# Inclusive $\pi^0$ production for online polarimetry in SPD

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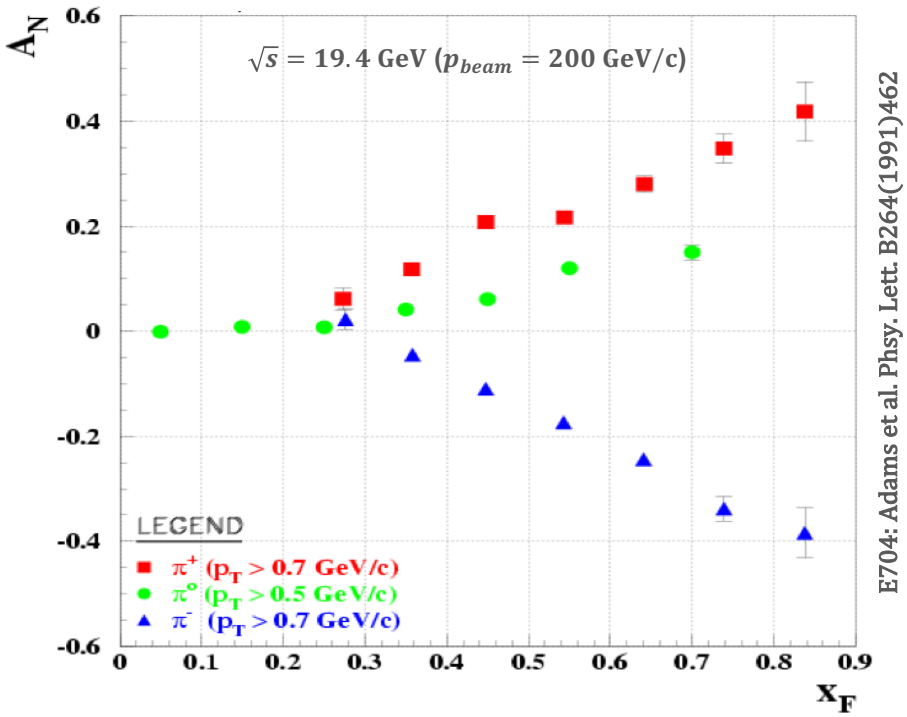
# Inclusive $\pi^0$ for local polarimetry

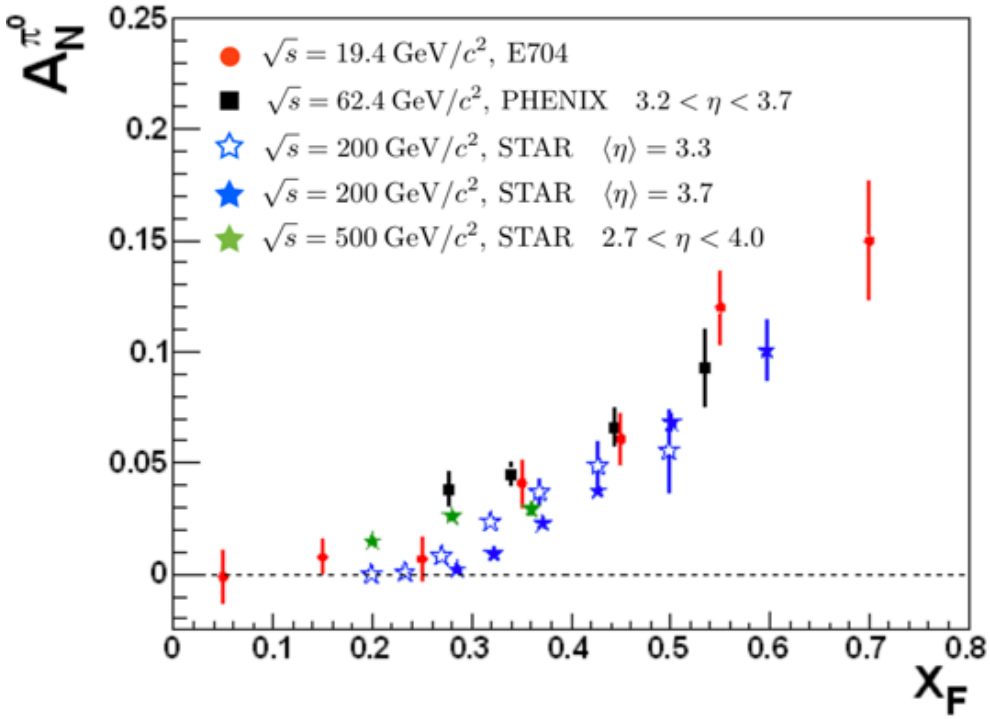
$$A_N = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$

$A_N$ is a measure of the beam polarization

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




$A_N$ nearly independent of $\sqrt{s}$

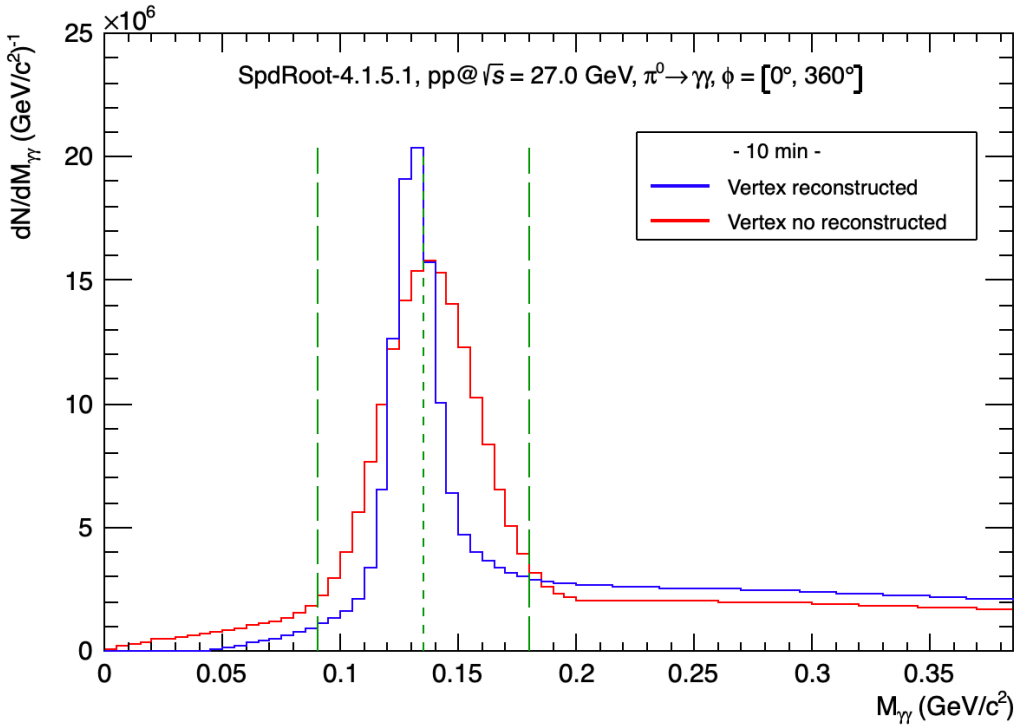


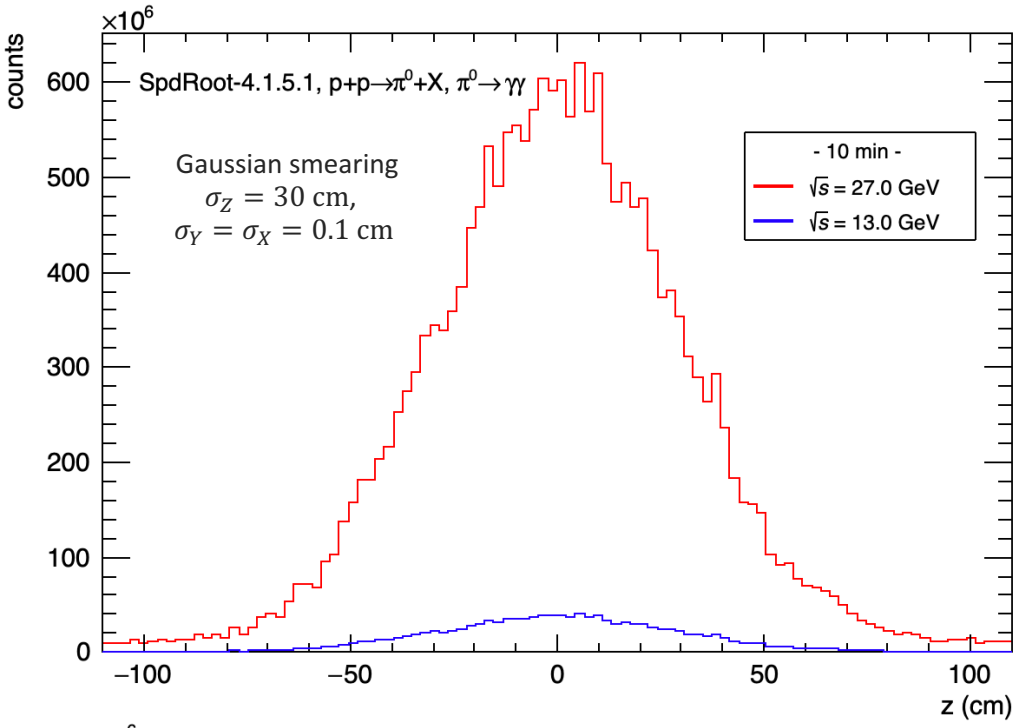
# Simulation settings

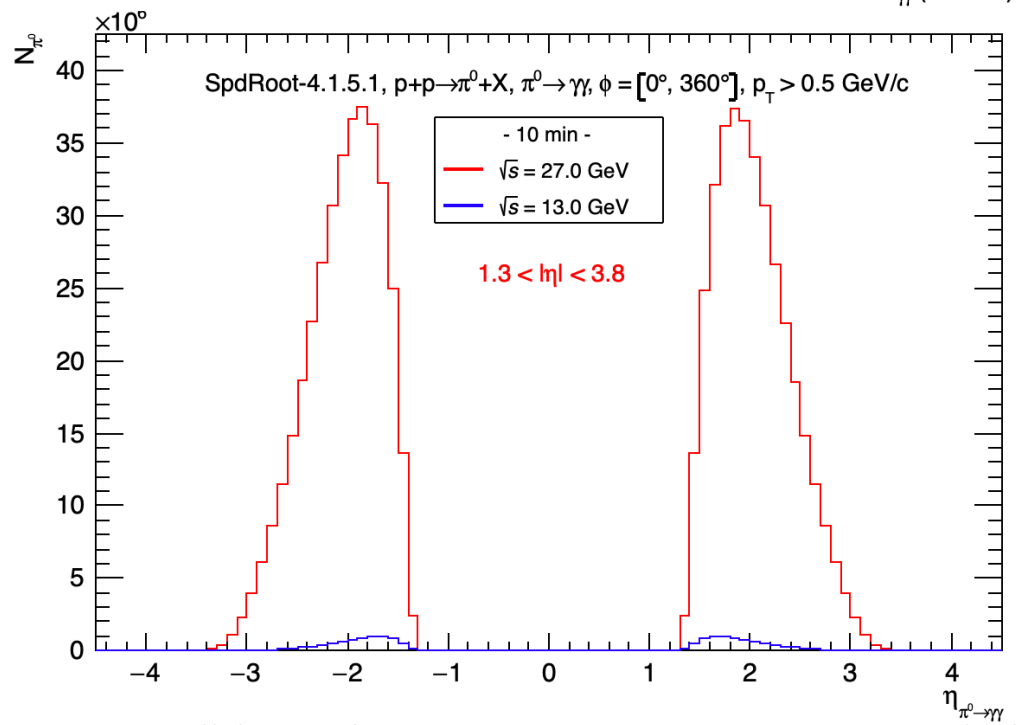
$$p + p \rightarrow \pi^0 + X$$
$$\pi^0 \rightarrow \gamma\gamma$$

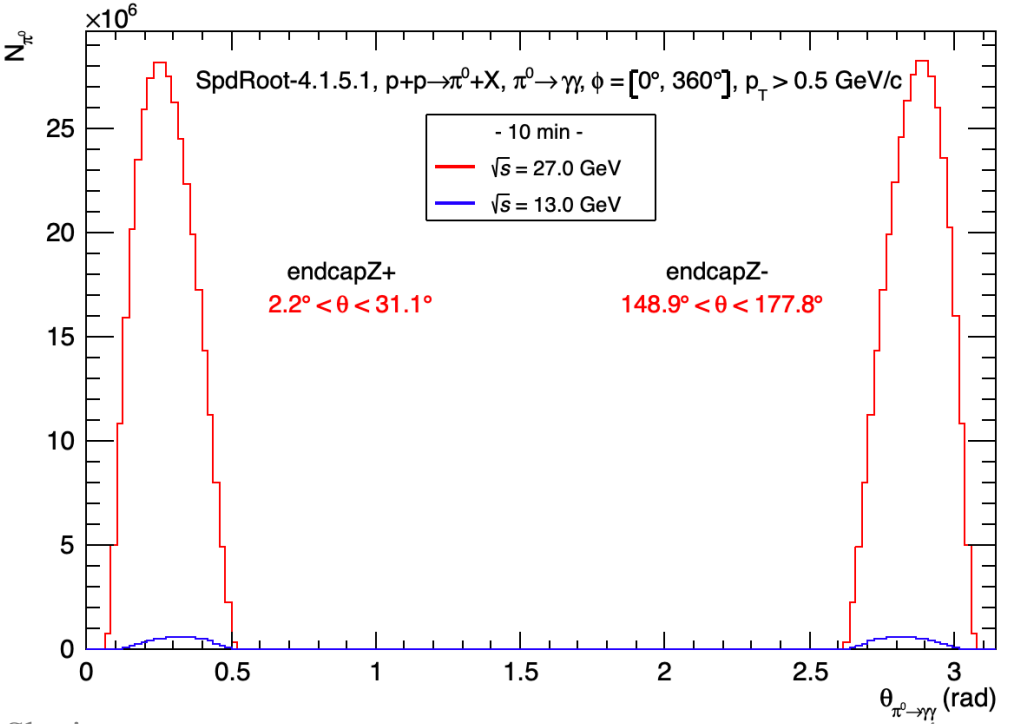
- SpdRoot version 4.1.5.1
- Two energies: $pp$ @ $\sqrt{s} = 13$ GeV and $pp$ @ $\sqrt{s} = 27$ GeV
- Particle generator: Pythia 8 (number of events: $\sim$100M) ← using DIRAC platform
- Minimum Bias: *SoftQCD:inelastic* ↔ inelastic, non diffractive events and diffractive topologies
- **MC truth info!**
- Vertex assumed at (0, 0, 0) → Gaussian smeared: $\sigma_z = 30\ cm$ and $\sigma_{x,y} = 0.1\ cm$.
- Photon trajectory extrapolated to the ECAL endcap "planes".
- $z$ position fixed, assuming $\mathrm{ECALTECMinDist} = 188.6$ cm
- Energy of the MC-particle, smeared by $\frac{\sigma_E}{E} = 2\% \oplus \frac{5.5\%}{\sqrt{E}}$
- $E^{\gamma}_{min}$ = 400 MeV
- $\pi^0$ selected from the $M_{\mathrm{inv}}$ of $\gamma\gamma$ pairs

# General characteristics



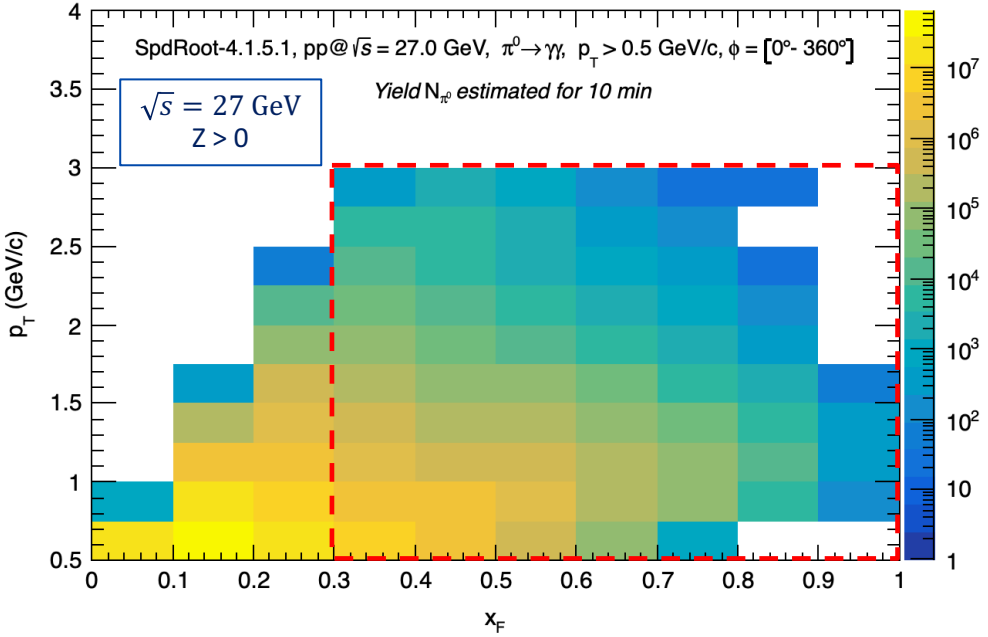



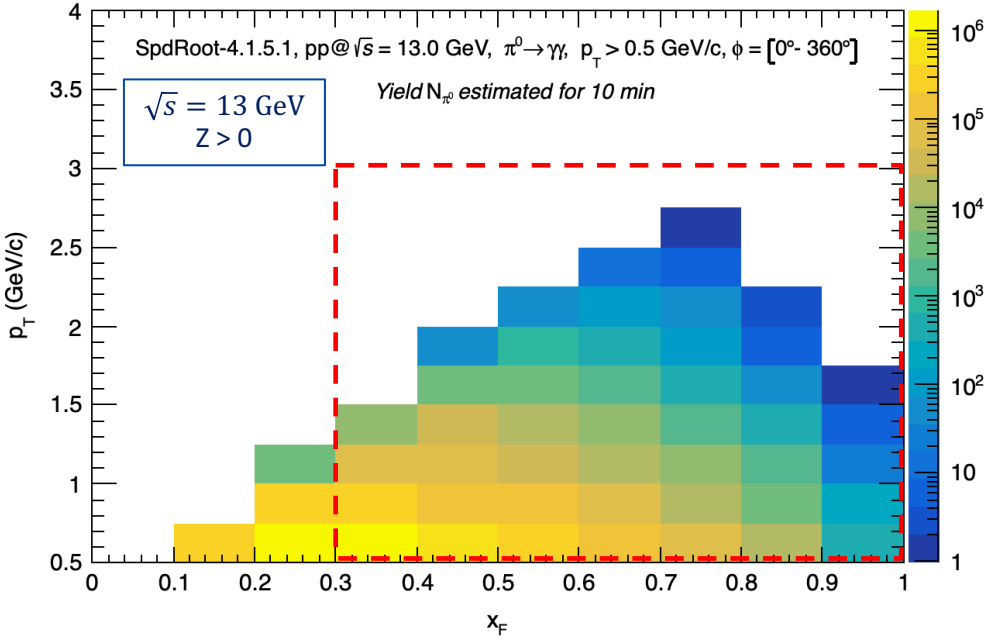



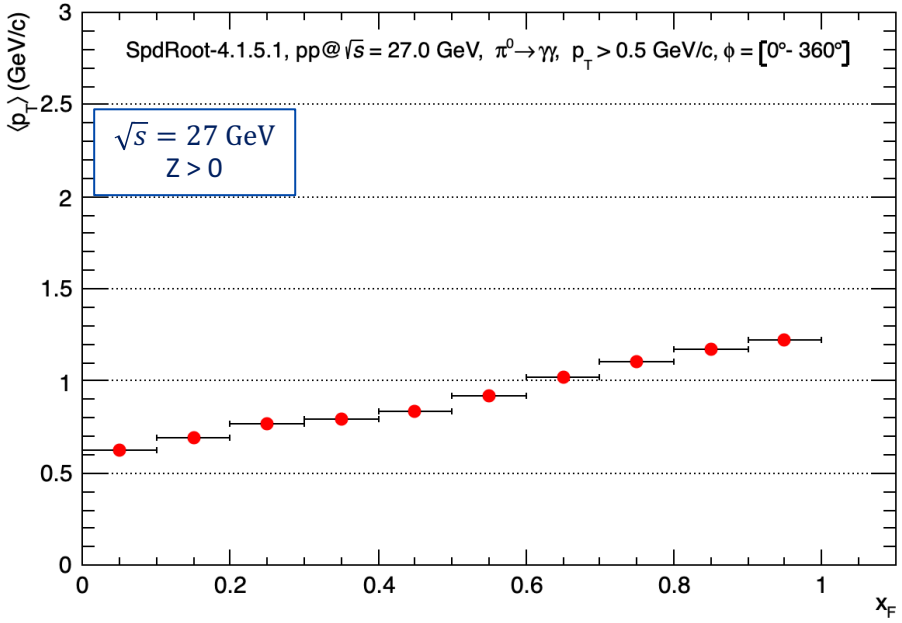
# General characteristics

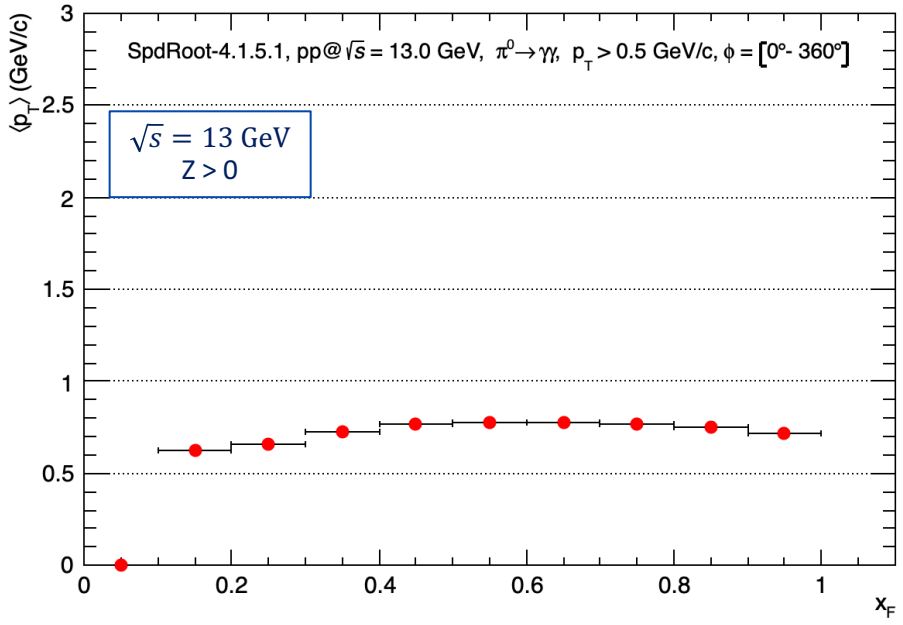
$pp$ @ $\sqrt{s} = 27$ GeV




$pp$ @ $\sqrt{s} = 13$ GeV



# Extraction of $A_N$

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

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

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

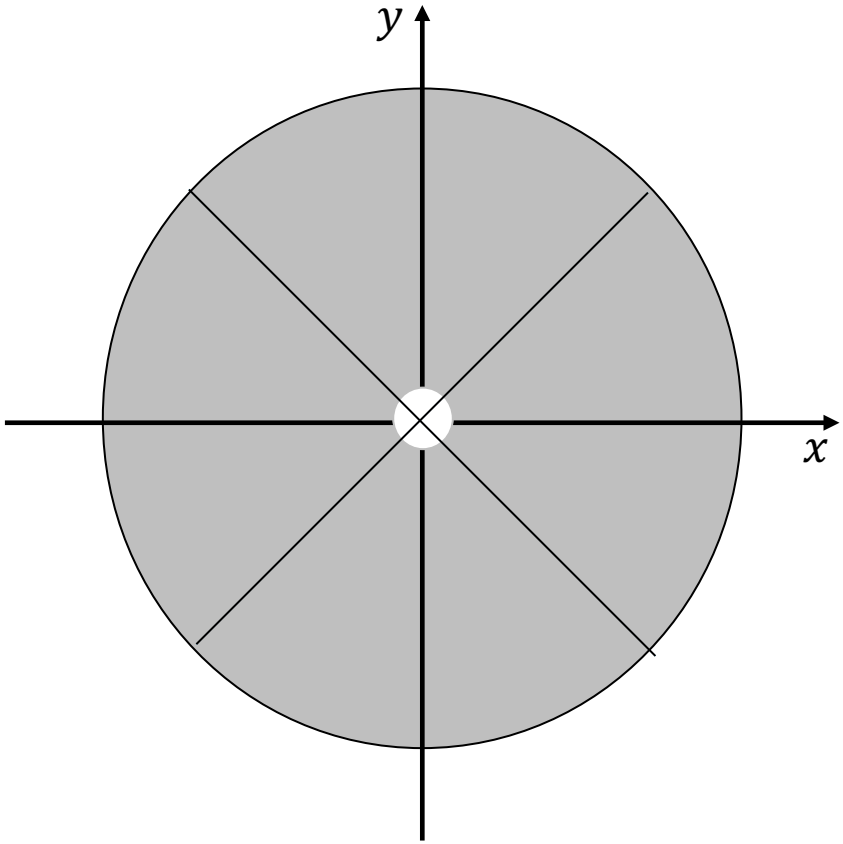
$$N_{\boldsymbol{\pi^0}}(\varphi) = A[1 + P \cdot A_N \cdot \cos(\varphi + \varphi_0)]$$

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

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

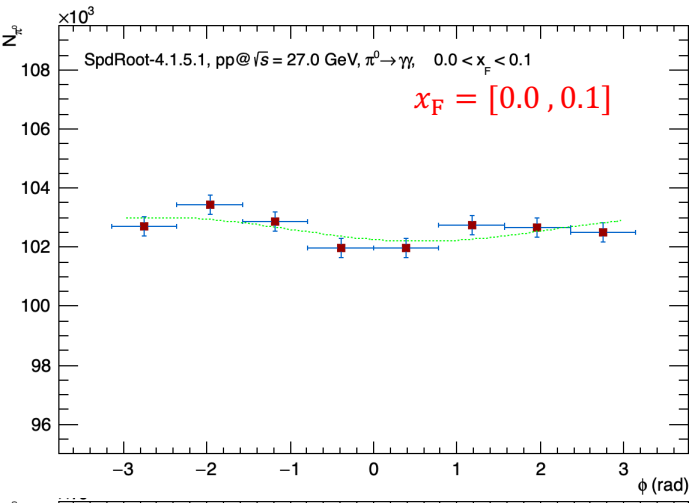
$P$: Beam polarization

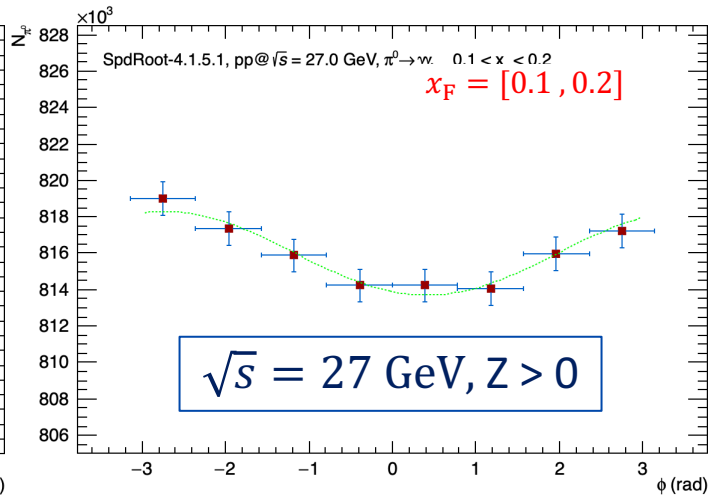
- $P$ = 0.7 was assumed



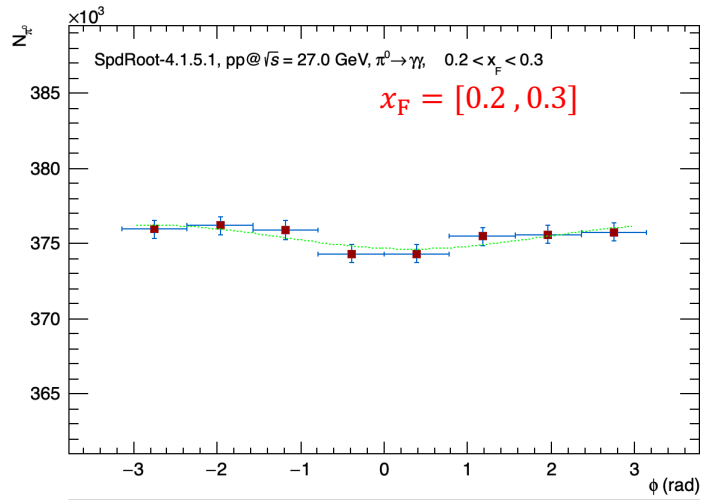

The spin dependent $\pi^0$ yields for each bin are extracted from the invariant mass spectra in different $x_F$ sub-ranges for each $\varphi$ bin.

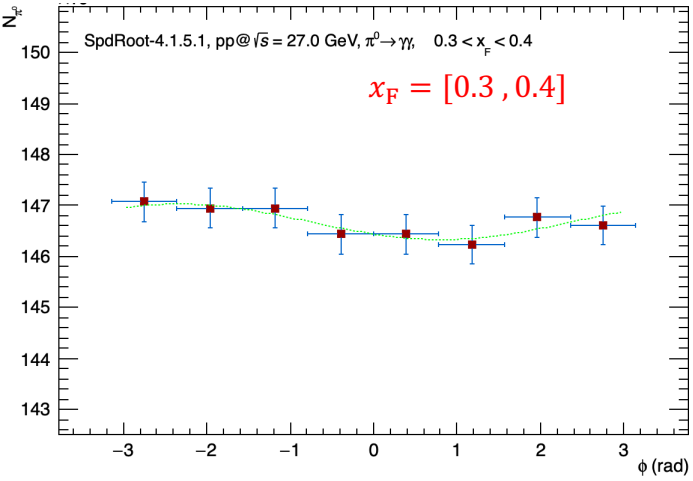
# Azimuthal cosine modulation of $\pi^0$ yields in $x_F$ intervals, $[p0] \cdot (1 + [p1] \cdot \cos([p2] + x))$

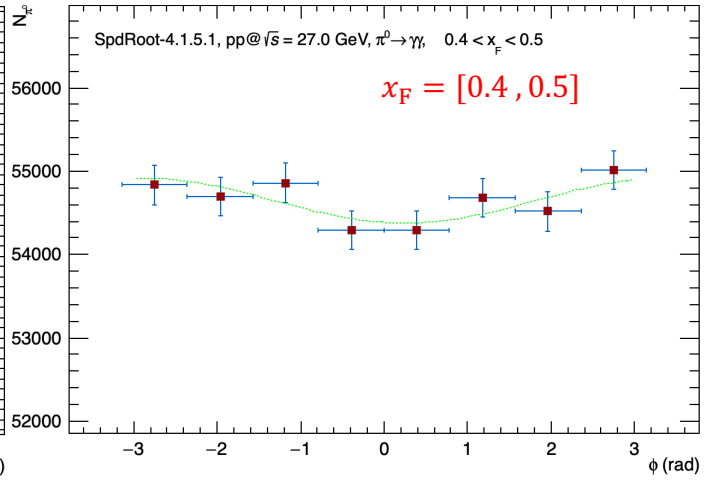


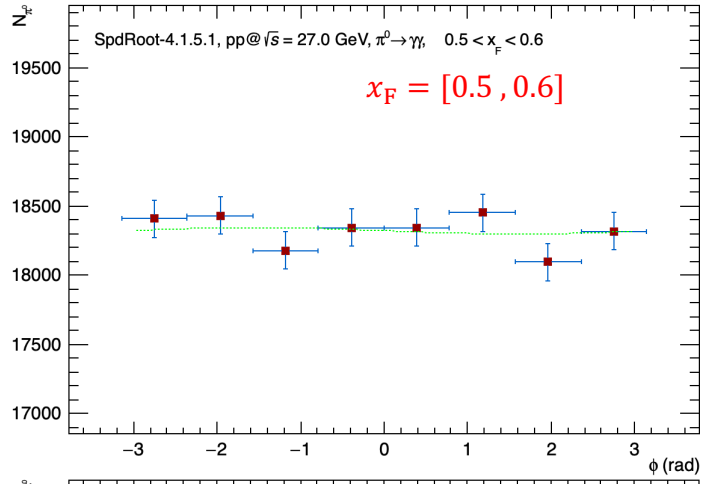



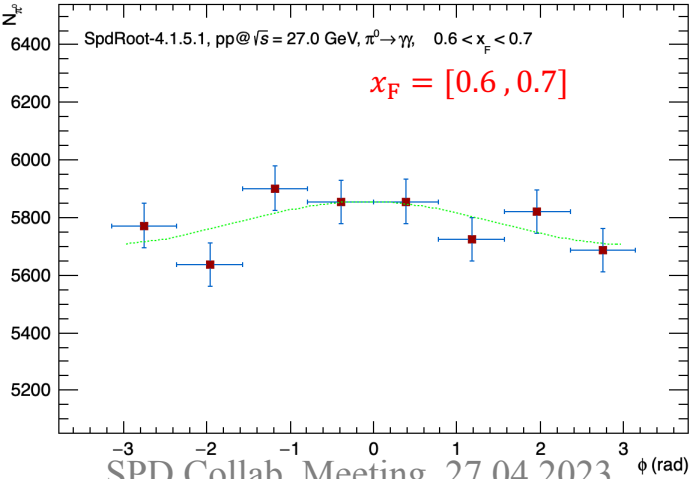

$\sqrt{s} = 27$ GeV, Z > 0

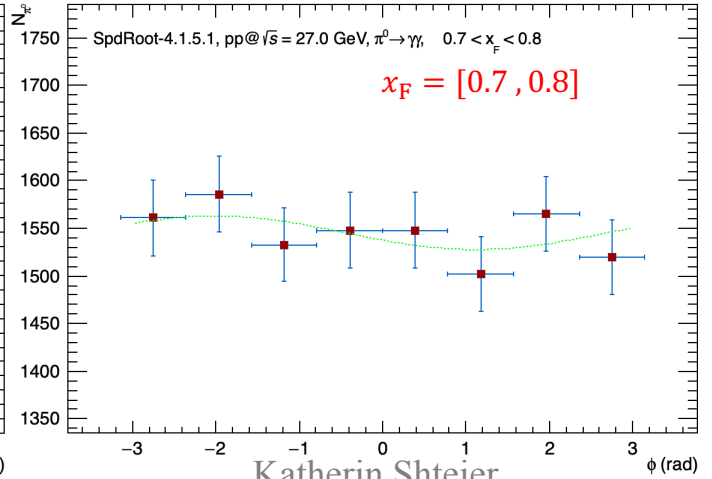


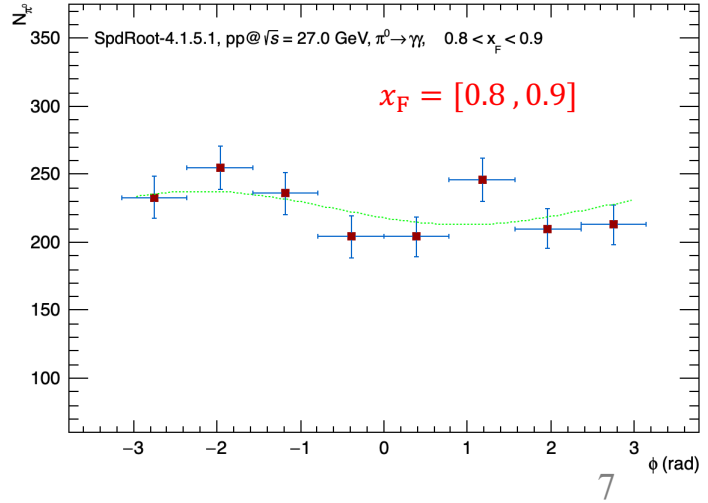



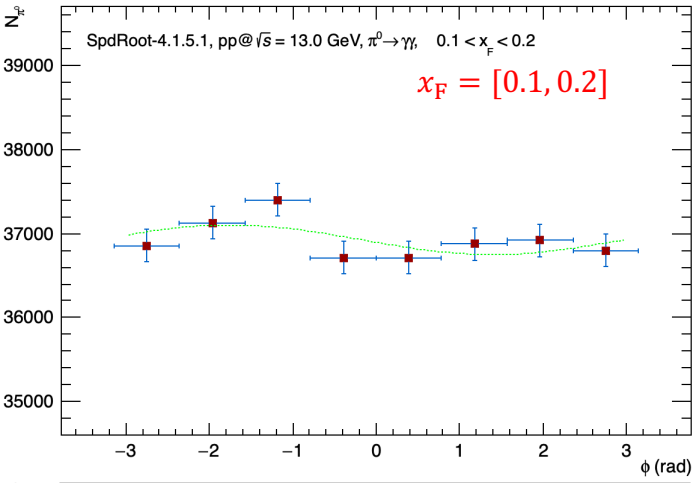



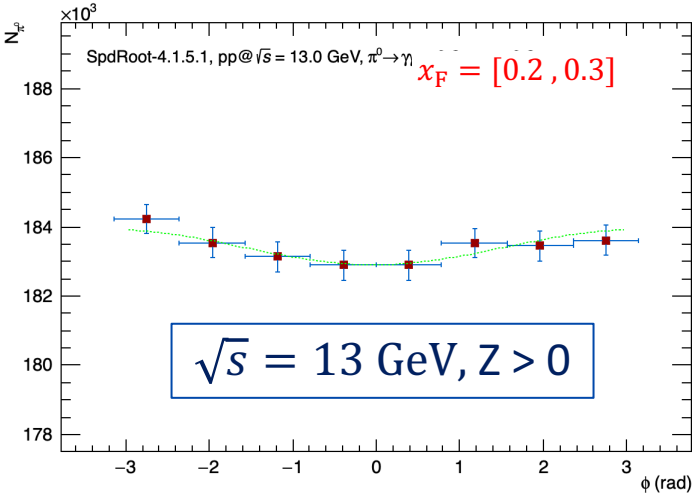



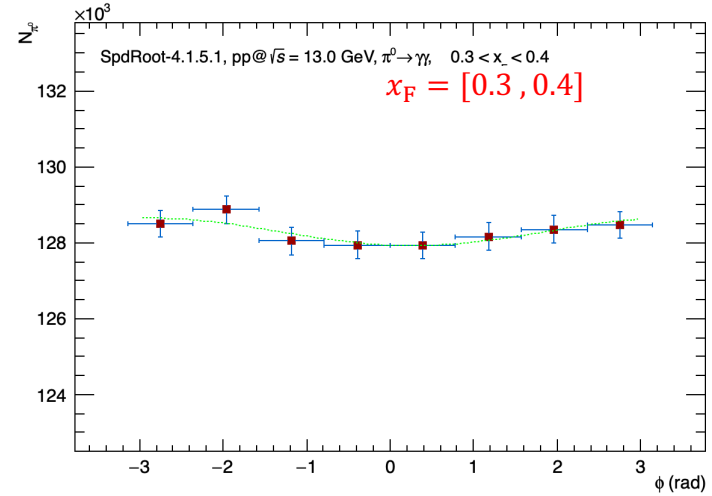



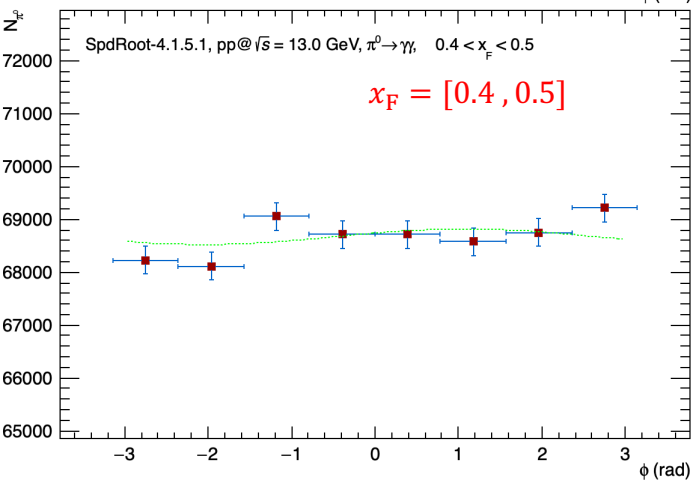
# Azimuthal cosine modulation of $\pi^0$ yields in $x_F$ intervals, $[p0] \cdot (1 + [p1] \cdot \cos([p2] + x))$

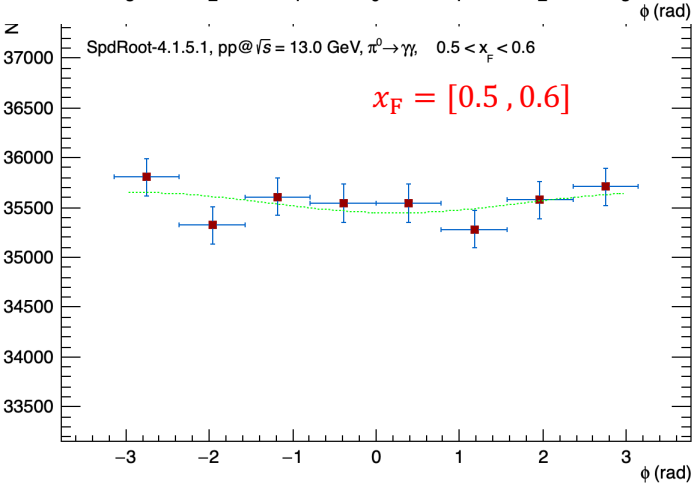


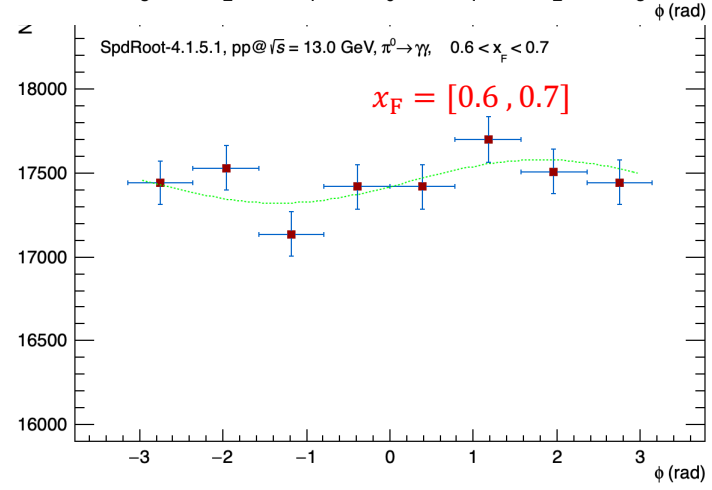



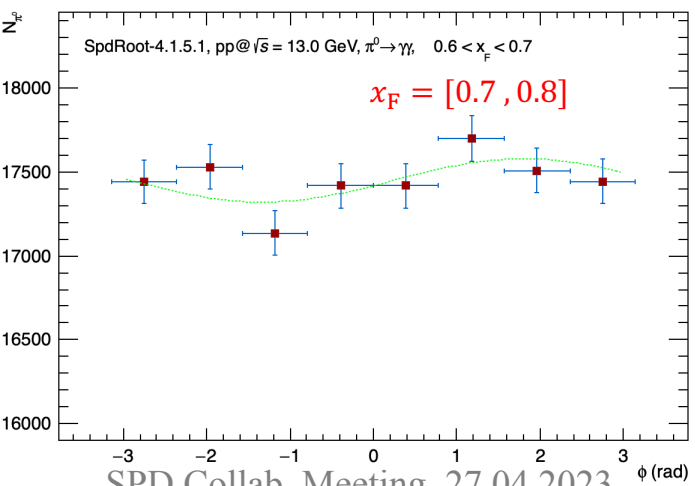

$\sqrt{s} = 13$ GeV, Z > 0

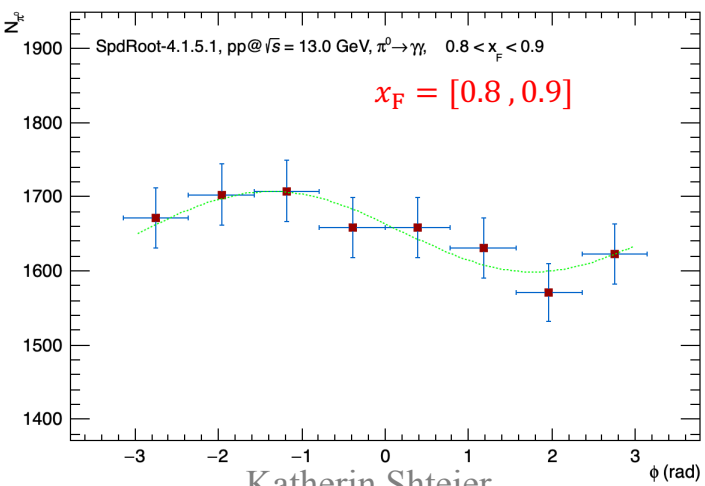


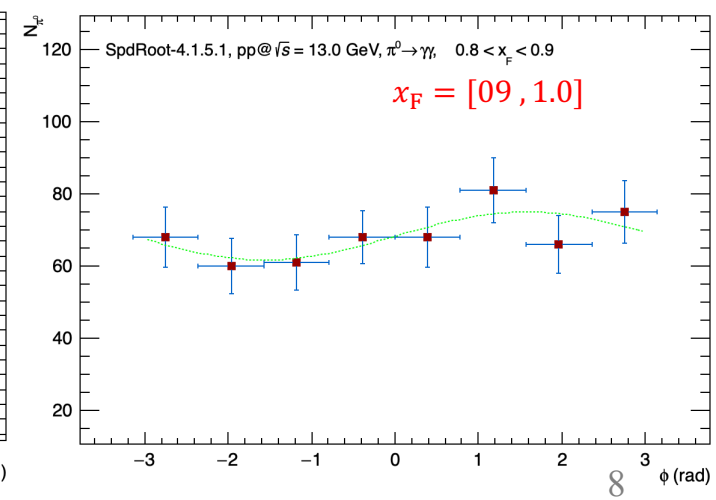



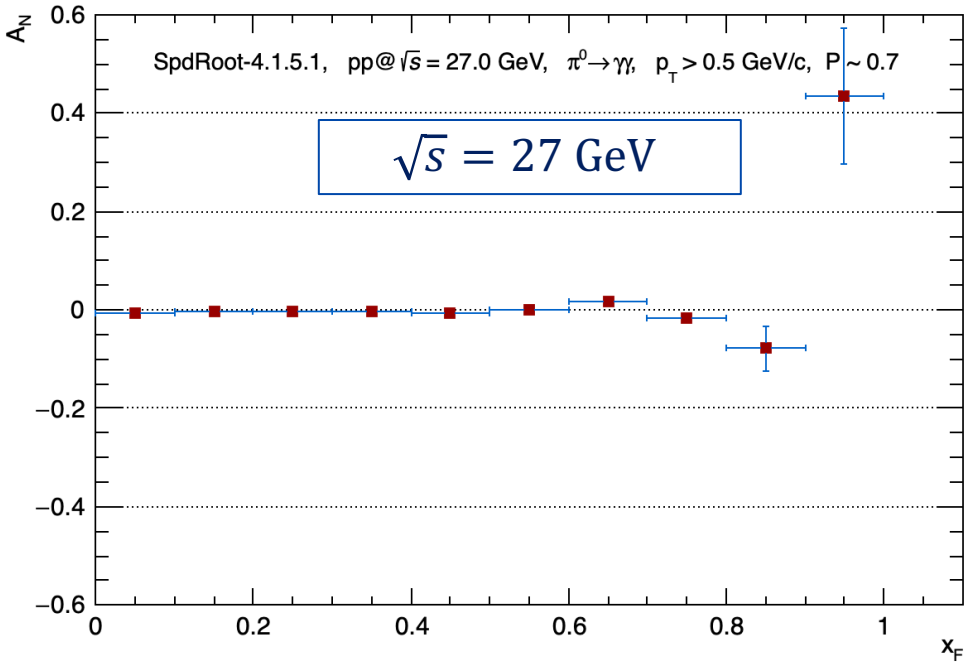



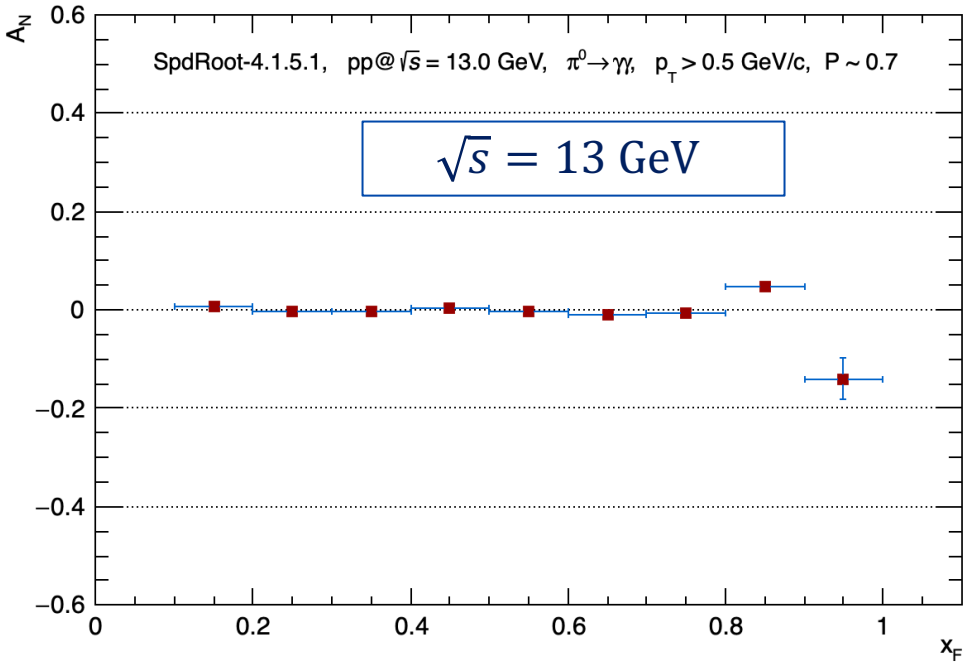



## $A_N$ *vs.* $x_F$


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
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
0
0.2
0.4
0.6
0.8
1


SpdRoot-4.1.5.1, pp@√s = 13.0 GeV, π⁰→γγ, p_T > 0.5 GeV/c, P ~ 0.7
√s = 13 GeV
A_N
x_F
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
0
0.2
0.4
0.6
0.8
1

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

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

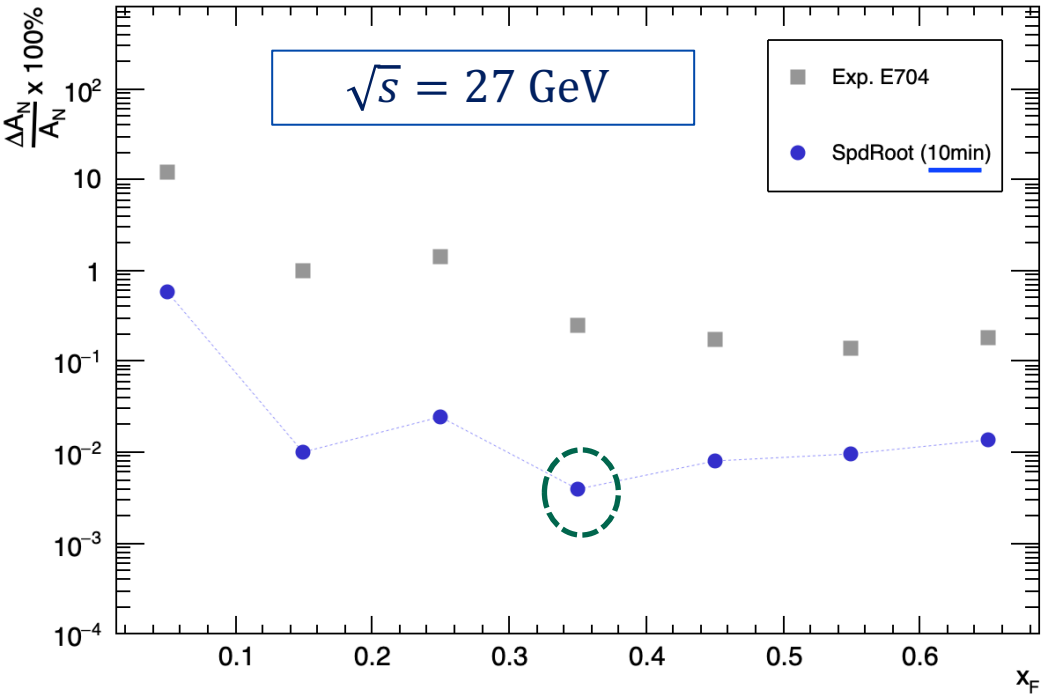
$\frac{\Delta A_N}{A_N}$ → SpdRoot

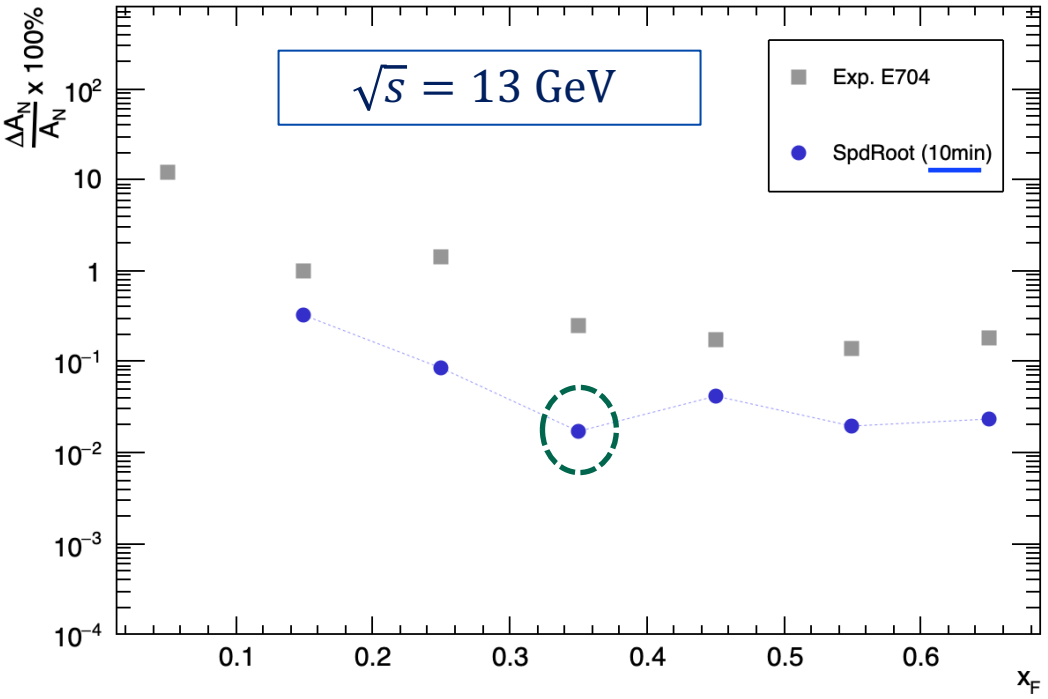
$\frac{\Delta A_N}{A_N}$ → E704

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

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

$\sigma_{tot}^{pp}(13\ \text{GeV}) = 38.4$ mb  $\mathcal{L} = 10^{31} s^{-1} cm^{-2}$  Reaction rate (13 GeV) = $3.8 \cdot 10^5 s^{-1}$




Better precision of the polarization measurement expected at:
$0.3 < x_F < 0.4$

# Estimated relative error of the polarization

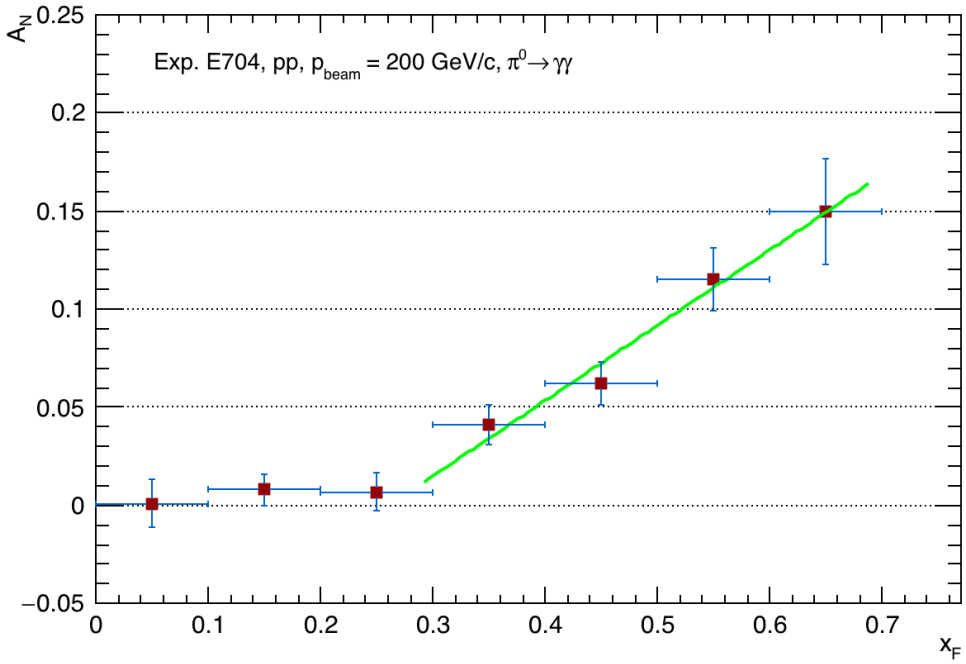
Raw asymmetry:

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

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

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

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

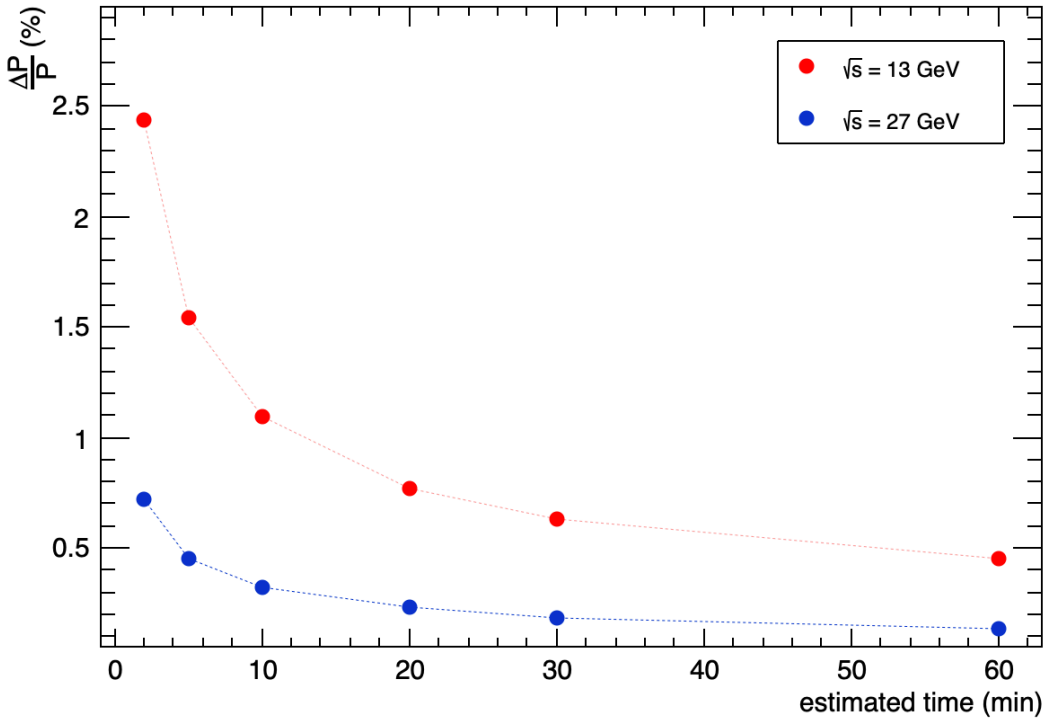



Taking the last experimental 4 points ($0.3 \leq x_F < 0.7$): $\frac{\Delta P}{P} = 0.0873$ ~9% (Experiment E704)

*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 $\sqrt{s} = 13$ GeV and $\sqrt{s} = 27$ GeV, in SPD ECAL endcaps.

| Estimated time | $\frac{\Delta P}{P}$ | |
|---|---|---|
| | $\sqrt{s}$ = 13 GeV | $\sqrt{s}$ = 27 GeV |
| 2 min | 2.44 % | 0.72 % |
| 5 min | 1.54 % | 0.45 % |
| 10 min | 1.09 % | 0.32 % |
| 20 min | 0.77 % | 0.23 % |
| 30 min | 0.63 % | 0.18 % |
| 1 h | 0.45 % | 0.13 % |



# Summary

- The accuracy of the beam polarization have been estimated at two different pp collision energies: 13 GeV and 27 GeV

- The determination of the polarization is expected to be more precise in the range $0.3 < x_F < 0.4$.

- From the asymmetry determination, based on MC truth simulations with SpdRoot, the statistical accuracy of the beam polarization, for 10 minutes, is estimated in: 1.1 % at 13 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.

Many thanks to Andrei Maltsev for his contribution on the MC info management for the ECAL!