STAR Spin Physics Program; Goals and Upgrades beyond 2015, and Migration toward eRHIC Capabilities

~~*Carl Gagliardi, TAMU*~~
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for the STAR Collaboration

2011 RHIC & AGS Annual Users' Meeting
Workshop on Future Strategy for the Facility
BNL, June 22, 2011

Berkeley Lab   U.S. Department of Energy | Office of Science

STAR - Solenoid Tracker at RHIC

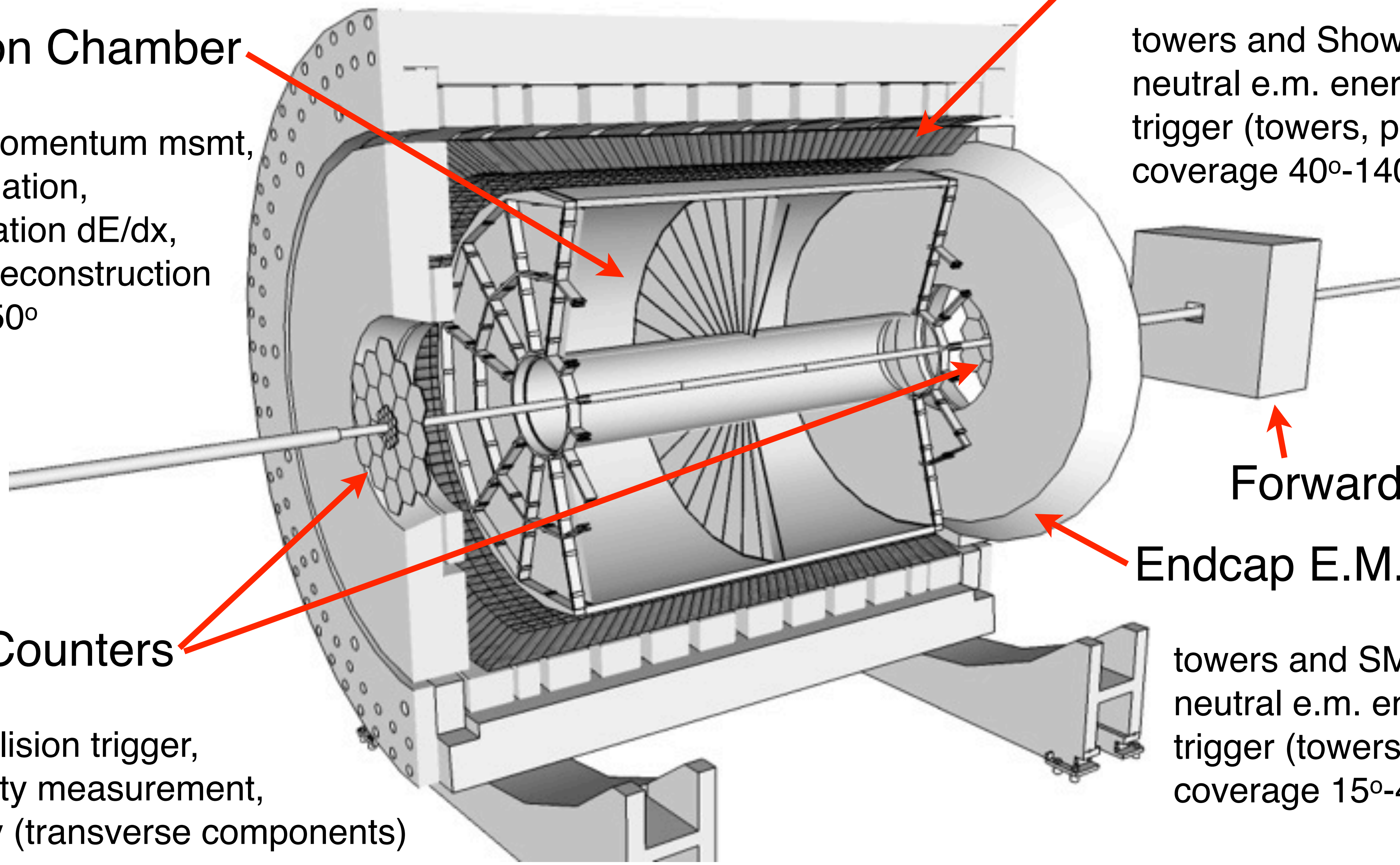
Nucl. Instrum. Meth. A499, 624, 2003

Time Projection Chamber

charged track momentum msmt,
charge determination,
particle identification dE/dx,
collision vertex reconstruction
coverage 30°-150°

Barrel E.M. Calorimeter

towers and Shower Maximum Det.
neutral e.m. energy measurement,
trigger (towers, patches of towers)
coverage 40°-140°



Forward Meson Spectr.

Endcap E.M. Calorimeter

towers and SMD.
neutral e.m. energy measurement,
trigger (towers, patches of towers)
coverage 15°-40°

Beam-Beam Counters

proton beam collision trigger,
relative luminosity measurement,
local polarimetry (transverse components)

0.5 T Solenoidal Magnetic Field

Several detectors not shown, e.g. ZDC, FPD, Time-of-Flight, Roman Pots, ...

A very versatile *general purpose* instrument, with an *evolutionary* and *physics-driven* upgrades.

Key Questions to be Addressed Next:

What are the properties of the strongly-coupled system produced at RHIC, and how does it thermalize?

Are the interactions of energetic partons with QCD matter characterized by weak or strong coupling? What is the detailed mechanism for partonic energy loss?

Where is the QCD critical point and the associated first-order phase transition line?

Can we strengthen current evidence for novel symmetries in QCD matter and open new avenues?

What other exotic particles are created at RHIC?

What is the partonic spin structure of the proton?

How do we go beyond leading twist and collinear factorization in perturbative QCD?

What is the nature of the initial state in nuclear collisions?

Subject of the STAR Decadal Plan for 2011-2020, available from http://www.bnl.gov/npp

Envisioned Measurements, Instrumentation, and Timeline

	Near term (Runs 11–13)	Mid-decade (Runs 14–16)	Long term (Runs 17–)
Colliding systems	p+p, A+A	p+p, A+A	p+p, p+A, A+A, e+p, e+A
Upgrades	FGT, FHC, RP, DAQ10K, Trigger	HFT, MTD, Trigger	Forward Instrum, eSTAR, Trigger
(1) Properties of sQGP	Υ, $J/\psi \to ee$, m_{ee}, v_2	Υ, $J/\psi \to \mu\mu$, Charm v_2, R_{CP}, Charm corr, Λ_c/D ratio, μ-atoms	p+A comparison
(2) Mechanism of energy loss	Jets, γ-jet, NPE	Charm, Bottom	Jets in CNM, SIDIS, c/b in CNM
(3) QCD critical point	Fluctuations, correlations, particle ratios	Focused study of critical point region	
(4) Novel symmetries	Azimuthal corr, spectral function	$e-\mu$ corr, $\mu-\mu$ corr	
(5) Exotic particles	Heavy anti-matter, glueballs		
(6) Proton spin structure	W A_L, jet and di-jet A_{LL}, intra-jet corr, $(\Lambda+\bar{\Lambda})$ D_{LL}/D_{TT}		$\bar{\Lambda}$ D_{LL}/D_{TT}, polarized DIS, polarized SIDIS
(7) QCD beyond collinear factorization	Forward A_N		Drell-Yan, F-F corr, polarized SIDIS
(8) Properties of initial state			Charm corr, Drell-Yan, J/ψ, F-F corr, Λ, DIS, SIDIS

Note: measurements are listed when they first become feasible. Many continue in future periods.

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Dunlop's talk yesterday

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Xu's talk yesterday

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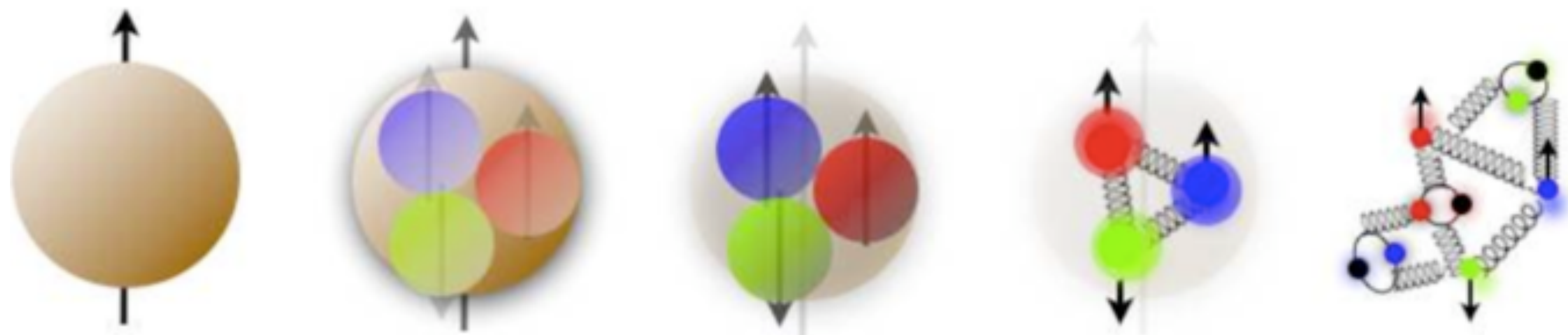
Focus of this Talk

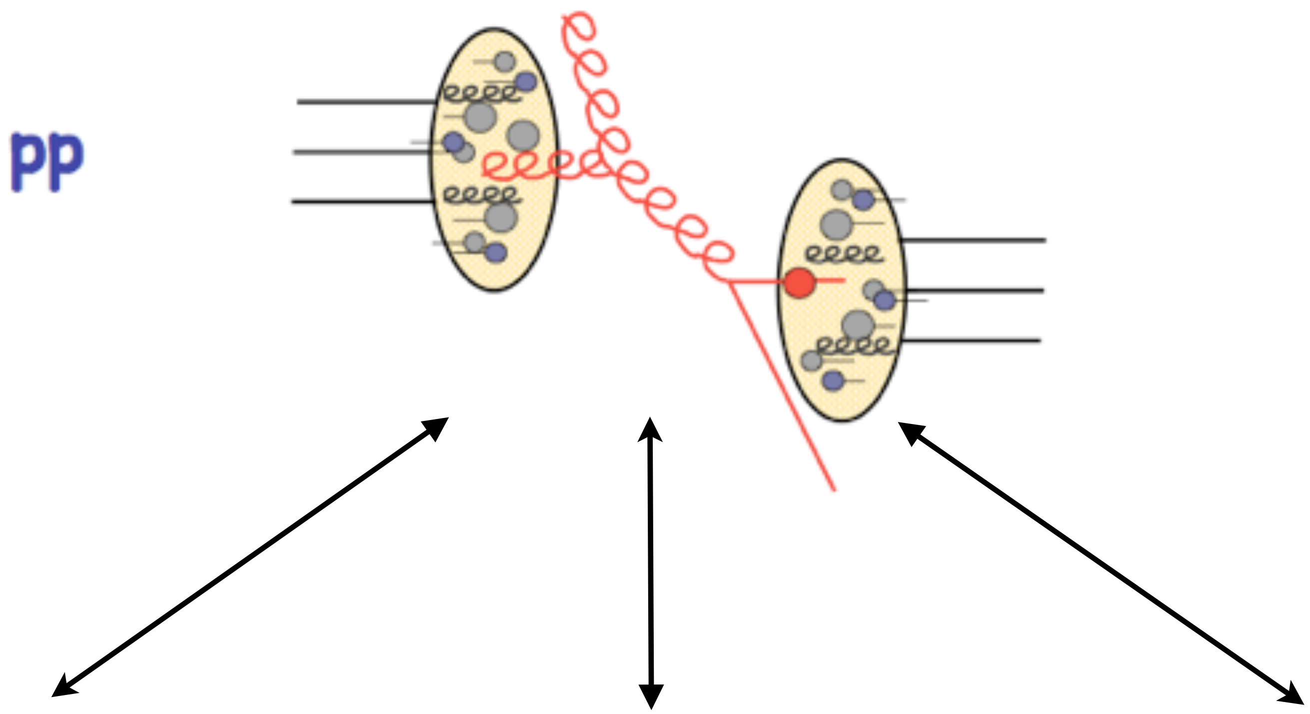


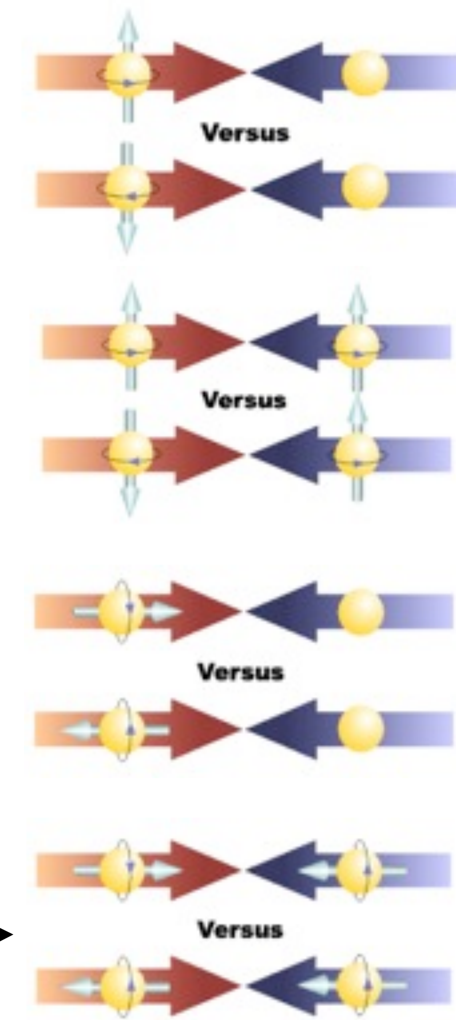
What is the partonic spin structure of the proton?

Some of the knowns and unknowns:

- Quark spins carry only a small fraction of the proton spin,
- RHIC is providing sensitive insights in the contribution from gluon spin,
- Insight in the proton's spin-sea remains limited and relies on fragmentation,
- Transverse spins in the nucleon remain poorly known to date,
- Orbital quark and gluon are likely to contribute, but by how much?
- ...

Measurements at RHIC with transverse beam polarizations offer a unique window on perturbative QCD beyond leading twist and collinear factorization.





$q, \bar{q}, g, \Delta q, \Delta \bar{q}, \Delta g$ $\hat{\sigma}, \Delta \hat{\sigma}$ $q, \bar{q}, g, \Delta q, \Delta \bar{q}, \Delta g \leftrightarrow$

$\sqrt{s}$ = 62 - 500 GeV

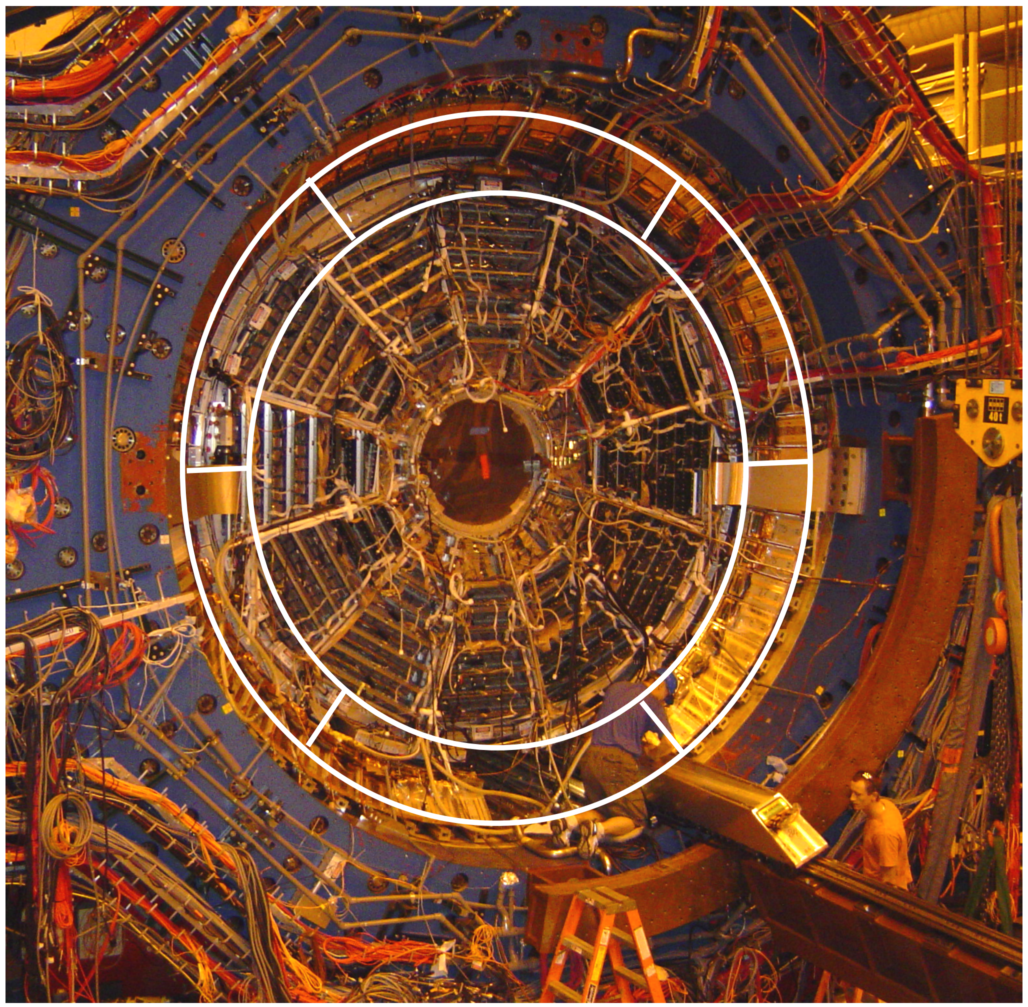
Theory: perturbative QCD evaluations, typically at next-to-leading order,

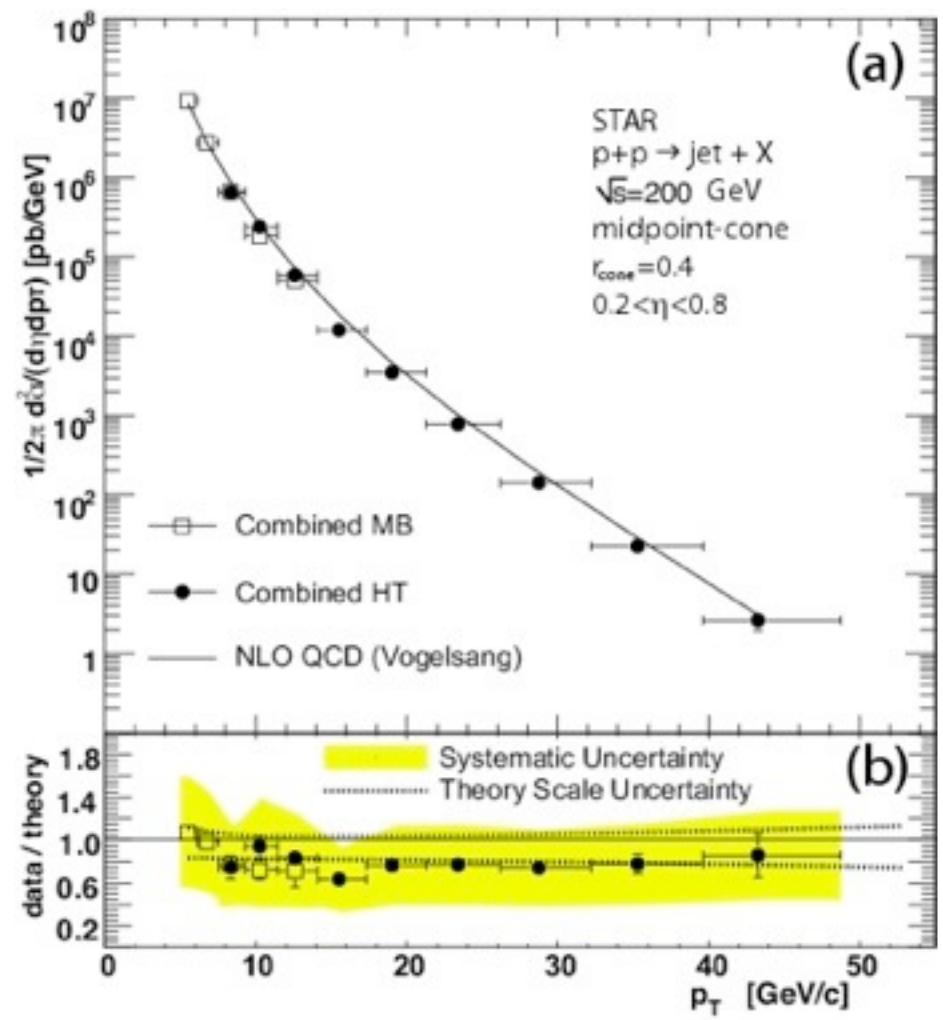
Experiment: observe cross sections (asymmetries) of (hadronized) final states,
test applicability of theoretical framework,
extend measurements to correlated and selective final states.

Combination: insight in $q, \bar{q}, g, \Delta q, \Delta \bar{q}, \Delta g$

Complementary insights from measurements of A_{LL}, A_{L}, A_{N}, D_{LL}, inclusive probes, correlations ...

Gluon Polarization - Inclusive Jets





STAR is uniquely suited, at RHIC, for central-rapidity jet measurements,
Measured cross section is well-described by perturbative QCD evaluation at NLO,

B. Abelev et al., Phys.Rev.Lett.97:252001,2006
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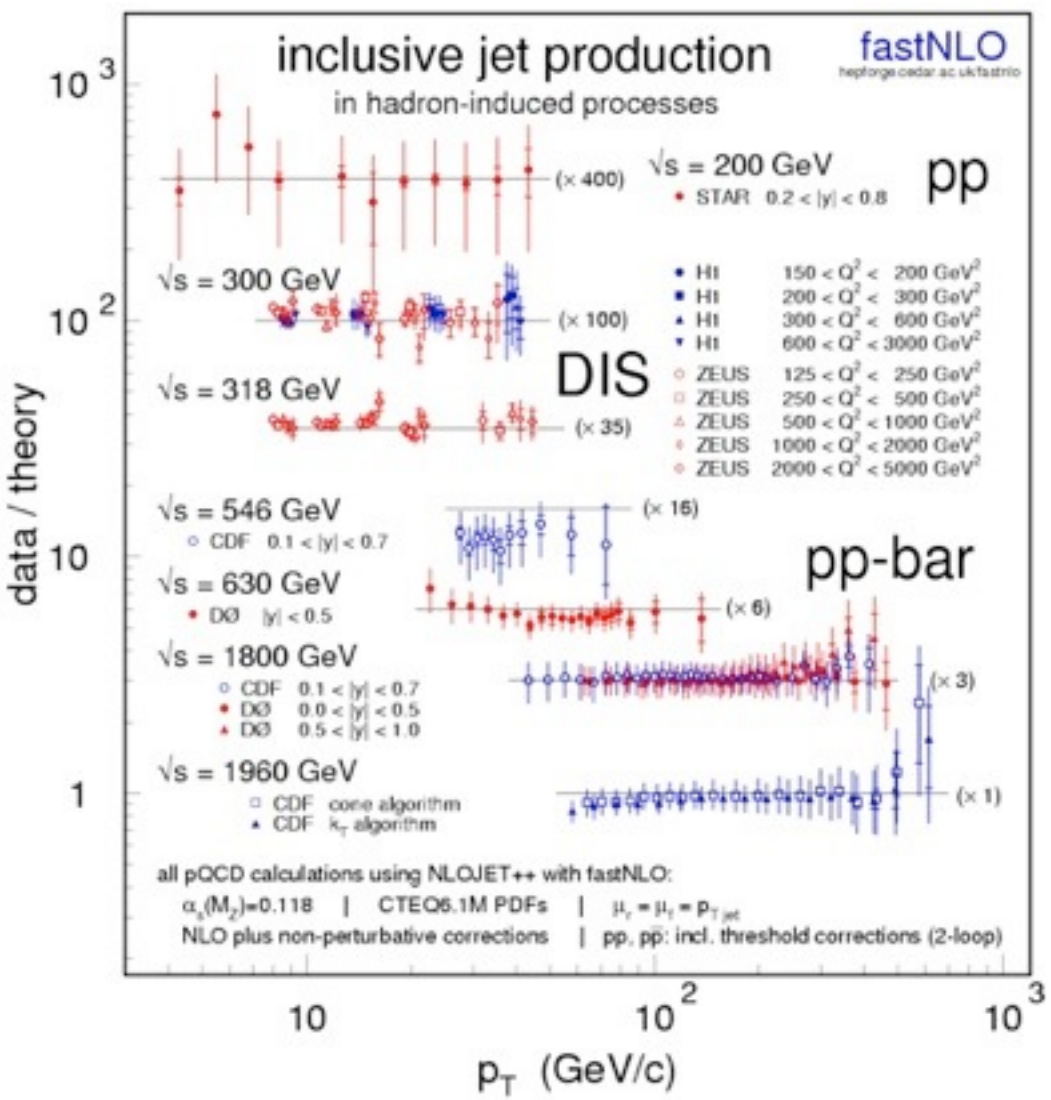
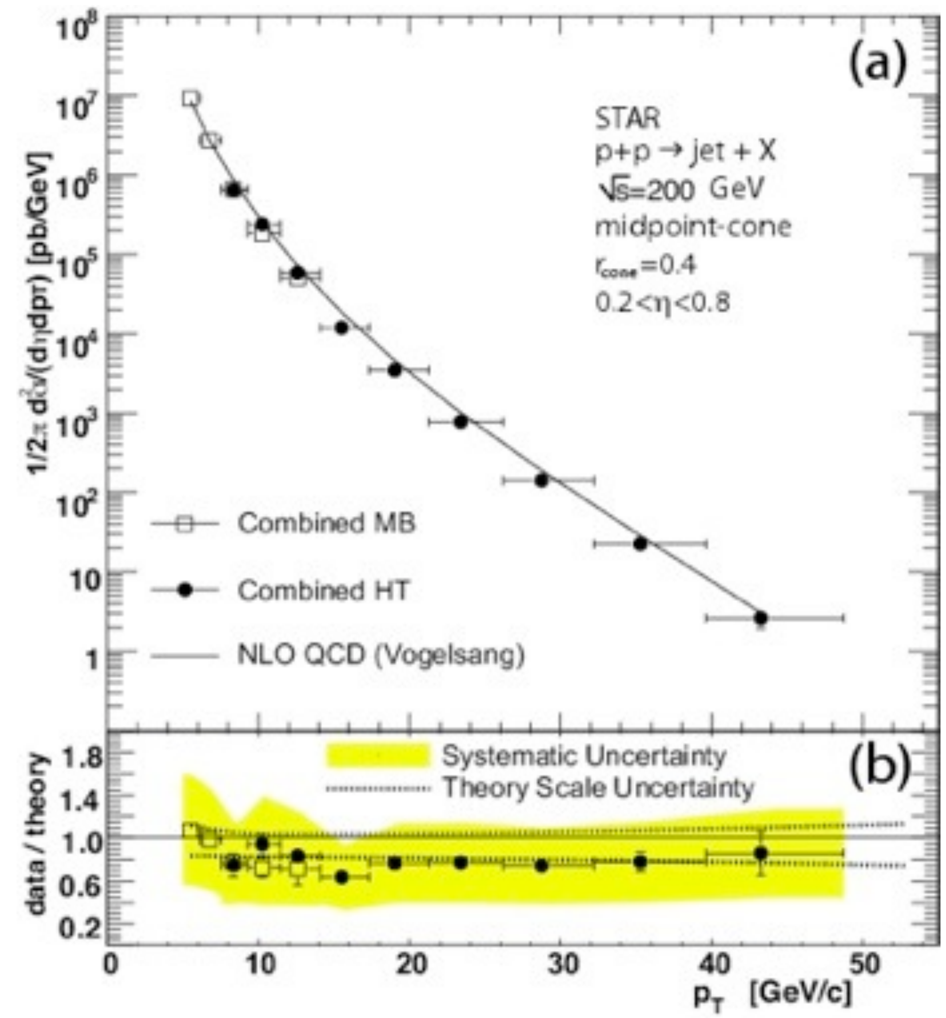
Gluon Polarization - Inclusive Jets

T. Kluge, K. Rabbertz, M. Wobisch,
http://projects.hepforge.org/fastnlo/





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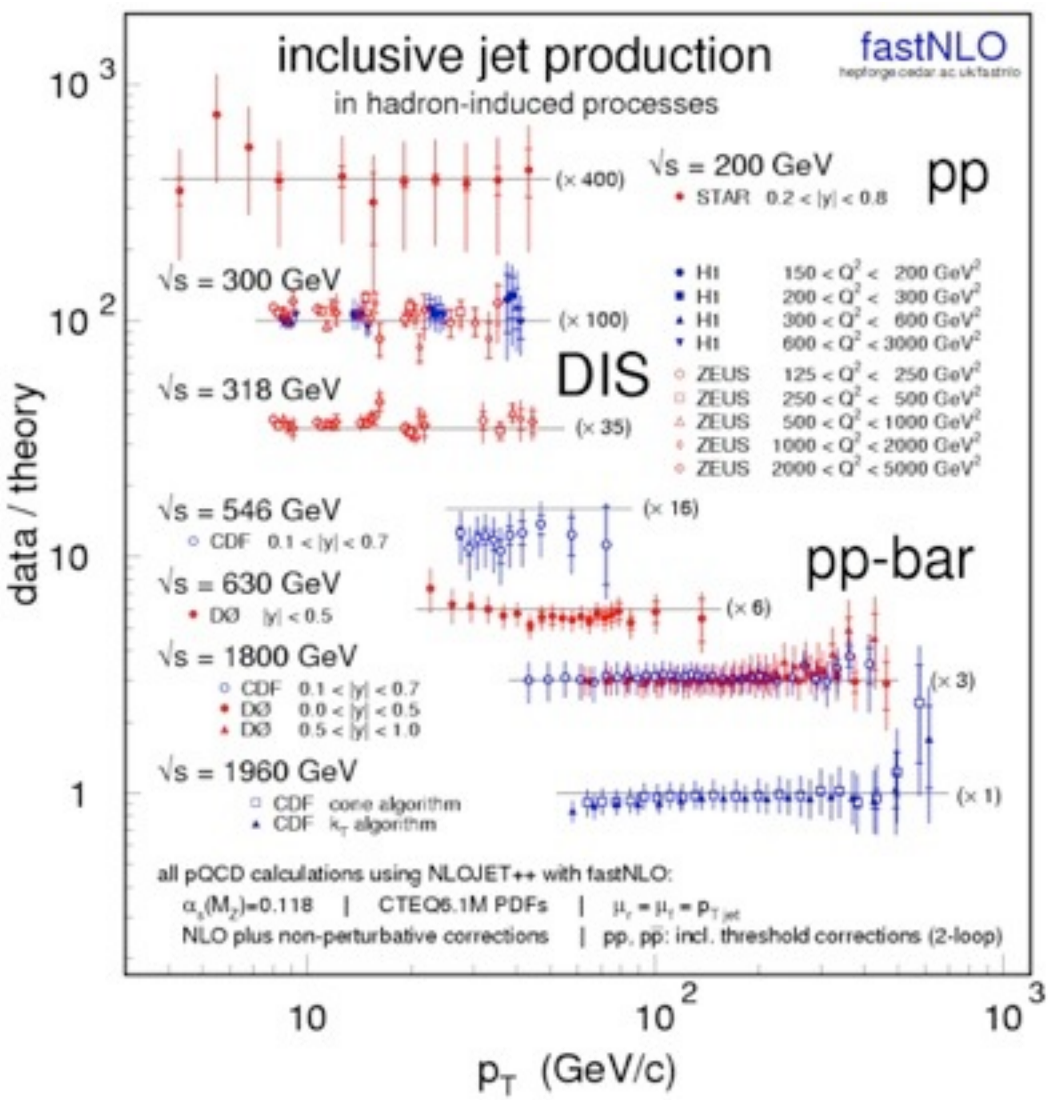
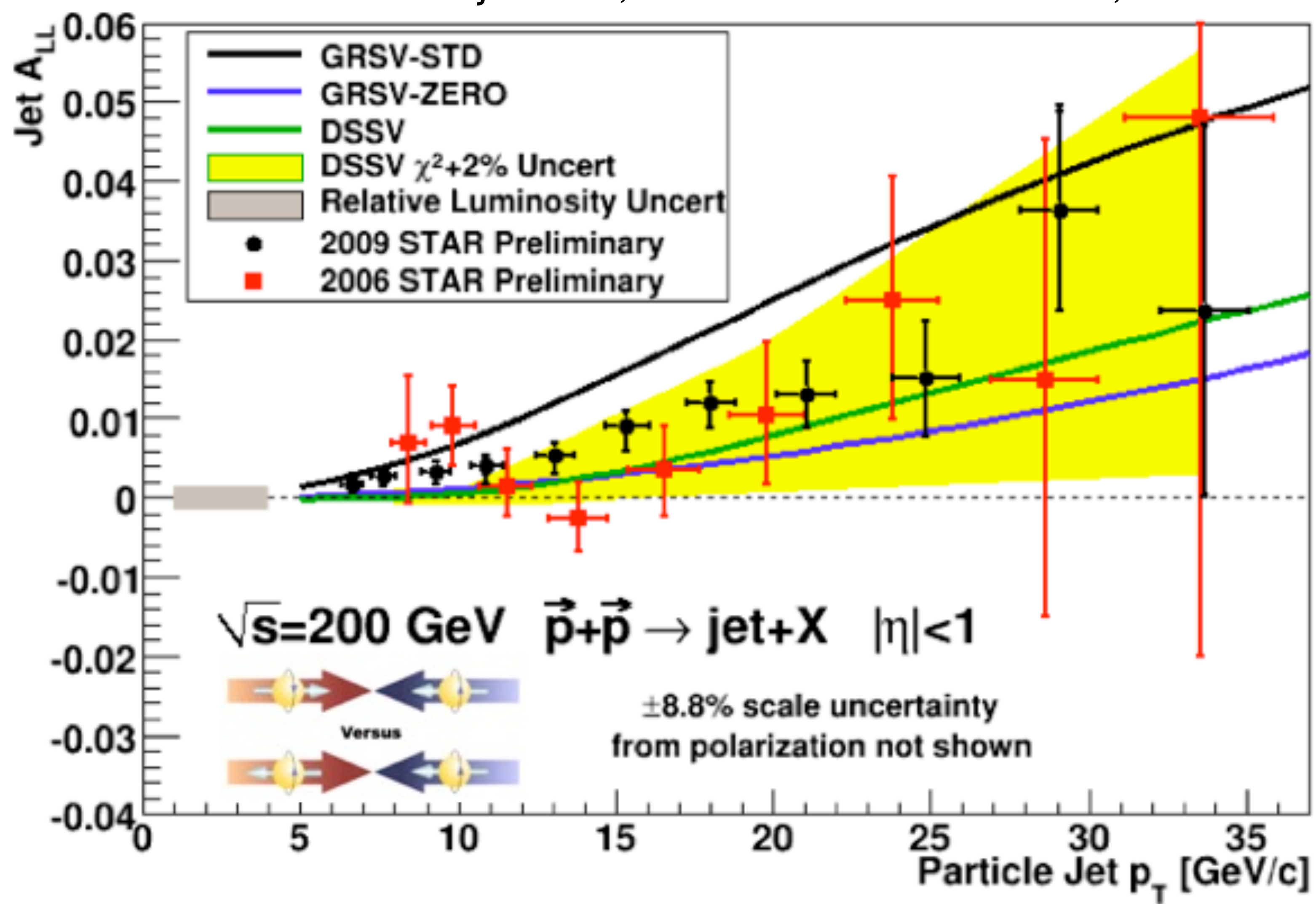


Pibero Djawotho, for the STAR collaboration, DIS2011



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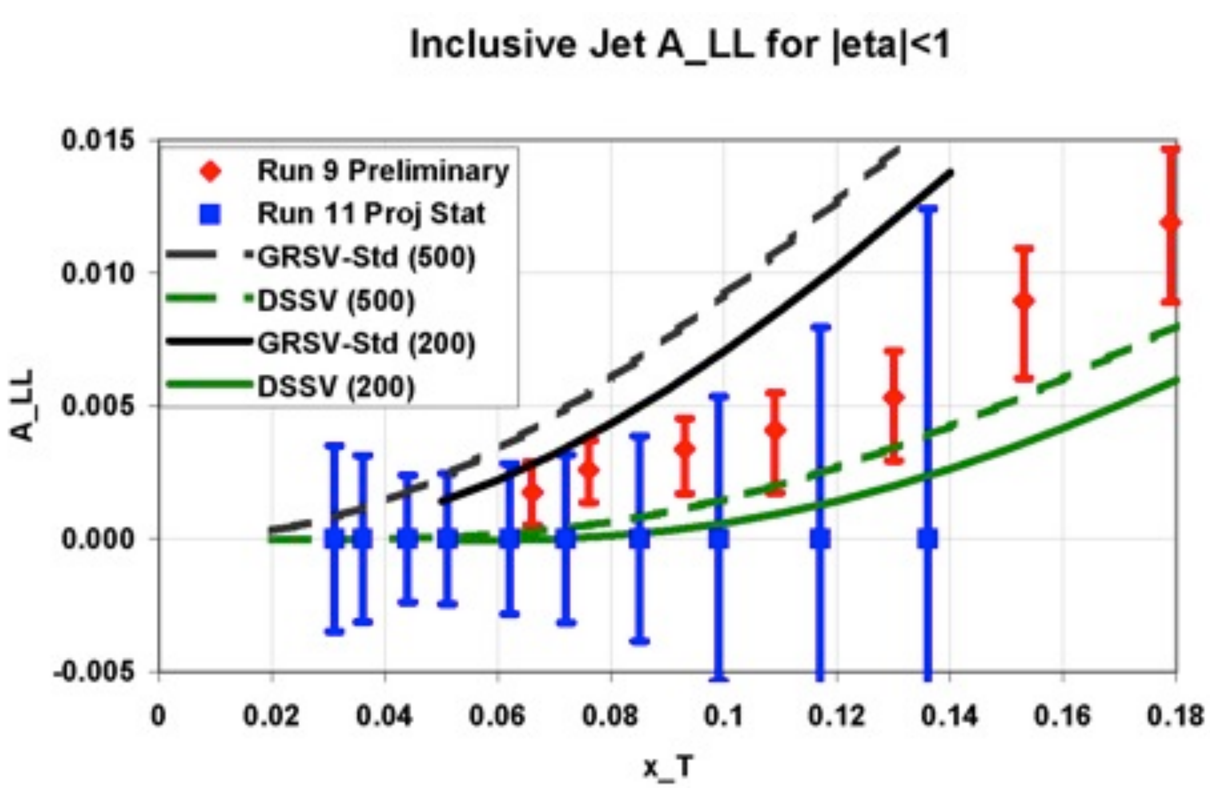
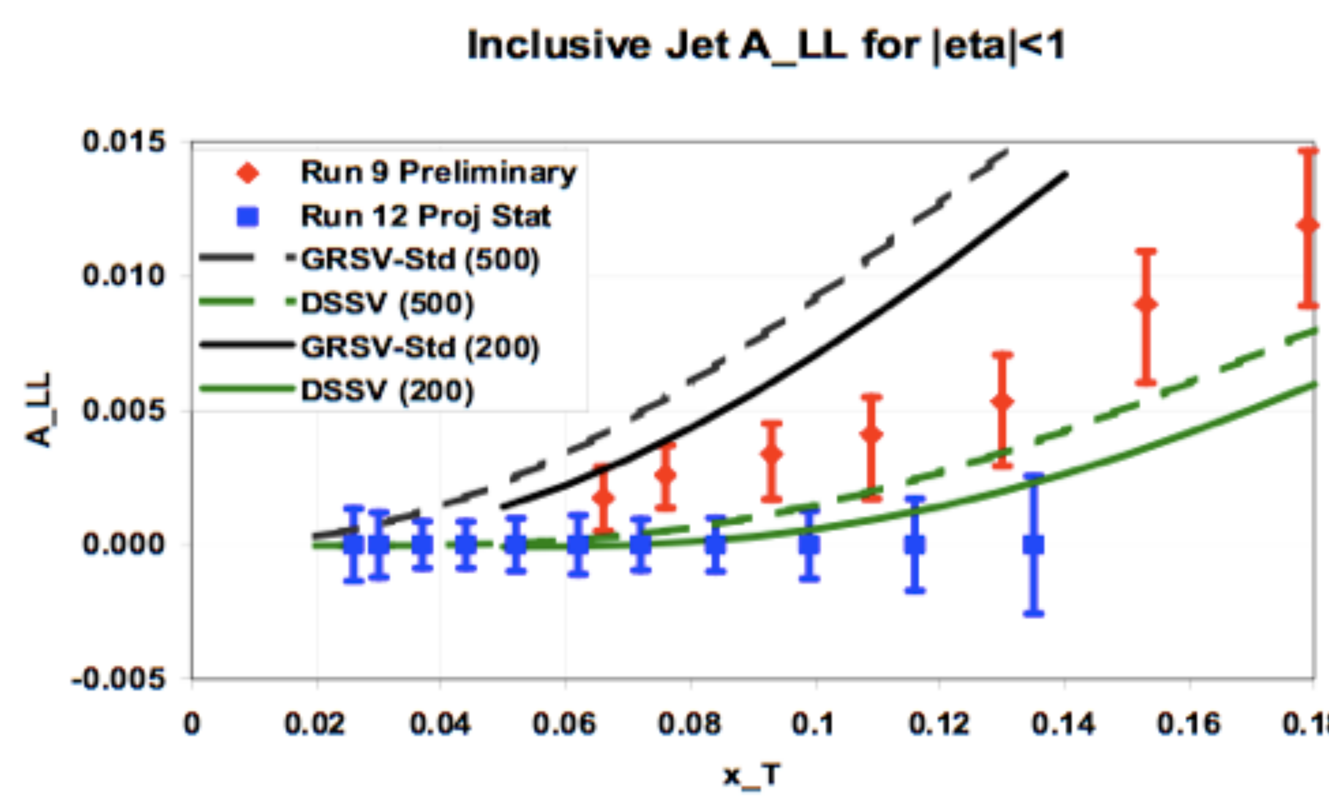
Precision insights in gluon polarization for ~0.03 < x < 0.3 from A_{LL},
Near-to-mid-term: precision, resolve x (correlations), and extend x range (√s, pseudorapidity).

Gluon Polarization - Inclusive Jets

Complementarity of √s = 200 GeV (data) and √s = 500 GeV (projected precision):





Near Term: Run-11 Run-12

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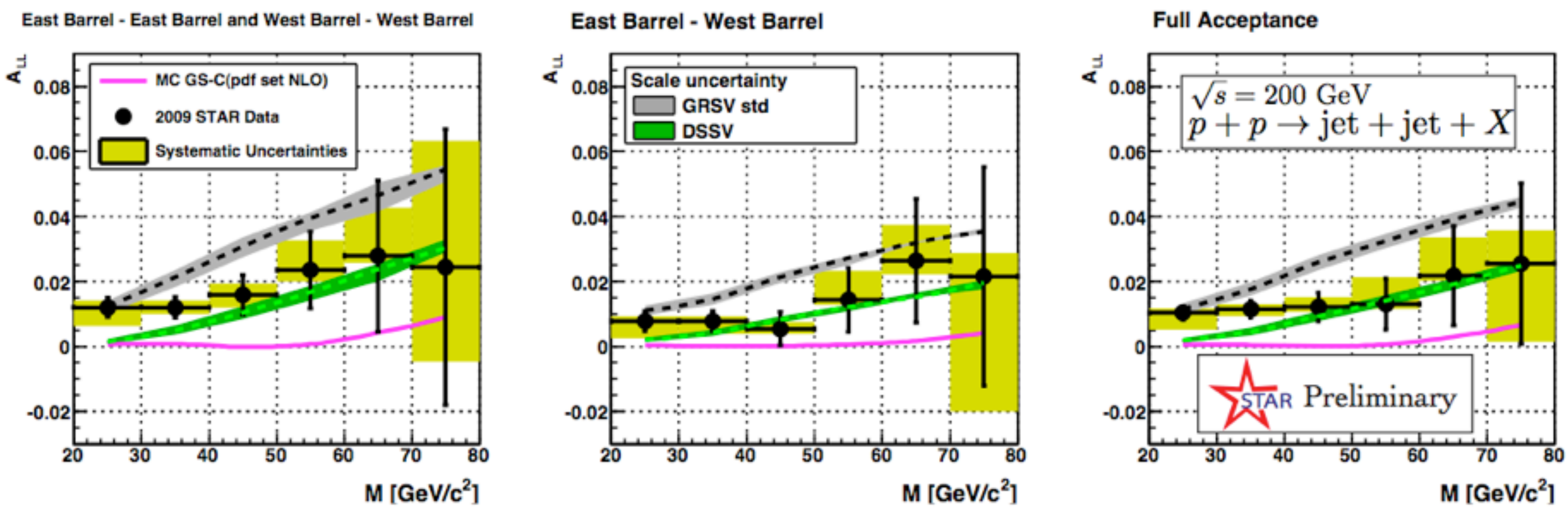
Gluon Polarization - Di-Jets

Sensitivity to Di-jets



Topology:  or both

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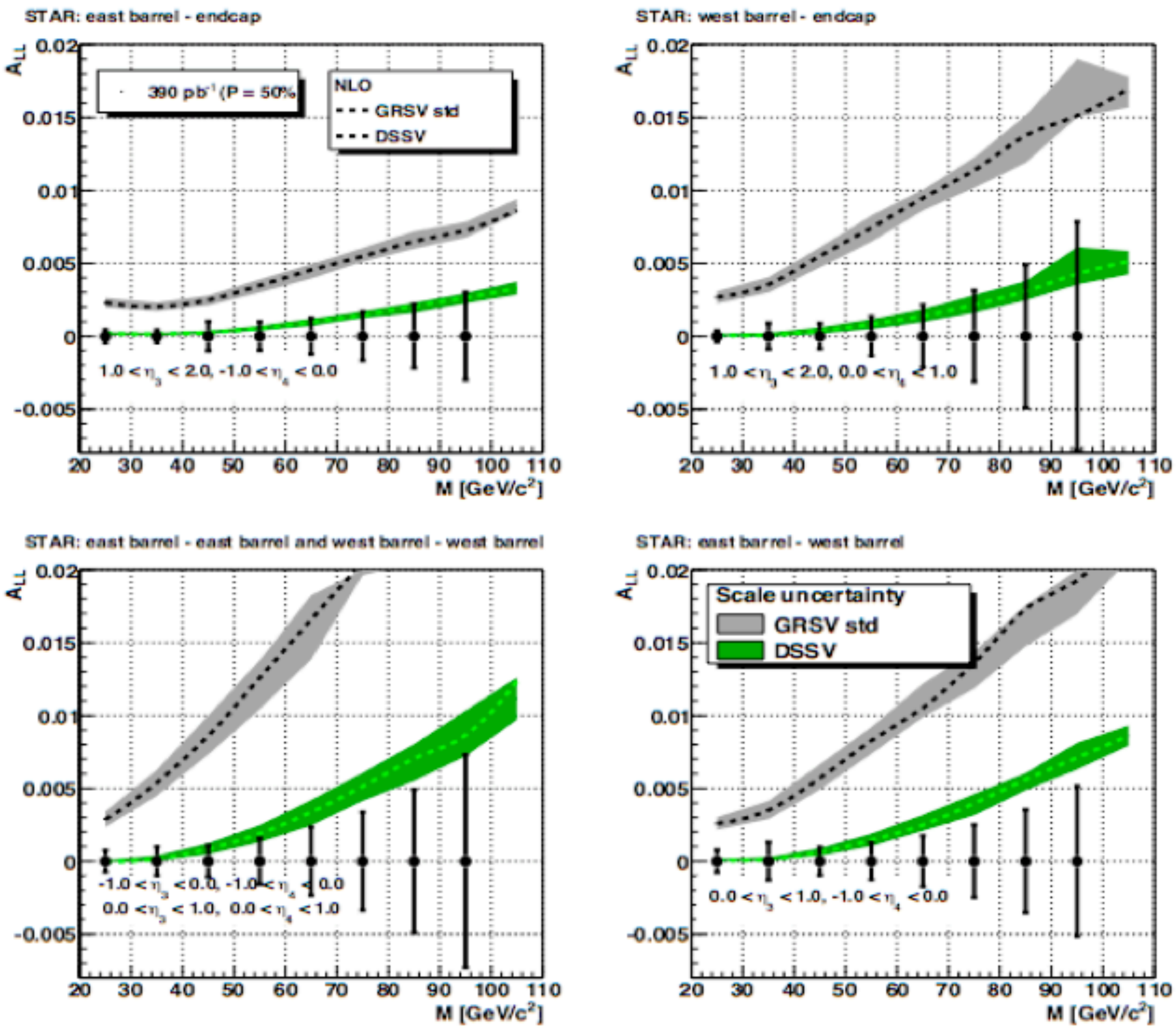
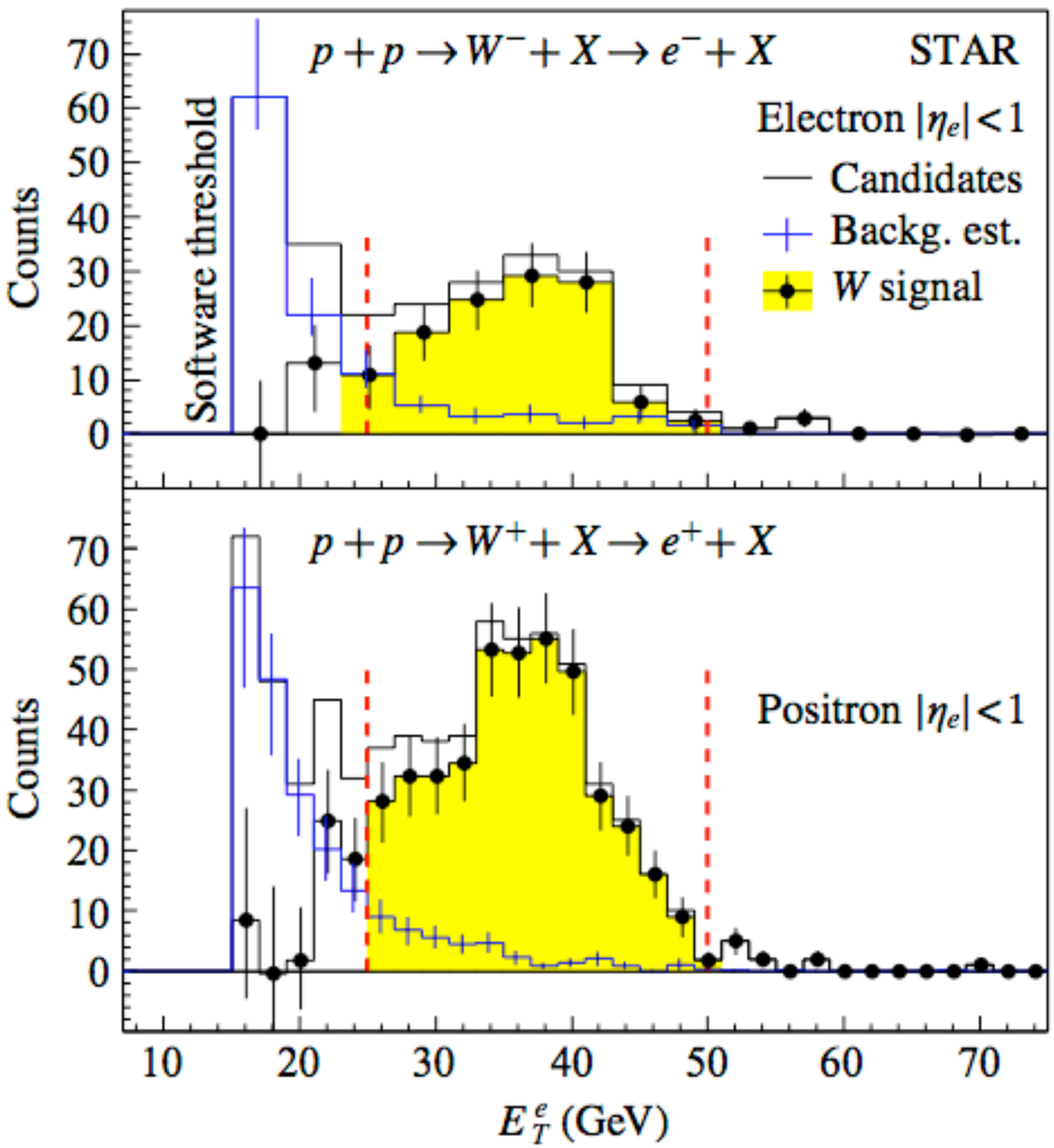
Gluon Polarization - Di-Jets

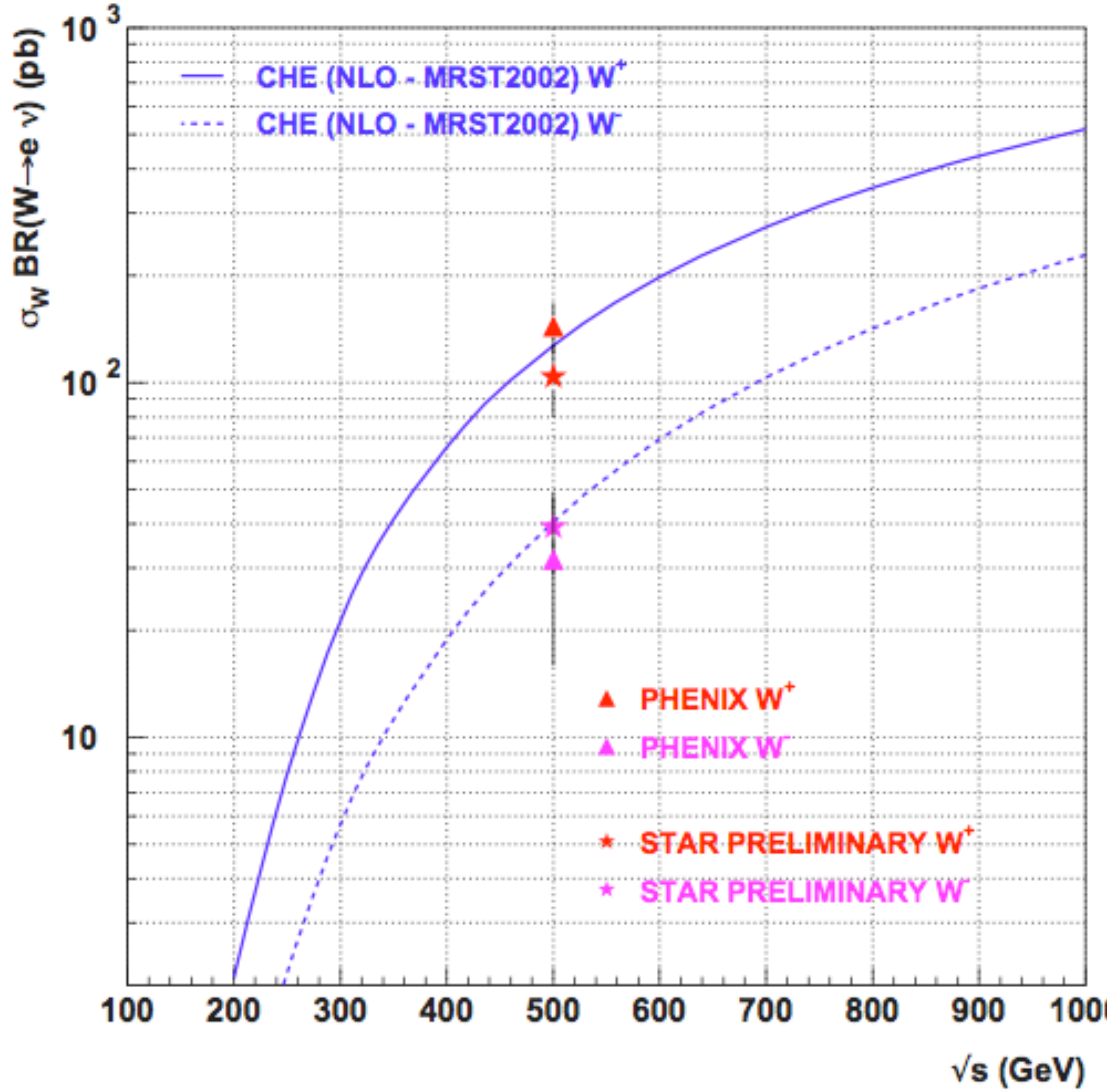
Projected di-jet precision for extended √s = 500 GeV running:



Near-to-mid-term: precision, resolve *x* (correlations), and extend *x* range (√s, pseudorapidity). Results (surprises) will drive a longer-term program, as may new forward detector capability.

Quark Polarization - leptonic W decay



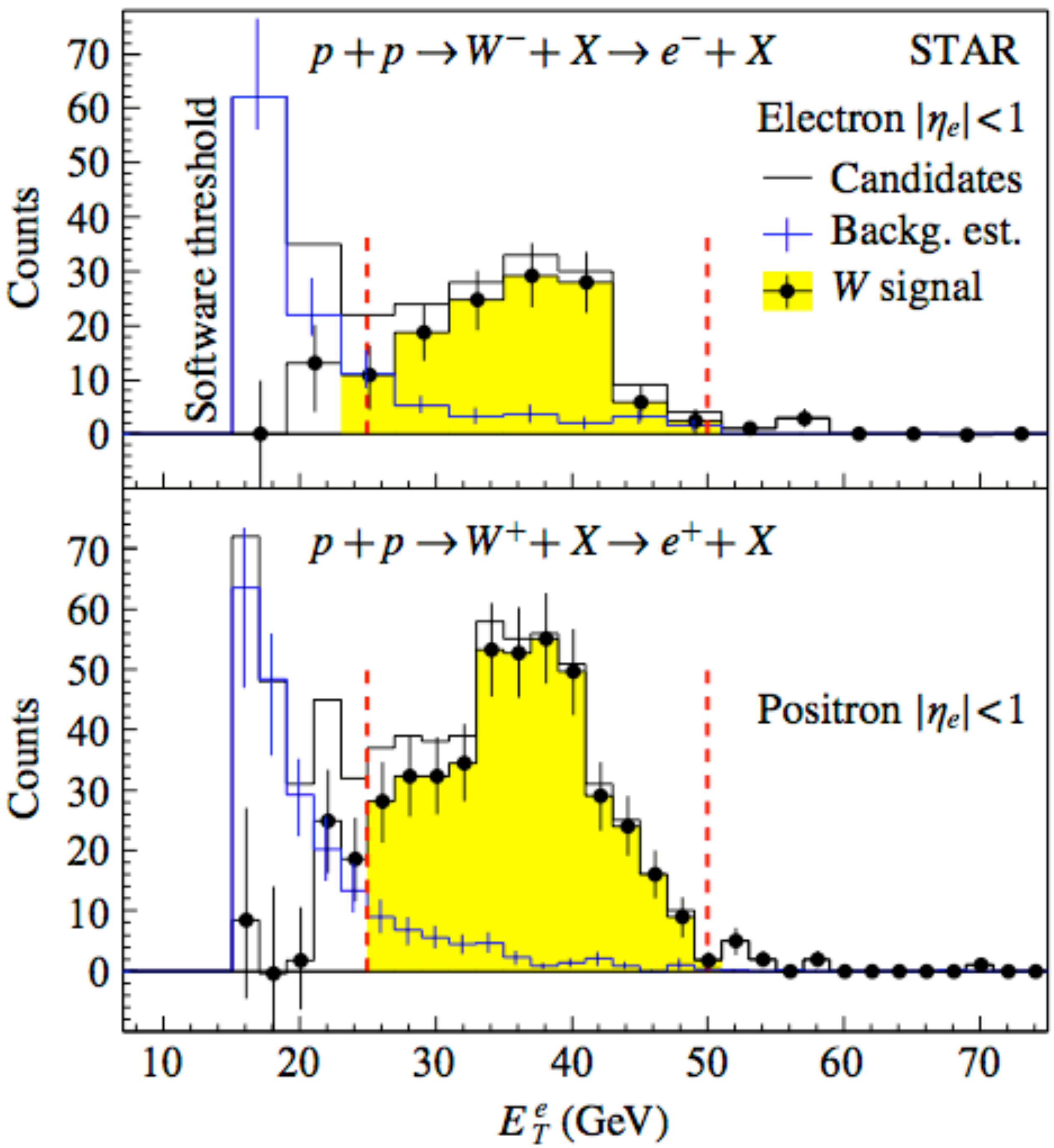


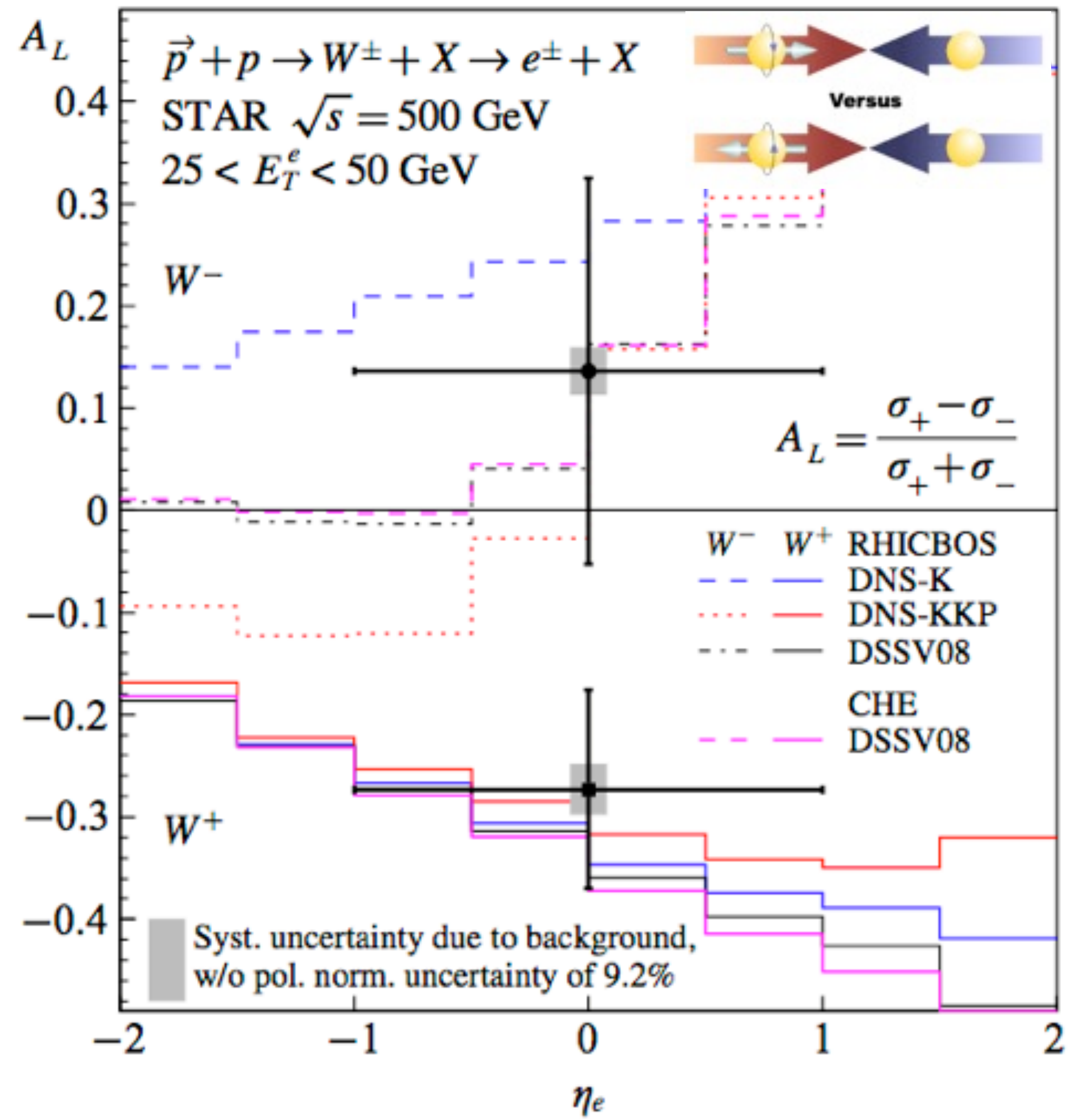
Yields agree with expectations, 139 W^- and 462 W^+ candidate events in 12 pb^{-1}

are expected to increase significantly with further increases in beam energy,

M.M. Agarwal et al, Phys.Rev.Lett.106:062002,2011

Quark Polarization - leptonic W decay





Yields agree with expectations, 139 W^- and 462 W^+ candidate events in 12 pb^{-1}
First asymmetries consistent with expectations based on quark polarizations,
Near-to-mid-term: FGT upgrade, coverage and precision with 2-3 runs,

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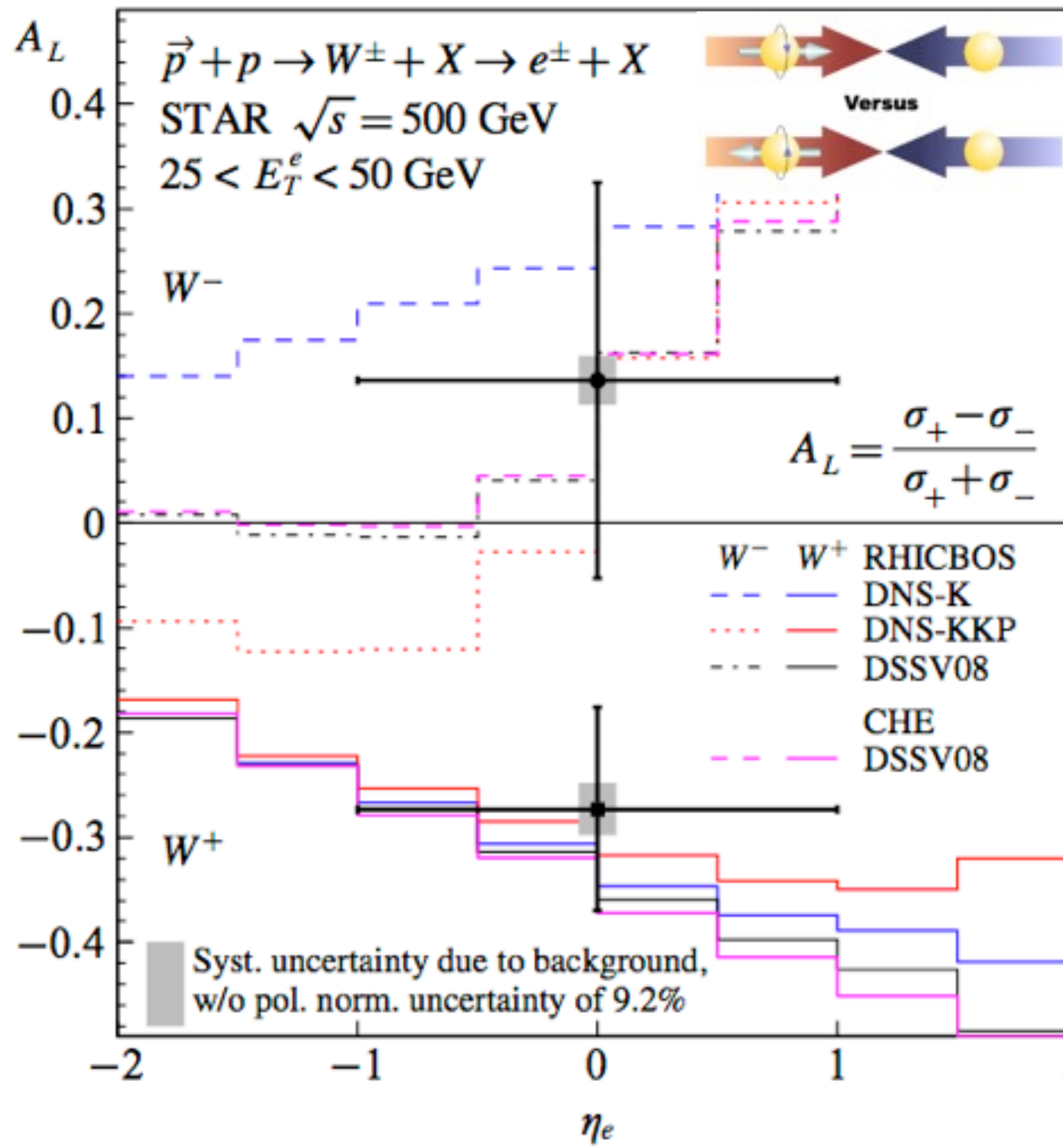
Quark Polarization - leptonic W decay



Six light-weight triple-GEM disks,

provide full charge-sign discrimination at high-pT in EEMC region,

currently being constructed,

c.f. Dunlop's talk (Tuesday).

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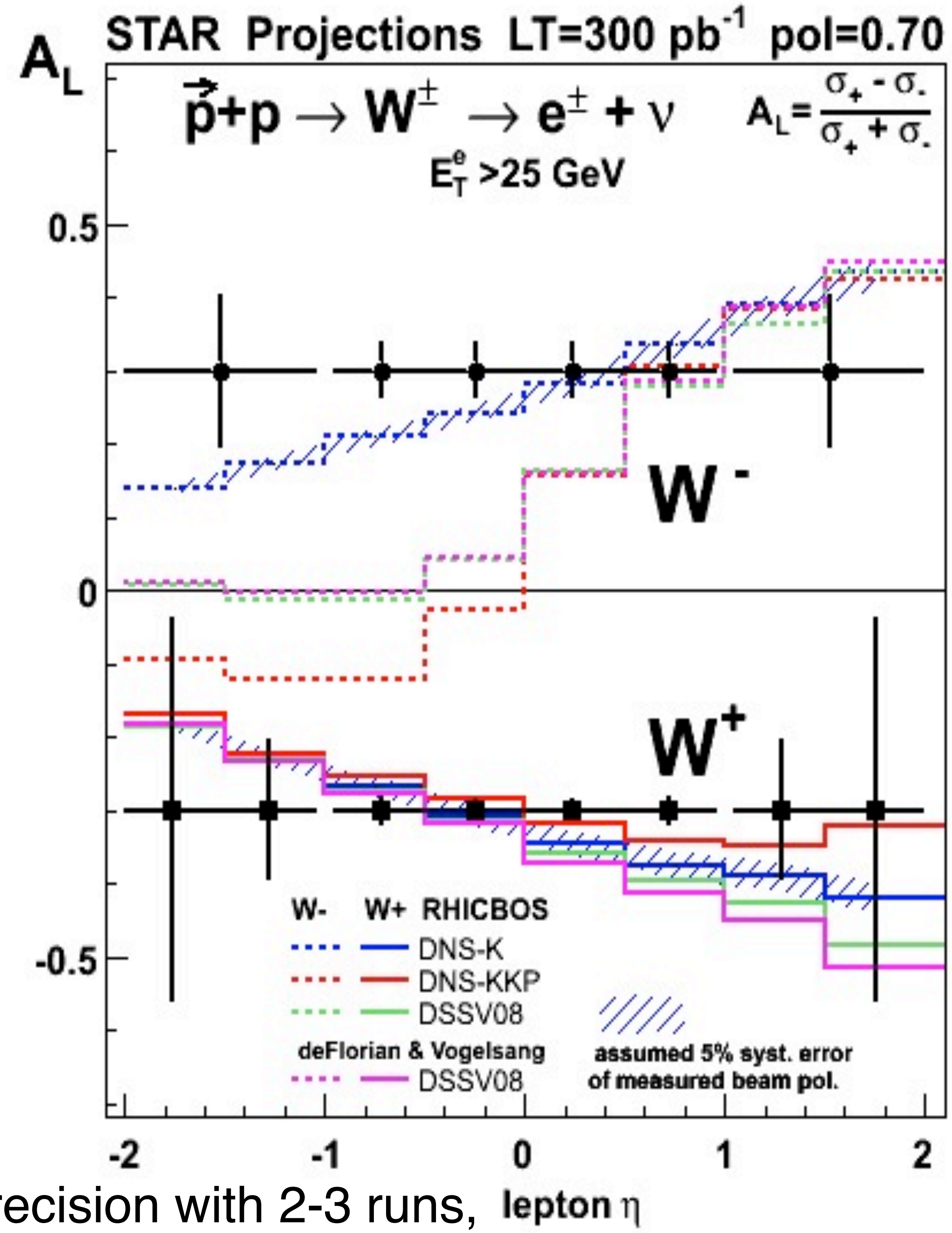

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Measurement relies heavily on future luminosity and polarization at √s = 500 GeV

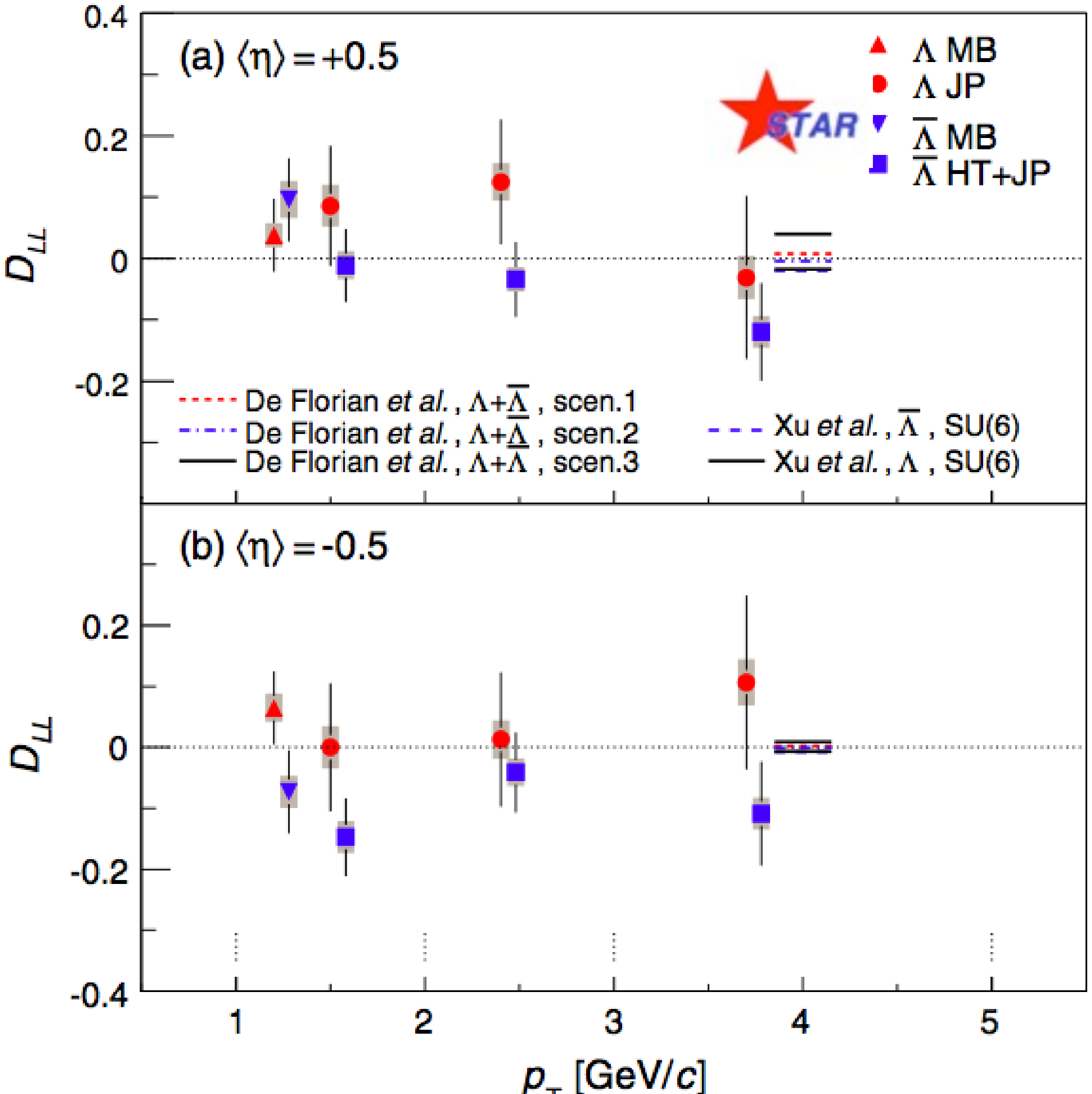
Near-to-mid-term: FGT upgrade, coverage and precision with 2-3 runs,
Surprises may of course extend this.

Note: W+charm, is exceedingly hard; strange quarks are thus likely to remain elusive.

Note: W physics with transverse spins is more demanding; STAR collected a small "benchmark" sample in Run11.

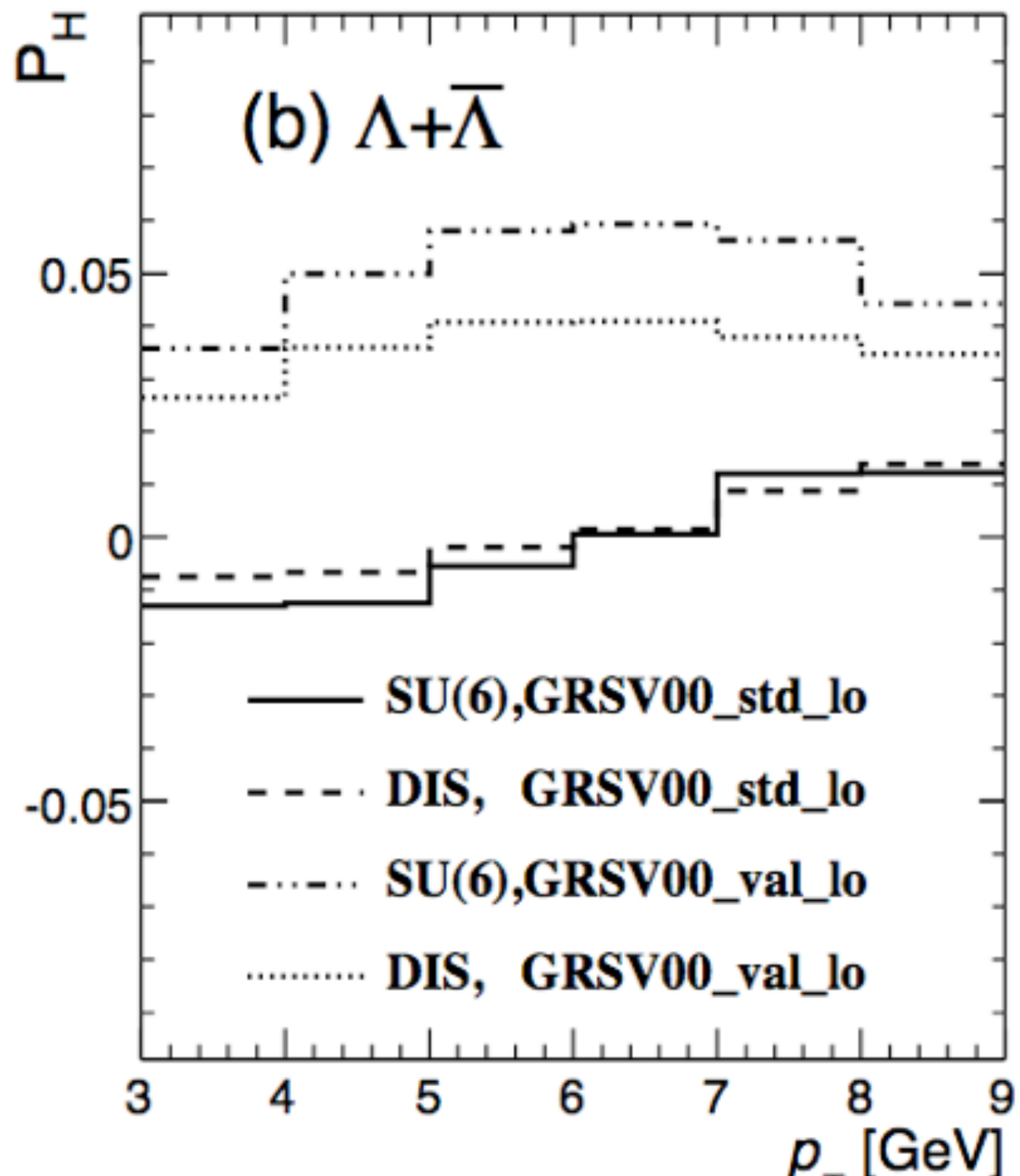
Quark Polarization - Hyperon Spin Transfer

B.I. Abelev et al, Phys. Rev. D 80, 111102 (2009)



√s = 200 GeV, run-5 data, mid rapidity

W.Zhou et al, Phys.Rev.D81:057501,2010

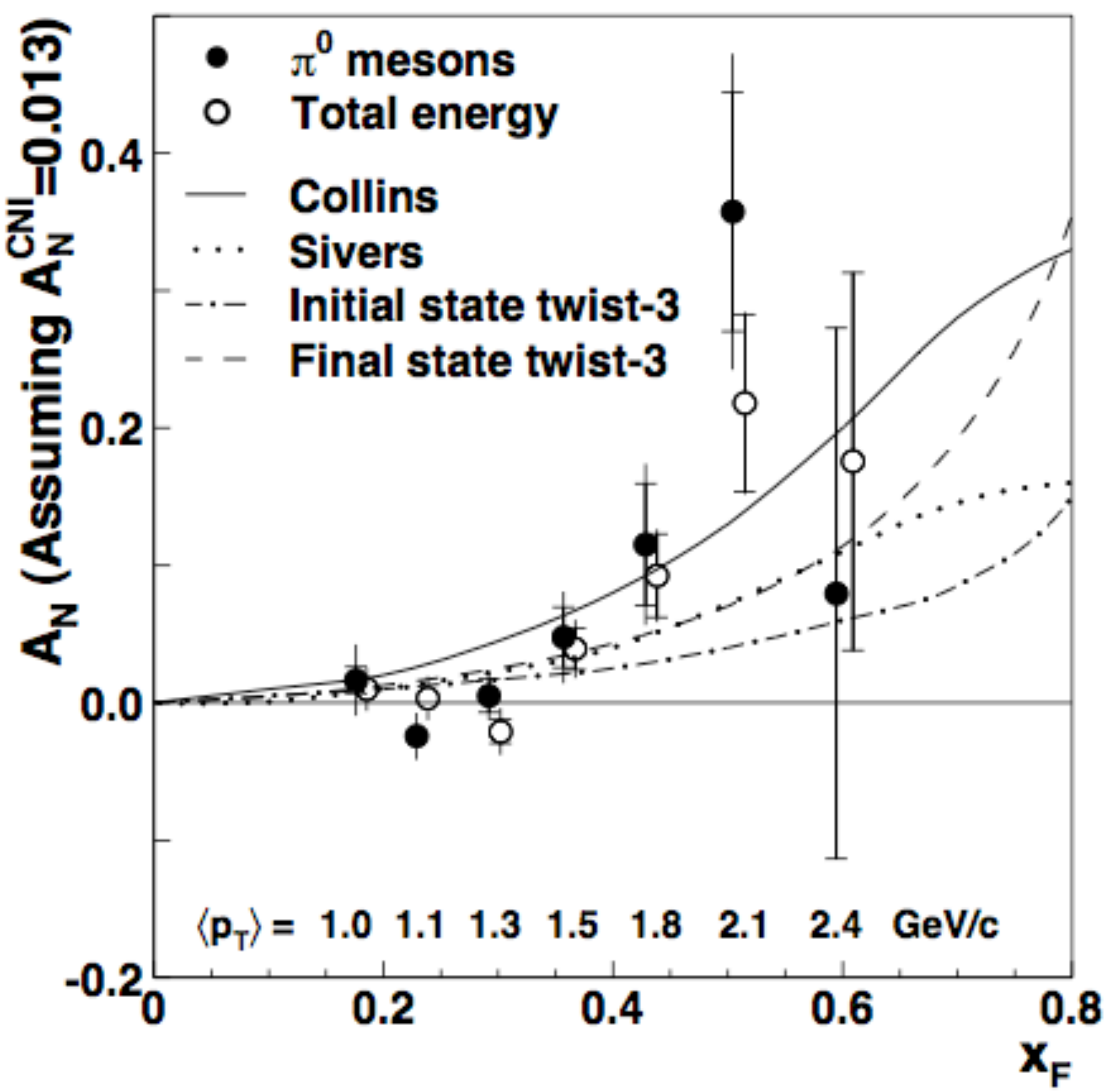


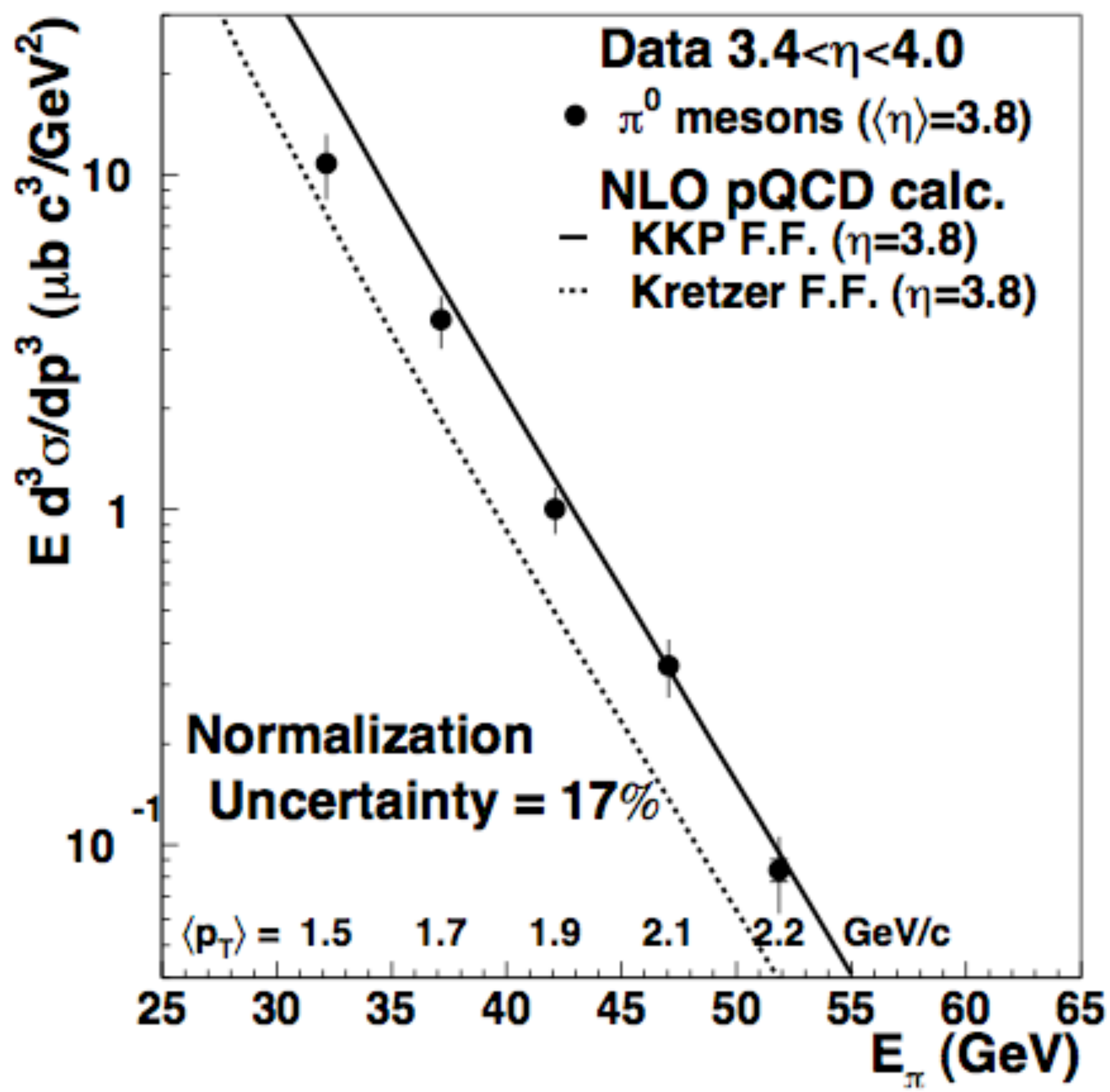
√s = 500 GeV, forward rapidity

Near-term: improved mid-rapidity precision,
Forward hadronic calorimetry (mid-to-long term) would facilitate triggering,
enable a number of hyperon measurements
Hyperon anti-Hyperon discrimination will further improve sensitivity.

Transverse Spin - Renewed Interest

J. Adams et al, PRL 92, 171801 (2004)



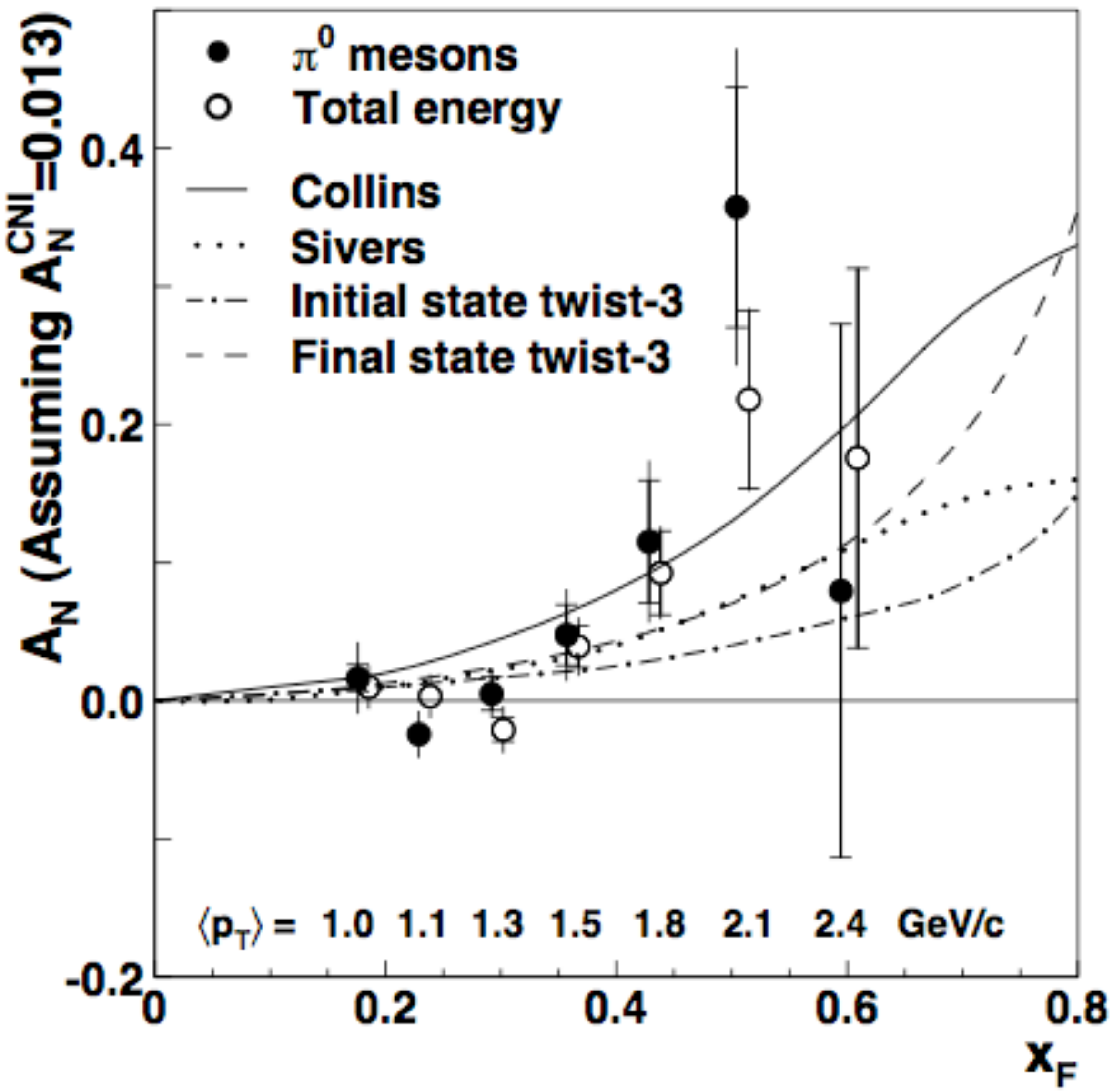


Unexpectedly large forward A_N observed at $\sqrt{s}$ = 200 GeV, in a regime where pQCD describes the production cross section,

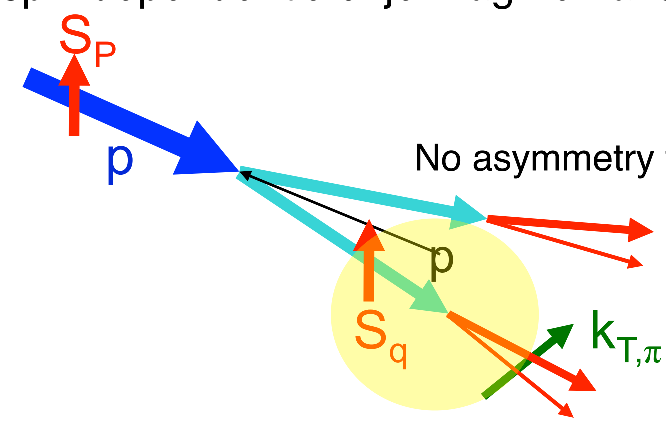
Rapidly evolving field, motivating significant forward instrumentation upgrades.

Transverse Spin Phenomena

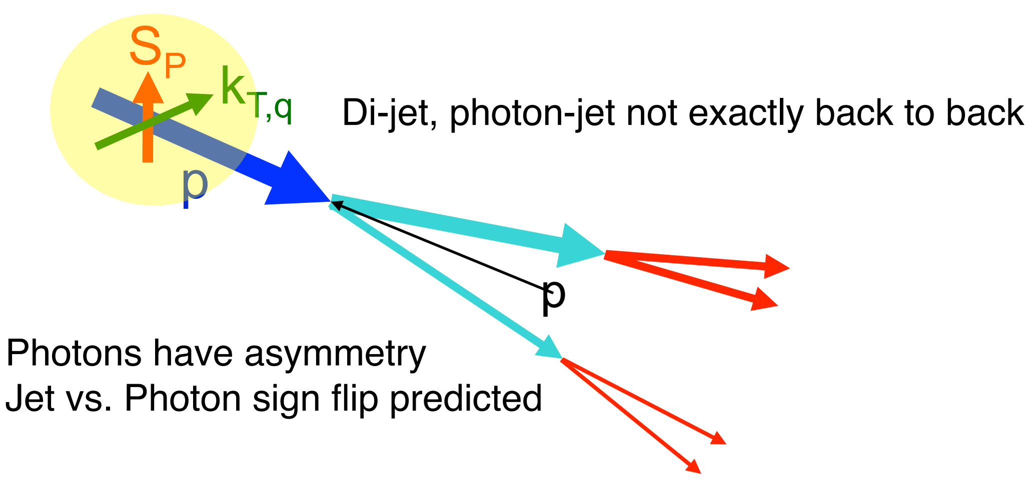
J. Adams et al, PRL 92, 171801 (2004)



- **Collins effect**: asymmetry comes from the transversity and the spin dependence of jet fragmentation.



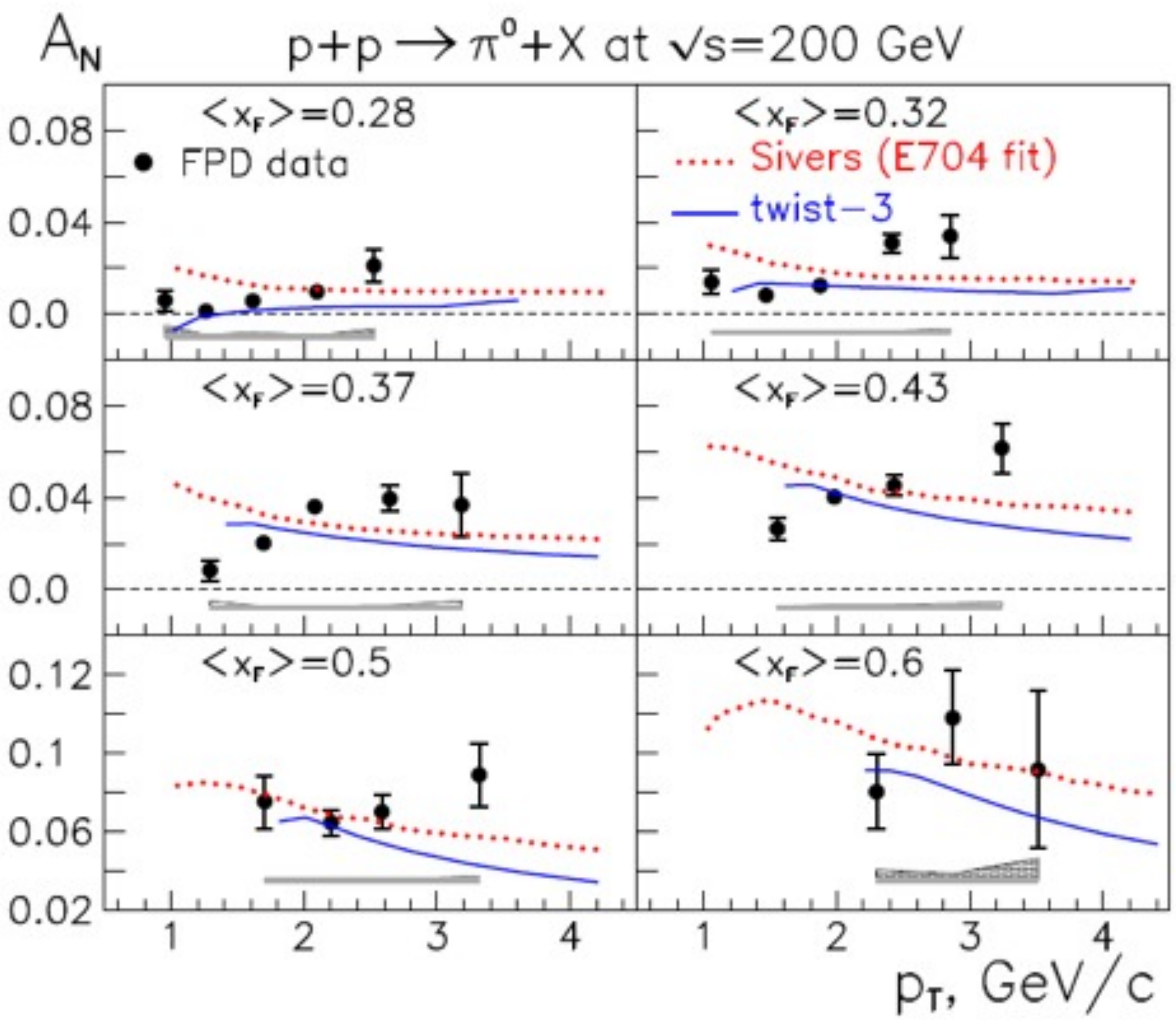
- **Sivers effect**: asymmetry comes from spin-correlated k_T in the initial parton distribution



What causes this?

An experimental handle beyond collinear twist-2 perturbative QCD?

STAR - Transverse Spin Phenomena



Phys.Rev.Lett.101:222001,2008

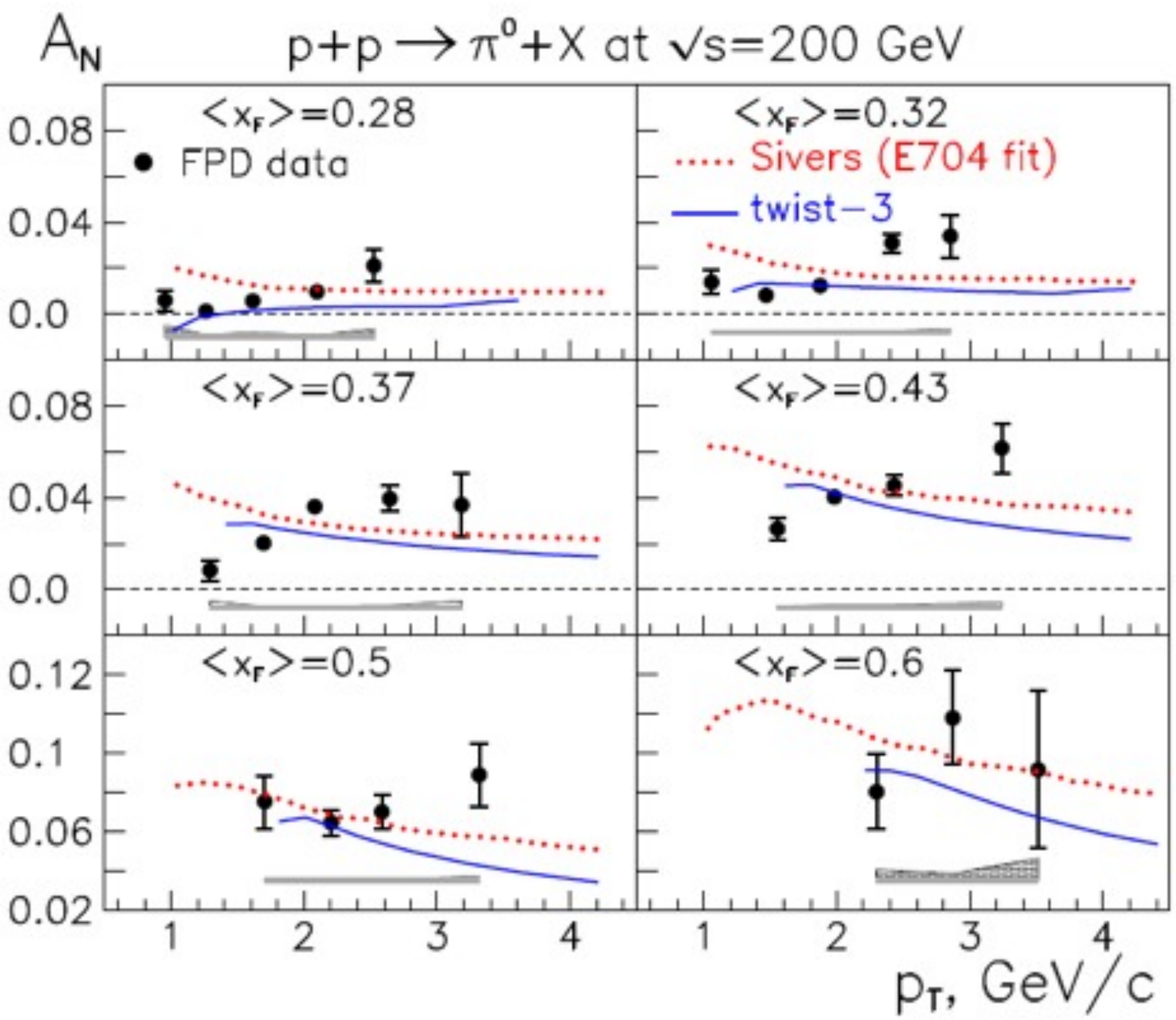
U. D'Alesio, F. Murgia, Phys. Rev. D **70**, 074009 (2004).
J. Qiu, G. Sterman, Phys. Rev. D **59**, 014004 (1998).

Model calculations can qualitatively explain x_F dependence of large A_N,

Models *generally* fall short for the p_T dependence,

Kanazawa and Koike, PRD 82, 034009 (2010), recently succeeded in their Twist-3 approach,

STAR - Transverse Spin Phenomena



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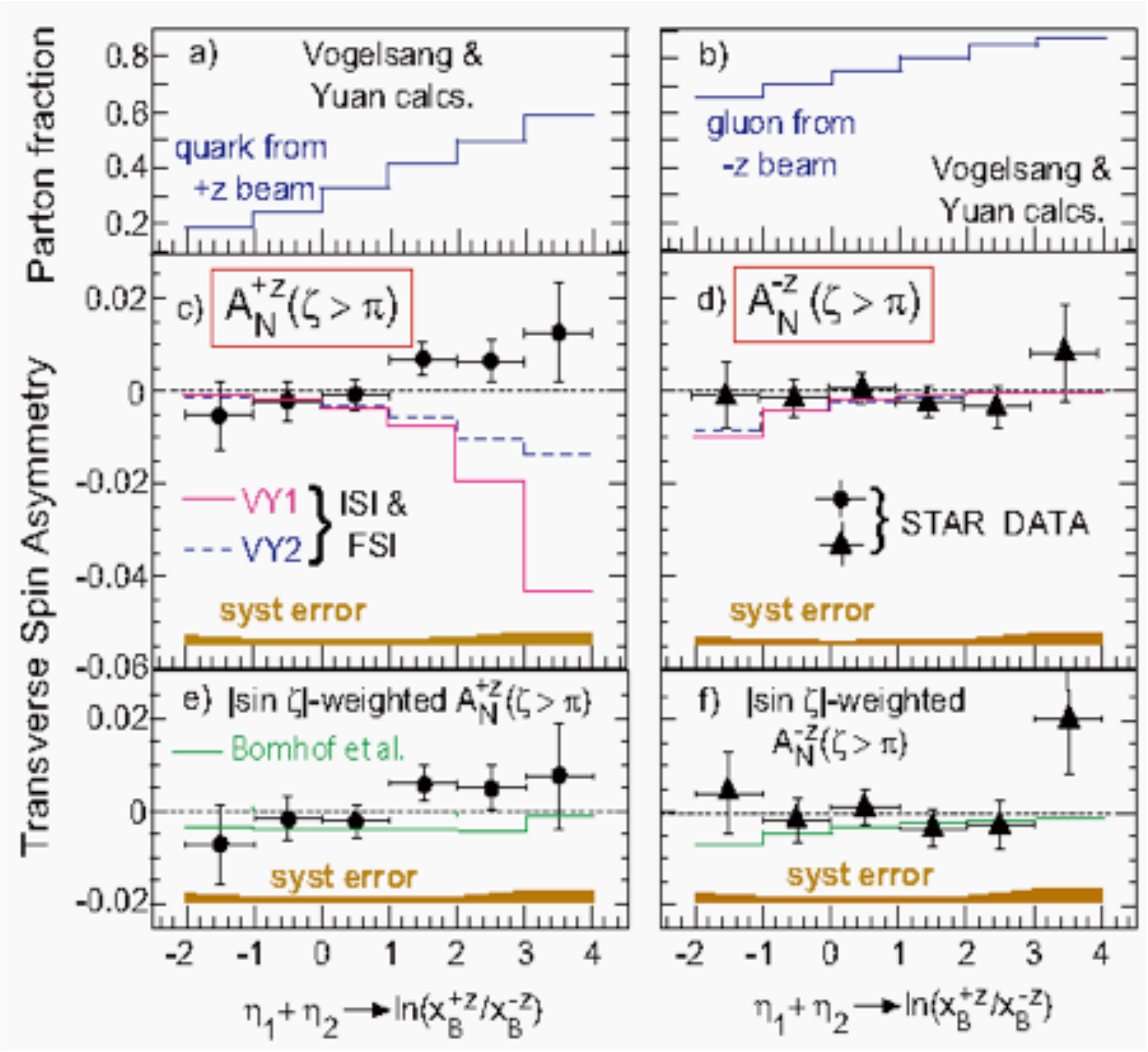
STAR - Transverse Spin Phenomena

Di-jet Sivers measurement



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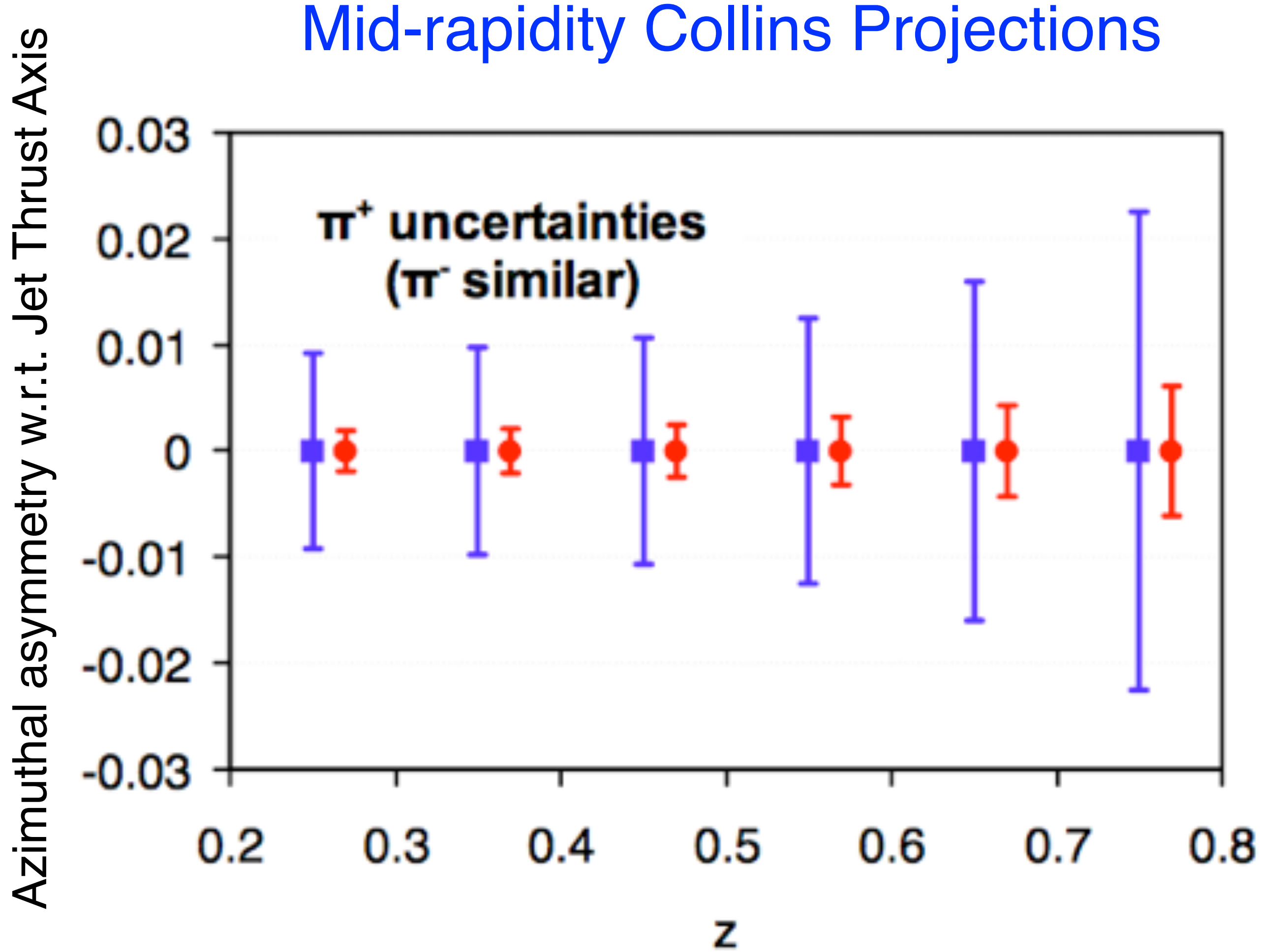
STAR - Transverse Spin Phenomena

Mid-rapidity Collins Projections



Run-6 analysis accuracy ($\sqrt{s}$ = 200 GeV)
projected precision 20pb^{-1}, 60% polarization
Asymmetries anticipated to be several percent

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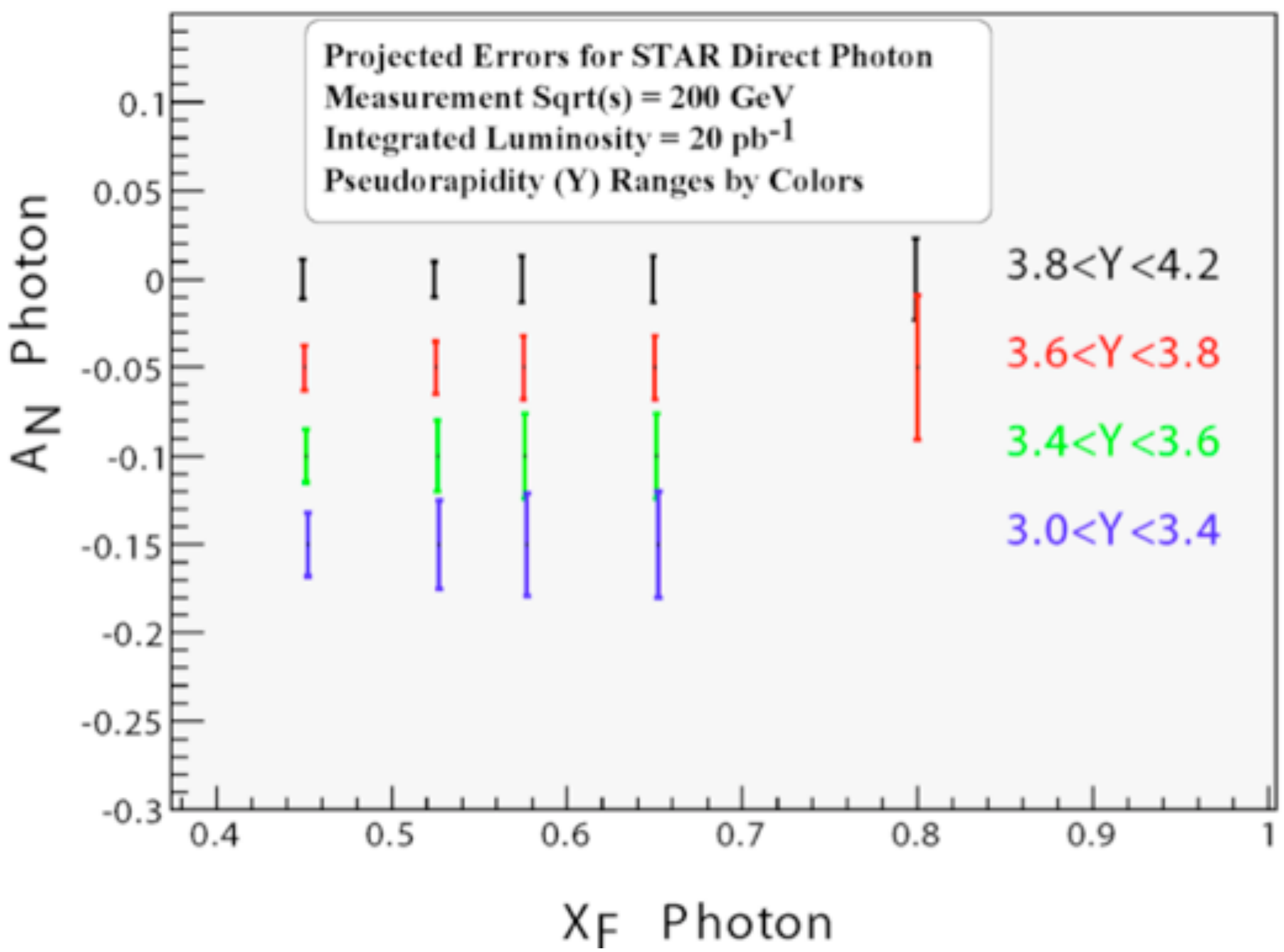
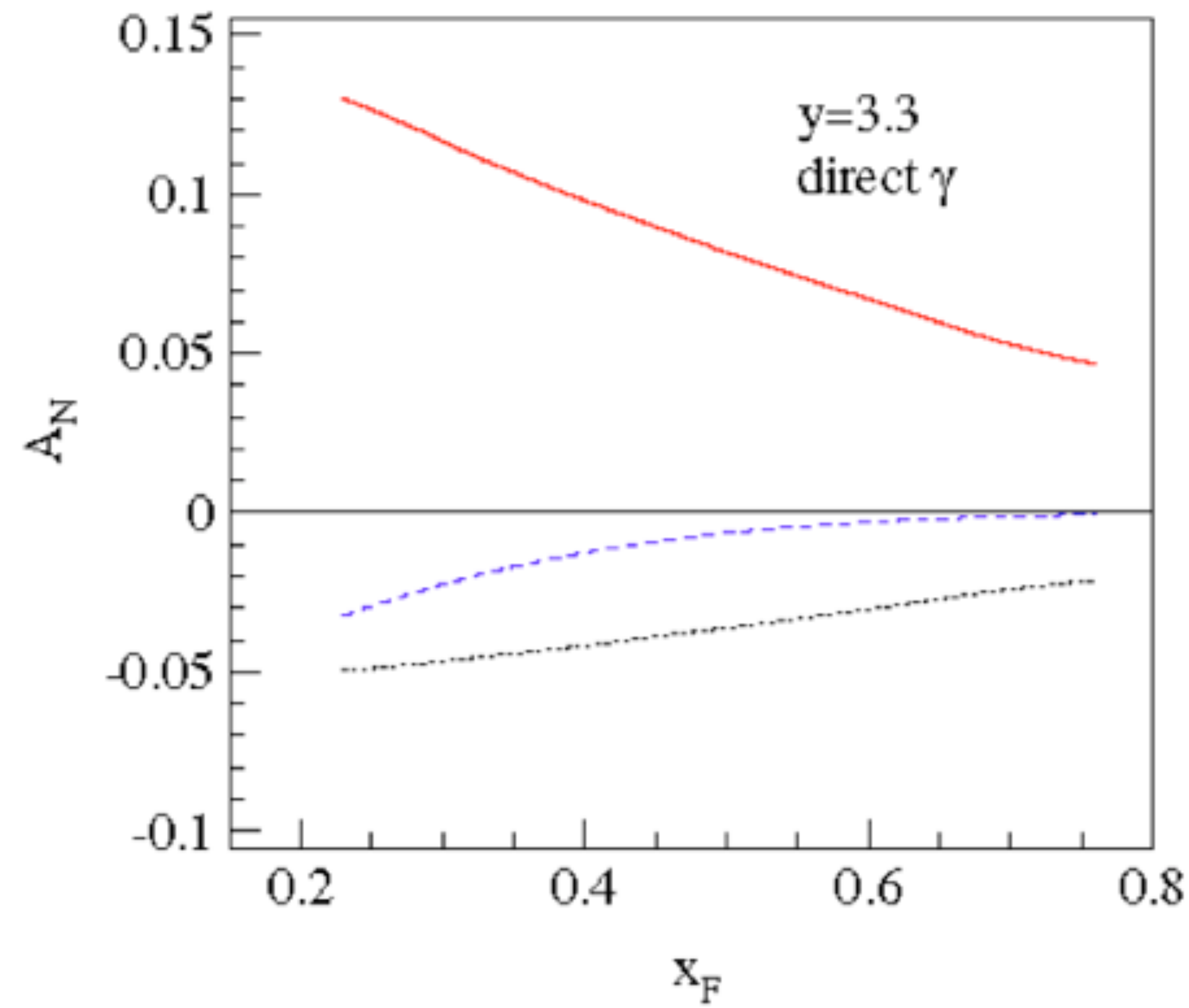
Central-rapidity transverse spin observables *generally* turn out smaller,

STAR - Transverse Spin Phenomena

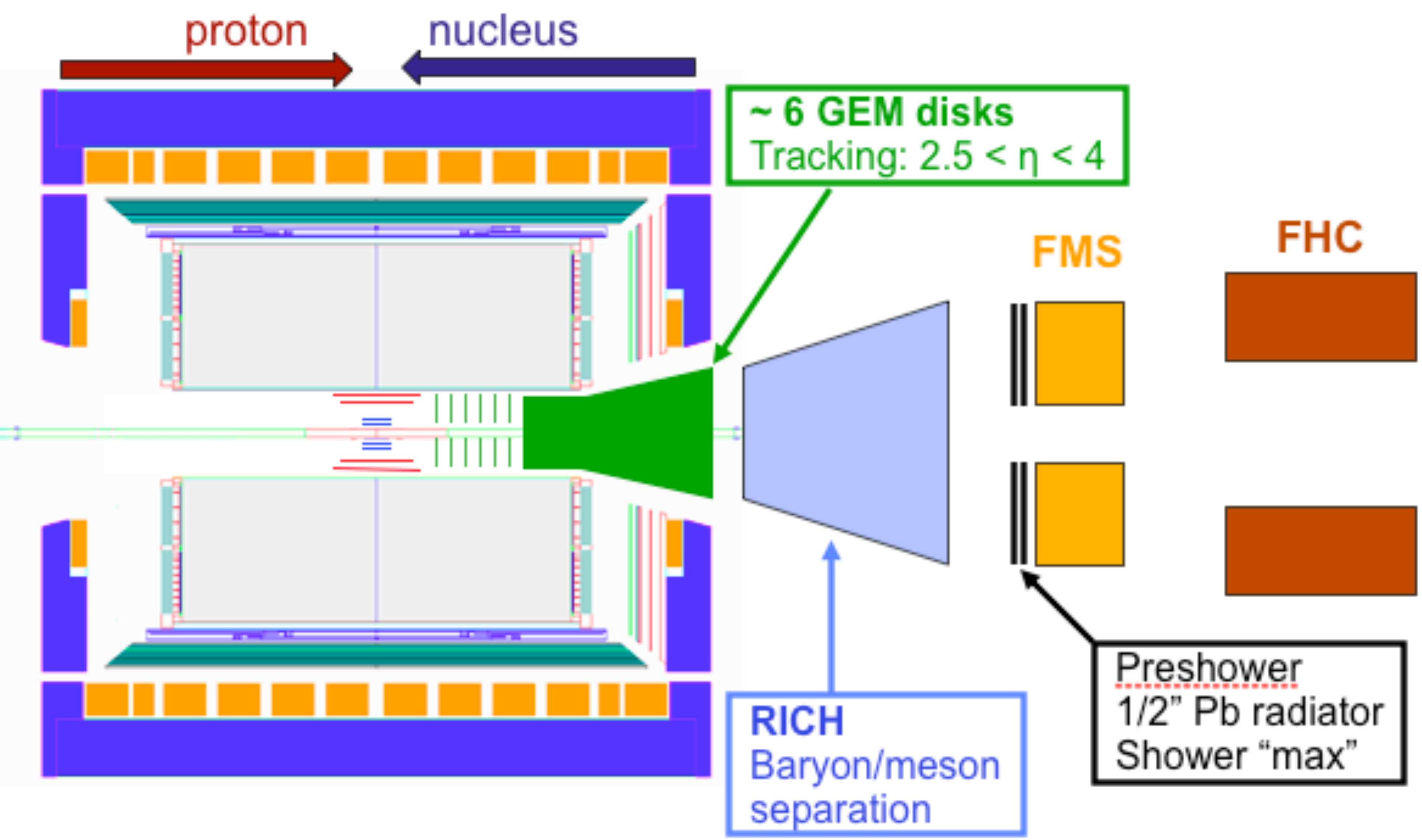




Near-term: continued characterization to much higher p_T, $\sqrt{s}$ = 500 GeV,
photon A_N - projections for 20pb^{-1}, 60% (c.f. Dunlop's talk)

Mid-to-longer term: large acceptance forward instrumentation upgrade to enable
full jet reconstruction, correlations, ..., Drell Yan in p+p and p(d)+A

STAR - Possible Forward Upgrade Concept



Capabilities:

- pions, eta,
- e/h, photon/pion
- jets,
- tracking in jets,
- Hyperons

Opportunities include:

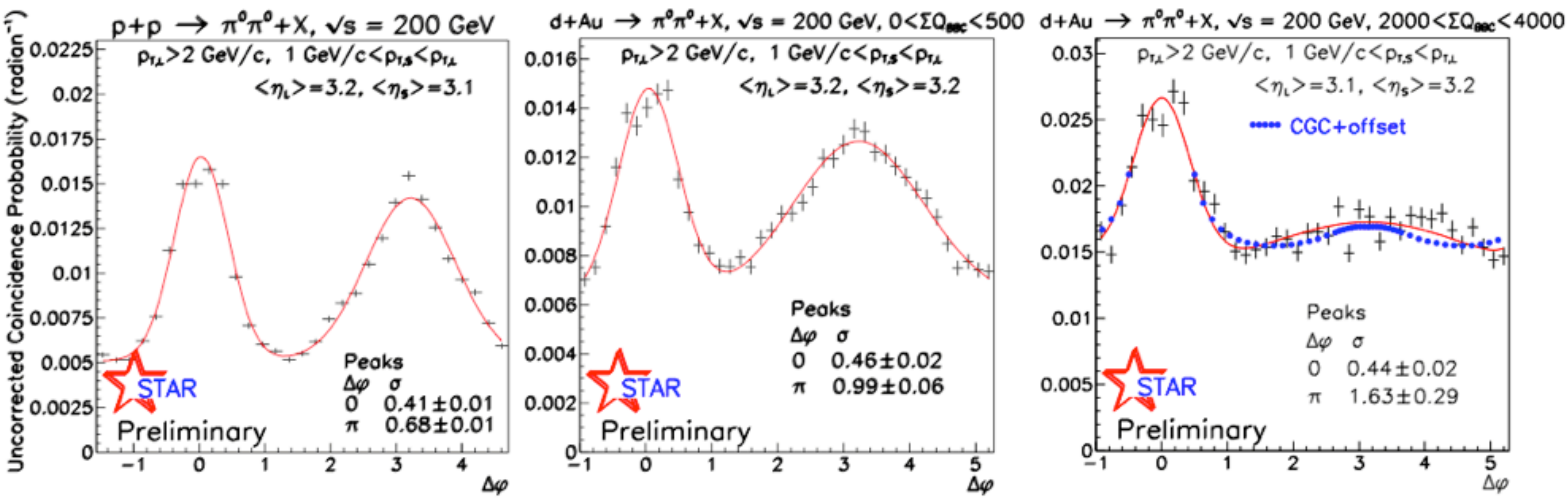
- correlations,
  - photon+jet, $\sqrt{s}$=500GeV
- Sivers, Collins,
  - including flavor
- Spin transfer
- Drell-Yan

Near-term: continued characterization to much higher pT, $\sqrt{s}$ = 500 GeV, photon A_N

Mid-to-longer term: large acceptance forward instrumentation upgrade to enable full jet reconstruction, correlations, ..., Drell Yan in p+p and p(d)+A

... driven by spin physics and p(d)+A physics

Recall Z. Xu's talk yesterday,



Ermes Braidot, *for the collaboration*, QM 2009

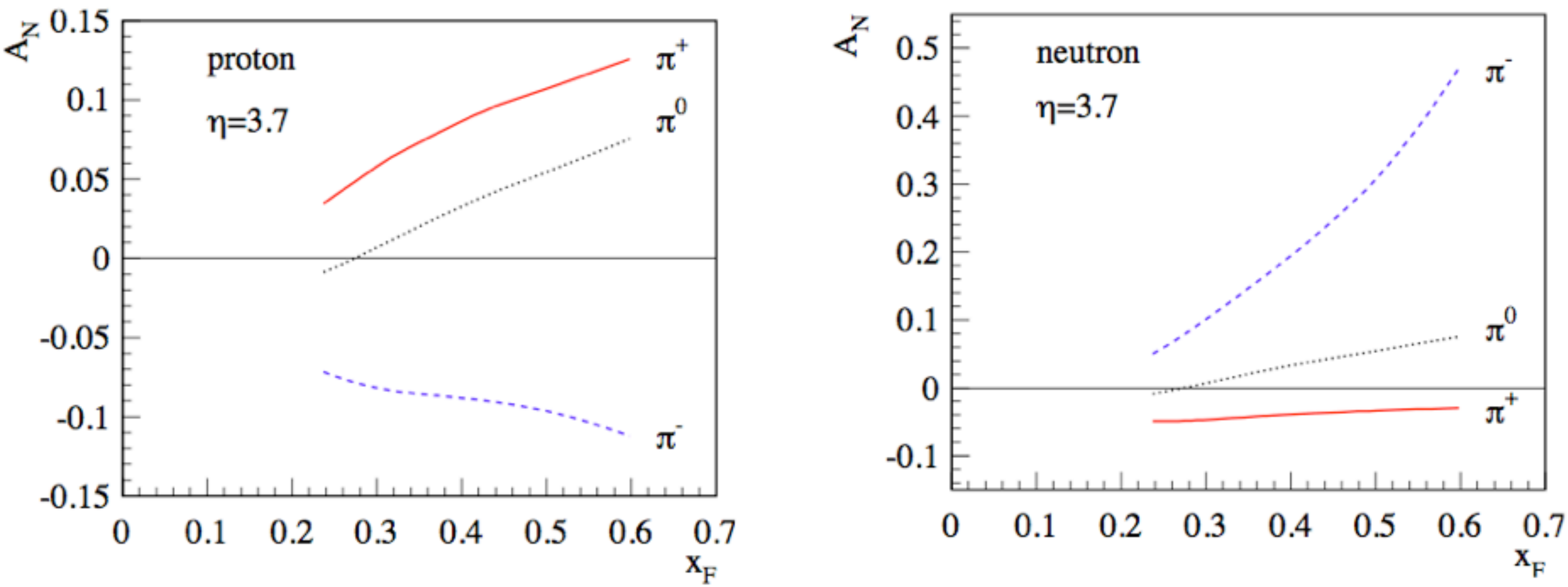
Polarized-proton nucleus scattering would appear to be in the realm of RHIC;
An interesting curiosity, or more? Theorists' guidance is sought and welcome.

Migration to eRHIC Capabilities

Polarized ^3He beams are envisioned for eRHIC,

STAR Roman Pots Phase-II upgrade is estimated to have significant acceptance for the spectator protons in collisions involving the neutron,

May offer attractive opportunities already at RHIC, in particular for transverse spin,



Zhongbo Kang, RHIC Spin Meeting, Iowa May 2010

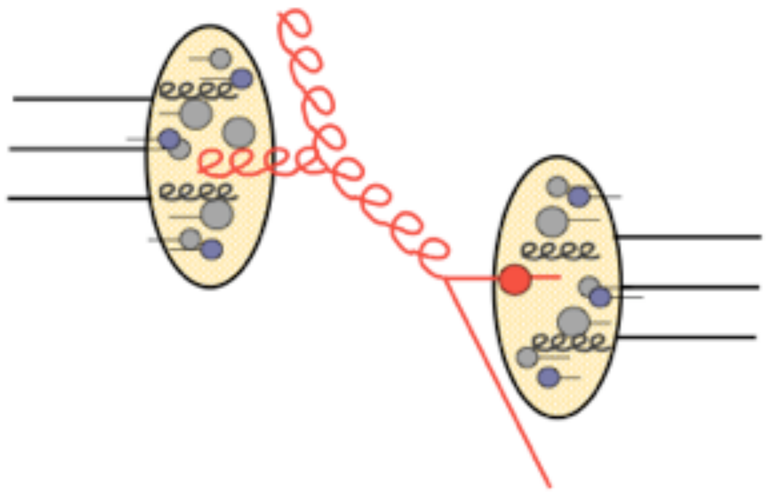
Migration to eRHIC Capabilities

4) Any plans or interest your Collaboration has in adapting your detector or detector subsystems (or detector R&D) to study electron-nucleon and electron-ion collisions with an eventual eRHIC upgrade. This is relevant only near the end of the decade addressed here, but will be important for planning purposes. (We may well be forced by financial or environmental considerations, even for a first MeRHIC stage, to consider options in which acceleration of the electron beam is carried out around the RHIC tunnel, requiring some scheme for getting an electron beamline through or around PHENIX and STAR. So it's worth considering if there is some way you could make use of the e-p and e-A collisions if we provided them.)

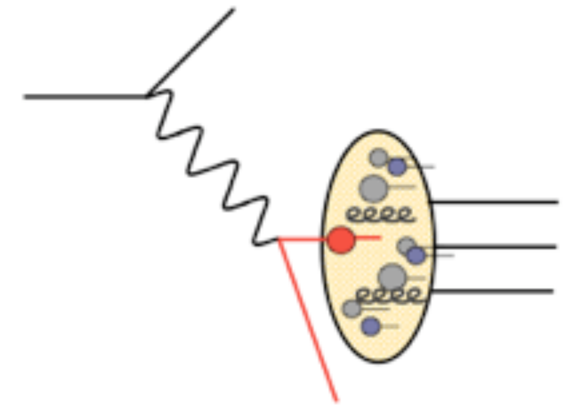
Steve Vigdor to Barbara Jacak and Nu Xu, Decadal Plan Charge December 2009.

Migration to eRHIC Capabilities

pp



DIS



$$Q^2 = -(e - e')^2$$

$$x = \frac{Q^2}{ys}$$

$$y = (q.p)/(e.p)$$

eRHIC physics case is the focus of several talks later today;

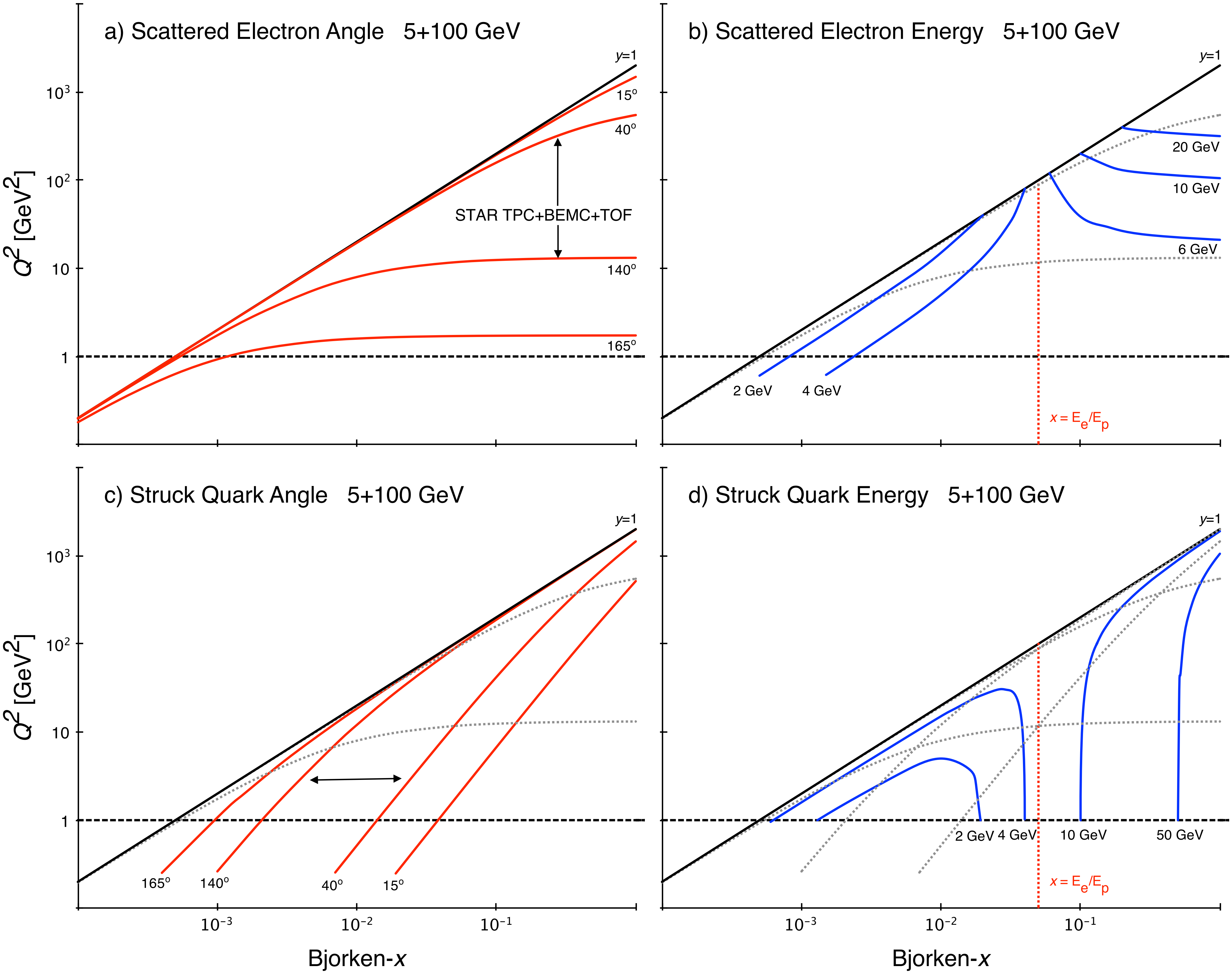
Deep-Inelastic Scattering, inclusive and semi-inclusive, is an integral *part* of it, that will allow us to study e.g. the gluon distribution in nuclei,

energy loss in cold nuclear matter,

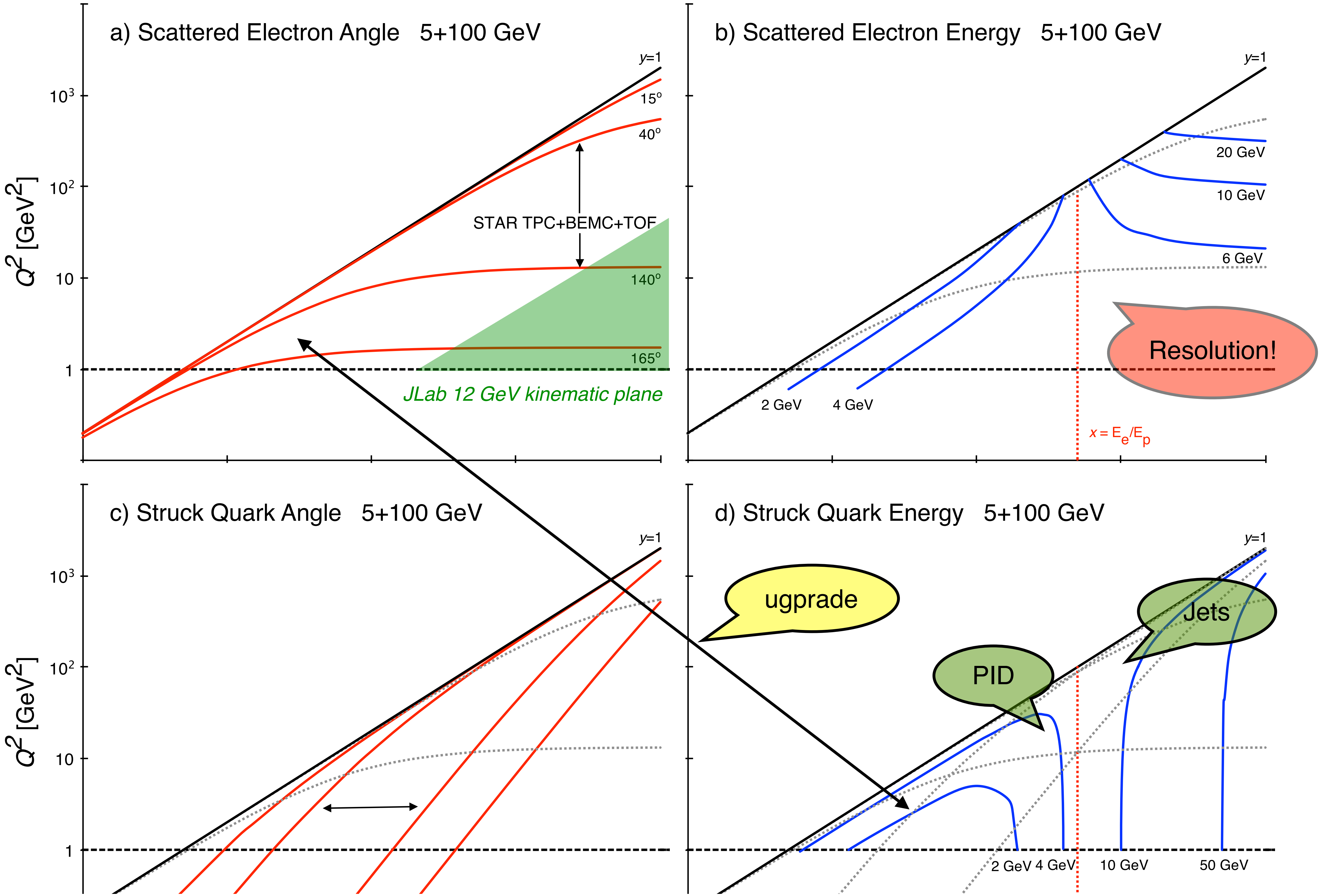
strange quarks in the nucleon,

Focus here on DIS with STAR in the *initial* (low energy-)stage of eRHIC.

STAR Evolution to eRHIC

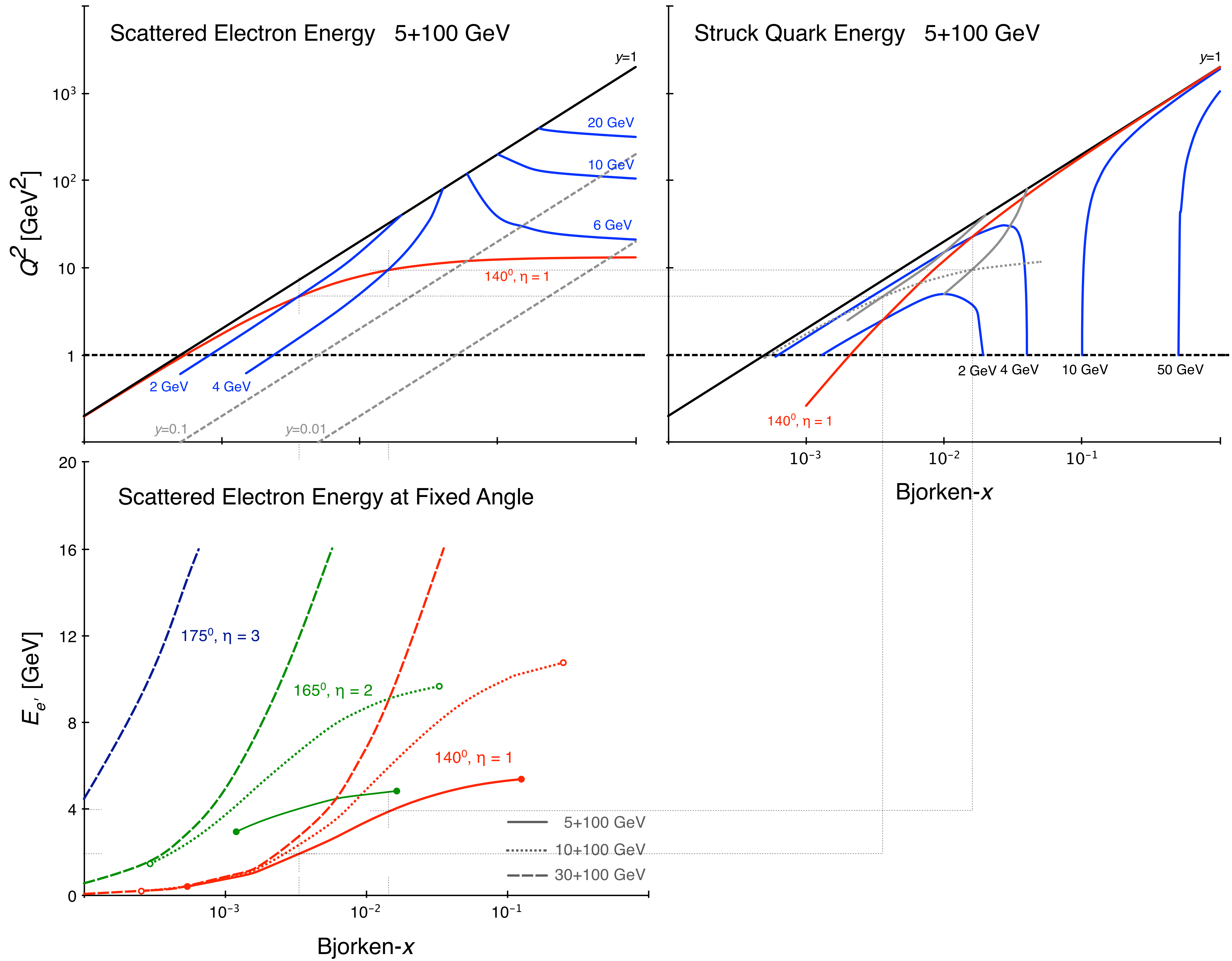


STAR Evolution to eRHIC

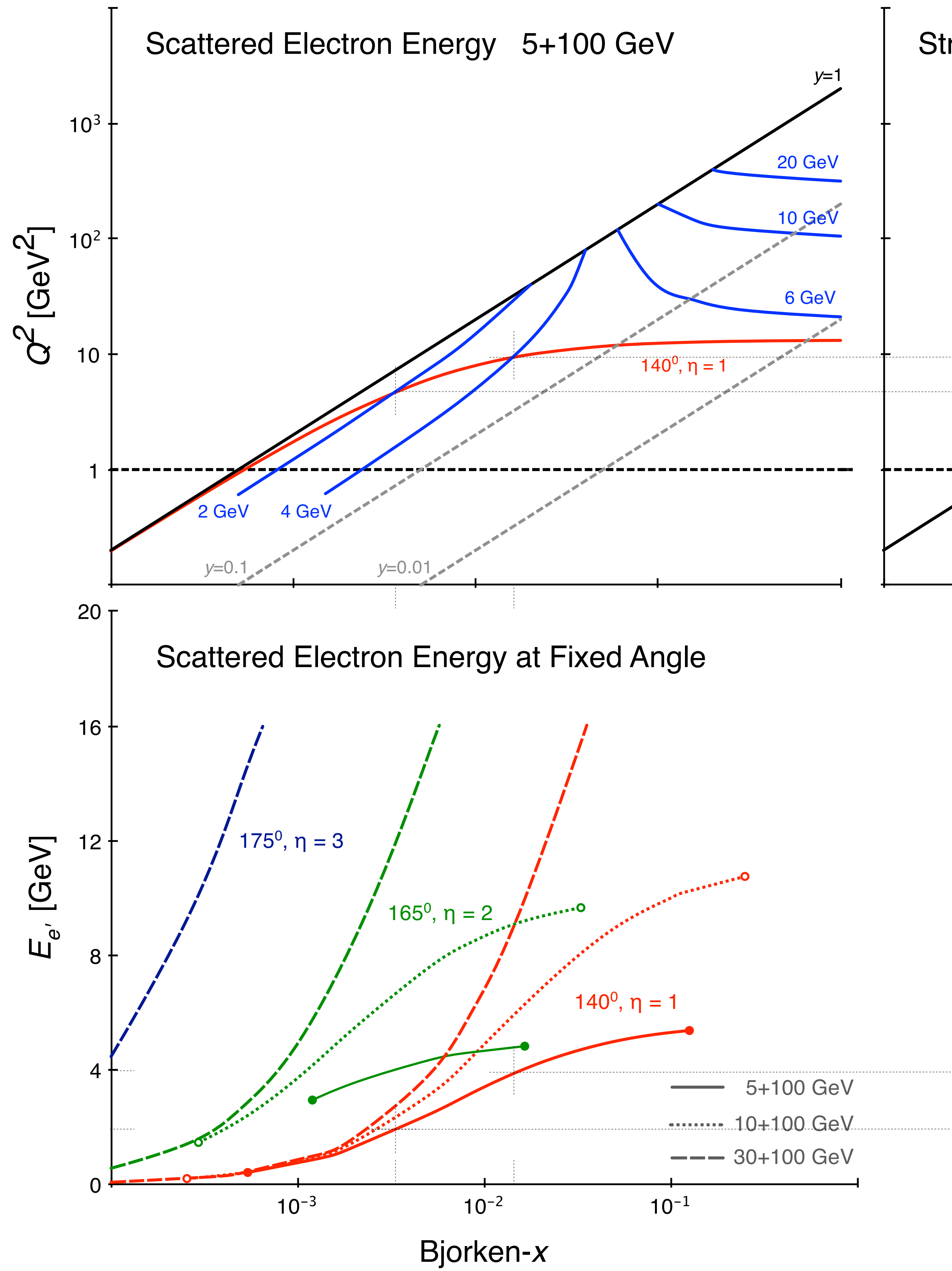


Electron beam in Yellow, Hadron beam in Blue.

Towards an eSTAR Concept



Towards an eSTAR Concept



Bending radii ~m,

Sagitta ~mm (over 40cm),

At 140°, dx/x~2 implies:

dE/E~0.5 at x ~ 10^{-3}
dE/E~0.3 at x ~ 10^{-2}
dE/E~0.04 at x ~ 10^{-1}

At 165°, dx/x~2 implies dE/E~0.09 at 5.10^{-3}

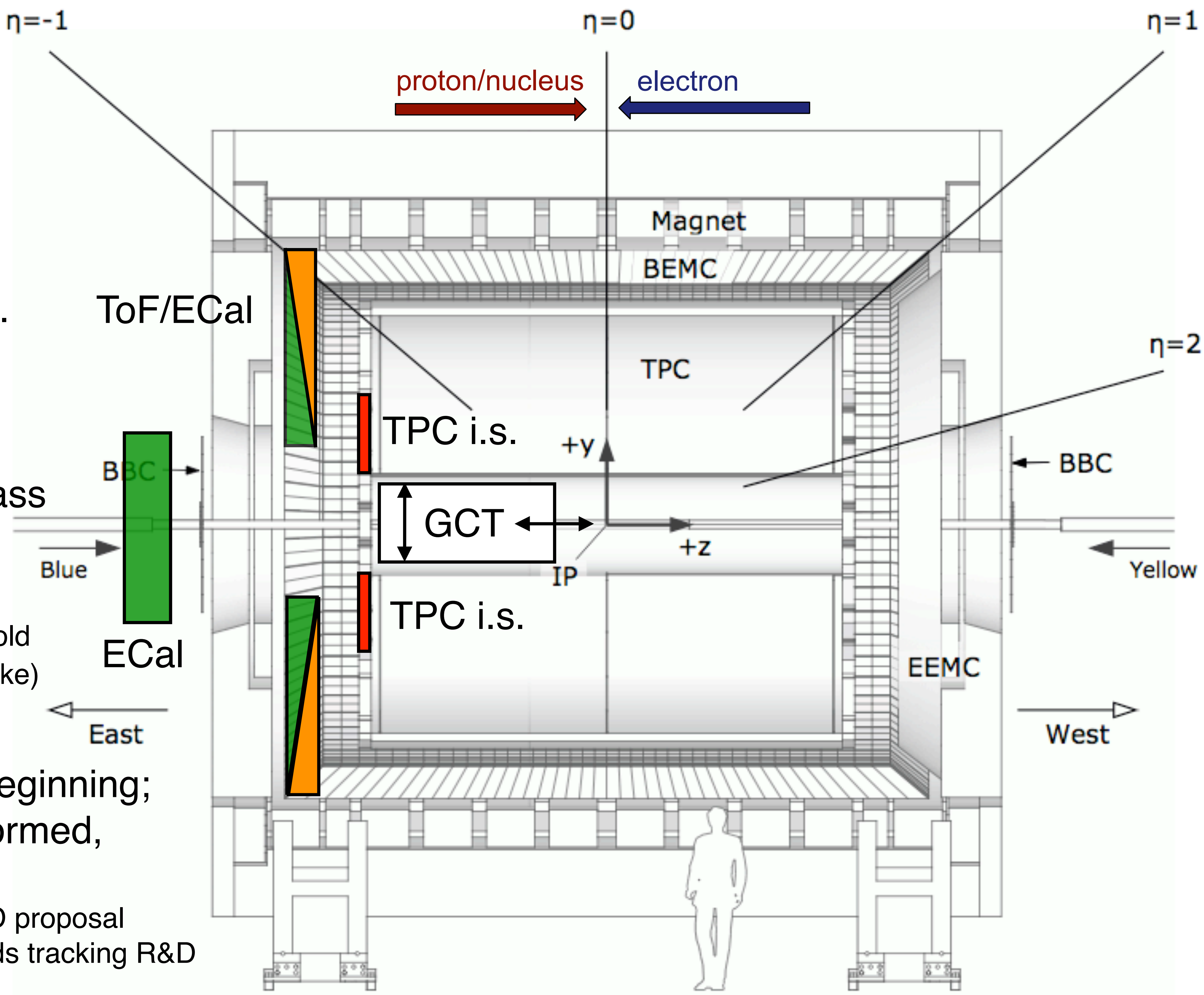
Towards an eSTAR Concept - Electron Side

ToF: π , K identification,
t_0, electron

ECal: 5 GeV, 10 GeV, ...
electron beams

GCT: a compact low-mass tracker with enhanced electron capability;

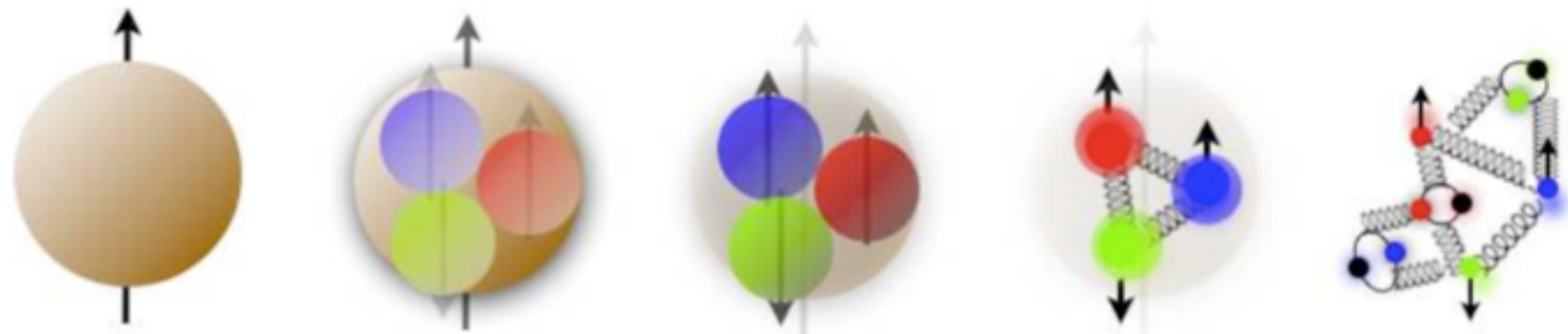
seek to combine high-threshold (gas) Cherenkov with TPC(-like) tracking.



Simulations and R&D beginning;
- eSTAR task force formed,
- EIC generic R&D:
  - Hadron Calorimeter R&D proposal
  - Multi-institute LOI towards tracking R&D

Note: Hadron Side not shown here.

Closing Remarks



Near-term:

Gluon polarization inclusive measurements are delivering the most precise insight to date, covering ~0.02 < *x* < 0.3 (√s = 500 GeV will widen this),

correlation measurements are key to *x*-dependence and, related, extrapolations over unmeasured *x*,

Quark polarization measurements have started, and will benefit greatly from a) the ongoing FGT tracking upgrade and b) a multi-run measurement period,

Transverse spin phenomena continue to surprise; photon A_N and other measurements should allow much better characterization,

Mid-term:

Full study of transverse spin phenomena and p(d)+A measurements form the drivers for a major instrument upgrade (concept) to provide large acceptance in the forward region.

Long-term:

STAR acceptance and PID capabilities appear a reasonable match to inclusive and semi-inclusive DIS at eRHIC for *low* electron and *all* hadron beam energies - <u>not</u> for *high* electron energies.

eSTAR could thus be a path to a timely staged EIC. Task force formed to investigate further, and quantify measurement capabilities.