Current Status of the NICA Project and Physics Prospects

Grigory Nigmatkulov (for the MPD Collaboration)
National Research Nuclear University MEPhI

NICA: Unique and complementary

ESFRI Roadmap Landscape Analysis 2021

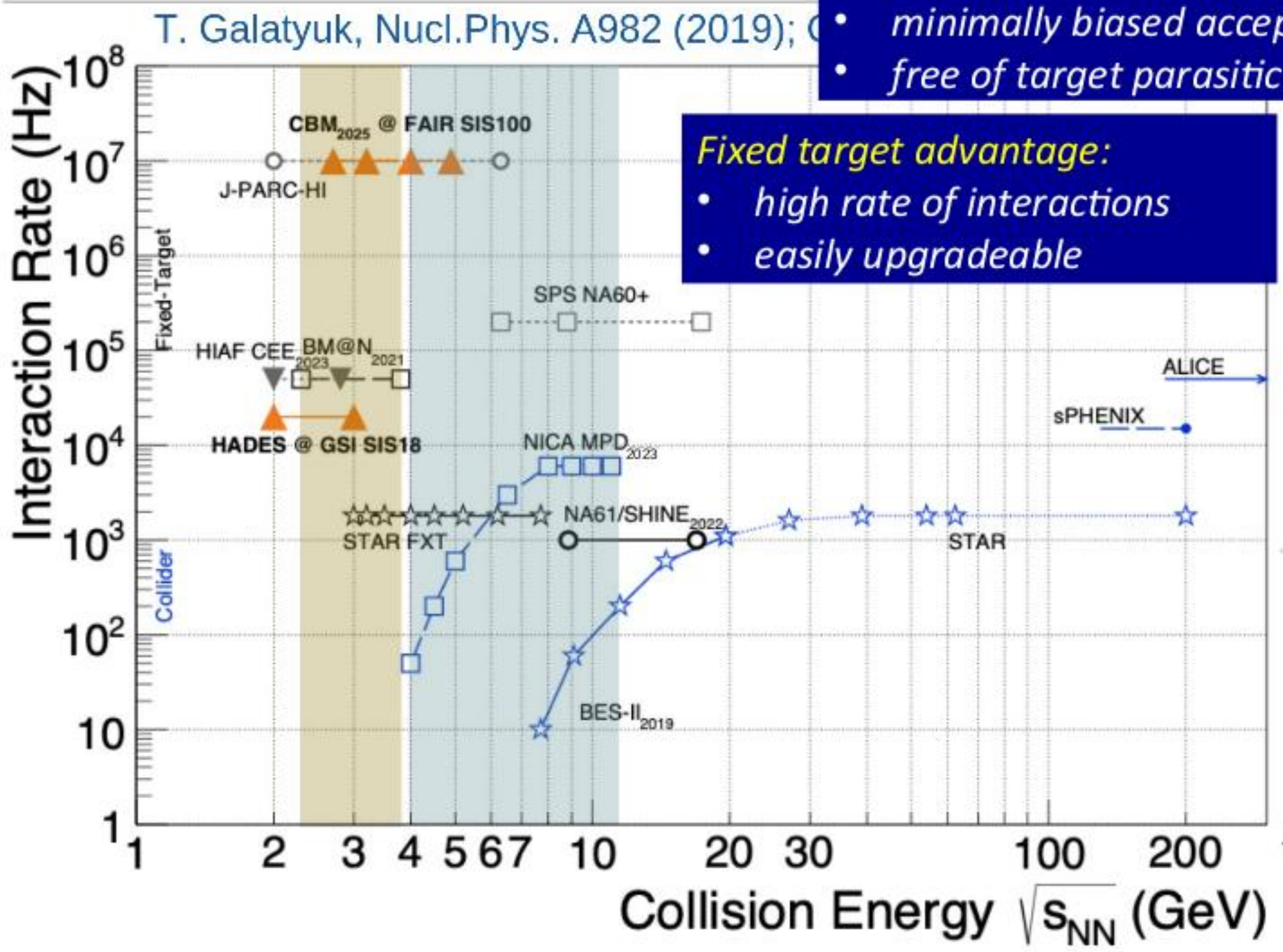
Collider advantage:

- *coverage of max. phase space*
- *minimally biased acceptance*
- *free of target parasitic effects*

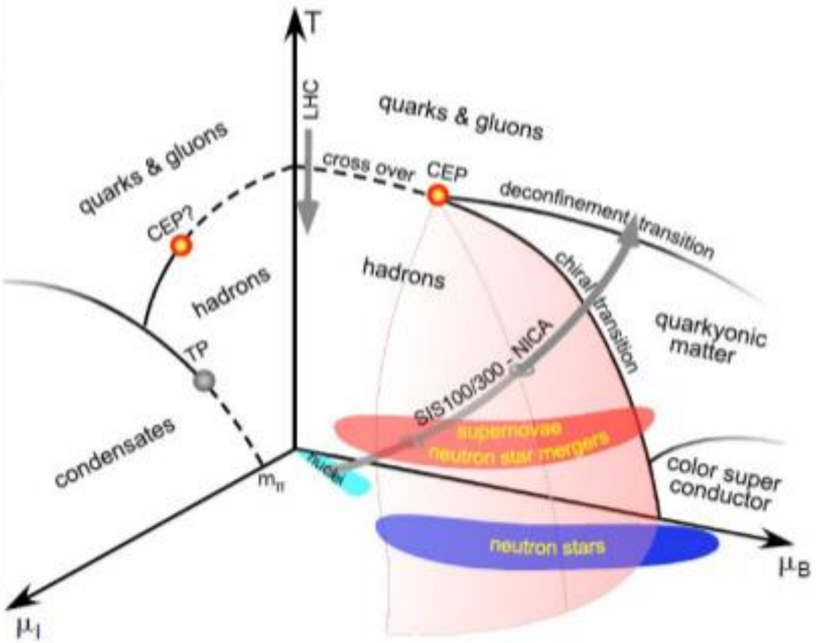
In NICA energy range maximum possible net-baryon density is reached

Fixed target advantage:

- *high rate of interactions*
- *easily upgradeable*



NUPECC Long Range Plan 2017



Grigory Nigmatkulov for the MPD Collaboration

The Host Institute

JOINT INSTITUTE FOR NUCLEAR RESEARCH

SCIENCE BRINGS NATIONS TOGETHER

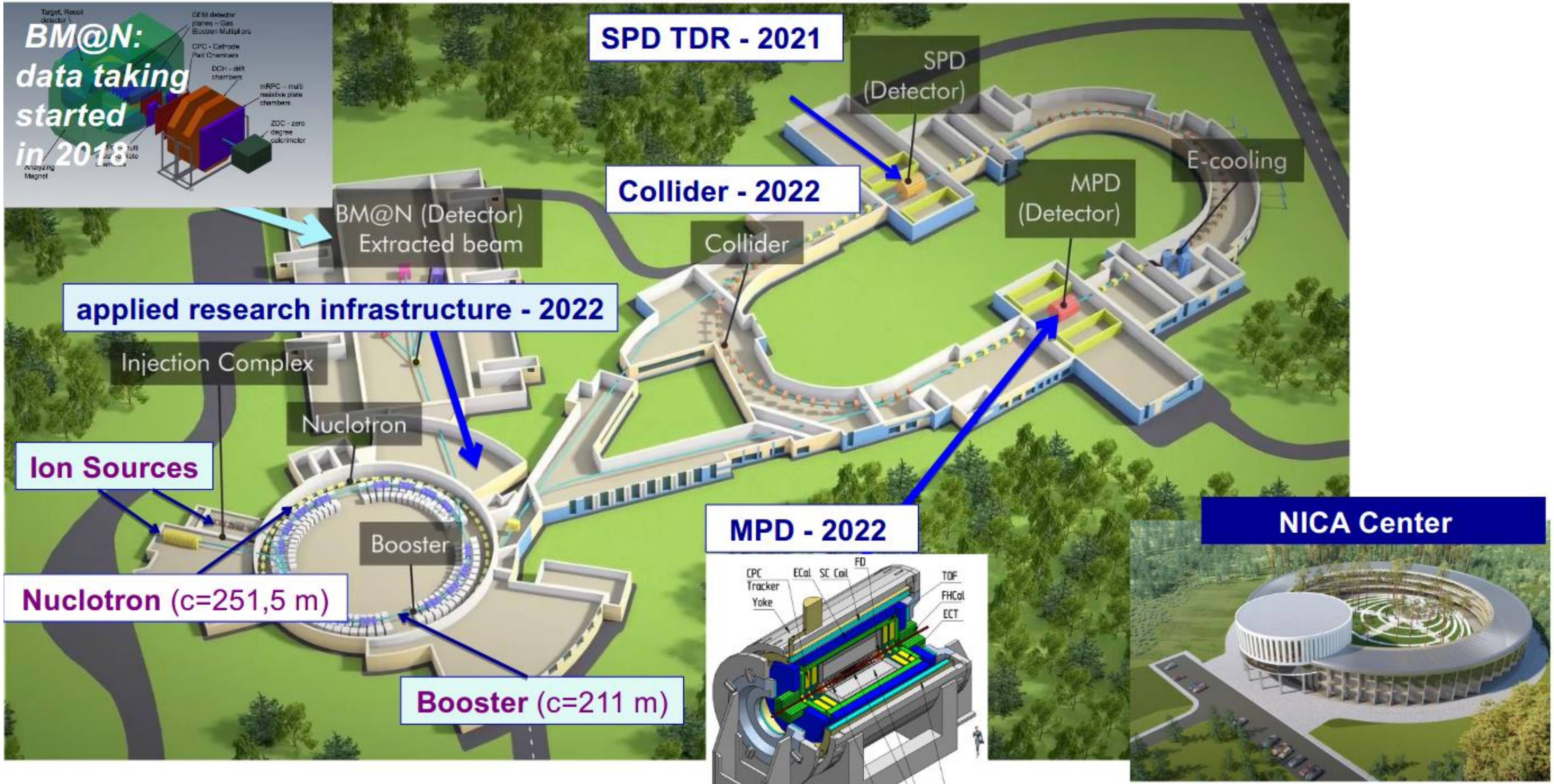
1956

Joint Institute for Nuclear Research (JINR) –
International Intergovernmental Organization established through the Convention of March 26, 1956 by 11 founding States and registered with the United Nations on 1 February 1957

Governed by the
Committee of Plenipotentiaries
*representing governments of **18** countries*

CERN** and **JINR** have reciprocal **observer status

NICA Accelerator Complex in Dubna



Budget: approx. 500 M$

NICA construction live

January 2022

Main parameters of accelerator complex

Nuclotron

Parameter	SC synchrotron
particles	↑p, ↑d, nuclei (Au, Bi, ...)
max. kinetic energy, GeV/u	10.71 (↑p); 5.35 (↑d) **3.8** (Au)
max. mag. rigidity, Tm	38.5
circumference, m	251.52
vacuum, Torr	10^{-9}
intensity, ***Au*** */pulse*	1 10^{9}

Booster

	value
ion species	A/Z ≤ 3
max. energy, MeV/u	**600**
magnetic rigidity, T m	1.6 – 25.0
circumference, m	210.96
vacuum, Torr	10^{-11}
intensity, ***Au*** */pulse*	1.5 10^{9}

The Collider

Design parameters, Stage II

45 T*m, 11 GeV/u for Au^{79+}

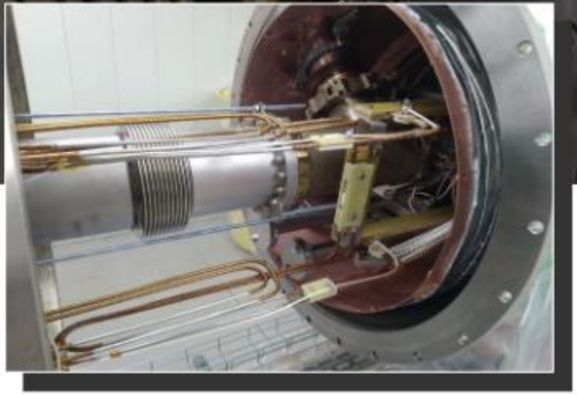
Ring circumference, m	**503,04**
Number of bunches	**22**
r.m.s. bunch length, m	**0,6**
β, m	**0,35**
Energy in c.m., Gev/u	**4-11**
r.m.s. Δp/p, 10^{-3}	**1,6**
IBS growth time, s	**1800**
Luminosity, cm^{-2} s^{-1}	**$1x10^{27}$**

Stage I:

- ***without ECS in Collider, with stochastic cooling***
- ***reduced number of RF***
- ***reduced luminosity (10^{25} is the goal for 2023)***

Collision system limited by source. *Now Available: C(A=12), N(A=14), Ne(A=20), Ar(A=40), Fe(A=56), Kr(A=78-86), Xe(A=124-134), Bi(A=209)*

Booster commissioning

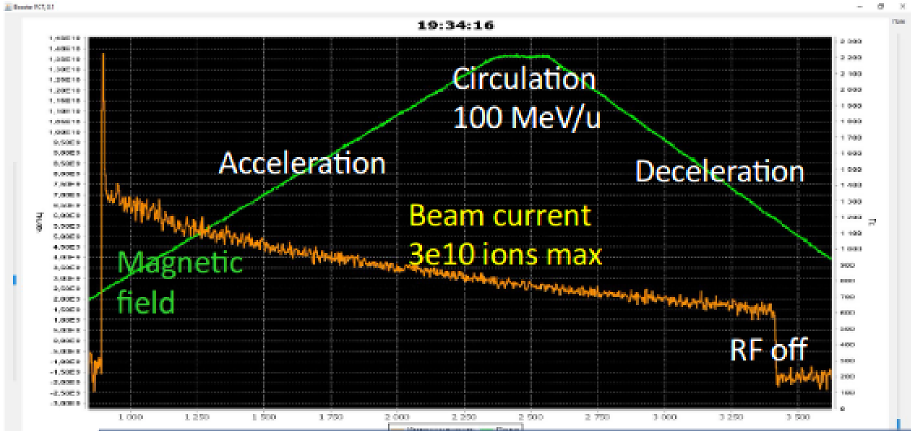


- ✓ ***Booster fully assembled in the tunnel***
- ✓ ***Commissioning and test ongoing for beam diagnostics, beam acceleration, electron cooling, power supply, magnets, cryogenics***

First Booster run – Dec 30th, 2020

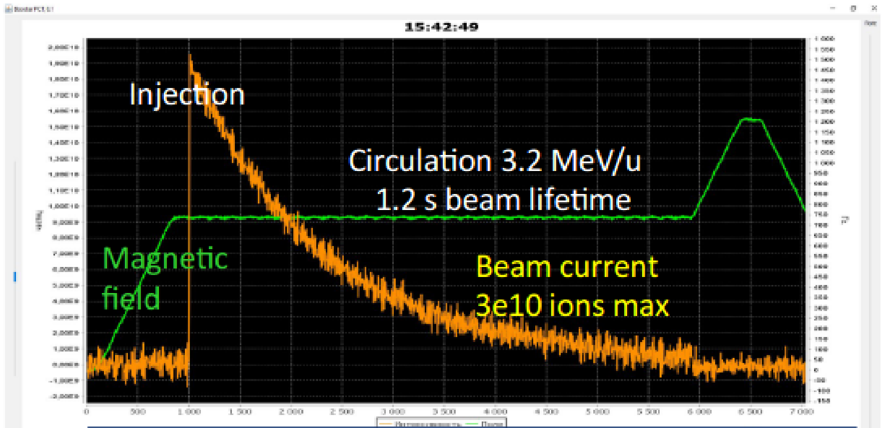
Booster – the first technical run:
Injected He^{1+}, 3,2MeV/u, 6,5*10^{10} ppp
Accelerated up to 100 MeV/u
(project 600 MeV/u)

operation at design magnetic field & ramp rate



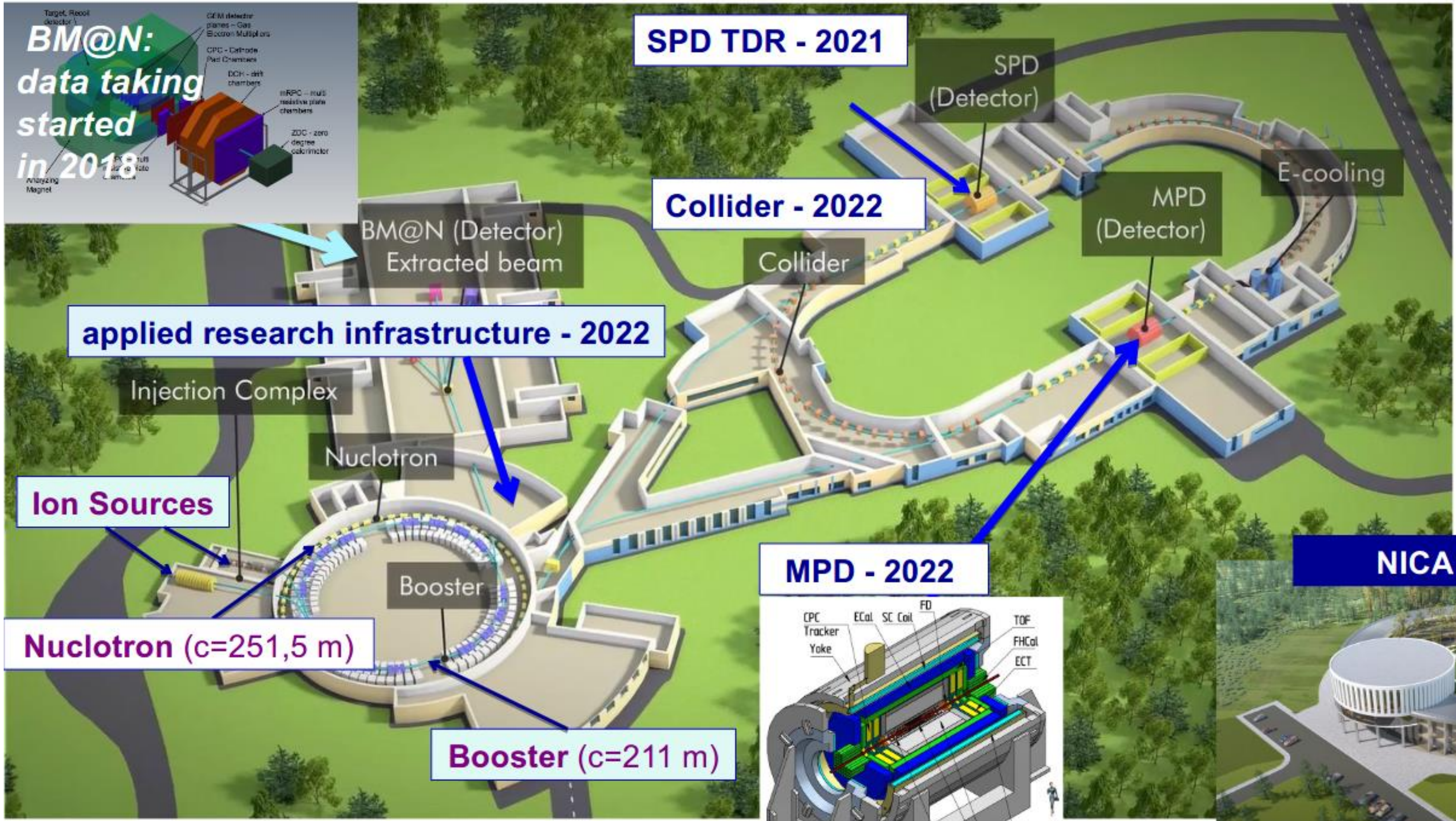
FCT signal when injecting into rising field, capturing (~60%), accelerating & decelerating:

no transient losses on the MF table & after.



*Beam loss indicated the integral pressure in the beam pipe ~ 2-3 * 10^{-10} Torr*

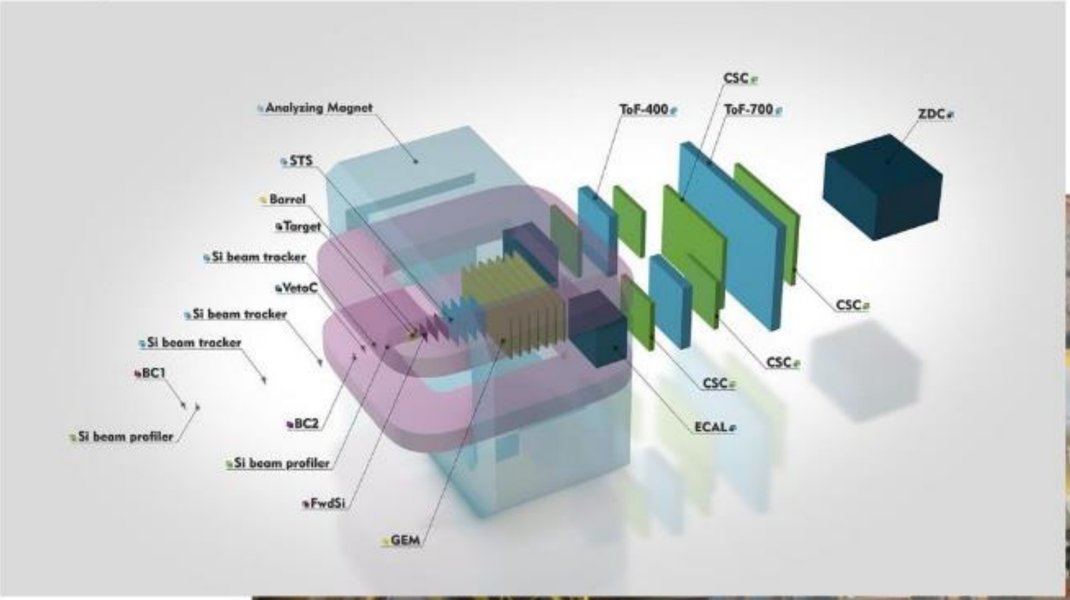
NICA Accelerator Complex in Dubna

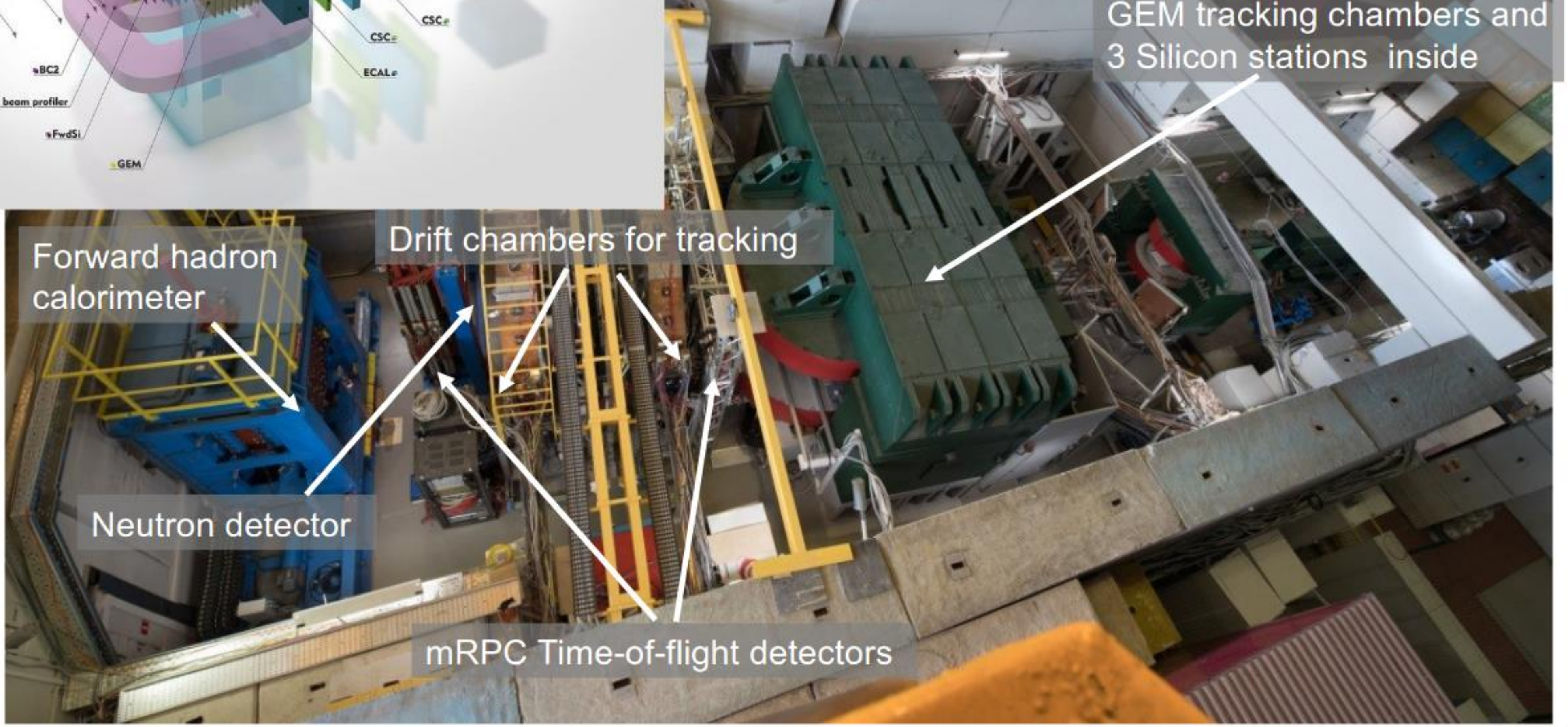


Budget: approx. 500 M$

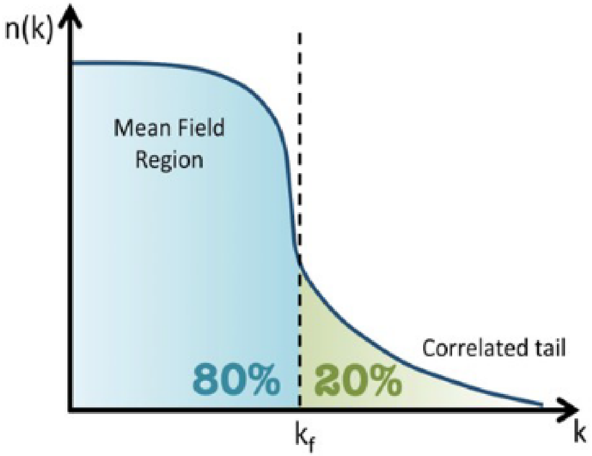
First physics from BM@N at NICA

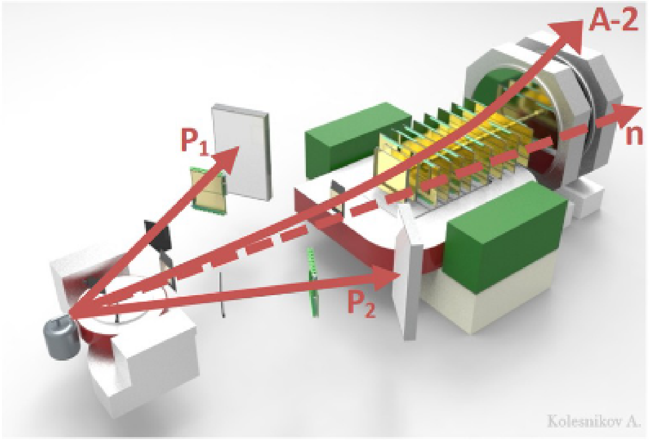
Baryonic Matter @ Nuclotron (BM@N)
10 countries, 20 institutions,
246 participants





Experiment with BM@N: Short-Range Correlations (SRC)





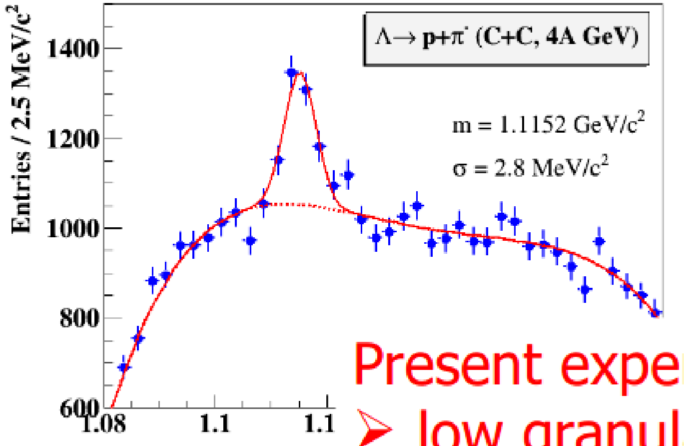
Experiment at BM@N with a 4A GeV C-beam:

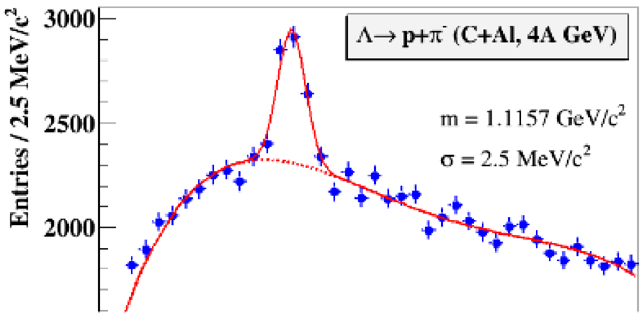
$^{12}C + p \rightarrow 2p + {}^{10}_{4}Be + p$ (pp SRC)

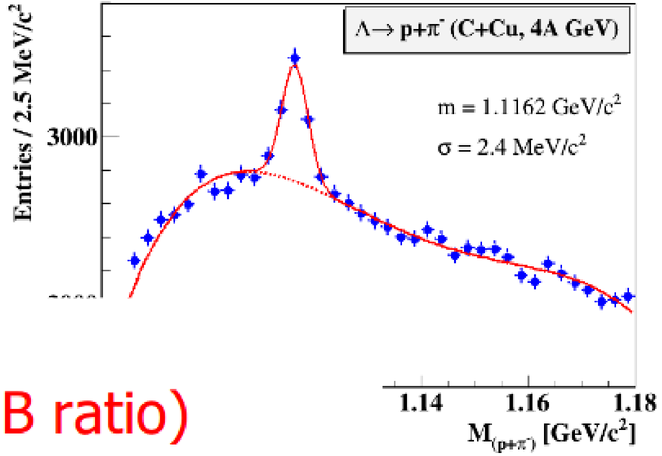
First fully exclusive measurement in inverse kinematics probing the residual A-2 nuclear system!

M. Patsyuk et al., arXiv:2102.02626
Accepted for publication in **nature physics**

Experiment with BM@N: Λ's in C + C, Al, Cu at 4A GeV



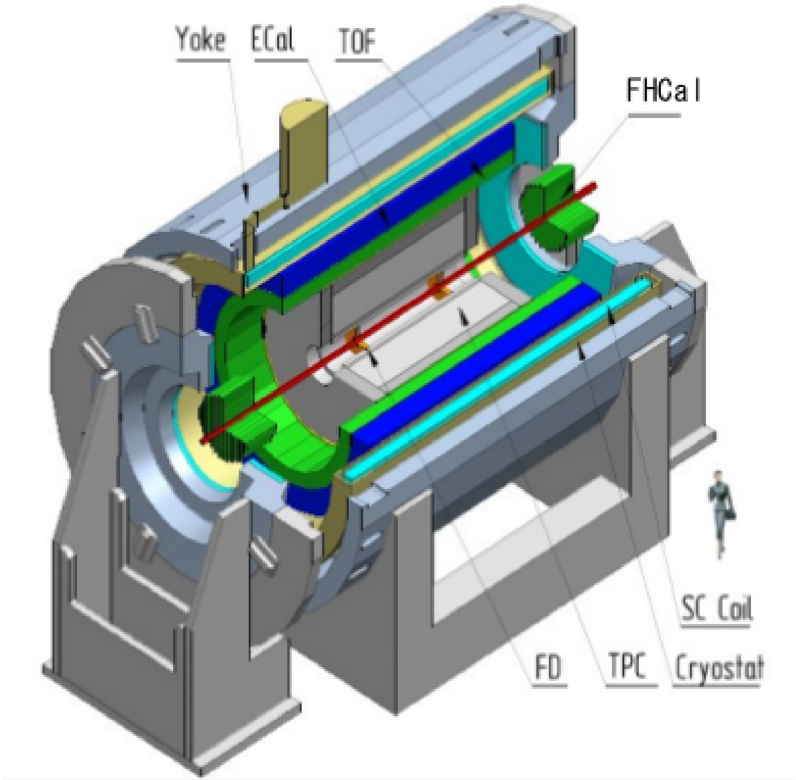




Present experimental limitations:

- low granularity tracking systems (small S/B ratio)
- air gaps in beam line from Nuclotron (low beam quality)
- no vacuum beam pipe in BM@N (large background)

Multi-Purpose Detector (MPD) Collaboration



NICA

13 Countries, >500 participants,
43** Institutes and **JINR

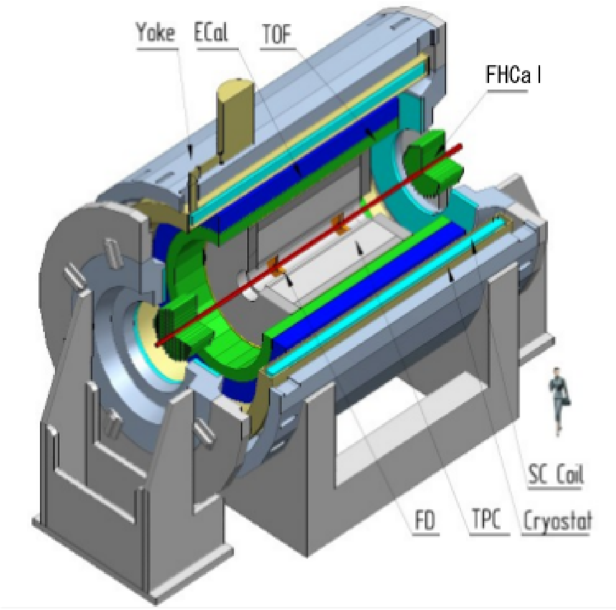
*Spokesperson: **Adam Kisiel***
*Inst. Board Chair: **Alejandro Ayala***
*Project Manager: **Slava Golovatyuk***

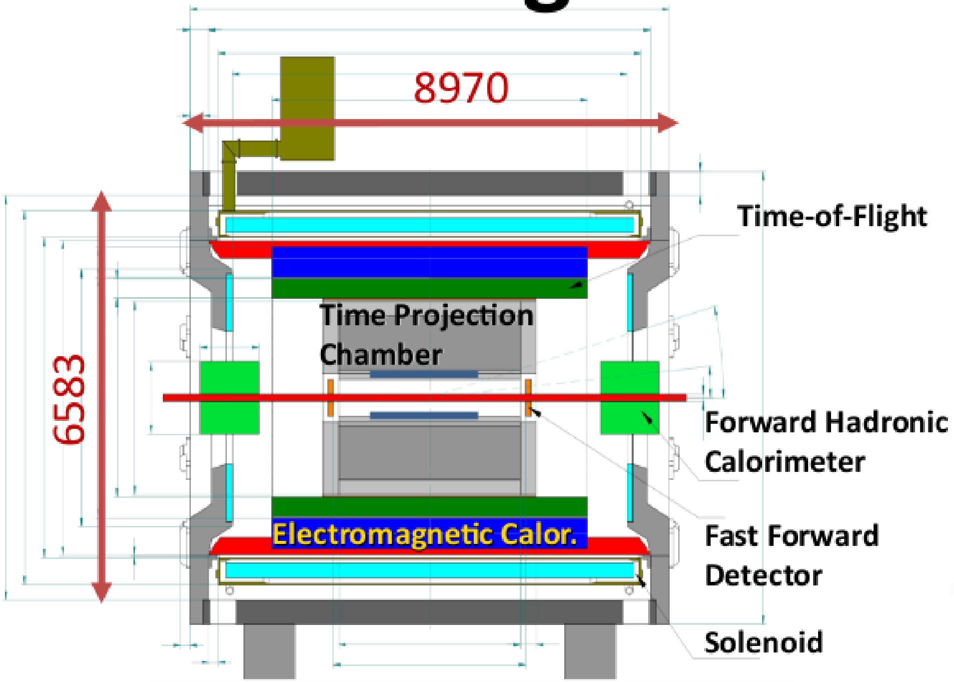
Deputy Spokespersons:
Victor Riabov, Zebo Tang

*International Collaboration established in **2018***
Still growing, open for new member institutions

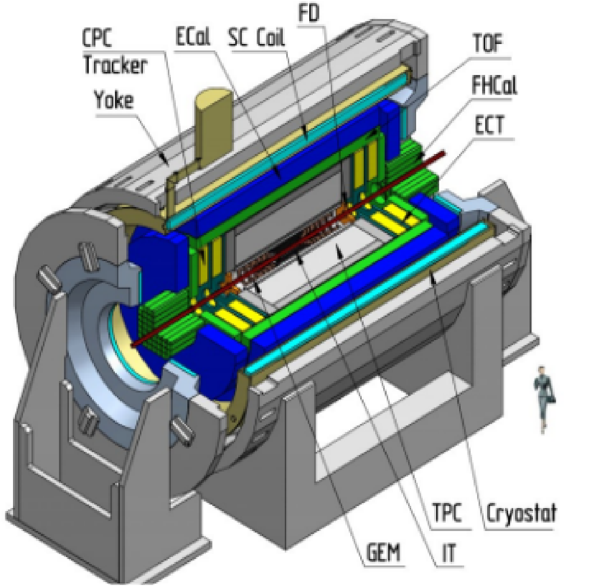
*AANL, Yerevan, **Armenia;***
*Baku State University, NNRC, **Azerbaijan**;*
*Plovdiv University Paisii Hilendarski, **Bulgaria;***
*University Tecnica Federico Santa Maria, Valparaiso, **Chile**;*
*Tsinghua University, Beijing, **China**;*
*USTC, Hefei, **China**;*
*Huzhou University, Huizhou, **China**;*
*Central China Normal University, **China**;*
*Fudan University, Shanghai, **China**;*
*Shandong University, Qingdao, **China**;*
*SNST, UCAS, Beijing, **China**;*
*University of South China, **China**;*
*Three Gorges University, **China**;*
*Institute of Modern Physics, CAS, Lanzhou, **China**;*
*Palacky University, Olomouc, **Czech Republic**;*
*NPI CAS, Rez, **Czech Republic**;*
*Tbilisi State University, Tbilisi, **Georgia**;*
***Joint Institute for Nuclear Research**;*
*FCFM-BUAP Puebla, **Mexico**;*
*FC-University of Colima, Colima, **Mexico**;*
*FCFM-UAS, Culiacán, **Mexico**;*
*ICN-UNAM, Mexico City, **Mexico**;*
*CINVESTAV, Mexico City, **Mexico**;*
*Universidad Autónoma Metropolitana, Iztapalpa, **Mexico**;*
*Institute of Applied Physics, Chisinev, **Moldova**;*
*WUT, Warsaw, **Poland**;*
*NCBJ, Otwock – Świerk, **Poland**;*
*University of Wrocław, **Poland**;*
*University of Silesia, Katowice, **Poland**;*
*University of Warsaw, **Poland**;*
*Jan Kochanowski University, Kielce, **Poland**;*
*Institute of Nuclear Physics, PAS, Cracow, **Poland**;*
*Belgorod National Research University, **Russia**;*
*INR RAS, Moscow, **Russia**;*
*NRNU MEPhI, Moscow, **Russia**;*
*Moscow Institute of Science and Technology, **Russia**;*
*North Osetian State University, **Russia**;*
*NRC Kurchatov Institute, ITEP, **Russia**;*
*Kurchatov Institute, Moscow, **Russia**;*
*St. Petersburg State University, **Russia**;*
*SINP, Moscow, **Russia**;*
*PNPI, Gatchina, **Russia**;*
*Vinča Institute of Nuclear Sciences, Belgrade, **Serbia**;*
*Pavol Jozef Šafárik University, Košice, **Slovakia**;*

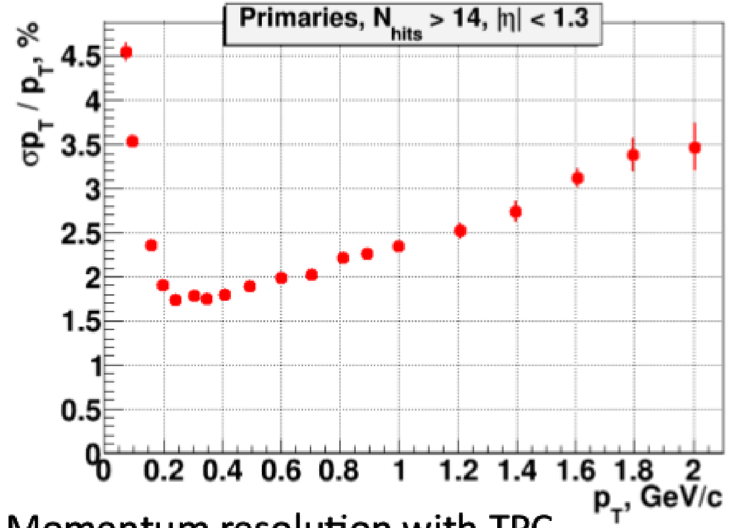
MPD - stage I and II



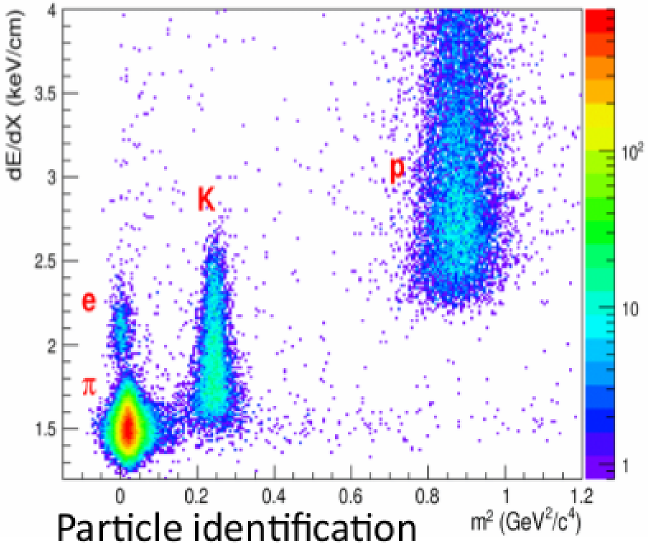


MPD - Stage II

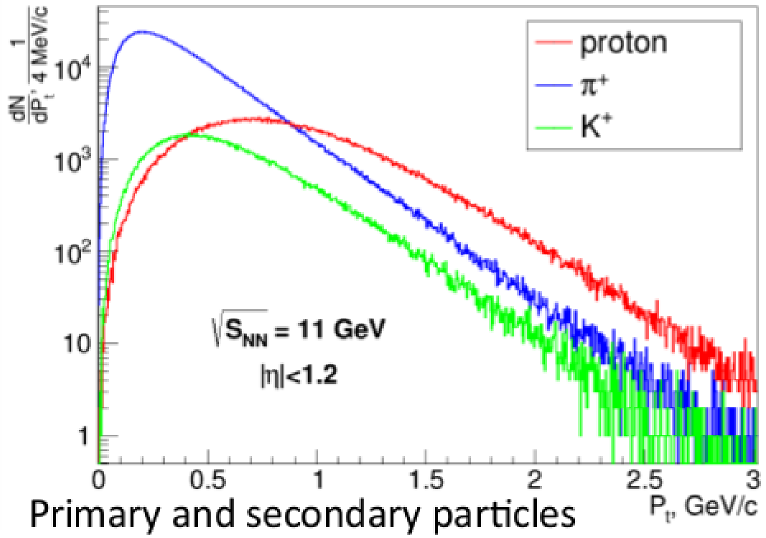




Momentum resolution with TPC



Particle identification



Primary and secondary particles

Interior of MPD Hall

Installation of the MPD Supercoducting coil inside the iron Magnet Yoke in MPD Pit 29 July 2021

MPD assembling milestones 2022-2023

Year 2020

1. Jul. 15^{th} - MPD Hall and pit ready to store and unpack Yoke parts
2. Aug. - The first 13 plates of Magnet Yoke are assembled for alignment checks
3. Sep. 15^{th}-Oct. 1^{st} - Solenoid is ready for transportation from ASG (Italy)
4. Nov. 10^{th} - Solenoid arrives at MPD Hall
5. Nov.-Dec. - Assembling of Magnet Yoke

Year 2021

6. Jul.-Aug. - Solenoid installation into Iron Yoke and alignment
7. Aug.-Dec. - Electrical test, pressure tests and vacuum tests

Year 2022

8. Jan. 24 -Feb. 25^{th} - Assembling Iron Yoke, Cryogenic platform and Cryostat. Vacuum test
9. May 20^{th}-Jul. 30^{th} - Solenoid cooling down to Liquid Nitrogen temperature
10. Aug. 15^{th} - Cryogenic infrastructure ready
11. Aug.-Oct. 20^{th} - Cooling down to Liquid Helium temperature
12. Nov.-Dec. - Magnetic Field measurement

Year 2023

13. Jan. 20^{th} -Feb. 10^{th} - Support Frame Installation, Mounting of the Moving Platforms
14. Feb. 15^{th} -Apr. 10^{th} - Installation of ECal half-sectors
15. Mar. -Jul. - Assembly of the Electronics Platform
16. Apr. - Jul. - Cabling
17. Apr. 1^{st} -Jun. 5^{th} - Installation of TOF modules
18. May. 15^{th} -Aug. 1^{st} - TPC installation
19. Jun. -Jul. - Installation of beam pipe, FHCal, Cosmic Ray test system
20. Aug. - Switch-on of the MPD, Commissioning

MPD Physics Programme

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

V. Riabov, Chi Yang

Electromagnetic probes

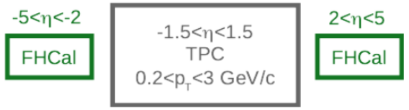
- Electromagnetic calorimeter meas.
- Photons in ECAL and central barrel
- Low mass dilepton spectra in-medium modification of resonances and intermediate mass region

Wangmei Zha, A. Zinchenko

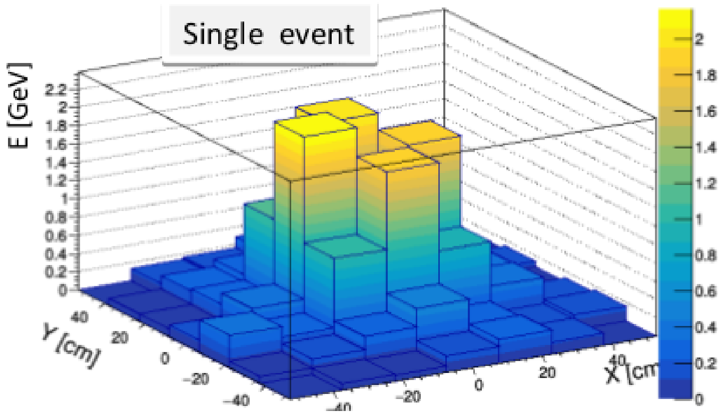
Heavy flavor

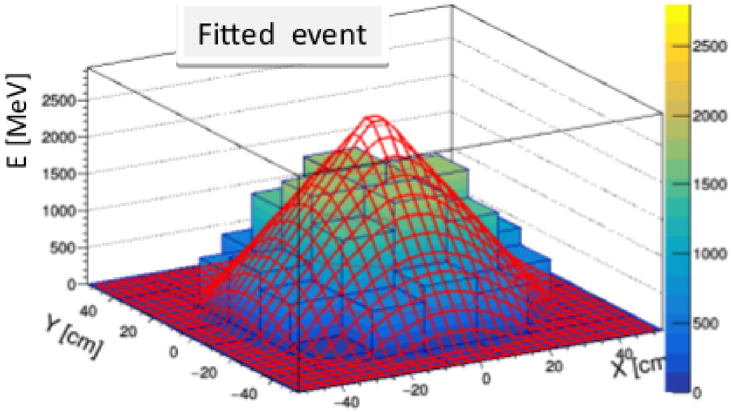
- Study of open charm production
- Charmonium with ECAL and central barrel
- Charmed meson through secondary vertices in ITS and HF electrons
- Explore production at charm threshold

Centrality and reaction plane in FHCal

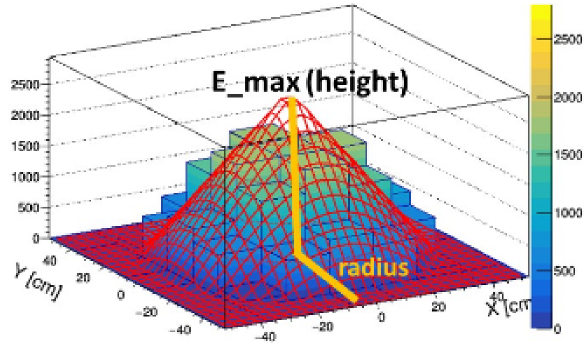


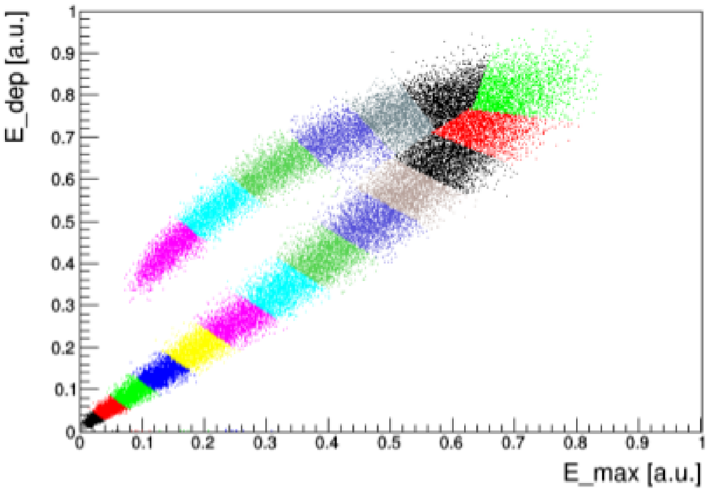
Energy distribution in FHCal modules



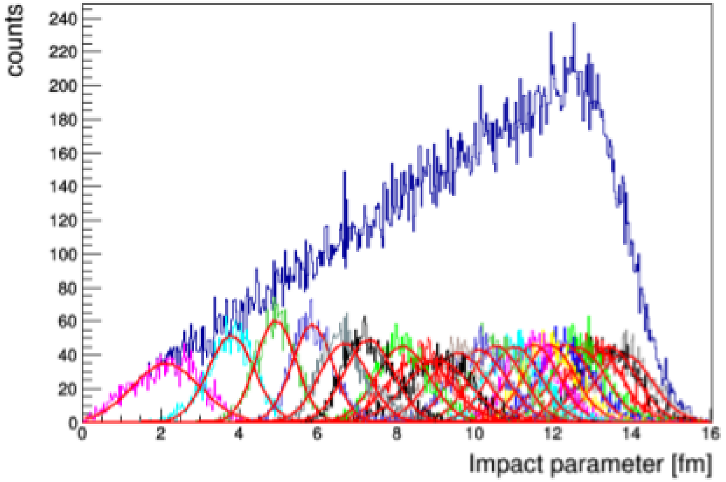


Initially we have experimental energy deposition E_{dep} in FHCal.

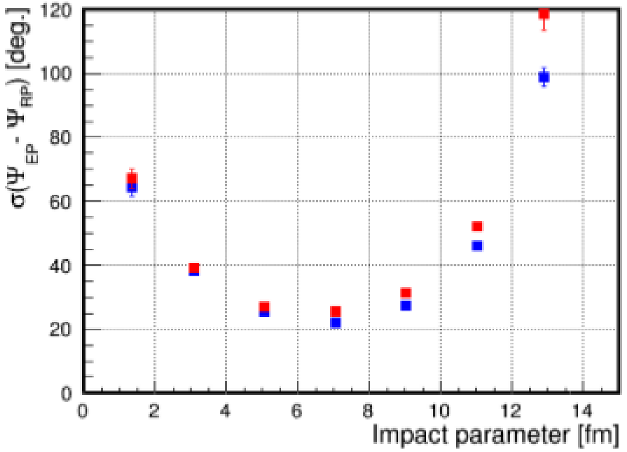




Each color bin is 5% fractions of the total number of events.

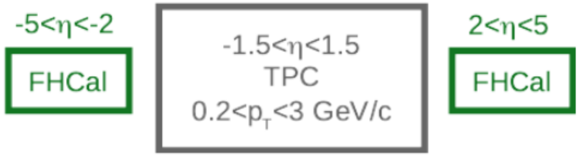


Centrality resolution



Reaction plane resolution

Event plane method using FHCal



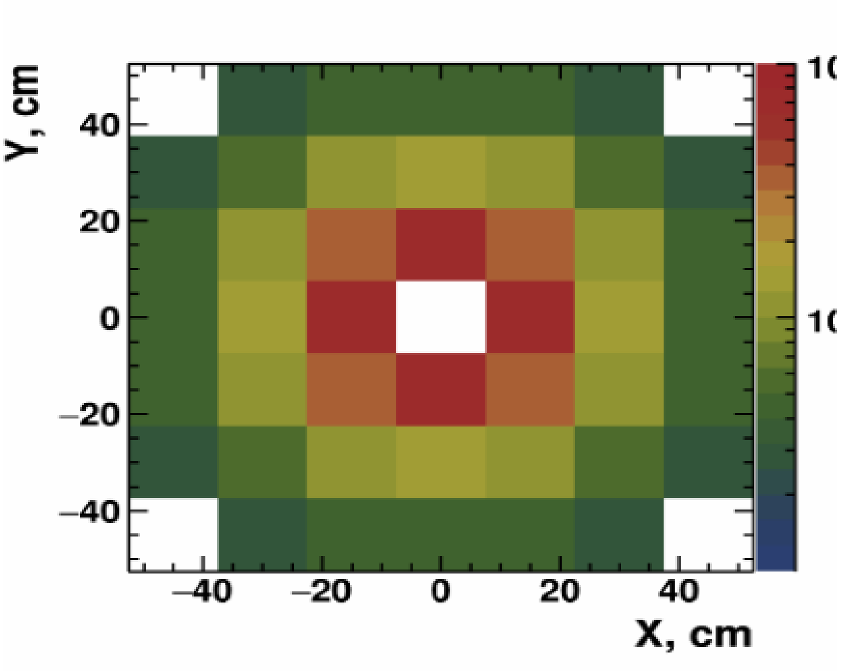
- Using v_1 of particles in FHCal to determine Q_n

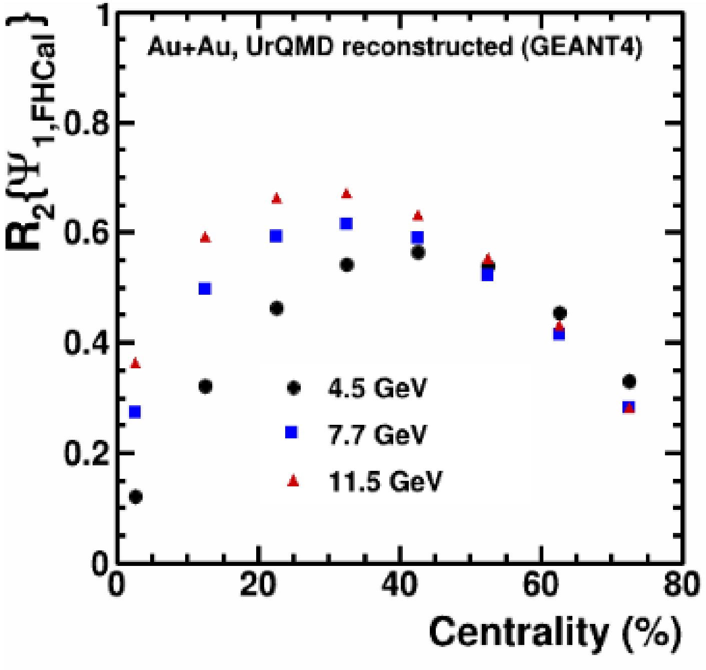
$$Q_1 = \frac{\sum_j E_i e^{i\phi_j}}{\sum_j E_j}, \quad \Psi_{1,\mathrm{FHCal}} = \tan^{-1}\left(\frac{Q_{1,y}}{Q_{1,x}}\right)$$

$$E - \text{energy deposited in FHCal modules}\,(2 < |\eta| < 5)$$

$$\mathrm{R}_2^{\mathrm{EP}}\{\Psi_{1,\mathrm{FHCal}}\} = \langle\cos\left[2(\Psi_{1,\mathrm{FHCal}} - \Psi_{\mathrm{RP}})\right]\rangle$$

$$v_2^{\mathrm{EP}}\{\Psi_{1,\mathrm{FHCal}}\} = \frac{\langle\cos\left[2(\phi - \Psi_{1,\mathrm{FHCal}})\right]\rangle}{\mathrm{R}_2^{\mathrm{EP}}\{\Psi_{1,\mathrm{FHCal}}\}}$$



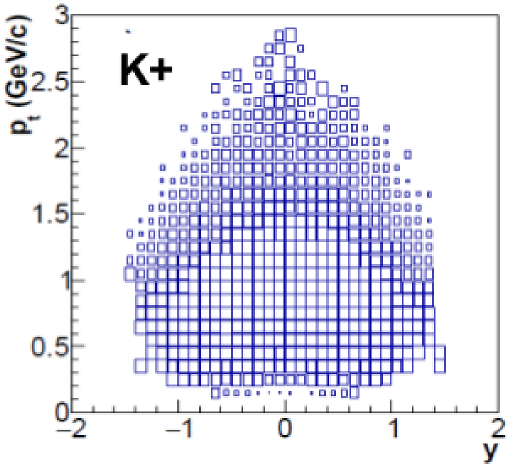


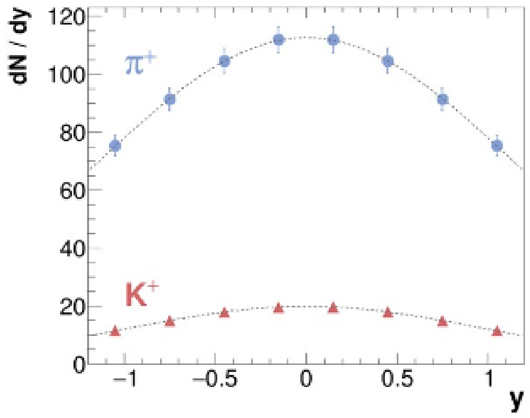
Hadroproduction with MPD

- **Particle spectra, yields & ratios are sensitive to bulk fireball properties and phase transformations in the medium**
- **Uniform acceptance and large phase coverage are crucial for precise mapping of the QCD phase diagram**

✓ *0-5% central Au+Au at 9 GeV from the PHSD event generator, which implements partonic phase and CSR effects*

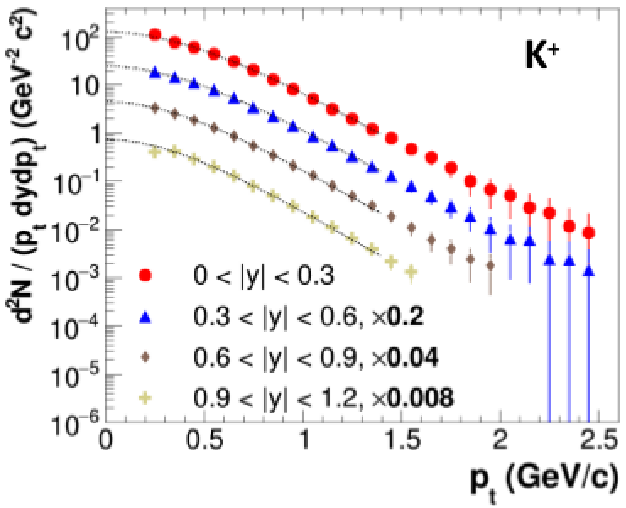
✓ *Recent reconstruction chain, combined dE/dx+TOF particle ID, spectra analysis*

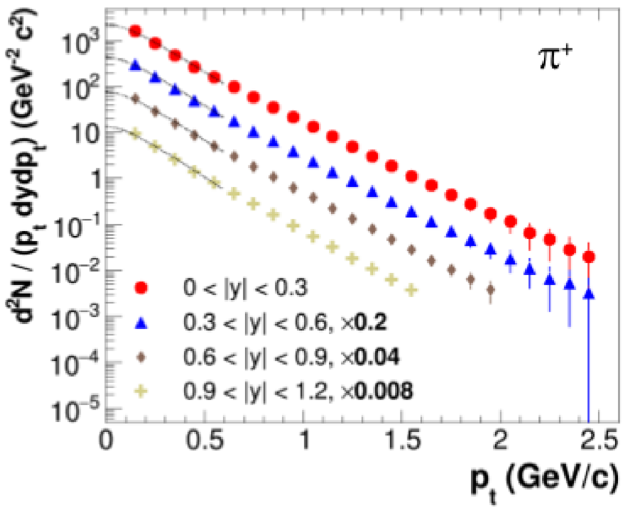




- MPD provides large phase-space coverage for identified pions and kaons (> 70% of the full phasespace at 9 GeV)
- Hadron spectra can be measured from p_T=0.2 to 2.5 GeV/c
- Extrapolation to full p_T-range and to the full phase space can be performed exploiting the spectra shapes (see BW fits for p_T-spectra and Gaussian for rapidity distributions)

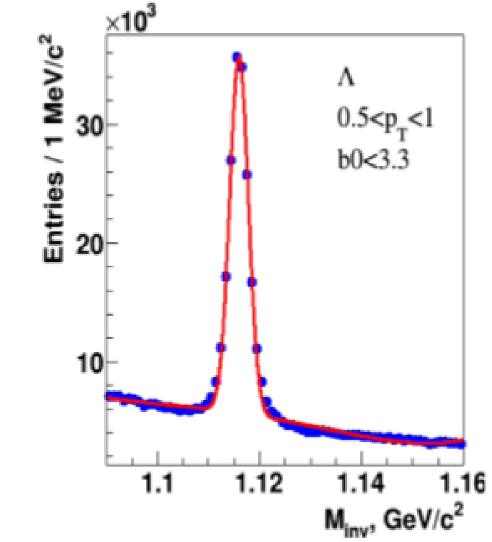
Ability to cover full energy range of the „horn" with consistent acceptance

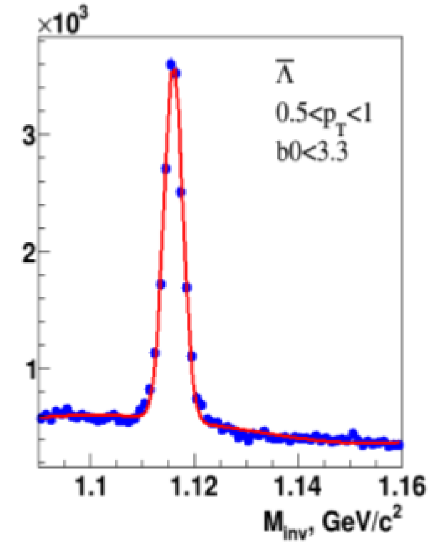


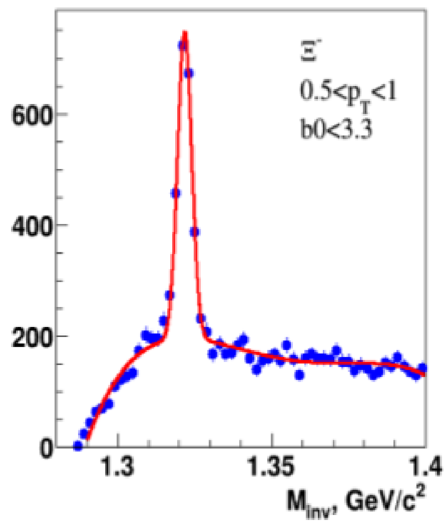


Strange and multi-strange baryons

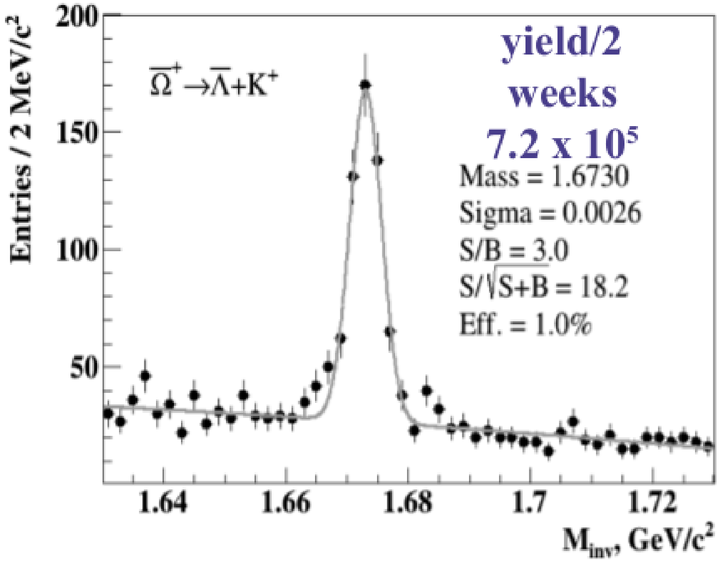
Stage'1 (TPC+TOF): Au+Au @ 11 GeV, PHSD + MPDRoot reco.

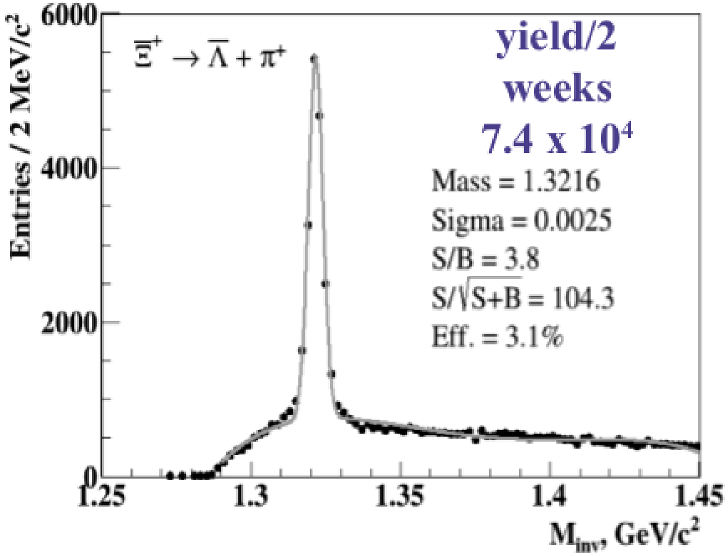


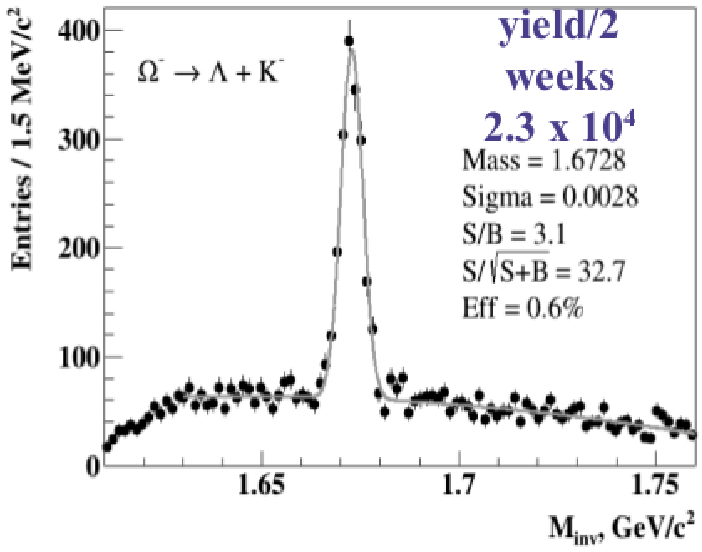




- Detailed p_T spectra for hyperons in multiple centrality intervals
- Large and consistent acceptance
- Clean signal enhanced by good PID
- Significant yield of rare hyperons

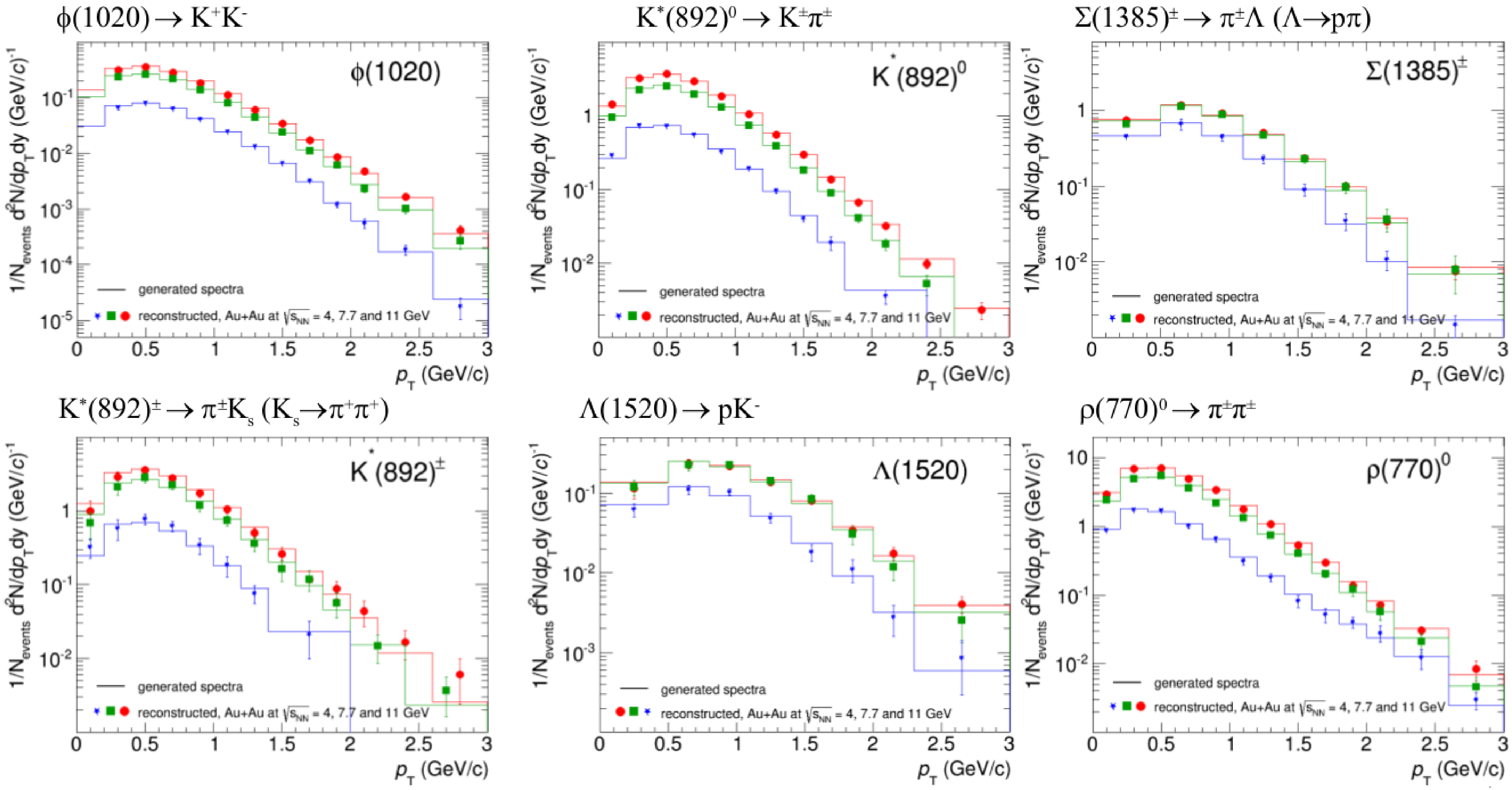






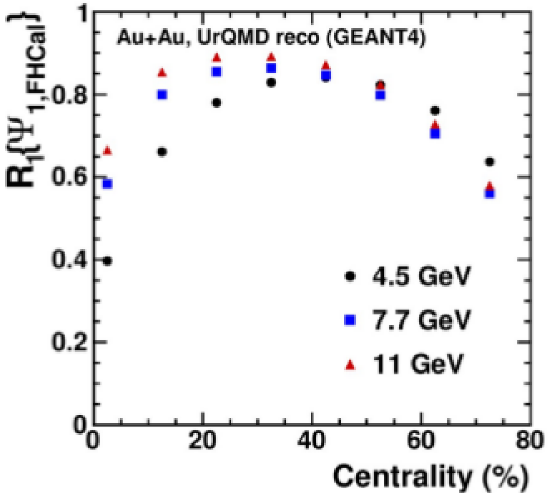
Resonances at MPD

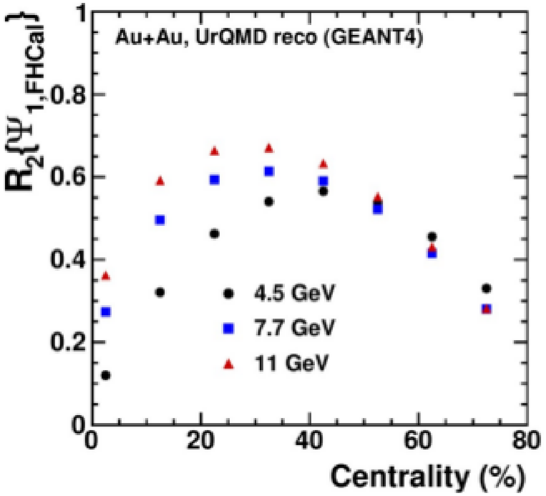
· Minbias Au+Au@11 (UrQMD) · Full reconstruction and realistic PID · Topology cuts and secondary vertex · Event mixing for background

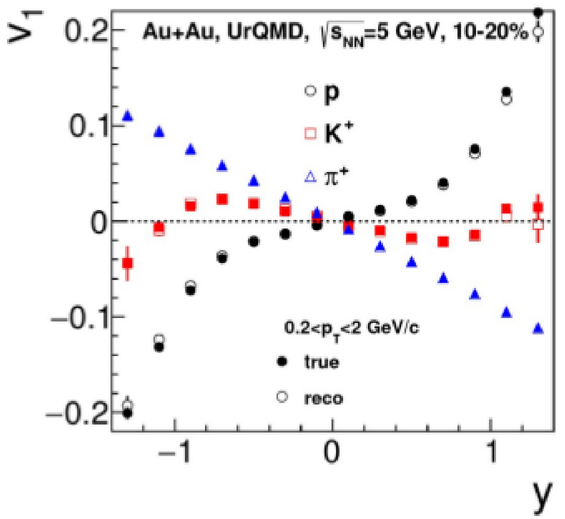


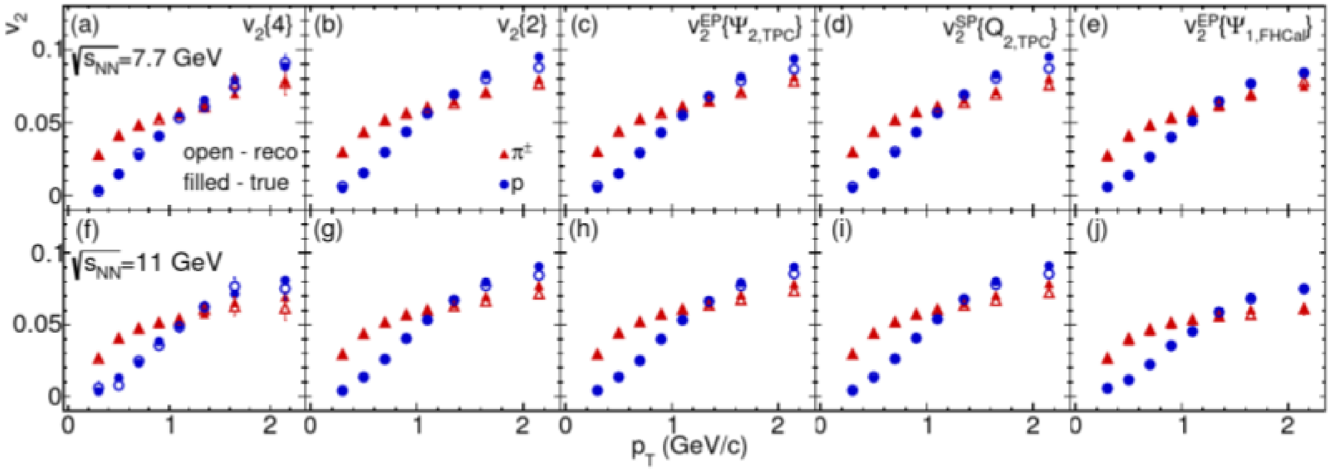
Performance of collective flow studies

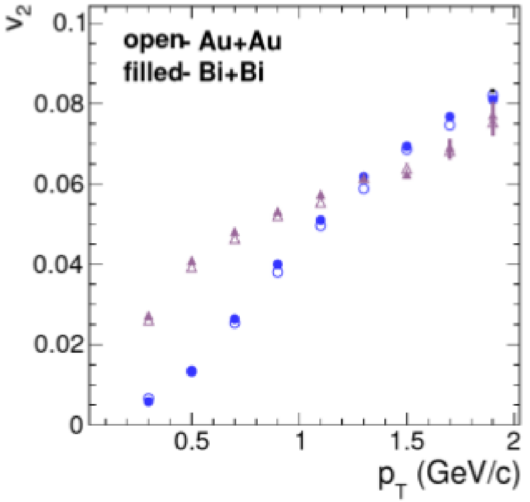
Au+Au, $\sqrt{s_{NN}}$ = 4.5, 7.7, 11 GeV, UrQMD, GEANT4 + MPDRoot reco.





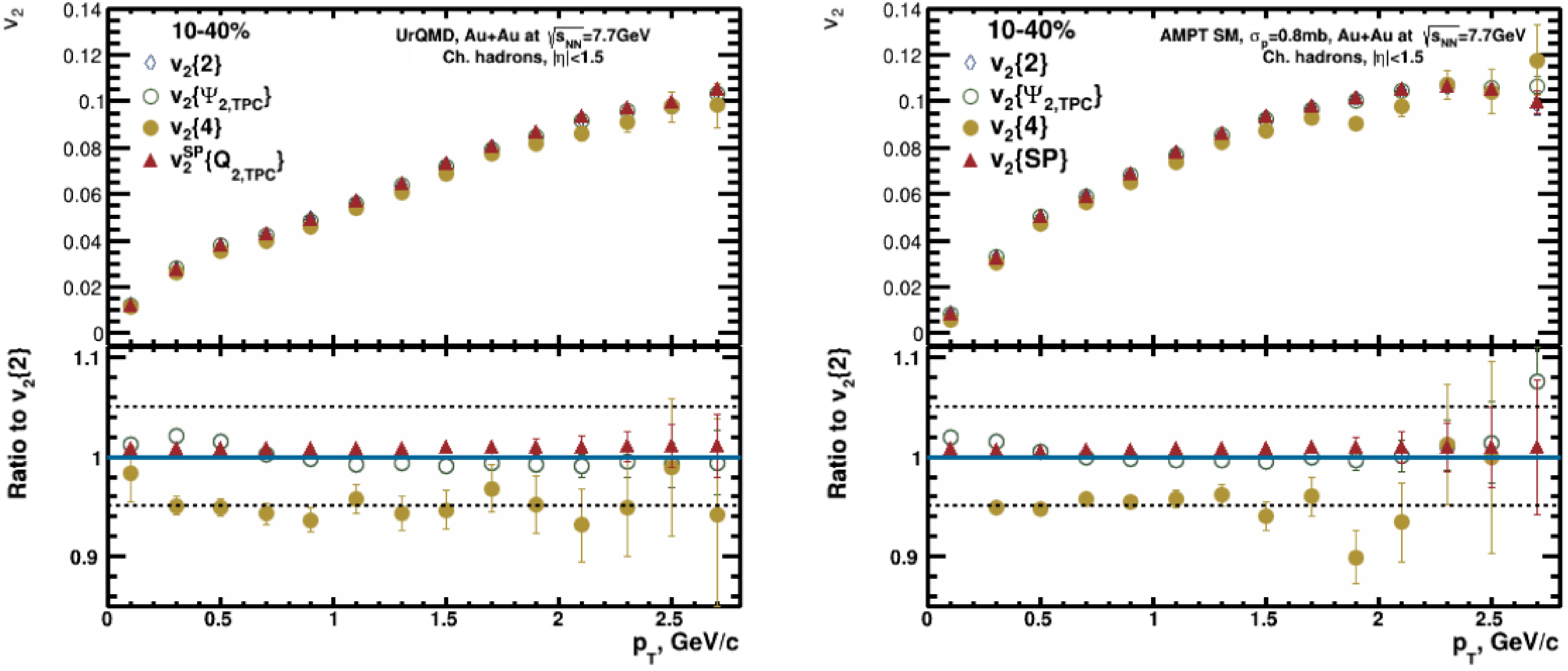






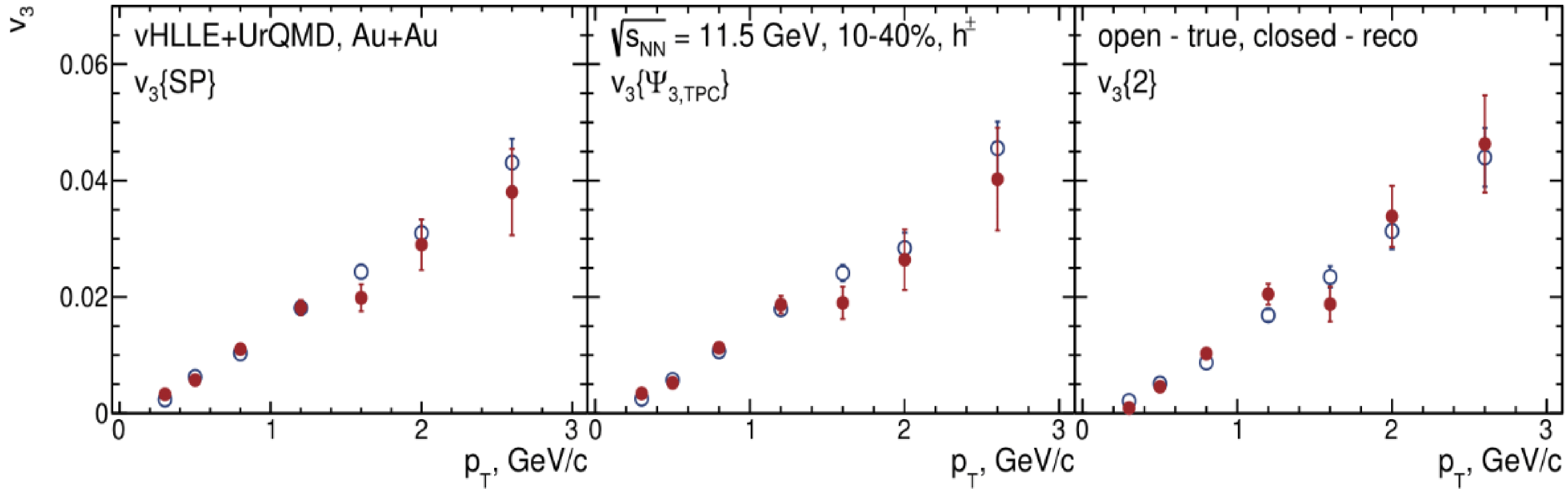
Collective flows a unique and direct way to probe EOS of QCD matter. Excellent flow measurement capabilities in MPD

Sensitivity of different methods to flow fluctuations



$$v_2\{2\} \approx v_2^{\mathrm{SP}}\{Q_{2,\mathrm{TPC}}\}, v_2\{4\} < v_2\{2\}$$

Triangular flow with MPD at NICA



Models show that higher harmonic ripples are more sensitive to the existence of a QGP phase

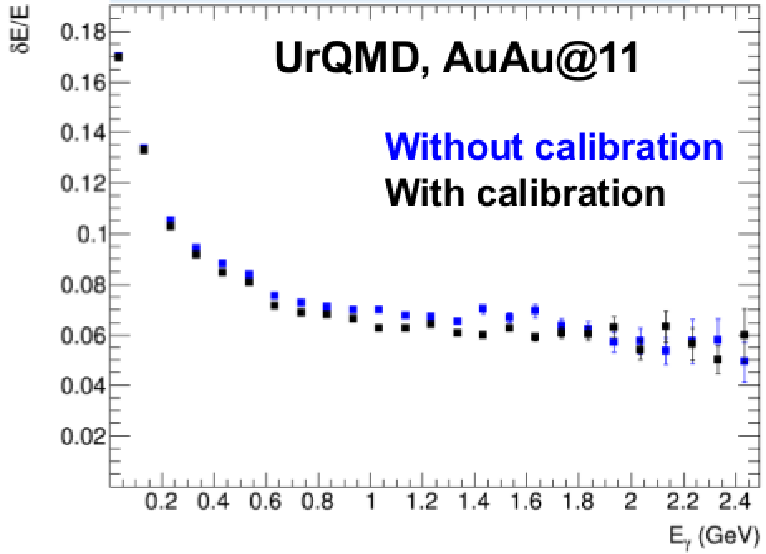
In models, v_3 goes away when the QGP phase disappears????

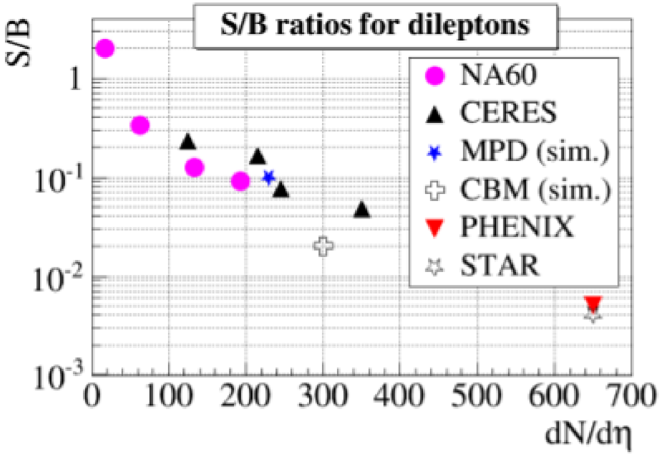
15 M of reconstructed vHLLE+UrQMD events for Au+Au at 11.5 GeV

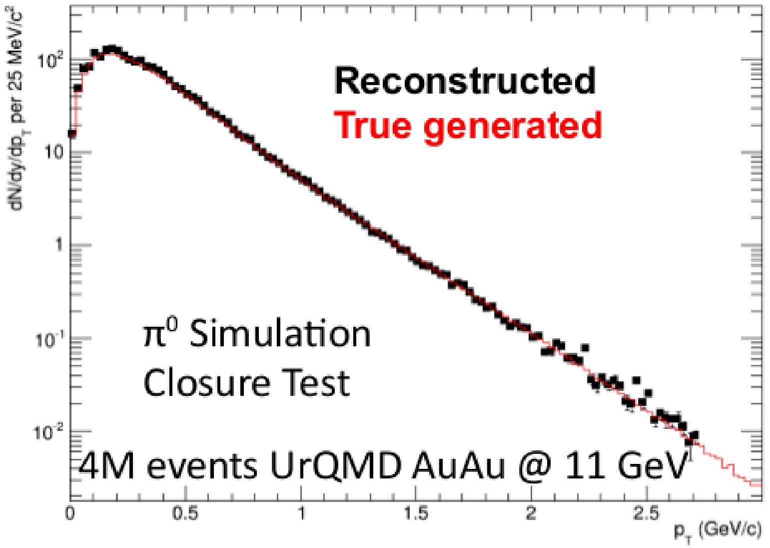
Electromagnetic probes in ECAL

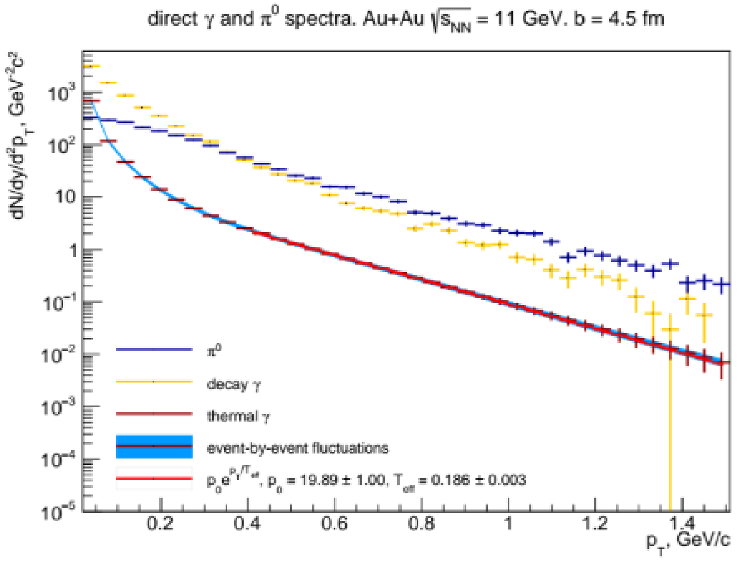
- Realistic ECAL reconstruction & analysis – large acceptance ECAL with good energy resolution: ideal tool for measurement of neutral mesons in a wide momentum range

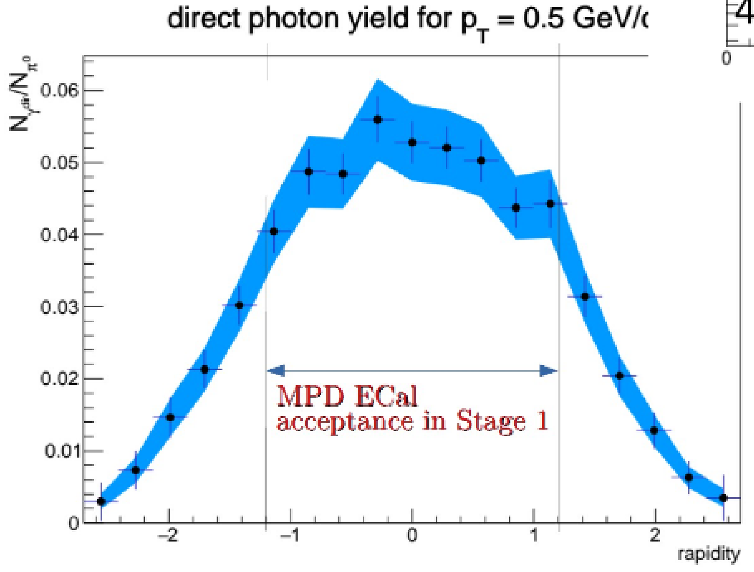
Photon energy resolution





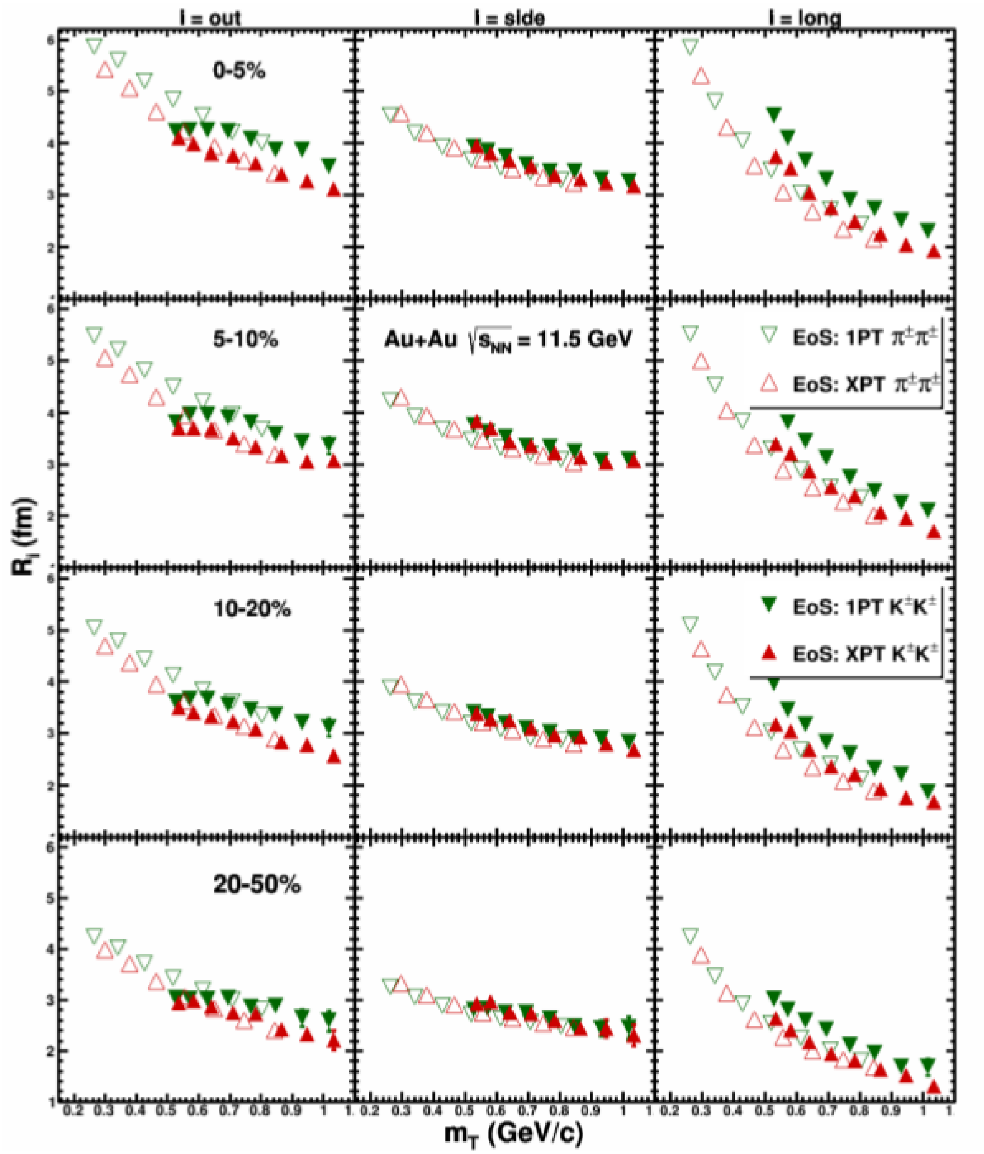






- Promising feasibility studies for prompt photon measurements in MPD

Femtoscopic probes in MPD



- Pion and kaon results for the cross over (XPT) and 1st-order (1PT) phase transitions
- Femtoscopic radii of pions decrease with increasing transverse mass
  - Influence of radial flow
- R_{side} values for pions and kaons are similar
  - Similar size of the particle-emitting region
- R_{out} for both pions and kaons show similar behavior
  - Similar particle emission duration?
- R_{long} for kaons is generally larger than that for pions at the same m_T
  - Influence of resonances?

Summary

- The MPD international collaboration is active and constantly growing
- All components of the MPD 1st stage configuration advanced in production, commissioning expected for 2022 and 2023
- Intensive preparations for the MPD Physics programme with initial beams at NICA