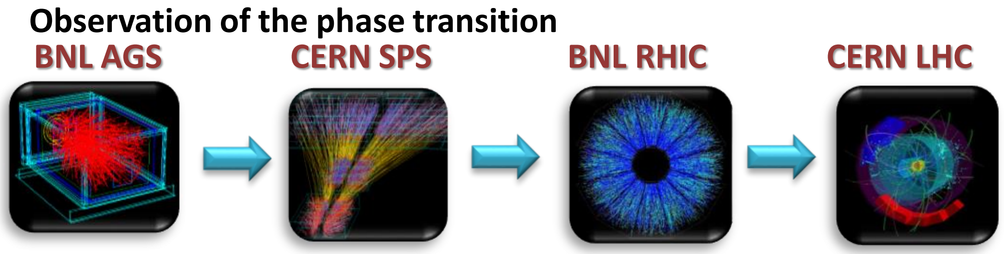
Status of the MPD experiment at NICA

Arkadiy Taranenko (NRNU MEPhI)
for the MPD Collaboration

The Critical Point and Onset of Deconfinement Conference (CPOD 2021) , March 15 - 19, 2021

NICA: Unique and complementary

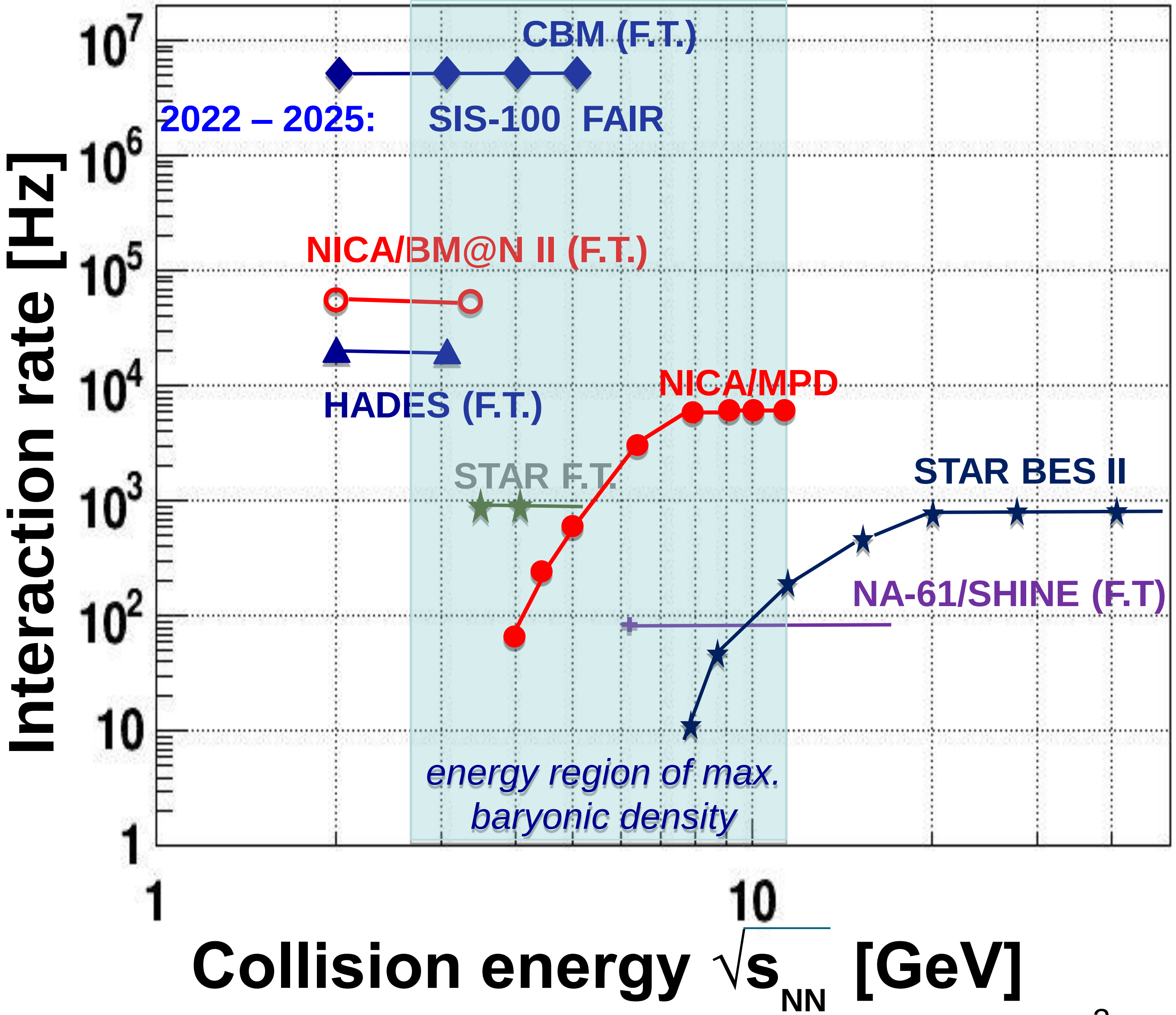


Collider advantage:

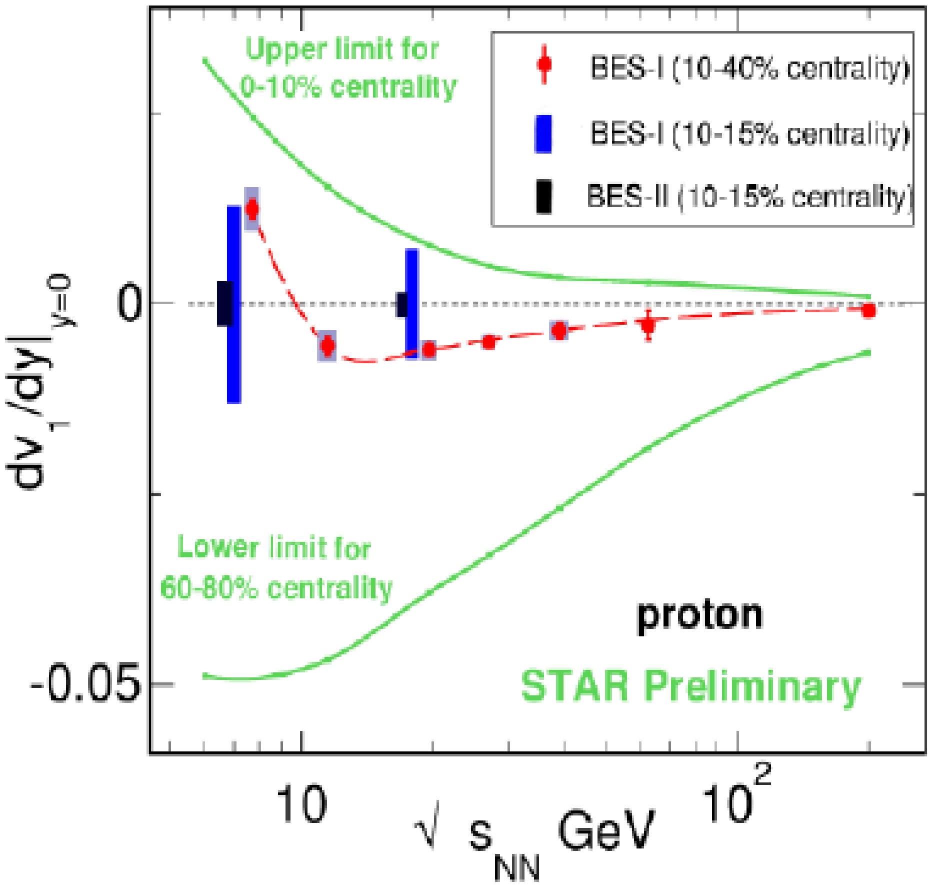
- *coverage of max. phase space*
- *minimally biased acceptance*
- *free of target parasitic effects*

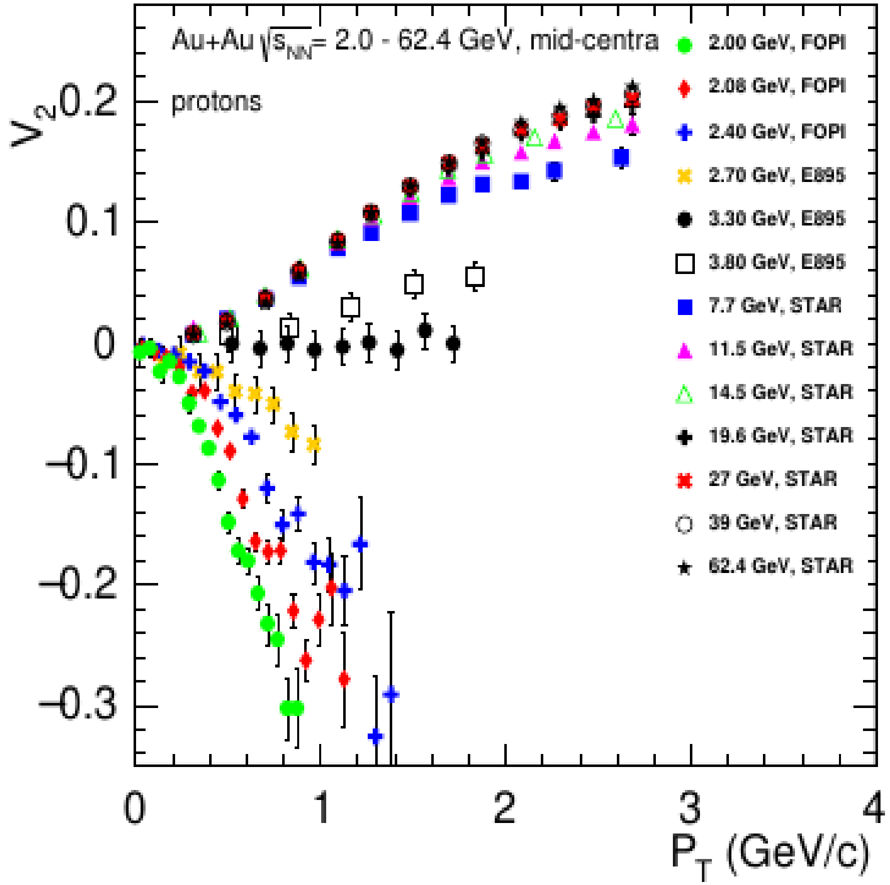
Fixed target advantage:

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



Anisotropic Flow at NICA energies



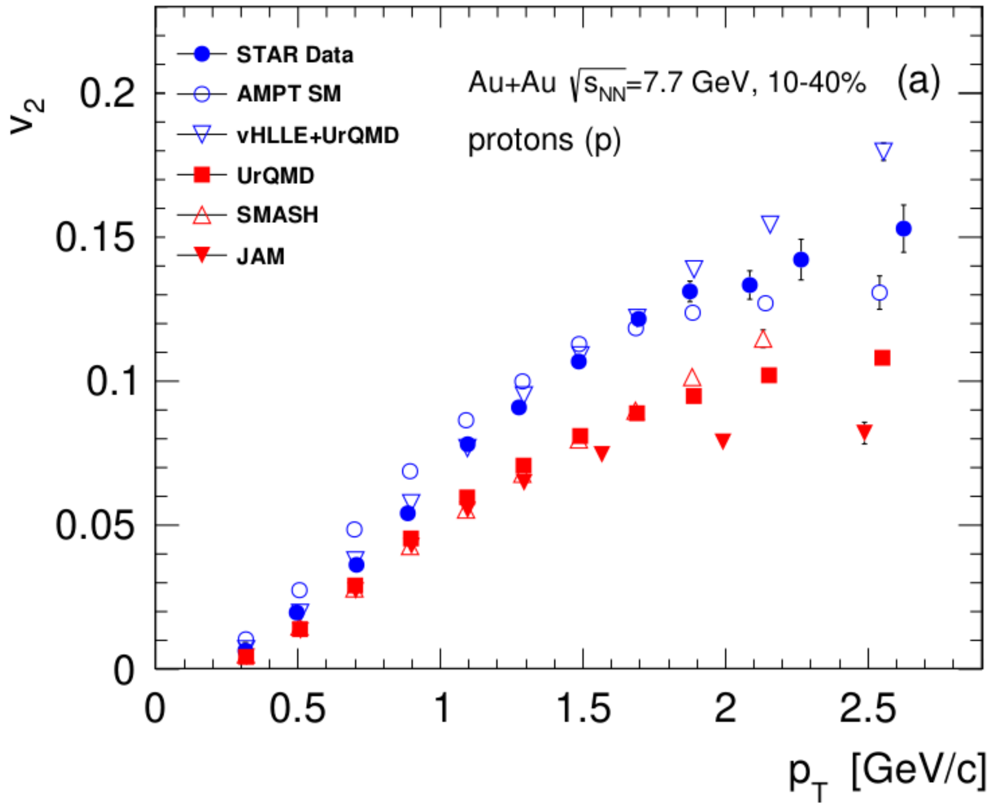


Anisotropic flow at NICA energies:

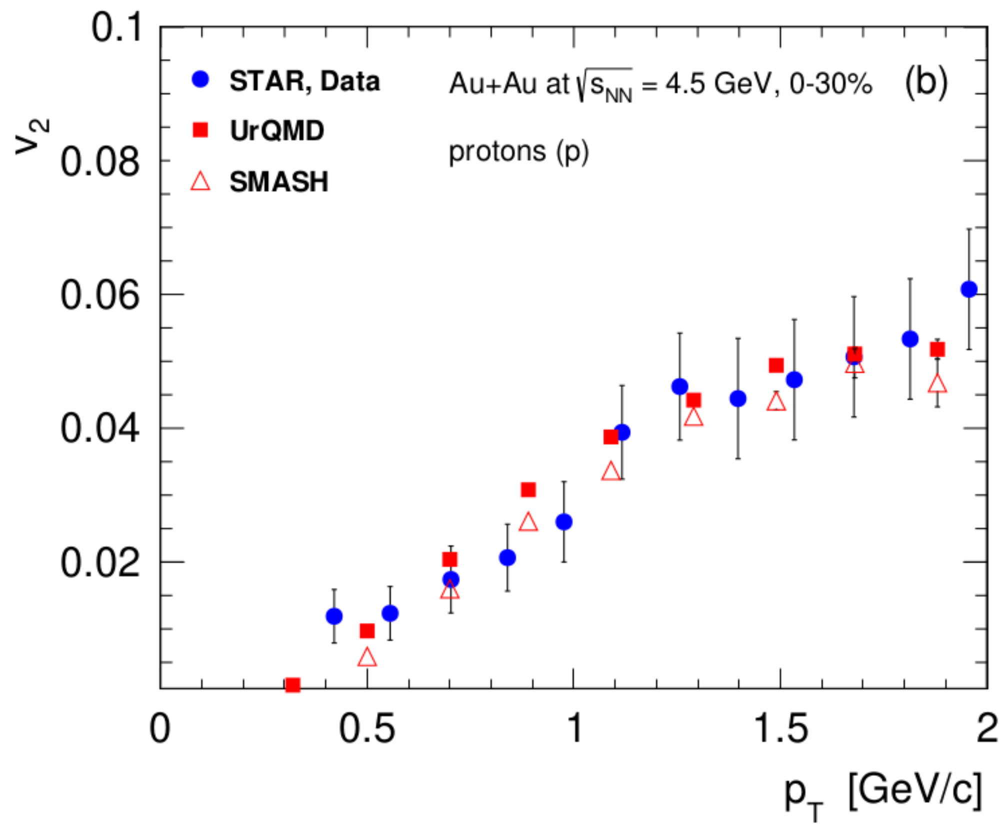
- **Lack of existing differential measurements of v_n (p_T, centrality, PID, …)**
- **Strong energy dependence of v_n at $\sqrt{s_{NN}}$=3-11 GeV**

Elliptic flow at NICA energies: Models vs Data comparison

STAR Data Phys. Rev. C 93, 014907 (2016)



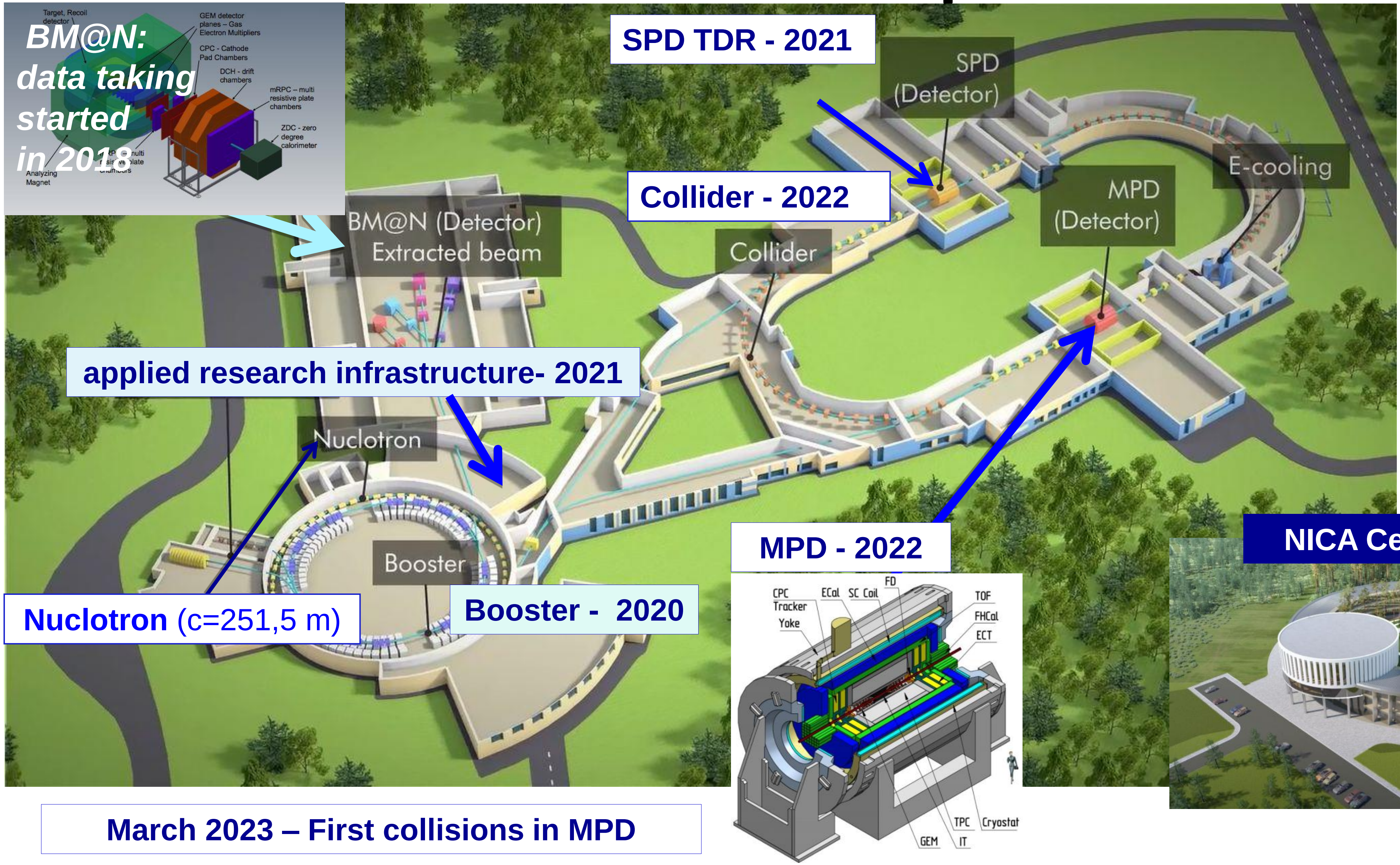
STAR Data: https://arxiv.org/abs/2007.14005



Pure String/Hadronic Cascade models give smaller v_2 signal compared to STAR data for Au+Au $\sqrt{s_{NN}}$=7.7 GeV and above

and give similar v_2 signal compared to STAR data for Au+Au $\sqrt{s_{NN}}$=4.5 GeV

NICA Accelerator Complex in Dubna



BM@N: data taking started in 2018

SPD TDR - 2021

Collider - 2022

applied research infrastructure- 2021

Nuclotron (c=251,5 m)

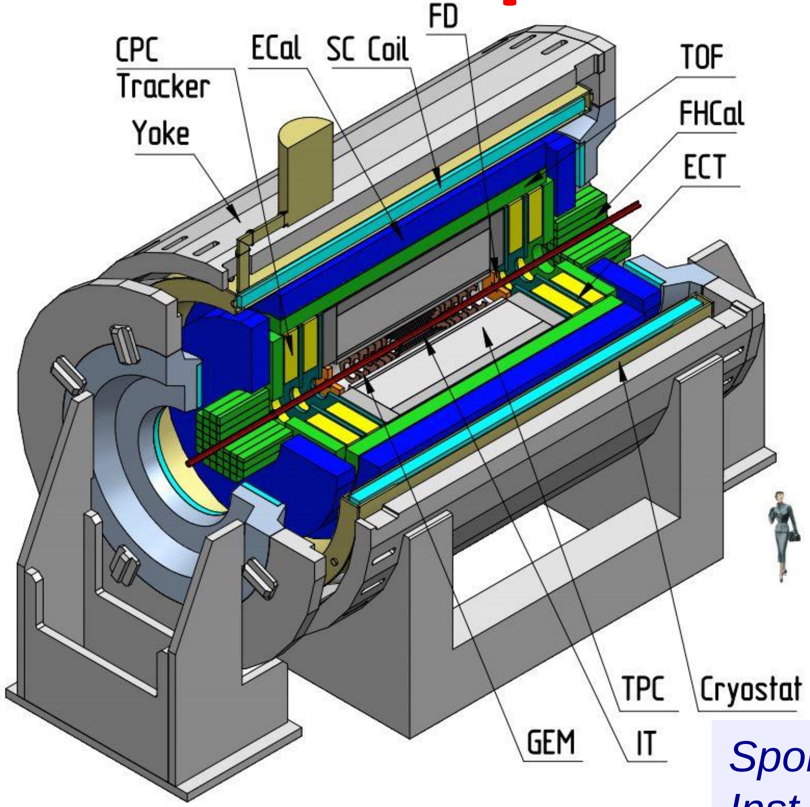
Booster - 2020

MPD - 2022

NICA Center - 2022

March 2023 – First collisions in MPD

Multi-Purpose Detector (MPD) Collaboration



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

NICA

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

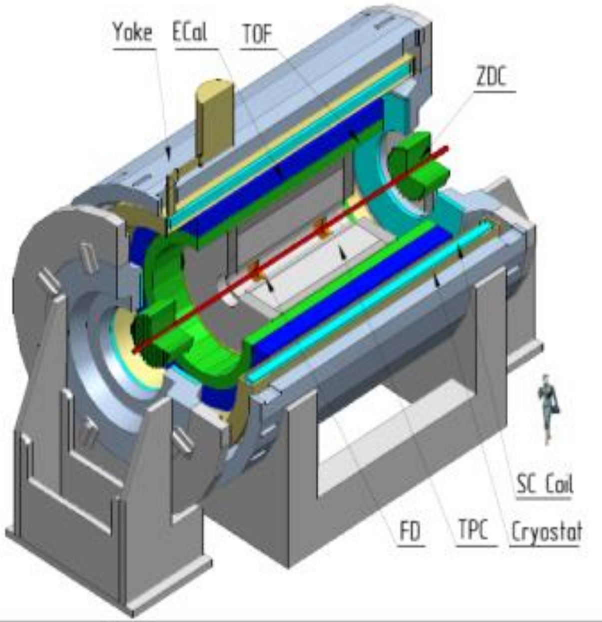
Deputy Spokespersons:
Victor Riabov, Zebo Tang

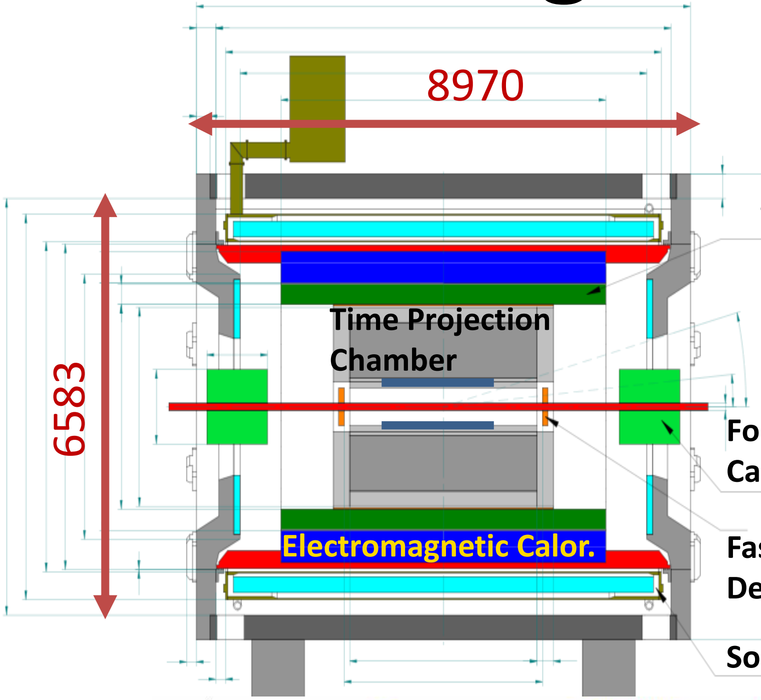
*AANL, Yerevan, **Armenia;***
*Baku State University, NNRC, **Azerbaijan**;*
*University of Plovdiv, **Bulgaria;***
*University Tecnica Federico Santa Maria, Valparaiso, **Chile**;*
*Tsinghua University, Beijing, **China**;*
*USTC, Hefei, **China**;*
*Huzhou University, Huizhou, **China**;*
*Institute 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**;*
***Joint Institute for Nuclear Research**;*

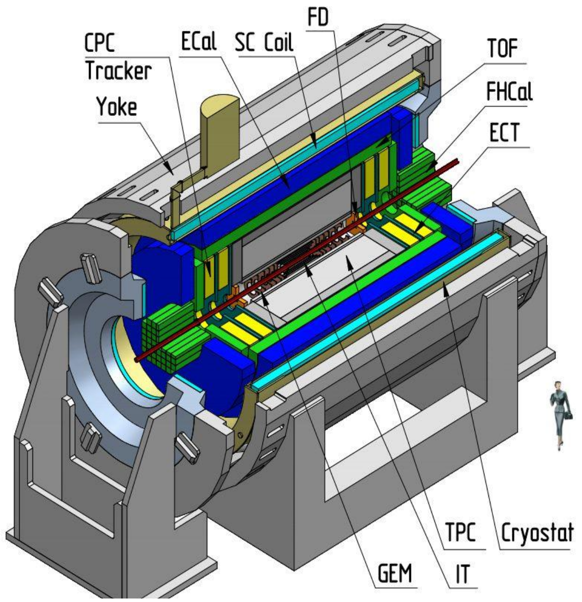
*FCFM-BUAP (Mario Rodriguez) Puebla, **Mexico**;*
*FC-UCOL (Maria Elena Tejeda), Colima, **Mexico**;*
*FCFM-UAS (Isabel Dominguez), Culiacán, **Mexico**;*
*ICN-UNAM (Alejandro Ayala), Mexico City, **Mexico**;*
*CINVESTAV (Luis Manuel Montaño), Mexico City, **Mexico**;*
*Institute of Applied Physics, 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**;*

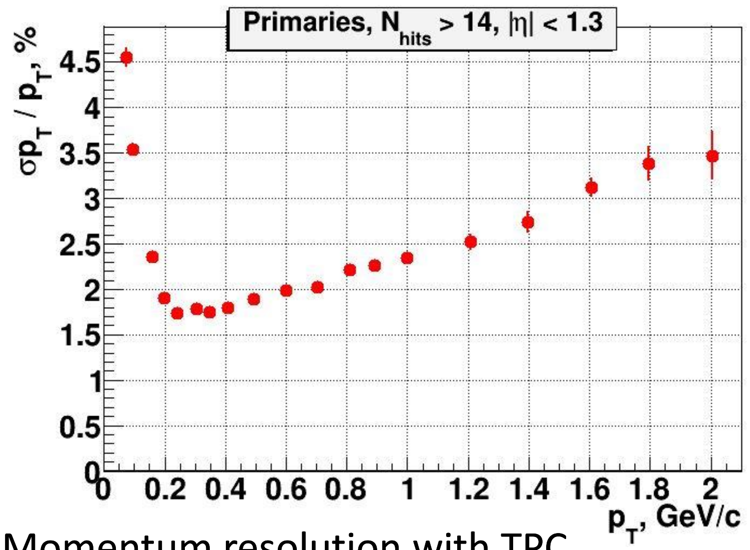
MPD - stage I and II



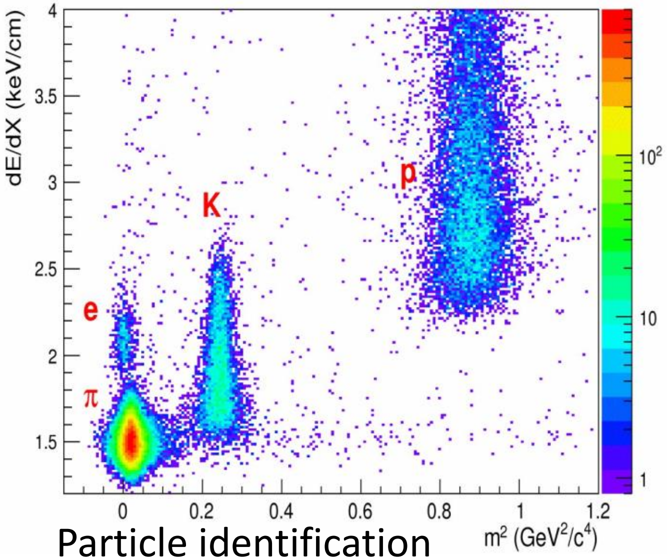


MPD - Stage II

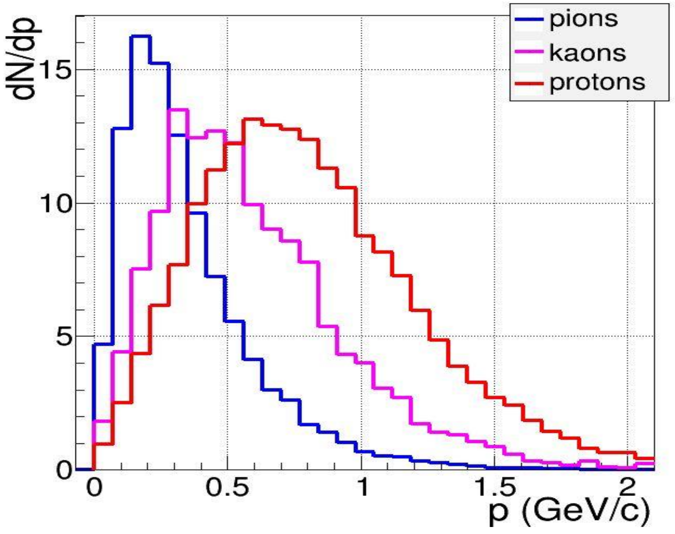




Momentum resolution with TPC



Particle identification



Momentum dist. of secondary particles

NICA

MPD Hall crane weight test

MPD Civil Construction status

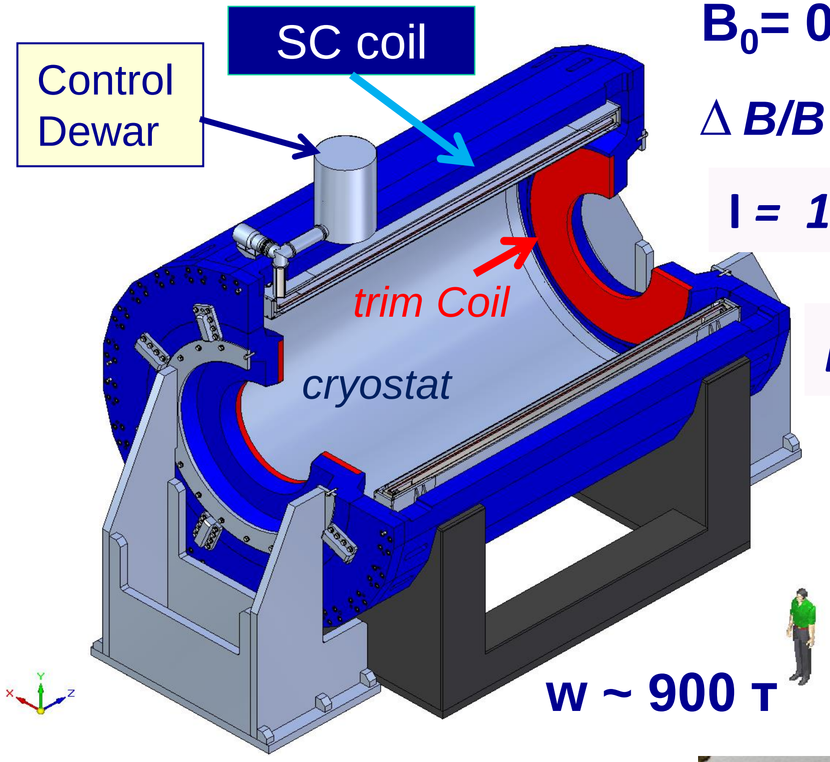
- **MPD Hall ready for** limited scope of equipment installation, remaining works still ongoing

- **Assembly of the magnet yoke** – start with 13 modules (out of 28) installed with average 200 µm precision, full yoke done in Dec 2021

Sep 9th

MPD Superconducting Solenoid

*test assembly of the **magnet yoke**: required accuracy is confirmed*



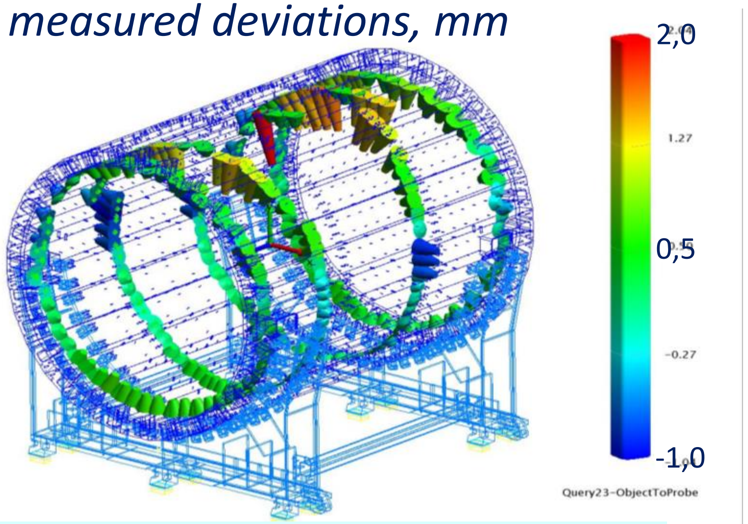
$B_0 = 0.5T$

$\Delta B/B \sim 3x10^{-4}$

I = 1790 A

E = 14.6 MJ

measured deviations, mm



Cryostat with SC coil delivered from Italy

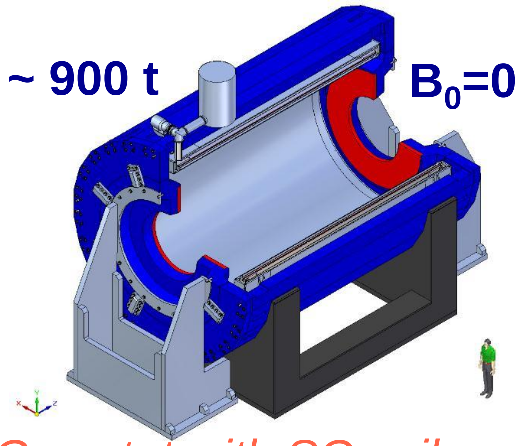
MPD hall, Nov. 6

arrival at the Dubna river, Nov. 5

stages	dates
magnet complete assembly with the cryostat, power & cryogenics supply, & test	February-September 2021
magnetic field measurements	Oct.-Nov. 2021
ready for detector installation	Dec. 2021

MPD Systems in production

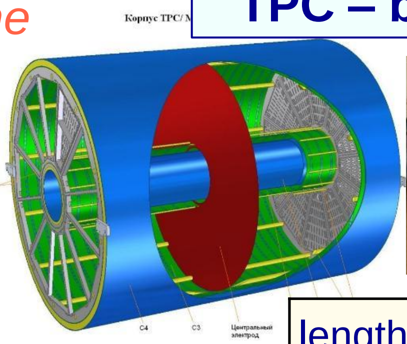
SC Solenoid + Iron Yoke



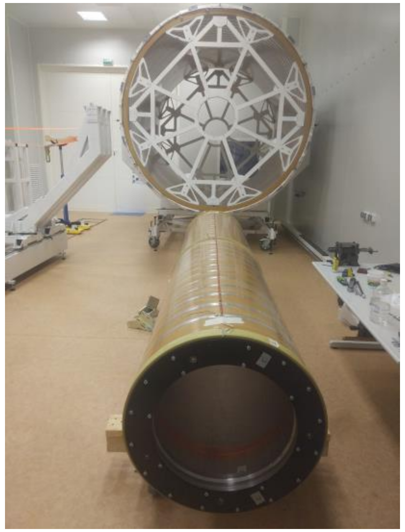
Cryostat with SC coil
- delivered, awaits test
Yoke – assembled

21/24 ROCs done
Cyllinders done
Electronics in
mass production

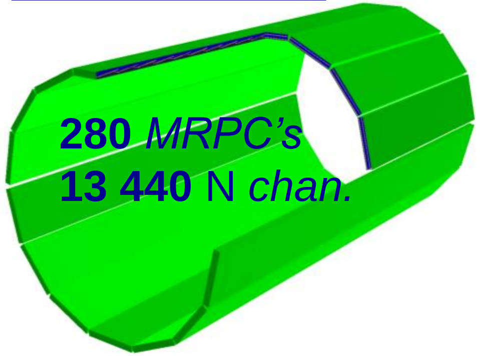
TPC – basic tracker

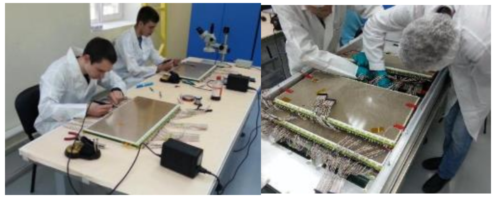


length	*340 см*
out Radii	*140 см*
N chan.	***95 232***



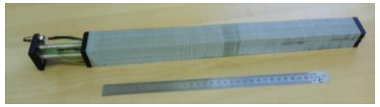
TOF system





40% of MRPCs ready
Mass production cont.

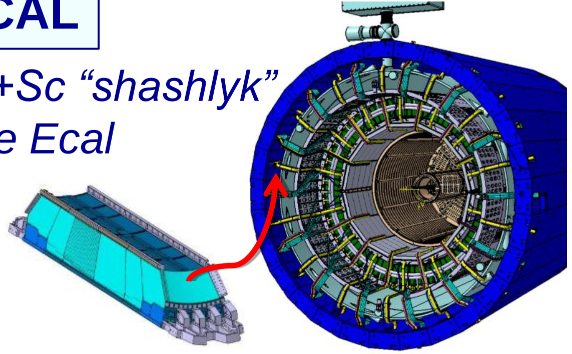
~ **38 400** towers



ECAL

Pb+Sc "shashlyk"
type Ecal

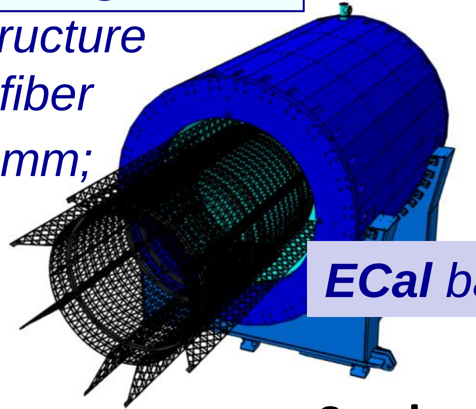
3/25 sectors done
14/25 sectors expected
for Stage I



Integration

support structure
of carbon fiber

sagite ~ ***5*** *mm;*
0,13 X_0

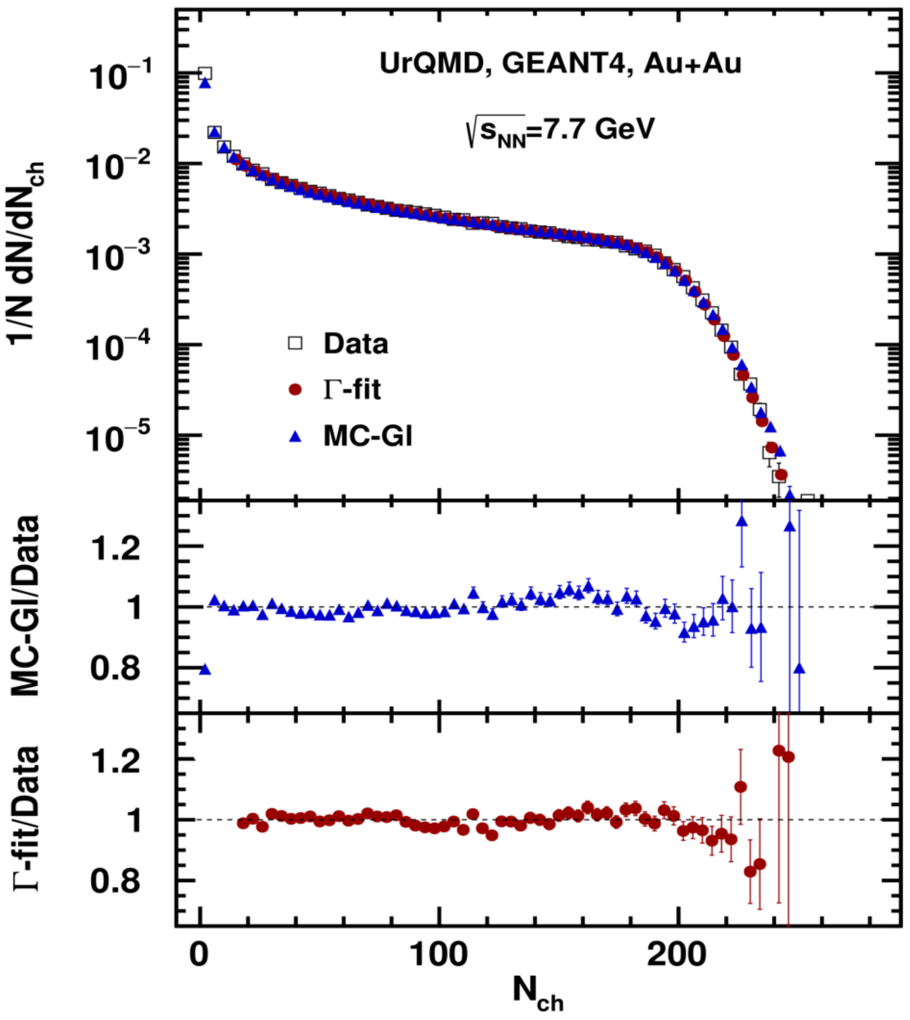


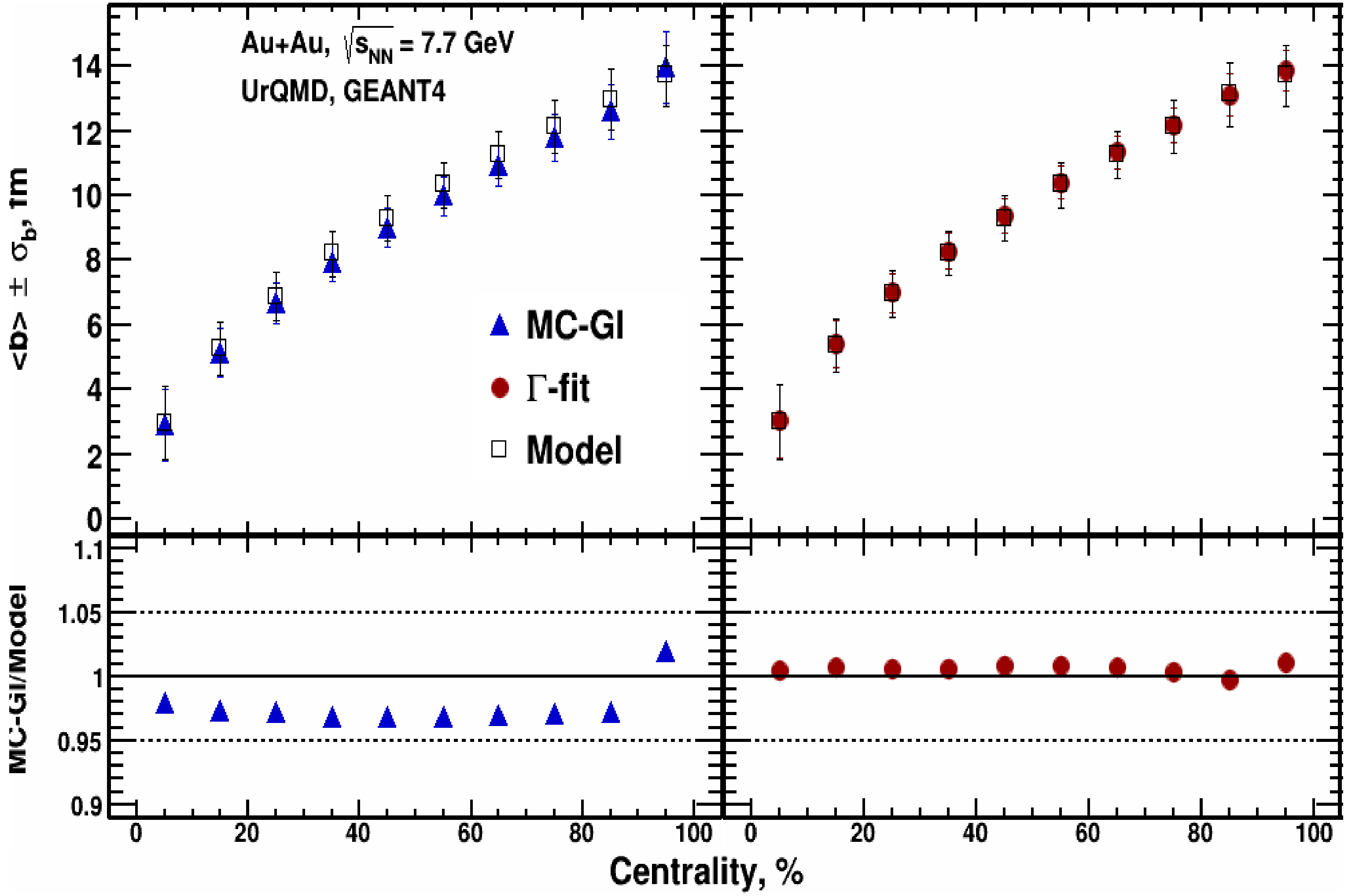
***ECal** barrel ~* ***100** t*

See back up slides 24-31 for each detector system

Centrality determination in MPD : multiplicity of charged particles in TPC

dN/dN_{ch} $(|\eta| < 0.5)$

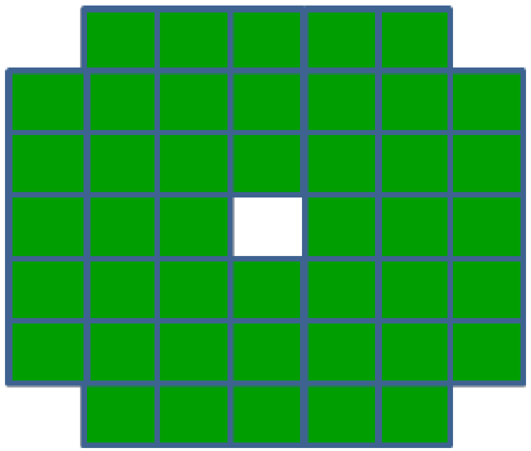


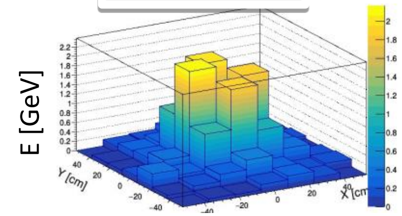


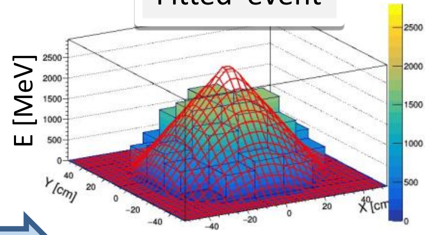
Reconstructing the impact parameter by the **MC Glauber approach (MC-Gl)** and by **Bayesian inversion method (Γ-fit)**

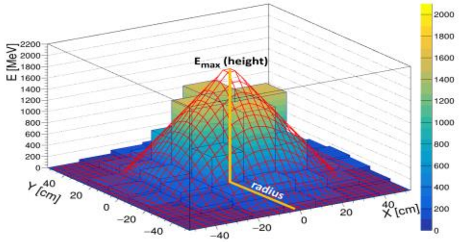
Centrality using energy of spectators in FHCal

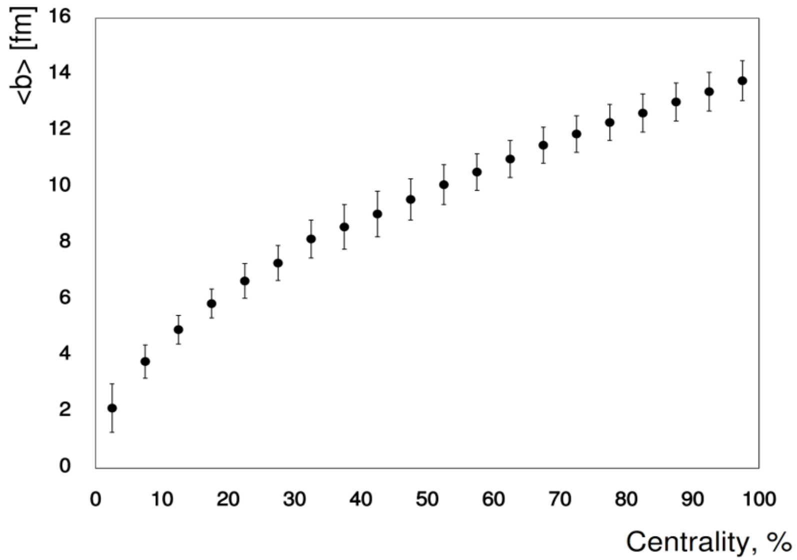
FHCAl (2 < | η | < 5)

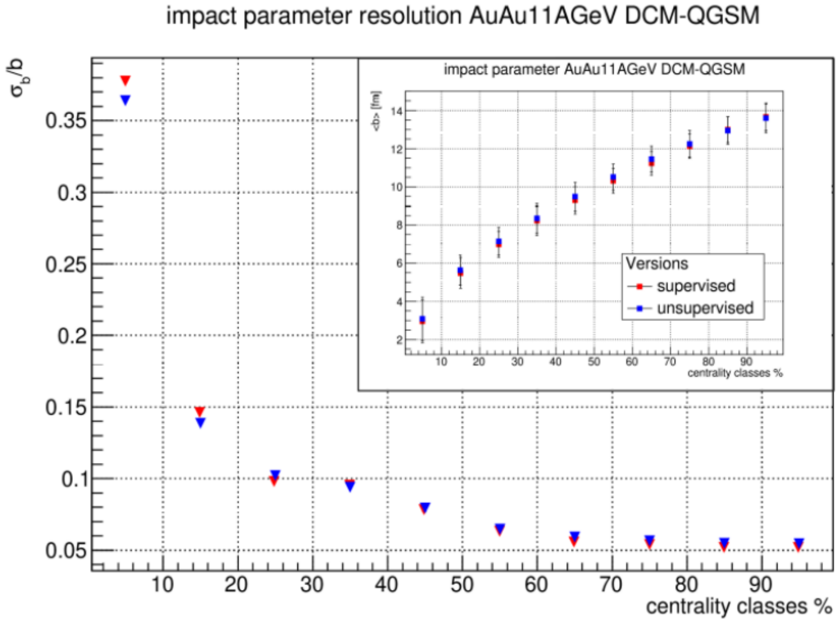


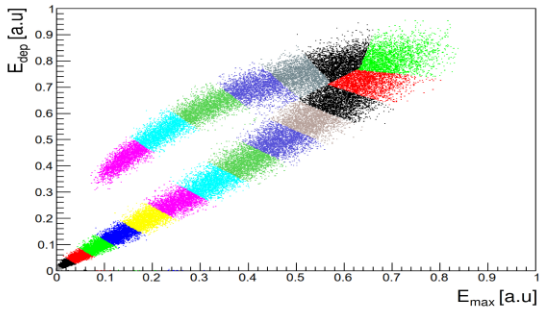


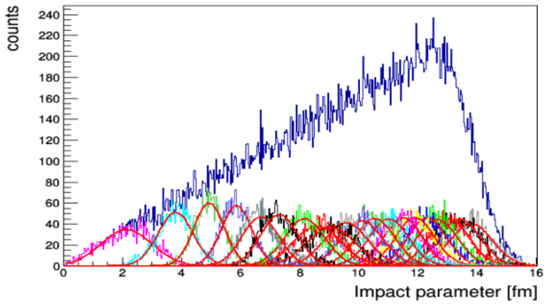


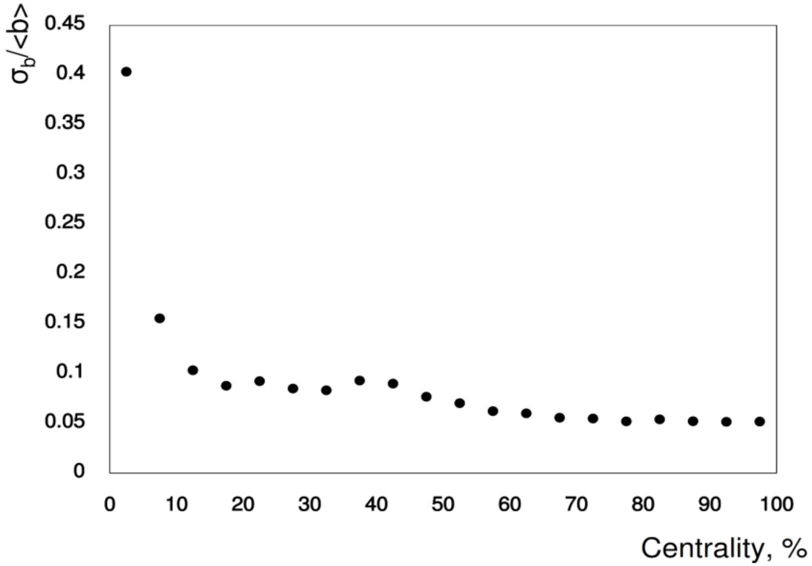










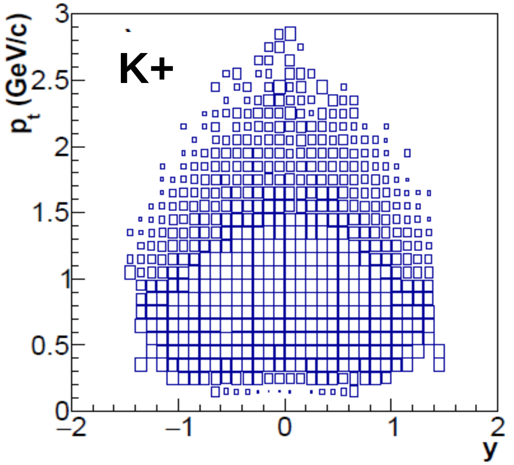


Hadroproduction with MPD

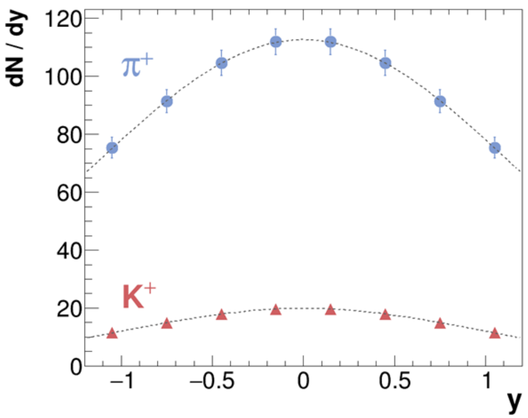
- **Particle spectra, yields & ratios are sensitive to bulk fireball properties and phase transformations in the medium**
- **Uniform acceptance and large phase coverage are crucial for precise mapping of the QCD phase diagram**

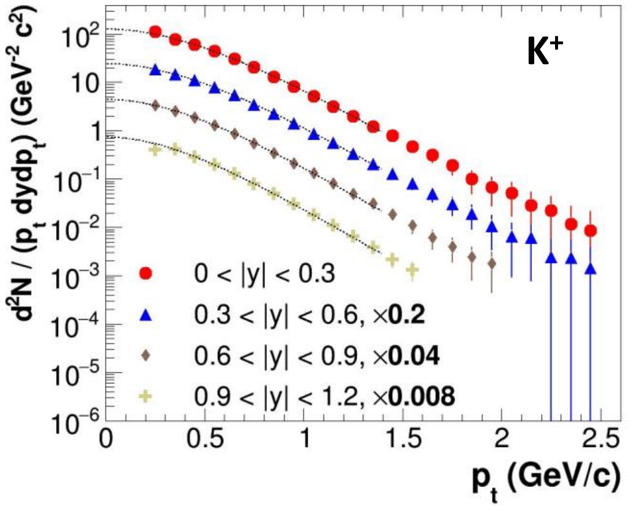
✓ *0-5% central Au+Au at 9 GeV from the PHSD event generator, which implements partonic phase and CSR effects*

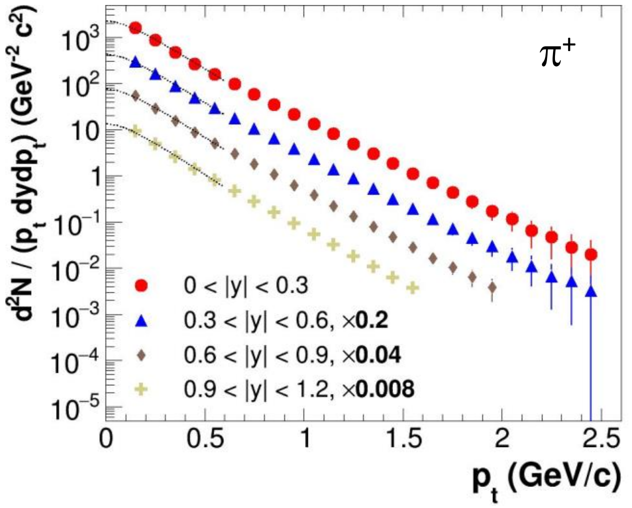
✓ *Recent reconstruction chain, combined dE/dx+TOF particle ID, spectra analysis*



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

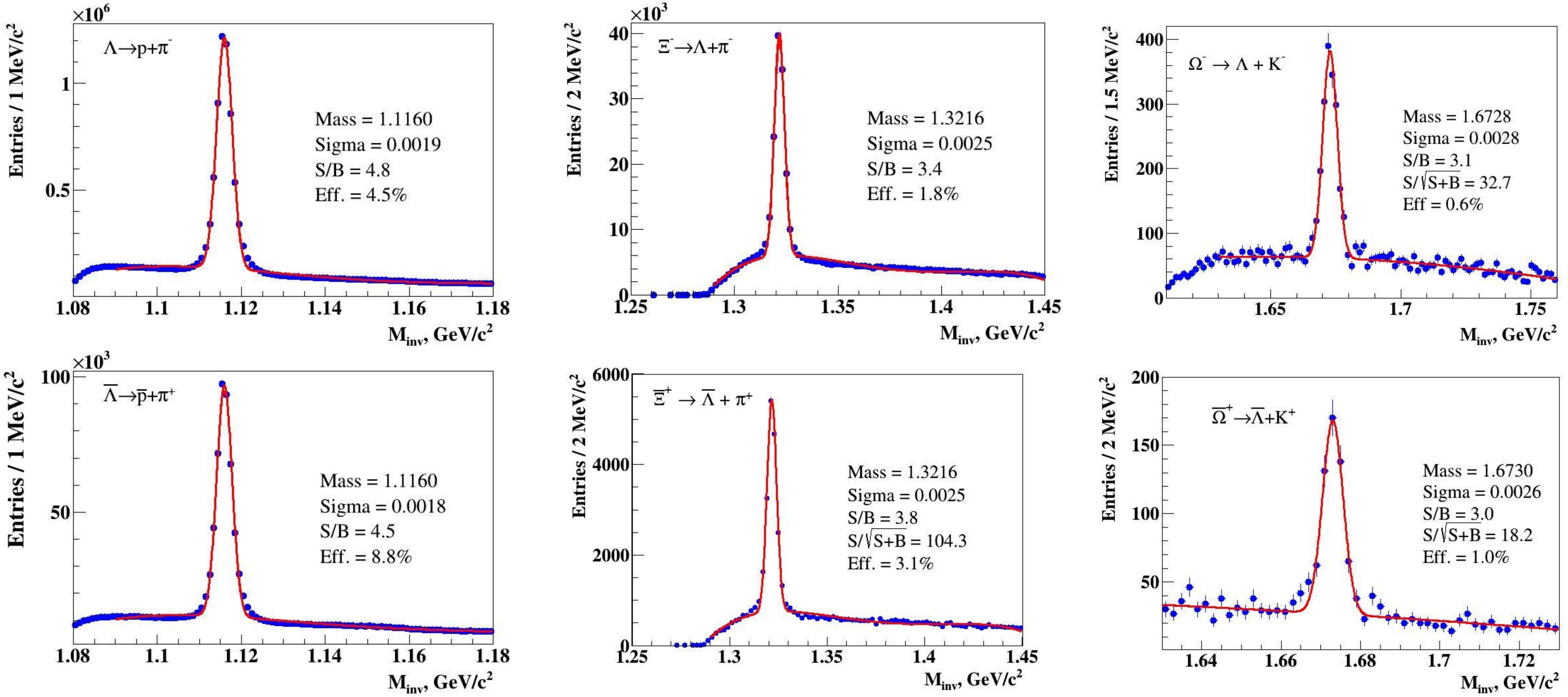






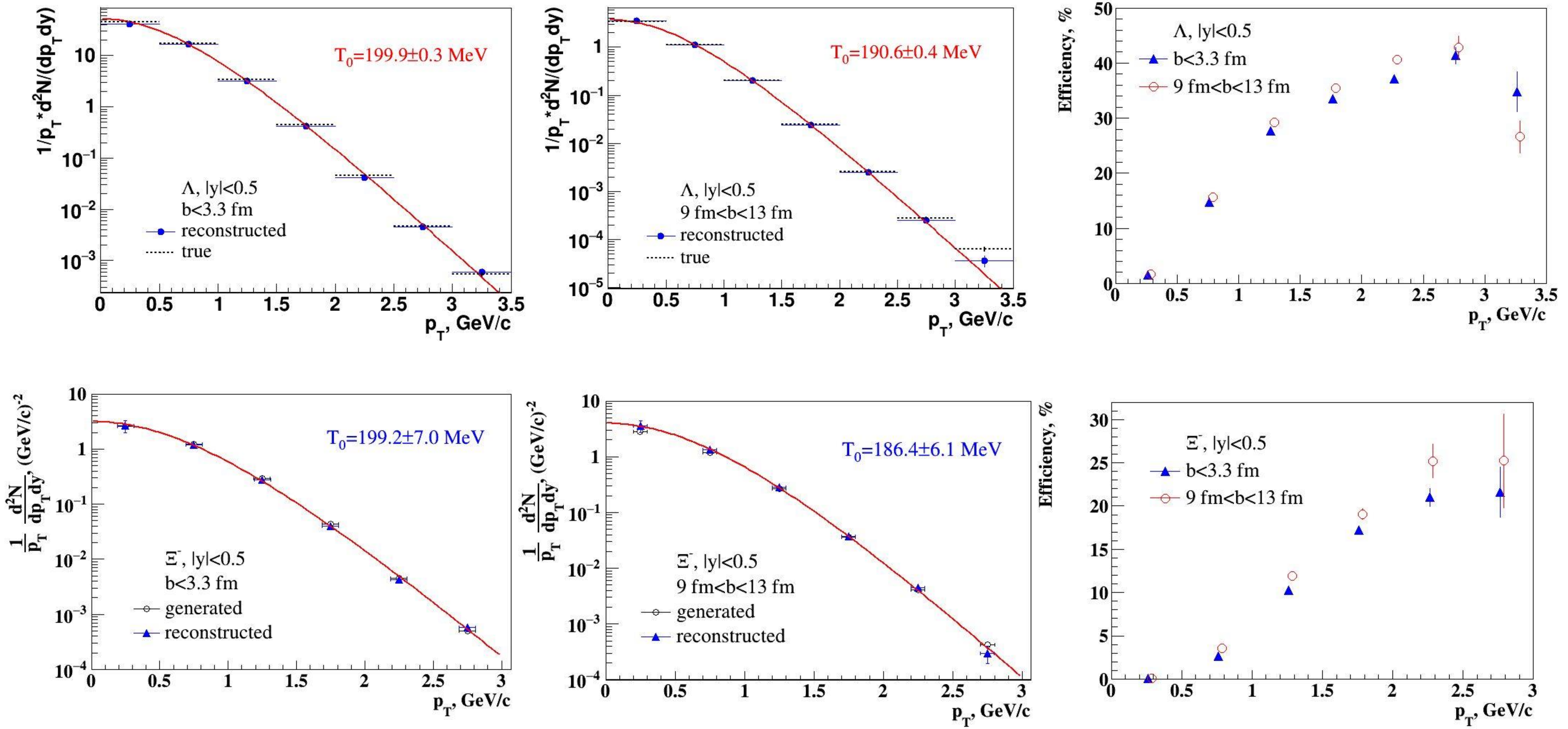
Strange and multi-strange baryons

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



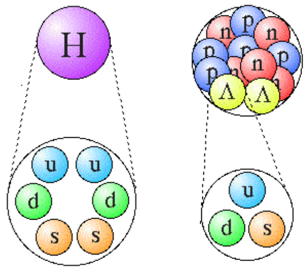
particle	Λ	anti-Λ	Ξ^-	anti-Ξ^+	Ω^-	anti–Ω^+
yield in 10 weeks	$3 \cdot 10^8$	$3.5 \cdot 10^6$	$1.5 \cdot 10^6$	$8.0 \cdot 10^4$	$7 \cdot 10^4$	$1.5 \cdot 10^4$

Efficiency and p_T spectrum



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

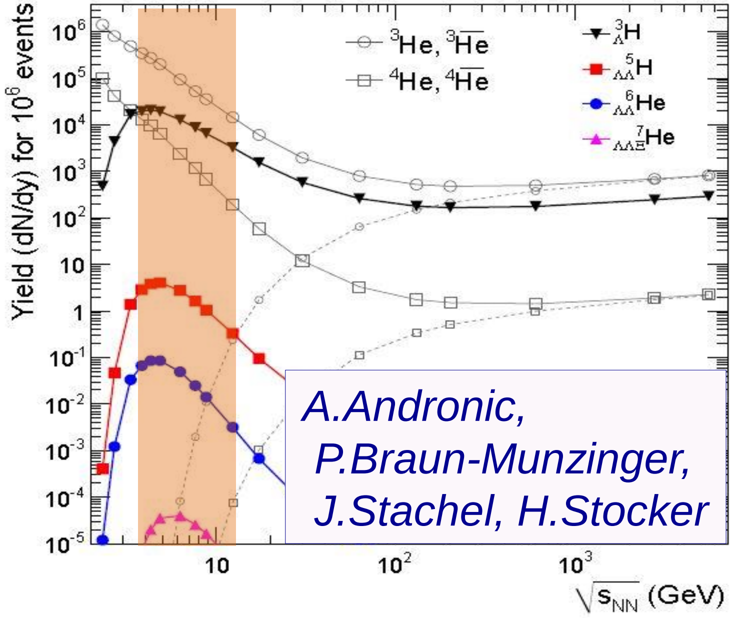
Hypernuclei at MPD



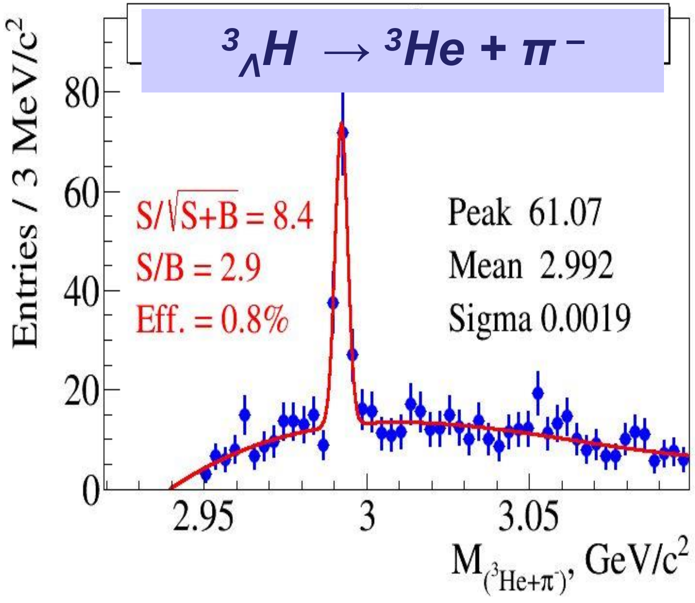
astrophysical research indicates the appearance of hyperons in the dense core of a ***neutron star***

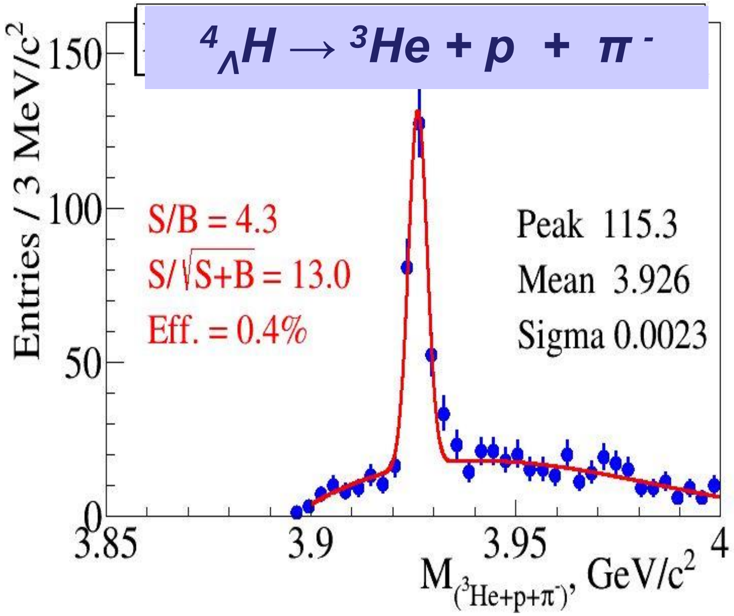
Stage 2: *central* ***Au+Au @ 5*** *AGeV; DCM-QGSM*

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



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



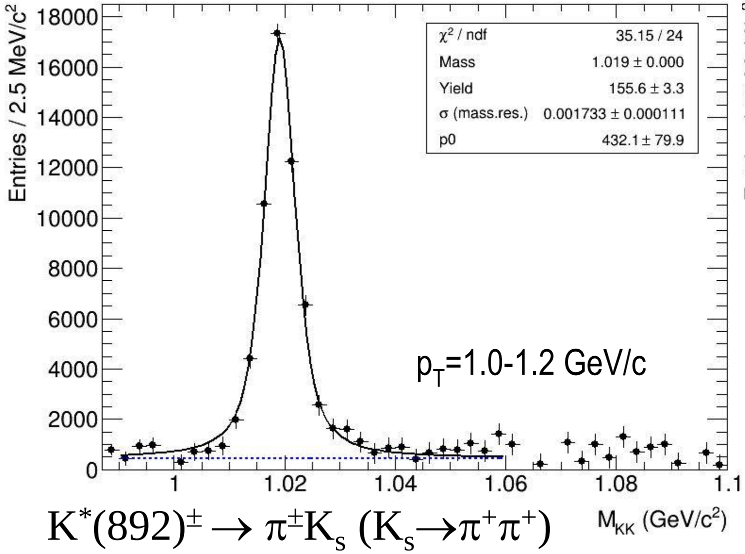


Resonances at MPD

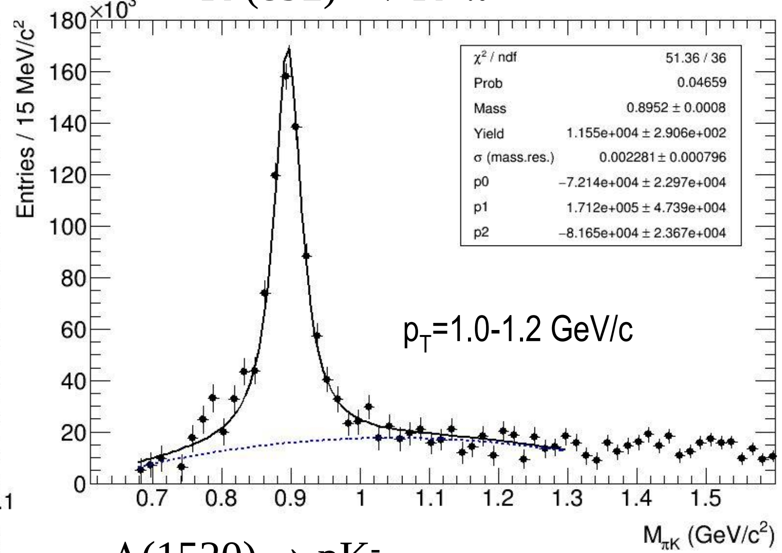
NICA

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

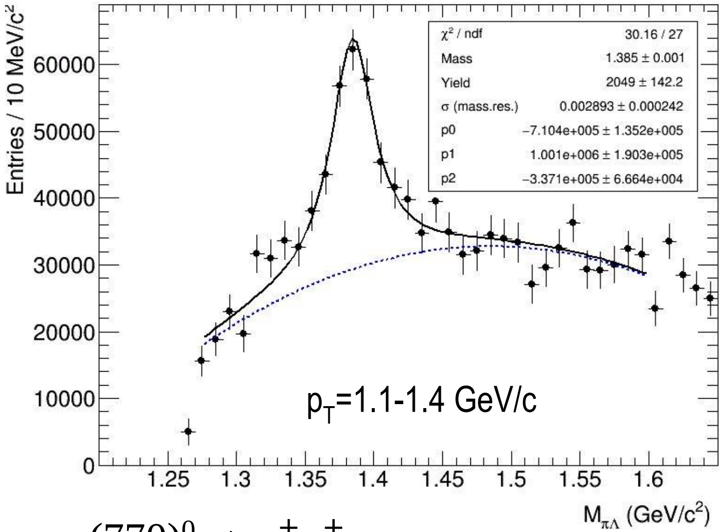
$\phi(1020) \rightarrow K^+K^-$



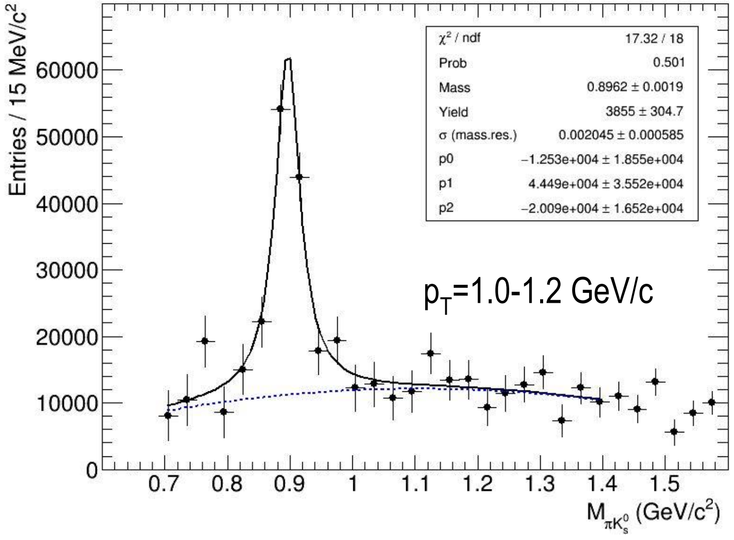
$K^*(892)^0 \rightarrow K^\pm\pi^\pm$



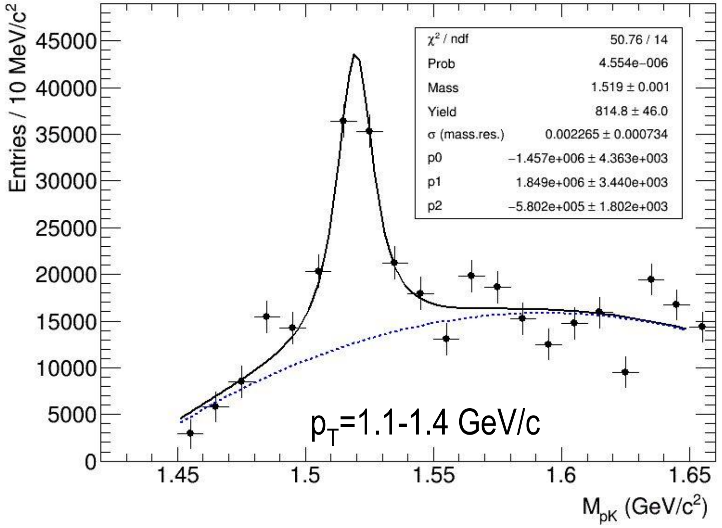
$\Sigma(1385)^\pm \rightarrow \pi^\pm\Lambda$ ($\Lambda \rightarrow p\pi$)



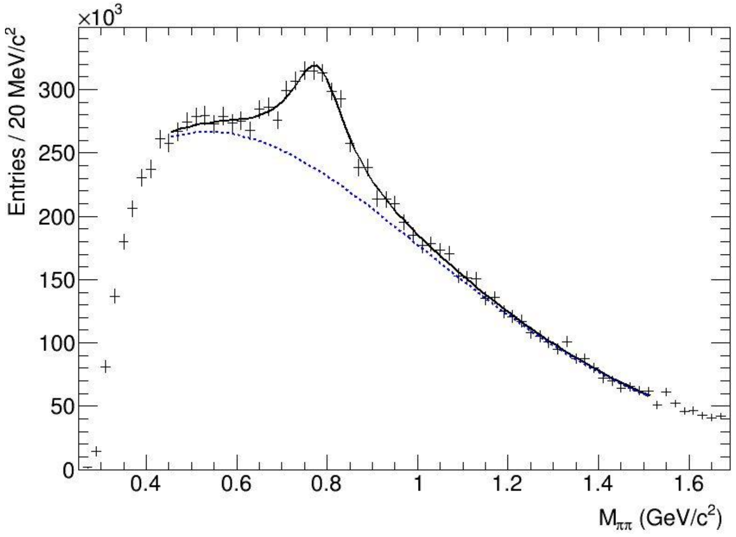
$K^*(892)^\pm \rightarrow \pi^\pm K_s$ ($K_s \rightarrow \pi^+\pi^+$)



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

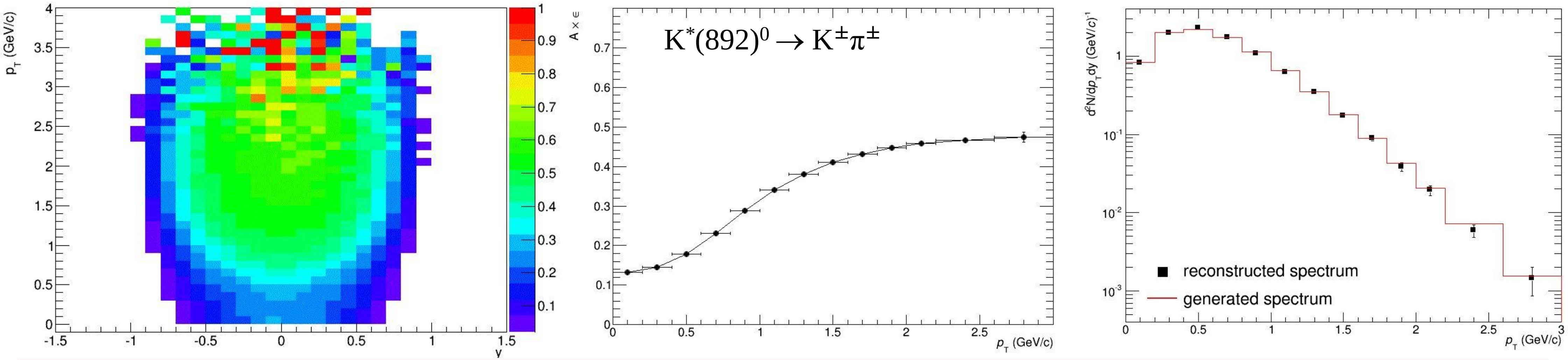


$\rho(770)^0 \rightarrow \pi^\pm\pi^\pm$



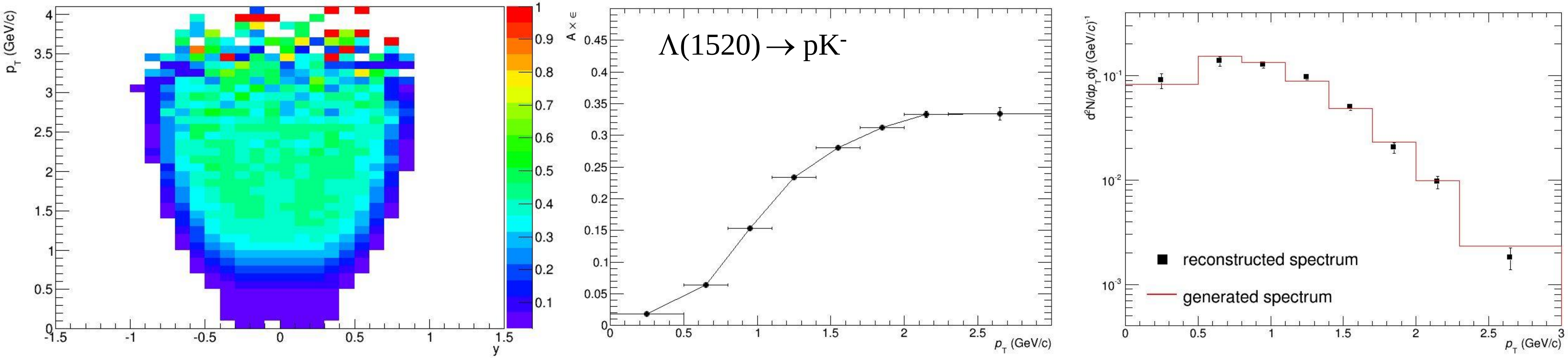
Efficiencies and closure tests examples

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

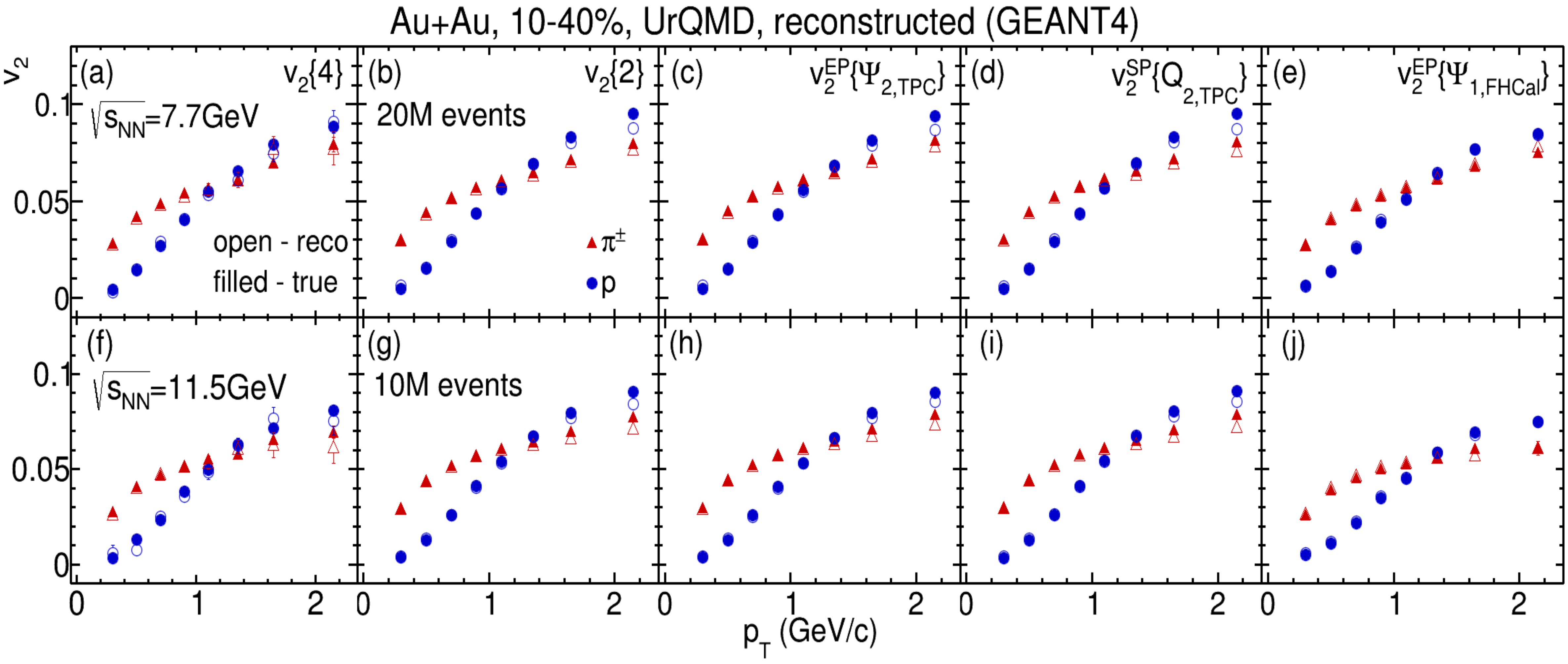


Reconstruction efficiency

Closure Test

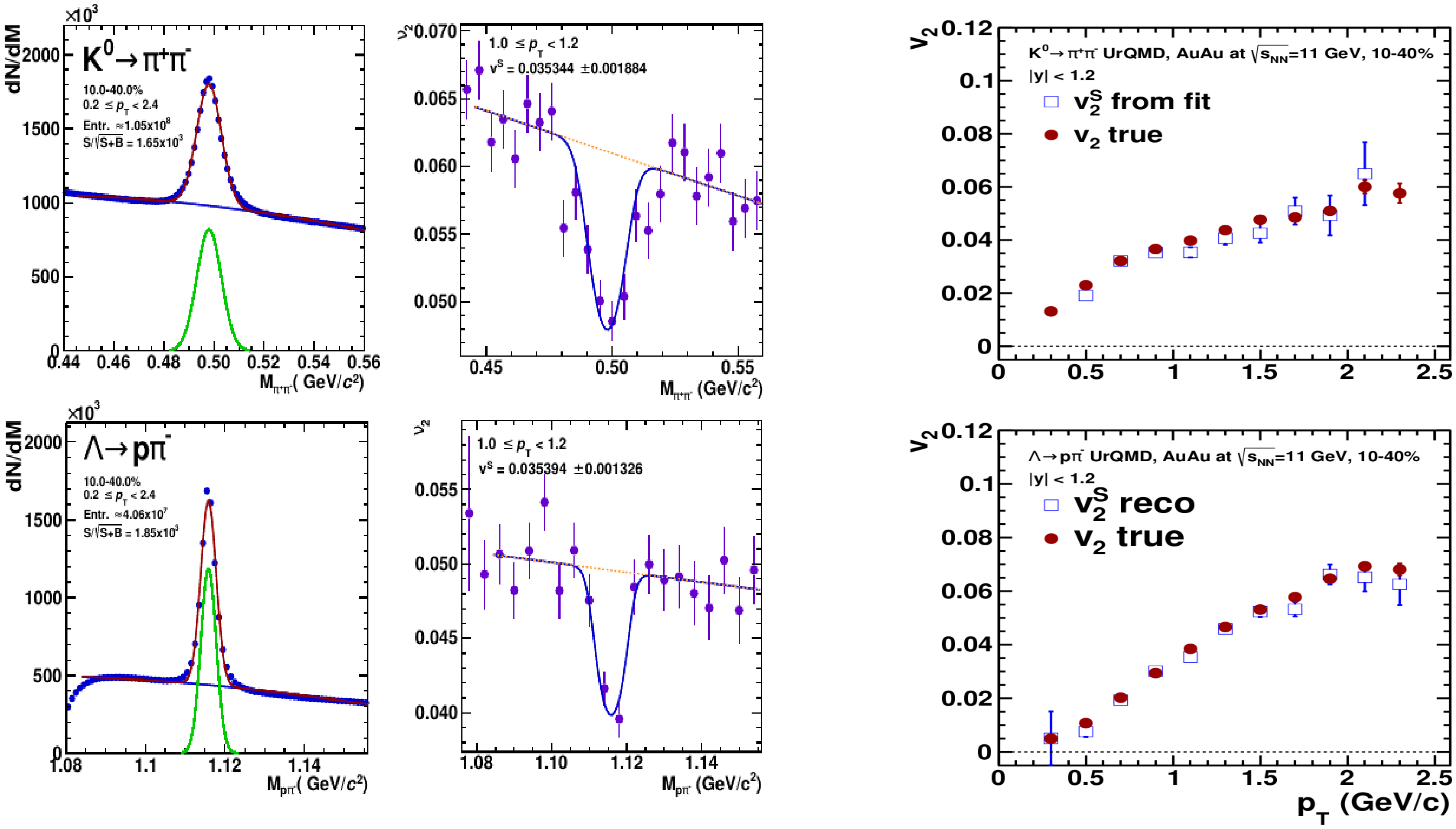


Performance study of v_2 of pions and protons in MPD



Reconstructed and generated v_2 of pions and protons have a good agreement for all methods

Performance study of v_2 of K_s^0 and Λ in MPD



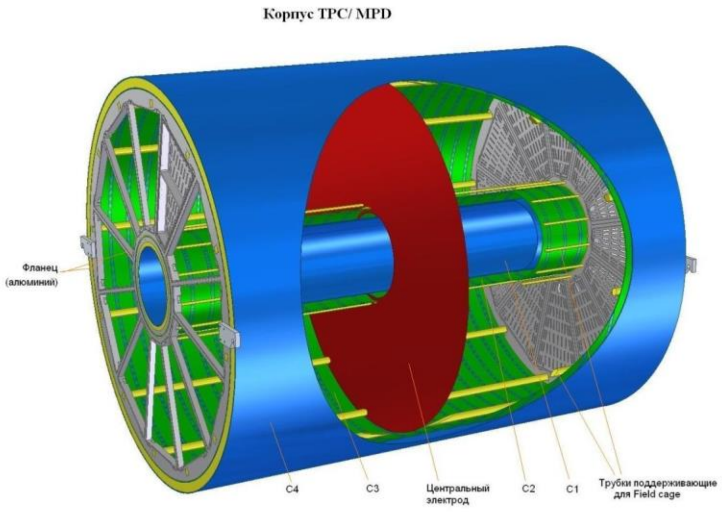
Reconstructed and generated v_2 of K_s^0 **and** Λ have a good agreement for all methods

Summary

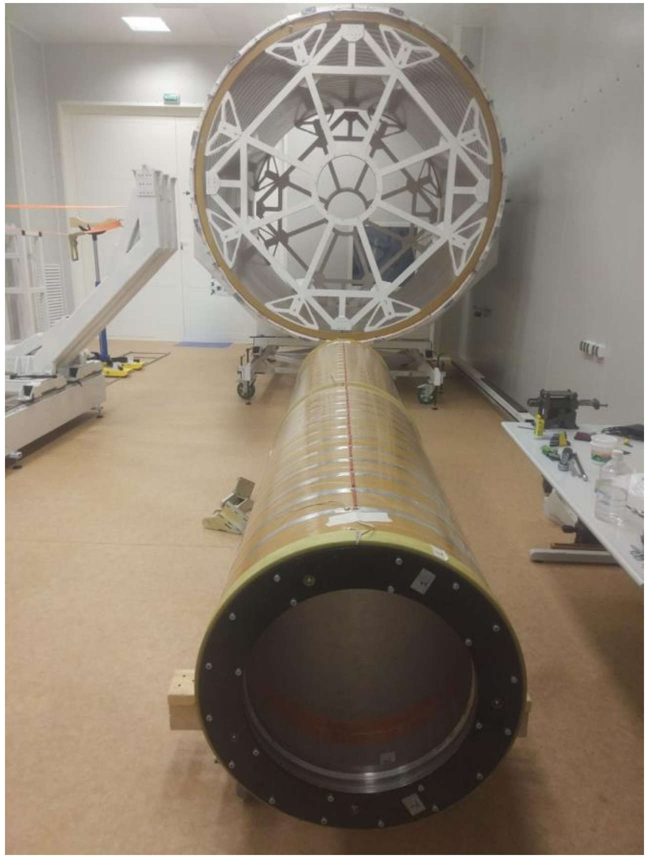
- The NICA Accelerator Complex in construction with important milestones achieved and clear plans for 2021 and 2022
- All components of the MPD 1st stage detector advanced in production, commissioning expected for 2022
- Intensive preparations for the MPD Physics program with initial beams at NICA in 2023

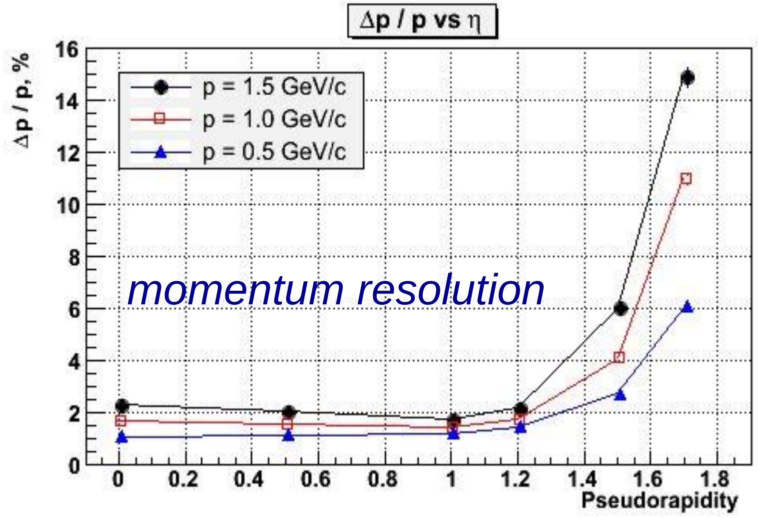
Thank you for you attention

Time Projection Chamber (TPC): main tracker

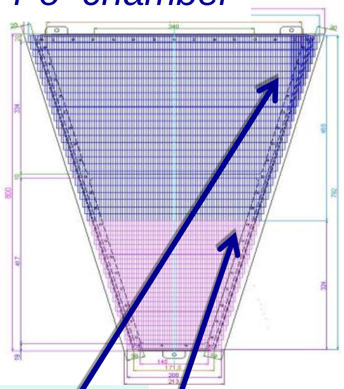


length	*340 см*
outer Radii	*140 см*
inner Radii	*27 см*
gas	*90%Ar+10%CH_4*
drift velocity	*5.45 см / μs;*
drift time	*< 30 μs;*
# R-O chamb.	*12 + 12*
# pads/ chan.	***95 232***
max rate	*< 7kGz (L= 10^{27})*





r-o chamber



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

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

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

MPD Time-of-Flight

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

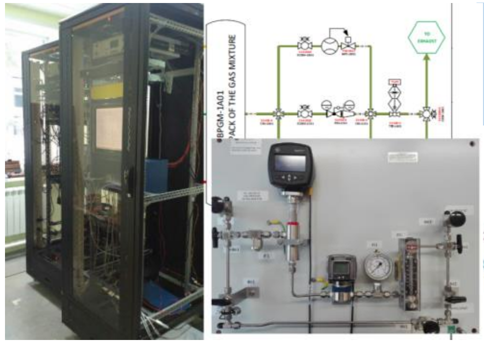
All procedure of detector assembling and optical control is performed in a clean rooms ISO class 6-7.

Glass cleaning with ultrasonic wave & deionized water

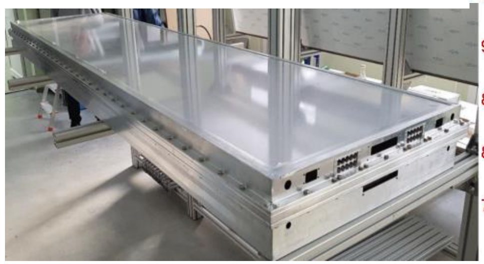
Automatic painting of the conductive layer on the glass

MRPC assembling

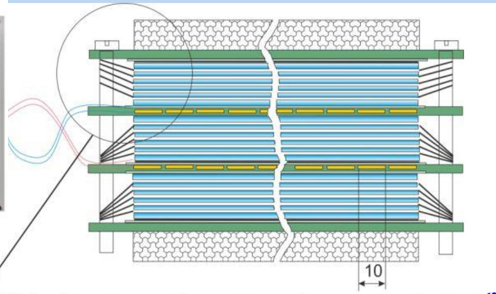
Soldering HV connector and readout pins

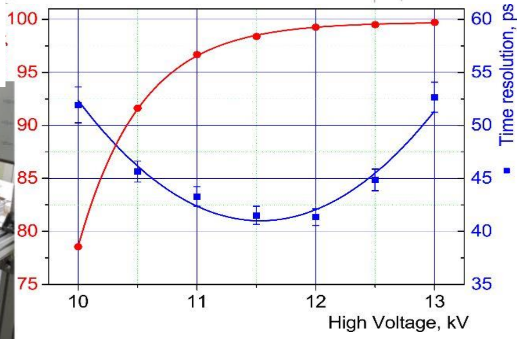


TOF gas system: Responsibility of the Polish group (WUT)



Dimensions of sensitive area 600 x300 mm^2





Single detector time resolution: 50ps

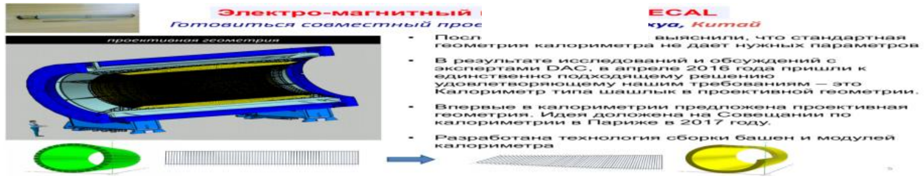
	Number of detectors	Number of readout strips	Sensitive area, m^2	Number of FEE cards	Number of FEE channels
MRPC	1	24	0.192	2	48
Module	10	240	1.848	20	480
Barrel	280	6720	51.8	560	**13440** (1680 chips)

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)

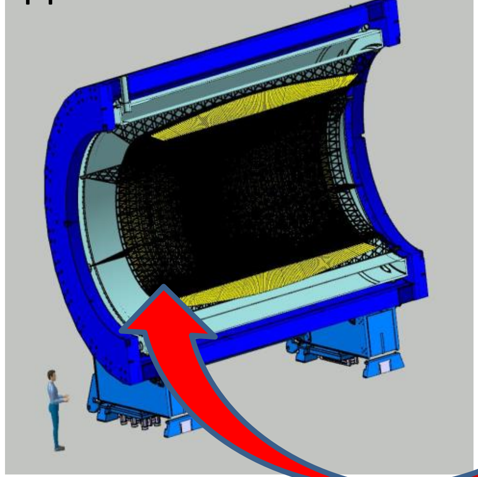
- *Pb+Sc "Shashlyk"* — *read-out: WLS fibers + MAPD* — *L ~35 cm (~ 14 X_0)*
- *Segmentation (4x4 cm^2)* — *σ(E) better than 5% @ 1 GeV* — *time resolution ~500 ps*

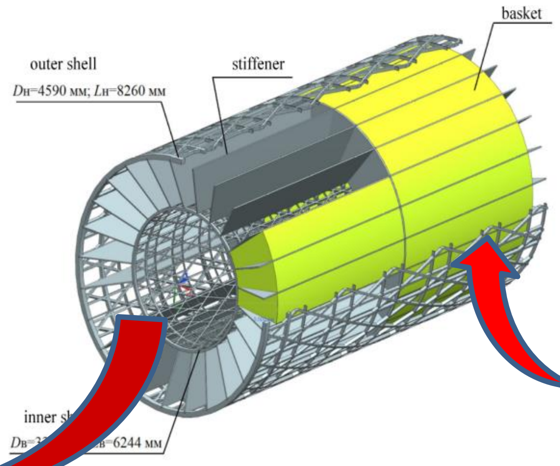
Barrel ECAL = <u>38400</u> ECAL towers (2x25 half-sectors x 6x8 modules/half-sector x 16 towers/module)

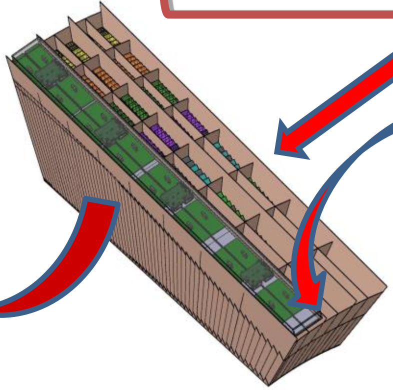


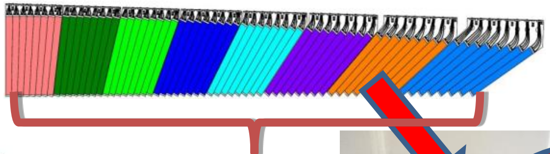
Projective geometry

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









Sectors in dedicated Containers

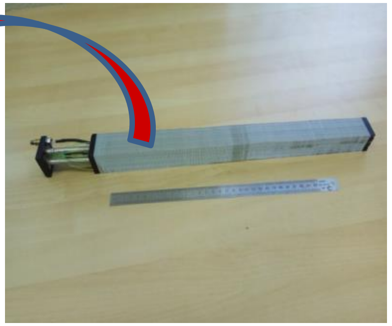
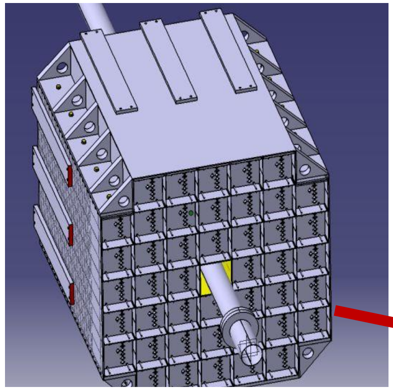
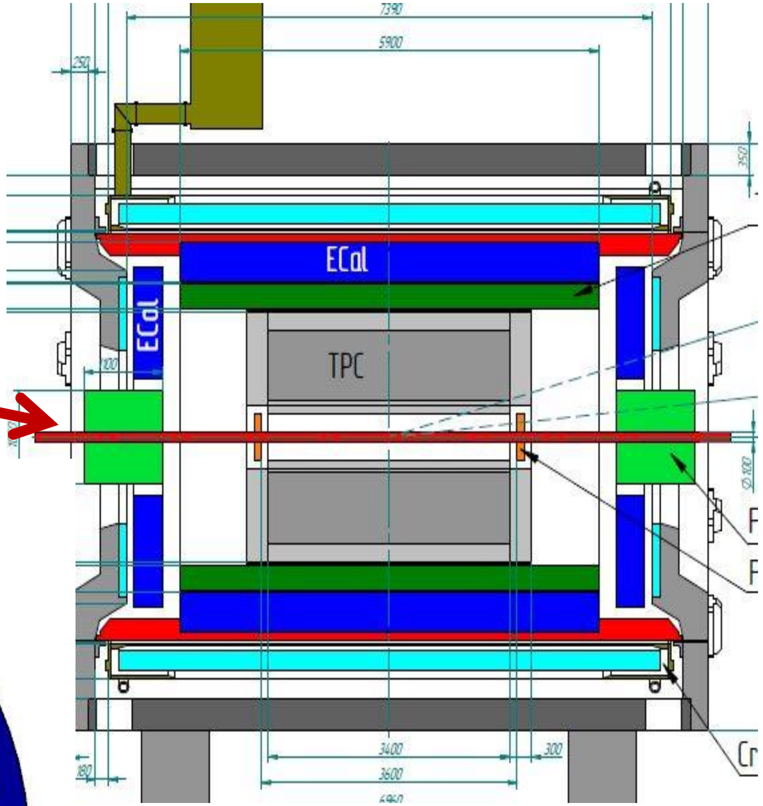
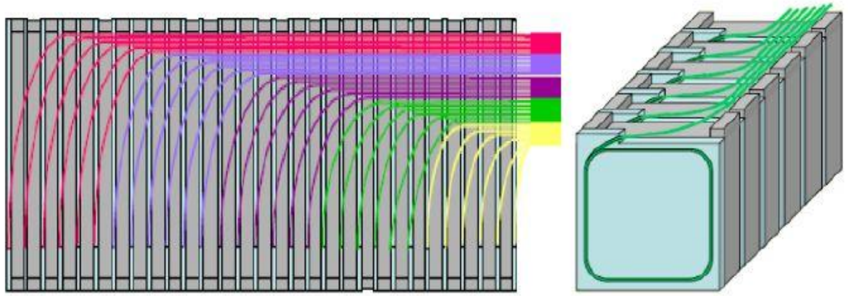


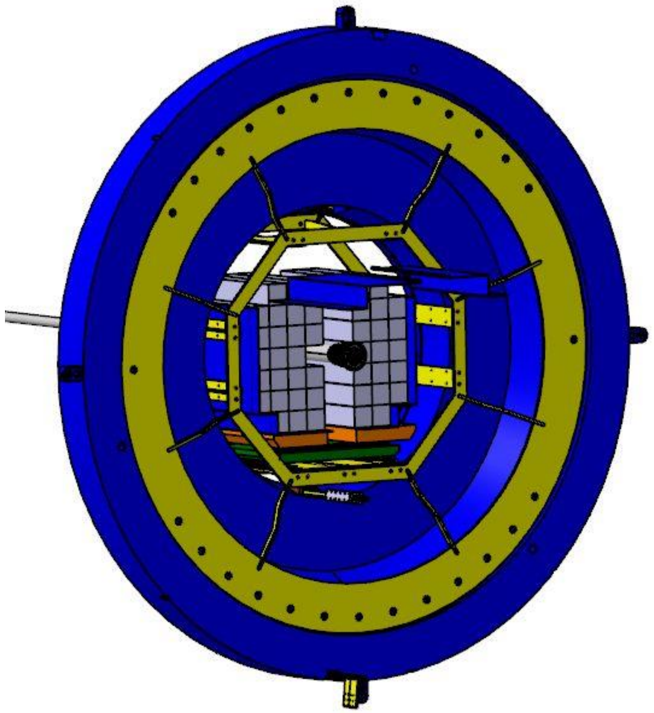
Photo of one element

Forward Hadron Calorimeter (FHCal)



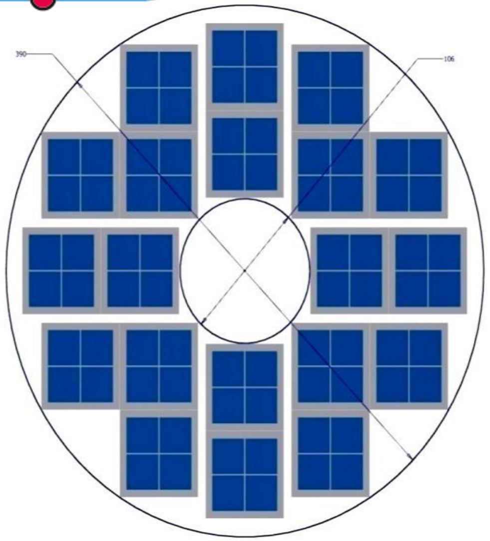


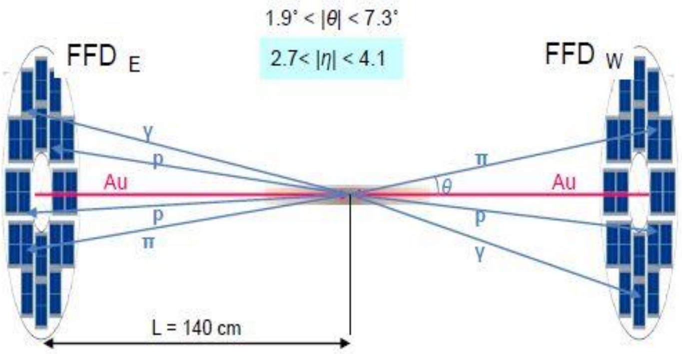




- Two-arms at ~3.2 m from the interaction point.
- Each arm consists of 44 individual modules.
- Module size 150x150x1100cm^3 (42 layers)
- Pb(16mm)+Scint.(4mm) sandwich
- 7 longitudinal sections
- 6 WLS-fiber/MAPD per section
- 7 MAPDs/module

FFD - Fast Trigger L_0 for MPD





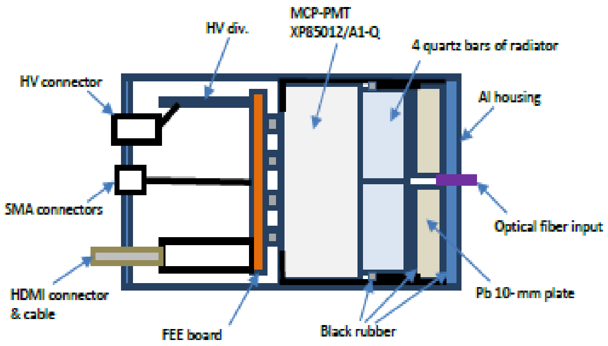


Fig. 4-1. A scheme of the FFD module.

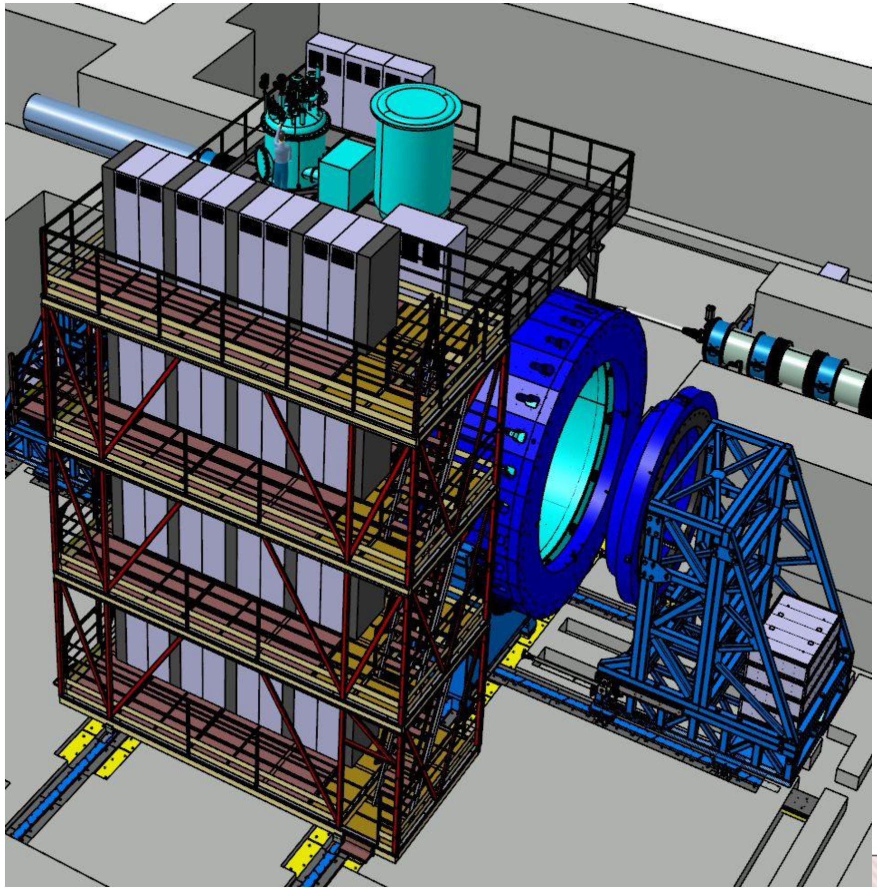
FFD provides information on
- interaction rate (luminosity adjustment)
- bunch crossing region position

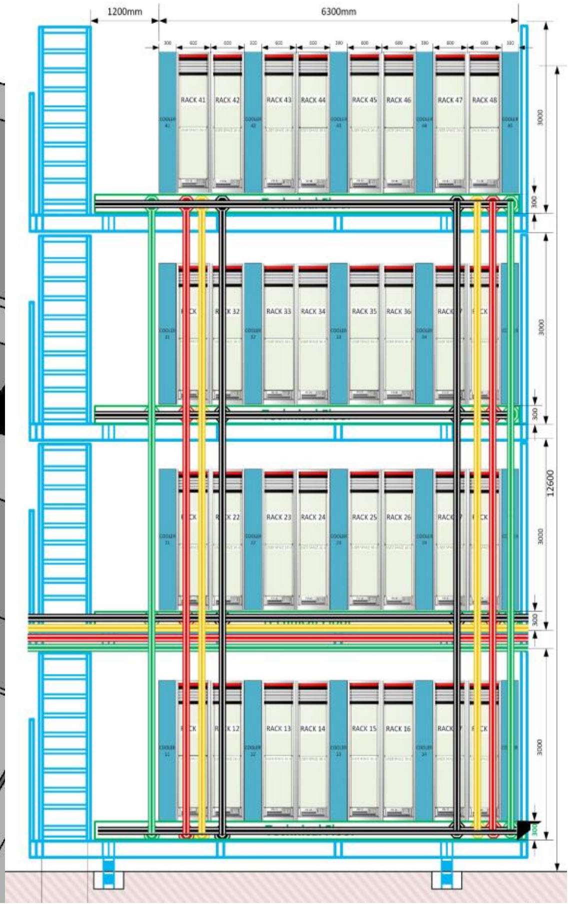
15 mm quartz radiator
10 mm Lead converter

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

MPD Cosmic Ray Detector (MCORD)

NCBJ, Świerk - WUT, Warsaw – UJK, Kielce (Poland) 18 scientists+12 engineers
Project leader: M. Bielewicz (NCBJ)

As soon as possible - start tests of MPD subsystems before Collider operation
Cosmic Ray Detector required for Commissioning and tests of the MPD.
The signals from MCORD will be used for TPC and TOF tests after their installation.
We'll need the elements of MCORD (scintillation panels with readout electronics) in March 2021
CDR for MCORD under evaluation of the MPD DAC

Cosmic Ray Detector consists of plastic scintillators with SiPM (Phototubes) light converters

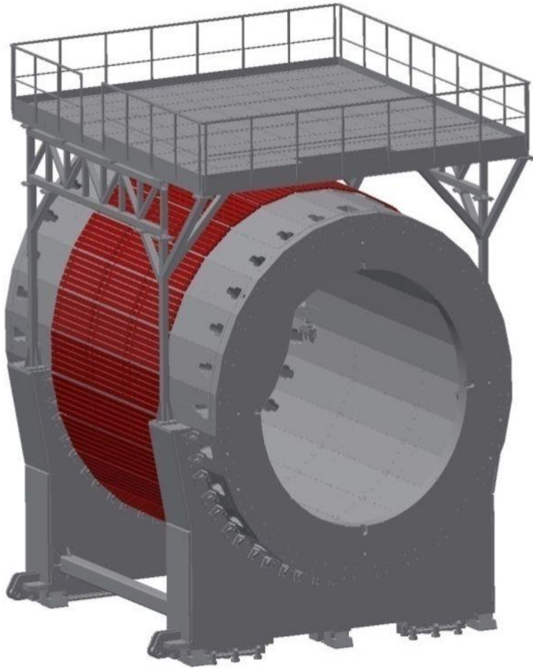
a) Trigger (for testing or calibration)
- testing before completion of MPD (testing of TOF, ECAL modules and TPC)
- calibration before experimental session

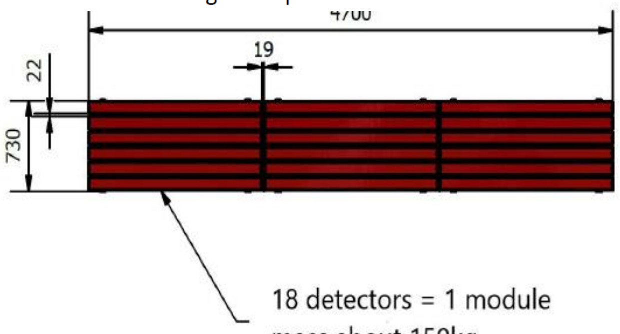
b) Veto (normal mode - track and time window recognition)
Mainly for TPC and eCAL

Additionally

c) Astrophysics (muon shower and bundles)
- unique for horizontal events

Working in cooperation with TPC





5. MCORD Detector

SCINTILLATORS

Number of scintillators:	660 pcs
Dimensions of scintillators:	95x25x1500 [mm]
Dimensions of detector:	100x30x1554 [mm]
Scintillators are placed in the rectangle profile	10x30x2.5 [mm]
Weight of detector:	6.5 kg
Material of scintillators casing:	Aluminum alloy

MODULES

Number of detector in one module:	18
Number of Modules:	28
Dimensions of module:	730x90x4700 [mm]
Weight of one module:	150 kg

SiPM/MMPC

Number of SiPMs (Chanels)	1320
Number of SiPMs (with two fibers)	2640

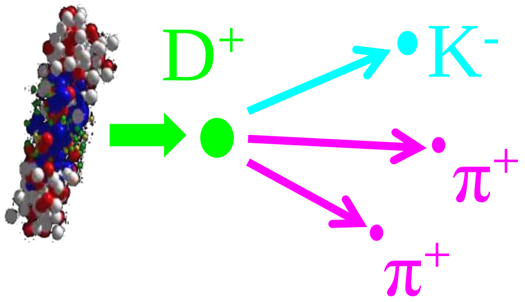
RESOLUTION

Position resolution: In X axis – up to 5 cm, In Y axis – 5-10 cm
Time Resolution – about 300-500 ps

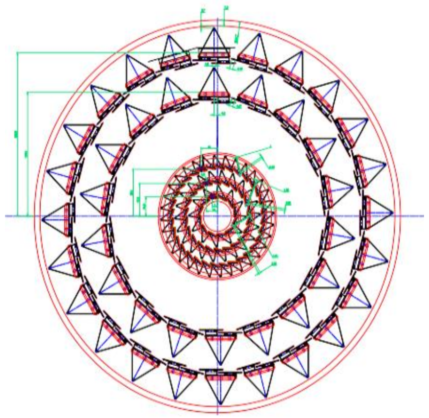
Number of events (particles):	about 100-150 per sec per m2
Calculated Coincidence factor:	about 98%

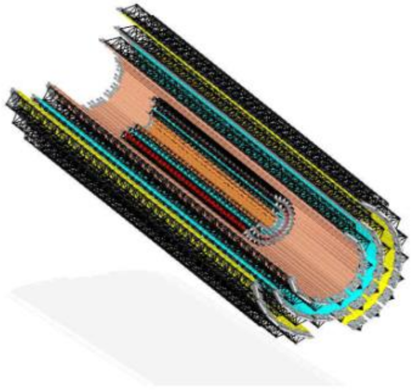
Inner Tracker System (ITS): precise tracking

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

Milestones of MPD assembling in 2020-2022

Year 2020

1. July 15th - MPD Hall and pit are ready to store and unpack Yoke parts
2. August - The first 13 plates of Magnet Yoke are assembled for alignment checks
3. Sept 15 - Oct 1st - Solenoid is ready for transportation from ASG (Italy)
4. November 6th - Solenoid arrived in Dubna
5. Nov-Dec - Assembling of Magnet Yoke at JINR

Year 2021

6. Jan- Sep - Preparation for switching on the Solenoid (Cryogenics, Power Supply et cet.)
7. Oct - Nov - Magnetic Field measurement
8. Dec - Installation of Support Frame

Year 2022

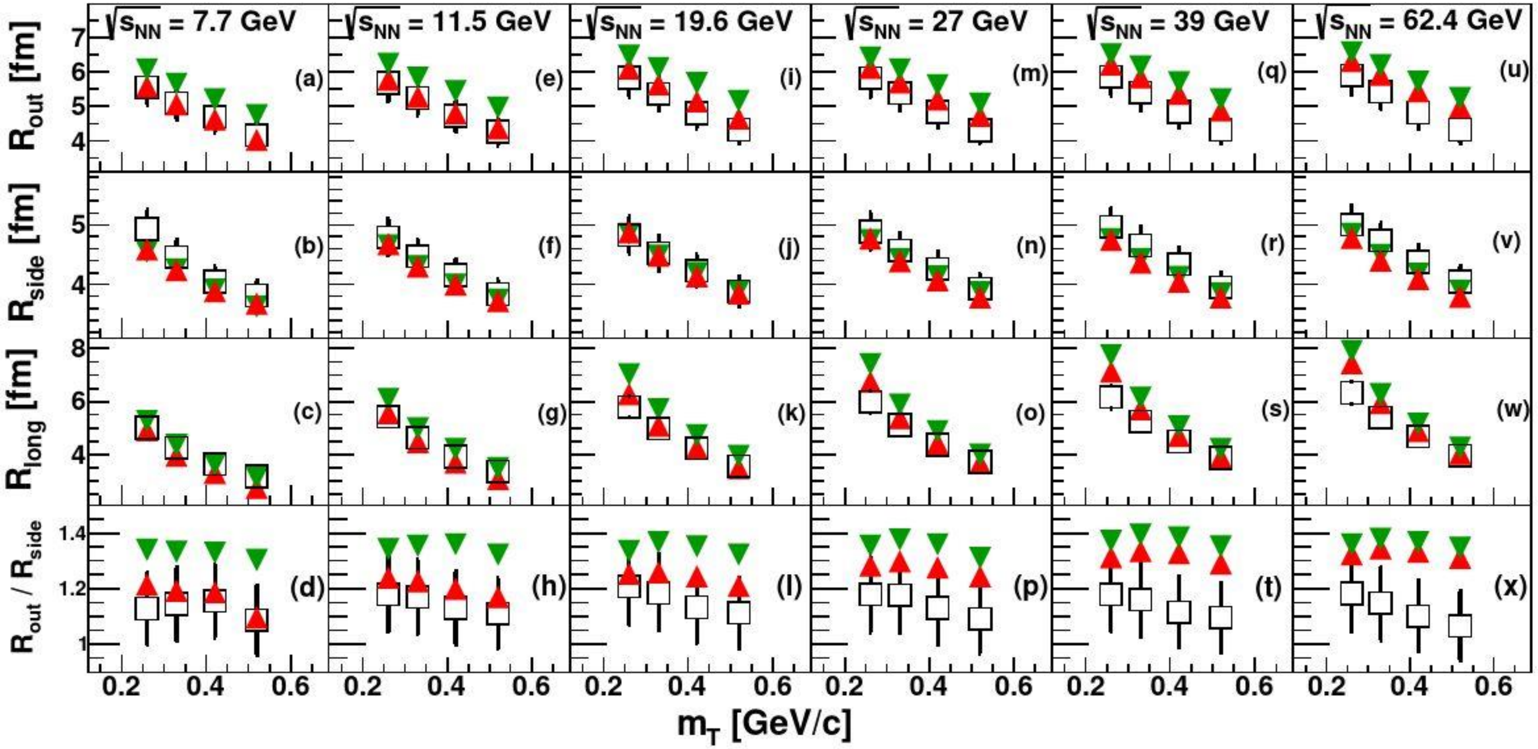
9. Jan- Jun - Installation of TOF, TPC, Electronics Platform, Cabling
10. Jul - Installation of beam pipe, FHCal, Cosmic Ray test system
11. Jul-Dec - Cosmic Ray tests
12. December - Commissioning

- **Year 2023**

13. **March - Run on the beam**

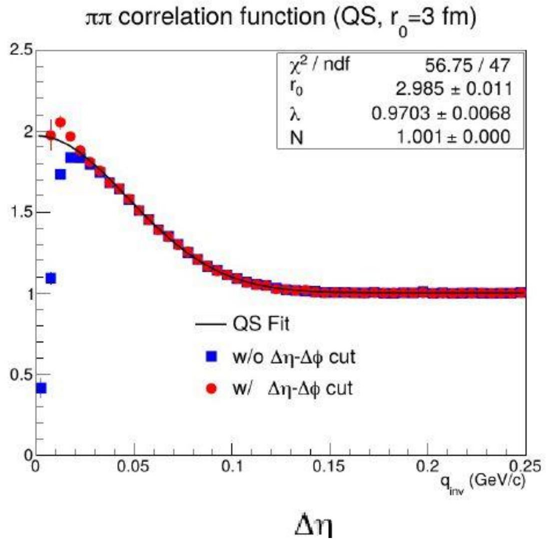
System size sensitive to phase transition

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



1st order phase transition

cross-over transition

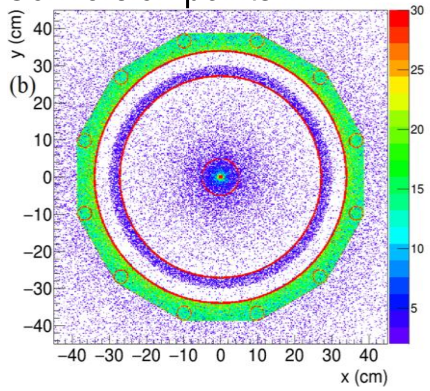


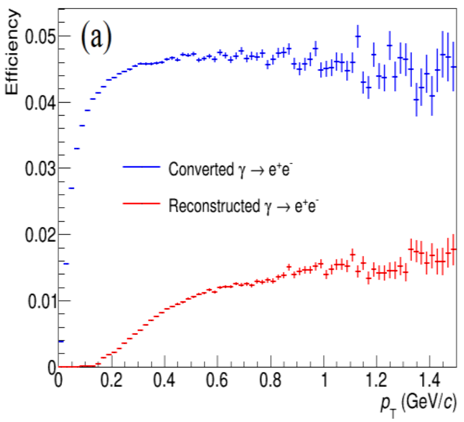
- Clear sensitivity of pion source size to the nature of the phase transitions
- Important and sensitive cross-check of detector performance (two-track resolution)

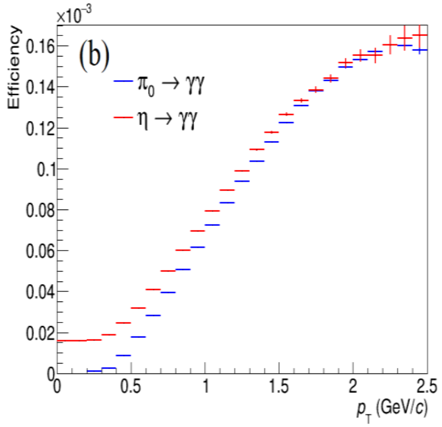
π^0 and η Reconstruction via conversion

- Photon reconstruction, complimentary to ECAL
- Direct photons, neutral mesons, geometry scan etc …
- Minbias AuAu@11, UrQMD - conversion on the beam pipe and inner layers of the TPC

Conversion points in MPD

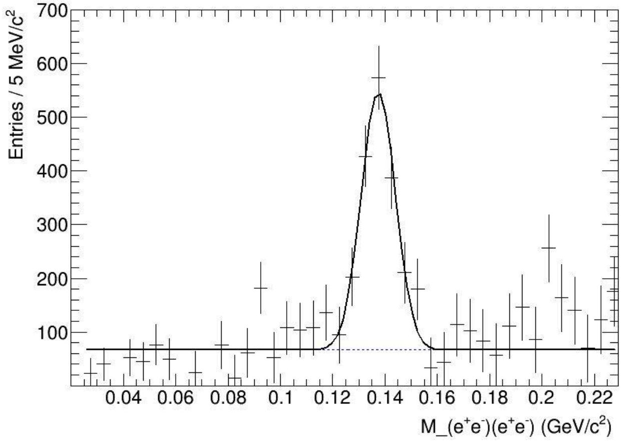




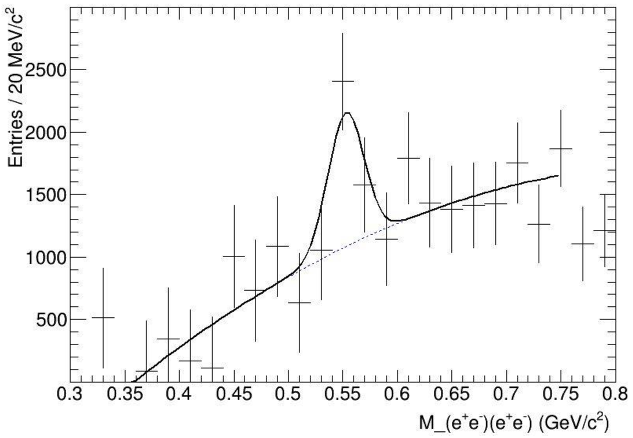


α) γ-conversion efficiency in the beam pipe & TPC vs p_T
b) MPD efficiency for π^0 and η reconstruction vs meson's p_T

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



$\eta \to \gamma\gamma \to (e^+e^-)(e^+e^-)$



- Standard MPD configuration allows to reconstruct π^0 and [illegible] via conversion pairs

Setup, event and track selection

Model → GEANT4 → Reconstruction → Flow analysis

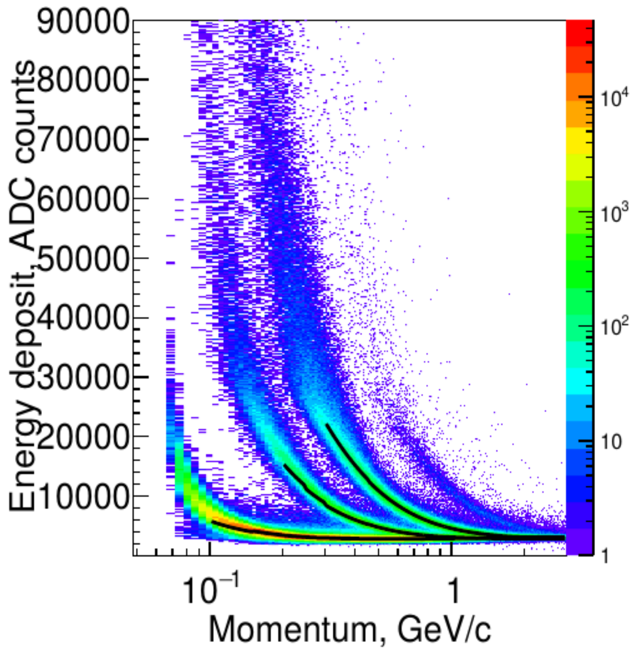
- Au+Au: UrQMD
  - N_{events}= 10 M *at* $\sqrt{s_{NN}}$ = 4.5, 11.5 GeV
  - N_{events}= 25 M *at* $\sqrt{s_{NN}}$ = 11 GeV (for K^0, Λ)
  - N_{events}= 20 M at $\sqrt{s_{NN}}$ = 7.7 GeV
- Bi+Bi:
  - N_{events}= 17 M *at* $\sqrt{s_{NN}}$ = 7.7 GeV

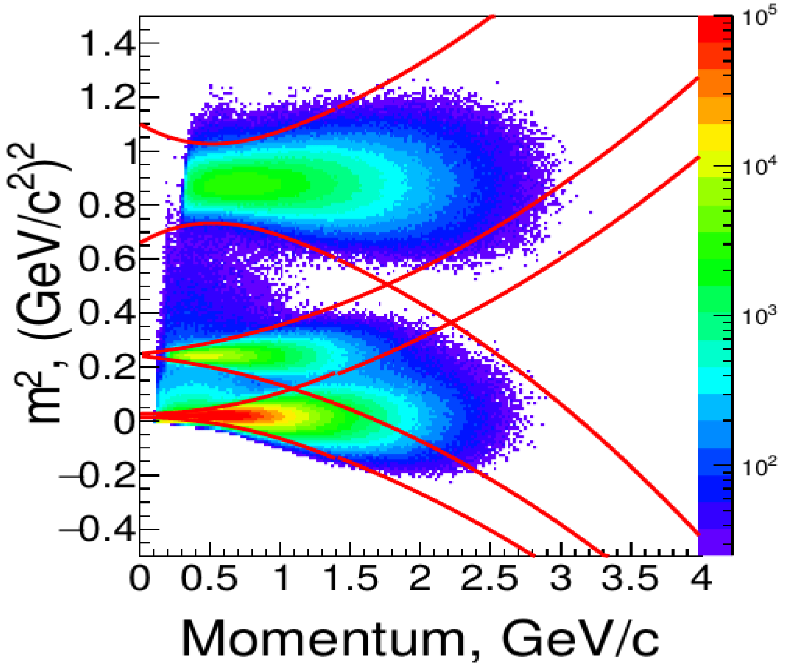
- TPC
- FHCal
- TOF
- ...

Event classification:
- Track multiplicity
- FHCal energy

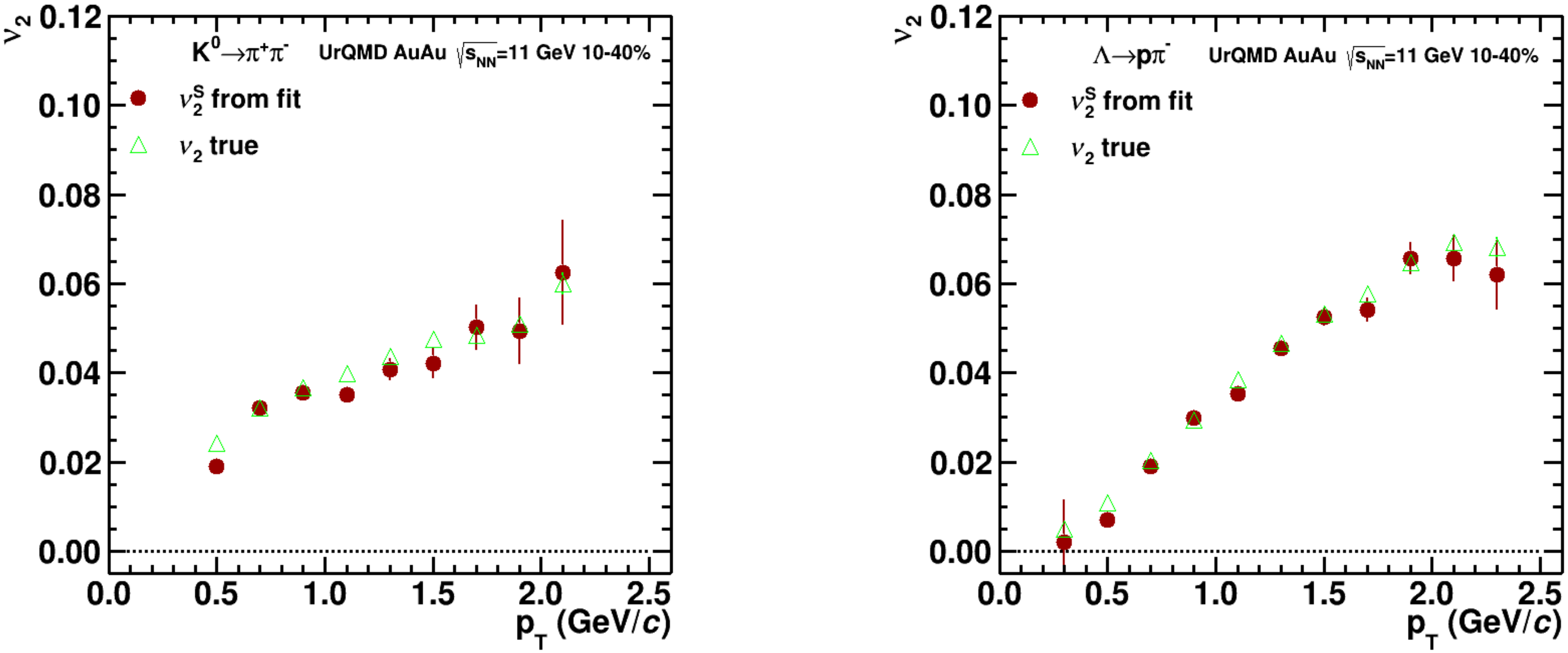
Track selection:
- $N_{TPC\ hits}$ > 16
- 0.2 < p_T< 3 GeV/c
- $|\eta|$ < 1.5
- PID based on TPC+TOF (MpdPid)

MPDRoot, August 2020





Performance study for v_2 of V0 particles



Reasonable agreement between reconstructed and generated v_2 signals for both K^0 and Λ

Event plane method using v_1 of particles in FHCal

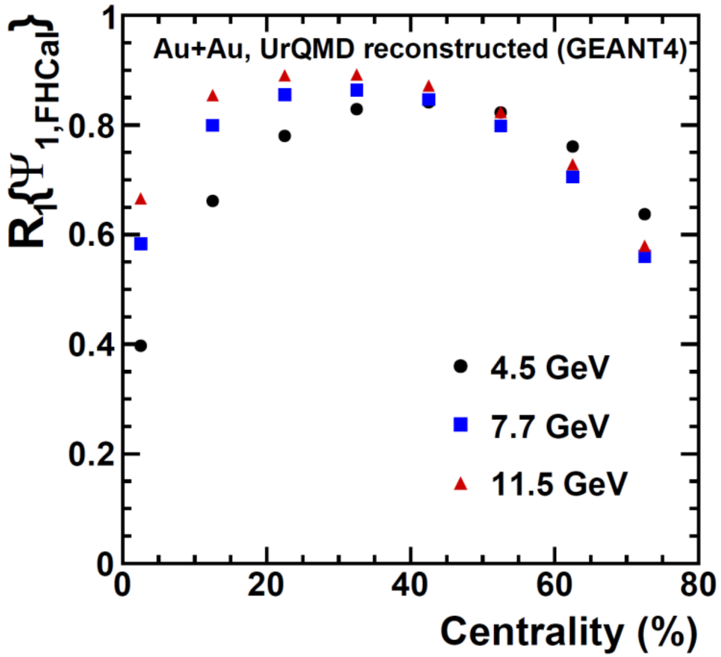
Using v_1 of particles in FHCal to determine Q_n

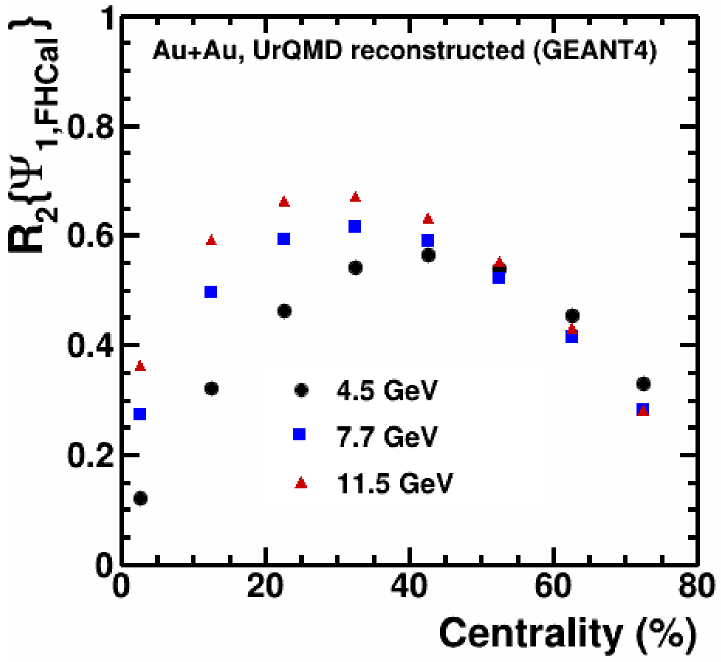
$$Q_1 = \frac{\sum E_i e^{i\varphi_i}}{\sum E_i}, \Psi_{1,\mathrm{FHCal}} = \tan^{-1}\left(\frac{Q_{1,y}}{Q_{1,x}}\right) \qquad (1)$$

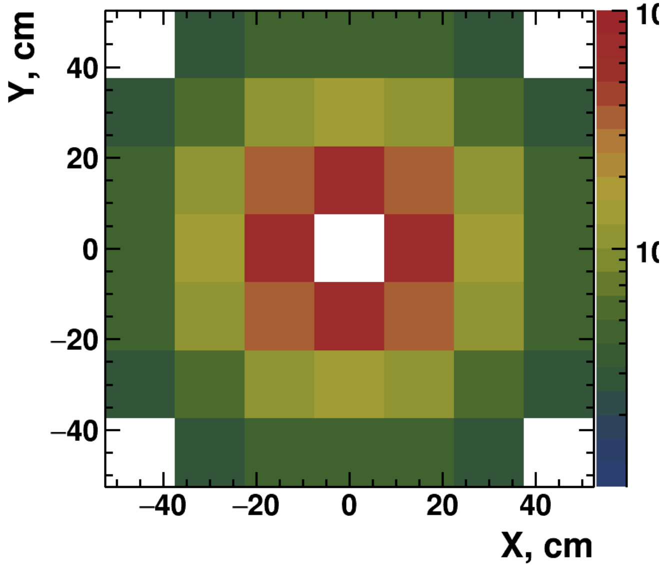
E – energy deposition in FHCal modules (2<|η|<5)

$$R_n\{\Psi_{1,\mathrm{FHCal}}\} = \langle \cos[n(\Psi_{\mathrm{RP}} - \Psi_{1,\mathrm{FHCal}})] \rangle \qquad (2)$$

$$v_2\{\Psi_{1,\mathrm{FHCal}}\} = \frac{\langle \cos[n(\varphi - \Psi_{1,\mathrm{FHCal}})] \rangle}{R_n\{\Psi_{1,\mathrm{FHCal}}\}} \qquad (3)$$







Energy distribution in FHCal