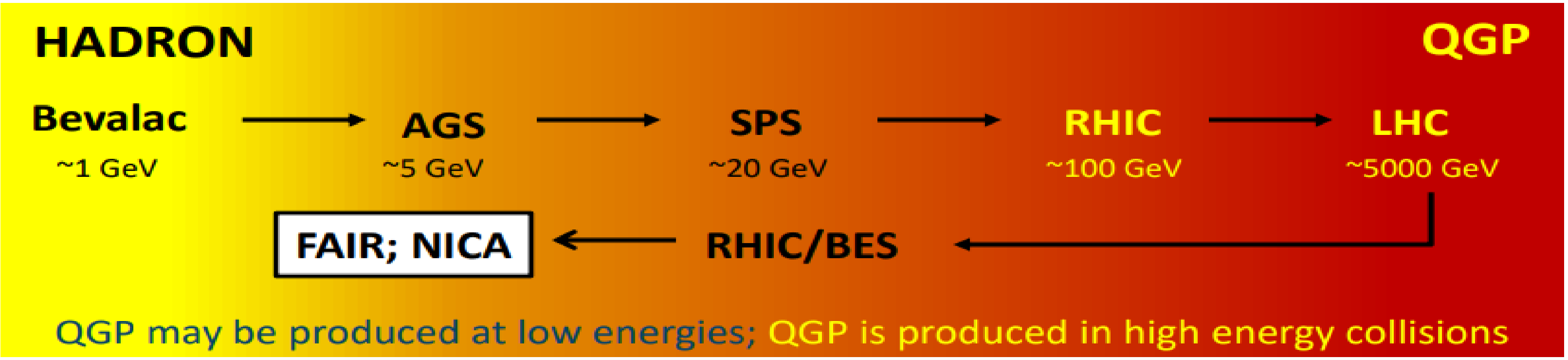
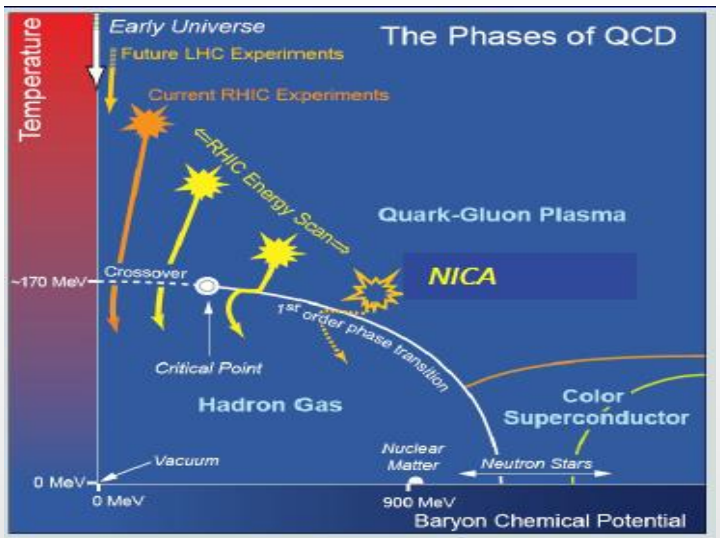
Nuclotron based Ion Colider fAcility

Current status of the MPD@NICA Project

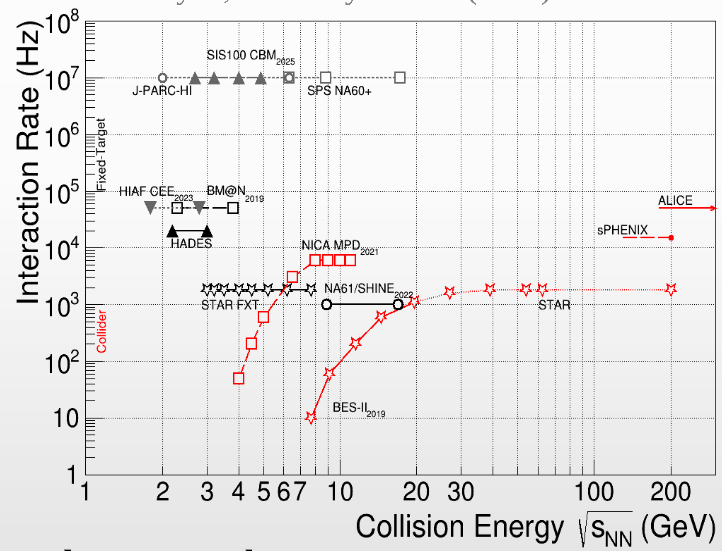
Mikhail Malaev

Introduction



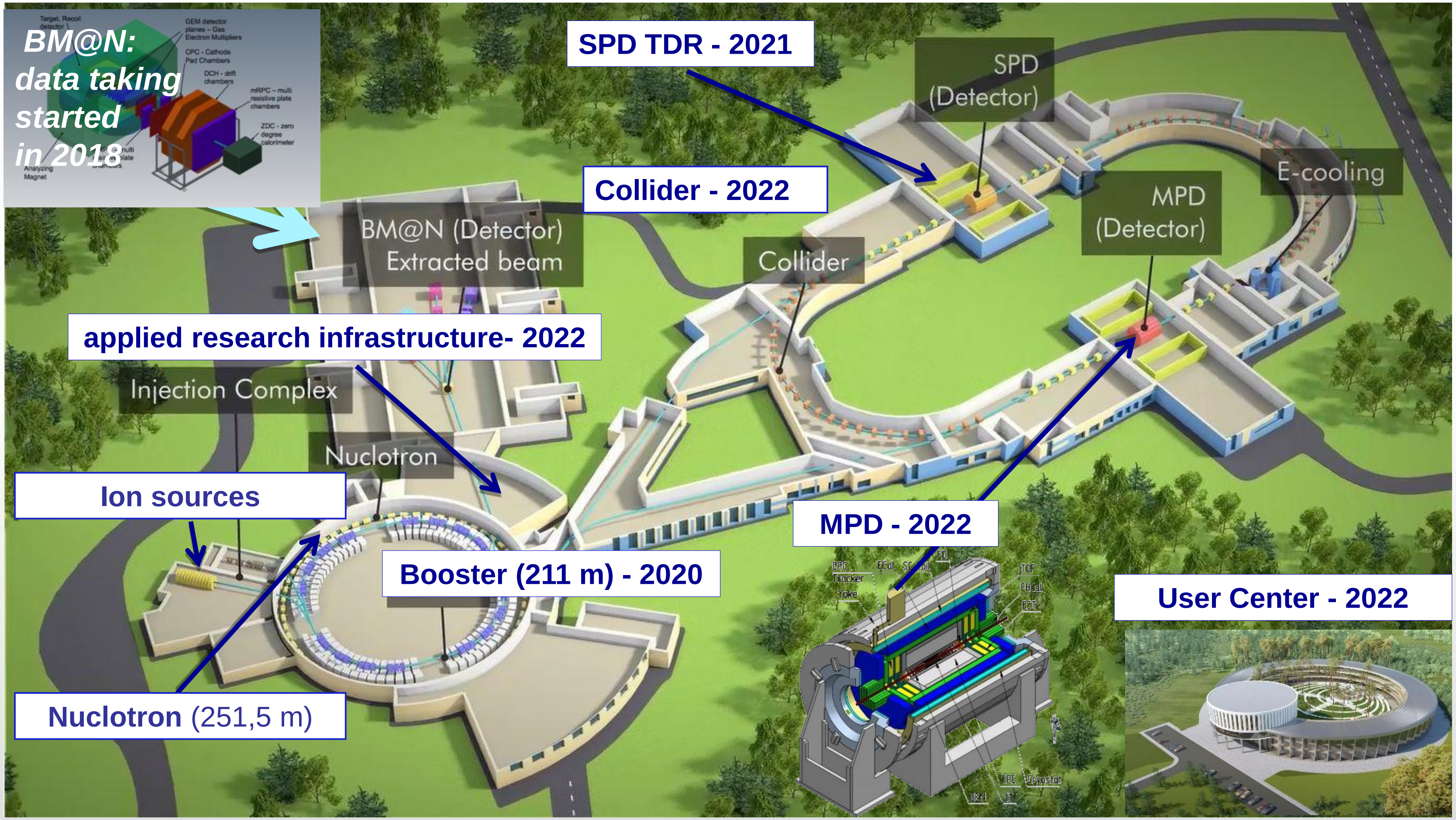


T. Galatyuk, Nucl.Phys. A982 (2019)



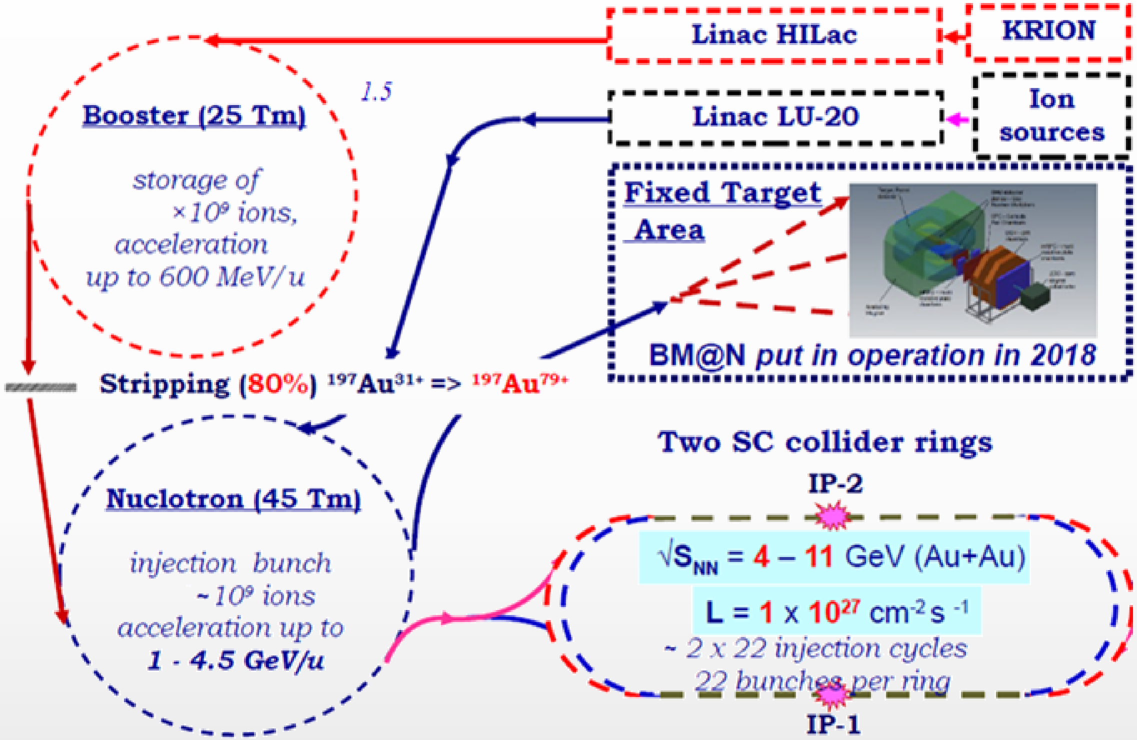
- ❖ Study of the QCD medium at extreme net baryon densities, phase transition at $\rho_c \sim 5\rho_0$
- ❖ Studied in several ongoing and future experiments:
  - ✓ collider experiments: maximum phase space, minimally biased acceptance, free of target parasitic effects
  - ✓ fixed-target experiments: high rate of interactions, easily upgradeable, better vertex-finder for heavy flavor decays

Accelerator Complex in Dubna



- ❖ Budget ~ 500 M$
- ❖ First collisions in MPD – end of 2023

Accelerator Complex in Dubna



❖ Expected limitations in Stage-I:

- ✓ without electron cooling in collider, with stochastic cooling, reduced number of RFs → not-optimal beam optics
- ✓ reduced luminosity (~10^{25} is the goal for 2023) → collision rate ~ 100 Hz
- ✓ collision system available with the current sources: C (A=12), N (A=14), Ar (A=40), Fe (A=56), Kr (A=78-86), Xe (A=124-134), Bi (A=209) → start with Bi+Bi @ 9.2 GeV in 2023, Au+Au @ 4-11 GeV to come later

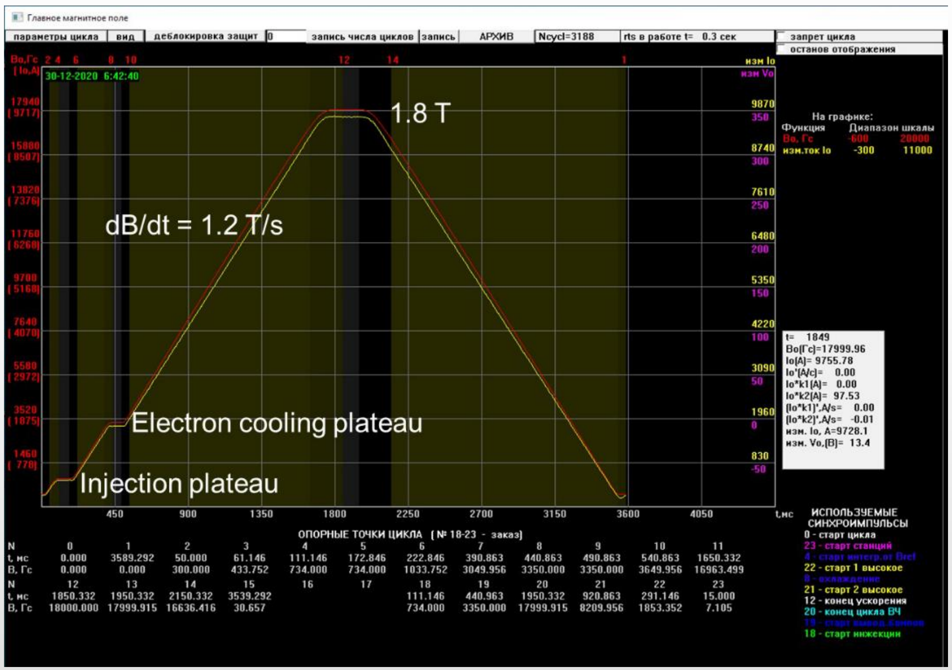
Booster commissioning

- Booster is fully assembled in the magnet yoke of the old synchrotron (solid basement, protection)
- Commissioning and tests are ongoing (cryogenics, magnets, power supply, beam acceleration, electron cooling etc.)

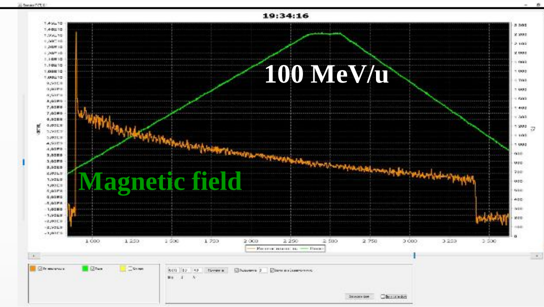
Booster technical run – Dec 30th, 2020

- The first technical run:
  - ✓ injected He^{1+} @ 3.2 MeV/u, $6.5 \cdot 10^{10}$ ppp
  - ✓ accelerated up to 100 MeV/u

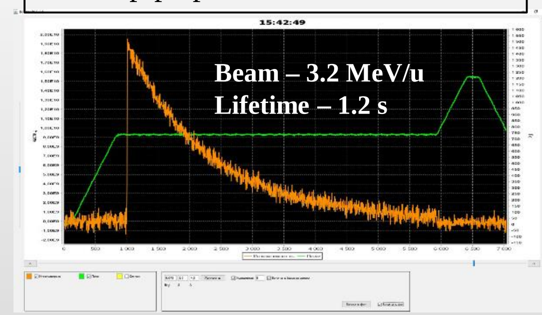
Operational at design magnetic field & ramp rate



Acceleration/flattop/deceleration with no transient losses

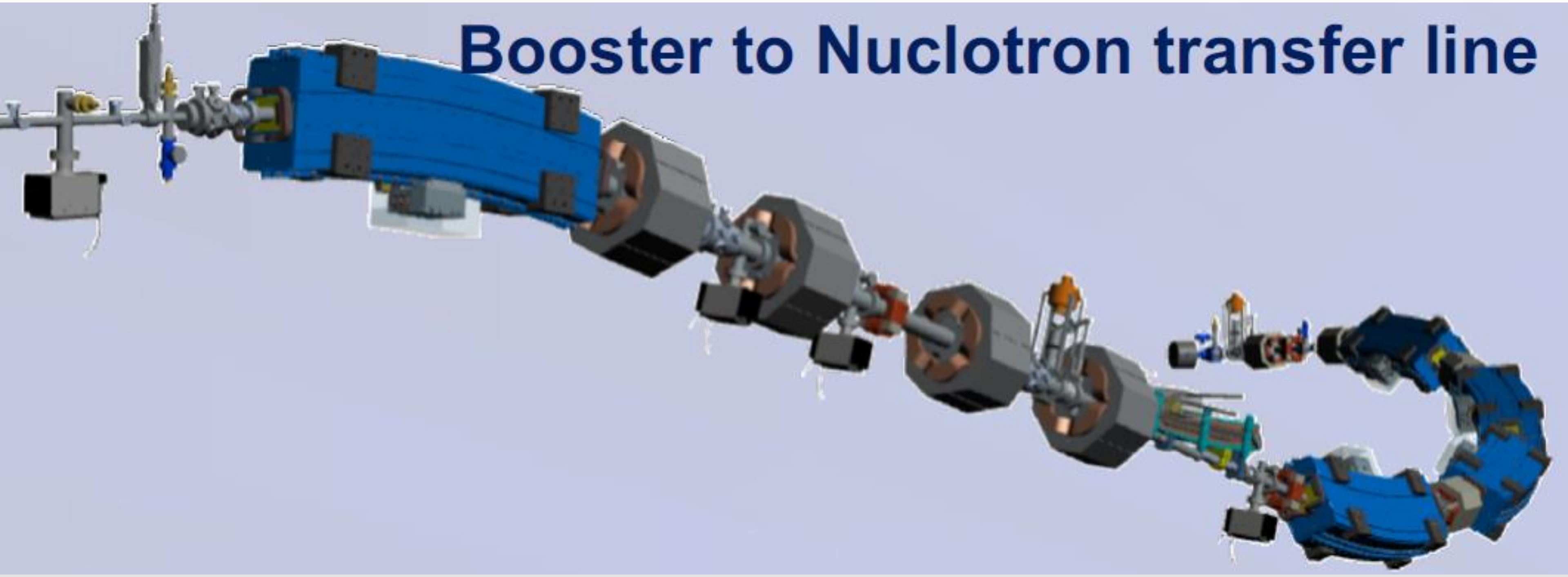


Beam pipe pressure ~ $2\text{-}3 \cdot 10^{-10}$ Torr



Booster 2nd technical run – Sept, 2021

- **Transfer line from Booster to Nuclotron assembled (5 dipole + 8 quadrupoles + 1 septum + 3 steering magnets – in collaboration with BINP)**
- **Complicated geometry with 3D-rotation**



Beam of Fe^{14+} ions (240 MeV/u, 3.10^8 ions) successfully accelerated, extracted from Booster and transferred to Nuclotron

NICA schedule

- Year 2021:
  - ✓ extensive commissioning of Booster
  - ✓ heavy-ion (Fe/Kr/Xe) run of full Booster + Nuclotron setup
- Year 2022:
  - ✓ completion of collider and Nuclotron-to-collider transfer lines
  - ✓ assembly of the MPD detector
- Year 2023:
  - ✓ technical run with Bi+Bi @ 9.2 GeV (7.7 GeV is the second priority) with luminosity ~ 10^{25} $cm^{-2}s^{-1}$
  - ✓ collect ~ 100 M minimum bias events with the MPD to be used for detector alignment, calibration and physics
- Year 2024:
  - ✓ Au+Au beams (source), beam acceleration in collider up to top energy (Au+Au @ 11 GeV)
- Year 2025 and beyond:
  - ✓ reaching design luminosity, system size and collision energy scan by request

Multi-Purpose Detector (MPD) Collaboration

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

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

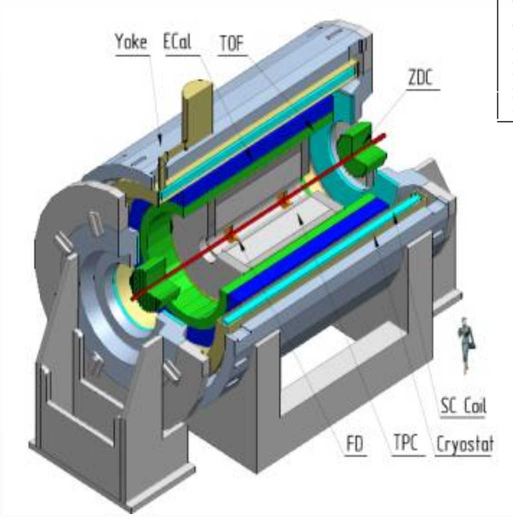
Spokesperson: ***Adam Kisiel***
Inst. Board Chair: ***Fuqiang Wang***
Project Manager: ***Slava Golovatyuk***

Deputy Spokespersons:
Victor Riabov, Zebo Tang

Joint Institute for Nuclear Research*;*
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****;*
Institute of Nuclear and Applied Physics, CAS, Shanghai, ***China****;*
Central China Normal University, ***China****;*
Shandong University, Shandong, ***China****;*
IHEP, Beijing, ***China****;*
University of South China, ***China****;*
Three Gorges University, ***China****;*
Institute of Modern Physics of CAS, Lanzhou, ***China****;*
Palacky University, Olomouc, ***Czech Republic****;*
NPI CAS, Rez, ***Czech Republic****;*
Tbilisi State University, Tbilisi, ***Georgia****;*
FCFM-BUAP (Mario Rodriguez) Puebla, ***Mexico****;*
FC-UCOL (Maria Elena Tejeda), Colima, ***Mexico****;*
FCFM-UAS (Isabel Dominguez), Culiacán, ***Mexico****;*
ICN-UNAM (Alejandro Ayala), Mexico City, ***Mexico****;*
CINVESTAV (Luis Manuel Montaño), Mexico City, ***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****;*
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****;*

Multi-Purpose Detector

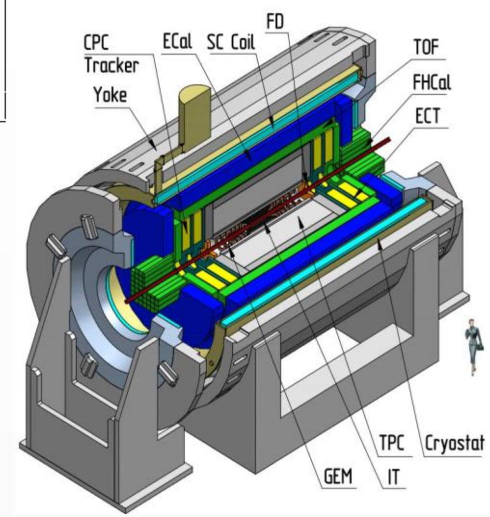
Stage- I



Length	340 cm
Vessel outer radius	140 cm
Vessel inner radius	27 cm
Default magnetic field	0.5 T
Drift gas mixture	90% Ar+10% CH_4
Maximum event rate	7 kHz ($L = 10^{27}$ $cm^{-2}s^{-1}$)

upgrade

Stage- II



TPC: $|\Delta\varphi| < 2\pi$, $|\eta| \leq 1.6$

TOF, EMC: $|\Delta\varphi| < 2\pi$, $|\eta| \leq 1.4$

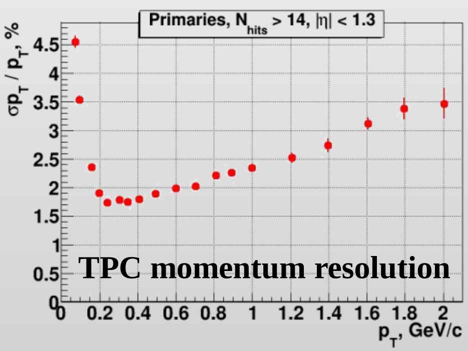
FFD: $|\Delta\varphi| < 2\pi$, $2.9 < |\eta| < 3.3$

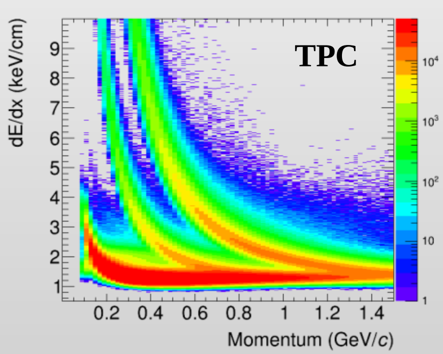
FHCAL: $|\Delta\varphi| < 2\pi$, $2 < |\eta| < 5$

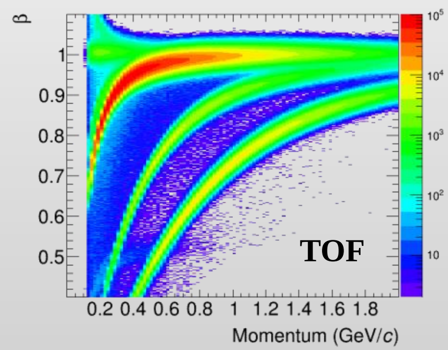
+ **ITS** (heavy-flavor measurements)

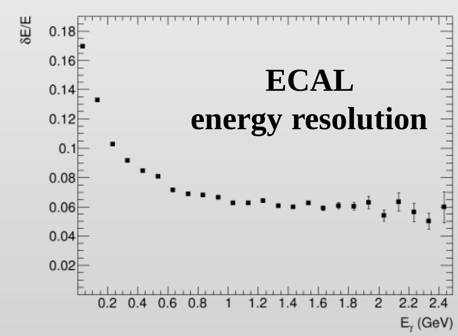
+ **forward spectrometers**

Au+Au @ 11 GeV (UrQMD + full chain reconstruction)









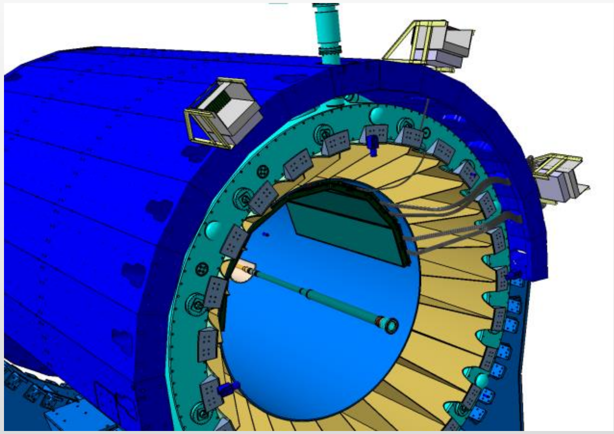
MPD status

- ❖ MPD hall is available for detector activities
- ❖ Installation of the MPD superconducting coil inside the magnet yoke - 29 July, 2021
- ❖ Next steps: cryogenic tests of the magnet, magnetic field measurements, installation of support structure, installation of detectors …

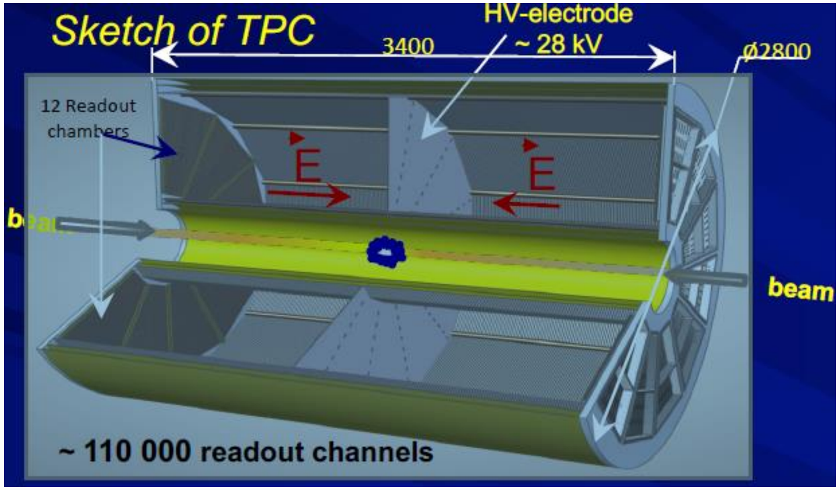
Support Frame for detectors inside of the Solenoid

The structure of Support Frame is made of carbon fiber which allows for deformation less than 5 mm under load with detectors (~80 T).
Producer - The Central Research Institute for Special Machinery, Khotkovo, Moscow region is a leading Russian enterprise in design and production of structures on the basis of advanced polymer composite materials for rocket & space engineering, transport, power, petrochemical machinery and other industries.

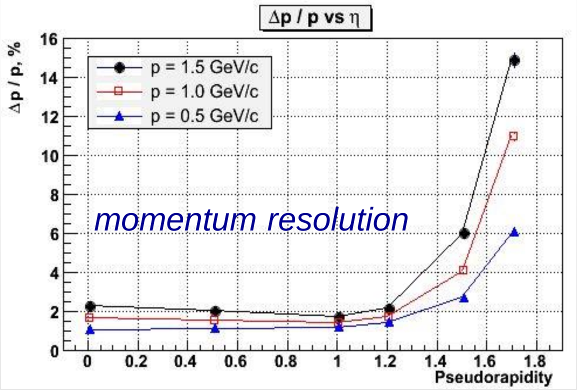
- the Frame will be transported to Dubna in November 2021
- December 2021 (as soon as Magnetic field measurements is finished)
- Representatives of the Company will participate in the process of installation of Support Frame into MPD and its alignment

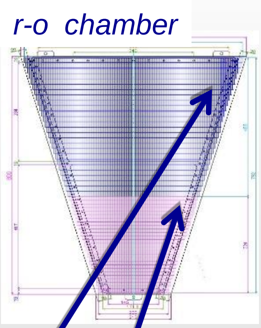


Time Projection Chamber (TPC): main tracker



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})*





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

pad structure:
- rows – 53
- large pads 5 ×18 mm²

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

MPD Time-of-Flight

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

Glass cleaning with ultrasonic wave & deionized water

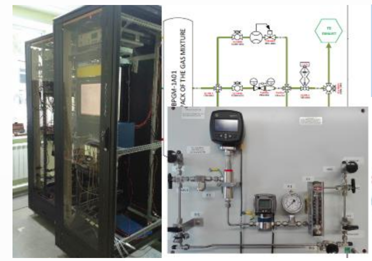
Automatic painting of the conductive layer on the glass

MRPC assembling

Soldering HV connector and readout pins

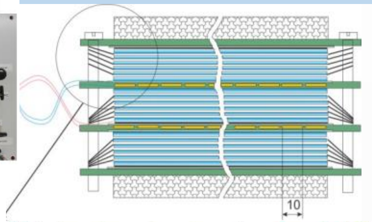
	Number of detectors	Number of readout strips	Sensitive area, m²	Number of FEE cards	Number of FEE channels
MRPC	1	24	0.192	2	48
Module	10	240	1.848	20	480
Barrel	280	6720	51.8	560	**13440** (1680 chips)

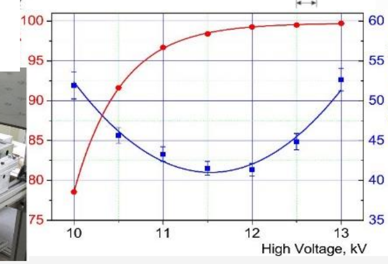
All procedure of detector assembling and optical control is performed in a clean rooms ISO class 6-7.



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

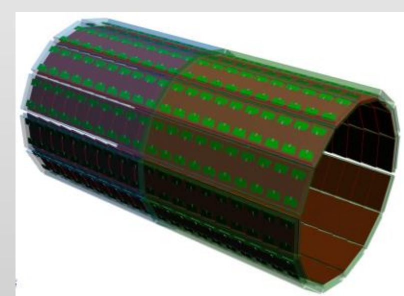
Dimensions of sensitive area 600 x300 mm^2





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



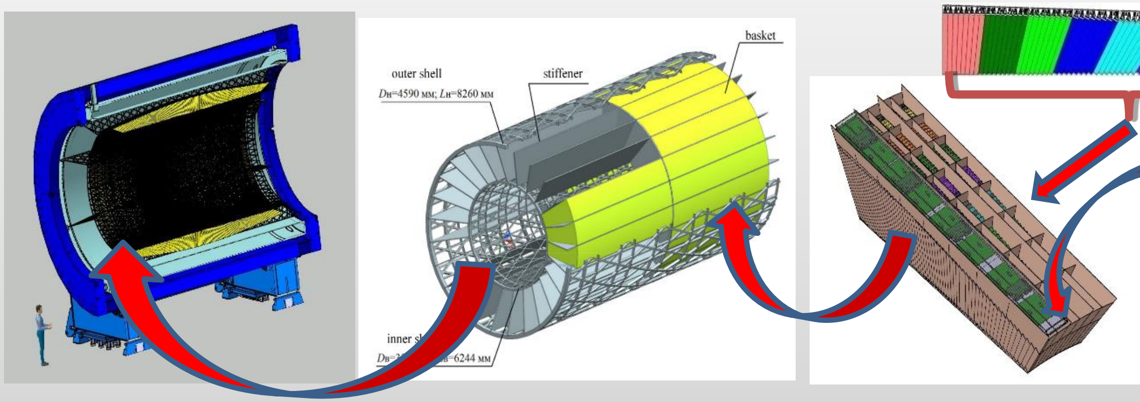
Electromagnetic Calorimeter (ECAL)

- *Pb+Sc "Shashlyk"* — *read-out: WLS fibers + MAPD* — *L ~35 cm (~ 14 X_0)*
- *Segmentation (4x4 cm^2)* — *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)

So far ~300 modules (16 towers each) = 3 sectors are produced
Another 3 sectors are planned to be completed by May 2022
Chinese collaborators will produce 8 sectors by the end of 2022
25% of all modules are produced by JINR (production area in Protvino) 75% produced in China, currently funding is secured for approx. 25%

Projective geometry



Sectors in dedicated Containers

Photo of one tower

Forward Hadron Calorimeter (FHCal)

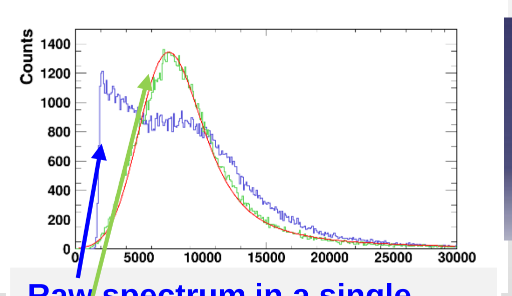
- Two-arms at ~3.2 m from the interaction point.
- Each arm consists of 44 individual modules.
- Module size 15x15x110cm^3 (42 layers)
- Pb(16mm)+Scint.(4mm) sandwich
- 7 longitudinal sections
- 6 WLS-fiber/MAPD per section
- 7 MAPDs/module

The activities with modules:

- Tests with cosmic muons;
- Tests of Front-End-Electronics (FEE);
- Study of FEE electronic noises;
- Development of FHCal trigger;
- Development of Slow Control.

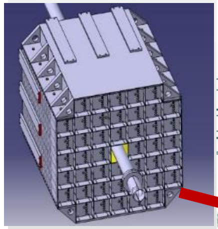
- All (90+spare) FHCal modules are assembled and are used for the tests.
- 100 Front-End-Electronics (FEE) boards are produced and tested.

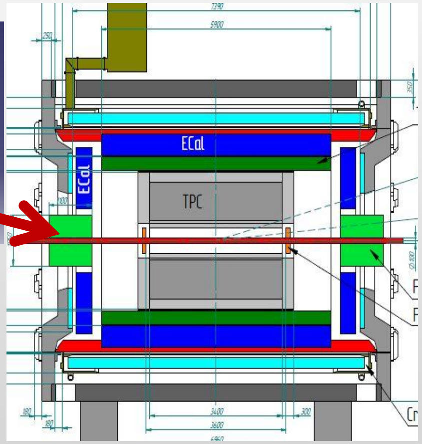
FHCal energy calibration with cosmic



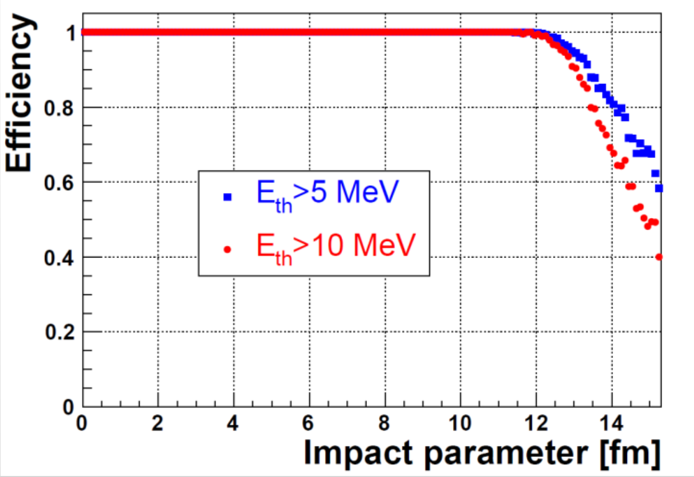
Raw spectrum in a single section

Corrected to the pass length in scintillators

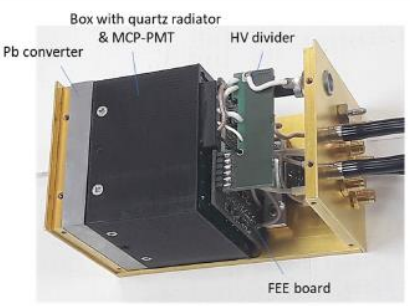


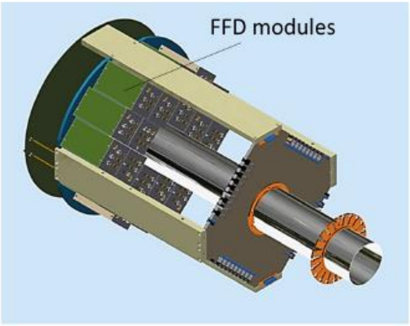


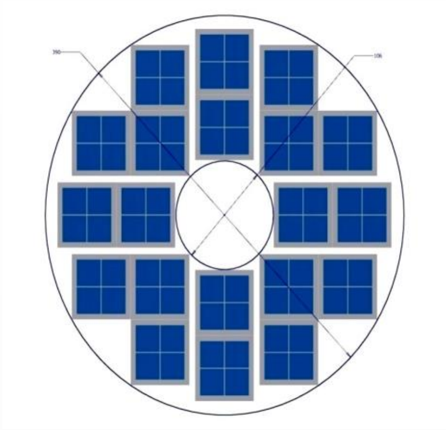
FHCal Trigger efficiency

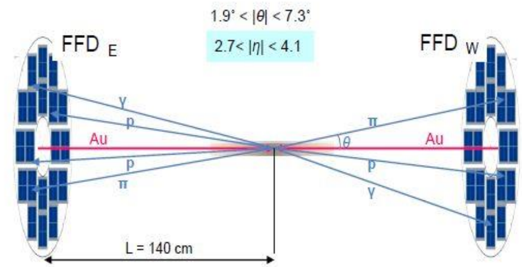


FFD - Fast Trigger L_0 for MPD









FFD provides information on
- interaction rate (luminosity adjustment)
- bunch crossing region position

The FFD sub-detector consists of 20 modules based on Planacon multianode MCP-PMTs 80 independent channels

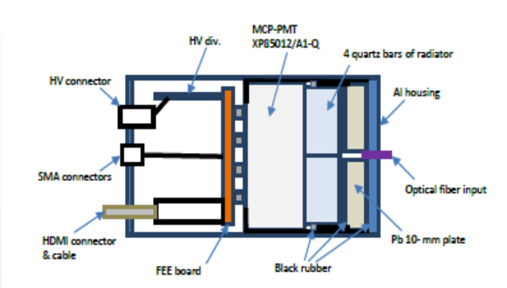


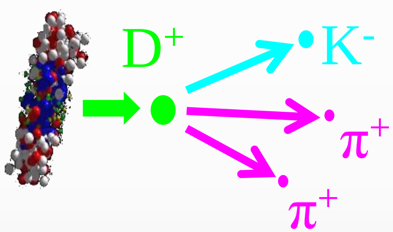
Fig. 4-1. A scheme of the FFD module.

15 mm quartz radiator
10 mm Lead converter

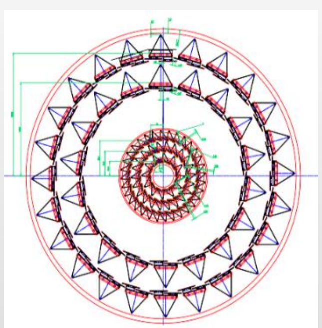
MPD trigger group is created on the basis of FFD team
Beside FFD we consider the signals from FHCal to be implemented into trigger L0
The FHCal team have produced trigger electronics.
Monte Carlo studies will be used to optimize the properties of the L0 trigger

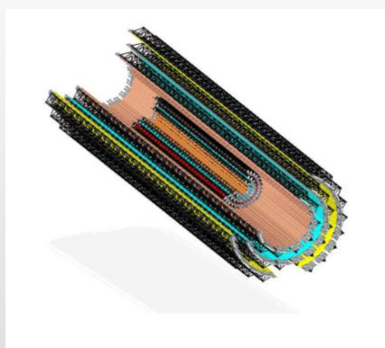
Inner Tracker System (ITS): precise tracking

Consortium includes JINR, NICA (BM@N & MPD) , **FAIR, Russian, Polish and Ukrainian Institutes + CCNU Central China Normal Univ., IMP- Institute of Modern Physics, USTC – Hefei**

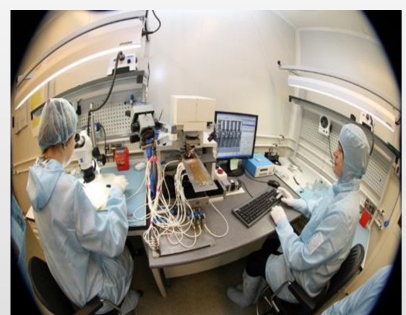


Protocol # 134 between CERN and JINR states the legal terms for transaction of CERN developed novel technology and the know-how for building the MPD-ITS on the basis of Monolithic Active Pixel Sensors *(the **MAPS**)* ALPIDE, signed in 2018. This document laid a clear road towards the MPD ITS.





MPD ITS based on ALICE type staves



MPD physics program

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

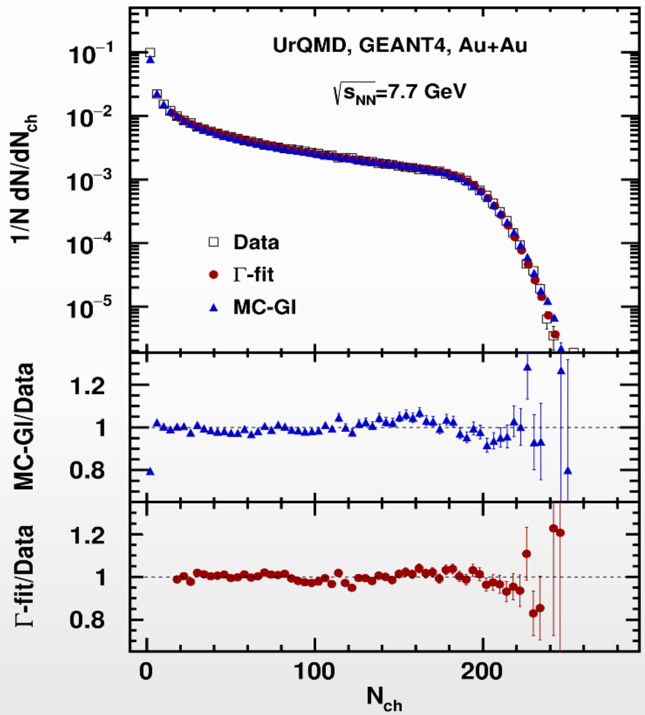
Electromagnetic probes
- Electromagnetic calorimeter meas.
- Photons in ECAL and central barrel
- Low mass dilepton spectra in-medium modification of resonances and intermediate mass region

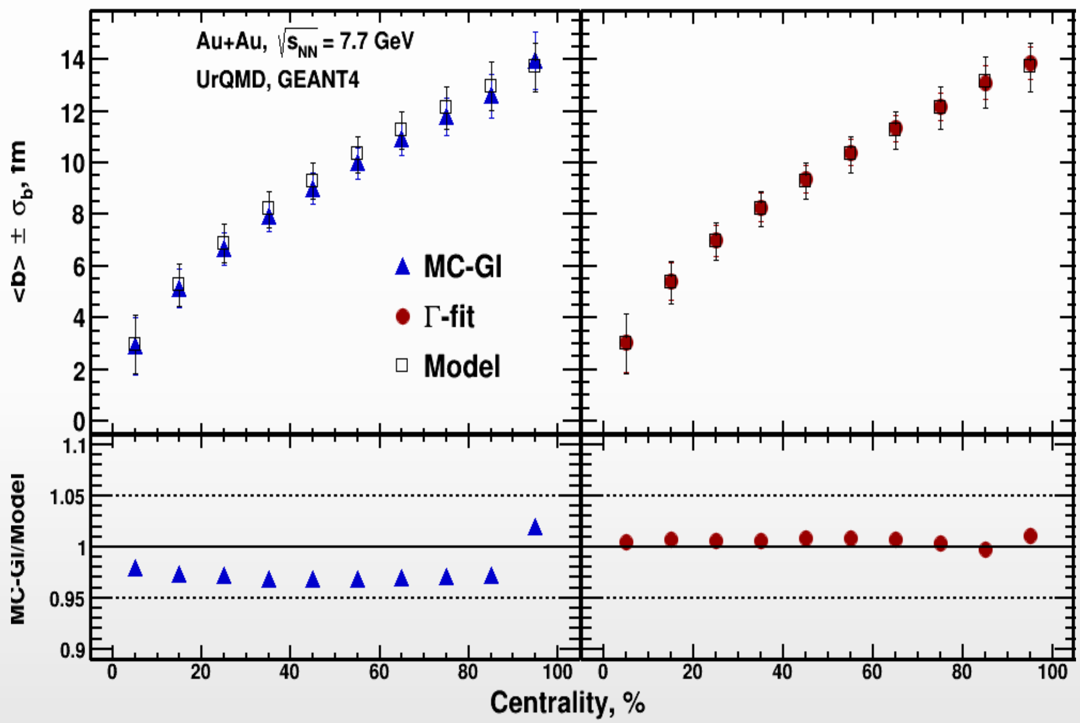
Wangmei Zha, A. Zinchenko

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 by TPC multiplicity

- ❖ AuAu@7.7 GeV (UrQMD)
- ❖ Reconstruction of the impact parameter by **MC Glauber (MC-Gl)** and by **Bayesian inversion method (Γ-fit)**

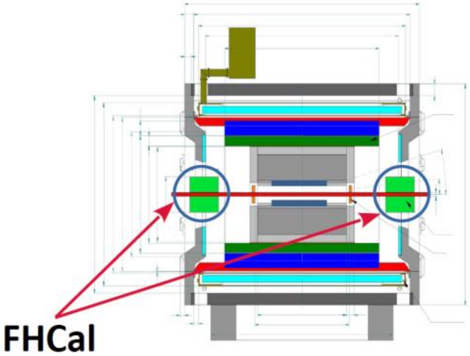




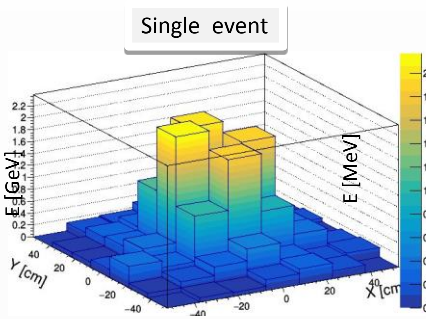
- ❖ Comparable results with PHSD and SMASH event generators at different energies

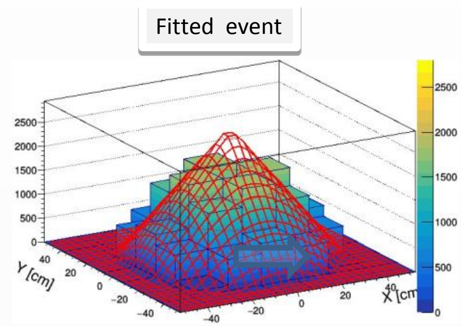
Centrality and reaction plane by FHCAL

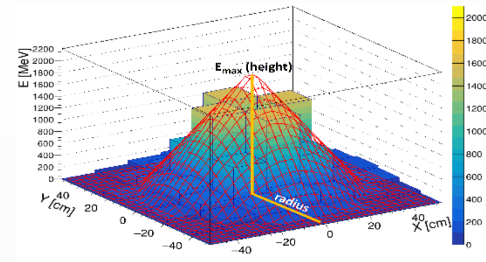
- FHCAL is a hadronic calorimeter, ~ 1 m^2, segmentation 15x15 cm^2, $2 < |\eta| < 5$

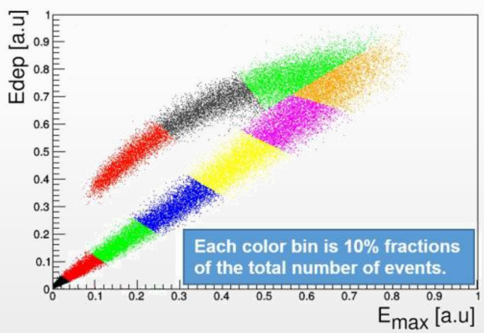


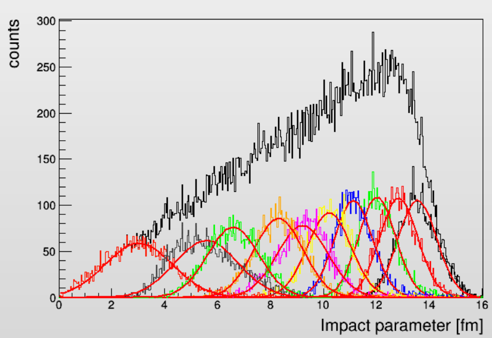
Two-dimensional fit of the energy depositions in FHCAL

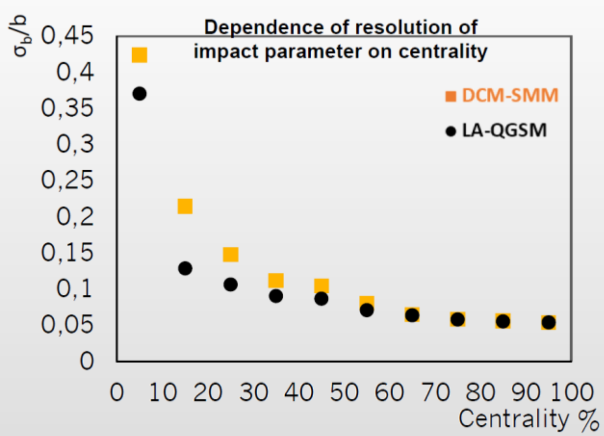


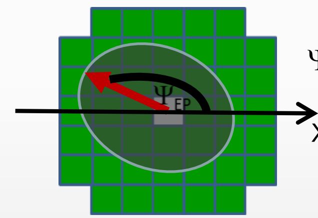






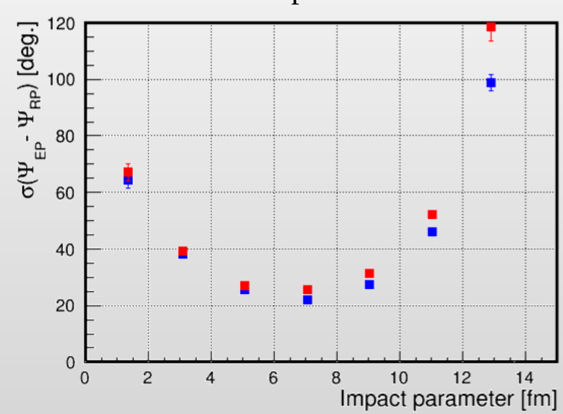






$$\Psi_{EP} = acrtg \frac{\sum E_i \sin(\varphi_i)}{\sum E_i \cos(\varphi_i)}$$

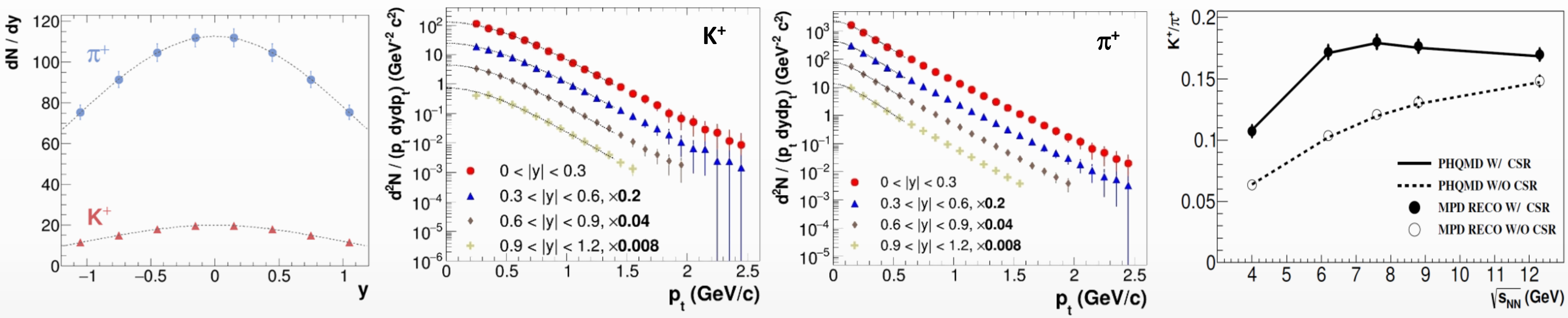
Reaction plane resolution



Identified hadron spectra

- ❖ Particle spectra, yields and ratios probe bulk properties of the fireball and flow
- ❖ Advantage of the MPD is in large and uniform acceptance, excellent PID capabilities using combined analysis of TPC (dE/dx) and TOF signals

- ❖ 0-5% central AuAu@9 GeV (PHSD, with partonic phase and chiral symmetry restoration effects):

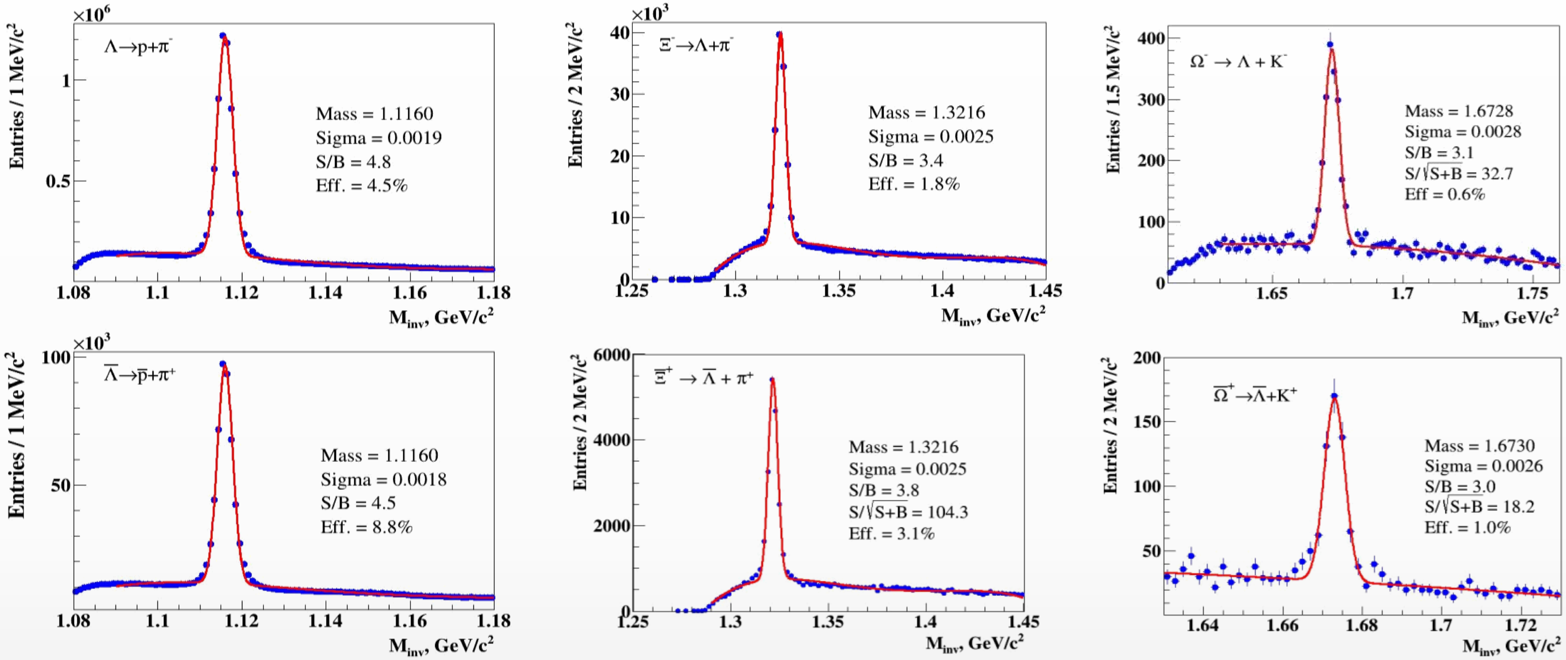


- ✓ MPD samples ~ 70% of the π/K/p production in the full phase space
- ✓ hadron spectra are measured from 0.2 MeV/c to 2.5 GeV/c in transverse momentum with the TPC&TOF
- ✓ unmeasured hadron yields at low p_T and large values of rapidity can be extracted from extrapolation of the measured spectra (B-W for p_T spectra and Gaussian for rapidity spectra in exampled above)

- ❖ Ability to cover full energy range of the “horn” with consistent acceptance across different collision systems and collision energies

Weak decays of strange baryons

❖ AuAu@11 GeV (PHSD):

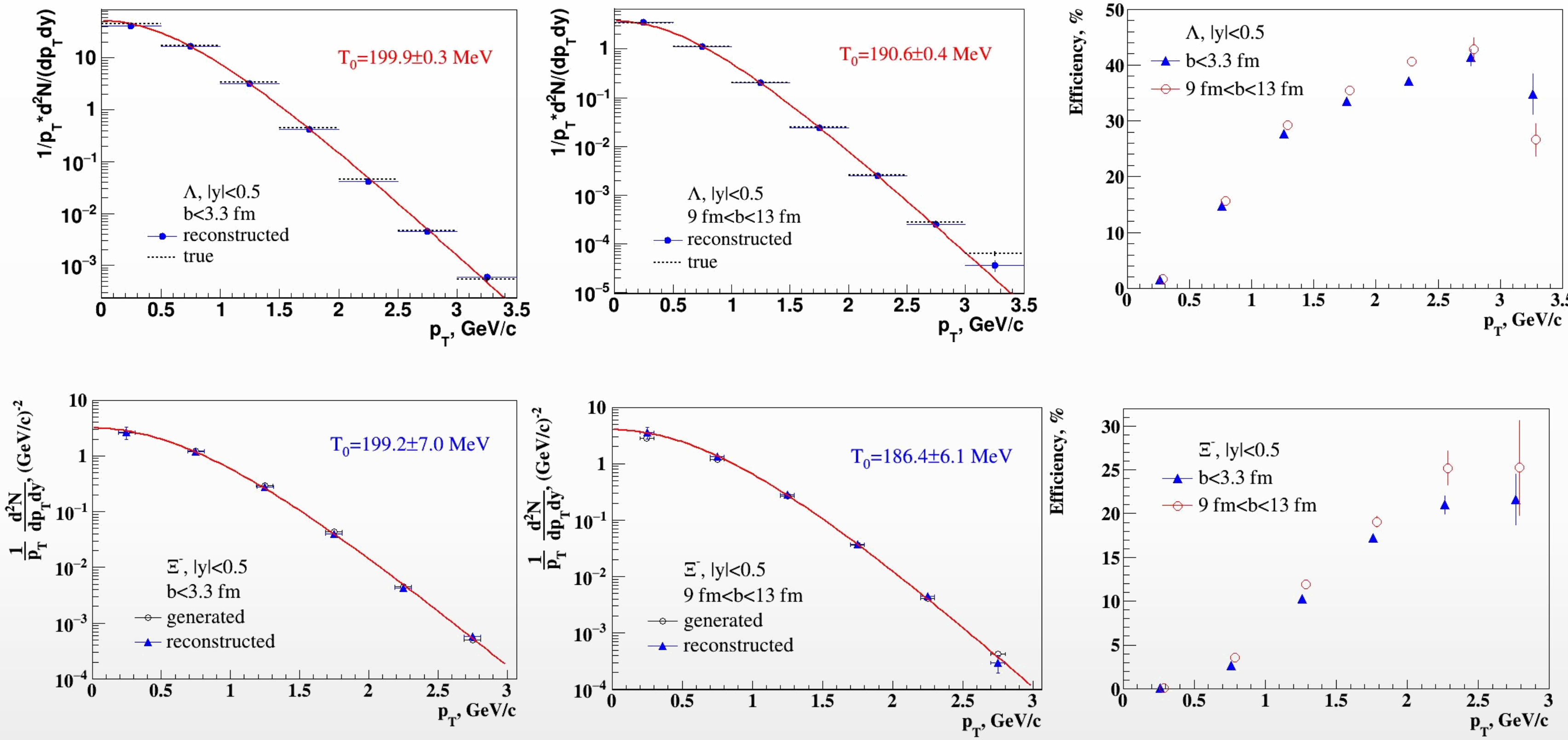


✓ Strange baryons can be reconstructed with good S/B ratios using charged hadron identification in the TPC&TOF and different decay topology selections

✓ Relative yields of the baryons for ~ 500 M sampled events:

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

Efficiencies and p_T spectra



- ✓ Capability to reconstruct baryon yields down to low momenta with reasonable efficiencies
- ✓ High-p_T reach is limited by statistics
- ✓ Reconstructed spectra are consistent with the generated ones → MC closure test

Short-lived resonances

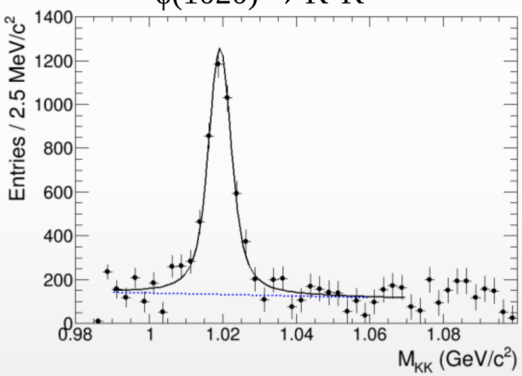
- Resonances probe reaction dynamics and particle production mechanisms vs. system size and $\sqrt{s_{NN}}$:
  - ✓ hadron chemistry and strangeness production, lifetime and properties of the hadronic phase, spin alignment of vector mesons, flow etc.

increasing lifetime ⟶

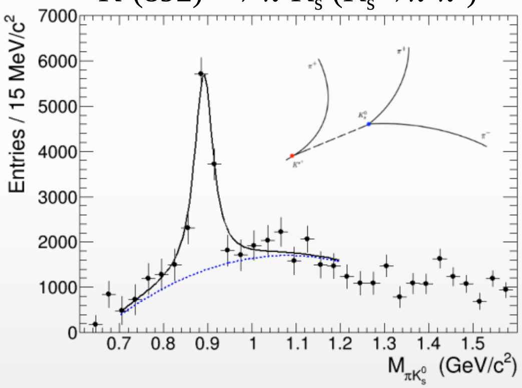
	ρ(770)	$K^*(892)$	Σ(1385)	Λ(1520)	Ξ(1530)	ϕ(1020)
cτ (fm/c)	1.3	4.2	5.5	12.7	21.7	46.2
$\sigma_{rescatt}$	$\sigma_\pi\sigma_\pi$	$\sigma_\pi\sigma_K$	$\sigma_\pi\sigma_\Lambda$	$\sigma_K\sigma_p$	$\sigma_\pi\sigma_\Xi$	$\sigma_K\sigma_K$

- AuAu@11 GeV (UrQMD) after mixed-event background subtraction:

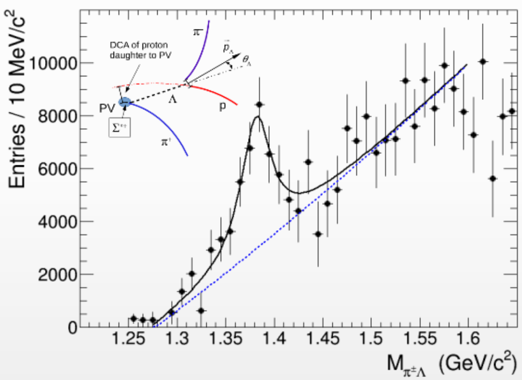
$\phi(1020) \to K^+K^-$



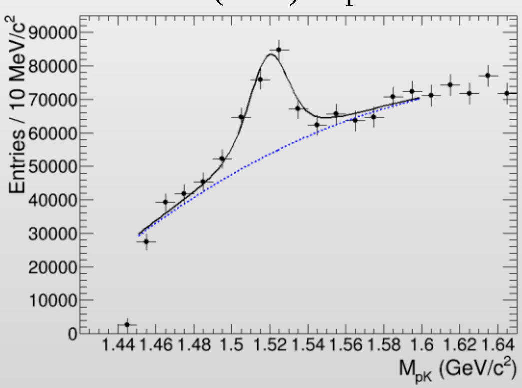
$K^*(892)^\pm \to \pi^\pm K_s$ ($K_s \to \pi^+\pi^+$)



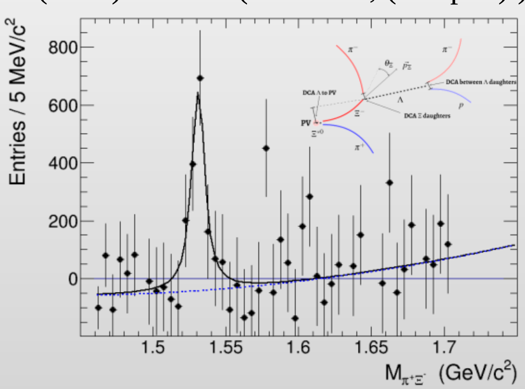
$\Sigma(1385)^\pm \to \pi^\pm\Lambda$ ($\Lambda \to p\pi$)



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



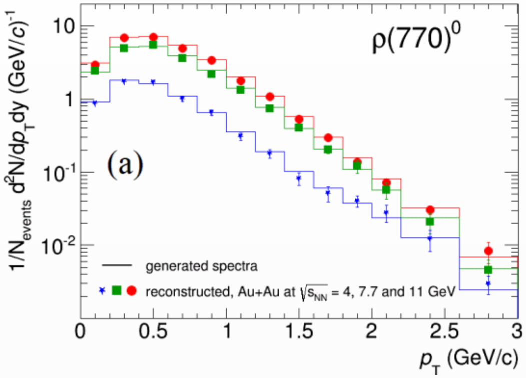
$\Xi(1530)^0 \to \pi^+\Xi^-$ ($\Xi^- \to \Lambda\pi^-$, ($\Lambda \to p\,\pi^-$))

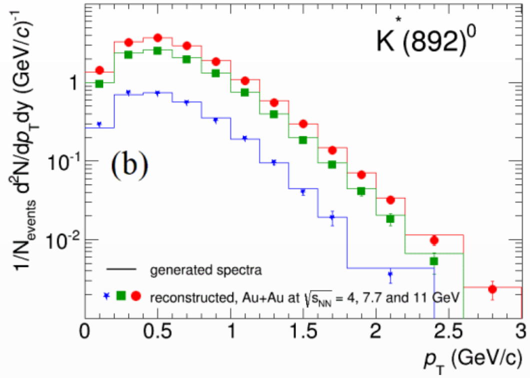


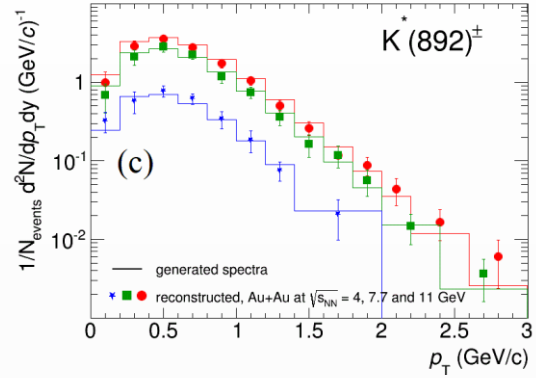
- ✓ MPD is capable of reconstruction the resonance peaks in the invariant mass distributions using combined charged hadron identification in the TPC and TOF
- ✓ decays with weakly decaying daughters require additional second vertex and topology cuts for reconstruction

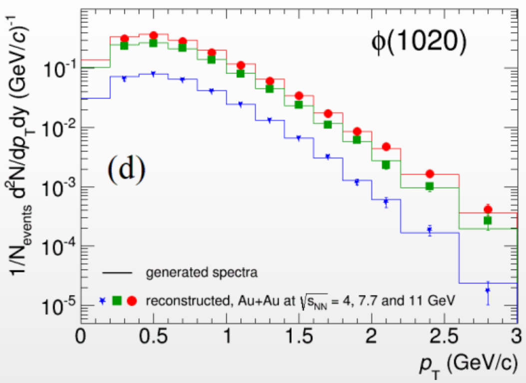
MC closure tests

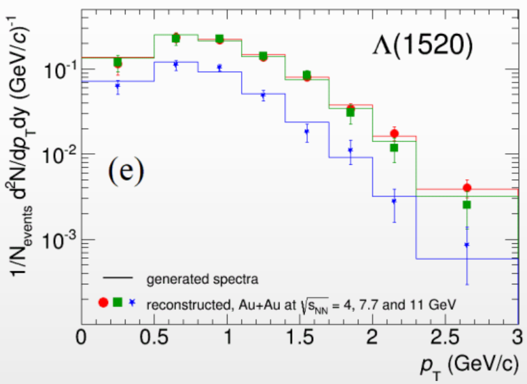
❖ Full chain simulation and reconstruction, p_T ranges are limited by the possibility to extract signals, $|y| < 1$

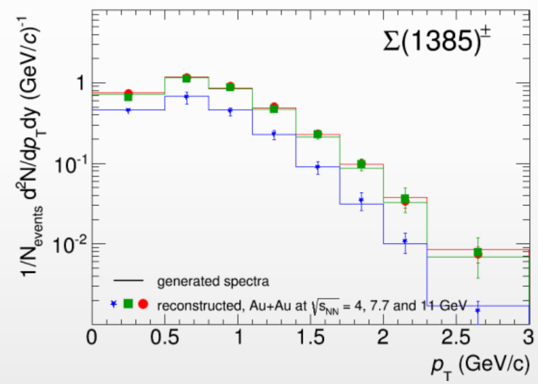


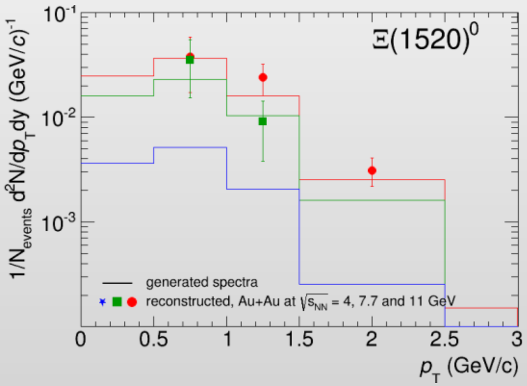












❖ Reconstructed spectra match the generated ones within uncertainties

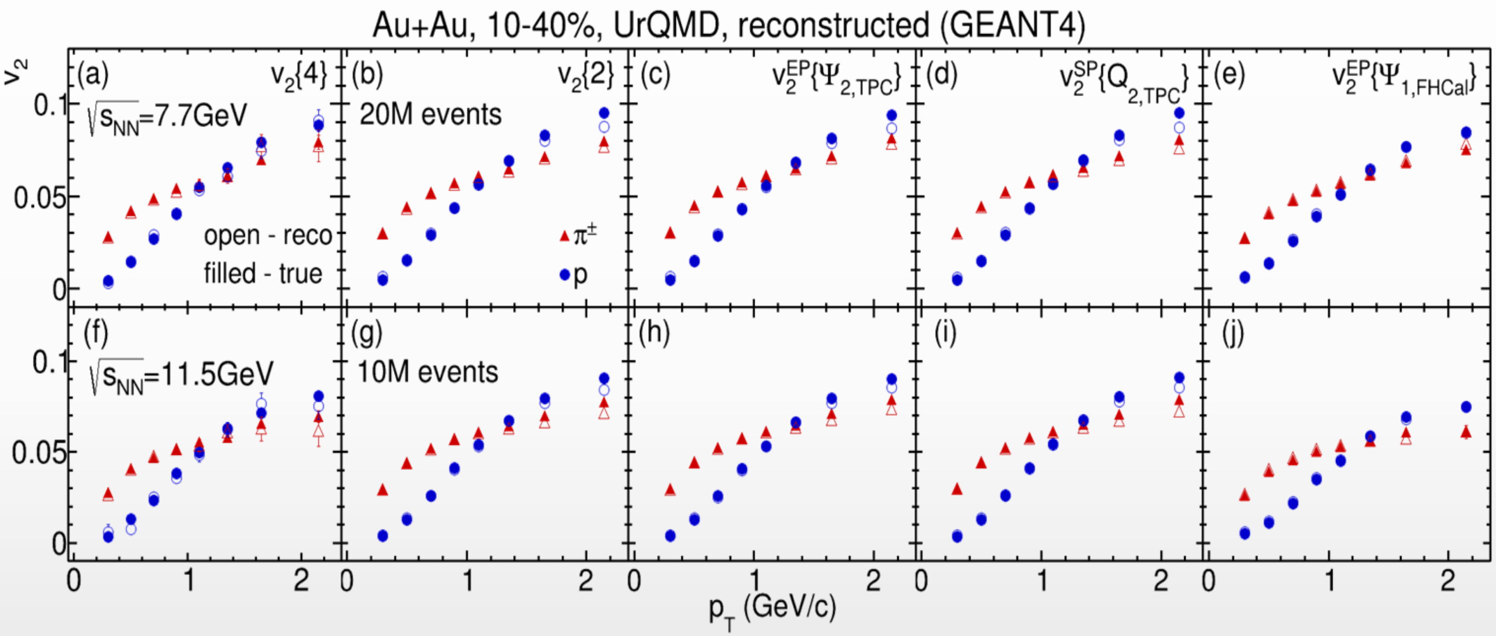
❖ First measurements for resonances will be possible with accumulation of ~ 10^7 A+A events

❖ Measurements are possible starting from ~ zero momentum → sample most of the yield, sensitive to possible modifications

❖ Measurements of $\Xi(1530)^0$ are very statistics hungry

v_2 for pions and protons

- Flow has high sensitivity to the transport properties of the QCD matter: EoS, speed of sound (c_s), specific viscosity (η/s), etc.
- Lack of existing differential measurements of v_n vs. p_T, centrality, species, etc.)

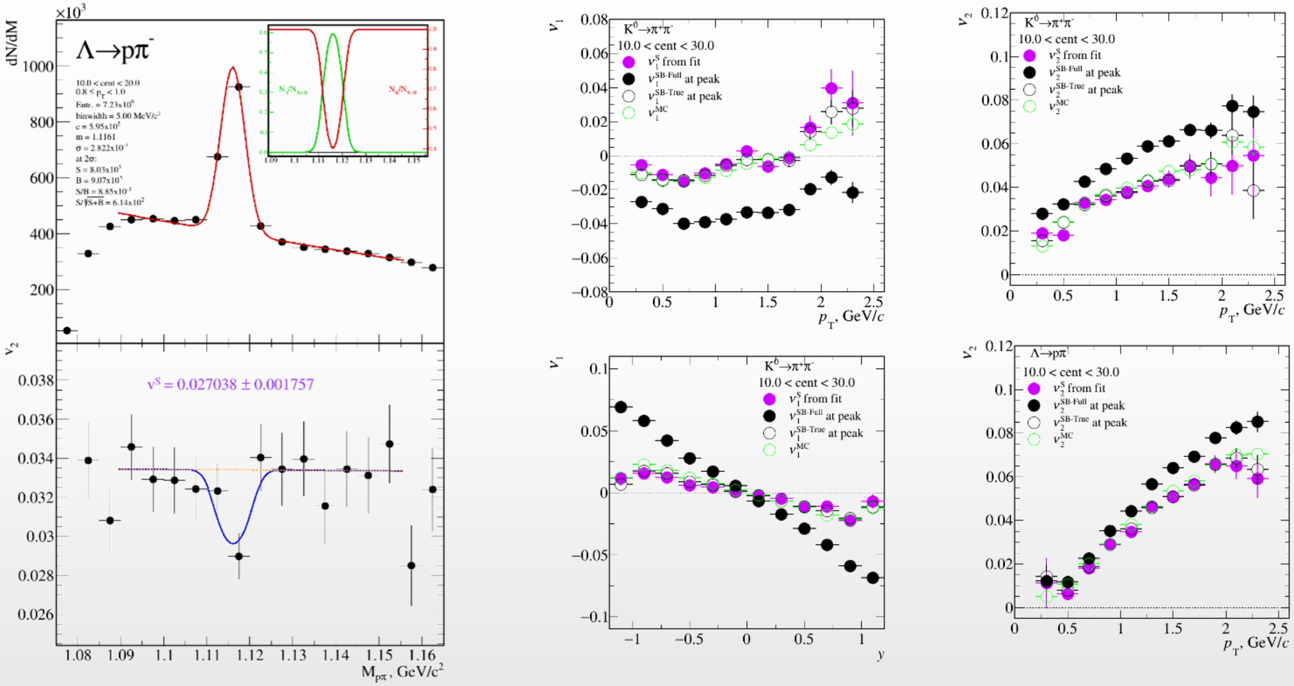


- Reconstructed and generated v_2 of pions and protons are in good agreement for all methods

Collective flow for V0 (K_s^0 and Λ)

- 25 M AuAu@11 GeV (UrQMD)
- Differential flow signal extraction using invariant mass fit method

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



v_1/v_2 flow after fit

Measured flow for (S+BG)

Measured flow for true pairs

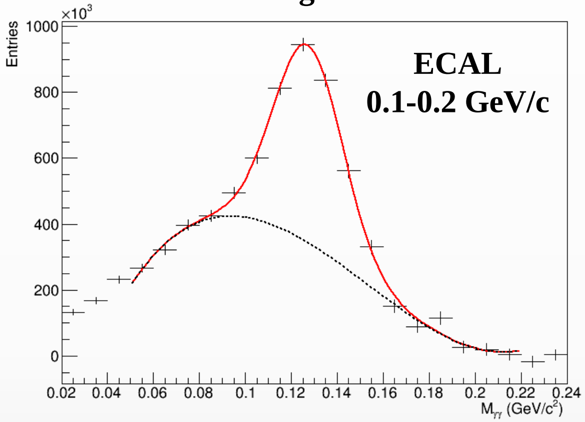
Flow from event generator

- Reasonable agreement between reconstructed and generated v_n signals for K_s^0 and Λ

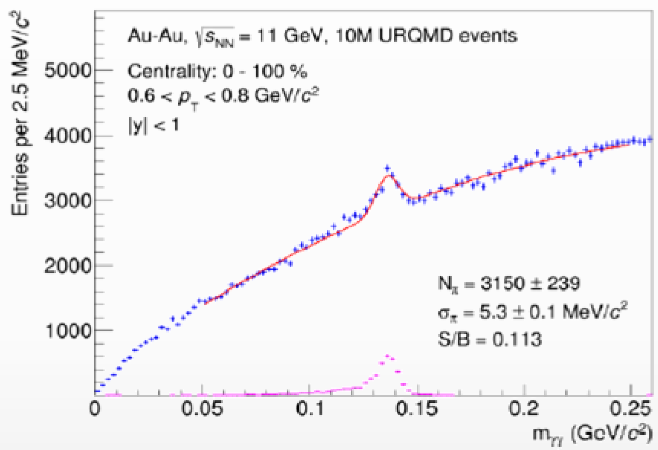
Neutral mesons

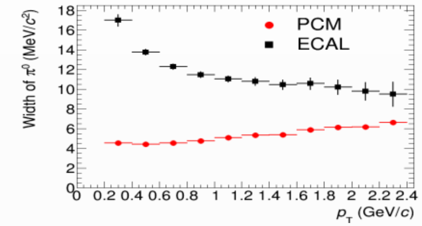
- Extend p_T range of charged particle measurements, various species (η, ω, η’, etc.)
- AuAu@11 GeV (UrQMD): realistic ECAL reconstruction and analysis in high multiplicity environment + photon conversion method

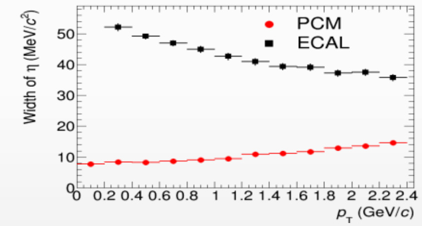
mixed-event background subtracted



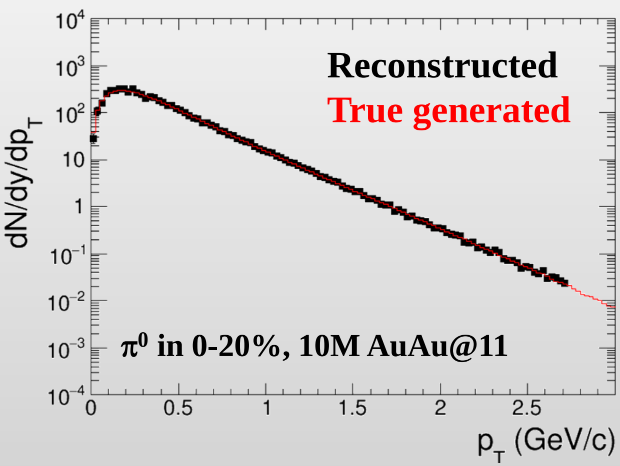
$\pi^0 \to \gamma\,(\gamma \to e^+e^-) + \gamma\,(\gamma \to e^+e^-)$

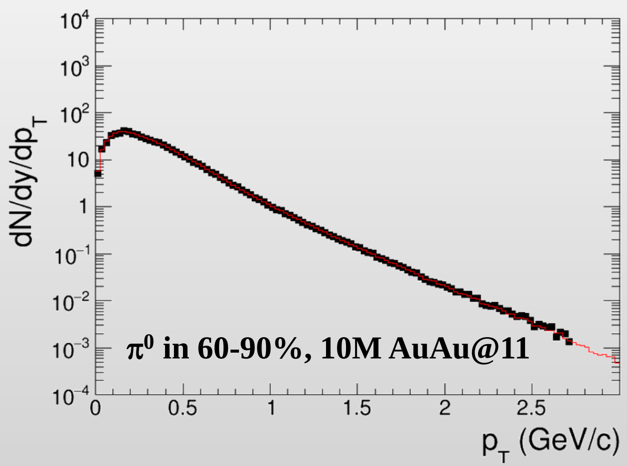


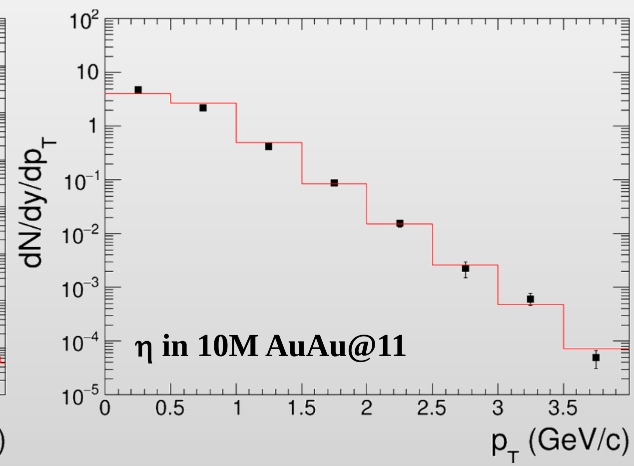




- π^0 and η MC closure tests: reconstructed spectra match the generated ones

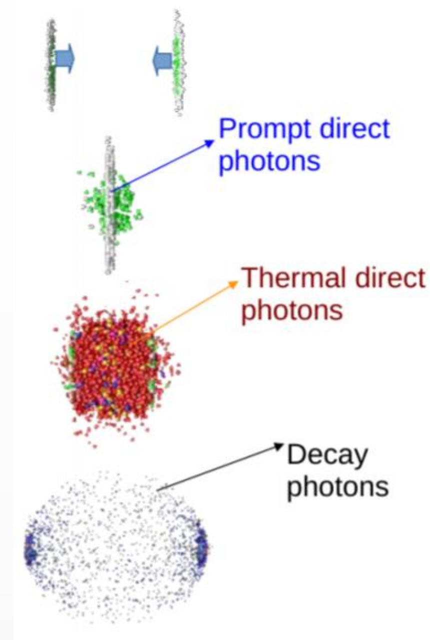




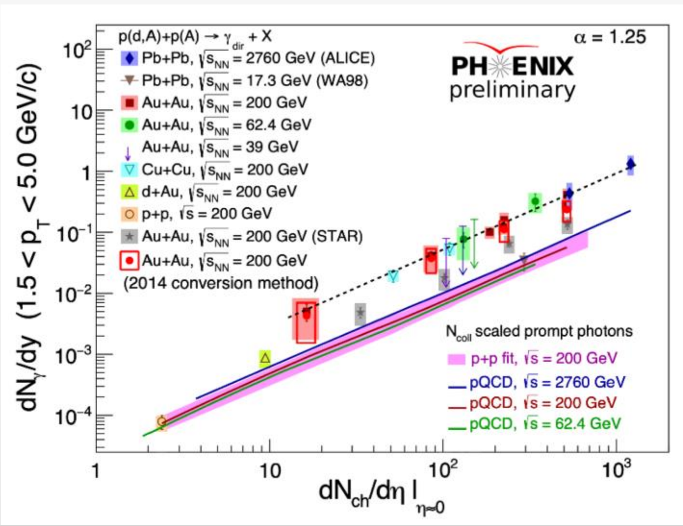


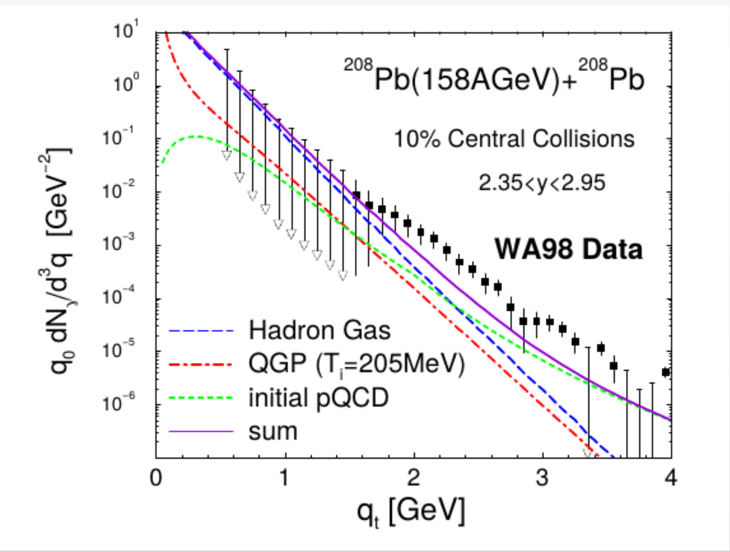
Photons: Motivation

- Direct photons – photons not from hadronic decays.
- Produced throughout the system evolution:
  - ✓ QCD matter is transparent for photons, once produced they leave the interaction region unaffected preserving their properties
  - ✓ estimation of the effective system temperature at low energy
  - ✓ hard scattering probe at high energy



- Experimental measurements in A+A collisions are available from the LHC (2.76 TeV), RHIC (62-200 GeV) and WA98 (17.2 GeV)
- No measurements at NICA energies, interested in the measurement of direct photon yields and flow vs. p_T and centrality





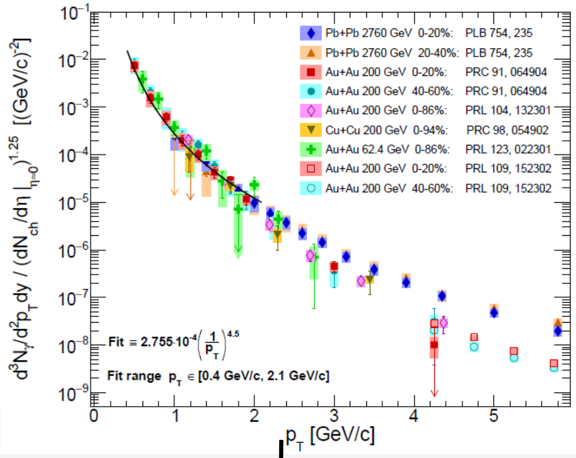
Direct photon yields at NICA

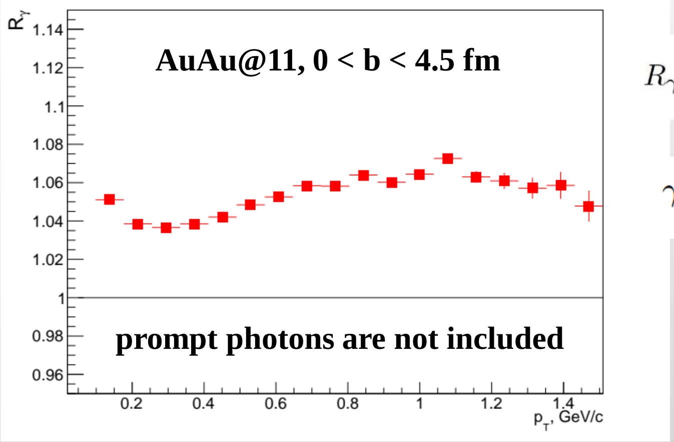
Estimation of the direct photon yields @NICA

model calculations

empirical scaling

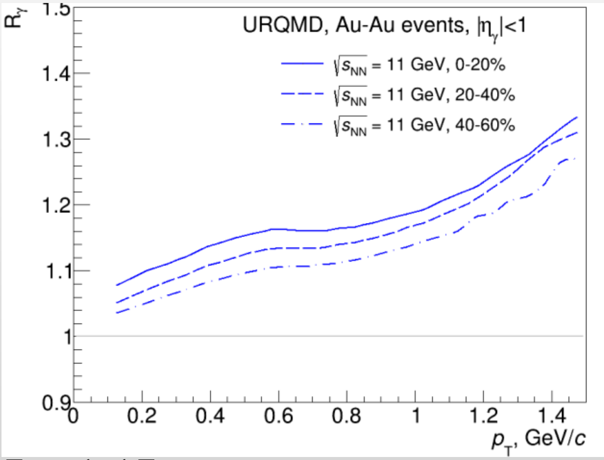
- UrQMD v3.4 with hybrid model (3+1D hydro, bag model EoS, hadronic rescattering and resonances within UrQMD)
- Each cell have Ti, Ei, μbi:
  - T is high – QGP phase (Peter Arnold, Guy D. Moore, Laurence G. Yaffe, JHEP 0112:009 2001)
  - T is low – HG phase (Simon Turbide, Ralf Rapp, Charles Gale, Phys.Rev.C69:014903,2004)
  - T is intermediate – mixed phase
- Integrate over all cells and all time steps
- Calculations reproduce hydro calculations for the SPS





$$R_\gamma = \frac{\gamma_{\text{inc}}}{\gamma_{\text{decay}}} = \frac{\gamma_{\text{inc}}/\pi^0}{\gamma_{\text{decay}}/\pi^0_{\text{param}}}$$

$$\gamma_{\text{direct}} = \left(1 - \frac{1}{R_\gamma}\right) \cdot \gamma_{\text{inc}}$$

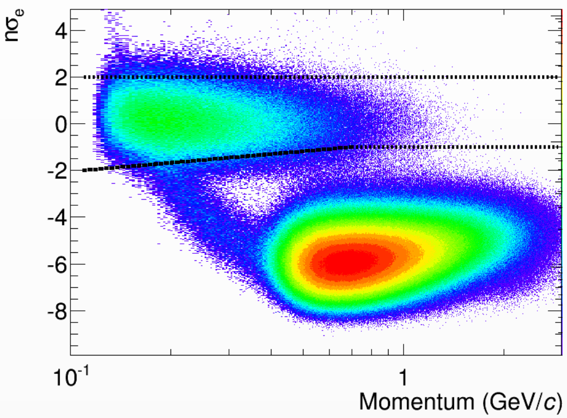


- Non-zero direct photon yields are predicted, Rγ ~ 1.05 – 1.15

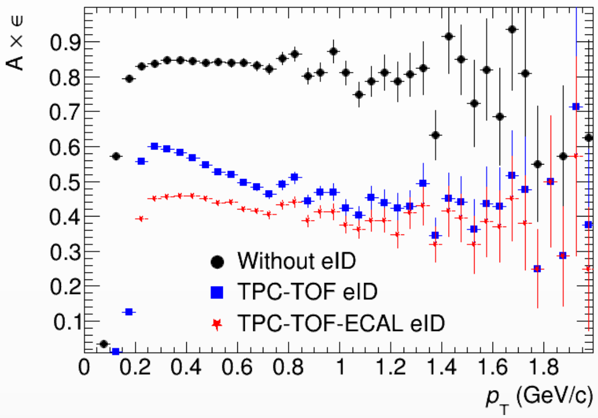
Dielectrons

- Dielectron spectra are sensitive probes of the deconfinement and the chiral symmetry restoration
- AuAu@11 GeV (UrQMD for background & PHQMD for signal)

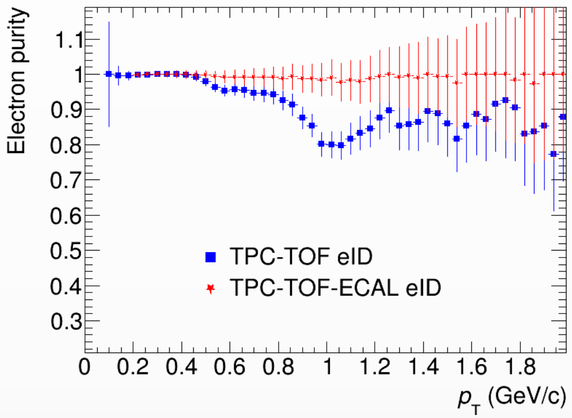
$n \cdot \sigma_e^{TPC}$ with $2\sigma_e$ PID in the TOF

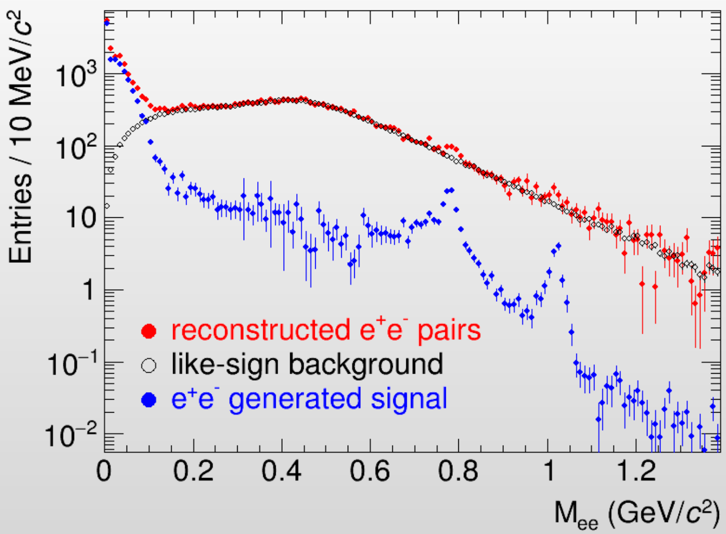


Efficiency of e-track reconstruction



Electron purity





- S/B (integrated in 0.2-1.5 GeV/c^2) ~ 5-10%
- Methods to improve S/B ratio while preserving reasonable efficiency for the pairs are being developed and matured

Summary

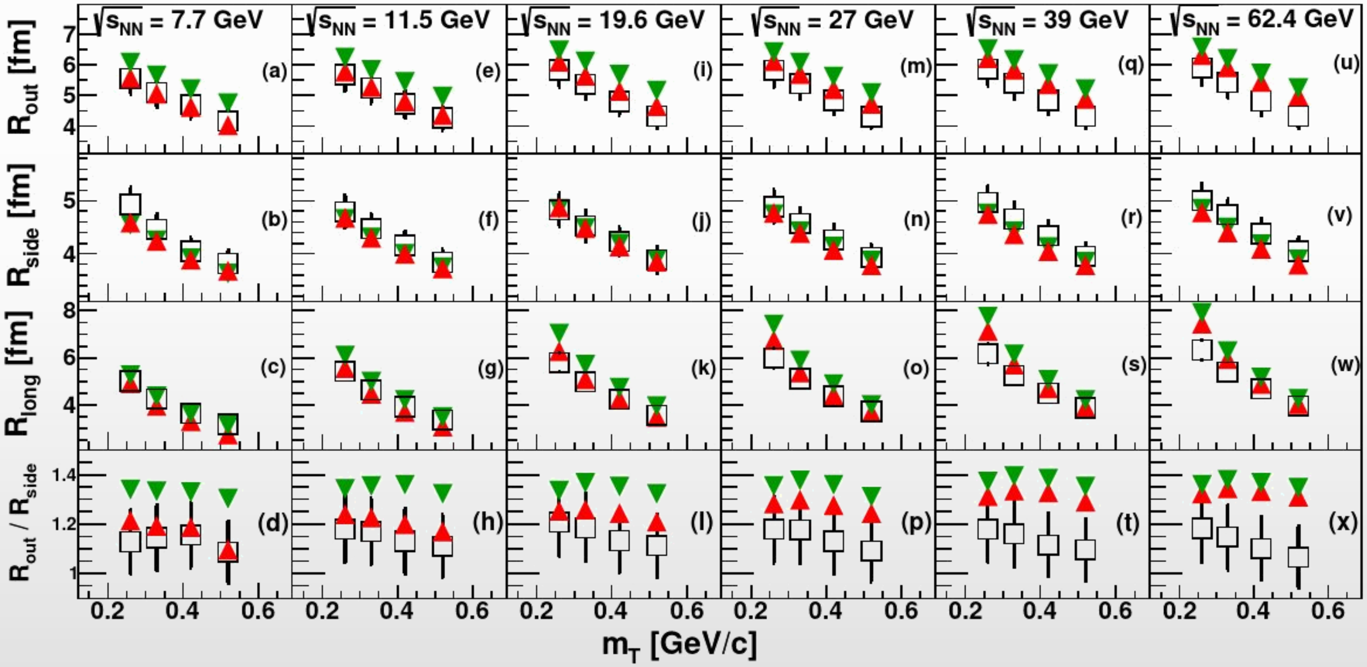
- The NICA Accelerator Complex is under construction with important milestones achieved
- Commissioning of the MPD Stage-I detector with the first Bi beams is expected in 2023, followed by Au beams at maximum energy in 2024. Further program will be driven by the physics demands
- Intensive preparations of the MPD hardware and analysis tools for the first beams are ongoing

BACKUP

Two particle correlations

- Femtoscopy is used in heavy-ion collision to determine the size of the particle-emitting region and space-time evolution of the produced system.
- Measurement for pions are straightforward and robust, large discovery potential in correlations for kaons and protons, as well as correlations including hyperons

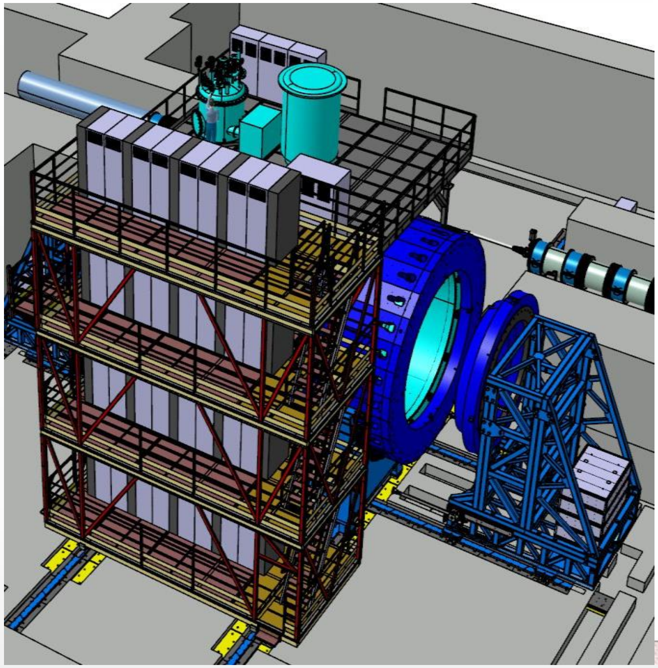
AuAu@7.7 GeV (vHLLE), extracted 3D pion radii versus m_T vs. STAR data (PRC 96, 024911(2017))

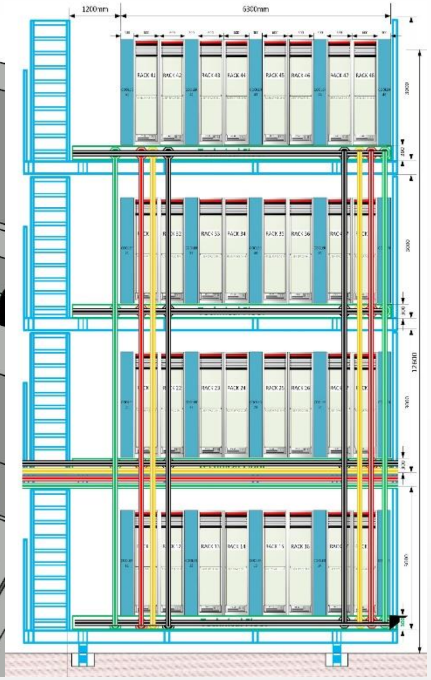


1st order phase transition
cross-over transition

- Simulations predict sensitivity of pion source size to the nature of the phase transition

MPD Electronics Platform





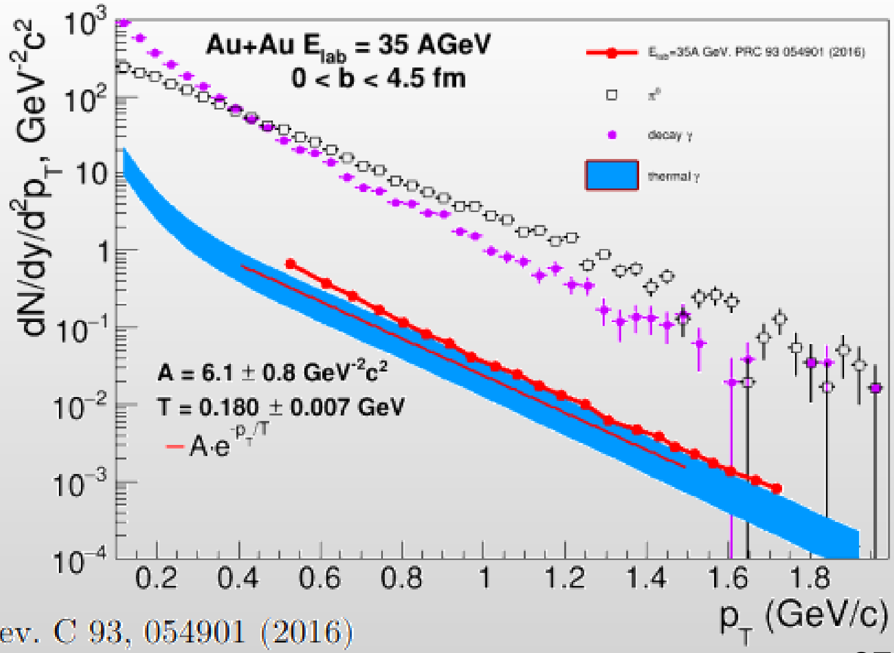
- Electronics platform has 4 levels with 8 racks on each level
- Each Rack provides cooling, fire safety and radiation control system
- Cable ducts connect detectors inside of MPD and Electronics Platform
- The mechanical part of the Platform is ready

The design of the MPD Electronics Platform is a major contribution of the Polish groups to MPD
M. Peryt (WUT) – leader of the „Engineering Support" Sector of VBLHEP

Simulation setup

- ✓ UrQMD v3.4 with hybrid model (3+1d hydro, **bag model** EoS, hadronic rescattering and resonances within UrQMD)
- ✓ π^0 and decay photon spectrum are calculated **within the same simulation**
- ✓ impact parameter range $0<b<9$ fm
- ✓ In hydrodynamical evolution, for each volume we calculate thermal gamma yield based on T, energy density (e), QGP fraction, baryonic chemical potential. We integrate these yields over time (until freeze-out time) and space.
- ✓ Two extreme cases: calculate thermal gamma emission from the volume above freeze-out criterion ($e > e_{freezeout}$), or calculate for all volumes. Reality somewhere in between (all volumes interact during hydro evolution). Comparing these options one can estimate theoretical uncertainties

$$\frac{d^3 N^{\gamma,therm}}{dy\, d^2 k_T} = \int_\Omega dV\, dt\, R_\gamma|k, T(x), \mu(x), u(x)|$$



Why simulations in PRC 93 054901 (2016) and PRC 81 044904 (2010) have almost the same yield despite ~5 times difference in energy (35 vs 158 AGeV)?

Comparison with S. Endres, H. van Hees, M. Bleicher, Phys. Rev. C 93, 054901 (2016)

The Bayesian inversion method (Γ-fit): main assumptions

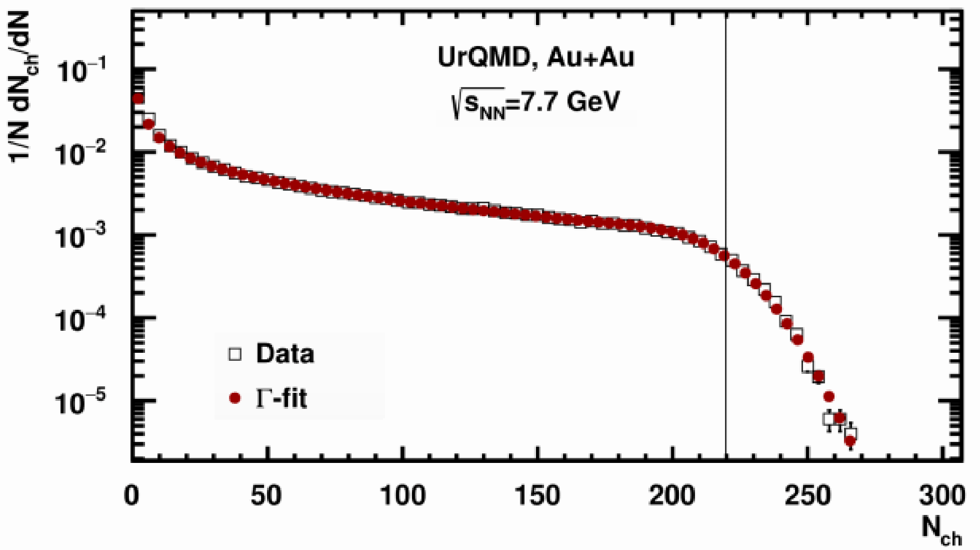
- Relation between multiplicity N_{ch} and impact parameter b is defined by the fluctuation kernel:

$$P(N_{ch}|c_b) = \frac{1}{\Gamma(k(c_b))\theta^k} N_{ch}^{k(c_b)-1} e^{-n/\theta}$$

c_b – impact parameter based centrality

$$c_b = \frac{1}{\sigma_{inel}} \int_0^b P_{inel}(b')2\pi b' db' \simeq \frac{\pi b^2}{\sigma_{inel}}$$

σ_{inel} – geometrical inelastic NN cross section

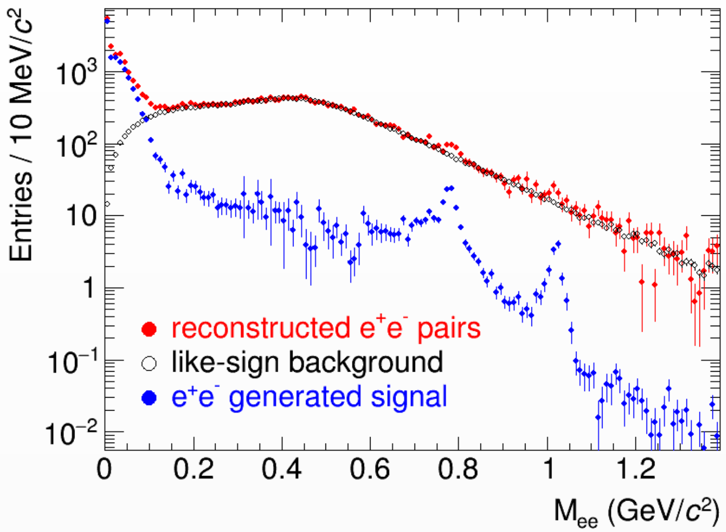


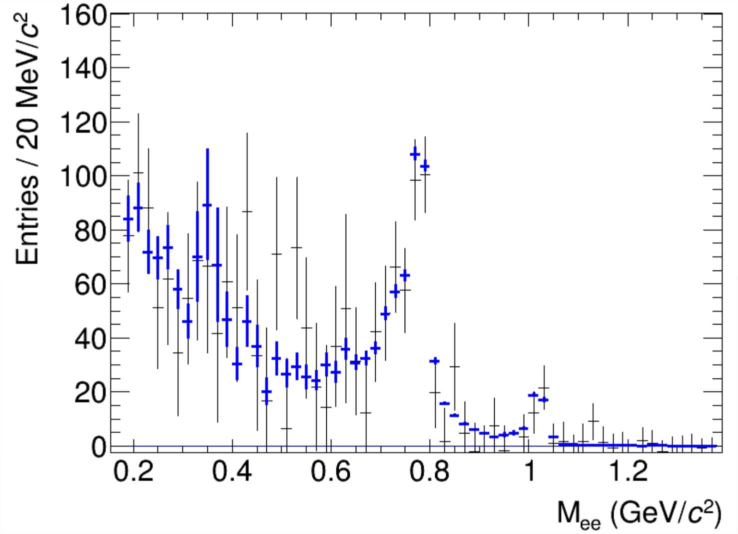
$P_{inel}(b)$ – probability of inelastic NN collision ($P_{inel}(b) \approx 1$)

R. Rogly, G. Giacalone and J. Y. Ollitrault, Phys.Rev. C98 (2018) no.2, 024902

Implementation in MPD: https://github.com/Dim23/GammaFit

Summary for dielectrons





- S/B (integrated in 0.2-1.5 GeV/c2) ~ 5-10%
- Methods to improve S/B ratio with a minimal penalty for pair reconstruction are being developed and matured
- Meaningful measurements for e^+e^- continuum and LVMs would require ~ 10^8 AuAu/BiBi sampled events, first observations will be possible with ~50 M events

NICA and Nuclotron beams

NICA collider beams:

- Heavy ion collisions up to $^{197}Au^{79+}$ + $^{197}Au^{79+}$ at:

  $\sqrt{s_{NN}}$ = 4 - 11 GeV , $L_{average}$ = 10^{27} $cm^{-2}s^{-1}$

  same or higher $L_{average}$ for lighter ions

- Polarized proton and deuteron collisions:

  $p\uparrow p\uparrow$ $\sqrt{s_{pp}}$ = 12 - 26 GeV $L_{max} \approx 10^{32}$ $cm^{-2}s^{-1}$

  $d\uparrow d\uparrow$ $\sqrt{s_{NN}}$ = 4 - 13.8 GeV

Nuclotron extracted beams (for fixed target experiments):

- Light ions and polarized beams of p and d:

  Li - Au = 1 - 4.5 GeV /u

  $p\uparrow$ = 5 - 12.6 GeV

  $d\uparrow$ = 2 - 5.9 GeV/u

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, $cm^{-2}\ s^{-1}$	**1×10^{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)*