Feasibility studies using enhanced particle production: an afterburner for the MPD experiment

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Outline

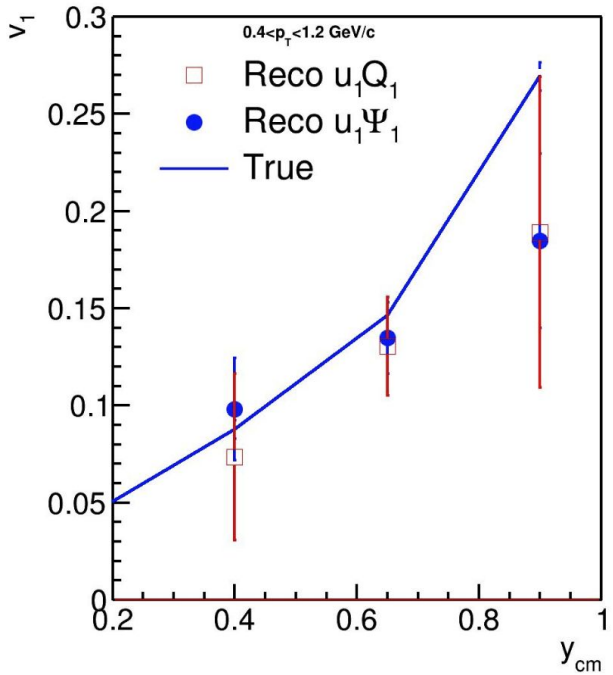
- Motivation
- How event re-sampling works
- MC Results for UrQMD Xe+Xe @ 2.86 GeV
- MPD in Fix-Target Mode (FXT)
  - Dataset
  - Enhanced Λ production via the afterburner
  - v1 and v2 of Λ hyperons for Xe+Xe at Ekin=2.5 AGeV for MPD-FXT
- Summary and outlook

Motivation to enhance signal

- Important for analysis with low reconstruction efficiency (e.g. direct photons, resonances, ϕ-mesons, Σ, Λ…)
- Precise measurements of **global polarization** and **anisotropic flow** of Λ-hyperons require **high statistics**
- **Anisotropic flow** and **global polarization**[1] analysis are sensitive to the **QCD matter properties**
- BM@N energy[2] overlap with MPD-FXT ($\sqrt{s_{NN}} \approx 2.3–3.5$ GeV [3]) enables common analysis strategies

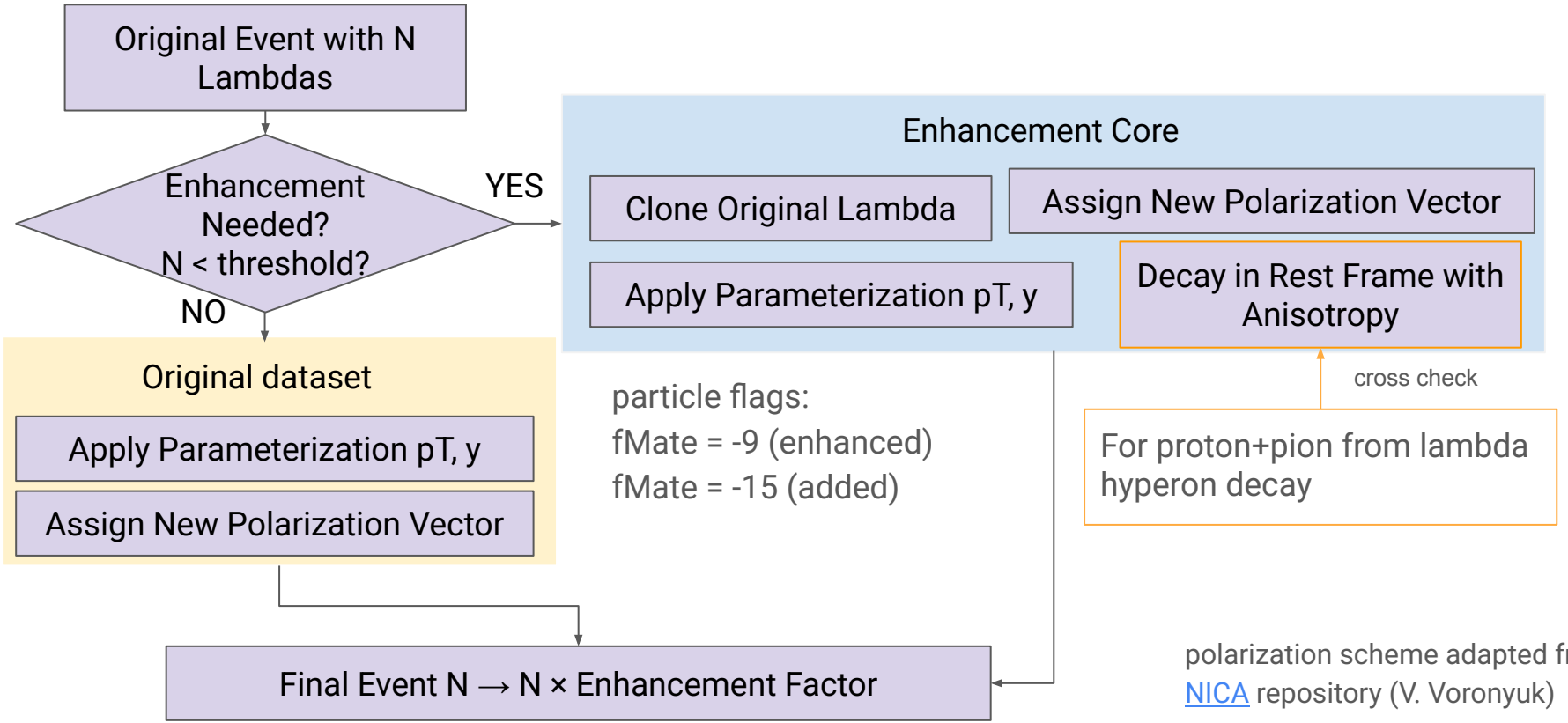
[1] Z. Liang, X. Wang, PRL 94, 102301 (2005)
[2] EPJ Web of Conferences 182, 02061 (2018)
[3] Phys.Part.Nucl. 56 (2025) 3, 921-927

M.Mamaev, 15th Collaboration Meeting of the BM@N Experiment at NICA, 203 (2025)



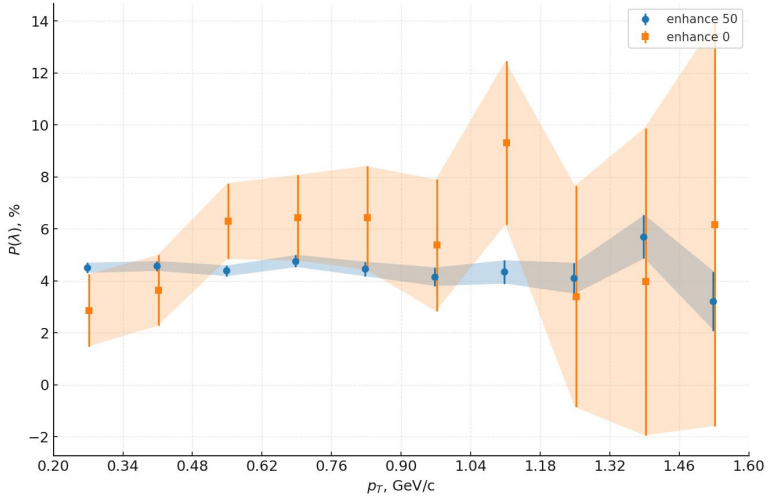
Performance with JAM model (true); reco results are systematically lower

How event re-sampling works



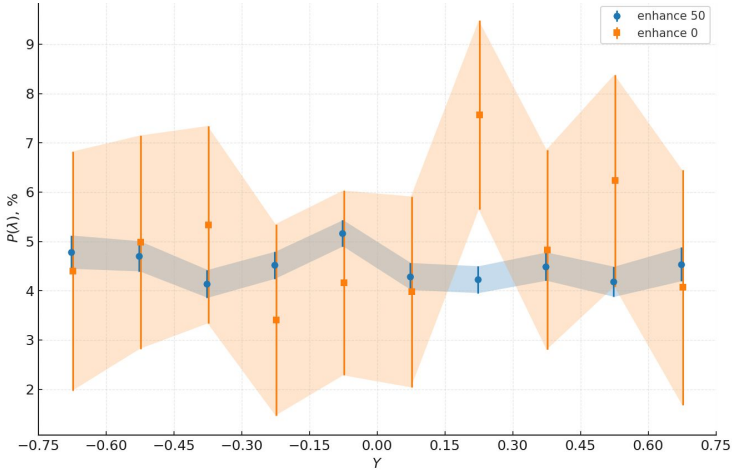
polarization scheme adapted from NICA repository (V. Voronyuk)

MC Results for UrQMD Xe+Xe @ 2.87 GeV



Global polarization depend on p_T

$0.2 < p_T < 1.6$ GeV/c

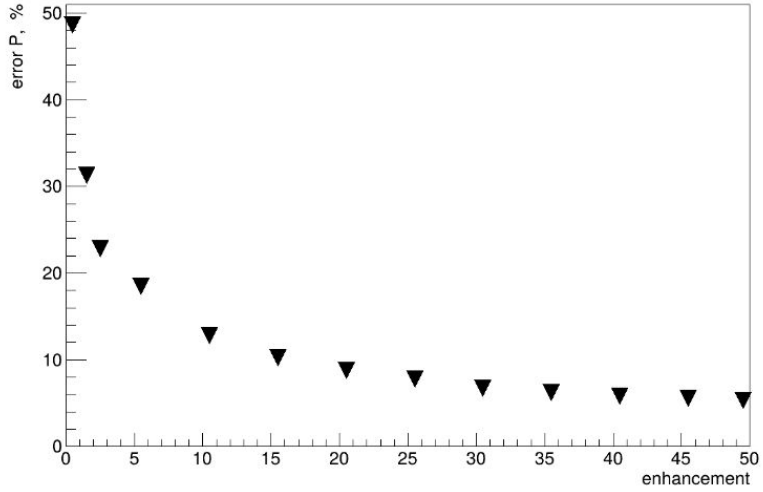


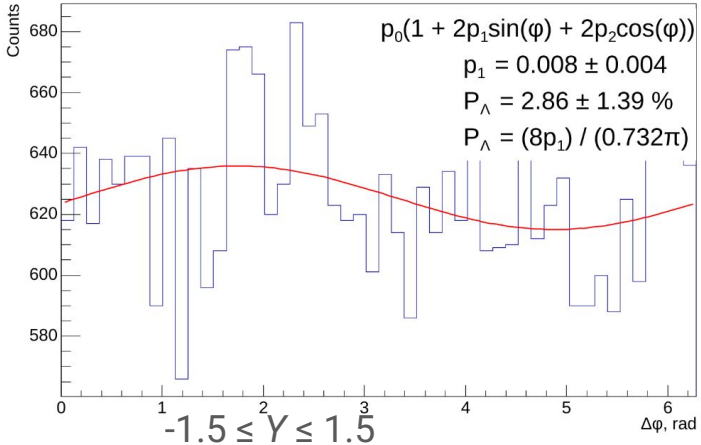
Global polarization depend on rapidity

$-0.75 < Y < 0.75$

MC Results
for UrQMD Xe+Xe @ 2.87 GeV

- Reasonable enhancement ~5-10;
- Enhancement improve quality of global polarization;
- Reduce statistical uncertainty from 48 % to 4.4 %



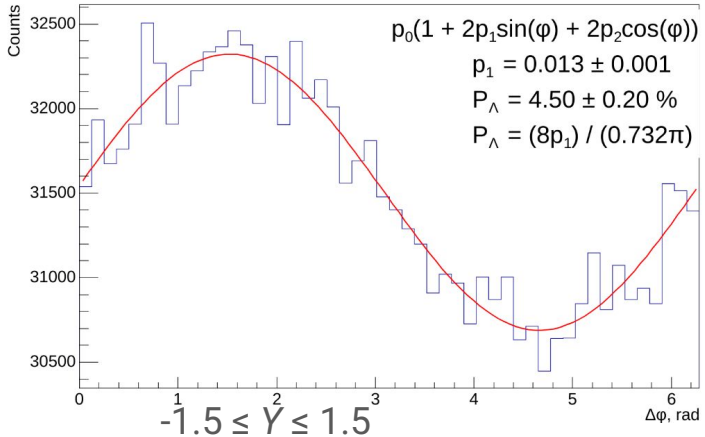


-1.5 ≤ Y ≤ 1.5

0.2 ≤ p_T ≤ 0.34 GeV/c

enhancement
(50 lambda in event)

~65k events

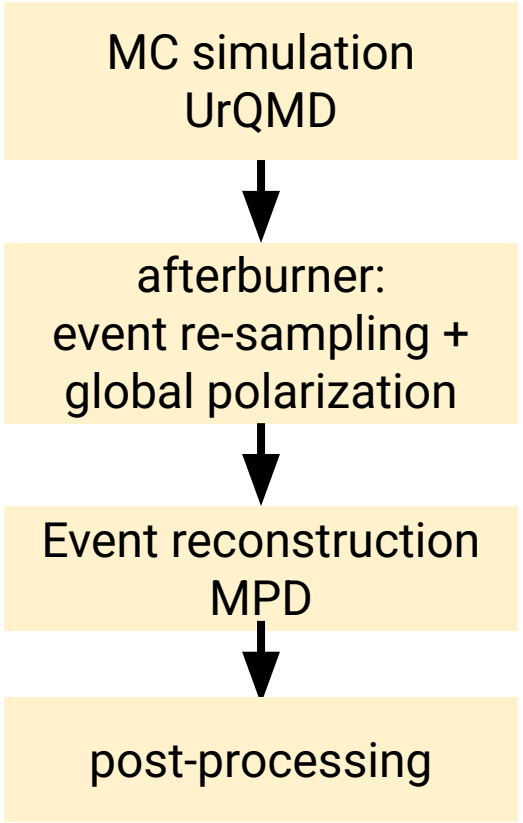


-1.5 ≤ Y ≤ 1.5

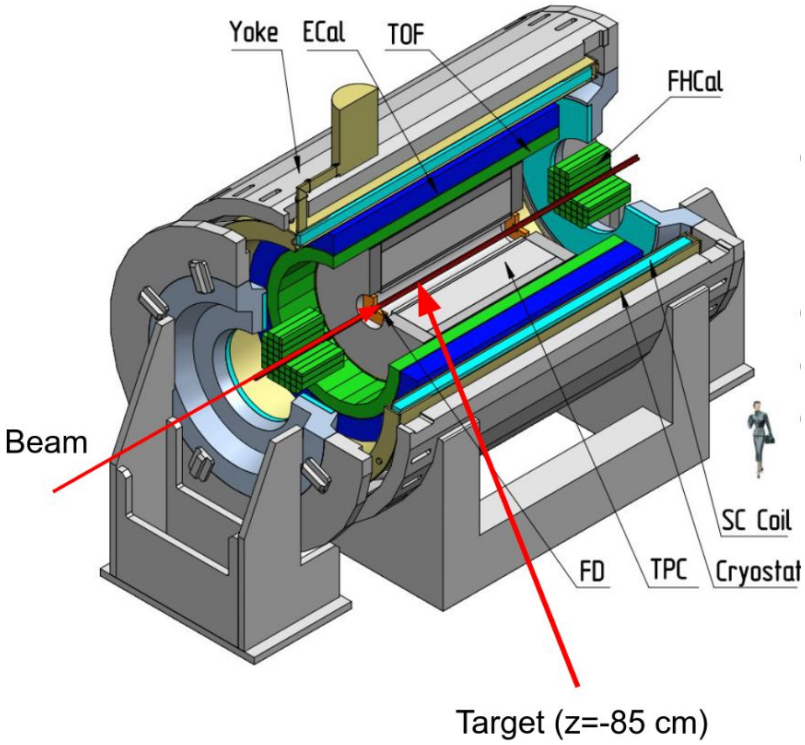
0.2 ≤ p_T ≤ 0.34 GeV/c

Reconstruction: dataset

1. UrQMD Xe+Xe @ 2.87 GeV, 10M events, UniGen format
2. Global hyperon polarization generated from the afterburner $\mathbf{P} = \{P_x, P_y, P_z\}$
3. Enhanced statistics with 5 additional Λ hyperons per event



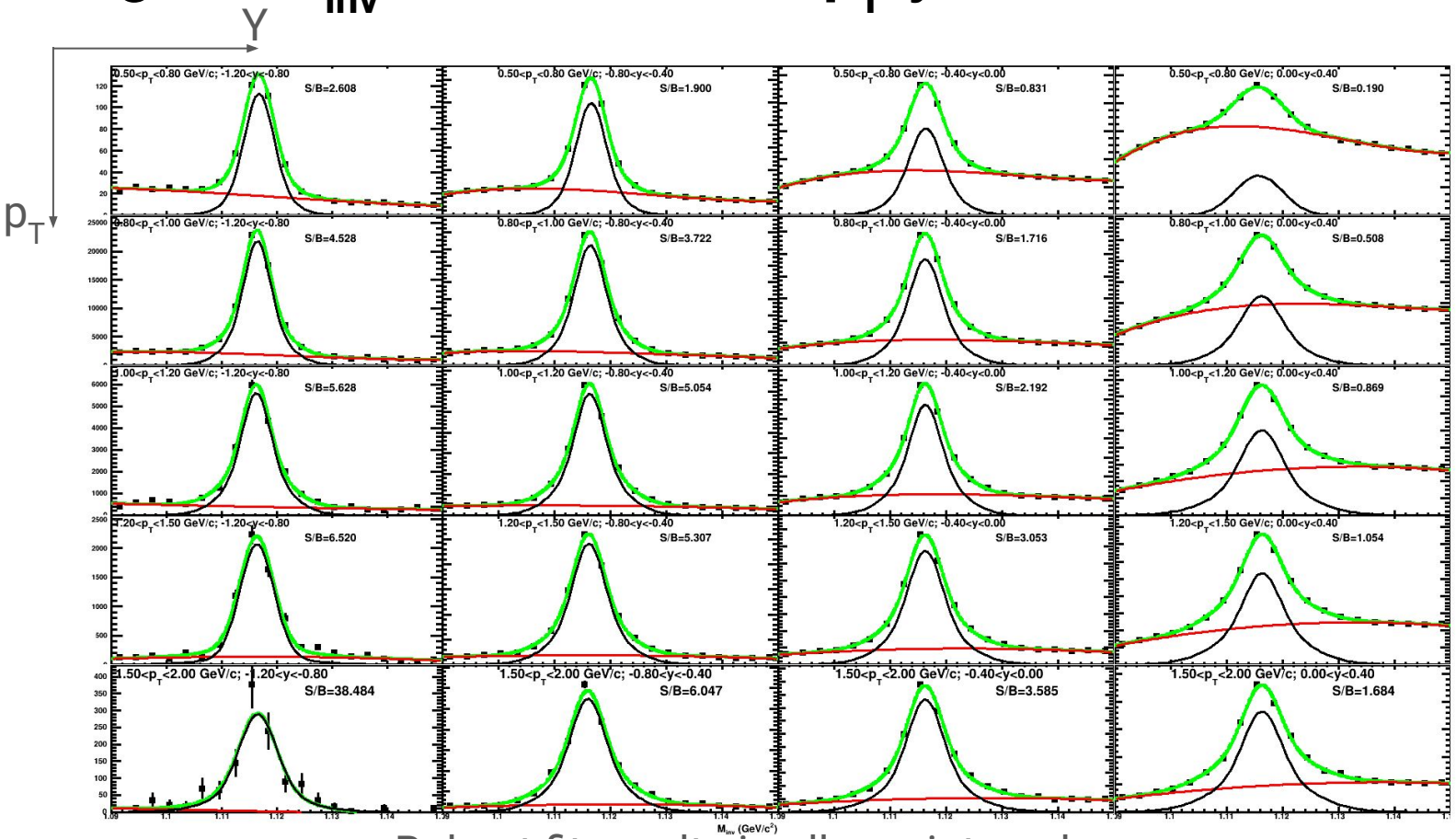
MPD in Fixed-Target Mode (FXT)



- Model used: UrQMD 3.4:
  - Xe+Xe,
    $E_{kin} = 2.5\ AGeV\ (\sqrt{s_{NN}} = 2.87\ GeV)$
- point-like target at z = -85 cm, y = 1 cm
- GEANT4 transport
- Enhanced Λ production (via UniGen afterburner)
  - 5 additional Λ hyperons per event
  - Realistic v_1, v_2, P_Λ parameterizations

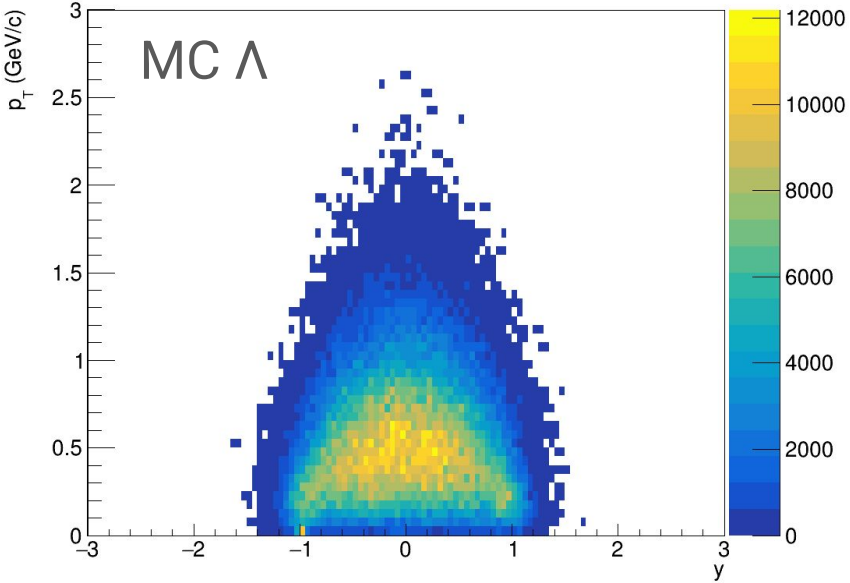
Enhanced production is necessary to obtain statistically significant results w/o modeling a huge amount of data.

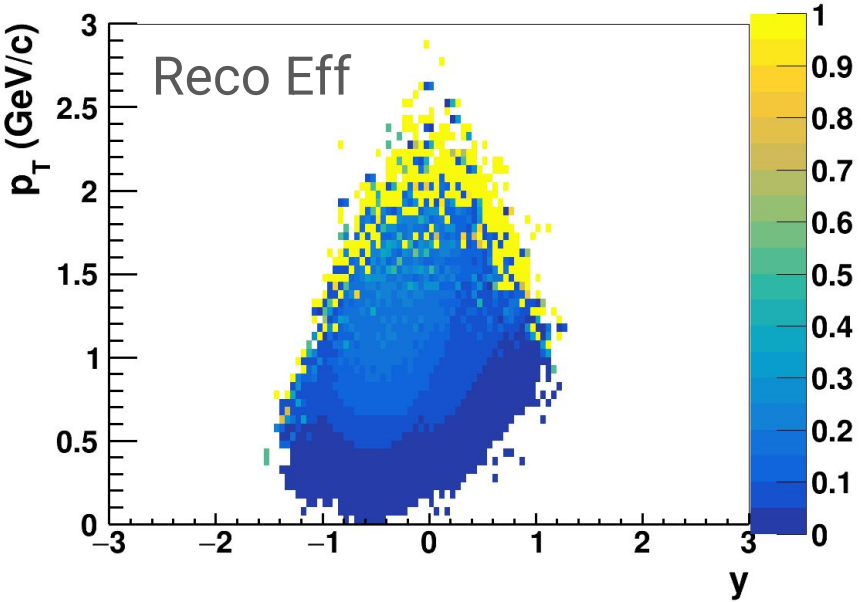
Fitting the m_{inv} distributions in p_T-y bins



Robust fit results in all p_T-y intervals

Λ hyperon reconstruction efficiency



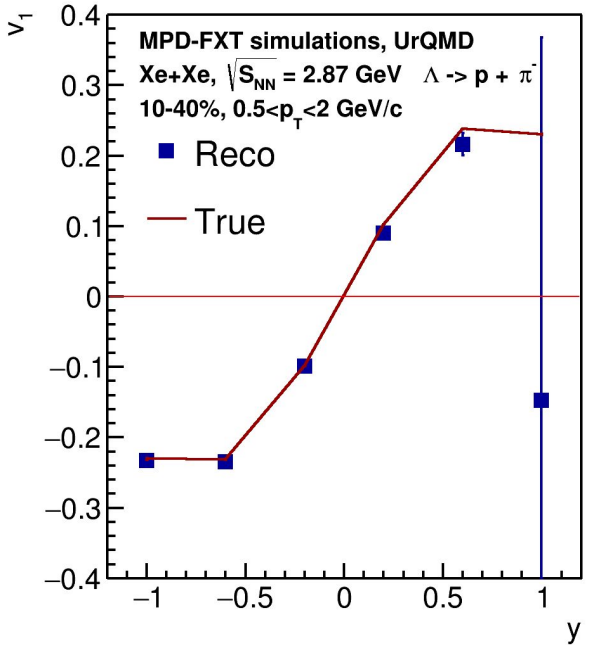


MPD-FXT acceptance covers midrapidity for Λ reconstruction in CM

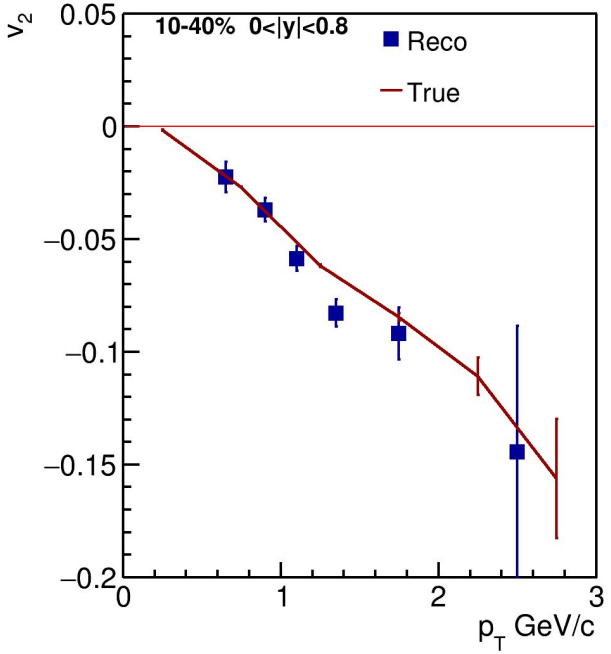
v_1 and v_2 of Λ hyperons for Xe+Xe at E_{kin}=2.5 AGeV for MPD-FXT

Data by V.Troshin

- the red line represents the true MC signal;
- the blue markers represent the reconstructed values
- reasonable **agreement** with simulated data;



$v_1(Y)$ for 10-40% centrality



$v_2(p_T)$ for 10-40% centrality

SUMMARY AND OUTLOOK

- Script for event re-sampling in Unigen format developed:
  - Boosts statistics without generating new events and significantly reduces statistical uncertainties
- Anisotropic flow of Λ hyperons measured in MPD-FXT Xe+Xe collisions at 2.5 AGeV:
  - enhanced lambda production via the UniGen afterburner
  - shows reasonable **agreement** with simulated data

Key applications: Feasibility studies for MPD and BM@N experiments:

  - global polarization;
  - higher-order harmonics (v_3, v_4);
  - rare particles

Future work:

- Investigate reconstruction efficiency and other systematic effects. Possible effects from lambda enhancement
- Feasibility studies for MPD experiment

Backup slides

Flow methods for P_Λ calculation

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

Tested in HADES: M Mamaev et al 2020 PPNuclei 53, 277–281
M Mamaev et al 2020 J. Phys.: Conf. Ser. 1690 012122

P in scalar product (SP) method:

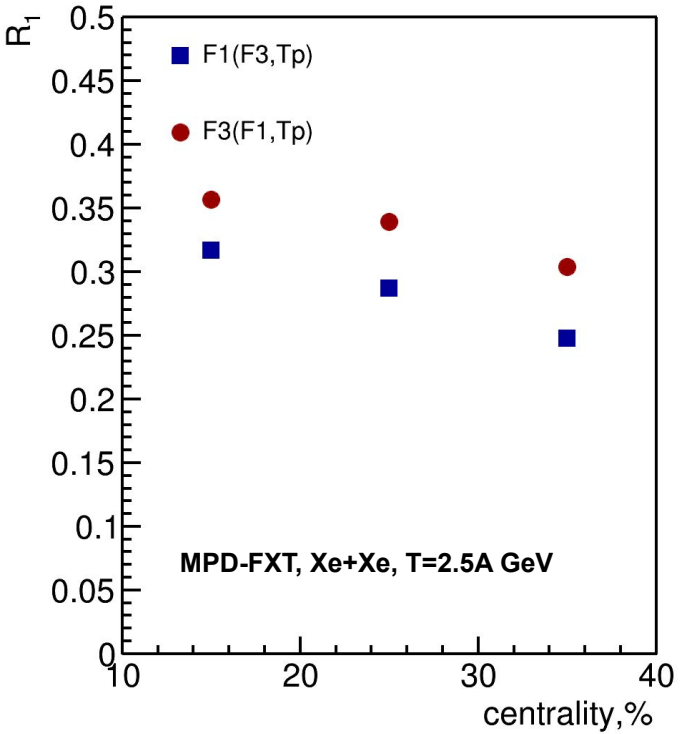
$$P = \frac{8}{\pi\alpha}\frac{\langle u_1 Q_1^{F1}\rangle}{R_1^{F1}}$$ **using xy/yx components!**

Where R_1 is the resolution correction factor

$$R_1^{F1} = \langle \cos(\Psi_1^{F1} - \Psi_1^{RP})\rangle$$

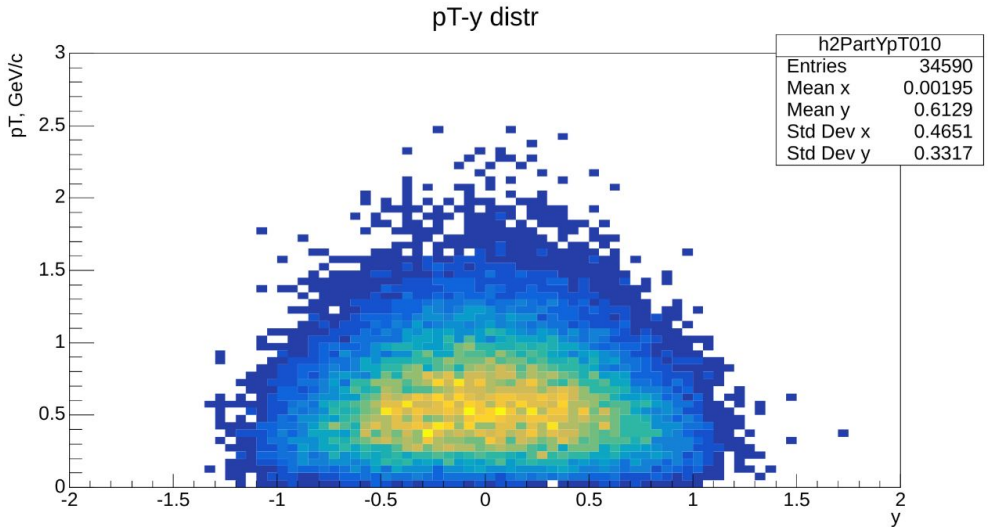
Symbol "F1(F3,Tp)" means R_1 calculated via (3S resolution):

$$R_1^{F1(F3,Tp)} = \frac{\sqrt{\langle Q_1^{F1}Q_1^{F3}\rangle\langle Q_1^{F1}Q_1^{Tp}\rangle}}{\sqrt{\langle Q_1^{F3}Q_1^{Tp}\rangle}}$$



Lambda parameterization

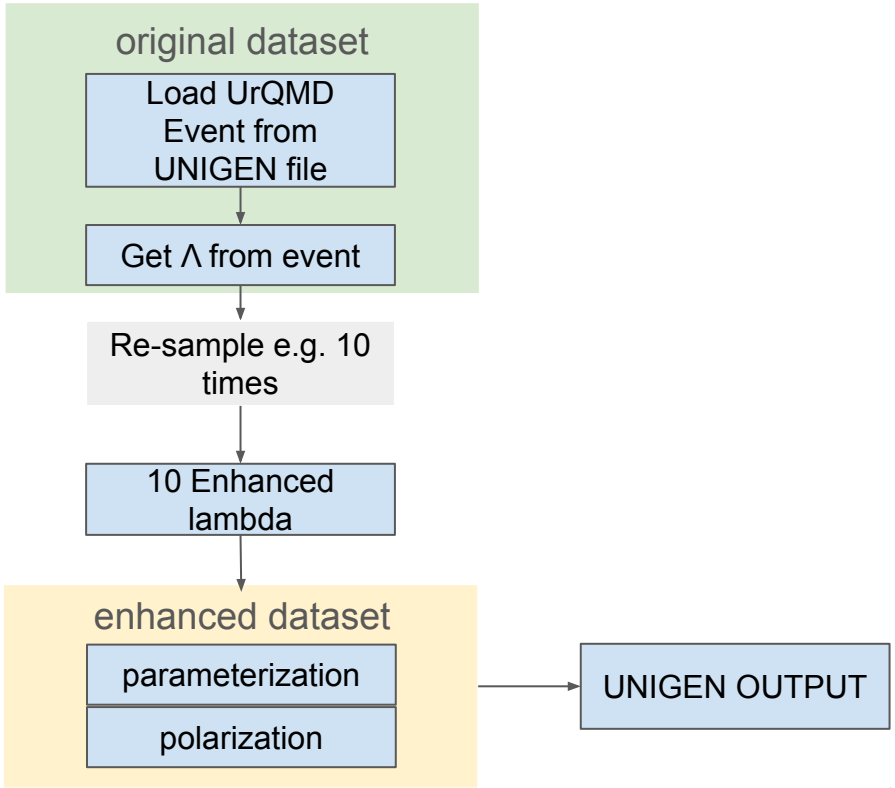
- Directed flow (v1) parametrized as a function of √sNN, centrality, pT, and y
- Elliptic flow (v2) obtained from function get_V2(sNN, centrality, pT, y)
- Flow coefficients constrained: -1 ≤ v1 ≤ 1
- Azimuthal angle φ generated according to probability density:
- f(φ) ~ 1 + 2*v1*cos(φ) + 2*v2*cos(2φ)
- Implementation available in repository: read_unigen_root.cpp



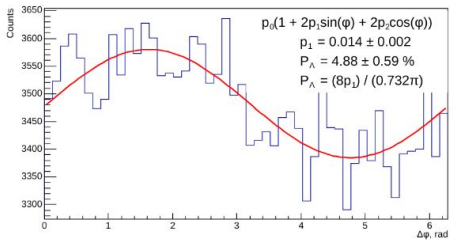
pT and rapidity (y) sampled from 2D histogram:
h_pt_y->GetRandom2(lambda_y, lambda_pT, rand)

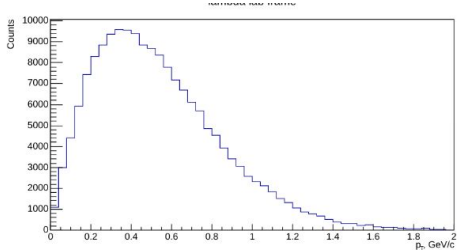
EVENT RE-SAMPLING FOR Λ POLARIZATION

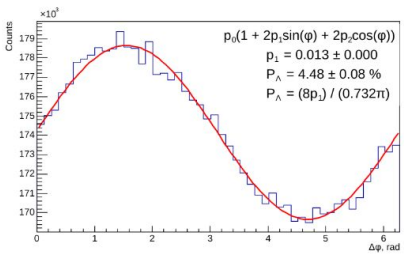
- Scheme adapted from NICA repository (V. Voronyuk)
- Polarization measured via proton azimuthal angle in Λ rest frame
- Re-sampling improves statistical precision of polarization measurements

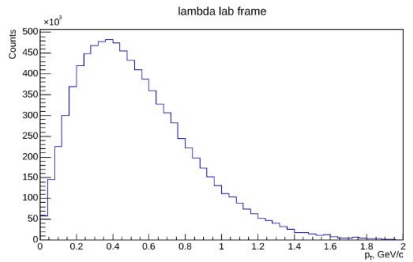


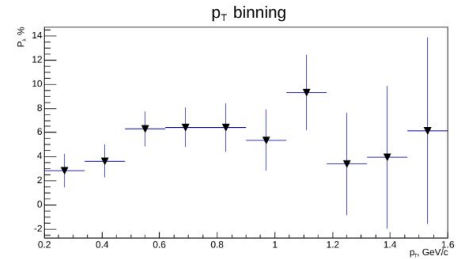
Comparison

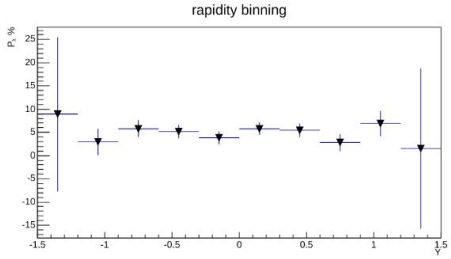


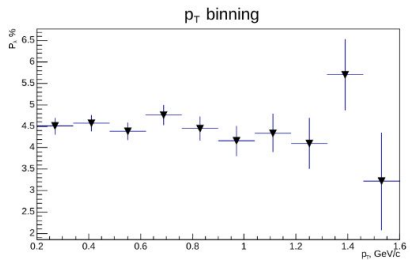


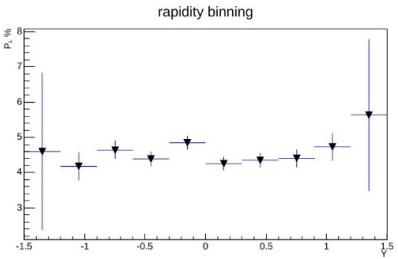








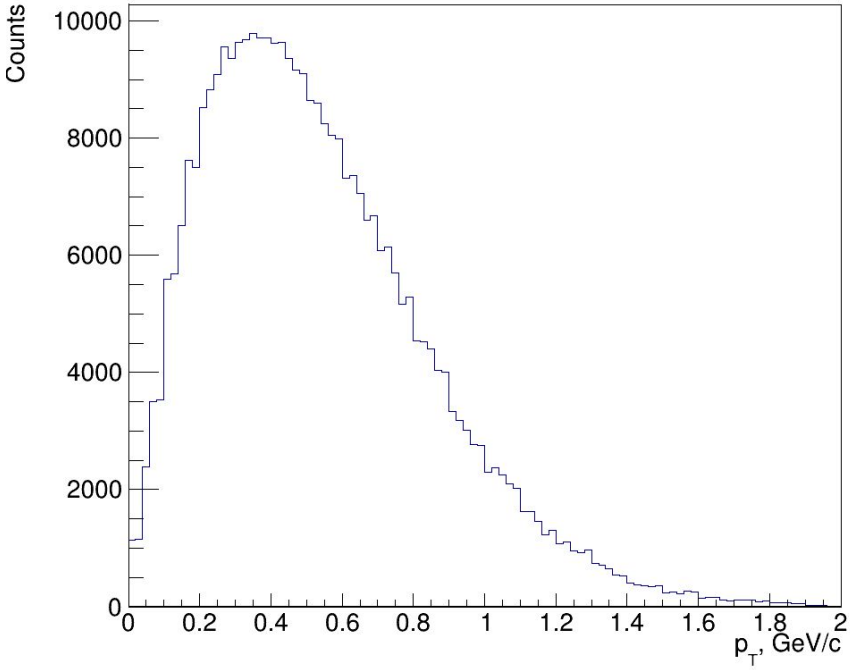


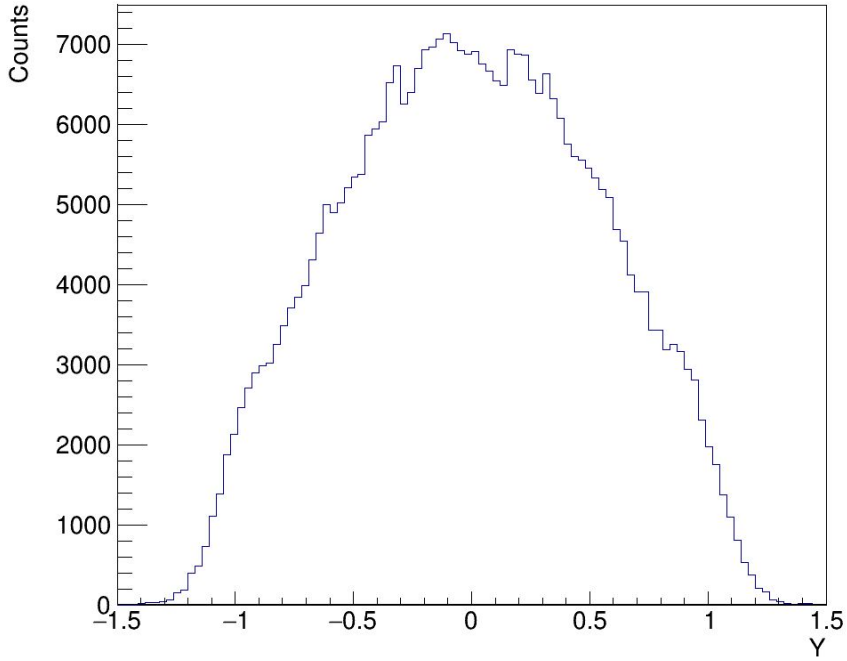


enhancement = 0

enhancement = 50
(+ added lambda in each event)

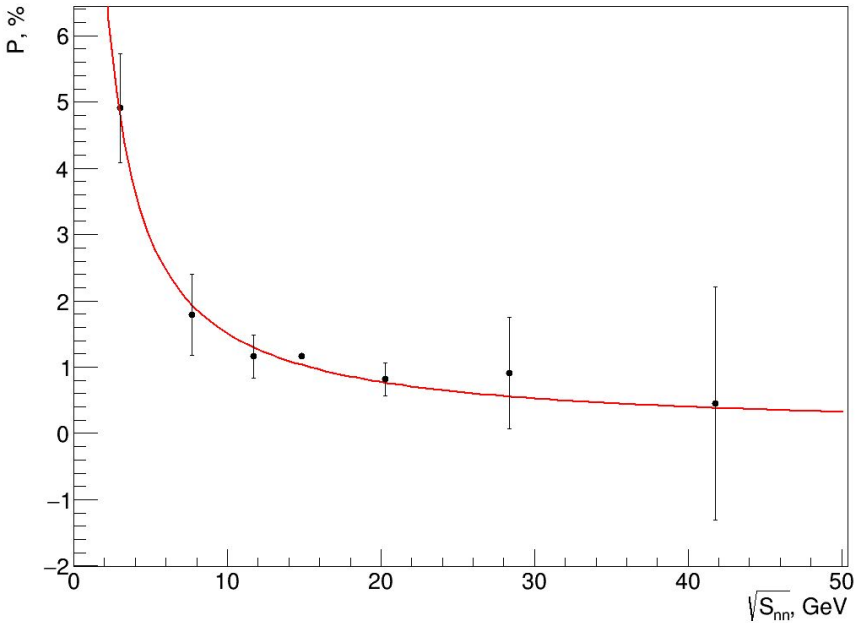
Lambda from model

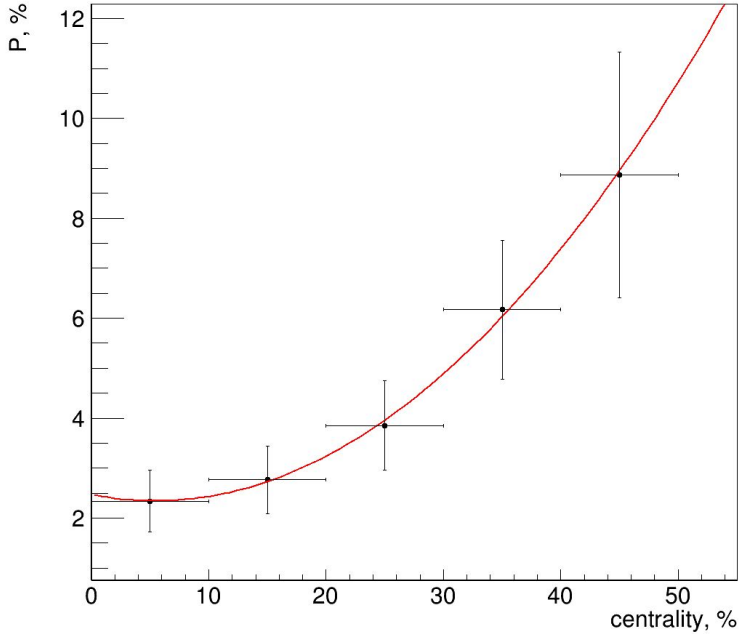




Mean number of lambda in each event <Nlamb>= 328 000 / 1M event

Global polarization parameterization





$P(E,cent)=(2.8569/E^{0.955513})*(2.4702-0.0461*cent+0.0042*cent^2)$

Uniform distribution in p_T-y

Global Polarization

Phys.Rev.C 104 (2021) L061901, 2021.
Global Polarization for 3 GeV

P(E), centrality 20-50%
P(cent), centrality 0-50%, pT>0.7, -0.2<y<1
P(pT), centrality 0-50%, -0.2<y<1
P(y), centrality 0-50%, pT>0.7

Directed flow

Phys.Lett.B 827 (2022) 137003, 2022.
Directed flow for 3 GeV

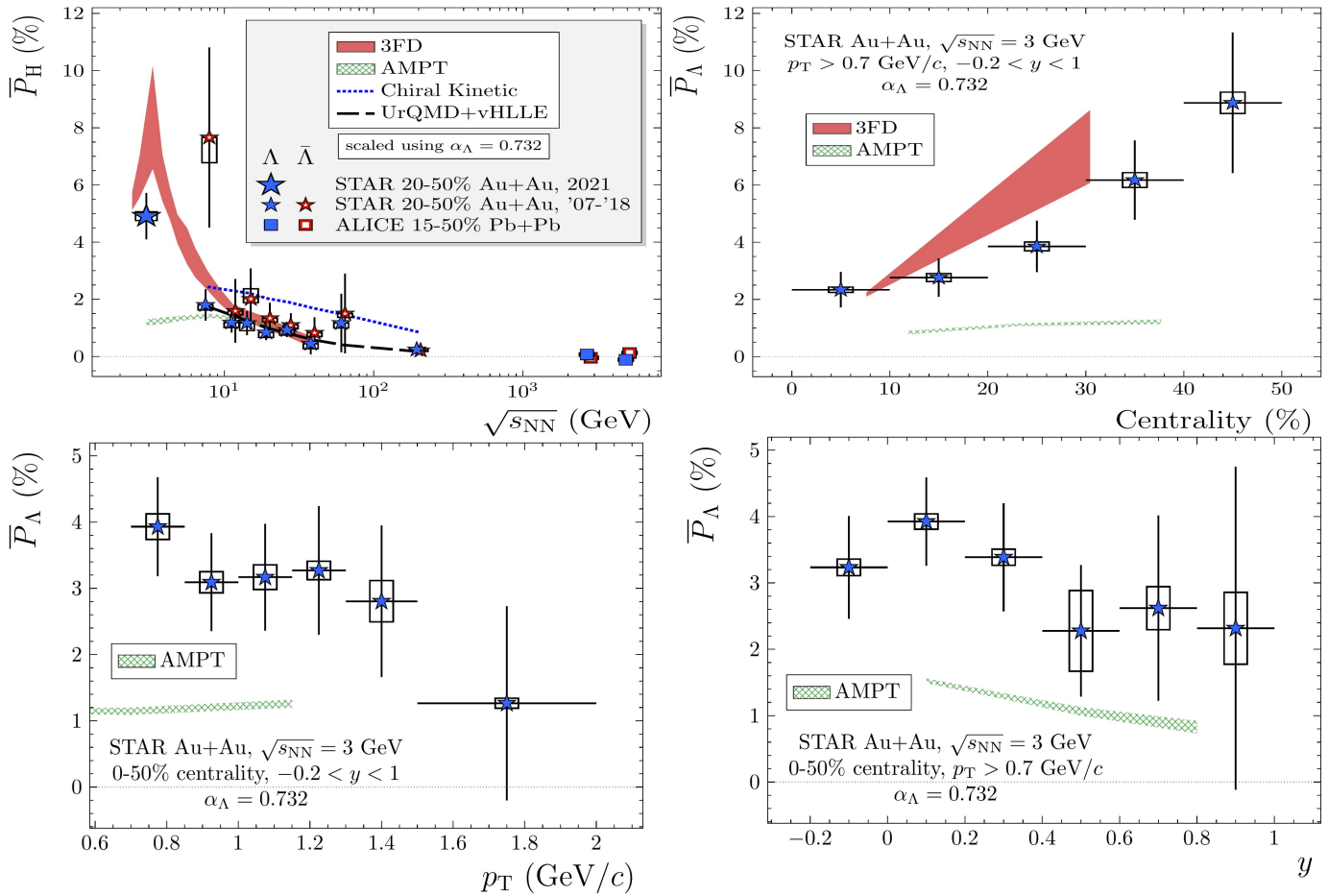
v1(y), centrality 10-40%, 0.4<pT<2
v2(y), centrality 10-40%, 0.4<pT<2

Phys.Rev.Lett. 130 (2023) 212301, 2023.
Directed flow for 3 GeV

v1(y), centrality 5-40%, 0.4<pT<0.8

JHEP 10 (2024) 139, 2024.
Production for 3 GeV

dN/dy, for diff centrality bins
<pT>(Npart), at midrapidity
dN(pT,y,cent)


$\overline{P}_H$ (%)
3FD
AMPT
Chiral Kinetic
UrQMD+vHLLE
scaled using $\alpha_\Lambda = 0.732$
Λ $\bar{\Lambda}$
STAR 20-50% Au+Au, 2021
STAR 20-50% Au+Au, '07-'18
ALICE 15-50% Pb+Pb
$\sqrt{s_{NN}}$ (GeV)
$\overline{P}_\Lambda$ (%)
STAR Au+Au, $\sqrt{s_{NN}} = 3$ GeV
$p_T > 0.7$ GeV/c, $-0.2 < y < 1$
$\alpha_\Lambda = 0.732$
3FD
AMPT
Centrality (%)
$\overline{P}_\Lambda$ (%)
AMPT
STAR Au+Au, $\sqrt{s_{NN}} = 3$ GeV
0-50% centrality, $-0.2 < y < 1$
$\alpha_\Lambda = 0.732$
p_T (GeV/c)
$\overline{P}_\Lambda$ (%)
AMPT
STAR Au+Au, $\sqrt{s_{NN}} = 3$ GeV
0-50% centrality, $p_T > 0.7$ GeV/c
$\alpha_\Lambda = 0.732$
y