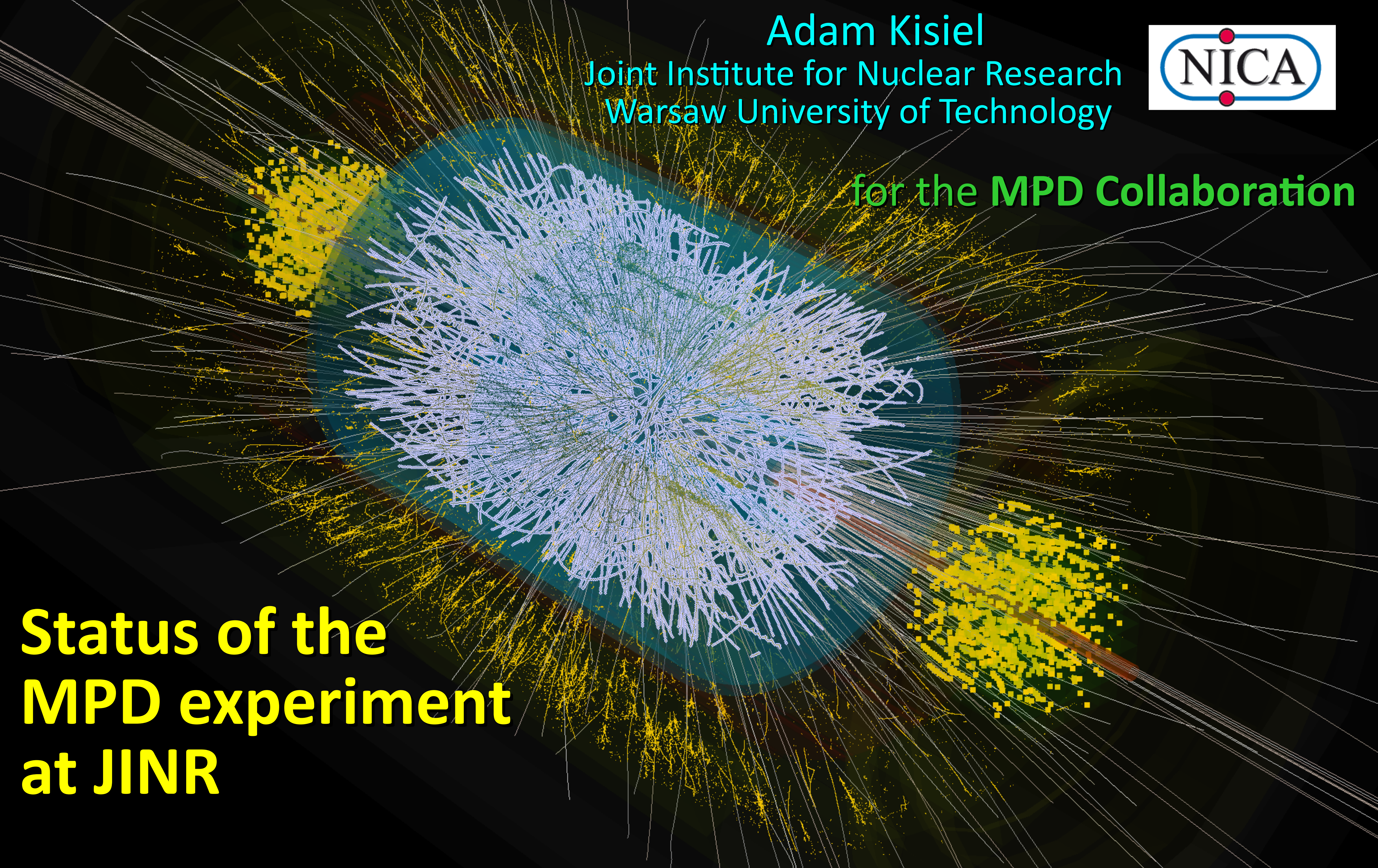


Adam Kisiel
Joint Institute for Nuclear Research
Warsaw University of Technology

for the **MPD Collaboration**

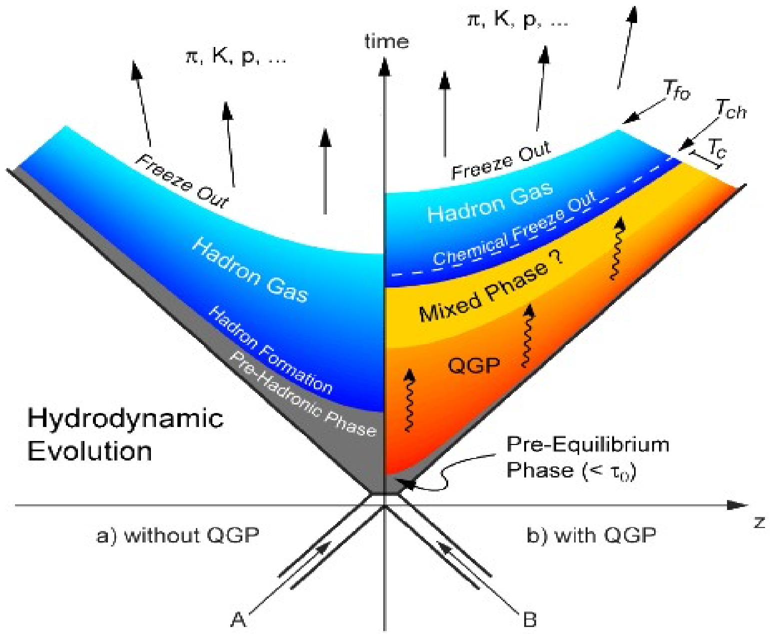
Status of the MPD experiment at JINR

The Host Institute

Joint Institute for Nuclear Research (JINR) –
International Intergovernmental Organization established through the Convention of March 26, 1956 by 11 founding States and registered with the United Nations on 1 February 1957

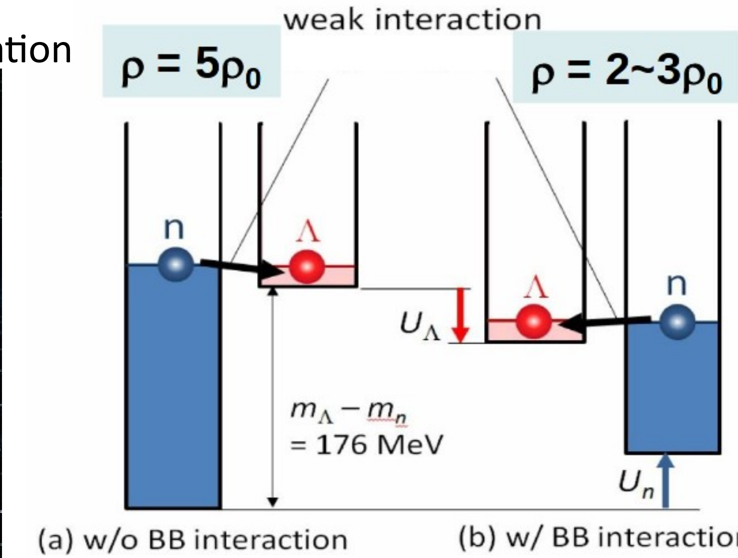
Governed by the **Committee of Plenipotentiaries** *representing governments of* ***18*** *countries*

Unexplored phase space in QCD diagram



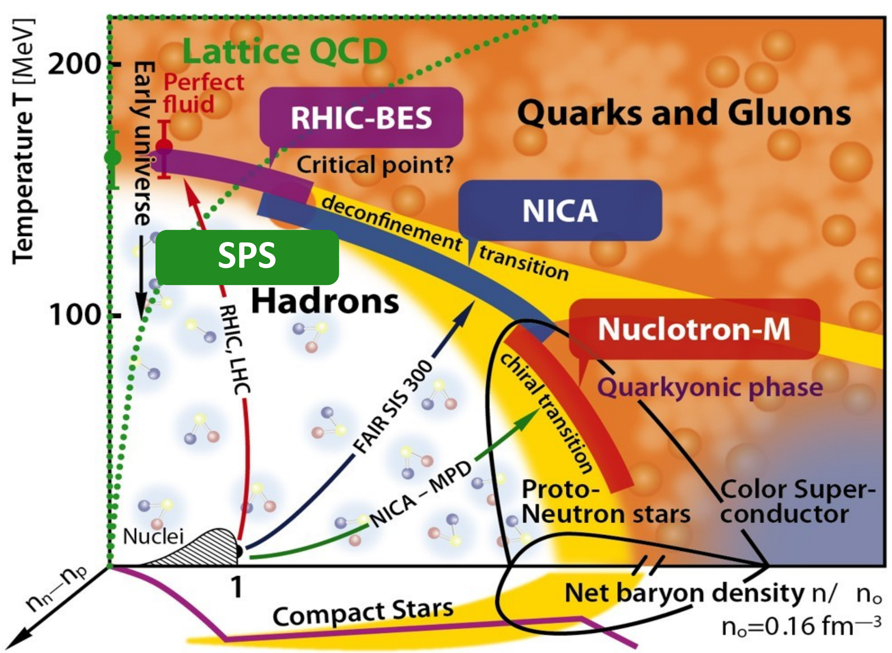
core of neutron stars reaches density several times larger than nuclear density

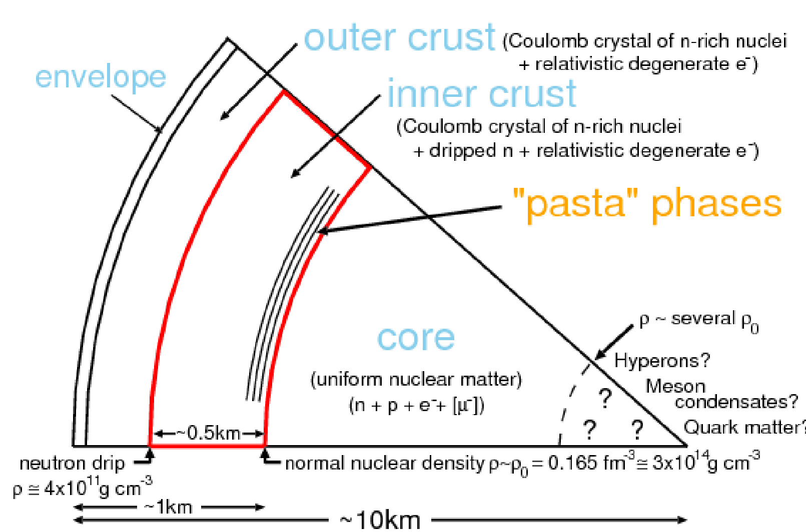
Credit: LIGO Collaboration



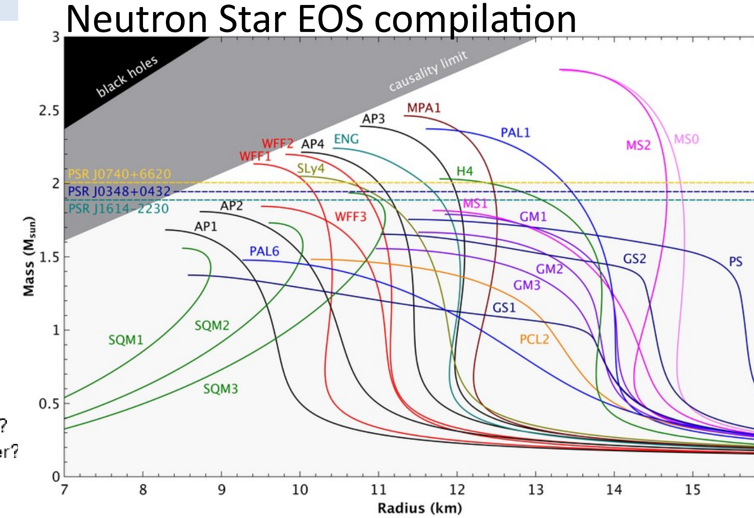
H. Tamura, Hadron 2017

neutron star mergers probe region of high density and moderate temperature – phase transition?





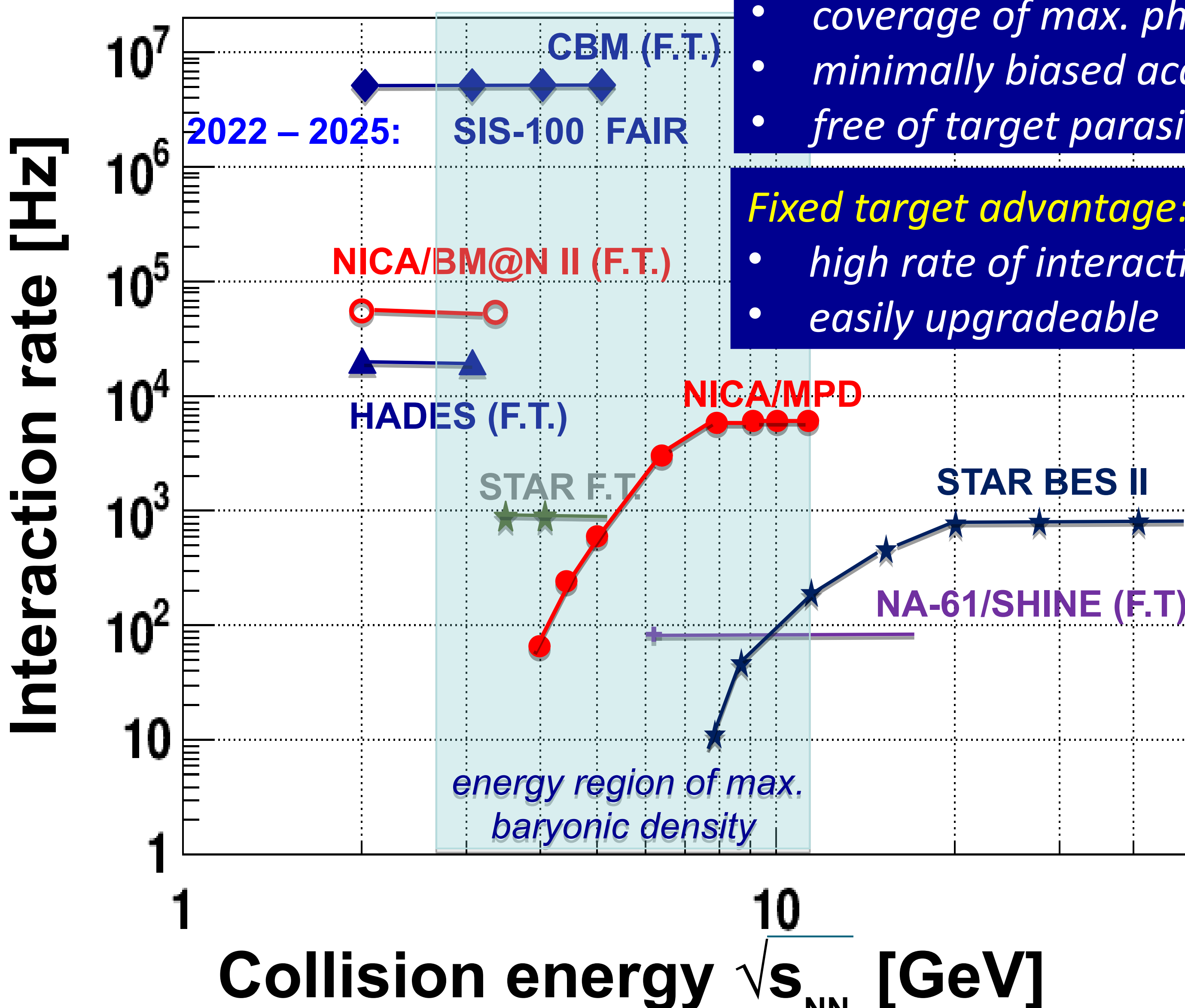
Neutron Star EOS compilation



NICA: Unique and complementary

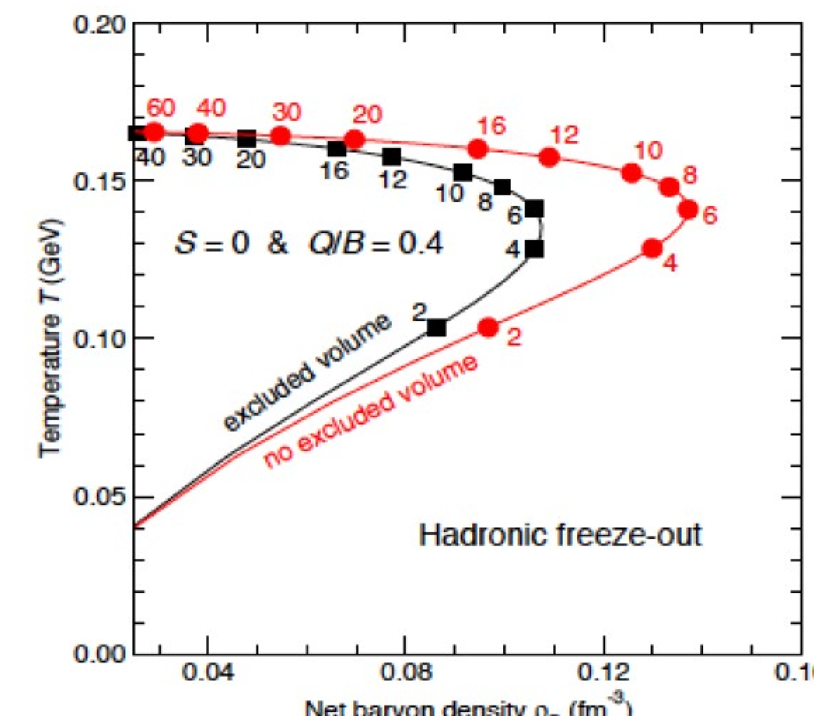
Collider advantage:
- *coverage of max. phase space*
- *minimally biased acceptance*
- *free of target parasitic effects*

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

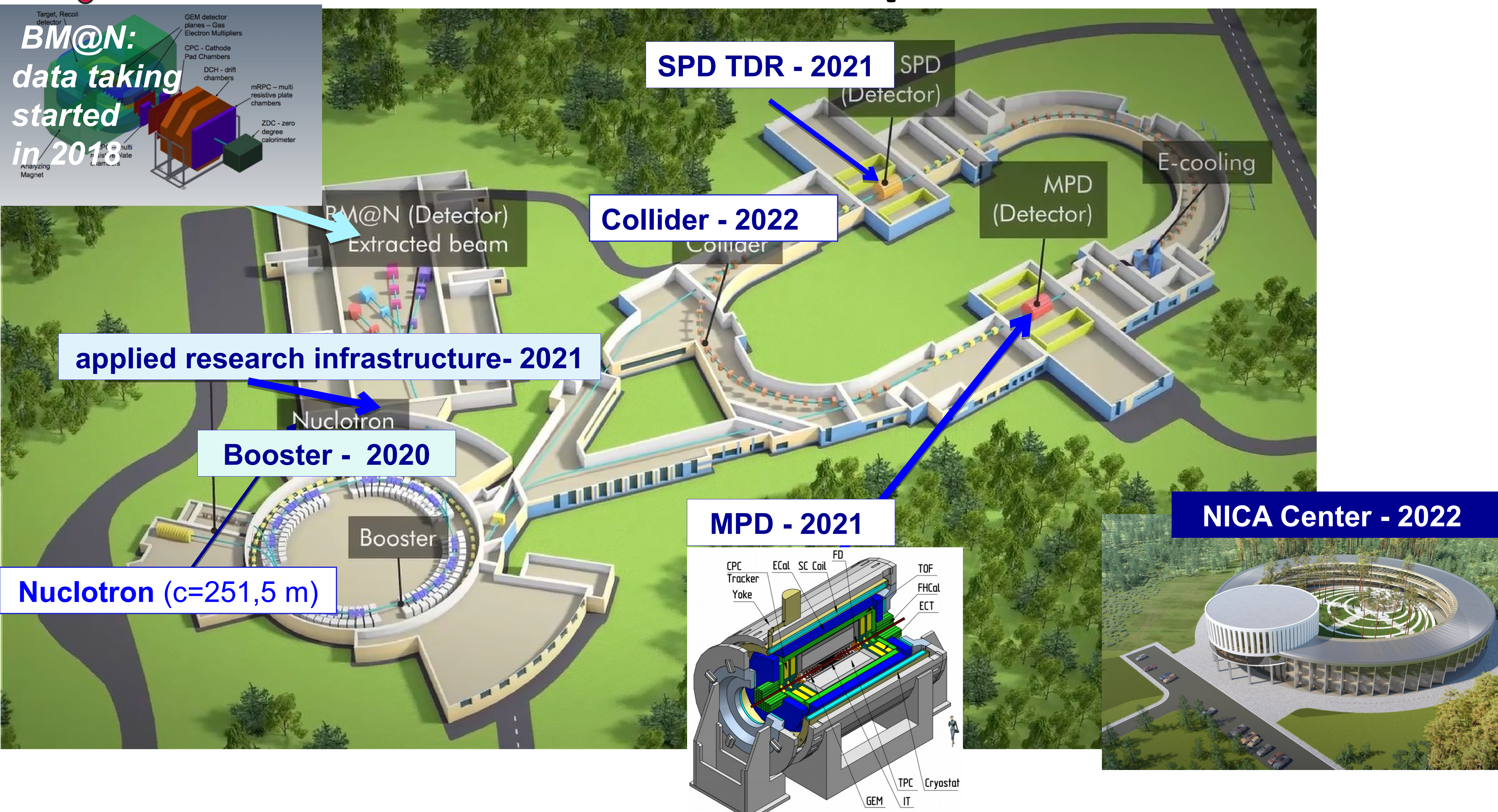


In NICA Collider energy range maximum possible net-baryon density is reached

Highest baryon density at freeze-out for $s^{1/2}$~6 GeV, slightly lowering with ex.volume

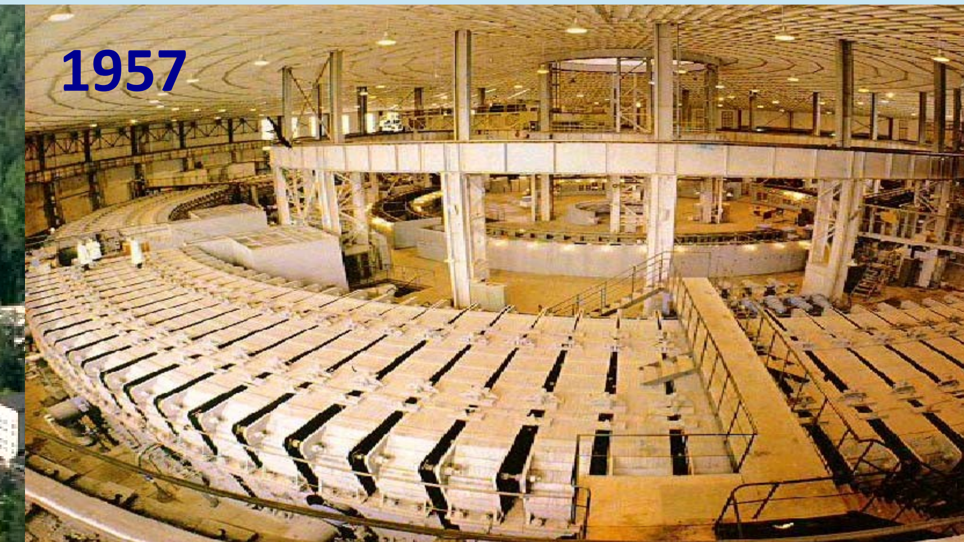


NICA Accelerator Complex in Dubna



History of NICA Accelerator Complex

Synchrophasotron –10 GeV proton synchrotron (1957)
pioneering research in RNP since '70-ties;



*Nuclotron ring (c= **251,5** m)*

SC synchrotron- **Nuclotron (1993)** *based on*
*superconducting fast cycling magnets developed at **LHE JINR***

Status of the Accelerator Complex

Linac HILac ← **KRION**

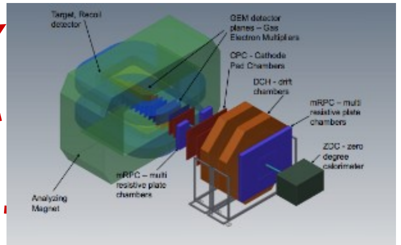
Linac LU-20 ← **Ion sources**

Booster (25 Tm)

storage of (2 ÷ 4)×10⁹ ions, acceleration up to 600 MeV/u

Stripping (80%) $^{197}Au^{31+}$ => $^{197}Au^{79+}$

Fixed Target Area



BM@N ***put in operation in 2018***

Nuclotron (45 Tm)

injection bunch ~ 2×10⁹ ions acceleration up to ***1 - 4.5 GeV/u***

Two SC collider rings

IP-2

$\sqrt{s_{NN}}$ = 4 – 11 GeV (Au+Au)

L = 1 x 10^{27} cm^{-2} s^{-1}

~ 2 x 22 injection cycles

22 bunches per ring

IP-1

Main parameters of accelerator complex

Nuclotron

Type сю	**SC synchrotron**
particles	↑p, ↑d, nuclei (Au, Bi, ...)
max. kinetic energy, GeV/u	10.71 (↑p); 5.35 (↑d) **3.8** (Au)
max. mag. rigidity, Tm	38.5
circumference, m	251.52
vacuum, Torr	10^{-9}
*intensity, **Au** /pulse*	1 10^{9}

Booster

	value
ion species	A/Z ≤ 3
max. energy, MeV/u	**600**
magnetic rigidity, T m	1.6 – 25.0
circumference, m	210.96
vacuum, Tor	10^{-11}
*intensity, **Au** /p*	1.5 10^{9}

The Collider

Design parameters, Stage II

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

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

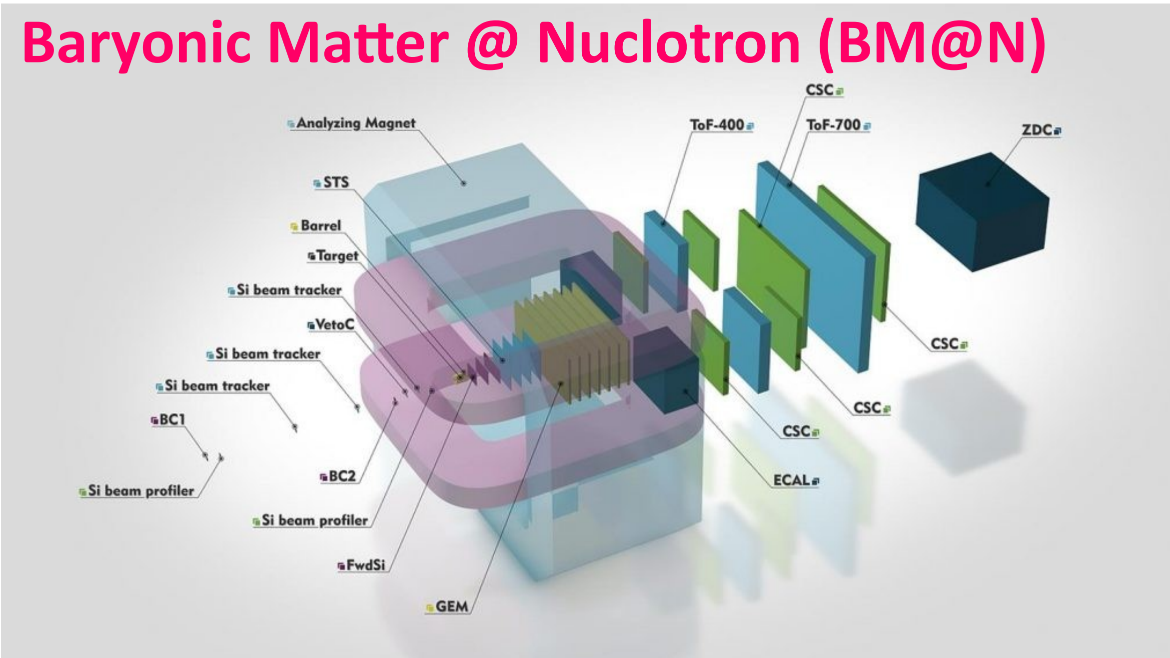
Stage I:

- ***without ECS***
- ***reduced number of RF***
- ***reduced luminosity***

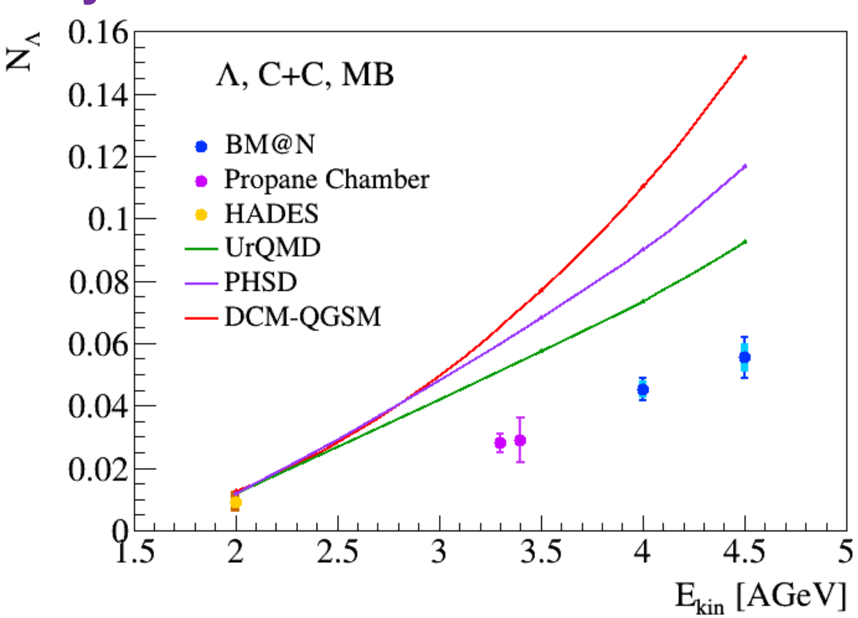
First physics from BM@N at NICA

BM@N

Baryonic Matter @ Nuclotron (BM@N)



Λ yield in min bias C+C interactions

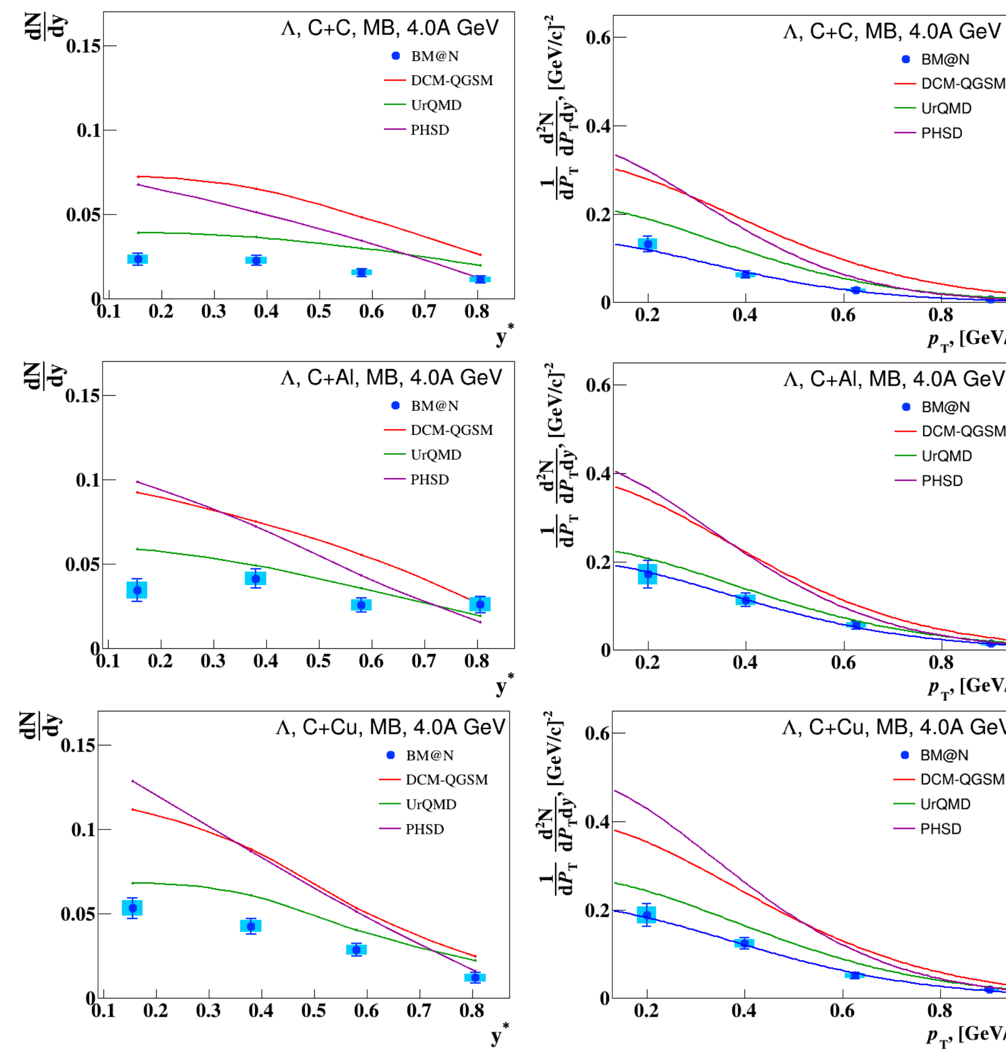


Analyses of experimental data in Ar, Kr beams and SRC data in carbon beam are in progress

BM@N: Λ hyperon yield in 4 AGeV Carbon-nucleus interactions

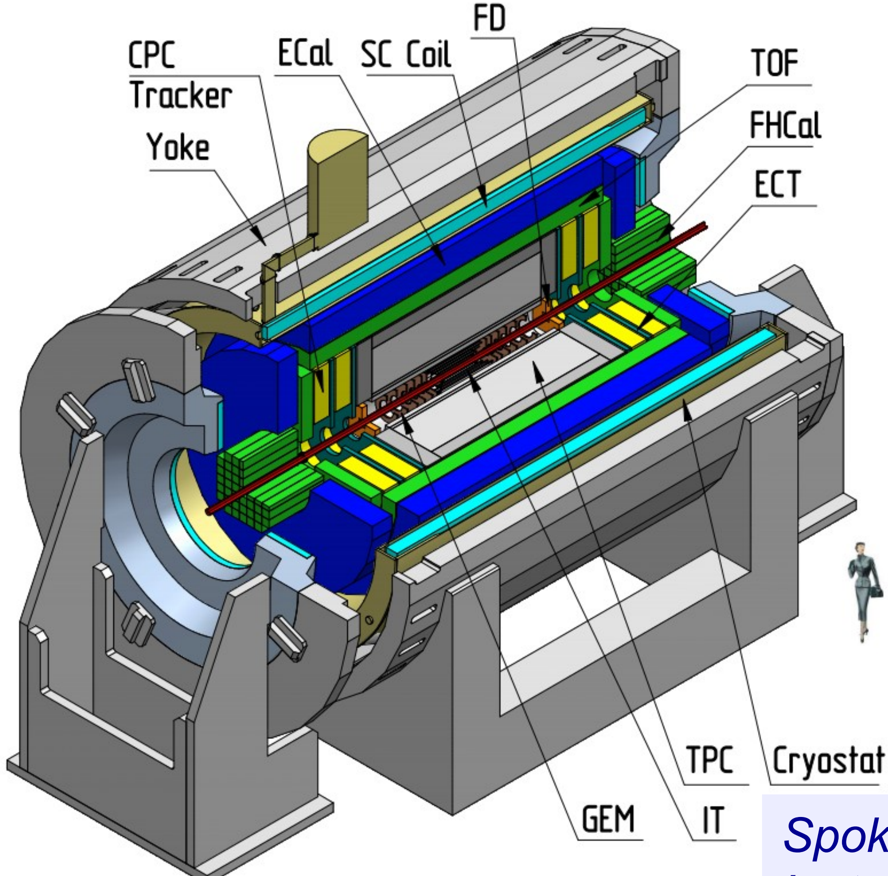
Λ yield as a function of rapidity in c.m.s.

Λ yield as a function of transverse momentum



courtesy of the BM@N experiment

Multi-Purpose Detector (MPD) Collaboration



***11** Countries, **475** participants,*
38** Institutes and **JINR

NICA

*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 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**;*

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

Deputy Spokespersons:
Zebo Tang, Victor Riabov

*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**;*
*Huizhou University, Huizhou, **China**;*
*Institute of Nuclear and Applied Physics, CAS, Shanghai, **China**;*
*Central China Normal University, **China**;*
*Shandong University, Shandong, **China**;*

MPD Physics Programme

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

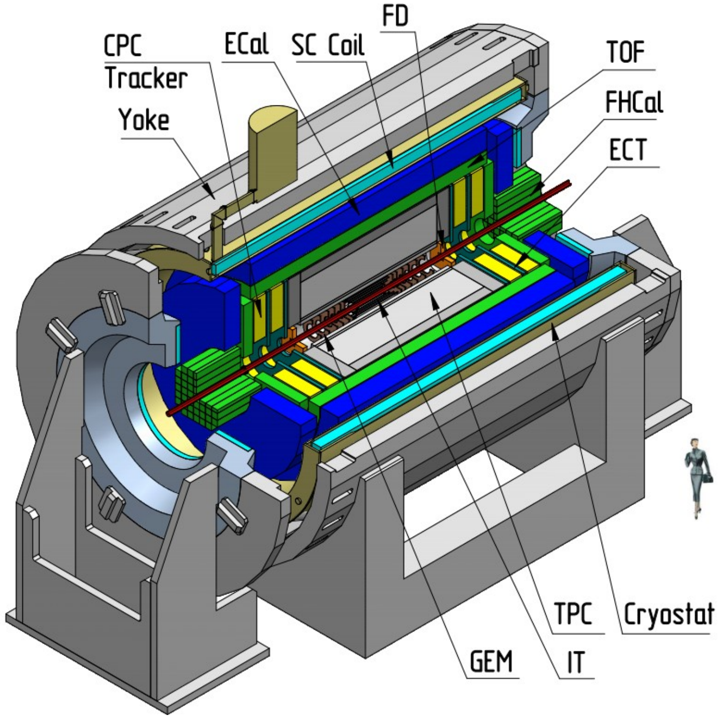
Spectra of light flavor and hypernuclei
- Light flavor spectra
- Hyperons and hypernuclei
- Total particle yields and yield ratios
- Kinematic and chemical properties of the event
- Mapping QCD Phase diagram

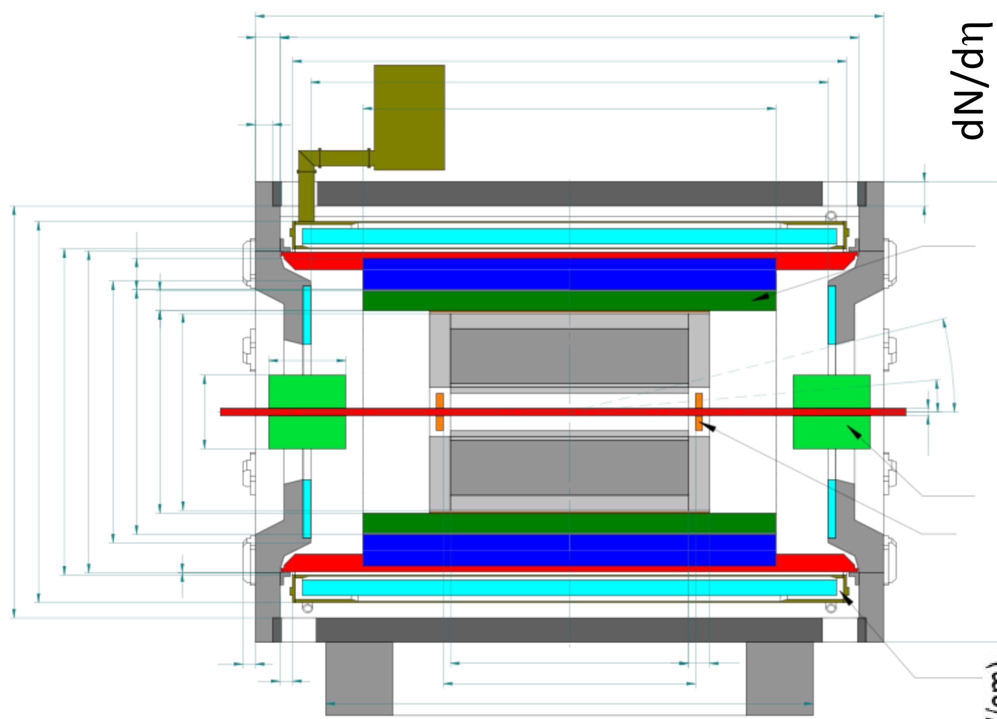
Correlations and Fluctuations
- Collective flow for hadrons
- Vorticity, Λ polarization
- E-by-E fluctuation of multiplicity, momentum and conserved quantities
- Femtoscopy
- Forward-Backward corr.
- Jet-like correlations

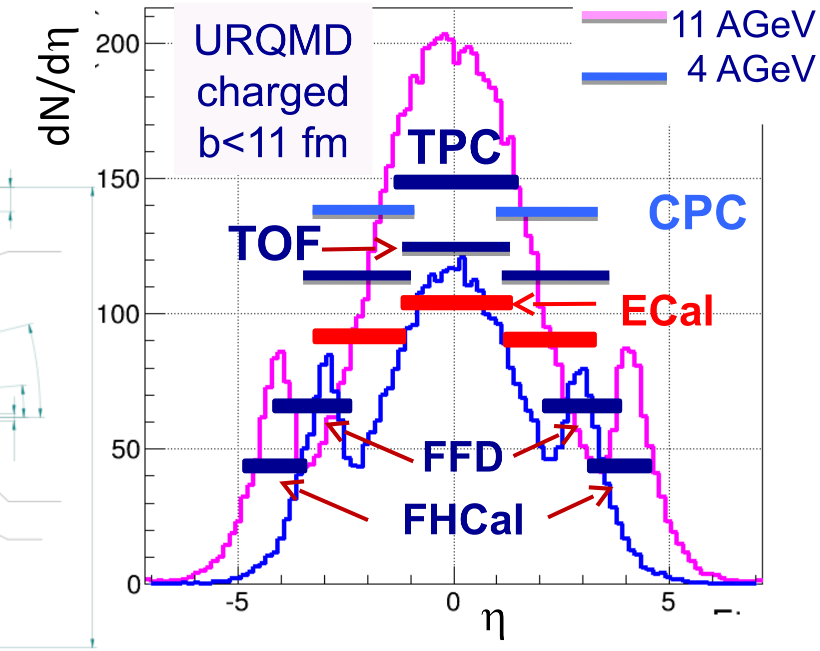
Electromagnetic probes
- Electromagnetic calorimeter measurements
- Photons in ECAL and central barrel
- Low mass dilepton spectra and search for in-medium modification of resonances and intermediate mass region

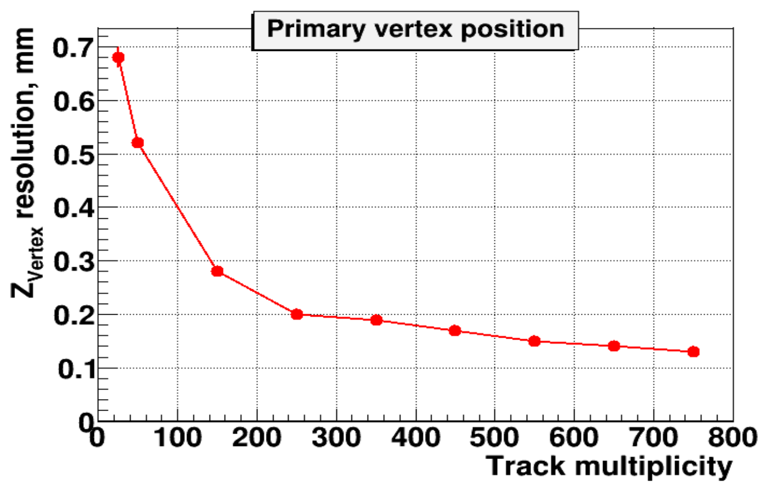
Heavy flavor
- Study of open charm production
- Charmonium with ECAL and central barrel
- Charmed meson through secondary vertices in ITS and HF electrons
- Explore production at charm threshold

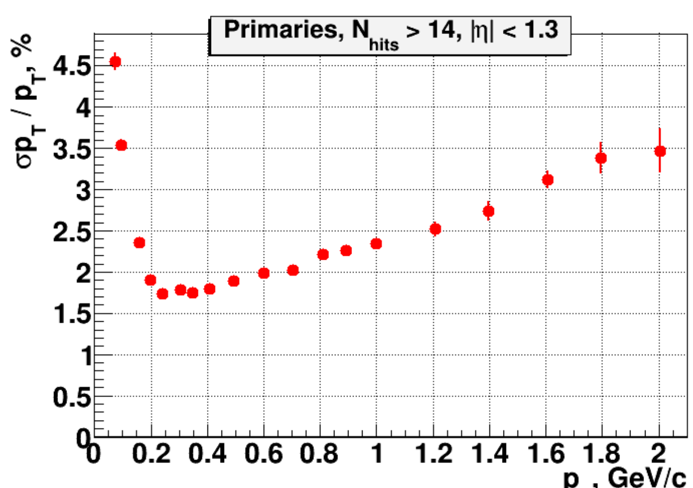
MPD (1st and 2nd stage)

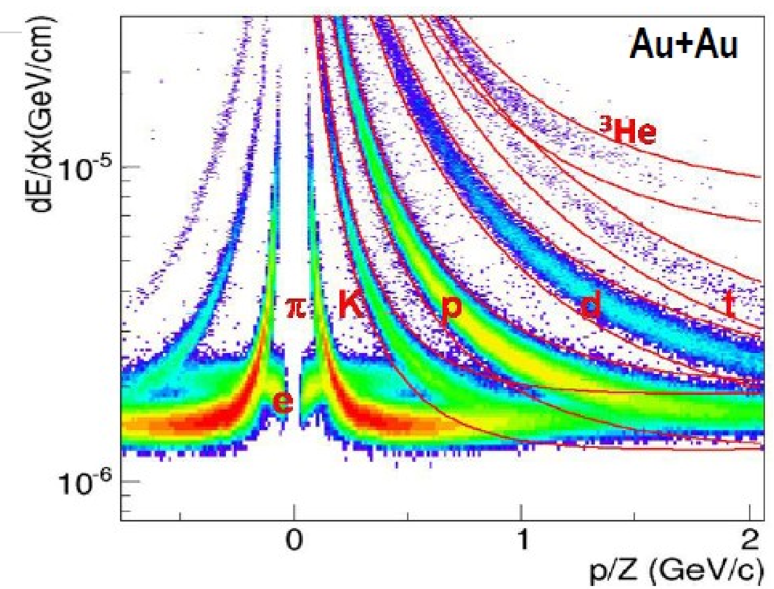












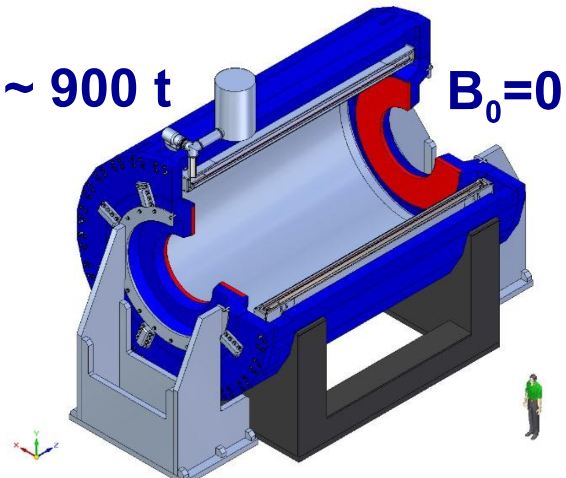
- 2π in azimuth, 3-D tracking (TPC), Powerful PID (TPC, TOF): - π/K up to 1.5 GeV/c, - K/p up to 3 GeV/c, Low material budget, High rate (<=6 kHz)

MPD Systems in production

SC Solenoid

~ 900 t

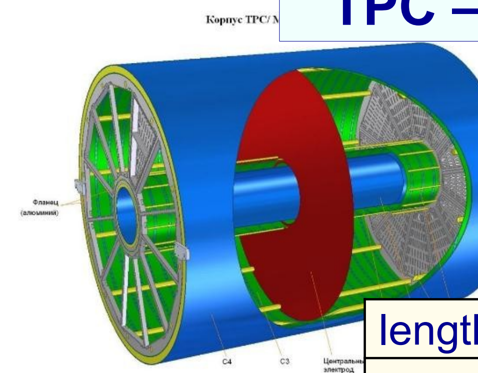
B_0=0.5 T

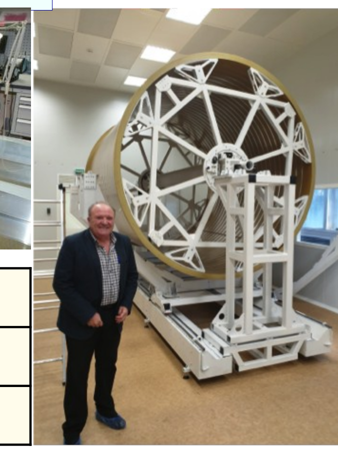


Yoke – produced & delivered

cryostat with SC coil - ready for cold tests

TPC – basic tracker





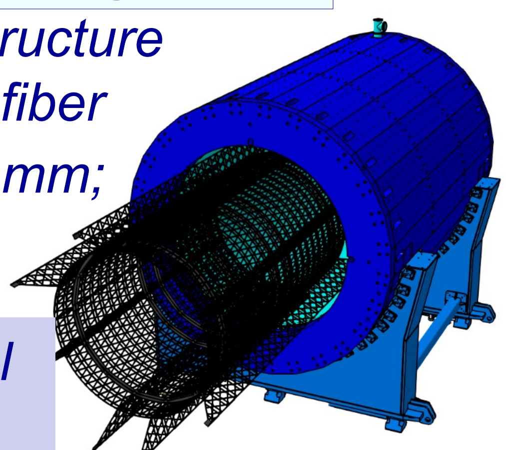
length	*340 см*
out Radii	*140 см*
N chan.	***95 232***

TOF system

Integration

support structure of carbon fiber

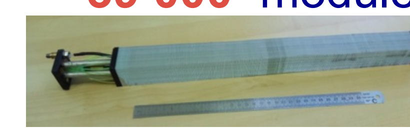
sagite ~ ***5*** *mm; 0,13* X_0



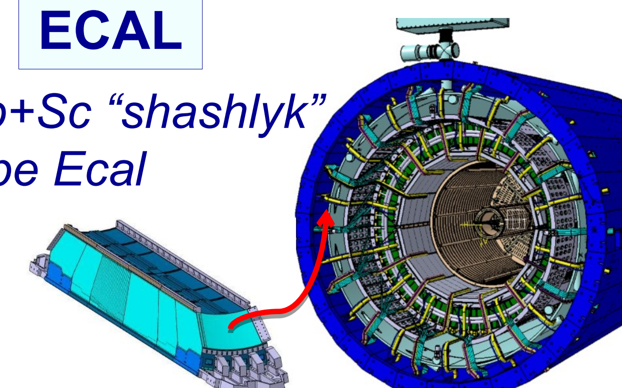
ECal *barrel ~* ***100*** *t*

ECAL

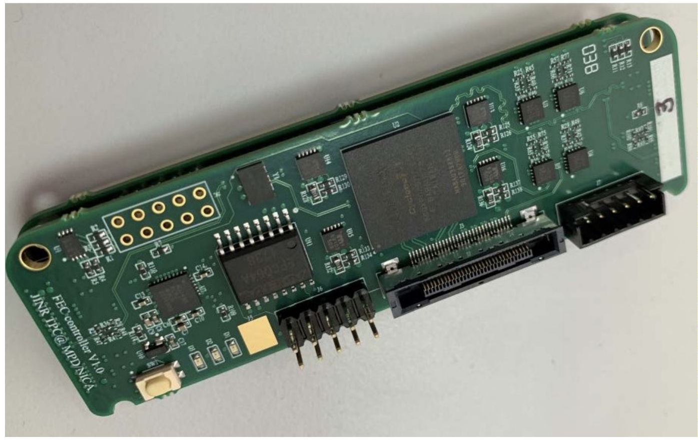
~ **39 000** modules

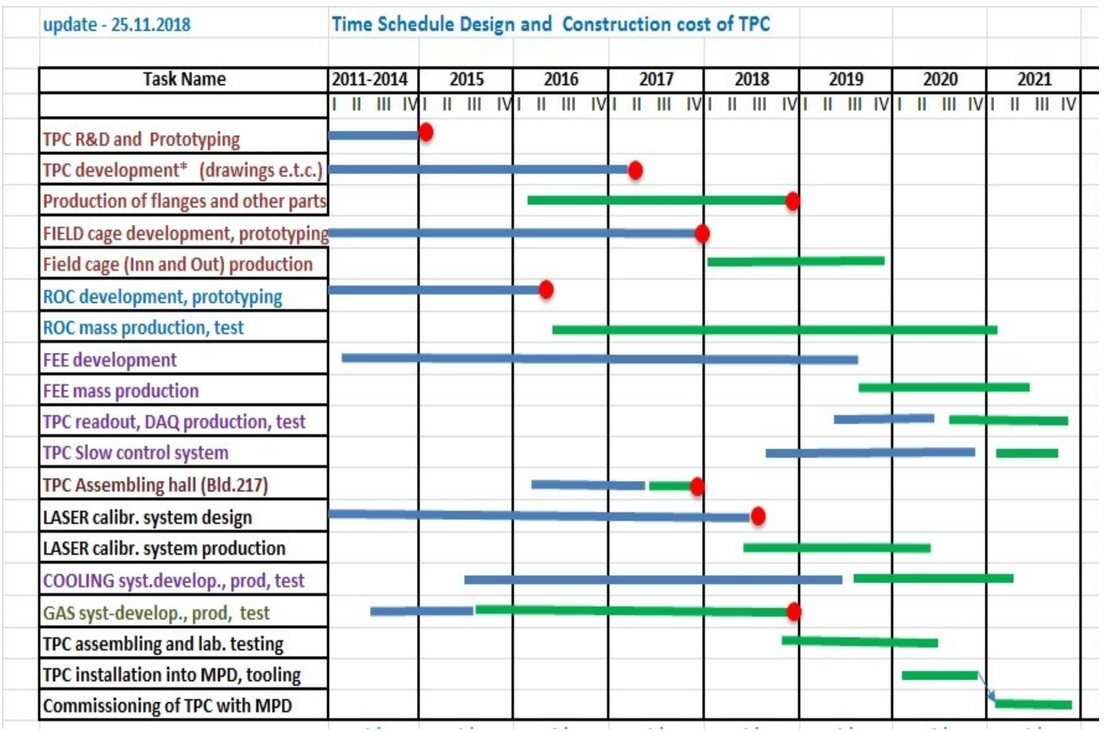


Pb+Sc "shashlyk" type Ecal



MPD Time Projection Chamber





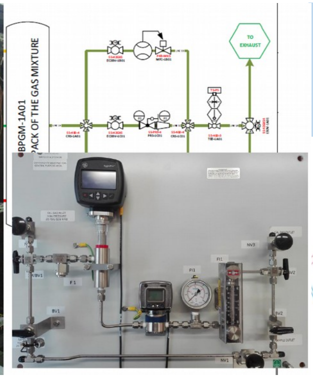
item	Date
Testing FEC v1.0 finished	Feb. 2019
Receive SAMPA V4 chips at Dubna 4500 (all)	June 2019
32 preproduction vervion 2.1 FE Card assembled (1/2ROC)	Jul. 2019
Testing of half ROC equipped with FE Cards	Aug. – Dec.2019
Production FE Cards for 1 ROC and Testing 2020	Dec. 2019-Apr.
Instrumentation and test ROC 2, 3, 4	May 2020
Production FE Cards for the first 10 ROCs (Total 14)	July 2020
Production FE Cards for the second 10 ROCs (Total 24)	August 2020

MPD Time-of-Flight

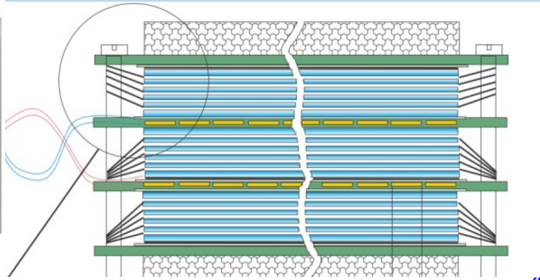
Automatic painting of the conductive layer on the glass

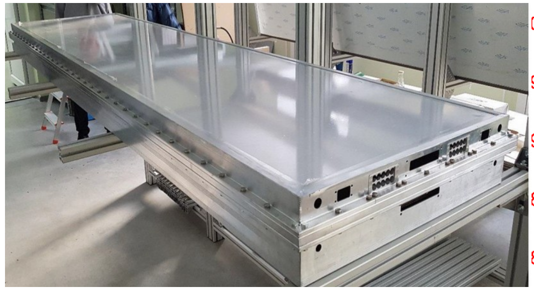
MRPC assembling

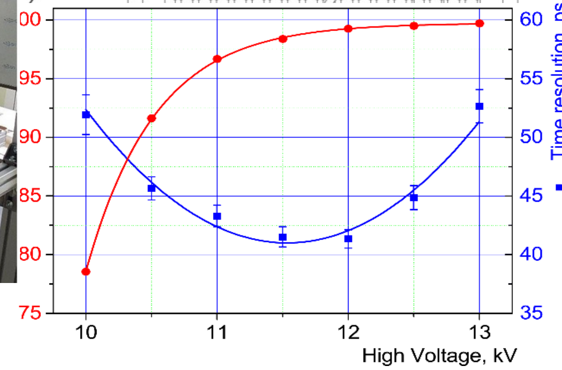
Soldering HV connector and readout pins



Dimensions of sensitive area
600 x300 mm²







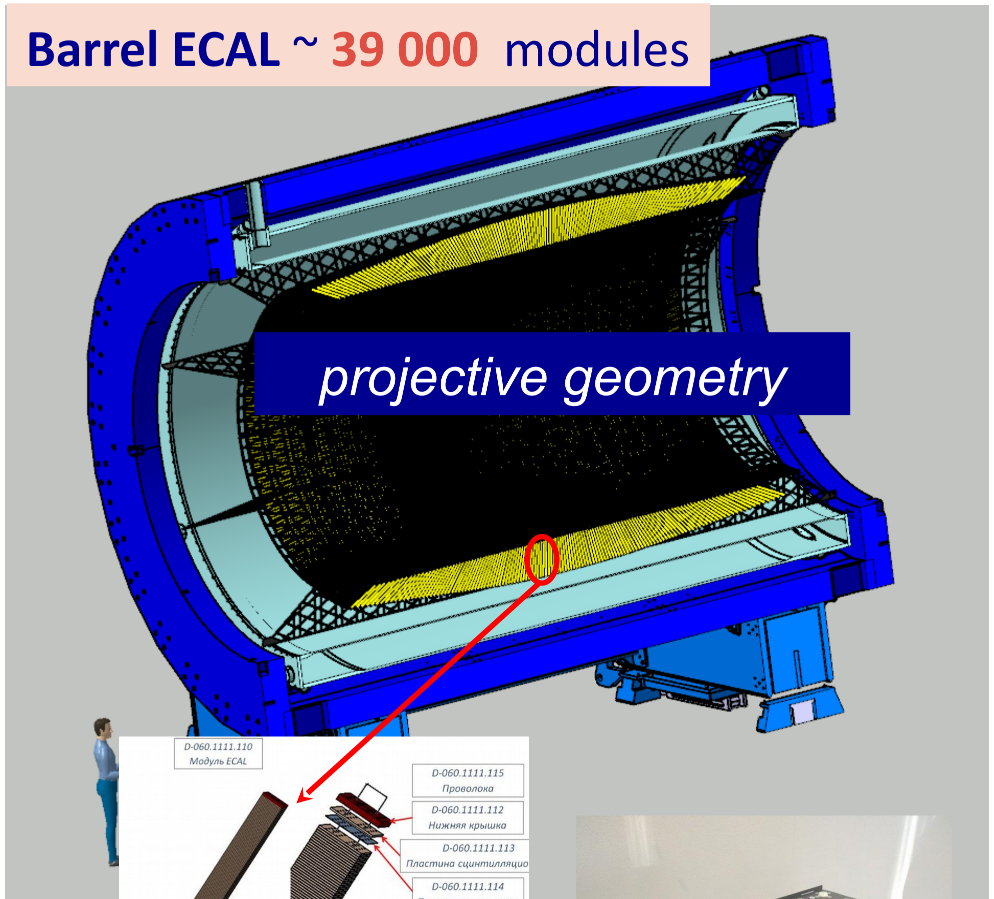
Single detector time resolution: 50ps

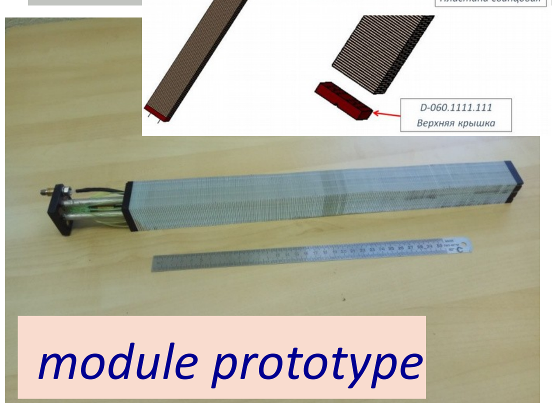
	Number of detectors	Number of readout strips	Sensitive area, m^2	Number of FEE cards	Number of FEE channels
MRPC	1	24	0.192	2	48
Module	10	240	1.848	20	480
Barrel	280	6720	51.8	560	**13440** (1680 chips)

Purchasing of all detector materials completed
So far 33% of all mRPCs are assembled
At IIIrd quater of 2020 all mRPCs will be assembled.
Assembled half sectors of TOF are under Cosmics tests
Investigation of solutions for detector integration and technical installations

Electromagnetic Calorimeter (ECAL)

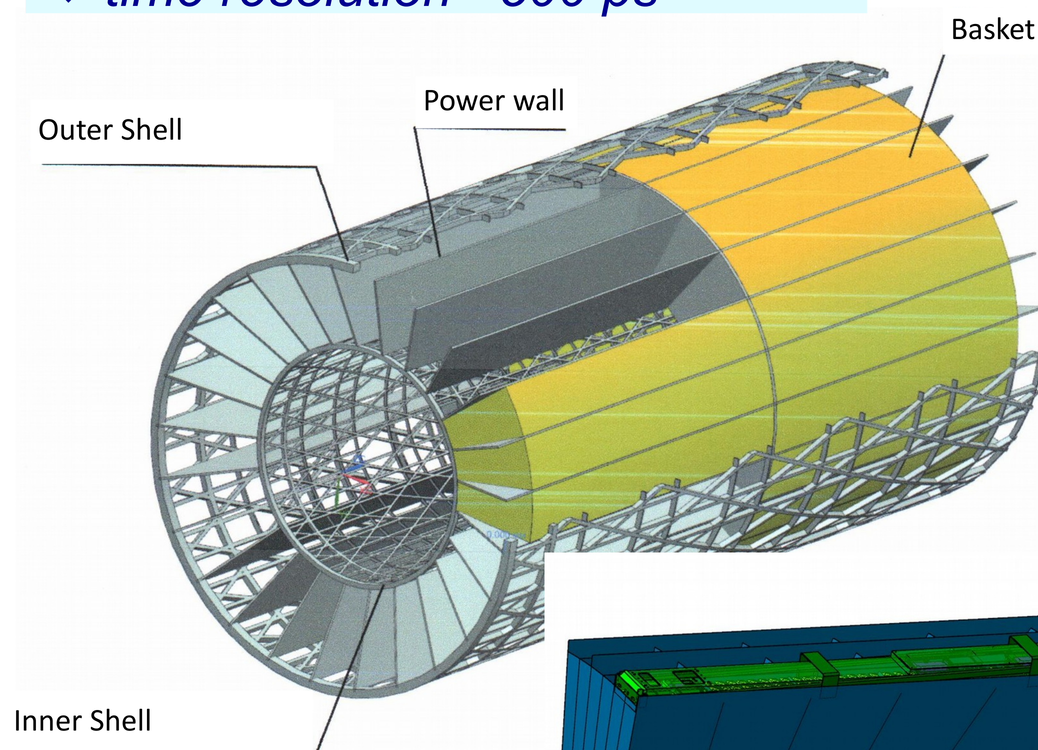
Barrel ECAL ~ 39 000 modules

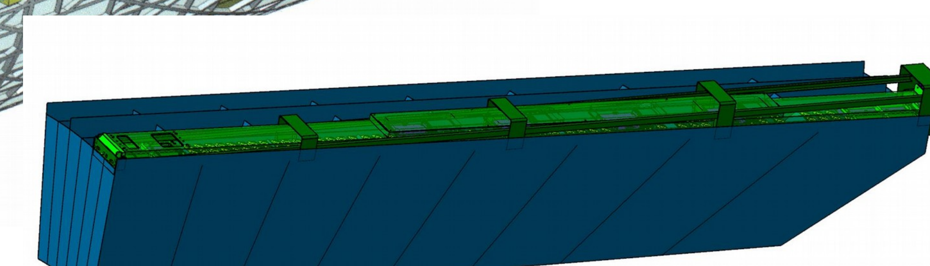




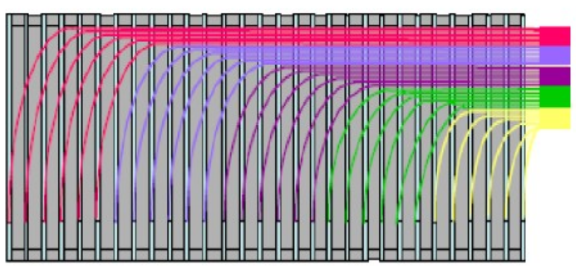
- *Pb+Sc "Shashlyk"*
- *read-out: WLS fibers + MAPD*
- *L ~35 cm (~ 11.8 X_0)*
- *Segmentation (4x4 cm^2)*
- *σ(E) better than 5% @ 1 GeV*
- *time resolution ~500 ps*

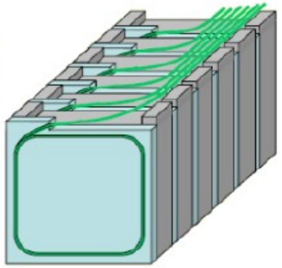
Technical specification for ECAL modules ready
Production started in two sites in Russia, soon in China
First module installation expected in IIIrd QTR of 2020
Calibration and test ongoing



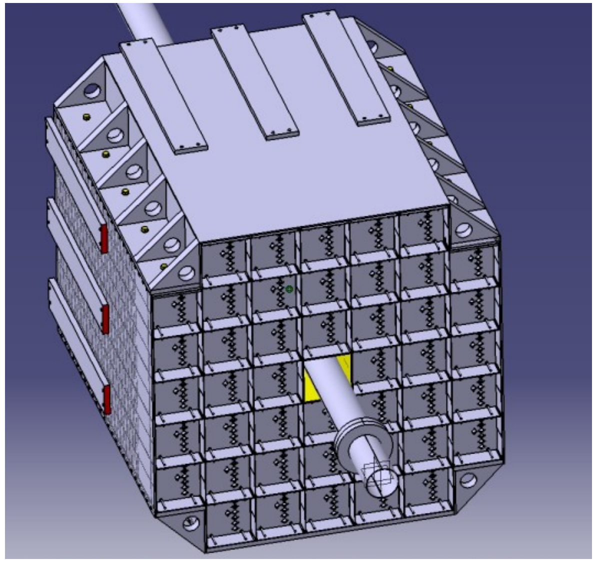

Basket with electronics integration

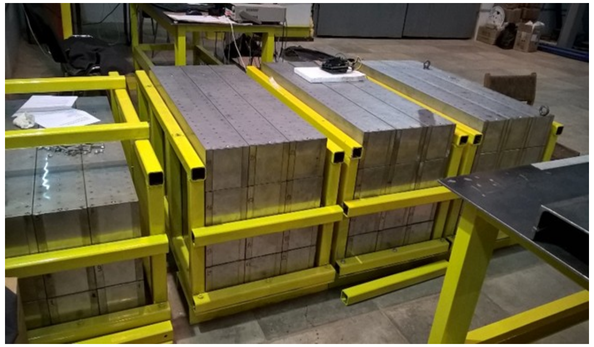
Forward Detectors: FHCal and FFD





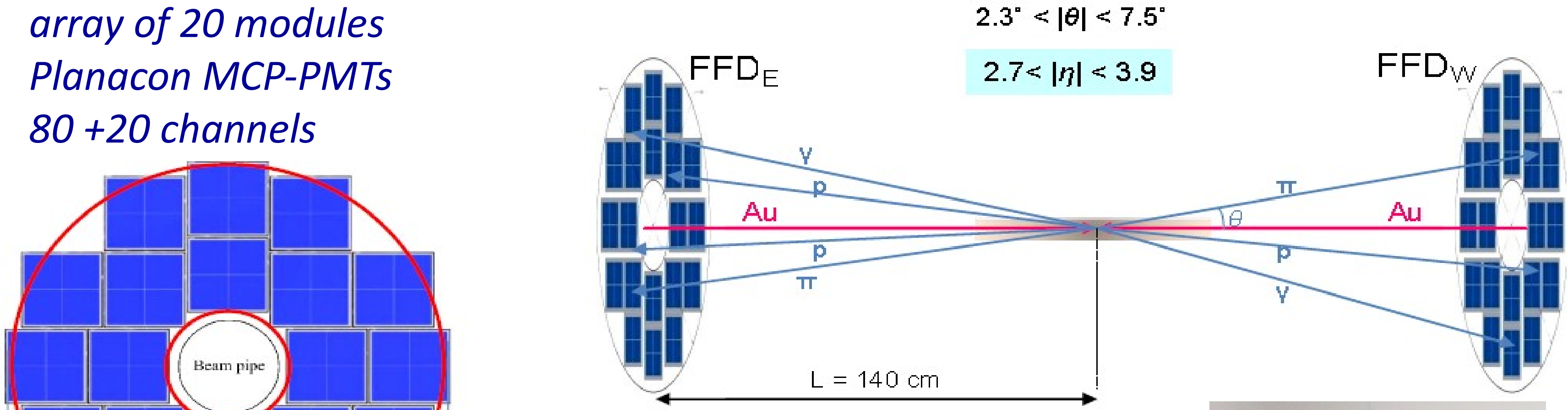
- **Two-arms at ~3.2 m from the interaction point.**
- **Each arm consists of 45 individual modules.**
- **Module size 150x150x1100cm³ (55 layers)**
- **Pb(16mm)+Scint.(4mm) sandwich**
- **7 longitudinal sections**
- **6 WLS-fiber/MAPD per section**
- **7 MAPDs/module**





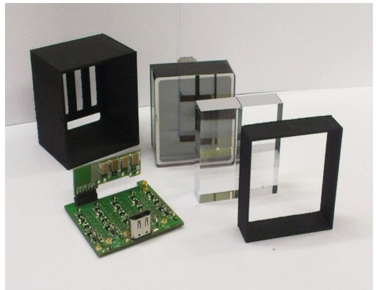
1. All modules produced according to plan, Produced modules are under test on Cosmic
2. FE Electronics is under production – will be ready at the end of 2019
3. Design of the Support platform for FHCal is under way

array of 20 modules
Planacon MCP-PMTs
80 +20 channels



15 mm quartz radiator
10 mm lead converter

time resolution < 50 ps



MPD Civil Construction status

- MPD Hall close to ready for equipment installation

MPD Hall external covering

MPD Hall crane weight test

Transportation of MPD Magnet Yoke parts into the MPD pit (inside MPD Hall)

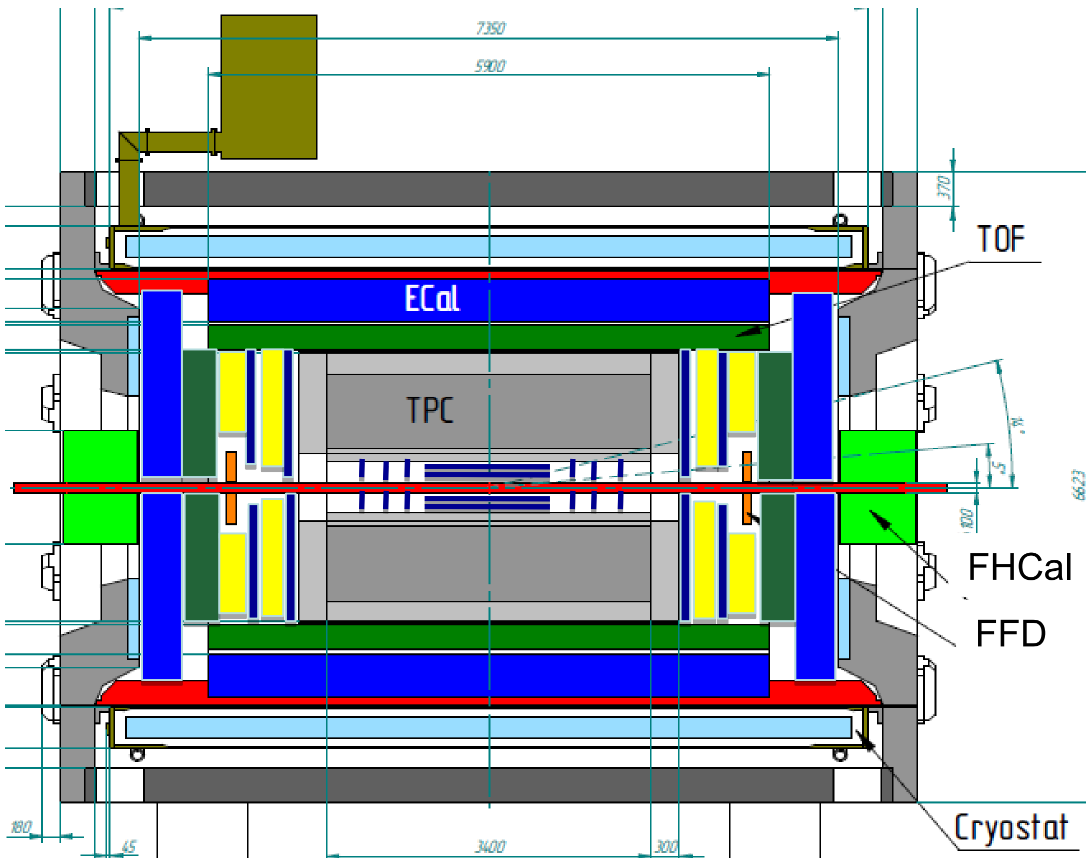
MPD Stage 2 and ITS

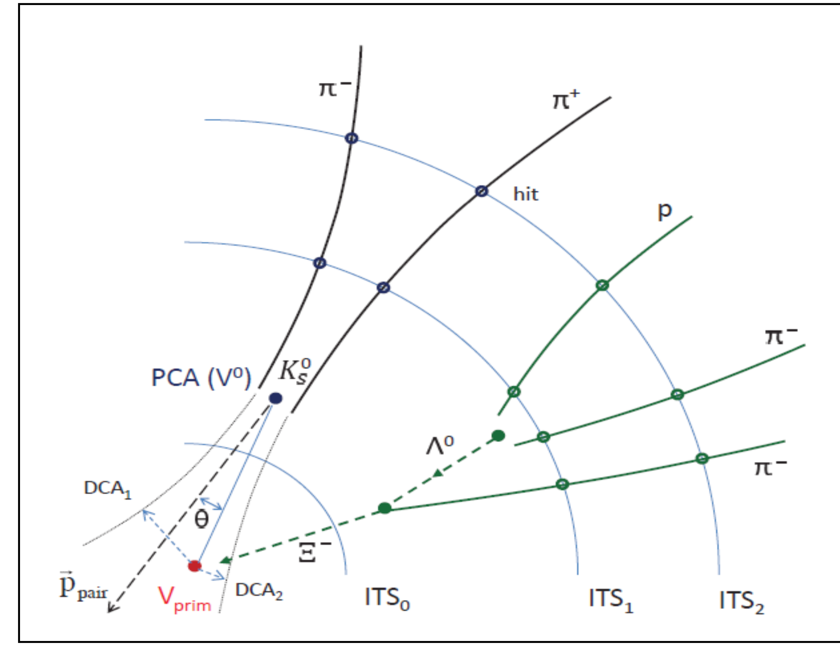
Stage I: TPC, TOF, ECAL, ZDC, FFD + ITS(OB)

Stage II : ITS(IB) + EndCap (CPC, Straw, TOF, ECAL)

Transfer of High Tech Instrumentation Know-How from CERN to NICA-MPD

Design of MPD ITS fully based on expertise from ALICE





$\Xi^- \rightarrow \Lambda + \pi^-$
$\quad \llcorner\!\rightarrow p + \pi^-$

$\Omega^- \rightarrow \Lambda + K^-$
$\quad \llcorner\!\rightarrow p + \pi^-$

$D^+ \rightarrow K^- + \pi^+ + \pi^+$

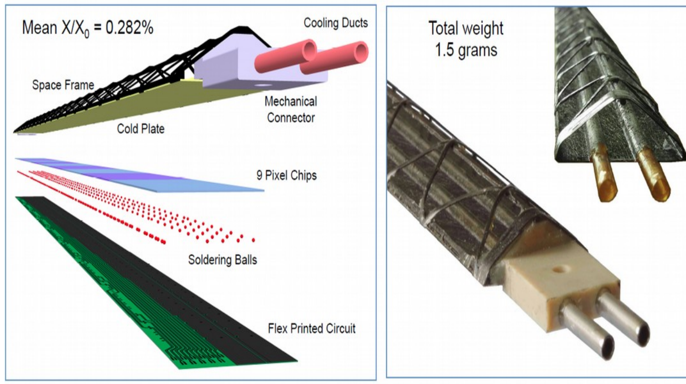
$D^0 \rightarrow K^- + \pi^+$

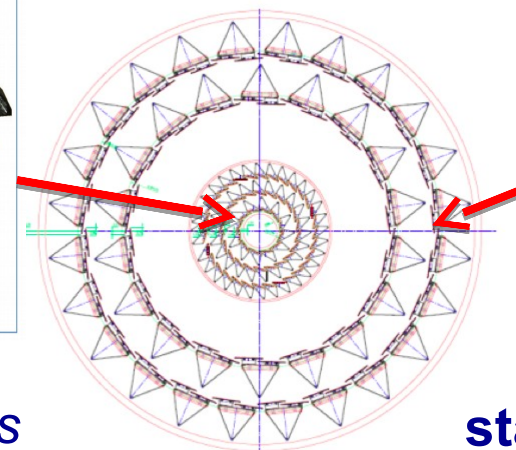
$\Lambda_c \rightarrow p + K^- + \pi^+$

STAR has shown that MFT (based on pixel detectors) allows for specific DCA selections improving S/B ratio for dileptons

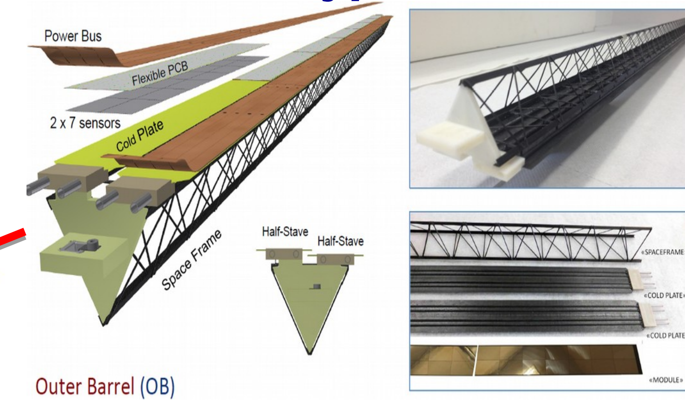
ITS: new possibilities in Stage 2 (2025)

***Inner Barrel (IB) – 3** layers*
modified staves





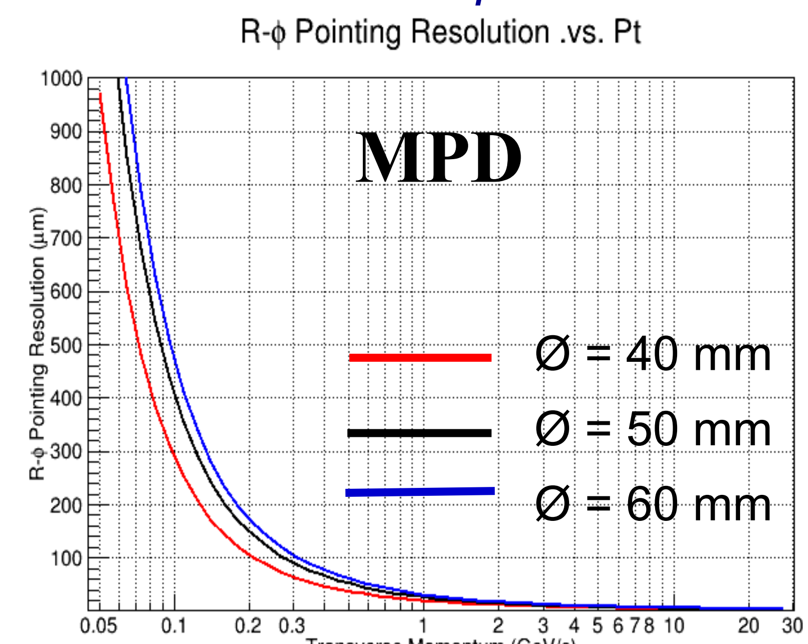
***Outer Barrel (OB) – 2** layers*
ALICE type staves



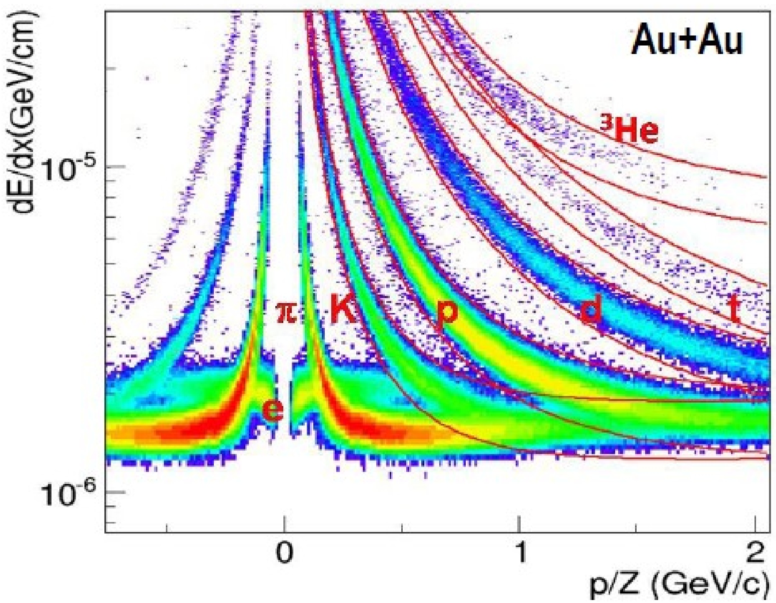
stave: 2 *modules x* **9** *chips*

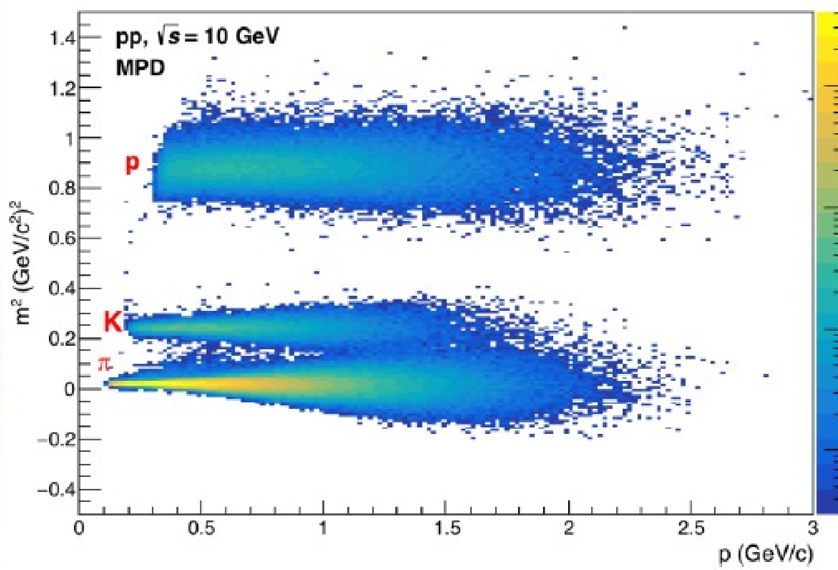
stave: *14* *modules x* ***14*** *chips*

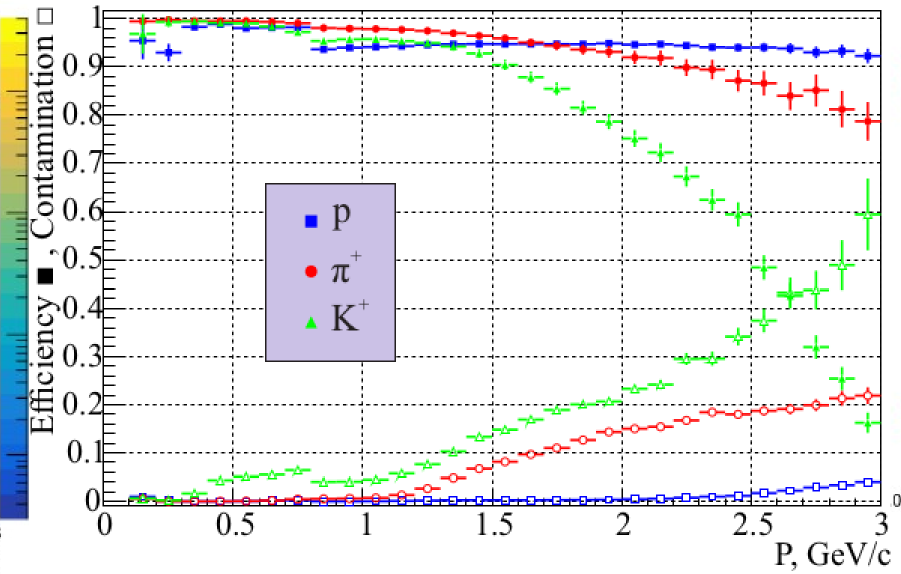
layer #	type	staves/ layer	Rmin, mm	Rmax, mm	length, mm	chips/ layer	X0, %
1	IB	12	22,4	26,7	540	216	0,3
2	IB	22	40,7	45,9	540	396	0,3
3	IB	32	59,8	65,1	540	576	0,3
4	OB	18	144,1	147,9	1470	3528	1,0
5	OB	24	194,1	197,6	1470	4704	1,0
total		**108**				**9420**	**2,9**



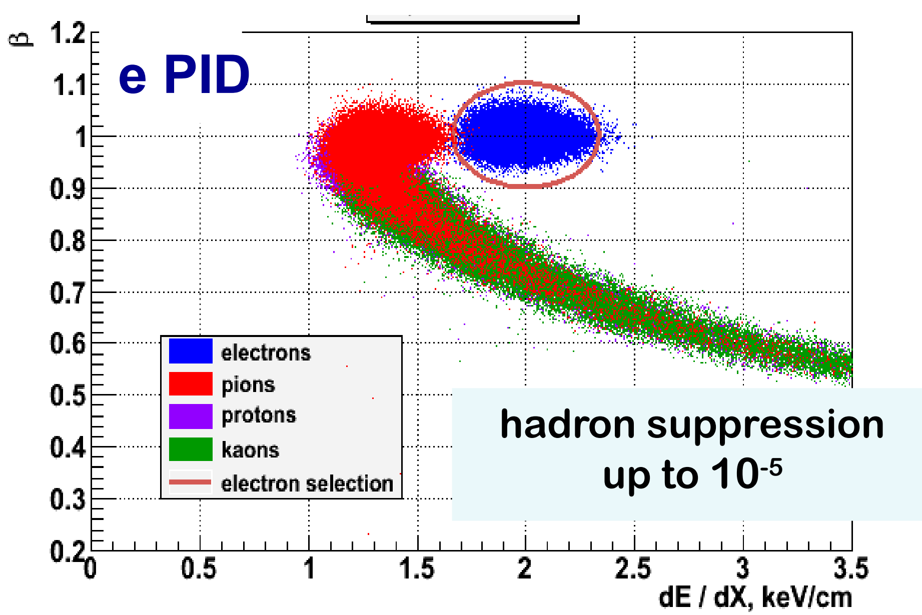
PID Performance in MPD







Efficiency and Contamination



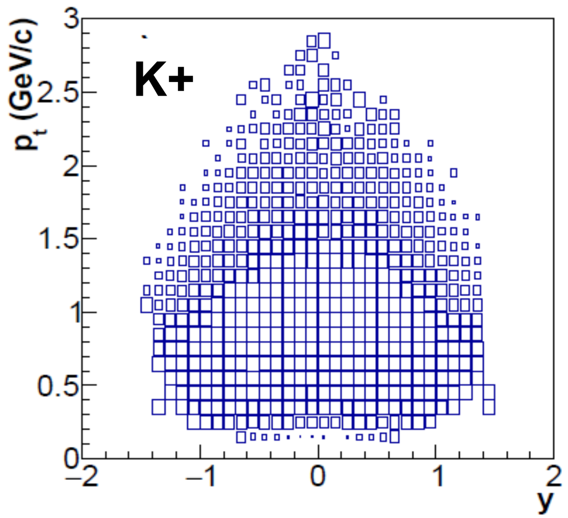
- Combined (dE/dx+TOF) PID for hadrons provides π/K up to 2 GeV/c and K/p up 3 GeV/c
- An extra hadron suppression in the electrons will be provided by ECAL

Hadroproduction with MPD

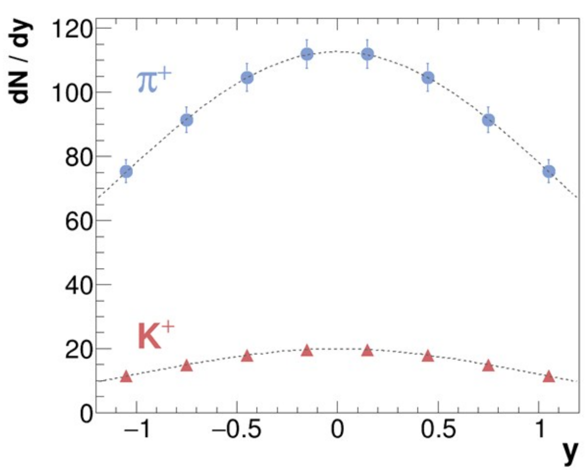
- **Particle spectra, yields & ratios are sensitive to bulk fireball properties and phase transformations in the medium**
- **Uniform acceptance and large phase coverage are crucial for precise mapping of the QCD phase diagram**

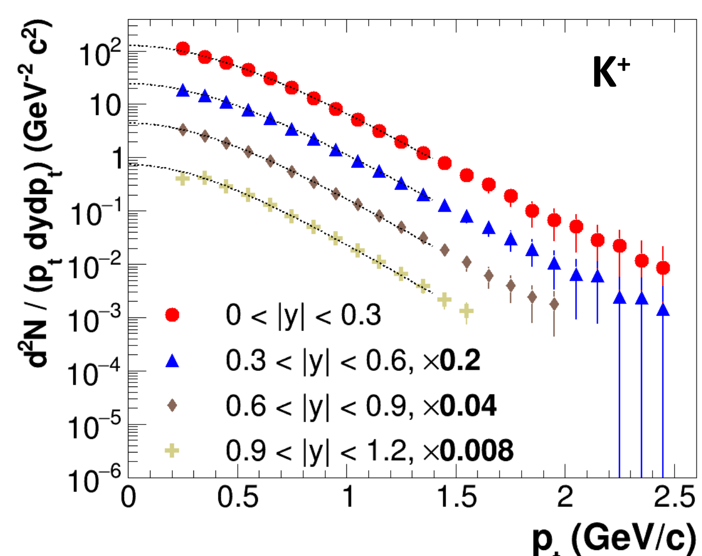
✓ *0-5% central Au+Au at 9 GeV from the PHSD event generator, which implements partonic phase and CSR effects*

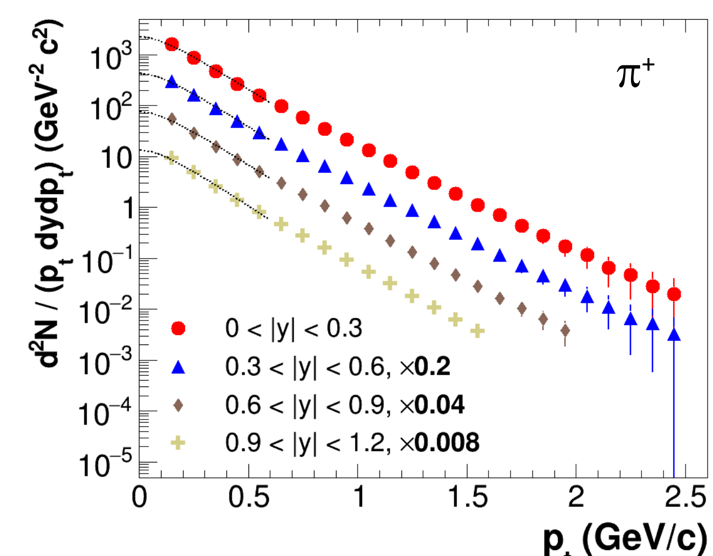
✓ *Recent reconstruction chain, combined dE/dx+TOF particle ID, spectra analysis*



- 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)

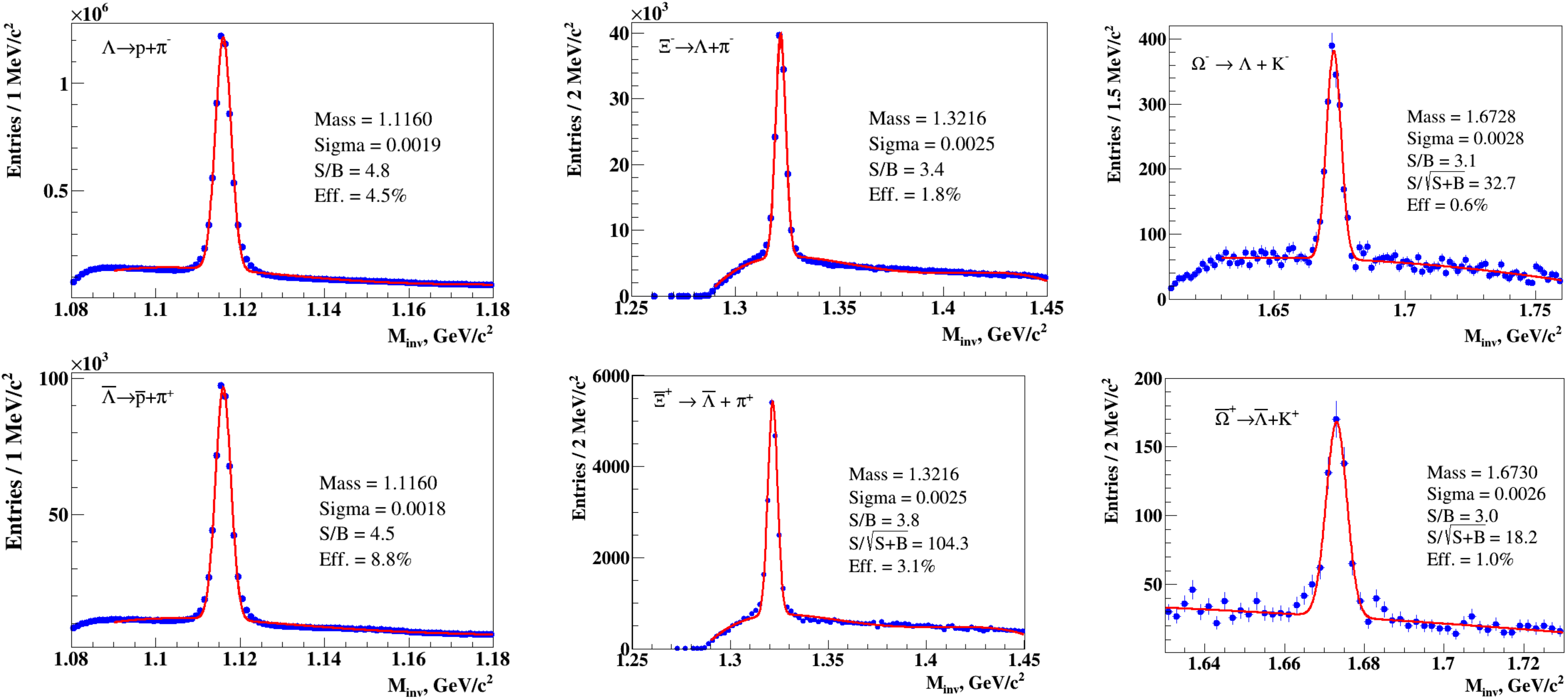






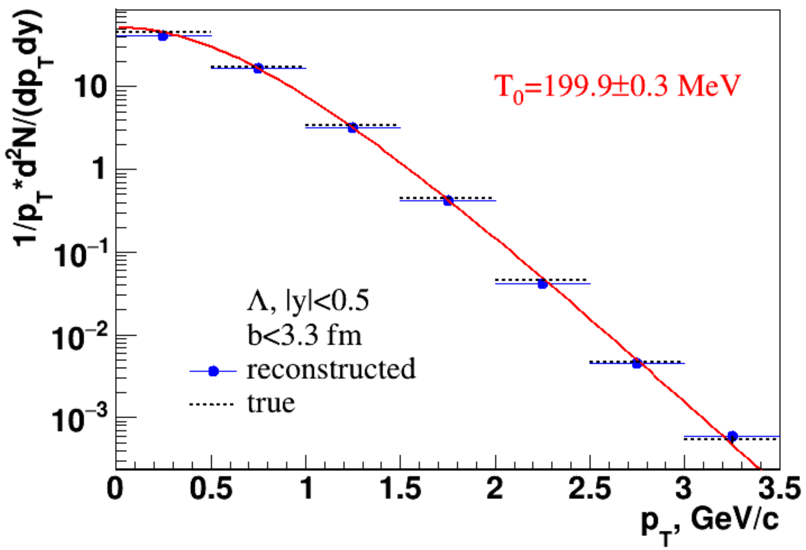
Strange and multi-strange baryons

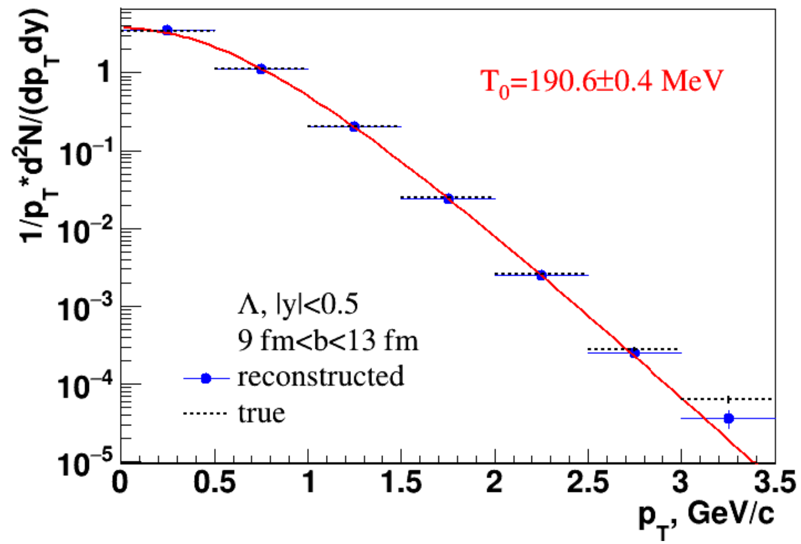
Stage'1 (TPC+TOF): Au+Au @ 11 GeV, PHSD + MPDRoot reco.

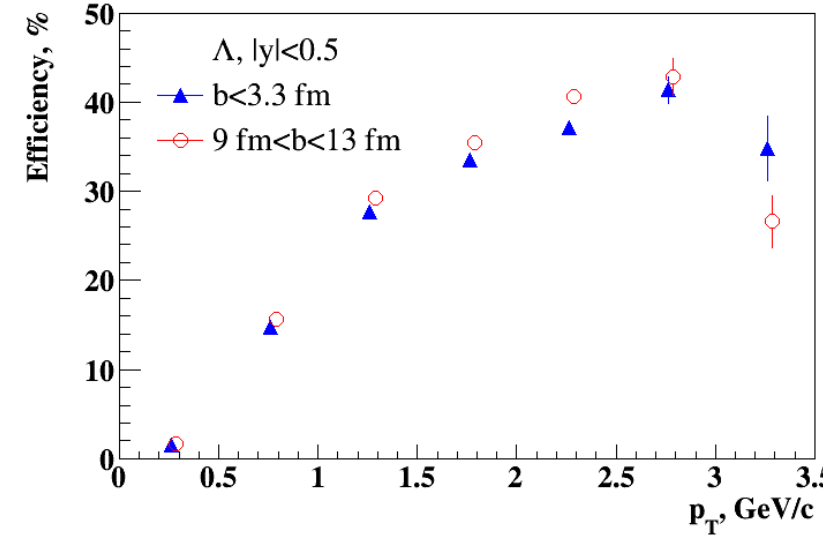


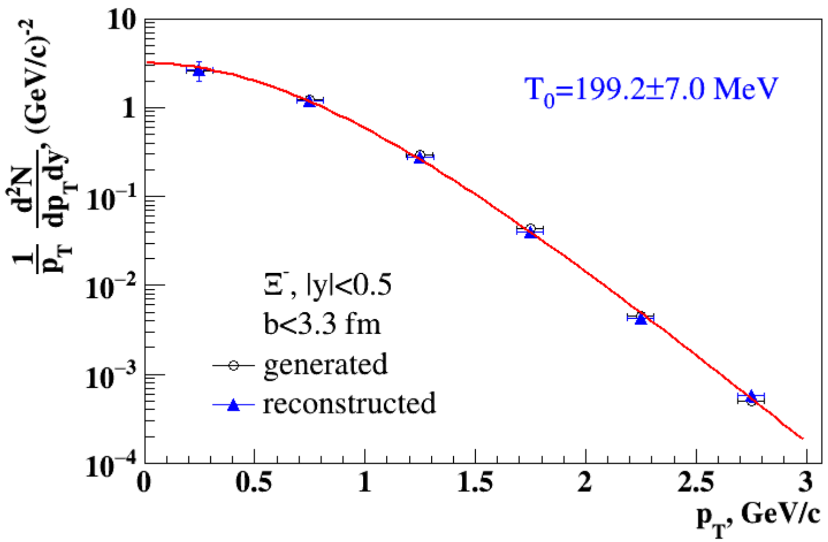
particle	Λ	anti-Λ	Ξ^-	anti-Ξ^+	Ω^-	anti–Ω^+
yield in 10weeks	$3 \cdot 10^8$	$3.5 \cdot 10^6$	$1.5 \cdot 10^6$	$8.0 \cdot 10^4$	$7 \cdot 10^4$	$1.5 \cdot 10^4$

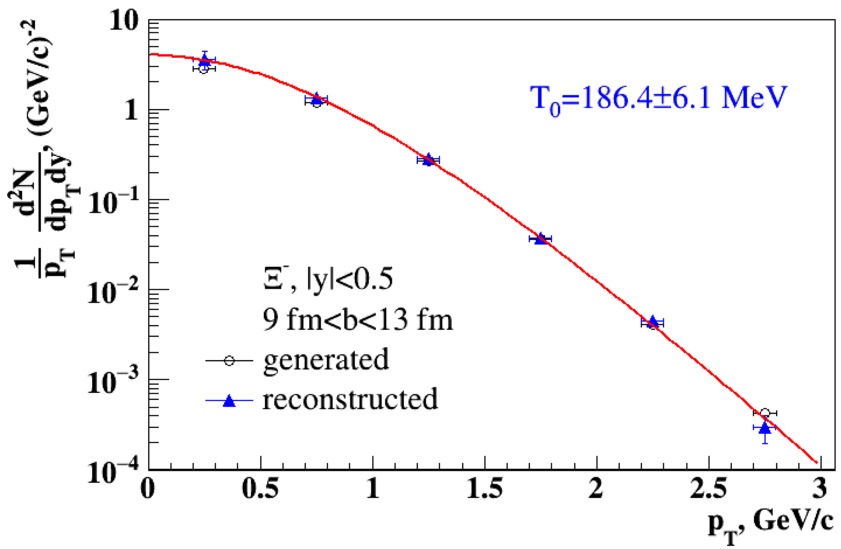
Efficiency and p_T spectrum

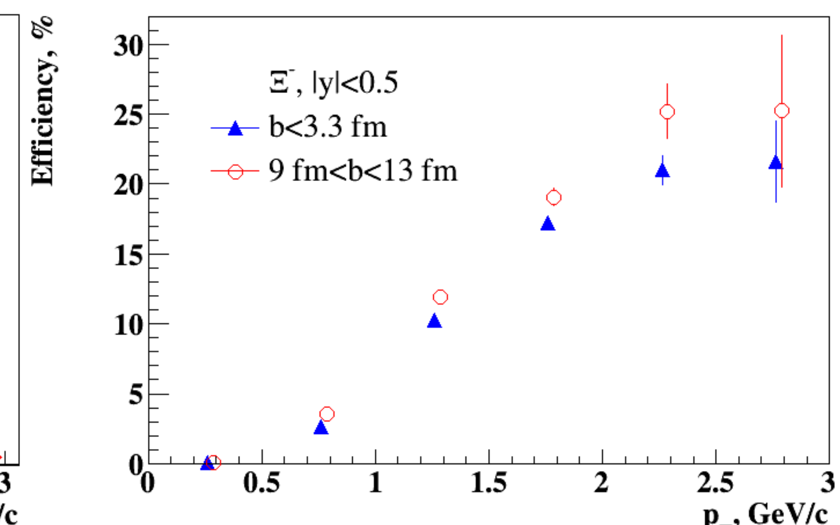










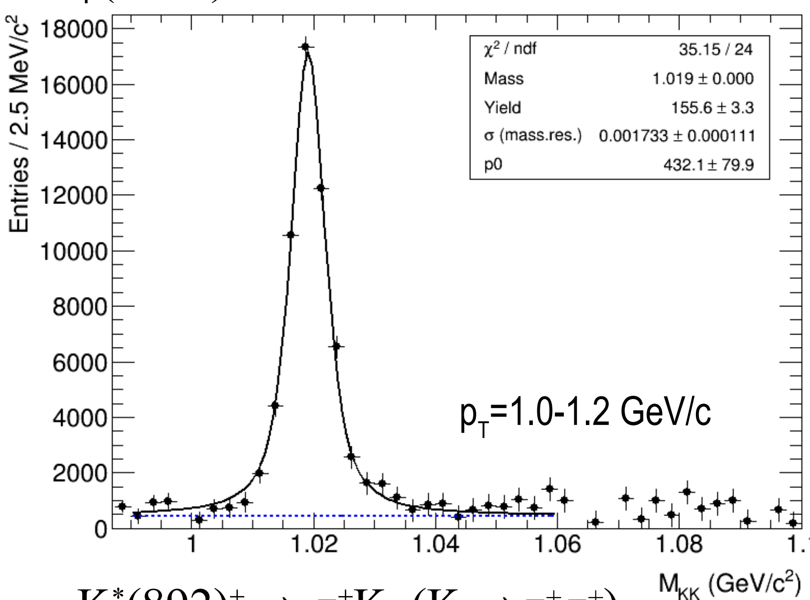


Full p_T spectrum and yield extraction, reasonable efficiency down to low p_T

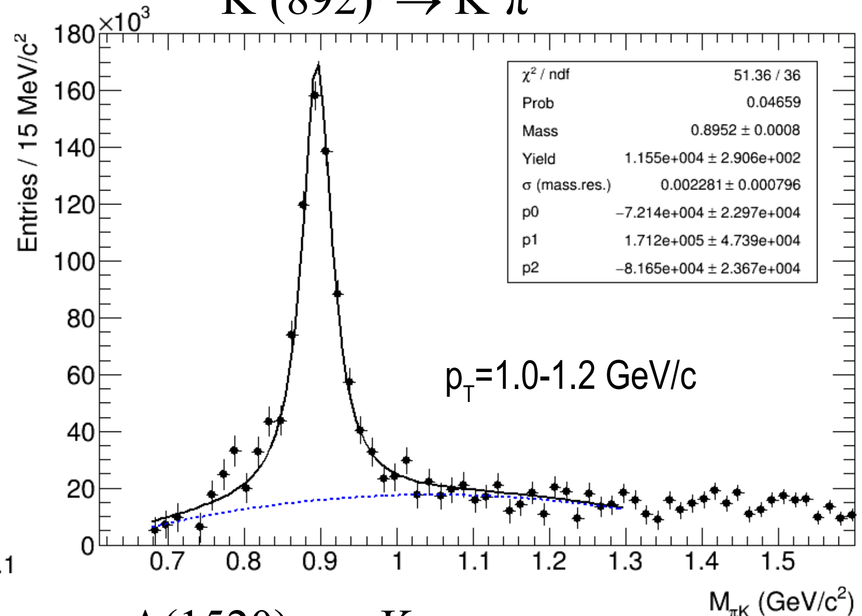
Resonances at MPD

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

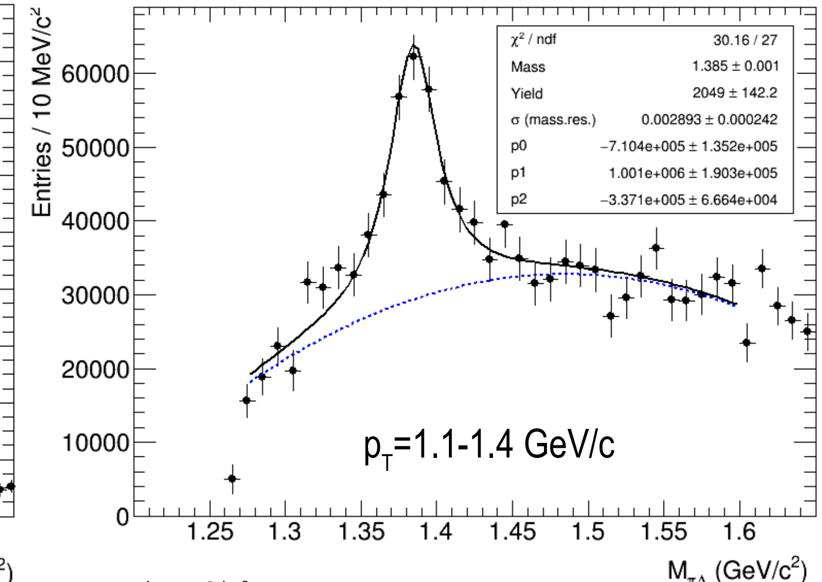
$\phi(1020) \rightarrow K^+K^-$



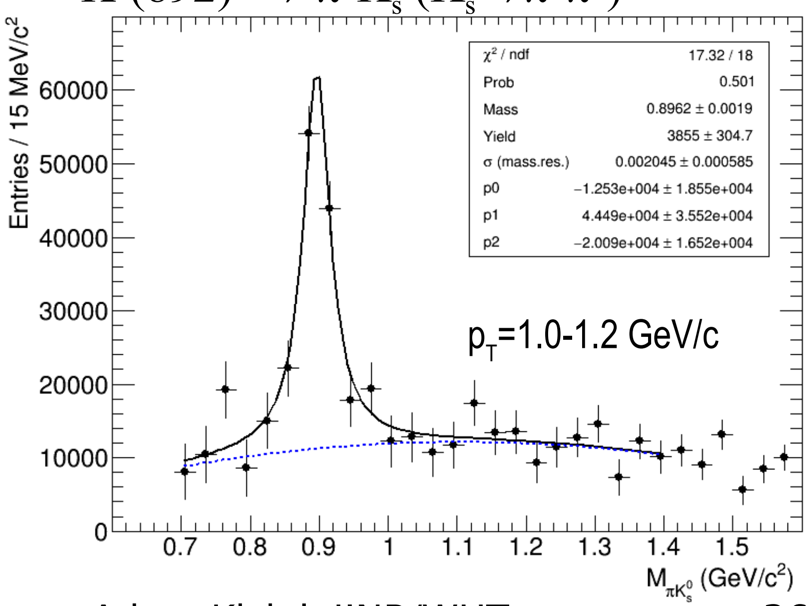
$K^*(892)^0 \rightarrow K^{\pm}\pi^{\pm}$



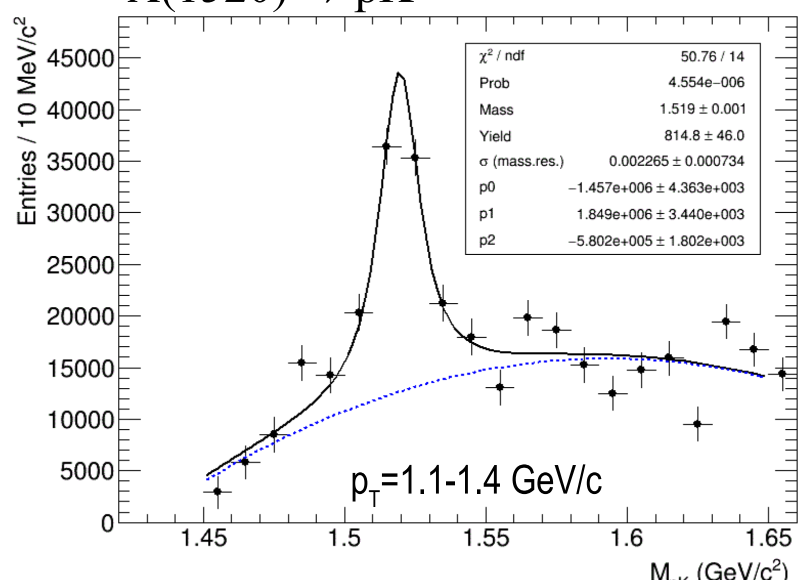
$\Sigma(1385)^{\pm} \rightarrow \pi^{\pm}\Lambda$ $(\Lambda \rightarrow p\pi)$



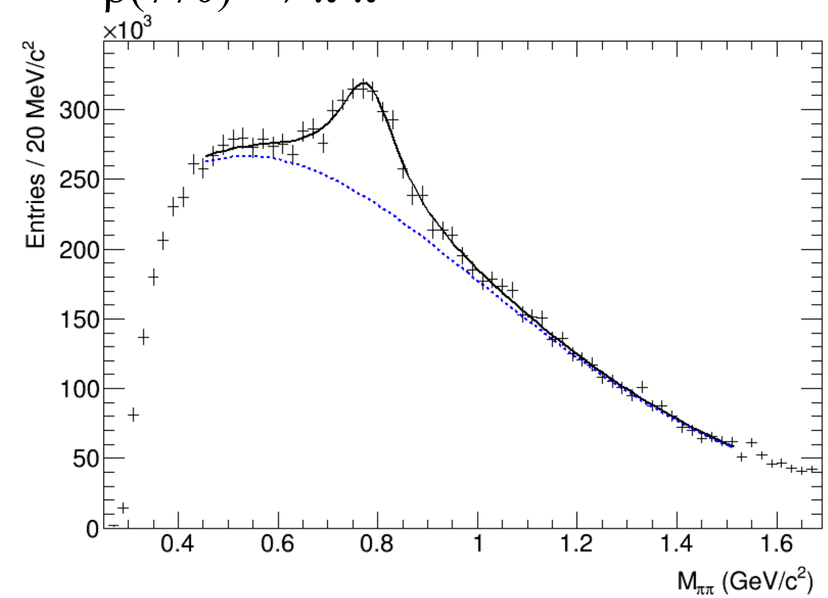
$K^*(892)^{\pm} \rightarrow \pi^{\pm}K_s$ $(K_s \rightarrow \pi^+\pi^+)$



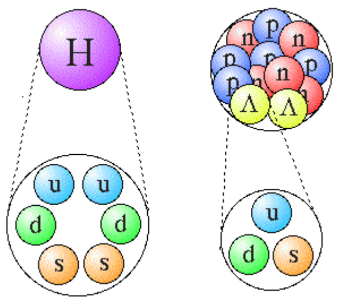
$\Lambda(1520) \rightarrow pK^-$



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



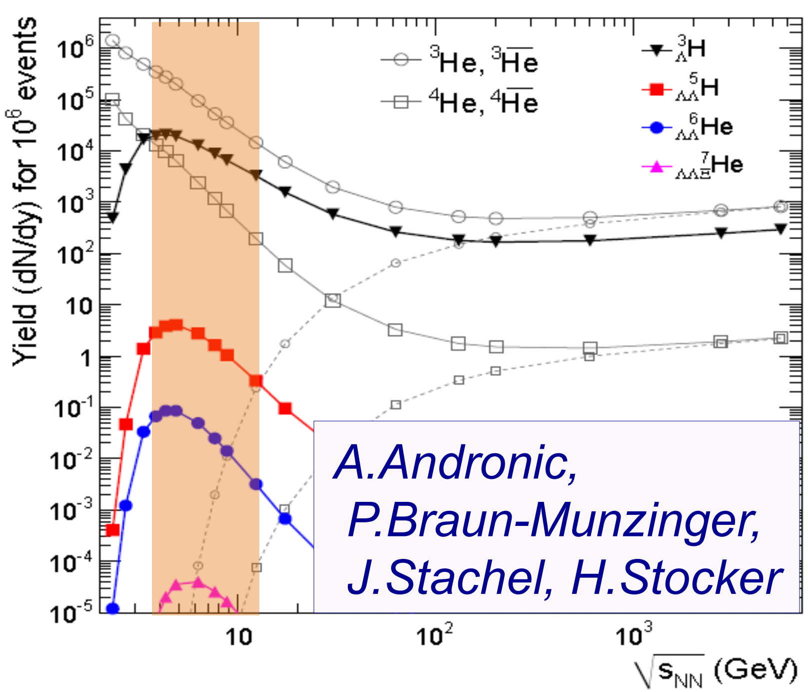
Hypernuclei at MPD

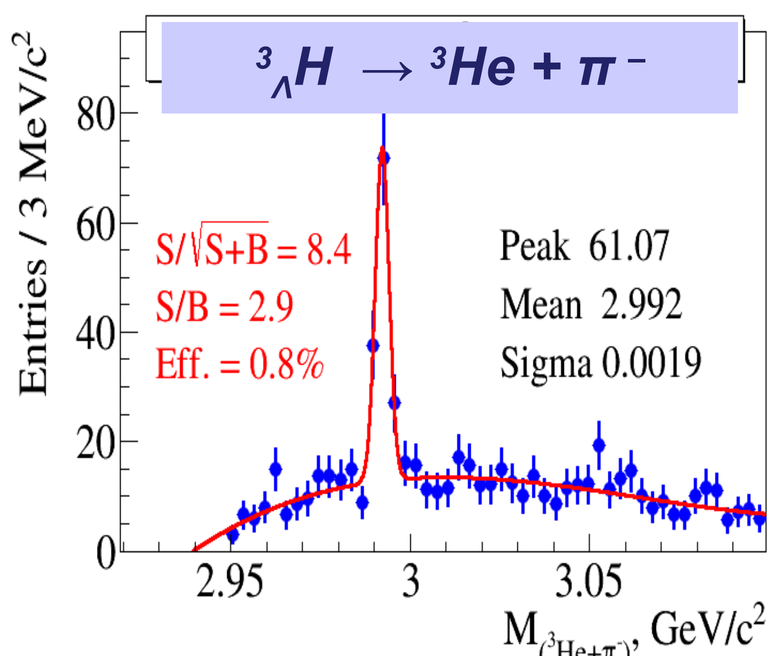


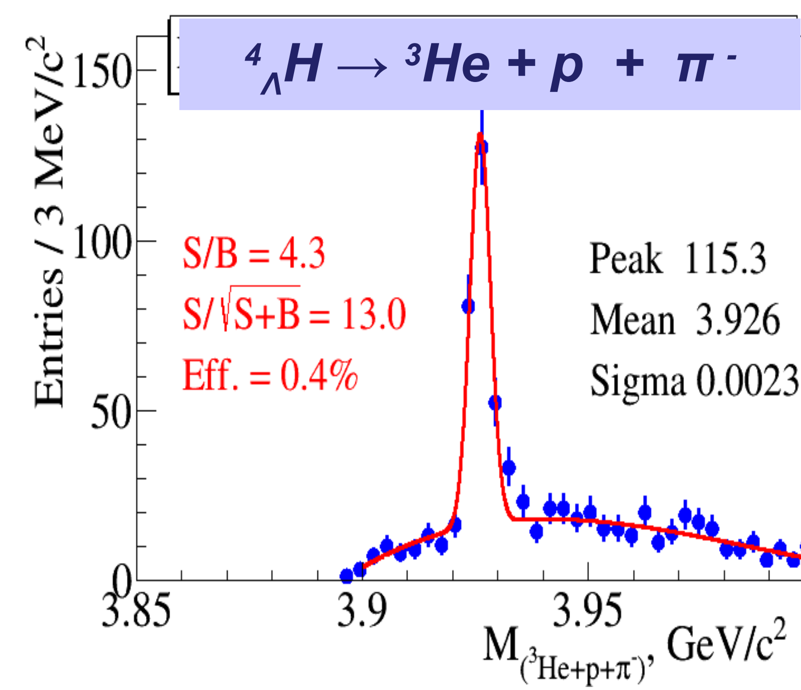
*astrophysical research indicates the appearance of hyperons in the dense core of a **neutron star***

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

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

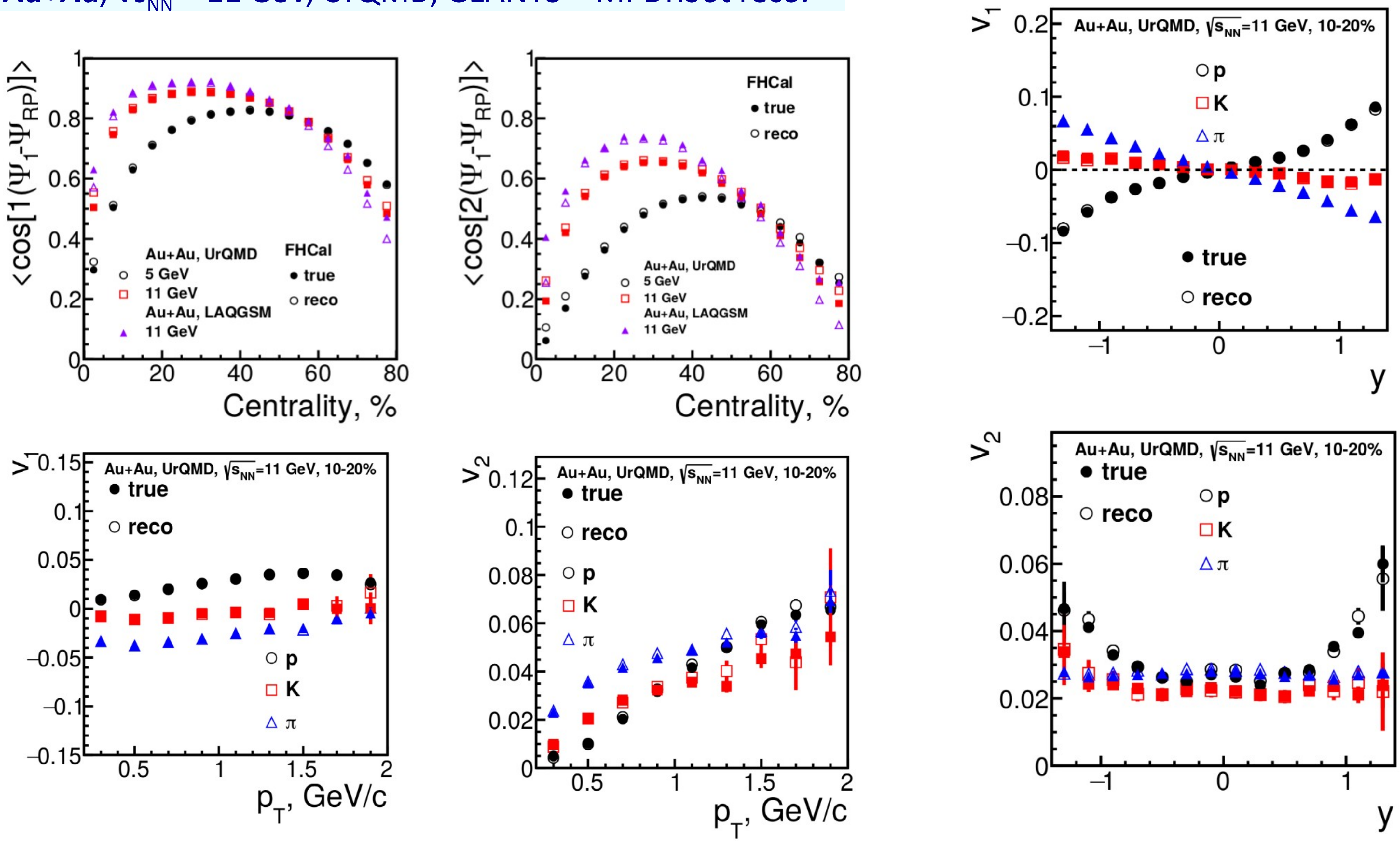






Performance of collective flow studies

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



Anisotropic Flow of Reconstructed Decays

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

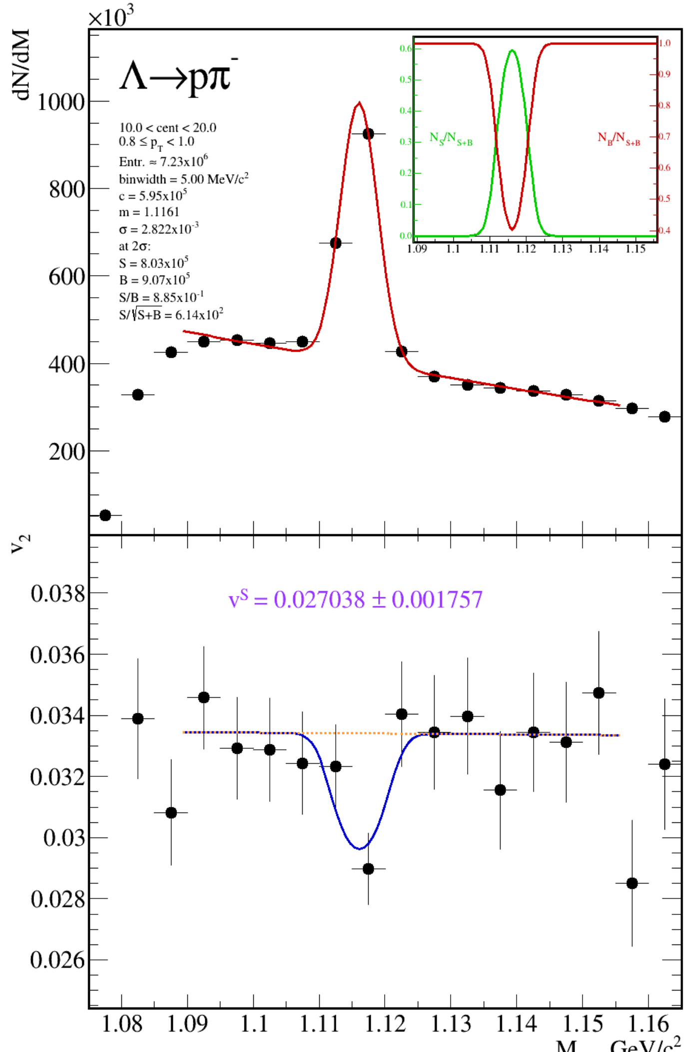
Extracted flow signal after fit

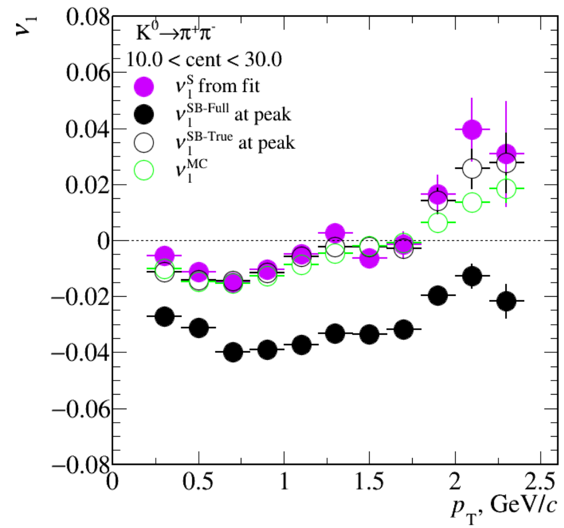
Measured flow (s+bg) at peak region

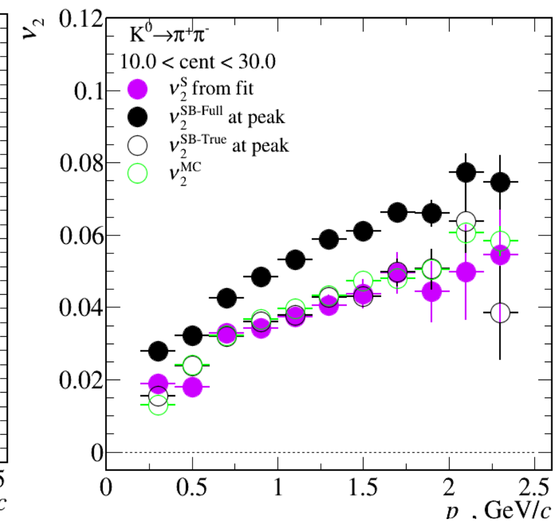
Measured flow only for True

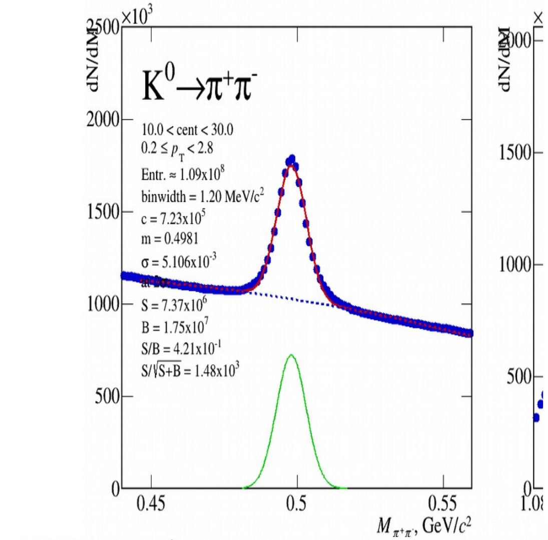
Measured flow from MC/model

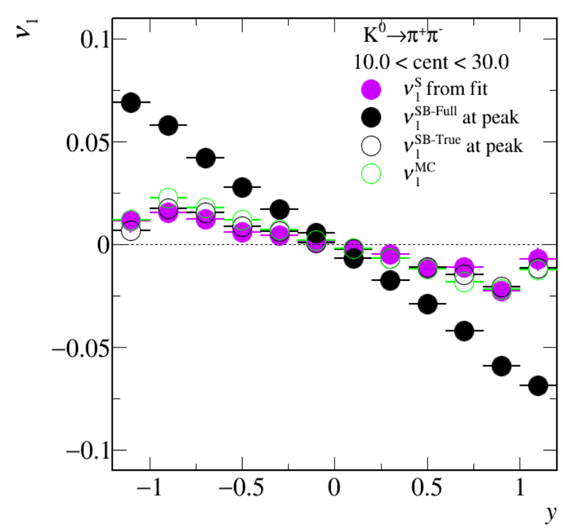
Cuts not optimised for S/B

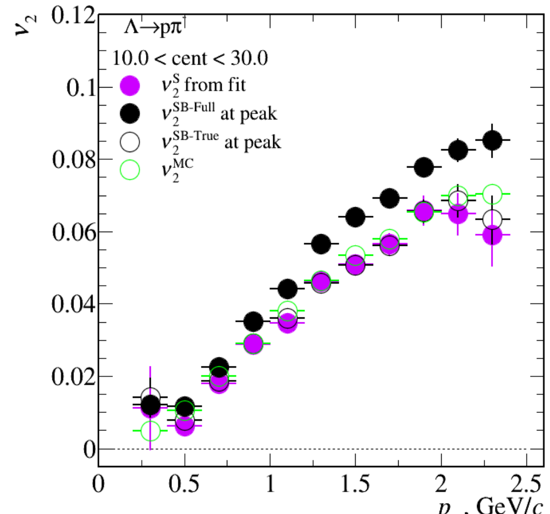


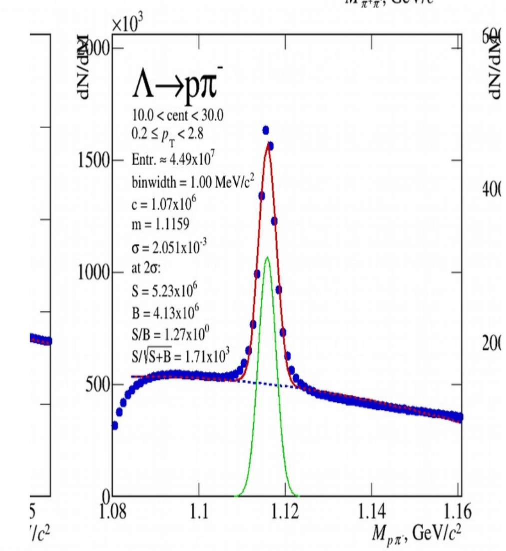












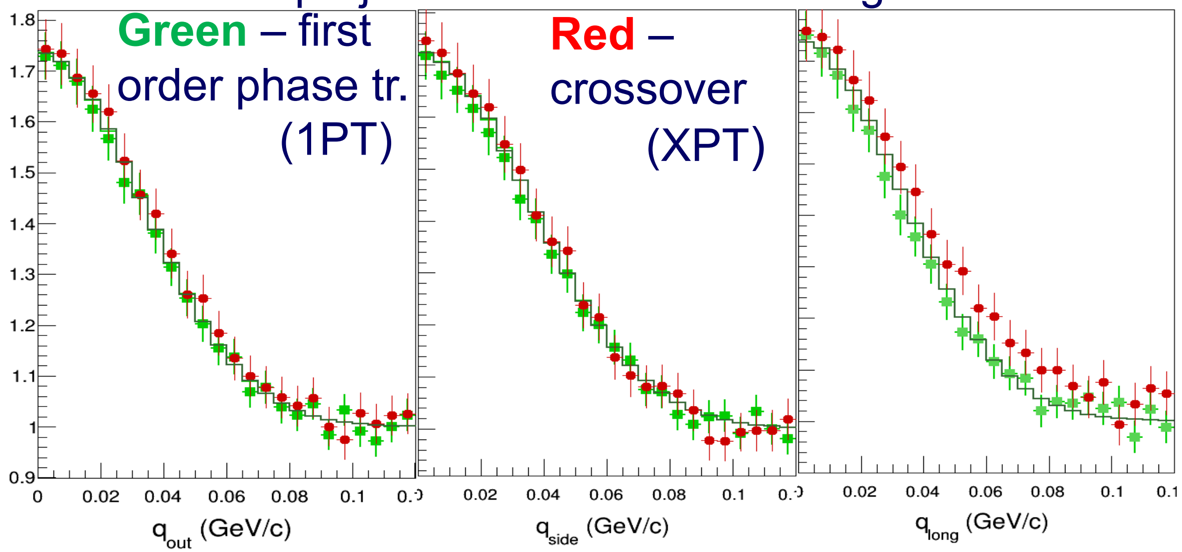
Performance of the MPD Detector for the Study of Multi-strange Baryon Production in Heavy-ion Collisions at NICA

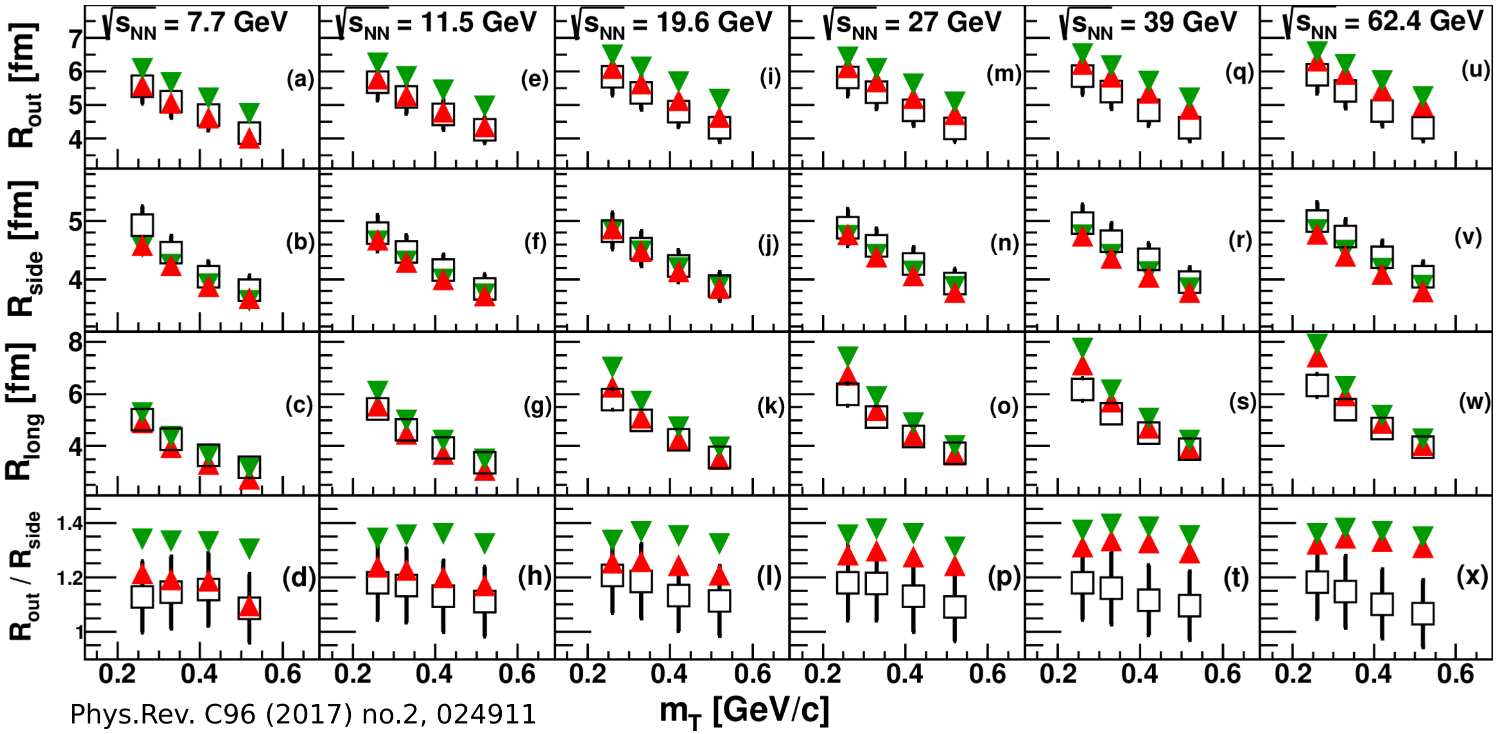
N. Geraksiev, V. Kolesnikov, V. Vasendina, A. Zinchenko for the MPD Collaboration

Femtoscopy in MPD

- MC input: vHLLE+UrQMD model implements hydro stage with different EoS, tuned to reproduce experimental data
- Data set : Au+Au collisions at 11 GeV, MPD full reconstruction chain
- Kaon particle ID and (CF) reconstruction

3D kaon CF projections on Out-Side-Long directions





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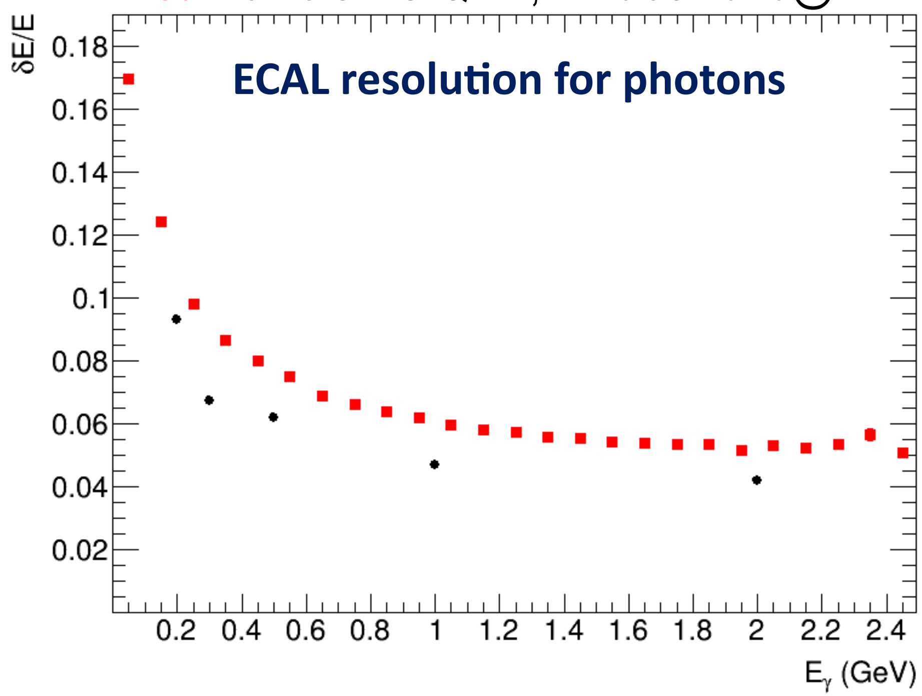
Study of collective effects, space-time characteristics of the emitting source at kinetic freeze-out, collision dynamics and quark-hadron phase transitions

Electromagnetic Calorimeter simulation

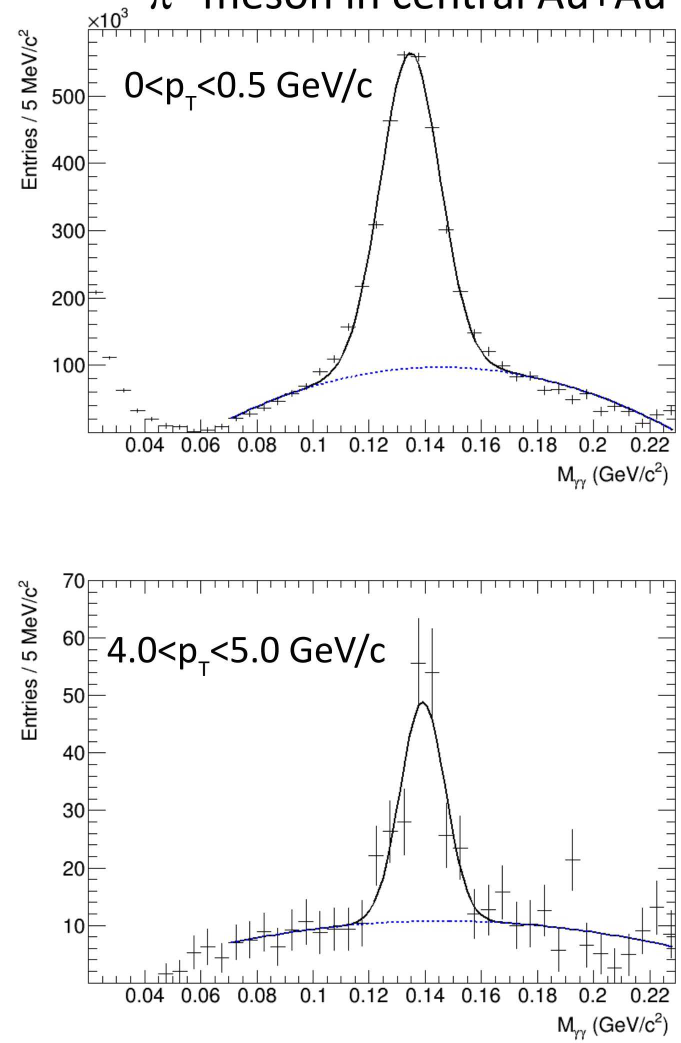
- Realistic ECAL reconstruction & analysis – large acceptance ECAL with good energy resolution: ideal tool for measurement of neutral mesons in a wide momentum range

Black markers – single photons

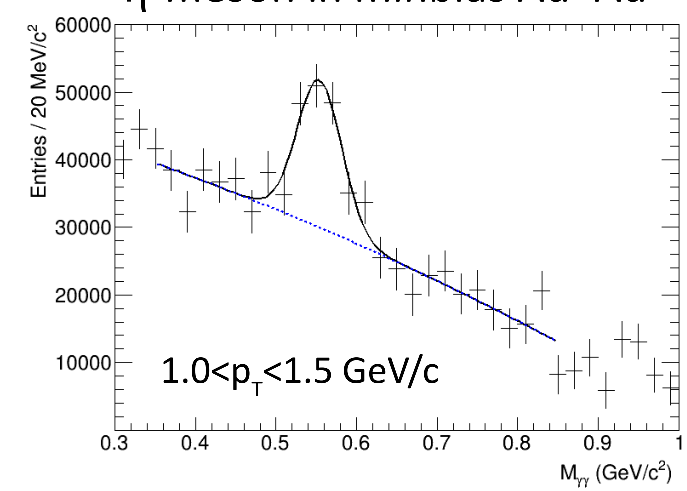
Red markers – UrQMD, minbias AuAu@11



π^0-meson in central Au+Au

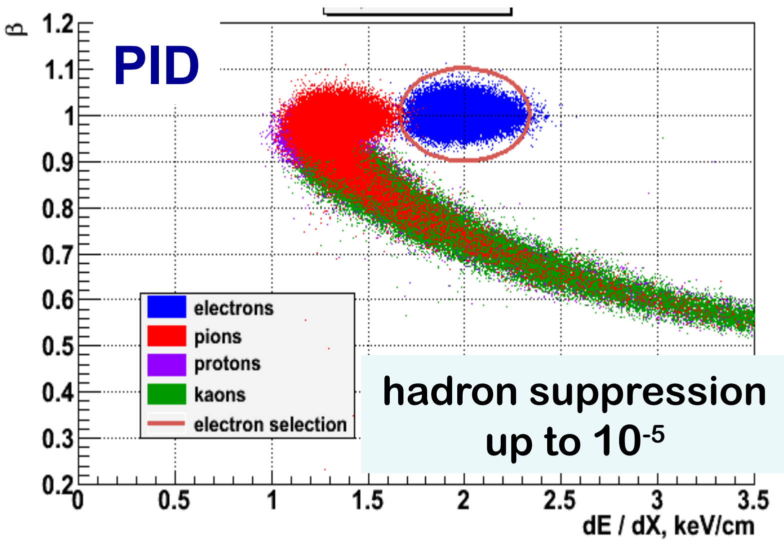


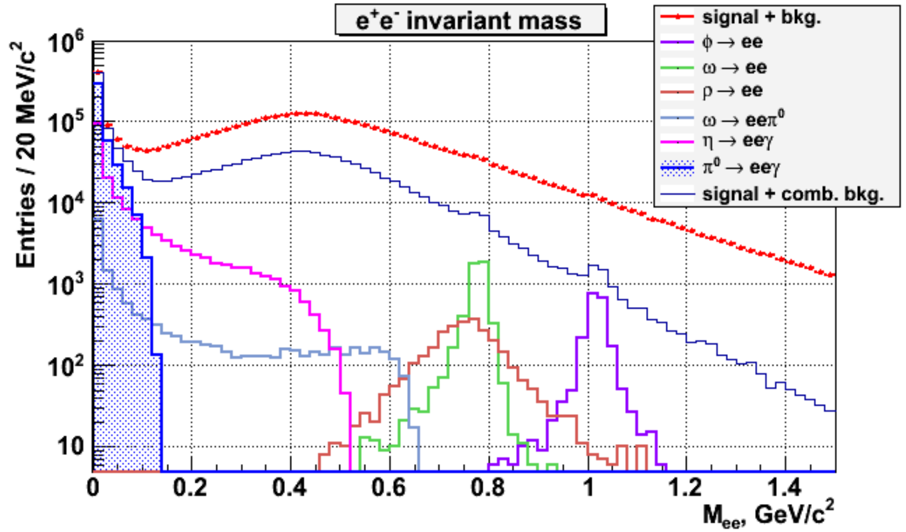
η-meson in minbias Au+Au

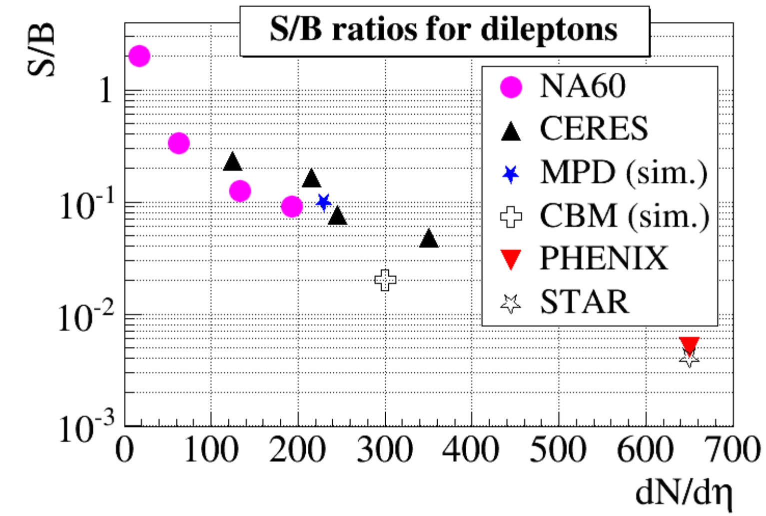


Prospects of dilepton studies

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

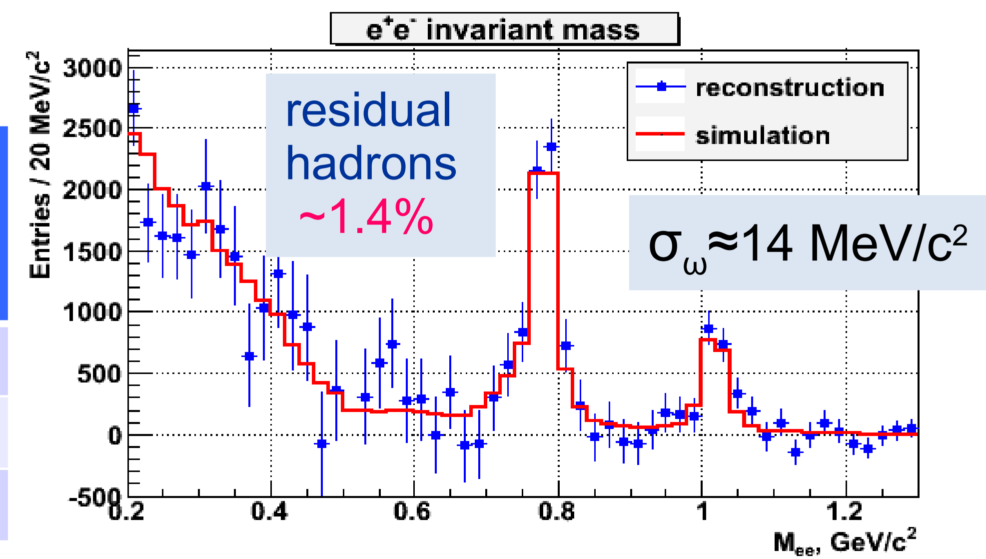






Yields, central Au+Au at $\sqrt{s_{NN}}$ = 8.8 GeV

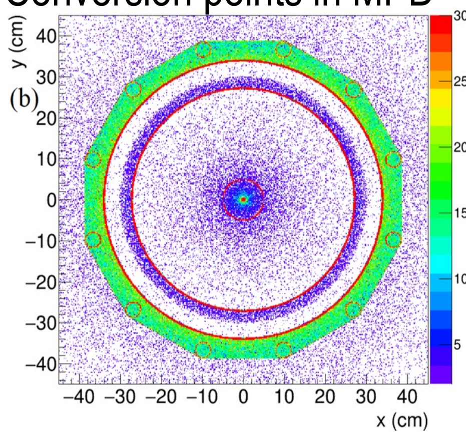
Particle	Yields 4π	Yields y=0	Decay mode	BR	Effic. %	Yield /1 w
ρ	31	17	e+e-	$4.7 \cdot 10^{-5}$	35	$7.3 \cdot 10^{4}$
ω	20	11	e+e-	$7.1 \cdot 10^{-5}$	35	$7.2 \cdot 10^{4}$
φ	2.6	1.2	e+e-	$3 \cdot 10^{-4}$	35	$1.7 \cdot 10^{4}$

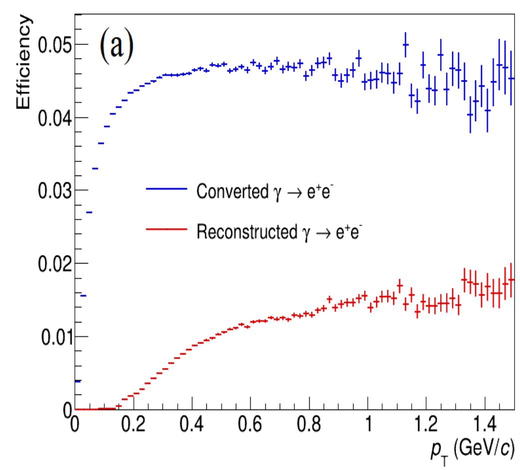


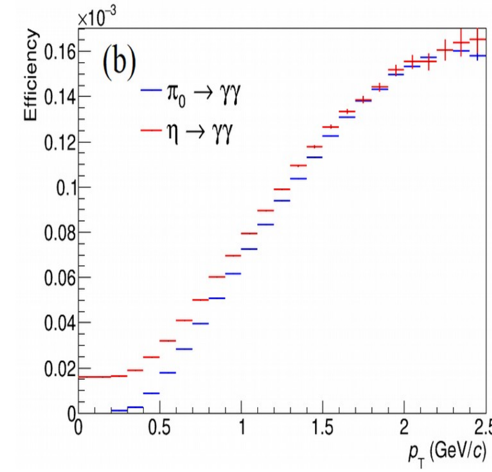
π^0 and η Reconstruction via conversion

- 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



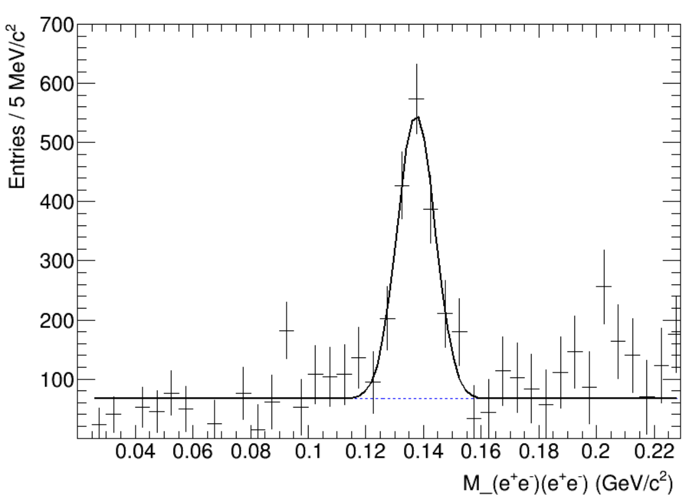




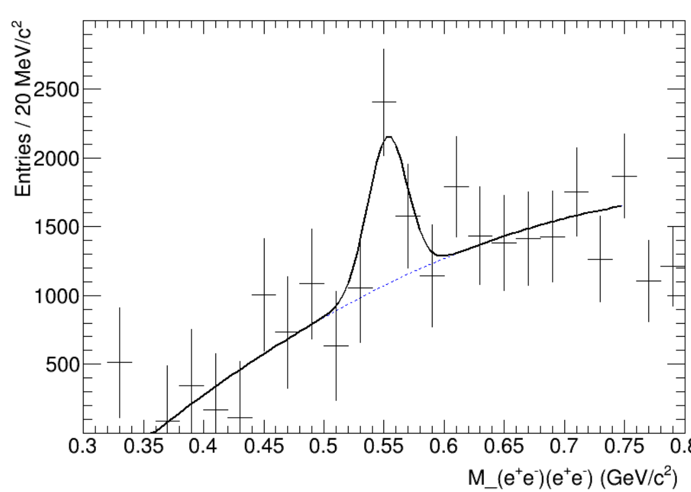
α) γ-conversion efficiency in the beam pipe & TPC vs p_T

b) MPD efficiency for π^0 and η reconstruction vs meson's p_T

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

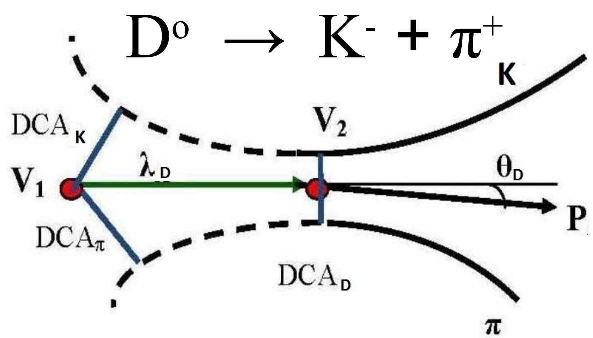


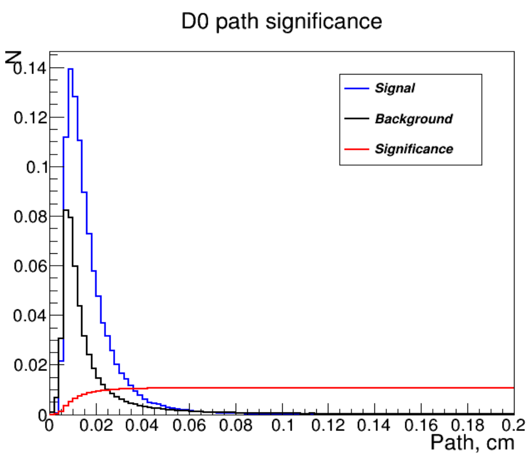
$\eta \to \gamma\gamma \to (e^+e^-)(e^+e^-)$

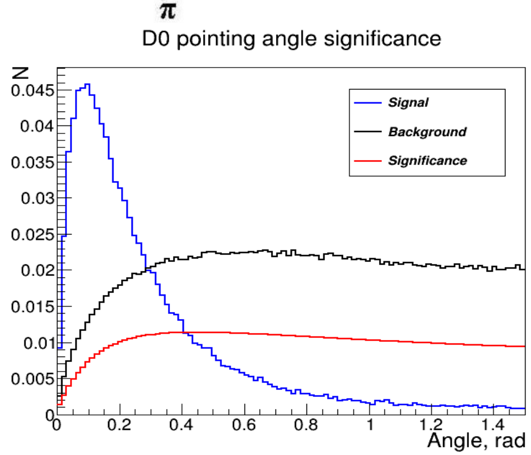


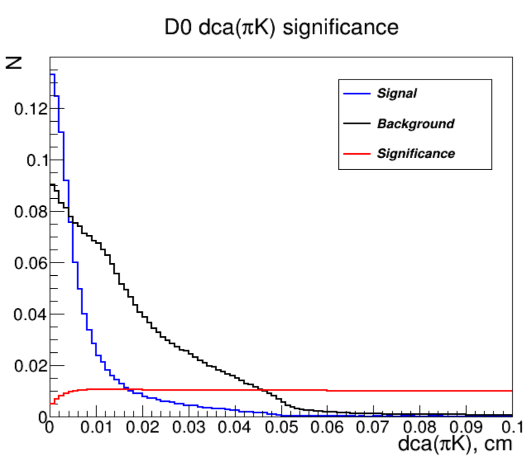
- Standard MPD configuration allows to reconstruct π^0 and η via conversion pairs

Open charm selection with ITS









$DCA_K > 0.01$ cm

$DCA_\pi > 0.01$ cm

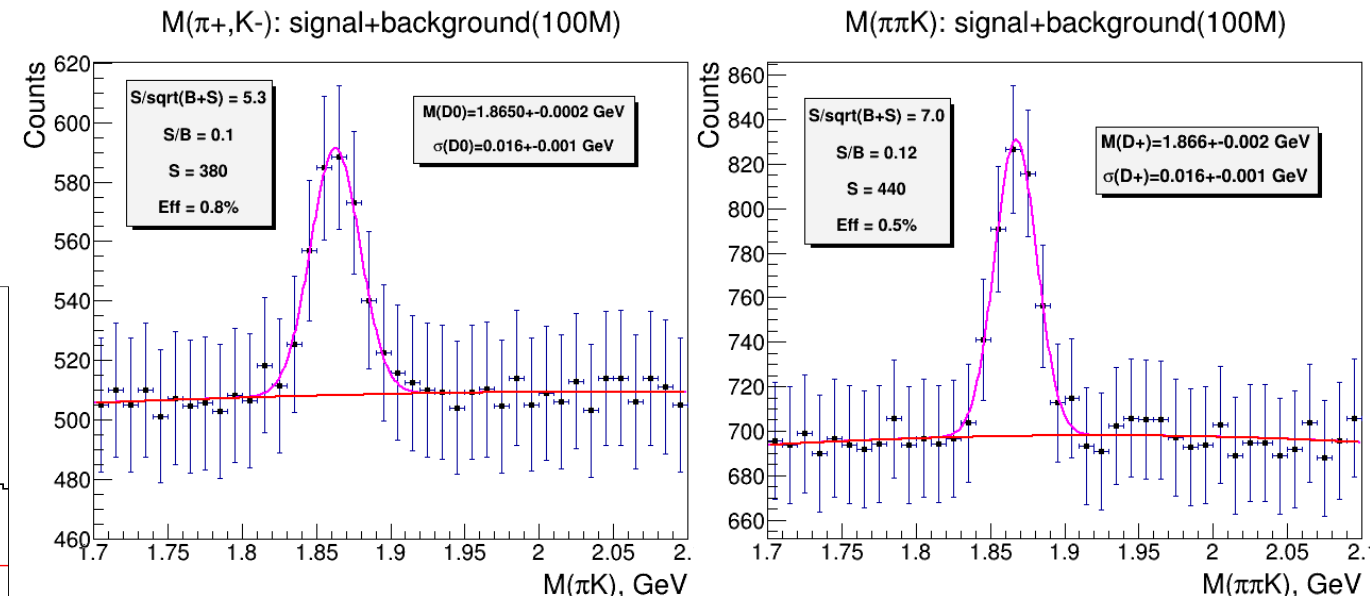
$dist(\pi K) < 0.02$ cm

$path(D^0) > 0.025$ cm

$angle(D^0) < 0.2$ rad

Reconstruction down to p_T close to 0

D^0 and D^+ sigal with full ITS



100M central Au+Au events at $\sqrt{s_{NN}}$=9 GeV

Particle	D^0		D^+	
Decay channel	$D^0 \rightarrow K^- + \pi^+$		$D^+ \rightarrow K^- + \pi^+ + \pi^+$	
Multiplicity (HSD)	10^{-2}		10^{-2}	
BR,%	3.9		9.1	
IB option	ITS3(50μ)	ITS2(200μ)	ITS3(50μ)	ITS2(200μ)
S/B(2σ)	0.43	0.10	0.65	0.27
Significance	15.1	2.2	28.5	7.6
Efficiency,%	1.9	0.13	2.3	0.3

Summary

- NICA allows to access less-explored area of the QCD phase diagram with direct connection to astrophysics
- First stage of NICA Complex operational, data analysis ongoing
- Construction of the Booster and NICA Collider on schedule
- All components of the MPD 1st stage detector advanced in production, commissioning expected for 2020-2021
- Performance studies for full physics program under way