Transverse Spin Asymmetries in Neutral Strange Particle Production

Thomas Burton

BNL EIC group seminar

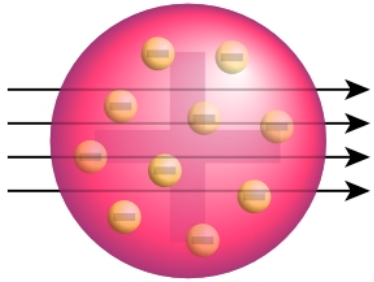
Thursday 27th August 2009

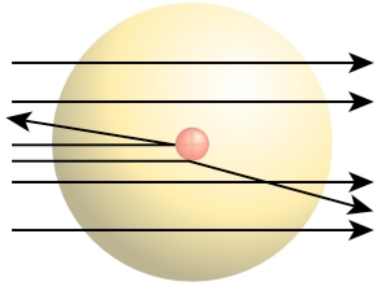
Overview

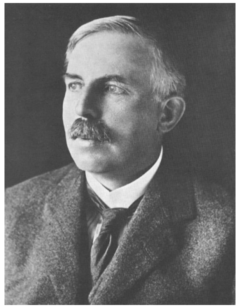
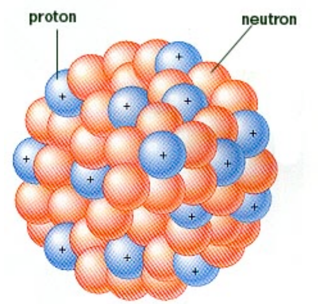
- Nucleon structure and spin composition.
- Transverse spin asymmetries:
  - Transversity
  - Collins Mechanism
  - Sivers Mechanism
- Strange particle identification and asymmetry calculation.
- Interpretation.

History of Nucleon Structure

- Geiger/Marsden experiment: atoms contain nuclei.
- Rutherford, Chadwick: Nuclei contain nucleons.
- Dirac: magnetic moment of point spin-1/2 fermions
- Anomalous magnetic moments indicate nucleons are not point particles.

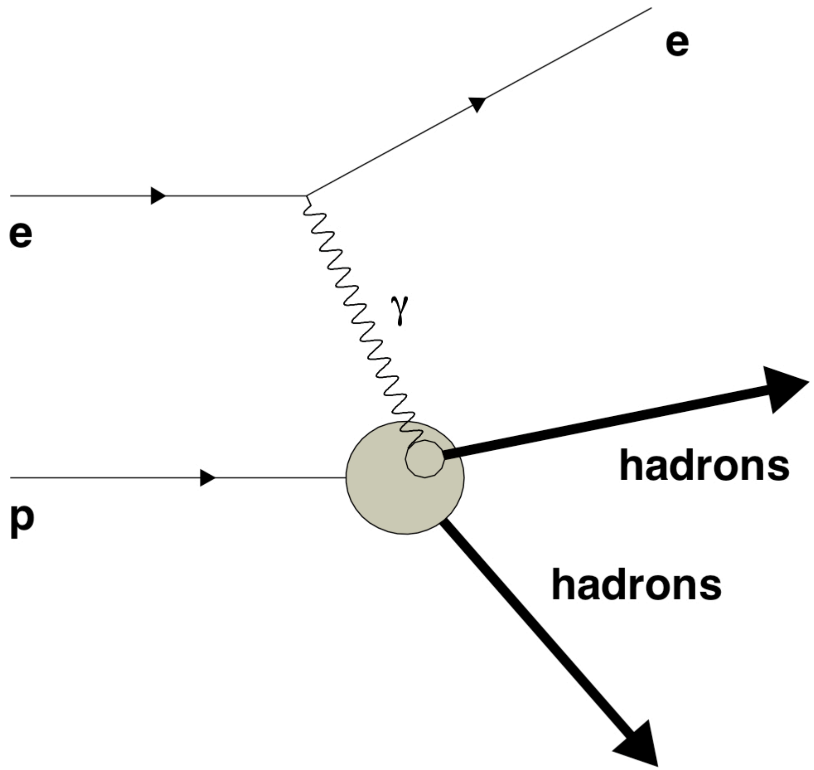


Deep Inelastic Scattering

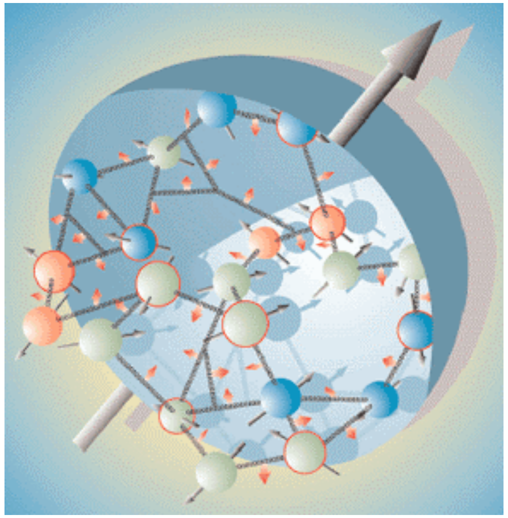
- Structure functions show "scaling": depend only on x in limit $Q^2 \rightarrow$ infinity.
- Measurements of F_1 and F_2 provide evidence of charged, spin-1/2 point constituents in nucleons (quarks).
- Parton Distribution Functions (PDFs) give probability distribution as a function of x.

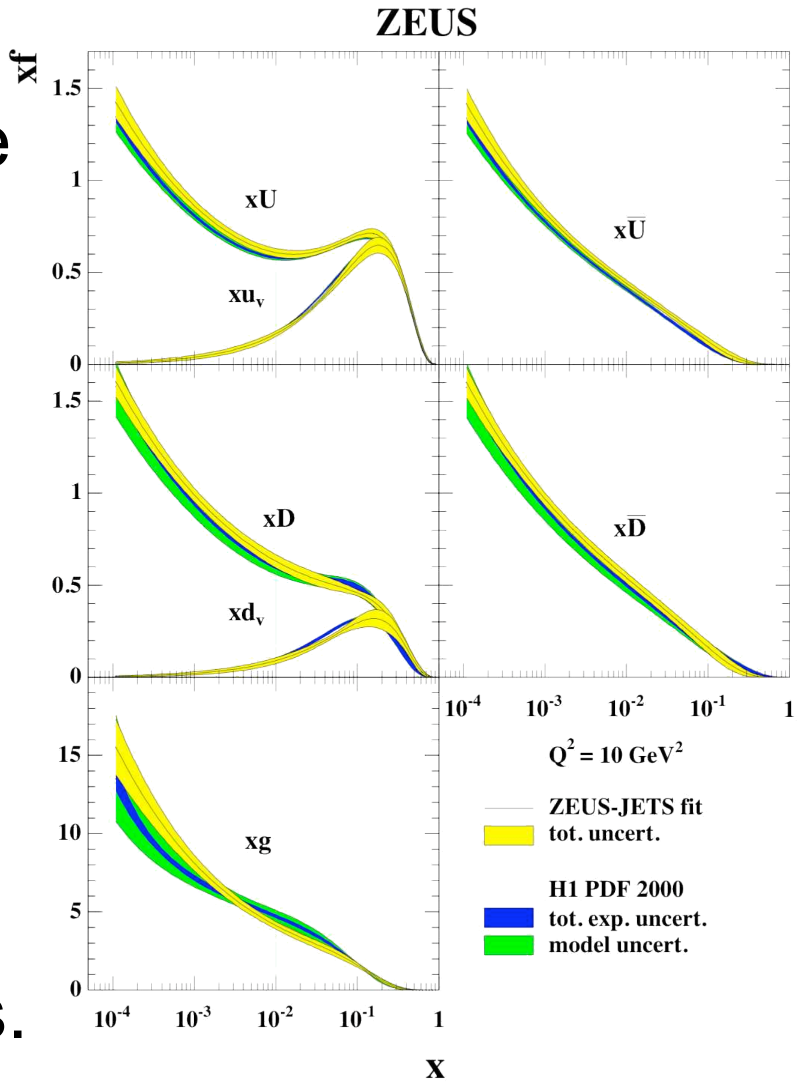
$$\frac{d\sigma}{dE\,d\Omega} \propto AF_1(x) + BF_2(x)$$



PDFs of proton:

- At large x, distributions dominated by u, d: valence structure of proton.

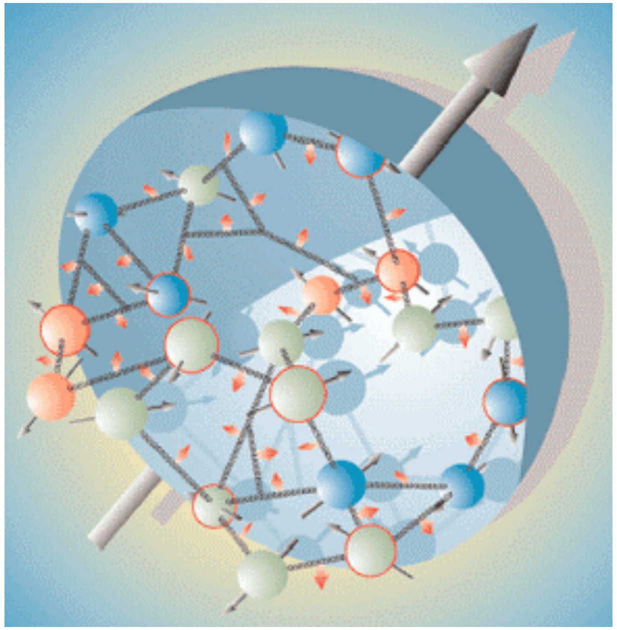




- Low x: many (anti-)quarks and gluons: “sea” of particles.

Nucleon Spin

- Simple quark model: spins-1/2 nucleon from sum of 3 spin-1/2 quarks.
- Sea quarks & gluons have spin - do they contribute?
- *Question: what is the contribution to nucleon spin from these different sources?*

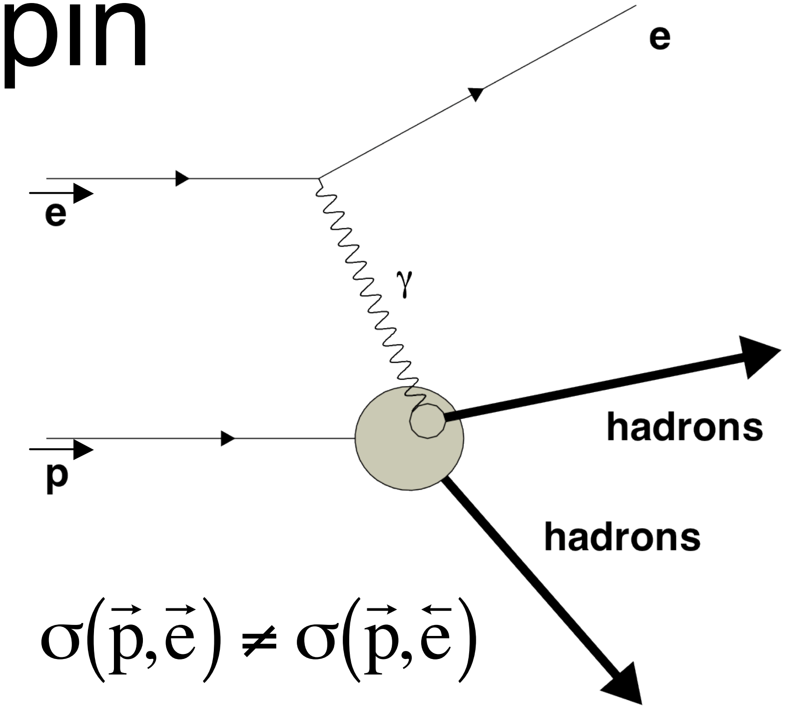


$$\frac{1}{2} = S_{\text{nucleon}} = J_{\text{quark}} + J_{\text{gluon}}$$

$$= S_{\text{quark}} + L_{\text{quark}} + S_{\text{gluon}} + L_{\text{gluon}}$$

Quark spin

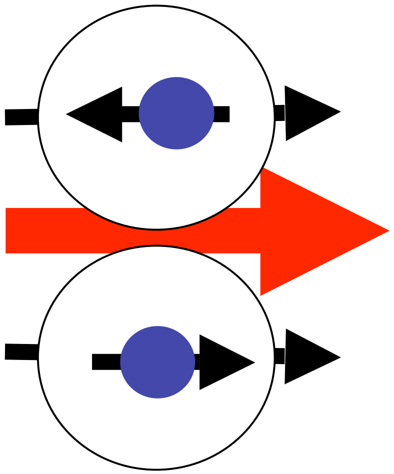
- Measure quark spin contribution using *Polarised* Deep Inelastic Scattering (pDIS),.
- *Spin-dependent cross section* is related to a spin-dependent structure function, g_1.
- g_1 is related to *quark helicity distributions, Δq(x)*.



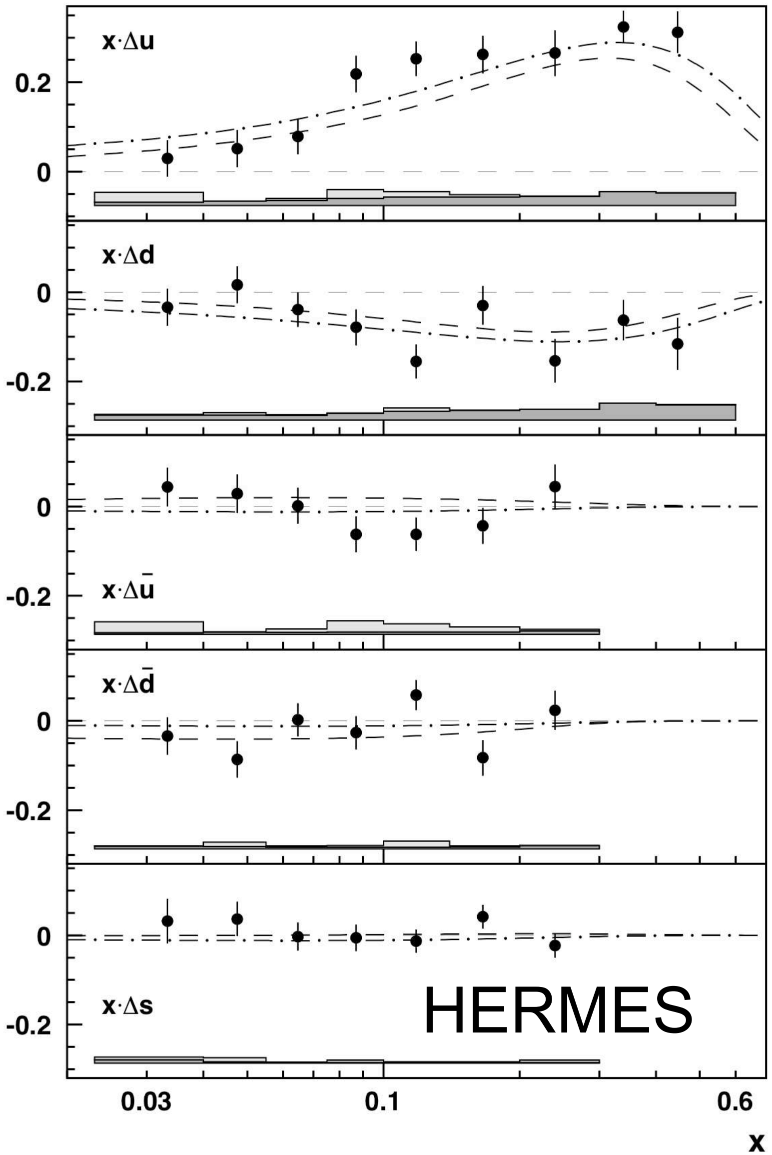
$$\sigma(\vec{p},\vec{e}) \neq \sigma(\vec{p},\overleftarrow{e})$$

$$g_1(x) = \sum_{q,\bar{q}} \Delta q(x)$$

$$\Delta q(x) = q^{\rightarrow}(x) - q^{\leftarrow}(x)$$

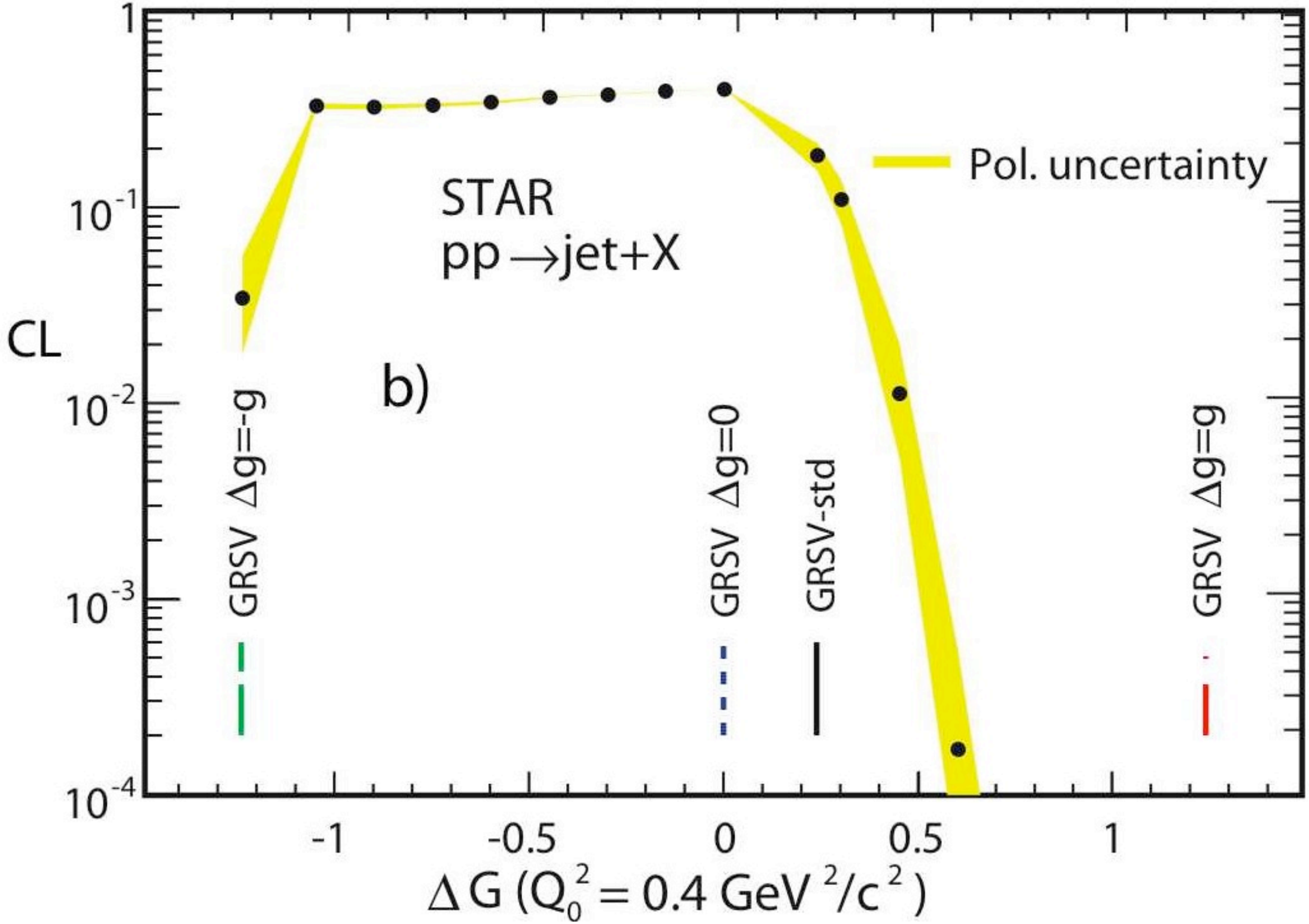


Helicity PDFs



- u quark positive.
- d quark negative.
- Sea has small polarisation.
- Integrate over x to gives total quark contribution…
- S_{quark} ~ 30%: (anti-)quarks are less than half the nucleon spin.
- Remainder must be due to L_{quark} and J_{gluon}.

Other contributions



Pause for breath:

“Where does nucleon spin come from?”

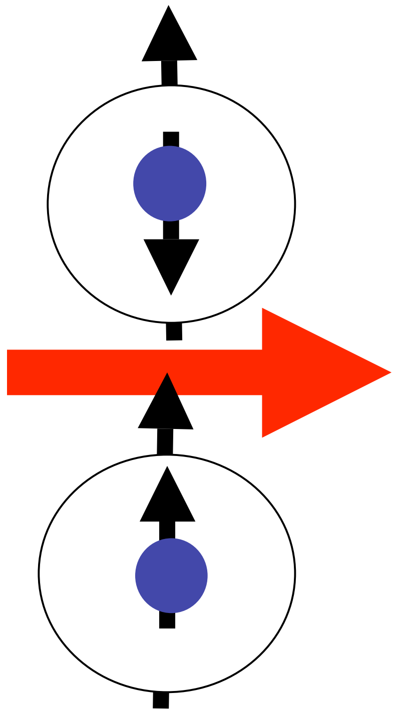
- Quark contribution small: ~ 30%
- Gluon contribution - large enough to provide the remainder?
- How important are orbital contributions?

Transverse Spin

- 3 different parton distributions are needed to describe nucleon:

$$\delta q(x) = q^{\uparrow}(x) - q^{\downarrow}(x)$$

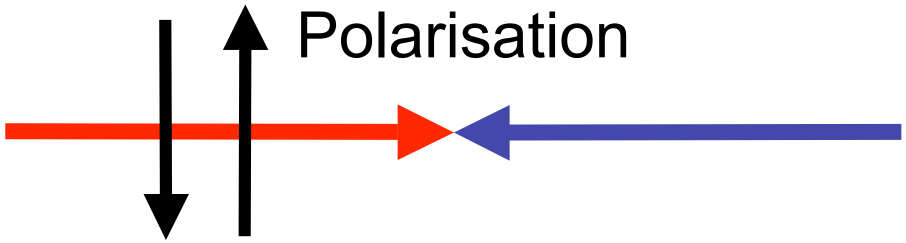
  - unpolarised, $q(x)$,
  - helicity, $\Delta q(x)$,
  - transversity, $\delta q(x)$.



- Poorly constrained compared to $q(x)$ and $\Delta q(x)$.
  - Constraint: $2|\delta q(x)| \leq q(x) + \Delta q(x)$

Effects of Transversity

- The *single spin asymmetry*:

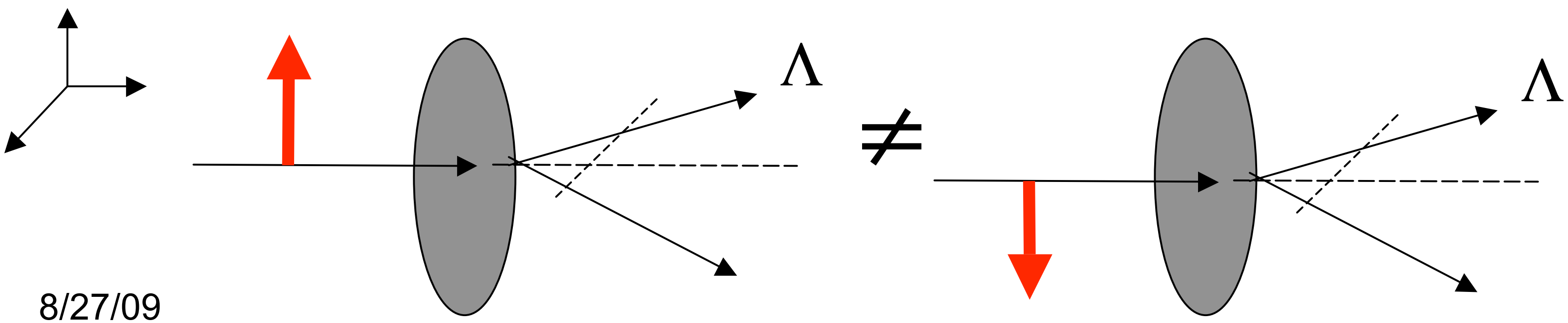


$$N(\phi) \sim 1 + A_N P \cos\phi$$

$$A_N = \frac{1}{P|\cos\phi|}\left(\frac{L^{\uparrow} - L^{\downarrow}}{L^{\uparrow} + L^{\downarrow}}\right)$$

  – Compare particle production upon a flip of polarisation direction.

- Asymmetry occurs because of a combination of transversity and the *“Collins Mechanism”*:



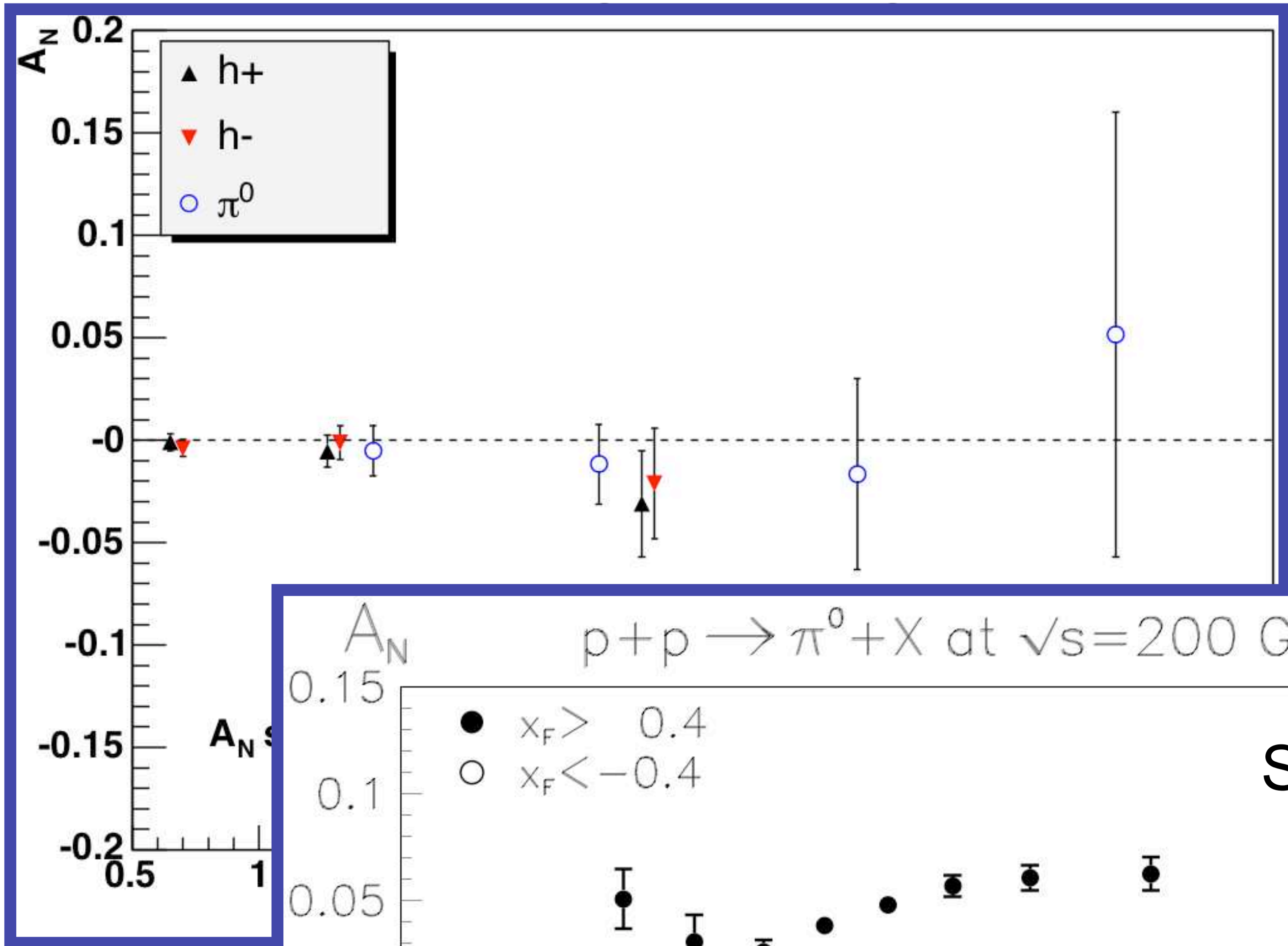
...nmetries

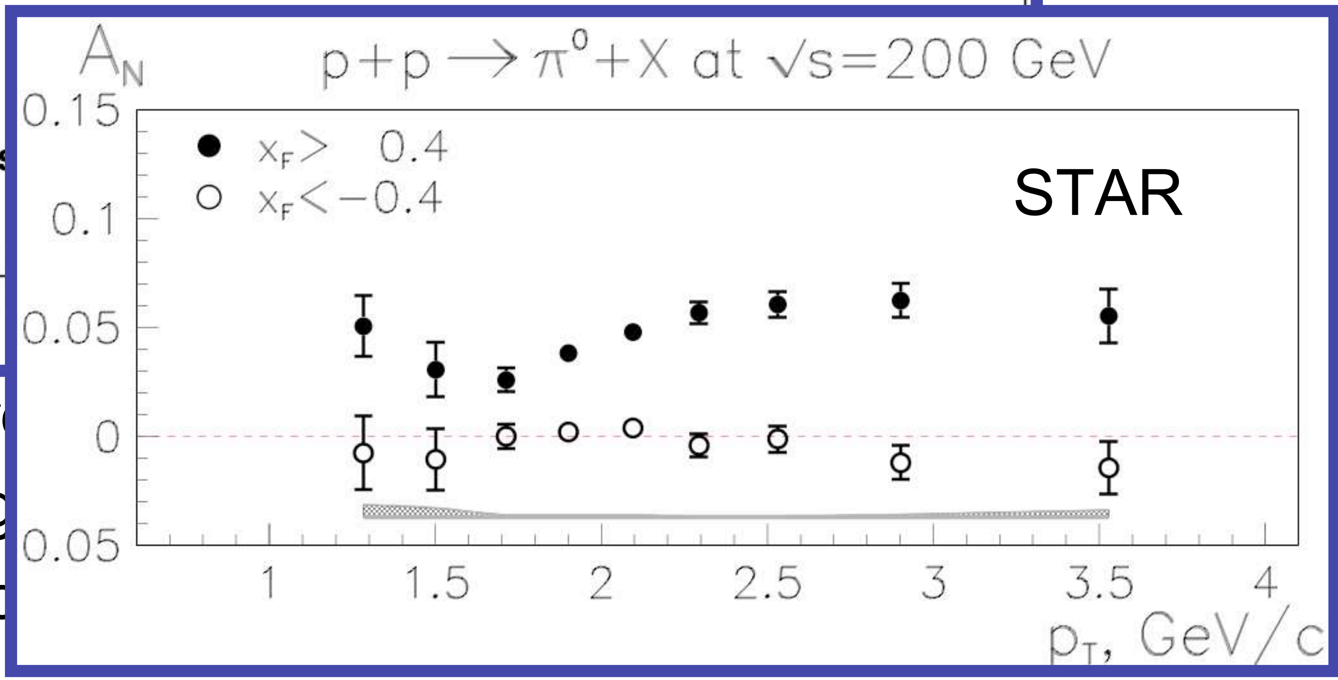
...0s:

...ally at forward

...um:

...QCD

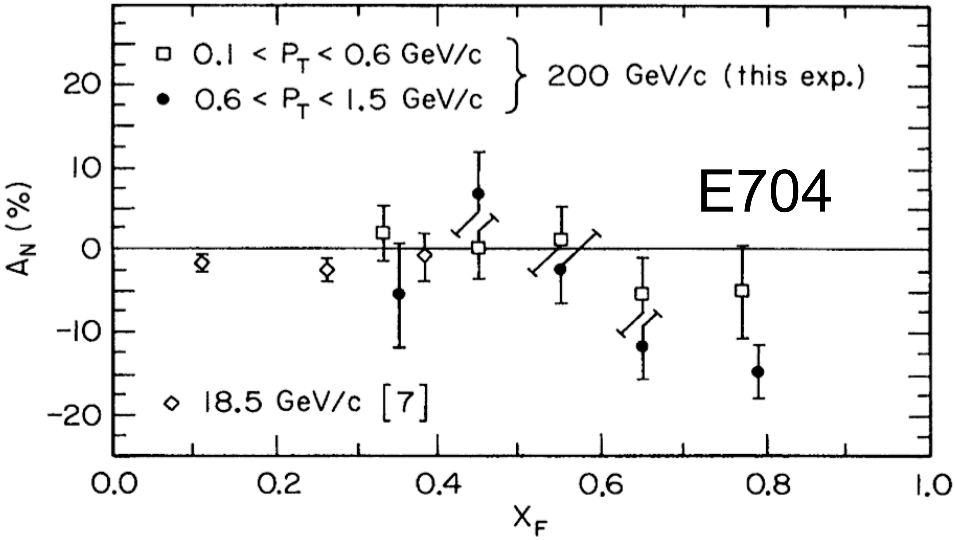


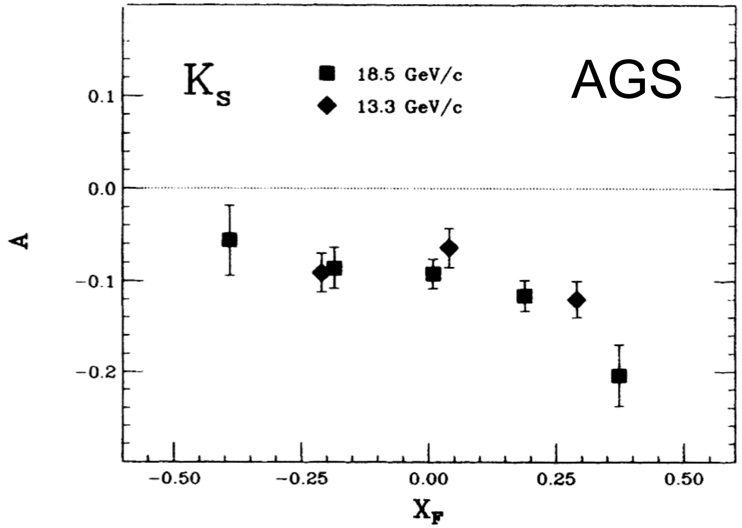


- RHIC r... ...um:
  - Larg...
  - Zero...

Strange particle SSAs

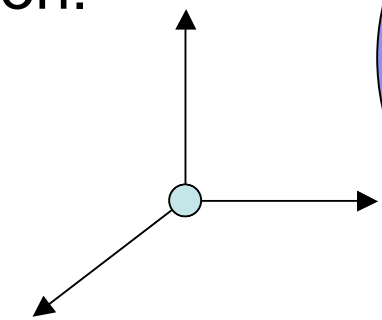
- Prior measurements at mid-rapidity show:
  - small Λ asymmetry,
  - large negative K^0_S asymmetry,
  - anti-Λ has large errors.
- Measurements are made at:
  - low centre-of-mass energy < 20 GeV.
  - Low momentum p_T < 2 GeV/c
- Are these results dependent on energy and p_T?
- Measuring strange particles can give information on the strange quarks.

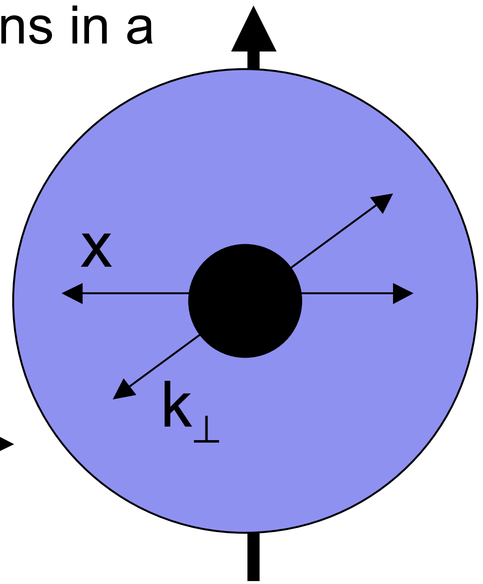




Sivers Mechanism

- Possible source of transverse spin asymmetries.
  - Not related to transversity/Collins itself, but may be present with them.
- A relation between proton transverse spin and parton transverse momentum, k_T.
- Describe via a $k_\perp$-dependent distribution: $f(x,k_\perp)$.
  - Represents the distribution of unpolarised partons in a transversely polarised proton.
- Asymmetry in $k_\perp$ manifests as a directional preference in particle production.





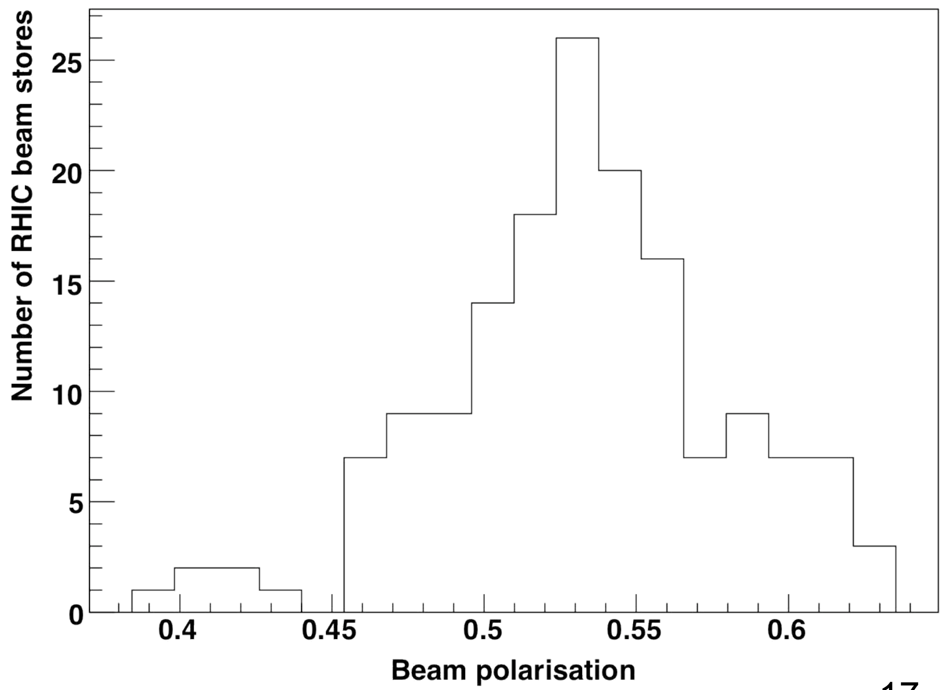
Summary

- Single spin asymmetries related to:
  - transversity distribution
  - Collins fragmentation functions
  - Sivers distribution functions
- Modern measurements e.g. at RHIC can be analysed in well-tested framework of pQCD.

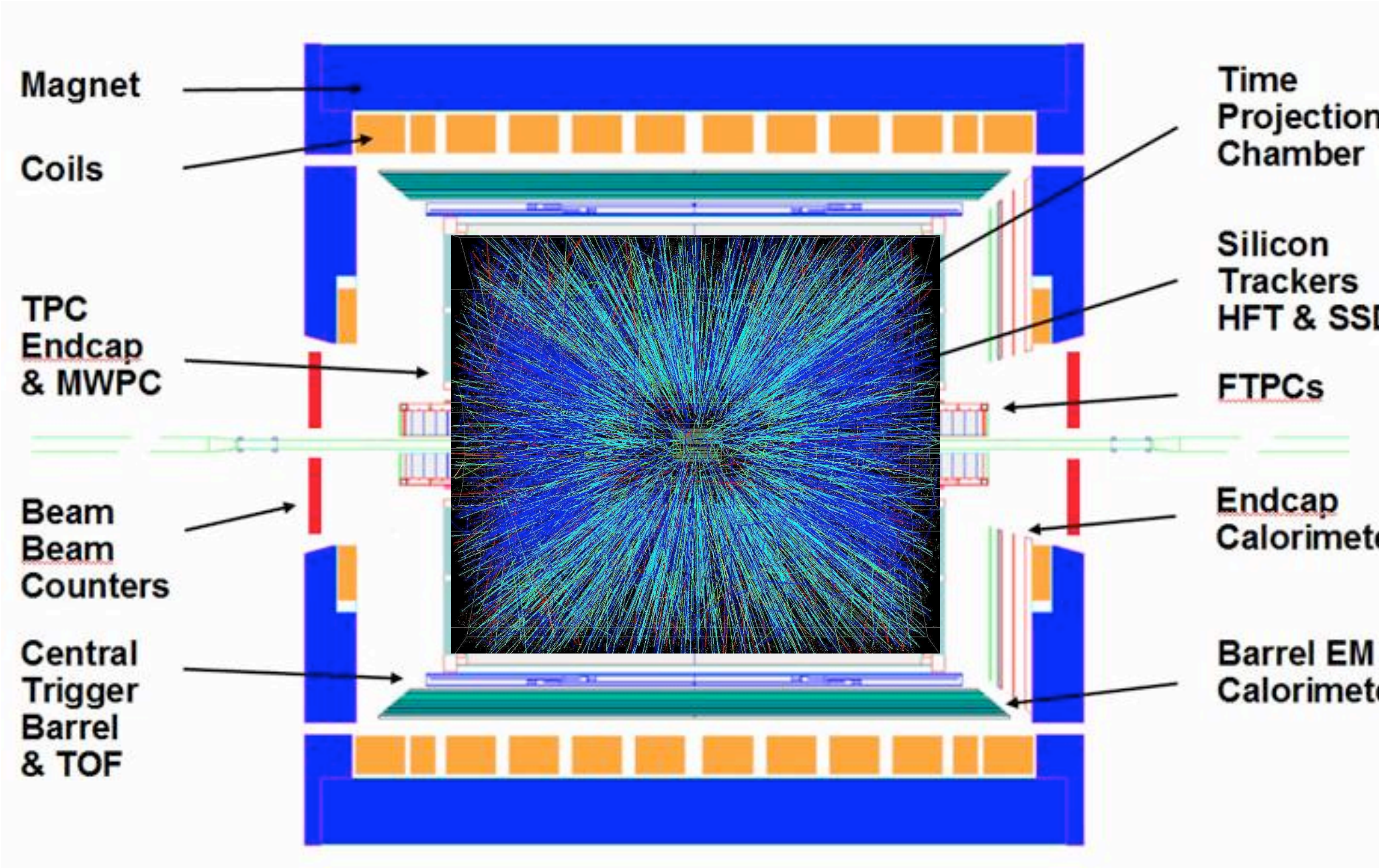
2006 Data

- Proton-proton collisions with tranversely polarised beams.
- Beam energy 100 GeV (200 GeV centre-of-mass energy).
- 3.1 million events.
- 354 STAR runs.

Typically achieved 50 to 60% polarisation.

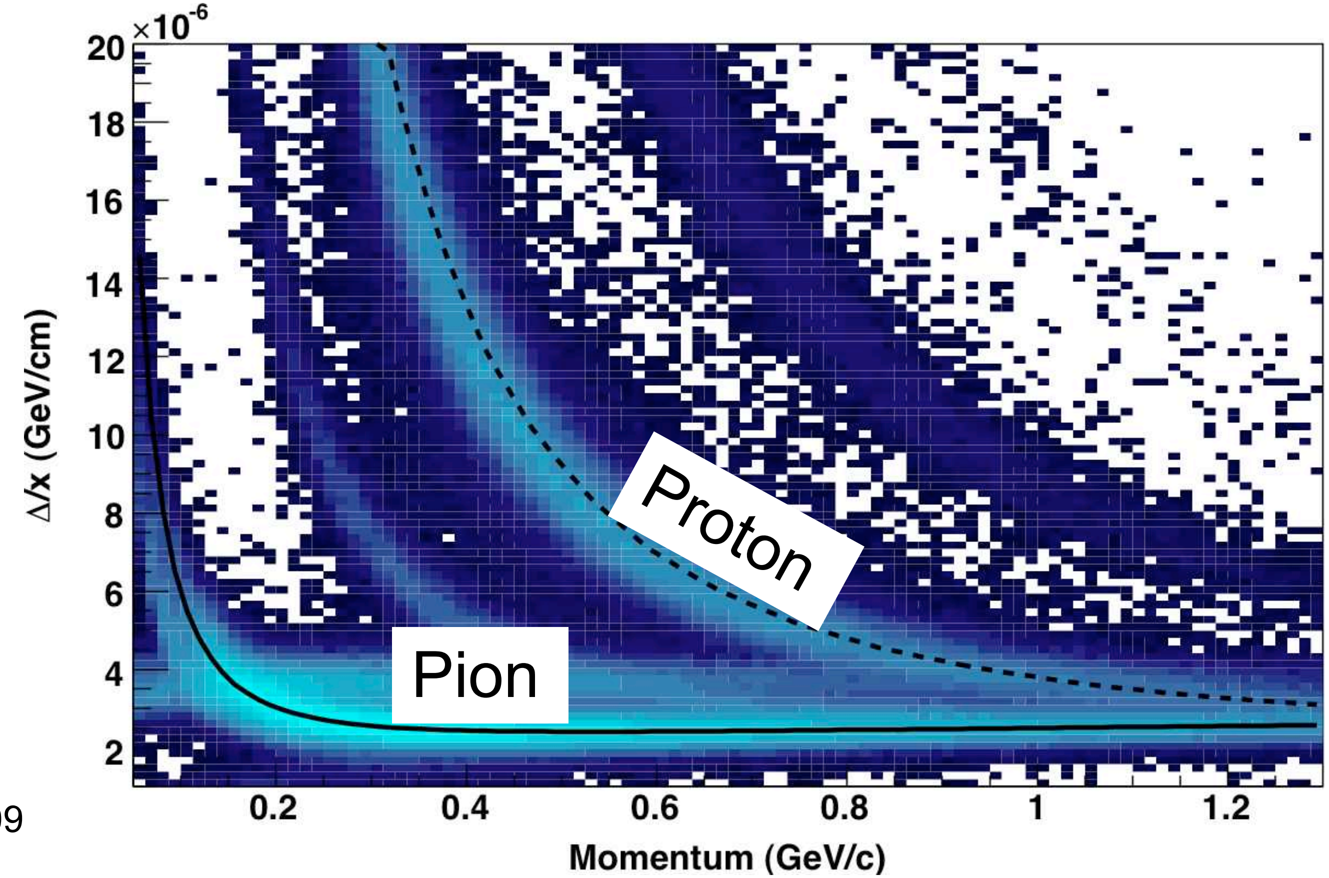


STAR


Magnet
Coils
TPC
Endcap
& MWPC
Beam
Beam
Counters
Central
Trigger
Barrel
& TOF
Time
Projection
Chamber
Silicon
Trackers
HFT & SSD
FTPCs
Endcap
Calorimeter
Barrel EM
Calorimeter

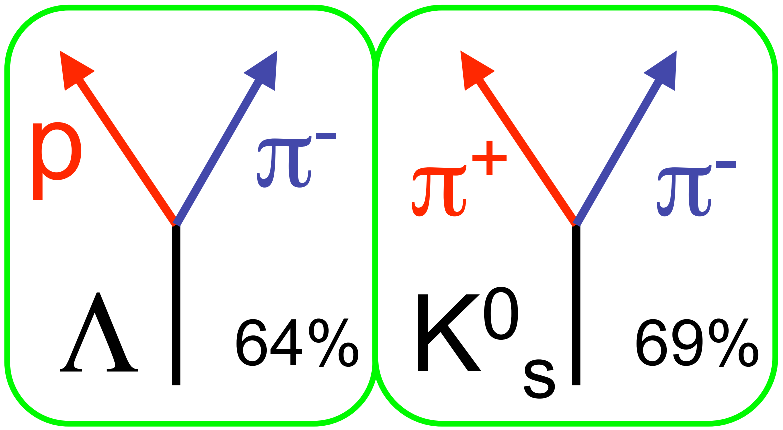
Charged particle Identification

- Charged particle identification limited to low momentum via energy loss measurements
  – Not used because I want to measure larger to p_T.



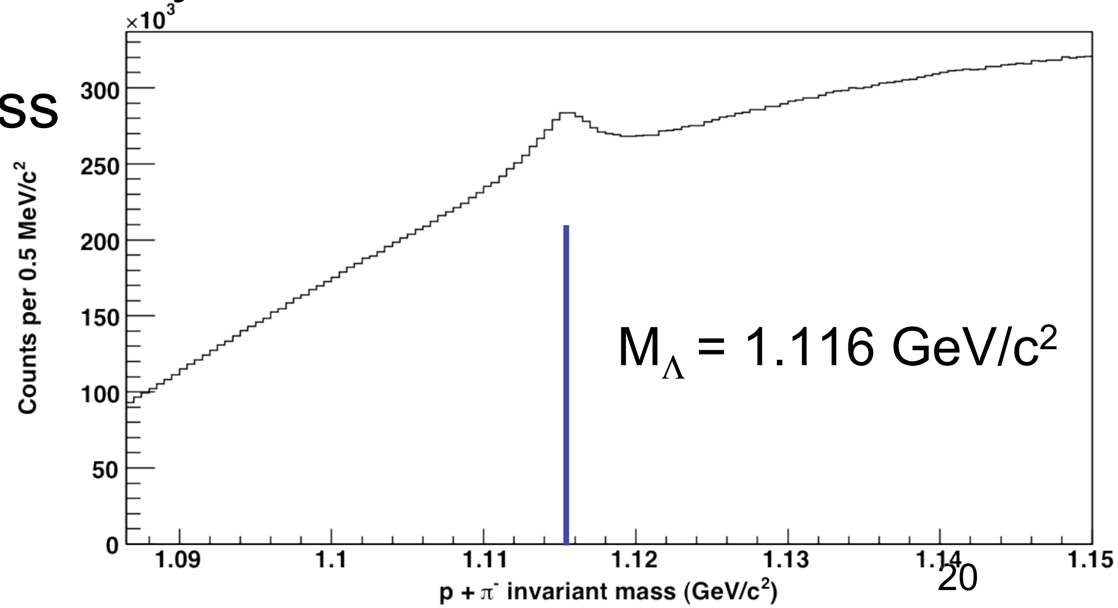
Strange particle identification

- Strange particles decay predominantly into 2 charged "daughter" particles
  - Neutral parent is not detected
  - Charged daughters can be detected.

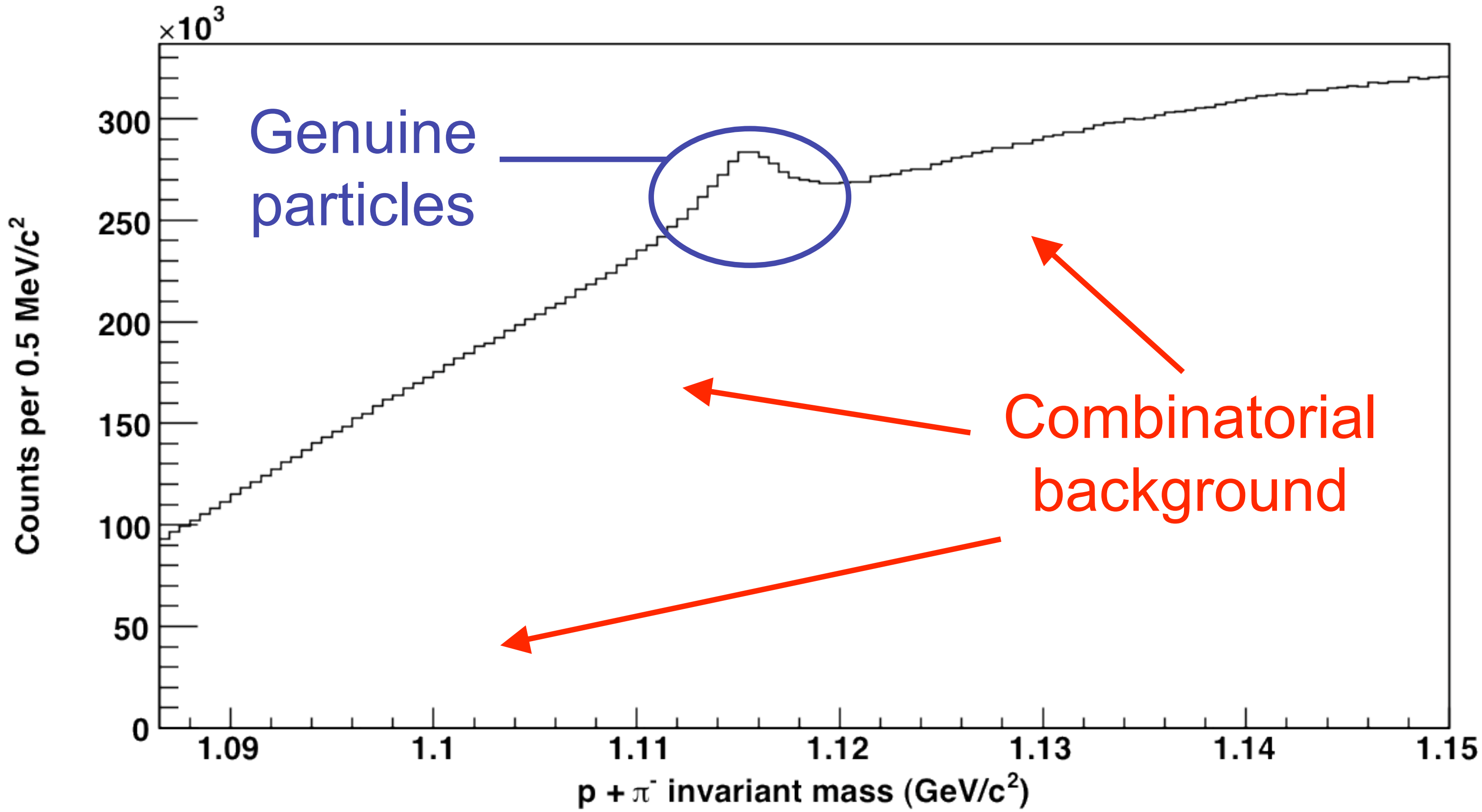


- Form every pair of oppositely charged particles and calculate invariant mass distributions:

$$M^2 = \left(\sum_{+,-} E\right)^2 - \left(\sum_{+,-} \overline{p}\right)^2$$

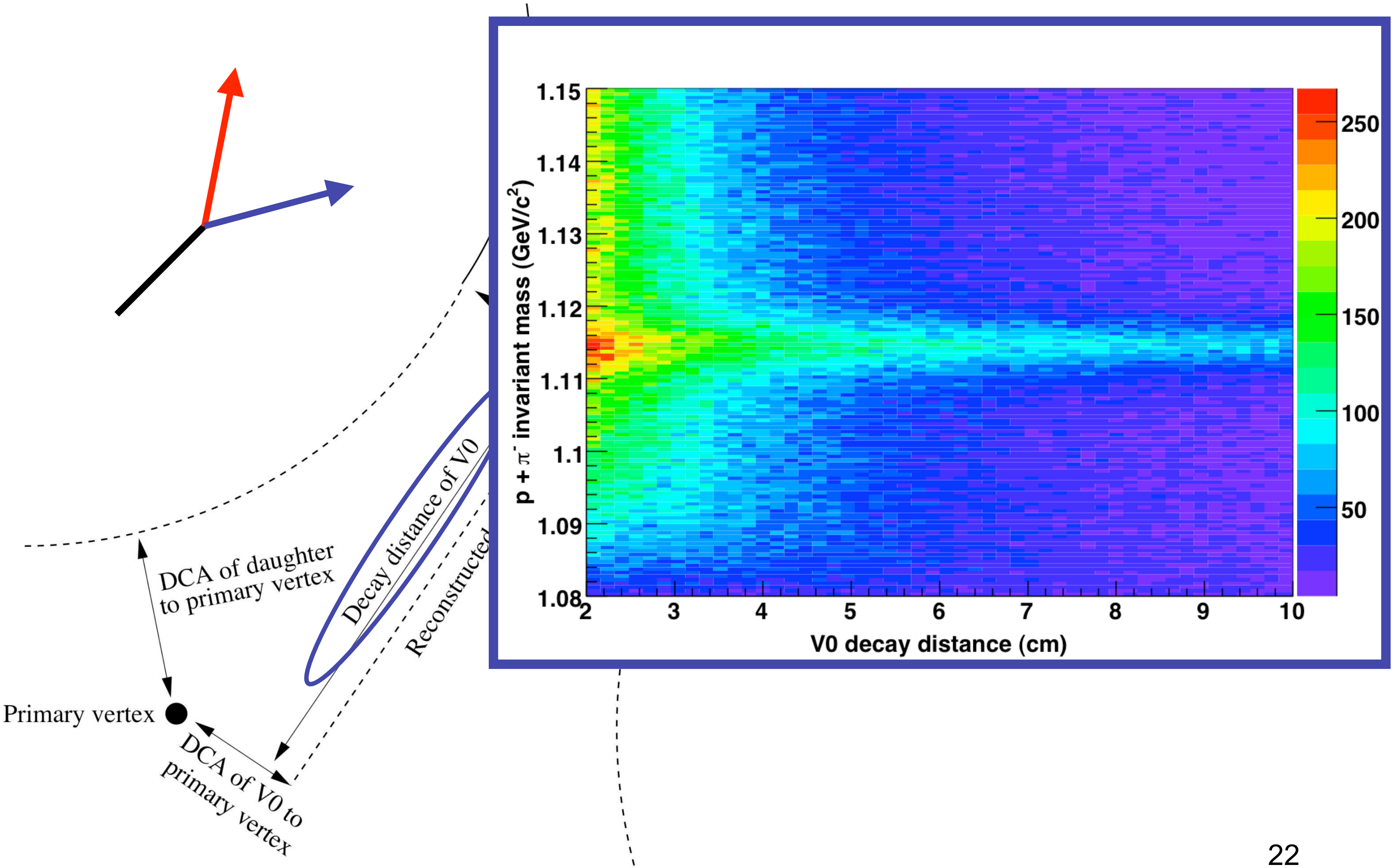


Reducing background



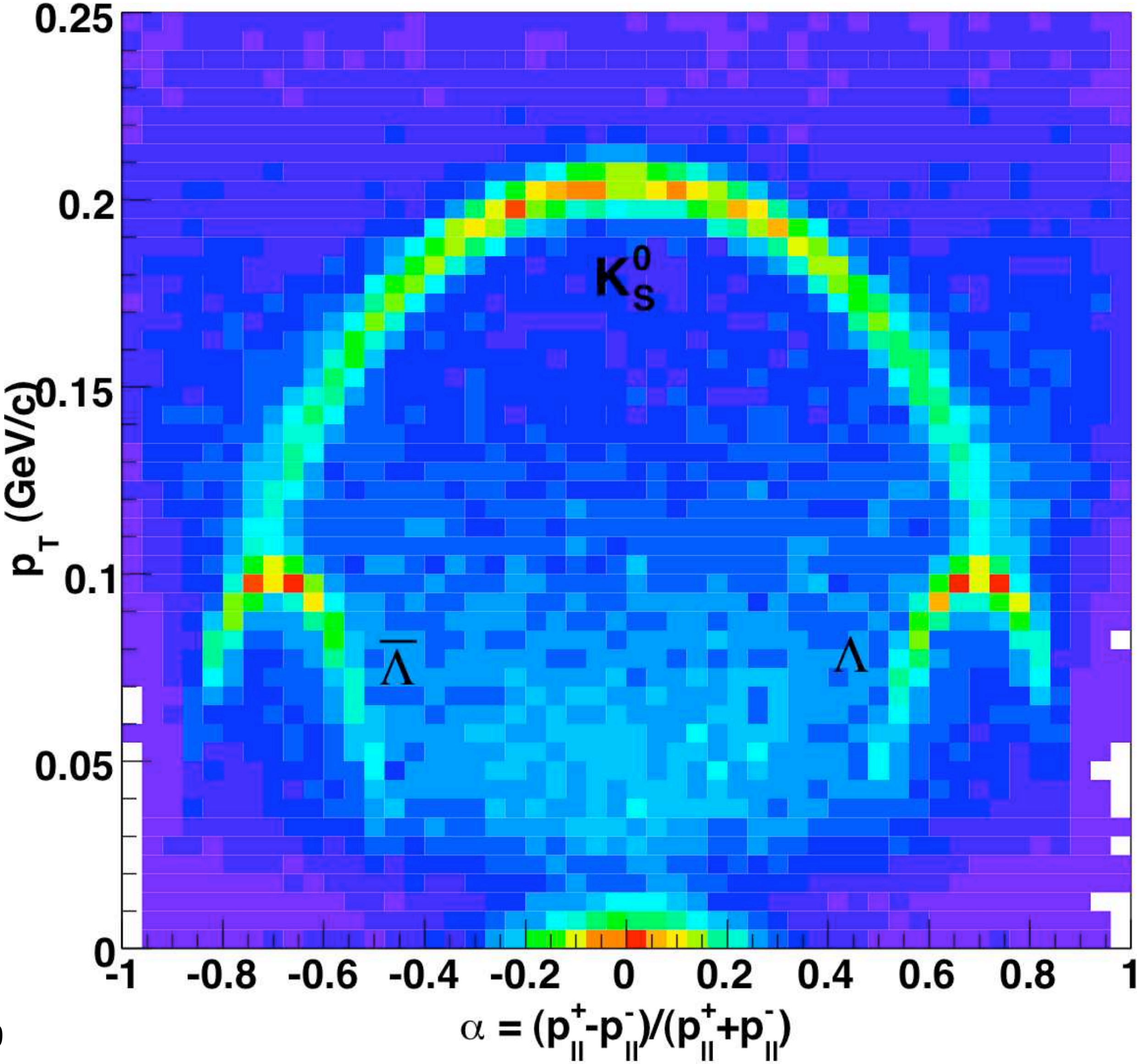
- Decay topology allows reduction of background by applying constraints to the decay vertex.

“V0” decay

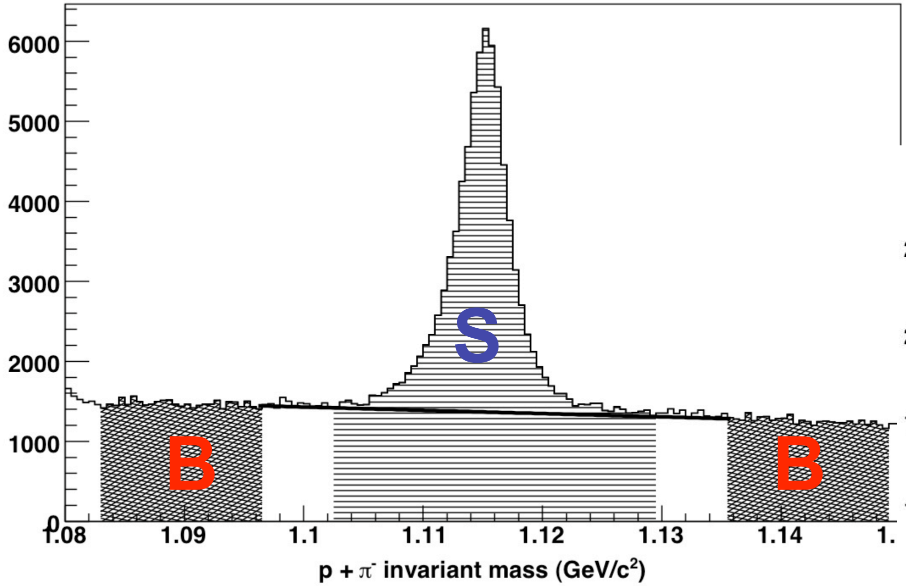


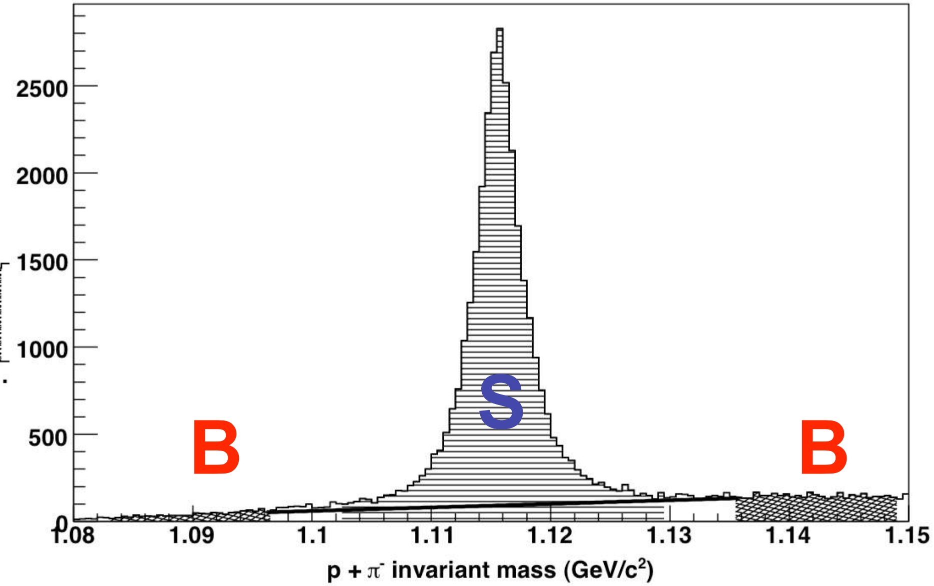
Primary vertex
DCA of daughter to primary vertex
Decay distance of V0
Reconstructed
DCA of V0 to primary vertex
p + π⁻ invariant mass (GeV/c²)
V0 decay distance (cm)
1.15
1.14
1.13
1.12
1.11
1.1
1.09
1.08
2
3
4
5
6
7
8
9
10
250
200
150
100
50

Armenteros Plot



Determining Yields

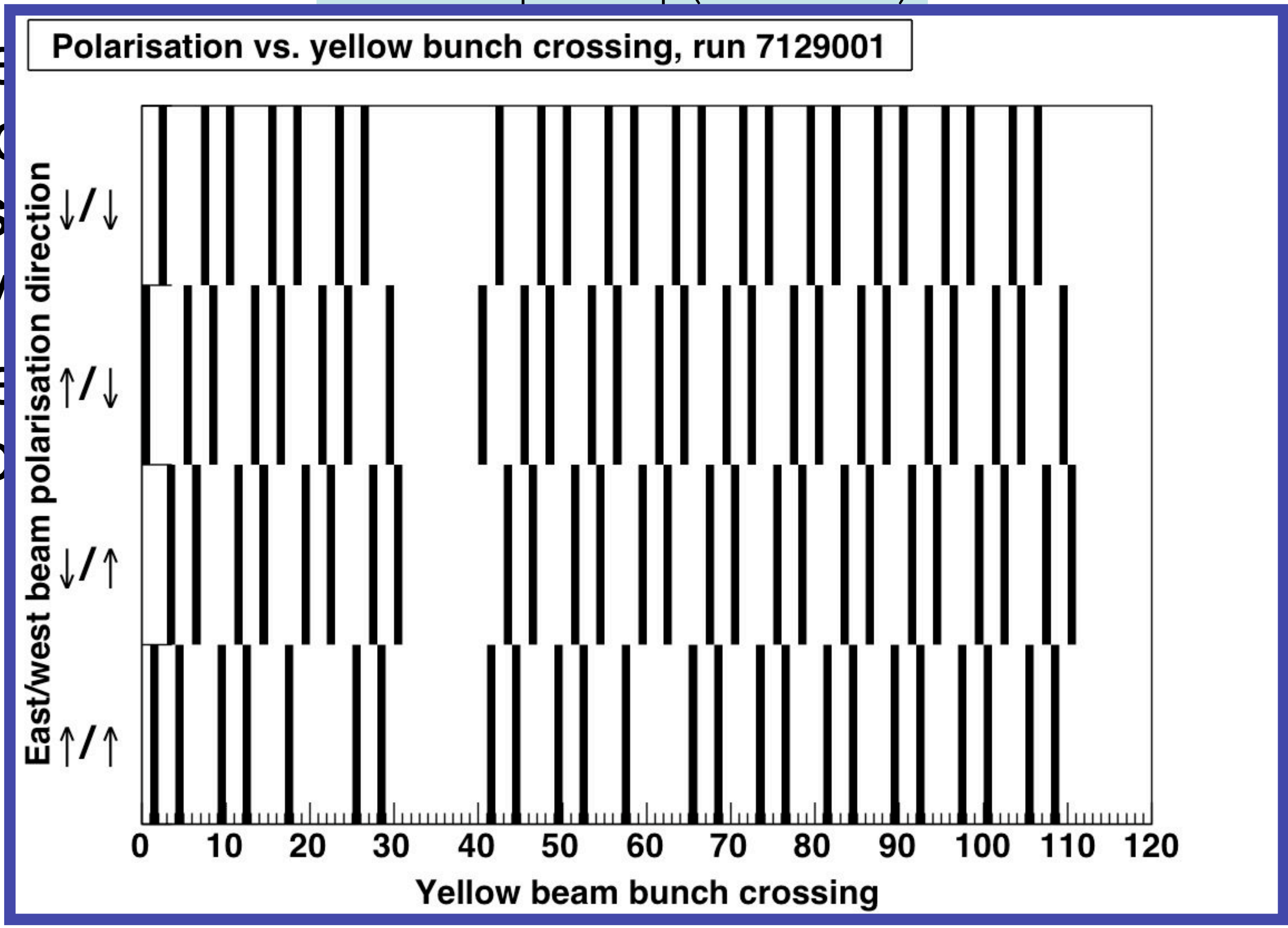




- Use counting method to determine yield.
  - Select cuts to give a linear background
  - Determine yield on a statistical basis.
  - Subtract **background** counts from **signal** counts

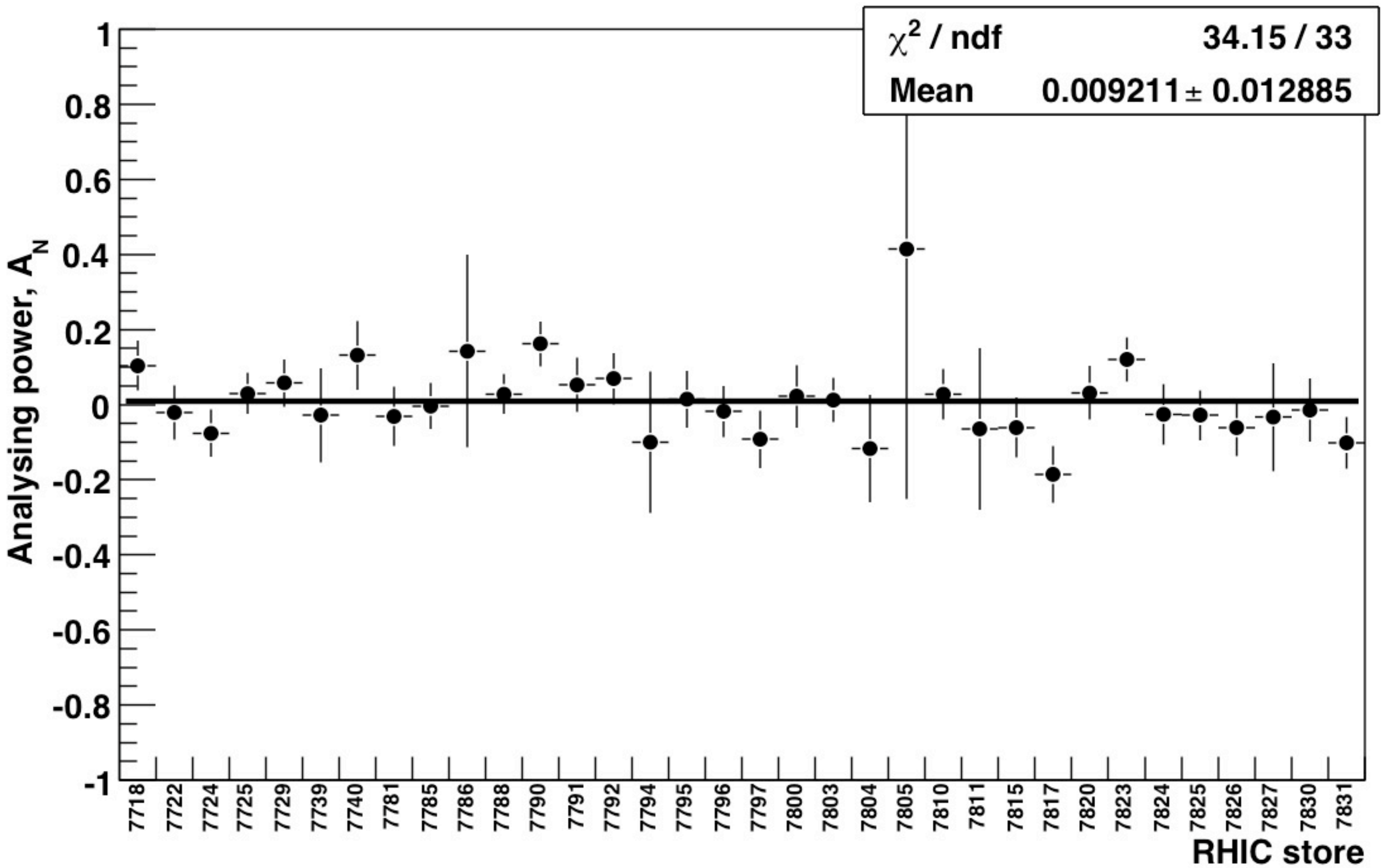
Asymmetry calculation

$$A_N = \frac{1}{P|\cos\phi|}\left(\frac{L^{\uparrow} - L^{\downarrow}}{L^{\uparrow} + L^{\downarrow}}\right)$$



- Be
  st
  as
  av
- Be
  po
  –
  –
  d
  n.

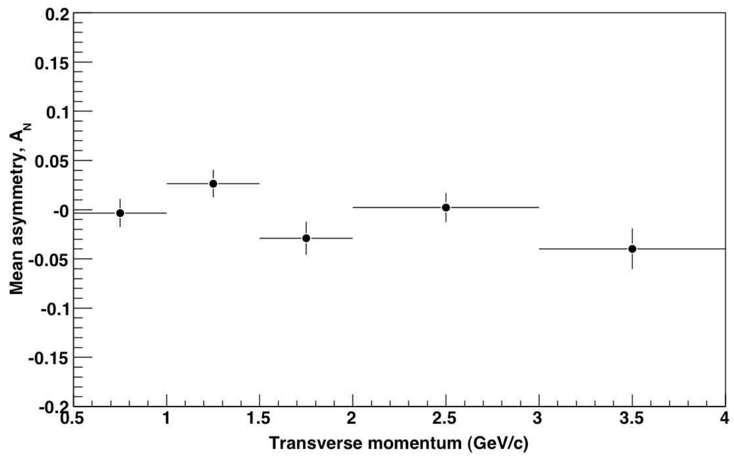
Asymmetry Calculation

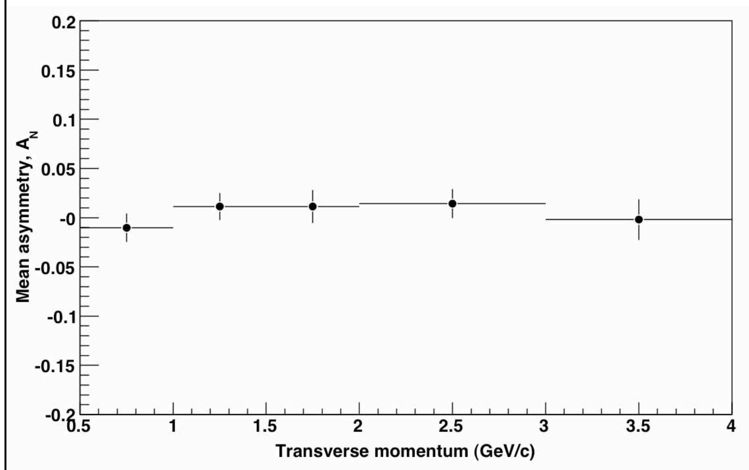


Results

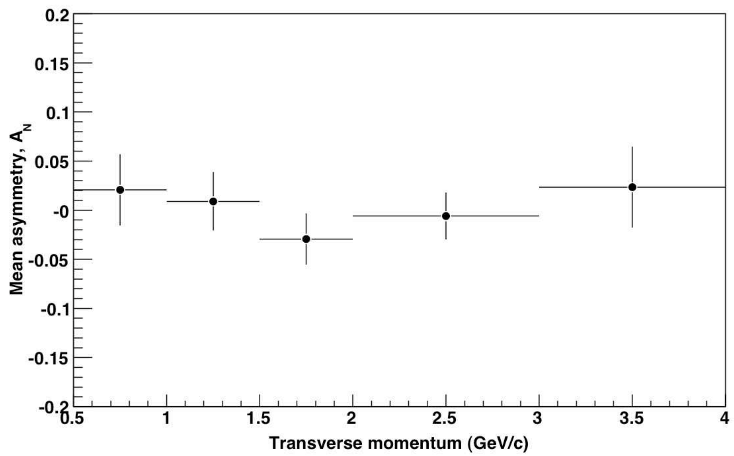
Small forward angles | Small backward angles

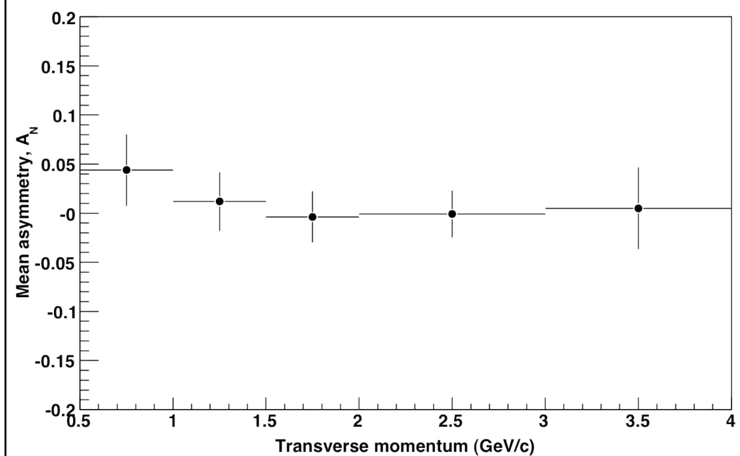
K^0_s





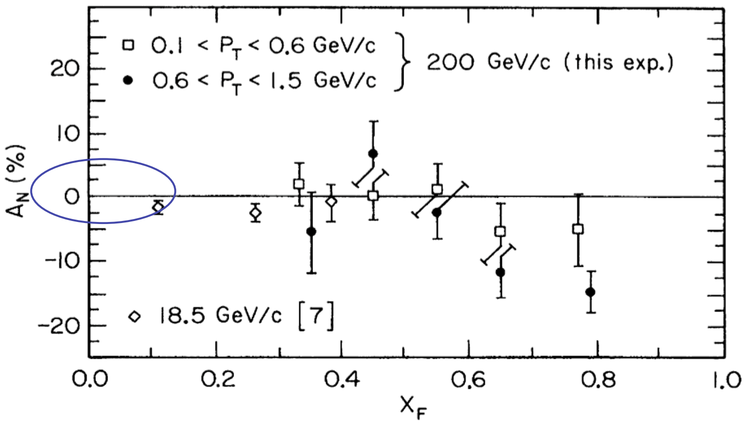
Λ

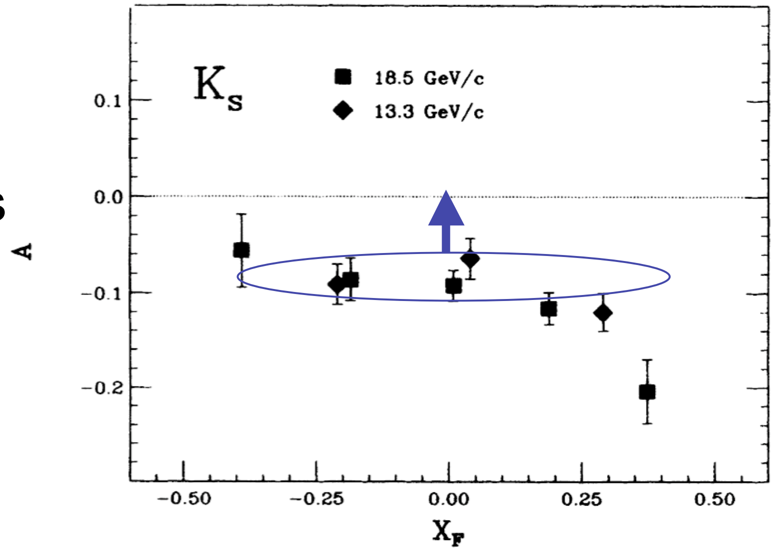




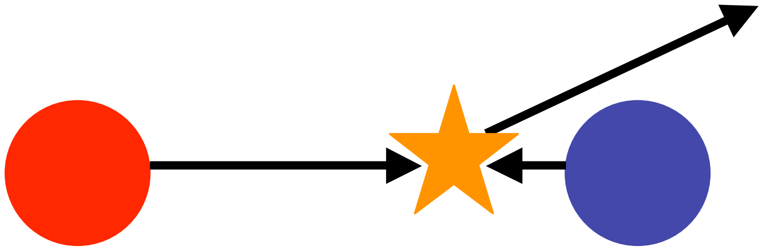
How does this compare?

- Λ: consistent with low-energy result.
- Anti-Λ: consistent with low-statistics low-energy result.
- K^0_S: differs from low-energy result:
  - negative asymmetry is absent at high energy.
  - Intermediate energy measurements would be interesting to follow trend.
  - These results agree with π^0 results for comparable kinematic range.

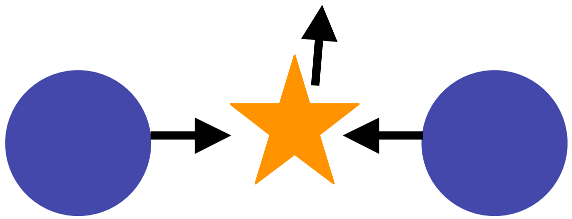




What does zero mean?



Large asymmetries at large forward angles due to valence + sea collisions.



Small asymmetries around 90° due to sea + sea collisions.

- Collisions involving valence quarks show significant transverse spin phenomena.
- Transverse spin effects for the sea are small.
  - c.f. helicity distributions.

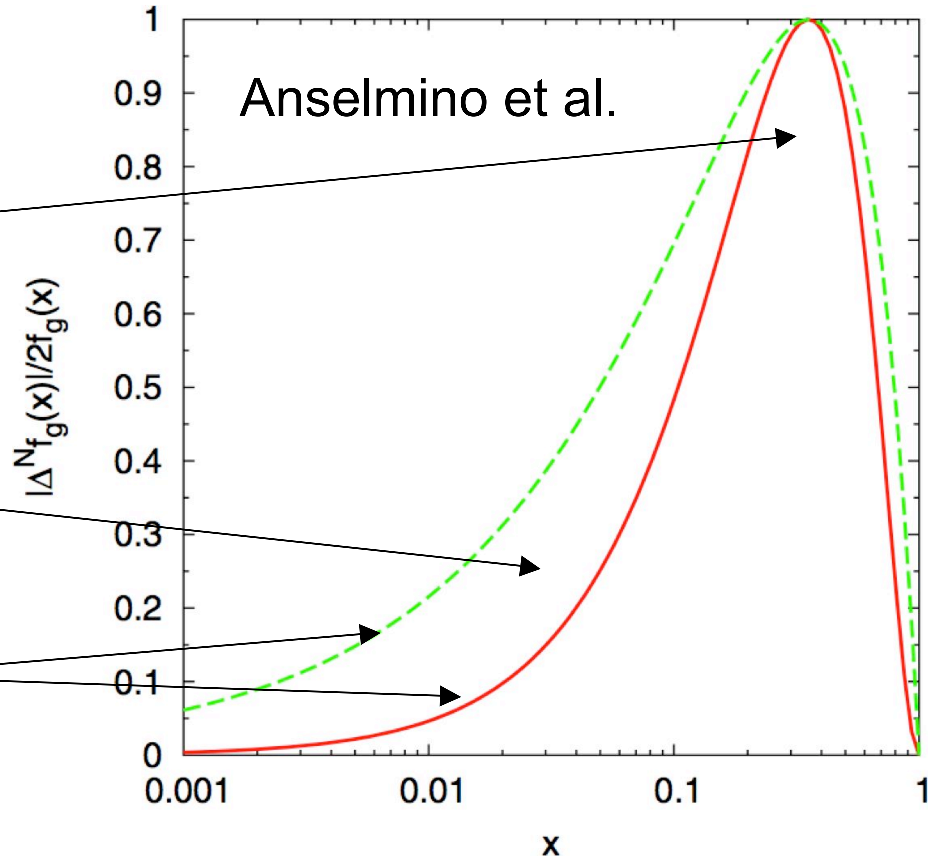
Gluon Sivers Distribution

- Strange particles may allow constraints on s quark distribution as well and u & d.
- Mid-rapidity production can strongly constrain gluon distribution

Poor constraint at forward angles where valence quarks dominate

Can constrain well where gluons dominate

Depends on assumptions about sea quarks



Summary

- Transverse spin asymmetries yield information about
  - The transversity distribution,
  - Collins and Sivers mechanisms.
- Mid-rapidity strange particle asymmetries are small
  - Transverse spin effects are small for the sea.
  - Mechanisms producing asymmetries depend on energy.
  - Can put limits on gluon Sivers distribution

Outlook

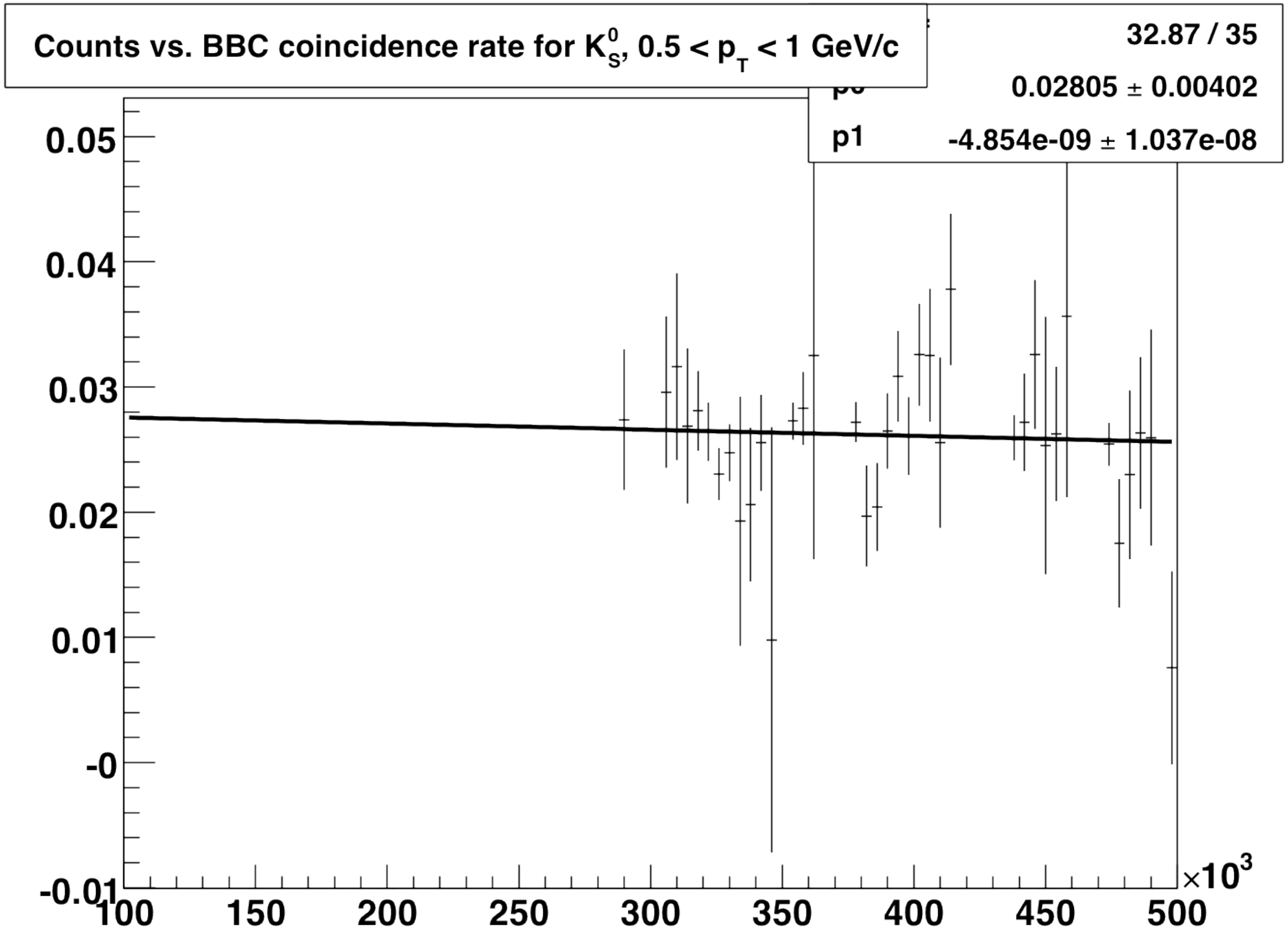
- Transversity have begun to be extracted.
- Transverse spin programmes continue at COMPASS, BELLE, STAR, PHENIX, JLab…
- EIC has the potential to further investigate transverse-momentum-dependent distributions.

STAR

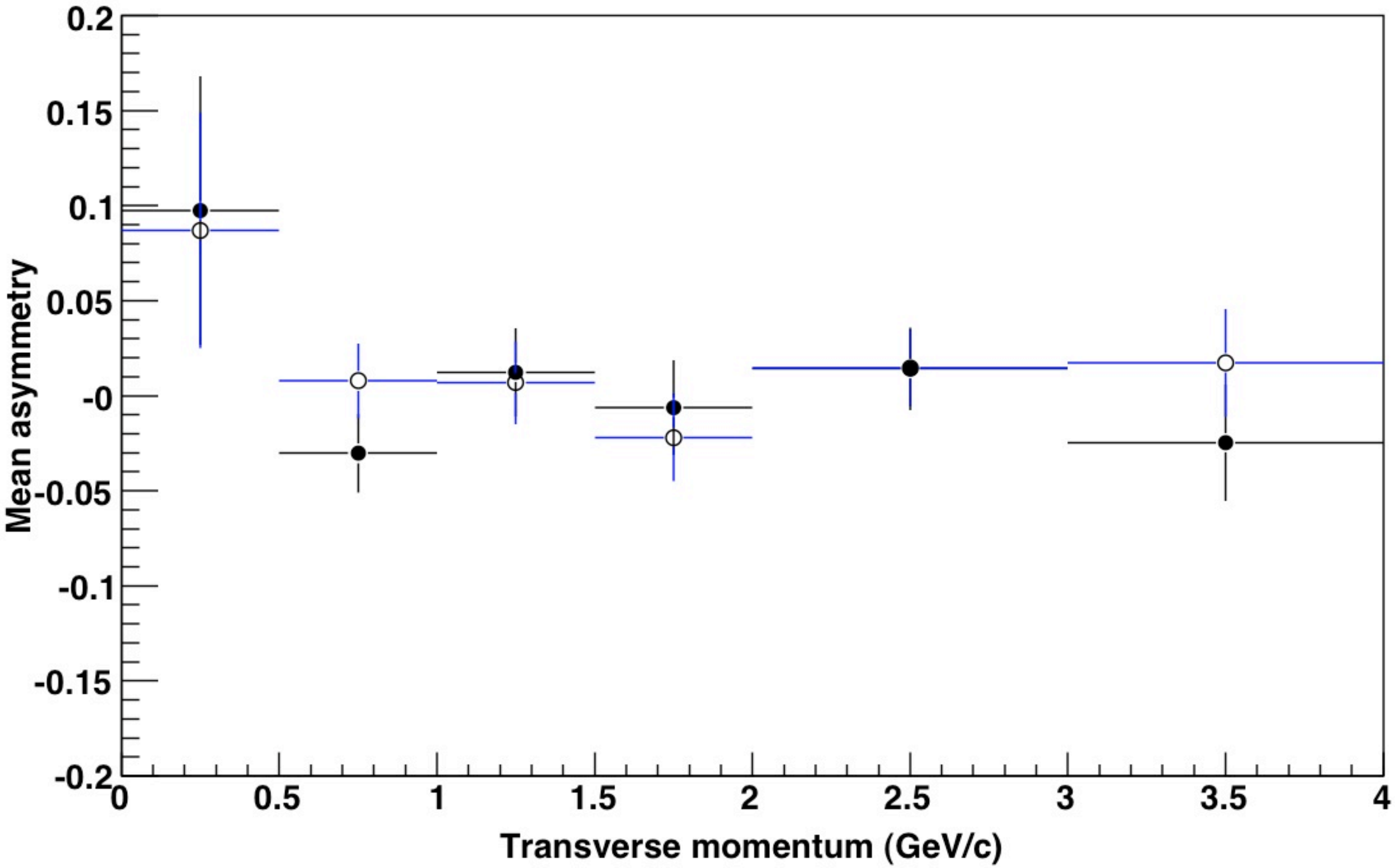
Thanks to…

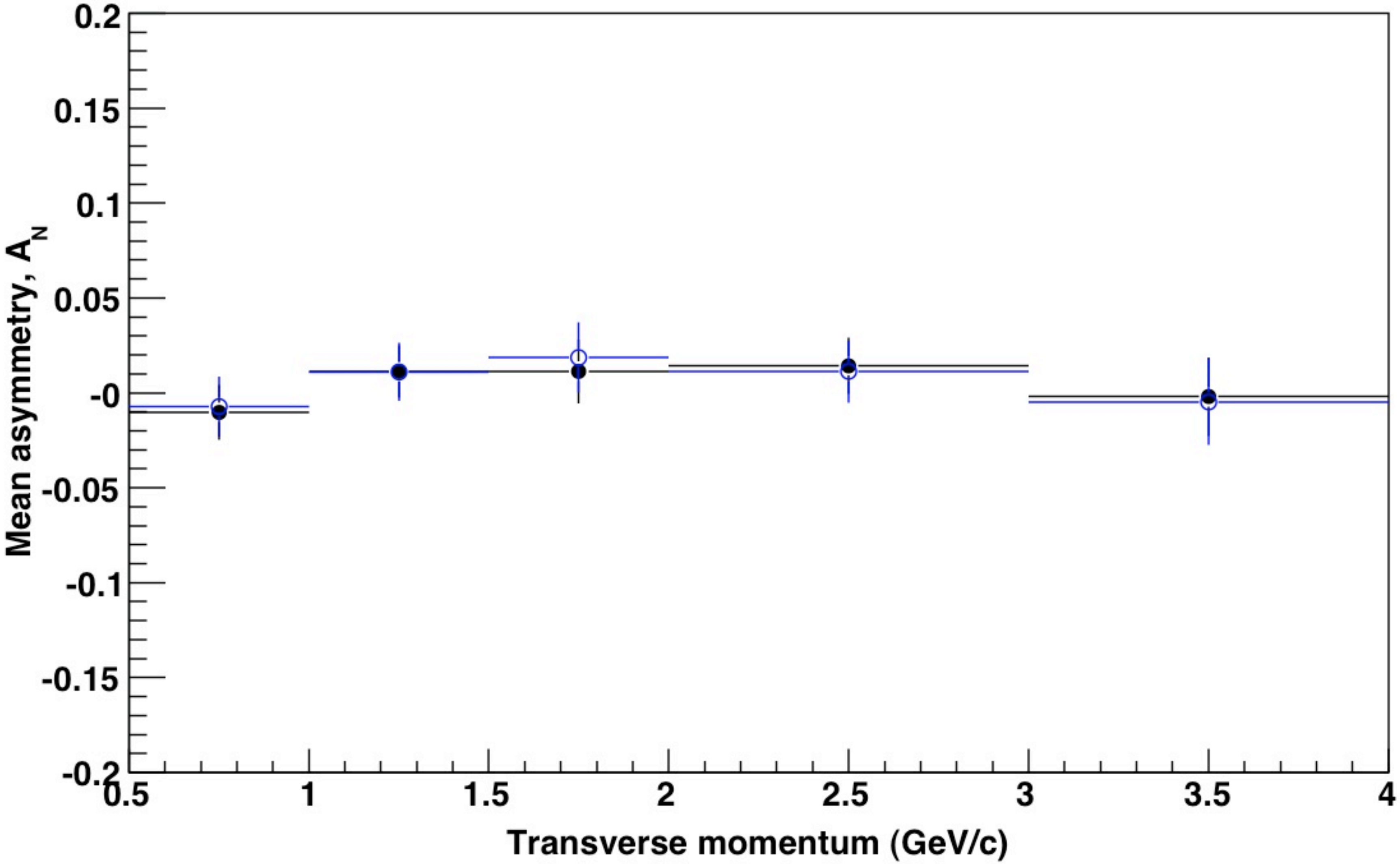
- STAR (Ernst Sichtermann, Carl Gagliardi, Jim Sowinski…)
- Birmingham group (Peter Jones, John Nelson, Lee Barnby, Essam Elhalhuli…)
- Yourselves.

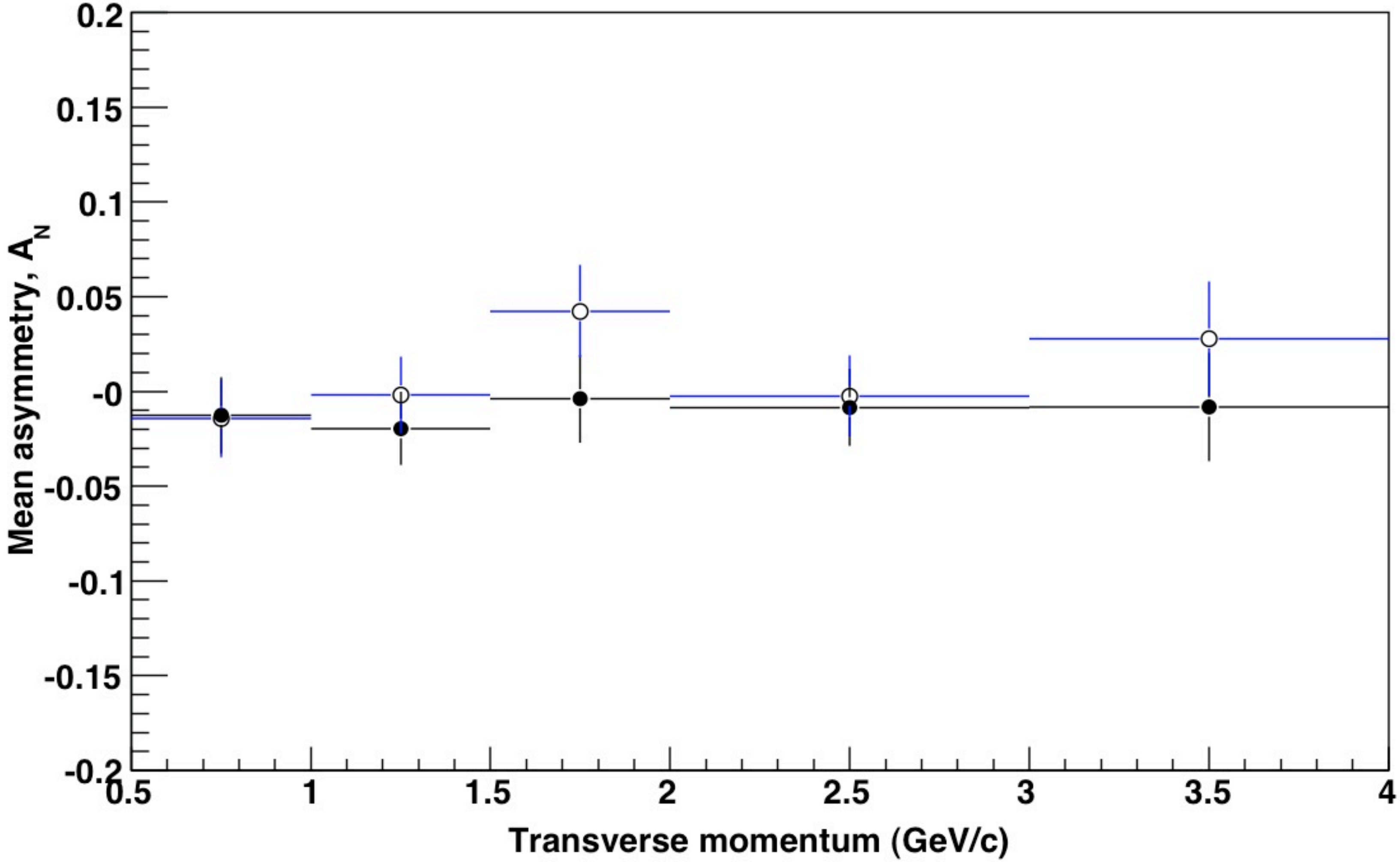
- Room 2-163
- tpb160@bham.ac.uk



Counts vs. BBC coincidence rate for K^0_S, 0.5 < p_T < 1 GeV/c
32.87 / 35
0.02805 ± 0.00402
p1
-4.854e-09 ± 1.037e-08
0.05
0.04
0.03
0.02
0.01
-0
-0.01
100
150
200
250
300
350
400
450
500
$\times 10^3$


0.2
0.15
0.1
0.05
-0
-0.05
-0.1
-0.15
-0.2
Mean asymmetry
0
0.5
1
1.5
2
2.5
3
3.5
4
Transverse momentum (GeV/c)


Mean asymmetry, A_N
0.2
0.15
0.1
0.05
-0
-0.05
-0.1
-0.15
-0.2
0.5
1
1.5
2
2.5
3
3.5
4
Transverse momentum (GeV/c)



Mean asymmetry, A_N
0.2
0.15
0.1
0.05
-0
-0.05
-0.1
-0.15
-0.2
0.5
1
1.5
2
2.5
3
3.5
4
Transverse momentum (GeV/c)

- Using luminosity:

$$A_N P = \frac{1}{\cos\phi} \frac{\left(N^{\Uparrow\Uparrow}/\mathscr{R}^{\Uparrow\Uparrow} + N^{\Uparrow\Downarrow}/\mathscr{R}^{\Uparrow\Downarrow}\right) - \left(N^{\Downarrow\Uparrow}/\mathscr{R}^{\Downarrow\Uparrow} + N^{\Downarrow\Downarrow}\right)}{\left(N^{\Uparrow\Uparrow}/\mathscr{R}^{\Uparrow\Uparrow} + N^{\Uparrow\Downarrow}/\mathscr{R}^{\Uparrow\Downarrow}\right) + \left(N^{\Downarrow\Uparrow}/\mathscr{R}^{\Downarrow\Uparrow} + N^{\Downarrow\Downarrow}\right)}.$$

- Cancelling luminosity:

$$A_N P = \frac{1}{\cos\phi} \frac{\sqrt{\left(L^{\Uparrow\Uparrow} + L^{\Uparrow\Downarrow}\right)\left(R^{\Downarrow\Uparrow} + R^{\Downarrow\Downarrow}\right)} - \sqrt{\left(L^{\Downarrow\Uparrow} + L^{\Downarrow\Downarrow}\right)\left(R^{\Uparrow\Uparrow} + R^{\Uparrow\Downarrow}\right)}}{\sqrt{\left(L^{\Uparrow\Uparrow} + L^{\Uparrow\Downarrow}\right)\left(R^{\Downarrow\Uparrow} + R^{\Downarrow\Downarrow}\right)} + \sqrt{\left(L^{\Downarrow\Uparrow} + L^{\Downarrow\Downarrow}\right)\left(R^{\Uparrow\Uparrow} + R^{\Uparrow\Downarrow}\right)}}.$$