Anisotropic flow measurement from NA61/SHINE and NA49 experiments at CERN SPS

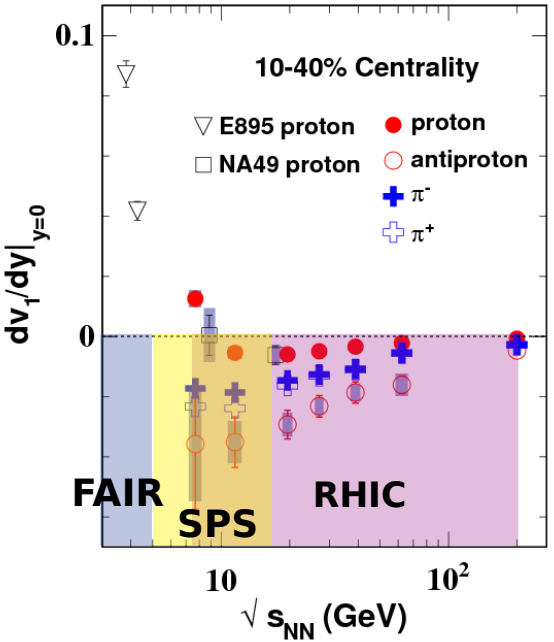
Evgeny Kashirin (*MEPhI*)
Viktor Klochkov (*GSI / Frankfurt University*)
Oleg Golosov (*MEPhI*)
Ilya Selyuzhenkov (*GSI / MEPhI*)

For the NA61/SHINE and NA49 Collaborations

25 May 2018, Krakow

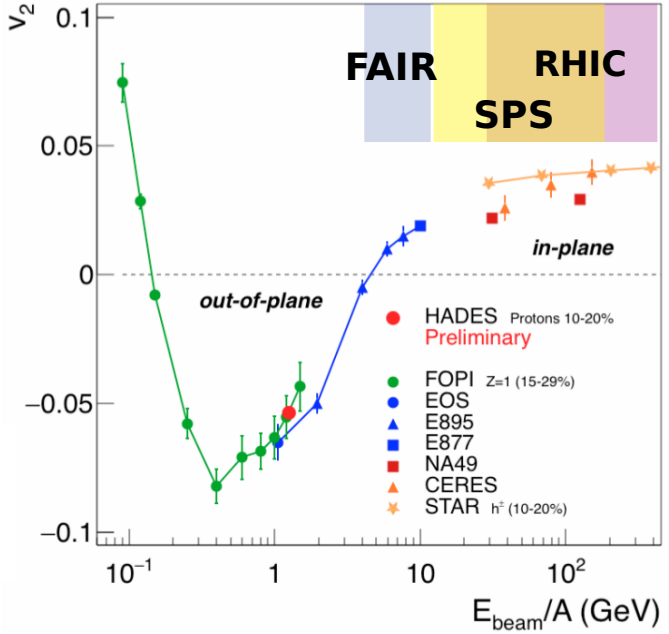
Collective flow at SPS / RHIC energies

Directed flow (slope)



STAR Collaboration
PRL 112 (2014) 162301

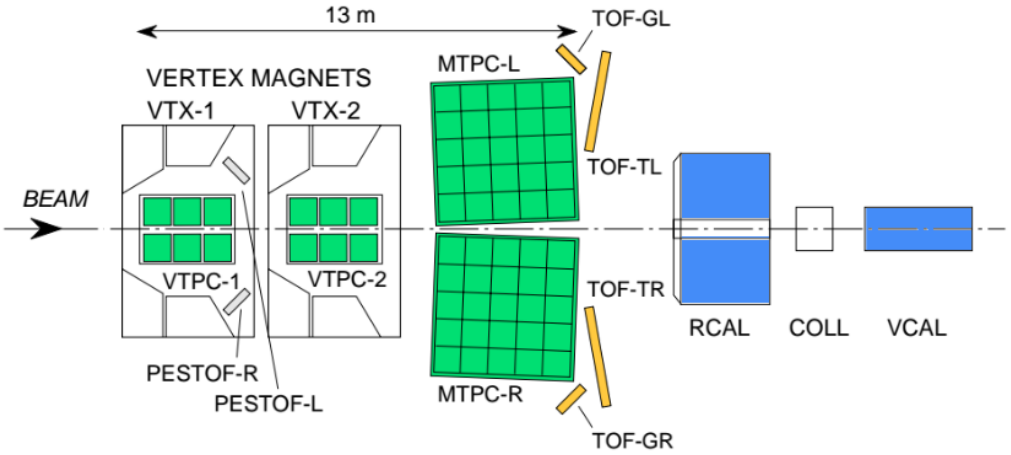
Elliptic flow

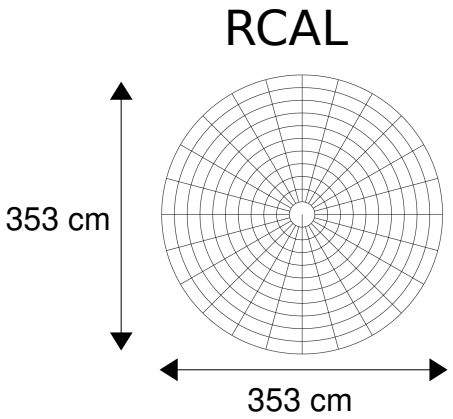


HADES Collaboration
JPCS 742 (2016) 012008

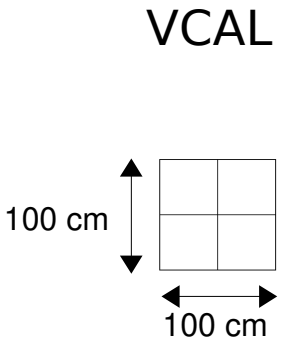
- NA61/SHINE Pb-ion beam energy scan (p_{LAB} = 13-150*A* GeV/*c*):
  - extend existing NA49 data
  - complementary to STAR@RHIC
  - bridge to FAIR beam energies
- Advantage of NA49/61 SHINE fixed target setup
  - forward rapidity tracking with TPC
  - projectile spectators (forward calorimeter - PSD/VCAL)

Pb-ion beam energy scan with NA49 (1996-2002)



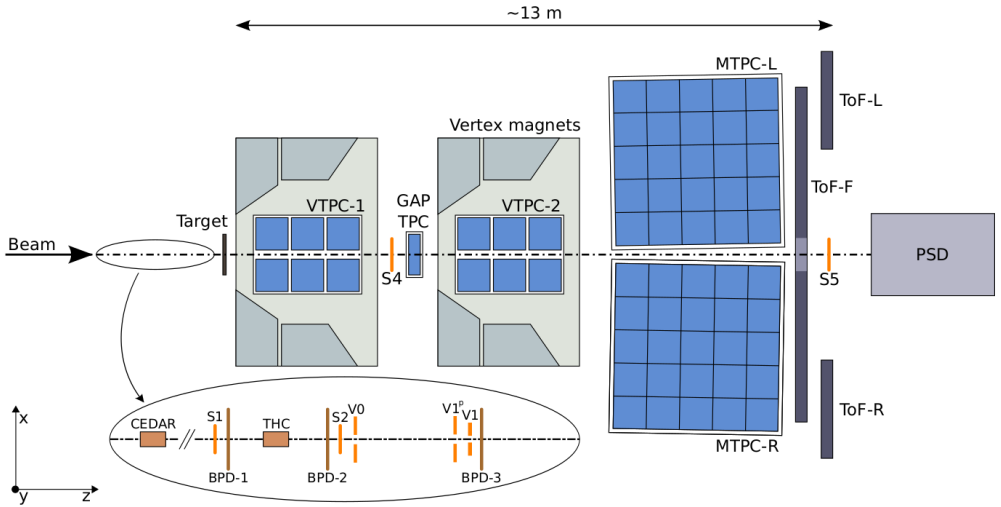


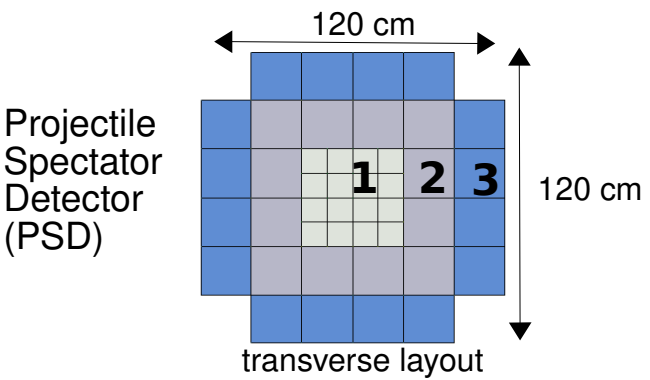
24 sections x 10 rings



- Large acceptance hadron spectrometer (TPC)
  - full coverage of forward hemisphere
  - tracking + identification down to $p_T \sim 0$ GeV/*c*
- Forward rapidity calorimeters
- 20*A*, 30*A*, **40*A***, 80*A*, 158*A* GeV/*c* data

Pb beam energy scan with NA61/SHINE





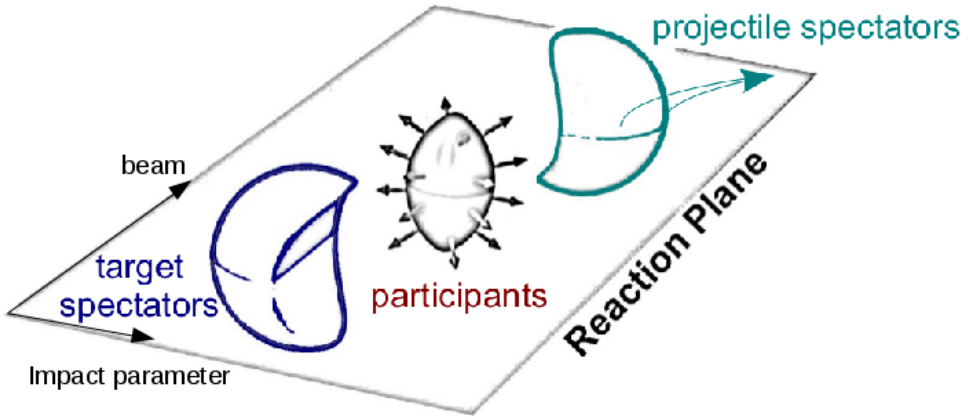
- Similar TPC configuration
- Forward rapidity calorimeter (PSD)
- Pb+Pb beam momentum scan:
  - 13*A*, **30*A* GeV/*c*** recorded in 2016 (pilot run at 150*A* GeV/*c*)
  - 150*A* GeV/*c* coming later this year 2018

Collision geometry and the anisotropic transverse flow

Asymmetry in coordinate space converts due to interaction into momentum asymmetry with respect to the symmetry plane:

$$\rho(\phi) = \frac{1}{2\pi}\left[1+2\sum_{n=1}^{\infty} v_n \cos\left(n\left(\phi-\Psi_s\right)\right)\right]$$

$$v_n = \left\langle \cos\left(n\left[\phi-\Psi_s\right]\right)\right\rangle$$

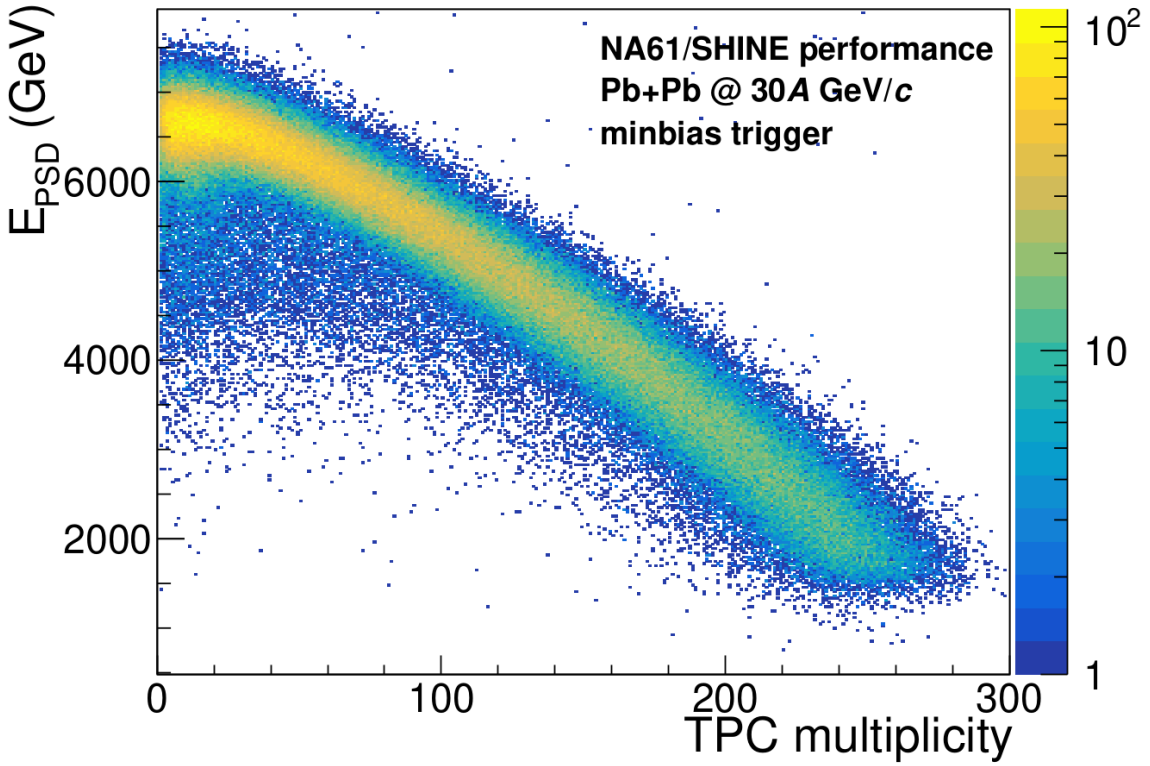


Ψ_s can be estimated with produced particles Ψ_{pp} or with projectile (target) spectators Ψ_{proj} (Ψ_{spec})

Needed components to calculate v_n:

- momentum (ϕ, y, p_T)
- centrality estimation
- particle identification
- Ψ_s estimation

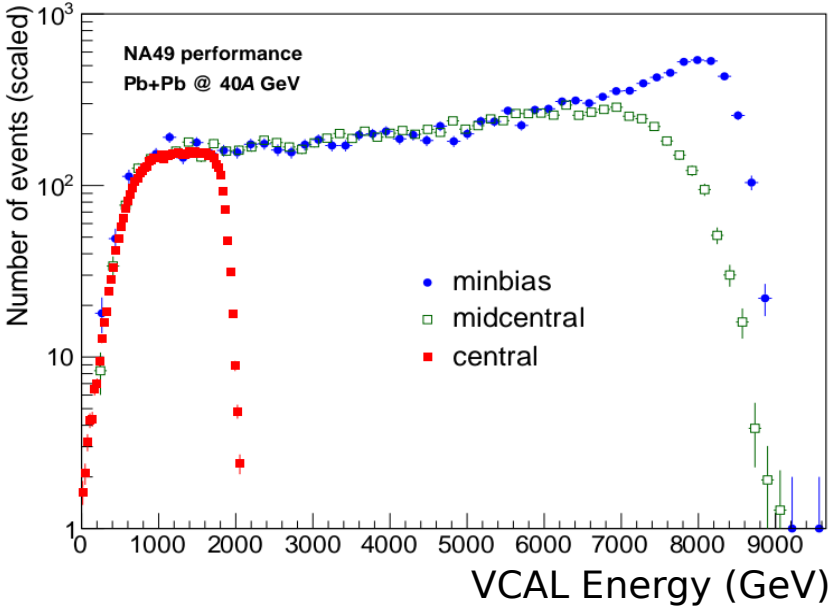
Event selection



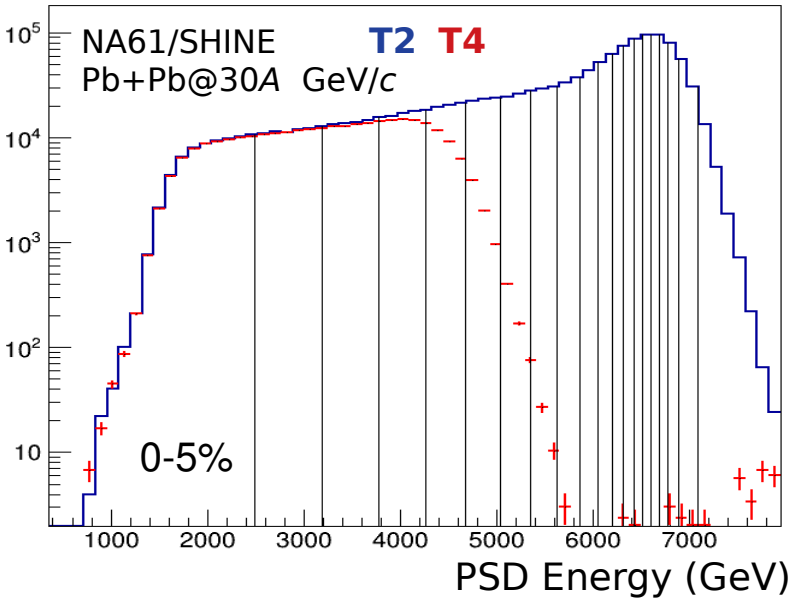
- Event has fitted vertex
- Good reconstructed vertex position
- Good beam position
- No overlap events / beam particles

* more details in backup

Trigger efficiency and centrality estimation



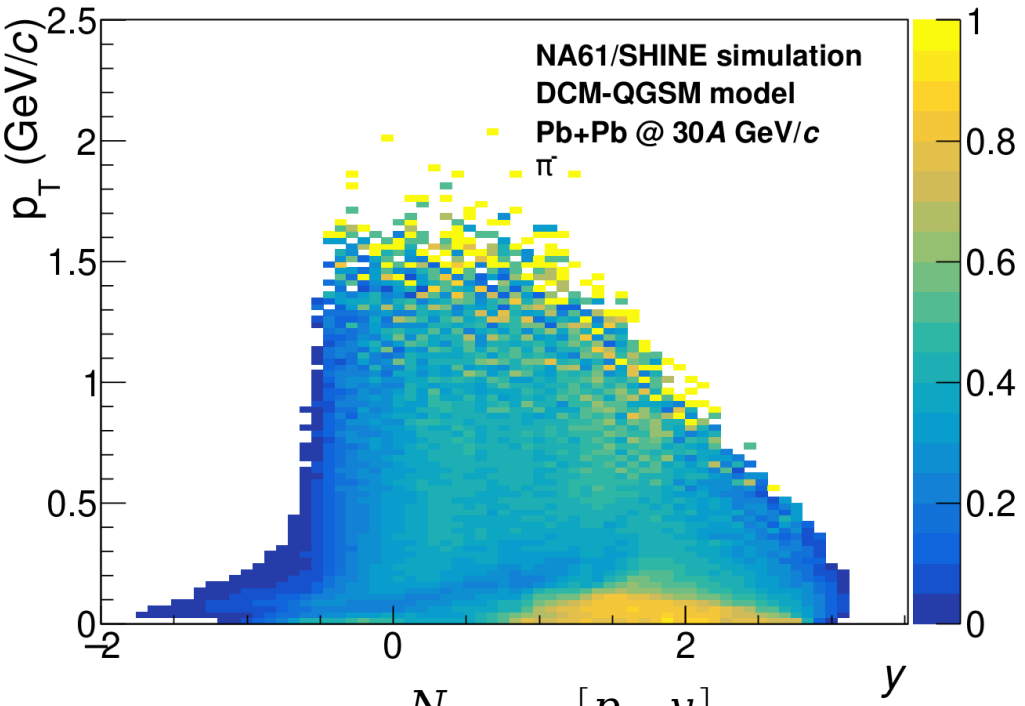
335k minimal bias events
437k central events



1.1M for minimum bias trigger **T4**
0.6M for central trigger **T2**

Track selection & Corrections for detector p_T/y non-uniformity

Example of p_T/y correction map



$$w[p_T, y] = \frac{N_{identified}[p_T, y]}{N_{simulated}[p_T, y]}$$

Number of clusters:

$N_{clusters}$ [VTPC1+VTPC2] > 15

$N_{clusters}$ [Total] > 30

$0.55 < N_{cl}$[Total] / N_{cl}[Total, Pot] < 1

Distance of closest approach to vertex

$|b_x| < 2$ cm

$|b_y| < 1$ cm

TPC energy loss (dE/dx)

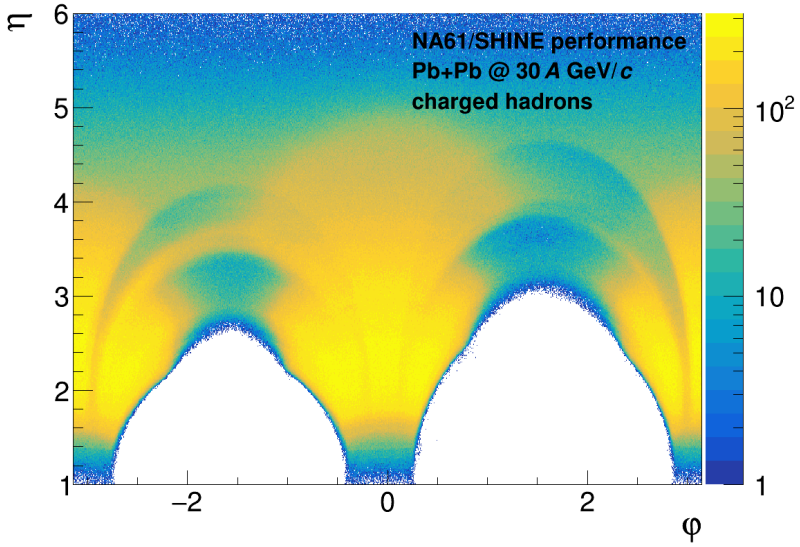
charged pions & proton identification

Tracking efficiency

GEANT4 Monte-Carlo with DCM-QGSM

same track selection and efficiency extraction for NA49

Corrections for detector azimuthal non-uniformity



QnVector Corrections Framework

- Data driven corrections for azimuthal acceptance non-uniformity
  I. Selyuzhenkov and S. Voloshin [PRC77 034904 (2008)]
- QnVector Corrections Framework (used by ALICE)
  J. Onderwaater, V. Gonzalez, I. Selyuzhenkov
  https://github.com/jonderwaater/FlowVectorCorrections
- Recentering, twist, and rescaling corrections applied
  time dependent (run-by-run) and as a function of centrality

Flow Analysis Framework

- Extended flow-vector corrections for p_T/*y*-differential
- Multi-dimensional correlations of flow-vectors
  L. Kreis (GSI / Heidelberg) and I. Selyuzhenkov (GSI / MEPhI)

Scalar product method with 1st harmonic Q-vector

u_n and Q_n vectors:

$$u_n = \begin{pmatrix} \cos n\phi \\ \sin n\phi \end{pmatrix} \qquad Q_n = \sum_j w_j u_n^j$$

Directed flow:

$$v_{1,i} = \frac{\langle 2\, u_{1,i} Q^A_{1,i} \rangle}{R^A_{1,i}} \qquad i, j, k = [x, y]$$

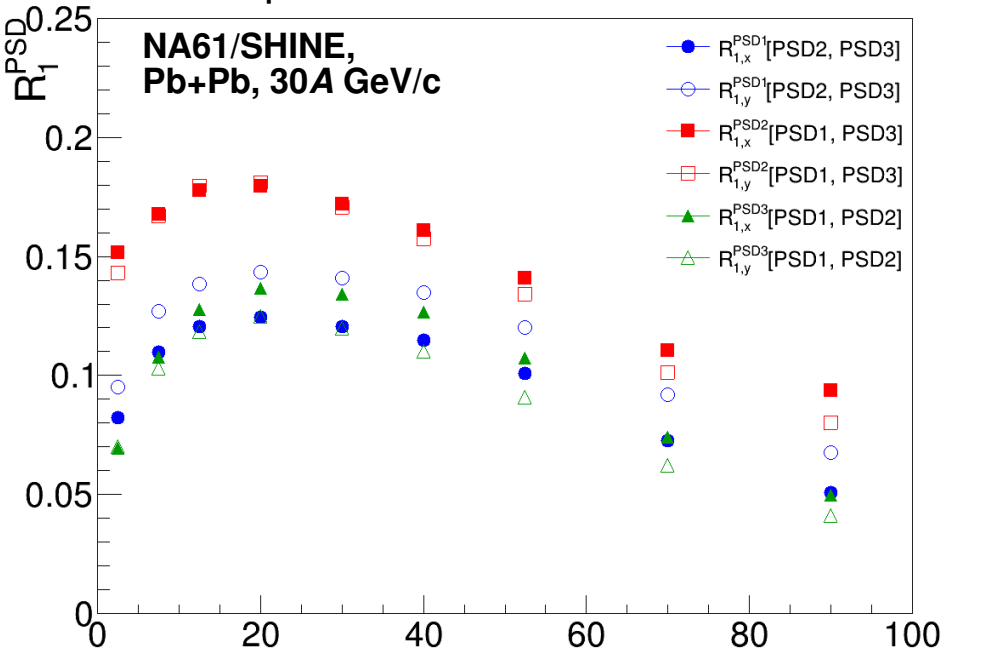
Elliptic flow:

$$v_2 = \frac{4 \langle u_{2,i} Q^A_{1,j} Q^B_{1,k} \rangle}{R^A_{1,j} R^B_{1,k}}$$

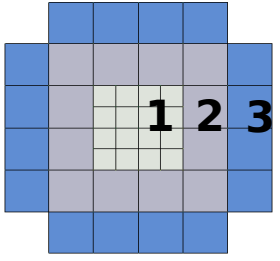
First harmonic resolution correction factor:

$$R^A_{1,i} = \sqrt{2 \frac{\langle Q^A_{1,i} Q^B_{1,i} \rangle \langle Q^A_{1,i} Q^C_{1,i} \rangle}{\langle Q^B_{1,i} Q^C_{1,i} \rangle}}$$

Scalar product correction factor



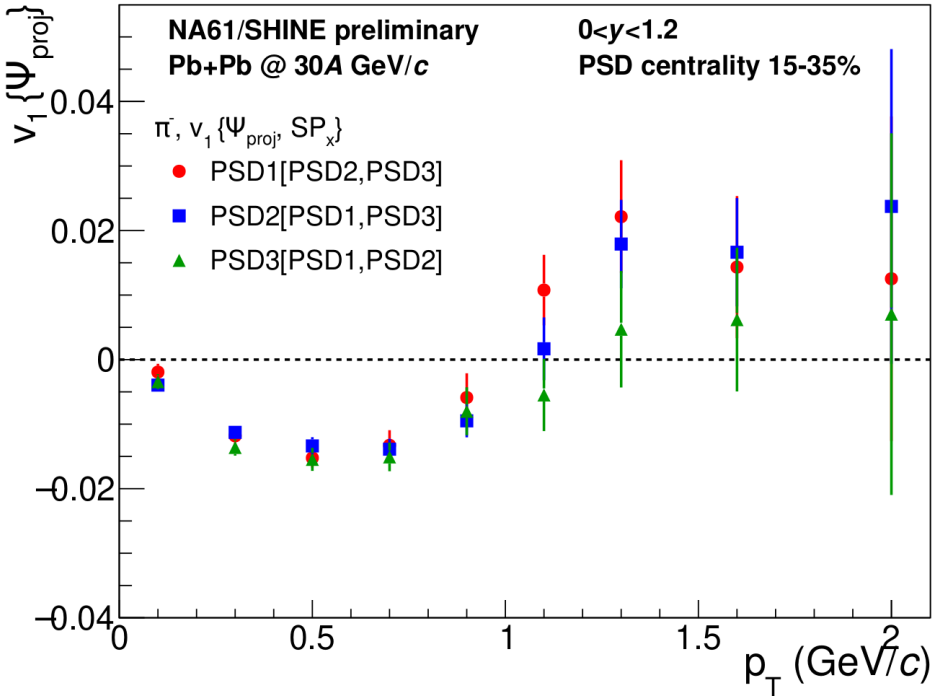
NA61:



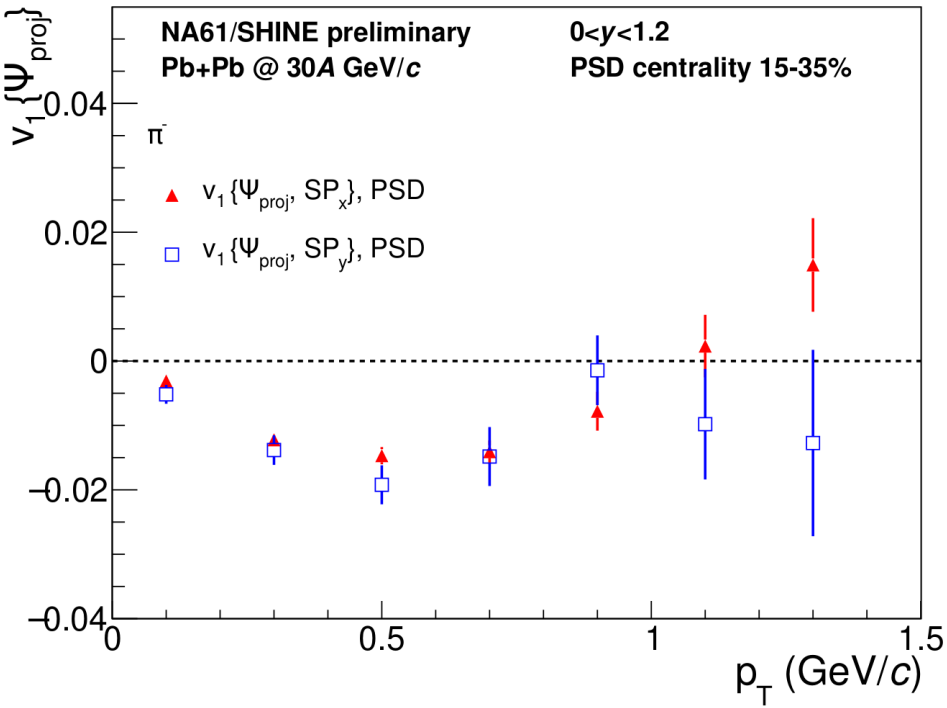
NA49:

VCAL,
RCAL (5 inner rings)
RCAL (5 outer rings)

“Systematics” for directed flow (v_1) components



Consistent results for PSD subevents



x/y components show consistent results, while results for y-component shows larger errors

For preliminary results: only x-component is used and PSD subevents are combined

NA61/SHINE & NA49
Preliminary results

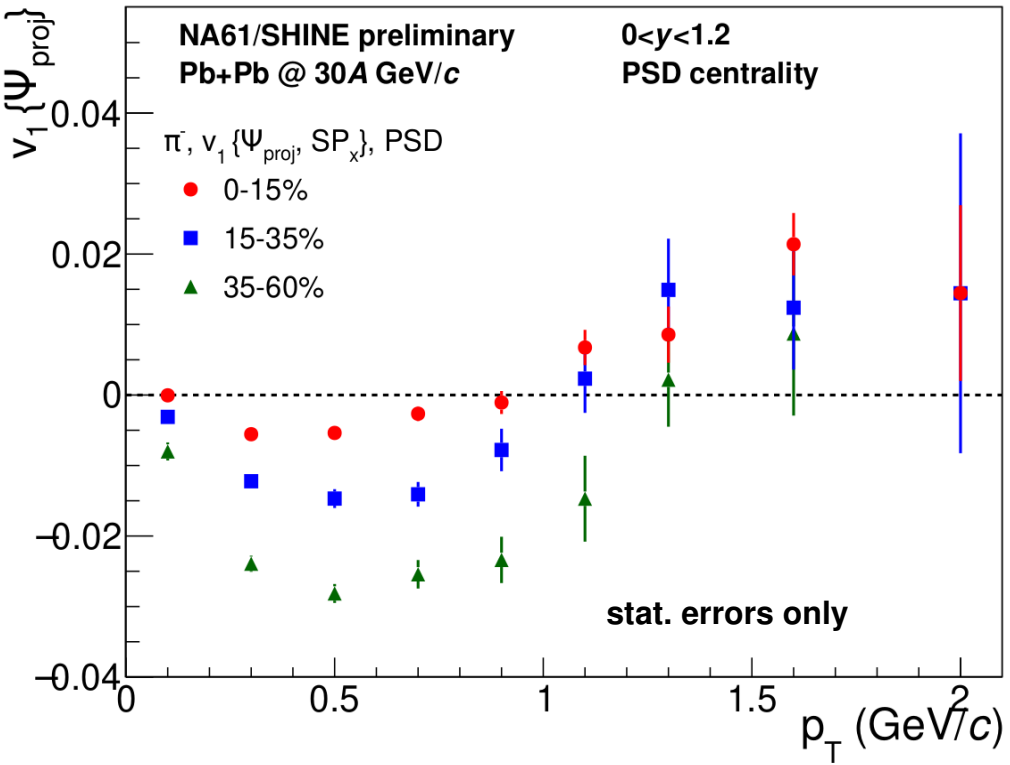
Results are presented for correlations between
charged pions and protons* (in the TPC acceptance) and
all hadrons at forward rapidity (in the PSD/VCAL acceptance)

The results are corrected for detector non-uniformity.
No corrections for secondary interactions and weak decays are done yet.
Only statistical uncertainties are shown.

**hadrons produced by strong interaction processes and their electromagnetic decays*

NA61/SHINE acceptance:
TPC https://edms.cern.ch/document/1549298/1
PSD https://edms.cern.ch/document/1867336/1

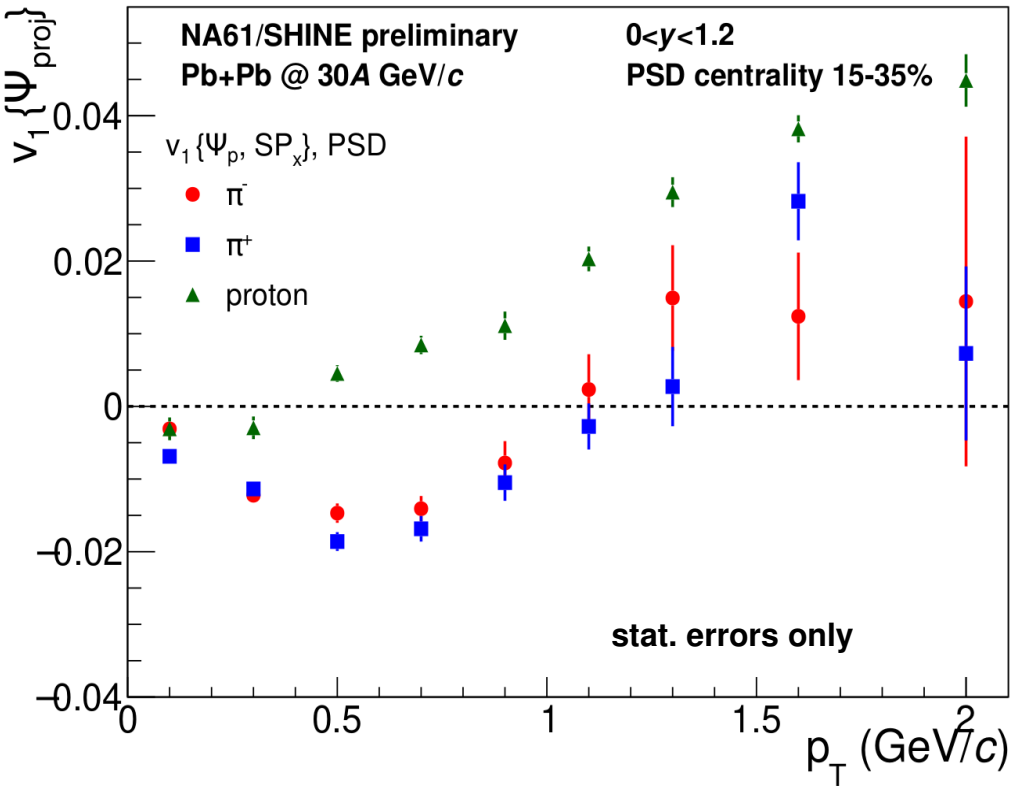
Charged pion v_1 vs transverse momentum



General features:

- Strong centrality dependence of v_1
- $v_1(p_T \sim 0\ \mathrm{GeV}/c) = 0$
- v_1 changes sign at $p_T \sim 1\ \mathrm{GeV}/c$

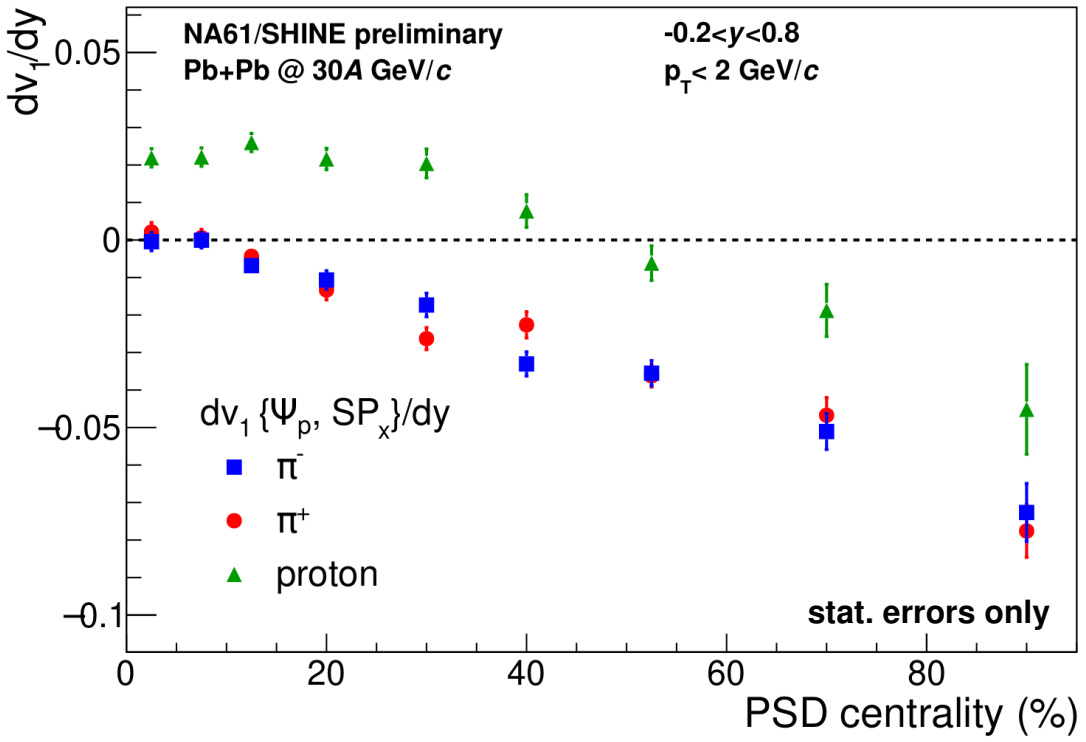
Particle type dependence of v1(pT)



- Significant mass dependence of v_1
- Difference between π^+ and π^- v_1 is sensitive to the electromagnetic effects

@see Mirosław Kiełbowicz presentation
https://indico.ifj.edu.pl/event/199/contributions/1147/

Slope of v_1 at midrapidity vs. centrality



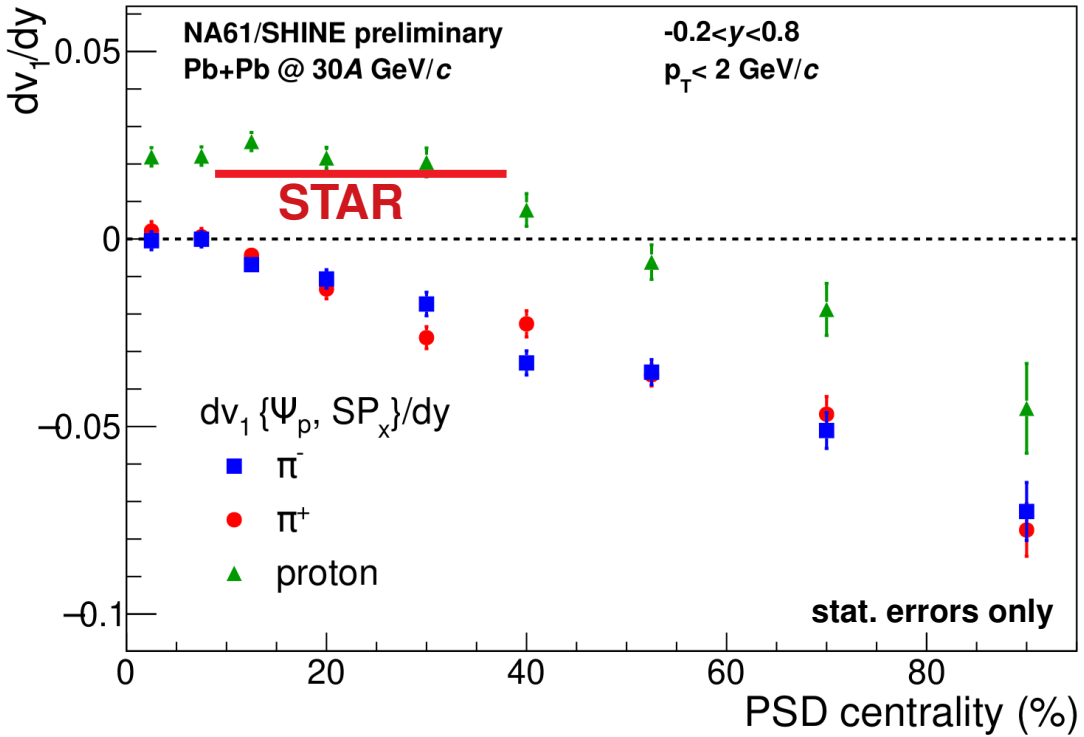
Slope extraction procedure:

- 1st order polynomial fit with 2 parameters (slope and offset):
- offset for π^+/π^- consistent with 0 (all centrality)
- Offset for protons is below 6×10^{-3} for centrality 0-60% and increasing up to 3×10^{-2} for centrality >60%.

Observations:

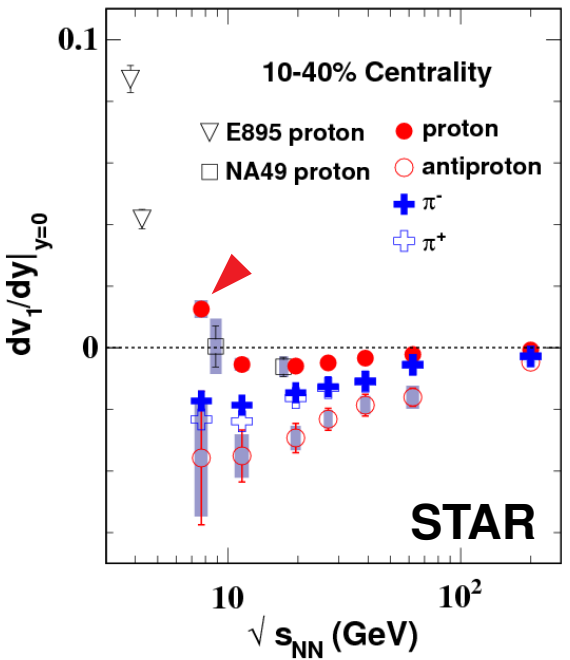
- Slope of proton v_1 changes sign at about 50% centrality
- Slope of pions v_1 is always negative

Slope of v_1 at midrapidity: comparison with STAR



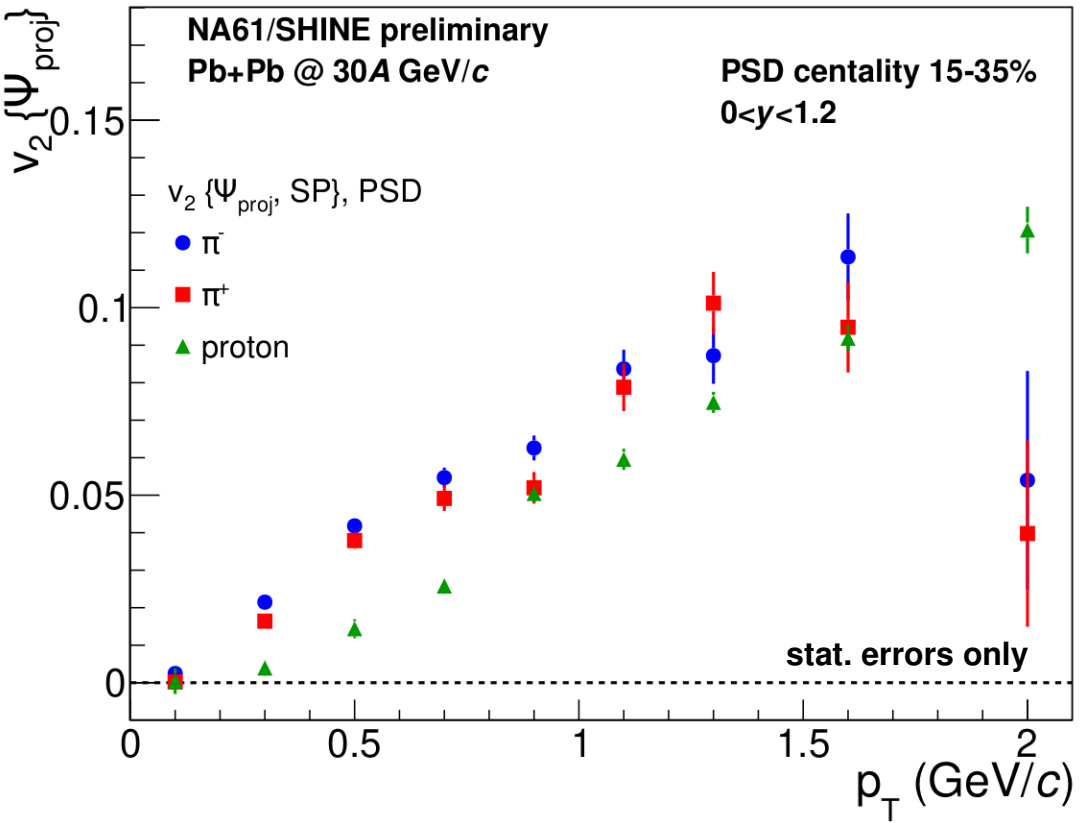
Slope extraction is sensitive to fit function and rapidity range

STAR Collaboration PRL 112 (2014) 162301



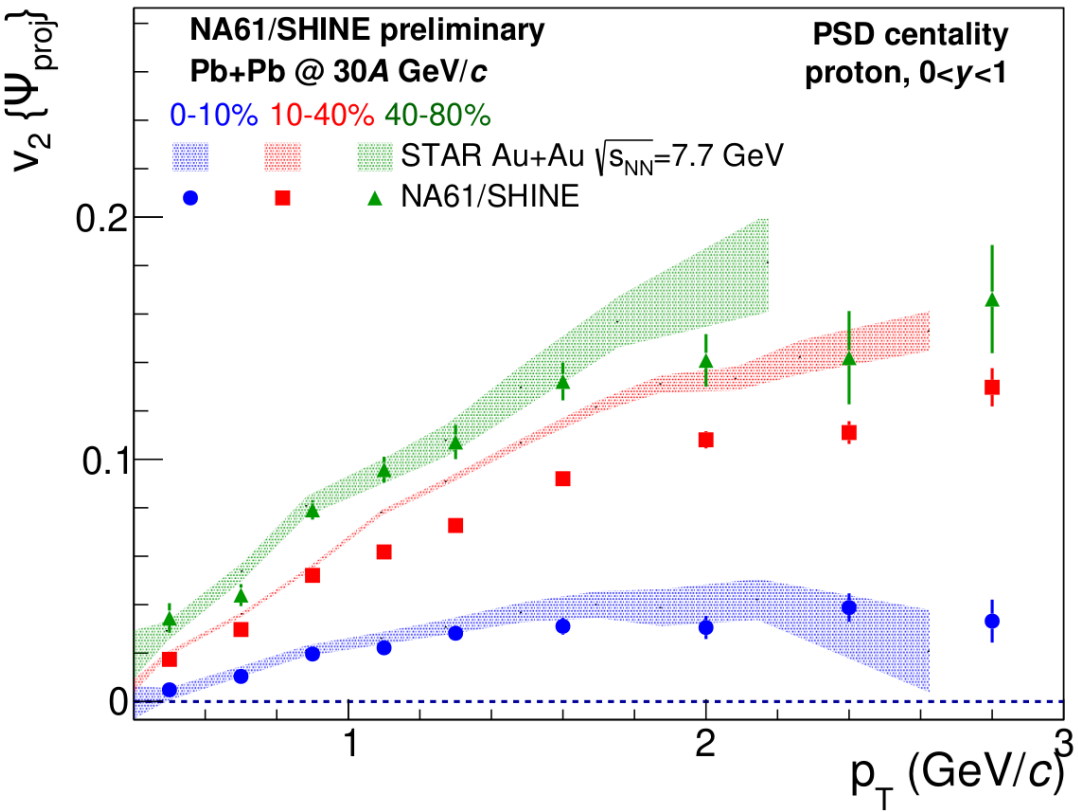
Preliminary results for centrality dependence presented by STAR Collaboration:
NPA 956 (2016) 260

Elliptic flow $v_2(p_T)$: particle type dependence



- Clear mass dependence
- Difference between π^+ and π^- v_2 is small

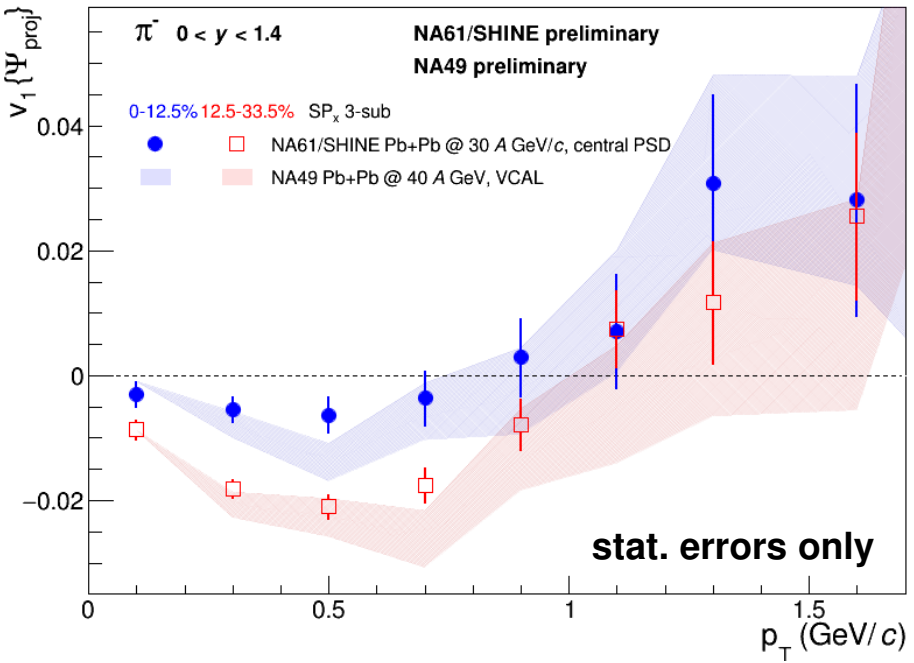
Comparison of proton v_2 with STAR

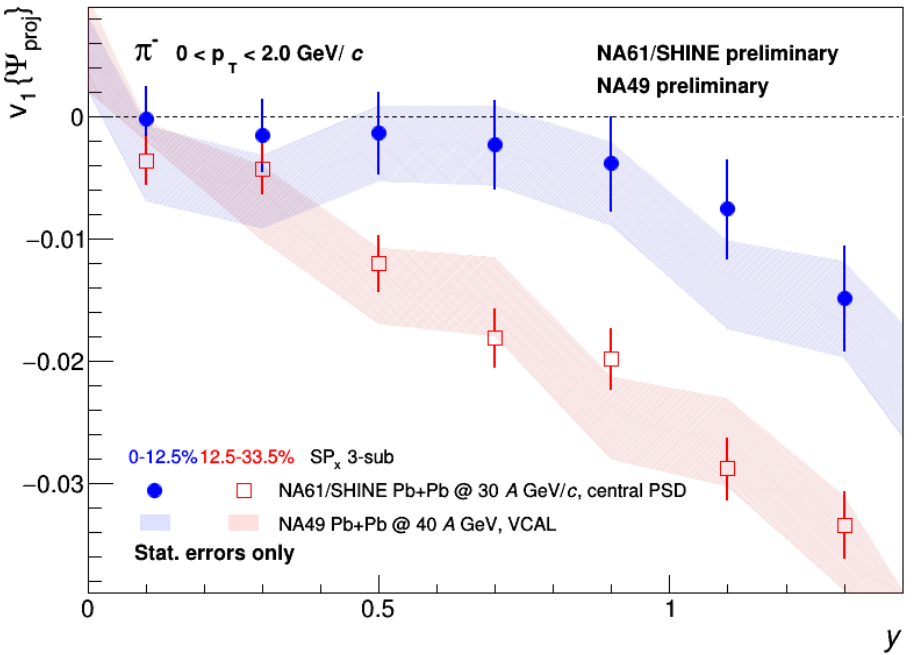


STAR Collaboration PRC 88 (2013) 014902

- Similar results for central and peripheral
- Tension for mid-central collisions could be due to different centrality estimators:
  - Particle multiplicity at midrapidity (STAR)
  - Projectile spectators (NA61/SHINE)

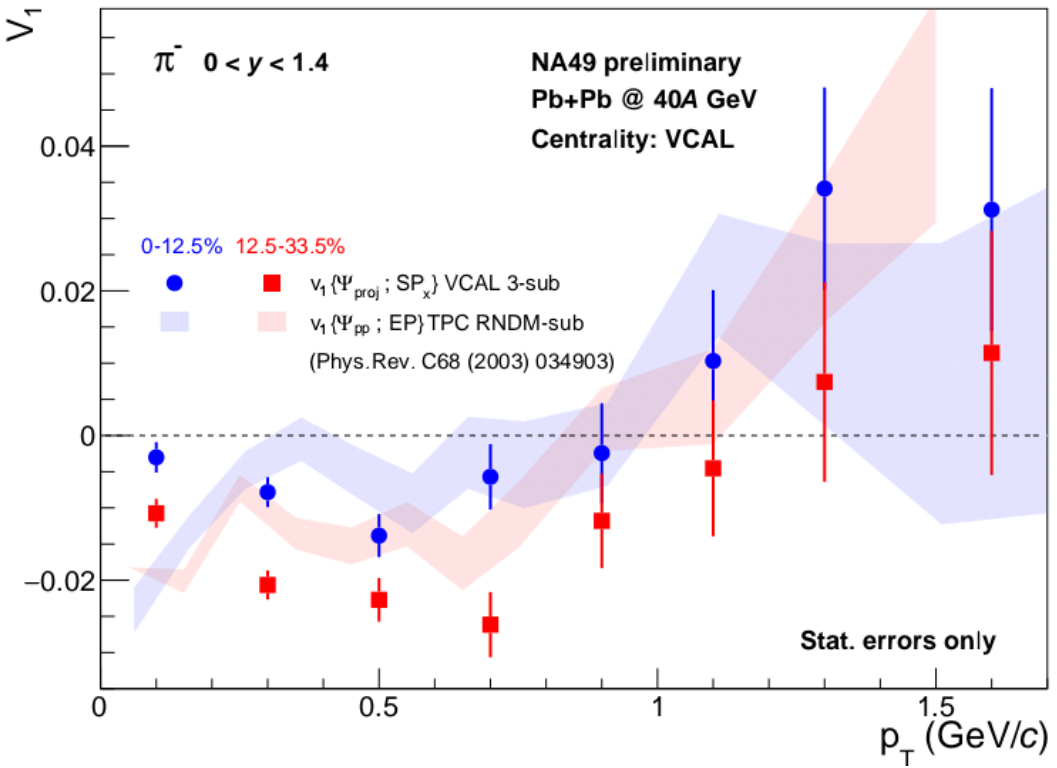
Comparison of negative pion v_1 in NA61/SHINE with NA49





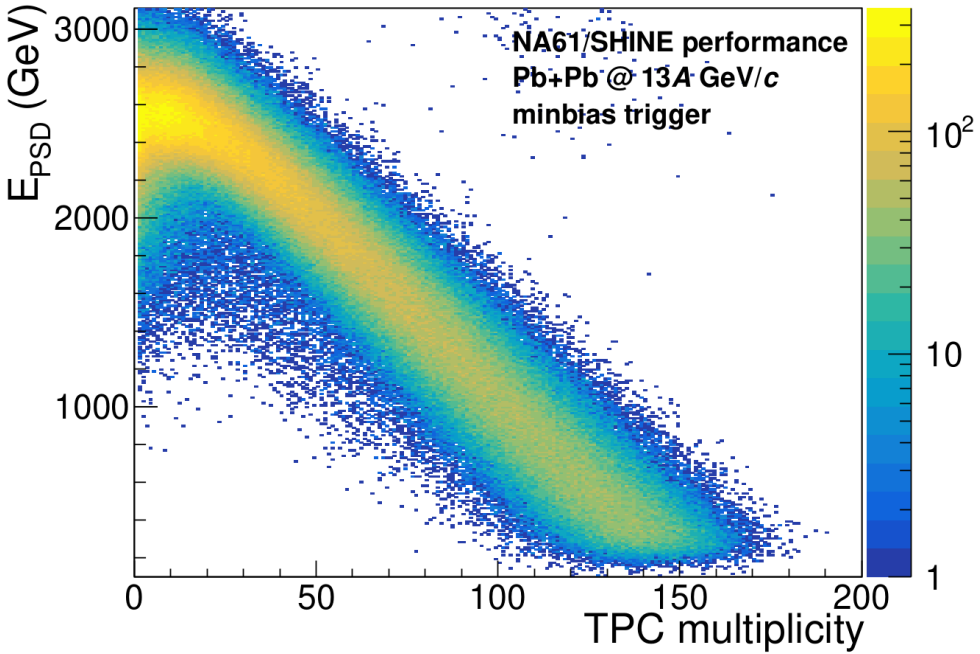
- Similar results to new NA49 analysis of pions relative to the spectator plane

Comparison of $v_1(p_T)$ Pb+Pb@40*A* GeV/c with NA49 published data

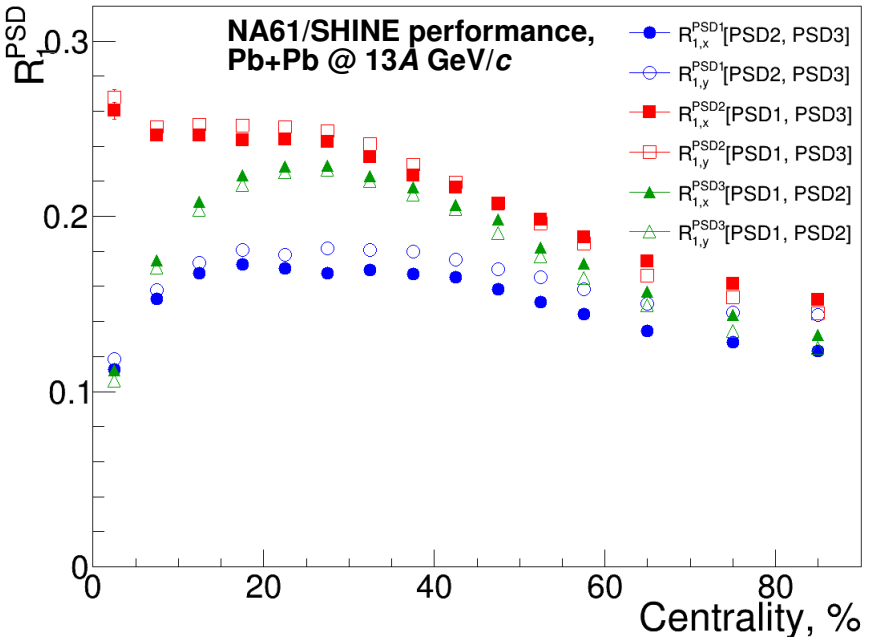


Difference is sensitive to symmetry plane estimator

Outlook for Pb ion beam energy scan: Pb+Pb @ 13*A* GeV/*c*



Scalar product correction factor



- Good performance of the Projectile Spectator Detector at lowest SPS energy
  - very close to the top energy of CBM @ FAIR
    (CBM will have a similar forward calorimeter for centrality and spectator plane determination)

Summary

- Preliminary results for charged pions and protons directed and elliptic flow for Pb+Pb collisions at 30*A* GeV/*c* recorded in 2016 by the NA61/SHINE experiment are presented differentially vs. centrality, rapidity and transverse momentum
- For Pb+Pb collisions at 40*A* GeV/*c* directed flow for charged pions and protons was measured and compared with results published by NA49 collaboration in 2003.
- NA61 results are compared also to the new analysis of the NA49 data using forward calorimeters and to the STAR@RHIC Beam Energy Scan data

Outlook

- Complete systematic analysis of the Pb ion beam energy scan data: 13*A* (2016) and 150*A* GeV/*c* (fall this year 2018)
- Study collective effects in smaller collision systems available from NA61/SHINE system size (Be+Be, Ar+Sc, Xe+La) and beam energy (13A–158*A* GeV/*c*) scan

BACKUP

Backup: Event selection

	Pb-Pb@30*A* GeV/c	Pb-Pb@40A GeV/c (NA49)
Vertex Fit	-0.35 < x < 0.3 -0.37 < y < 0.8 -594 < z < -590 good vertex fit	-0.05 < x < 0.95 -0.50 < y < 0.50 579.5 < z < -578.5 good vertex fit
Beam Position Detector	BPD1 x [-0.4, 0.0] y [-0.6, 0.8] BPD2 x [-0.2, 0.1] y [-0.3, 0.3] BPD3 x [-0.34, 0.22] y [-0.35, 0.05]	
Trigger	Minbias T4, Central T2	Minbias, Central
WFA	Beam: 4000ns Interaction: 25000ns	

Slope of v_1 (STAR Preliminary)

STAR Collaboration NPA 956 (2016) 260