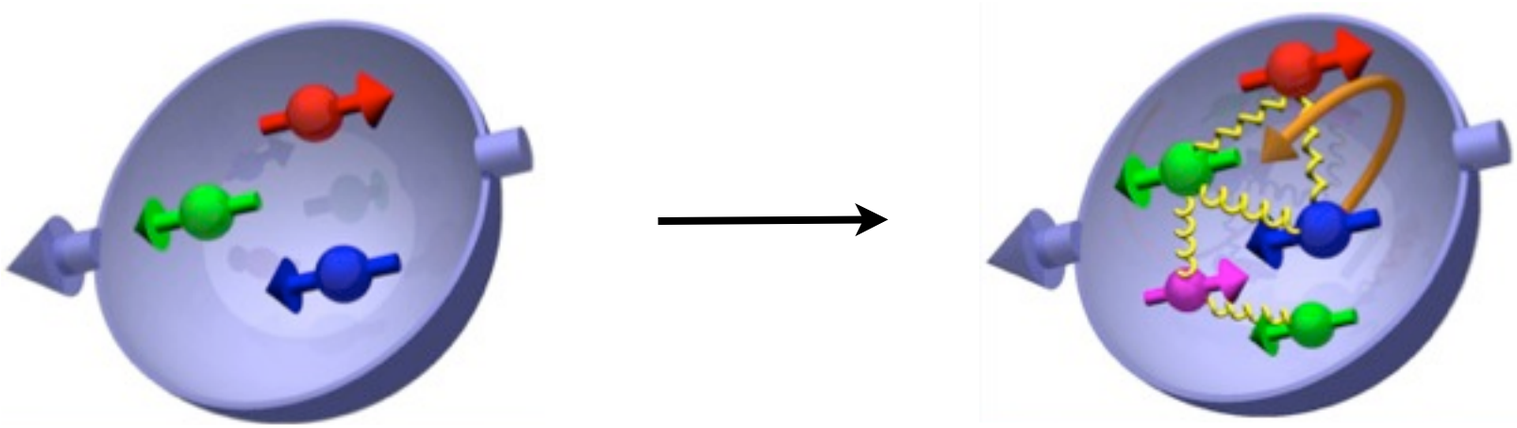
Longitudinal Spin Transfer to Hyperons in Polarized p+p Collisions at $\sqrt{s}$=200 GeV

Ernst Sichtermann (LBNL), *for the* STAR *Collaboration*

Nucleon Spin Puzzle

The surprising *smallness* of the spin dependent part of the inclusive DIS cross section renewed the interest in nucleon spin structure,



EMC (1988): Quark and anti-quark spins combined contribute little to the proton spin, Strange (anti-)quarks are negatively polarized.

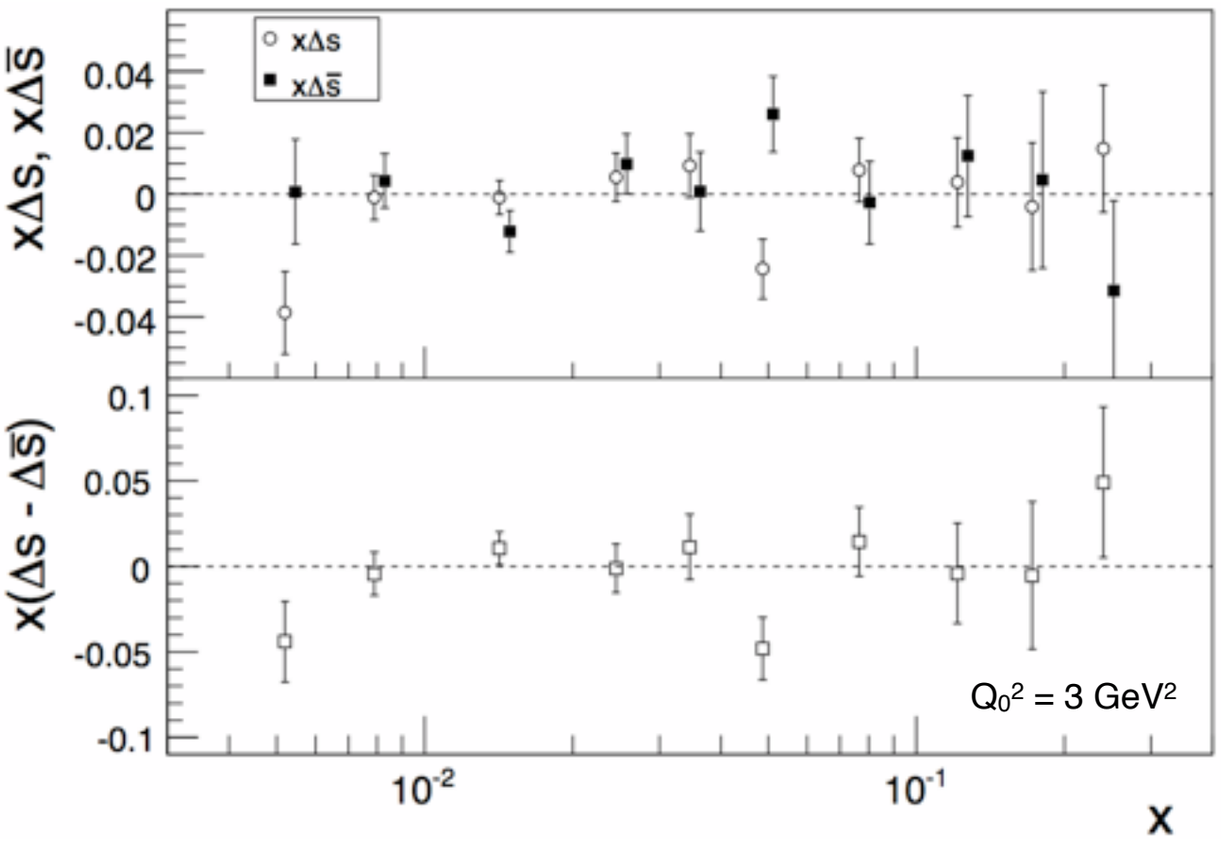
Among the many open questions, what is the role of *strange (anti-)quark spins*, is there a *hyperon spin puzzle?*

What insight(s) can hyperon polarization measurements at RHIC give?

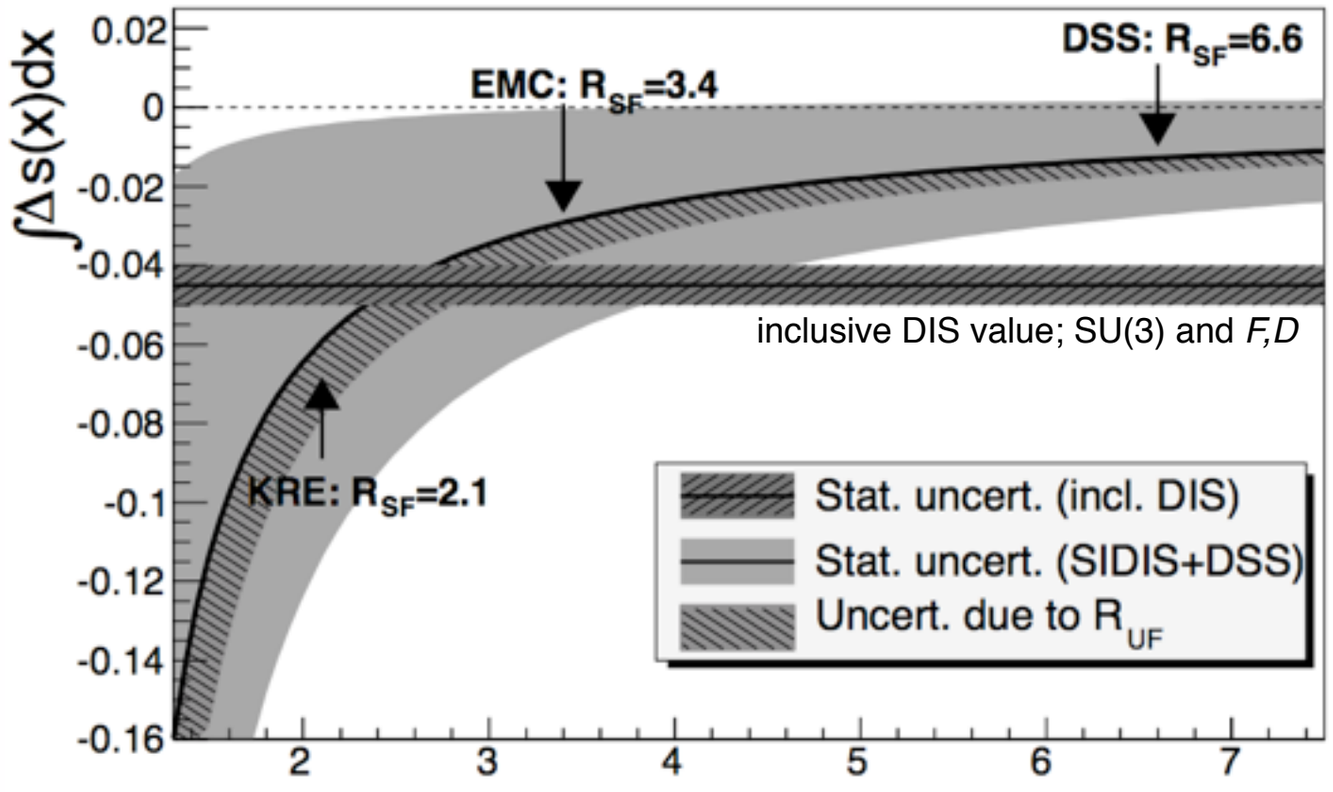
Nucleon Spin Puzzle

Semi-inclusive DIS data with identified Kaons in the final state add precision, and pose yet more questions:

COMPASS, Phys.Lett.B693 (2010) 227



COMPASS, Phys.Lett.B680 (2009) 217



$$R_{SF} = \frac{\int D_{\bar{s}}^{K^+}(z)dz}{\int D_u^{K^+}(z)dz}$$

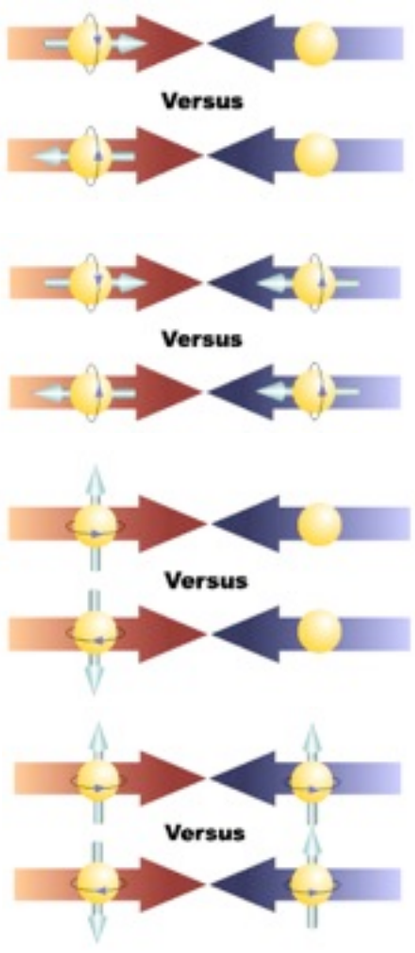
Clear call for complementary measurements,

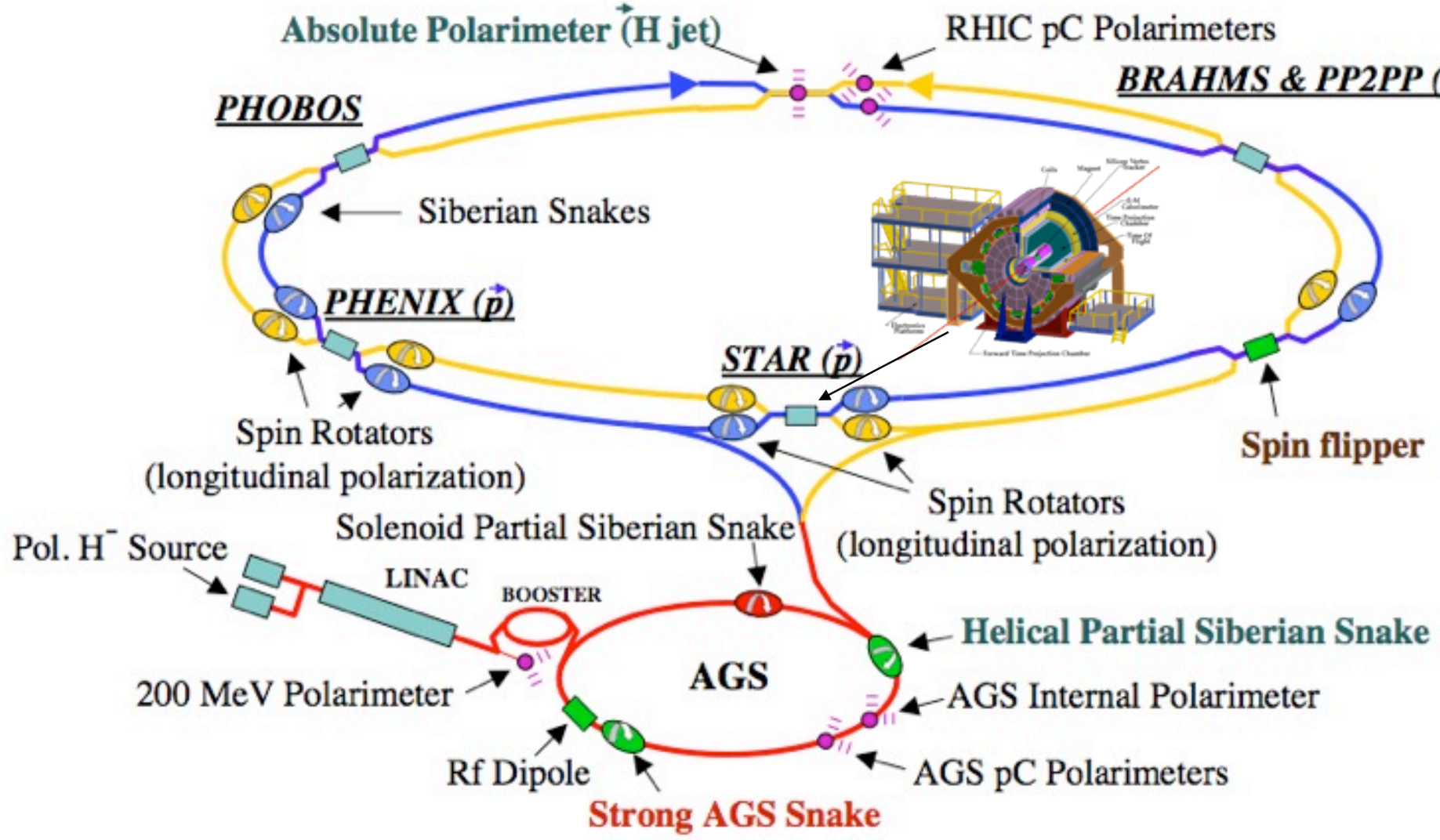
Notoriously hard at RHIC; charm-associated W production (Sudoh, 2005 RHIC-II w.s.),
Try hyperon spin-transfer.

RHIC - Polarized Proton Collider to Study Spin in QCD

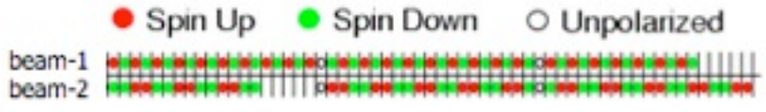
Opportunities to study many facets:

√s = 200 - 500 GeV



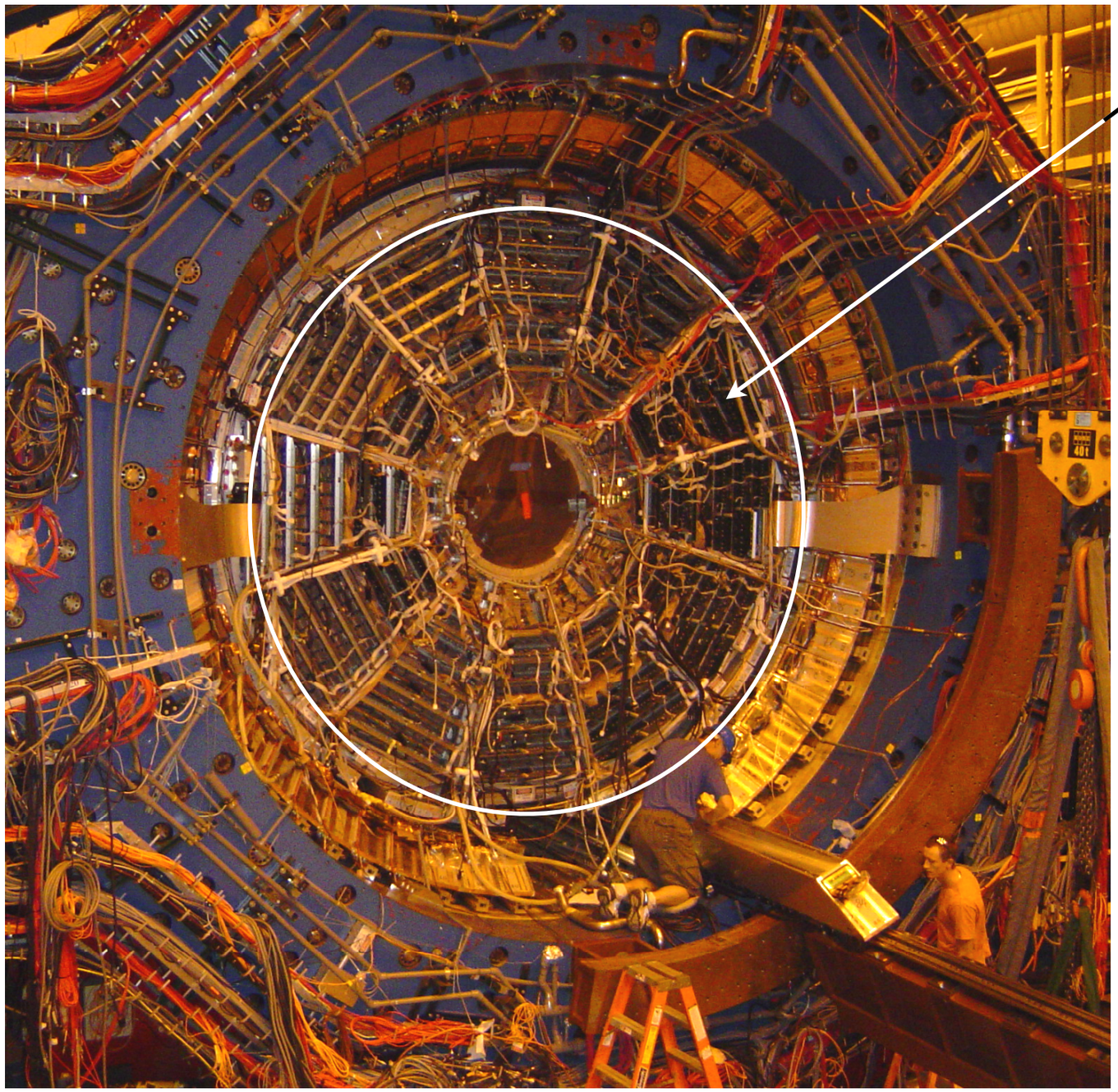


with good systematic controls, e.g.:

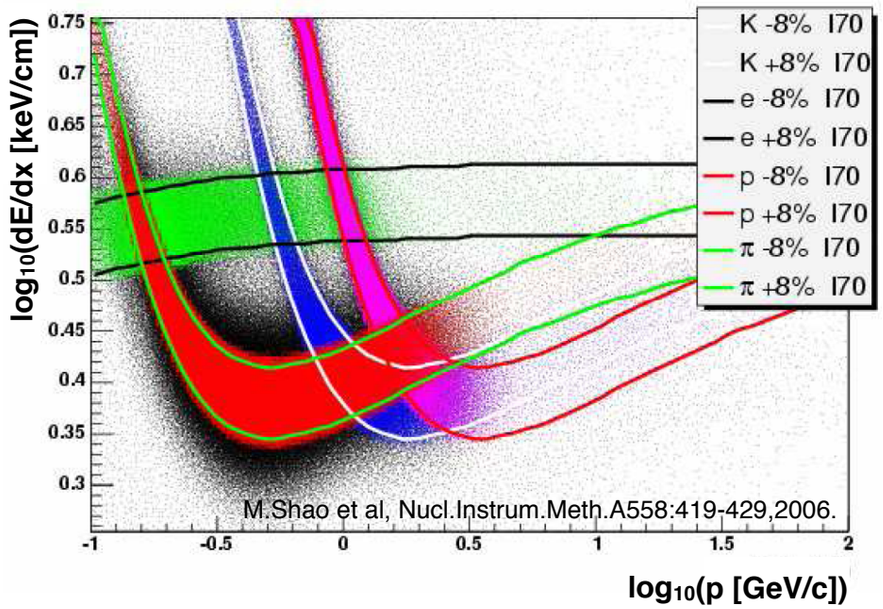


This talk: √s = 200 GeV, ~ 3 pb^{-1}, P_b ~50% (longitudinal), collected in Y2005
~22 pb^{-1}, P_b ~57% (longitudinal), collected in Y2009

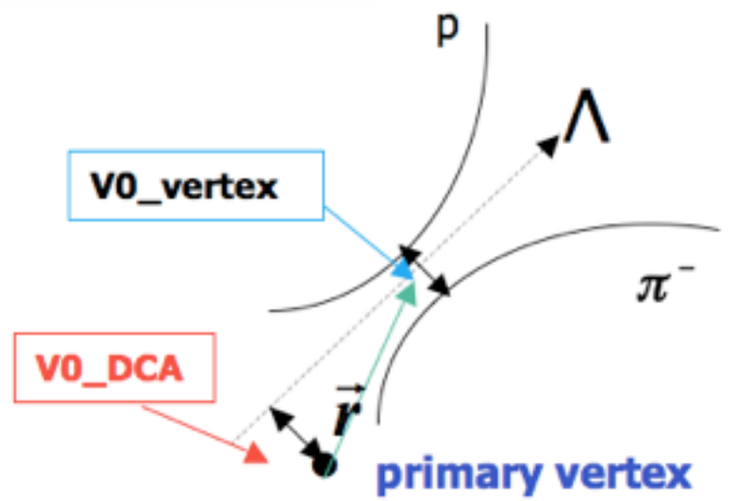
STAR - Solenoid Tracker At RHIC



Time Projection Chamber enables PID,

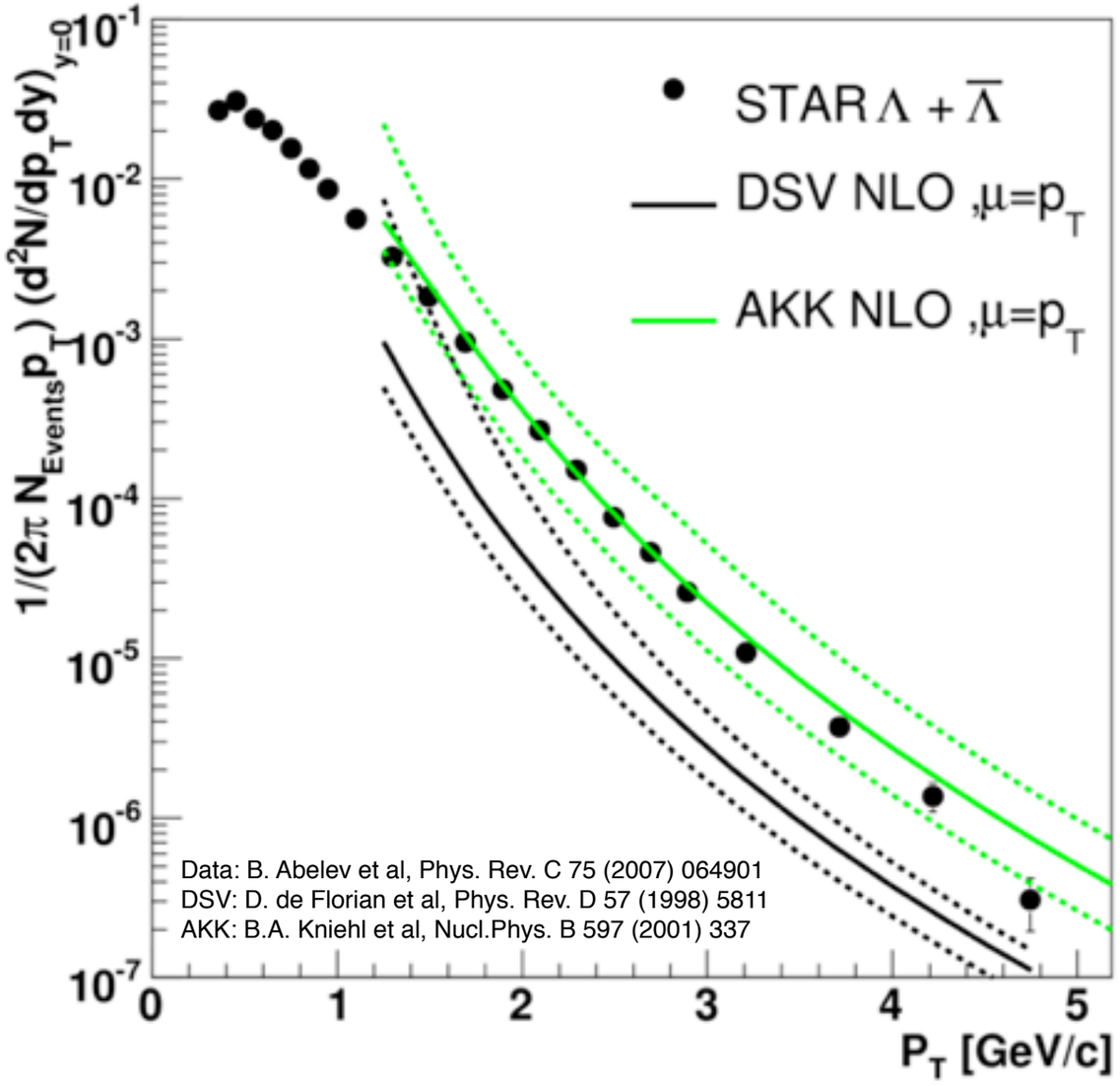


and topological reconstruction,

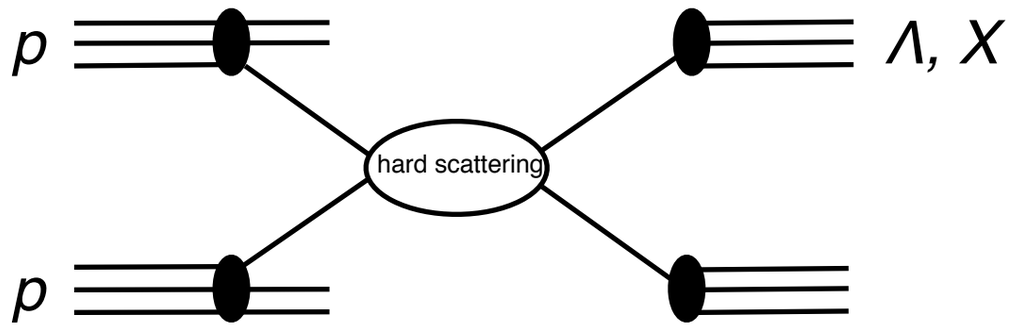


for $|\eta| \leq \sim 1.3$

Differential Cross Section



Factorized framework,



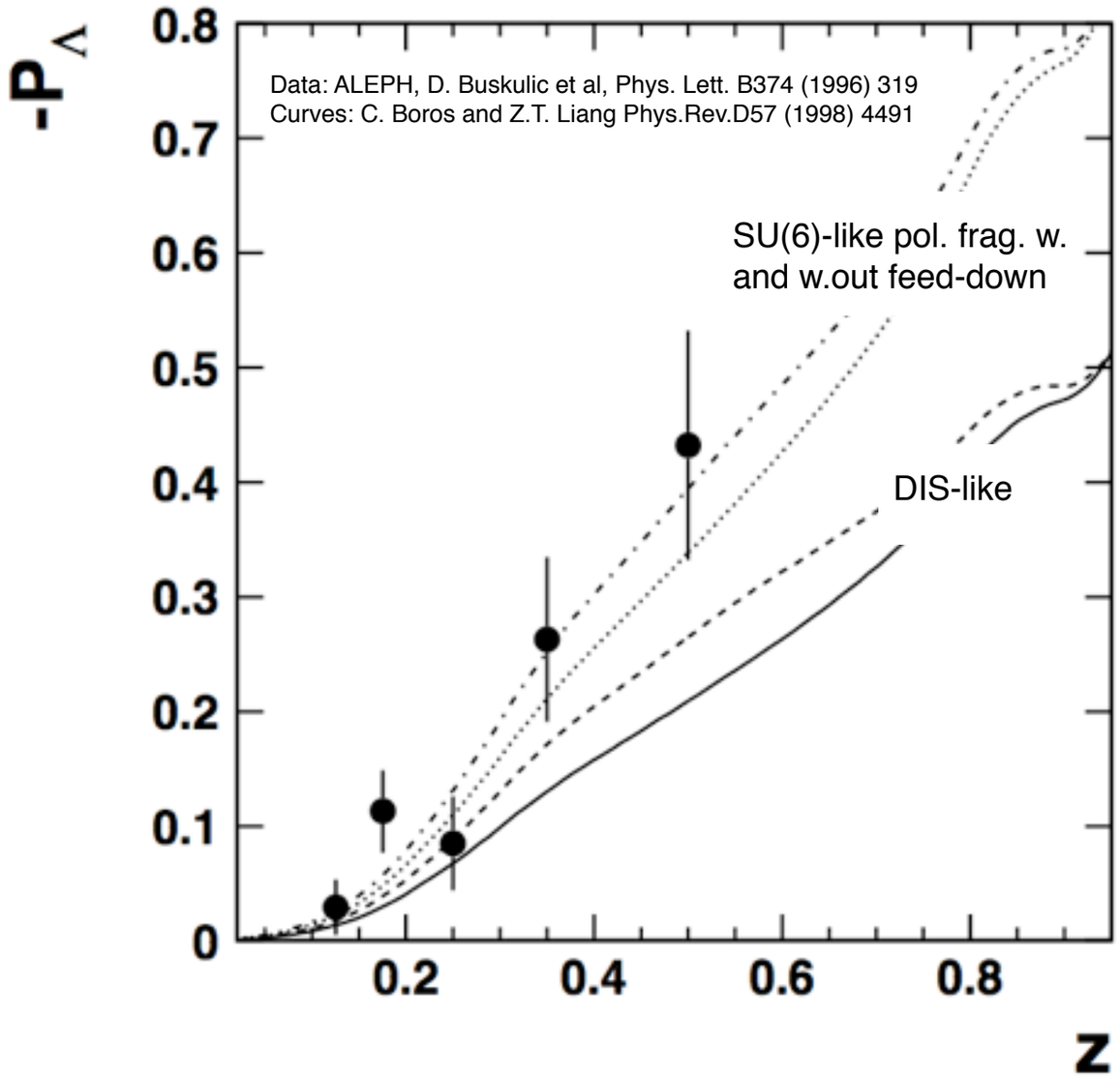
$$f, \Delta f \quad \otimes \quad \hat{\sigma}, \Delta\hat{\sigma} \quad \otimes \quad D, \Delta D$$

enables perturbative description.

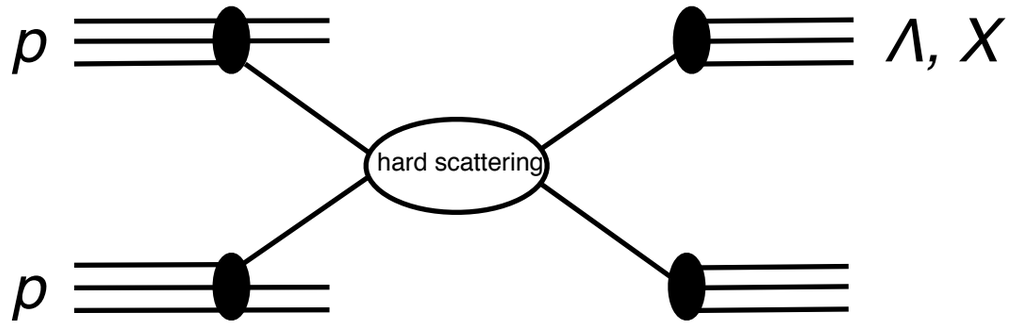
Agreement of STAR data and theory, for a *suitable* choice of *D*, is a necessary condition for interpretation.

Note: The AKK 2008 update again undershoots the STAR data,
Opportunities exist also to extend the data to higher p_T (eventually).

Spin-dependent Fragmentation



Factorized framework,



$$f, \Delta f \quad \otimes \quad \hat{\sigma}, \Delta\hat{\sigma} \quad \otimes \quad D, \Delta D$$

enables perturbative description.

Polarized fragmentation is sizable, especially for large fragmentation momentum-fractions *z*,

Note: data remain scarce,
ΔD is thus often *modeled*.

D_{LL} - Longitudinal Spin Transfer

At RHIC,

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

that is, the longitudinal polarization of the Λ for a specific beam-helicity configuration.

This polarization can be determined in the usual way,

$$\frac{dN}{d\Omega} \propto A(\cos\theta^*)(1 + \alpha P_{\Lambda}\cos\theta^*)$$

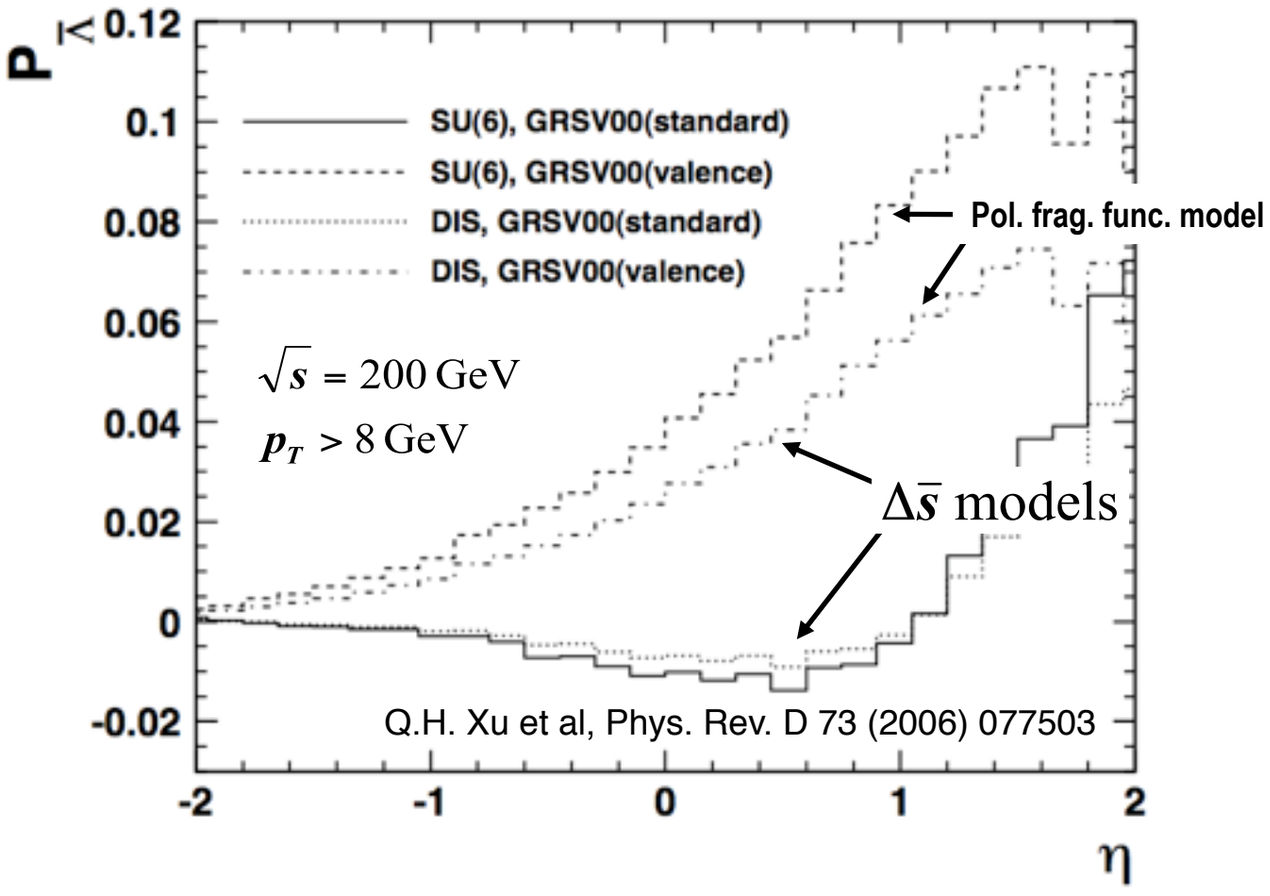
from the angular distribution of the $p + \pi$ decay mode with B.R. ~64%.

Here,

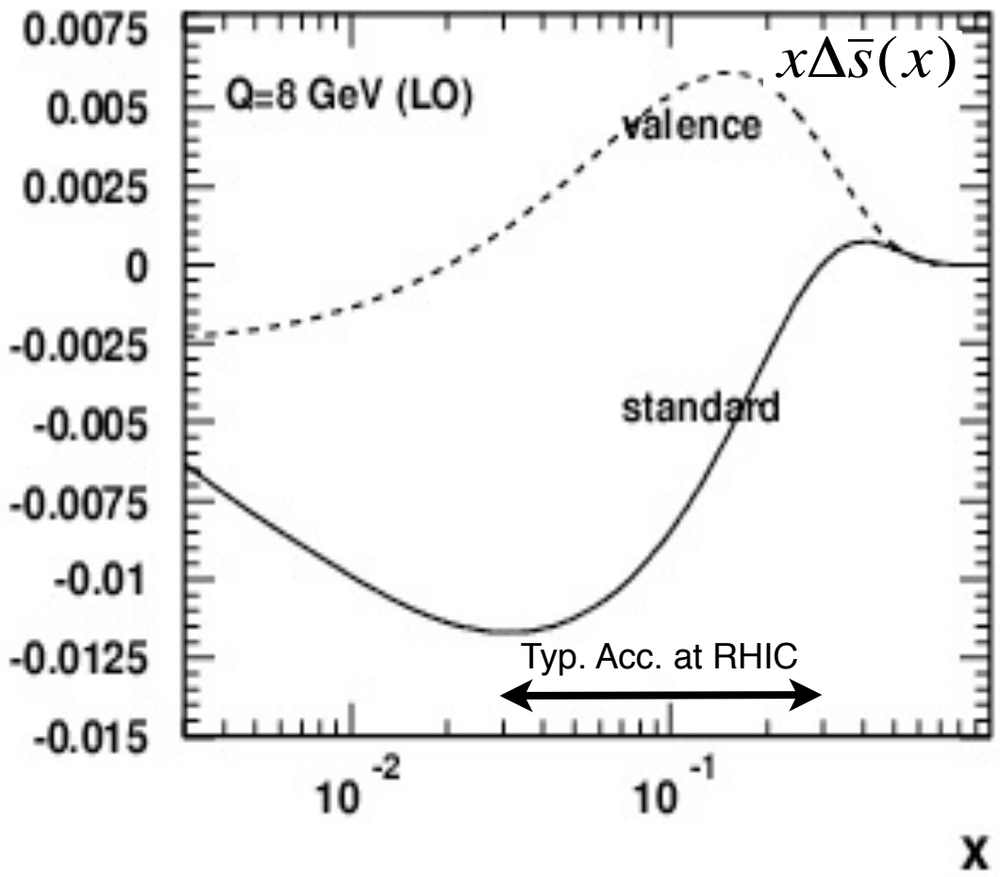
A is the detector acceptance (which can be canceled in a ratio analysis),
θ^* is the angle defined by the Λ momentum and the p direction in the Λ rest frame,
$\alpha = 0.642 \pm 0.013$ is the decay parameter.

D_{LL} - Longitudinal Spin Transfer

Expectations at LO show sensitivity of D_{LL} for the $\overline{\Lambda}$ to the $\overline{s}$ helicity distribution, $\Delta\overline{s}$,



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



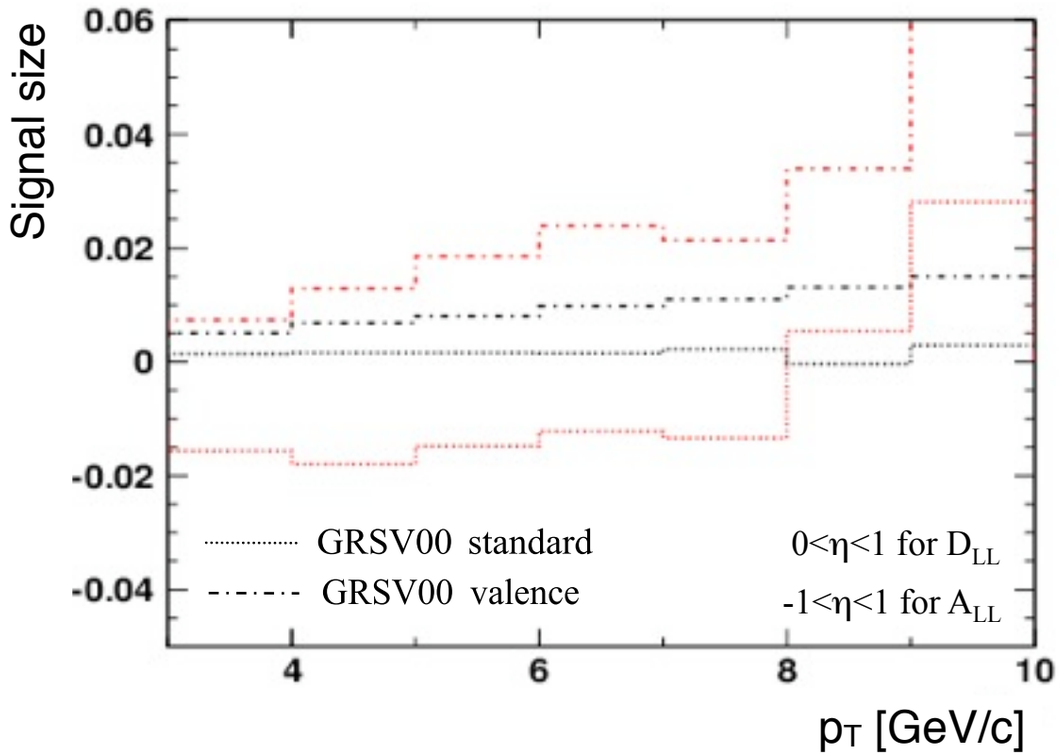
more so than to the fragmentation in this model.

The Λ D_{LL} is less sensitive to Δs, partly due to larger *u* and *d* quark fragmentation contributions.

Promising measurement: neither the role of (anti-)strange quarks nor polarized fragmentation is well known/understood - effects are potentially large enough to be observed.

For the Spin-Aficionados - Measure D_{LL} or A_{LL}?

The same expectations versus p_T as D_{LL} and A_{LL}:



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

$$A_{LL} \equiv \frac{\sigma_{p^+p^+\to\Lambda X} - \sigma_{p^+p^-\to\Lambda X}}{\sigma_{p^+p^+\to\Lambda X} + \sigma_{p^+p^-\to\Lambda X}}$$

\+ D_{LL} expected sensitivity is ~4 larger,

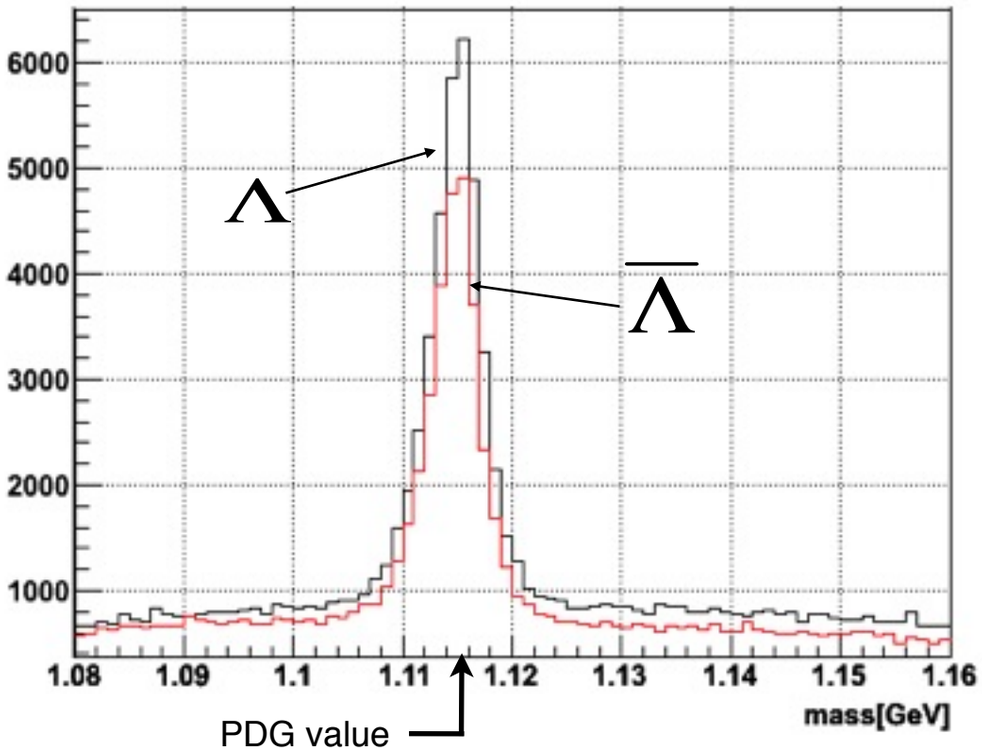
\- D_{LL} analysis requires more selections than for A_{LL}, i.e. loose some statistics,

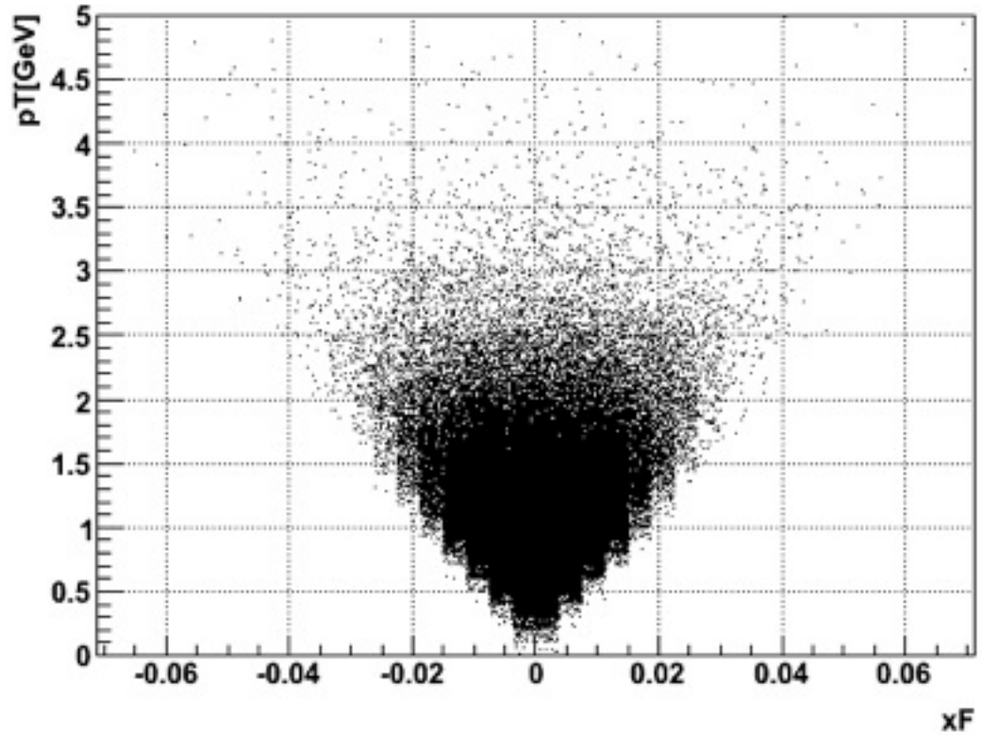
\+ D_{LL} is a single beam-spin measurement, analyzing power of the $p+\pi$ decay mode is relatively large.

Net advantage owing to the (anti-)Λ spin being carried mostly by the (anti-)s quark spin.

STAR Initial Data - 2005

~3.10^6 *minimum bias* events (beam-collision triggered, band-width limited),





~ 30.10^3 Λ candidates,

~ 25.10^3 $\overline{\Lambda}$

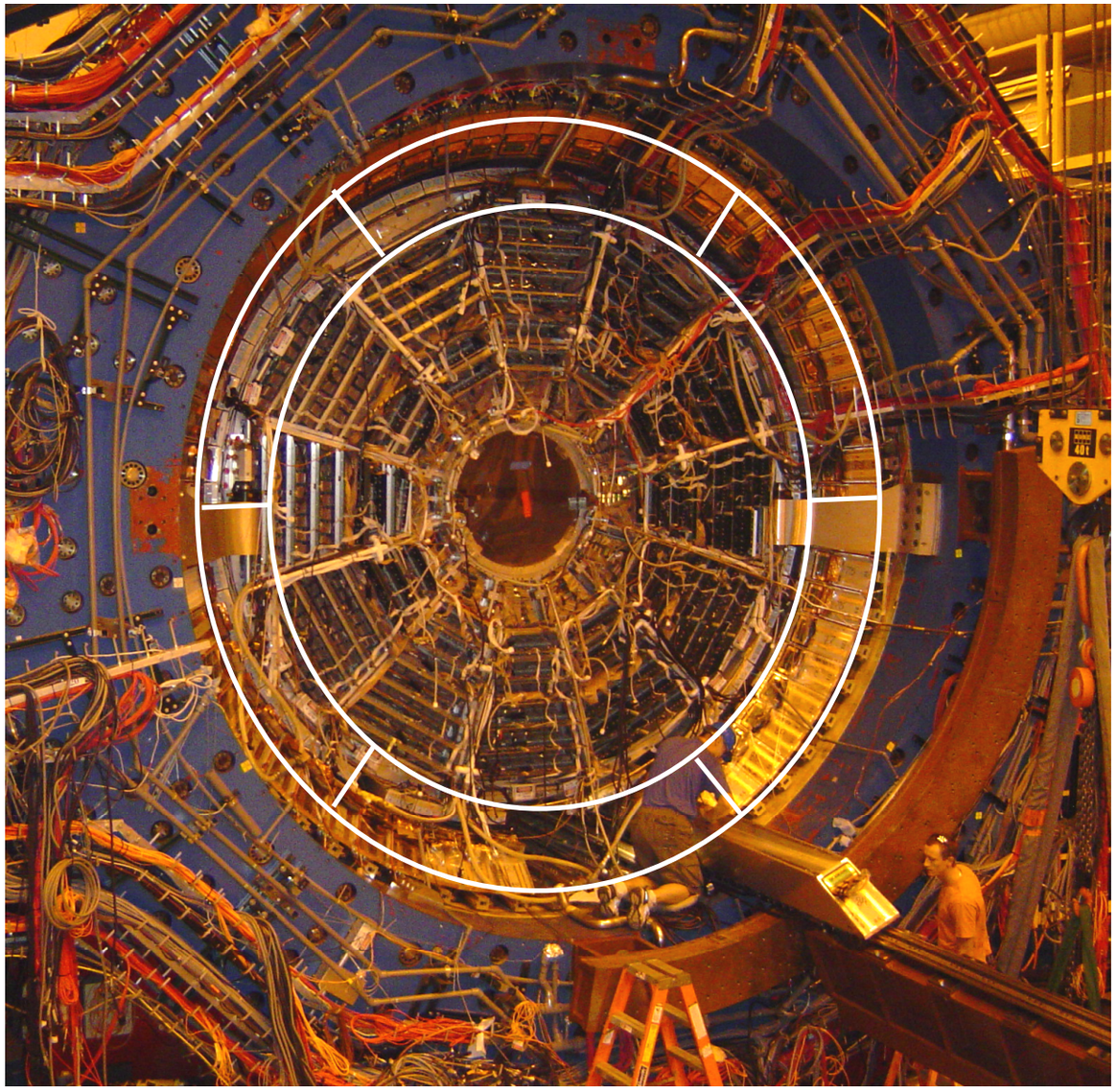
$\langle p_T \rangle \approx 1.3$ GeV/c

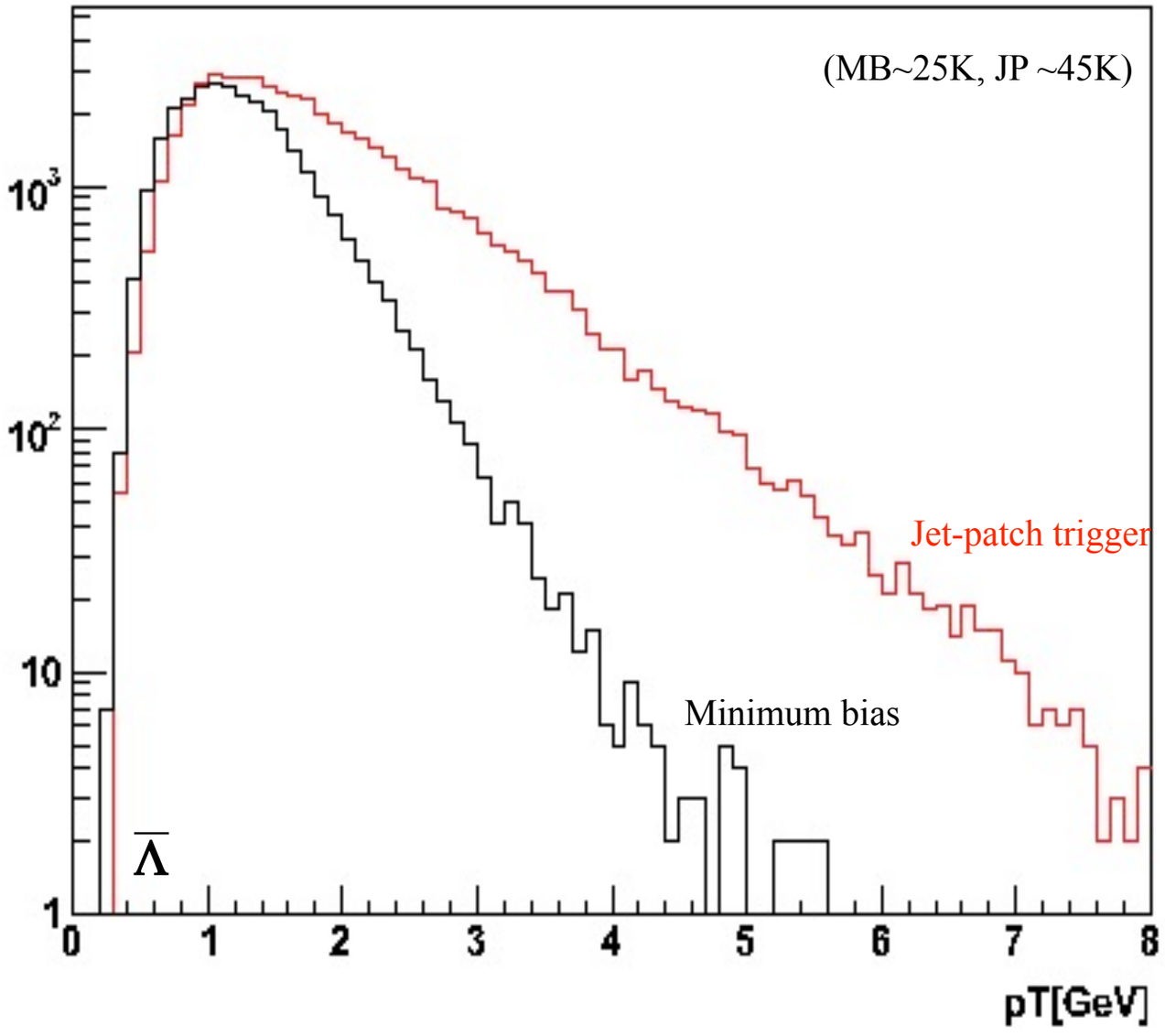
$\langle |x_F| \rangle \approx 0.008$

Take away: analyze data triggered on hard-processes...

STAR Triggered Data - 2005

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





Although this is <u>not</u> a “Hyperon Trigger”, it did record a (biased) sample of Λ and $\overline{\Lambda}$ candidates with considerably higher p_T; focus on $\overline{\Lambda}$ here.

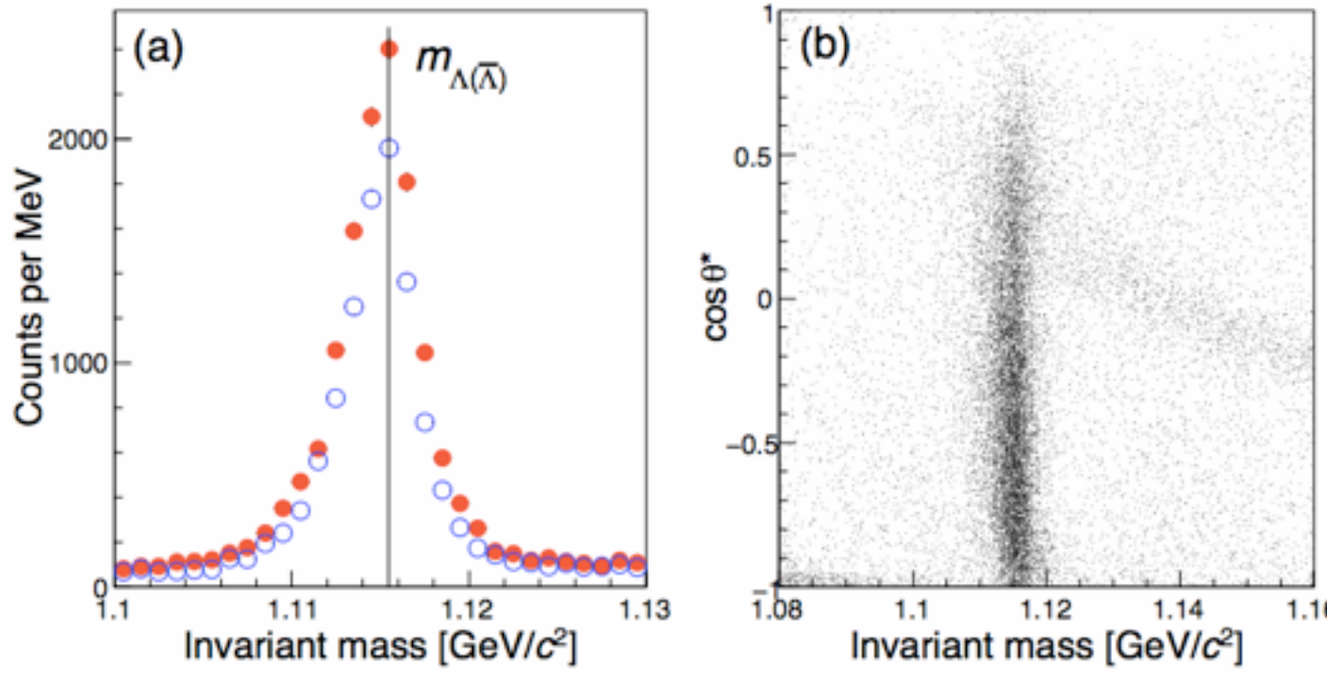
Analysis Characteristics

Uses the $\Lambda \rightarrow p + \pi$ weak decay mode,

$$\frac{dN}{d\Omega} \propto A(\cos\theta^*)(1 + \alpha P_\Lambda \cos\theta^*)$$

Restrict $\cos\theta^*$ to eliminate K^0_S background
caused by misidentified π,
(refined in later analyses).

STAR, Phys.Rev.D80 (2009) 111102



Use beam spin configurations and symmetries to (largely) cancel *A(cosθ*)* and extract,

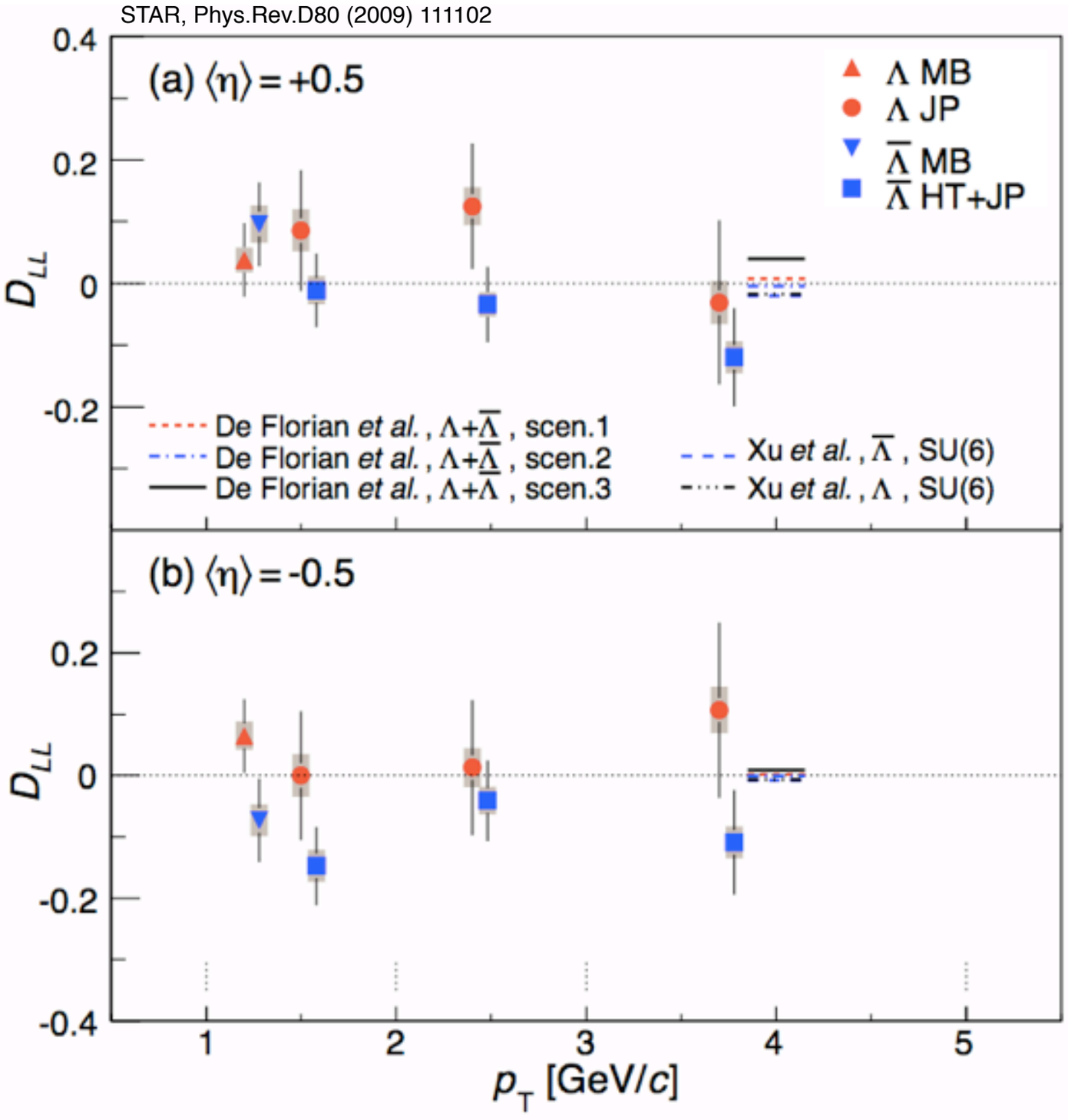
$$D^{\Lambda}_{LL} = \frac{1}{\alpha \cdot P_b \cdot \langle \cos\theta^* \rangle} \cdot \frac{N^+_\Lambda - N^-_\Lambda}{N^+_\Lambda + N^-_\Lambda}$$

in small *cosθ** intervals. Here, $N^+_\Lambda = N^{++}_\Lambda \cdot \frac{\mathcal{L}^{--}}{\mathcal{L}^{++}} + N^{+-}_\Lambda \cdot \frac{\mathcal{L}^{--}}{\mathcal{L}^{+-}}$ and $N^-_\Lambda = N^{-+}_\Lambda \cdot \frac{\mathcal{L}^{--}}{\mathcal{L}^{-+}} + N^{--}_\Lambda$

The luminosity ratios are measured at STAR and beam polarization in RHIC.

STAR Initial Results - 2005

STAR, Phys.Rev.D80 (2009) 111102



D_{LL} proof-of-concept from RHIC,

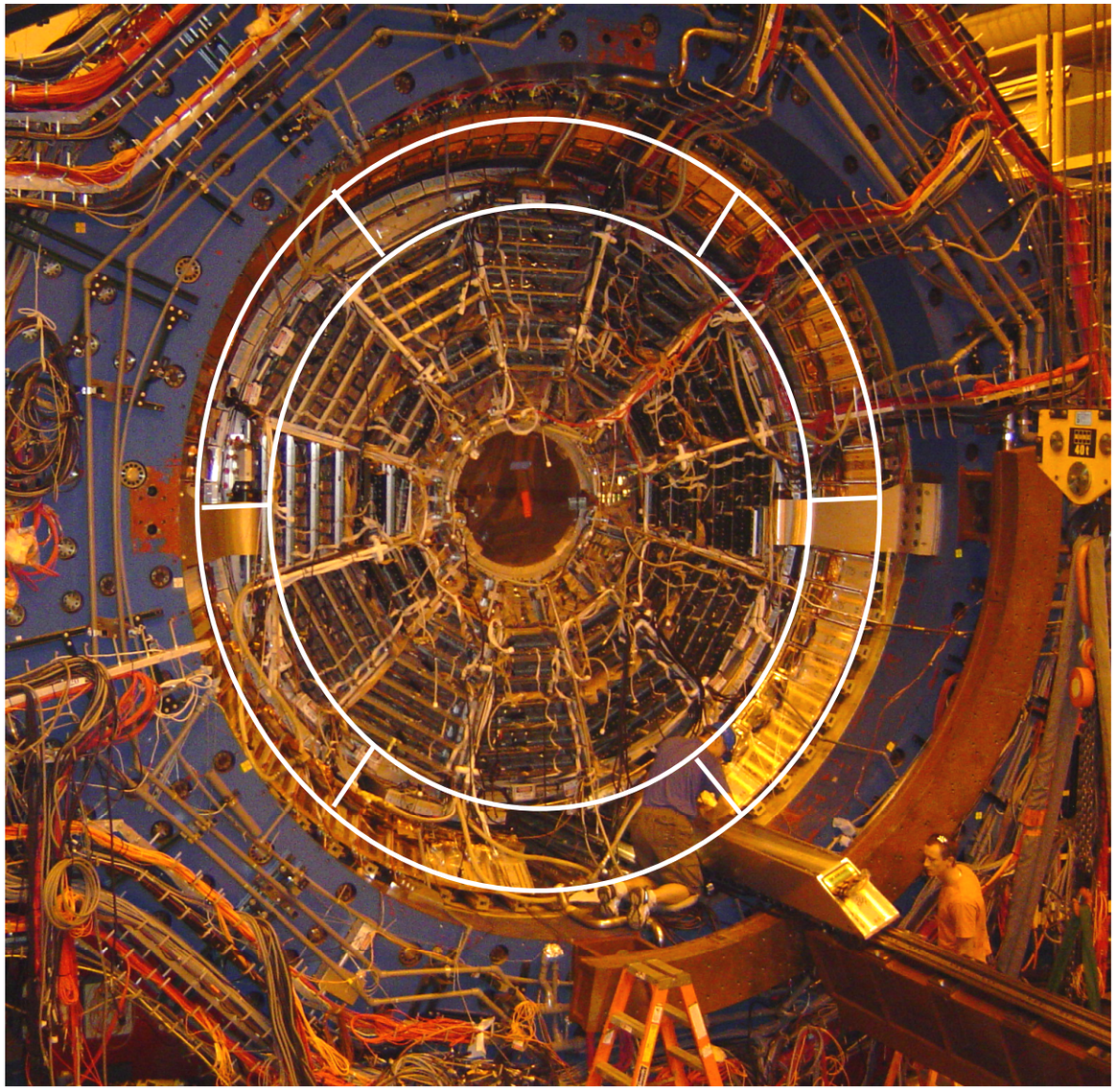
Statistics limited,

Systematics under control,

$\langle p_T \rangle \approx 1.3$ GeV/c, $\langle |x_F| \rangle \approx 0.008$

Take away: need better precision and higher p_T

STAR - 2009



Full-coverage Barrel EMCal,

Trigger improvement,

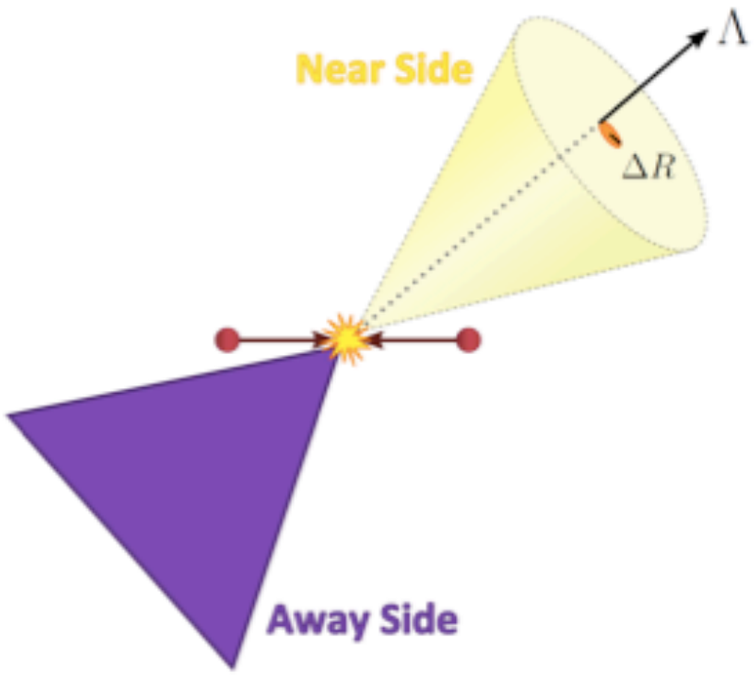
DAQ-1000,

RHIC luminosity and polarization, even though the run was cut short and FoM remained a factor below our initial projections,

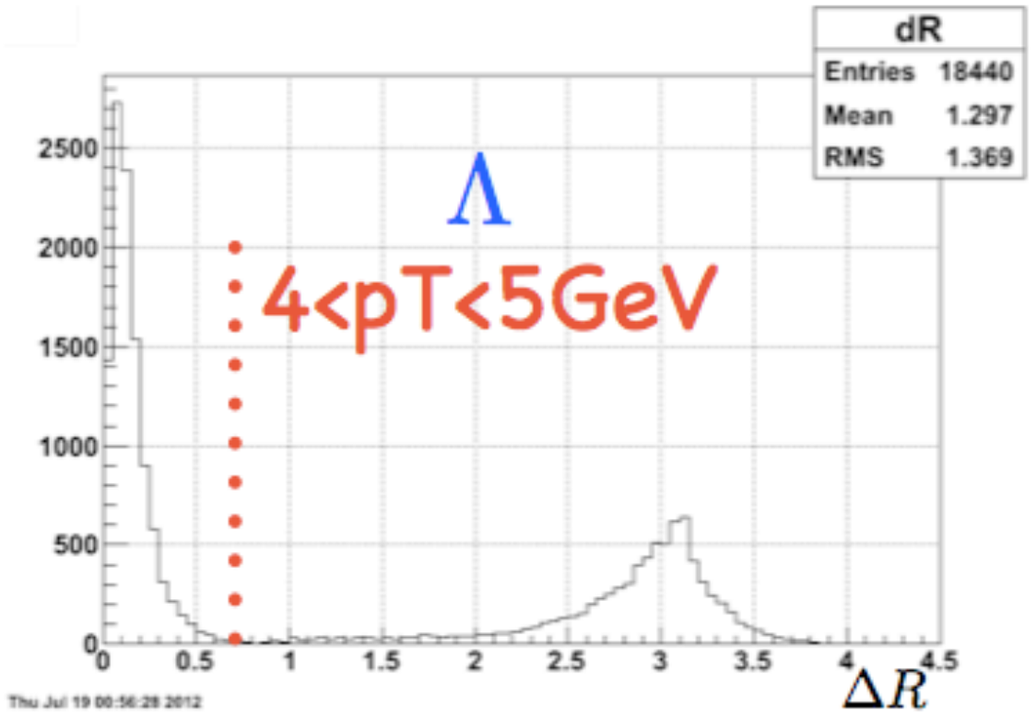
Good reasons for continued 200 GeV!

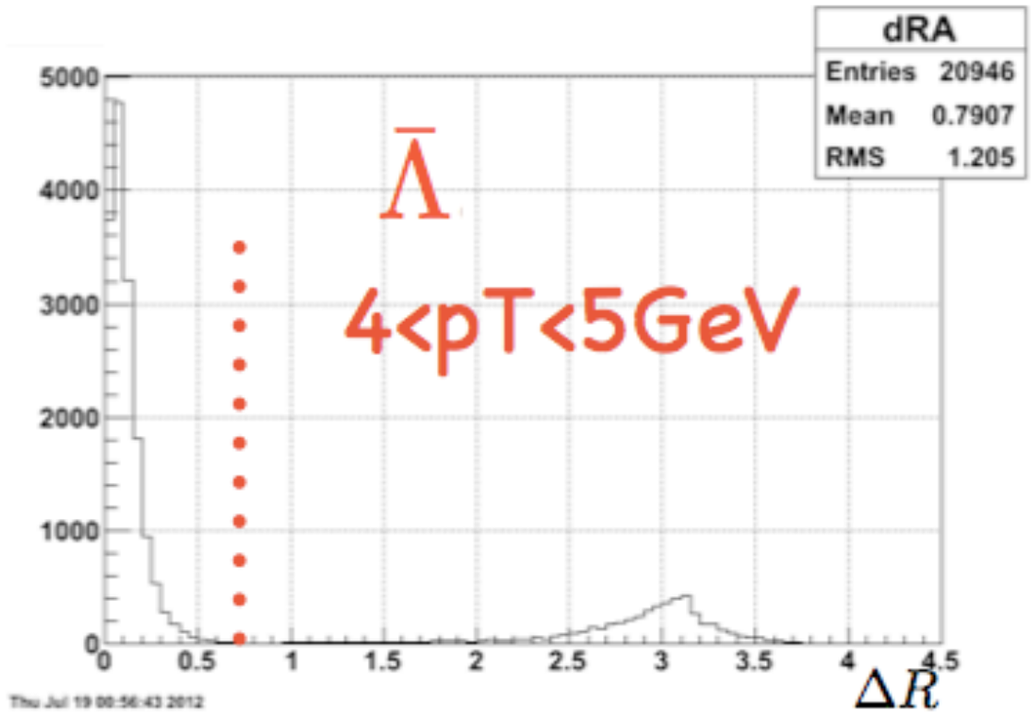
R. Cendejas (UCLA/LBNL) PhD Thesis 2012,
J. Deng (Shandong U.)

STAR - 2009



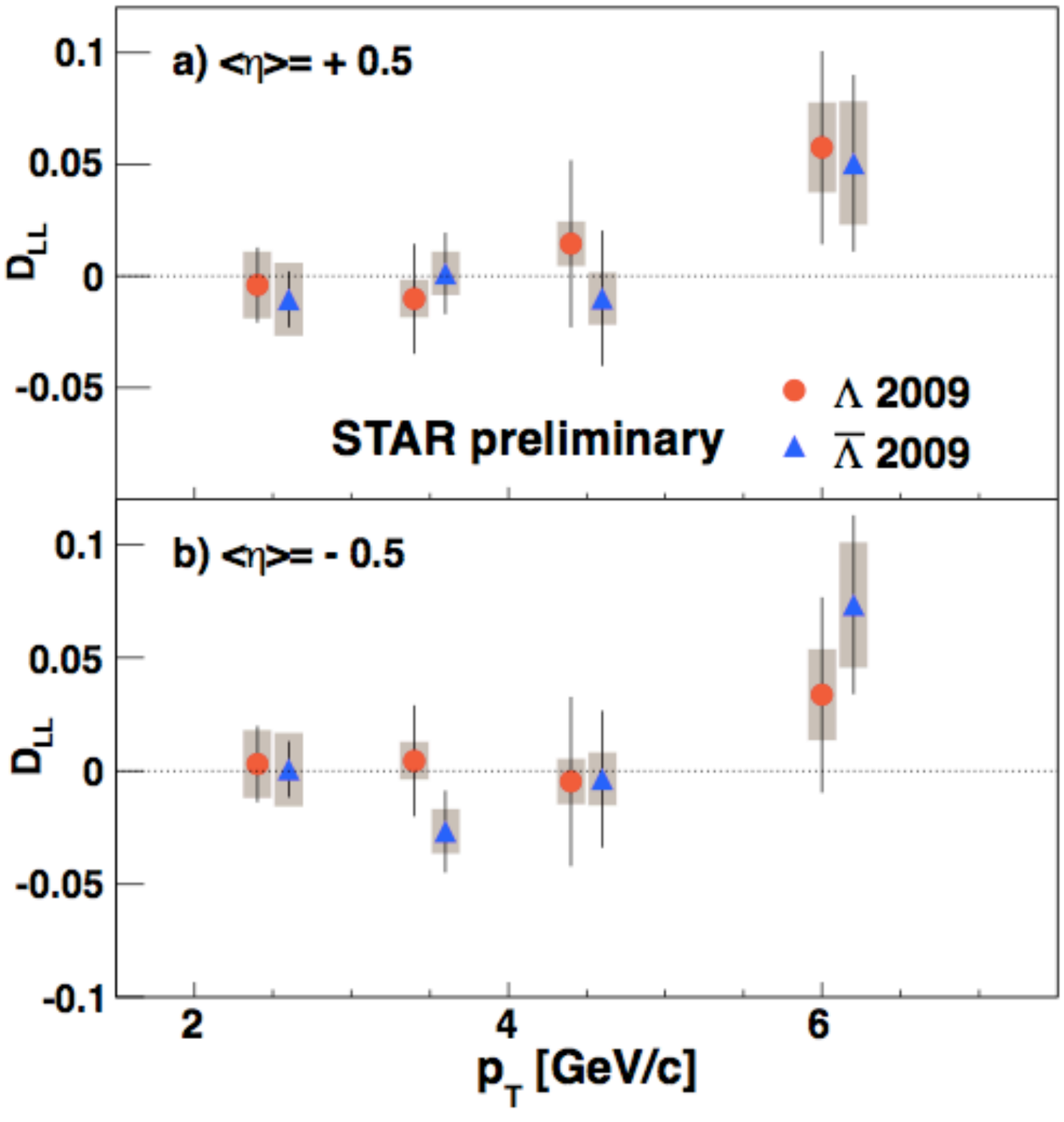
$$\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2}, \Delta R < 0.7$$
$$\Delta\phi = \phi_\Lambda - \phi_{jet}$$
$$\Delta\eta = \eta_\Lambda - \eta_{jet}$$





Decision to focus, at least initially, on Hyperons that are part of the near-side (trigger) jet.

STAR - 2009

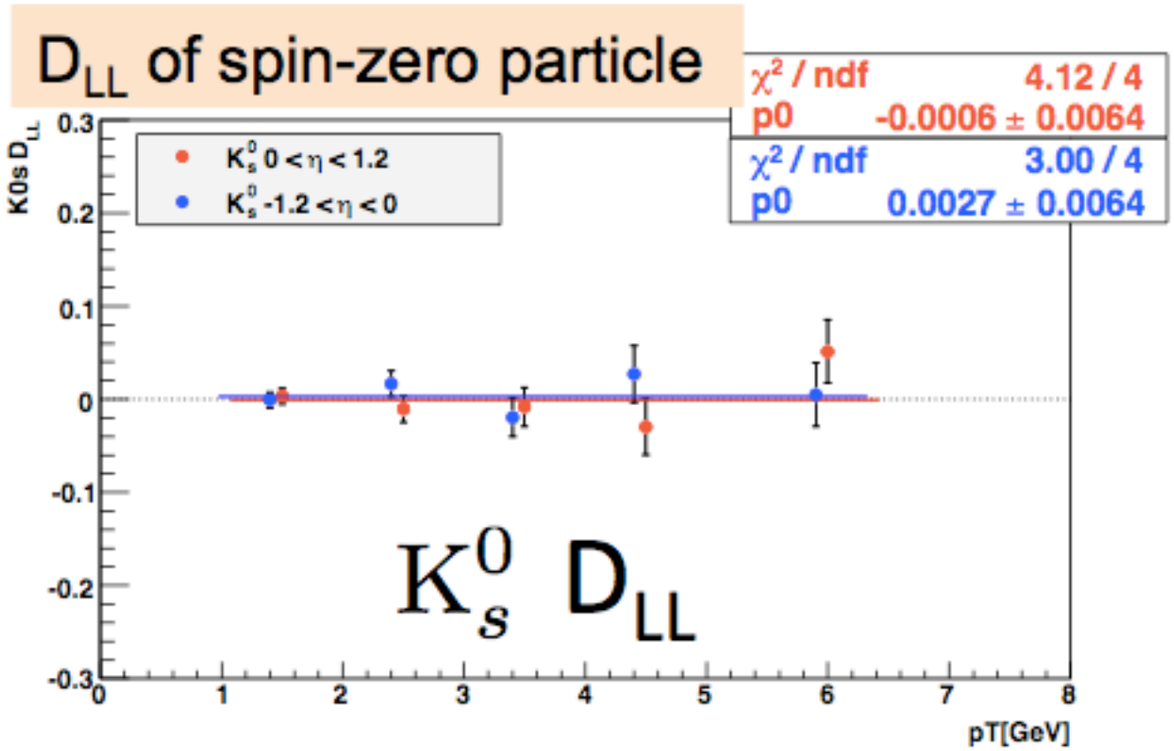


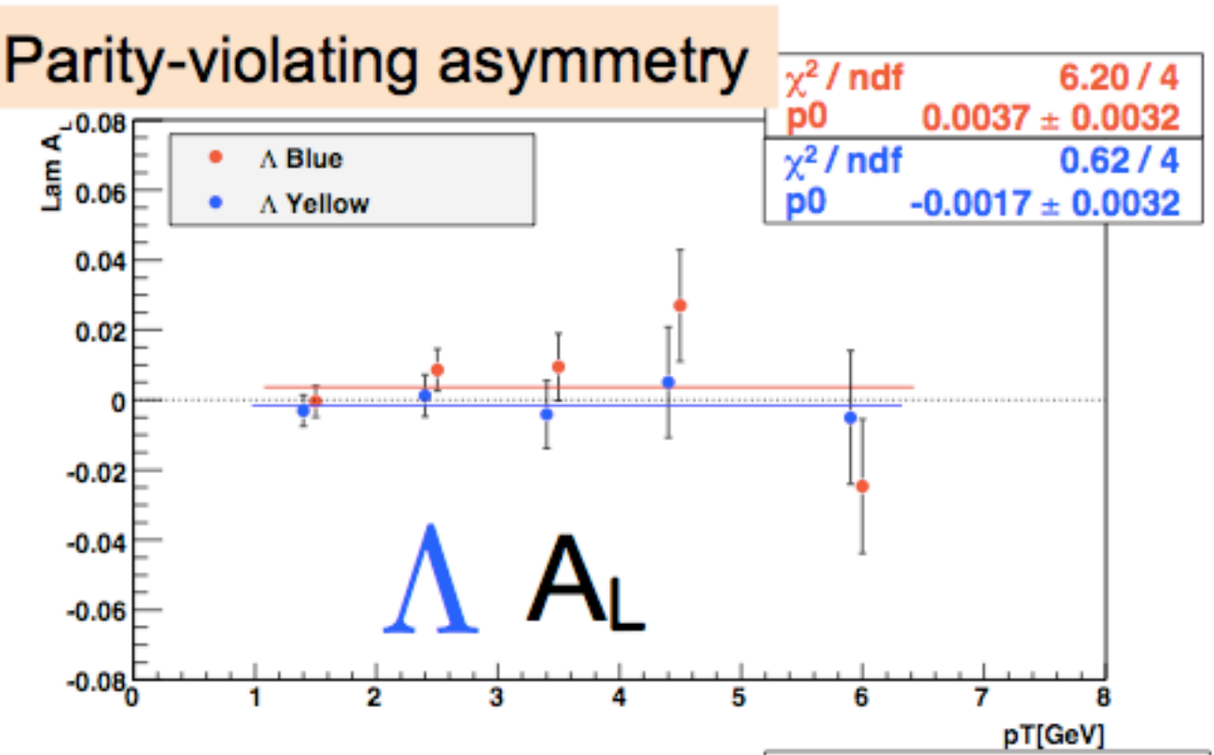
Systematic uncertainties vary from 0.01 to 0.03 for each point which include:

- 4.7% Beam polarization
- 2.0% Decay parameter
- 1.9% Residual trans. pol.
- 5×10^{-3} Relative luminosity
- $<6\times10^{-3}$ Residual background.
- ≤0.03 Trigger bias, increases with p_T.
- ≤0.01 Pile-up, decreases with p_T.

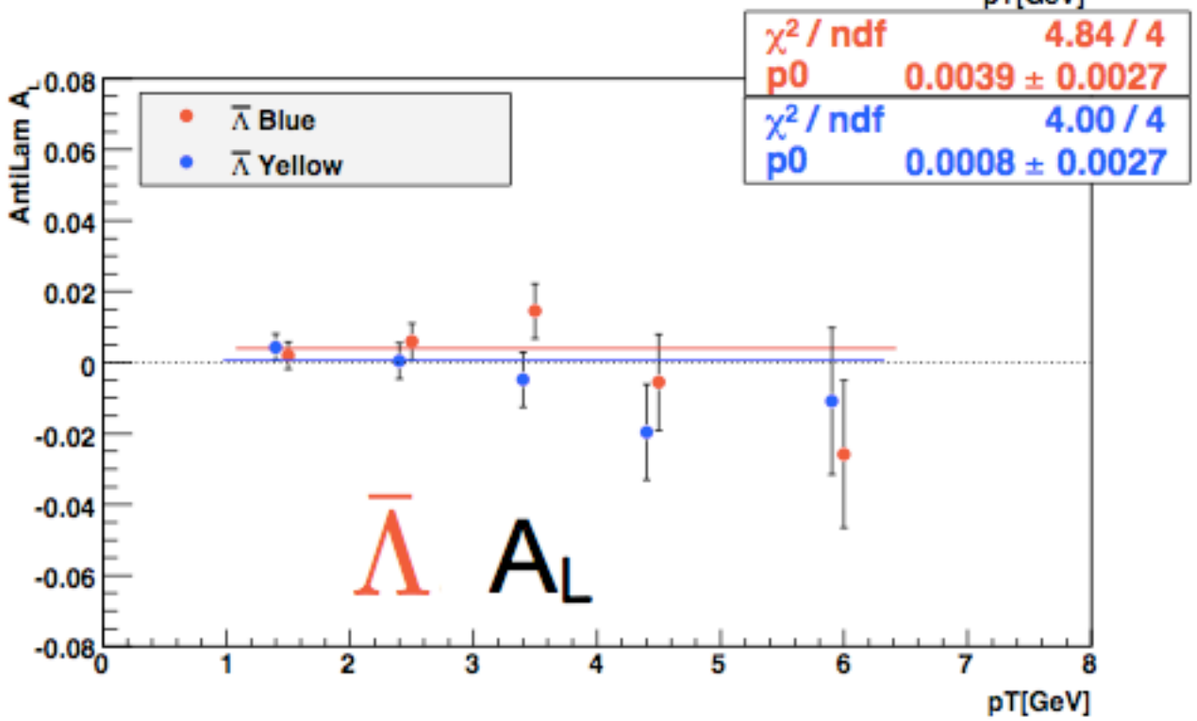
J. Deng for the collaboration, SPIN 2012
R. Cendejas for the collaboration, DNP 2012

Some Cross-Checks

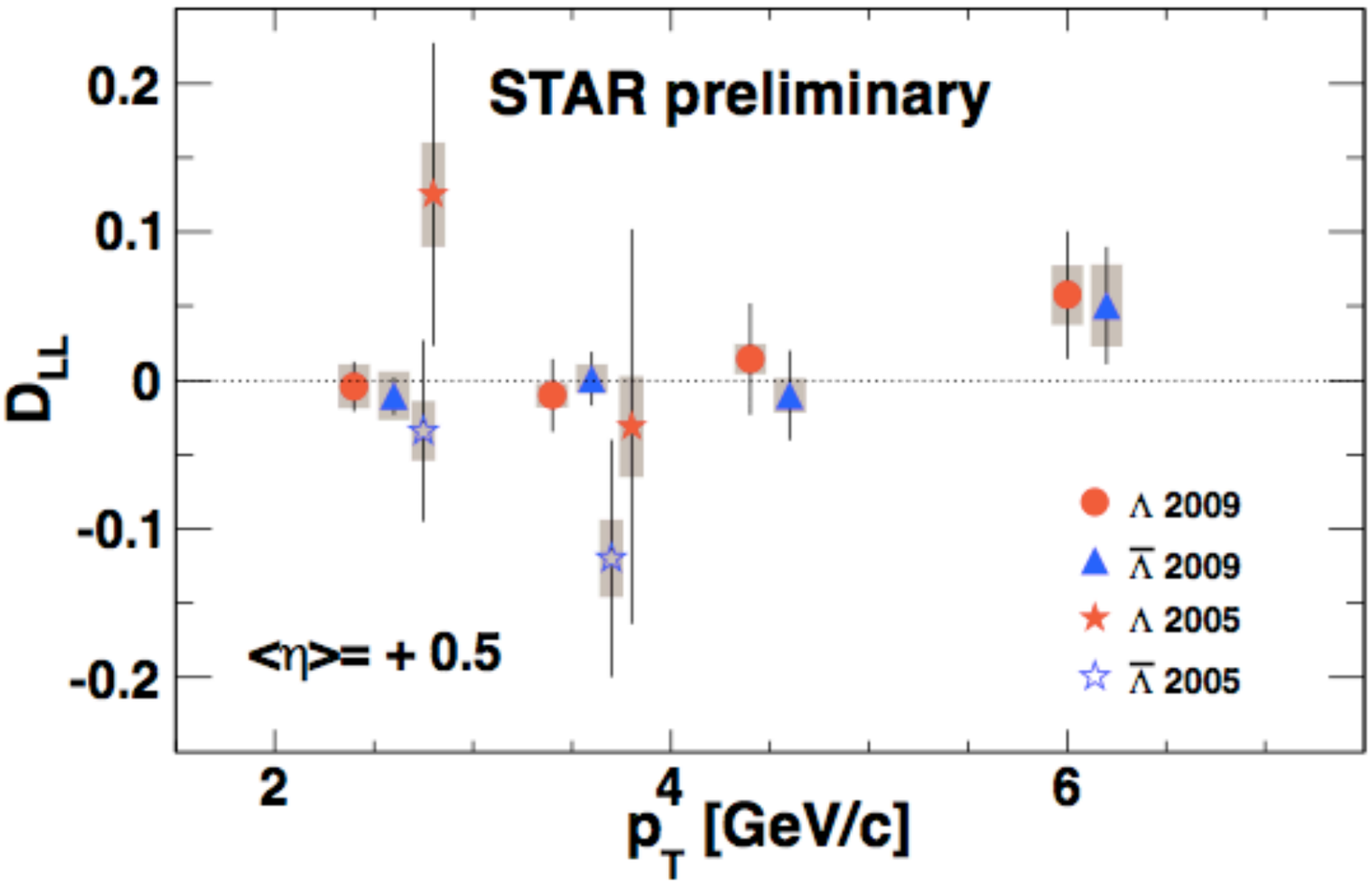




Measurements with the expected null-results.



Compared to Published Results



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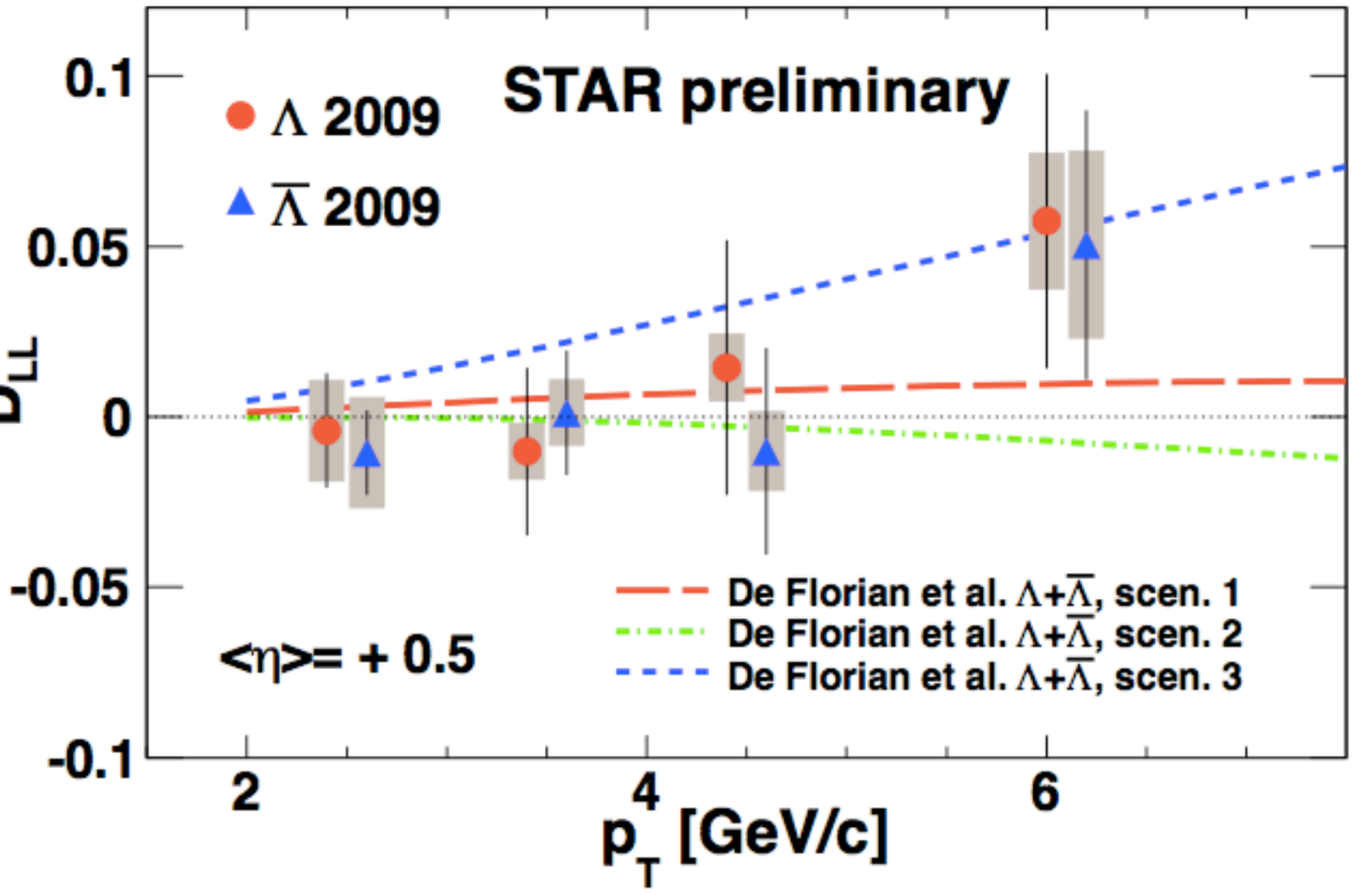
J. Deng for the collaboration, SPIN 2012
R. Cendejas for the collaboration, DNP 2012

D_{LL} out to p_T ~5.9 GeV with ~4% precision (2009), c.f. ~8% at 3.7 GeV published (2005).

Compared to Expectations - I



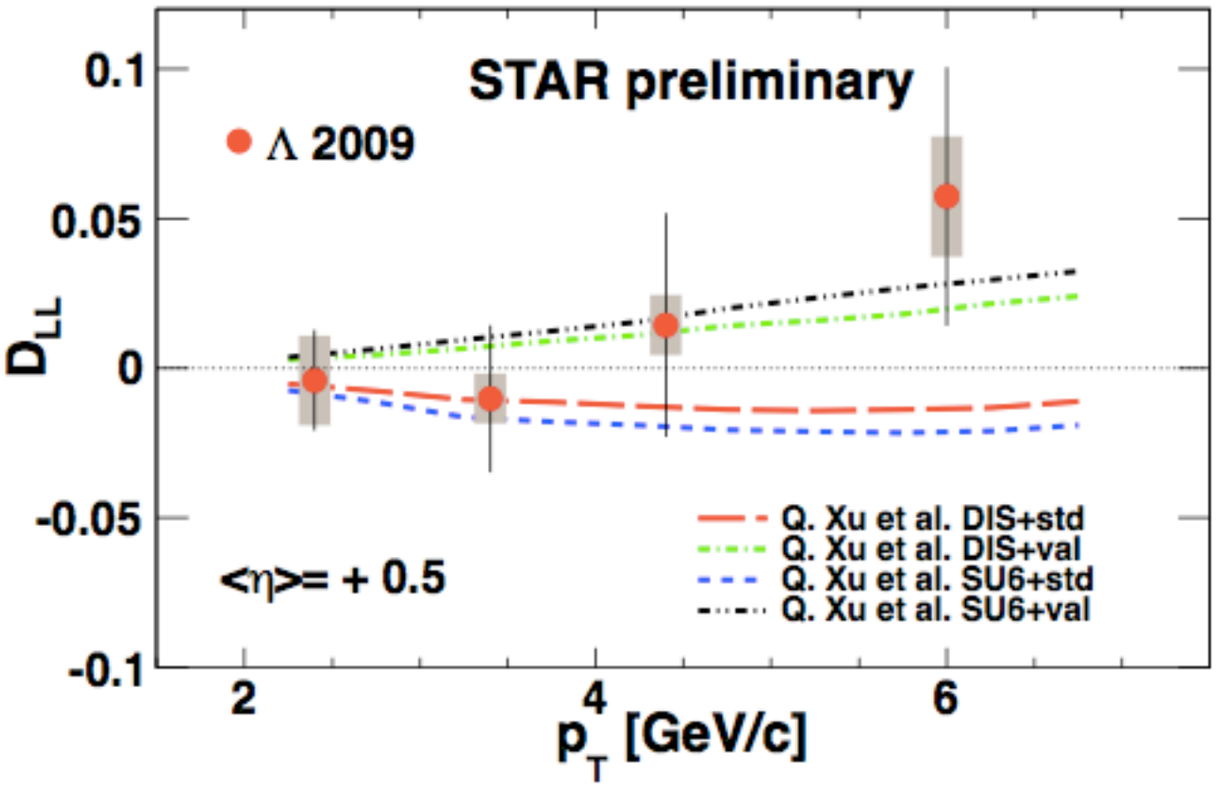
D. de Florian, M. Stratmann, and W. Vogelsang, PRL. 81.
(updated calculation to low p_T)

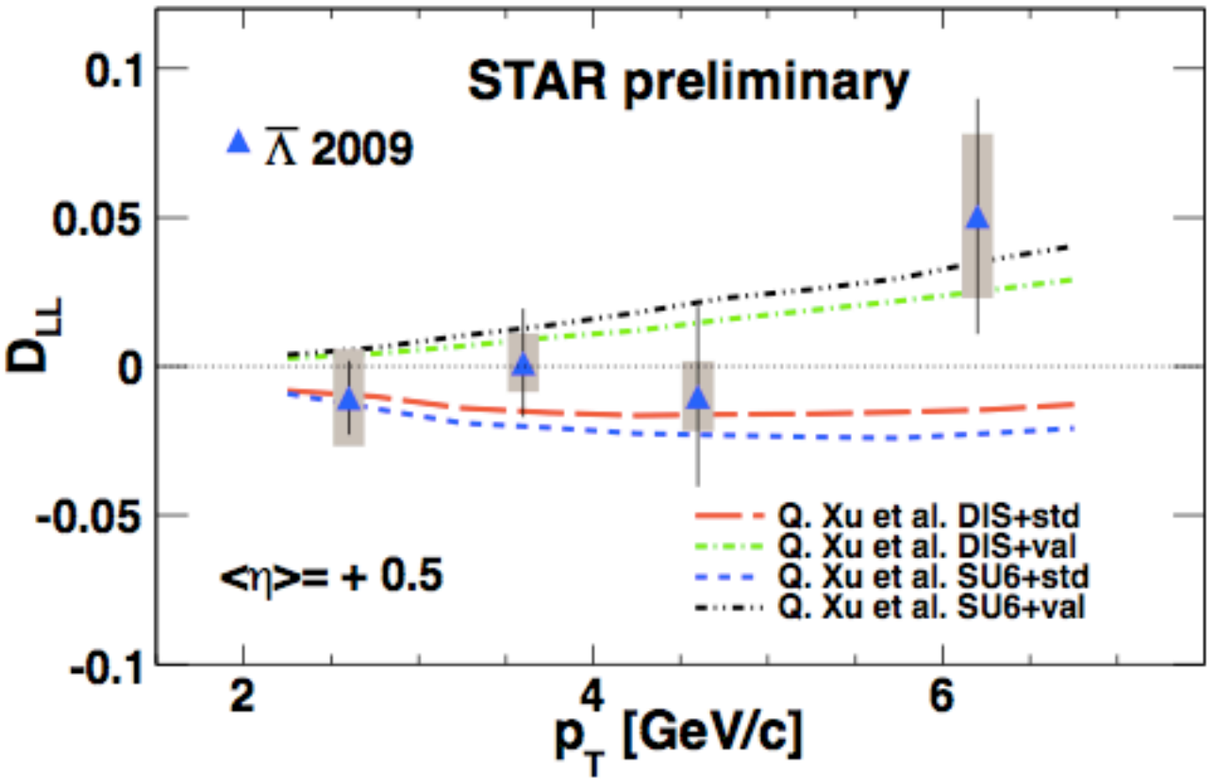
scen. 1: SU(6) picture.
scen. 2: DIS picture.
scen. 3: equal contribution.

J. Deng for the collaboration, SPIN 2012
R. Cendejas for the collaboration, DNP 2012

Compared to Expectations - II

Q. Xu et al, Phys.Rev.D65 (2002) 114008, D73 (2006) 077503

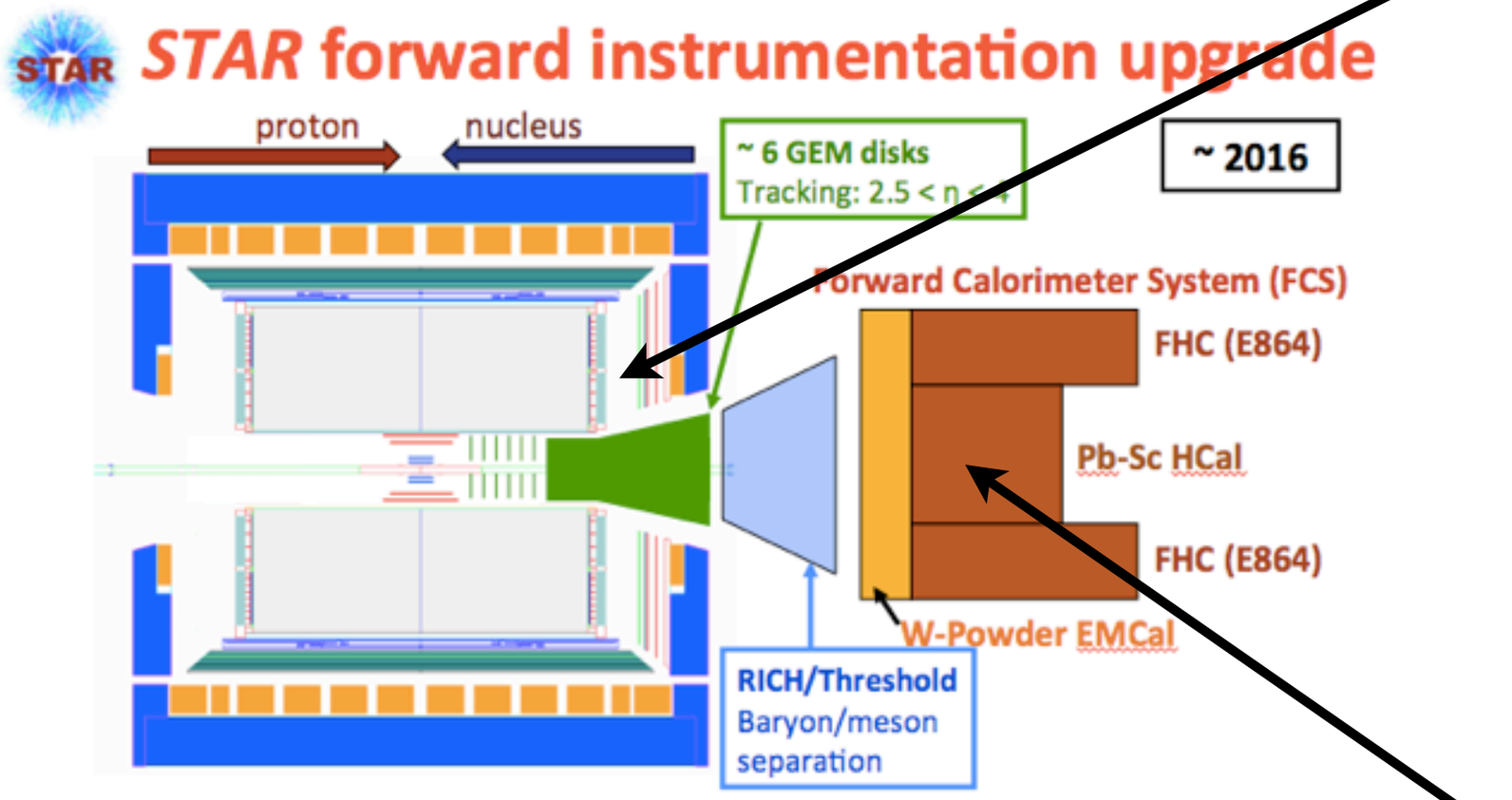




Data do not currently discriminate “model”-expectations,
precision may re-interest our theory friends, “models” → fits
analysis of away-side sample in progress.

Looking Ahead

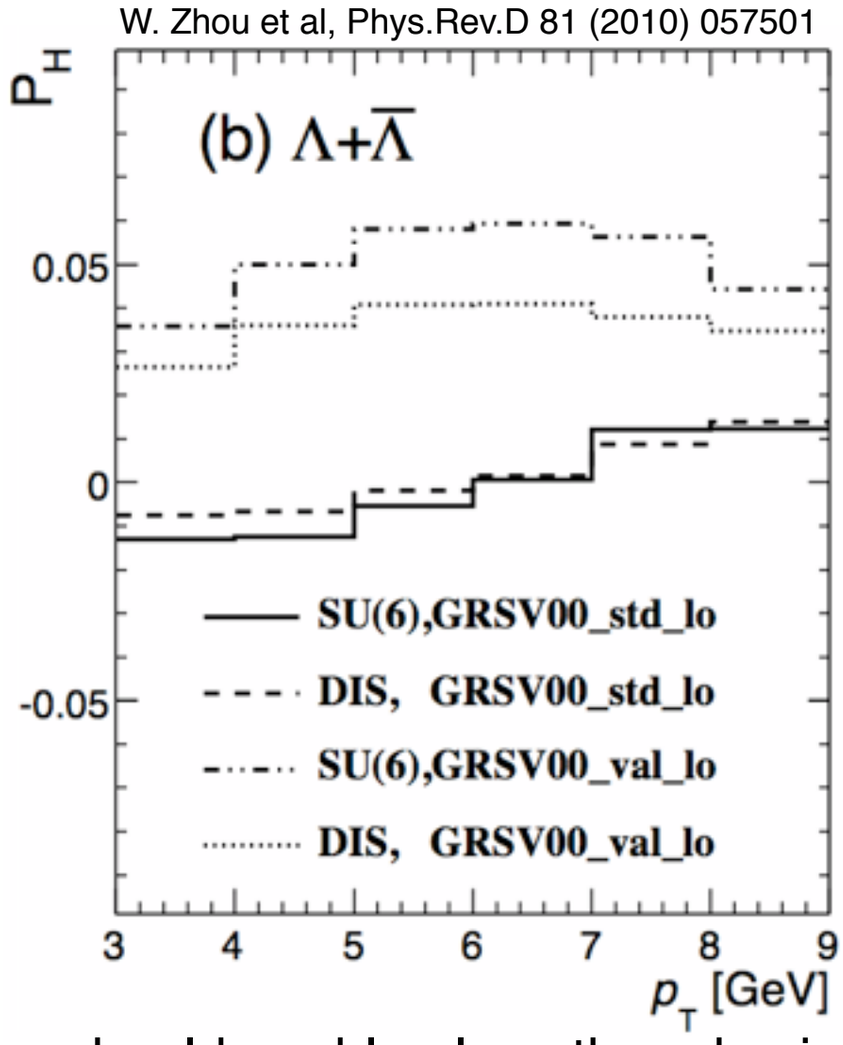
- H.Z. Huang for the collaboration, QM2012



- Forward instrumentation optimized for p+A and transverse spin physics
  - Charged-particle tracking
  - *e*/*h* and γ/π^0 discrimination
  - Possibly Baryon/meson separation

- TPC inner sector upgrade will extend acceptance to larger rapidity where D_{LL} is expected to be larger.

- Forward Calorimeter upgrade



should enable also other physics with (forward) Hyperons.

- STAR Decadal Plan discussed in Jamie's talk tomorrow,

- Stay Tuned, Thanks!