Unigen-based afterburner for realistic flow and polarization signals and enhanced particle productions

D. Flusova, V. Troshin, P. Parfenov, A. Taranenko

OUTLINE

- Motivation
- Unigen format
- Afterburner general workflow
- How event re-sampling works
- Results
- General usage
- Summary and outlook

MOTIVATION

- Precise measurements of polarization and anisotropic flow of lambda hyperons require high statistics
- Higher-order harmonics (v3, v4) are particularly demanding
- Available dataset is limited → insufficient for detailed analysis
- Important for analysis with low reconstruction efficiency (e.g. direct photons, resonances, phi-mesons, sigma, lambda …)
- Enhanced production of necessary particles with realistic signals

UNIGEN FORMAT

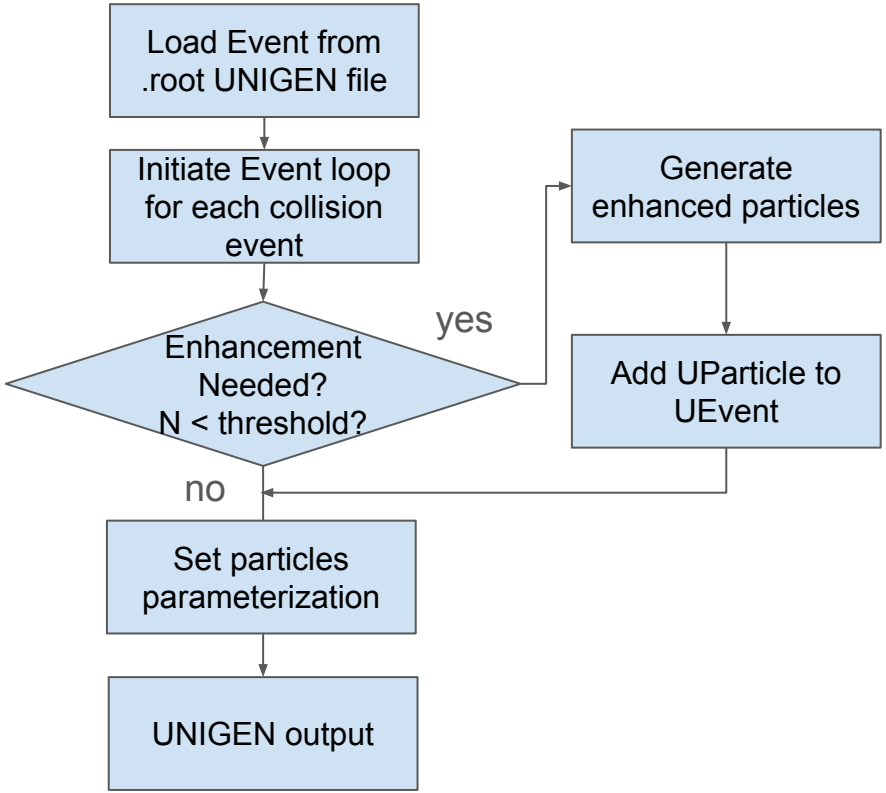
Code available in MPDROOT repository (dev branch)

TFile
├─ **URun** run/header metadata
└─ **TTree** "events" sequence of UEvent objects
  └─ **UEvent** one collision snapshot (can be time-stepped)
    └─ **TClonesArray<UParticle>** particles in that snapshot

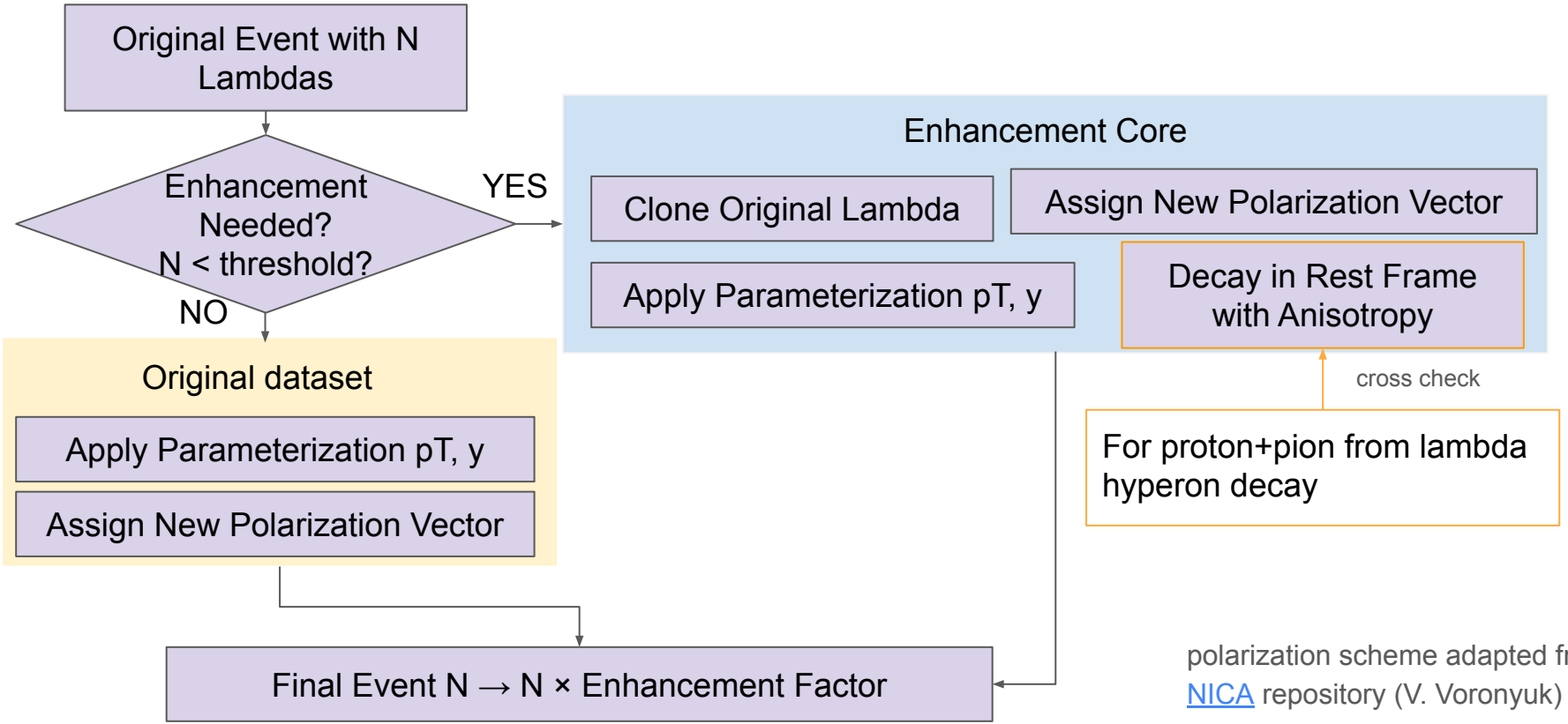
- **URun**: generator name, beam/target parameters (A, Z, momentum), impact parameter range, cross section, requested number of events.
- **UEvent**: : event number, impact parameter value, reaction plane angle, optional. Holds the **list of particles**.
- **UParticle**: Stores information about **a single particle**. PDG code, momentum (px, py, pz, E), space-time coordinates (x, y, z, t)...

AFTERBURNER GENERAL WORKFLOW

- Each particle is used as a template to generate new ones
- New statistically independent particles preserve original correlations
- Output format identical to the input (Unigen)
- Enhanced UParticles with fMate = -9 (enhanced) and fMate = -15 (added)

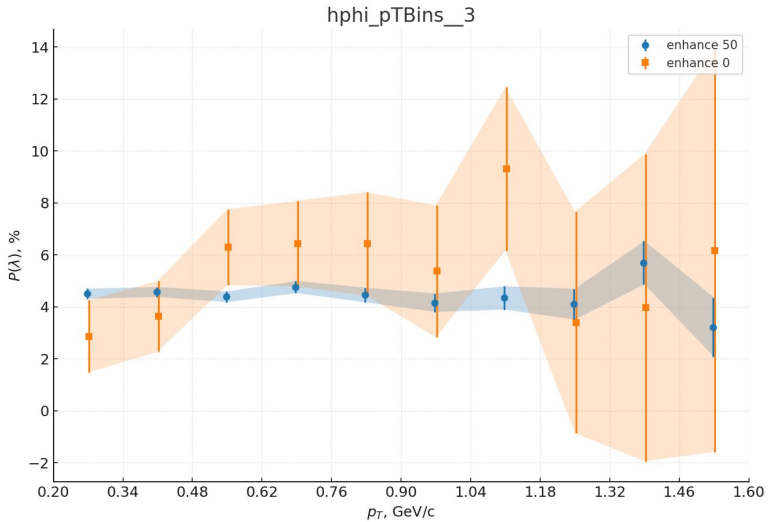


HOW EVENT RE-SAMPLING WORKS

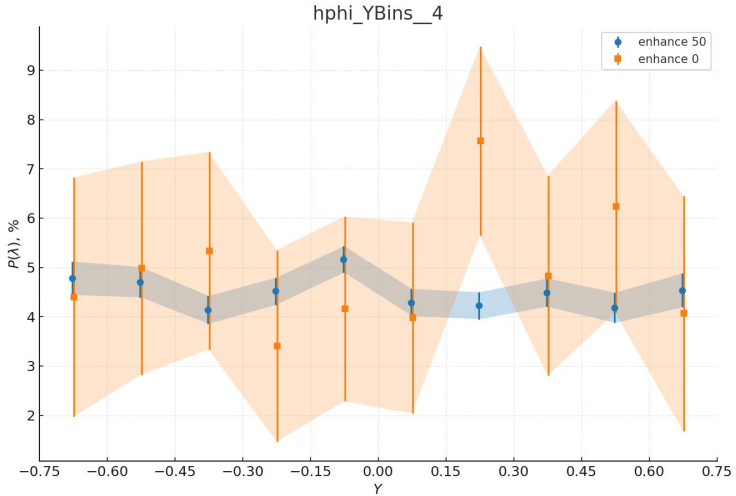


polarization scheme adapted from NICA repository (V. Voronyuk)

RESULTS



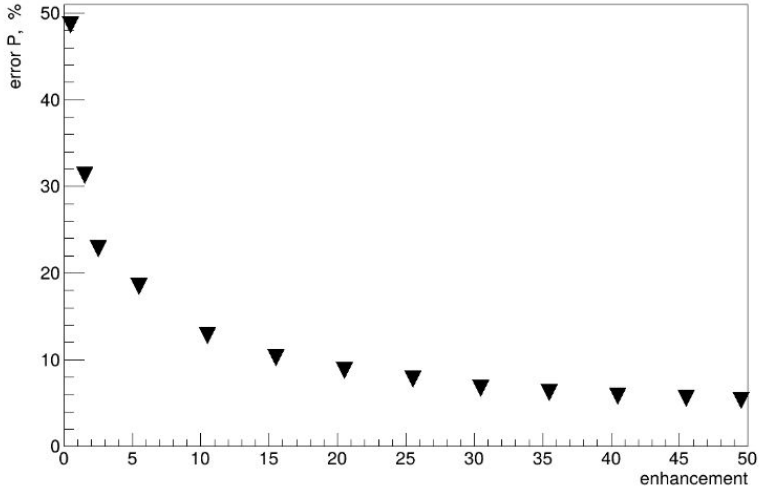
Polarization depend on pT
0.2 < pT < 1.6 GeV/c

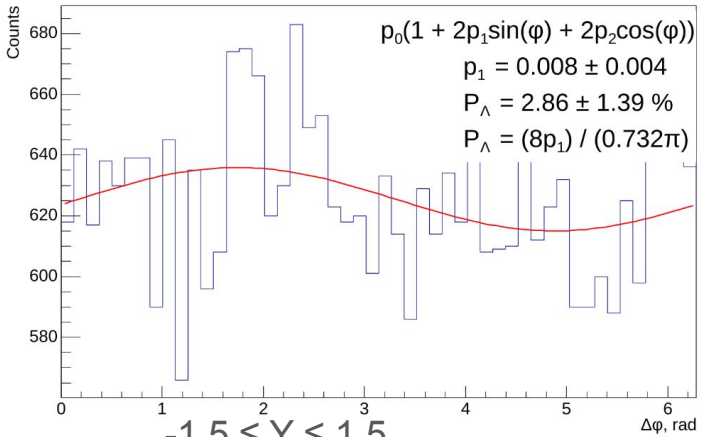


Polarization depend on rapidity
-0.75 < Y < 0.75

RESULTS

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



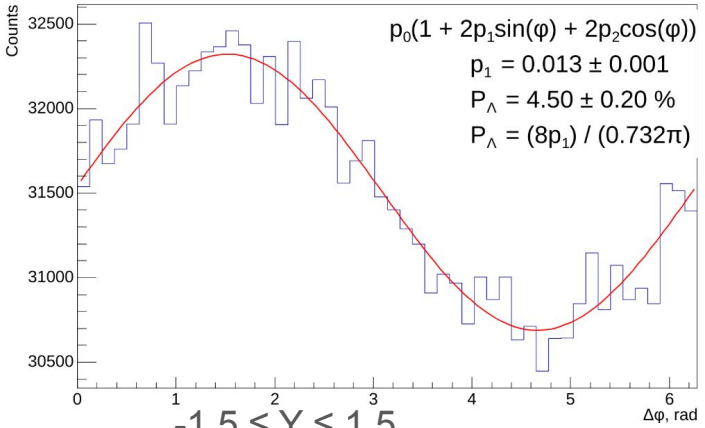


-1.5 ≤ Y ≤ 1.5

0.2 ≤ pT≤ 0.34 GeV/c

enhancement
(50 lambda in event)

~65k events



-1.5 ≤ Y ≤ 1.5

0.2 ≤ pT≤ 0.34 GeV/c

GENERAL USAGE

Purpose: reduce statistical errors, improve clarity of physical effects

Applications: global polarization, higher harmonics, rare particles, feasibility studies

Usage:

– Clone repository: https://github.com/DariaFlu/global-polarization-

– Read README, generate dictionaries

– Set file paths in simulate_lambda_decays.C

– Run with mpdroot

– Postprocess (e.g., calc_global_polarization.C)

– Continue with further analysis

Current version is not very user-friendly → planned improvements

SUMMARY AND OUTLOOK

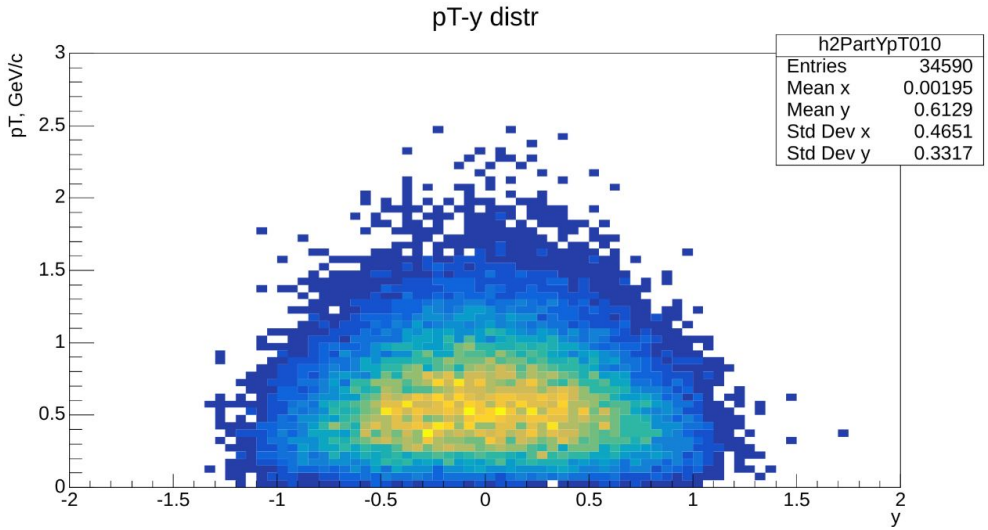
- Script for event re-sampling in Unigen format developed
- Boosts statistics without generating new events
- Significantly reduces statistical uncertainties

Key applications:

- Global polarization
- Higher-order harmonics (v3, v4)
- Rare particles
- Future work: usability improvements and pipeline automation

Lambda parameterization

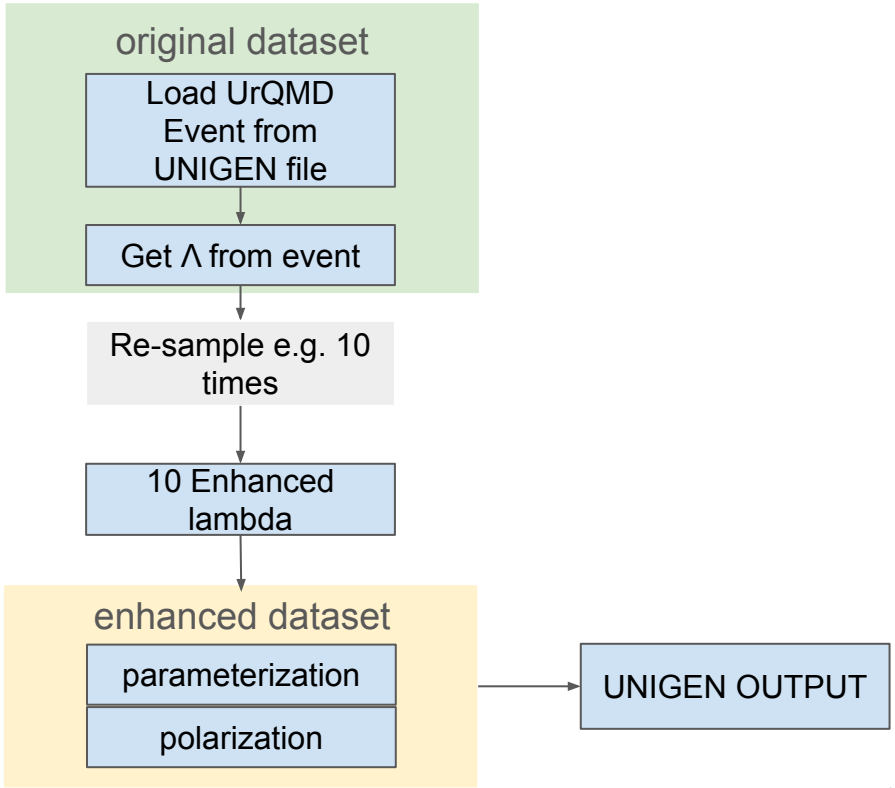
- Directed flow (v1) parametrized as a function of √sNN, centrality, pT, and y
- Elliptic flow (v2) obtained from function get_V2(sNN, centrality, pT, y)
- Flow coefficients constrained: -1 ≤ v1 ≤ 1
- Azimuthal angle φ generated according to probability density:
- f(φ) ~ 1 + 2*v1*cos(φ) + 2*v2*cos(2φ)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



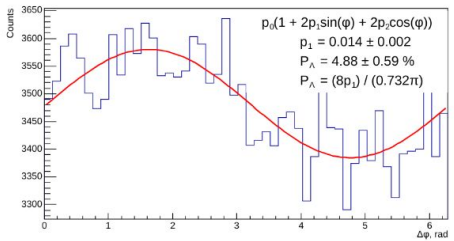
pT and rapidity (y) sampled from 2D histogram:
h_pt_y->GetRandom2(lambda_y, lambda_pT, rand)

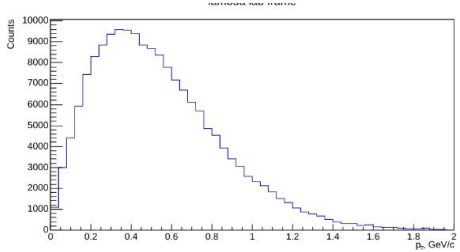
EVENT RE-SAMPLING FOR Λ POLARIZATION

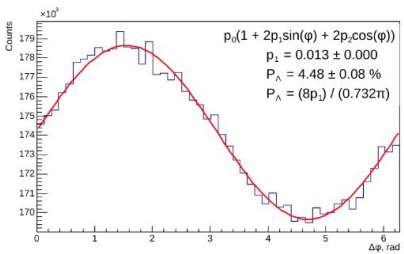
- Scheme adapted from NICA repository (V. Voronyuk)
- Polarization measured via proton azimuthal angle in Λ rest frame
- Re-sampling improves statistical precision of polarization measurements

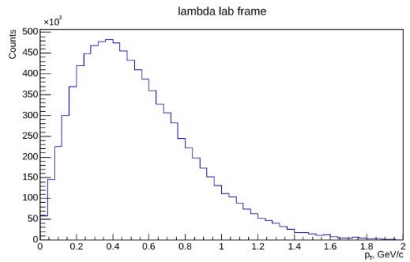


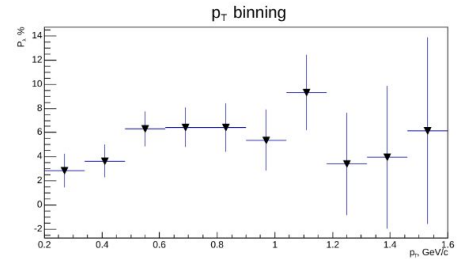
Comparison

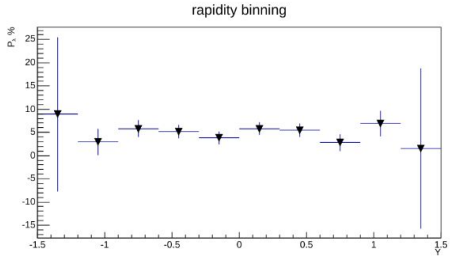


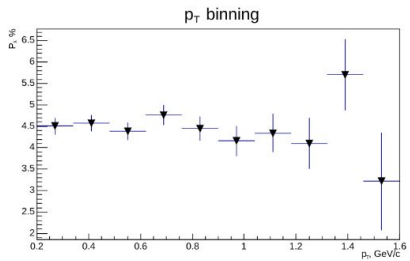


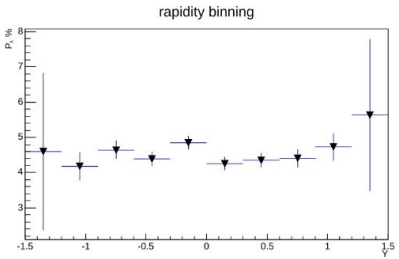








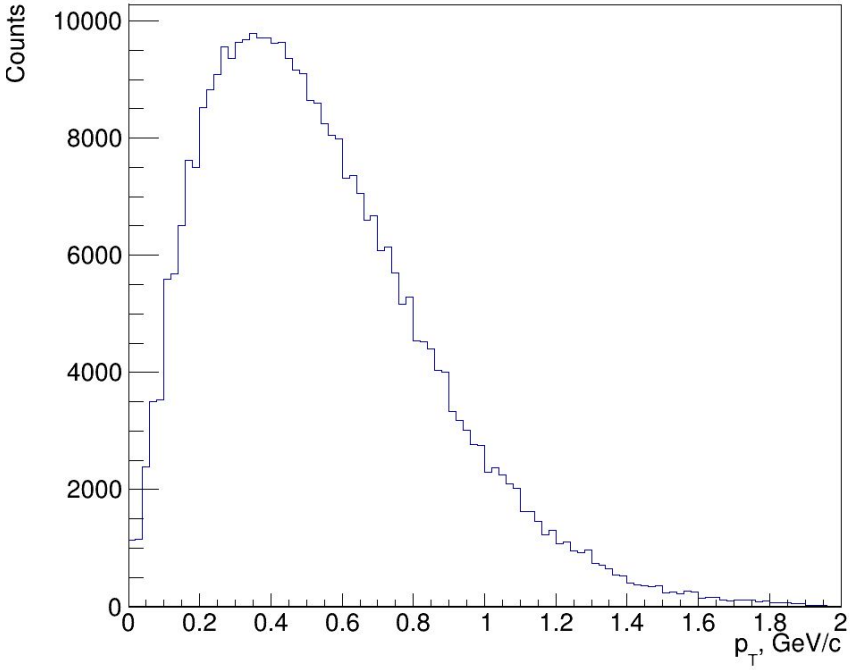


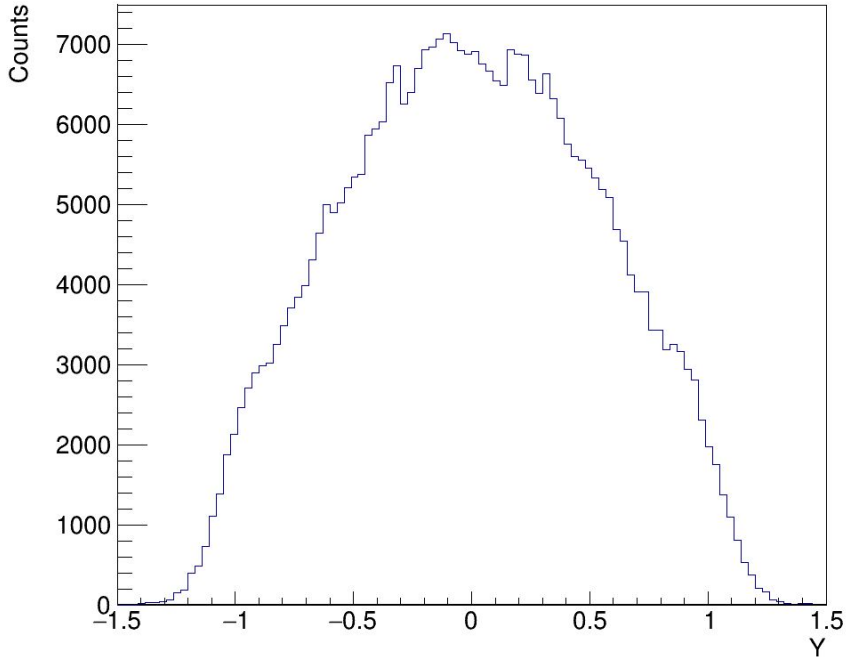


enhancement = 0

enhancement = 50
(+ added lambda in each event)

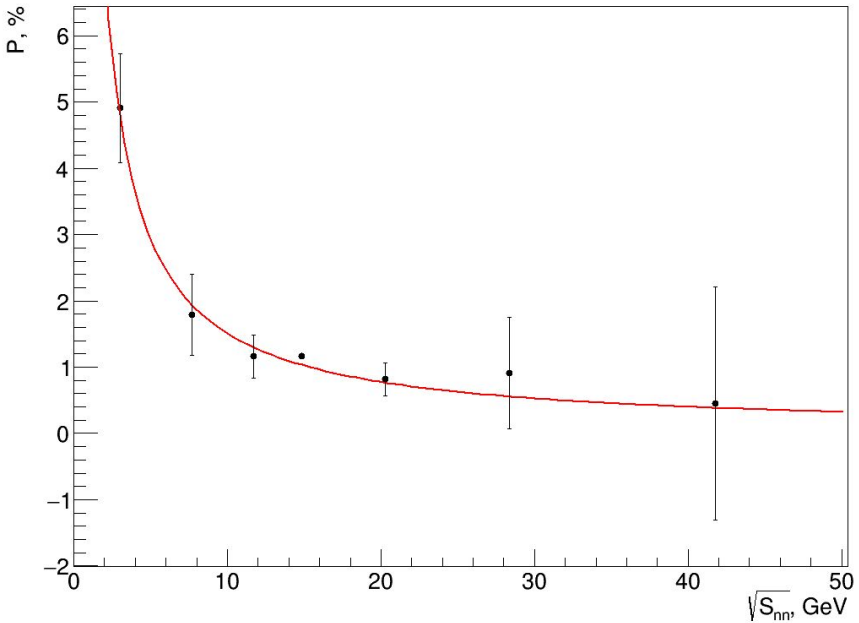
Lambda from model

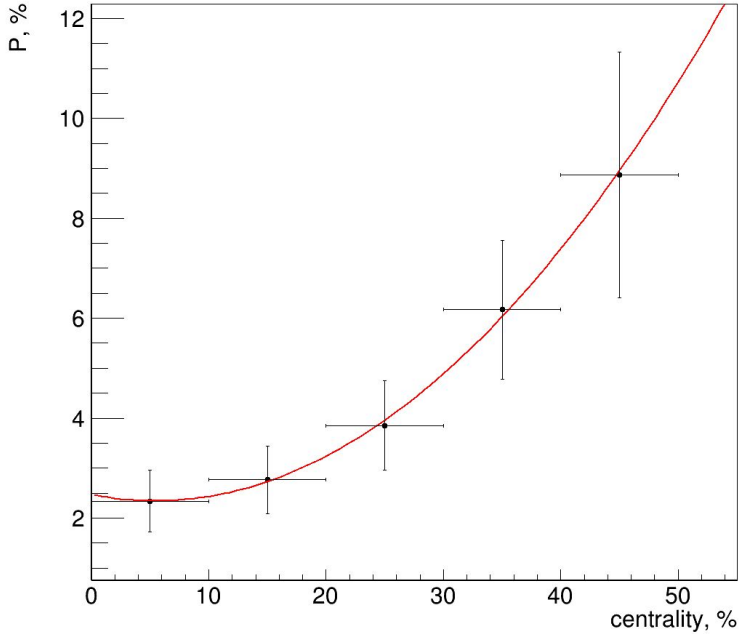




Mean number of lambda in each event <Nlamb>= 328 000 / 1M event

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

Analysis note kaon antiflow , Au+Au 3.2 GeV

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

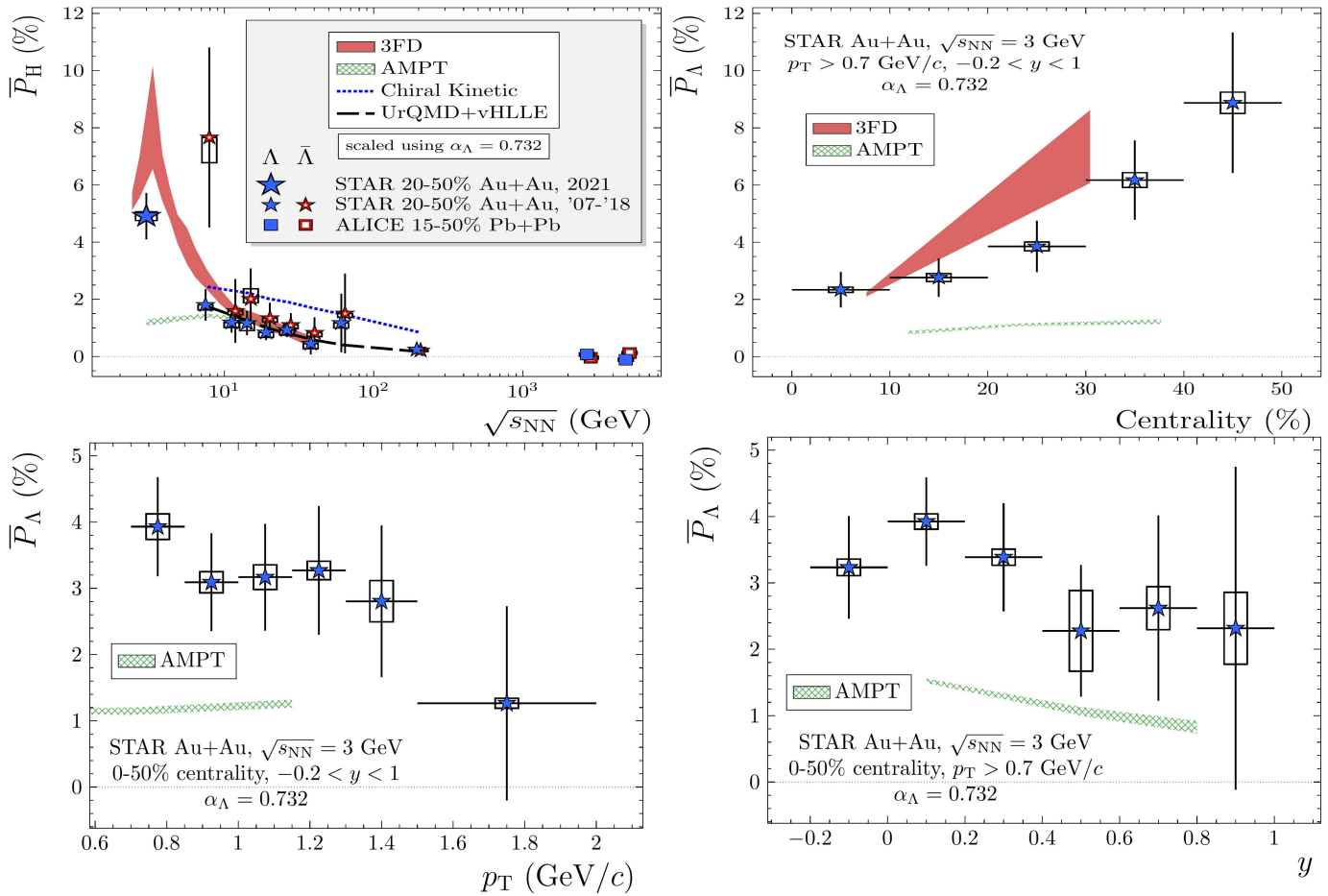
v1(y), centrality 10-40%, 0.4<pT<2
v2(y), centrality 10-40%, 0.4<pT<2

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