Performance study for the hyperon global polarization measurements with MPD

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for the MPD Collaboration

March 19th, 2024
MPD Cross-PWG Meeting

Outline

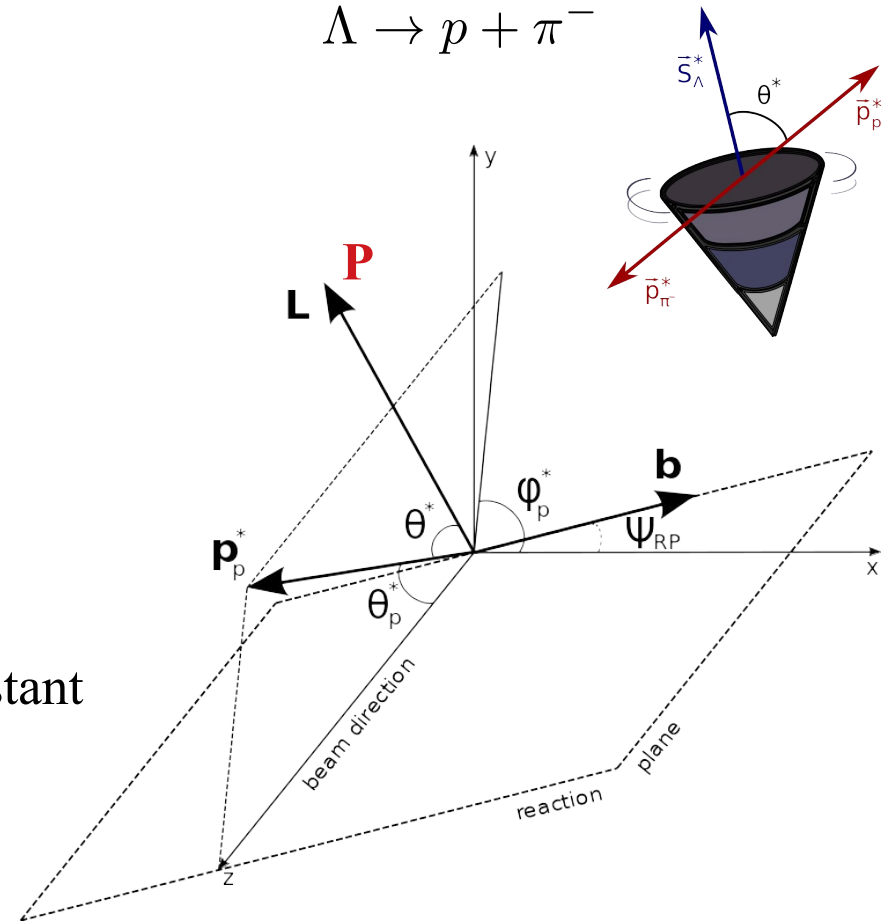
- Introduction
- Δφ-method
- Generalized invariant mass fit method
- Results
- Summary

Global hyperon polarization

- w.r.t. reaction plane (RP)
- Emerges in HIC due to the system angular momentum
- Measured through the weak decay:

$$\frac{\mathrm{d}N}{\mathrm{d}\cos\theta^*} = \frac{1}{2}(1 + \alpha_{\mathrm{H}}|\vec{P}_{\mathrm{H}}|\cos\theta^*)$$

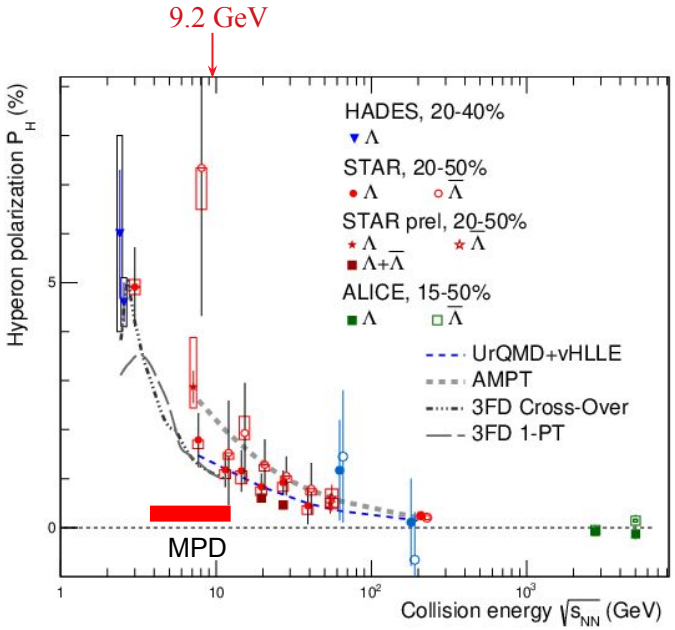
- * — denotes hyperon rest frame
- θ^* — angle between the decay particle(proton) and polarization direction
- $\alpha_\Lambda \simeq -\alpha_{\bar{\Lambda}} \simeq 0.732$ - hyperon decay constant



Global Polarization at Nuclotron-NICA energies

- Predicted and observed <u>global polarization signals rise</u> as the collision energy is reduced:

  NICA energy range will provide new insight
- $\Lambda(\bar{\Lambda})$ - splitting of global polarization
- Comparison of models, detailed study of energy and kinematical dependences, improving precision
- Probing the vortical structure using various observables



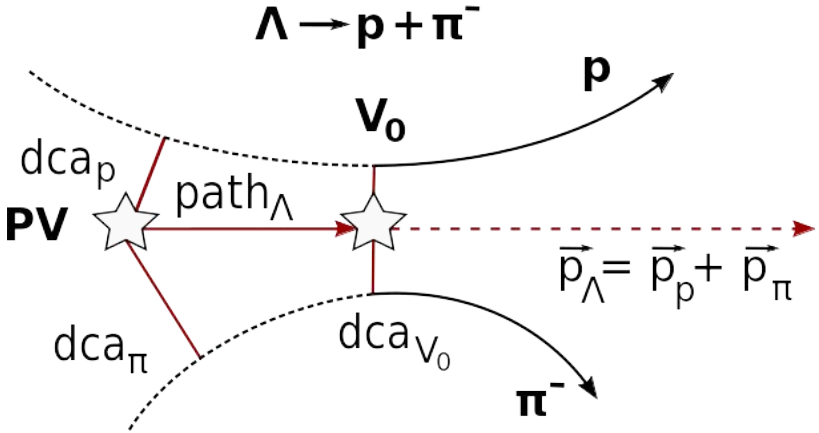
S. Singha, EPJ Web Conf. 276 (2023) 06012

J. Adam et al. (STAR Collaboration), Phys. Rev. C 98, 014910 (2018)
O. Teryaev and R. Usubov, Phys. Rev. C 92, 014906 (2015)

Measurements of global hyperon polarization

- Polarization can be measured using the azimuthal angle of proton in Lambda rest frame φ^*

$$\overline{P}_{\Lambda/\bar{\Lambda}} = \frac{8}{\pi\alpha}\frac{1}{R^1_{\mathrm{EP}}}\left\langle \sin(\Psi^1_{\mathrm{EP}} - \phi^*)\right\rangle$$



→ Determine centrality

→ Determine event plane $(\Psi^1_{\mathrm{EP}}, R^1_{\mathrm{EP}})$

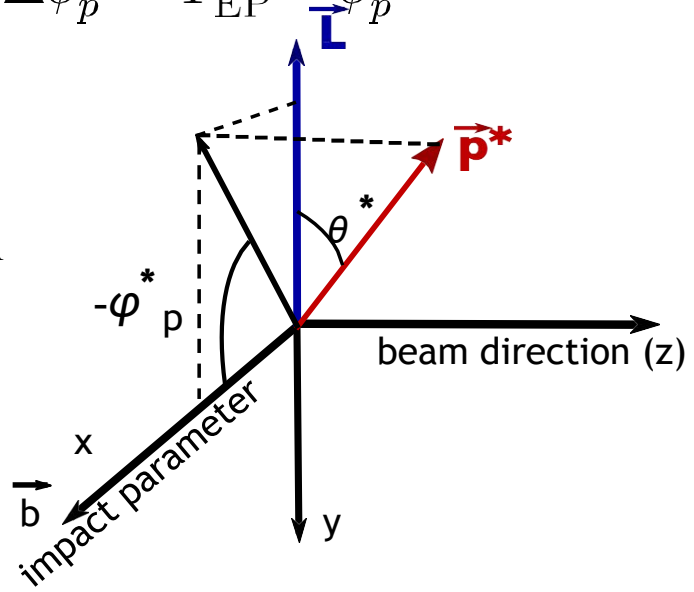
→ Reconstruct Lambda

→ Measure global polarization

- PV — primary vertex
- V_0 — vertex of hyperon decay
- dca — distance of closest approach
- path — decay length

Δφ-method

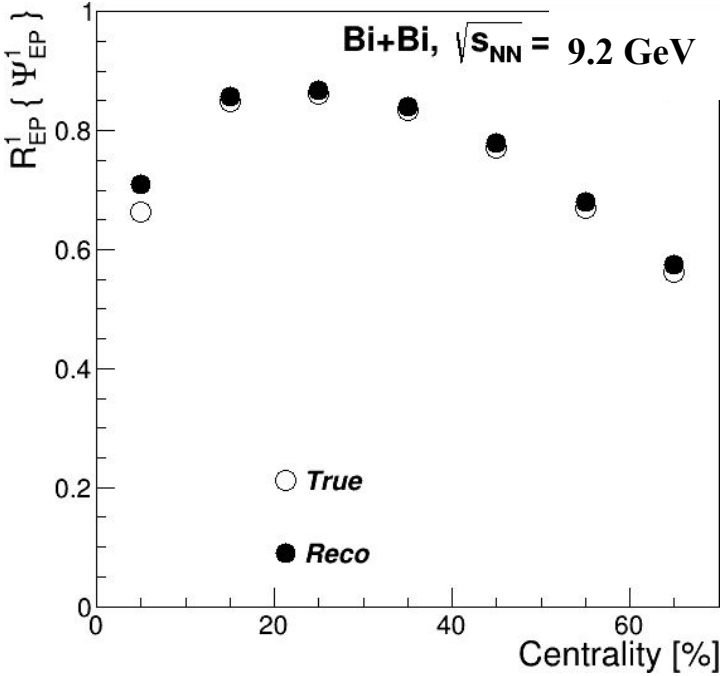
- Obtain invariant mass distribution in bins of $\Delta\phi_p^* = \Psi_{\mathrm{EP}}^1 - \phi_p^*$
  - Net amount of Λ in each bin
  - Distribution of $N_\Lambda(\Delta\phi_p^*)$
- Fit of the distribution to get $\langle \sin(\Delta\phi_p^*) \rangle \rightarrow P_\Lambda$
  - $dN/d\Delta\varphi_P^*$
  - $P_\Lambda = \frac{8}{\pi\alpha_\Lambda}\frac{p_1}{R_{\mathrm{EP}}^1}$



$$\overline{P}_{\Lambda/\bar{\Lambda}} = \frac{8}{\pi\alpha}\frac{1}{R_{\mathrm{EP}}^1}\left\langle \sin(\Psi_{\mathrm{EP}}^1 - \phi_p^*) \right\rangle$$

$$\frac{dN}{d\Delta\phi_P^*} = p_0(1 + 2p_1 \sin\Delta\phi_p^* + 2p_2 \cos\Delta\phi_p^* + 2p_3 \sin 2\Delta\phi_p^* + 2p_4 \cos 2\Delta\phi_p^* + \dots)$$

Event Plane (EP) measurements



- Good performance for EP measurements using FHCal is observed for PHSD model Bi+Bi at 9.2 GeV

  True: w.r.t. reaction plane (RP) angle

  Reco: determined using sub-event method

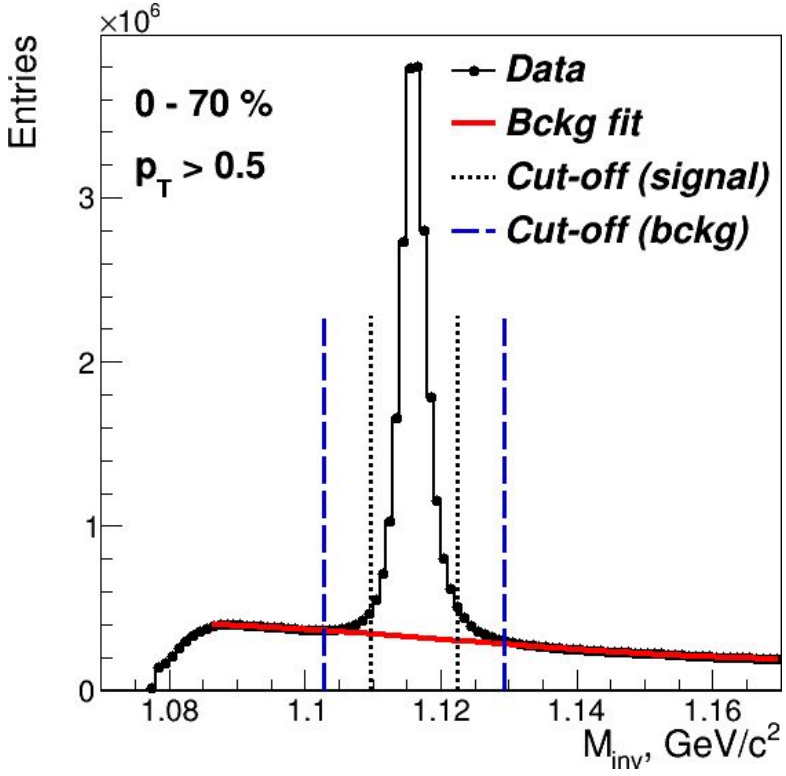
$$R_1 = \langle \cos(\Phi_1^F - \Psi^{RP}) \rangle$$

$$R_1(\Phi_1(F_N, F_S)) = \sqrt{\langle \cos(\Phi_1^{F_N} - \Phi_1^{F_S}) \rangle}$$

$\chi \to \sqrt{2}\chi$ - approximation to full event

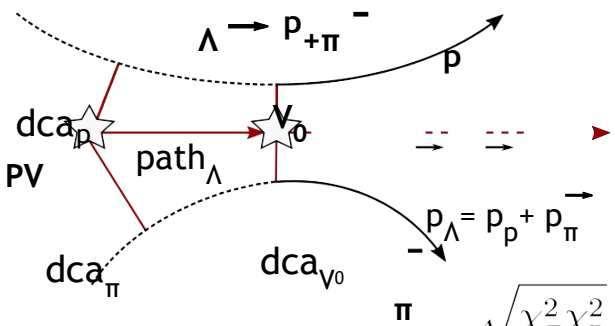
$$R_n(\Phi_n) = \frac{\sqrt{(\Pi)}}{2\sqrt{(2)}} \chi e^{-\frac{\chi^2}{4}} [I_{(n-1)/2}(\frac{\chi^2}{4}) + I_{(n+1)/2}(\frac{\chi^2}{4})]$$

Λ selection



Fitting procedure (sideband method):

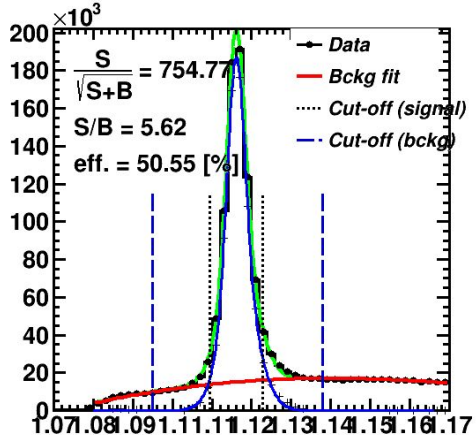
- Global fit (Gauss + Legendre polynomials)
- Background fit in sidebands (± 7σ)
- Signal Cut-off: <M>± 3σ
- Λ selection criteria:
  - «ω»-selection (1 parameter)
  - «χ»-selection (5 parameters)



$$\omega_2 = \ln \frac{\sqrt{\chi^2_\pi \chi^2_p}}{\chi^2_\Lambda + \chi^2_{V_0}}$$

Common inv. mass fit method

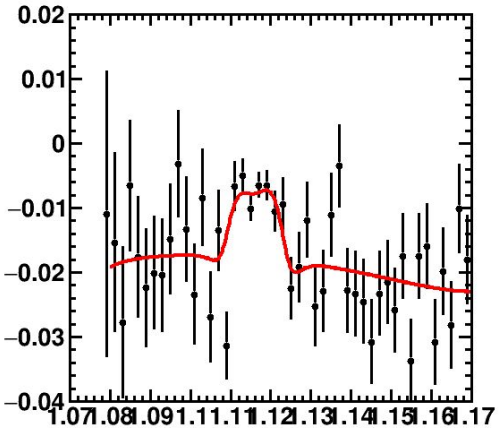
- Use invariant mass distribution
- Calculate Sig/All, Bg/All ratios
- Fit $\langle \sin(\Psi_{EP} - \varphi_p^*) \rangle$ as a function of inv. mass:



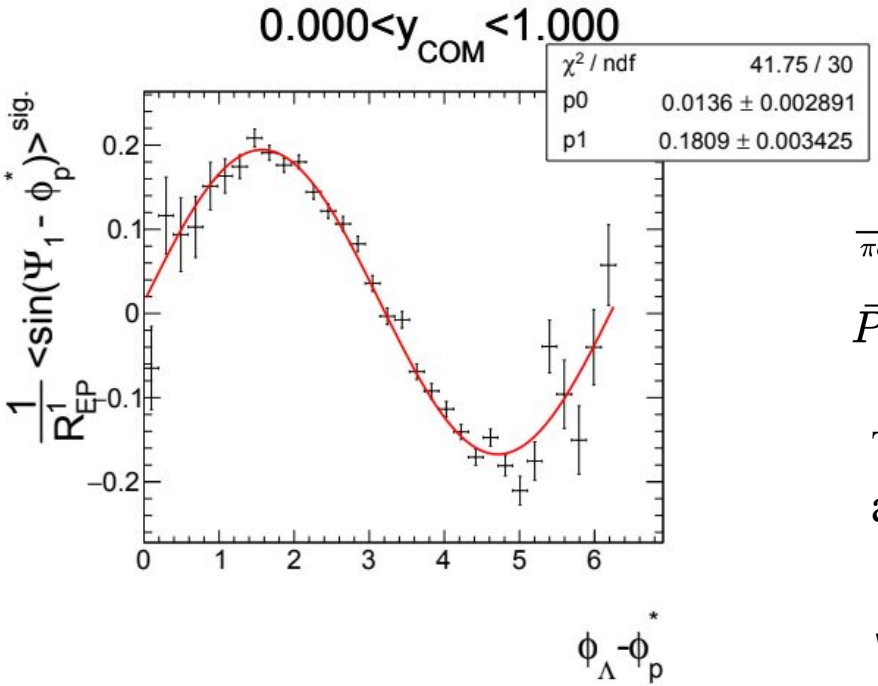
$$P^{SB}(m_{inv}, p_T) = P^{S}(p_T)\frac{N^{S}(m_{inv},p_T)}{N^{SB}(m_{inv},p_T)} + P^{B}(m_{inv}, p_T)\frac{N^{B}(m_{inv},p_T)}{N^{SB}(m_{inv},p_T)}$$

- Use $P^S(p_T) = \langle \sin(\Psi_{RP} - \varphi_p^*) \rangle^S$ to find P_H:

$$\overline{P}_{\Lambda/\bar{\Lambda}} = \frac{8}{\pi\alpha}\frac{1}{R^1_{\mathrm{EP}}}\left\langle \sin(\Psi^1_{\mathrm{EP}} - \phi^*_p)\right\rangle$$



Generalized inv. mass fit method



M.S. Abdallah et al. (STAR Collaboration), Phys. Rev. C 104, L061901 (2021)

Fit $P^S = \langle \sin(\Psi_{RP} - \varphi_p^*) \rangle^S$ in bins of $\varphi_\Lambda - \varphi_p^*$ for $\eta>0$, $\eta<0$ using formula:

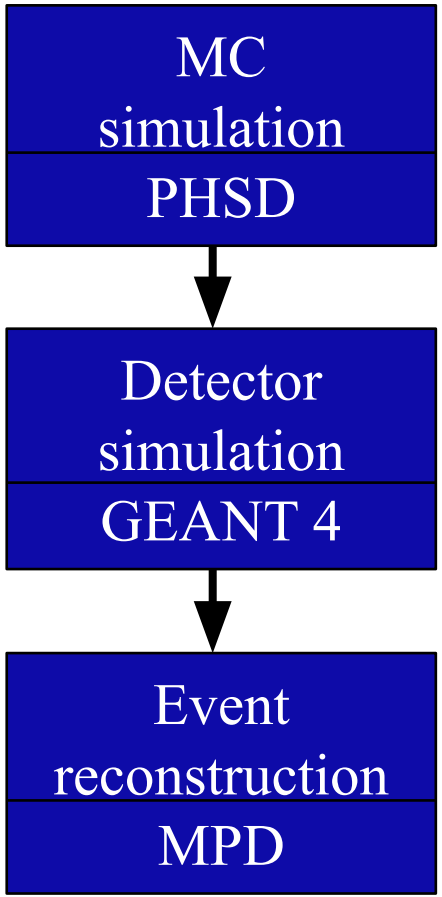
$$\frac{8}{\pi\alpha_\Lambda}\frac{1}{R_{EP}^{(1)}}\langle \sin(\Psi_1 - \phi_p^\star)\rangle^{sig} = \overline{P_\Lambda}^{true} + cv_1 \sin(\phi_\Lambda - \phi_p^\star)$$

$$\bar{P}_H = \tfrac{1}{2}[\bar{P}_H(\eta > 0) + \bar{P}_H(\eta < 0)]$$

This fit corrects effects of directed flow and acceptance contributions to P_H

We use generalized inv. mass fit method further in this work

Monte-Carlo simulation



- MC simulation using PHSD generator

N.S. Tsegelnik, E.E. Kolomeitsev, V. Voronyuk, Phys.Rev.C 107 (2023) 034906
N.S. Tsegelnik, E.E. Kolomeitsev, V. Voronyuk, Particles 2023, 6, 373-384

  - **Bi-Bi @ 9.2GeV, 15M MB events, b [0,12]fm**
  - Global hyperon polarization
    - Thermodynamical (Becattini) approach

F. Becattini, et. al. Ann. Phys. 338 (2013) 32

    - Hyperon polarization vector (**P** = {P_x,P_y,P_z})

- Transfer of polarization during hyperon decays (feed-down effect)
- Anisotropic decay of Λ hyperons:

$$\frac{\mathrm{d}N}{\mathrm{d}\cos\theta^*} = \frac{1}{2}(1 + \alpha_{\mathrm{H}}|\vec{P}_{\mathrm{H}}|\cos\theta^*)$$

Systematics

For Δφ-method:

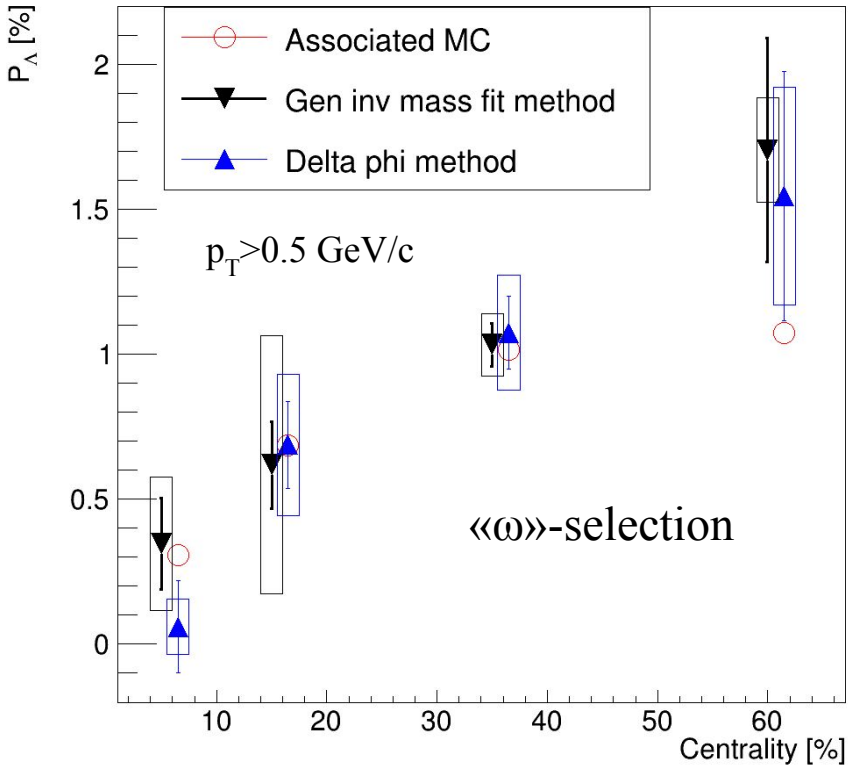
- σ for fitting signal at all distributions: 3± 0.5σ
- Resolution: comparison of 2-sub event and 3-sub event
- Δφ bins: 20±4
- Bg polarization: fit the Bg in Δφ bins instead of Sig

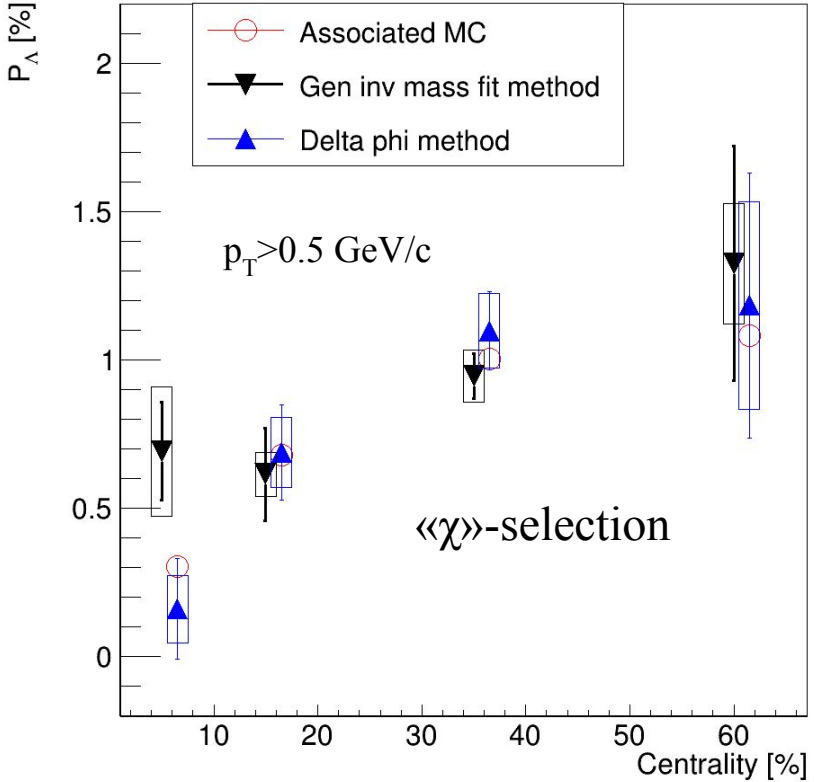
For Gen inv mass fit method:

- σ for fitting signal at all distributions: 3± 0.5σ
- Resolution: comparison of 2-sub event and 3-sub event
- $\varphi_{\Lambda} - \varphi_{p}^{*}$ bins: 16±4
- Bg polarization: fit the $\langle \sin(\Psi_{RP} - \varphi_{p}^{*}) \rangle$ with *pol0* and *pol1*

To do: comparison of event mixing and sidebands fit for Bg

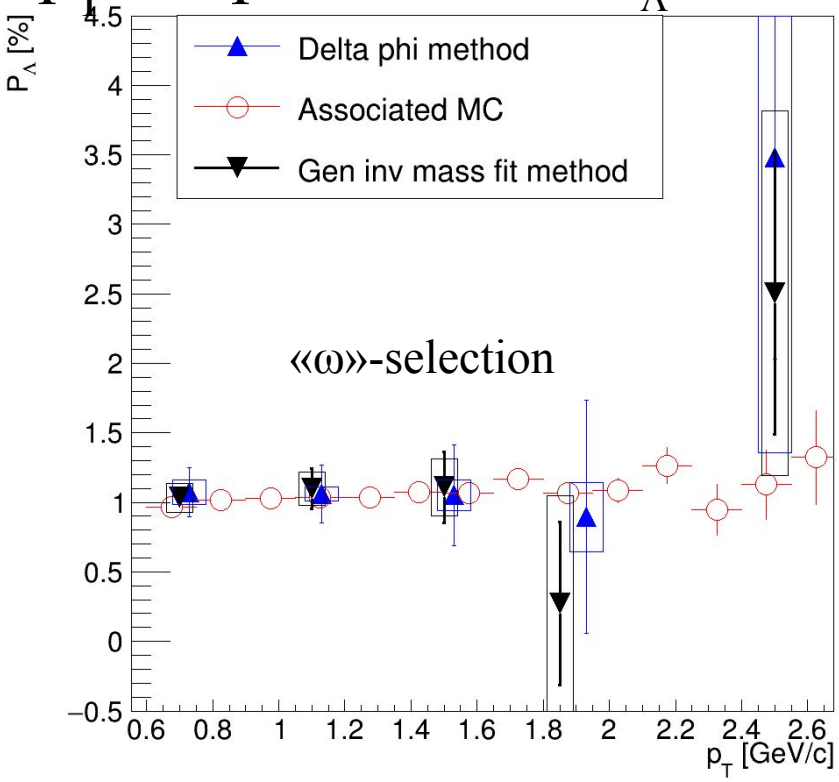
Centrality dependence of P_Λ

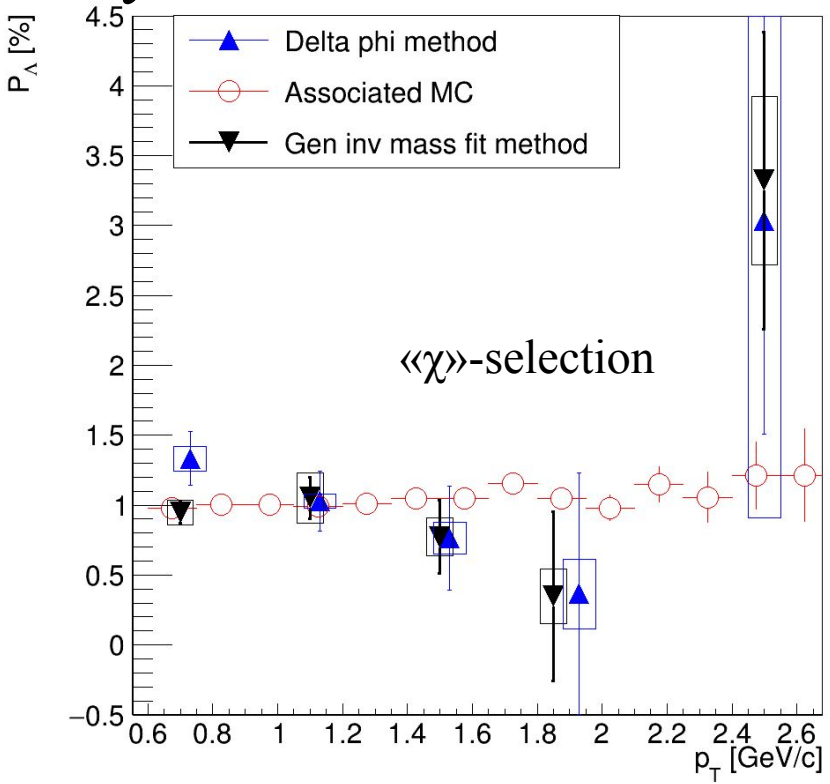




Both methods have a good agreement with Associated MC

p_T - dependence of P_Λ for centrality 20-50%

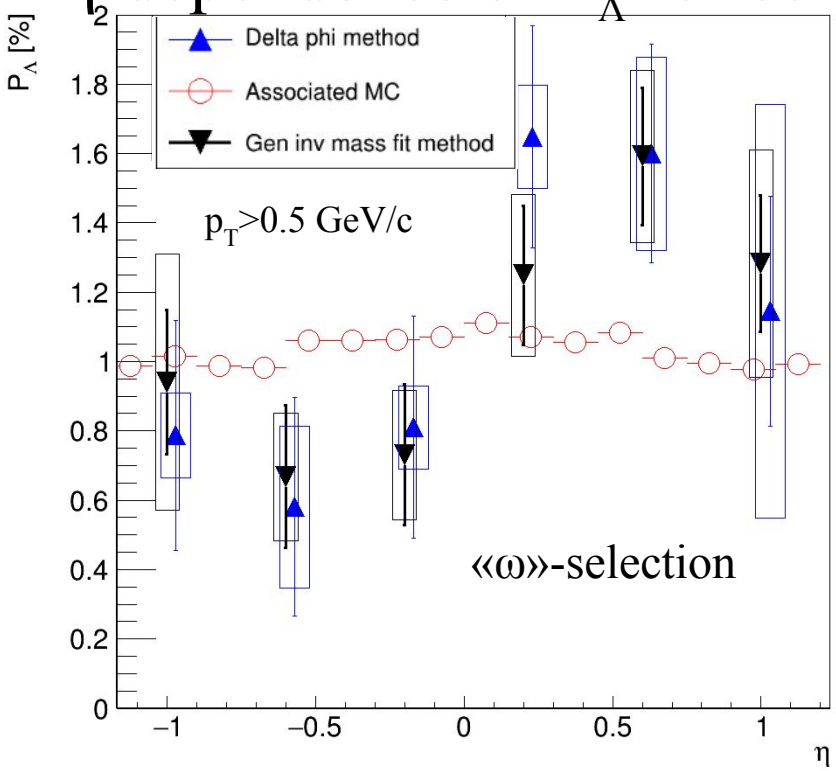


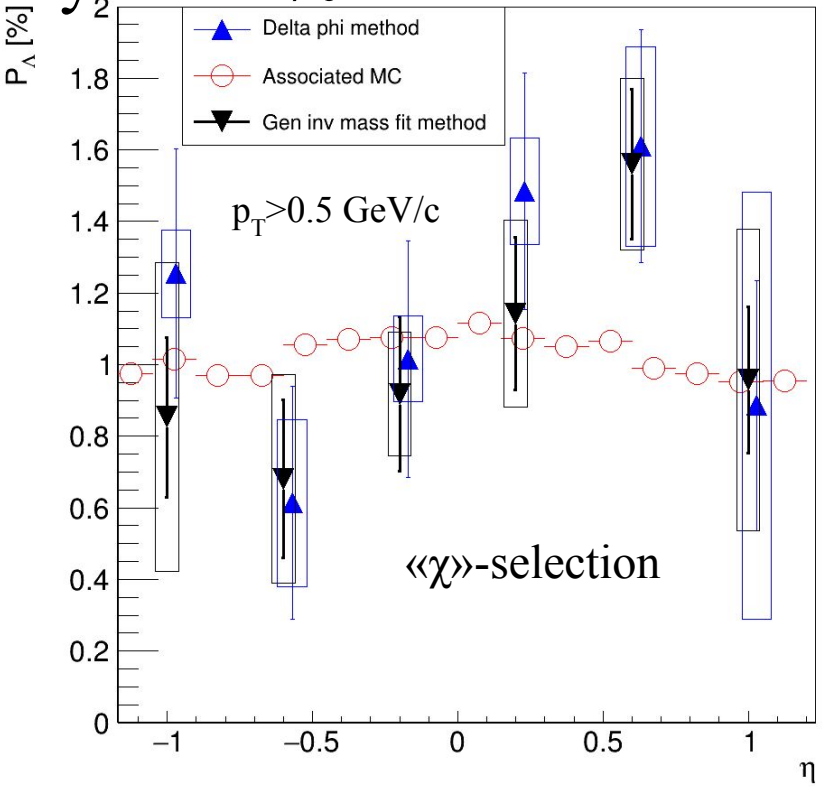


Both methods have a good agreement with Associated MC

Need more statistics to study high p_T region

η-dependence of P_Λ for centrality 20-50%





Both methods have an agreement with Associated MC

Need more statistics to study η-dependence

Summary

- Implementation of generalized invariant mass fit method
  - Gen inv. mass fit method is used in STAR collaboration and takes into account the effects of non-uniform acceptance and v_1 - may be applicable in fixed-target program at MPD
- Both methods have a good agreement with Associated MC
- The statistics size of 15M events is not enough for p_T-η measurements

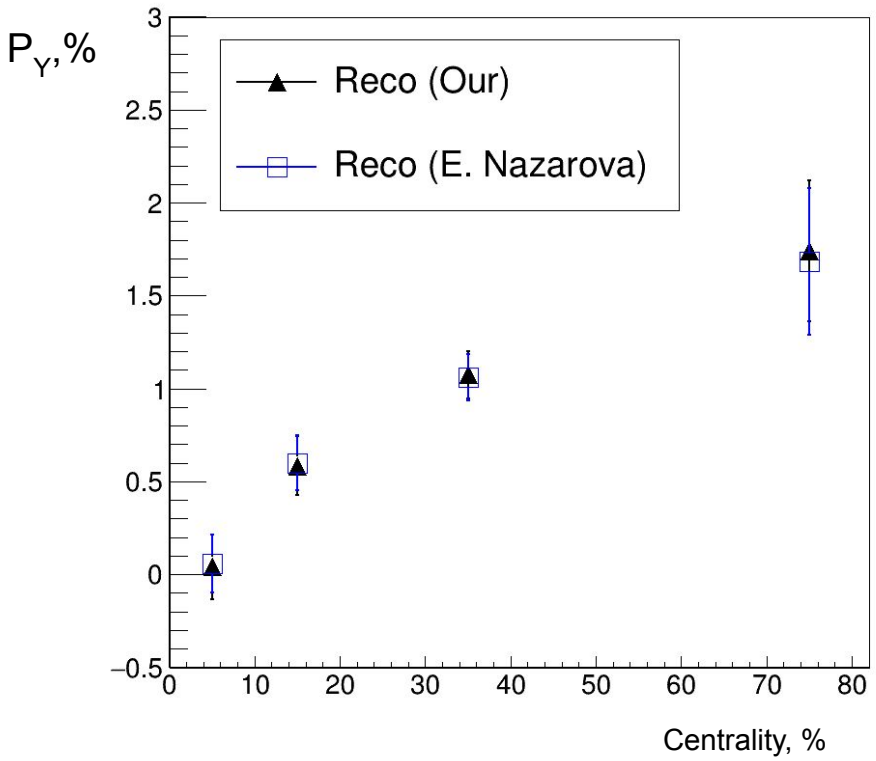
Outlook

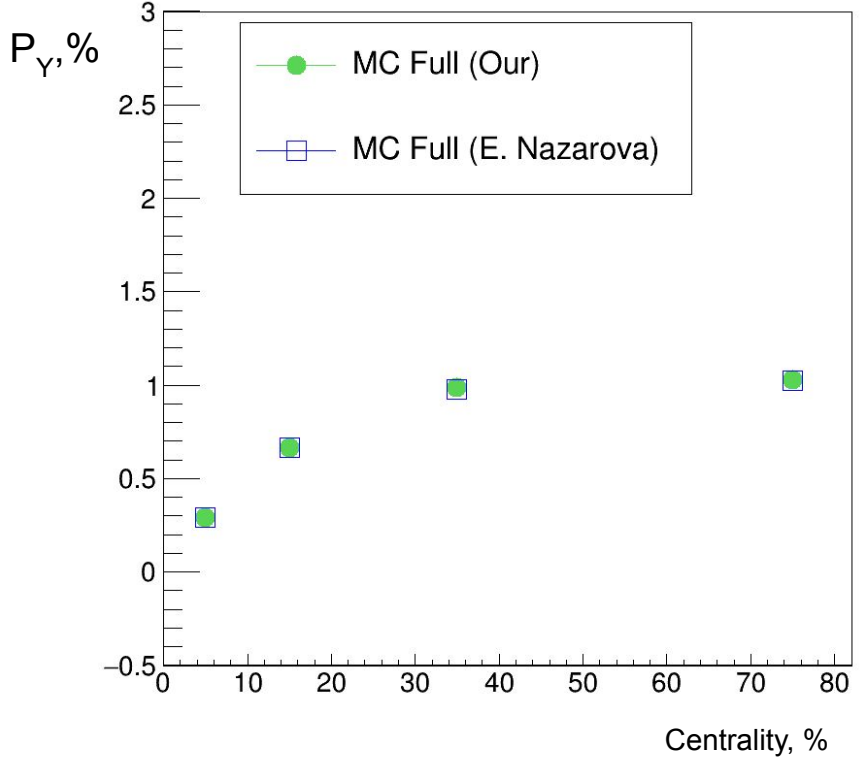
- Analysis of systematics
- $\bar{\Lambda}$-global polarization measurements
- Performance study with larger statistics(30-50M events)

Thank you for your attention!

BACKUP

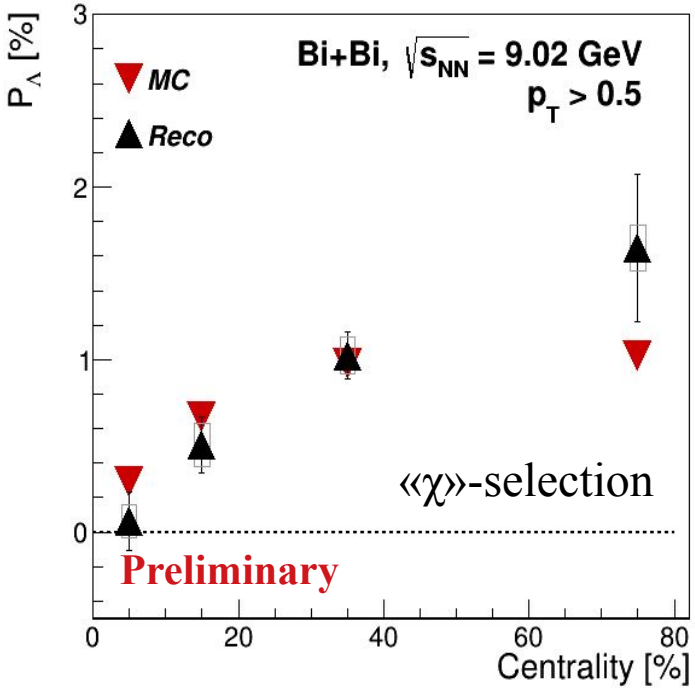
Comparison with E. Nazarova

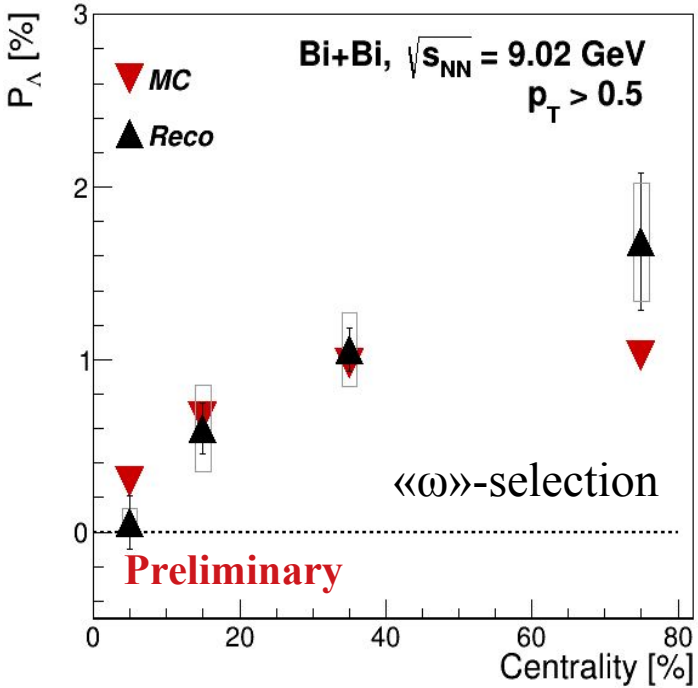




Full - all lambda

Results for Λ Polarization by E. Nazarova

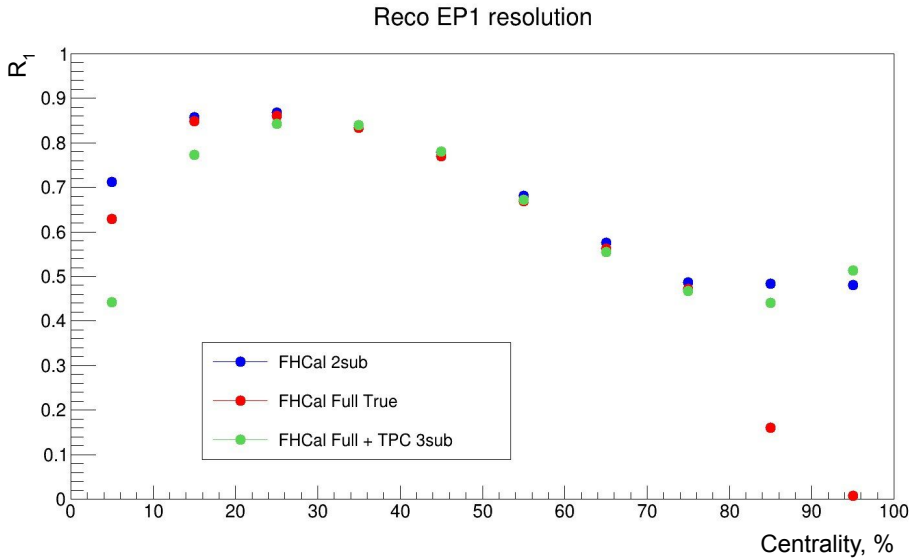


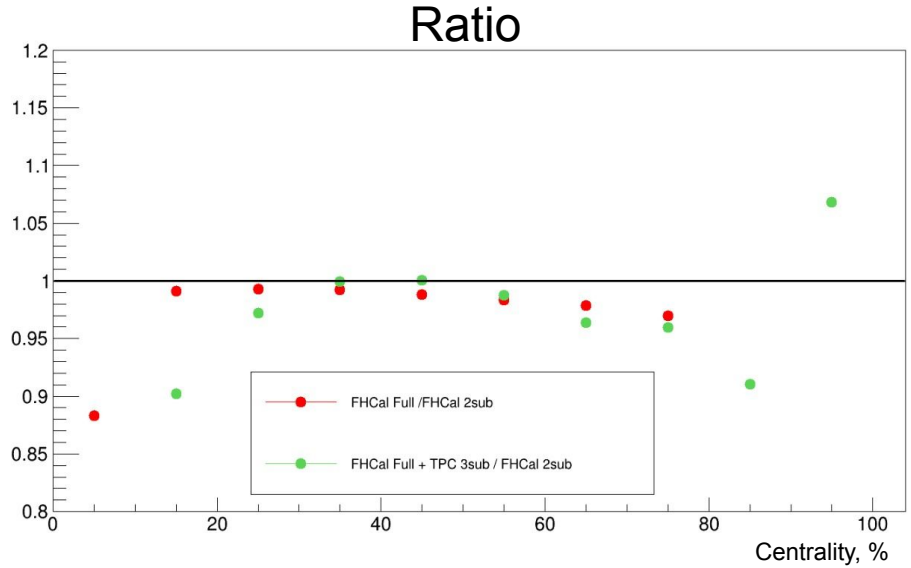


Nazarova E., SPIN 2023

- No significant variation using either type of selection
- Results are consistent and in good agreement with MC
- 0-10% and 50-70% centrality intervals have the largest deviation between reco and MC
- Lower statistics, reconstruction optimized for mid-central events

Resolution measurements





$$R_1 = \langle \cos(\Phi_1^F - \Psi^{RP}) \rangle \quad (1)$$

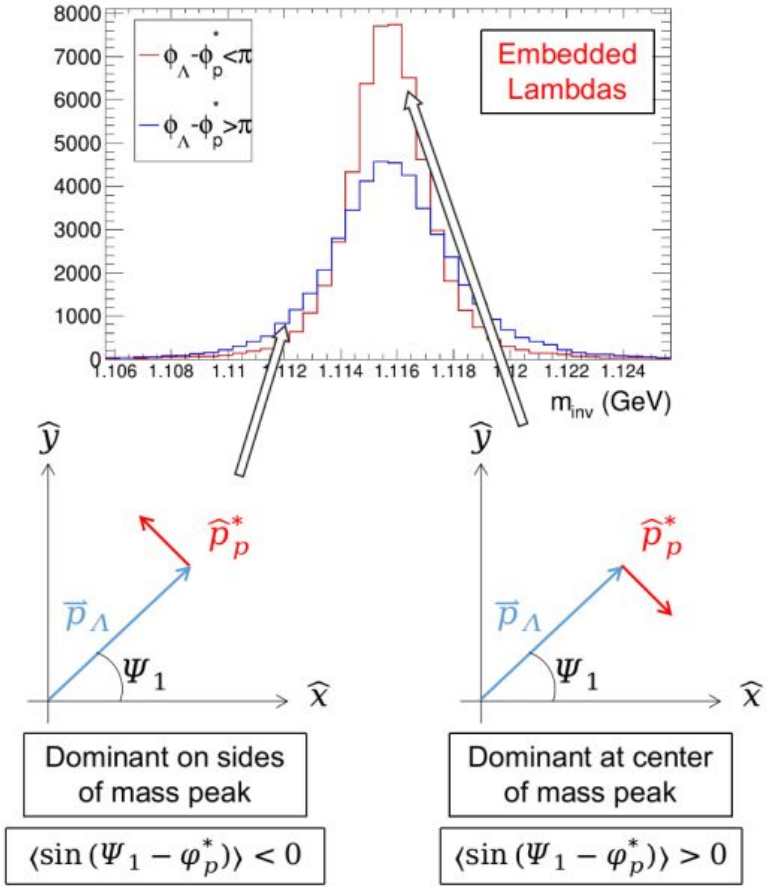
$$R_1(\Phi_1(F_N, F_S)) = \sqrt{\langle \cos(\Phi_1^{F_N} - \Phi_1^{F_S}) \rangle} \quad (2)$$

$$R_1(\Phi_1(T_N, T_S, F)) = \sqrt{\frac{2\langle \cos(\Phi_1^{T_N} - \Phi_1^{T_S}) \rangle \langle \cos(\Phi_1^{T_S} - \Phi_1^{F}) \rangle}{\langle \cos(\Phi_1^{T_N} - \Phi_1^{F}) \rangle}} \quad (3)$$

$$R_n(\Phi_n) = \frac{\sqrt{(\Pi)}}{2\sqrt{(2)}} \chi e^{-\frac{\chi^2}{4}} [I_{(n-1)/2}(\frac{\chi^2}{4}) + I_{(n+1)/2}(\frac{\chi^2}{4})] \quad (4)$$

- FHCal Full True from Eq. (1)
- FHCal 2sub event from Eq.(2)
- FHCal Full + TPC 3sub from Eq.(3)
- F - FHCal, T - TPC, N,S - right and left part of detector
- Eq.(4) - extrapolation to full event

Generalized inv. mass fit method



This method can deal with tracks crossing: daughter particles tracks with opposite charges are bended in the opposite directions in the magnetic field, and these tracks may cross each other -> creates 2 peaks distribution.
Solution: fit Sig with 2 gausses

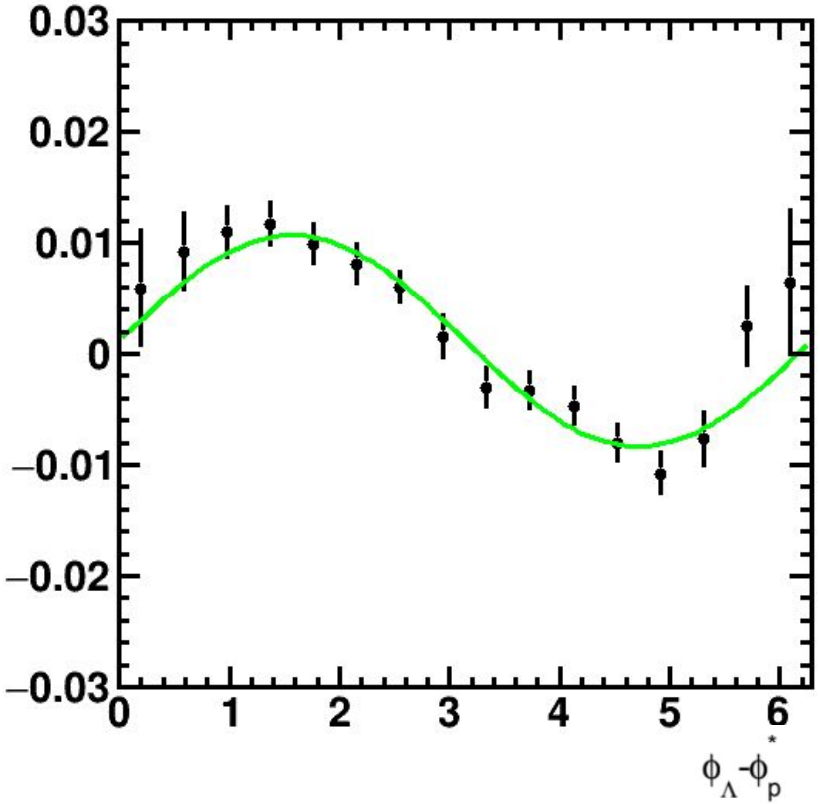
Warning: with detector asymmetry it would provide the effect of v_1 on the polarization measurements and odd pseudorapidity dependence

M.S. Abdallah et al. (STAR Collaboration), Phys. Rev. C 104, L061901 (2021)

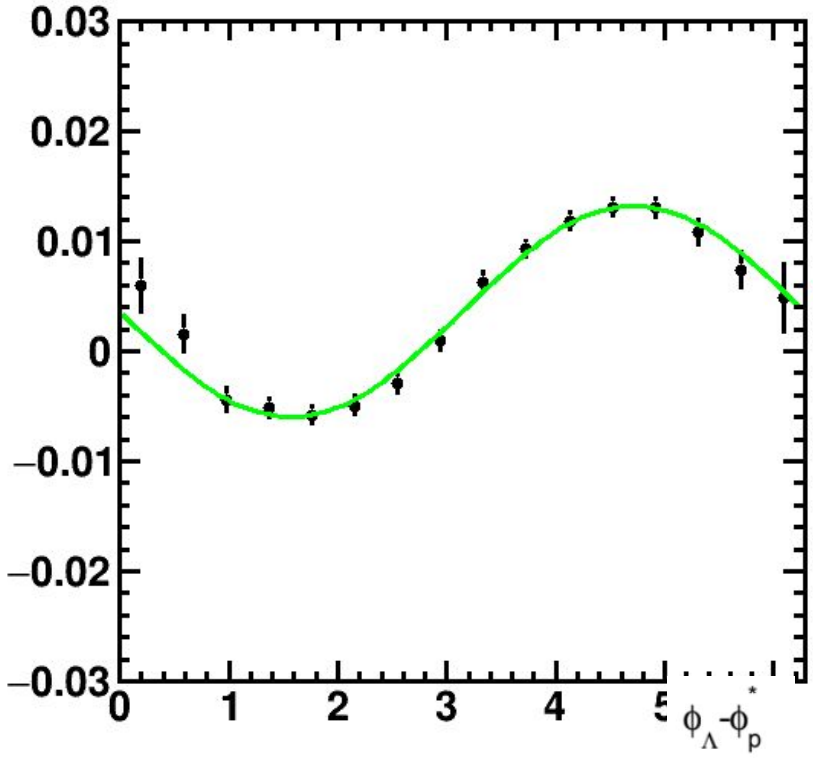
Examples pseudorapidity

$\langle \sin(\Psi_{RP} - \phi_p^*) \rangle^{sig}$

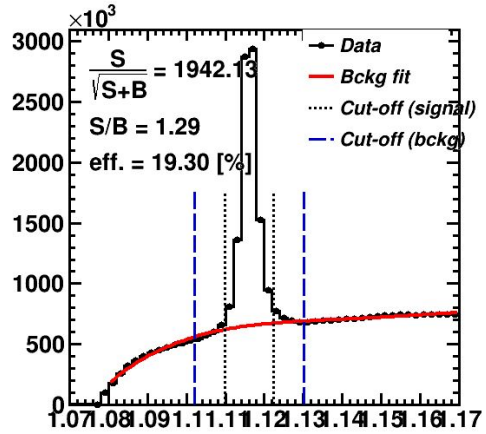
-0.8 < η < -0.4

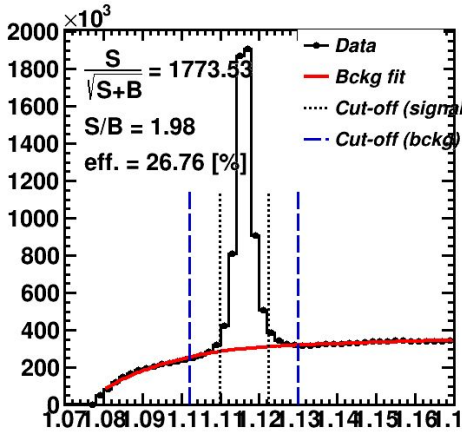


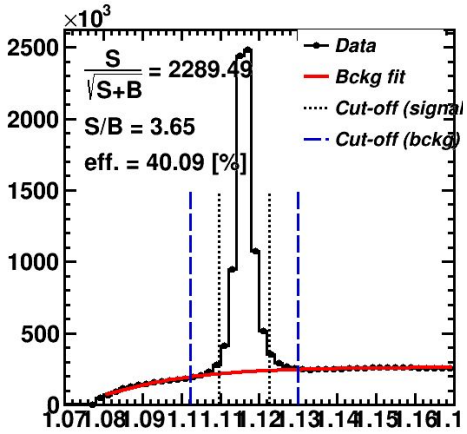
0 < η < 0.4

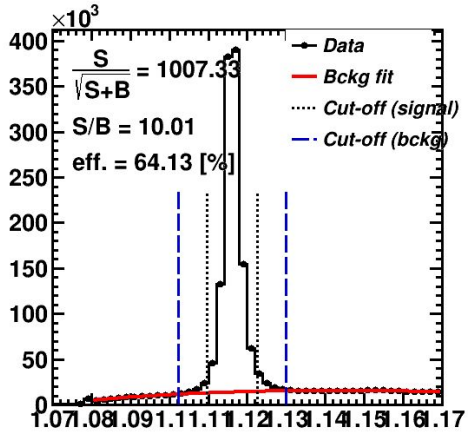


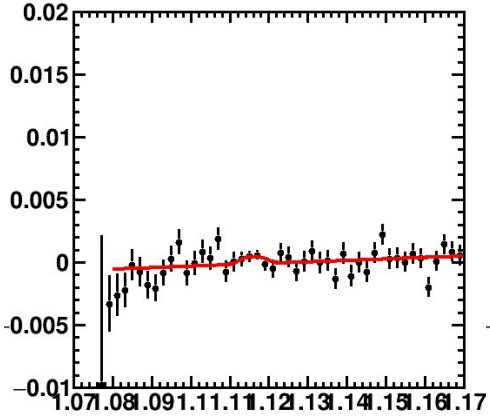
Examples of fitting procedure: Centrality

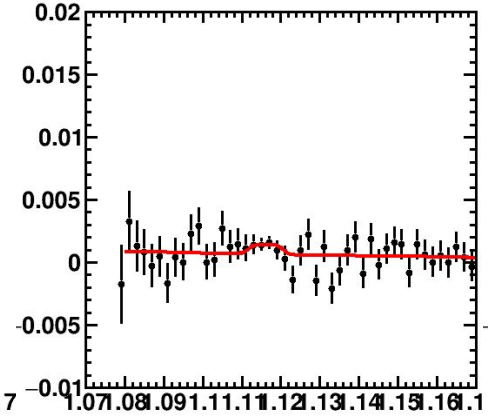


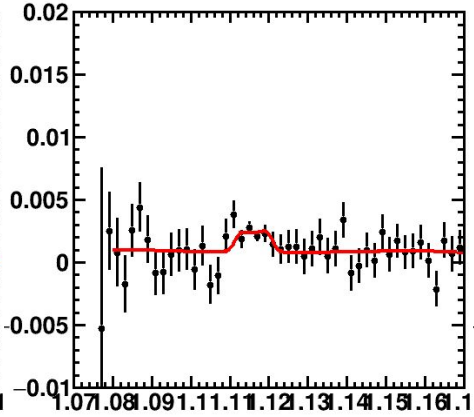


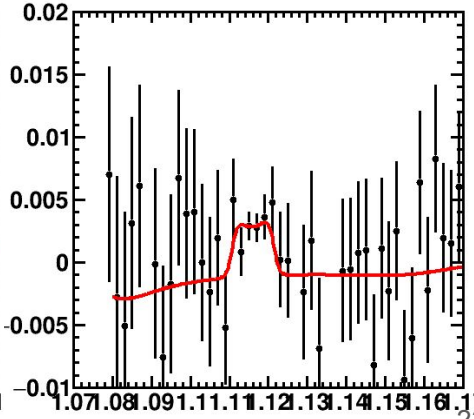




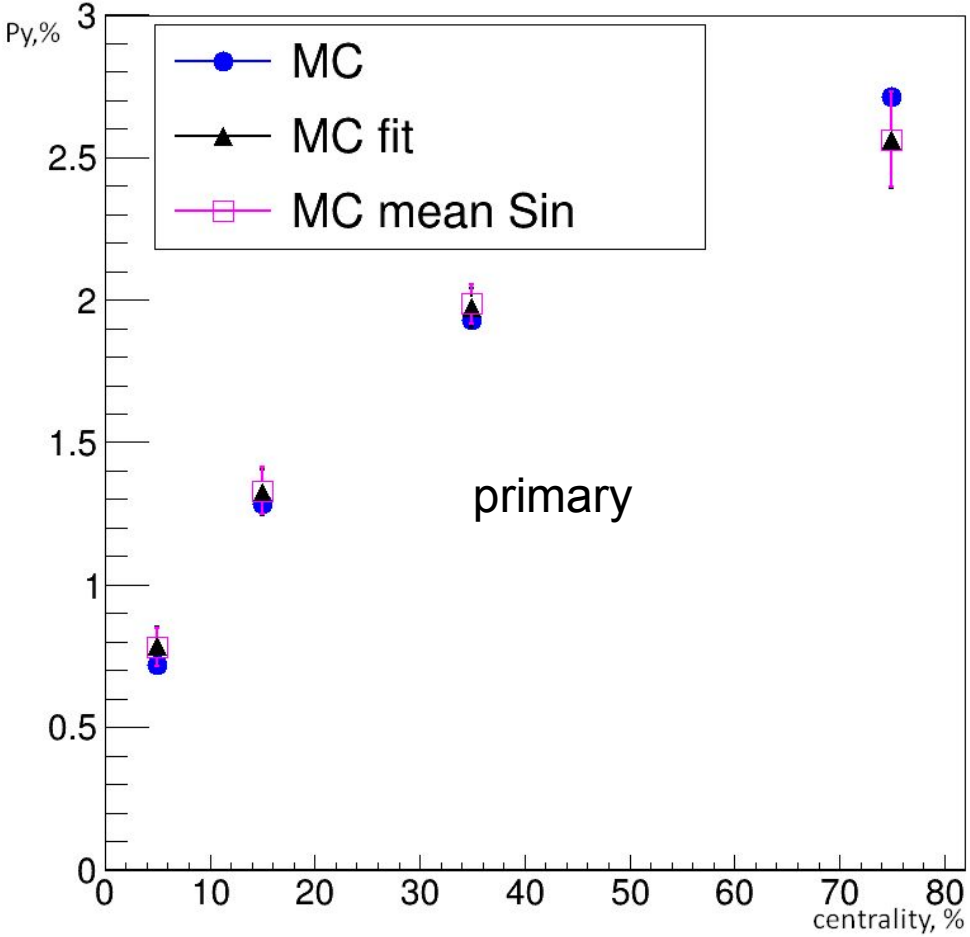




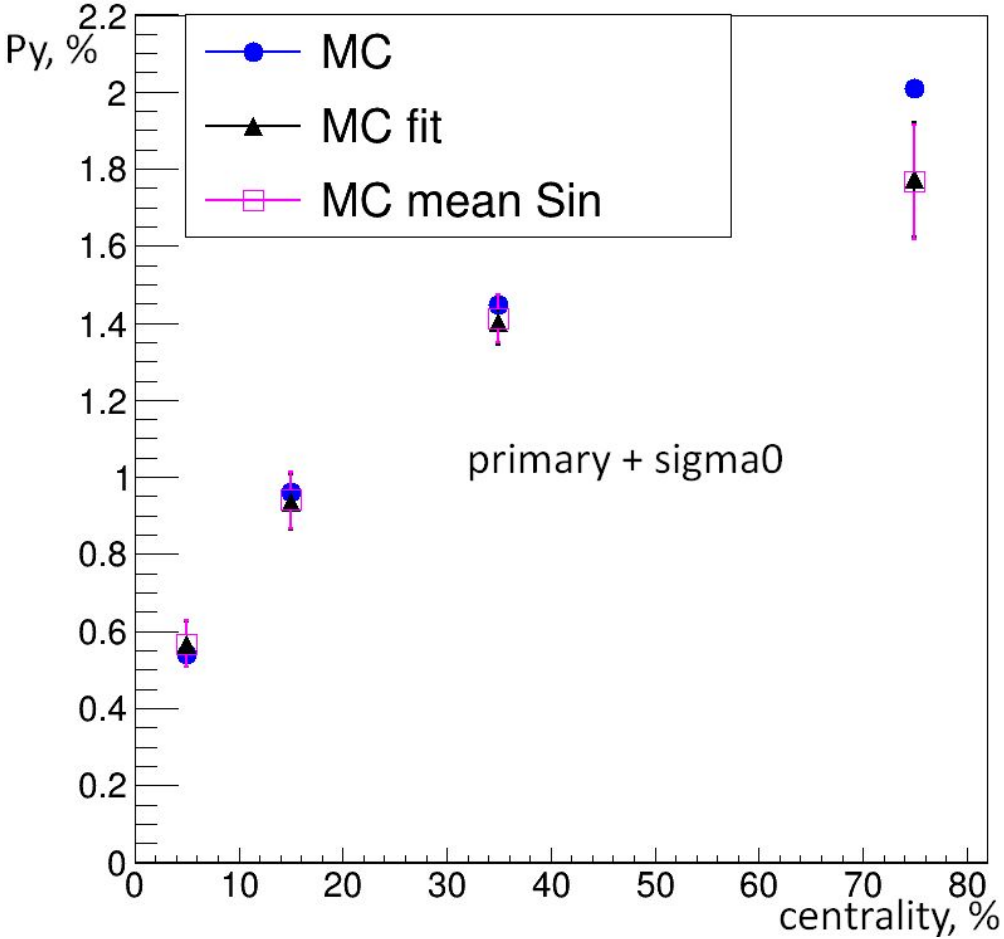




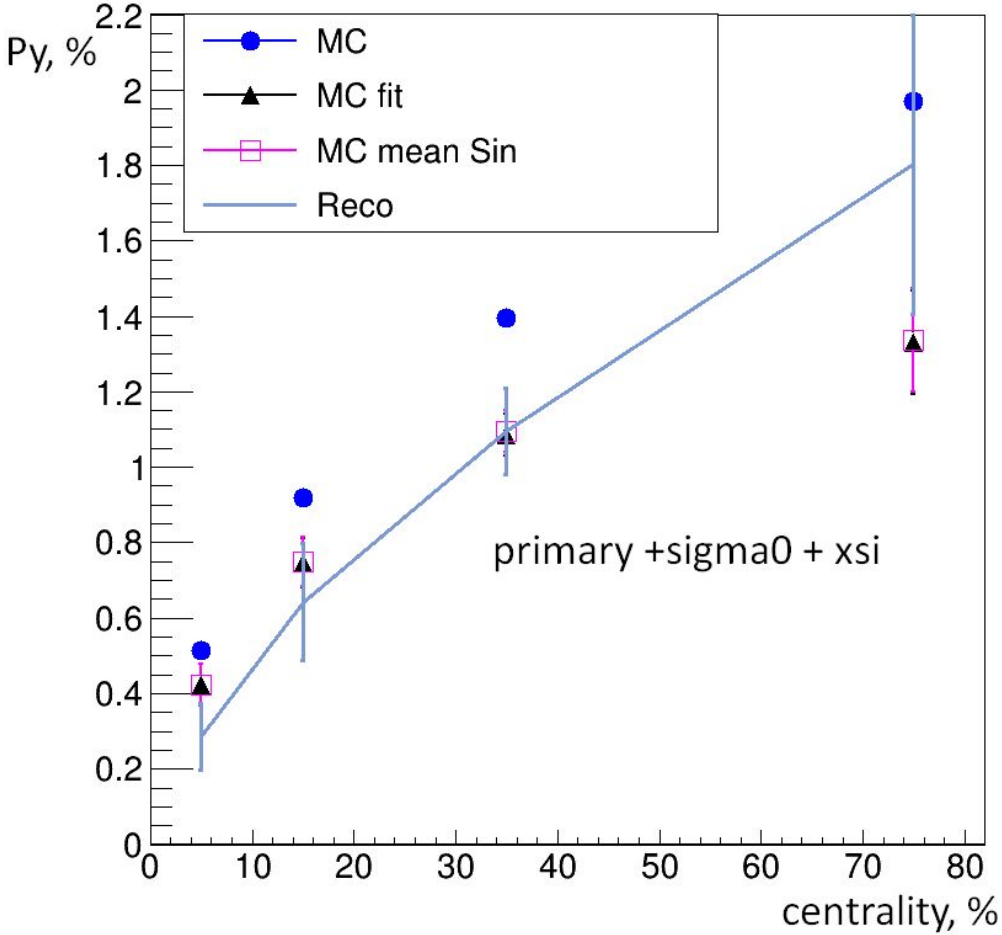
Primary


Py,%
MC
MC fit
MC mean Sin
primary
centrality, %
0
0.5
1
1.5
2
2.5
3
0
10
20
30
40
50
60
70
80

Primary + sigma0



Primary + sigma0 +xi



Wrong polarization for Lambda from Xi