Inclusive π^0 production for online polarimetry in SPD

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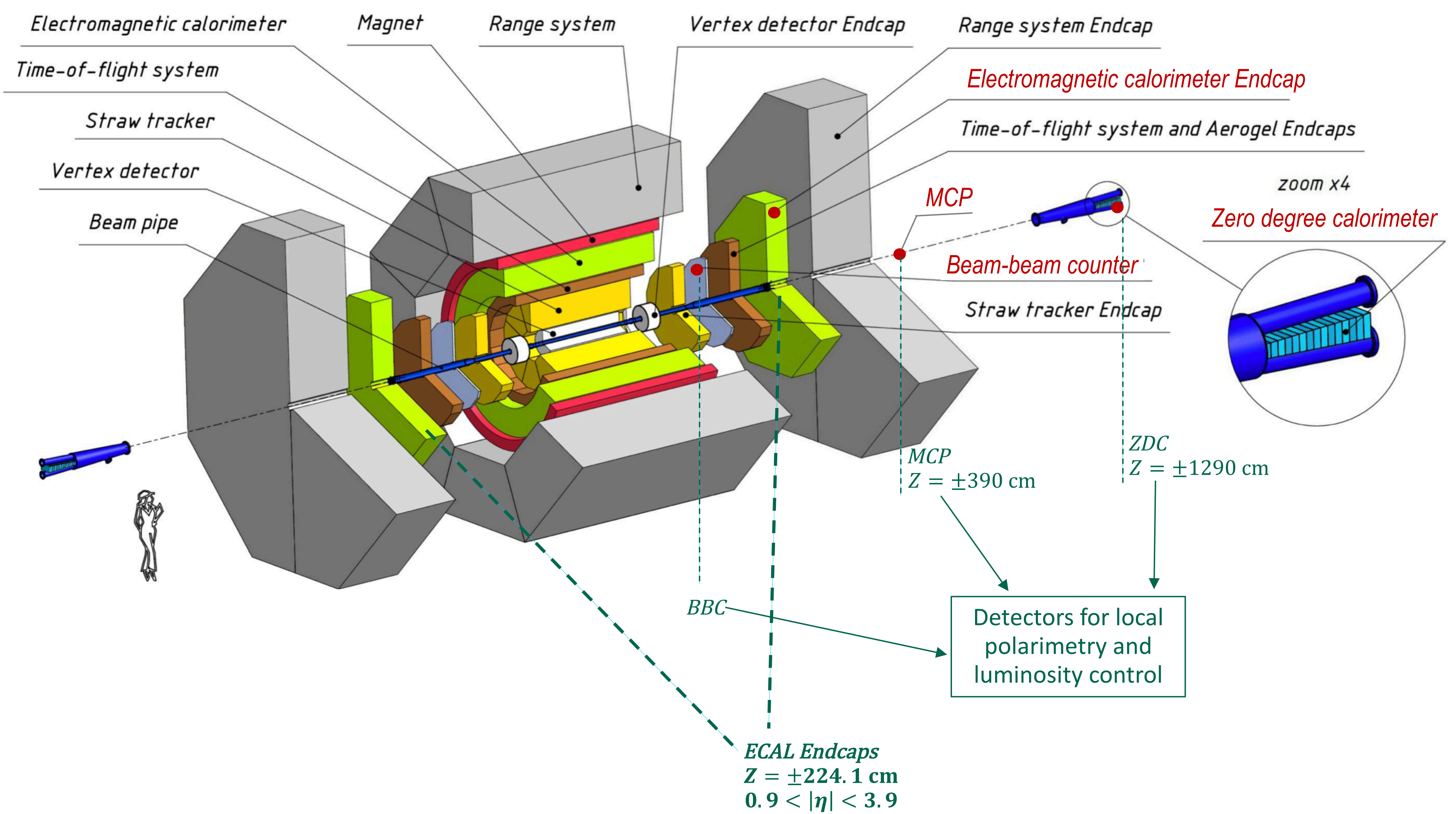
Schematic view of the SPD



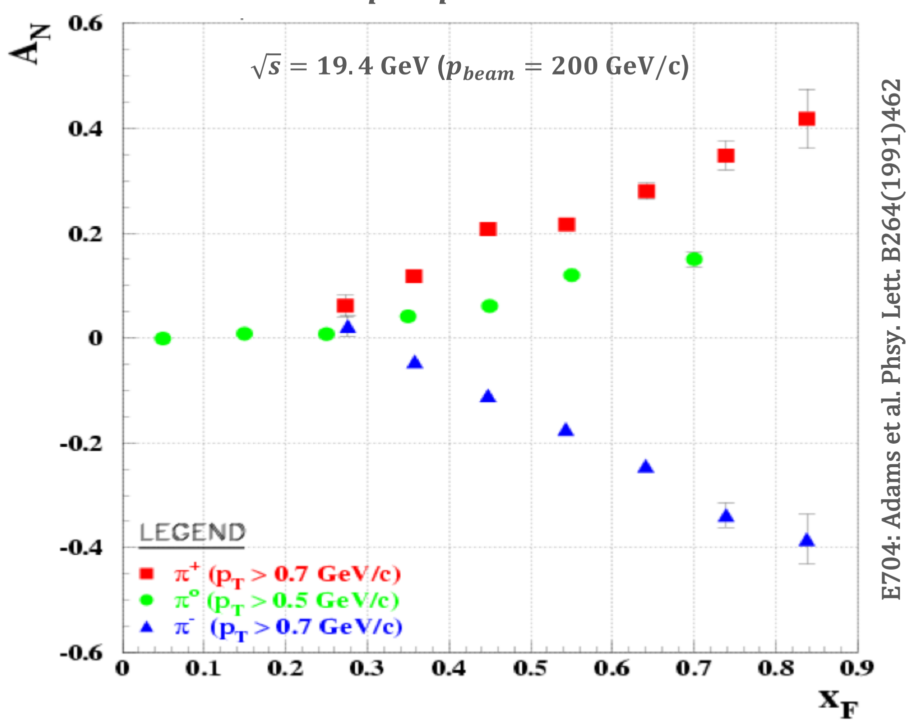
$$A_N = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$

A_N is a measure of the beam polarization

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

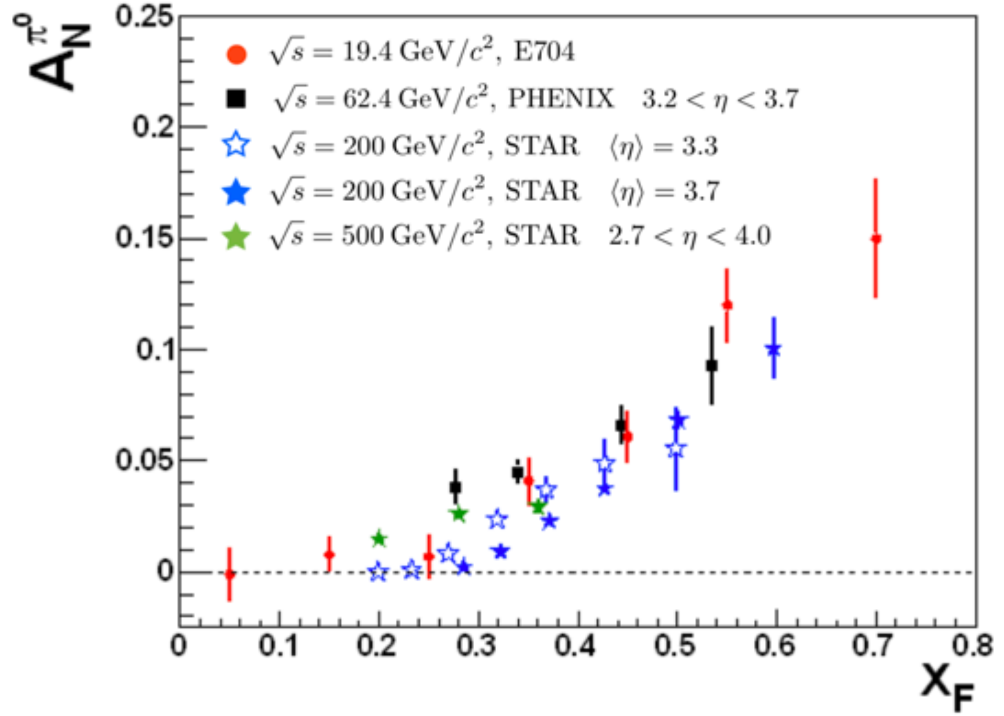
In 1991 the E704 experiment, with $\boldsymbol{p}^{\uparrow}$ at higher p_T values, extended the results on large A_N.

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



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

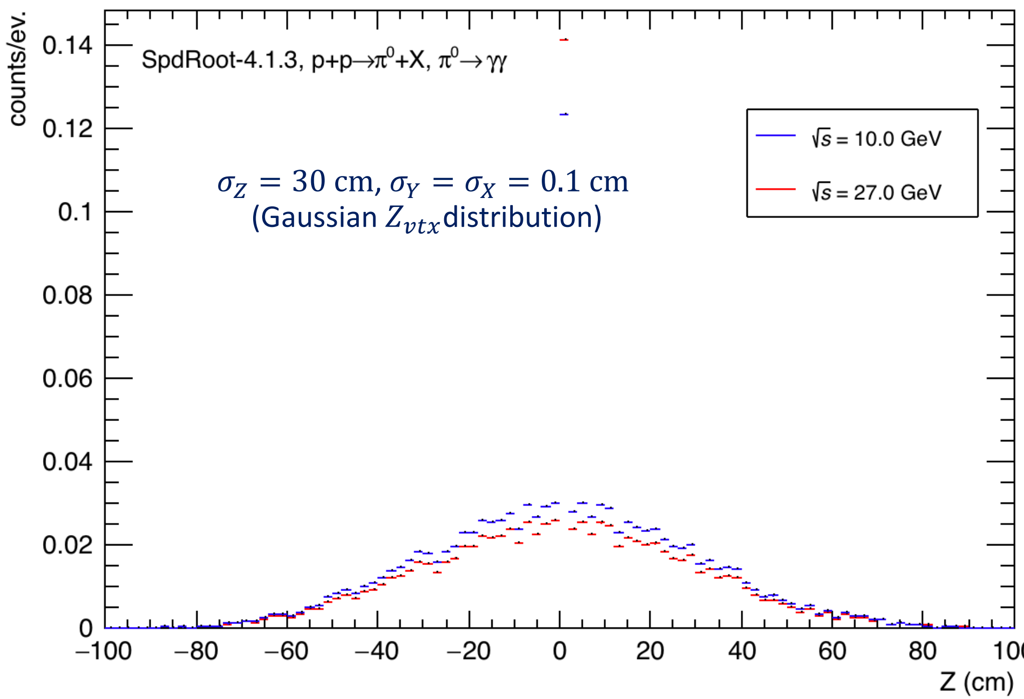
A_N nearly independent of $\sqrt{s}$

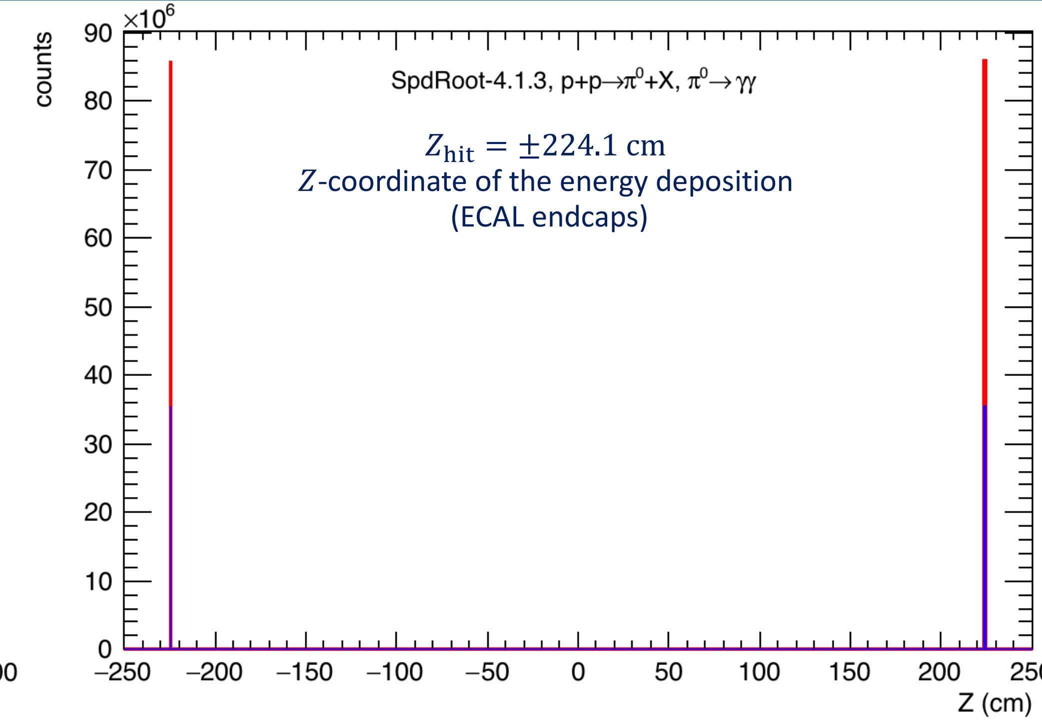


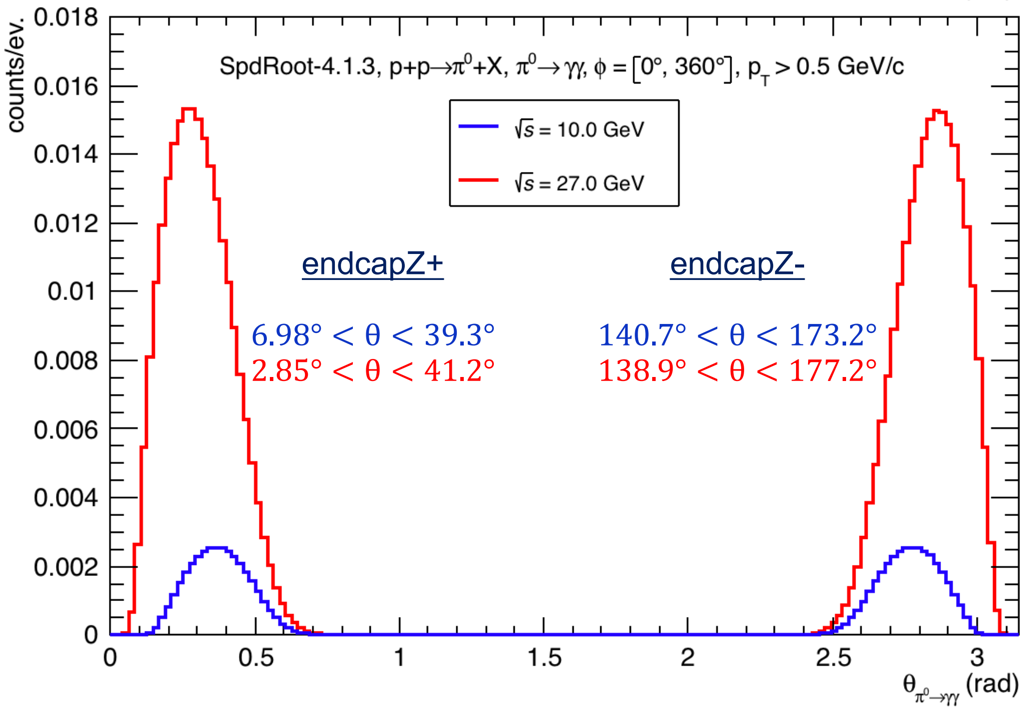
$$\boldsymbol{p + p \to \pi^0 + X}$$
$$\pi^0 \to \gamma\gamma$$

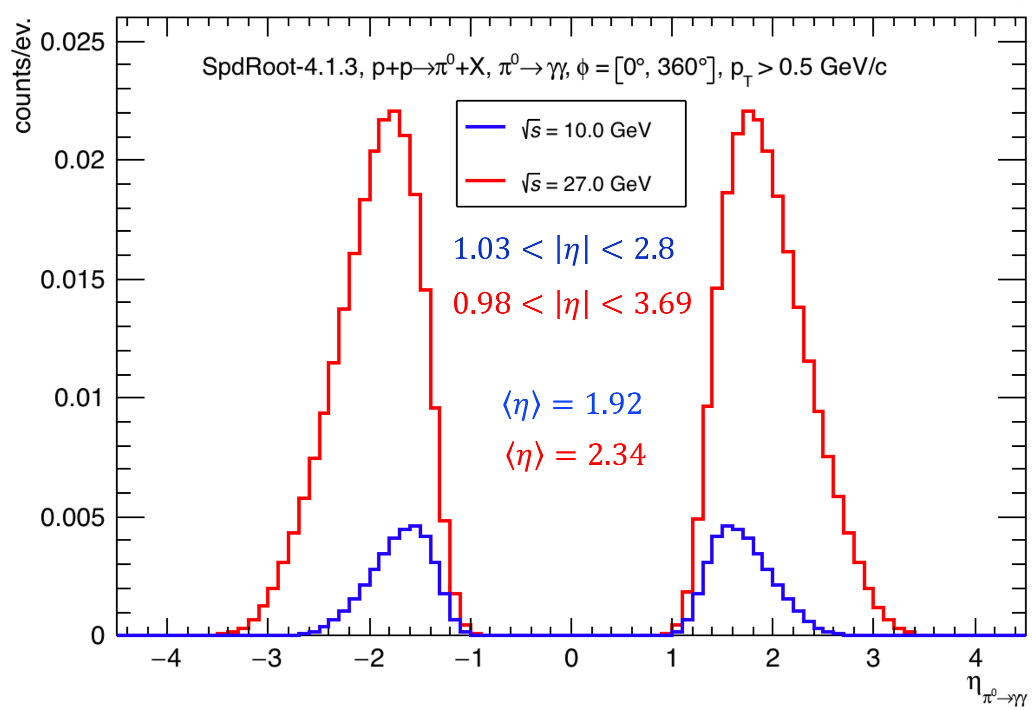
- SpdRoot version 4.1.3
- Two energies: pp @ $\sqrt{s} = 10$ GeV and pp @ $\sqrt{s} = 27$ GeV
- Particle generator: Pythia 8 (number of events: $\sim 80\text{M}$)
- Minimum Bias: *SoftQCD:inelastic* ↔ inelastic, non diffractive events and diffractive topologies
- Smeared vertex in $\Delta Z = \pm 30\ cm$ (Gaussian distribution)
- E^{γ}_{min} = 400 MeV (γ : reconstructed particle)
- Reconstructed photons detected in the ECAL Endcaps
  - detId = +1 (endcapZ+) $Z = +224.1$ cm
  - detId = -1 (endcapZ-) $Z = -224.1$ cm
- π^0 are reconstructed from the M_{inv} of γ pairs

General characteristics



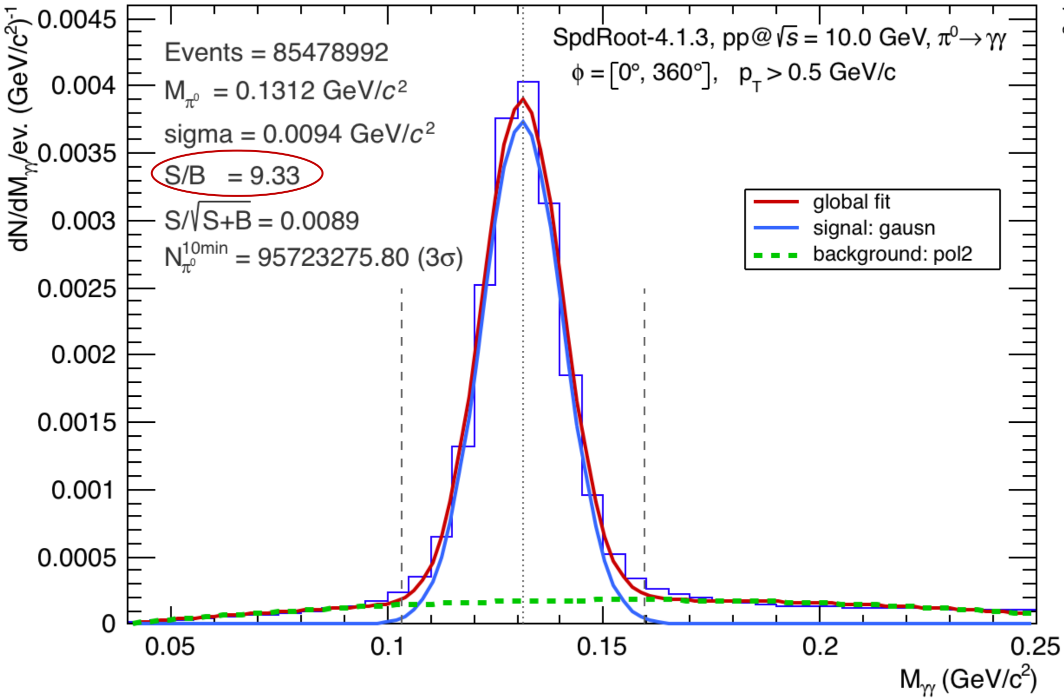




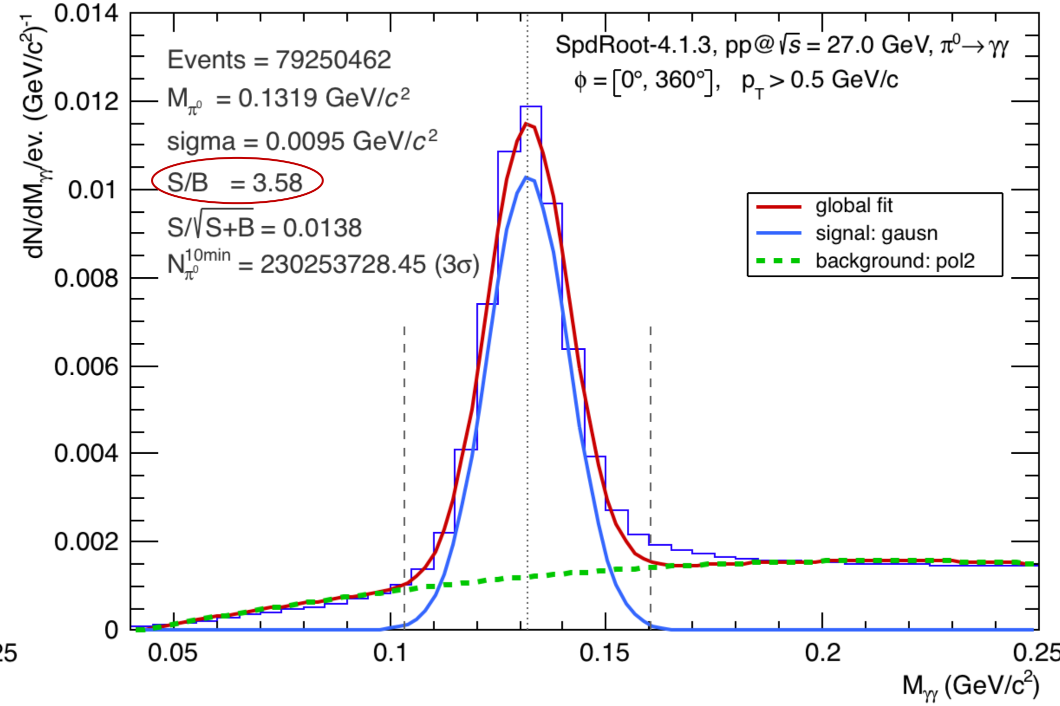


General characteristics

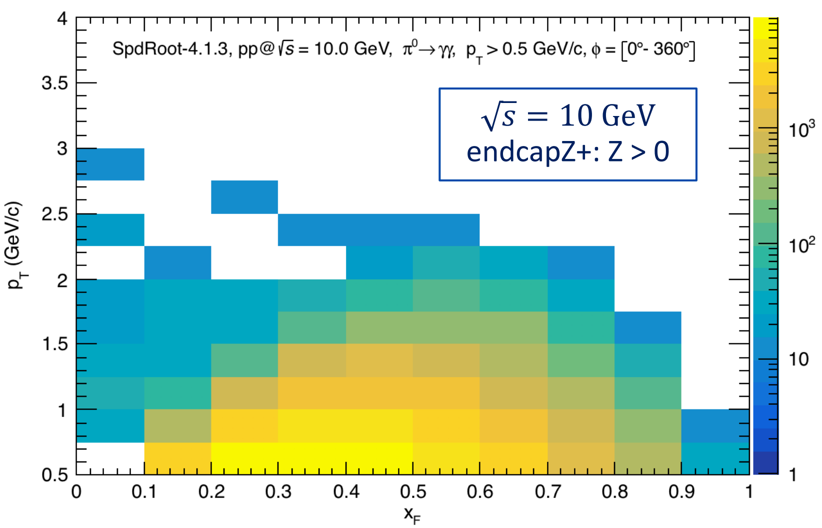
$pp\ @\ \sqrt{s} = 10$ GeV

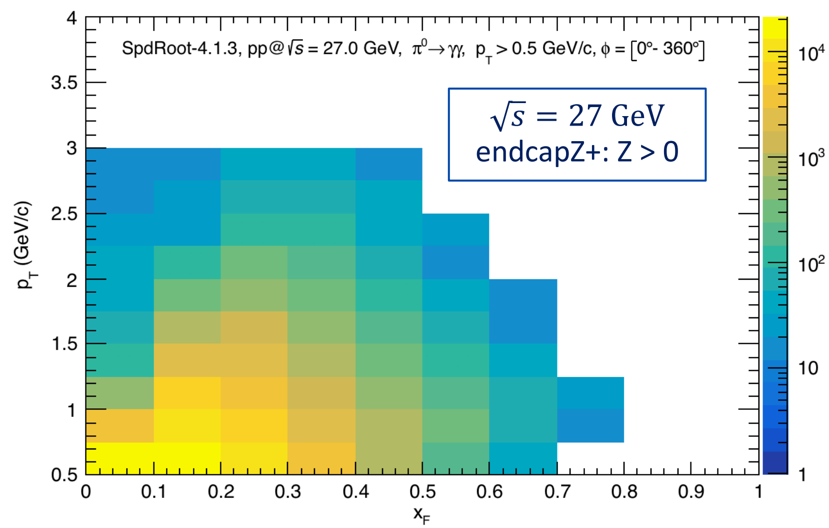


$pp\ @\ \sqrt{s} = 27$ GeV

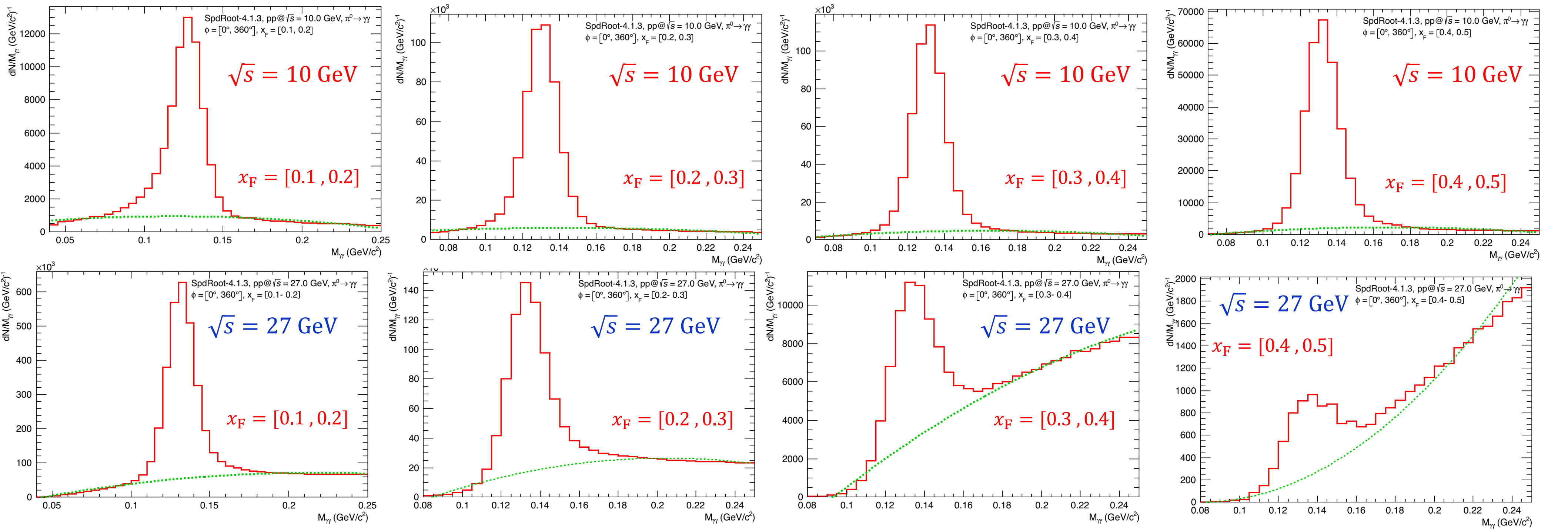


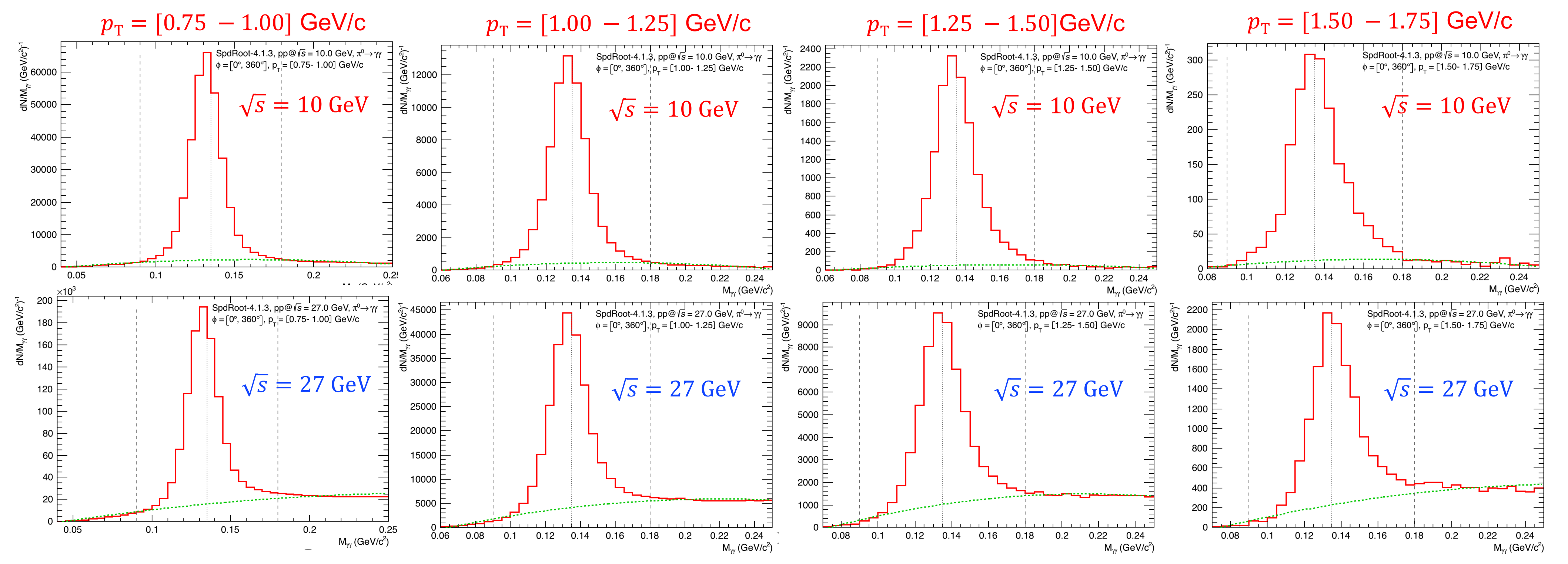
$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} exp\left[-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right] + p_1 + p_2 x + p_3 x^2$$





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.

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

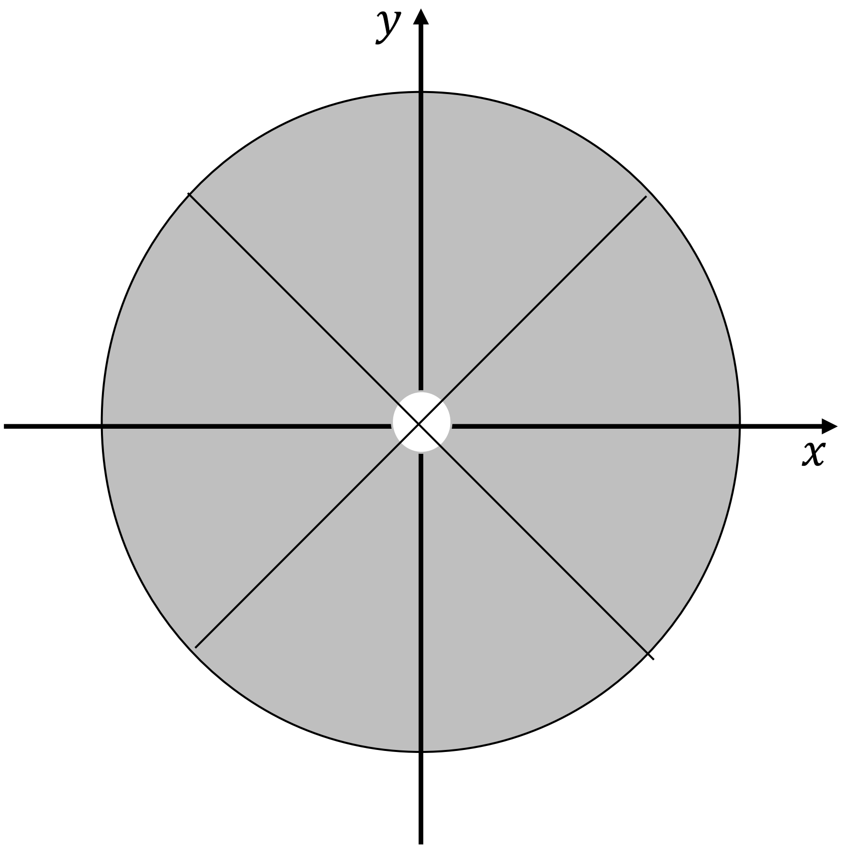
$$N_{\boldsymbol{\pi^0}}(\varphi) = A[1 + P \cdot A_N \cdot \cos(\varphi + \varphi_0)]$$

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

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

P: Beam polarization

- P ~ 0.7 was assumed



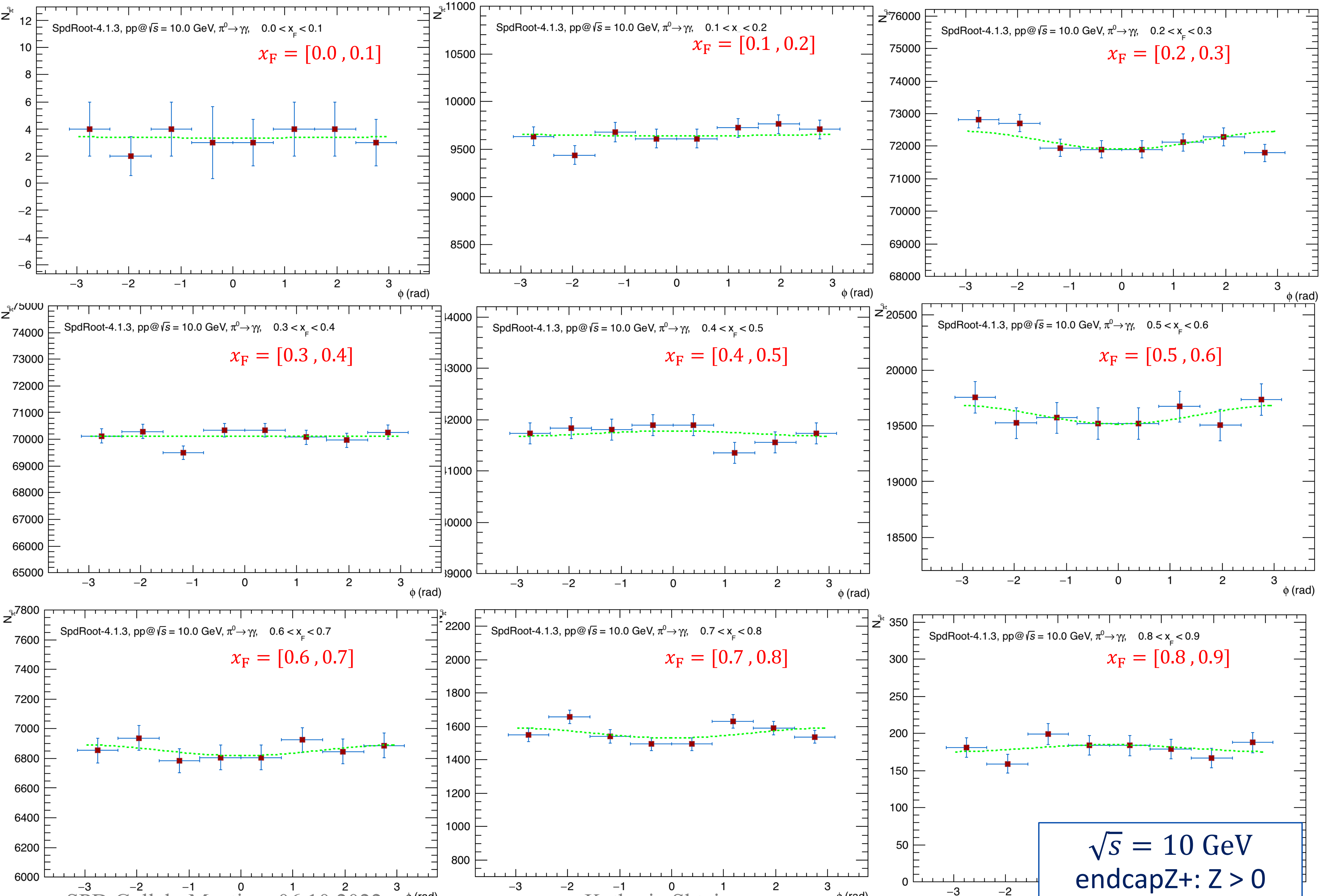
- The cosine modulation fittings were performed for two cases:

1- pure cosine function, 2- adding a free phase

- The spin dependent π^0 yields for each bin are extracted from the

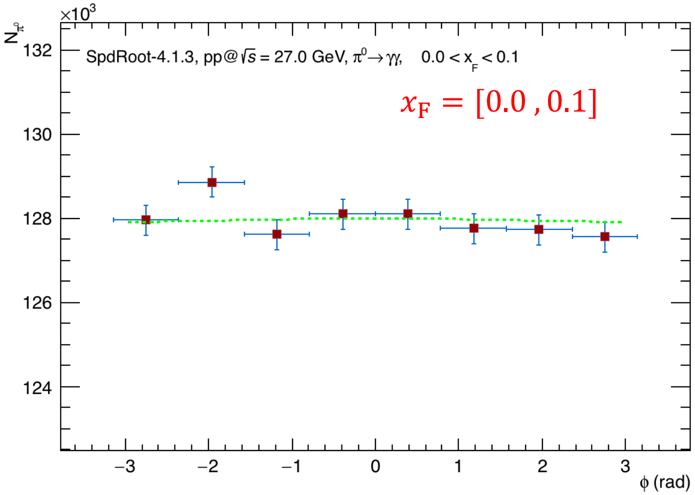
invariant mass spectra in different x_{F} sub-ranges for each φ bin.

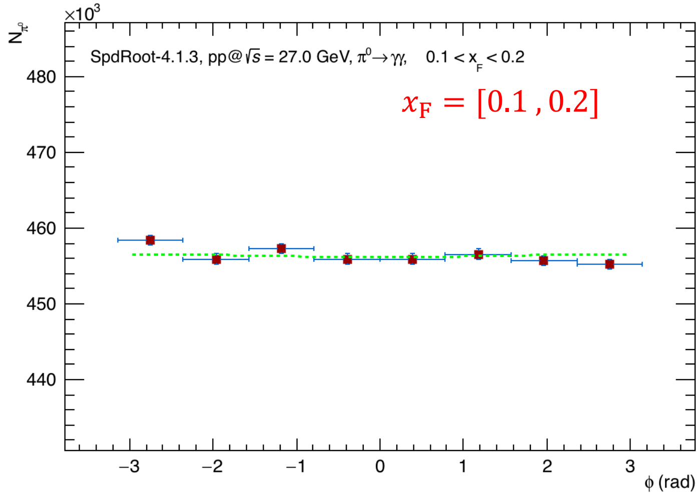
Azimuthal cosine modulation of π^0 yields in x_F intervals, $A(1+cos\varphi)$

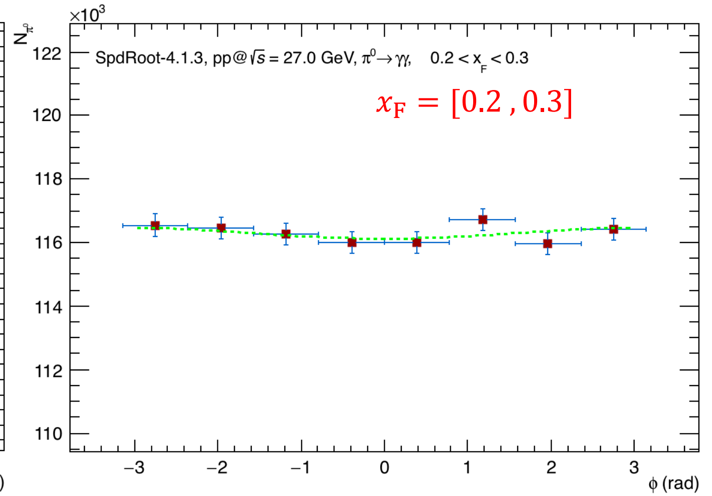


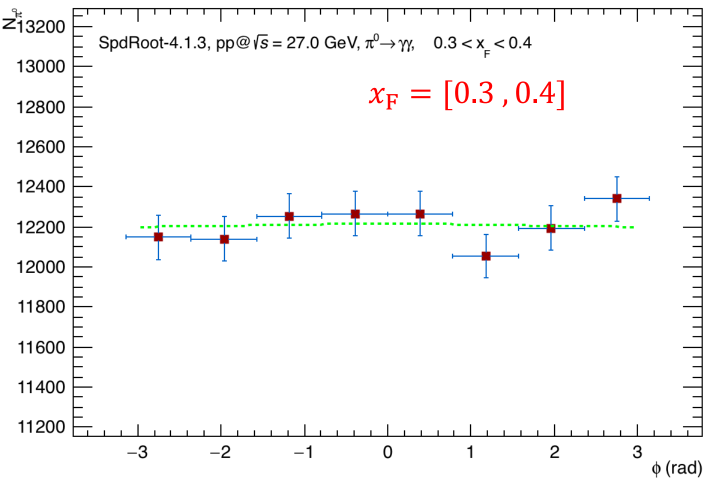
$\sqrt{s} = 10$ GeV
endcapZ+: Z > 0

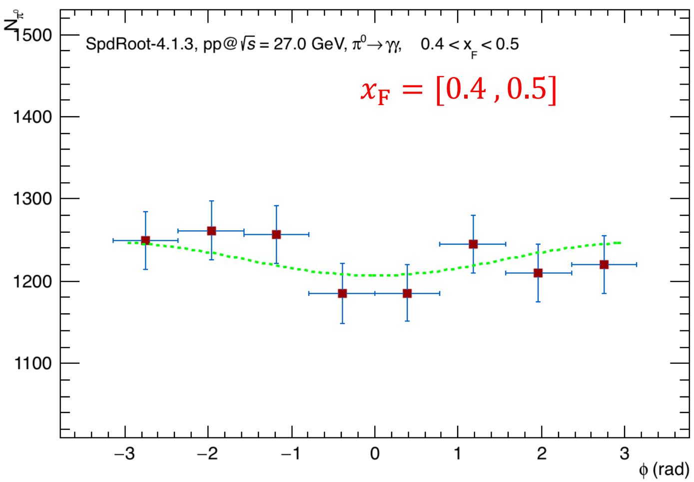
Azimuthal cosine modulation of π^0 yields in x_F intervals, $A(1+cos\varphi)$

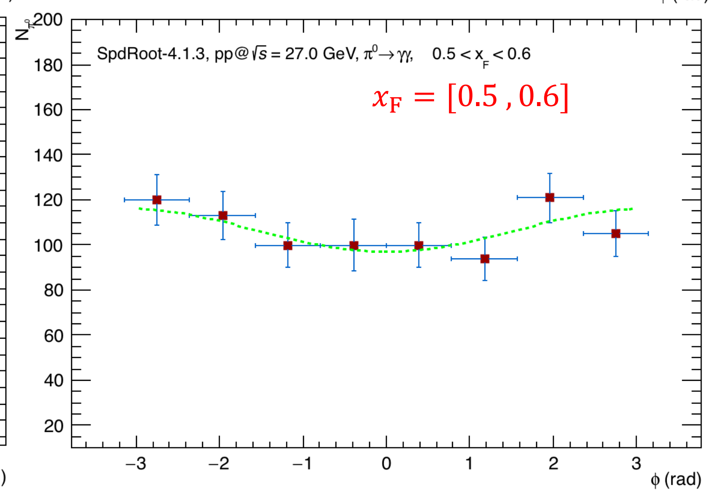


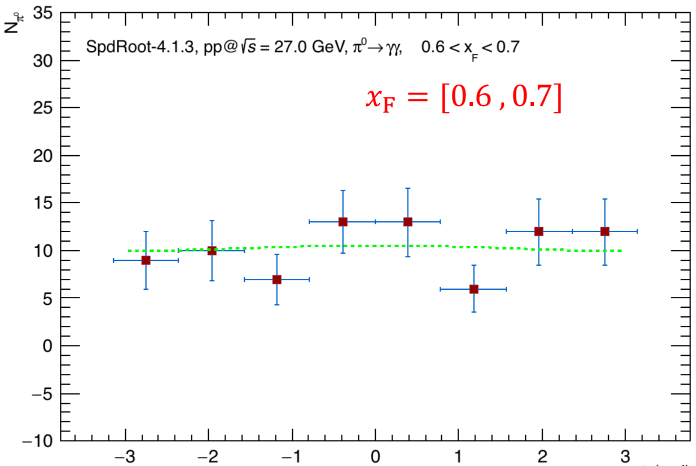


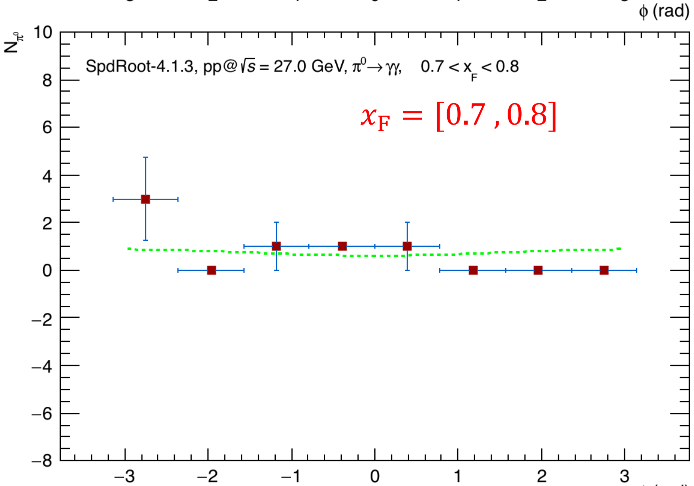






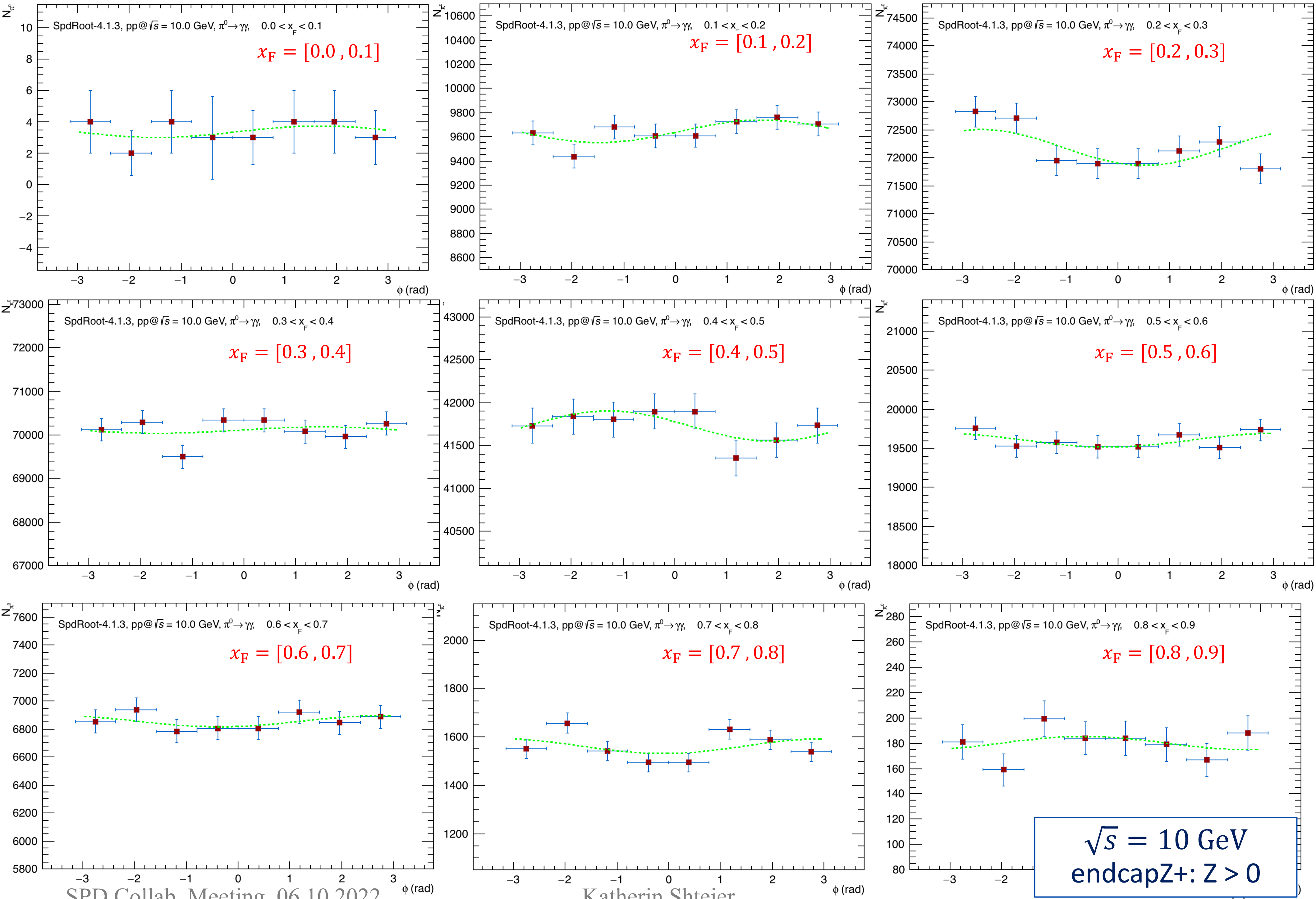




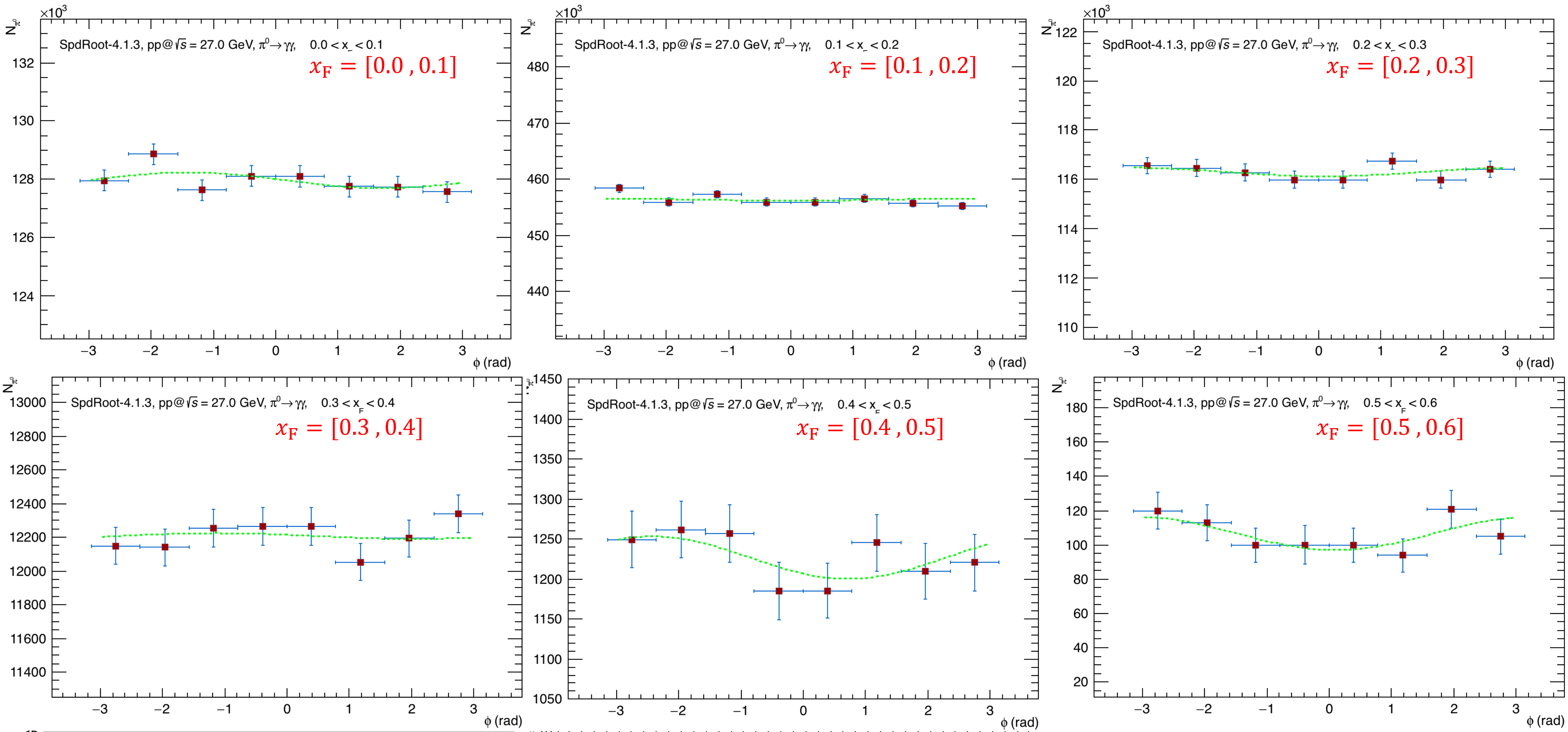


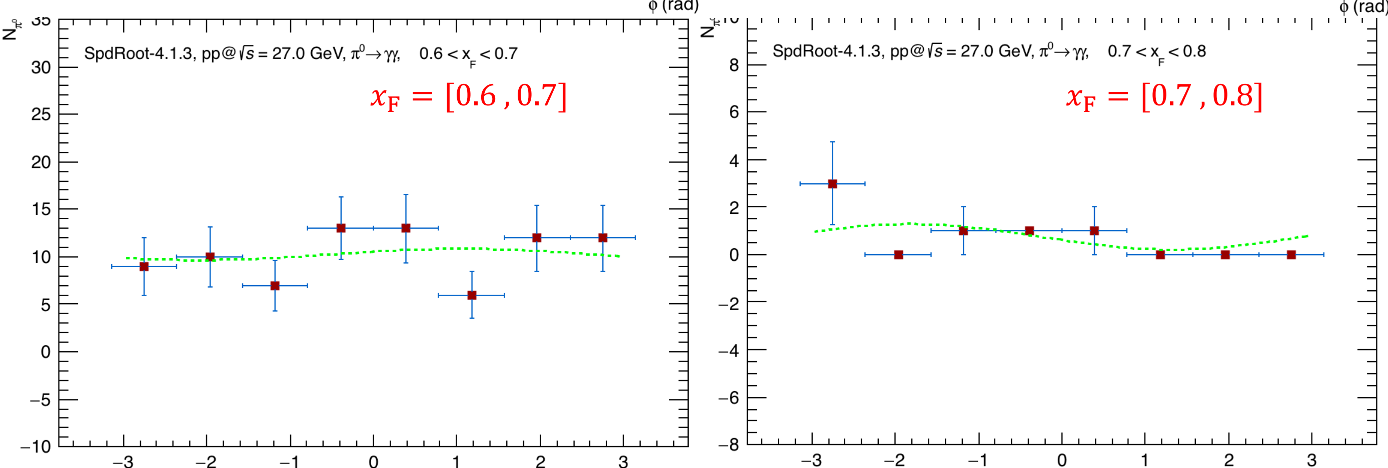
$\sqrt{s} = 27$ GeV
endcapZ+: Z > 0

Azimuthal cosine modulation of π^0 yields in x_F intervals, $A(1 + B\cos(\varphi + \varphi_0))$



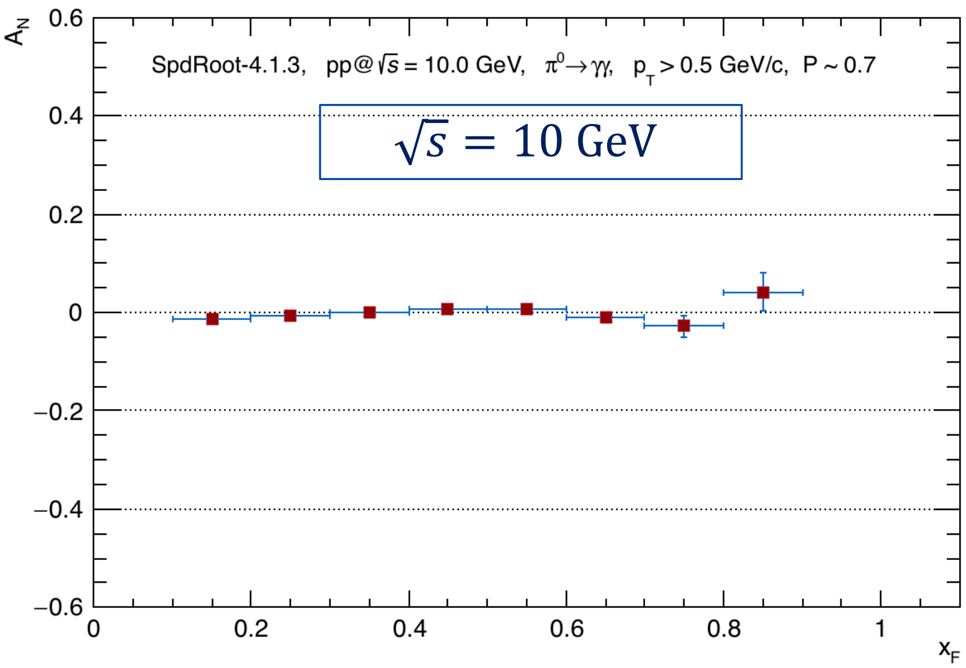
Azimuthal cosine modulation of π^0 yields in x_F intervals, $A(1 + B\cos(\varphi + \varphi_0))$

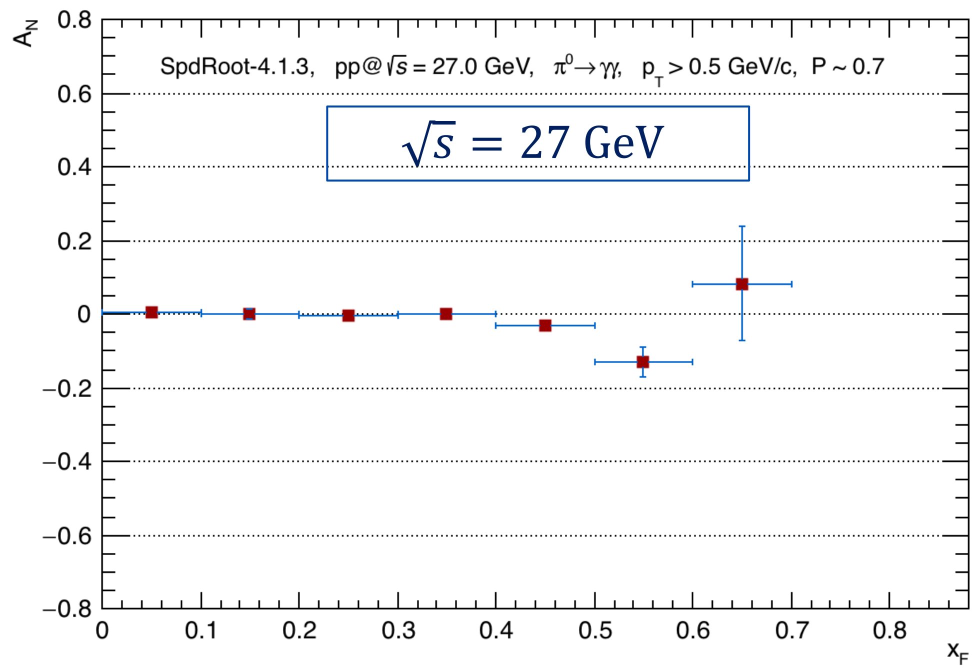




$\sqrt{s} = 27$ GeV
endcapZ+: Z > 0

A_N in x_F intervals





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

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

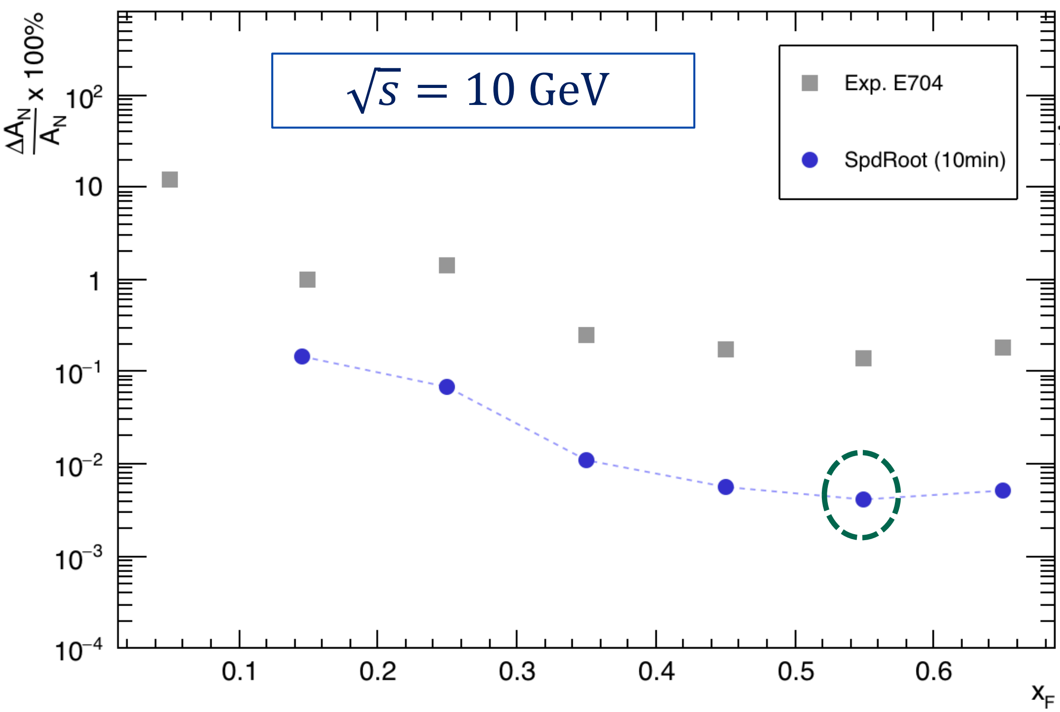
$$\frac{\Delta A_N}{A_N} \sim \frac{\Delta P}{P}$$

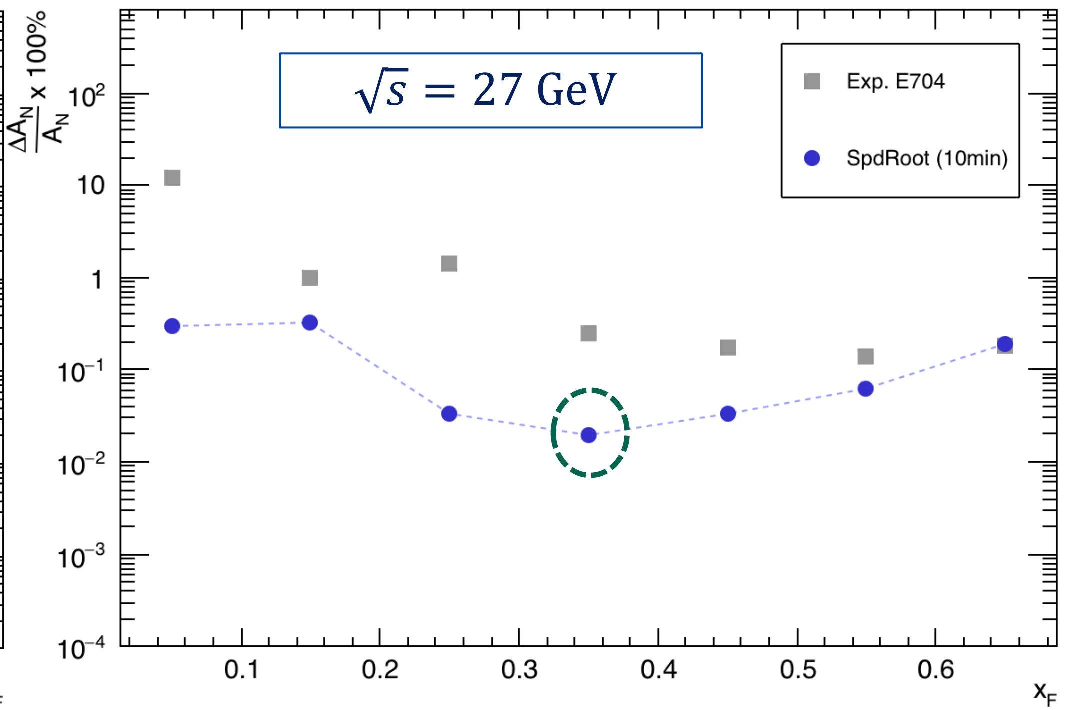
$$\frac{\Delta A_N \rightarrow \text{SpdRoot}}{A_N \rightarrow \text{E704}}$$

ΔA_N scaled to different times of data-taking (SPDRoot)

$\mathcal{L} = 10^{32} s^{-1} cm^{-2}$ $\sigma_{tot}^{pp}(10 \text{ GeV}) = 37.9$ mb $\sigma_{tot}^{pp}(27 \text{ GeV}) = 40.0$ mb

Reaction rate (10 GeV) =$3.79 \cdot 10^6 s^{-1}$ Reaction rate (27 GeV) = $4 \cdot 10^6 s^{-1}$





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

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

Pure cosine function

Relative of A_{N} error estimated (10 GeV)

x_{F}	$\frac{\Delta A_N}{A_N}$ (%)		
	SpdRoot (10min)	SpdRoot (5min)	SpdRoot (2min)
0.0 -0.1	-	-	-
0.1 -0.2	13.64	19.29	30.50
0.2 -0.3	6.79	9.60	15.18
0.3 -0.4	1.03	1.45	2.30
0.4 -0.5	0.74	1.04	1. 65
0.5 -0.6	0.39	0.55	0.86
0.6 -0.7	0.50	0.71	1.12

Relative of A_{N} error estimated 27 GeV

x_{F}	$\frac{\Delta A_N}{A_N}$ (%)		
	SpdRoot (10min)	SpdRoot (5min)	SpdRoot (2min)
0.0 -0.1	31.69	44.82	70.87
0.1 -0.2	2.69	3. 81	6.03
0.2 -0.3	3.11	4. 40	6.96
0.3 -0.4	1.78	2.52	3.98
0.4 -0.5	3.50	4.95	7.83
0.5 -0.6	5.67	8.02	12.68
0.6 -0.7	17.23	24.37	38.53

With a free phase included

Relative of A_{N} error estimated (10 GeV)

x_{F}	$\frac{\Delta A_N}{A_N}$ (%)		
	SpdRoot (10min)	SpdRoot (5min)	SpdRoot (2min)
0.0 -0.1	-	-	-
0.1 -0.2	10.43	14.75	23.32
0.2 -0.3	6.76	9.55	15.11
0.3 -0.4	1.08	1.52	2.41
0.4 -0.5	0.57	0.80	1. 27
0.5 -0.6	0.41	0.57	0.91
0.6 -0.7	0.52	0.74	1.17

Relative of A_{N} error estimated 27 GeV

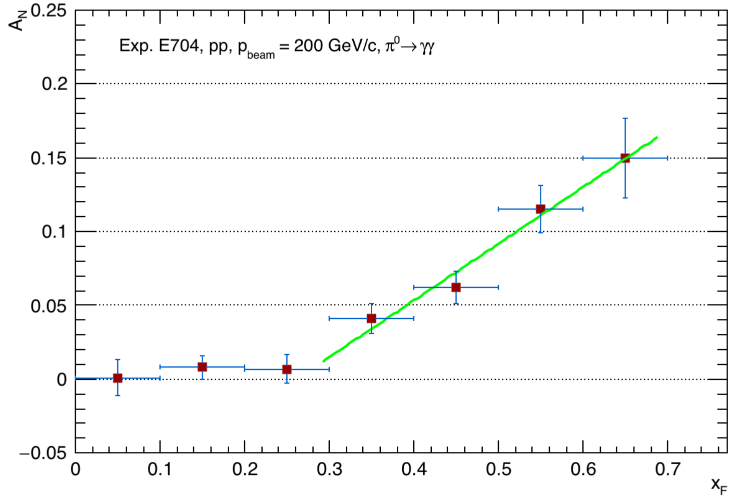
x_{F}	$\frac{\Delta A_N}{A_N}$ (%)		
	SpdRoot (10min)	SpdRoot (5min)	SpdRoot (2min)
0.0 -0.1	30.33	42.89	67.81
0.1 -0.2	31.89	45.10	71.32
0.2 -0.3	3.41	4. 82	7.62
0.3 -0.4	1.93	2.74	4.33
0.4 -0.5	3.36	4.75	7.50
0.5 -0.6	6.18	8.73	13.82
0.6 -0.7	18.69	26.43	41.79

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]*

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

Pure cosine function

Estimated time	$\frac{\Delta P}{P}$ $\sqrt{s}$ = 10 GeV	$\frac{\Delta P}{P}$ $\sqrt{s}$ = 27 GeV
2 min	0.61 %	3.41 %
5 min	0.39 %	2.15 %
10 min	0.27 %	1.52 %

Free phase included

Estimated time	$\frac{\Delta P}{P}$ $\sqrt{s}$ = 10 GeV	$\frac{\Delta P}{P}$ $\sqrt{s}$ = 27 GeV
2 min	0.62 %	4.59 %
5 min	0.39 %	2.90 %
10 min	0.28 %	2.05 %

Summary

- The inclusive $pp \to \pi^0 X$ 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 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 $0.3 < x_F < 0.4$ at 27 GeV, while at 10 GeV is better for $0.5 < x_F < 0.6$.

- From the asymmetry determination, based on SPDRoot simulations, the statistical accuracy of the beam polarization is estimated in:

$\sqrt{s}$ = 10 GeV

- 2 minutes: $\frac{\Delta P}{P} \sim$**0.60%**
- 5 minutes: $\frac{\Delta P}{P} \sim$**0.38%**
- 10 minutes: $\frac{\Delta P}{P} \sim$**0.27%**

$\sqrt{s}$ = 27 GeV

- 2 minutes: $\frac{\Delta P}{P} \sim$**4.59%**
- 5 minutes: $\frac{\Delta P}{P} \sim$**2.90%**
- 10 minutes: $\frac{\Delta P}{P} \sim$**2.05%**