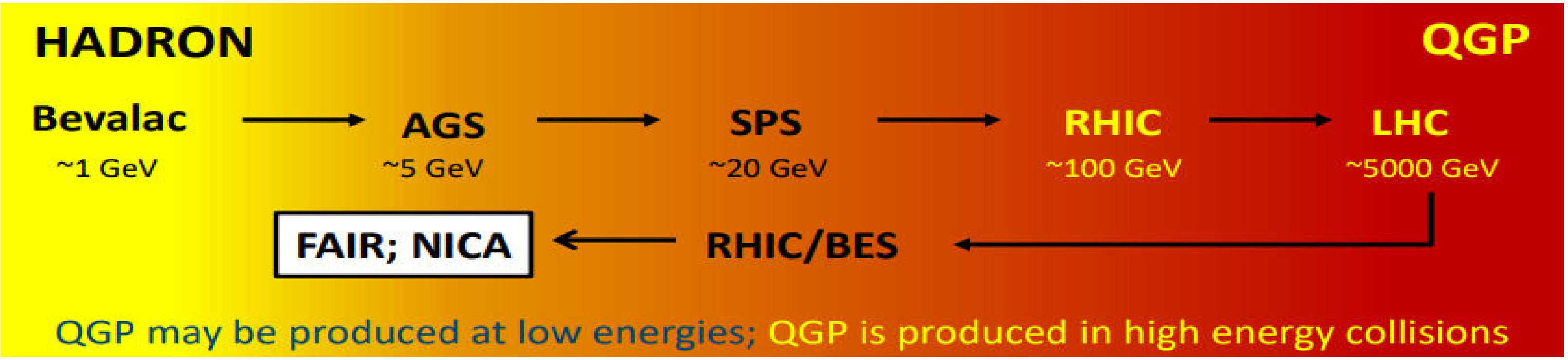
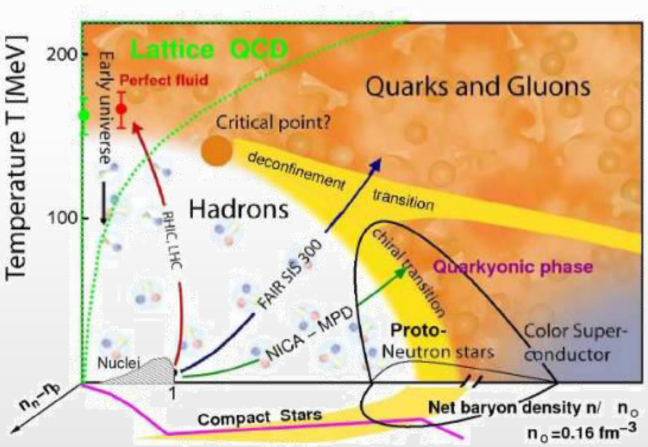
MPD Collaboration Status

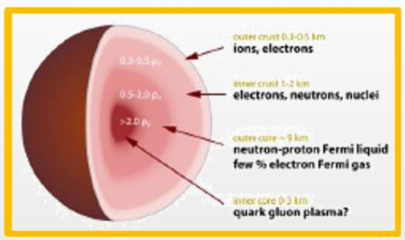
V. Riabov for the MPD Collaboration

Heavy-ion collisions





high baryon densities
→ inner structure of
compact stars



- ❖ At μ_B ~ 0, smooth crossover (lattice QCD calculations + data)
- ❖ At large μ_B, 1st order phase transition is expected → QCD critical point
- ❖ At NICA, both BM@N and MPD study QCD medium at extreme net baryon densities

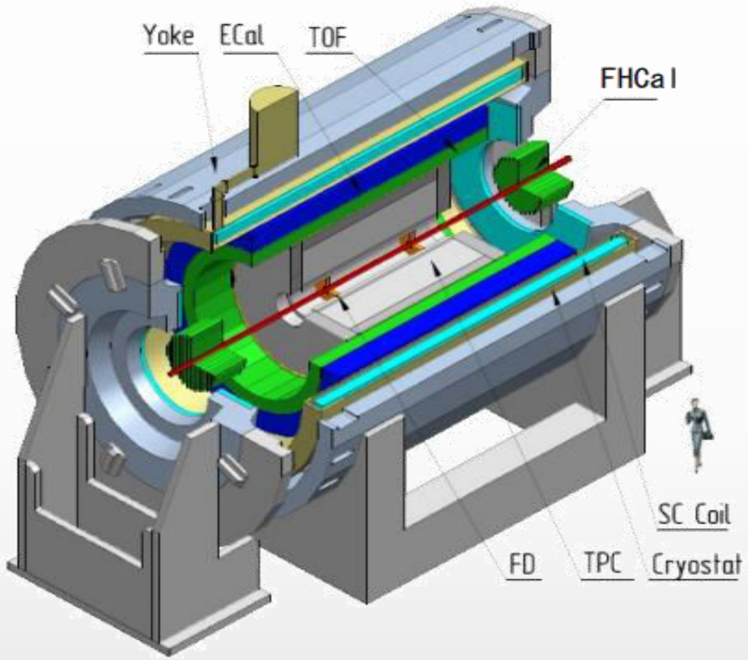
Multi-Purpose Detector (MPD) Collaboration

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

10** Countries, **>450** participants, **31** Institutes and **JINR

Organization

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



***Joint Institute for Nuclear Research**;*
*AANL, Yerevan, **Armenia;***
*University of Plovdiv, **Bulgaria;***
*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**;*
*Tbilisi State University, Tbilisi, **Georgia**;*
*FCFM-BUAP (Heber Zepeda) Puebla, **Mexico**;*
*FC-UCOL (Maria Elena Tejeda), Colima, **Mexico**;*
*FCFM-UAS (Isabel Dominguez), Culiacán, **Mexico**;*
*ICN-UNAM (Alejandro Ayala), Mexico City, **Mexico**;*
*Institute of Applied Physics, Chisinev, **Moldova**;*
*Institute of Physics and Technology, **Mongolia**;*
*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**, Serbia**;*
*Pavol Jozef Šafárik University, Košice, **Slovakia***

NICA

MPD schedule

❖ Latest estimates provided by V. Golovatyuk (subject to change)

	Year 2022	
8	Jan 20 - April 30	Cables for Solenoid probes signals installation
9	May 16 - Dec 25th	Assembling Iron yoke, Cryogenic platform and Cryostat. New LHe and LN pipes ordering
10	Sept - Dec 30	Cryogenic infrastructure for cooling down by temporary scheme, power Supply and Control system preparation
	Year 2023	
11	Jan 15 - February 15th	Vacuum test of Solenoid with Cryostat
12	Feb 15 - April 20	Solenoid cooling down to Liquid Helium temperature
13	May 10 - July 20	Magnetic Field measurements
14	July 25 - August 10	Support Frame installation
15	August 20 – Sept 30th	Installation ECal sectors, Moving Platforms mounting
16	Sept 17 – Oct 10th	Installation TOF modules, FHCal into poles
17	Oct 11 - Nov 30	TPC installation
18	Sept 18 - Nov 30	Cabling
19	Dec 4 - Dec 25	Installation of beam pipe
	Year 2024	
20	Jan 10 - Feb	Switching on the MPD, Commissioning

❖ Preparation of the MPD detector and experimental program is ongoing, all activities are continued

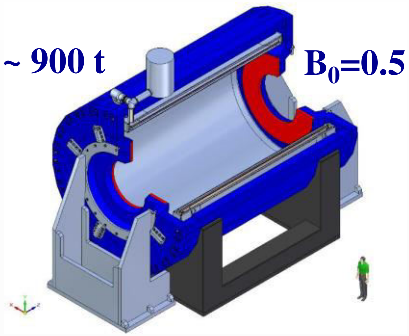
❖ All components of the MPD 1-st stage detector are in advanced state of production (subsystems, support frame, electronics platforms, LV/HV, control systems, cryogenics, cabling, etc.)

MPD magnet

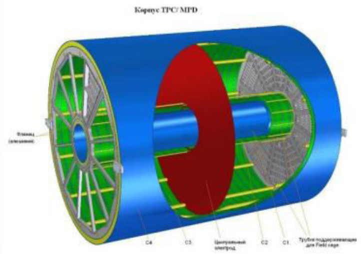
- ❖ Barrel Magnet Yoke is completely assembled
- ❖ Cryogenic platform has been mounted, next step is mounting of the refrigerator, vacuum pumps, control electronics, etc.
- ❖ Assembling the refrigerator for installation on the platform
- ❖ Works on the magnet control system, cryogenics and power supplies
- ❖ Magnetic field mapper and magnetic field measurements

MPD subsystems in production

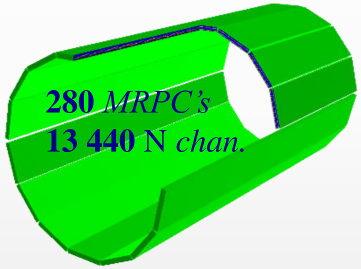
SC Solenoid + Iron Yoke

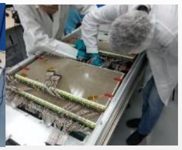


TPC – central tracking detector



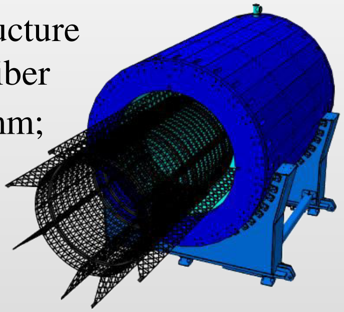
TOF





Support structure

support structure
of carbon fiber
sagite ~ **5** mm;
0,13 X_0



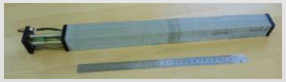
ECAL ~ 100 t

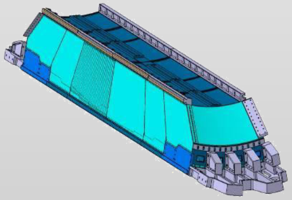
ECAL

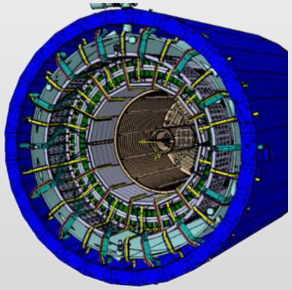
Pb+Sc "shashlyk"

38 400 towers

70% sectors in
production for Stage I





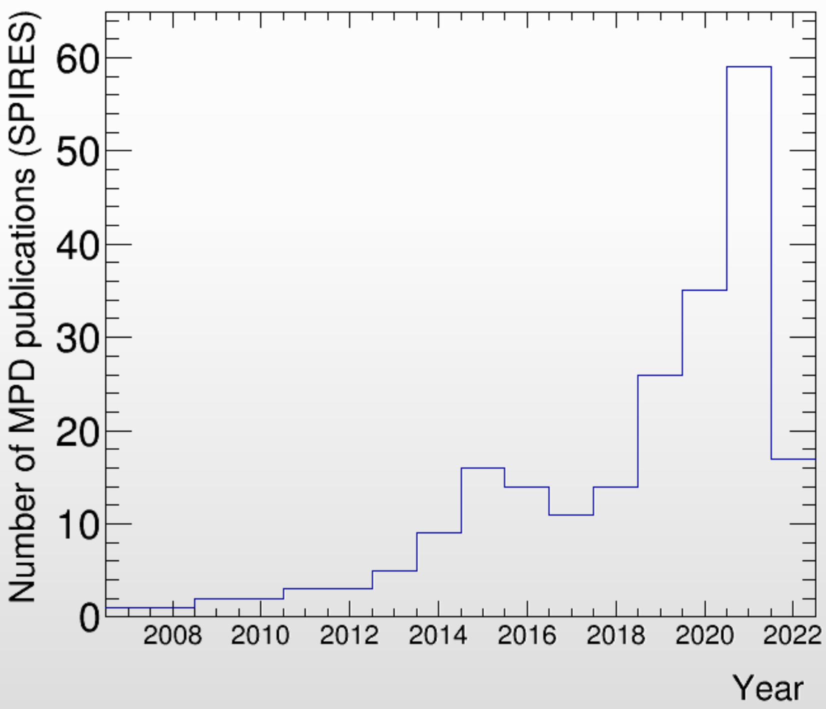


*** Excursion to the MPD Hall on Wednesday morning**
**** See subsystem reports for details**

Collaboration activity

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

- MPD publications: ~ 220 in total for hardware, software and physics studies:
  - ✓ RFBR grant program (now completed) attracted many new Russian institutions in the NICA activities
  - ✓ financial support for participation of Russian institutions in the MPD-NICA is needed for success of the project



Presence at conferences

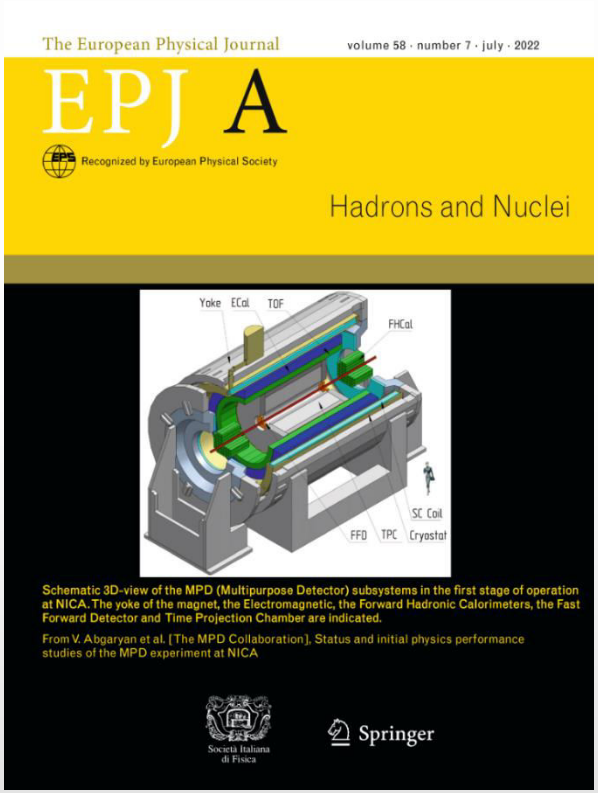
- MPD was presented at all major conferences in the field:
  - ✓ Quark Matter (QM-2022), 4-10 April
  - ✓ Nucleus-2022, July 11-16
  - ✓ International Conference on High Energy Physics (ICHEP-2022), July 6-13
  - ✓ International Scientific Forum "Nuclear Science and Technologies (NST-2022), September 26-30
  - ✓ European Nuclear Physics Conference (EuNPC-2022), October 24-28
  - ✓ International Symposium on Origin of Matter and Evolution of Galaxies, October 25-28
  - ✓ DAE-BRNS CETHENP-2022, November 15-17
  - ✓ XVIII Mexican Workshop on Particles and Fields (XVIII MWPF), November 21-25
  - ✓ International Conference on Particle Physics and Astrophysics (ICPPA-2022), Nov.,29-Dec.,2

- Over twenty plenary and parallel talk given in 2022

First collaboration paper

- First collaboration paper recently published EPJA (~ 50 pages): Eur.Phys.J.A 58 (2022) 7, 140

Status and initial physics performance studies of the MPD experiment at NICA



Eur. Phys. J. A manuscript No.
(will be inserted by the editor)

Status and initial physics performance studies of the MPD experiment at NICA

The MPD Collaboration[1]

[1]The full list of Collaboration Members is provided at the end of the manuscript

Received: April 20, 2022/ Accepted: date

Abstract The Nuclotron-based Ion Collider fAcility (NICA) is under construction at the Joint Institute for Nuclear Research (JINR), with commissioning of the facility expected in late 2022. The Multi-Purpose Detector (MPD) has been designed to operate at NICA and its components are currently in production. The detector is expected to be ready for data taking with the first beams from NICA. This document provides an overview of the landscape of the investigation of the QCD phase diagram in the region of maximum baryonic density, where NICA and MPD will be able to provide significant and unique input. It also provides a detailed description of the MPD set-up, including its various subsystems as well as its support and computing infrastructures. Selected performance studies for particular physics measurements at MPD are presented and discussed in the context of existing data and theoretical expectations.

Keywords NICA · MPD · QCD

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1 Introduction

The Multi-Purpose Detector (MPD) is one of the two dedicated heavy-ion collision experiments of the Nuclotron-based Ion Collider fAcility (NICA), one of the flagship projects, planned to come into operation at the Joint Institute for Nuclear Research (JINR) in 2022. Its main scientific purpose is to search for novel phenomena in the baryon-rich region of the QCD phase diagram by means of colliding heavy nuclei in the energy range of 4 GeV $\leq \sqrt{s_{NN}} \leq$ 11 GeV.

Editorial Committee: A. Ayala, D. Blaschke, S. Golovatyuk, A. Kisiel, V. Kolesnikov, V. Riabov, O. Rogachevsky, A. Taranenko

IRC: I. Tserruya (chair), F. Wang, Z. Tang

MPD physics program

G. Feofilov, A. Aparin

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

V. Kolesnikov, Xianglei Zhu

Spectra of light flavor and hypernuclei
- Light flavor spectra
- Hyperons and hypernuclei
- Total particle yields and yield ratios
- Kinematic and chemical properties of the event
- Mapping QCD Phase Diag.

K. Mikhailov, A. Taranenko

Correlations and Fluctuations
- Collective flow for hadrons
- Vorticity, Λ polarization
- E-by-E fluctuation of multiplicity, momentum and conserved quantities
- Femtoscopy
- Forward-Backward corr.
- Jet-like correlations

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

❖ Cross-PWG format of meetings for discussion of results and analysis techniques
  - ✓ increase the attendance
  - ✓ improve communication between different analysis groups

MPD mass productions

- Mass productions to deliver a clear and consistent picture of the MPD physical capabilities with the first data sets and prepare for the real data analyses

- https://mpdforum.jinr.ru/c/mcprod/26:

  Request 25: General-purpose, 50M UrQMD BiBi@9.2 → **DONE**

  Request 26: General-purpose (trigger), 1M DCM-QGSM-SMM BiBi@9.2 → **DONE**

  Request 27: General-purpose (trigger), 1M PHQMD BiBi@9.2 → **DONE**

  Request 28: General-purpose with reduced magnetic field, 10M UrQMD BiBi@9.2 → **DONE**

  Request 29: General-purpose (hypernuclei), 20M PHQMD BiBi@9.2 → **production**

  Request 30: General-purpose (hyperon polarization), 15M PHSD BiBi@9.2 → **QA**

  Request 31: General-purpose (femtoscopy), 50 M UrQMD BiBi@9.2 with freeze-out → **QA**

  Request 32: General purpose (flow), 15M vHLLE+UrQMD with XPT → **in preparation**

  Request 33: General purpose (flow), 15M vHLLE+UrQMD with 1PT → **in preparation**

- Production and analysis of data sets, which are comparable in size to the first expected real data samples test the existing computing and software infrastructure, the communication bridges between the analyzers, software group and specialists from the laboratory of information technologies (LIT)

- Thanks to Andrey Moshkin and the whole software team !!!

Handling of data sets

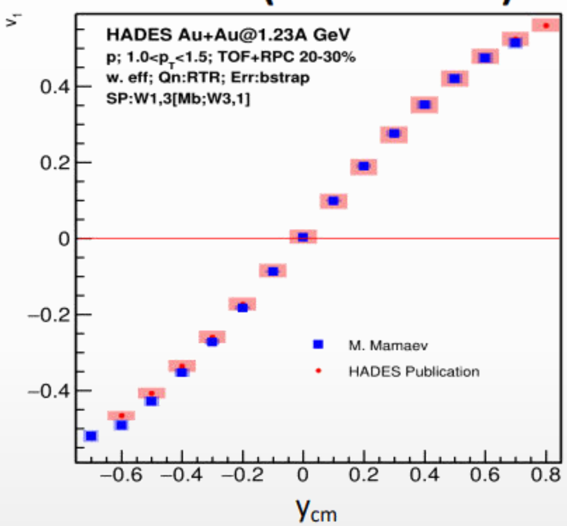
- Dedicated Task Force groups (TF):
  - ✓ trigger system efficiency and performance
  - ✓ event vertex and start time reconstruction
  - ✓ event centrality categorization
  - ✓ charged particle identification (TPC, TOF)
  - ✓ electron and photon identification (ECAL)
  - ✓ estimation of the detector material budget
- TF results and recommendations should be used centralized to make sure that all analyses are performed in a consistent way and can be compared
- As more and more analyzers start to work with the data we will have a series of crow-PWG meetings to discuss the analysis methods
- Production of physics feasibility results
- Second collaboration paper, better understanding of our capabilities with the first data sets, priorities for different analyses, analysis technics and group leaders, …

Advancements in analyses

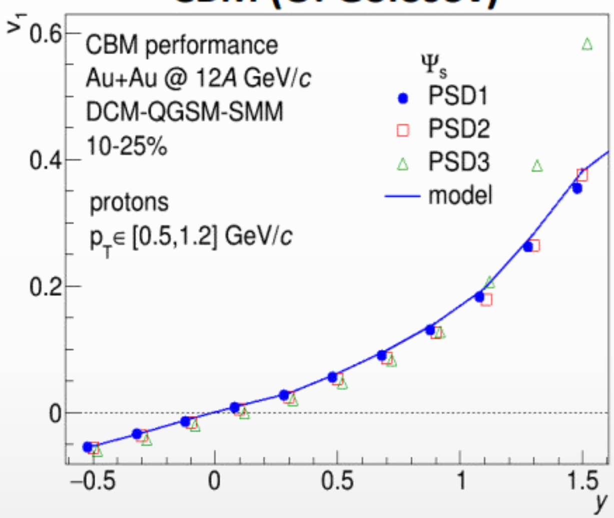
Advancements in analyses

❖ Implementation of QnAnalysis framework/package for flow measurements in MPD

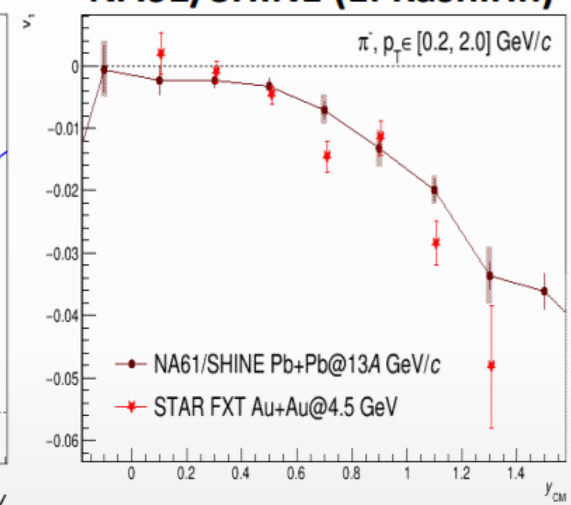
HADES (M. Mamaev)



CBM (O. Golosov)



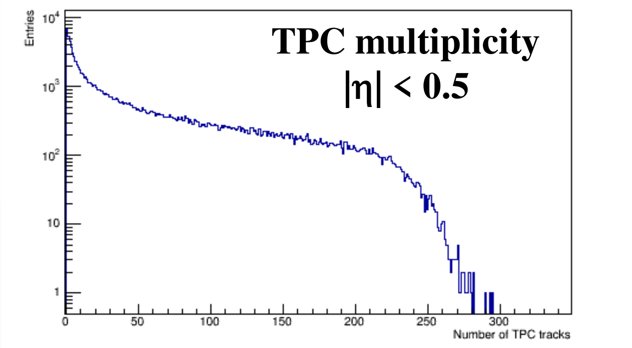
NA61/SHINE (E. Kashirin)

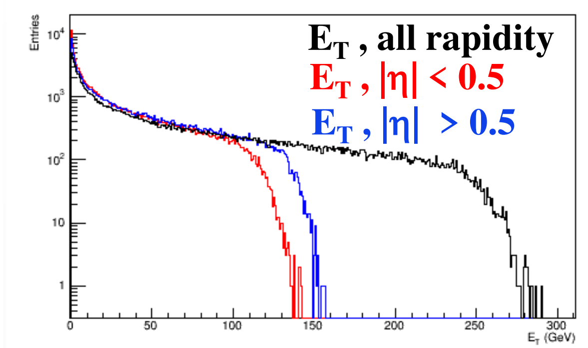


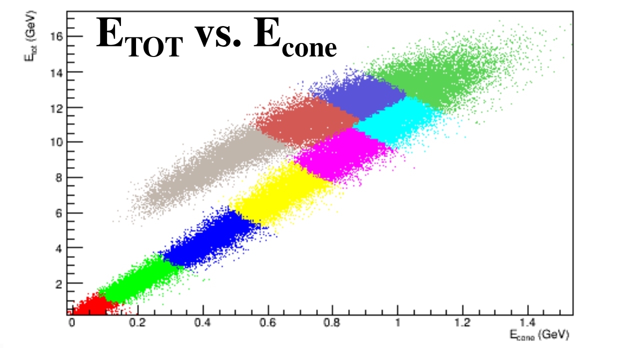
QnAnalysis is already used in the current (HADES, ALICE) and future (CBM) experiments
Now it is available in MPD

Centrality categorization

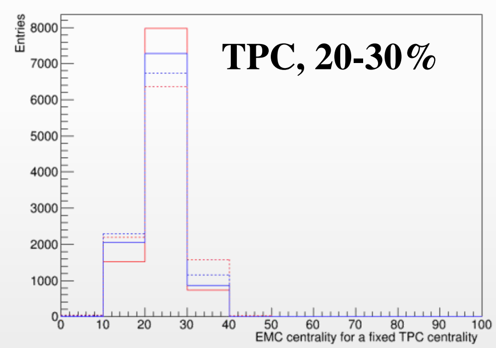
- ❖ Use TPC multiplicity, transverse energy E_T and FHCAL energy to determine event centrality

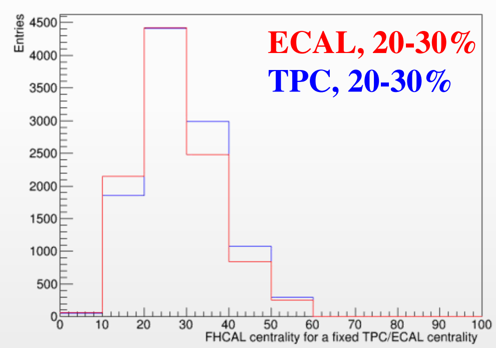


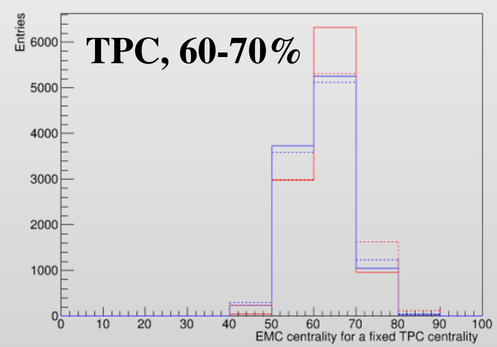


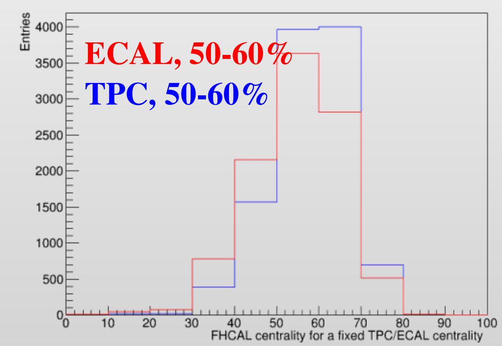


- ❖ TPC and ECAL produce similar results for centrality
- ❖ FHCAL centrality has a very wide correlation with the TPC/ECAL centrality; resolution by impact parameter is worse



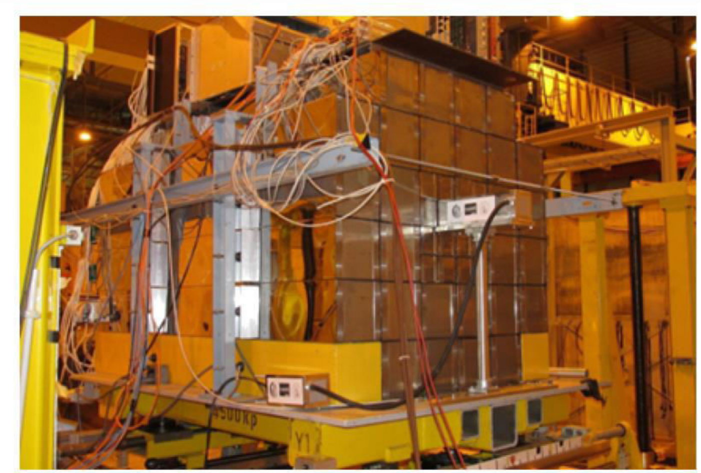




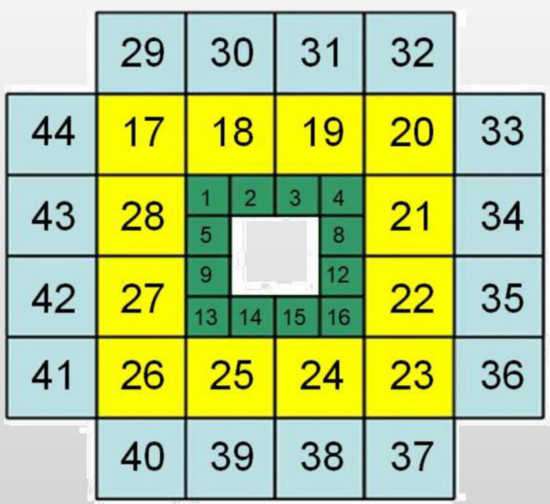


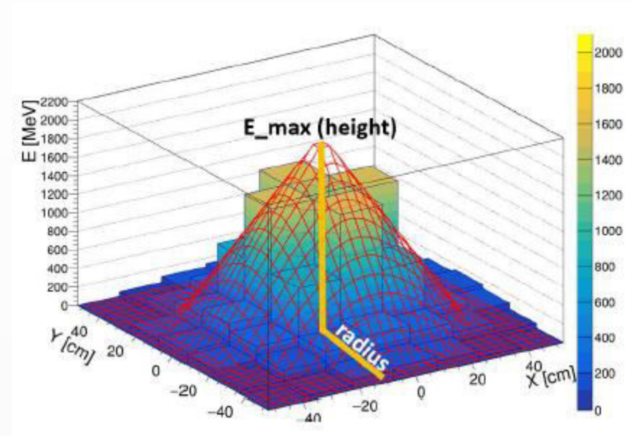
Verification of fragmentation models with NA61 data

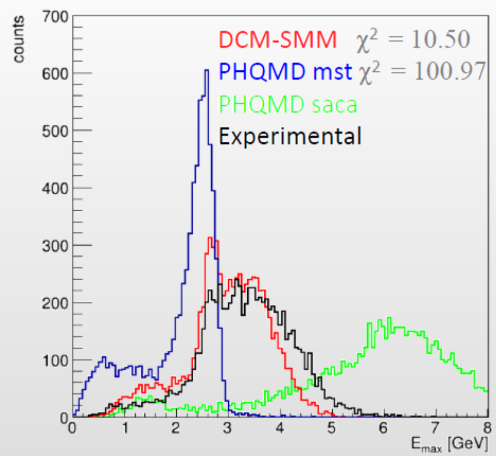
❖ Experimental data for hadronic calorimeter (PSD) in Pb-Pb at 30 GeV/n, fixed-target

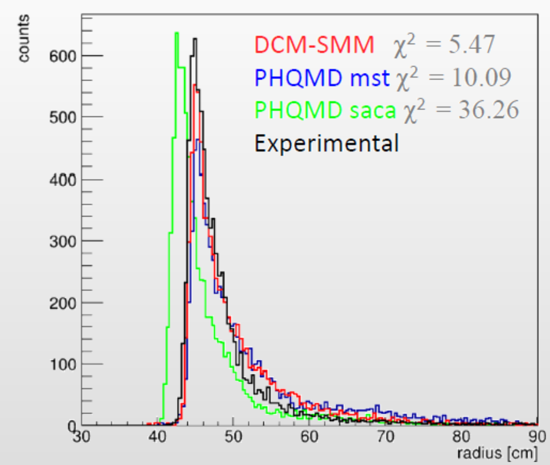


PSD on the beam line downstream of the NA61/SHINE









The DCM-SMM reproduces the measurement results, PHQMD not

NICA

Light (hyper)nuclei

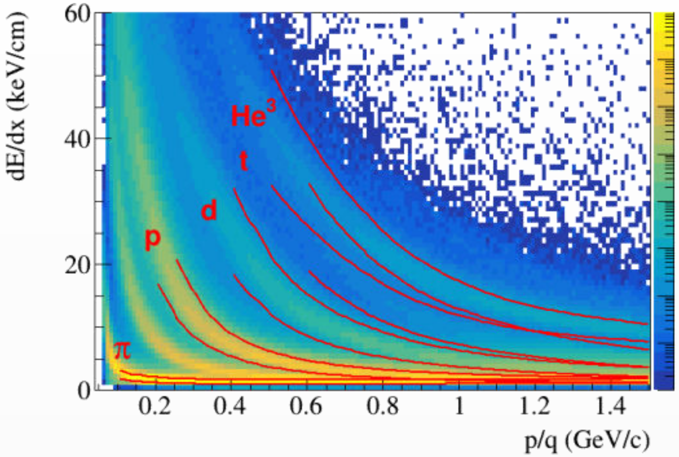
- ❖ Production mechanism usually described with two classes of phenomenological models :
  - ✓ statistical hadronization (SHM) → production during phase transition, $dN/dy \propto \exp(-m/T_{chem})$ [1]
  - ✓ coalescence → (anti)nucleons close in phase space ($\Delta p < p_0$) and matching the spin state form a nucleus [2]
- ❖ Hyper nuclei measurement studies are crucial:
  - ✓ microscopic production mechanism, Y-N potential, strange sector of nuclear EoS
  - ✓ strong implications for astronuclear physics → hyperons expected to exist in the inner core of neutron stars
- ❖ Observables of interest: precise measurements of binding energies, lifetimes and branching ratios

- ❖ Galactic Cosmic Rays composed of nuclei (protons, … up to Fe) and E/A up to 50 GeV
- ❖ Cosmic rays are a serious concern to astronauts, electronics, and spacecraft.
- ❖ The damage is proportional to Z^2, therefore the component due to ions is important
- ❖ Damage from secondary production of p, d, t, ^{3}He, and ^{4}He is also significant
- ❖ Need input information for transport codes for shielding applications (Geant-4, Fluka, PHITS, etc.):
  - ✓ total, elastic/reaction cross section
  - ✓ particle multiplicities and coellecense parameters
  - ✓ outgoing particle distributions: $d^2N/dEd\Omega$

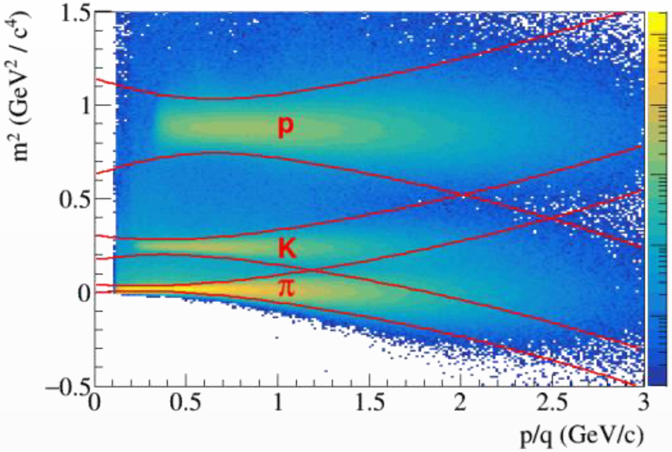
[1] Andronic et al., Nature 561 (2018) 321–330
[2] Butler et al., Phys. Rev. 129 (1963) 836

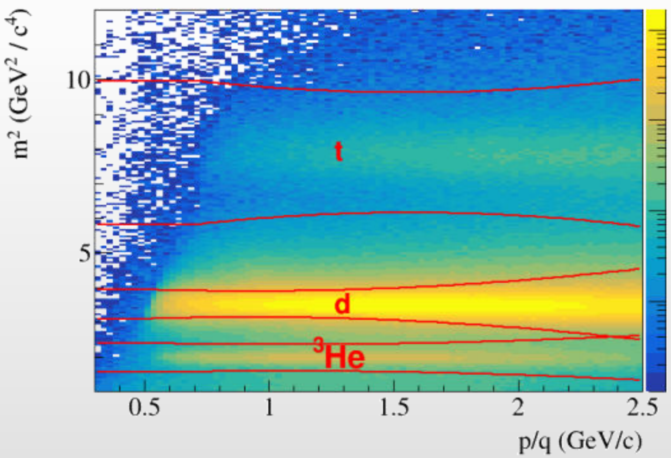
High energy heavy ion reaction data

dE/dx vs momentum in TPC



m² vs. momentum in TOF



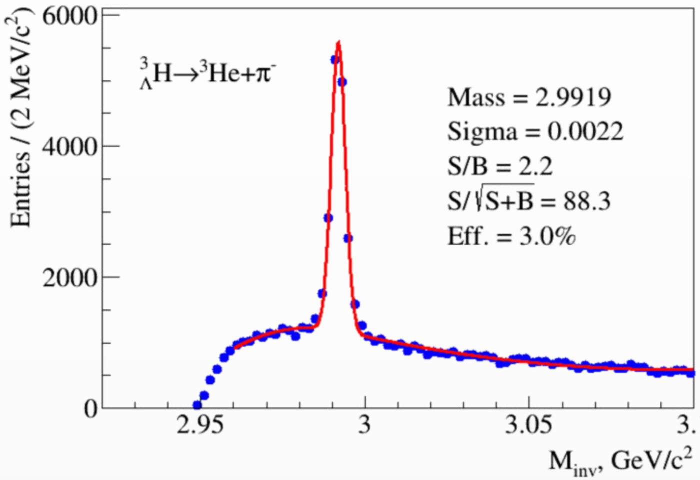


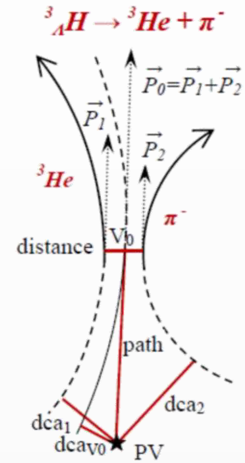
MPD has excellent light fragment identification capabilities in a wide rapidity range → unique capability of the MPD in the NICA energy range

Reconstruction of hypertritons

BiBi@9.2 GeV (PHQMD), 40 M events → full event/detector simulation and reconstruction

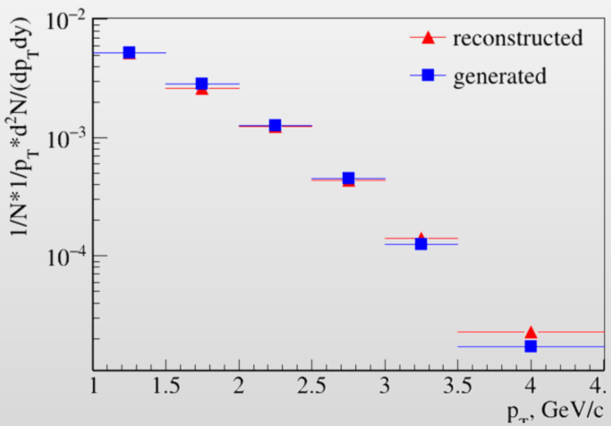
Phys.Part.Nucl.Lett. 19 (2022) 1, 46-53



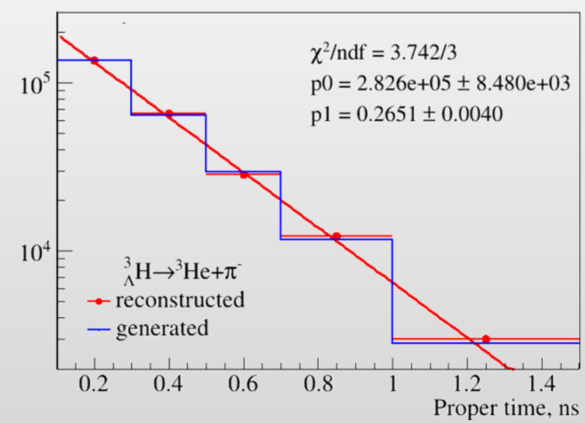


Decay channel	Branching ratio	Decay channel	Branching ratio
$\pi^- + {}^3He$	24.7%	$\pi^- + p + p + n$	1.5%
$\pi^0 + {}^3H$	12.4%	$\pi^0 + n + n + p$	0.8%
$\pi^- + p + d$	36.7%	$d + n$	0.2%
$\pi^0 + n + d$	18.4%	$p + n + n$	1.5%

Spectrum is reconstructed up to p_T=4.5 GeV/c

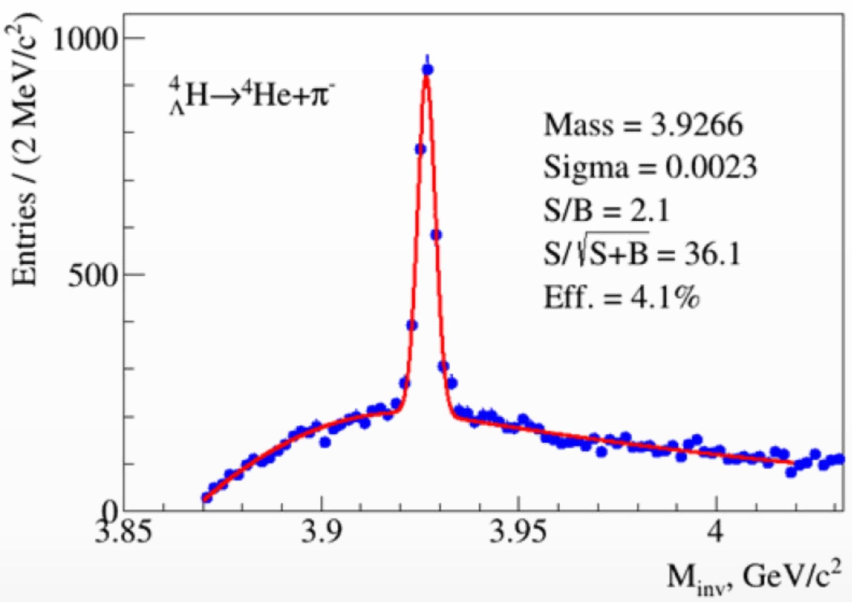


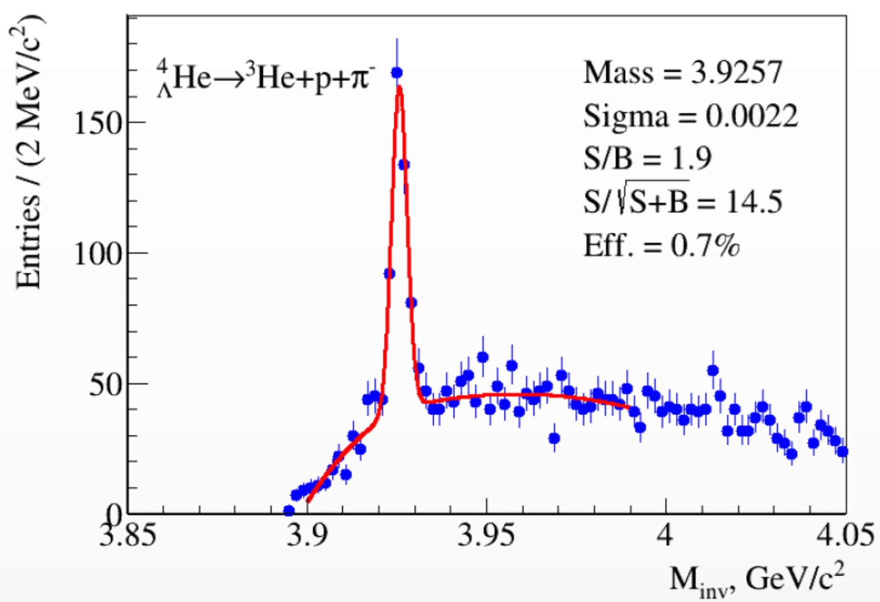
$$N(\tau) = N(0)\exp\left(-\frac{\tau}{\tau_0}\right) = N(0)\exp\left(-\frac{ML}{cp\tau_0}\right),$$



❖ First measurements for hypertriton will be possible with accumulation of ~ 50 M BiBi@9.2 events

Heavier hypernuclei

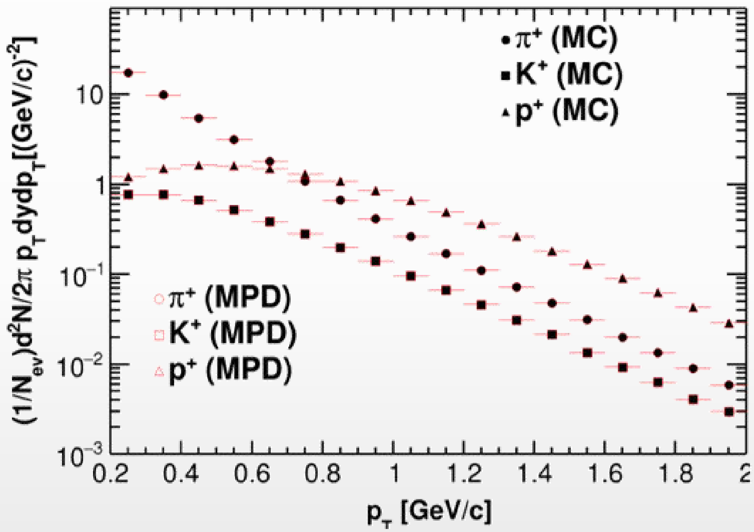


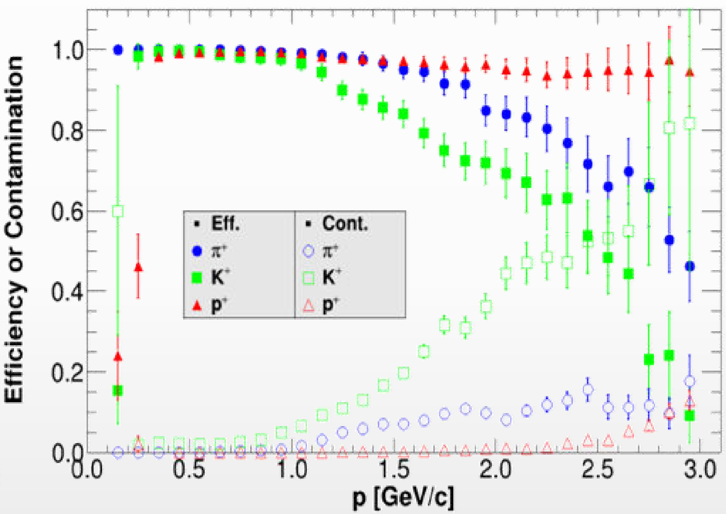


- Monte Carlo events enriched with hypernuclei distributed by (η-p_T) phase space predicted by PHQMD
- Signals for heavier hypernuclei can be reconstructed with the equivalent statistics of ~140 M events

Improved PID

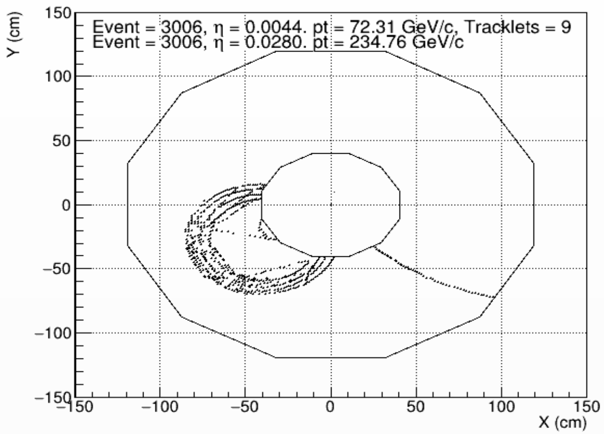
- Development of methods for identification of charged tracks using the TPC and TOF
- Purpose: higher efficiency and purity of the signals
- Options: different field configurations, systems and energies, methods, including machine learning approaches (Decision Tree Approach)



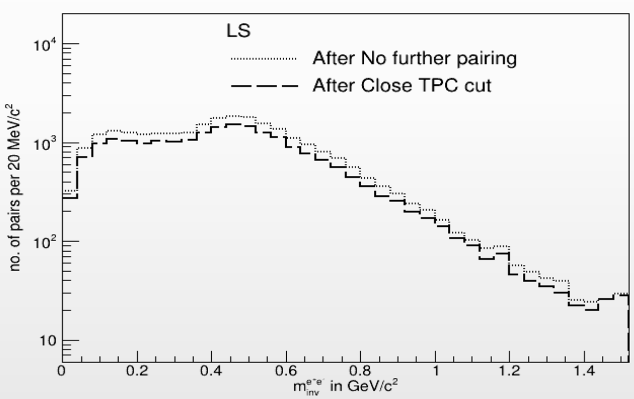


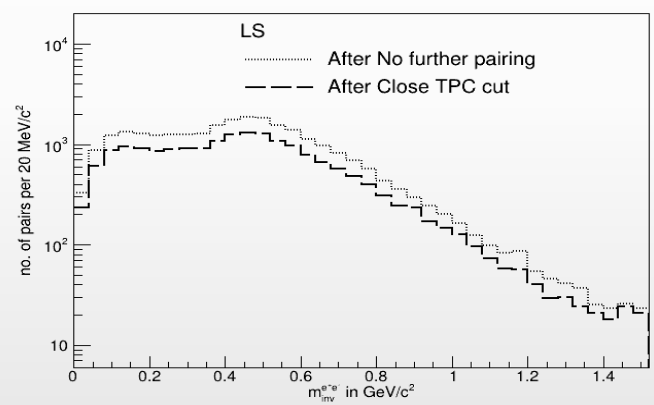
- Critical questions:
  - ✓ extend measurements to lower momenta ($\langle p_T \rangle \sim 0.2$ GeV/c for light hadrons)
  - ✓ understand fraction of π/K/p from decays and materials

Dielectrons



- With current track reconstruction algorithm, low p_T tracks are not reconstructed properly even though full hit information is available in the detector for tracks with $p_T \gtrsim 30$ MeV → major source of CB.
- Tracks with p_T <~ 100 MeV do not cross the TPC (hence don't reach TOF → Not defined as fully reconstructed).





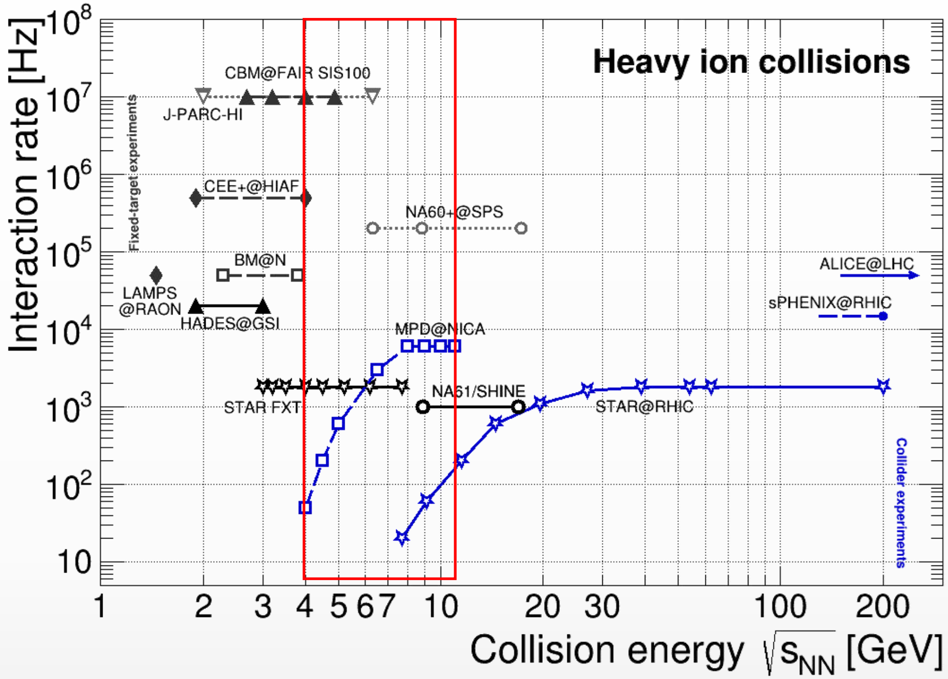
- Optimization steps:
  - ✓ new DCA parameterizations
  - ✓ loose cuts on the partner
  - ✓ crossing angle correction improves low-pT track reconstruction
- Observe 30% reduction of combinatorial background → expects further improvements

Summary

- Preparation of the MPD detector and experimental program is ongoing, all activities are continued
- Commissioning of the MPD Stage-I detector is expected in 2023
- Start of data taking with BiBi@9.2 in 2024
- Further program will be driven by the physics demands and NICA capabilities

BACKUP

Heavy-ion collisions



- Many ongoing programs and future experiments in comparable energy ranges
- Physical program of the MPD should be considered in close cooperation with BM@N
- Continuously develop MPD physical program based on the recent advancements in the field:
- Close cooperation with theoreticians to look for new signals/observables unique for the MPD

RHIC BES program

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

Au+Au Collisions at RHIC

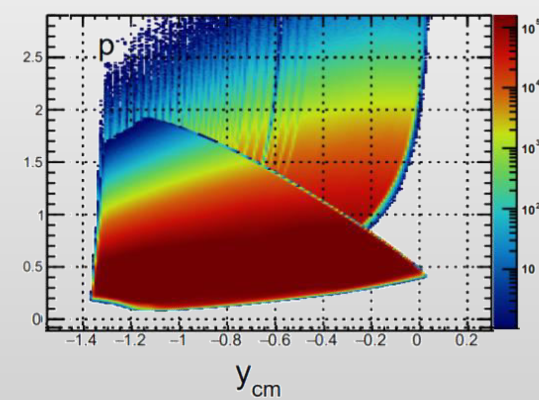
Collider Runs						Fixed-Target Runs					
	$\sqrt{s_{NN}}$ (GeV)	#Events	μ_B	y_{beam}	run		$\sqrt{s_{NN}}$ (GeV)	#Events	μ_B	y_{beam}	run
1	200	380 M	25 MeV	5.3	Run-10, 19	1	13.7 (100)	50 M	280 MeV	-2.69	Run-21
2	62.4	46 M	75 MeV		Run-10	2	11.5 (70)	50 M	320 MeV	-2.51	Run-21
3	54.4	1200 M	85 MeV		Run-17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

❖ A very impressive and successful program with many collected datasets, already available and expected results

❖ Limitations:

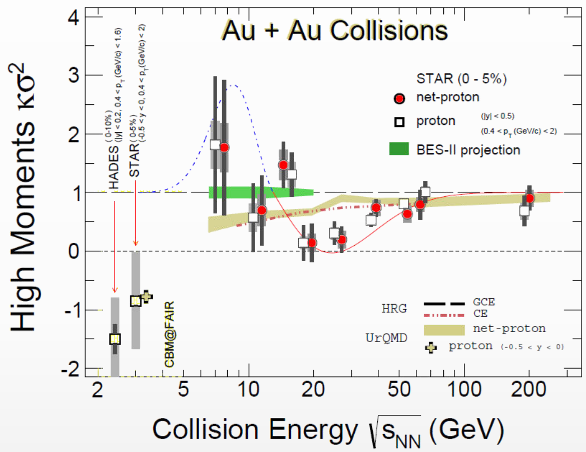
- ✓ Au+Au collisions only
- ✓ Among the fixed-target runs, only the 3 GeV data have full mid-rapidity coverage for protons ($|y| < 0.5$), which is crucial for physics observables

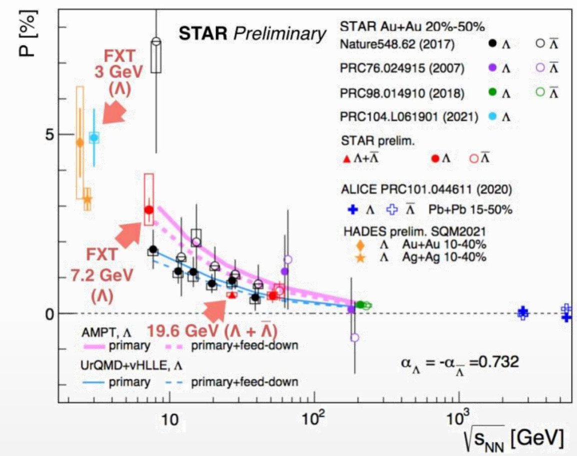
Au+Au @ 3.9 GeV

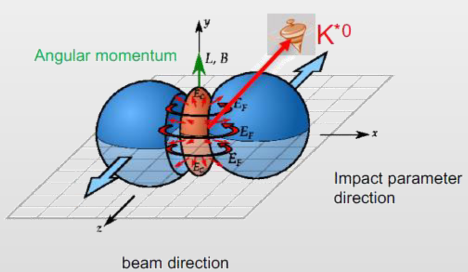


Hot topics to fill the gaps

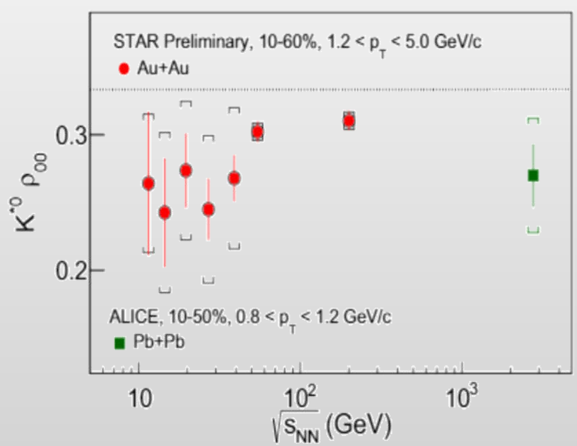
- Critical fluctuations for (net)proton/kaon multiplicity distributions
- Global hyperon polarization in mid-central A+A collisions (Λ, Ξ, Ω)
- Spin alignment of vector mesons ($K^*(892)$, $\phi(1020)$)
- Dielectron continuum and LVMs
- ….

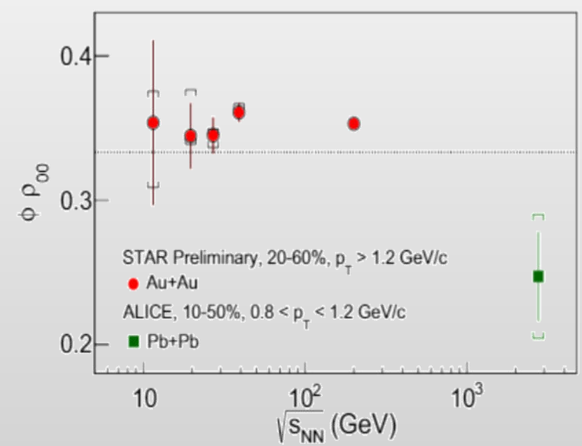






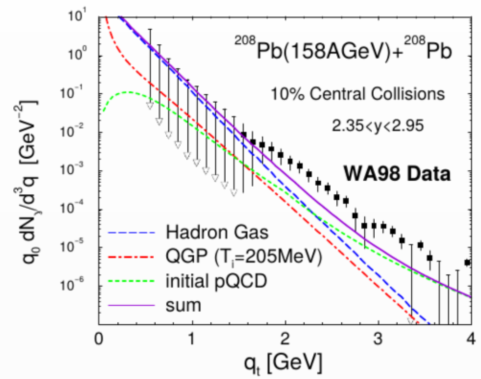
$$\frac{dN}{d\cos\theta} = N_0\left[1 - \rho_{0,0} + \cos^2\theta\left(3\rho_{0,0} - 1\right)\right]$$





Direct photons

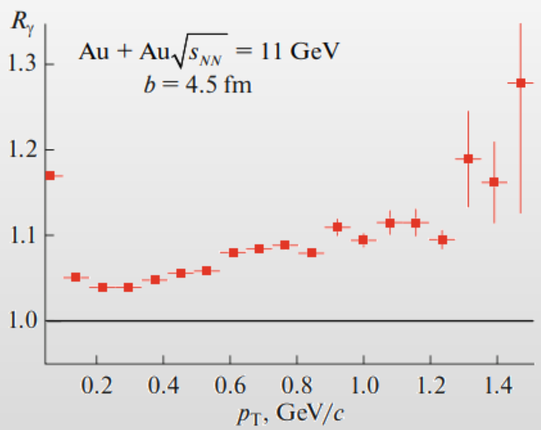
- Direct photons – photons not from hadronic decays:
  - ✓ penetrating probe
  - ✓ low-E - most direct estimation of the effective system temperature
  - ✓ high-E - hard scattering probe
- Direct photons in A-A collisions:
  - ✓ LHC, PbPb @ 2.76 and 5 TeV
  - ✓ RHIC, Au-Au(CuCu) @ 62-200 GeV
  - ✓ SPS, PbPb @ 17.2 GeV
- No measurements at NICA energies: yields and flow vs. p_T and centrality



<u>Direct photon yields @NICA</u>

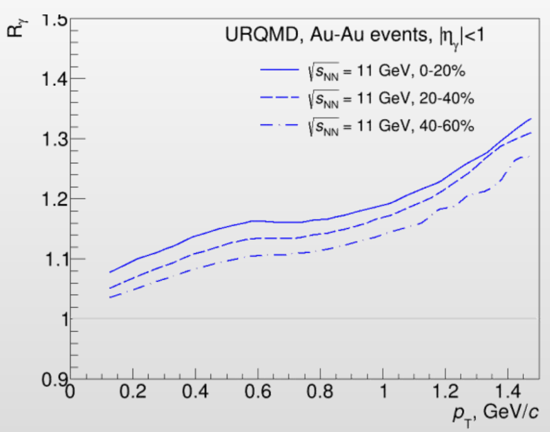
model calculations

empirical scaling



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

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



- Non-zero direct photon yields are predicted with Rγ ~ 1.05 – 1.15 and v2 ~ 0.5% at top NICA energy
- MPD can provide <u>unique measurements</u> for direct photon production in the NICA energy range

Unique possibilities

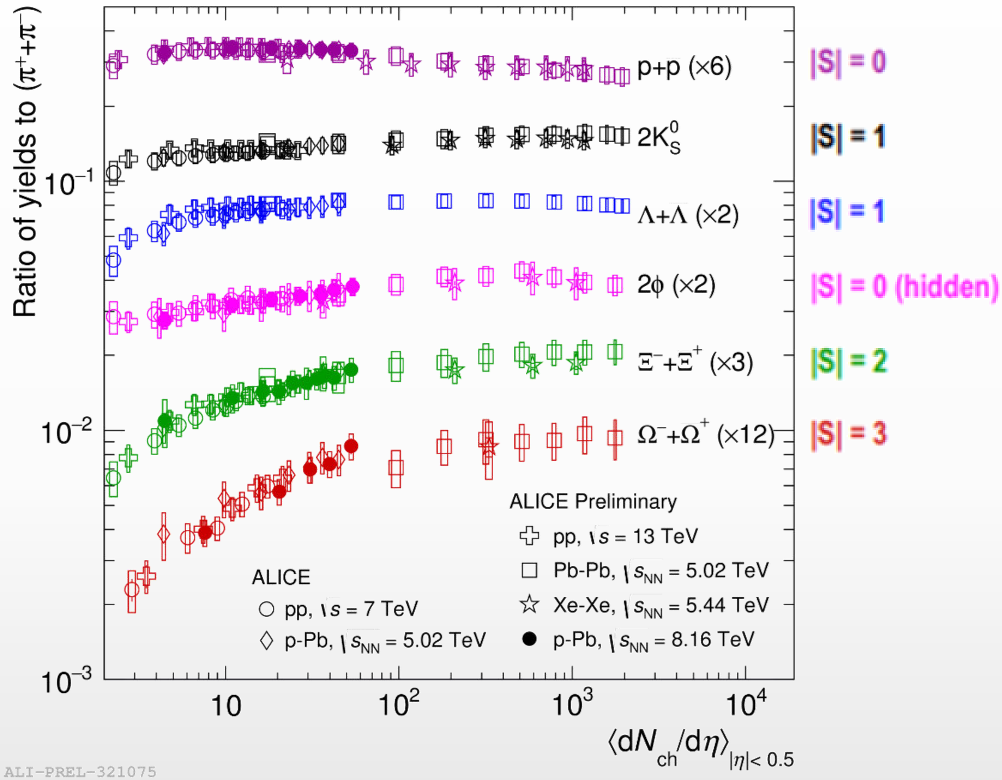
- MPD strategy – high-luminosity scans in **energy** and **system size** to measure a wide variety of signals:
  - ✓ order of the phase transition and search for the QCD critical point → structure of the QCD phase diagram
  - ✓ hypernuclei and equation of state at high baryon densities → inner structure of compact start, star mergers

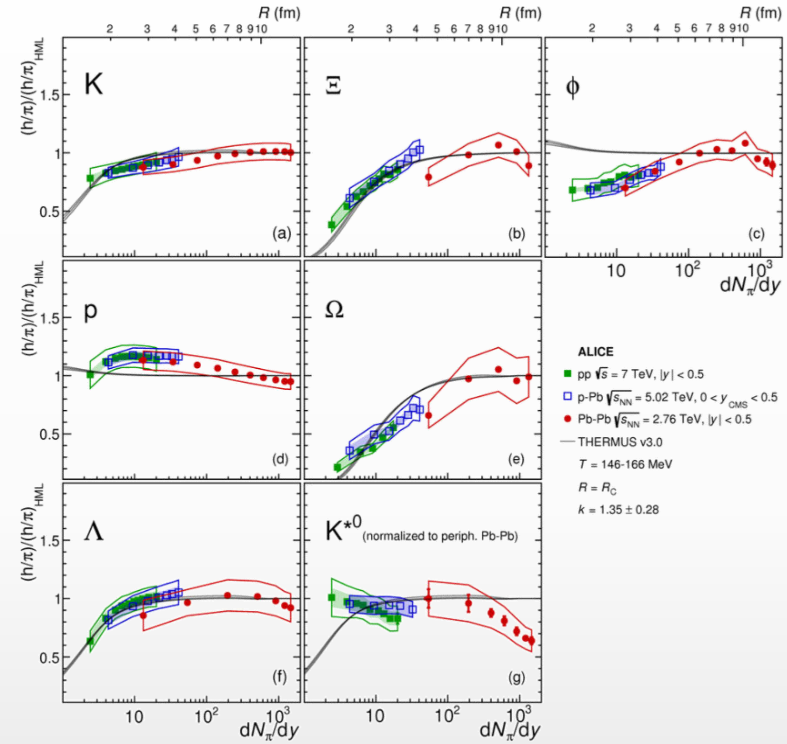
- Scans to be carried out using the **same apparatus** in the same configuration/geometry with all the advantages of collider experiments:
  - ✓ maximum phase space, minimally biased acceptance, free of target parasitic effects
  - ✓ correlated systematic effects for different systems and energies → simplified extraction of physical signals

Strangeness enhancement: pp, p-A, A-A

❖ Predicted and experimentally observed in heavy-ion collisions at AGS, SPS, RHIC and LHC energies

Nature Phys. 13 (2017) 535





❖ Discovery of ALICE - smooth evolution of enhancement vs. multiplicity in pp, p-A and A-A

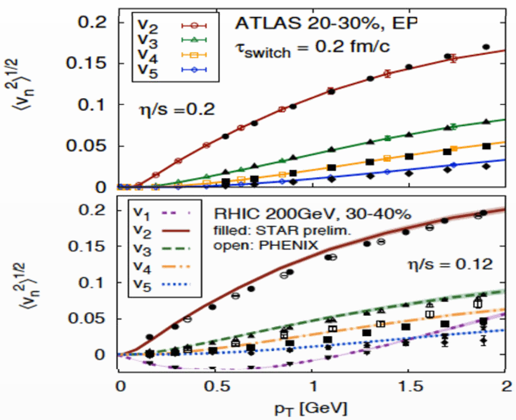
❖ Origin of the strangeness enhancement in small/large systems is still under debate:
- ✓ strangeness enhancement in QGP contradicts with the observed collision energy dependence
- ✓ strangeness suppression in pp within canonical suppression models reproduces most of results except for ϕ(1020)

❖ System size scan for (multi)strange baryon and meson production is a key to understanding of strangeness production → <u>unique capability of the MPD</u> in the NICA energy range

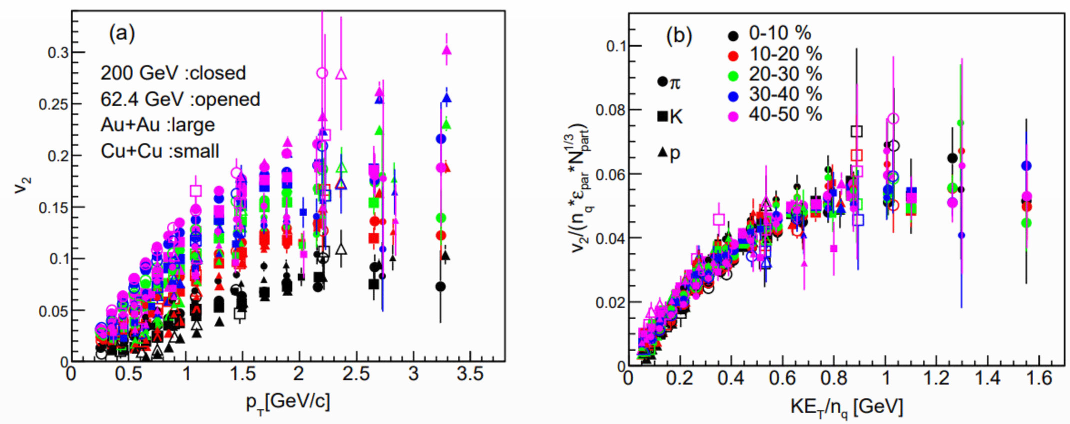
Anisotropic flow in large/small systems

❖ A+A: initial eccentricity and its fluctuations drive v_n with specific viscous modulation

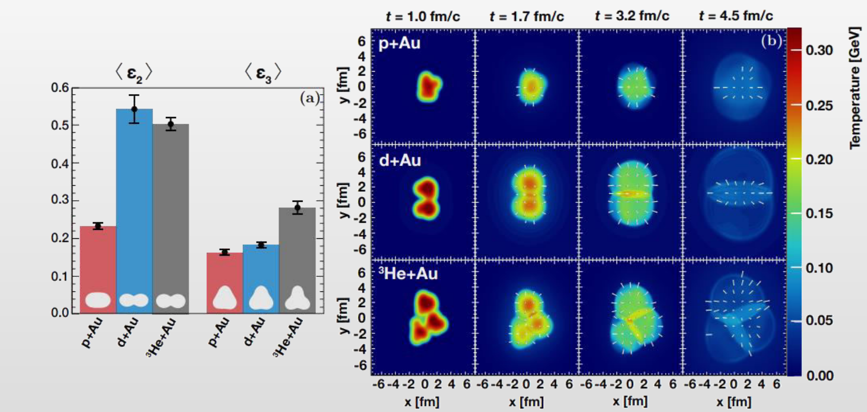
Gale, Jeon et al., Phys. Rev. Lett. 110, 012302



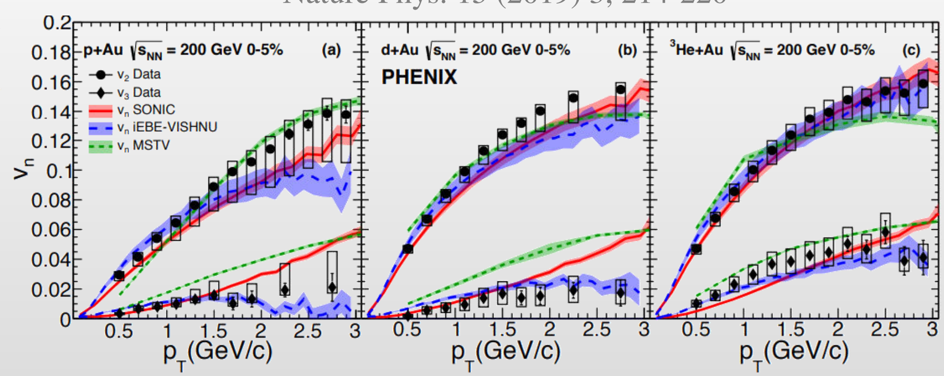
Phys.Rev.C 92 (2015) 3, 034913



❖ p/d/³He+A: v_n's are correlated to the initial geometry, the only explanation is formation of short-lived QGP droplets in collisions of light and heavy nuclei



Nature Phys. 15 (2019) 3, 214-220

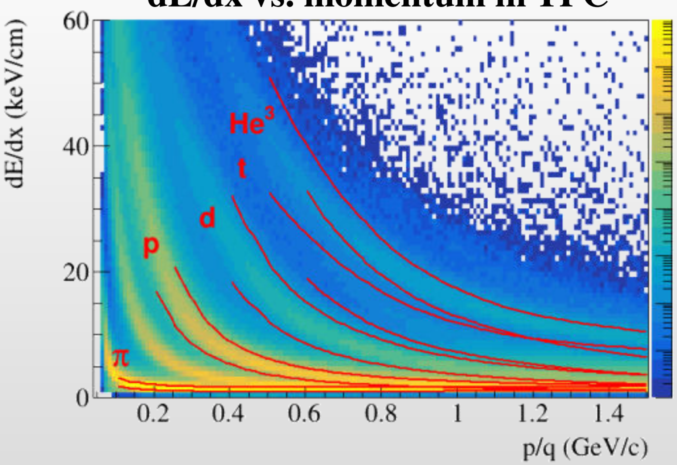


System size scan for flow measurements is vital for understanding of the medium transport properties and onset of the phase transition → <u>unique capability of the MPD</u> in the NICA energy range

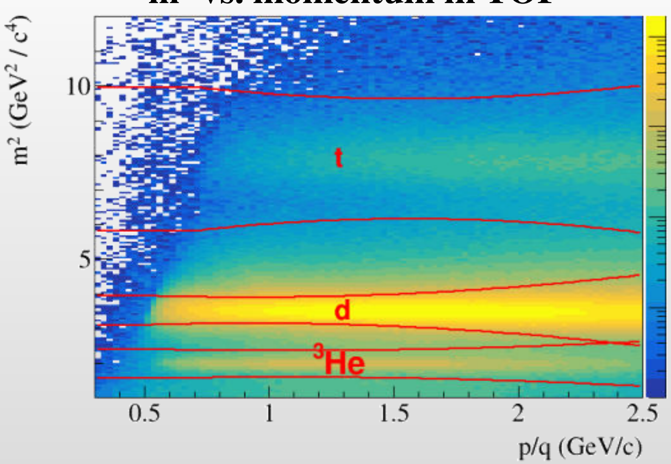
High-energy heavy-ion reaction data

- Galactic Cosmic Rays composed of nuclei (protons, … up to Fe) and E/A up to 50 GeV
- Cosmic rays are a serious concern to astronauts, electronics, and spacecraft.
- The damage is proportional to Z^2, secondary production of p, d, t, ^{3}He, and ^{4}He is also significant
- Need input information for transport codes for shielding applications (Geant-4, Fluka, PHITS, etc.):
  - ✓ total, elastic/reaction cross section
  - ✓ particle multiplicities and coallecense parameters
  - ✓ outgoing particle distributions: $d^2N/dEd\Omega$
- NICA can deliver different ion beam species and energies:
  - ✓ Targets of interest (C = astronaut, Si = electronics, Al = spacecraft) + He, C, O, Si, Fe, etc.
- No data exist for projectile energies > 3 GeV/n

dE/dx vs. momentum in TPC



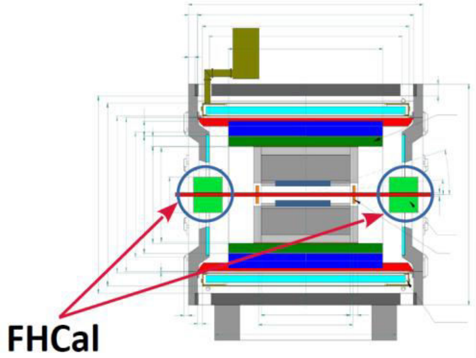
m² vs. momentum in TOF

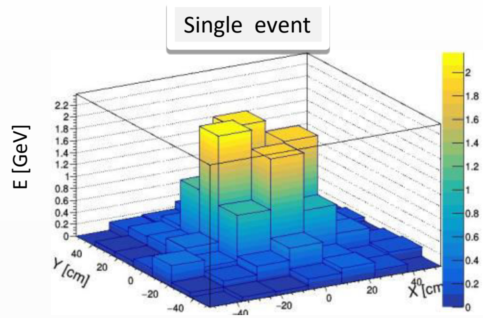


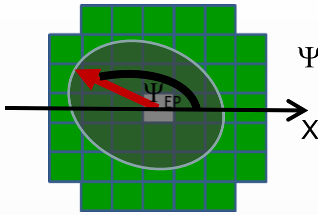
Light fragment identification in a wide y-range → unique capability of the MPD in the NICA range

Reaction plane measurements

- FHCAL is a hadronic calorimeter, ~ 1 m^2, 44 towers by 15x15 cm^2, 2 < |η| < 5

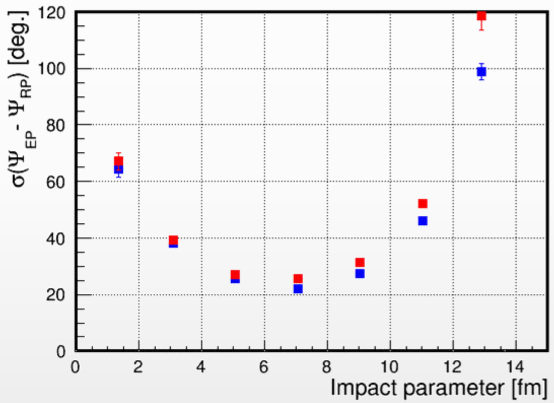




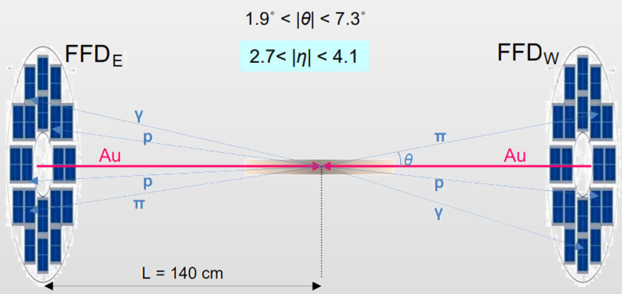


$$\Psi_{EP} = acrtg \frac{\sum E_i \sin(\varphi_i)}{\sum E_i \cos(\varphi_i)}$$

Reaction plane resolution



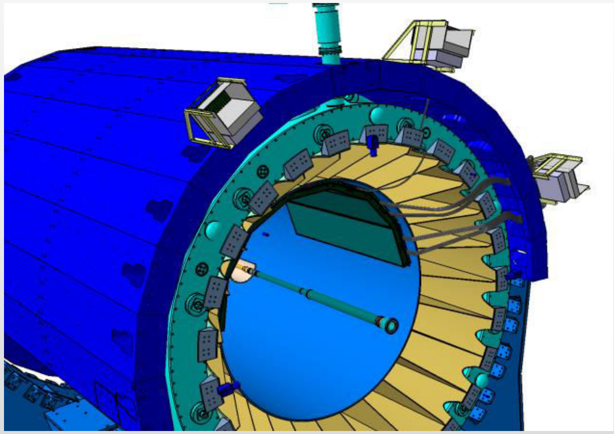
- FHCAL is considered as the main detector for event-plane measurements
- Need further studies for the FFD, which can also be used for reaction plane measurements



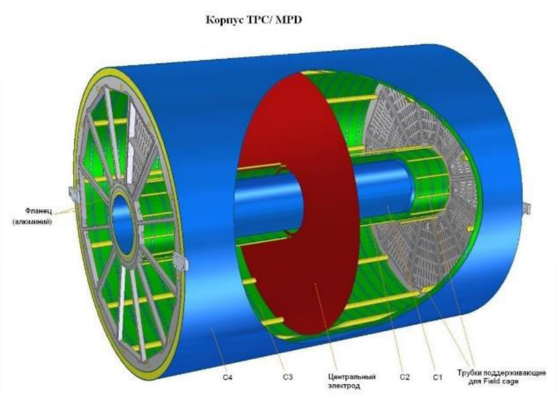
Support Frame for detectors inside of the Solenoid

The structure of Support Frame is made of carbon fiber which allows for deformation less than 3 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.

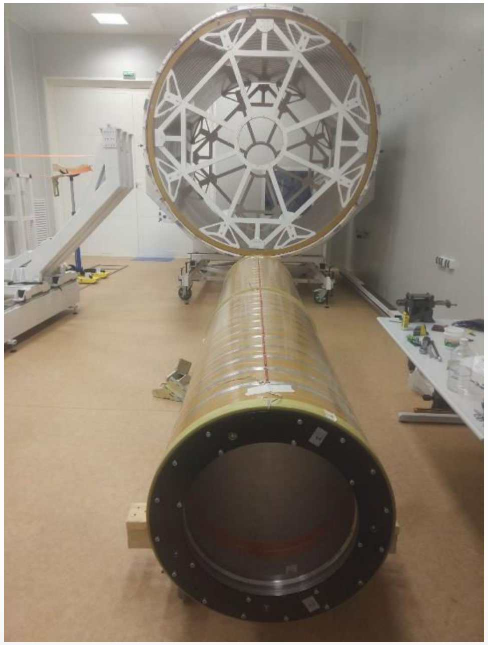
- the Frame will be transported to Dubna in November 2021
- December 2021 (as soon as Magnetic field measurements is finished)
- Representatives of the Company will participate in the process of installation of Support Frame into MPD and its alignment

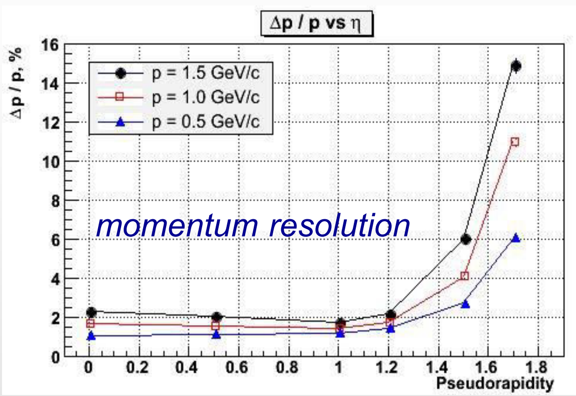


Time Projection Chamber (TPC): main tracker

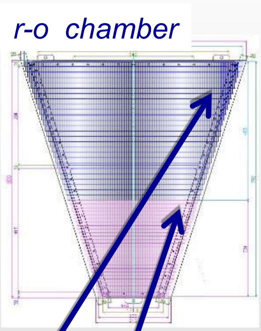


length	*340 см*
outer Radii	*140 см*
inner Radii	*27 см*
gas	*90%Ar+10%CH_4*
drift velocity	*5.45 см / μs;*
drift time	*< 30 μs;*
# R-O chamb.	*12 + 12*
# pads/ chan.	***95 232***
max rate	*< 7kGz (L= 10^{27})*





TPC/MPD Front-end card



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)*

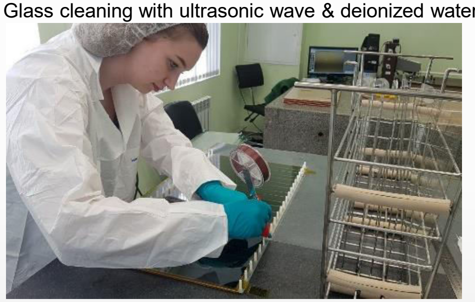
pad structure:
- rows – 53
- large pads 5 × 18 mm²
-

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

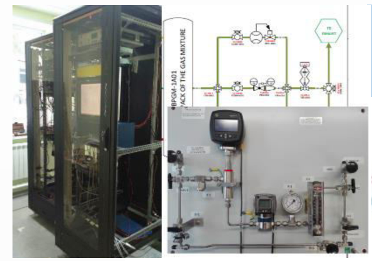
Automatic painting of the conductive layer on the glass



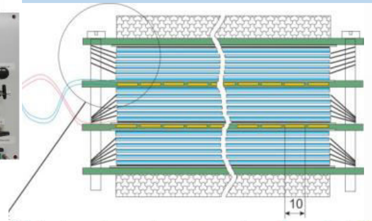
MRPC assembling

Soldering HV connector and readout pins

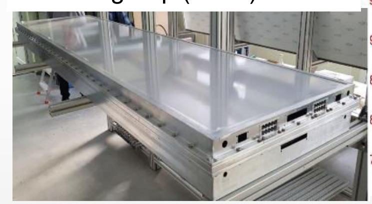
All procedure of detector assembling and optical control is performed in a clean rooms ISO class 6-7.

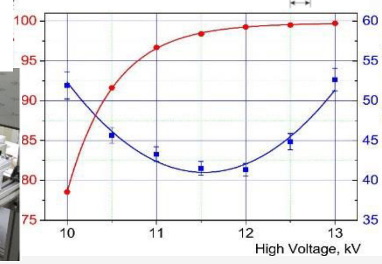


TOF gas system: Responsibility of the Polish group (WUT)



Dimensions of sensitive area 600 x300 mm^2





Single detector time resolution: 50ps

	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)

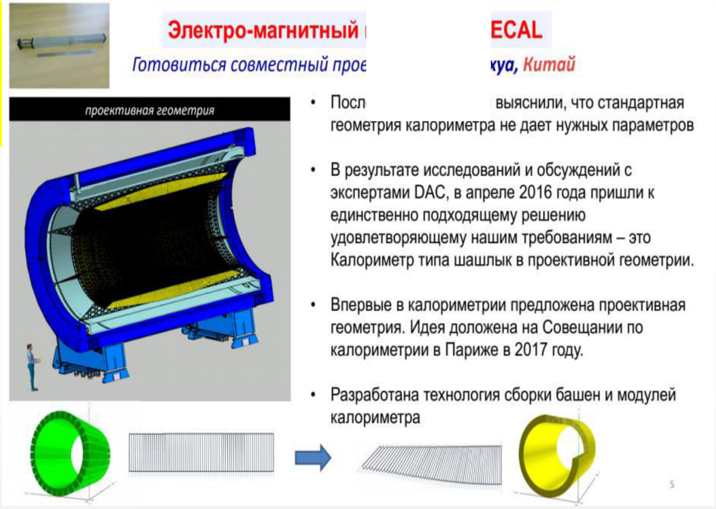
Purchasing of all detector materials completed
So far 40% of all MRPCs are assembled
Assembled half sectors of TOF are under Cosmics tests
Investigation of solutions for detector integration and technical installations

Electromagnetic Calorimeter (ECAL)

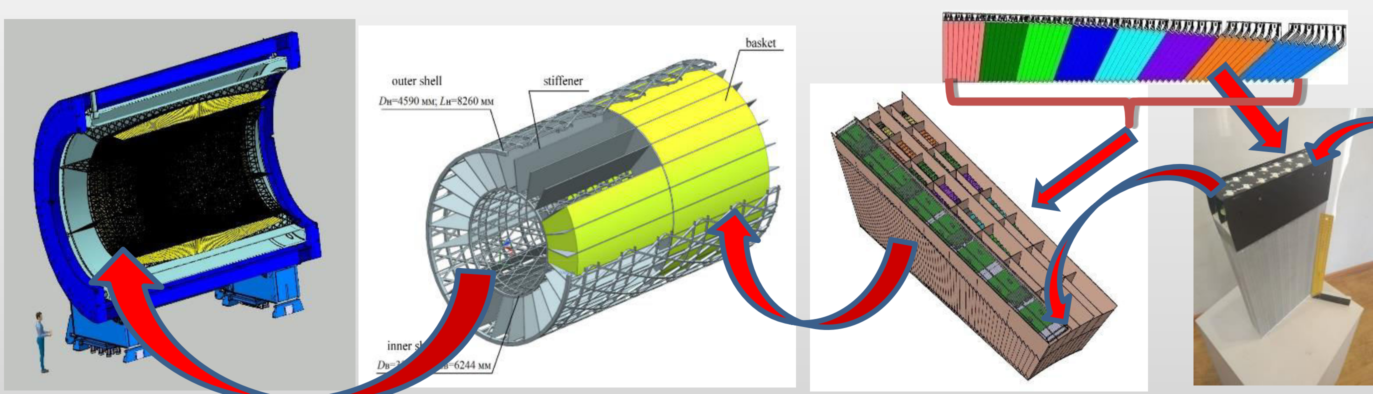
- ❖ *Pb+Sc "Shashlyk"* — *read-out: WLS fibers + MAPD* — *L ~35 cm (~ 14 X_0)*
- ❖ *Segmentation (4x4 cm^2)* — *σ(E) better than 5% @ 1 GeV* — *time resolution ~500 ps*

Barrel ECAL = 38400 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 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%



Projective geometry



Sectors in dedicated Containers

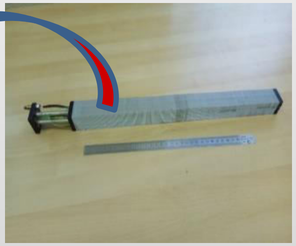


Photo of one tower

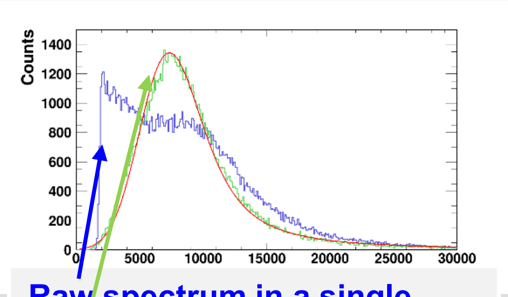
Forward Hadron Calorimeter (FHCal)

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

The activities with modules:

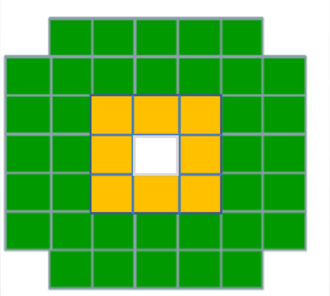
- **Tests with cosmic muons;**
- **Tests of Front-End-Electronics (FEE);**
- **Study of FEE electronic noises;**
- **Development of FHCal trigger;**
- **Development of Slow Control.**

FHCal energy calibration with cosmic

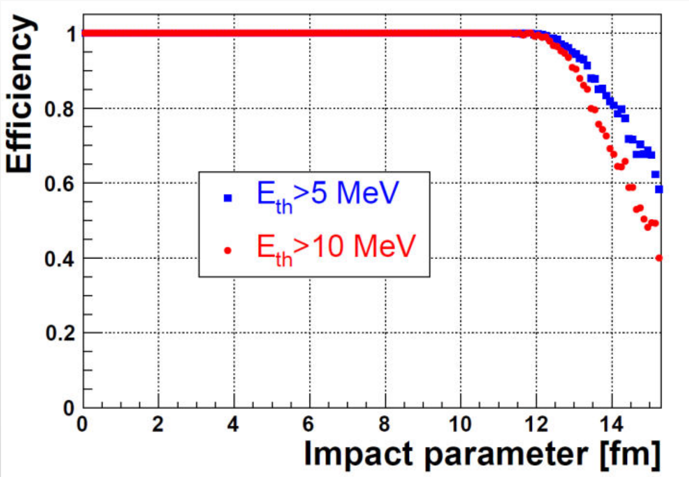


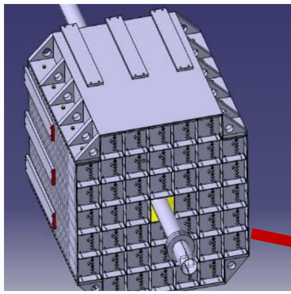
Raw spectrum in a single

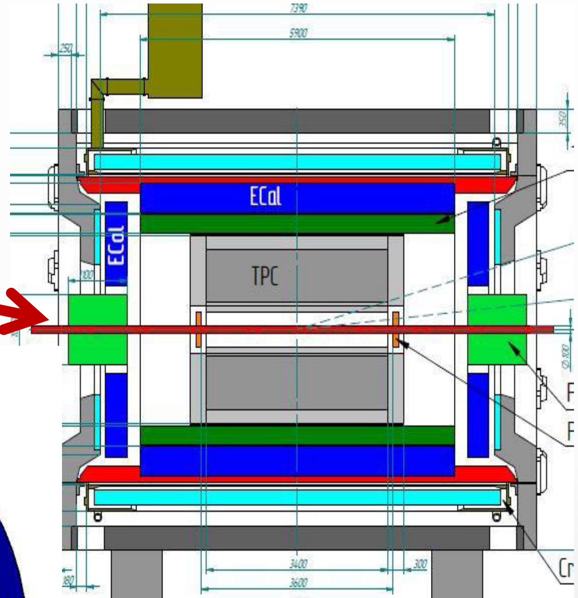
Corrected to the pass length in scintillators

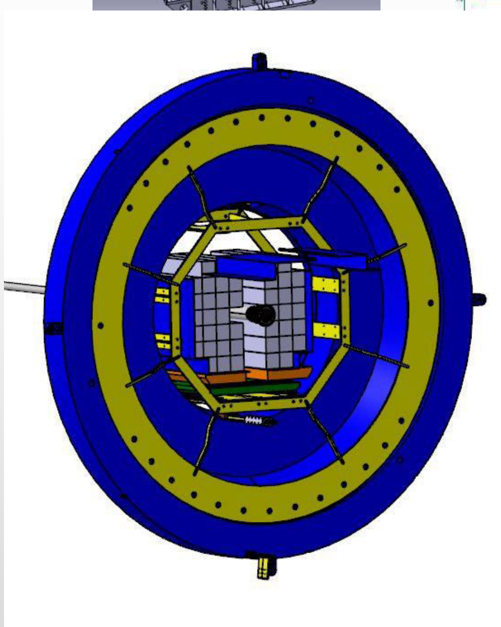


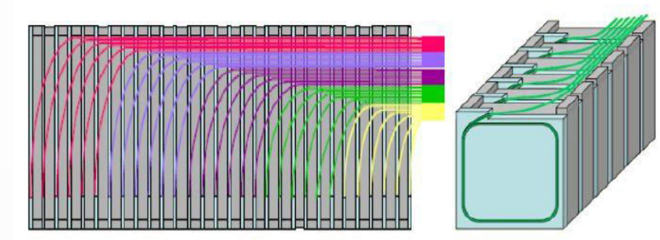
FHCal Trigger efficiency

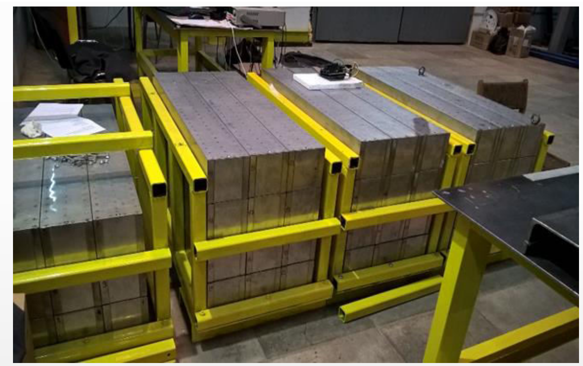






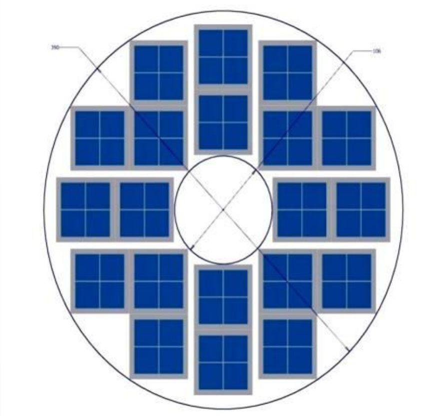


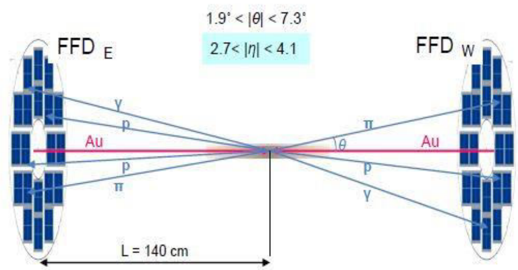




- Two-arms at ~3.2 m from the interaction point.
- Each arm consists of 44 individual modules.
- Module size 150x150x1100cm^3 (42 layers)
- Pb(16mm)+Scint.(4mm) sandwich
- 7 longitudinal sections
- 6 WLS-fiber/MAPD per section
- 7 MAPDs/module

FFD - Fast Trigger L_0 for MPD





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

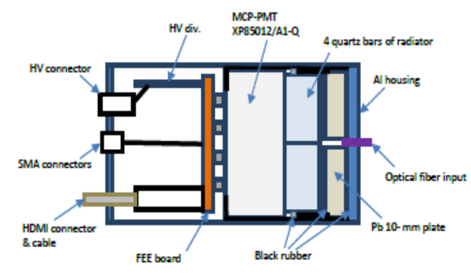


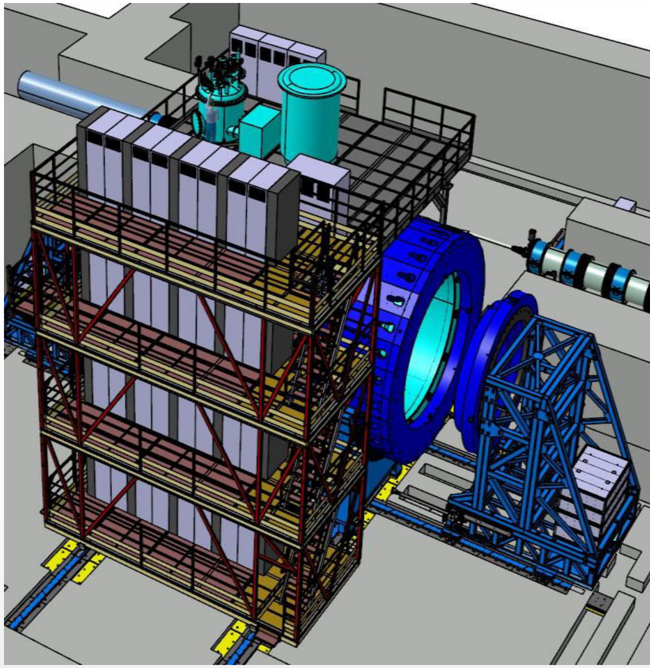
Fig. 4-1. A scheme of the FFD module.

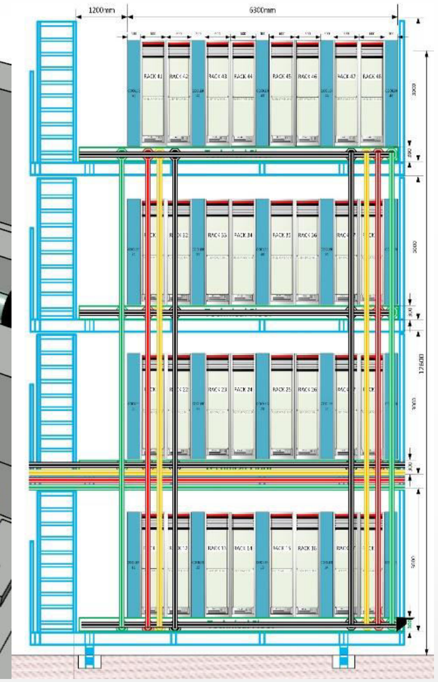
15 mm quartz radiator
10 mm Lead converter

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

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

MPD Electronics Platform



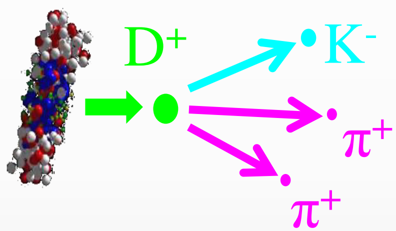


- Electronics platform has 4 levels with 8 racks on each level
- Each Rack provides cooling, fire safety and radiation control system
- Cable ducts connect detectors inside of MPD and Electronics Platform
- The mechanical part of the Platform is ready

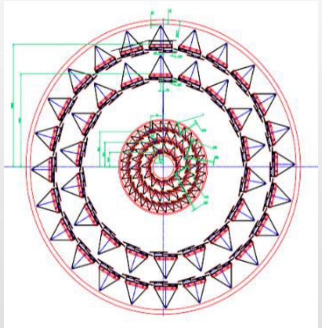
The design of the MPD Electronics Platform is a major contribution of the Polish groups to MPD
M. Peryt (WUT) – leader of the „Engineering Support" Sector of VBLHEP

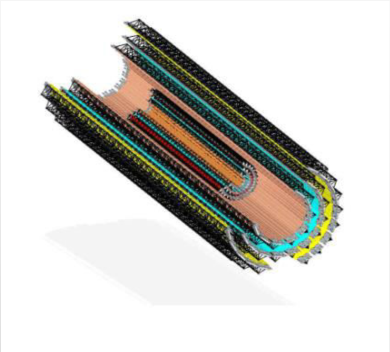
Inner Tracker System (ITS): precise tracking

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.



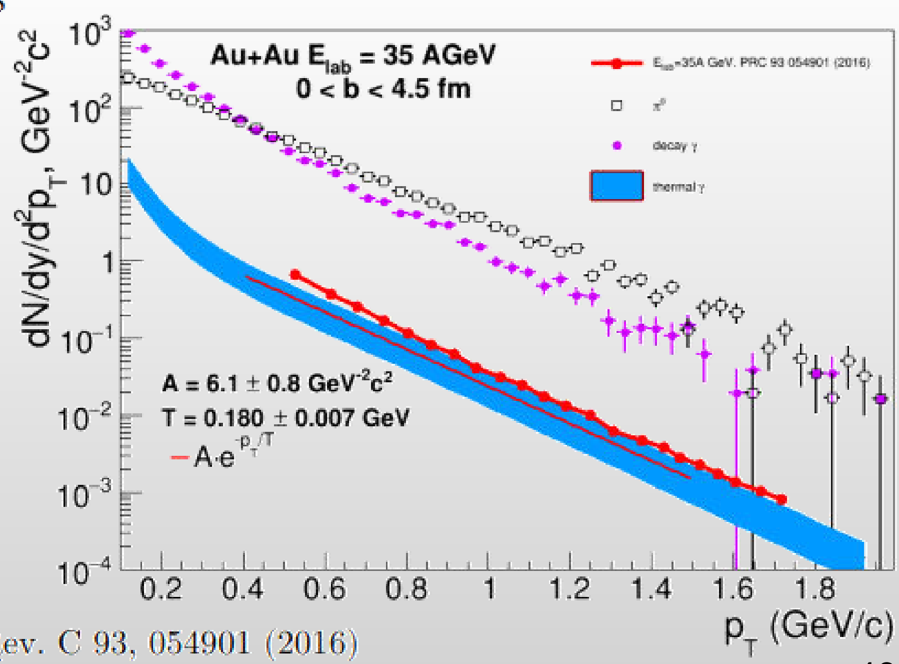


MPD ITS based on ALICE type staves

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

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



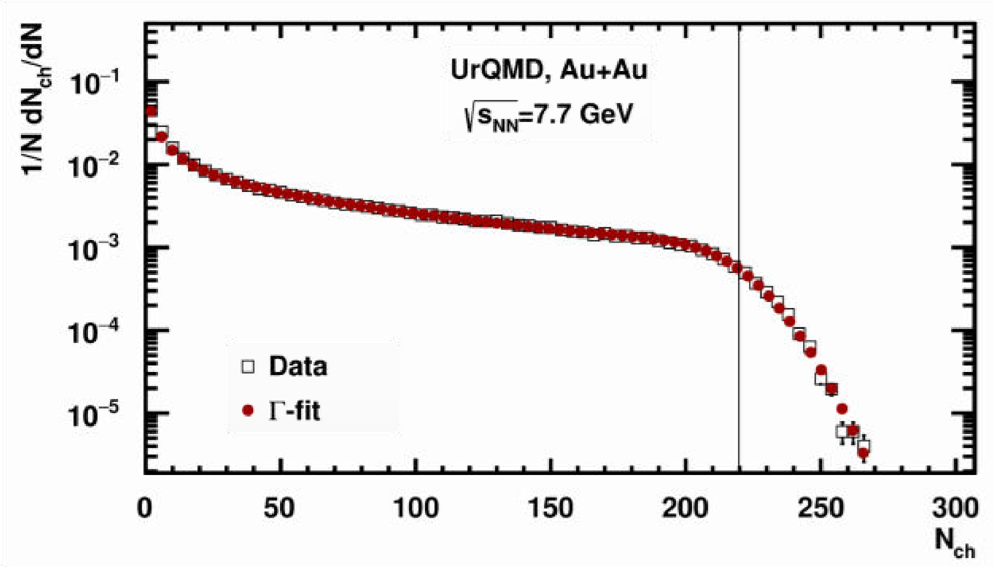
Why simulations in PRC 93 054901 (2016) and PRC 81 044904 (2010) have almost the same yield despite ~5 times difference in energy (35 vs 158 AGeV)?

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:

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



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

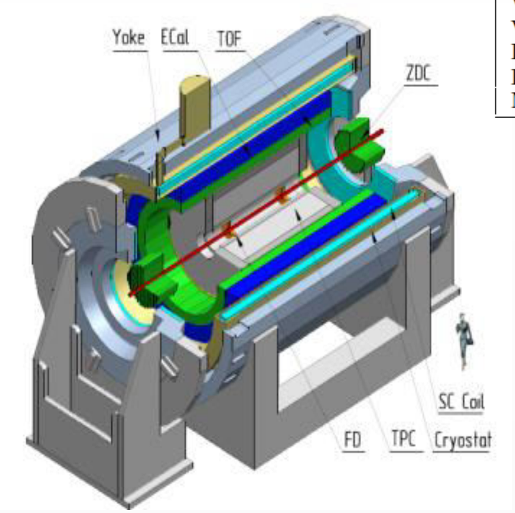
$P_{inel}(b)$ – probability of inelastic NN collision ($P_{inel}(b) \approx 1$)

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

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

Multi-Purpose Detector

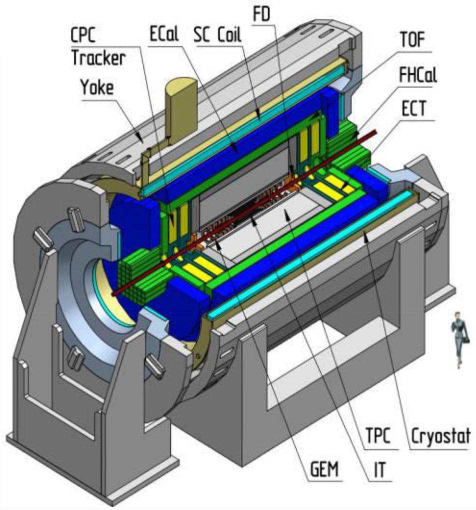
Stage- I



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

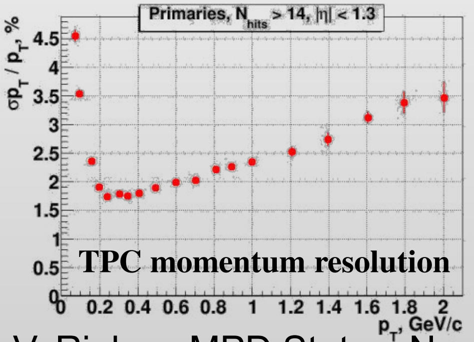
Stage- II

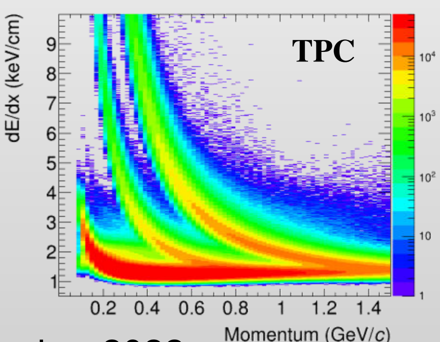


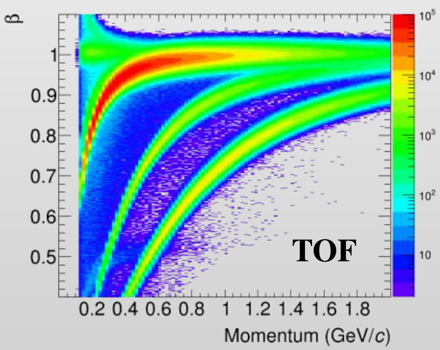
TPC: $|\Delta\varphi| < 2\pi$, $|\eta| \leq 1.6$
TOF, EMC: $|\Delta\varphi| < 2\pi$, $|\eta| \leq 1.4$
FFD: $|\Delta\varphi| < 2\pi$, $2.9 < |\eta| < 3.3$
FHCAL: $|\Delta\varphi| < 2\pi$, $2 < |\eta| < 5$

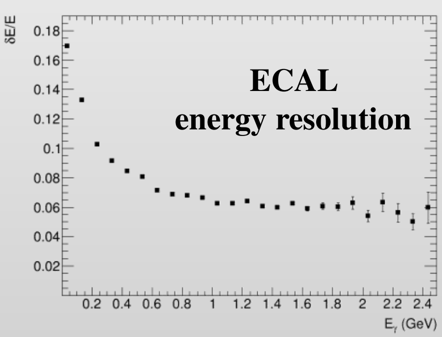
+ ITS (heavy-flavor measurements)
+ forward spectrometers

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



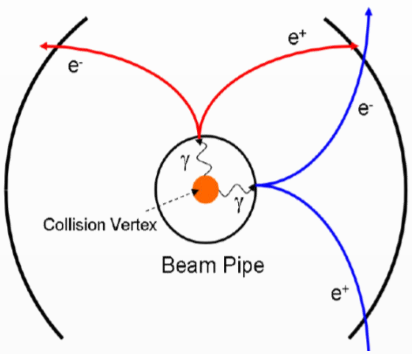


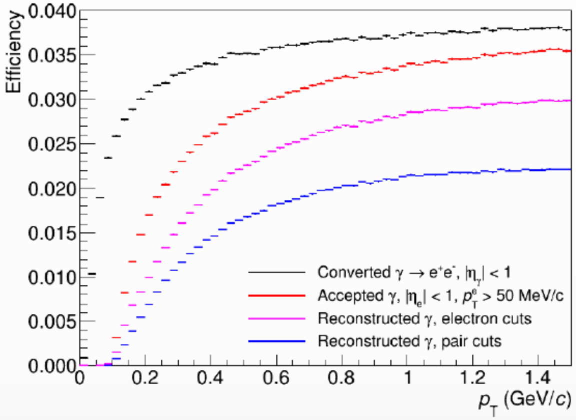


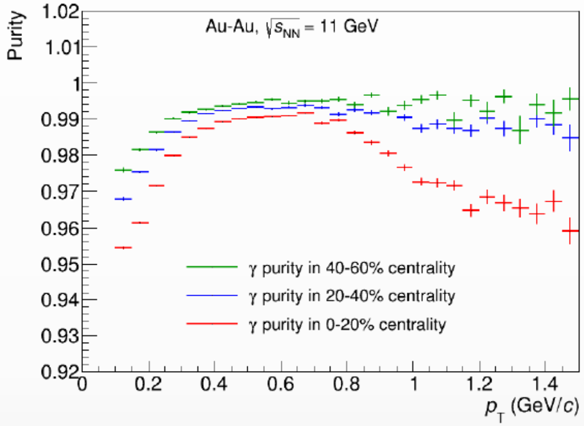


Photons

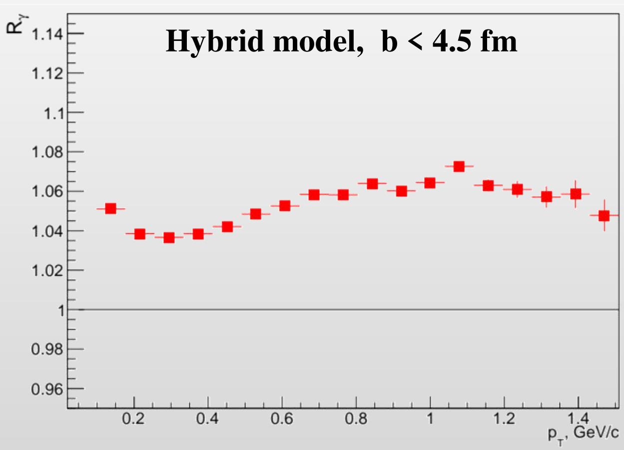
- AuAu@11 GeV (UrQMD)
  - ✓ EMCAL: large acceptance but modest resolution and small S/B at low momentum
  - ✓ Conversion method: low efficiency (~ 1.5%) but high purity (> 95%) and good energy resolution

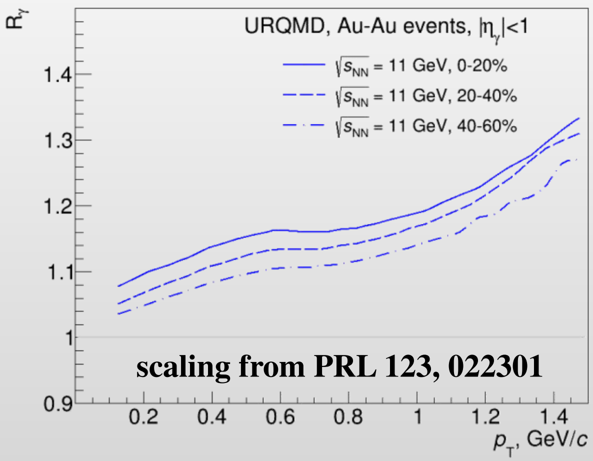






- $R_\gamma = \frac{\gamma^{incl}}{\gamma^{hadron}}$, Rγ estimations from 5% to 10% at p_T > 0.5 GeV/c at top NICA energies



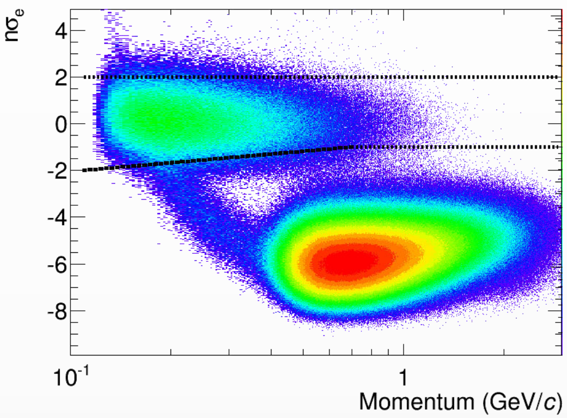


- Rγ values ~5% have been measured by PHENIX → potential for direct photon measurements @MPD

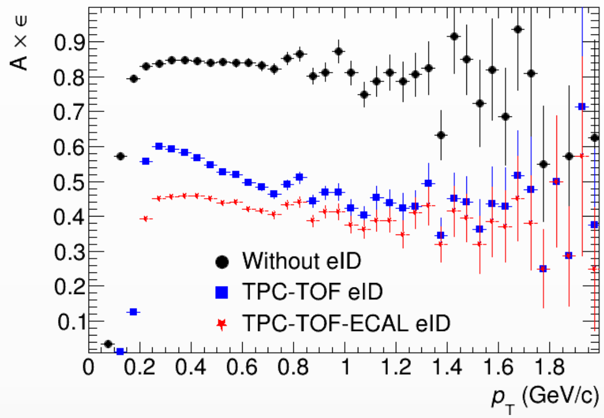
Dielectrons

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

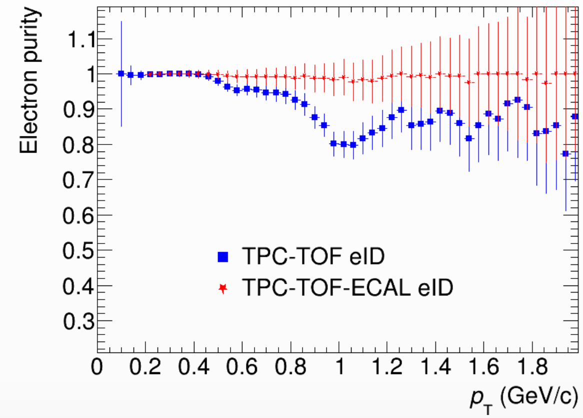
$n \cdot \sigma_e^{TPC}$ with $2\sigma_e$ PID in the TOF

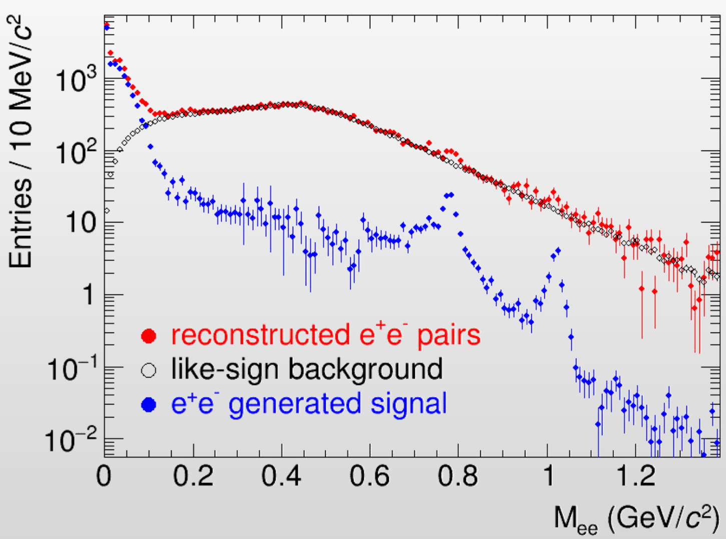


Efficiency of e-track reconstruction



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