On the statistical accuracy of A_N for local polarimetry with π^0 in the SPD (a SpdRoot assessment)

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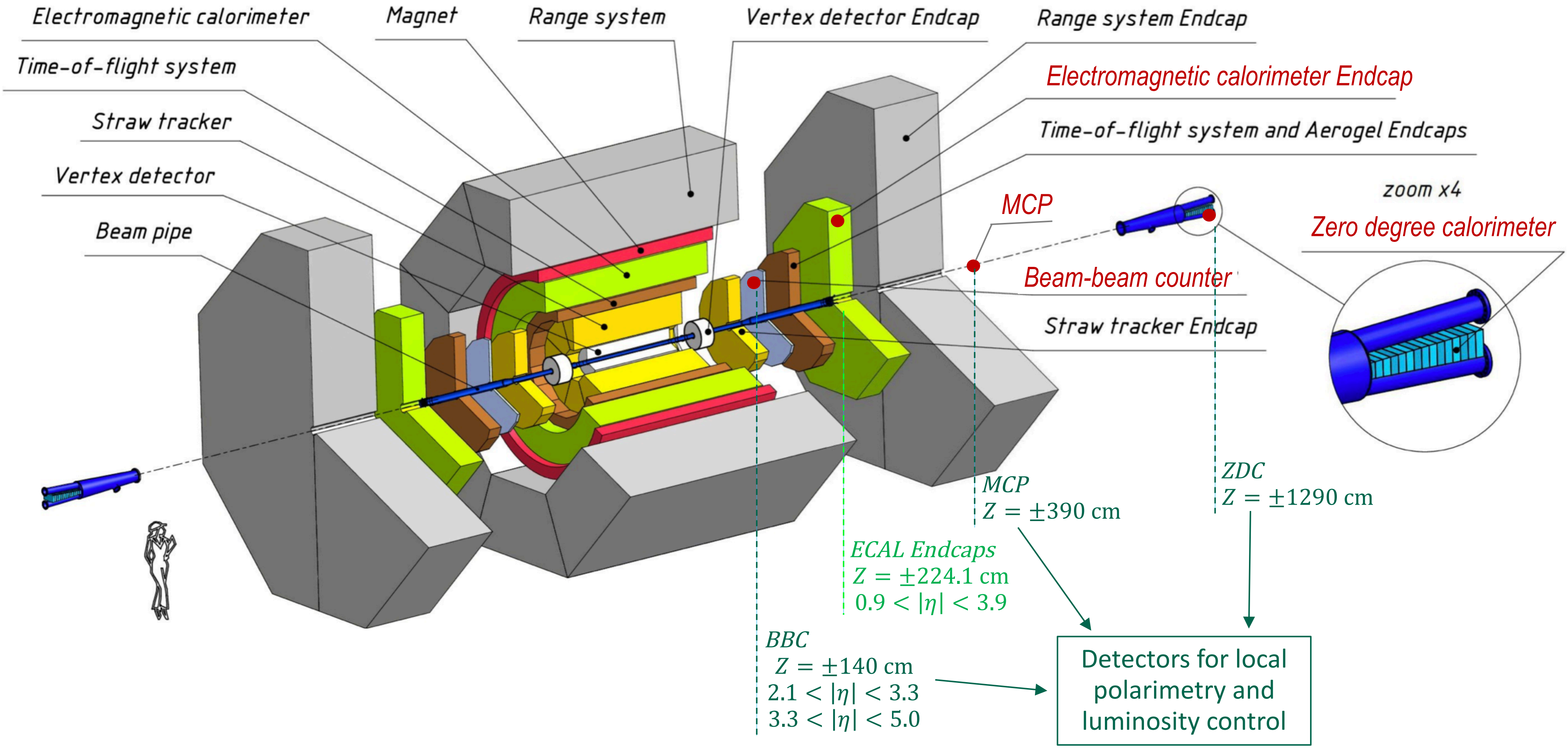
Schematic view of the SPD



MCP
$Z = \pm 390$ cm

ZDC
$Z = \pm 1290$ cm

ECAL Endcaps
$Z = \pm 224.1$ cm
$0.9 < |\eta| < 3.9$

BBC
$Z = \pm 140$ cm
$2.1 < |\eta| < 3.3$
$3.3 < |\eta| < 5.0$

Detectors for local polarimetry and luminosity control

Inclusive π^0production from pp interactions

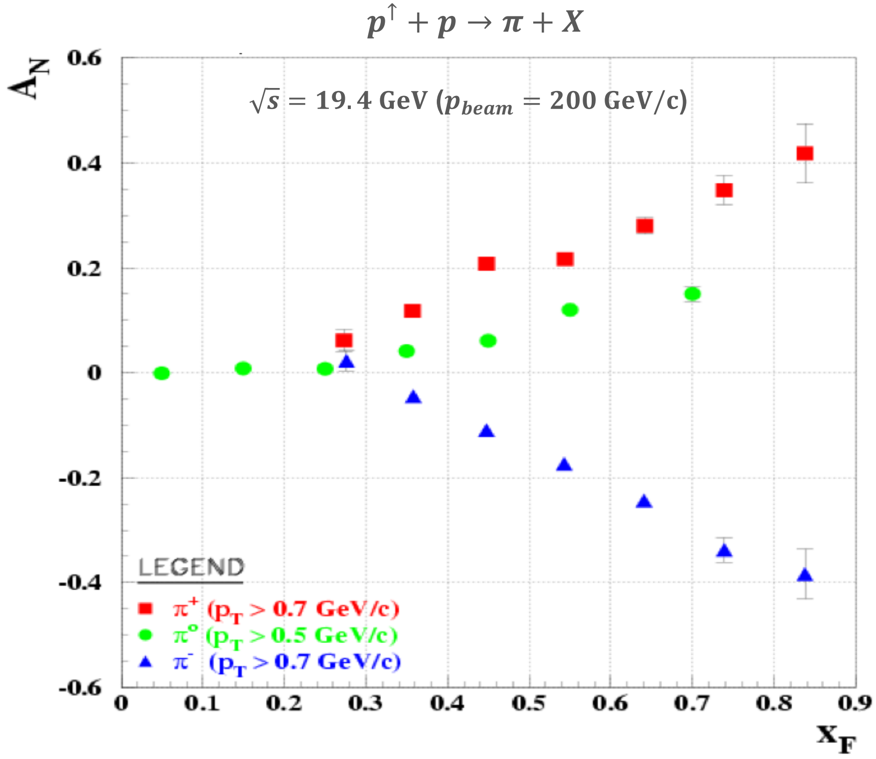
Single Spin Asymmetry (SSA): $A_N^{\pi^0}$ ⟶ probes the spin structure of the proton.

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

$$A_\mathrm{N} = \frac{\sigma^\uparrow - \sigma^\downarrow}{\sigma^\uparrow + \sigma^\downarrow}$$

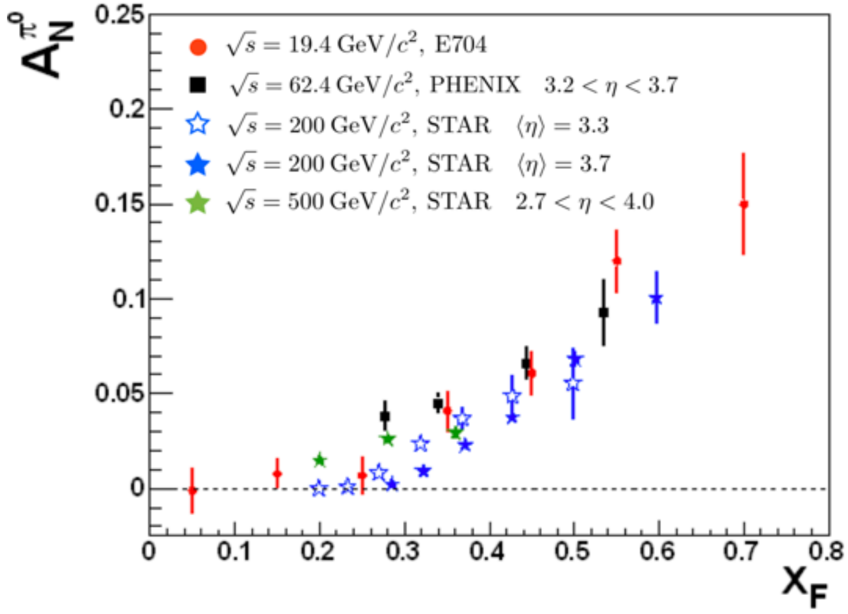
A_N is a measure of the beam polarization

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



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

A_N nearly independent of $\sqrt{s}$



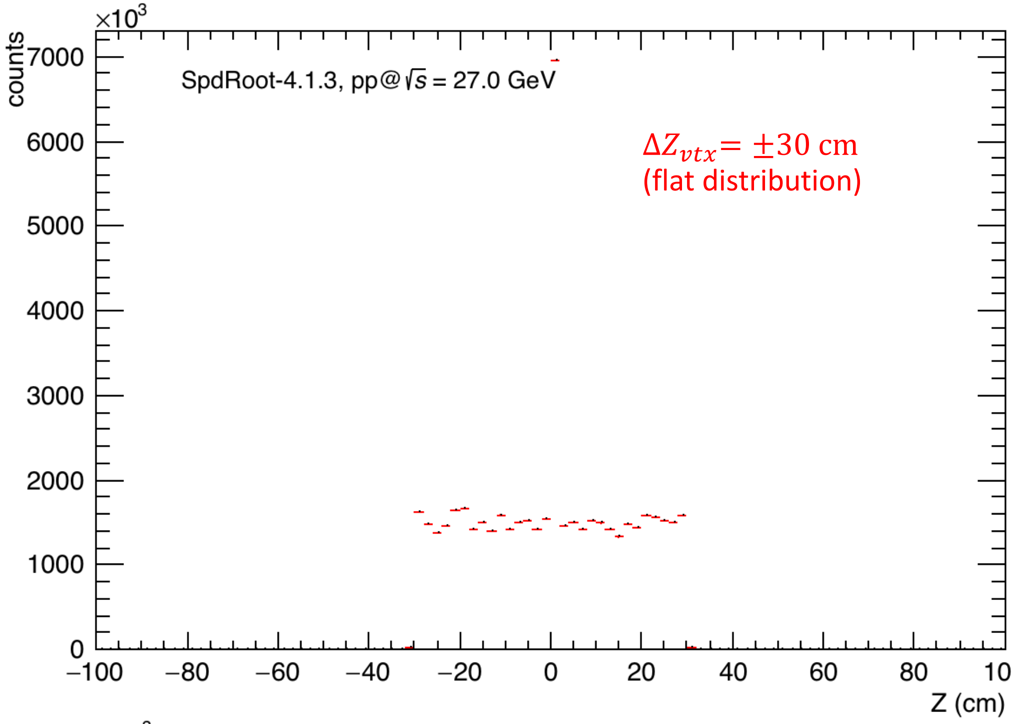
The single spin pion asymmetry of the process $p^\uparrow + p \rightarrow \pi^0 + X$ is considered one of the best tests to verify perturbative regime by QCD.

Simulation settings

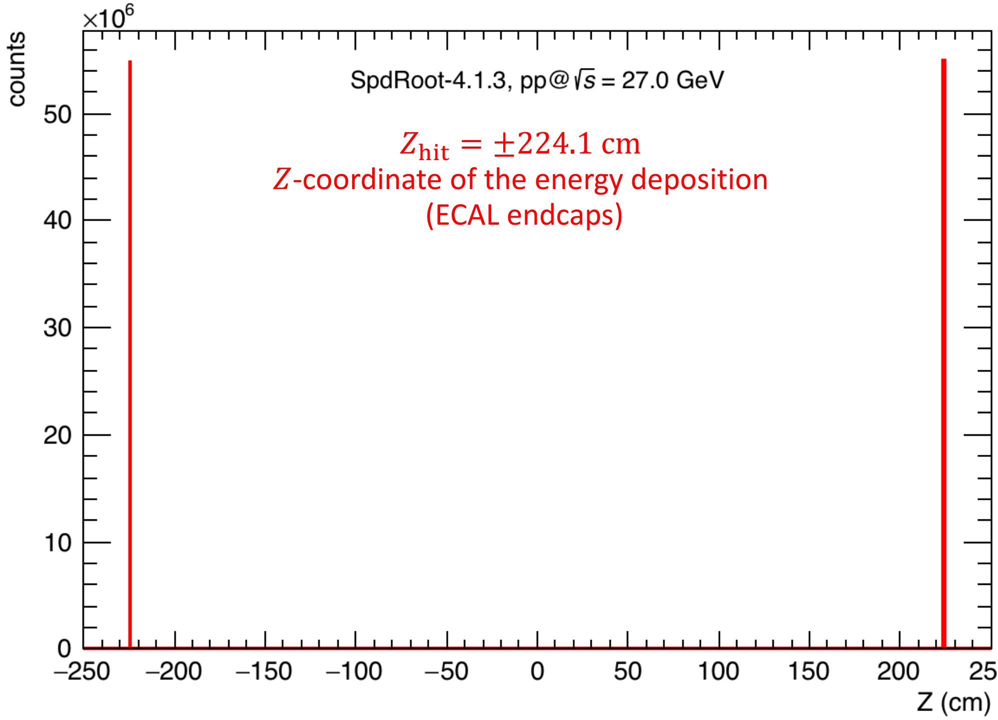
$$\boldsymbol{p} + \boldsymbol{p} \rightarrow \underset{\searrow \gamma\gamma}{\boldsymbol{\pi^0}} + \boldsymbol{X}$$

- ☐ SpdRoot version 4.1.3
- ☐ Particle generator: Pythia 8 (number of events: 10^8)
- ☐ Minimum Bias: *SoftQCD:inelastic* ↔ inelastic, non diffractive events and diffractive topologies
- ☐ Smeared vertex in $\Delta Z = \pm 30\ cm$ (flat distribution)
- ☐ E^{γ}_{min}= 400 MeV (γ : reconstructed particle)
- ☐ Monte Carlo truth is used to identify photons: the PDG code is obtained through a method implemented in the analysis macro to find the Monte Carlo particle corresponding to the reconstructed photon.
- ☐ Reconstructed photons detected in the ECAL Endcaps
  detId = +1 (endcapZ+) $Z = +224.1$ cm
  detId = -1 (endcapZ-) $Z = -224.1$ cm
- ☐ ECAL endcap energy resolution $E \sim \frac{5.4\%}{\sqrt{E}}$ (estimated for $E_{\gamma} = 0\ - 10$ GeV with $\theta = 10^o\ - 15^o$)
- ☐ $\pi^0$are reconstructed from the M_{inv} of γ pairs

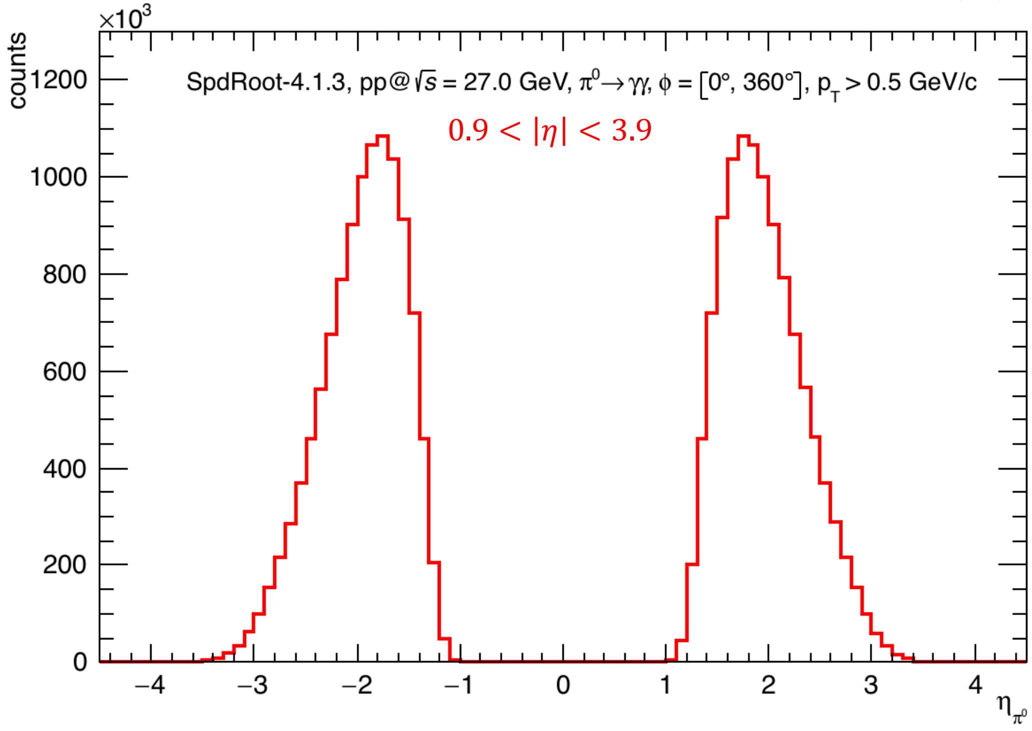
General characteristics



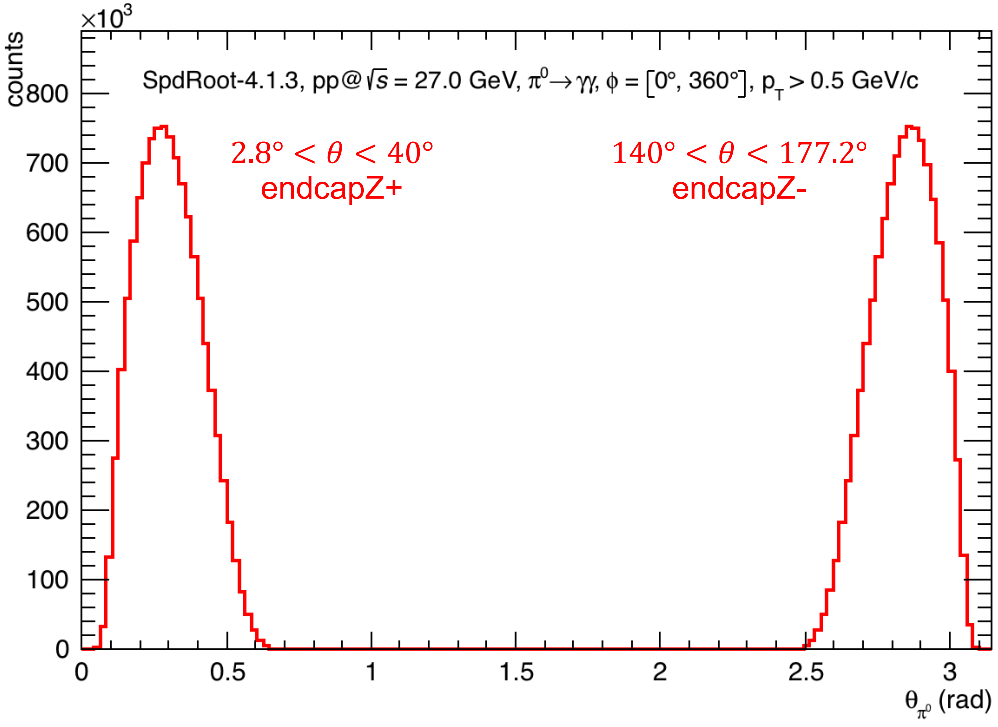
$\Delta Z_{vtx} = \pm 30$ cm
(flat distribution)



$Z_{\mathrm{hit}} = \pm 224.1$ cm
Z-coordinate of the energy deposition
(ECAL endcaps)



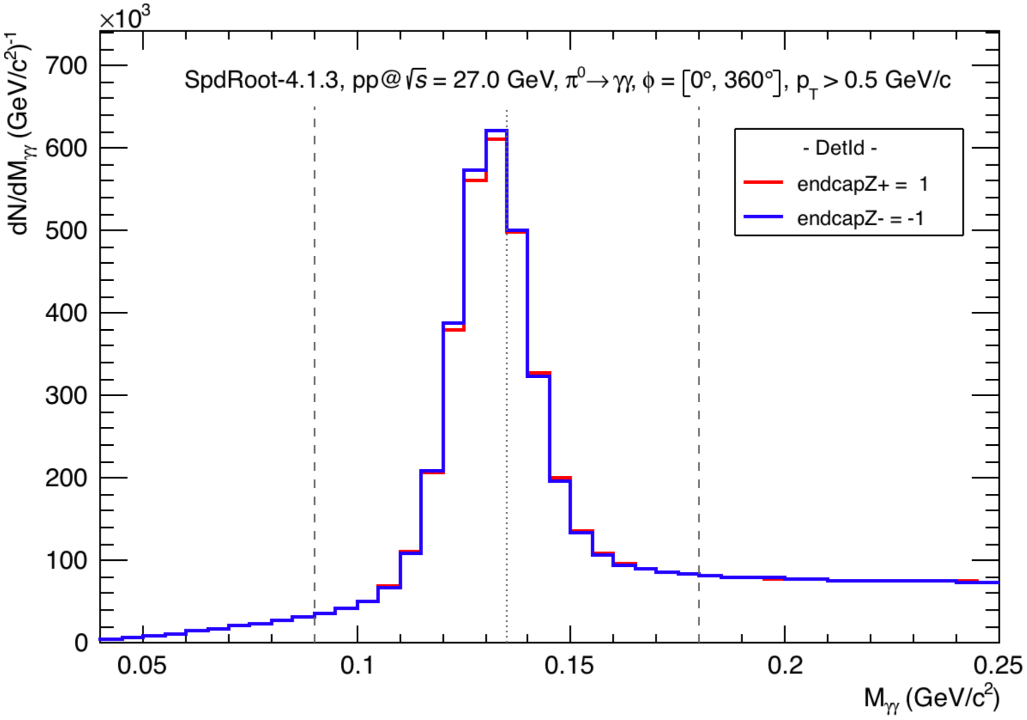
$0.9 < |\eta| < 3.9$

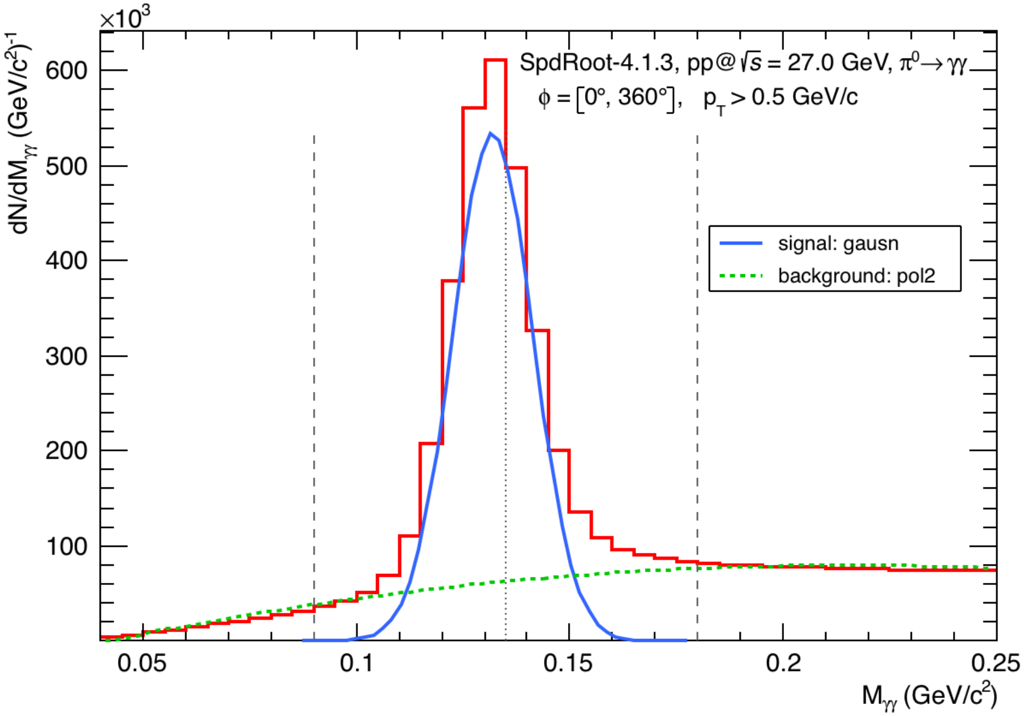


$2.8° < \theta < 40°$
endcapZ+

$140° < \theta < 177.2°$
endcapZ-

General characteristics





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.

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

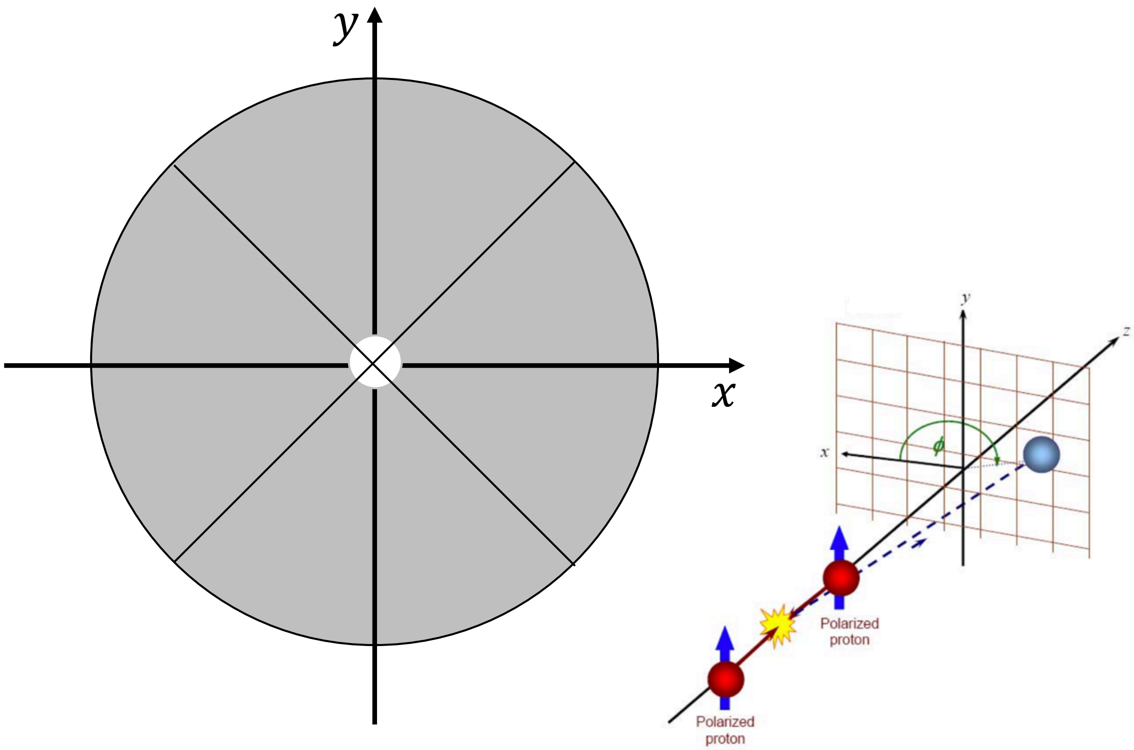
$$N_{\boldsymbol{\pi^0}}\,(\phi) = A(1 + B\cos\phi)$$

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

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

P: Beam polarization

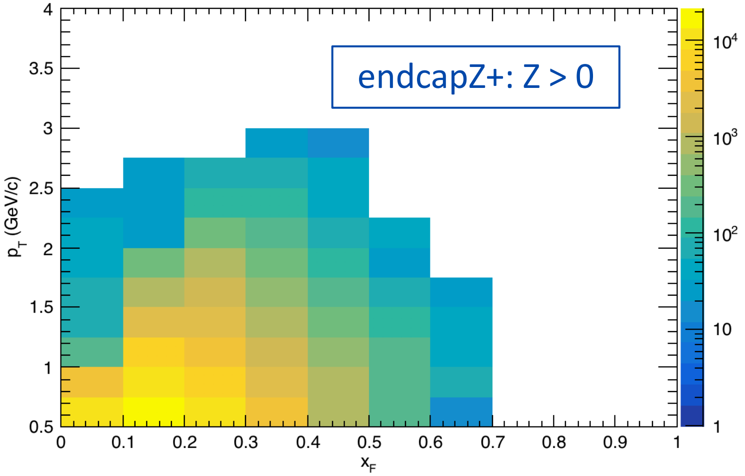
- *P* ~ 0.7 was assumed

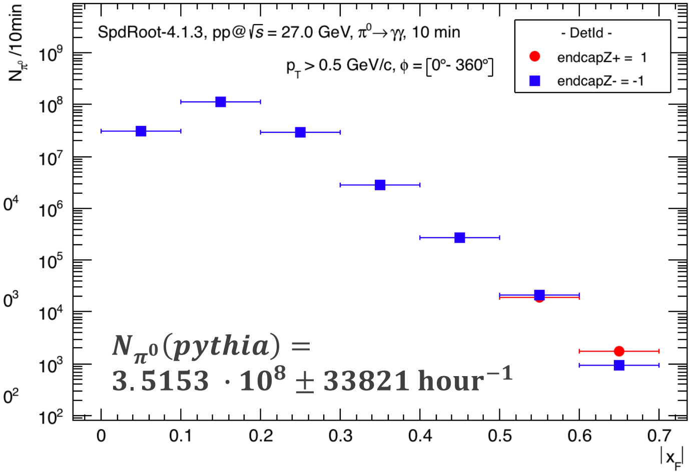


- The spin dependent π^0 yields for each bin are extracted from the invariant mass spectra in different x_{F} sub-ranges for each ϕ bin.
- The invariant mass was fitted with a **polynomial** function for the background and a **normalized Gaussian** distribution representing the signal peak.

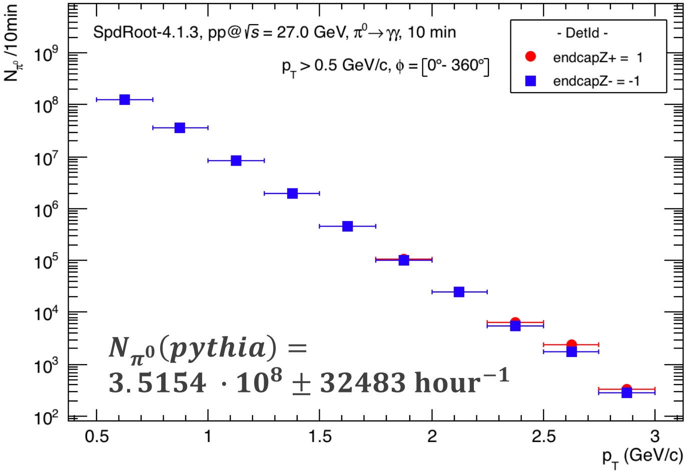
Estimation of π^0 yield in the ECAL endcaps

Expected in 10 min at a reaction rate $4 \cdot 10^6 s^{-1}$

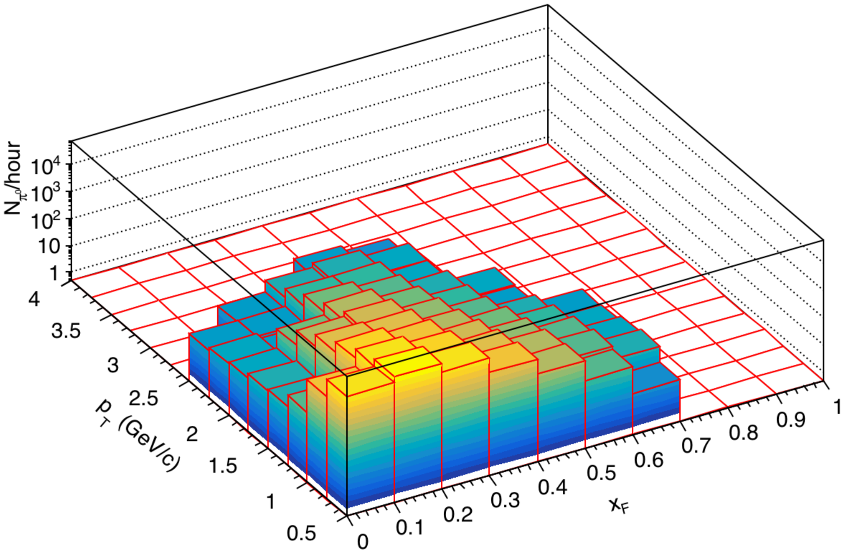




$N_{\pi^0}(pythia) =$
$3.5153 \cdot 10^8 \pm 33821\ \text{hour}^{-1}$



$N_{\pi^0}(pythia) =$
$3.5154 \cdot 10^8 \pm 32483\ \text{hour}^{-1}$



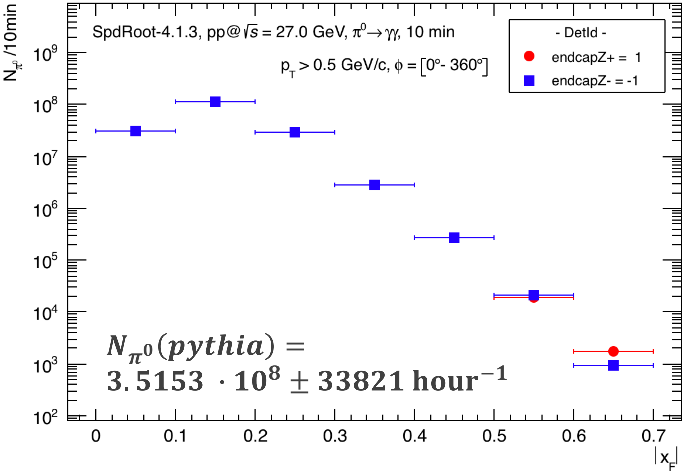
Both ECAL endcaps

x_F	$N_{\pi^0}(\text{spdroot})$
0.0 – 0.1	6.06491e+07 ± 7787.8
0.1 – 0.2	2.26635e+08 ± 15054
0.2 – 0.3	5.8021e+07 ± 7617.15
0.3 – 0.4	5.6518e+06 ± 2377
0.4 – 0.5	5.33338e+05 ± 730
0.5 – 0.6	4.1166e+04 ± 202.8
0.6 – 0.7	2661.9 ± 51.6

p_T (GeV/c)	$N_{\pi^0}(\text{spdroot})$
0.50 – 0.75	2.57118e+08 ± 16035
0.75 – 1.00	7.210669e+07 ± 8492
1.00 – 1.25	1.72052e+07 ± 4147.9
1.25 – 1.50	3.93689e+06 ± 1984
1.50 – 1.75	9.04157e+05 ± 950.9
1.75 – 2.00	2.05179 e+05 ± 452.9
2.00 – 2.25	4.95929e+04 ± 222.7
2.25 – 2.50	1.19629e+04 ± 109.3
2.50 – 2.75	488.04 ± 63.94
2.75 – 3.00	617.9 ± 24.86

Estimation of π^0 yield in the ECAL endcaps

Both ECAL endcaps



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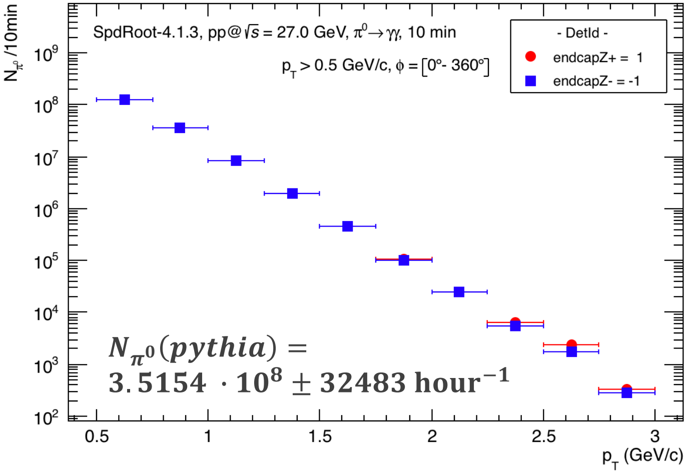

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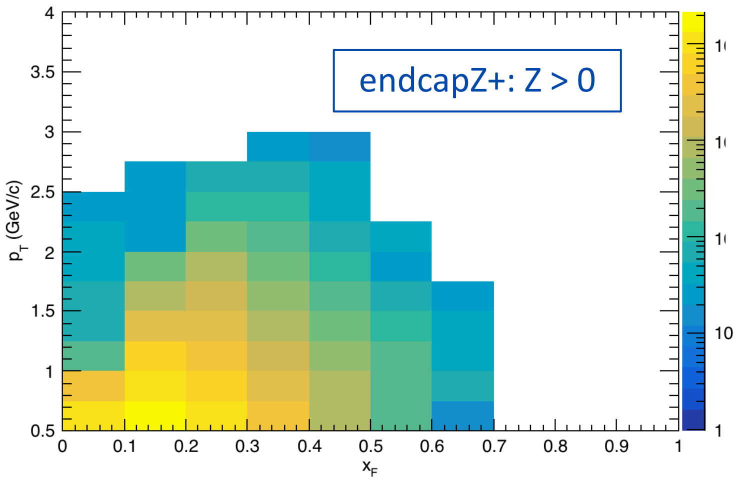
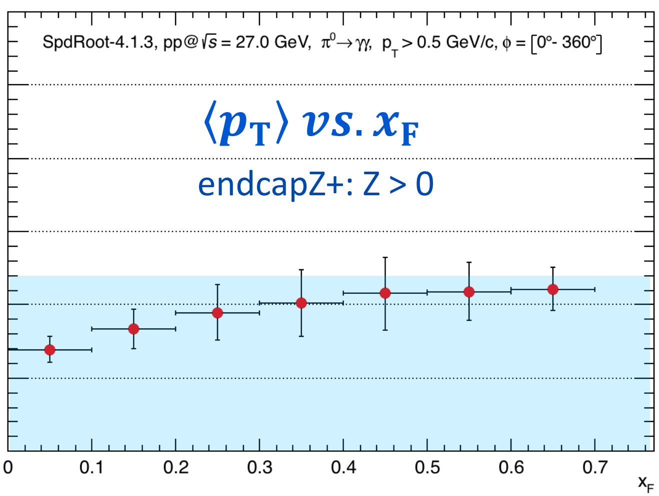
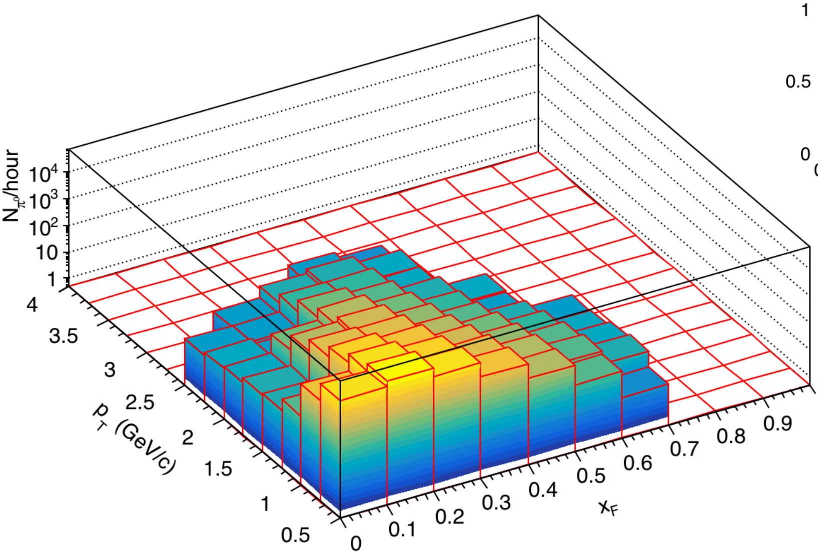


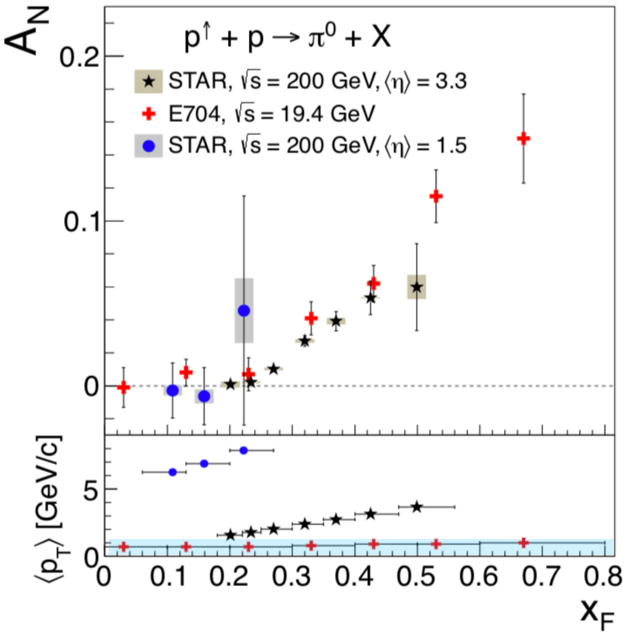
endcapZ+: Z > 0



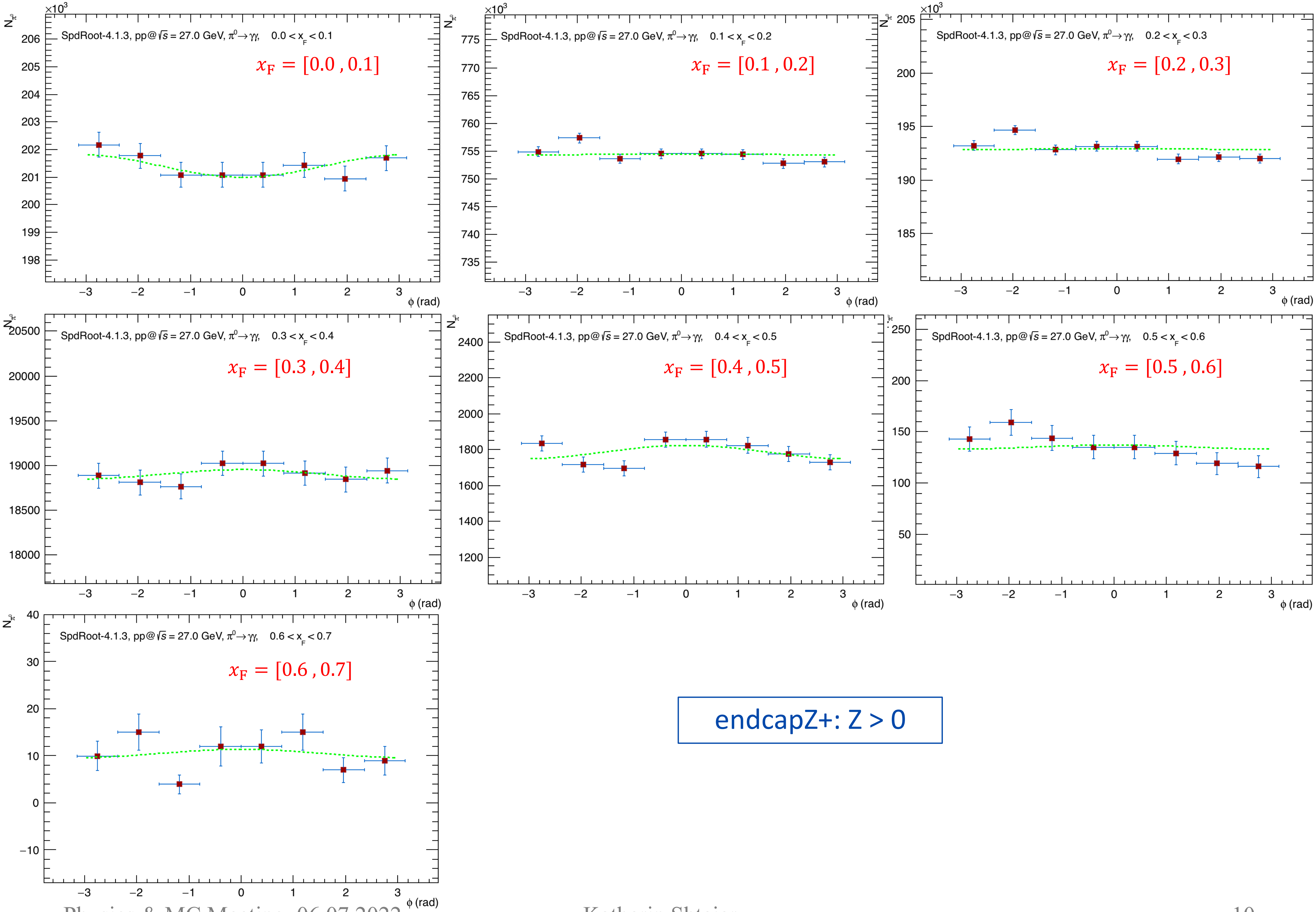
$\langle p_T \rangle\ vs.\ x_F$

endcapZ+: Z > 0



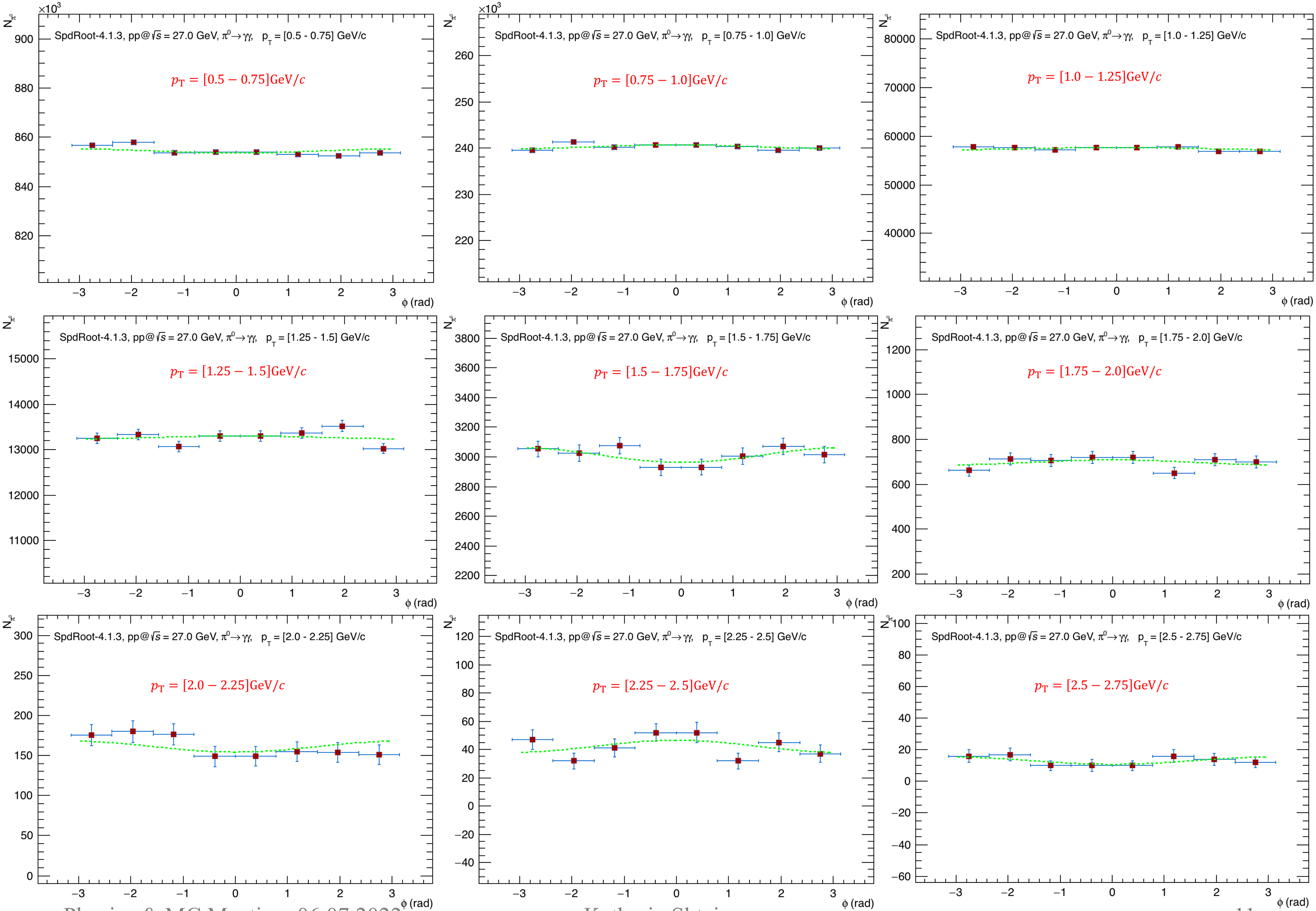


Azimuthal cosine modulation of π^0 yields in x_F intervals



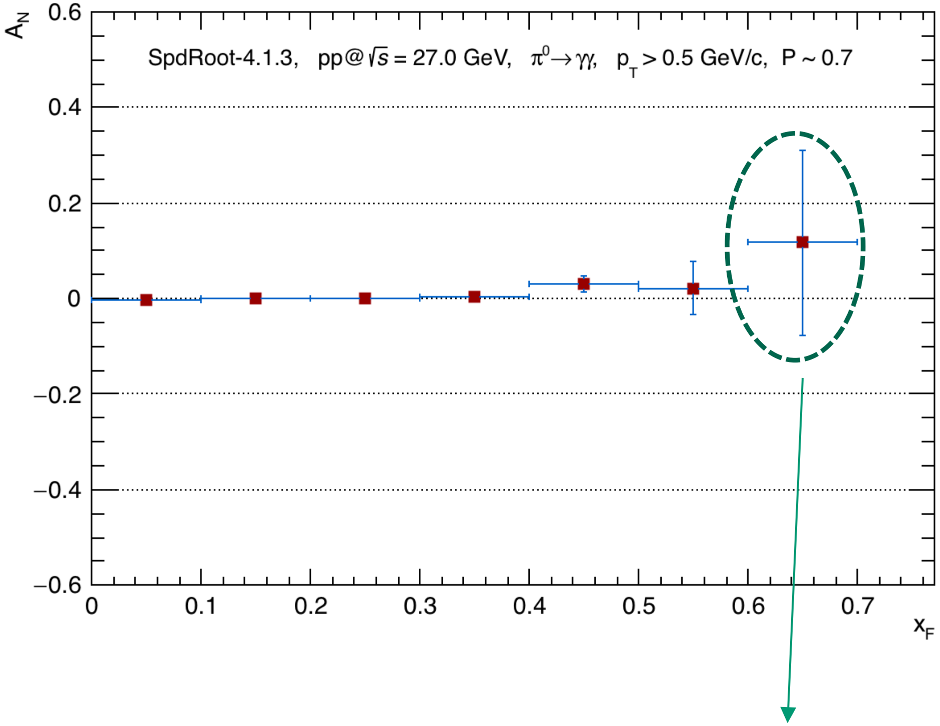
endcapZ+: Z > 0

Azimuthal cosine modulation of π^0 yields in p_T intervals



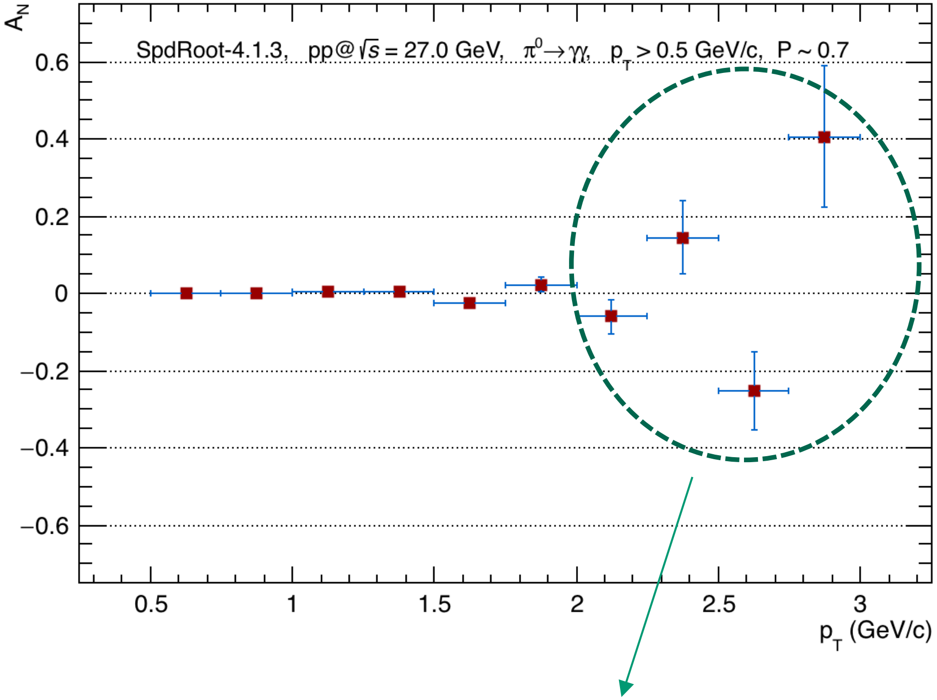
A_N in the ECAL endcap

A_N in x_F intervals



Poor statistics

A_N in p_T intervals



Poor statistics

Relative error for A_N

By using the measured A_N from the E704 experiment at $\sqrt{s} = 19.4$ GeV, we can estimate the relative error of $\frac{\Delta A_N}{A_N}$ *vs.* x_F

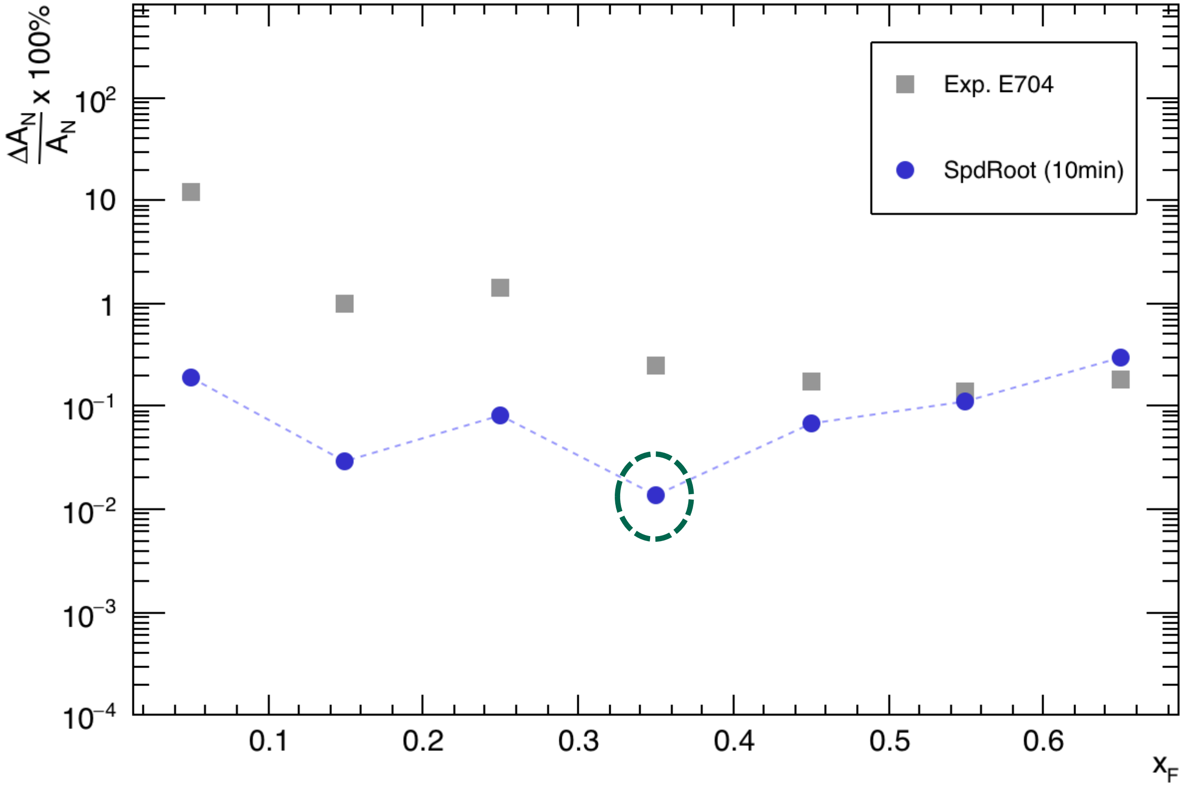
$$\frac{\Delta A_N}{A_N} \sim \frac{\Delta P}{P}$$

$$\frac{\Delta A_N}{A_N}$$

ΔA_N → SpdRoot

A_N → E704

ΔA_N scaled to 10 min of data-taking (SPDRoot)



Relative of A_N error estimated for 10 min

x_F	$\frac{\Delta A_N}{A_N}$ (%)		
	SpdRoot (10min)	**SpdRoot (5min)**	**SpdRoot (2min)**
0.0 -0.1	18.97	26.84	42.43
0.1 -0.2	2.94	4.16	6.57
0.2 -0.3	8.23	11.64	18.40
0.3 -0.4	1.37	1.94	3.06
0.4 -0.5	6.69	9.46	14.96
0.5 -0.6	11.25	15.91	25.15
0.6 -0.7	29.8	42.19	66.70

The determination of the polarization is expected to be precise for $0.3 < x_F < 0.4$.

Estimated relative error of the polarization

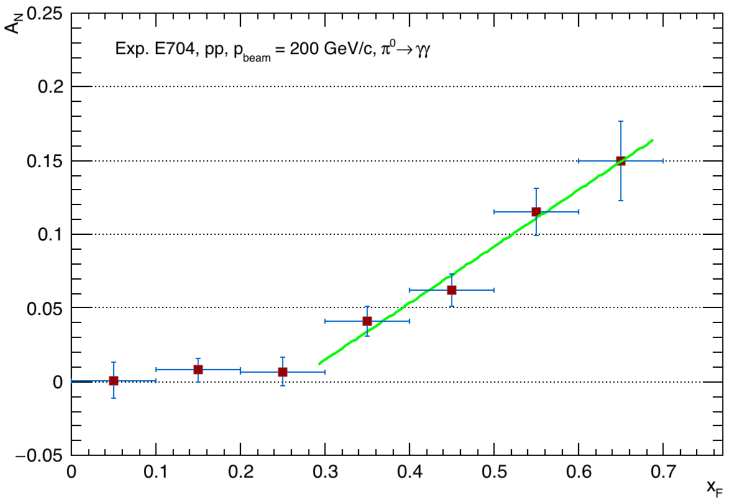
Raw asymmetry:

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

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

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

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



Taking the last 4 points ($0.3 \leq x_F < 0.7$):

$\frac{\Delta P}{P} \approx 0.0873$ 8.7% (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]*

MC-SpdRoot (32 s) $\frac{\Delta P}{P} \approx 0.057646$ 5.76 %

MC-SpdRoot (2 m) $\frac{\Delta P}{P} \approx 0.0297683$ 2.98 %

MC-SpdRoot (5 m) $\frac{\Delta P}{P} \approx 0.0188271$ 1.88 %

MC-SpdRoot (10 m) $\frac{\Delta P}{P} \approx 0.0133128$ 1.33 %

SpdRoot estimation of the statistical accuracy of the beam polarization measurement, with $pp \to \pi^0 X \;@\; \sqrt{s} = 27\ GeV$, in SPD ECAL endcaps.

Summary

- 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.

- The determination of the polarization is expected to be more precise, at least, for $0.3 < x_F < 0.4$.

- From the asymmetry determination, the statistical accuracy of the beam polarization in 10 minutes is estimated in $\frac{\Delta \boldsymbol{P}}{\boldsymbol{P}} \sim \mathbf{1.33\%}$, from SPDRoot simulations, while a relative error of the polarization, of $\frac{\Delta \boldsymbol{P}}{\boldsymbol{P}} \sim \mathbf{2.98}\%$ can be predicted for 2 minutes.

- TODO:

○ Estimate the systematic uncertainties

○ Introduce the phase smearing in the cosine function

○ Expand the energy range ($\sqrt{s}$) of this analysis