# Future STAR Polarization Measurements in Small Systems: Toroidal Vorticity

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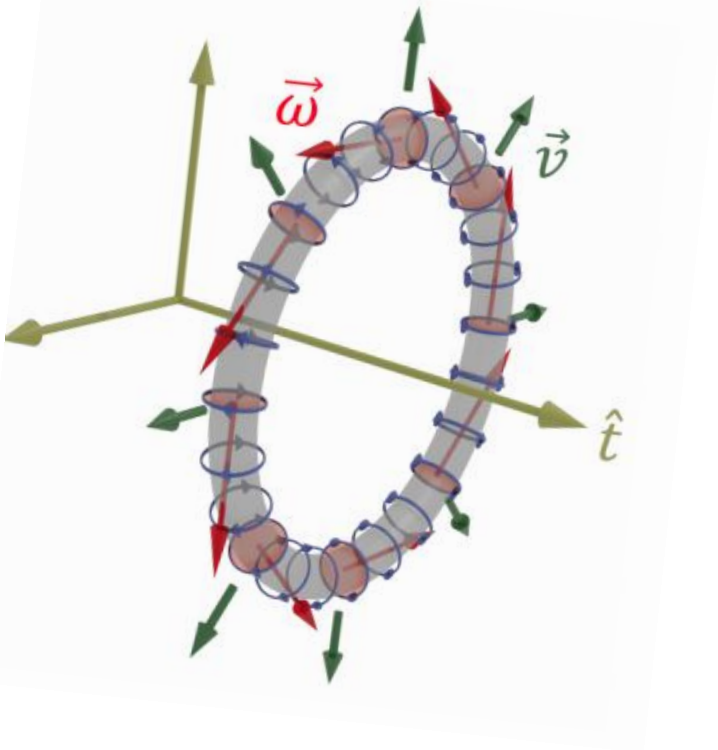
U.S. DEPARTMENT OF ENERGY | Office of Science

THE OHIO STATE UNIVERSITY

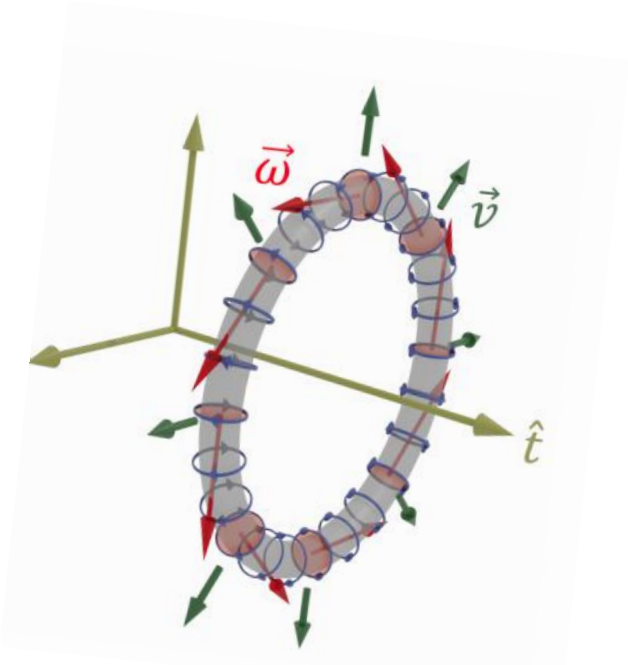
# Effects of cylindrical flow




M.A. Lisa, J.G.P. Barbon, D.D. Chinellato, W.M. Serenone, C. Shen, J. Takahashi, G. Torrieri, Phys. Rev. C **104**, 011901 (2021)

# The toroidal vorticity observable

- The toroidal voriticity is measured with $\overline{R}^{\hat{t}}_{\Lambda} \propto \hat{p}^{*}_{p} \bullet (\hat{p}_{\Lambda} \times \hat{z})$

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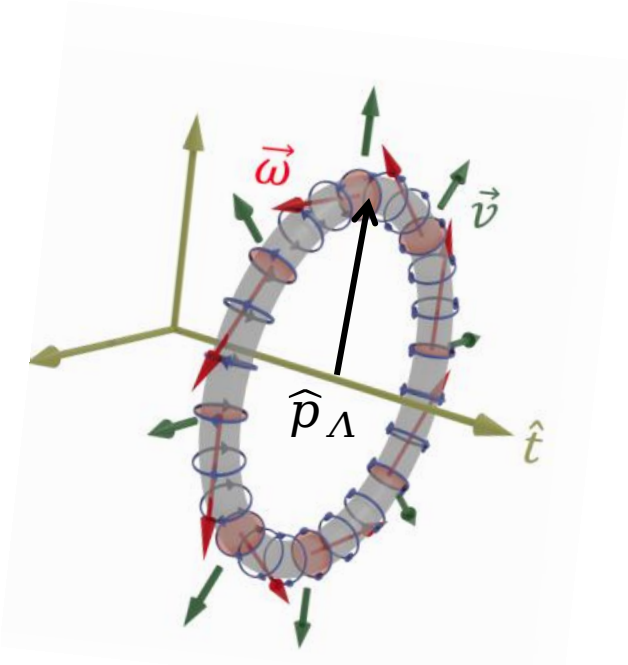


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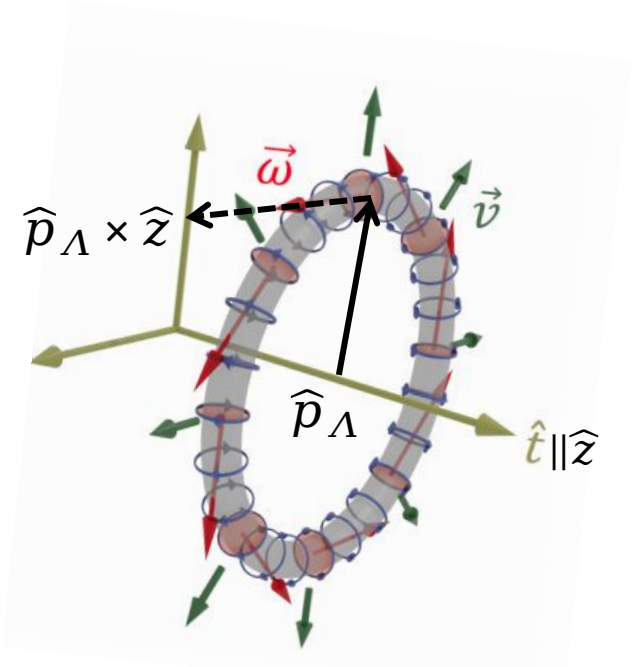


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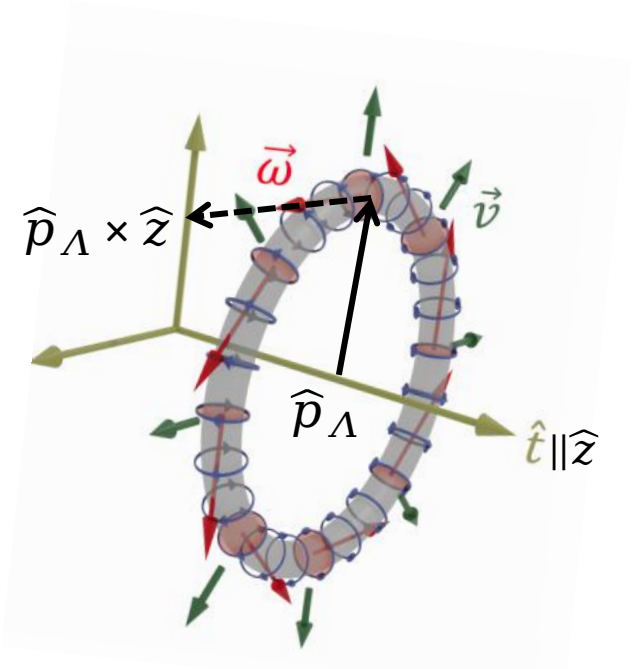


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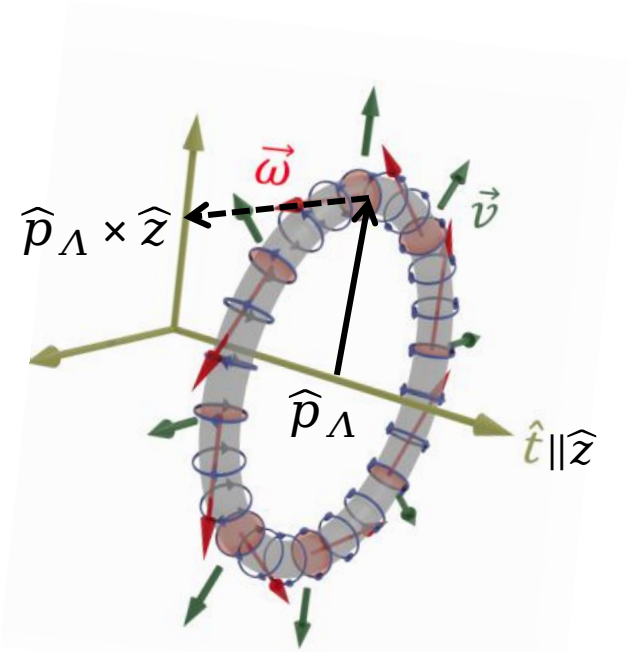


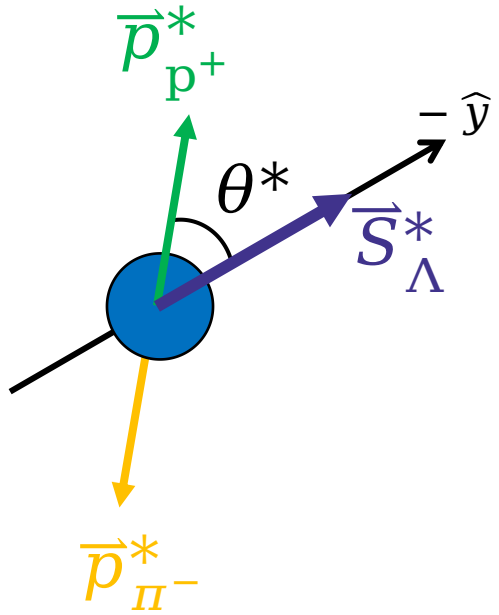


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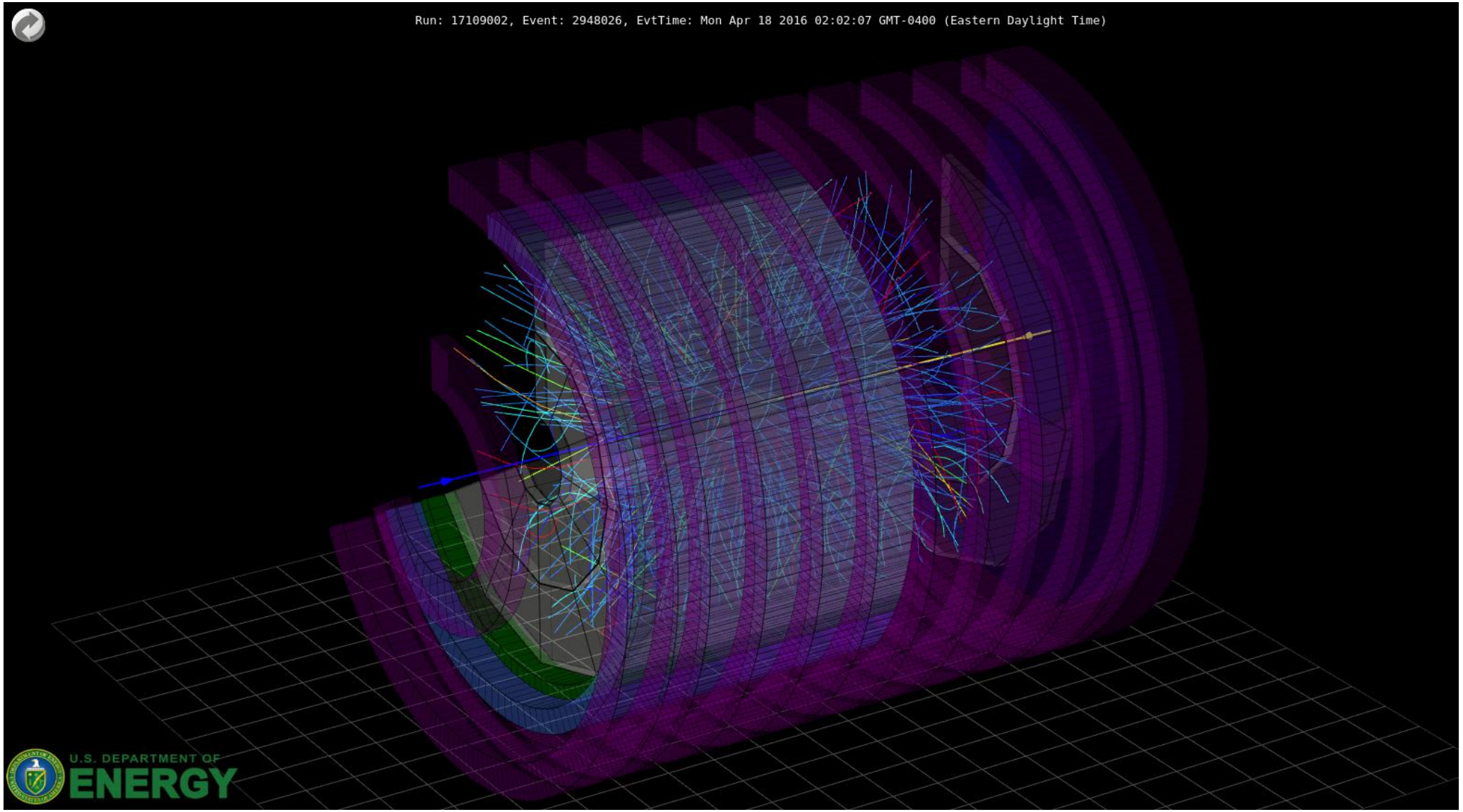

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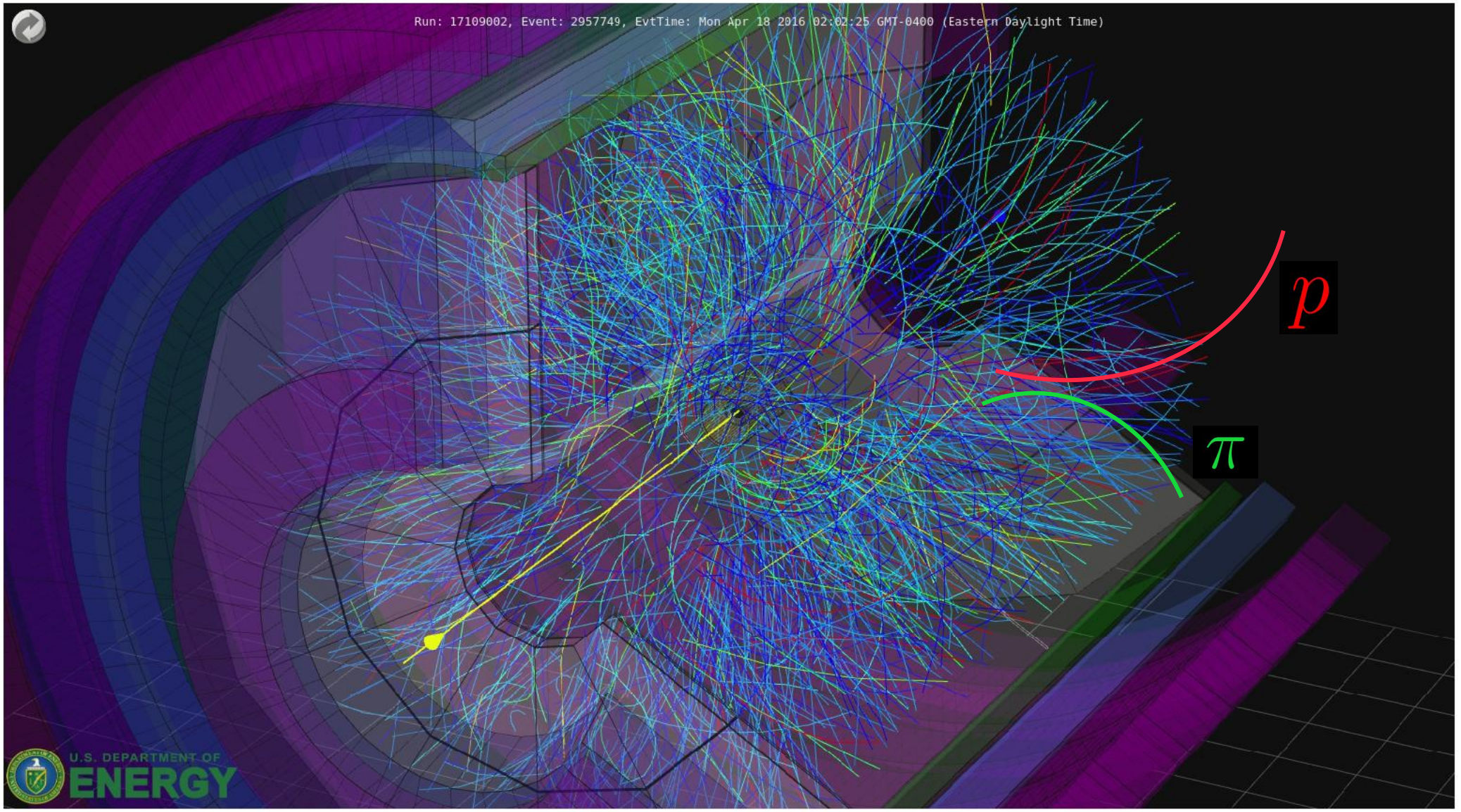

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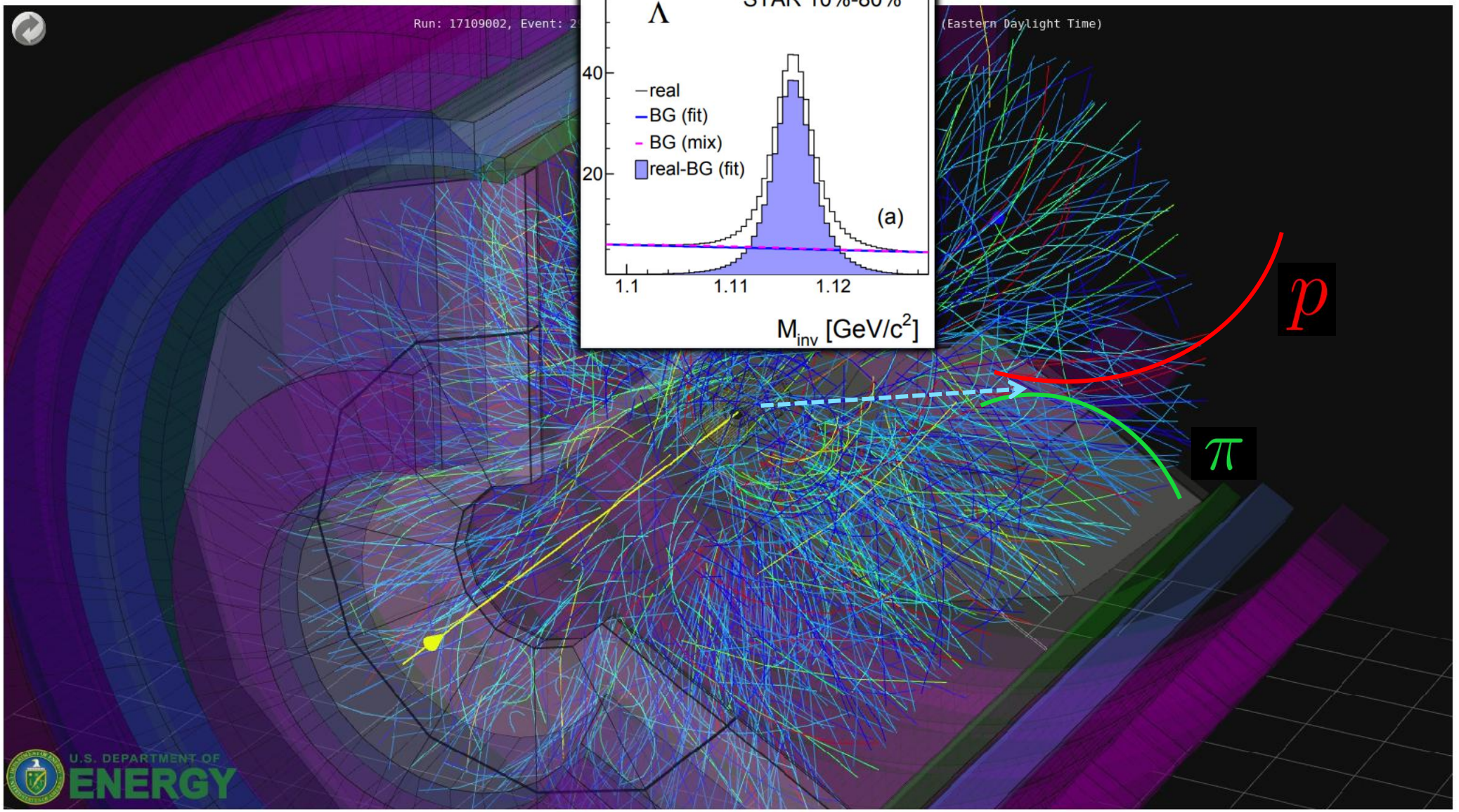
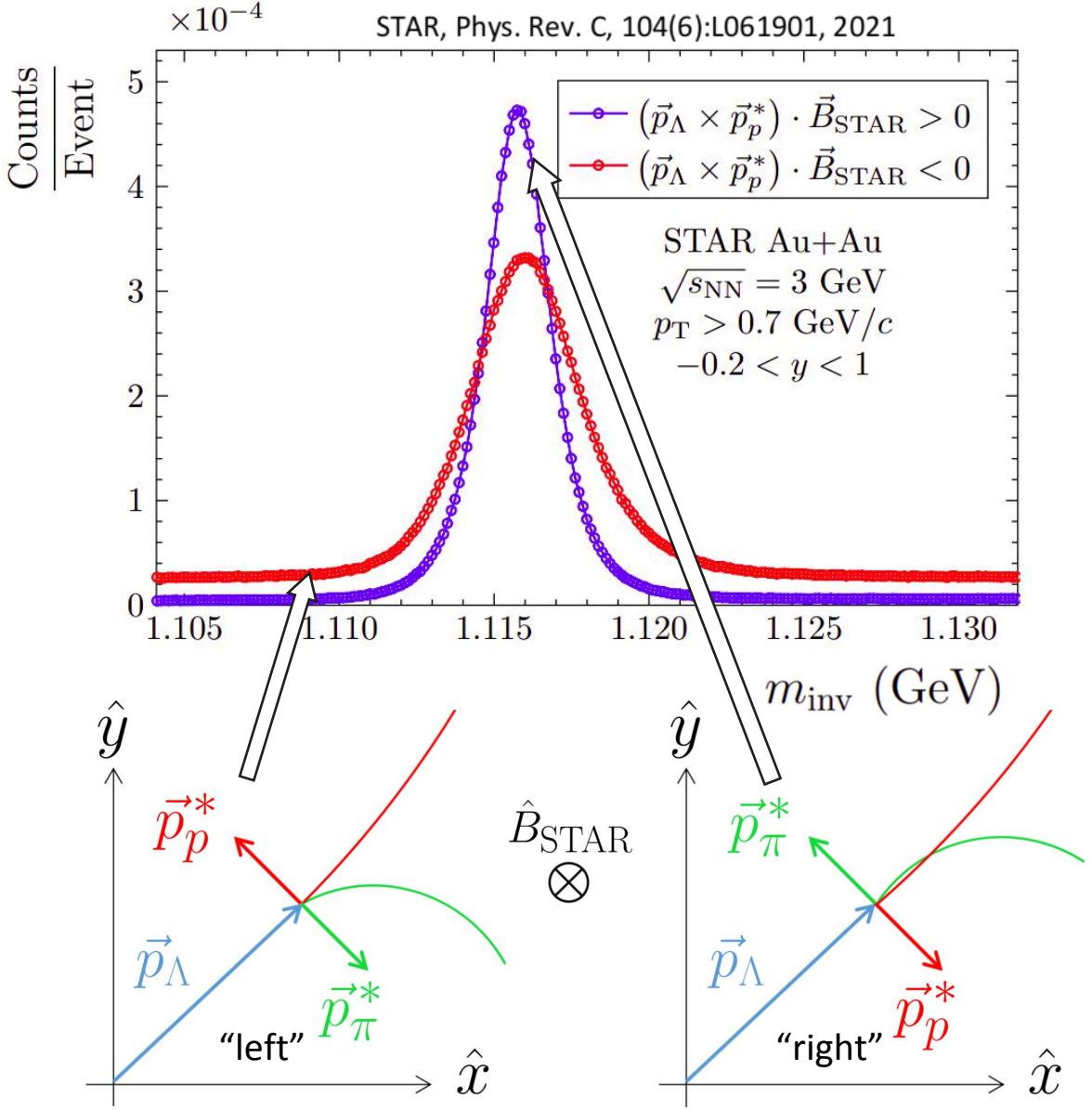
STAR, Phys.Rev.C 98 (2018) 014910



# STAR detector efficiencies

- The width of the $m_{inv.}$ distribution depends on the orientation of the daughter emission angle: $\varphi_\Lambda - \varphi_p^*$; "*" denotes $\Lambda$ frame)
  - This is directly related to the direction of $\Lambda$ spin at the moment of decay!
  - Let's first consider the two cases:
    $(\vec{p}_\Lambda \times \vec{p}_p^{\,*}) \cdot \vec{B}_{\mathrm{STAR}} < 0$ ("left")
    $(\vec{p}_\Lambda \times \vec{p}_p^{\,*}) \cdot \vec{B}_{\mathrm{STAR}} > 0$ ("right")
- This dependence is purely a reconstruction effect from imperfect detector resolution



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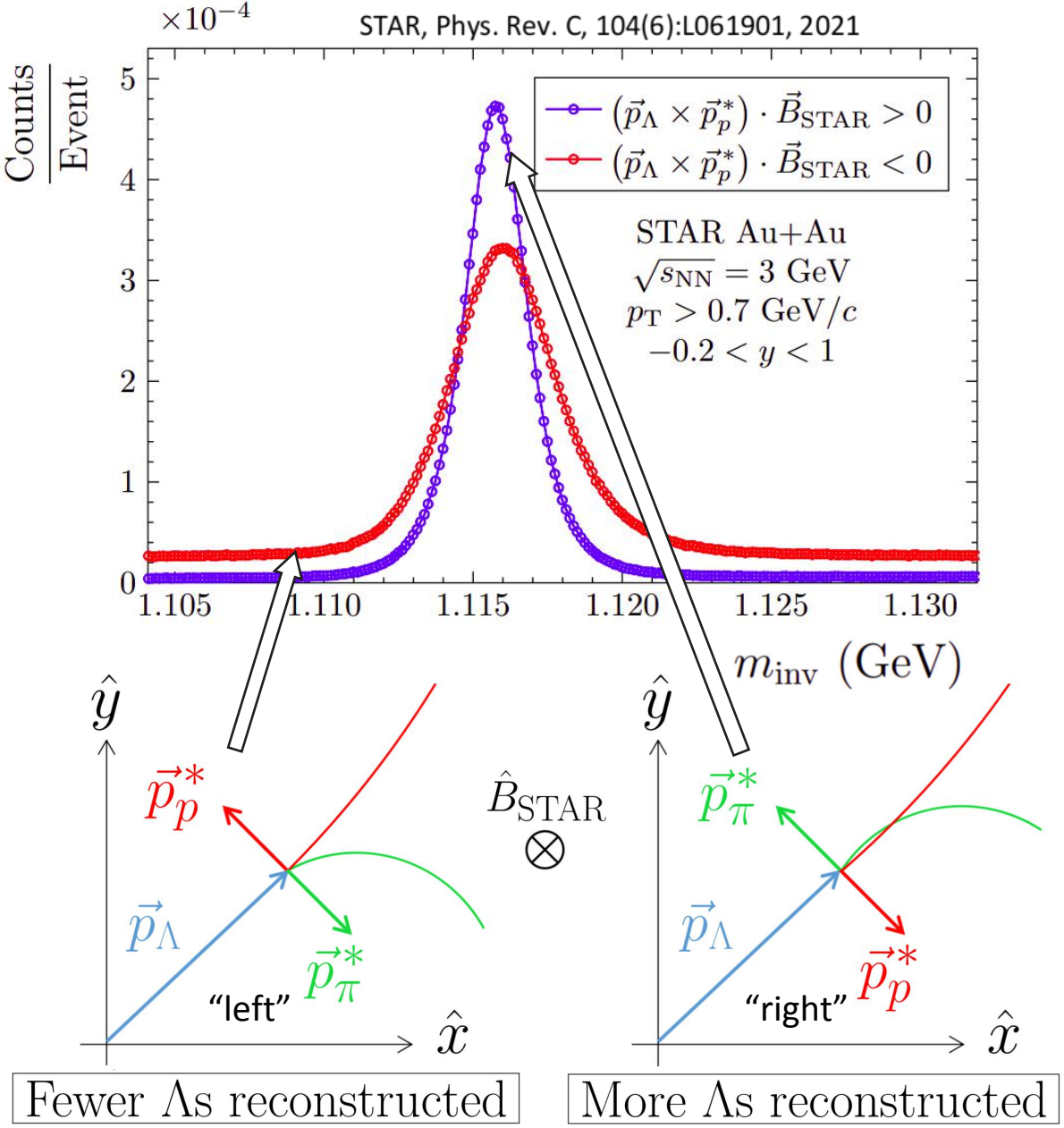
- This efficiency also affects the number of reconstructed $\Lambda$s with respect to $\varphi_\Lambda - \varphi_p^*$ ("*" denotes $\Lambda$ frame)



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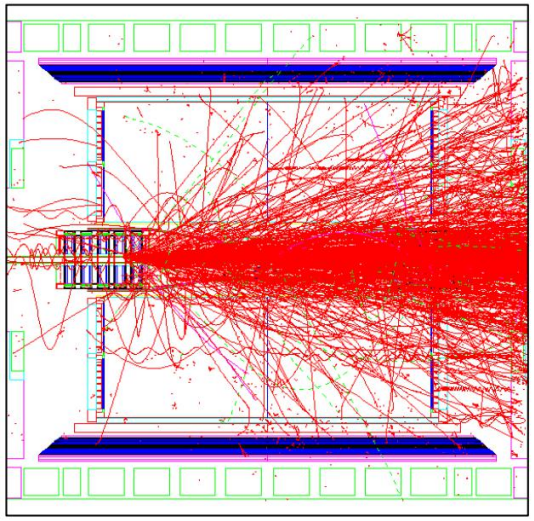
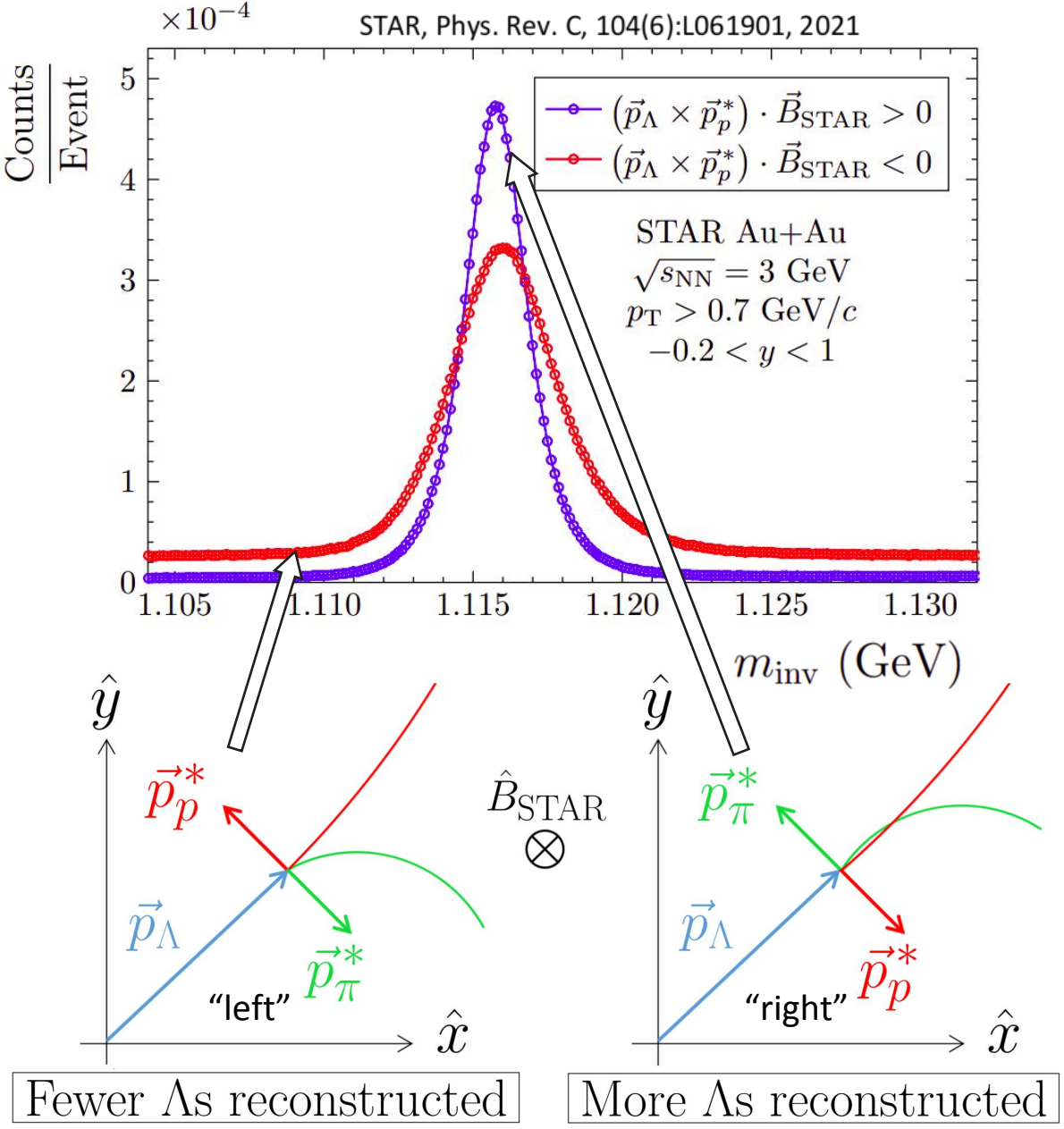
Simulate the STAR detector and its efficiencies





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  - *It is characterized by an asymmetry of the $\varphi_\Lambda - \varphi_p^*$ distribution*

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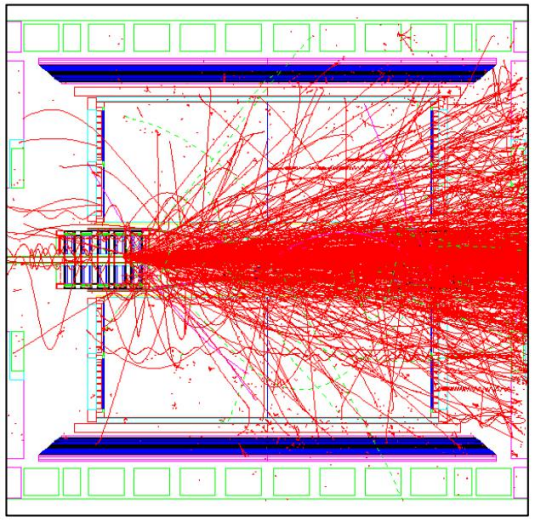
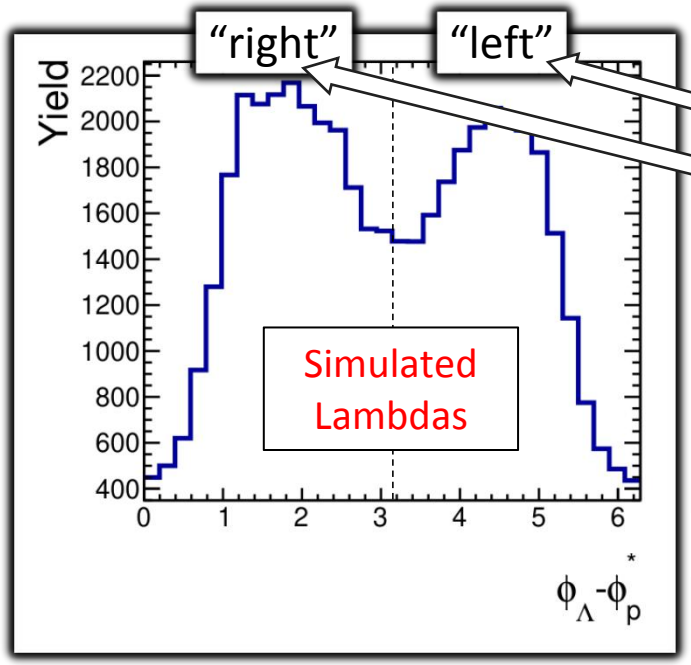
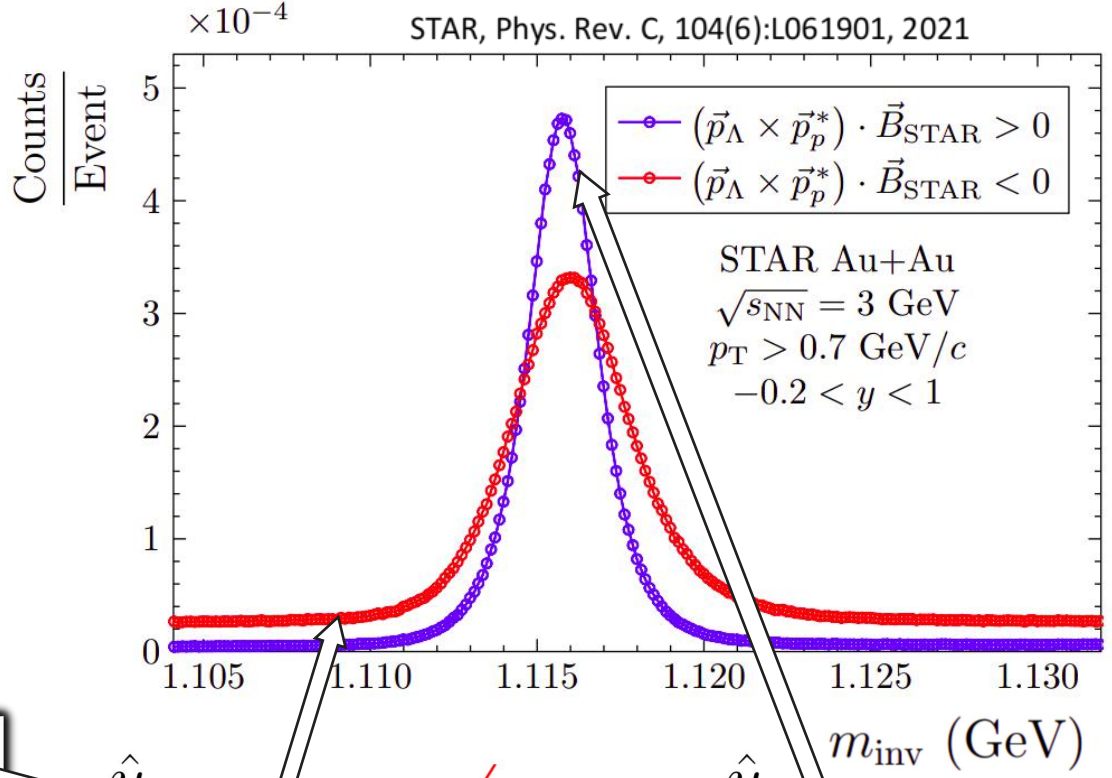
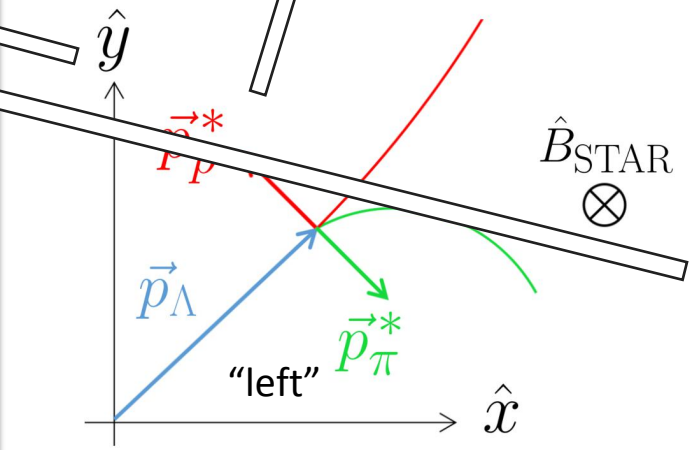


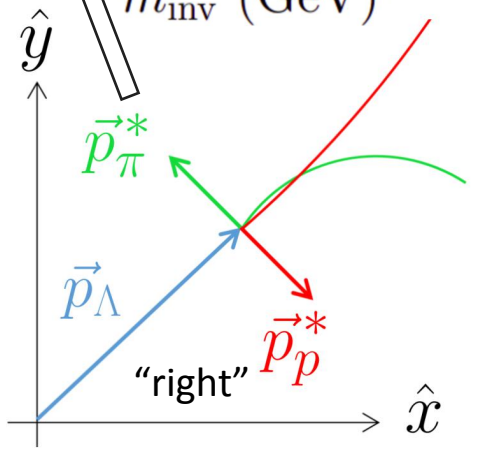



Fewer $\Lambda$s reconstructed

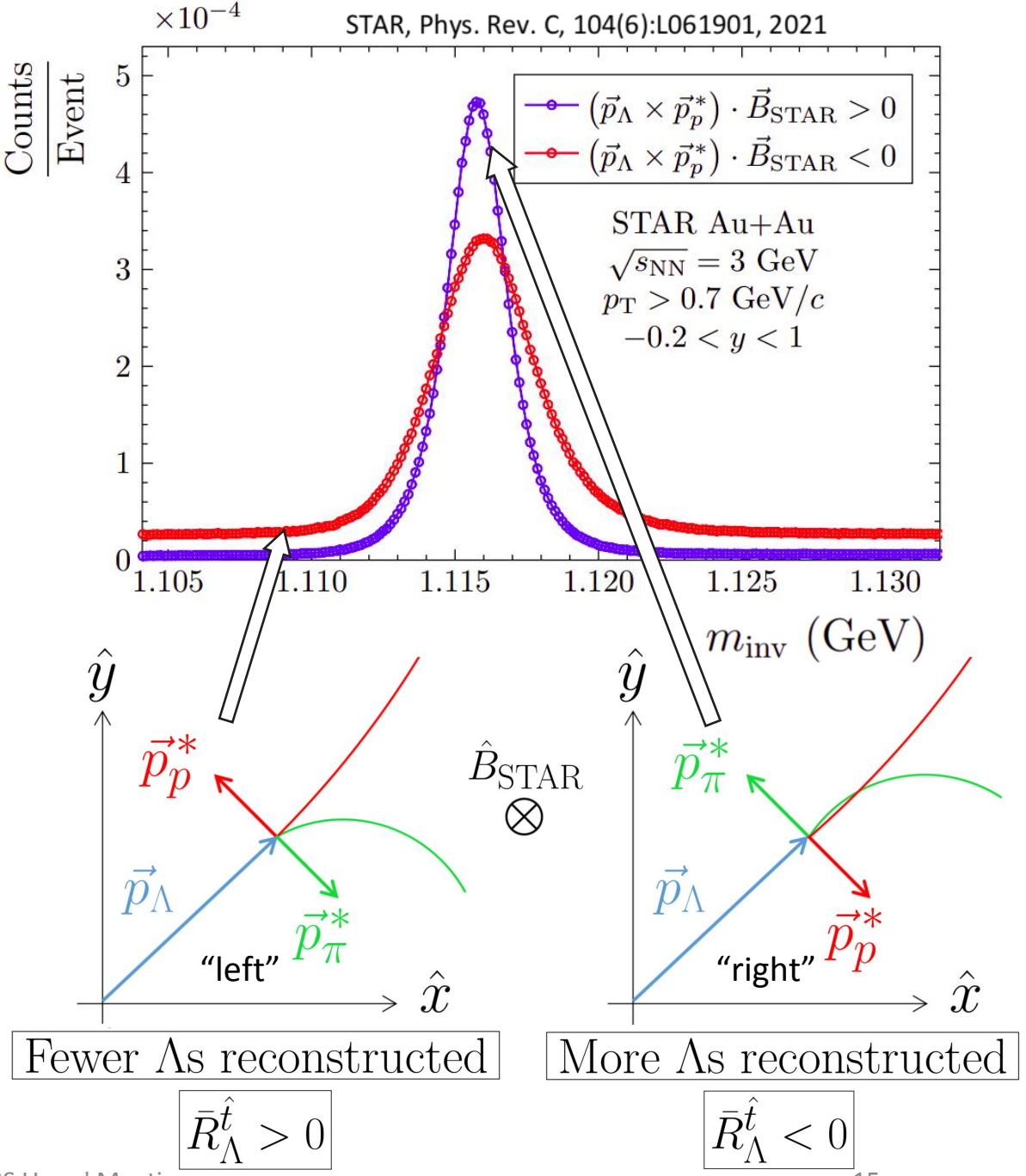
$\hat{B}_{\rm STAR}$ $\otimes$




More $\Lambda$s reconstructed

# STAR detector efficiencies

- This efficiency also affects the number of reconstructed $\Lambda$s with respect to $\varphi_\Lambda - \varphi_p^*$ ("*" denotes $\Lambda$ frame)
  - *It is characterized by an asymmetry of the $\varphi_\Lambda - \varphi_p^*$ distribution*
- These decay classes correspond to a sign of $\overline{R}_\Lambda^{\hat{t}}$ so that $\overline{R}_\Lambda^{\hat{t}}$ depends strongly on $m_{\mathrm{inv}}$



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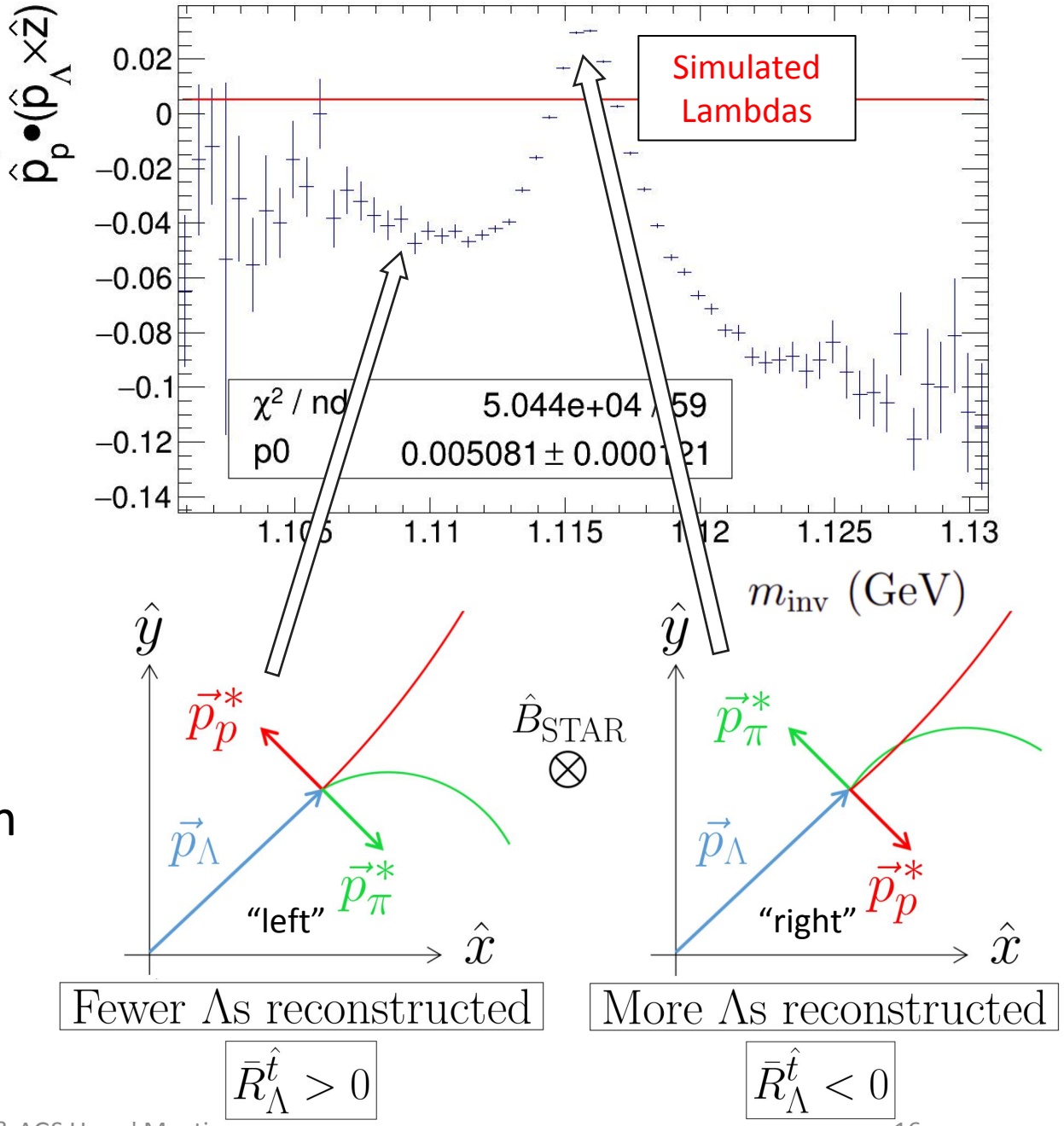
- These decay classes correspond to a sign of $\overline{R}_\Lambda^{\hat{t}}$ so that $\overline{R}_\Lambda^{\hat{t}}$ depends strongly on $m_{\text{inv}}$
  - This $m_{\text{inv}}$-dependent behavior is visible in simulations of the STAR detector with known efficiencies



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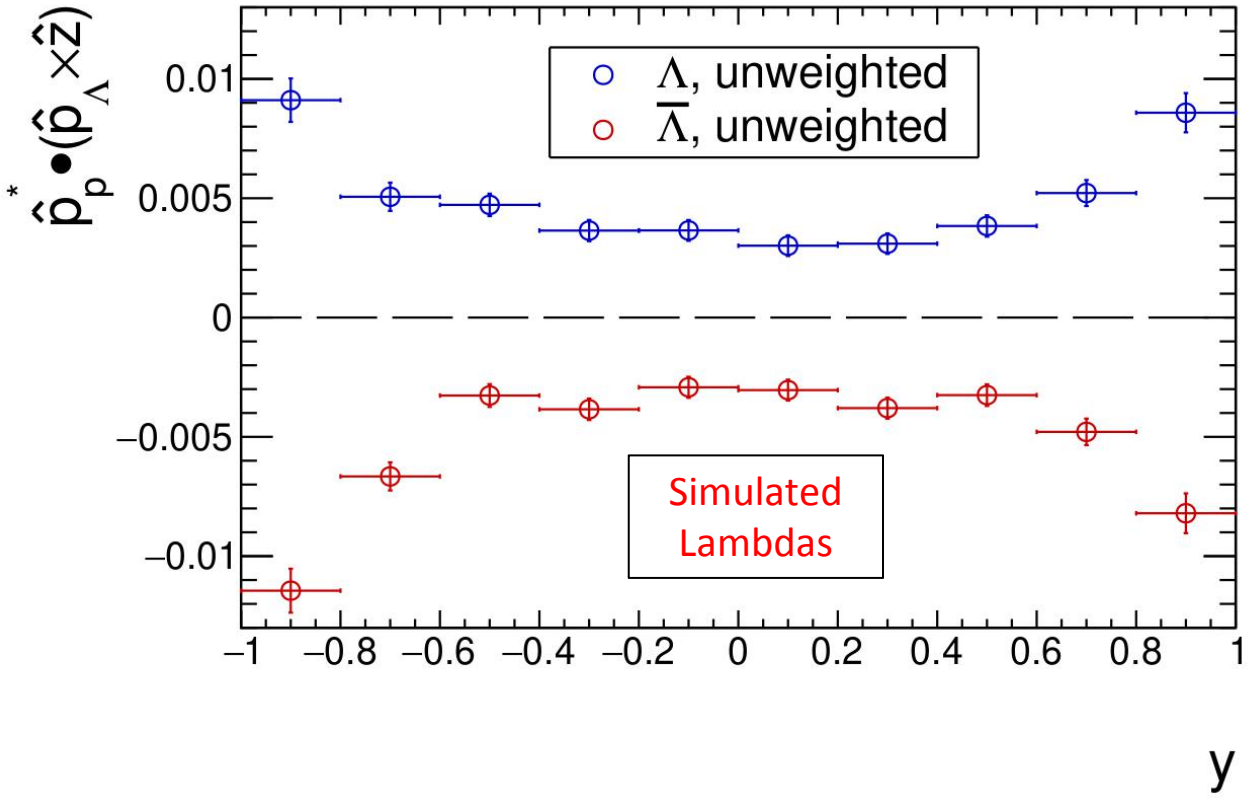
- *The long story short...*
- We will see non-zero contributions to $\overline{R}^{\hat{t}}_{\Lambda}$ purely based on tracking effects...



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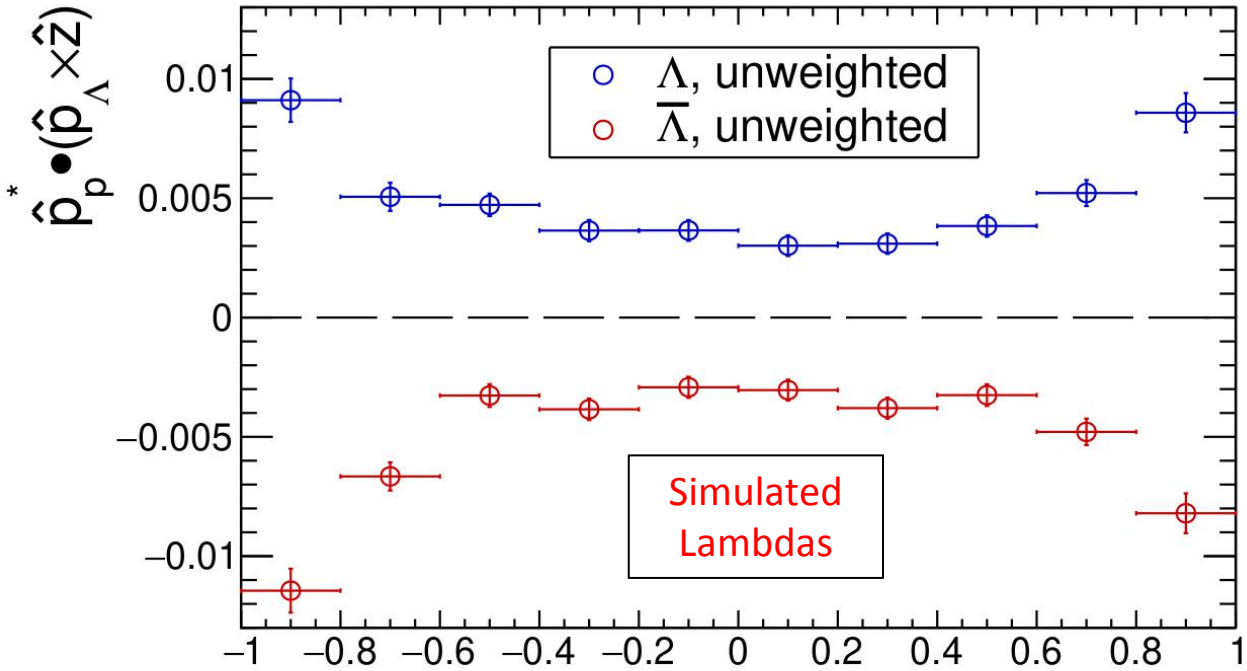
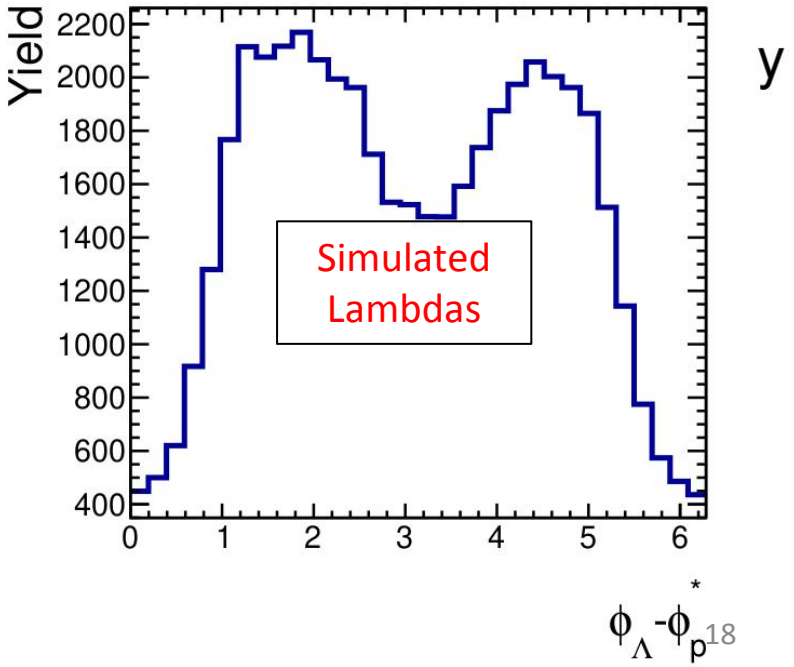
  1. characterized by an asymmetry of the $\varphi_{\Lambda} - \varphi^{*}_{p}$ distribution
  2. caused by the STAR magnetic field ($\vec{B}_{\mathrm{STAR}} \parallel \hat{z}$) breaking a symmetry



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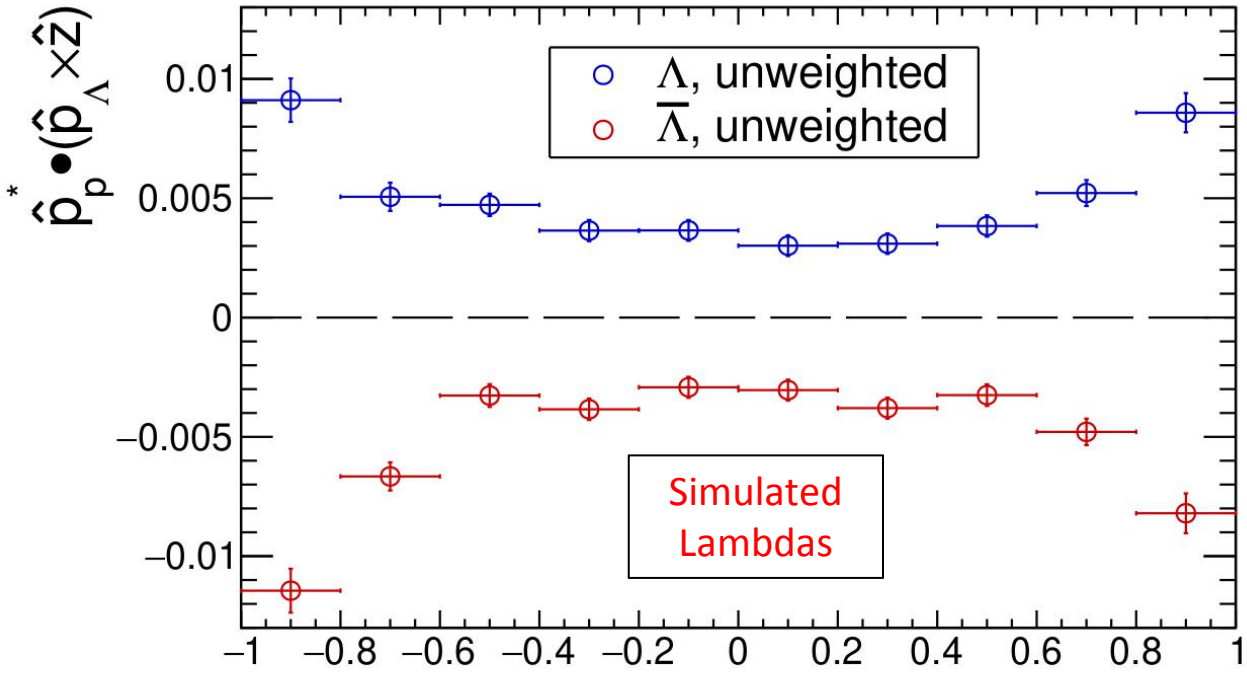


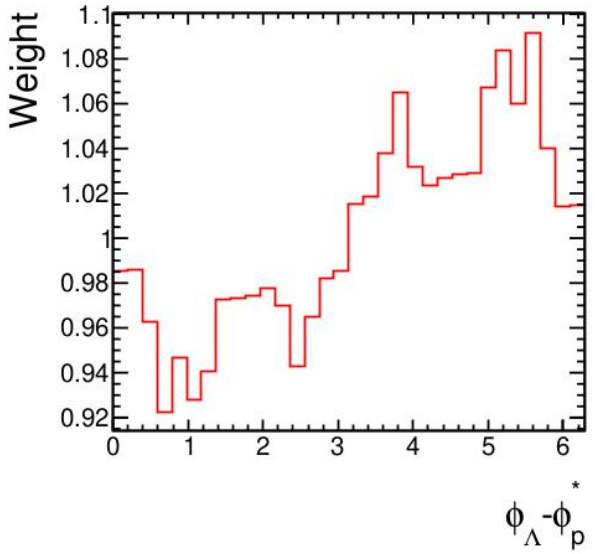


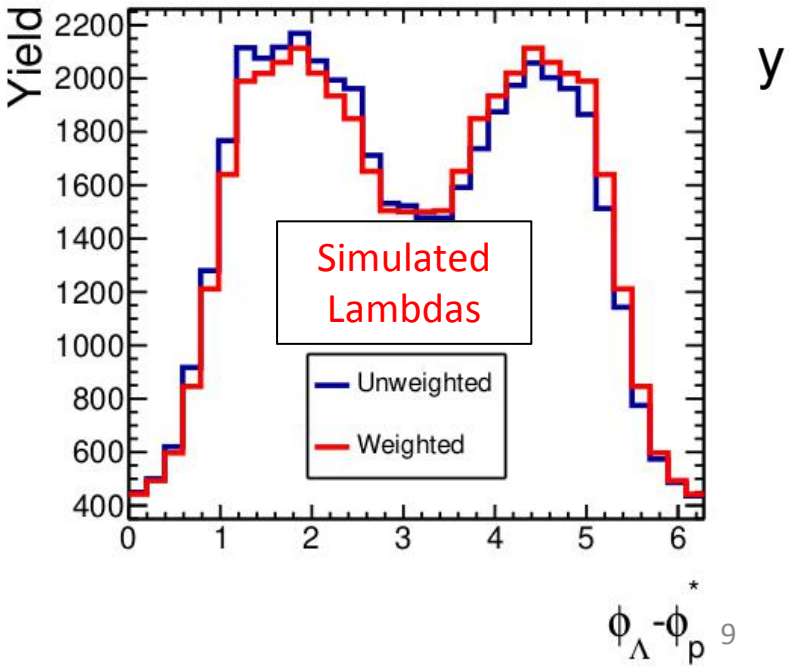

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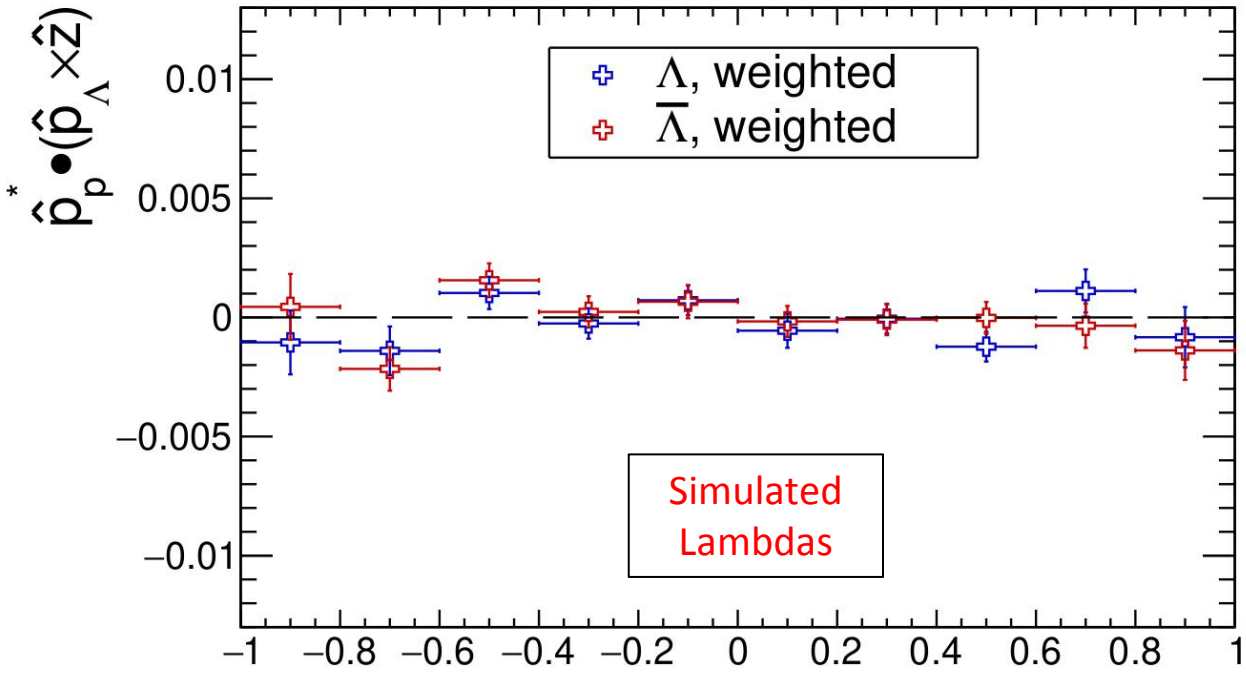


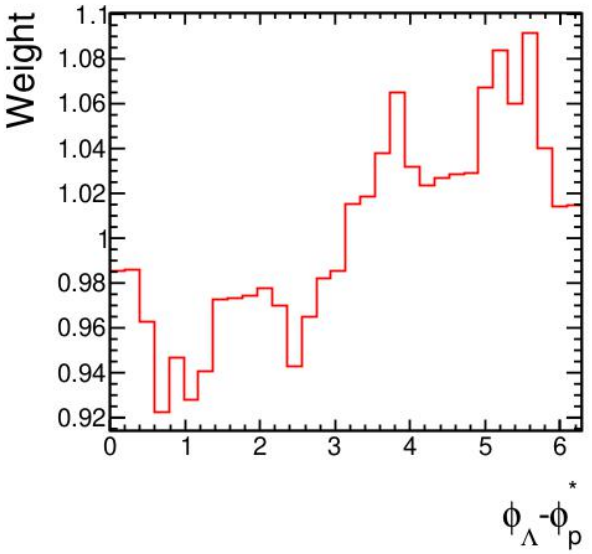


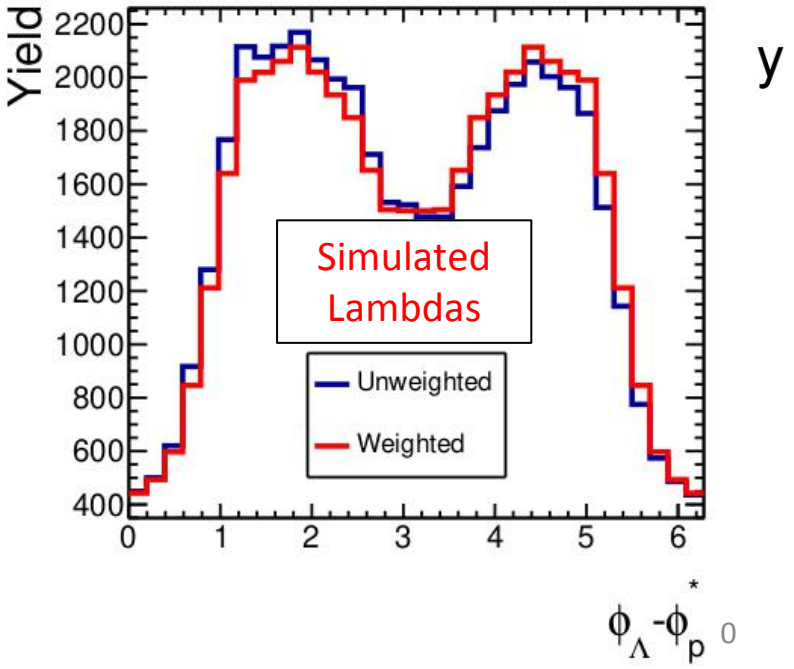

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- Theses effects are characterized by embedding, and so weights may be applied to symmetrize the distribution
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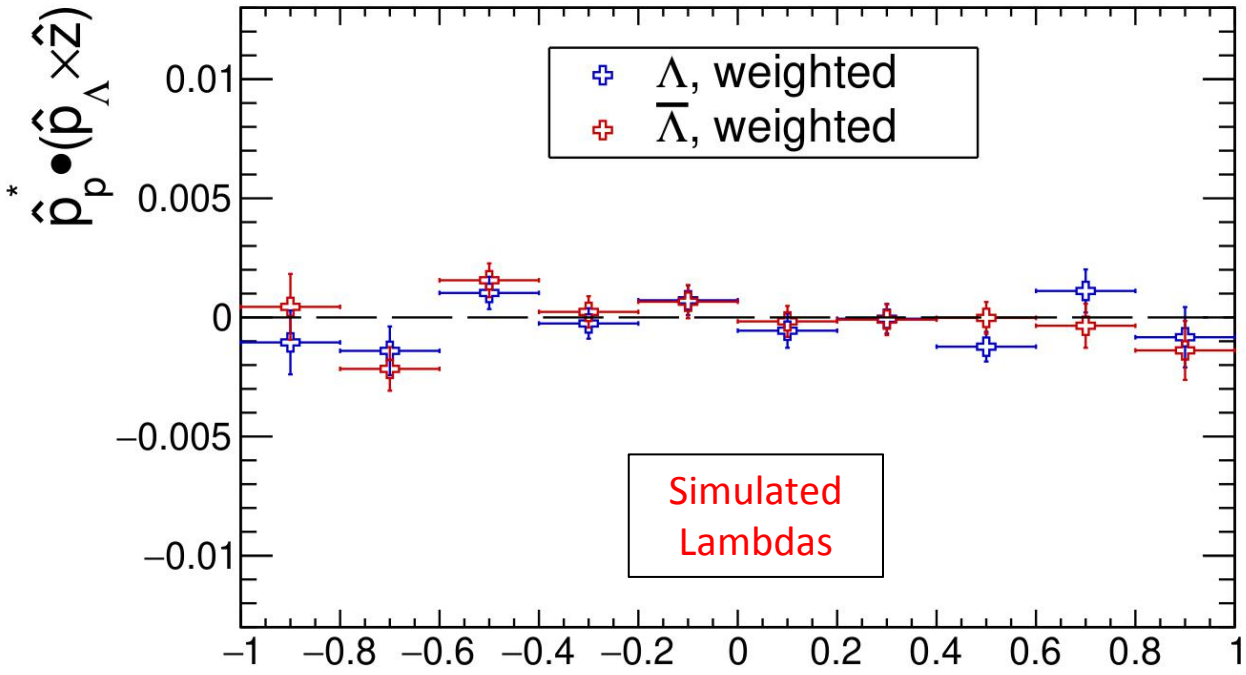
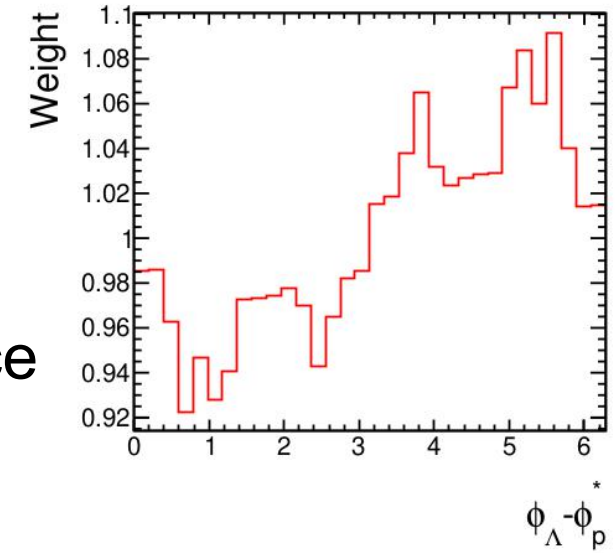
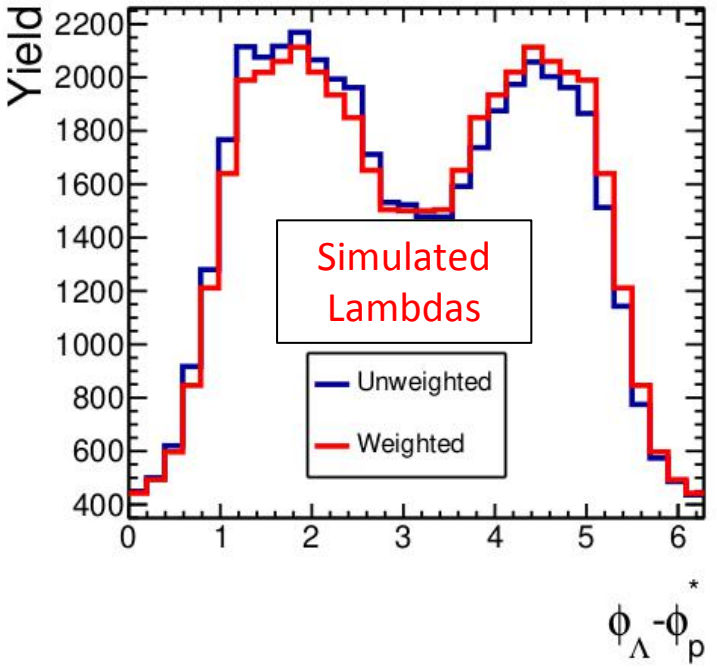
- Pursuing this in actual data, however, may be dubious
  - Requires very precise characterization of acceptance effects



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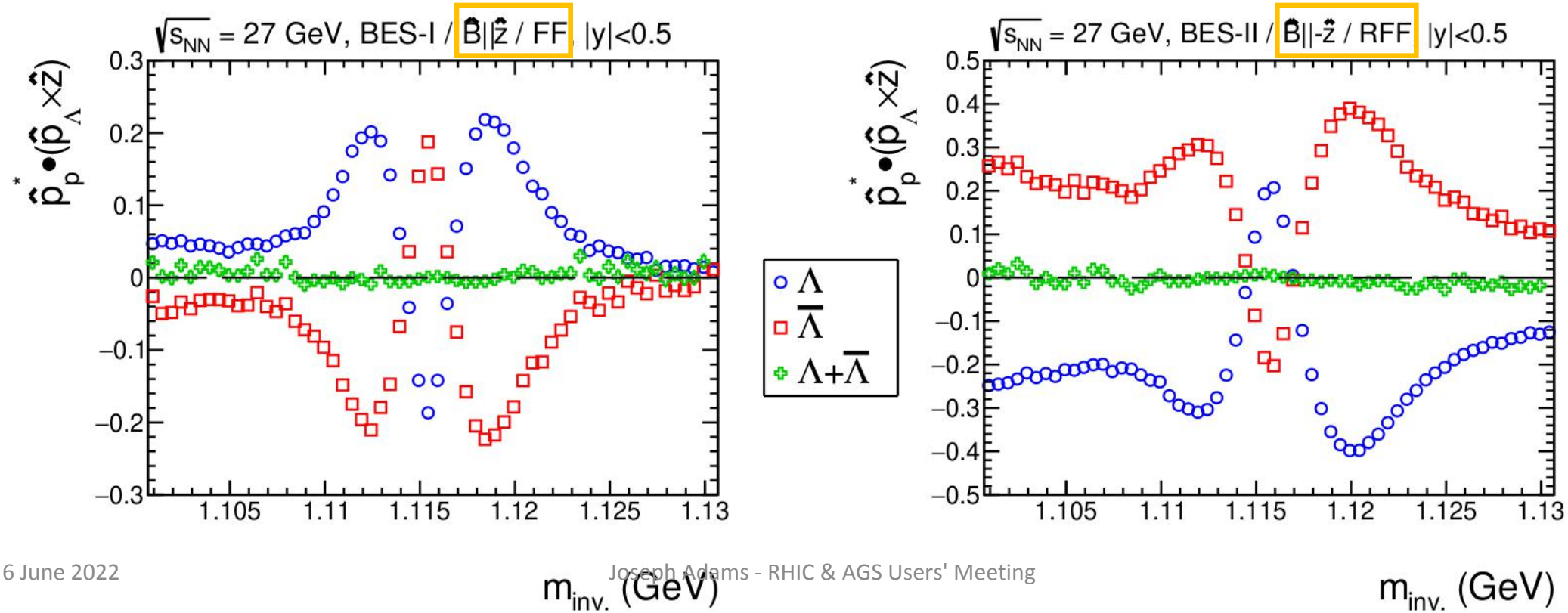
  - Recall that the reconstruction efficiency depends on $(\vec{p}_{\Lambda} \times \vec{p}^{\,*}_{p}) \bullet \vec{B}_{\mathrm{STAR}}$
  - *In the absence of toroidal vorticity*, this is effectively the sum $\overline{R}^{\hat{t}}_{\Lambda} + \overline{R}^{\hat{t}}_{\overline{\Lambda}}$
    - The efficiency effects are equal and opposite for Lambdas and Anti-Lambdas



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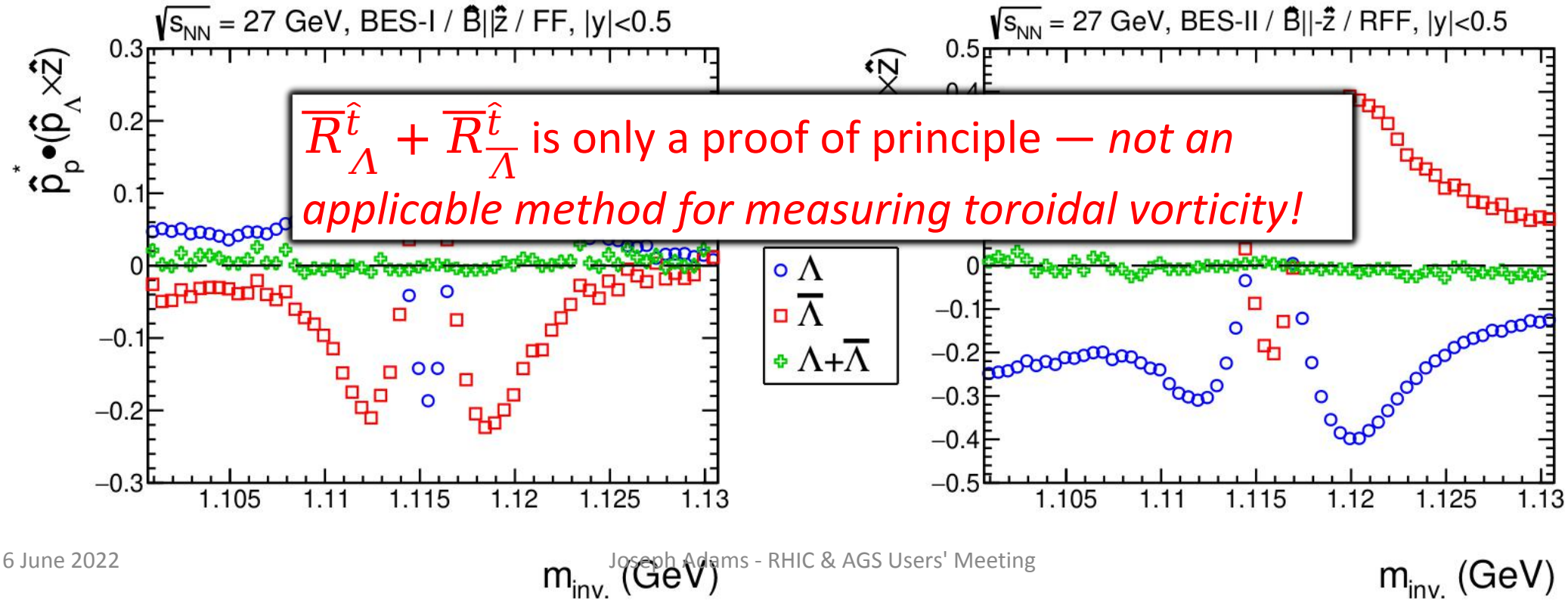

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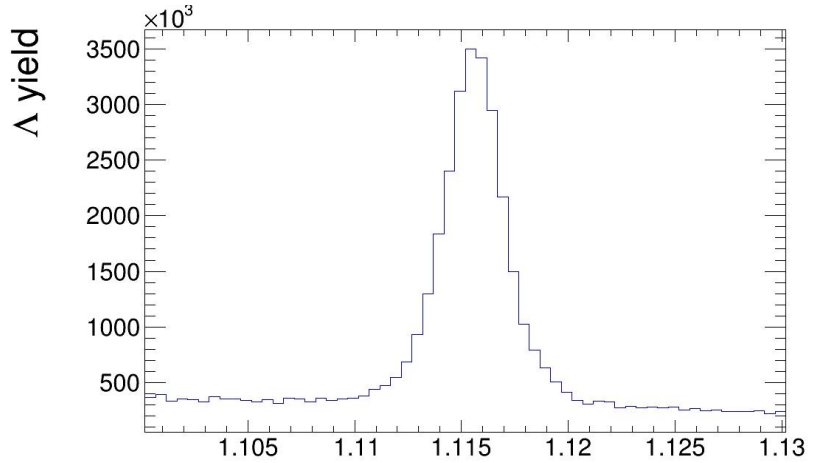
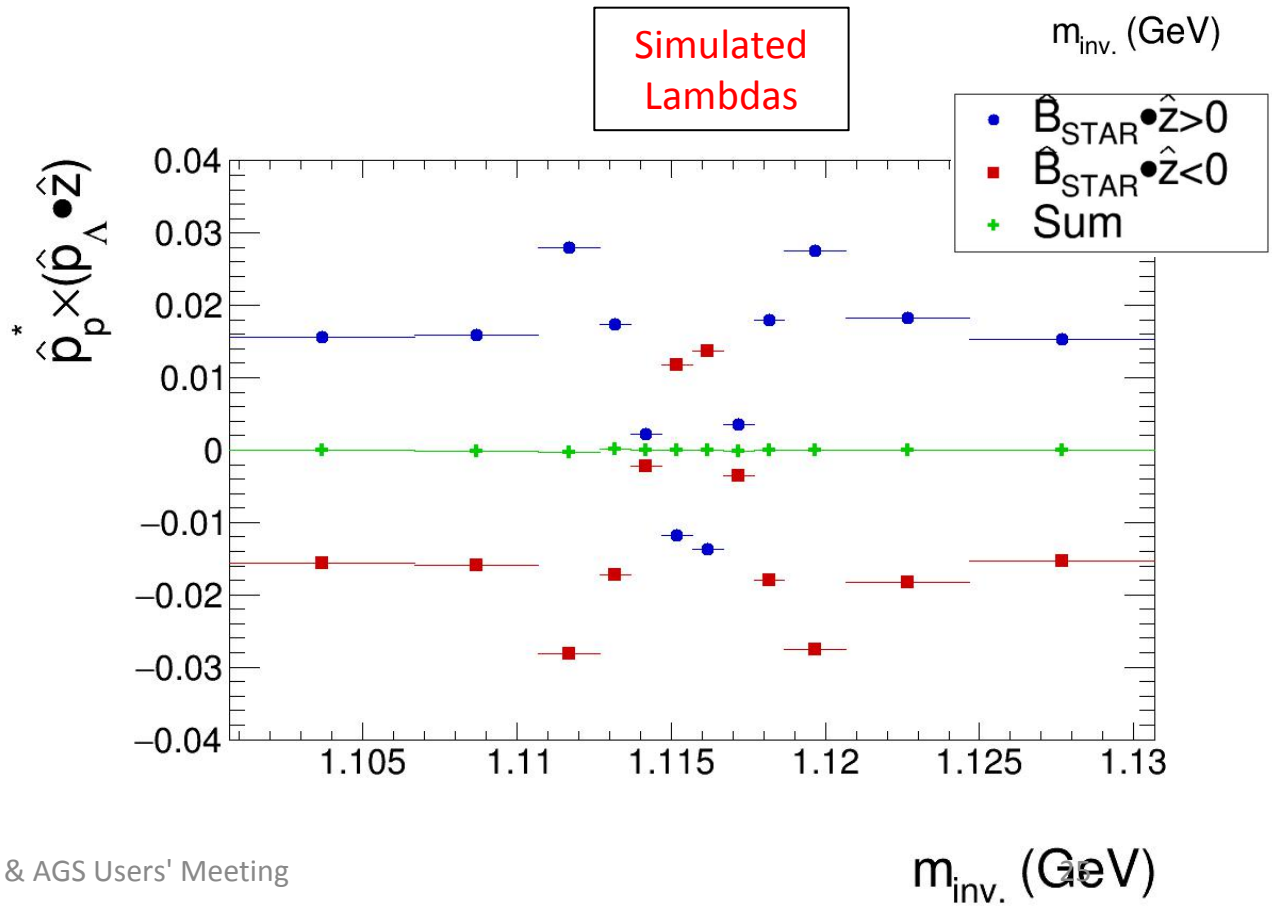
- This method can also be shown using simulations of the STAR detector with the known efficiencies
- Generate samples of non-polarized $\Lambda$s with $\overrightarrow{B}_{\mathrm{STAR}} > 0$ and $\overrightarrow{B}_{\mathrm{STAR}} < 0$
  - $\overline{R}^{\hat{t}}_{\Lambda}$ measurements are equal and opposite



# Summary

- Detector efficiencies lead to $m_{inv.}$-dependent $\overline{R}^{\hat{t}}_{\Lambda}$ and artificial $\overline{R}^{\hat{t}}_{\Lambda} > 0$
- Swapping of STAR magnetic field during the upcoming p+A run will provide a firm ground for claiming this discovery
- A discovery of toroidal vorticity in p+A collisions is possible with STAR