Lambda Polarization in Heavy-ion Collisions at STAR

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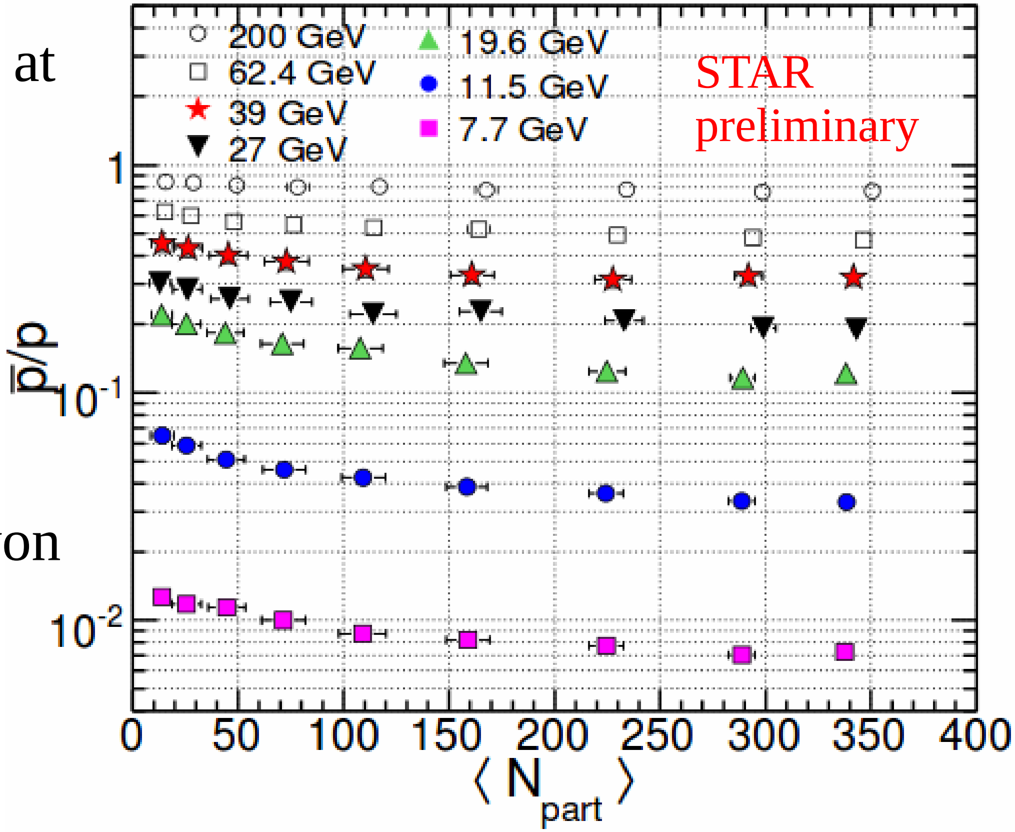
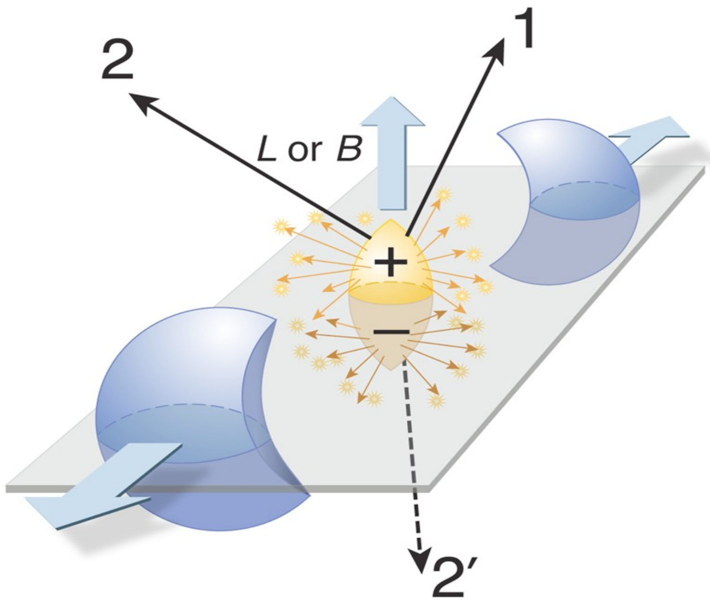
Baryon Stopping in the BES

- Fireball μ_B from baryon stopping increases at low $\sqrt{s}$ AuAu collisions, which we are exploring in the BES at STAR

- Peripheral collisions have large angular momentum (~10^4-10^5 ħ)

- L is transferred, in part, to fireball via baryon stopping



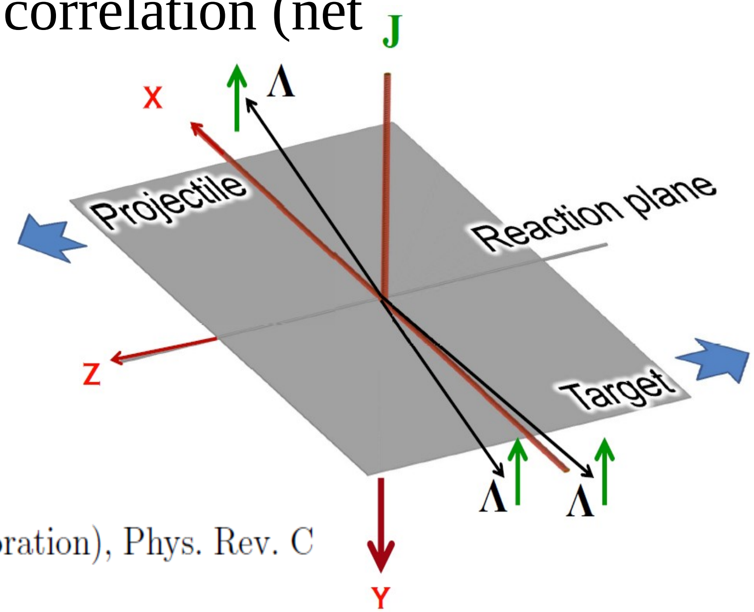


Stopping Dynamics and Thermalization

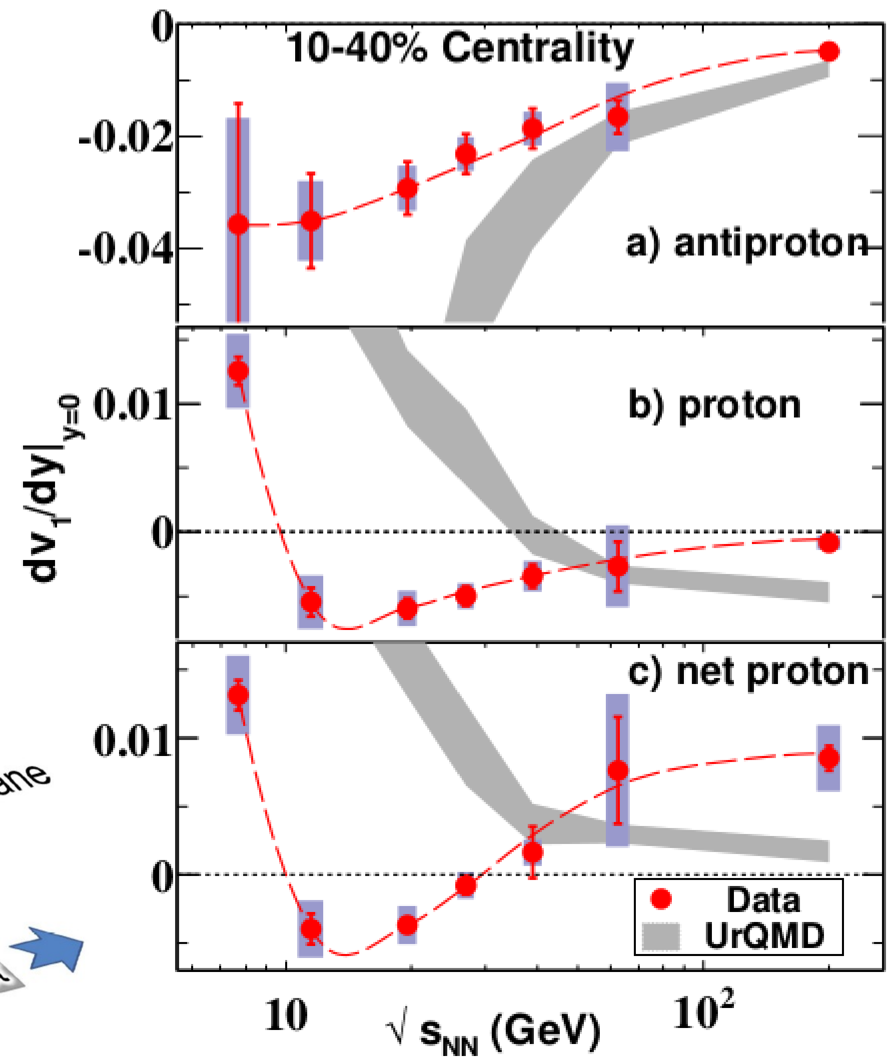
- Stopped baryons have interesting dynamics and thermalization is quick, eg. net proton directed flow

- Through thermalization parton spins can couple to AuAu fireball orbital angular momentum

- Net partonic spin would transfer to emitted particles leading to an intrinsic spin – fireball angular momentum correlation (net polarization)



B. I. Abelev, et al., (STAR Collaboration), Phys. Rev. C **76**, 024915 (2007).



Phys. Rev. Lett. 112 (2014) 162301

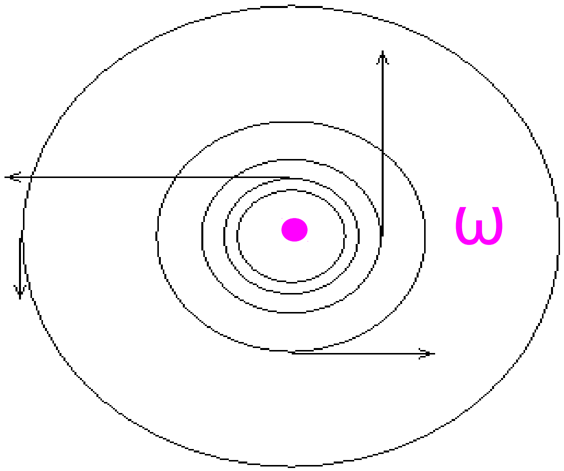
Model Predictions

- Becattini, Csernai, and Wang use 3+1 inviscid hydro with vorticity ($\vec{\omega} = \nabla \times \vec{v}$) put in by hand for prediction

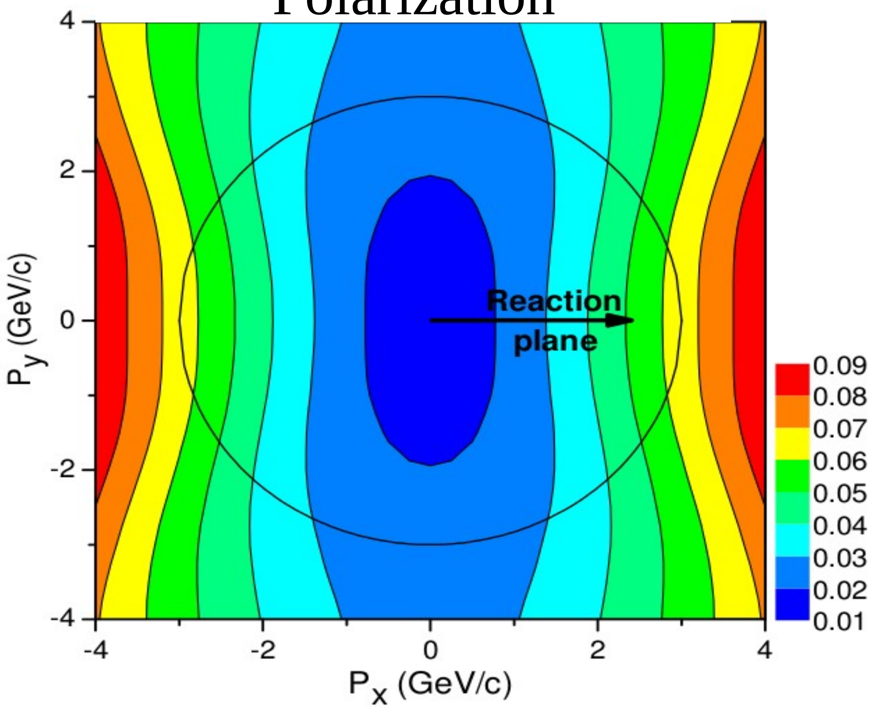
- Polarization is maximal for
  - Semi Peripheral collisions
  - Few GeV Λ momentum
  - Λ emitted in reaction plane

- Predict maximum Polarization: 7-9% (overall consistent with previous STAR measurement)

- More recent prediction with viscosity added is more modest (< 1%) – general predictions are consistant



Polarization



F. Becattini, L. Csernai and D. J. Wang, Phys. Rev. C **88** (2013) 034905

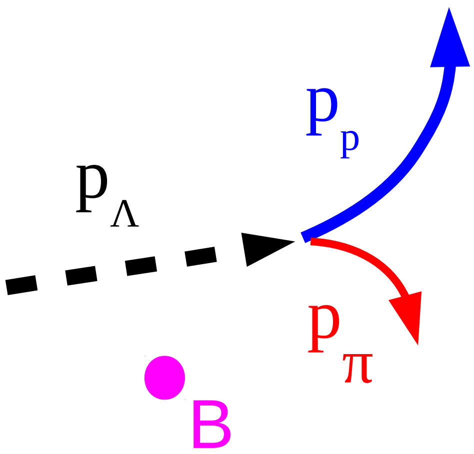
Lambda Baryon: Spin Probe

- Because of parity violating decay Λ baryons are self analyzing
  - Momentum of the proton daughter boosted into the Λ rest frame, $\hat{\mathbf{p}}^*$,points preferentially in the direction of the polarization $\mathbf{P}_i$ of the Λ,

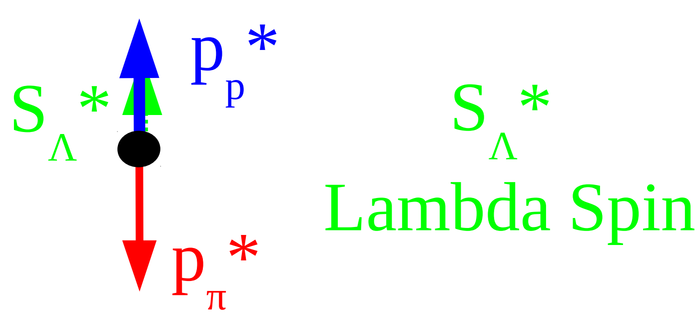
$$\frac{dN}{d\Omega} = \frac{N}{4\pi}\left(1 + \alpha_\gamma \mathbf{P}_i \cdot \hat{\mathbf{p}}\right)$$

  - α_γ is the decay parameter (~0.642)
  - Equally true for $\overline{\Lambda}$ and corresponding antiprotons

$$\Lambda \rightarrow p + \pi$$



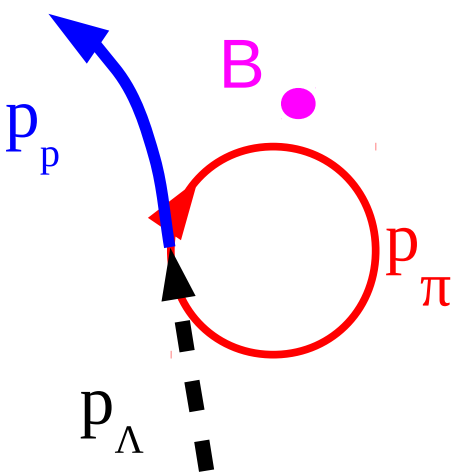
Boost into Λ rest frame:

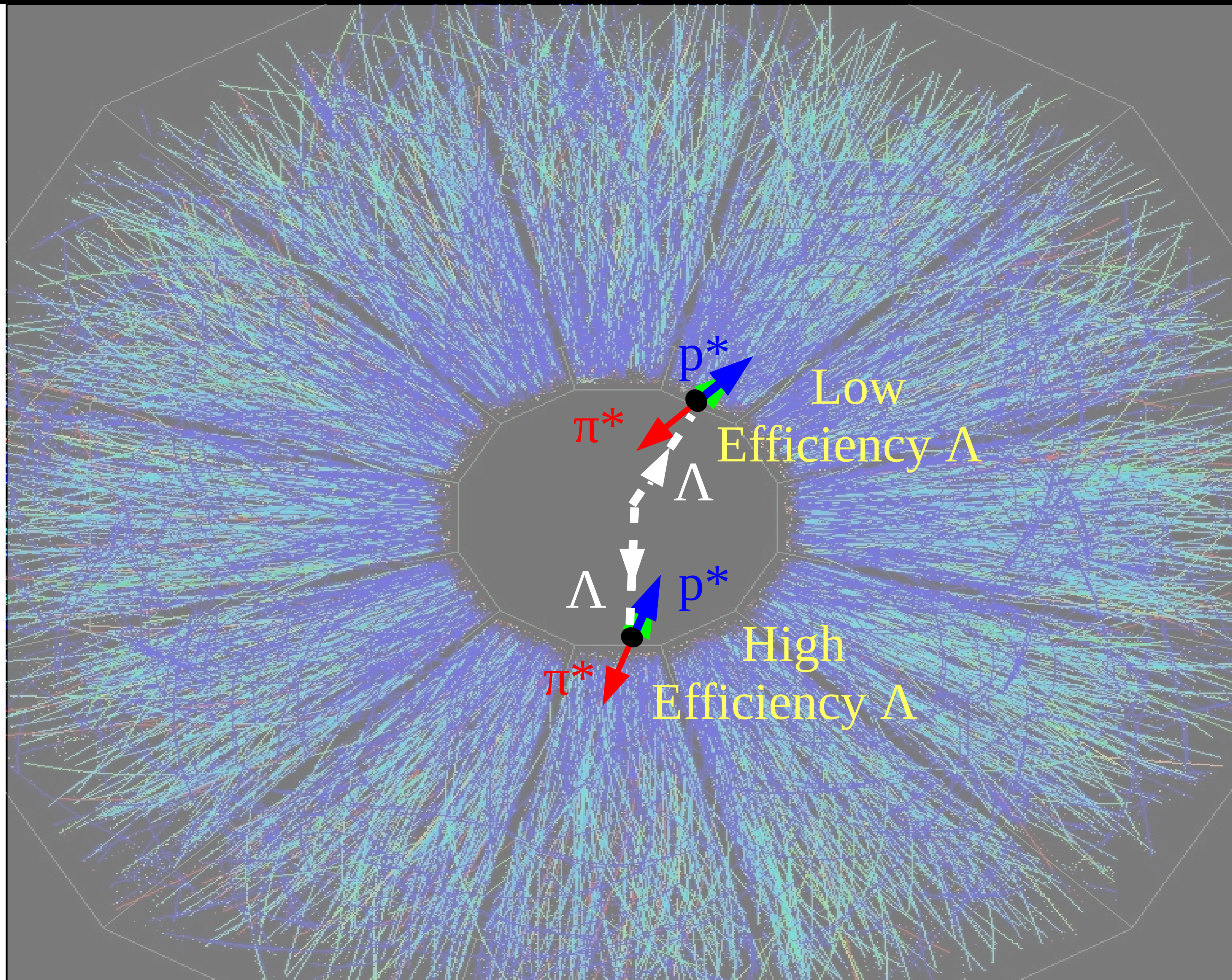


Lambda Decay Kinematic Efficiency

- Serious efficiency issue for decays where the pion points backwards in Λ rest frame

Low Efficiency





Measurement Technique

• Zeroth component of the spin four vector in the Lambda frame is zero
• Take Lambda frame spin three vector component in the direction of proton momentum in rest frame (ignore α for now)

$$S^* = \frac{1}{2\left|\vec{p}_p^*\right|}(0, -\vec{p}_p^*)$$

• (Standard) boost spin vector into the Lab frame

$$\vec{S} = \vec{S}^* + \frac{\gamma_\Lambda^2}{\gamma_\Lambda + 1}(\vec{\beta}_\Lambda \cdot \vec{S}^*)\vec{\beta}_\Lambda$$

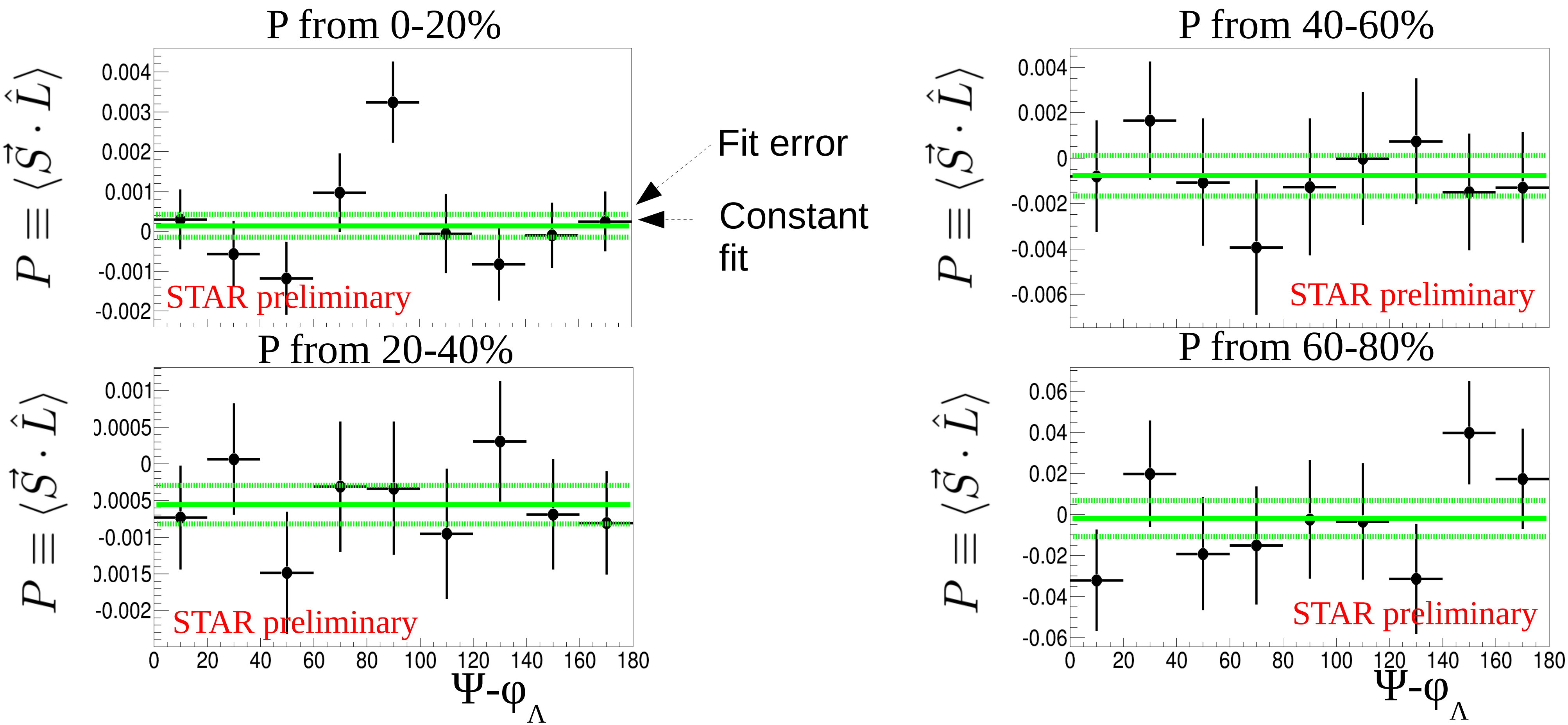
• The Polarization (P) is a measure of how aligned the spin is with the angular momentum

$$\hat{L} = (-\sin(\Psi), \cos(\Psi), 0)$$

$$P \equiv \langle \vec{S} \cdot \hat{L} \rangle$$

Polarization Plots: AuAu 39GeV $P \equiv \langle \vec{S} \cdot \hat{L} \rangle$

- Λ Polarization as a function of φ_Λ for centrality ranges 0-20%, 20-40%, 40-60%, 60-80%
- Because of low efficiency when pion p_T is small the x axis is 0°- 180°
- Many, many plots (7-39GeV AuAu): consistent null result
- Green is straight line fit with error

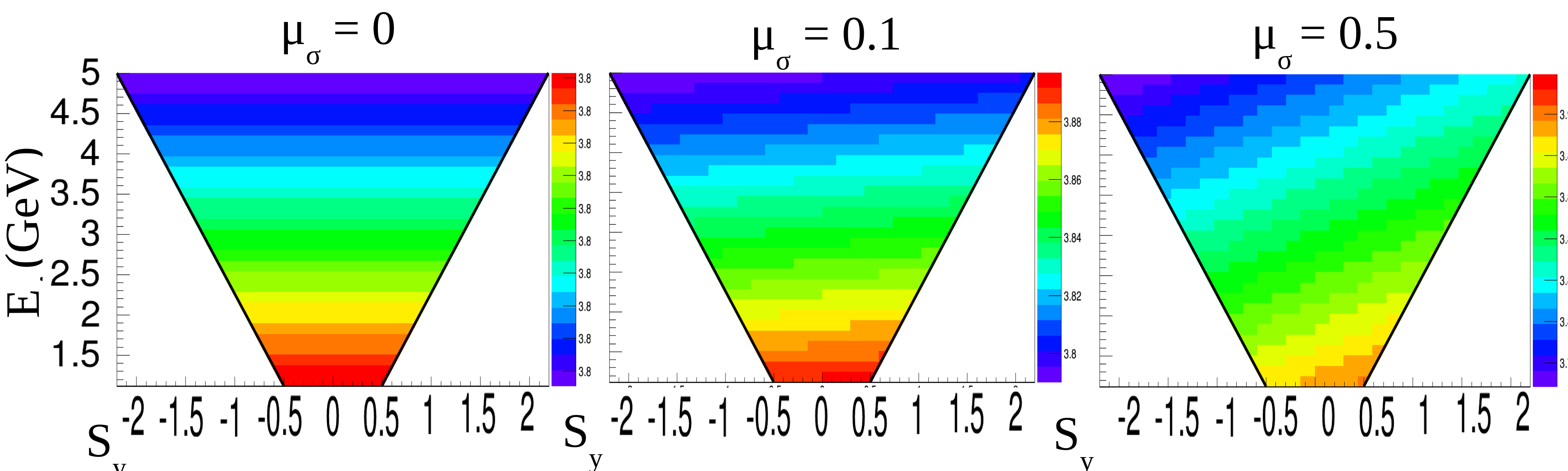


New Approach: Chemical Potential

- Goal: quote bound on polarization simply with as few ad-hoc cuts as possible (ie. without choosing pt, phi, rapidity)
- Look at correlation of spin with system angular momentum and consider a corresponding polarization chemical potential (like baryon chemical potential)
- Still depends on beam energy and centrality

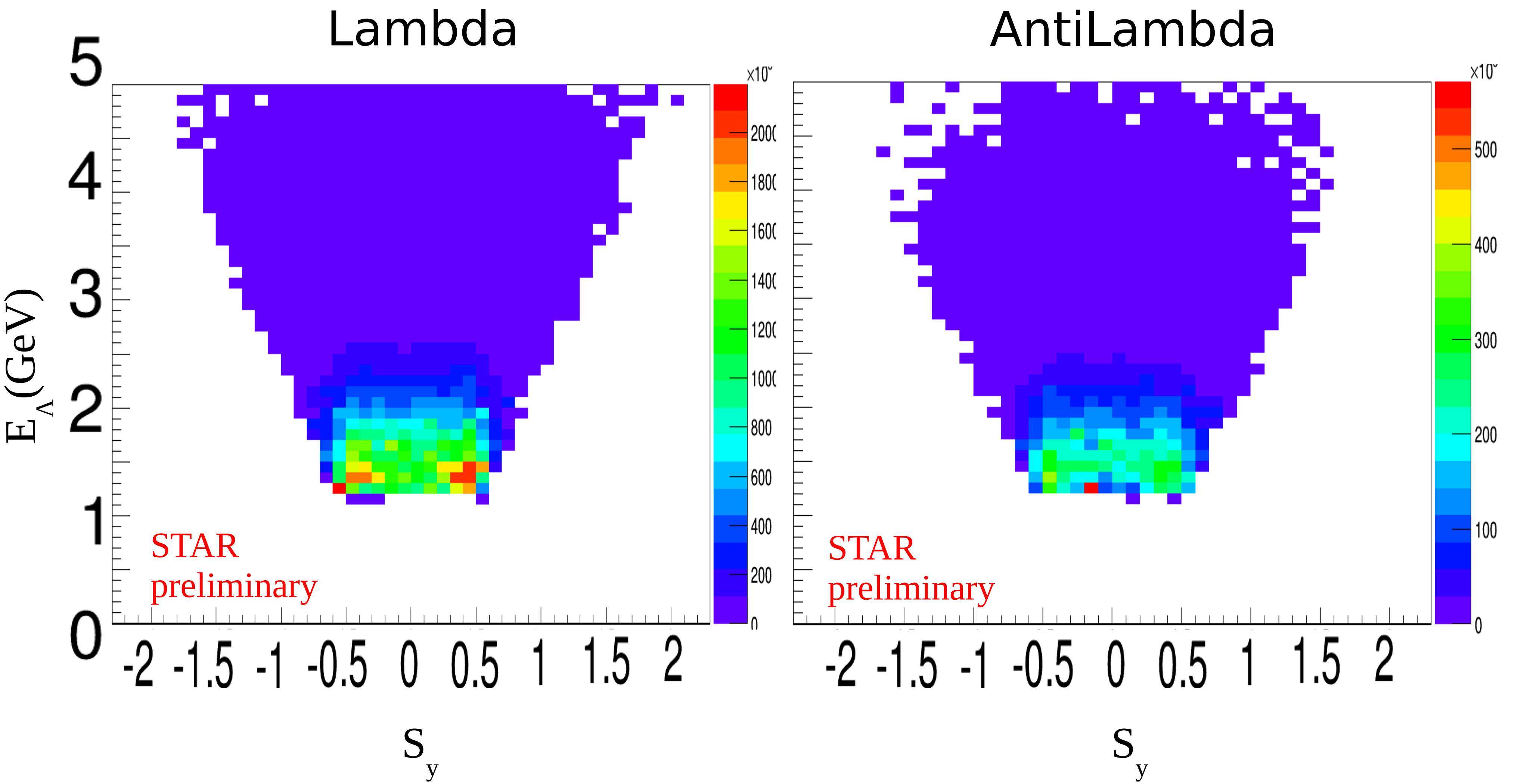
$$S_y \equiv \vec{S} \cdot \hat{L} \qquad e^{-(E-\mu_\sigma S_y - \mu_B B)/T}$$

- This exponential is plotted below (μ_B = 205 MeV, B = 1, T = 150 MeV)



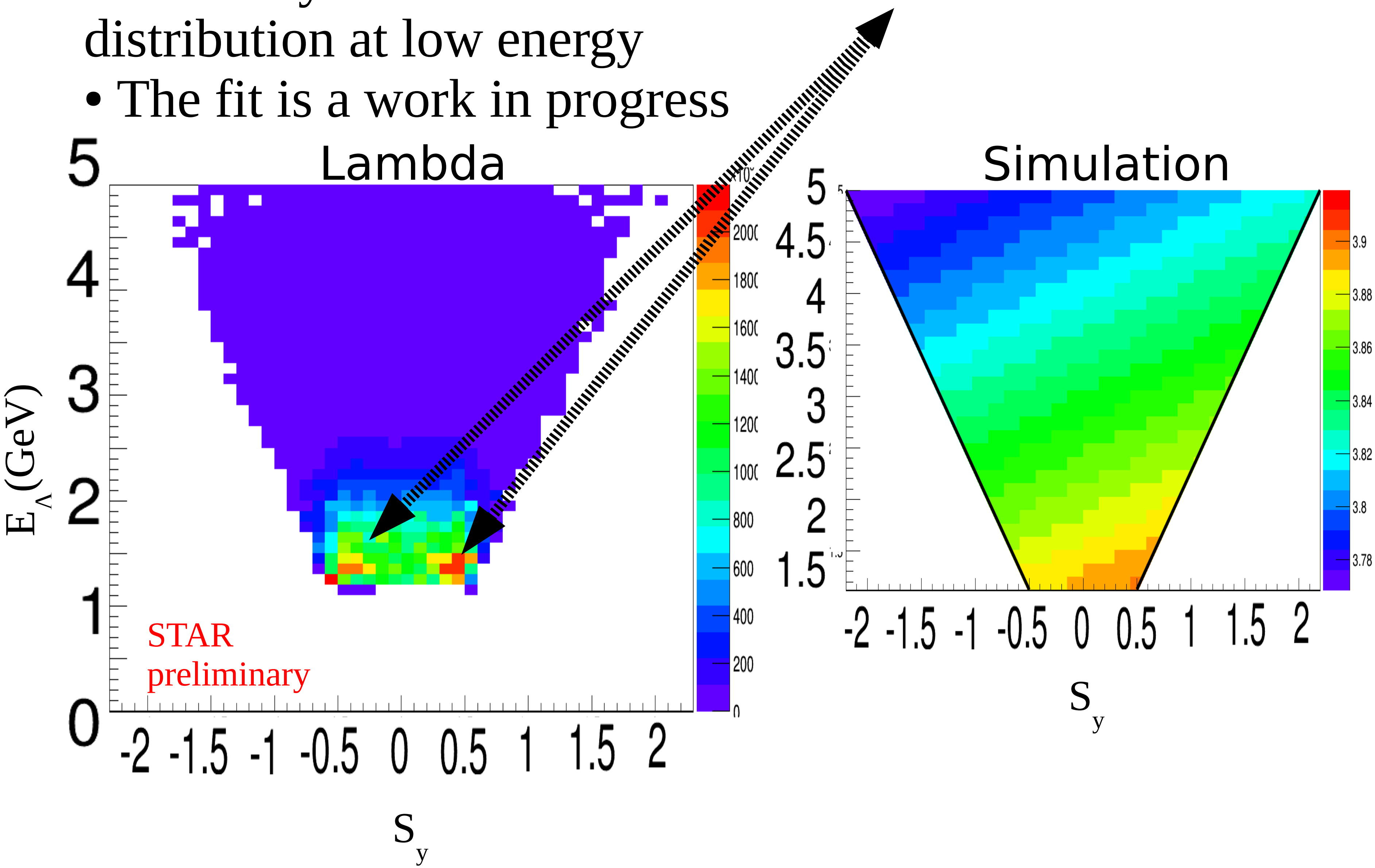
Chemical Potential 19GeV

Efficiency corrected E_Λ vs S_y for AuAu 19GeV collision Lambdas and AntiLambdas



Chemical Potential Fitting

- Currently fit fails because of “lobes” in the data distribution at low energy
- The fit is a work in progress



Conclusions

- No net Λ polarization seen at STAR for AuAu 7, 11, 19, 27, and 39 GeV

- Chemical potential method offers comprehensive measure of polarization

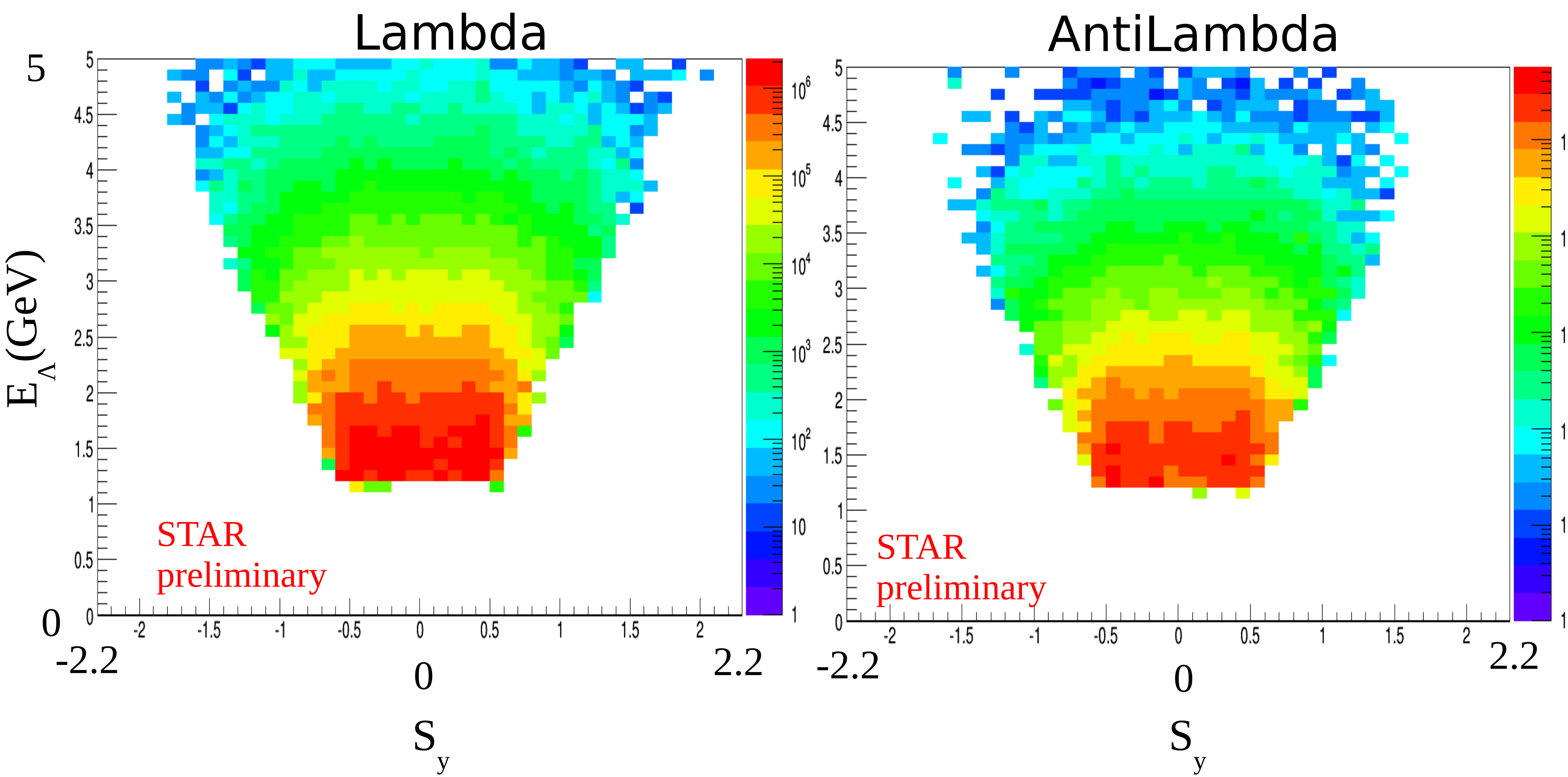
- Upper bound measurement of polarization pending study of systematic errors and fit

- In addition to BES consider AuAu 62.4 and AuAu 200GeV measurements

BACKUP SLIDES

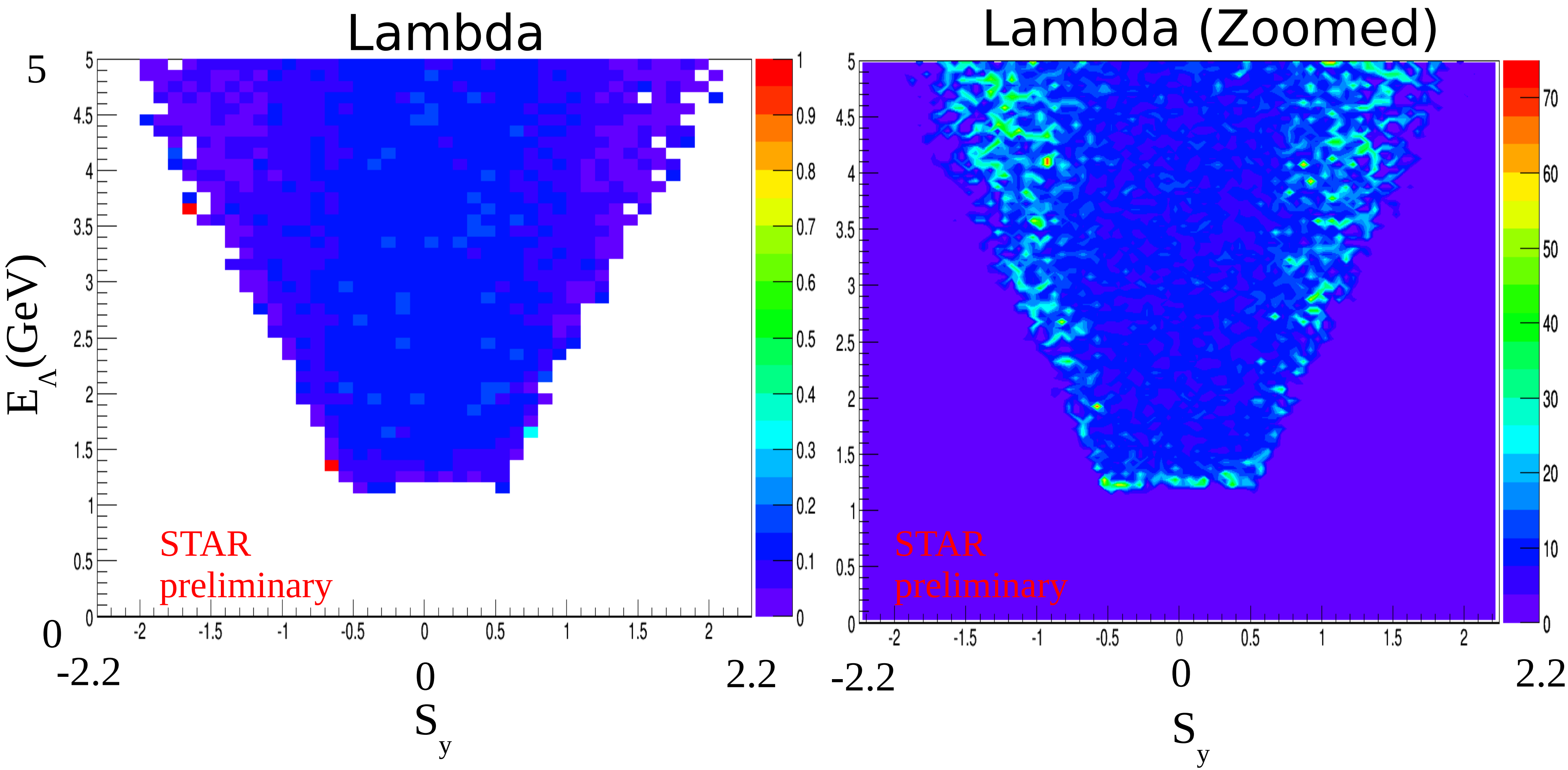
Chemical Potential 19GeV

- E_Λ vs S_y for 19GeV Lambdas and AntiLambdas LOG SCALE

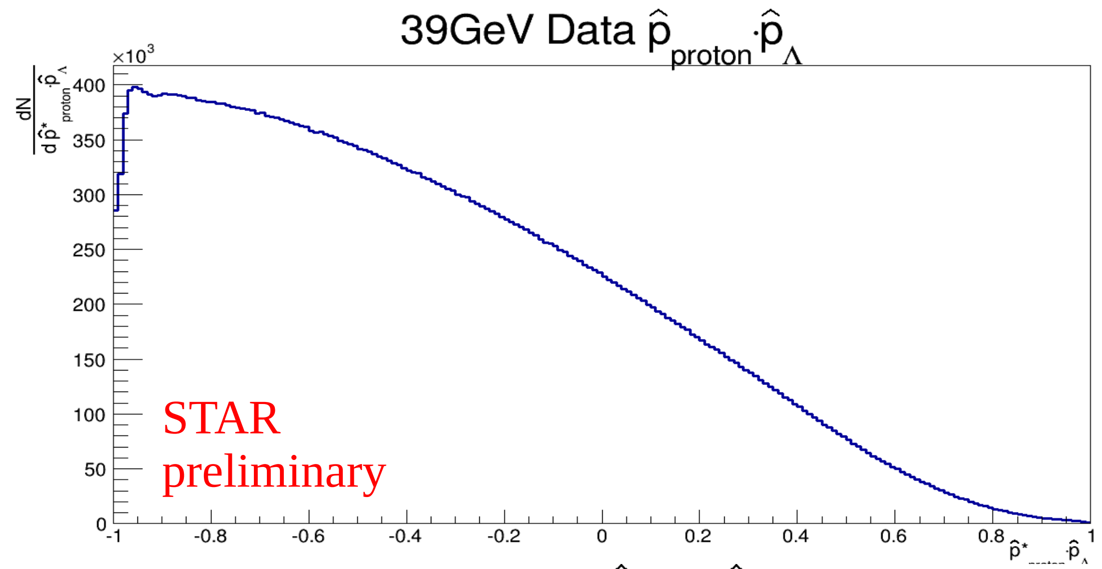


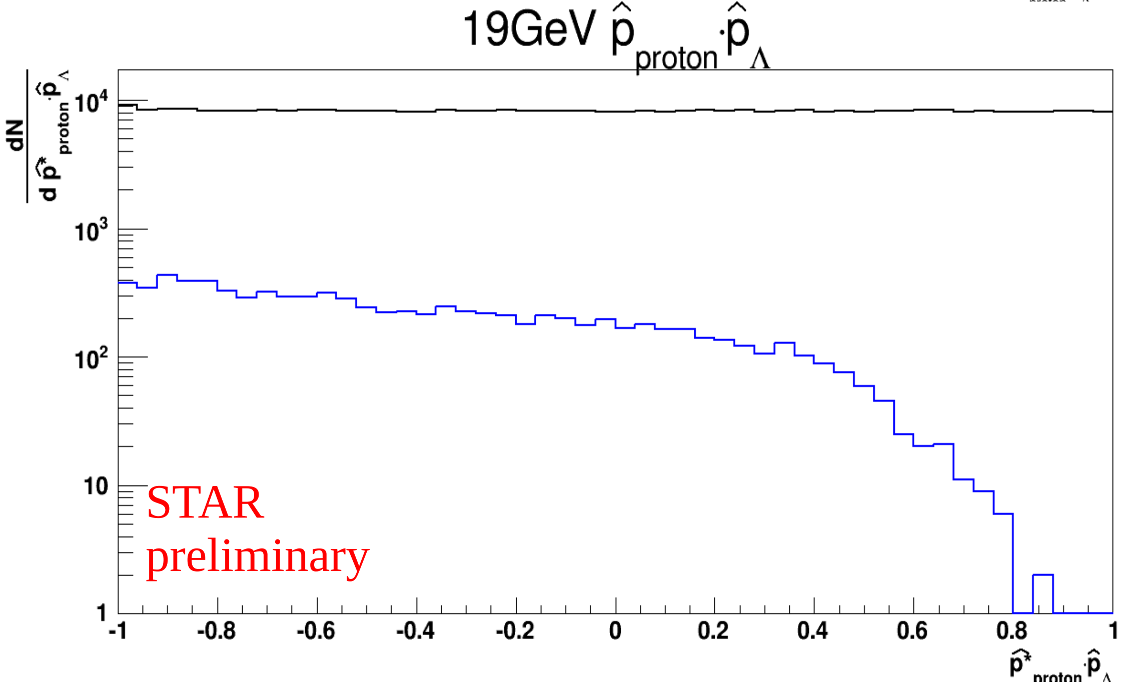
Efficiency Corrections 19GeV

- E_Λ vs S_y efficiency correction for 19GeV Lambdas and LOG SCALE



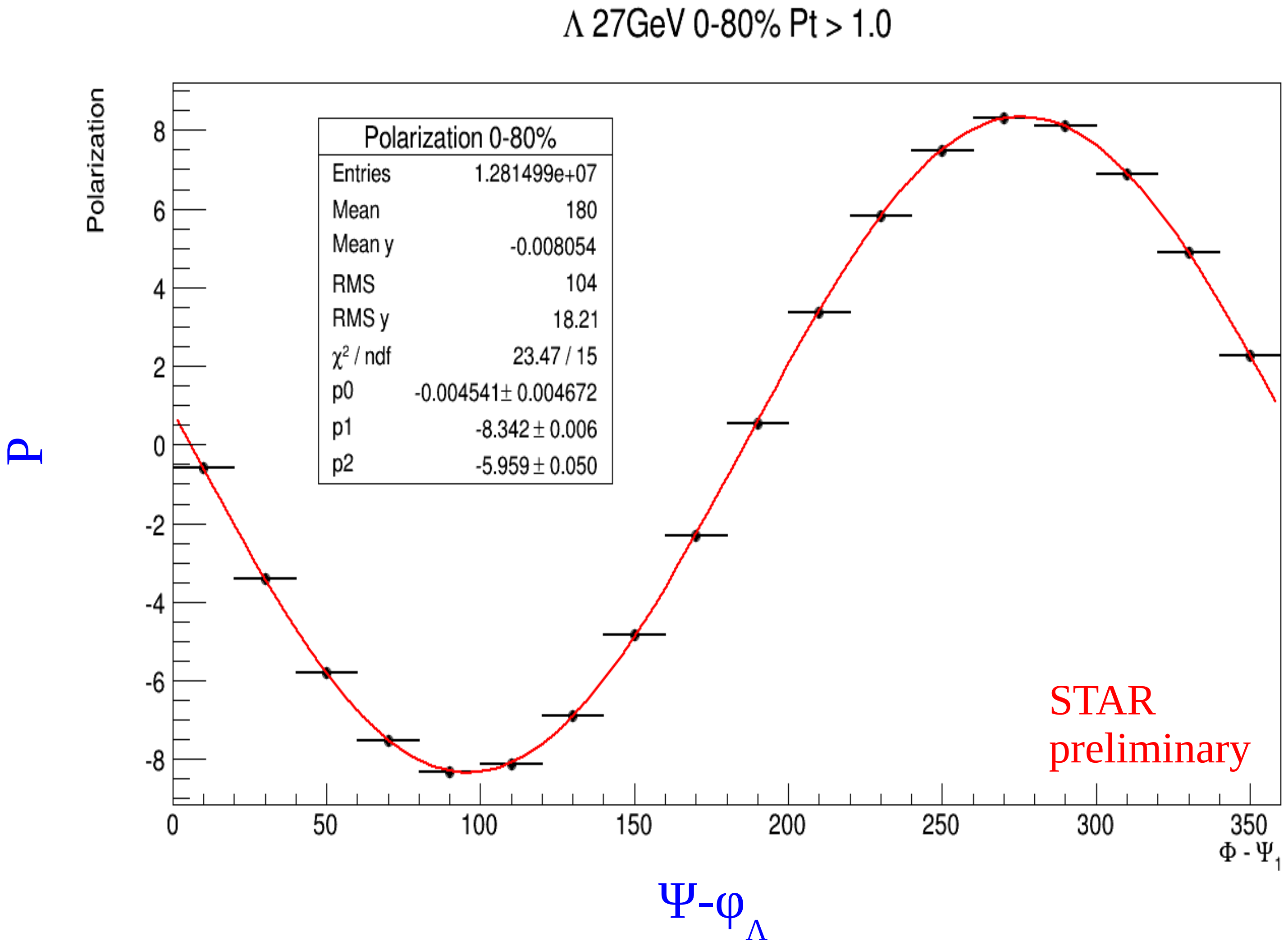
Lambda Efficiency





Lambda 1st Order Polarization

- Manifestation of decay kinematic efficiency affect



Event Cuts

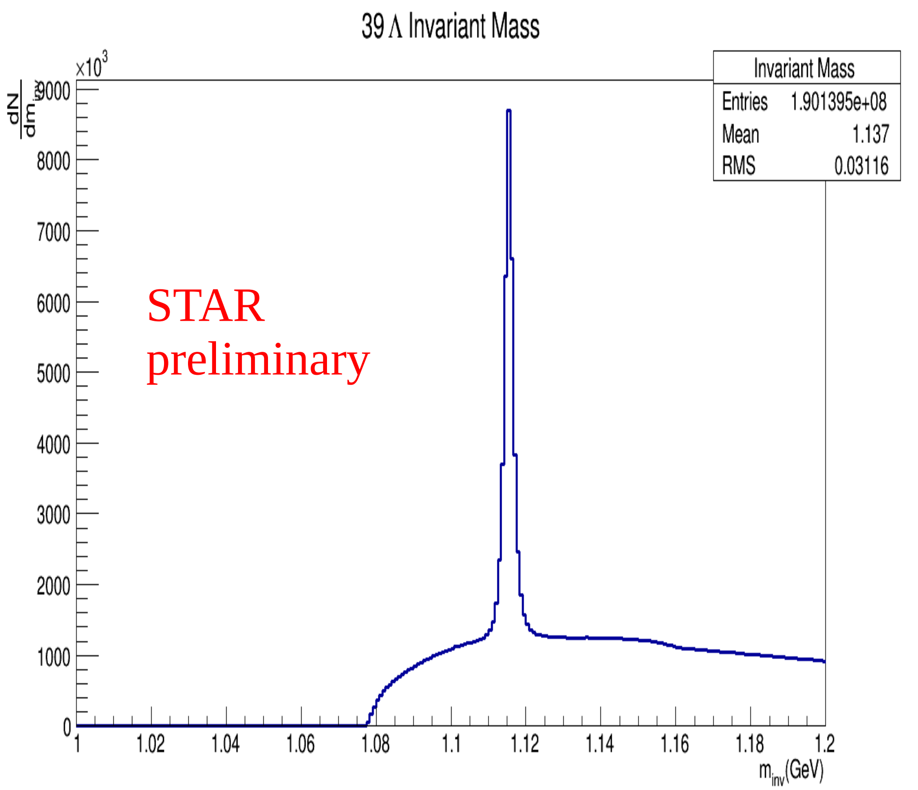
- Triggers MB
  - 39GeV: 280001 and 280002
  - 27GeV: 360001 and 360002
  - 19GeV: 340001, 340011, and 340021
  - 11GeV: 310004 and 310014
  - 7GeV: 290001 and 290004
- Event Cuts
  - |ZVtz| < 40cm
  - Tof Multiplicity > 2
  - Rvtx < 2cm
  - BBC ADC Sum West and Sum East > 75

Lambda Cuts

*Cuts from Alex Schm

- Basic Track Cuts
  - If proton has ToF $0.5 < m^2 < 1.5$ (TPC |nsigma|< 3)
  - If pion has ToF $0.017-0.013*p < m^2 < 0.04$ (TPC |nsigma|< 3)
- Lambda Topological cuts
  - Daughter DCA < 1 cm, 1.108 < mass < 1.122 (see table below for more

	Both have ToF	Proton has ToF	Pion has ToF	Neither has ToF
Proton DCA	0.1	0.15	0.5	0.6
Pion DCA	0.7	0.8	1.5	1.7
Lambda DCA	1.3	1.2	0.75	0.75
Lambda Decay Length	2	2.5	3.5	4

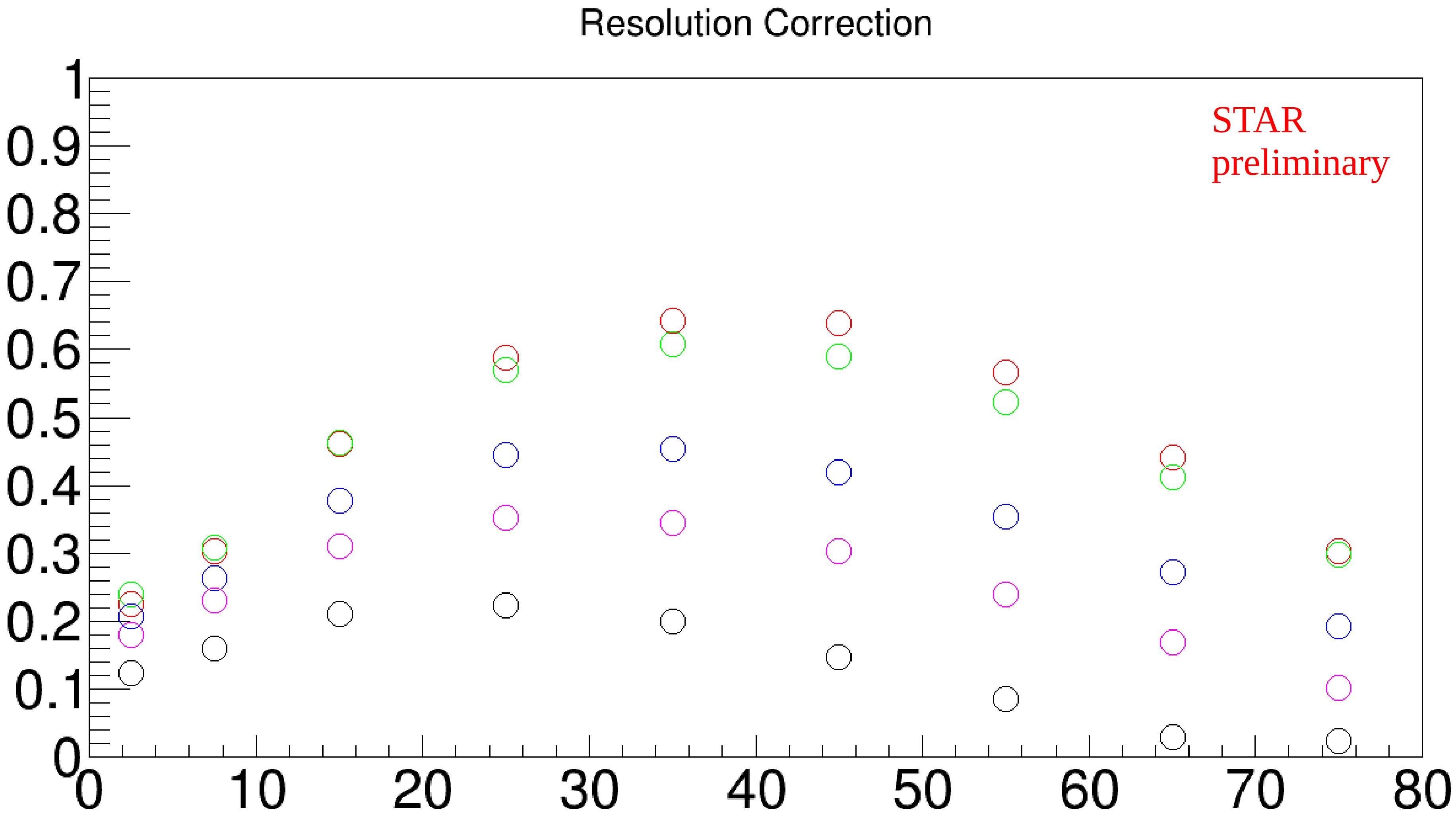


Lambda Stats

Energy (GeV)	Events (Millions)	Lambdas (Millions)	AntiLambas (Millions)	Peak EP Resolution
39	97	42	16	0.21
27	39	21	5.4	0.33
19	29	9.4	2.4	0.42
11	14	6.4	0.39	0.57
7	4	1.7	0.03	0.56

Event Plane Resolution

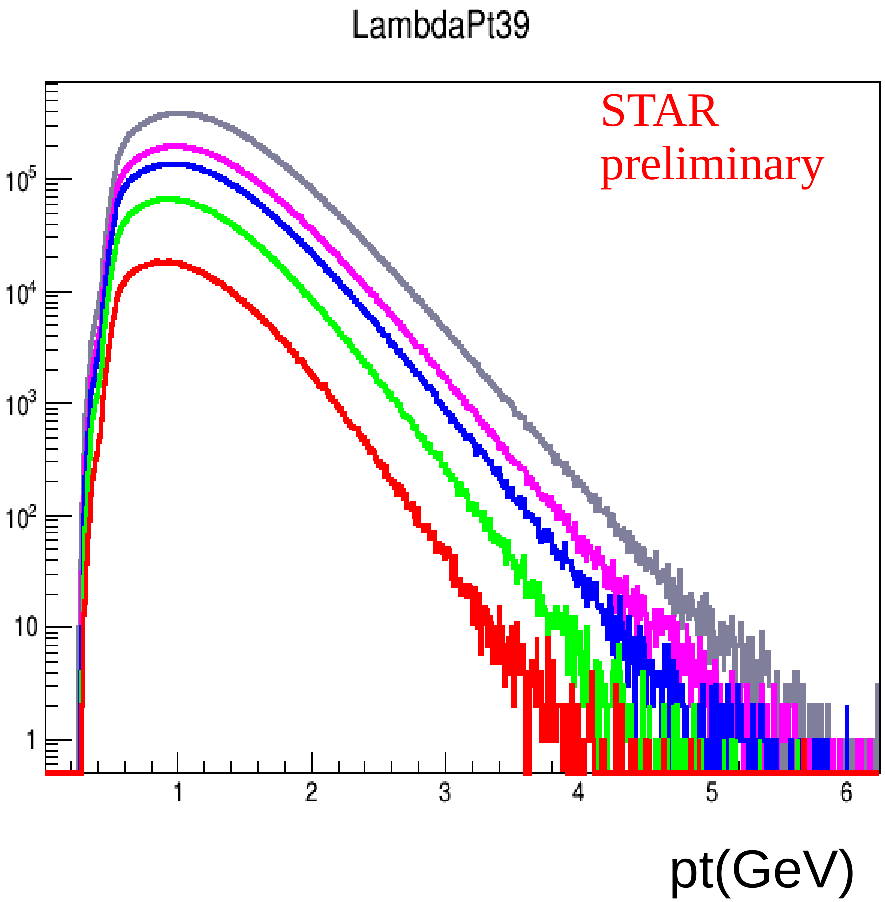
- In descending order from 7-39 GeV



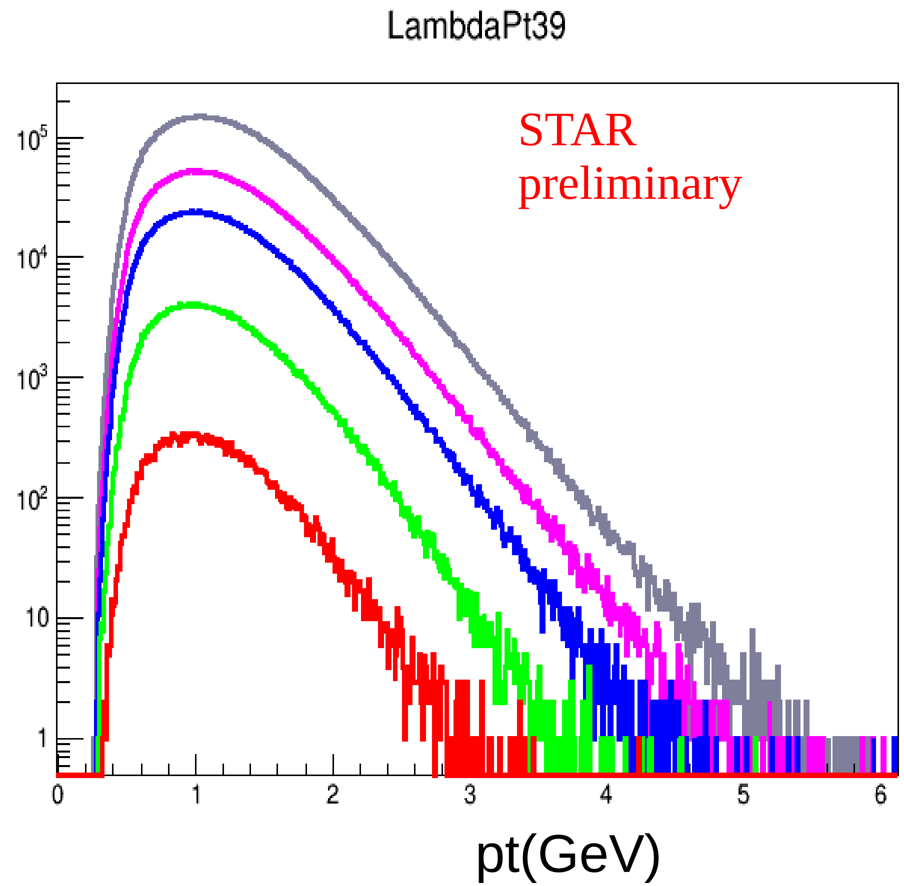
Lambda Pt Distribution

- In descending order from 39-7 GeV

Lambdas



AntiLambdas



Polarization Plots: AuAu 7GeV

$$P \equiv \langle \vec{S} \cdot \hat{L} \rangle$$

- Λ Polarization as a function of φ_Λ for centrality ranges 0-20%, 20-40%, 40-60%, 60-80%
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- Many, many plots (7-39GeV AuAu): consistent null result
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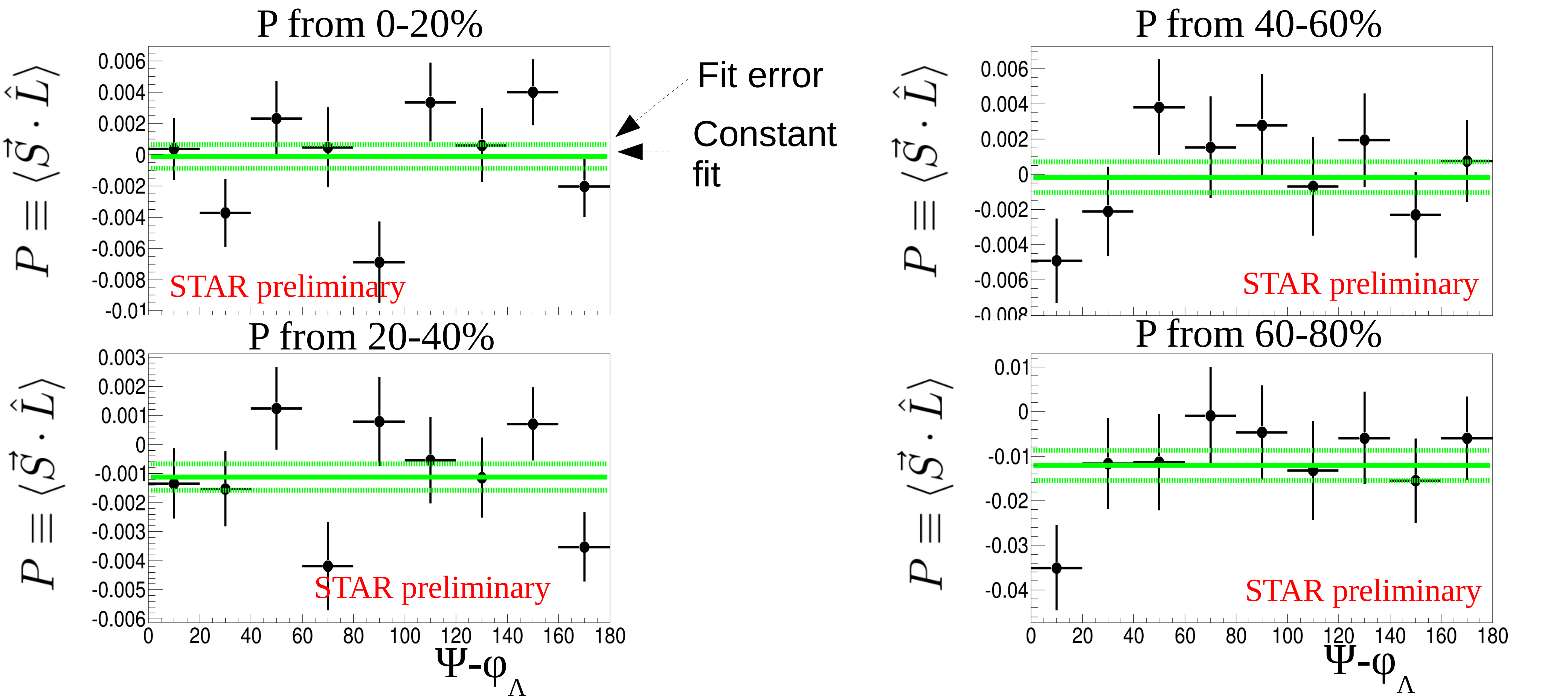
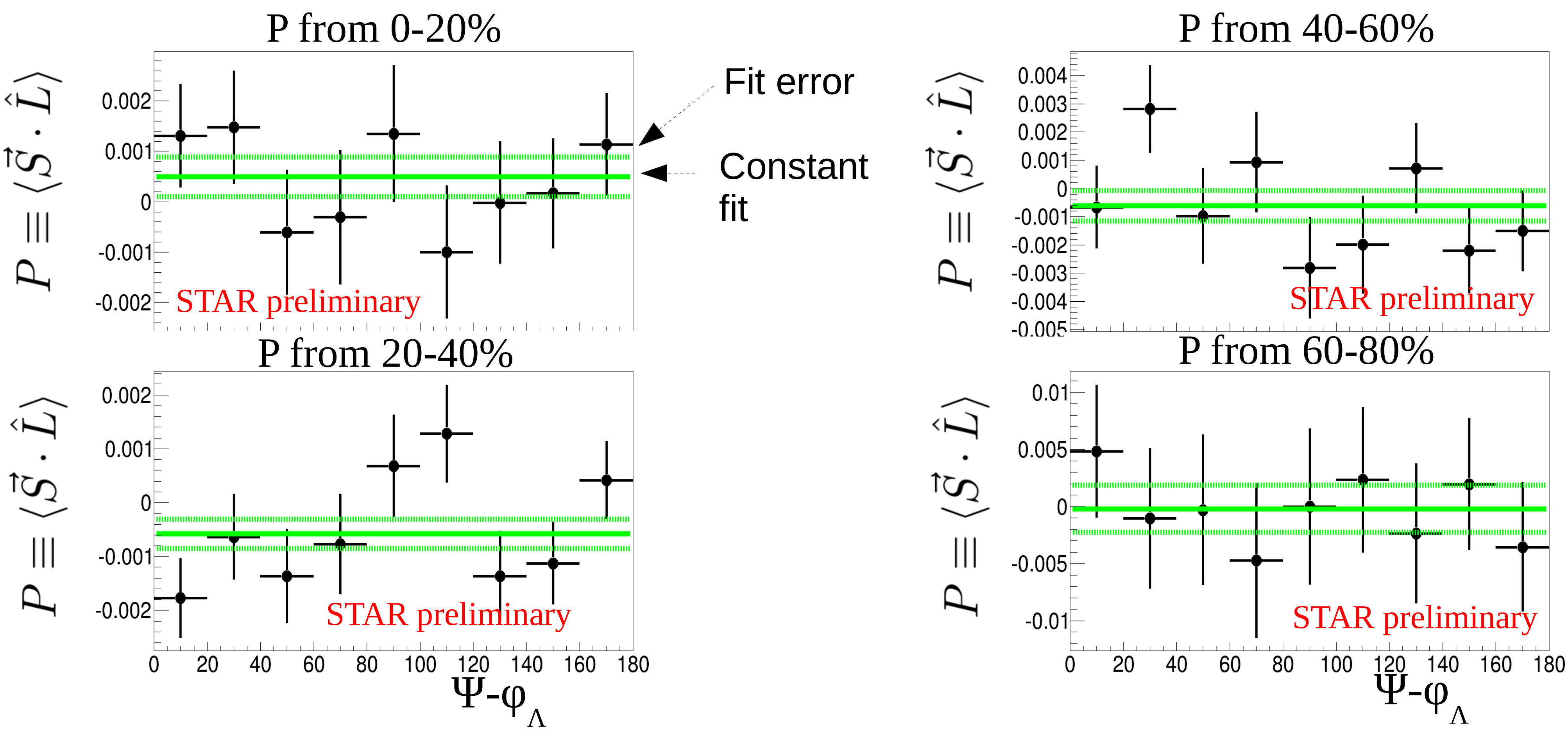


Polarization Plots: AuAu 11GeV

$P \equiv \langle \vec{S} \cdot \hat{L} \rangle$

- Λ Polarization as a function of φ_Λ for centrality ranges 0-20%, 20-40%, 40-60%, 60-80%
- Because of low efficiency when pion p_T is small the x axis is 0°- 180°
- Many, many plots (7-39GeV AuAu): consistent null result
- Green is straight line fit with error



Polarization Plots: AuAu 19GeV $P \equiv \langle \vec{S} \cdot \hat{L} \rangle$

- Λ Polarization as a function of φ_Λ for centrality ranges 0-20%, 20-40%, 40-60%, 60-80%
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- Many, many plots (7-39GeV AuAu): consistent null result
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