# Transverse Single-Spin Asymmetries (TSSAs) in $\pi^{\pm}$ Production at Mid-rapidity in Transverse Polarized $p + p$ Collisions at $\sqrt{s} = 510$ GeV in PHENIX

*Single Spin Asymmetry*

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# The Proton Spin Structure

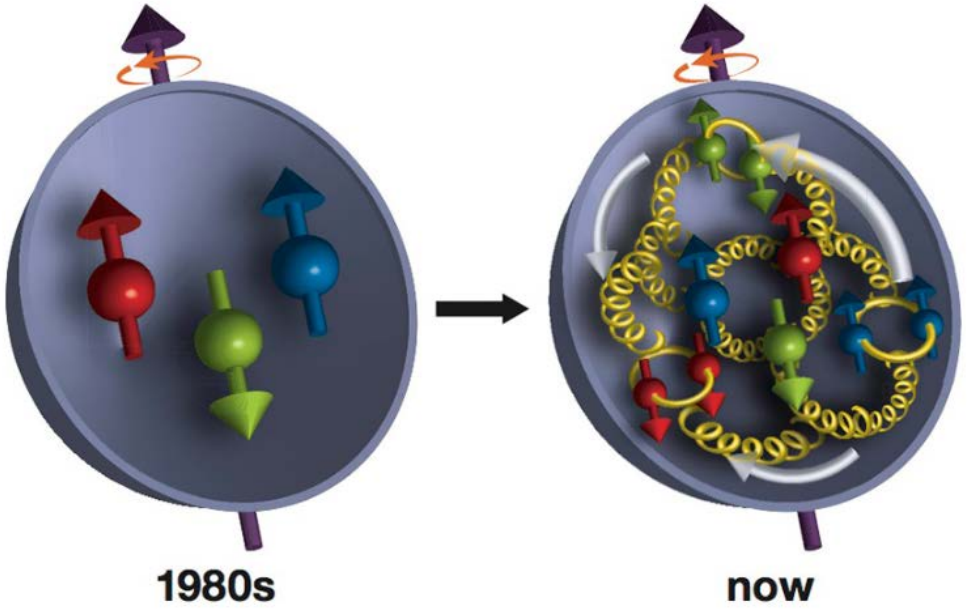
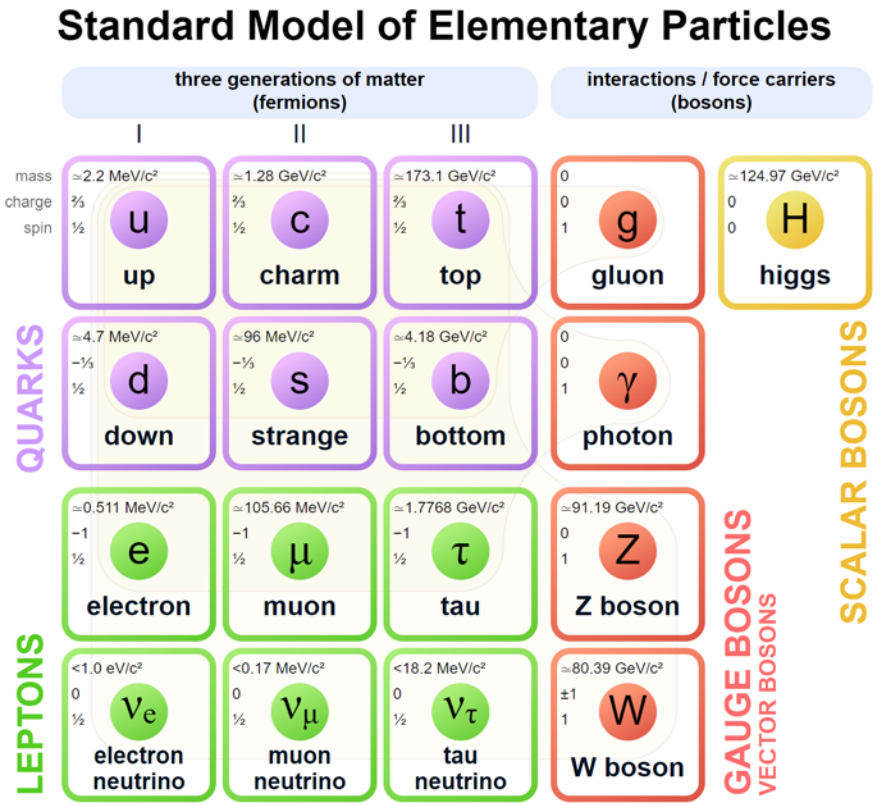



Image courtesy of Brookhaven National Laboratory




In the 1980s, scientists discovered that a proton's three valance quarks (red, green, blue) account for only a fraction of the proton's overall spin. New measurements from RHIC's PHENIX experiment reveal that gluons (yellow corkscrews) contribute as much as or possibly more than the quarks.

# The Proton Spin Structure

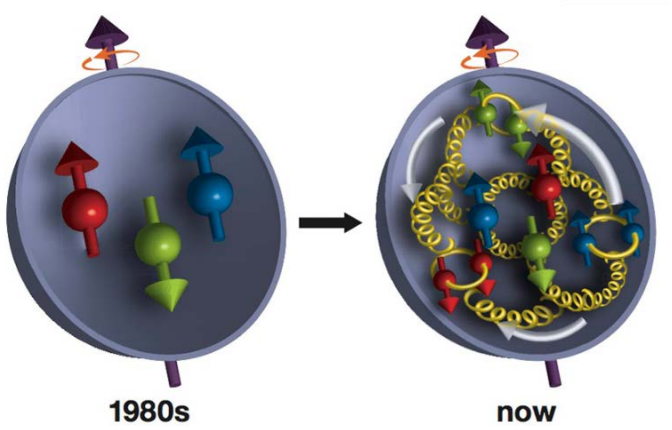


Image courtesy of Brookhaven National Laboratory

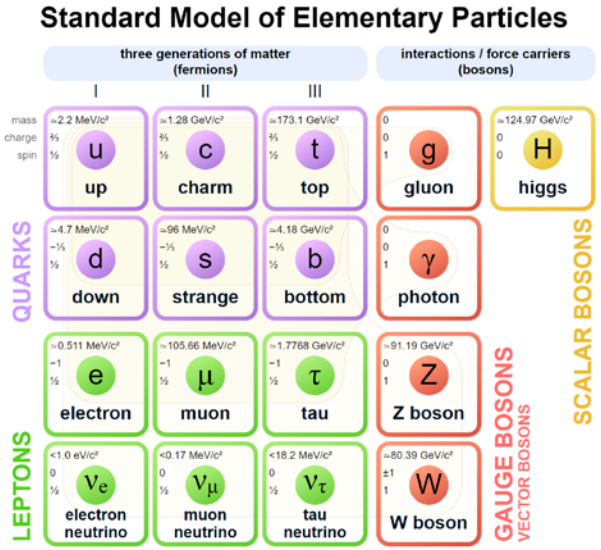
1988 EMC measured:

$\Sigma = 0.123 \pm 0.013 \pm 0.019$ $\Longrightarrow$ Spin Puzzle!

$$S_{proton} = \frac{1}{2} = \frac{1}{2}\Delta q + \Delta G + L_{q,g}$$

$$\frac{1}{2} = \frac{1}{2}\left(\Delta u_v + \Delta d_v + \underbrace{\Delta q_s}\right) + \Delta G + L_q + L_g$$

$$\Delta u_v + \Delta d_v + \Delta q_s + \Delta \bar{u}_s + \Delta \bar{d}_s + \Delta \bar{s}_s$$

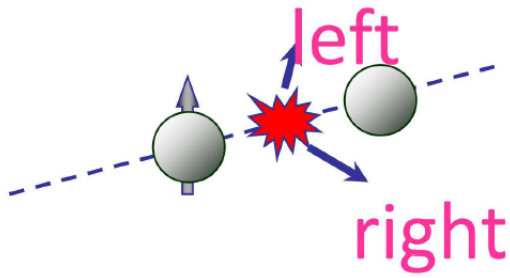



Full description of proton's spin needs
orbital angular momentum

How is proton's spin correlated with the motion of quarks and gluons?
-> Transverse Momentum Dependent (TMD) Functions

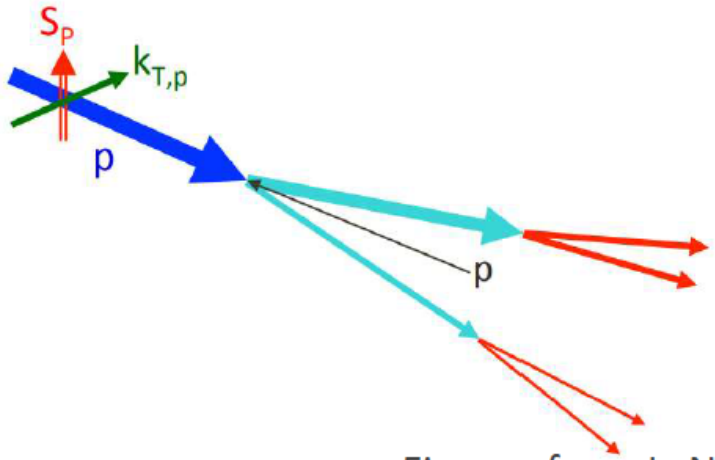
# Transverse Single Spin Asymmetry

$$A_N = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$$

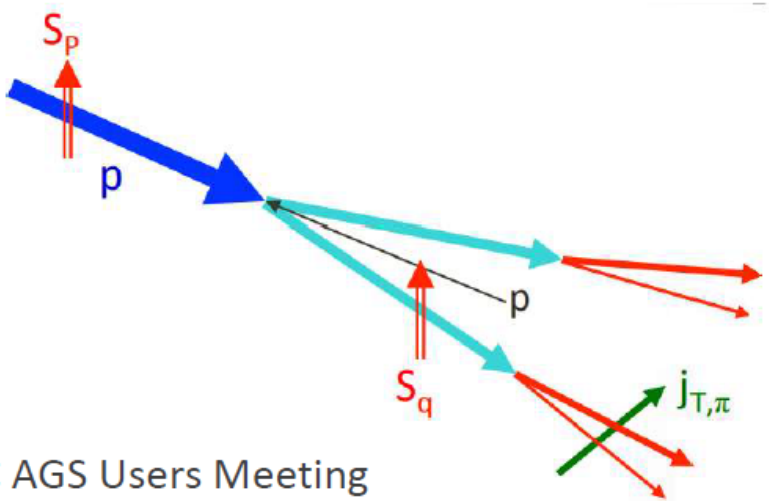



Sources of Transverse SSA's

Initial State Effects:
For example Sivers functions: correlation between proton spin and parton $k_T$

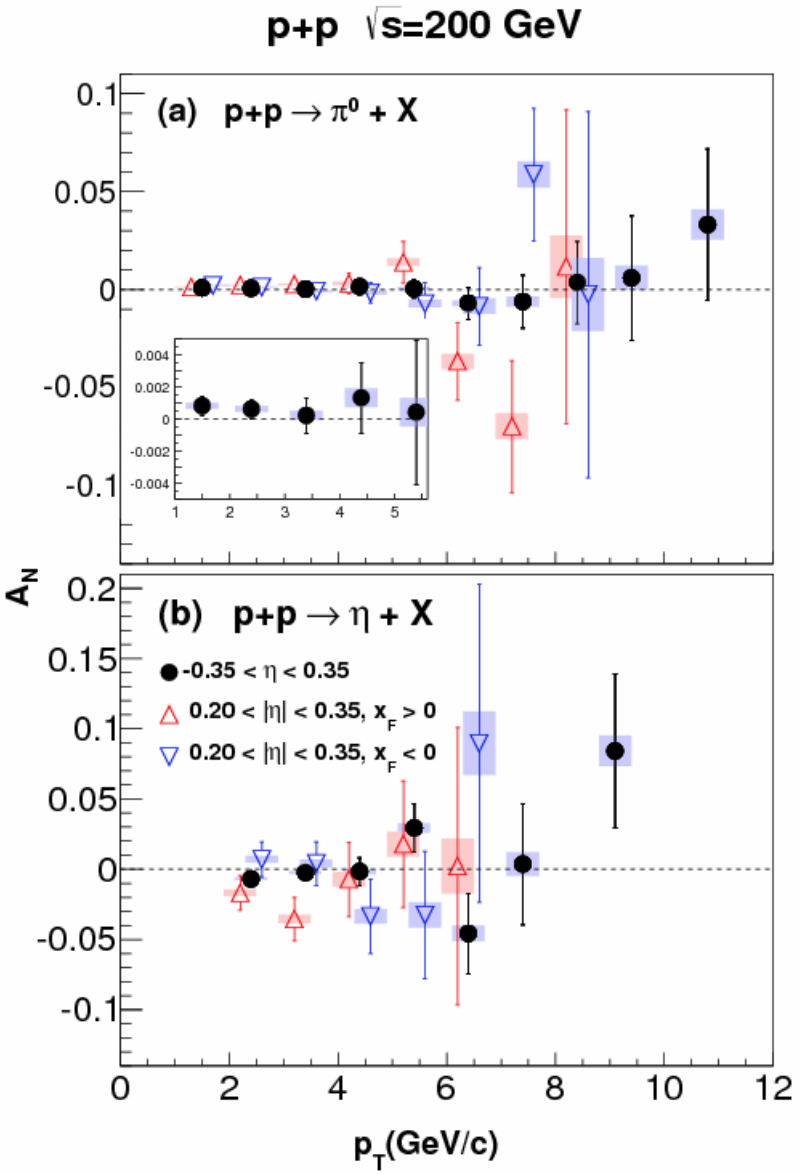


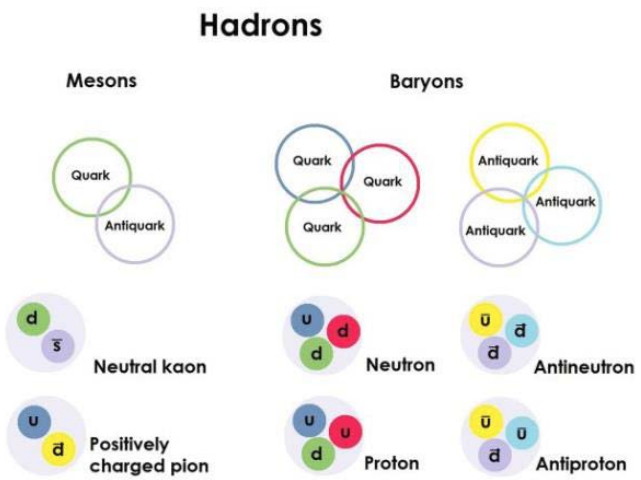

Final State effects:
Collins Function: spin momentum correlation in a Fragmentation Function

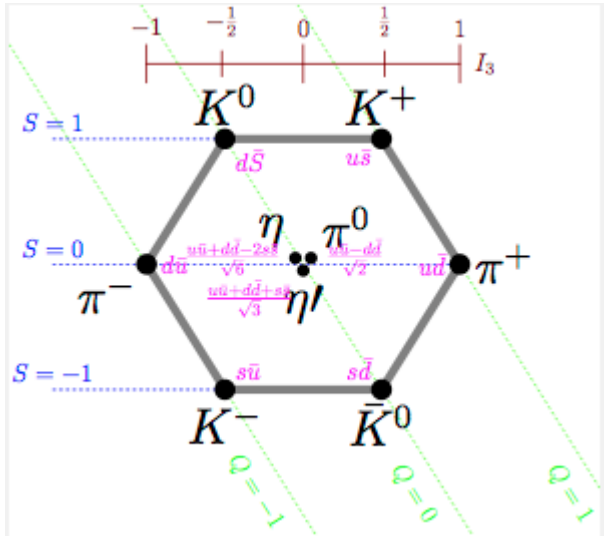



Figures from L. Nogach 2006 RHIC AGS Users Meeting

# Transverse Single Spin Asymmetry



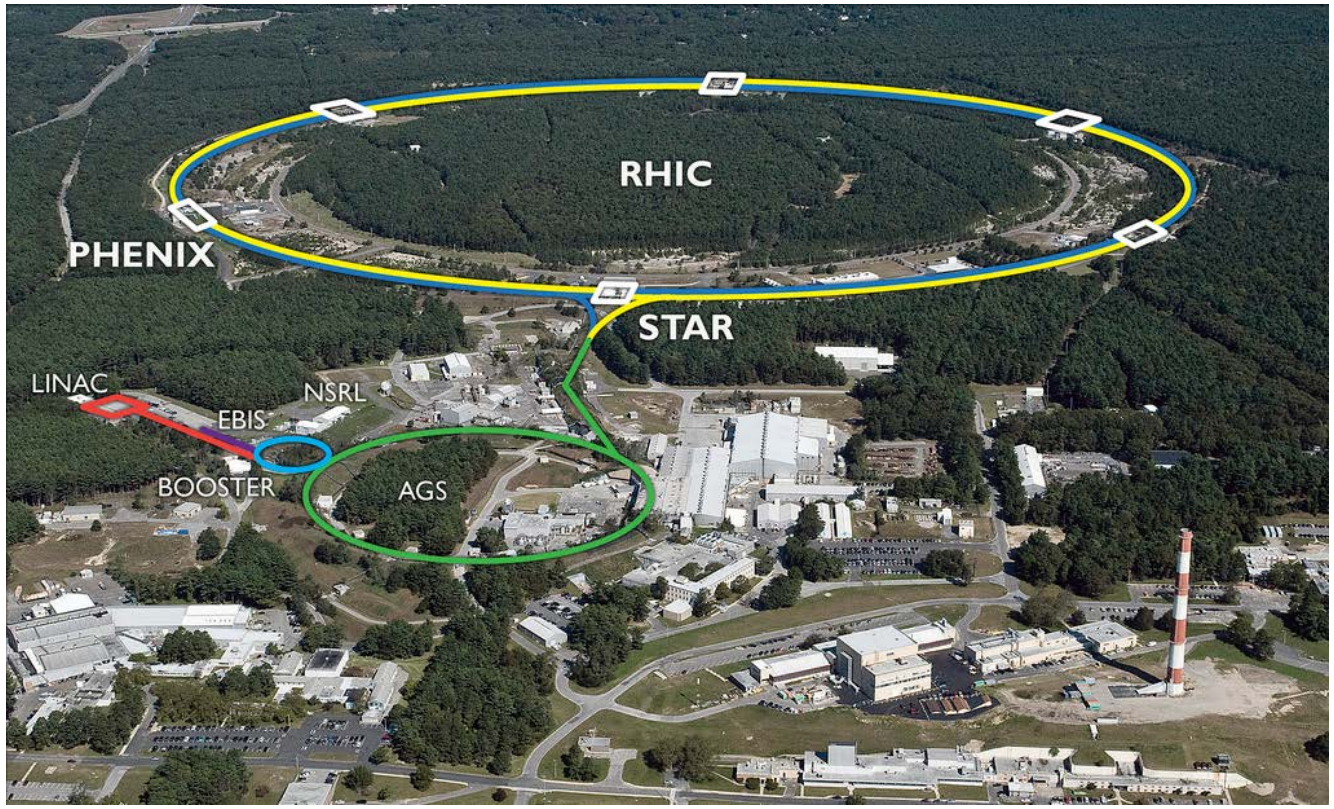

The asymmetry of π0 and η in midrapidity:

- Consistent with zero within errors

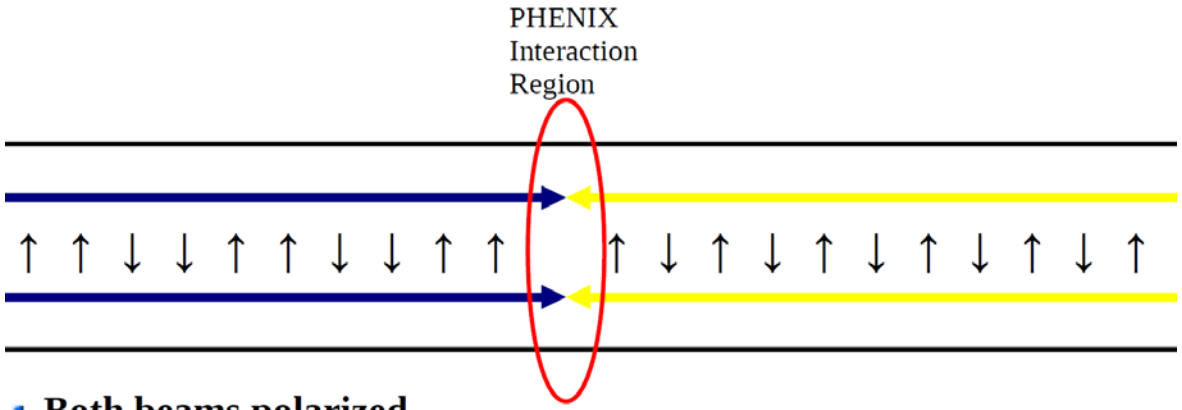
How does it change from neutral to charged hadron?

PRD90, 012006 (2014)

# RHIC



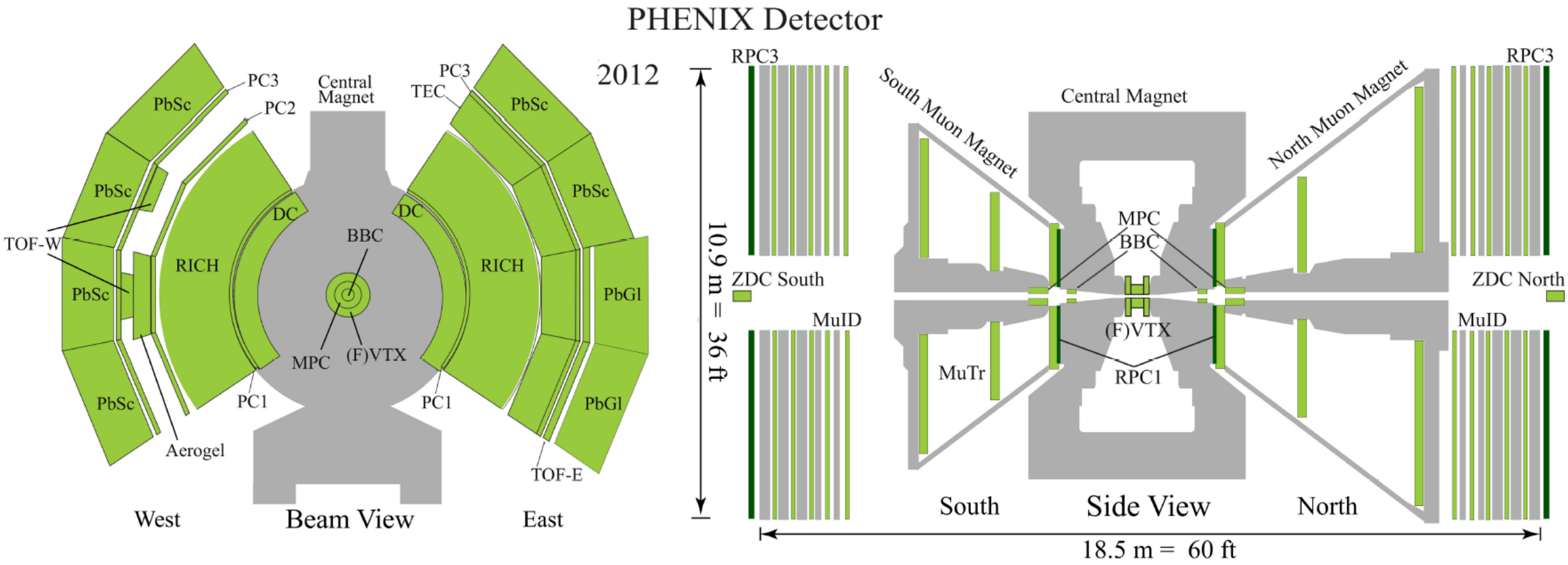

## Polarized Beams




- **Both beams polarized**
- Variation of bunch polarization direction minimizes systematic uncertainties in measurement
- For transversely polarized beams, allows for two independent $A_N$ measurements

View of the Brookhaven National Laboratory, NY, USA

# PHENIX Detector System




2 central arm: Mid rapidity, $|\eta| < 0.35$

- Identified charged hadrons : $\pi^0$, $\eta$, direct photon, $J/\psi$, heavy flavor.

# Calculation (Formula)

$$A_N = \frac{1}{\langle | \cos\phi | \rangle} \frac{1}{P} A_N^{raw}$$

$$\sigma_{A_N} = |A_N| \sqrt{\left(\frac{\sigma_{A_N^{raw}}}{A_N^{raw}}\right)^2 + \left(\frac{\sigma_P}{P}\right)^2}$$

Square Root Formula

$$A_N^{raw} = \frac{\sqrt{N_L^{\uparrow} N_R^{\downarrow}} - \sqrt{N_L^{\downarrow} N_R^{\uparrow}}}{\sqrt{N_L^{\uparrow} N_R^{\downarrow}} + \sqrt{N_L^{\downarrow} N_R^{\uparrow}}}$$

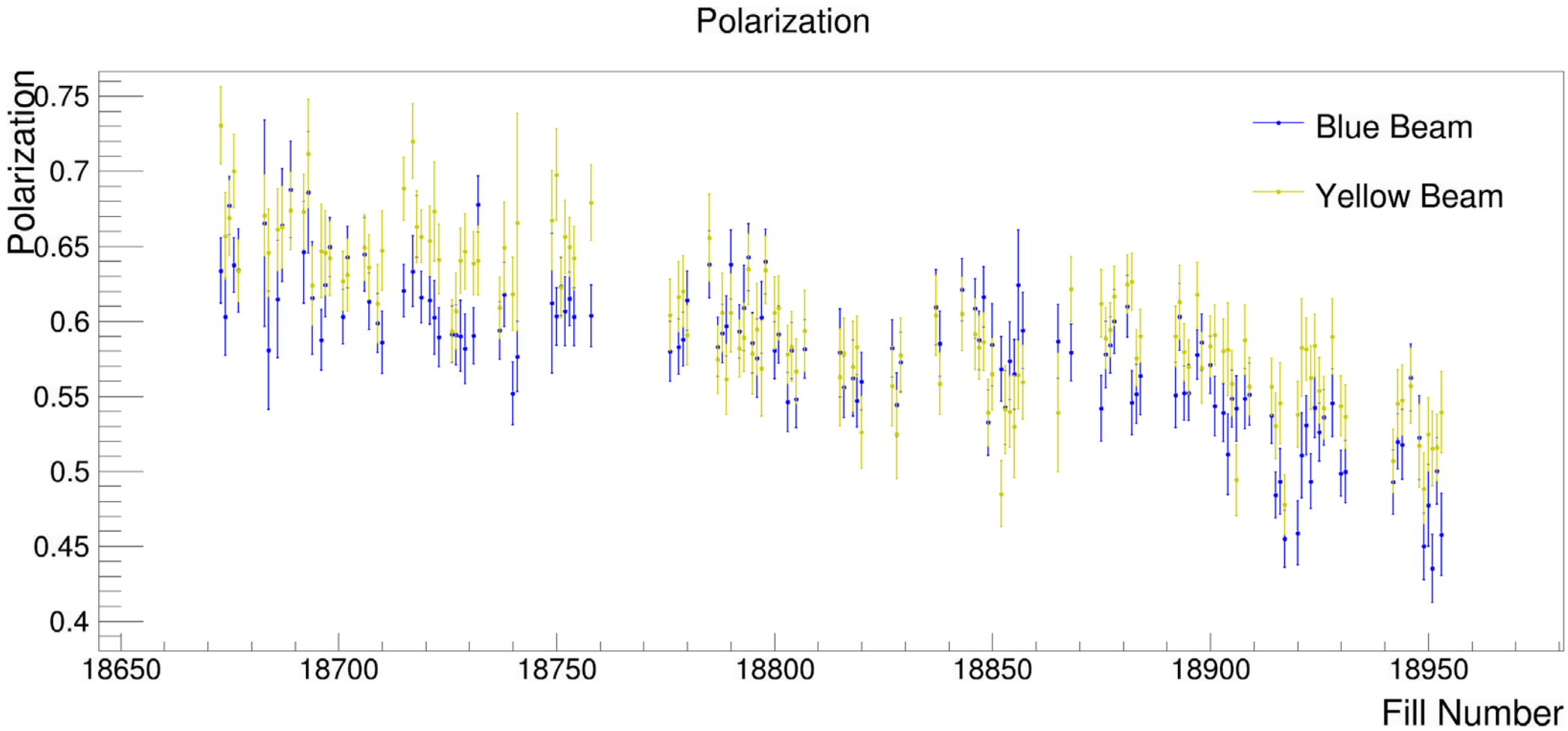
$$\sigma_{A_N^{raw}} = \frac{\sqrt{N_L^{\uparrow} N_R^{\downarrow} N_L^{\downarrow} N_R^{\uparrow}}}{\left(\sqrt{N_L^{\uparrow} N_R^{\downarrow}} + \sqrt{N_L^{\downarrow} N_R^{\uparrow}}\right)^2} \sqrt{\frac{1}{N_L^{\uparrow}} + \frac{1}{N_L^{\downarrow}} + \frac{1}{N_R^{\uparrow}} + \frac{1}{N_R^{\downarrow}}}$$

Relative Luminosity Formula

$$A_N^{raw} = \frac{N_L^{\uparrow} - \mathcal{R} N_L^{\downarrow}}{N_L^{\uparrow} + \mathcal{R} N_L^{\downarrow}}$$

$$\sigma_{A_N^{raw}} = \frac{2\mathcal{R} N_L^{\uparrow} N_L^{\downarrow}}{\left(N_L^{\uparrow} + \mathcal{R} N_L^{\downarrow}\right)^2} \sqrt{\frac{1}{N_L^{\uparrow}} + \frac{1}{N_L^{\downarrow}}}$$

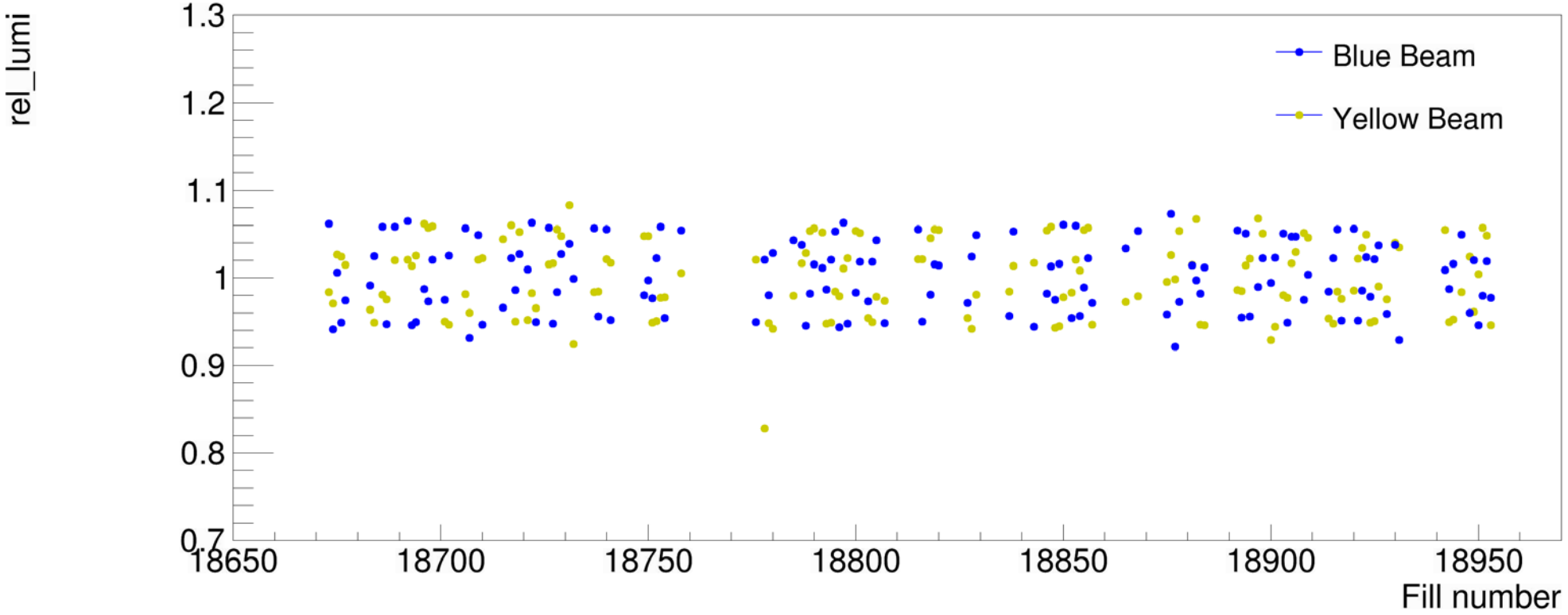
# Polarization vs fillnumber




- The proton beam is never 100% polarized and collisions between unpolarized protons dilute the $A_N$ measurement.

- The dilution must be corrected by dividing by the average beam polarization.

# Rel_lumi vs fillnumber

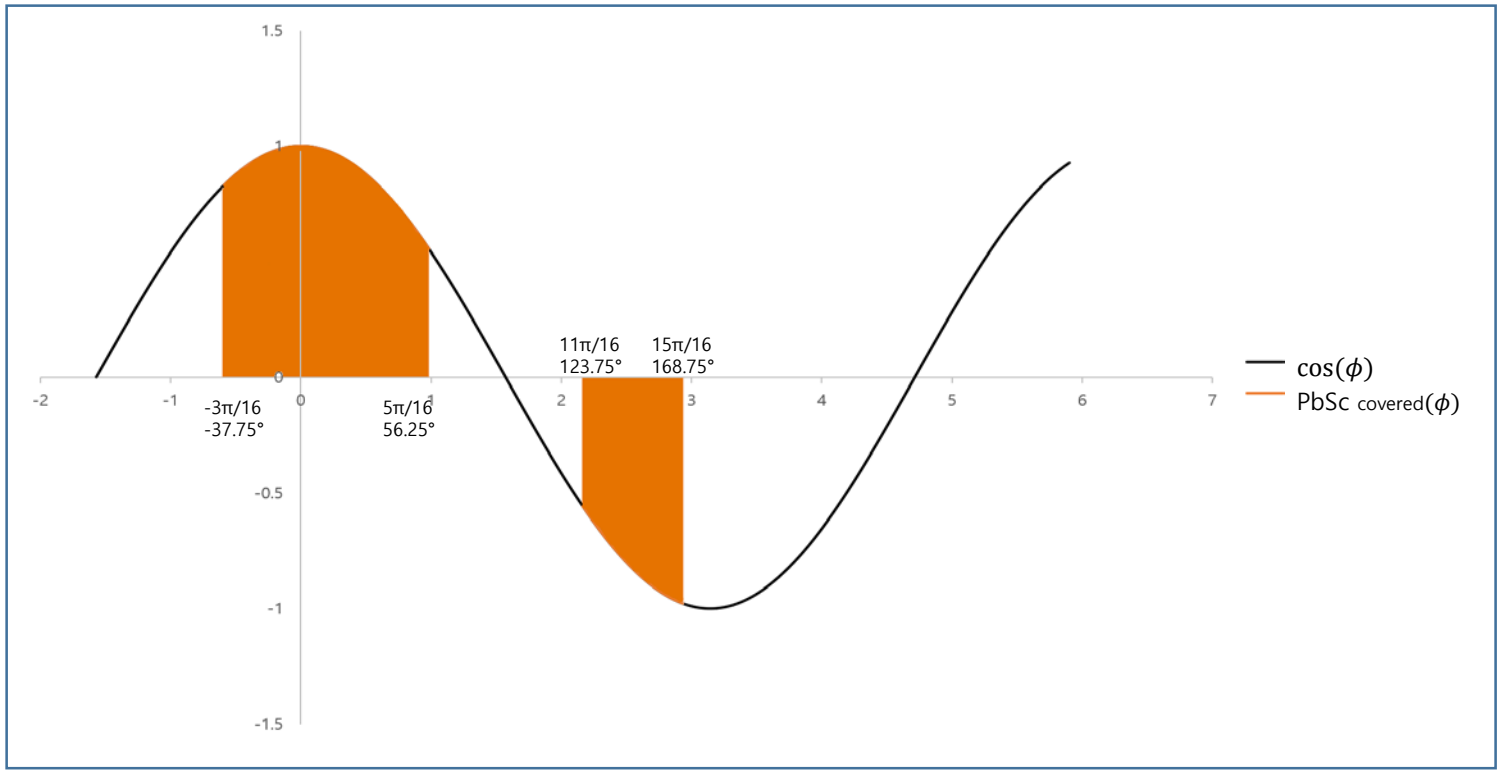



$R = L_{\uparrow}/L_{\downarrow}$

**Fill number = 18778**
rellumiB = 1.02079
rellumiY = 0.827717

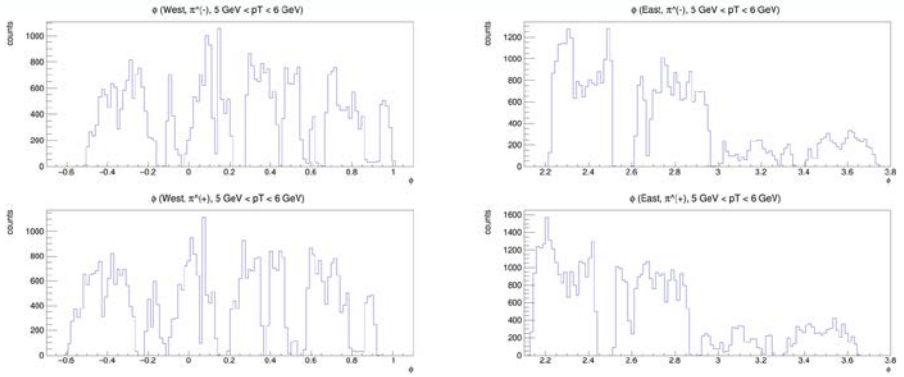
The relative luminosity asymmetry formula uses counts that are only on one side of the detector at a time and then calculates the asymmetry for when the beam was spin up versus spin down.

# Acceptance Correction

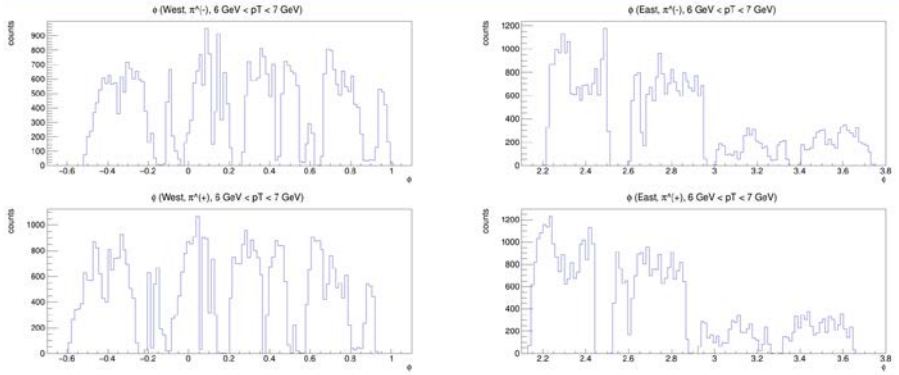



$$\langle | \cos\phi | \rangle = \frac{\sum_{i=1}^{N} | \cos\phi_i |}{N}$$

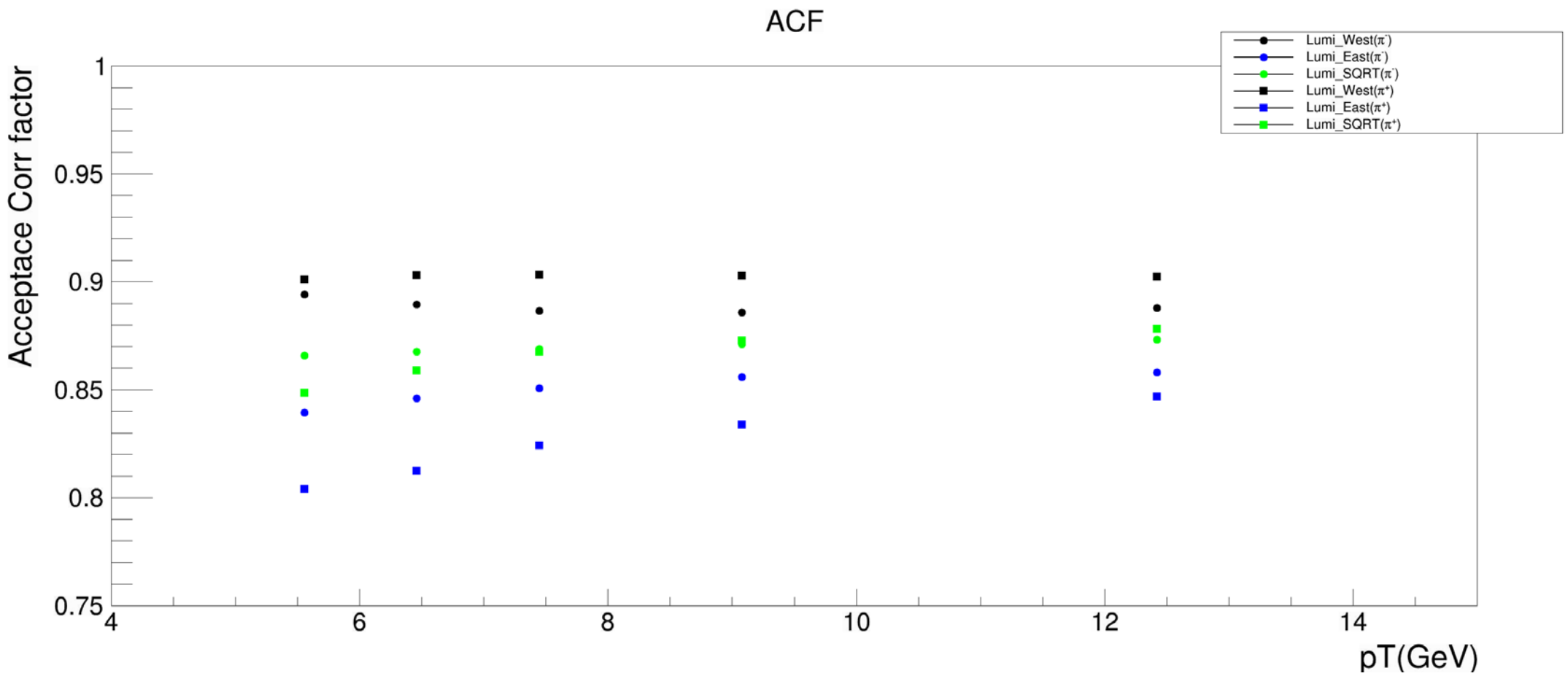
Phi distribution 5 GeV < pT < 6 GeV



Phi distribution 6 GeV < pT < 7 GeV



# ACF

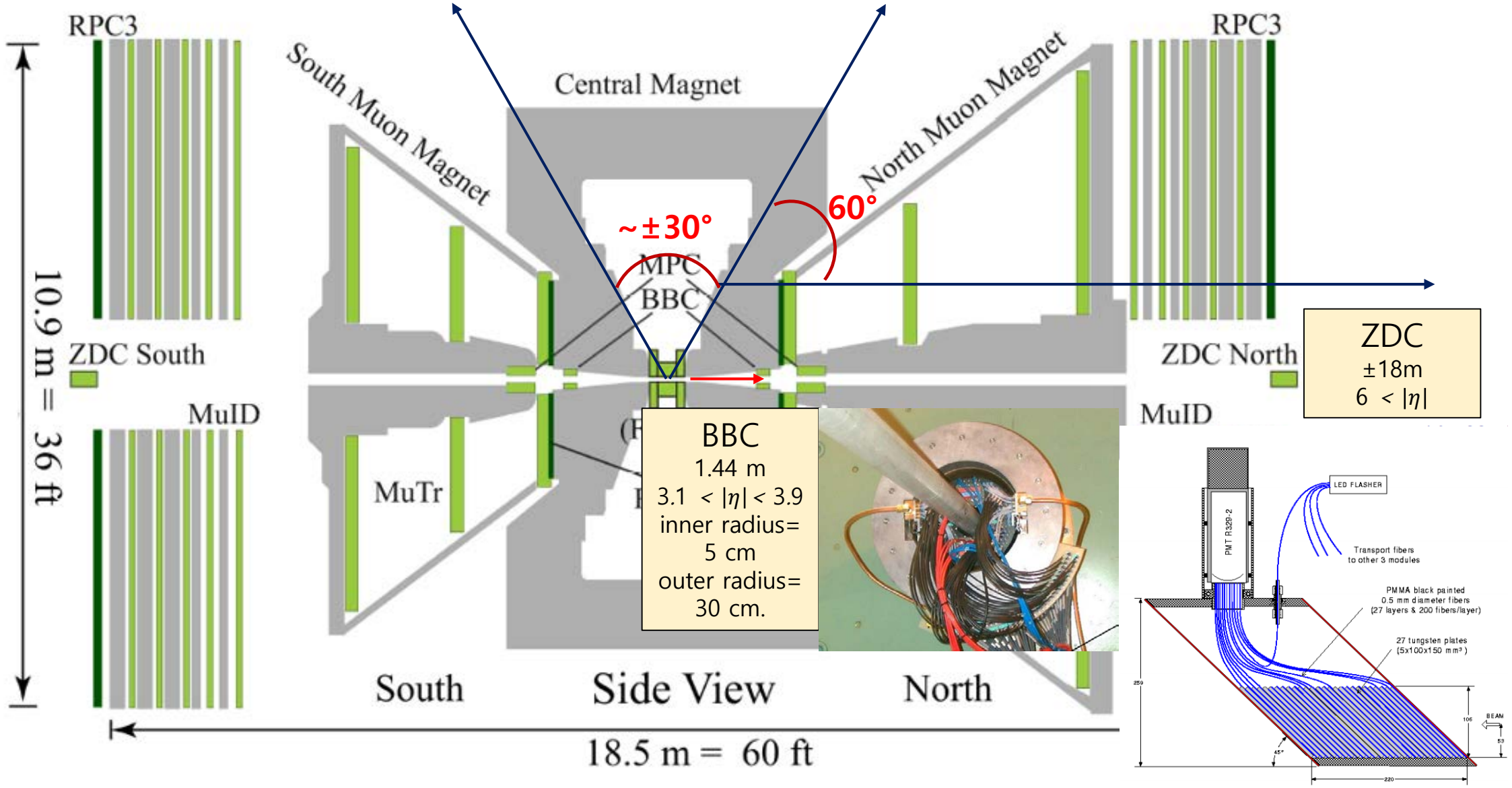

ACF
Acceptace Corr factor
1
0.95
0.9
0.85
0.8
0.75
4
6
8
10
12
14
pT(GeV)
Lumi_West(π⁻)
Lumi_East(π⁻)
Lumi_SQRT(π⁻)
Lumi_West(π⁺)
Lumi_East(π⁺)
Lumi_SQRT(π⁺)



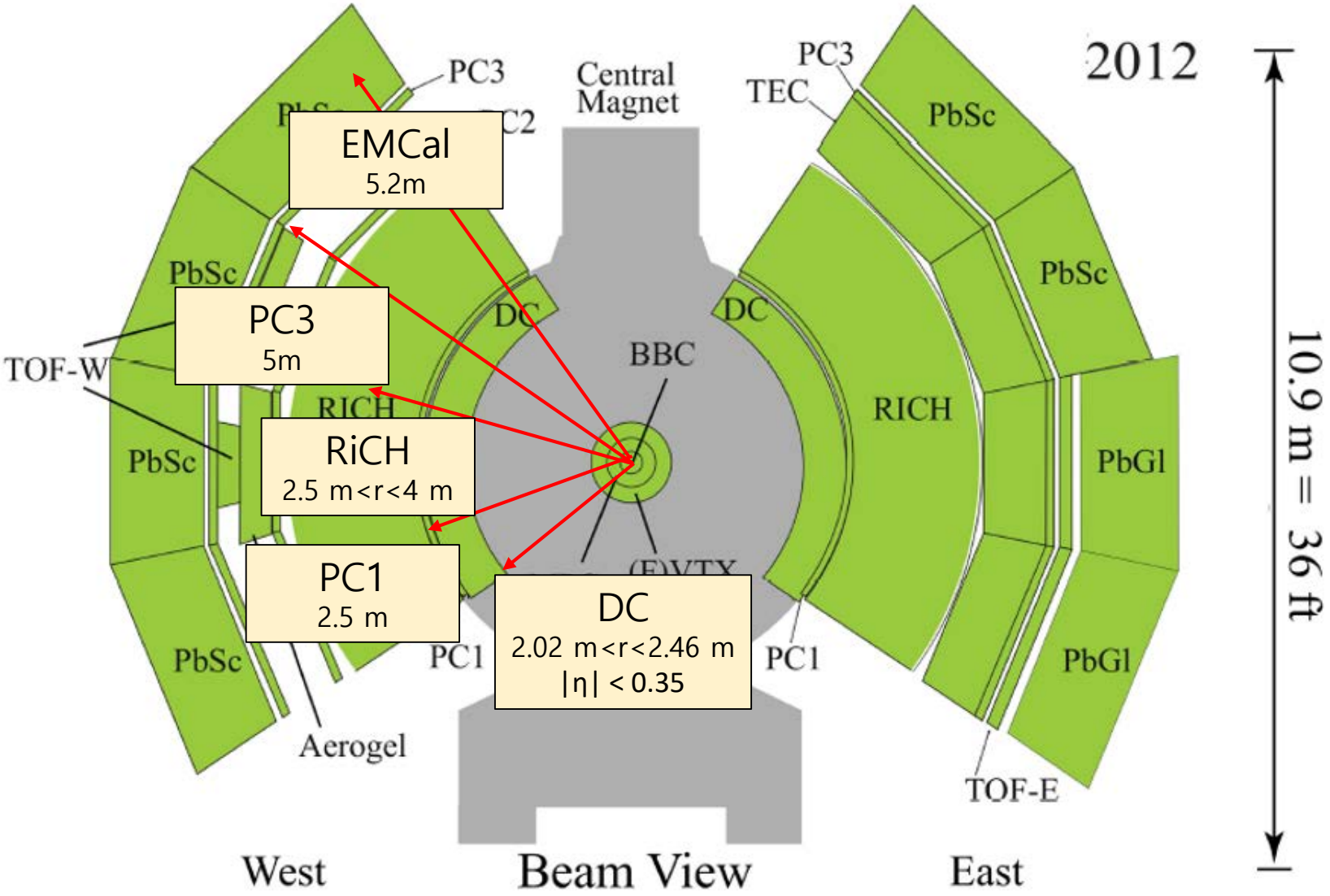
# Thank you.

# BACK UP

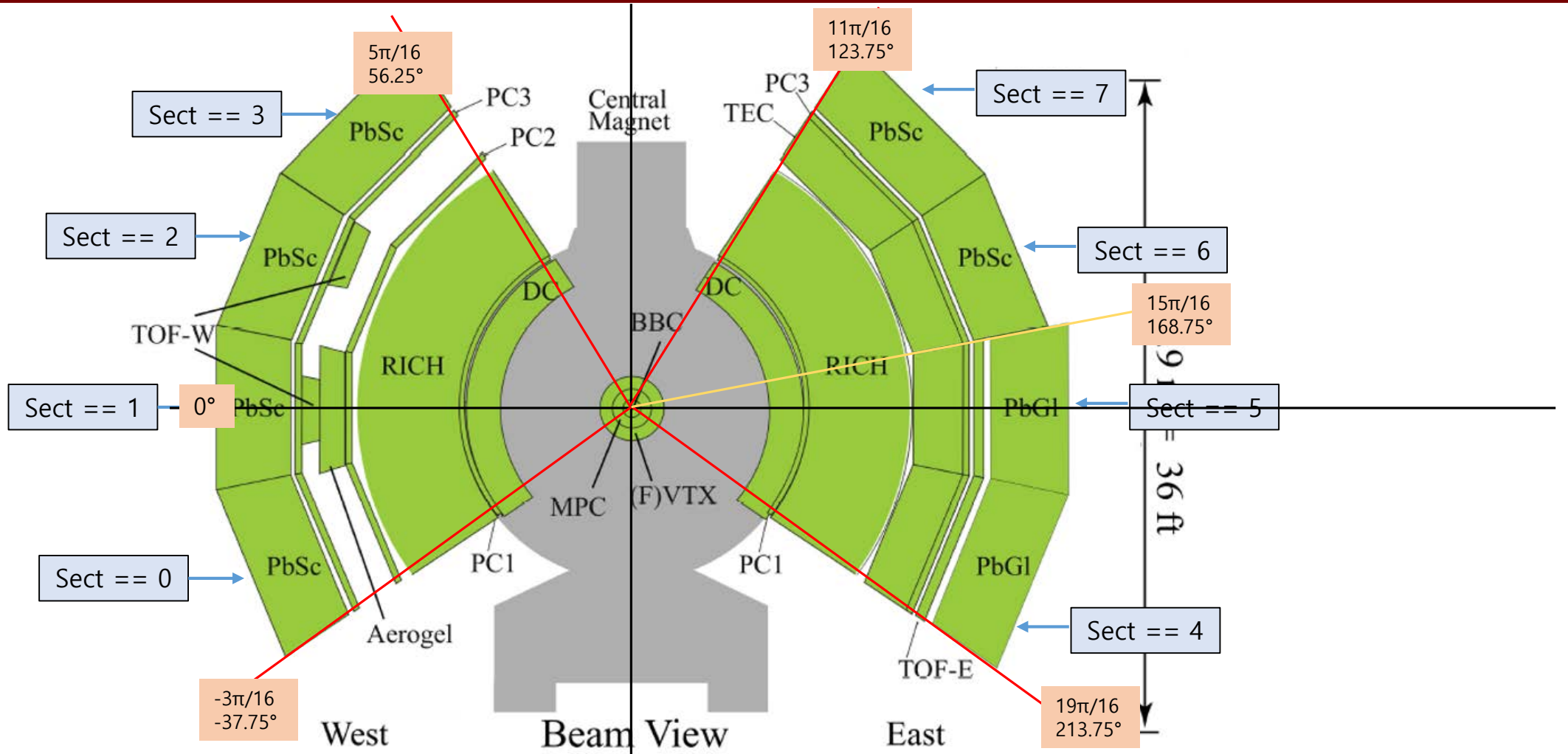
# PHENIX Detector System



# PHENIX Detector System



# PHENIX Detector System



# Rel. luminosity(Norbert's)

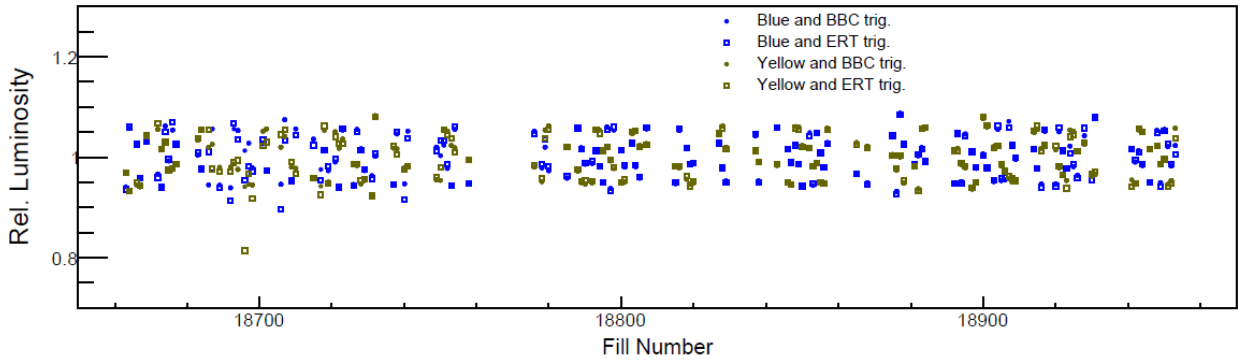



Figure 41: Relative luminosity factor calculated for each fill in Run-15 $p+p$.

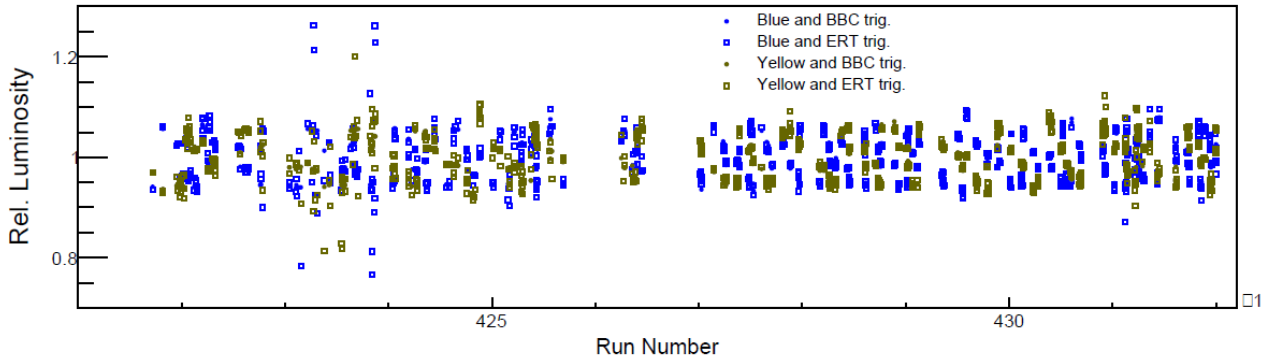
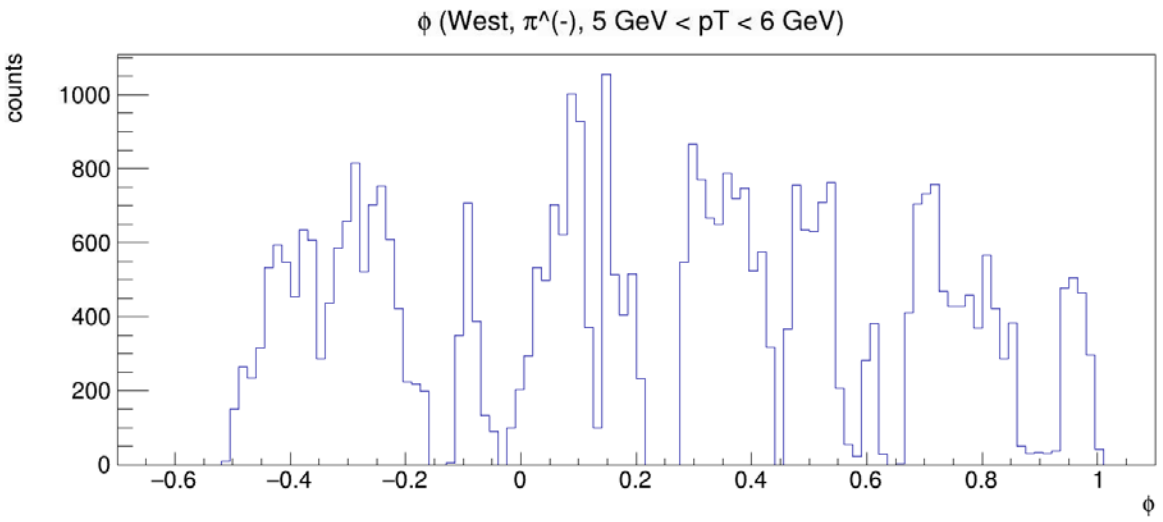
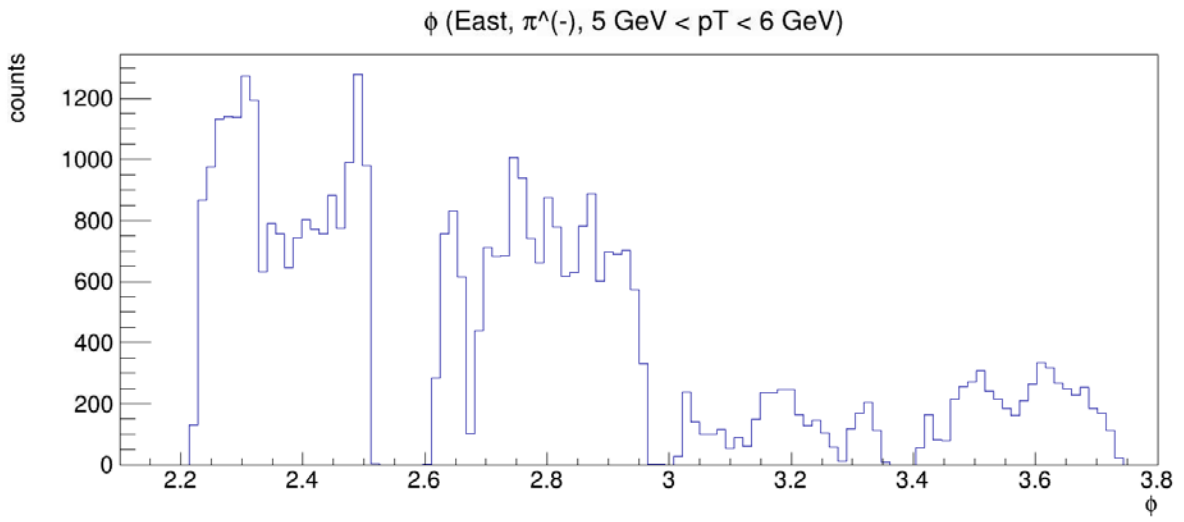


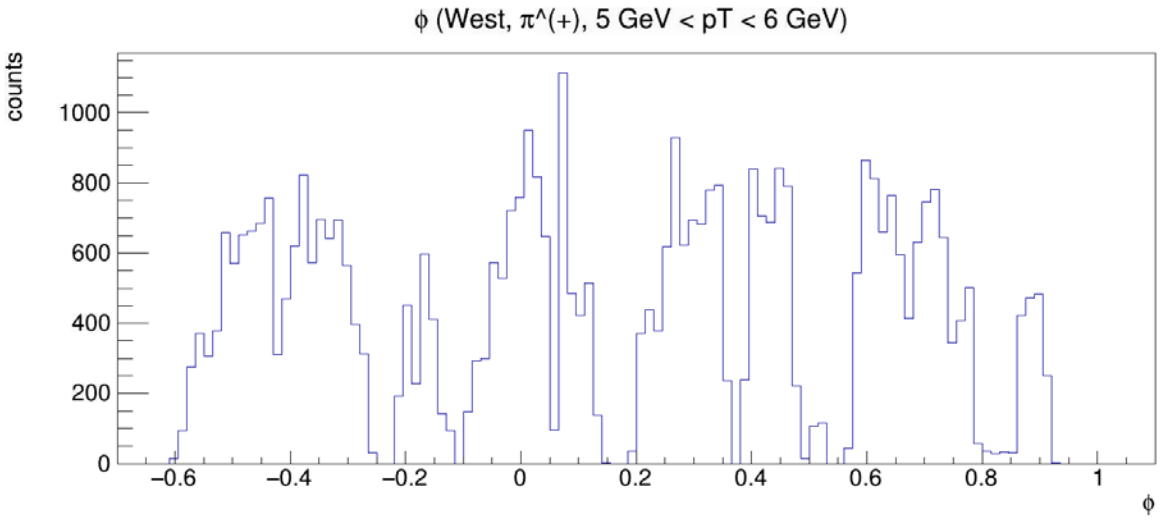

Figure 42: Relative luminosity factor calculated for each run in Run-15 $p+p$.

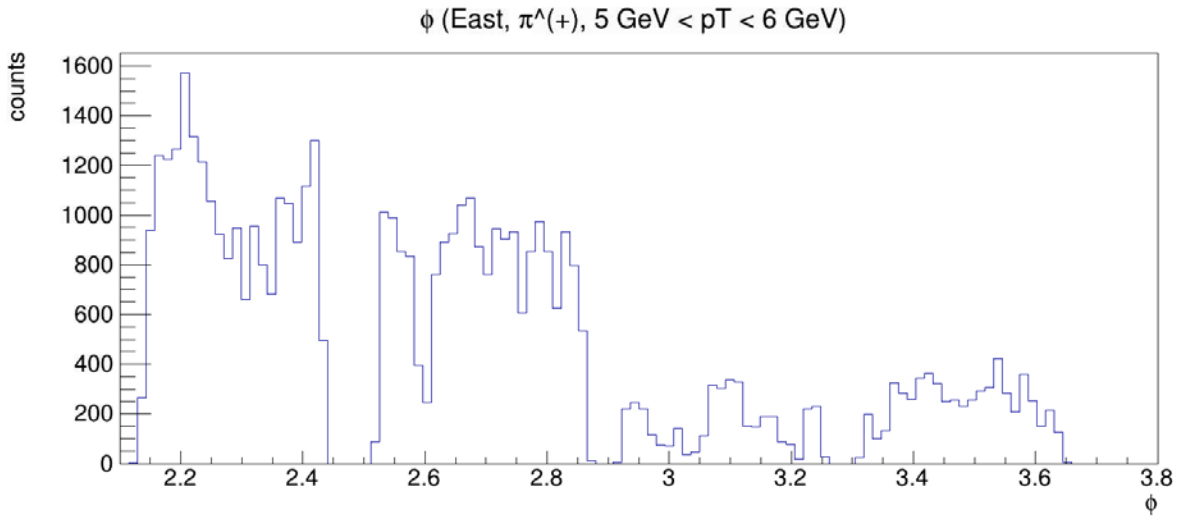
AN 1269(Norbert's)

# Phi distribution 5 GeV < pT < 6 GeV

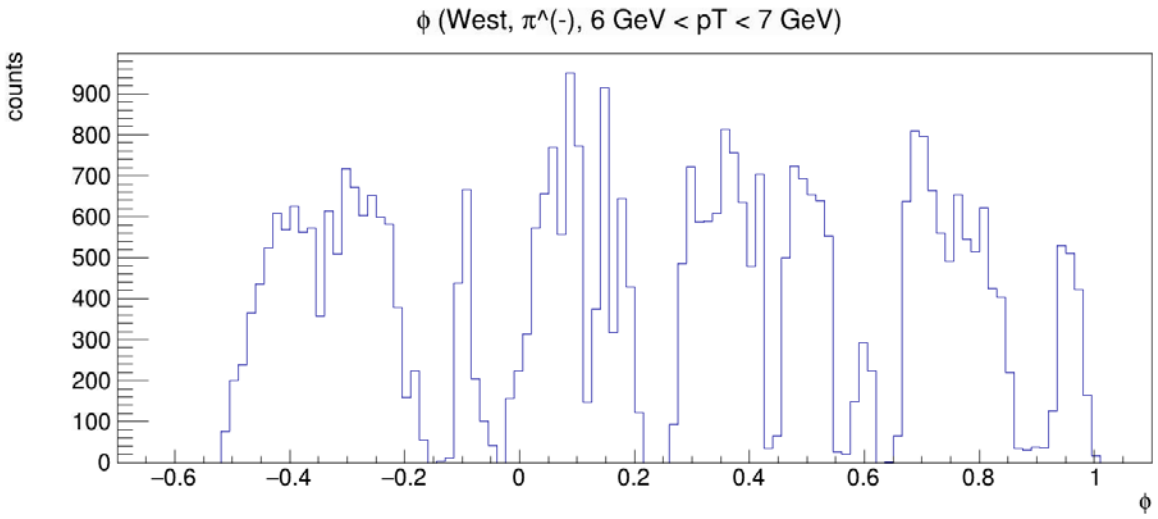


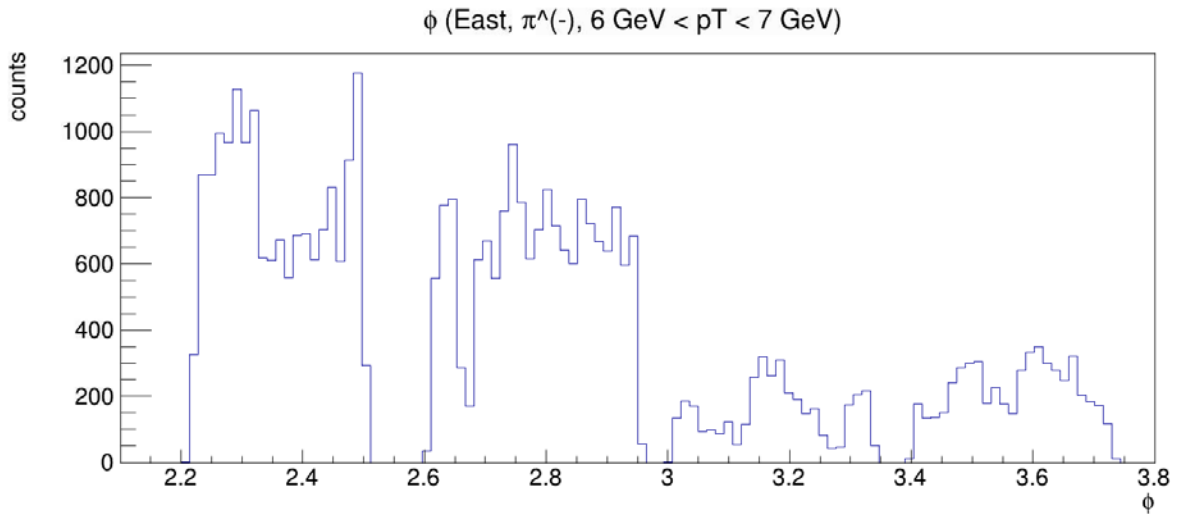



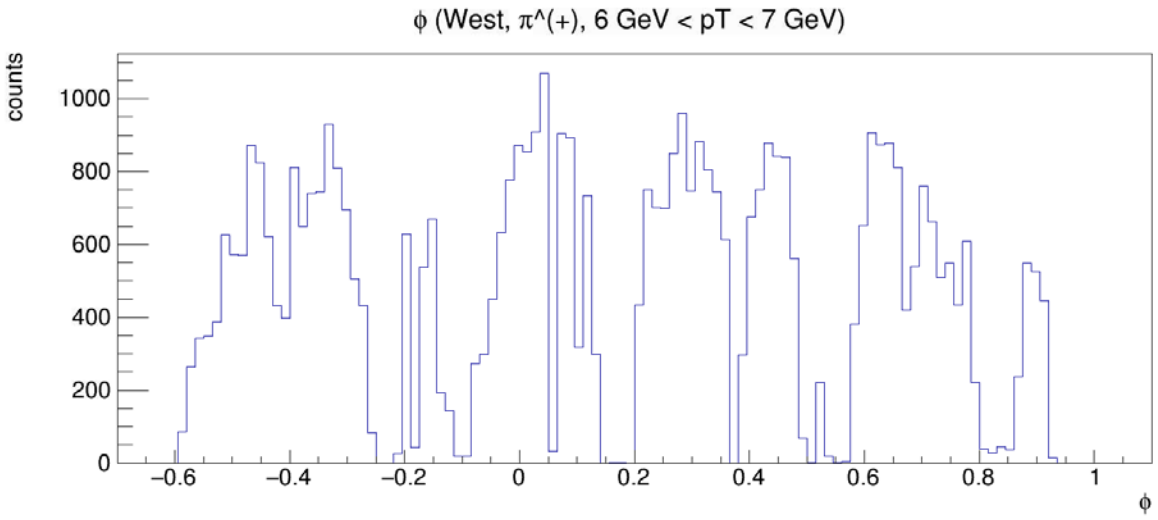



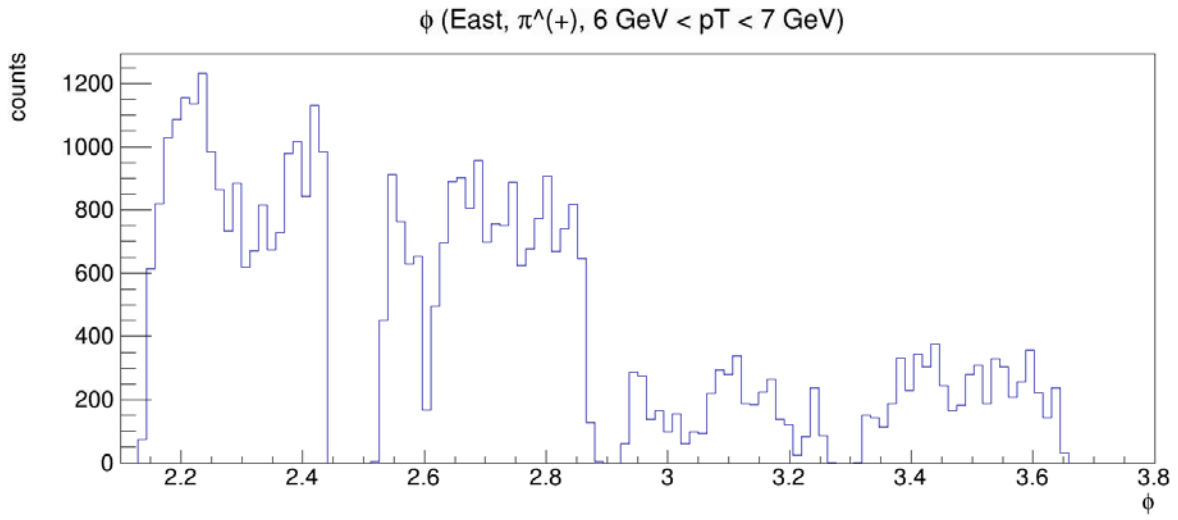



# Phi distribution 6 GeV < pT < 7 GeV

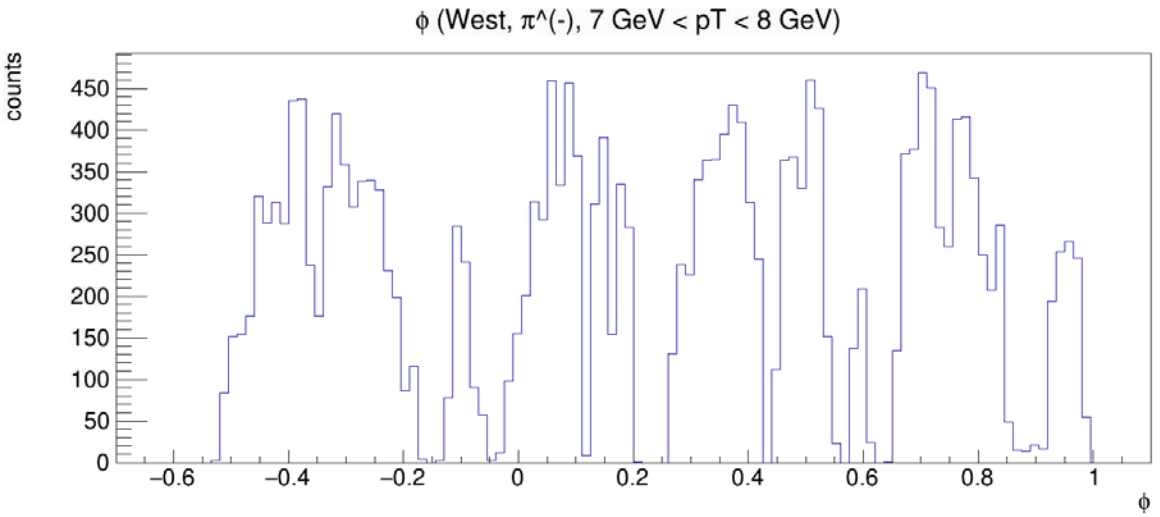


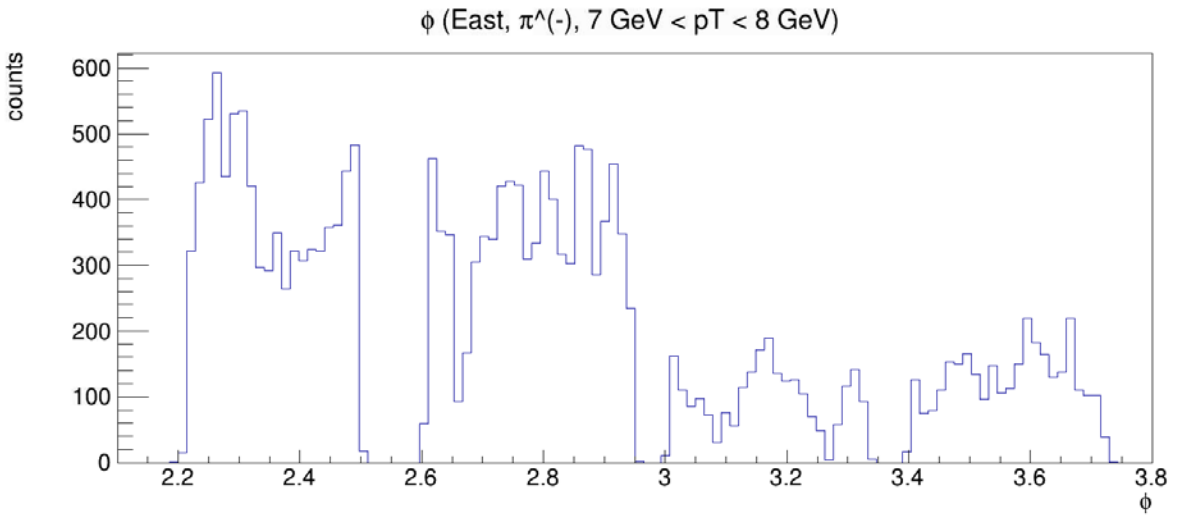



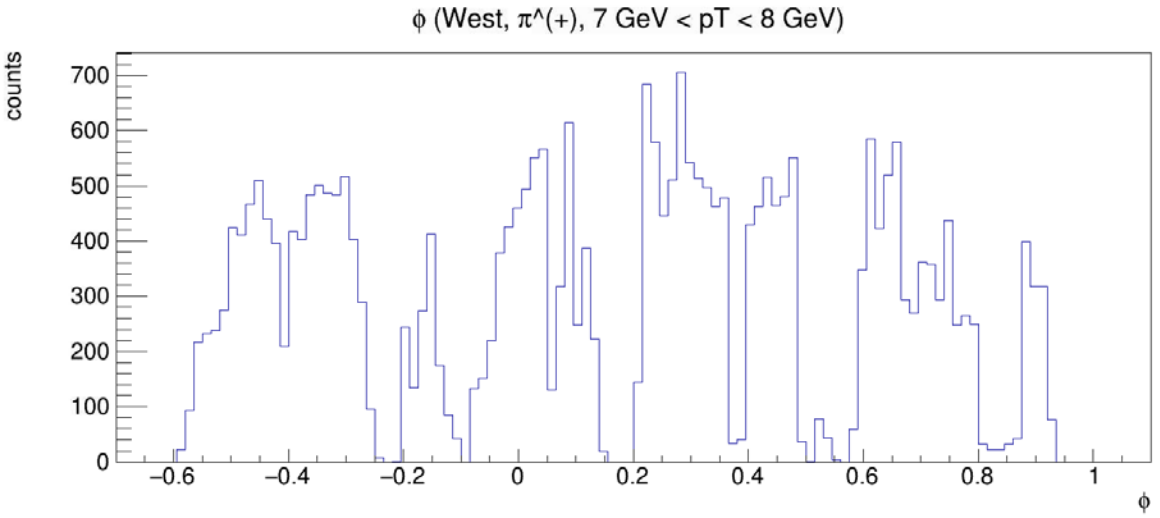



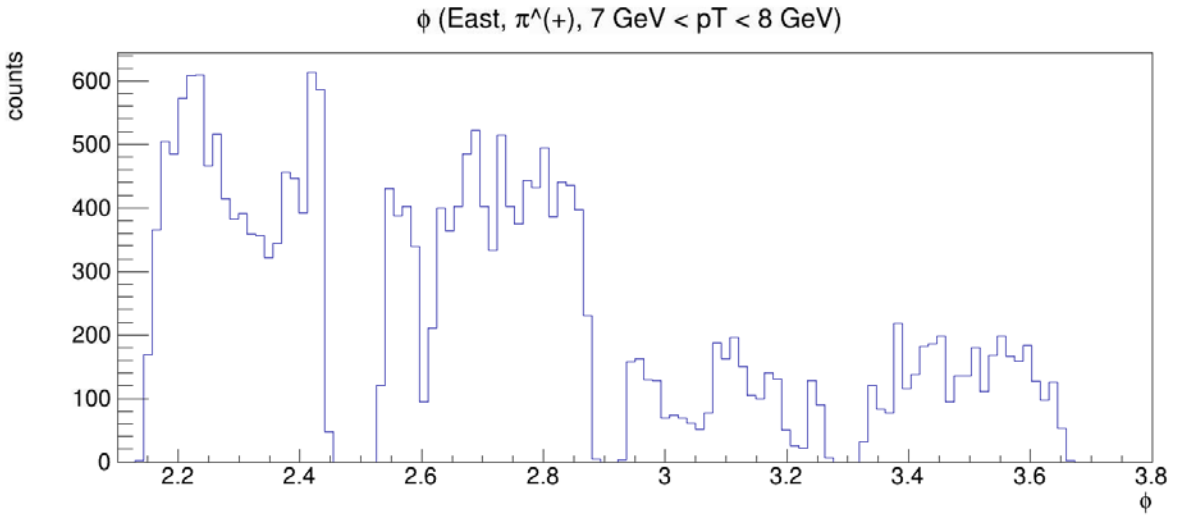



# Phi distribution 7 GeV < pT < 8 GeV

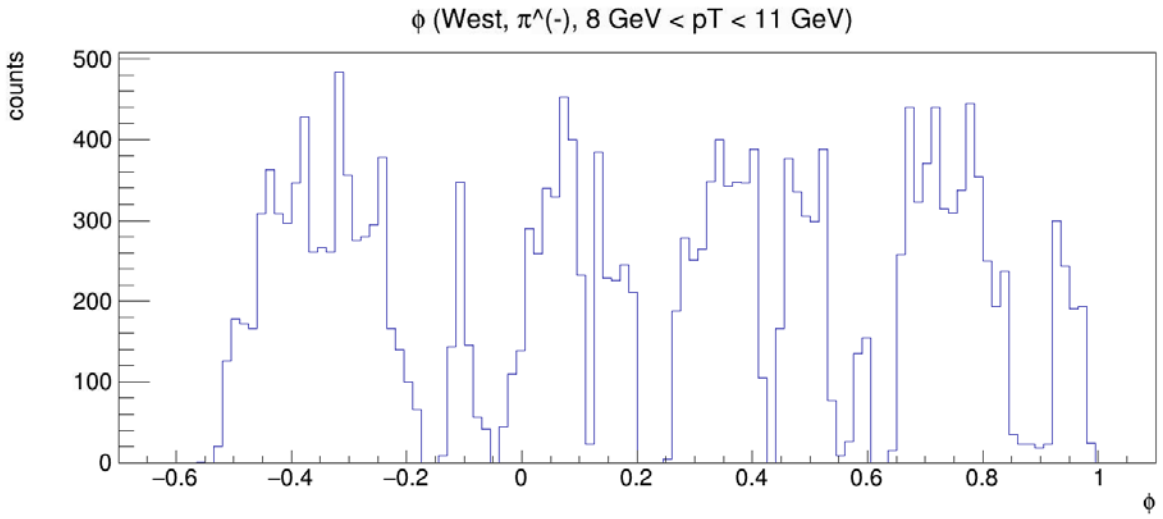


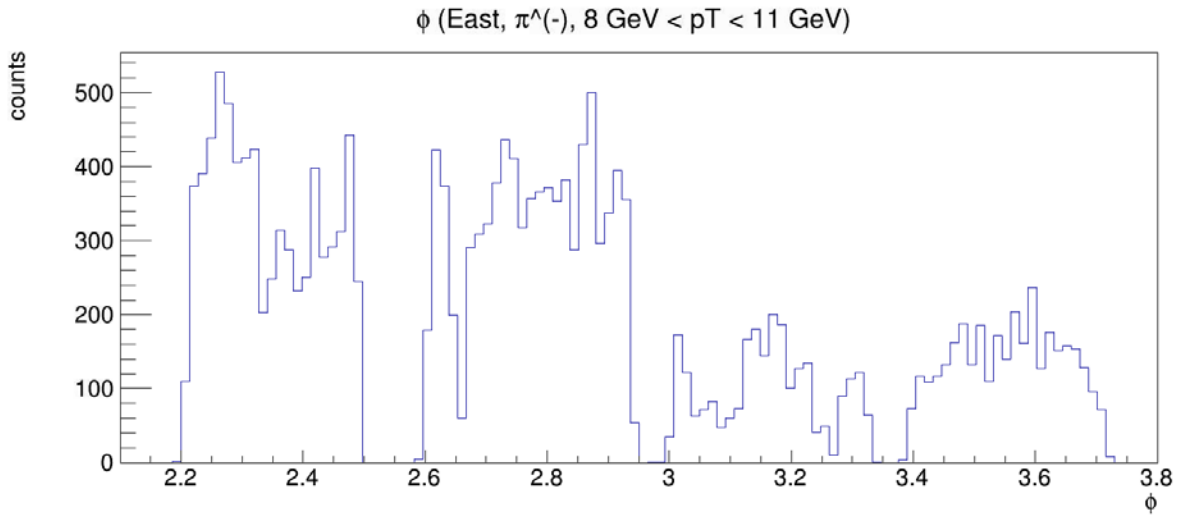



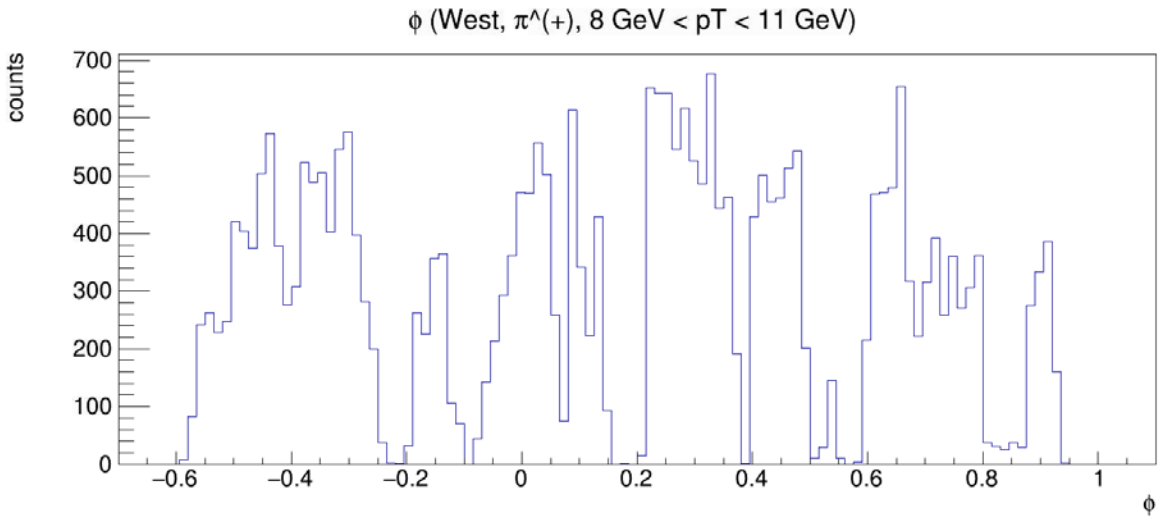



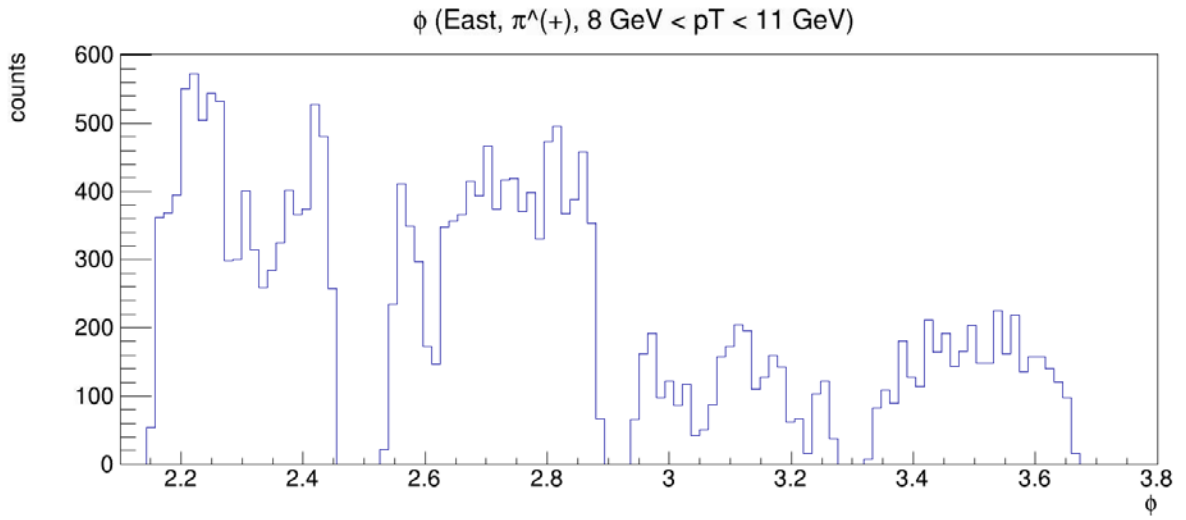



# Phi distribution 8 GeV < pT < 11 GeV



# Phi distribution 11 GeV < pT < 15 GeV