Longitudinal spin transfer of Lambda and anti-Lambda in pp collisions at STAR

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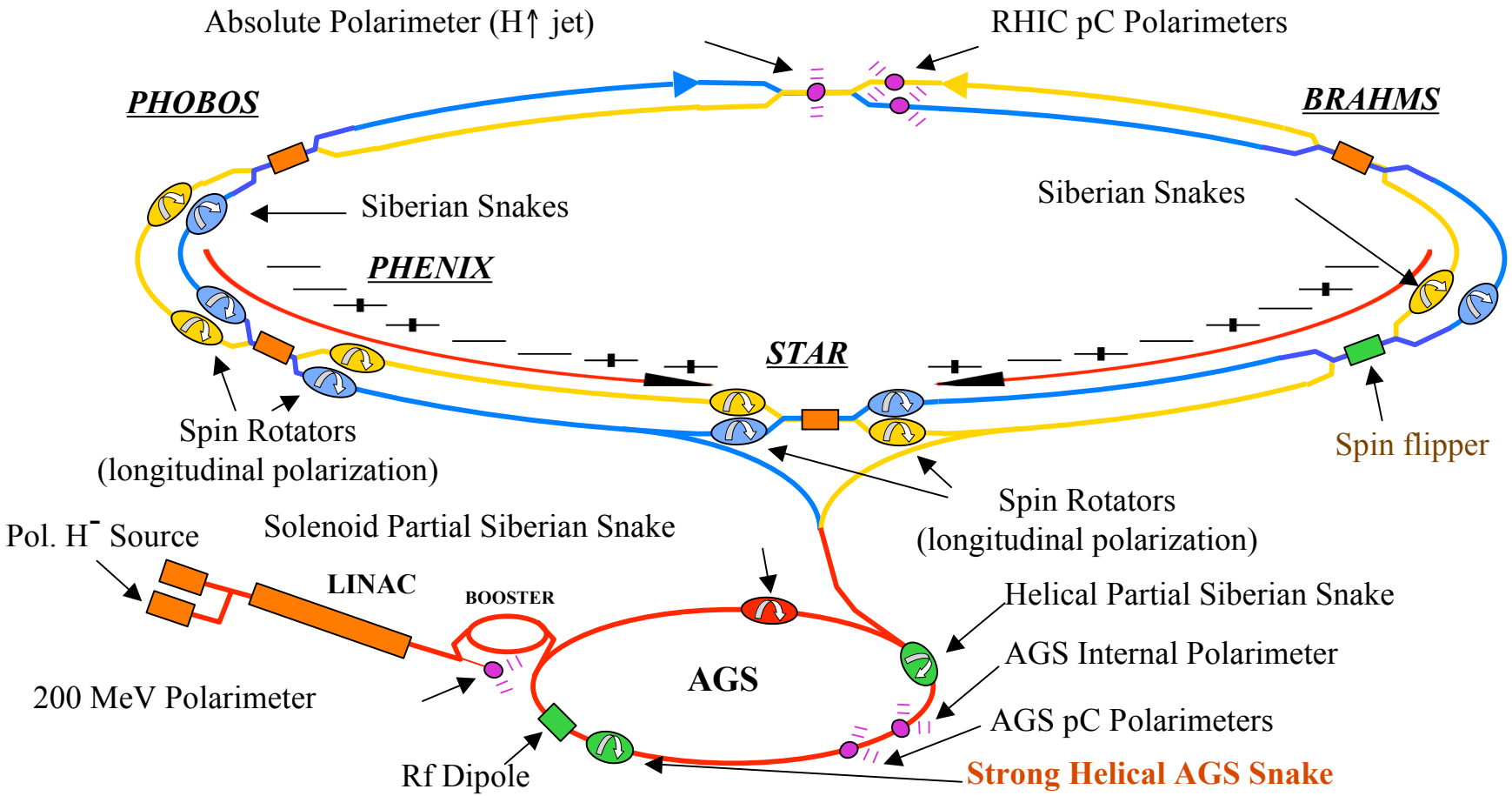
Dubna Spin workshop, September 4, 2009

- Introduction
- Longitudinal spin transfer of hyperons in pp at STAR
- Summary & outlook

RHIC- the first polarized pp collider in the world



pp Run Year	2002	2003	2004	2005	2006	2008	2009(200/500)
< Polarization> %	15	30	40-45	45-50	60	45	55 / 35*
L_{max} [10^{30} $s^{-1}cm^{-2}$]	2	6	6	16	30	35	40 / 85*
L_{int} [pb^{-1}] at STAR (Long./Transverse)	0 / 0.3	0.3 / 0.25	0.4 / 0	3.1 / 0.1	8.5 / 3.4	0 /3.1	22 /10.5*

*first 500 GeV run

Spin structure of nucleon

- Spin sum rule (longitudinal case):

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + < L_{q,g} >$$

Quark spin, Best known (~30%) -DIS

Gluon spin, Poorly known, @RHIC

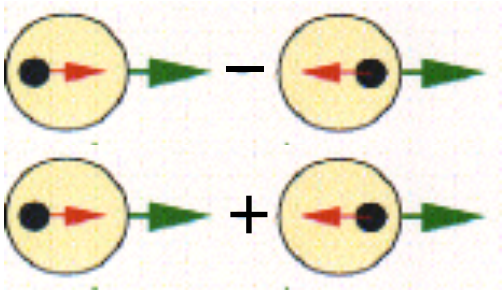
Orbital Angular Momenta Little known -DVCS

$$\Delta\Sigma = \Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \underbrace{\Delta s + \Delta\bar{s}}_{\Delta S} \qquad [\Delta q = \int_0^1 \Delta q(x)dx]$$

- Polarized parton densities:

$$\Delta q(x) = q^+(x) - q^-(x)$$

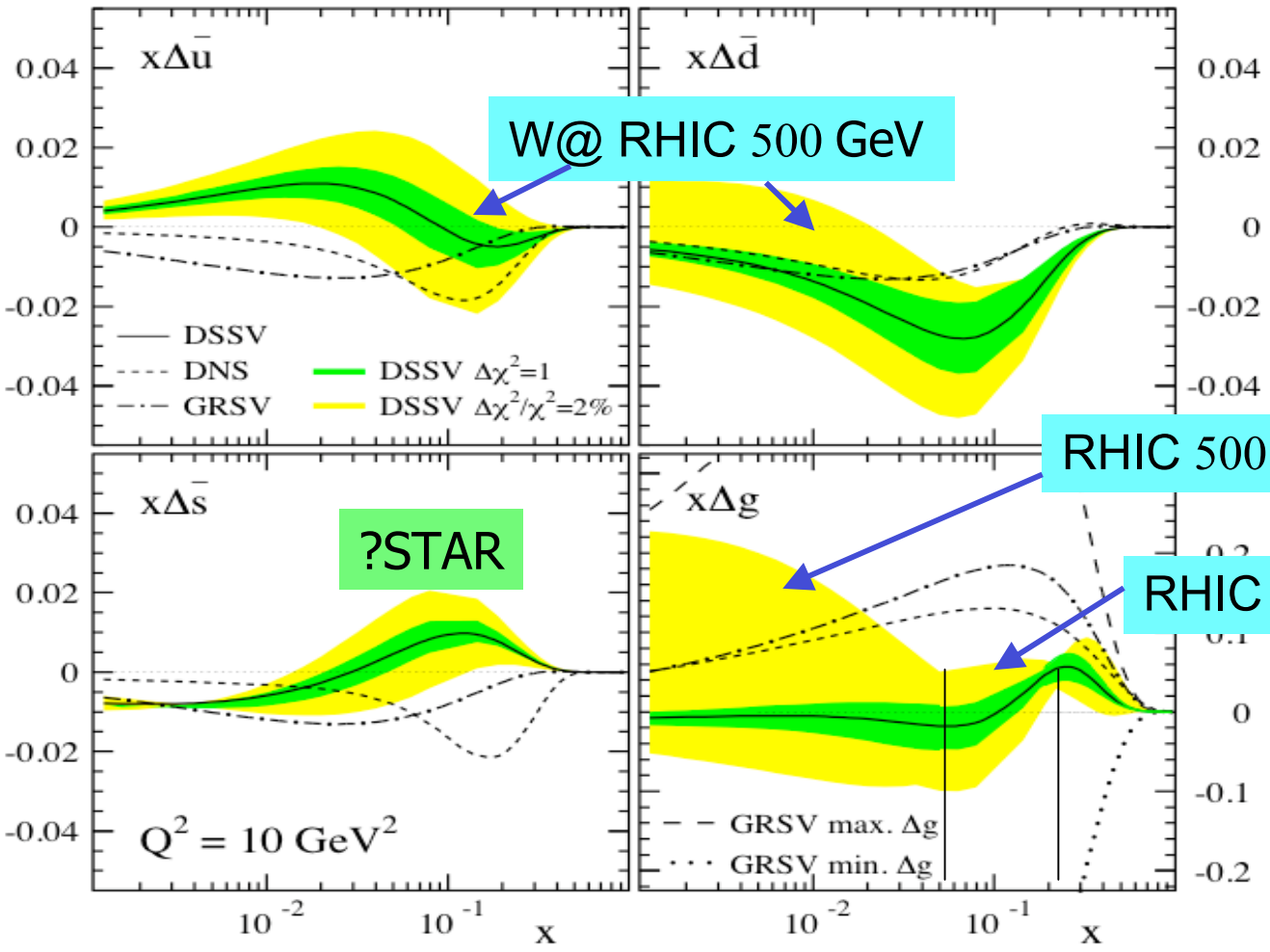
$$q(x) = q^+(x) + q^-(x)$$



From the recent global analysis

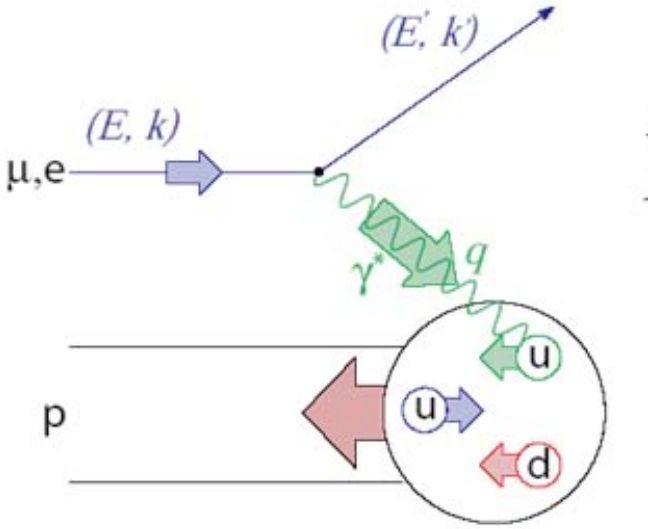
--fit all the available data in DIS, SDIS and *pp*

D. de Florian et al, PRL101(2008)



ΔS from polarized DIS

- Inclusive DIS:

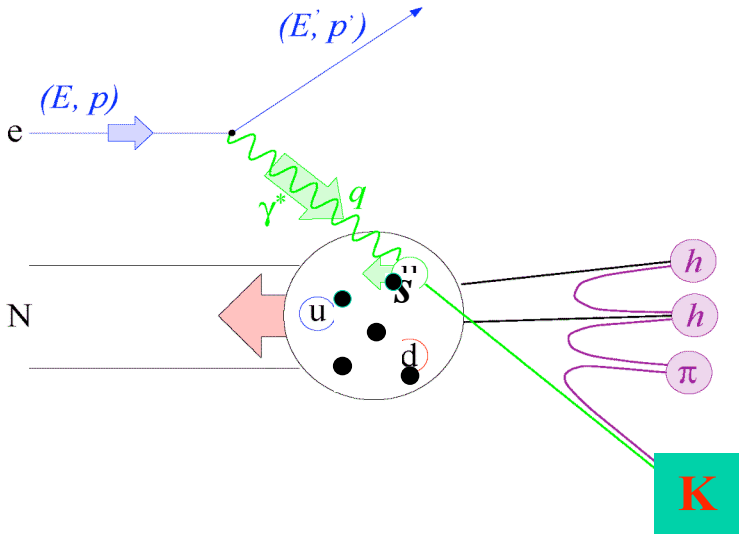


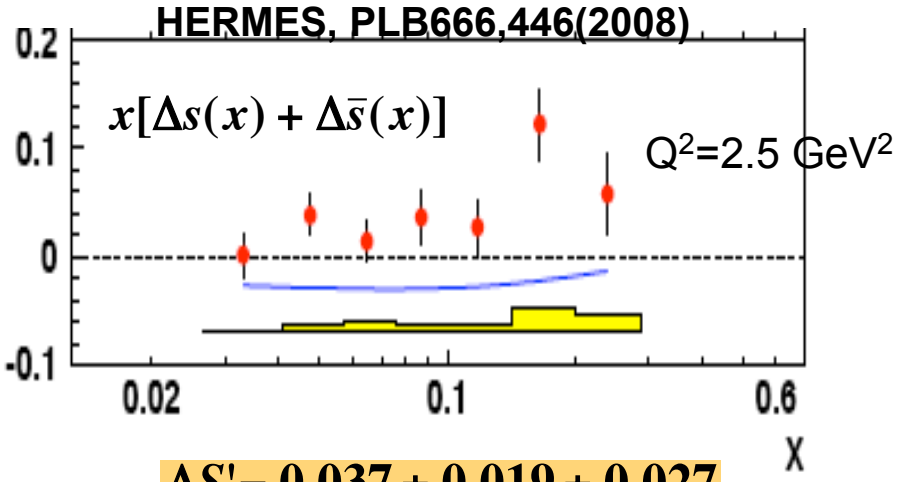
-- with neutron, hyperon β decay data using SU(3)_f symmetry,

$\Rightarrow \Delta\Sigma = 0.33 \pm 0.03 \pm 0.03$

$$\begin{cases} \Delta U \sim 0.84, \\ \Delta D \sim -0.43, \\ \Delta S \sim -0.08 \end{cases} \qquad [\Delta q = \int_0^1 \Delta q(x)\,dx]$$

- Semi-inclusive DIS:





$\Delta S' = 0.037 \pm 0.019 \pm 0.027$

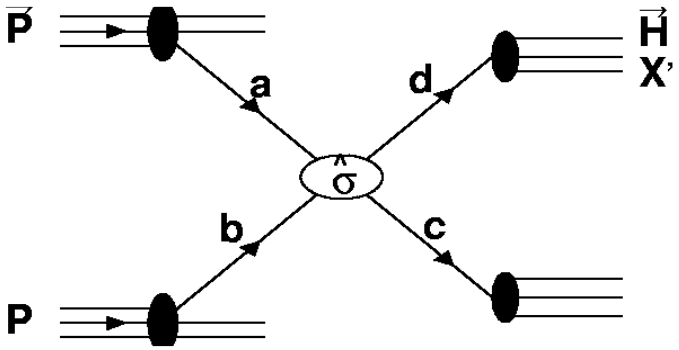
-COMPASS also did similar analysis

Measurements in other channels/reactions are needed!

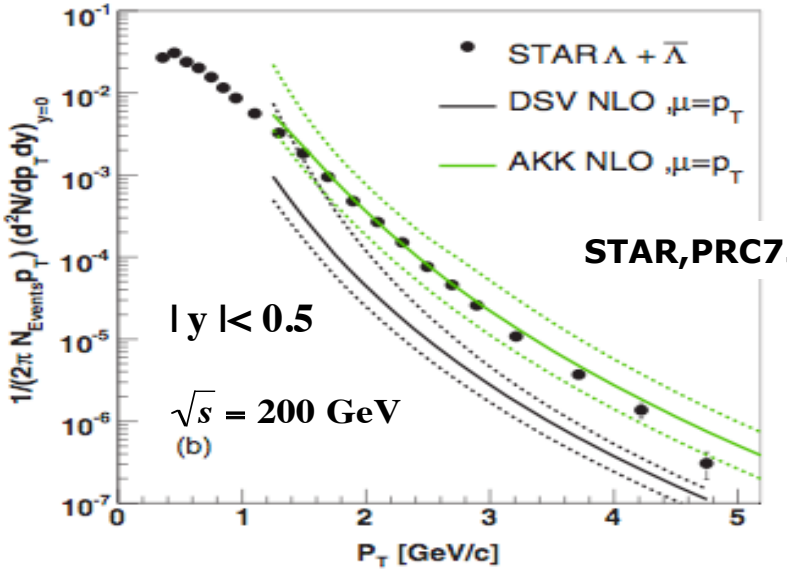
Hyperon production in pp at RHIC

- The factorized framework enables perturbative description,

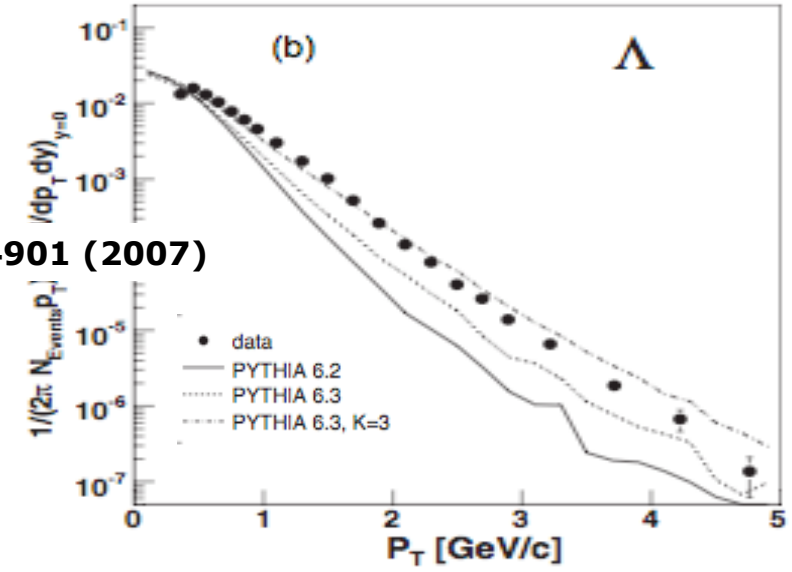
$$d\sigma \propto \int f_a(x_1) \cdot f_b(x_2) \otimes d\hat{\sigma} \otimes D^{\Lambda}(z)$$



- Data from RHIC on $\Lambda(\overline{\Lambda})$



STAR,PRC75,064901 (2007)



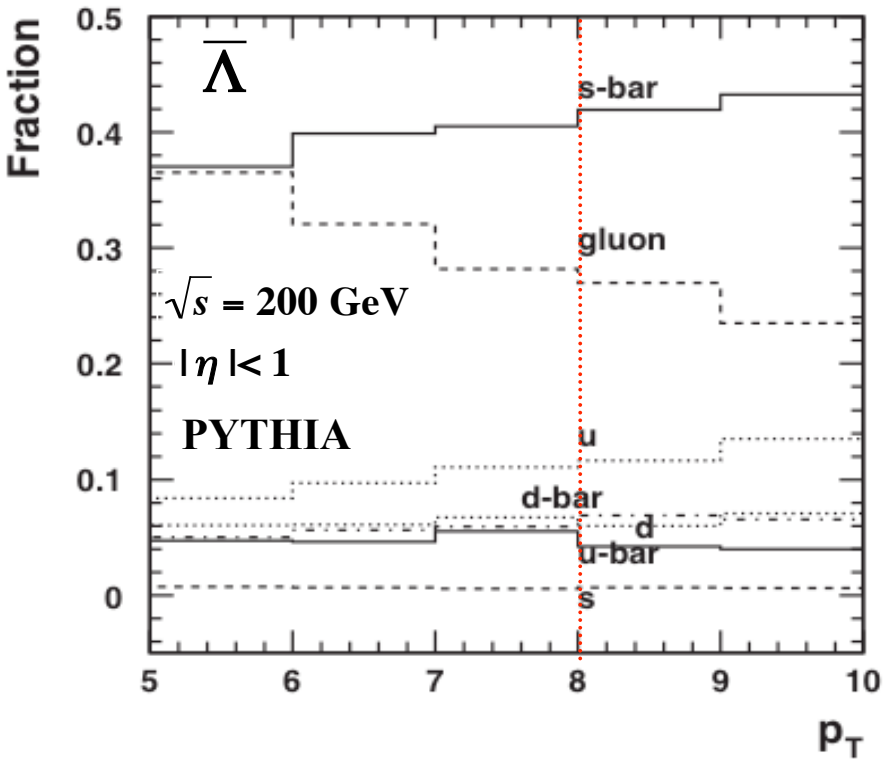
- STAR data on $\Lambda + \overline{\Lambda}$ described by pQCD with suitable choice of D^{Λ}.

Study ΔS at RHIC with hyperons?

- Hyperons contain at least one strange (valence) quark, and thus are expected to carry information of strangeness polarization in nucleon.

  u quark should dominate Lambda's production, how about anti-Lambda?

  - *s-bar frag. dominates anti-Lambda's production at high p_T!*
  - *decay contribution is smaller!*



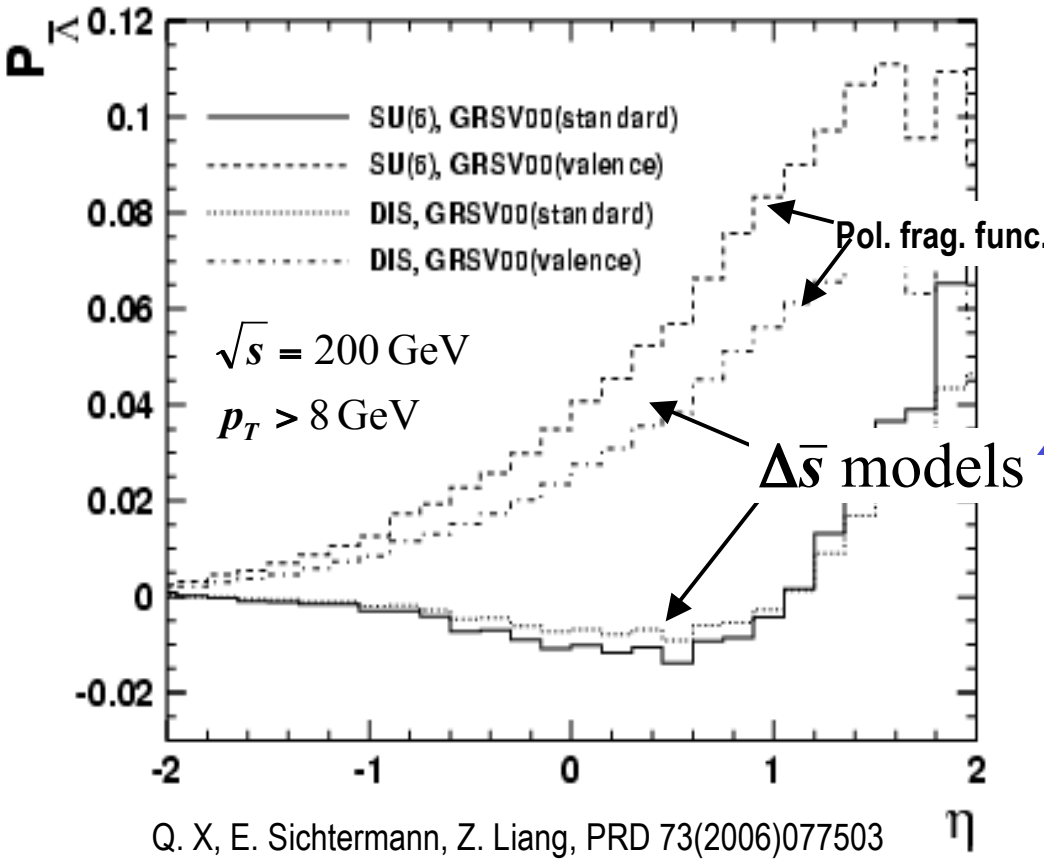
- Longitudinal spin transfer in *pp*:

$$D_{LL} \equiv \frac{\sigma_{p^+p\to\overline{\Lambda}^+X} - \sigma_{p^+p\to\overline{\Lambda}^-X}}{\sigma_{p^+p\to\overline{\Lambda}^+X} + \sigma_{p^+p\to\overline{\Lambda}^-X}} = P_{\overline{\Lambda}}^{+}$$

➡ How sensitive will anti-Lambda D_{LL} be to $\Delta\overline{s}$?

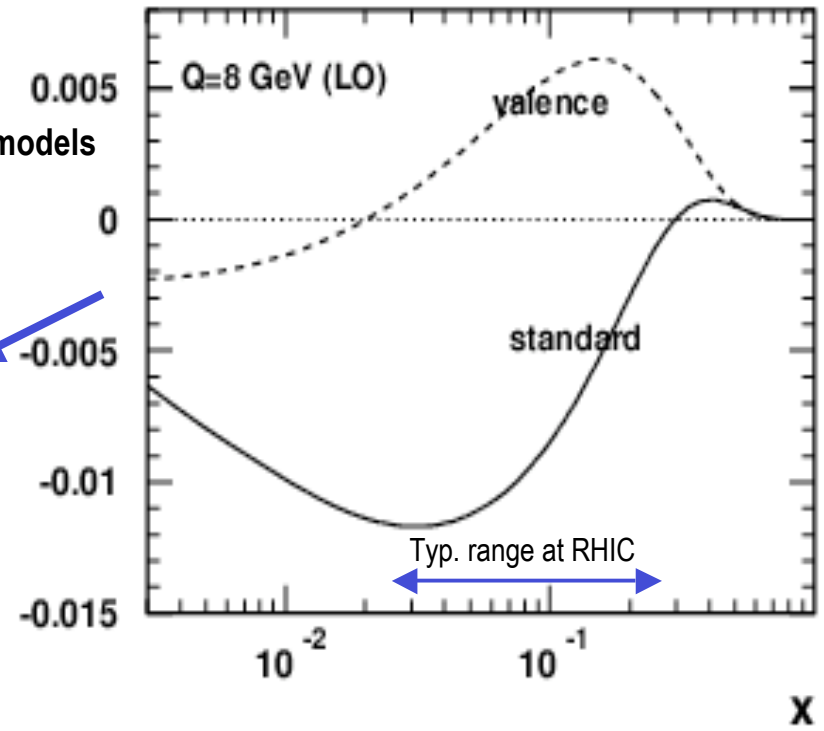
D_{LL}-Longitudinal spin transfer at RHIC

- Expectations at LO show sensitivity of D_{LL} for anti-Lambda to $\Delta\bar{s}$:



Q. X, E. Sichtermann, Z. Liang, PRD 73(2006)077503

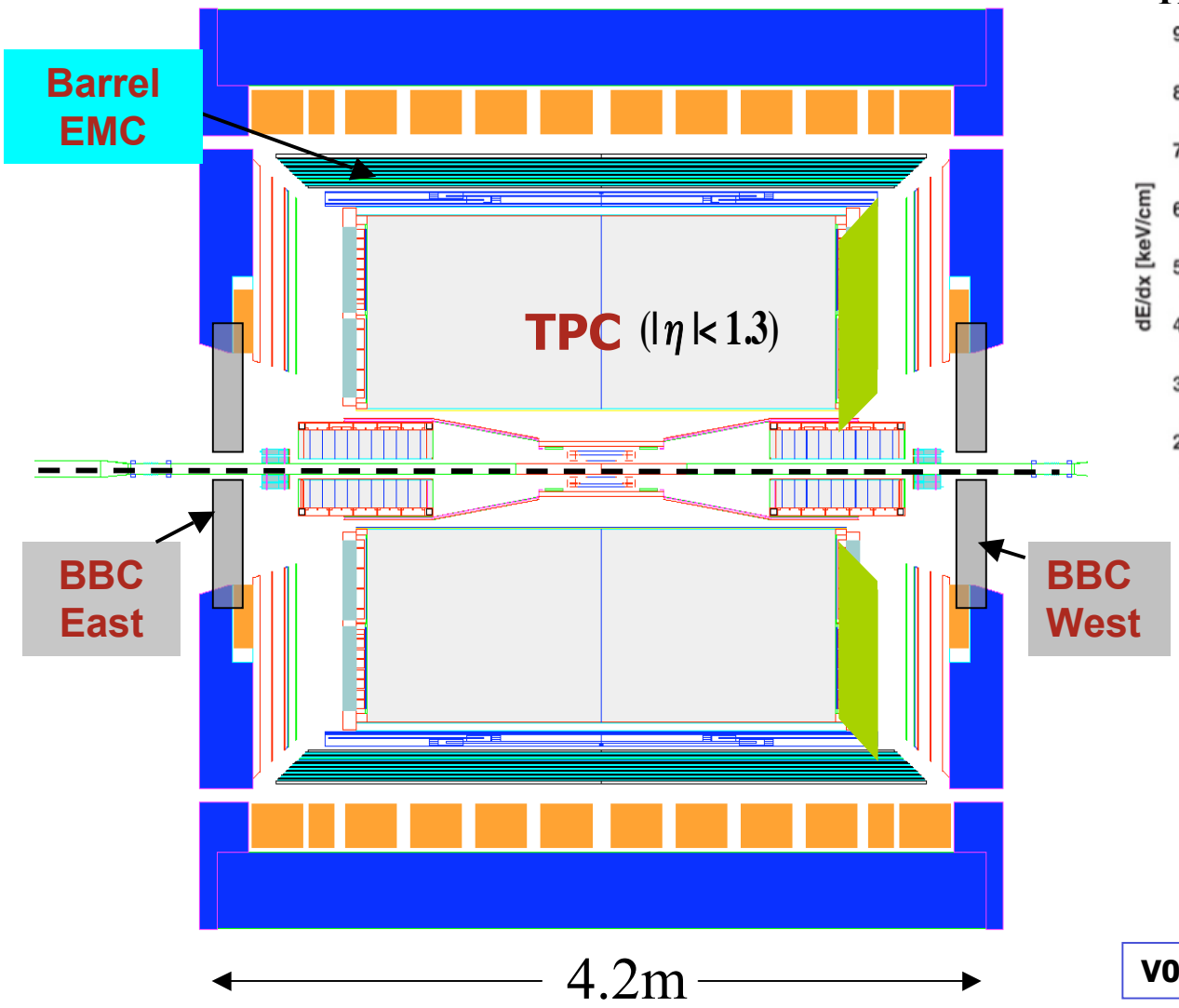
GRSV00-M.Gluck et al, Phys.Rev.D63(2001)094005



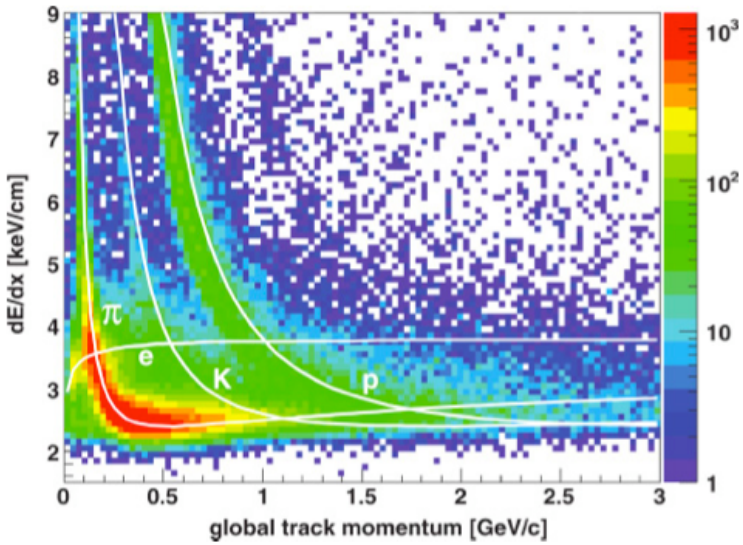
- Λ D_{LL} is less sensitive to Δs, due to large u,d quark fragmentation.

- Promising measurements---effects potentially large enough to be observed.

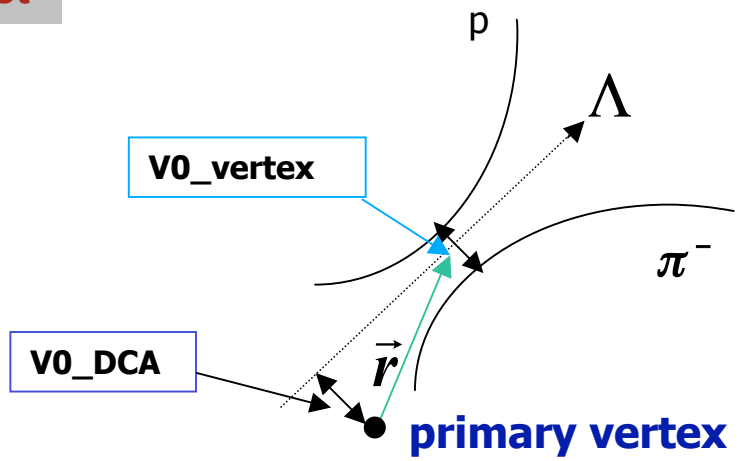
STAR - Solenoid Tracker At RHIC



Time Projection Chamber enables PID



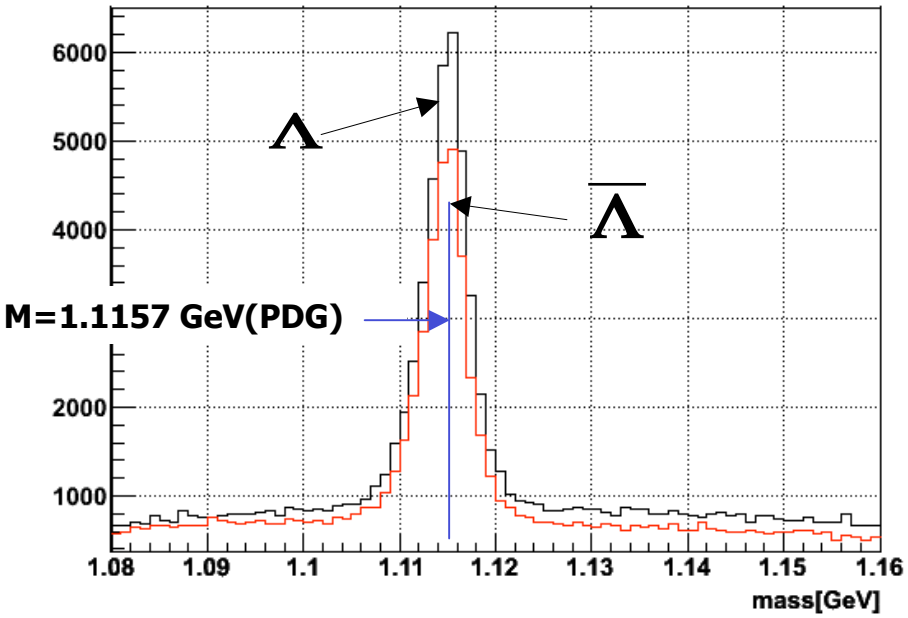
Plus topological reconstruction:

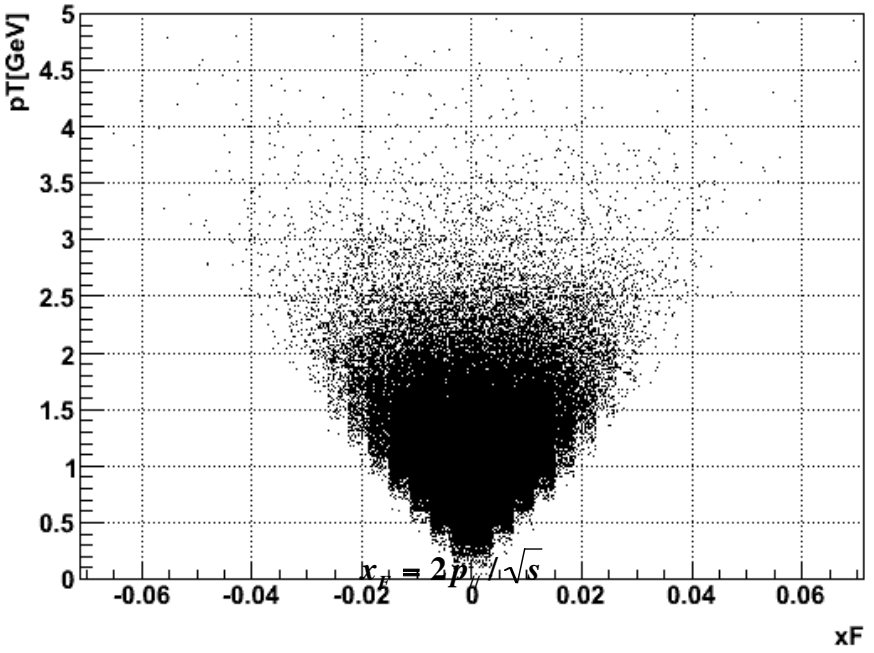


for |η|<~1.3

STAR data - 2005

~3X10^6 events collected with a beam-collision trigger (minimum bias, bandwidth limited),





<p_T>~1.3 GeV

<$|x_F|$>~0.0075

Extraction of spin transfer D_{LL}

- Λ polarization is usually extracted from the momentum distribution of its weak decay ($\Lambda \rightarrow p\pi^-$):

$$dN = \frac{N_{tot}}{2} A(\cos\theta^*)(1 + \alpha P_\Lambda \cos\theta^*)$$

$$\cos\theta^* \propto \vec{P}_\Lambda \cdot \vec{p}^*_p$$

α: decay parameter: 0.642
A(cosθ*): detector acceptance

D_{LL} can thus be extracted from Λ counts with opposite beam polarization within a small interval of cosθ*:

$$D_{LL} = \frac{1}{\alpha \cdot P_{beam} < \cos\theta^* >} \cdot \frac{N^+ - N^-}{N^+ - N^-}$$

, where the acceptance cancels.

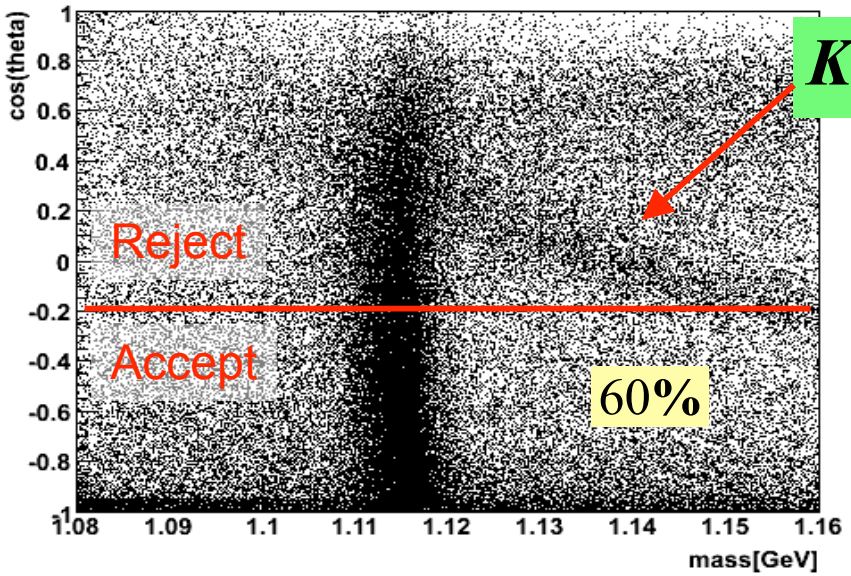
$$N^+_\Lambda = N^{++} \frac{L_{--}}{L_{++}} + N^{+-} \frac{L_{--}}{L_{+-}}$$

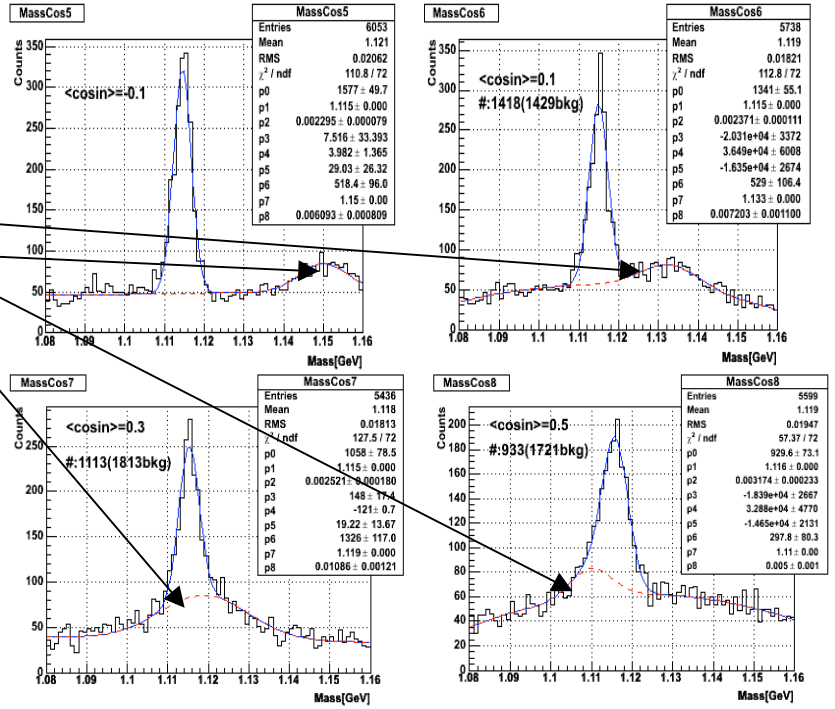
$$N^-_\Lambda = N^{-+} \frac{L_{--}}{L_{-+}} + N^{--}$$

Relative luminosity ratio measured with BBC, and P_b in RHIC.

Signal and Background

- Background from K_{0s}:
  --- a cut of cosθ*<-0.2 applied.



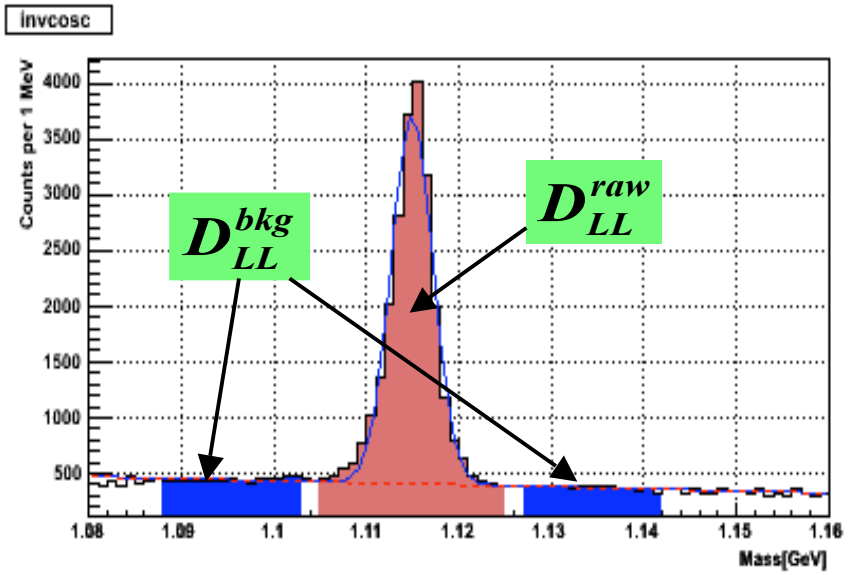


- Subtracting bg. contribution to D_{LL}

$$D_{LL}^{sig} = \frac{D_{LL}^{raw} - rD_{LL}^{bkg}}{1-r}$$

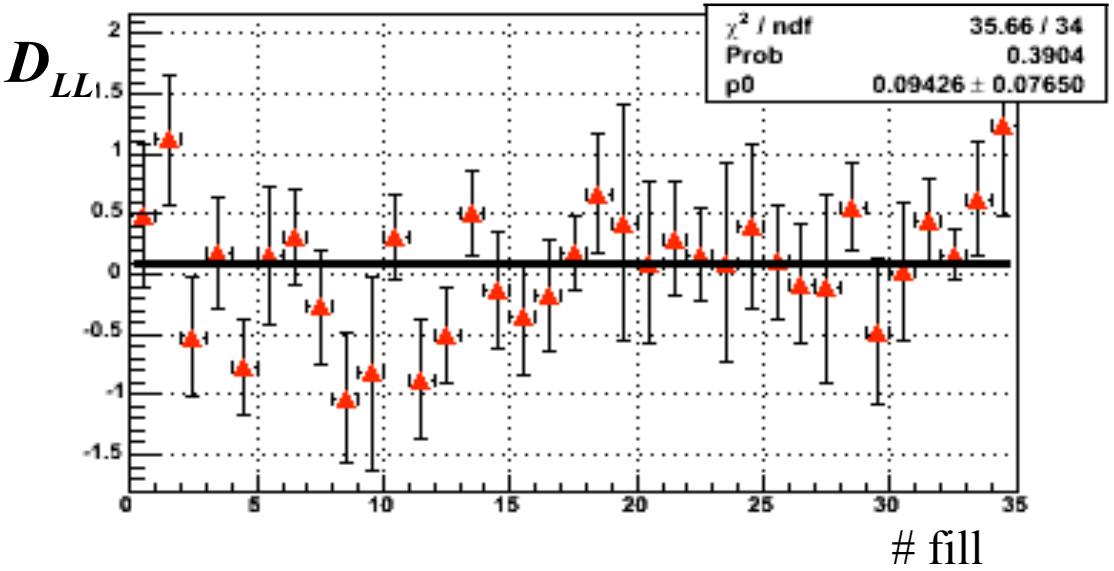
$$\delta D_{LL}^{sig} = \frac{\sqrt{\delta^2 D_{LL}^{raw} - r^2\delta^2 D_{LL}^{bkg}}}{1-r}$$

r: fraction of background under the peak

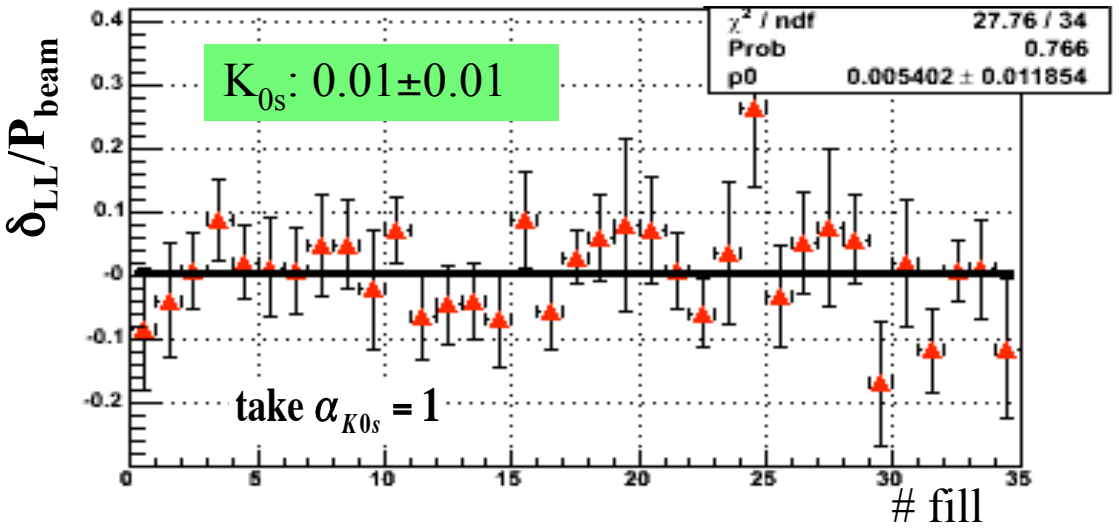


Cross-check of D_{LL}

- The extracted D_{LL} exhibits the expected statistical variation with time:

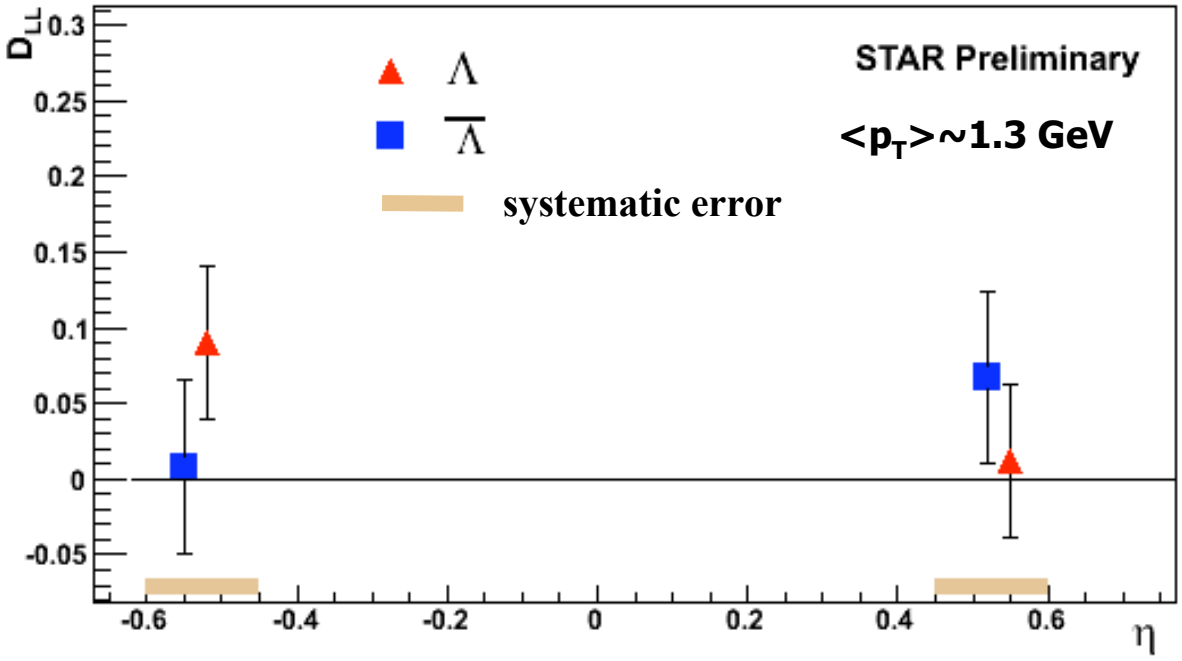


- Null measurements with spin-0 K_{0s} (larger statistics than Λ)



Results I

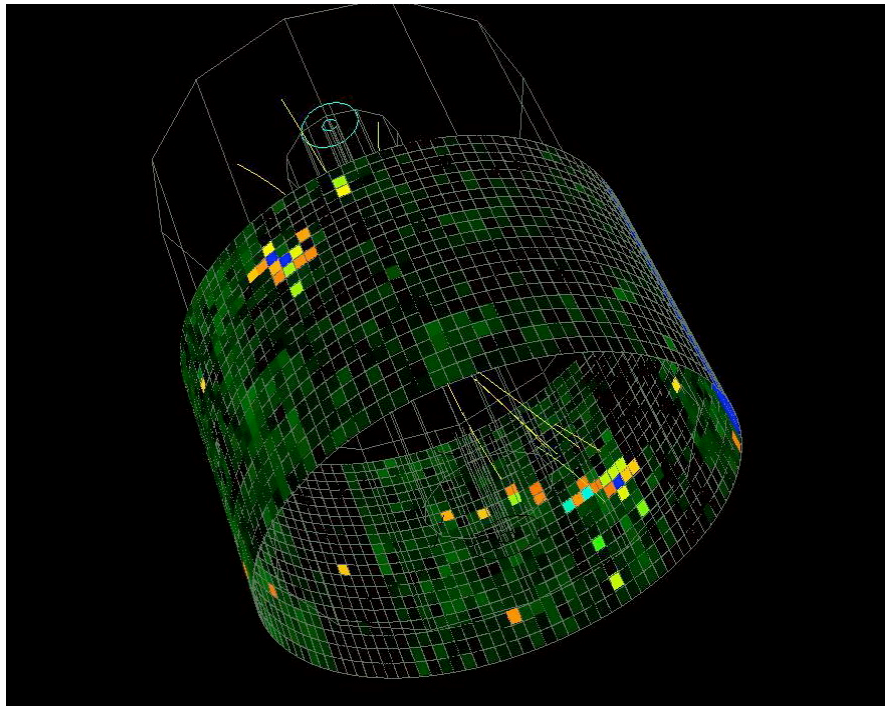
- First D_{LL} results from RHIC:

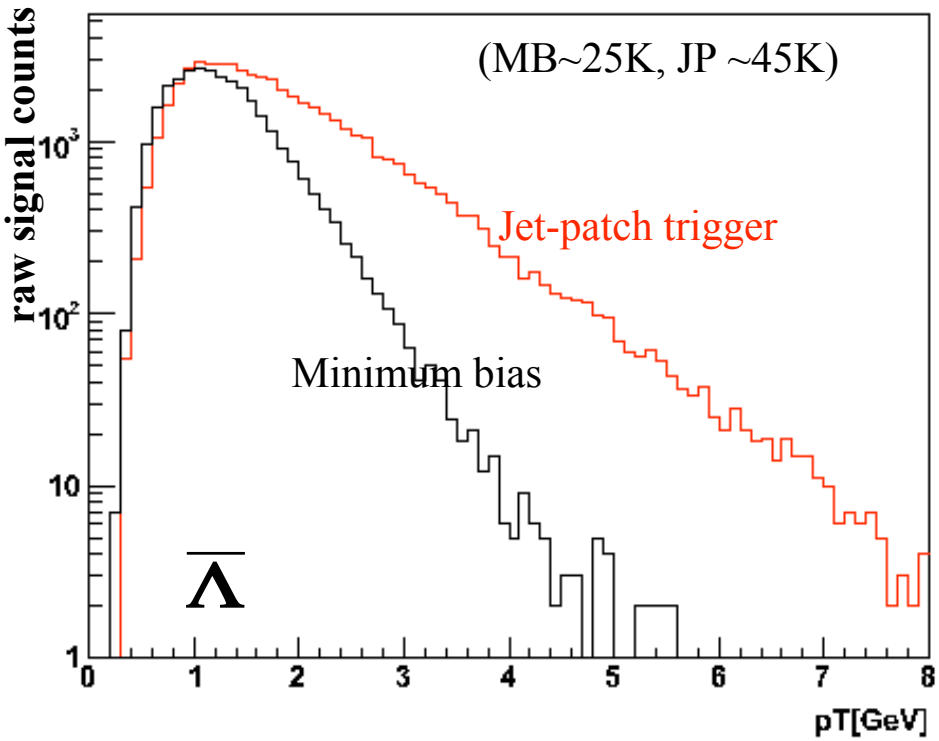


- Statistics and p_T limited,
- Need better precision and higher p_T.

STAR triggered data - 2005

STAR was triggered on energy deposits in jet-patches of the Barrel E.M. Calorimeter,

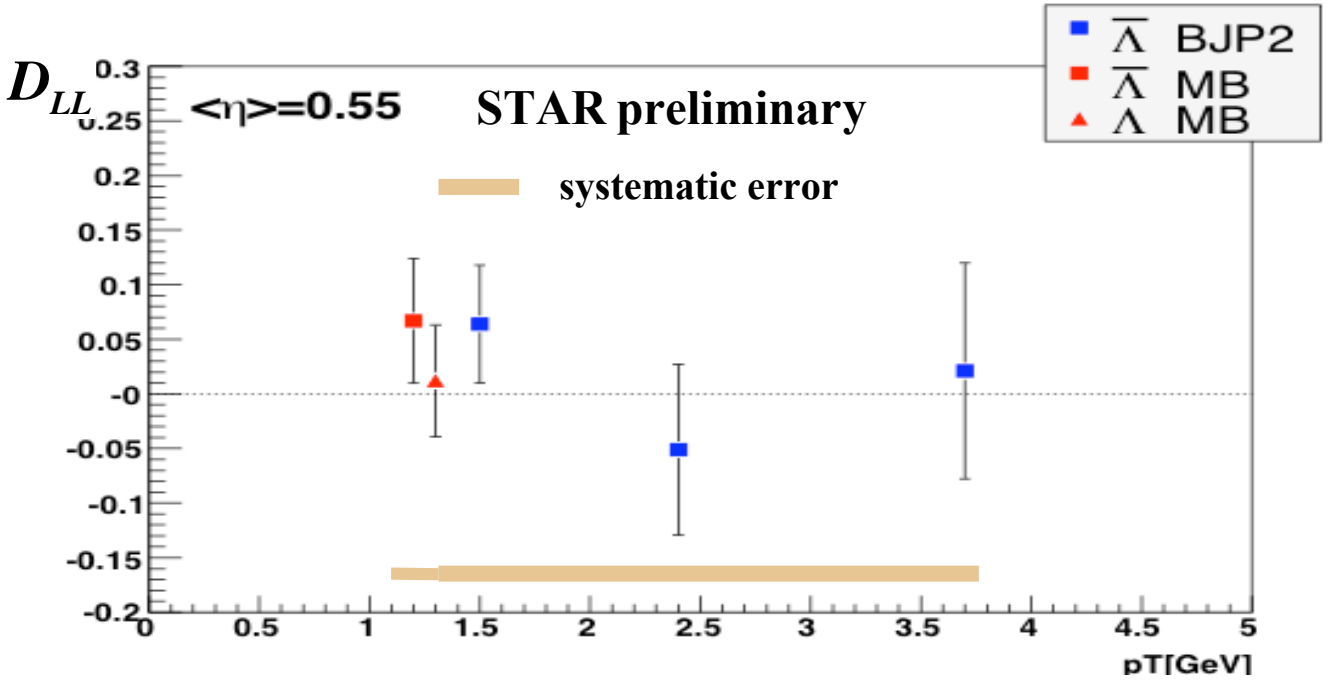




Trigger on high p_T jets --> higher p_T hyperons in jets

Recorded a (biased) sample of Λ and $\overline{\Lambda}$ candidates with considerably higher p_T, although not directly triggered.

Results II

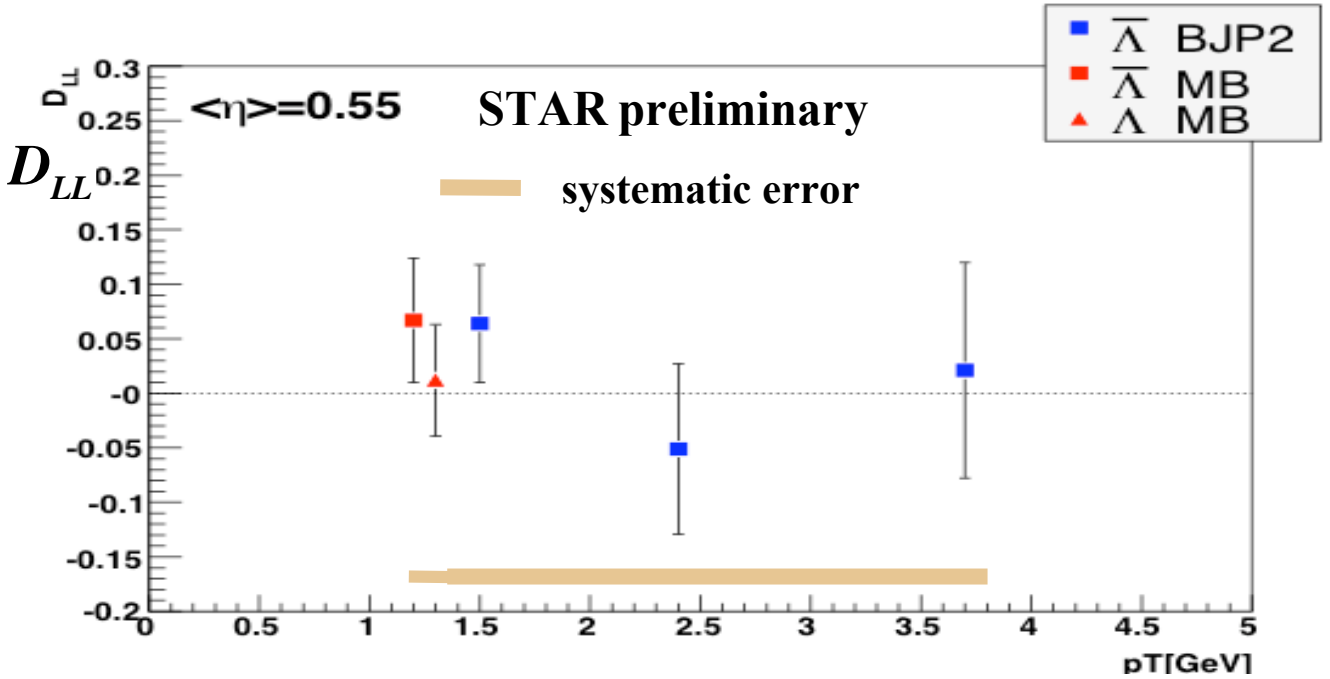


Systematic uncertainties:

- 5% scale uncertainty from RHIC beam polarization measurement.
- 2% from decay-parameter (0.642±0.013).
- 2% from non-longitudinal beam polarization components at STAR.
- <0.01 from relative luminosity measurement.
- <5% background fraction.
- <4% pile-up effects in TPC.
- <15% trigger bias estimated from MC simulation.

Summary

- The production of $\Lambda + \overline{\Lambda}$ at RHIC is well described with pQCD.
- Expectations for $\overline{\Lambda}$ spin transfer measurements at RHIC, show sensitivity to $\Delta\bar{s}$ at high p_T .
- The first proof-of-principle measurement has been performed, with a minimum bias trigger, and extended the p_T coverage with a jet trigger.



Outlook I - Transverse spin transfer

- Transverse spin transfer of hyperons to study transverse spin structure of nucleon:

$$P_T^H = \frac{d\sigma^{(p_\uparrow p \to H_\uparrow X)} - d\sigma^{(p_\uparrow p \to H_\downarrow X)}}{d\sigma^{(p_\uparrow p \to H_\uparrow X)} + d\sigma^{(p_\uparrow p \to H_\downarrow X)}}$$

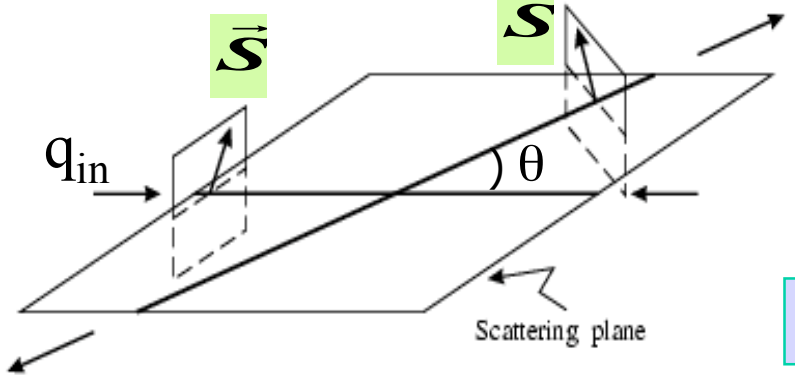
$$d\Delta_T\sigma^{(\vec{p}_\perp p \to \vec{H}_\perp X)} \propto \sum_{abcd} \int dx_a dx_b dz \delta f_a(x_a) f_b(x_b) \Delta_T D_c^H(z) d\Delta_T\hat{\sigma}^{(\vec{a}_\perp b \to \vec{c}_\perp d)}$$

transversity distribution :
$\delta f(x) = f_\uparrow(x) - f_\downarrow(x)$

$\Delta_T D_{\Lambda/q}(z) = D_{\Lambda^\uparrow/q^\uparrow}(z) - D_{\Lambda^\downarrow/q^\uparrow}(z)$

pQCD

- Transverse polarization direction in the hard scattering:



J.Collins et al., NPB420 (1994)565

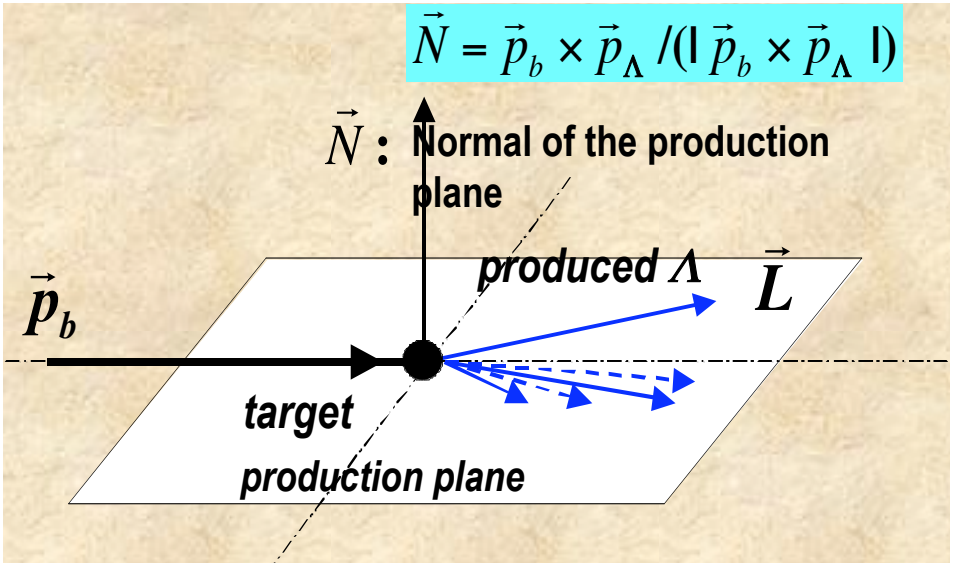
Helicity density matrix:

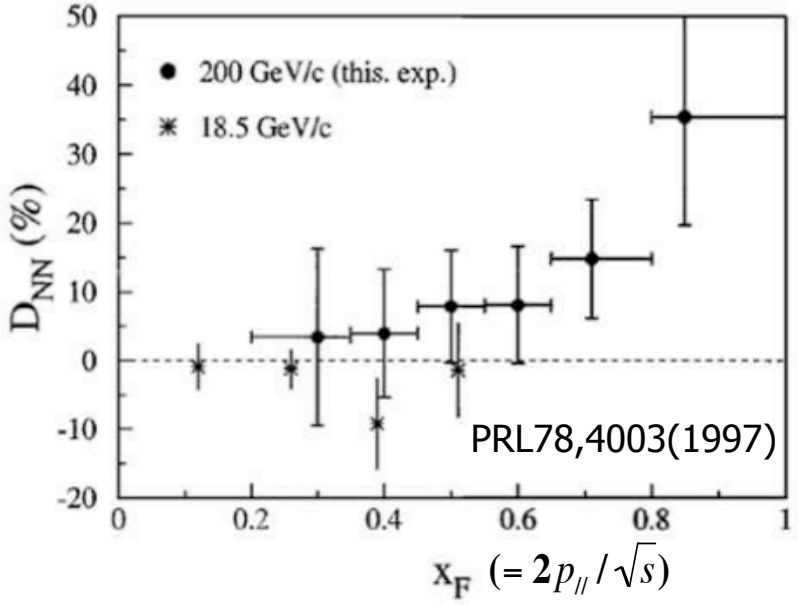
$$\rho = \frac{1}{2}\begin{pmatrix} 1 & P_T e^{-i\phi} \\ P_T e^{i\phi} & 1 \end{pmatrix}$$

A rotation in the scattering plane!

How to measure transfer spin transfer ?

- Possible measurements on transverse spin transfer:
  - ♣ D_{TT} : final state polarization along the pol. of outgoing hard quark
    (considering the rotation in scattering plane)--- jet correlation
  - ♣ D_{NN} , spin transfer w.r.t. production plane:





D_{NN}: production plane close to hard scattering plane;
but precision reduced ~ one half (beam pol. projected to N.)

Outlook II - forward hyperon physics

- A proposal of FHC at STAR may enable the study of forward Lambda physics together with FMS through $\Lambda \rightarrow n\pi^0$ ($x_F \sim 0.4$).