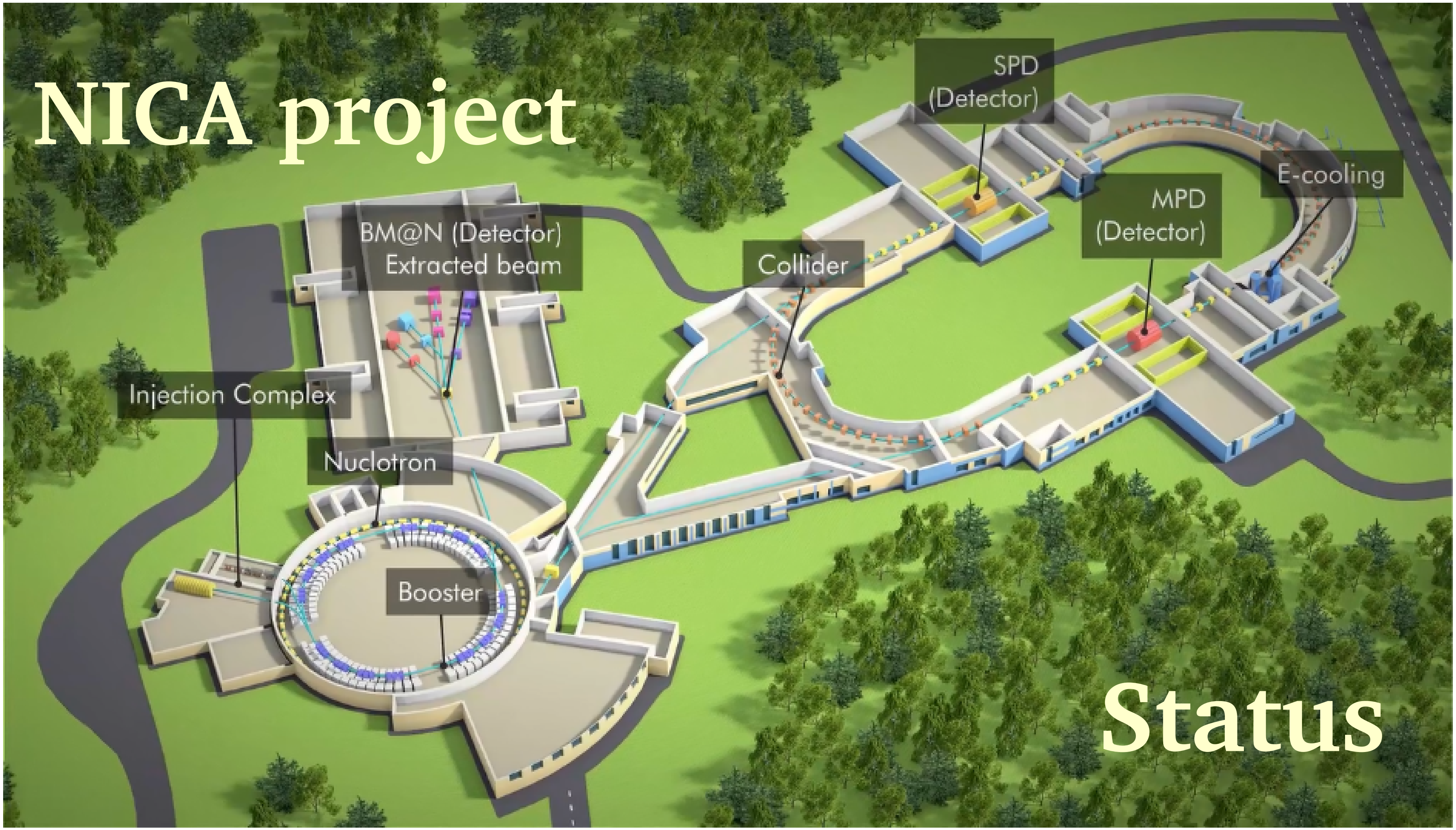
NICA project



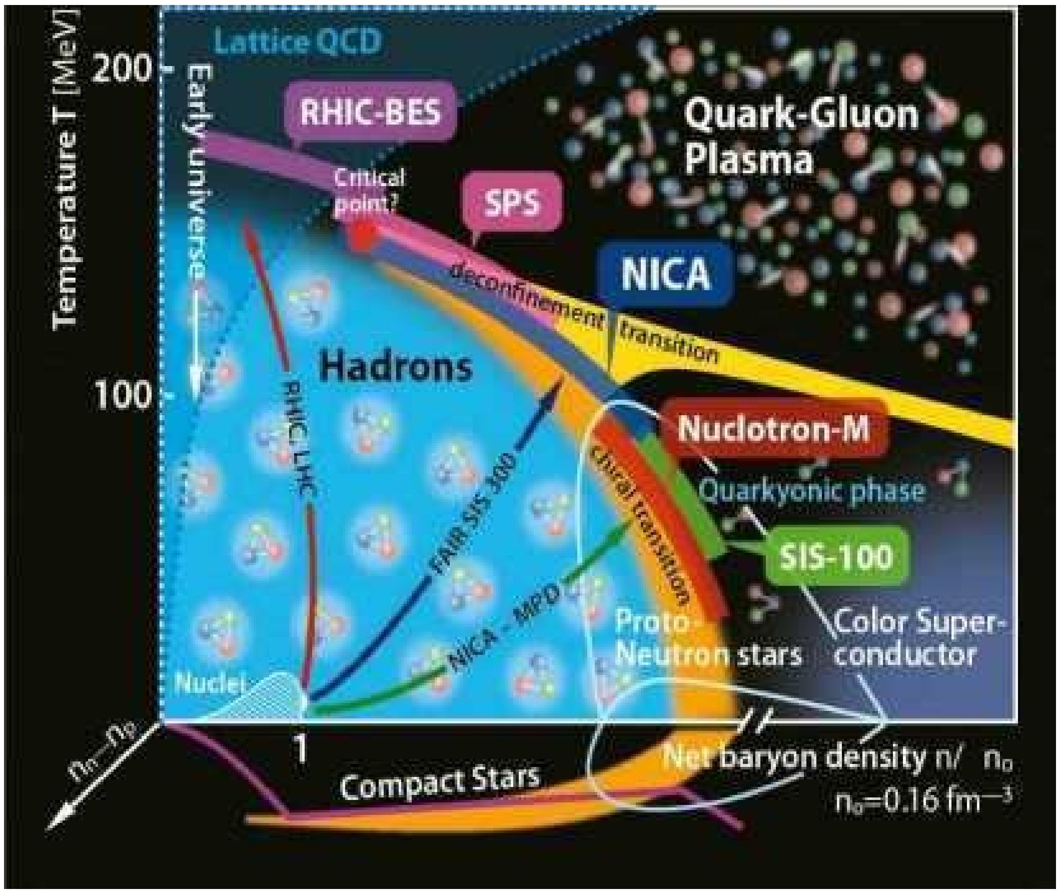
Status

ROGACHEVSKY Oleg

- *for MPD collaboration*

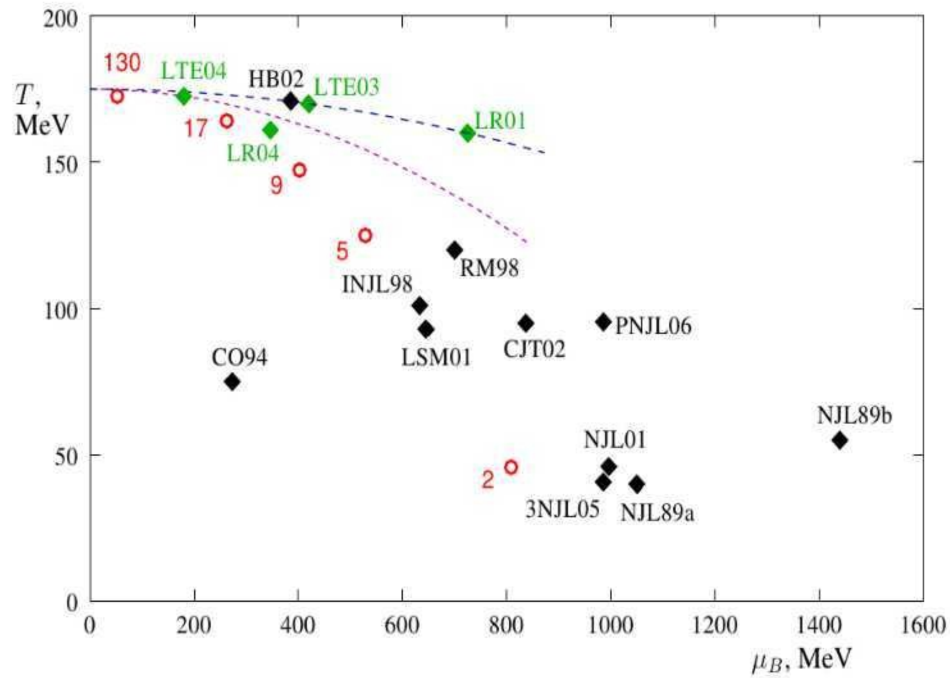
XXIV International Baldin Seminar
September, 17, 2018
Dubna

QCD phase diagram



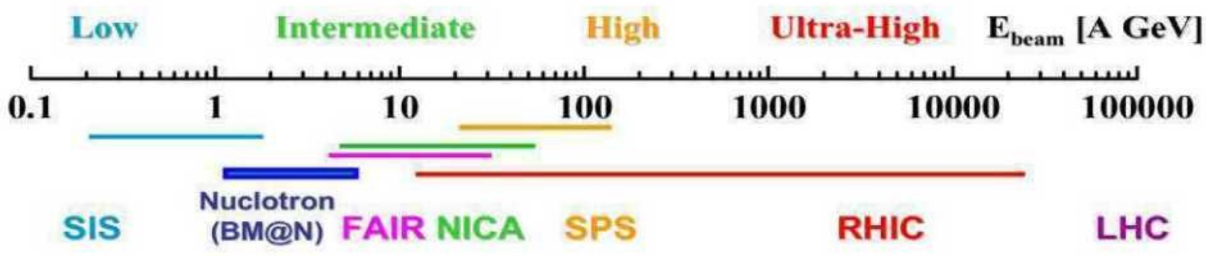
M. Stephanov

arXiv:hep-lat/0701002



Resent & future experiments for Heavy Ion Collisions

Facility	SPS	RHIC BES II	Nuclotron-M	NICA	SIS/100 (300)	LHC
Laboratory	CERN Geneva	BNL Brookhaven	JINR Dubna	JINR Dubna	FAIR GSI Darmstadt	CERN Geneva
Experiment	NA61 SHINE	STAR PHENIX	BM@N	MPD	HADES CBM	ALICE ATLAS CMS
Start of data taking	2011	2010	2015	2020	2025	2009
$\sqrt{s_{NN}}$ GeV	4.9 – 17.3	7.7 – 200	< 3.5	4 - 11	2.3 – 4.5	up to 5500
Physics	CP & OD	CP & OD	HDM	OD & HDM	OD & CP	PDM



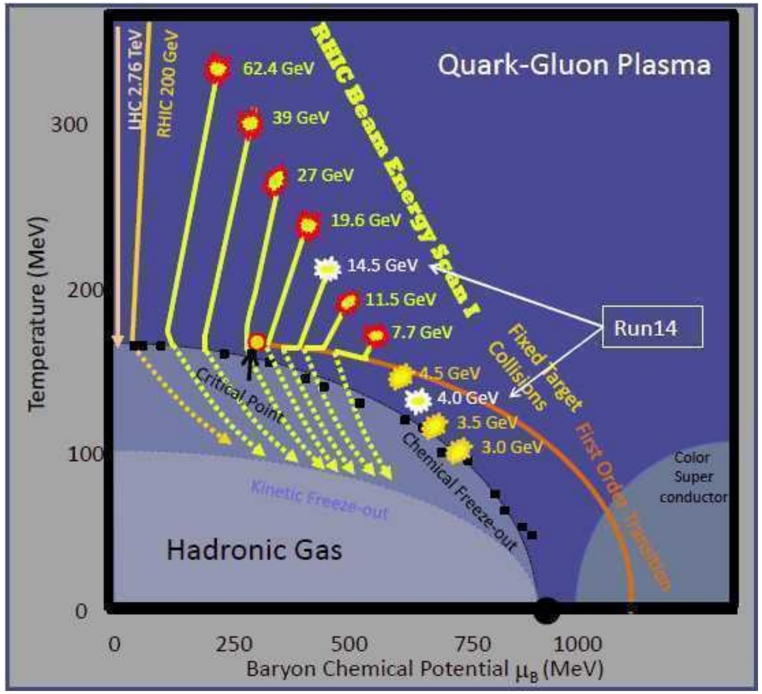
CP — critical point

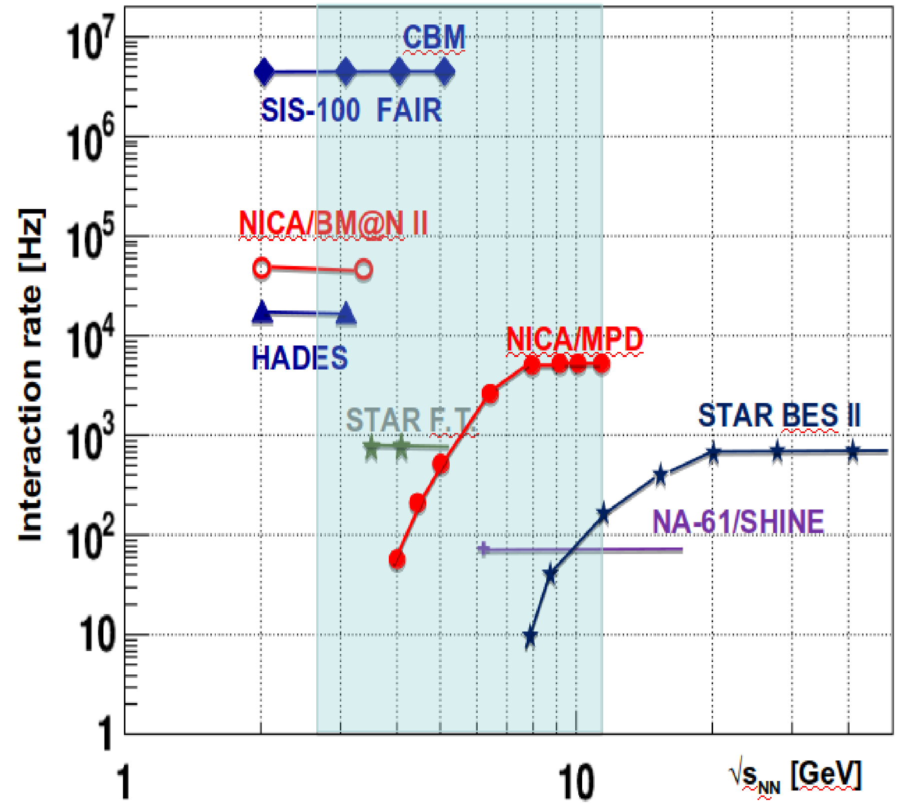
OD — onset of deconfinement, mixed phase, 1st order phase transition

HDM — hadrons in dense matter

PDM — properties of deconfined matter

STAR BEC II & NICA

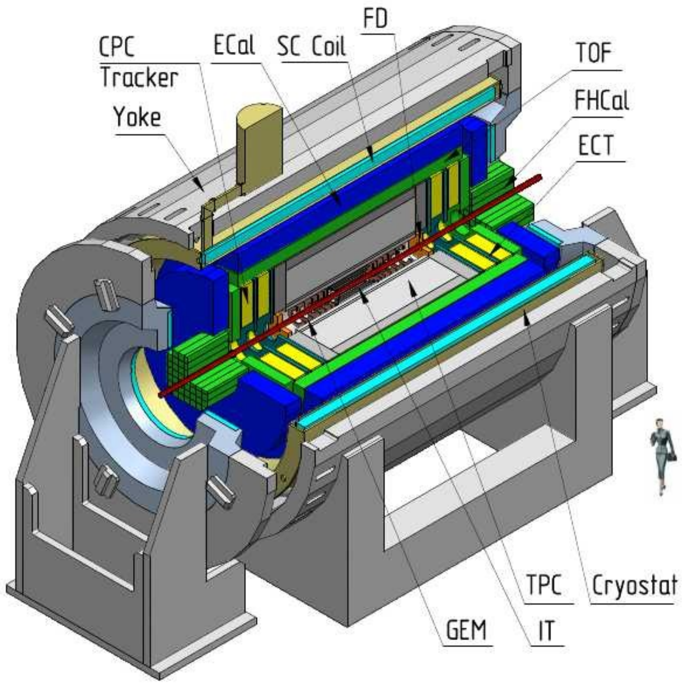




$\sqrt{s_{NN}}$ (GeV)	μ_B (MeV)	Needed Events (10^6)
7.7	420	100
9.1	370	160
11.5	315	230
14.5	**260**	**300**
19.6	205	400

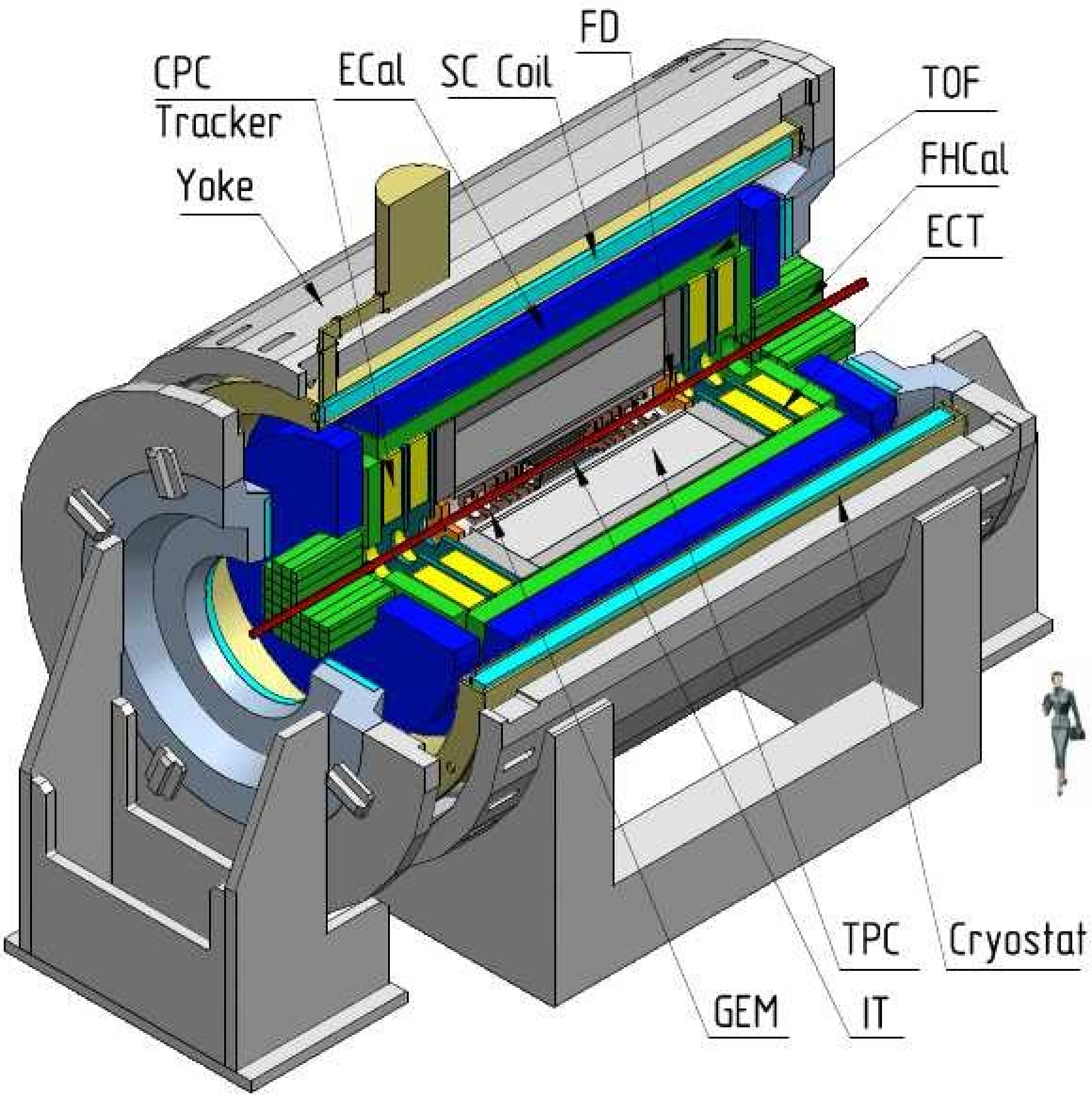
2019	Au+Au @ 14.5-20 GeV + fixed target	• QCD critical point • Phase transition • CME, CVE,…	Full iTPC, eTOF, and EPD
2020	Au+Au @ 7-11 GeV + fixed target	• QCD critical point • Phase transition • CME, CVE,…	

MPD collaboration - 2018



Baku State University, NNRC, ***Azerbaijan****;*
University of Plovdiv, ***Bulgaria;***
University Tecnica Federico Santa Maria, Valparaiso, ***Chili****;*
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****;*
Palacky University, Olomouc, ***Czech Republic****;*
NPI CAS, Rez, ***Czech Republic****;*
Tbilisi State University, Tbilisi, ***Georgia****;*
Tubingen University, Tubingen, ***Germany****;*
Tel Aviv University, Tel Aviv, ***Israel****;*
Joint Institute for Nuclear Research;
IPT, Almaty, ***Kazakhstan****;*
UNAM, Mexico City, ***Mexico****;*
Institute of Applied Physics, Chisinev, ***Moldova****;*
WUT, Warsaw, ***Poland****;*
NCN, Otwock – Swierk, ***Poland****;*
UW, Wroclaw, ***Poland****;*
Jan Kochanowski University, Kielce, ***Poland****;*
INR RAS, Moscow, ***Russia****;*
MEPhI, Moscow, ***Russia****;*
*PNPI, Gatchina****, Russia****;*
INP MSU, Moscow, ***Russia****;*
SPSU - Dept. of NP, ***Russia;***
St. Petersburg, ***Russia****;*
SPSU – Dept. of HEP, St. Petersburg, ***Russia****;*
KI NRS, Moscow, ***Russia****;*

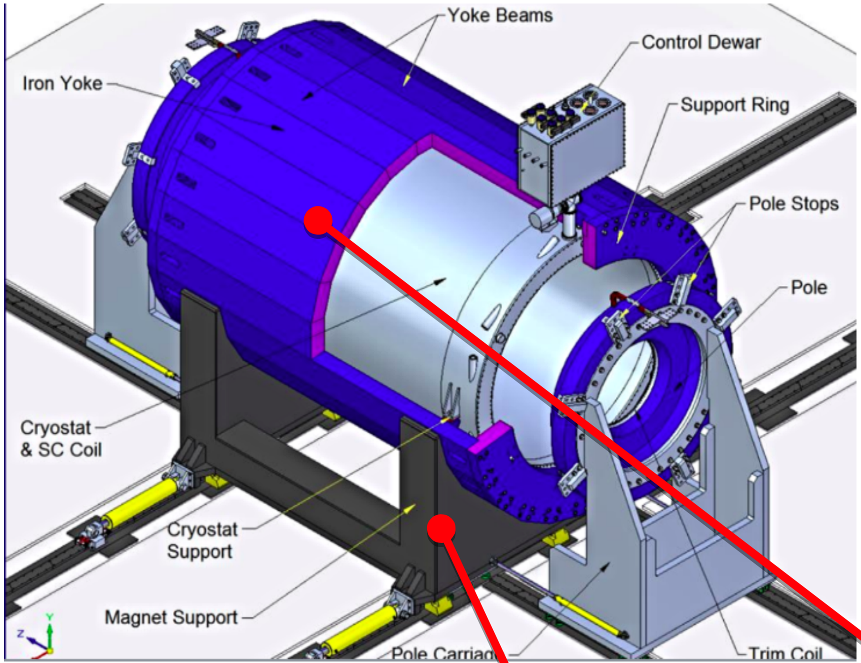
MPD detectors status



Magnet yoke (Vitkovice HM)

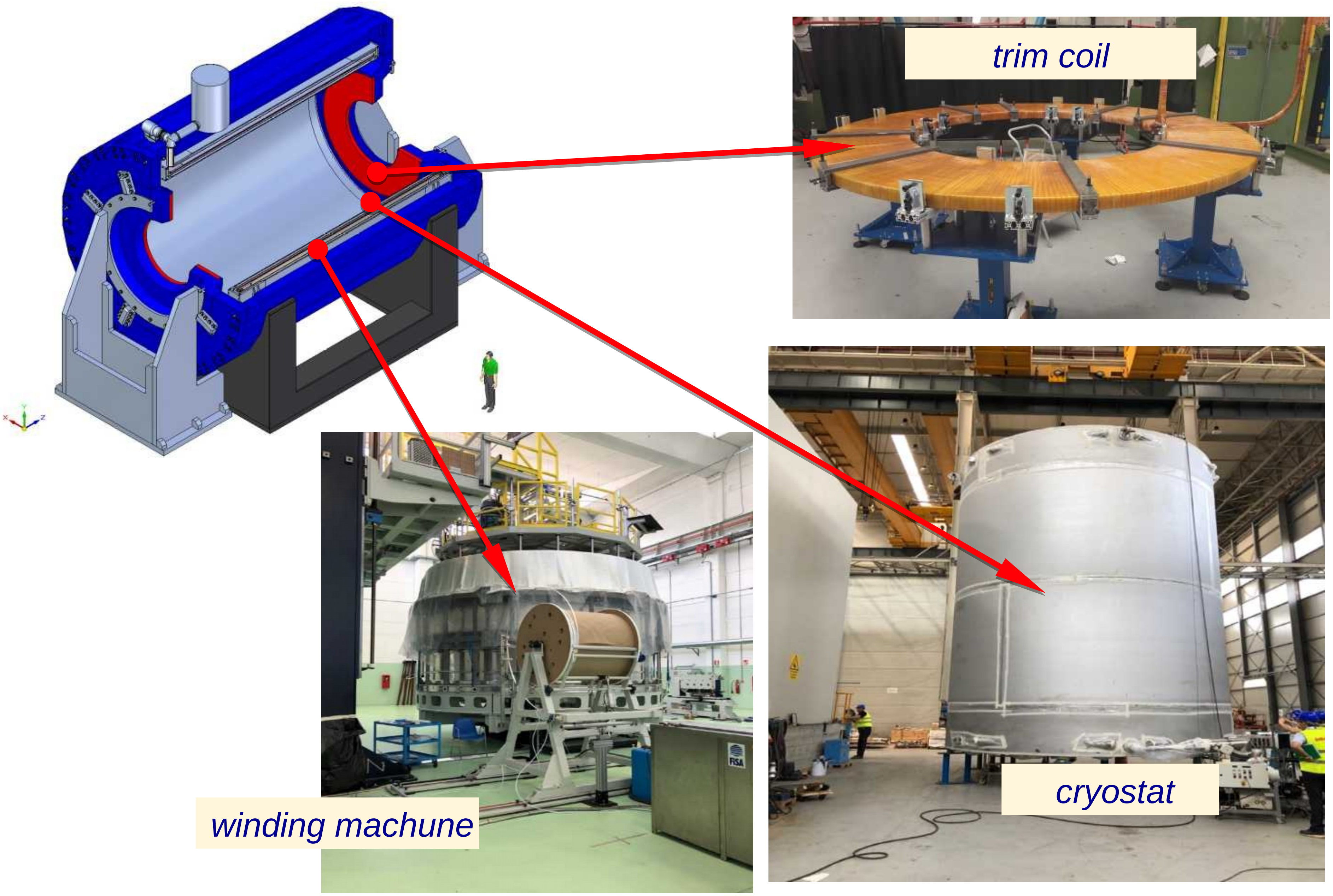
*final assembly in the MPD hall - **June 2019***

yoke control assembly at HM Vitkovice



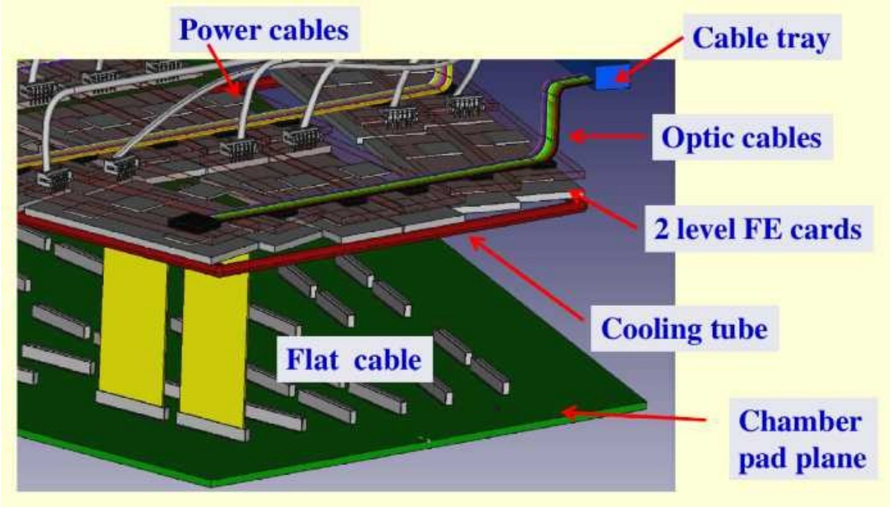
Coil winding & cryostat (ASG Genove)

final assembly in the MPD hall - ***June 2019***



Time Projection Chamber

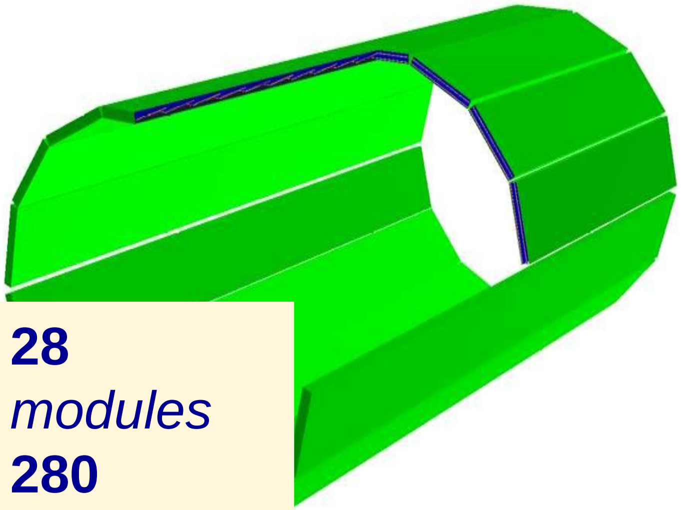
TPC gas system commisioned



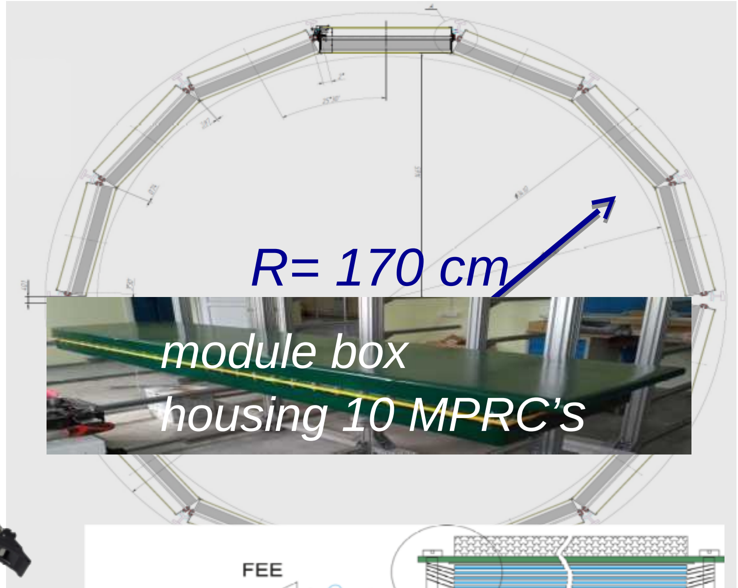
ROC chamber + electronics integration concept

manipulator for ROC chamber installation

Time Of Flight detector



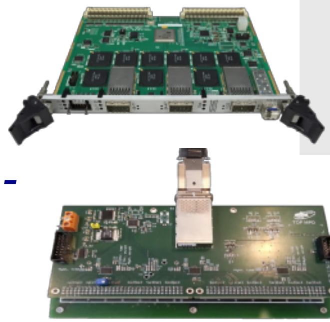
28 *modules*
280 *MPRC's*
13 440 *ch.*

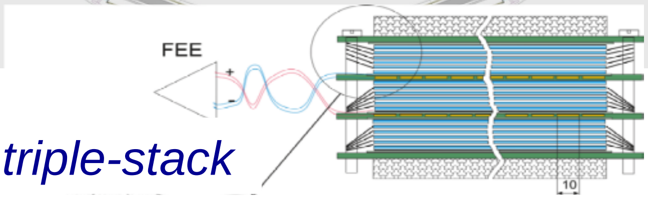


R= 170 cm

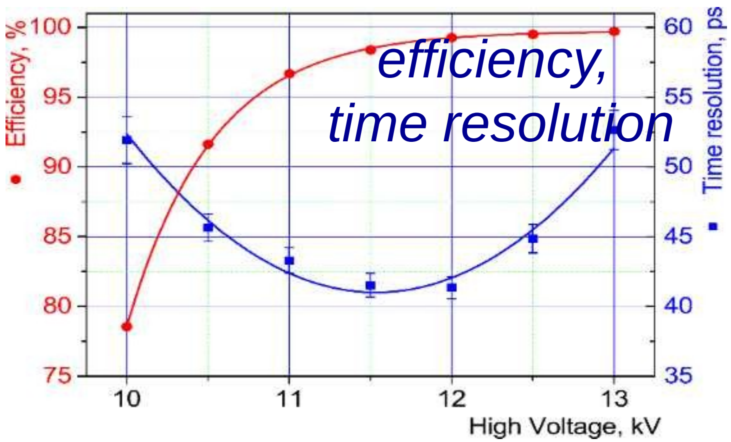
module box housing 10 MPRC's

basic electronics - NINO & HPTDC

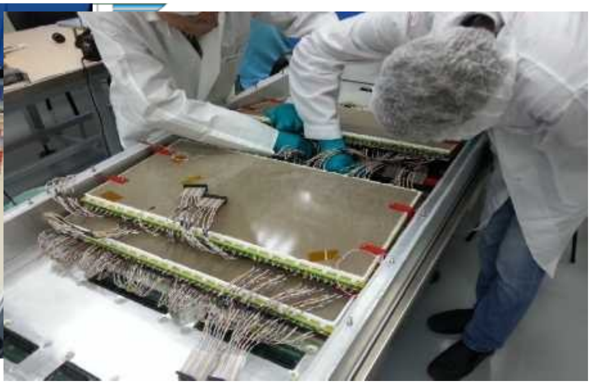




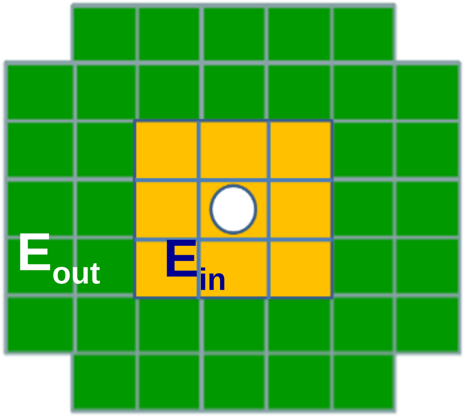
triple-stack MRPC (5 gaps of 200 μm each)

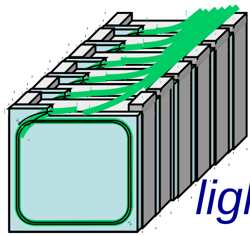


efficiency, time resolution



FHCal: reaction plane and centrality





light collection
WLS-fibers & SiPM

2 x **45** modules (15 x 15 cm² each)
located left and right at ~3.2 m from the **IP**)

acceptance: $2.2 < |\eta| < 4.8$

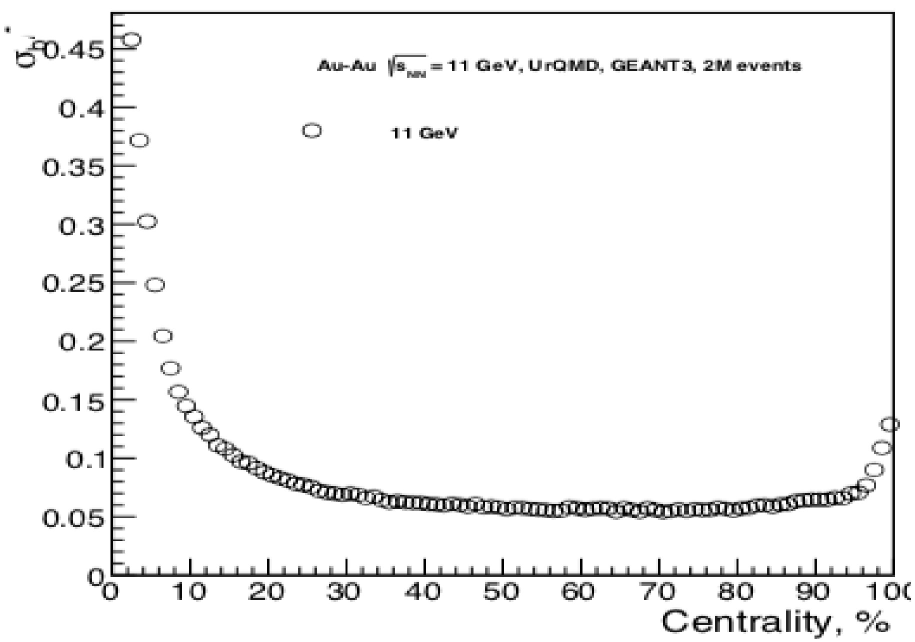
$\sigma(E)/(E) = 53\%/\sqrt{E(GeV)} + 10\%$

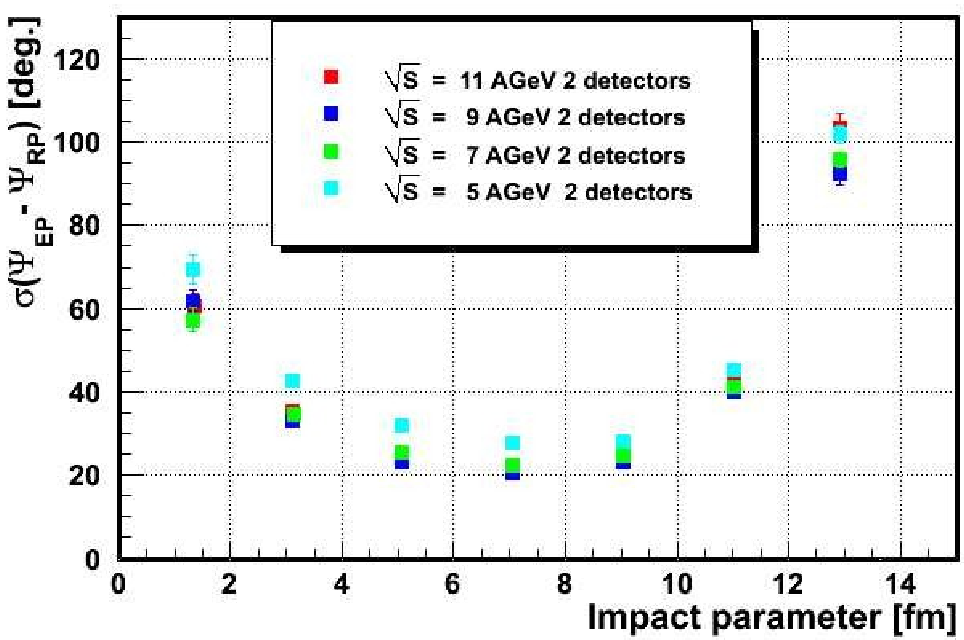
transverse granularity allows to measure:

- *the reaction plane with accuracy* **~** **20^0-30^0**
- *the centrality with accuracy below* **10%.**

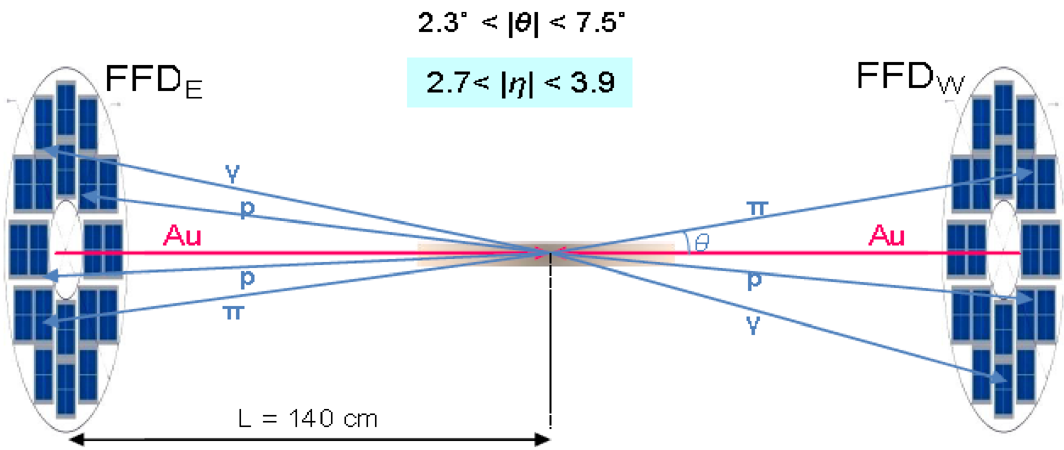
σ_h/b

Au+Au, UrQMD

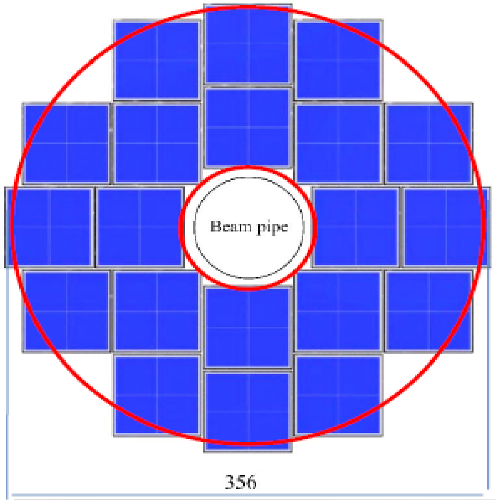




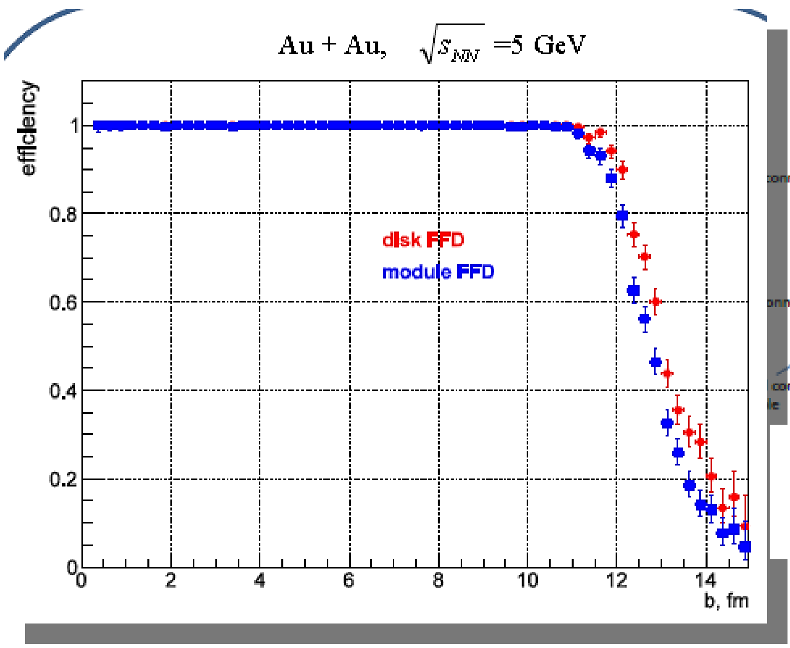
Fast forward detector

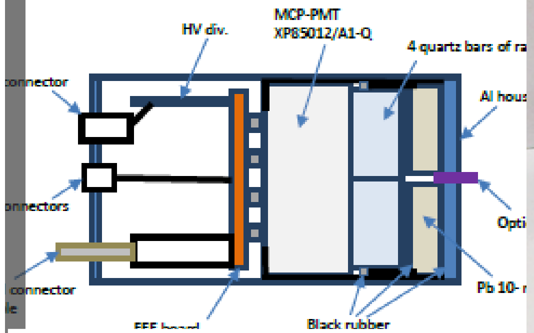


array of 20 modules
Planacon MCP-PMTs
80 +20 channels

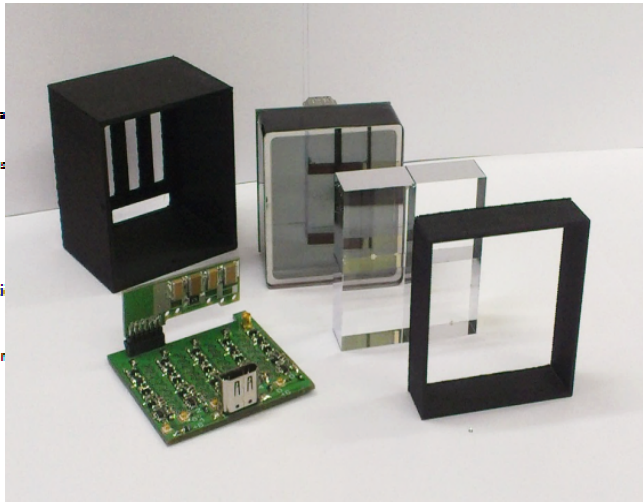


time resolution < 50 ps

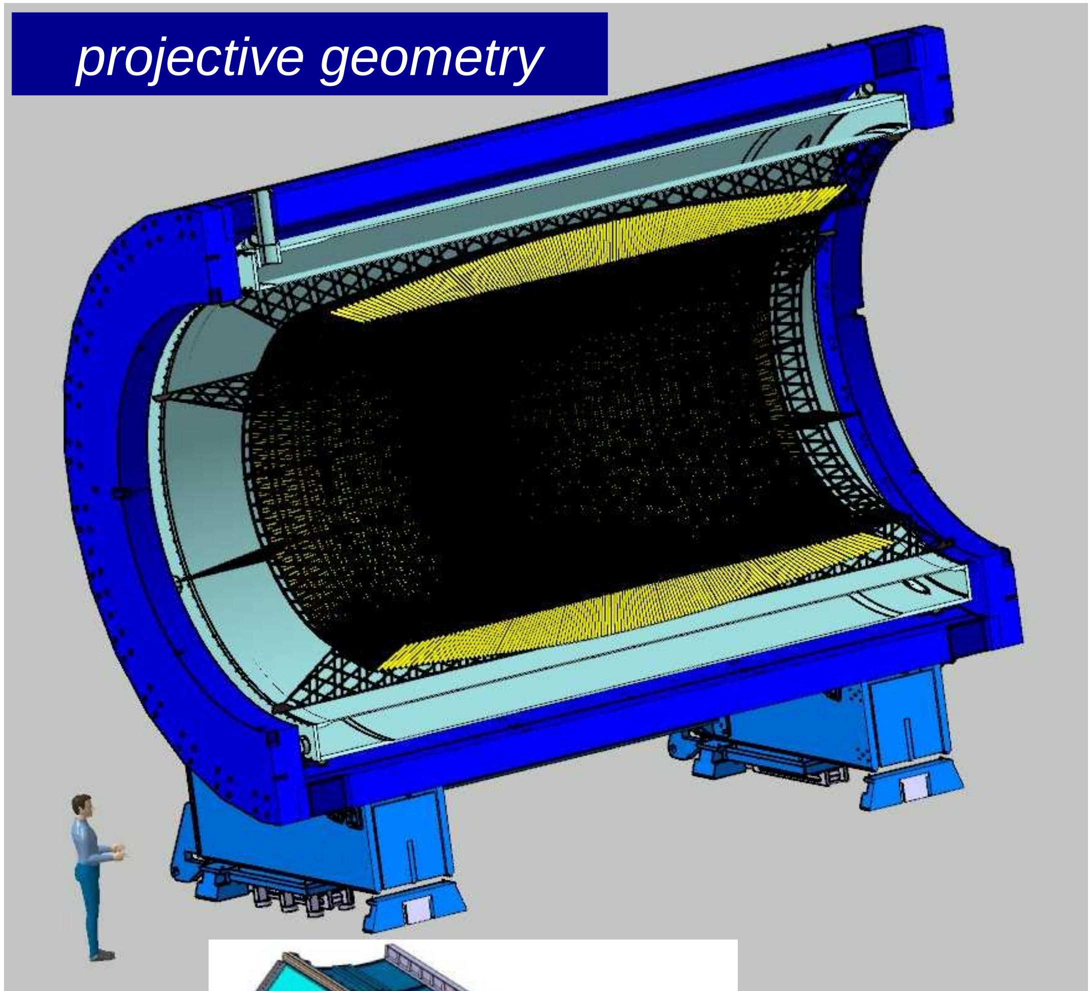


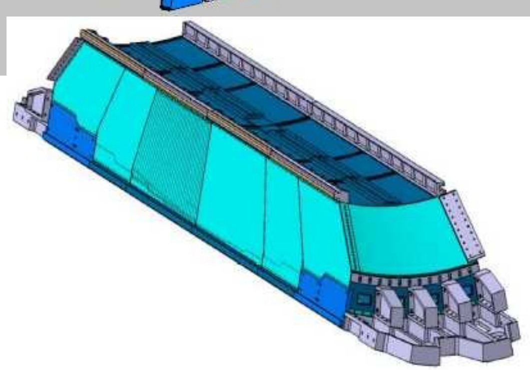


15 mm quartz radiator
10 mm lead converter



Electromagnetic calorimeter

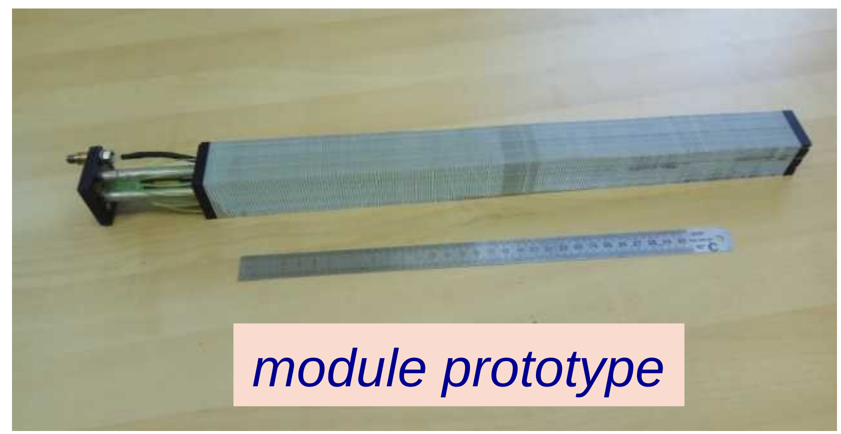




block of modules

Barrel ECAL ~ **43 000** modules

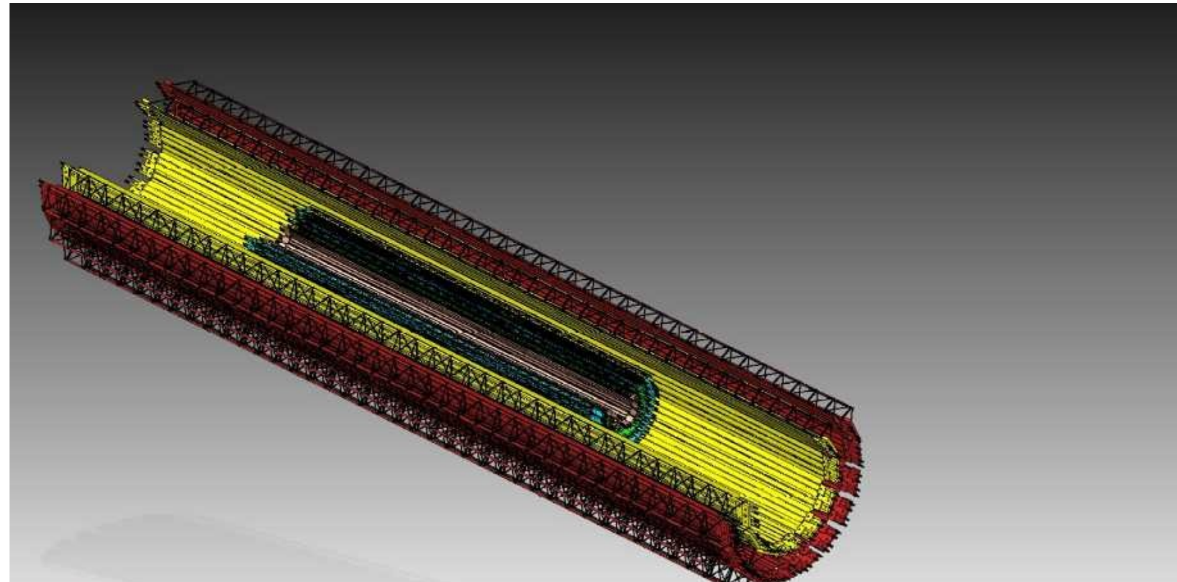
- *Pb+Sc "Shashlyk"*
- *read-out: WLS fibers + MAPD*
- *L ~35 cm (~ 14 X_0)*
- *Segmentation (4x4 cm^2),*
- *σ(E) better than 5% @ 1 GeV;*
- *time resolution ~500 ps*



Inner Tracking System (stage II)

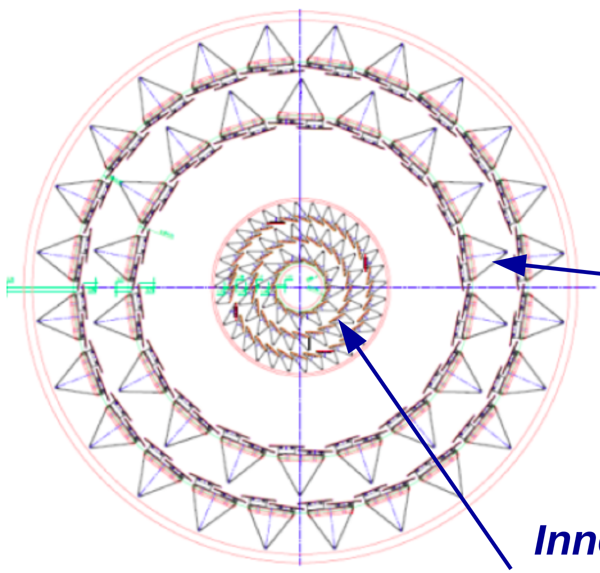
ALICE/CERN technology transfer to **MPD/JINR:**

- ***MAPS*** *of new* ***ALICE ITS*** *for* ***MPD***
- *carbon fiber space frames;*



~ 9 500 ALPIDE MAPS

*in **5** position-sensitive cylinders of **two** barrels*



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

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

***$4{,}9 \cdot 10^9$** pixels*
*active area **$3{,}9$ m^2***

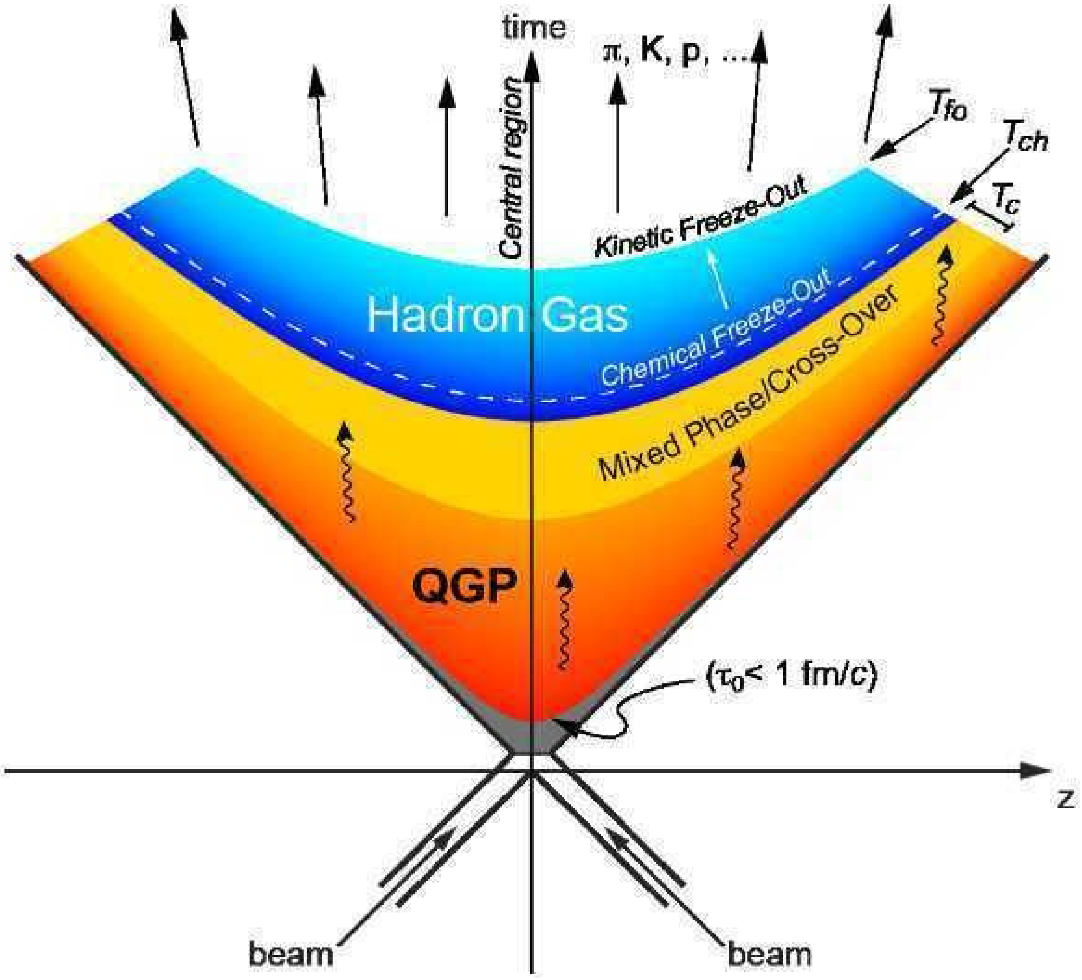
max bandwidth:
***400 – 1200** Mbps*

Feasibility study for heavy Ion collision at NICA

- UrQMD — hadrons, leptons
- QGSM — hadrons, leptons, fragments
- Hybrid UrQMD
- VHLLE
- THESEUS
- pHSD

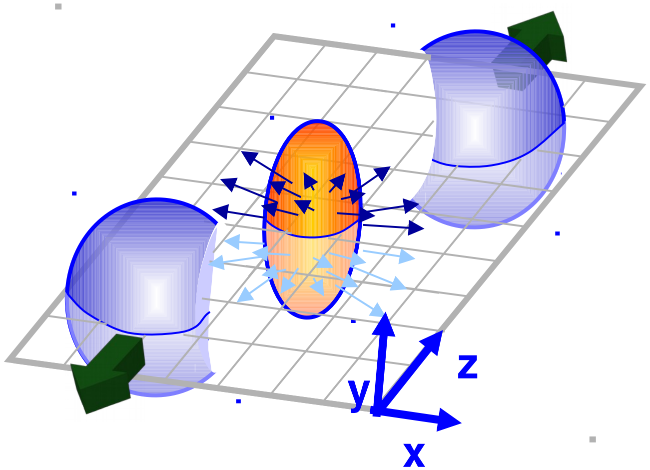
(Hybrid UrQMD, VHLLE, THESEUS: Phase transition)

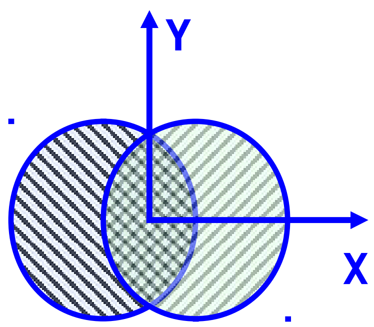
QGP in nucleus collisions



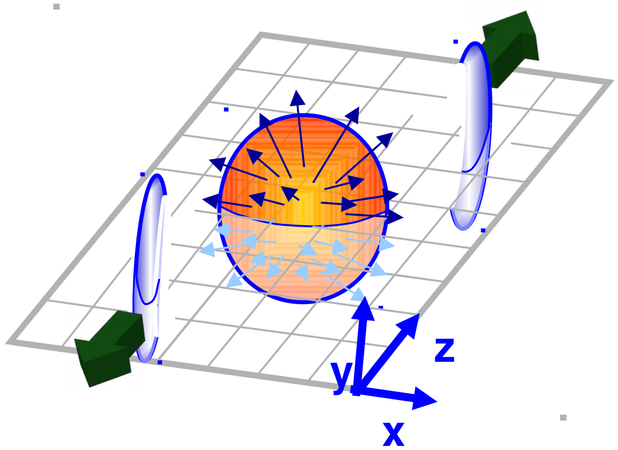
Nucleus collisions - flow

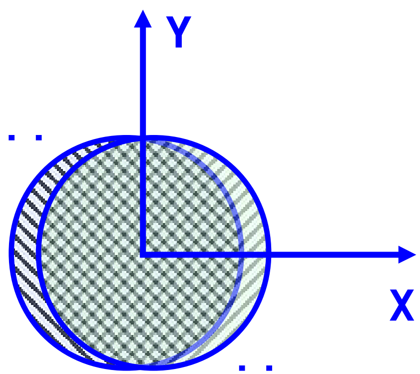
Peripheral Collision

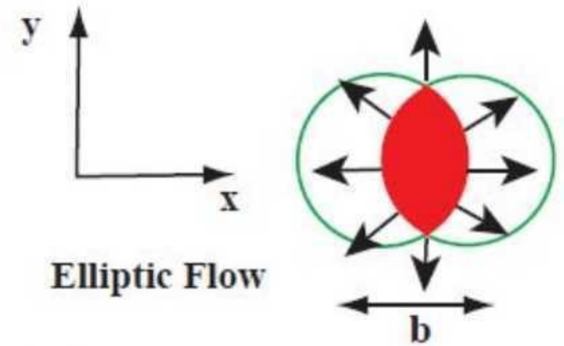


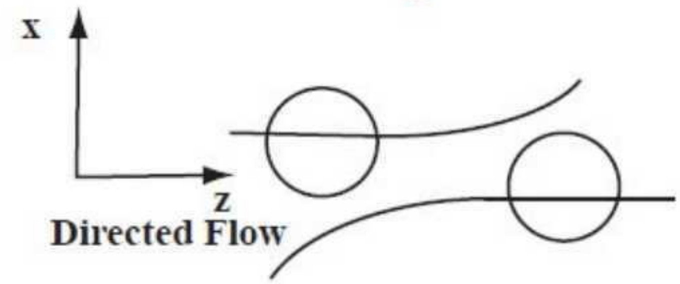


(near) Central Collision









Strangeness in QGP

In 1982 J. Rafelski and B. Müller predicted that enhancement of strangeness production is a signal of QGP.

"Strangeness Production in the Quark-Gluon Plasma"

Phys. Rev. Lett. 48(1982)

" A substantial enhancement of production rates of multi-strange anti-baryons in nuclear collisions in particular at central rapidity and at highest transverse masses has therefore been proposed as a characteristic signature of QGP."

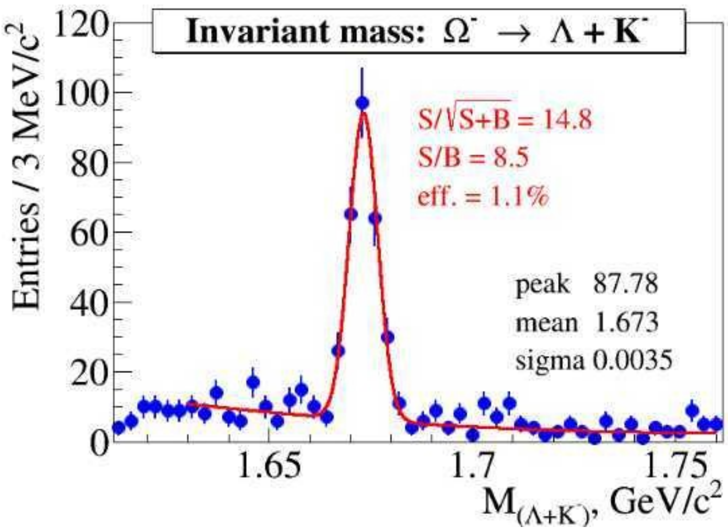
J.R. Phys. Lett. 62(1991)

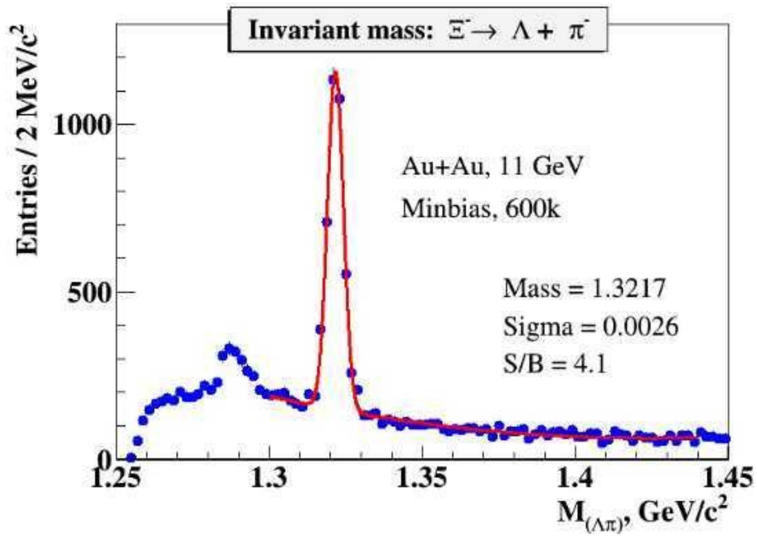
Idea: if s-(anti)quarks are created at QGP stage, then their number should not be changed during further evolution since s-(anti)quarks number is small and since density decreases => there is no chance for their annihilation!

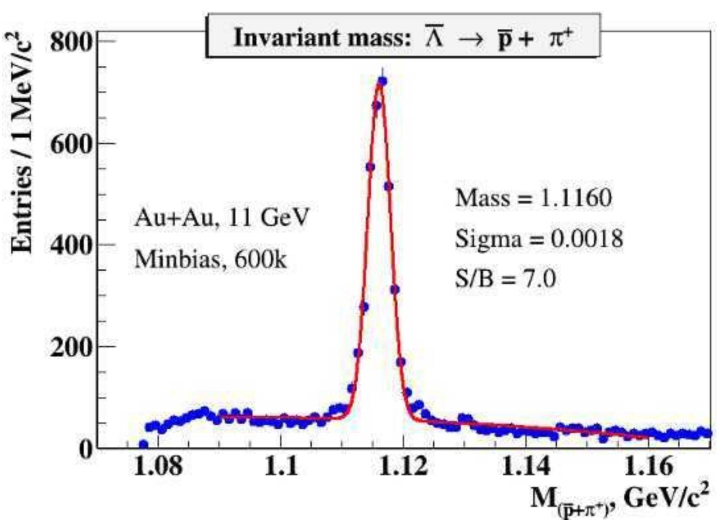
Hence, we should observe chemical enhancement of strangeness !

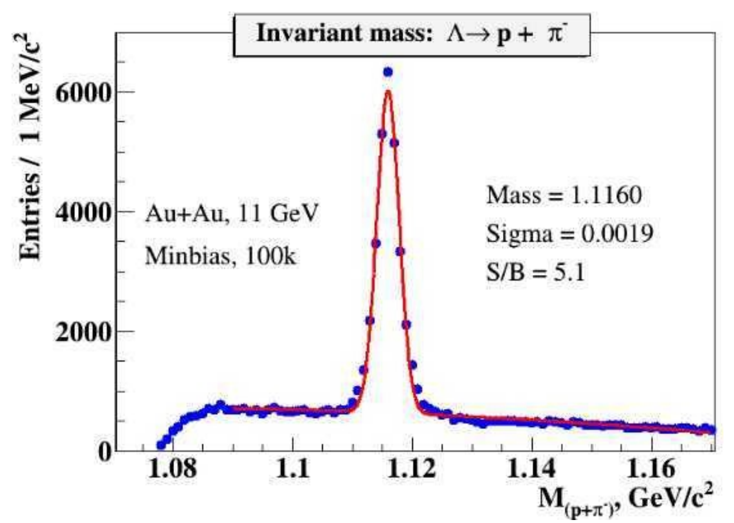
Strange and multi-strange baryons

Stage'1 (TPC+TOF): Au+Au @ 11 GeV, UrQMD



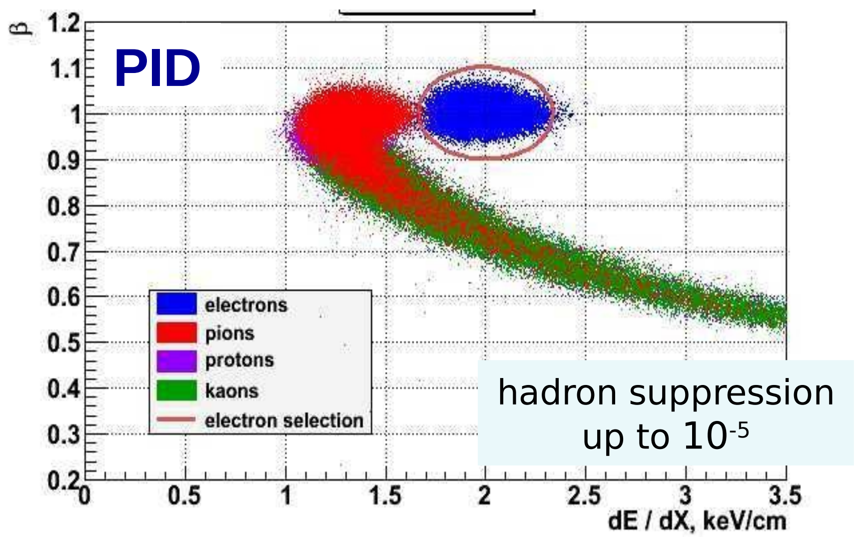


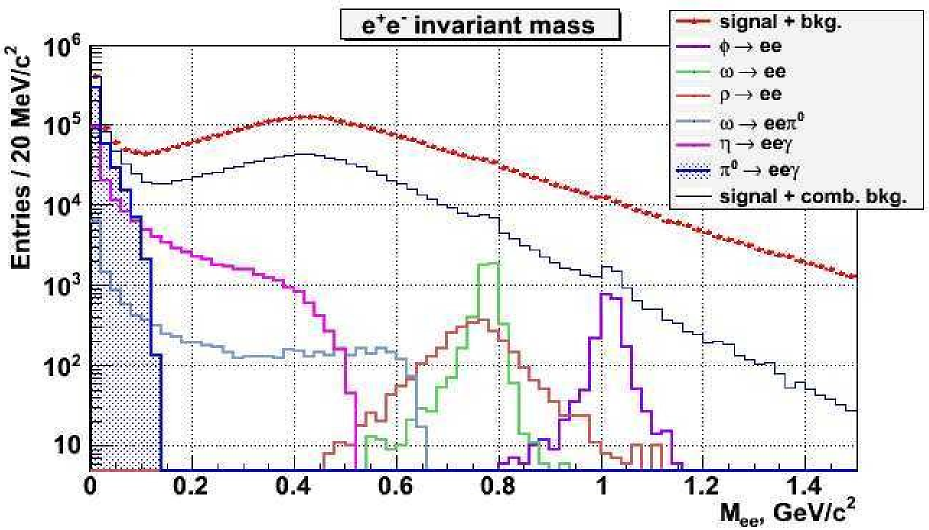


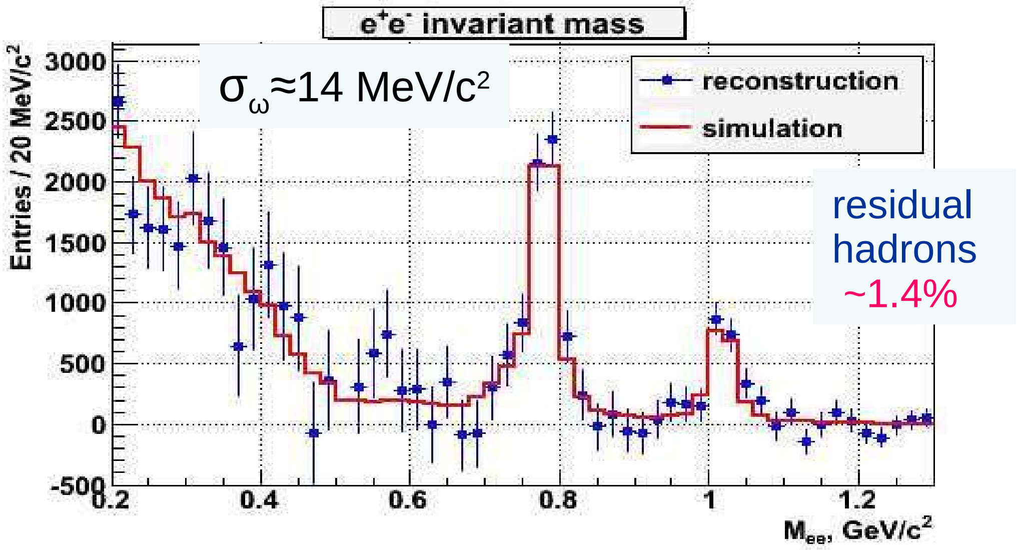


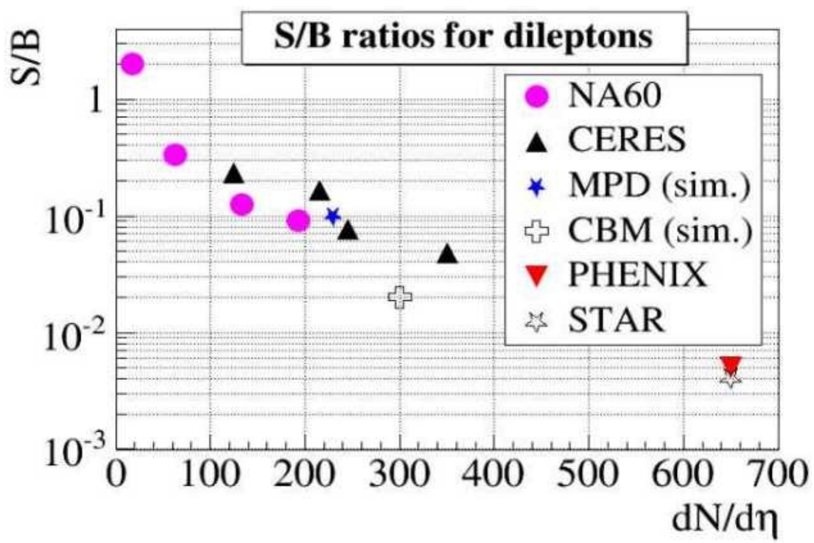
Dilepton study

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







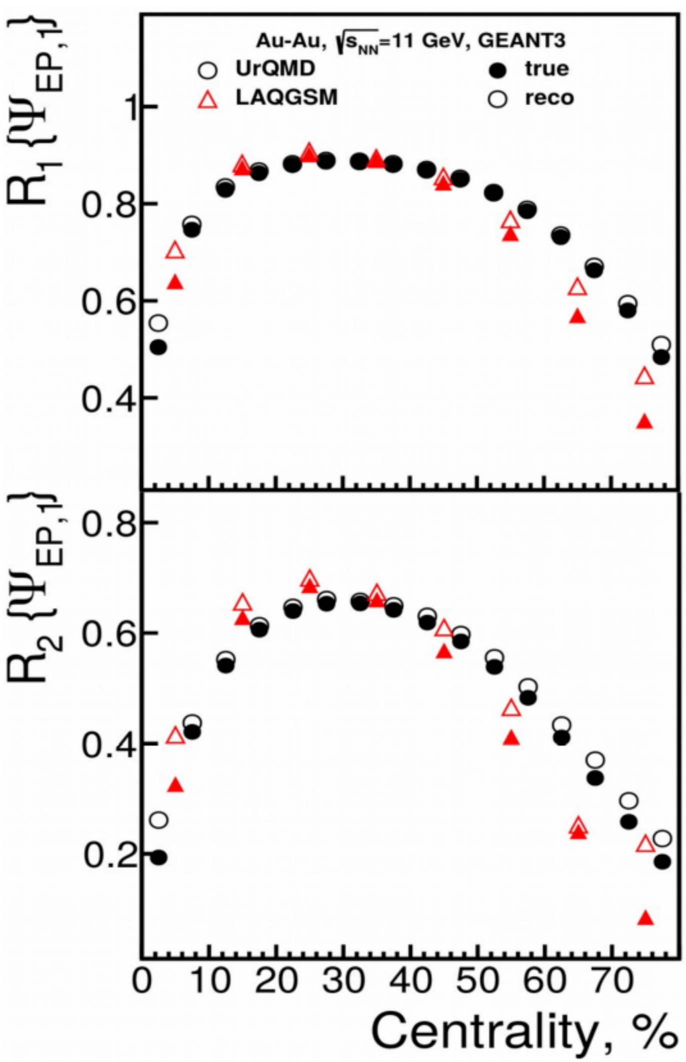


Flow performance

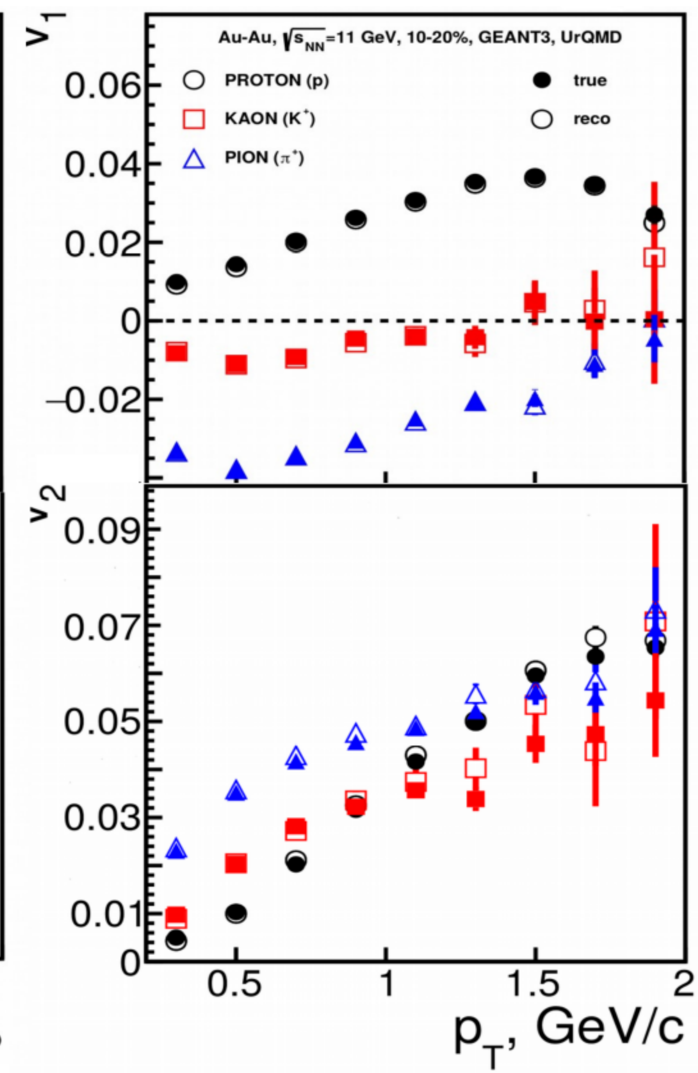
Au+Au@11 A GeV; GEANT3;
UrQMD (LAQGSM), 4M events

$v_n = \{\cos[n(\phi - \Psi_{EP,1})]\} / R_n(\Psi_{EP,1})$ *- azimuthal flow coefficients*

event plane resolution



flow harmonics (v_1 / v_2)

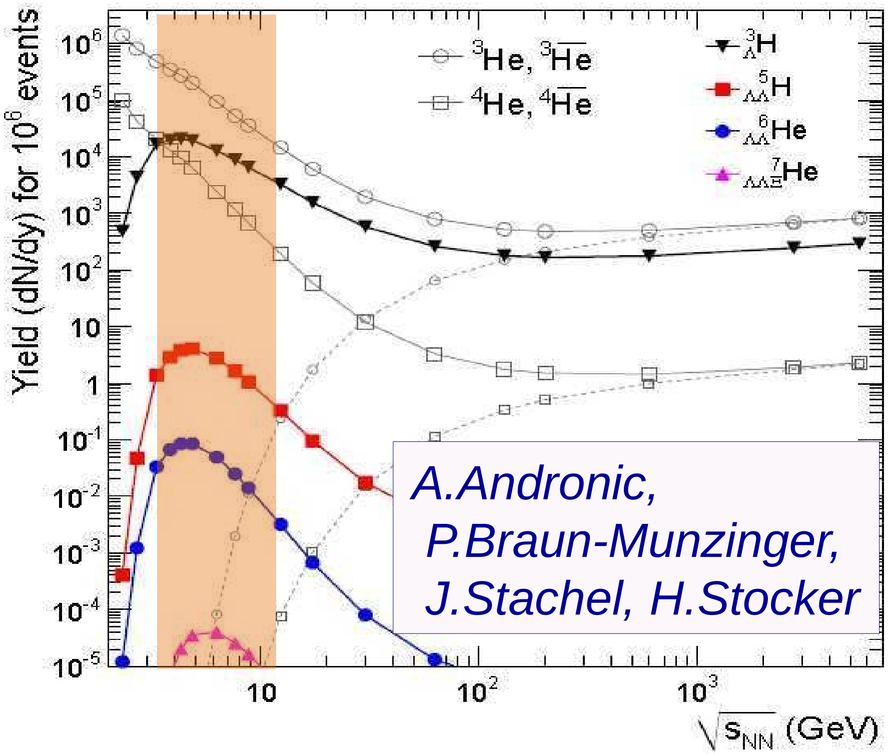


***$R_n(\Psi_{EP,1})$ –** resolution correction factor*

ϕ – azimuthal angle of produced particle
$\Psi_{EP,1}$ – event plane angle

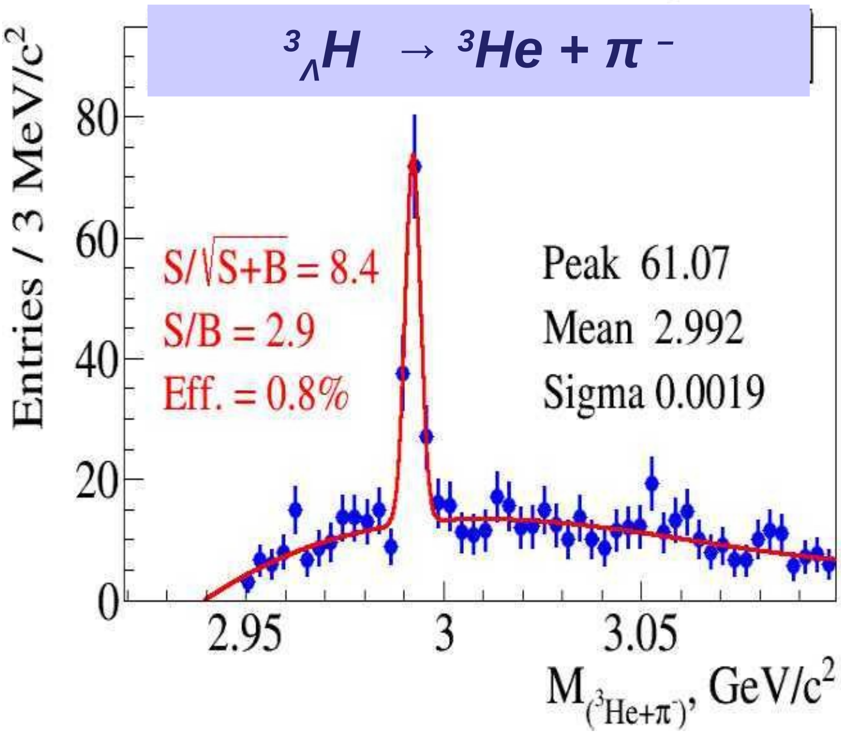
event plane: **FHCal**
centrality: **TPC**
PID: **TOF+TPC**

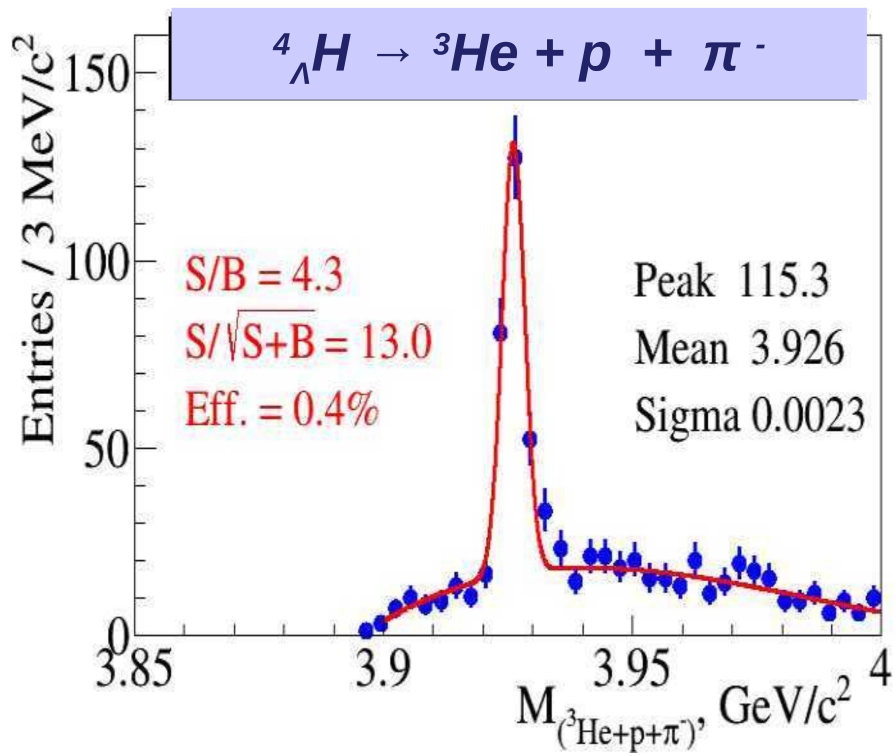
Hyper nuclei



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

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

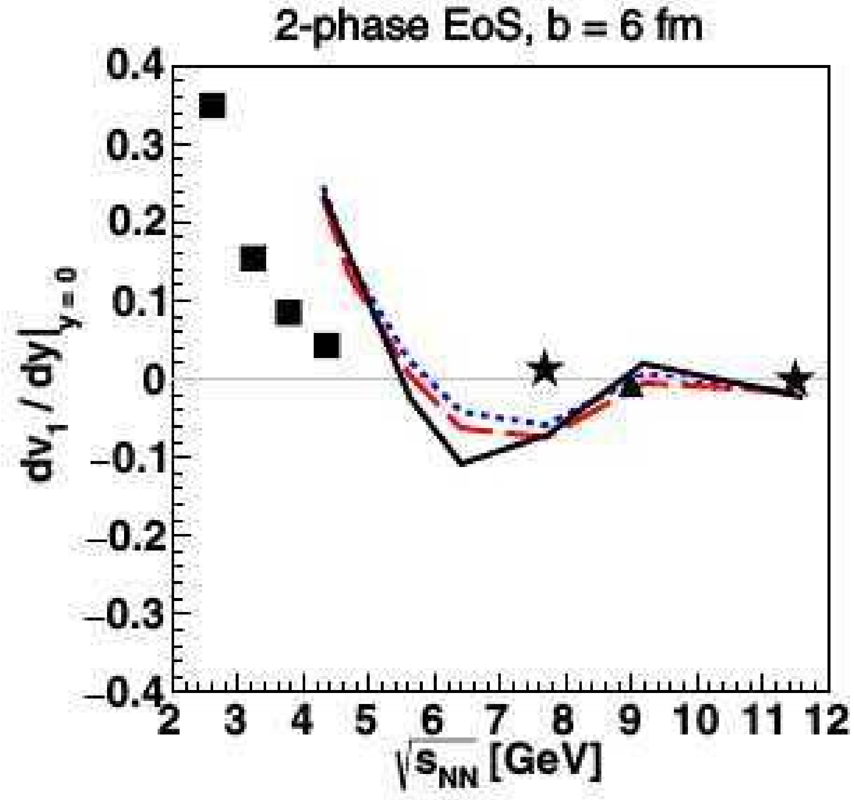


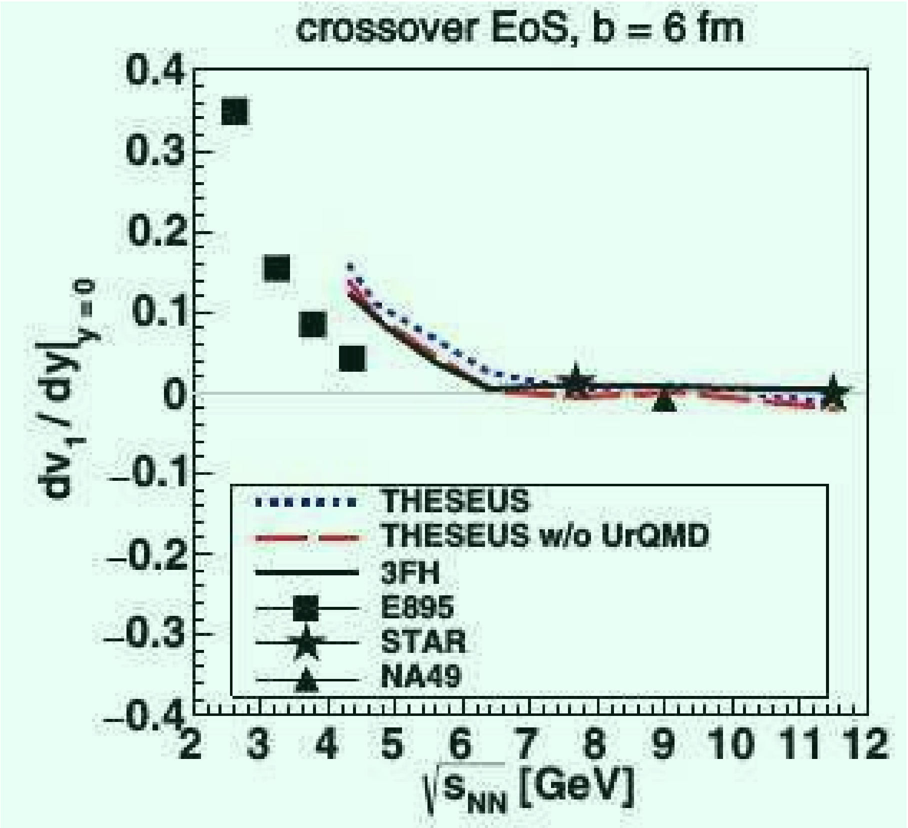


Directed flow slope

P. Batyuk et al. Phys. Rev. C 94, 044917 (2016)

$$v_1(y) = \langle \cos(\phi - \Psi_{RP}) \rangle = \left\langle p_x / \sqrt{p_x^2 + p_y^2} \right\rangle,$$

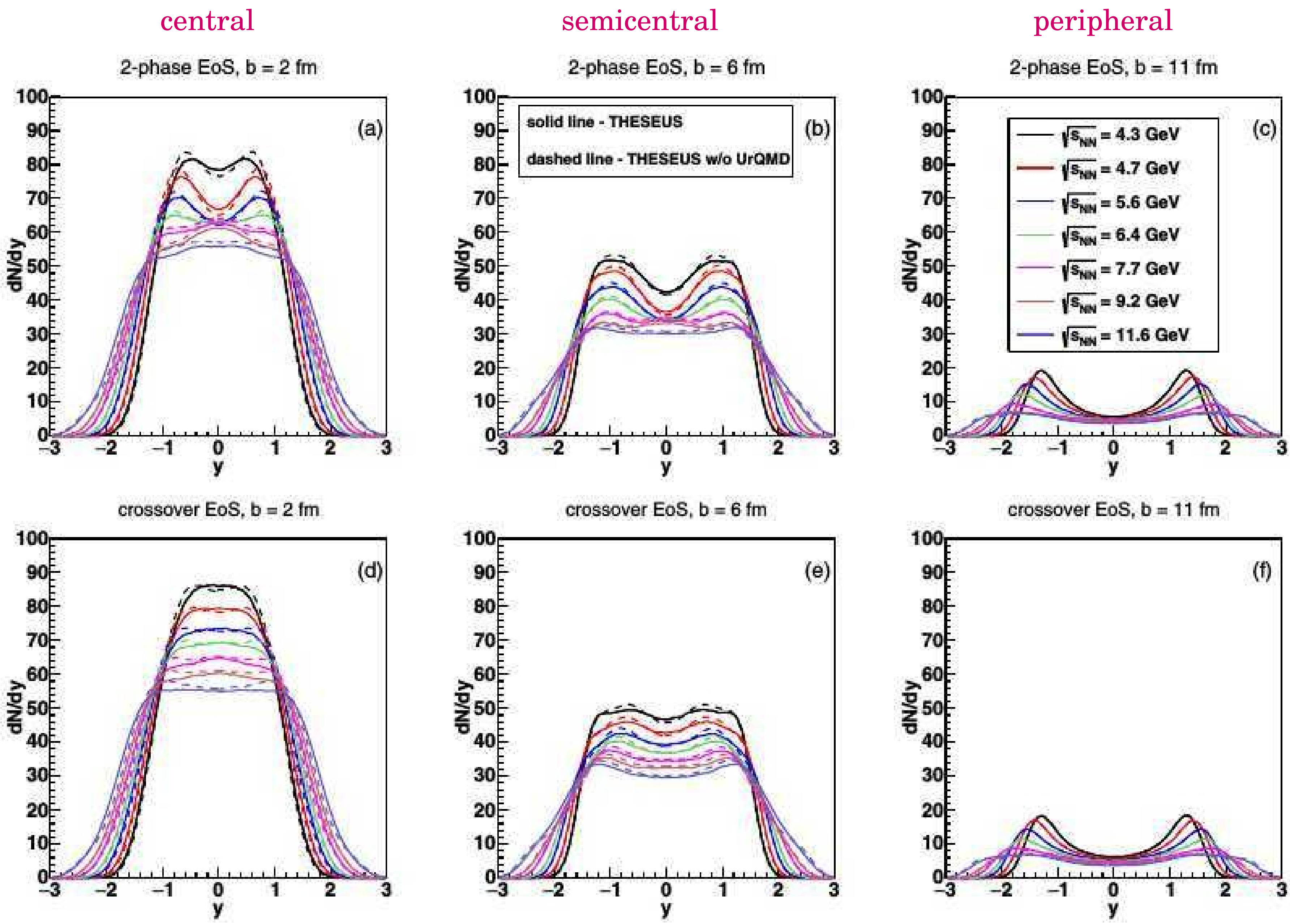




Energy scan of the slope of the directed flow (dv_1/dy) of protons for semicentral (b = 6 fm) Au+Au collisions

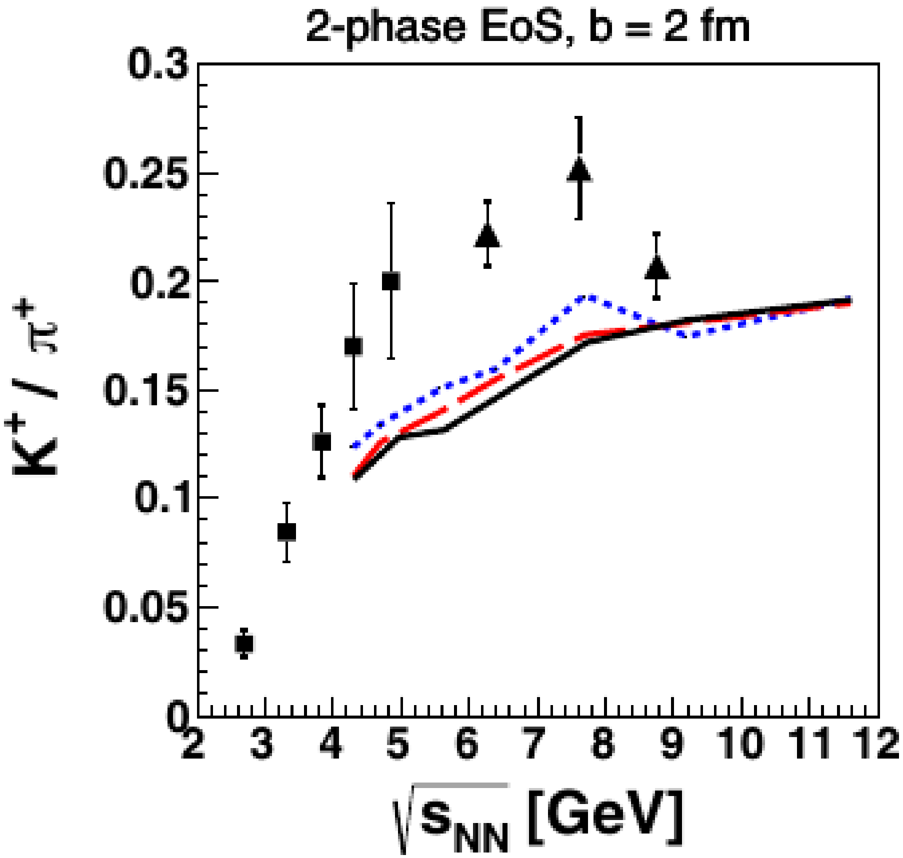
Proton rapidity in Theseus

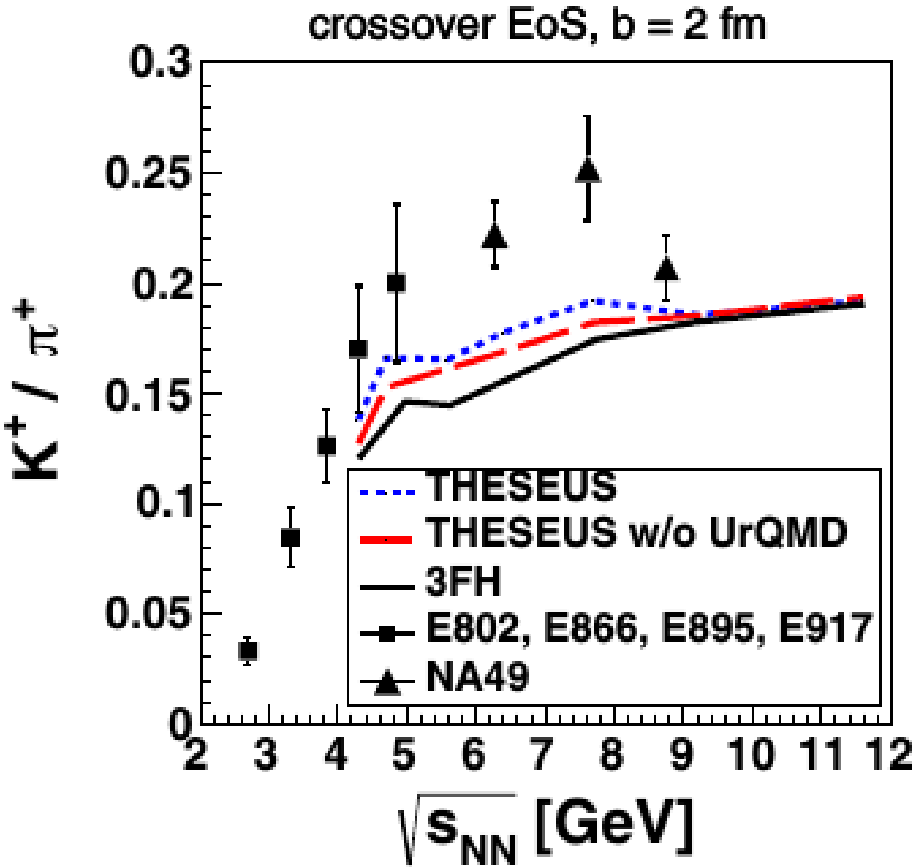
THESEUS



K^+/π^+ ratio

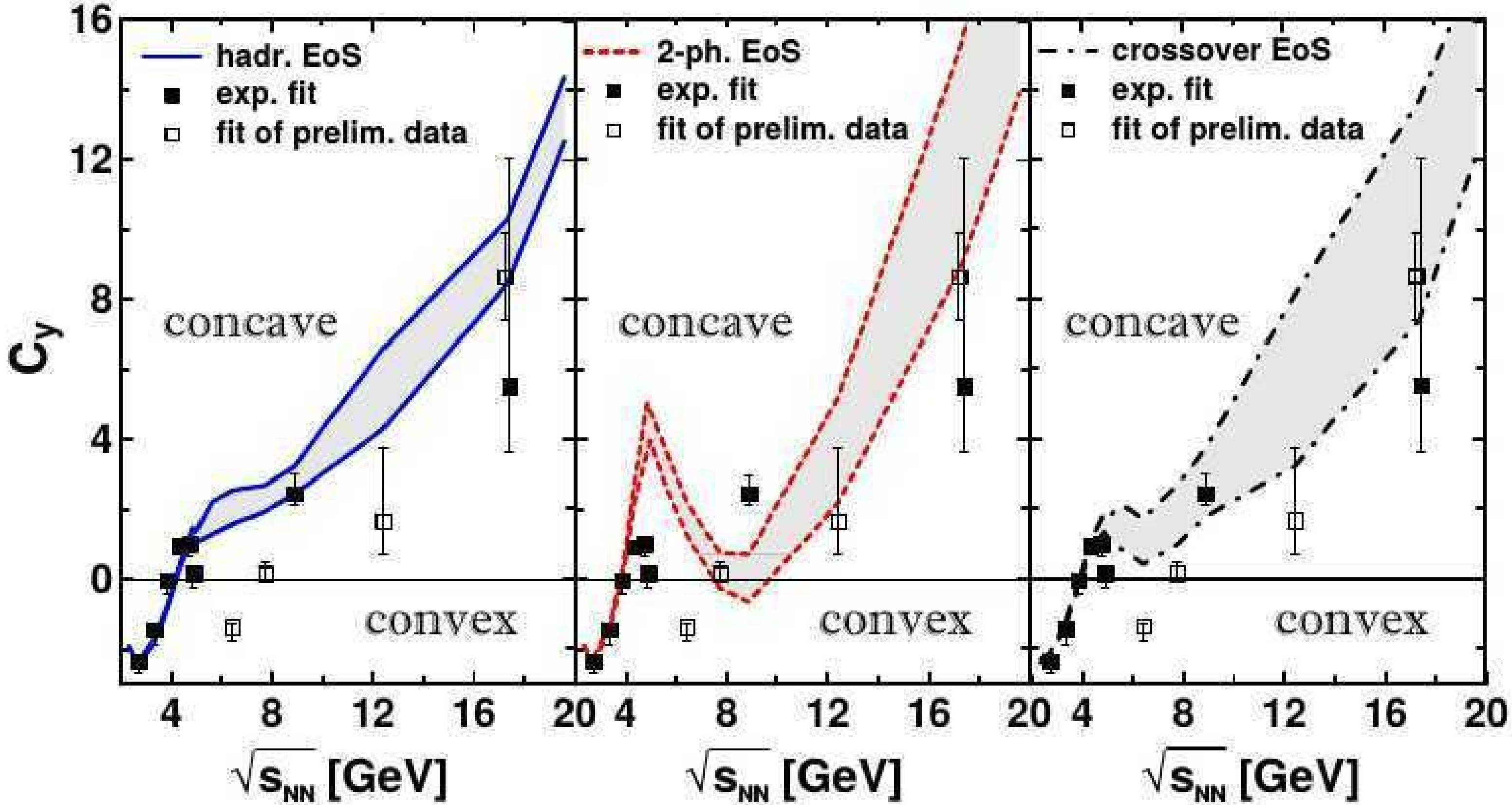
THESEUS





Net-proton mid rapidity curvature

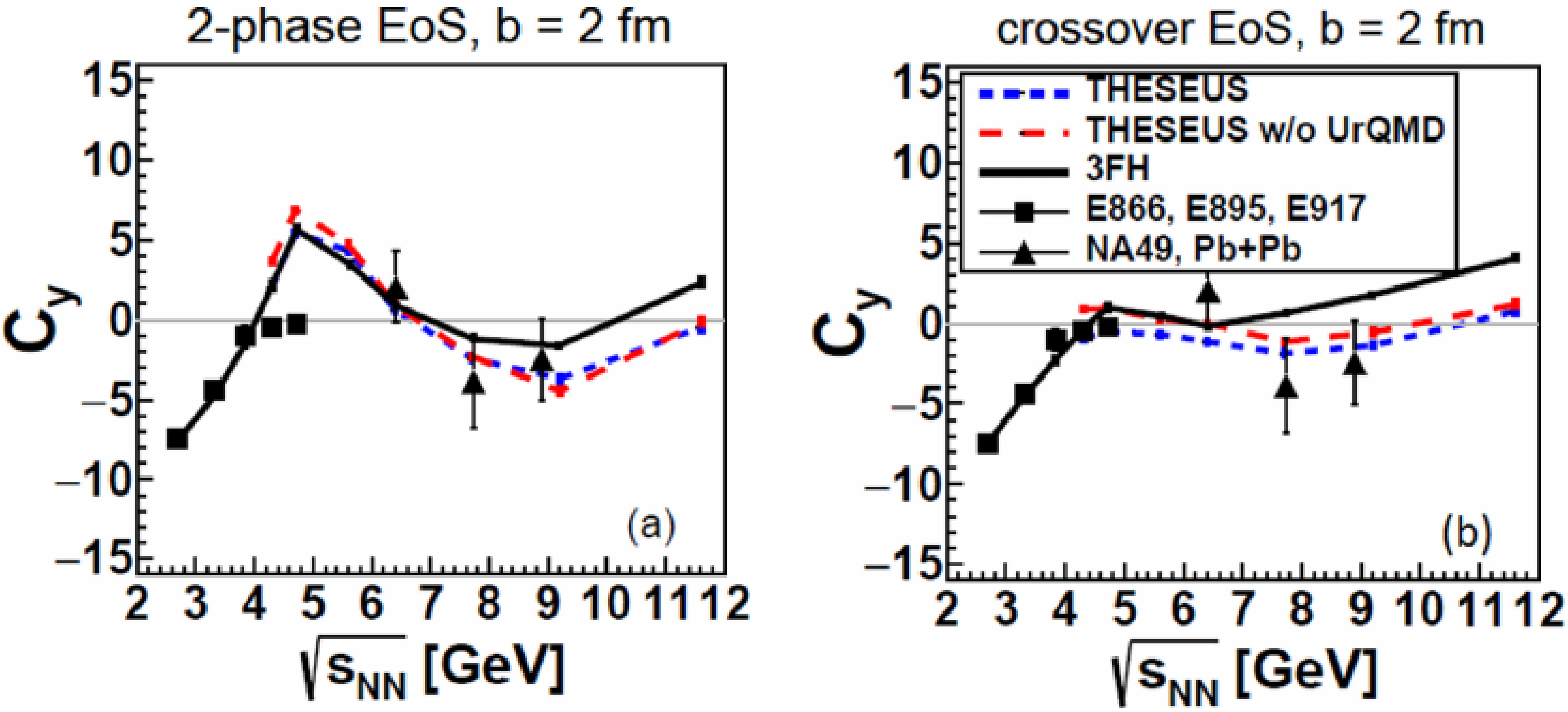
Yu.B. Ivanov, Phys. Lett. B721 123 (2013)



$$C_y = \left(y_{\rm beam}^3 \frac{d^3N}{dy^3} \right)_{y=0} \Big/ \left(y_{\rm beam} \frac{dN}{dy} \right)_{y=0} = (y_{\rm beam}/w_s)^2 \left(\sinh^2 y_s - w_s \cosh y_s \right)$$

Net proton rapidity curvature

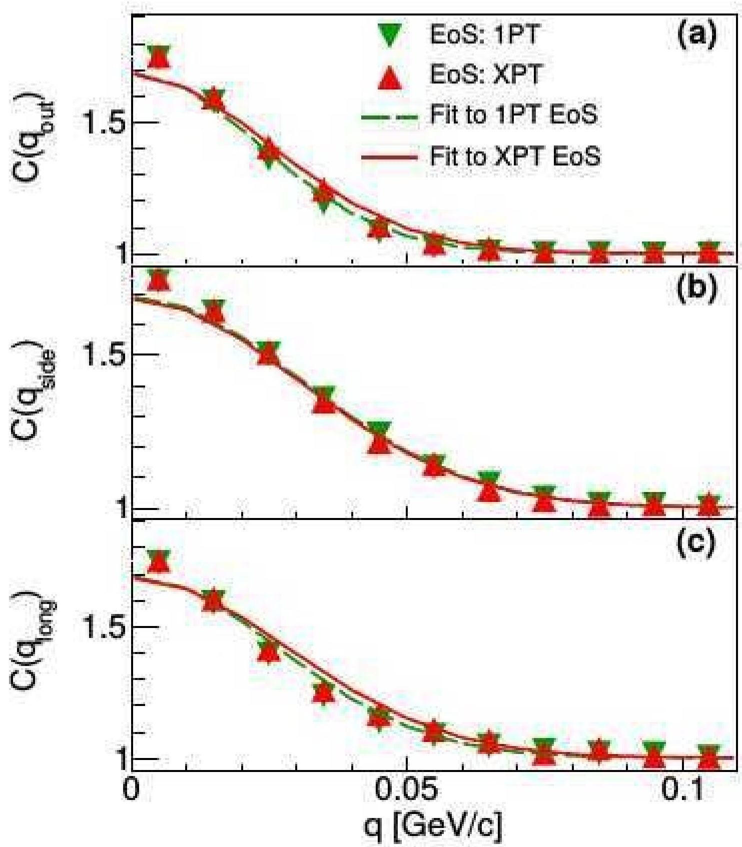
THESEUS

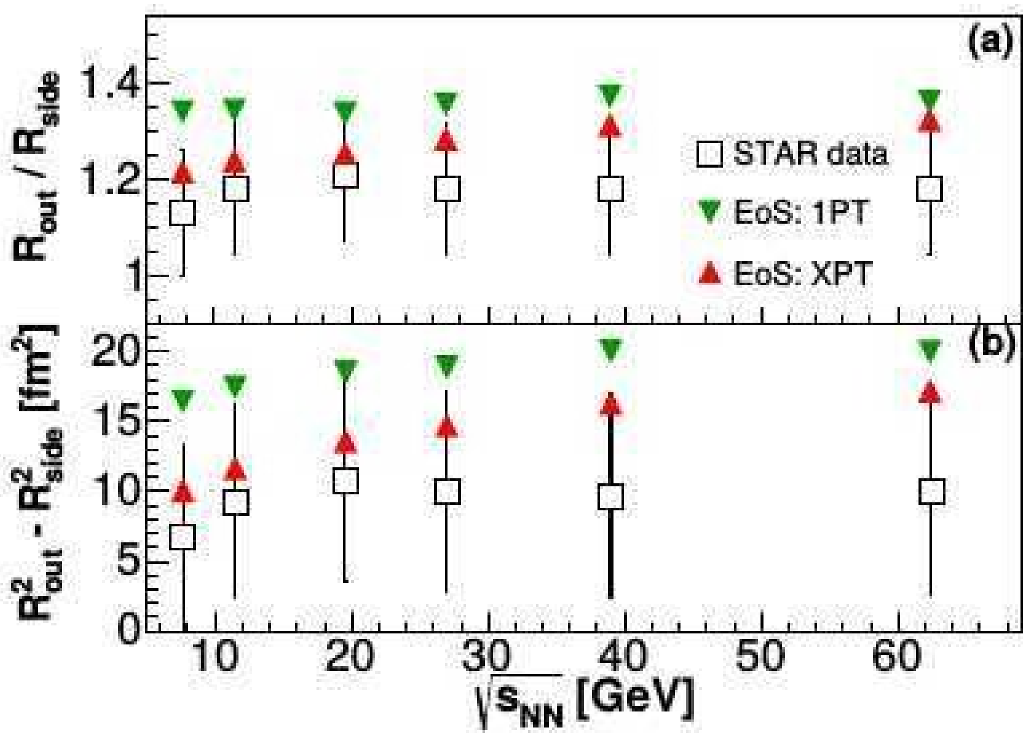


Femtoscopy study @ NICA

VHLLE+URQMD MODEL
Phys. Rev. C 91, 064901 (2015)

$$C(\mathbf{q}) = N\left(1 + \lambda \exp(-R_{\rm out}^2 q_{\rm out}^2 - R_{\rm side}^2 q_{\rm side}^2 - R_{\rm long}^2 q_{\rm long}^2)\right)$$

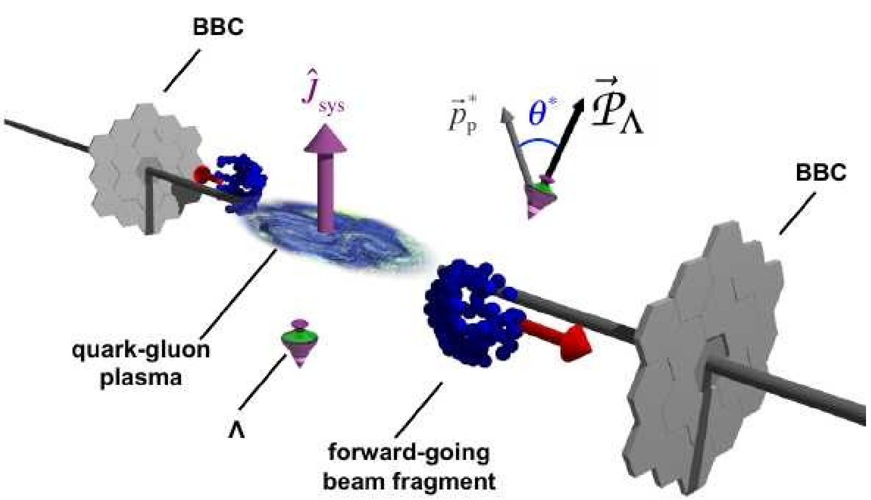


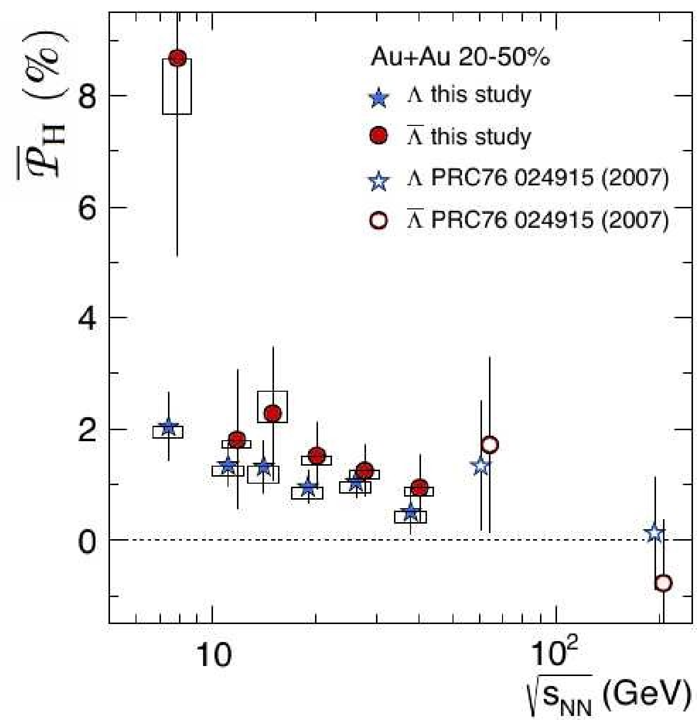


STAR data (0.15 < k_T < 0.25 GeV/c, 0-5% centrality)

Global Λ^0 hyperon polarization in nuclear collisions

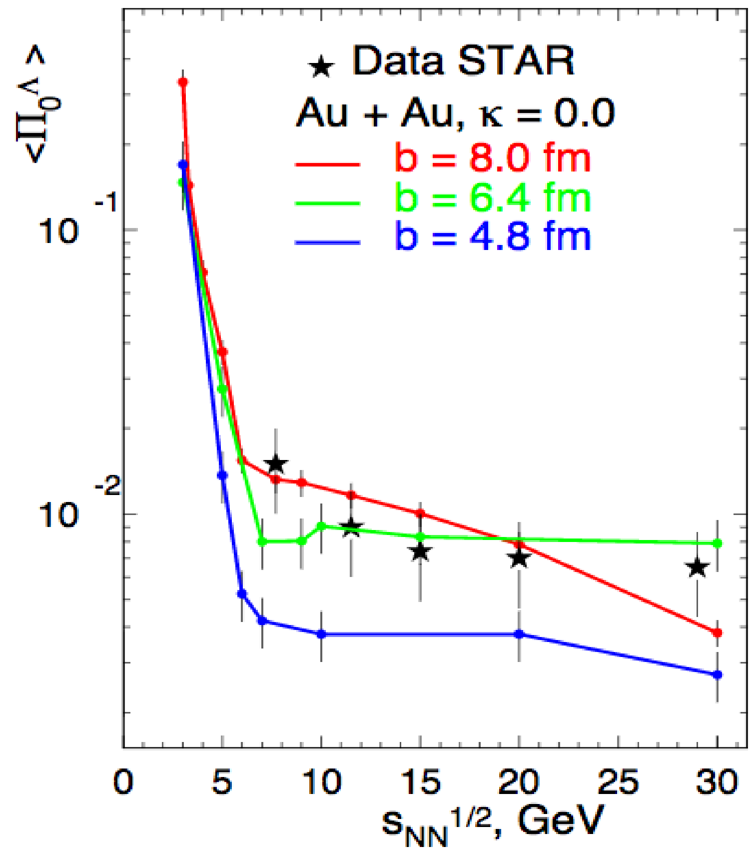
O. R., A. Sorin, O. Teryaev, Phys. Rev. C 82, 054910, 2010;
M.Baznat, et. al, arXiv:1701.00923





arXiv:1701.06657

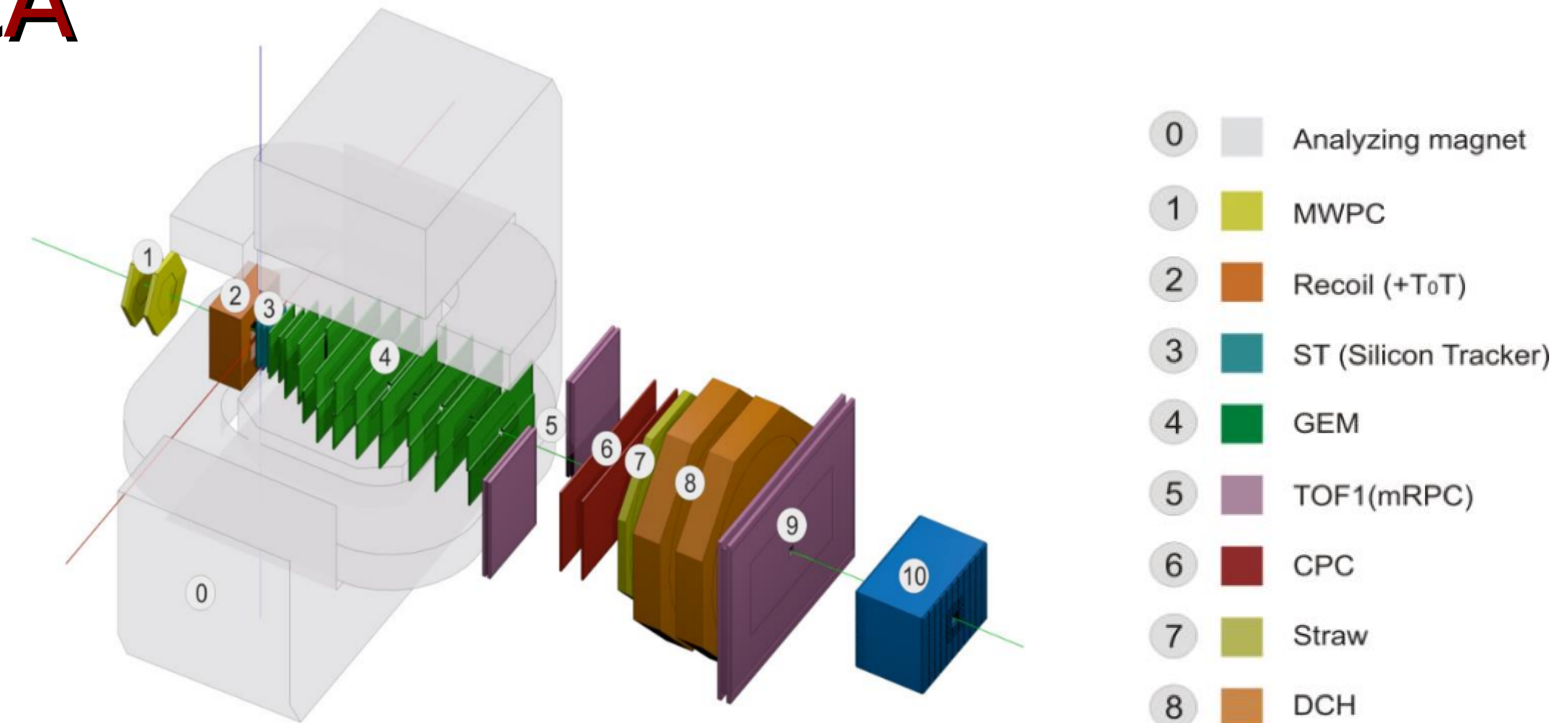
The average polarization P_H (where H = Λ or Λ) from 20-50% central Au+Au collisions as a function of collision energy.



$$\alpha_\Lambda = -\alpha_{\bar{\Lambda}} = 0.642 \pm 0.013$$

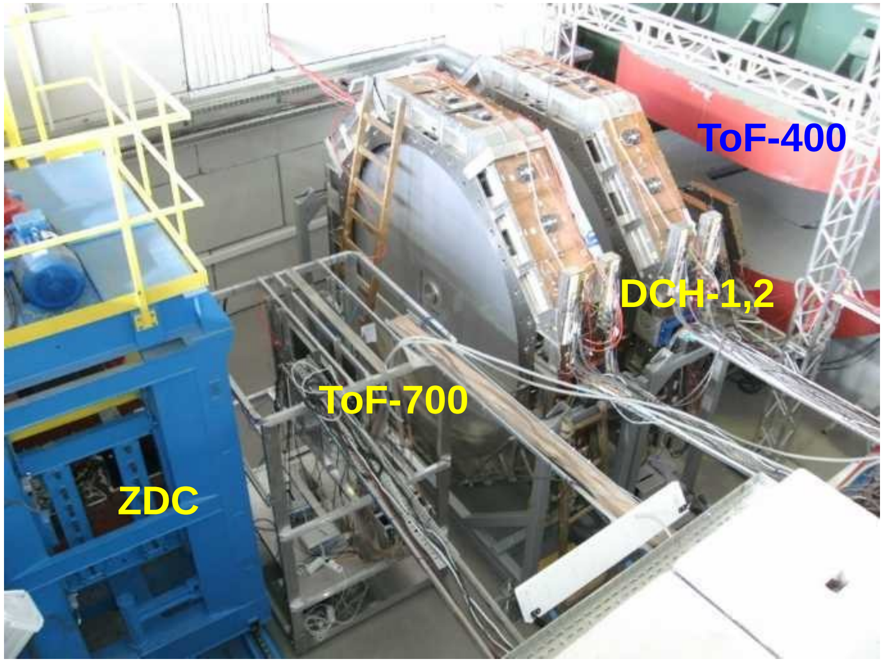
$$\frac{dN}{d\cos\theta^*} = \frac{1}{2}\left(1 + \alpha_H |\vec{\mathcal{P}}_H| \cos\theta^*\right)$$

BM@N: fixed target experiment at NICA

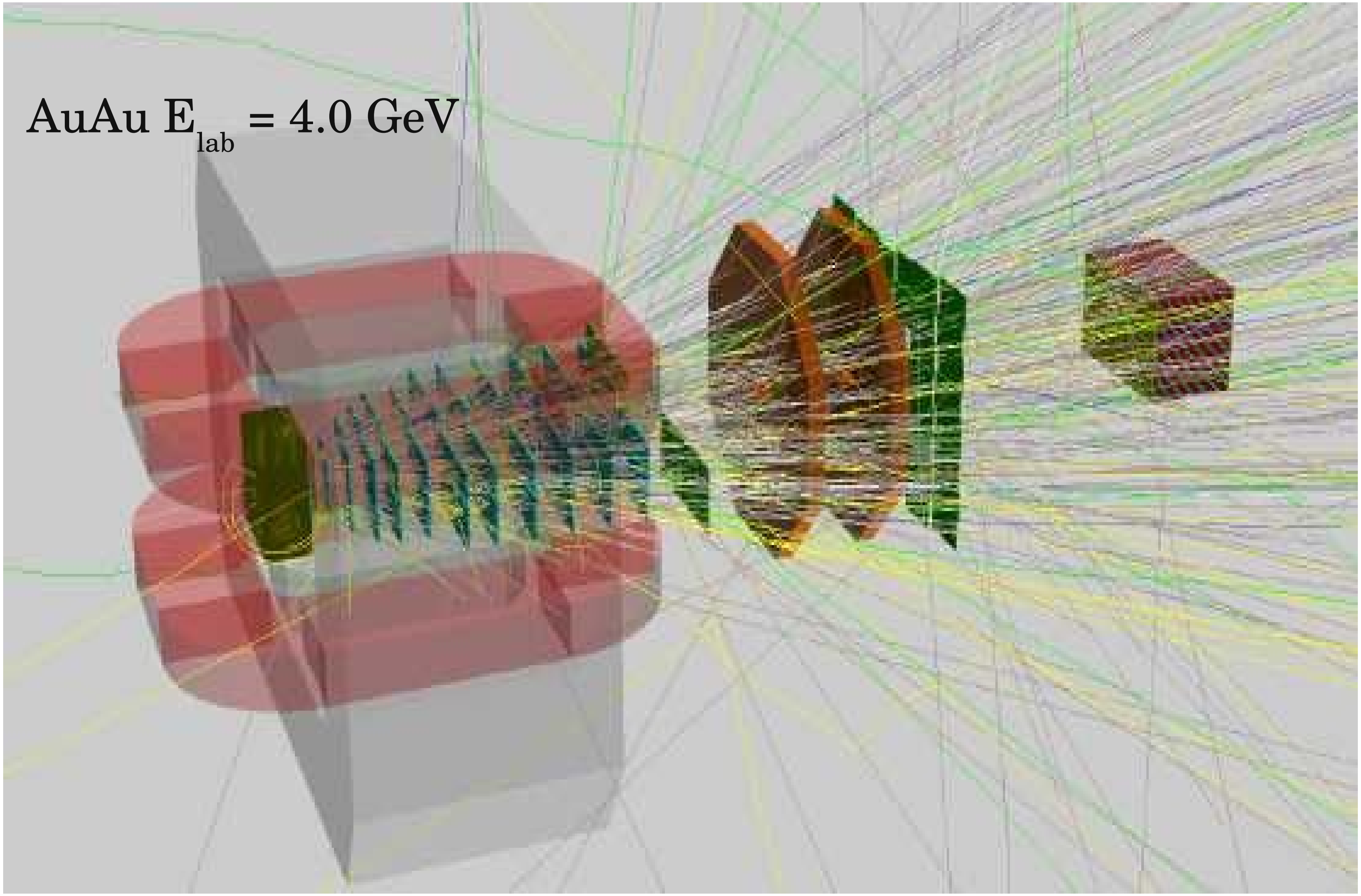


Year	2016	2017 spring	2018 spring	2020	2021 and later
Beam	d(↑)	C	Ar,Kr, C(SRC)	Au	Au,p
Max.intensity per spill	0.5M	0.5M	0.5M	1M	5M
Trigger rate, Hz	5k	5k	10k	10k	20k→50k
Central tracker status	6 GEM half planes	6 GEM half planes	6 GEM half planes + 3 small Si planes	7 GEM full planes + small + large Si planes	7 GEM full planes + small + large Si planes
Experimental status	technical run	technical run	technical run+physics	stage1 physics	stage2 physics

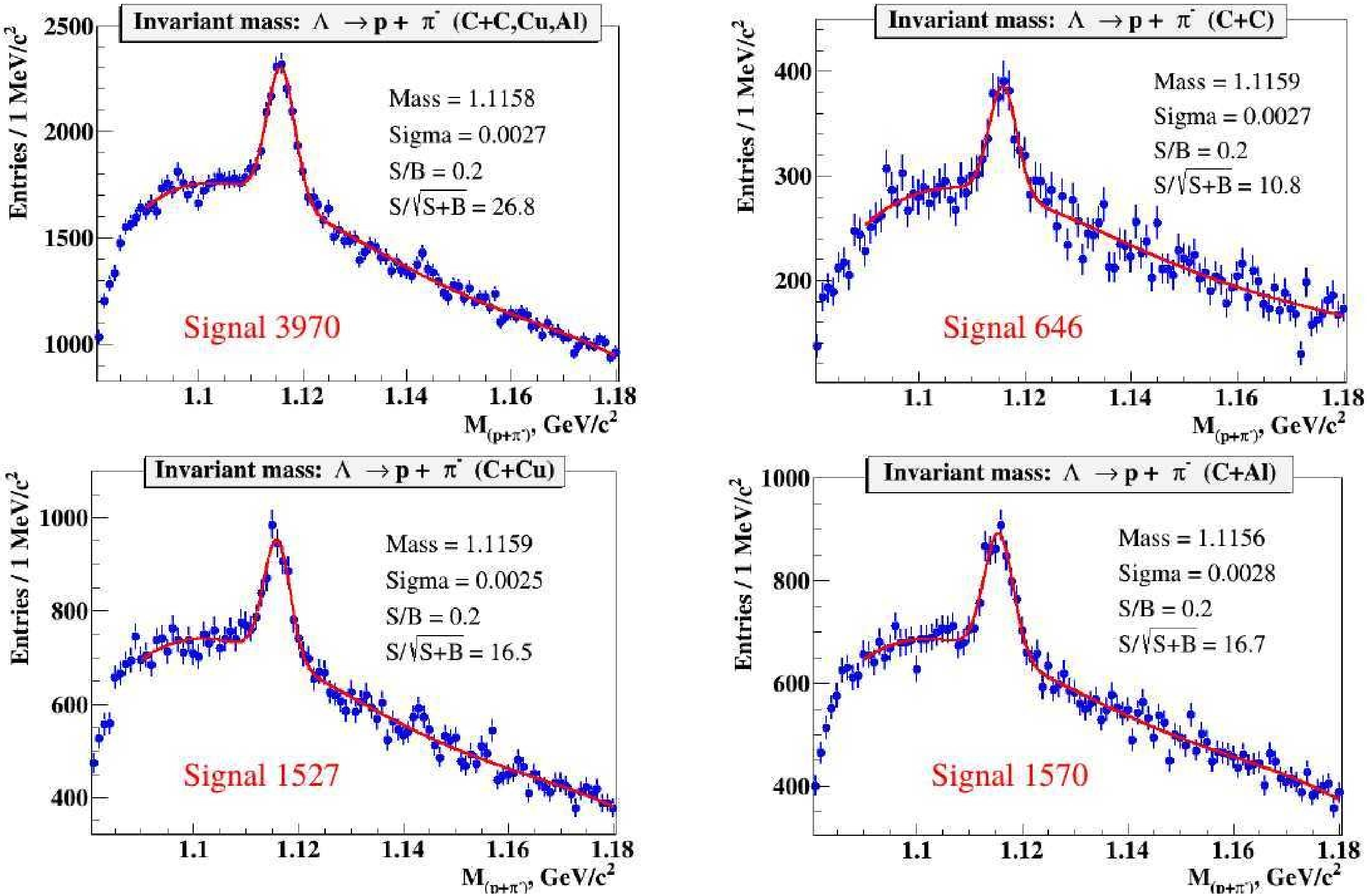
BM@N experiment at NICA



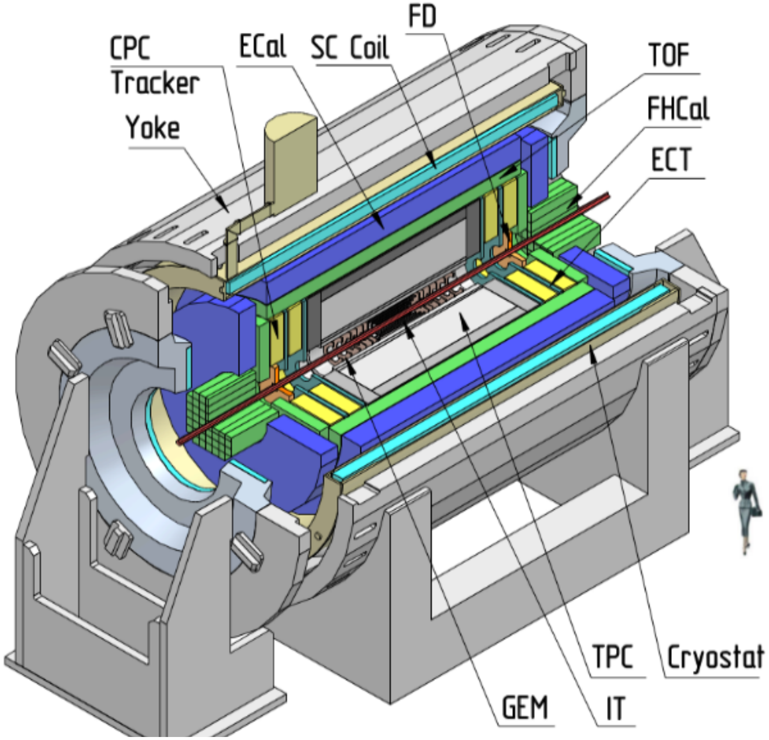
GEMs tracker

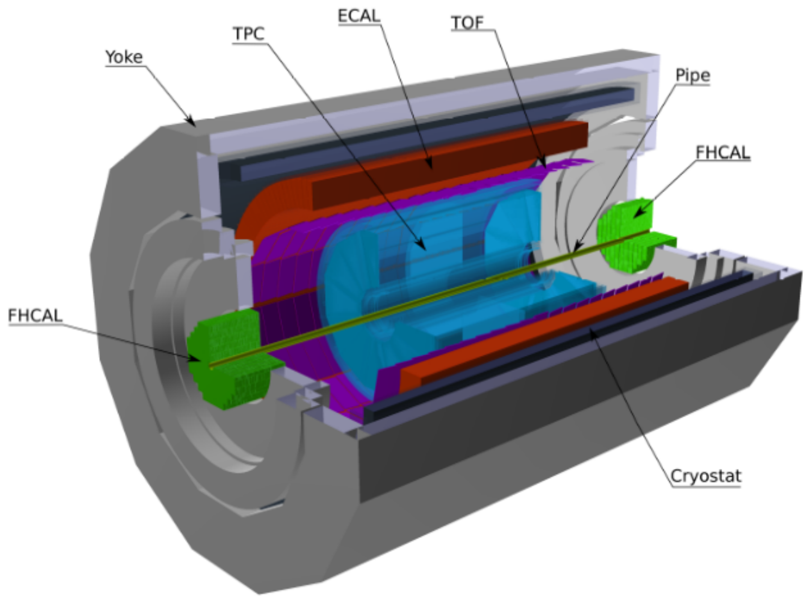


BM@N Λ^0 reconstruction
(E_{kin}^{beam} = 4.0 AGeV)

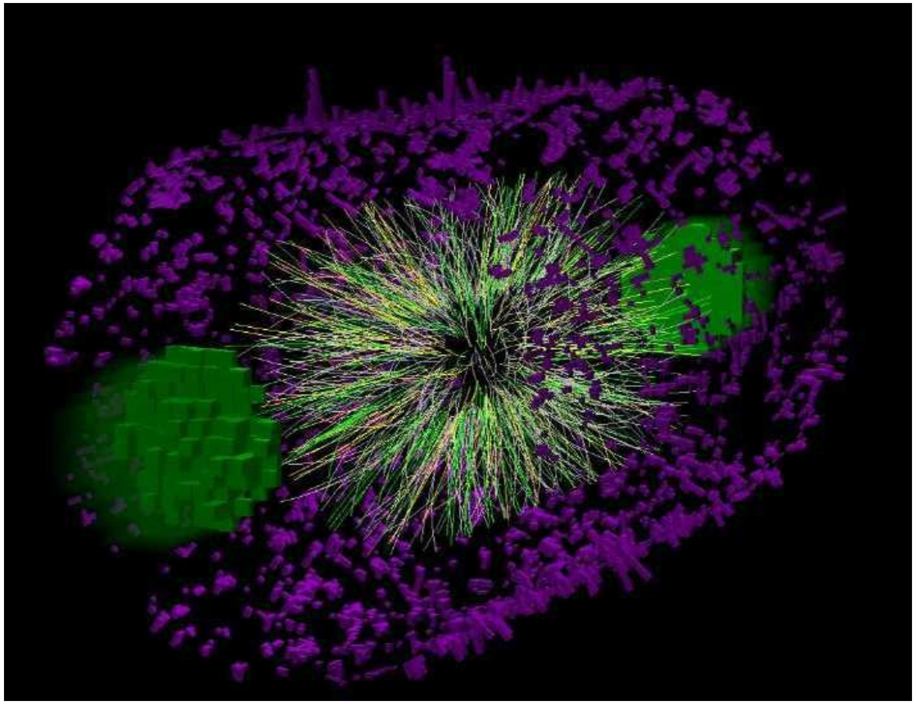


Software simulation experiments at NICA

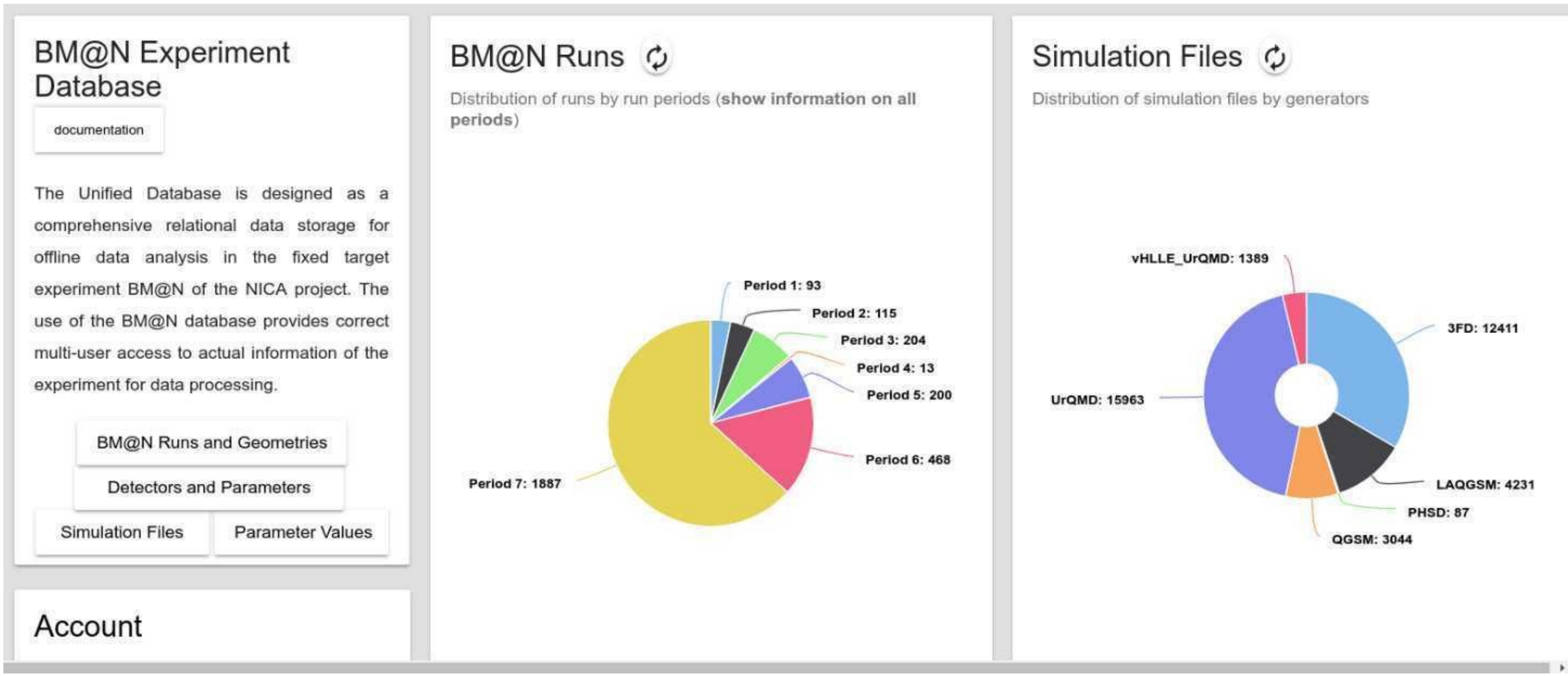




MPD event display
AuAu $\sqrt{s}$ = *11 GeV*



Event generators + exp. data databases



- ✔ UrQMD
- ✔ QGSM
- ✔ PHSD

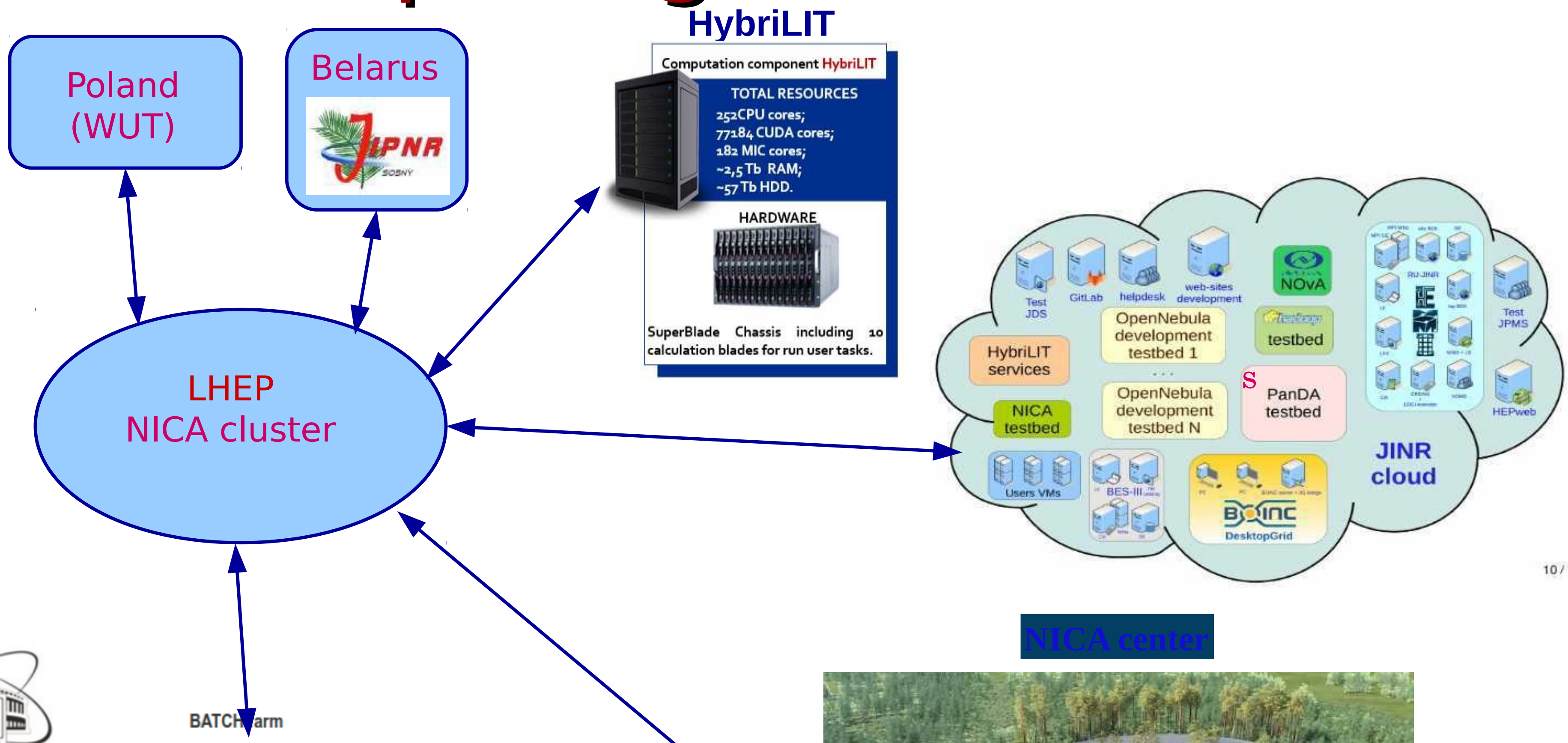
- ✔ Hybrid UrQMD
- ✔ vHLLE_UrQMD
- ✔ 3FD(Theseus)

Interactions
AuAu MC
pC MC+exp
CC

Energy s
2, 4, 7, 9, 11

32902 files
~ 10^6 events
for each
interaction

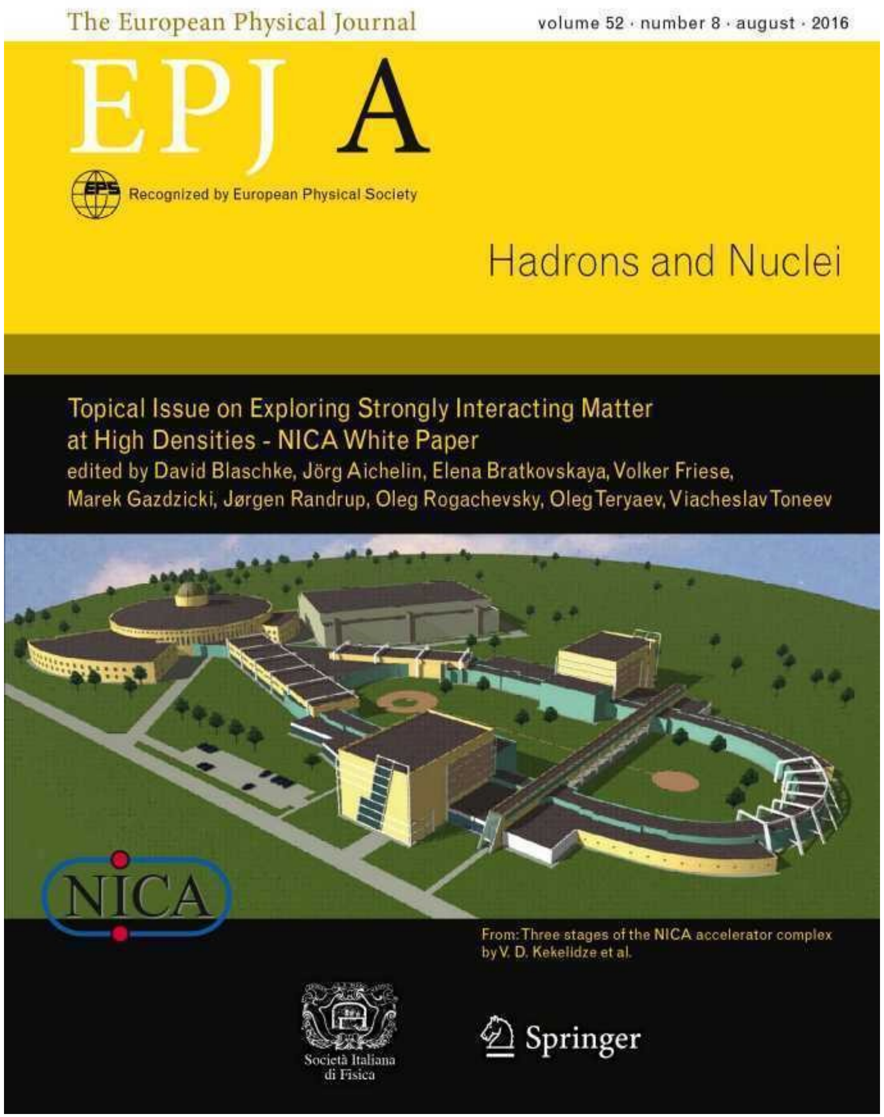
NICA computing



Laboratory	Jobs number	CPU time (kiloSPECint2000*hour)	Wall time (kiloSPECint2000*hour)
mpd	2517	45892.88	46287.04
LIT	35	43415.25	4093.52
lnovai	28636	38951.69	74460.88
compass	8110	16663.03	42517.94
DLNP	3430	11016.49	17784.63
lbes	5771	1653.52	6732.95
VBLHEP	1	9.17	9.17
BLTP	2	0.53	0.54
lstar	2	0.01	0.14

Total CPU time used: 157602.58 kiloSPECint2000*hour

NICA White Paper



ФИЗИКА ЭЛЕМЕНТАРНЫХ ЧАСТИЦ И АТОМНОГО ЯДРА
2016. Т. 47. ВЫП. 4

FEASIBILITY STUDY OF HEAVY ION PHYSICS PROGRAM AT NICA

P. N. Batyuk [1,*], *V. D. Kekelidze* [1], *V. I. Kolesnikov* [1], *O. V. Rogachevsky* [1], *A. S. Sorin* [1,2], *V. V. Voronyuk* [1]

on behalf of the BM@N and MPD collaborations

[1] Joint Institute for Nuclear Research, Dubna

[2] National Research Nuclear University "Moscow Engineering Physics Institute" (MEPhI), Moscow

There is strong experimental and theoretical evidence that in collisions of heavy ions at relativistic energies the nuclear matter undergoes a phase transition to the deconfined state — Quark–Gluon Plasma. The caused energy region of such a transition was not found at high energy at SPS and RHIC, and search for this energy is shifted to lower energies, which will be covered by the future NICA (Dubna), FAIR (Darmstadt) facilities and BES II at RHIC. Fixed target and collider experiments at the NICA facility will work in the energy range from a few A GeV up to $\sqrt{s_{NN}} = 11$ GeV and will study the most interesting area on the nuclear matter phase diagram.

The most remarkable results were observed in the study of collective phenomena occurring in the early stage of nuclear collisions. Investigation of the collective flow will provide information on Equation of State (EoS) for nuclear matter. Study of the event-by-event fluctuations and correlations can give us signals of critical behavior of the system. Femtoscopy analysis provides the space-time history of the collisions. Also, it was found that baryon stopping power revealing itself as a "wiggle" in the excitation function of curvature of the (net) proton rapidity spectrum relates to the order of the phase transition.

The available observations of an enhancement of dilepton rates at low invariant masses may serve as a signal of the chiral symmetry restoration in hot and dense matter. Due to this fact, measurements of the dilepton spectra are considered to be an important part of the NICA physics program. The study of strange particles and hypernuclei production gives additional information on the EoS and "strange" axis of the QCD phase diagram.

In this paper a feasibility of the considered investigations is shown by the detailed Monte Carlo simulations applied to the planned experiments (BM@N, MPD) at NICA.

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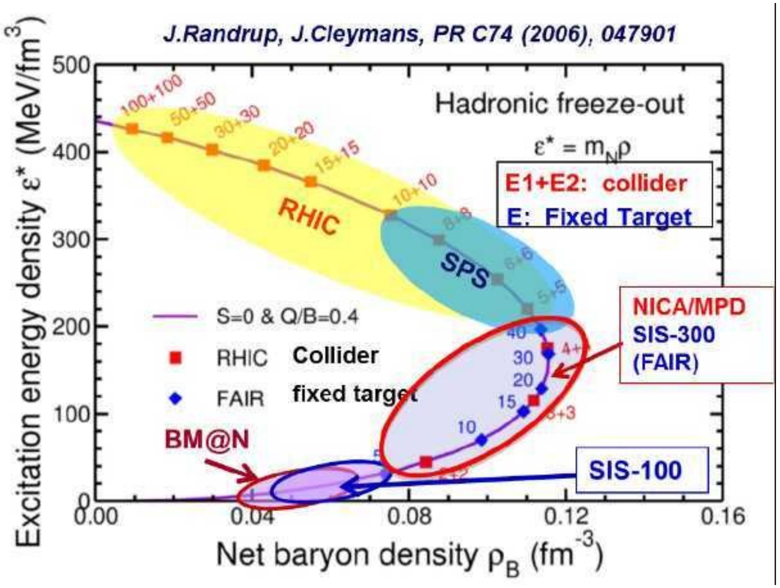
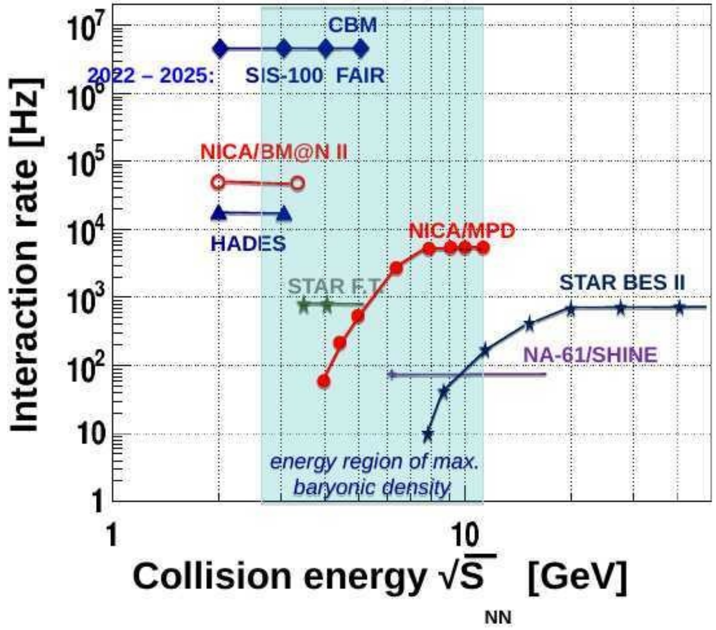
NICA advantagies

J. Cleymans
MPD collaboration Meeting April, 2018



- ✔ Maximum in K^+/π^+ ratio is in the NICA energy region,
- ✔ Maximum in Λ/π ratio is in the NICA energy region,
- ✔ Maximum in the net baryon density is in the NICA energy region,
- ✔ Transition from a baryon dominated system to a meson dominated one happens in the NICA energy region.



Basic NICA milestones

- ***2018*** – *start of* ***BM@N*** *experiment*
- ***2018*** – *start of* ***Booster*** *commissioning*
- ***2020*** – *completion of civil constructions* ***(b. 17)***
- ***2019*** – ***MPD*** *magnet commissioning*
- ***2019*** – *start of* ***MPD*** *detectors assembly*
- ***2020*** – *start of* ***Collider*** **assembly**
- ***2020*** – *start of* ***Collider*** *commissioning*
- ***2020*** – *start of* ***MPD*** *commissioning*
- ***2020*** – *completion of* ***«Center NICA»*** *construction*
- ***2020 –*** *start of assembly of* ***Computer center*** *elements*

Thank you for attention

Welcome

to NICA physics