CBM physics performance studies for anisotropic flow measurements

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for the CBM Collaboration

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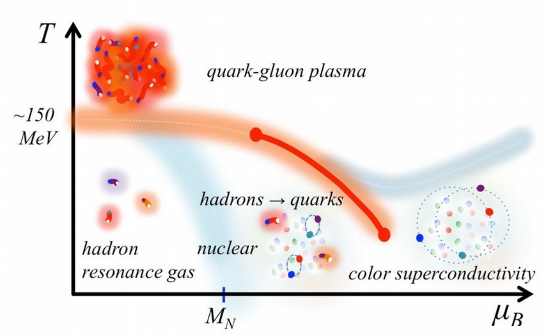
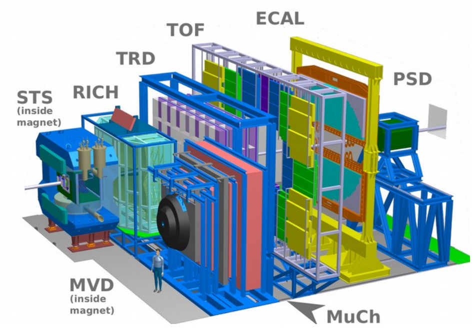
6/06/2019

Outline

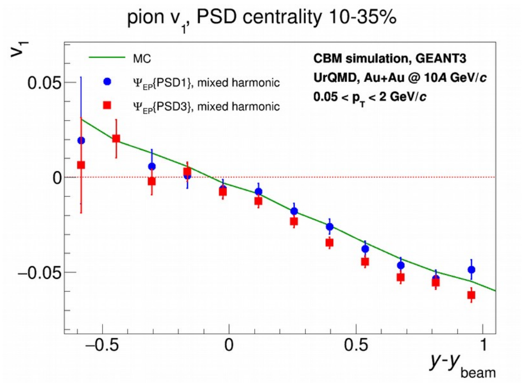
- Physics motivation



- CBM experimental setup



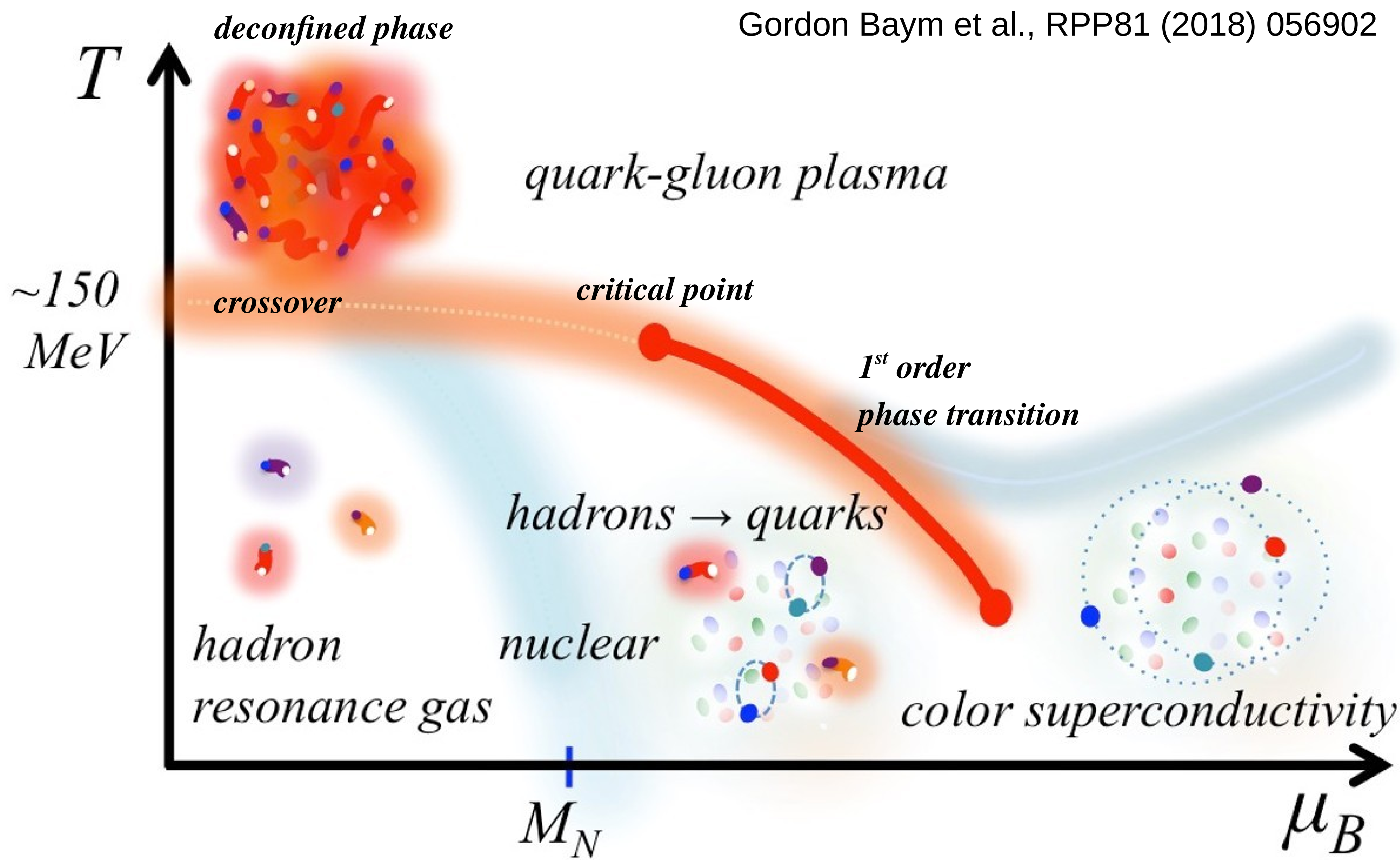
- Flow performance studies



- Conclusions and outlook

Structure of the QCD matter phase diagram

Gordon Baym et al., RPP81 (2018) 056902



Structure of the QCD matter phase diagram

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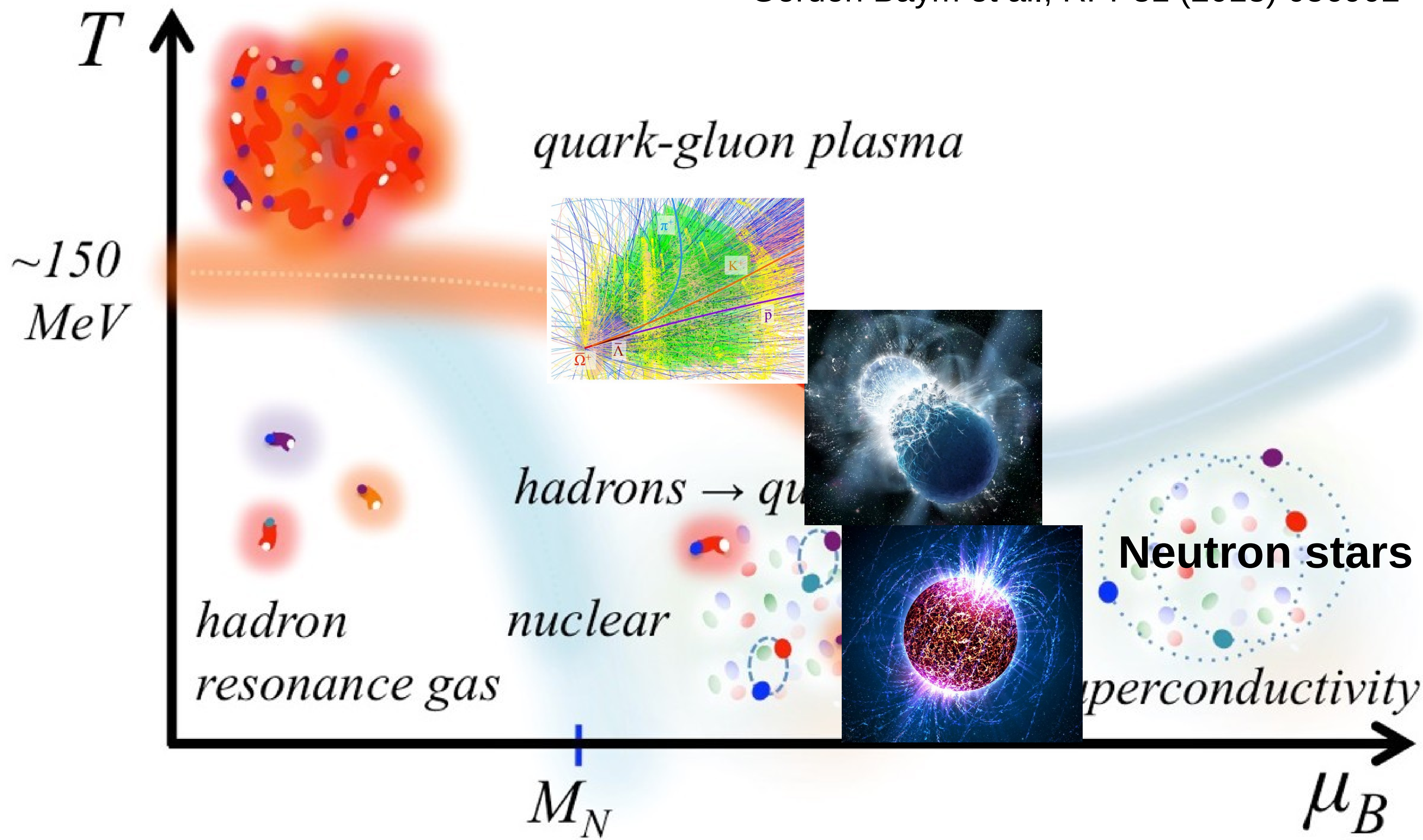
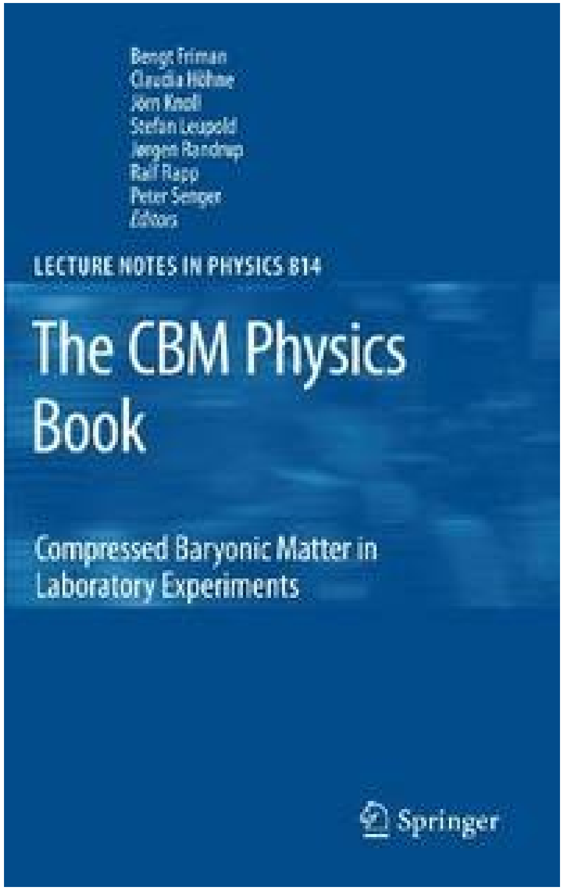


CBM physics and observables

- Quark matter equation-of-state at large baryon densities,
  coexistence (quarkyonic) & partonic phases:
  - Hadron yields, collective flow, correlations, fluctuations
  - (Multi-)strange hyperons (K, Λ, Σ, Ξ, Ω)
  - production at (sub)threshold energies
- Chiral symmetry at large baryon densities
- Hypernuclei
- Charm production and propagation at threshold energies
  - Excitation function in p+A collisions (J/ψ, D^0 , D^{+-})
  - Charmonium suppression in cold nuclear matter

CBM collaboration, EPJA 53 (2018) 60

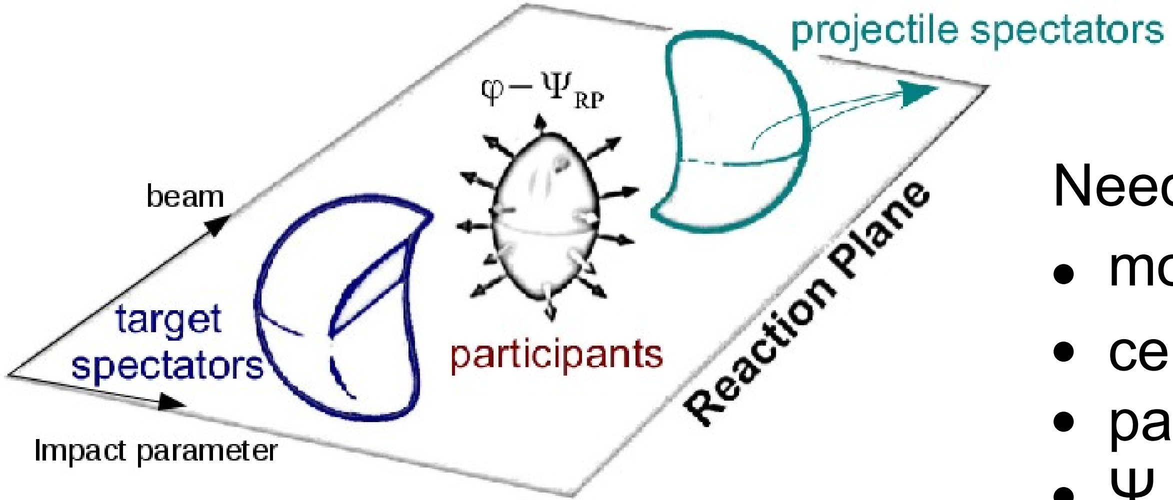


Collision geometry and anisotropic transverse flow

Asymmetry in coordinate space converts due to interaction into momentum asymmetry with respect to the symmetry plane (reaction plane - RP)

$$\rho(\varphi - \Psi_{RP}) = \frac{1}{2\pi}\left(1 + 2\sum_{n=1}^{\infty} v_n \cos\left(n(\varphi - \Psi_{RP})\right)\right)$$

$$v_n = \langle \cos[n(\varphi - \Psi_{RP})] \rangle$$

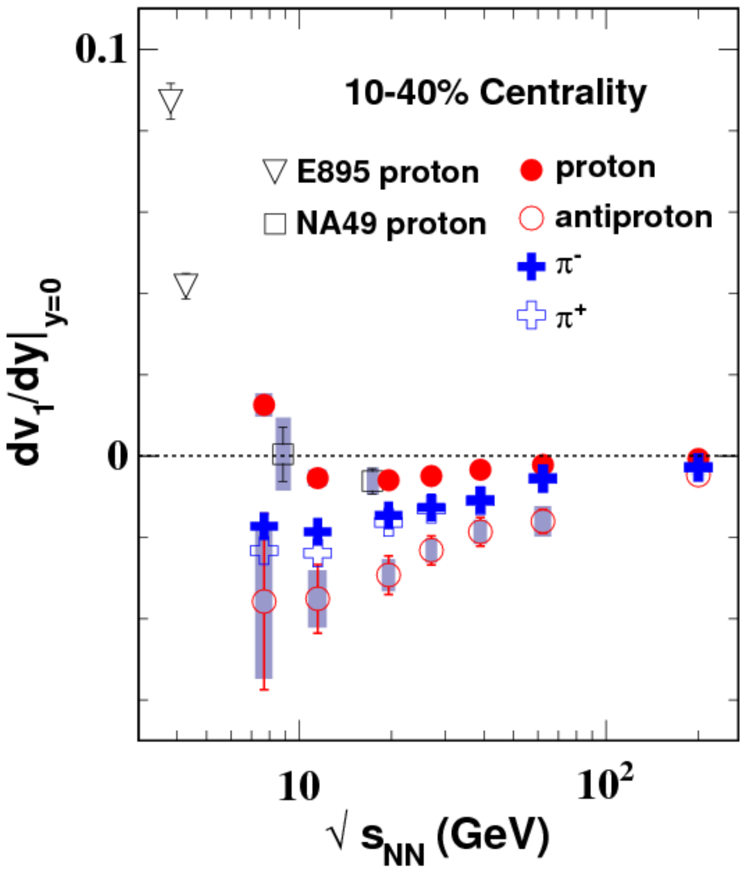


Needed components to calculate v_n:

- momentum (φ, Y, p_T)
- centrality estimation
- particle identification
- Ψ_{RP} estimation

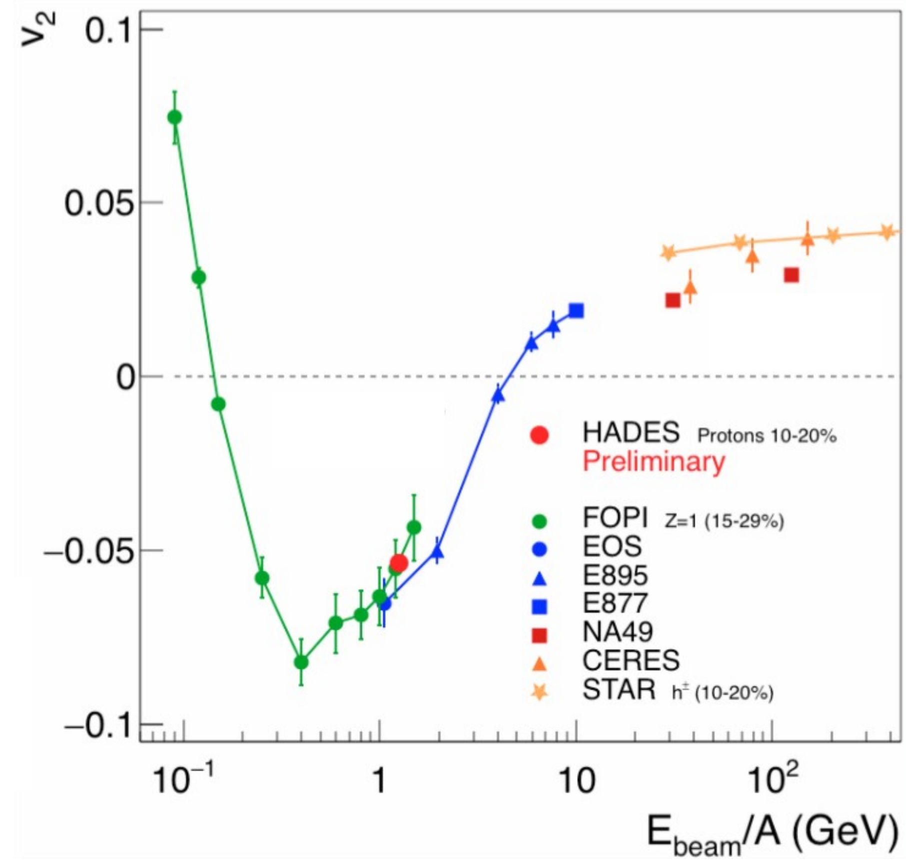
Collective flow at FAIR energies

Directed flow (slope)



STAR Collaboration
PRL 112 (2014) 162301

Elliptic flow

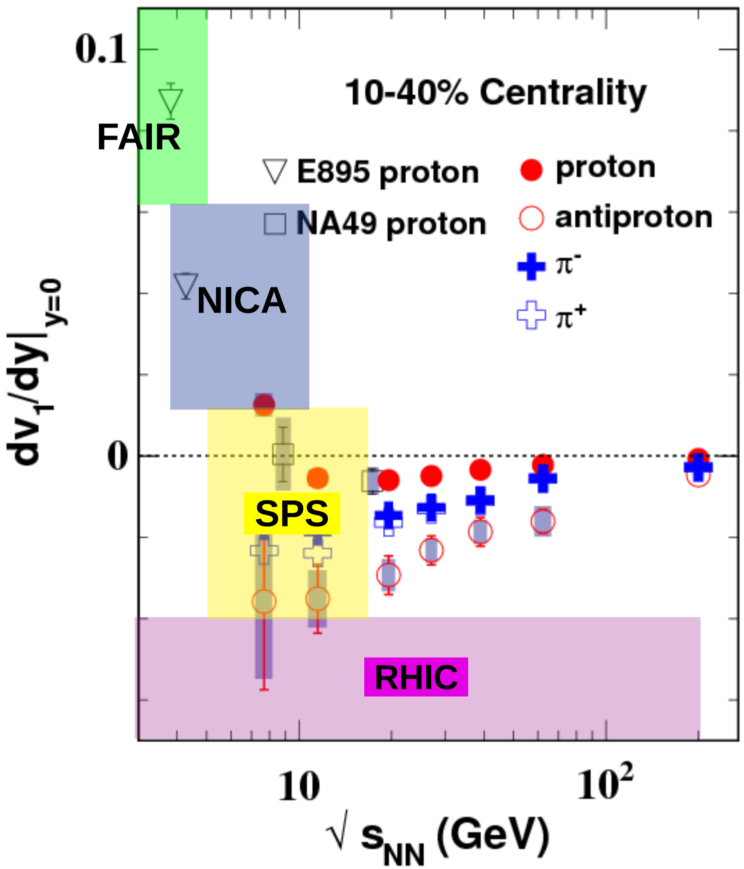


HADES Collaboration
JPCS 742 (2016) 012008

CBM will extend existing data and provide new measurements for identified particles including multistrange hyperons and di-leptons

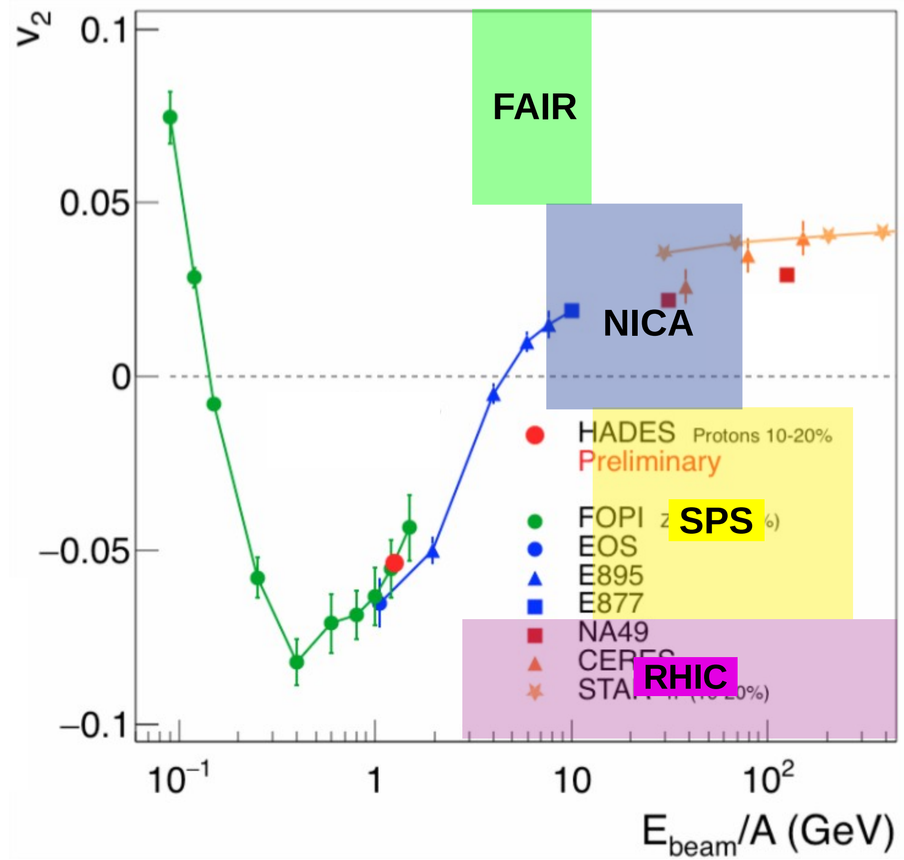
Collective flow at FAIR energies

Directed flow (slope)



STAR Collaboration
PRL 112 (2014) 162301

Elliptic flow

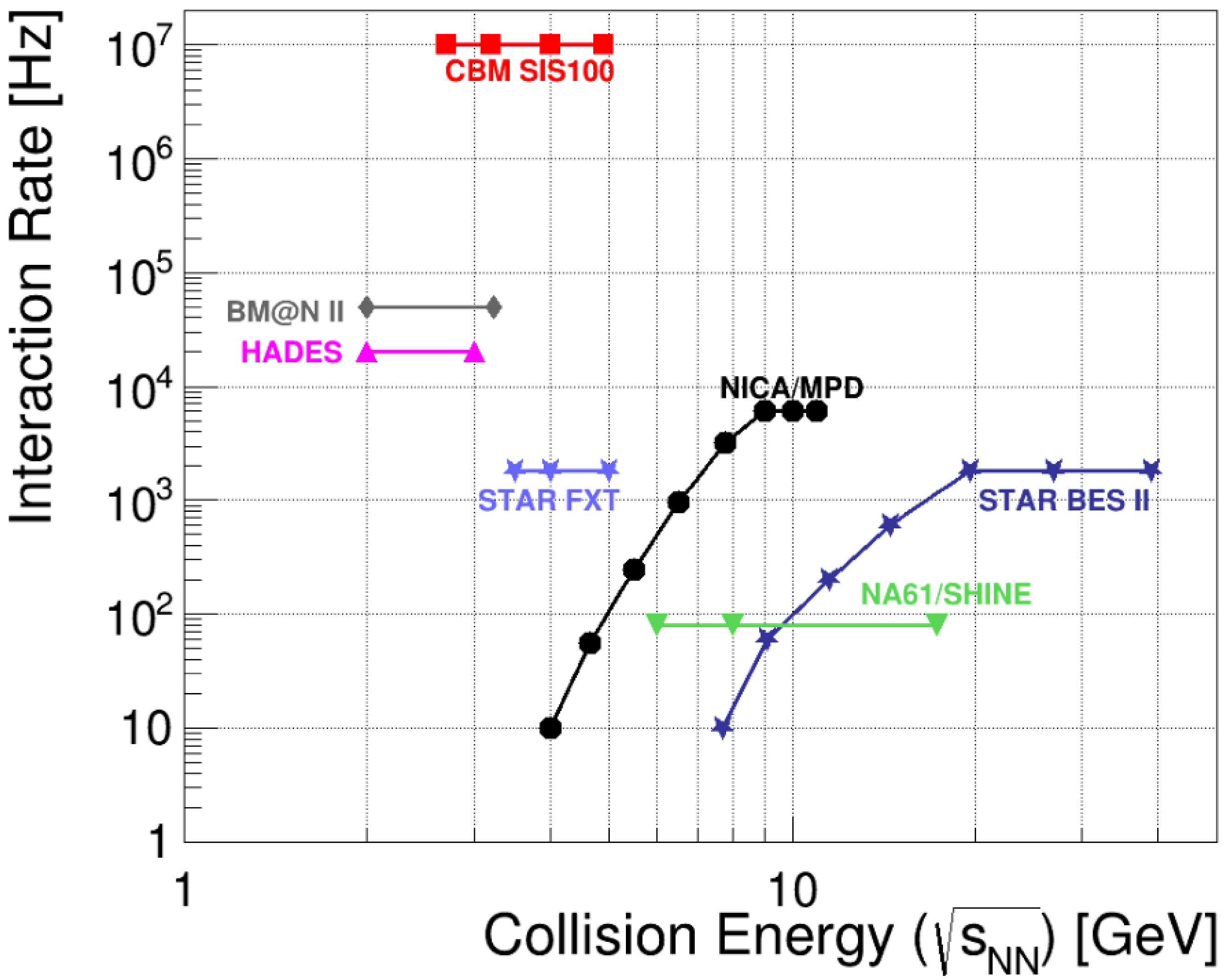


HADES Collaboration
JPCS 742 (2016) 012008

CBM will extend existing data and provide new measurements for identified particles including multistrange hyperons and di-leptons

Experiments in the high net-baryon density

CBM collaboration, EPJA 53 (2018) 60

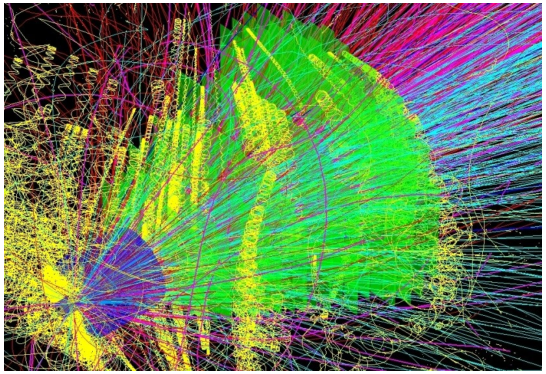


CBM will operate at high reaction rates: 10^5 - 10^7 Au+Au collisions/sec

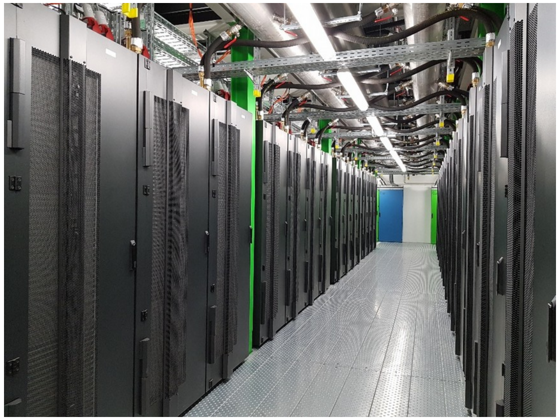
Main experimental requirements

- High statistics needs high event rates: 10^5 - 10^7 Au+Au collisions/sec
- Fast, radiation hard detectors & front-end electronics
- Free-streaming readout & 4 dimensional (space+time) event reconstruction
- Particle identification: hadrons and leptons, displaced (~50 μm) vertex reconstruction for charm measurements
- High speed data acquisition & performance computing farm for online event selection

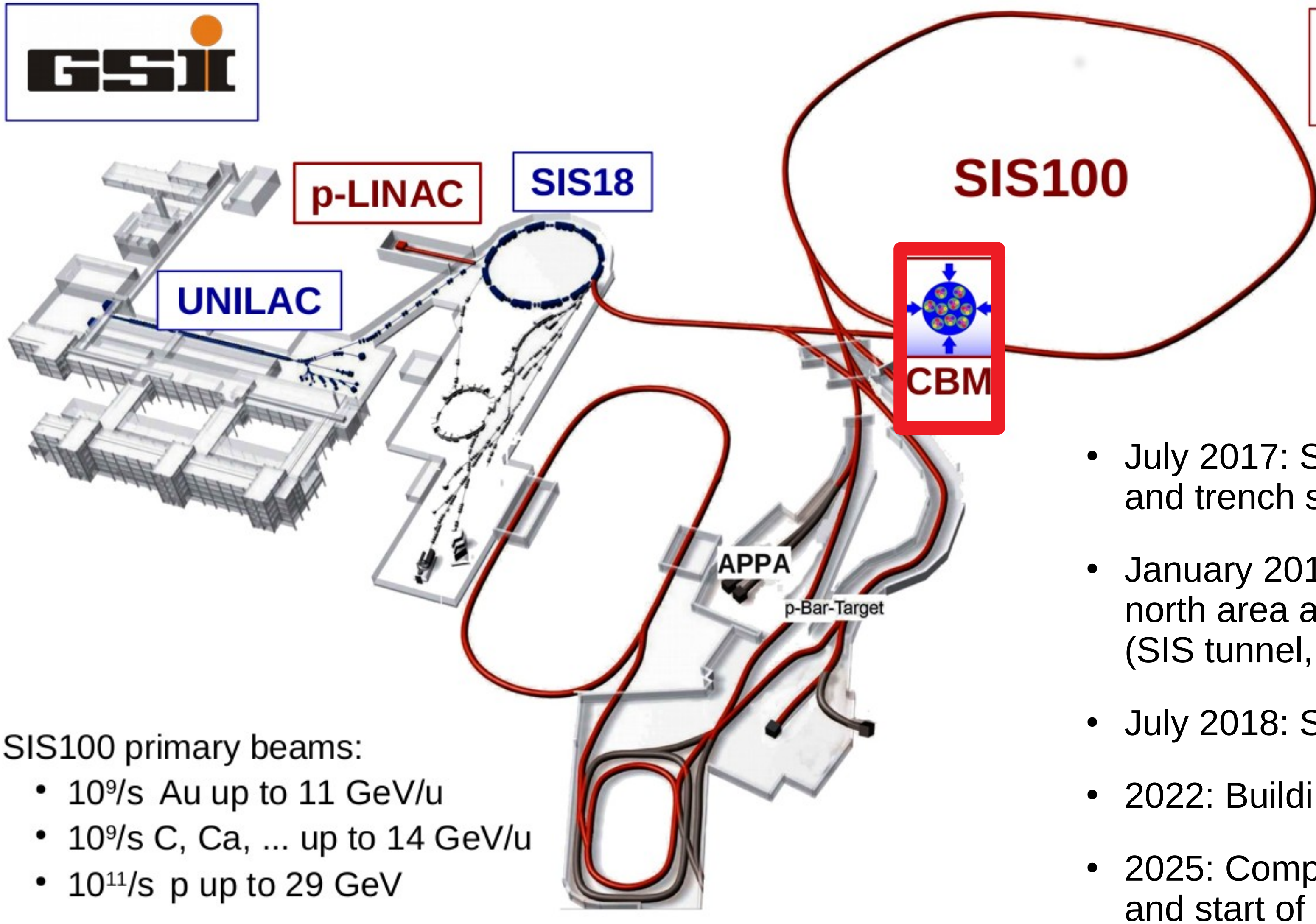
central Au+Au collision @ 10*A* GeV/*c*



GSI IT Center



CBM at FAIR, Darmstadt



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

Timeline

- July 2017: Start of excavation and trench sheeting
- January 2018: Civil construction north area awarded (SIS tunnel, CBM building)
- July 2018: Start of shell construction
- 2022: Buildings completed
- 2025: Completion of full facility and start of operations

CBM detector subsystems

STS

Silicon Tracking System*

MVD

Micro Vertex Detector*

* magnetic field

MuCh or RICH

MuonChamber System/
Ring Imaging Cherenkov Detector

TRD

Transition Radiation Detector

ToF

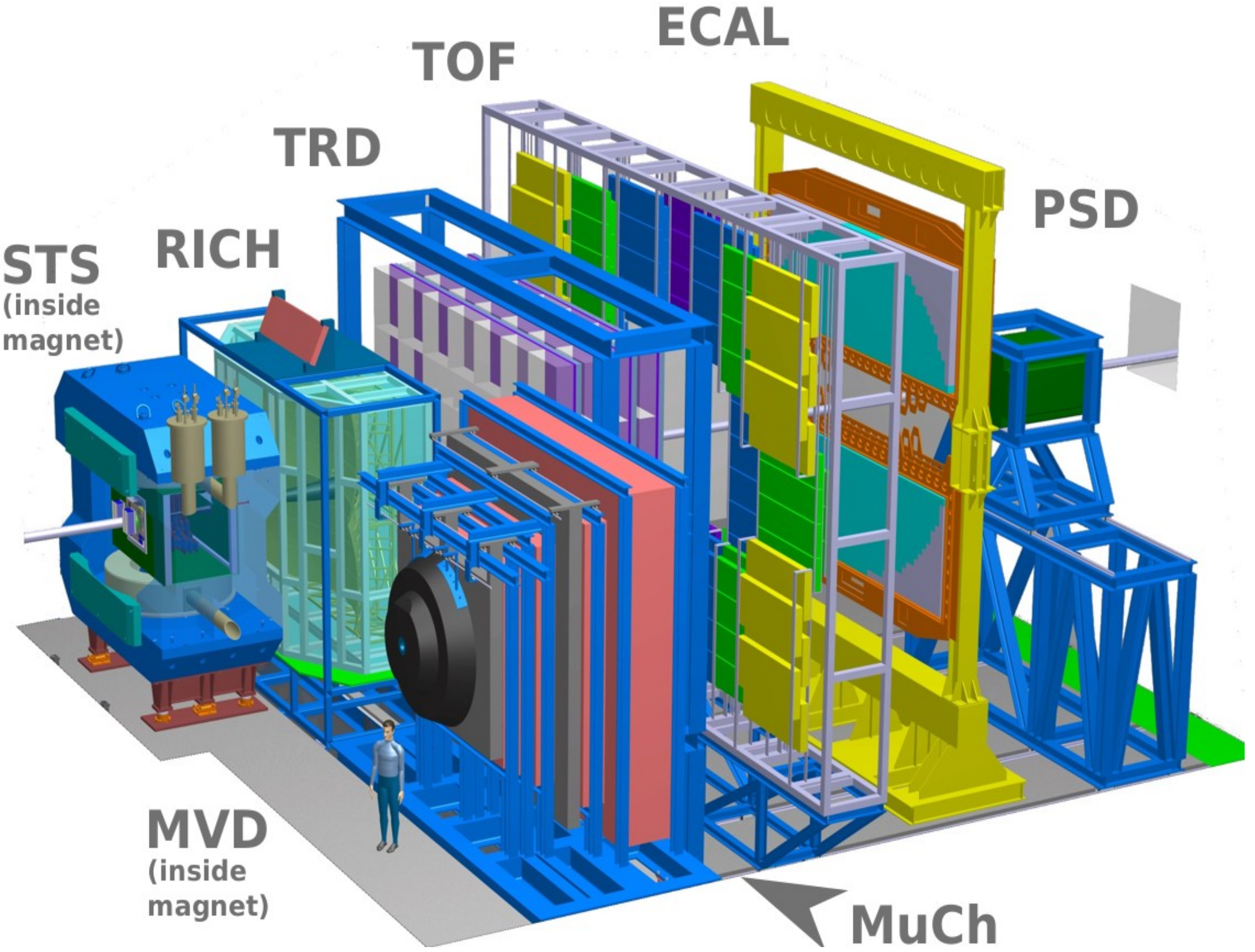
Time-of-Flight Detector

ECAL

Electromagnetic Calorimeter

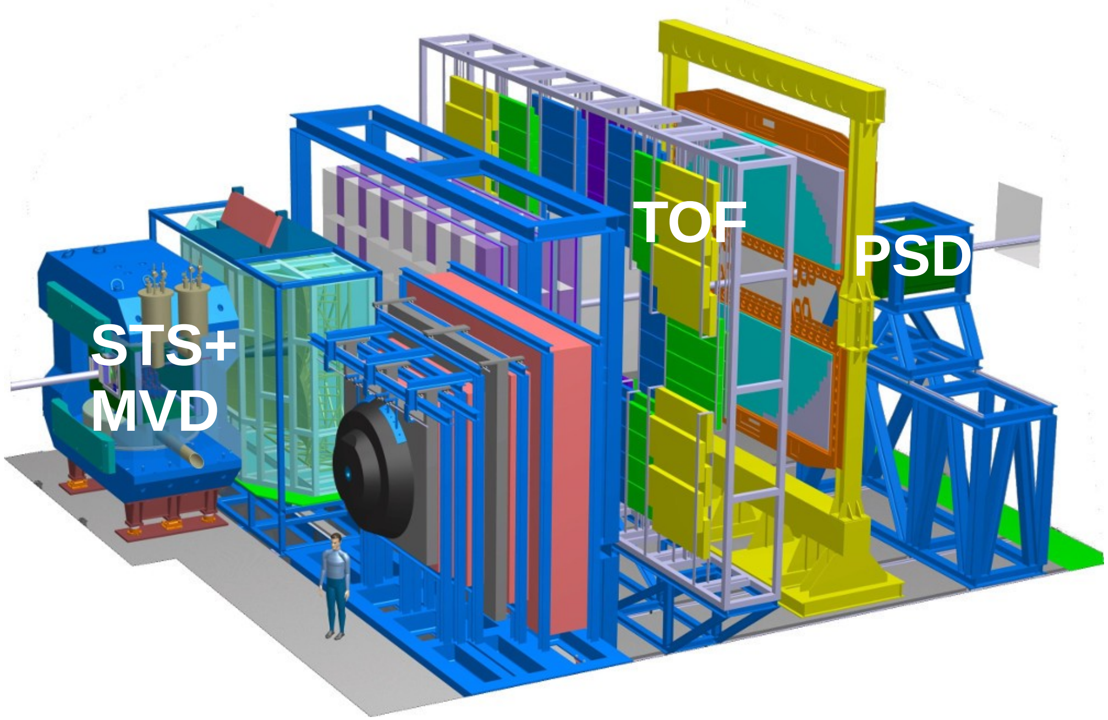
PSD

Projectile Spectator Detector

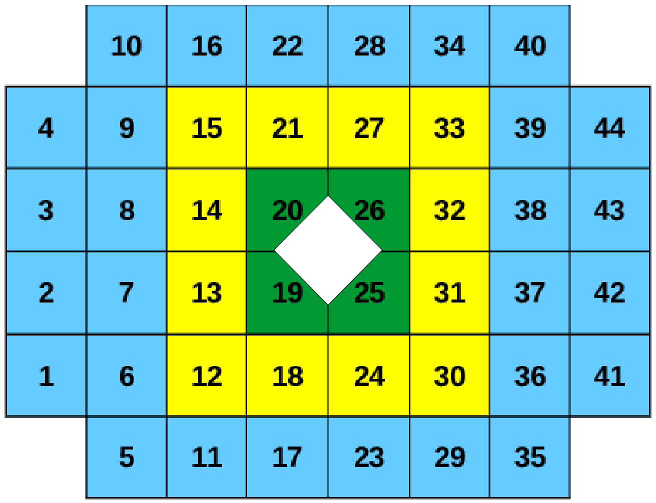


Detector subsystems relevant to flow measurement

- Particle momentum (φ,Y, p_T): STS+MVD
- Centrality estimation: event classes defined with PSD energy (STS multiplicity)
- Particle identification: TOF
- Reaction plane (Ψ_{RP}): PSD transverse energy asymmetry (φ distribution in STS)



PSD transverse layout

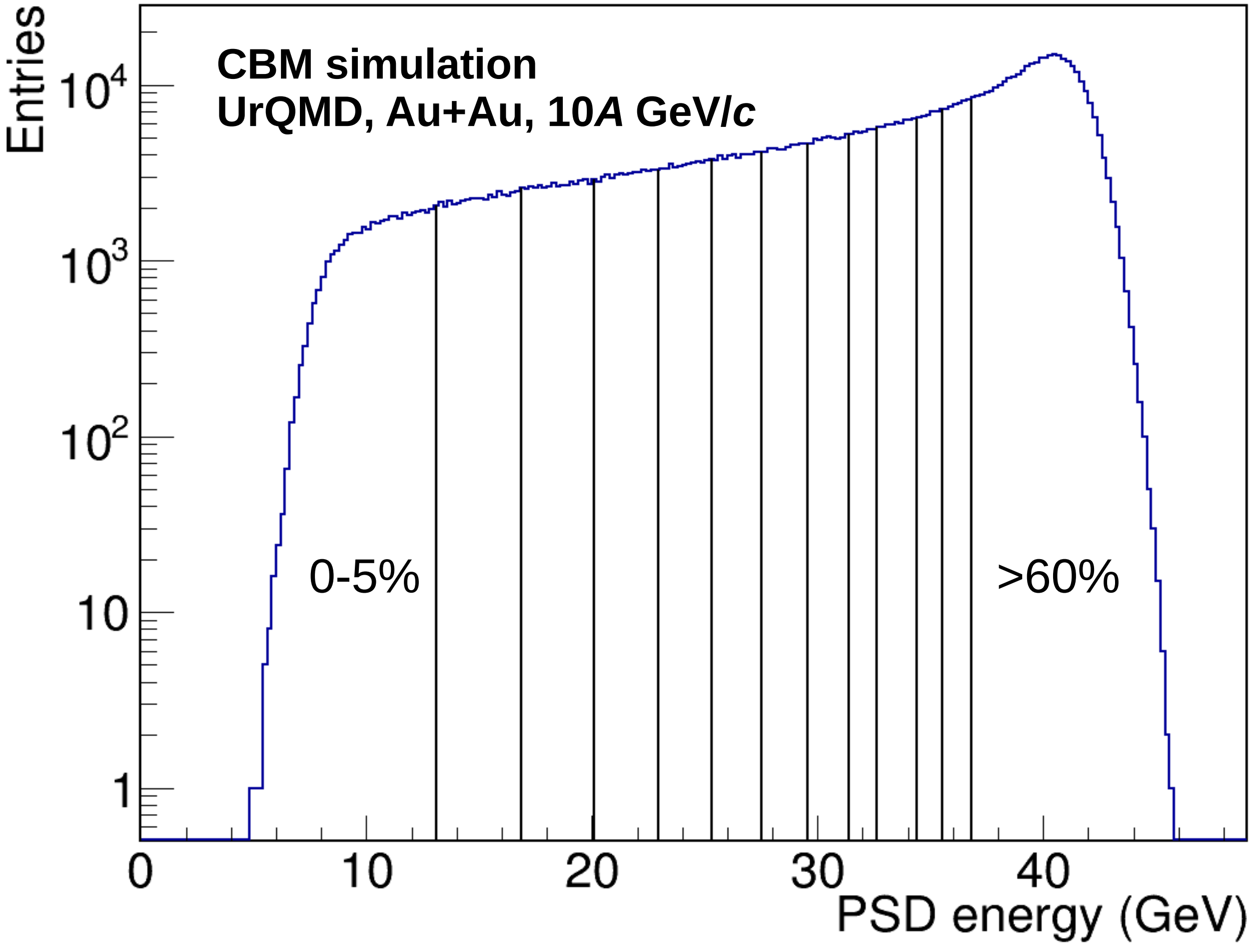


Hole size: 20 cm
(side of the square)

Simulation setup

Model	UrQMD v3.4 (no fragments)
System	Au+Au
Beam momemtum	10*A* GeV/*c*
Statistics	3M events
CBM geometry	MVD, STS, RICH, TDR, TOF, PSD
PSD geometry	20 cm hole size 44 modules
Transport code	GEANT3
Detector response	CBMROOT JUL17

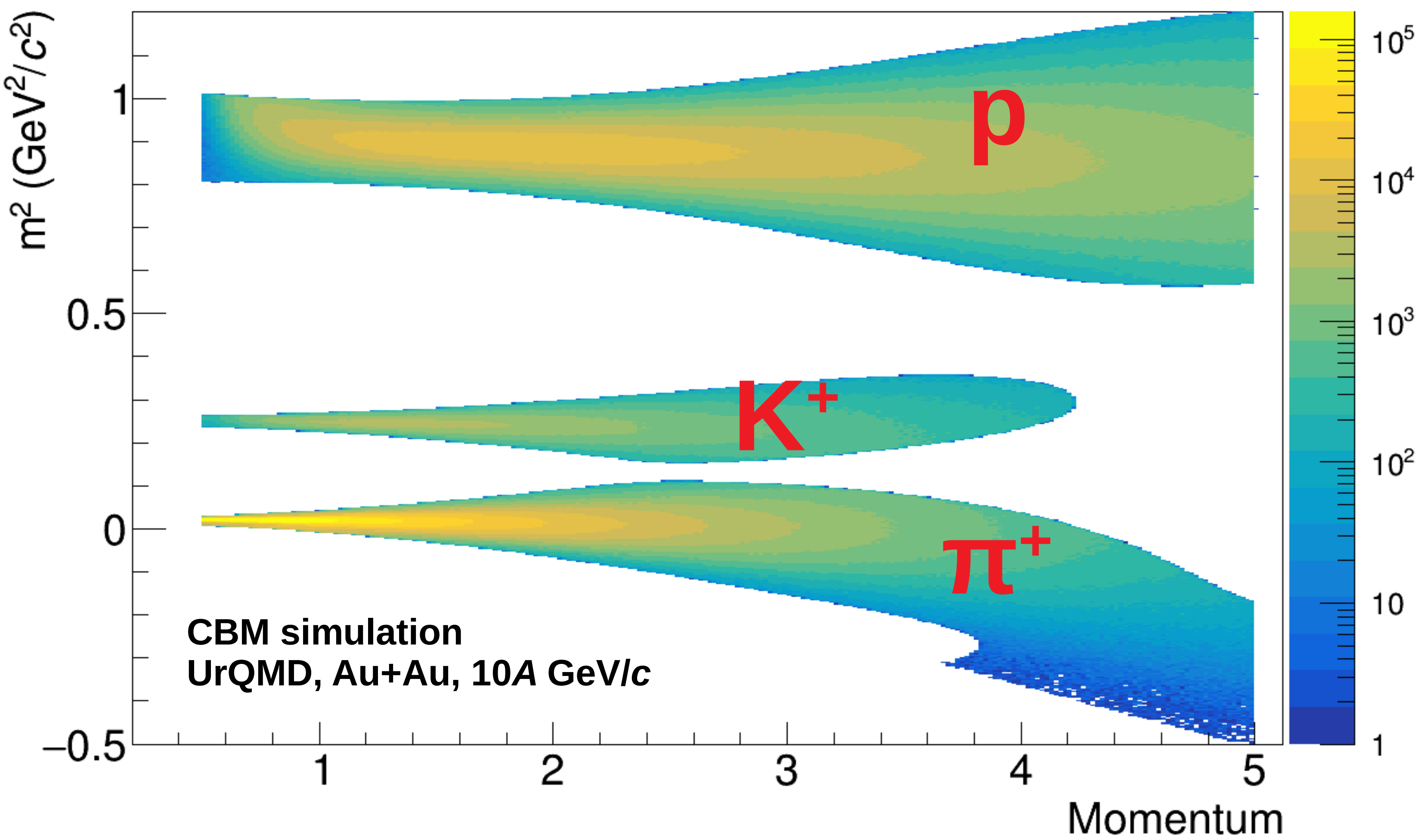
Centrality determination with PSD energy



Centrality classes are defined using forward rapidity energy

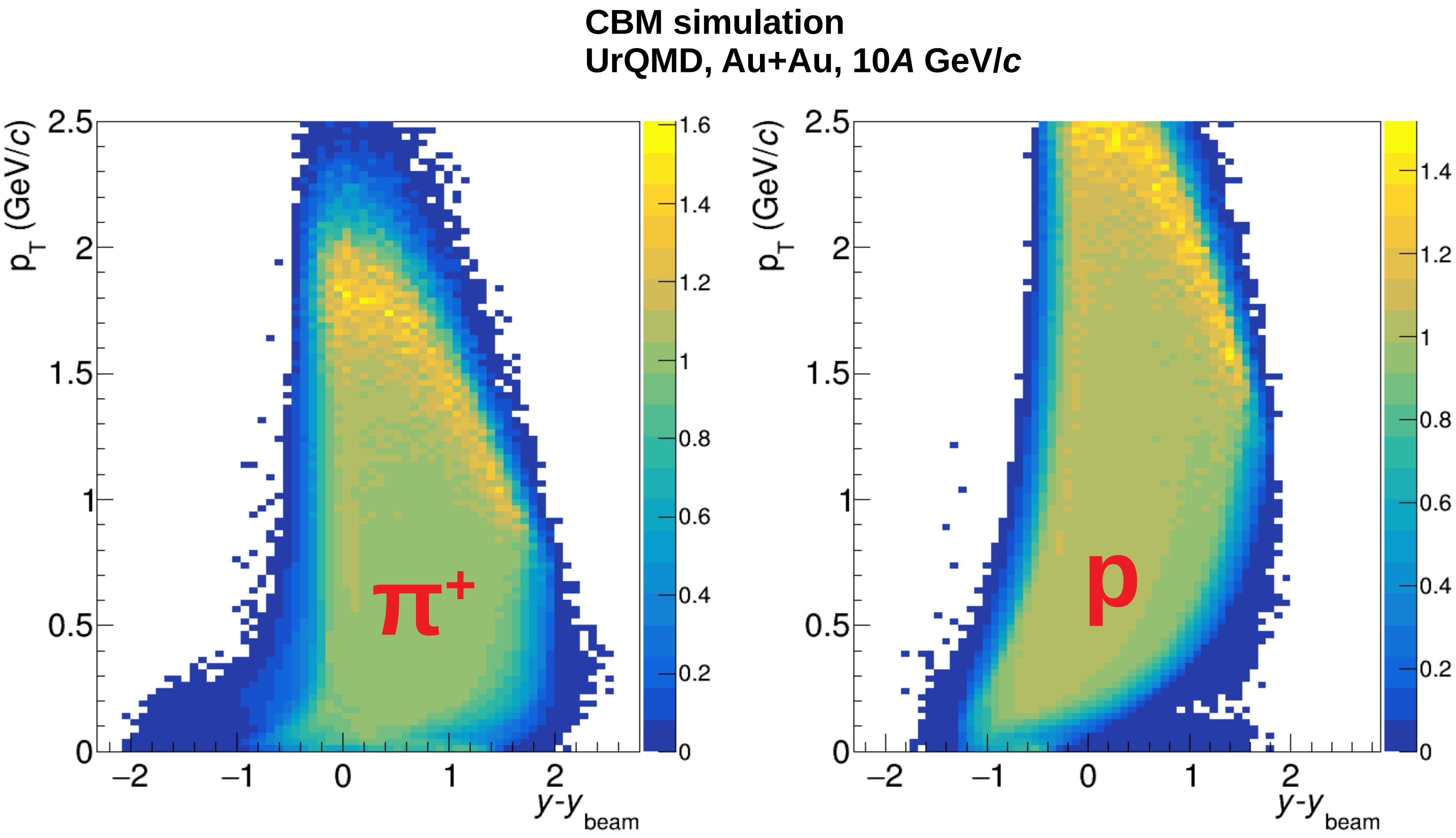
Particle identification with Bayesian approach

Purity > 90%



Time-of-Flight technique provides clear separation between charged hadrons

Tracking efficiency correction

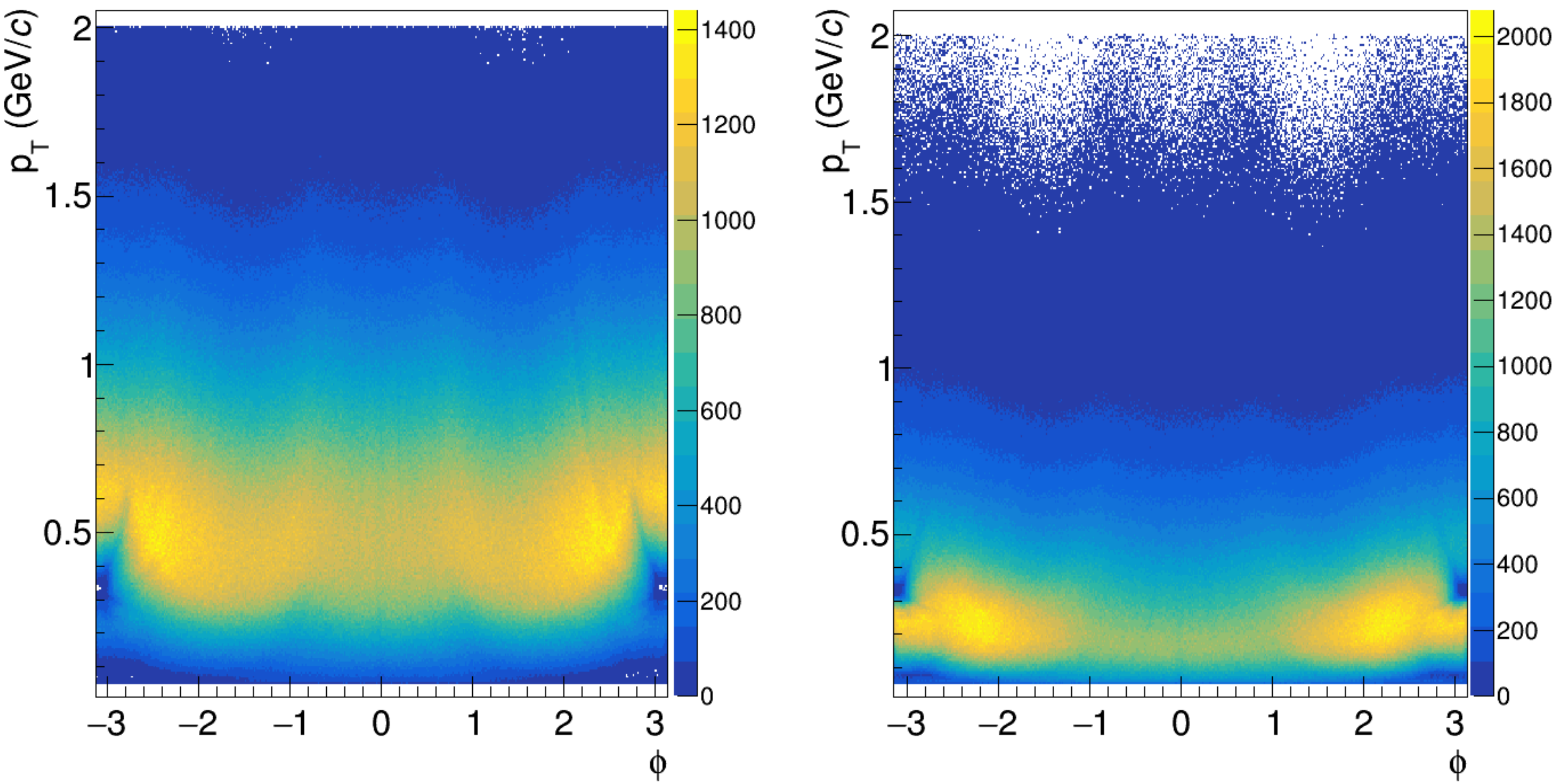


Correction for tracking efficiency was applied

Azimuthal angle acceptance

CBM simulation
UrQMD, Au+Au, 10*A* GeV/*c*

proton π^+



Non-uniformity of azimuthal acceptance – corrections are needed

Event plane and scalar product methods

$$v_n = \langle \cos[n(\varphi - \Psi_{RP})] \rangle$$

- v_n with respect to symmetry plane estimated using group of particles (subevent) A:

$$v_n(A;i) = \frac{\langle 2 u_i Q_i^n(A) \rangle}{R_i^n(A)} \qquad i = (x, y)$$

$$\vec{u}_n = (\cos(n\varphi), \sin(n\varphi)) \qquad \vec{Q}_n = \frac{1}{N} \sum \omega_j \vec{u}_{n,j}$$

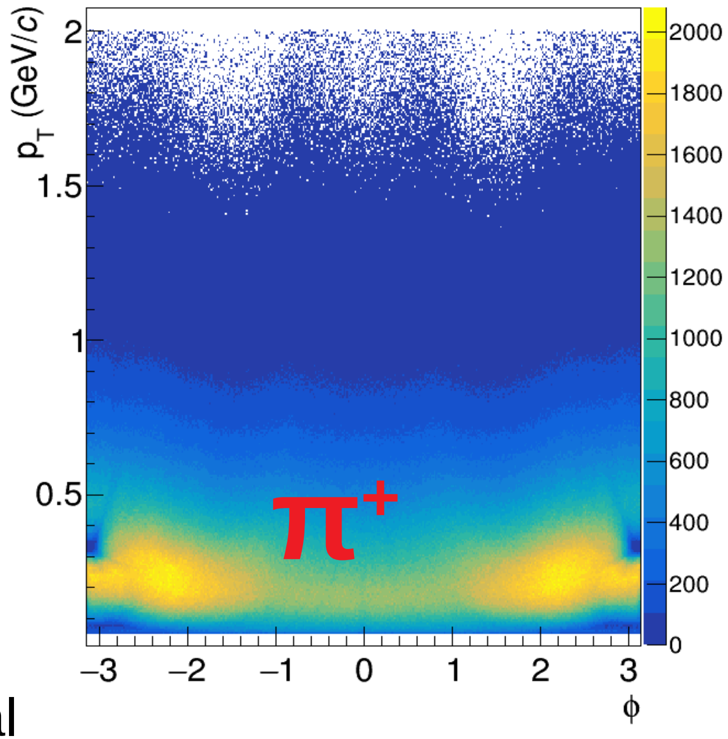
- mixed harmonic method:

$$R_i^n(A; B, C, D) \propto \sqrt{\frac{\langle Q_i^1(A) Q_i^1(B) \rangle \langle Q_i^1(A) Q_i^1(C) Q_i^2(D) \rangle}{\langle Q_i^1(B) Q_i^1(C) Q_i^2(D) \rangle}}$$

Corrections for detector azimuthal non-uniformity

Flow Vector 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/FlowCorrections/FlowVectorCorrections
- Recentering, twist, and rescaling corrections applied time dependent (run-by-run) and as a function of centrality

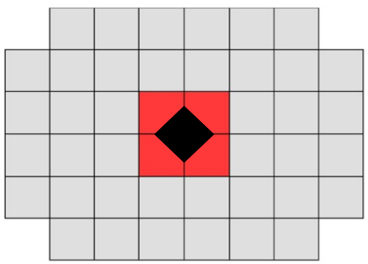


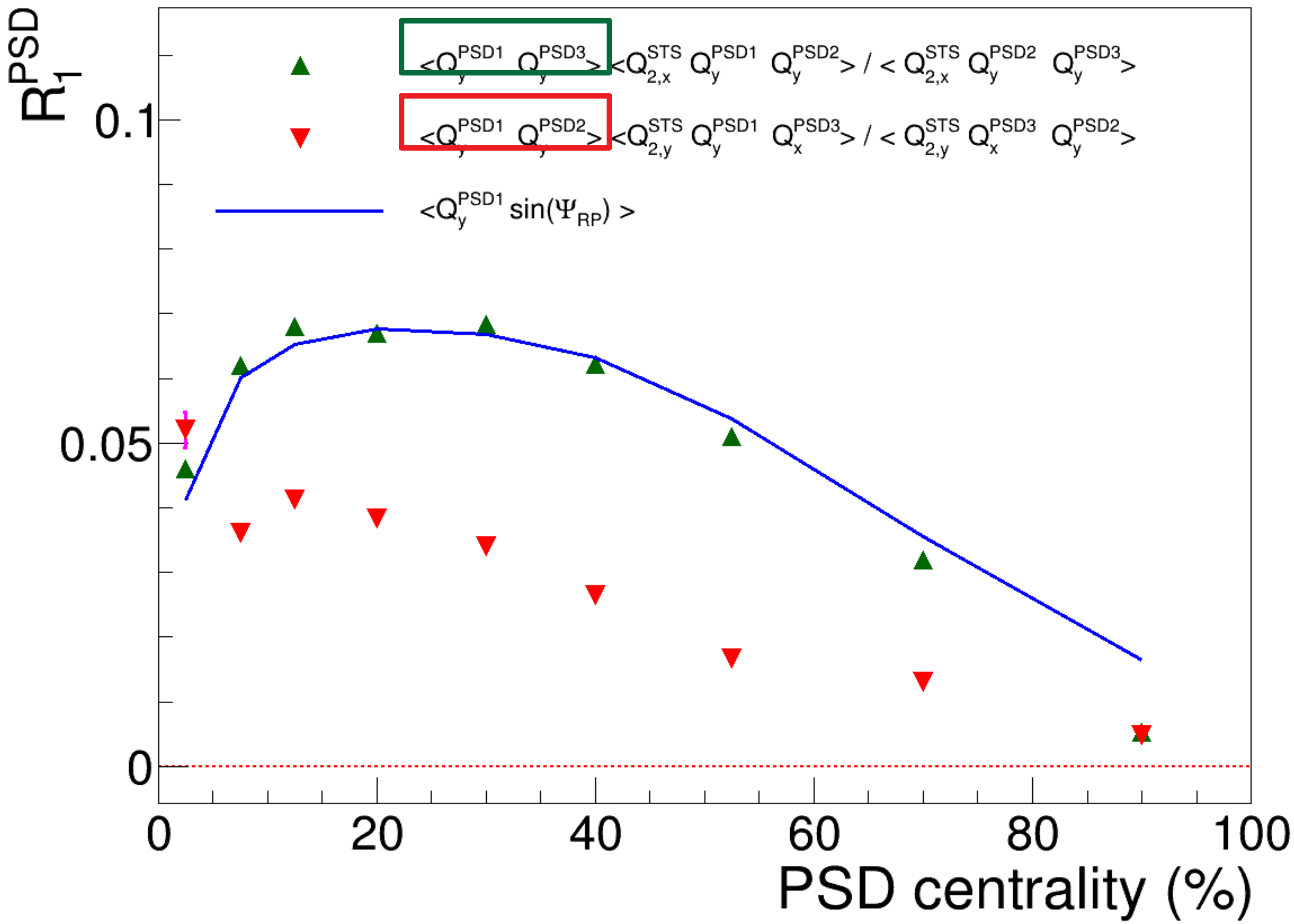
Flow Analysis Framework

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

Correction factor for mixed harmonic

PSD1





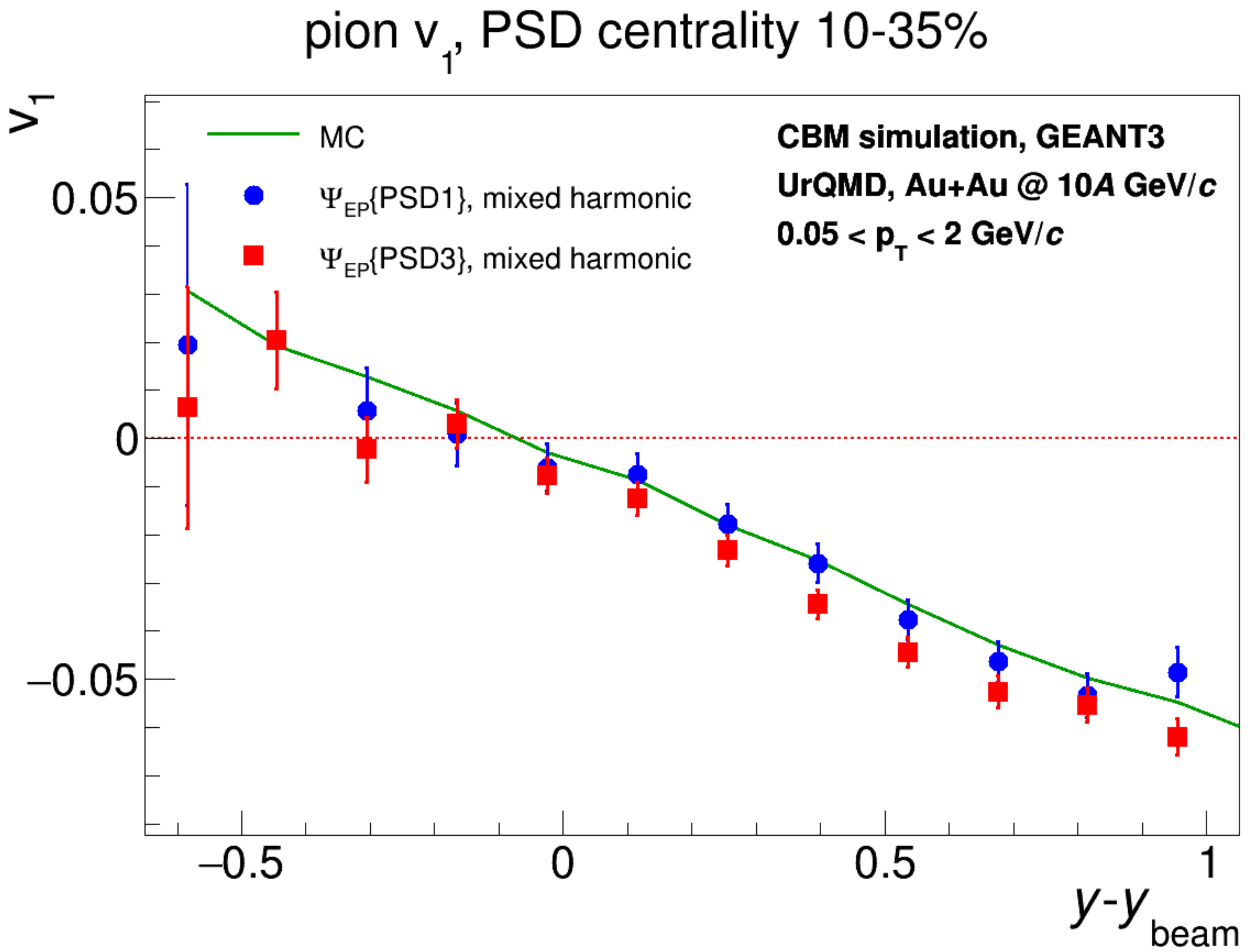
Neighboring PSD subevents correlation is distorted due to autocorrelations

Results

Results are presented for correlations between
positively charged identified hadrons (pions and kaons)
and all hadrons at forward rapidity (in the PSD acceptance).

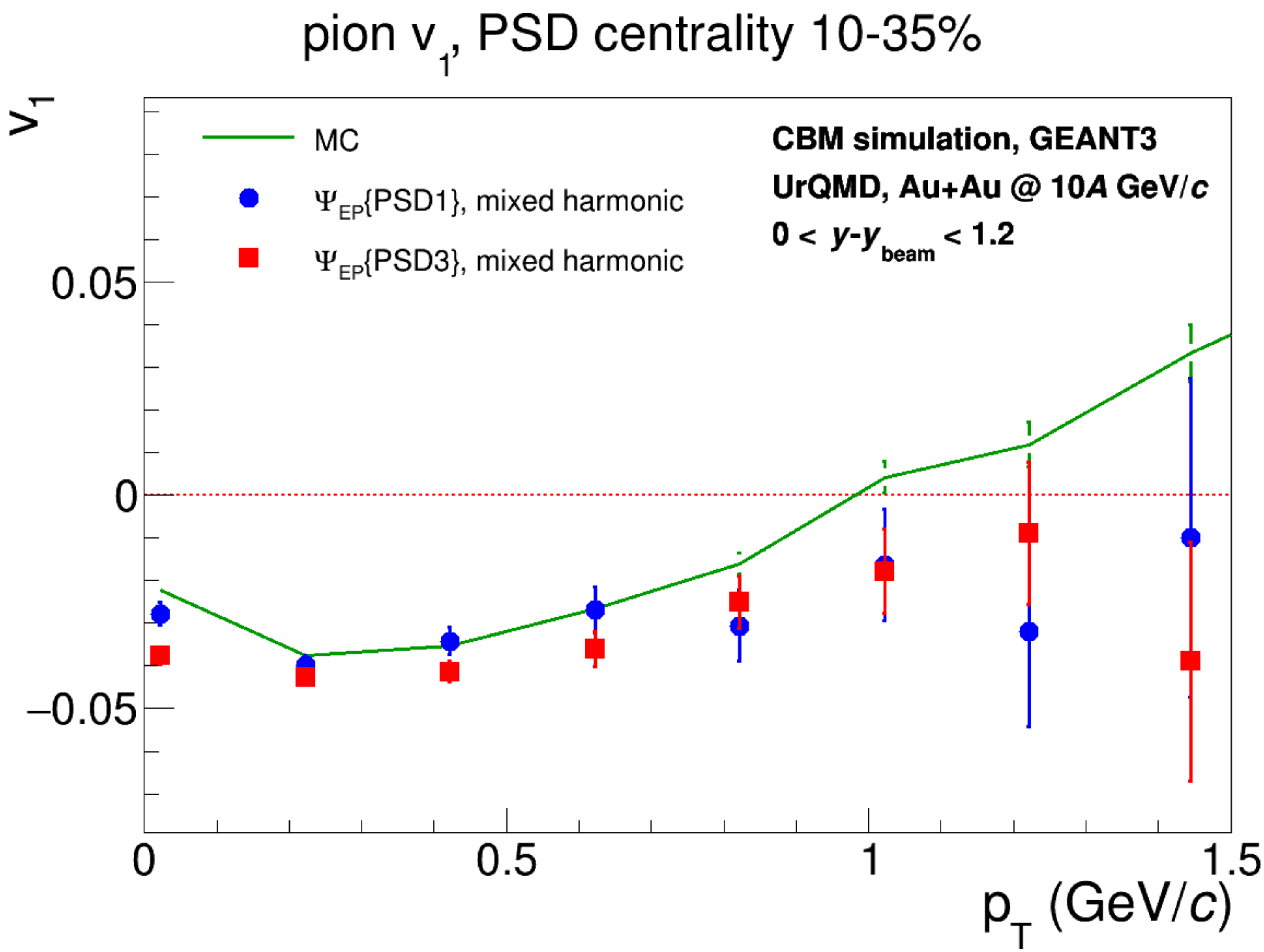
The results are corrected for detector non-uniformity.
Correction for PID efficiency is not done yet.
Only statistical uncertainties are shown.

π^+ v_1 vs rapidity



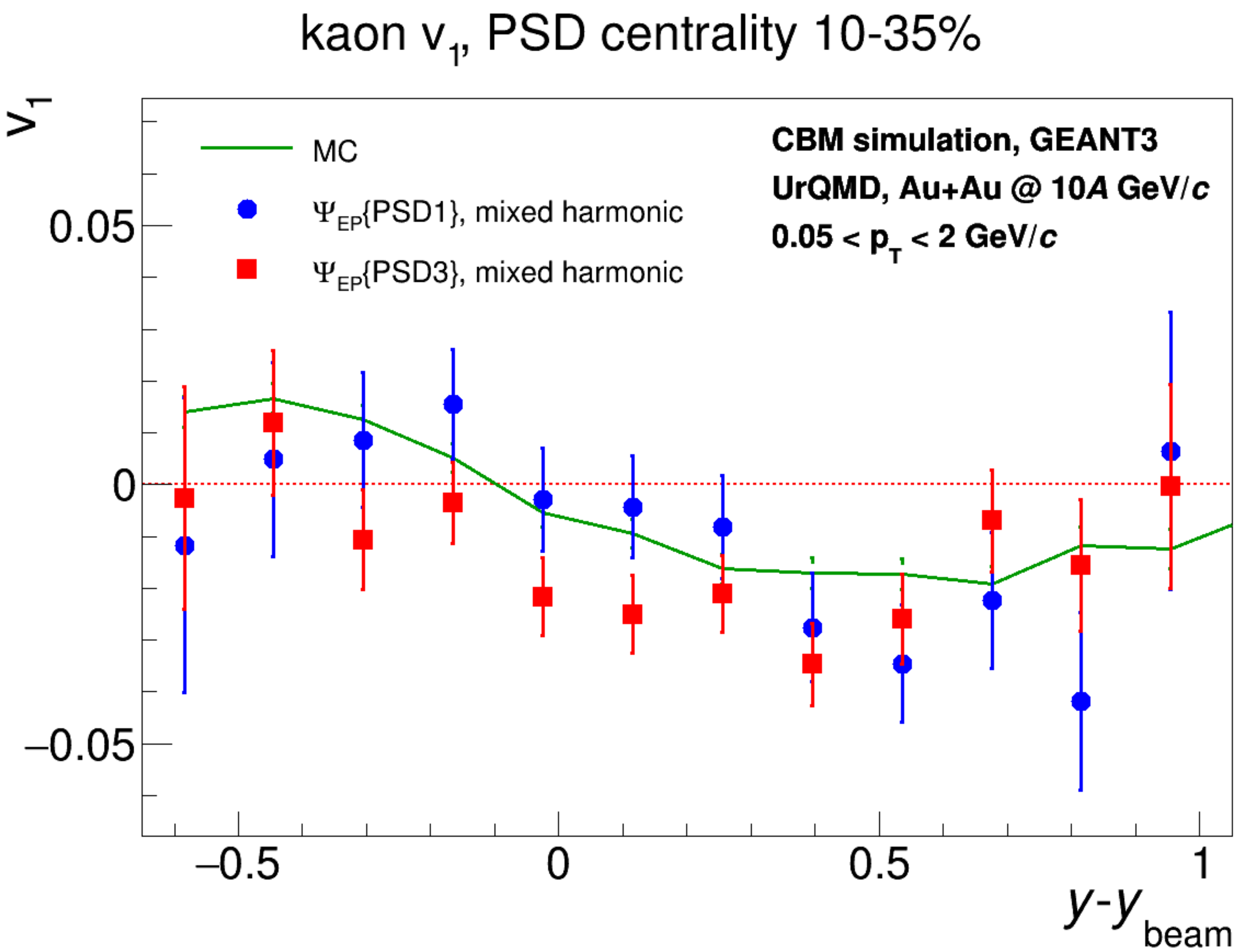
Good agreement between simulated and reconstructed values

π^+ v_1 vs transverse momentum



Good agreement between simulated and reconstructed values

K^+ v_1 vs rapidity



Large statistics simulation is needed.

Summary

- CBM detector performance for flow measurement has been studied
  - π^+ and K^+ directed flow for Au+Au collisions at 10*A* GeV/*c*

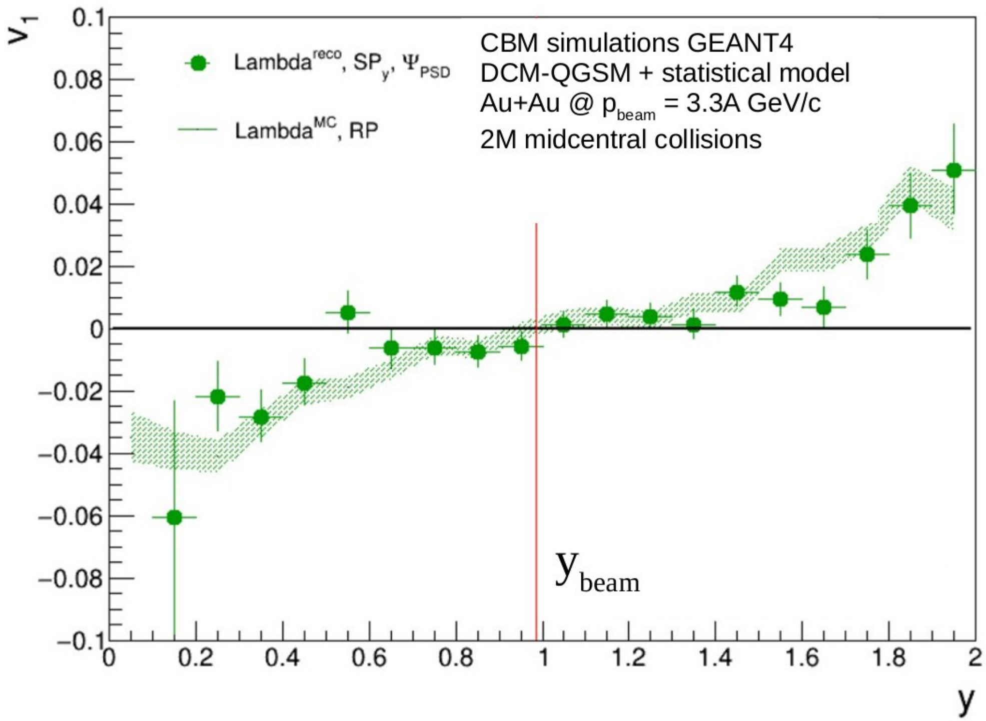
    differentially vs rapidity and transverse momentum
  - Centrality estimation using PSD
  - Particle identification using TOF
  - Acceptance corrections used in the ALICE experiment adopted to CBM
  - Resolution correction with mixed harmonic
- Developed procedure allows to reconstruct model parameters

Outlook

- PID efficiency correction
- Performance for weakly decaying particles (Λ, Σ, Ξ, Ω)
- common Monte-Carlo production using GEANT4 is being prepared

  - PSD fast simulation in under investigation

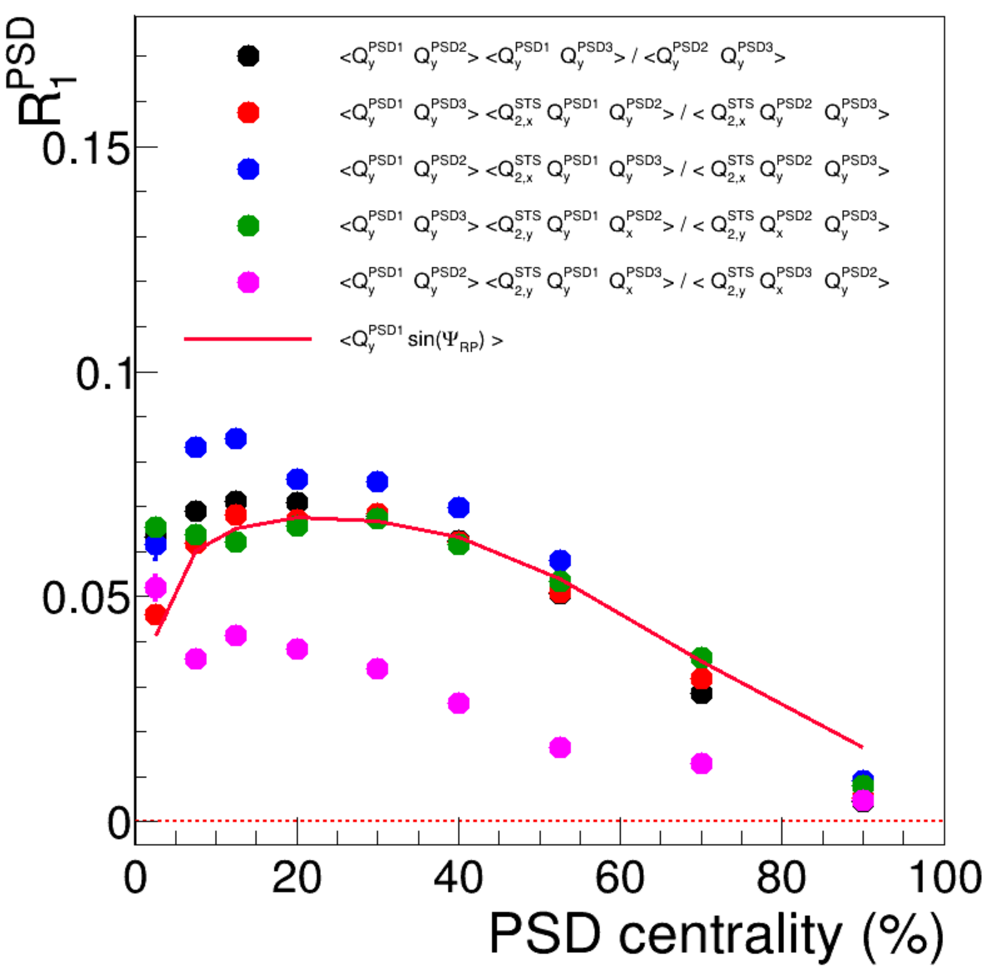
Ongoing performance studies for lambda hyperon



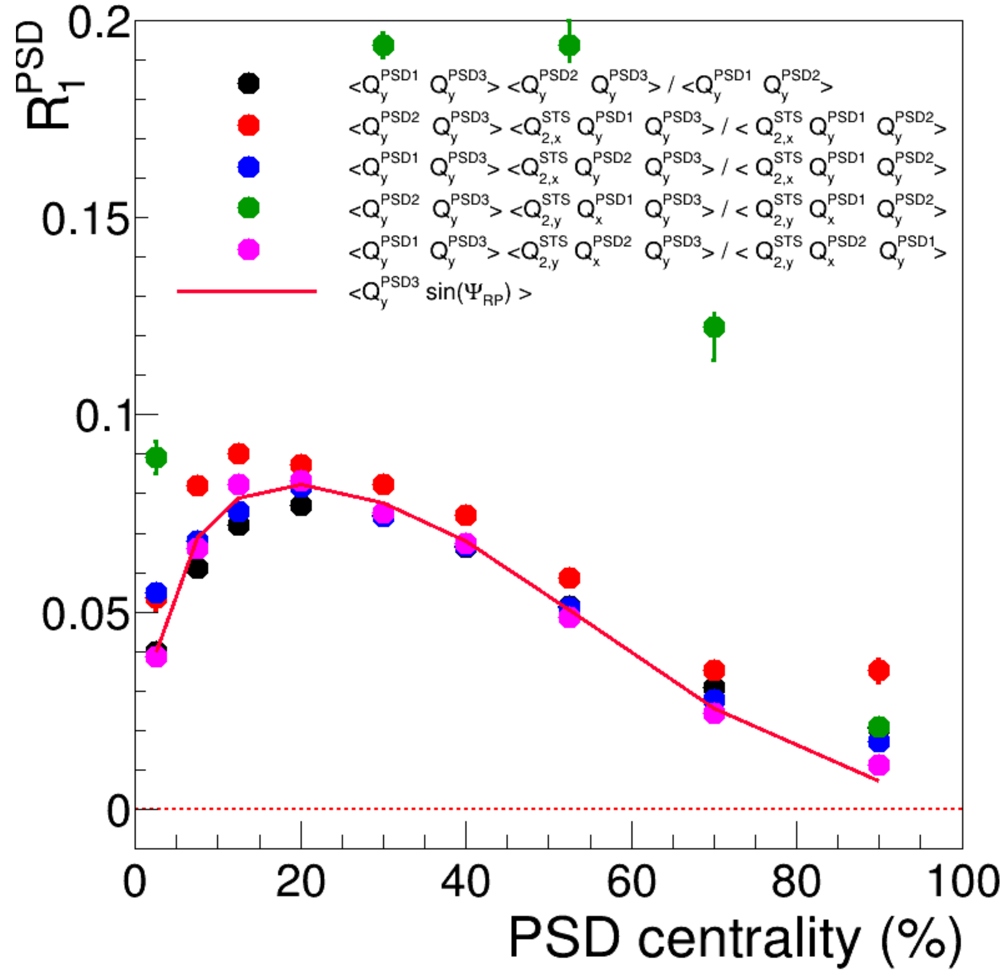
Backup

Correction factor for mixed harmonic

PSD1, y-component

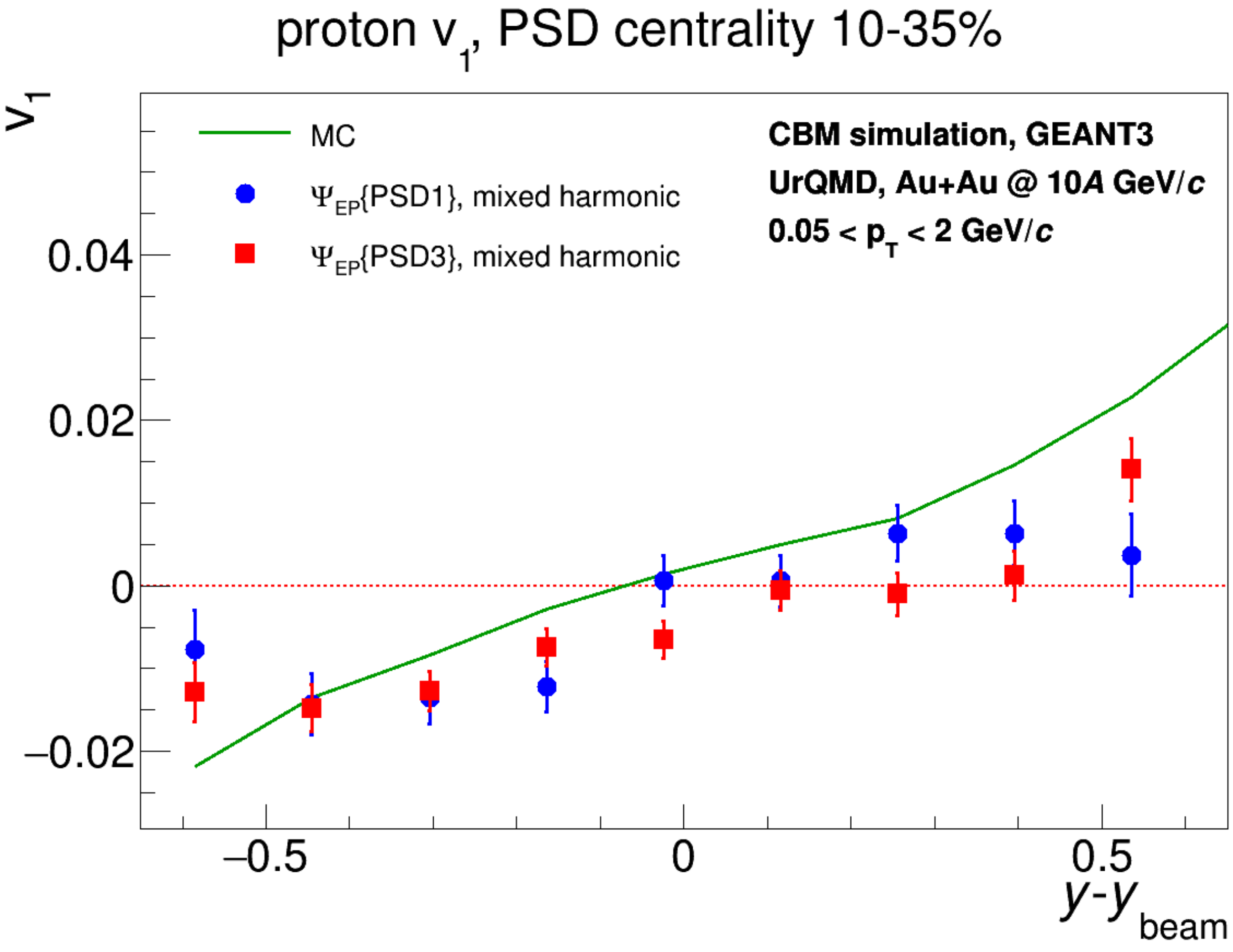


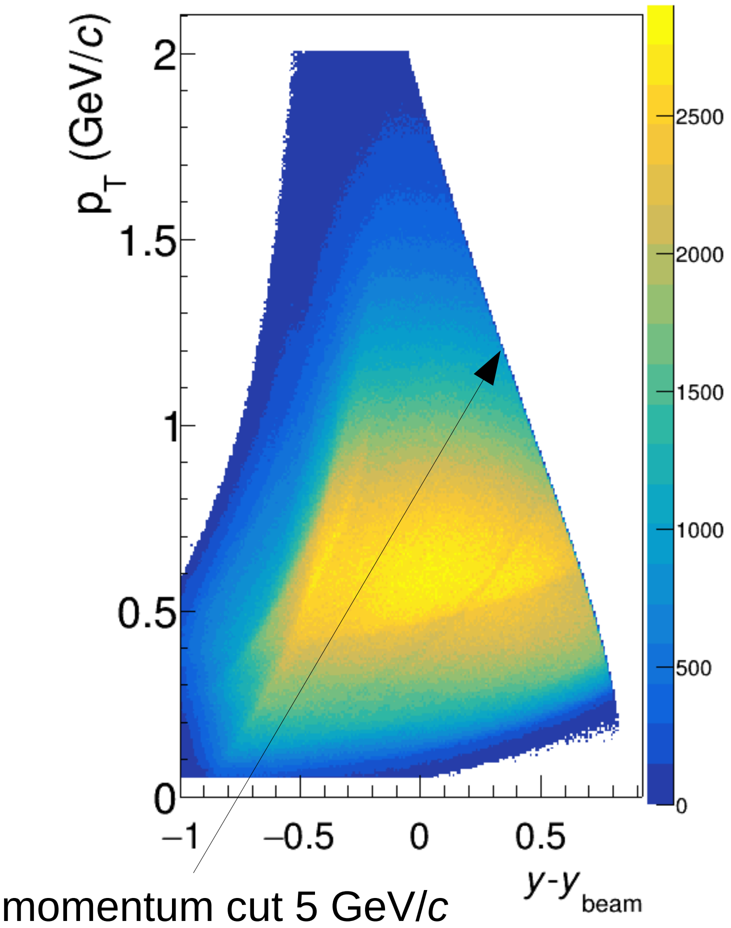
PSD3, y-component



Mixed harmonic calculation removes/suppresses contribution from non-flow

proton v_1 vs rapidity

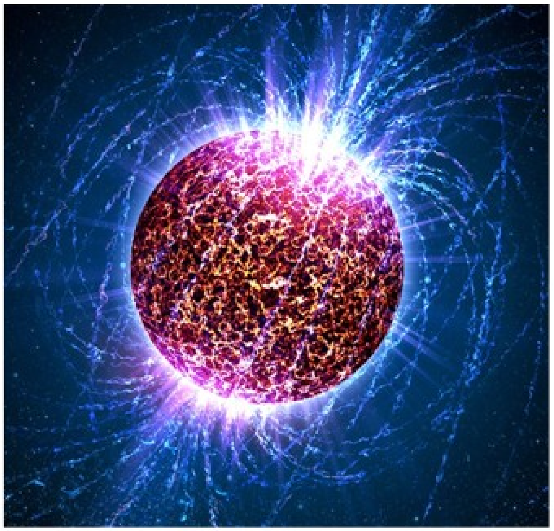




Non uniform acceptance for protons results in difference between simulated and measured flow

Dense Baryonic Matter

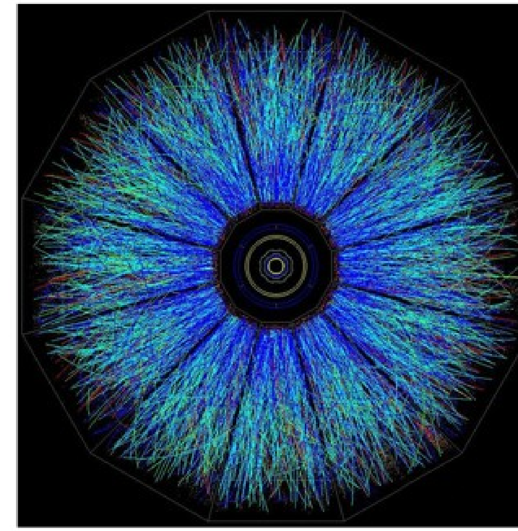
Neutron stars



Neutron star merger

GW170817

Heavy ion collisions

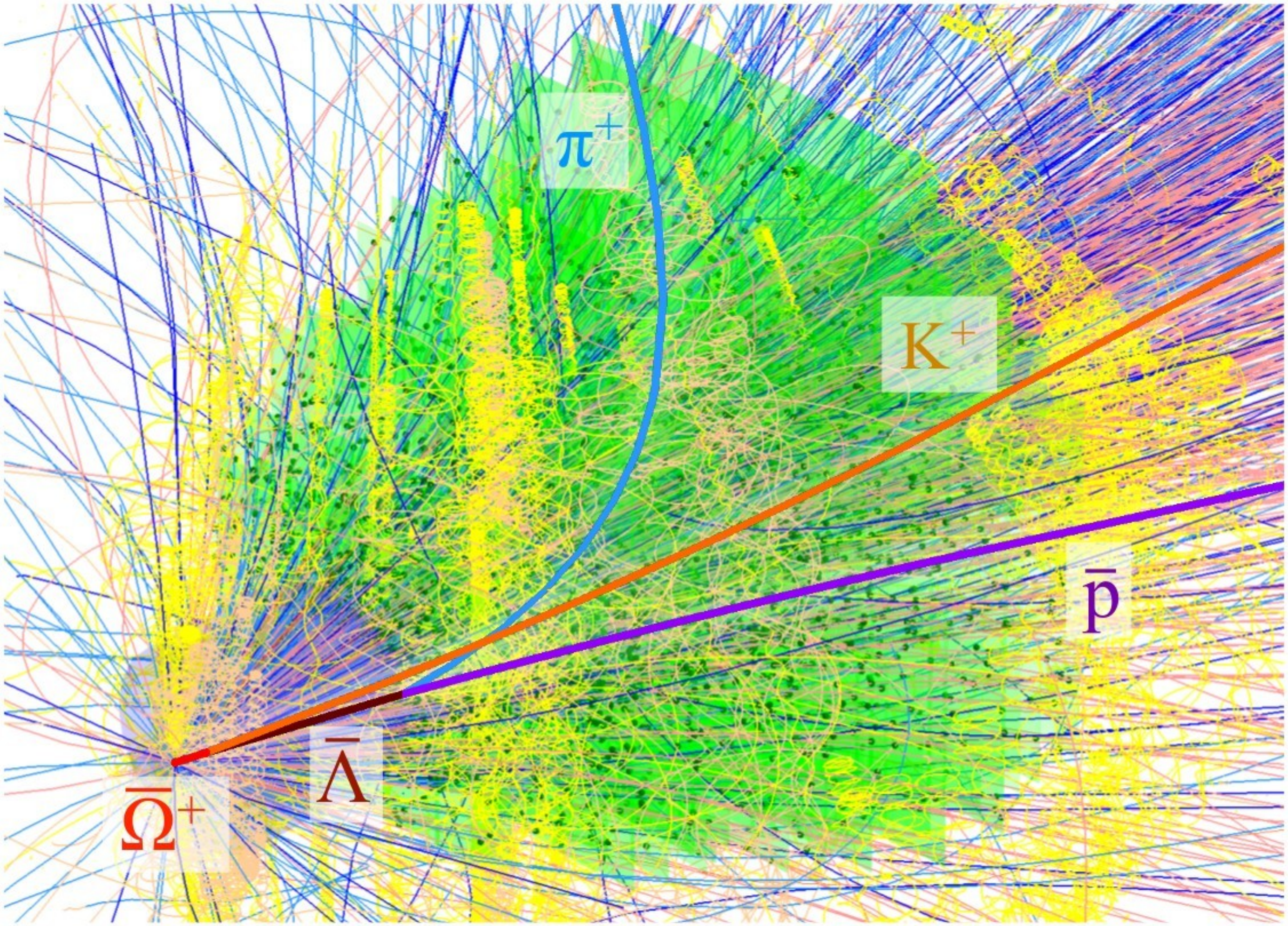


SIS100 energies

	Neutron stars	Neutron star merger	Heavy ion collisions
Temperature	T < 10 MeV	T ~ 10-100 MeV	T < 120 MeV
Density	$\rho < 10\ \rho_0$	$\rho < 2 – 6\ \rho_0$	$\rho < 5 – 15\ \rho_0$
Lifetime / Reaction time	~ infinity	T ~ 10 ms	$t \sim 10^{-23}$ s

Challenges of event and track reconstruction in CBM

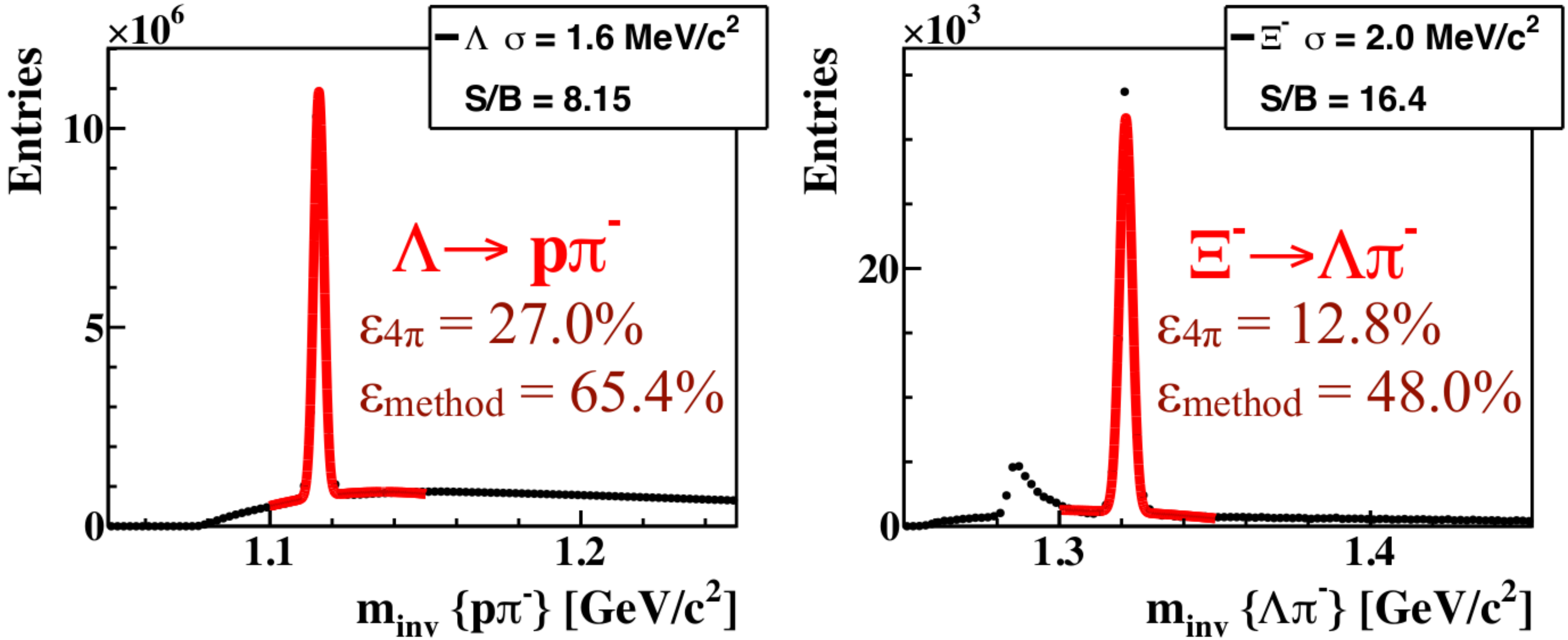
CBM simulation
central Au+Au collision @ 10*A* GeV/*c*



- High multiplicity collisions
- Events in the selected time window (time slice) will overlap in time
- High interaction rate → reconstruction will be in 4D (space, time)
- Decay topology reconstruction

Multi-strange reconstruction

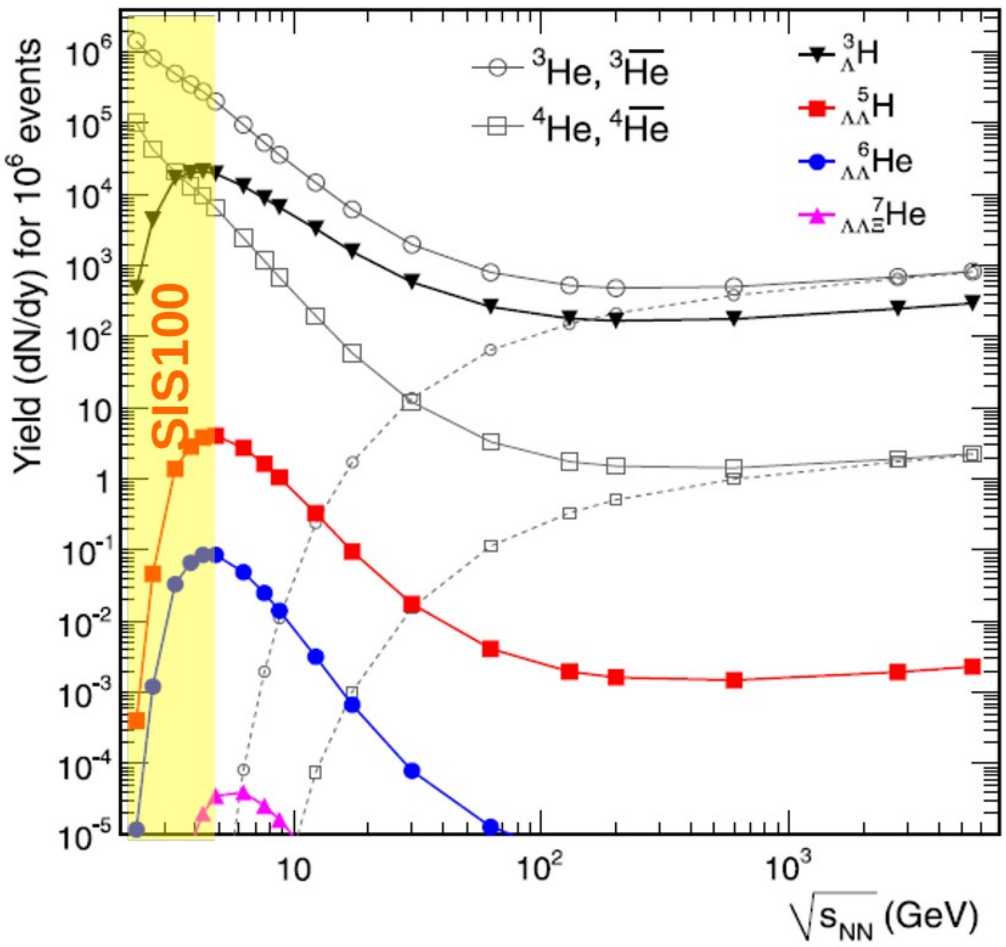
AuAu, 10 AGeV, 5M central UrQMD events, realistic PID



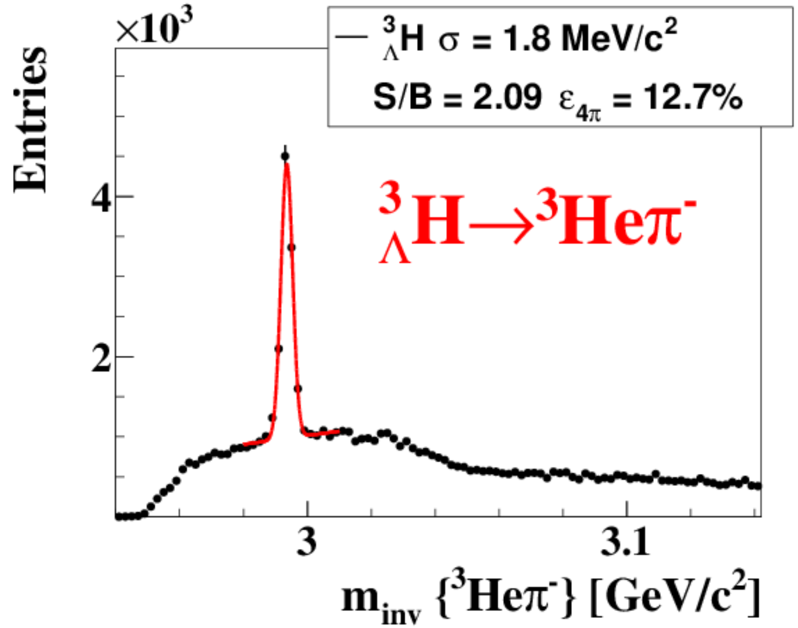
Decay topology reconstruction
using the KFParticleFinder package

Hypernuclei

A. Andronic, PLB697 203 (2011)



CBM simulation
Au+Au 10*A* GeV/*c*
minbias
5M events

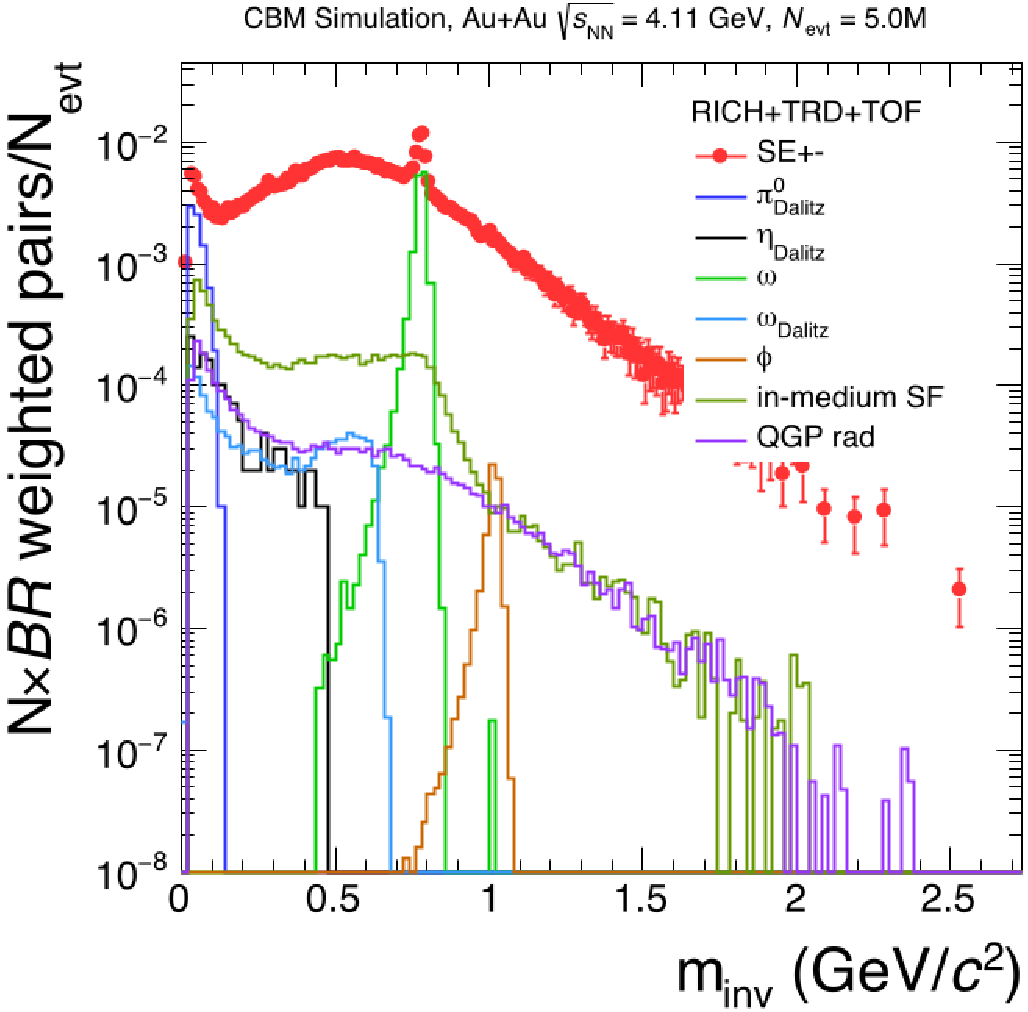


CBM physics cases

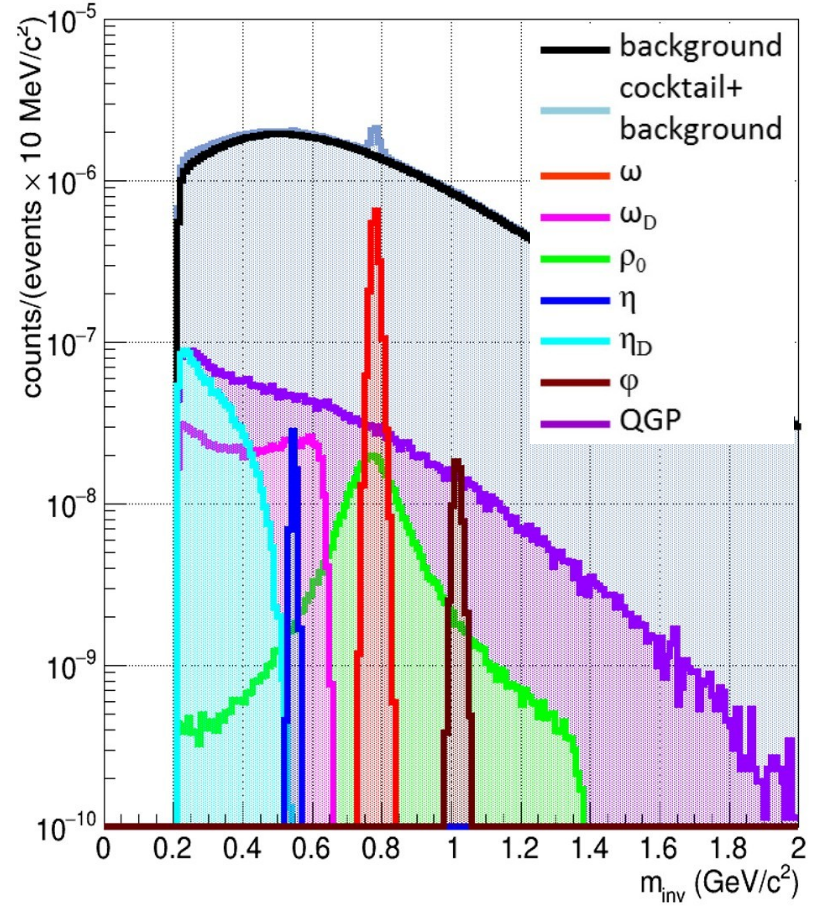
- Λ-N, Λ-Λ interaction
- (Double-)lambda hypernuclei
- Meta-stable strange states

Dilepton measurements: e^+e^- and $\mu^+\mu^-$

di-electrons



di-muons

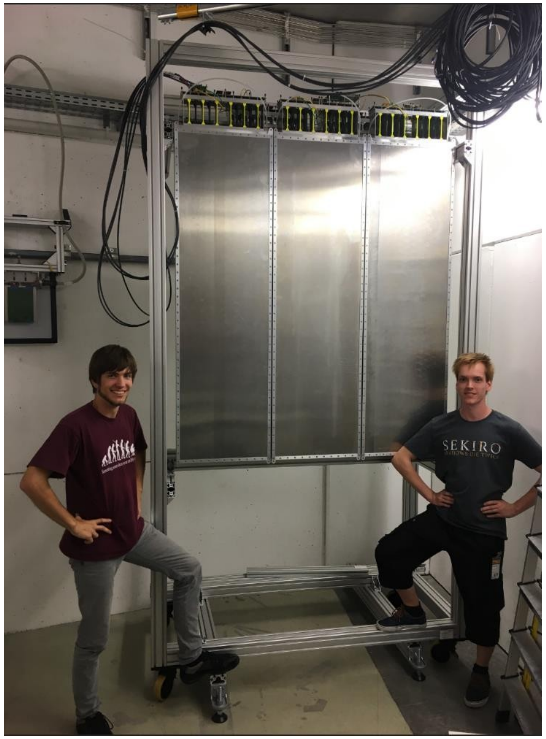


- In-medium modifications of light vector mesons
- ρ, ω, φ → $e^+ + e^-$ ($\mu^+ + \mu^-$) via dilepton measurements

CBM FAIR phase-0 program (before the start of operation in 2025)

- Use 430 out of 1100 CBM RICH multi-anode photo-multipliers (MAPMT) in HADES RICH photon detector (2019)
- Use 10% of the CBM TOF modules including read-out chain at STAR/RHIC (BES II 2019/2020)
- 4 Silicon Tracking Stations in the BM@N in JINR (start 2020 with Au-beams up to 4.5 A GeV)
- Projectile Spectator Detector at BM@N (2020)
- Tests and performance studies at the NA61/SHINE experiment @ CERN SPS
- mini CBM @ GSI/SIS18: full system test with high-rate A+A collisions (2019-2021)

mTOF at mCBM cave
(September, 2018)



CBM area excavation