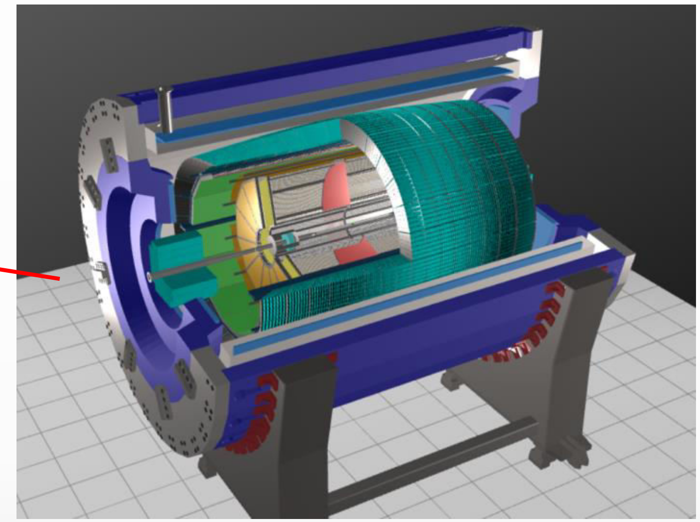
MPD Collaboration Status

V. Riabov for the MPD Collaboration

MPD at NICA

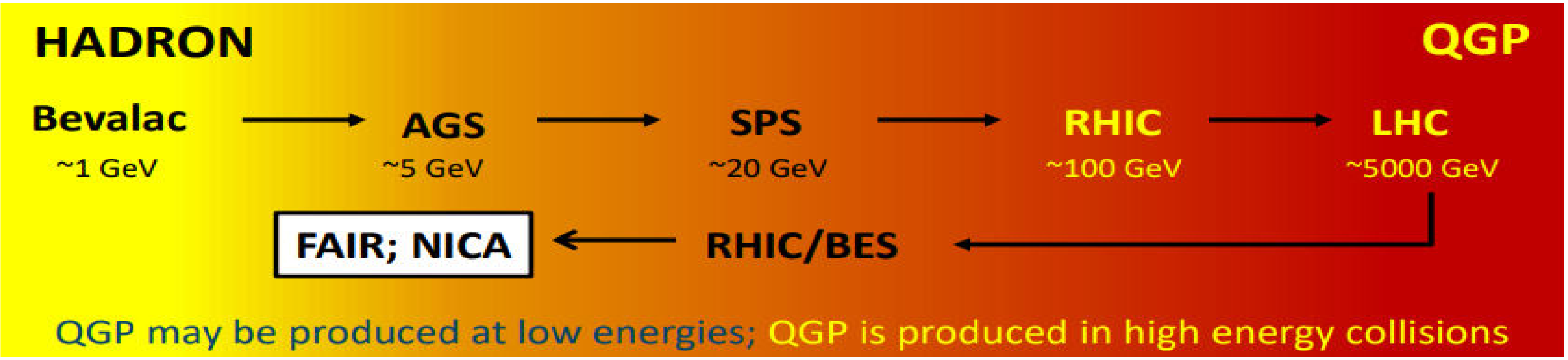
❖ One of two experiments at NICA collider to study heavy-ion collisions at $\sqrt{s_{NN}}$= 4−11 GeV

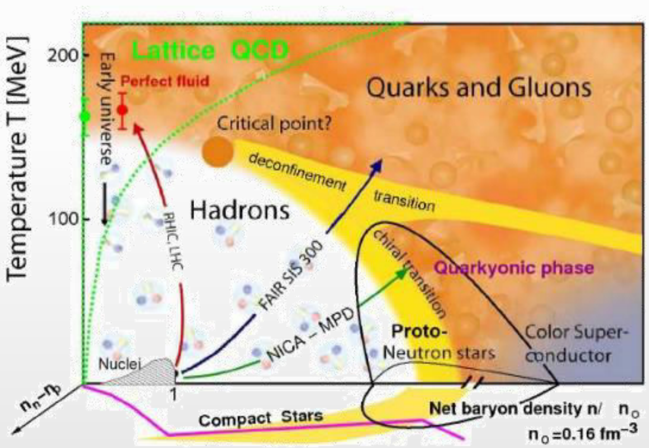


❖ Expected beam configuration in first year(s) of operation:

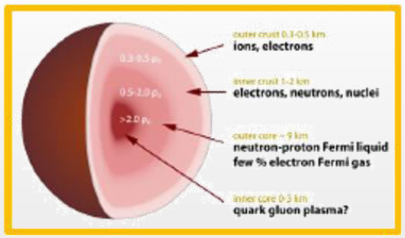
- ✓ not-optimal beam optics → wide z-vertex distribution, σ_z ~ 50 cm
- ✓ reduced luminosity (~10^{25}) → collision rate ~ 50 Hz
- ✓ first beams: Bi+Bi in 2025

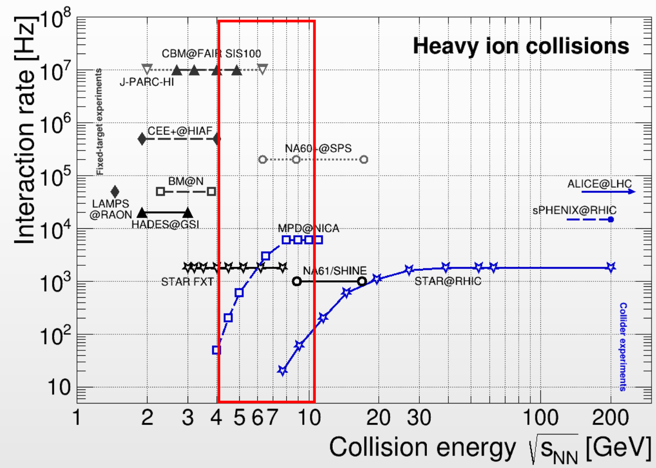
Relativistic heavy-ion collisions





high baryon densities
→ inner structure of
compact stars





- ❖ At $\mu_B \sim 0$, smooth crossover (lattice QCD calculations + data)
- ❖ At large μ_B, 1st order phase transition is expected → QCD critical point
- ❖ BM@N and MPD will study QCD medium at extreme net baryon densities
- ❖ Many ongoing (NA61/Shine, STAR-BES) and future experiments (CBM) in ~ same energy range

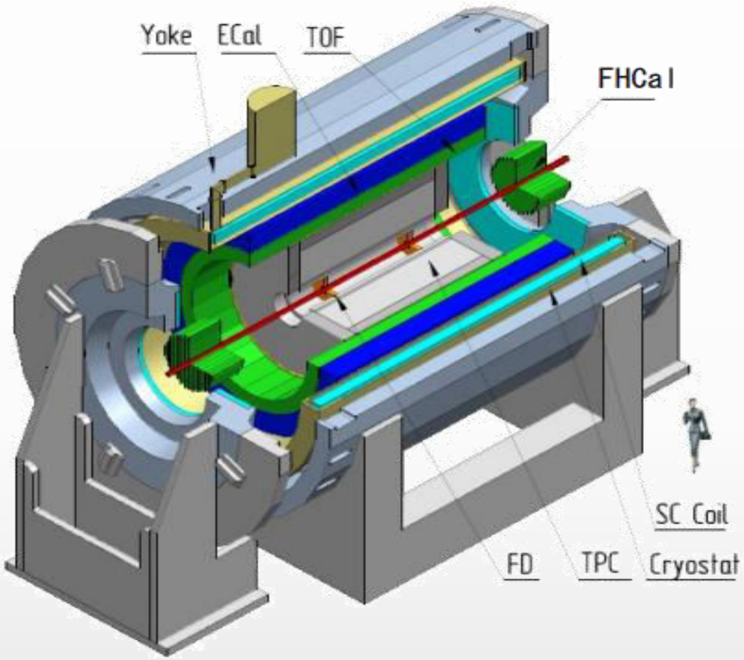
Multi-Purpose Detector (MPD) Collaboration

***MPD** International Collaboration was established in **2018** to construct, commission and operate the detector*

11** Countries, **>500** participants, **35** Institutes and **JINR

Organization

Acting Spokesperson:	***Victor Riabov***
Deputy Spokespersons:	***Zebo Tang, Arkadiy Taranenko***
Institutional Board Chair:	***Alejandro Ayala***
Project Manager:	***Slava Golovatyuk***



__Joint Institute for Nuclear Research__;
A.Alikhanyan National Lab of Armenia, Yerevan, __Armenia;__
University of Plovdiv, __Bulgaria;__
Tsinghua University, Beijing, __China__;
University of Science and Technology of China, Hefei, __China__;
Huzhou University, Huzhou, __China__;
Institute of Nuclear and Applied Physics, CAS, Shanghai, __China__;
Central China Normal University, __China__;
Shandong University, Shandong, __China__;
University of Chinese Academy of Sciences, Beijing, __China__;
University of South China, __China__;
Three Gorges University, __China__;
Institute of Modern Physics of CAS, Lanzhou, __China__;
Tbilisi State University, Tbilisi, __Georgia__;
Institute of Physics and Technology, Almaty, __Kazakhstan__;
Benemérita Universidad Autónoma de Puebla, __Mexico__;
Centro de Investigación y de Estudios Avanzados, __Mexico__;
Instituto de Ciencias Nucleares, UNAM, __Mexico__;
Universidad Autónoma de Sinaloa, __Mexico__;
Universidad de Colima, __Mexico__;
Universidad de Sonora, __Mexico__;
Institute of Applied Physics, Chisinev, __Moldova__;
Institute of Physics and Technology, __Mongolia__;

Belgorod National Research University, __Russia__;
Institute for Nuclear Research of the RAS, Moscow, __Russia__;
National Research Nuclear University MEPhI , Moscow, __Russia__;
Moscow Institute of Science and Technology, __Russia__;
North Osetian State University, __Russia__;
National Research Center "Kurchatov Institute", __Russia__;
Peter the Great St. Petersburg Polytechnic University Saint Petersburg, __Russia__;
Plekhanov Russian University of Economics, Moscow, __Russia__;
St.Petersburg State University, __Russia__;
Skobeltsyn Institute of Nuclear Physics, Moscow, __Russia__;
Petersburg Nuclear Physics Institute, Gatchina, __Russia__;
Vinča Institute of Nuclear Sciences, __Serbia__;
Pavol Jozef Šafárik University, Košice, __Slovakia__

MPD schedule

❖ Latest estimates provided by V. Golovatyuk

	Year 2023	
12	Jan 15 - April 15th	Preparation for Vacuum test of Solenoid with Cryostat
13	April 20 May 15th	Vacuum tests
14	May 15 - June 15th	Solenoid cooling down to Liquid Nitrogen temperature (-80K)
15	June 15 – September 15	Activities in the MPD Hall stopped
16	October – December	Cooling down to the Liquid N2 and further down to He temperature (-4K)
	Year 2024	
17	January. - February 15	Supplying the current to the Solenoid and Correction coils, testing the hit evacuation system
15	March - May 15	Magnetic Field measurements
15	June 1 - June 10	Support Frame installation
16	June 20 – August 30th	Installation ECal sectors
17	Sept 1 – September 30th	Installation TOF modules, FHCal into poles
18	Oct 1st - Nov 30	TPC installation
19	Sept 18 - Nov 30	Cabling
20	Dec 4 - Dec 25	Installation of beam pipe
	Year 2025	
21	Jan 10 - Feb	Move the MPD on Collider beam line, Commissioning

Updated schedule does not rely on component delivery from western countries

Activities in the MPD Hall

Top platform (cryogenics, power supplies, control system)

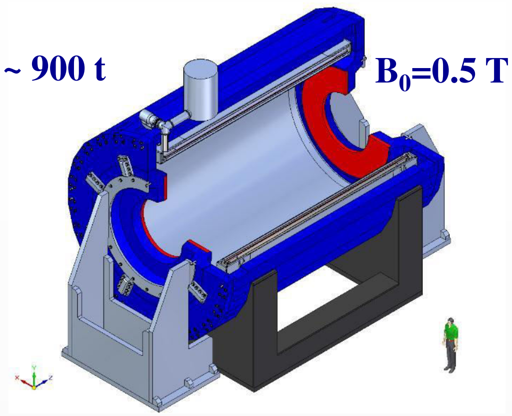
Control Dewar and Satellite Refrigerator

Current leads and pipes in the Control Dewar

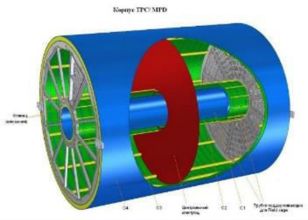
- Yoke, TRIM coils, top platform, chimney assembled, ongoing tests of the refrigerators and control Dewar
- Pipes, LN2 tanks, LHe pipe, heaters and other equipment re-ordered in Russia and delivered
- Cooling to LN2/LHe temperature by the end of year

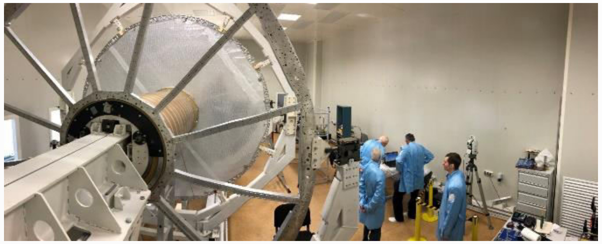
Barrel subsystems in production

SC Solenoid + Iron Yoke



TPC – central tracking detector





TPC cylinders, central membrane, service wheels, readout chambers, gas system - ready - final vessel assembly by the end of year

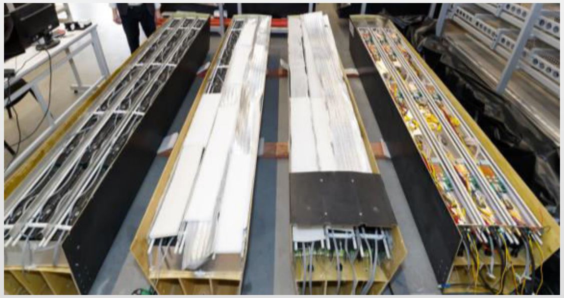
Support structure

Carbon fiber support frame delivered and unpacked, sagita ~ 5 mm at full load

TOF - ready

ECAL

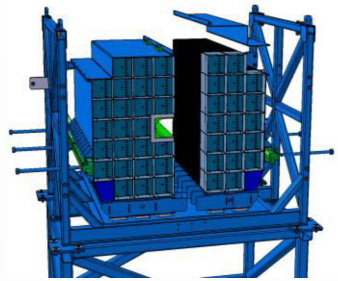
Half-sectors at different stages of assembly



66% of modules have been produced in China and Russia → 32 half-sectors
16.5% of modules is under construction in Russia → extra 8 half-sectors
Assembly of half-sectors and electronics is ongoing

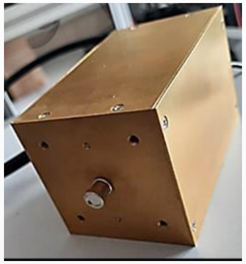
Forward subsystems in production

FHCAL



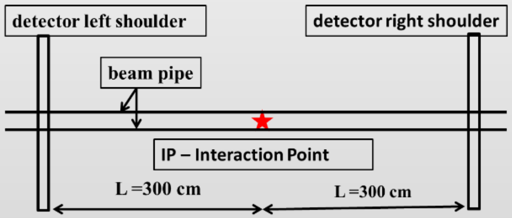
FHCAL modules have been produced and tested → installation in autumn 2023

FFD



Cherenkov modules of FFDE and FFDW are available, mechanics of FFD sub-detectors is available for installation in container with vacuum beam tube

Beam and luminosity monitoring



Measurement of transverse sizes of the bunches
Transvers and longitudinal convergence of bunches
Vertices distribution along the beam

- ❖ Trigger: condition: $|T_L^{min} - T_R^{min}| < 10$ ns; 77% in AuAu@11 GeV
- ❖ Observables & methods:
  - ✓ counting rate and z-vertex distribution ($\sigma_{z\text{-vertex}} \sim 5$ cm with $\delta\tau \sim 300$ ps)
  - ✓ Van der Meer and ΔZ scans for optimization of beam optics
- ❖ Beam tests of prototypes
- ❖ Mass production of scintillator detectors

Conferences

- MPD presentations at conferences since last CM:
  - ✓ 18th National Conference on Nuclear Physics, China, May 2023
  - ✓ Hadrons-2023, Italy, June 5-9
  - ✓ Grid-2023, Russia, July 3-7
  - ✓ ISHEPP-2023, Russia, September 18-23
  - ✓ Nucleus-2023, Russia, October 9-13
  - ✓ XX Mexican School on Particles and Fields – 2023, Mexico, October 30 – November 3

- Over 25 plenary and parallel talks presented by collaboration members

MPD physics program

G. Feofilov, A. Aparin

Global observables

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

V. Kolesnikov, Xianglei Zhu

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 Diag.

K. Mikhailov, A. Taranenko

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

D. Peresunko, Chi Yang

Electromagnetic probes

- Electromagnetic calorimeter meas.
- Photons in ECAL and central barrel
- Low mass dilepton spectra in-medium modification of resonances and intermediate mass region

Wangmei Zha, A. Zinchenko

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

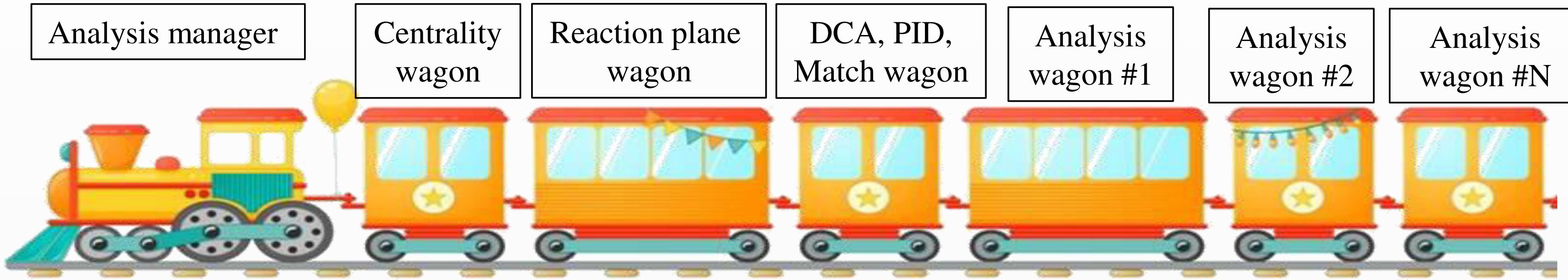
Cross-PWG format of meetings for discussion of results and analysis techniques since 2022

MPD mass productions

- Centralized large-scale MC productions for physics feasibility studies → consistent results for different groups, preparation for real data analyses
- https://mpdforum.jinr.ru/c/mcprod/26:
  - Request 25: General-purpose, 50M UrQMD BiBi@9.2 → **DONE**
  - Request 26: General-purpose (trigger), 1M DCM-QGSM-SMM BiBi@9.2 → **DONE**
  - Request 27: General-purpose (trigger), 1M PHQMD BiBi@9.2 → **DONE**
  - Request 28: General-purpose with reduced magnetic field, 10M UrQMD BiBi@9.2 → **DONE**
  - Request 29: General-purpose (hypernuclei), 20M PHQMD BiBi@9.2 → **DONE**
  - Request 30: General-purpose (hyperon polarization), 15M PHSD BiBi@9.2 → **DONE**
  - Request 31: General-purpose (femtoscopy), 50 M UrQMD BiBi@9.2 with freeze-out → **QA passed, in production**
  - Request 32: General purpose (flow), 15M vHLLE+UrQMD with XPT → **DONE**
  - Request 33: General purpose (flow), 15M vHLLE+UrQMD with 1PT → **DONE**
- Test existing computing and software infrastructure
- Develop realistic analysis methods and techniques, set priorities for different analyses
- Thanks to A. Moshkin (production manager), LIT specialists, computing/software team !!!

Handling the big data sets

- ❖ Centralized Analysis Framework for access and analysis of data:
  - ✓ consistent approaches and results across collaboration, easier storage and sharing of codes and methods
  - ✓ reduced number of input/output operations for disks and databases, easier data storage on tapes
- ❖ Analysis manager reads event into memory and calls wagons one-by-one to modify and/or analyze data:

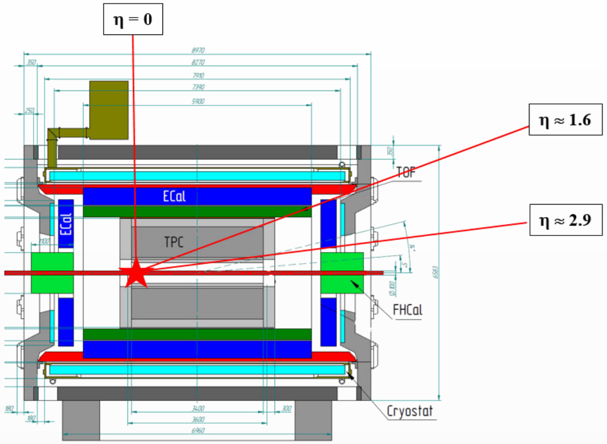


- ❖ The Analysis manager and the first Wagons have been created, in MpdRoot @ mpdroot/physics
  - ✓ mpdroot/physics/evCentrality
  - ✓ mpdroot/physics/evPlane
  - ✓ mpdroot/physics/evPID
  - ✓ mpdroot/physics/globalPolarization
  - ✓ mpdroot/physics/hyperons
  - ✓ mpdroot/physics/pairKK
  - ✓ mpdroot/physics/pairPK
  - ✓ mpdroot/physics/pairPiK
  - ✓ mpdroot/physics/pairPiKs
  - ✓ mpdroot/physics/pairPiLambda
  - ✓ mpdroot/physics/pairPiPi
  - ✓ mpdroot/physics/photons
- ❖ Eventually all analysis codes will be committed to MpdRoot as wagons
- ❖ First runs of the Analysis Train started in August, https://mpdforum.jinr.ru/c/analysis-train-requests/31
- ❖ Results for all analyses/wagons run on a big production (~ 50 M events) in a day !!!

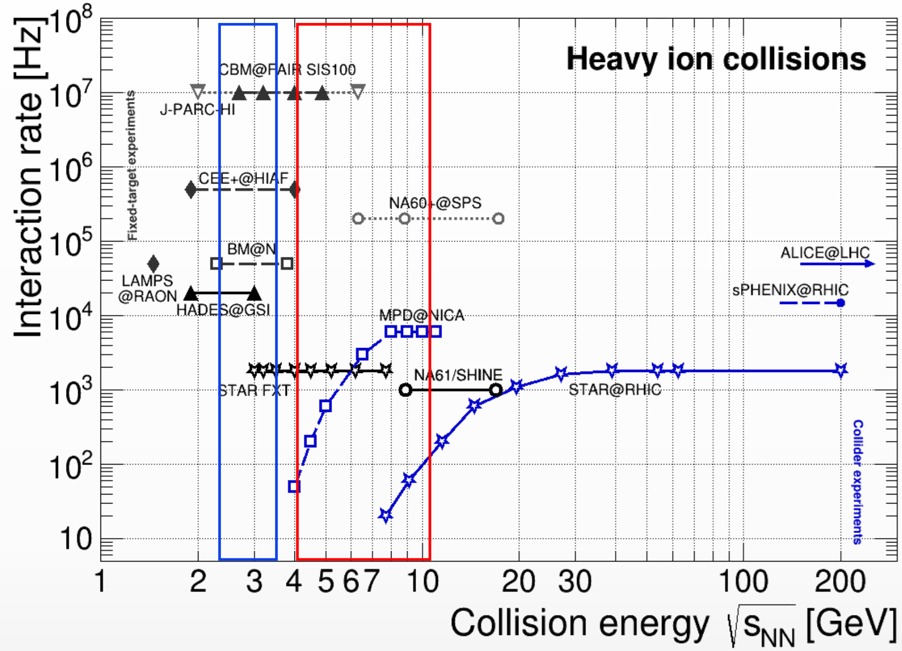
Advancements in analyses

Fixed target configurations

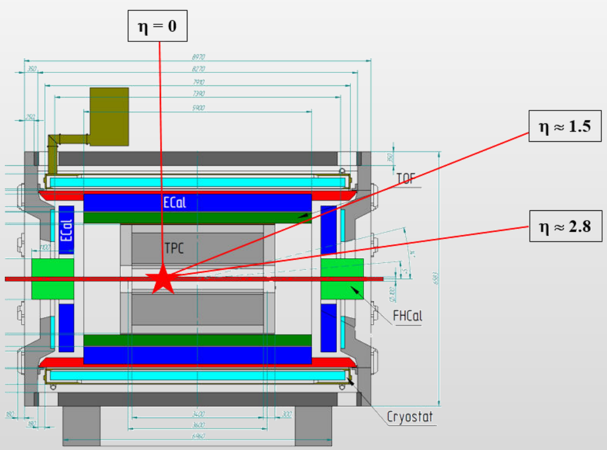
- With a target located at z = -150 cm



E_{beam}	$\sqrt{s_{NN}}$ collider mode	$\sqrt{s_{NN}}$ FXT mode	η_{CM}	CMS coverage
2.0	4	2.4	0.7	-0.7; 0.9 (2.2)
5.5	11	3.5	1.23	-1.23; 0.37 (1.67)



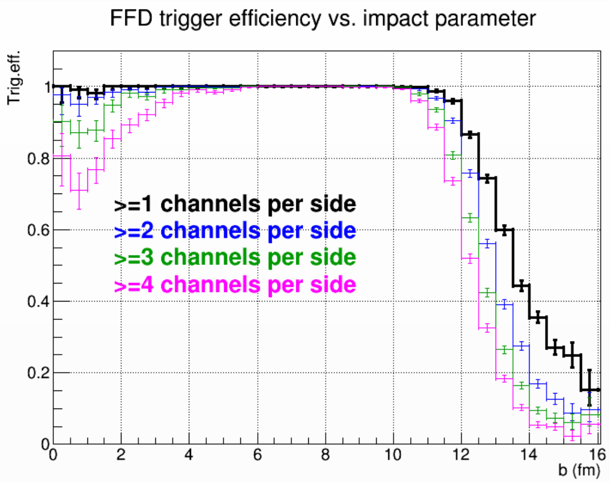
- With a target located at z = -115 cm

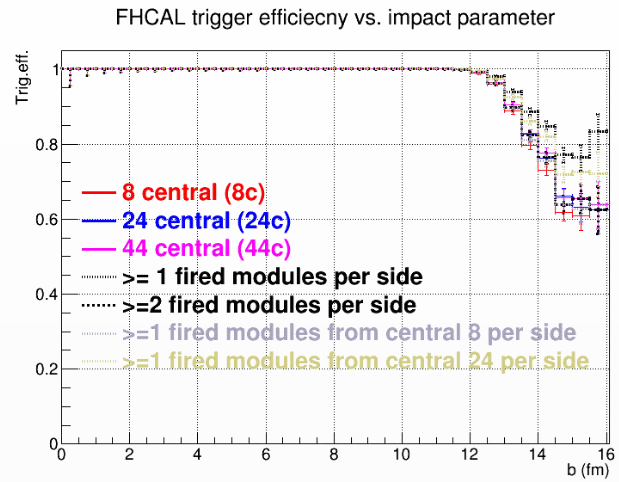


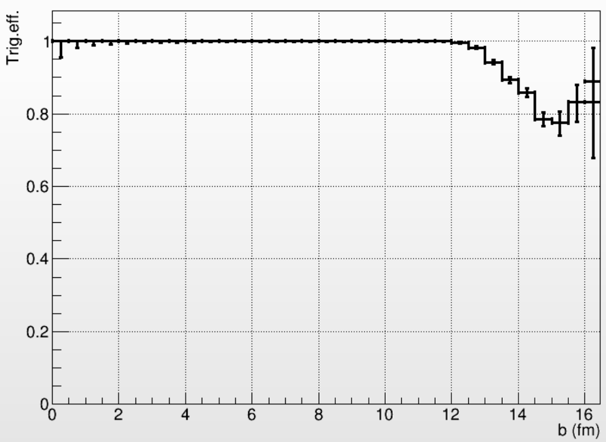
❖ Fixed-target mode: one beam + thin wire (~ 100 μm) close to the edge of the MPD central barrel:

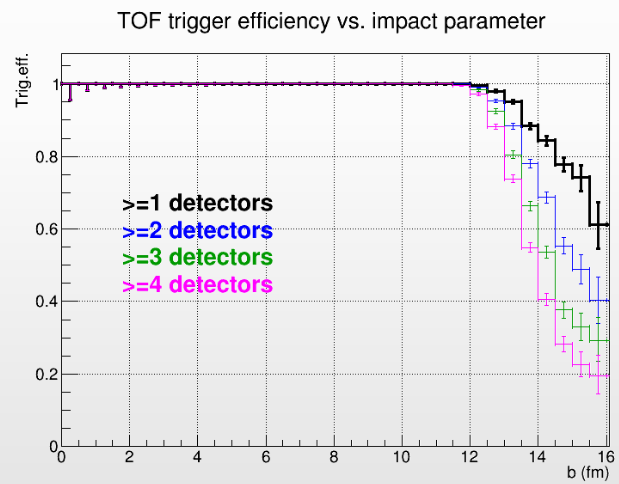
- ✓ extends energy range of MPD to $\sqrt{s_{NN}}$ = 2.4-3.5 GeV (overlap with HADES, BM@N and CBM)
- ✓ solves problem of low event rate at lower collision energies (only ~ 50 Hz at $\sqrt{s_{NN}}$ = 4 GeV at design luminosity)
- ✓ backup start-up solution (too low luminosity, only one beam, etc.)
- ✓ potential problems with online T0 and vertex at lower beam energies

Trigger efficiency, E = 2 AGeV, Z_{vertex} = -115 cm









- Efficiency:

✓ FFD: 74, 78, 82, 88%

✓ FHCAL: 95, 96, 97, 98%

✓ FFD|FHCAL: 98%

✓ TOF: 91, 93, 95, 98%

- Only signals from the West FFD/FHCAL detectors are used (DCM-QGSM-SMM)
- Trigger efficiency is high enough to collect data in the fixed-target mode:
  - ✓ marginal dependence on the target position within 115-150 cm
  - ✓ weak dependence on collision energy (better at higher energy and track multiplicity)
- Problems with T_0, pure online vertex resolution, background ???

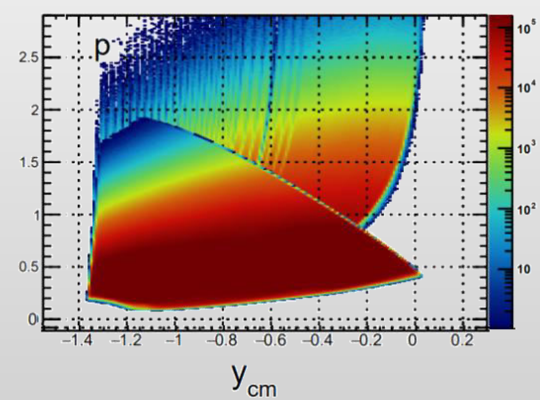
RHIC BES program

- Data taking by STAR at RHIC: $3 < \sqrt{s_{NN}} < 200$ GeV ($750 < \mu_B < 25$ MeV)

Au+Au Collisions at RHIC											
Collider Runs						Fixed-Target Runs					
	$\sqrt{s_{NN}}$ (GeV)	#Events	μ_B	y_{beam}	run		$\sqrt{s_{NN}}$ (GeV)	#Events	μ_B	y_{beam}	run
1	200	380 M	25 MeV	5.3	Run-10, 19	1	13.7 (100)	50 M	280 MeV	-2.69	Run-21
2	62.4	46 M	75 MeV		Run-10	2	11.5 (70)	50 M	320 MeV	-2.51	Run-21
3	54.4	1200 M	85 MeV		Run-17	3	9.2 (44.5)	50 M	370 MeV	-2.28	Run-21
4	39	86 M	112 MeV		Run-10	4	7.7 (31.2)	260 M	420 MeV	-2.1	Run-18, 19, 20
5	27	585 M	156 MeV	3.36	Run-11, 18	5	7.2 (26.5)	470 M	440 MeV	-2.02	Run-18, 20
6	19.6	595 M	206 MeV	3.1	Run-11, 19	6	6.2 (19.5)	120 M	490 MeV	1.87	Run-20
7	17.3	256 M	230 MeV		Run-21	7	5.2 (13.5)	100 M	540 MeV	-1.68	Run-20
8	14.6	340 M	262 MeV		Run-14, 19	8	4.5 (9.8)	110 M	590 MeV	-1.52	Run-20
9	11.5	157 M	316 MeV		Run-10, 20	9	3.9 (7.3)	120 M	633 MeV	-1.37	Run-20
10	9.2	160 M	372 MeV		Run-10, 20	10	3.5 (5.75)	120 M	670 MeV	-1.2	Run-20
11	7.7	104 M	420 MeV		Run-21	11	3.2 (4.59)	200 M	699 MeV	-1.13	Run-19
						12	3.0 (3.85)	2000 M	750 MeV	-1.05	Run-18, 21

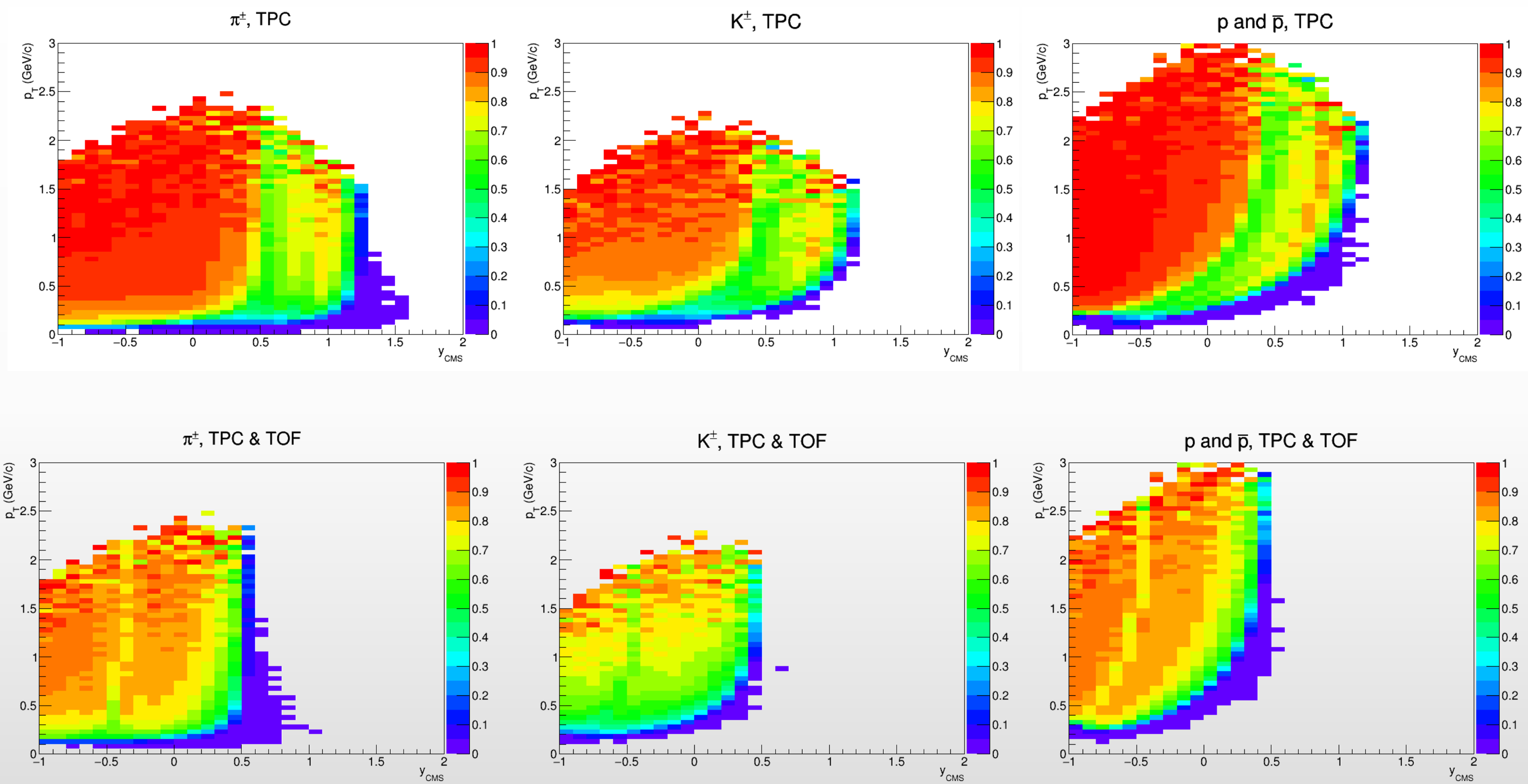
- A very impressive and successful program with many collected datasets, already available and expected results
- Limitations:
  - ✓ Au+Au collisions only
  - ✓ Among the fixed-target runs, only the 3 GeV data have full mid-rapidity coverage for protons ($|y| < 0.5$), which is crucial for physics observables

Au+Au @ 3.9 GeV



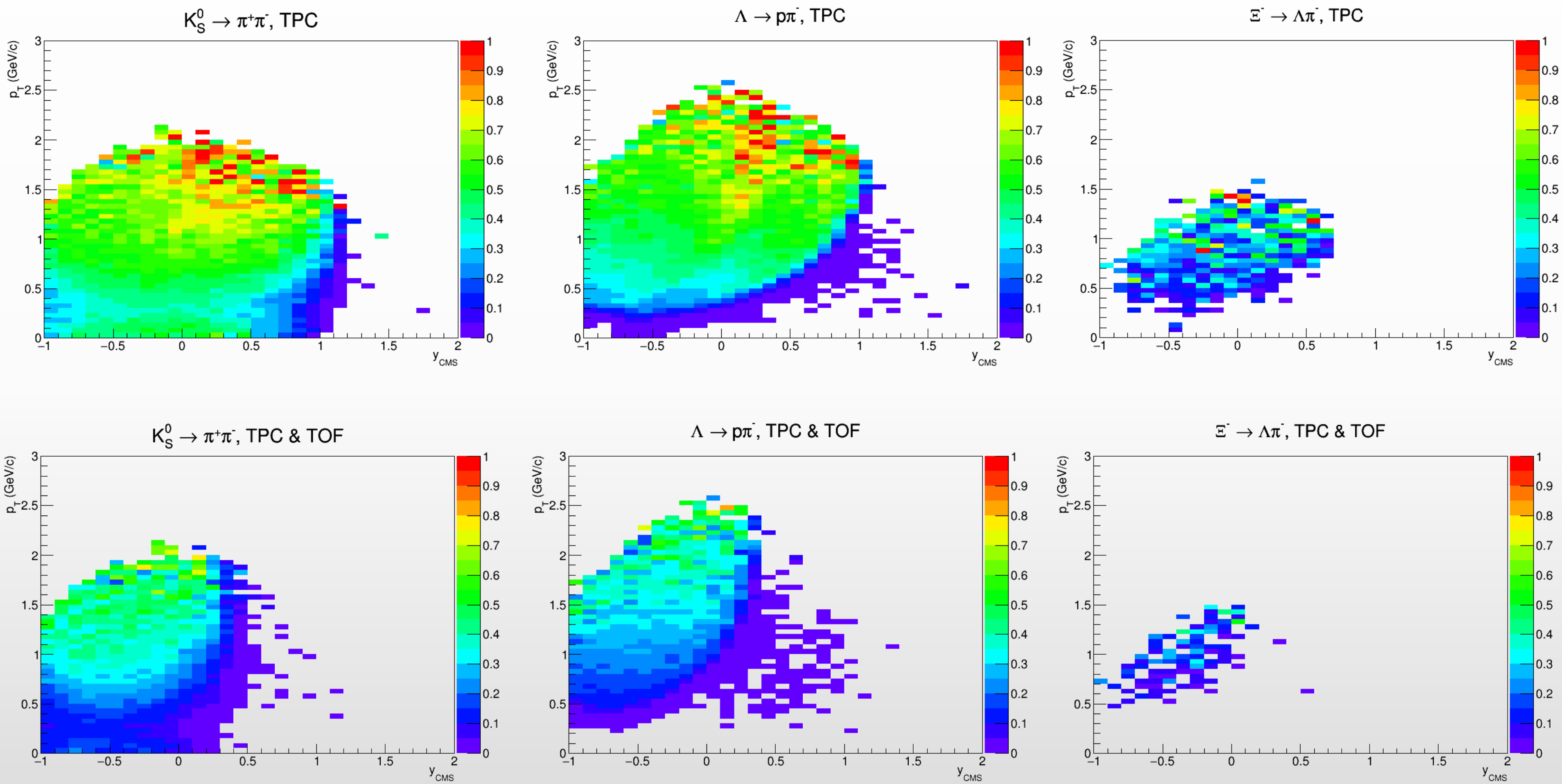
Efficiency for π/K/p, E_{lab} = 5.5·A GeV

- $N_{hits} > 10$; DCA < 2 cm; Primary particles ($R_{production} < 1$ cm)



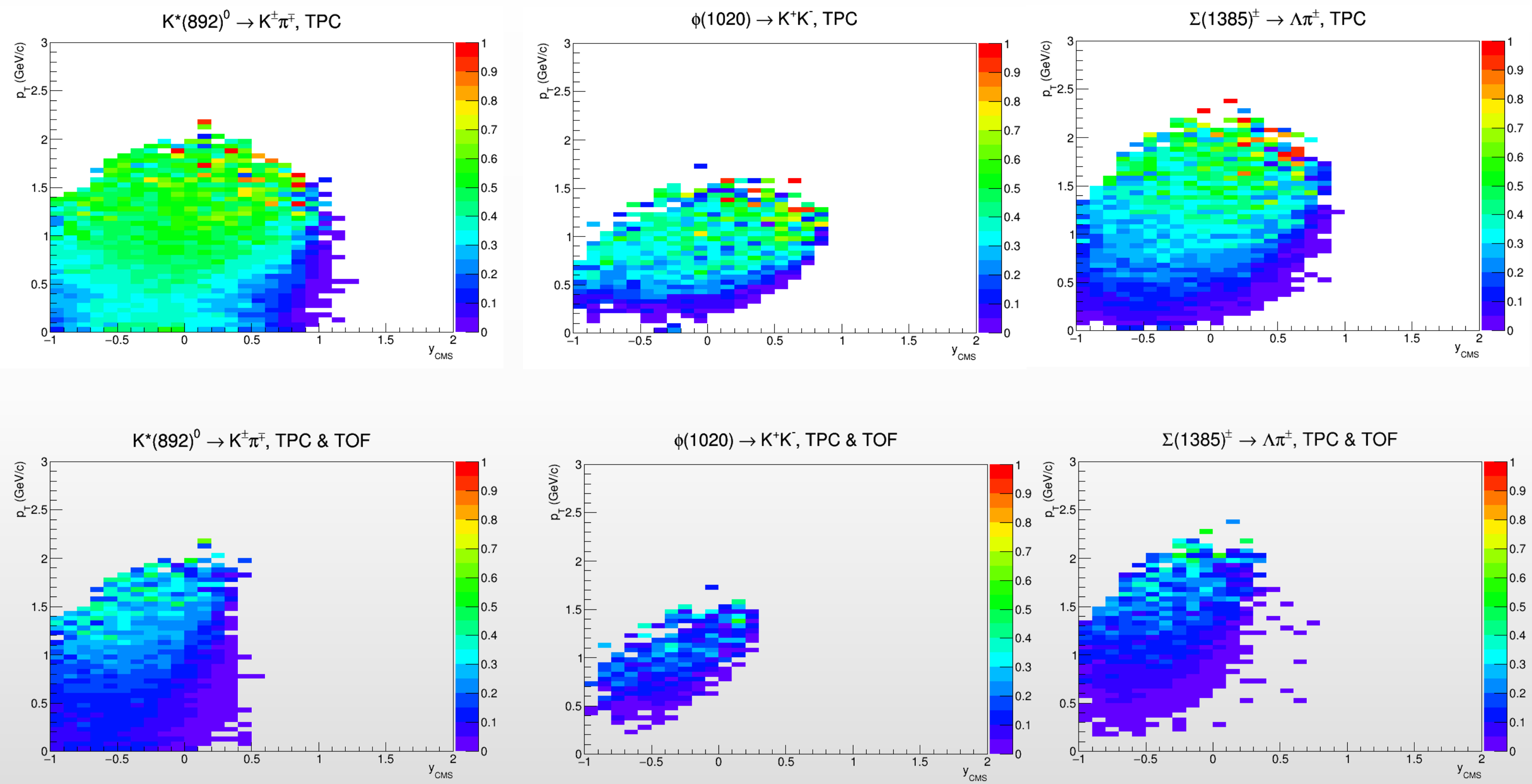
Efficiency for $K_s^0/\Lambda/\Xi^-$, $E_{lab} = 5.5 \cdot A$ GeV

- $N_{hits} > 10$; $p_T > 0.1$ GeV/c; Primary particles ($R_{production} < 1$ cm)



Efficiency for $K^*(892)^0/\phi(1020)/\Sigma(1385)^\pm$, $E_{lab} = 5.5 \cdot A$ GeV

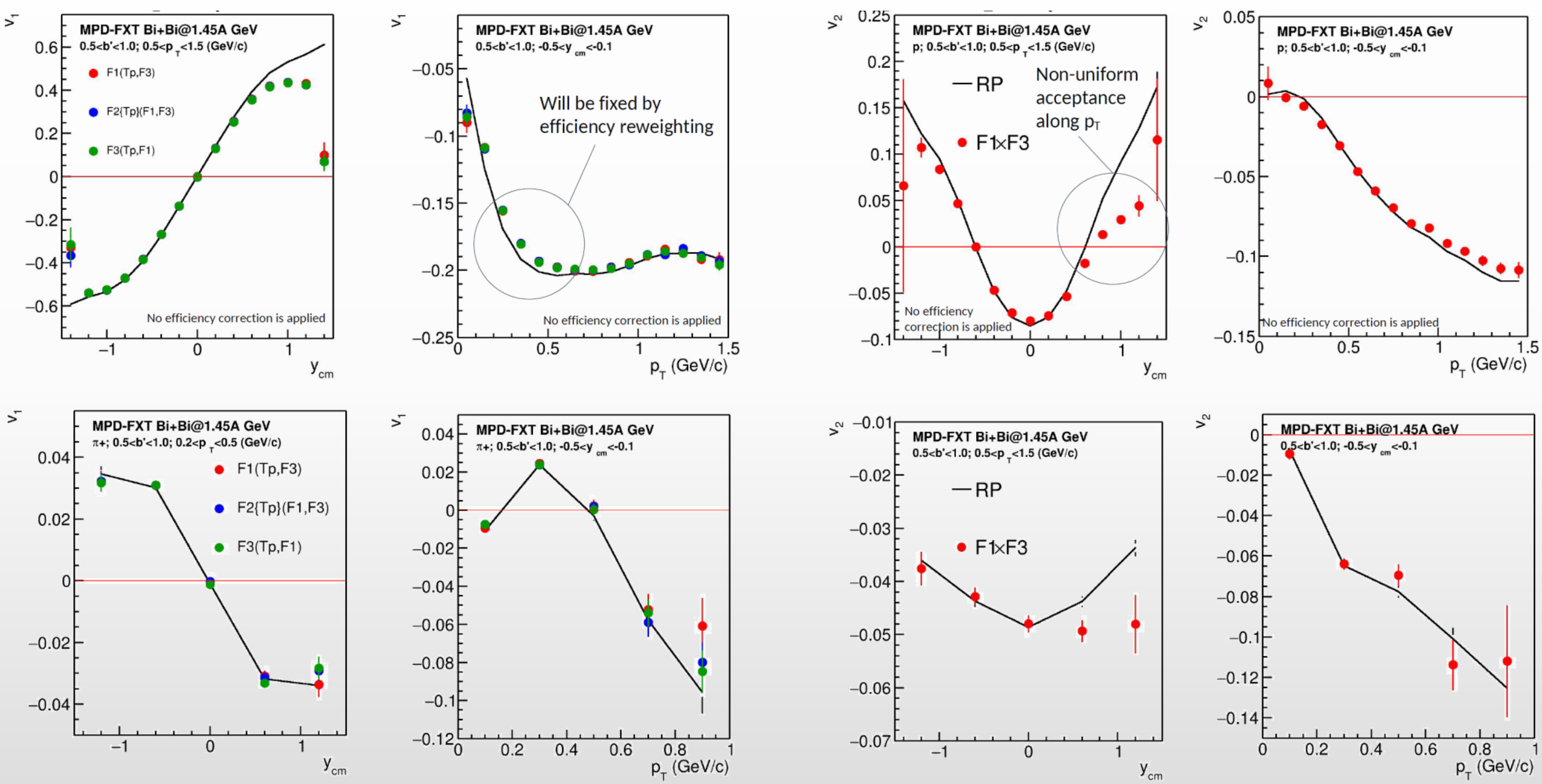
- $N_{hits} > 10$; $p_T > 0.1$ GeV/c; Primary particles ($R_{production} < 1$ cm)



MPD should be able light and heavy identified hadrons at midrapidity

MPD-FXT, v_1 & v_2 for protons/pions

❖ Request 33 mass production (UrQMD mean-field, fixed-target mode)

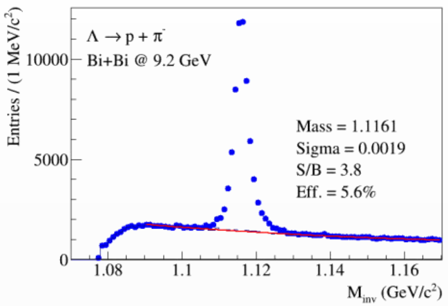


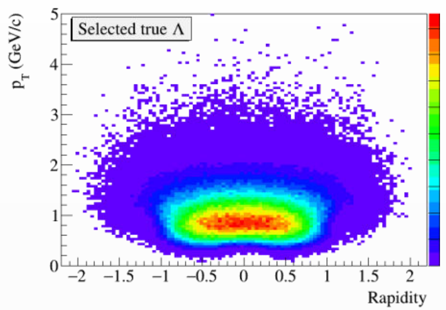
Reconstructed v_1 & v_2 are qualitatively consistent with truly generated signals at $|y_{cms}| < 0.5$

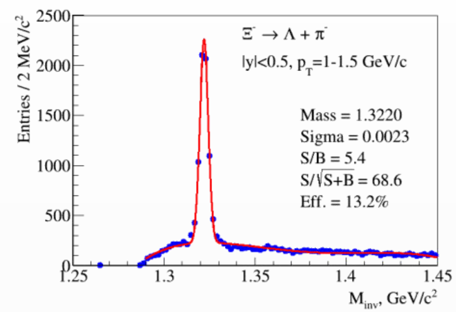
Efficiency corrections and larger statistics are needed for numerical conclusions

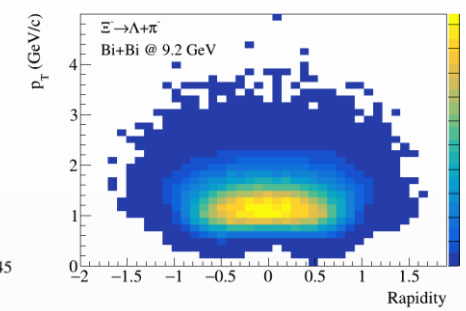
Hyperon reconstruction

❖ Request 25 mass production (UrQMD, BiBi@9.2 GeV, 50M events)

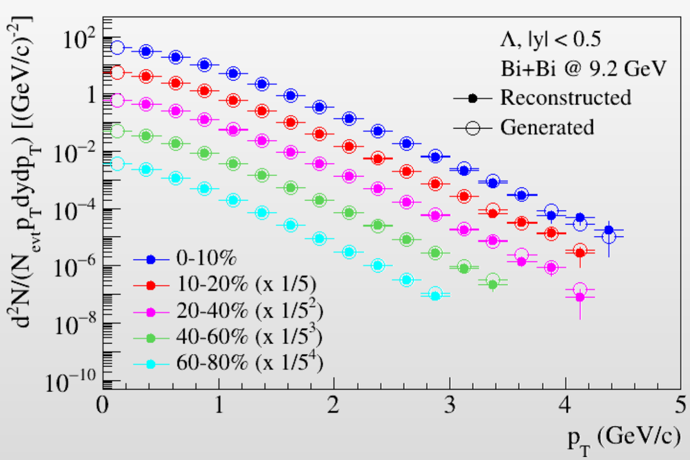


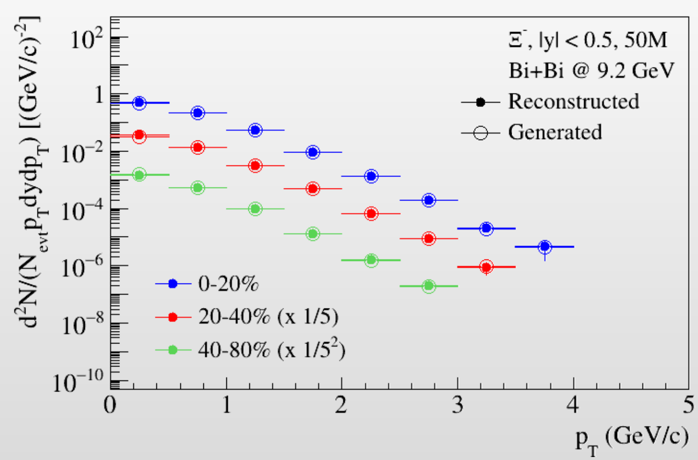






- different background estimates (fit function vs mixed-event)
- different PID selections for high-p_T daughter particles
- testing alternative Machine Learning techniques

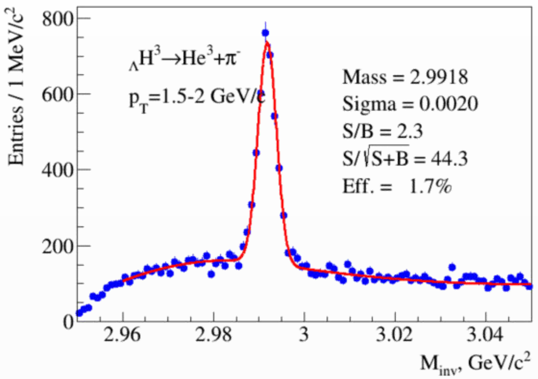


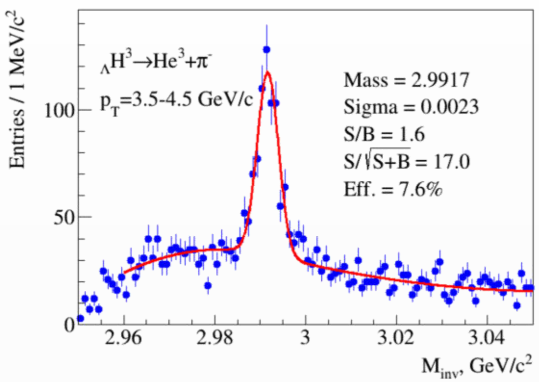


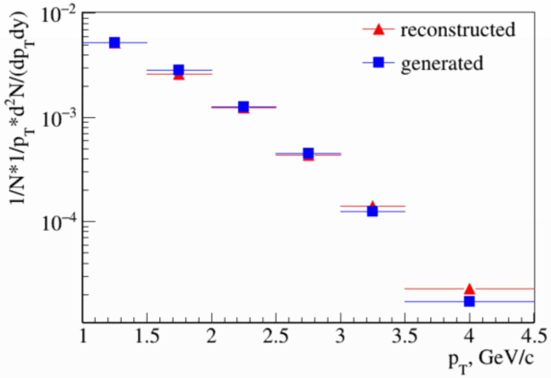
Differential production spectra are reconstructed in different centrality bins

Hypenuclei reconstruction

❖ Request 29 mass production (PHQMD, BiBi@9.2 GeV, 40M events)



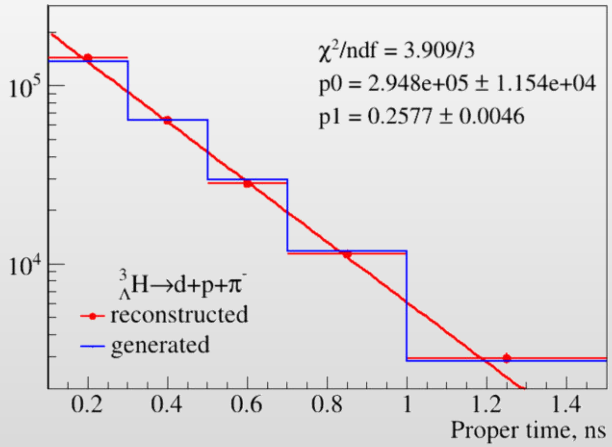


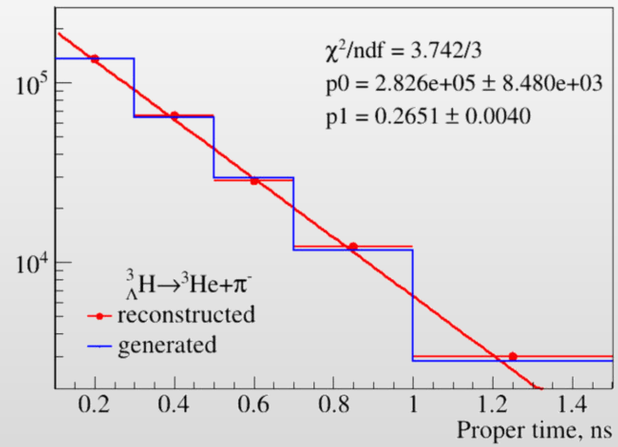


2- and 3-prong decay modes were studied separately to estimate systematics

$$N(\tau) = N(0)\exp\left(-\frac{\tau}{\tau_0}\right) = N(0)\exp\left(-\frac{ML}{cp\tau_0}\right),$$

Decay channel	Branching ratio	Decay channel	Branching ratio
$\pi^- + {}^3He$	24.7%	$\pi^- + p + p + n$	1.5%
$\pi^0 + {}^3H$	12.4%	$\pi^0 + n + n + p$	0.8%
$\pi^- + p + d$	36.7%	$d + n$	0.2%
$\pi^0 + n + d$	18.4%	$p + n + n$	1.5%

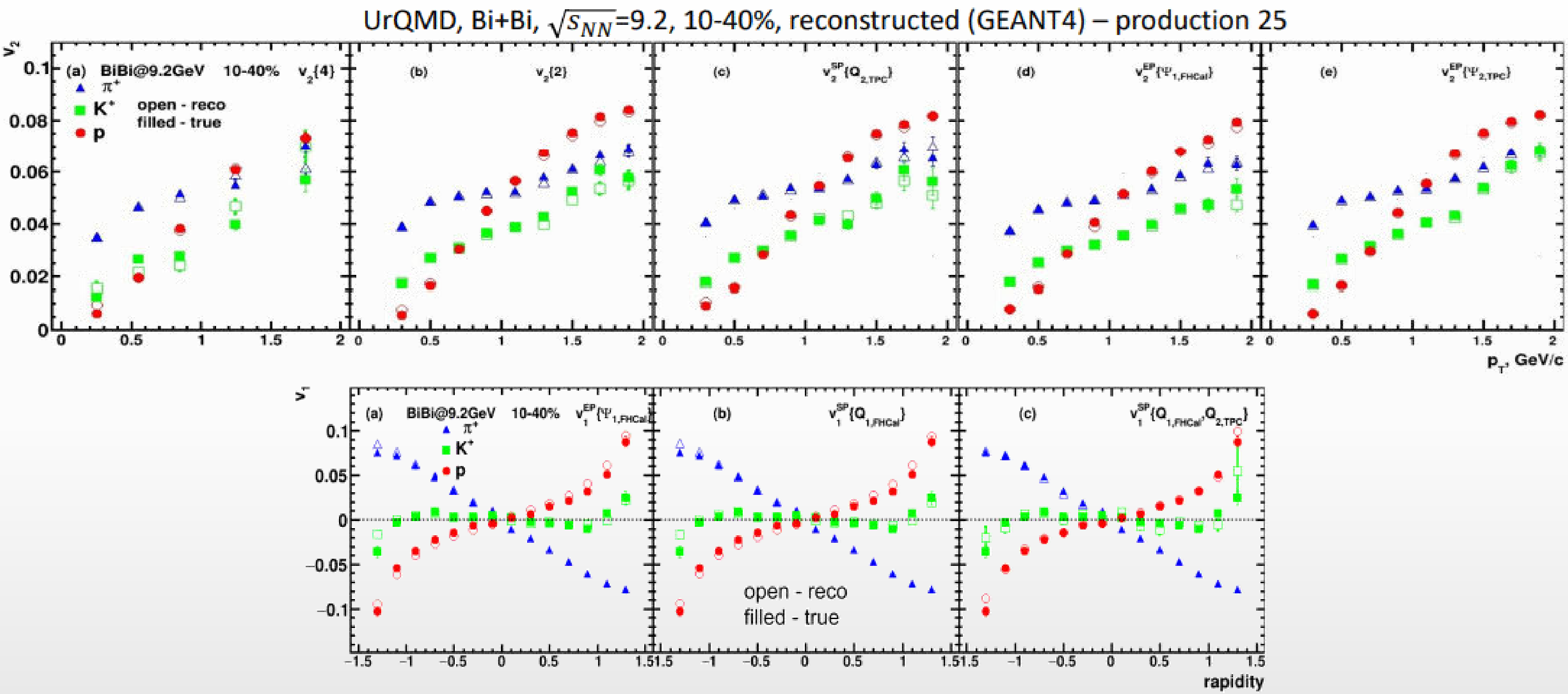




Results for different decay modes are consistent

Performance for v_1, v_2 of identified hadrons

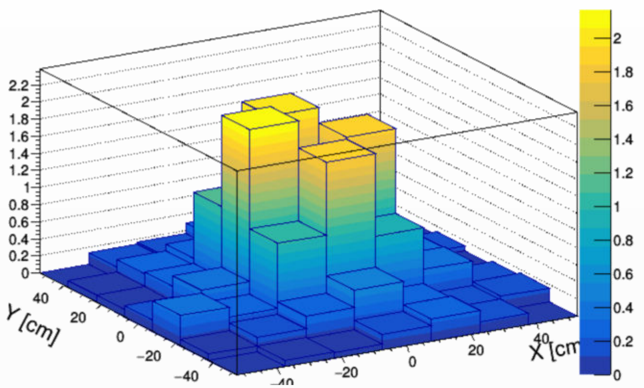
- Request 25 mass production (UrQMD, BiBi@9.2 GeV, 50M events)

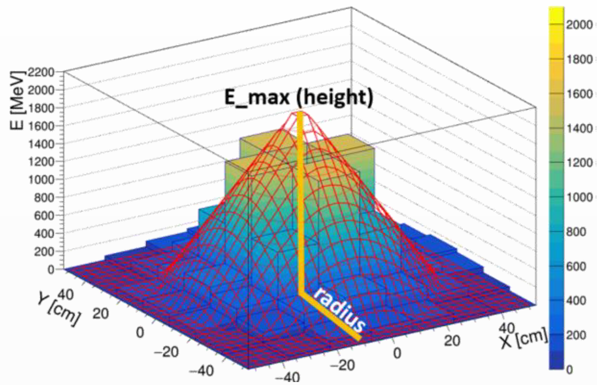


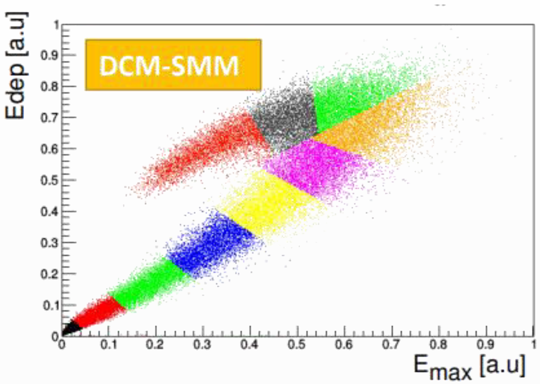
Reconstructed and generated v_1 and v_2 for identified hadrons are in good agreement for all methods

Centrality with FHCAL

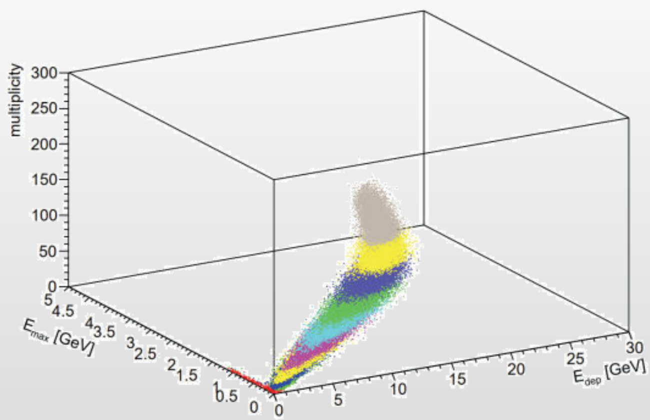
❖ Old approach – only FHCAL signals are analyzed:

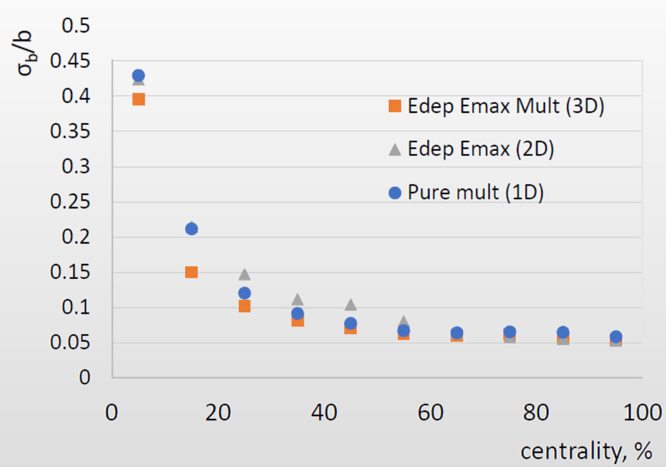






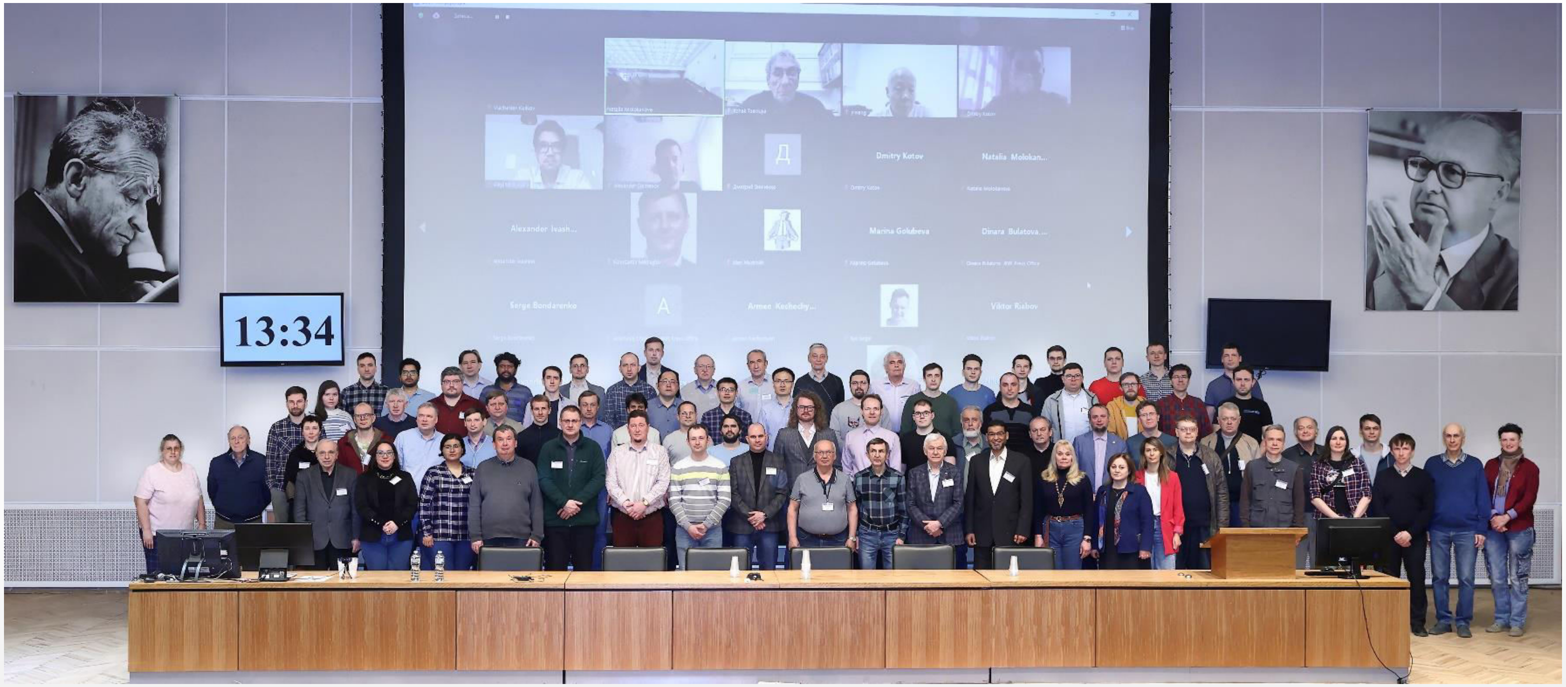
❖ New approach – adding TPC multiplicity for 3D analysis:





Improved resolution for most central and (semi)central collisions

Summary



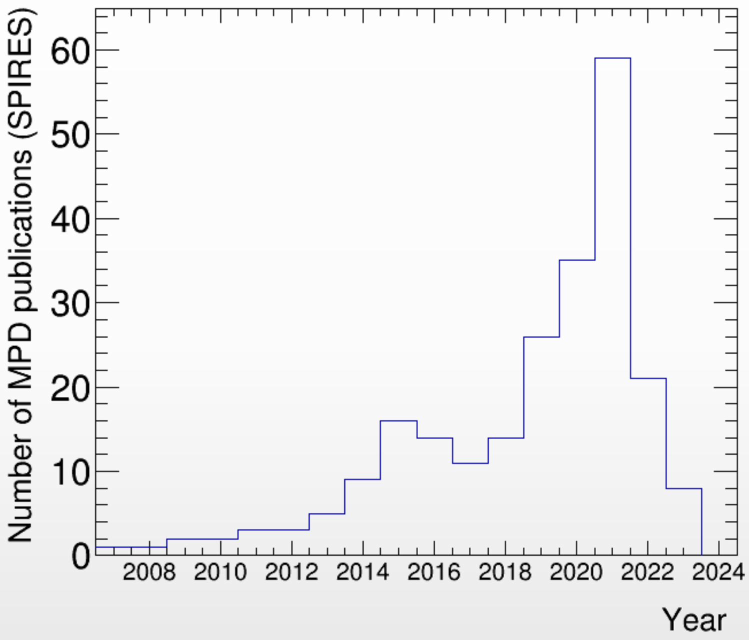
- ❖ Preparation of the MPD detector and experimental program is continued
- ❖ Commissioning and start of data taking → 2025
- ❖ Further program will be driven by the physics demands and NICA capabilities

BACKUP

Collaboration activity

- Many ongoing construction works, theoretical and physics feasibility studies, see reports on hardware/software/physics topics at the collaboration meeting

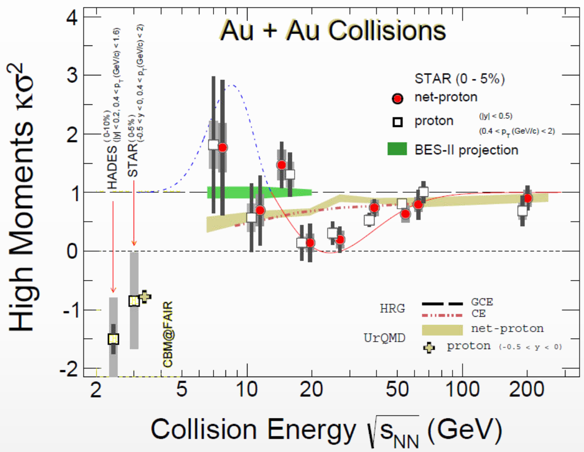
- MPD publications: over 200 in total for hardware, software and physics studies:

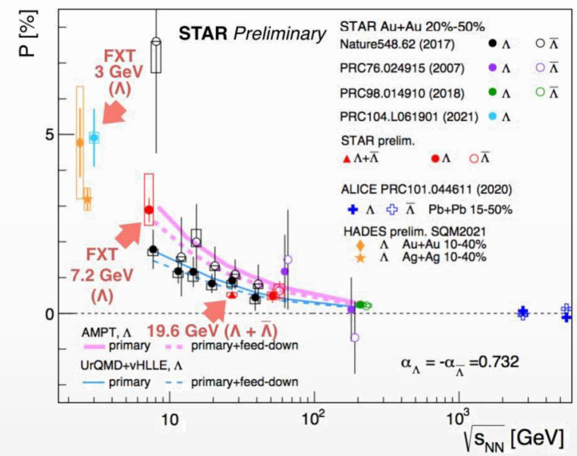


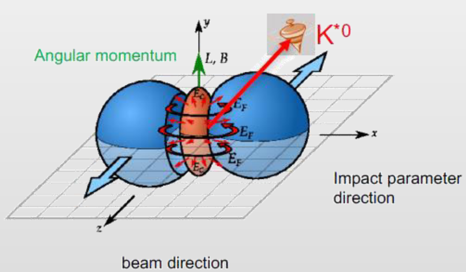
- Support of Russian institutions in the NICA project:
  - ✓ 2019-2021: RFBR grant program, 2019-2021
  - ✓ 2022: internal JINR grants for students/PhD, 2022
  - ✓ 2023: internal JINR grants for leaders/students/PhD, 2023
  - ✓ 2023 and beyond: expect support by Russian Ministry of Science

Hot topics to fill the gaps

- Critical fluctuations for (net)proton/kaon multiplicity distributions
- Global hyperon polarization in mid-central A+A collisions (Λ, Ξ, Ω)
- Spin alignment of vector mesons ($K^*(892)$, $\phi(1020)$)
- Dielectron continuum and LVMs
- ….







$$\frac{dN}{d\cos\theta} = N_0\left[1 - \rho_{0,0} + \cos^2\theta\left(3\rho_{0,0} - 1\right)\right]$$