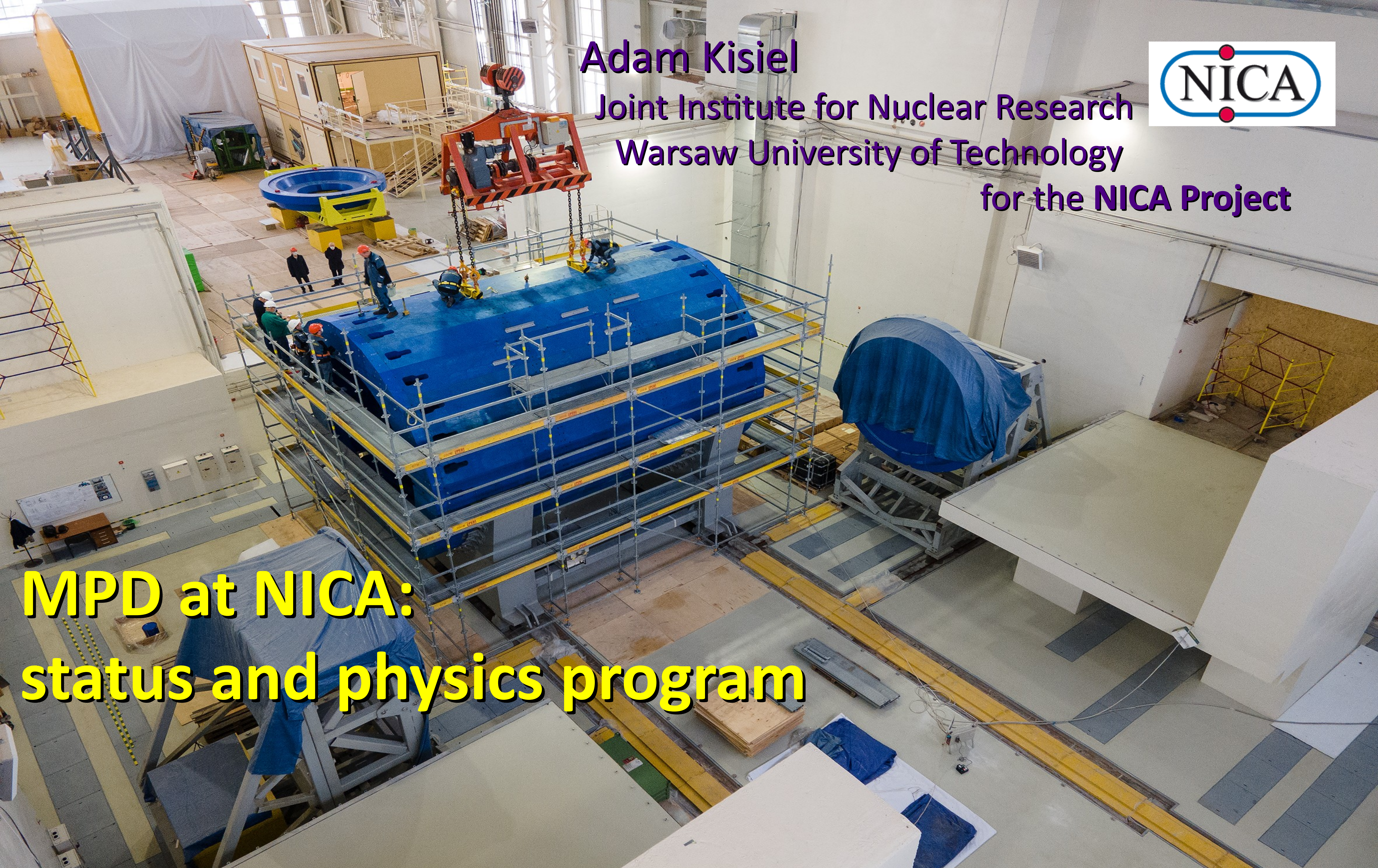


MPD at NICA: status and physics program

Adam Kisiel
Joint Institute for Nuclear Research
Warsaw University of Technology
for the NICA Project

The Host Institute

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: Unique and complementary

Collider advantage:

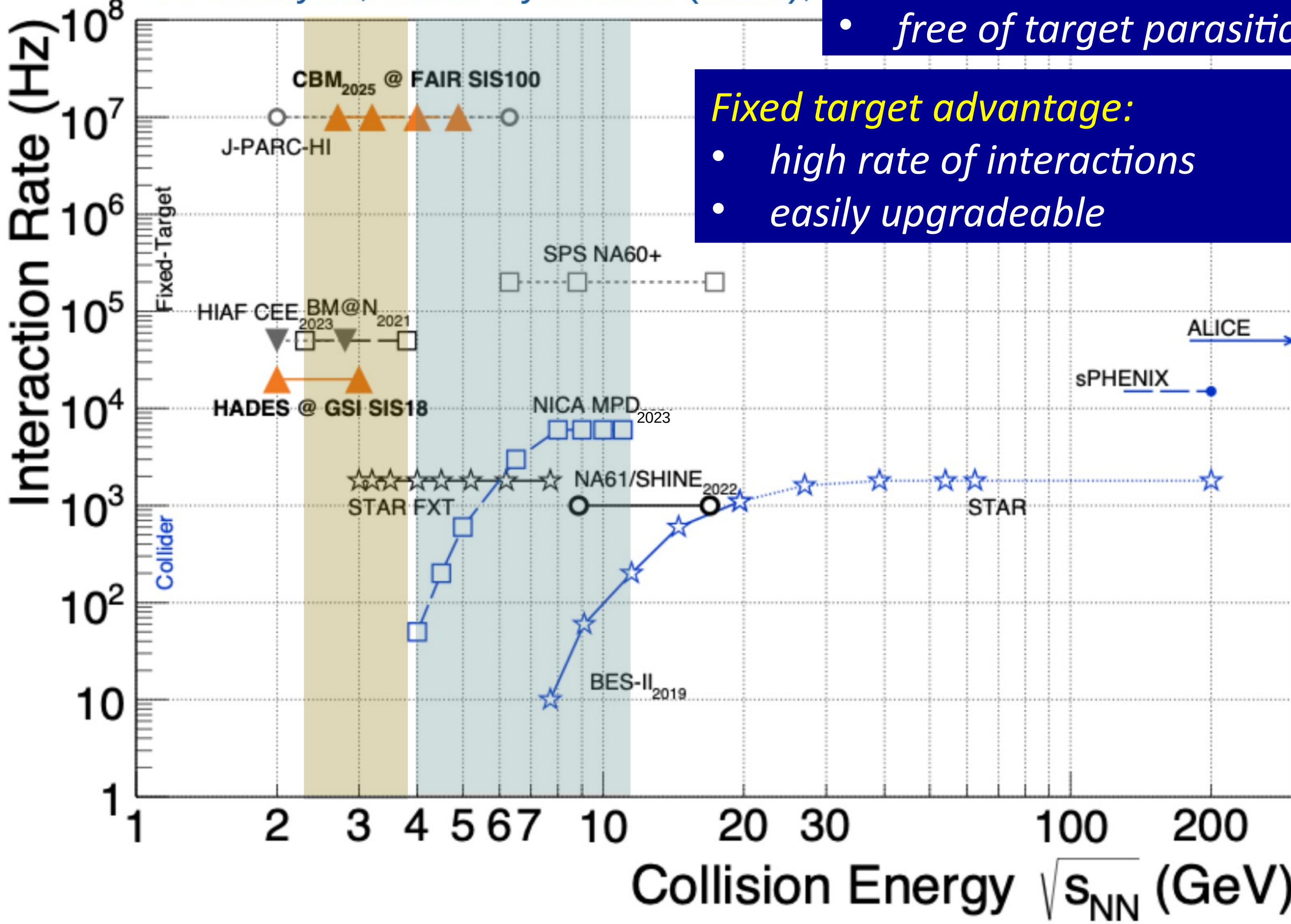
- *coverage of max. phase space*
- *minimally biased acceptance*
- *free of target parasitic effects*

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

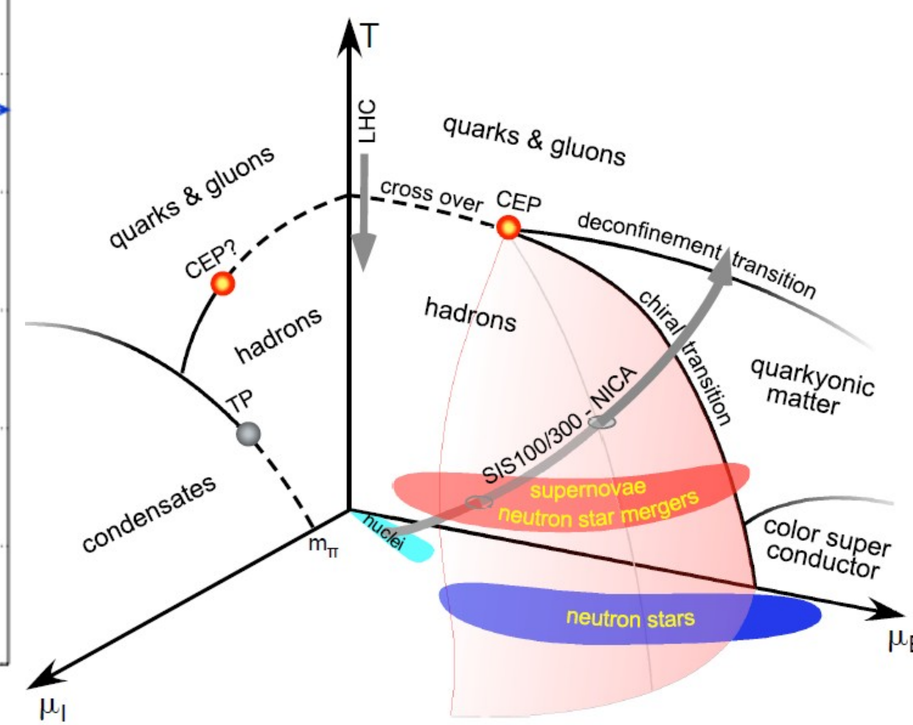
Fixed target advantage:

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

T. Galatyuk, Nucl.Phys. A982 (2019);



NUPECC Long Range Plan 2017

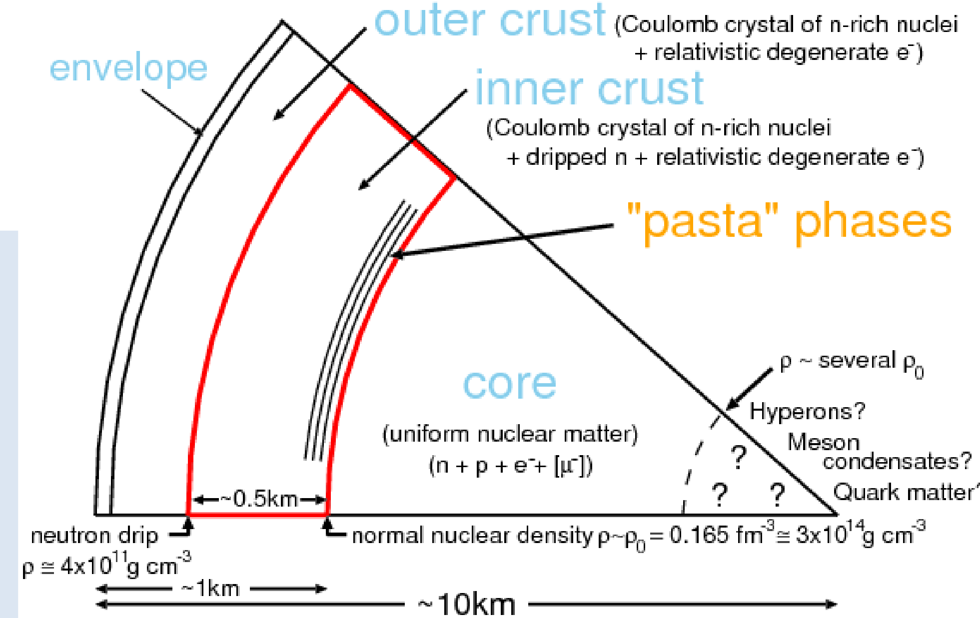


Access neutron star matter in laboratory

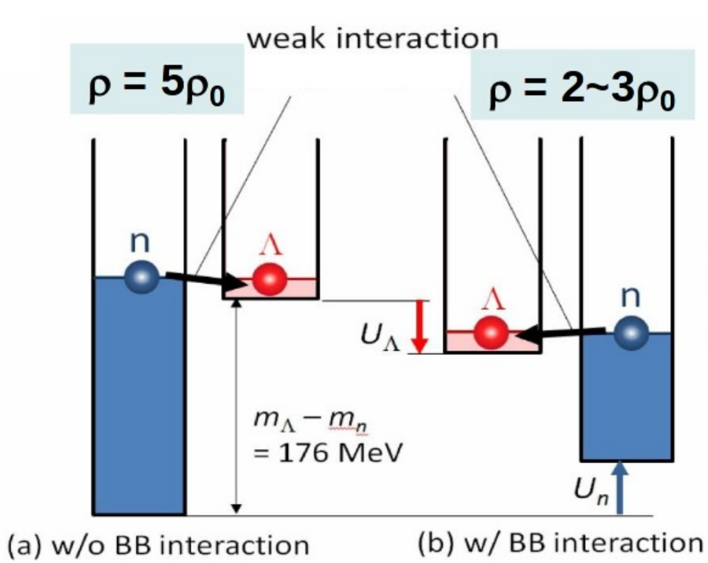
core of neutron stars reaches density several times nuclear density

appearance of strangeness changes Equation-of-State, depends on strangeness-nucleon interaction

Credit: LIGO Collaboration

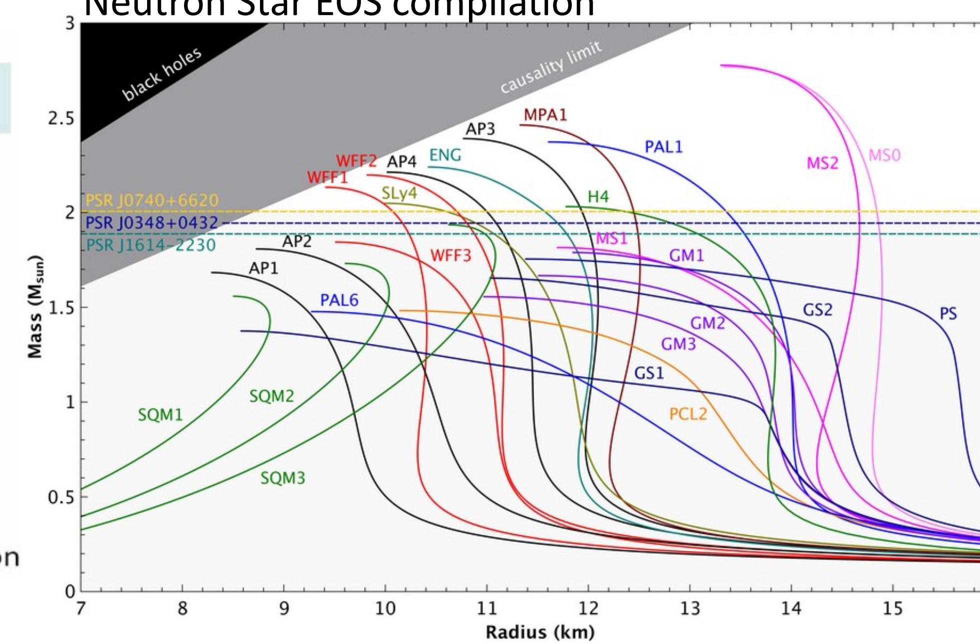


Demorest et al., Nature 467, 1081

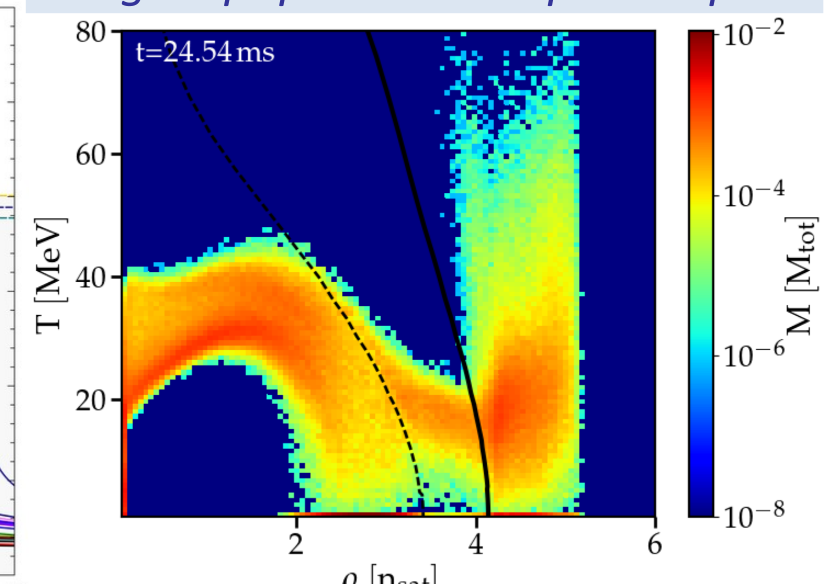


H. Tamura, Hadron 2017

Neutron Star EOS compilation

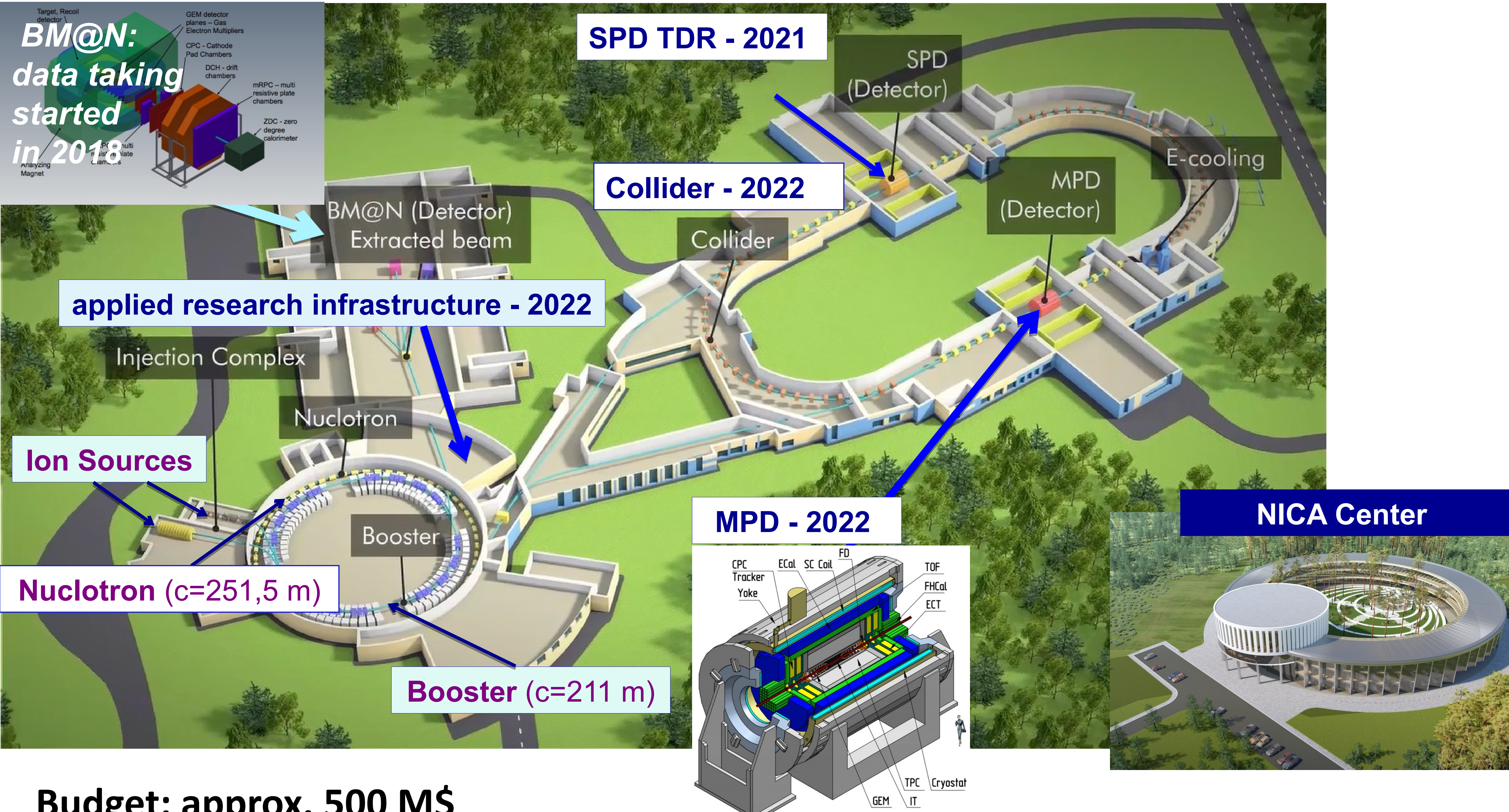


mergers populate NICA phase space



Blacker et al., Phys. Rev. D 102, 123023

NICA Accelerator Complex in Dubna



Budget: approx. 500 M$

NICA construction live

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}**

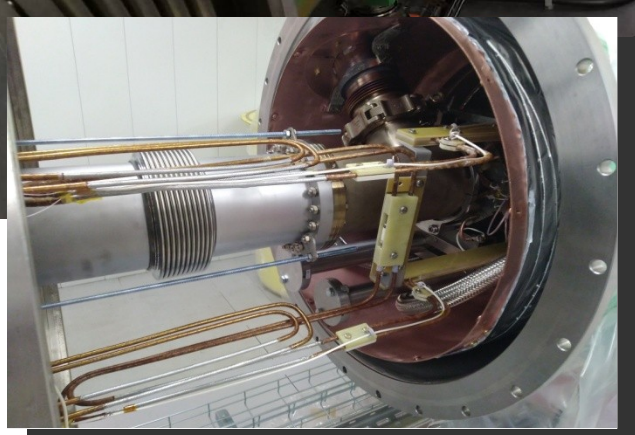
Stage I:

- ***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)*

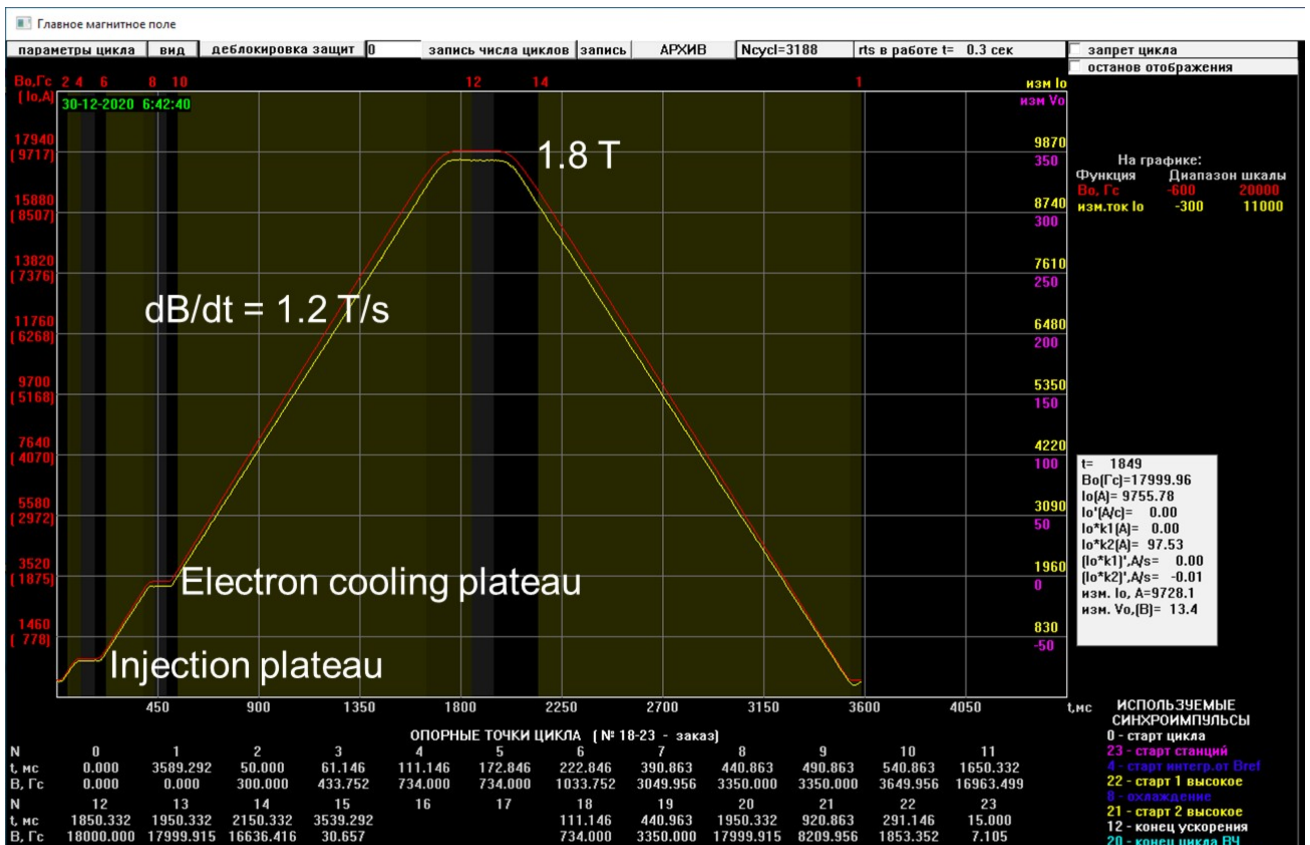
Booster commissioning

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

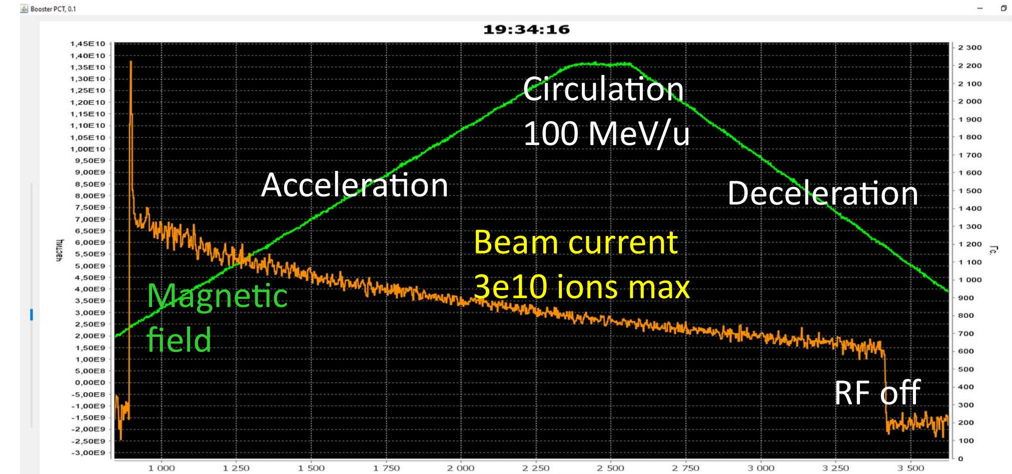


First Booster run – Dec 30th, 2020

Booster – the first technical run:
Injected He1+, 3,2MeV/u, 6,5*10^10 ppp
Accelerated up to 100 MeV/u
(project 600 MeV/u)

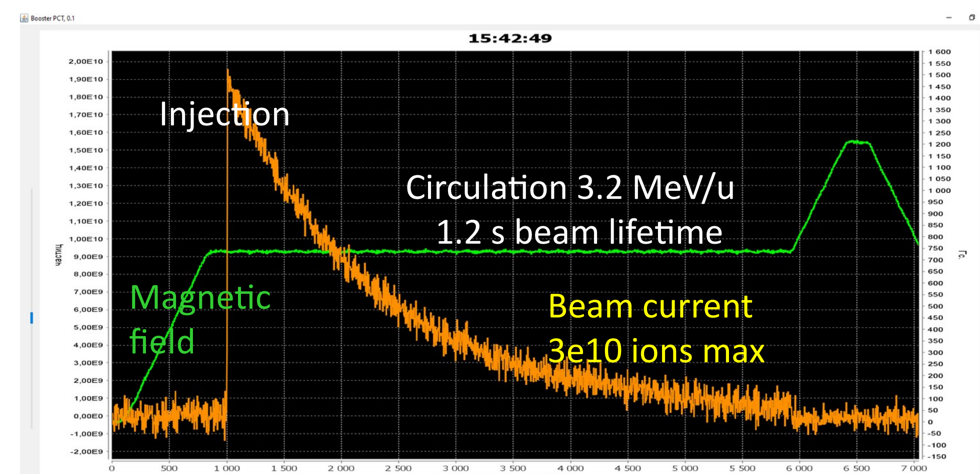


operation at design magnetic field & ramp rate



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

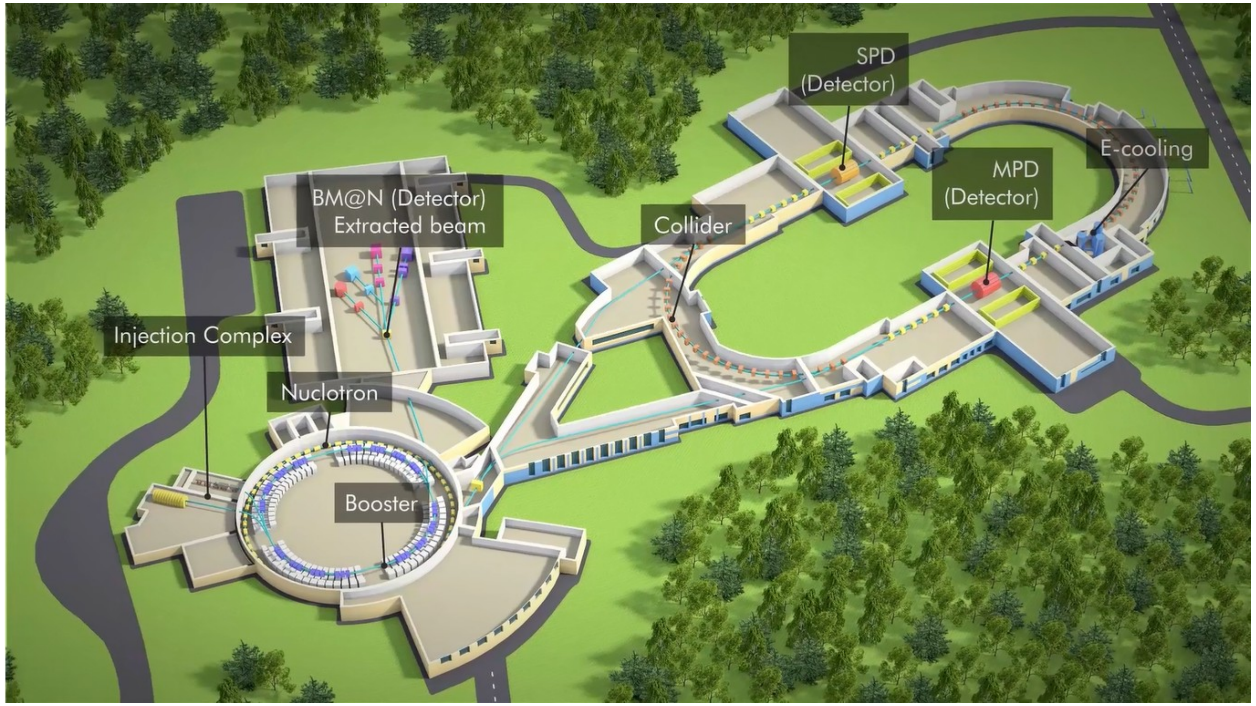
no transient losses on the MF table & after.



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

NICA running plan

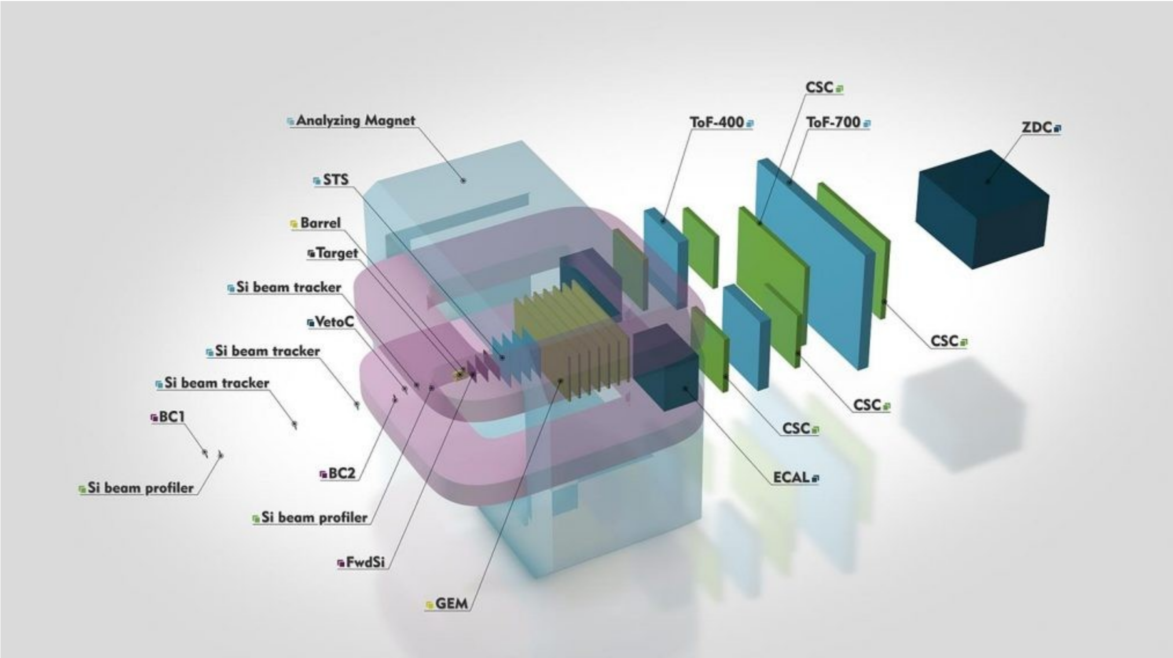
- **Year 2021:**
  - Extensive commissioning of Booster accelerator
  - Heavy-ion (Fe/Kr/Xe) run of full Booster+Nuclotron setup
- **Year 2022:**
  - Completion of Collider and transfer lines

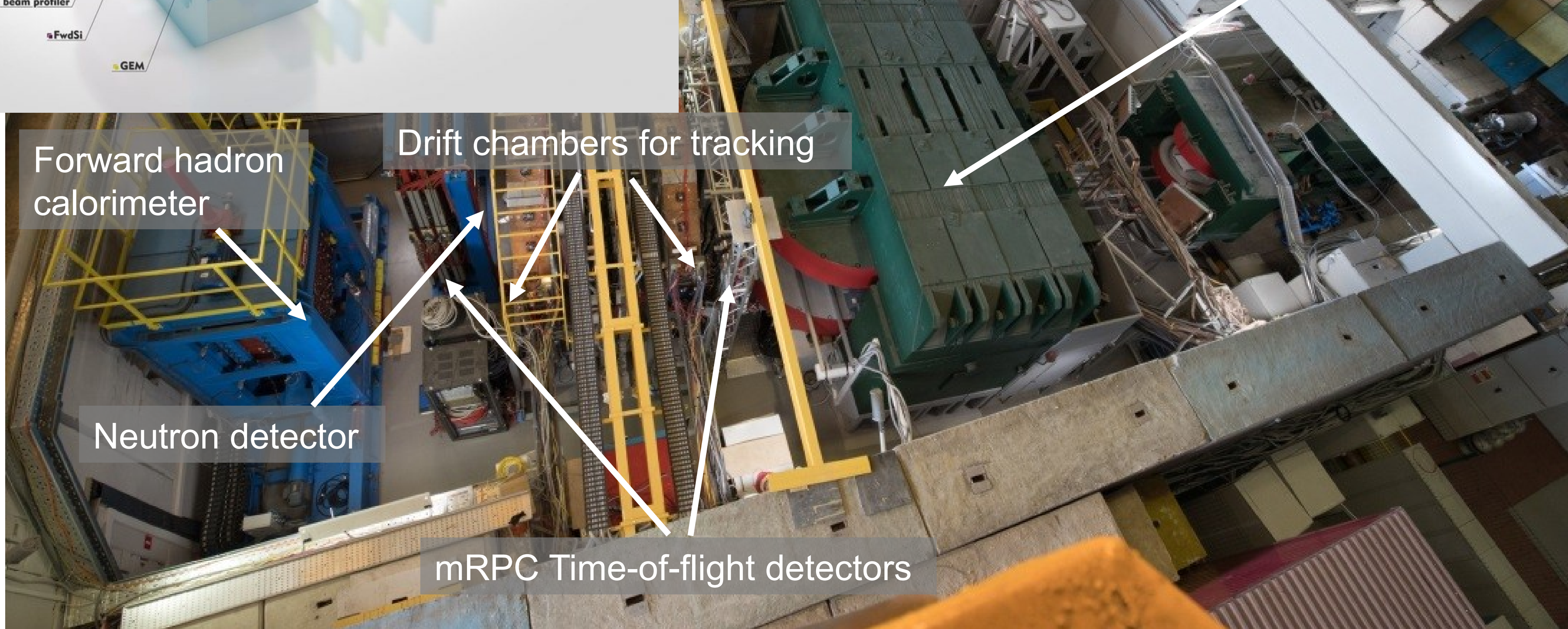


- **Year 2023:**
  - Initial run of NICA with Bi+Bi @ 9.2 AGeV (other energies a second priority)
  - Goal to reach luminosity of 10^{25} cm^{-2}s^{-1}, collect 10^8 good minimum-bias events
- **Year 2024:**
  - Goal to have Au+Au collisions and acceleration in Collider (up to 11 AGeV)
- **Beyond 2024:**
  - Maximizing luminosity, possibility of collision energy and system size scan

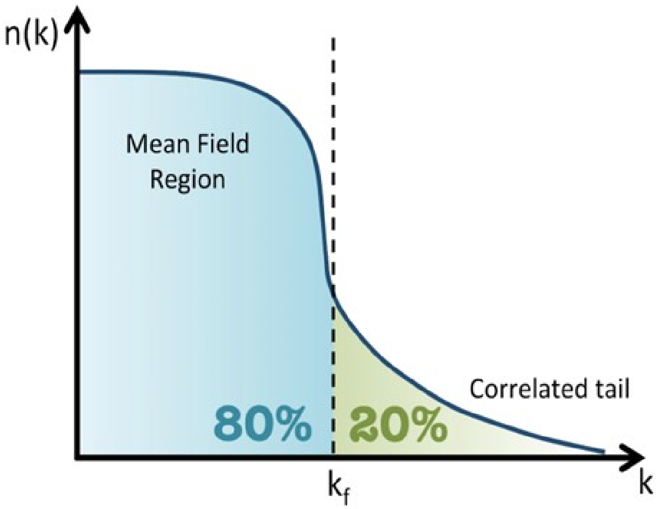
First physics from BM@N at NICA

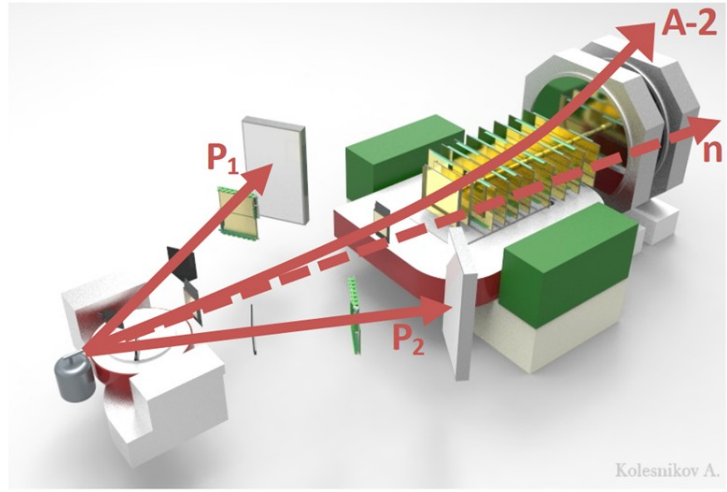
Baryonic Matter @ Nuclotron (BM@N)
10 countries, 20 institutions,
246 participants





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





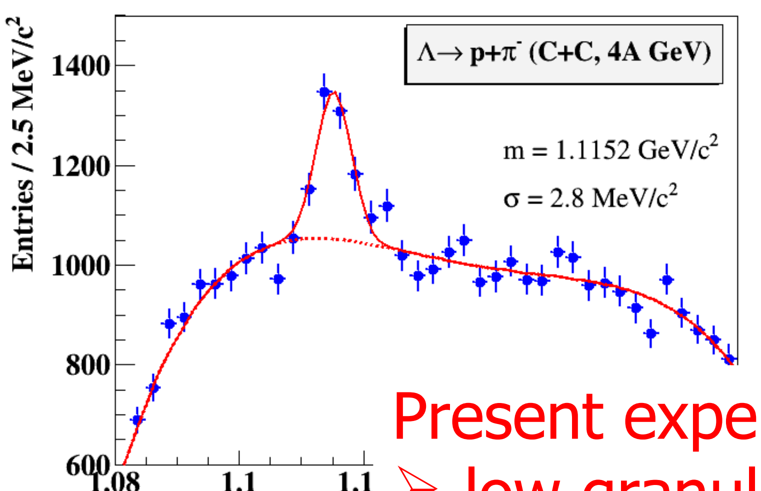
Experiment at BM@N with a 4A GeV C-beam:

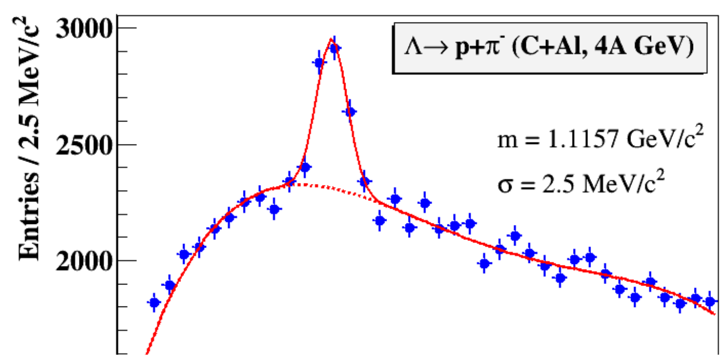
$^{12}C + p \rightarrow 2p + {}^{10}_{4}Be + p$ (pp SRC)

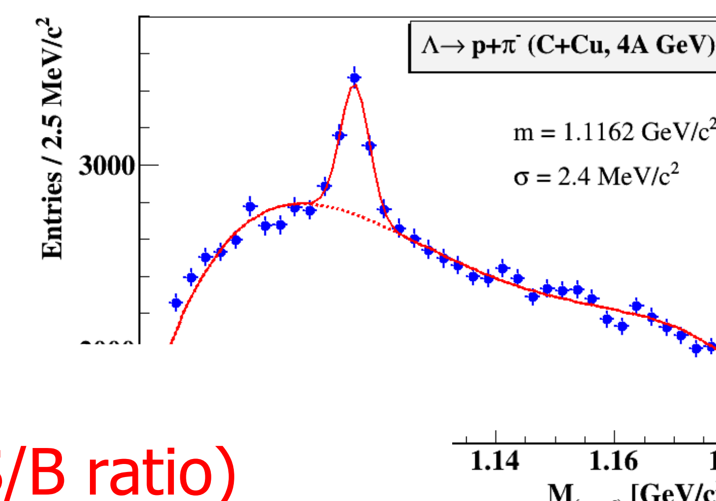
First fully exclusive measurement in inverse kinematics probing the residual A-2 nuclear system!

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



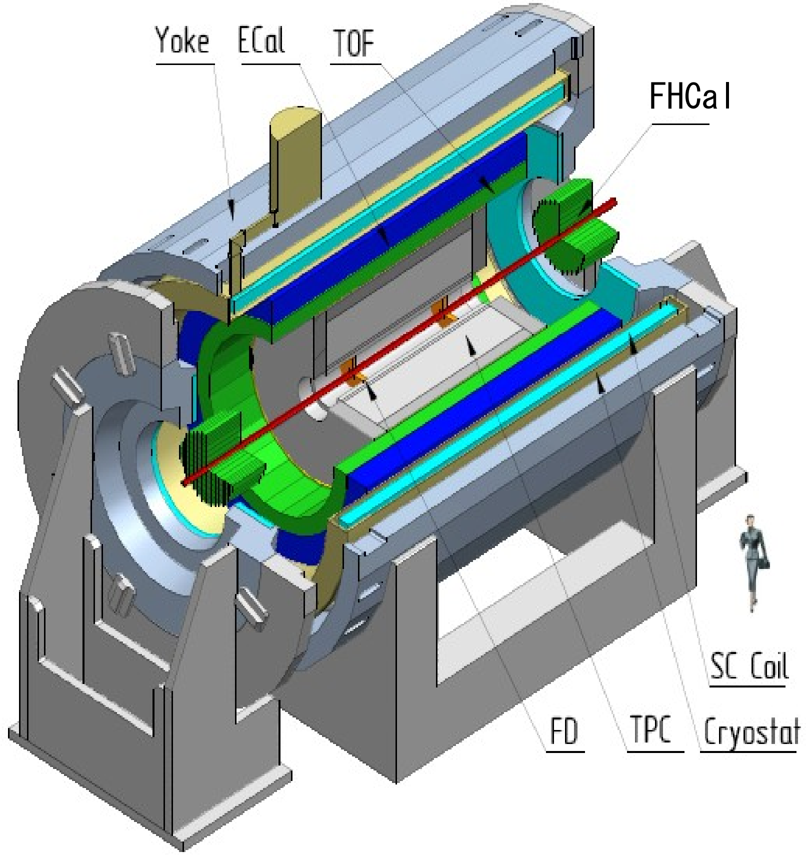




Present experimental limitations:

- 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

***12** Countries, **>500** participants,*
42** Institutes and **JINR

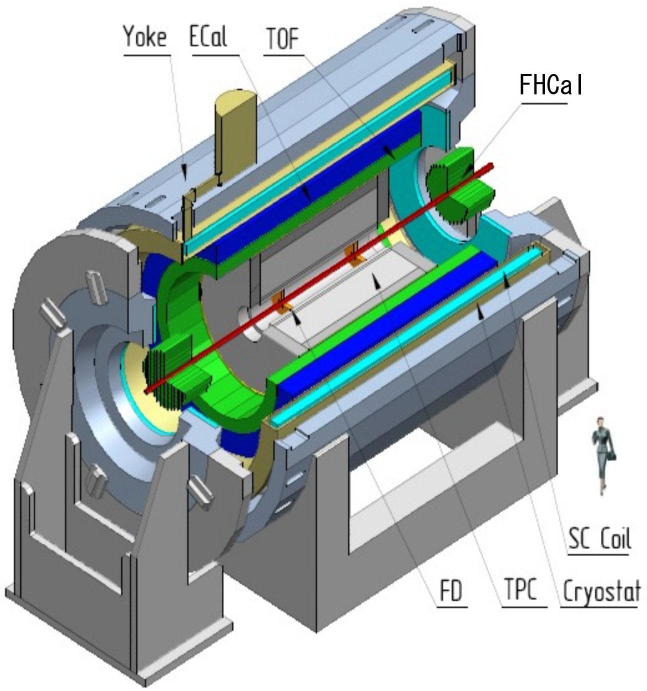
*Spokesperson: **Adam Kisiel***
*Inst. Board Chair: **Fuqiang Wang***
*Project Manager: **Slava Golovatyuk***

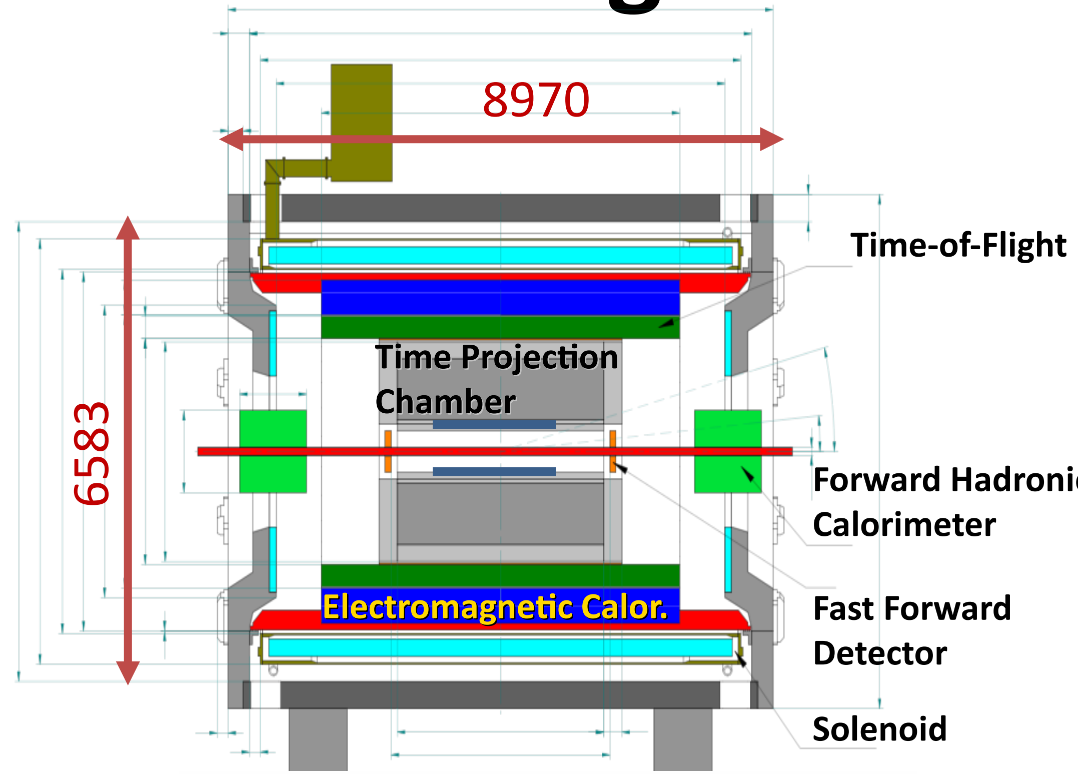
Deputy Spokespersons:
Victor Riabov, Zebo Tang

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

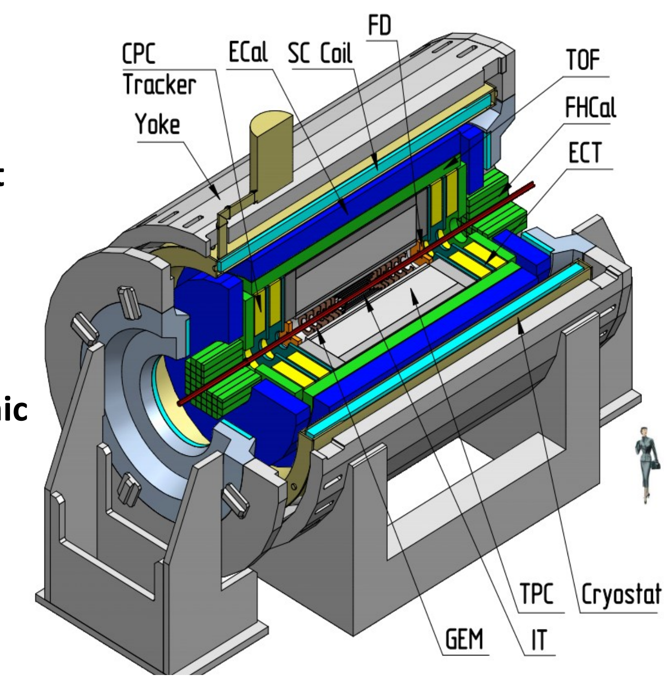
*AANL, Yerevan, **Armenia;***
*Baku State University, NNRC, **Azerbaijan**;*
*Plovdiv University Paisii Hilendarski, **Bulgaria;***
*University Tecnica Federico Santa Maria, Valparaiso, **Chile**;*
*Tsinghua University, Beijing, **China**;*
*USTC, Hefei, **China**;*
*Huzhou University, Huizhou, **China**;*
*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**;*
*NCNR, 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**;*

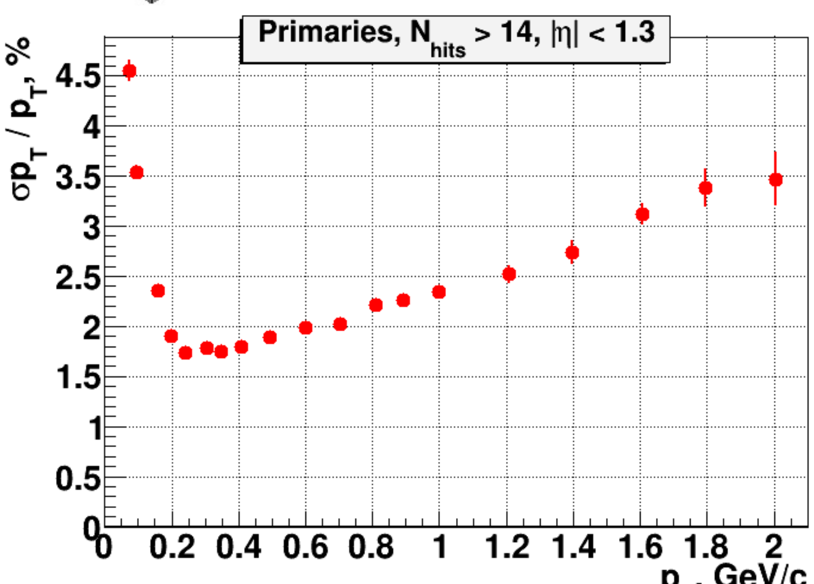
MPD - stage I and II



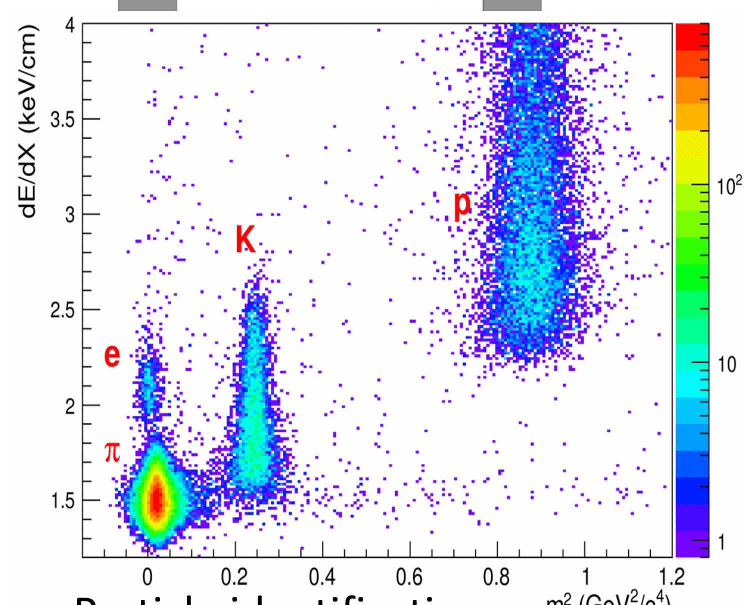


MPD - Stage II

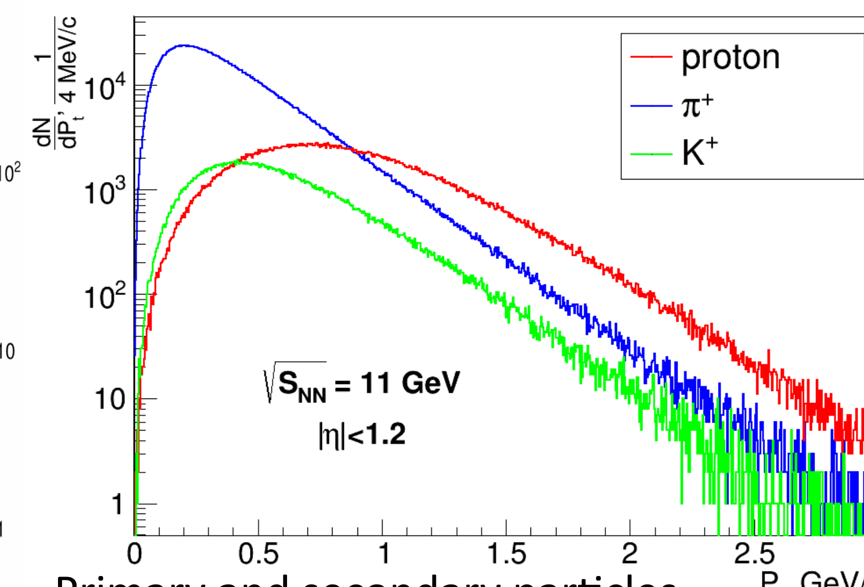




Momentum resolution with TPC



Particle identification

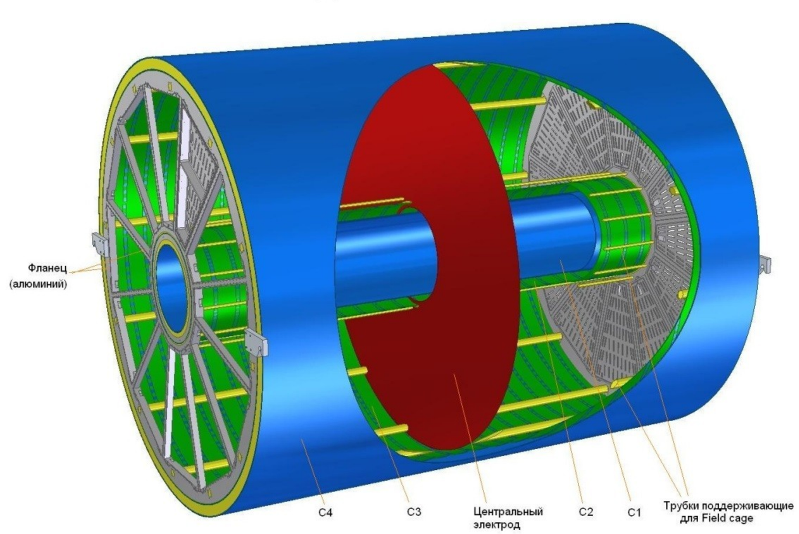


Primary and secondary particles

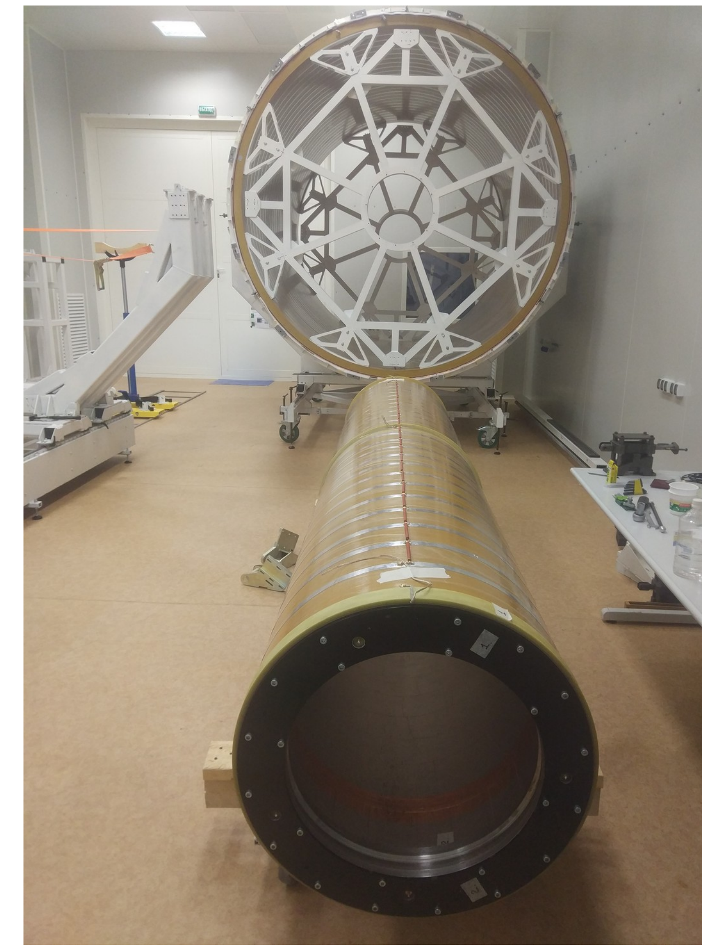
Interior of MPD Hall

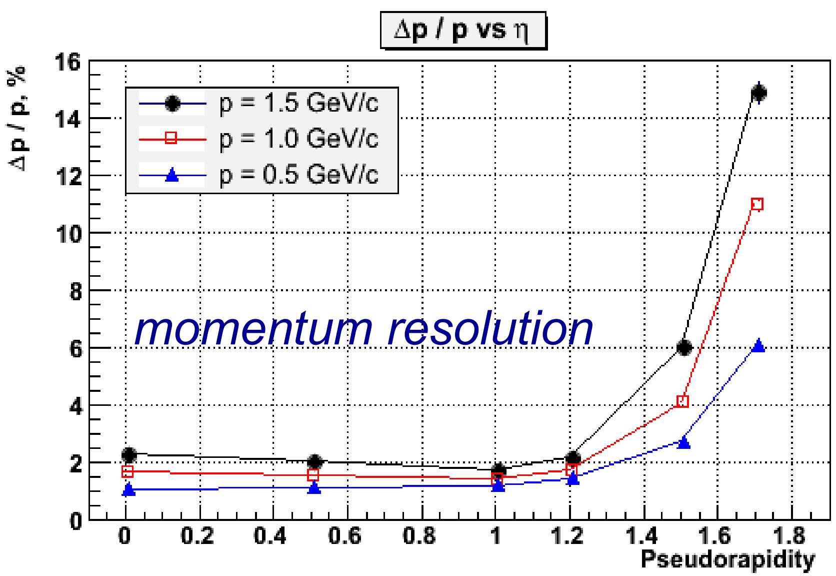
Installation of the MPD Supercoducting coil inside the iron Magnet Yoke in MPD Pit 29 July 2021

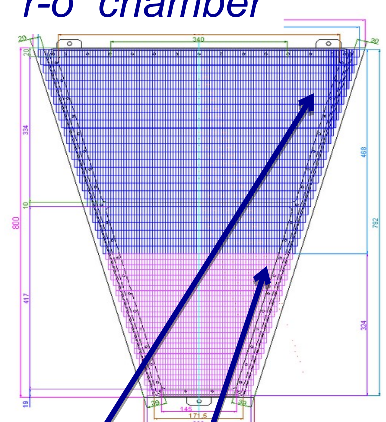
Time Projection Chamber (TPC): main tracker



length	*340 см*
outer radius	*140 см*
inner radius	*27 см*
gas	*90%Ar+10%CH_4*
drift velocity	*5.45 см / μs;*
drift time	*< 30 μs;*
# R-O chamb.	*12 + 12*
# pads/ chan.	***95 232***
max rate	*< 7kHz (L=10^{27})*







FE electronics: **FEC64SAM** –
dual ***SAMPA*** *card (****ALICE*** *technology)*

pad structure:
- rows – 53
- large pads 5×18 mm^2
- small pads 5×12 mm^2

Read-Out Chambers (ROCs) are ready and tested (production at JINR)
Electronics sets in production
Two sites (Moscow, Minsk) tested for electronics production
C1-C2 and C3-C4 cylinders assembled
TPC flange under finalization

MPD Time-of-Flight

Mass production staff: 4 physicists, 4 technicians, 2 electronics engineers
Productivity: ~ 1 detector per day (1 module/2 weeks)

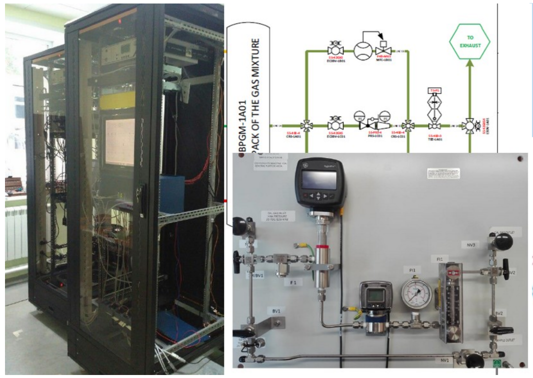
All procedure of detector assembling and optical control is performed in a clean rooms ISO class 6-7.

Glass cleaning with ultrasonic wave & deionized water

Automatic painting of the conductive layer on the glass

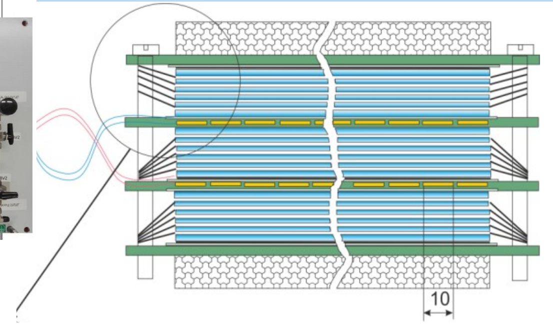
MRPC assembling

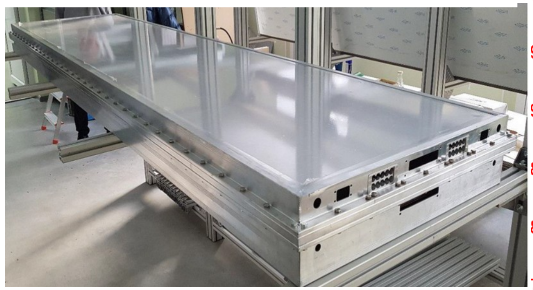
Soldering HV connector and readout pins

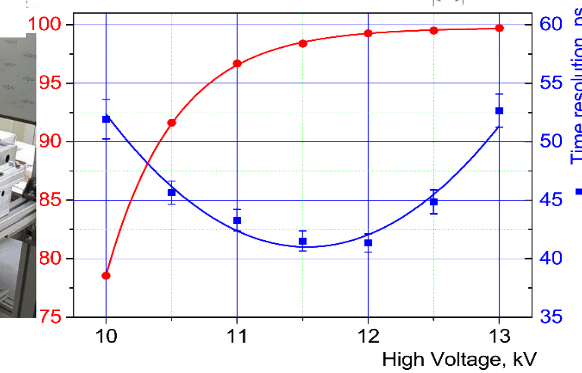


TOF gas system

Dimensions of sensitive area 600 x300 mm^2







Single detector time resolution: 50ps

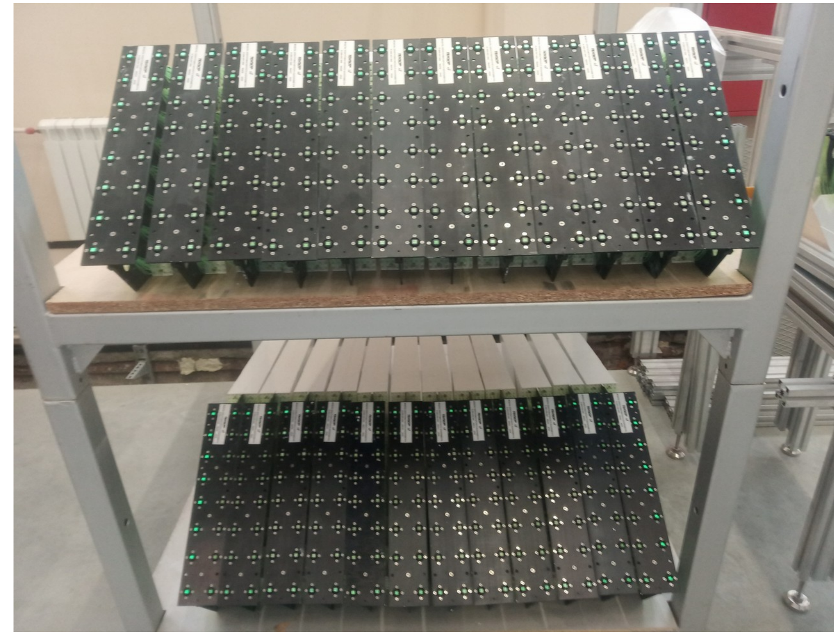
Purchasing of all detector materials completed
So far 40% of all MRPCs are assembled
Assembled half sectors of TOF are under Cosmics tests
Investigation of solutions for detector integration and technical installations

	Number of detectors	Number of readout strips	Sensitive area, m^2	Number of FEE cards	Number of FEE channels
MRPC	1	24	0.192	2	48
Module	10	240	1.848	20	480
Barrel	280	6720	51.8	560	**13440** (1680 chips)

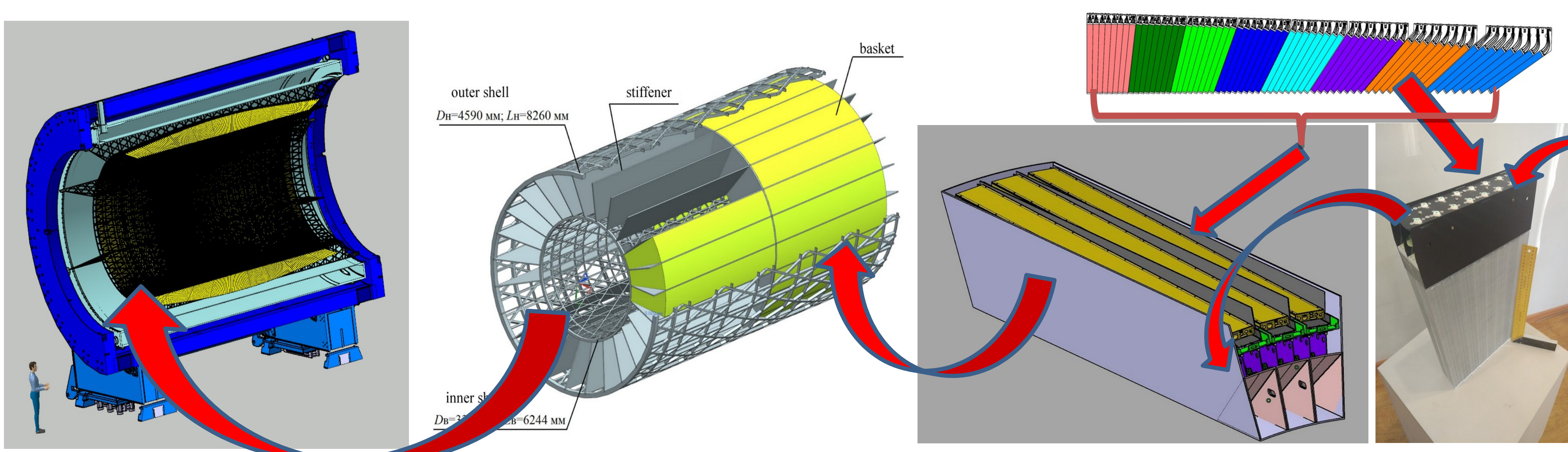
Electromagnetic Calorimeter (ECAL)

Barrel ECAL = 38400 ECAL towers
(2x25 half-sectors x 6x8 modules/half-sector
x 16 towers/module)

~**350** modules (16 towers each) = 3 sectors produced
420 modules – production started, finish by the end of 2021
Sectors assembling procedure under development.
Mass assembling of ECal sectors start in September-October 2021



Sectors in dedicated Containers



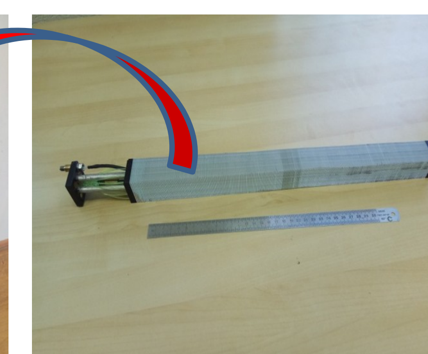
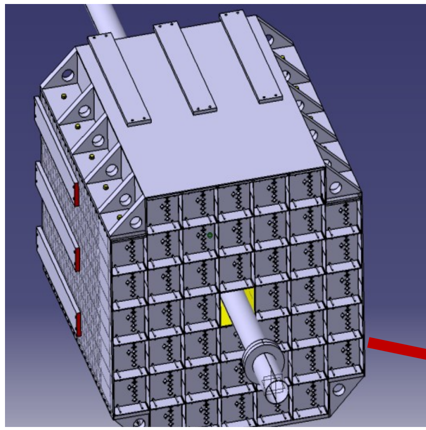
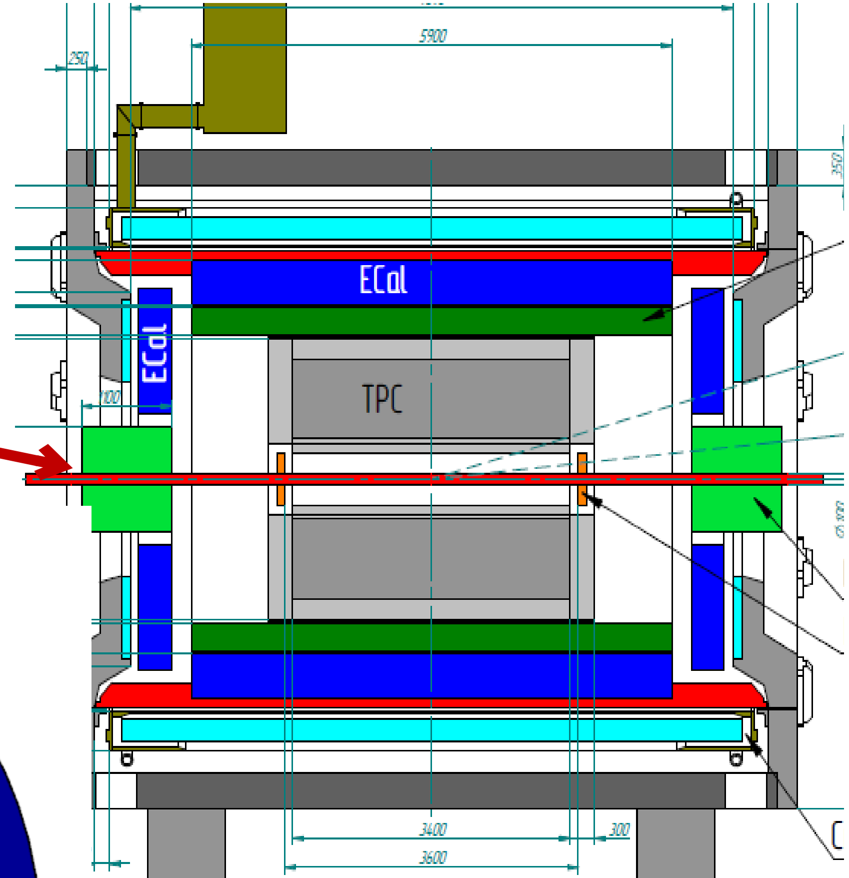


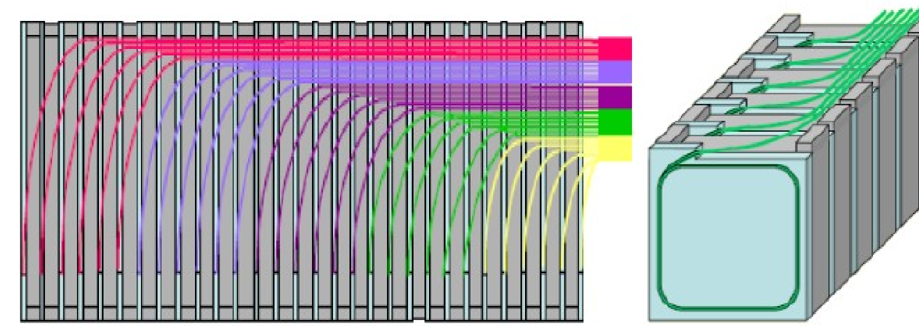
Photo of one element

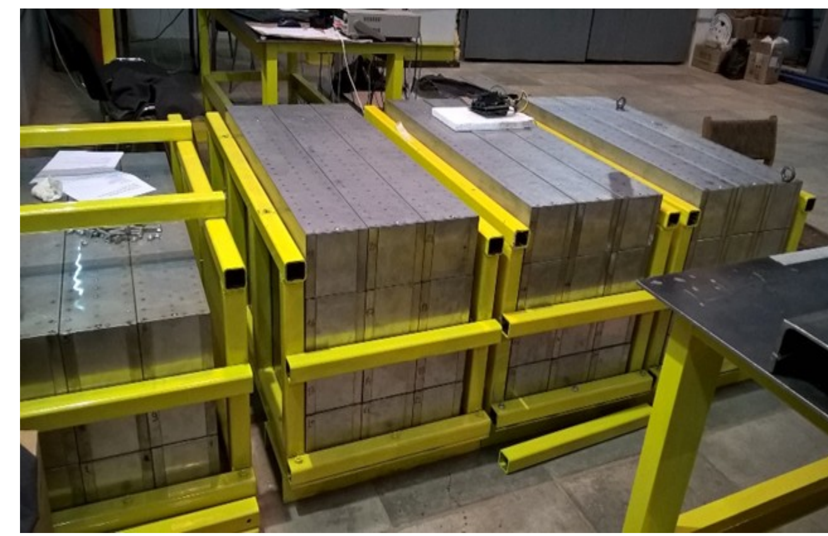
Pb+Sc "Shashlyk" ; read-out: WLS fibers + MAPD; L ~35 cm (~ 14 X_0); Segm. (4x4 cm^2); σ(E) ~ 5% @ 1 GeV; time res. ~500 ps

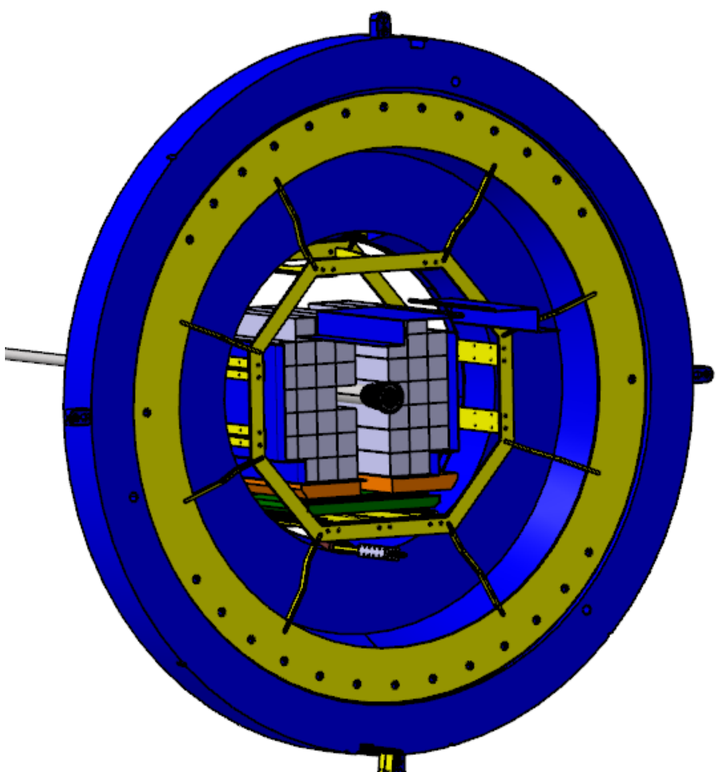
Forward Hadron Calorimeter (FHCal)











- Two-arms at ~3.2 m from the interaction point.
- Each arm consists of 44 individual modules.
- Module size 150x150x1100cm^3 (42 layers)
- Pb(16mm)+Scint.(4mm) sandwich
- 7 longitudinal sections
- 6 WLS-fiber/MAPD per section
- 7 MAPDs/module

MPD Physics Programme

G. Feofilov, A. Ivashkin

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

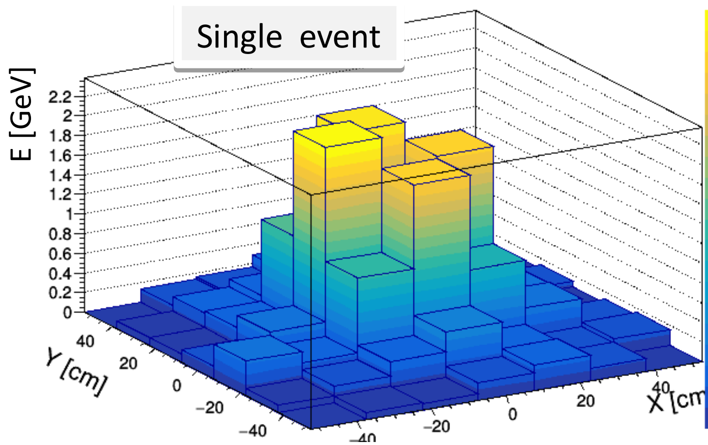
Wangmei Zha, A. Zinchenko

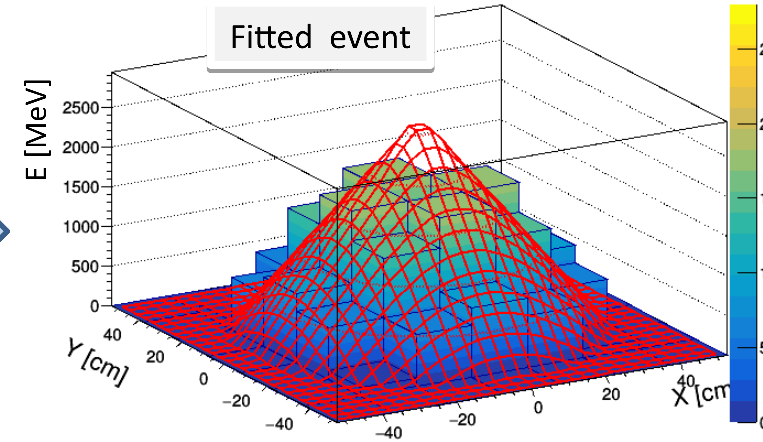
Heavy flavor

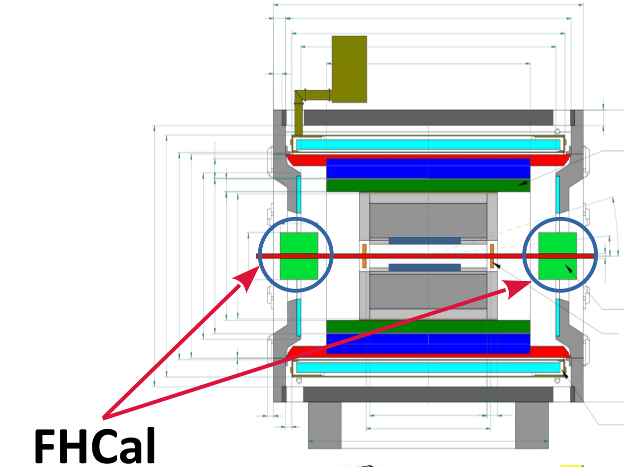
- Study of open charm production
- Charmonium with ECAL and central barrel
- Charmed meson through secondary vertices in ITS and HF electrons
- Explore production at charm threshold

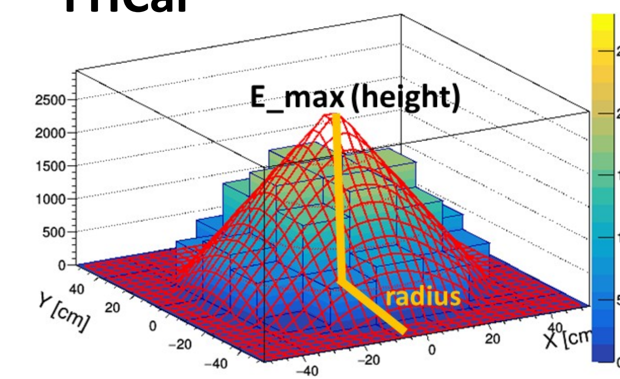
Centrality and reaction plane in FHCal

Energy distribution in FHCal modules

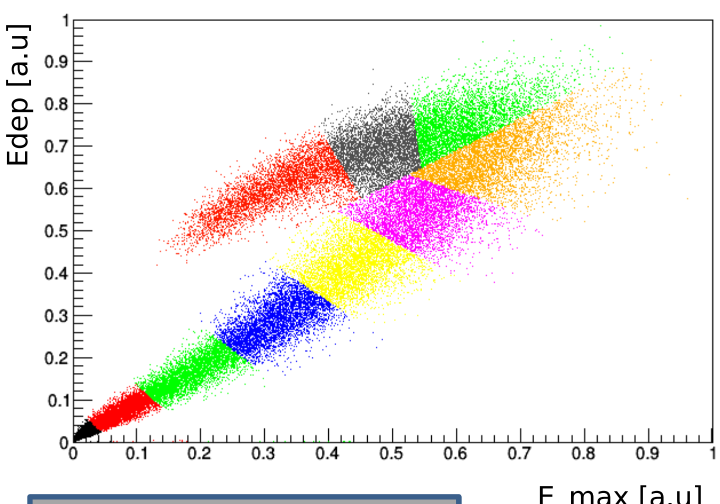




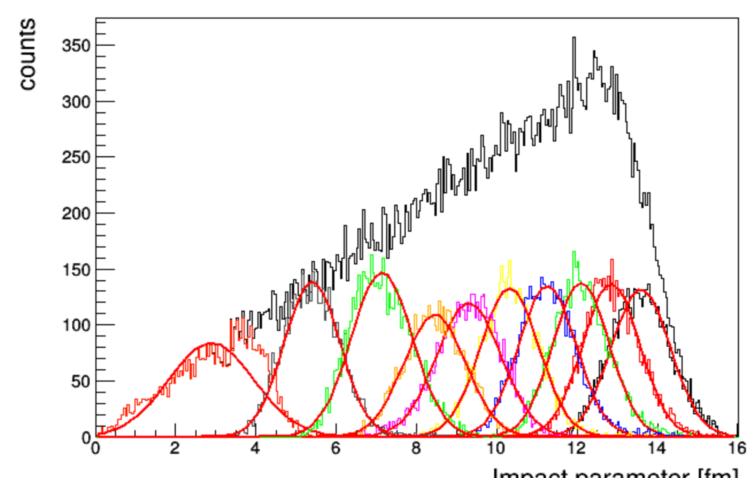




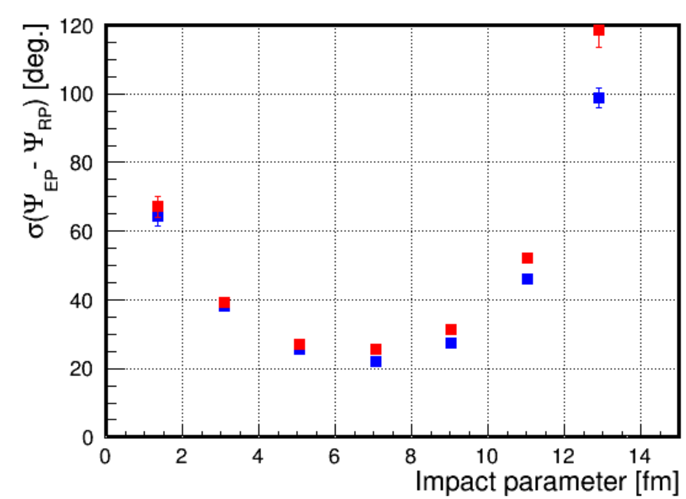
Initially we have experimental energy deposition E_{dep} in FHCal.



Each color bin is 10% fractions of the total number of events.



Centrality resolution



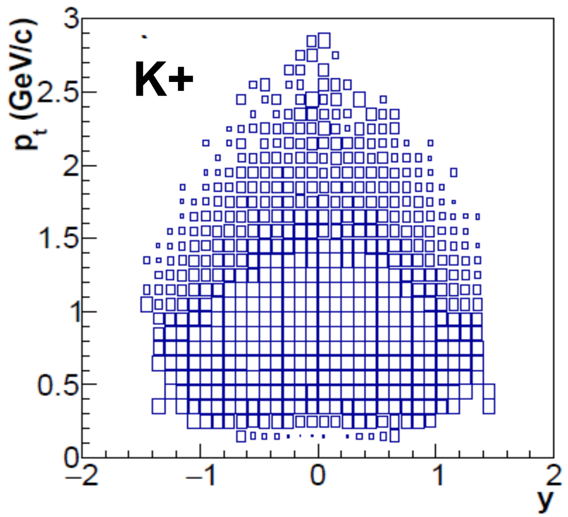
Reaction plane resolution

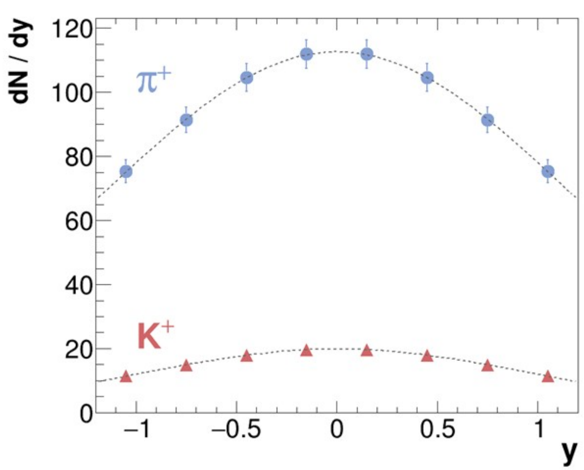
Hadroproduction with MPD

- **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*

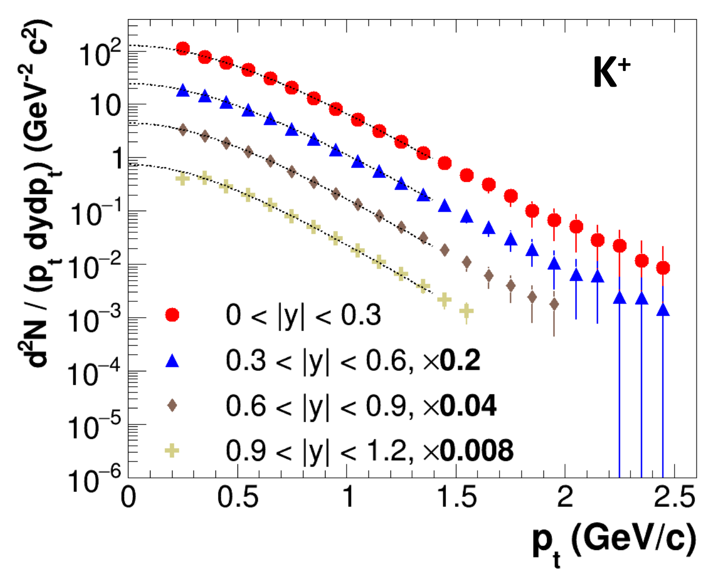
✓ *Recent reconstruction chain, combined dE/dx+TOF particle ID, spectra analysis*

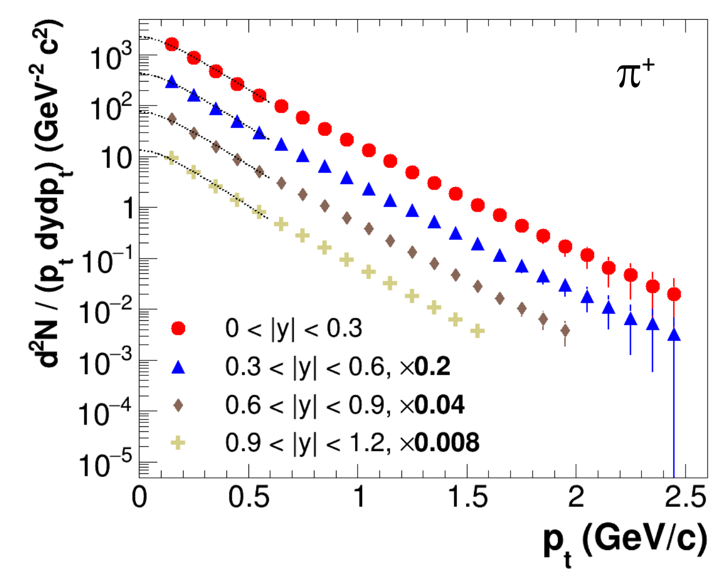




- MPD provides large phase-space coverage for identified pions and kaons (> 70% of the full phasespace at 9 GeV)
- Hadron spectra can be measured from p_T=0.2 to 2.5 GeV/c
- Extrapolation to full p_T-range and to the full phase space can be performed exploiting the spectra shapes (see BW fits for p_T-spectra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

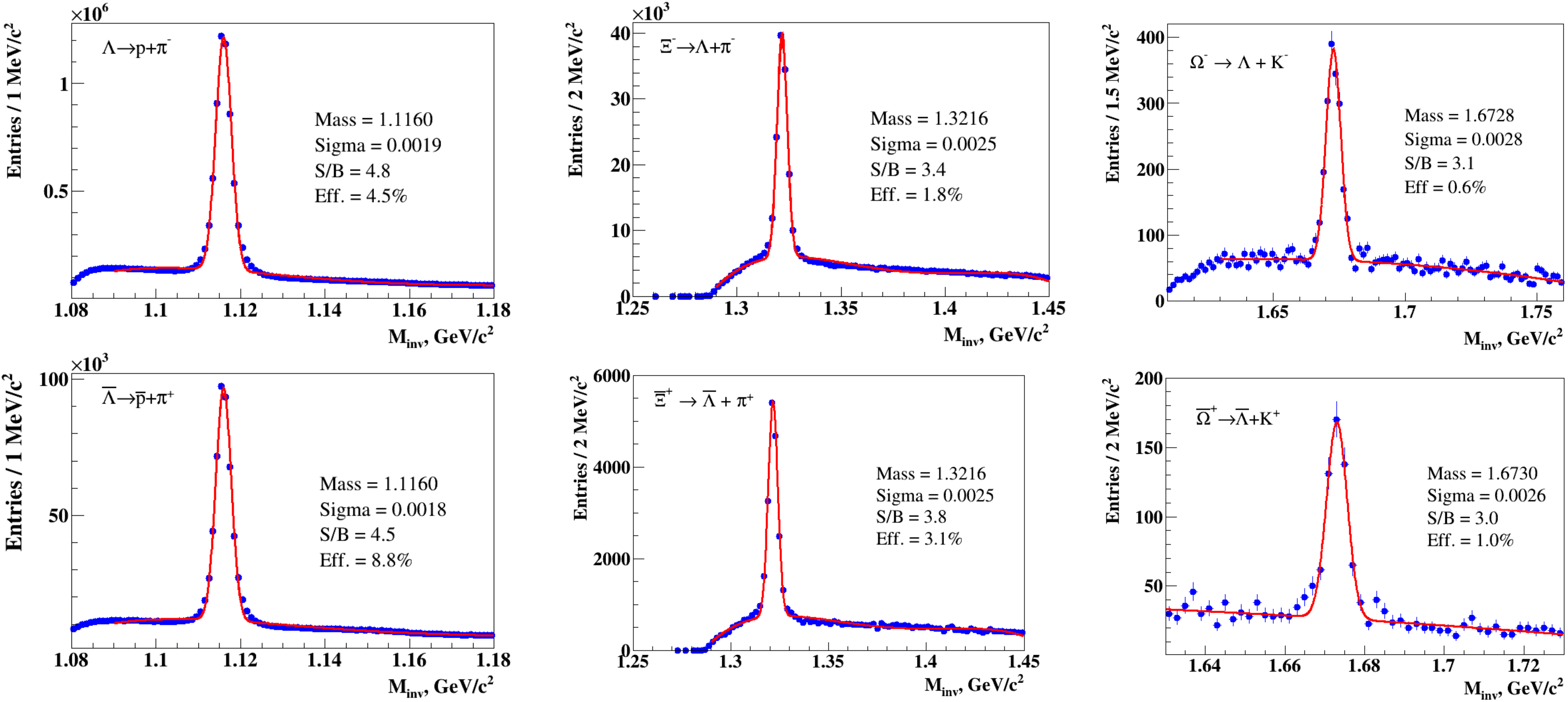
Ability to cover full energy range of the „horn" with consistent acceptance





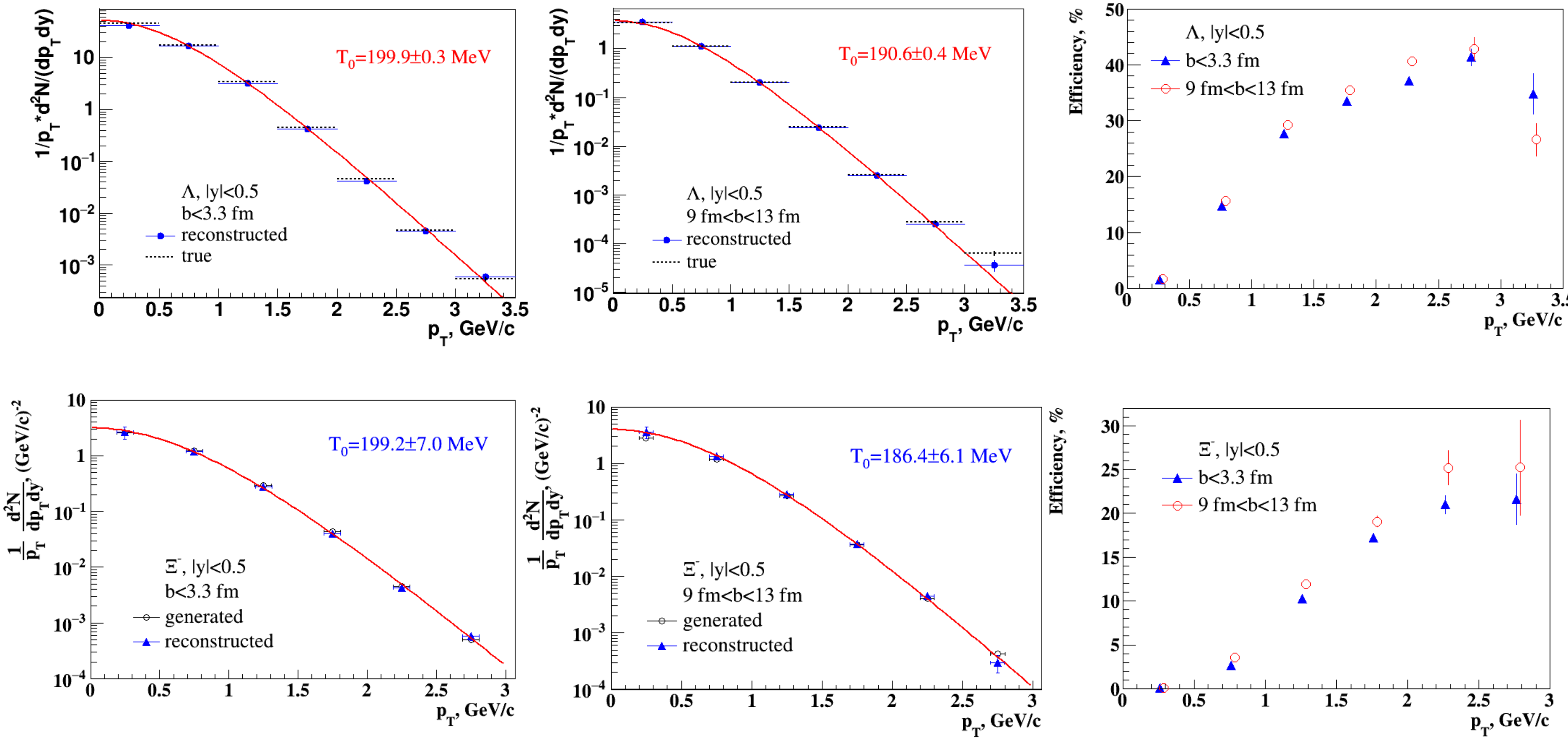
Strange and multi-strange baryons

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



particle	Λ	anti-Λ	Ξ^-	anti-Ξ^+	Ω^-	anti–Ω^+
yield in 10 weeks	$3 \cdot 10^8$	$3.5 \cdot 10^6$	$1.5 \cdot 10^6$	$8.0 \cdot 10^4$	$7 \cdot 10^4$	$1.5 \cdot 10^4$

Efficiency and p_T spectrum

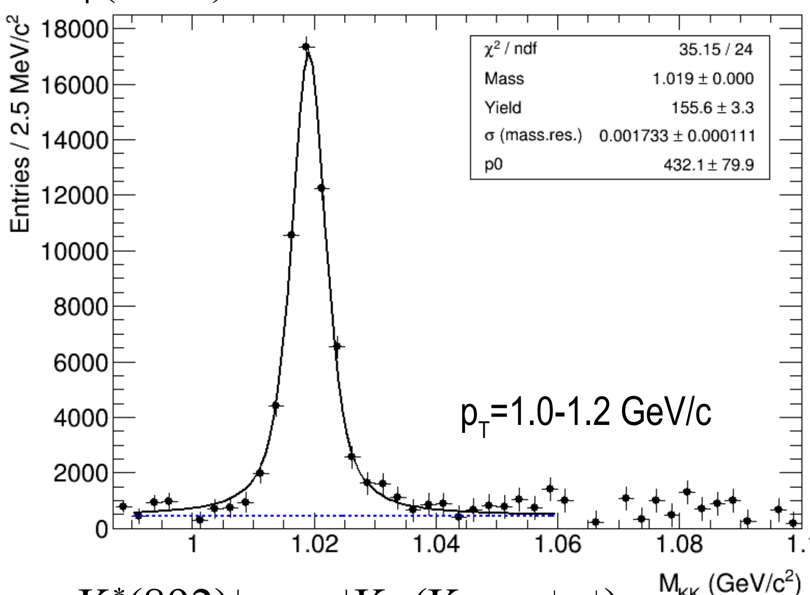


Full p_T spectrum and yield extraction, reasonable efficiency down to low p_T

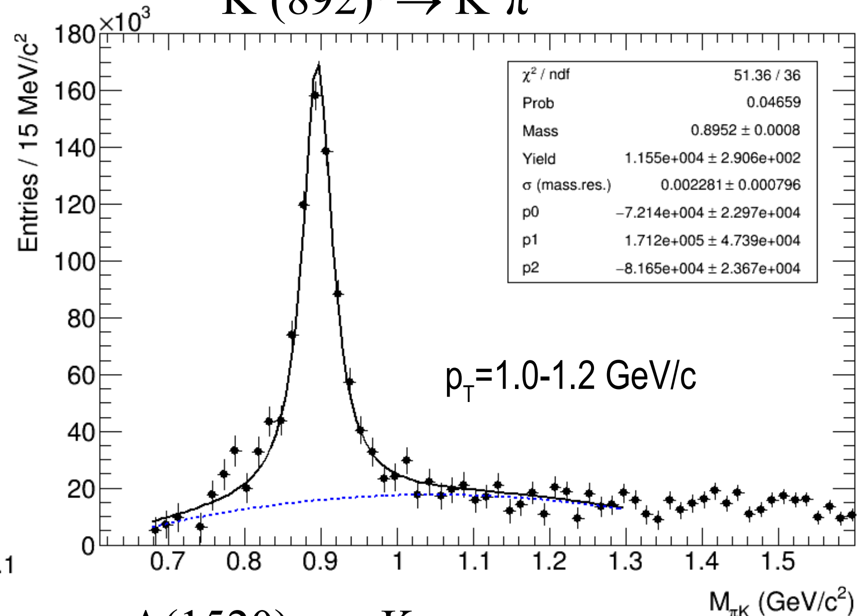
Resonances at MPD

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

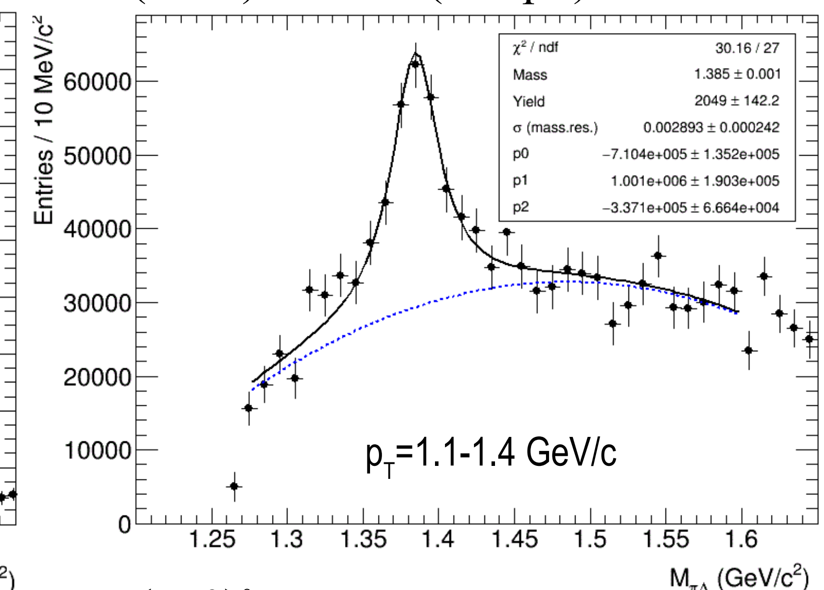
$\phi(1020) \to K^+K^-$



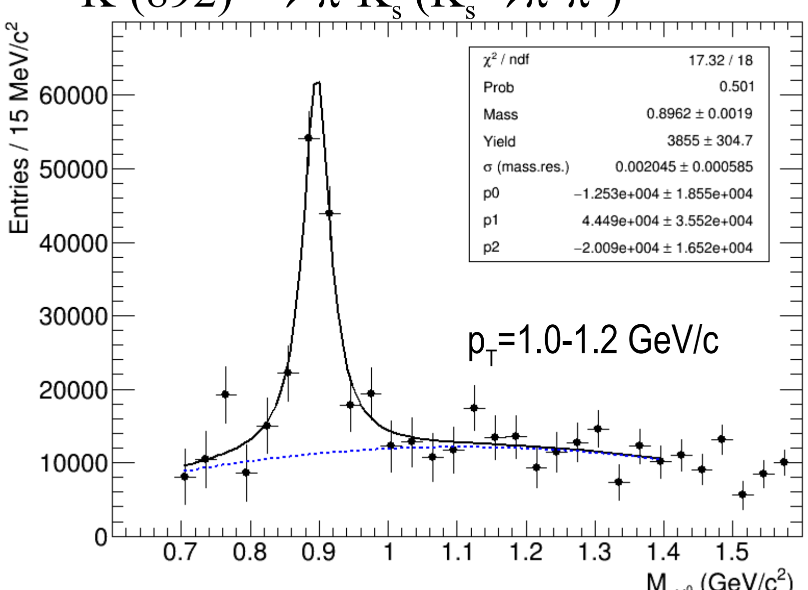
$K^*(892)^0 \to K^\pm\pi^\pm$



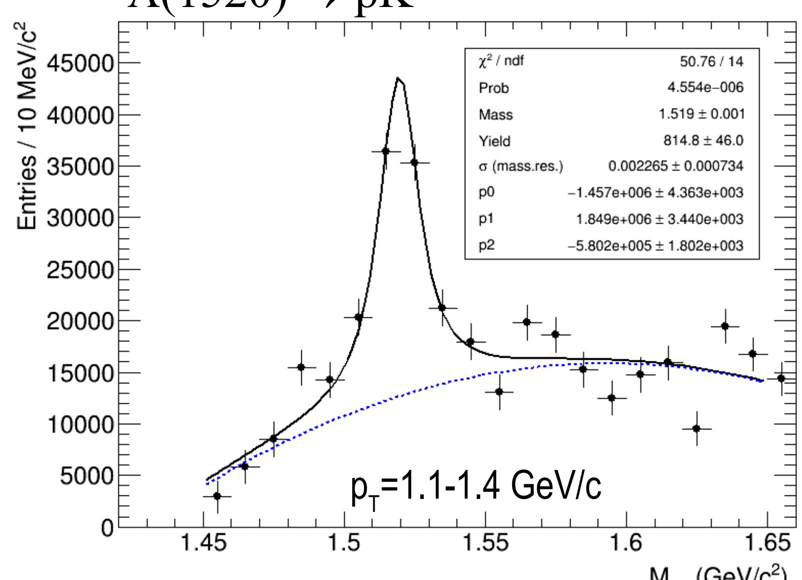
$\Sigma(1385)^\pm \to \pi^\pm\Lambda\ (\Lambda \to p\pi)$



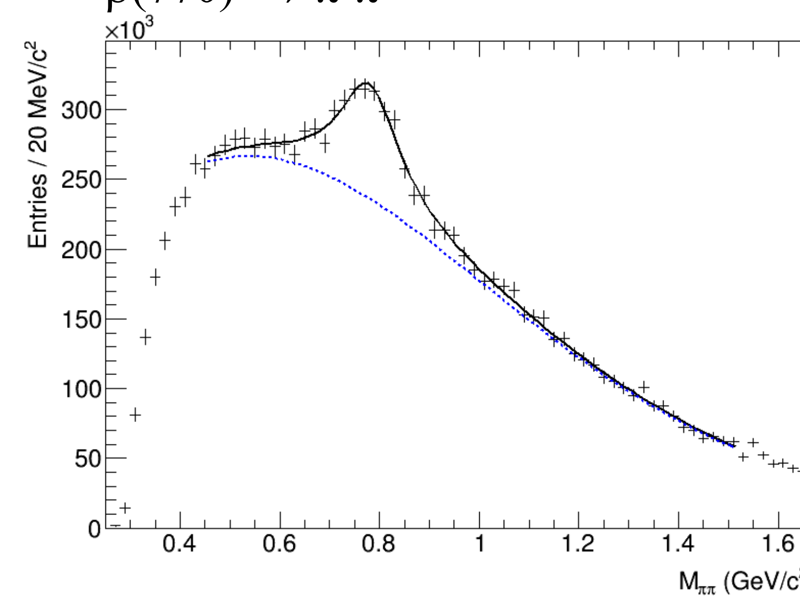
$K^*(892)^\pm \to \pi^\pm K_s\ (K_s \to \pi^+\pi^+)$



$\Lambda(1520) \to pK^-$

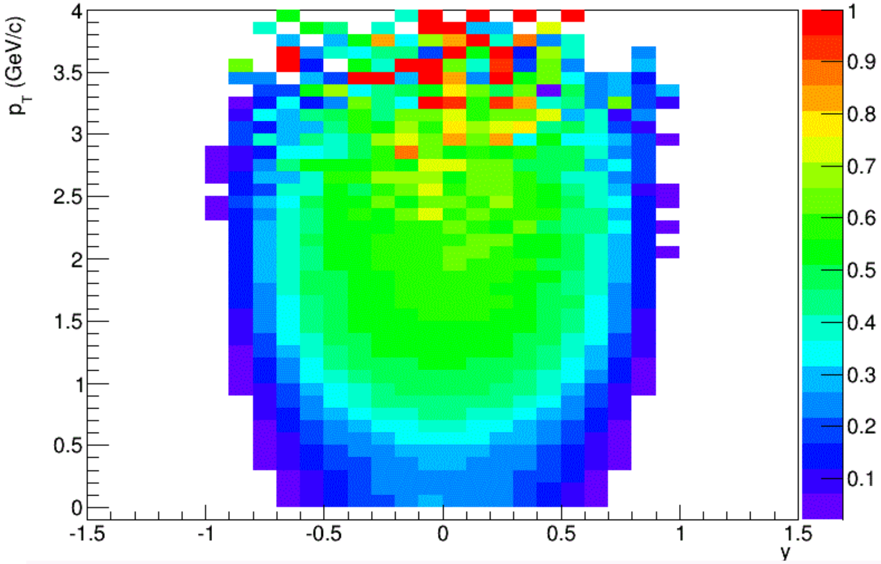


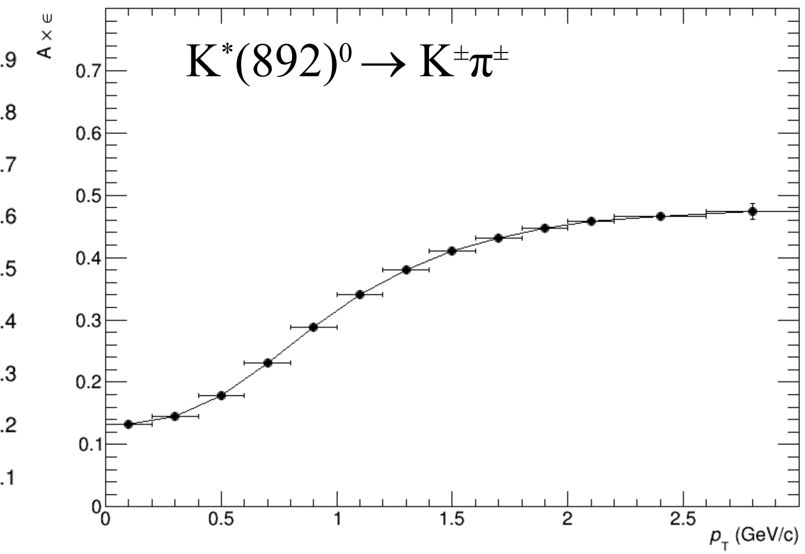
$\rho(770)^0 \to \pi^\pm\pi^\pm$

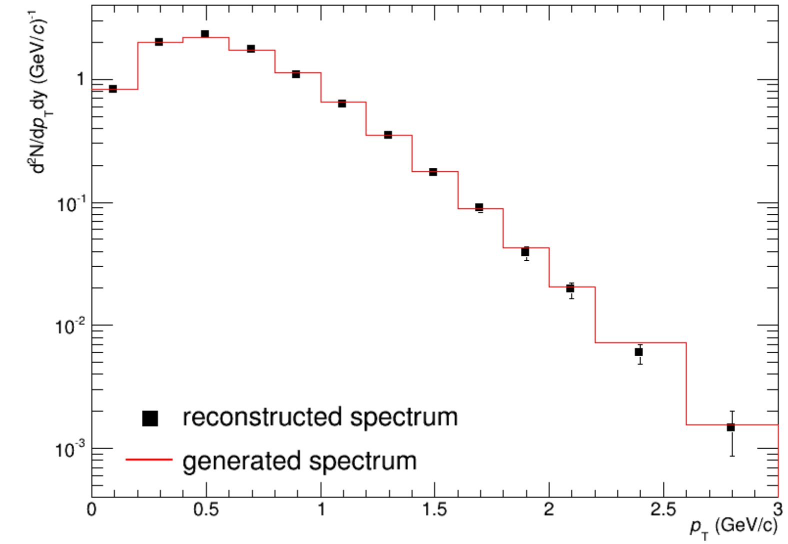


Efficiencies and closure tests examples

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

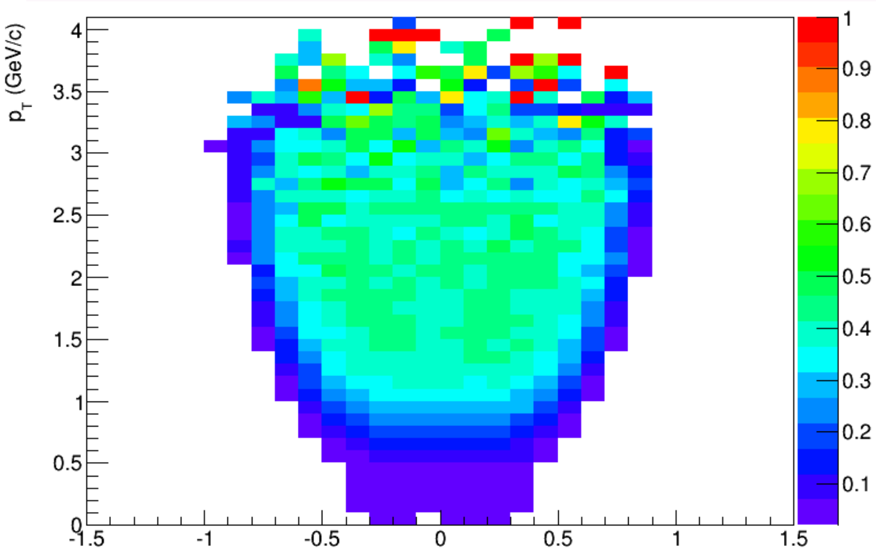


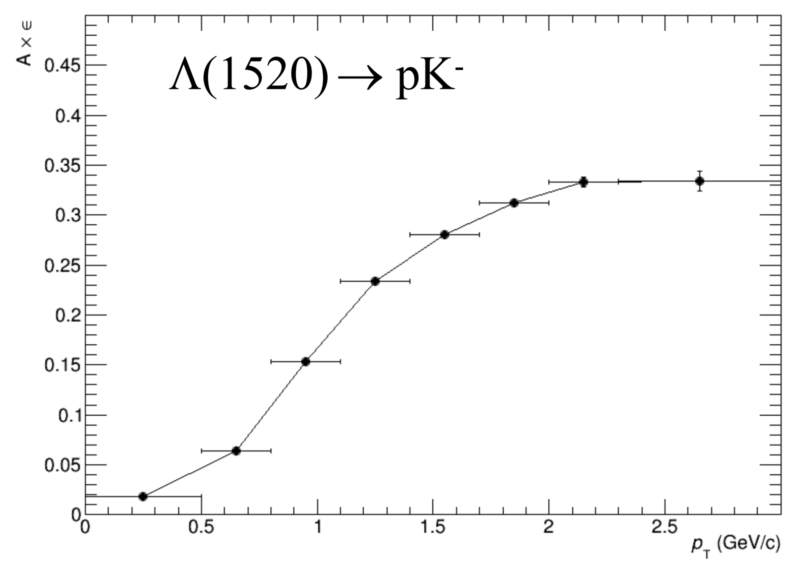


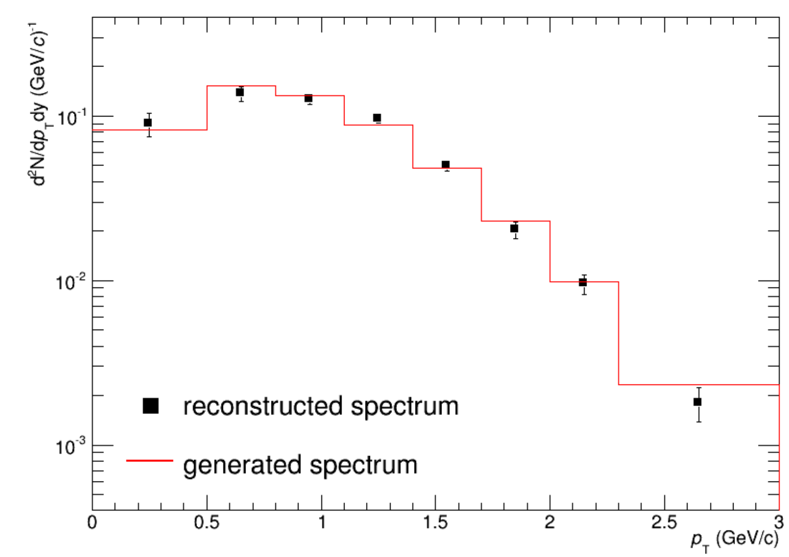


Reconstruction efficiency

Closure Test

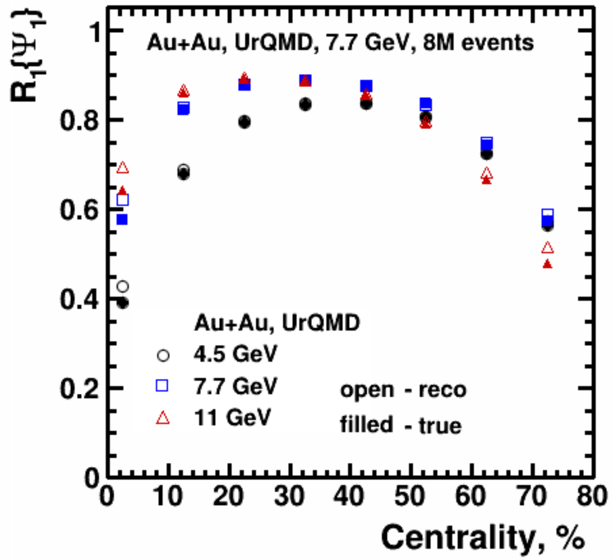


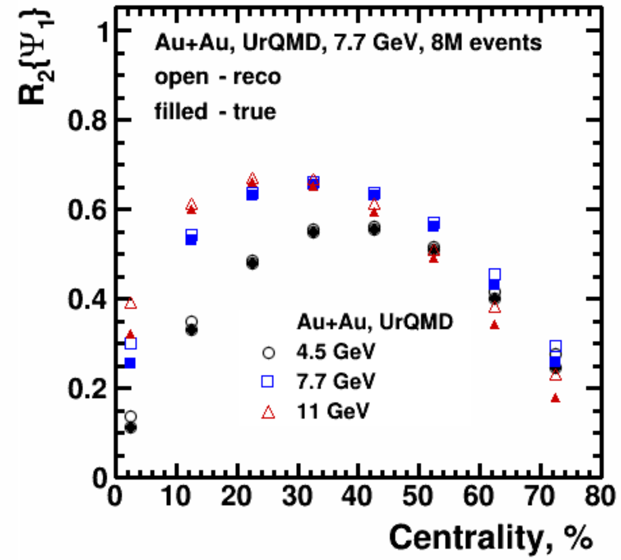


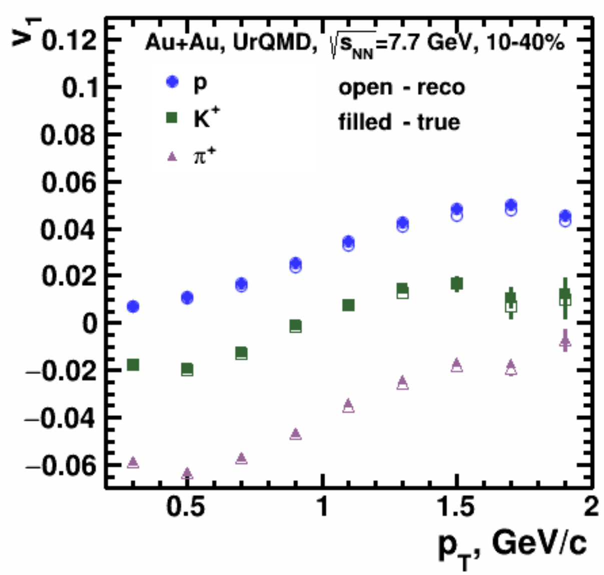


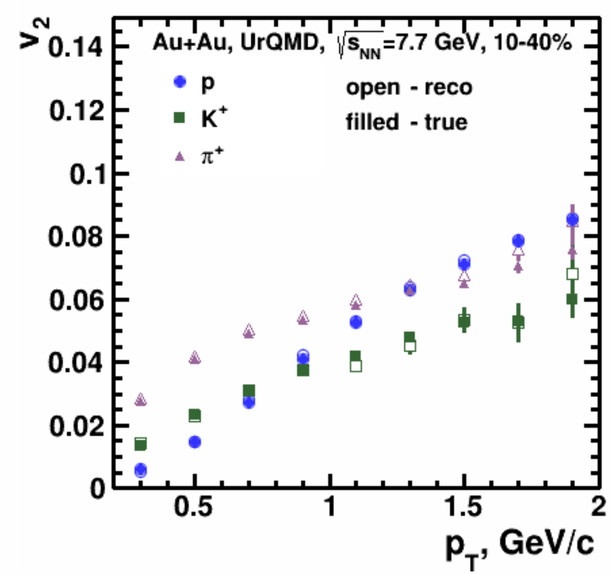
Performance of collective flow studies

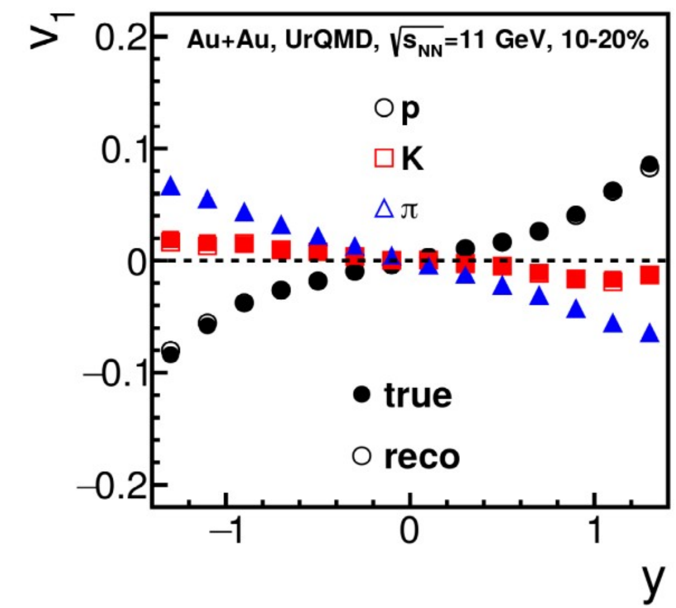
Au+Au, $\sqrt{s_{NN}}$ = 7.7, 11 GeV, UrQMD, GEANT3 + MPDRoot reco.

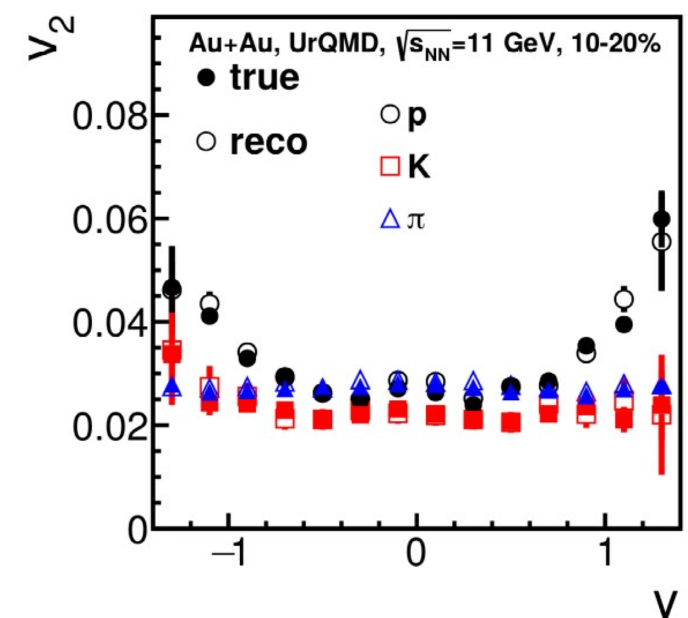












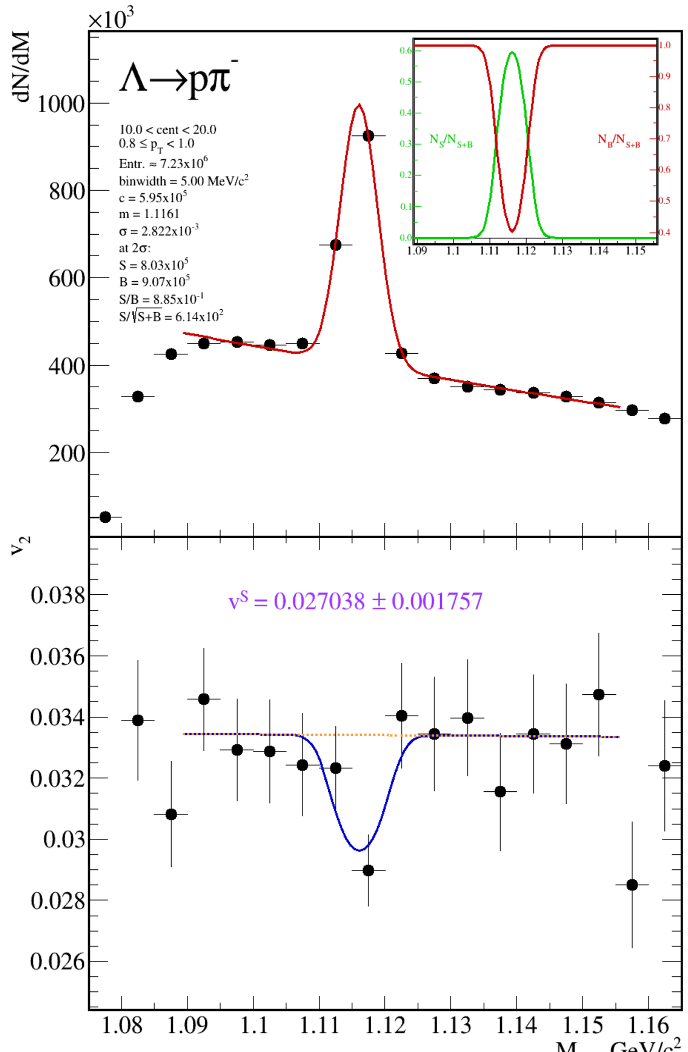
Collective flow a unique and direct way to probe EOS of QCD matter. Excellent flow measurement capabilities in MPD

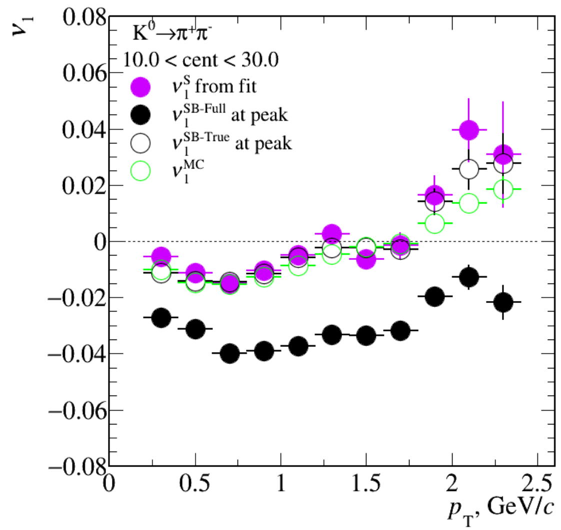
Anisotropic Flow of Reconstructed Decays

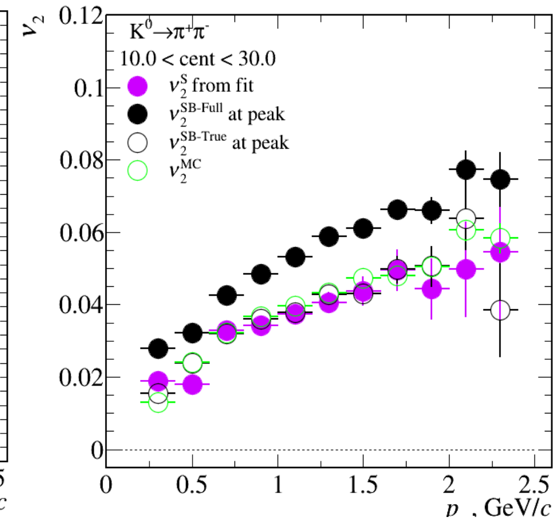
$$v_2^{SB}(m_{inv},p_T) = v_2^S(p_T)\frac{N^S(m_{inv},p_T)}{N^{SB}(m_{inv},p_T)} + v_2^B(m_{inv},p_T)\frac{N^B(m_{inv},p_T)}{N^{SB}(m_{inv},p_T)}$$

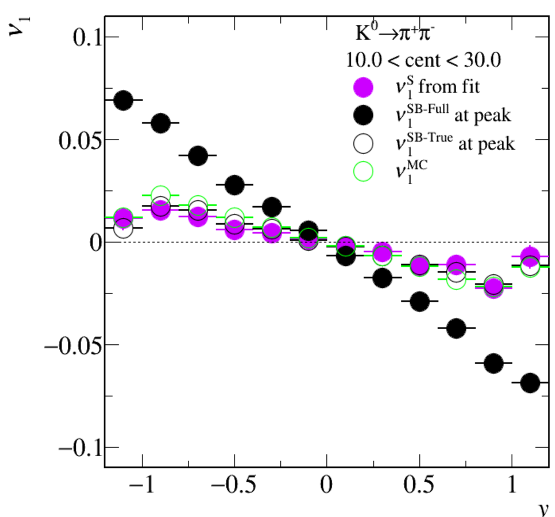
Extracted flow signal after fit
Measured flow (s+bg) at peak region
Measured flow only for True
Measured flow from MC/model

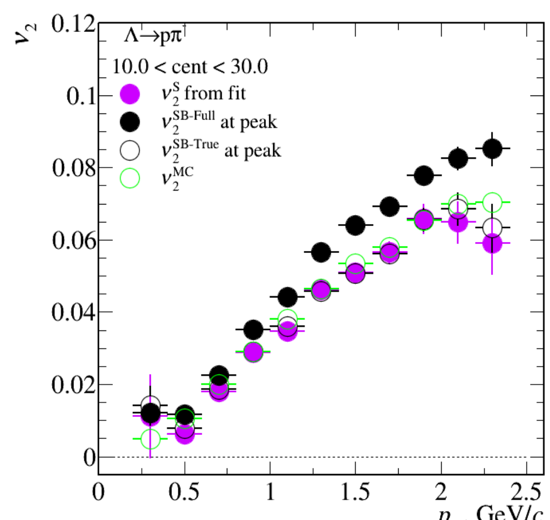
Cuts not optimised for S/B

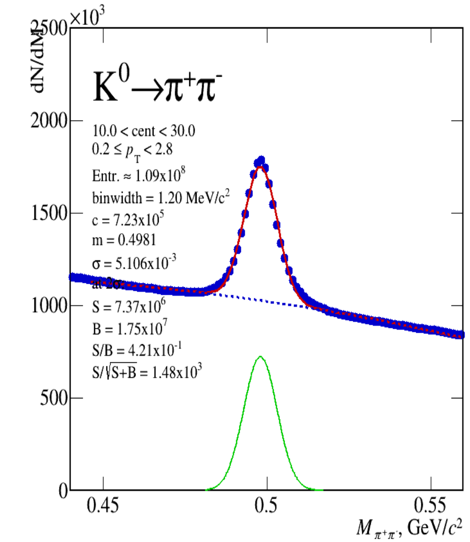


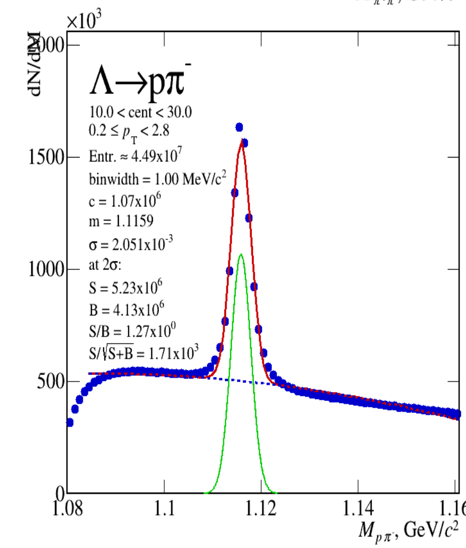








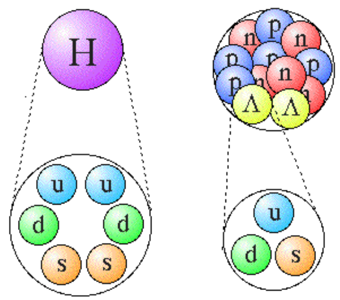




Performance of the MPD Detector for the Study of Multi-strange Baryon Production in Heavy-ion Collisions at NICA

N. Geraksiev, V. Kolesnikov, V. Vasendina, A. Zinchenko for the MPD Collaboration

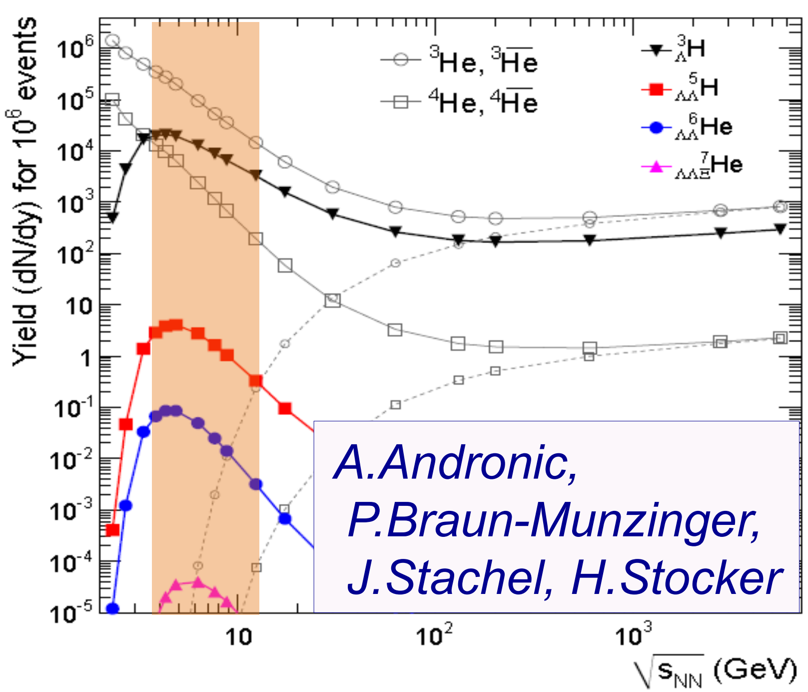
Hypernuclei at MPD



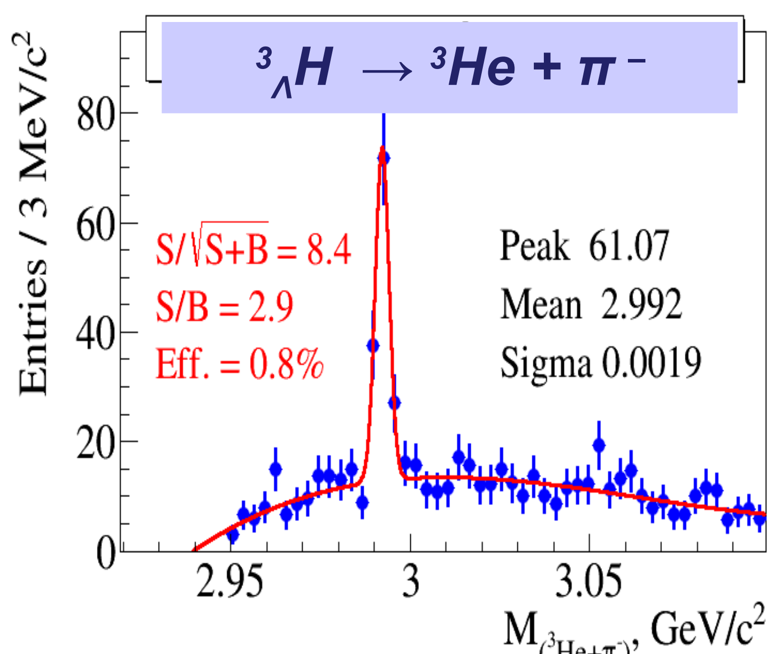
astrophysical research indicates the appearance of hyperons in the dense core of a ***neutron star***

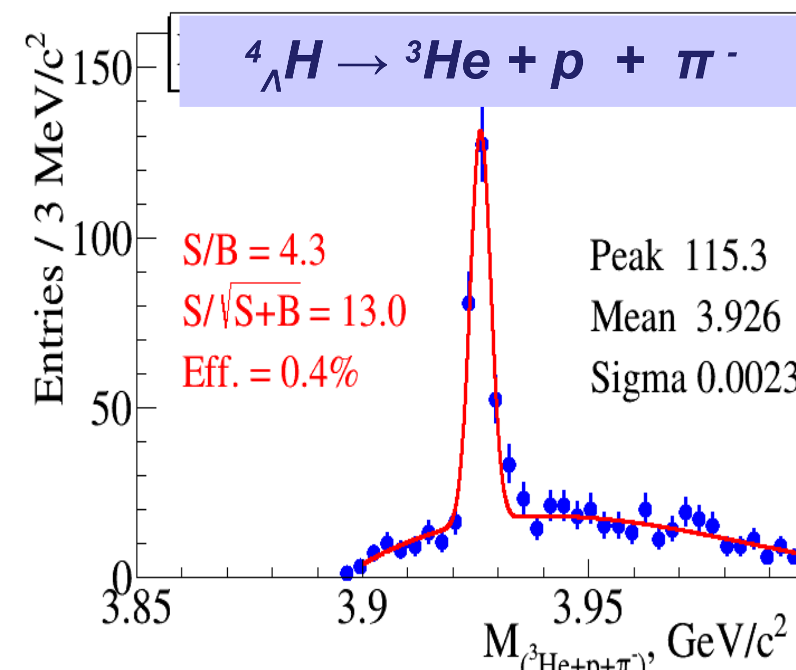
Stage 2: *central* ***Au+Au @ 5*** *AGeV; DCM-QGSM*

hyper nucleus	yield in 10 weeks
$^{3}_{\Lambda}He$	$9 \cdot 10^{5}$
$^{4}_{\Lambda}He$	$1 \cdot 10^{5}$



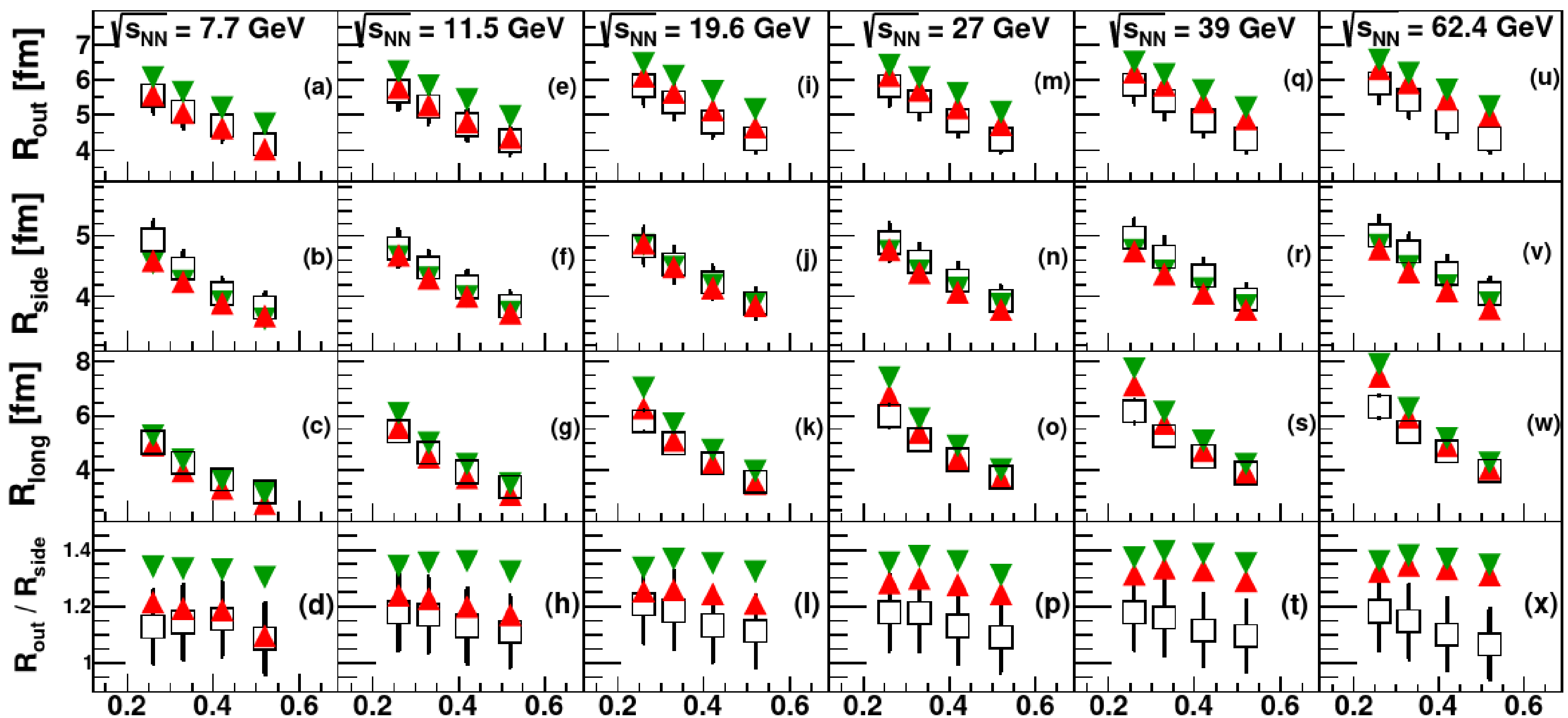
A.Andronic, P.Braun-Munzinger, J.Stachel, H.Stocker





System size sensitive to phase transition

- Femtoscopy based on two-particle correlation technique (similar to HBT effect in astronomy) probes system size in HIC
- Measurement for pions straightforward and robust, large discovery potential in correlations for kaons and protons, as well as correlations including hyperons



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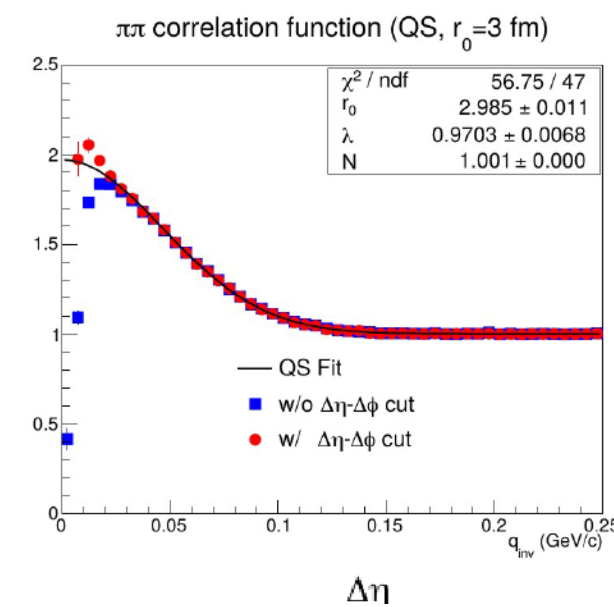
1st order phase transition
cross-over transition

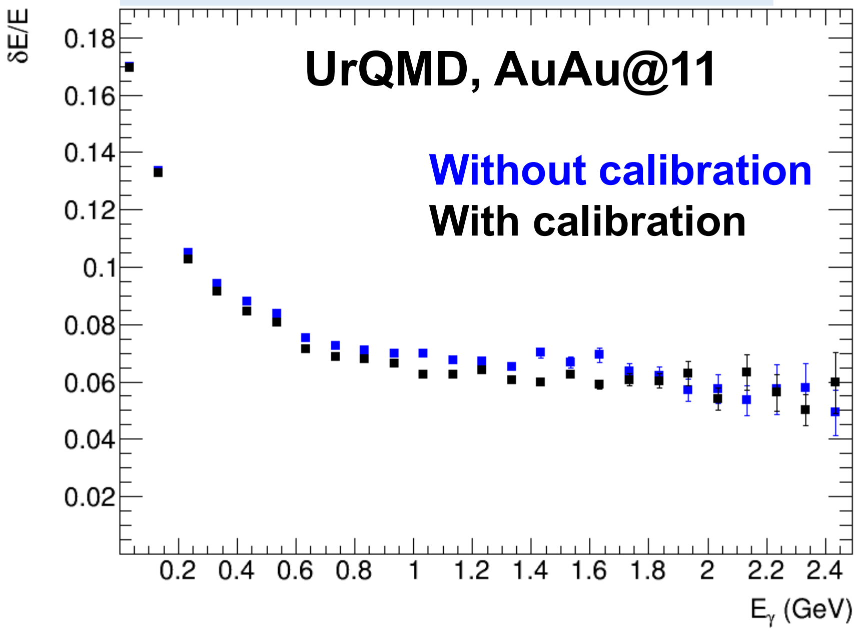


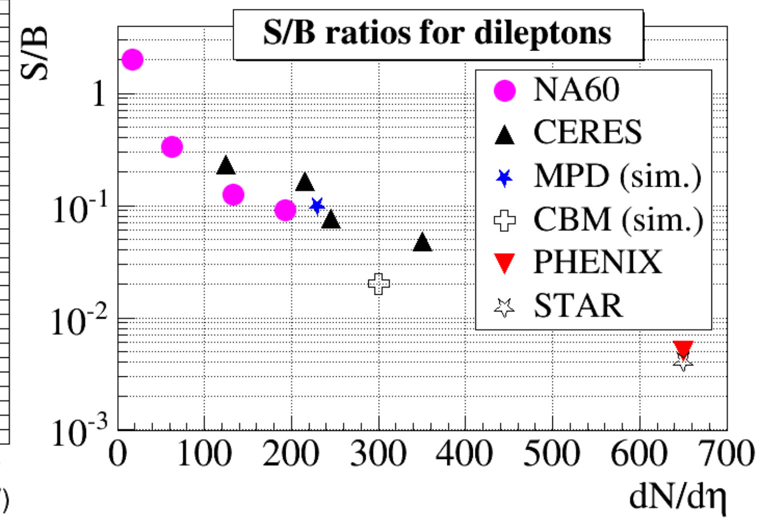
- Clear sensitivity of pion source size to the nature of the phase transitions
- Important and sensitive cross-check of detector performance (two-track resolution)

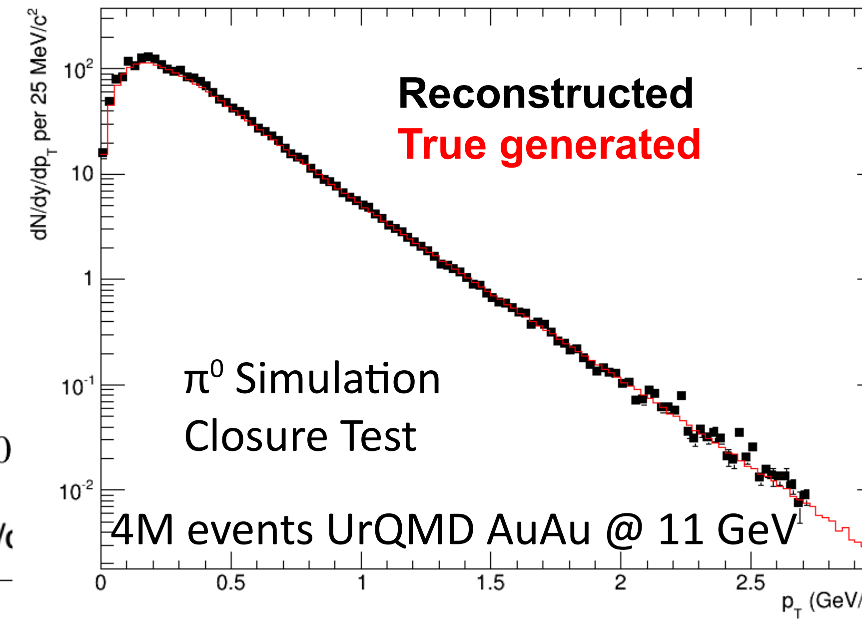
Electromagnetic probes in ECAL

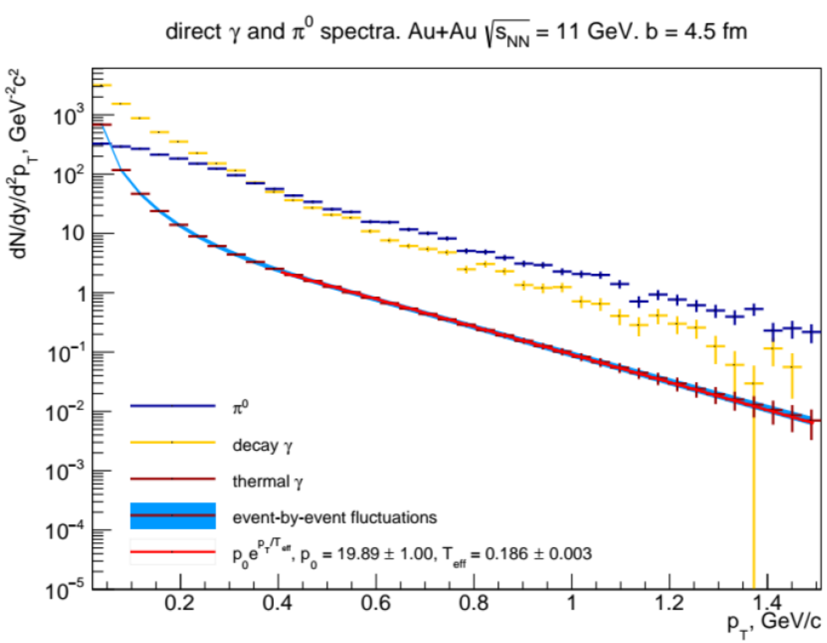
- Realistic ECAL reconstruction & analysis – large acceptance ECAL with good energy resolution: ideal tool for measurement of neutral mesons in a wide momentum range

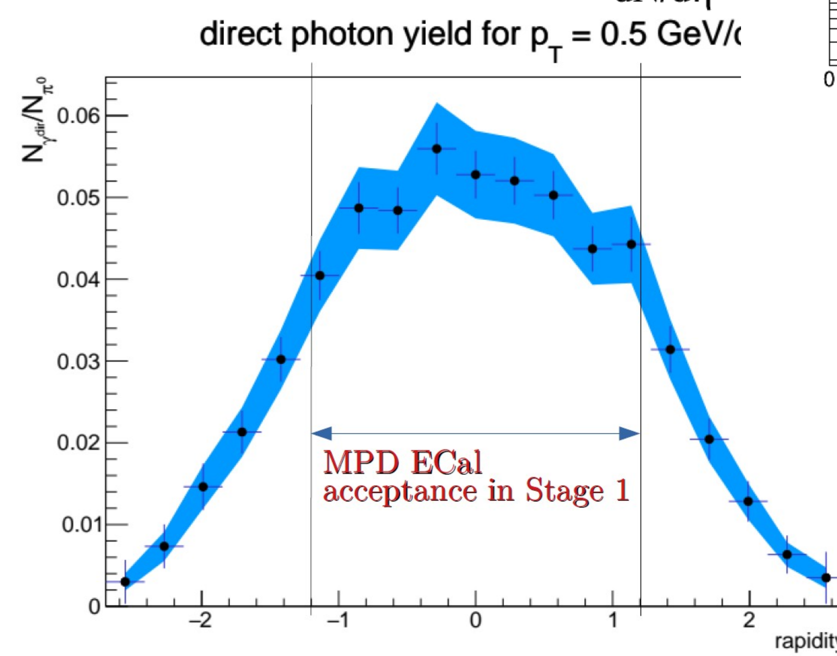
Photon energy resolution







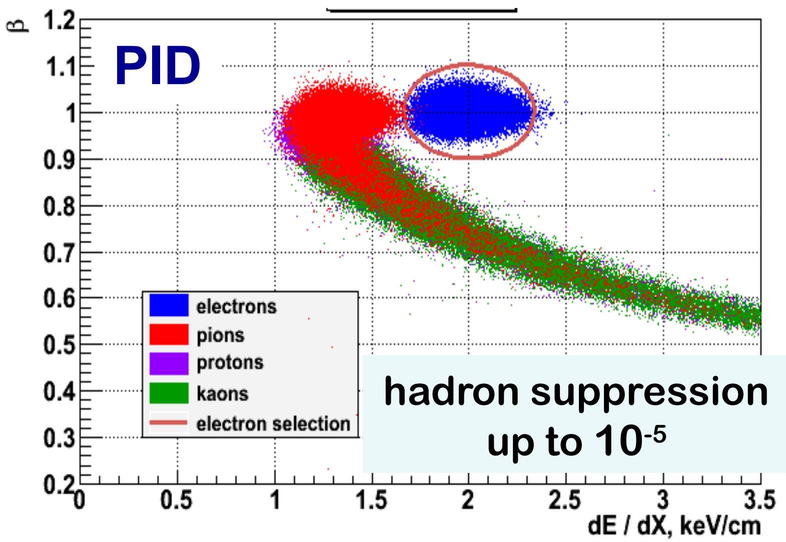


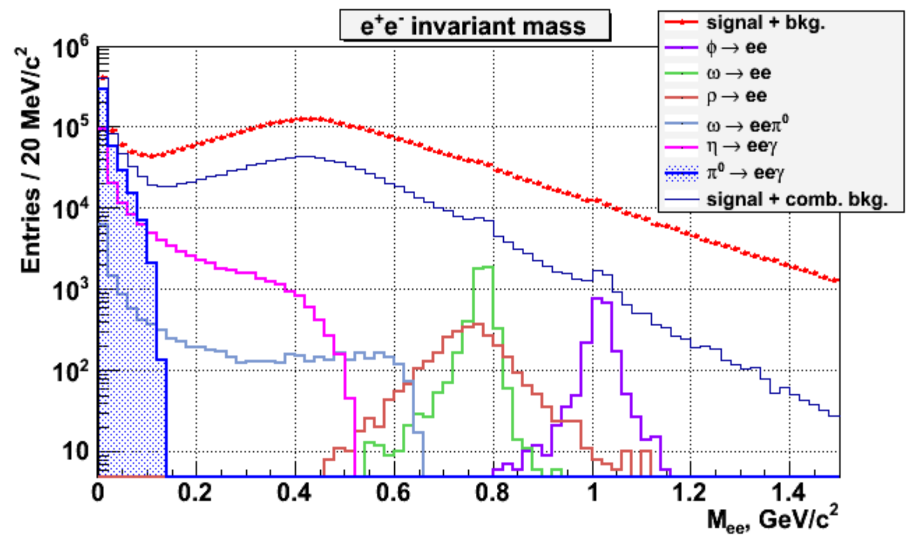


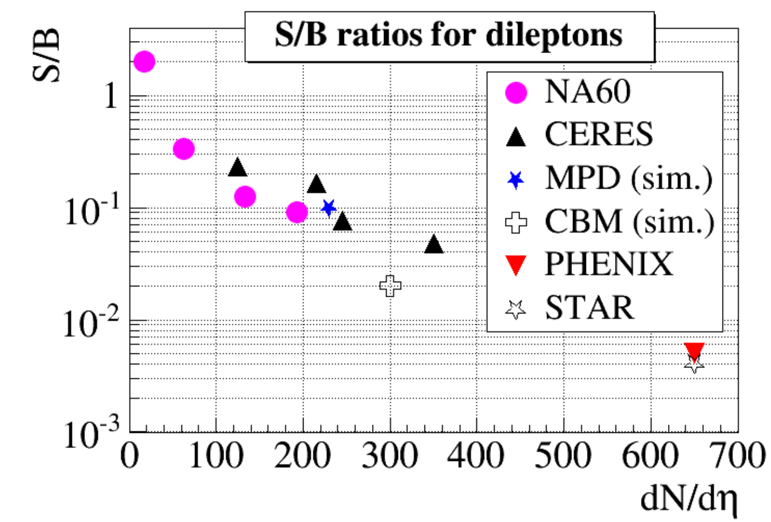
- Promising feasibility studies for prompt photon measurements in MPD

Prospects of dilepton studies

- **Event generator:** *UrQMD+Pluto (for the cocktail) central Au+Au @ 8 GeV*
- **PID**: *dE/dx (from TPC) + TOF (σ ~100 ps) + ECAL*

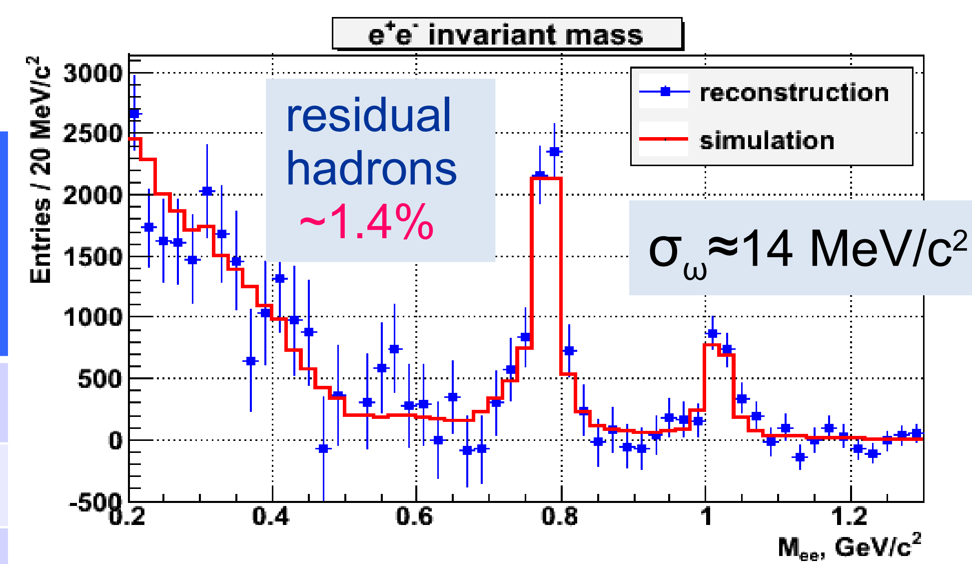






Yields, central Au+Au at $\sqrt{s_{NN}}$ = 8.8 GeV

Particle	Yields 4π	Yields y=0	Decay mode	BR	Effic. %	Yield /1 w
ρ	31	17	e+e-	$4.7 \cdot 10^{-5}$	35	$7.3 \cdot 10^{4}$
ω	20	11	e+e-	$7.1 \cdot 10^{-5}$	35	$7.2 \cdot 10^{4}$
ϕ	2.6	1.2	e+e-	$3 \cdot 10^{-4}$	35	$1.7 \cdot 10^{4}$



Summary

- The NICA Complex advanced in construction with important milestones achieved and clear plans for 2021 and 2022
- All components of MPD 1st stage in production
- Broad MPD Physics program with initial NICA beams
- International collaboration to carry out complete QCD phase diagram investigation for at least another decade