Forward Particle Production and Transverse Single Spin Asymmetries

OUTLINE

• Transverse single spin effects in p+p collisions at $\sqrt{s}=200$ GeV
• Towards understanding forward $\pi^0$ cross sections
• Plans for the future

L.C. Bland
Brookhaven National Laboratory
RBRC Workshop on Parton Orbital Angular Momentum
Albuquerque 25 February 2006
Developments for runs 2 (1/02), 3 (3/03 → 5/03) and 4 (4/04 → 5/04)

- Helical dipole snake magnets
- CNI polarimeters in RHIC, AGS
- fast feedback
- $\beta^*=1\text{m}$ operation
- spin rotators $\rightarrow$ longitudinal polarization
- polarized atomic hydrogen jet target

2/25/2006
L.C. Bland, RBRC Parton OAM
RHIC Spin Physics Program

- *Direct measurement* of polarized gluon distribution *using multiple probes*

- Direct measurement of *anti-quark polarization* using *parity violating production of* $W^{\pm}$

- *Transverse spin*: Transversity & transverse spin effects: possible connections to orbital angular momentum?
STAR detector layout

• TPC: $-1.0 < \eta < 1.0$
• FTPC: $2.8 < |\eta| < 3.8$
• BBC: $2.2 < |\eta| < 5.0$
• EEMC: $1 < \eta < 2$
• BEMC: $-1 < \eta < 1$
• FPD: $|\eta| \sim 4.0 \& \sim 3.7$

STAR characterized by azimuthally complete acceptance over broad range of pseudorapidity.

2/25/2006 L.C.Bland, RBRC Parton OAM
Single Spin Asymmetry

Definitions

- **Definition:**
  \[ A_N = \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}} \]

- **d\sigma^{\uparrow(\downarrow)}** – differential cross section of \( \pi^0 \) when incoming proton has spin up(down)

Two measurements:

- **Single arm calorimeter:**
  \[ A_N = \frac{1}{P_{\text{Beam}}} \cdot \left( \frac{N^{\uparrow} - R N^{\downarrow}}{N^{\uparrow} + R N^{\downarrow}} \right) \quad R = \frac{L^{\uparrow}}{L^{\downarrow}} \]
  
  R – relative luminosity (by BBC)
  
  \( P_{\text{beam}} \) – beam polarization

- **Two arms (left-right) calorimeter:**

  \[ A_N = \frac{1}{P_{\text{Beam}}} \cdot \left( \frac{\sqrt{N_L^{\uparrow} \cdot N_R^{\downarrow}} - \sqrt{N_R^{\uparrow} \cdot N_L^{\downarrow}}}{\sqrt{N_L^{\uparrow} \cdot N_R^{\downarrow}} + \sqrt{N_R^{\uparrow} \cdot N_L^{\downarrow}}} \right) \]

  No relative luminosity needed

**Positive** \( A_N \): more \( \pi^0 \) going left to polarized beam

\( \pi^0, x_F < 0 \) \quad \pi^0, x_F > 0

\( p^{\uparrow} \) \to \quad \text{Left} \quad \text{Right} \quad \text{p}
First $A_N$ Measurement at STAR

prototype FPD results

STAR collaboration

Similar to result from E704 experiment
($\sqrt{s}=20$ GeV, $0.5 < p_T < 2.0$ GeV/c)

Can be described by several models available as predictions:

- **Sivers**: spin and $k_\perp$ correlation in parton distribution functions (initial state)
- **Collins**: spin and $k_\perp$ correlation in fragmentation function (final state)
- **Qiu and Sterman (initial state) / Koike (final state)**: twist-3 pQCD calculations, multi-parton correlations

$\sqrt{s}=200$ GeV, $<\eta> = 3.8$
Dynamical Origins of Transverse SSA

\[ p_t + p \rightarrow \pi^0 + X \]


  Flavor dependent correlation between the proton spin (\( S_p \)), momentum (\( P_p \)) and transverse momentum (\( k^T \)) of the unpolarized partons inside:

  \[
  f_q(x, k^\perp_q, S_p) = f_q(x, k^\perp_q) + \frac{1}{2} \Delta^N_q f_q(x, k^\perp_q) \frac{S_p \cdot (P_p \times k^\perp_q)}{|S_p||P_p||k^\perp_q|}
  \]

- **Collins effect [Nucl Phys B396 (1993) 161]:**

  Correlation between the quark spin (\( s_q \)), momentum (\( p_q \)) and transverse momentum (\( k^T \)) of the pion. The fragmentation function of transversely polarized quark \( q \) takes the form:

  \[
  \hat{D}_{\pi/q}(z, k^\perp_\pi, s_q) = \hat{D}_{\pi/q}(z, k^\perp_\pi) + \frac{1}{2} \Delta^N \hat{D}_{\pi/q}(z, k^\perp_\pi) \frac{s_q \cdot (p_q \times k^\perp_\pi)}{|p_q \times k^\perp_\pi|}
  \]
Present Status

Run 3 Preliminary Result:
- more Forward angles
- final FPD Detectors

Run 3 Preliminary Backward Angle Data:
- No significant asymmetry seen.
A. Ogawa, for STAR: [hep-ex/0502040]

Run 3 + Run 5 Preliminary
<η>=3.7,4.0
D. Morozov, for STAR [hep-ex/0512013]

Uses online beam polarization values

\( p+p \rightarrow \pi^0+X \text{ at } \sqrt{s}=200\text{GeV} \)
$x_F$ and $p_T$ range of FPD data

$p + p \rightarrow \pi^0 + X, \sqrt{s} = 200$ GeV, $<\eta> = 4.1$

Correlation between $<p_T>$ and $<x_{F,\pi}>$ for $PRL 92$ (2004) 171801

Bin boundaries for $\Lambda_n$

Correlation between $<p_{T,n}>$ and $<x_{F,n}>$

$\rightarrow$ Expect $\gamma/\pi^0 \geq 1$

$\eta = 2.5$

$\eta = 3.0$

$\eta = 3.5$

$\eta = 4.0$

2/25/2006 L.C.Bland, RBRC Parton OAM
$A_N(p_T)$ from run3+run5 at $\sqrt{s}=200$ GeV

- Combined statistics from run3 and run5 with $x_F>0.4$

- There is evidence that analyzing power at $x_F>0.4$ decreases with increasing $p_T$

- To do: systematics study

Uses online beam polarization values
**Forward \( \pi^0 \) production in hadron collider**

- Large rapidity \( \pi \) production \((\eta_\pi > 4)\) probes asymmetric partonic collisions

- Mostly **high-\( x \) valence quark + low-\( x \) gluon**
  - \( 0.3 < x_q < 0.7 \)
  - \( 0.001 < x_g < 0.1 \)
- \(<z> \) nearly constant and high \(0.7 \sim 0.8\)

- Large-\( x \) quark polarization is known to be large from DIS

- Directly couple to gluons \( \Rightarrow \) probe of low \( x \) gluons
But, do we understand forward $\pi^0$ production in $p + p$?

At $\sqrt{s} < 200$ GeV, not really...

Bourrely and Soffer (hep-ph/0311110, Data references therein):

NLO pQCD calculations underpredict the data at $\sqrt{s} < 200$ GeV (ISR and fixed target)

$\sigma_{\text{data}} / \sigma_{\text{pQCD}}$ appears to be function of $\theta, \sqrt{s}$ in addition to $p_T$
The error bars are point-to-point systematic and statistical errors added in quadrature.

The inclusive differential cross section for $\pi^0$ production is consistent with NLO pQCD calculations at $3.3 < \eta < 4.0$.

The data at low $p_T$ are more consistent with the Kretzer set of fragmentation functions, similar to what was observed by PHENIX for $\pi^0$ production at midrapidity.

D. Morozov (IHEP), XXXXth Rencontres de Moriond - QCD, March 12 - 19, 2005

NLO pQCD calculations by Vogelsang, et al.
STAR-FPD
Cross Sections

Similar to ISR analysis
B140 (1978) 189.

\[ E \frac{d^3\sigma}{dp^3} \propto (1-x_F)^C p_T^{-B} \]
\[ C \approx 5 \]
\[ B \approx 6 \]

Expect QCD scaling of form:

\[ E \frac{d^3\sigma}{dp^3} \propto x_T^{-a} (1-x_F)^C p_T^{-n} = \left( \frac{\sqrt{s}}{2} \right)^a (1-x_F)^C p_T^{-n-a} \Rightarrow B = n + a \]

⇒ Require \( \sqrt{s} \) dependence to disentangle \( p_T \) and \( x_T \) dependence

2/25/2006
L.C.Bland, RBRC Parton OAM
• PYTHIA prediction agrees well with the inclusive $\pi^0$ cross section at $\eta \sim 3-4$

• Dominant sources of large $x_F$ $\pi^0$ production from:

  1. $q + g \rightarrow q + g \ (2 \rightarrow 2) \rightarrow \pi^0 + X$

  2. $q + g \rightarrow q + g + g \ (2 \rightarrow 3) \rightarrow \pi^0 + X$
Plans for the Future

• STAR Forward Pion Detector upgrade (FPD++) planned as an engineering test of the FMS during RHIC run 6

• STAR Forward Meson Spectrometer (FMS) planned for installation by RHIC run 7

⇒ Disentangle the dynamical origins to transverse SSA in p+p collisions via measurements of $A_N$ for

- jet-like events
- direct photon production
FPD++ Physics for Run6

We intend to stage a large version of the FPD to prove our ability to detect jet-like events, direct photons, etc.

The center annulus of the run-6 FPD++ is similar to arrays used to measure forward $\pi^0$ SSA. The FPD++ annulus is surrounded by additional calorimetry to increase the acceptance for jet-like events and direct $\gamma$ events.
STAR Configuration for Run 6
Basic physics Goals
Ideas to be tested using FPD++ in RHIC run 6

• Prototype for FMS (planned completion for RHIC run 7)
• Discriminate dynamical origin of the forward $A_N$
  – Measurement of jetlike events and $A_N$ for those
  • Similar to FPD (left/right symmetric) but with larger active area
  • Measure shape of forward jet
  – Measure direct photons cross section, possibly $A_N$, requiring separation of $\pi^0$ and direct gamma
• Continue the study of $\pi^0$ asymmetry in pp
• other
New FMS Calorimeter
Lead Glass From FNAL E831
804 cells of 5.8cm×5.8cm×60cm
Schott F2 lead glass

Loaded On a Rental Truck for Trip To BNL
Students prepare cells at test Lab at BNL

Individual lead glass detectors are prepared and tested prior to installation in the calorimeter. In total, 13 students have been involved in this work since May, 2005.
Status report

- Calorimeter cells for free thanks to FNAL / U.Col. and Protvino
- Cells were refurbished and tested at BNL
- South calorimeter in place on new FMS platform, readout electronics in place and tested
- *In situ* cell-by-cell tests followed installation
Completed FPD++

Provides left/right symmetric calorimeters for detection of jet-like events
Jet spin asymmetry

- Is the single spin asymmetry observed for $\pi^0$ also present for the jet the $\pi^0$ comes from?
- Answer discriminates between Sivers and Collins contributions
- Trigger on energy in small cells, reconstruct $\pi^0$ and measure the energy in the entire FPD++
- Average over the Collins angle and define a new $x_F$ for the event, then measure analyzing power versus $x_F$

Expect that jet-like events are ~15% of $\pi^0$ events
Planned readout

- Trigger on summed energy
  \( E_{\text{trig}} \) is energy sum from only the small cells of one calorimeter

- Determine total energy for event
  \( E_{\text{sum}} \) is the energy sum from all cells of one calorimeter

- Photon and \( \pi^0 \) finding will be based on existing FPD software
  ⇒ Reconstruct photon multiplicity \( (N_\gamma) \); \( \pi^0 \), … invariant mass; etc.
Azimuthal symmetry of FPD++ around thrust axis, selected by $E_{\text{trig}}$ condition, enables

- integration over the Collins angle ⇒ isolating the Sivers effect, or
- dependence on the Collins angle ⇒ isolating the Collins/Heppelmann effect
How do we detect direct photons?

Isolate photons by having sensitivity to partner in decay of known particles:

\[ \pi^0 \rightarrow \gamma \gamma \quad \text{M=0.135 GeV BR=98.8\%} \]
\[ K^0 \rightarrow \pi^0 \pi^0 \rightarrow \gamma \gamma \gamma \quad 0.497 \quad 31\% \]
\[ \eta \rightarrow \gamma \gamma \quad 0.547 \quad 39\% \]
\[ \omega \rightarrow \pi^0 \gamma \rightarrow \gamma \gamma \gamma \quad 0.782 \quad 8.9\% \]

Detailed simulations underway
Where do decay partners go?

- Gain sensitivity to direct photons by ensuring we have high probability to catch decay partners

This means we need dynamic range, because photon energies get low (~0.25 GeV), and sufficient area (typical opening angles are only a few degrees at our $\eta$ ranges).

\[ z_{\gamma\gamma} = \frac{|E_1 - E_2|}{E_1 + E_2} \]

\[ \phi_{\gamma\gamma} = \text{opening angle} \]

\[ M_m = 0.135 \text{ GeV}/c^2 \ (\pi^0) \]

\[ M_m = 0.548 \text{ GeV}/c^2 \ (\eta) \]

for candidate photon with $E_1 = E_{\gamma}$,

\[ E_2 = \frac{1 - z_{\gamma\gamma}}{1 + z_{\gamma\gamma}} E_{\gamma}, \text{ gives the energy of second photon} \]

\[ \sin \frac{\phi_{\gamma\gamma}^\text{max}}{2} = \frac{M_m c^2}{2 E_\gamma} \sqrt{1 + z_{\gamma\gamma}}, \quad \sin \frac{\phi_{\gamma\gamma}^\text{min}}{2} = \frac{M_m c^2}{E_1 + E_2} = \frac{1}{\gamma_m} \] give max and min opening angle
Sample decays on FPD++

With FPD++ module size and electronic dynamic range, have $>95\%$ probability of detecting second photon from $\pi^0$ decay.
STAR Forward Meson Spectrometer

[hep-ex/0502040]

F. Bieser², L. Bland¹, R. Brown¹, H. Crawford², A. Derevshchikov⁴, J. Drachenberg⁵, J. Engelage², L. Eun³, C. Gagliardi⁵, S. Heppelmann³, E. Judd², V. Kravtsov⁴, Yu. Matulenko⁴, A. Meschanin⁴, D. Morozov⁴, L. Nogach⁴, S. Nurushev⁴, A. Ogawa¹, C. Perkins², G. Rakness¹,³, K. Shestermanov⁴, and A. Vasiliev⁴

¹ Brookhaven National Laboratory
² University of Berkeley/Space Sciences Institute
³ Pennsylvania State University
⁴ IHEP, Protvino
⁵ Texas A&M University
Forward Meson Spectrometer for Run 7

- FMS will provide full azimuthal coverage for range $2.5 \leq \eta \leq 4.0$
- broad acceptance in $x_F$-$p_T$ plane for inclusive $\gamma, \pi^0, \omega, K^0, \ldots$ production in p+p and d(p)+Au collisions
- broad acceptance for $\gamma - \pi^0$ and $\pi^0 - \pi^0$ from forward jet pairs to probe low-$x$ gluon density in p+p and d(p)+Au collisions
STAR detector layout with FMS

TPC: -1.0 < \( \eta \) < 1.0

FTPC: 2.8 < \(|\eta|\) < 3.8

BBC : 2.2 < \(|\eta|\) < 5.0

EEMC: 1 < \( \eta \) < 2

BEMC: -1 < \( \eta \) < 1

FMS: 2.5 < \( \eta \) < 4.0

With FMS addition, STAR will have nearly contiguous electromagnetic calorimetry for \(-1 < \eta < 4\)
Three Highlighted Objectives In FMS Proposal
(not exclusive)

1. A \textbf{d(p)+Au}→π^0π^0+X measurement of the parton model gluon density distributions \(xg(x)\) in \textbf{gold nuclei} for \(0.001 < x < 0.1\). For \(0.01 < x < 0.1\), this measurement tests the universality of the gluon distribution.

2. Characterization of correlated pion cross sections as a function of \(Q^2 (p_T^2)\) to search for the onset of \textbf{gluon saturation effects} associated with \textbf{macroscopic gluon fields}. \textbf{(again d-Au)}

3. Measurements with \textbf{transversely polarized protons} that are expected to resolve the origin of the \textbf{large transverse spin asymmetries} in reactions for \textbf{forward \(\pi^0\) production}. \textbf{(polarized pp)}
• constrain $x$ value of gluon probed by high-$x$ quark by detection of second hadron serving as jet surrogate

• span broad pseudorapidity range (-1 < $\eta$ < +4) for second hadron $\Rightarrow$ span broad range of $x_{\text{gluon}}$

• provide sensitivity to higher $p_T$ for forward $\pi^0$ $\Rightarrow$ reduce 2$\rightarrow$3 (inelastic) parton process contributions thereby reducing uncorrelated background in $\Delta \phi$ correlation.
Timeline for the Baseline RHIC Spin Program
Ongoing progress on developing luminosity and polarization

Research Plan for Spin Physics at RHIC (2/05)

Program divides into 2 phases:

\[ \sqrt{s}=200 \text{ GeV with present detectors for gluon polarization (}\Delta g\text{) at higher } x \text{ & transverse asymmetries;} \]

\[ \sqrt{s}=500 \text{ GeV with detector upgrades for } \Delta g \text{ at lower } x \text{ & } W \text{ production} \]
Summary / Outlook

• Large transverse single spin asymmetries are observed for large rapidity $\pi^0$ production for polarized p+p collisions at $\sqrt{s} = 200$ GeV

  ➢ $A_N$ grows with increasing $x_F$ for $x_F > 0.35$

  ➢ $A_N$ is zero for negative $x_F$

• Large rapidity $\pi^0$ cross sections for p+p collisions at $\sqrt{s} = 200$ GeV is in agreement with NLO pQCD, unlike at lower $\sqrt{s}$. Particle correlations are consistent with expectations of LO pQCD (+ parton showers).

• Plan partial mapping of $A_N$ in $x_F-p_T$ plane for $\pi^0$ and measurement of $A_N$ for jet-like events in RHIC run-6

• Propose increase in forward calorimetry in STAR to probe low-$x$ gluon densities and further studies of transverse SSA (complete upgrade by 11/06).
Backups
Time/luminosity dependent gain shift corrections

FTPC-FPD matching
Photon conversion in beam pipe

\[ p + p \rightarrow \pi^0 (+ X) \rightarrow \gamma (+ \gamma) \rightarrow e^+ e^- \]

⇒ FPD position known relative to STAR
Why Consider Forward Physics at a Collider?

Kinematics

Deep inelastic scattering

\[ Q^2 = 2(EE' - \vec{k} \cdot \vec{k'}) \]
\[ \nu = E - E' \]
\[ x = Q^2 / 2Mv \]

Hard scattering hadroproduction

Can Bjorken $x$ values be selected in hard scattering?

Assume:
1. Initial partons are collinear
2. Partonic interaction is elastic

\[ \Rightarrow p_{T,1} \approx p_{T,2} \]

Studying pseudorapidity, $\eta = -\ln(\tan \theta/2)$, dependence of particle production probes parton distributions at different Bjorken $x$ values and involves different admixtures of $gg$, $qg$ and $qq'$ subprocesses.
Simple Kinematic Limits

Mid-rapidity particle detection:
\[ \eta_1 \approx 0 \text{ and } <\eta_2> \approx 0 \]
\[ \Rightarrow x_q \approx x_g \approx x_T = \frac{2p_T}{\sqrt{s}} \]

Large-rapidity particle detection:
\[ \eta_1 >> \eta_2 \]
\[ \Rightarrow x_q \approx x_T e^{\eta_1} \approx x_F \text{ (Feynman } x) \text{, and} \]
\[ x_g \approx x_F e^{-(\eta_1+\eta_2)} \]

\[ \Rightarrow \text{Large rapidity particle production and correlations involving large rapidity particle probes low-x parton distributions using valence quarks} \]
Constraining the $x$-values probed in hadronic scattering


Collinear partons:
- $x^+ = p_T^+/\sqrt{s} \, (e^+\eta_1 + e^+\eta_2)$
- $x^- = p_T^-/\sqrt{s} \, (e^-\eta_1 + e^-\eta_2)$

CONCLUSION: Measure two particles in the final state to constrain the $x$-values probed
How can one infer the dynamics of particle production?

Particle production and correlations near $\eta \approx 0$ in p+p collisions at $\sqrt{s} = 200$ GeV

Inclusive $\pi^0$ cross section

- PHENIX Data
- KKP NLO
- Kretzer NLO

Two particle correlations ($h^\pm$)
- opposite sign
- same sign

STAR, Phys. Rev. Lett. 90 (2003), nucl-ex/0210033

At $\sqrt{s} = 200$GeV and mid-rapidity, both NLO pQCD and PYTHIA explains p+p data well, down to $p_T \sim 1$GeV/c, consistent with partonic origin

Do they work for forward rapidity?
Back-to-back Azimuthal Correlations with large $\Delta \eta$

Midrapidity $h^{\pm}$ tracks in TPC
- $-0.75 < \eta < +0.75$

Leading Charged Particle (LCP)
- $p_T > 0.5$ GeV/c

Trigger by forward $\pi^0$
- $E_\pi > 25$ GeV
- $\langle \eta_\pi \rangle = 4$

$S = $ Probability of “correlated” event under Gaussian

$B = $ Probability of “un-correlated” event under constant

$\sigma_s = $ Width of Gaussian
PYTHIA (with detector effects) predicts

- "S" grows with $<x_F>$ and $<p_{T,\pi}>$
- $\sigma_s$ decrease with $<x_F>$ and $<p_{T,\pi}>$

PYTHIA prediction agrees with p+p data

Larger intrinsic $k_T$ required to fit data
New Physics at high gluon density

1. Shadowing. Gluons hiding behind other gluons. Modification of \( g(x) \) in nuclei. Modified distributions needed by codes that hope to calculate energy density after heavy ion collision.

   - Coherent gluon contributions.
   - Macroscopic gluon fields.
   - Higher twist effects.
   - “Color Glass Condensate”

---

**Figure 3** Diagram showing the boundary between possible “phase” regions in the \( \tau = \ln(1/x) \) vs \( \ln Q^2 \) plane

η Dependence of $R_{dAu}$

From isospin considerations, $p + p \rightarrow h^-$ is expected to be suppressed relative to $d + $ nucleon $\rightarrow h^-$ at large $\eta$ [Guzey, Strikman and Vogelsang, Phys. Lett. B 603, 173 (2004)]

Observe significant rapidity dependence similar to expectations from a “toy model” of $R_{pA}$ within the Color Glass Condensate framework.

G. Rakness (Penn State/BNL), XXXXth Rencontres de Moriond - QCD, March 12 - 19, 2005


Towards establishing consistency between FPD ($\pi^0$)/BRAHMS($h^-$)

Extrapolate $x_F$ dependence at $p_T=2.5$ GeV/c to compare with BRAHMS $h^-$ data. Issues to consider:

• $<\eta>$ of BRAHMS data for $2.3<p_T<2.9$ GeV/c bin. From Fig. 1 of PRL 94 (2005) 032301 take $<\eta>=3.07 \Rightarrow <x_F>=0.27$

• $\pi^-/h^-$ ratio?

Results appear consistent but have insufficient accuracy to establish $p+p\rightarrow\pi^-/\pi^0$ isospin effects
Systematics

Measurements utilizing independent calorimeters consistent within uncertainties

Systematics:

- Normalization uncertainty = 16%:
  - position uncertainty (dominant)

- Energy dependent uncertainty = 13% - 27%:
  - energy calibration to 1% (dominant)
  - background/bin migration correction
  - kinematical constraints
FPD Detector and $\pi^0$ reconstruction

- Robust di-photon reconstructions with FPD in d+Au collisions on deuteron beam side.
- Average number of photons reconstructed increases by 0.5 compared to p+p data.
**d+Au → π⁰+π⁰+X, pseudorapidity correlations with forward π⁰**

**HIJING 1.381 Simulations**

- increased $p_T$ for forward $\pi^0$ over run-3 results is expected to reduce the background in $\Delta \phi$ correlation
- detection of $\pi^0$ in interval $-1<\eta<+1$ correlated with forward $\pi^0$ ($3<\eta<4$) is expected to probe $0.01<x_{\text{gluon}}<0.1 \Rightarrow$ provides a universality test of nuclear gluon distribution determined from DIS
- detection of $\pi^0$ in interval $1<\eta<4$ correlated with forward $\pi^0$ ($3<\eta<4$) is expected to probe $0.001<x_{\text{gluon}}<0.01 \Rightarrow$ smallest $x$ range until eRHIC
- at d+Au interaction rates achieved at the end of run-3 ($R_{\text{int}} \sim 30$ kHz), expect $9,700 \pm 200$ ($5,600 \pm 140$) $\pi^0-\pi^0$ coincident events that probe $0.001<x_{\text{gluon}}<0.01$ for “no shadowing” (“shadowing”) scenarios.

![Graph showing pseudorapidity correlations](image.png)
STAR Forward Calorimetry
Recent History and Plans

• Prototype FPD proposal Dec 2000
  – Approved March 2001
  – Run 2 polarized proton data (published 2004 spin asymmetry and cross section)

• FPD proposal June 2002
  – Review July 2002
  – Run 3 data pp dAu (Preliminary $A_n$ Results)

Disentangling Dynamics of Single Spin Asymmetries
Spin-dependent particle correlations

Collins/Hepplemann mechanism requires transversity and spin-dependent fragmentation

Sivers mechanism asymmetry is present for forward jet or $\gamma$

Large acceptance of FMS will enable disentangling dynamics of spin asymmetries