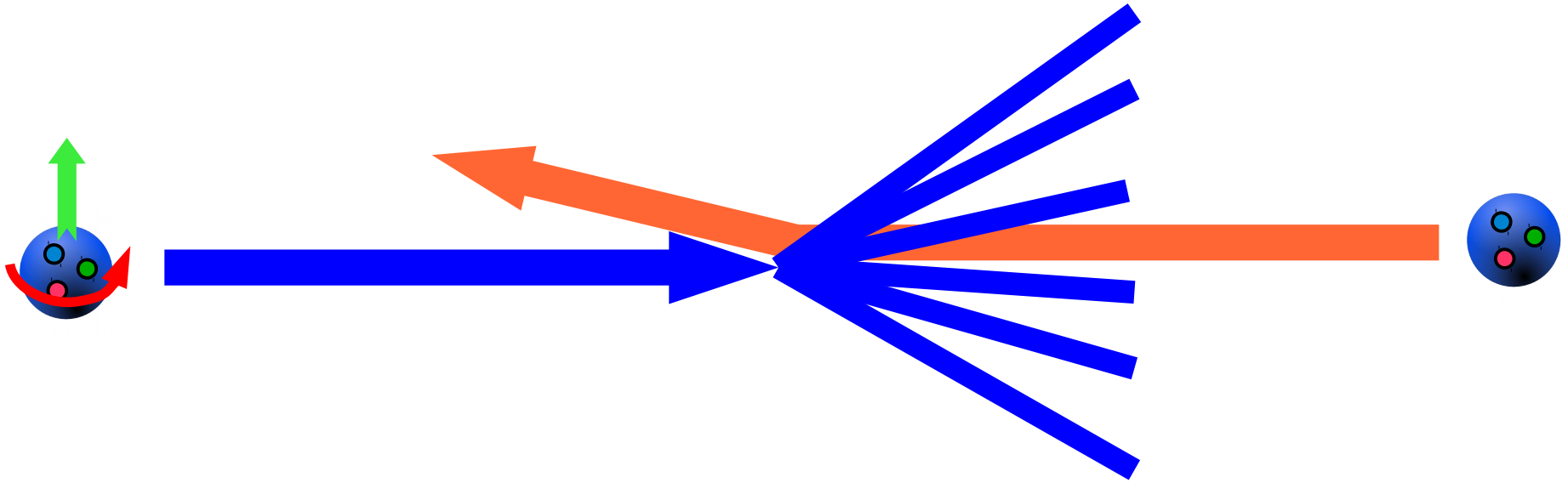
Searching for Diffractive Contributions to the Forward π^0 Transverse Single-Spin Asymmetry in $\sqrt{s} = 200$ GeV Polarized pp Collisions



Christopher Dilks

for the STAR Collaboration

DNP 2018 – Waikoloa, HI

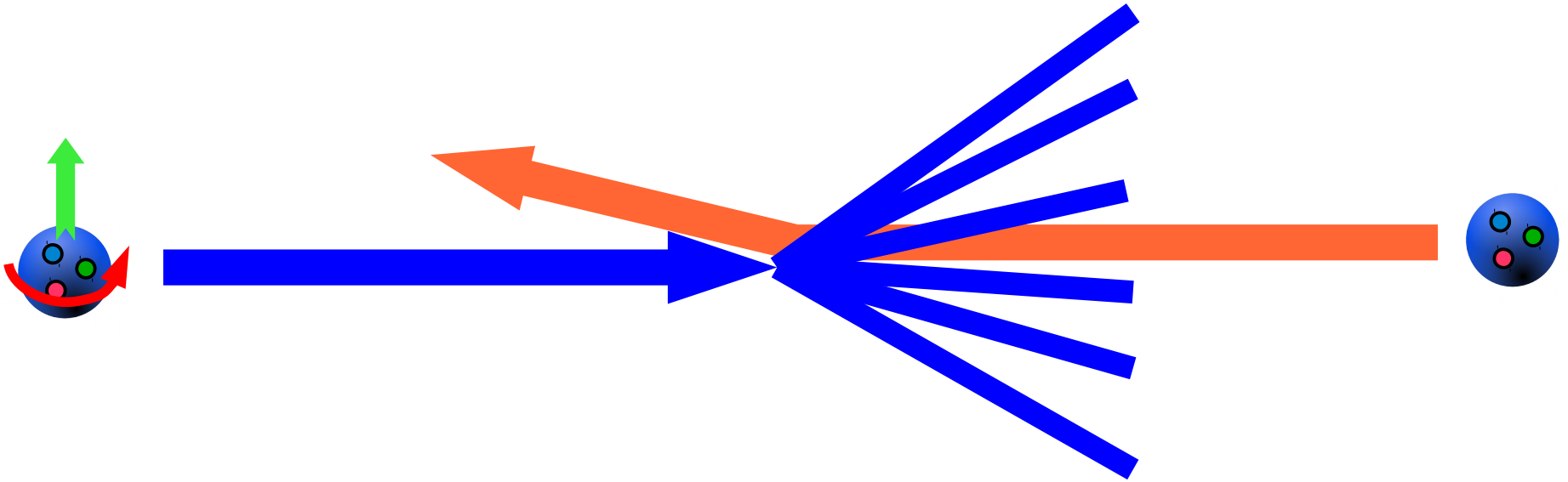
26 October 2018

PennState

STAR

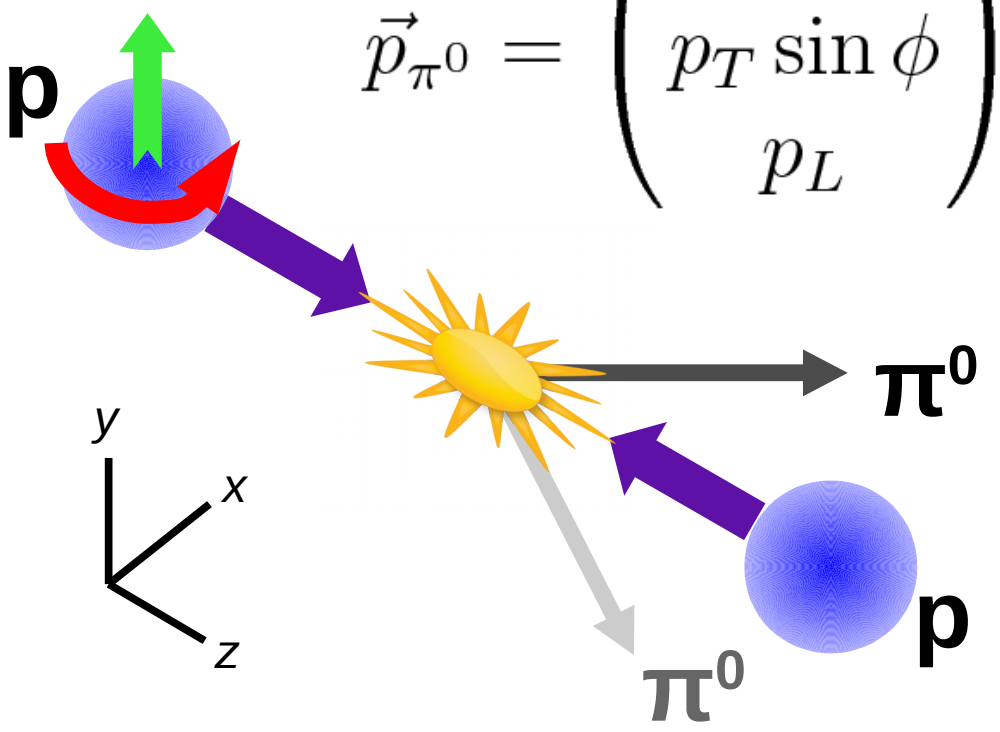
Outline

- Transverse Spin Asymmetry: A_N
- The Experiment at RHIC
- The Measurement



Transverse Single Spin Asymmetry: A_N

$$\vec{p}_{\pi^0} = \begin{pmatrix} p_T \cos\phi \\ p_T \sin\phi \\ p_L \end{pmatrix}$$

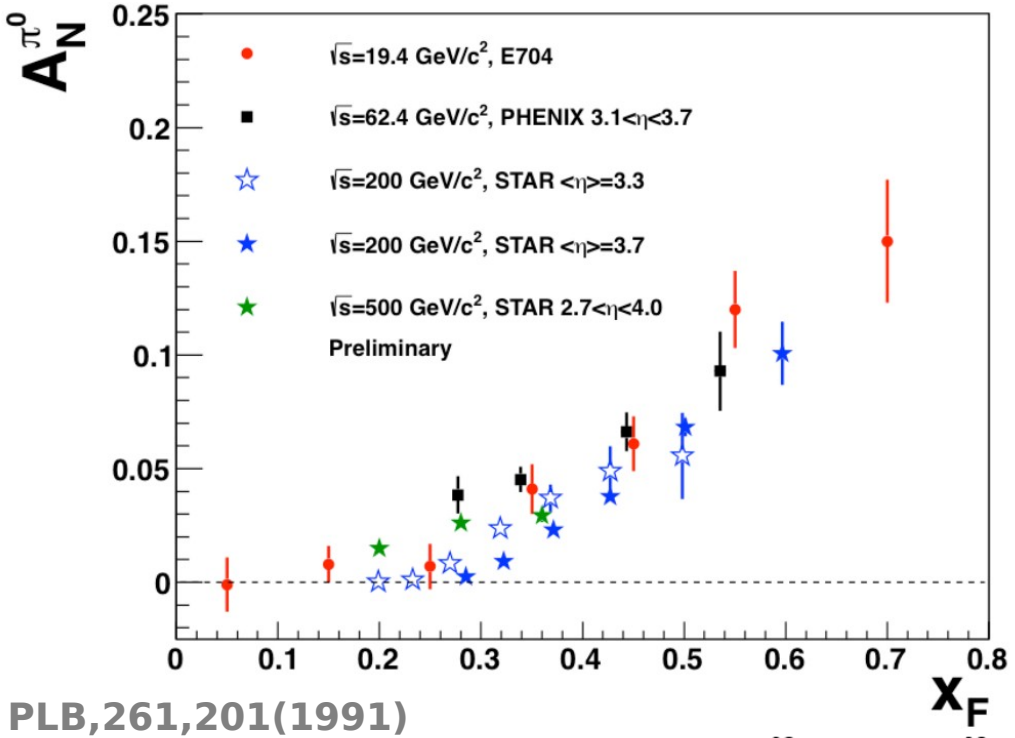


If $A_N > 0$,

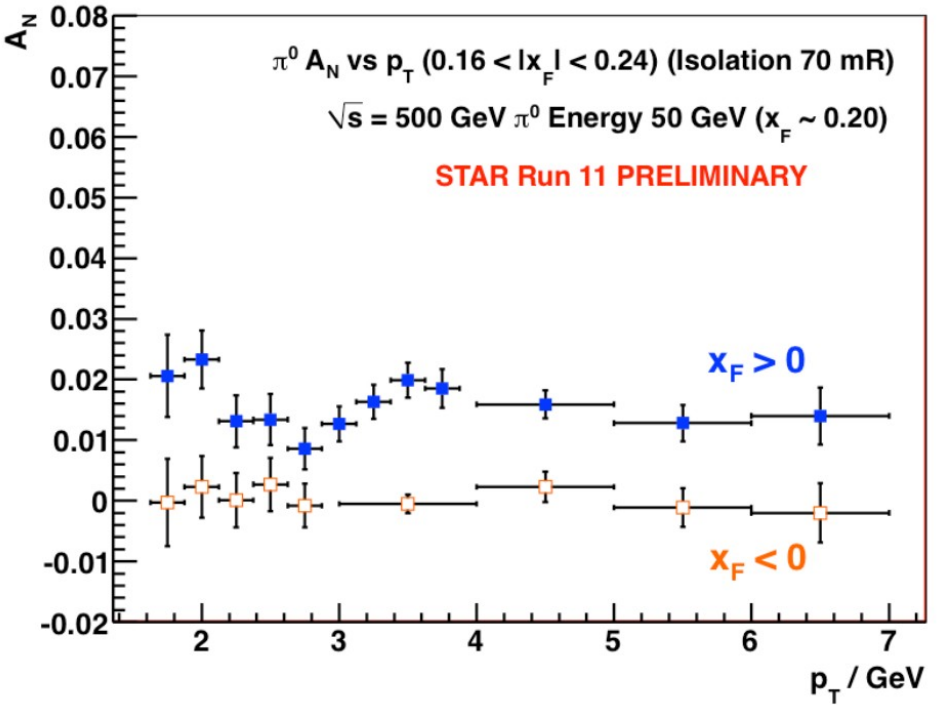
- Spin-up proton tends to produce more π^0s to the left, than to the right
- Spin-down: vice versa

$$A(\phi) = \frac{d\sigma^{\uparrow}(\phi) - d\sigma^{\downarrow}(\phi)}{d\sigma^{\uparrow}(\phi) + d\sigma^{\downarrow}(\phi)} \sim A_N \cdot \cos\phi$$

Transverse Single Spin Asymmetry: A_N



PLB,261,201(1991)
PRL,101,222001(2008)
PRD,90,012006(2014)



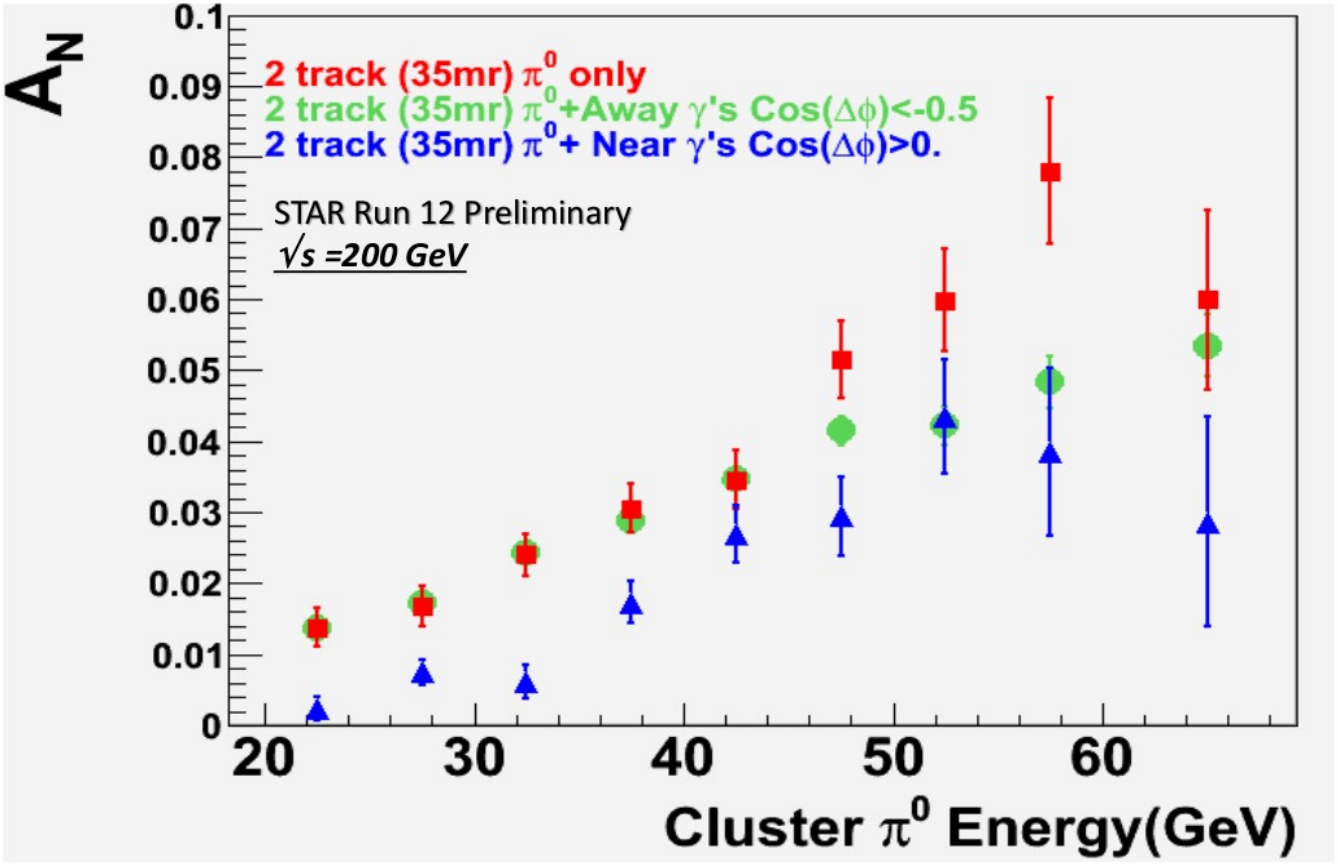
S. Heppelmann – CIPANP 2012

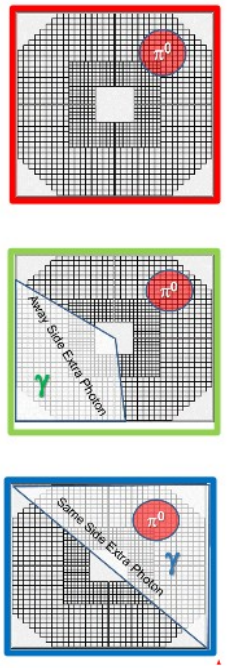
$$x_F = \frac{p_L}{\sqrt{s}/2} = \frac{p_L}{E_p}$$

Large π^0 A_N, independent of √s and rising with x_F, observed since 1976

- Collins, Sivers, suggest $A_N \sim 1/p_T$
- Twist-3 suggests flatter p_T dependence
- May rise as a function of p_T at low x_F

π^0 Event Topology Dependence





More Isolated

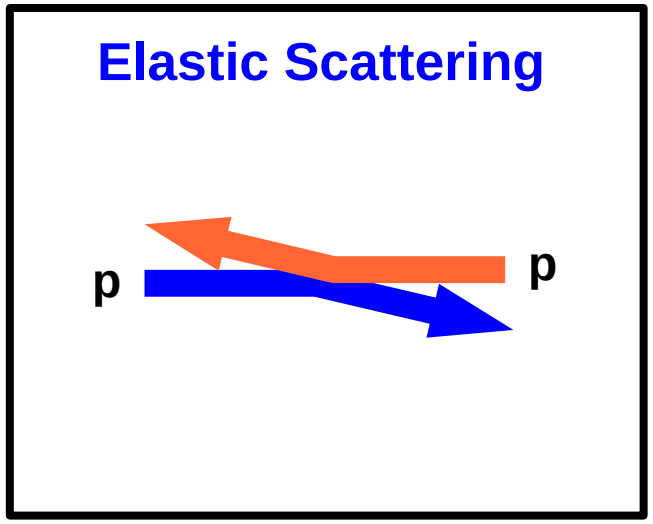
Less Isolated

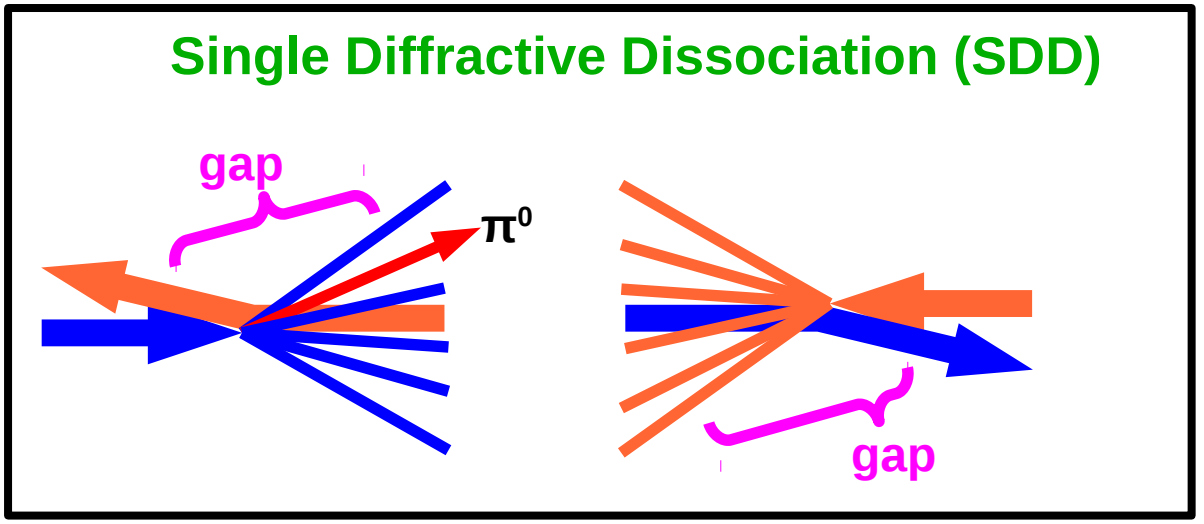
S. Heppelmann – DIS 2013

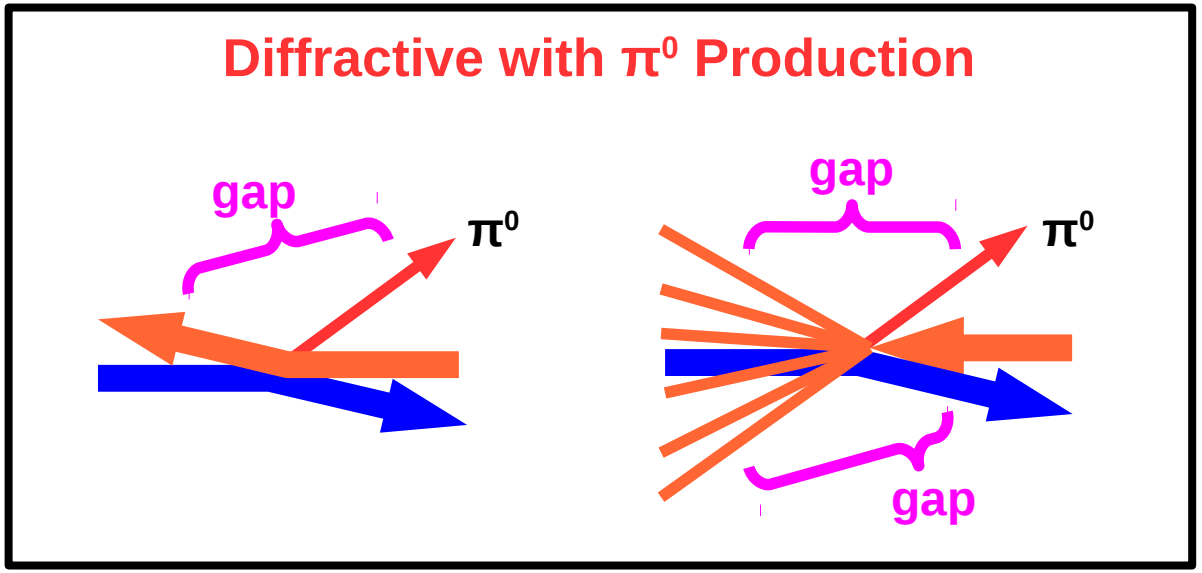
- **Isolated pions** have larger A_N than those with nearby energy deposits
- Pion A_N is therefore **event topology-dependent**

Diffractive Contributions

- Large forward π^0 A_N and its topology dependence not fully understood
- Any contributions from diffractive π^0 production?







Diffractive Contributions

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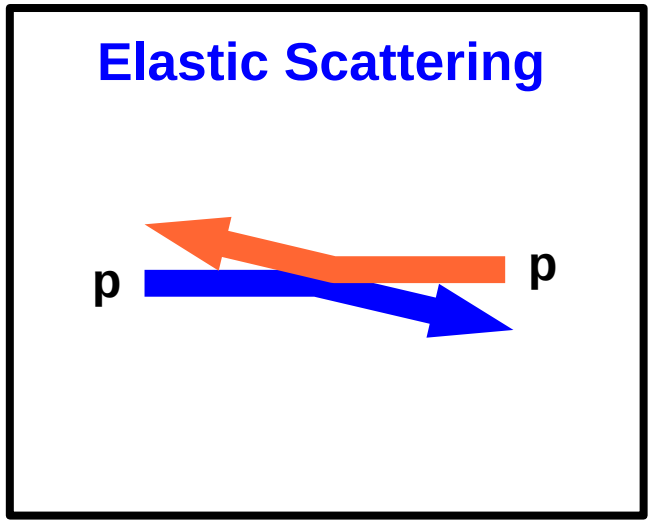
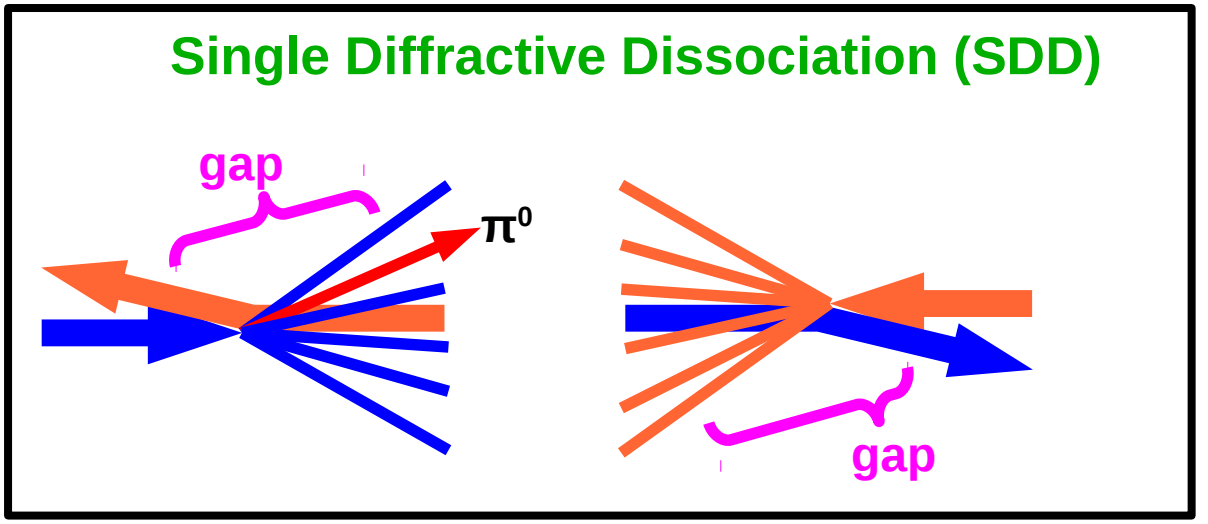
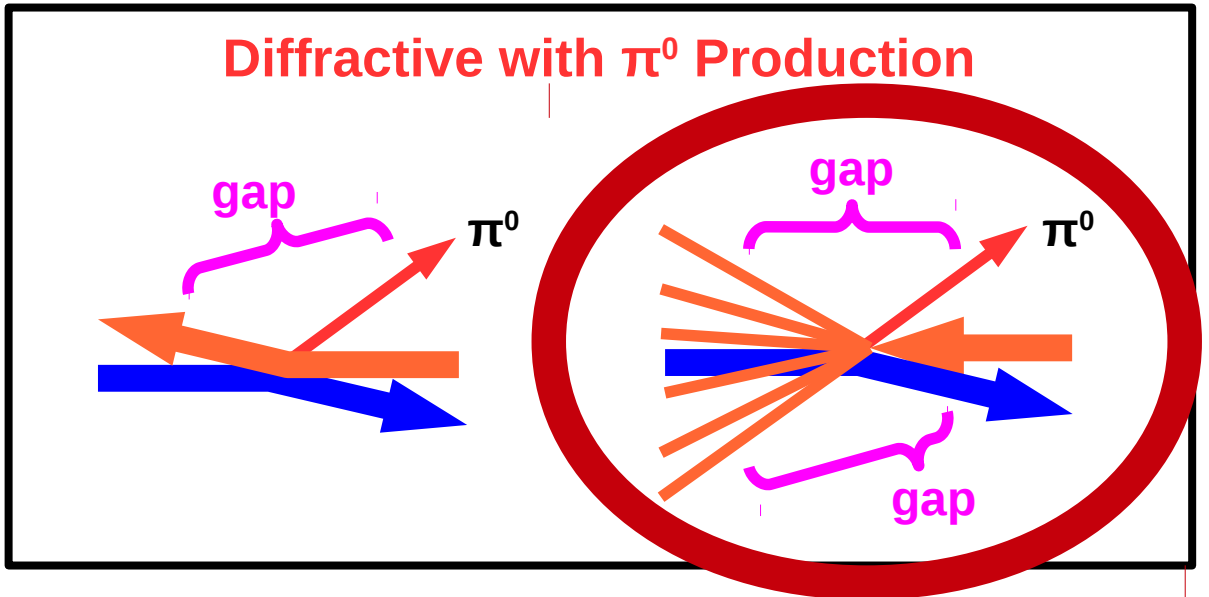






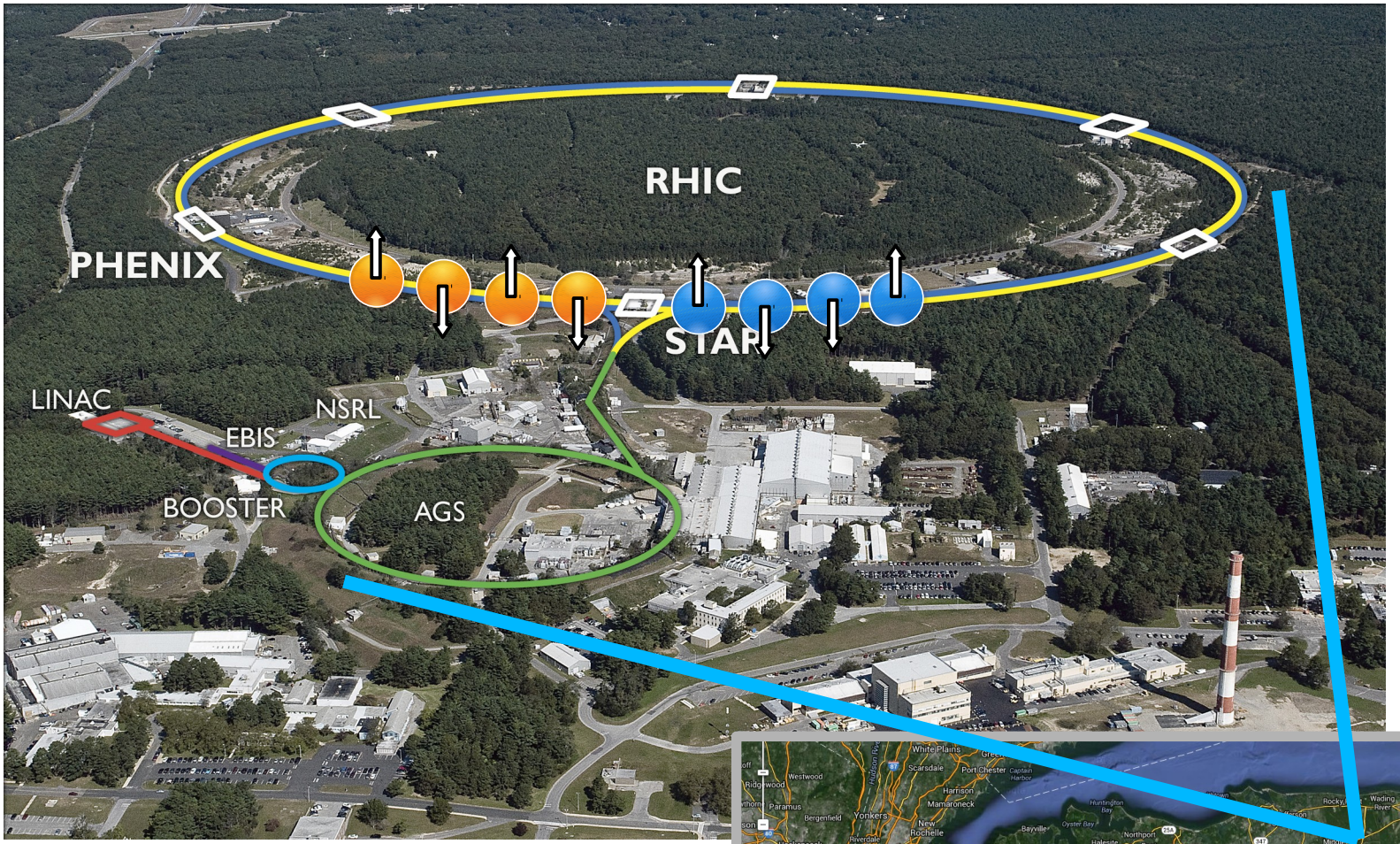
This talk:

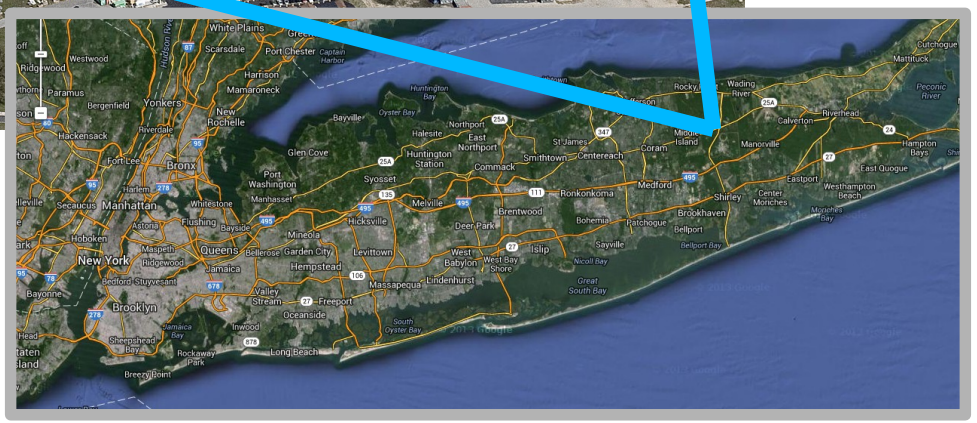
pp

↓

pπ⁰X

RHIC: Relativistic Heavy Ion Collider

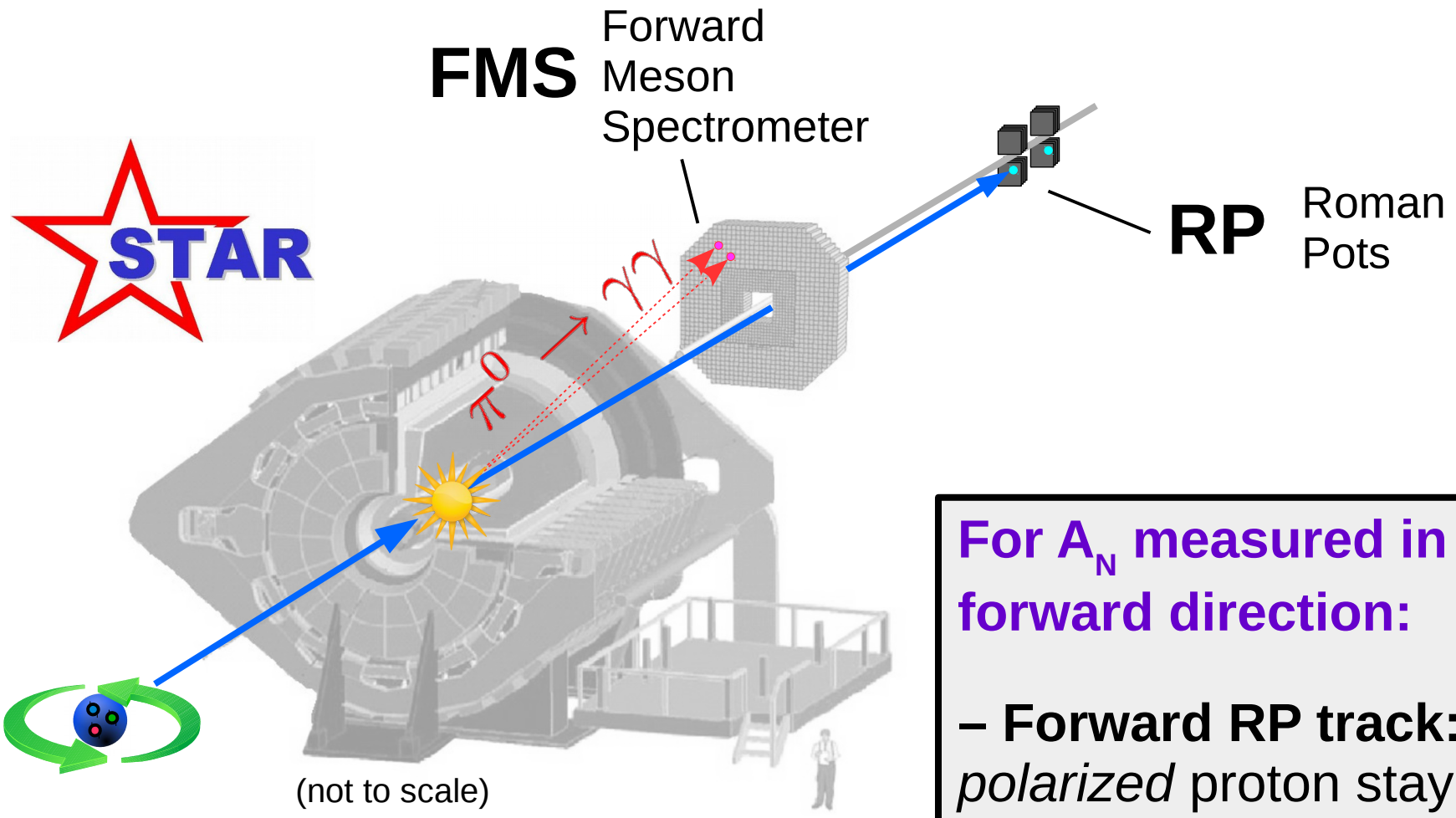




Brookhaven National Laboratory

Long Island, NY

Detectors and Orientation

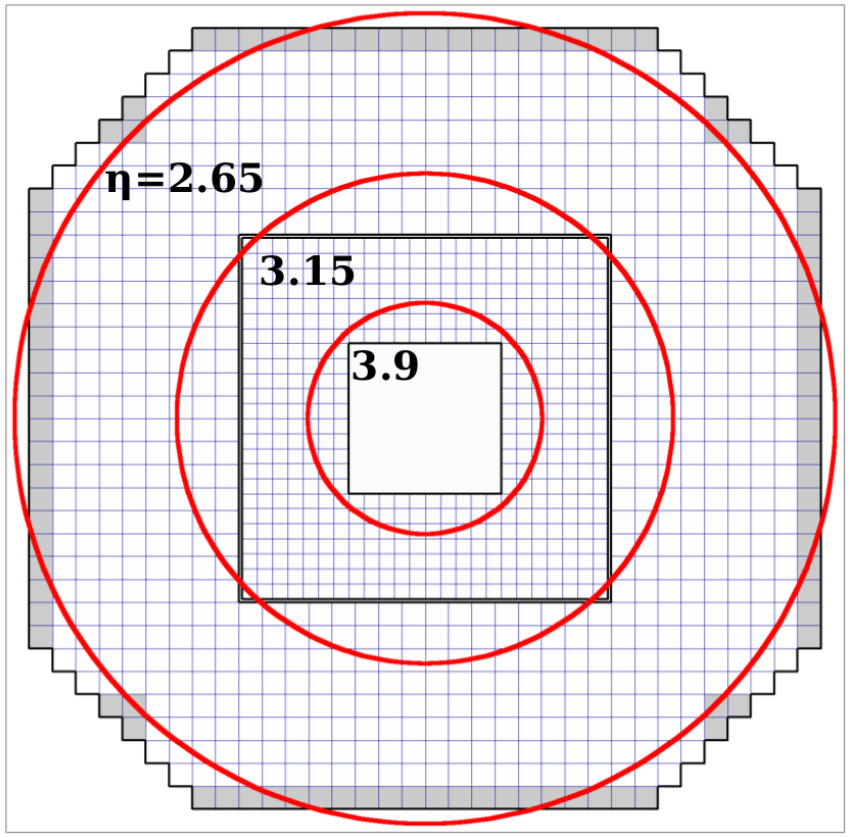


For A_N measured in the forward direction:

– Forward RP track:
polarized proton stayed intact

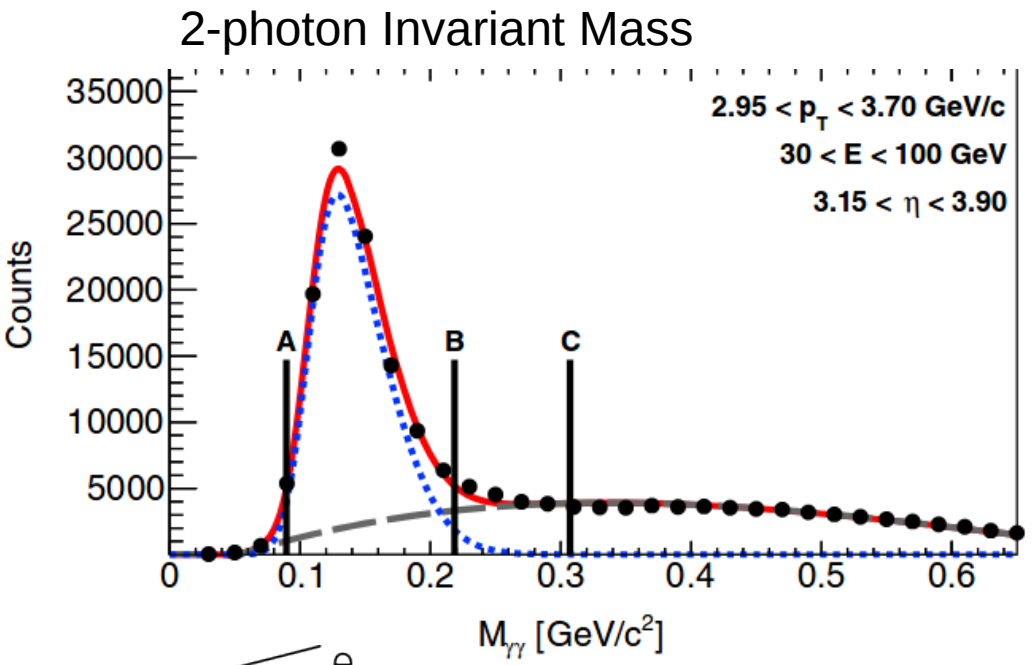
– Backward RP track:
unpolarized proton stayed intact

FMS: Forward Meson Spectrometer

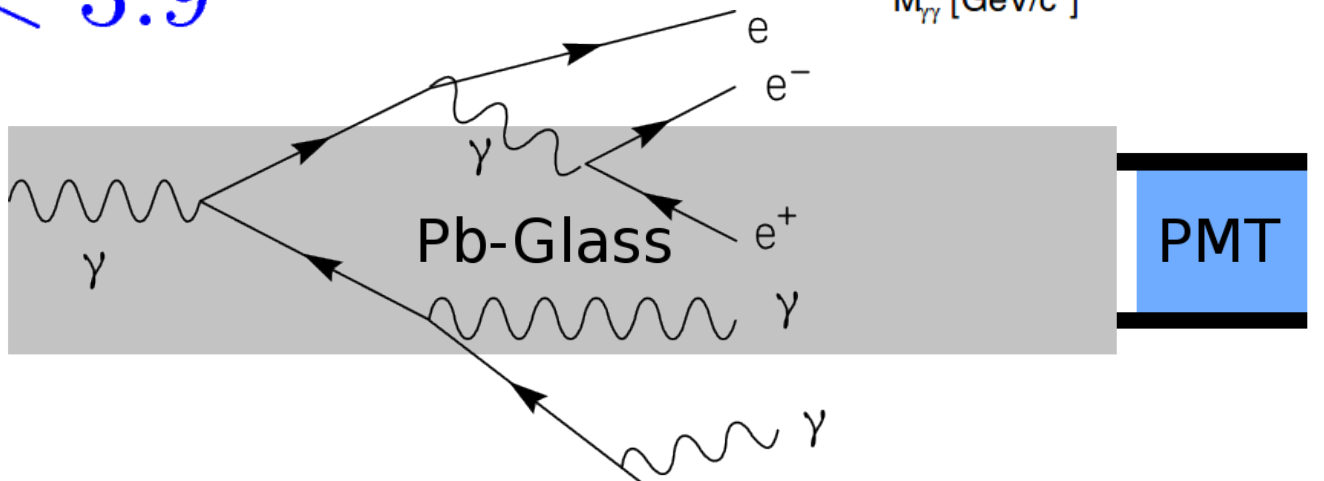


$2.65 < \eta < 3.9$

- Lead-Glass Electromagnetic Calorimeter
- Array of ~1200 Pb-glass cells coupled to Photomultiplier Tubes (PMTs)
- Primary Observables: $\pi^0 \rightarrow \gamma\gamma$ (also η, etc.)



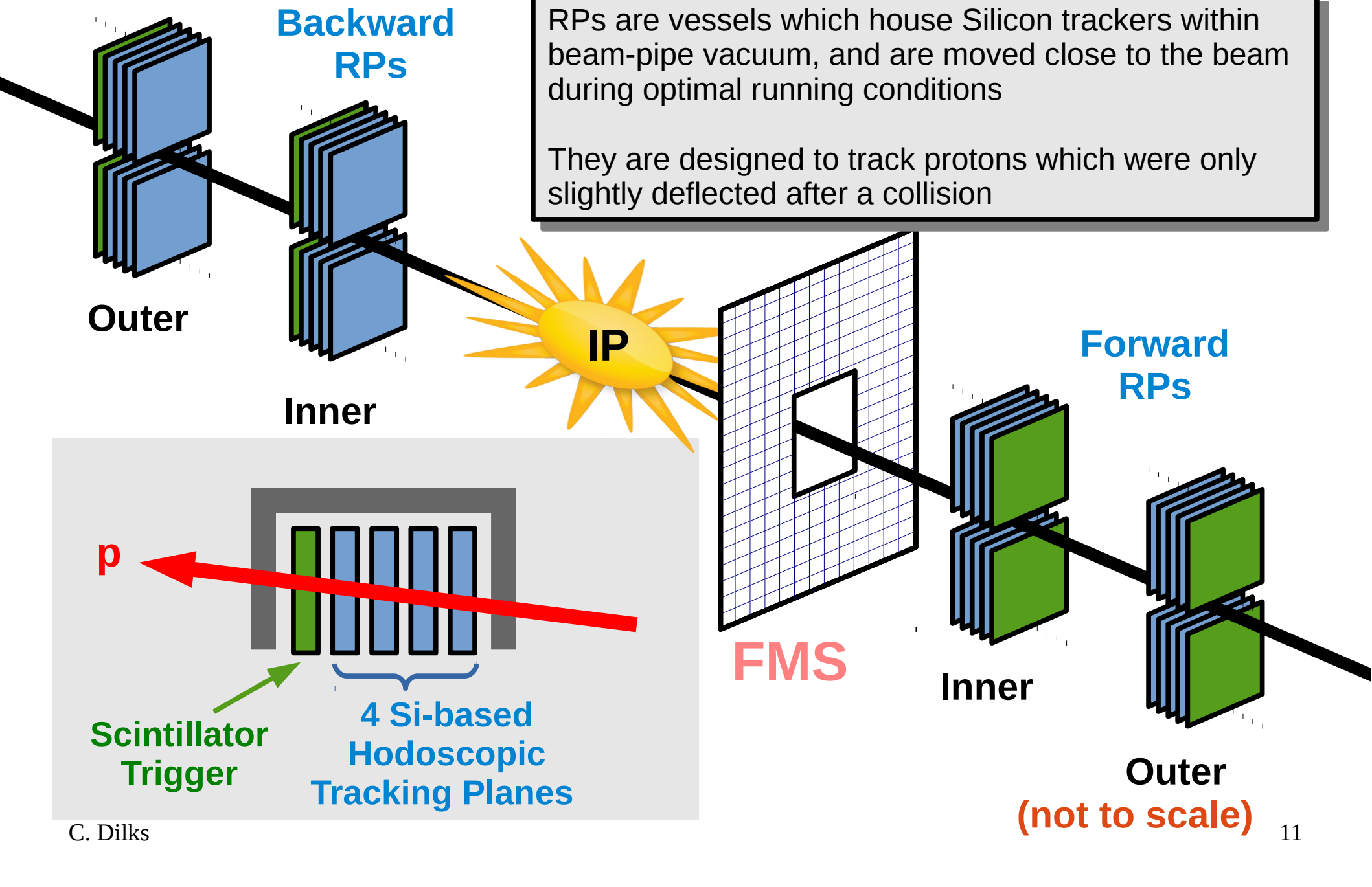
EM Shower in Pb-Glass Cell



RP: Roman Pot Detectors

RPs are vessels which house Silicon trackers within beam-pipe vacuum, and are moved close to the beam during optimal running conditions

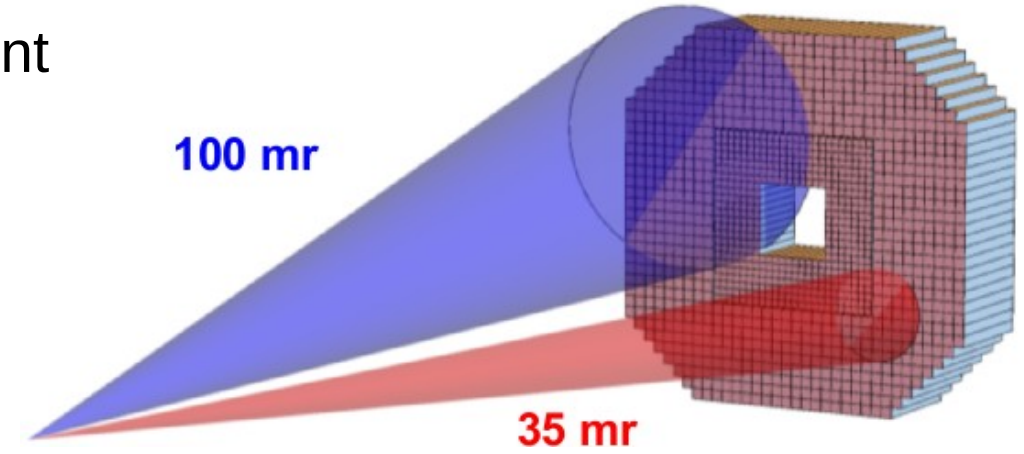
They are designed to track protons which were only slightly deflected after a collision



Event Selection

Pions

- 100 mrad Isolation
- Highest energy pair in the event
- Mass within π^0 mass window
- $12 < E < 70$ GeV
- $Z = | E_1 - E_2 | / E < 0.8$
- p_T trigger threshold cut



Protons

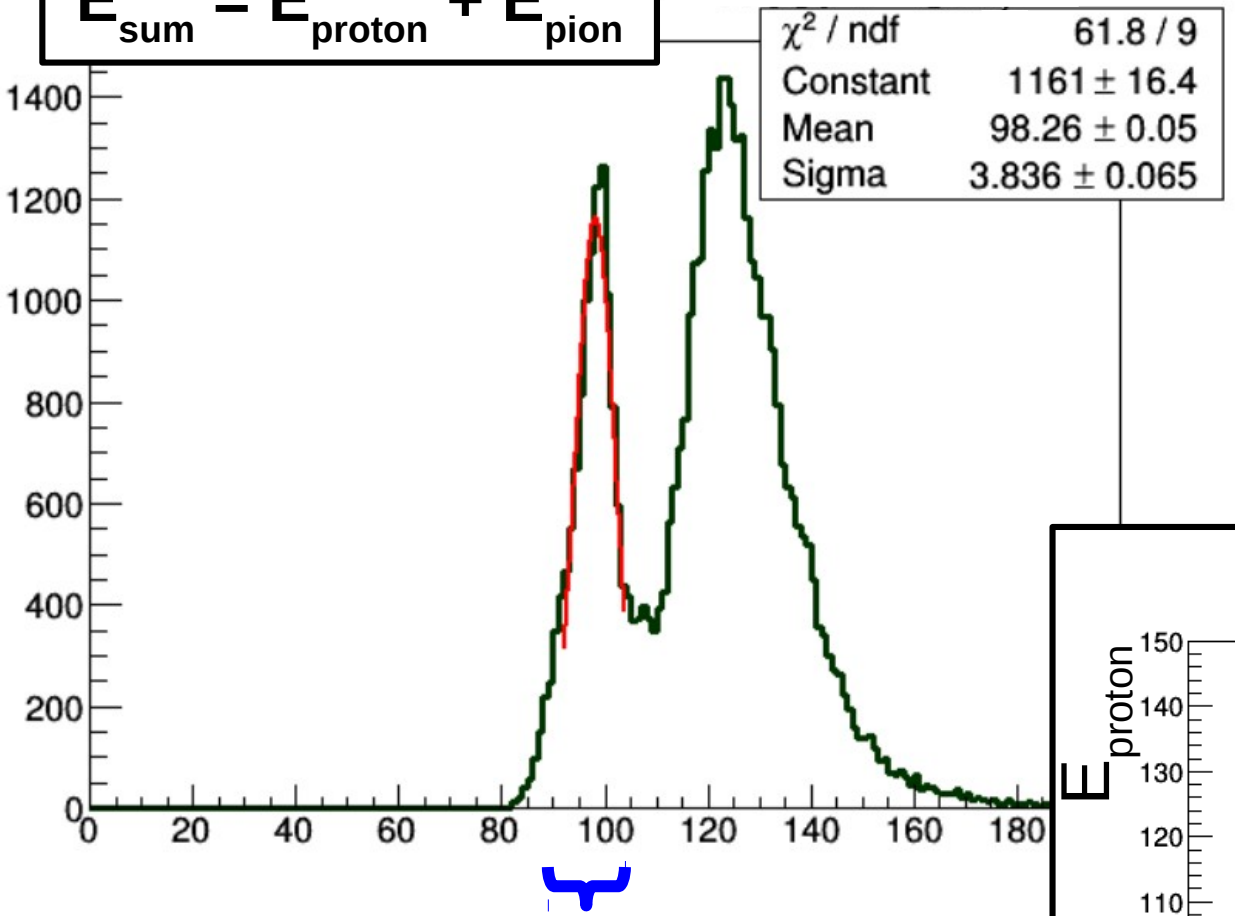
- Hits in both inner and outer Roman Pots
- Track within geometric acceptance
- Hit at least 6 of 8 tracking planes

Additional cuts for selecting p+p → p+π0+X:

- One good track in forward RP, and no activity in backward RP
- No hits in BBC (Beam Beam Counter), a scintillator spanning $2.1 < \eta < 5$ (this is a *rudimentary* rapidity gap cut)

Diffractive pp → pπ⁰X

$E_{sum} = E_{proton} + E_{pion}$

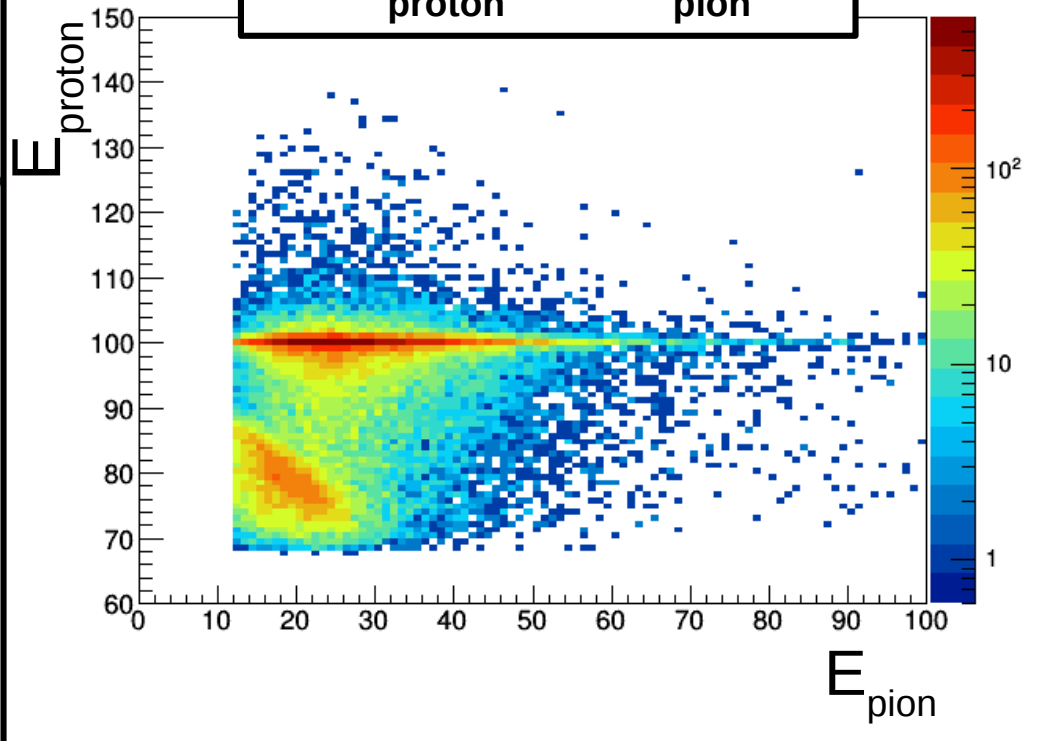


pp → pπ⁰X

- **not acceptance corrected**

- **√s = 200 GeV → 100 GeV protons**
- **E_{sum} = 100 GeV indicates diffractive π^0 production**

E_{proton} vs. E_{pion}



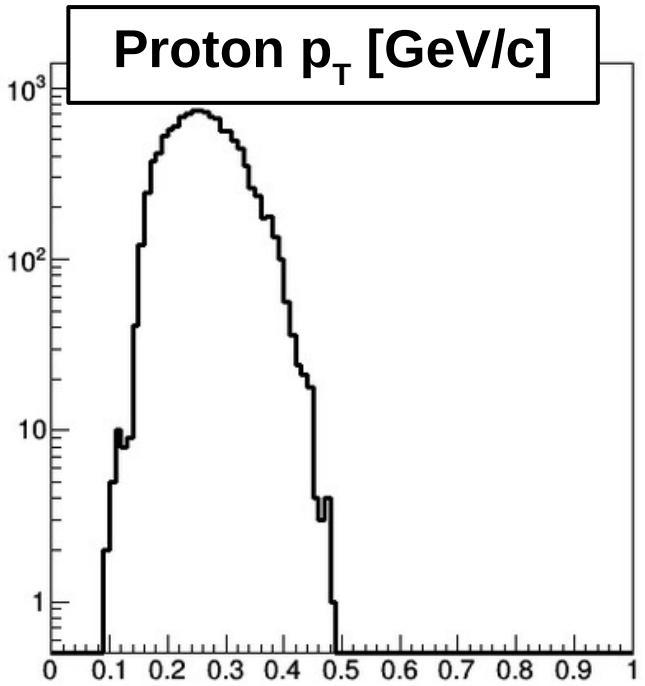
Diffractive $pp \rightarrow p\pi^0X$ Kinematics

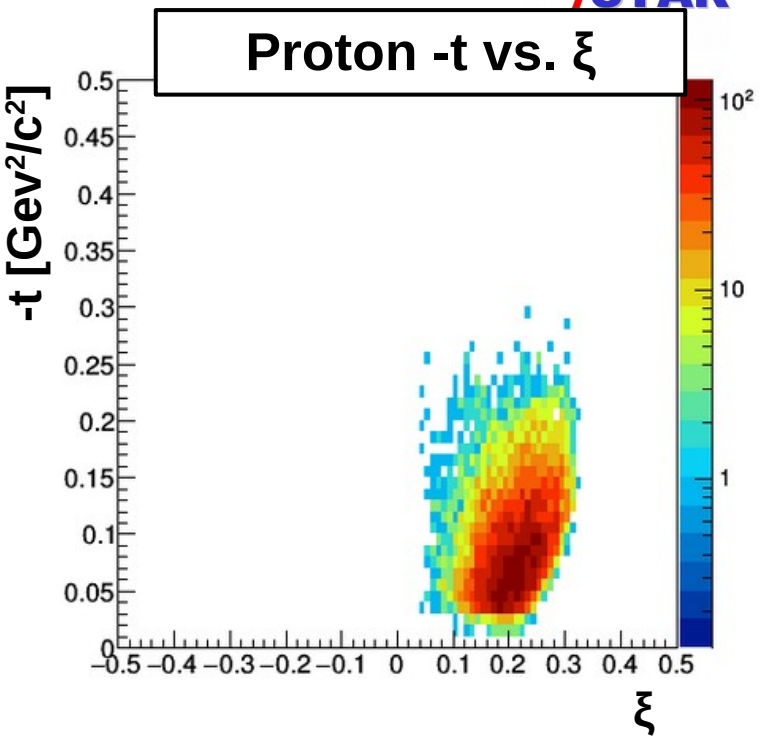
Proton Kinematics

Transverse momentum:
p_T ~ 0.1 – 0.5 GeV/c

Momentum transfer:
$-t$ ~ 0.01 – 0.25 $(GeV/c)^2$

Fractional momentum loss:
ξ ~ 0.1 – 0.3

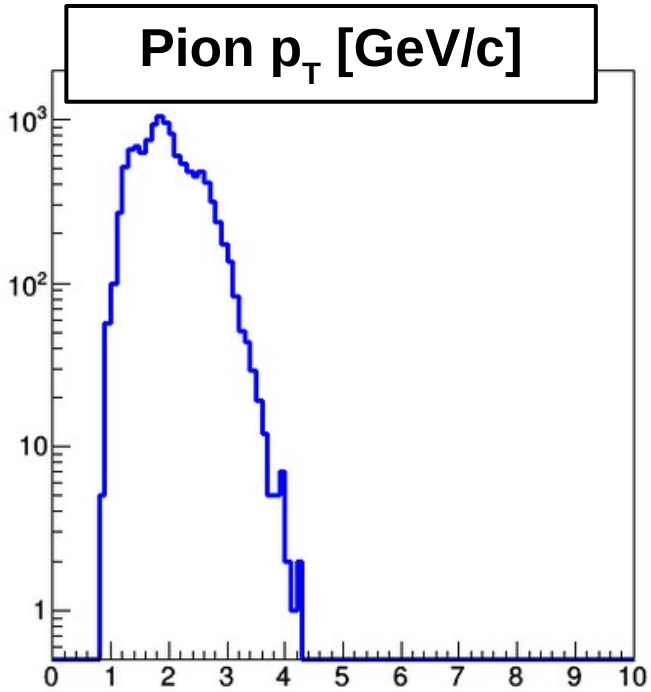


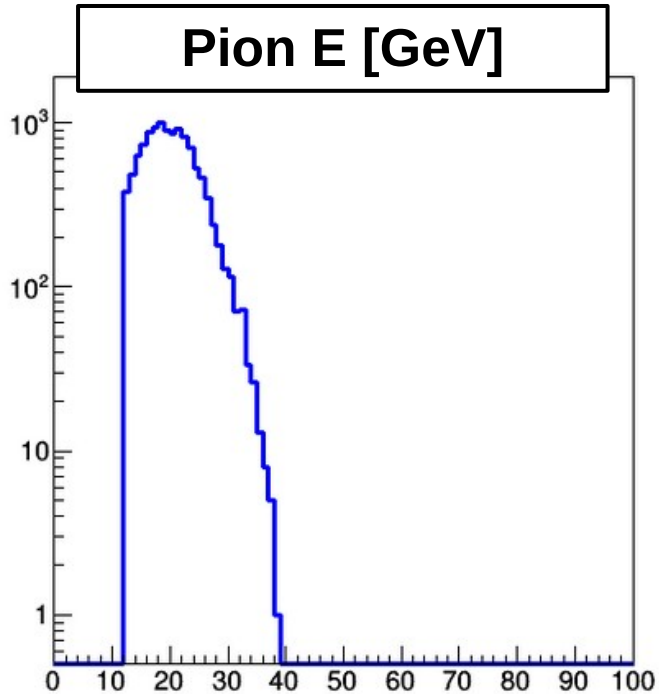


Pion Kinematics

Transverse Momentum:
p_T ~ 1 – 4 GeV/c

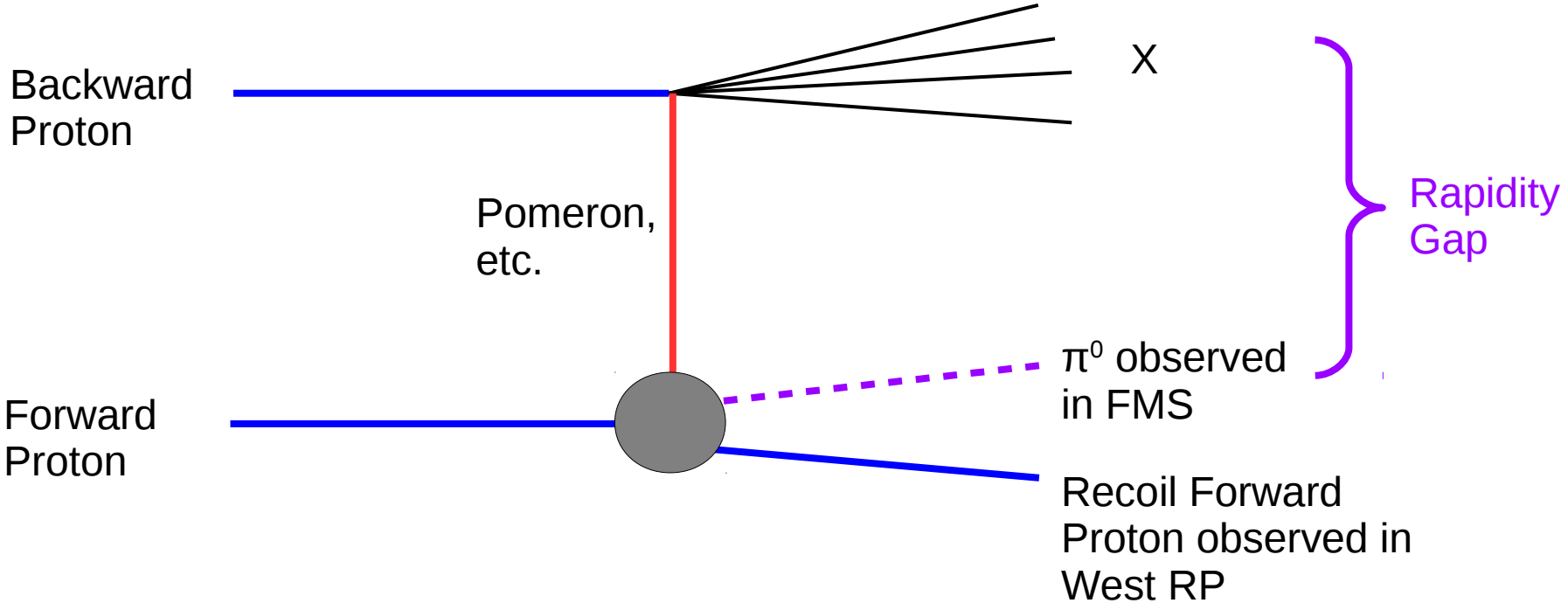
Energy:
E ~ 10 – 40 GeV
x_F ~ 0.1 – 0.4





C. Dilks

Some Ideas for a Possible Model



- Remnants "X" should have p_T which balances pion p_T
- If the proton were to fluctuate into a proton+π^0 state before/at the Pomeron vertex, the π^0 may have angular momentum correlated to proton spin
- There are also models involving GPDs

Outlook on Asymmetries

$\cos \phi_{\pi^0}$ **Usual π^0 asymmetry modulation**

Do diffractive π^0s contribute to the inclusive π^0 A_N?

$\cos \phi_p$ **Compare to proton A_N**

$f\left(\phi_{\pi^0}, \phi_p\right)$ **Are there any modulations which involve both the proton and pion azimuthal angles?**

Estimating ~2-4% statistical uncertainty on A_N

Summary

- STAR is beginning to explore diffractive contributions to large transverse single spin asymmetries, A_N
- Large A_N is observed for forward π^0s
- We observe a substantial amount of $pp \rightarrow p\pi^0X$ events, with the π^0 in the forward direction
- Analysis of possible asymmetries is underway

backup

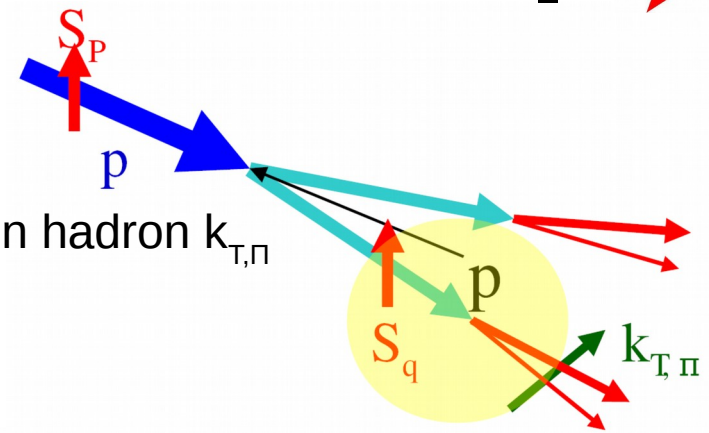
Mechanisms for a nonzero A_N

Collins Mechanism

Azimuthal dependence of hadrons in each jet

Correlation between struck parton spin and fragmentation hadron $k_{T,\Pi}$

Applicable for low-p_T (<<Q) processes

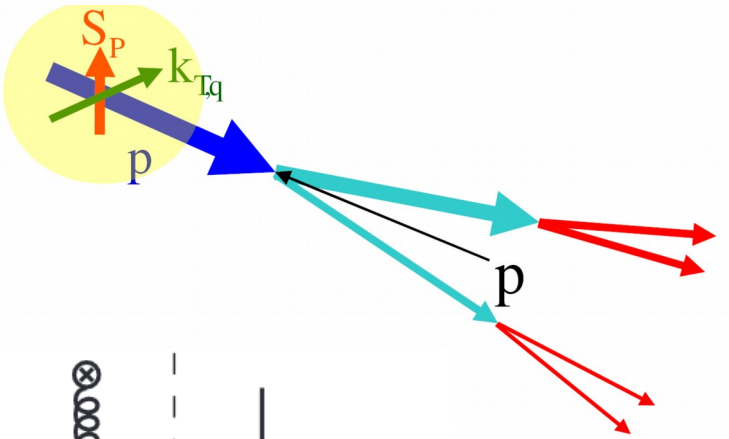


Sivers Mechanism

Azimuthal dependence of jet production

Correlation between initial parton $k_{T,q}$ and proton spin

p_T << Q processes

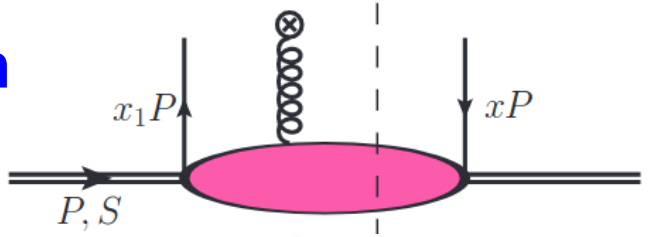


Collinear Twist-3 Factorization

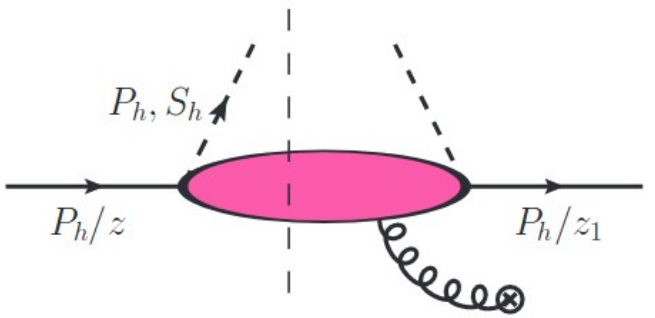
Include additional an additional parton interacting:
– initial parton distributions (PDFs)
– final state fragmentation functions (FFs)

Large contribution from twist-3 FFs

Applicable for high p_T (~Q) hard scale



twist-3 PDF



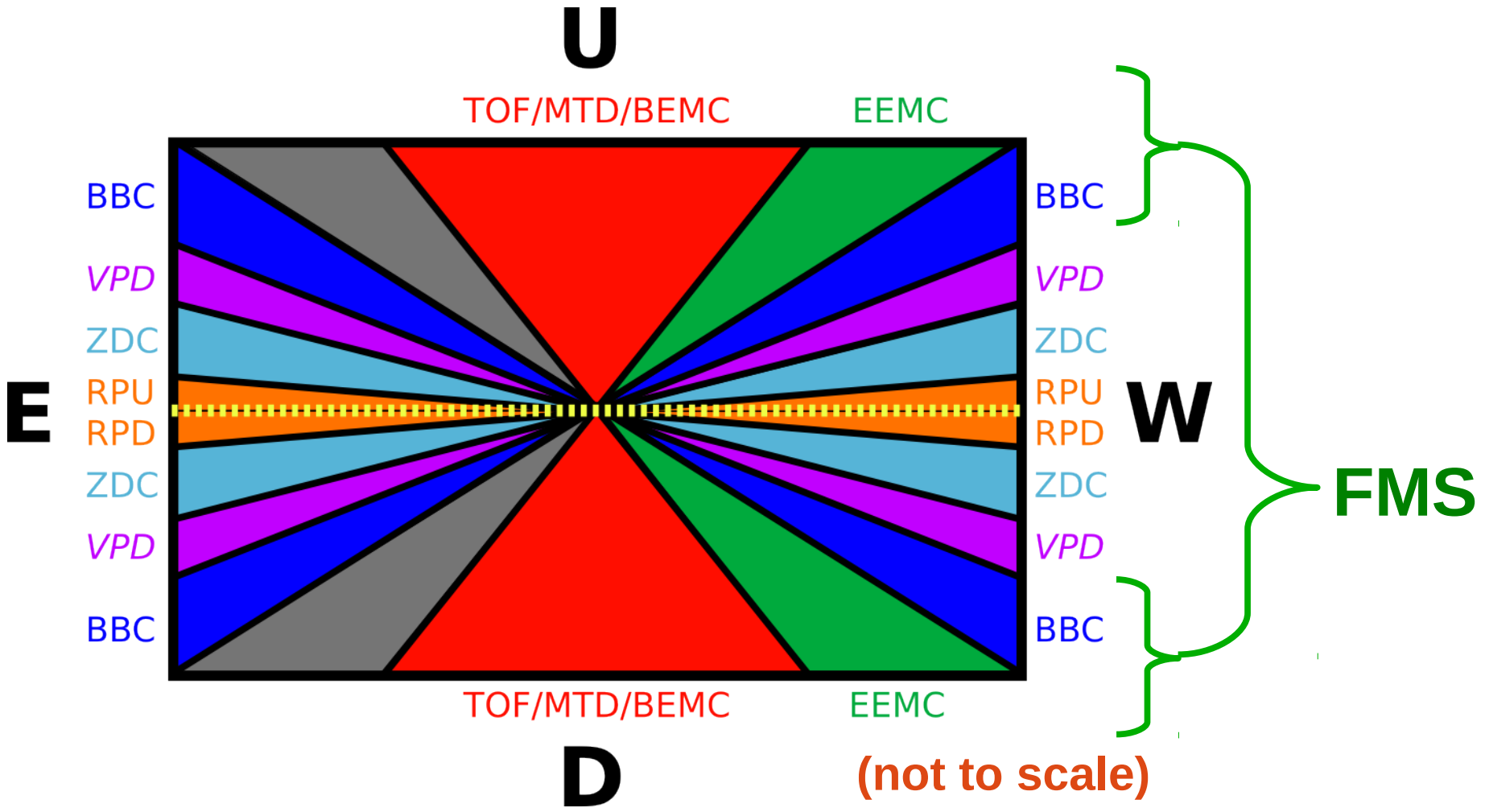
twist-3 FF

Pitonyak, International Journal of Modern Physics A 31, No. 32,1630049 (2016)

Approximate Acceptance

- **FMS Pions**
  - $10 < E < 100$ GeV
  - $1 < p_T < 10$ GeV/c
  - $2.65 < \eta < 3.9$
- **RP Protons**
  - $0.1 < p_T < 0.9$ GeV/c
  - $0.01 < -t < 0.5$ (GeV/c)^2
  - $\xi < 0.3$

Detectors for assessing Rapidity Gaps



- TOF/MTD/BEMC: | η | < 1
- EEMC: 1 < η < 2
- BBC small tiles: 3.3 < | η | < 5 (@3.74m) … overlaps with small FMS cells
- VPD: 4.2 < | η | < 5 (@5.68m) … overlaps with BBC
- ZDC: 6.5 < | η | < 7.5 (@18.0m)