Review of methods for measuring collective flow and global polarization of Λ hyperons

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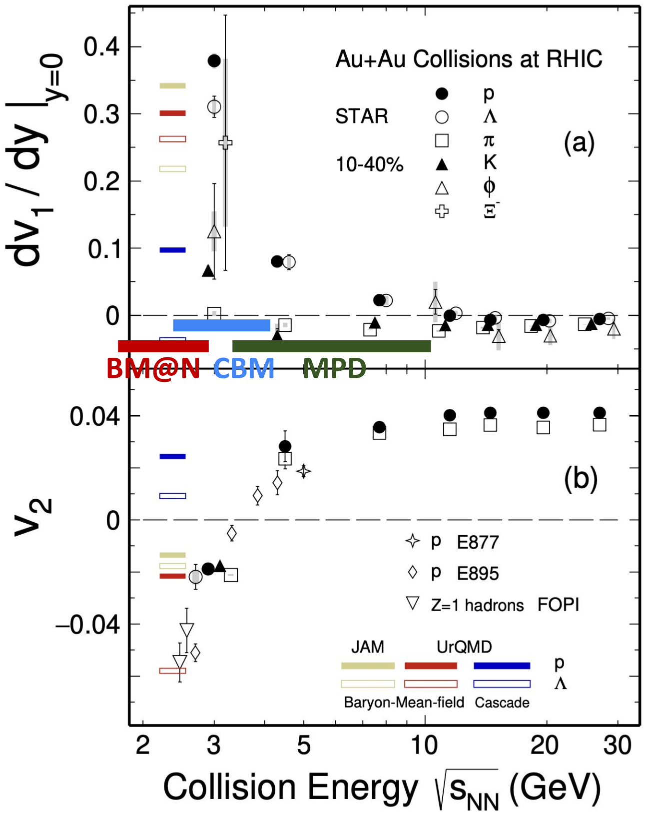
Outline

- Introduction
- Anisotropic flow and global polarization measurements
- Track crossing
- Reconstructed efficiency
- Radial distance asymmetry
- Detector occupancy
- Summary

Anisotropic transverse flow in heavy-ion collisions at Nuclotron-NICA energies



Strong energy dependence of dv_1/dy and v_2 at $\sqrt{s_{NN}}$ =4-11 GeV.

Anisotropic flow at FAIR/NICA energies is a delicate balance between:

- The ability of pressure developed early in the reaction zone
- Long passage time (strong shadowing by spectators).

Differential flow measurements $v_n(\sqrt{s_{NN}}$, centrality, pid, p_T, y) will help to study:

- effects of collective (radial) expansion on anisotropic flow
- interaction between collision spectators and produced matter
- baryon number transport

Several experiments (MPD, BM@N, STAR FXT, CBM, HADES, NA61/SHINE) aim to study properties of the strongly-interacted matter in this energy region.

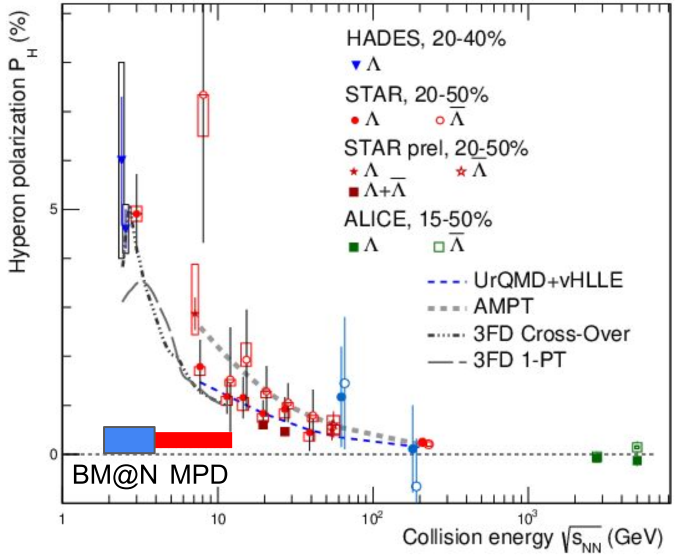
M. Abdallah et al. [STAR Collaboration] 2108.00908 [nucl-ex]

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

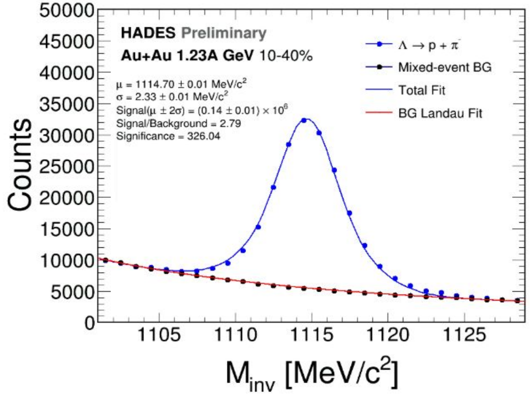


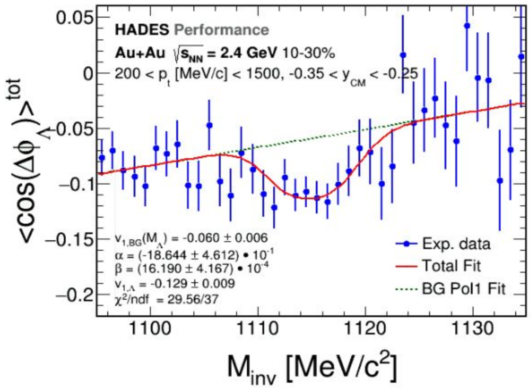
S. Singha, EPJ Web Conf. 276 (2023) 06012

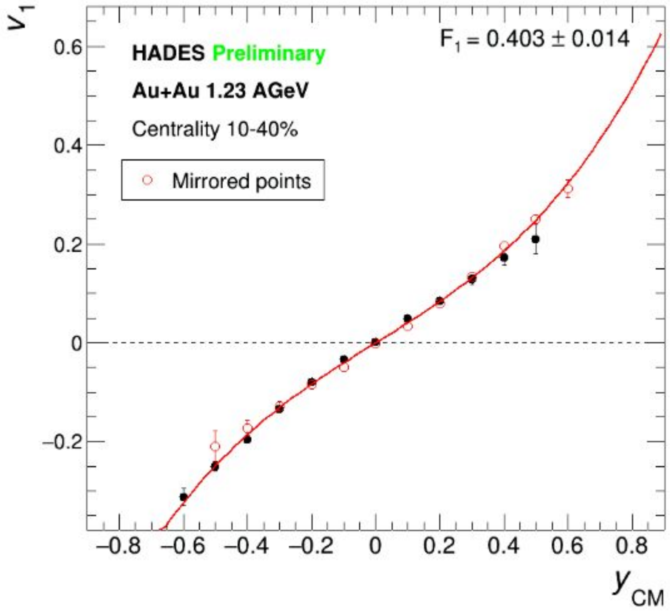
J. Adam et al. (STAR Collaboration), Phys. Rev. C 98, 014910 (2018)

O. Teryaev and R. Usubov, Phys. Rev. C 92, 014906 (2015)

v_n of V0 particles: invariant mass fit method







Reasonable directed flow measurements for reconstructed Λ

$$v_2^{SB}(m_{inv},p_T) = v_2^{S}(p_T)\frac{N^{S}(m_{inv},p_T)}{N^{SB}(m_{inv},p_T)} + v_2^{B}(m_{inv},p_T)\frac{N^{B}(m_{inv},p_T)}{N^{SB}(m_{inv},p_T)}$$

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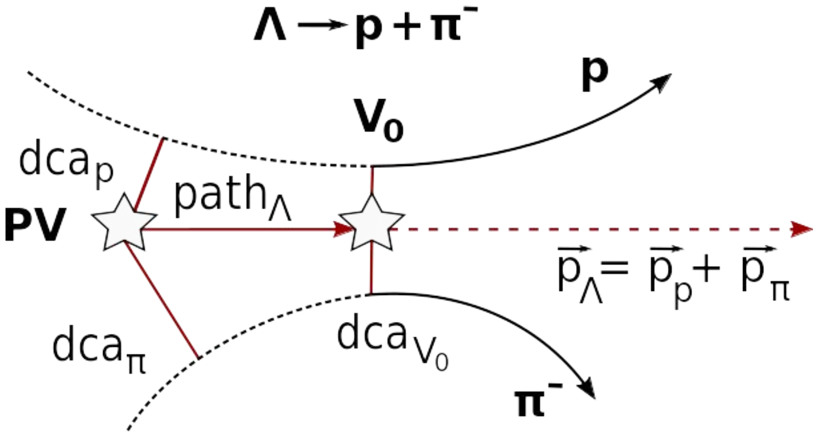
Measurements of global hyperon polarization

- 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 ($\Psi^1_{\mathrm{EP}}, R^1_{\mathrm{EP}}$)

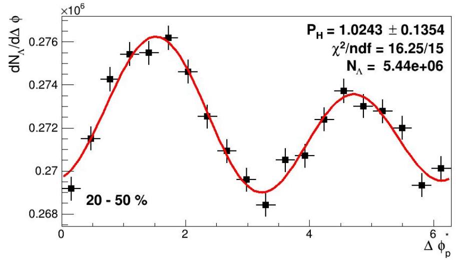
→ Reconstruct Lambda

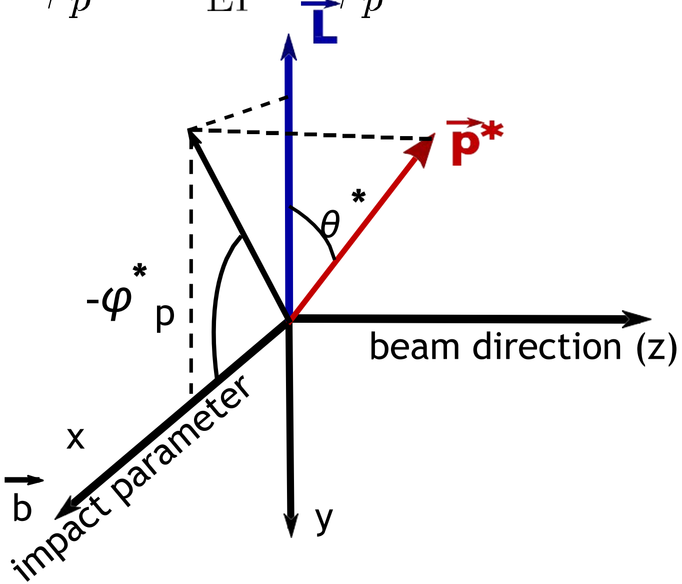
→ Measure global polarization

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





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

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

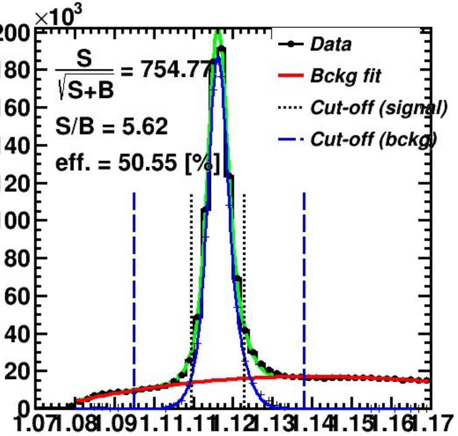
Inv. mass fit method

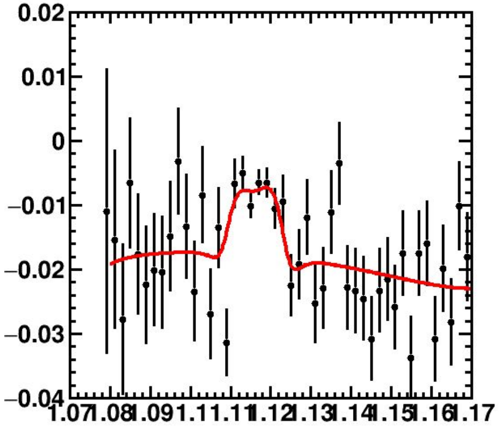
- Use invariant mass distribution
- Calculate Sig/All, Bg/All ratios
- Fit $\langle\sin(\Psi_{EP} - \varphi_p^*)\rangle$ as a function of inv. mass:

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

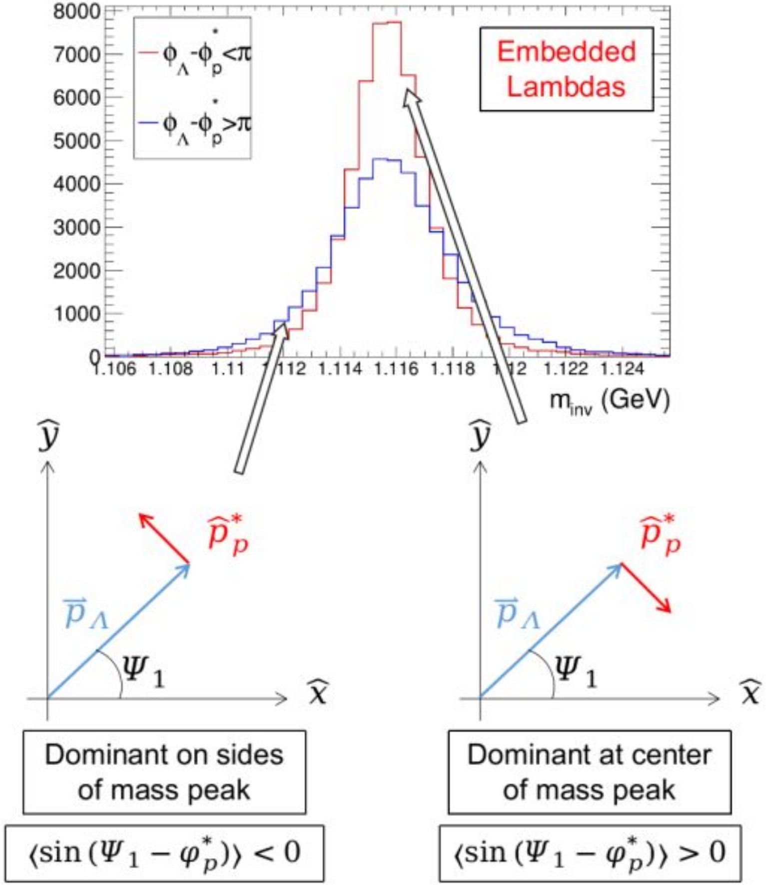
- Use $P^S(p_T) = \langle\sin(\Psi_{RP} - \varphi_p^*)\rangle^S$ to find P_H:

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





Track crossing and v_1 contribution

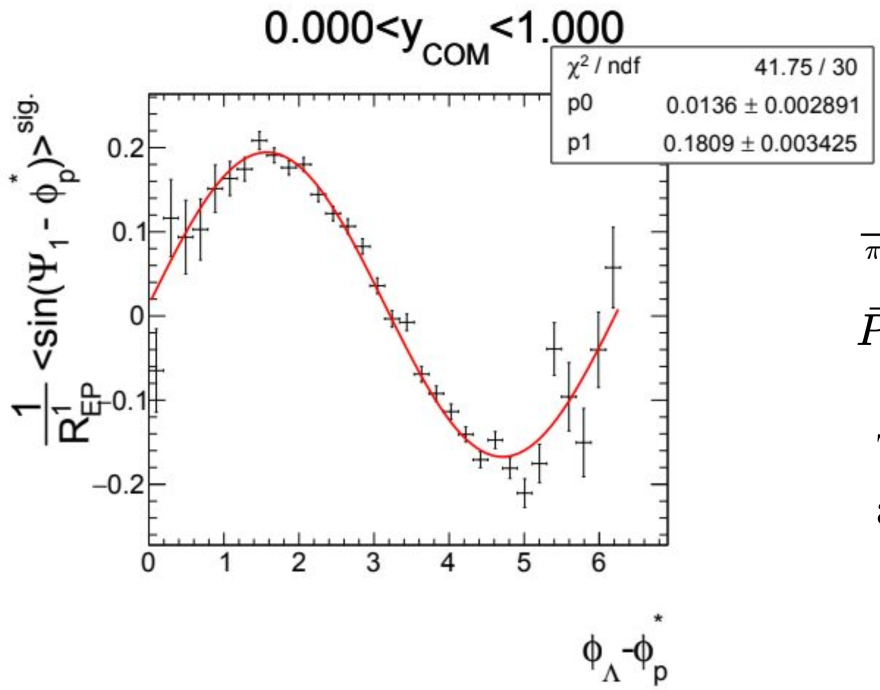


Problem: daughter particles tracks with opposite charges are bended in the opposite directions in the magnetic field, and these tracks may cross each other that leads 2 peaks distribution.
Solution: fit signal with 2 gausses

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)

Generalized inv. mass fit method



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

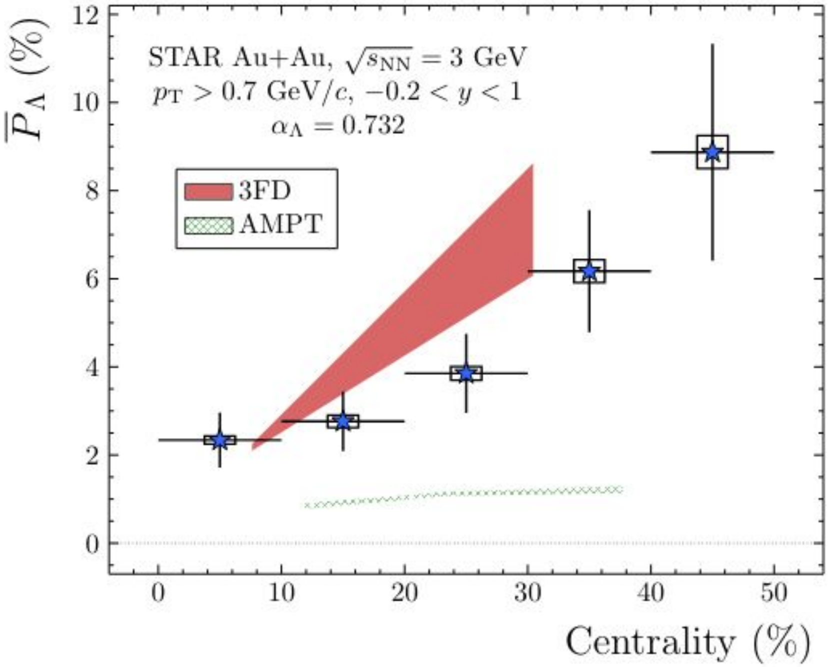
$$\frac{8}{\pi \alpha_\Lambda} \frac{1}{R_{EP}^{(1)}} \langle \sin(\Psi_1 - \phi_p^\star) \rangle^{sig} = \overline{P_\Lambda}^{true} + c v_1 \sin(\phi_\Lambda - \phi_p^\star)$$

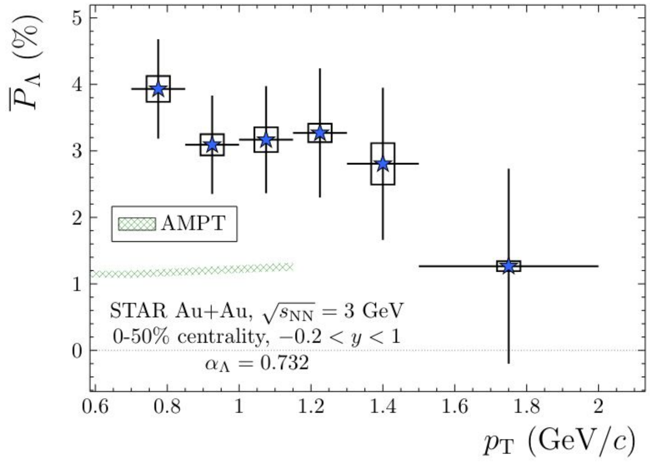
$$\bar{P}_H = \frac{1}{2}[\bar{P}_H(\eta > 0) + \bar{P}_H(\eta < 0)]$$

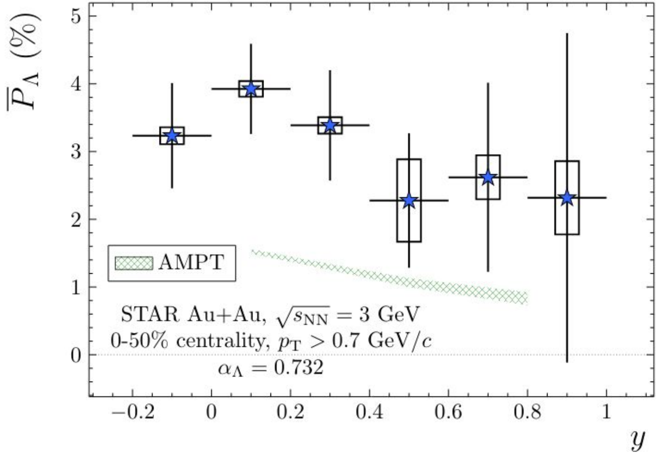
This fit corrects effects of directed flow and acceptance contributions to P_H

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

Global polarization: STAR results







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

No dependence within uncertainties

Corrections for reconstruction efficiency

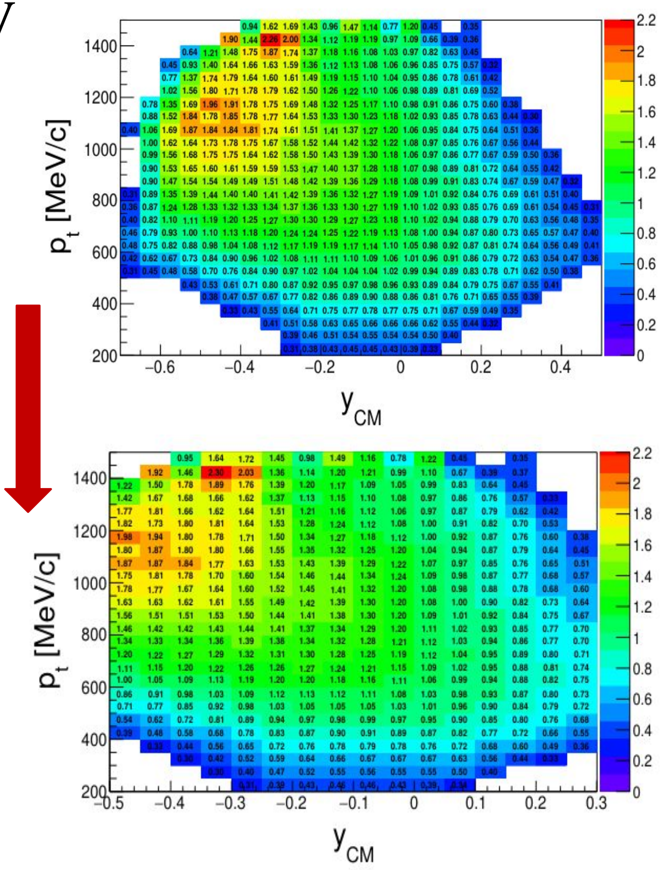
Problem: collective flow and global polarization are the observables with amplitude ~ 10^{-1}-10^{-2} and 10^{-3} correspondingly

Very limited acceptance leads to increasing the fluctuations of the mean due to low efficiency

Solution: weighting with relative reconstruction efficiency

$$\bar{\epsilon} = \frac{\int dy \int dp_t \frac{dN_{Reco}}{dy\,dp_t} \epsilon(p_t, y)}{\int dy \int dp_t \frac{dN_{Reco}}{dy\,dp_t}},$$

- Avoiding the shift of the mean
- Do not facing with the increasing of fluctuations



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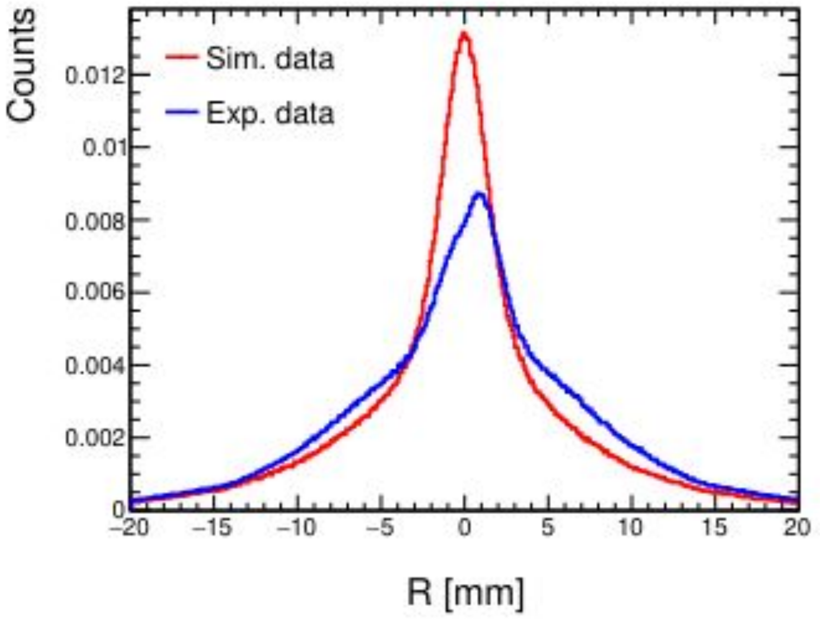
Corrections for the radial distance asymmetry

Radial distance R - is the minimum distance of the reconstructed track to the beam axis

Problem: asymmetry of the radial distance wrt. vertex.
Solution: take the R distribution in the inv. mass range under the peak of Λ and calculate the weights that do this distribution flat after the correction



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Corrections for detector occupancy

Problem: efficiency loss due to strong varying track densities

Result: effect on v_1 pseudorapidity dependence

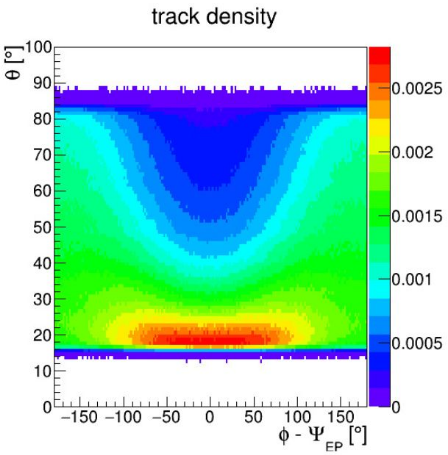
Solution:

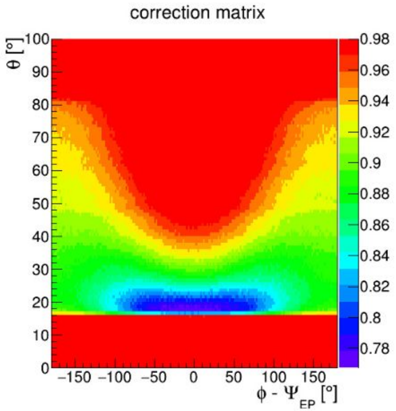
- centrality bins for occupancy
- $\epsilon(N_{\text{track}}) = \epsilon_0(1 - k \cdot N_{\text{track}})$

To obtain corrections due to occupancy for Λ the multiplication of proton and pion occupancy is used:

$$\epsilon_\Lambda = \epsilon_p \cdot \epsilon_{\pi^-}$$

- Very high effect on v_1 slope that cannot be explained with systematics
- Occupancy corrections for Λ is not working correctly





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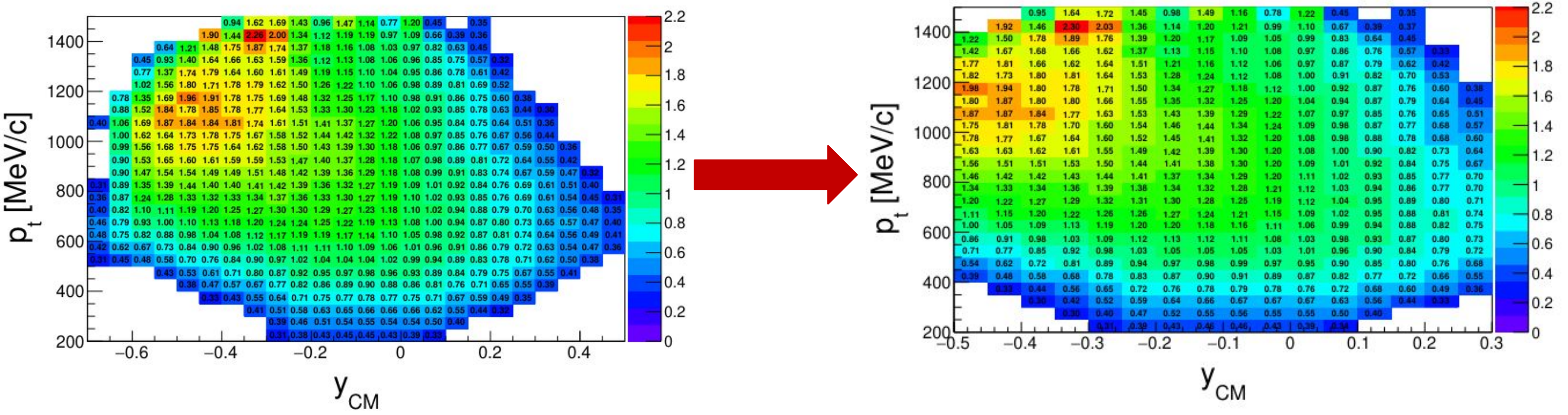
Summary

- Inv. mass fit method is a standard method for v_n measurements of V0 particles
- $\Delta\varphi$-method and inv. mass fit method gives reasonable result for global polarization measurements
  - Generalized inv. mass fit method is possible to correct acceptance effects and directed flow contribution
- Corrections reconstructed efficiency and radial distance asymmetry provides a reasonable effects
- Corrections for detector occupancy are still important to be studied

Thank you for your attention!

BACKUP

Corrections for reconstruction efficiency



- cut efficiency <0.3
- Provide a relative efficiency
- Smooth it by Savitzky-Golay filter

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