Constraining Quark Transversity through Collins Asymmetry Measurements at STAR

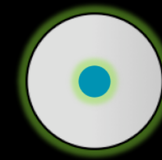
PANIC11 RUTHERFORD CENTENNIAL

Renee Fatemi
University of Kentucky
for the STAR Collaboration

Parton Dynamics inside of Matter

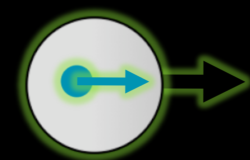
$$f(x)$$

Number density of partons with flavor f and momentum fraction x inside a nucleon



$$\Delta f(x)$$

Number density of longitudinally polarized partons inside longitudinally polarized nucleons (Helicity)



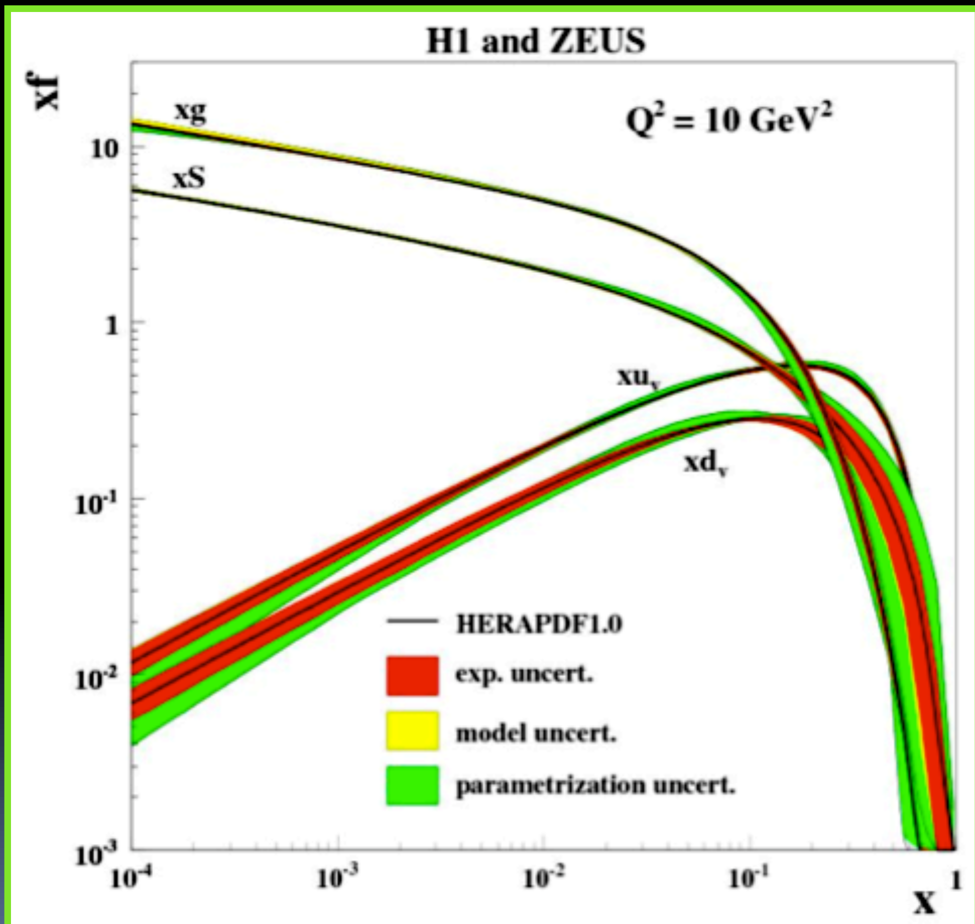
$$\Delta_T f(x)$$

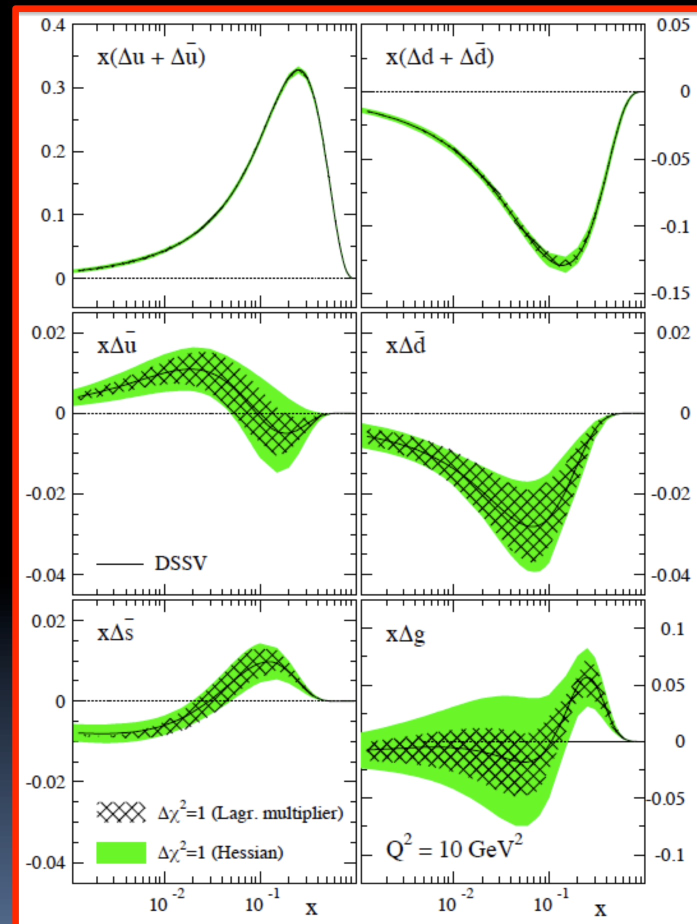
Number density of transversely polarized partons inside a transversely polarized nucleon (Transversity)

Nucleon Momentum

At **LEADING TWIST** in a **COLLINEAR FRAMEWORK** these functions form a **COMPLETE** description of partonic kinematics

Momentum and Helicity Distributions

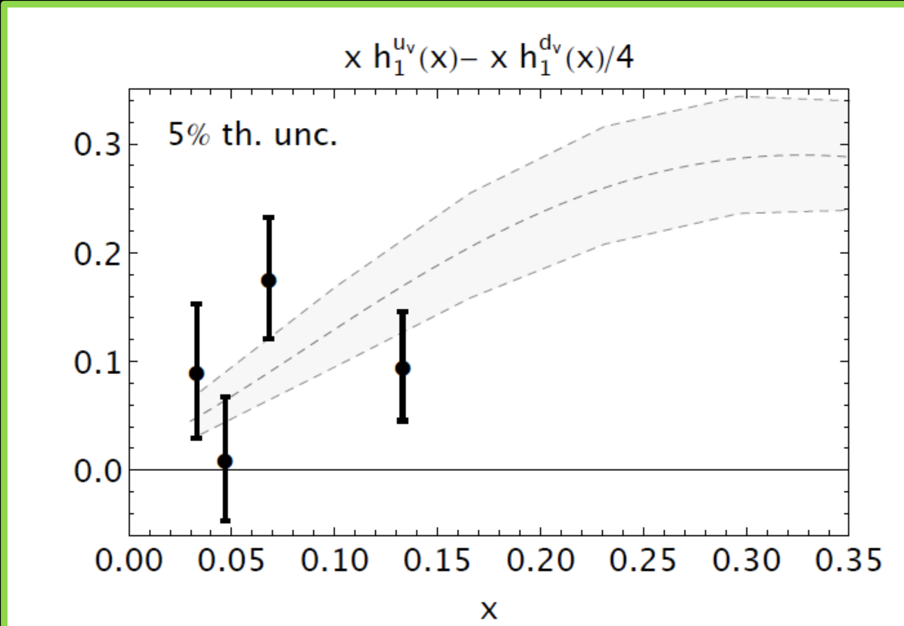




DSSV Phys.Rev.D80:034030,2009

Transversity is less constrained

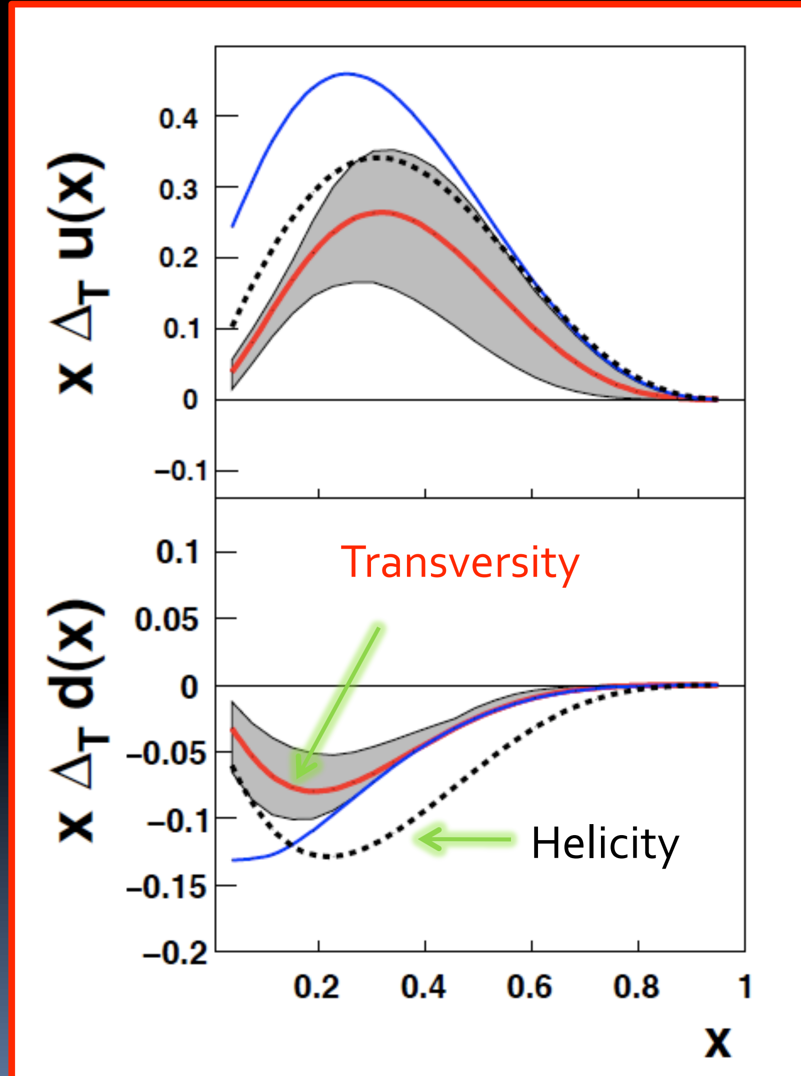
arXiv:1104.3855



- First indications are $\Delta_T f(x) < \Delta f(x)$.
- Soffer bound requires:

$$\left|\Delta_T f(x)\right| \leq \frac{1}{2}\left[f(x) + \Delta f(x)\right]$$

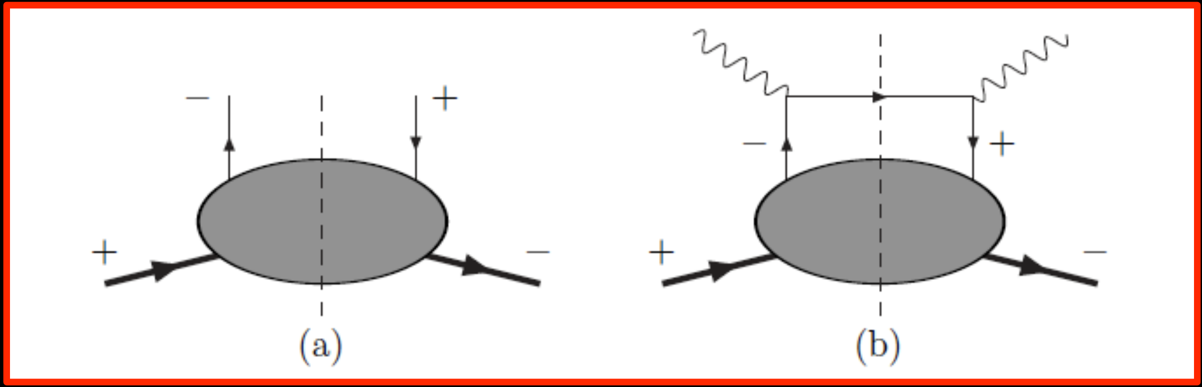
- Kinematic x range smaller and fits generally less constrained

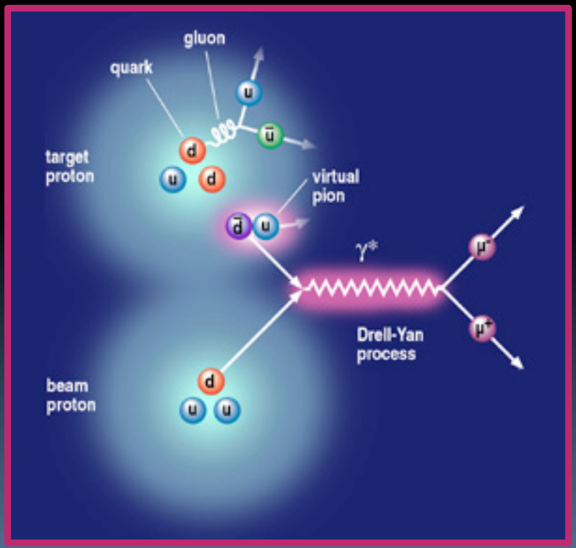


Nucl.Phys.Proc.Suppl. 191 (2009) 98-107

Why don't we know more ?

$\Delta_T f(x)$ is CHIRAL ODD. In a helicity basis this corresponds to a helicity flip of both the incoming nucleon and parton.





- Not observable in inclusive DIS because flipping of chirality is highly suppressed!
- Must access $\Delta_T f(x)$ by coupling to a second chiral odd function.
- Ralston and Soper proposed Drell-Yan but …
  - low rates compared to other hadronic processes
  - anti-quark transversity is probably very small
- Could also look at inclusive jet A_{TT} however …
  - Gluons are abundant and have ZERO Δ_T distribution
  - A_{TT} must be smaller than already small A_{LL}

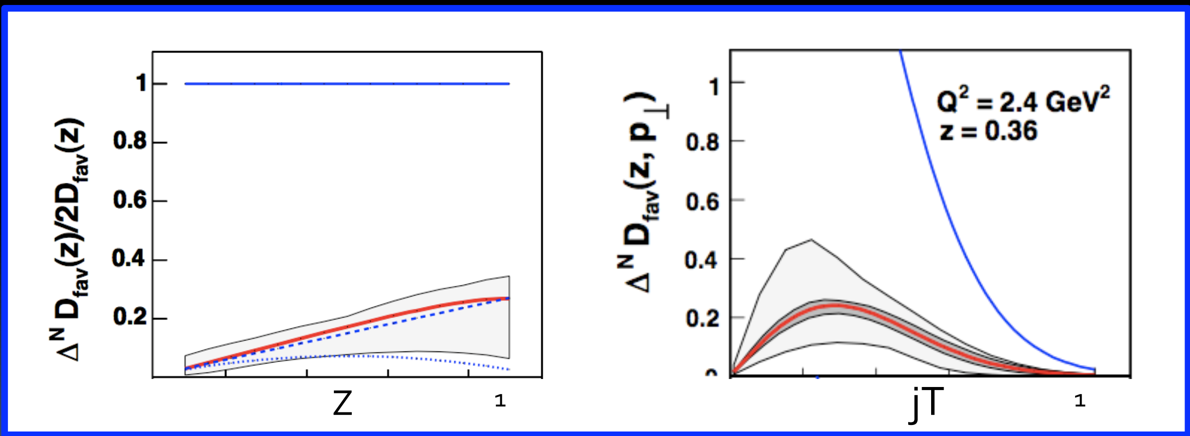
Another Experimental Approach:
Single spin asymmetries

- Coupling of a chiral odd fragmentation function with the beam $\Delta_T f(x)$

$$A \approx \sum_{f_1 f_2} \frac{\Delta_T f_1(x_1) f_2(x_2) \hat{a}(s,t,u) \Delta D^{\pi}_{f_1}(z, j_T)}{f_1(x) f_2(x) D^{\pi}_{f_1}(z, j_T)}$$

- **Collins Functions** – spin of transversely polarized quark is correlated with jT kick given to fragmentation hadron

Nucl.Phys.Proc.Suppl. 191 98-107, 2009

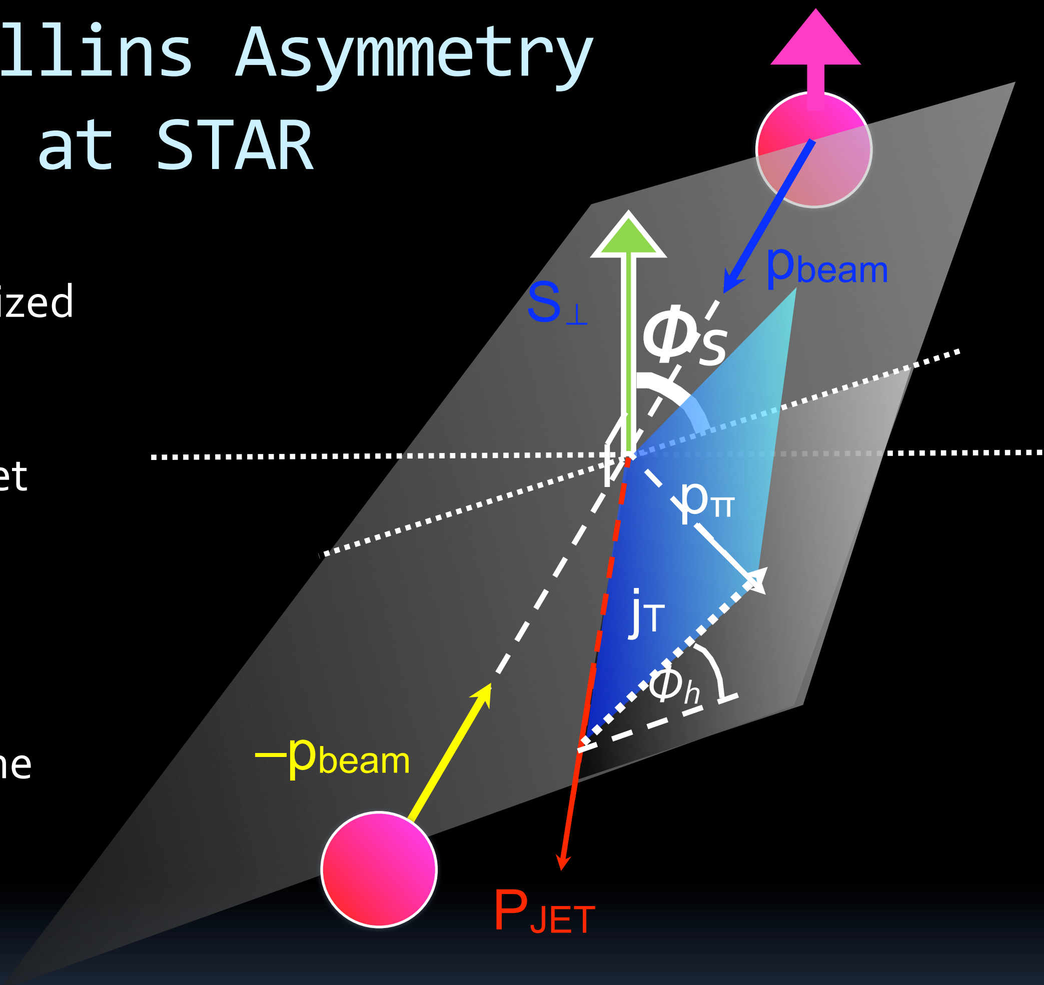


- Measured at Belle and in SIDIS and extracted in a Global Analysis.
- Relatively large Increasing with fragmentation z.

- Interference Fragmentation Functions – another Chiral-odd FF. Measurement involves SSA between correlated charged and neutral pions. Won't be discussed here but analysis is proceeding in STAR Collaboration.

Mid-Rapidity Collins Asymmetry Analysis at STAR

- RHIC provides the transversely polarized protons at $\sqrt{s}$ = 200 GeV
- STAR provides the full mid-rapidity jet reconstruction and charged pion identification
- Look for spin dependent azimuthal distributions of charged pions inside the jets! First proposed by F. Yuan in **Phys.Rev.Lett.100:032003.**
- **Measure average weighted yield:**

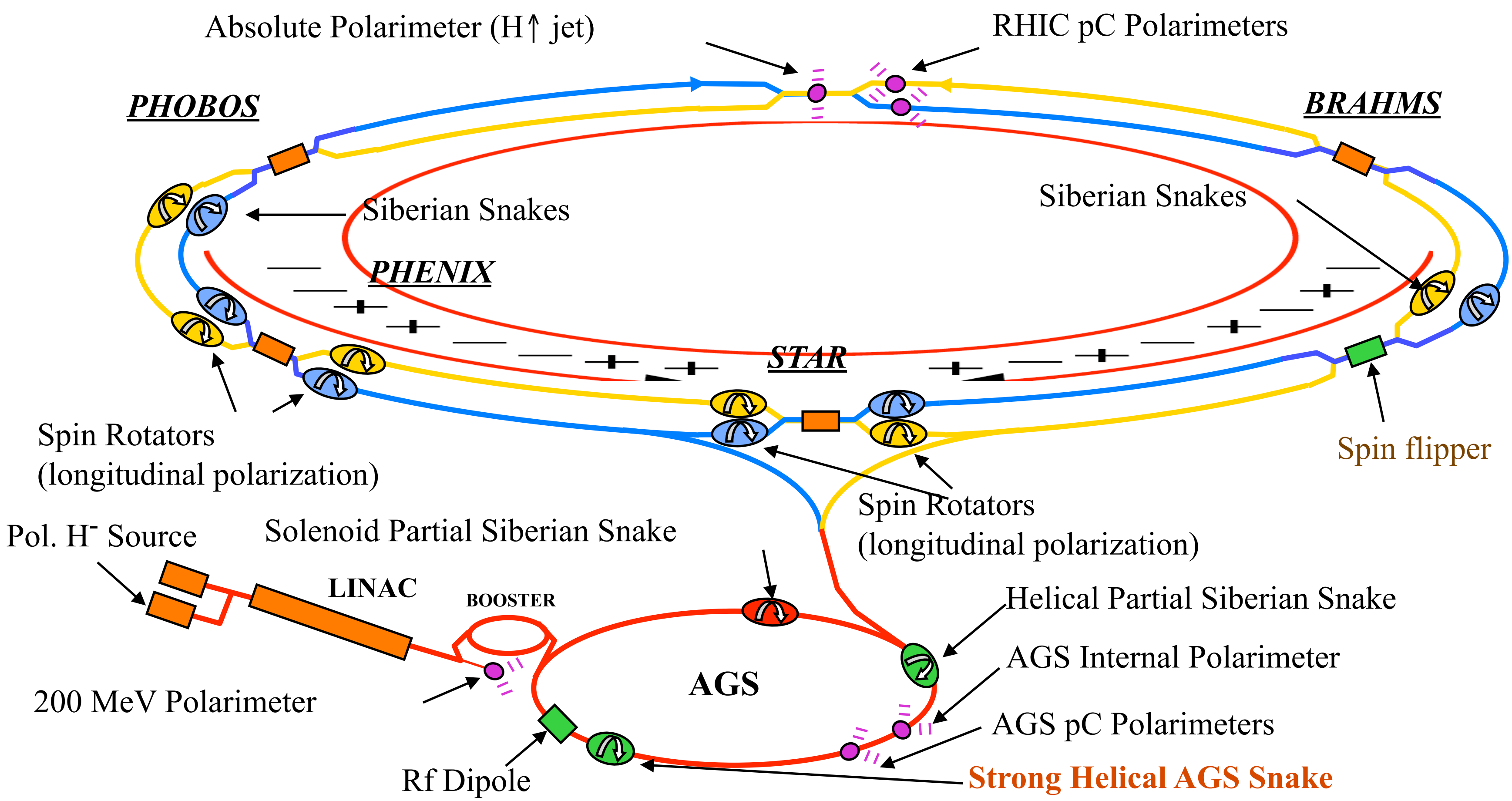


$$A_{\exp} = \frac{2\int N \sin(\phi_C)\, d\phi_c}{P_{Beam} N}$$

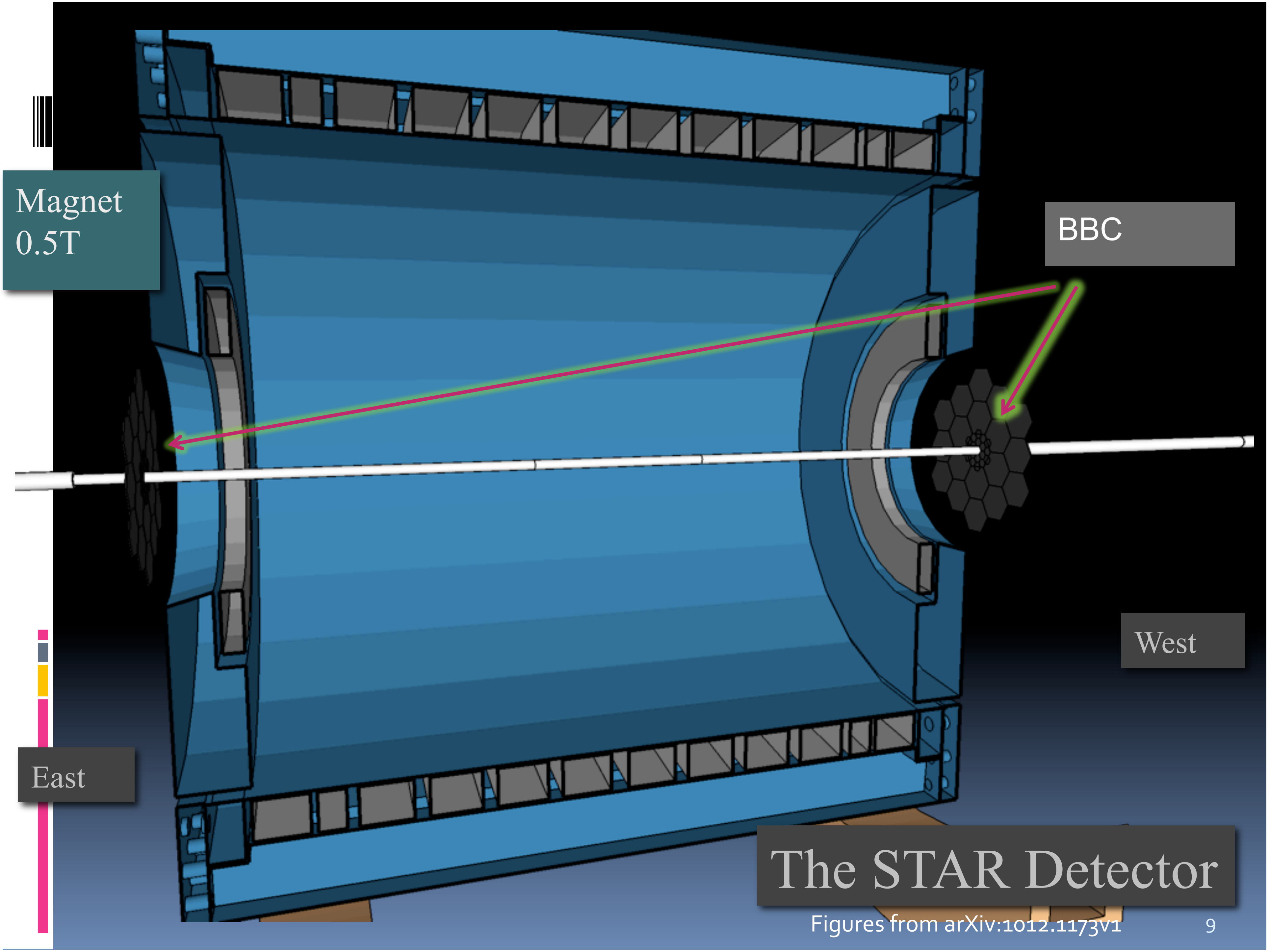
$$d\sigma \approx d\sigma^{UU}\left[1 + A_N \sin(\phi_h - \phi_s)\right]$$

Relativistic Heavy Ion Collider

…worlds 1st $\vec{p}\vec{p}$ Collider



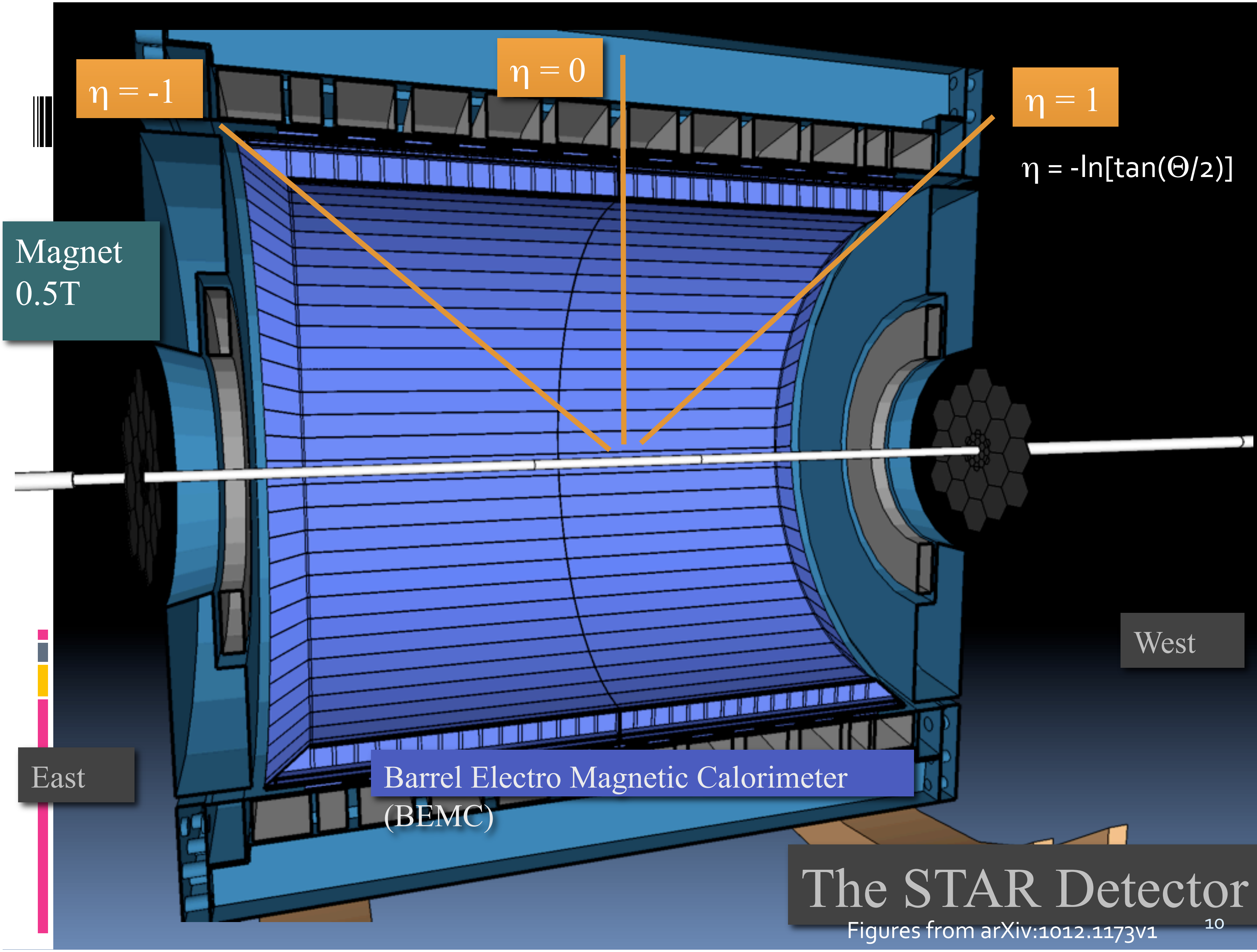
2006 Transverse Run: ~58% polarization and 2.2 pb^{-1} integrated lumi



The STAR Detector

Figures from arXiv:1012.1173v1

The STAR Detector



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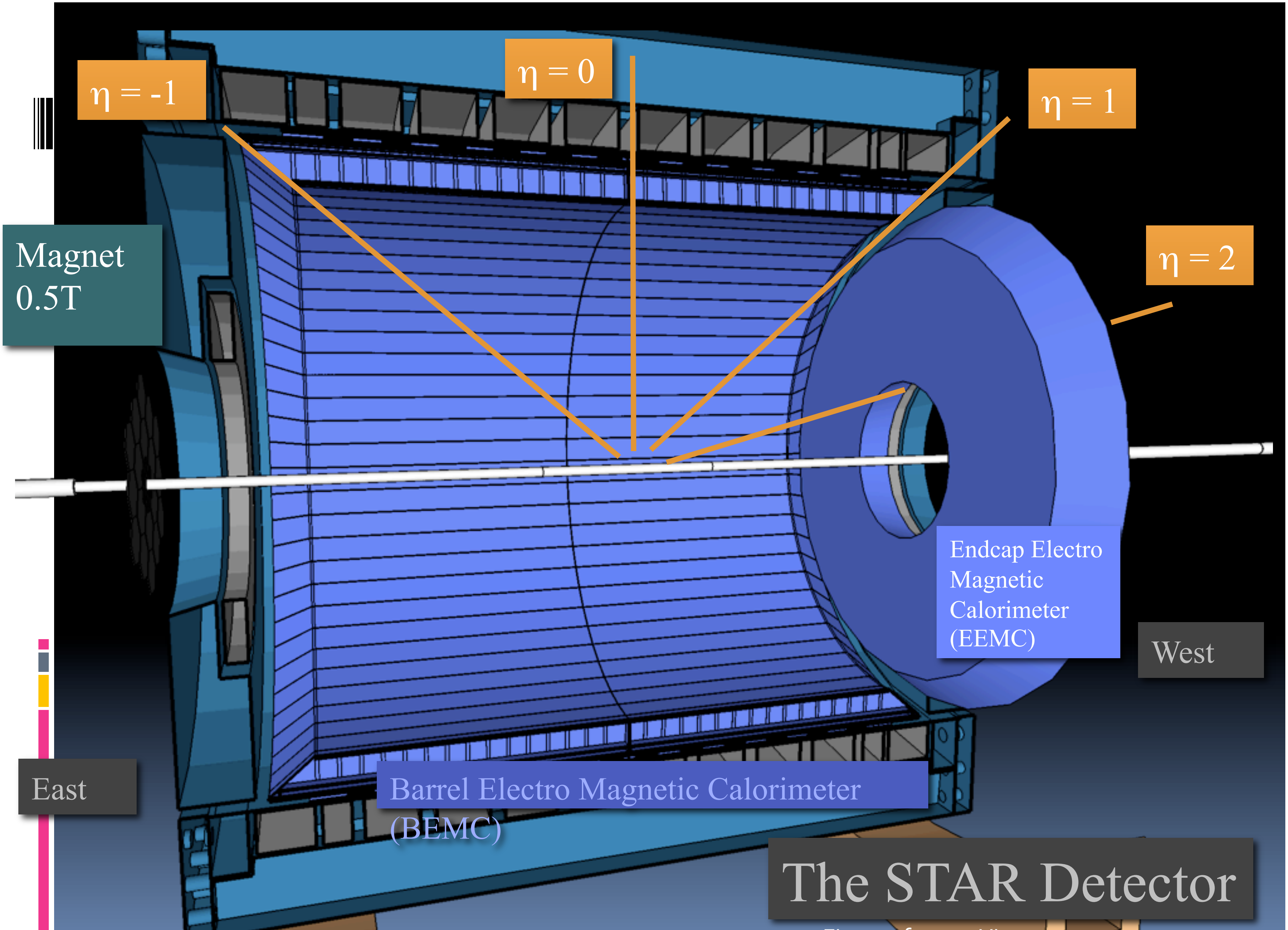
The STAR Detector



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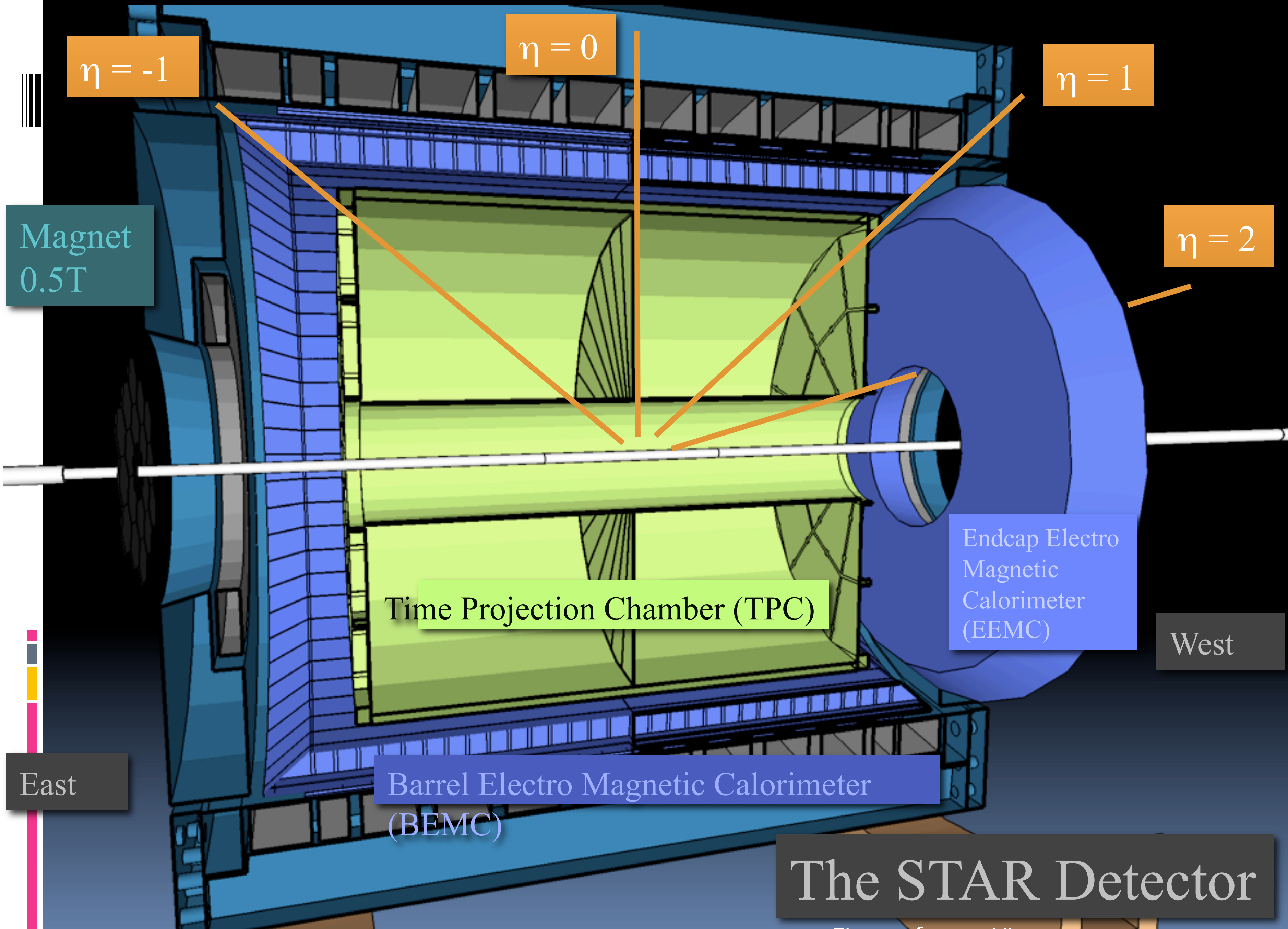

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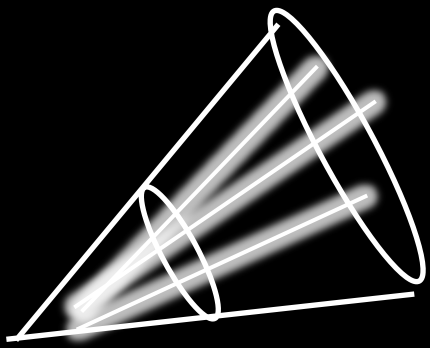
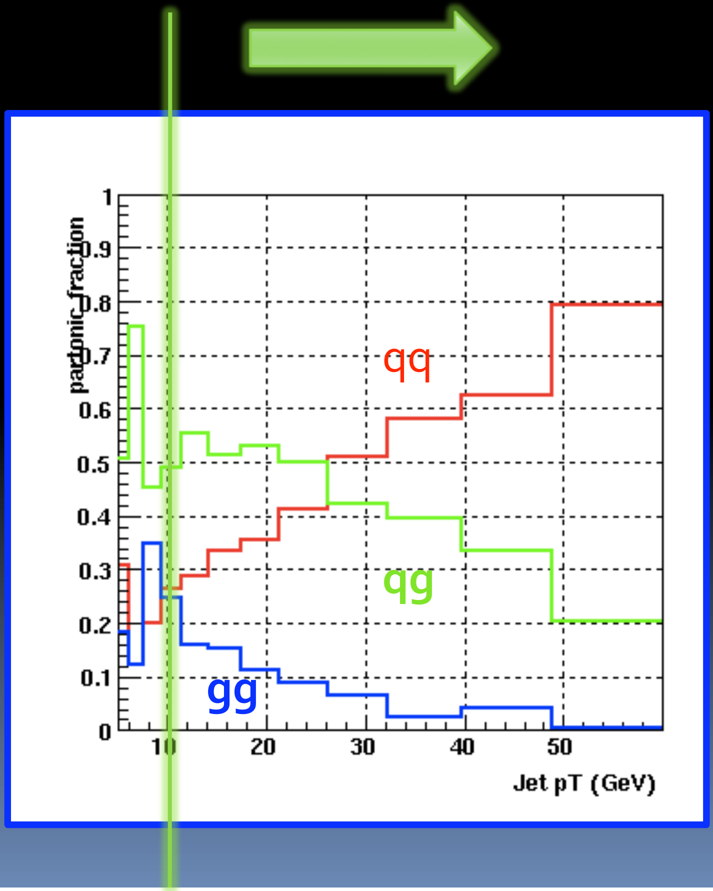
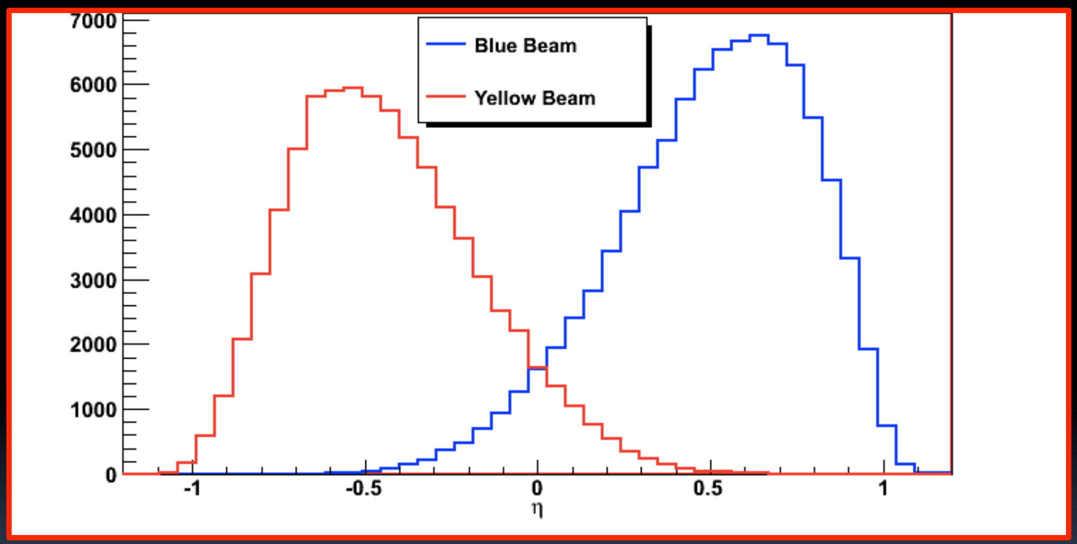
Jet Reconstruction



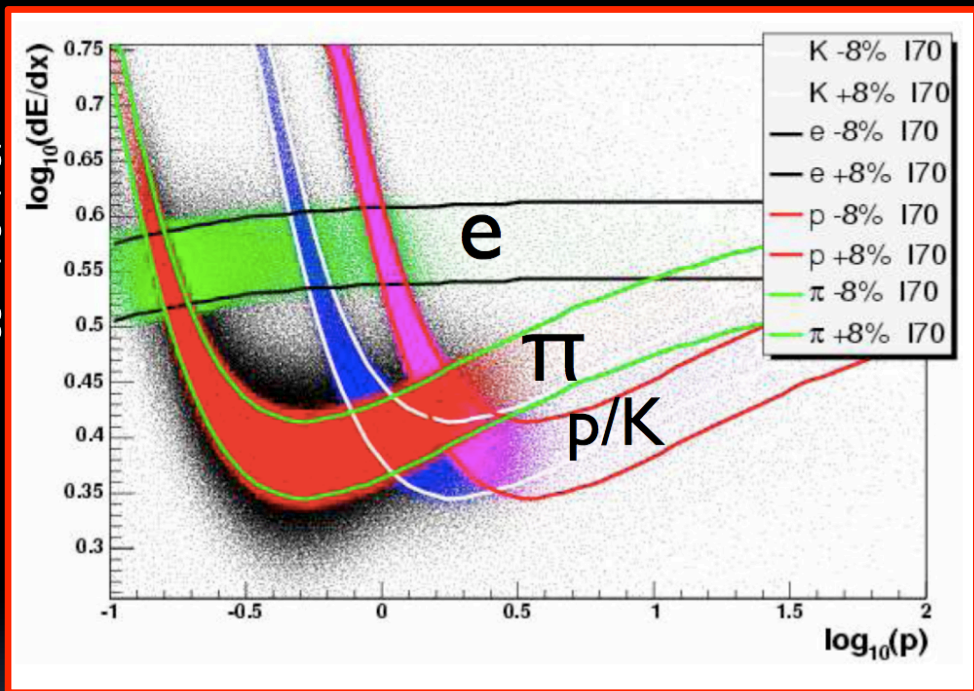
- Collect Data with Jet Patch Trigger
- Reconstruct with Mid-point Cone Algorithm
- Radius = 0.7 and split/merge = 0.5
- Require Jet pT > 10 GeV to minimize gluon dilution



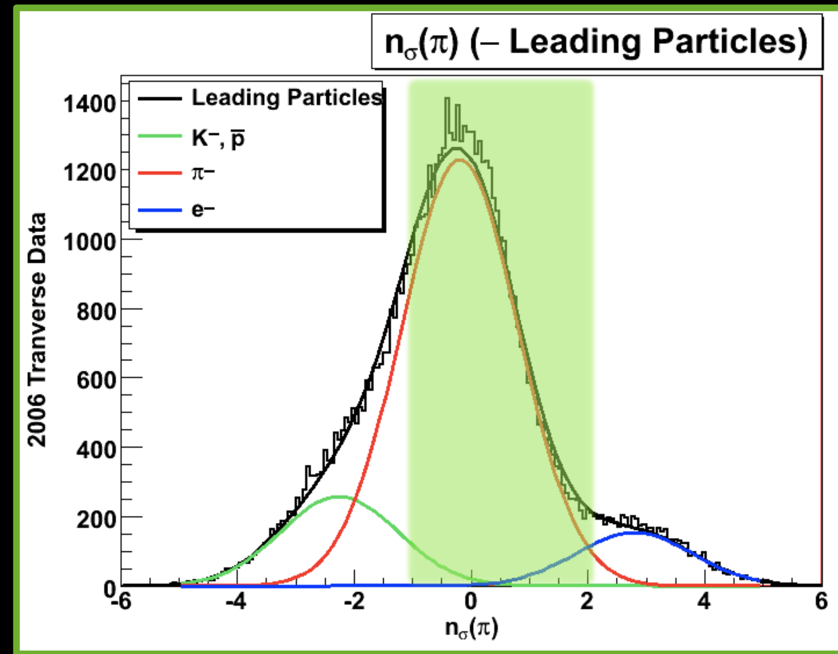


Minimize acceptance of jets from the unpolarized beam by only taking jets in the forward (WRT polarized proton) half of detector

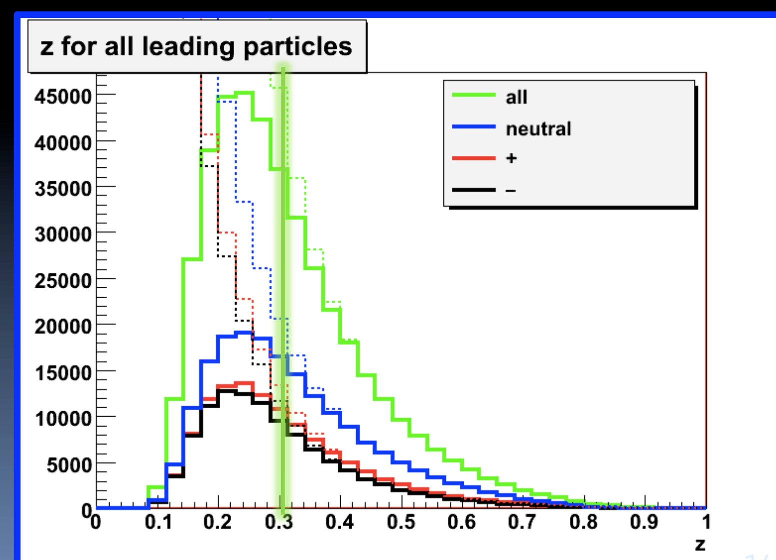
Charged pion identification



Nucl.Instrum.Meth. A558:419-429,2006



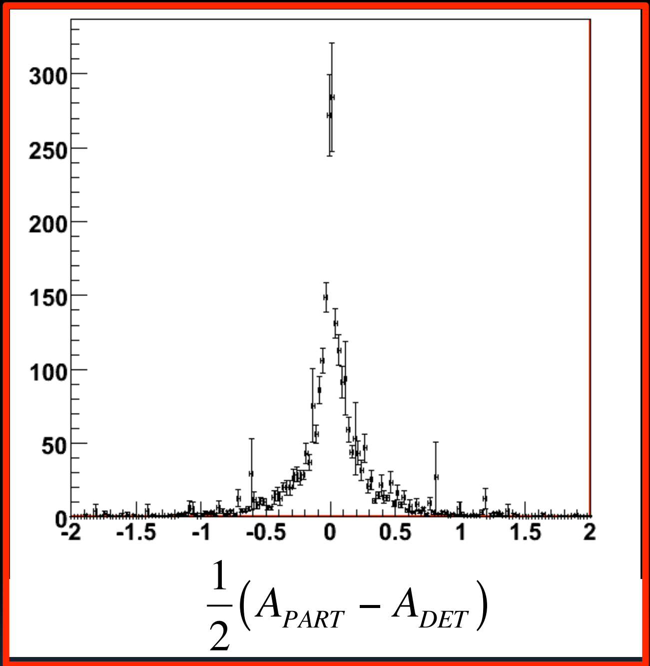
Nearly inclusive sample because 90% of pions are "leading" for z > 0.3



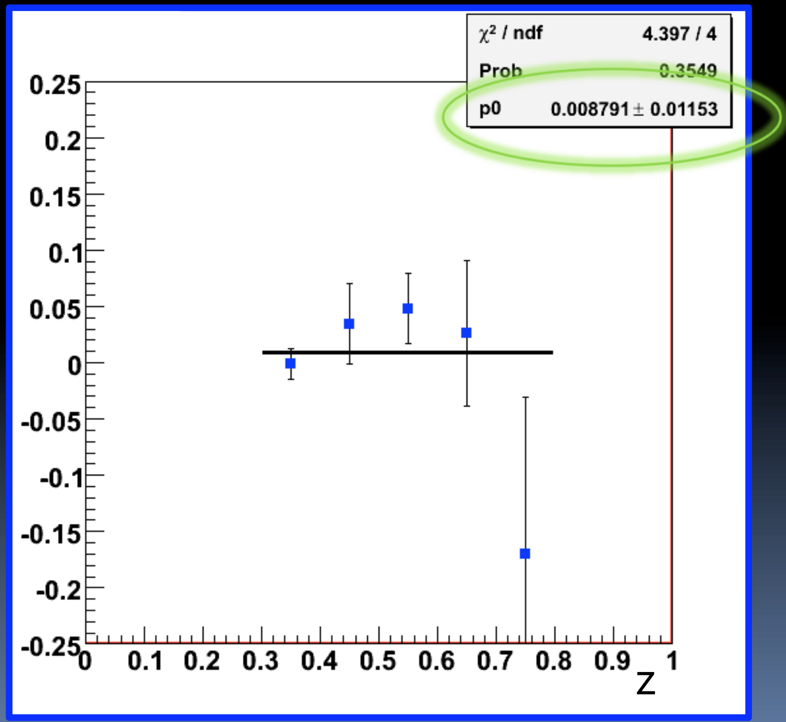
- Use dE/dx in TPC to isolate pions
- Apply $-1 < n_\sigma(\pi) < 2$ Cut
- Require π to be the leading charged particle
- Contamination from Kaons and Electrons < 6%

Detector Effects on $A/2 = \langle \sin(\phi_h - \phi_s) \rangle$

Note factor of 2 is over here!

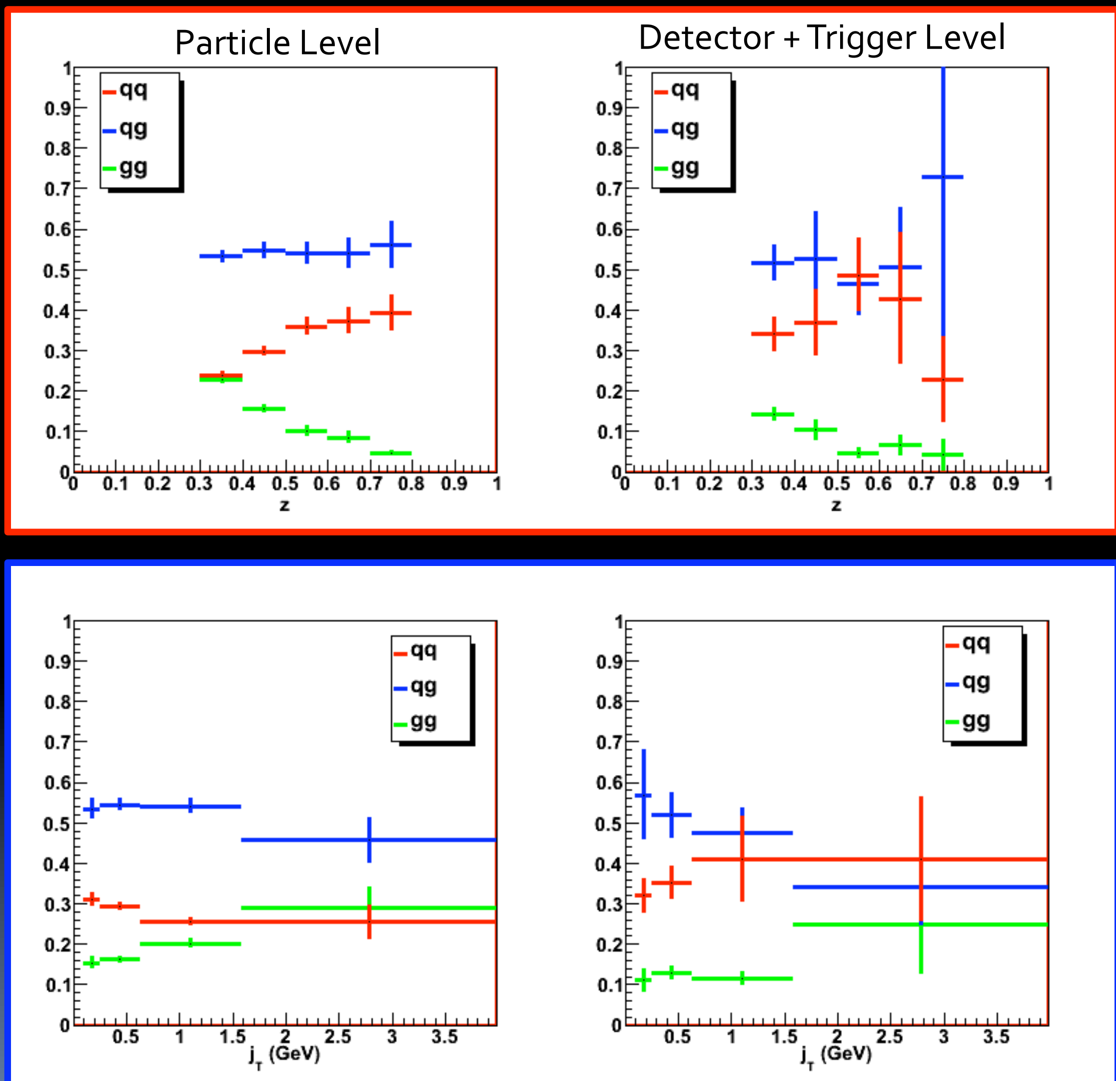


Use Simulation (PYTHIA + GEANT) to calculate asymmetry at the particle A_{PART} and detector A_{DET} level. Look for offsets in $\Delta A = A_{PART} - A_{DET}$



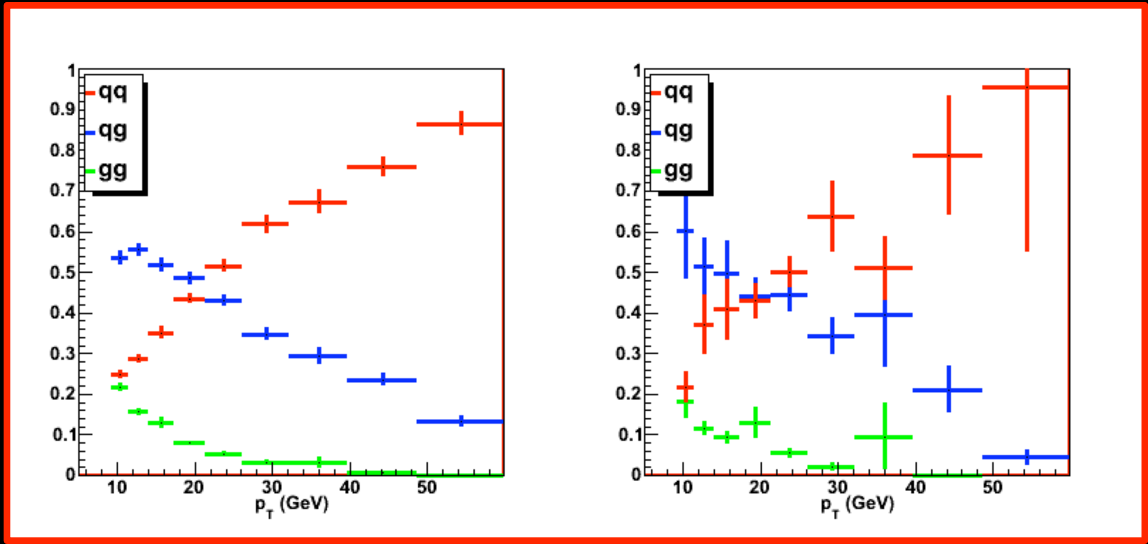
- Offsets are consistent with zero
- No apparent z or jT dependence
- Limited by simulation statistics!
- **Current leading Systematic Error**

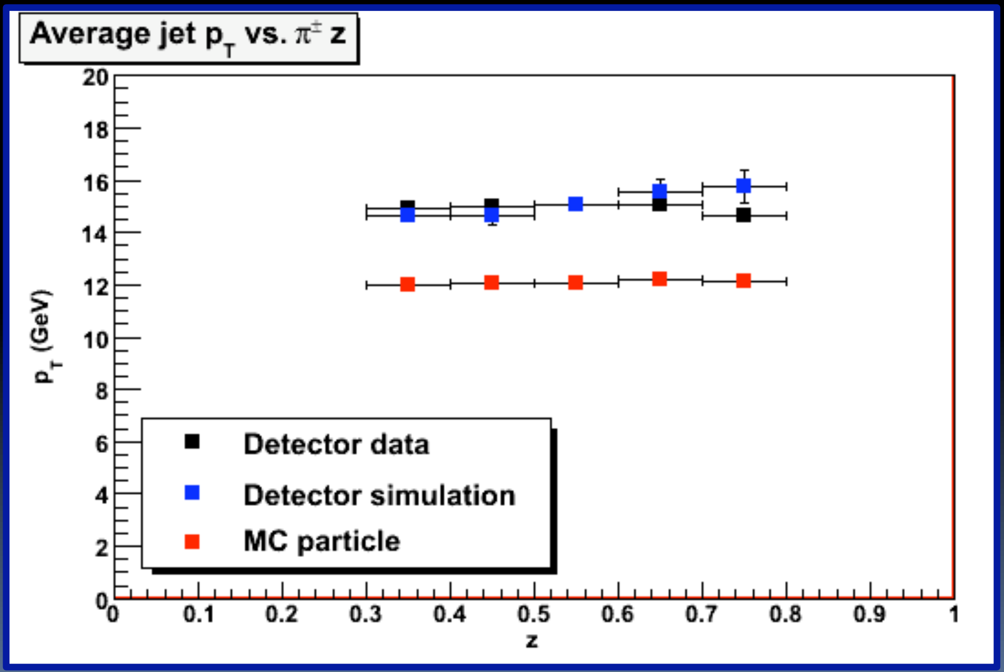
Trigger Bias



- The mix of partonic sub-processes is changed by detector reconstruction and trigger bias.
- **qq** scattering enhanced
- **gg** scattering suppressed
- Measured asymmetries will be **ELEVATED** compared to theoretical expectations.
- Asymmetric systematic error of ~10% on asymmetry

What causes the quark enhancement?





Looking at jet pT instead of z we see that the bias for quark jets isn't that big ....

The average jet pT is higher in triggered jets than in particle jets.

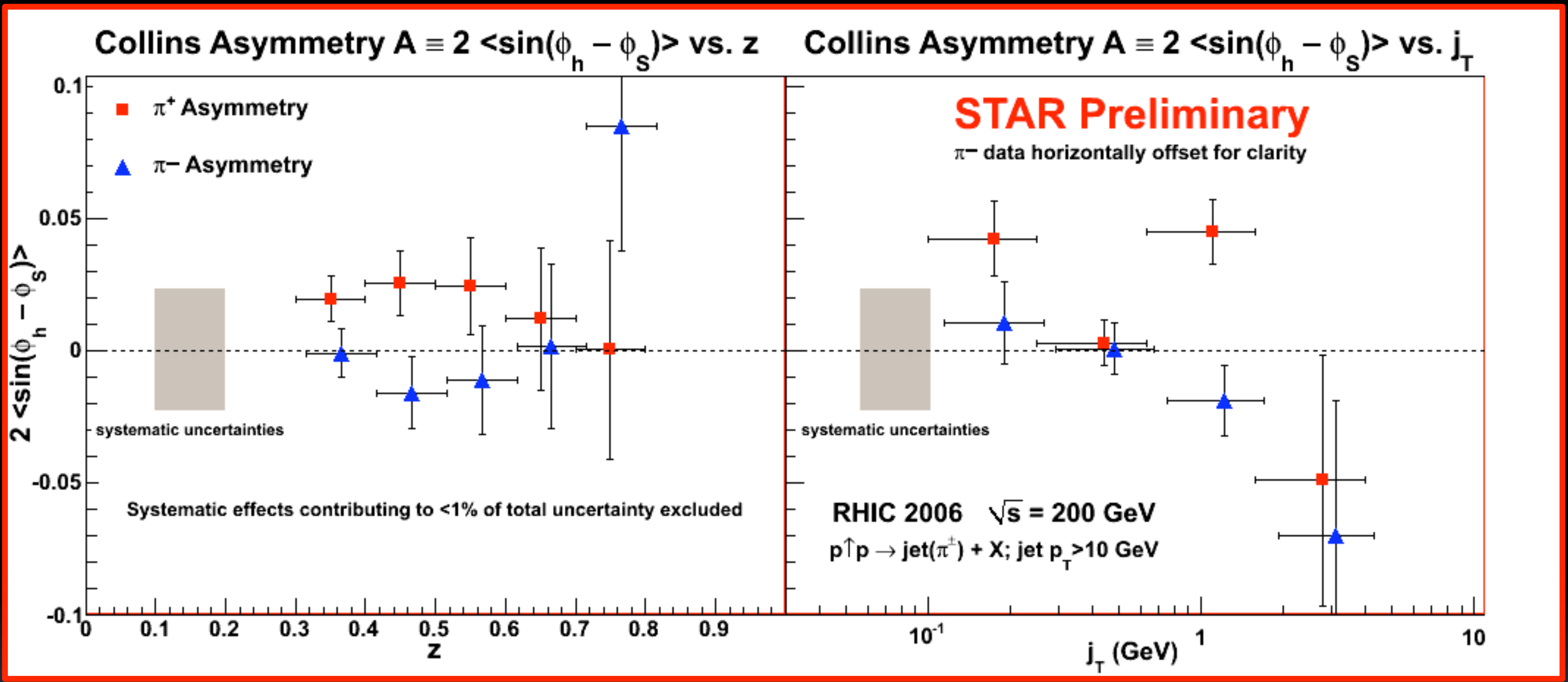
And the fraction of quark jets increase with increasing jet pT!

Systematic Error Table

$2\langle \sin(\varphi_h - \varphi_s) \rangle$

ERROR	MAGNITUDE	EFFECT ON MEASURED ASYMMETRY
Kinematic Accuracy	2.3×10^{-2}	↑ ↓
Trigger Bias	2.52×10^{-3}	↑
Kinematic Resolution	1.74×10^{-3}	↓
K+/- e+/- contamination	1.2×10^{-3}	↓
Spin Orientation	7.0×10^{-4}	↓
Relative Luminosity	4.0×10^{-5}	↑ ↓
Beam Polarization	4.8%	↑ ↓

Azimuthal Asymmetry of Leading Charged Pions in Mid-Rapidity Jets at STAR



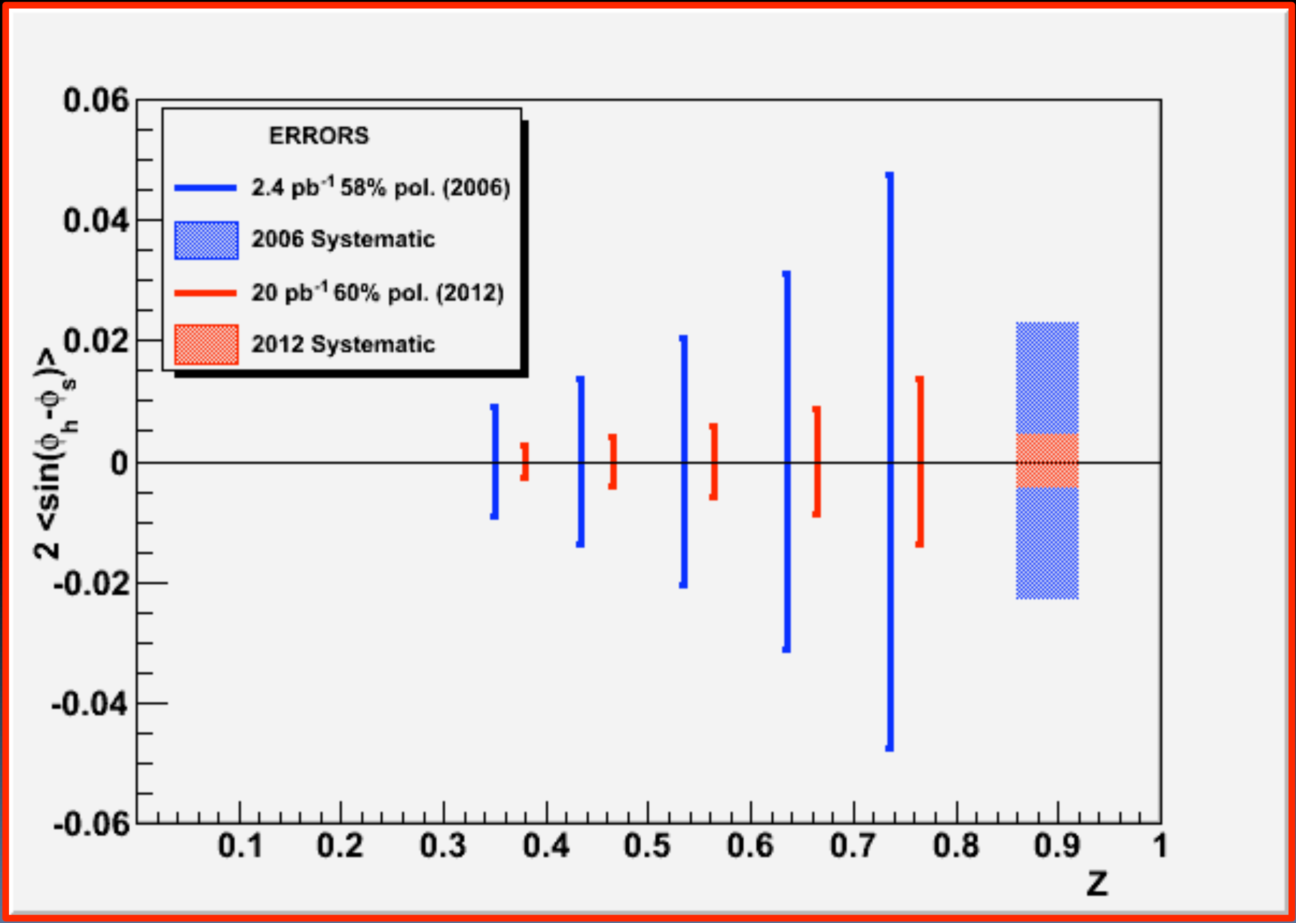
Average π^+ asymmetry = 0.02082 +/- 0.0064 +/- 0.02306

Average π^- asymmetry = -0.0040 +/- 0.0068 +/- 0.02306

Expected asymmetry from global analysis ~ +/- 0.07

Azimuthal Asymmetry of Leading Charged Pions in Mid-Rapidity Jets at STAR

RUN 12 Projections



Conclusions

- Knowledge about the Transversity Distributions is essential for a complete picture of how partons live inside of matter

- The chiral odd nature of the transversity distributions makes them challenging to measure .

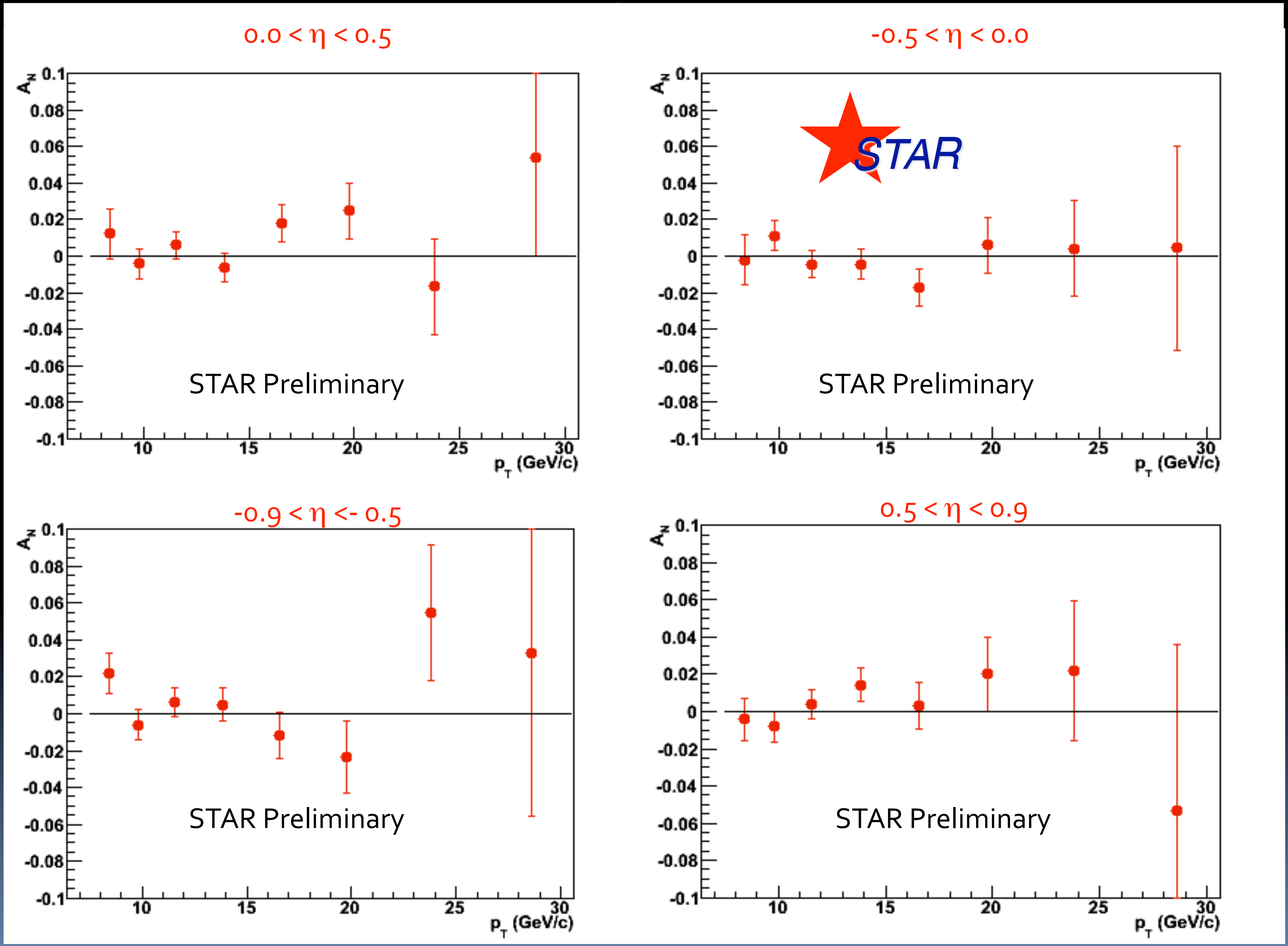
- In proton-proton collisions, the spin dependent azimuthal distribution of hadrons inside of jets is sensitive to the convolution of the transversity and Collins distributions

- Asymmetries presented here are TANTALIZNG – but limited at high (low) z by statistical (systematic) errors.

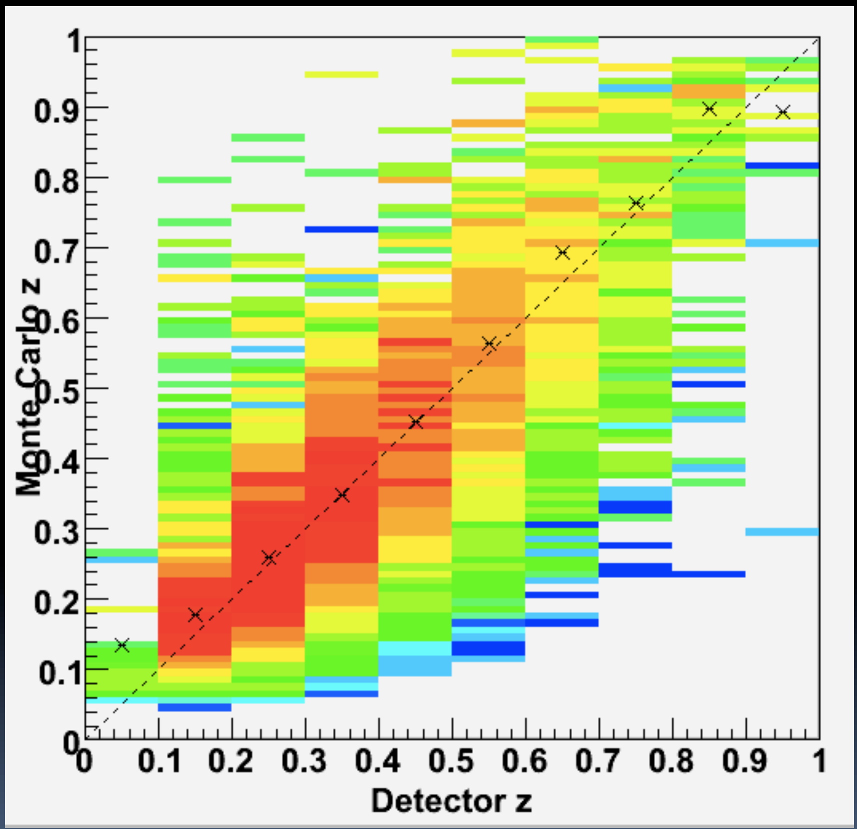
- These errors will be reduced with continued running, new analysis methods and additional simulation statistics.

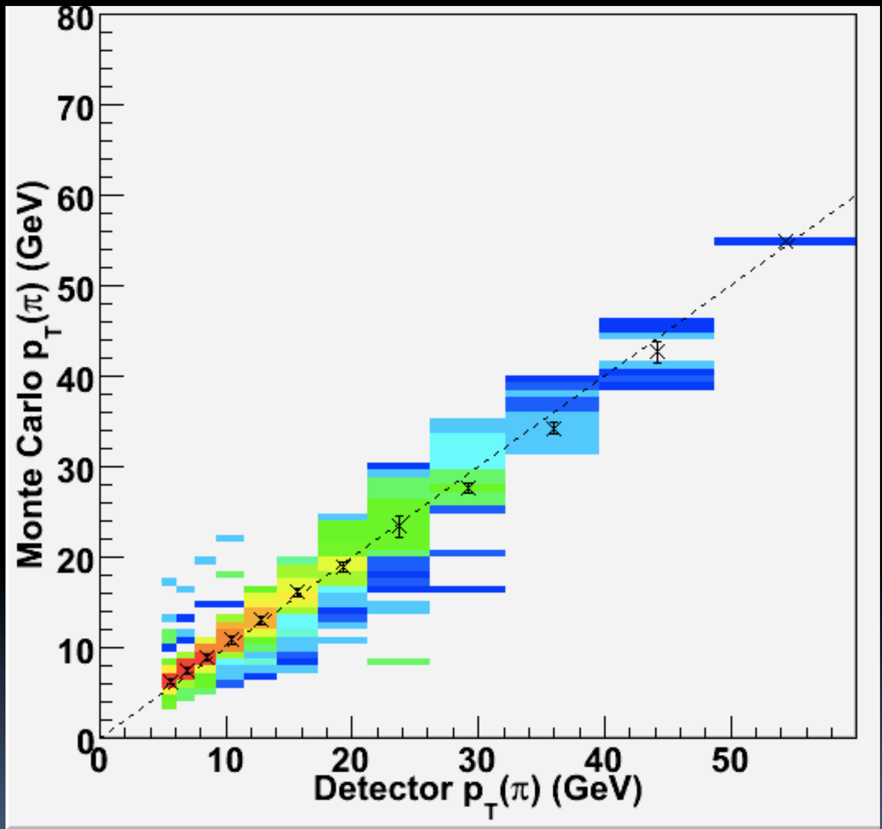
BACKUP

Run 2006 Inclusive Jet A_N



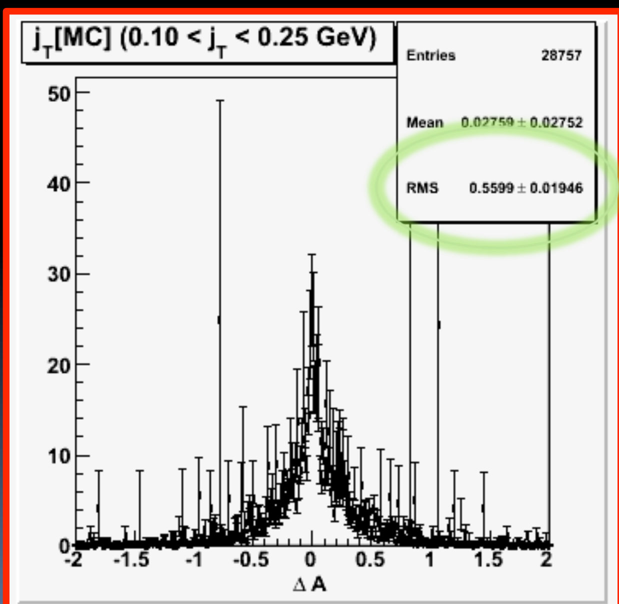
On average Detector kinematics track with Particle kinematics





Detector Resolution Effects

- Detector resolution **SMEARS** the asymmetry.
- Effect proportional to size of asymmetry.
- Width of $\Delta A = A_{PART} - A_{DET}$ gives resolution



Take largest RMS out of all jT and z bins. Use it to smear A = 0.01.

Result: 8.7% reduction in A