Global polarization of Lambda hyperons in Au+Au Collisions at RHIC BES

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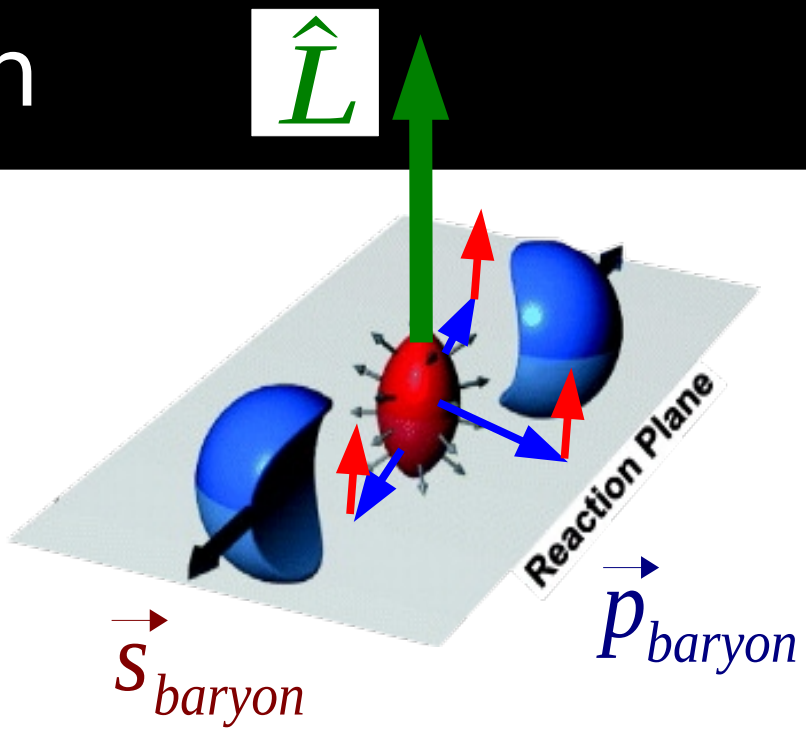
Motivation

Peripheral HICs have large **angular momentum** ($\sim 10^4$-10^5 ħ)

- (partly) transferred to fireball at mid rapidity
  - Related to baryon stopping?



- (partial) **thermalization** of angular d.o.f.s would align hadron spins with $\hat{L}$
  - *Global polarization*
  - Prior RHIC studies yielded null results[1]

- $\hat{L}$, *system angular momentum direction, is out-of reaction plane*

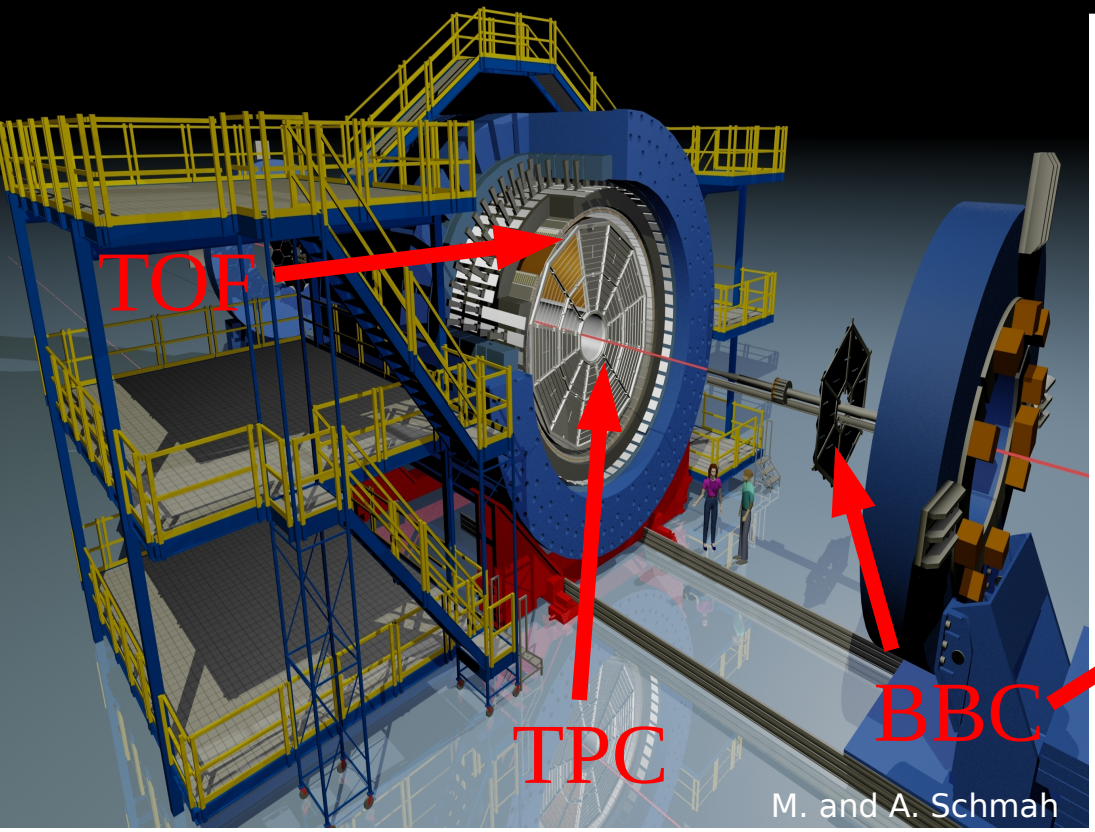
- **Vorticity** quantifies curl of velocity field $\vec{\omega} = \nabla \times \vec{v}$
  - In a hydro description of HIC, vorticity probed by global polarization[2,3]
  - Largely unexplored in current transport models

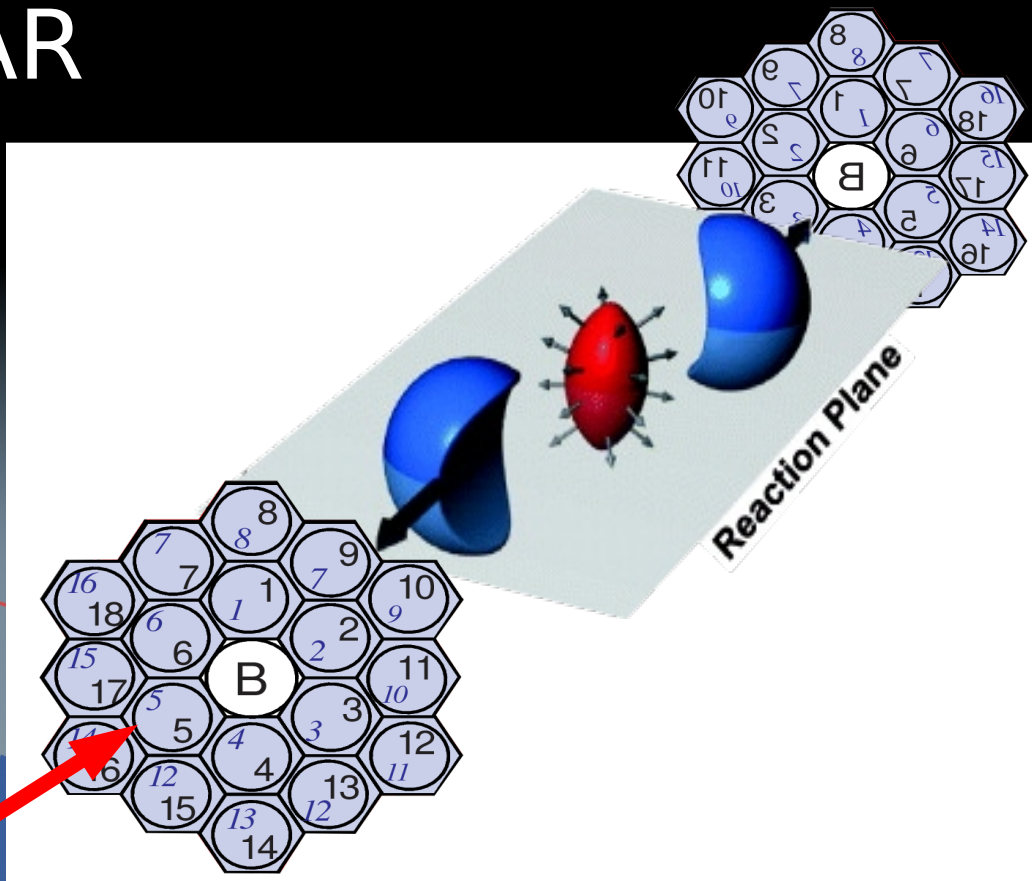
[1]B. I. Abelev et al. (STAR Collaboration)
Phys. Rev. C 76, 024915 – Published 29 August 2007

[2]F. Becattini, L. P. Csernai, and D. J. Wang
Phys. Rev. C 88, 034905 – Published 13 September 2013

[3]F. Becattini, F. Piccinini, and J. Rizzo
Phys. Rev. C 77, 024906 – Published 21 February 2008

STAR





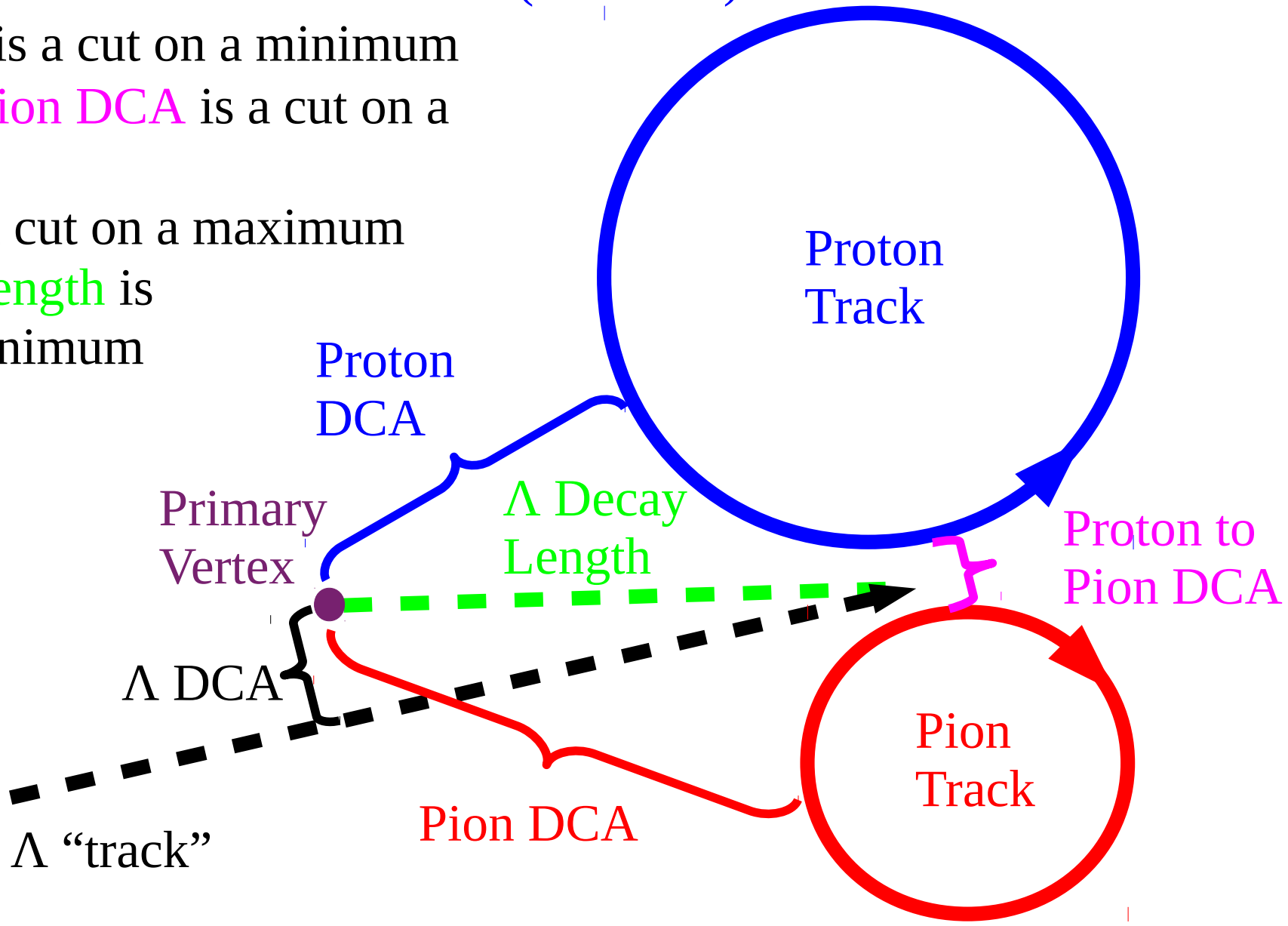
- Study Au+Au collision in the BES:
  - 7, 11, 19, 27, and 39GeV

- Tracking is performed by the TPC
- PID is done using the TPC + TOF

- BBC detects participants to determine first order event plane

Lambda Topological Cut Schematic

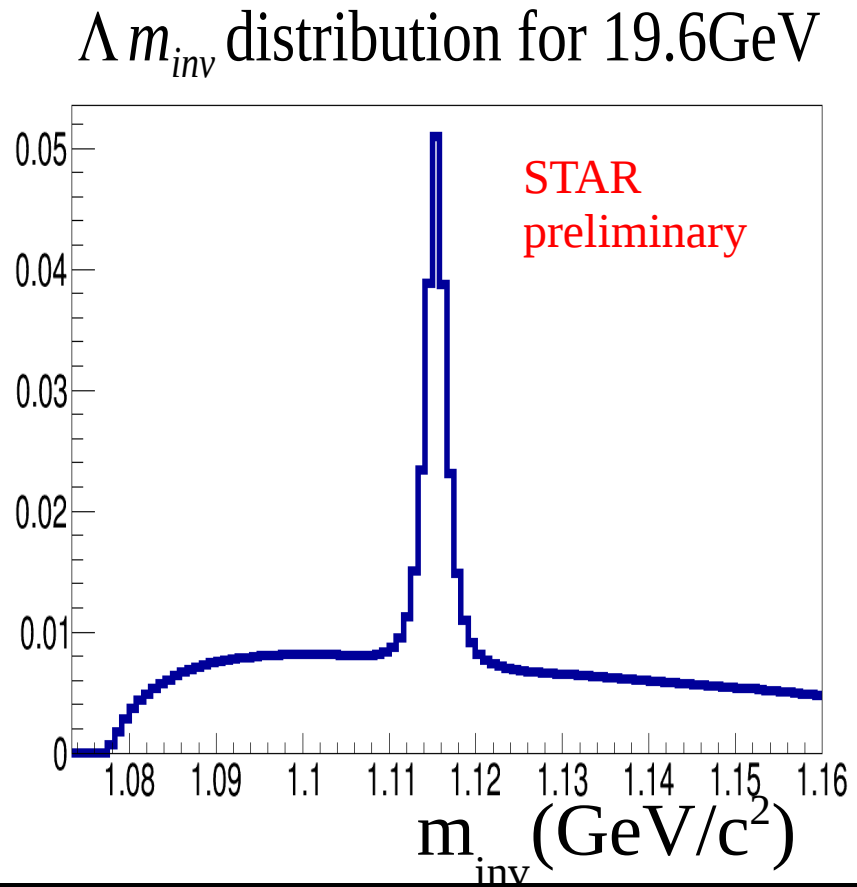
- Proton DCA is a cut on a minimum (DCA > x)
- Pion DCA is a cut on a minimum
- Proton to Pion DCA is a cut on a maximum
- Λ DCA is a cut on a maximum
- Λ Decay Length is a cut on a minimum



Lambda Reconstruction Cuts

- Basic Track Cuts
  - If proton has ToF $0.5\text{GeV}^2 < m^2 < 1.5\ \text{GeV}^2$ (TPC $|n_\sigma| < 3$)
  - If pion has ToF $(0.017\text{-}0.013*p)\text{GeV}^2 < m^2 < 0.04\ \text{GeV}^2$ (TPC $|n_\sigma| < 3$)
  - Track pt > 0.2GeV
- Lambda Topological cuts
  - Daughter distance of closest approach to primary vertex < 1 cm, 1.108GeV < mass < 1.122GeV

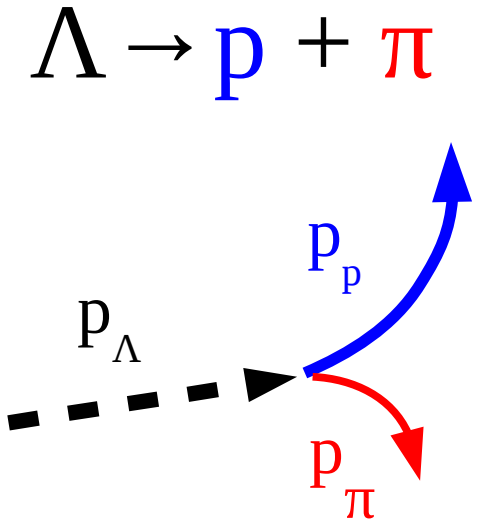
	Both have ToF	Proton has ToF	Pion has ToF	Neither has ToF
Proton DCA	0.1	0.15	0.5	0.6
Pion DCA	0.7	0.8	1.5	1.7
Lambda DCA	1.3	1.2	0.75	0.75
Lambda Decay Length	2	2.5	3.5	4



Lambda Baryon: Spin Probe

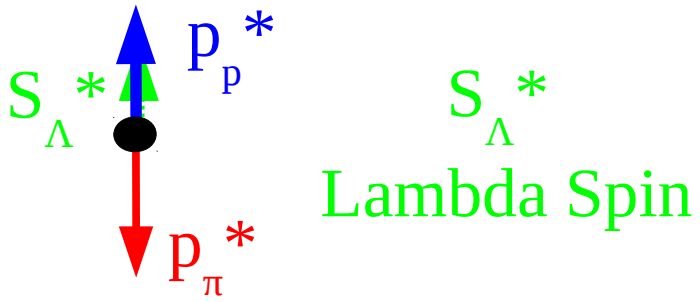
- Lambdas are “self analyzing”:
  - protons are preferentially emitted in the direction of the spin
  - '*' denotes Lambda rest frame

$$\frac{1}{N}\frac{dN}{d\Omega^*} = \frac{1}{4\pi}\left(1 + \alpha \vec{S}^*_\Lambda \cdot \hat{p}^*_p\right)$$



- α = 0.642, $\vec{S}^*_\Lambda$ is the Lambda Spin and $\hat{p}^*_p$ is the proton's momentum

Boost into Λ rest frame:



Measurement Technique

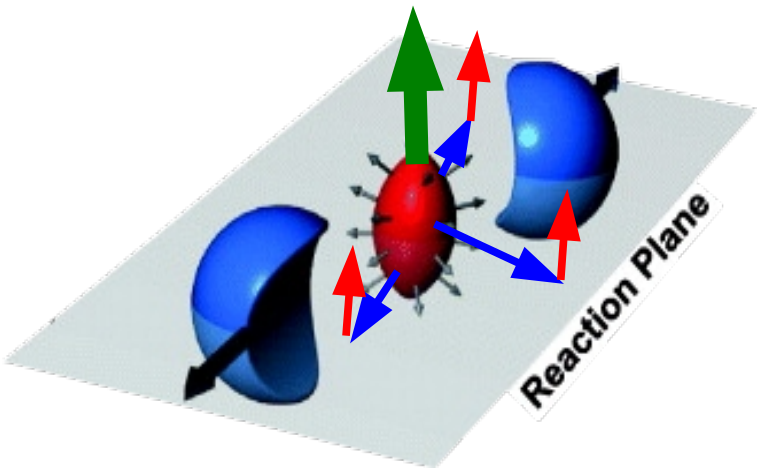
• Assume that the Lambda spin points in the direction of the proton momentum (i.e. ignore the fact that it's just a “tendency” for now)

$$\vec{S}^* = \frac{1}{2\left|\vec{p}_p^*\right|}(0, -\vec{p}_p^*) \qquad \vec{S} = \vec{S}^* + \frac{\gamma_\Lambda^2}{\gamma_\Lambda + 1}(\vec{\beta}_\Lambda \cdot \vec{S}^*)\vec{\beta}_\Lambda$$

• Here β is the velocity, γ is the boost factor

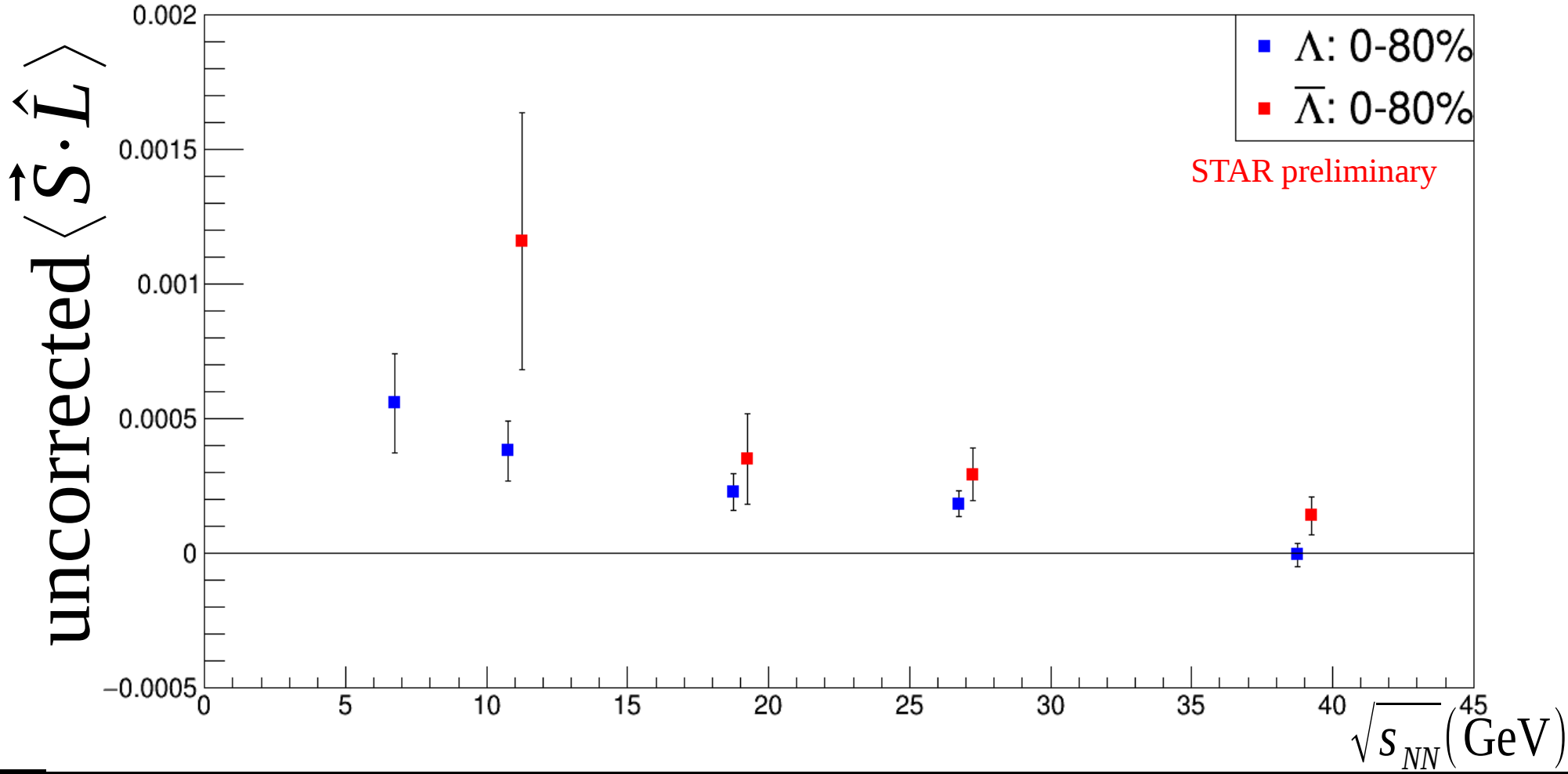
• Angular momentum direction, $\hat{L}$, is found from the first order event plane

• Is $\vec{S} \cdot \hat{L} > 0$ preferred?



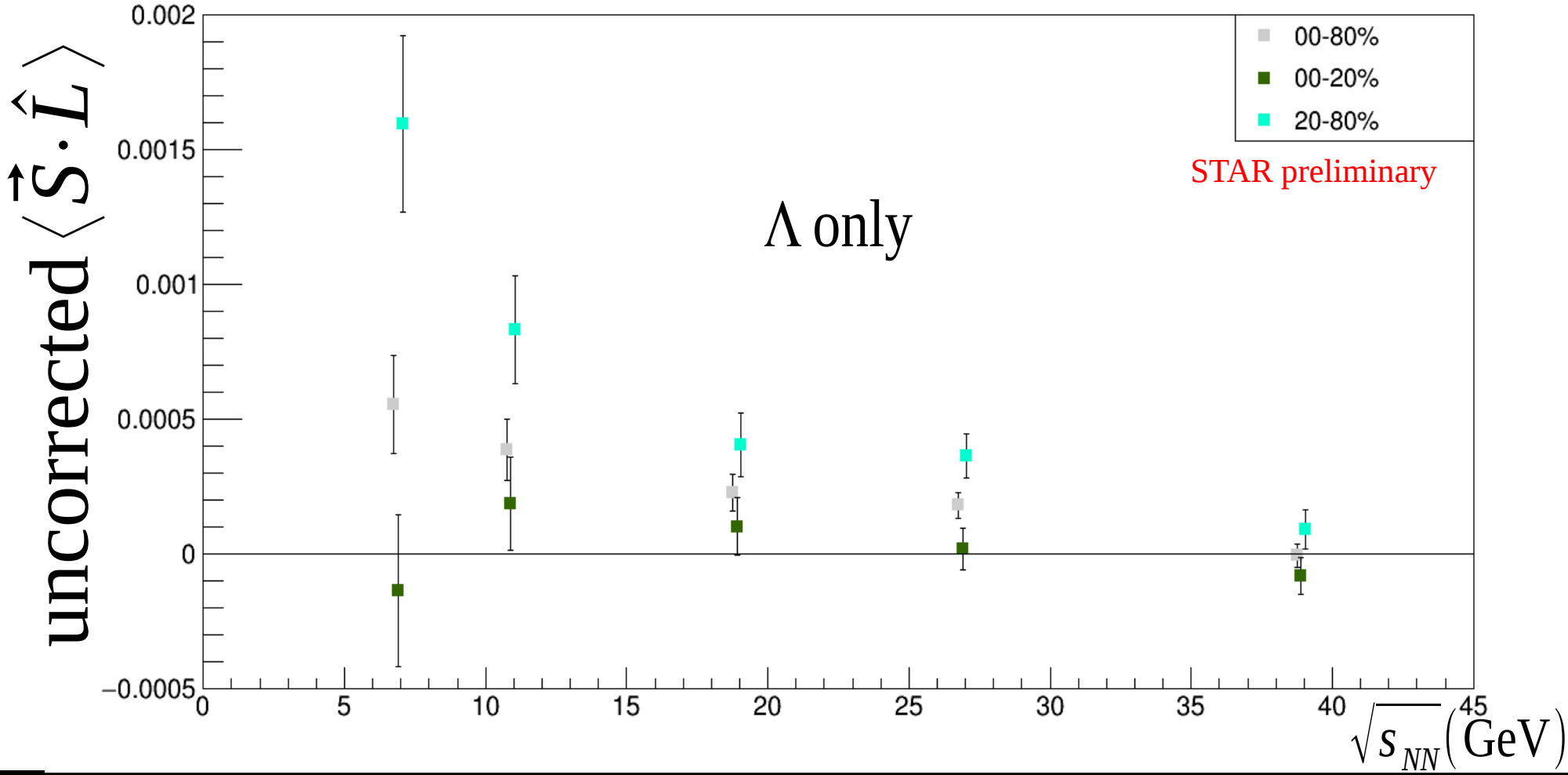
Λ and $\bar{\Lambda} \langle \vec{S} \cdot \hat{L} \rangle vs \sqrt{s}$

- Spins preferentially align with net angular momentum
- Statistically-challenged. All centralities, all momenta
- Results not corrected for event plane resolution



Λ Centrality dependence of $\langle \vec{S} \cdot \hat{L} \rangle$ vs $\sqrt{s}$

- Uncorrected signal stronger for peripheral collisions
  - Resolution correction underway



Conclusions

- First observation of global polarization in HIC!

- Significance of MinBias signal is at ~3σ level

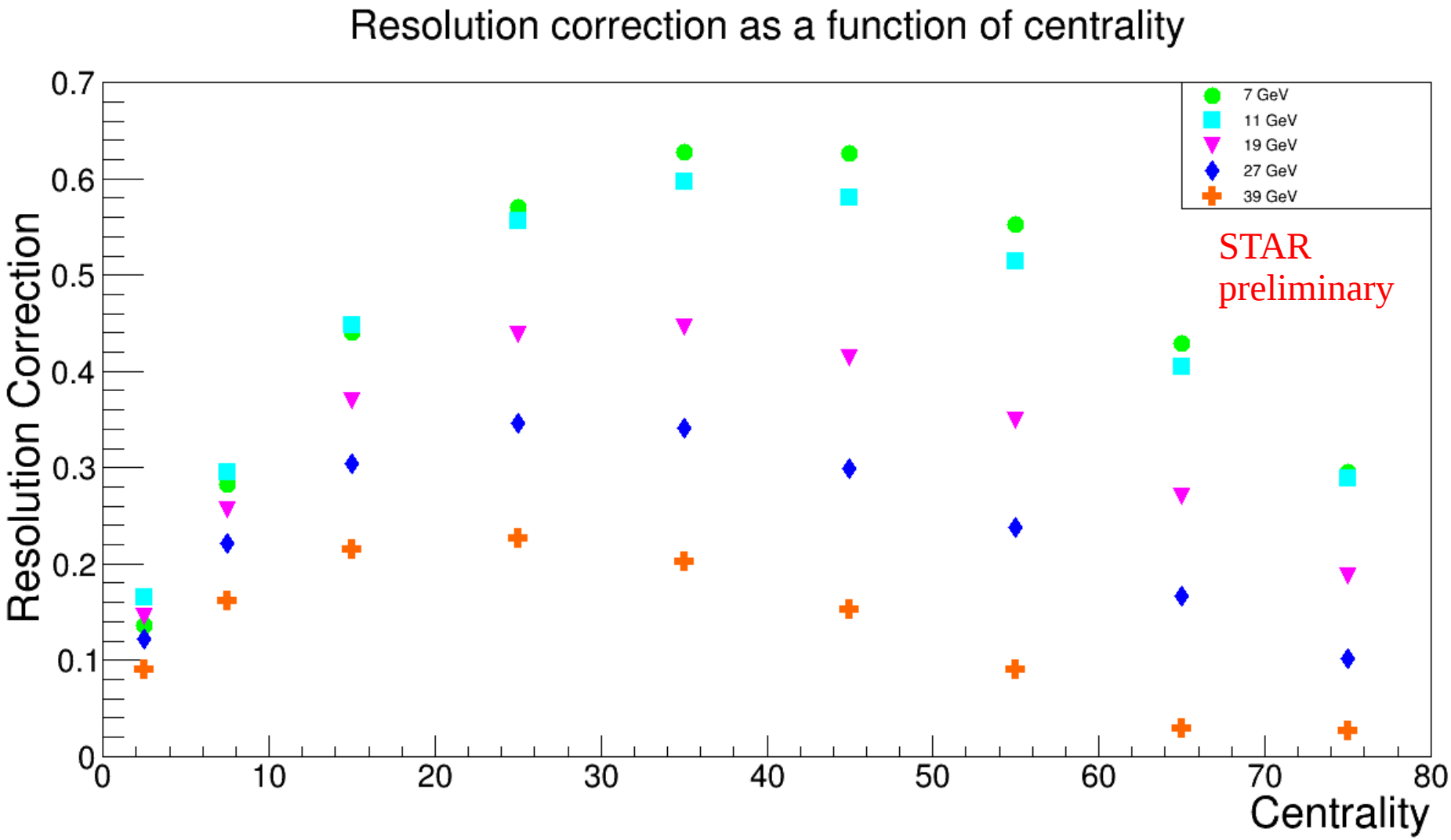
$\sqrt{s_{NN}}$(GeV)	7.7	11.5	19.6	27	39
Λ Nσ	3.05	3.39	3.33	3.8	-0.16
$\overline{\Lambda}$ Nσ		2.42	2.05	3.04	1.96

- Work underway on corrections
  - event plane resolution
  - distribution of proton emission relative to lambda spin
  - acceptance effects

BACKUP SLIDES

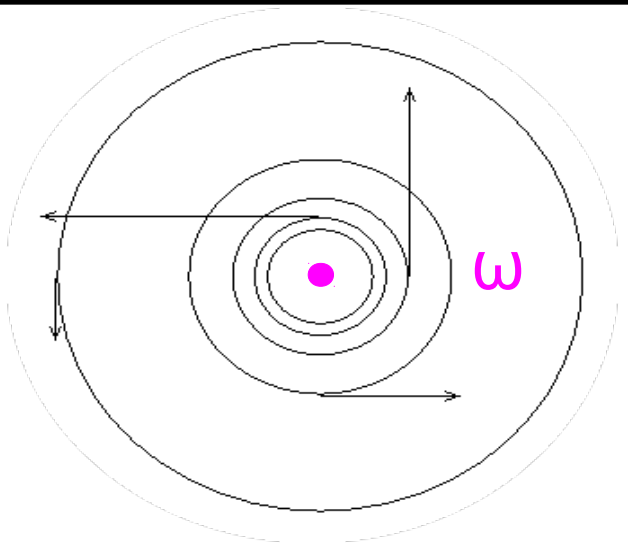
Event Plane Resolution

- In descending order from 7-39 GeV



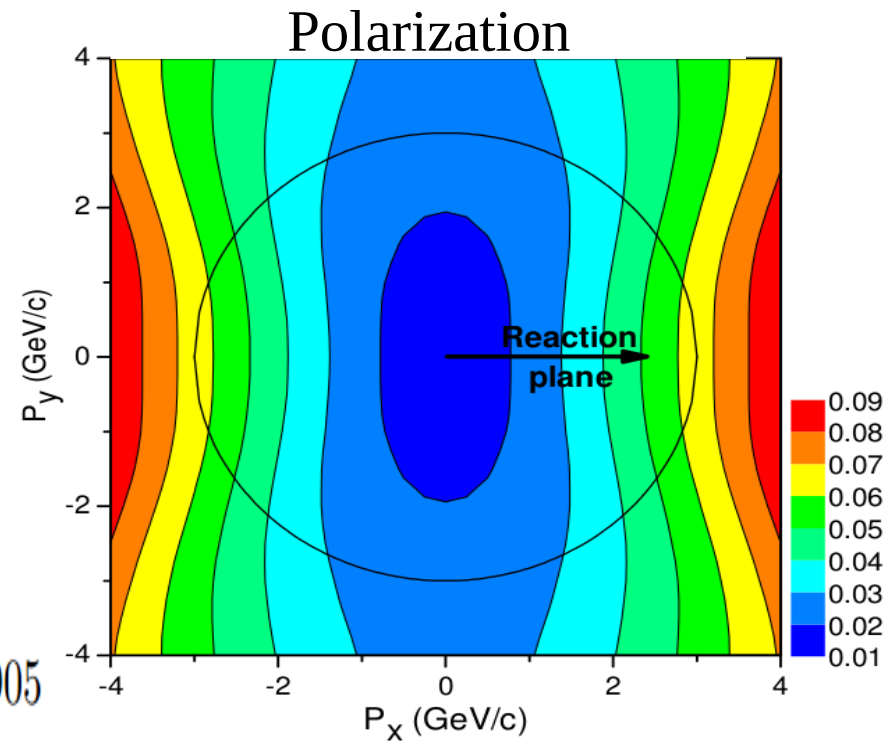
Model Predictions

- 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
  - Large Λ momentum
  - Λ emitted in reaction plane

- Predict maximum Polarization: ~< 1%



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

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

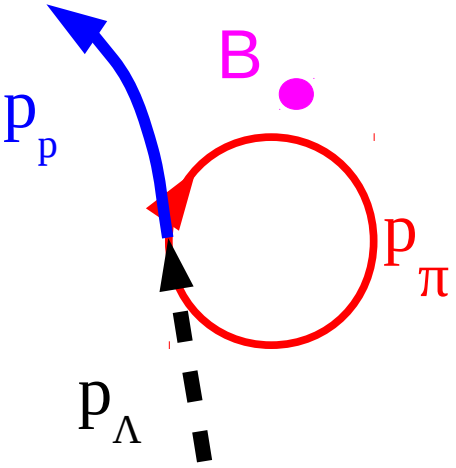
Lambda Stats

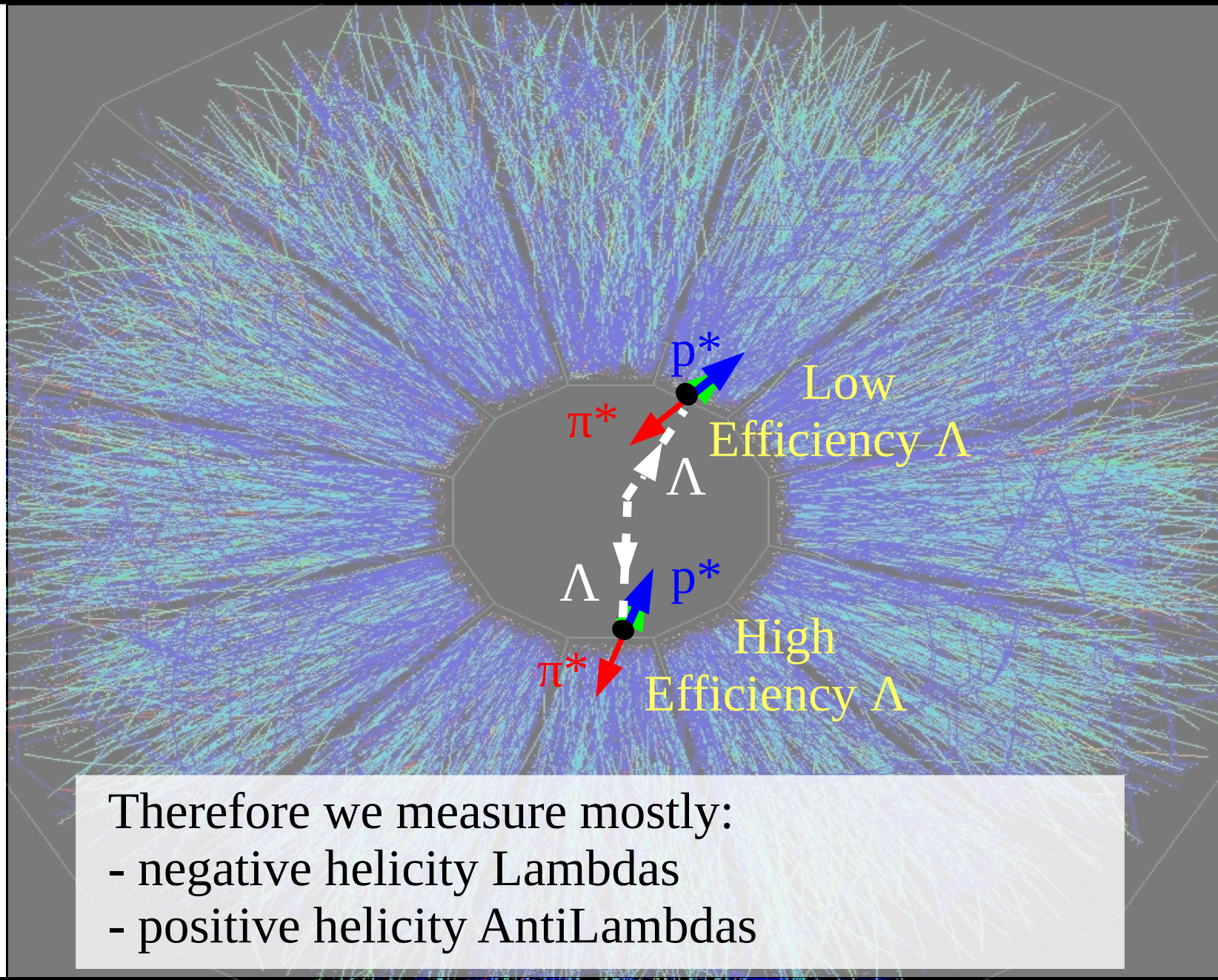
Energy (GeV)	Events (Millions)	Lambdas (Millions)	AntiLambas (Millions)	Peak EP Resolution
39	97	42	16	0.21
27	39	21	5.4	0.33
19	29	9.4	2.4	0.42
11	14	6.4	0.39	0.57
7	4	1.7	0.03	0.56

Lambda Decay Kinematic Efficiency

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

Low Efficiency



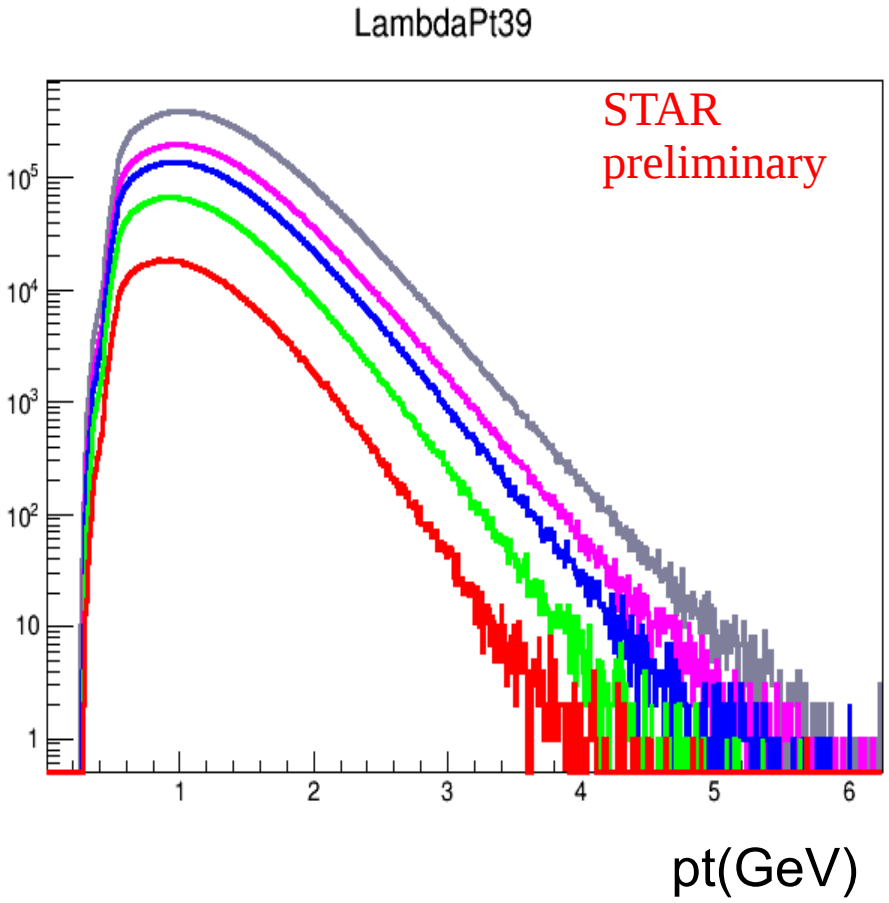


Therefore we measure mostly:
- negative helicity Lambdas
- positive helicity AntiLambdas

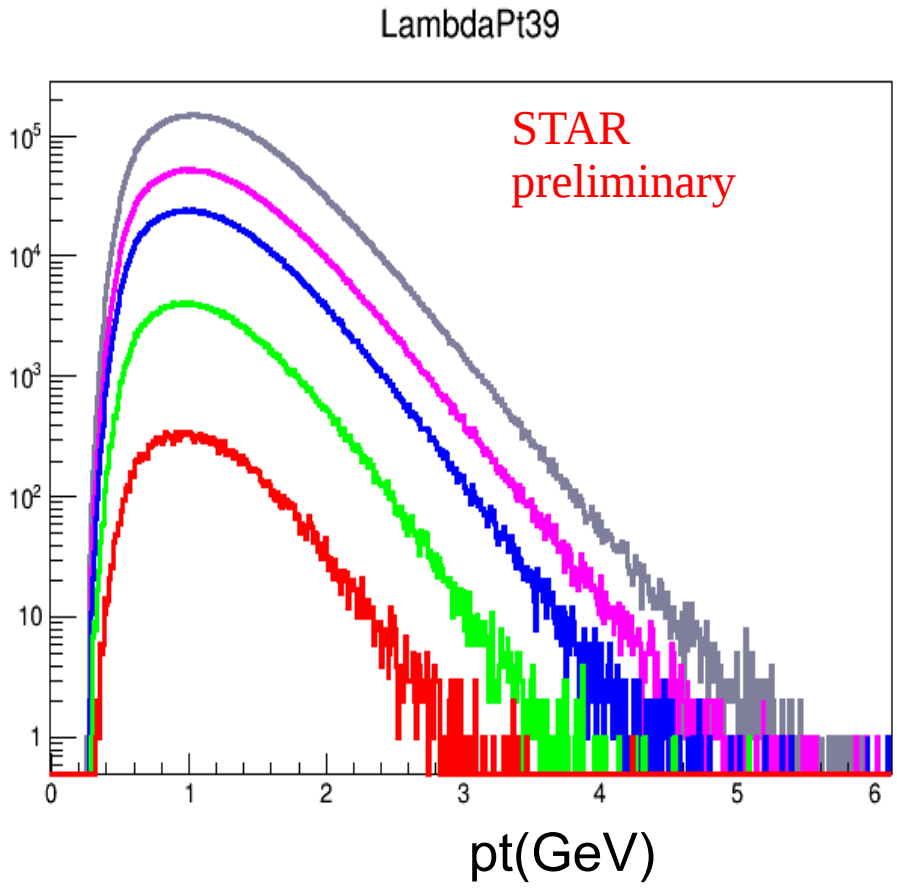
Lambda Pt Distribution

- In descending order from 39-7 GeV

Lambdas



AntiLambdas



Magnetic Chemical Potential

- In reality there is another coupling Sy could see
- Aside from lambda spin coupling with STAR's magnetic field (which we'll ignore) there is potential coupling with the magnetic field from the collision (μ_H)

$$e^{-(E-\mu_\sigma S_y-\mu_H(S_y\mu_m)-\mu_B B)/T}$$

$$\mu_{m,\Lambda} = -0.6 \qquad \mu_{m,\Sigma^0} > 0$$

- The magnetic moment of the Sigma + expected to be > 0. Maybe we can see Lambda AntiLambda splitting (?)