Local polarimetry with inclusive neutral pions in SPD at NICA

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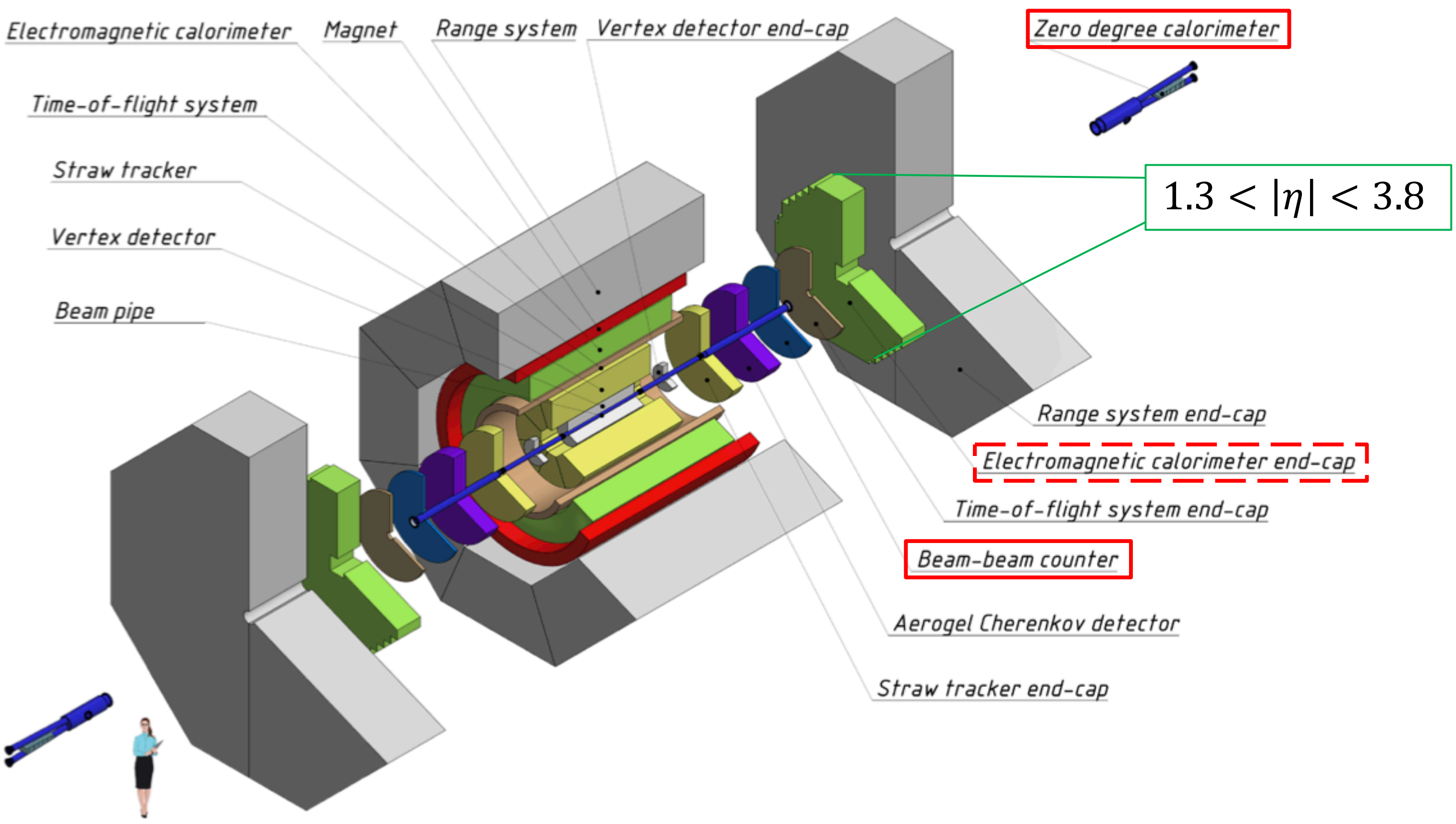
ISHEPP - 2023

Layout of SPD



Inclusive π^0 for local polarimetry

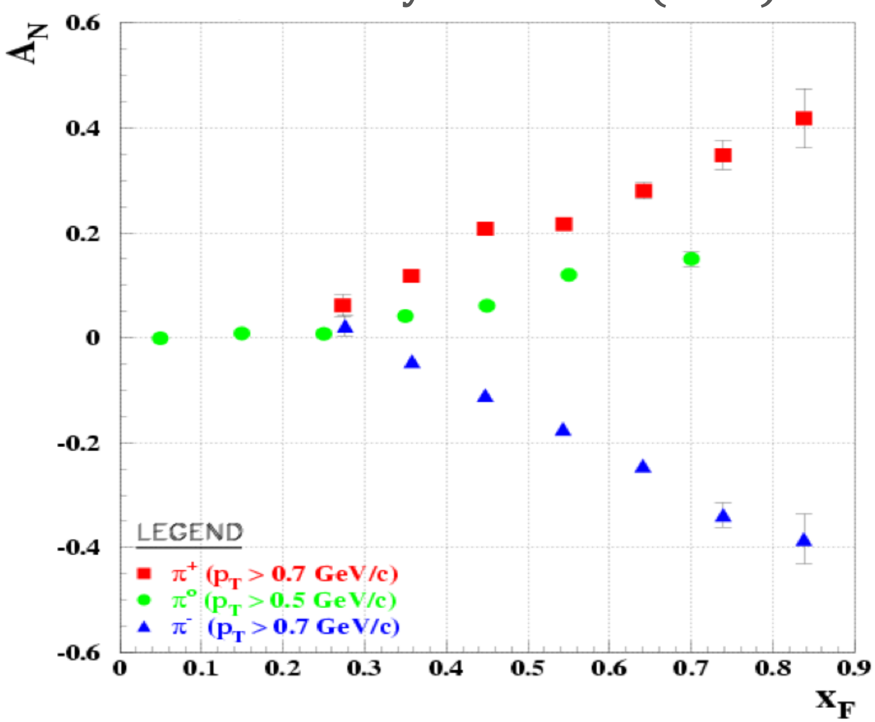
$$A_N = \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}}$$

A_N is a measure of the beam polarization

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

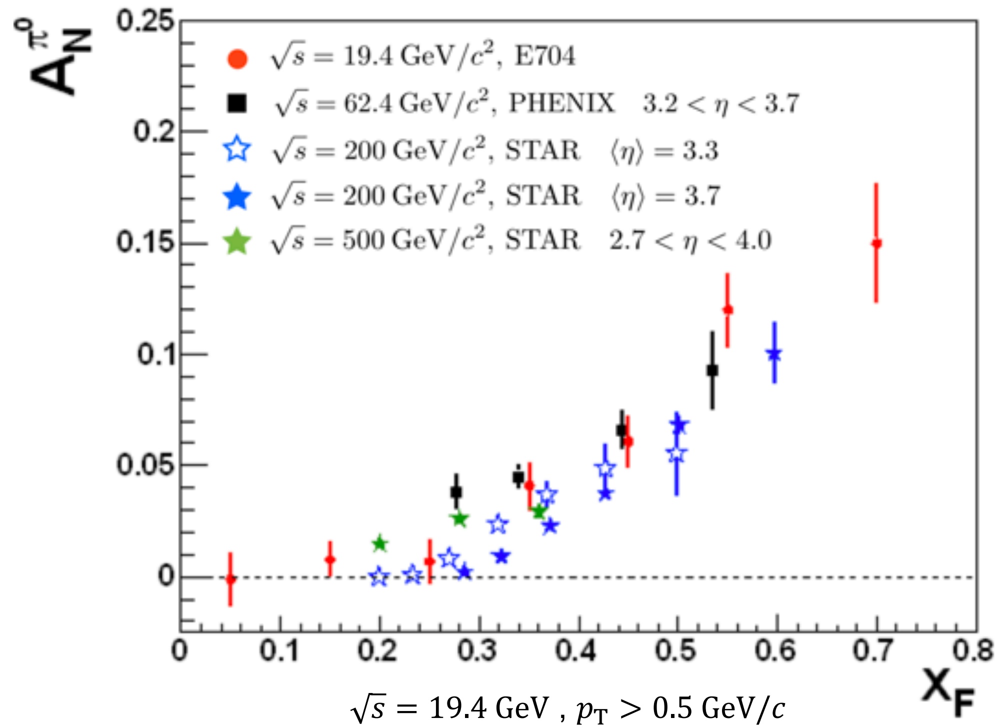
$$\sqrt{s} = 19.4 \text{ GeV } (p_{beam} = 200 \text{ GeV/c})$$

FNAL E704 Collaboration
Adams et al. Phys. Lett. B264(1991)462



$$p^{\uparrow} + p \rightarrow \pi^0 + X$$

A_N nearly independent of $\sqrt{s}$



$\sqrt{s} = 19.4$ GeV , $p_T > 0.5$ GeV/c

$\sqrt{s} = 62.4$ GeV , $p_T > 1.0$ GeV/c

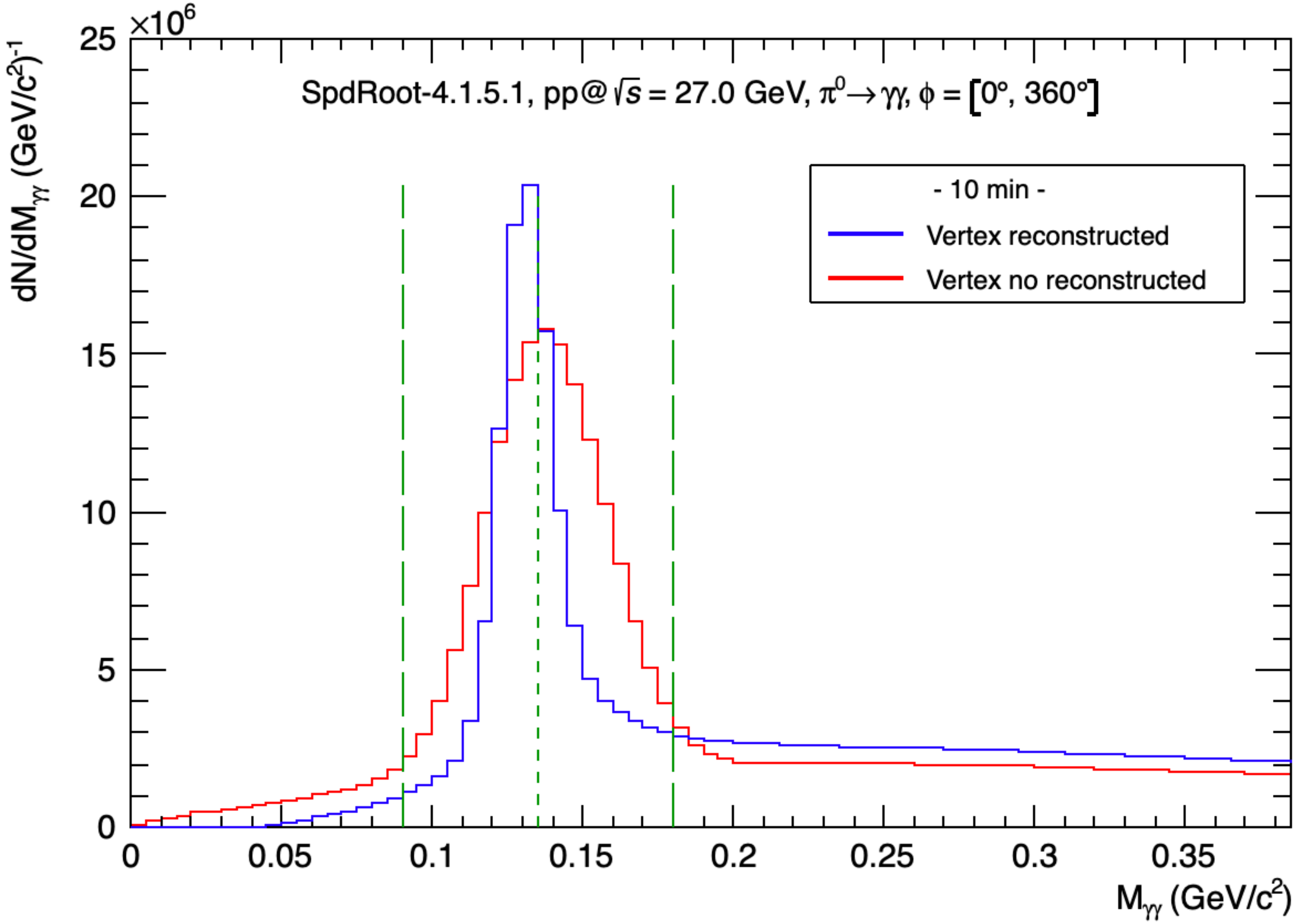
$\sqrt{s} = 200$ GeV , $p_T > 1.2$ GeV/c

$\sqrt{s} = 500$ GeV , $p_T > 2.0$ GeV/c

Simulation settings

$$p + p \rightarrow \pi^0 + X$$
$$\pi^0 \rightarrow \gamma\gamma$$

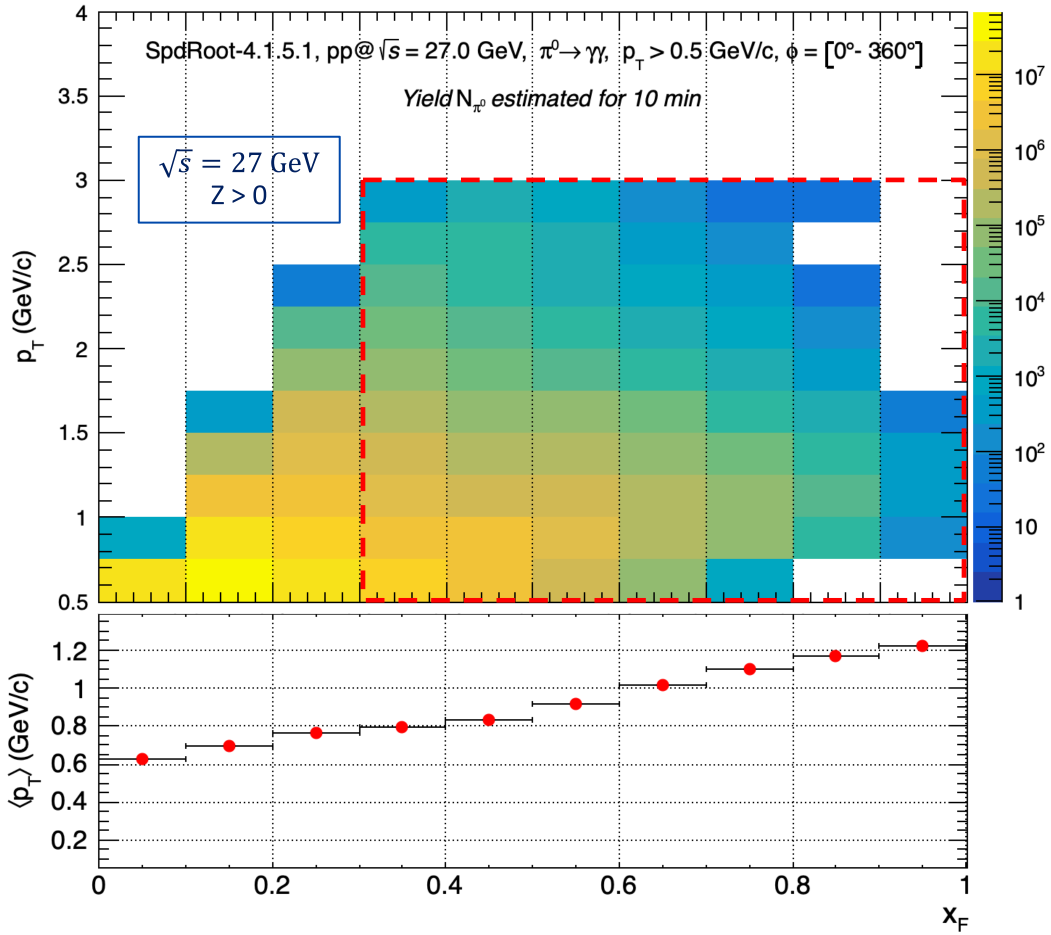
- SpdRoot version 4.1.5.1
- Two energies: pp @ $\sqrt{s} = 10$ GeV and pp @ $\sqrt{s} = 27$ GeV
- Particle generator: Pythia 8 (number of events: $\sim 100\text{M}$)
- Minimum Bias: *SoftQCD:inelastic* ↔ inelastic, non diffractive events and diffractive topologies
- **MC truth info!**
- Vertex assumed at (0, 0, 0) → Gaussian smeared: $\sigma_z = 30\ cm$ and $\sigma_{x,y} = 0.1\ cm$.
- Set of "ECAL particles" selected in each event and the initial energy per particle collected.
- Photon trajectory extrapolated to the ECAL endcap "planes".
- z position fixed, assuming $\text{ECALTECMinDist} = 188.6$ cm (x,y smeared)
- Energy of the MC-particle, smeared by $\frac{\sigma_E}{E} = 2\% \oplus \frac{5.5\%}{\sqrt{E}}$
- E^{γ}_{min}= 400 MeV
- π^0 selected from the M_{inv} of $\gamma\gamma$ pairs



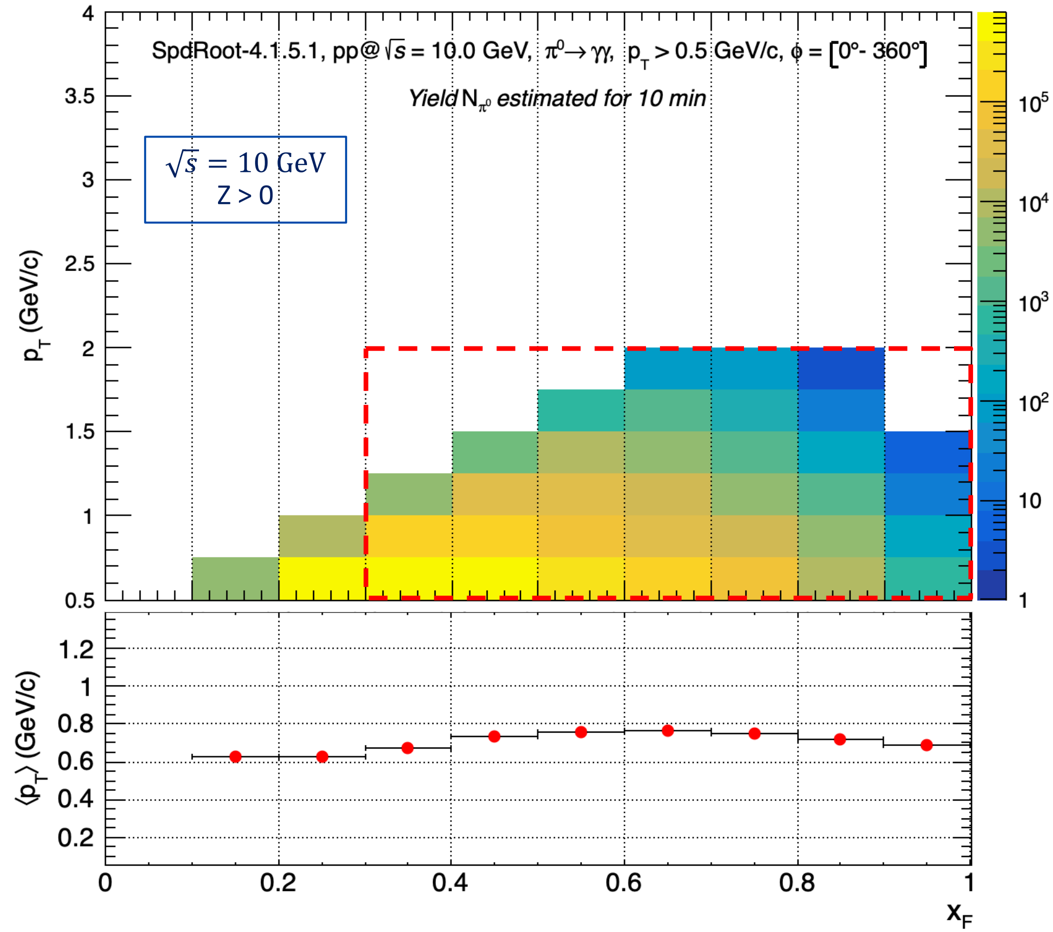
$Mass\ windows$: $\pm 45\ \mathrm{MeV}/c^2$

Kinematic topology

$pp\ @\ \sqrt{s} = 27$ GeV



$pp\ @\ \sqrt{s} = 10$ GeV



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

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

$$\frac{d\sigma}{d\varphi} = \frac{d\sigma}{d\varphi_0}[1 + \underbrace{P \cdot A_N \cdot \cos(\varphi + \varphi_0)}_{\text{Azimuthal cosine modulation}}]$$

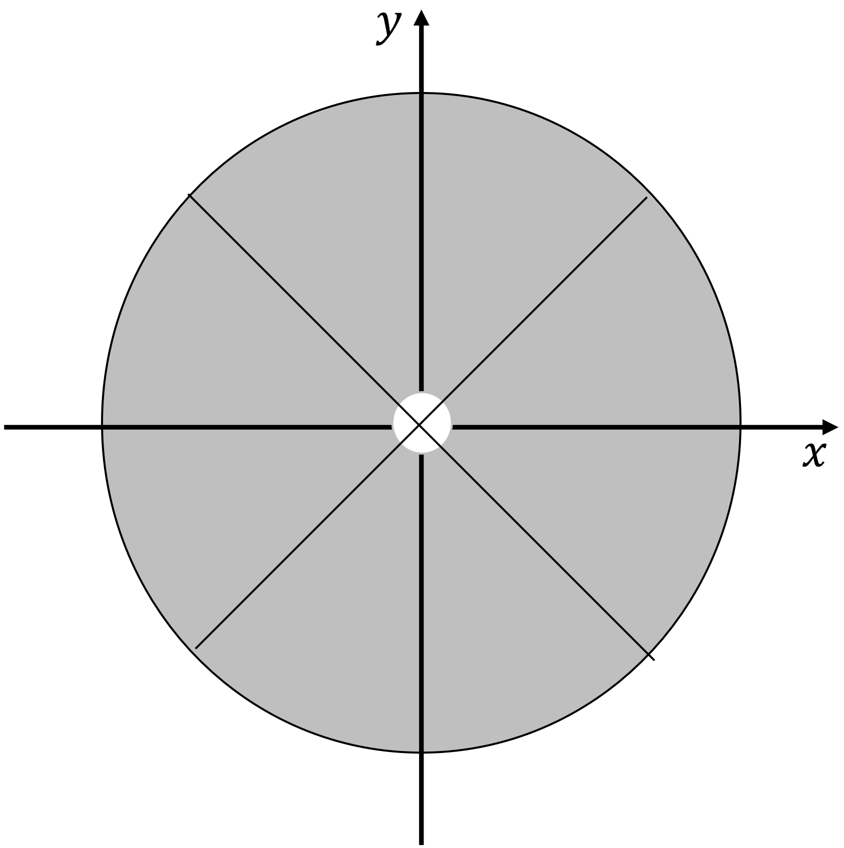
$$N_{\boldsymbol{\pi^0}}(\varphi) = A[1 + P \cdot A_N \cdot \cos(\varphi + \varphi_0)]$$

$$A_N = \frac{Amp}{P}$$

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

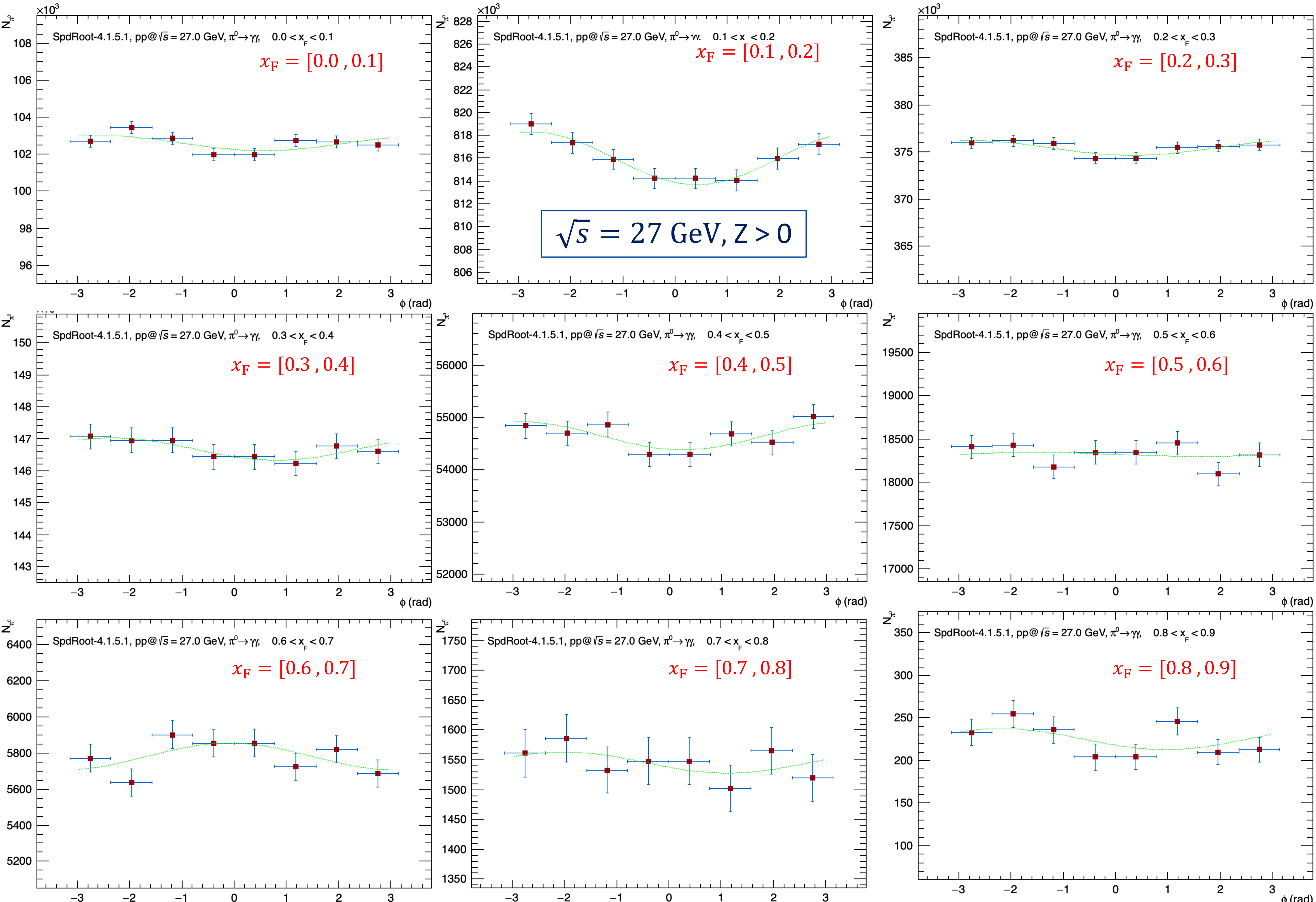
P: Beam polarization

- P = 0.7 was assumed



The spin dependent π^0 yields for each bin are extracted from the invariant mass spectra in different x_{F} sub-ranges for each φ bin.

Azimuthal cosine modulation of π^0 yields in x_F intervals, $[p0] \cdot (1 + [p1] \cdot \cos([p2] + x))$



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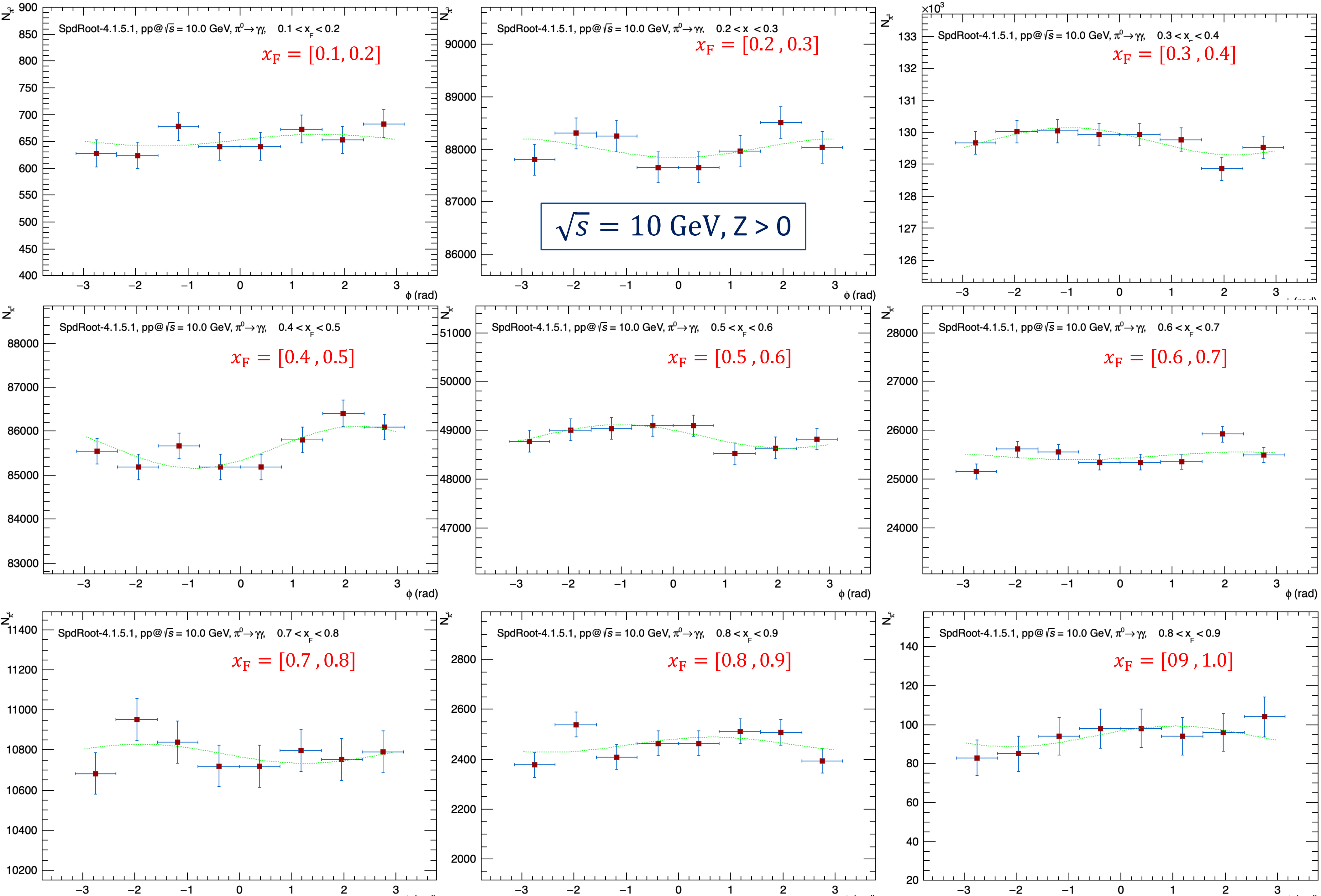
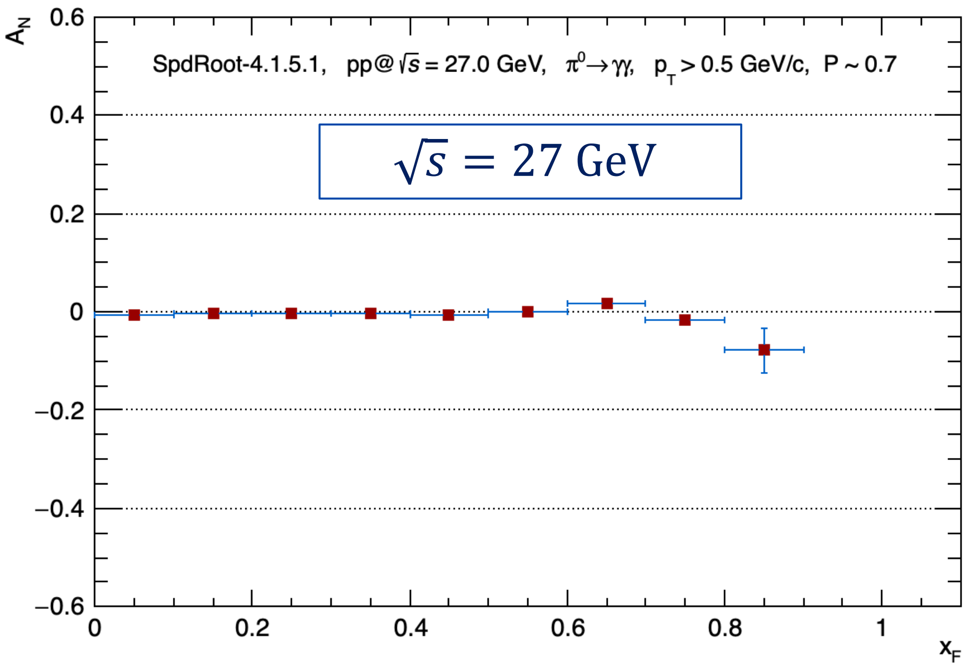
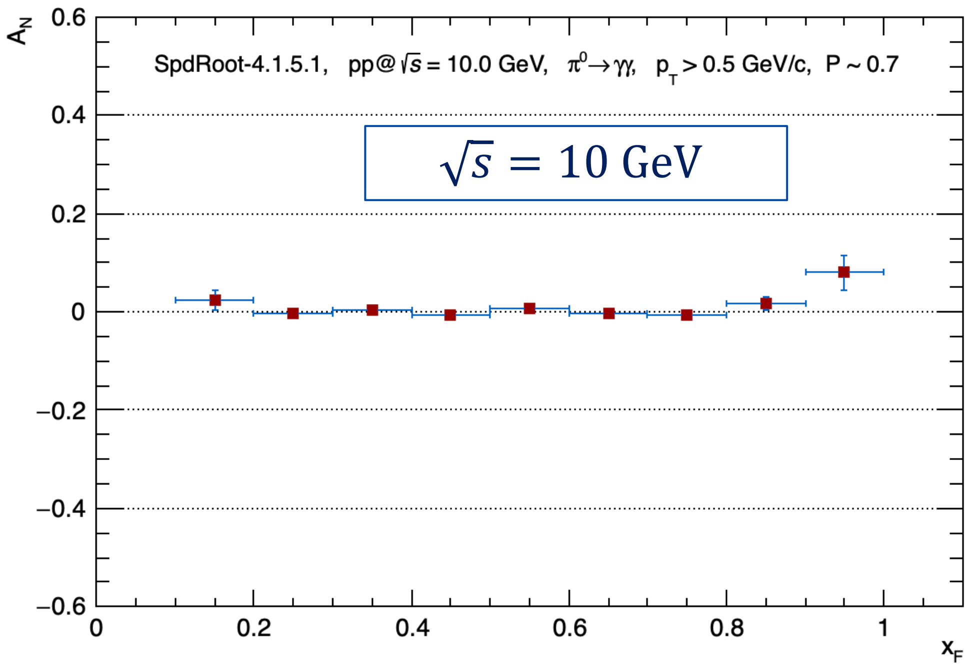


A_N vs. x_F


SpdRoot-4.1.5.1, pp@√s = 27.0 GeV, π⁰→γγ, p_T > 0.5 GeV/c, P ~ 0.7
√s = 27 GeV
A_N
x_F


SpdRoot-4.1.5.1, pp@√s = 10.0 GeV, π⁰→γγ, p_T > 0.5 GeV/c, P ~ 0.7
√s = 10 GeV
A_N
x_F

Relative error for A_N (pp @ $\sqrt{s} = 10$ GeV, pp @ $\sqrt{s} = 27$ GeV)

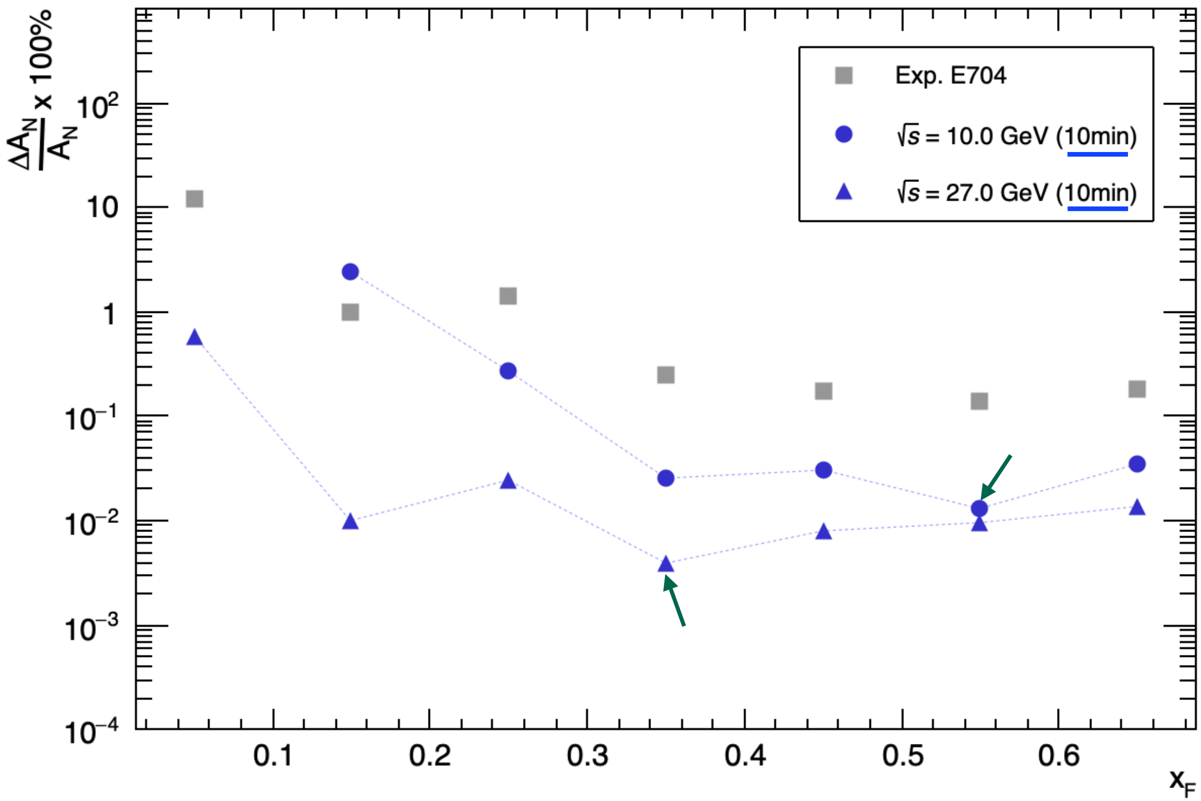
$\frac{\Delta A_N}{A_N}$ *vs.* x_F

$\frac{\Delta A_N}{A_N}$ → SpdRoot (ΔA_N), E704 (A_N)

$\frac{\Delta A_N}{A_N} \sim \frac{\Delta P}{P}$

$\sigma_{tot}^{pp}(27\text{ GeV}) = 40.0$ mb $\quad \mathcal{L} = 10^{32} s^{-1} cm^{-2} \quad$ Reaction rate (27 GeV) = $4 \cdot 10^6 s^{-1}$

$\sigma_{tot}^{pp}(10\text{ GeV}) = 37.9$ mb $\quad \mathcal{L} = 10^{31} s^{-1} cm^{-2} \quad$ Reaction rate (10 GeV) = $3.79 \cdot 10^5 s^{-1}$



Better precision of the polarization measurement expected at:

$0.3 < x_F < 0.4$ ($\sqrt{s} = 27$ GeV)

$0.5 < x_F < 0.6$ ($\sqrt{s} = 10$ GeV)

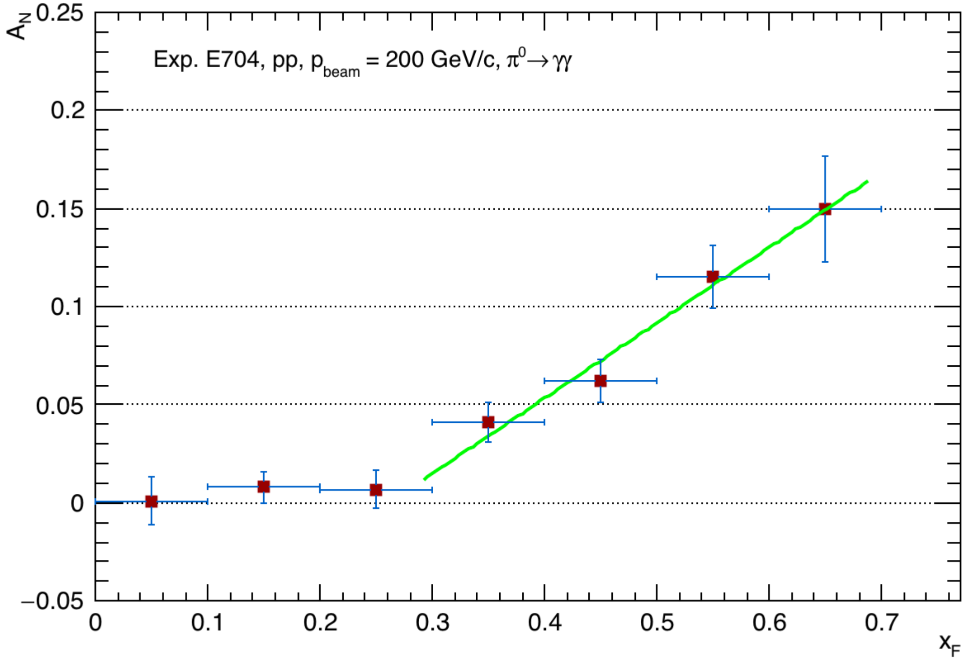
Raw asymmetry:

$$P \cdot A_N \cdot \cos\phi = \epsilon(\phi) \Leftrightarrow \epsilon(\phi) = \frac{N^{\uparrow}(\phi) - N^{\downarrow}(\phi)}{N^{\uparrow}(\phi) + N^{\downarrow}(\phi)}$$

$$P \cdot A_N \sim \epsilon$$

$$\frac{\Delta A_N}{A_N} \sim \frac{\Delta P}{P}$$

$$\frac{\Delta P}{P} = \frac{1}{\sqrt{\sum_i \left(\frac{A_{N_i}}{\Delta A_{N_i}}\right)^2}}$$

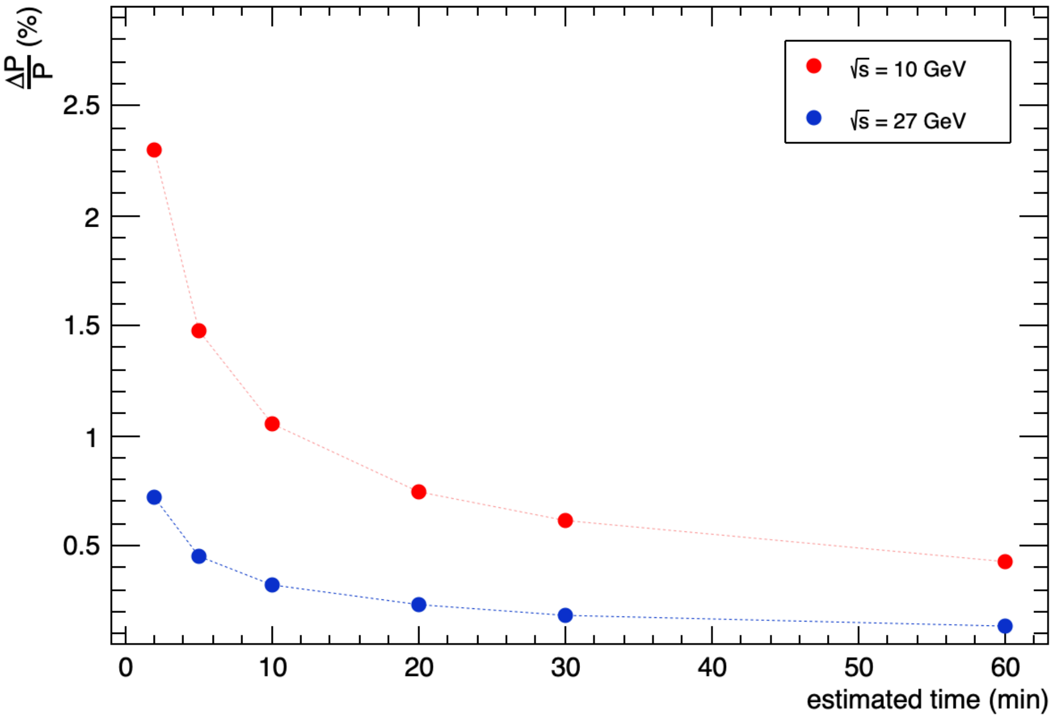


Taking the last experimental 4 points ($0.3 \leq x_F < 0.7$): $\frac{\Delta P}{P} = 0.0873$ ~9% (Experiment E704)

*The error of the beam polarization in the experiment **E704** is estimated in **10%**, as reported in FERMILAB-Pub-91/15-E[E581,E704]*

Estimation of the statistical accuracy of the beam polarization measurement, with $pp \to \pi^0 X$ at $\sqrt{s} = 10$ GeV and $\sqrt{s} = 27$ GeV, in SPD ECAL endcaps.

Estimated time	$\frac{\Delta P}{P}$	
	$\sqrt{s}$ = 10 GeV	$\sqrt{s}$ = 27 GeV
2 min	2.30 %	0.72 %
5 min	1.48 %	0.45 %
10 min	1.05 %	0.32 %
20 min	0.74 %	0.23 %
30 min	0.61 %	0.18 %
1 h	0.43 %	0.13 %



- The accuracy of the beam polarization have been estimated at two different pp collision energies: 10 GeV and 27 GeV

- The determination of the polarization is expected to be more precise in the range $0.3 < x_F < 0.4$ ($\sqrt{s} = 27$ GeV) and $0.5 < x_F < 0.6$ ($\sqrt{s} = 10$ GeV).

- From the asymmetry determination, based on MC truth simulations with SpdRoot, the statistical accuracy of the beam polarization, for 10 minutes, is estimated in: 1.05 % at 10 GeV and 0.32 % at 27 GeV.

- The inclusive $pp \rightarrow \pi^0 X$ reaction, detected in the ECAL Endcaps, is proposed to participate in the local polarimetry at SPD, by measuring and monitoring the transverse single spin asymmetry.

- Main difficulty: the few availability of accurate experimental data in the energy range of interest for SPD.