SPD local polarimetry with π^0 $(pp \to \pi^0 X)$

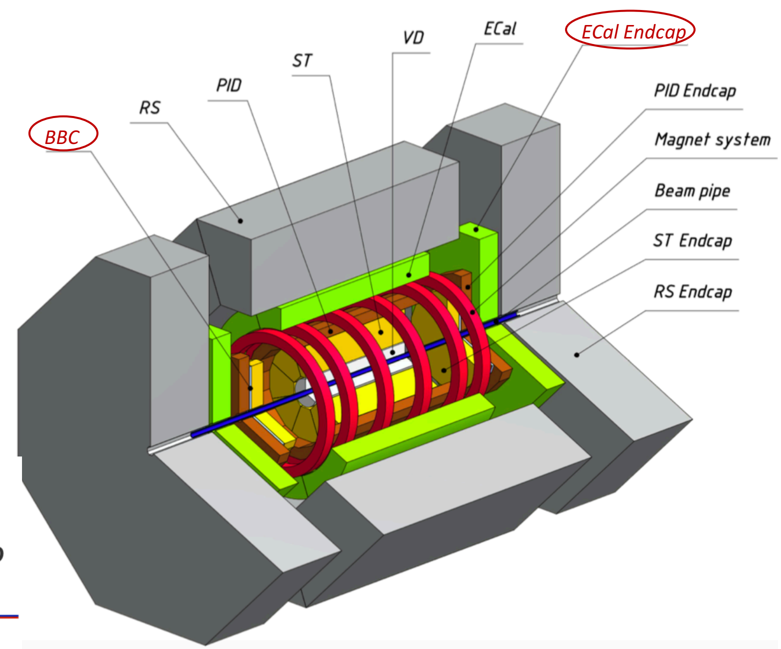
SPD goal — Investigate **polarized** phenomena in order to contribute to disentangle nucleon <u>spin problems</u> (i.e. proton "crisis")

Polarimetry — Measures the degree of polarization [1] to correctly scale any asymmetry measurement

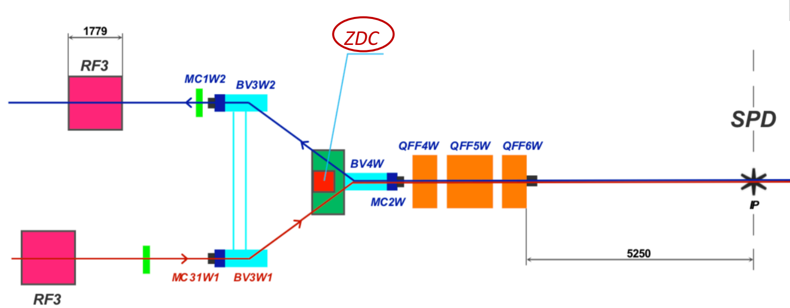
Key issue: maximize the number of ions in the bunches which are polarized in the needed direction

- Major polarimetry (pC-CNI and Absolute polarimeters: based on gas jet, targeting stations, etc.)

- **Local polarimetry**
  - Permanent online beam polarization monitoring to reduce systematic errors coming from the beam polarization variation.
  - Beam polarization monitoring independent on the major polarimeters.

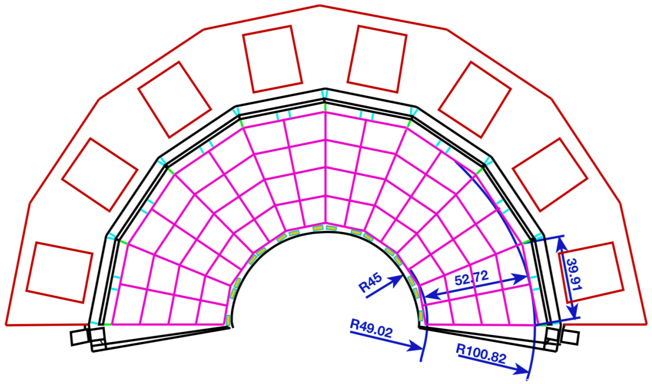


Challenge: lack of precise polarization data in the SPD energy range



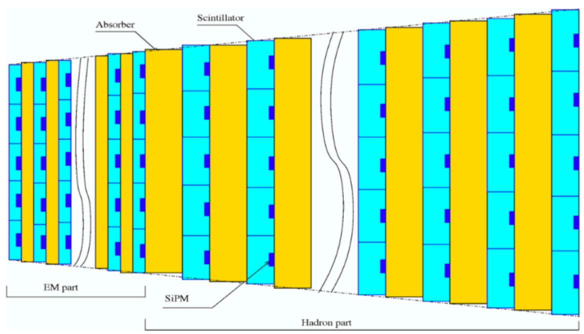
(1) Polarization is understood as the fraction of protons in the bunch with their spins aligned along the polarization vector
(2) pC-CNI: pC elastic scattering in the Coulomb Nuclear Interference

Methods for local polarimetry in SPD

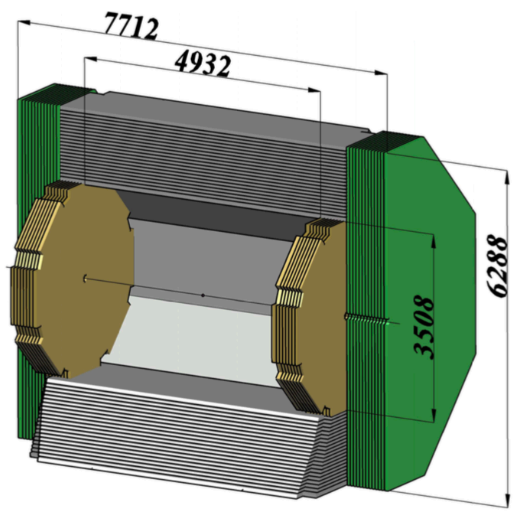


- Charged particles in forward direction
  - Beam – Beam Counters (BBCs)

    $3.3 < |\eta| < 5.0$ and $2.1 < |\eta| < 3.3$



- Very forward neutron production ($pp \rightarrow nX$)
  - ZDC and ZDC $\otimes$ BBC



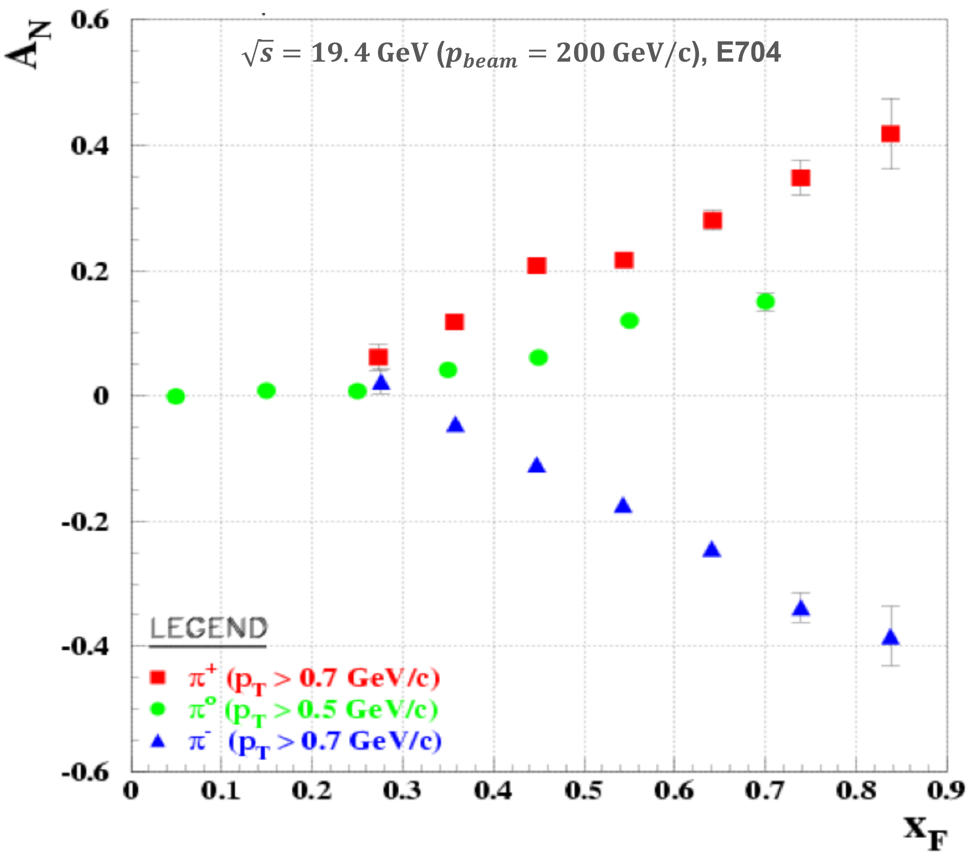
- Single transverse spin asymmetry, A_{N}, for inclusive $\boldsymbol{\pi}^{\mathbf{0}}$ production at high x_{F} ($pp \rightarrow \boldsymbol{\pi}^{\mathbf{0}}X$)
  - ECal end-cups around the beam pipe
  - No information is needed on vertex position $\Rightarrow$ fast $\boldsymbol{\pi}^{\mathbf{0}}$ reconstruction

In the early 70's was believed that SSA (A_N) was nearly vanishing in the framework of pQCD.

$$A_N = \frac{\sigma^\uparrow - \sigma^\downarrow}{\sigma^\uparrow + \sigma^\downarrow}$$

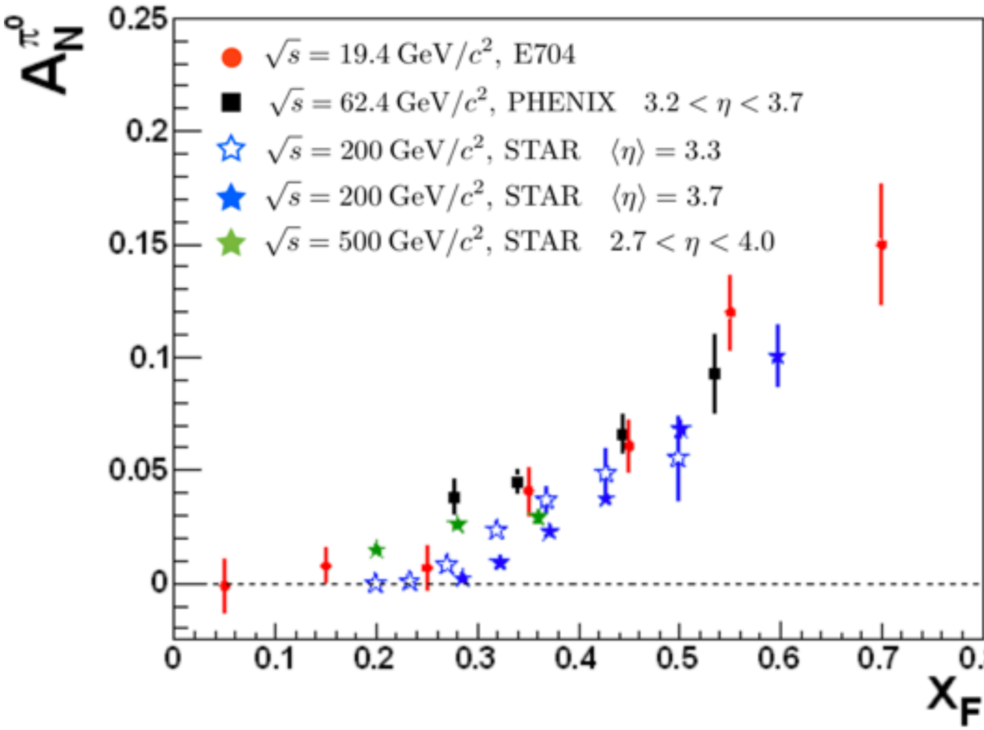
In 1991 the E704 experiment, with $\boldsymbol{p}^\uparrow$ at higher p_T values, extended the results on large A_N.

$p^\uparrow + p \to \pi + X$



E704: Adams et al. Phsy. Lett. B264(1991)462

A_N nearly independent of $\sqrt{s}$



$p^{\uparrow} + p \rightarrow \boldsymbol{\pi^0} + X$ SPD setup: $\phi = 2\pi$

The cross section of hadron production in polarized $p^{\uparrow} + p$ collisions, is modified in azimuth.

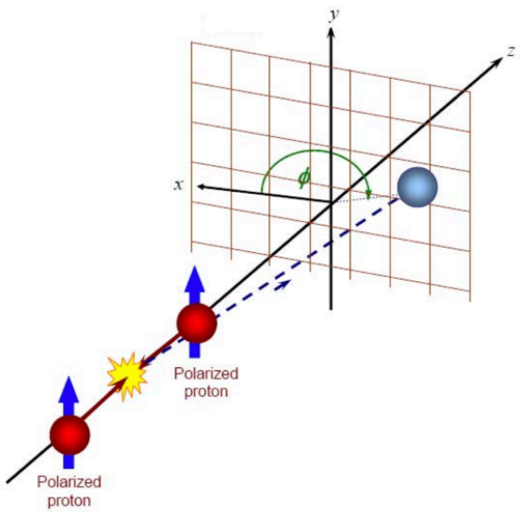
$$\frac{d\sigma}{d\phi} = \frac{d\sigma}{d\phi_0}(1 + \underbrace{P \cdot A_{\mathrm{N}} \cdot \cos\phi}_{\text{Azimuthal cosine modulation}})$$

$$N_{\boldsymbol{\pi^0}}(\phi) = A + B\cos\phi$$

$$A_N = \frac{B}{A \cdot P}$$

$N_{\boldsymbol{\pi^0}}(\phi)$: Yield of π^0

P: Beam polarization



Two methods used in PHENIX to measure the raw asymmetry

$$P \cdot A_N \cdot \cos\phi = \epsilon(\phi)$$

1 $$\epsilon_{pol}(\phi) = \frac{N^{\uparrow}(\phi) - N^{\downarrow}(\phi)}{N^{\uparrow}(\phi) + N^{\downarrow}(\phi)}$$

Two different yields (up - ↑ and down - ↓) in <u>one azimuthal region</u>. Needs to account for the relative luminosity effects:

$$\mathcal{R} = \frac{\mathcal{L}^{\uparrow}}{\mathcal{L}^{\downarrow}}$$

2 $$\epsilon_{sqrt}(\phi) = \frac{\sqrt{N^{\uparrow}(\phi) \cdot N^{\downarrow}(\phi+\pi)} - \sqrt{N^{\downarrow}(\phi) \cdot N^{\uparrow}(\phi+\pi)}}{\sqrt{N^{\uparrow}(\phi) \cdot N^{\downarrow}(\phi+\pi)} + \sqrt{N^{\downarrow}(\phi) \cdot N^{\uparrow}(\phi+\pi)}}$$

Yields from <u>two azimuthal regions</u> in opposite sides of the calorimeter (ϕ and $\phi + \pi$) and two polarization directions (up - ↑ and down - ↓). Relative luminosity effects can be ignored.

$$\boldsymbol{p + p \to \pi^0 + X}$$

$$\pi^0 \to \gamma\gamma$$

Min. bias

SoftQCD:all	= on
PDF:pSet	= 15
BeamRemnants:primordialKT	= on
BeamRemnants:primordialKTsoft	= 1.1
BeamRemnants:primordialKThard	= 1.8
BeamRemnants:halfScaleForKT	= 2.0
BeamRemnants:halfMassForKT	= 4.0
BeamRemnants:reducedKTatHighY	= 0.7
BeamRemnants:primordialKTremnant	= 0.4
PhaseSpace:pTHatMinDiverge.	= 0.5

In Pythia this QCD process selection is intended to represent the total cross section of hadron collisions

$\boldsymbol{Pythia\ 8244}$

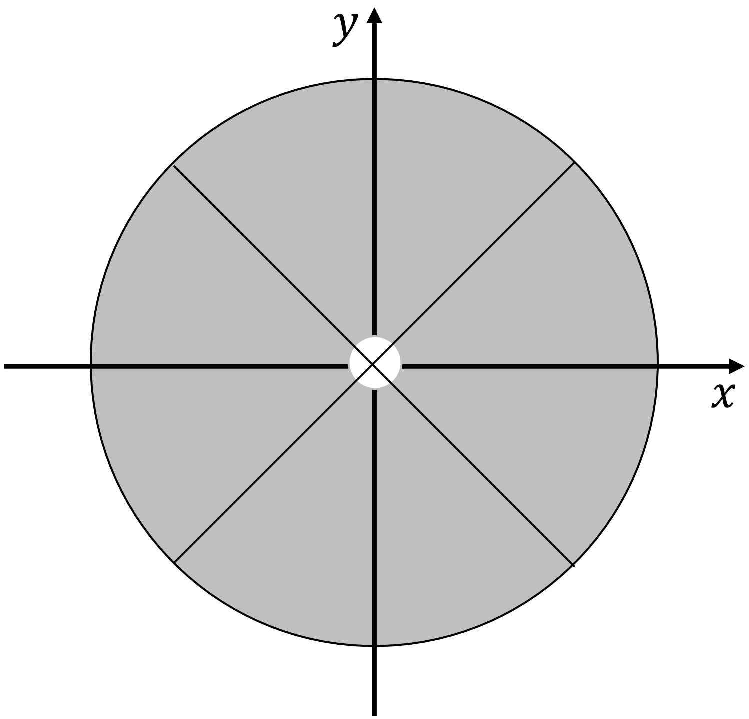
$\sqrt{s} = 27\ GeV$, 10^8 events

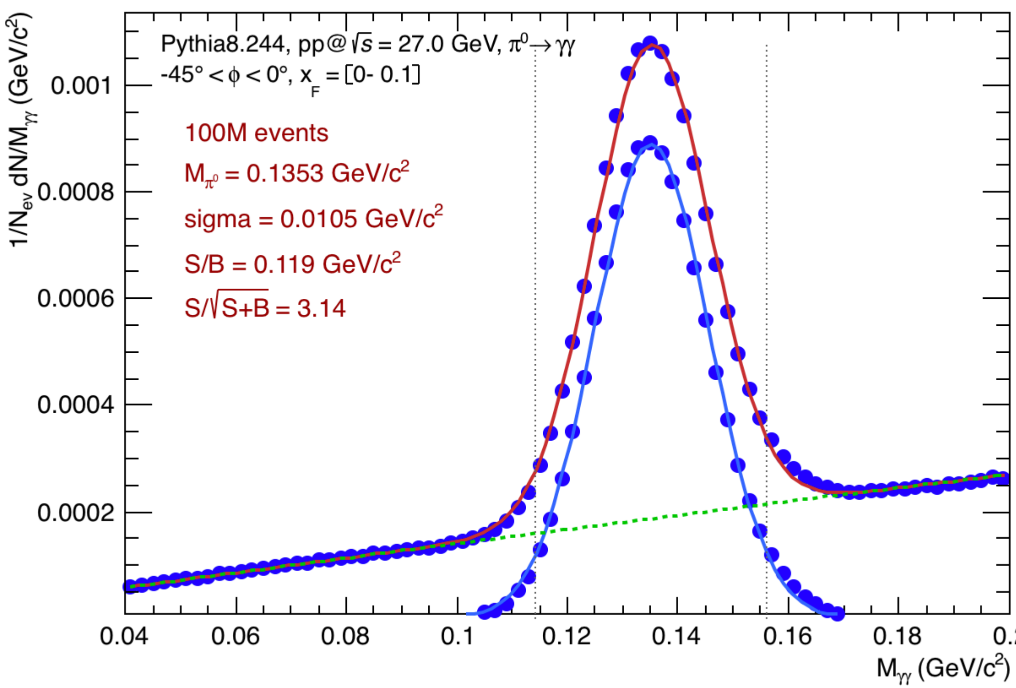
- Gaussian smearing on E_γ according to the ECal end-caps energy resolution:

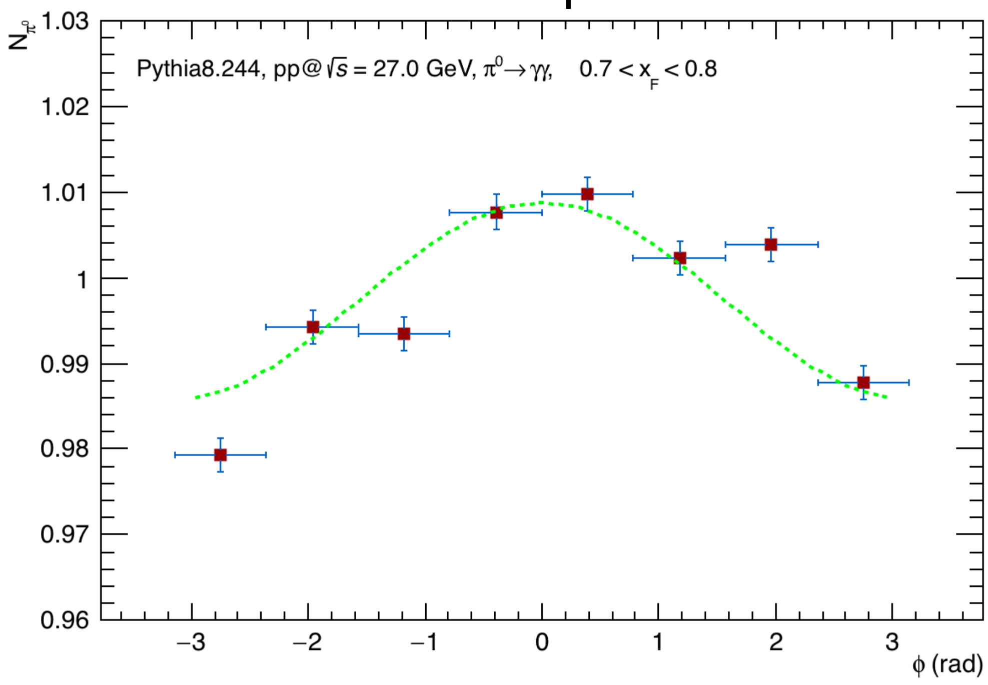
$$\frac{\sigma_E}{E} = \frac{6.58\%}{\sqrt{E}} \oplus \frac{1.97\%}{E}$$

- Uniform distribution to smear the vertex in $\Delta Z = \pm 30\ cm$
- Cut low energy photons: $E^{\gamma}_{min} = 400\ MeV$

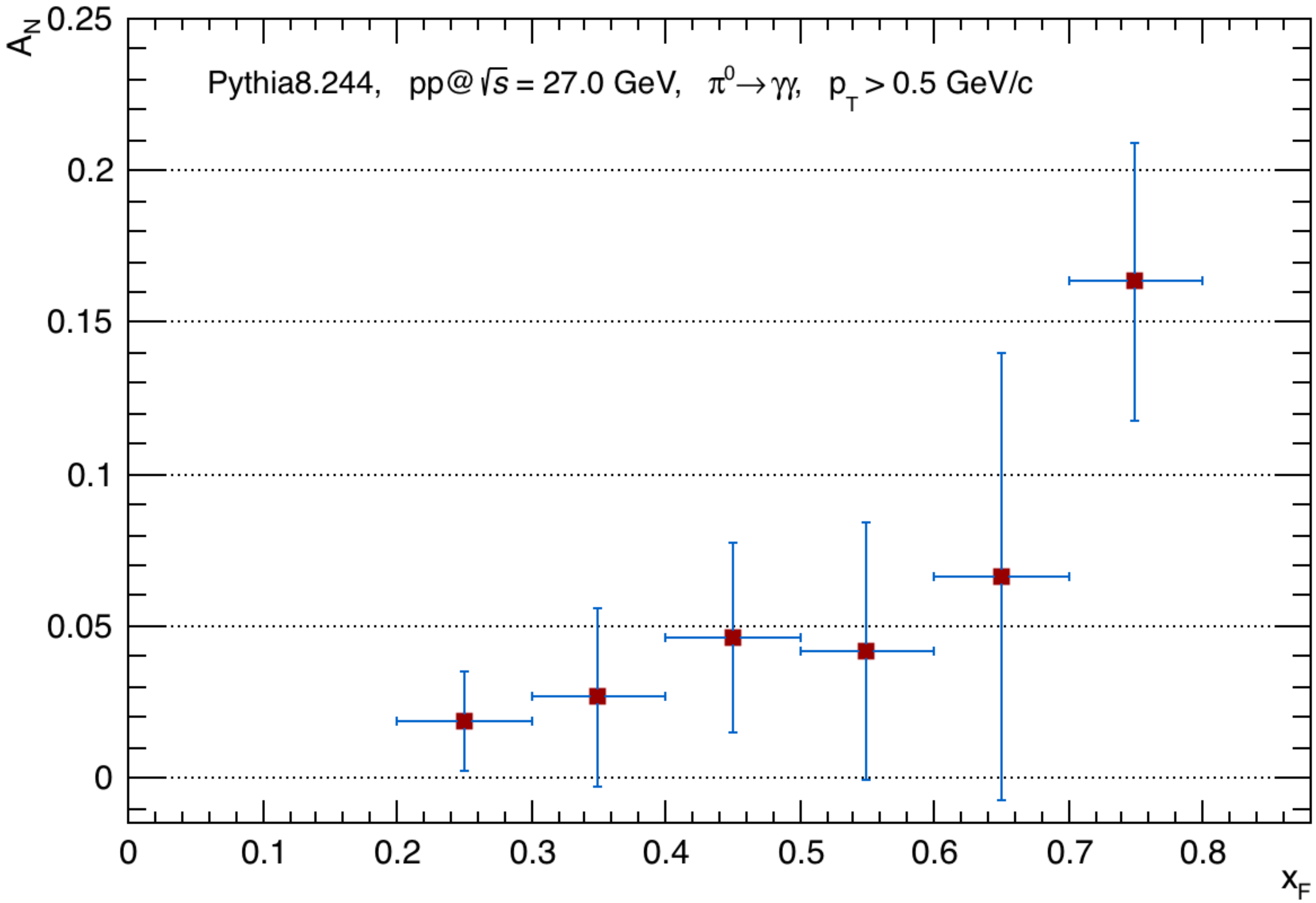
- 8 azimuthal bins.
- The spin dependent π^0 yields for each bin are extracted from the invariant mass spectra in different p_T and x_F sub-ranges for each ϕ bin.
- The invariant mass was fitted with a polynomial function for the background and a normalized Gaussian distribution representing the signal peak.
- *P* ~ 0.7 was assumed



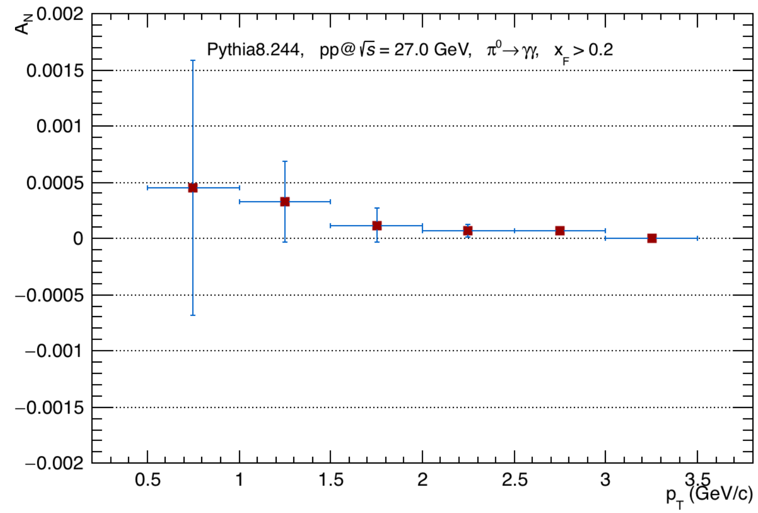




Transverse SSA (A_N)



$\langle x_F \rangle$	A_N	stat.
0.25	0.0188	0.0161
0.35	0.0267	0.0294
0.45	0.0458	0.0312
0.55	0.0417	0.0426
0.65	0.0660	0.0736
0.75	0.1636	0.0459
0.85	0.2241	0.1701



Summary

The transverse single spin asymmetry as function of x_{F} shows a clear rising non-zero asymmetry, going from 0 to ~20%

The $p^{\uparrow} + p \rightarrow \boldsymbol{\pi^0} + X$ inclusive reaction seems to be suitable for local polarimetry in SPD

The same study based on a cluster shape size is in progress taking into account the proposed ECal cell size.

TODO: the π^0reconstruction , using the geometry of ECal end-caps that should be implemented in SPDRoot.

BACKUP

Polarimetry (RHIC case)

External "**major**" polarimeters

pC-CNI Polarimeter

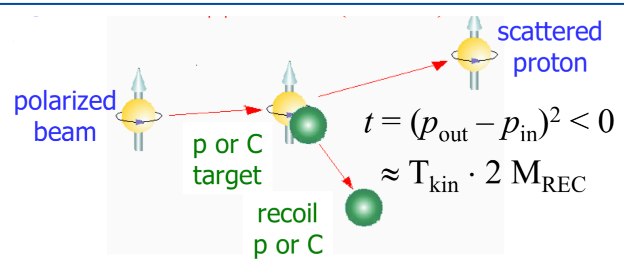
$$p^{\uparrow} + C \rightarrow p + C$$

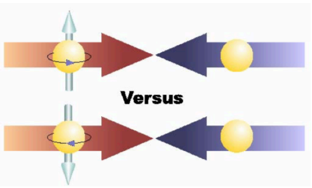
$$P_{beam} = \frac{\epsilon_{pC}}{A_N^{pC}} = \frac{1}{A_N^{pC}} \frac{N_L^C - N_R^C}{N_L^C + N_R^C}$$

Known from measurement and theory (A_N^{pC})

P_{beam}: beam polarization
$N_L (N_R)$: number of protons to the left (right) of the vertical beam polarization normalized to the luminosity

pC-CNI: - Relative polarization measurement.
- Fast and highly precise method.
- Needs to be normalized $\vec{H}$-Jet





H-Jet Polarimeter

$$p^{\uparrow} + p \rightarrow p + p$$

$$A_N^{target} = A_N^{beam}$$

$$A_N = \frac{\epsilon_{target}}{P_{target}} = \frac{\epsilon_{beam}}{P_{beam}}$$

Measures A_N for pC with the same beam (calibration)

$$P_{beam} = \frac{\epsilon_{target}}{\epsilon_{beam}} \cdot P_{target}$$

No prior knowledge of A_N is needed (self-calibrating)

H-Jet: - Independent and absolute method of polarization.
- Calibrates the pC polarimeter
- Slow