Anisotropic flow of Λ-hyperons in MPD@NICA

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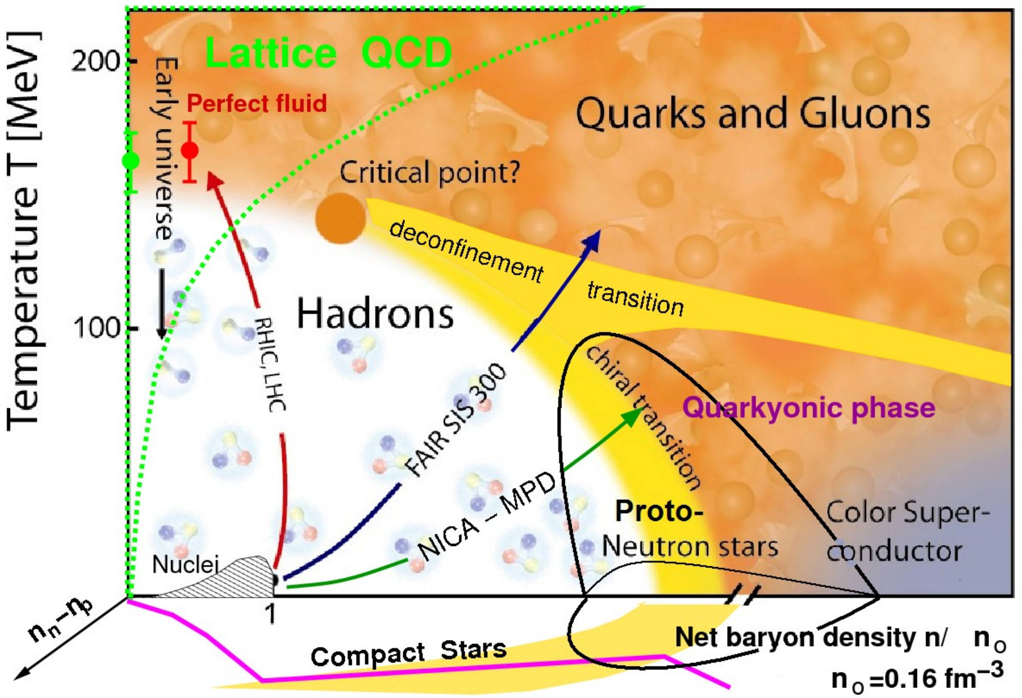
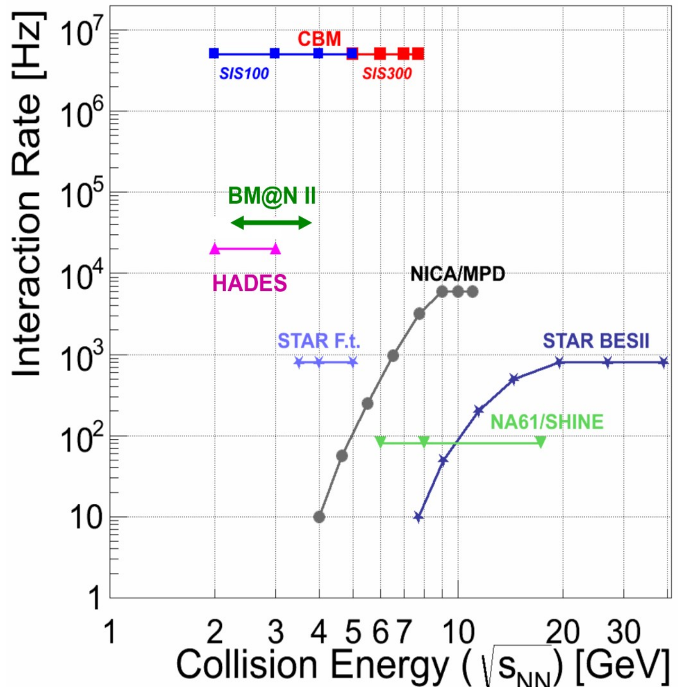
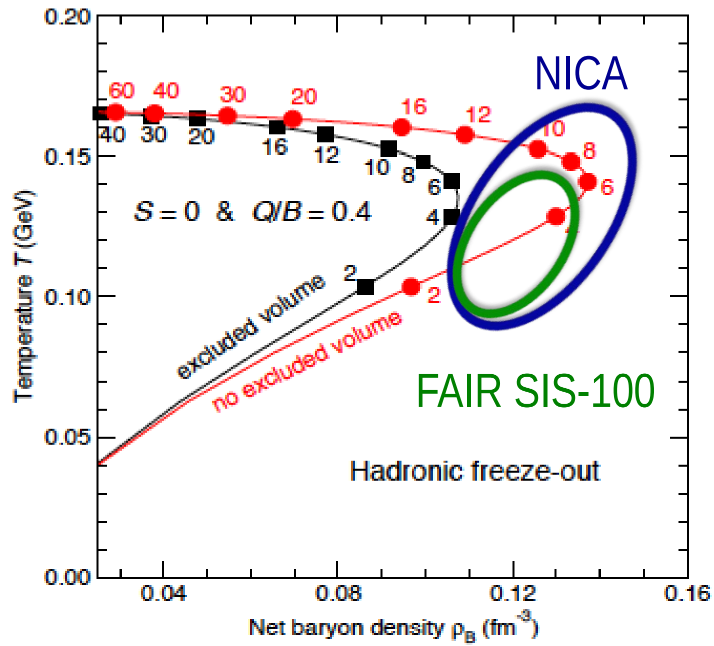
A wide HIC experimental program at low energies

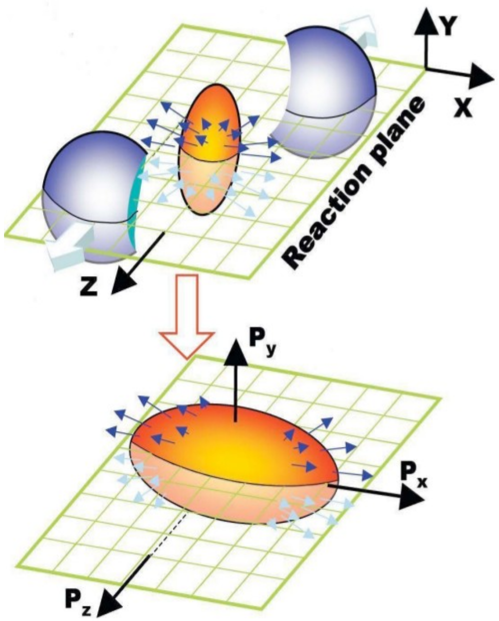






* Study Hot and Dense Barionic Matter
* Highest Net Barion Density
* Equation of State, Bulk properties
* Deconf. Ph. Trans. , Critical Point
* Observables:
Multiplicity, Spectra, Ratios, Critical phenomena, Collective Flow, strangeness enh, E-b-e flucts, HBT, EM probes and many more

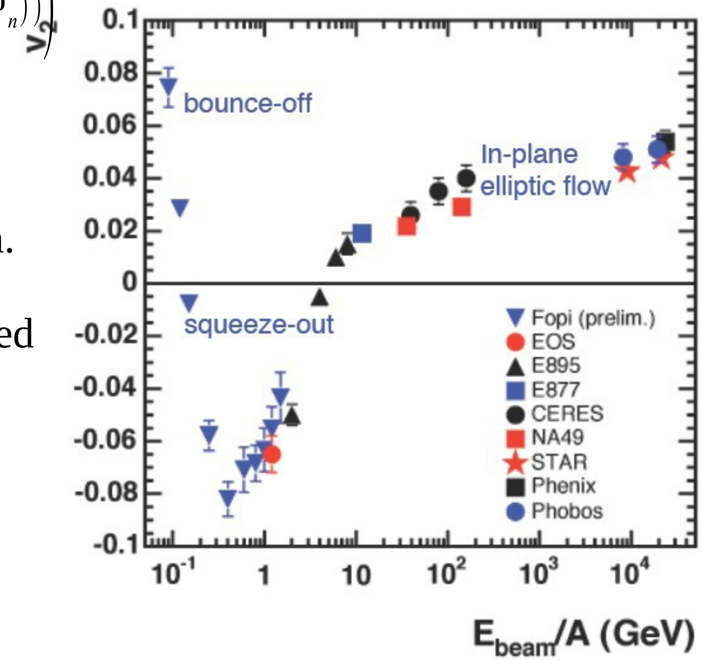
Anisotropic Flow @ NICA



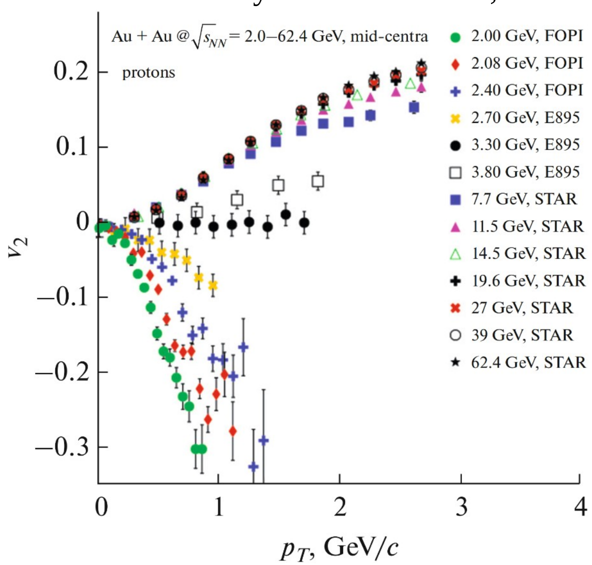
$$E\frac{d^3N}{d^3\boldsymbol{p}}=\frac{dN}{2\pi\, p_T\, dp_T\, dy}\left(1+2\sum_{n=1}^{\infty}v_n(p_T,y)\cos(n(\phi-\Psi_n))\right)$$

$$v_n(p_T,y)=\langle\cos[n(\phi-\Psi_n)]\rangle$$

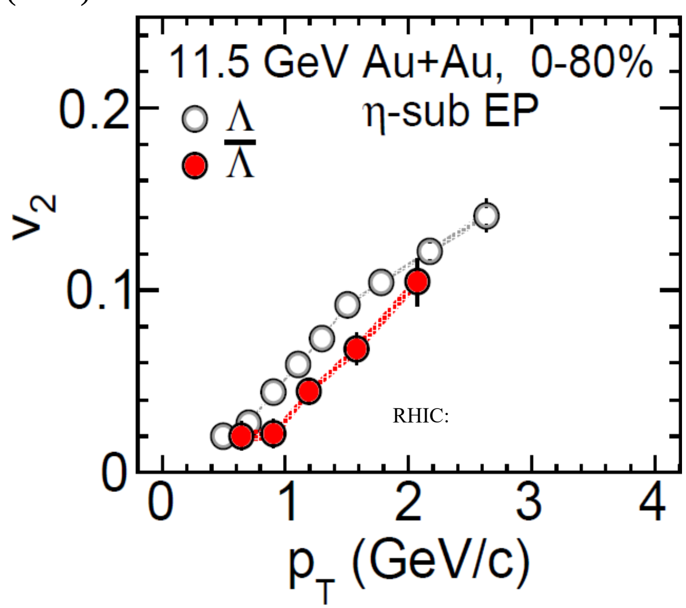
At Nuclotron-NICA energy range elliptic flow as a function of energy changes sign. Both directed and elliptic flow can give information about the EOS of the produced system.
At RHIC a difference between v2 of particles and their corresponding antiparticles was observed. NICA is expected to measure this.

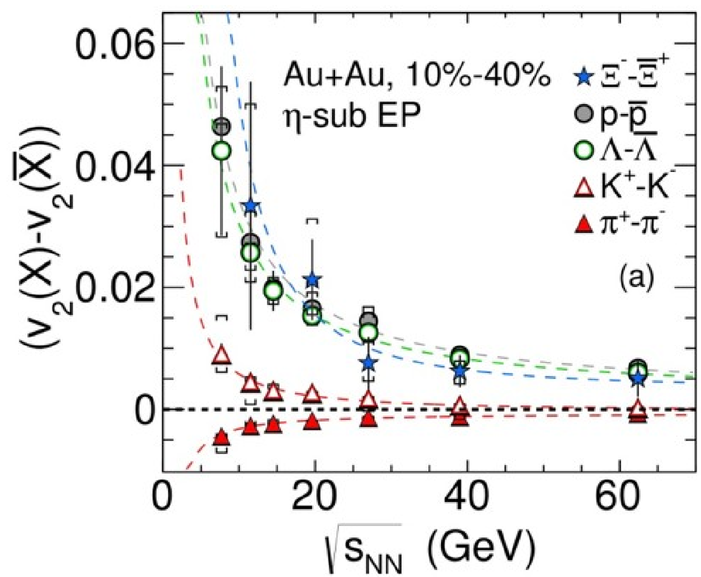


Taranenko et. al. Phys. Part. Nuclei 51, 309–313 (2020)



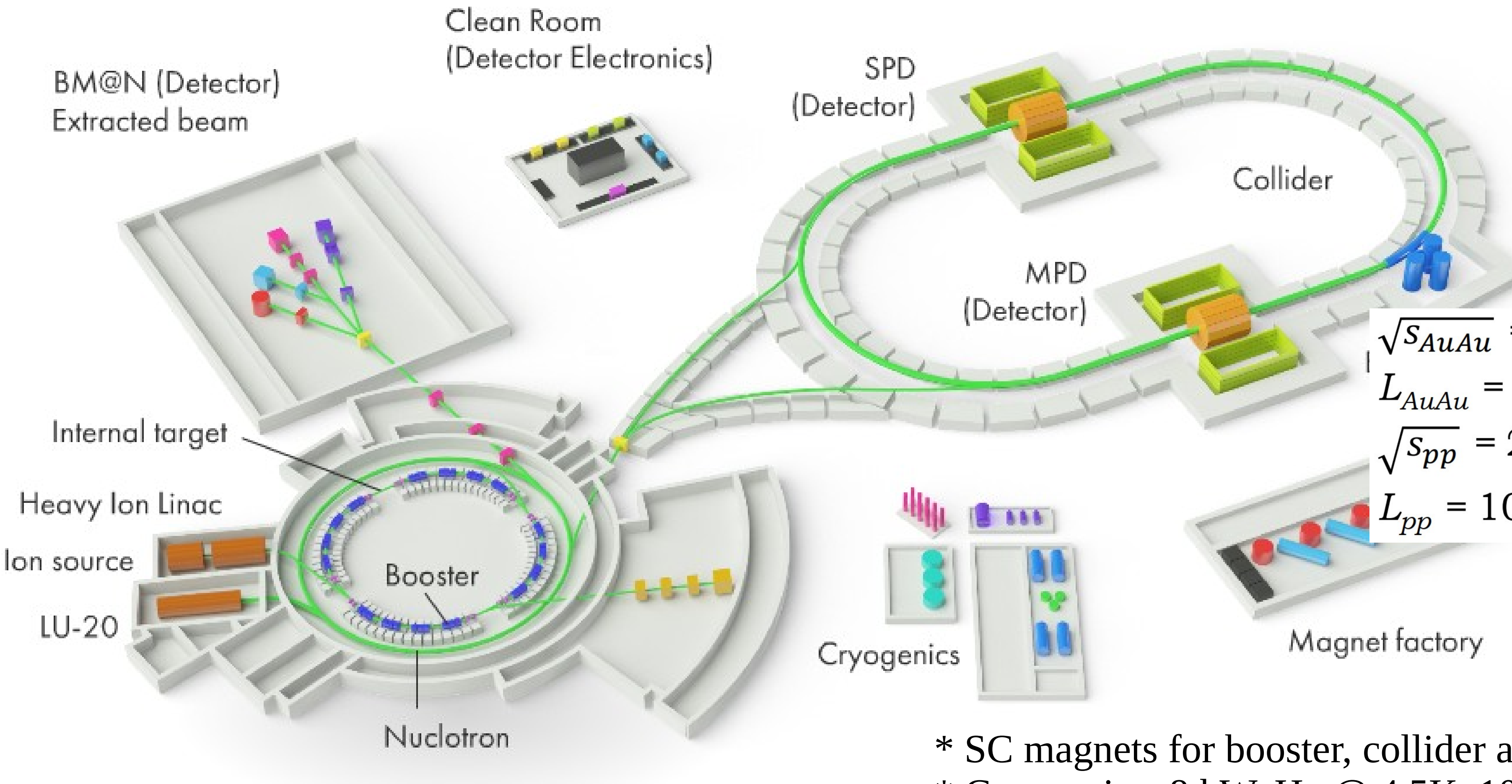
RHIC BES. (STAR Collaboration) Phys. Rev. C 88, 014902





Nuclotron-based Ion Collider fAcility

* AA (up to $^{197}Au^{79+}$), AB, pp and dd polarized beams
* 3 Detector Programs: BM@N, MPD, SPD

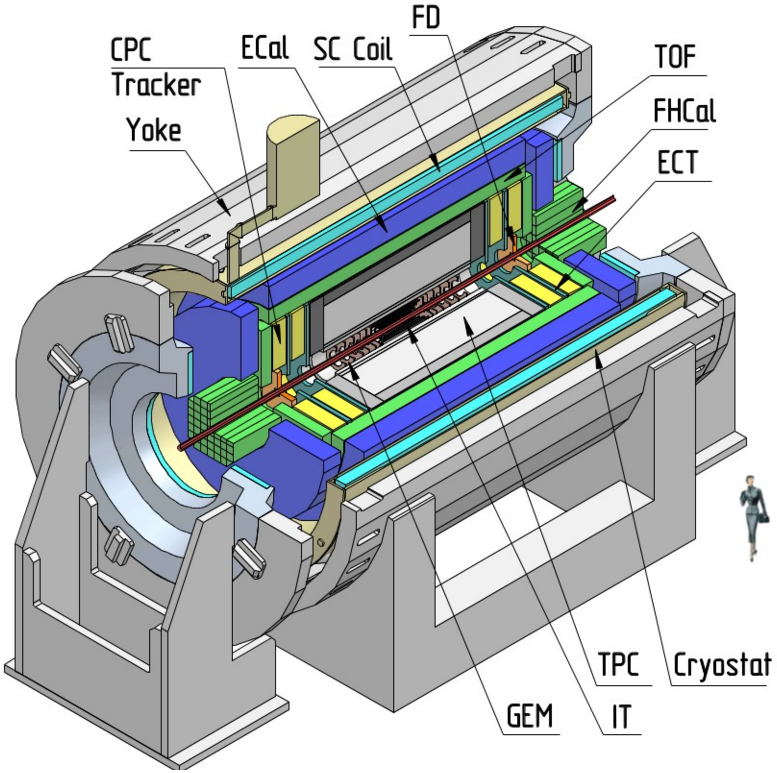


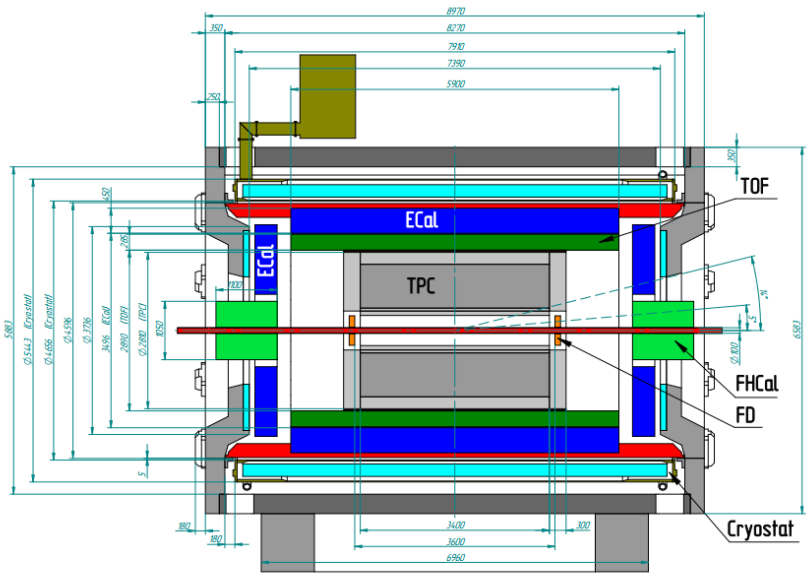
$\sqrt{s_{AuAu}}$ = 11 GeV,
L_{AuAu} = 10^{27} cm^{-2}s^{-1}
$\sqrt{s_{pp}}$ = 27 GeV
L_{pp} = 10^{32} cm^{-2}s^{-1}

* SC magnets for booster, collider and SIS-100
* Cryogenics: 8 kW, He @ 4.5K, 1000 l/h

* Injection complex: 4 sources, 2 linacs
* Booster, Nuclotron, Collider

Multi-Purpose Detector





1[st] stage:

TPC, **TOF**, FFD, ECAL, **FHCal.**

2[nd] stage:

ITS + GEM + EndCap

(CPC, Straw, TOF, ECAL)

Requirements:

- homogenic MF 0.5 T
- up to $7\cdot10^3$ ev/s, mult. up to 1400
- large acceptance
- low material budget
- precise tracking and pid

Global observables
- Total event multiplicity
- Total event energy
- Centrality determination
- Total cross-section measurement
- Event plane measurement at all rapidities
- Spectator measurement

Spectra of light flavor and hypernuclei
- Light flavor spectra
- Hyperons and hypernuclei
- Total particle yields and yield ratios
- Kinematic and chemical properties of the event
- Mapping QCD Phase diagram

Correlations and Fluctuations
- Collective flow for hadrons
- Vorticity, Λ polarization
- E-by-E fluctuation of multiplicity, momentum and conserved quantities
- Femtoscopy
- Forward-Backward corr.
- Jet-like correlations

Electromagnetic probes
- Electromagnetic calorimeter measurements
- Photons in ECAL and central barrel
- Low mass dilepton spectra and search for in-medium modification of resonances and intermediate mass region

Heavy flavor
- Study of open charm production
- Charmonium with ECAL and central barrel
- Charmed meson through secondary vertices in ITS and HF electrons
- Explore production at charm threshold

Time Projection Chamber

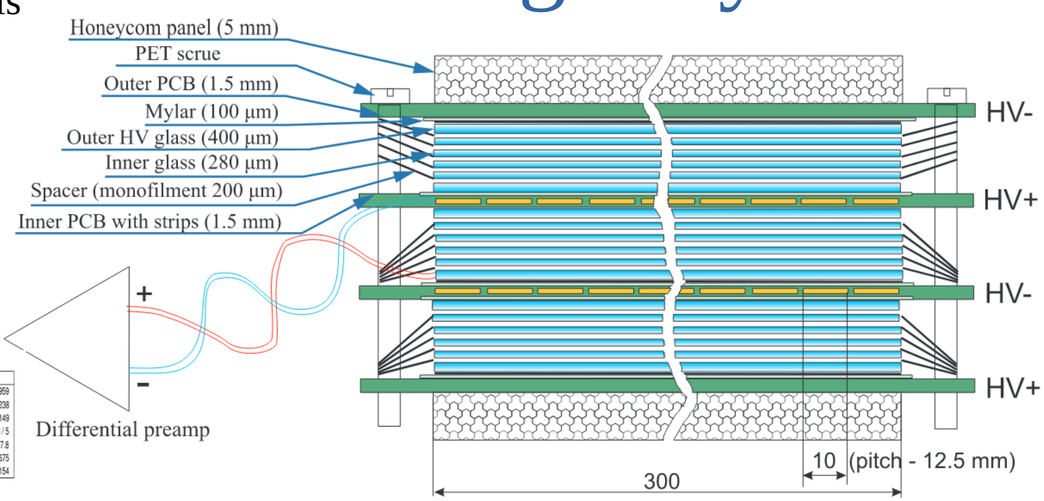
length	*340 см*
out Radii	*140 см*
N chan.	***95 232***

* Main tracking detector for MPD
* Provides dE/dx through charge
* Central HV anode Ar/CH4 (90/10) gas,
* MWRPC and Cathode Pad Readout
* to be replaced by GEM in stage 2
* Eloss resolution of 8%
* Particle seperation and identification
* Accurate determination of primary vertex
* Precise p_T resolution up to $|\eta| < 1.2$
* Precise primary vertex position
* Most prototyping done, mass production
* Should be ready by 2021

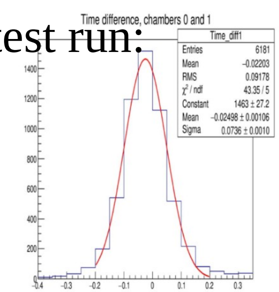
Time of Flight System

Provides time of particle flight which along with momentum is used for velocity or mass determination and particle identification

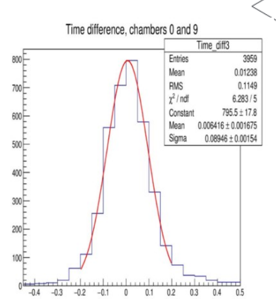
* Three stacks of mRPC
* Main elementin of TOF-400 and TOF-700 walls at BM@N of TOF barrel and EndCap TOF for MPD.
* Matched impedance to FE (NINO based)



BM@N December 2016 test run:
ToF-700 chamber ~65 ps
ToF-400 chamber ~53 ps



TOF400_1 - TOF400_2

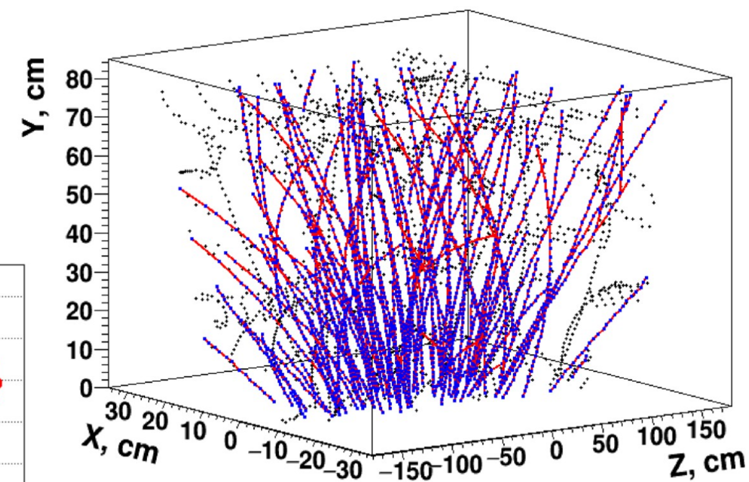


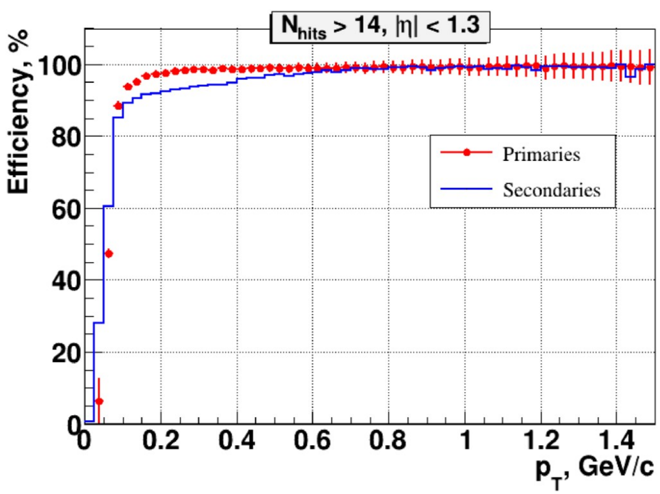
TOF700 - TOF400

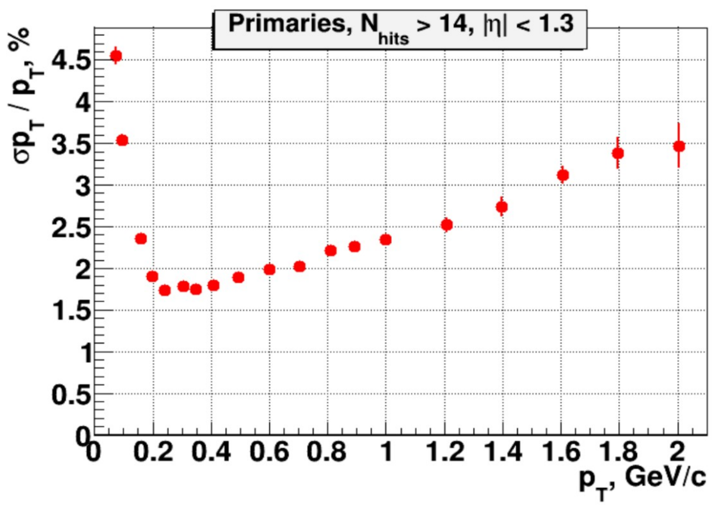
Expected TOF+FFD resolution for MPD ~ 80 ps

Track Reconstruction

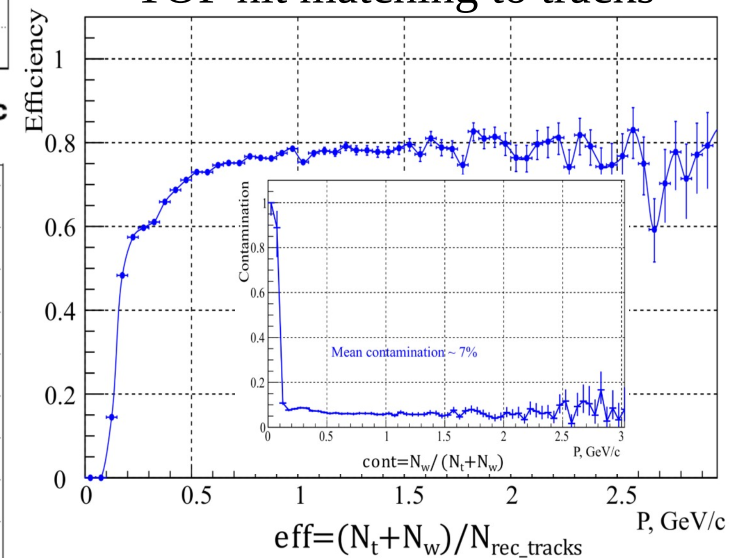
- Realistic cluster simulation and response: ionization, drift and diffusion, gas gain fluct, pad response, electronics shaping, signal digitization
- Cluster/hit finder MLEM (Bayesian unfolding)
- Tracks reconstructed by a two-pass Kalman Filter
- Tracks are matched to hits in TOF

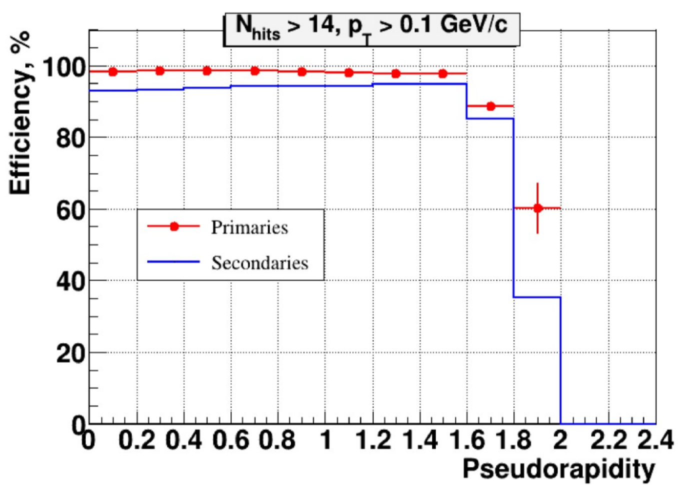


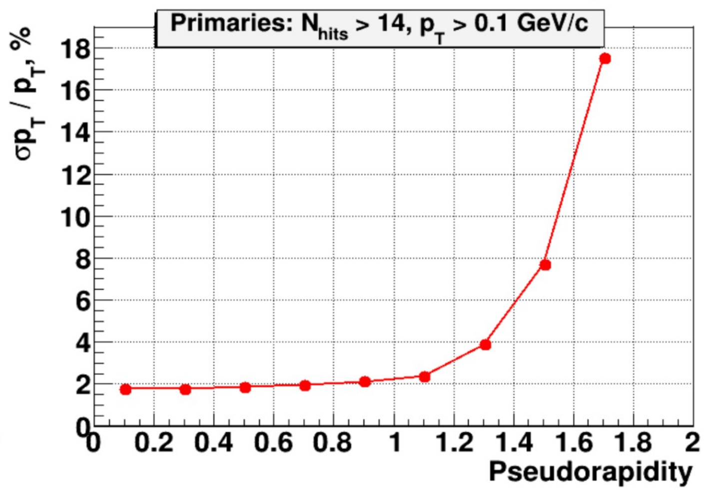




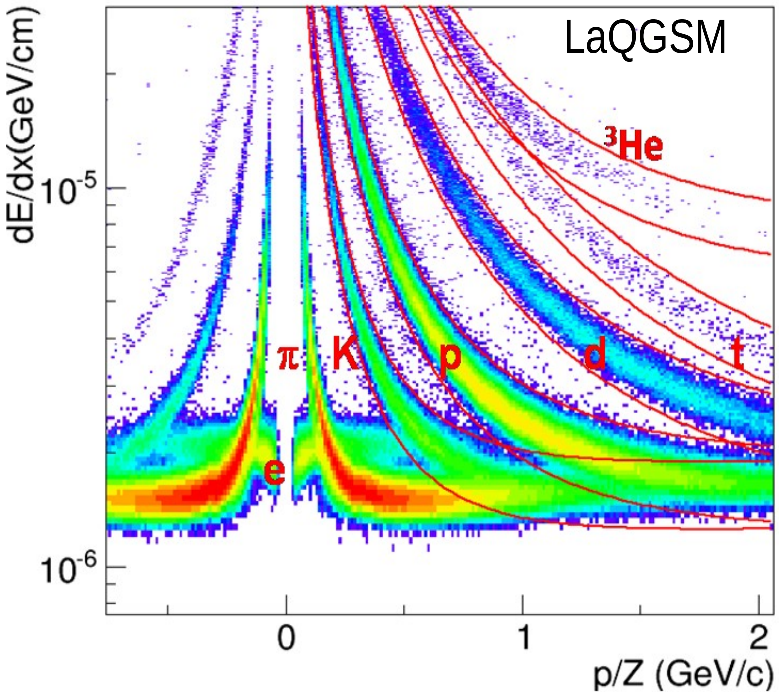
TOF hit matching to tracks

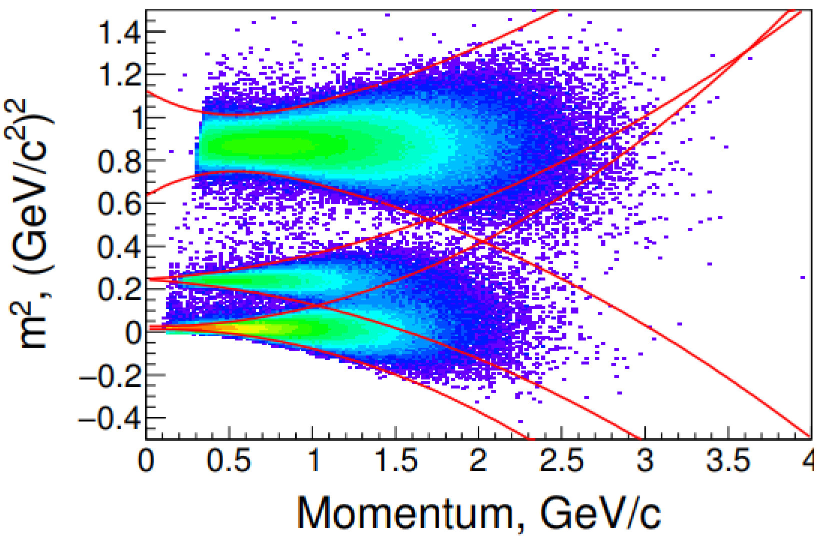


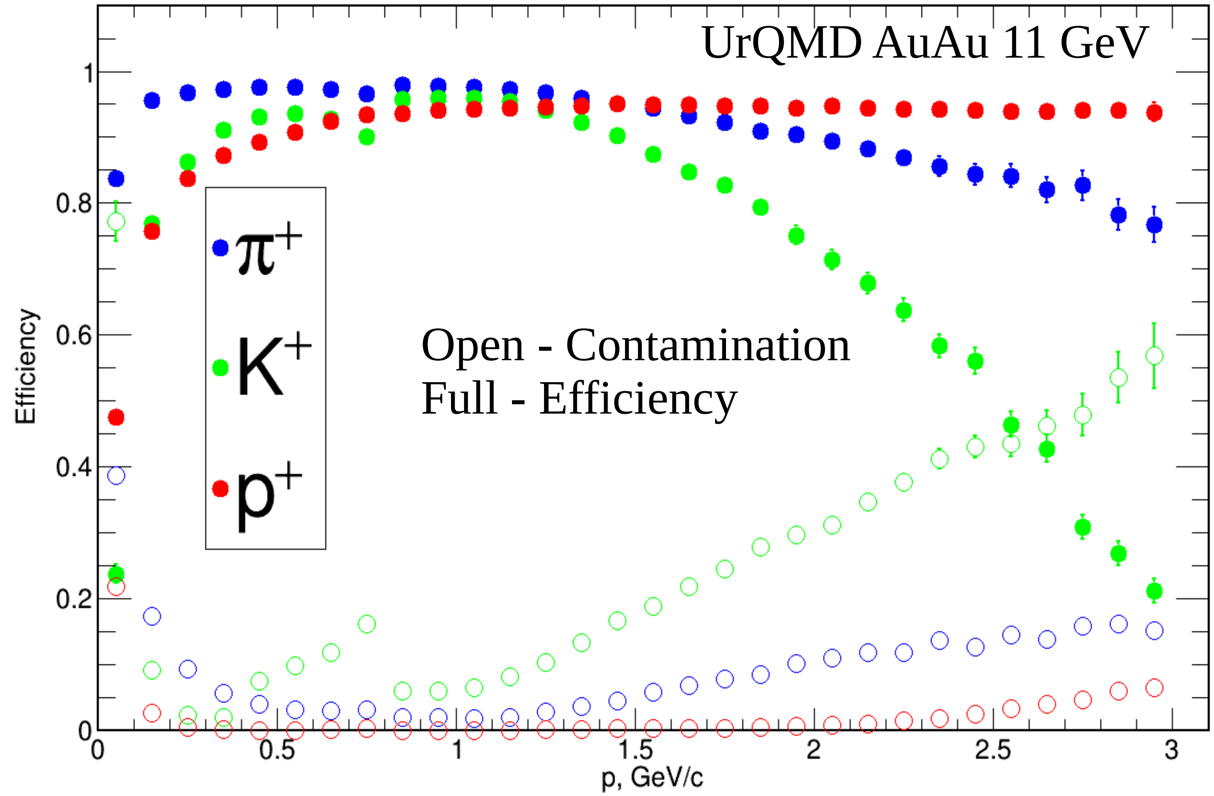




Particle Identification







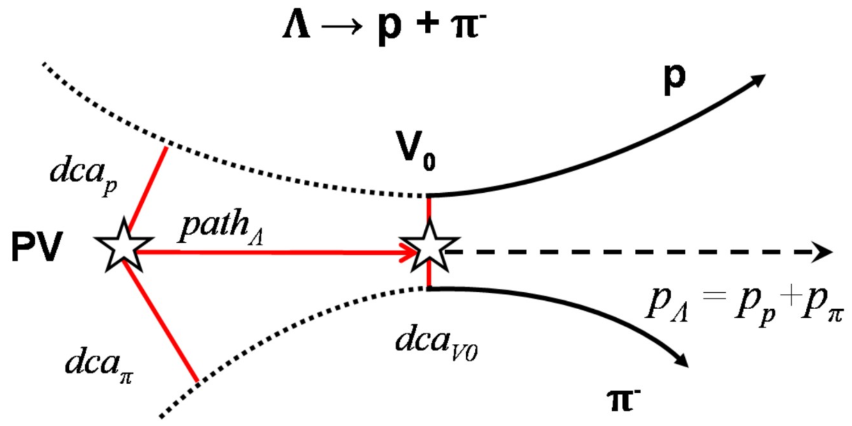
- A combined particle identification is available with both dE/dx from TPC and time of flight (m^2 and/or β)

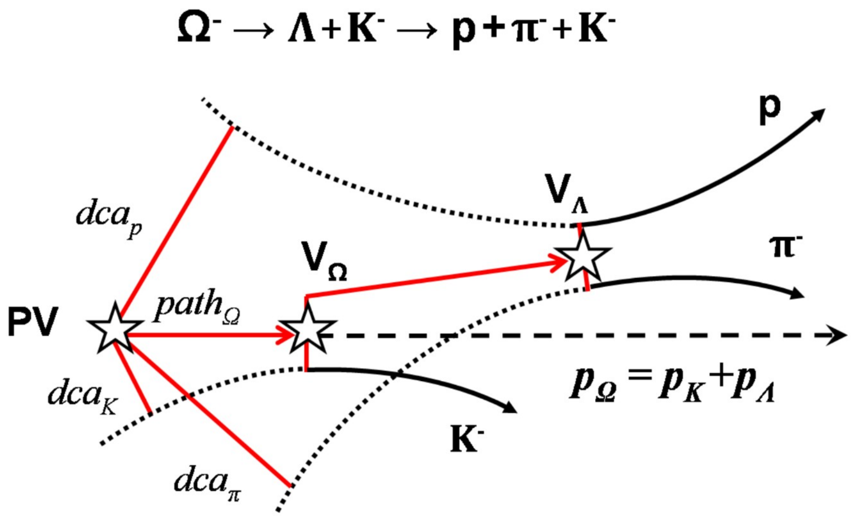
$$m^2 = p^2 \left(\frac{ct^2}{l^2} - 1 \right)$$

A A Mudrokh and A I Zinchenko
doi:10.1088/1742-6596/798/1/012071

Hyperon Reconstruction

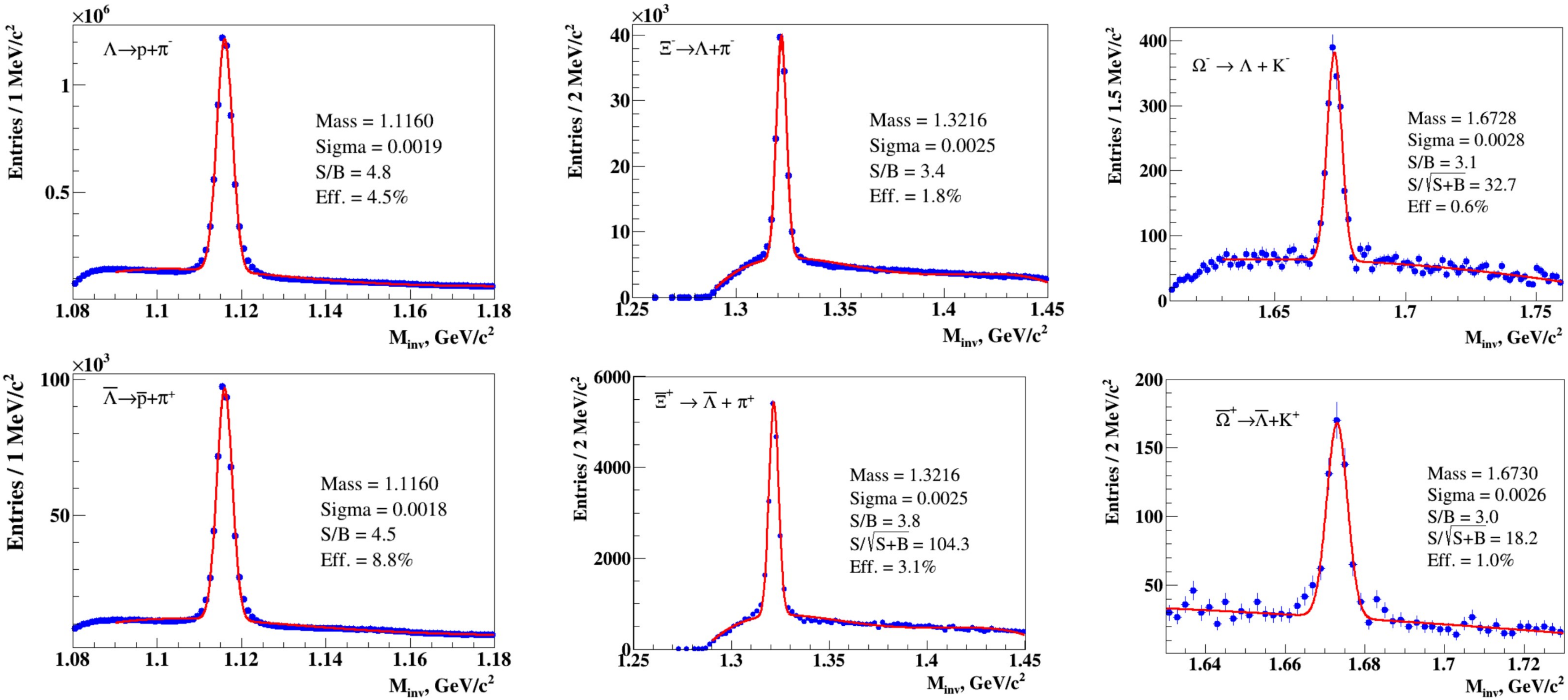
- Secondary Vertex Reconstruction.
- Based on Kalman Filter approach described in:
  R.Luchsinger, Ch.Grab “Vertex reconstruction by means of the method of Kalman filter”, Comp. Phys. Comm., 76(1993) 263.
- Implementation based on MpdParticle paradigm.
- Topological and kinematical cuts can be optimized
- Multiple published results for hyperons and hypernuclei feasibility studies.





Latest feasibility study

- Drnoyan, J., Levterova, E., Vasendina, V., Zinchenko, A., & Zinchenko, D. Perspectives of Multistrange Hyperon Study at NICA/MPD from Realistic Monte Carlo Simulation. Physics of Particles and Nuclei Letters, 17(1), 32–43 (2020).

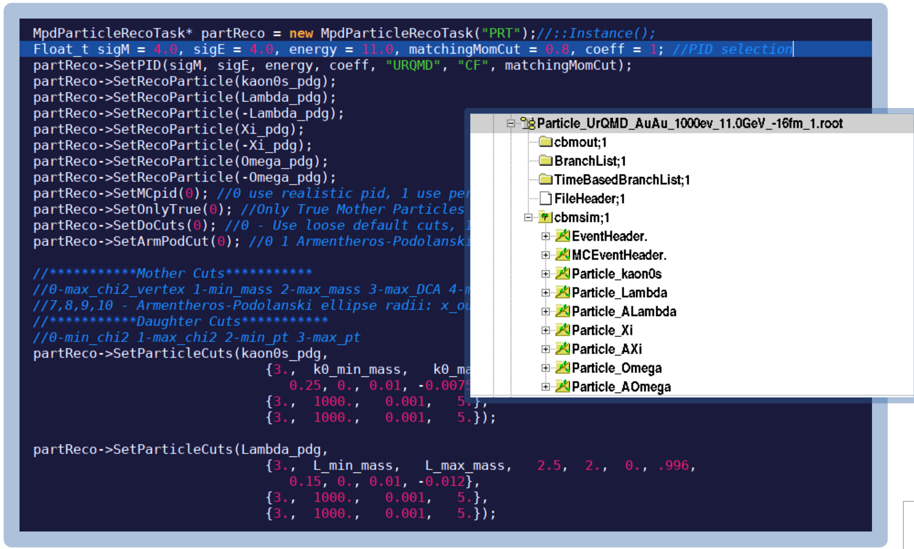


The results show that under some realistic assumptions on the experiment running scenario after, the amount of reconstructed multi-strange hyperons should be sufficient to produce multi-differential distributions for physics analyses.

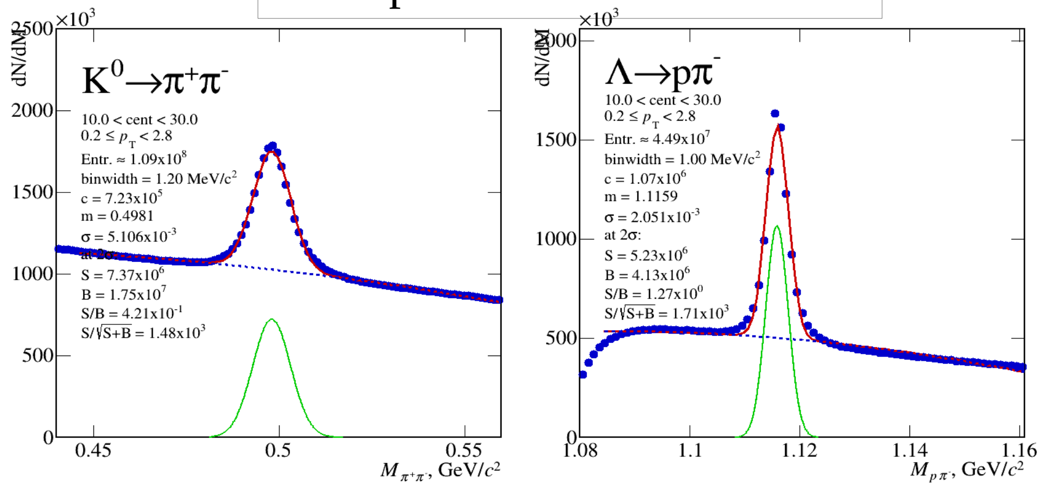
There is an expectation that a MVA / ML approach for selection may improve these results

Mpd Particle Reconstruction Task

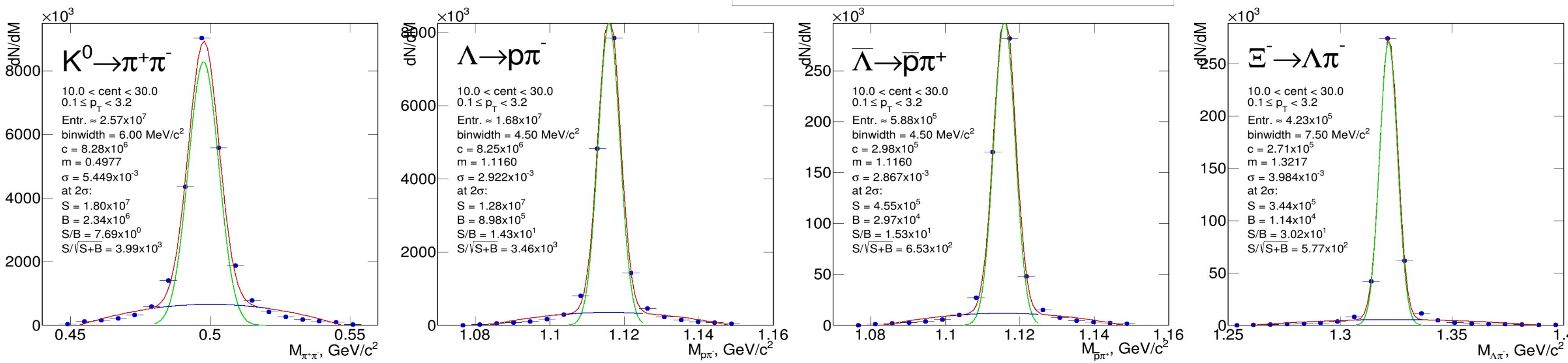
- Based on previously discussed code and results
  by A.Zinchenko: MpdParticle, MpdMotherFitter and macros
- Unifies multiple particle decay reconstructions in a single FairTask in a single run on event
- K_s^0, Λ, $\overline{\Lambda}$, Ξ^- , Ω^- $\overline{\Xi}^+$ and $\overline{\Omega}^+$ are implemented



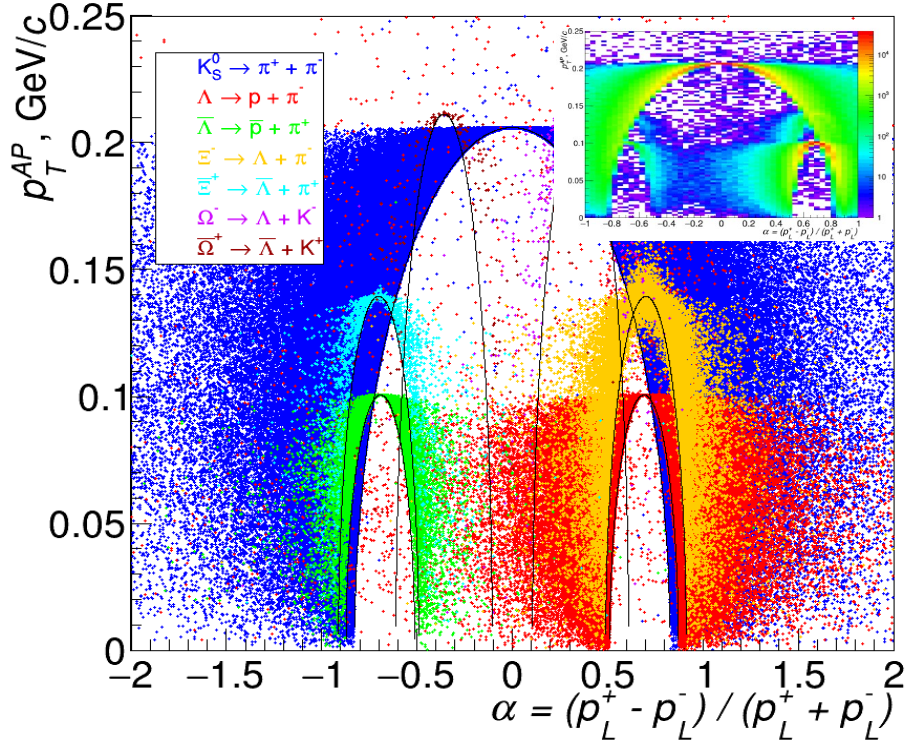
"Reco" with
non-optimized standard cuts

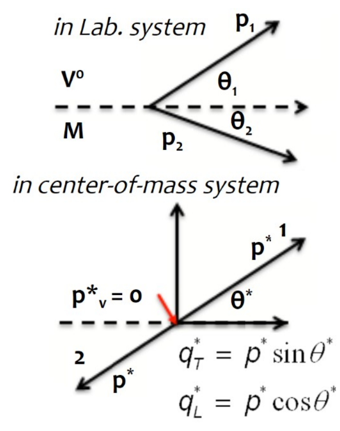


"True" with very loose cuts



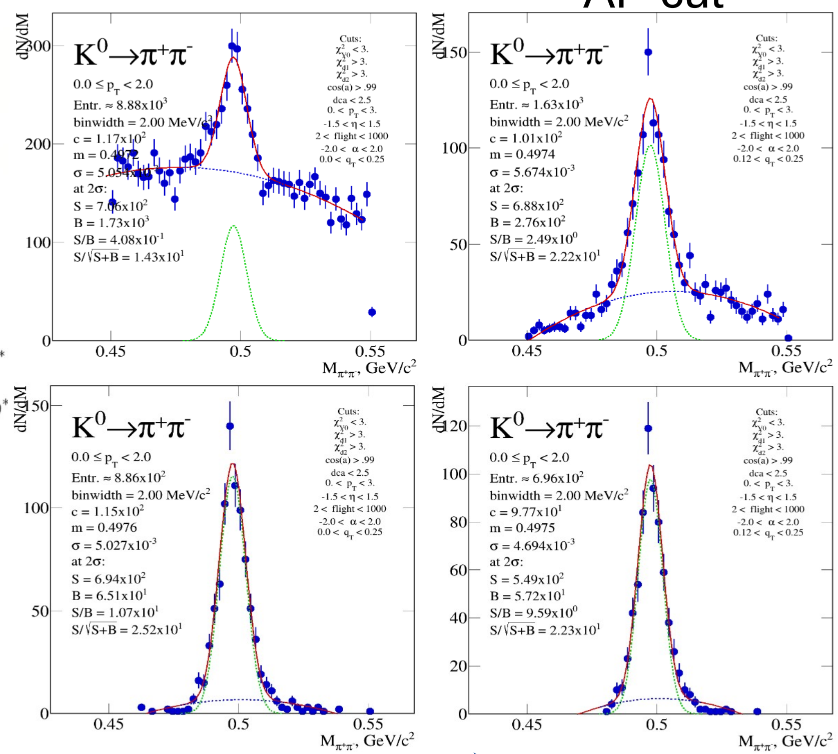
Some Testing on Armentheros-Podolanski Plot Cuts



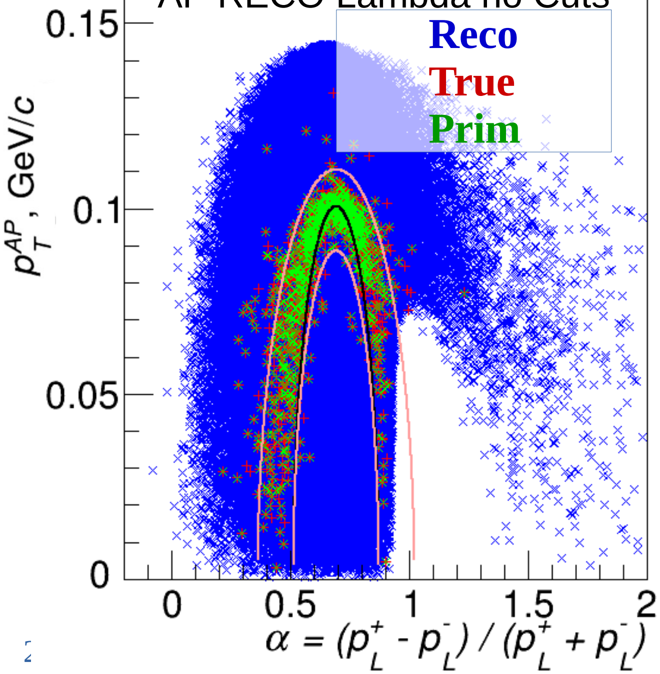


No AP cut

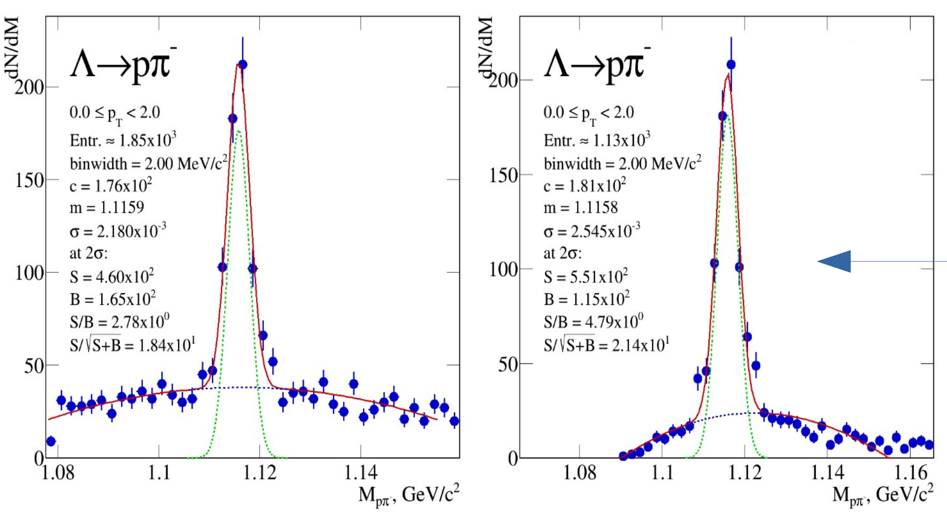
Ellipse+q_T>0.12 AP cut



AP RECO Lambda no Cuts



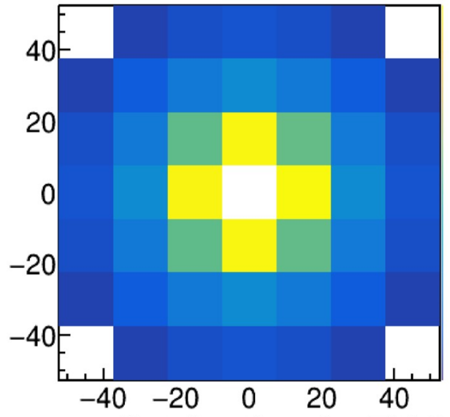
Standard Cuts + AP Cut



Top = Reco
Bottom = True
Left = Before
Right = After

FHCal-based Flow Event-plane Method

Forward and Backward arms of FHCal at high rapidity



Energy distribution in FHCal

$2 < \eta < 5$
$-2 > \eta > -5$

FHCal measures the energy of non-interacting nucleons and fragments (spectators) in AA collisions. Lead-scintilator, WLS fibers, MAPD

$$Q_x^m = \frac{\sum E_i \cos(m\phi_i)}{\sum E_i}$$
$$Q_y^n = \frac{\sum E_i \sin(m\phi_i)}{\sum E_i}$$

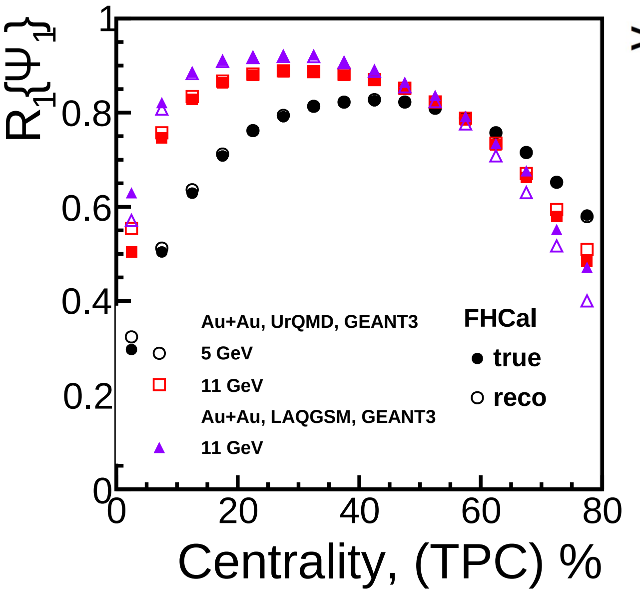
$$\Psi_m^{EP} = \frac{1}{m} Atan2(Q_y^m, Q_x^m)$$

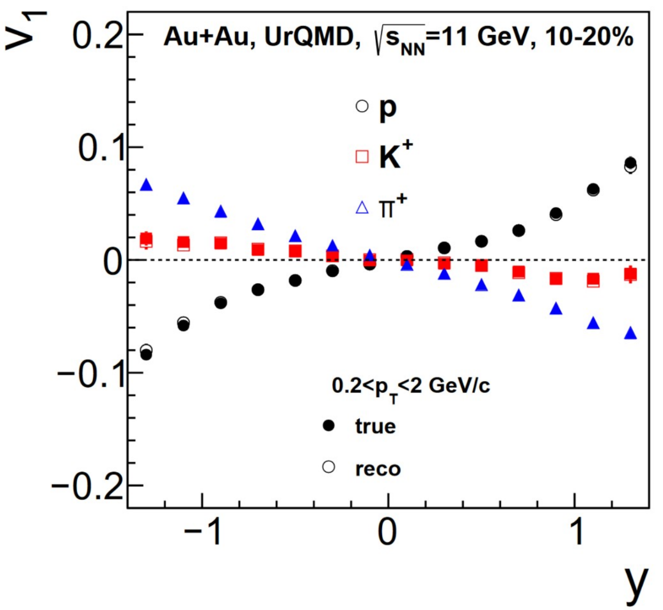
$$Res^2\{\Psi_n^{EP,L}, \Psi_n^{EP,R}\} = \langle \cos(n(\Psi_n^{EP,L} - \Psi_n^{EP,R}))\rangle$$

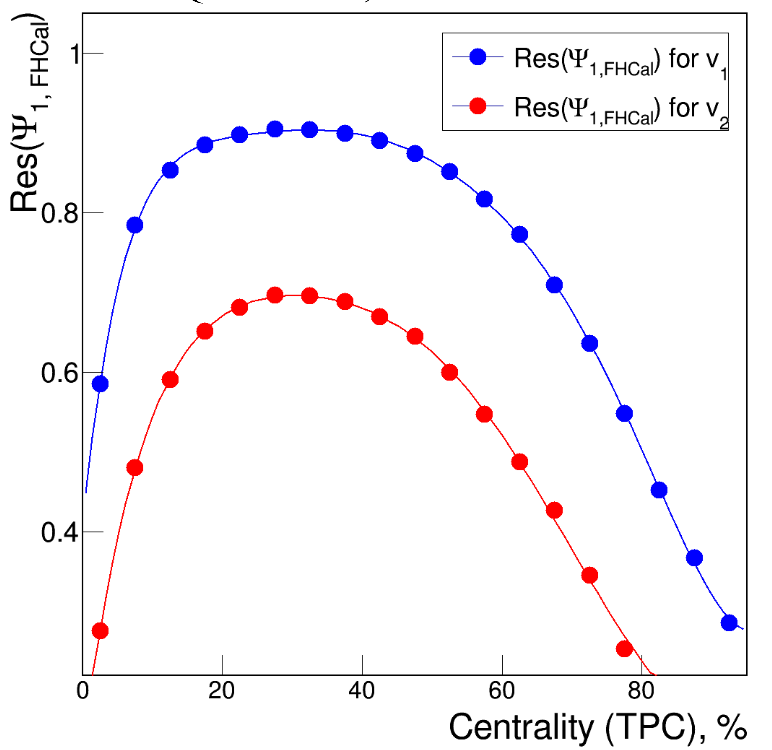
$$v_n = \frac{\langle \cos(n(\varphi - \Psi_n^{EP}))\rangle}{Res\{\Psi_n^{EP}\}}$$

A. Taranenko, P. Parfenov et al., MEPhI
arXiv:1712.09523v1 [hep-ex] 27 Dec 2017
arXiv:1901.03125v1 [hep-ex] 10 Jan 2019

This study:
UrQMD AuAu, 11 GeV Geant4

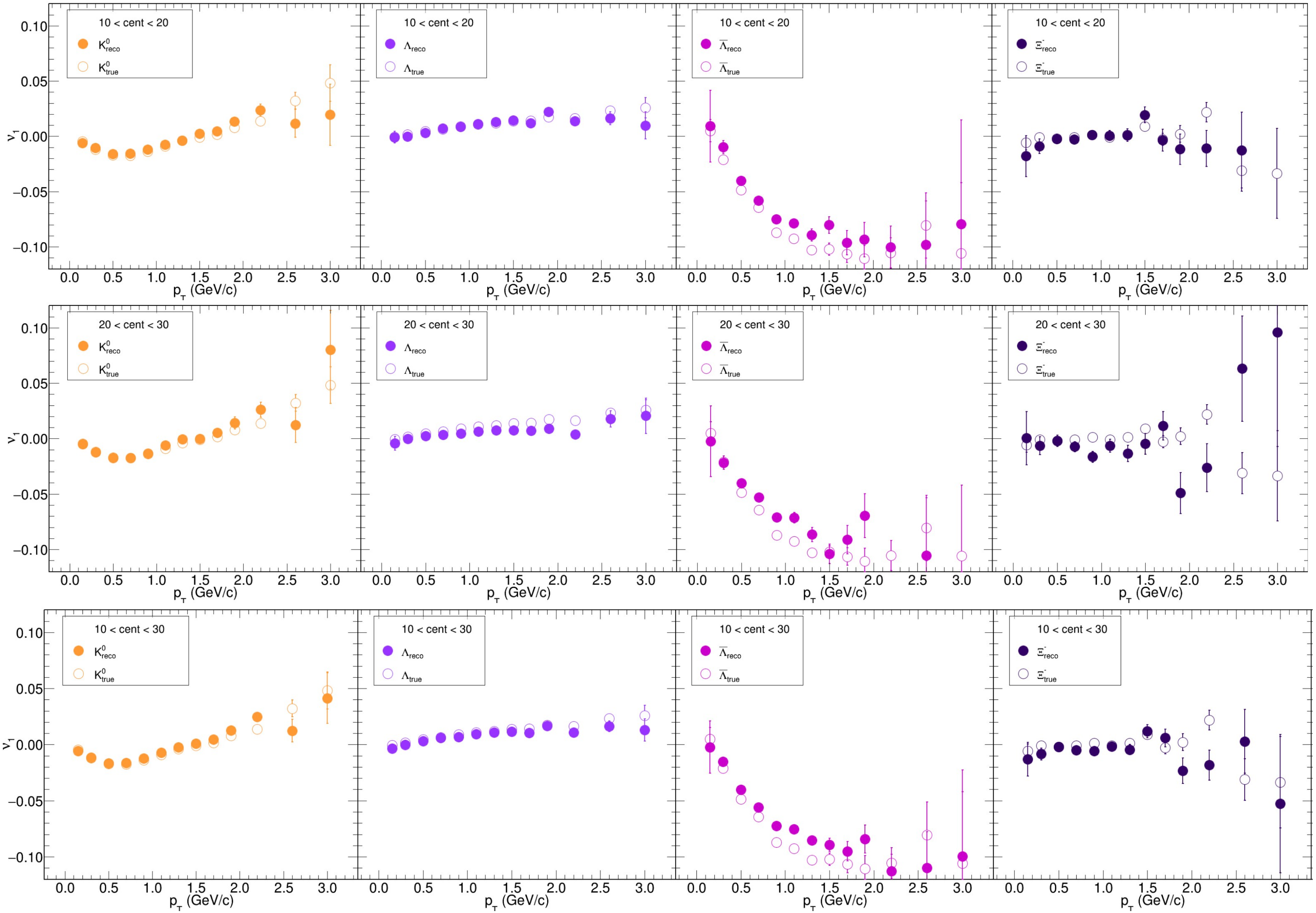




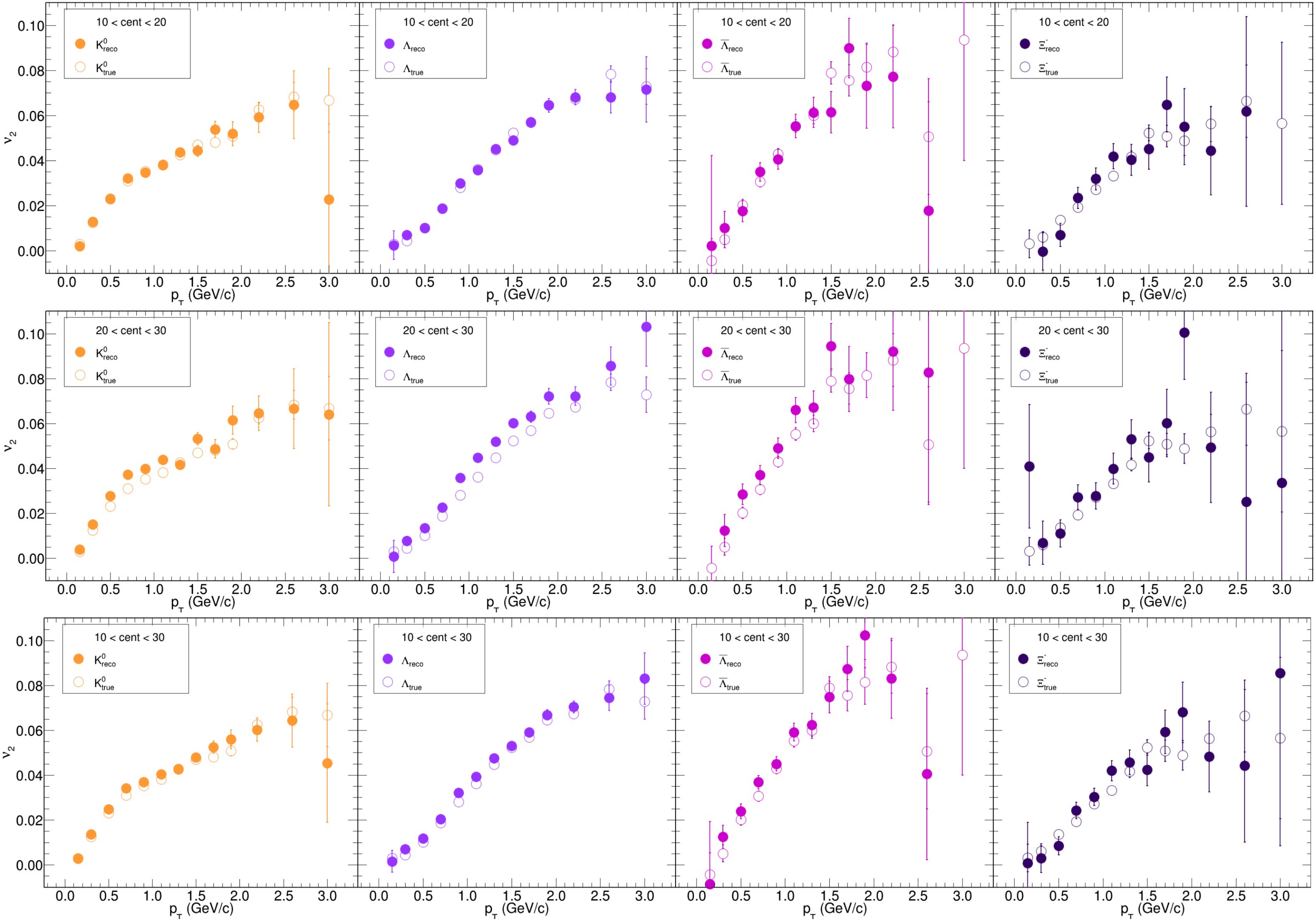


https://git.jinr.ru/nica/mpdroot/tree/dev/macro/physical_analysis/Flow

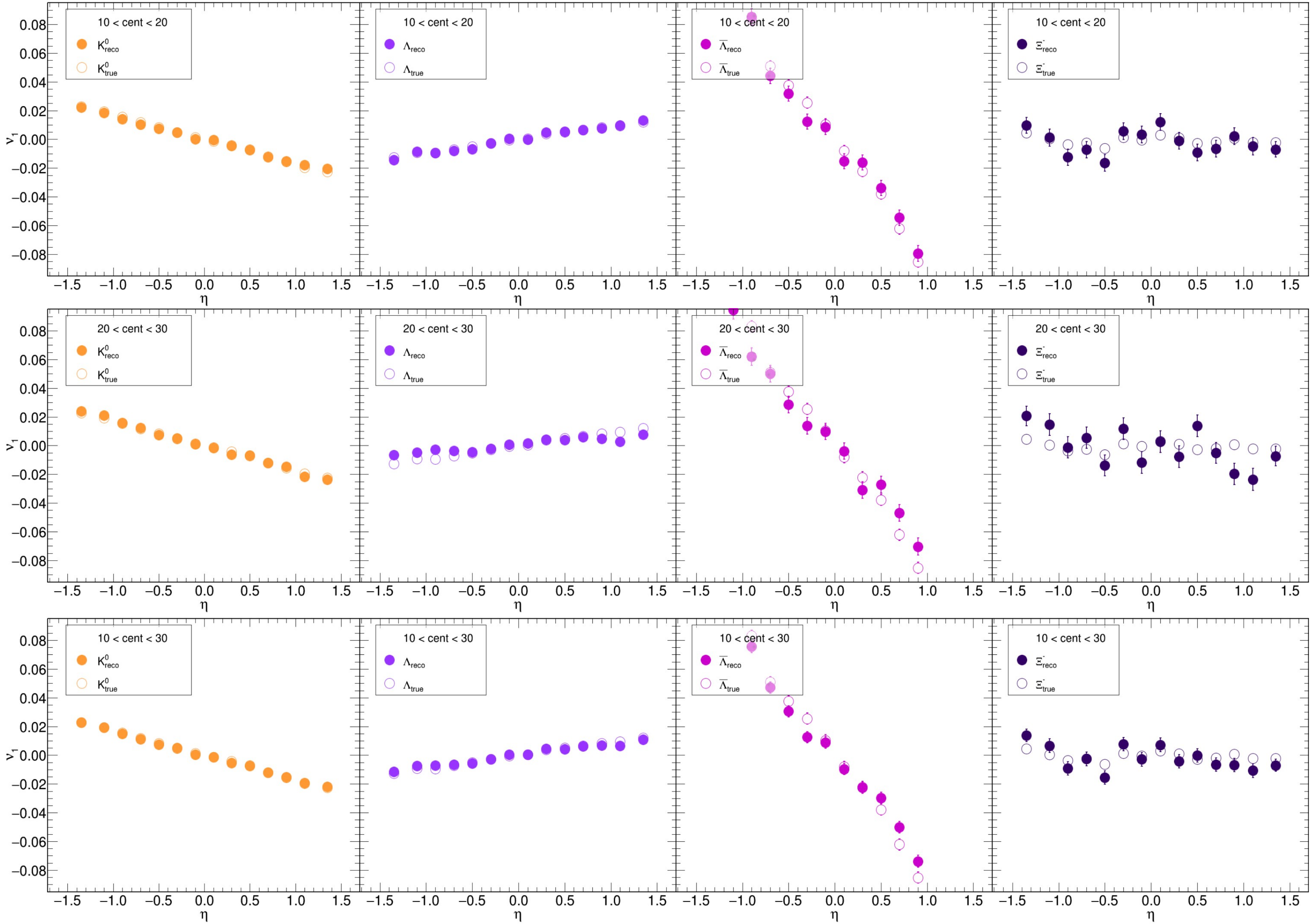
Directed Flow vs Transverse Momentum for Reco-mcid and MC-true-prim



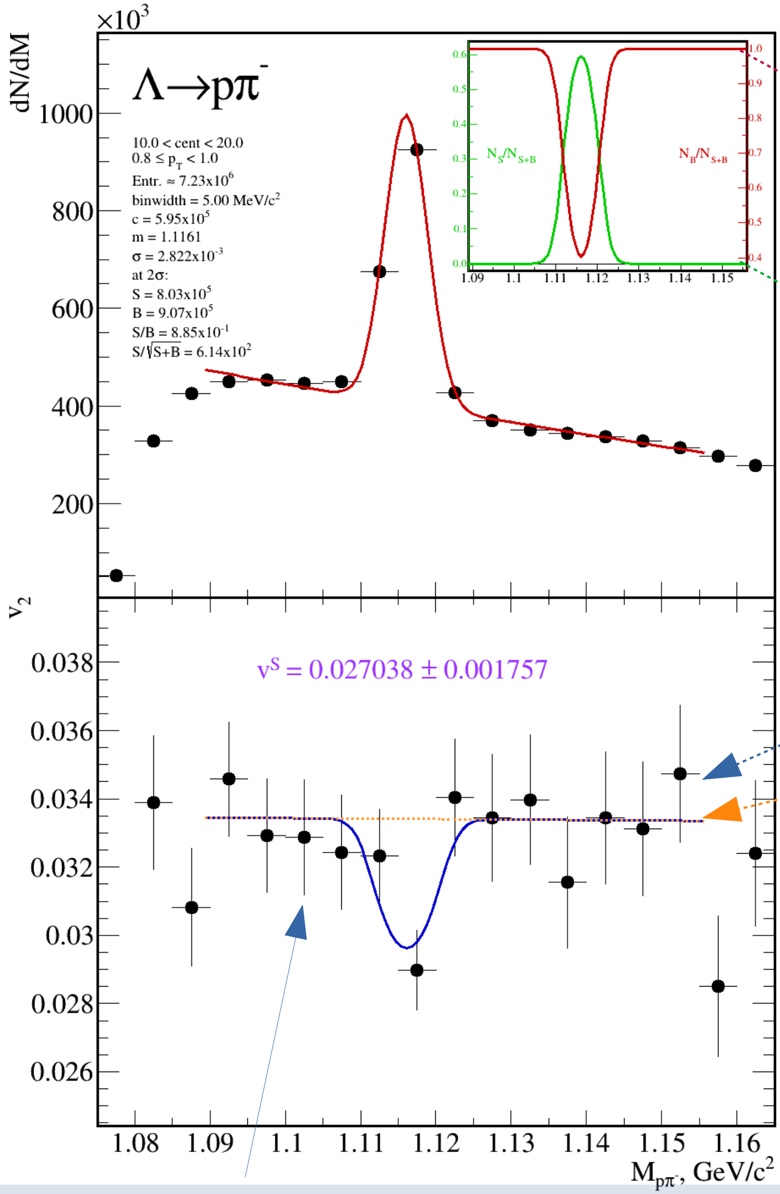
Elliptic Flow vs Transverse Momentum for Reco-mcid and MC-true-prim



Directed Flow vs Pseudo-rapidity for Reco-mcid and MC-true-prim



Flow Signal Extraction

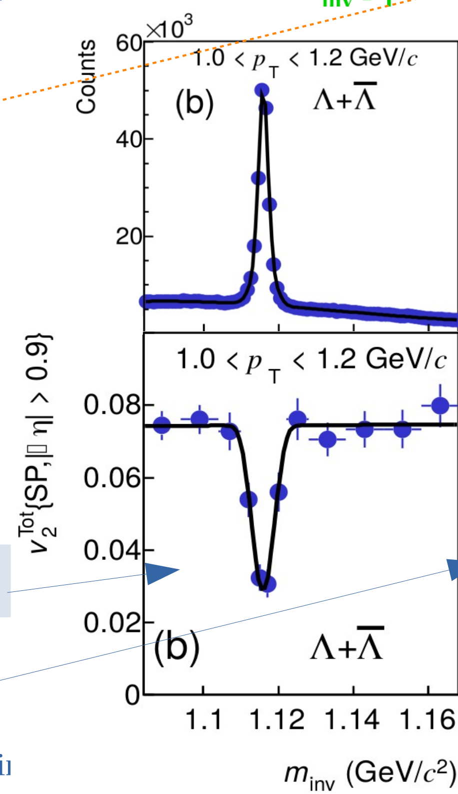


The total (s+bg) flow signal can be expressed as a sum of the decay particle signal flow and background flow multiplied by the respective relative yields in m_{inv} .

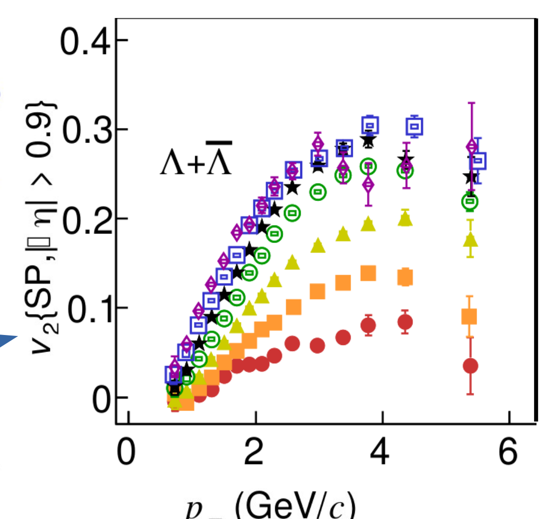
The background flow contribution can be extrapolated with a pol function fitted to the side-bands region.

The total flow signal vs m_{inv} is fitted simultaneously by the combined function and the signal contribution (as a parameter) is extracted from the fit (also error).

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



The procedure is repeated for each bin (a separate fit)



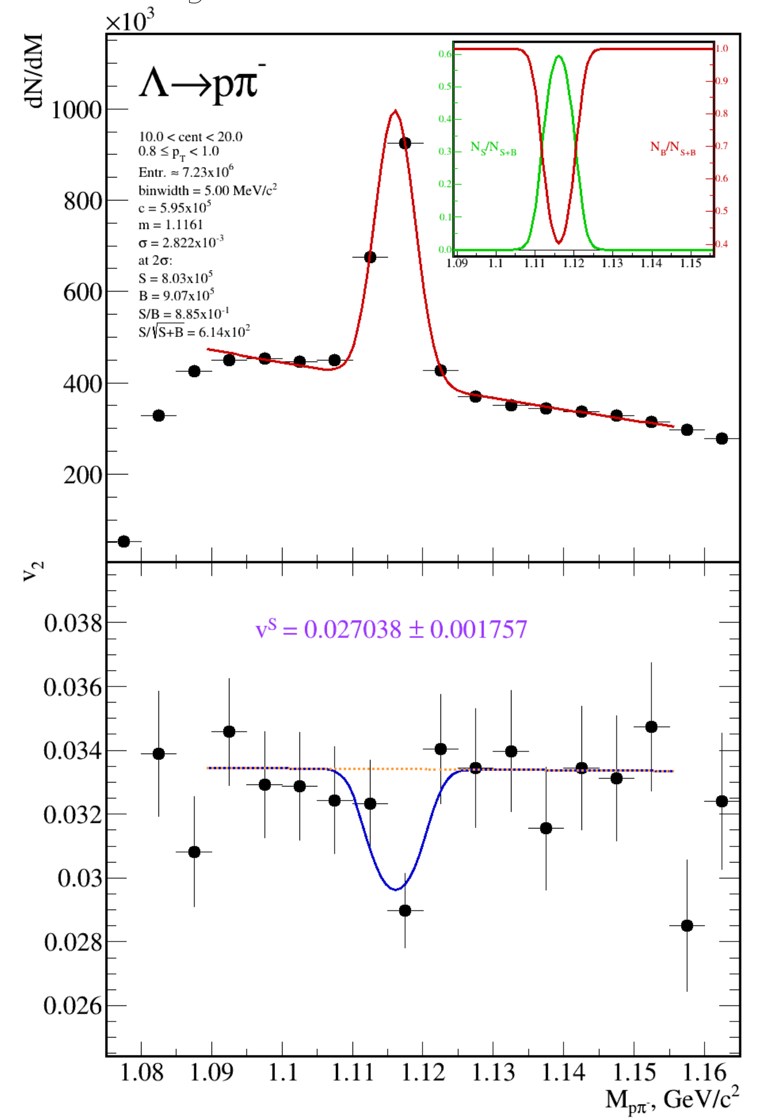
Magnitude of S and fluctuations of BG are important!

arXiv:nucl-th/0407041v2 N. Borghini, J.-Y. Ollitrault
arXiv:0801.3466 [nucl-ex] STAR Collaboration
arXiv:1405.4632 [nucl-ex] ALICE Collaboration

Legend Description

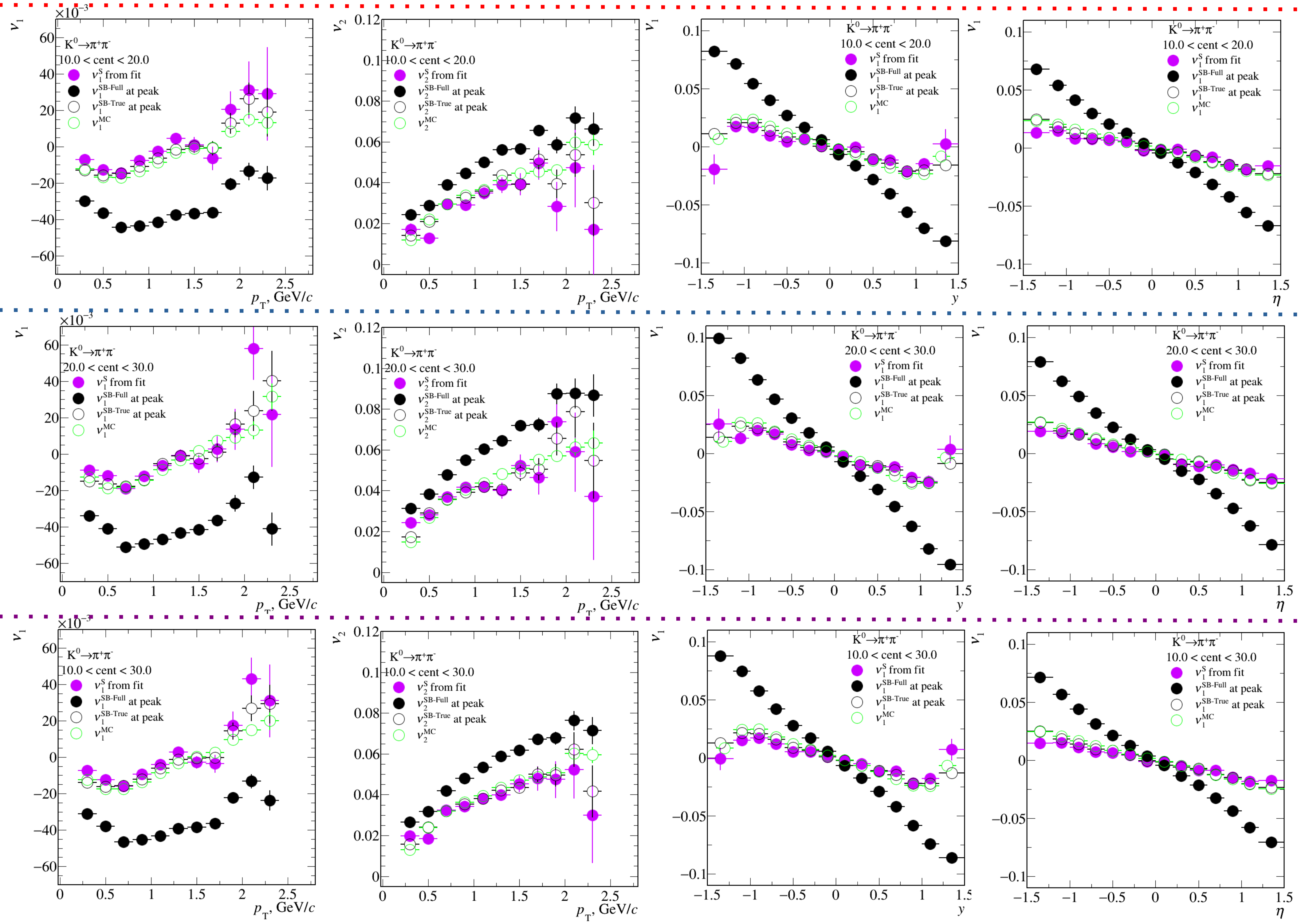
- v_2^S from fit — **Extracted flow signal after fit**
- $v_2^{SB\text{-}Full}$ at peak — **Measured flow (s+bg) at peak region**
- $v_2^{SB\text{-}True}$ at peak — Measured flow at peak region only for True particles (from signal)
- v_2^{MC} — Measured flow from MC

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

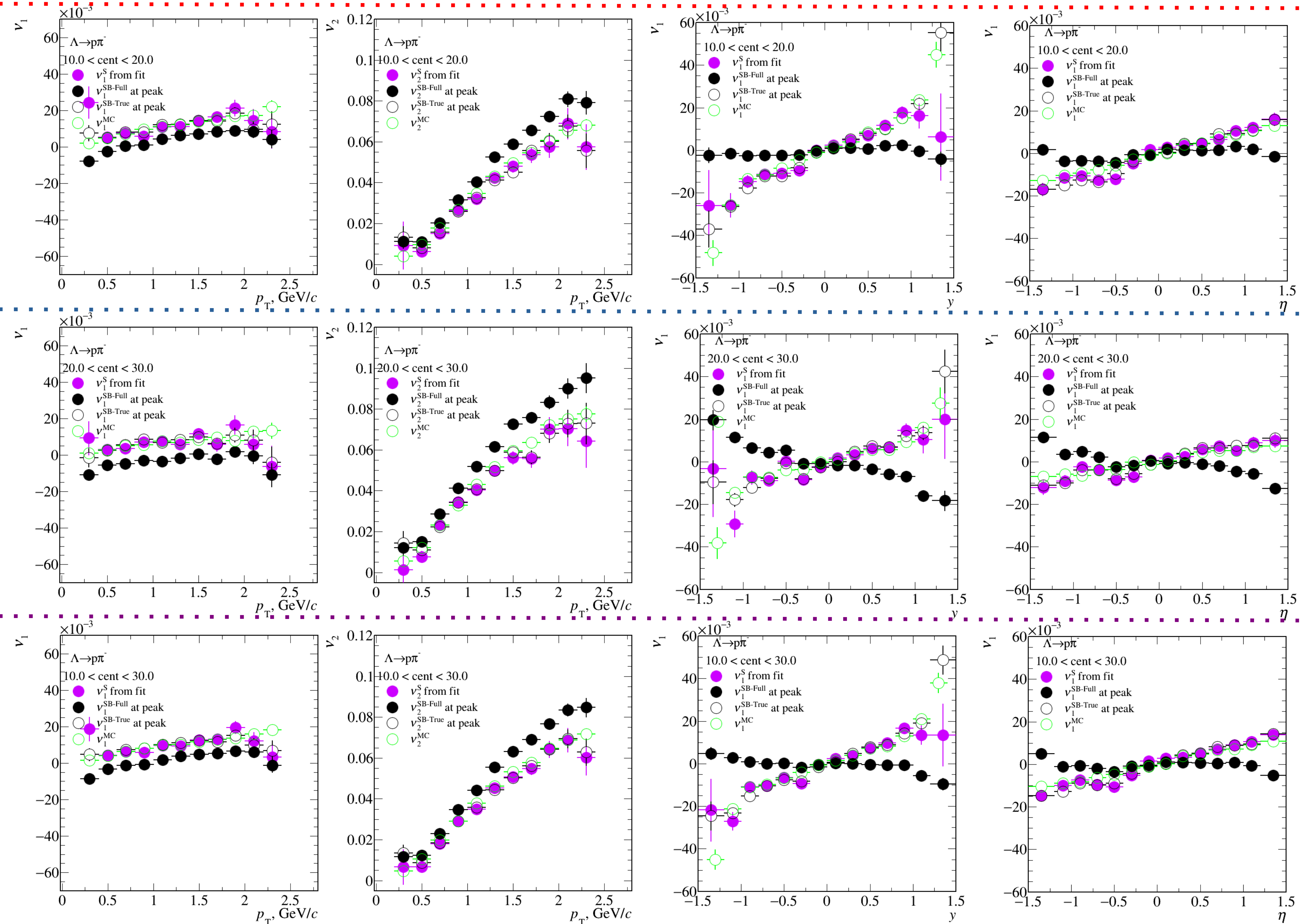


Basically True and MC represent the full and empty circles in previous slides,
where the background was disregarded.
It is important to note that True now have cuts!!!
Any systematic deviation in True should affect in **Extracted** as well.
The error bars of **Extracted** are the errors from the fit parameters.

Extracted Flow K^0 c:10..20, 20..30, 10..30; v1pt, v2pt, v1y, v1η; 30 mass bins



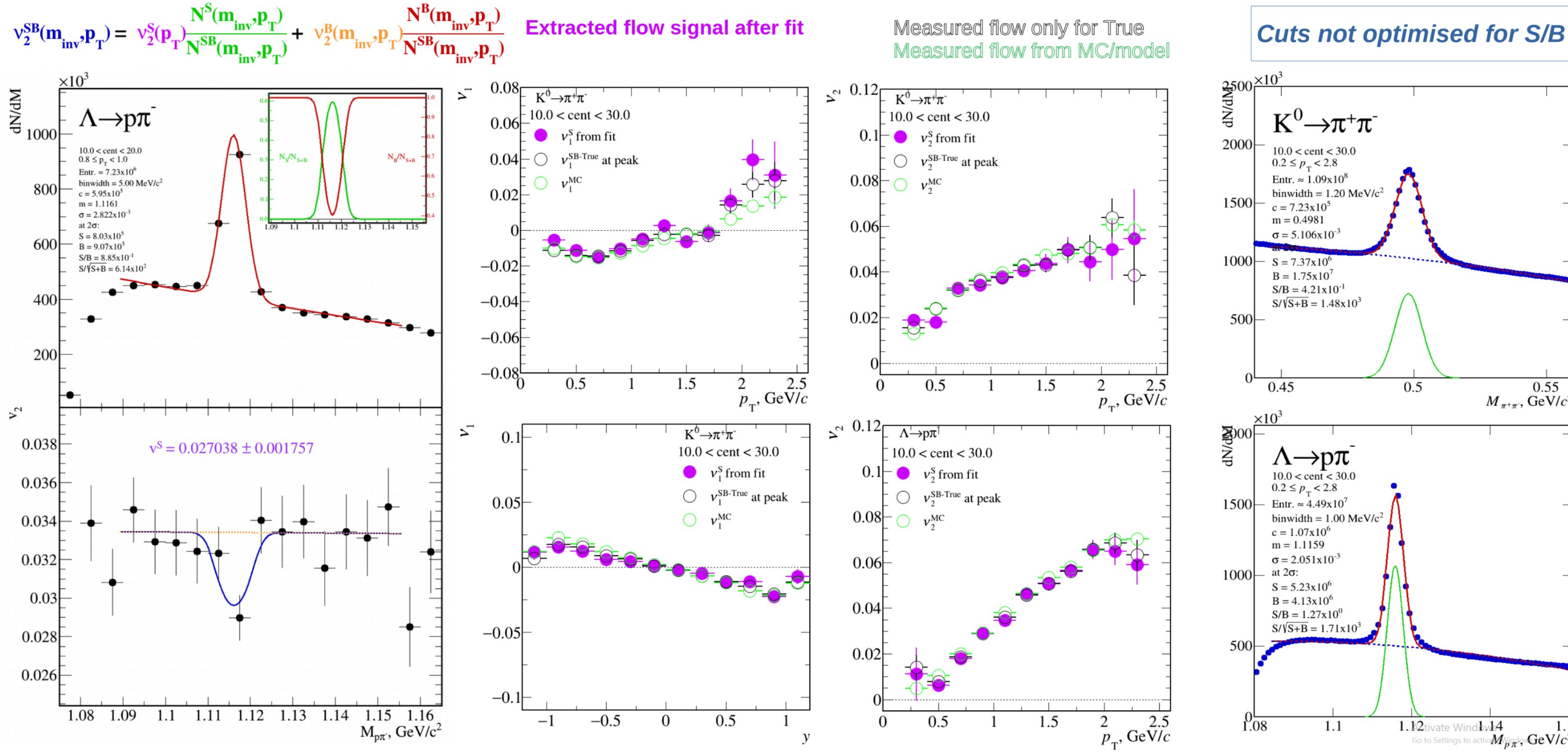
Extracted Flow Λ c:10..20, 20..30, 10..30; v1pt, v2pt, v1y, v1η; 30 mass bins



Summary

BG subtractiion with M_{inv} fit is working
However, a more detailed analysis is required

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



Plan to move towards UrQMD+vHLLE+UrQMD

A 3+1 dimensional viscous hydrodynamic code for relativistic heavy ion collisions

Iu. Karpenko[a,b], P. Huovinen[a,c], M. Bleicher[a,c]

arXiv:1312.4160v1 [nucl-th] 15 Dec 2013
Comput. Phys. Commun. 185 (2014), 3016

The basic hadronic observables at RHIC BES are roughly reproduced!

Iu. A. Karpenko, K, Huovinen, Petersen, Bleicher, Phys.Rev. C91 (2015) no.6, 064901

P. Batyuk has made a convenient user interface!

https://github.com/yukarpenko/vhlle
https://github.com/pbatyuk/vHLLE_package

Study of collective flow effect at the NICA beam energy with UrQMD model approach

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August 2015

Status of the performance studies of anisotropic flow with MPD at NICA

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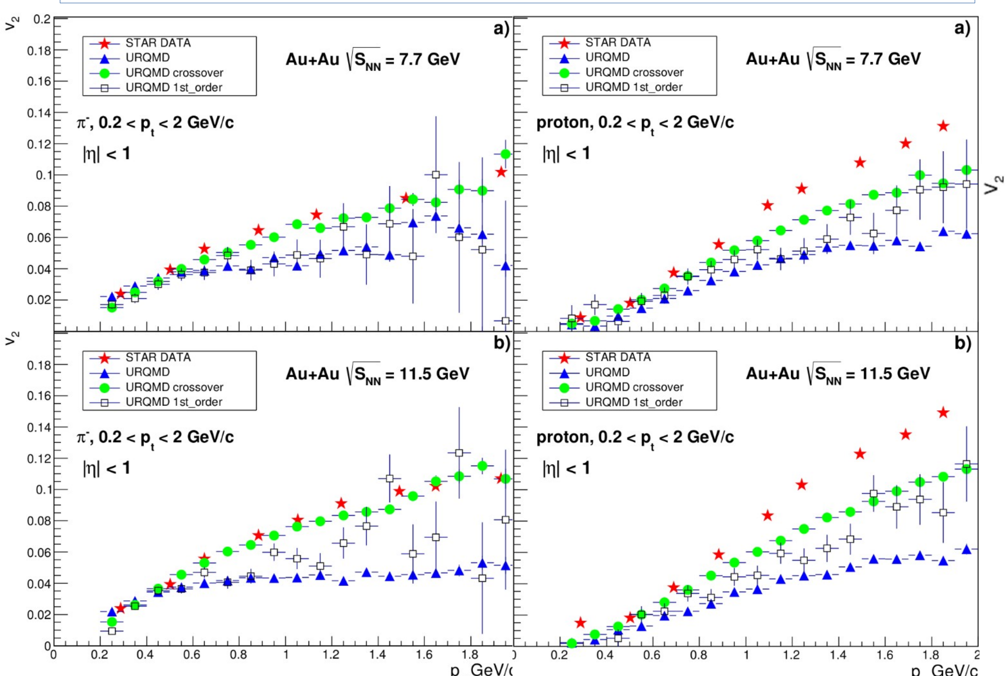
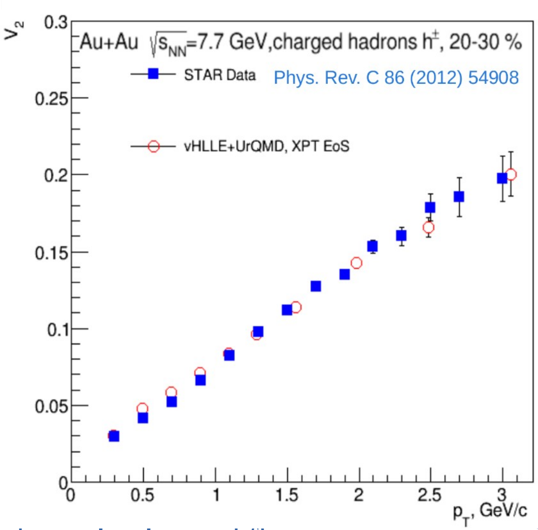
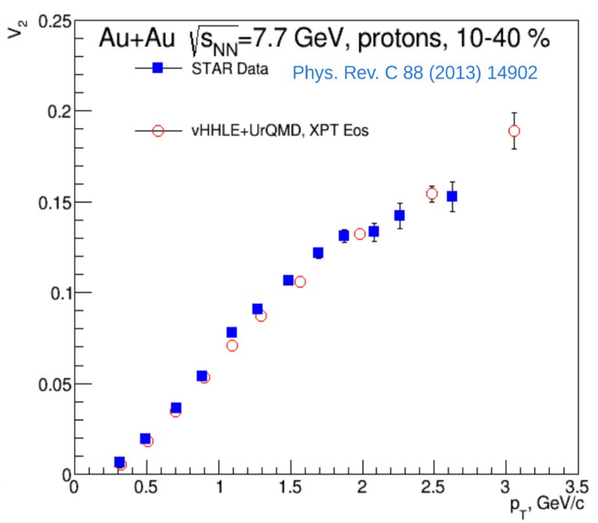
A. Taranenko (MEPhI)

QFTHEP-2019
Sochi, Russia
24.09.2019







Conclusions & Plans

* Analysis of 7 particle (true) is in principle ready. K_s^0, Λ, $\overline{\Lambda}$, Ξ^- were analysed.

Statistics is currently not enough for flow studies of true $\overline{\Xi}^+$, Ω^-, $\overline{\Omega}^+$.

* Flow signal extraction was performed on K_s^0 and Λ particles.

Analysis was performed for 3 centrality classes and several mass bin conf
Even at low signal magnitude and low statistics the results are promising,
However, flow fit extraction is very signal dependent.

* An increase of statistics and hydrodynamic evolution in model should provide for better results.

Switch to vHLLE+UrQMD

* Implement centrality selection by FHCal? (currently im_par and tpc_mult)

* Cut optimization.

Additional cuts and techniques for particle reconstruction should improve the current results.

MVA / ML approaches will be tested soon.

Thank you!