# Polarimetry with $\pi^0$ in the SPD

**SPD goal**: Investigate **polarized** phenomena in order to contribute to disentangle nucleon spin problems (i.e. proton "crisis")

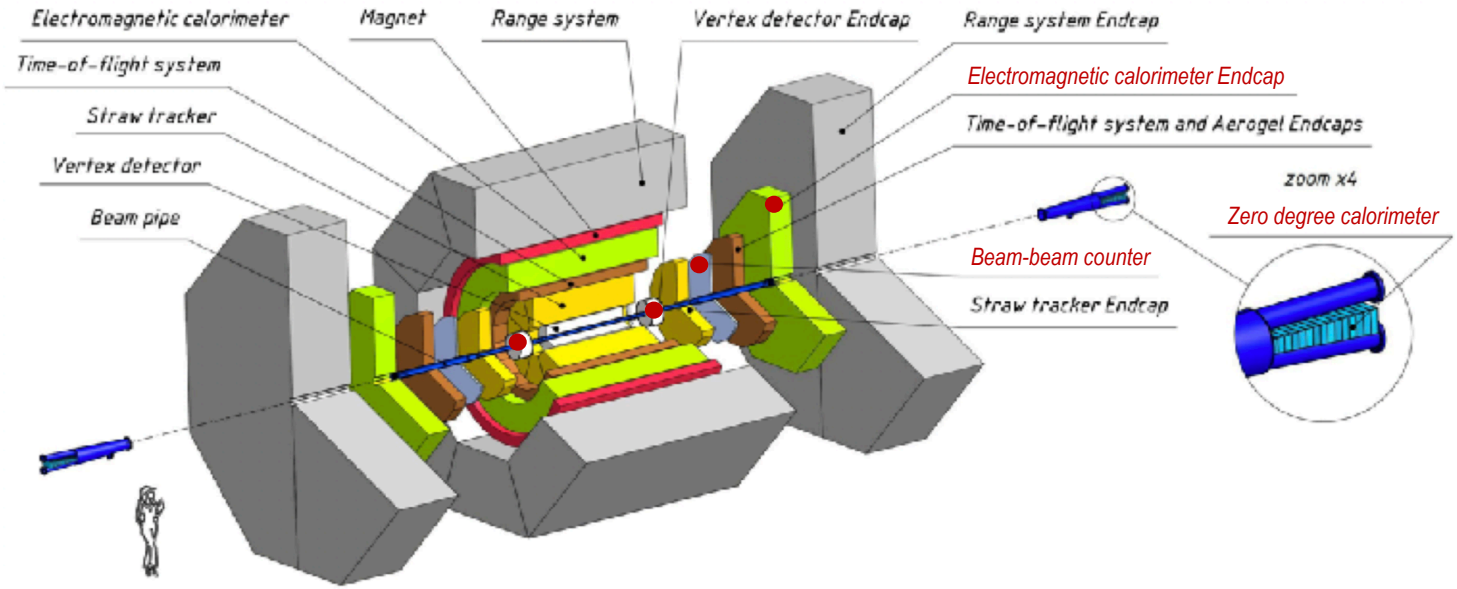
**Polarimetry**: Measures the degree of polarization [(1)] to correctly scale any asymmetry measurement

**Key issue**: maximize the number of ions in the bunches which are polarized in the needed direction

## ❖ Local polarimetry

- Permanent online beam polarization monitoring to reduce systematic errors coming from the beam polarization variation.
- Beam polarization monitoring independent on the major polarimeters.

**Challenge**: lack of precise polarization data in the SPD energy range.




(1) Polarization is understood as the fraction of protons in the bunch with their spins aligned along the polarization vector

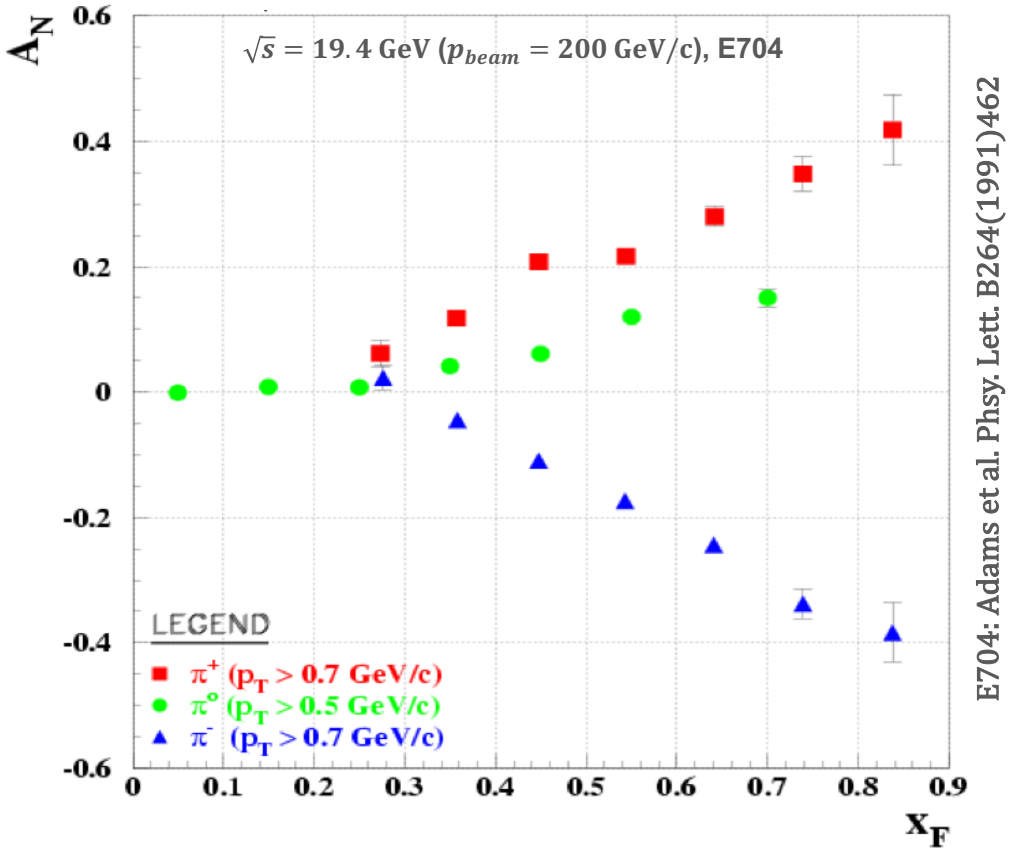
# $A_N$ for inclusive $\pi^0$ production in *pp* interactions

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 $p^{\uparrow}$ at higher $p_T$ values, extended the results on large $A_N$.

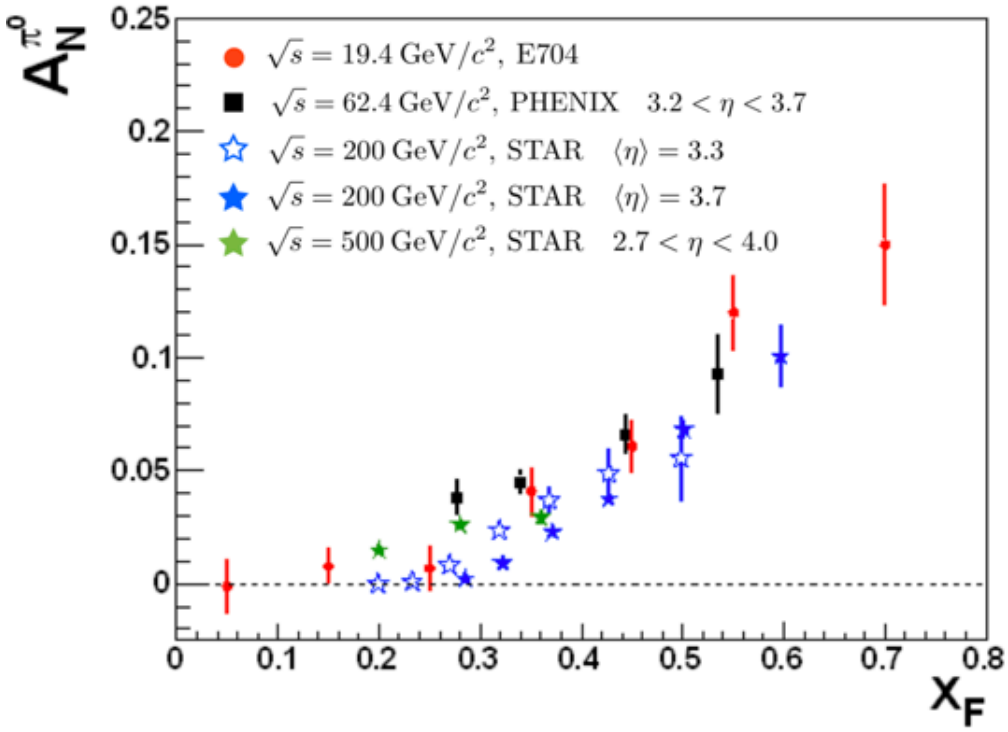
$$A_N = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$

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

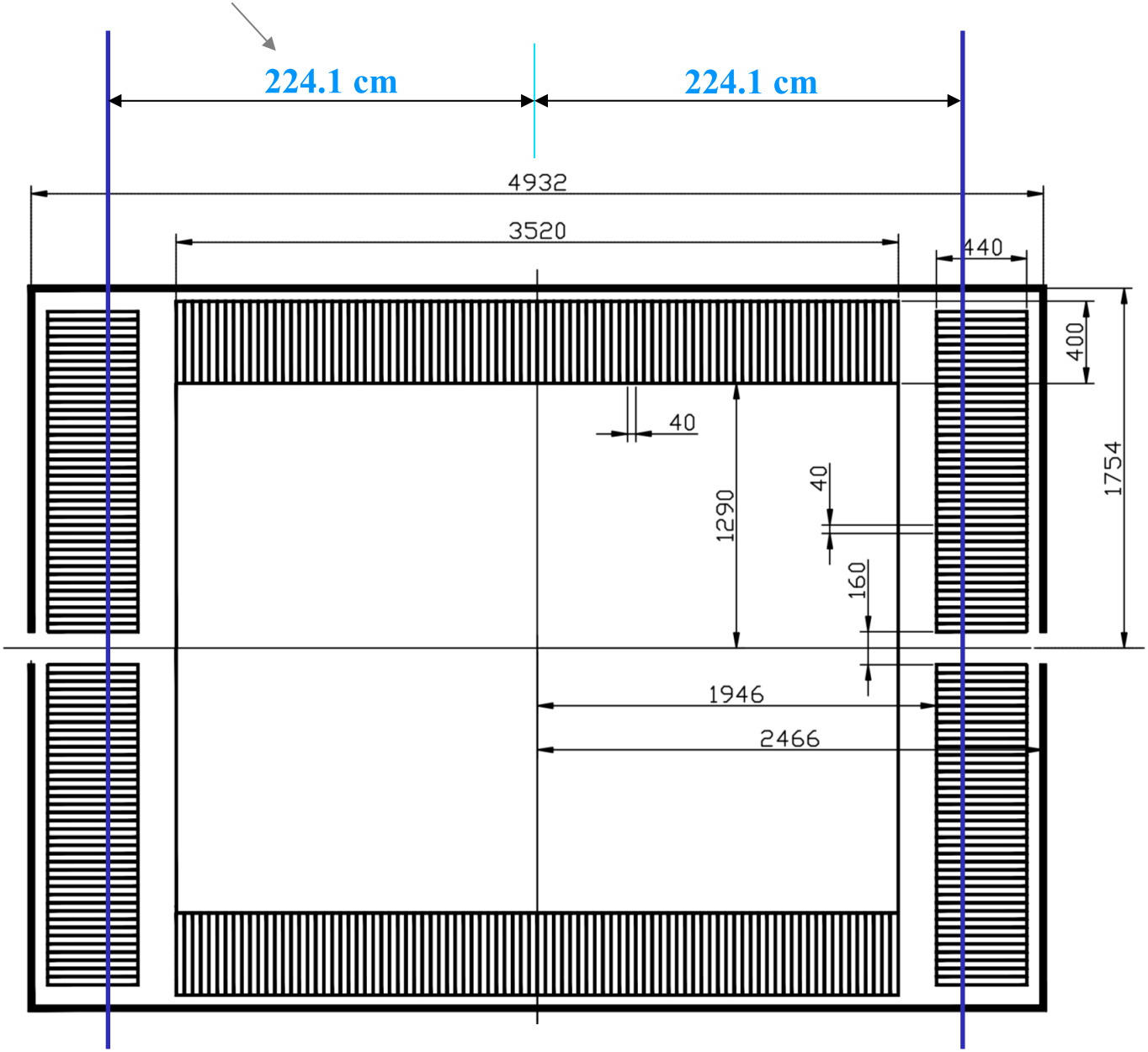



E704: Adams et al. Phsy. Lett. B264(1991)462

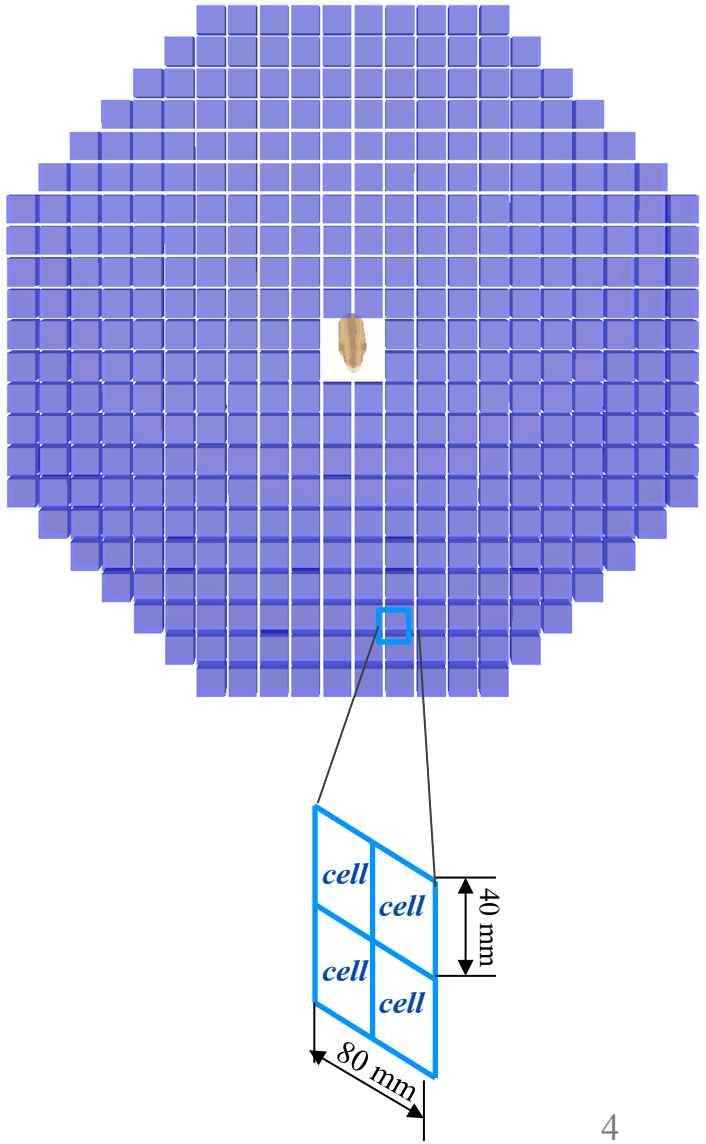
$A_N$ nearly independent of $\sqrt{s}$



Position of the photon impact in the Endcap (hit position), from SpdEcalRCParticle




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



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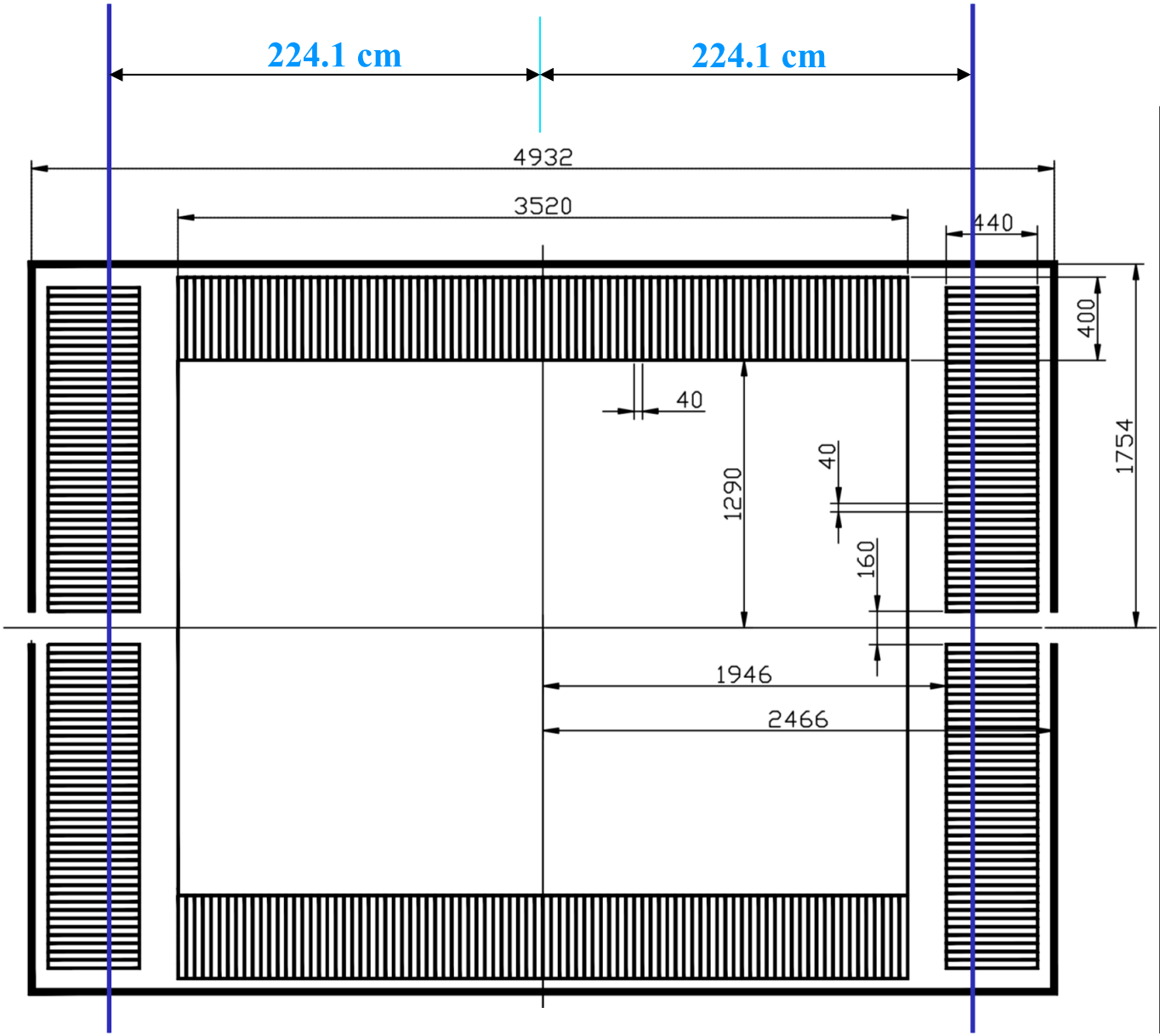



**SpdRoot**

$\sqrt{s} = 27\ GeV, 10^7$ events,

$E^{\gamma}_{min} = 400$ MeV, $p_T > 0.5$ GeV/c,

Pythia8 generator

**Pythia 8244**

$\sqrt{s} = 27\ GeV, 10^8$ events,

$E^{\gamma}_{min} = 400$ MeV, $p_T > 0.5$ GeV/c,

Uniform distribution to smear the vertex in $\Delta Z = \pm 30\ cm$

Gaussian smearing on $E_\gamma$ according to the ECAL Endcap energy resolution

Min. Bias.

# 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.

$$\frac{d\sigma}{d\phi} = \frac{d\sigma}{d\phi_0}(1 + P \cdot A_N \cdot \cos\phi)$$

Azimuthal cosine modulation

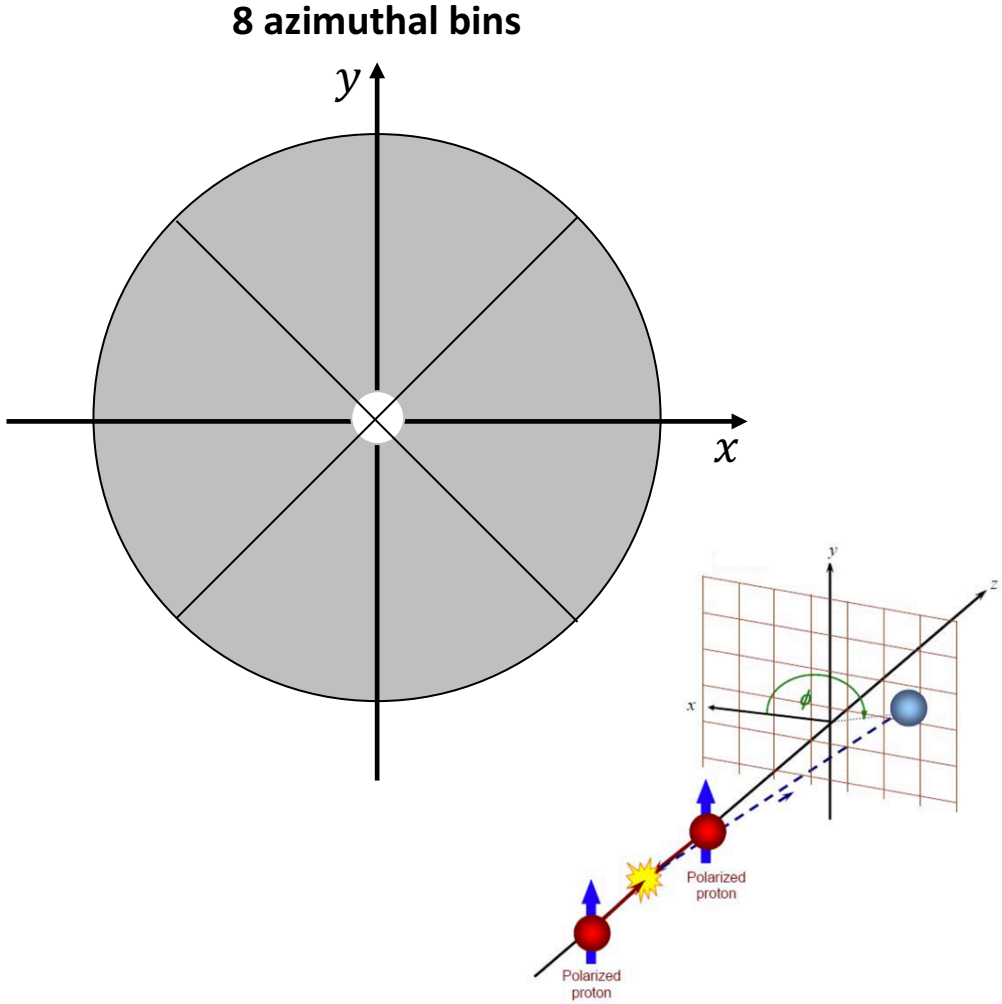
$$N_{\boldsymbol{\pi^0}}(\phi) = A(1 + B\cos\phi)$$

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

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

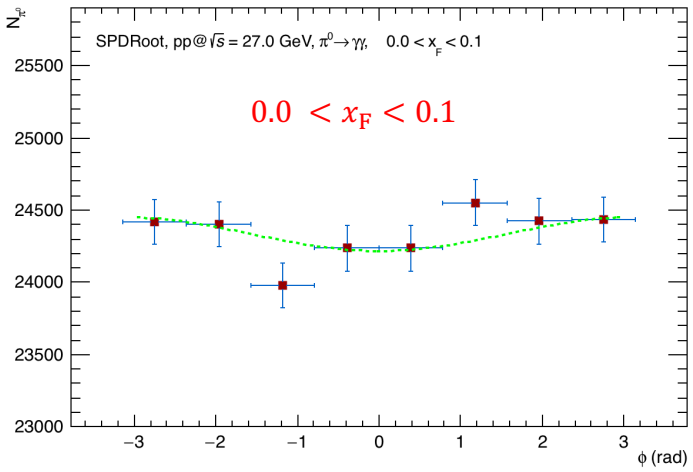
$P$: Beam polarization

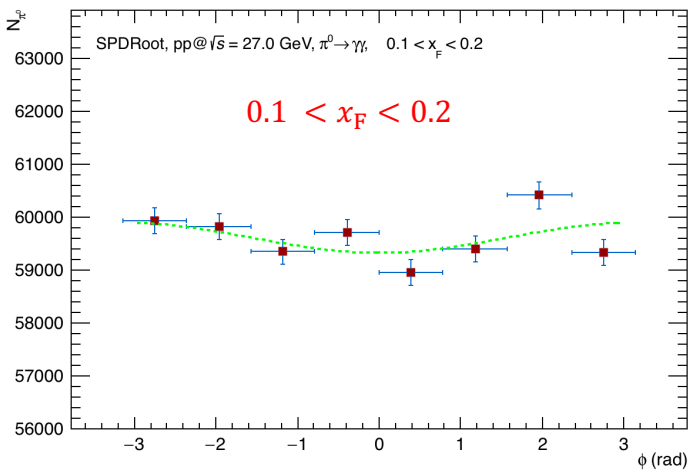
- $P \sim 0.7$ was assumed

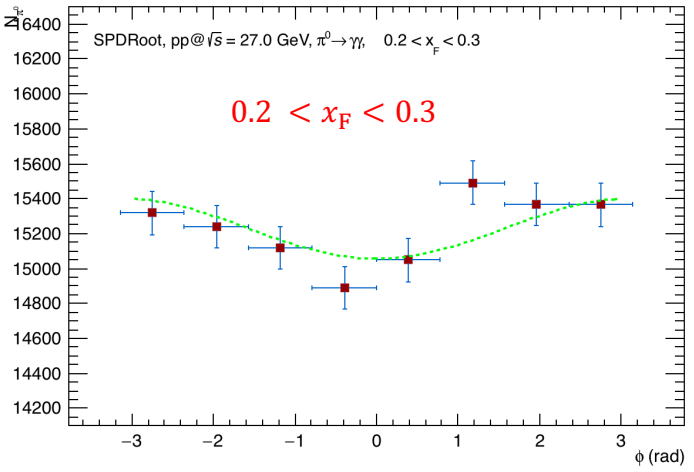


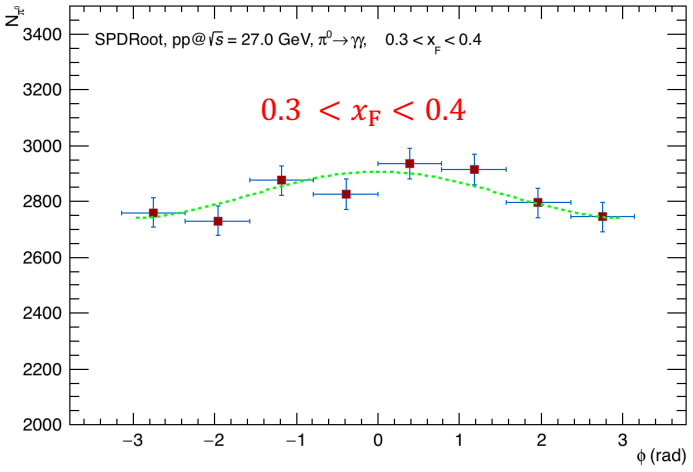

- The spin dependent $\pi^0$ yields for each bin are extracted from the invariant mass spectra in different $x_F$ sub-ranges for each $\phi$ bin.
- The invariant mass was fitted with a **polynomial** function for the background and a **normalized Gaussian** distribution representing the signal peak.

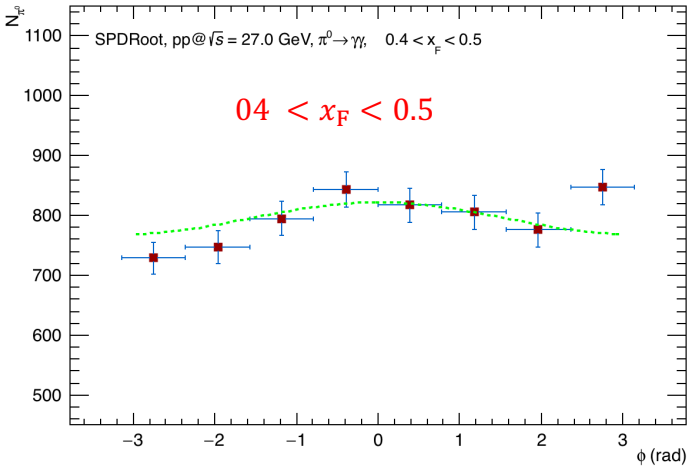
# Azimuthal cosine modulation of $\pi^0$ yields

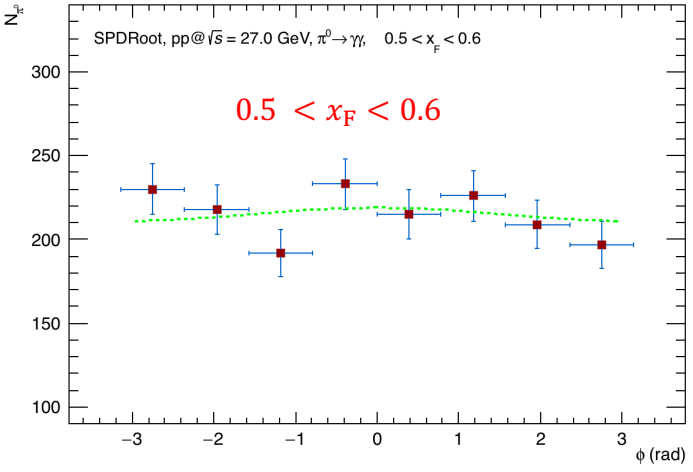


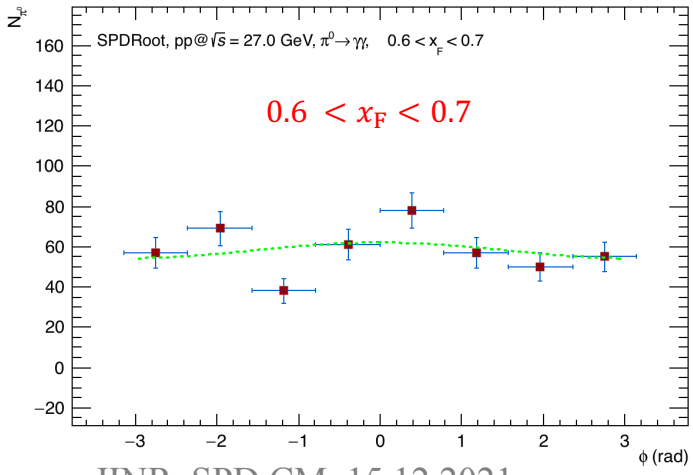



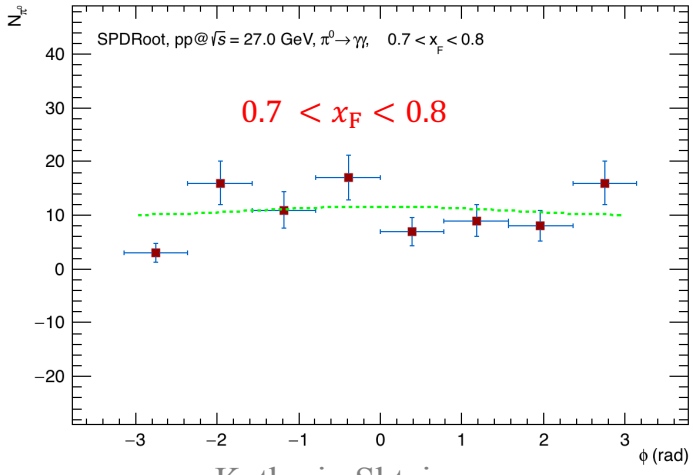



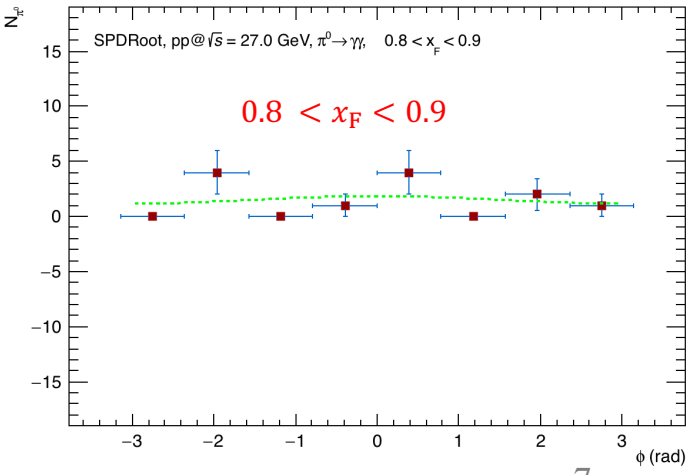



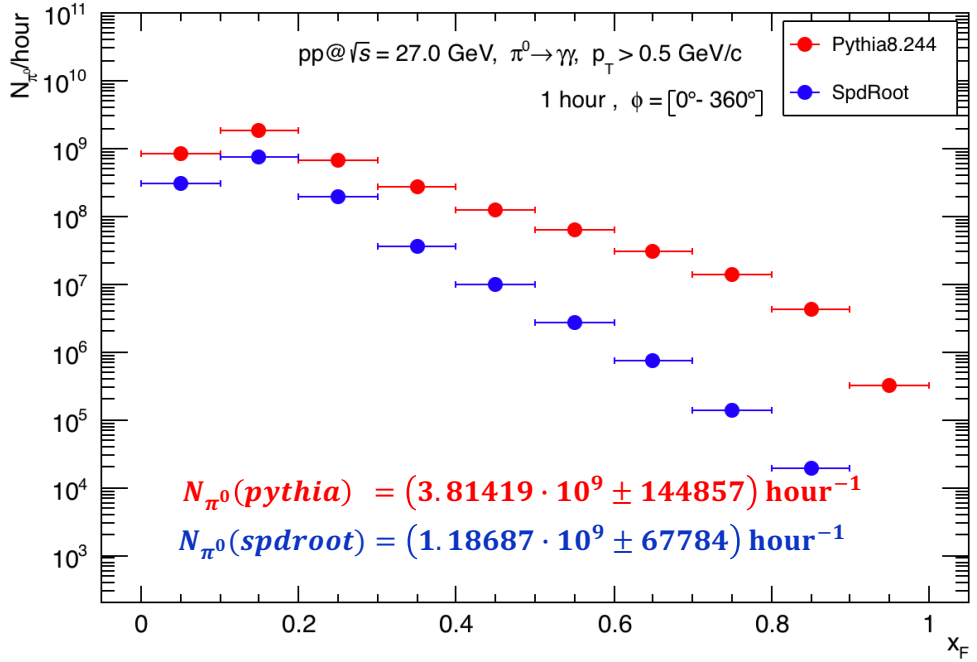



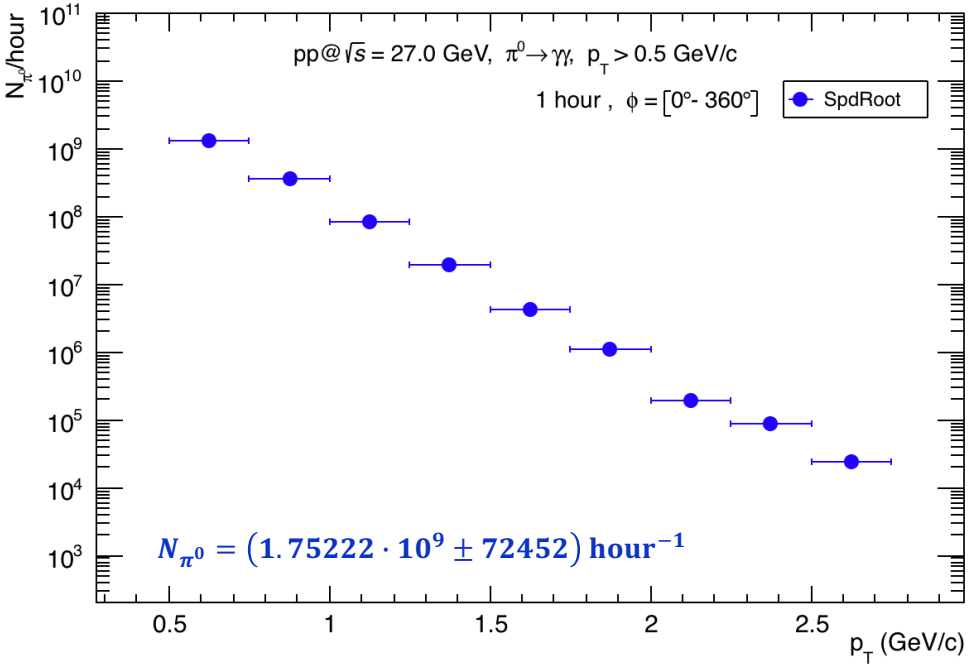



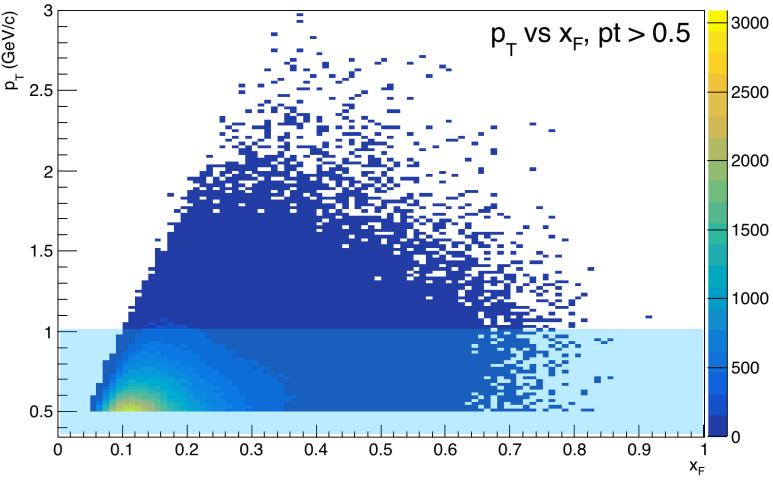



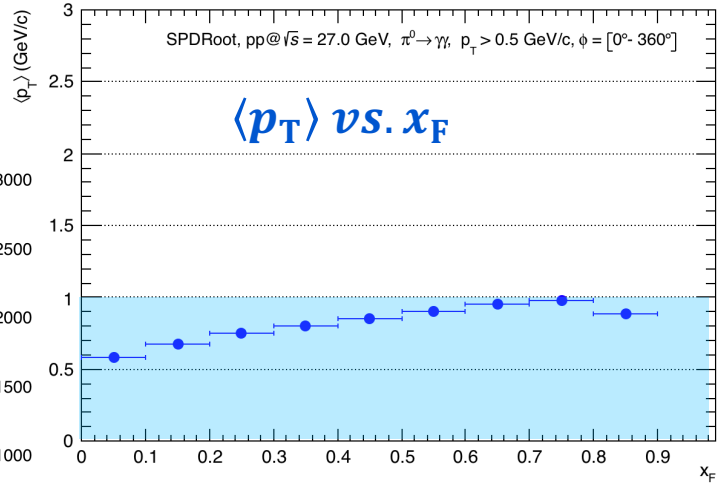



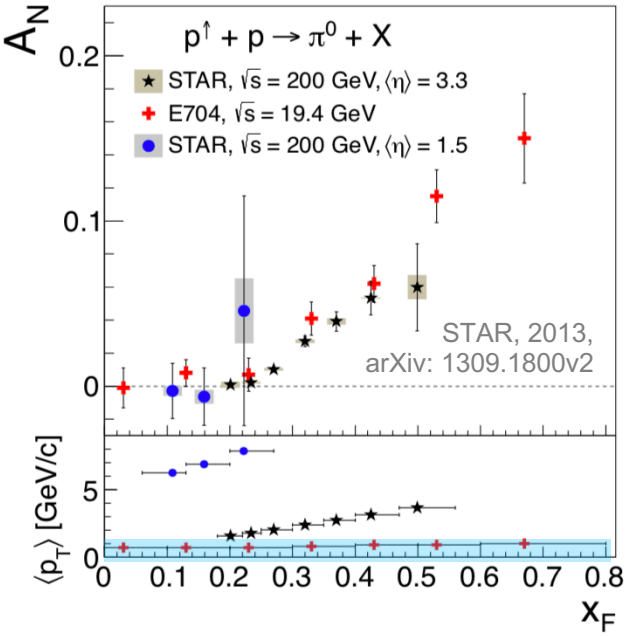
# Estimation of $\pi^0$ yield in the ECAL endcaps



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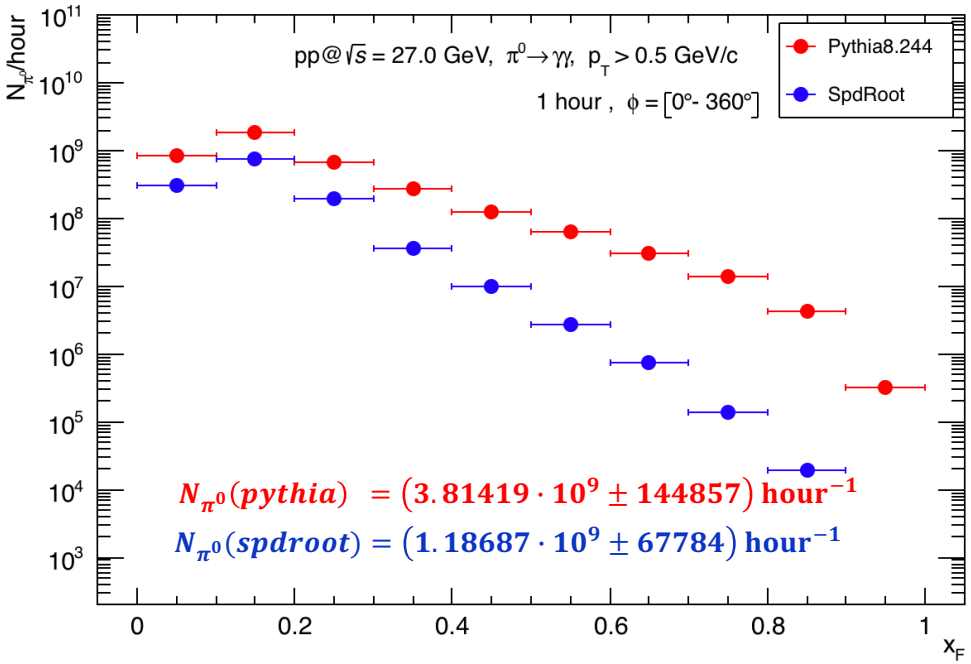
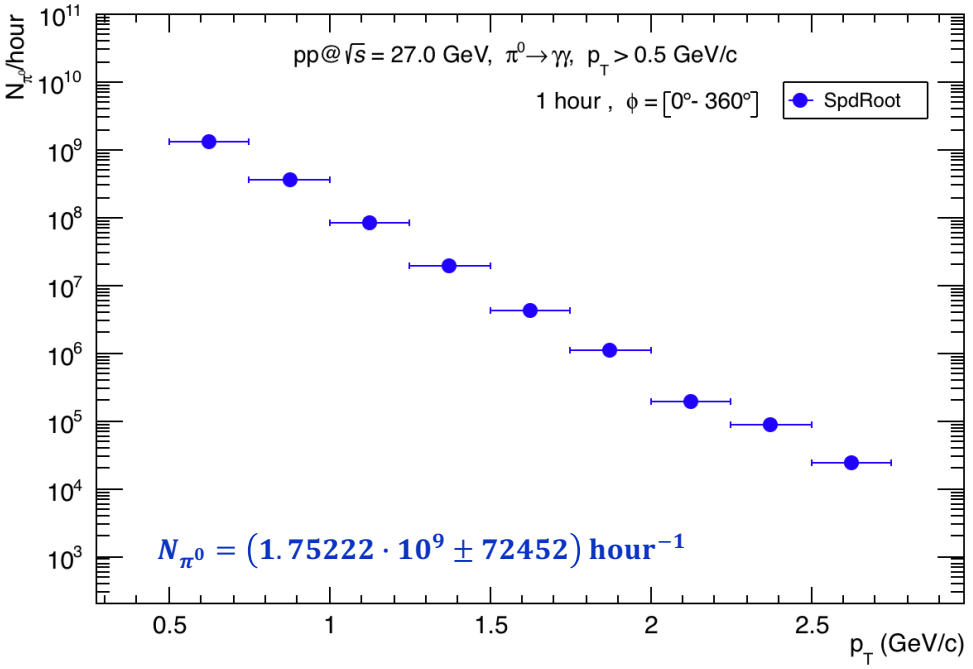


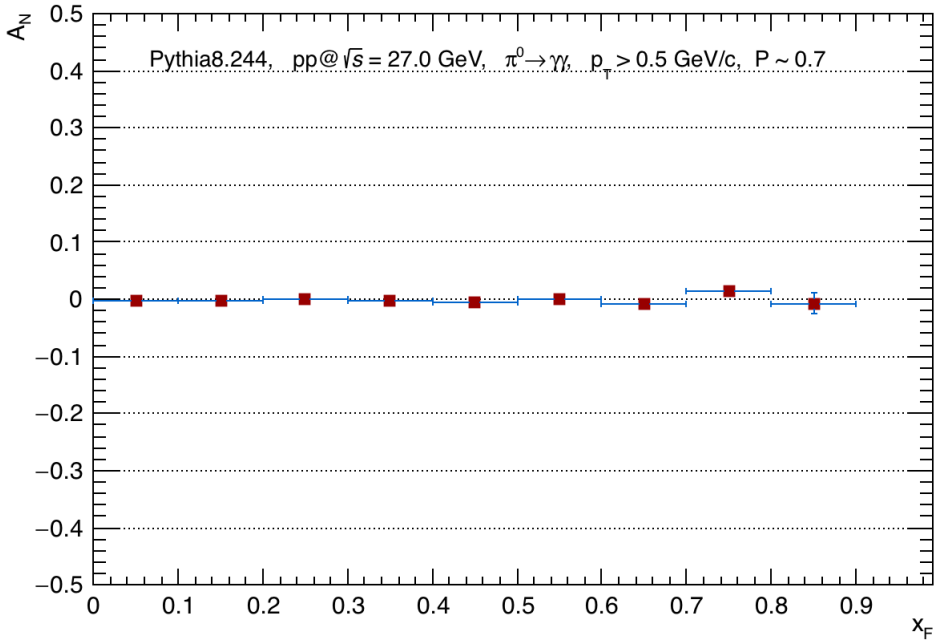

Expected in 1 hour at a reaction rate $4 \cdot 10^6 s^{-1}$

| $x_F$ | $N_{\pi^0}$(spdroot) |
|---|---|
| 0.0 – 0.1 | 2.80233e+08 ± 16740 |
| 0.1 – 0.2 | 6.86336e+08 ± 26198 |
| 0.2 – 0.3 | 1.75363e+08 ± 13242 |
| 0.3 – 0.4 | 3.25e+07 ± 5799 |
| 0.4 – 0.5 | 9.1539e+06 ± 3025 |
| 0.5 – 0.6 | 2.47566e+06 ± 1573 |
| 0.6 – 0.7 | 6.69600e+05 ± 818 |
| 0.7 – 0.8 | 1.25280e+05 ± 353 |
| 0.8 – 0.9 | 1.7280e+04 ± 131 |
| 0.9 – 1.0 | - |

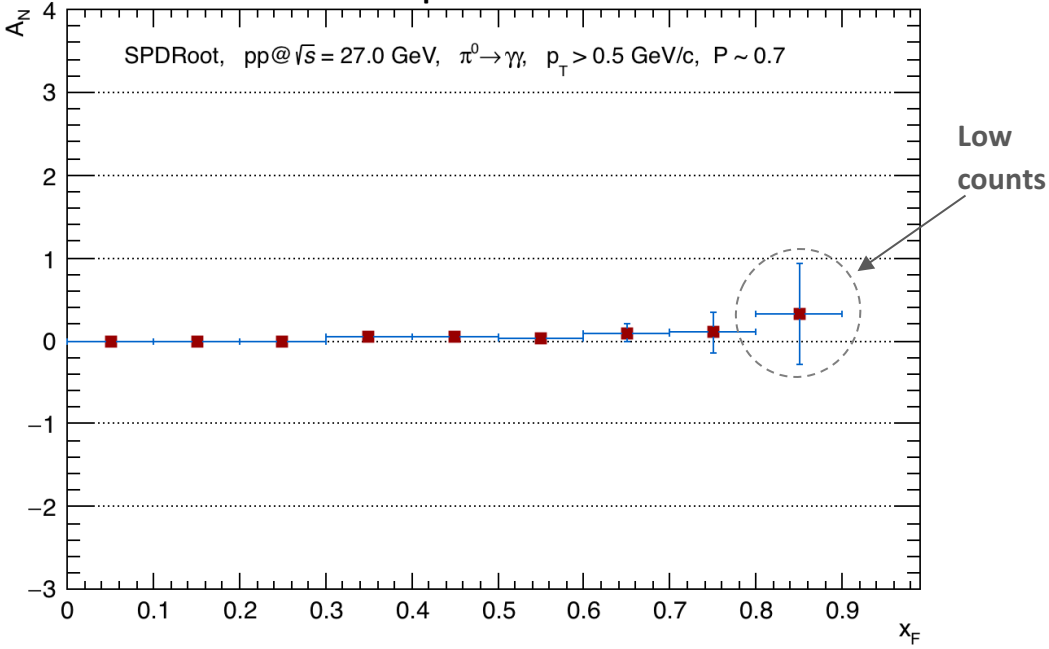
| $p_T$ (GeV/c) | $N_{\pi^0}$(spdroot) |
|---|---|
| 0.50 – 0.75 | 1.28159e+09 ± 35799 |
| 0.75 – 1.00 | 3.606118e+08 ± 18990 |
| 1.00 – 1.25 | 8.4756e+07 ± 9206 |
| 1.25 – 1.50 | 1.9464e+07 ± 4412 |
| 1.50 – 1.75 | 4.374e+06 ± 2091 |
| 1.75 – 2.00 | 1.11e+06 ± 1054 |
| 2.00 – 2.25 | 1.98e+05 ± 445 |
| 2.25 – 2.50 | 9.0e+04 ± 300 |
| 2.50 – 2.75 | 2.4e+04 ± 155 |
| 2.75 – 3.00 | 0.0 |

# $A_N$ in the ECAL endcaps

## Pure Pythia




## SpdRoot



# 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.* $x_F$

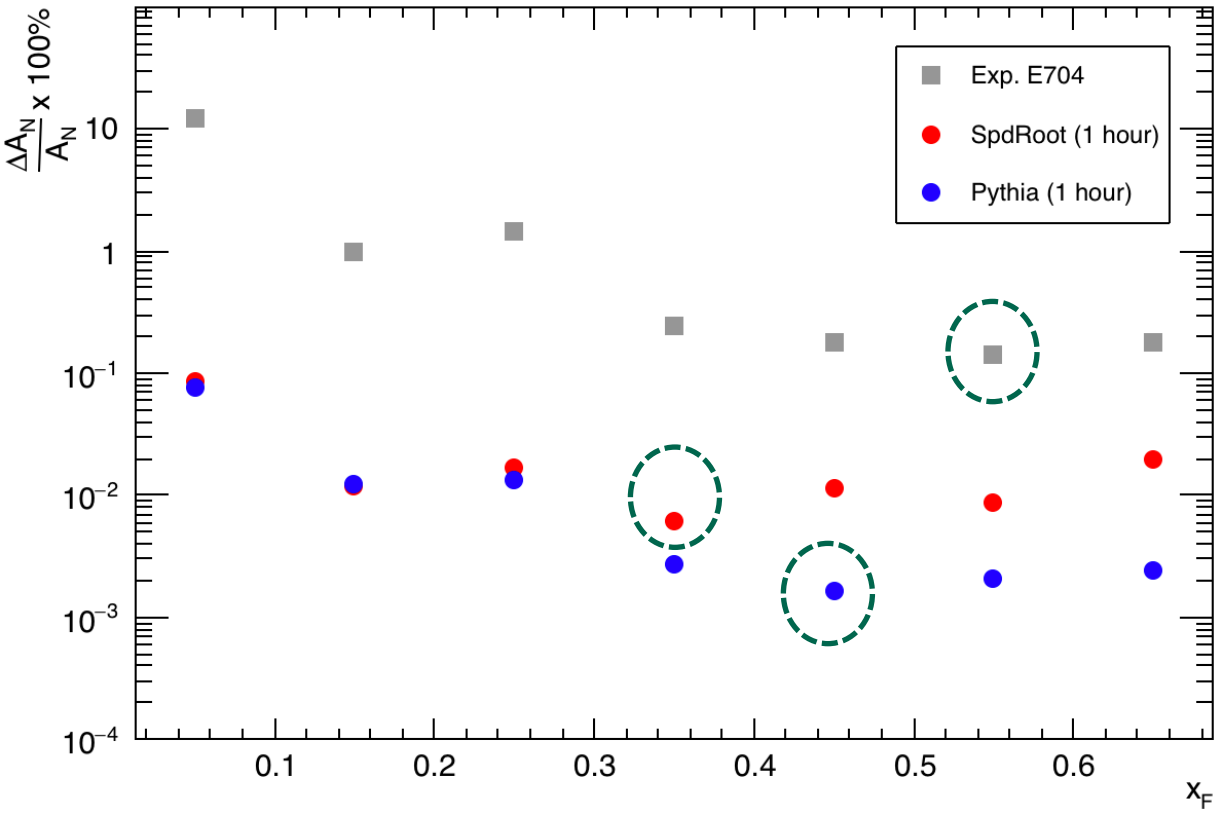
$$\frac{\Delta A_N}{A_N} \sim \frac{\Delta P}{P}$$

$\frac{\Delta A_N}{A_N}$ → SpdRoot

$\frac{\Delta A_N}{A_N}$ → E704

$\frac{\Delta A_N}{A_N}$ → Pythia

$\frac{\Delta A_N}{A_N}$ → E704




$\Delta A_N$ scaled to 1 hour of data-taking (Pythia and SPDRoot)

**Relative of $A_N$ error estimated for 1 hour**

| $x_F$ | $\frac{\Delta A_N}{A_N}$ (%) | |
|---|---|---|
| | SpdRoot (1h) | Pythia (1h) |
| 0.0 -0.1 | 9.13 | 7.54 |
| 0.1 -0.2 | 1.18 | 1.22 |
| 0.2 -0.3 | 1.99 | 1.32 |
| 0.3 -0.4 | 0.56 | 0.28 |
| 0.4 -0.5 | 1.07 | 0.16 |
| 0.5 -0.6 | 0.84 | 0.21 |
| 0.6 -0.7 | 1.90 | 0.24 |

The determination of the polarization is expected to be precise for $0.3 < x_F < 0.6$.

# Estimated relative error of the polarization

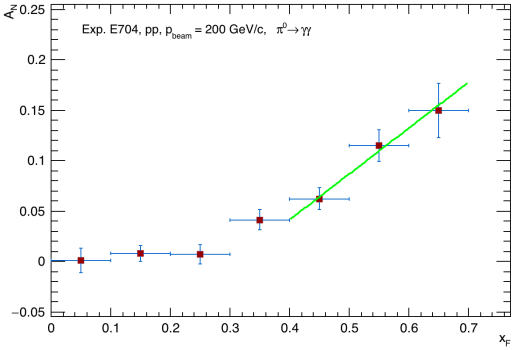
$$\frac{\Delta A_N}{A_N} \sim \frac{\Delta P}{P}$$

Raw asymmetry:

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

$P \cdot A_N \sim \epsilon$

$$\sigma_{Pol} = \frac{1}{\sqrt{\sum_i \left(\frac{1}{\sigma^2_{A_{N_i}}}\right)}} \Rightarrow \frac{\Delta P}{P} = \frac{1}{\sqrt{\sum_i \left(\frac{A_{N_i}}{\Delta A_{N_i}}\right)^2}} \Leftarrow \langle P \rangle = \frac{\sum_{i=1}^{n} w_i P_i}{\sum_{i=1}^{n} w_i}, \quad w_i = \left(\frac{1}{\Delta P_i}\right)^2$$




Taking the last 3 points ($0.4 \leq x_F \leq 0.7$):

$\frac{\Delta P}{P} \approx 0.0066$ 0.6% (MC - SPDRoot)

$\frac{\Delta P}{P} \approx 0.0011$ 0.1% (MC - Pythia)

$\frac{\Delta P}{P} \approx 0.0935$ 9.3% (Experiment E704)

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

$\frac{\Delta P}{P} \approx 0.0045$ 0.4% (MC - SPDRoot)

$\frac{\Delta P}{P} \approx 0.0010$ 0.1% (MC - Pythia)

$\frac{\Delta P}{P} \approx 0.0873$ 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]*

1 hour

We might define a beam polarization in SPD endcaps with a precision $\Rightarrow \frac{\Delta P}{P} \approx 0.6\%$

- The inclusive $pp \to \pi^0 X$ reaction, detected in the ECAL Endcaps, can be used for local polarimetry purposes, by measuring and monitoring the transverse single spin asymmetry.

- The determination of the polarization is expected to be precise for $0.3 < x_F < 0.6$.

- The statistical accuracy of the beam polarization in one hour, is estimated in $\sim 0.6\%$, from SPDRoot simulations.

- From the asymmetry determination, a relative error of the polarization, of $\frac{\Delta P}{P} \sim \mathbf{3.4\%}$ **can be predicted for 2 minutes**.