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

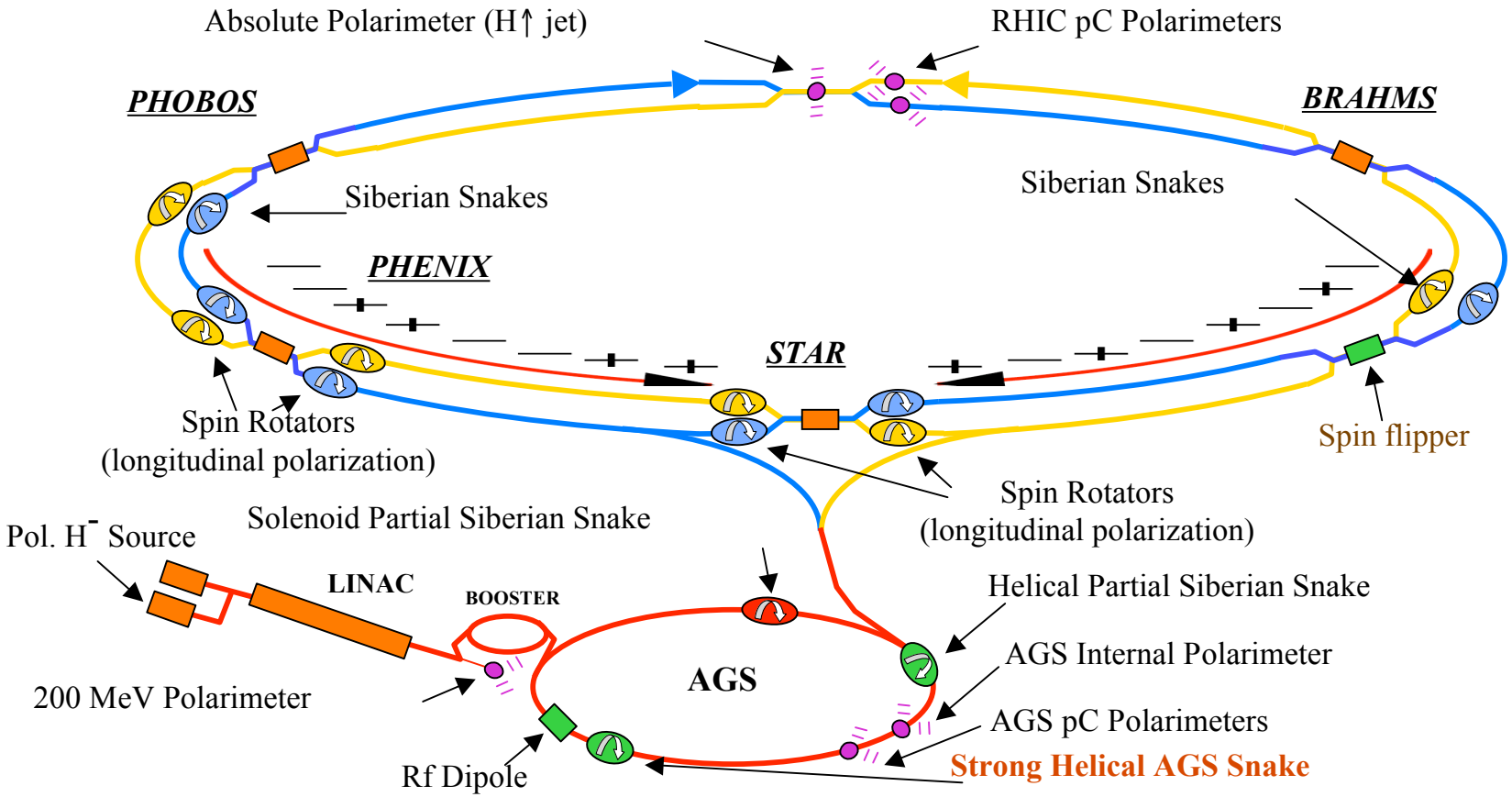
Qinghua Xu (Shandong Uni.) *for the STAR collaboration*

SPIN-2010, September 27, 2010, Juelich

Content:

- Nucleon spin structure and its strangeness part ΔS
- Measurement of longitudinal spin transfer of hyperons at STAR
- Summary & outlook

RHIC- polarized pp collider to study spin in QCD



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

- In the naive Quark Model, the nucleon is made of three quarks - p(uud), n(udd)

  The quark spins make up the nucleon spin, since the quarks are in the s-orbit:

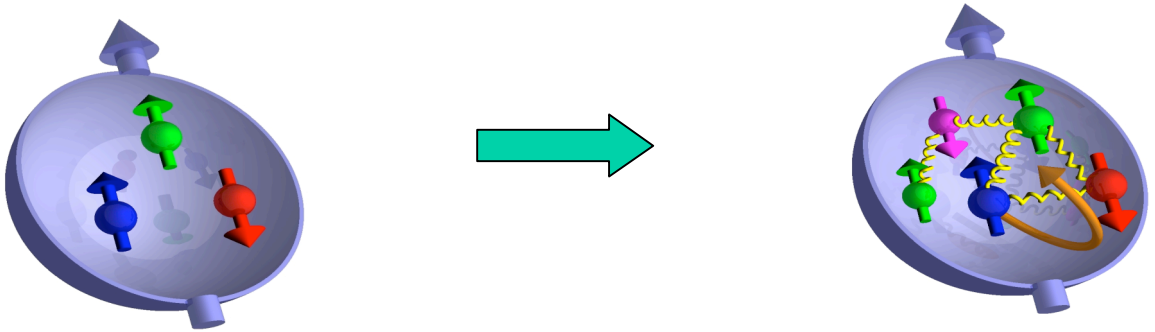
$$\Delta\Sigma = 1$$

- Ellis-Jaffe sum rule (1974) assumes strange quarks carry no net polarization, then relate $\Delta\Sigma$ to couplings in hyperons beta decay with SU(3)_f symmetry:

$$\Delta\Sigma \approx 0.6$$

- 1988 - European Muon Collaboration (polarized DIS)
  "Spin Crisis"--- proton spin carried by quark spin is rather small: $\Delta\Sigma \sim 0.2$

  As a result, **strange quarks** are expected to be polarized **negatively**.

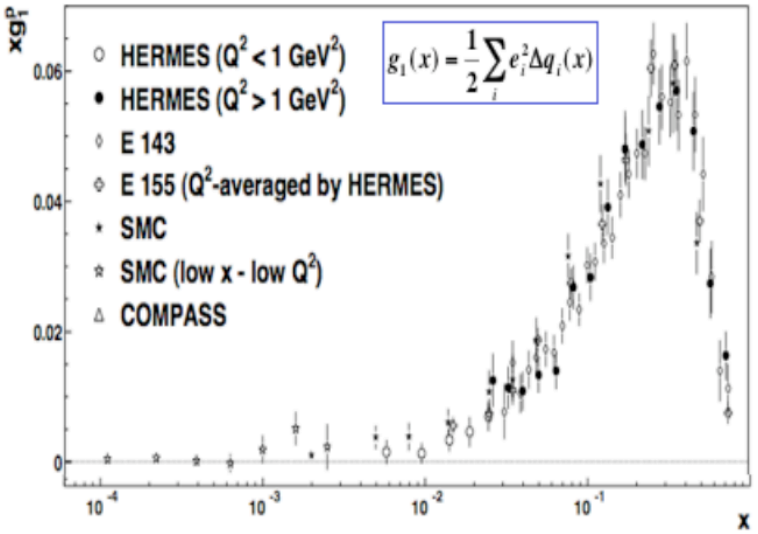


ΔS from polarized inclusive DIS

- Determination of ΔS , ΔΣ with polarized inclusive DIS:

$$\Gamma_1^p = \int_0^1 g_1^p(x)dx = \frac{1}{2}\int \sum_i e_i^2 \Delta q_i(x) = \frac{1}{18}[4\Delta U + \Delta D + \Delta S]$$

$$\Delta\Sigma = \underbrace{\Delta u + \Delta\bar{u}}_{\Delta U} + \underbrace{\Delta d + \Delta\bar{d}}_{\Delta D} + \underbrace{\Delta s + \Delta\bar{s}}_{\Delta S}$$



Each flavor's contribution to nucleon spin:

$$\Delta q = \int_0^1 \Delta q(x)\,dx$$

$\Delta q(x) = q^+(x) - q^-(x)$: helicity distribution function

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

$\Rightarrow \Delta\Sigma = 0.33 \pm 0.03 \pm 0.01 \pm 0.03$:

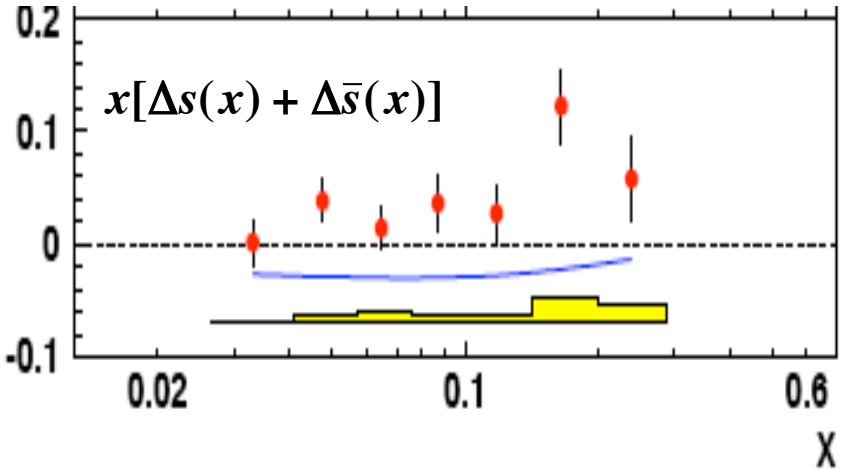
$\Delta U \sim 0.84$,
$\Delta D \sim -0.43$, (HERMES, $Q^2 = 5$ GeV^2)
$\Delta S \sim -0.08 \pm 0.01 \pm 0.01 \pm 0.01$*

*COMPASS also obtained similar results.

ΔS from semi-inclusive DIS

- Recent measurements in semi-inclusive DIS - consistent with zero:

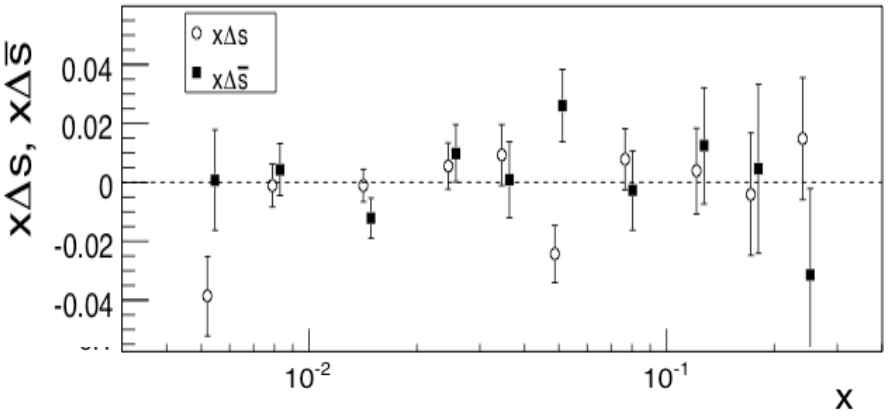
HERMES, PLB666,446(2008)



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

0.02<x<0.6, at a scale Q^2=2.5 GeV^2.

COMPASS, PLB680, 217(2009);1007.4061



$\Delta S' = -0.01 \pm 0.01 \pm 0.02$)

0.004<x<0.3, at Q^2=3 GeV^2

➡ Different as inclusive DIS results?

Our knowledge on ΔS is far from comprehensive.

Study ΔS at RHIC with hyperons?

- Λ's contain a strange quark, whose spin is expected to carry most of the Λ spin
- Λ polarization can be measured in experiment via weak decay

$$\frac{dN}{d\Omega} \propto 1 + \alpha (\vec{P}_\Lambda \cdot \vec{p}^{\,*}_p)$$

Unit vector along proton momentum in Λ's rest frame.

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

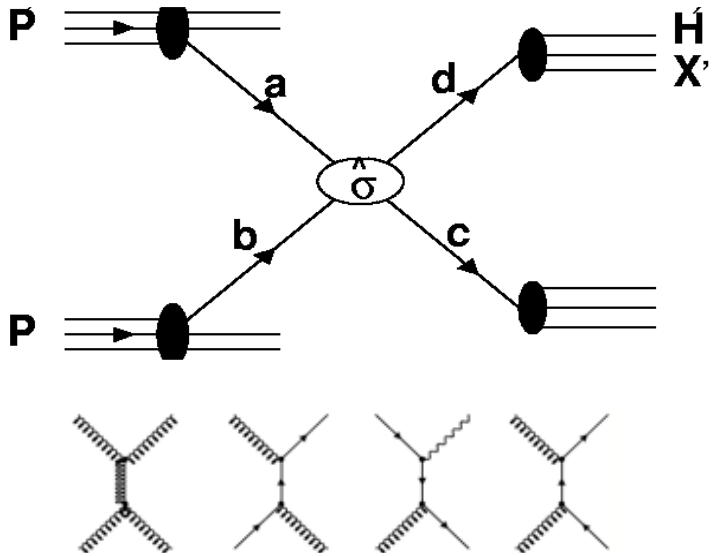
decay parameter 0.642 ±0.013

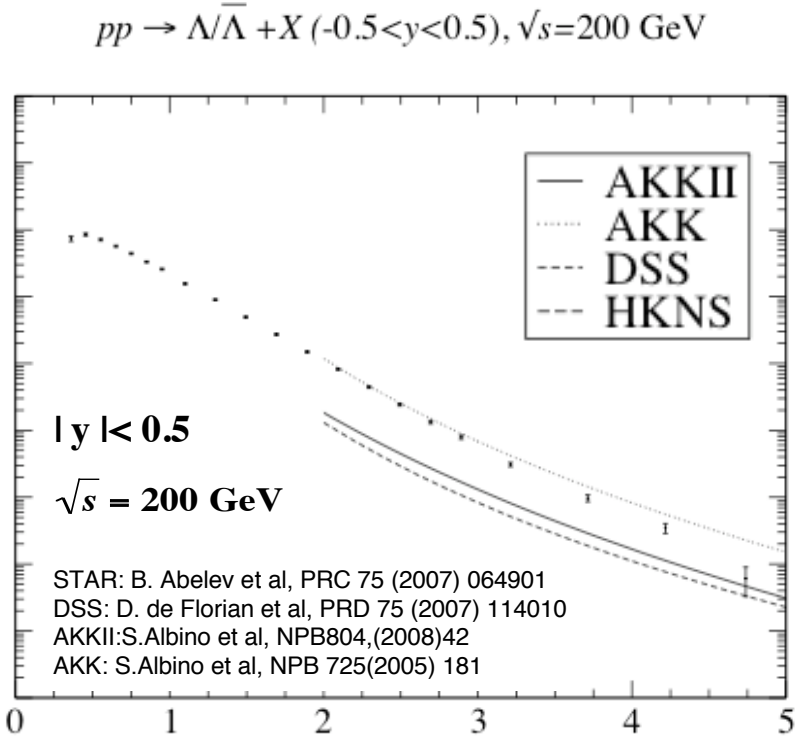
Λ polarization vector

- Can $\Lambda(\bar{\Lambda})$ polarization measurements provide sensitivity to ΔS at RHIC?

Hyperon production in pp collisions

- The factorized framework enables perturbative description,





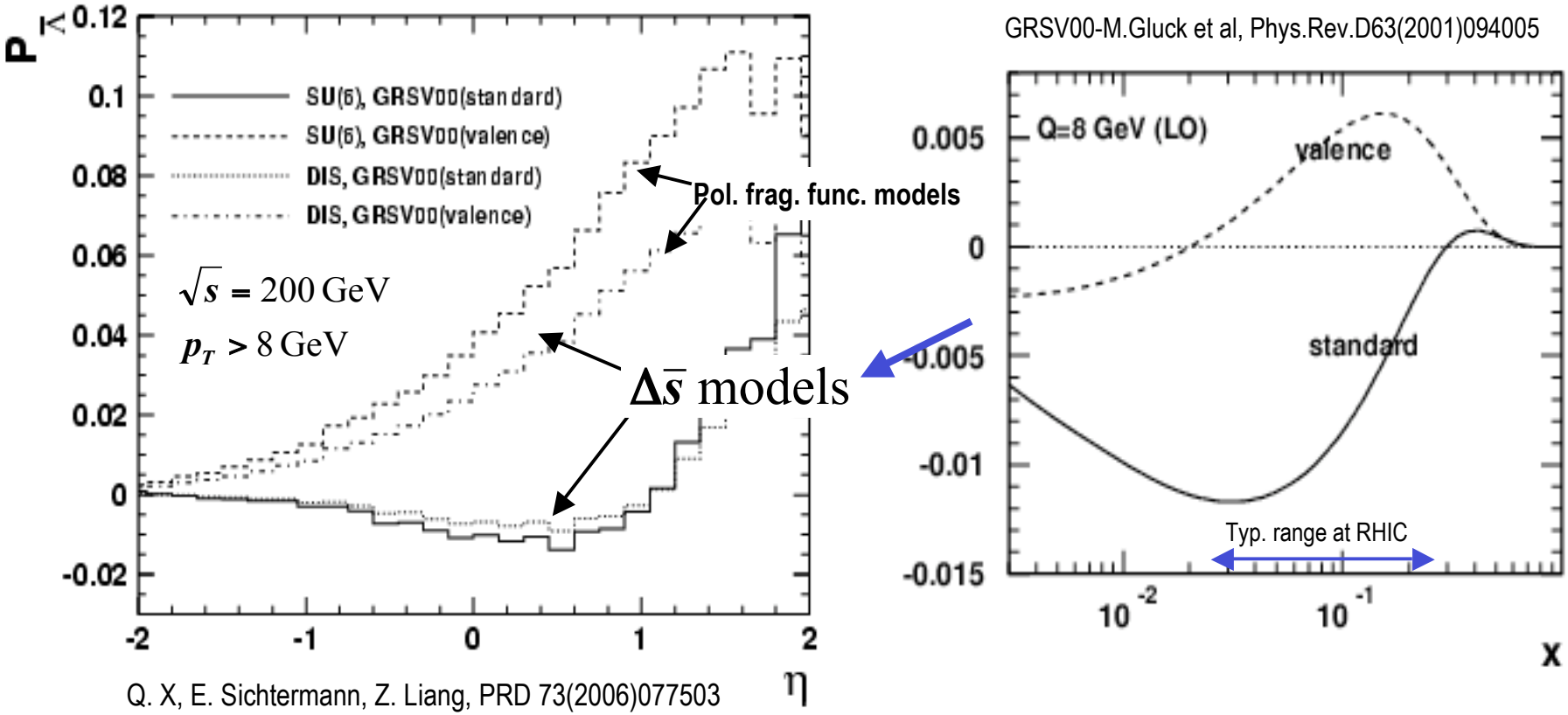
$$d\sigma \propto \int f_a(x_1) \cdot f_b(x_2) \otimes d\hat{\sigma} \otimes D^{\Lambda}(z)$$

- Hyperon spin transfer D_{LL} provides access to Δf and ΔD :

$$D_{LL} \equiv \frac{\sigma_{p^+ p \to \bar{\Lambda}^+ X} - \sigma_{p^+ p \to \bar{\Lambda}^- X}}{\sigma_{p^+ p \to \bar{\Lambda}^+ X} + \sigma_{p^+ p \to \bar{\Lambda}^- X}} = \frac{d\Delta\sigma}{d\sigma}$$

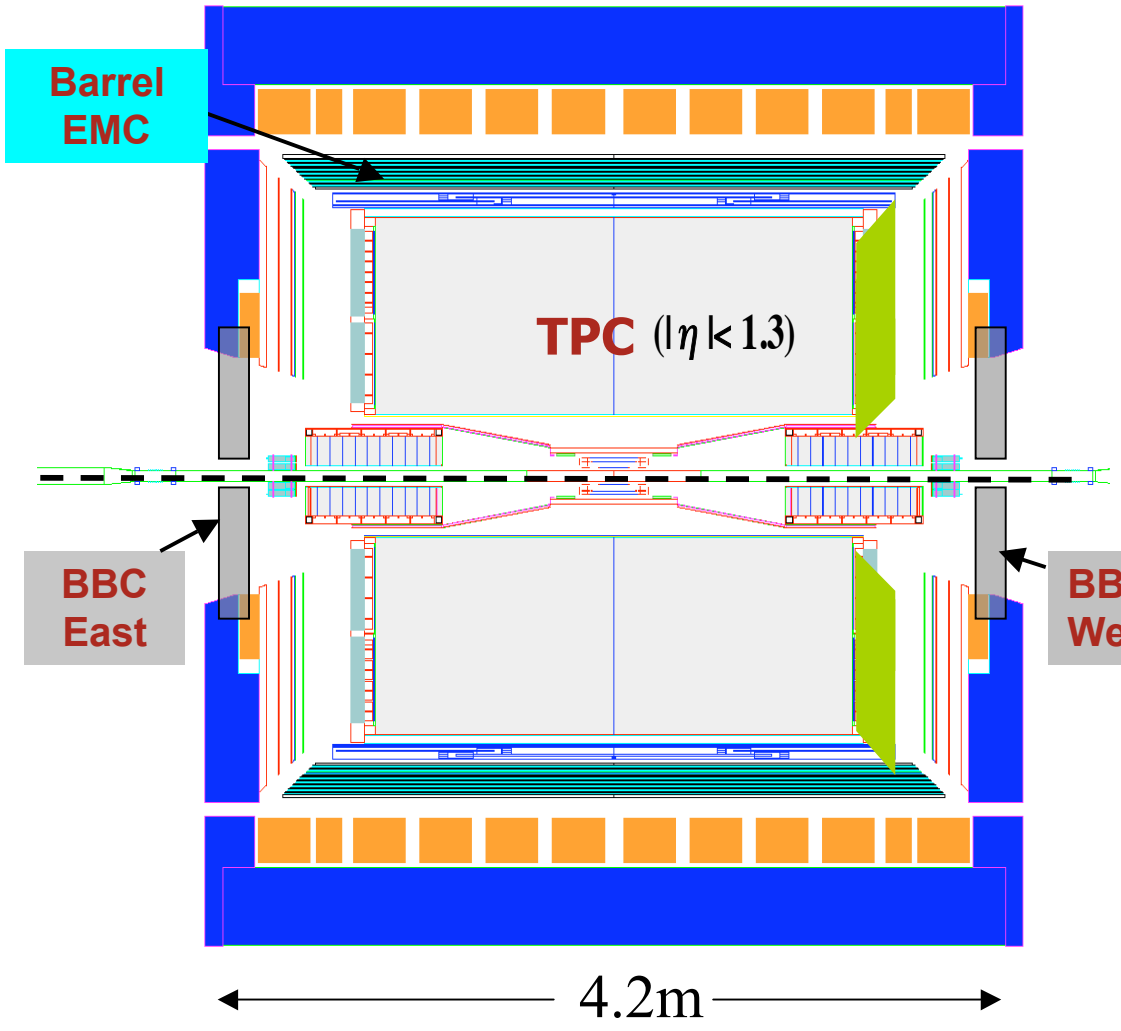
D_{LL}-Longitudinal spin transfer at RHIC

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

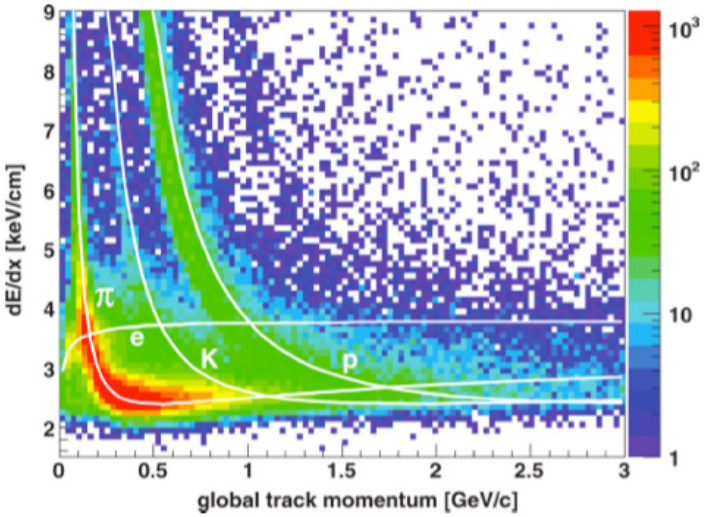


- Λ D_{LL} is less sensitive to Δs, due to large u,d quark fragmentation.
- Promising measurements---effects potentially large enough to be observed.

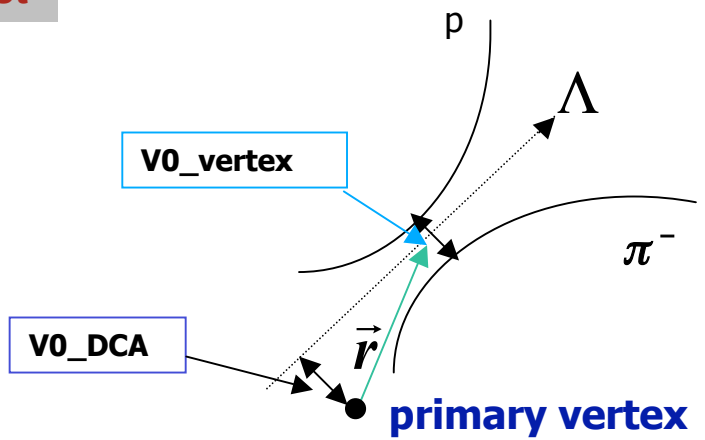
STAR - Solenoid Tracker At RHIC



Time Projection Chamber enables PID



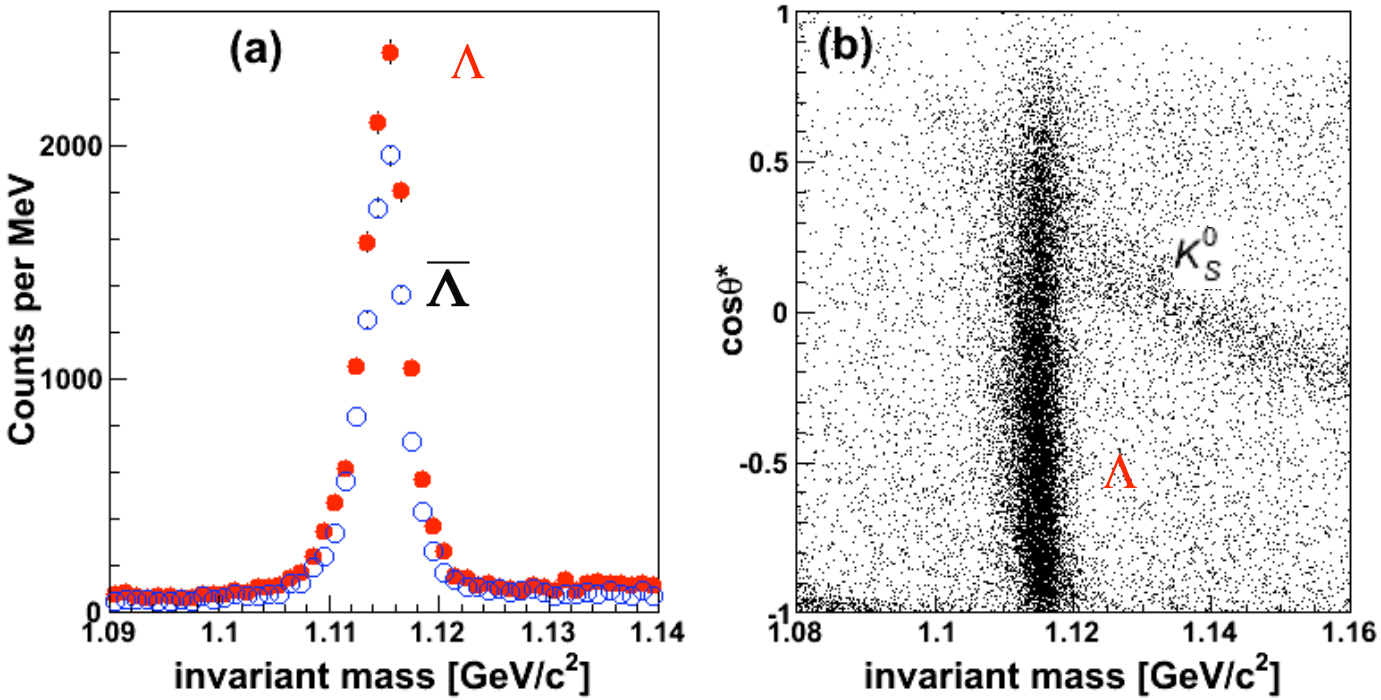
Plus topological reconstruction:



for |η|<~1.3

STAR data - 2005

~1.8X10^6 events collected with minimum bias trigger (MB) after QA:



-residual background fraction is ~10% under the mass peak (1.109,1.121GeV), including random background and mis-identified K^0_s.

Extraction of spin transfer D_{LL}

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

$$dN = \frac{N_{tot}}{2} A(\cos\theta^*)(1 + \alpha P_\Lambda \cos\theta^*) \qquad \cos\theta^* \propto \vec{P}_\Lambda \cdot \vec{p}_p^{\,*}$$

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

- D_{LL} has been 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.

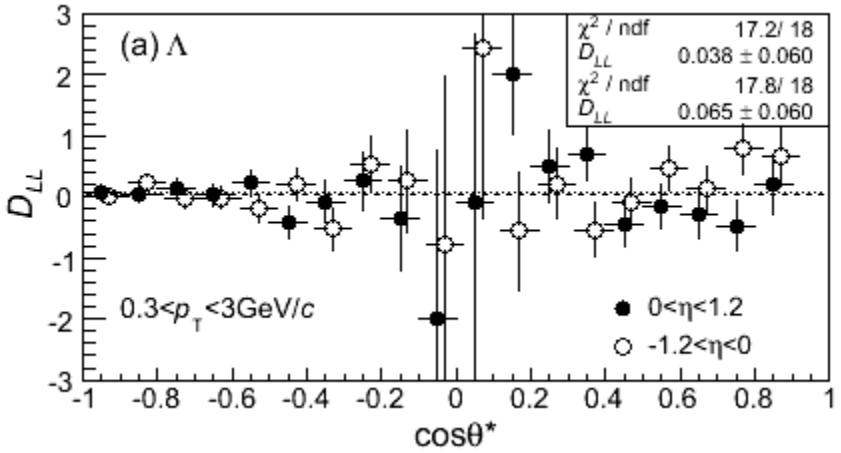
$$N_\Lambda^+ = N^{++} \frac{L_{--}}{L_{++}} + N^{+-} \frac{L_{--}}{L_{+-}}$$

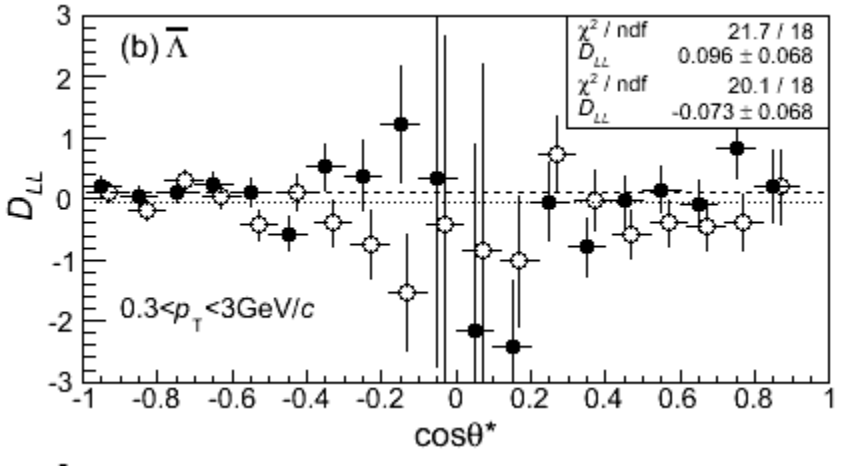
$$N_\Lambda^- = N^{-+} \frac{L_{--}}{L_{-+}} + N^{--}$$

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

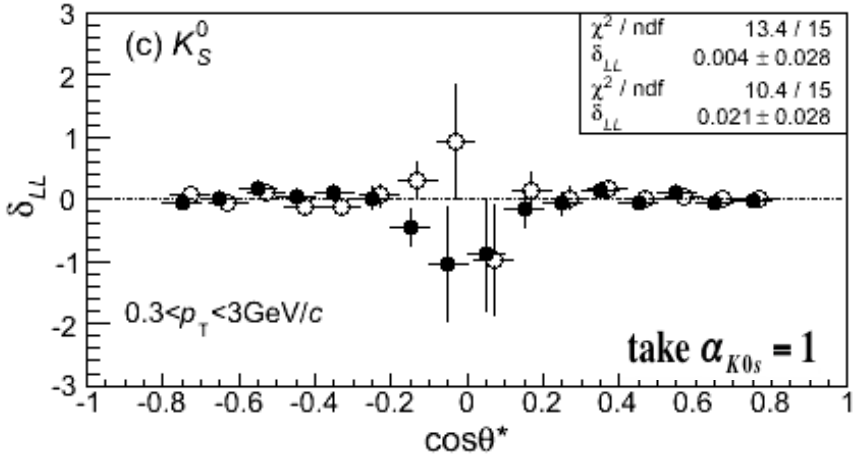
STAR data - 2005

- Extraction of D_{LL} with minimum bias (MB) data :





- Cross check with spin-0 K^0_S results are consistent with 0 as expected with 2 times larger statistics.

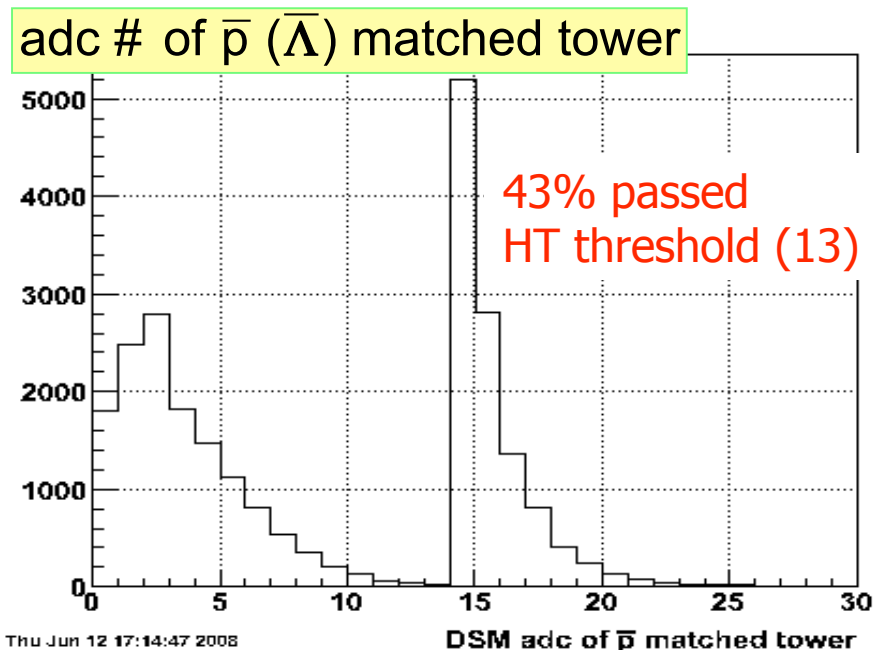


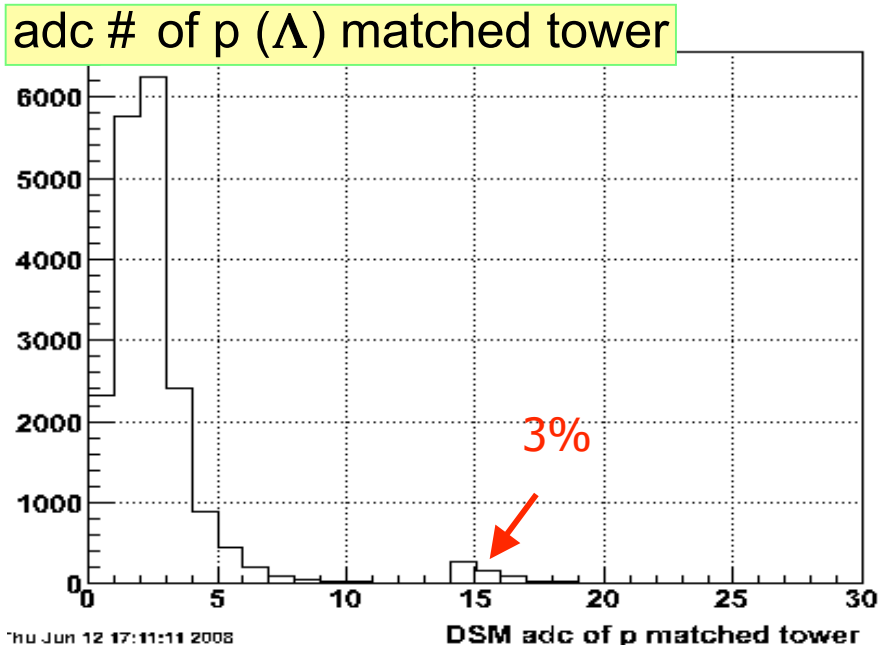
$$D_{LL} = \frac{1}{\alpha \cdot P_{beam} < \cos\theta^* >} \cdot \frac{N^+ - N^-}{N^+ + N^-}$$

$\langle p_T \rangle_{MB} \sim 1.2$ GeV

STAR triggered data - 2005 HT trigger for anti-proton

- TPC track (anti-proton from anti-Lambda) is projected to BEMC tower ($\Delta\eta \times \Delta\phi = 0.05 \times 0.05$), check whether its DSM adc # passes high tower (HT) trigger threshold:

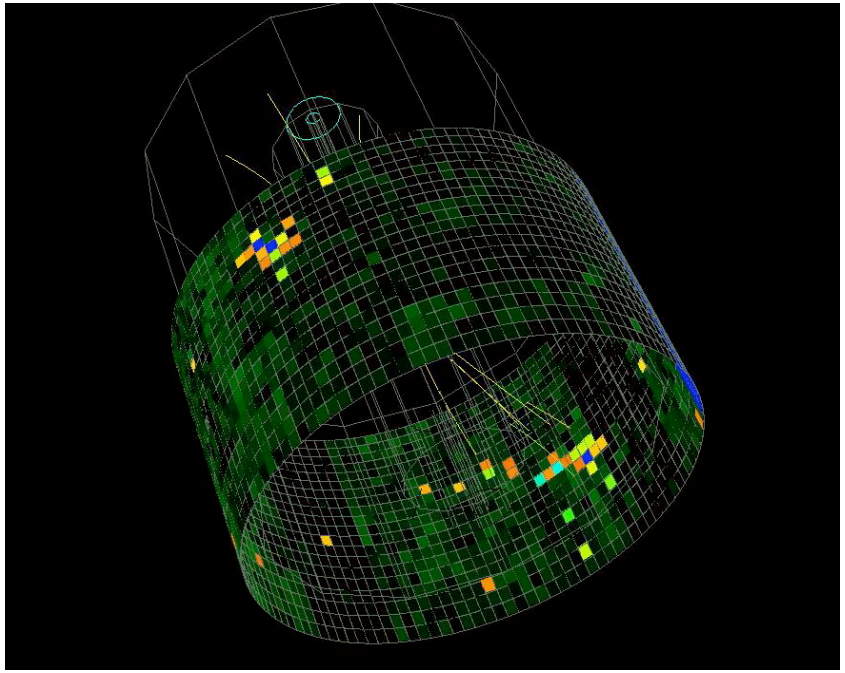


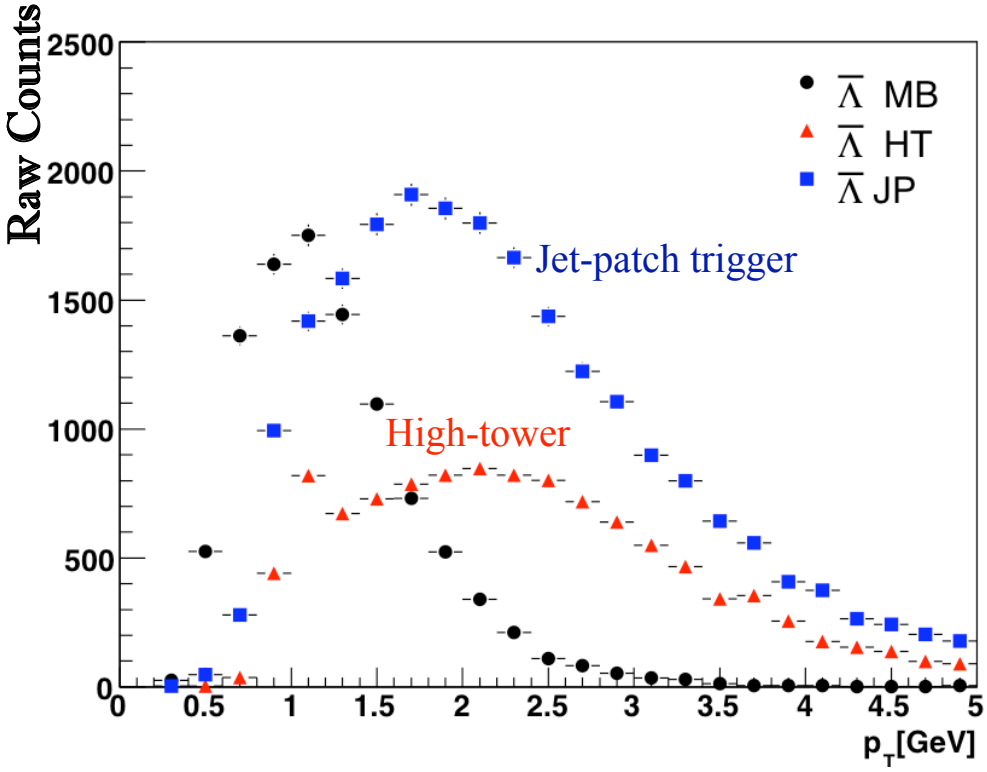


- Large fraction (43%) of anti-proton matched tower passed threshold, and only tiny fraction in the case of p from Λ, consistent with annihilation effect.
- D_{LL} analysis with this special sample is almost trigger bias free, with p_T extended to 4 GeV.

STAR triggered data - 2005

- STAR was also triggered on energy deposits in jet-patches (JP) of the Barrel EMC,

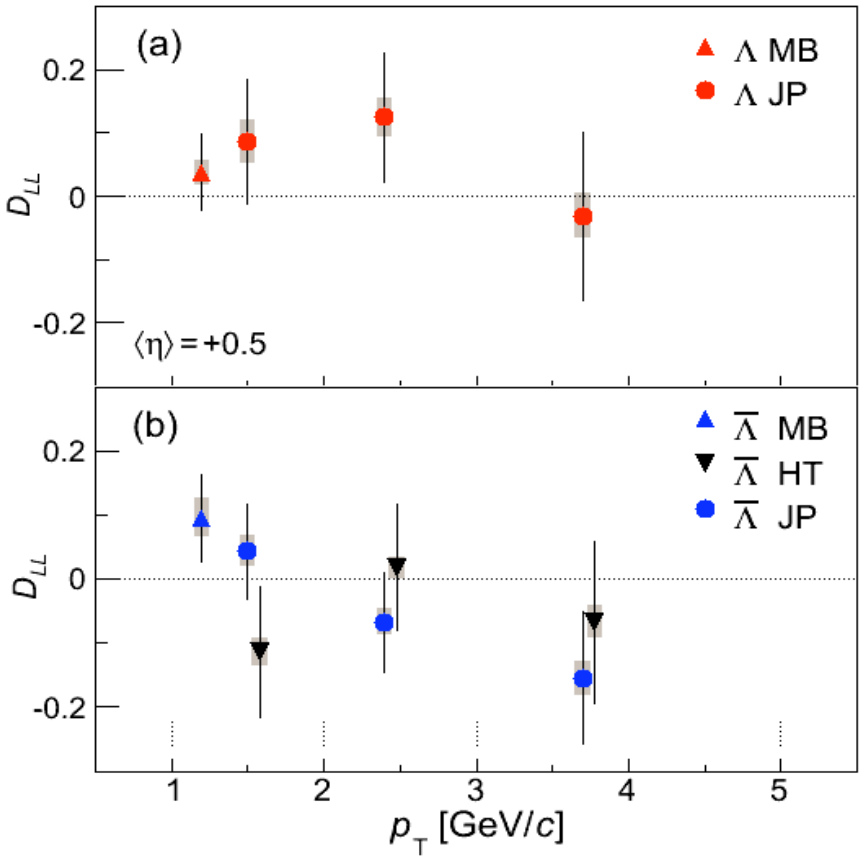




Trigger on high p_T jets --> higher p_T hyperons in jets

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

D_{LL} results with HT & JP samples



- Systematic uncertainties vary from 0.01 to 0.03 for each point, which include:

  6% RHIC measurement of P_beam,

  2% residual transverse pol. at STAR,

  2% decay parameter α (0.642±0.013),

  < 0.01 relative luminosity measurement,

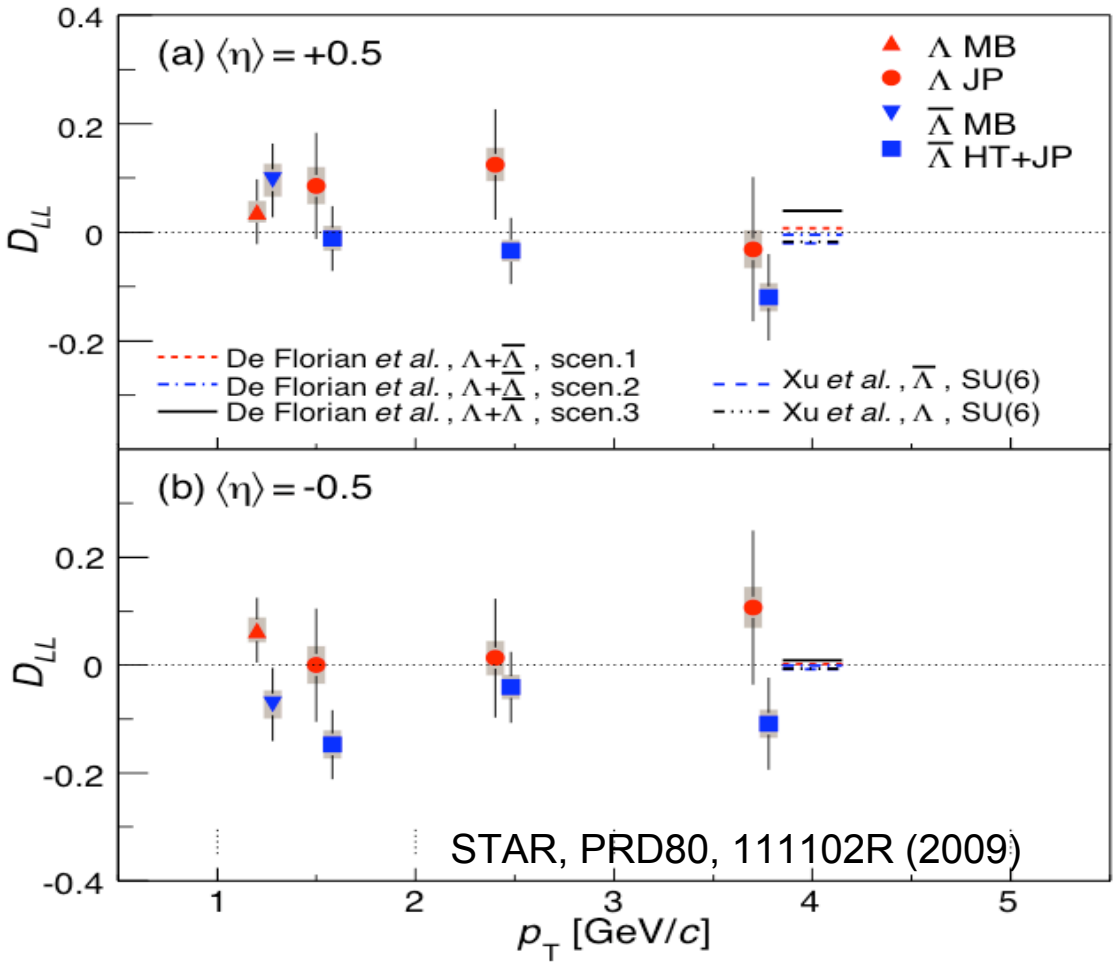
  23% (5%) pile-up effect for MB (JP) ,

  0.01~0.03 residual background,

  <0.01 trigger bias -JP (MC simulation).

STAR, PRD80, 111102R (2009)

D_{LL} Results of STAR



At $<p_T>$ = 3.7 GeV and $<\eta>$ = 0.5 :

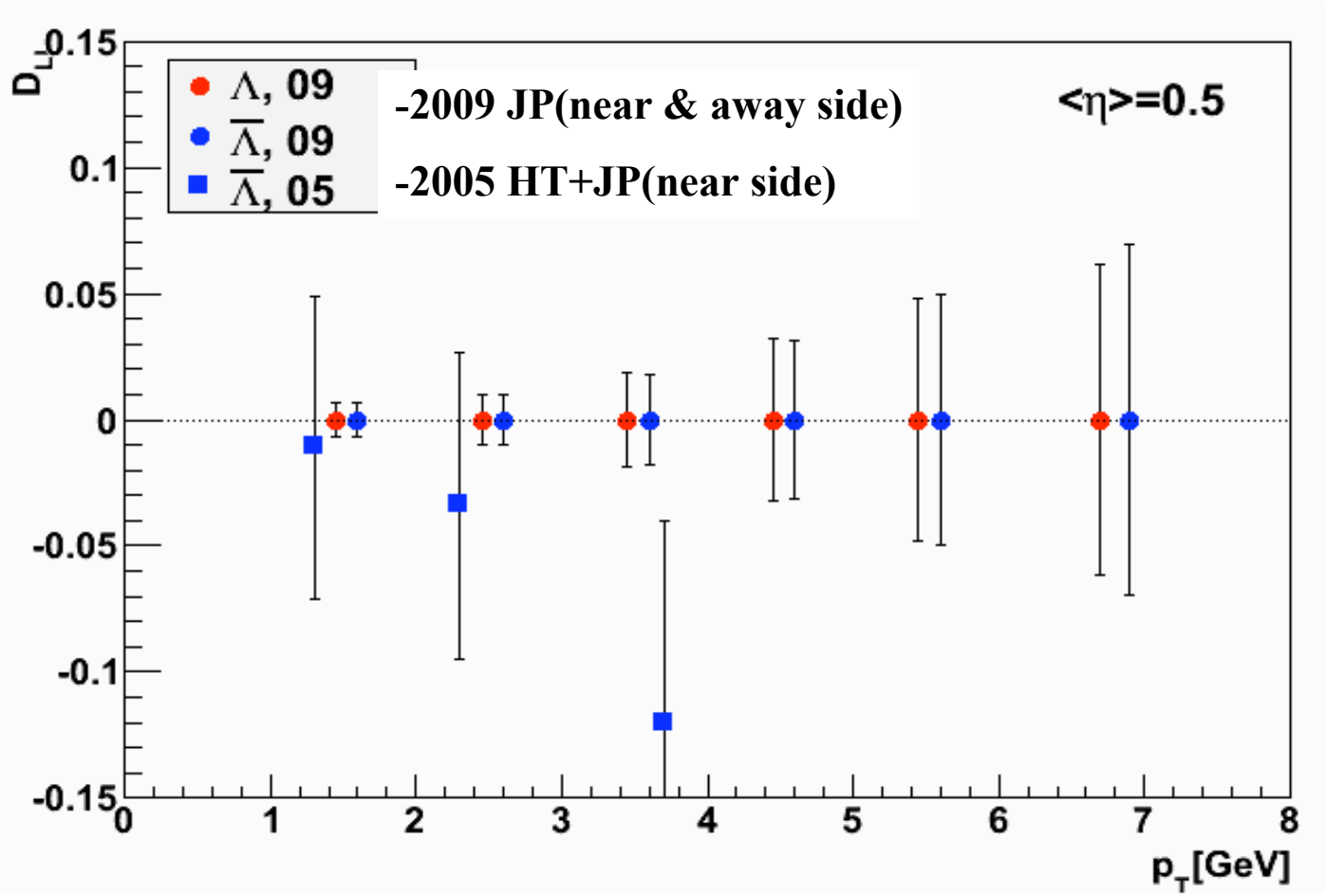
$$D_{LL}(\Lambda) = -0.03 \pm 0.13(stat) \pm 0.04(sys)$$

$$D_{LL}(\overline{\Lambda}) = -0.12 \pm 0.08(stat) \pm 0.04(sys)$$

- D_{LL} for Lambda and anti-Lambda are consistent with each other
- Uncertainties are similar to the spread in model expectations.

Prospects from 2009 data

- Achieved (2005) and projected (2009) uncertainties on D_{LL}:



- p_T coverage will be extended significantly with 2009 data.

Summary

- Expectations for (anti-)Lambda spin transfer D_{LL} measurements at RHIC, show sensitivity to strange quark polarization (Δs) at high p_T .

- We have performed the first proof-of-principle measurement with data of 2005 at RHIC:
  -reached ~10% precision with transverse momentum up to 4 GeV;
  the uncertainties are similar to the spread of models.

$$\langle p_T \rangle = 3.7 \text{ GeV and } \langle \eta \rangle = 0.5: \quad D_{LL}(\Lambda) = -0.03 \pm 0.13(stat) \pm 0.04(sys)$$
$$D_{LL}(\bar{\Lambda}) = -0.12 \pm 0.08(stat) \pm 0.04(sys)$$

- p_T coverage is doubled out to ~8 GeV with data of 2009, and the statistics is expected to be further improved in future RHIC runs.

Outlook I -Transverse spin transfer and δq(x)

- Transverse spin transfer of hyperons can provide access to transverse spin structure of nucleon:

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

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

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

Transversely polarized fragmentation function, may be obtained at BELLE

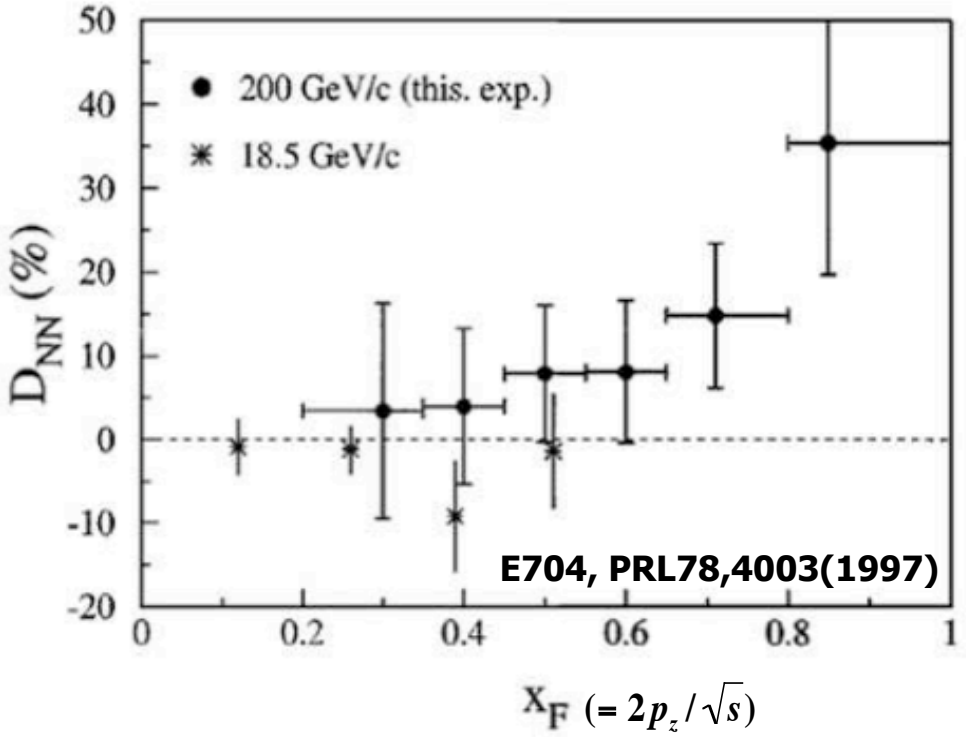
pQCD

- Transverse spin transfer can give insights into transversity.
- Such measurements can be made at mid-rapidity with TPC at STAR.

Transverse spin transfer in pp

- Measurements on transverse spin transfer:

  -D_{NN} : spin transfer w.r.t. production plane (E704,1997):



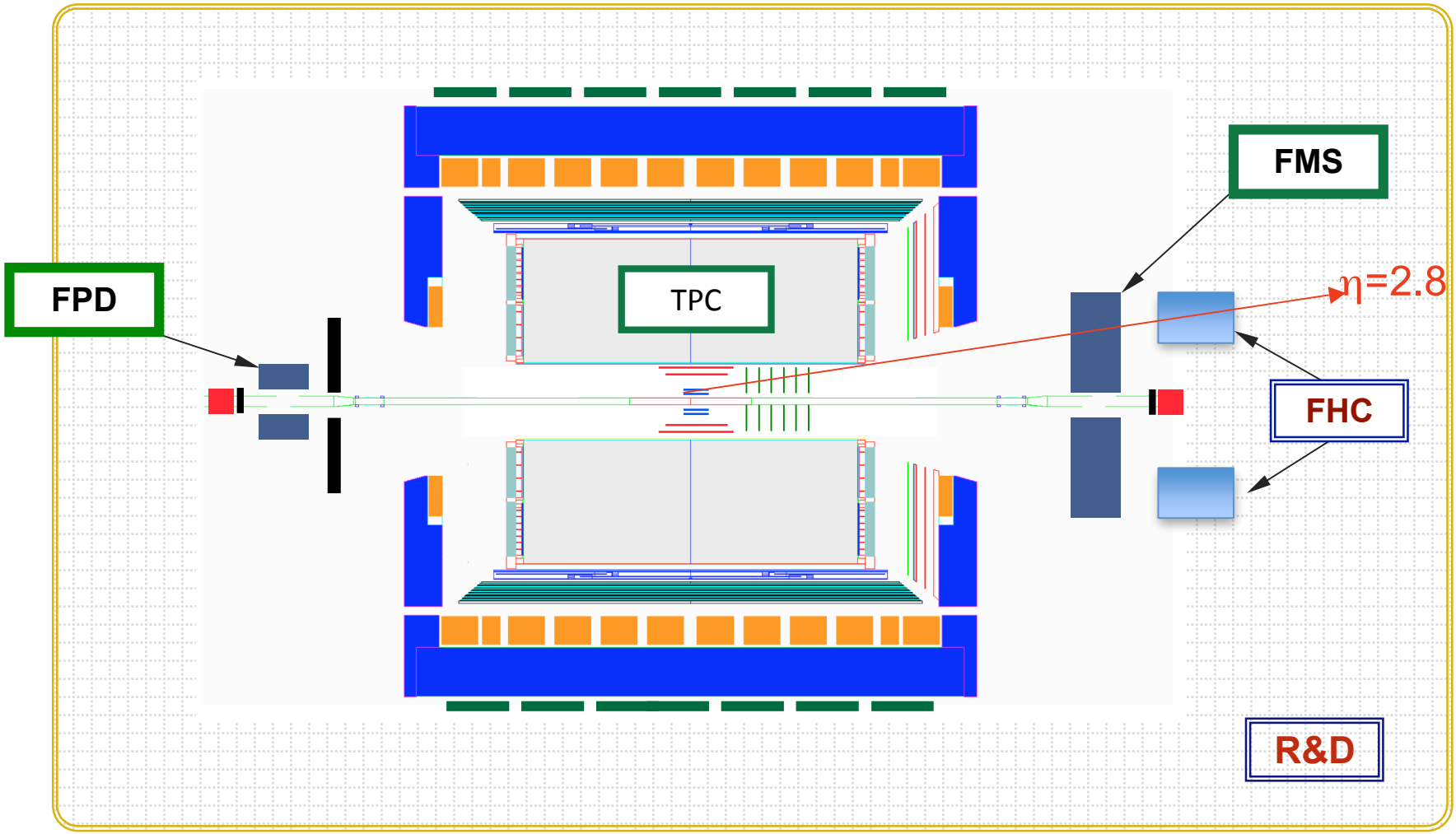
$$\vec{N} = \frac{\vec{p}_b \times \vec{p}_\Lambda}{|\vec{p}_b \times \vec{p}_\Lambda|}$$

D_{NN}: production plane close to hard scattering plane;

- Significant spin transfer was found at large x_F range.
- Similar measurements possible at RHIC?

Outlook II- Forward hyperon physics

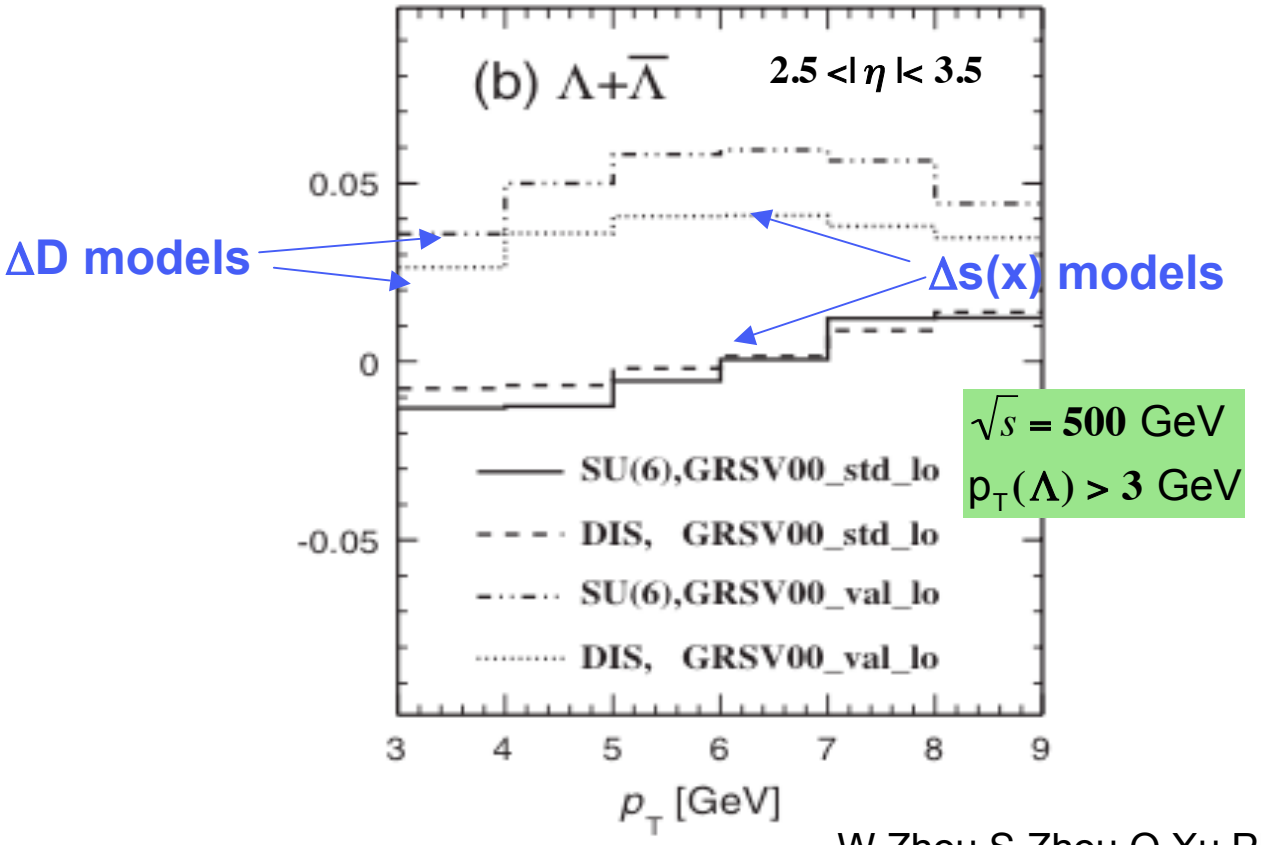
- Addition of Forward Hadron Calorimeter (FHC) at STAR may enable the study of forward Λ physics together with FMS through $\Lambda \rightarrow n\pi^0$ (Br=36%).



Longitudinal spin transfer at forward region

Provide access to pol. p.d.f. and fragmentation functions

$$\Delta\sigma \propto \int \Delta f_a(x_1) \cdot f_b(x_2) \otimes \Delta\hat{\sigma}_{ab->cd} \otimes \Delta D^{\Lambda}(z)$$



-W.Zhou,S.Zhou,Q.Xu,PRD81,057501(2010)

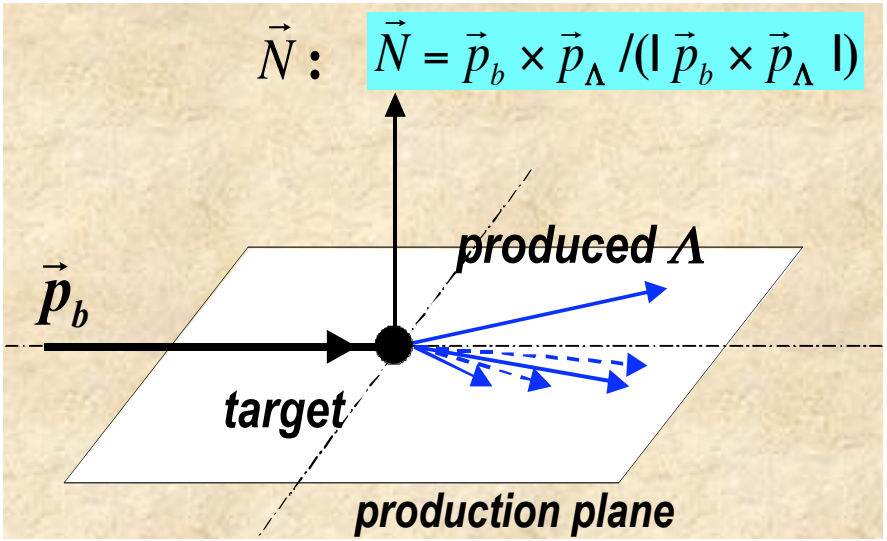
Induced Λ polarization in unpolarized pp

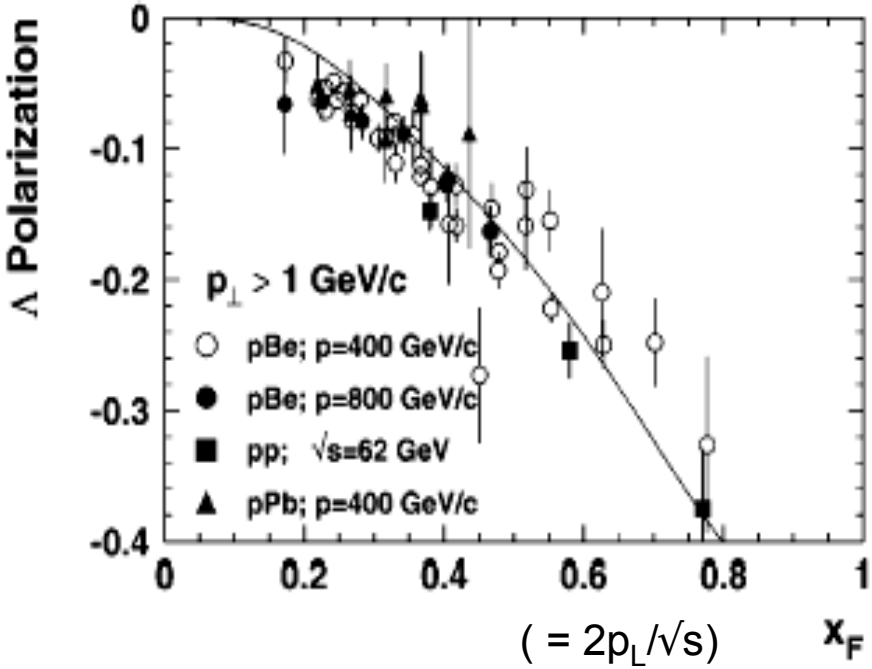
- Large polarization with unpolarized beam p + p → $\Lambda_{\uparrow}$ + X , observed in many experiments.

  -G.Bunce *et al,* PRL36,1113,(1976)

- LO pQCD calculation gives ~0 ($\propto m_q$).

  Kane, Pumplin & Repko, PRL41,1689(1978).





➢ Measurement at higher energy (at RHIC) is expected !

Thank you!