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, $p_\mathrm{T} > 0.5$ GeV$/c$

- Candidates to π^0 selected from $\gamma\gamma$ combinations (invariant mass)

- Photon candidates:

  - ✓ no especial constraint is applied to identify photons (i.e. pdg-based filtering)
  - ✓ candidates to π^0 selected from all possible $\gamma\gamma$ combinations (invariant mass)

- Fitting the invariance mass distribution: $gausn + pol2$

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

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

- Fitting the invariance mass distribution: $gausn + pol2$

$$f(x) = [p0] \cdot exp(-0.5 \cdot ((x - [p1])/[p2]) \cdot ((x - [p1])/[p2]))/(sqrt(2\pi) \cdot [p2]) + [p3] + [p4] \cdot x + [p5] \cdot pow(x, 2)$$

- Two methods to extract yield:

  ✓ Method 1: Yield from the signal, $N_{\pi^0}^{sig}$

  - The integral of the Gaussian "signal" peak, that is obtained after the background has been subtracted.

  ✓ Method 1: Yield from the raw peak, $N_{\pi^0}^{raw}$

  - The integral of the fit function in certain limits of the "raw" peak, without background subtraction.

  - The integral errors are calculated using the parameter uncertainties and the covariance matrix obtained from the fit.

Method 1: Cosine modulation fitting

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

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

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

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.

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

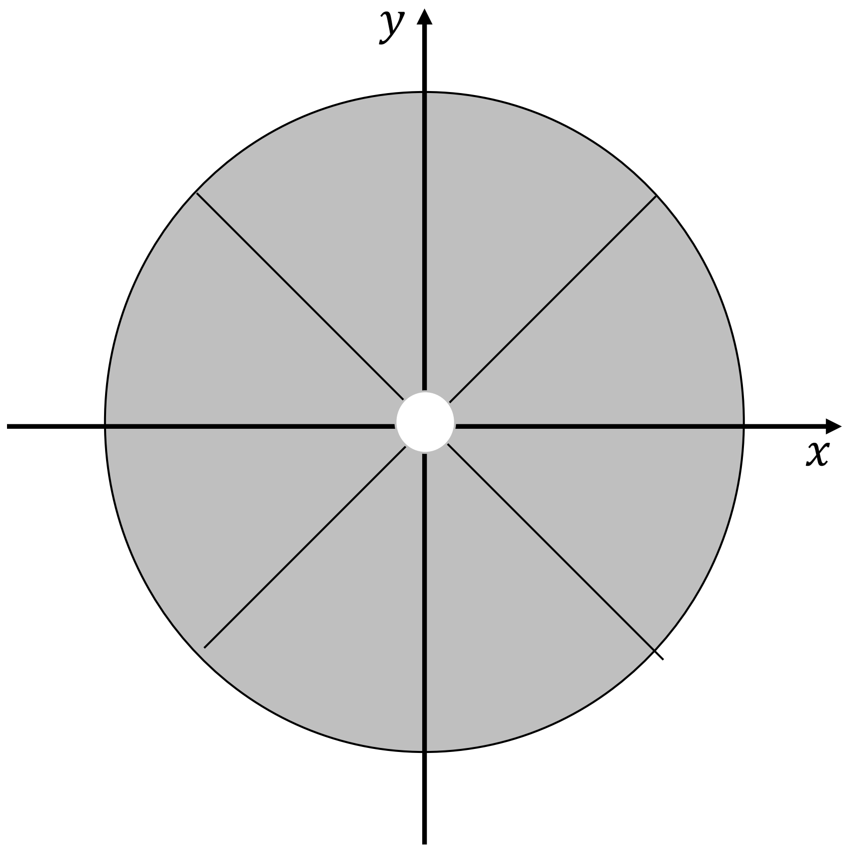
$$A_N = \frac{Amp}{P}$$

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

P: Beam polarization

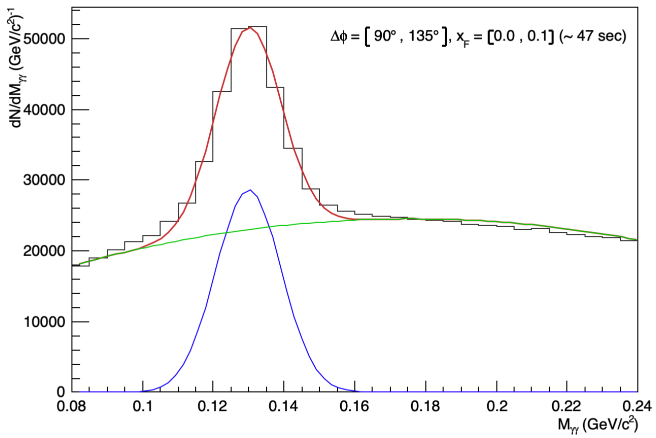
- *P* = 0.7 was assumed

$$\sigma_{A_N} = \mathrm{GetParError}(Amp)$$

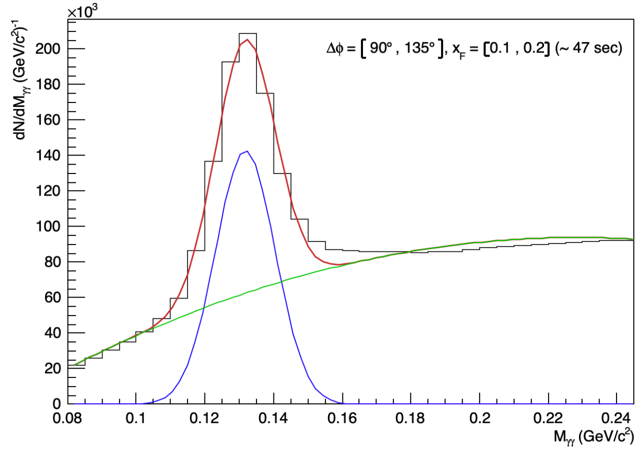


Inv. Mass $vs. x_F$, $\Delta\phi = 90 , 135\ deg$

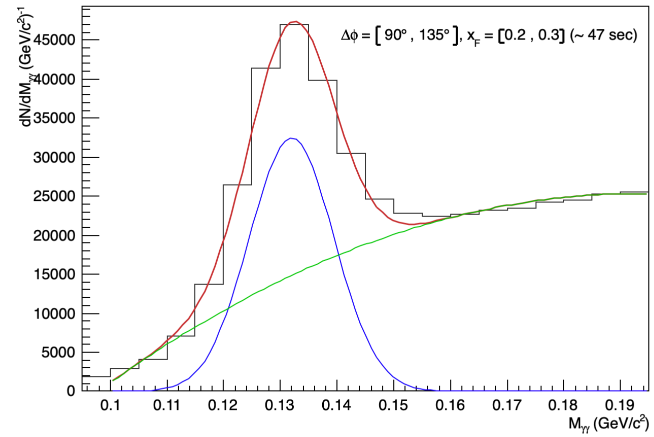
$x_F = [0.0 - 0.1]$



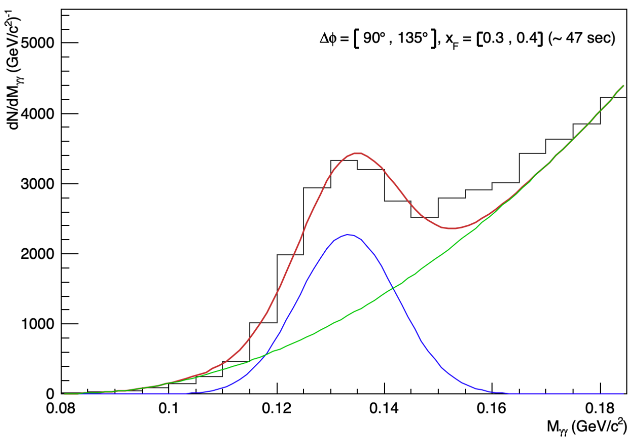
$x_F = [0.1 - 0.2]$



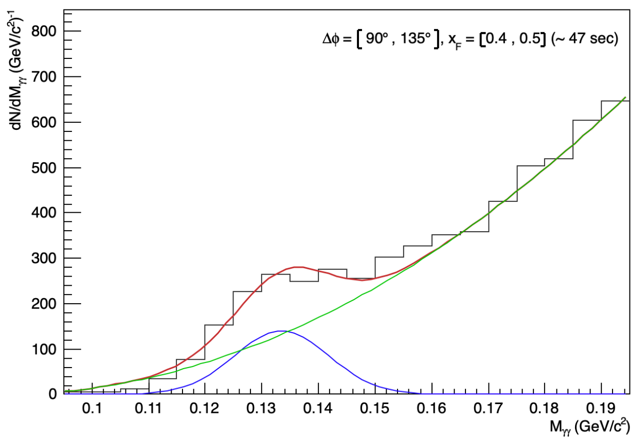
$x_F = [0.2 - 0.3]$



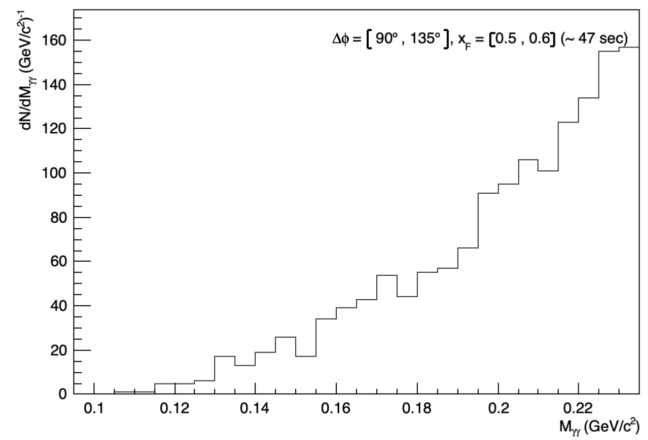
$x_F = [0.3 - 0.4]$



$x_F = [0.4 - 0.5]$



$x_F = [0.5 - 0.6]$

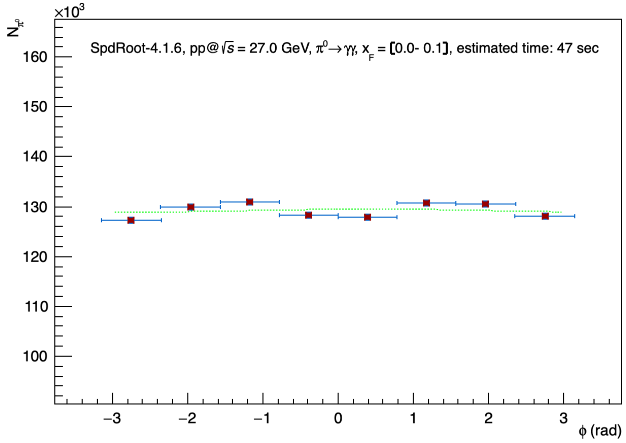


$Fit: gausn + pol2$

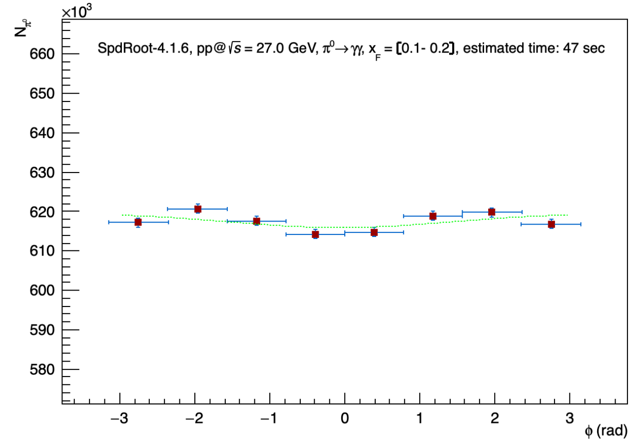
$\Delta\phi = 90 , 135\ deg$

Azimuthal cosine modulation of π^0 yields in x_F intervals

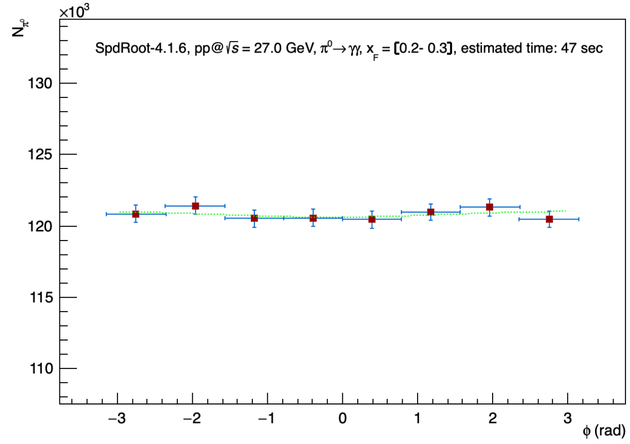
$x_F = [0.0 - 0.1]$



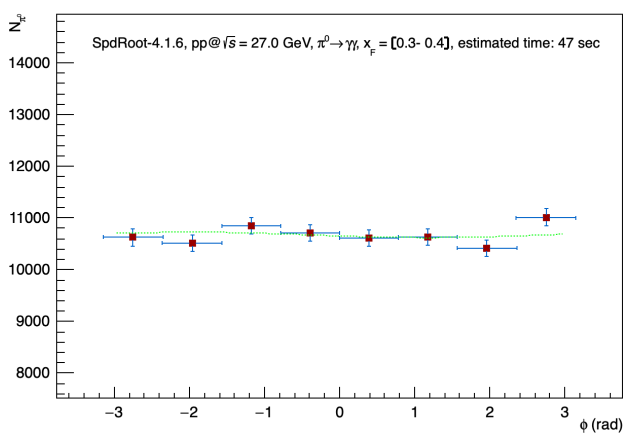
$x_F = [0.1 - 0.2]$



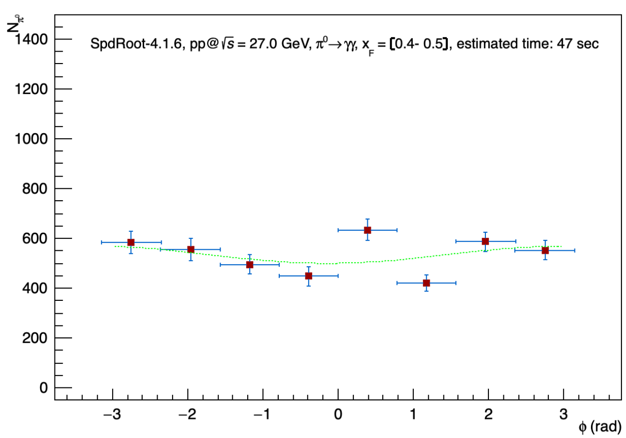
$x_F = [0.2 - 0.3]$



$x_F = [0.3 - 0.4]$



$x_F = [0.4 - 0.5]$



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.

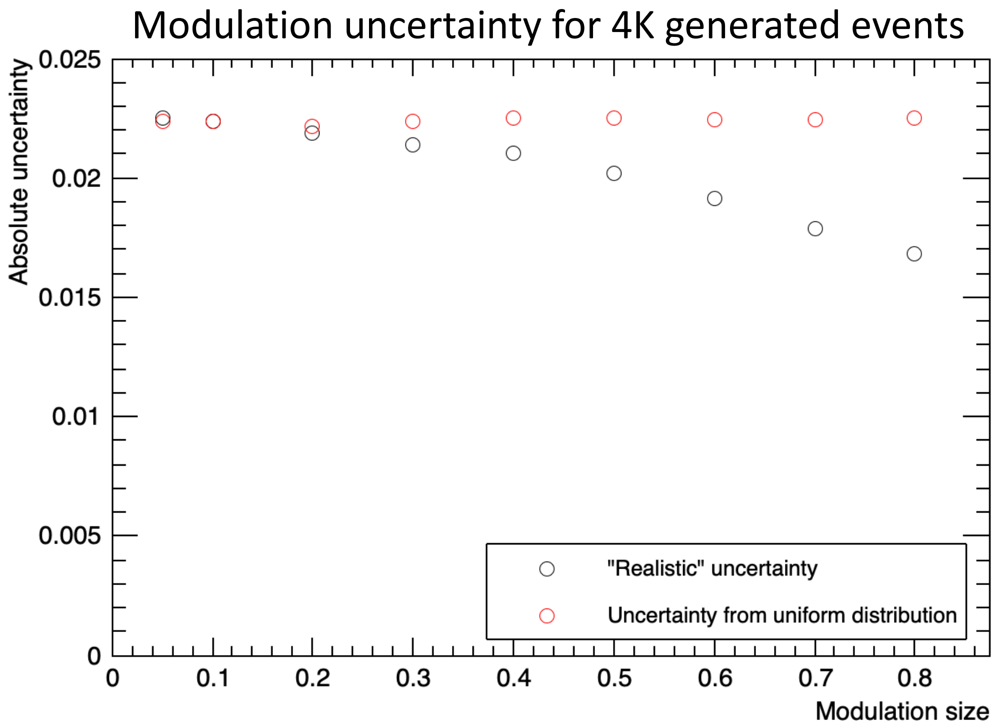
How reliable is to extract the statistical uncertainty of the amplitude modulation of a flat distribution?

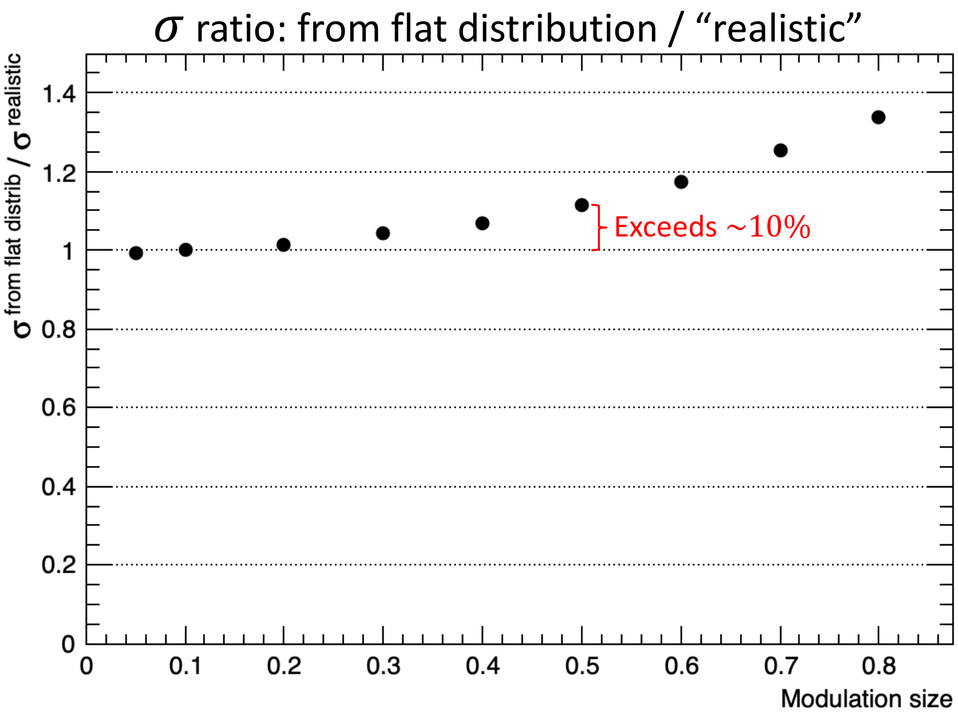
Statistical uncertainty of uniformly distributed A_N?

Contribution from Igor Denisenko!

The reliability of extracting the statistical uncertainty of A_N from the fit $c \cdot (1 + A_\mathrm{N} \cdot \cos(\phi + b))$ 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

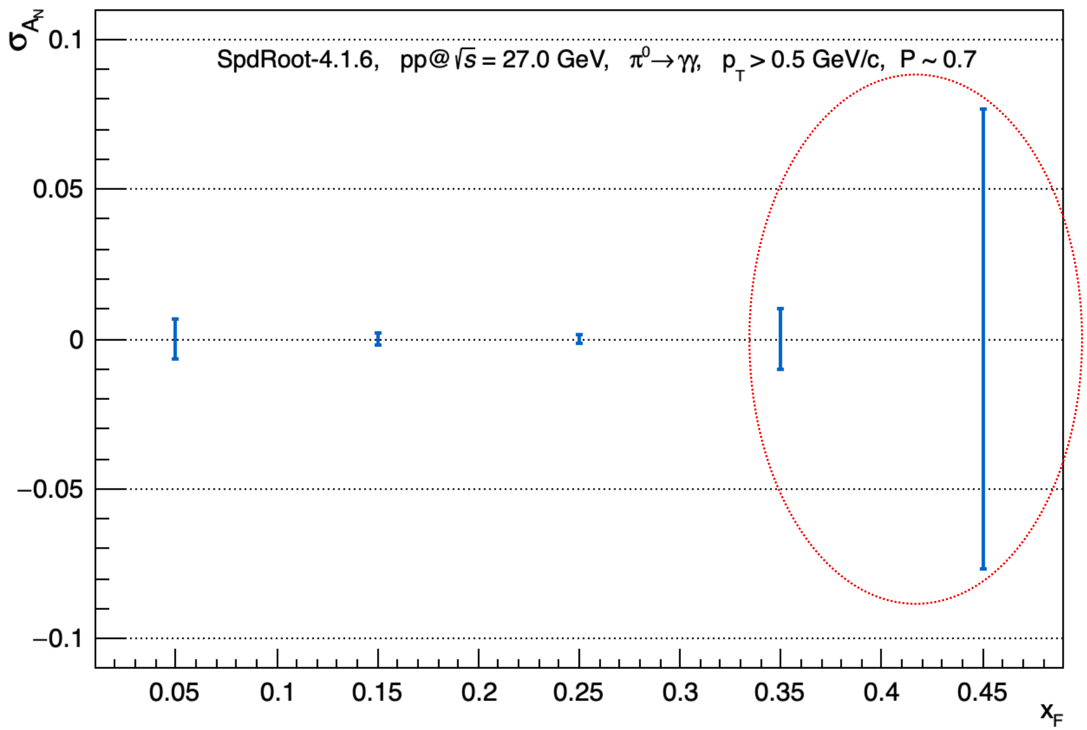




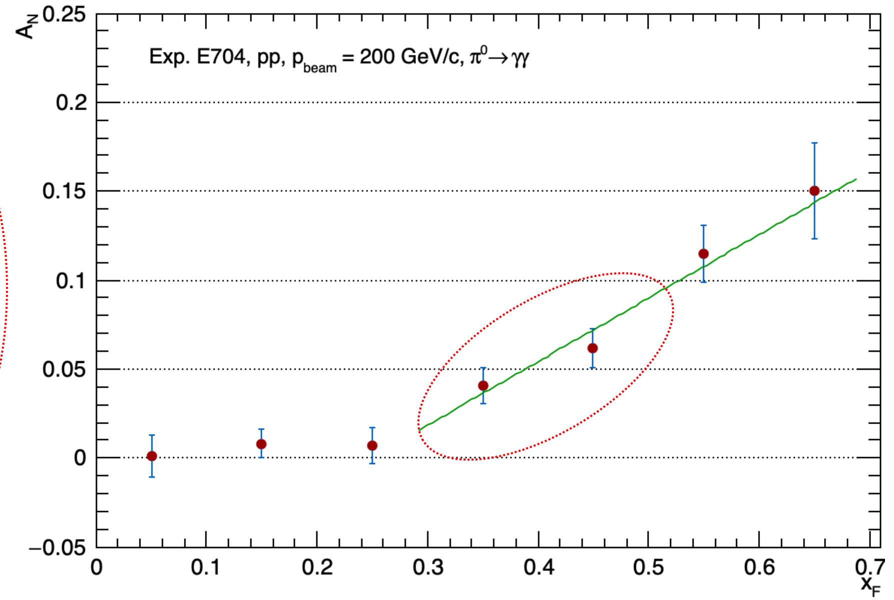
The statistical uncertainty of the amplitude modulation can be reasonably estimated for $A_N \approx 0$

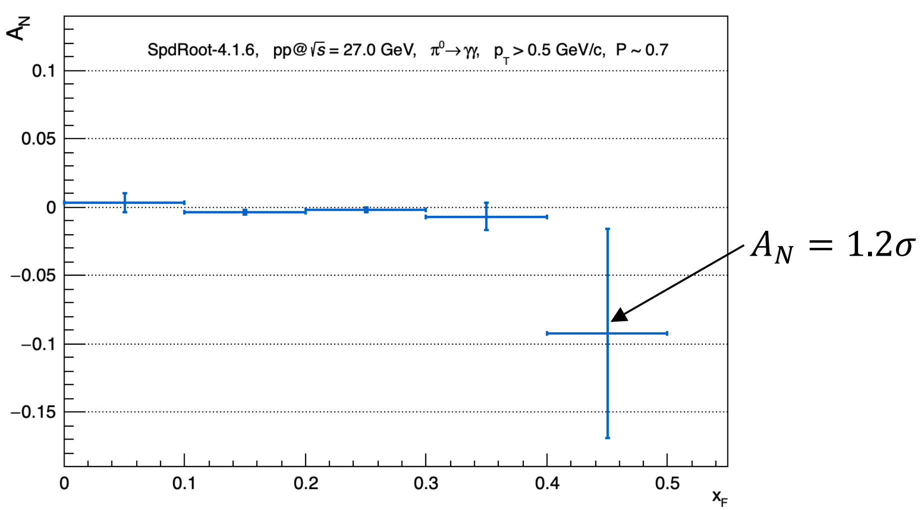
Method 1: Cosine modulation fitting

$\boldsymbol{A_N}$ ***vs.*** $\boldsymbol{x_F}$ *(spdroot)*



Experiment E704 (1991)

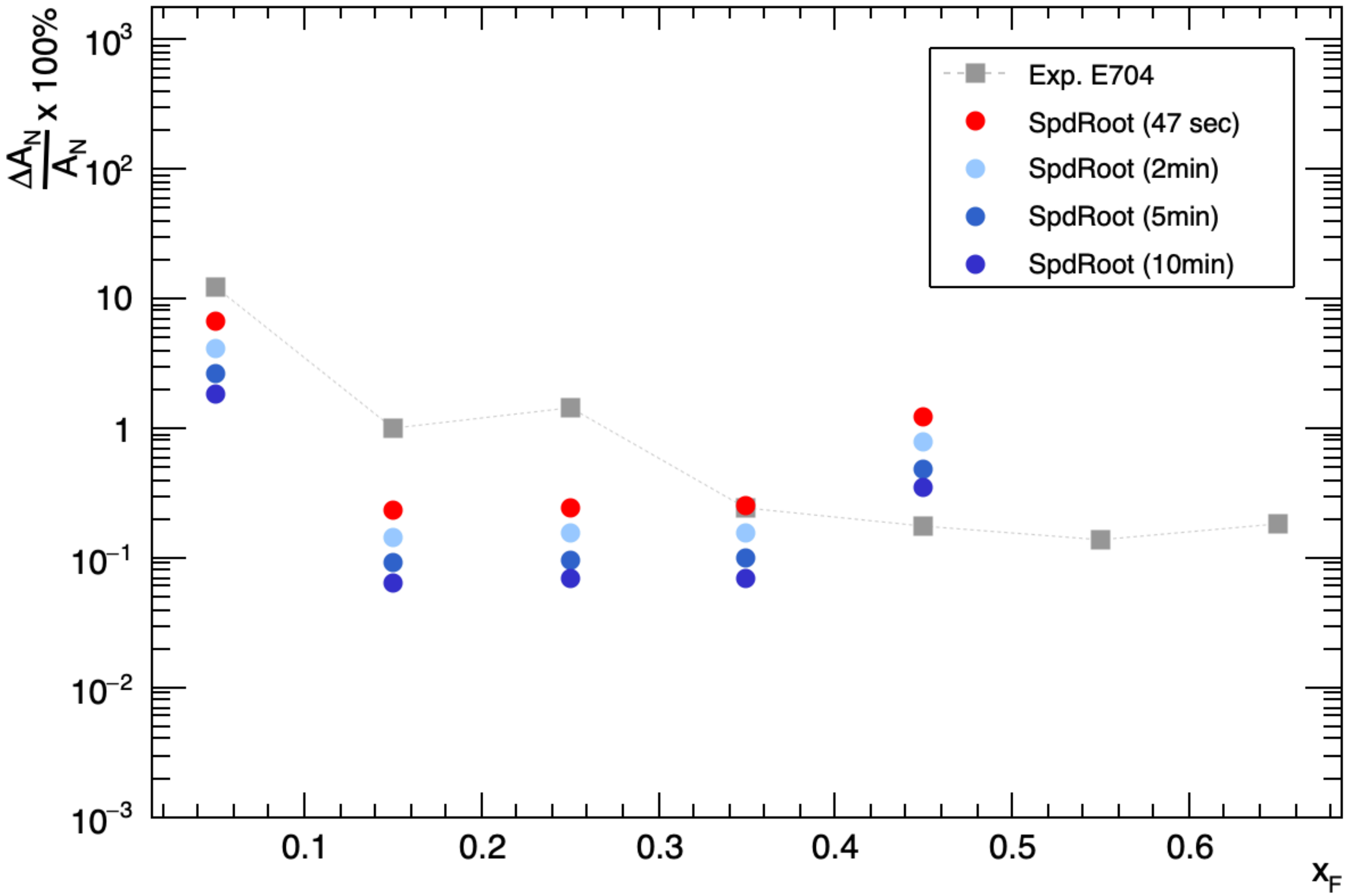




$\frac{\Delta A_N}{A_N}$ — ΔA_N → SpdRoot; A_N → E704

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

Method 1: Cosine modulation fitting



$$\frac{\Delta A_\mathrm{N}}{A_\mathrm{N}} \; vs. \; x_\mathrm{F}$$

ΔA_N → SpdRoot

A_N → E704

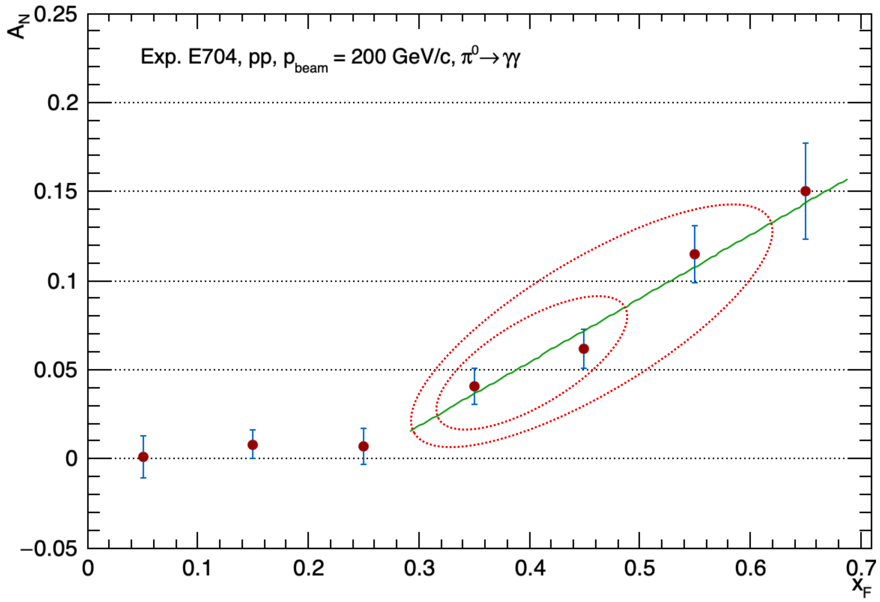
$$\frac{\Delta A_\mathrm{N}}{A_\mathrm{N}} \sim \frac{\Delta P}{P}$$

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%***

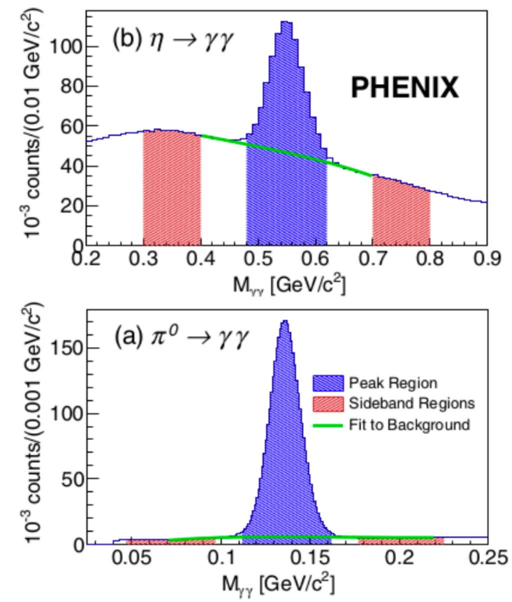
(FERMILAB-Pub-91/15-E[E581,E704])

Method 1: Cosine modulation fitting

Estimation of the statistical accuracy of the beam polarization measurement, with $pp \to \pi^0 X$ at $\sqrt{s} = 27\ \text{GeV}$, 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 %

Another approach: projected statistical uncertainty of A_N



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

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

3) **Corrected statistical uncertainty of A_N:** $$\sigma_{A_N^{sig}}(\phi) = \frac{\sqrt{\sigma^2_{A_N^{raw}}(\phi) - r^2\cdot\sigma^2_{A_N^{bkg}}(\phi)}}{1-r}$$

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

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

$$\begin{cases} \mathcal{R} = \mathcal{L}^{\uparrow}/\mathcal{L}^{\downarrow} \sim 1 \\ N^{\uparrow} \sim N^{\downarrow} = N \\ \sigma_N = \sqrt{N} \quad \text{(Poisson } N\text{)} \end{cases}$$

$$r = \frac{N^{bkg}}{N^{raw}}$$

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

$\boldsymbol{P}$: beam polarization

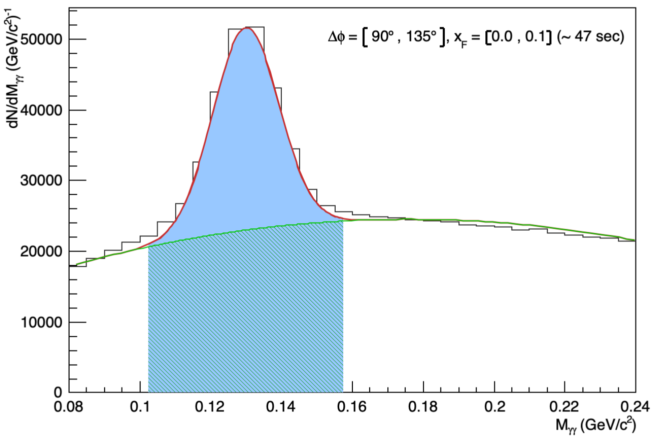
$\frac{1}{\langle|\cos(\phi)|\rangle}$: azimuthal acceptance correction factor

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

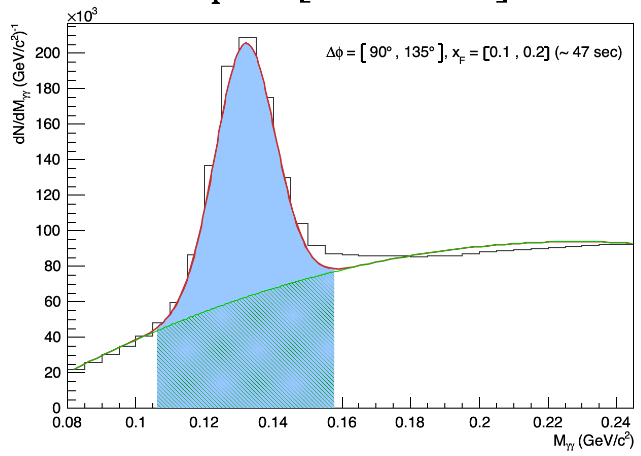
Amaresh's Analysis Note "Prospects of Open-Charm Asymmetry Measurements at the SPD" (*indico.jinr.ru/event/4594/attachments/18860/32246/D_Meson_Report.pdf*)

Method 2: Background correction

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



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



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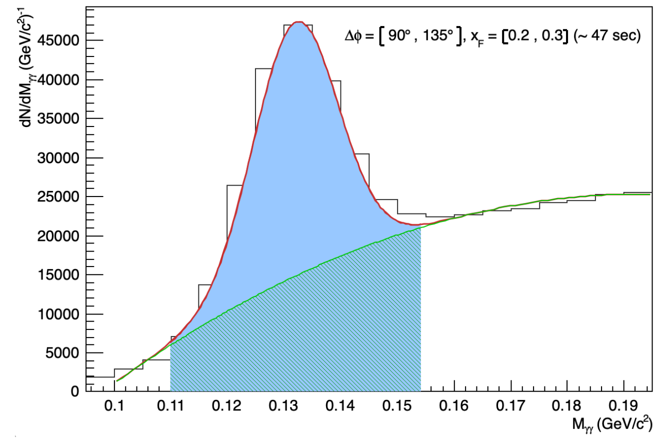
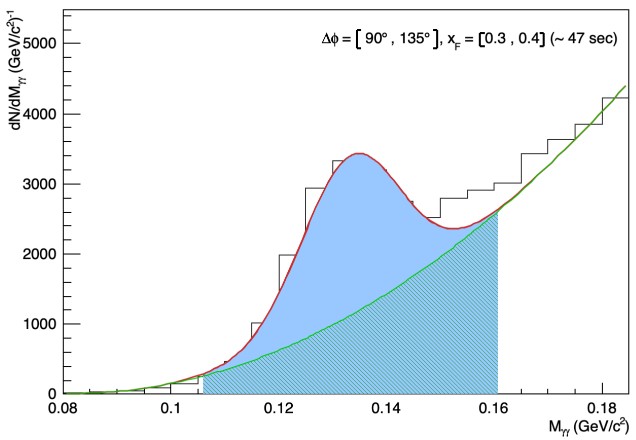
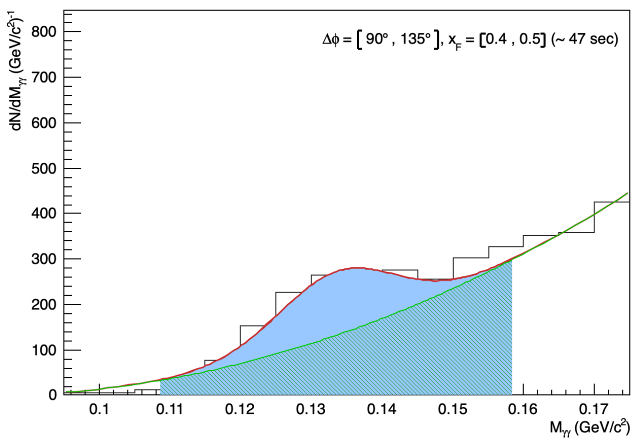


$x_{\mathrm{F}} = [0.3 - 0.4]$



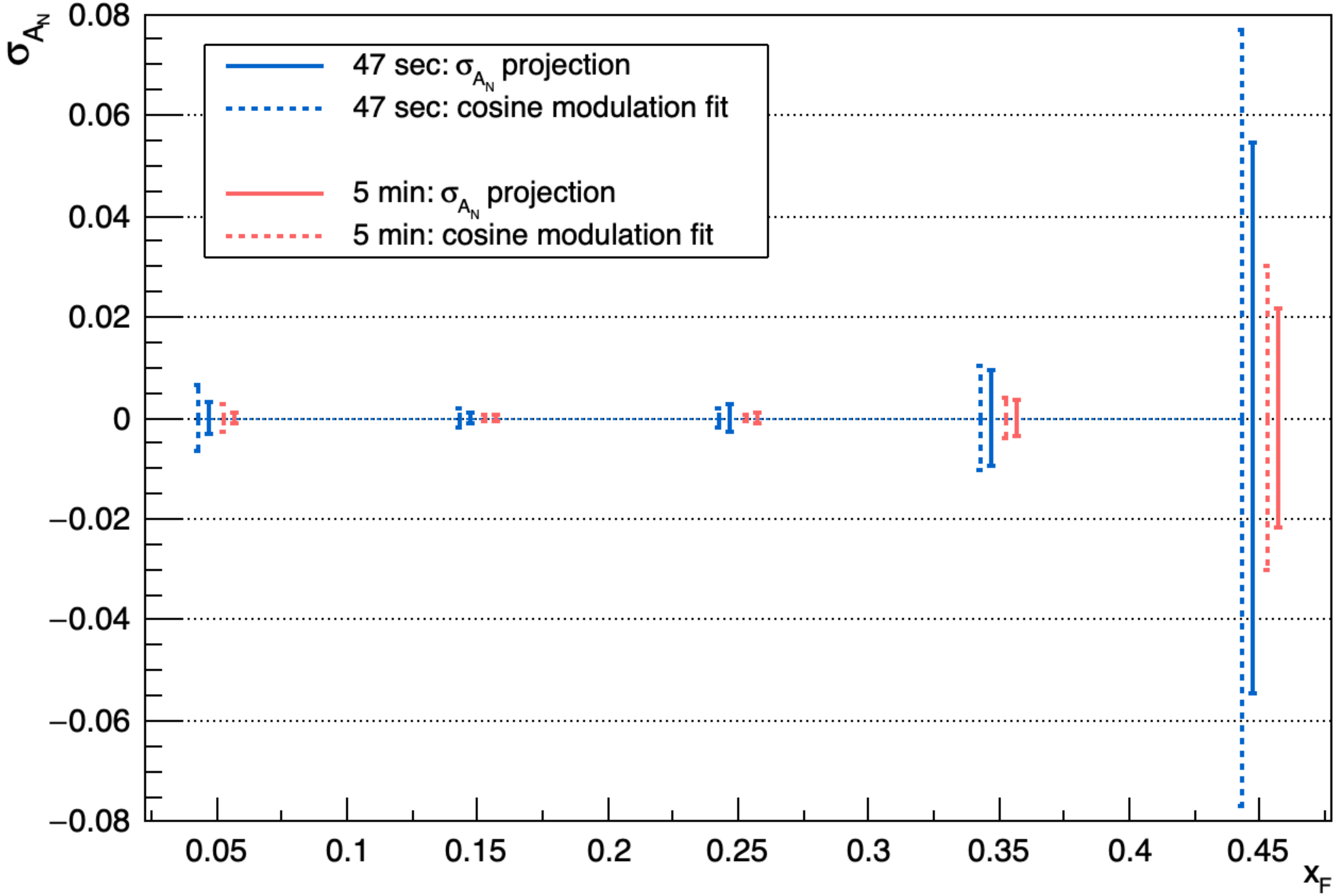
$x_{\mathrm{F}} = [0.4 - 0.5]$



$Fit: gausn + pol2$

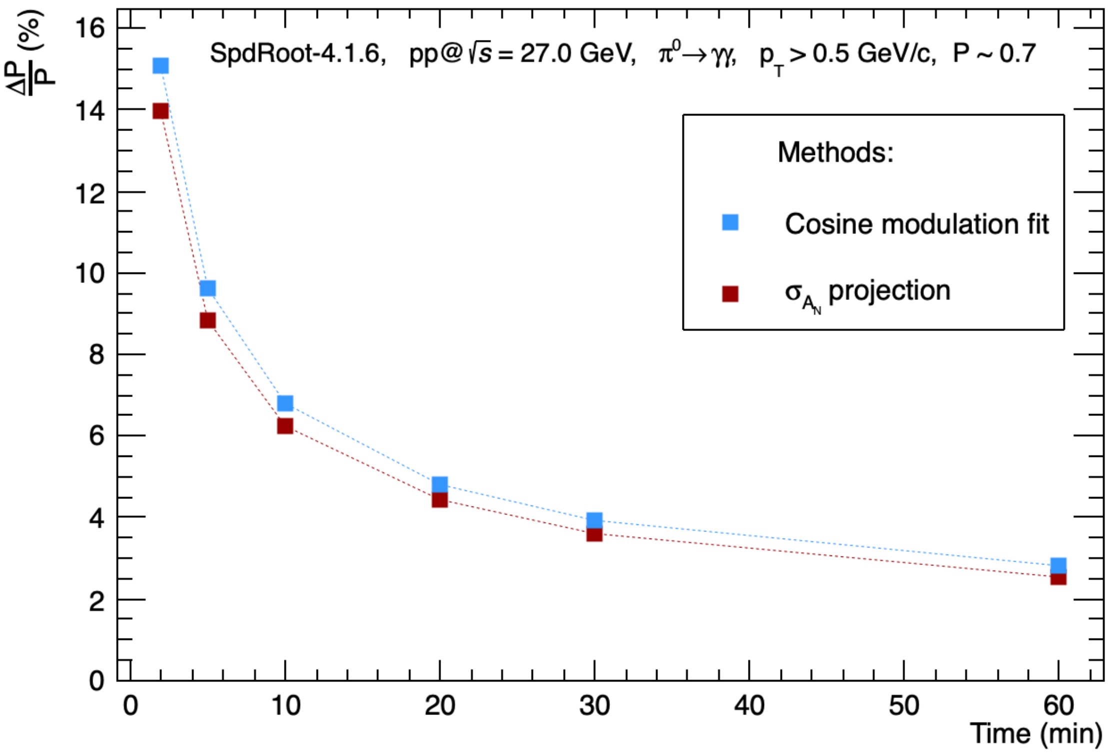
$\Delta\phi = 90\,, 135\; deg$

Another approach: projected statistical uncertainty of A_N



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

	$\frac{\Delta P}{P}$	
Estimated time	Cosine modulation fitting	Background corrected
2 min	15.1 %	13.9 %
5 min	9.6 %	8.8 %
10 min	6.8 %	6.3 %
20 min	4.8 %	4.4 %
30 min	3.9 %	3.6 %
1 h	2.8 %	2.5 %



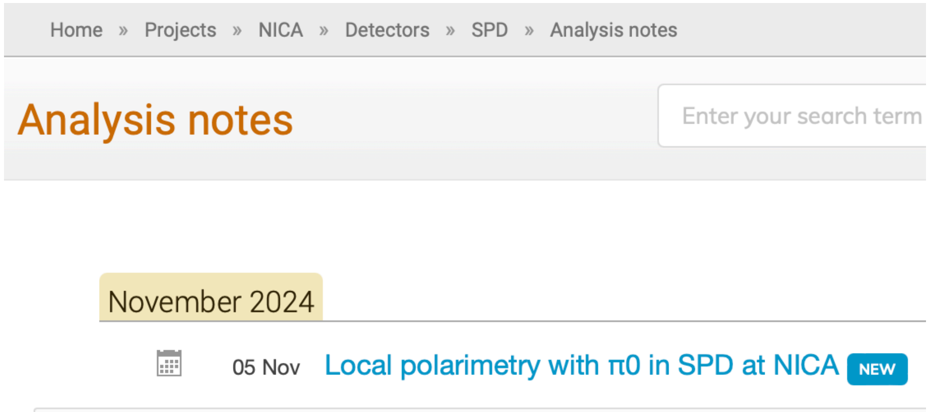
- ✓ The energy and position of π^0 decayed photons in the endcaps of the SPD ECAL are quantities which are accessible online, with no necessity of particle identification or vertex reconstruction.

- ✓ The accuracy of the beam polarization has been estimated for *pp* collisions at $\sqrt{s} = 27$ GeV by Monte Carlo simulations based on SpdRoot-4.1.6, using two approaches, giving close results.

- ✓ Based on the azimuthal asymmetry of π^0 detected in the ECAL-endcaps, the accuracy of the beam polarization has been estimated at **~9% for 5 min.** of data taking, assuming an **average polarization of 0.7**.

- ✓ Analysis note is ready in the SPD *indico* page

✓ Analysis note is ready in the SPD *indico* page: *indico.jinr.ru/category/758/*



Local polarimetry with π^0 in SPD at NICA

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Abstract. The Spin Physics Detector (SPD) will be installed in the second interaction point of the Nuclotron-based Ion Collider fAcility (NICA) at the Joint Institute for Nuclear Research in Dubna. The main goal is to study the spin structure of the proton and deuteron, and other spin-related phenomena with polarized proton and deuteron beams at a collision energy up to $\sqrt{s} = 27$ GeV and luminosity up to 10^{32} cm^{-2}s^{-1}. For local polarimetry and luminosity control in SPD, several detectors are proposed. This work presents an analysis of the possibilities of using the inclusive $p + p \to \pi^0 + X$ reaction, in the end-caps of the electromagnetic calorimeter (ECAL) for local polarimetry purposes. The accuracy of the azimuthal asymmetry of this reaction, as a measure of the beam polarization, is investigated with Monte Carlo simulations in the frame of the SpdRoot code.

1. Introduction

The main objective of SPD is to investigate polarized phenomena in order to disentangle crucial issues of the nucleon spin physics. In this context, the polarimetry plays an important role. It is necessary to have a good monitoring of polarization and luminosity, trying to make the number of ions that are polarized in the needed direction as large as possible. At the same time, spin-dependent physical observables have to be extracted from the spin asymmetry measurements, which in turn, should be correctly scaled according to the degree of the beam polarization.

Measurement and monitory systems in NICA are planned to provide precise, relative and absolute determination of the polarization degree of the beams. However the major polarimetry methods provide an information which needs to be cross-checked locally in each detector experiment. The local online monitoring of the beam polarization, with independence of the major polarimeters, should help to reduce the systematic errors coming from polarization variations.

In SPD, the transverse single-spin azimuthal asymmetry can be exploited to measure the degree to which the beam polarization is transverse (vertically or radially) or longitudinal. The main challenge of the local polarimetry in SPD is the lack of data from *pp* collisions in the energy range of a few MeV's up to $\sqrt{s} = 27$ GeV ($\sqrt{s}$ is the center-of-mass energy). Several detectors are suggested to participate in the local polarimetry. Such is the case of the Beam-Beam Counters