Status report to the proposal SPSC-P-330
Report from the NA61/SHINE experiment at the CERN SPS

Antoni Aduszkiewicz for the NA61/SHINE Collaboration

University of Warsaw (Poland)

Addendum to the the NA61/SHINE Proposal SPSC-P-330
Beam momentum scan with Pb+Pb collisions by NA61/SHINE at the CERN SPS

Ilya Selyuzhenkov

MEPhI (Russia), GSI (Germany)

CERN SPSC, October 20, 2015

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2 **Recorded data**

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   - 3.1 The upgrade and maintenance of the super-conducting magnets
   - 3.2 The Projectile Spectator Detector upgrade
   - 3.3 The extension of the drift velocity monitoring system
   - 3.4 New beam detectors for primary ion beams
   - 3.5 The DRS-based read-out upgrade
   - 3.6 The extension of the TPC tracking system: Forward TPCs

4 **Software and calibration modifications**
   - 4.1 The "legacy" software maintenance
   - 4.2 The NA61/SHINE offline software development
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   - 4.4 The calibration upgrade
   - 4.5 NA61/SHINE IT infrastructure

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   - 5.1 New results for strong interaction physics
   - 5.2 New results for neutrino physics
   - 5.3 New results for cosmic-ray physics

6 **Data-taking plan: 2016–2018**

7 **Proposals to extend the NA61/SHINE physics programme**

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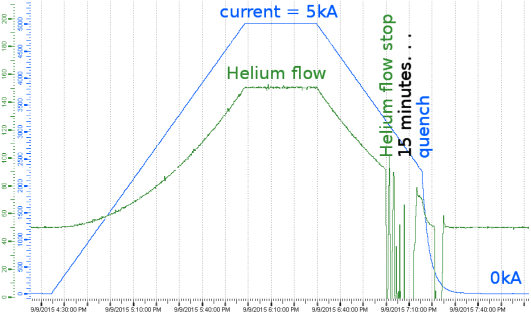
The super-conducting magnets: VERTEX-1 and VERTEX-2

Operation of the magnets has vital importance for the programme of NA61/SHINE
During the last year both magnets failed several times mostly due to failures of the cryogenic system:

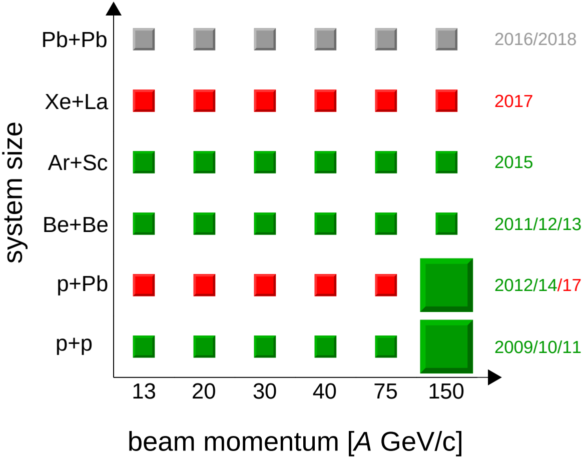
- VERTEX-2 failed on March 19, during the argon beam period. The second 150A GeV/c beam period was cancelled and the 40A and 75A GeV/c periods were prolonged
- VERTEX-1 failed first on September 9 (first day of the proton beam period). Investigation was carried out by A.Dudarev (PH-ADO). It was concluded:
  - A resistive transition (quench) occurred
  - There is a constant excessive resistance between a current lead and the coil
  - The incident was caused by an instability of the helium flow control
  - For future operation, an improved magnet protection system is strongly recommended



VERTEX-1 incident aftermath

- We appreciate fast reaction from PH (PH-ADO, PH-DT) after the incident
- The damage and the possibility for a repair will be assessed at the end of 2015
- We expect CERN to repair and maintain the magnets and the associated infrastructure, as it was agreed in Memorandum of Understanding

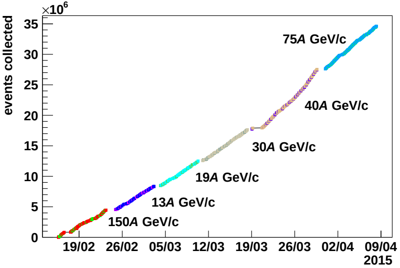
Status of the NA61/SHINE 2D scan



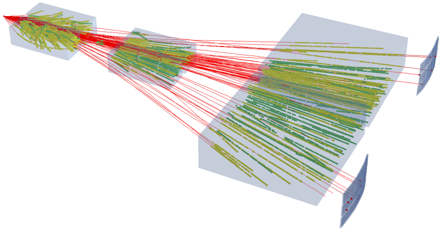
- Green: Data collected within the NA61/SHINE strong interaction programme
- Red: Approved data-taking programme
- Gray: Reactions requested in the Addendum
- Small box $\approx 2 \cdot 10^6$ events. Large box $\approx 5 \cdot 10^7$ events

Successful data taking with the first argon beam at CERN

- First argon beam at CERN, and the first NA61/SHINE data taking with primary ion beams was an important success
- In February–April 2015 NA61/SHINE completed the energy scan with Ar+Sc collisions at 13*A*, 19*A*, 30*A*, 40*A*, 75*A* and 150*A* GeV/*c*
- Ar+Sc collisions seem to be the most promising in the search for critical point



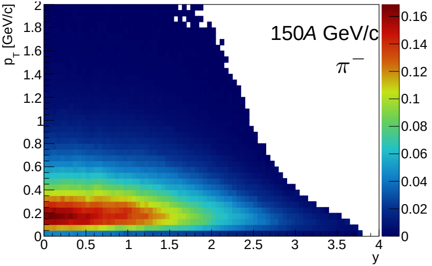
Ar+Sc collision at 150*A* GeV/*c* in the NA61/SHINE detector

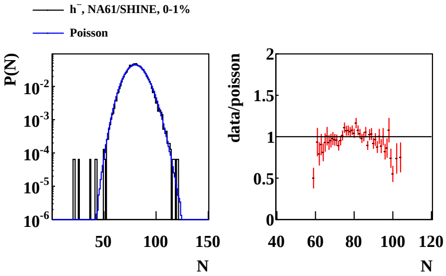


First preliminary results from the analyses of ^{40}Ar+^{45}Sc collisions

Hardware upgrades and well operating software allowed for fast calibration and analysis of the data:

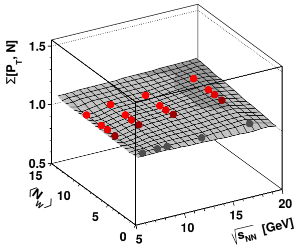
- Double-differential π^- spectra in central Ar+Sc collisions at 40*A* and 150*A* GeV/*c*
- Distributions of multiplicity of the negatively charged hadrons at 150*A* GeV/*c* as a first step of the multiplicity fluctuation analysis. Width of the multiplicity distribution is smaller than that of the Poissonian distribution. **No indication for the critical point**



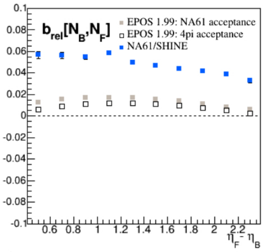


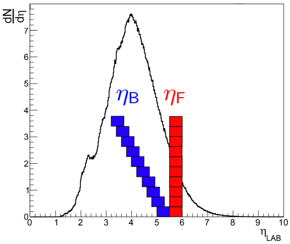
Progress in search for the critical point of strongly interacting matter

- Multiplicity and transverse momentum fluctuations in Be+Be and p+p collisions at 20*A*–158*A* GeV/*c*.
  No evidence for critical point.
  Results from Ar+Sc coming soon.
  NA49 sees indications of increased fluctuations in Si+Si
- Pseudo-rapidity correlations of multiplicity in Be+Be collisions at 150*A* GeV/*c*, at various η ranges are not described by string fragmentation models



p+p: paper submitted to EPJ C
arXiv:1510.00163 [hep-ex]

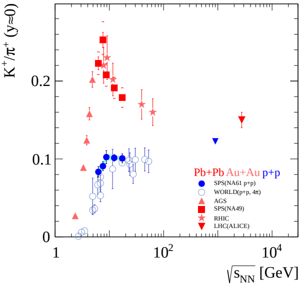




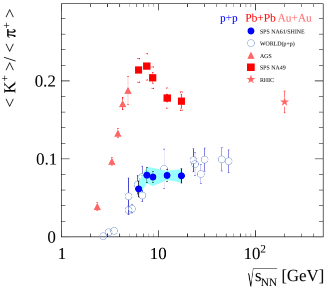
Progress in study of onset of deconfinement

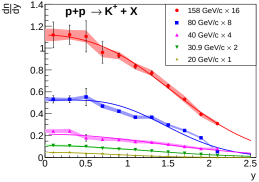
- Mean multiplicities of $\pi^{\pm}$, $K^{\pm}$ and $\bar{p}$ in p+p interactions at 20–158 GeV/c in 4π phase-space. Horn in p+p interactions?
- Paper draft in work

2014: $y = 0$



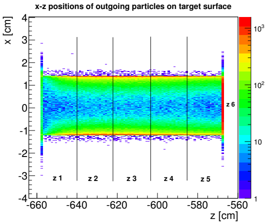
2015: 4π

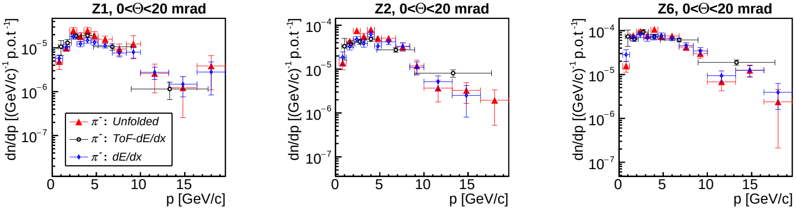




New results for neutrino physics

- Final, close to publication data on p+(T2K replica) interactions at 31 GeV/c, the high statistics measurement for T2K
  Ph.D. Thesis of A.Häsler, University of Geneva,
  paper in preparation
- π^- (p, θ) spectra derived using three analysis methods are in agreement



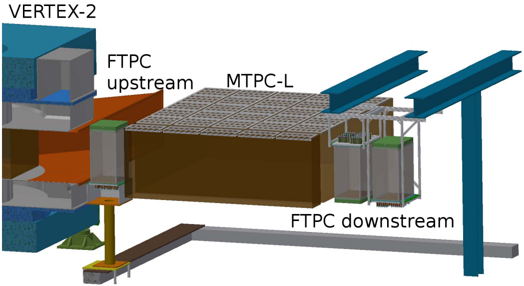


- Paper on high statistics p+C interactions at 31 GeV/c submitted to EPJ C, arXiv:1510.02703 [hep-ex]

Status of the measurements for Fermilab ν beams

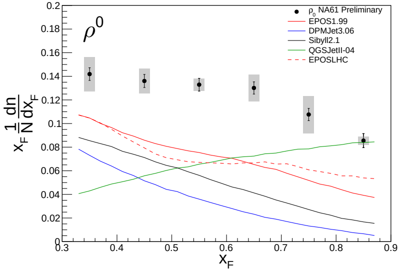
- In 2015 four US groups joined NA61/SHINE:
  - Fermilab
  - Los Alamos National Laboratory
  - University of Colorado
  - University of Pittsburgh
- The data taking this year was cancelled due to VERTEX-1 failure
- The program requires detector upgrade: addition of new Forward-TPCs extending the acceptance in the forward region
- Project of University of Colorado, with collaboration from Wigner Research Centre for Physics of the Hungarian Academy of Sciences. To be completed mid-summer 2016

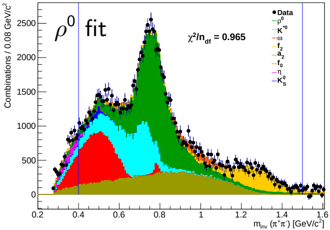
beam →

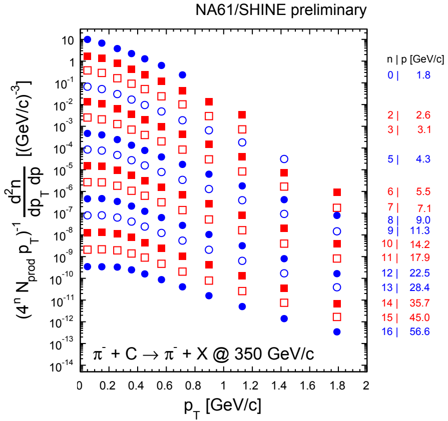


New preliminary results for cosmic ray physics

- x_F spectra of ρ^0 in $\pi^- + C$ interactions at 158 GeV/c, which are essential to model air showers. **Models fail to reproduce the data**
- Double-differential spectra of $\pi^\pm$ in $\pi^- + C$ interactions at 158 and 350 GeV/c







PoS (ICRC2015) 330,
arXiv:1509.06586 [nucl-ex]

Future of NA61/SHINE after 2020

NA61/SHINE plans to continue data taking on hadron-proton, hadron-nucleus and nucleus-nucleus collisions at the CERN SPS after the Long Shutdown 2.
In particular. . .

- Precise measurements of open charm and multi-strange hyperon production with the Large Acceptance Vertex Detector and possibly increased data taking rate
  $\Rightarrow$ LAVD and upgrade of the NA61/SHINE read-out electronics and DAQ required
- Precise measurements of hadron production cross sections needed for cosmic ray studies, in particular for the AMS experiment
  $\Rightarrow$ new electro-magnetic calorimeter required
- Precise measurements of hadron emission from replica targets of the neutrino beam facilities at Fermilab and J-PARC
  $\Rightarrow$ high precision tracking detector located close to the replica targets required

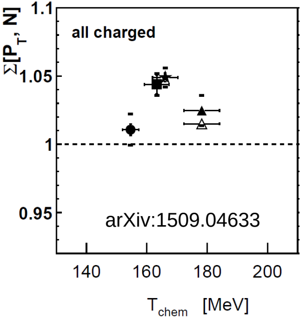
Data taking request for 2016–2018

Beam Primary	Beam Secondary	Target	Momentum (A GeV/c)	Year	Days	Physics
p			400			
	h^+	A	40–400	2016	4×7	installation/tests
p			400			
	p	p	400	2016	28	strong interactions
p			400			
	h^+	A	30–120	2016	42	ν
Pb		*Pb*	*13, 19, 30, 40*	*2016*	*40*	*strong interactions*
Pb		*Pb*	*150*	*2016*	*5*	*installation/tests*
p			400			
	p	p/Pb	13, 19, 30, 40, 75	2017	35	strong interactions
p			400			
	h^+	A	30–120	2017	42	ν
Xe		La	13, 19, 30, 40, 75, 150	2017	60	strong interactions
p			400			
	p	p/Pb	13, 19, 30, 40, 75	2018	35	strong interactions
p			400			
	h^+	A	30–120	2018	42	ν
Pb		*Pb*	*75, 150*	*2018*	*40*	*strong interactions*

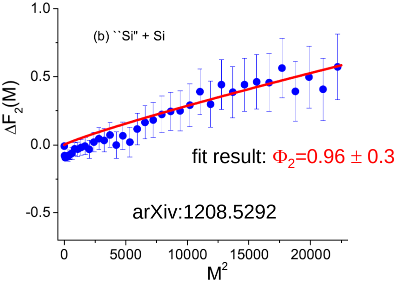
Status and plans of NA49 (SPSC-M-787)

- Pb+Pb reference for NA61; study of new methods and observables
- 2 papers submitted for publication since 10/2014, more in preparation

new strongly intensive measure $\Sigma[P_T,N]$ confirms previous NA49 results on p_T fluctuations



intermittency of proton production as predicted for critical point ($\Phi_2 = 5/6$)



Maximum of p_T fluctuations and intermittency of proton production in Si+Si collisions. Hint of critical point ? → new data of NA61 are crucial

Status Report: summary

- VERTEX-1 magnet was damaged at the beginning of the proton 400 GeV/c beam time. We expect CERN to repair and maintain the magnets and the associated infrastructure
- Data taking with the argon beam at CERN was successful. Required statistics of central Ar+Sc collisions was collected at all six beam momenta: 13A, 20A, 30A, 40A, 75A and 150A GeV/c
- Many new results concerning search of critical point and study of the onset of deconfinement in Ar+Sc, Be+Be and p+p collisions, spectra and cross-sections from analyses for the neutrino and cosmic-ray programmes are presented

We would like to thank the CERN PH, BE and EN Departments
for the strong support of NA61/SHINE

A new beam momentum scan with Pb+Pb collisions

Addendum to the the NA61/SHINE Proposal SPSC-P-330
http://cds.cern.ch/record/2059811

Ilya Selyuzhenkov

MEPhI, Moscow

EMMI/GSI, Darmstadt

on behalf of the NA61/SHINE Collaboration

119th Meeting of the SPSC at CERN

October 20, 2015

Why requesting a new beam momentum scan with Pb+Pb collisions?

- Collective effects due to strong and electromagnetic interactions

  → Extend world data at energies of CERN SPS and RHIC BES

- Event-by-event fluctuation measurements

  → profit from NA61/SHINE upgrades:

  extended acceptance, detection of projectile spectators

- First open charm production measurement at the SPS energies

  → Requires construction of a high-precision vertex detector

Collective effects due to strong and electromagnetic interactions

- Reference data for the NA61/SHINE beam momentum and system size scan

  → Disappearance of collectivity in small systems?

- Access mid- and forward rapidities with fixed target set-up

  → extend world data available from NA49 and RHIC BES

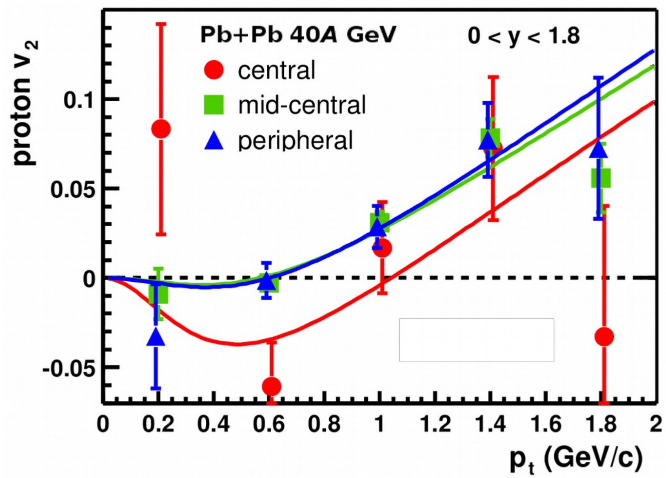
  → using spectators for flow studies

- Charge dependence of particle yields and flow

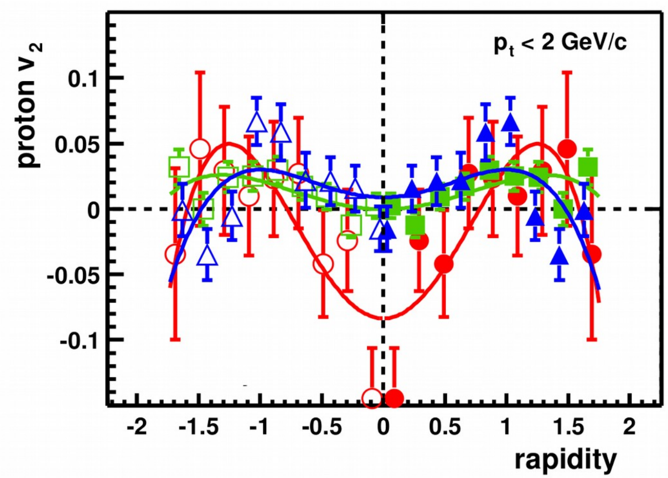
  → study effects induced by strong electric and magnetic fields

Existing flow results from NA49 for Pb+Pb collisions

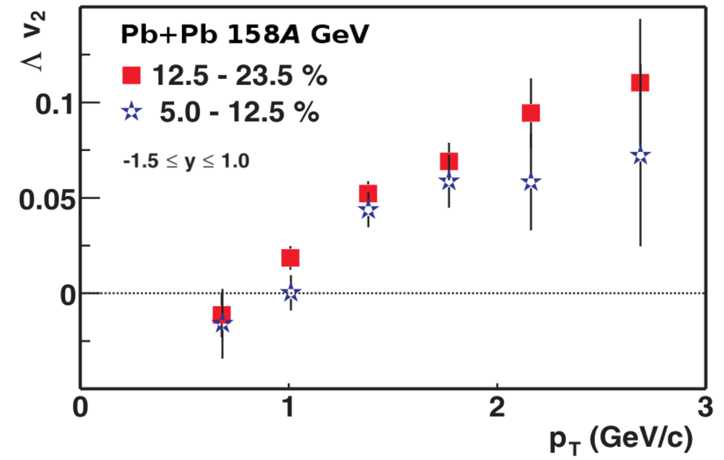
proton v_2 (p_T) E_{beam}= 40*A* GeV



proton v_2(y) E_{beam}= 40*A* GeV



Λ v_2(p_T) E_{beam} = 158*A* GeV



NA49 data:

p, π: PRC68 034903 (2003)

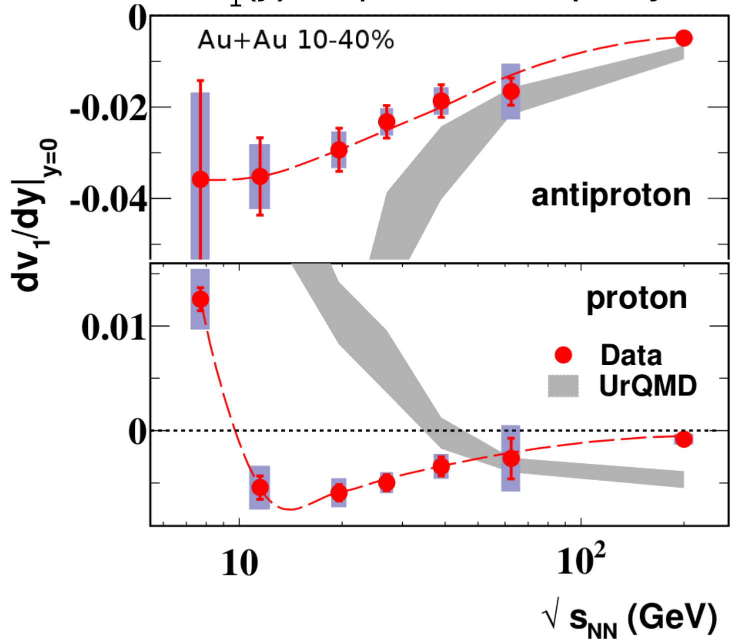
Λ: PRC75 044901 (2007)

NA49 data is only available at E_{beam} = 40*A* and 160*A* GeV

need other energies and more statistics for differential studies

Energy and rapidity dependence of flow harmonics: v_1

$v_1(y)$ slope at midrapidity



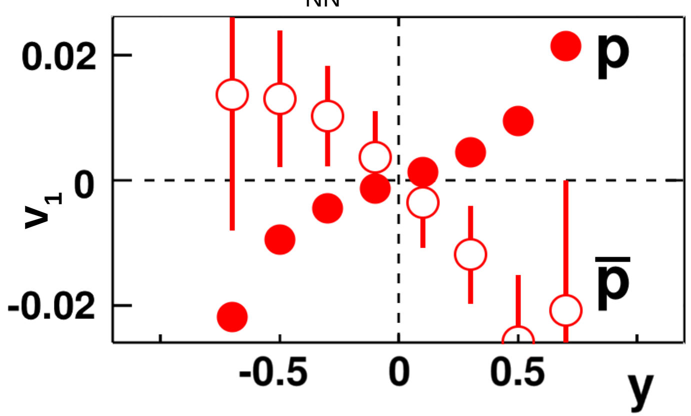
(anti-)proton v_1 from STAR at RHIC BES

PRL112 162301 (2014)

Sign change of v_1 slope at midrapidity predicted as a signal of the 1st order phase transition

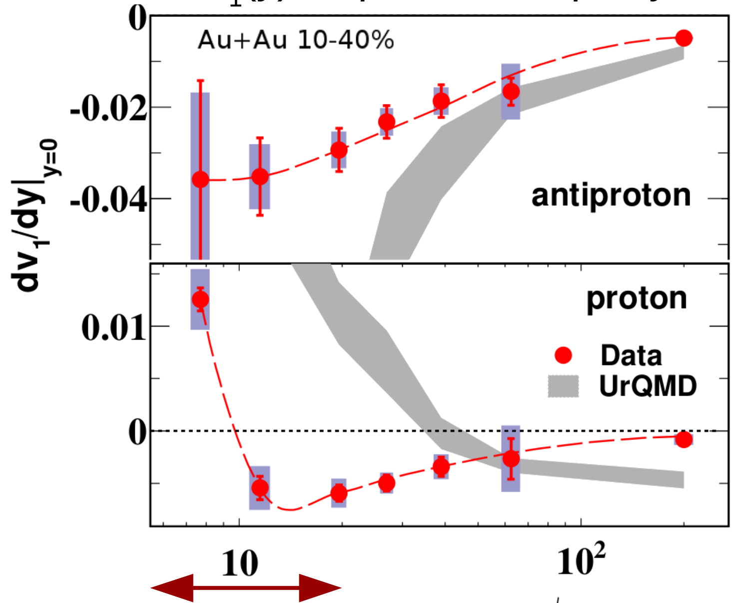
Models:
Steinheimer PRC89 054913 (2014) & references therein

Au+Au $\sqrt{s_{NN}}$ = 7.7GeV 10-40%



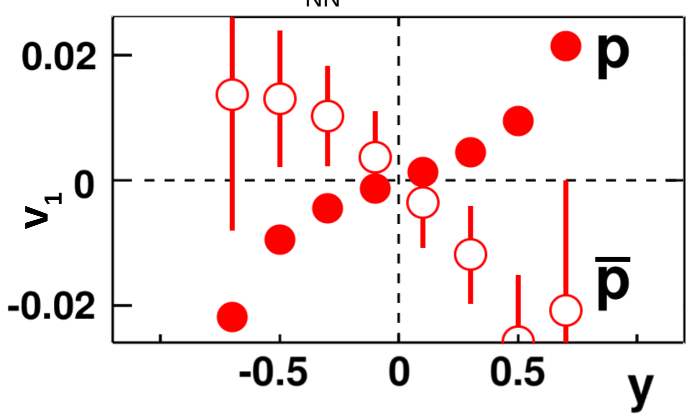
Energy and rapidity dependence of flow harmonics: v_1

$v_1(y)$ slope at midrapidity



NA61/SHINE

Au+Au $\sqrt{s_{NN}}$ = 7.7GeV 10-40%



NA61/SHINE acceptance at
p_{beam}=30A GeV/c: 0< y <1.8

With NA61/SHINE:

→ extend towards forward rapidities

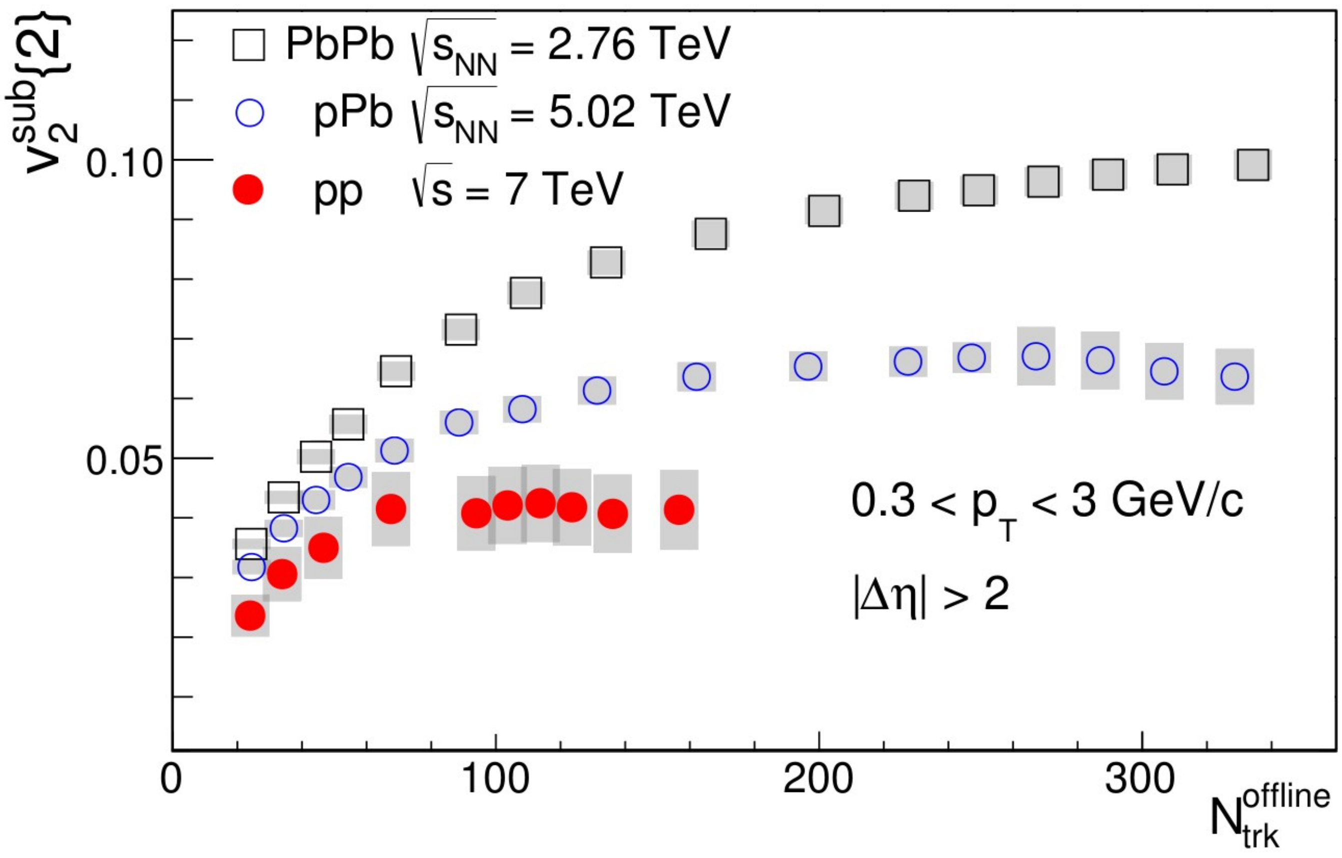
→ go down to p_{beam} = 13A GeV/c below RHIC collider mode

→ use spectators for reaction plane (not possible in STAR BES) (non-flow, geometrical vs. fluctuations)

→ higher flow harmonics

Collectivity in small systems: need for heavy-ion references

CMS Preliminary QM2015 (CMS-HIN-15-009)

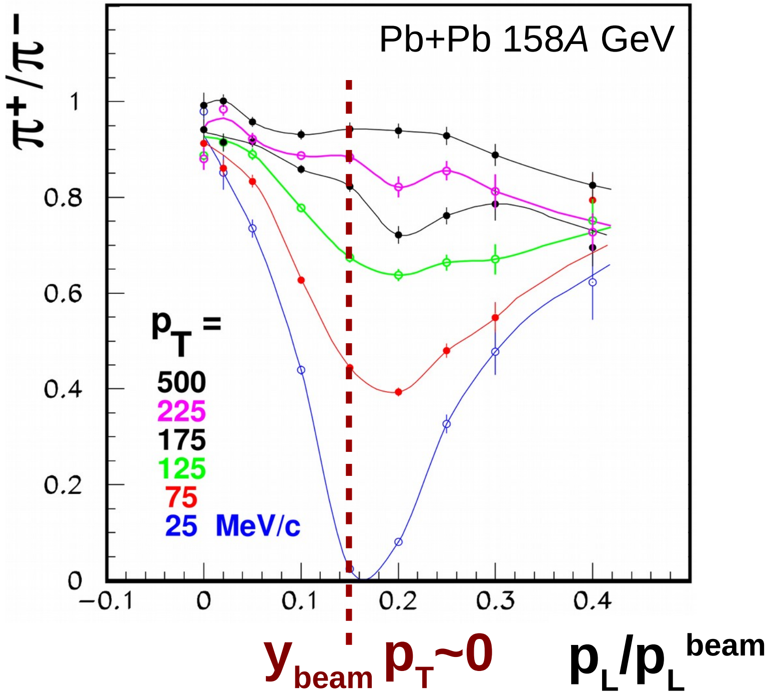


- Collectivity in small systems is a hot topic at RHIC & LHC
- Requires minbias/peripheral collisions for Pb+Pb

Probing electromagnetic effects with charged pions

charged pions yield ratio

NA49 Preliminary, Rybicki APP B42 867 (2011)



Charge dependence of pion spectra and v_1 may originate from:

- electromagnetic interaction between produced matter and spectators

  Rybicki, Szczurek PRC87 054909 (2013), Rybicki, Szczurek, Kłusek-Gawenda APP B46 737 (2015)

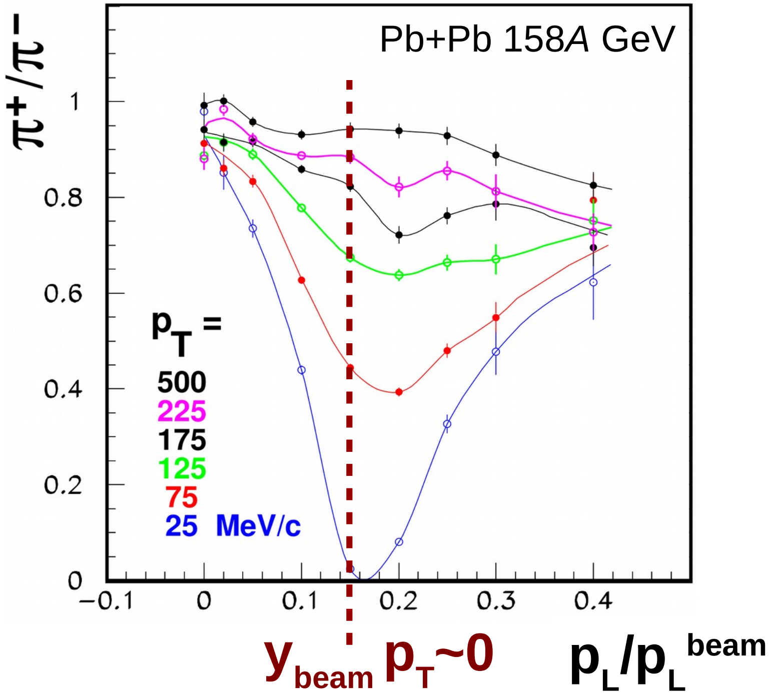
- strong magnetic field generated by moving charges induces charge currents inside produced matter

  Gursoy, Kharzeev, Rajagopal PRC89 054905 (2014)

Probing electromagnetic effects with charged pions

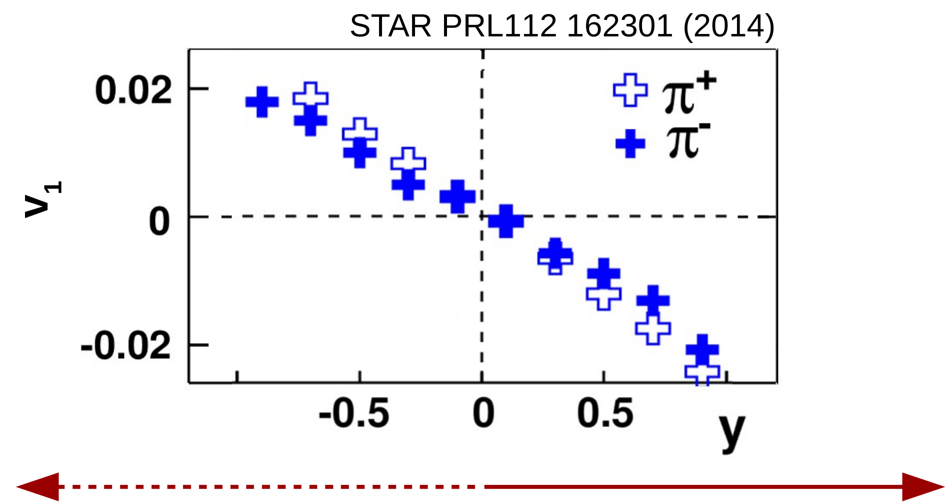
charged pions yield ratio

NA49 Preliminary, Rybicki APP B42 867 (2011)



charged pion v_1 vs. rapidity

Au+Au $\sqrt{s_{NN}}$ = 7.7 GeV 10-40%



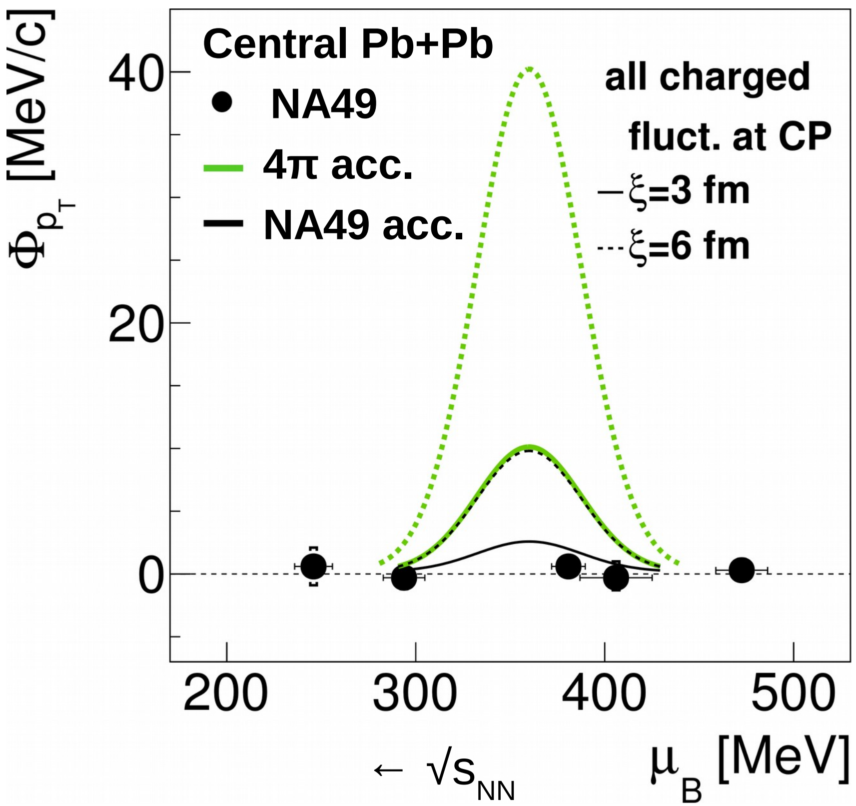
NA61/SHINE acceptance at p_{beam}=30*A* GeV/c: 0< y <1.8

Experimental information is limited at SPS and RHIC BES energies:

→ Effects are stronger at low energies and toward beam (forward) rapidites
→ NA61/SHINE setup is well suited to probe such effects

Event-by-event fluctuations and search for critical point

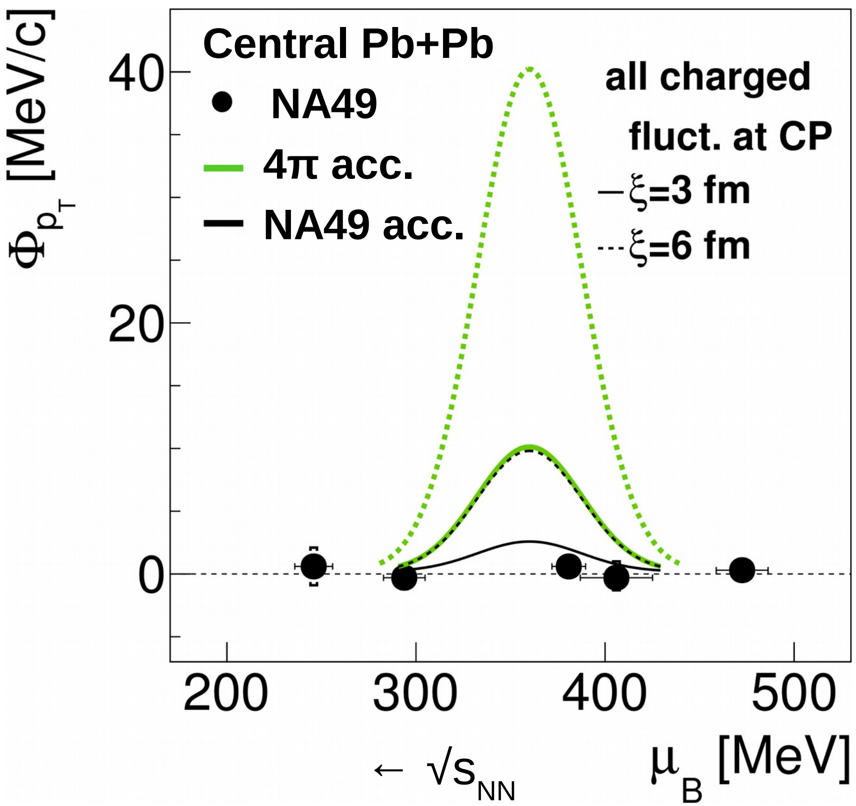
effect of acceptance cuts: model



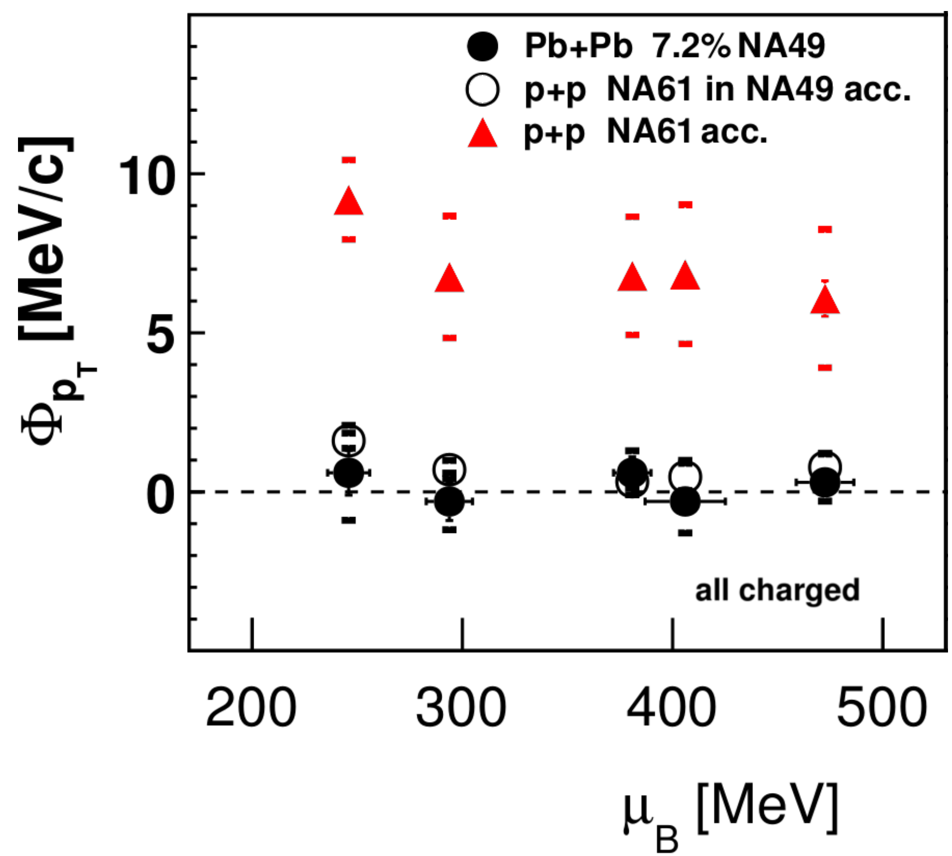
Reduced acceptance leads to loss of sensitivity

Event-by-event fluctuations and search for critical point

effect of acceptance cuts: model



effect of acceptance: pp data

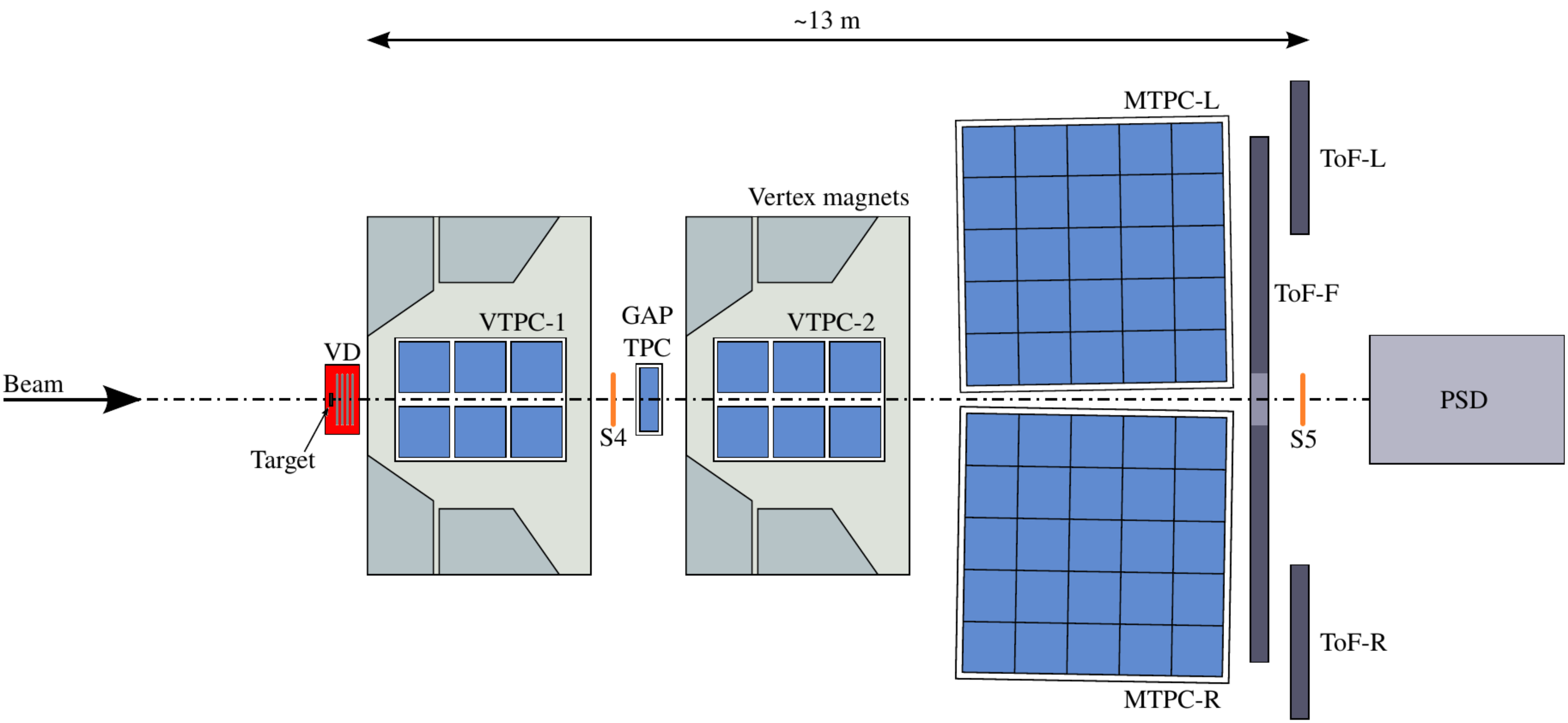


Profit from NA61/SHINE upgrades which improved experimental sensitivity to fluctuation measurements:

- Mid-rapidity coverage larger than for NA49
- Independent centrality estimation with projectile spectators

Open charm production measurements at SPS

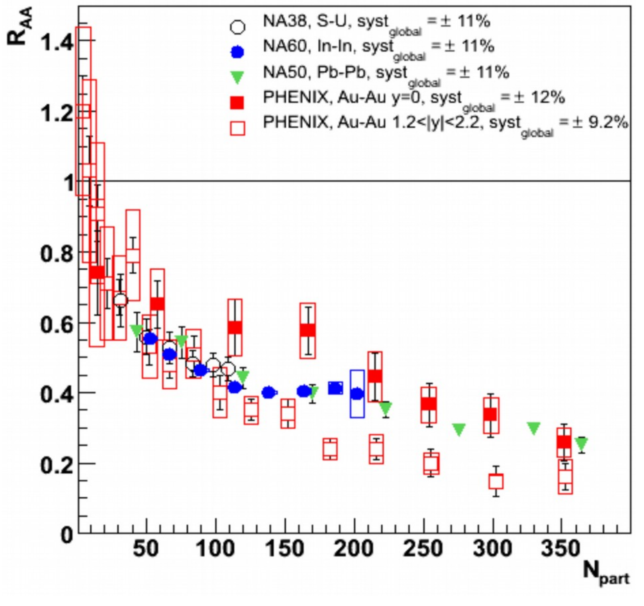
- First measurement of D^0 and $\overline{D}^0$ mesons in Pb+Pb collisions at SPS energies
- Require upgrade of NA61/SHINE with vertex detector to reconstruct displaced vertices of charm meson decays with a resolution of 7 (70) μm in the transverse (longitudinal) direction



Competing descriptions of charm production in hadron & nuclei collisions

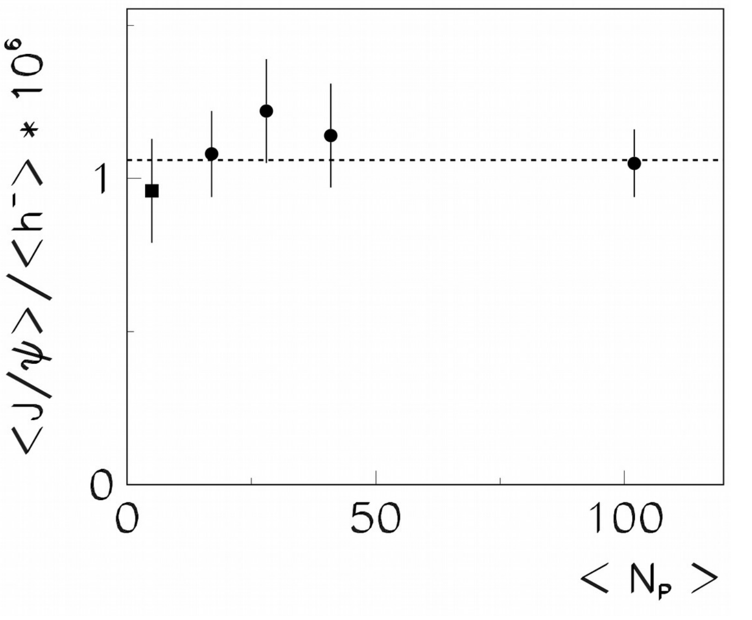
J/Psi scaling with # of collisions

Brambilla et al. EPJ C71 1534 (2011)



J/Psi scaling with # of wounded nucleons

Gazdzicki, Gorenstein PRL83 4009 (1999)

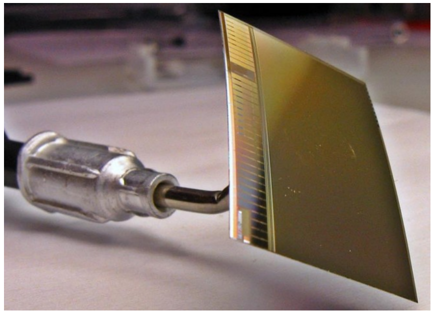


- Perturbative QCD:
  Charm quarks created at early stage & number remains mainly unchanged
  Charmonia are created via attractive interaction of $c\bar{c}$ pairs ($\sim N_{coll}$)
  production rate depends on $c\bar{c}$-state and space-time evolution of the matter
- Statistical production at the hadronization stage:
  J/ψ yield proportional to pion multiplicity $\sim N_{WN}$ (observed for Pb+Pb collisions at SPS)
- Expected system size dependence in these two approaches is different:
  → no direct measurements of open charm production exist at SPS
  → NA61/SHINE measurement will help to discriminate these mechanisms

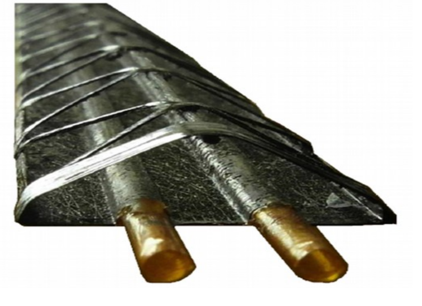
Small Acceptance Vertex Detector (SAVD)

Start the program with small acceptance detector

4 stations @ 5, 10, 15, and 20 cm
Each station: < 0.4% X_0
Placed inside helium box
Sensitive area: 32 cm²



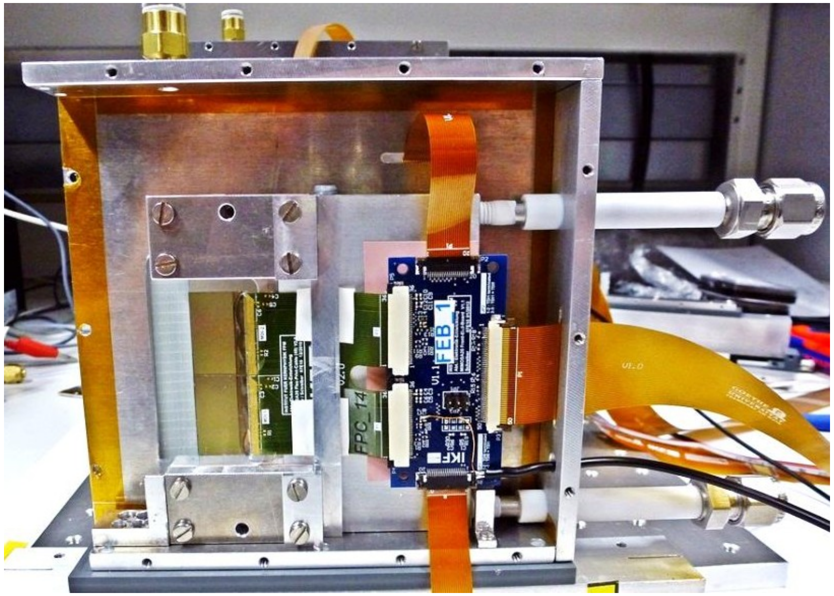
16 sensors:
MIMOSA-26AHR
1152x576 pixels of 18.4 x 18.4 µm²
3.5 µm resolution, 0.05% X_0
Readout time: 115.2 µs



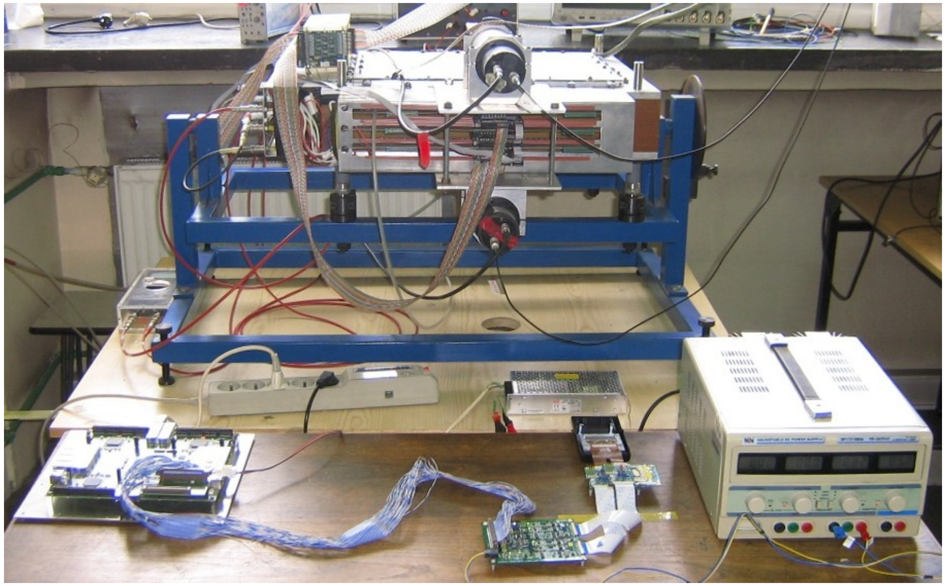
Ladders:
ALICE ITS (upgrade)
Liquid cooled
Material budget (all included): < 0.3% X_0

SAVD components integration

Sensor integration and operation
(Frankfurt)



DAQ / Slow control
(Krakow)



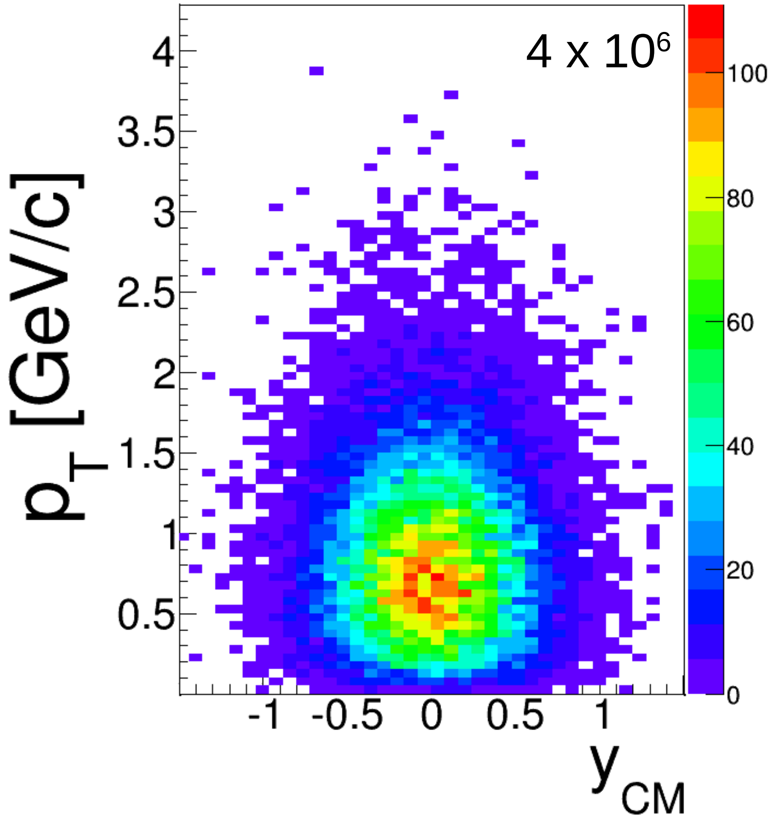
Prototype of CBM Micro Vertex Detector with 12 MINOSA sensors and DAQ system was successful tested at the CERN SPS

Based on GSI/HADES TRB3 standard
Being adapted to NA61

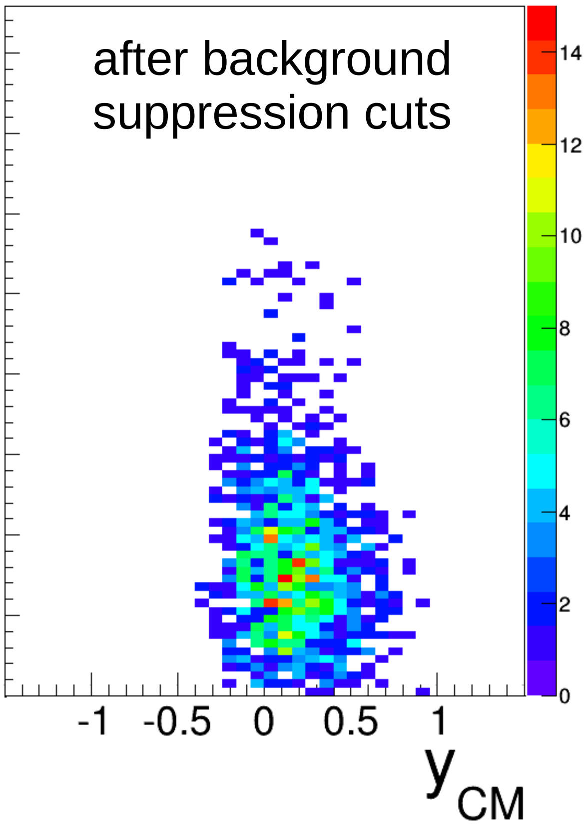
D-meson reconstruction in central Pb+Pb collisions at 150*A* GeV/*c*

$D^0/\bar{D}^0 \rightarrow K + \pi$: 0.0078/event (AMPT scaled up to HSD)

All



Reconstructed



1500 D^0+$\bar{D}^0$ in ~10 days

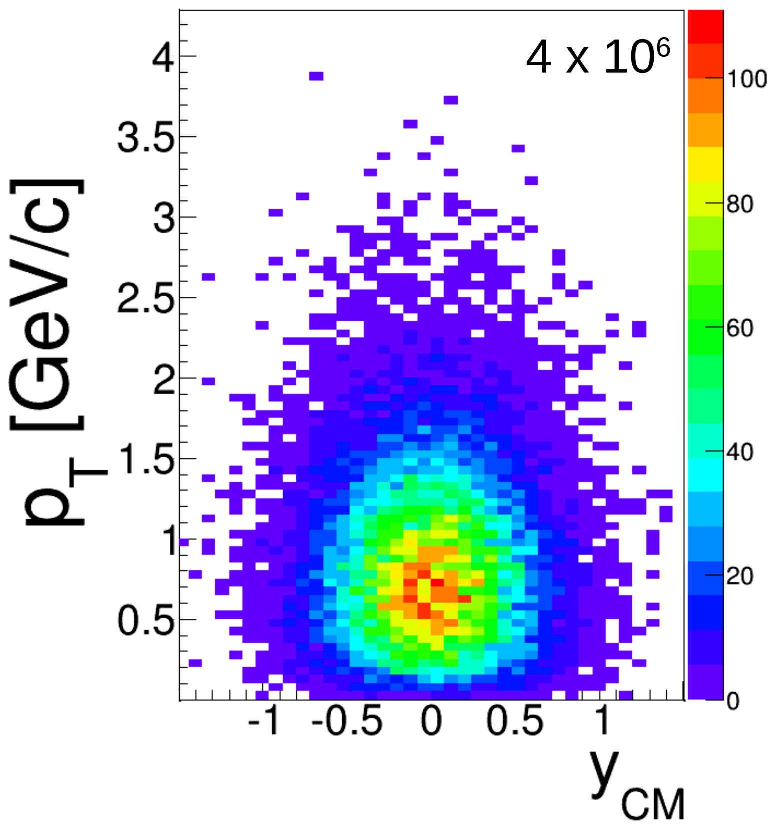
4% reconstruction efficiency with SAVD for NA61/SHINE fixed target setup (vs. 0.01% of ALICE at the LHC)

D-meson reconstruction in central Pb+Pb collisions at 150A GeV/c

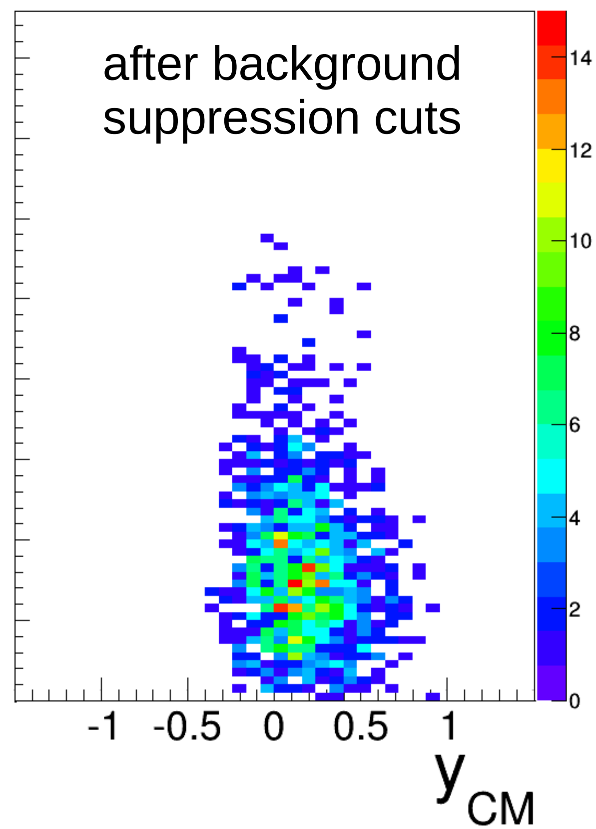
$D^0/\overline{D}^0 \rightarrow K + \pi$: 0.0078/event (AMPT scaled up to HSD)

Background: AMPT

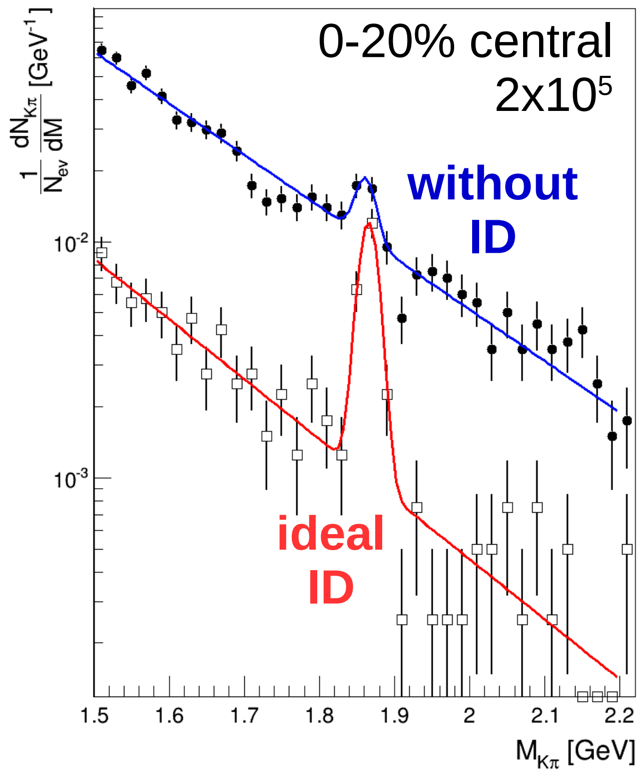
All



Reconstructed



K & π identification (ID)



1500 D^0+$\overline{D}^0$ in ~10 days

4% reconstruction efficiency with SAVD for NA61/SHINE fixed target setup (vs. 0.01% of ALICE at the LHC)

In preparation:

realistic D-meson daughters identification

Summary

The request of the NA61/SHINE to perform a new beam momentum scan with Pb+Pb collisions will allow:

- significantly extend previous studies of collective effects due to strong and electromagnetic interactions
- improve measurements of event-by-event fluctuations
- perform the first measurements of open charm production in Pb+Pb collisions at the SPS energies:
  → an upgrade by a high-precision vertex detector is required

Request

Pb+Pb beam momentum scan at the end of fixed target periods in 2016 & 2018

2016 40 days physics: p_{beam}=13*A*, 19*A*, 30*A*, 40*A* GeV/*c*

5 days test run with vertex detector: p_{beam}=150*A* GeV/*c*

2018 40 days physics: p_{beam}=75*A*, 150*A* GeV/*c*

Complete document at: http://cds.cern.ch/record/2059811

EUROPEAN LABORATORY FOR PARTICLE PHYSICS

Addendum to the the NA61/SHINE Proposal SPSC-P-330

Beam momentum scan with Pb+Pb collisions by NA61/SHINE at the CERN SPS

By the NA61/SHINE Collaboration
http://na61.web.cern.ch/

Abstract

This document presents the request of the NA61/SHINE Collaboration at the CERN SPS to perform a new beam momentum scan with Pb+Pb collisions. The new data are needed to

(i) significantly extend previous studies of collective effects due to strong and electromagnetic interactions,

(ii) improve measurements of event-by-event fluctuations and

(iii) perform the first measurements of open charm production in central Pb+Pb collisions at the SPS energies.

The charm production measurements require an upgrade of the NA61/SHINE facility by a high-precision vertex detector. The feasibility and expected performance of the proposed detector are presented.

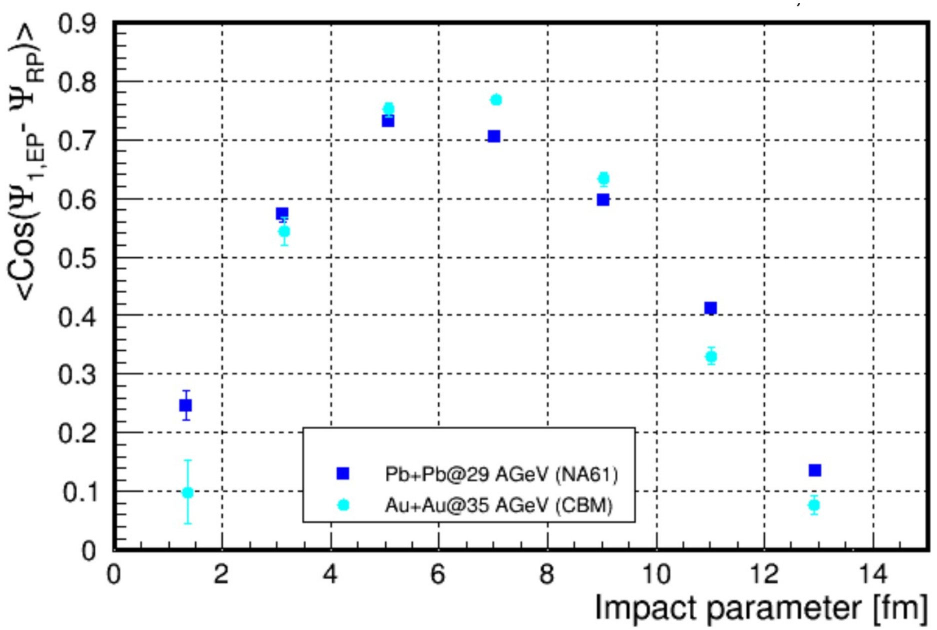
BACKUP

Beam	Target	p_{LAB}(A GeV/c)	Days	NA61/SHINE	NA49	STAR
Pb	Pb	13	10	$4 \cdot 10^6$	none	none
Pb	Pb	19	10	$4 \cdot 10^6$	$0.7 \cdot 10^6$	none
Pb	Pb	30	10	$4 \cdot 10^6$	$0.9 \cdot 10^6$	$3.8 \cdot 10^6$
Pb	Pb	40	10	$4 \cdot 10^6$	$1.5 \cdot 10^6$	none
Pb	Pb	75	20	$8 \cdot 10^6$	$0.3 \cdot 10^6$	$10.6 \cdot 10^6$
Pb	Pb	150	20	$8 \cdot 10^6$	$4.0 \cdot 10^6$	$17.5 \cdot 10^6$

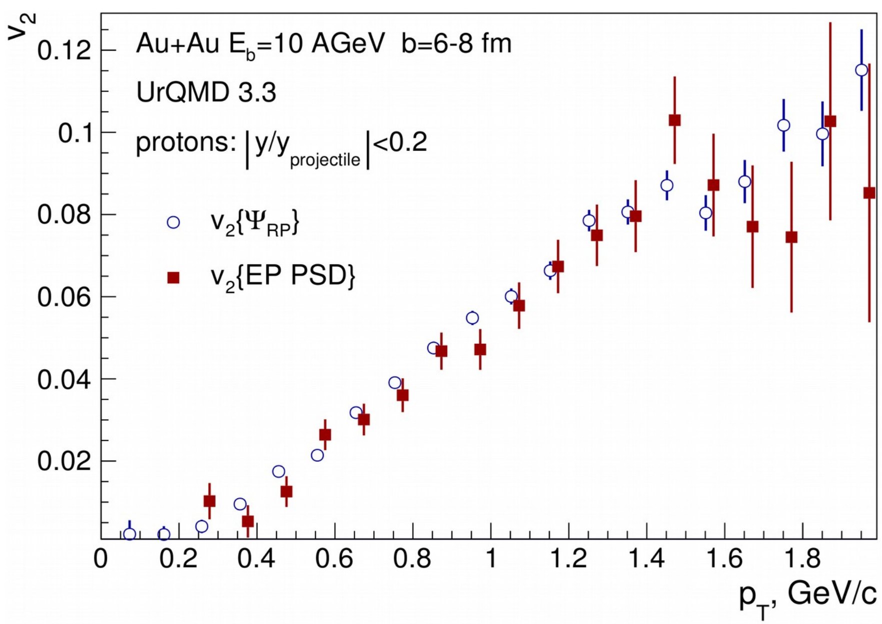
Table 1: The data samples and expected statistics from the NA61/SHINE beam momentum scan with Pb+Pb collisions. The last two columns show statistics registered by NA49 for Pb+Pb collisions and by STAR at RHIC for Au+Au collisions, respectively. The NA49 statistics is mostly for central Pb+Pb collisions with only $0.4 \cdot 10^6$ events per energy value recorded with a minimum bias trigger at 40A GeV/c and 158A GeV/c. Statistics for the STAR data at $\sqrt{s_{NN}}$ =7.7 GeV and 11.5 GeV is taken from Ref. [5] and at $\sqrt{s_{NN}}$ =14.5 GeV from Ref. [6]. The 5 day long test run with 150A GeV/c Pb beam in 2016 is not included in the table.

Can we use spectators for flow studies at low energies?

Correction for directed flow (v_1)
NA61 vs. CBM PSD simulations



Reconstructed proton v_2:
PSD EP (event plane) vs.
simulated v_2 relative RP (reaction plane)

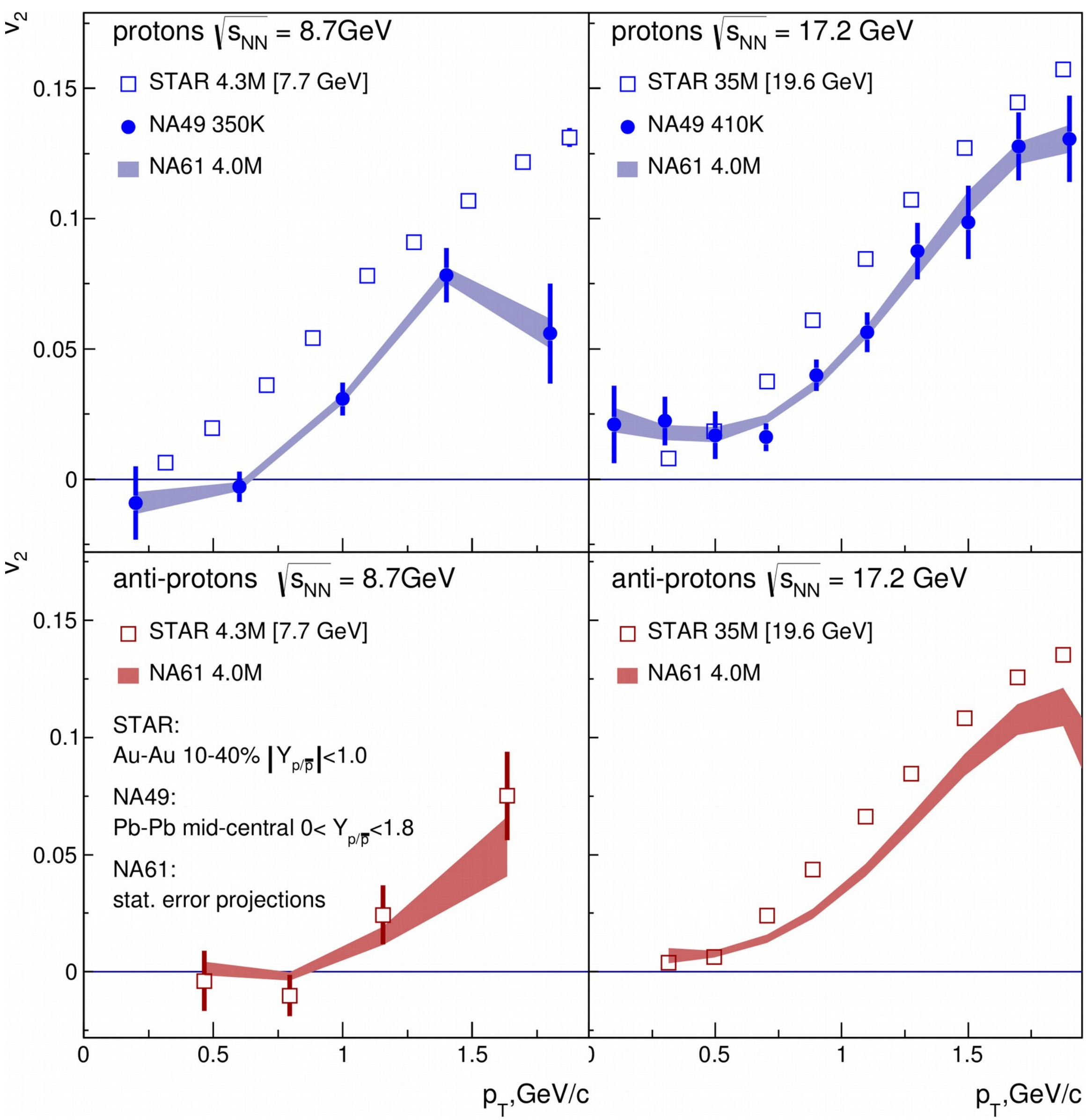


CBM PSD TDR online version
http://repository.gsi.de/record/109059

- similar resolution performance is for PSD of the NA61 and CBM
  → can rely on results from performance study with CBM PSD
- "input" model v_2 is recovered using "data-driven" method with 3 PSD subevents

What to expect with 10x more statistics than NA49

statistical error projections for v_2 of *p* & $\bar{p}$ for NA49 energies (40 and 158 AGeV)



Projections: proton v_2 from NA49

Stat. error projections for NA61/SHINE do not account for the different setup of NA49, STAR, and NA61/SHINE.

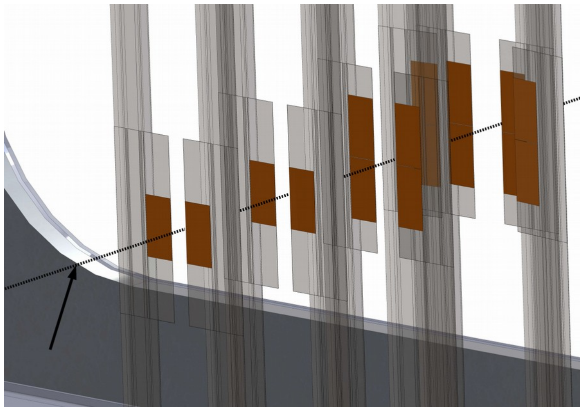
Anti-proton v_2 not measured by NA49

Projections: v_2 from STAR

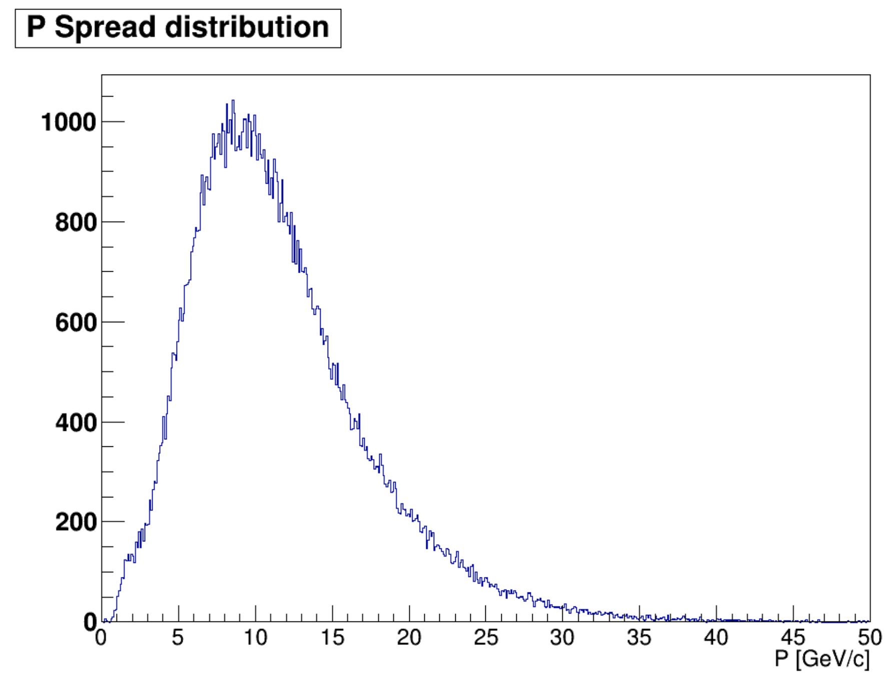
Possibility to measure flow of both, protons and anti-protons

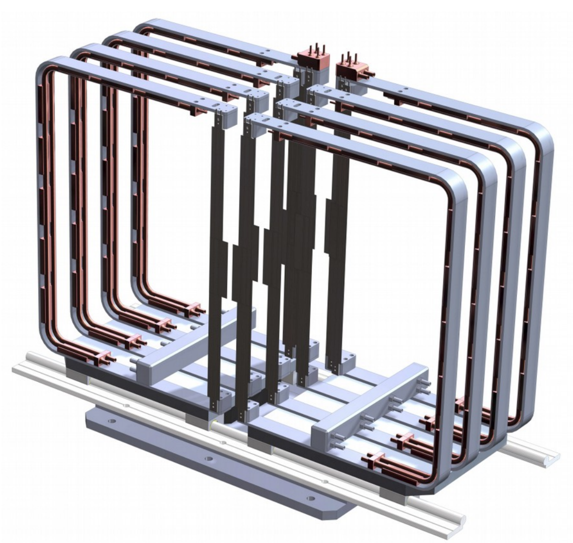
Important to measure at all values of the beam scan with the same setup

SAVD details



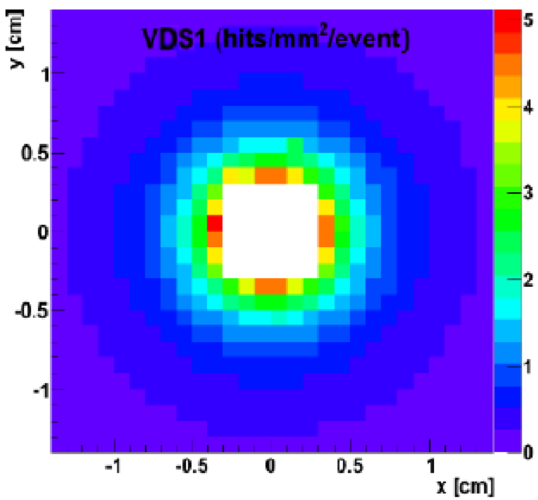
Momentum distribution of
K & pions from D^0 decays (in SAVD)



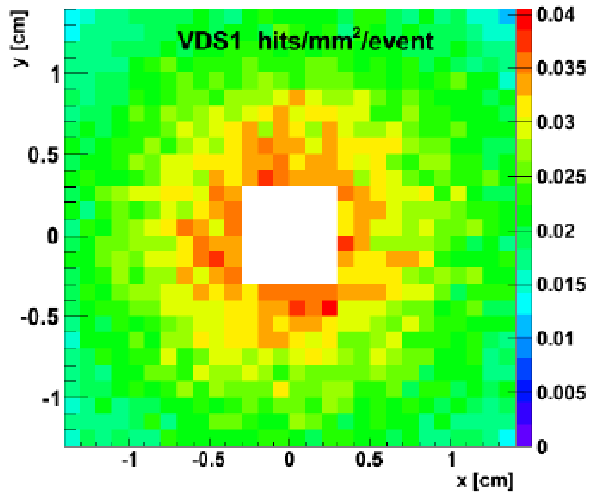


Radiation damage & occupancy vs. beam quality for Pb+Pb collisions at 150*A* GeV/*c*

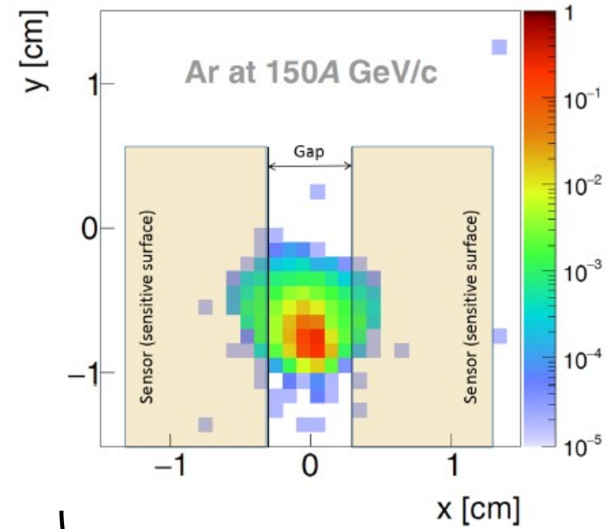
0-10% central Pb+Pb



Delta electrons



Beam ions



Max. occupancy: 0.8% (ok) → 0.8%

Max. non-ionizing: 3×10^{11} n_{eq}/cm^2 per run → $7 \times 10^{11} n_{eq}/cm^2$

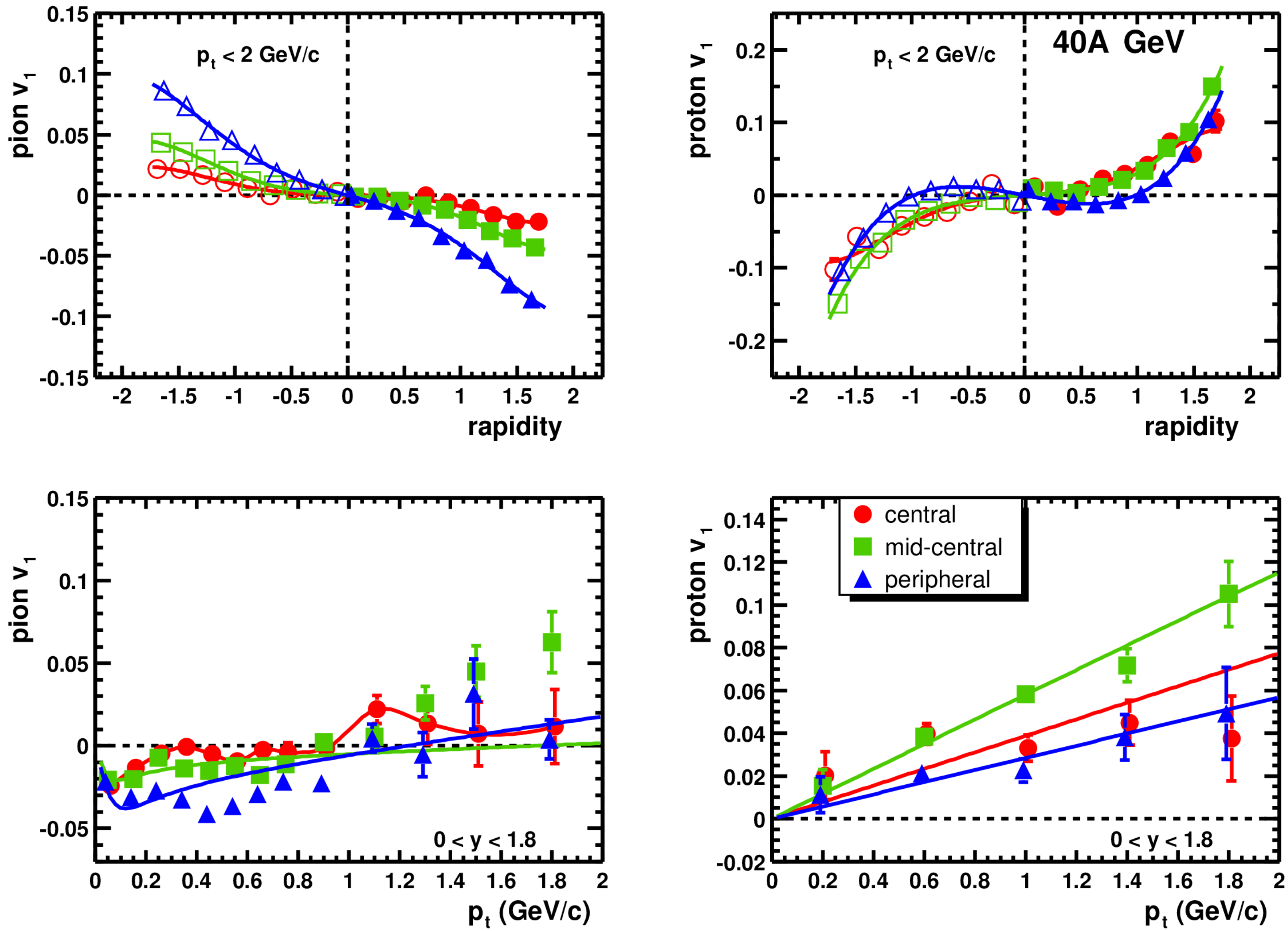
Max. ionizing damage: 25 krad/run (40 days) → 250 krad

MIMOSA-26AHR: Max. 10^{13} n_{eq}/cm^2 (ok) + 150 krad (not ok)

Might loose a small number of affected pixels (test result)
Investigating different options to overcome the issue:
→ Not a real problem at 150*A* GeV/*c*
→ Improved beam quality is needed at low (75*A* GeV/*c*) beam energy

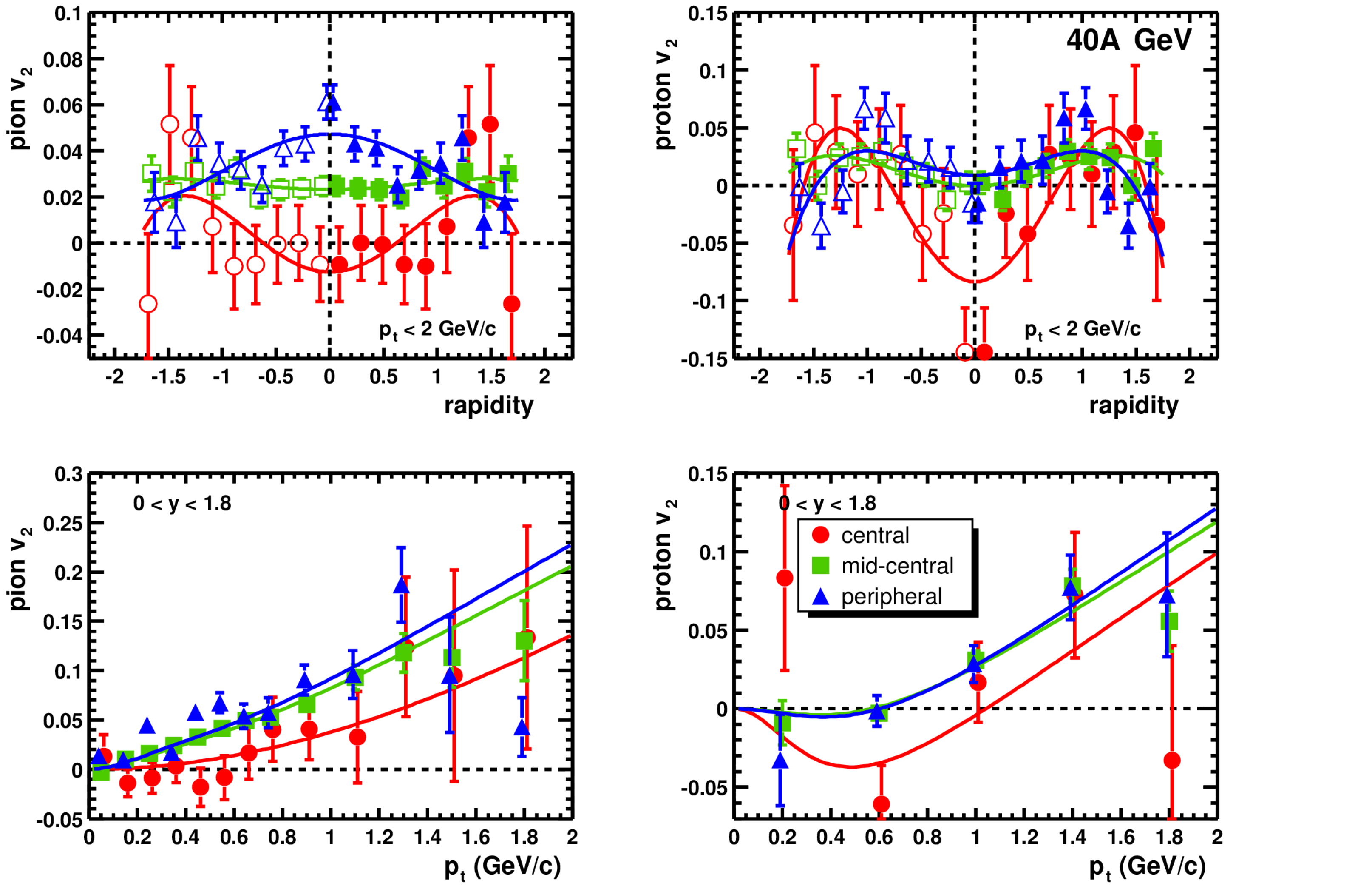
Existing NA49 results: pion/proton v_1 at 40A GeV

NA49 Collaboration PRC68 (2003) 034903



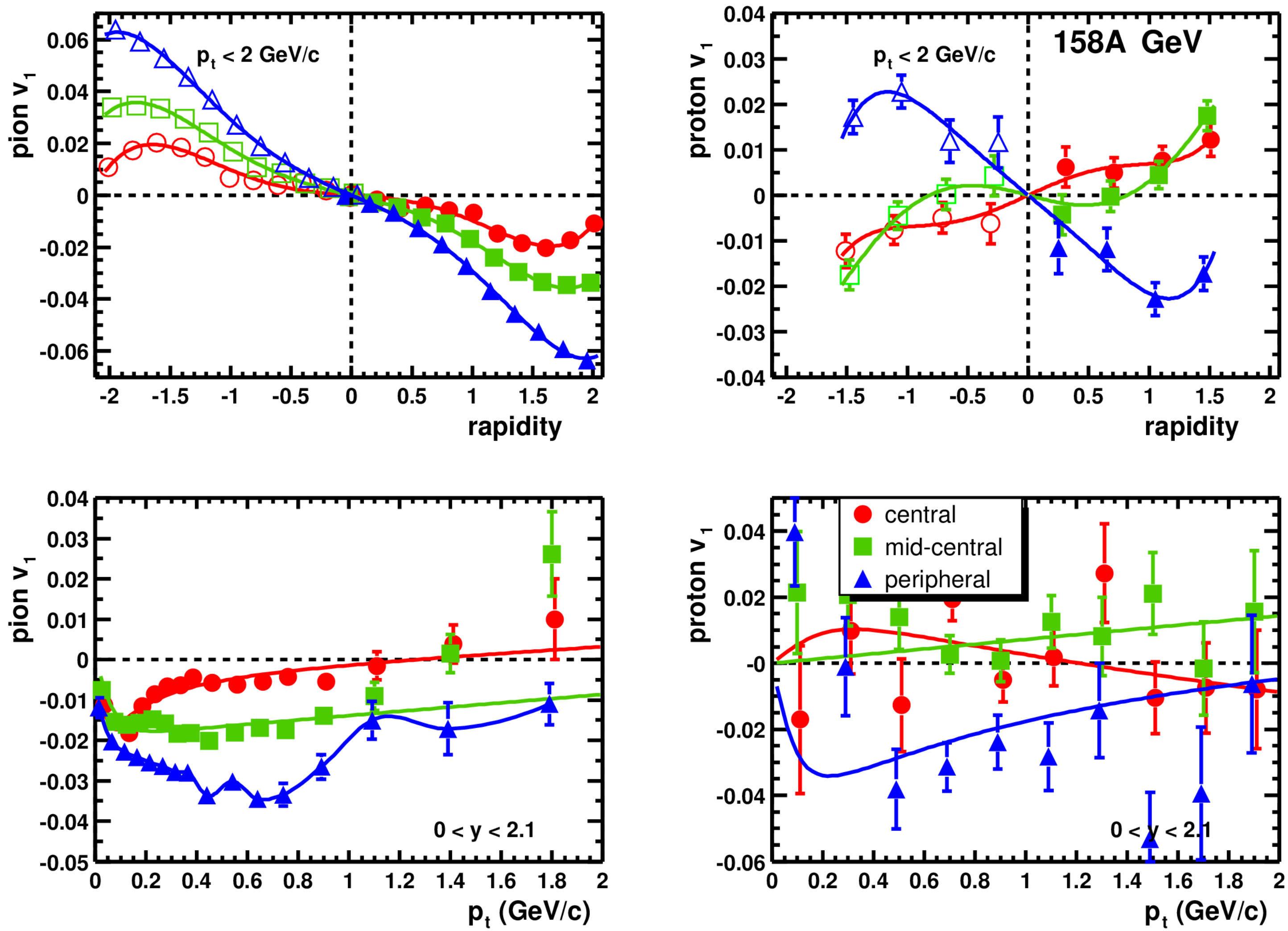
Existing NA49 results: pion/proton v_2 at 40A GeV

NA49 Collaboration PRC68 (2003) 034903



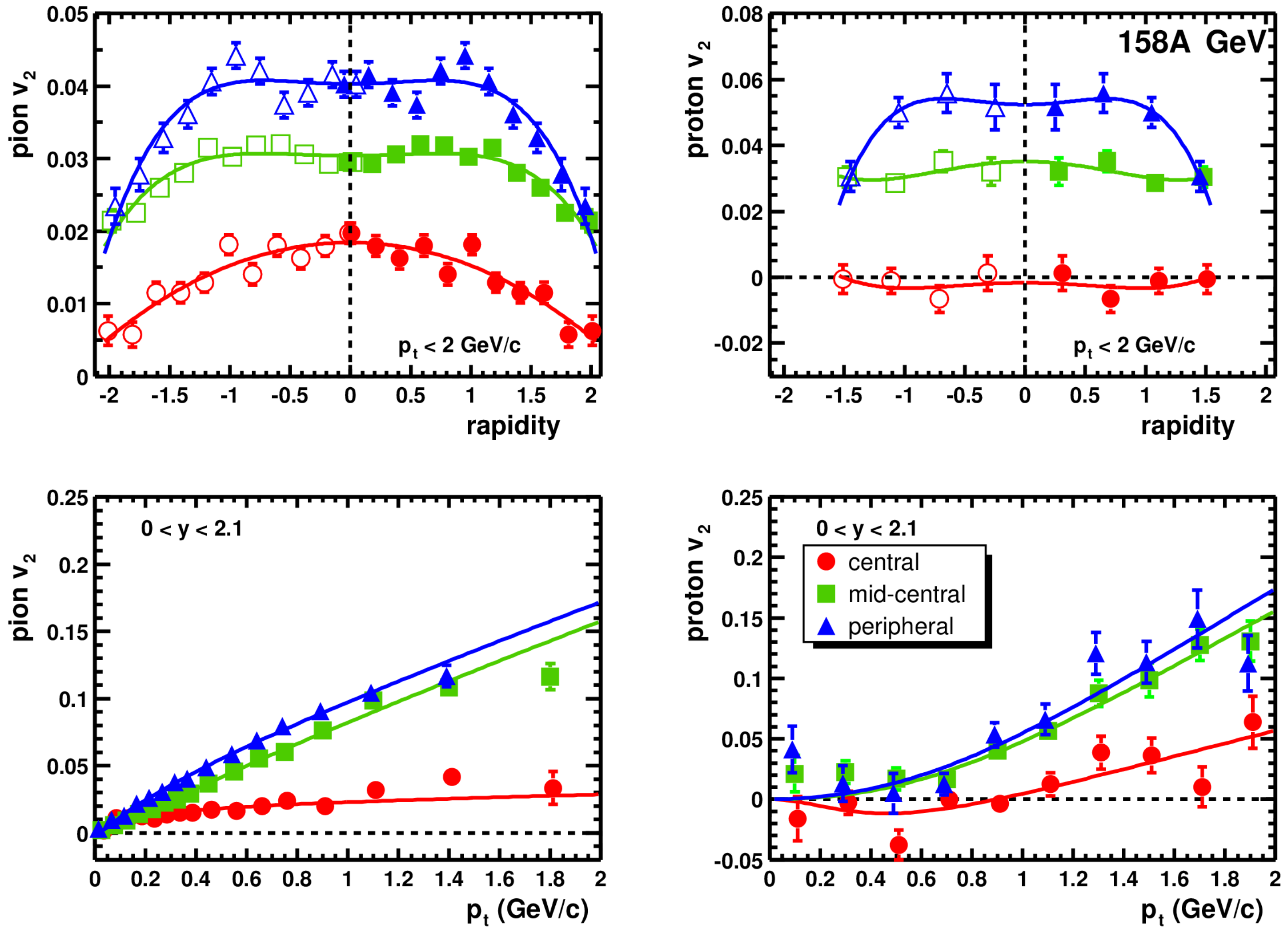
Existing NA49 results: pion/proton v_1 at 158A GeV

NA49 Collaboration PRC68 (2003) 034903



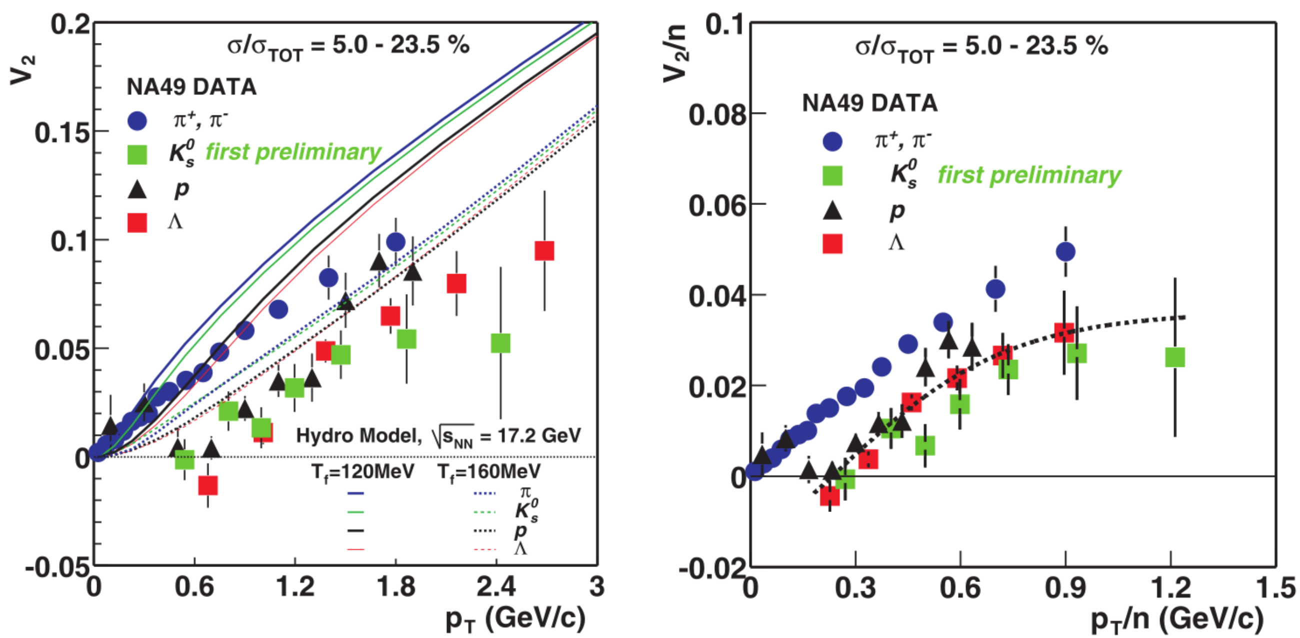
Existing NA49 results: pion/proton v_2 at 158A GeV

NA49 Collaboration PRC68 (2003) 034903



Existing NA49 results: strange particle flow

Grzegorz Stefanek PoS CPOD2006 (2006) 030

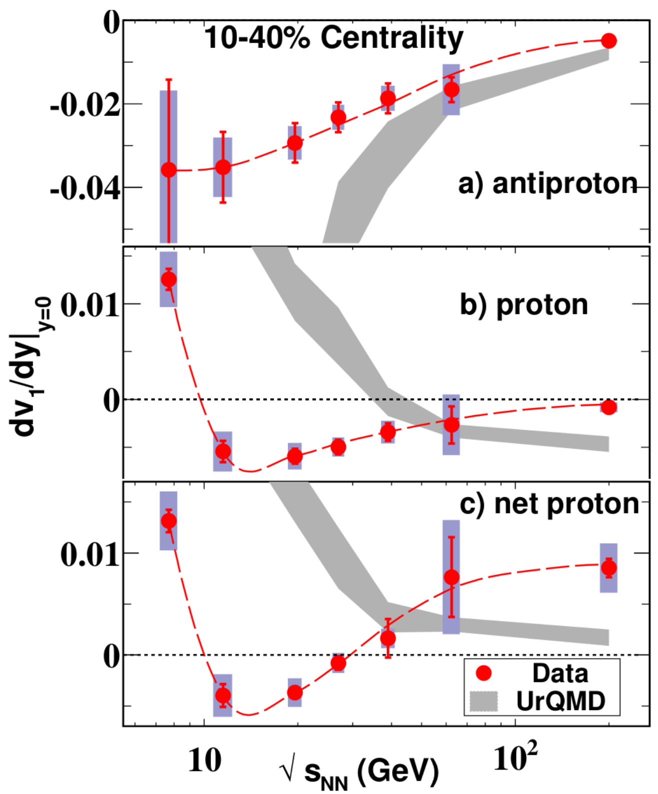


Only lambda v_2 is published

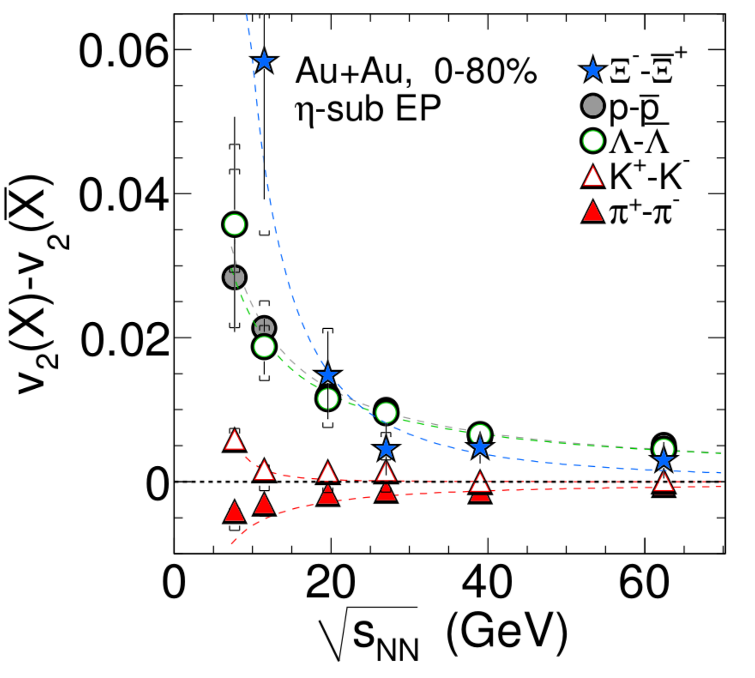
Figure 9: Left: $v_2(p_T)$ of charged pions, protons, Λ hyperons and K^0_s mesons from 158A GeV Pb+Pb mid-central collisions. Hydrodynamic model calculations at $\sqrt{s_{NN}} = 17.2$ GeV are shown as solid (T_f=120 MeV) and dashed (T_f=160 MeV) lines (see text for details). Right: v_2 scaled by the number of quark as a function of scaled p_T. All data are from 158A GeV Pb+Pb mid-central collisions. The dashed line is the scaled result of the fit to p, Λ and K^0_s.

Particle – anti-particle dependence of v_1 and v_2 from STAR@RHIC BES

STAR Collaboration PRL112 162301 (2014)

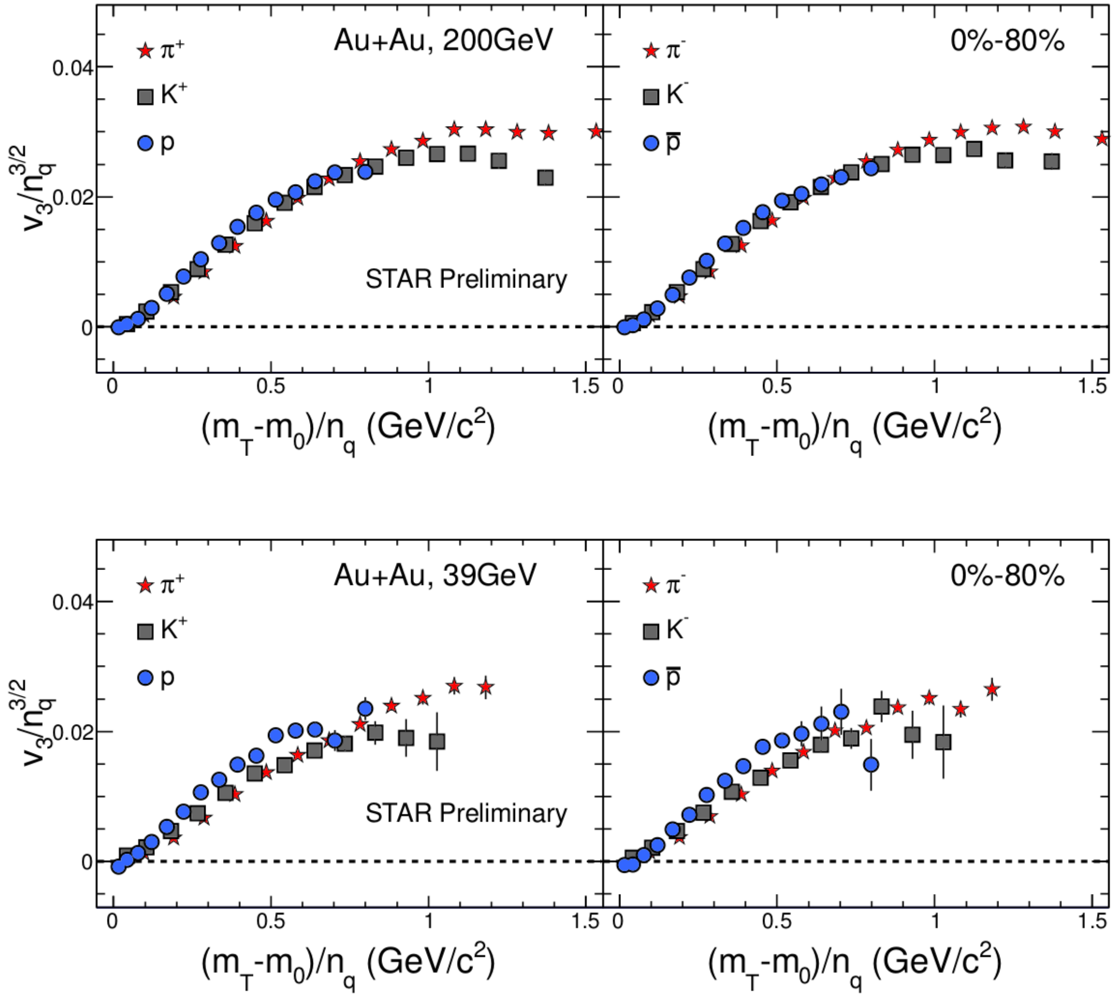


STAR Collaboration PRL110 142301 (2013)



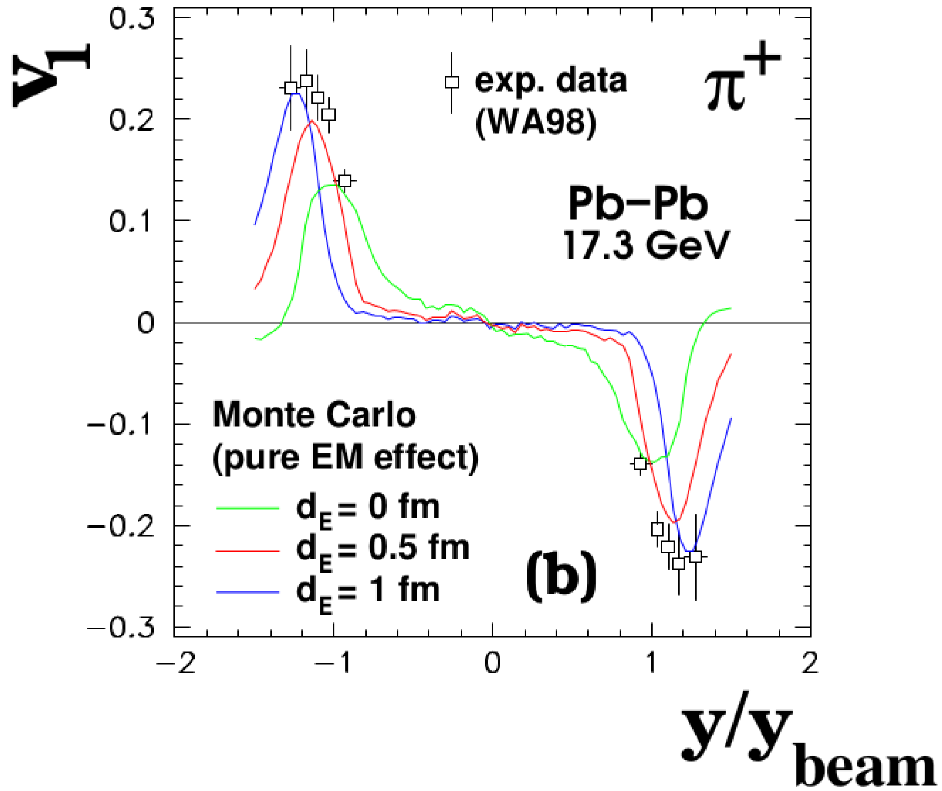
- Complement the STAR BES results and extend them for forward rapidities
- Spectators (forward particles) can be used with NA61:
  advantage over STAR (non-flow, geometrical effects vs. flow fluctuations)

Higher flow harmonics



- Only minbias data from RHIC BES for v_3
- Centrality dependence
- Fluctuations. What is the role of spectators?

WA98 results for v_1



NA61/SHINE Status report: recent publications

- Multiplicity and transverse momentum fluctuations in inelastic proton-proton interactions at the CERN Super Proton Synchrotron arXiv:1510.00163 [hep-ex]
- Production of Λ hyperons in inelastic p+p interactions at 158 GeV/c arXiv:1510.03720 [hep-ex]
- Measurements of $\pi^{\pm}$, $K^{\pm}$, K^0_S, Λ and proton production in proton-carbon interactions at 31 GeV/c with the NA61/SHINE spectrometer at the CERN SPS arXiv:1510.02703 [hep-ex]