CremlinPlus meeting: WP2: Task 2.3:

Software packages for simulation and data analysis, participation in physics performance studies

MEPhI / GSI /FAIR activities

Arkadiy Taranenko
Ilya Selyuzhenkov

July 1st, 2020
CREMLINplus WP2 kick-off meeting

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 871072

CREMLIN PLUS
Connecting Russian and European Measures for Large-scale Research Infrastructures

Overview

- CREMLINplus: WP2: Task 2.3 description
  - Participating members of the CremlinPlus project
- Common software packages for simulation and data analysis
  - Centrality (multiplicity, spectators / fragments)
  - Collective flow
  - Fast and online-capable algorithms for track finding, event reconstruction and event selection
- Physics performance studies
  - Centrality & collective flow & femtoscopy
    - NICA (MPD / BM@N), FAIR (CBM)
  - Event generators
    - Repository for different energies, systems, configurations (EoS, etc)
- Summary and next steps
  Planning a dedicated workshop on centrality & collective flow

CREMLINplus: WP2: Task 2.3

CREMLINplus WP2:NICA-FAIR/CBM **WP Leader: Jürgen Eschke (FAIR)** **Deputy WP Leader: Yuri Murin(JINR)**	**FAIR** **7,5 FTE** **over 48 Months** **(360 PM)**	**JINR** **9 FTE** **over 48months** **(432 PM)**	**EKUT** **Tübingen** **1 FTE** **(48 PM)**	**WUT** **Warsaw** **2 FTE** **(96 PM)**	**Mephi** **Moscow** **4 FTE** **(192 PM)**	**Wigner** **Budapest** **2 FTE** **(96 PM)**	**NPI** **Rez** **2 FTE** **(96 PM)**	**INR** **Moscow** **1 FTE** **(48 PM)**
Task 2.1: Integration, installation, and test of Silicon trackers for NICA and CBM (FAIR, JINR, EKUT) (Taskleader: Johann Heuser, GSI)	2	4	1					
Task 2.2: Developments for the data acquisition chain, for data preprocessing and computing (WUT, FAIR, JINR) (Taskleader: Wojtek Zabolotny, WUT)	2	2		2				
Task 2.3: **Development of common software packages for simulation and data analysis, participation in physics performance studies (MEPhI, FAIR, JINR, Wigner RCP)** **Taskleader: Arkadiy Taranenko, MEPhI** **deputy taskleader: Ilya Selyuzhenkov, GSI**	**2**	**2**			**4**	**2**		
Task 2.4: Development and construction of beam monitors, target chamber and beam pipe for NICA and CBM (FAIR, JINR) (Taskleader: Peter Senger, FAIR)	1	1						
Task 2.5: Development and construction of Zero Degree Calorimeters for NICA and CBM (INR RAS, NPI CAS) (Taskleader: Fedor Guber, INR)							2	1
Coordination of joint activities	0.5							

Participating members of the NRNU MEPhI / GSI

- Coordination
  - Arkadiy Taranenko (May 2020)
  - Ilya Selyuzhenkov (deputy, May 2020)

TEAM members:

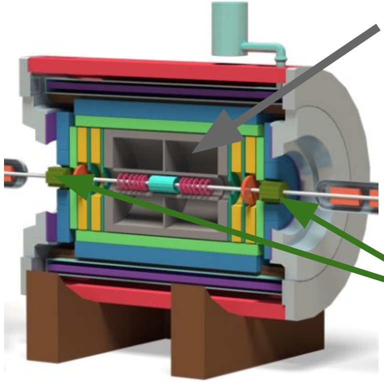
- Volker Friese
- Eion Clerkin (May 2020)
- Dominik Smith (July 2020)
- Sergei Gorbunov (Sept. 2020)

- PhD students
  - Petr Parfenov (May 2020)
  - Evgeny Kashirin (May 2020)
  - Oleg Golosov (May 2020)
  - Evgenia Khizhnjak
- (currently master students, starting Ph.D. in 2021)
  Ilya Segal, Mikhail Mamaev, Alexander Demanov

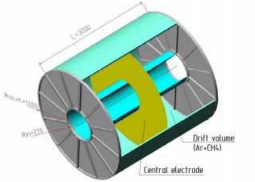
MPD experiment at NICA

Collider experiment:

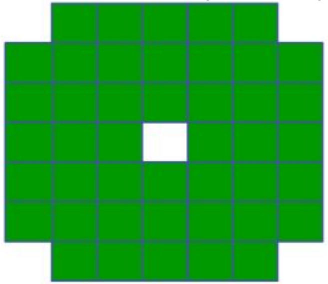
Au+Au, Bi+Bi at $\sqrt{s_{NN}}$ = 4 — 11 GeV



Time projection chamber (TPC)



Forward Hadron Calorimeter (FHCal)



EP plane and centrality determination

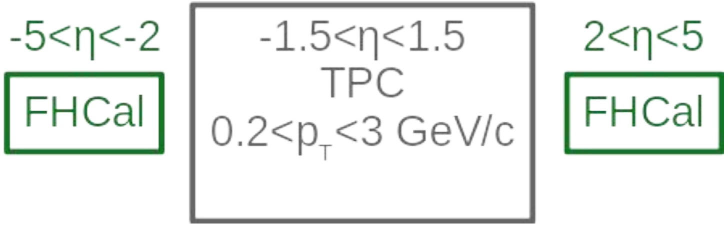
- FHCal ($2<|\eta|<5$)
- TPC ($|\eta|<1.5$)

Time Projection Chamber (TPC)

- Tracking of charged particles within ($|\eta| < 1.5$, 2π in φ)
- PID at low momenta

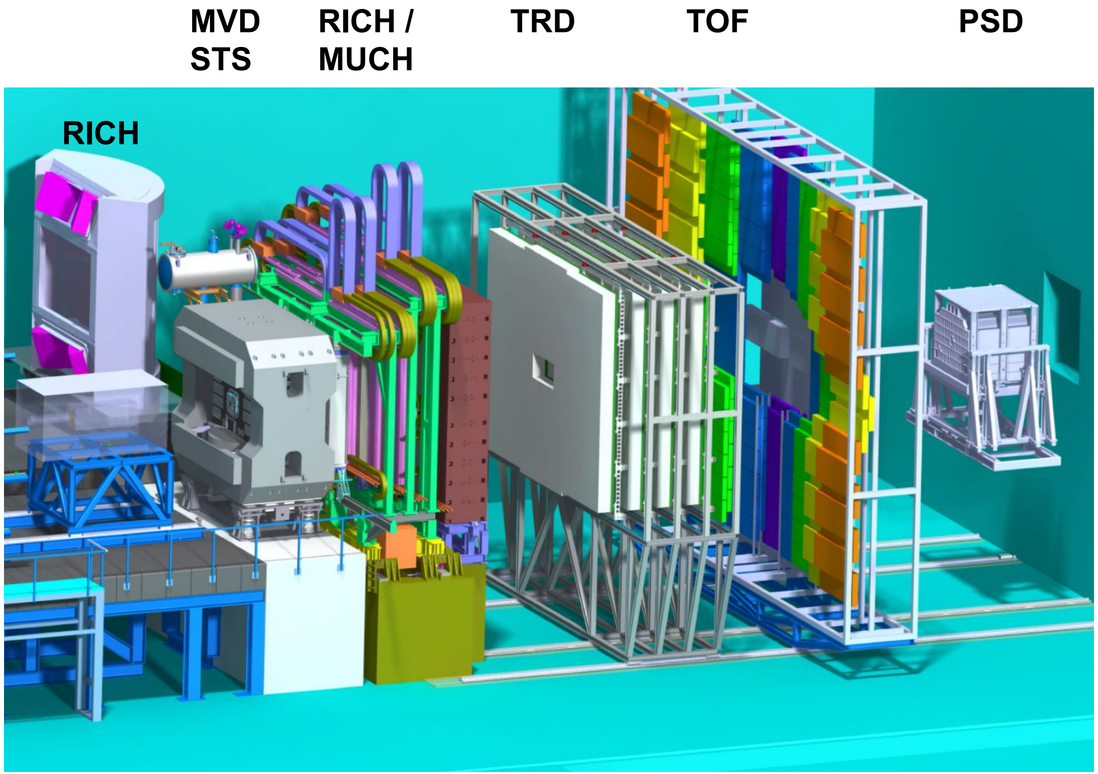
Time of Flight (TOF)

- PID at high momenta



CBM experiment at FAIR

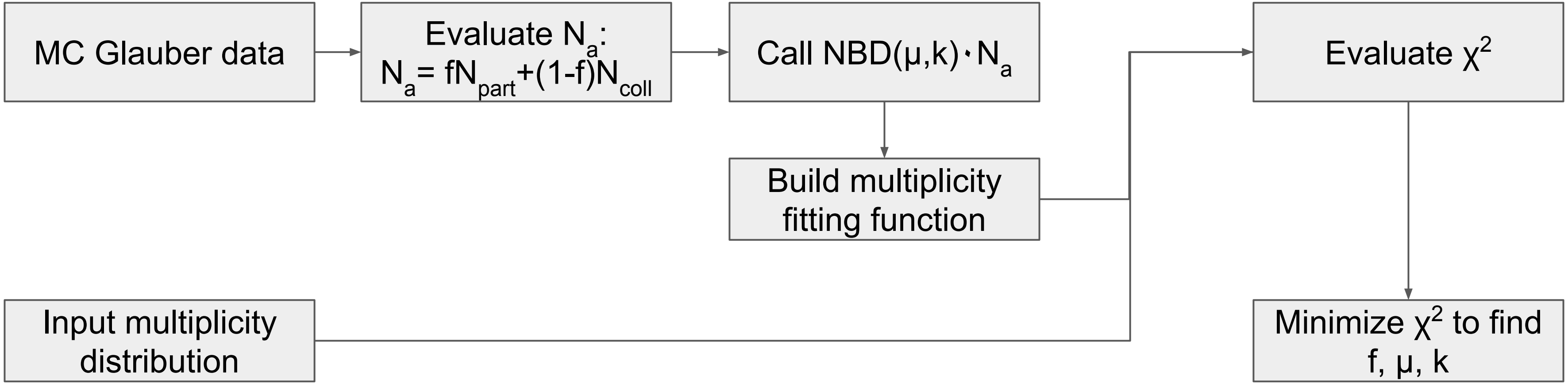
Fixed target experiment $\sqrt{s_{NN}}$ = 2.5—4.9 GeV



EP plane and centrality determination
PSD & MVD+STS, TOF
Tracking (MVD+STS)
4 < theta < 25; φ: (0, 2π)
PID
Time of Flight (TOF)

SIS100 primary beams:
10^9/s Au up to 11 GeV/u
10^9/s C, Ca, ... up to 14 GeV/u
10^{11}/s p up to 29 GeV

Centrality framework (developed in CBM)



Procedure is developed in CBM and tested with HADES, NA49, and NA61/SHINE:

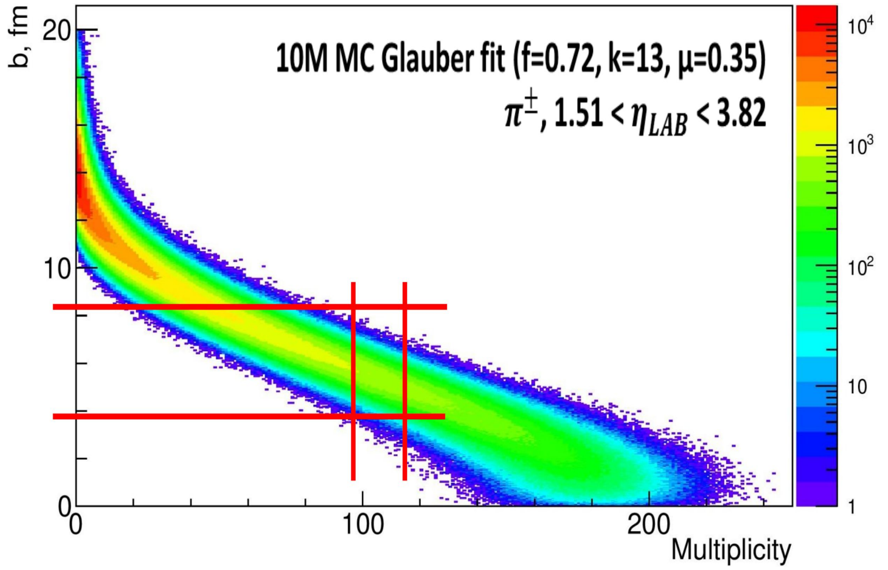
V. Klochkov, I. Selyuzhenkov Acta Phys.Polon.Supp. 10 (2017) 919

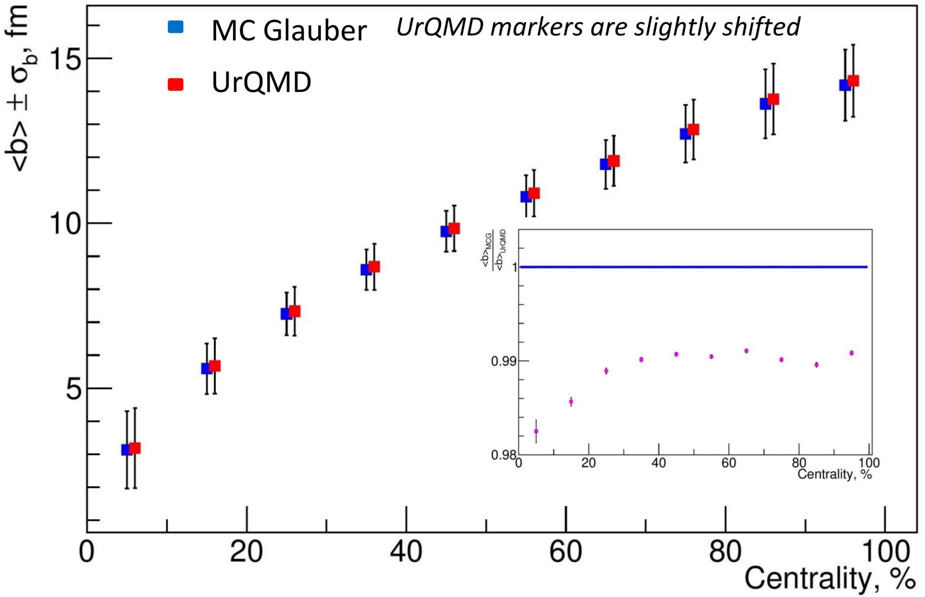
V. Klochkov et, al. EPJ Web Conf. 182 (2018) 02132

Implementation in CBM: https://cbmgsi.githost.io/pwg-c2f/centrality

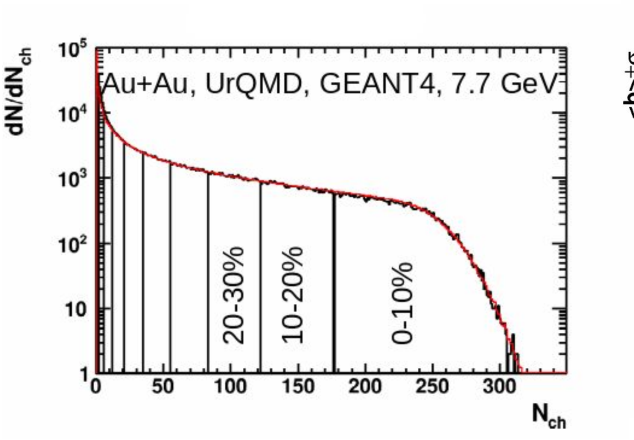
CBM

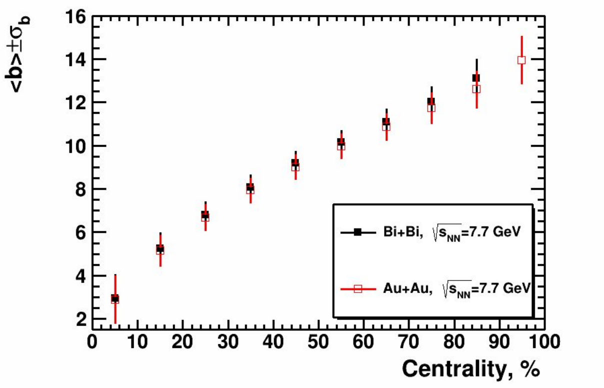
Centrality framework application: CBM @ FAIR

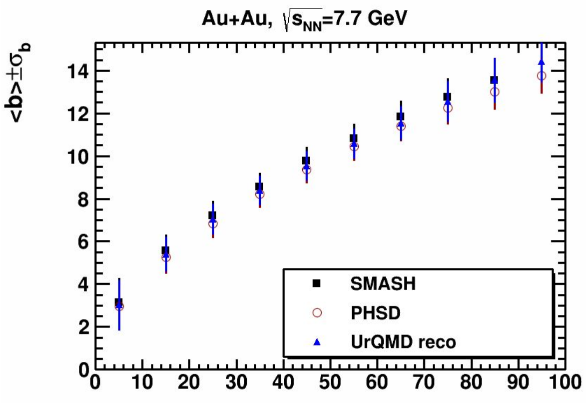




Centrality framework application: MPD @ NICA





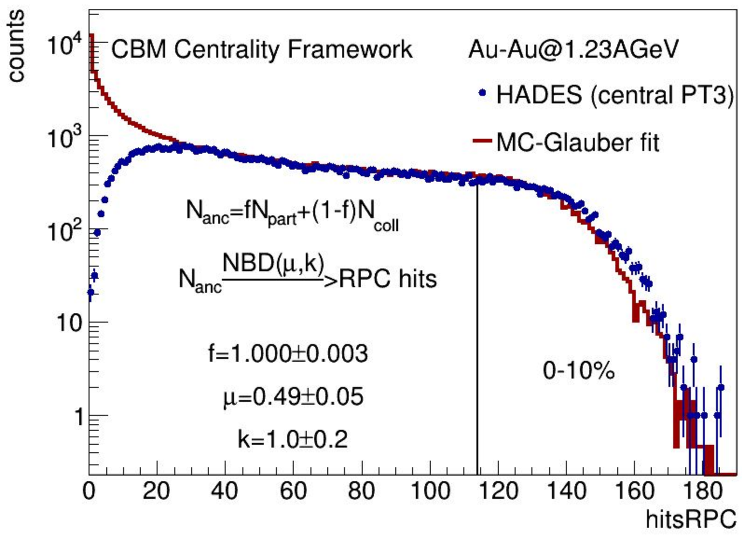


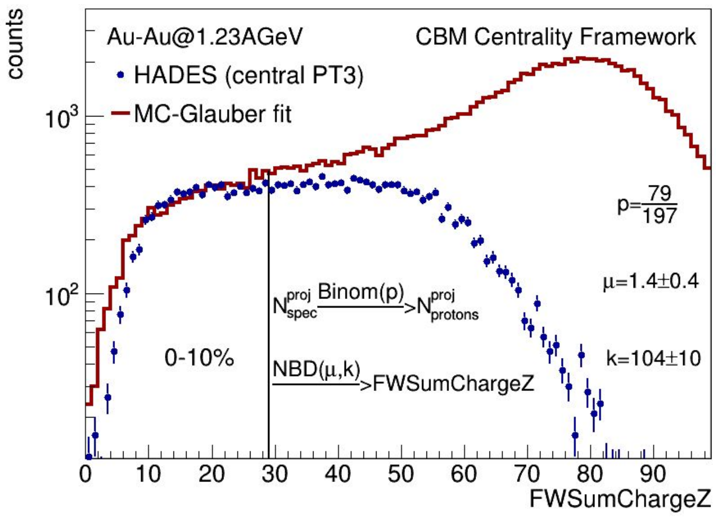
<b> obtained from the different models are in reasonable agreement

<b> weakly depend on the size of the colliding system

Implementation in MPD:
https://github.com/PeterParfenov/AnisotropicFlowMPD/tree/master/CentralityFramework

Centrality framework application: FAIR-PHASE-0 (HADES)

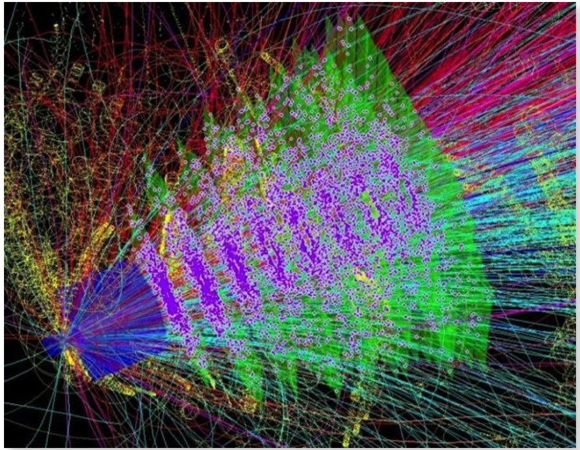


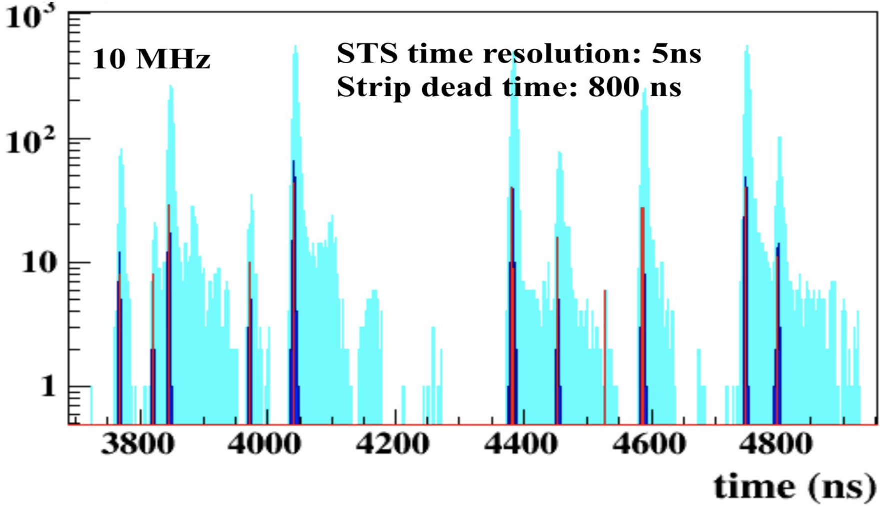


Consistent with published results in HADES centrality paper

HADES Collaboration Eur. Phys. J. A (2018) 54: 85 https://arxiv.org/abs/1712.07993

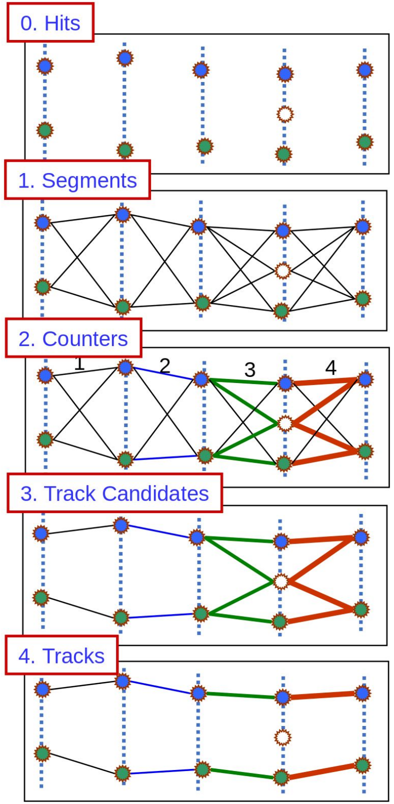
Fast and online-capable algorithms for track finding, event reconstruction and event selection

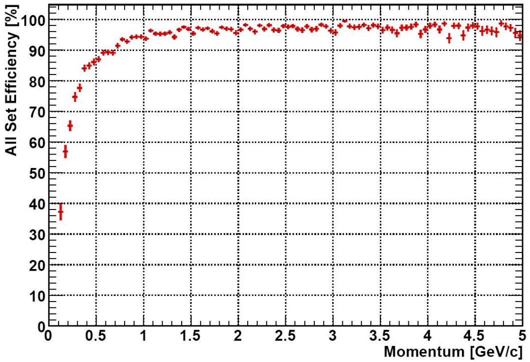




- Complex event topologies: hundreds of charged particles per event in the detector acceptance
- For CBM: streaming data; no event association by a hardware trigger
- Track finding and event selection to be performed in real-time at extreme interaction rates (up to 107/s)
- Need fast, robust and precise algorithms
- Employ inter- and intra-node parallelisation

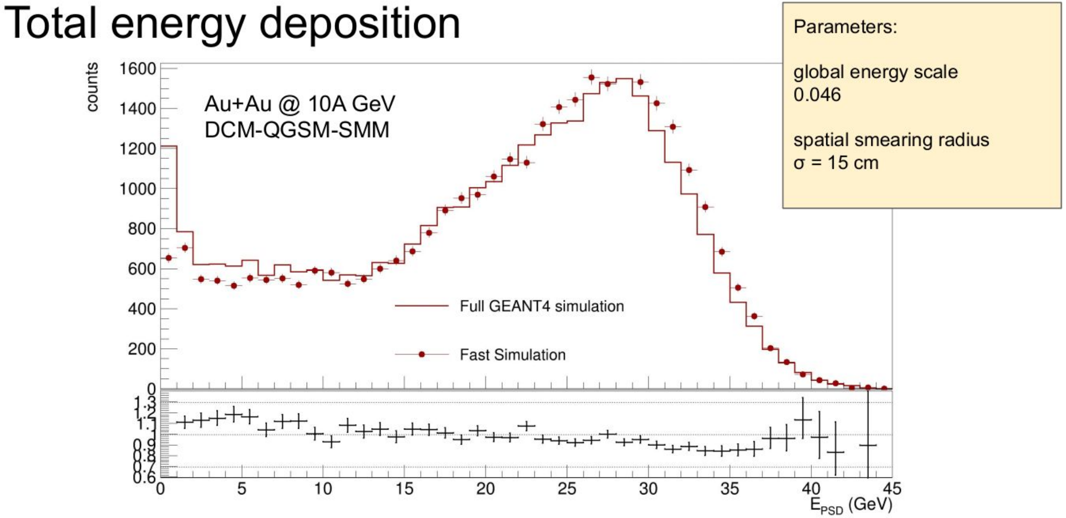
Fast and online-capable algorithms for track finding, event reconstruction and event selection





- Track-finding approach in CBM:
  Cellular Automaton (central tracking system)
  - Fast and good efficiency event-by-event
- Challenge: further develop the algorithm
  - for free-streaming data & for downstream detectors
- Application in other experiments:
  - Demonstrated for STAR, ALICE, NA61/SHINE
  - Option for BM@N / MPD

Fast simulations for common Monte-Carlo productions



Development of fast simulation algorithms required for common high statistics Monte-Carlo preparation:

- Hadronic calorimeters for MPD, CBM, and BM@N
- Requires realistic detector load (event generators with fragments)

Event generators and flow data repository

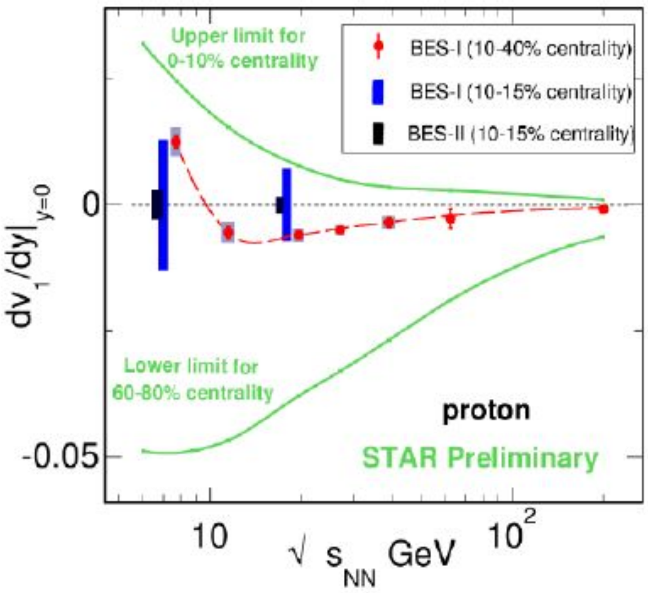
Anisotropic flow at FAIR / NICA energies - Experimental Data ($\sqrt{s_{NN}}$):

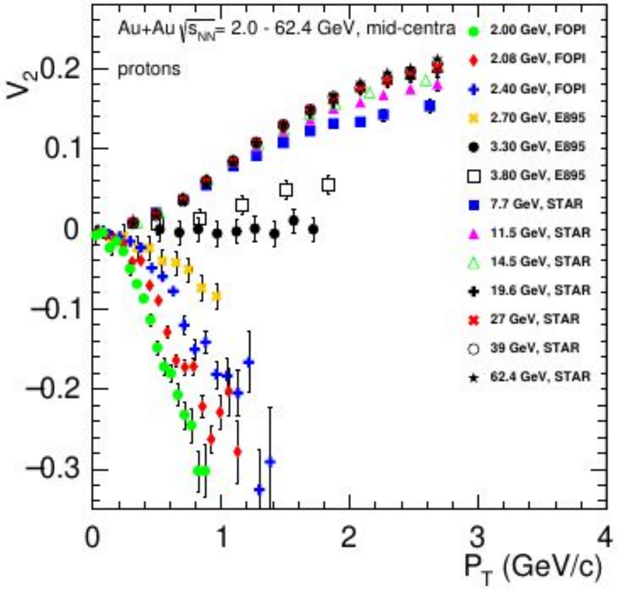
(1) E895 Collaboration Au+Au at 2.7, 3.32, 3.85 and 4.3 GeV
(2) NA61/NA49 Pb+Pb at 5.1, 7.6 and 8.9 GeV
(3) STAR Collaboration Au+Au at 4.5, 7.7 and 11.5 GeV
(4) HADES Au+Au at 2.3 GeV
(5) FOPI Au+Au at 2.00, 2.08, 2.40 GeV

Anisotropic flow at FAIR / NICA energies - Models:
(1) String/Hadronic Cascade Models: UrQMD, HSD, SMASH, JAM, DCM-QGSM
(2) Hybrid Models: viscous hydro+cascade (vHLLE+UrQMD and MUSIC+UrQMD) and parton/string models (AMPT, PHSD and PHQMD)

Anisotropic flow at FAIR / NICA energies physics performance study:
GEANT simulations + reconstruction in MPD (10M events for each point in energy):
(1) UrQMD + GEANT4 + recontruction Au+Au at 4.5, 7.7 and 11.5 GeV; Bi+Bi at 7.7 GeV
(2) vHLLE+UrQMD + GEANT4 + reconstruction Au+Au at 7.7 GeV;
GEANT simulations + reconstruction in CBM:
(1) UrQMD at p_{Lab}= 12, 3.3A GeV/c
(2) DCM-QGSM-SMM at p_{Lab}= 12, 3.3A GeV/c

Anisotropic flow at NICA / FAIR energies



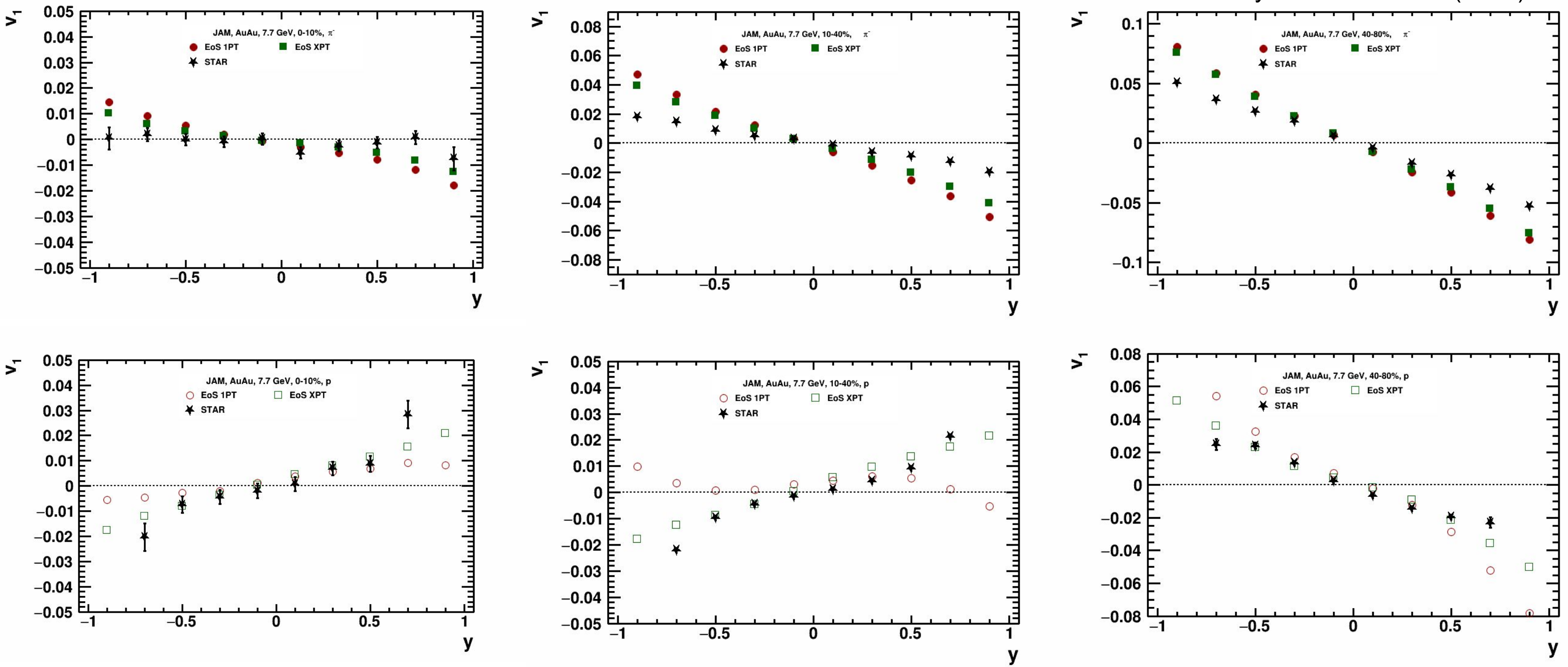


Anisotropic flow at NICA / FAIR energies reflects a delicate balance between:

- the ability of pressure developed early in the reaction zone and
- the passage time for removal of the shadowing by spectators

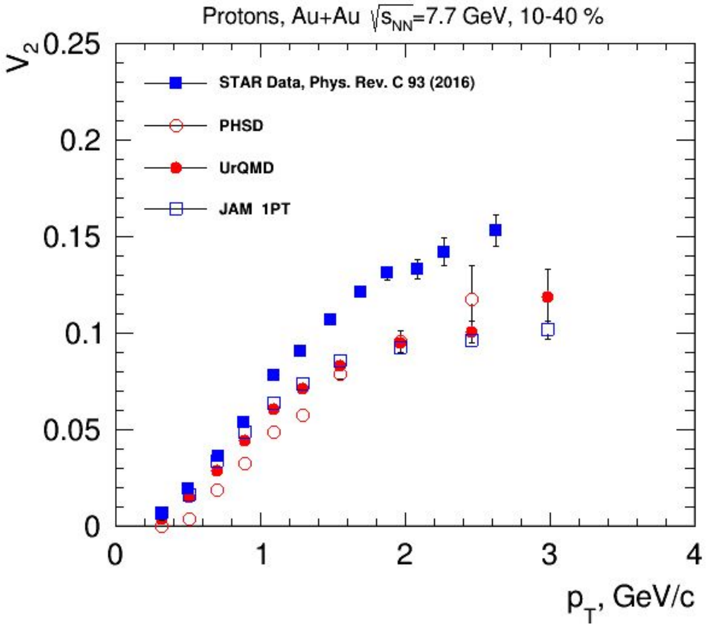
Event generators: comparison with experimental data - directed flow

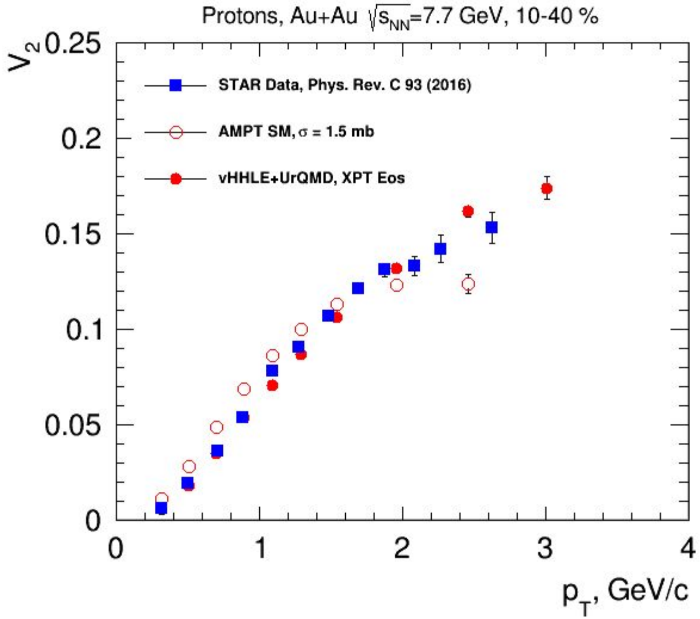
Phys. Rev. Lett. **112** (2014) 162301



Biggest difference between EoS in mid-central collisions

Event generators: comparison with experimental data - elliptic flow





Pure String/Hadronic Cascade models yield
smaller v_2 signal compared to STAR data for Au+Au $\sqrt{s_{NN}}$=7.7 GeV

Q_n-tools: corrections and analysis frameworks

Q_n-corrections framework developed for the ALICE experiment:
J. Onderwaater, I. Selyuzhenkov, V. Gonzalez

Based on technique proposed in:
I. Selyuzhenkov and S. Voloshin PRC77, 034904 (2008)

Q_n-Analysis framework (is being developed):
L. Kreis & I. Selyuzhenkov

Used configuration:

- Qn-vector:
  - Recentring
- u_n vector:
  - Recentring
  - twist+rescale
- Error calculations: Bootstrapping

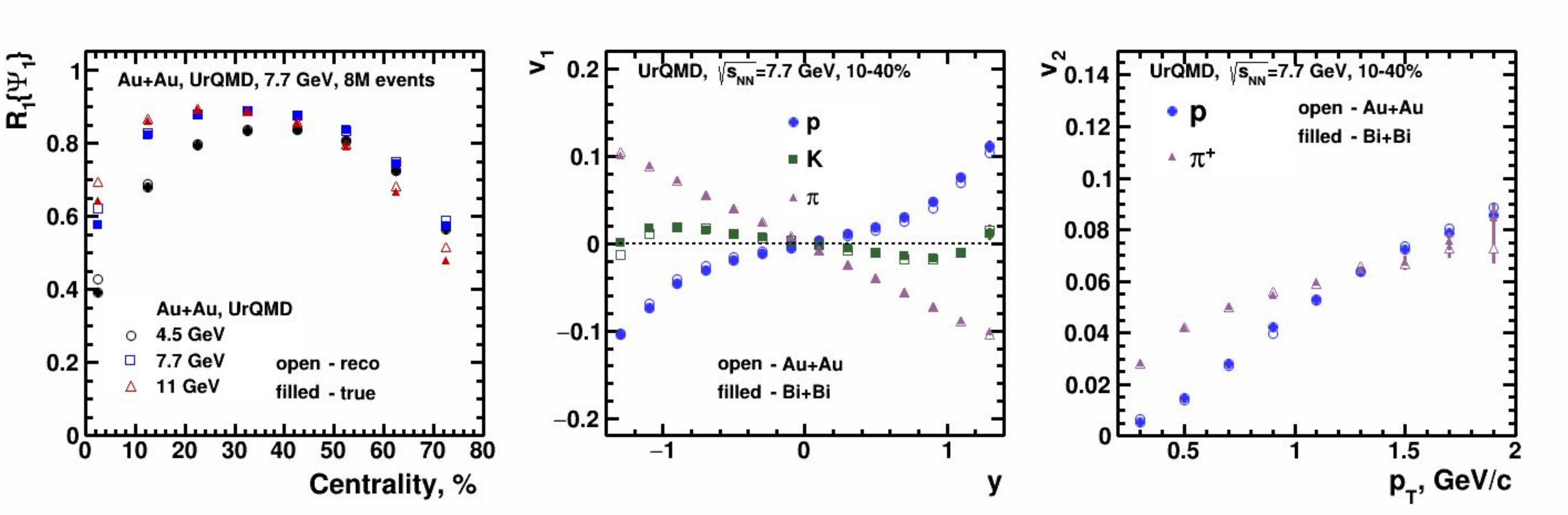
https://github.com/HeavyIonAnalysis/QnTools

Framework is tested and used in other experiments

ALICE SHINE NA49 HADES

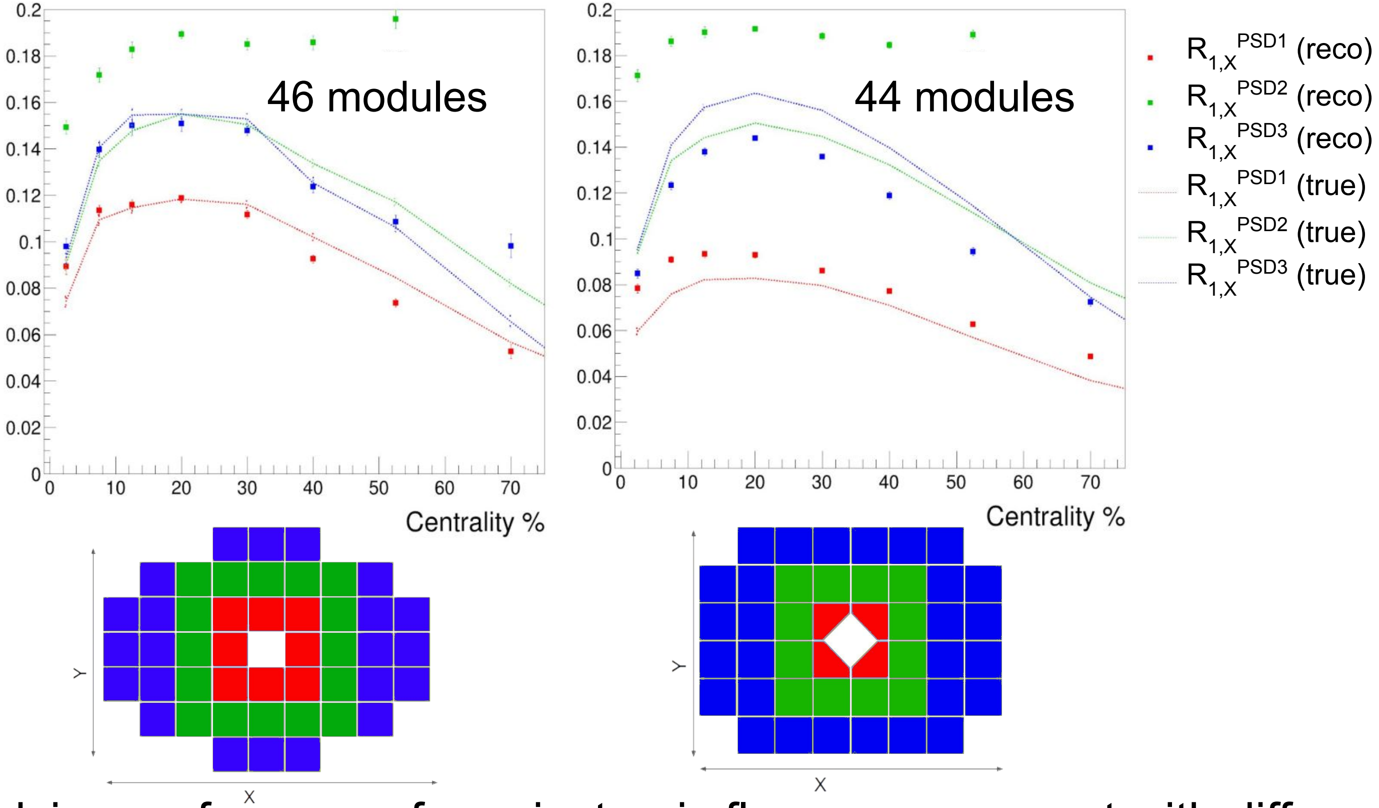
Flow performance studies: MPD@NICA

MC vs. reconstructed | Au+Au vs. Bi+Bi



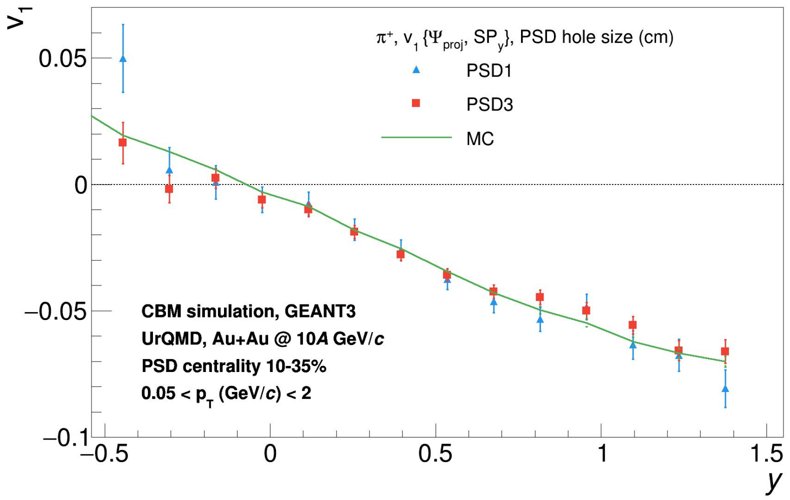
Good agreement between MC and reconstructed signals
Small difference between Au+Au and Bi+Bi

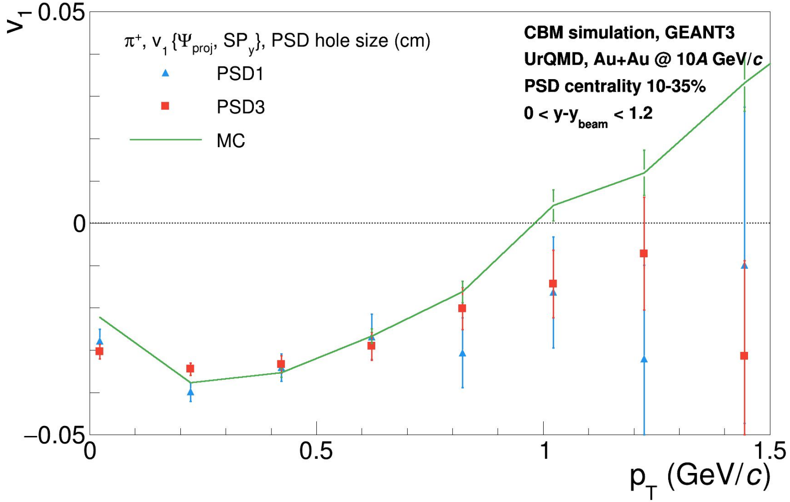
Flow performance studies: CBM@FAIR



Studying performance for anisotropic flow measurement with different PSD beam hole sizes and module layouts

CBM@FAIR: Flow performance studies





Good performance for anisotropic flow measurement of charged hadrons

Summary and next steps

- CREMLINplus: WP2: Task 3 description
  - Participating members of the CremlinPlus project
- Common software packages for simulation and data analysis
  - Centrality (multiplicity, spectators / fragments)
  - Collective flow
  - Fast and online-capable algorithms for track finding, event reconstruction and event selection
- Physics performance studies
  - Centrality & collective flow & femtoscopy
    - NICA (MPD / BM@N), FAIR (CBM)
  - Event generators
    - Repository for different energies, systems, configurations (EoS, etc)
- Summary and next steps

  Planning a dedicated workshop on centrality & collective flow

List of deliverables for WP2: task 2.3

Deliverable number	Deliverable title	Lead beneficiary	Type	Dissemination level	Due Date (in months)
D2.1	STS components assembled	14 - FAIR GMBH	Report	Public	24
D2.2	STS detectors tested	14 - FAIR GMBH	Report	Public	48
D2.3	Components of the STS data acquisition chain tested	32 - WUT	Report	Public	24
D2.4	Full functionality tests of the STS data acquisition chain	32 - WUT	Report	Public	48
D2.5	**Simulation results for selected observables**	**7 - MEPhI**	**Report**	**Public**	**24**
D2.6	**Physics performance for major observables**	**7 - MEPhI**	**Report**	**Public**	**48**
D2.7	Design of beam monitors, target chambers, beam pipes	14 - FAIR GMBH	Report	Public	12
D2.8	Beam monitors, target chambers, beam pipes constructed and installed	14 - FAIR GMBH	Report	Public	48
D2.9	Design of the ZDC detector modules	5 - INR RAS	Report	Public	12
D2.10	ZDC detector modules constructed and tested	5 - INR RAS	Report	Public	48

Workshop on analysis techniques for centrality determination and flow measurements at FAIR and NICA

The goal of the workshop is to assess the progress
in the analysis techniques development related to the event characterization
in heavy-ion collisions (centrality and reaction plane determination)
and flow measurements at future CBM@FAIR and MPD@NICA experiments.

Also related to these topics experimental activities with
relativistic heavy-ions at GSI (HADES) and Nuclotron (BM@N) will be discussed.

Dates:
August 24-28, 2020
Indico link: http://indico.oris.mephi.ru/event/181

Organizing co-chairs

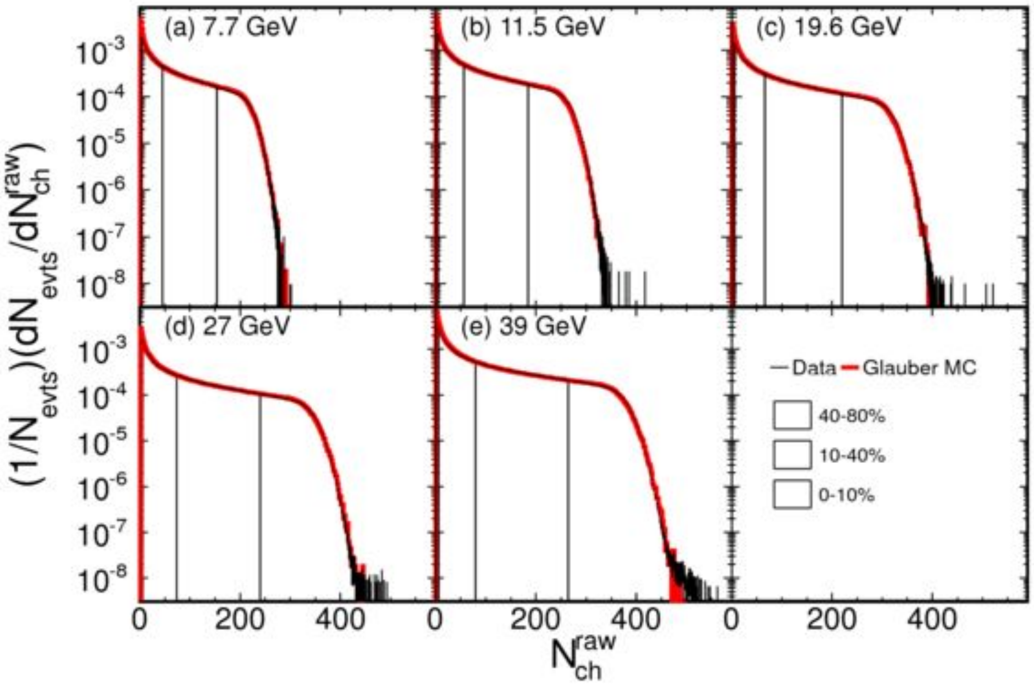
Arkadiy Taranenko (MEPhI)
Ilya Selyuzhenkov (GSI / MEPhI)

Backup slides

Centrality in STAR

- Uncorrected charged particle multiplicity distribution in TPC ($|\eta|<0.5$)
- Comparison with MC Glauber simulations
- Fitted using two-component model:

$$\left.\frac{dN_{ch}}{d\eta}\right|_{\eta=0} = n_{pp}\left[(1-x)N_{part}/2 + xN_{coll}\right]$$

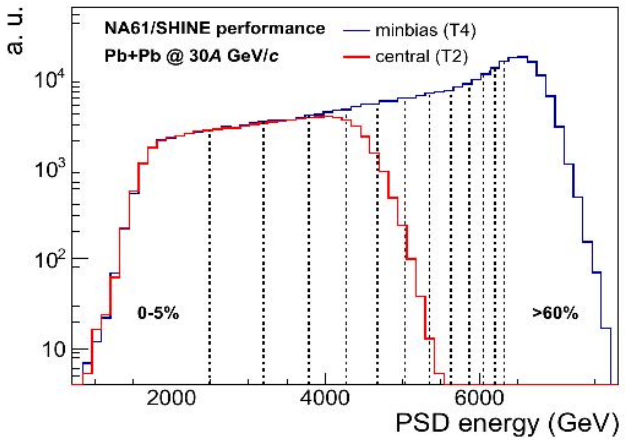


Similar centrality estimator is needed for comparisons with STAR

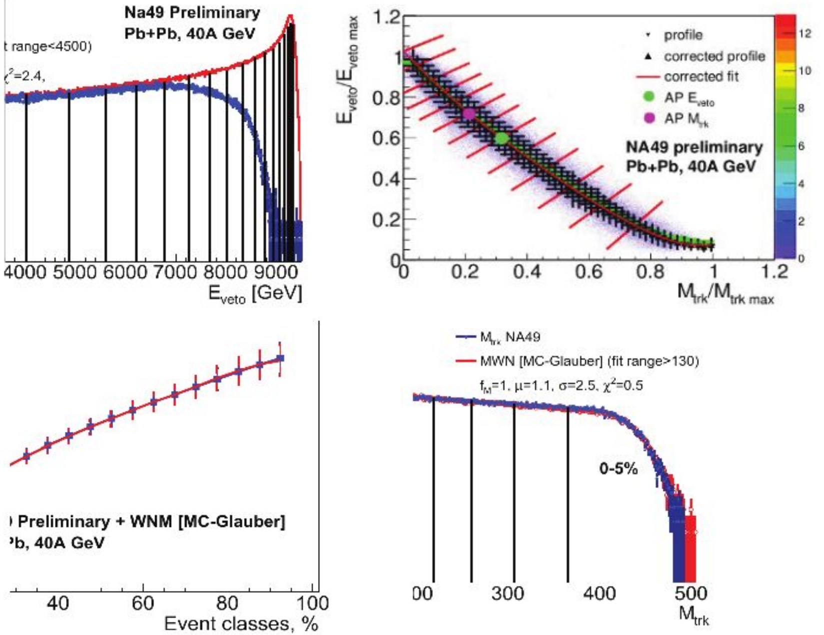
Phys. Rev. C 86 (2012) 54908

Centrality in NA49 & NA61/SHINE

Centrality Framework developed by V. Klochkov and I. Selyuzhenkov was used in both experiments



Nuclear Physics A 982, p. 439-442



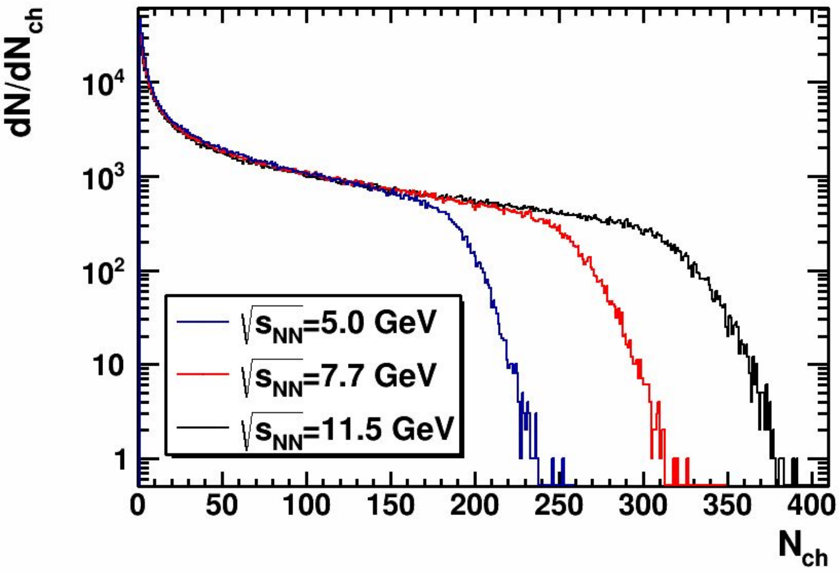
KnE Energy & Physics, p. 275–279

Both charged particle multiplicity and energy deposition were used

Charged particle multiplicity in MPD at NICA

Reconstructed data:

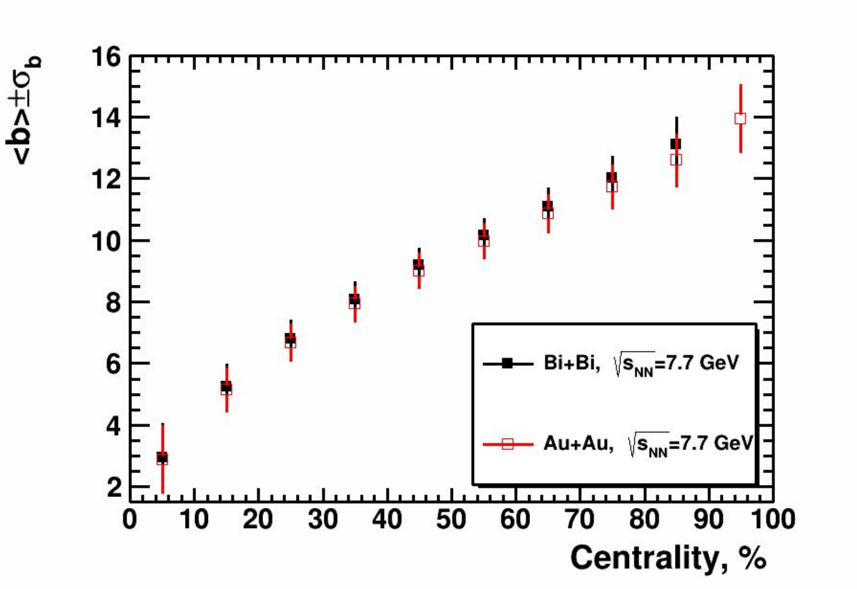
- UrQMD 3.4 simulation
  - Au+Au, N_{ev}=500k, $\sqrt{s_{NN}}$=5, 7.7, 11.5 GeV
  - Bi+Bi, N_{ev}=500k, $\sqrt{s_{NN}}$=7.7 GeV
- GEANT4 MPD detector simulation
- Reconstruction procedure:
  - Realistic tracking in TPC (Cluster Finder)

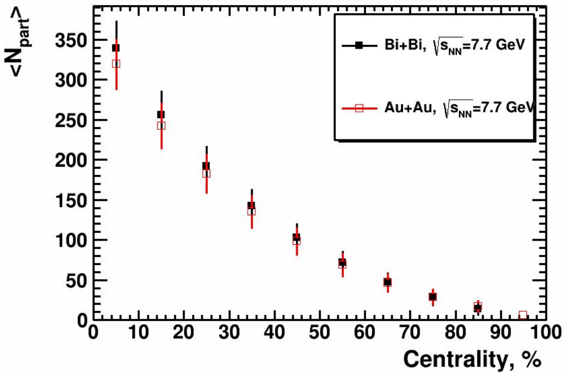


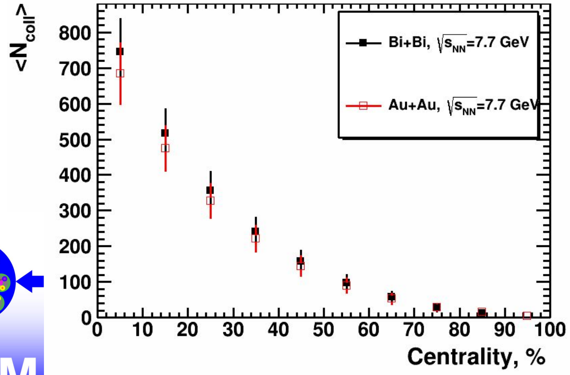
Used particle selection:

- $|\eta|<0.5$
- p_T>0.15 GeV/c

Centrality framework results: MPD at NICA







This centrality procedure was used in CBM, NA49, and NA61/SHINE:

Acta Phys.Polon.Supp. 10 (2017) 919

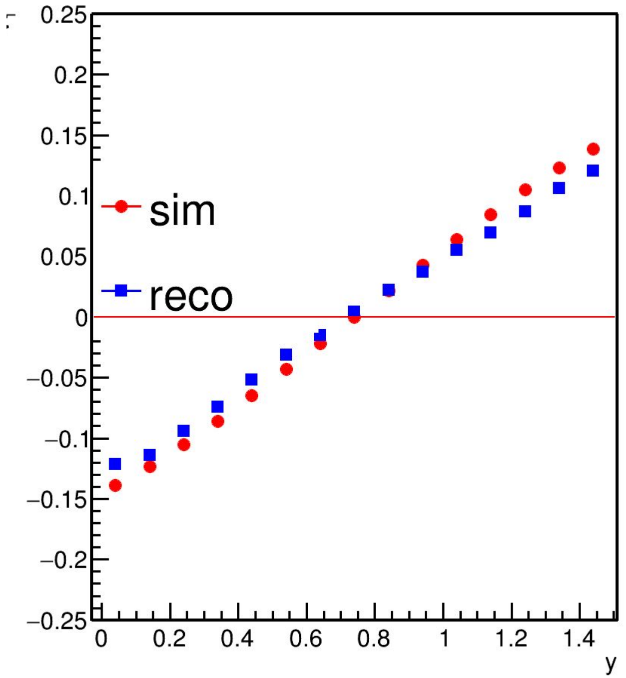
EPJ Web Conf. 182 (2018) 02132

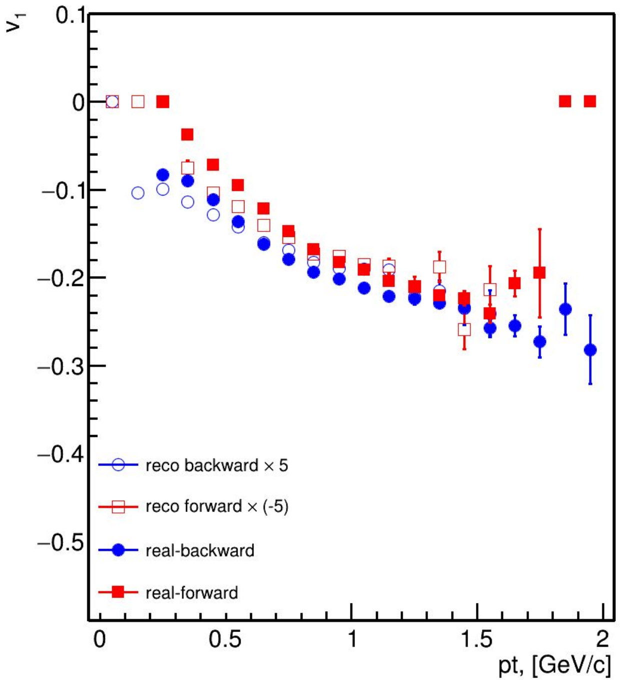
Implementation in CBM: https://cbmgsi.githost.io/pwg-c2f/centrality

Implementation in MPD:
https://github.com/PeterParfenov/AnisotropicFlowMPD/tree/master/CentralityFramework

CBM

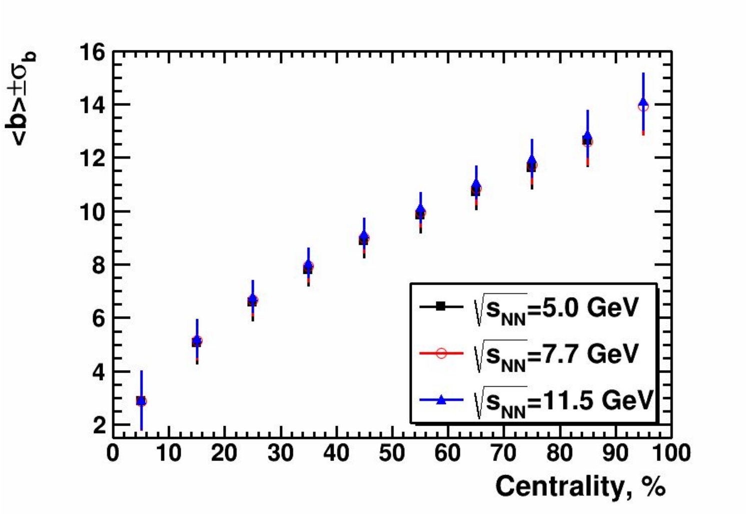
Flow performance studies: FAIR PHASE-0 (HADES)

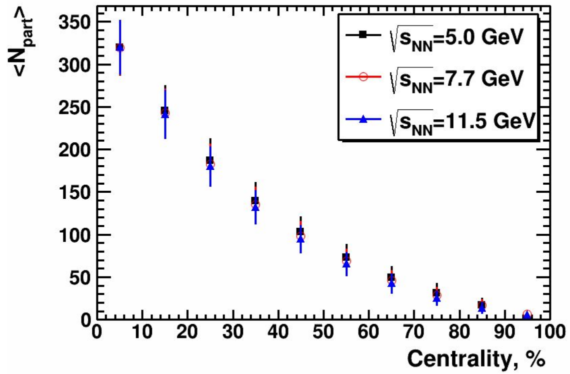


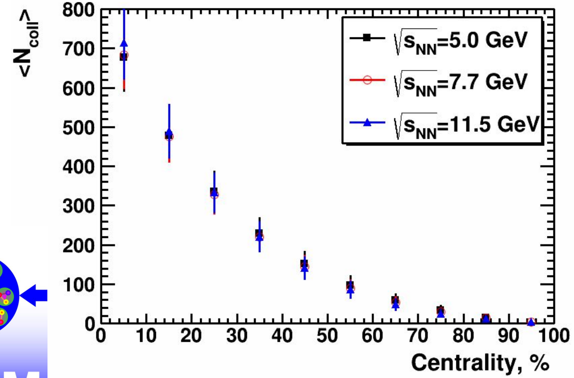


Investigating effects of occupancy corrections with MC vs. real data

Centrality framework results: MPD at NICA







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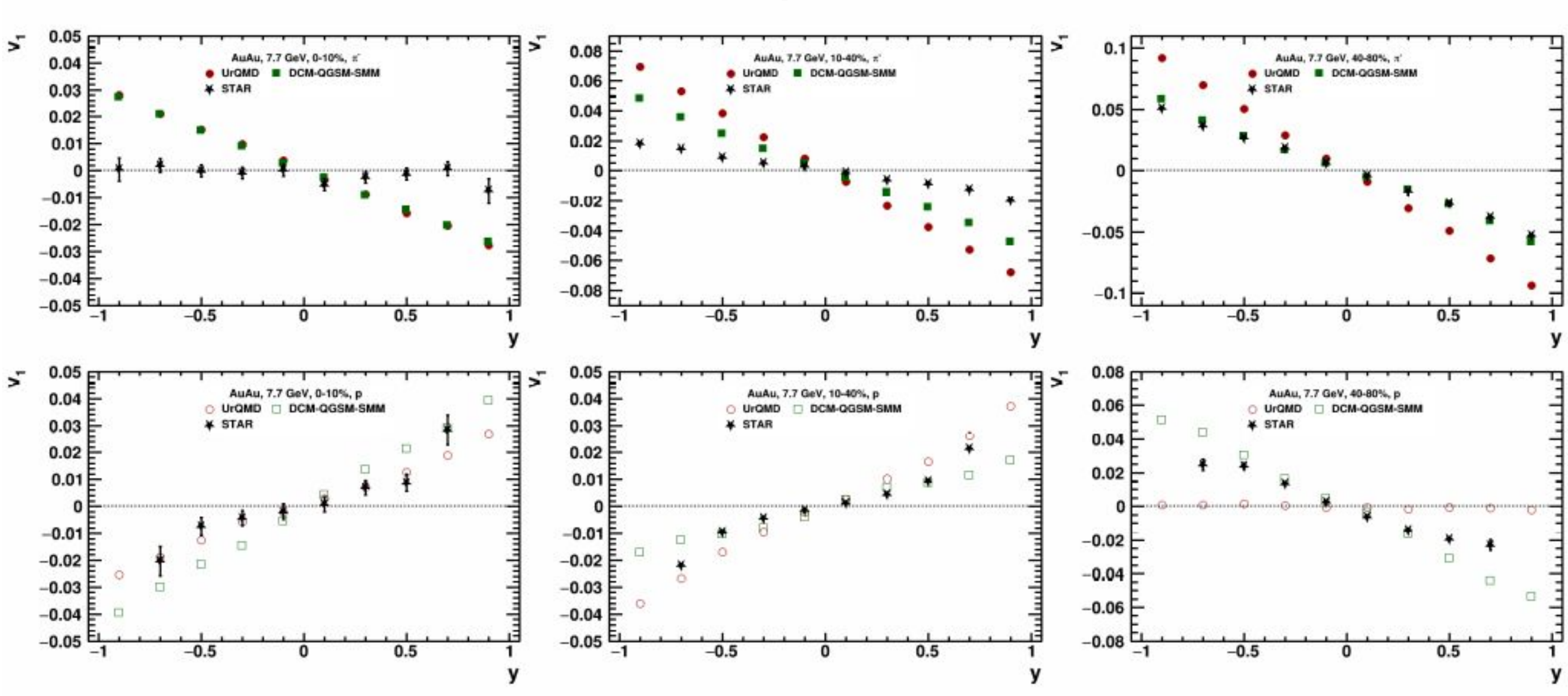
Implementation in CBM: https://cbmgsi.githost.io/pwg-c2f/centrality

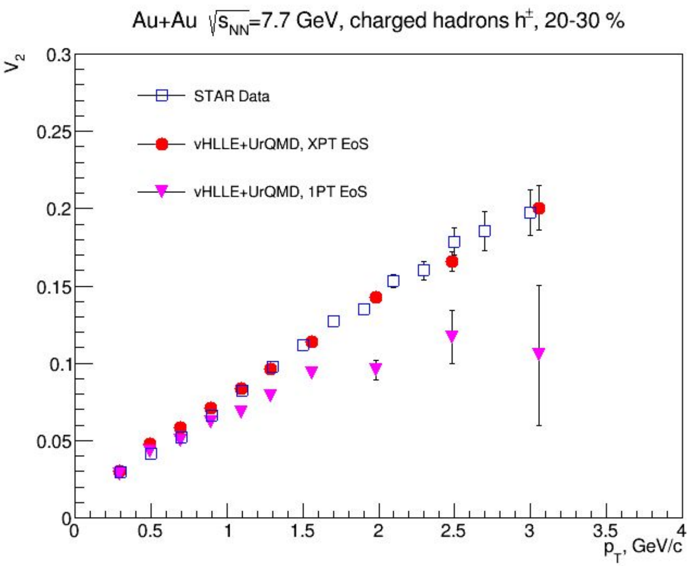
Implementation in MPD: https://github.com/PeterParfenov/AnisotropicFlowMPD/tree/master/CentralityFramework

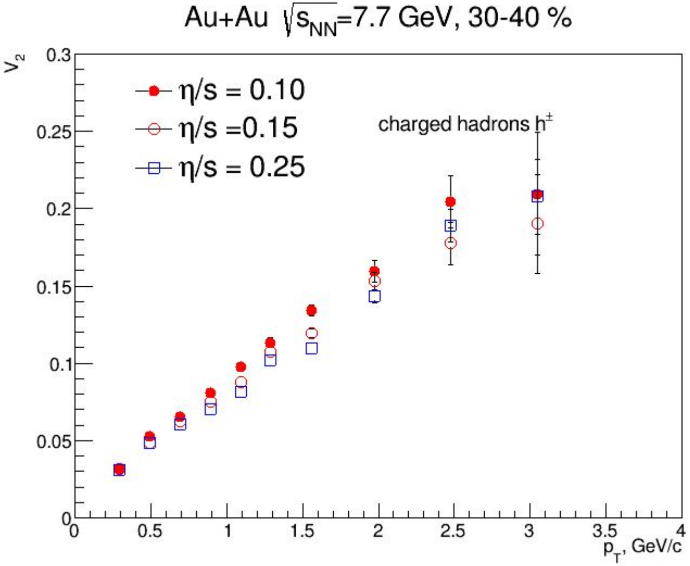
Directed flow: model comparison



DCM-QGSM-SMM better describes v_1 in peripheral collisions

Event generators: comparison with experimental data - elliptic flow

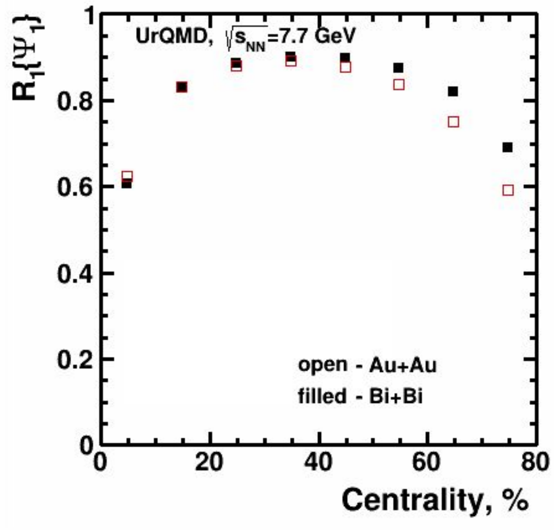




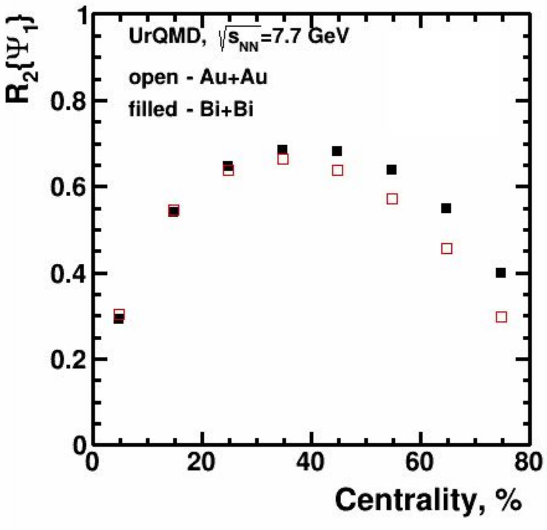
3D hydro model vHLLE + UrQMD shows sensitivity of v2 to the EoS (XPT EoS vs 1PT EoS) and specific shear viscosity (η/s)

Flow performance studies: MPD@NICA - EP comparison

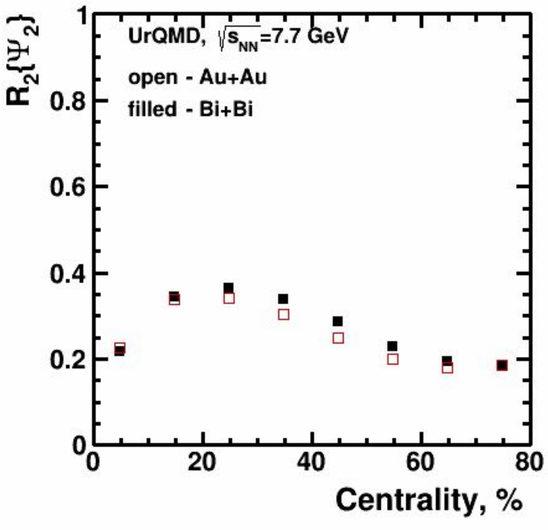
FHCal EP



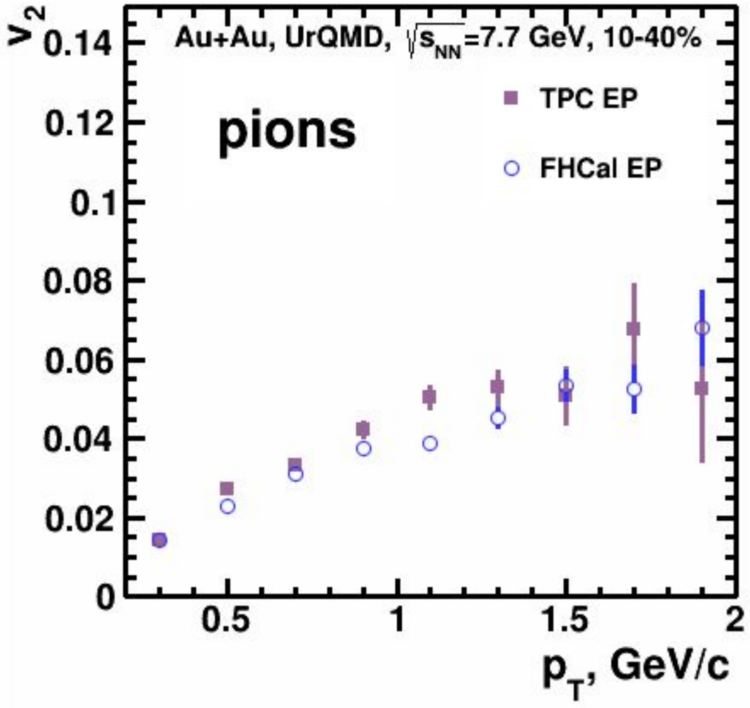
FHCal EP

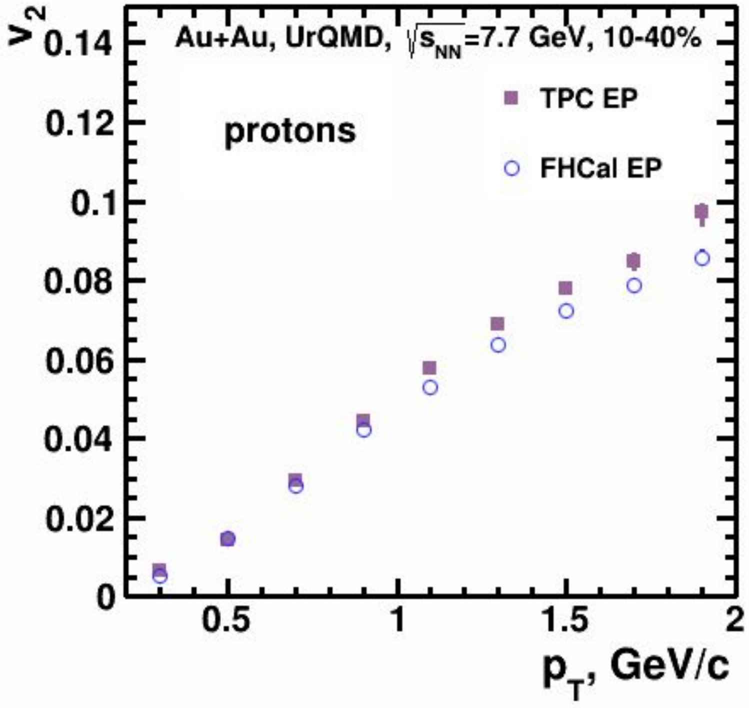


TPC EP

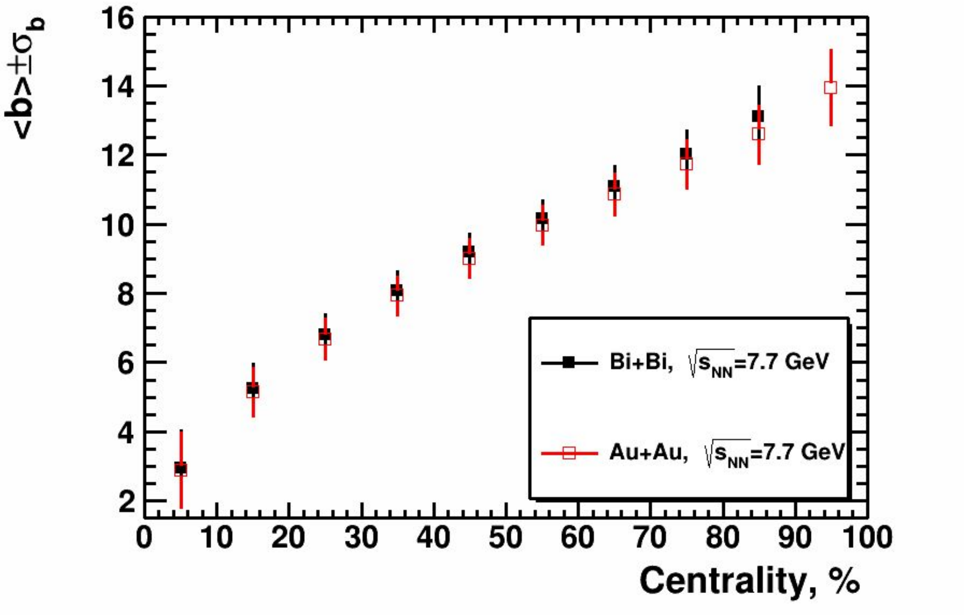


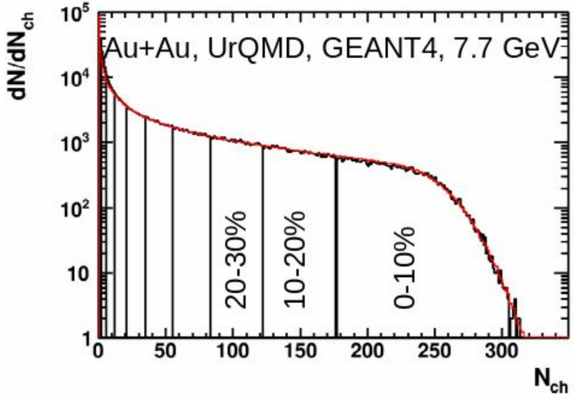
Flow performance studies: MPD@NICA - EP comparison

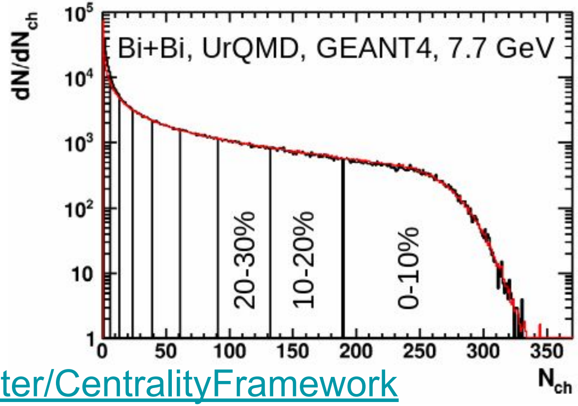




Centrality framework: application in MPD @ NICA



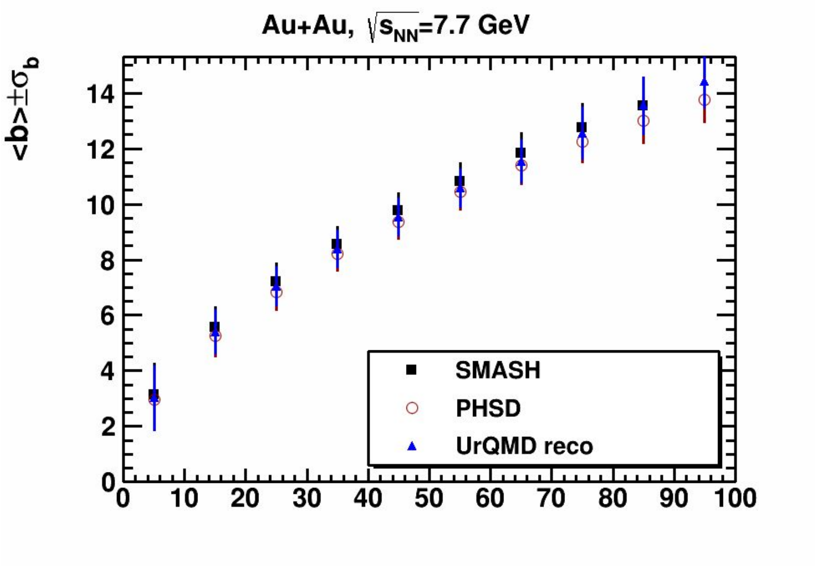


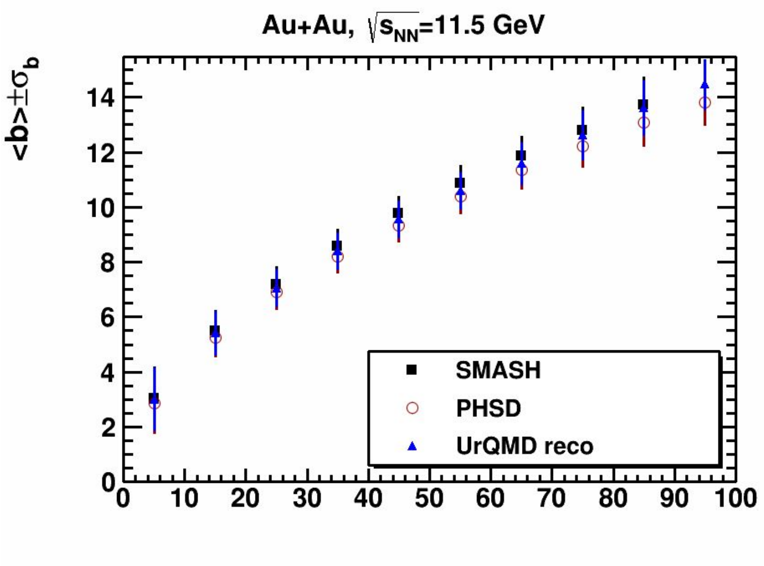


<b> weakly depend on the size of the colliding system

Implementation in MPD:
https://github.com/PeterParfenov/AnisotropicFlowMPD/tree/master/CentralityFramework

Centrality at MPD: model comparison

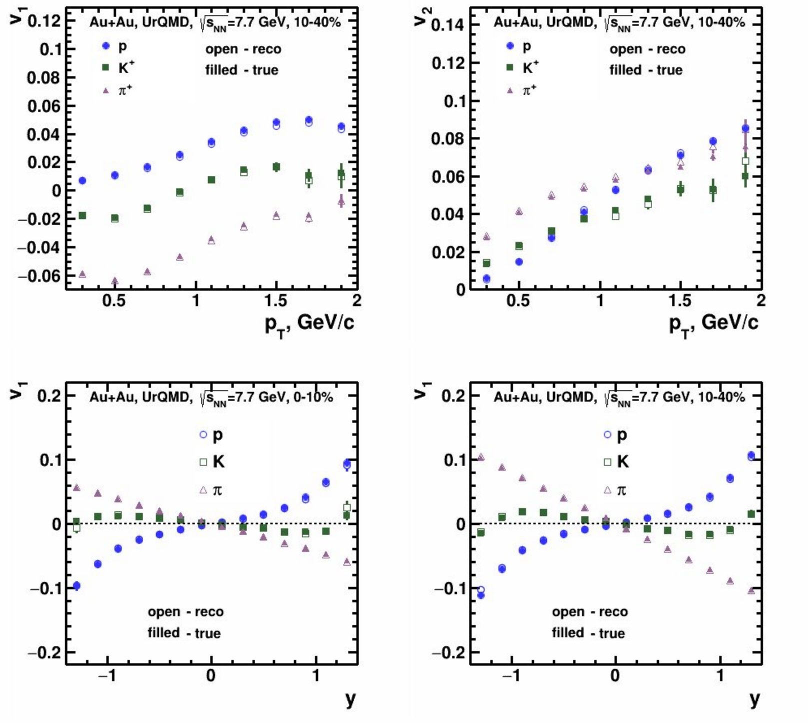




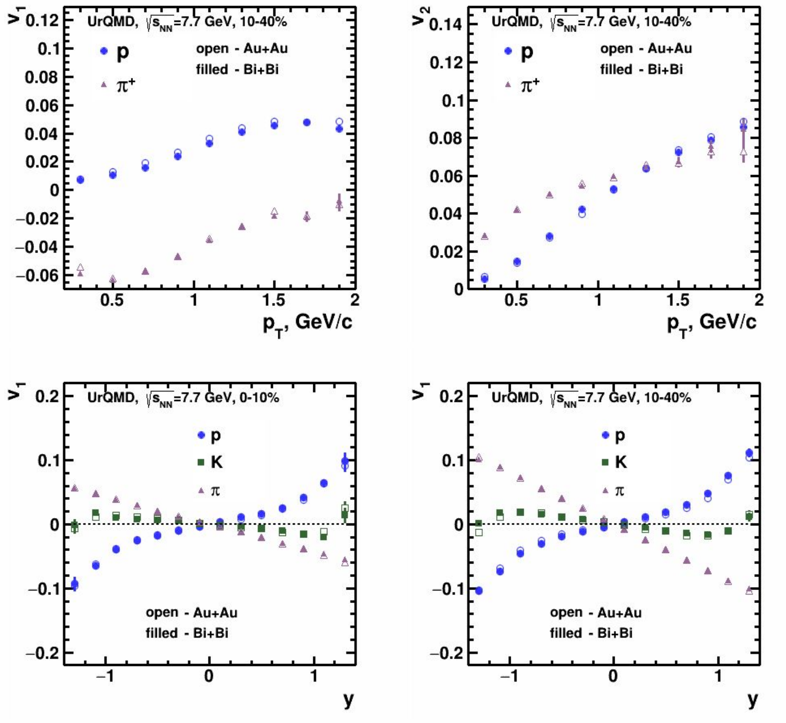
<b> obtained from the different models are in reasonable agreement

Flow performance studies: MPD@NICA

MC vs reconstructed



Au+Au vs Bi+Bi



Good agreement between MC and reconstructed signals

Small difference between Au+Au and Bi+Bi