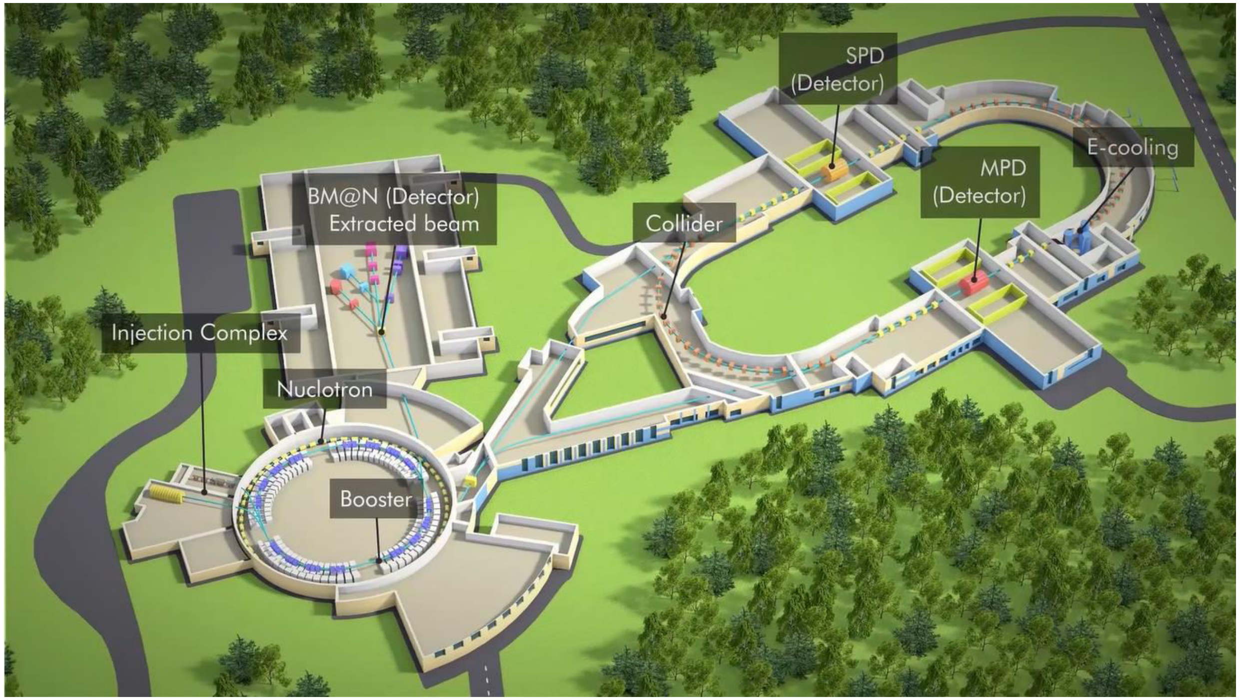
Экспериментальная программа ускорительного комплекса NICA (Дубна)

В. Рябов, ЛРЯФ ОФВЭ

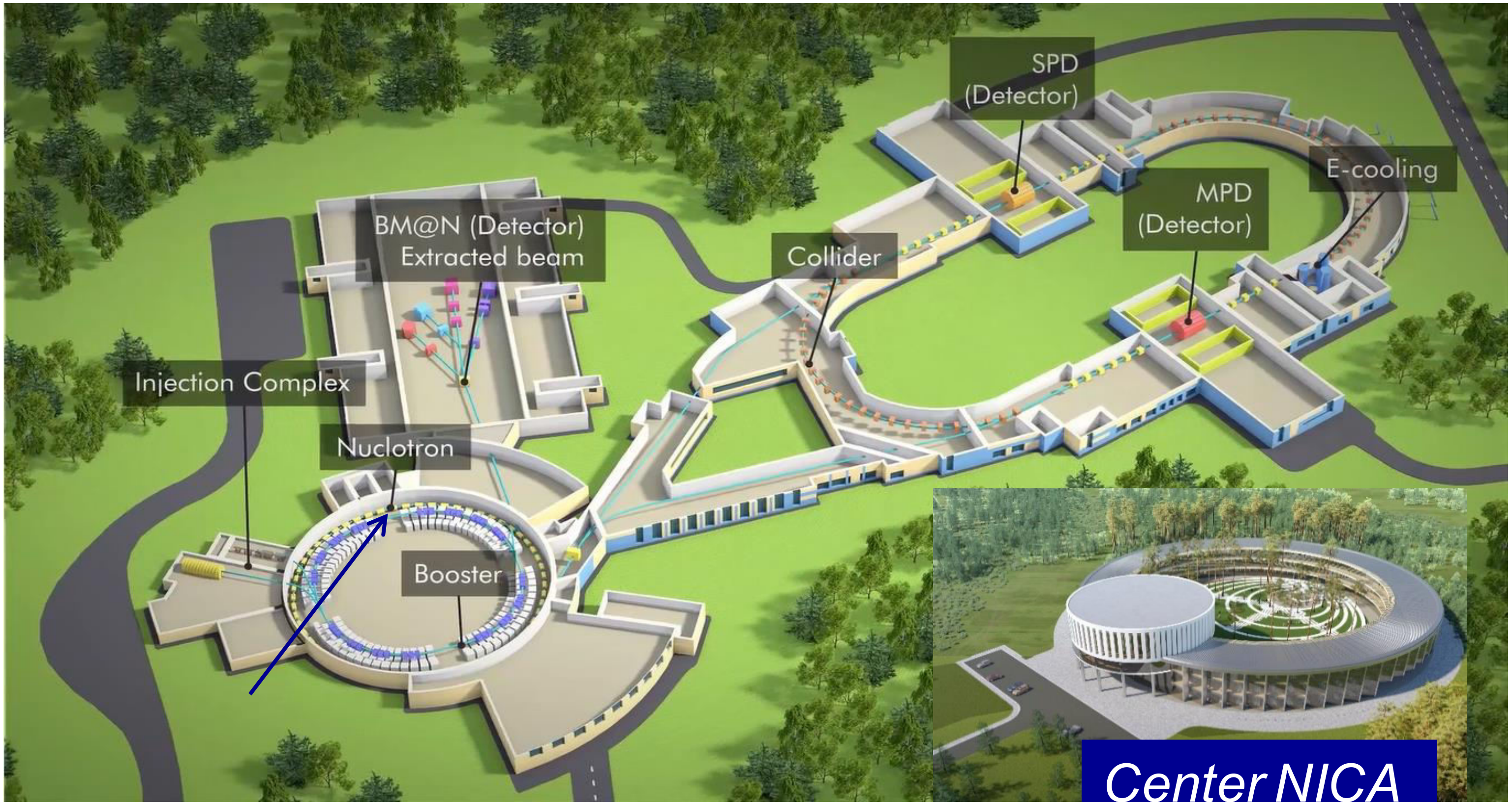


Nuclotron based **I**on **C**olider f**A**cility

Содержание

- Что такое NICA?
- Каковы цели создания NICA?
- Ускоритель и экспериментальные установки
- Статус ускорителя и экспериментальных установок
- Моделирование экспериментальной установки MPD

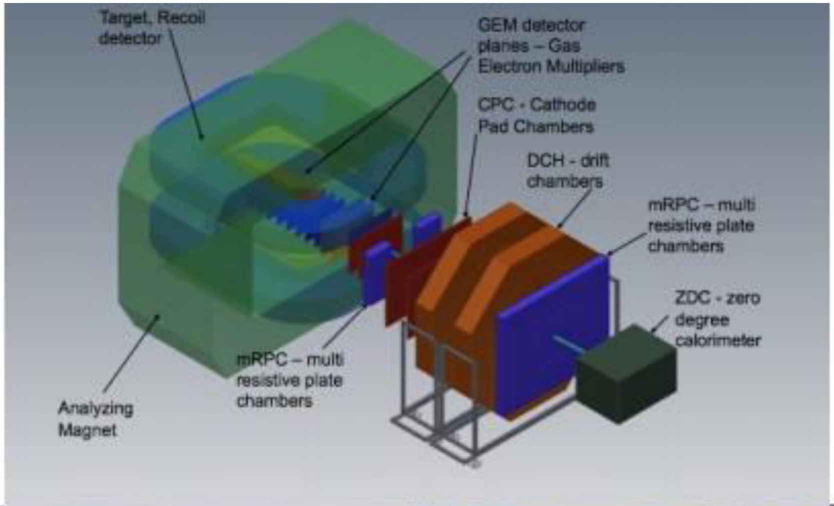
Комплекс NICA

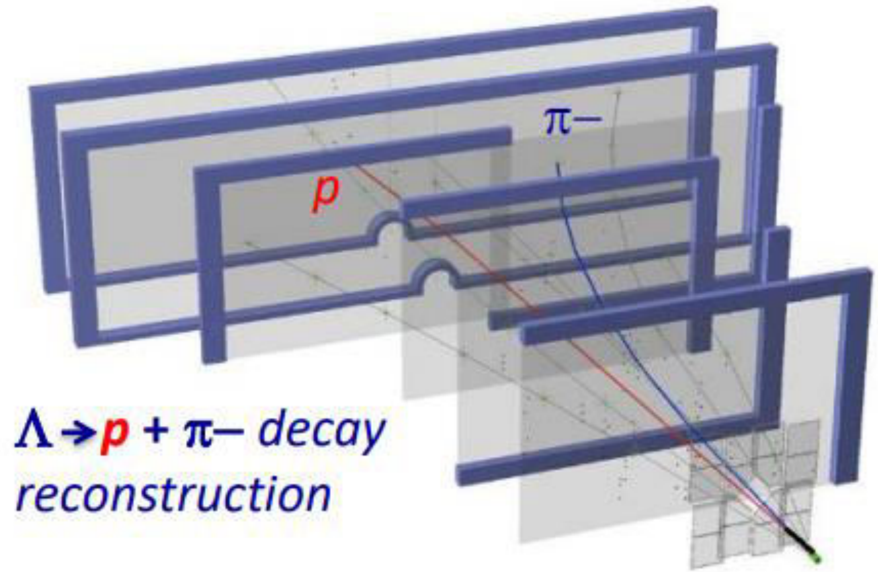


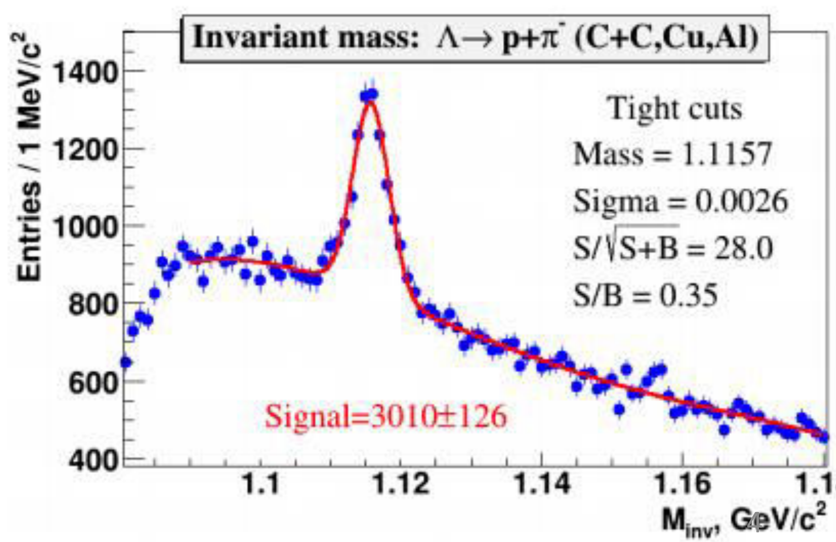
Ring circumference, m	**503,04**
Number of bunches	**22**
r.m.s. bunch length, m	**0,6**
max. int. Energy, Gev/u	**11,0**
r.m.s. Δp/p, 10-3	**1,6**
Luminosity, $cm^{-2}\ s^{-1}$	**1×10^{27}**

- Mega-science project
- Modernization of existing accelerator facility
- Construction of collider complex to collide:
  - relativistic ions from p to Au, $\sqrt{s_{NN}}$ = 4-11 GeV
  - polarized p and d, $\sqrt{s_{NN}}$ = 27 GeV (p)

Эксперимент BM@N (fixed target)
Baryonic Matter @ Nuclotron



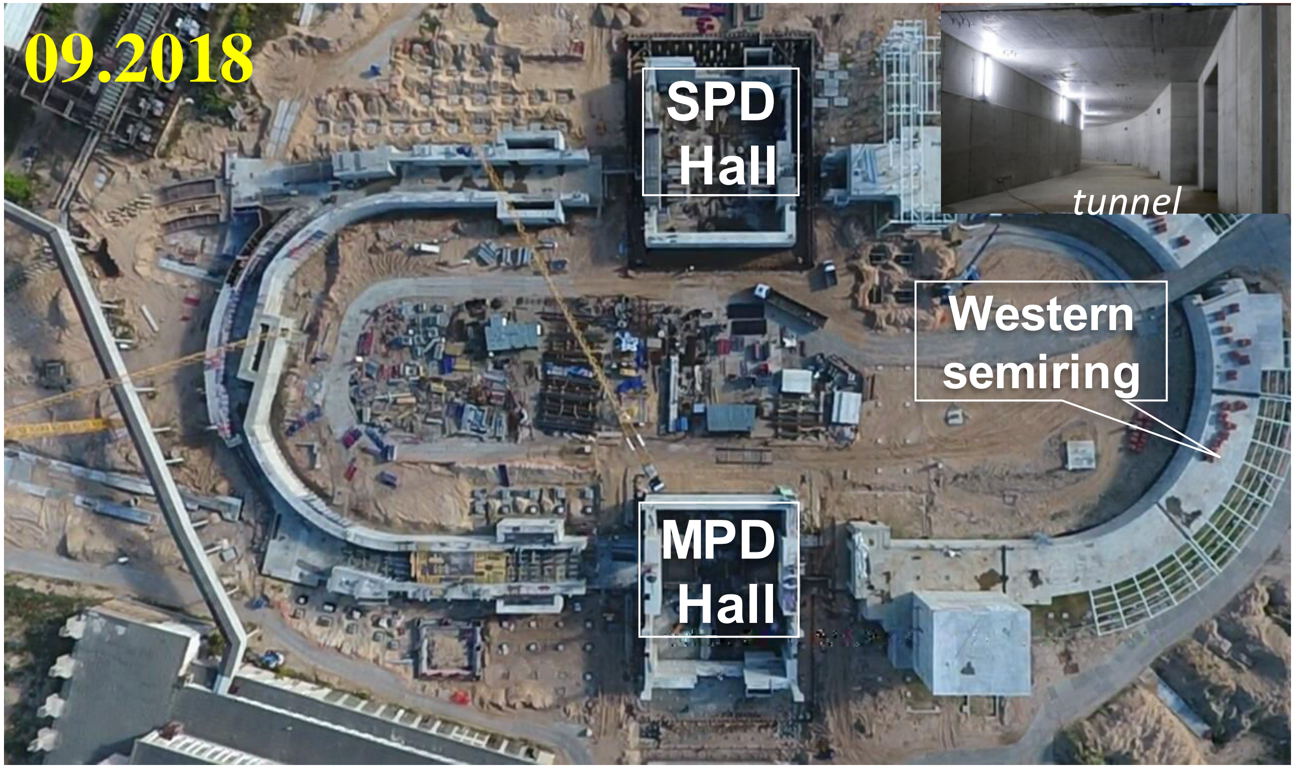




the first run: ***March 22 – April 3, 2018:***
targets: ***C, Al, Cu, Sn, Pb;***

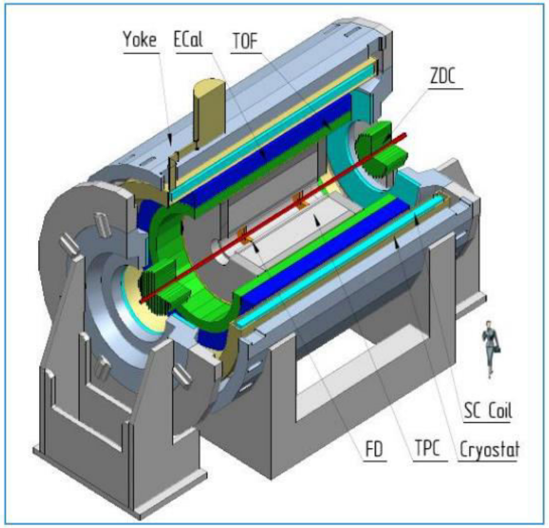
beams		*statistics*
$^{12}C^{6+}$	***4,0 -4,5 AGeV***	***20 M events***
$^{40}Ar^{16+}$	***3,2 AGeV***	***130 M events***
$^{84}Kr^{26+}$	***2,3 AGeV***	***50 M events***

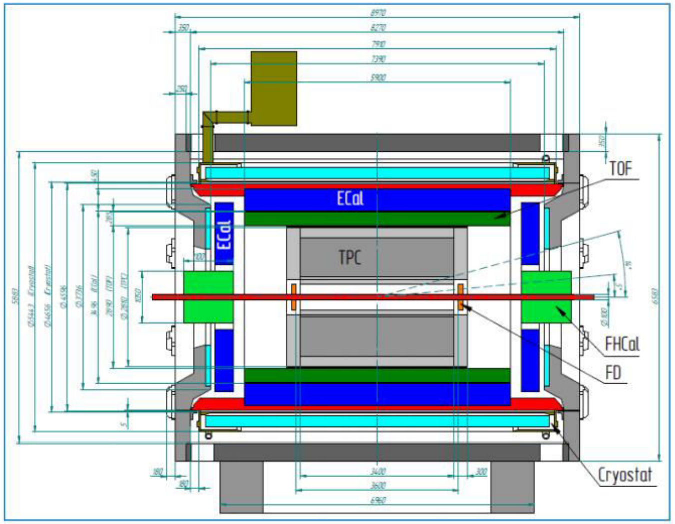
Строительство коллайдера NICA

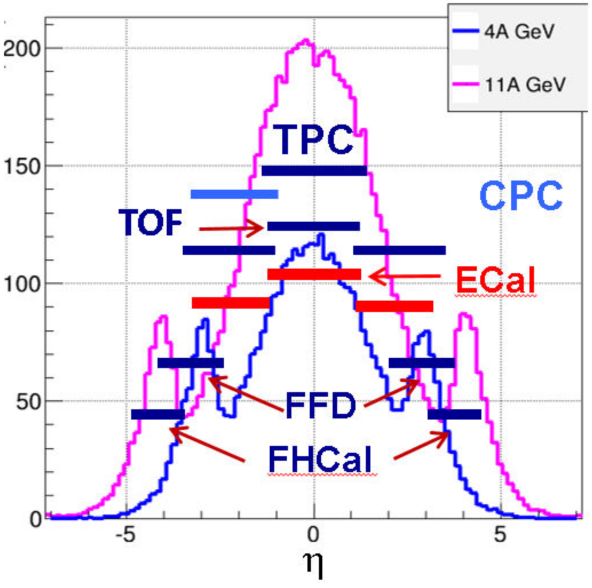


- Система инжекции (источники ионов, & Linacs) – запущены в 2016
- Магниты – производятся в Дубне (готовы для Booster), там же где и для SIS-100/FAIR
- Booster – в процессе строительства, монтаж магнитов с 09.2018, запуск в 2019
- Система электронного охлаждения – финальная стадия испытаний и запуска
- NICA/MPD – сстроительство тоннелей и экспериментальных залов
- MPD зал должен быть готов к установке оборудования в 2019 году

Эксперимент MPD (collider mode) Multi-Purpose Detector





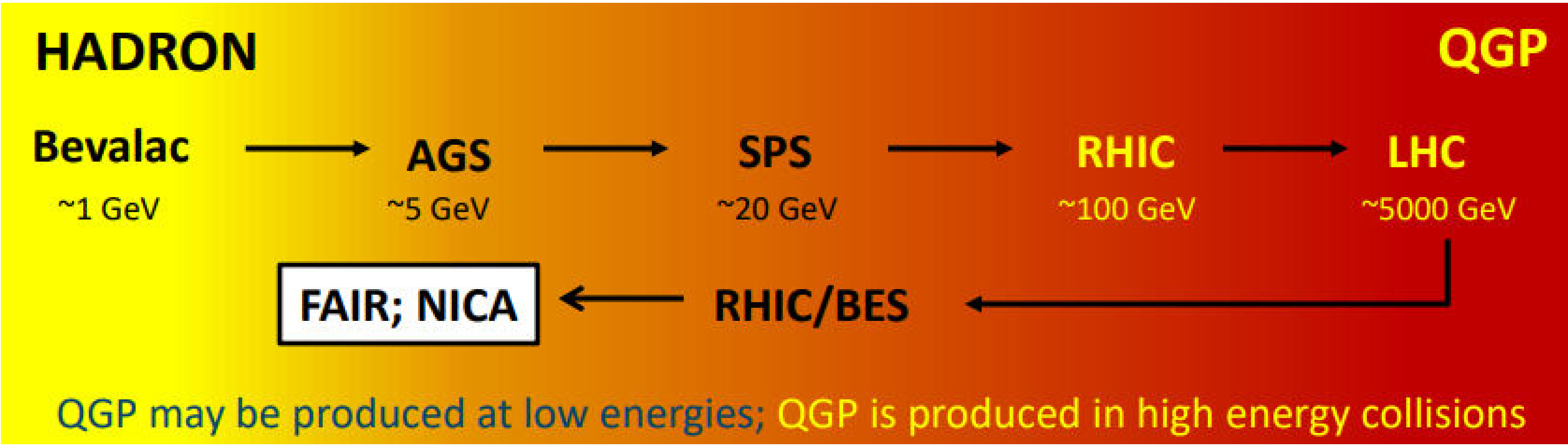


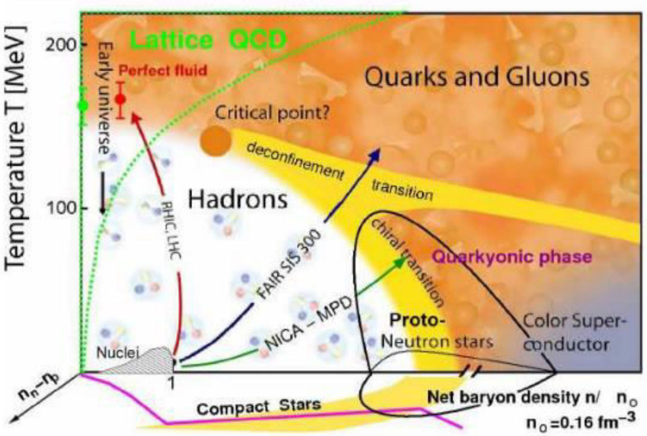
- Большой и однородный аксептанс
- Мало материалов (прозрачный)
- PID (TPC, TOF, ECAL)
- DAQ ~ 6 кГц

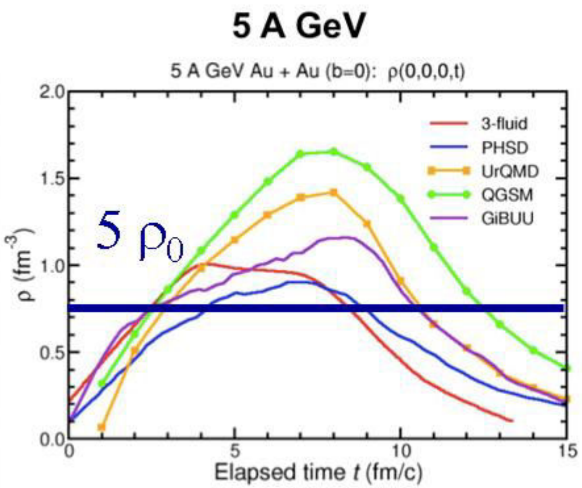
NICA milestones

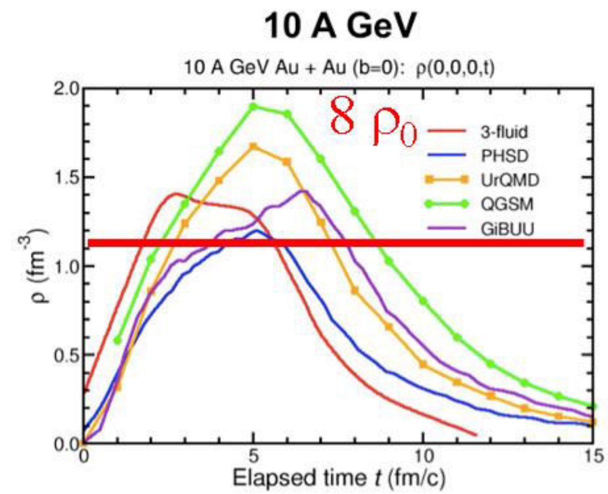
- *2018* – *start of* ***BM@N*** *experiment (min. configuration)*
- ***2018 –2019*** – ***Booster*** *commissioning*
- *2019* – *readiness of* ***MPD Hall***
- *2019* – ***MPD magnet*** *commissioning*
- *2020* – *completion of* ***civil construction*** *(build.* ***17)***
- *2020* – ***MPD*** *commissioning (****Stage I****)*
- *2021* – ***Collider*** *commissioning*
- *2020* – *completion of* ***"NICA Center"*** *construction*
- *2021* – *commissioning of* ***Computer center***
- *2023* – ***MPD*** *commissioning (****Stage II****)*
- *2025* – ***SPD*** *commissioning (****Stage I****)*

Цели проекта NICA





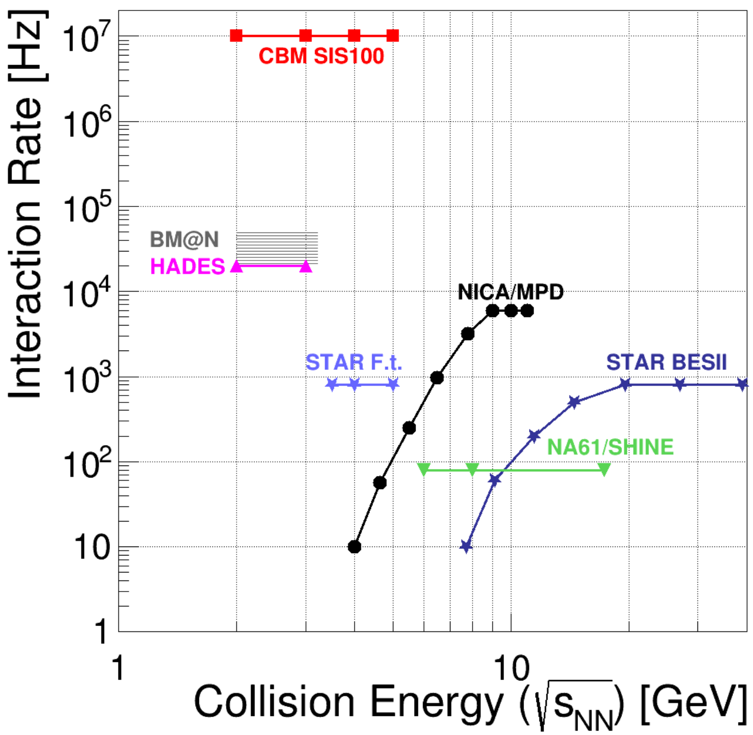




I.C. Arsene at al., Phys. Rev. C75 (2007) 24902.

- Изучение плотной и горячей ядерной материи при максимальных барионных плотностях (фазовый переход $\varepsilon_c \sim 0.5\text{-}1$ ГэВ/фм^3, $\rho_c \sim 5\rho_0$)
- Продолжение экспериментов на RHIC и LHC, 100-1000 ГэВ → 4- 11 ГэВ

NICA vs. HADES/BES-II/NA61/CBM



- Все эксперименты имеют сравнимое покрытие по энергии взаимодействия
- Специализированные установки (CBM, NICA/MPD) позволяют изучать редкие сигналы за счет более высокого темпа набора статистики
- NICA/MPD – коллайдерная установка, одновременно обладающая большим и симметричным аксептансом и позволяющая измерять редкие сигналы при отсутствии паразитических эффектов, присутствующих в экспериментах с фиксированной мишенью

NICA physical program

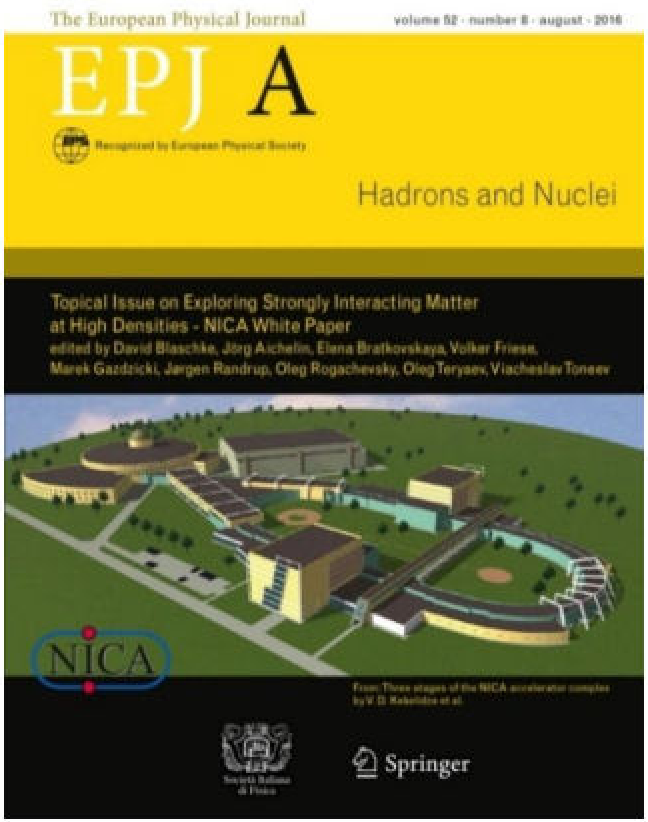
- Physics of heavy ion collisions is driven by data

- New data in less explored region of QCD phase diagram at high baryon density are highly required and could lead to:

  → observation and discovery of new phenomena;
  → Development of theoretical models

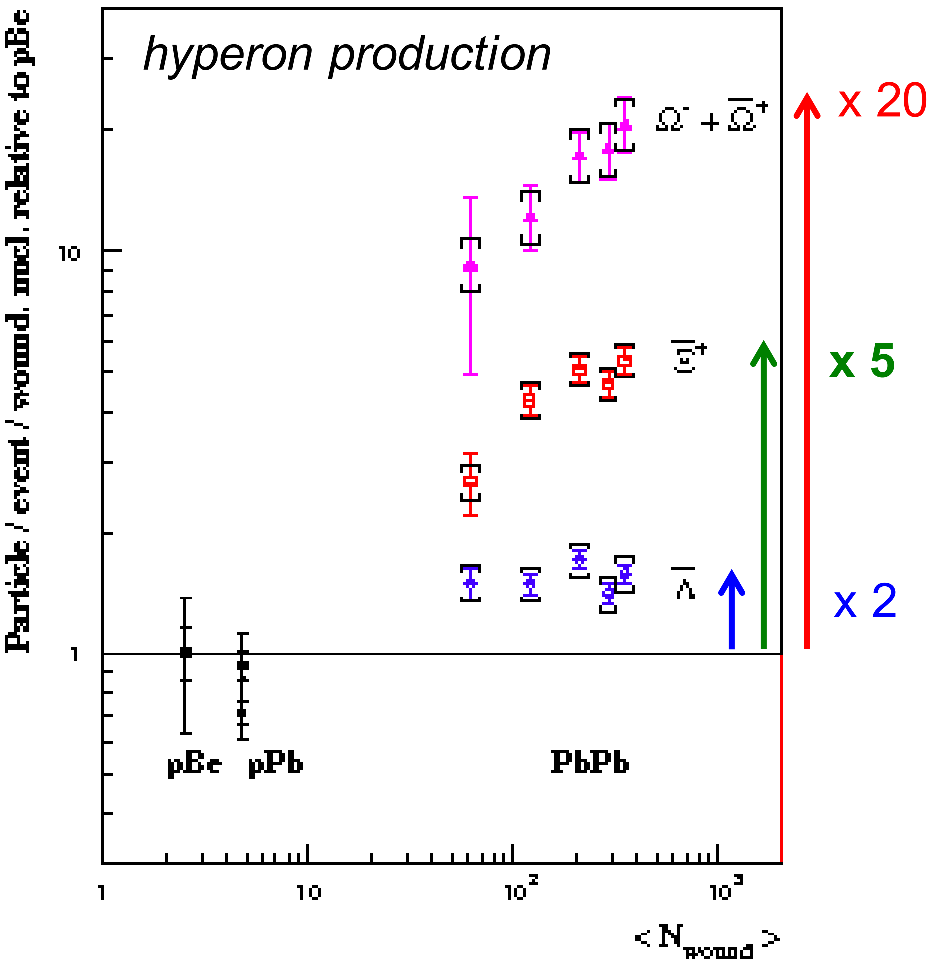
NICA program (White Paper)

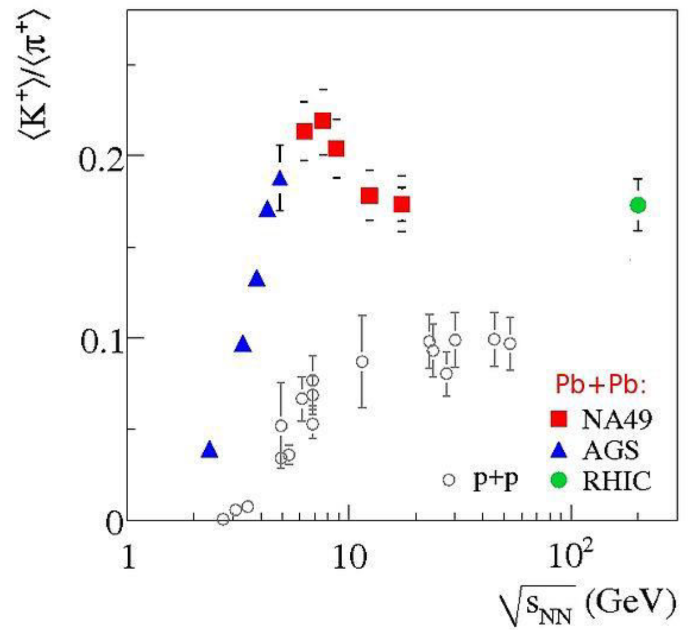
Main goal: *to obtain new data on hot nuclear matter in the region of max net-baryon density to explore the QCD phase diagram*

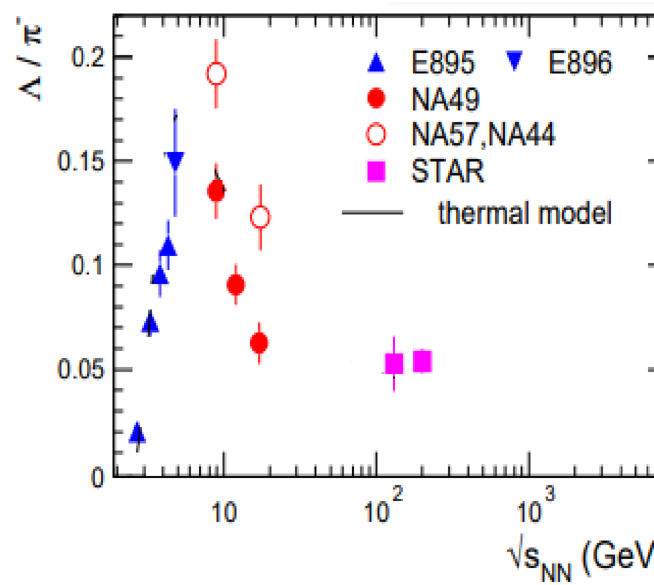


- ❑ **Bulk properties, EOS, deconfinement**
  - particle yields & spectra, ratios, femtoscopy, flow
- ❑ **In-Medium modification of hadron properties**
  - dileptons and dilepton slopes (LMR+IMR)
- ❑ ***Deconfinement (chiral) phase transition***
  - *strangeness production*
  - *Chiral Magnetic (Vortical) effects, Λ polarization*
- ❑ **Criticality in HIC**
  - event-by-event fluctuations and correlations
- ❑ **Strange DOF in nuclei, Y-N interactions**
  - hypernuclei

Strangeness enhancement: SPS, RHIC, LHC



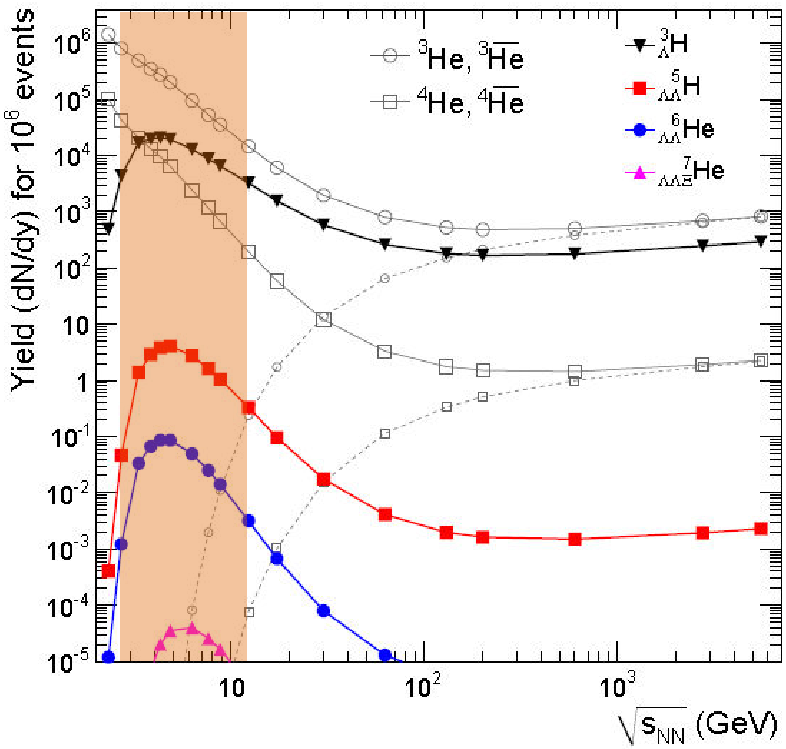




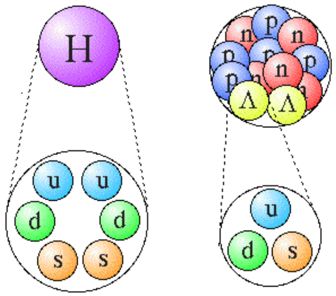
- In some models “horns” in particle ratios indicate onset of chiral symmetry restoration and deconfinement
- Requires mode detailed and precise data

Hypernuclei

- At relatively low beam energies, where the baryochemical potential and, hence, the baryon density is maximum (NICA/FAIR energy regime) objects with a large number of baryons and moderate strangeness are abundantly produced



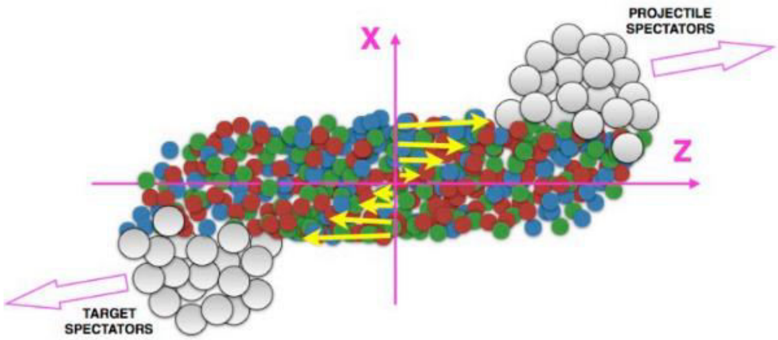
A. Andronic et al., Phys. Lett. B697 (2011) 203



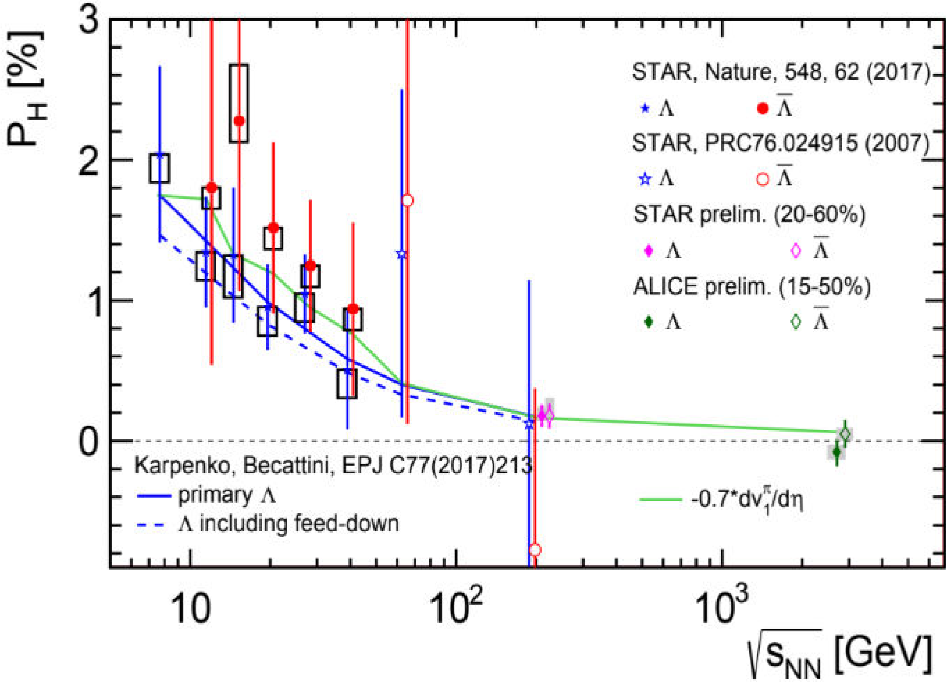
- Hypernuclei provides unique opportunity to study the strange particle-nucleus interaction in a many-body environment
- Astrophysical researches indicate an appearance of hyperons in the dense core of a neutron star

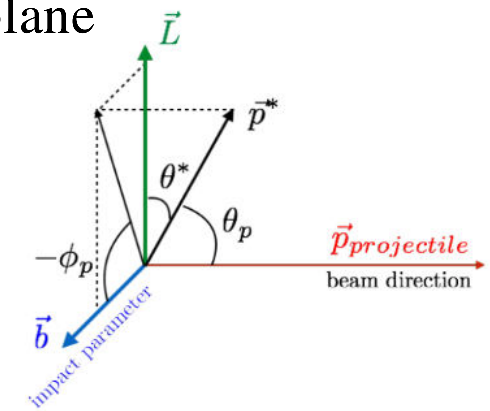
Global polarization

- Global polarization along one preferential direction – the system orbital momentum ‖ magnetic field



- Need to know the direction of the angular momentum → first harmonic event plane





$$\frac{dN}{d\cos\theta^*} \propto 1 + \alpha_H P_H \cos\theta^*$$

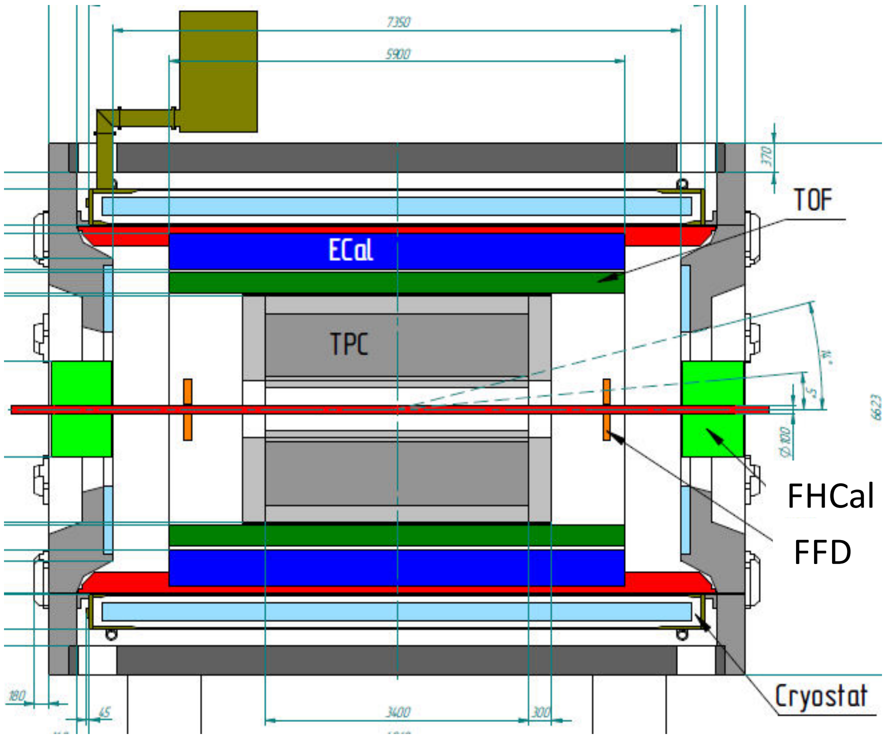
$$\Lambda \rightarrow p + \pi^-$$

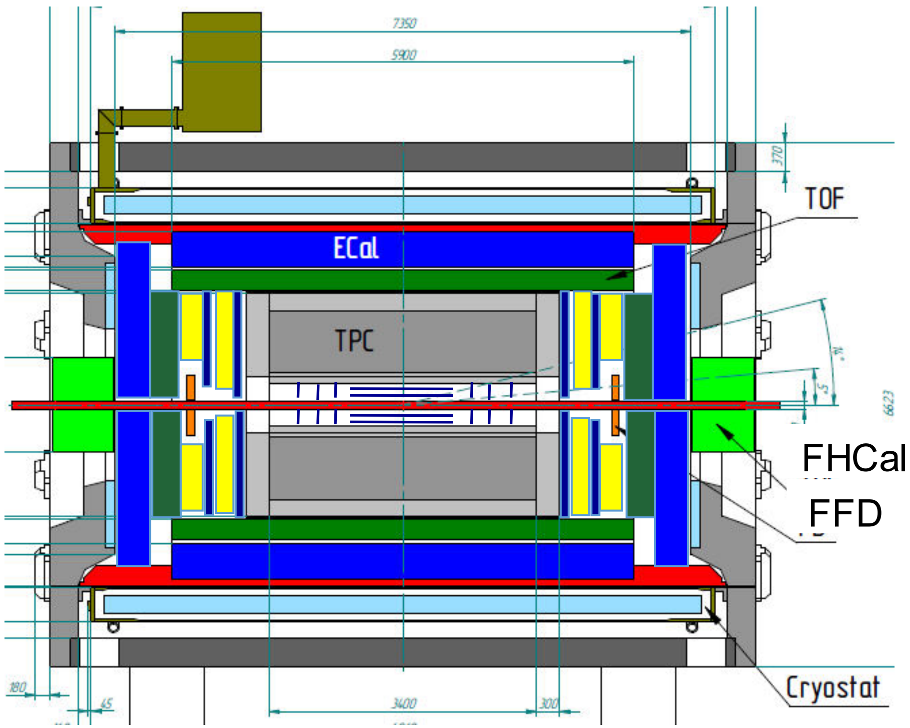
$$\alpha_\Lambda = -\alpha_{\bar{\Lambda}} \approx 0.624$$

MPD progress

MPD, Phase-I

- Стадия I: **TPC, TOF, FFD, FCAL и ECAL** → 2020
- Стадия II: **… + ITS + EndCap (CPC, Straw, TOF, ECAL)** →2023



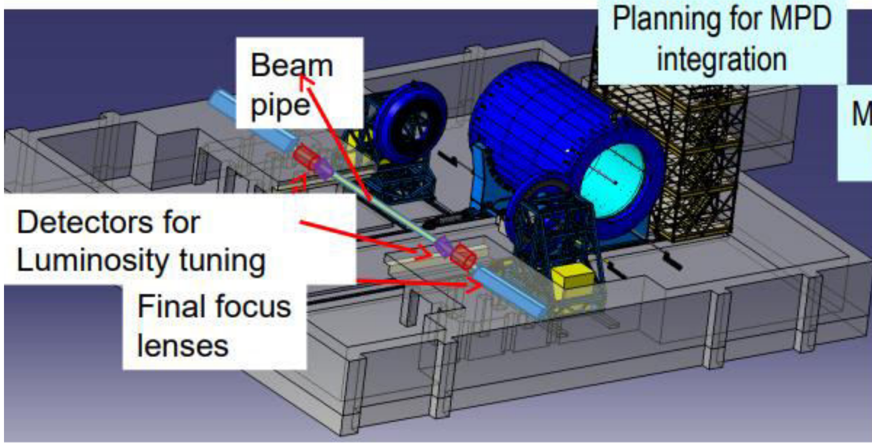


NICA-MPD infrastructure

- **MPD Hall will be soon ready for equipment installation!**
- **Preparatory works: designing place, tooling and service systems for MPD assembling and maintenance**

Working place inside/outside of the MPD Hall

- Place & tooling for MPD assembling
- Service & supply systems (cryo, cooling, power, etc.)



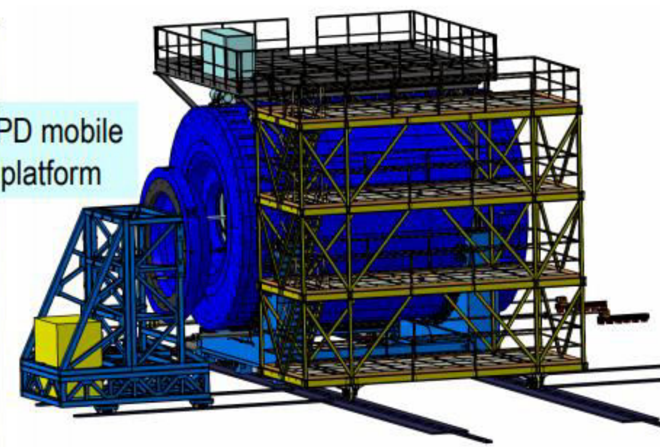
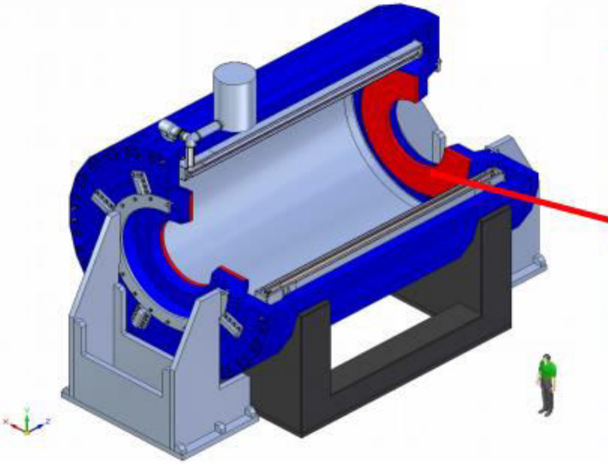


Figure 17; PLATFORM, LEVEL 1-4

Magnet fabrication: ASG (Genova) & Vitktovice HM



trim coil

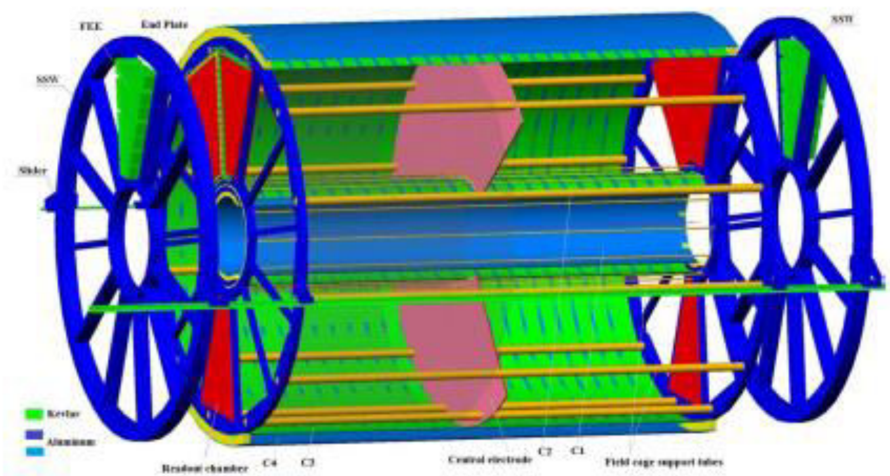
End of 2018 – SC coils are ready
March 2019 – Solenoid is ready
May 2019 – Transportation to Dubna
Oct 2019 – Assembling of Magnet Yoke and Solenoid at JINR
Nov 2019 – Magnetic field measurements

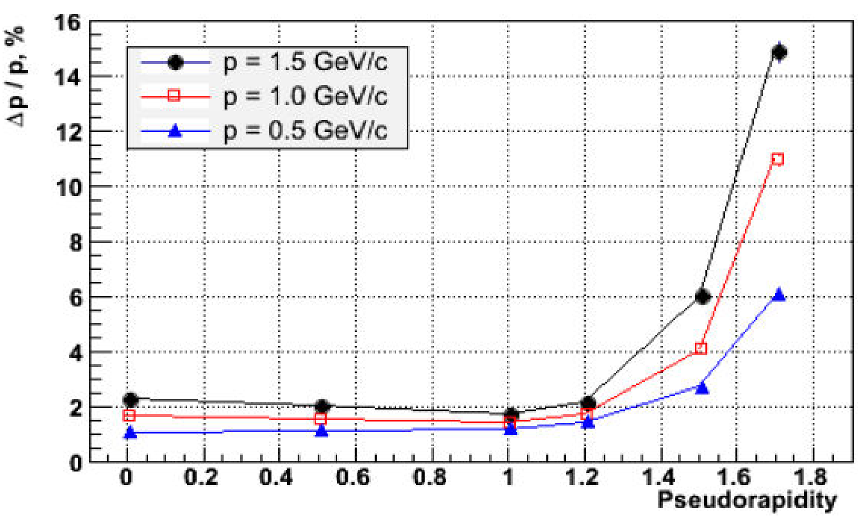
yoke control assembly at HM Vitkovice

winding machine

cryostat

TPC – Time Projection Chamber





Item	Dimension
Length of the TPC	340cm
Outer radius of vessel	140cm
Inner radius of vessel	27 cm
Outer radius of the drift volume	133cm
Inner radius of the drift volume	34cm
Length of the drift volume	170cm (of each half)
HV electrode	Membrane at the center of the TPC
Electric field strength	~140V/cm;
Drift gas	90% Ar+10% Methane, Atmospheric pres. + 2 mbar
Gas amplification factor	~ 10^4
Drift velocity	5.45 cm/μs;
Drift time	< 30μs;
Temperature stability	< 0.5°C
Number of readout chambers	24 (12 per each end-plate)
Segmentation in φ	30°
Pad size	$5x12mm^2$ and $5x18mm^2$
Number of pads	95232
Pad raw numbers	53
Maximal event rate	< 7 kHz (Lum. 10^{27})
Electronics shaping time	~180 ns (FWHM)
Signal-to-noise ratio	30:1
Signal dynamical range	10 bits
Sampling rate	10 MHz
Sampling depth	310 time buckets

TPC – Time Projection Chamber

C1

- Length: 3.4 m
- Diameter: 0.54 m

C2

- Length: 3.4 m
- Diameter: 0.676 m

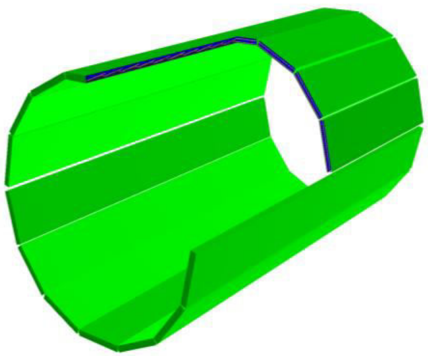
C3

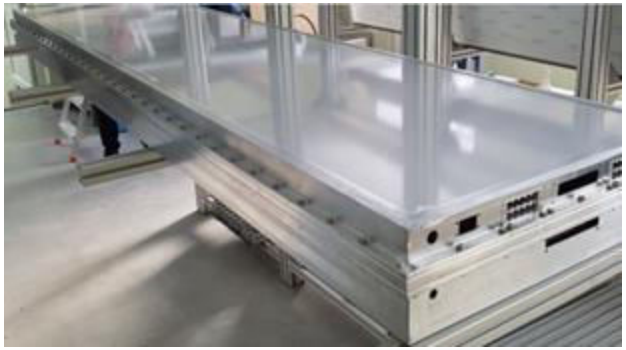
- Length: 3.4 m
- Diameter: 2.66 m

C4

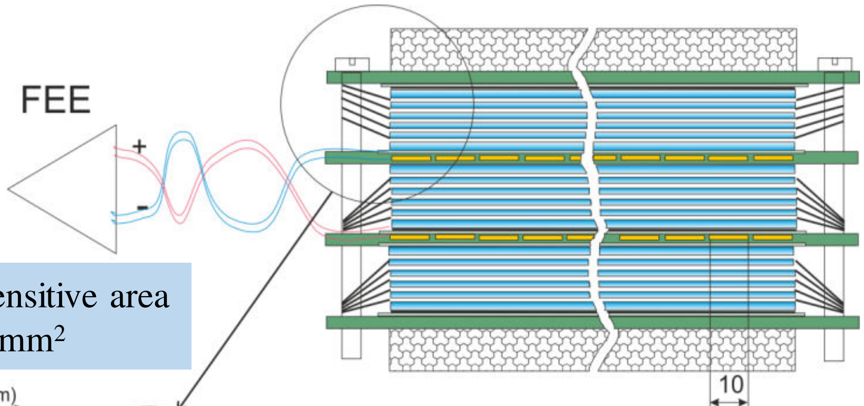
- Length: 3.4 m
- Diameter: 2.814 m

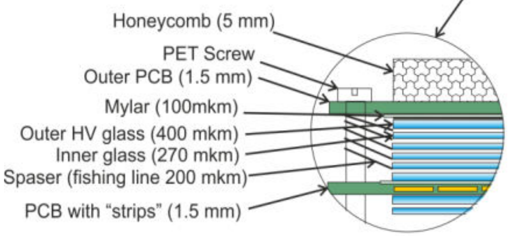
TOF – Time Of Flight

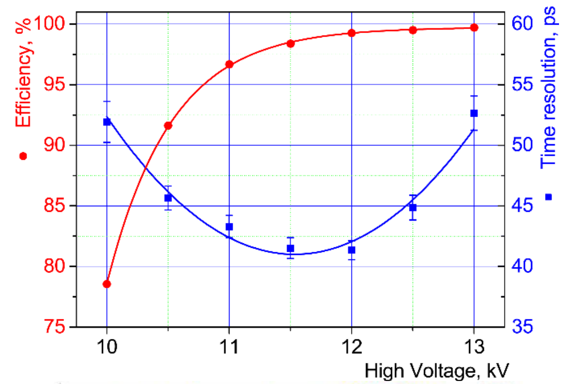


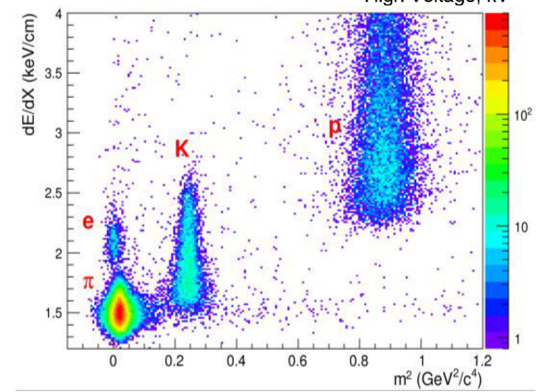


Dimensions of sensitive area
600 x300 mm^2









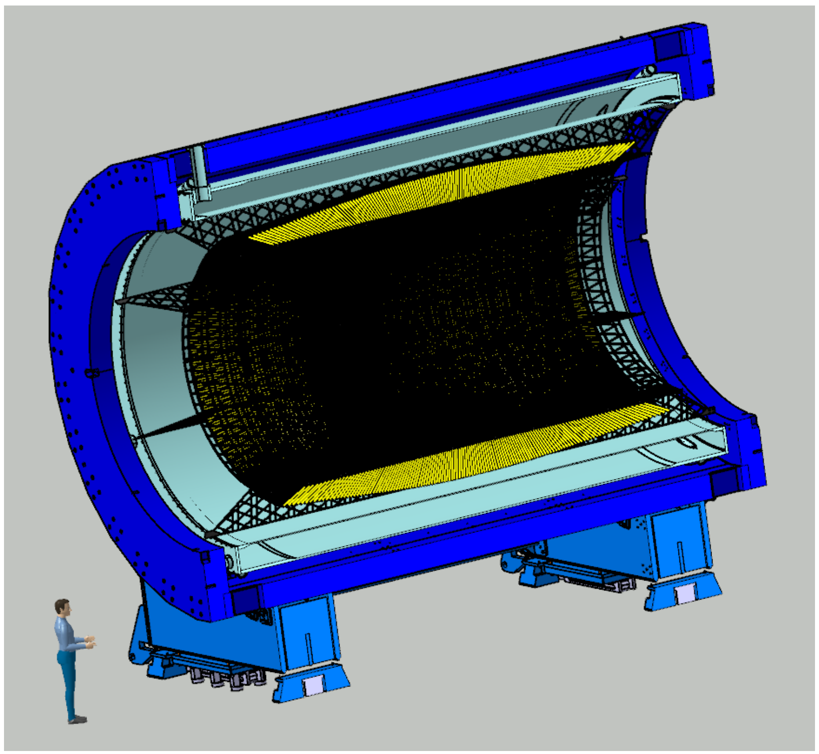
Main parameters of the TOF system.

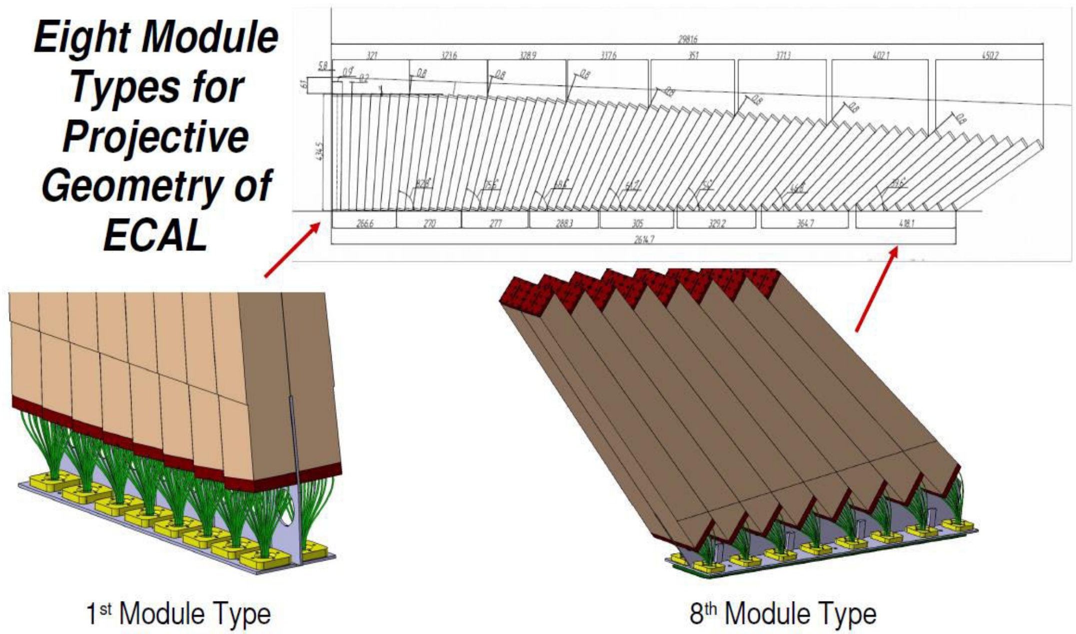
	Number of detectors	Number of readout strips	Sensitive area, m^2	Number of FEE cards	Number of FEE channels
MRPC	1	24	0.192	2	48
Module	10	240	1.848	20	480
Barrel	280	6720	51.8	560	13440 (1680 chips)

ECAL – Electromagnetic CALorimeter

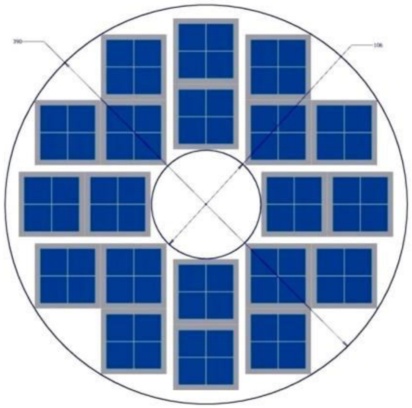
- Pb+Sc “Shashlyk”, 43,000 towers
- read-out: WLS fibers + MAPD
- L ~ 35 cm (~ 14 X_0)

- Segmentation (4x4 cm2),
- σ(E) better than 5% @ 1 GeV;
- time resolution ~500 ps

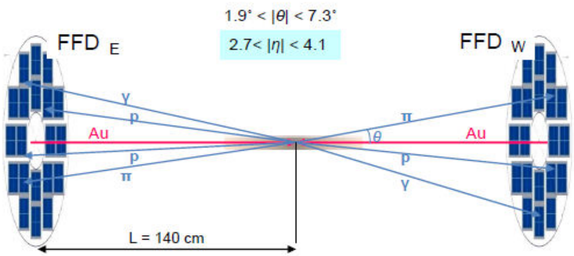




FFT – Fast Forward Detector



The FFD sub-detector consists of 20 modules based on Planacon MCP-PMTs



FFD provides information on
- fast triggering of Au-Au collision
- start signal for TOF
- bunch crossing region position

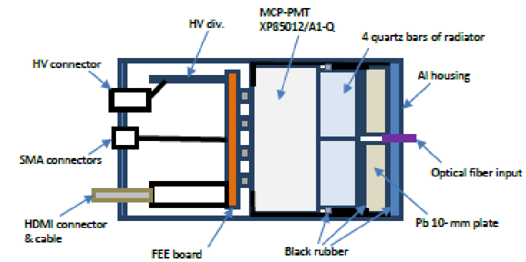
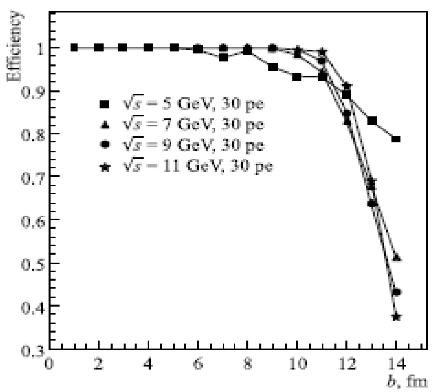
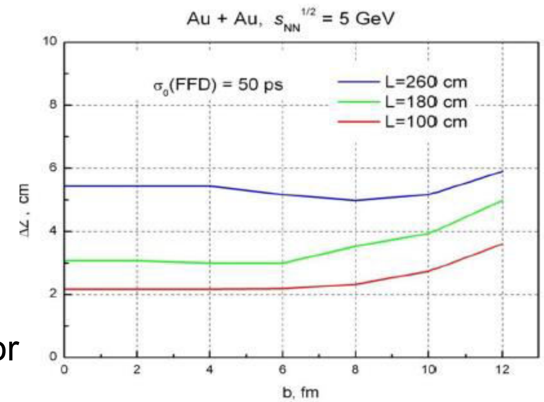


Fig. 4-1. A scheme of the FFD module.

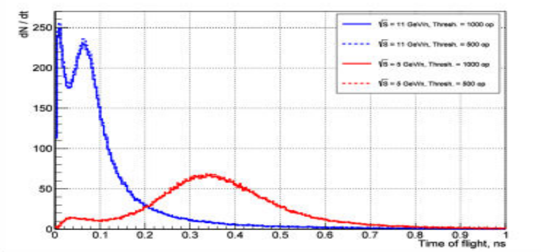
15 mm quartz radiator
10 mm Lead converter



FFD efficiency for peripheral collisions

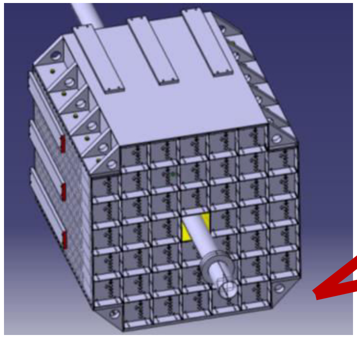


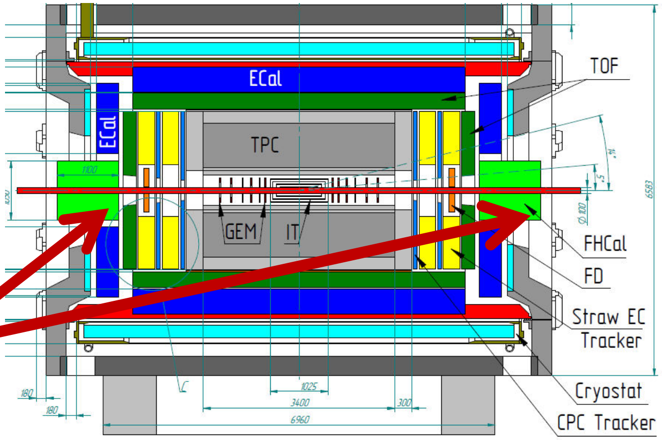
The vertex resolution for Au-Au collisions at $\sqrt{s}$=5GeV/n for three distances from interaction point



The delay of charged particle arrival in FFD modules in comparison with arrival time of photons for Au + Au collisions at $\sqrt{s_{NN}}$ = 5 (red) and 11 (blue) GeV and FFD position of 140 cm.

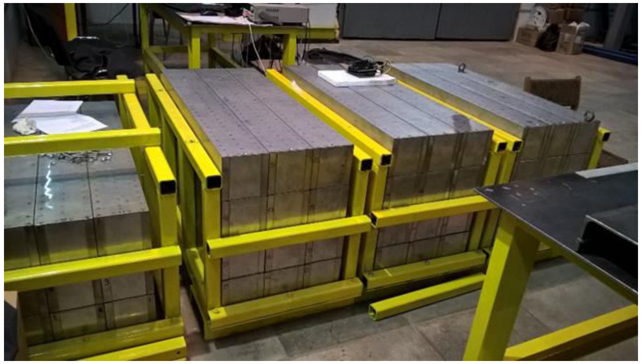
FHCAL – Forward Hadron CALorimeter

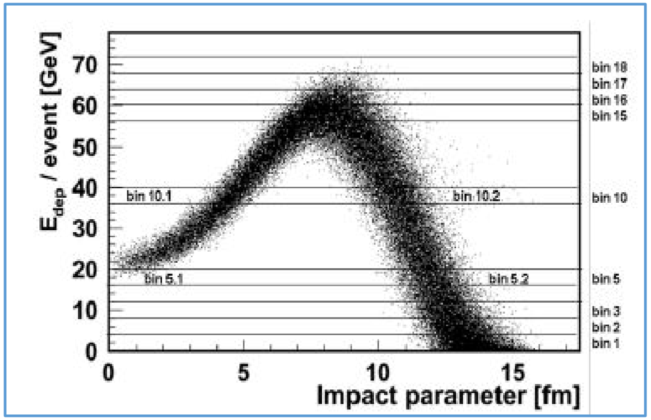


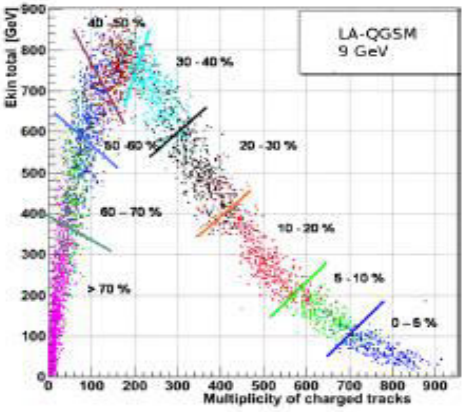


- Two-arms at ~3.2 m from the interaction point
- Each arm consists of 45 individual modules.
- Module size 150x150x1100cm^3 (55 layers)
- Pb(16mm)+Scint.(4mm) sandwich
- 7 longitudinal sections
- 6 WLS-fiber/MAPD per section
- 7 MAPDs/module
- reaction plane resolution ~ 20-30^0
- centrality resolution ~ 10%

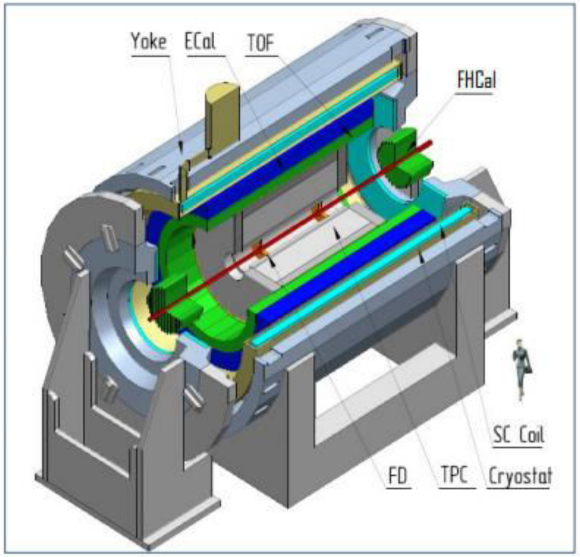
σ(E)/(E) = 56.1%/√E(GeV) +2.1%







MPD - Collaboration



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**;

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;
UNAM, Mexico City, **Mexico**;
Institute of Applied Physics, Chisinev, **Moldova**;
WUT, Warsaw, **Poland**;
NCNR, Otwock – Świerk, **Poland**;
UW, Wrocław, **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;**
PNPI, Gatchina**, Russia**;
SINP, Moscow, **Russia;**
SPSU, St. Petersburg, **Russia**;

> 430 members total
Spokesperson: Adam Kiesel

ПИЯФ в MPD

- **Участие в коллаборации MPD:**

Country	Institute name	First name(s)	Last name
RUSSIA	PNPI, Gatchina, RUSSIA	Aleksei	Ezhilov
RUSSIA	PNPI, Gatchina, RUSSIA	Oleg	Fedin
RUSSIA	PNPI, Gatchina, RUSSIA	Vadim	Guzey
RUSSIA	PNPI, Gatchina, RUSSIA	Dmitrii	Ivanishchev
RUSSIA	PNPI, Gatchina, RUSSIA	Alexey	Khanzadeev
RUSSIA	PNPI, Gatchina, RUSSIA	Leonid	Kochenda
RUSSIA	PNPI, Gatchina, RUSSIA	Dmitrii	Kotov
RUSSIA	PNPI, Gatchina, RUSSIA	Petr	Kravchov
RUSSIA	PNPI, Gatchina, RUSSIA	Evgeny	Kryshen
RUSSIA	PNPI, Gatchina, RUSSIA	Anna	Kyrianova
RUSSIA	PNPI, Gatchina, RUSSIA	Mikhail	Malayev
RUSSIA	PNPI, Gatchina, RUSSIA	Victor	Maleev
RUSSIA	PNPI, Gatchina, RUSSIA	Yuri	Naryshkin
RUSSIA	PNPI, Gatchina, RUSSIA	Denis	Pudzha
RUSSIA	PNPI, Gatchina, RUSSIA	Yuriy	Riabov
RUSSIA	PNPI, Gatchina, RUSSIA	Vladimir	Samsonov
RUSSIA	PNPI, Gatchina, RUSSIA	Victor	Solovyev
RUSSIA	PNPI, Gatchina, RUSSIA	Alexander	Vasilyev
RUSSIA	PNPI, Gatchina, RUSSIA	Marat	Vznuzdaev
RUSSIA	PNPI, Gatchina, RUSSIA	Mikhail	Zhalov
RUSSIA	PNPI, Gatchina, RUSSIA / MEPhI	Victor	Riabov

Showing 1 to 21 of 21 entries (filtered from 468 total entries) ‹ Previous Next ›

- **Вклады:**

✓ **Газовая система TPC**

✓ **Участие в разработке&производстве трековых форвардных камер – Стадия-II**

✓ **Моделирование (резонансы, конверсия, ECAL , ультрапериферия и т.д.), участие в сменах и т.д**

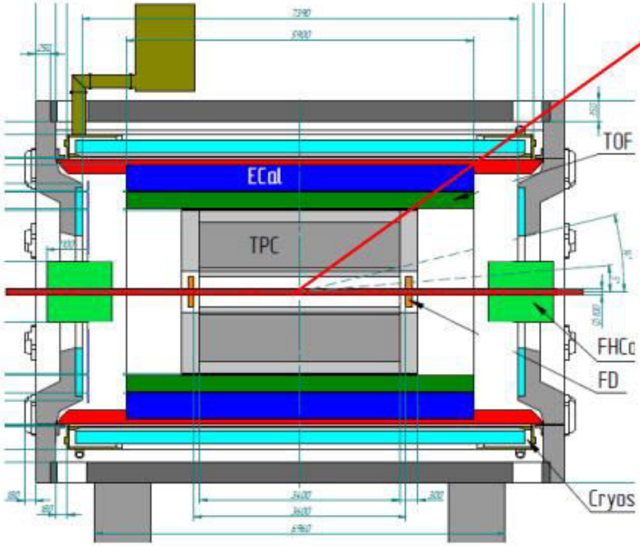
✓ **Административное и организационное участие**

MPD performance (Monte Carlo)

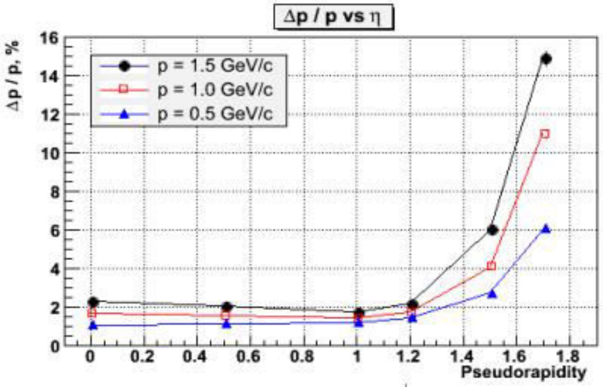
Event reconstruction chain in MPDRoot

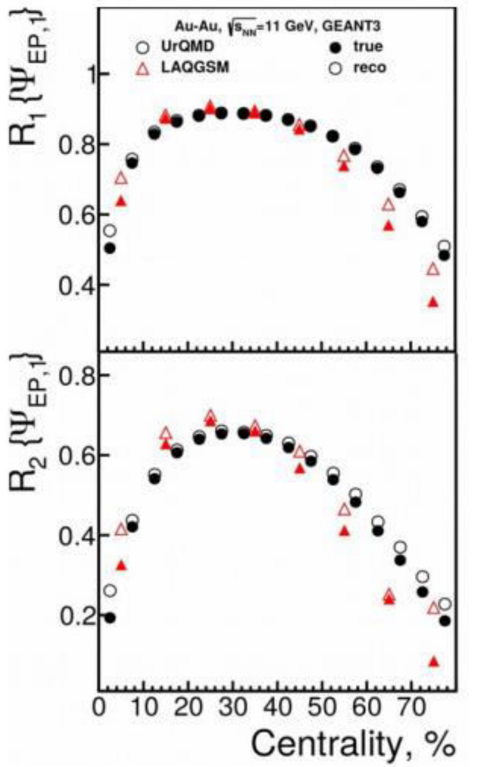
- Event generators: UrQMD, (D)QGSM, PHSD, EPOS
- Geant simulation
- Detector response simulation (TPC,TOF, FHCAL, ECAL)
- Clustering, tracking, matching (TPC, TOF, ECAL)
- Vertexing & pattern recognition (TPC)
- Event characterization: event plane (FHCAL) & centrality (TPC)

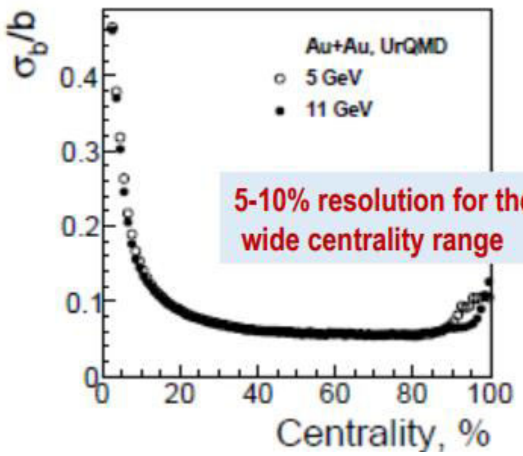
MPD global performance



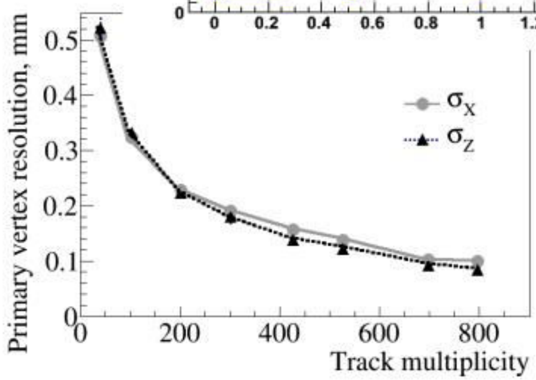
- ***TPC** tracking*: $|\eta|<1.6$ ($N_{points}>15$)
- ***PID***: *dE/dx+TOF+ECAL* $|\eta|<1.2$, $0.1<pT<4$ *GeV/c*
- ***FHCAL***: $2<|\eta|<5$
- ***Trigger&T0***: *FFD*





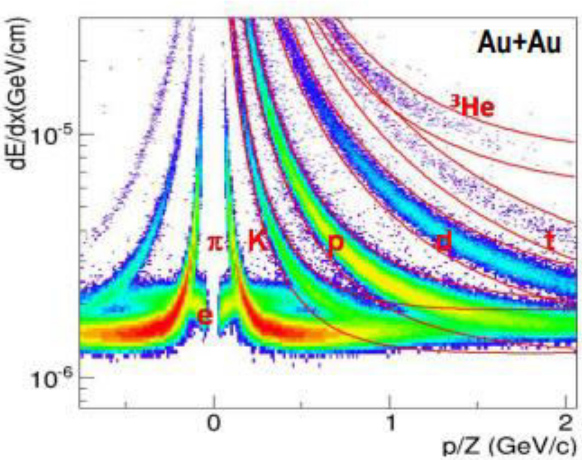


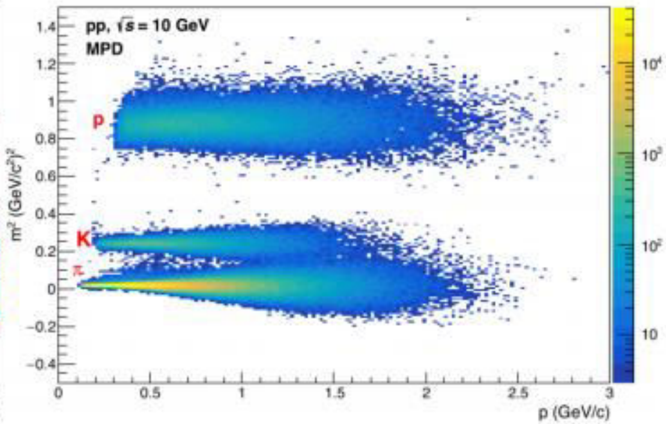
5-10% resolution for the wide centrality range

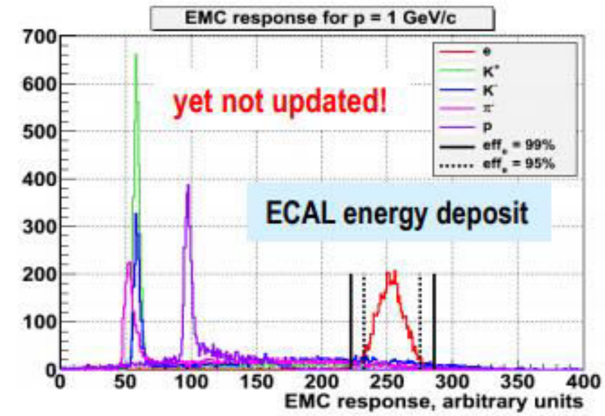


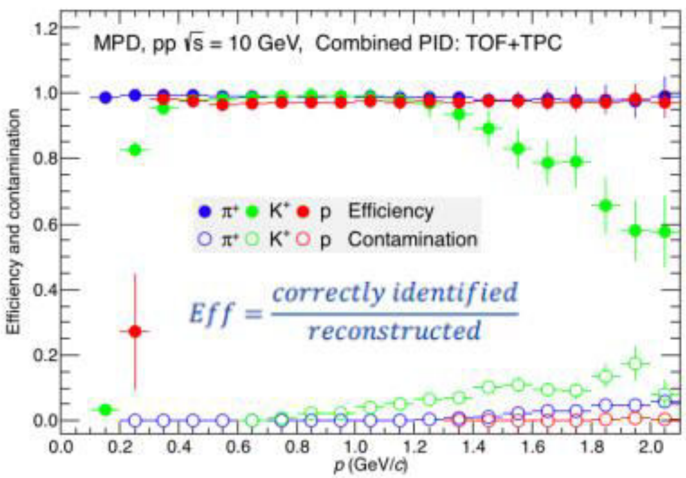
FHCAL coverage and granularity provides good event plane resolution

PID performance



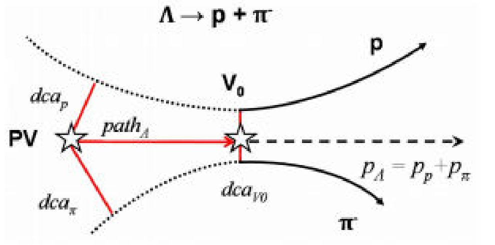






- Combined (dE/dx+TOF) PID for hadrons provides π/K up to 2 GeV/c and K/p up to 3 GeV/c
- An extra hadron suppression in the electron sample will be provided by ECAL

Strangeness production



Data set: 2M minbias Au+Au @ 11 GeV (PHSD)

MPD setup: TPC & TOF, ideal centrality binning (no FHCAL)

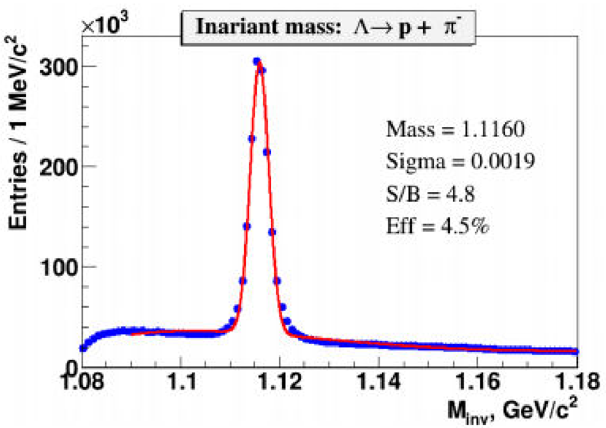
Selection criteria: $|\eta| < 1.3$, $N_{hits} \geq 10$ + standard quality/analysis cuts

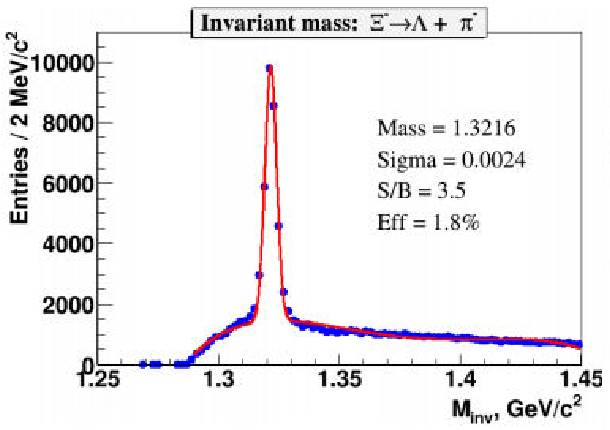
Realistic track reconstruction: clustering in TPC

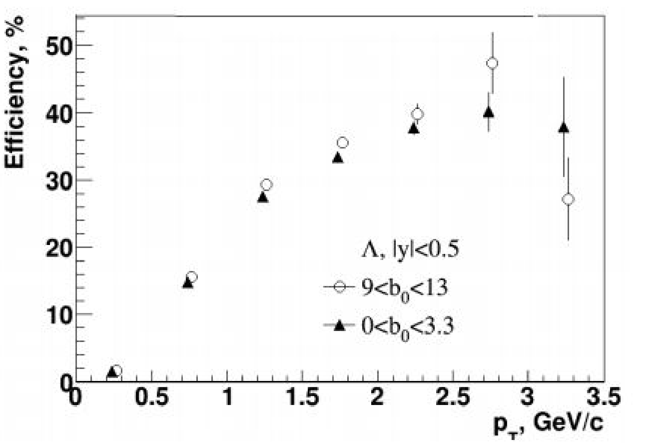
Realistic PID: combined dE/dx+TOF

Analysis: secondary vertex finding technique

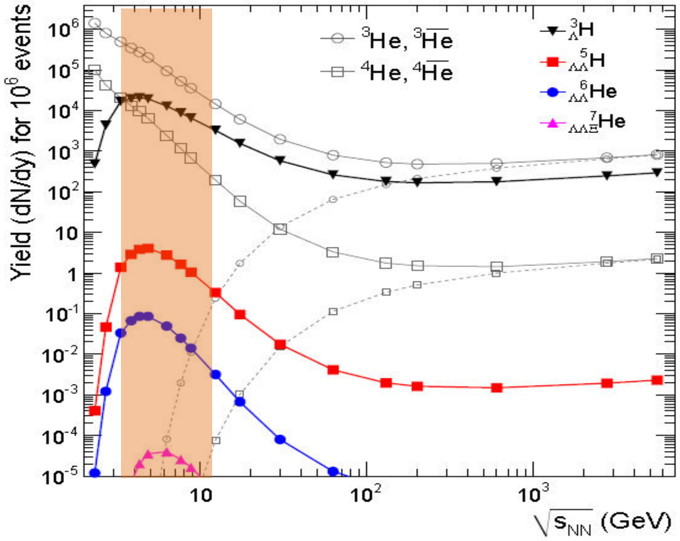
- **PV** – primary vertex
- **V_0** – vertex of hyperon decay
- **dca** – distance of the closest approach
- **path** – decay length





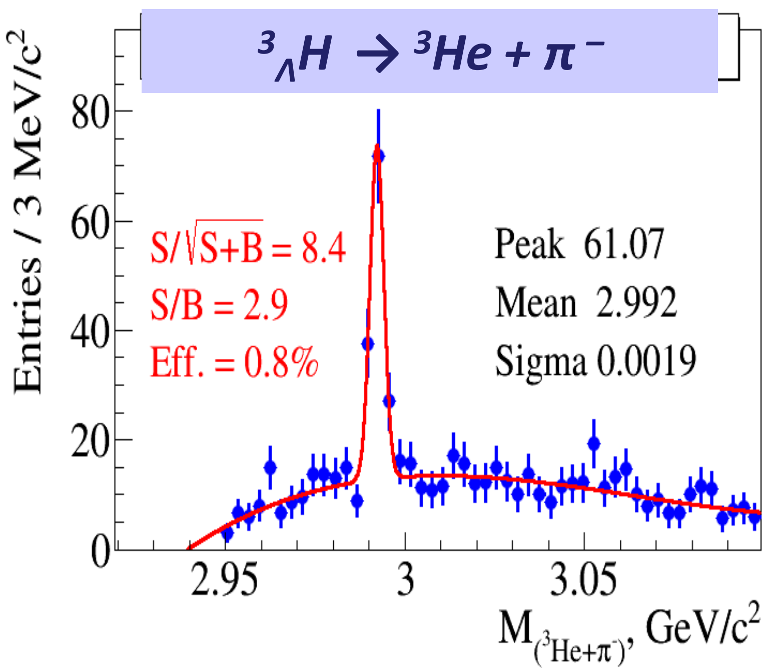


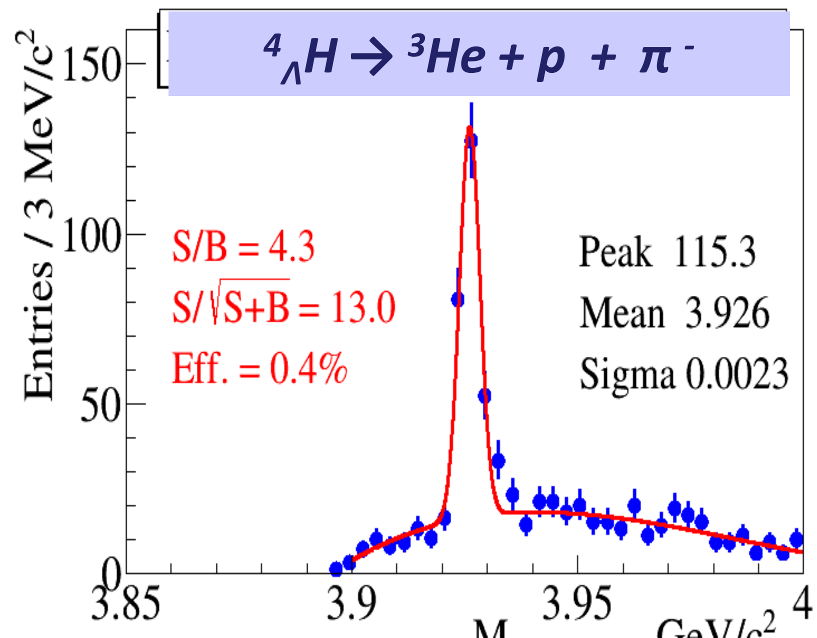
Hyper nuclei



central ***Au+Au*** *@* ***5*** *AGeV; DCM-QGSM*

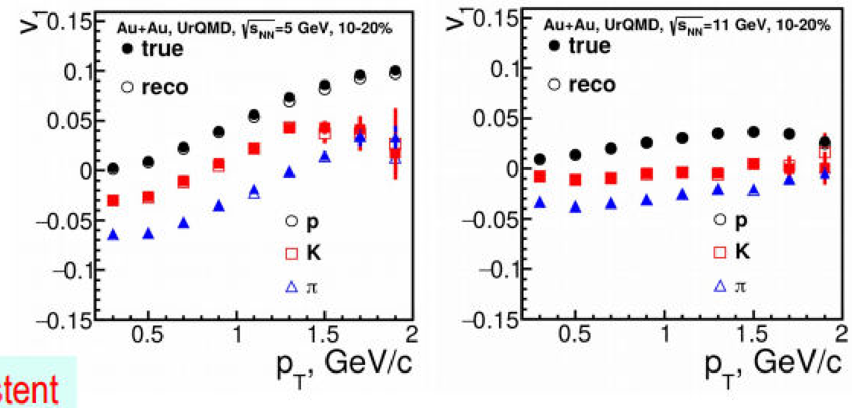
hyper nucleus	yield in 10 weeks
$^{3}_{\Lambda}He$	$9 \cdot 10^{5}$
$^{4}_{\Lambda}He$	$1 \cdot 10^{5}$



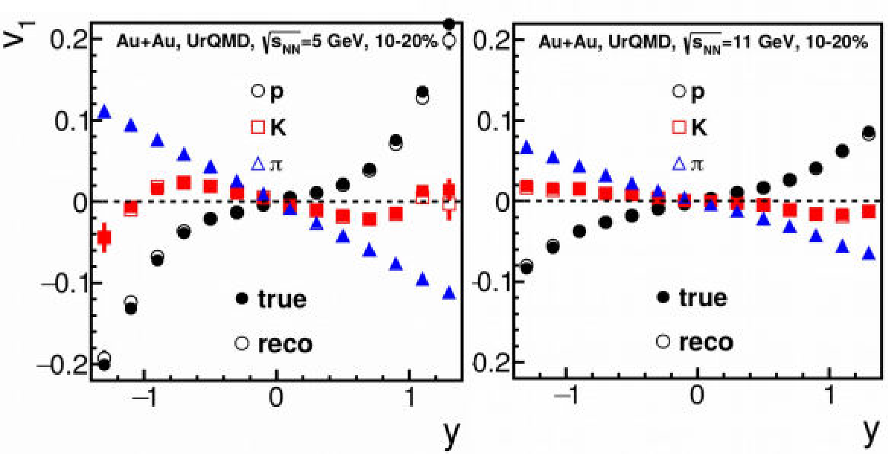


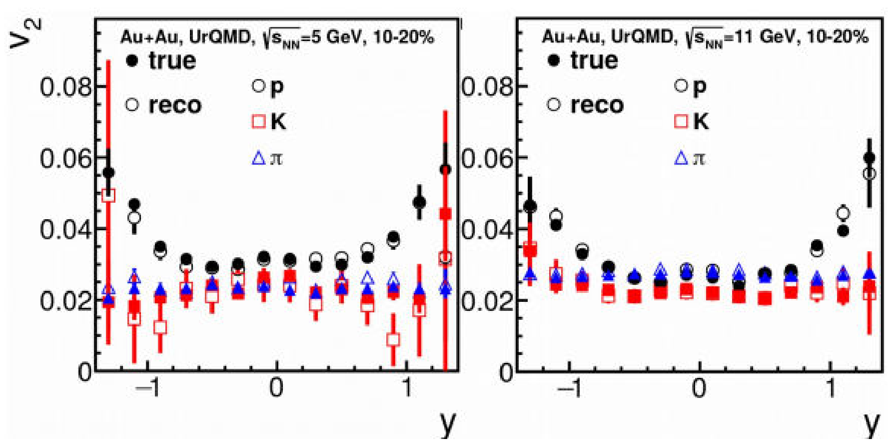
Anisotropic flow

- 4M Au+Au events at 5 and 11 GeV
- Recent MPD reconstruction chain, realistic PID
- N_{points}>32, DCA cut, 0.2<p_T<2 GeV/c, |η|<1.5
- Hadronic shower simulation in FHCAL (GEANT3,4)
- Event plane reconstruction with FHCAL



Both directed and elliptic flow parameters are consistent with those from MC simulation

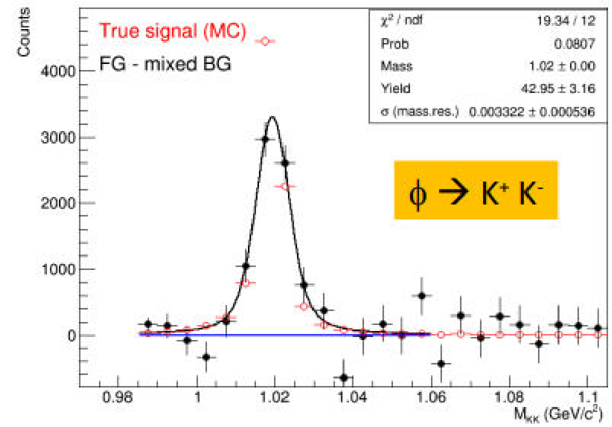


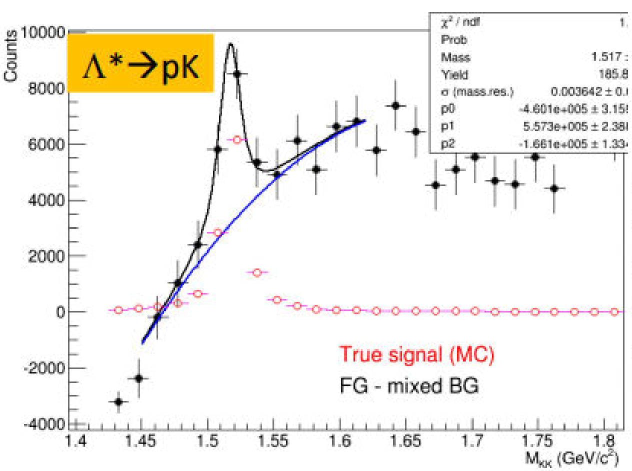


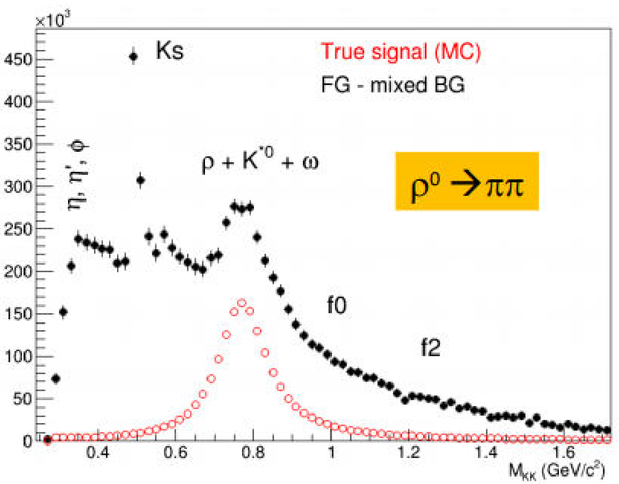
Short-lived resonances

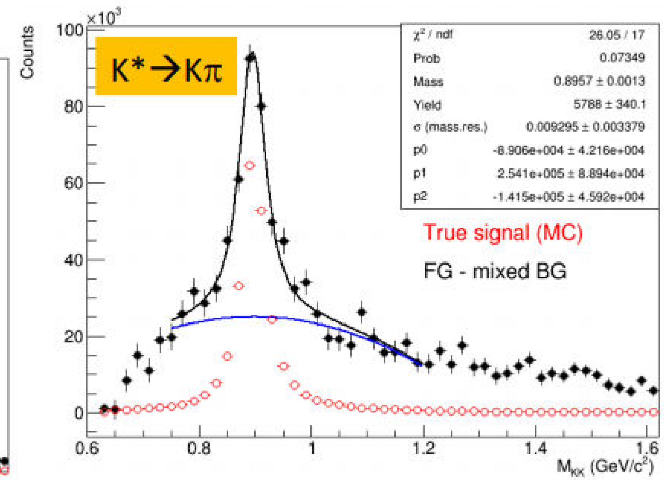
- 0.5M minbias Au+Au@11 GeV by UrQMD3.4
- |Zvrtx| < 50 cm
- number of TPC hits > 39, TPC sector edges cut
- $|\eta| < 1.0$, pT > 50 MeV/c
- $|DCA(x,y,z)| < 2\sigma$
- TPC+TOF PID probability (π/K/p) > 0.75
- Pair cut: $|y| < 1.0$
- Combinatorial background: event mixing ($|\Delta_{Zvrtx}| < 2$ cm, $|\Delta_{Mult}| < 20$)

Resonances at MPD – feasible!



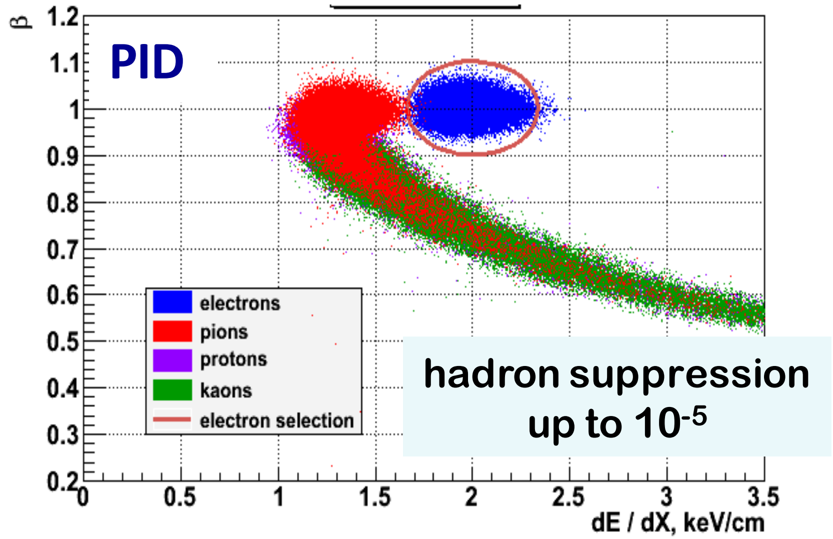


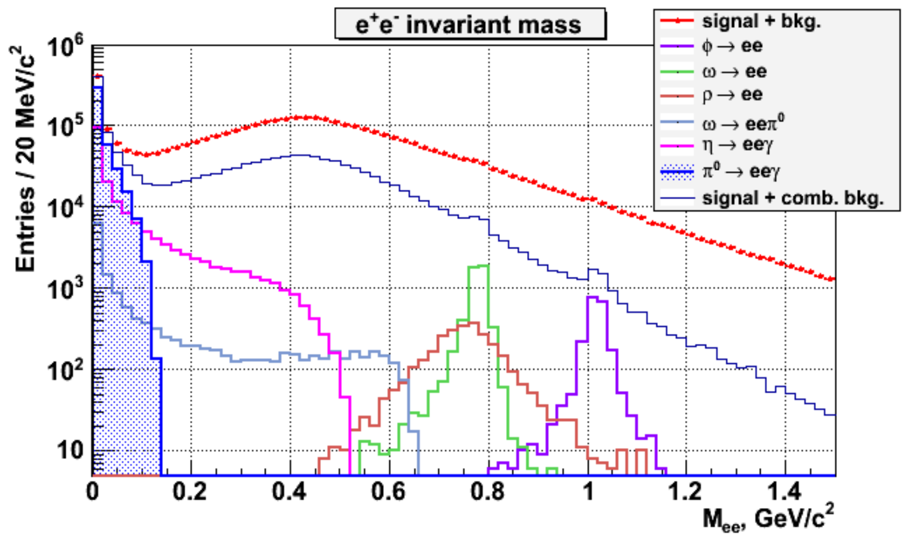


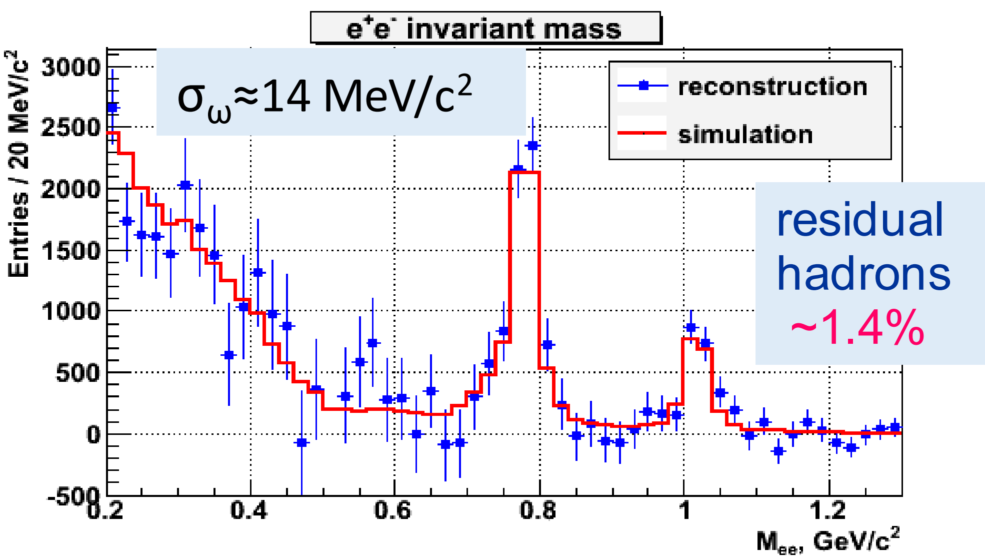


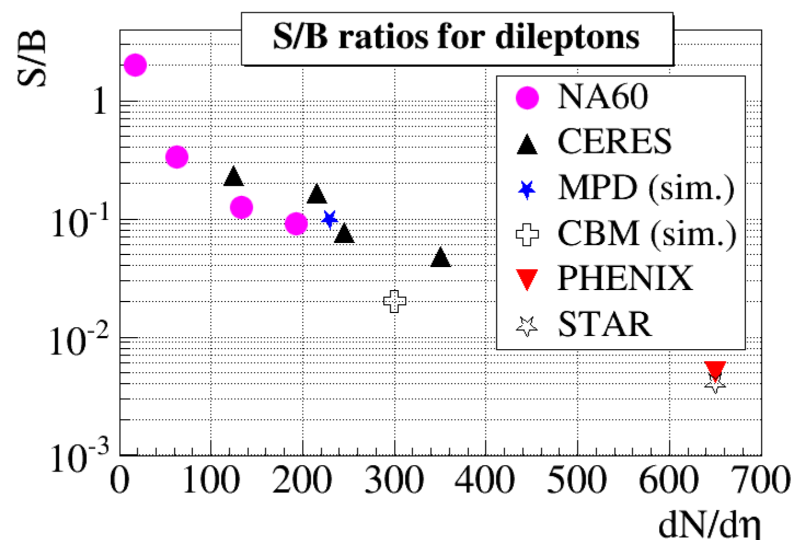
Di-leptons and LVM

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



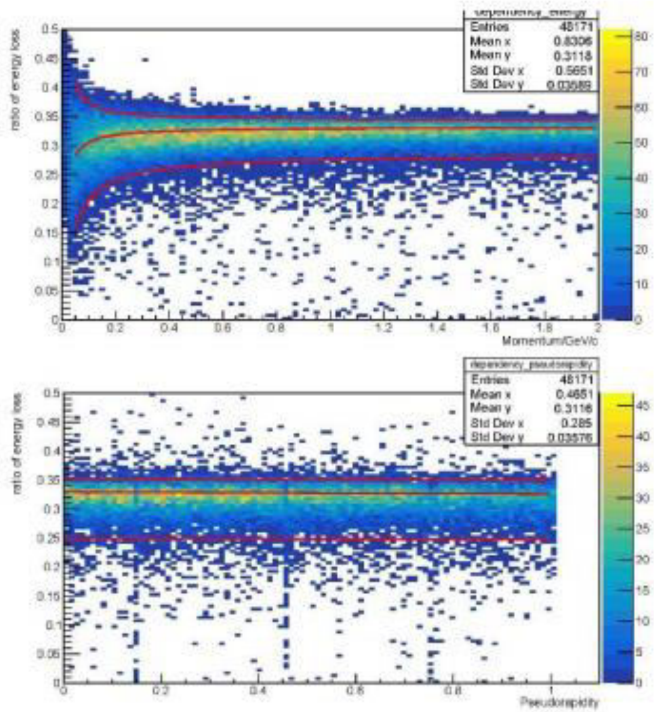




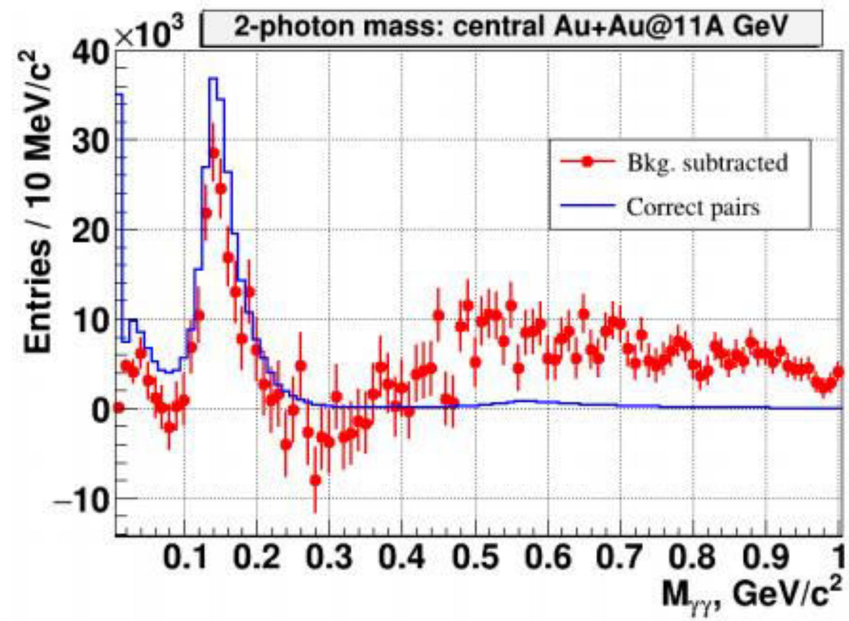


ECAL simulations

- MPDRoot – recent developments for ECAL reconstruction
- Several teams are doing π^0 reconstruction with ECAL
- π^0 source – ideal cocktail or Au+Au from UrQMD



Ratio of the reconstructed ECAL energy to the MC one versus momentum and eta for γ from π^0 decays



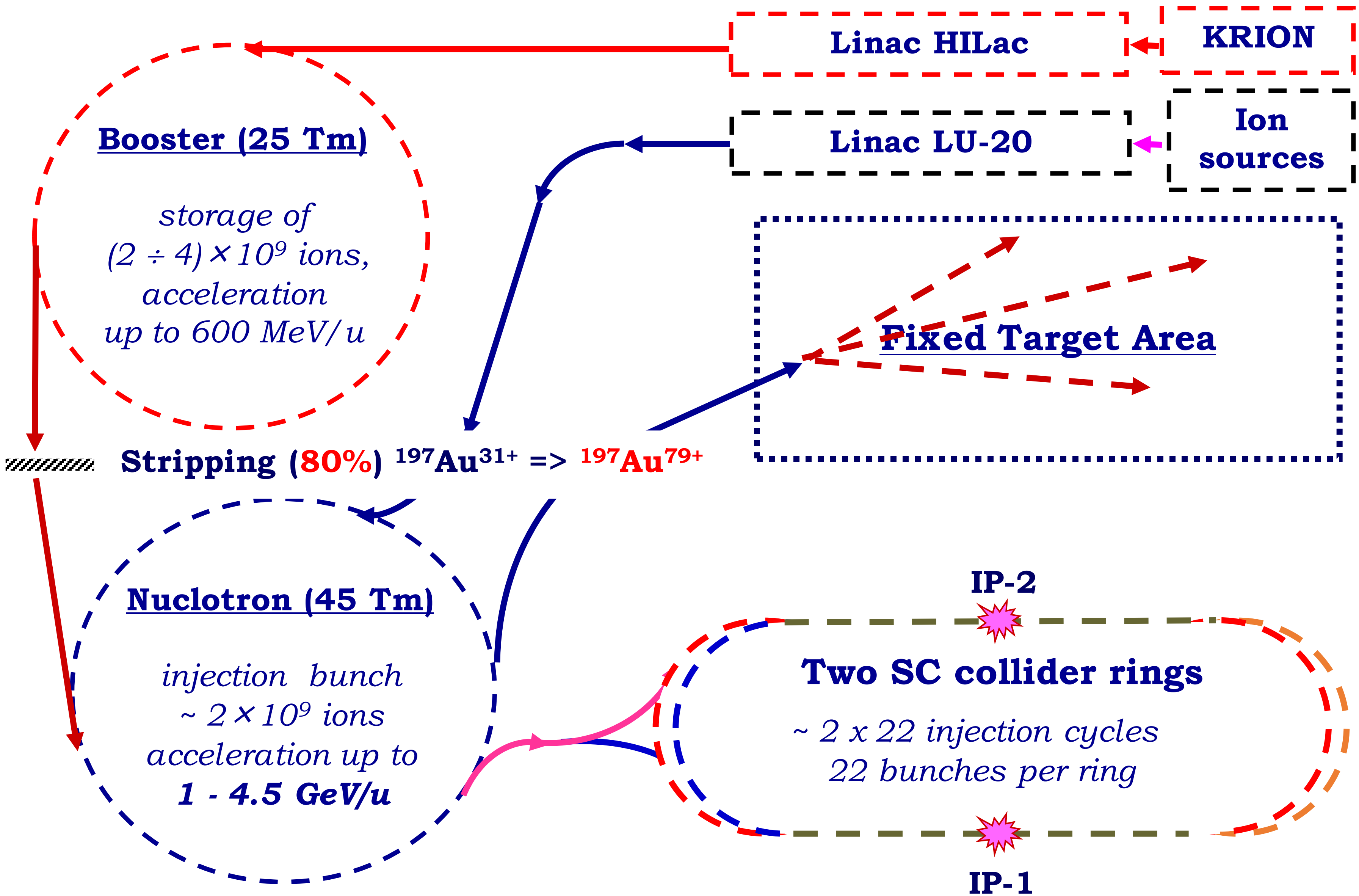
Reconstructed γ–γ invariant mass for π^0 cocktail

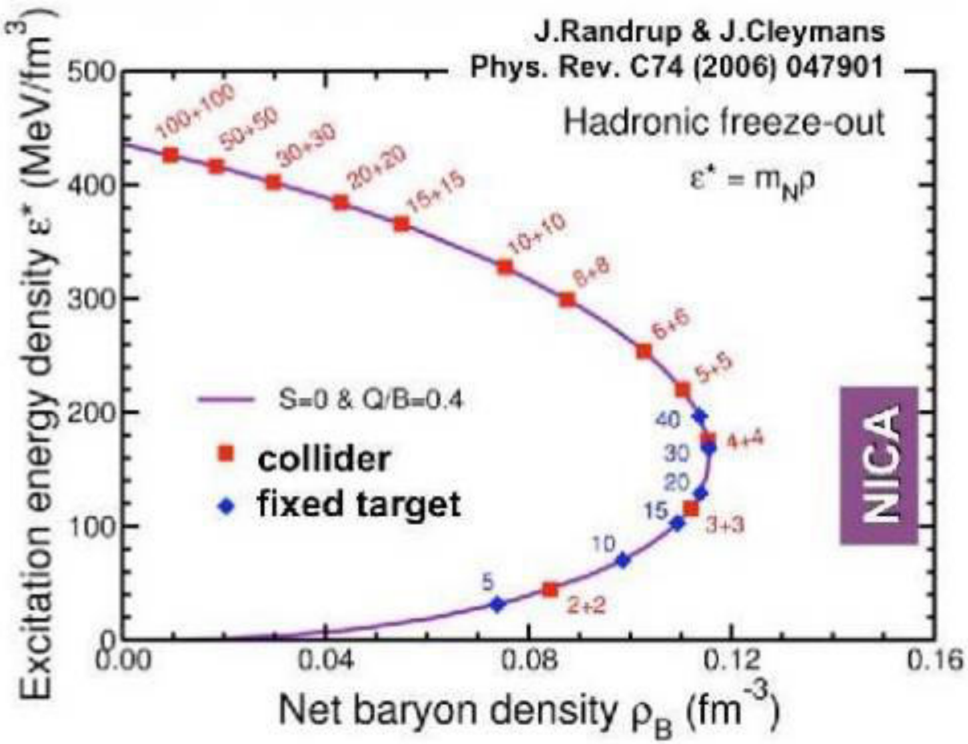
Заключение

- Проект NICA/MPD успешно реализуется, сроки исполнения близки к плановым показателям
- Созданы международные коллаборации BM@N и MPD, формируются организационные структуры коллабораций, MoU
- Моделирование установки MPD показывает ее применимость для изучения необходимых физических сигналов
- Участие в NICA/MPD является естественным продолжением деятельности ПИЯФ/ОФВЭ, участия в экспериментах RHIC/PHENIX и LHC/ALICE, сотрудничества с FAIR/CBM
- Формы и объем участия ПИЯФ в коллаборации находятся на стадии обсуждения

BACKUP

Structure of Accelerator Complex and Operation Regimes





J.Randrup & J.Cleymans
Phys. Rev. C74 (2006) 047901
Hadronic freeze-out
ε* = m_N ρ
S=0 & Q/B=0.4
collider
fixed target
NICA
100+100
50+50
30+30
20+20
15+15
10+10
8+8
6+6
5+5
4+4
3+3
2+2
40
30
20
15
10
5
Excitation energy density ε* (MeV/fm^3)
Net baryon density ρ_B (fm^-3)
0
100
200
300
400
500
0.00
0.04
0.08
0.12
0.16

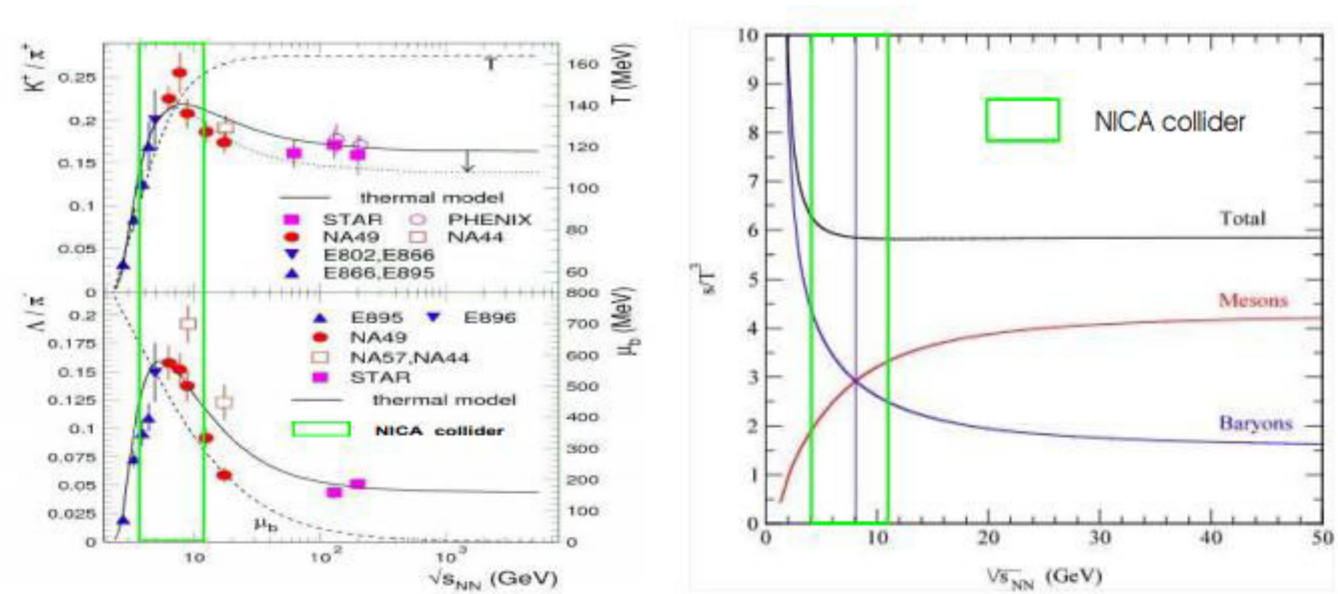


Figure 3.13: Left panel: Energy dependence of hadron yields relative to pions. Right panel: Baryonic and mesonic contributions to the entropy density as a function of the center of mass energy of heavy-ion collisions. When increasing the energy above that where the horn in the K^+/π^+ and Λ/π^+ ratios is observed, $\sqrt{s} \sim 10$ GeV, the system changes its character from baryon- to meson-dominated.

We introduce various moments definitions of the event-by-event multiplicity distributions: Mean, $M = < N >$, Variance, $\sigma^2 = < (\Delta N)^2 >$, Skewness, $S = < (\Delta N)^3 > /\sigma^3$, and Kurtosis, $\kappa = < (\Delta N)^4 > /\sigma^4 - 3$, where $\Delta N = N - < N >$. Skewness and Kurtosis are equal to zero for gaussian distributions. Thus, they are ideal probes to demonstrate the non-Gaussian fluctuations feature near the critical point, in particularly a sign change of the skewness or kurtosis may be a hint of that the system is evolving in the vicinity of the critical point [3, 78]. We have calculated the various moments of net-proton ($\Delta p = N_{\rm p} - N_{\bar{\rm p}}$) distributions from transport models. The kinetic coverage of protons and anti-protons used in our analysis is $0.4 < p_{\rm T} < 0.8$ GeV/c and $|y| < 0.5$. Fig. 3.14 (left panel) shows the number of participant ($N_{\rm part}$) dependence of moment

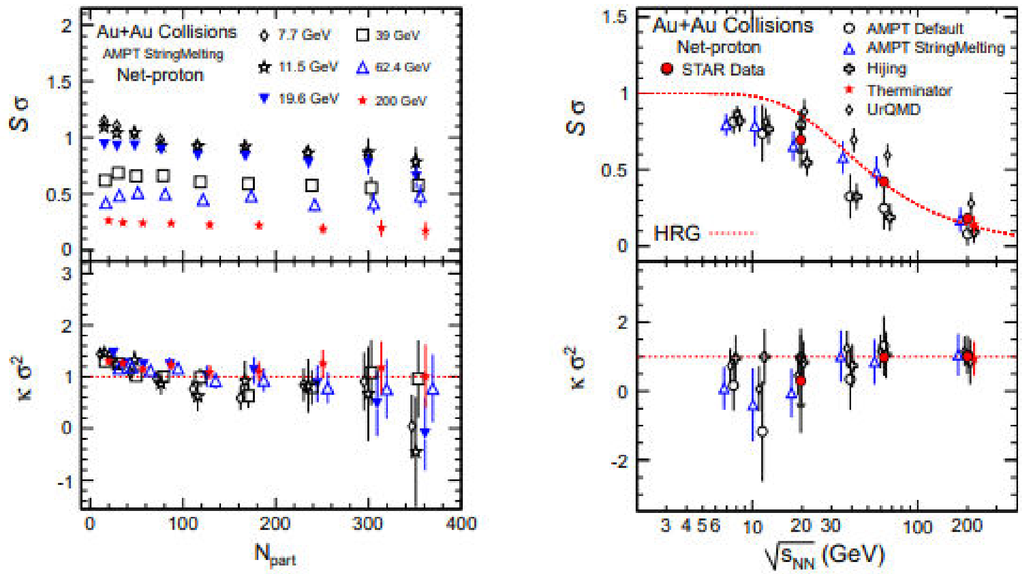


Figure 3.14: **Left panel:** Centrality dependence of moment products $S\sigma$, $\kappa\sigma^2$ of net-proton distributions for Au + Au collisions of various energies from AMPT String Melting model calculation. **Right panel:** Energy dependence of moment products $S\sigma$, $\kappa\sigma^2$ of net-proton distributions for Au + Au collisions of various models and STAR data.

products $S\sigma$, $\kappa\sigma^2$ of net-proton distributions from the AMPT string melting model for various energies. In Fig. 3.14 (right panel), the energy dependence of moment products $S\sigma$, $\kappa\sigma^2$ for most central net-proton distributions from STAR data [79] are compared with the results from various models. We see the data are in good agreement with the HRG model ($\kappa_{\rm B}\sigma_{\rm B}^2 = 1$, $S_B\sigma_{\rm B} = tanh(\mu_{\rm B}/T)$) [80] and the thermal model (Therminator) results. A large deviation from constant as a function of $N_{\rm part}$ and collision energy for $\kappa\sigma^2$ may indicate new physics, such as critical fluctuations [3]. Recent lattice QCD calculations from [81] have shown that $\kappa\sigma^2$ non-monotonically depends on colliding energy in the neighbourhood of the critical point.