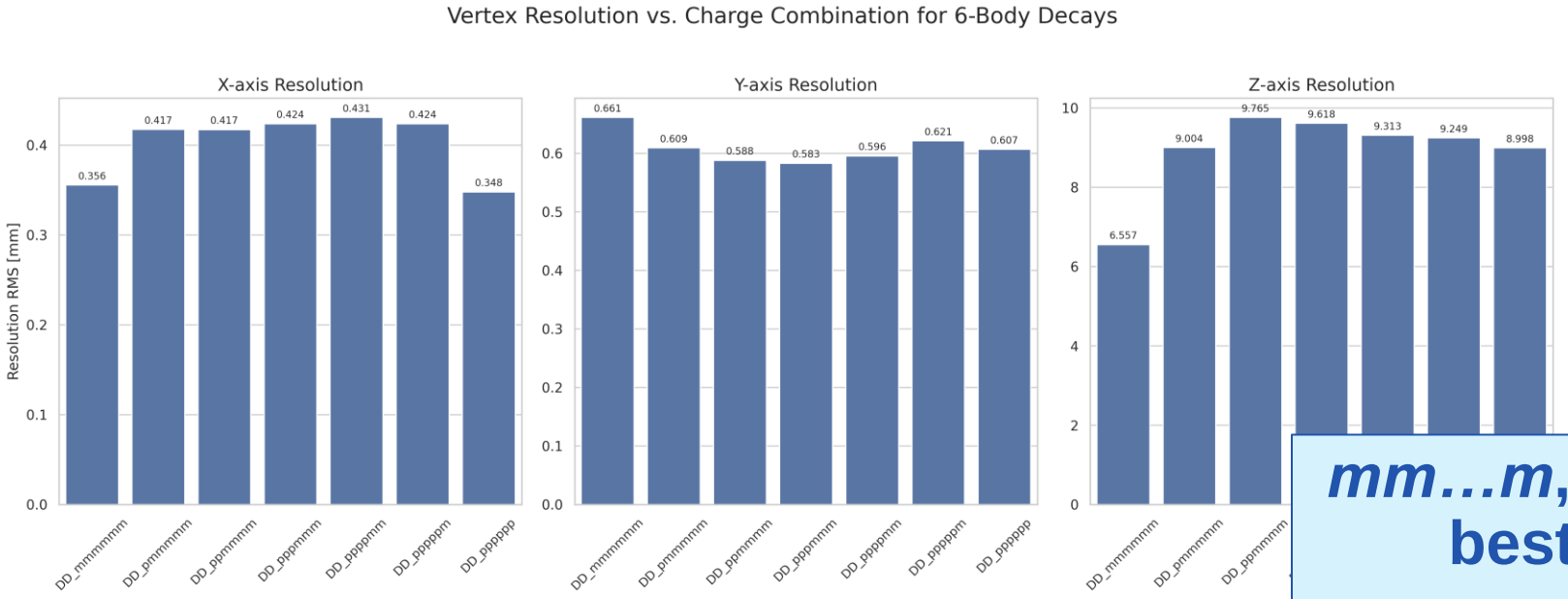


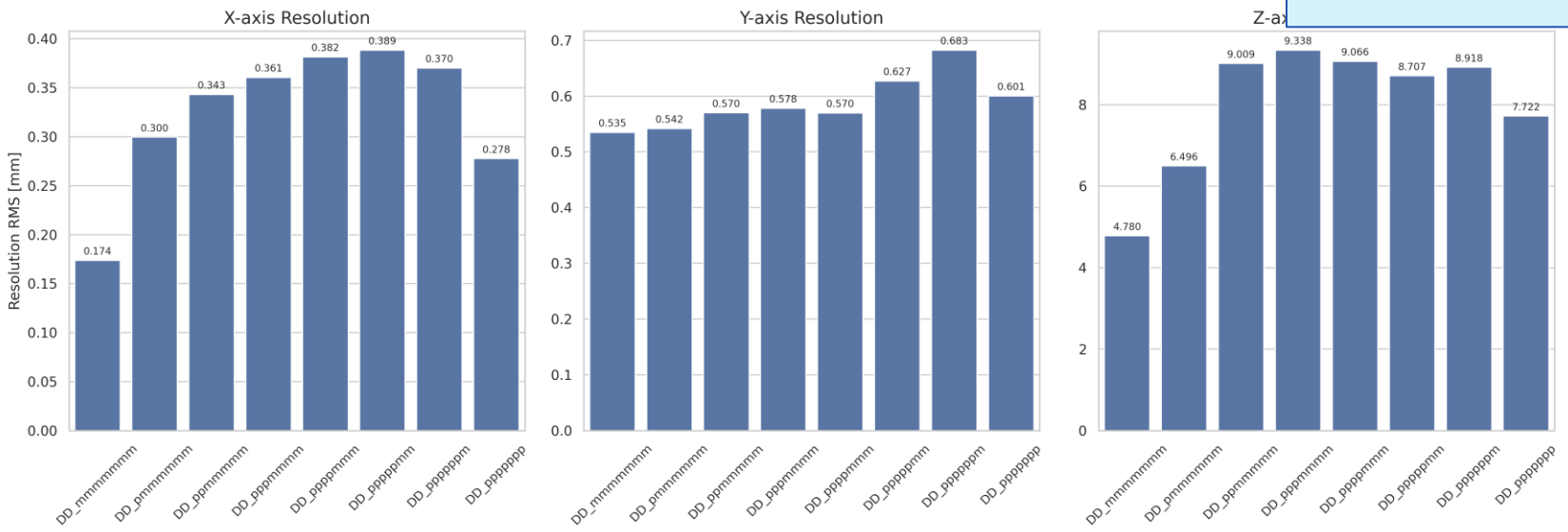




No significant difference between distinct charge comb

Resolution by charge comb



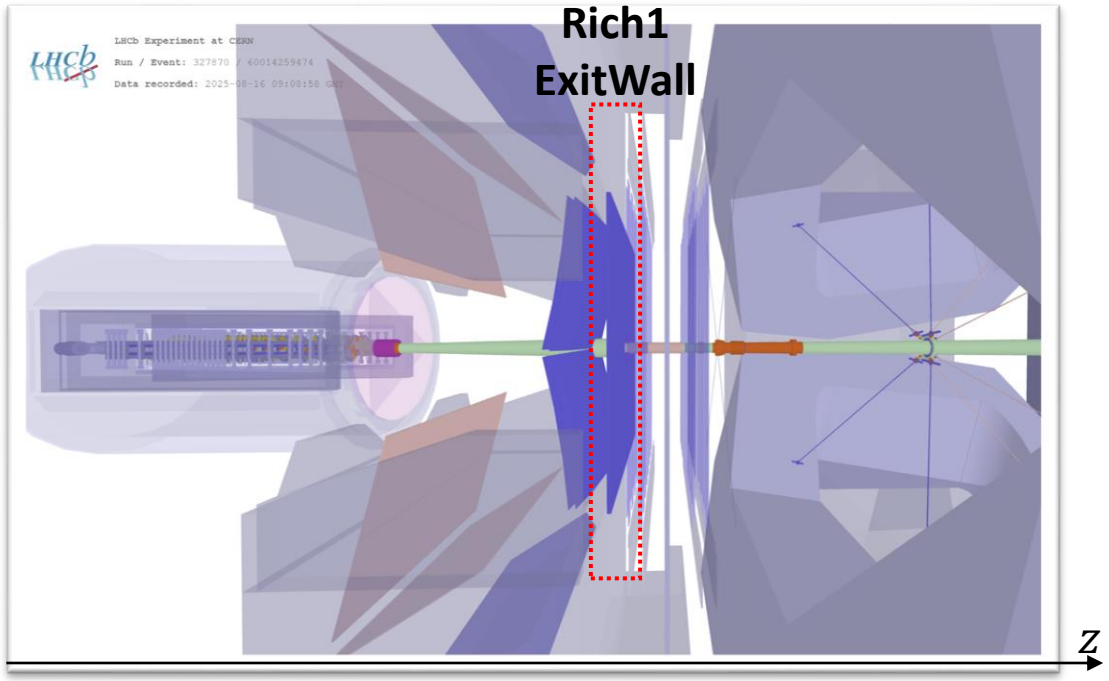


***mm…m*, *pp…p* have the best resolution,**

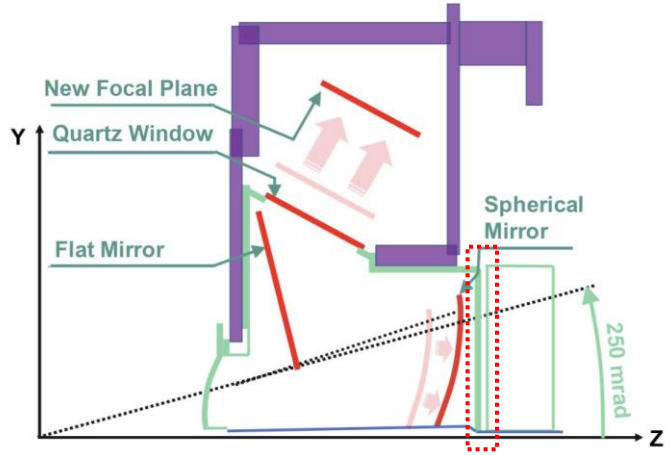
but with low statistics 😭

Material distribution comparison

- Vertex number ~ Material budget
- Sim10d → Sim10f
  - z_{vtx}: 2200~2250mm => **Rich1 ExitWall**
  - Rich1 in Sim10f may missed some materials



Rich1's ExitWall in Run3



Schematic of Rich1 in Run3

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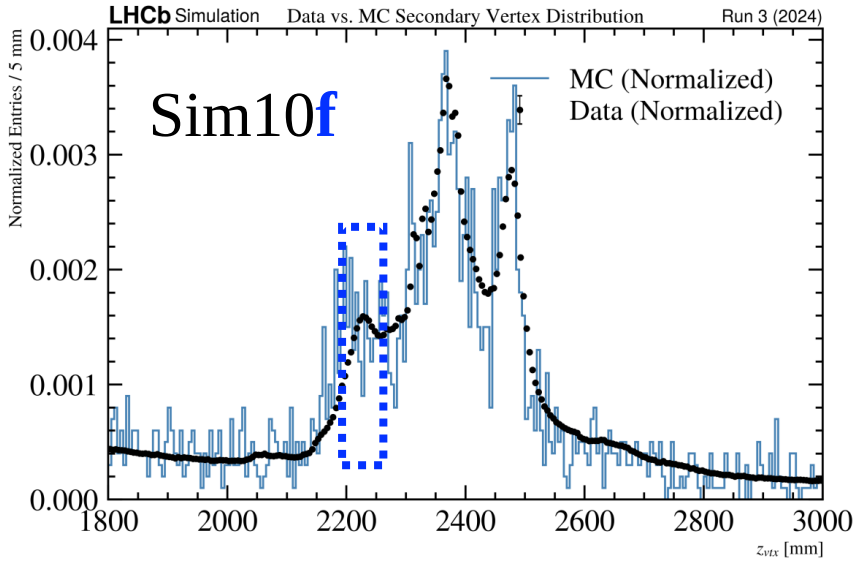
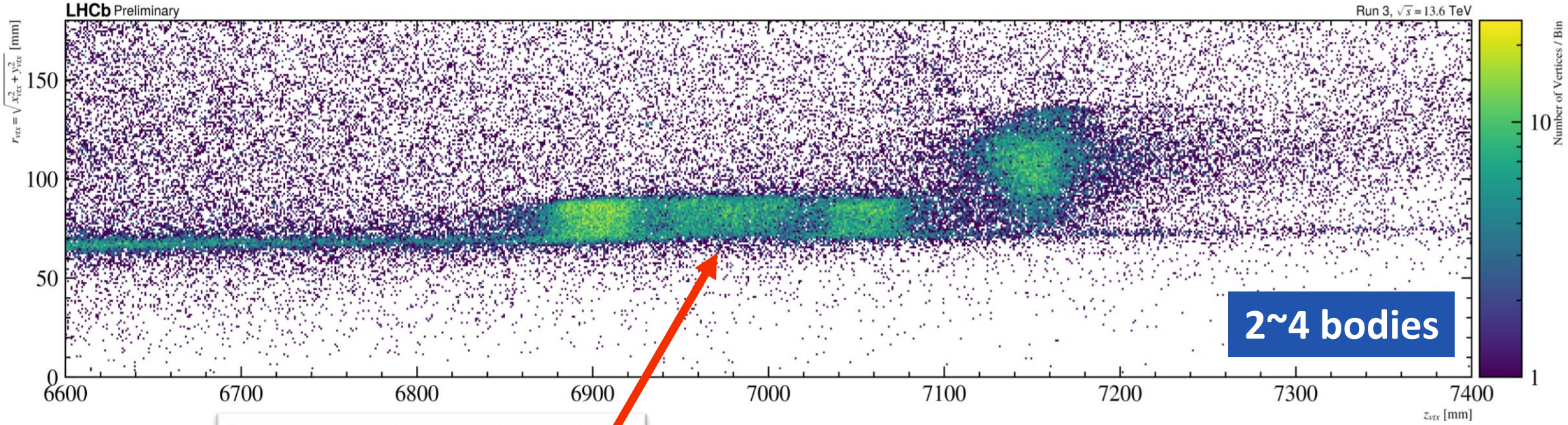
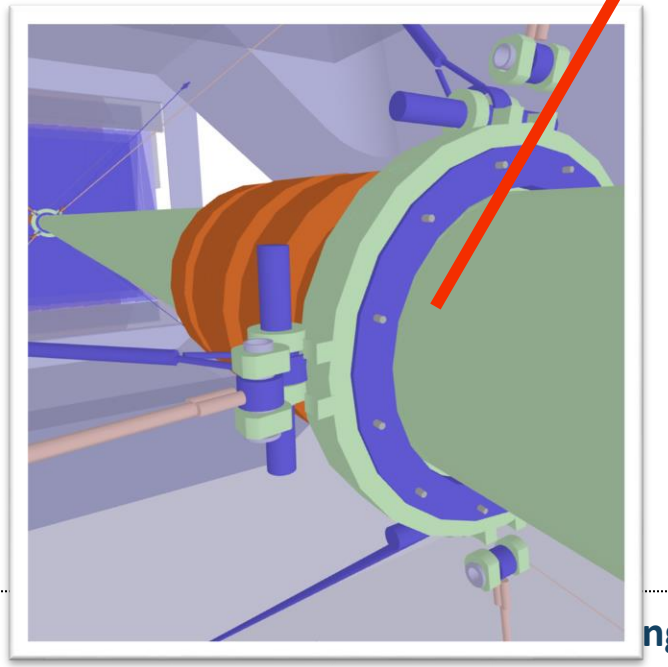


Reconstructed - beampipe





$z > 6600$ mm

$z < 7400$ mm

$R < 180$ mm

Signal

- For $n_{track} = 3$
- Signal Mask:
  - TrackOne_TRUEORIGIN_V*==TrackTwo_TRUEORIGIN_V*== TrackThree_TRUEORIGIN_V*, * represents X, Y, Z
  - Track{n}_TRUEID == 100 (hadronic interaction)
- BKG Mask:
  - !(Signal Mask)

Resolution

Body number	σ_x/mm	σ_y/mm	σ_z/mm	Signal Entries	SNR
2	30	9	148	3N	15%
3	23	7	96	4N	5%
4	16	5	70	5N	3%

Magnet

$z > 3000$ mm

$z < 6800$ mm

Body number	σ_x/mm	σ_y/mm	σ_z/mm	Signal Entries	SNR
2	36	10	167		
3	30	7	116		
4	26	6	100		

UT

$z > 2300$ mm

$z < 2700$ mm

Resolution

Body number	σ_x/mm	σ_y/mm	σ_z/mm
2	50	16	223
3	36	11	160
4	30	9	135

$z < 3000$ mm