Lambda Polarization at STAR in Polarized pp Collisions at RHIC at $\sqrt{s}$=200 GeV

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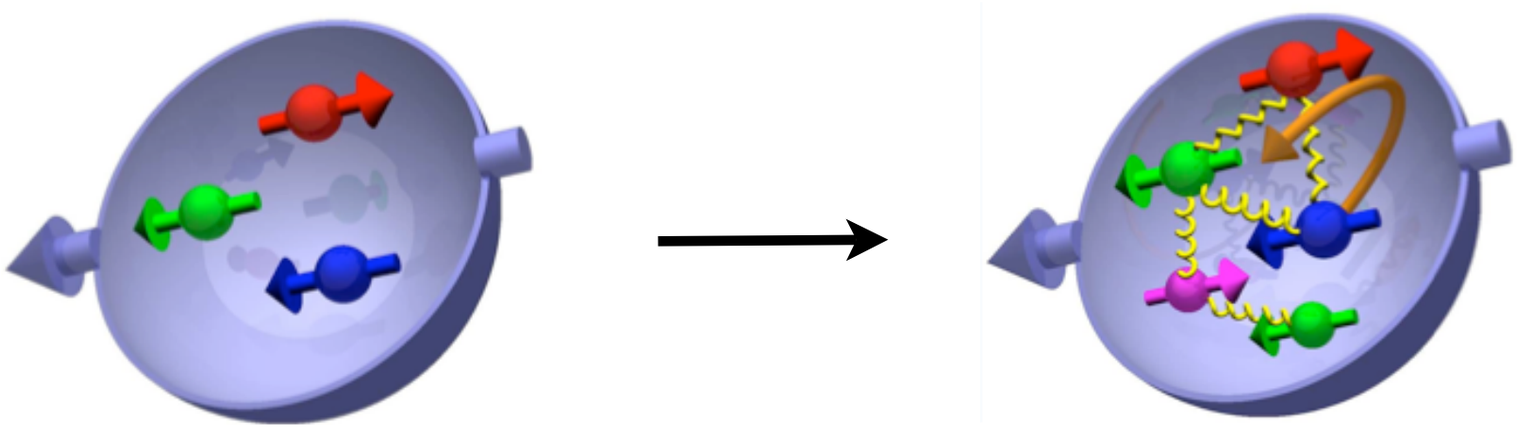
Nucleon Spin Puzzle

The surprising *smallness* of the spin dependent part of the inclusive DIS cross section renewed the interest in and continues to force us to rethink nucleon spin structure,



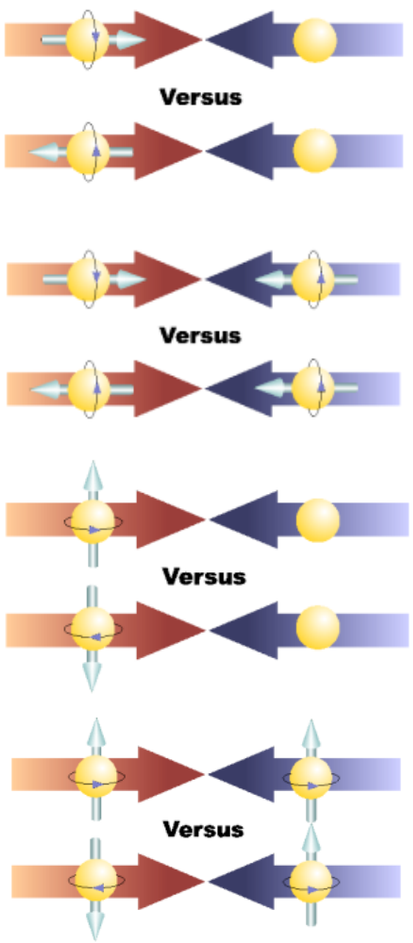
Among the many open questions, what is the *role of flavor*, is there a hyperon spin puzzle?

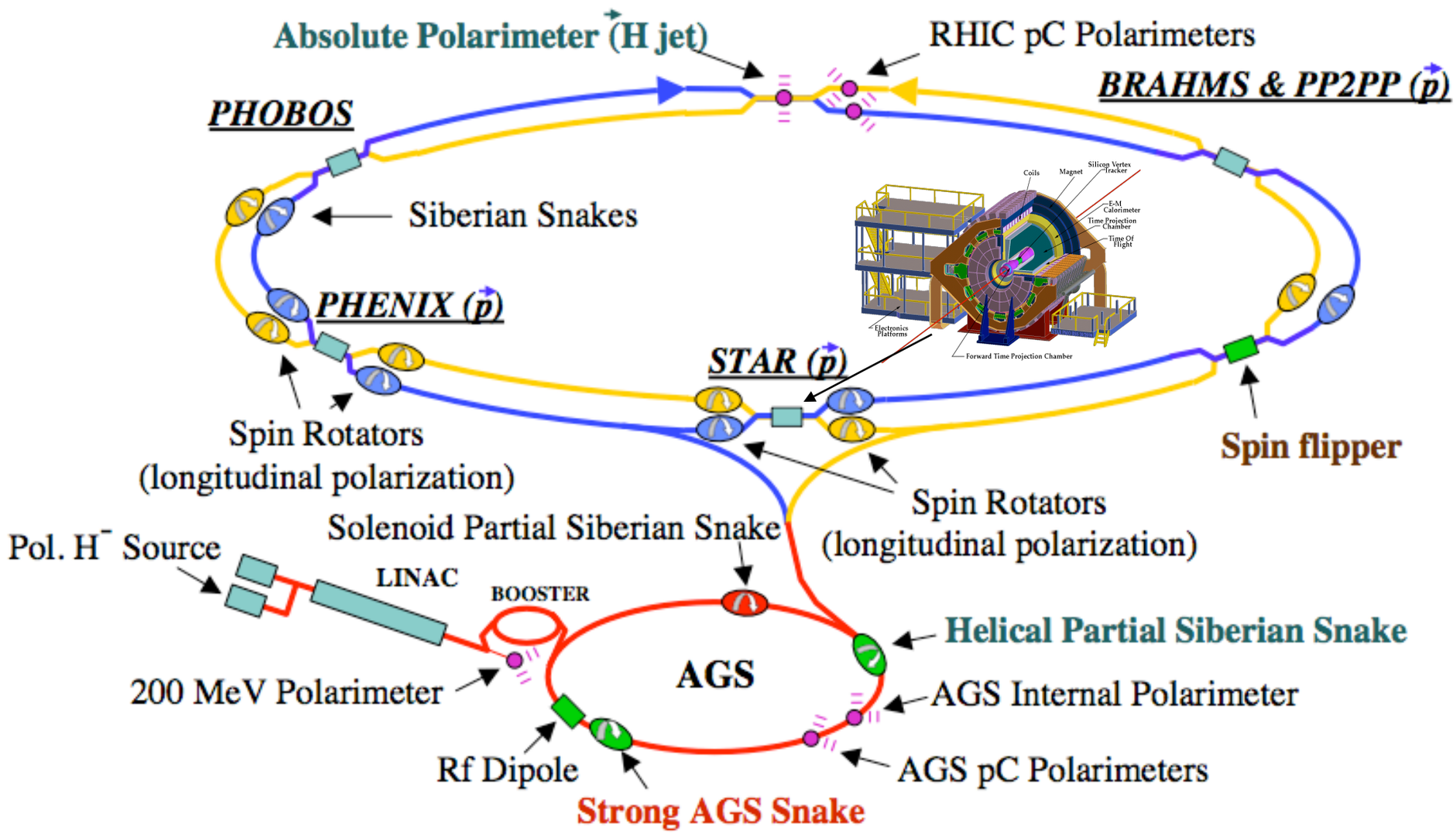
What insight(s) can hyperon polarization measurements at RHIC give?

RHIC - Polarized Protons to Study Spin in QCD

Opportunities to study many facets:

$\sqrt{s}$ = 200 - 500 GeV

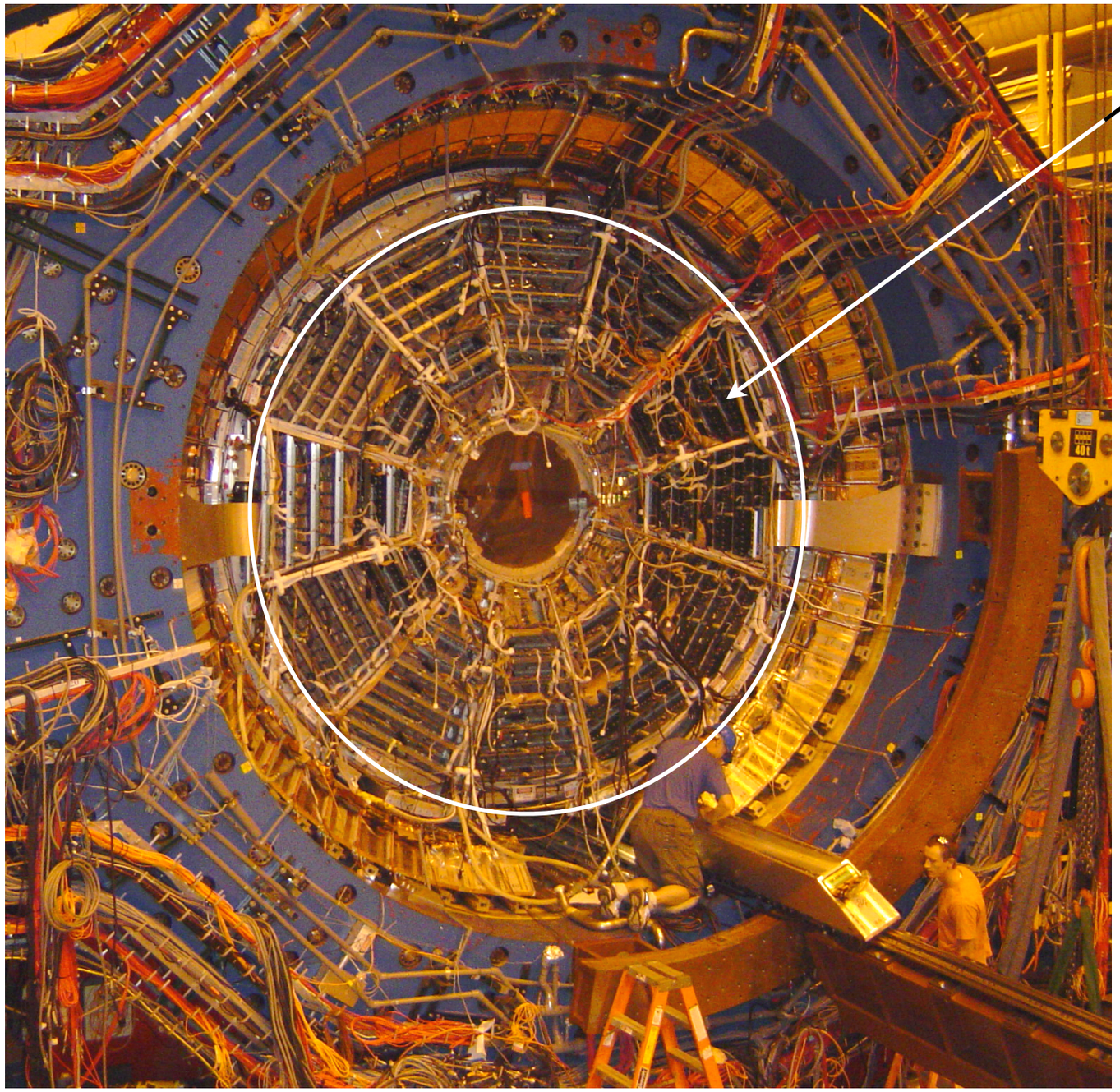




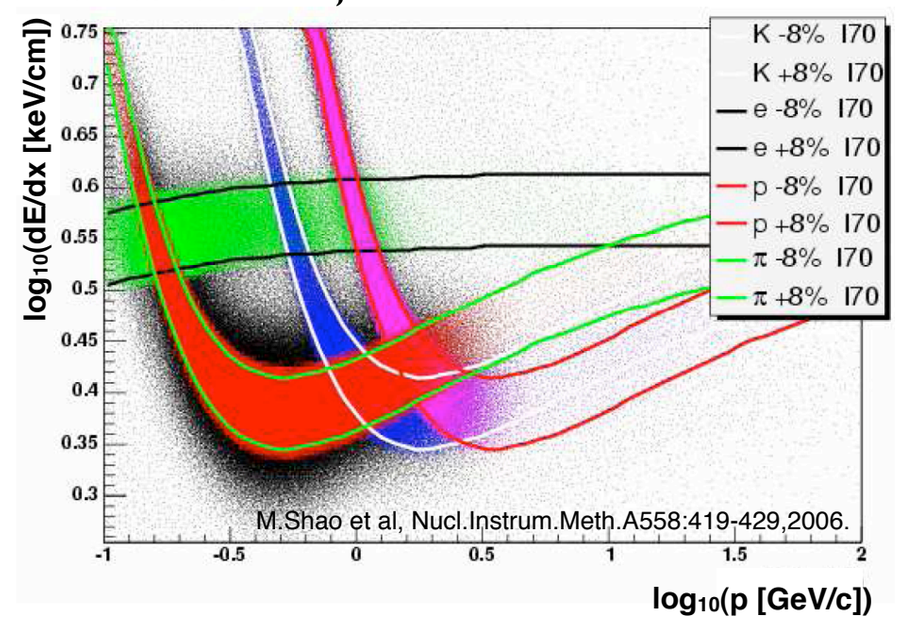
with good systematic controls, e.g.:

This work: $\sqrt{s}$ = 200 GeV, ~2 pb^{-1}, P_b ~50% (longitudinal), collected in Y2005

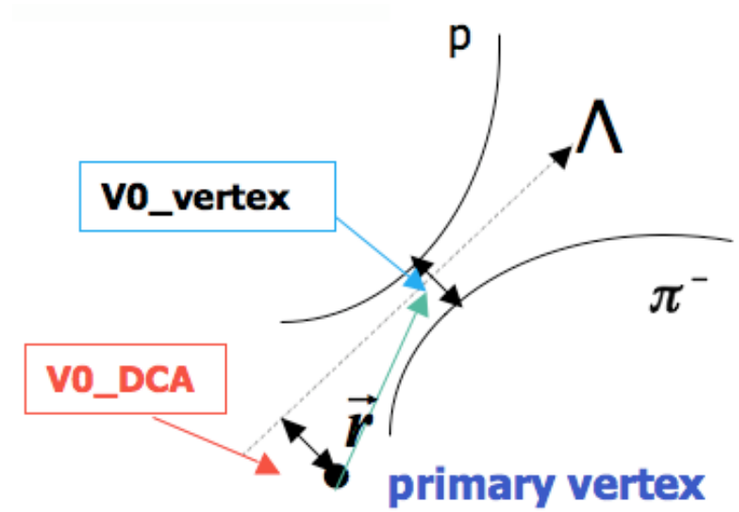
STAR - Solenoidal Tracker At RHIC



Time Projection Chamber enables PID,

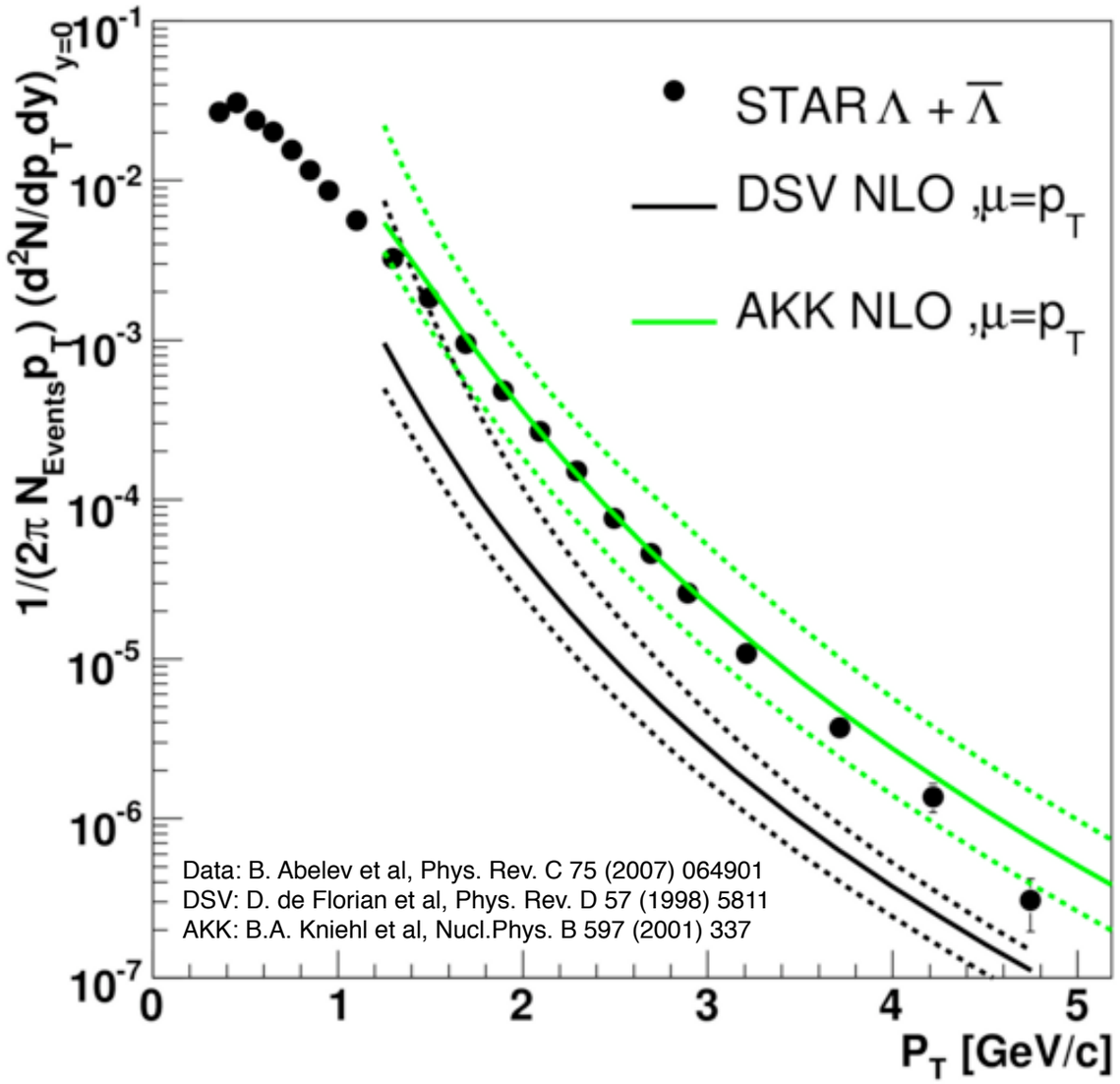


and topological reconstruction,

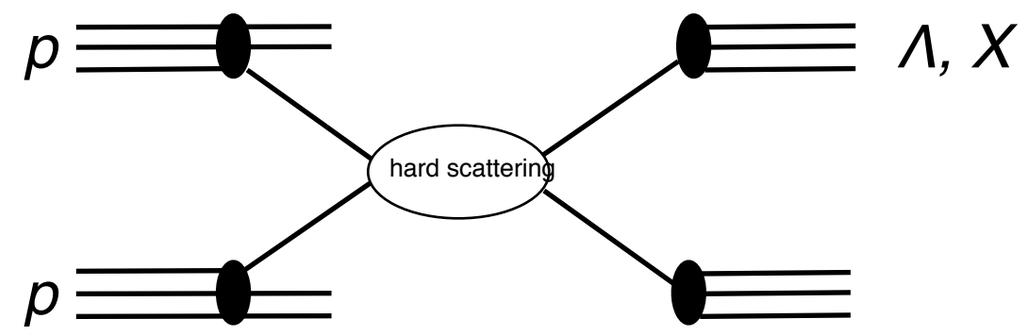


for $|\eta| \leq \sim 1.3$

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.

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 + π decay mode with B.R. ~64%.

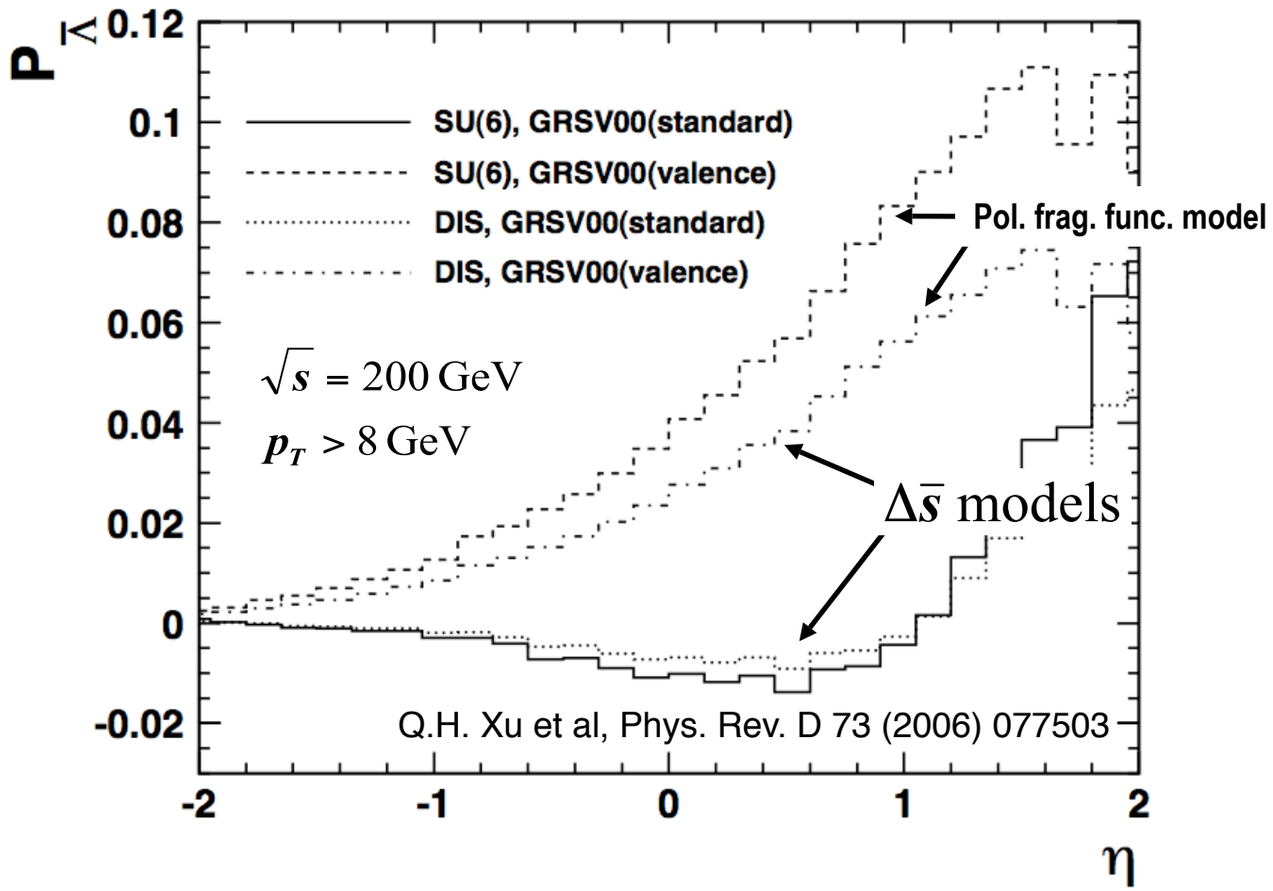
Here,

A is the detector acceptance,
θ* is the angle defined by the Λ momentum and the *p* direction in the Λ rest frame,
α = 0.642 ± 0.013 is the decay parameter.

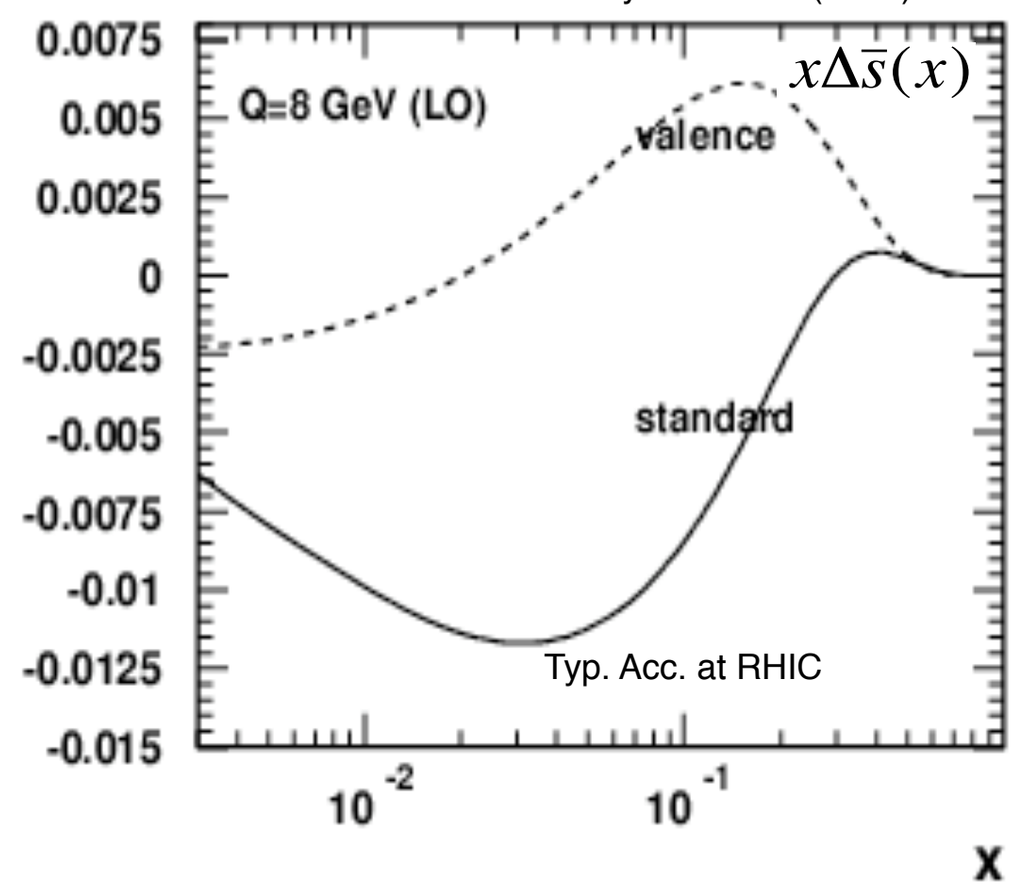
D_{LL} -Longitudinal Spin Transfer

Unlike for the differential cross section, NLO expectations do not currently exist for D_{LL} at RHIC.

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



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



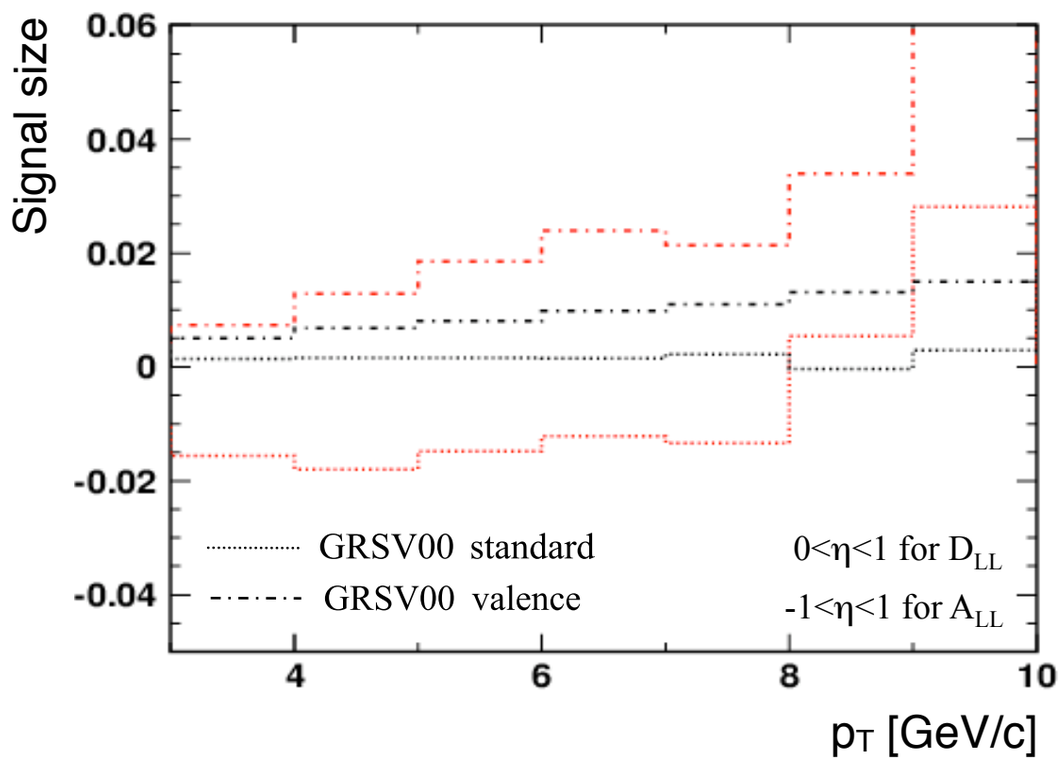
more so than to the fragmentation in this model.

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.

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,

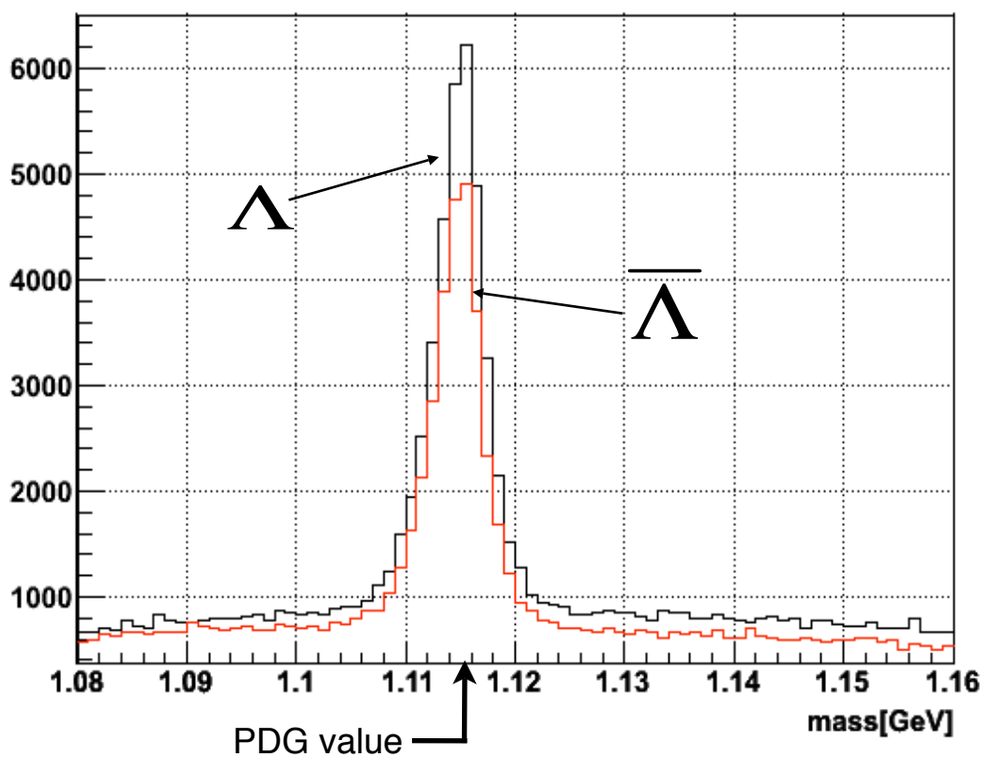
- current D_{LL} analysis requires more selections than for A_{LL}, i.e. loose some statistics,

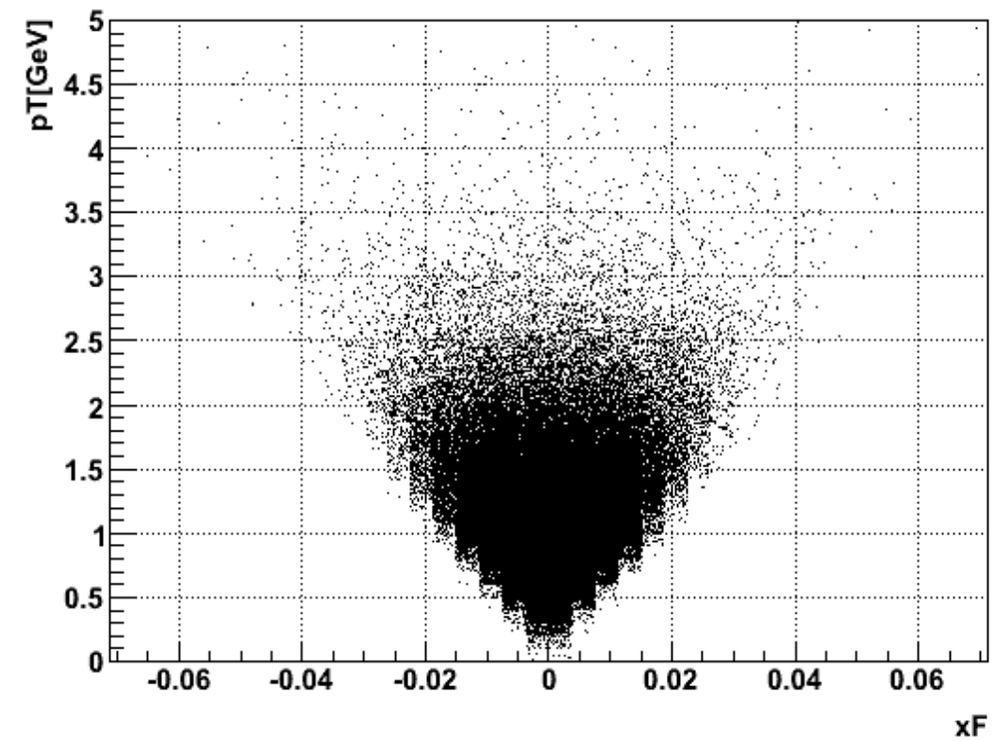
+ D_{LL} is a single beam-spin measurement, analyzing power of the $p+\pi$ decay mode is relatively large.

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

STAR Data - 2005

~3.10^6 events collected with a beam-collision trigger (minimum bias, bandwidth limited),





~ 30.10^3 Λ candidates,

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

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

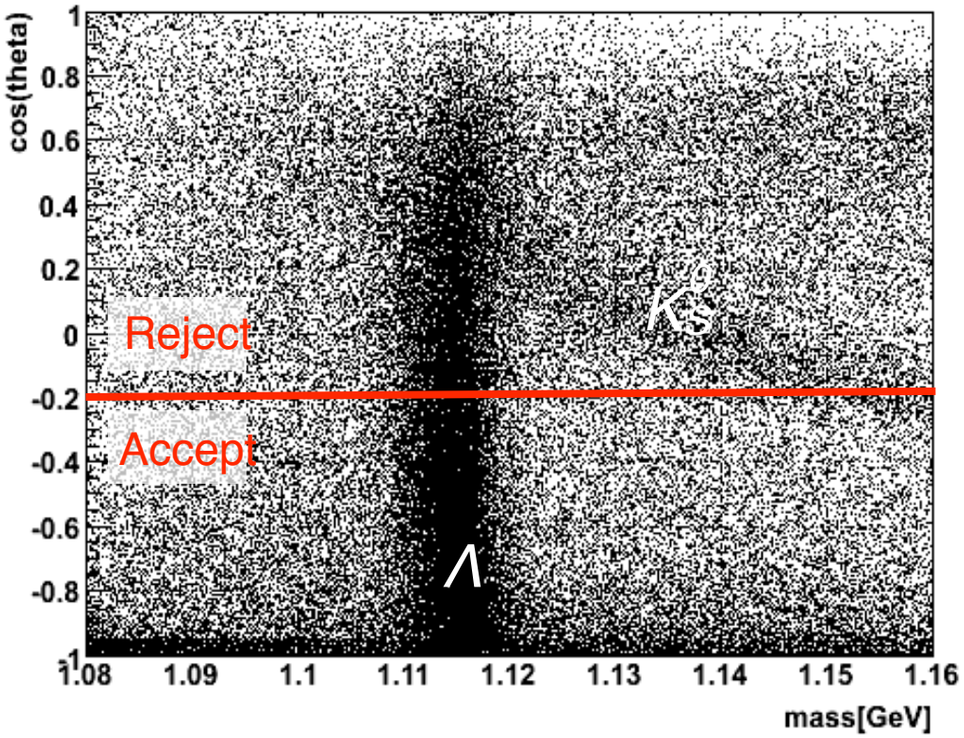
$\langle |x_F| \rangle \approx 0.008$

Analysis Features

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_S^0 background caused by misidentified π (cuts ~40%).



Use beam spin configurations and symmetries to (largely) cancel $A(\cos\theta^*)$ and extract,

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

in small $\cos\theta^*$ intervals. Here, $N_\Lambda^+ = N_\Lambda^{++} \cdot \frac{\mathcal{L}^{--}}{\mathcal{L}^{++}} + N_\Lambda^{+-} \cdot \frac{\mathcal{L}^{--}}{\mathcal{L}^{+-}}$ and $N_\Lambda^- = N_\Lambda^{-+} \cdot \frac{\mathcal{L}^{--}}{\mathcal{L}^{-+}} + N_\Lambda^{--}$

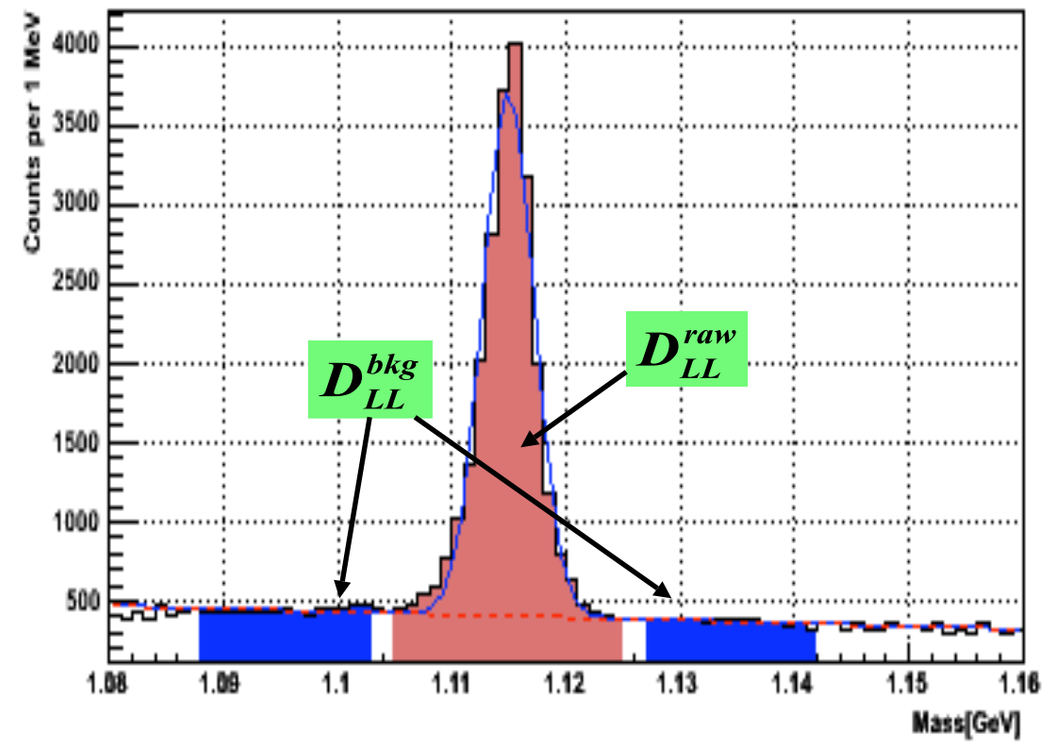
The luminosity ratios are measured at STAR and beam polarization in RHIC.

Analysis (Continued)

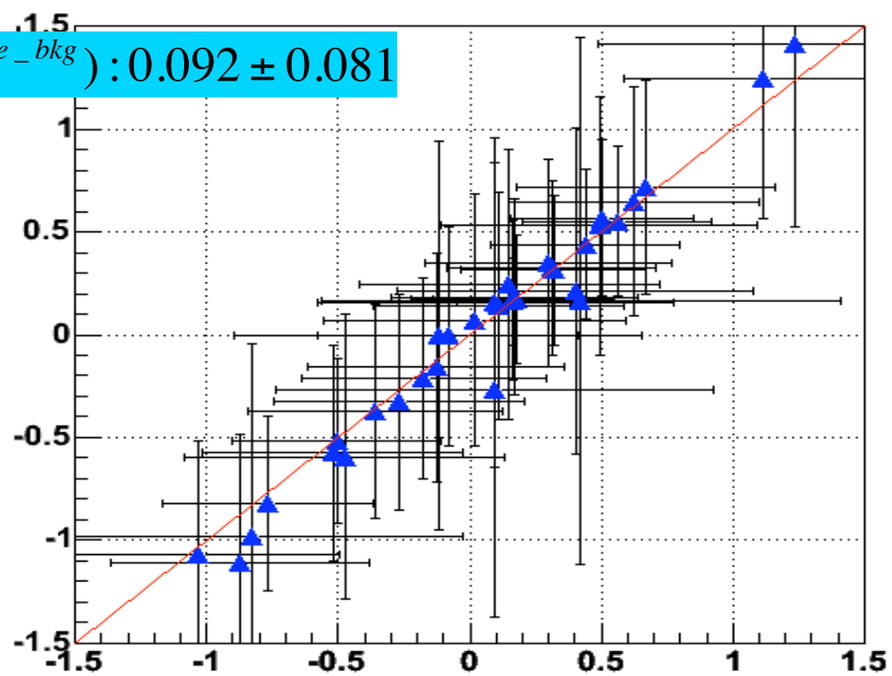
D_{LL} was extracted using side-bands to subtract,

- background counts from raw signal,

- background D_{LL} using a fitted background level.



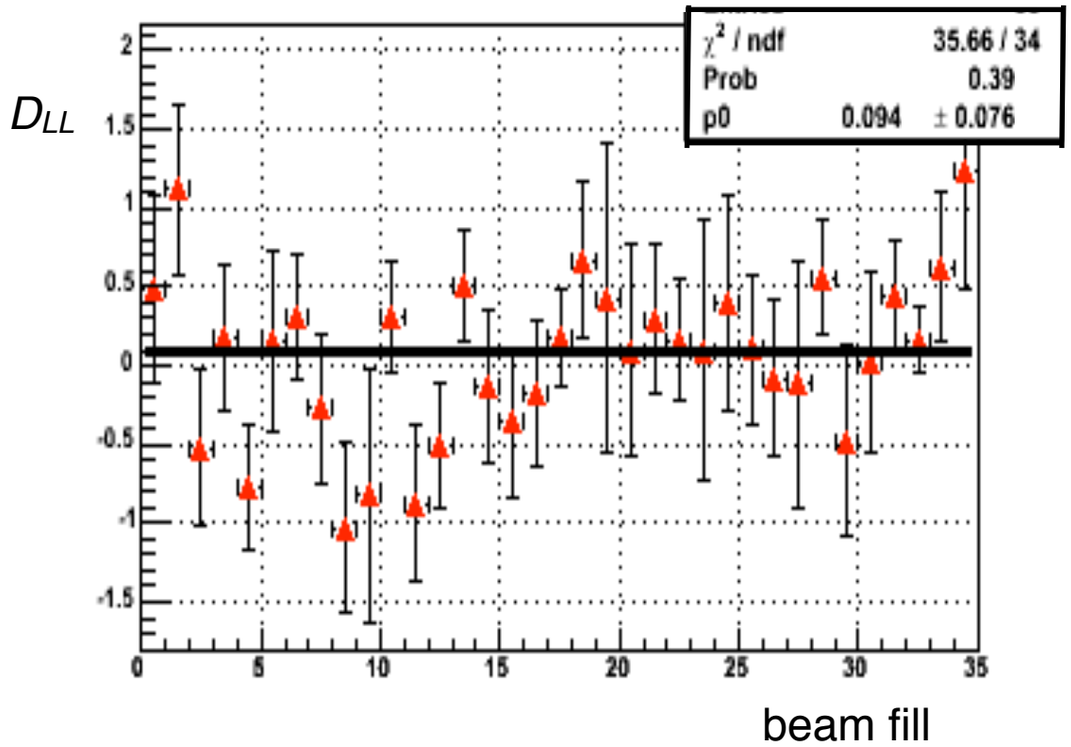
$$D_{LL}(N^{raw} - N^{side\_bkg}) : 0.092 \pm 0.081$$



$$D_{LL}^{sig} = (D_{LL}^{raw} - rD_{LL}^{bkg})/(1-r) : 0.094 \pm 0.077$$

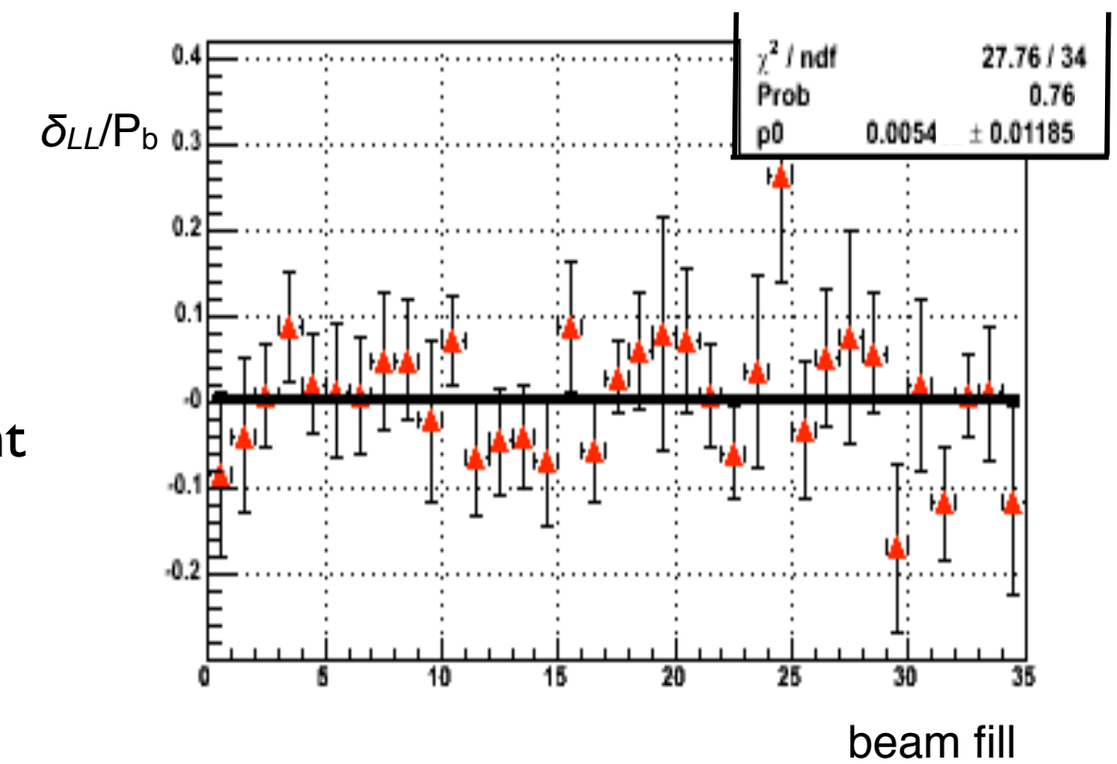
Results show good agreement within (strongly correlated) uncertainties.

Analysis (continued)

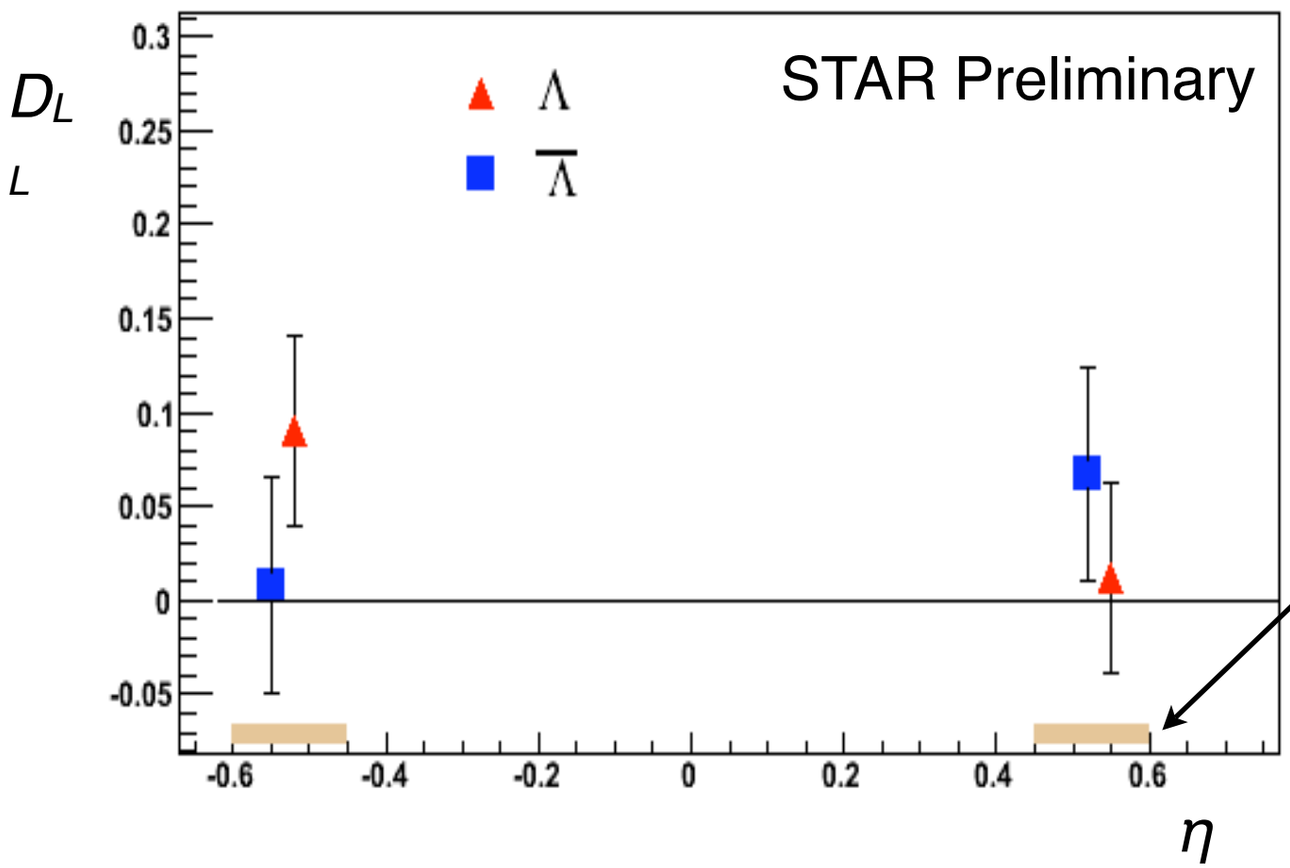


The extracted D_{LL} exhibits the expected statistical variation with time.

Control-measurement with the more abundant and spin-less K_S^0 shows no evidence for experiment systematics larger than ~0.01.



Results I



First D_{LL} from RHIC,

Statistics limited,

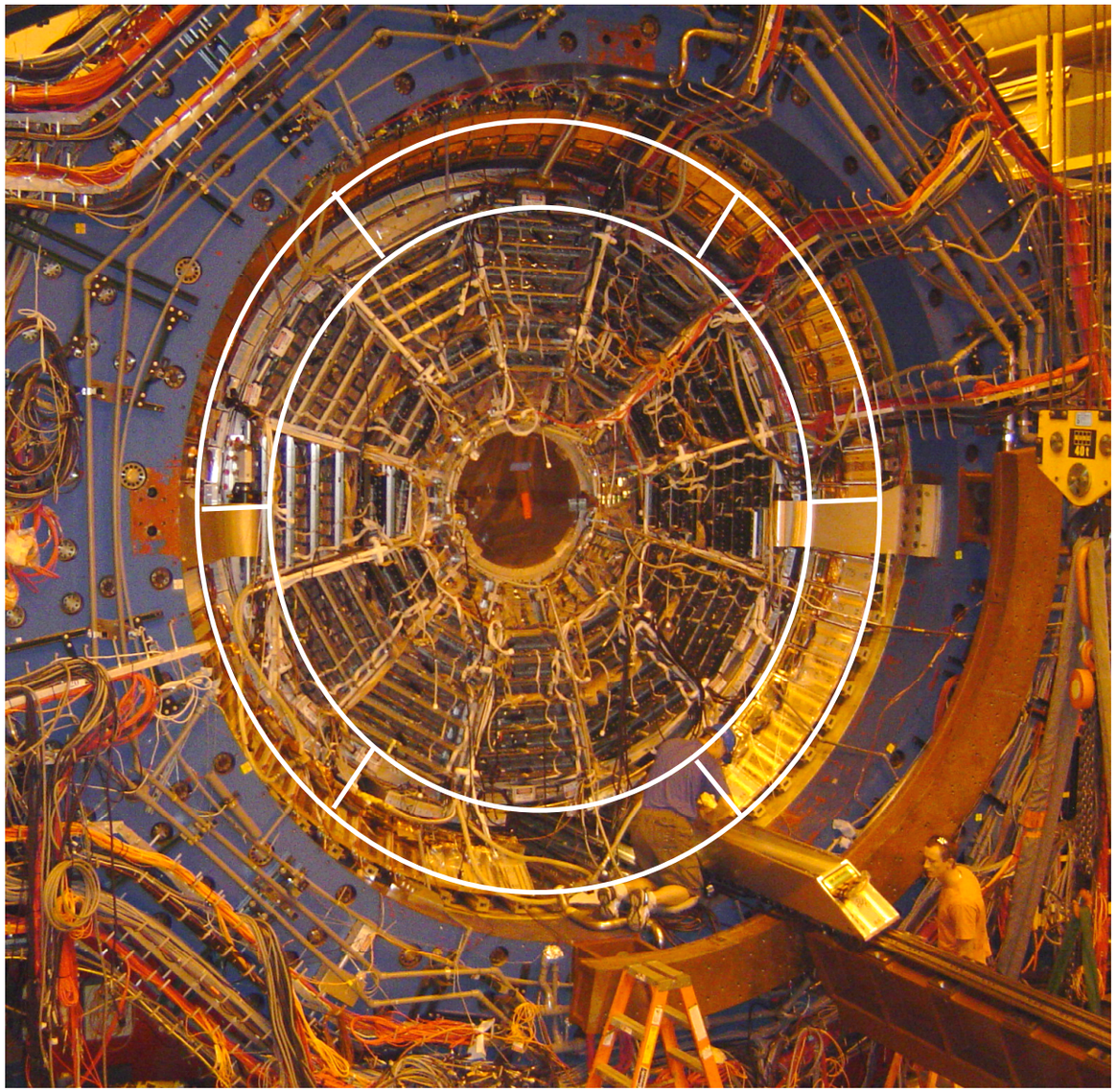
Systematics under control,

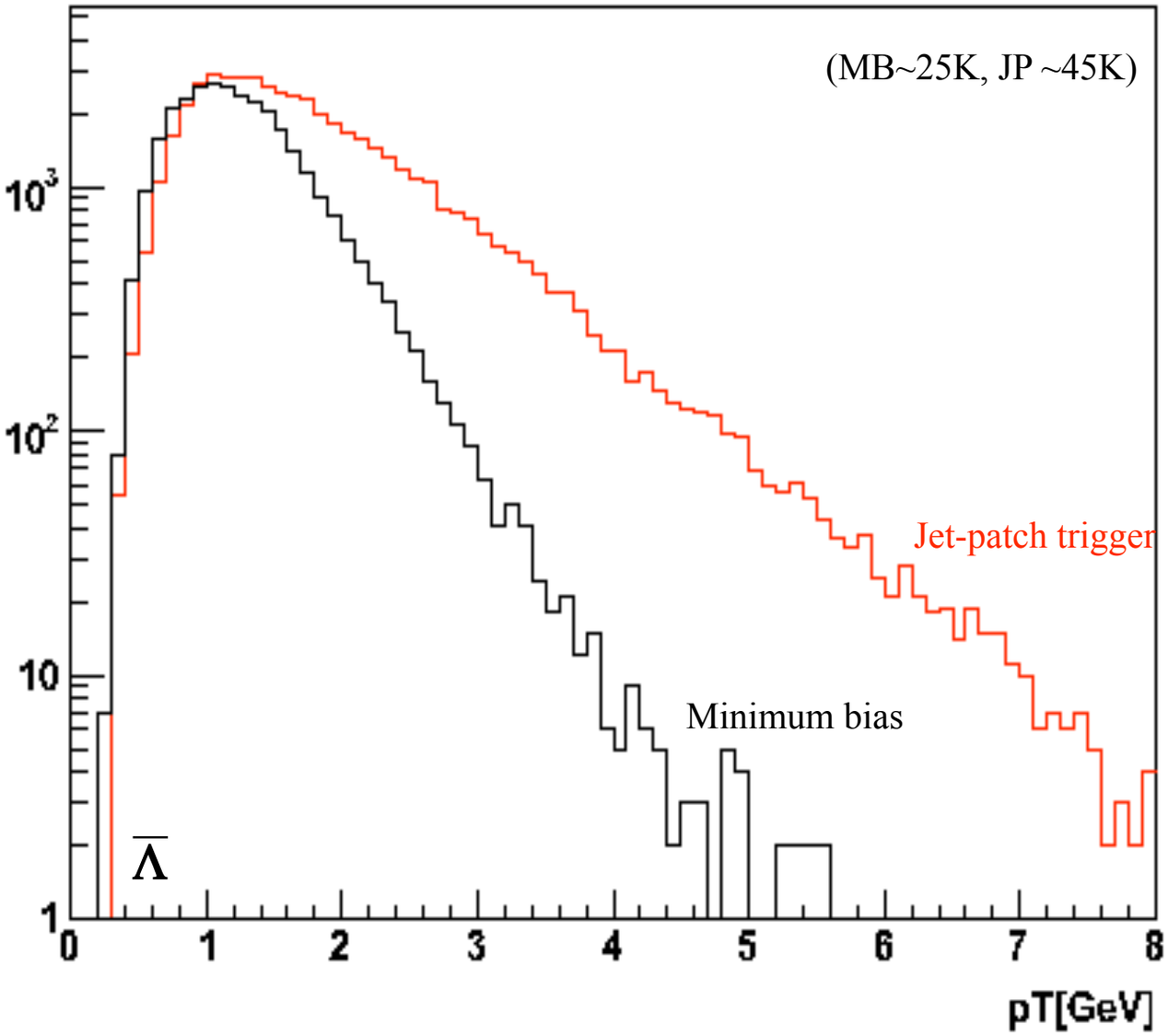
$\langle p_T \rangle \approx 1.3$ GeV/c, $\langle |x_F| \rangle \approx 0.008$

Need better precision and higher p_T

STAR Triggered Data - 2005

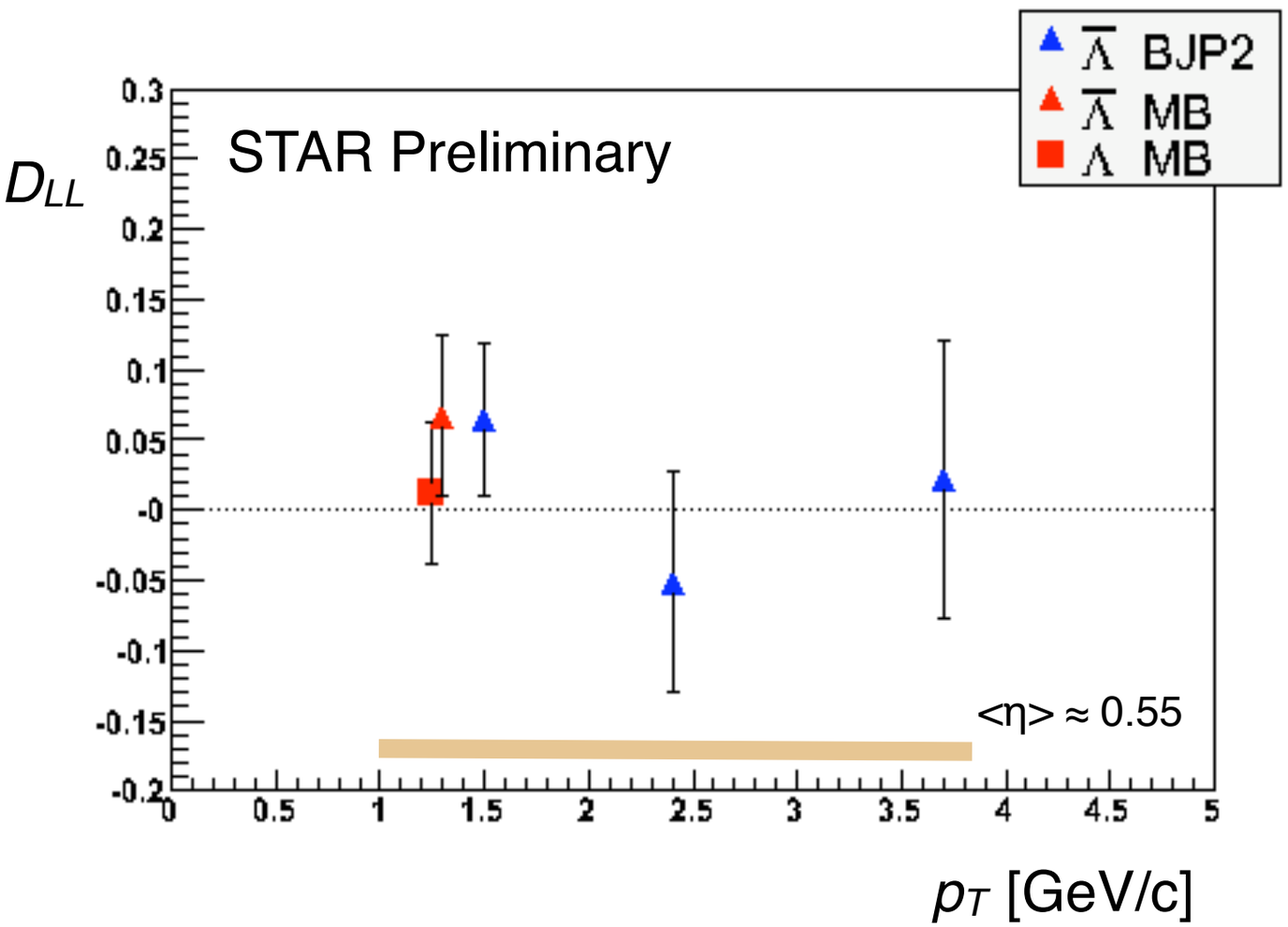
STAR was triggered on energy deposits in jet-patches of the Barrel E.M. Calorimeter,





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

Results II



Systematic Uncertainty Estimates:

- 5% RHIC measurement of P_b,
- 2% residual transverse pol. at STAR,
- 2% decay parameter α,
- < 0.01 relative luminosity measmnt,
- < 4% event pile-up in TPC,
- < 5% background,
- <15% trigger bias (MC simulation).

Summary and Outlook

- Perturbative QCD consistent with $\Lambda+\bar{\Lambda}$ yield observed in p+p coll. at $\sqrt{s}$ = 200 GeV,
- $\bar{\Lambda}$ D_{LL} sensitive to $\Delta\bar{s}$ and polarized fragmentation - effects of O (10^{-2}),
- STAR has performed first proof-of-principle measurements of Λ and $\bar{\Lambda}$ D_{LL} at RHIC;
- Observations are consistent with expectations but cannot (yet) discriminate,
- Eagerly anticipate polarized $p+p$ operations at RHIC with further improved L and P_b,
- Investigating possibilities to (better) trigger in STAR.