The inclusive π^0 on the SPD-ECAL endcaps for online polarimetry

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Generation

- SpdRoot version 4.1.6
- pp @ $\sqrt{s} = 27$ GeV
- Particle generator: Pythia 8
  (number of events: $1.8 \cdot 10^8$)
- Minimum Bias
- Vertex assumed at (0, 0, 0): Gaussian smeared: $\sigma_z = 30\ cm$ and $\sigma_{x,y} = 0.1\ cm$

$$\sqrt{s} = 27 \text{ GeV}$$

$$\mathcal{L} \approx 10^{32} cm^{-2} s^{-1} \qquad \sigma_{\text{pp}} = 40 \text{ mb}$$

$$\mathcal{R} = \mathcal{L} \cdot \sigma = 4 \cdot 10^6 s^{-1}$$

$$N_{ev} = 1.8 \cdot 10^8$$

$$t_{mc} = N_{ev} \cdot \frac{1}{\mathcal{R}} = 46.8\ sec$$

Realistic reconstruction

- Focus on the “ECAL” reconstructed particle
- Identified the cluster to which the particle belongs
- Position and energy taken from cluster$^{(*)}$
- Selected clusters that belong to the ECAL endcaps

$^{(*)}$ *Cluster splitting is not available yet.*

- Cuts: $E_\gamma > 400$ MeV, $p_T > 0.5$ GeV/c
- Candidates to π^0 selected from $\gamma\gamma$ combinations (invariant mass)
- Photon candidates:
  - ✓ no especial constraint is applied to select photons (i.e. pdg-based filtering)
  - ✓ candidates to π^0 selected from all possible $\gamma\gamma$ combinations (invariant mass)
- Fitting the invariance mass distribution: $gausn + pol2$

$$f(x) = [p0] \cdot exp(-0.5 \cdot ((x - [p1])/[p2]) \cdot ((x - [p1])/[p2]))/(sqrt(2\pi) \cdot [p2])$$

$$+ [p3] + [p4] \cdot x + [p5] \cdot pow(x, 2)$$

- The yield is extracted from the integral of the fit function in certain limits, using the parameters of the Gaussian "signal" peak.
- The integral errors are calculated using the parameter uncertainties and the covariance matrix obtained from the fit.

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

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

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

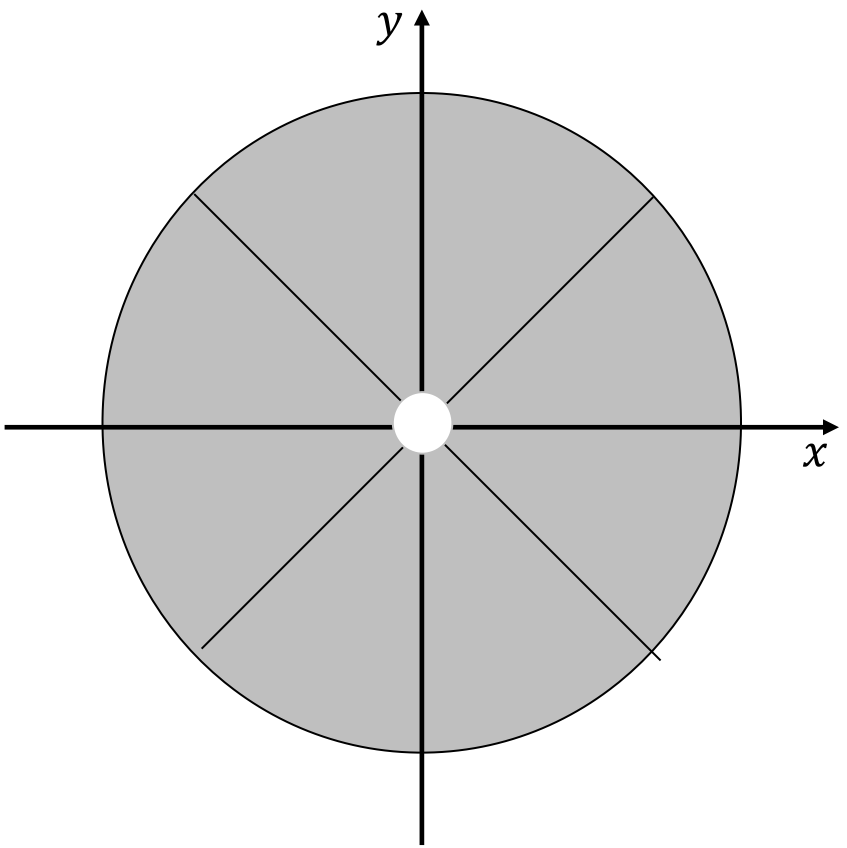
$$N_{\boldsymbol{\pi^0}}(\varphi) = A[1 + P \cdot A_N \cdot \cos(\varphi + \varphi_0)]$$

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

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

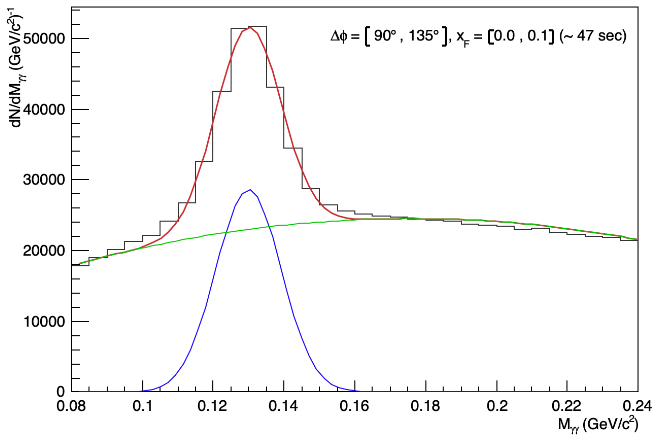
P: Beam polarization

- P = 0.7 was assumed

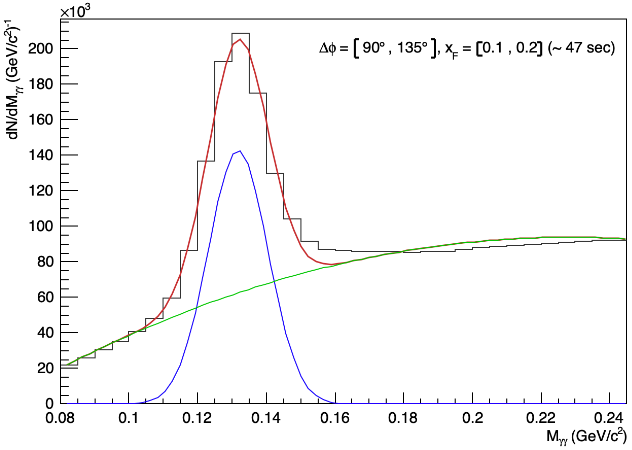


The spin dependent π^0 yields for each bin are extracted from the invariant mass spectra in different x_{F} sub-ranges for each φ bin.

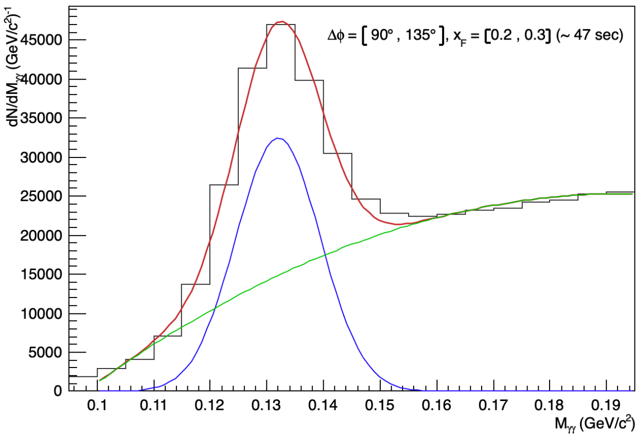
$x_{\mathrm{F}} = [0.0 - 0.1]$



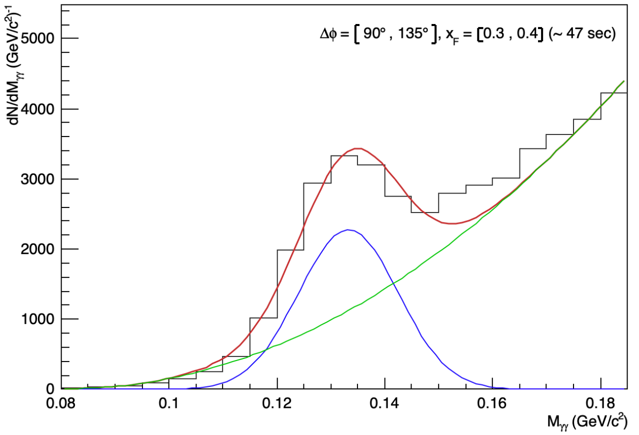
$x_{\mathrm{F}} = [0.1 - 0.2]$



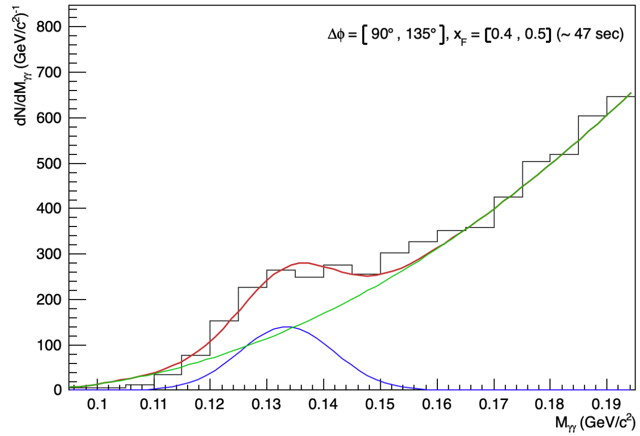
$x_{\mathrm{F}} = [0.2 - 0.3]$



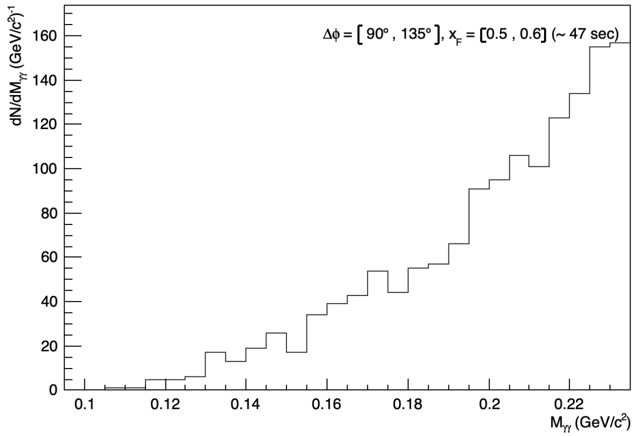
$x_{\mathrm{F}} = [0.3 - 0.4]$



$x_{\mathrm{F}} = [0.4 - 0.5]$



$x_{\mathrm{F}} = [0.5 - 0.6]$

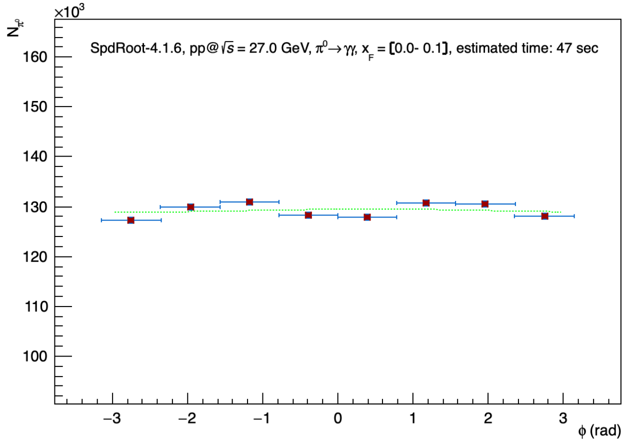


$Fit: gausn + pol2$

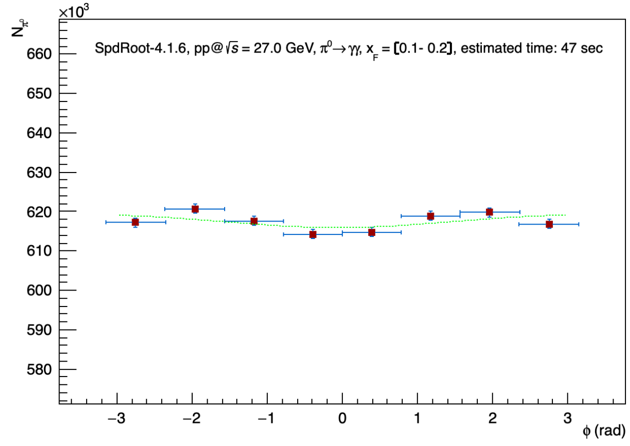
$\Delta\phi = 90\,, 135\; deg$

Azimuthal cosine modulation of π^0 yields in x_F intervals

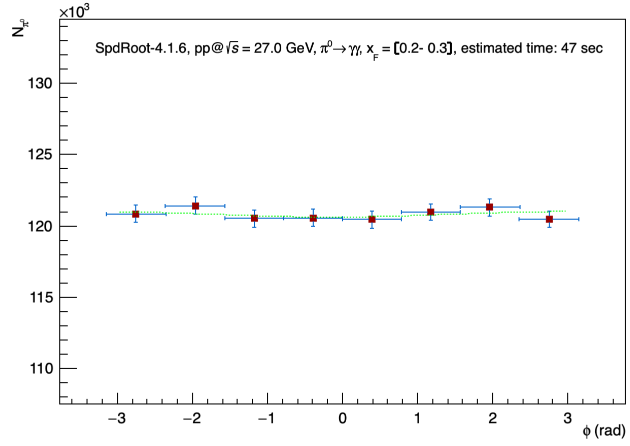
$x_F = [0.0 - 0.1]$



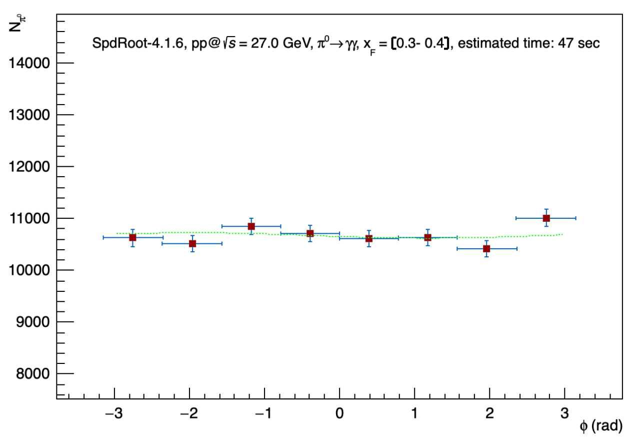
$x_F = [0.1 - 0.2]$



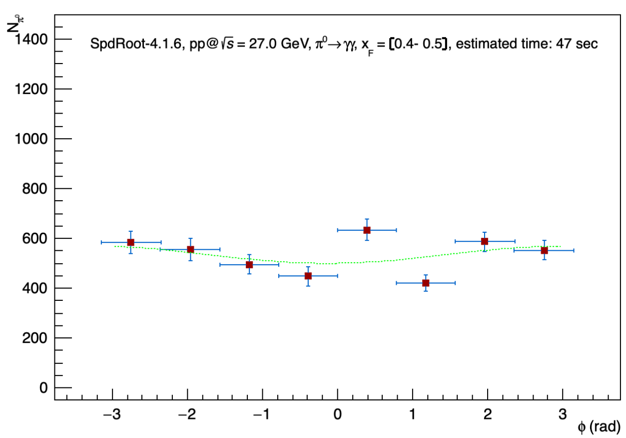
$x_F = [0.2 - 0.3]$



$x_F = [0.3 - 0.4]$



$x_F = [0.4 - 0.5]$



Azimuthal cosine modulation:

$$[p0] \cdot (1 + \underbrace{[p1]}_{P \cdot A_N} \cdot \cos([p2] + x))$$

$(P \sim 0.7)$

The modulation size is expected to be zero in unpolarized Monte Carlo simulations.

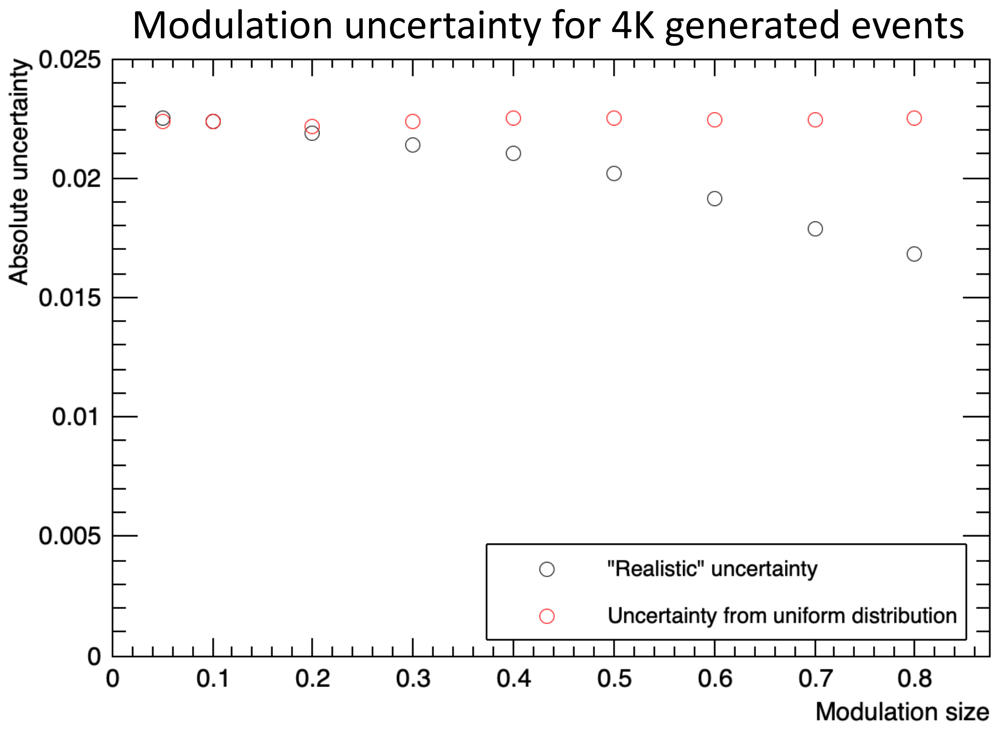
How reliable is to extract the statistical uncertainty of the amplitude modulation of a flat distribution?

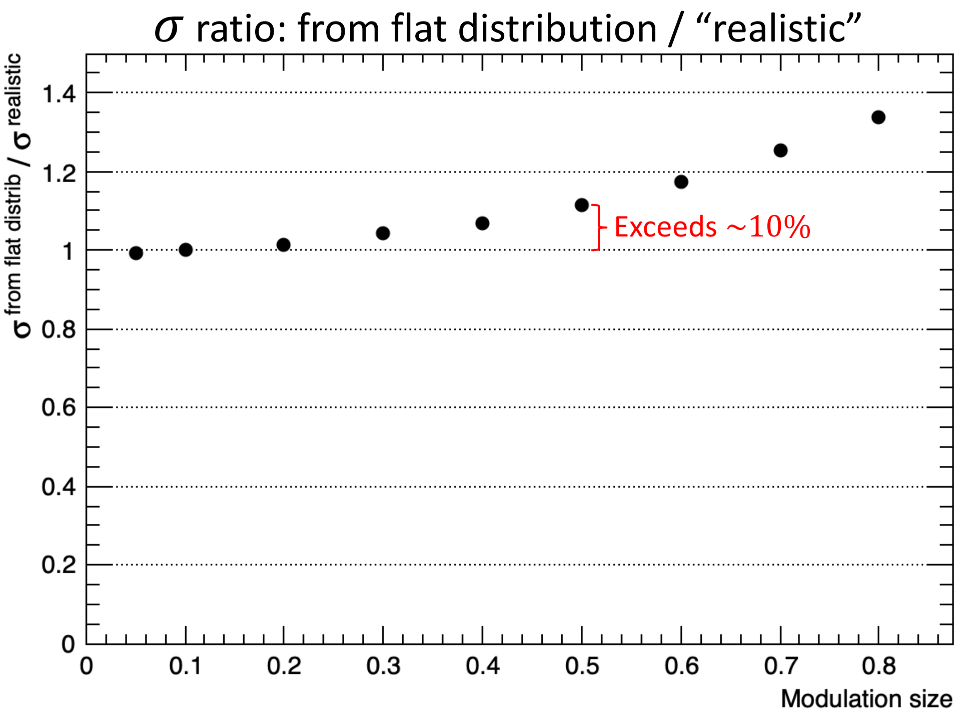
Statistical uncertainty of uniformly distributed A_N?

Contribution from Igor Denisenko!

The reliability of extracting the statistical uncertainty of A_N from the fit $c \cdot (1 + A_N \cdot \cos(\phi + b))$ of a flat distribution is evaluated using a toy modelling.

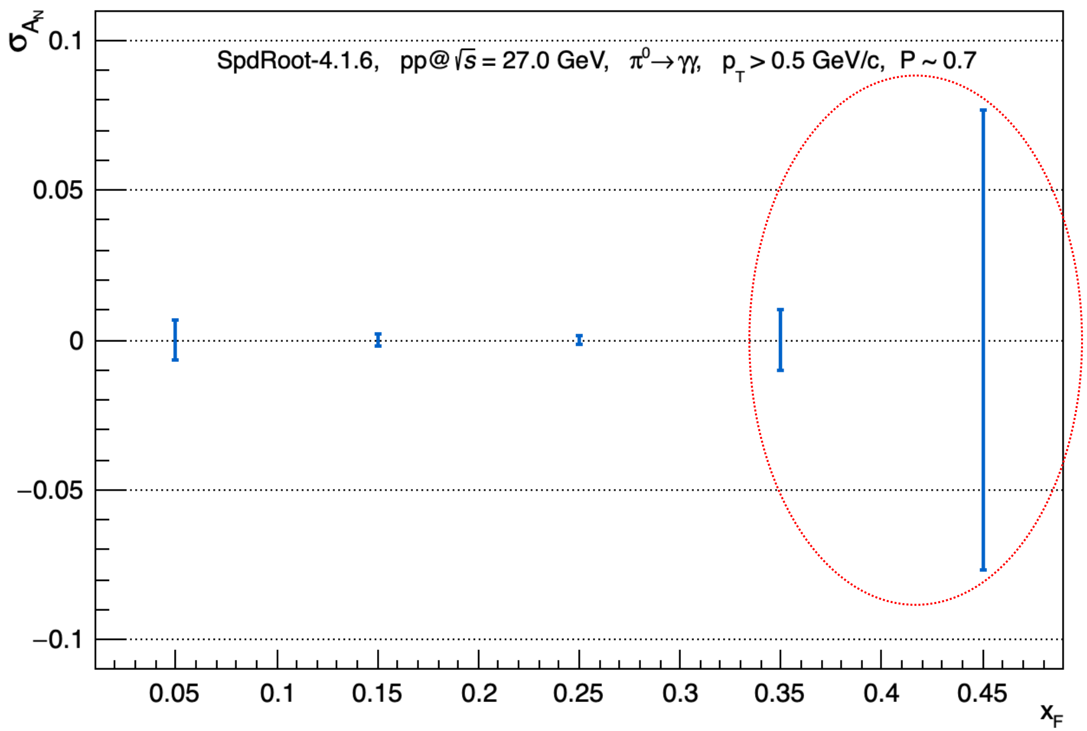
- Two distributions are generated $\begin{cases} f = 1 + [0] \cdot \cos(x).\ [-\pi, \pi] \\ f_0 = 1\ [-\pi, \pi] \end{cases}$
- Both are fitted with a cosine modulation function
- The σ_{A_N} is extracted in both cases



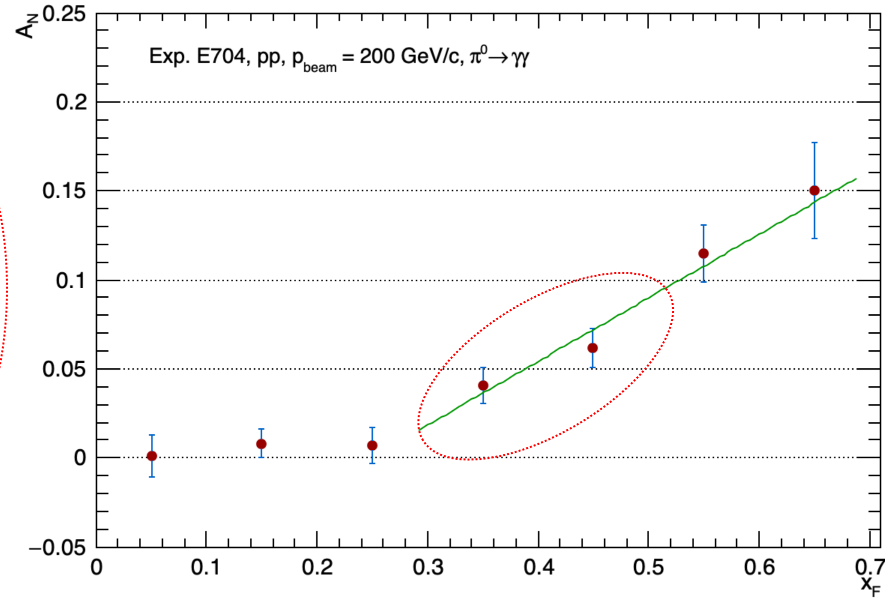


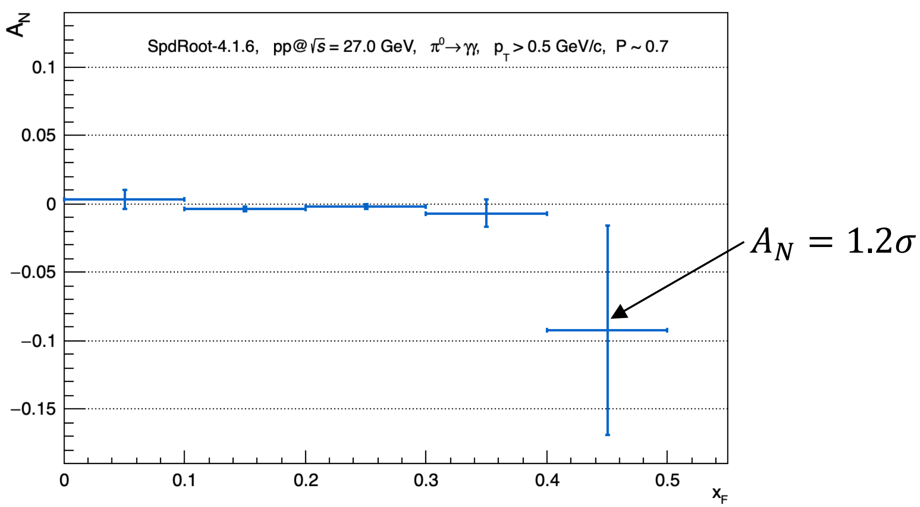
The statistical uncertainty of the amplitude modulation can be reasonably estimated for $A_N \approx 0$

A_N vs. x_F (spdroot)



Experiment E704 (1991)





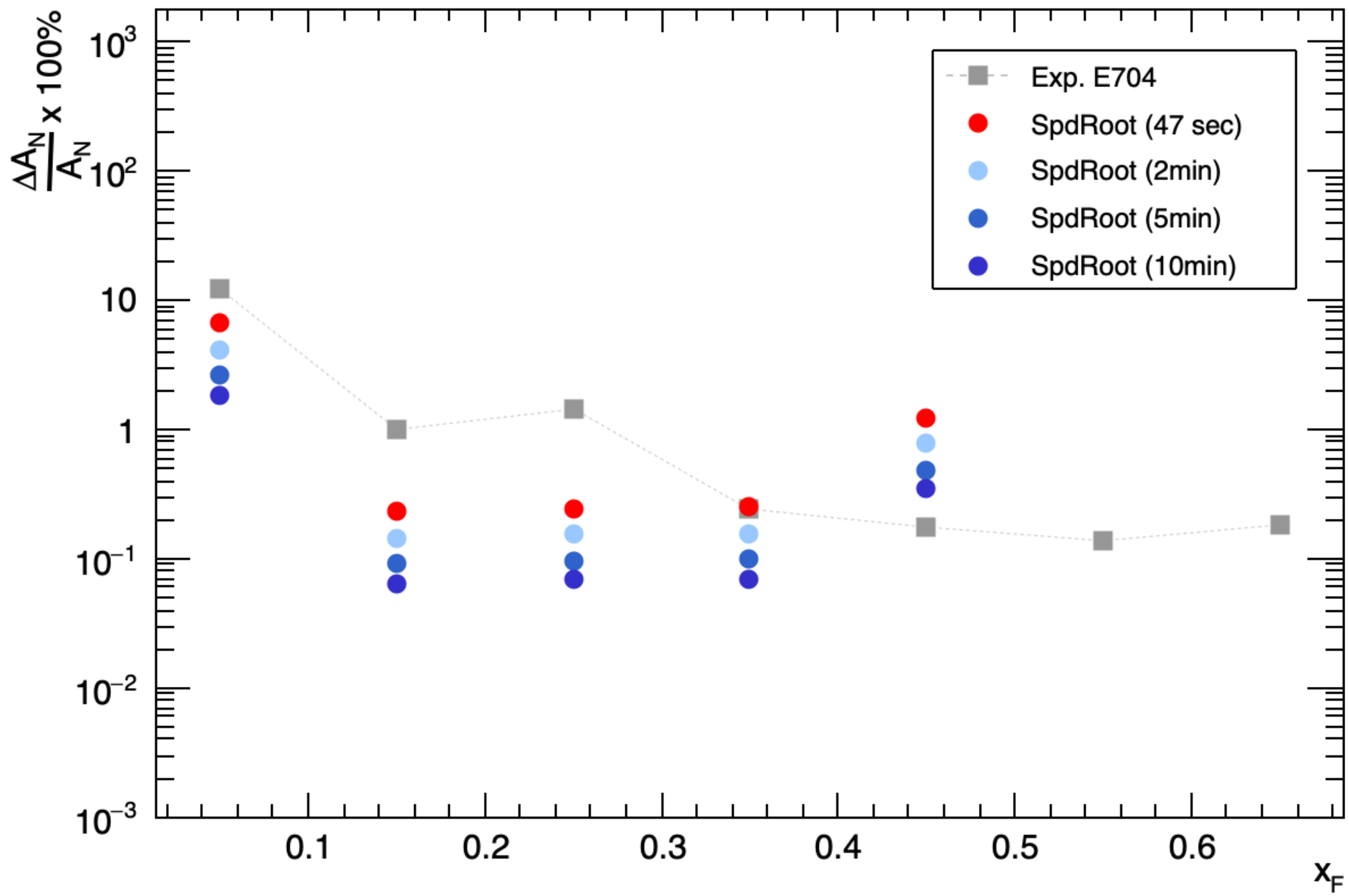
$\frac{\Delta A_N}{A_N}$ — ΔA_N → SpdRoot; A_N → E704

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

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

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

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

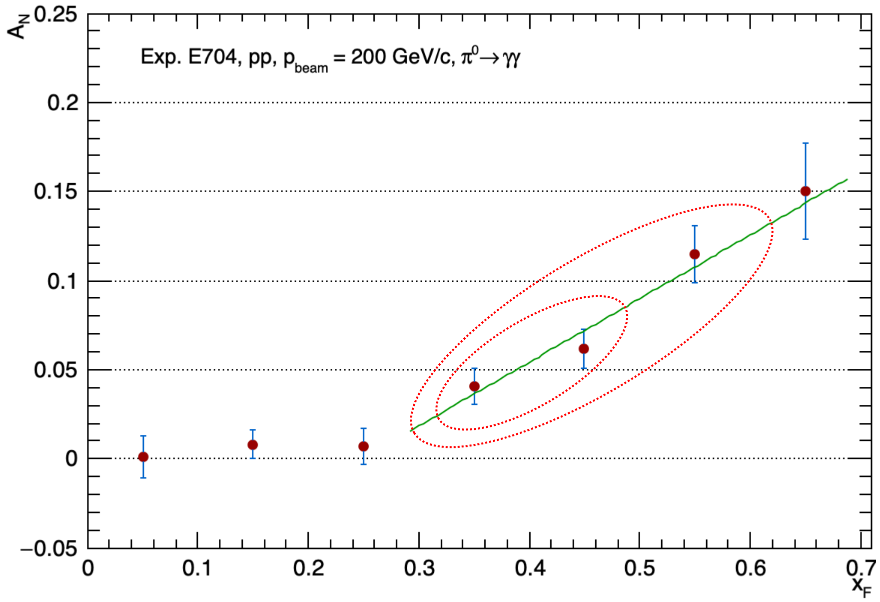


Better precision of the polarization measurement expected at:
$0.1 < x_F < 0.2$ ($\sqrt{s} = 27$ GeV)

Estimated relative error of the polarization

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

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



Taking **3** experimental points $(0.3 \leq x_F < 0.6)$: $\frac{\Delta P}{P} = 0.0998$ → 9.9 % (Experiment E704)

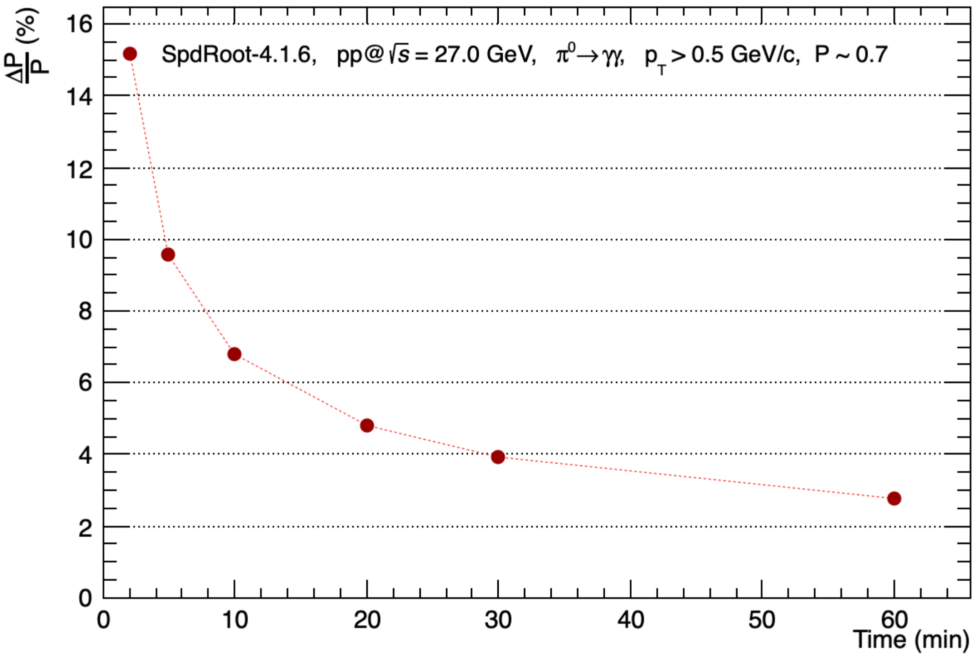
Taking **2** experimental points $(0.3 \leq x_F < 0.5)$: $\frac{\Delta P}{P} = 0.1434$ → 14.3 % (Experiment E704)

*The error of the beam polarization in the experiment **E704** is estimated in **10%***

(FERMILAB-Pub-91/15-E[E581,E704])

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

Estimated time	$\frac{\Delta P}{P}$
2 min	15.1 %
5 min	9.6 %
10 min	6.8 %
20 min	4.8 %
30 min	3.9 %
1 h	2.8 %



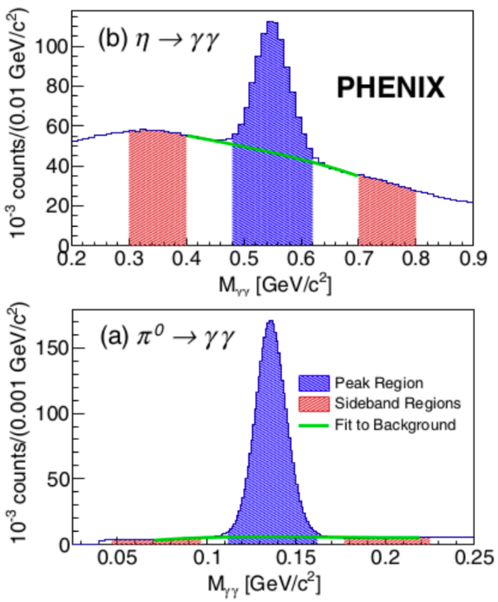
Summary of the first part

- ✓ The energy and position of π^0 decayed photons in the endcaps of the SPD ECAL are quantities which are accessible online, with no necessity of particle identification or vertex reconstruction.

- ✓ The accuracy of the beam polarization has been estimated for *pp* collisions at $\sqrt{s} = 27\ \mathrm{GeV}$ by Monte Carlo simulations based on SpdRoot-4.1.6

- ✓ Based on the azimuthal asymmetry of π^0 detected in the ECAL-endcaps, the accuracy of the beam polarization has been estimated at **9.6% for 5 min.** of data taking, assuming an **average polarization of 0.7**.

Another approach: projected statistical uncertainty of A_N



1) **Raw asymmetry:**

$$A_N(\phi) = \frac{1}{P\langle|\cos(\phi)|\rangle} \frac{N^{\uparrow}(\phi) - \mathcal{R} \cdot N^{\downarrow}(\phi)}{N^{\uparrow}(\phi) + \mathcal{R} \cdot N^{\downarrow}(\phi)}$$

$\boldsymbol{N(\phi)}$: counts in ϕ bins

$\boldsymbol{P}$: beam polarization

$\frac{\mathbf{1}}{\langle|\boldsymbol{cos(\phi)}|\rangle}$: azimuthal acceptance correction factor

$\langle|\boldsymbol{cos(\phi)}|\rangle = \frac{\int_{\phi_1}^{\phi_2} \cos(\phi) d\phi}{\phi_2 - \phi_1}$: average of the cosine of azimuth in the ϕ bin

$\boldsymbol{\mathcal{R}} = \mathcal{L}^{\uparrow}/\mathcal{L}^{\downarrow}$: relative luminosity

2) **Statistical uncertainty of A_N:**

$$\sigma_{A_N}(\phi) = \frac{1}{P\langle|\cos(\phi)|\rangle} \frac{1}{\sqrt{2N}}$$

$\mathcal{R} \sim 1$

$N^{\uparrow} \sim N^{\downarrow} = N$

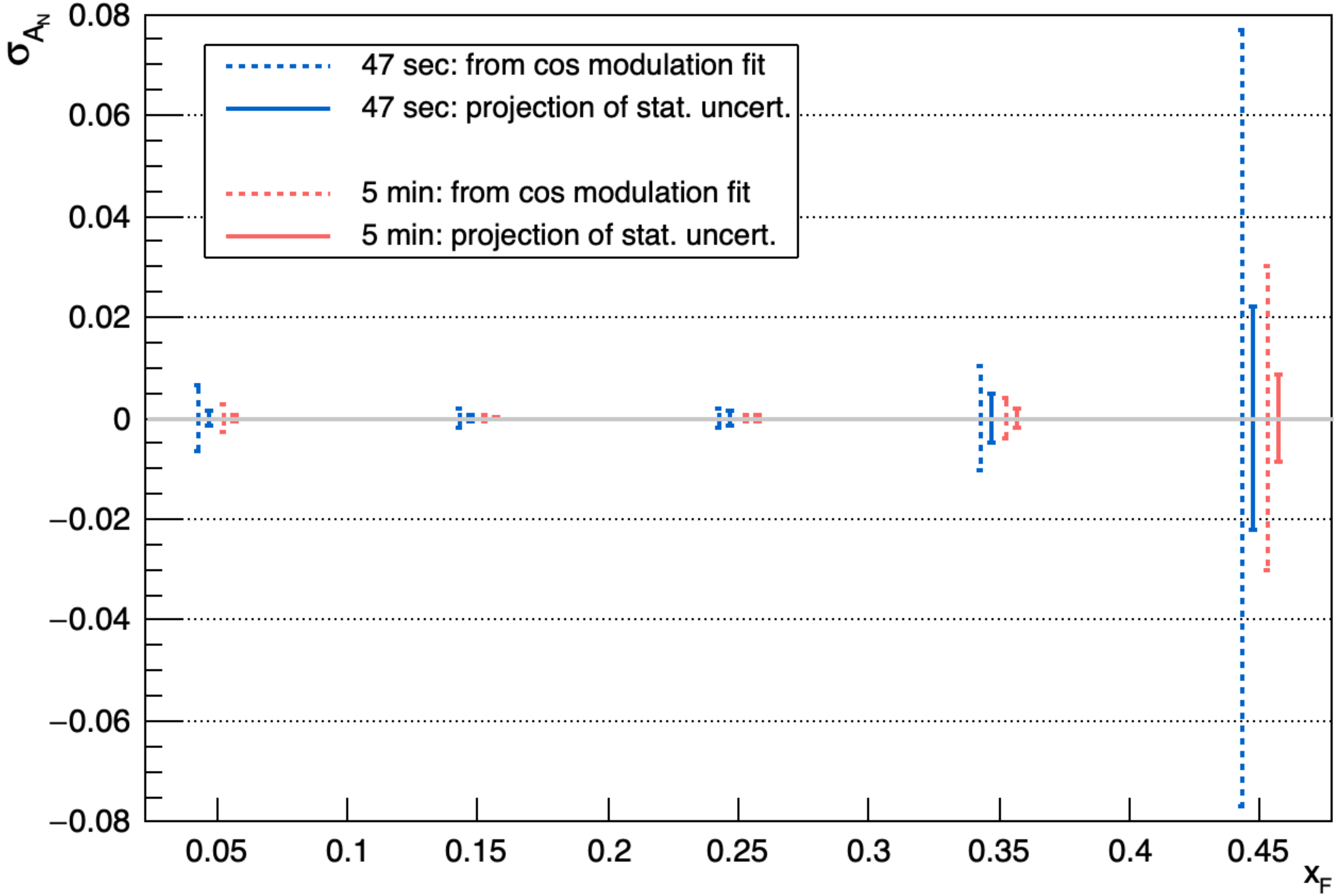
$\sigma_N = \sqrt{N}$: Poisson distribution of N

3) **The statistical uncertainties estimated independently for each $\boldsymbol{\phi}$ bin, $\boldsymbol{\sigma_{A_N}(\phi)}$, can be averaged as:**

$$\sigma_{A_N^{sig}}(x_F) = \frac{1}{\sqrt{\sum_{i=1}^{8} \frac{1}{\sigma^2_{A_N^{sig}}(\phi_i)}}}$$

Amaresh's Analysis Note “Prospects of Open-Charm Asymmetry Measurements at the SPD” (*indico.jinr.ru/event/4594/attachments/18860/32246/D_Meson_Report.pdf*)

Another approach: projected statistical uncertainty of A_N



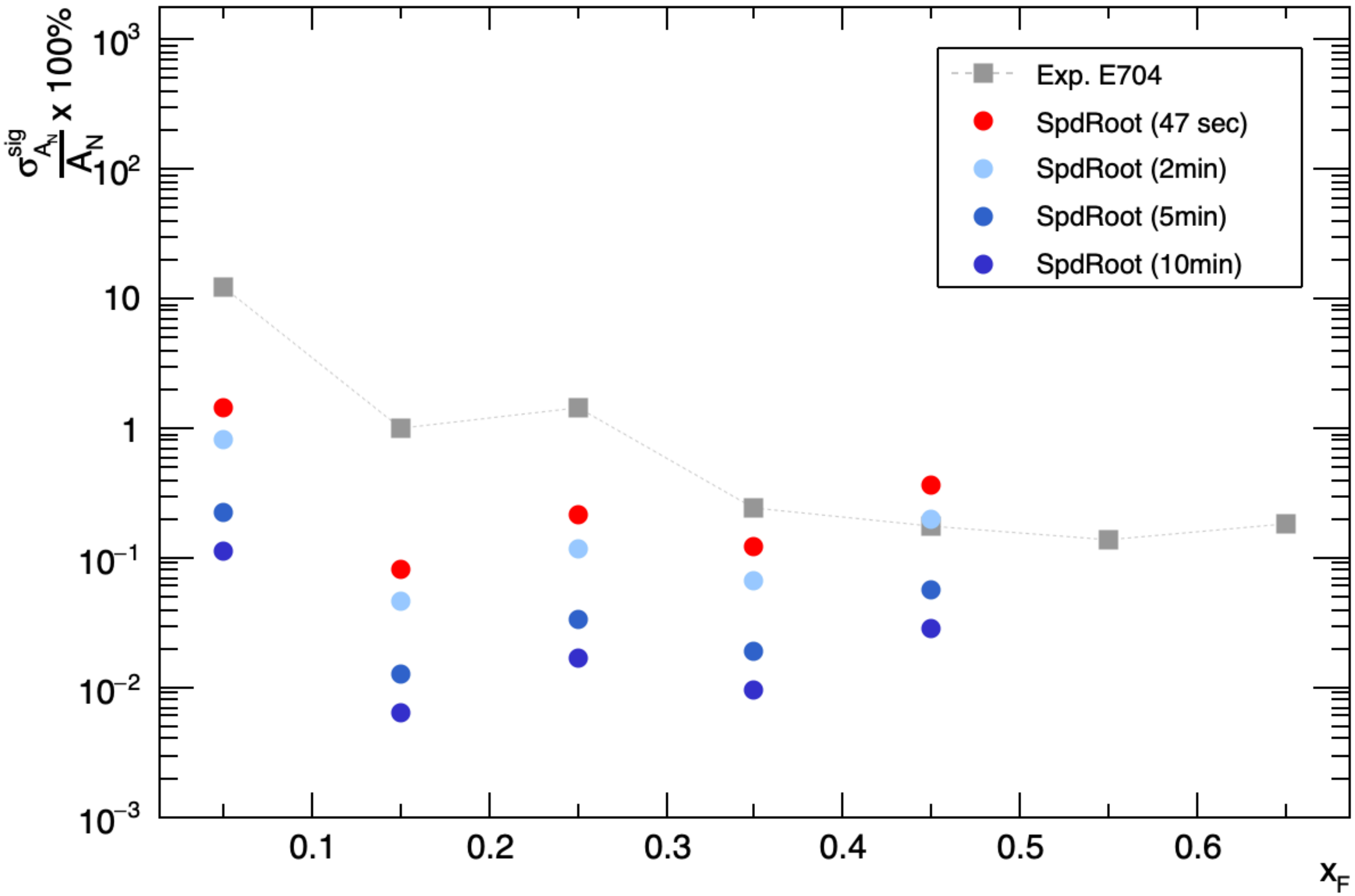
Another approach: projected statistical uncertainty of A_N

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

$\frac{\sigma^{sig}_{A_N}}{A_N}$ *vs.* x_F

$\frac{\sigma^{sig}_{A_N}}{A_N}$ — $\sigma^{sig}_{A_N}$ → SpdRoot; A_N → E704

$\frac{\sigma^{sig}_{A_N}}{A_N} \sim \frac{\Delta P}{P}$



Better precision of the polarization measurement expected at:
$0.1 < x_F < 0.2$ ($\sqrt{s} = 27$ GeV)

Method:
Calculation of the projected statistical uncertainty of A_{N}.

Estimated time	$\frac{\Delta P}{P}$
2 min	6.4 %
5 min	1.8 %
10 min	0.9 %
20 min	0.5 %
30 min	0.3 %
1 h	0.2 %

Correction for the background is needed!

Method:
Extracting the A_{N} from the modulation amplitude of the cosine function.

Estimated time	$\frac{\Delta P}{P}$
2 min	15.1 %
5 min	9.6 %
10 min	6.8 %
20 min	4.8 %
30 min	3.9 %
1 h	2.8 %