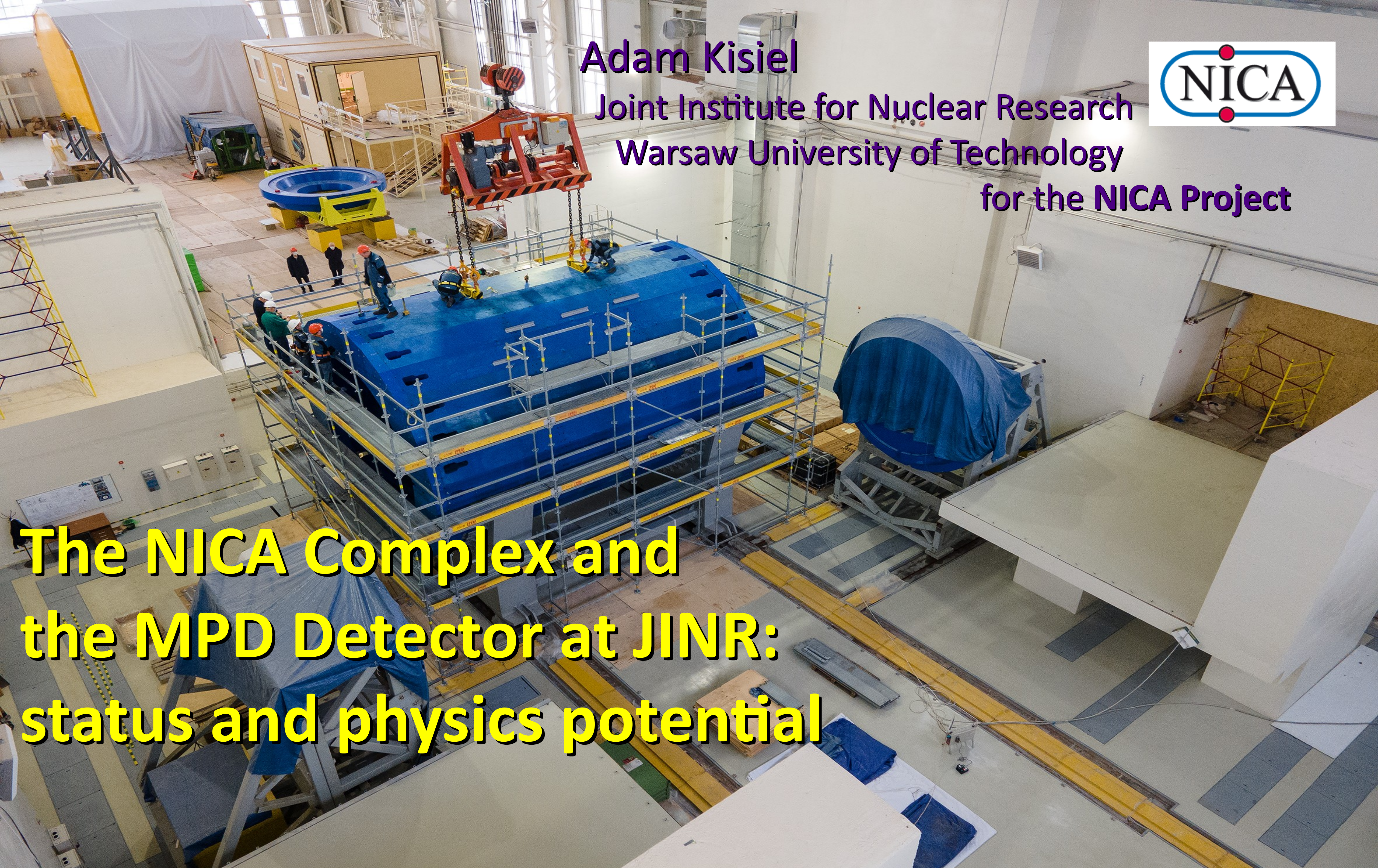
Adam Kisiel
Joint Institute for Nuclear Research
Warsaw University of Technology
for the **NICA Project**



The NICA Complex and the MPD Detector at JINR: status and physics potential

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***

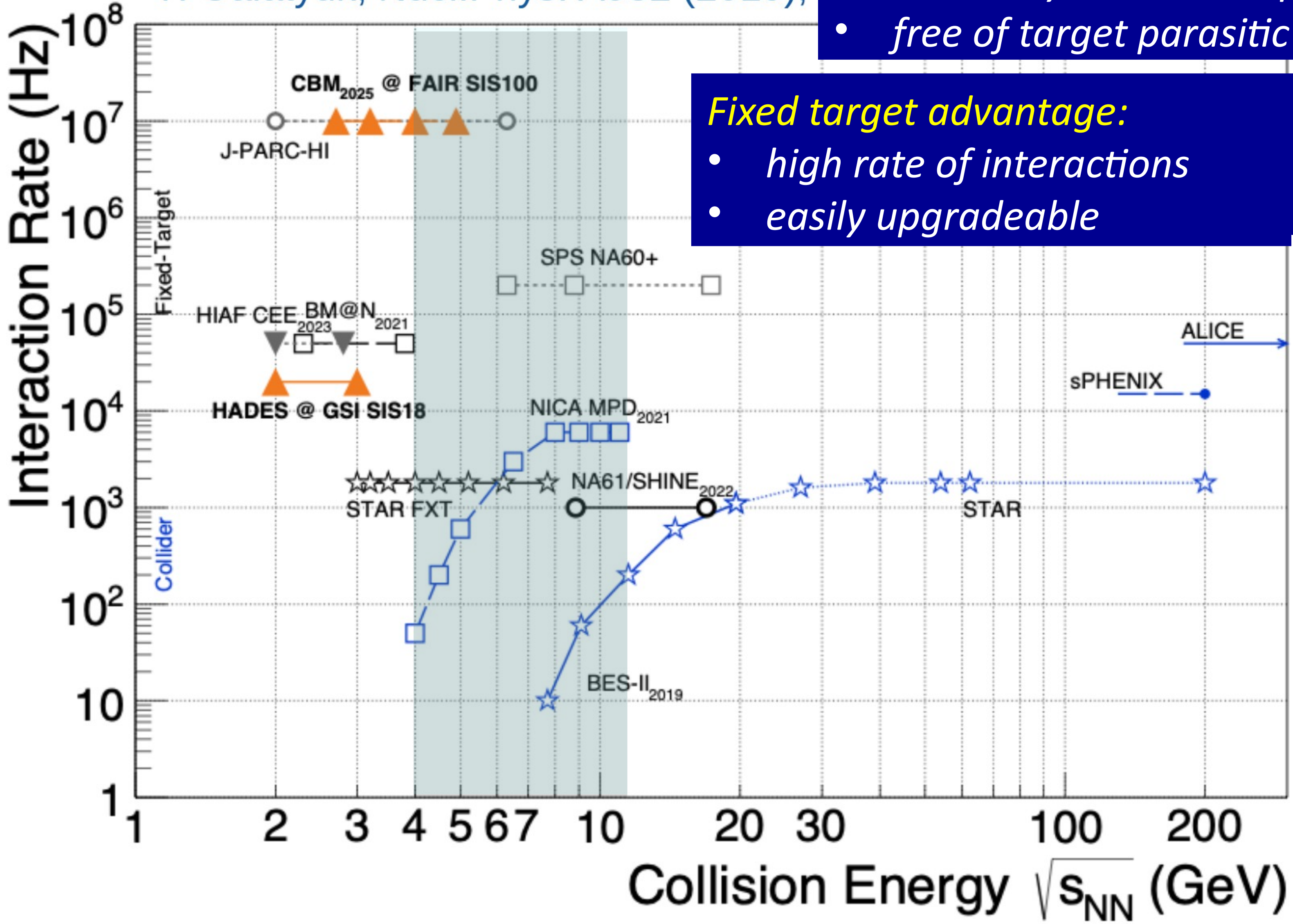
NICA: Unique and complementary

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

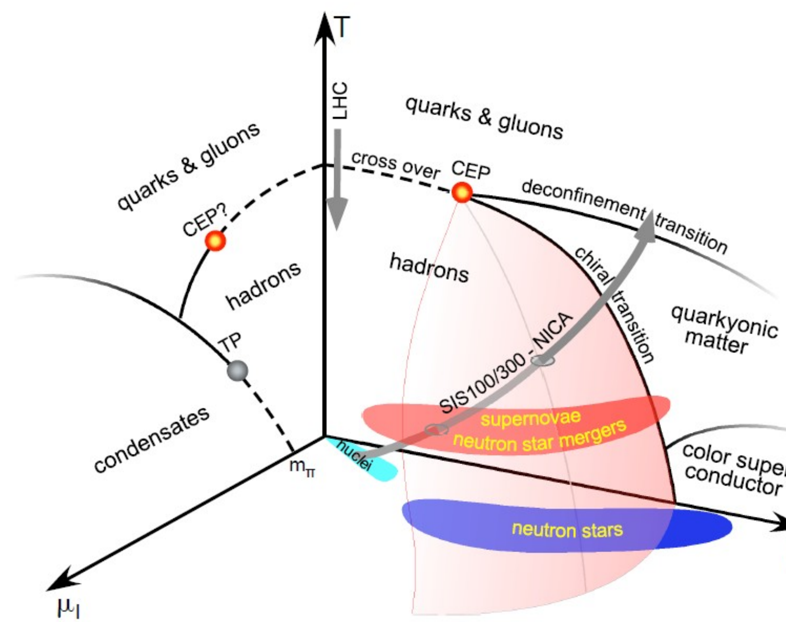
In NICA Collider energy range maximum possible net-baryon density is reached

Fixed target advantage:
- *high rate of interactions*
- *easily upgradeable*

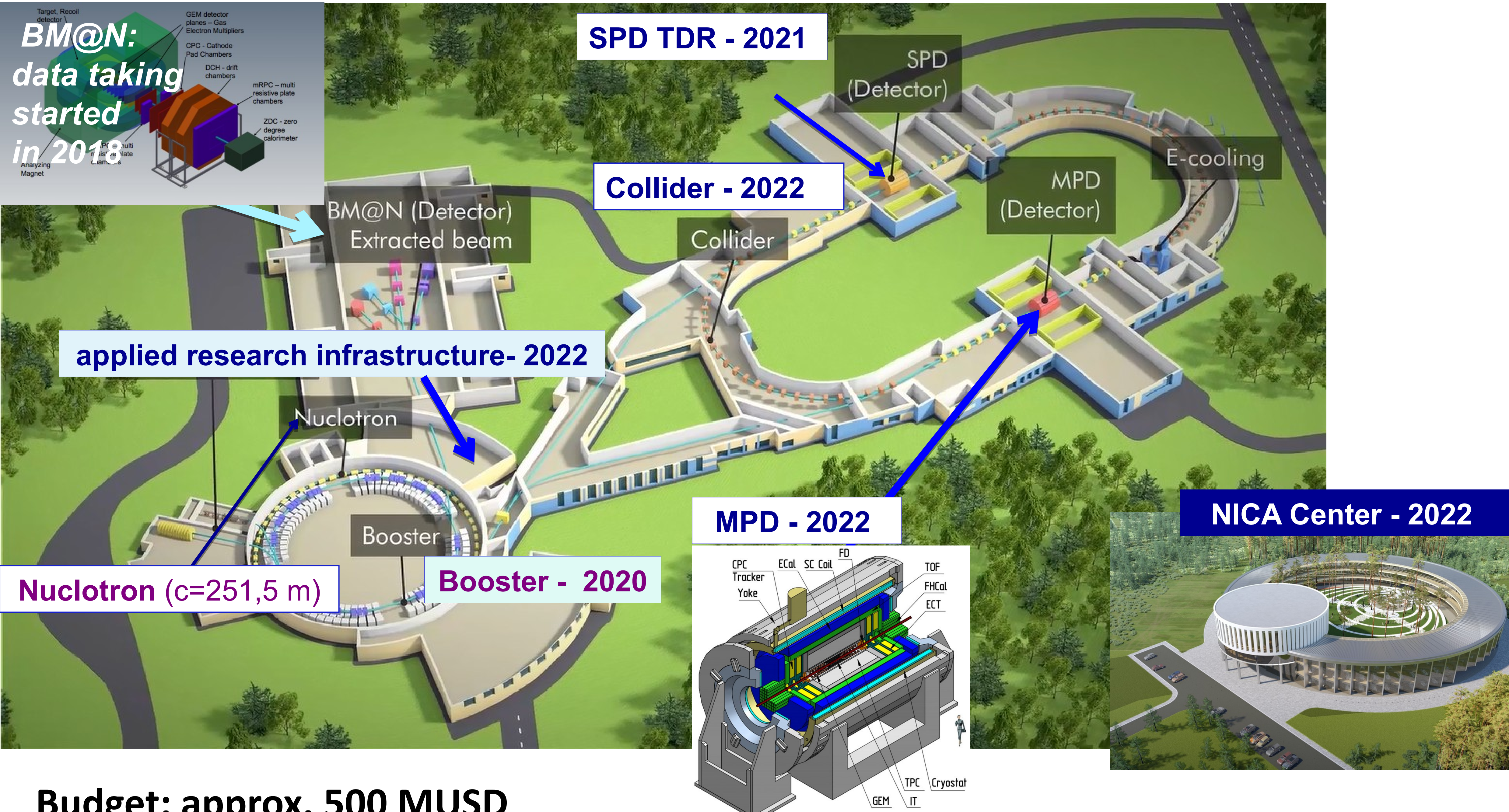
T. Galatyuk, Nucl.Phys. A982 (2019);



NUPECC Long Range Plan 2017



NICA Accelerator Complex in Dubna



Budget: approx. 500 MUSD

NICA construction live

NICA

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, Tor	10^{-11}
intensity, **Au** /p	$1.5\ 10^{9}$

The Collider

Design parameters, Stage II

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

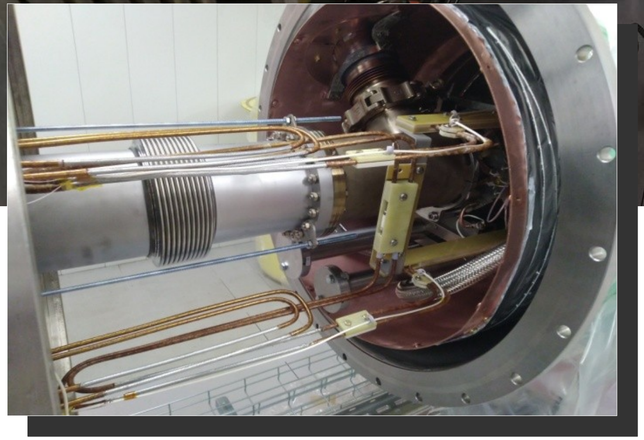
Ring circumference, m	**503,04**
Number of bunches	**22**
r.m.s. bunch length, m	**0,6**
β, m	**0,35**
Energy in c.m., Gev/u	**4-11**
r.m.s. $\Delta p/p$, 10^{-3}	**1,6**
IBS growth time, s	**1800**
Luminosity, $cm^{-2}\ s^{-1}$	**$1\text{x}10^{27}$**

Stage I:

- ***without ECS in Collider, with stochastic cooling***
- ***reduced number of RF***
- ***reduced luminosity***

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)*

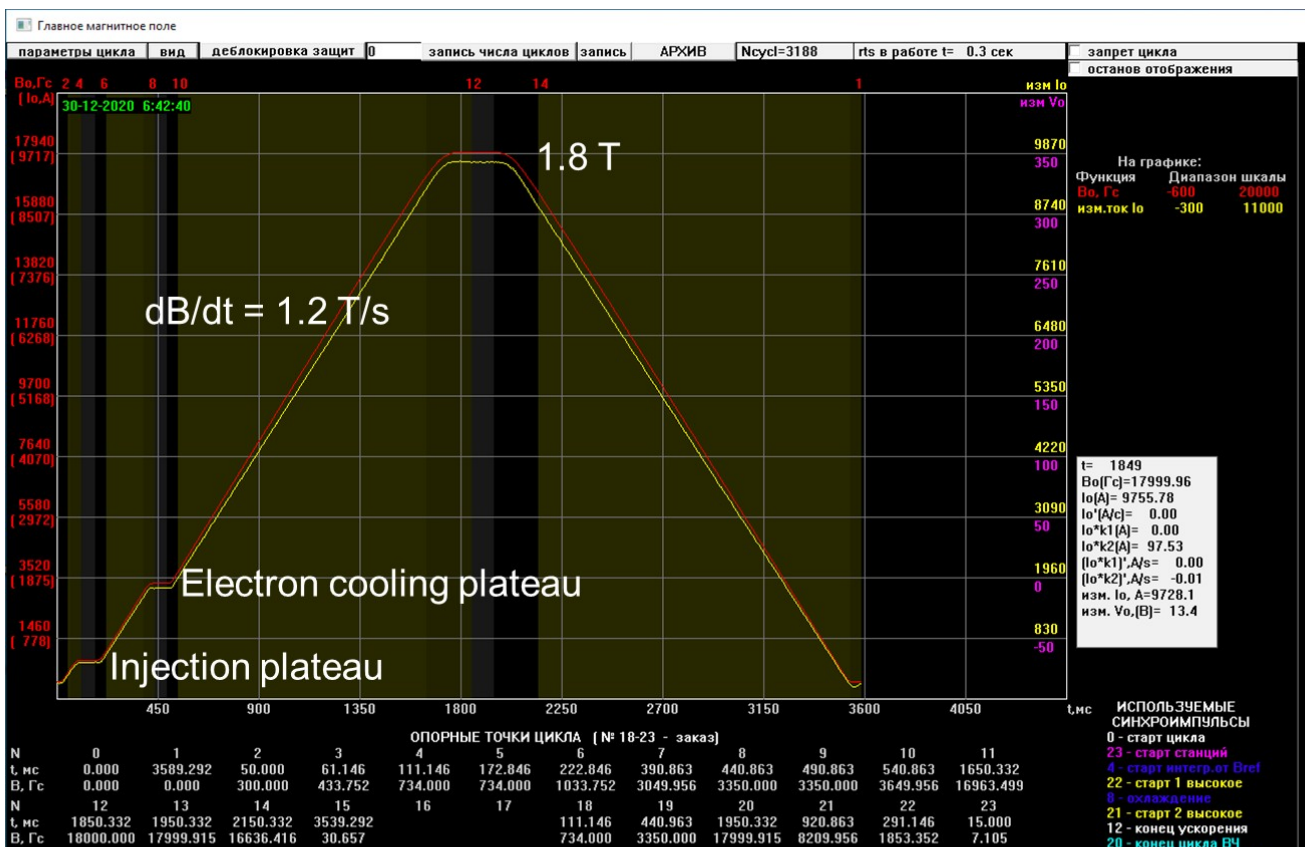
Booster commissioning



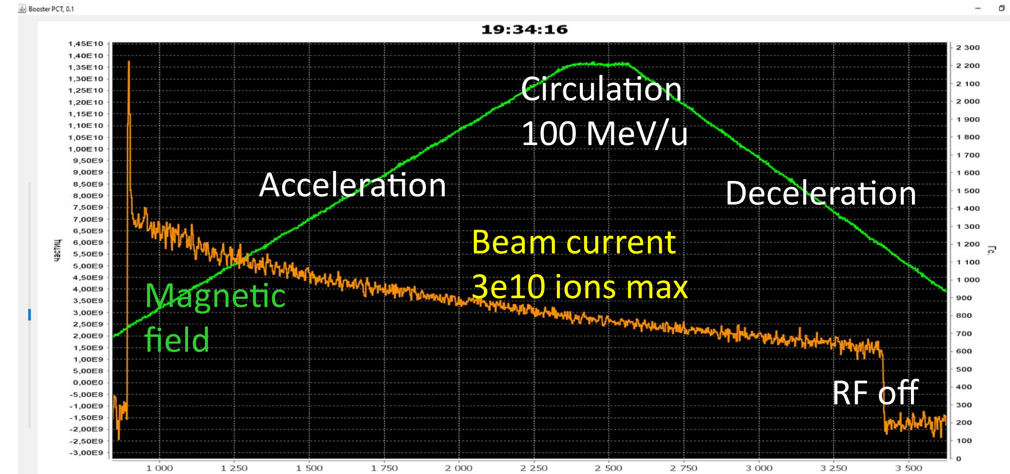
- ✓ ***Booster fully assembled in the tunnel***
- ✓ ***Commissioning and test ongoing for beam diagnostics, beam acceleration, electron cooling, power supply, magnets, cryogenics***

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)

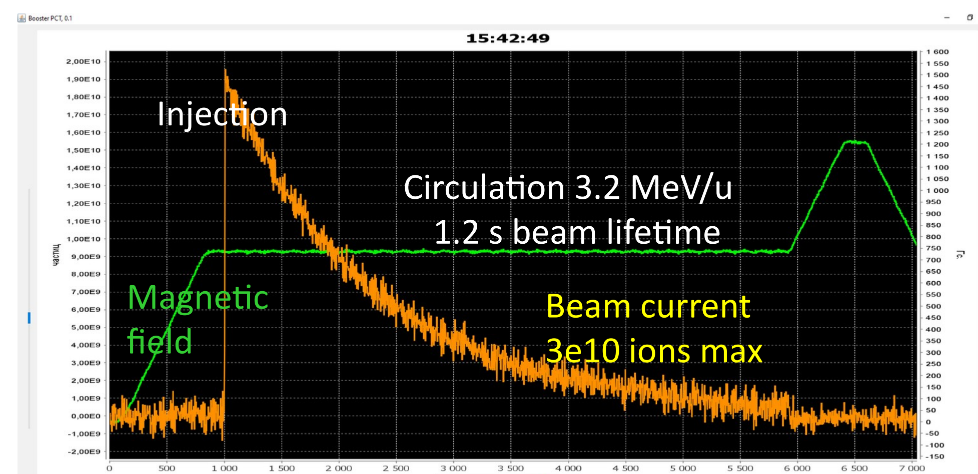


operation at design magnetic field & ramp rate



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

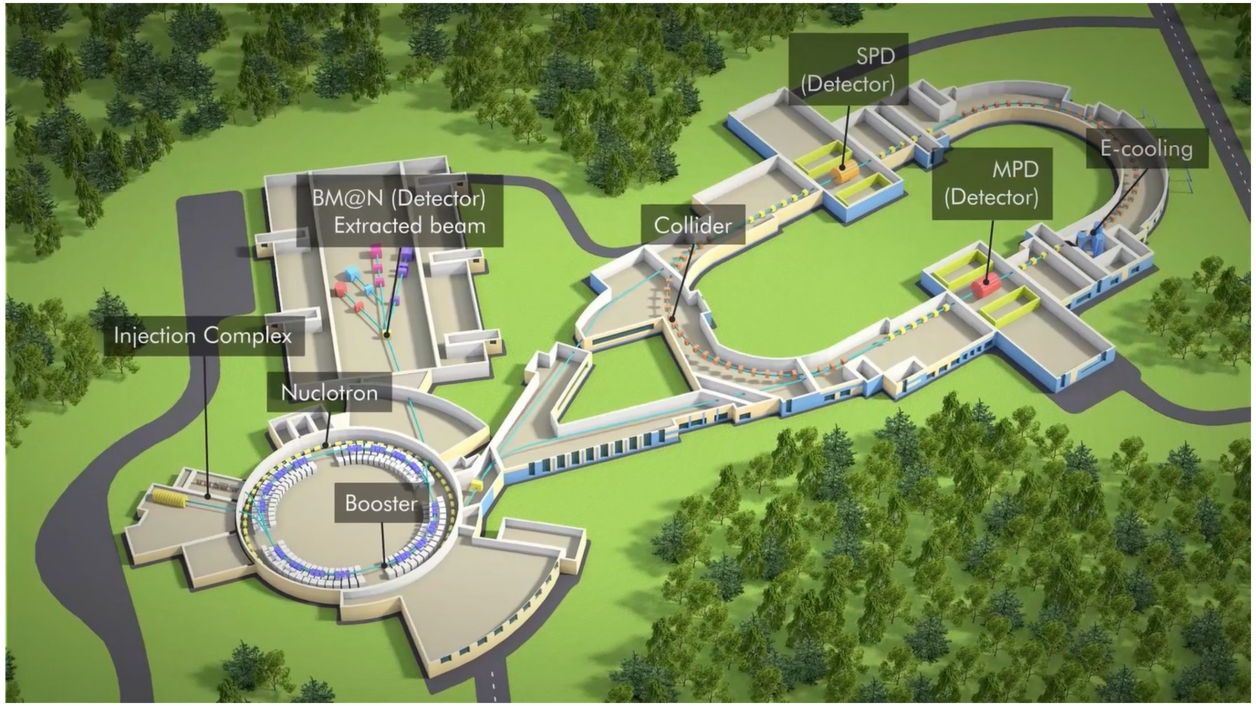
no transient losses on the MF table & after.



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

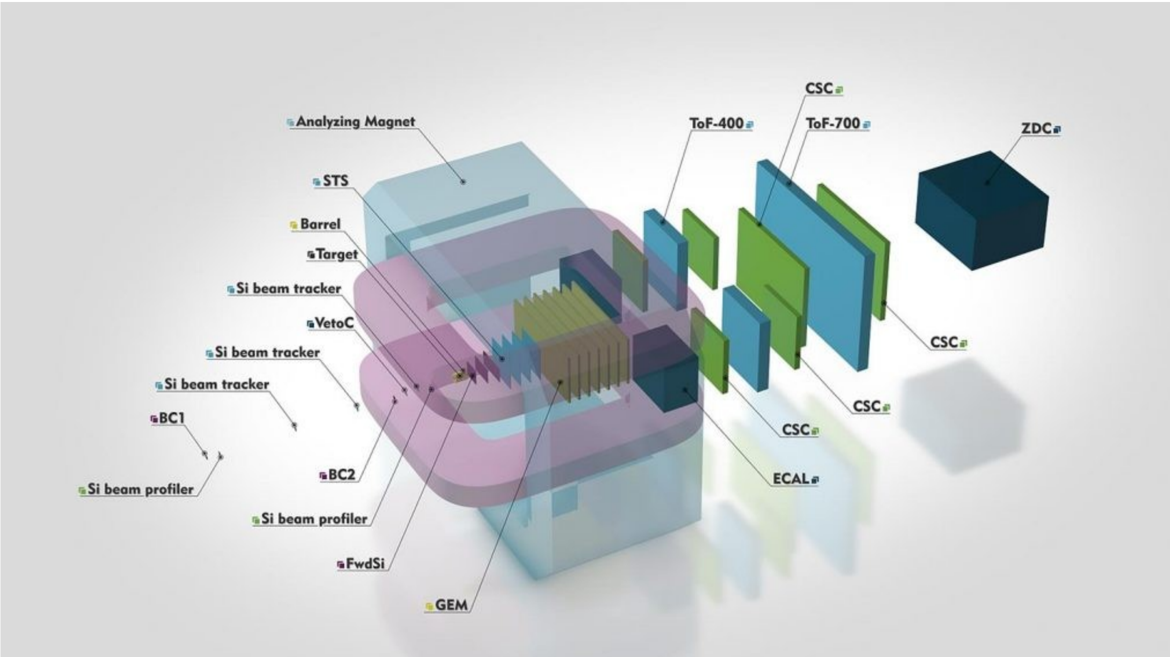
NICA Facility running plan

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

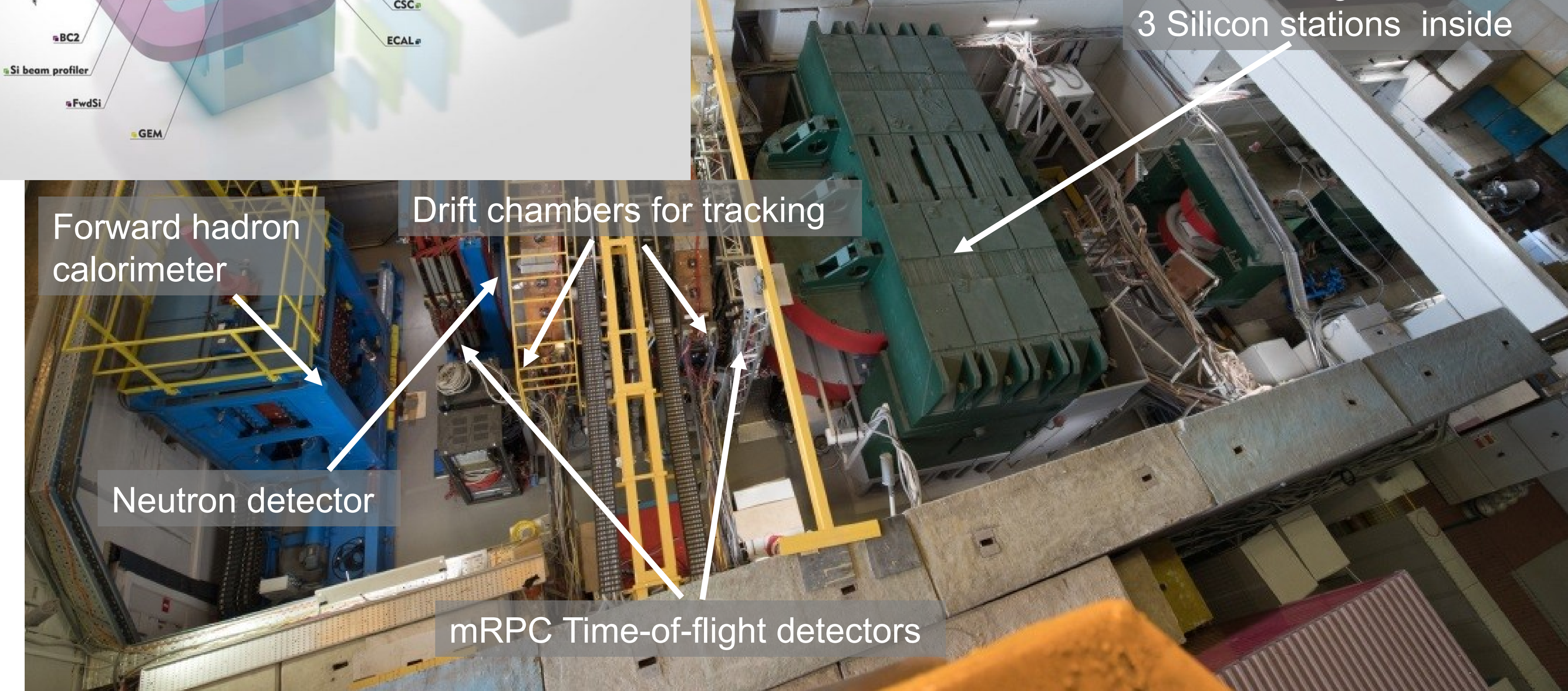


- **Year 2023:**
  - Initial run of NICA with Bi+Bi @ 9.2 AGeV (other energies a second priority)
  - Goal to reach luminosity of 10^{25} cm^{-2}s^{-1}
- **Year 2024:**
  - Goal to have Au+Au collisions and acceleration in NICA (up to 11 AGeV)
- **Beyond 2024:**
  - Maximizing luminosity, possibility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

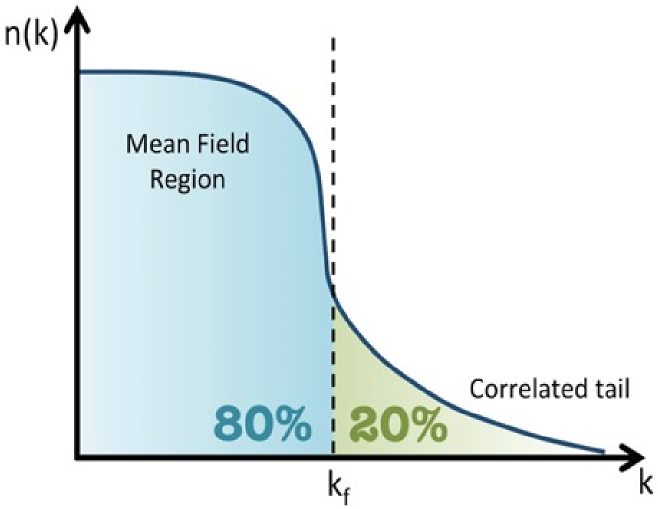
First physics from BM@N at NICA

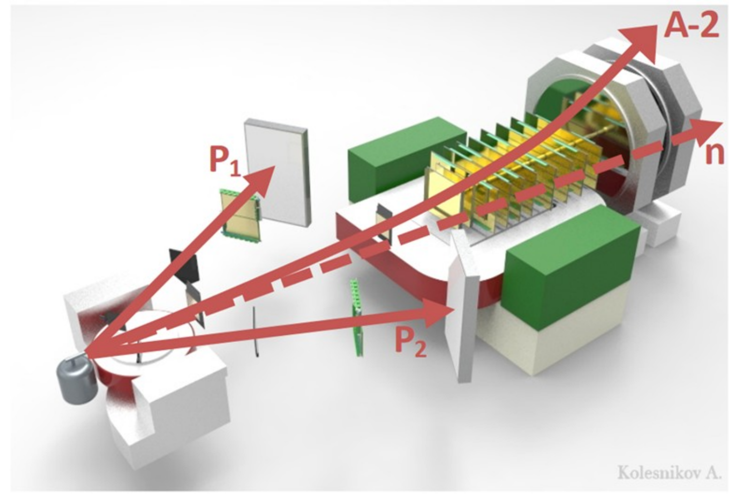


Baryonic Matter @ Nuclotron (BM@N)
10 countries, 20 institutions,
246 participants



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





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

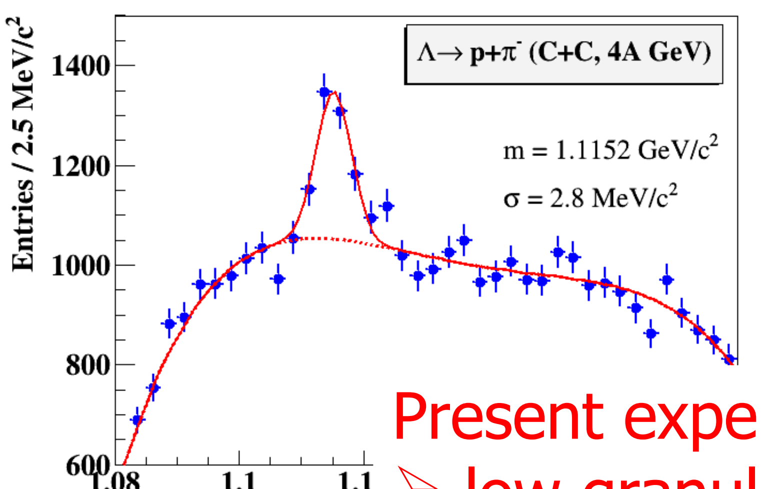
$^{12}C + p \rightarrow 2p + {}^{10}{}_{4}Be + p$ (pp SRC)

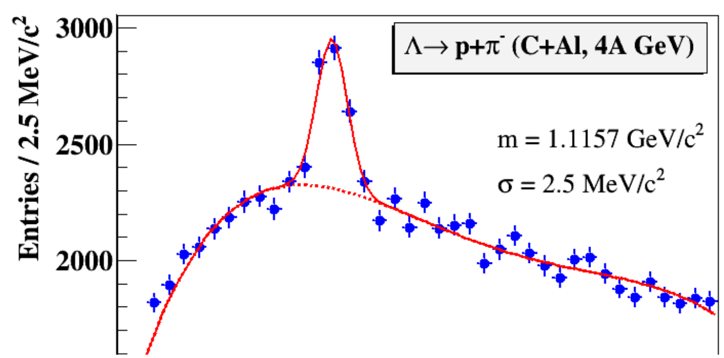
First fully exclusive measurement in inverse kinematics probing the residual A-2 nuclear system!

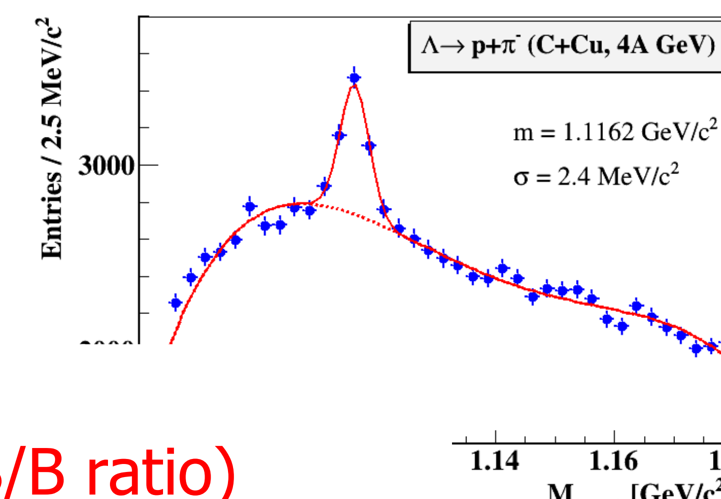
M. Patsyuk et al., arXiv:2102.02626

Accepted for publication in **nature physics**

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



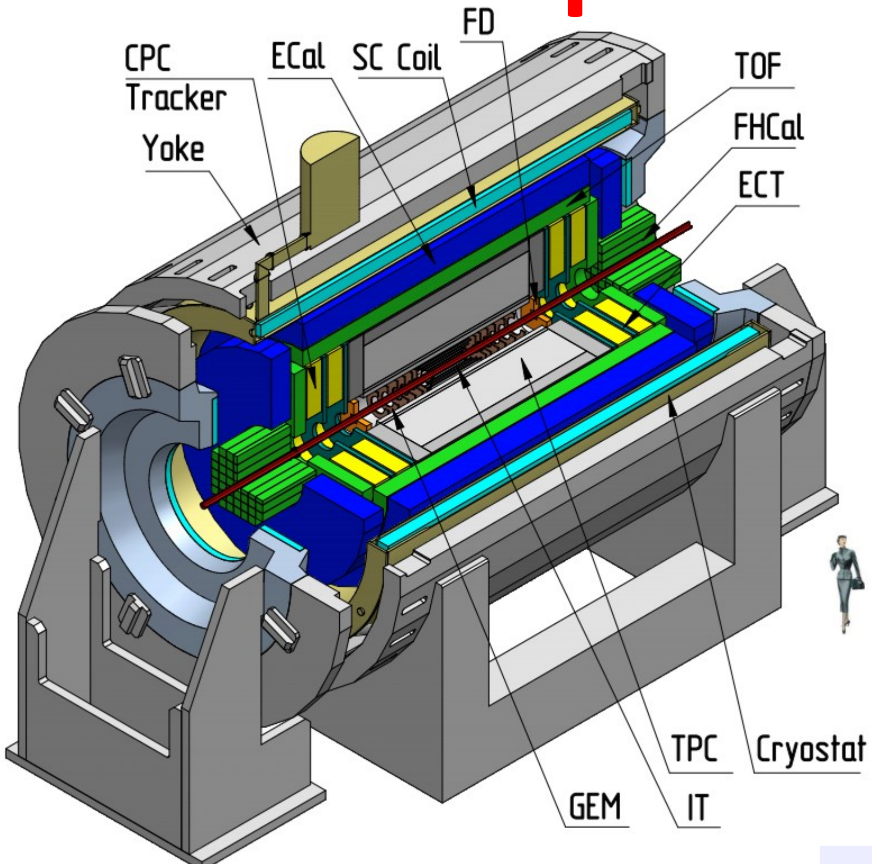




Present experimental limitations:

- 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

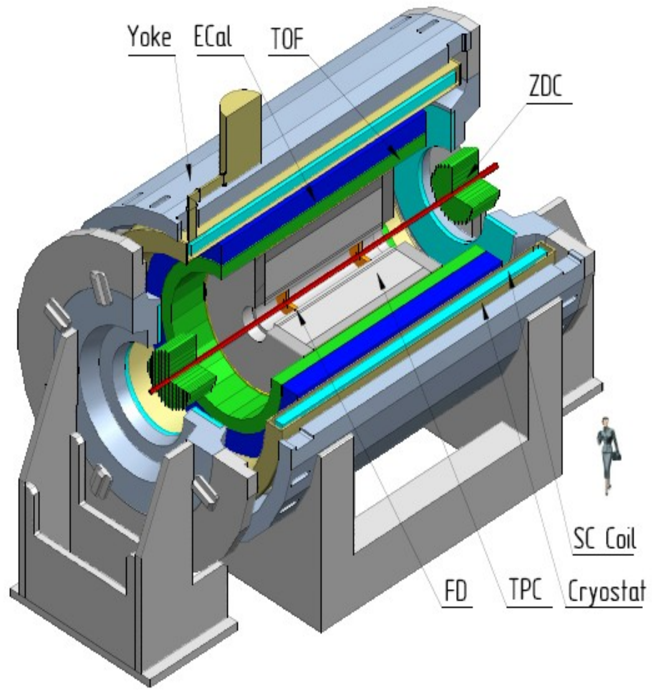


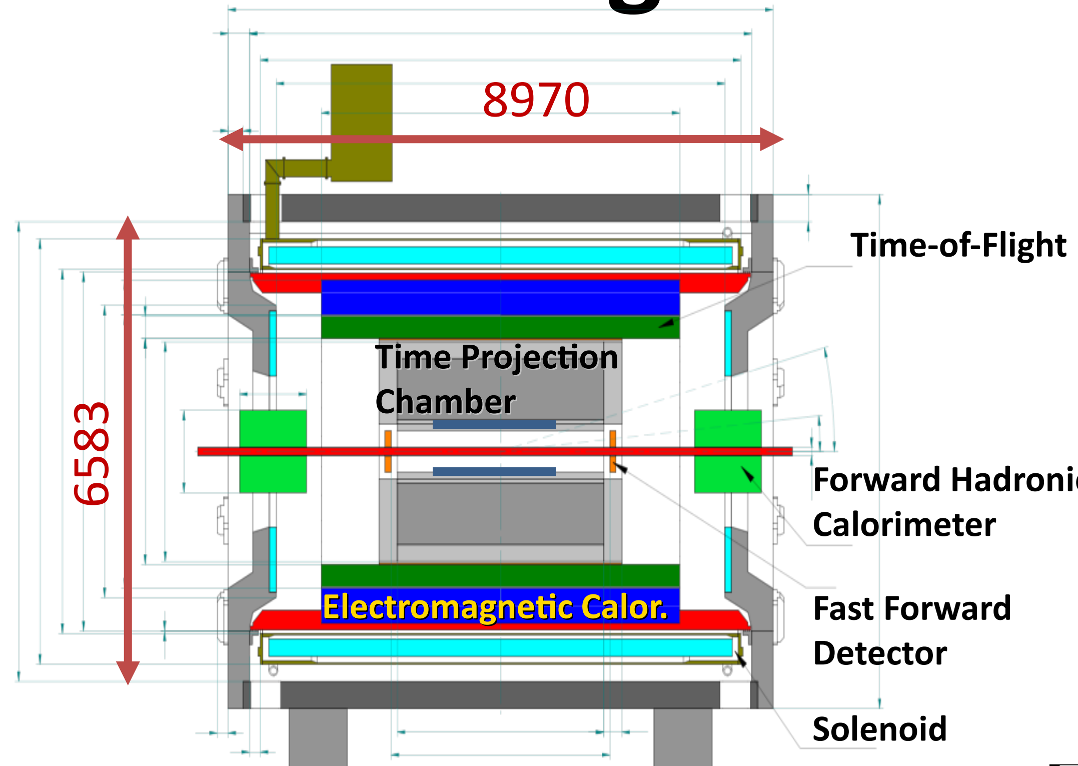
*Three Gorges University, **China**;*
*Institute of Modern Physics, CAS, Lanzhou, **China**;*
*Palacky University, Olomouc, **Czech Republic**;*
*NPI CAS, Rez, **Czech Republic**;*
*Tbilisi State University, Tbilisi, **Georgia**;*
***Joint Institute for Nuclear Research**;*
*FCFM-BUAP Puebla, **Mexico**;*
*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, **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**;*
*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**;*

*AANL, Yerevan, **Armenia;***
*Baku State University, NNRC, **Azerbaijan**;*
*University of Plovdiv, **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, Shandong, **China**;*
*IHEP, Beijing, **China**;*
*University of South China, **China**;*

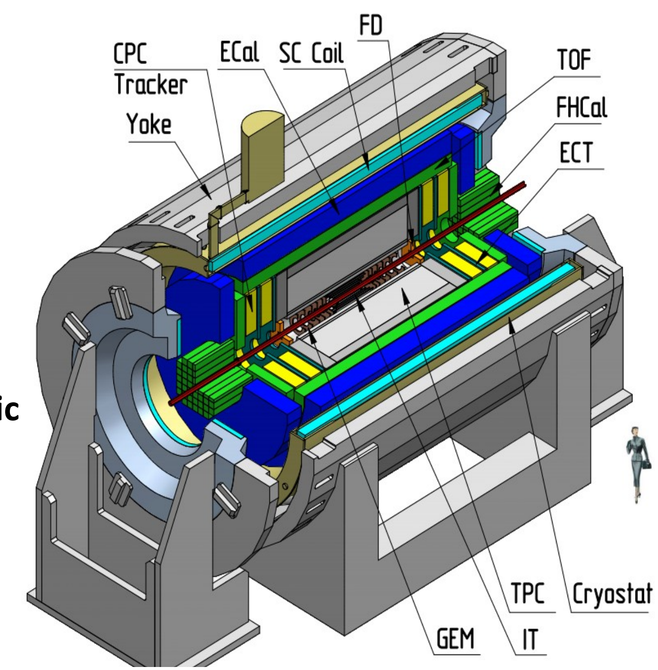
***12** Countries, **>500** participants,*
42** Institutes and **JINR

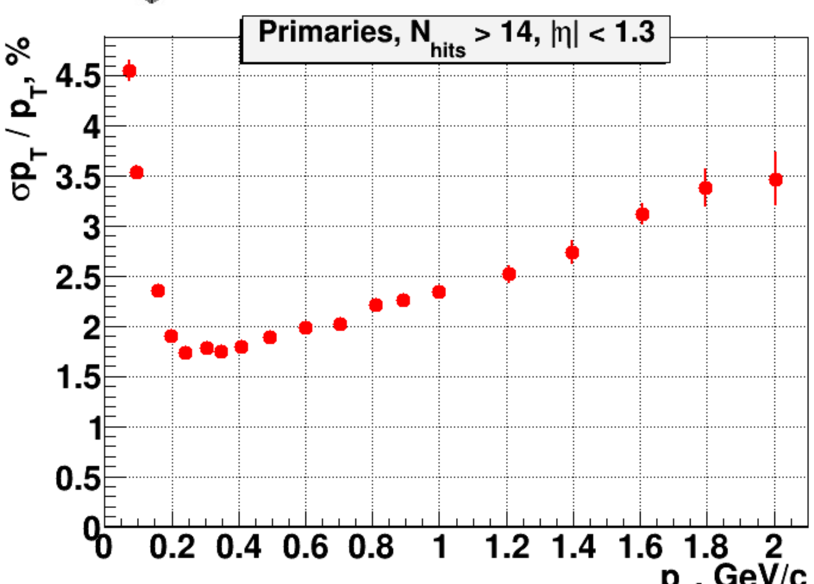
MPD - stage I and II



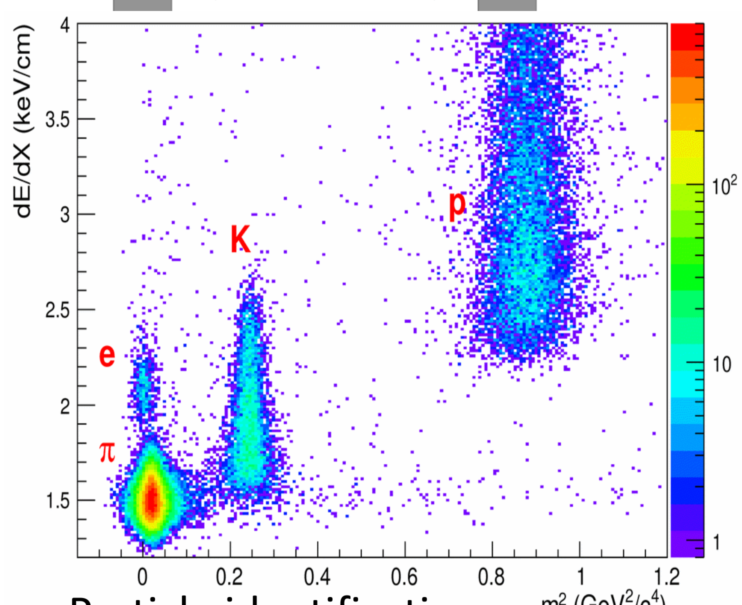


MPD - Stage II

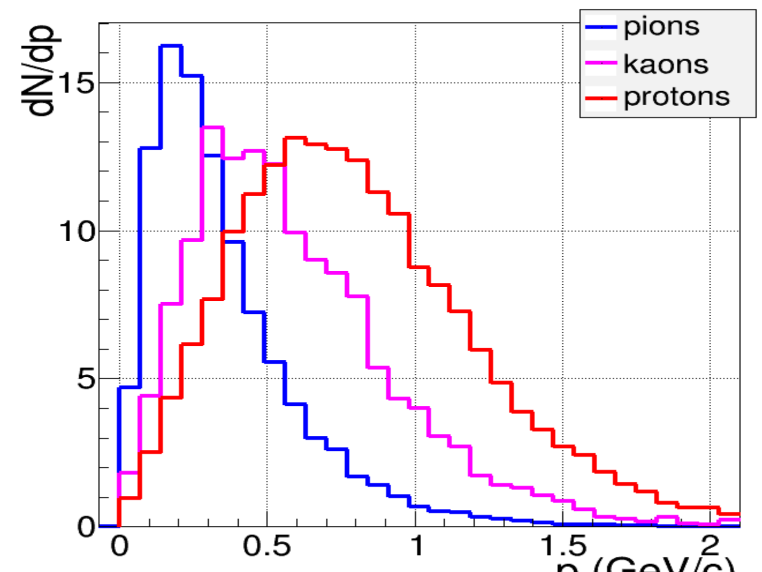




Momentum resolution with TPC



Particle identification

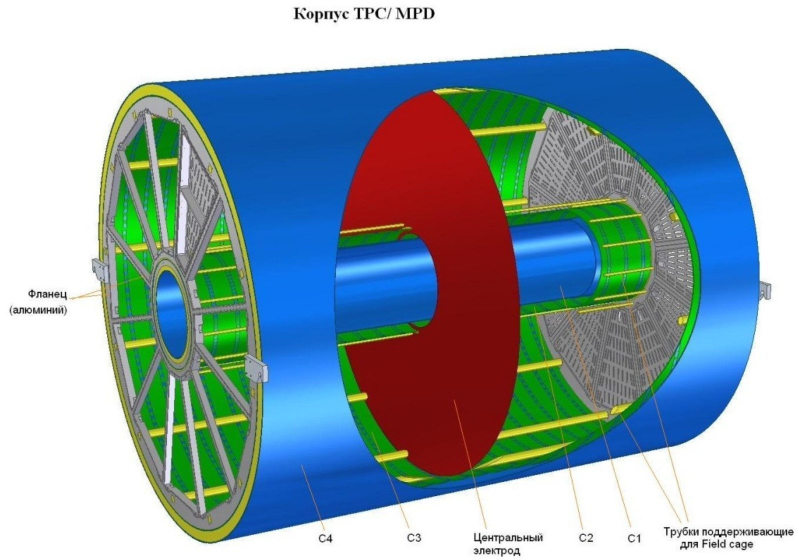


Momentum dist. of secondary particles

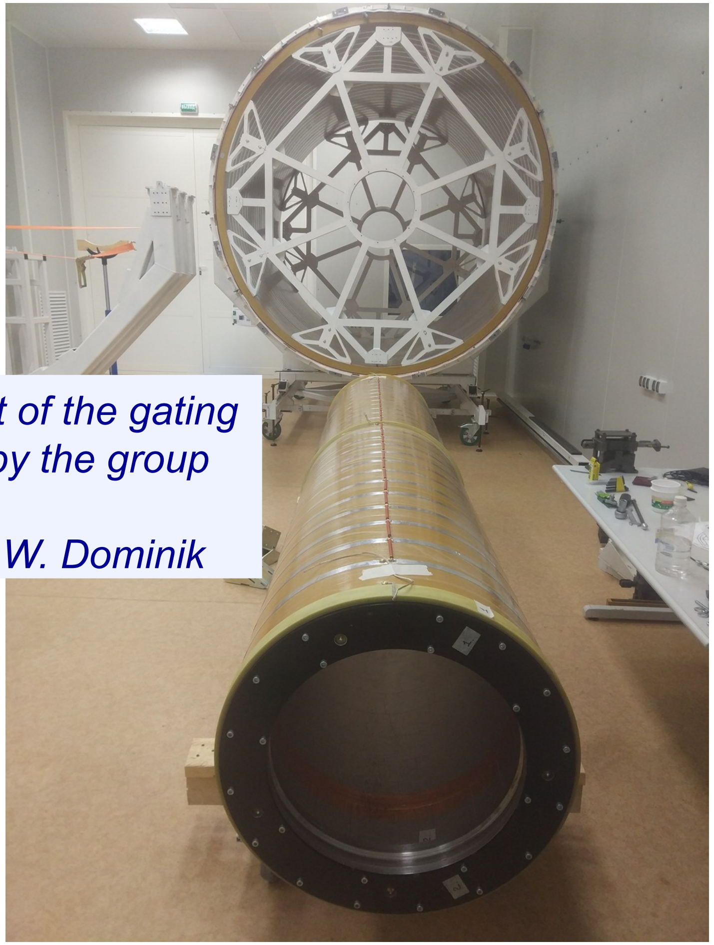
Interior of MPD Hall

Opening of solenoid sarcophagus: Mar. 23rd

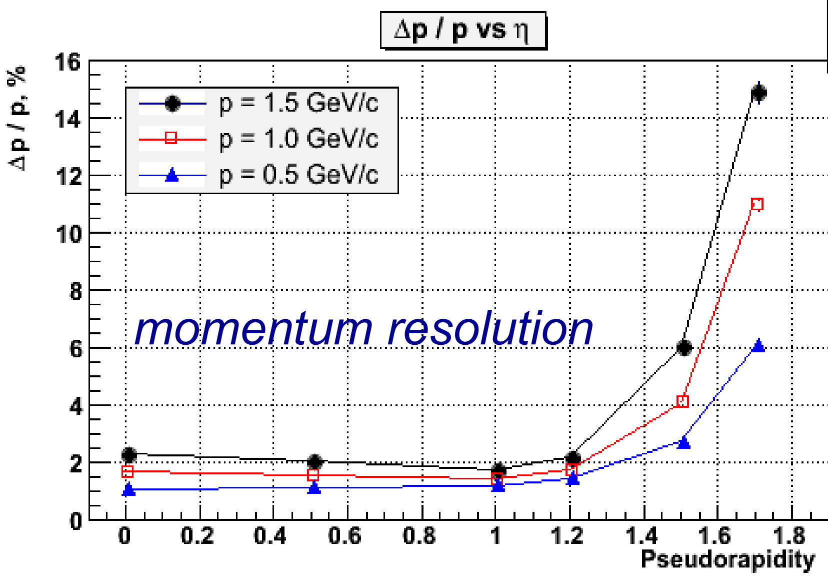
NICA Time Projection Chamber (TPC): main tracker

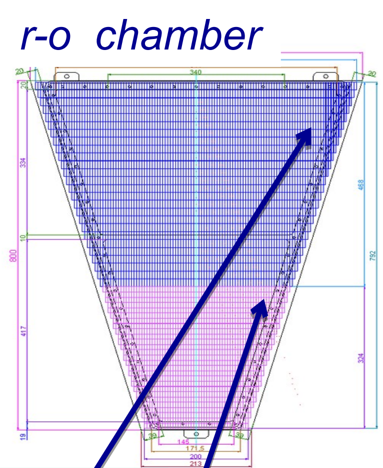


length	*340 см*
outer Radii	*140 см*
inner Radii	*27 см*
gas	*90%Ar+10%CH_4*
drift velocity	*5.45 см / μs;*
drift time	*< 30 μs;*
# R-O chamb.	*12 + 12*
# pads/ chan.	***95 232***
max rate	*< 7kGz (L= 10^{27})*



Development of the gating grid system by the group from UW, lead by prof. W. Dominik





21 (out of 24+2) Read-Out Chambers (ROCs) are ready and tested (production at JINR)
113 Electronics sets (8%) produced
Two sites (Moscow, Minsk) tested for electronics production
C1-C2 and C3-C4 cylinders assembled
TPC flange under finalization

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

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

NICA

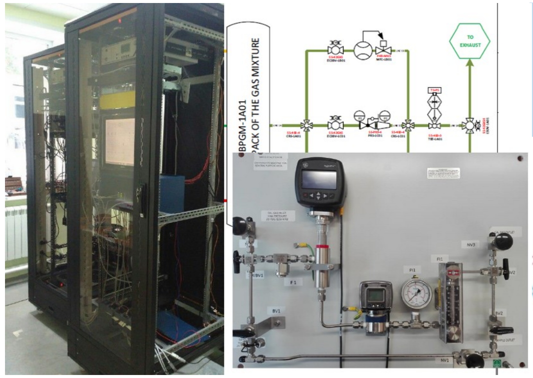
MPD Time-of-Flight

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.

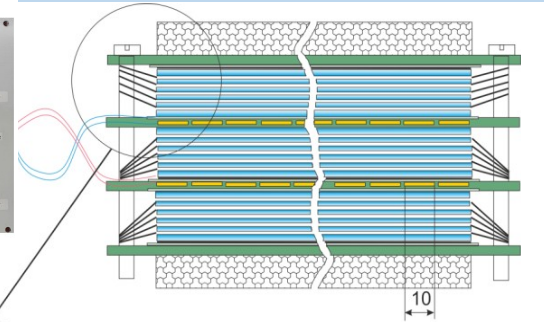
Glass cleaning with ultrasonic wave & deionized water

Automatic painting of the conductive layer on the glass



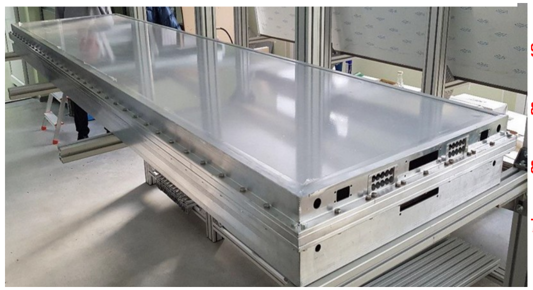
TOF gas system: Responsibility of the Polish group (WUT)

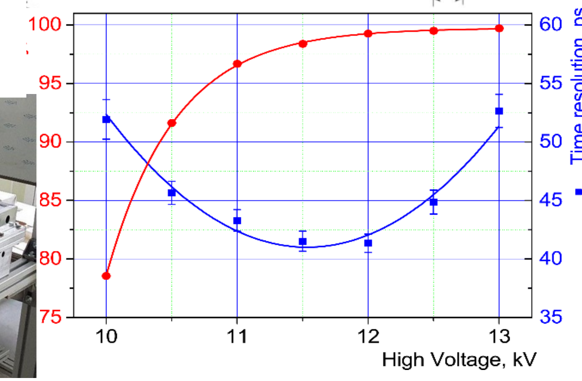
Dimensions of sensitive area 600 x300 mm²



MRPC assembling

Soldering HV connector and readout pins





	Number of detectors	Number of readout strips	Sensitive area, m²	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)

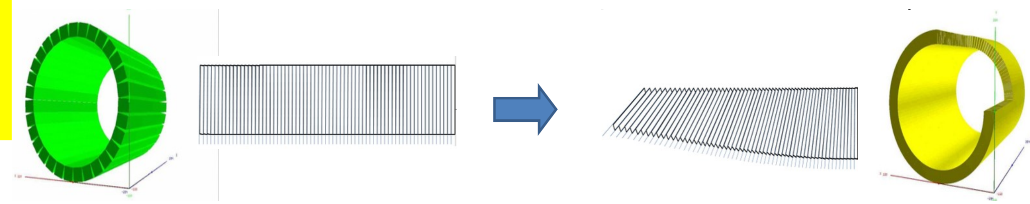
Single detector time resolution: 50ps

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

Electromagnetic Calorimeter (ECAL)

- *Pb+Sc "Shashlyk"* — *read-out: WLS fibers + MAPD* — *L ~35 cm (~ 14 X_0)*
- *Segmentation (4x4 cm²)* — *σ(E) better than 5% @ 1 GeV* — *time resolution ~500 ps*

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



Projective geometry

So far ~300 modules (16 towers each) = 3 sectors are produced
Another 3 sectors are planned to be completed by May 2021
Chinese collaborators will produce 8 sectors by the end of 2021
25% of all modules are produced by JINR (production area in Protvino)
75% produced in China, currently funding is secured for approx. 25%

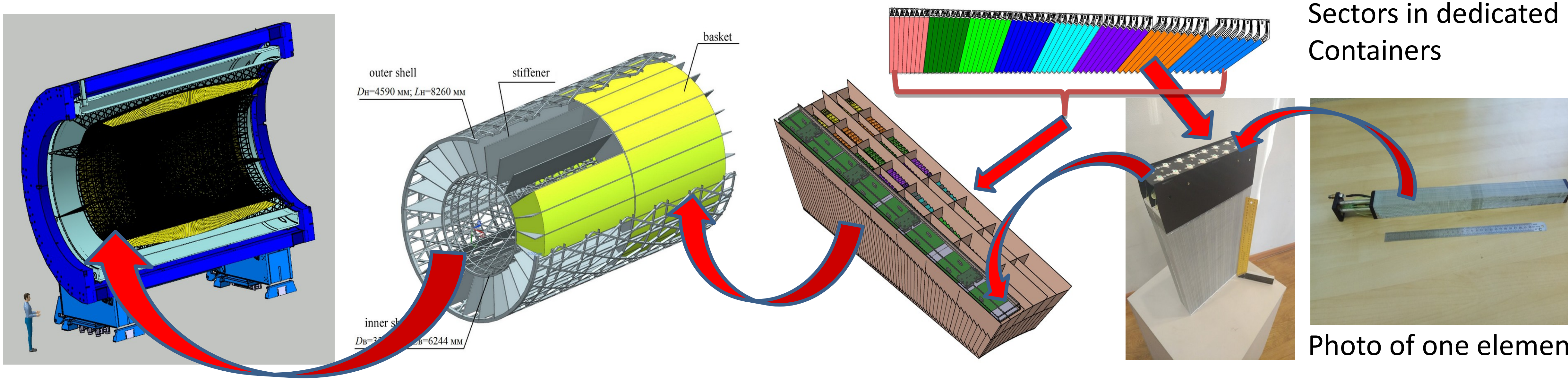


Photo of one element

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

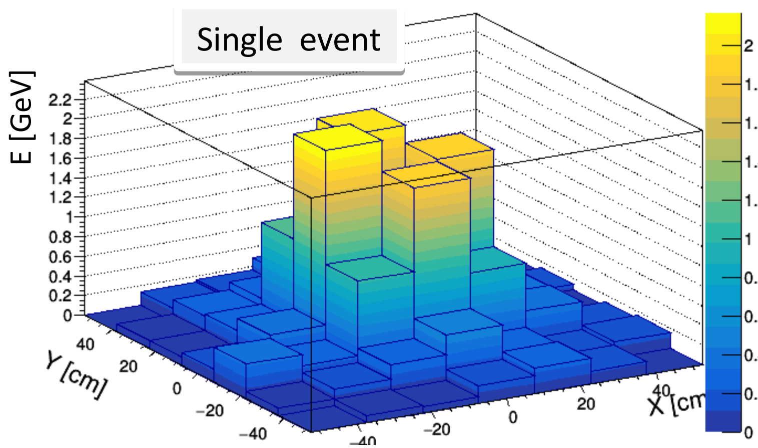
Wangmei Zha, A. Zinchenko

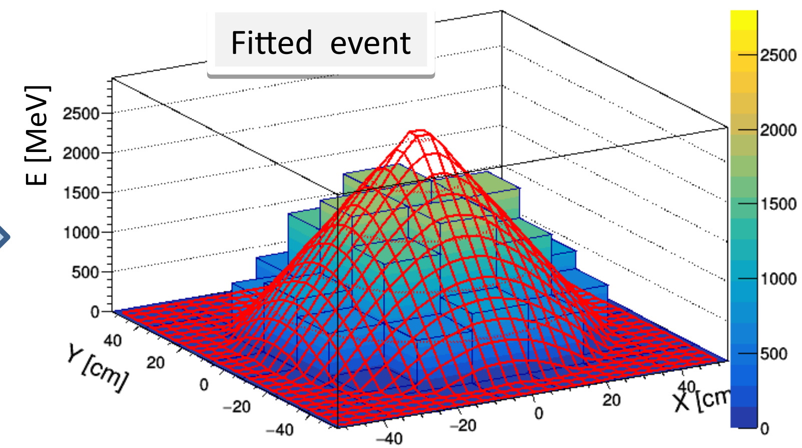
Heavy flavor

- 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

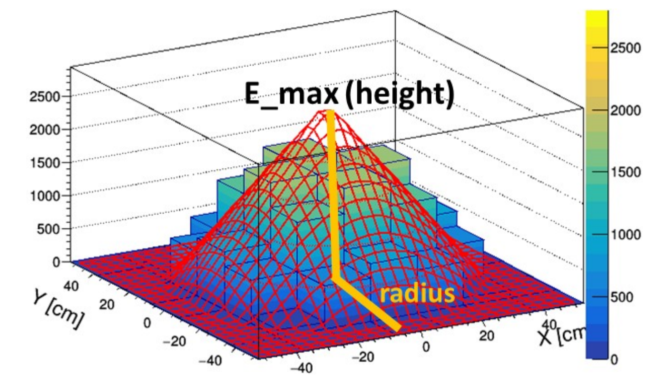
Centrality and reaction plane in FHCal

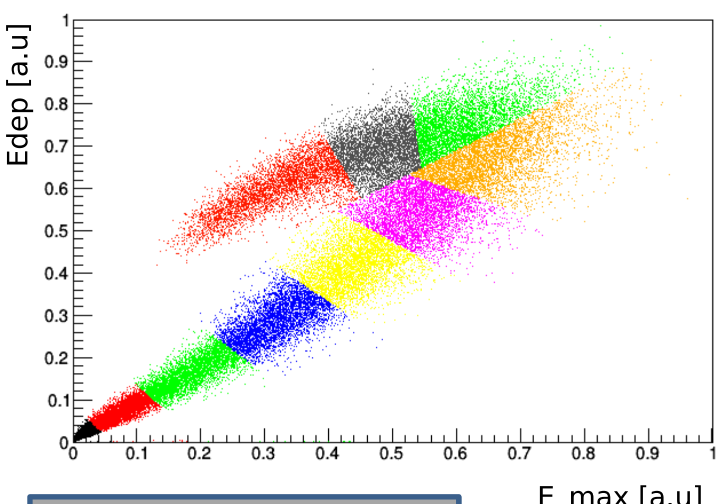
Energy distribution in FHCal modules



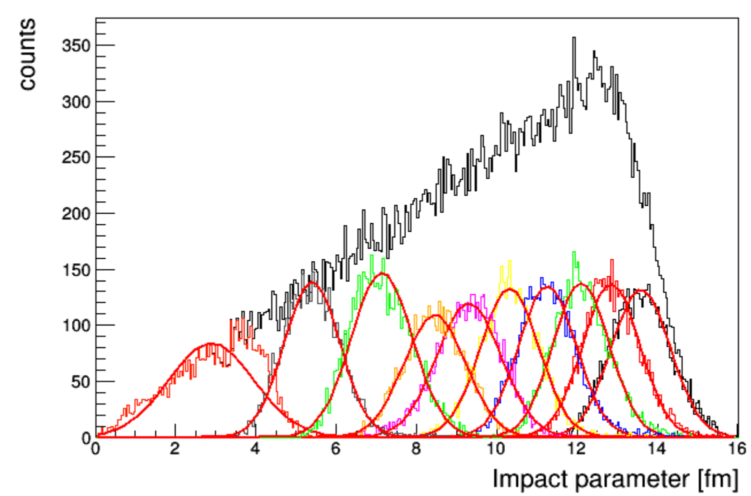


Initially we have experimental energy deposition E_{dep} in FHCal.

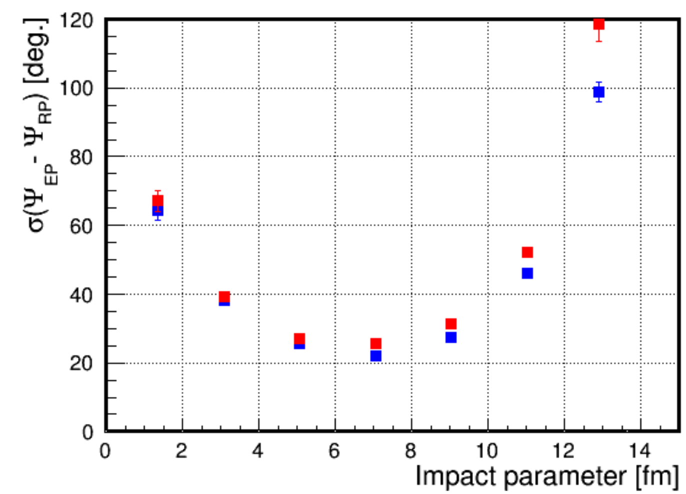




Each color bin is 10% fractions of the total number of events.



Centrality resolution

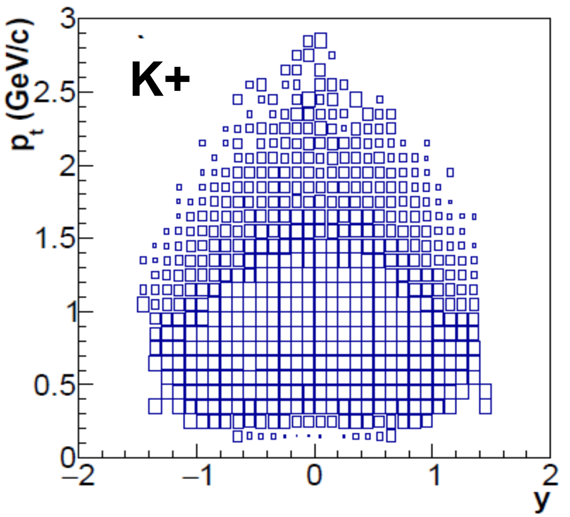


Reaction plane resolution

Hadroproduction with MPD

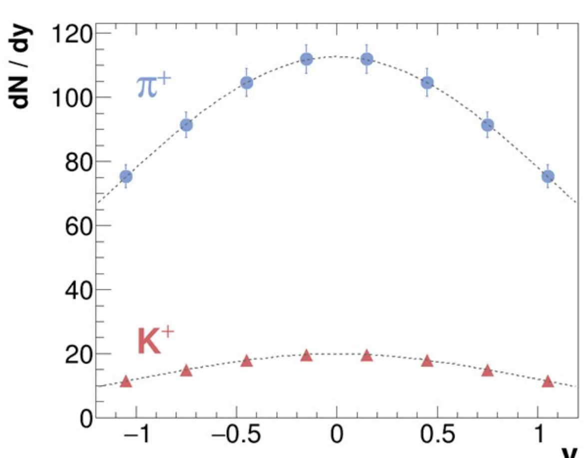
- **Particle spectra, yields & ratios are sensitive to bulk fireball properties and phase transformations in the medium**
- **Uniform acceptance and large phase coverage are crucial for precise mapping of the QCD phase diagram**

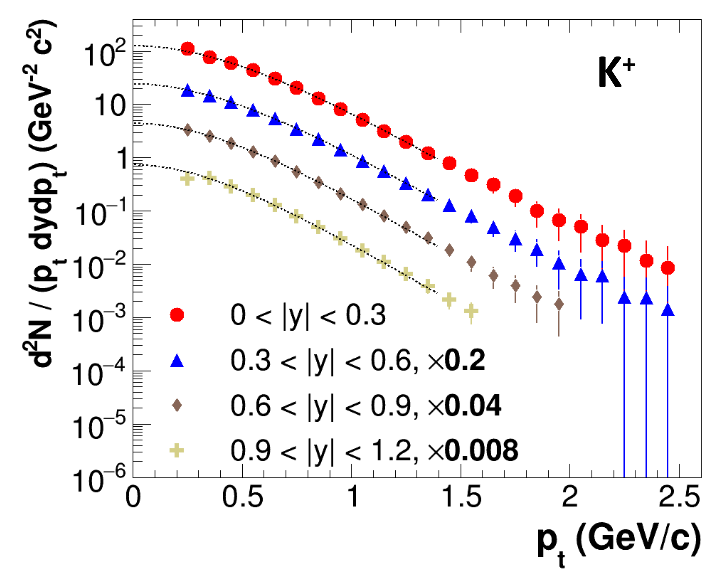
✓ *0-5% central Au+Au at 9 GeV from the PHSD event generator, which implements partonic phase and CSR effects*
✓ *Recent reconstruction chain, combined dE/dx+TOF particle ID, spectra analysis*

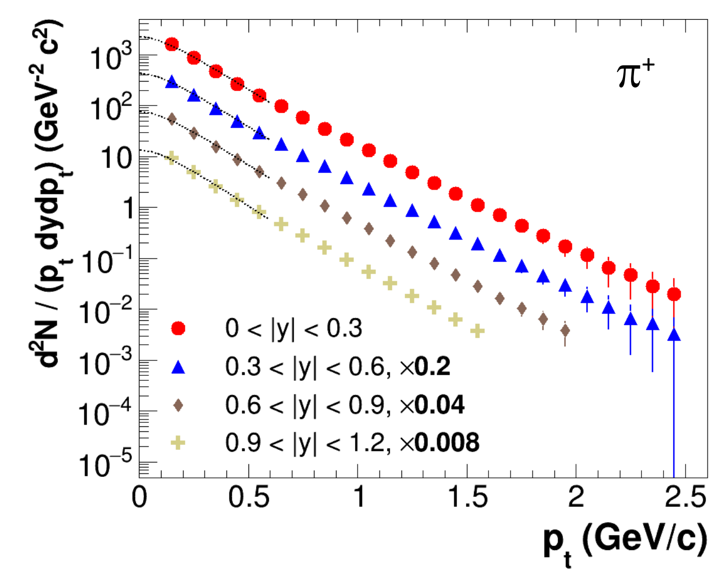


- MPD provides large phase-space coverage for identified pions and kaons (> 70% of the full phasespace at 9 GeV)
- Hadron spectra can be measured from p_T=0.2 to 2.5 GeV/c
- Extrapolation to full p_T-range and to the full phase space can be performed exploiting the spectra shapes (see BW fits for p_T-spectra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

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

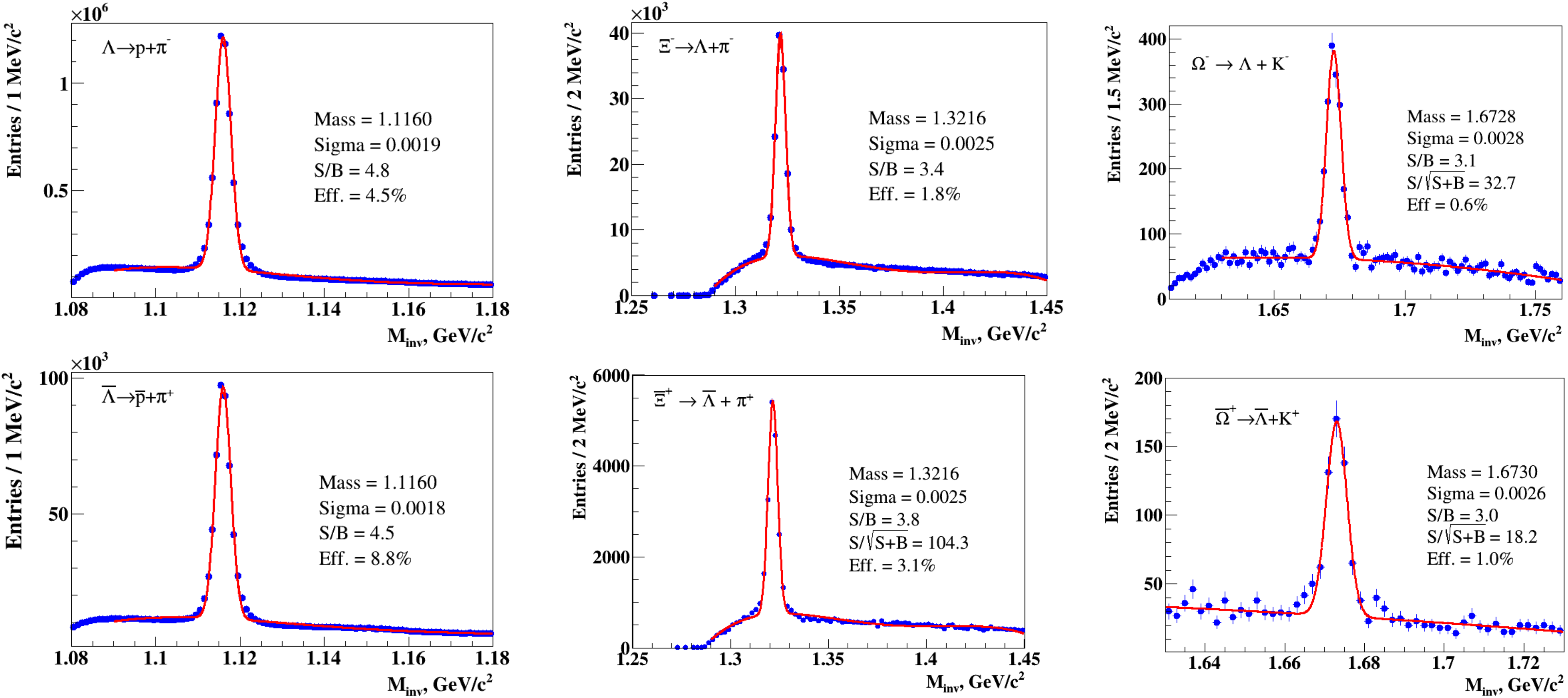






Strange and multi-strange baryons

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

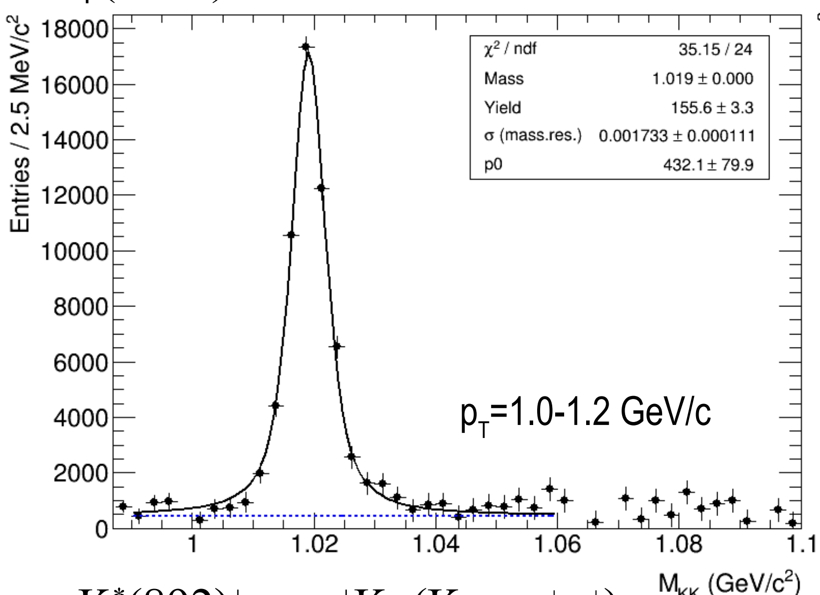


particle	Λ	anti-Λ	Ξ⁻	anti-Ξ⁺	Ω⁻	anti–Ω⁺
yield in 10 weeks	$3\cdot10^8$	$3.5\cdot10^6$	$1.5\cdot10^6$	$8.0\cdot10^4$	$7\cdot10^4$	$1.5\cdot10^4$

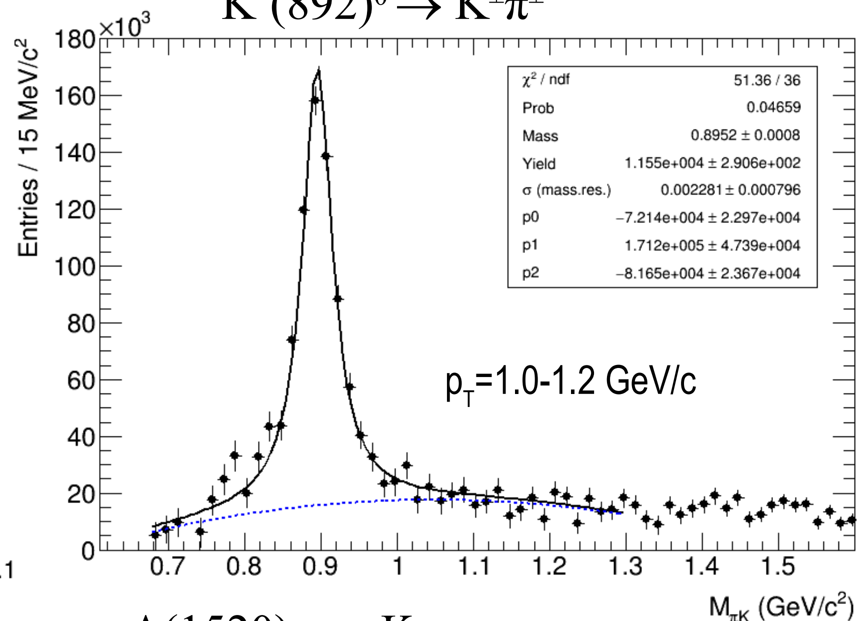
Resonances at MPD

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

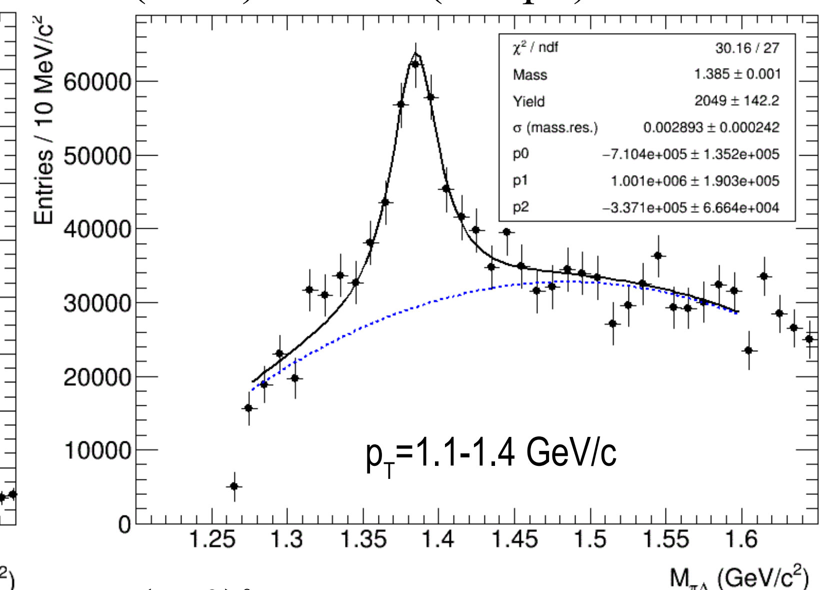
$\phi(1020) \rightarrow K^+K^-$



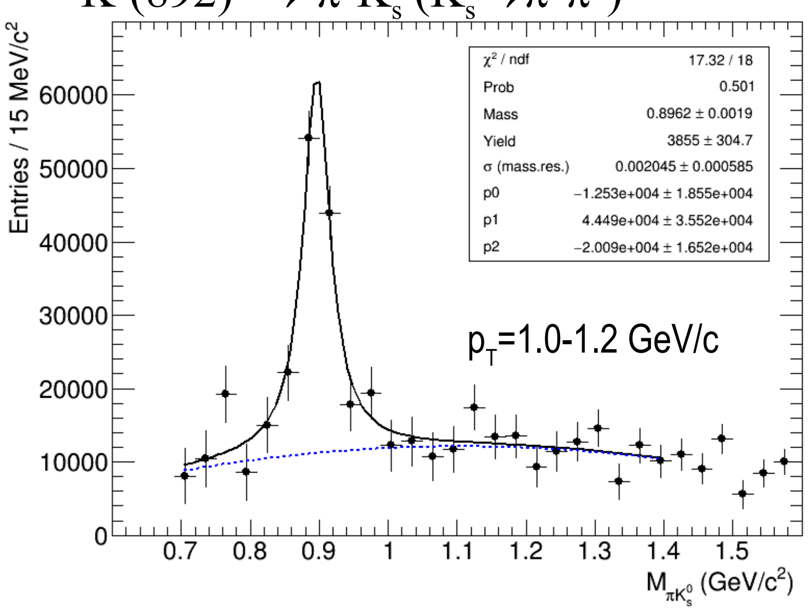
$K^*(892)^0 \rightarrow K^\pm\pi^\pm$



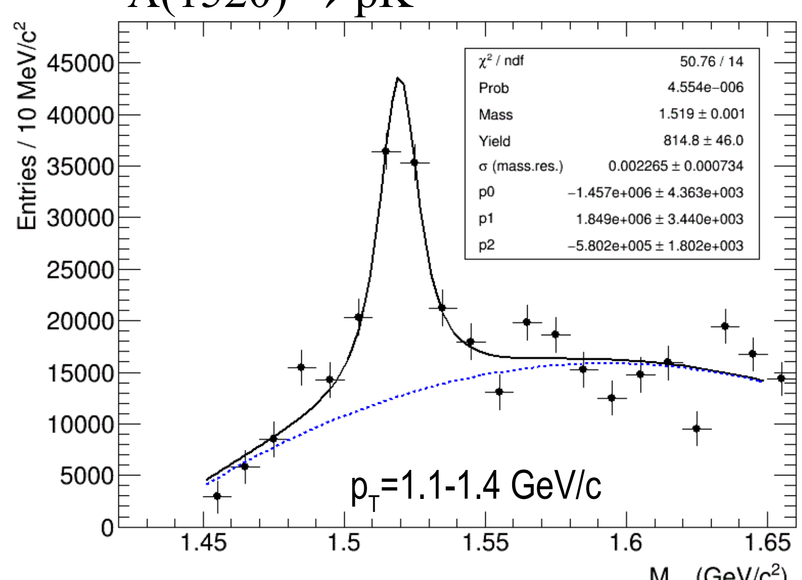
$\Sigma(1385)^\pm \rightarrow \pi^\pm\Lambda\ (\Lambda \rightarrow p\pi)$



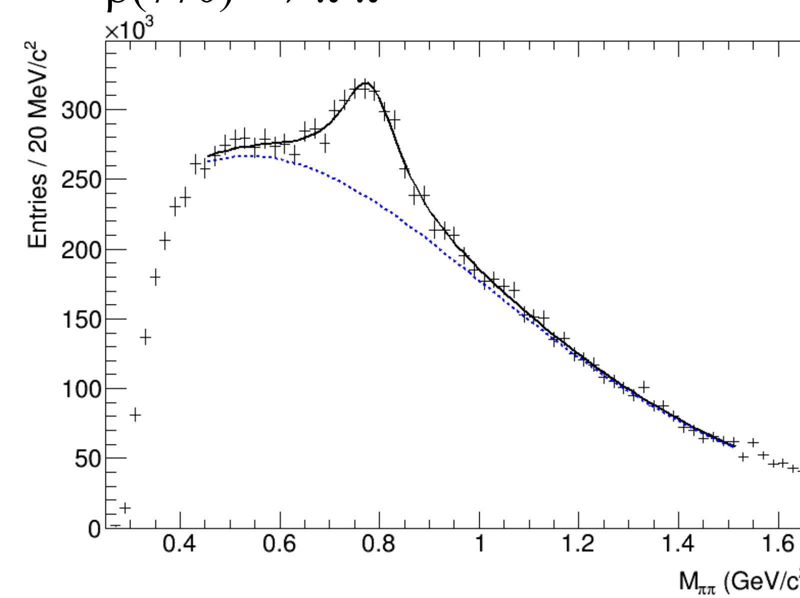
$K^*(892)^\pm \rightarrow \pi^\pm K_s\ (K_s \rightarrow \pi^+\pi^+)$



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

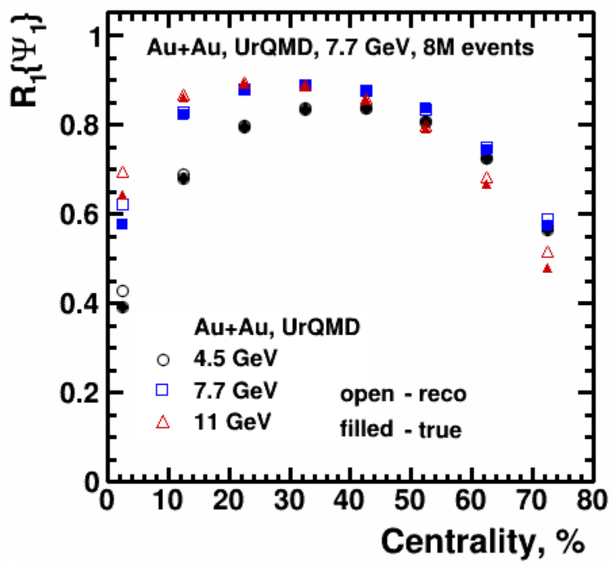


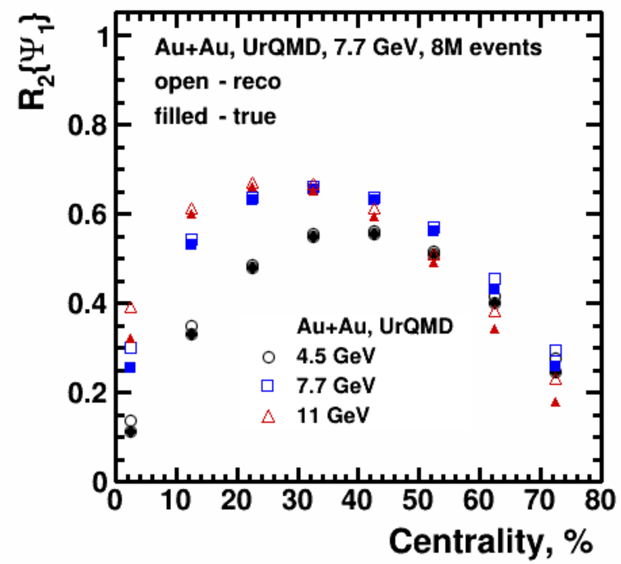
$\rho(770)^0 \rightarrow \pi^\pm\pi^\pm$

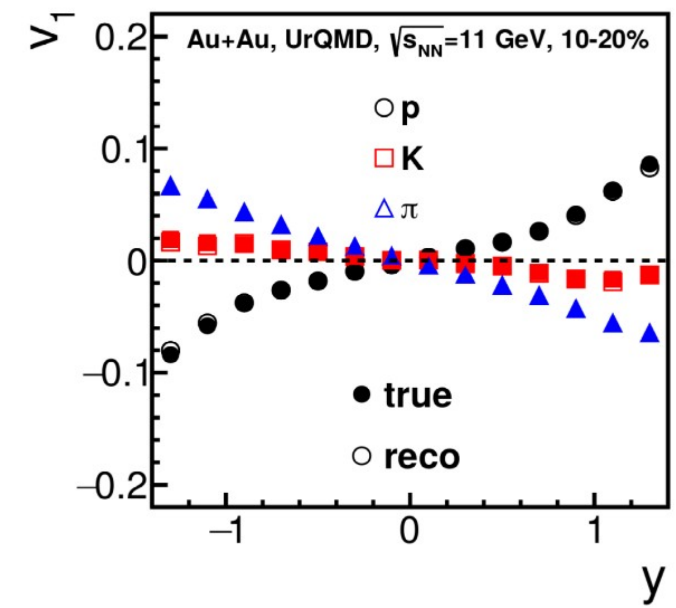


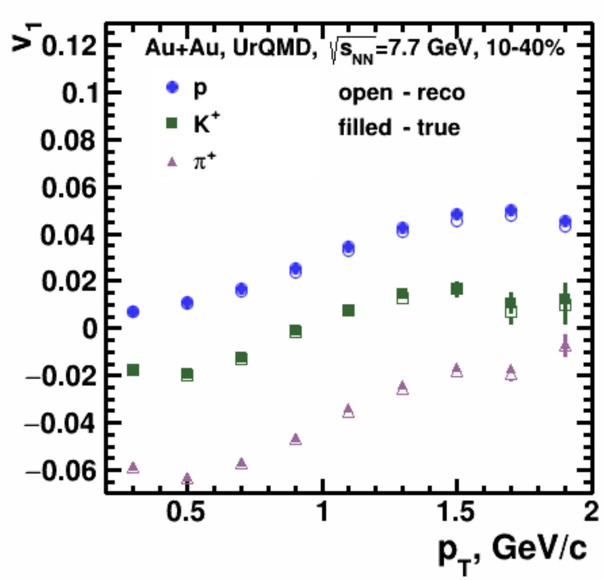
Performance of collective flow studies

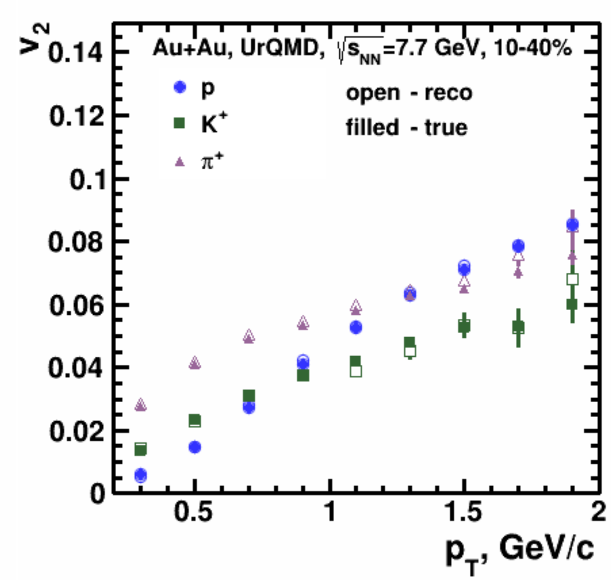
Au+Au, $\sqrt{s_{NN}}$ = 7.7, 11 GeV, UrQMD, GEANT3 + MPDRoot reco.

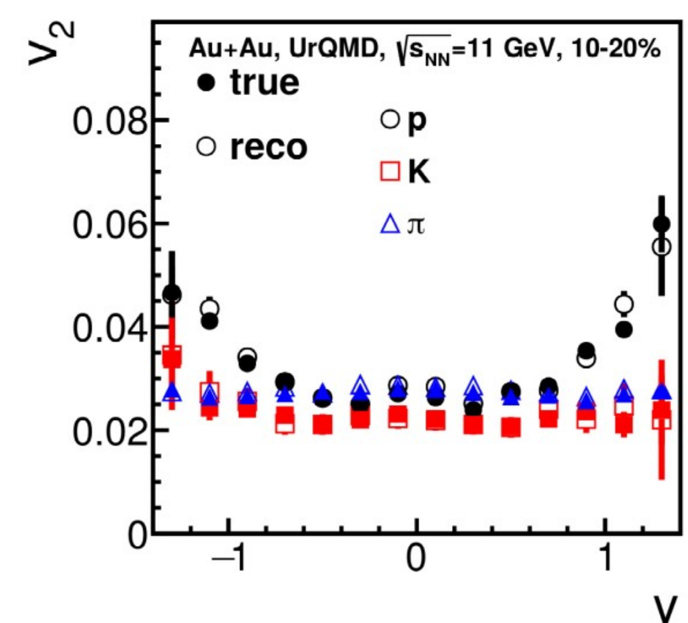








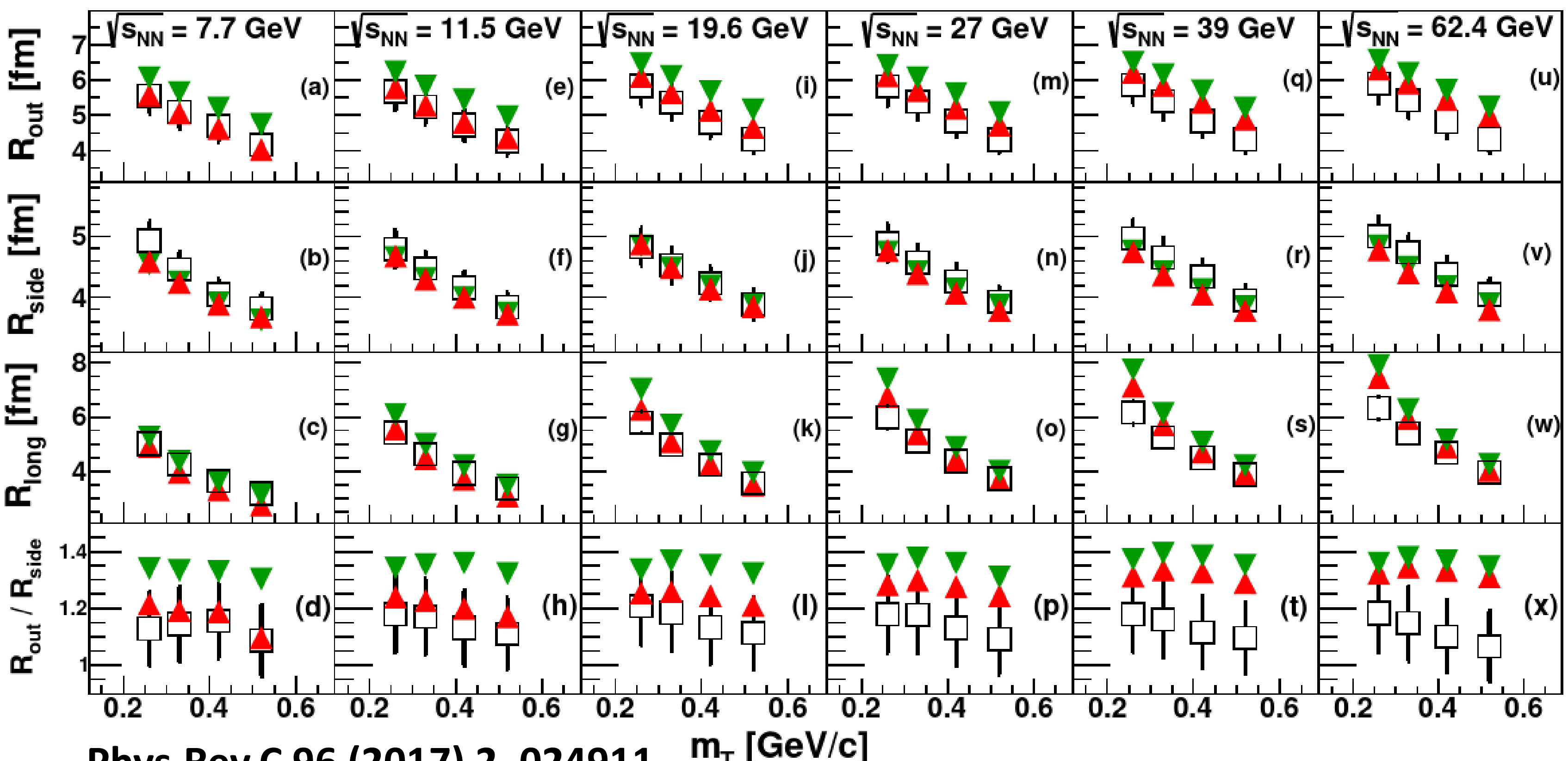




Collective flows a unique and direct way to probe EOS of QCD matter. Excellent flow measurement capabilities in MPD

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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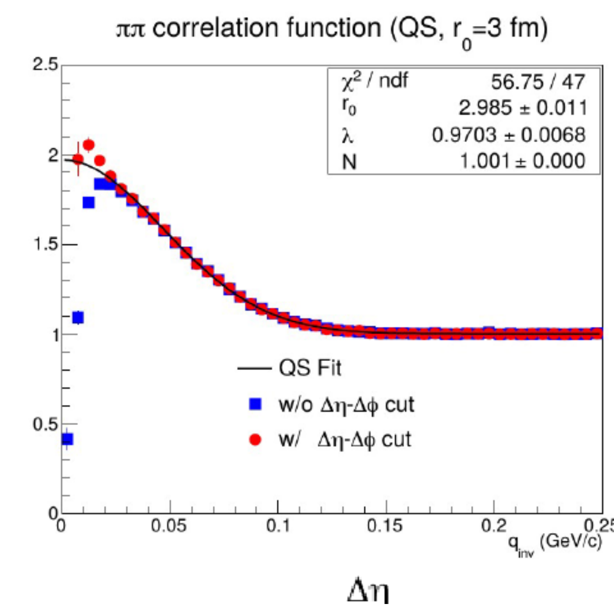
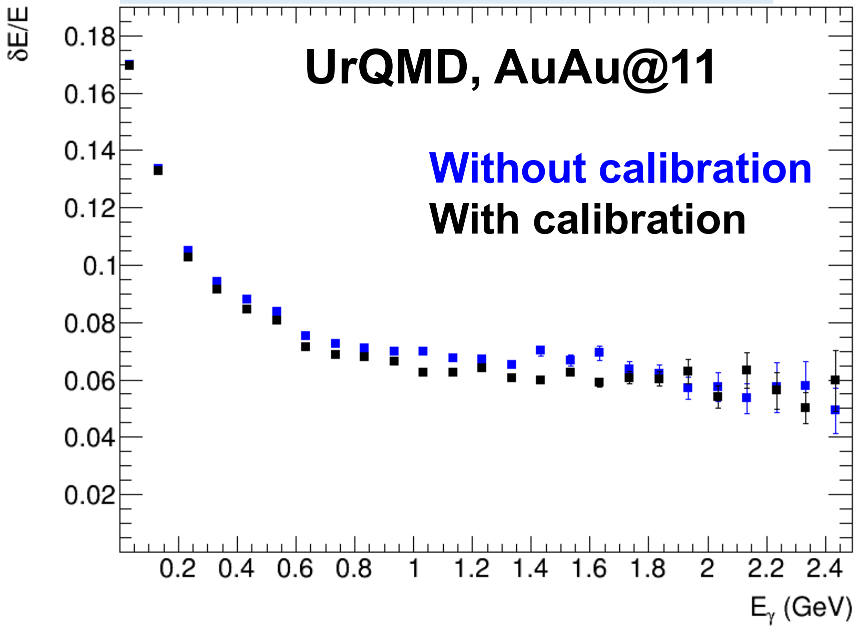
1st order phase transition
cross-over transition



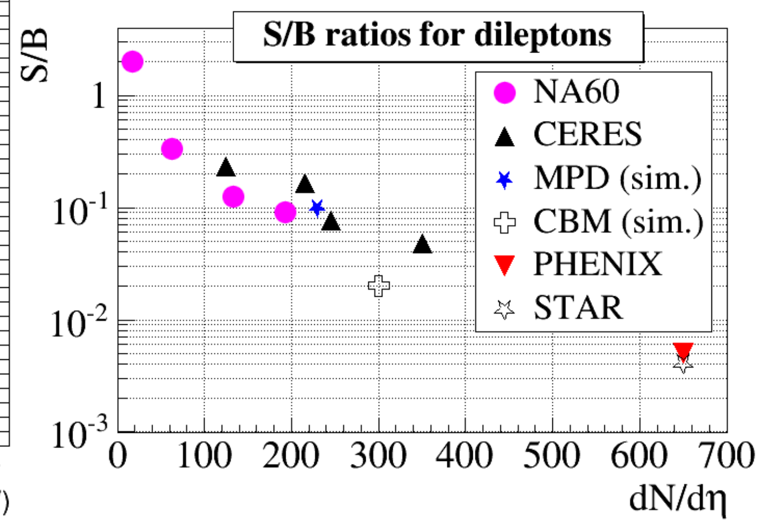
- Clear sensitivity of pion source size to the nature of the phase transitions
- Important and sensitive cross-check of detector performance (two-track resolution)

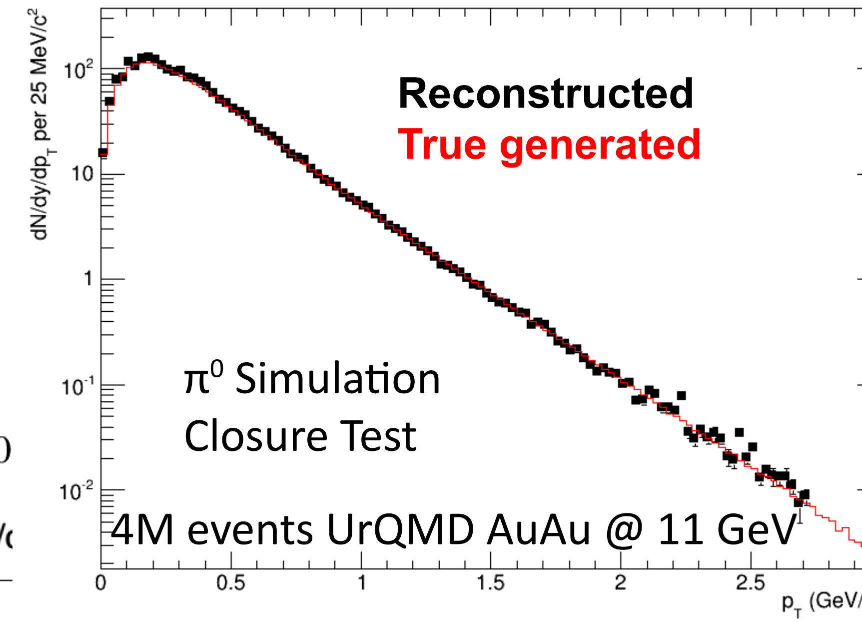
Electromagnetic probes in ECAL

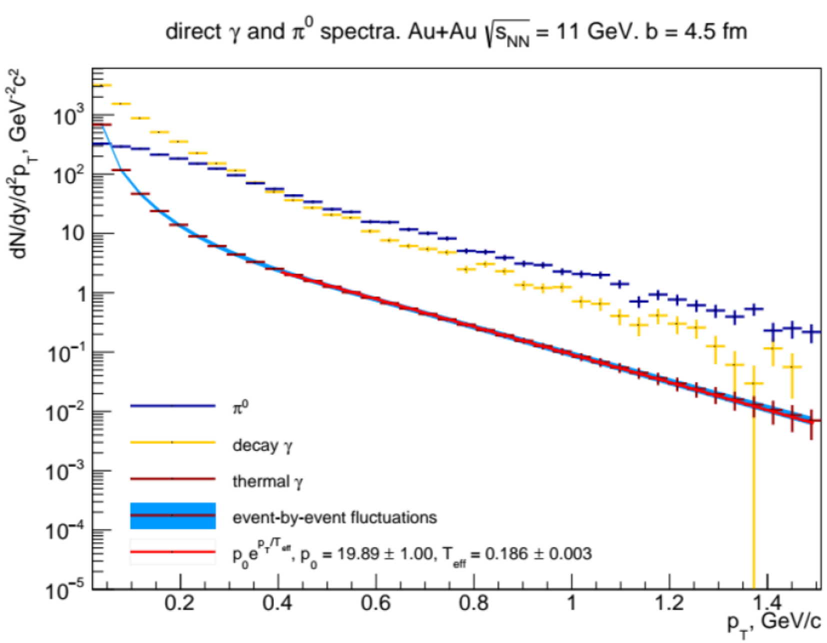
Photon energy resolution

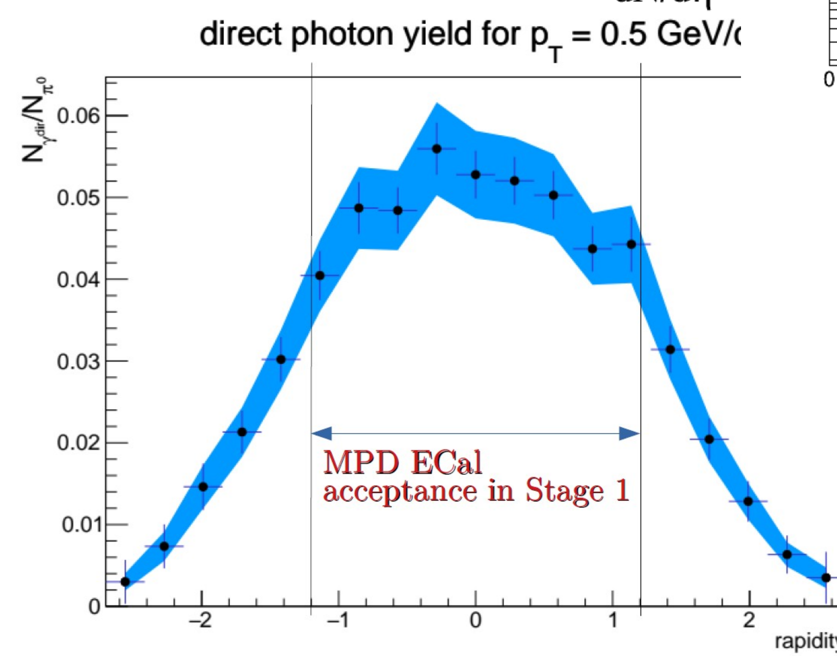


- Realistic ECAL reconstruction & analysis – large acceptance ECAL with good energy resolution: ideal tool for measurement of neutral mesons in a wide momentum range









- Promising feasibility studies for prompt photon measurements in MPD

Summary

- The NICA Accelerator Complex in construction with important milestones achieved and clear plans for 2021 and 2022
- All components of the MPD 1st stage detector advanced in production, commissioning expected for 2021 and 2022
- Intensive preparations for the MPD Physics programme with initial beams at NICA