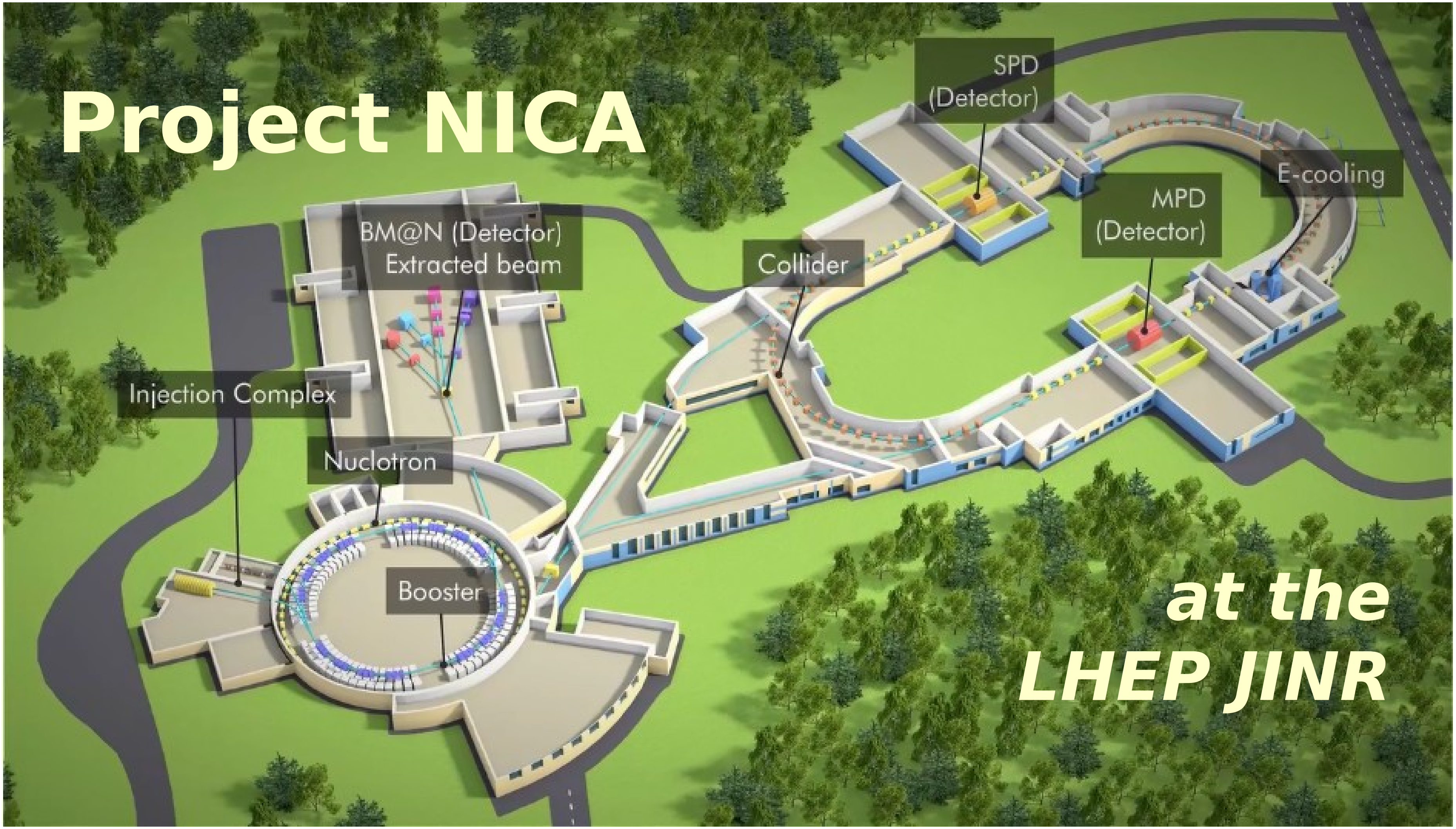
Project NICA

at the LHEP JINR



ROGACHEVSKY Oleg
for MPD collaboration

NEC 2017
September, 27 2017
Budva

NICA complex

Beams – p,d(h)..$^{197}Au^{79+}$

Collision energy $\sqrt{s}$= **4-11** GeV/u (Au), **12-27** (p)

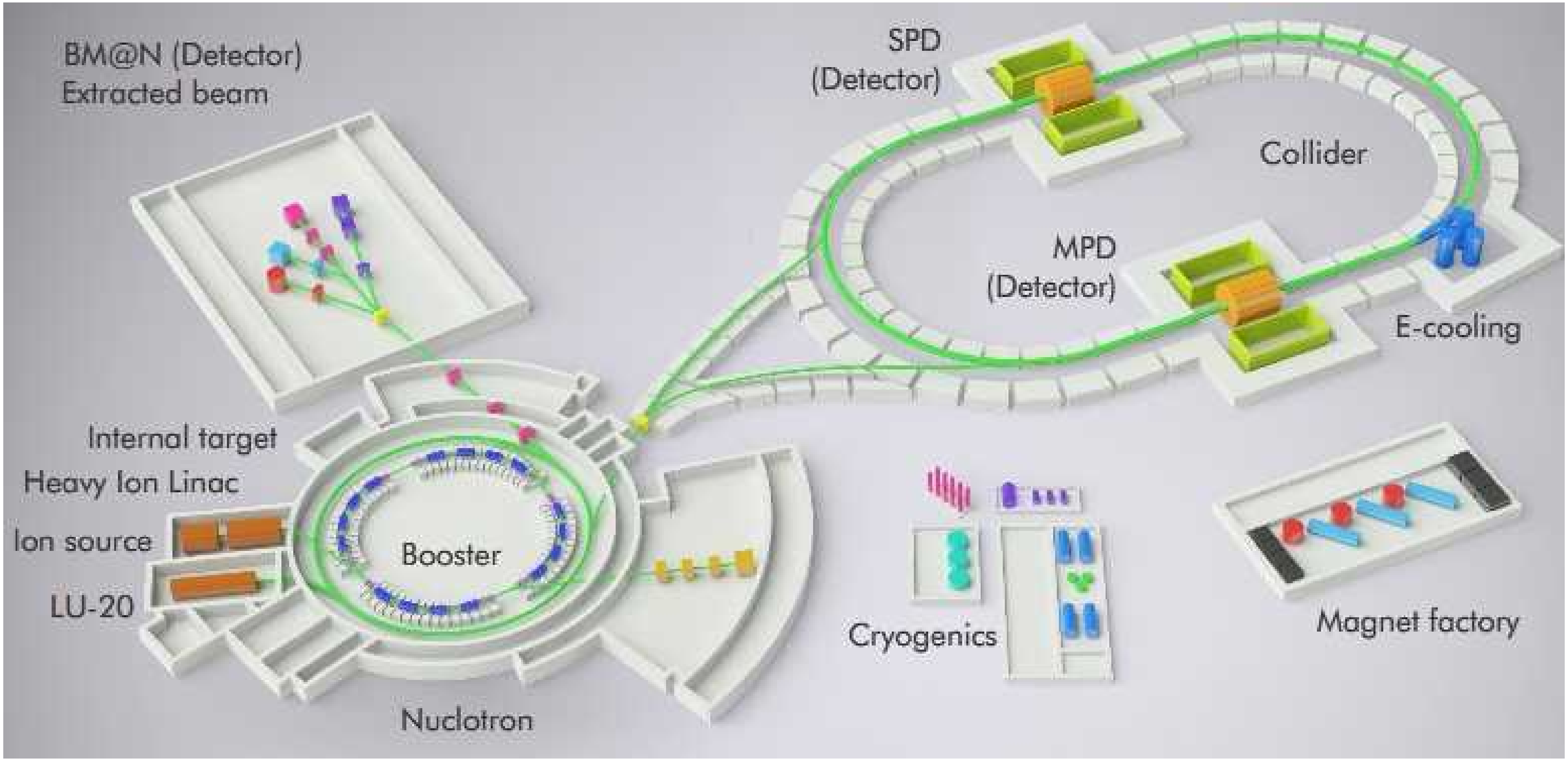
Beam energy (fixed target) - **1-6** GeV/u

Luminosity: 10^{27} cm^{-2}s^{-1}(Au), 10^{32} (p)

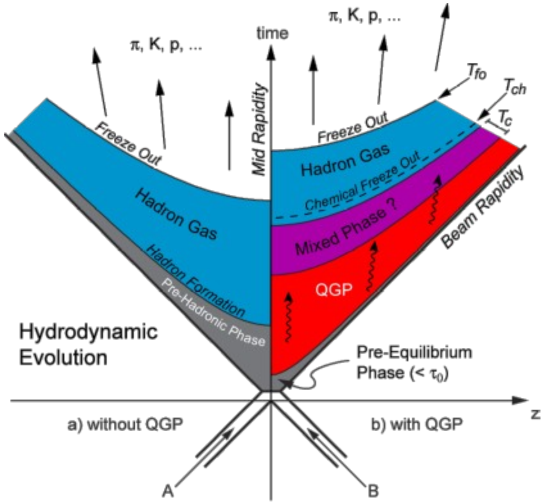
Experiments:

2 Interaction points – **MPD** and SPD

Fixed target experiment **BM@N**



QCD Phase diagram

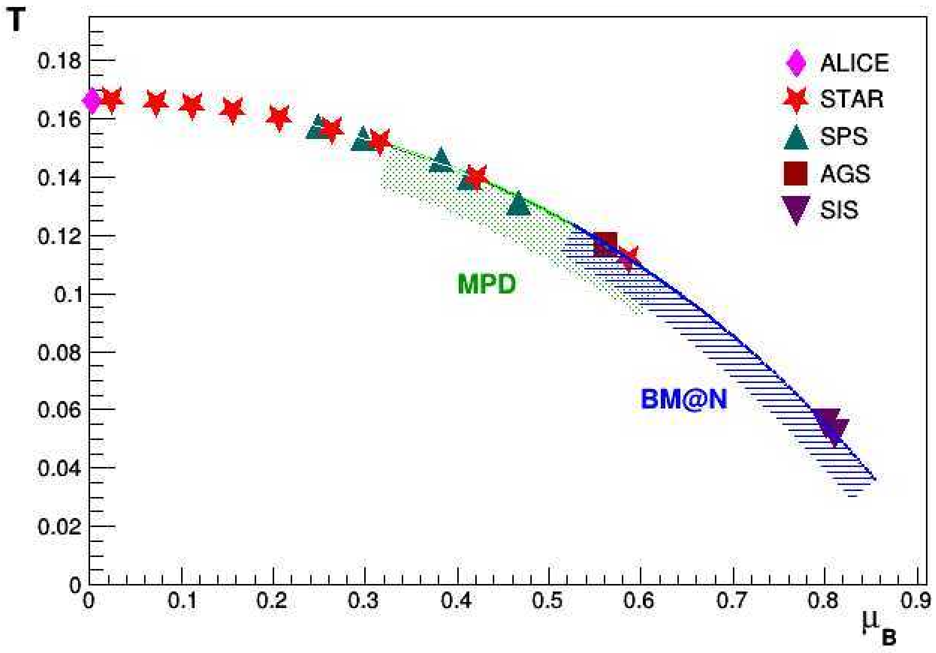


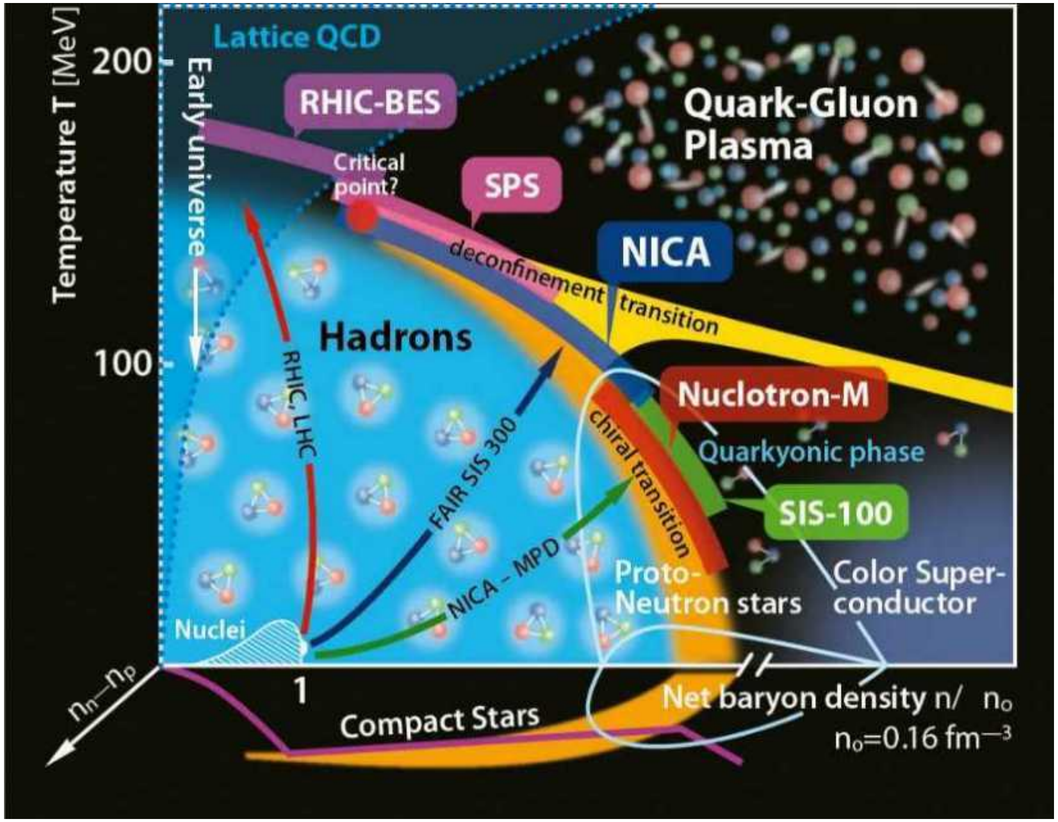
NICA energy scan:

MPD $4 < \sqrt{s} < 11$ GeV/u

BM@N $2.3 < \sqrt{s} < 3.4$ GeV/u

p, C, …, Au

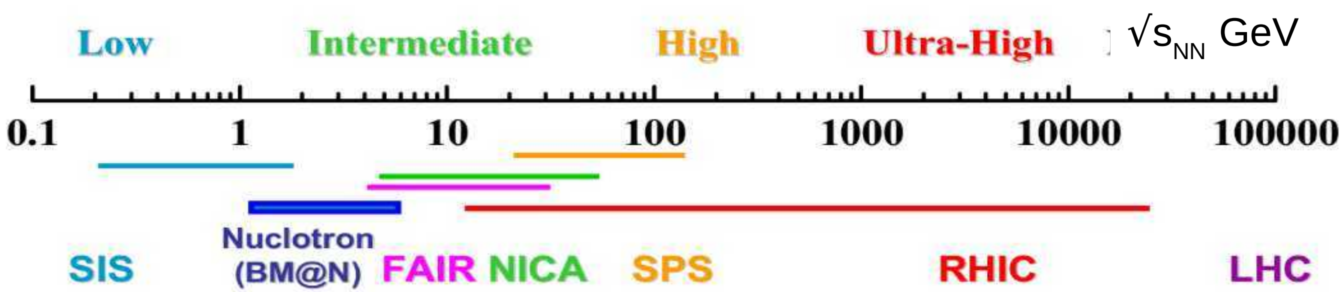




Current & future HI experiments

Facility	SPS	RHIC BES II	Nuclotron-M	NICA	SIS/100 (500 ?)	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	2020	2015	2021	2020/25	2009
$\sqrt{s_{NN}}$	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



CERN 2000

January 31, 2000

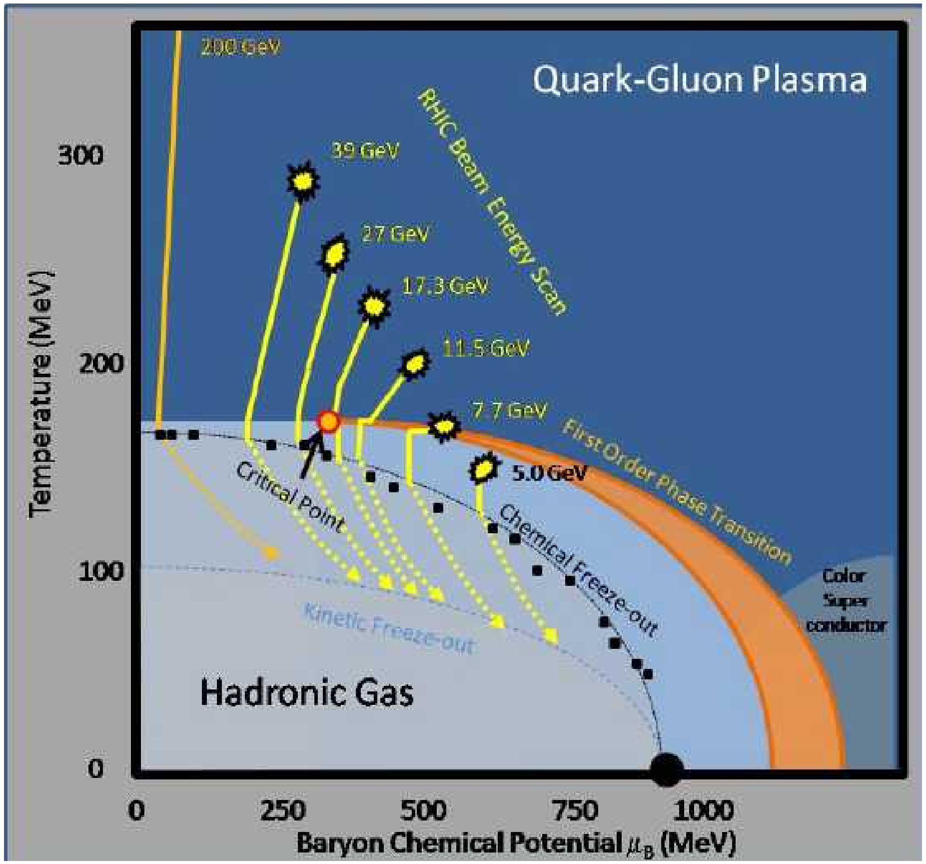
Evidence for a New State of Matter:
An Assessment of the Results from the CERN Lead Beam Programme

Ulrich Heinz and Maurice Jacob
Theoretical Physics Division, CERN, CH-1211 Geneva 23, Switzerland

A common assessment of the collected data leads us to conclude that we now have compelling evidence that a new state of matter has indeed been created, at energy densities which had never been reached over appreciable volumes in laboratory experiments before and which exceed by more than a factor 20 that of normal nuclear matter. The new state of matter found in heavy ion collisions at the SPS features many of the characteristics of the theoretically predicted quark-gluon plasma.

arXiv:nucl-th/0002042v1 16 Feb 2000

STAR BES program



Experimental Study of the QCD Phase Diagram and Search for the Critical Point: Selected Arguments for the Run-10 Beam Energy Scan at RHIC

The STAR Collaboration (B. I. Abelev et al.)

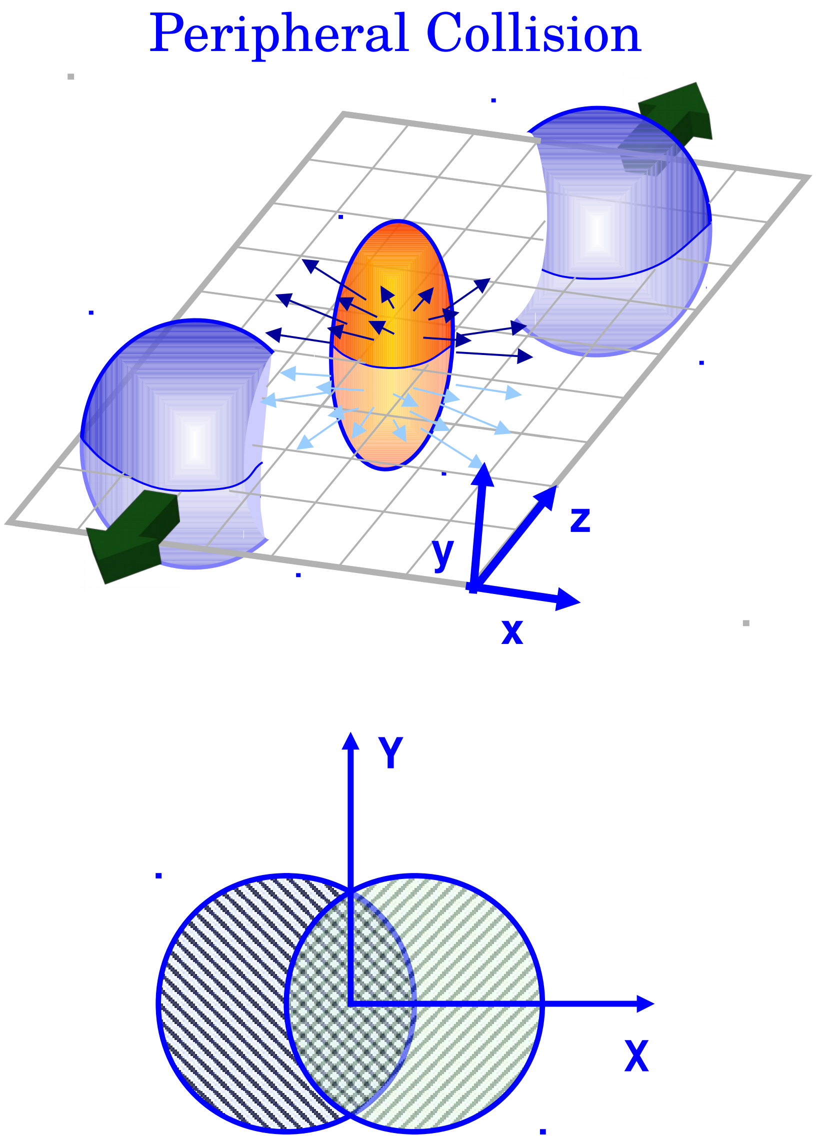
Introduction & Summary

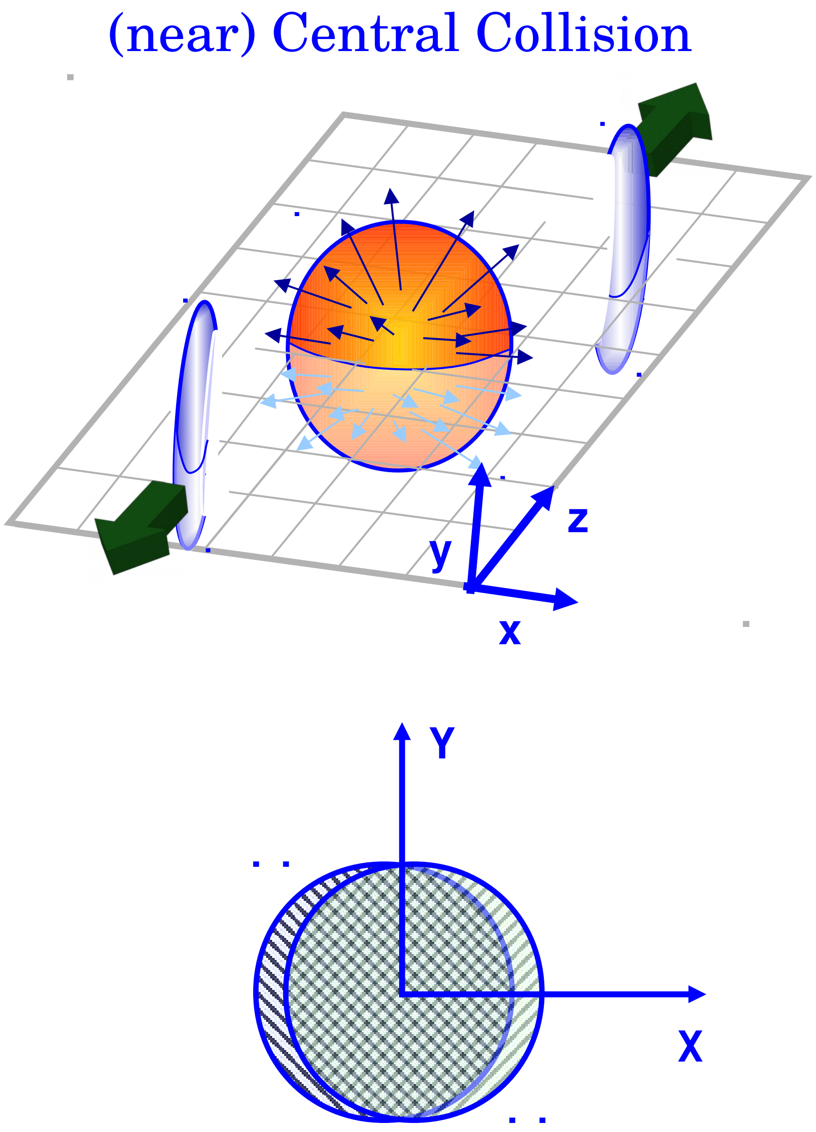
We present an overview of the main ideas that have emerged from discussions within STAR for the Beam Energy Scan (BES). The formulation of this concise and abridged document is facilitated by the existence of a much longer and more comprehensive companion document entitled *Experimental Exploration of the QCD Phase Diagram: Search for the Critical Point* [1]. The compelling arguments and motivations for the physics of our proposed Beam Energy Scan program, which have a particular role in guiding the run plan (see p. 13) as set out in our discussion of Tables 1 and 2, are (not in order of priority):

A. A search for turn-off of new phenomena already established at higher RHIC energies; QGP signatures are the most obvious example, but we define this category more broadly. If our current understanding of RHIC physics and these signatures is correct, a turn-off must be observed in several signatures, and such corroboration is an essential part of the "unfinished business" of QGP discovery [2]. The particular observables that STAR has identified as the essential drivers of our run plan are:
   (A-1) Constituent-quark-number scaling of v_2, indicating partonic degrees of freedom;
   (A-2) Hadron suppression in central collisions as characterized by the ratio R_{CP};
   (A-3) Untriggered pair correlations in the space of pair separation in azimuth and pseudorapidity, which elucidate the ridge phenomenon;
   (A-4) Local parity violation in strong interactions, an emerging and important RHIC discovery in its own right, is generally believed to require deconfinement, and thus also is expected to turn-off at lower energies.

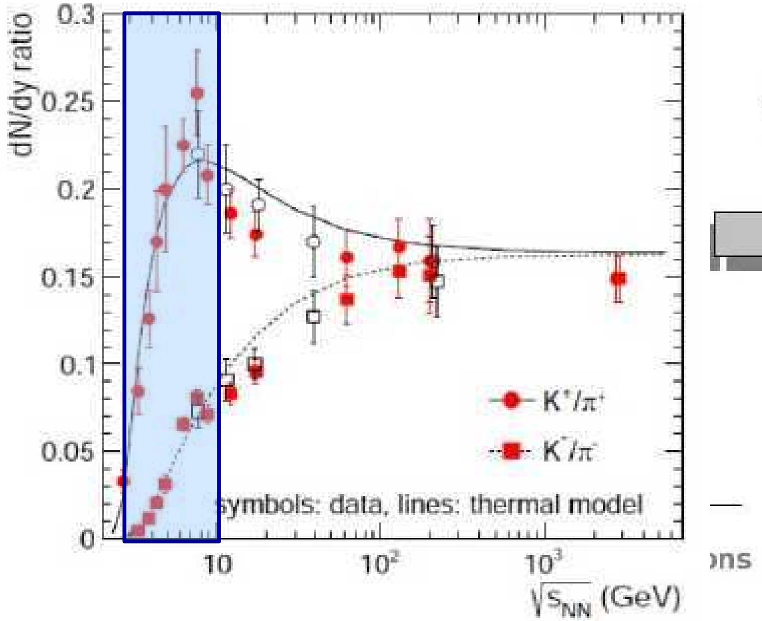
B. A search for signatures of a phase transition and a critical point. The particular observables that we have identified as the essential drivers of our run plan are:
   (B-1) Elliptic & directed flow for charged particles and for identified protons and pions, which have been identified by many theorists as highly promising indicators of a "softest point" in the nuclear equation of state;
   (B-2) Azimuthally-sensitive femtoscopy, which adds to the standard HBT observables by allowing the tilt angle of the ellipsoid-like particle source in coordinate space to be measured; these measurements hold promise for identifying a softest point, and complements the momentum-space information revealed by flow measurements, and
   (B-3) Fluctuation measures, indicated by large jumps in the baryon, charge and strangeness susceptibilities, as a function of system temperature – the most obvious expected manifestation of critical phenomena.

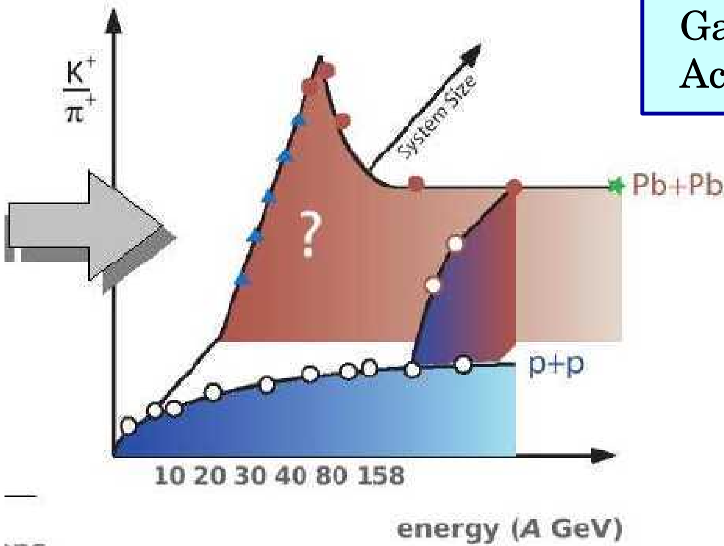
Nucleus collisions





NA49 energy & species scan

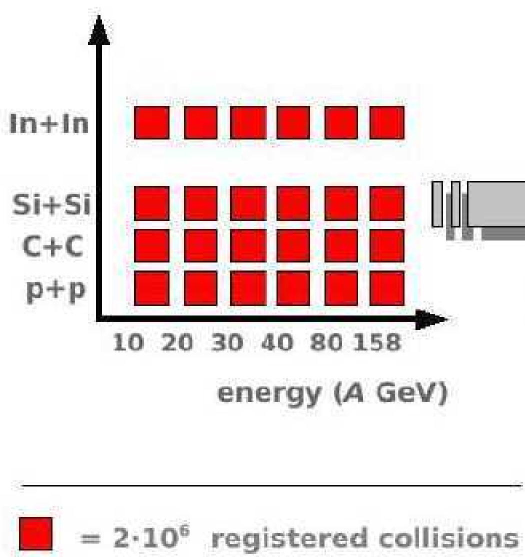


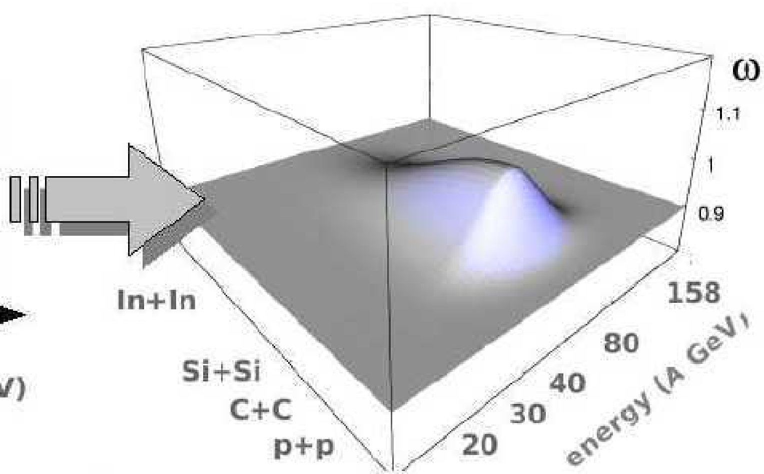


Gazdzicki M. Gorenstein M.
Acta. Phys. Pol., B30: 2705 1999

Horn
vanishing

arXiv:nucl-ex/0612007



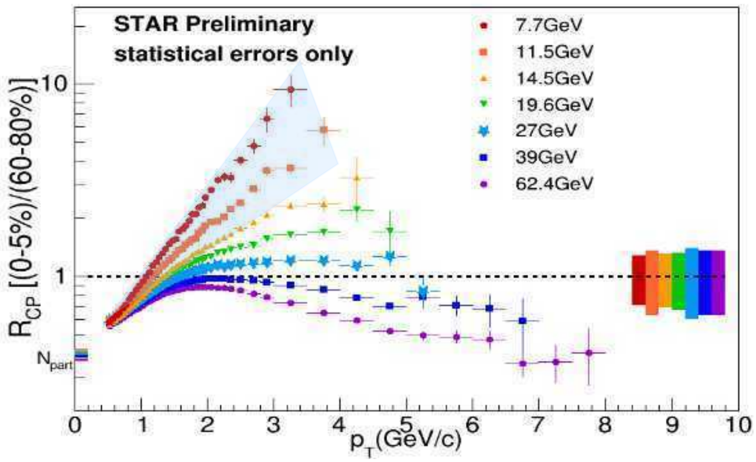


The scaled variance of the multiplicity distribution of negatively charged hadrons in the projectile hemi-sphere

STAR Beam Energy Scan results

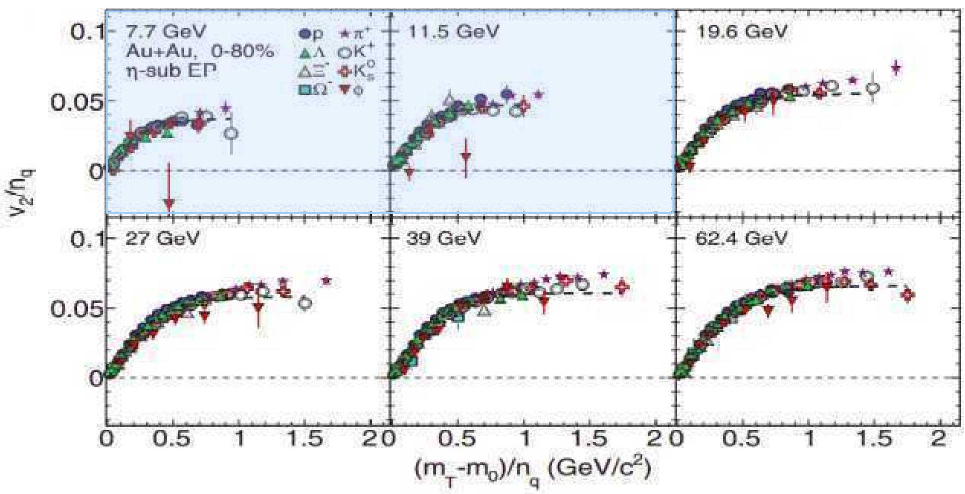
High P_T suppression

Stephen Horvat   Quark Matter 2015

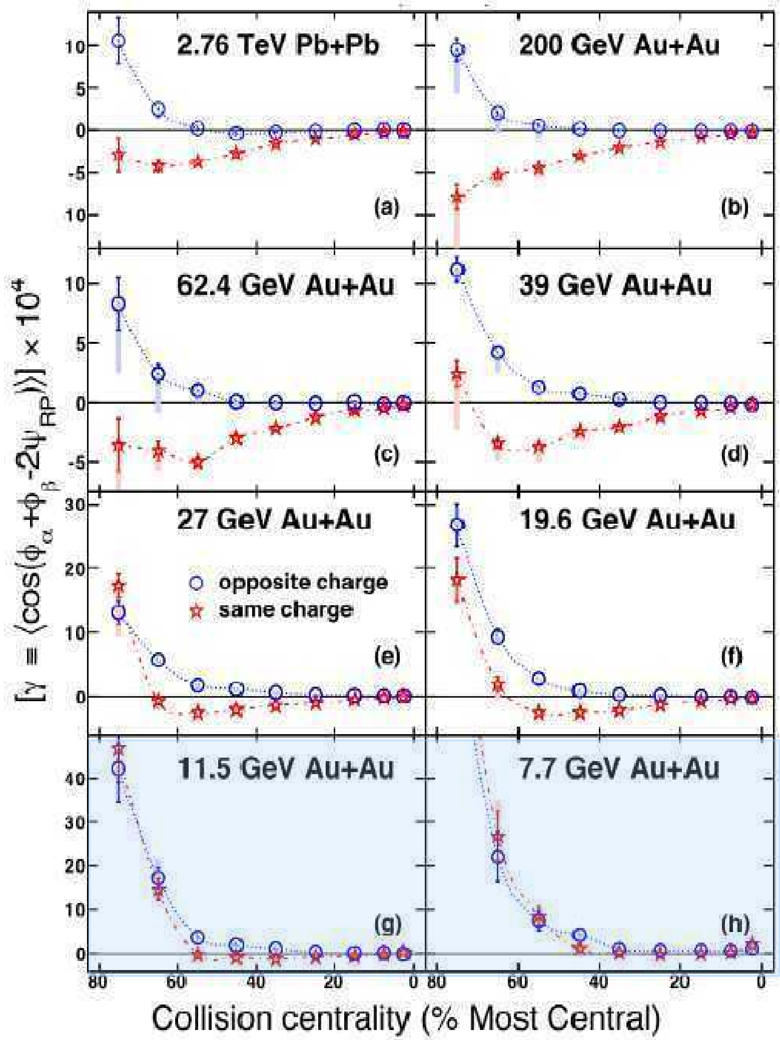


Number of constituent quarks scaling

Phys. Rev. C88, (2013), 014902



Chiral Magnetic Effect

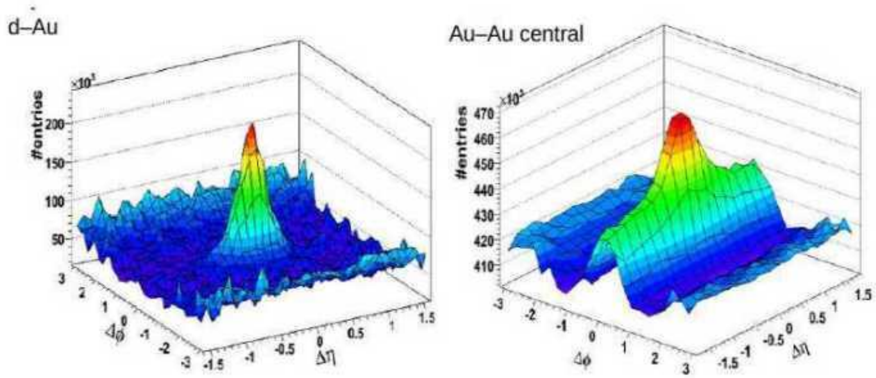


STAR BES I results

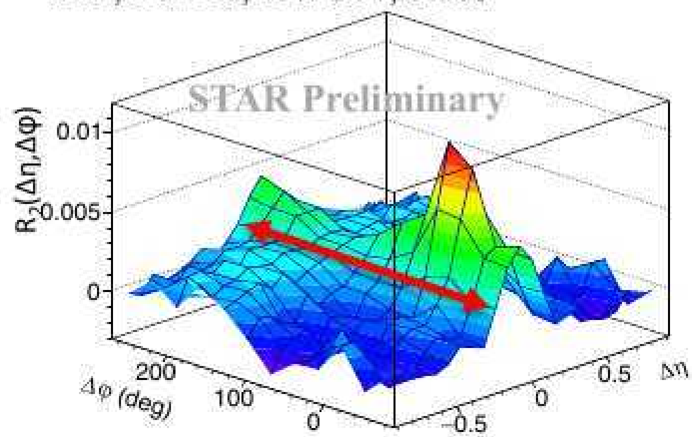
S. Jowzaee, Quark Matter 2017

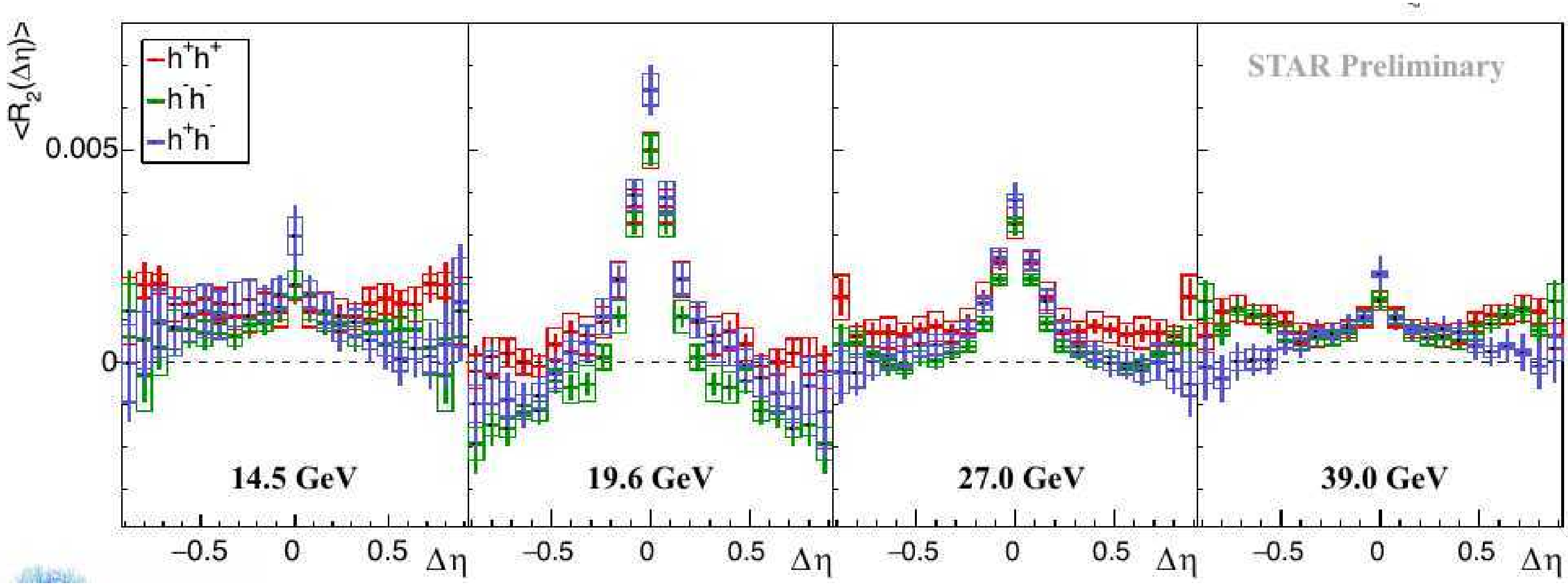
Ridge effect

B. Abelev et al., Phys. Rev. C80, 064912 (2009).



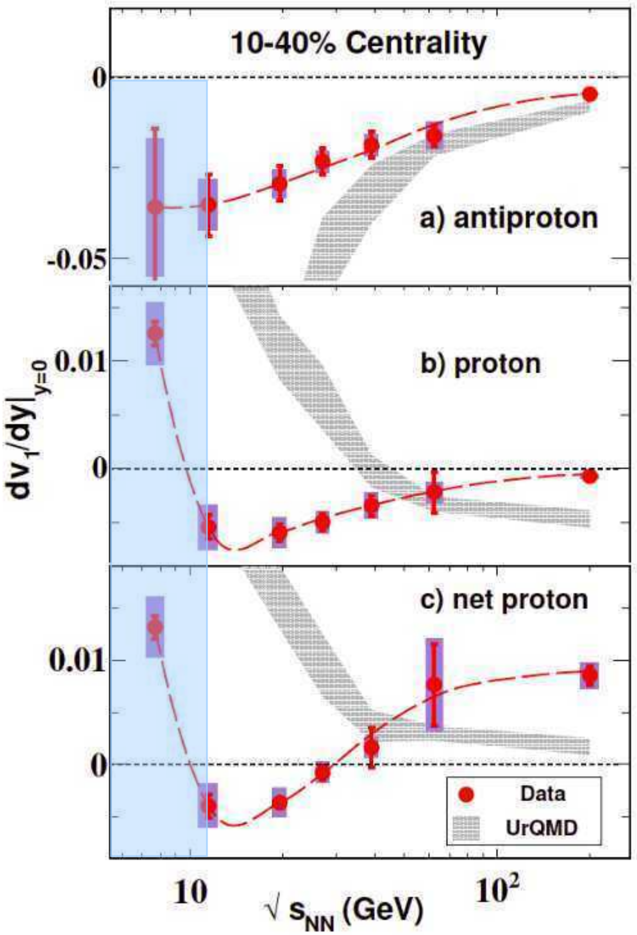
h^+h^+, Au+Au, 19.6GeV, 0-5%





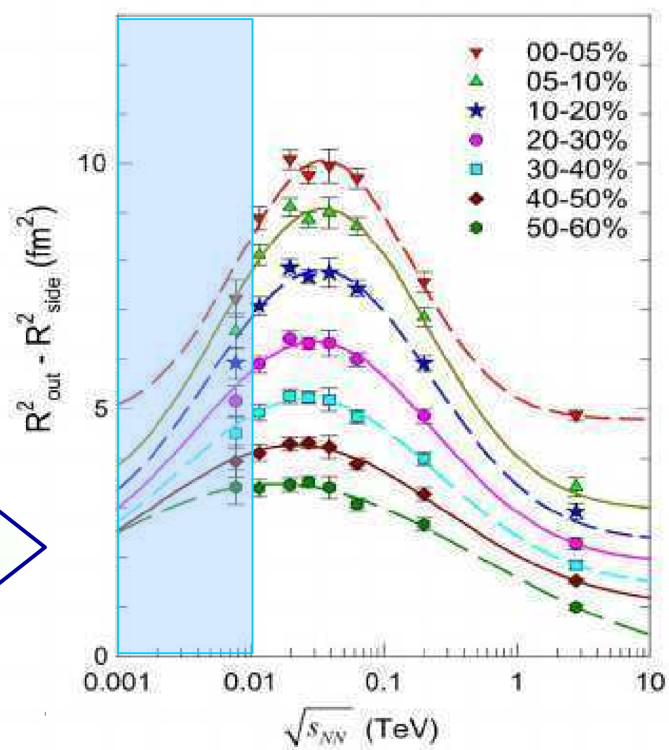
STAR BES I results

PRL 112 (2014) 162301



The rapidity-slope of the net proton directed flow v_1 , dv_1/dy. This quantity is sensitive to early pressure gradients in the medium.

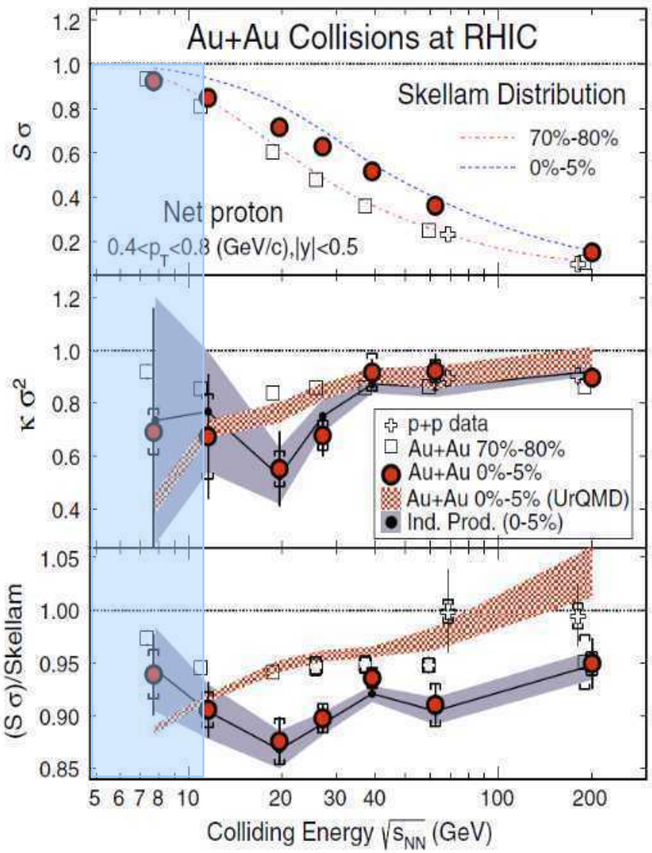
R. Lacey, PRL 114, 142301 (2015)



R^2_{out} - R^2_{side} – reflects the lifetime of the collision fireball and was predicted to reach a maximum for collisions in which a hydrodynamic fluid forms at temperatures where the equation of state is softest.

STAR BES I results

STAR, PRL 112, 032302 (2014)



The kurtosis of the event-by-event distribution of the net proton (i.e. proton minus antiproton) number per unit of rapidity, normalized such that Poisson fluctuations give a value of 1.

In central collisions, published results in a limited kinematic range show a drop below the Poisson baseline around $\sqrt{s_{NN}}$ =27 and 19.6 GeV.

New preliminary data over a larger p_T range, although at present still with substantial error bars, hint that the normalized kurtosis may, in fact, rise above 1 at lower $\sqrt{s_{NN}}$, as expected from critical fluctuations..

The grey band shows the much reduced uncertainties anticipated from BES-II in 2018-2019, for the 0-5% most central collisions.

Strangeness enhancement

J. Rafelski and B. Müller, PRL 48, 1066 (1982)

Strangeness Production in the Quark-Gluon Plasma

Johann Rafelski and Berndt Müller

Institut für Theoretische Physik, Johann Wolfgang Goethe-Universität, D-6000 Frankfurt am Main, Germany

(Received 11 January 1982)

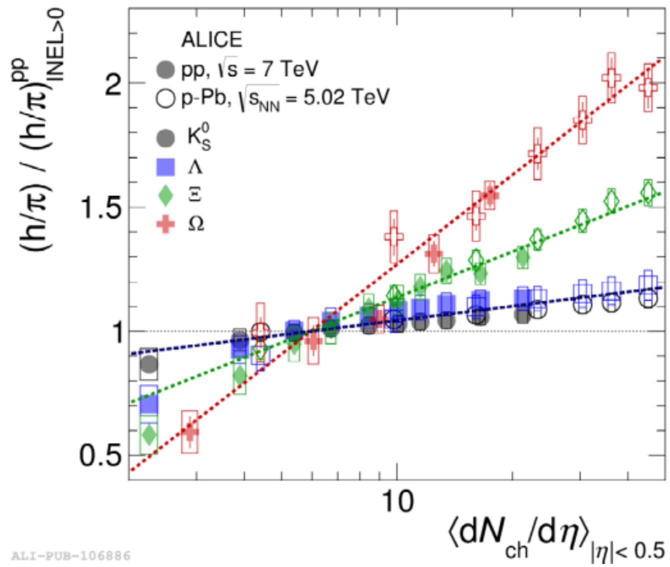
Rates are calculated for the processes $gg \to s\bar{s}$ and $u\bar{u}, d\bar{d} \to s\bar{s}$ in highly excited quark-gluon plasma. For temperature $T \geq 160$ MeV the strangeness abundance saturates during the lifetime ($\sim 10^{-23}$ sec) of the plasma created in high-energy nuclear collisions. The chemical equilibration time for gluons and light quarks is found to be less than 10^{-24} sec.

PACS numbers: 12.35.Ht, 21.65.+f

....

We thus conclude that strangeness abundance saturates in sufficiently excited quark-gluon plasma ($T > 160$ MeV, $E > 1$ GeV/fm^3), allowing us to utilize enhanced abundances of rare, strange hadrons ($\bar{\Lambda}$, $\bar{\Omega}$, etc.) as indicators for the formation of the plasma state in nuclear collisions.

Nature Physics 13 (2017) 535



First observation of a multiplicity dependent strangeness enhancement in high-multiplicity pp collisions

- enhancement is due to strangeness content and not due to mass
- multiplicity dependence of the enhancement is strikingly similar in pp and p-Pb, and approaches values similar to those measured in central Pb-Pb
- QCD inspired MC generators fail to describe these observations
- measurements in pp @ 13 TeV seems to indicate that hadrochemistry is driven by event activity regardless of collision energy

Collective phenomena

Volume 157B, number 2,3 PHYSICS LETTERS 11 July 1985

TRANSVERSE MOMENTUM ANALYSIS OF COLLECTIVE MOTION IN RELATIVISTIC NUCLEAR COLLISIONS *

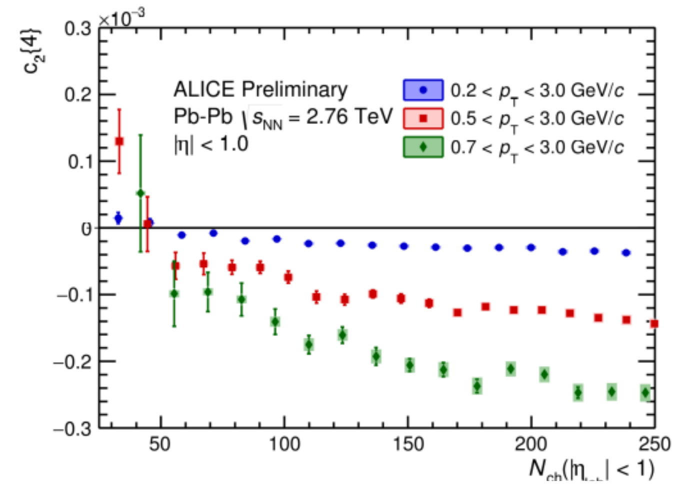
P. DANIELEWICZ [1] and G. ODYNIEC
Nuclear Science Division, Lawrence Berkeley Laboratory, University of California, Berkeley, CA 94720, USA

Received 15 March 1985

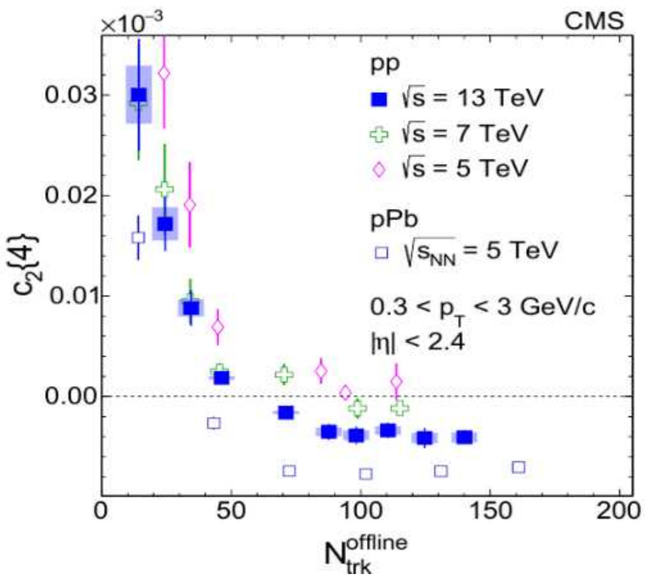
A novel transverse-momentum technique is used to analyse charged-particle exclusive data for collective motion in the Ar + KCl reaction at 1.8 GeV/nucleon. Previous analysis of this reaction, employing the standard sphericity tensor, revealed no significant effect. In the present analysis, collective effects are observed, and they are substantially stronger than in the Cugnon cascade model, but weaker than in the hydrodynamical model.

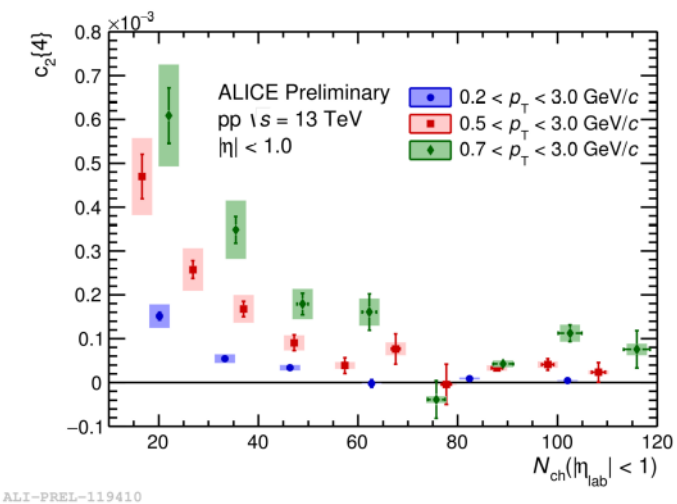
Katarina Gajdosova ISMD 2017

ALICE has not measured a definitive flow-like signature in pp collisions using c 2 {4}



Evidence for collectivity in pp collisions at the LHC
The CMS Collaboration





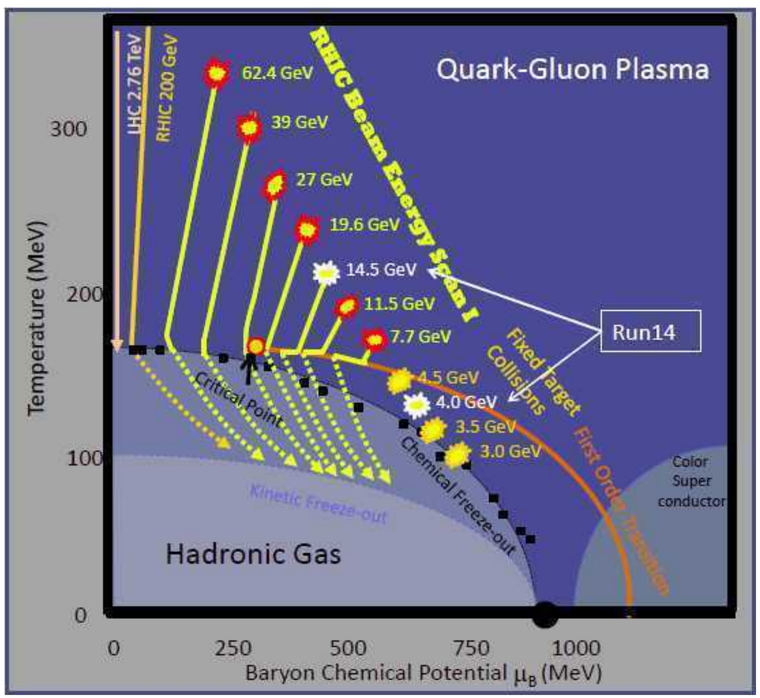
STAR Beam Energy Scan program

BES I

$\sqrt{s_{NN}}$ (GeV)	μ_B (MeV)	MinBias Events (10^6)	Time (weeks)	Year
7.7	420	4.3	4	2010
11.5	315	11.7	2	2010
14.5	**260**	**24.0**	**3**	**2014**
19.6	205	35.8	1.5	2011
27.0	155	70.4	1	2011
39.0	115	130.4	2	2010
62.4	70	67.3	1.5	2010

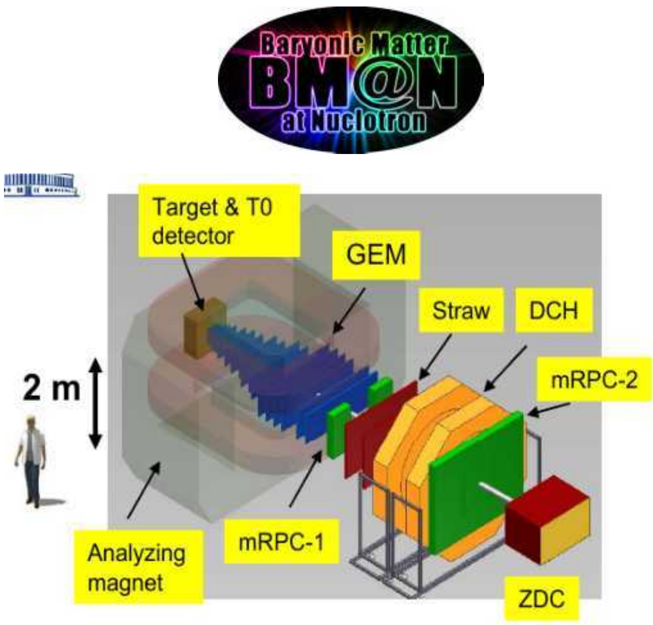
BES II

$\sqrt{s_{NN}}$ (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

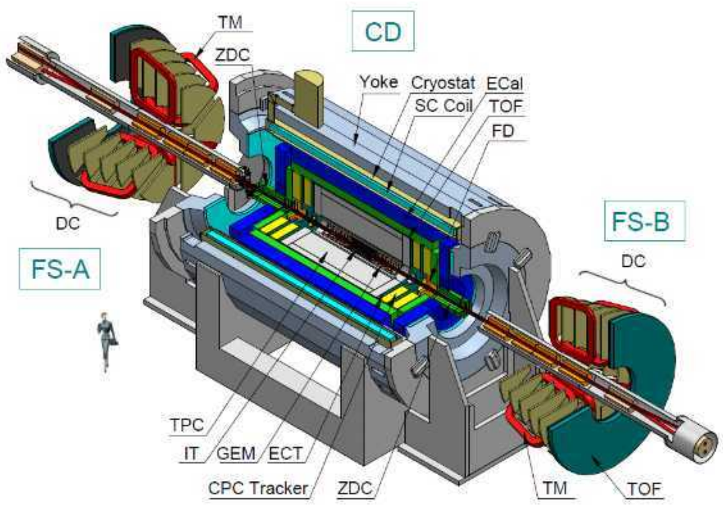


Year	System and Energy	Physics/Observables	Upgrade
2017	• p+p @ 500 GeV • Au+Au @ 62.4 GeV	• Spin sign change diffractive • Jets	FMS post-shower, EPD (1/8th), eTOF prototype
2018	• Zr+Zr, Ru+Ru @ 200 GeV • Au+Au @ 27 GeV	• CME, di-leptons • CVE	Full EPD? eTOF prototype
2019	Au+Au @ 14.5-20 GeV + fixed 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,…	
2020+	• Au+Au @ 200 GeV • p+A/p+p @ 200 GeV	• Unbiased jets, open beauty • PID FF, Drell-Yan, longitudinal correlations	• HFT+ • FCS, FTS

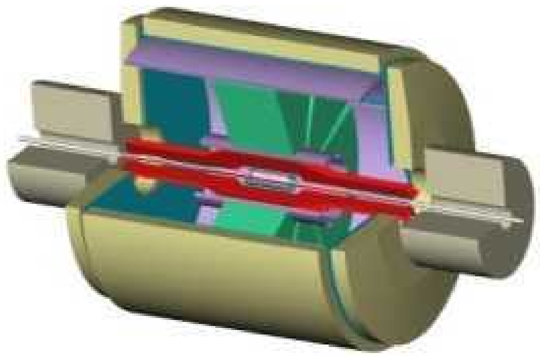
NICA experiments
&
Physics feasibility study



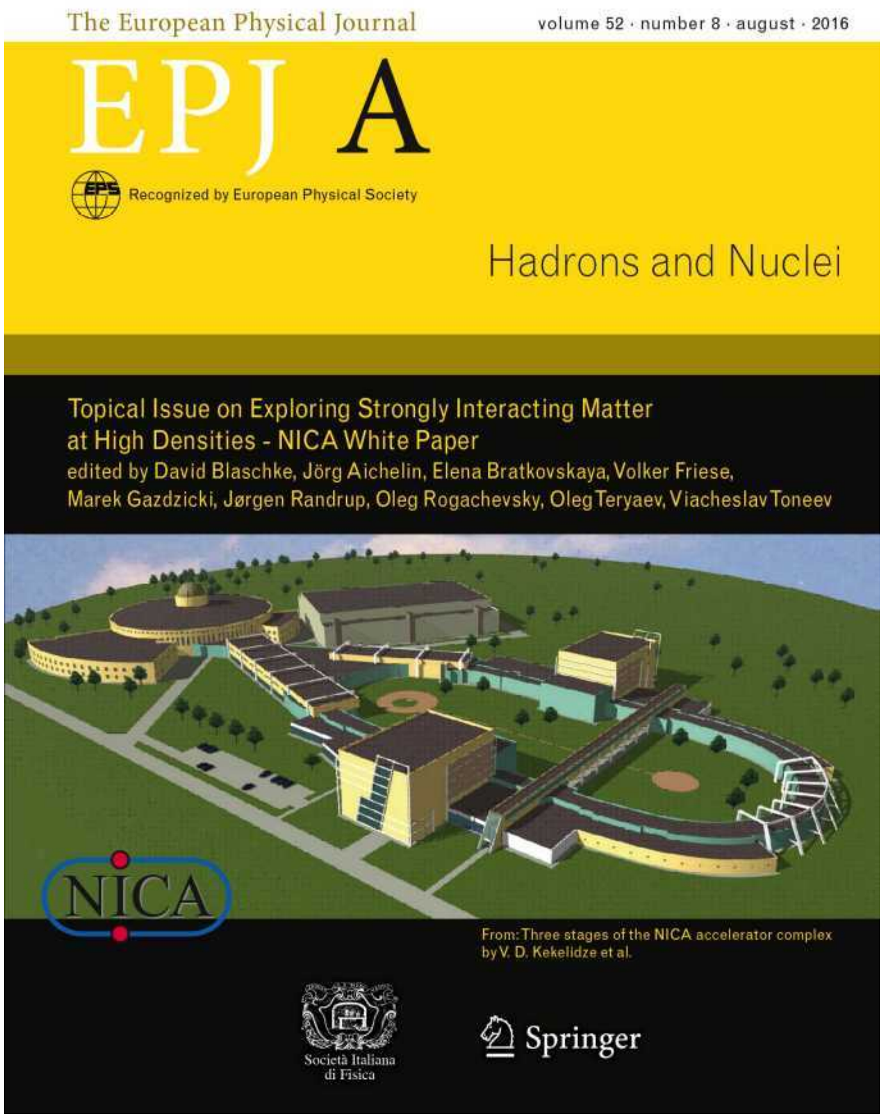
MPD



SPD



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.

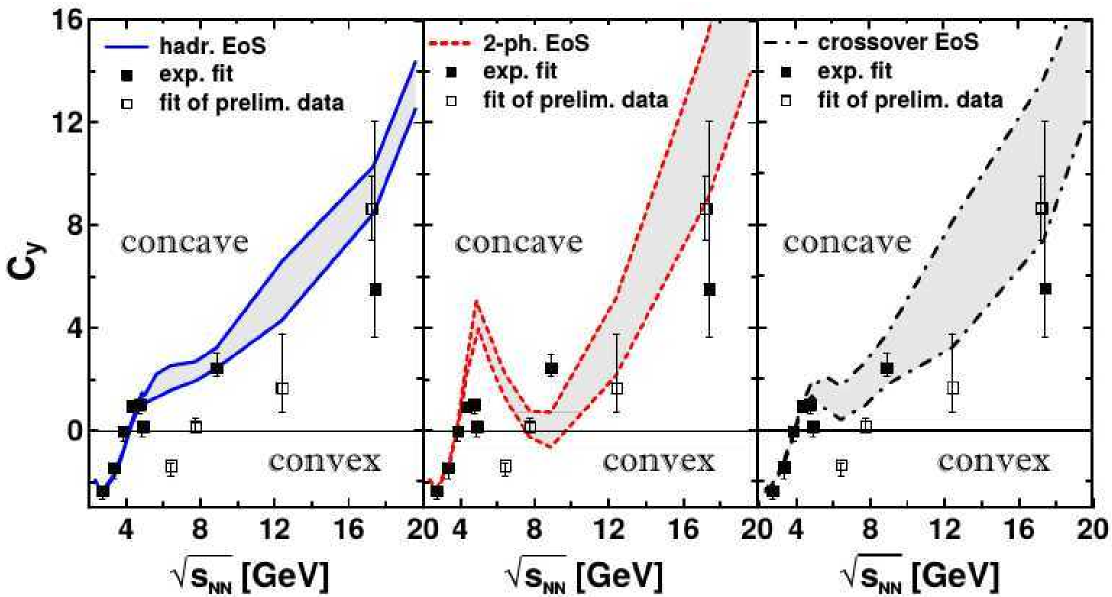
The available observations of an enhancement of dilepton rates at low invariant masses may serve as a signal of the chiral symmetry restoration in hot and dense matter. Due to this fact, measurements of the dilepton spectra are considered to be an important part of the NICA physics program. The study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

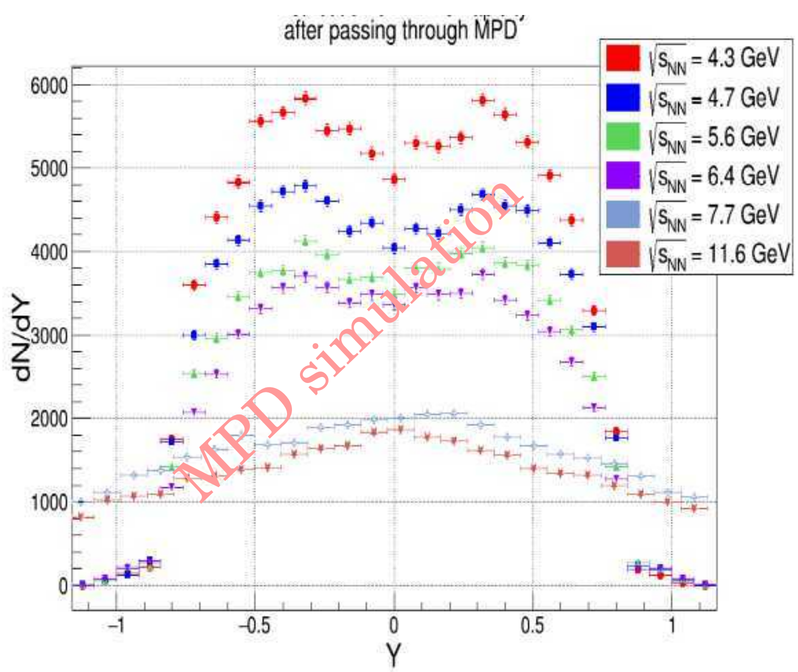
In this paper a feasibility of the considered investigations is shown by the detailed Monte Carlo simulations applied to the planned experiments (BM@N, MPD) at NICA.

Baryon stopping power

3FD

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



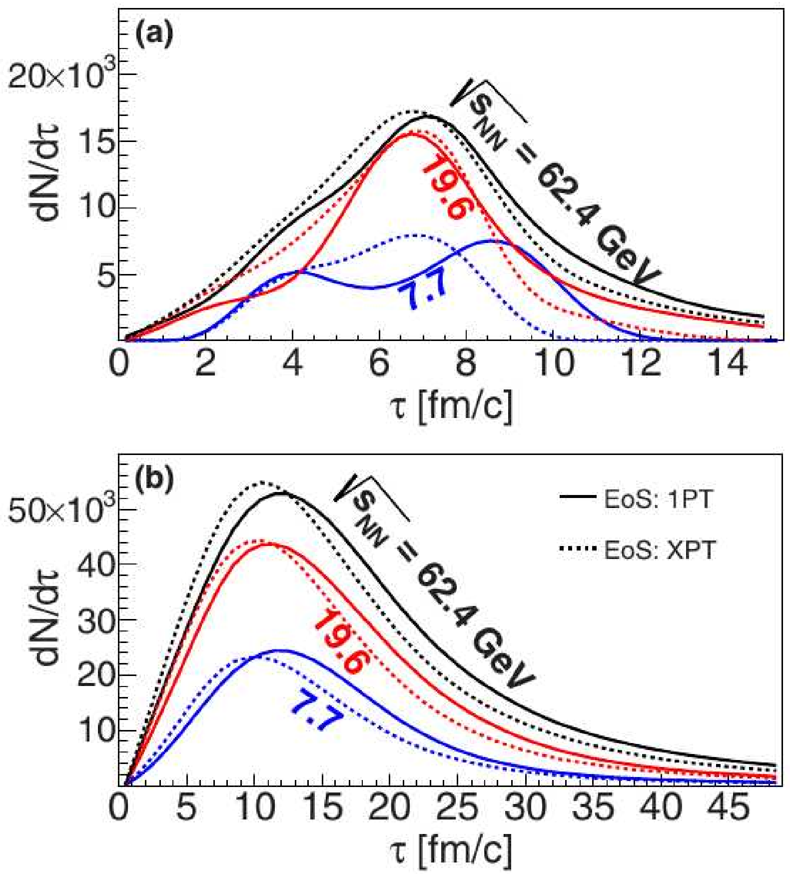


Yu.B. Ivanov, PL B721 (2013) 123
arXiv:1211.2579

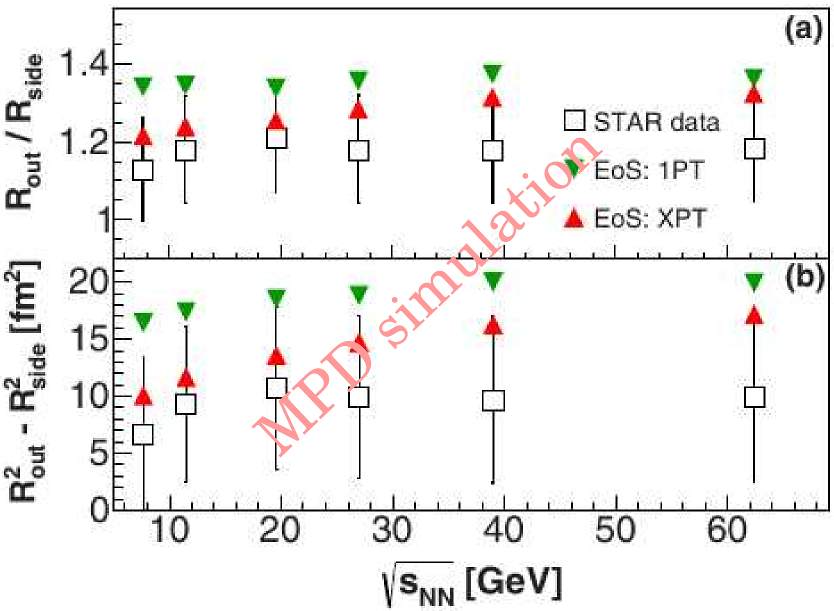
Femtoscopy for NICA

PHYSICAL REVIEW C 96, 024911 (2017)

vHLLE + UrQMD model

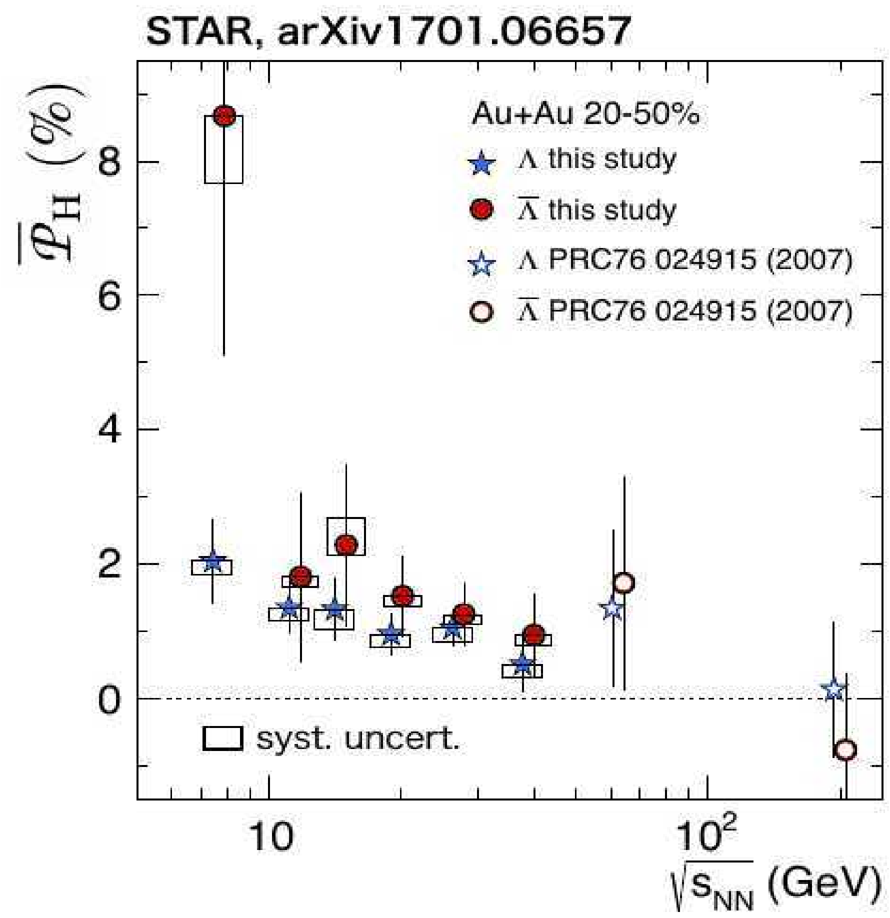


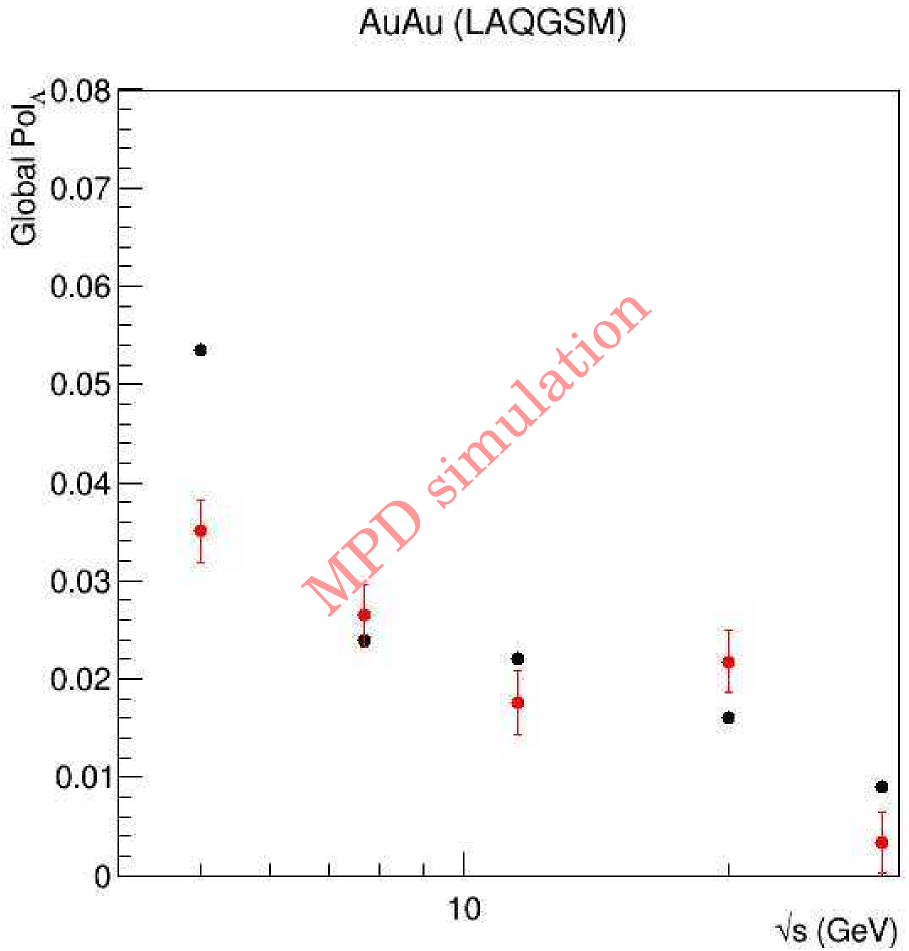
Pion emission times at the particlization surface (a) and the last interactions (b) in the center-of-mass system of colliding gold nuclei at different values of $\sqrt{s_{NN}}$.



Ratio of the out and side radii (a) and difference of the radii squared (b) as a function of $\sqrt{s_{NN}}$ derived from the STAR data (0.15 < kT < 0.25 GeV/c, 0–5% centrality) and compared with the model calculations using the two EoSs.

Global Λ polarization for MPD

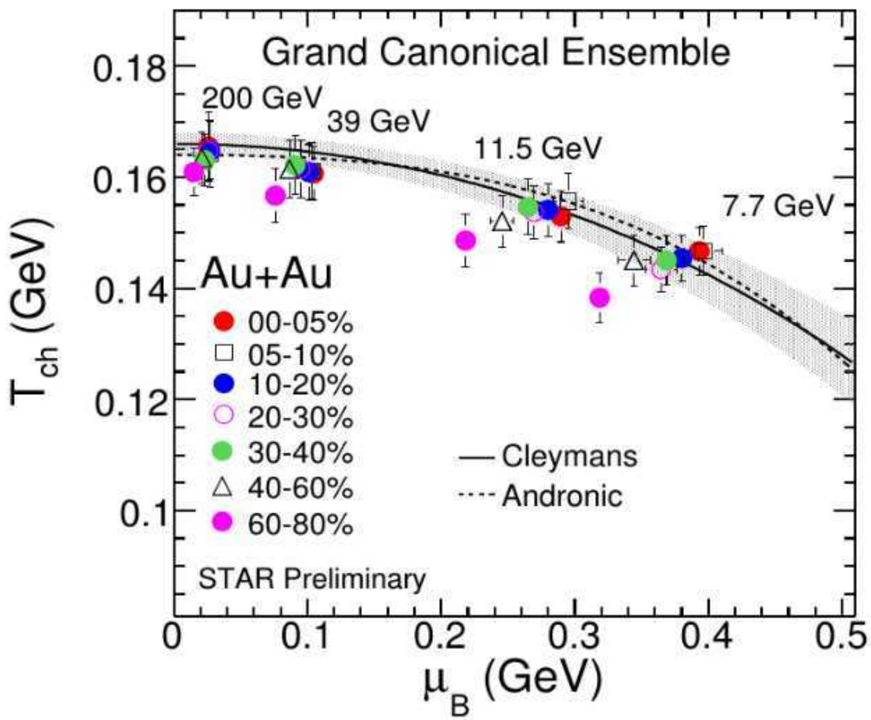




QCD Phase diagram

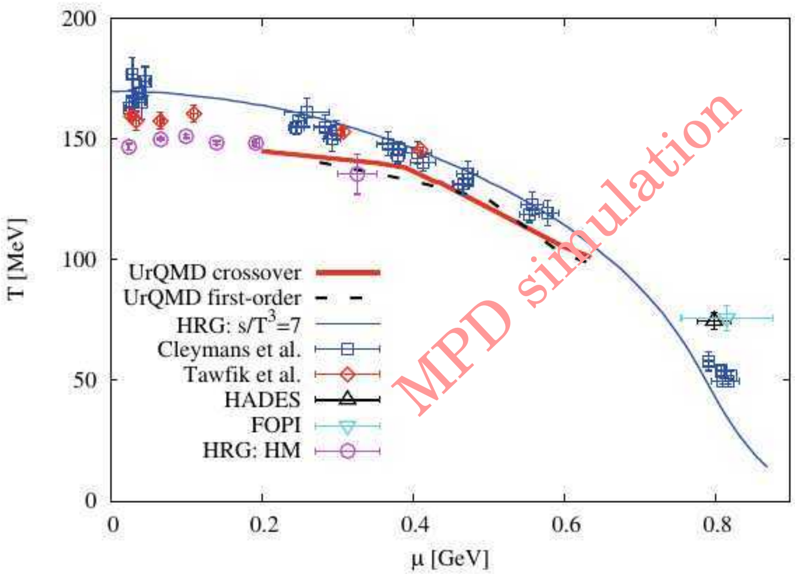
Grazyna Odyniec JoP 455 (2013) 012037

STAR BES

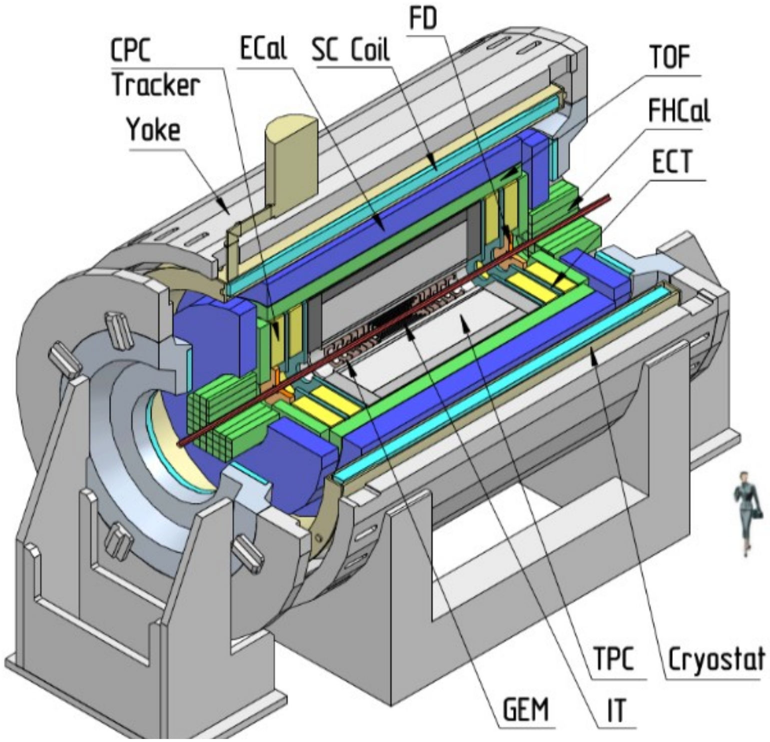


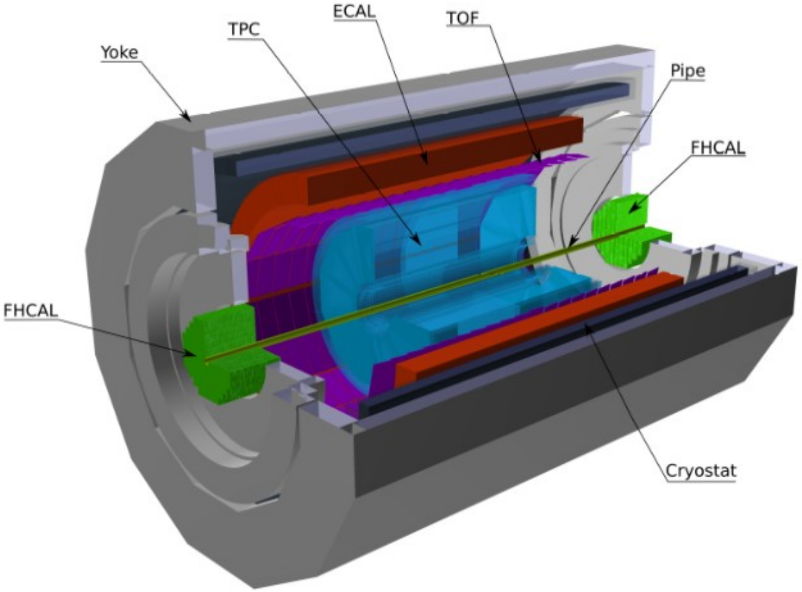
The dependence of T_{ch} on μ_B, fitted with the Grand Canonical approach in THERMUS Model

Eur. Phys. J. A (2016) 52: 324

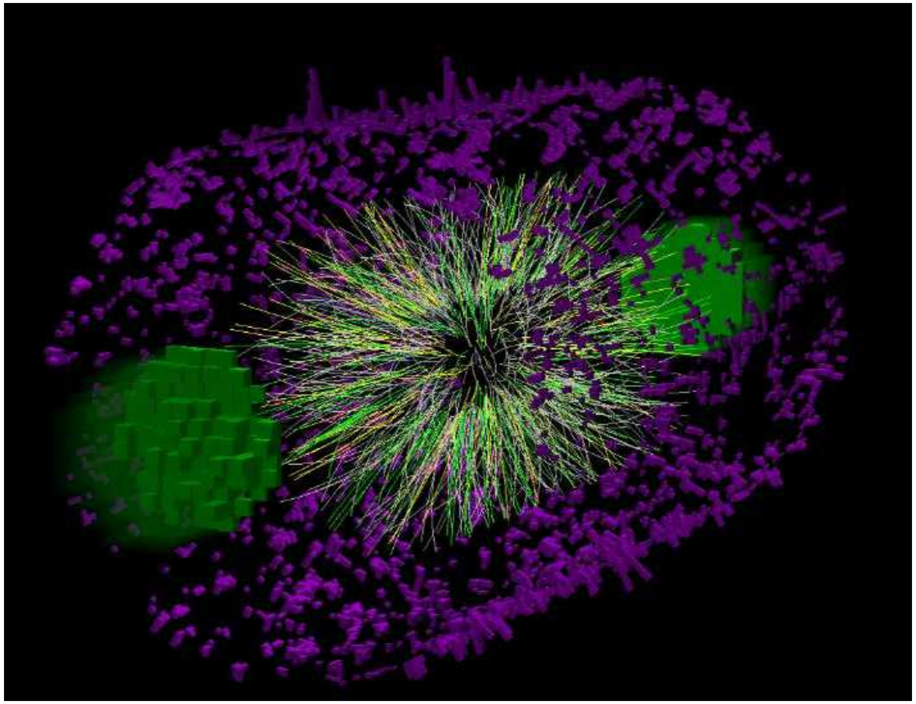


MPD experiment at NICA



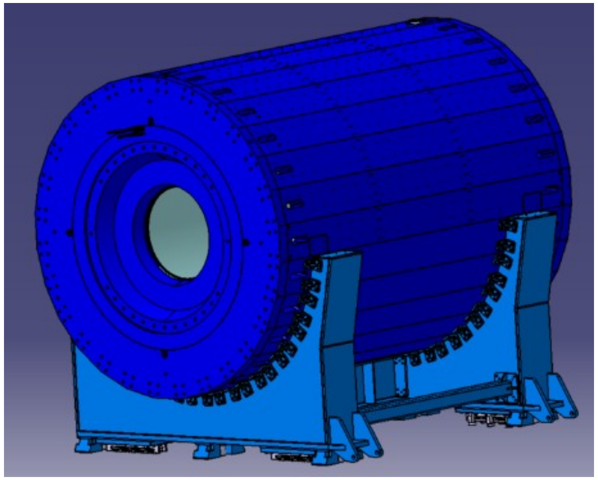


AuAu $\sqrt{s}$ = 11 GeV



MPD solenoid yoke

VHM, Vitkovice, Czech republic

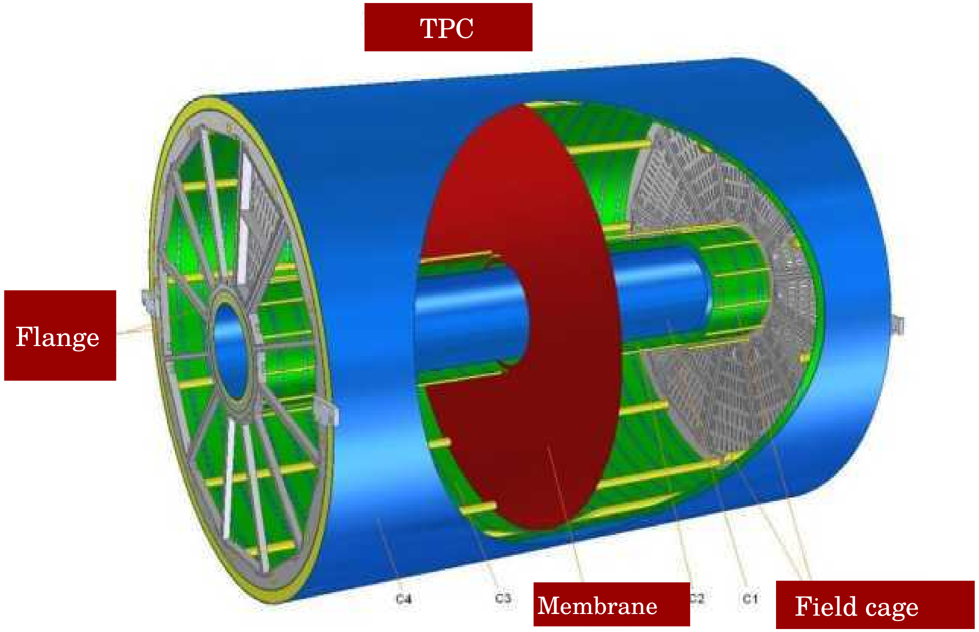


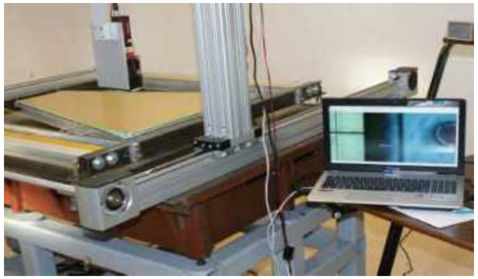
- **Iron Yoke**

Outer diameter	6583 mm
Length	9010 mm
Dist. In between poles	7390 mm
Weight	727 ton

28 plates 16 T each
2 support rings 42.5 T each
2 poles 50 T each

MPD Time Projection Chamber

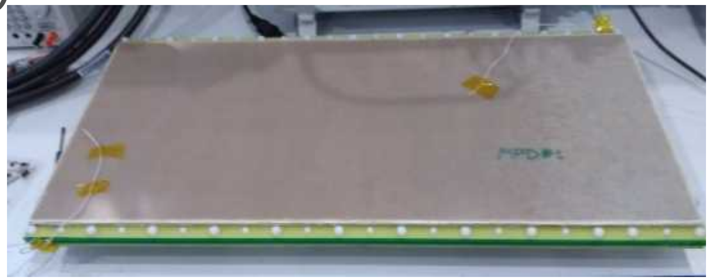


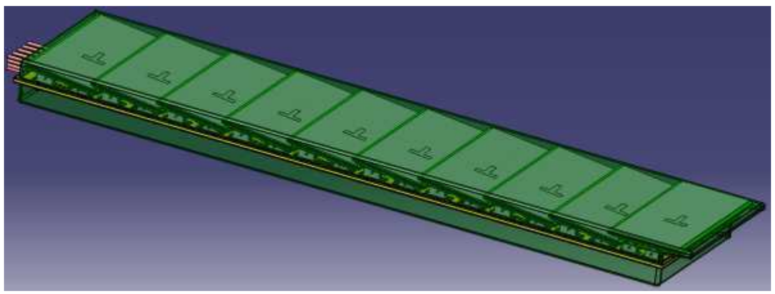


Item	Dimension
Length of the TPC	340cm
Outer radius of vessel	140cm
Inner radius of vessel	27 cm
Outer radius of the drift volume	133cm
Inner radius of the drift volume	34cm
Length of the drift volume	170cm (of each half)
HV electrode	Membrane at the center of the TPC
Electric field strength	~140V/cm;
Magnetic field strength	0.5 Tesla
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
Pad numbers after zero suppression	< 10%
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

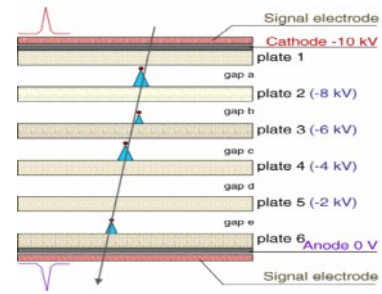
Time Of Flight detector

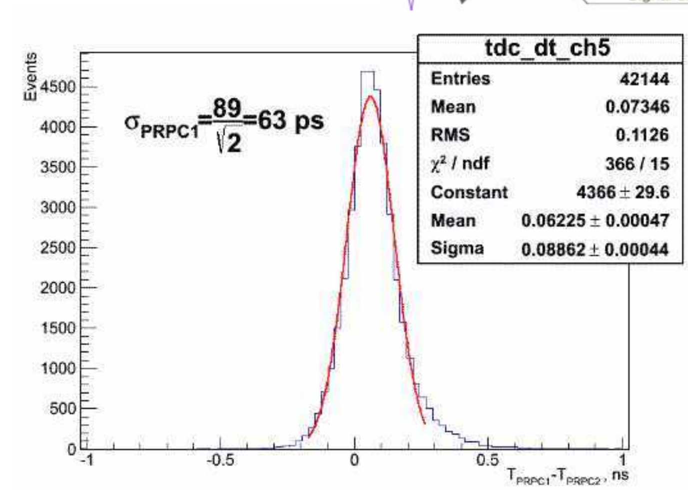
mRPC prototype with a strip





multigap resistive plate chamber

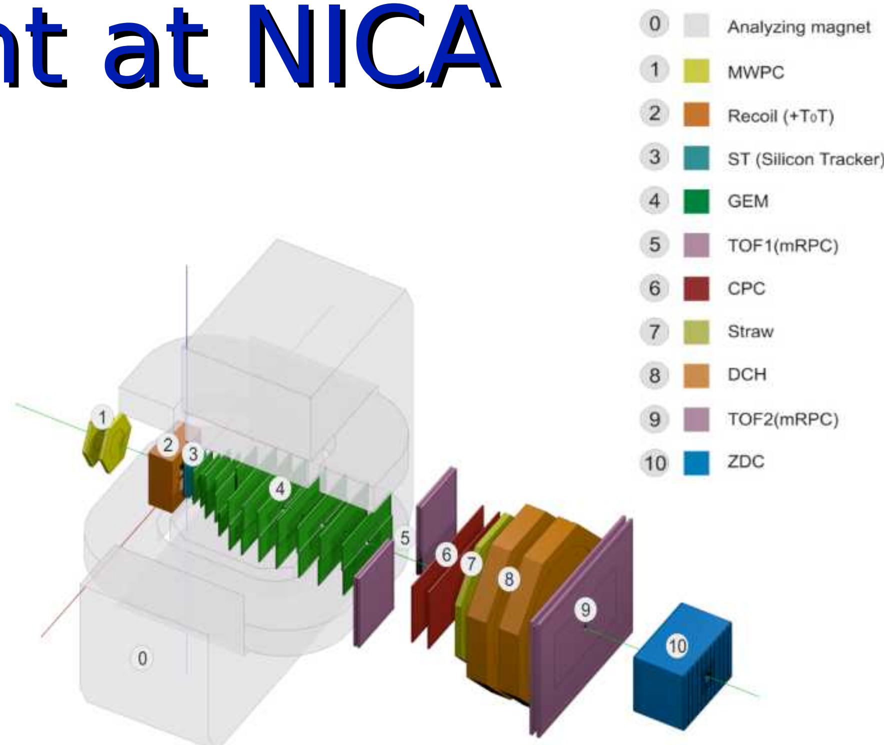




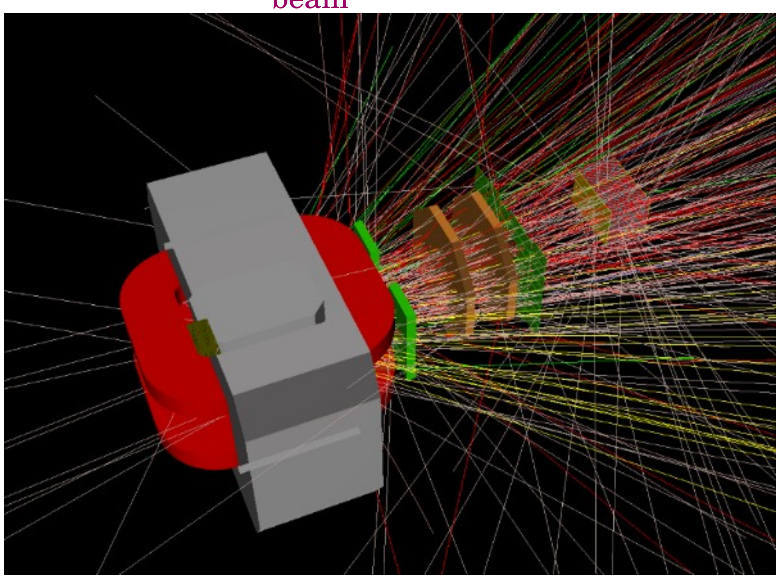
(T1 - T2) for two mRPCs

Full scale mRPC prototype with a strip

BM@N experiment at NICA

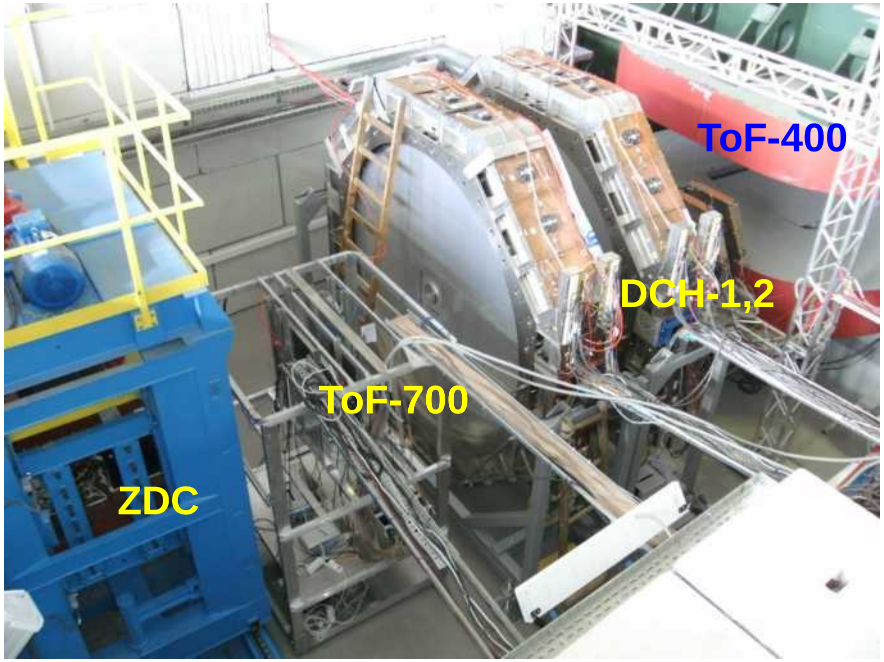


AuAu E_{beam} = 4 GeV



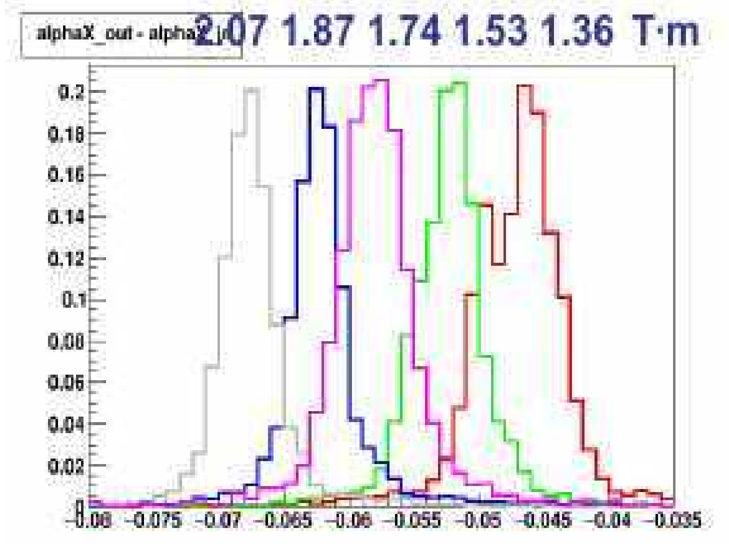
year	2016	2017 spring	2017 autumn	2019	2020 and later
beam	d(↑)	C, Ar	Kr	Au	Au, p
max.intensity, Hz	1M	1M	1M	1M	10M
trigger rate, Hz	10k	10k	20k	20k	50k
central tracker status	6 GEM half pl.	8 GEM half pl.	10 GEM half pl.	8 GEM full pl.	12 GEMs or 8 GEMs + Si planes
experim. status	techn. run	techn. run	physics run	stage 1 physics	stage 2 physics

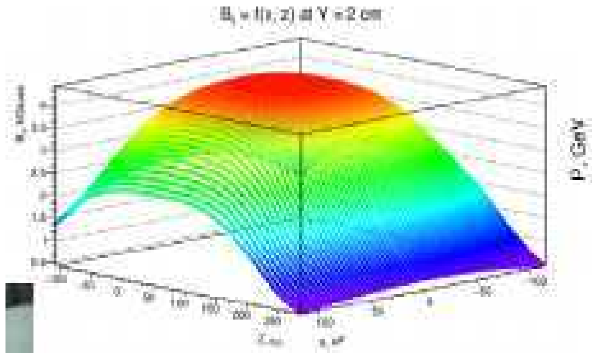
BM@N experiment at NICA

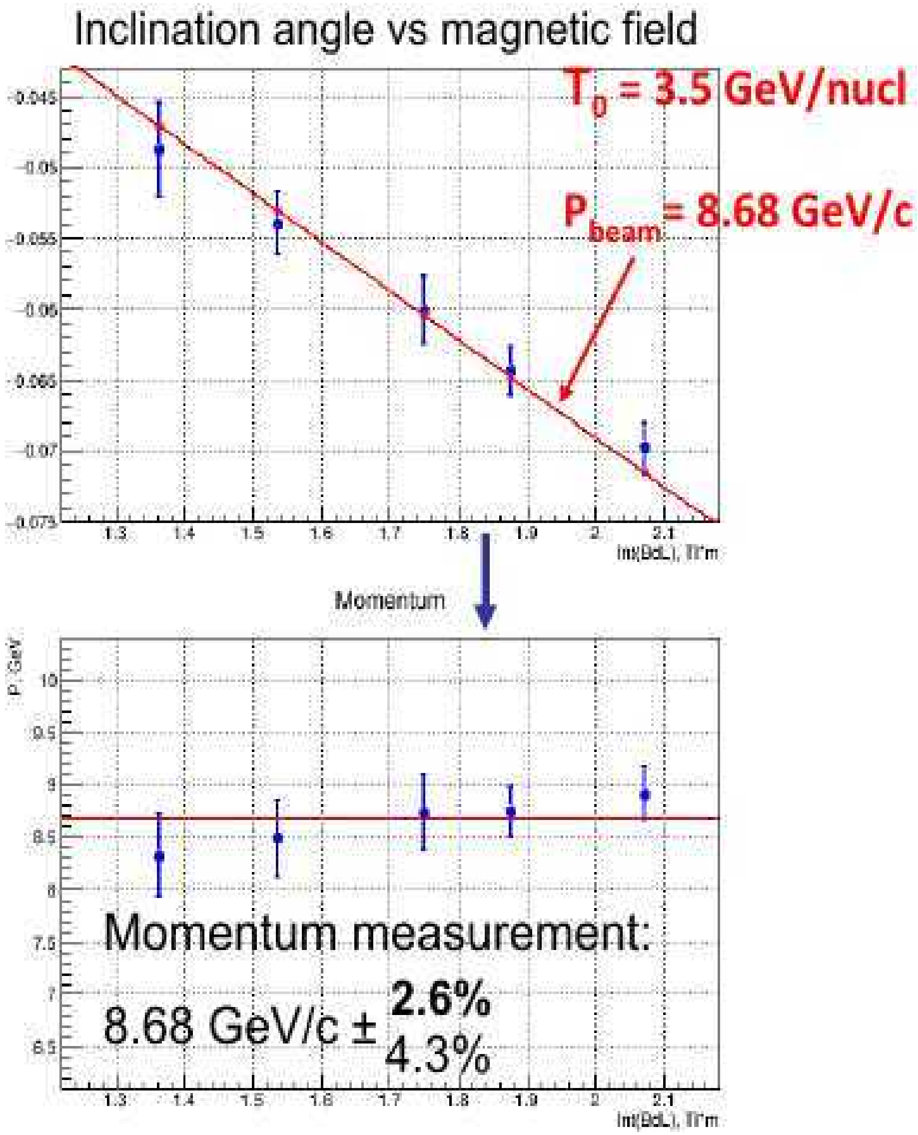


Deutron tracks and momentum reconstruction with BM@N Drift Chambers

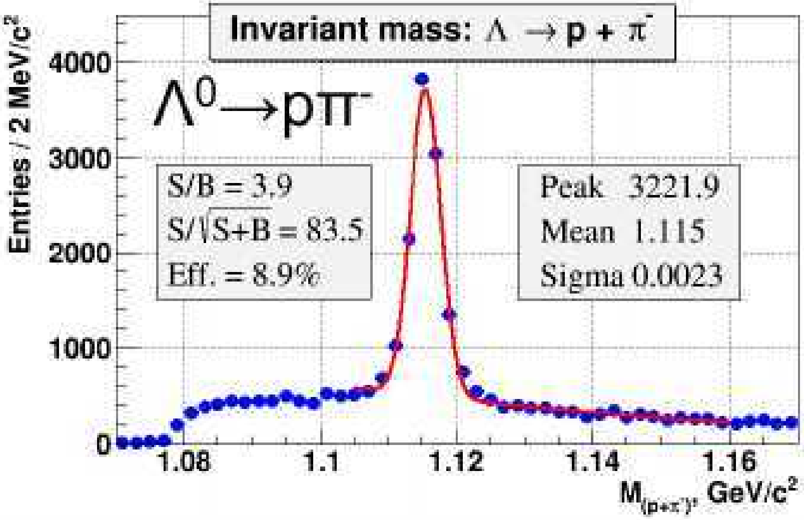
Deutron beam inclination at different values of magnetic field



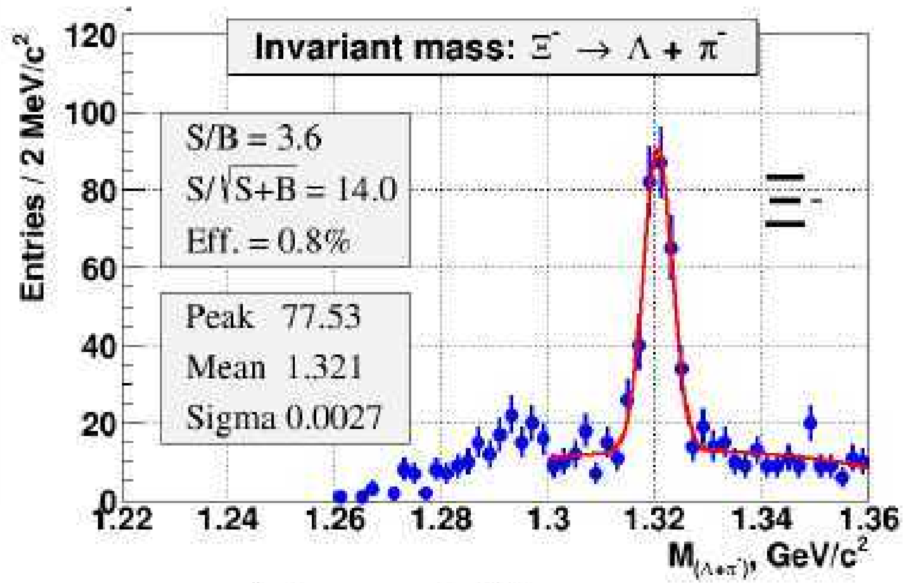




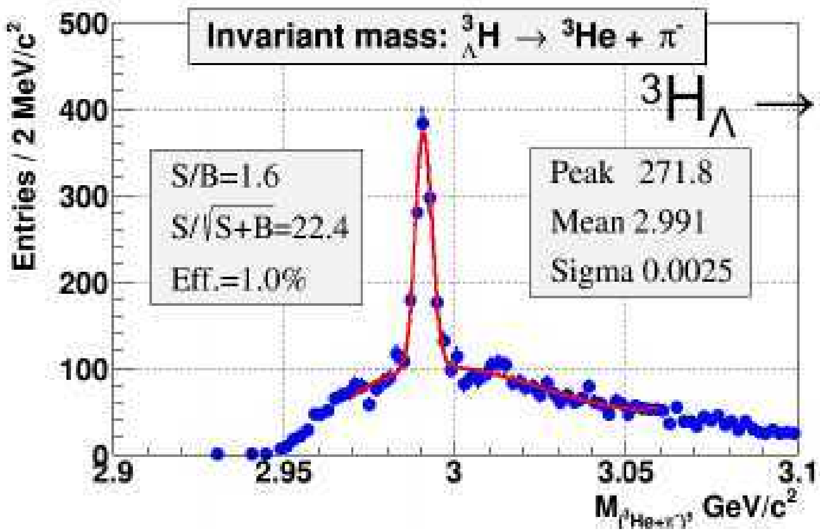
BM@N physics



Au+Au, 4.5 AGeV, UrQMD, 900k central

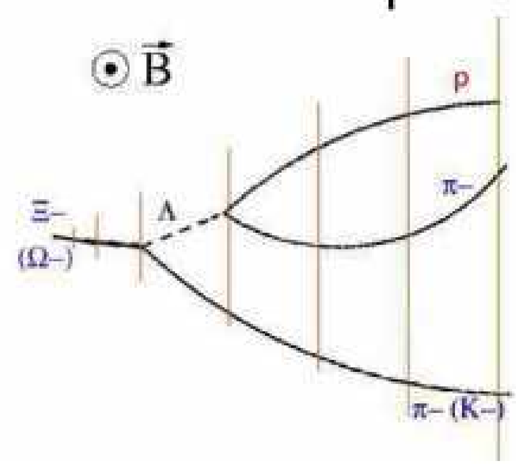


Au+Au, 4.5 AGeV, 2M central events

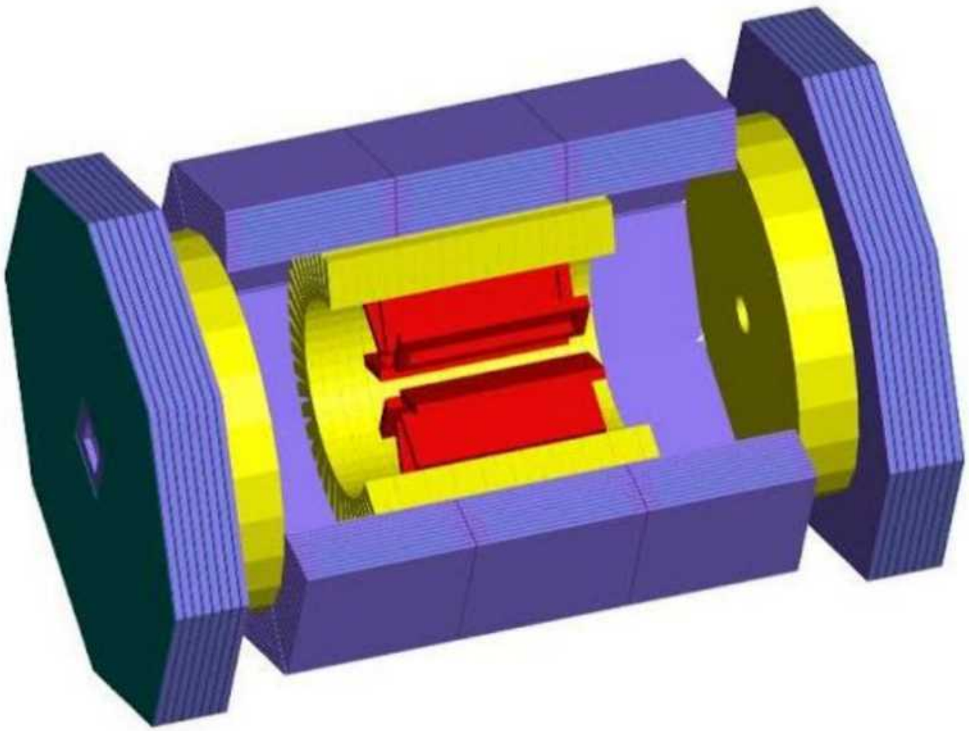


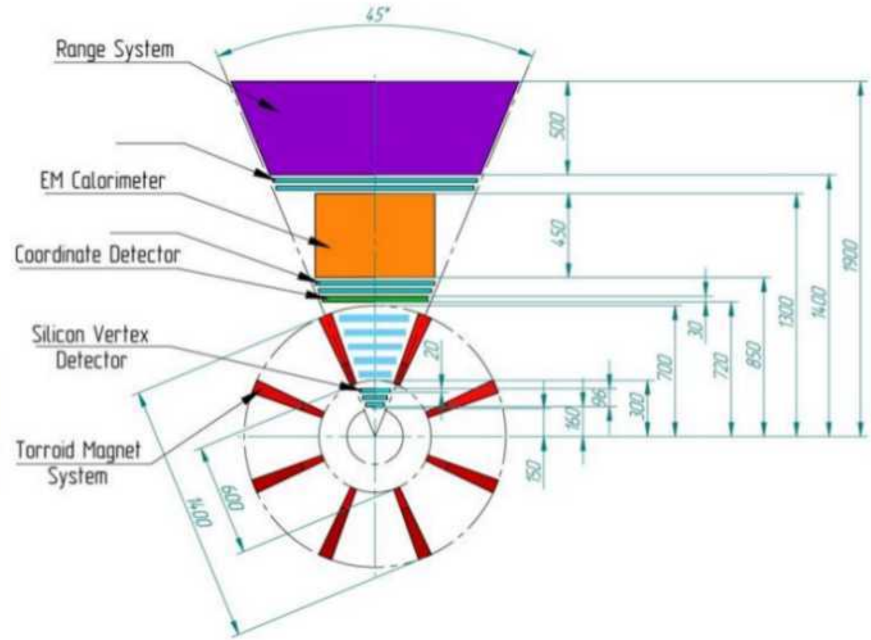
$^3H_\Lambda \rightarrow {}^3He\,\pi^-$

$\Xi^- \rightarrow \pi^- + \Lambda^0 \rightarrow p\pi^-$



Spin Physics Detector





Spin program with polarized beams

The spin program is an important and integral part of the NICA project. Indeed, ever since the "spin crisis" of 1987, the composition of the nucleon spin in terms of the fundamental constituents – quarks and gluons – remains in the focus of attention of many physicists. The highlights of the NICA spin program include measurements of Drell-Yan processes with longitudinally polarized proton and deuteron beams, spin effects in inclusive and exclusive production of baryons, light and heavy mesons and direct photons, and studies of helicity amplitudes and double spin asymmetries in elastic scattering. The SPD detector at NICA would allow to contribute significantly to the current and planned international program in spin physics.

SPD Letter of Intent

hep-ex
arXiv:1408.3959

Nec sine te, nec tecum vivere possum. (Ovid)*

Spin Physics Experiments at NICA-SPD with polarized proton and deuteron beams.

Compiled by the Drafting Committee:
I.A. Savin, A.V. Efremov, D.V. Peshekhonov, A.D. Kovalenko, O.V.Teryaev, O.Yu. Shevchenko, A.P. Nagajcev, A.V. Guskov, V.V. Kukhtin, N.D. Topilin.

(Letter of Intent presented at the meeting of the JINR Program Advisory Committee (PAC) for Particle Physics on 25–26 June 2014.)

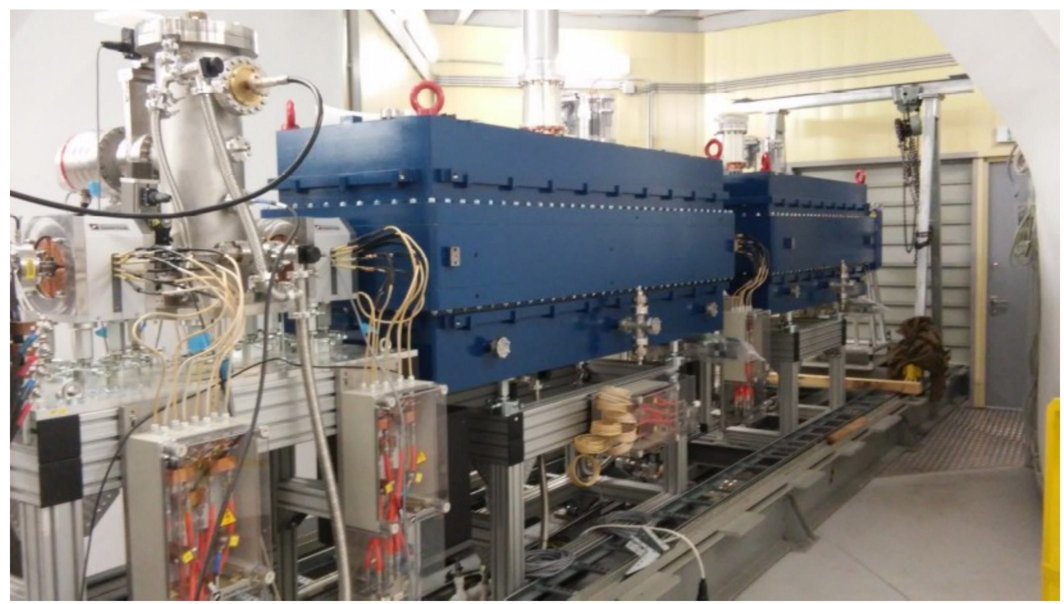
ABSTRACT

We propose to perform measurements of asymmetries of the DY pair's production in collisions of non-polarized, longitudinally and transversally polarized protons and deuterons which provide an access to all leading twist collinear and TMD PDFs of quarks and anti-quarks in nucleons. The measurements of asymmetries in production of J/Ψ and direct photons will be performed as well simultaneously with DY using dedicated triggers. The set of these measurements will supply complete information for tests of the quark-parton model of nucleons at the QCD twist-two level with minimal systematic errors.

Magnets for booster

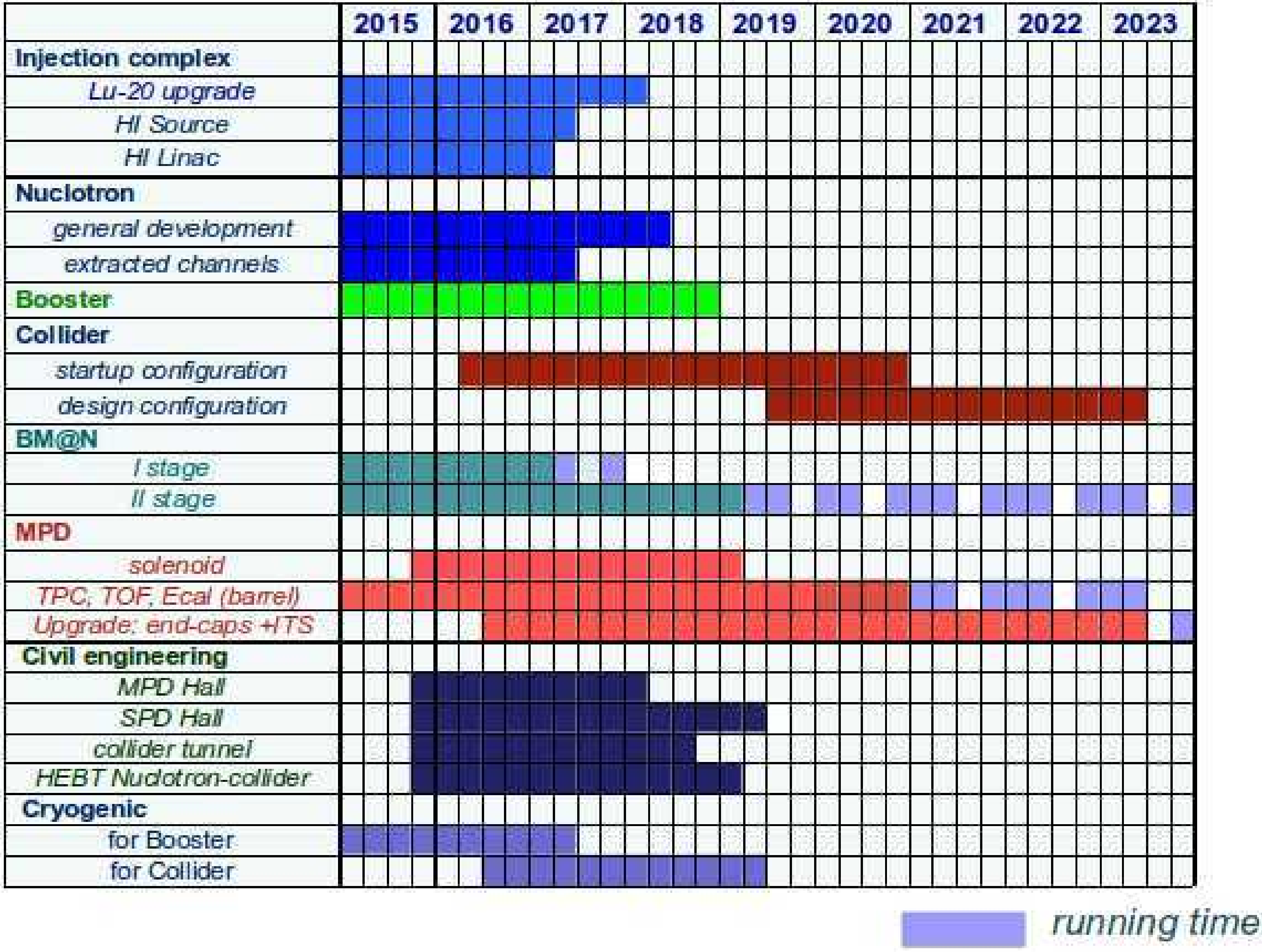
Booster magnet plan 02.08.2017

	(total)	Plan/ Tested
Dipole	40	26/21
Quadrupole	48	20/6



NICA Site

NICA Schedule

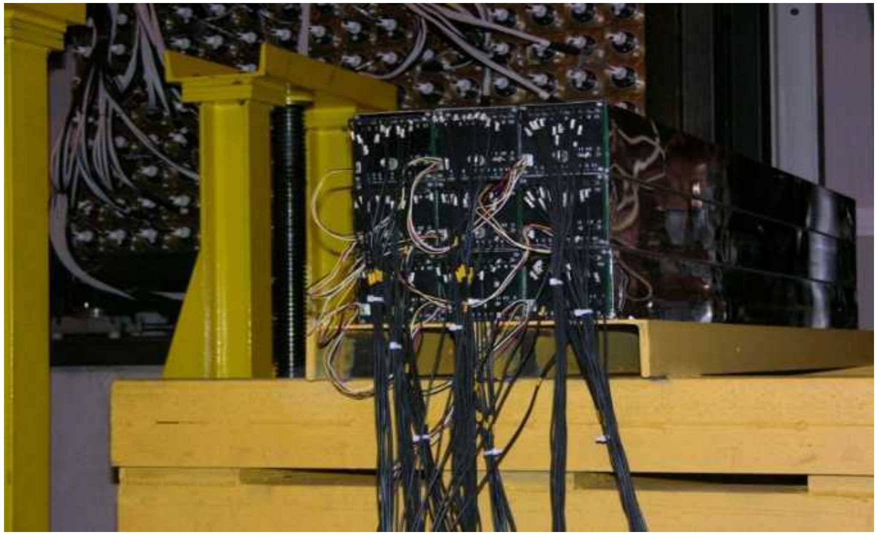


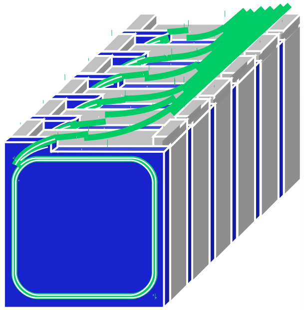

Thank you for attention

Forward Hadron Calorimeter

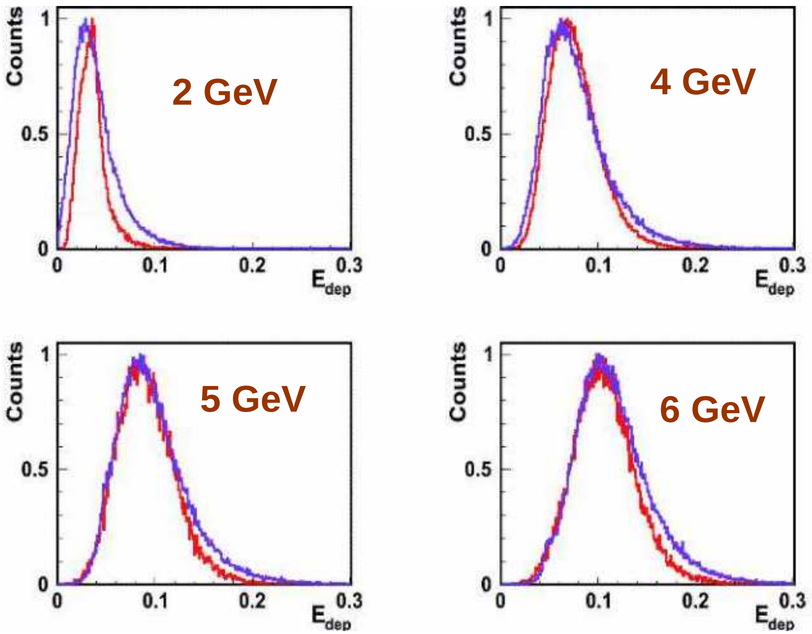
NA61, CBM, MPD

Module assembling at INR



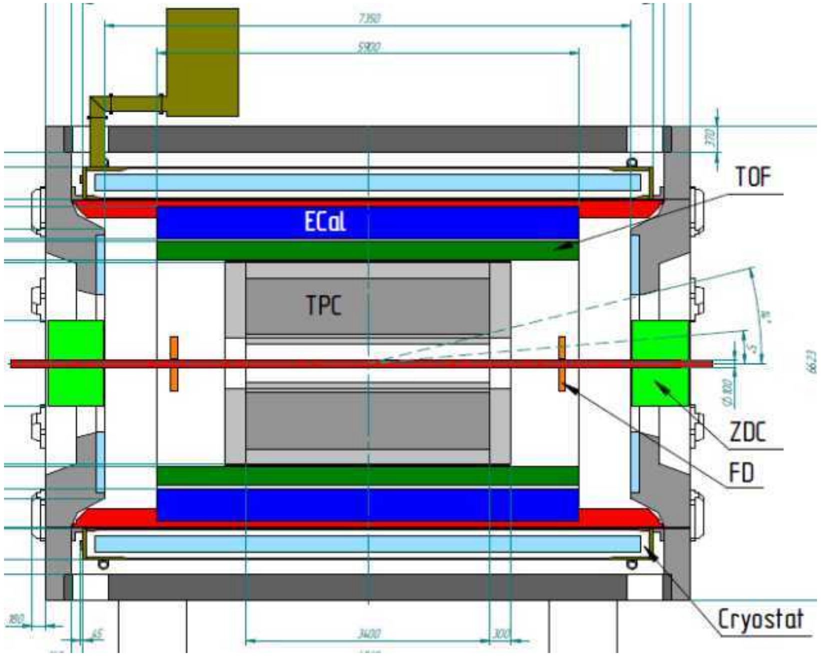


Beam test at *CERN*

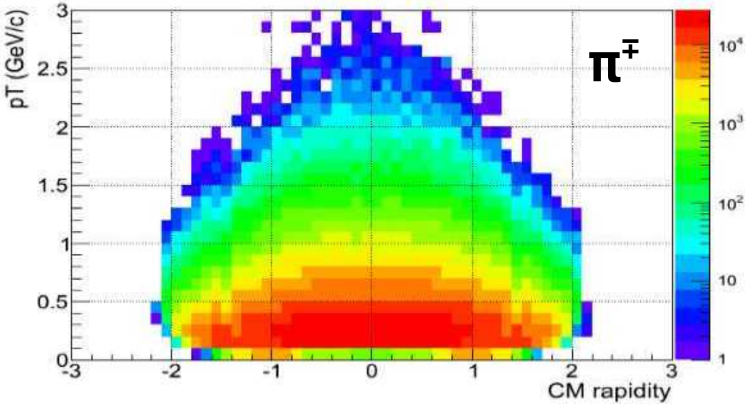


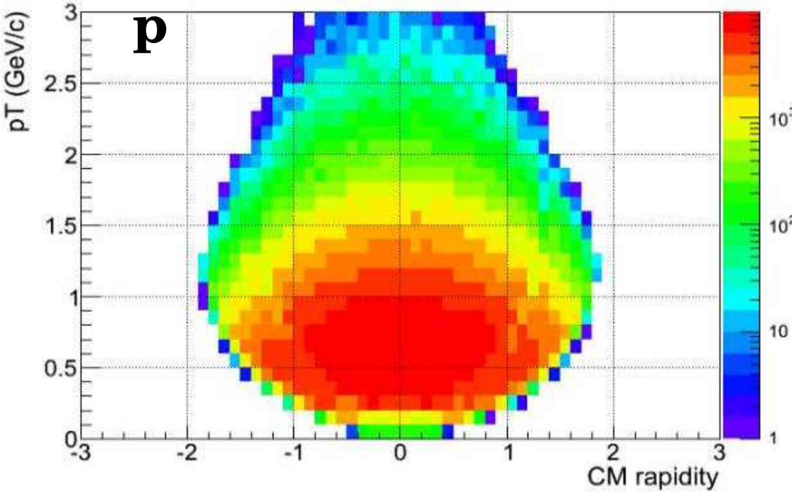
Transverse size 15x15 cm^2, length~160 cm, weight ~120 kg.
60 lead/scintillator sandwiches.
6 fiber/MAPD
10 MAPDs/module

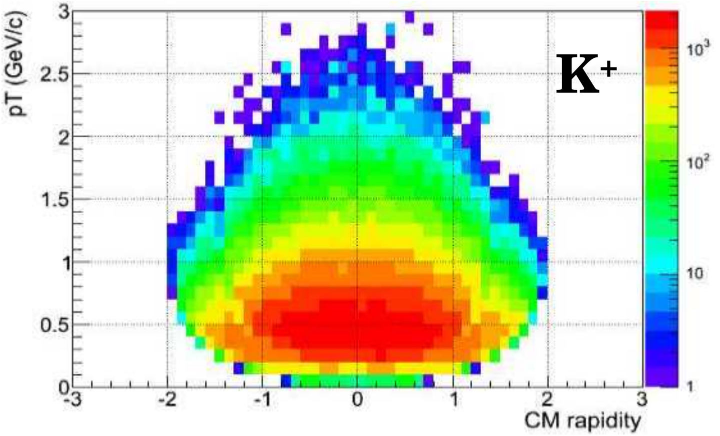
Phase space



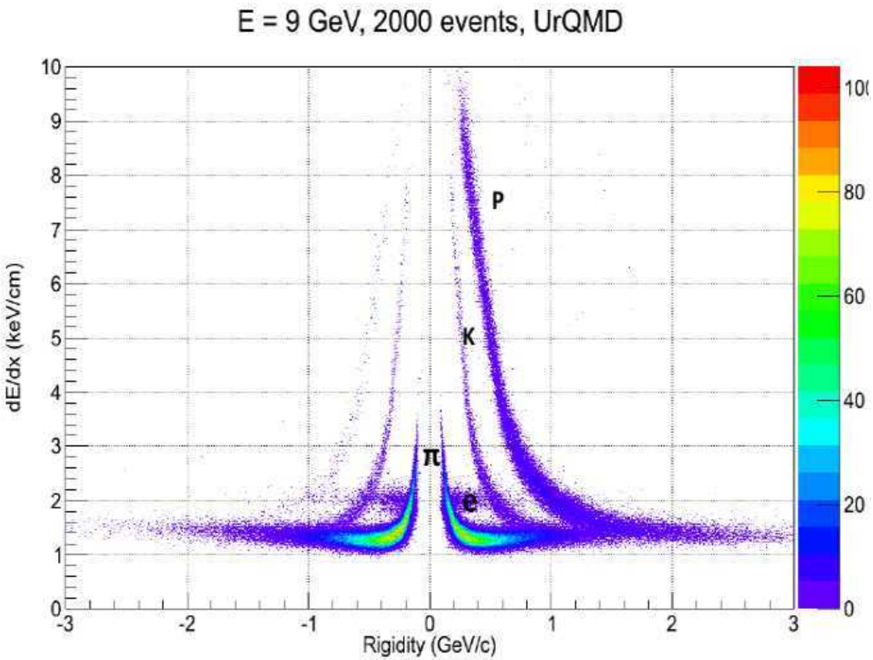
MPD registers on average :
~380 charged pions
~85 protons
~30 K+
in an event
(central Au+Au at 8 GeV)







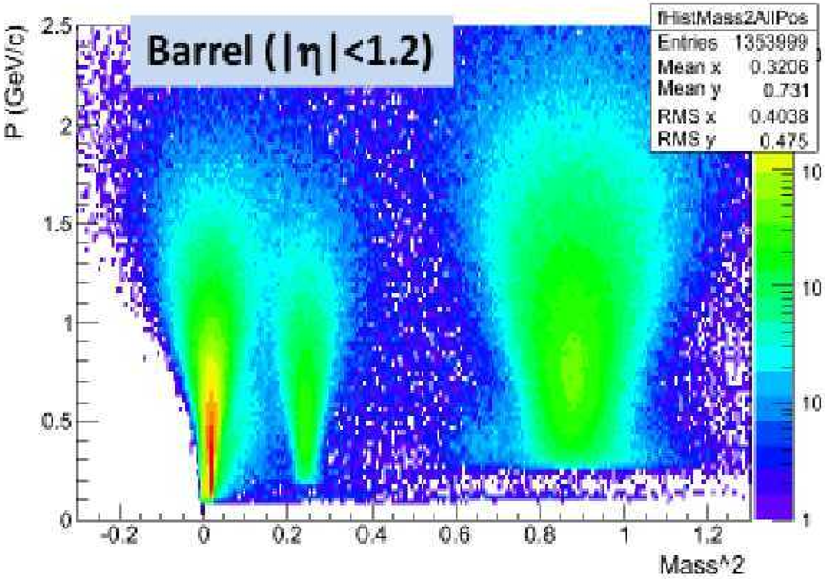
Charged Particle ID

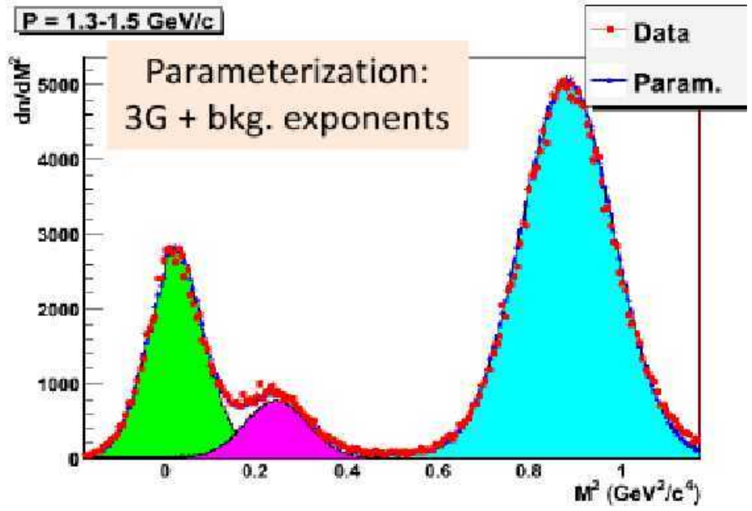


TPC
PID: Ionization loss (dE/dx) Separation:
e/h – 1.3..3 GeV/c
π/K – 0.1..0.6 GeV/c
K/p – 0.1..1.2 GeV/c

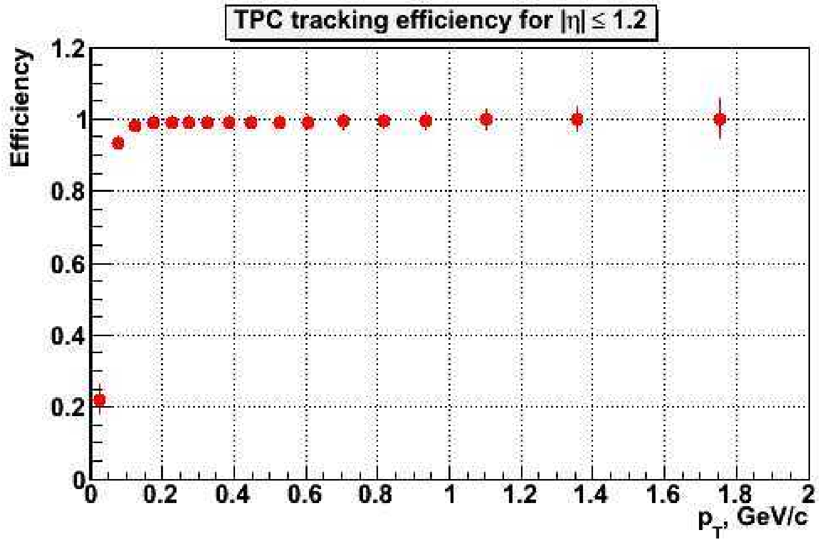
MPD PID (TOF):

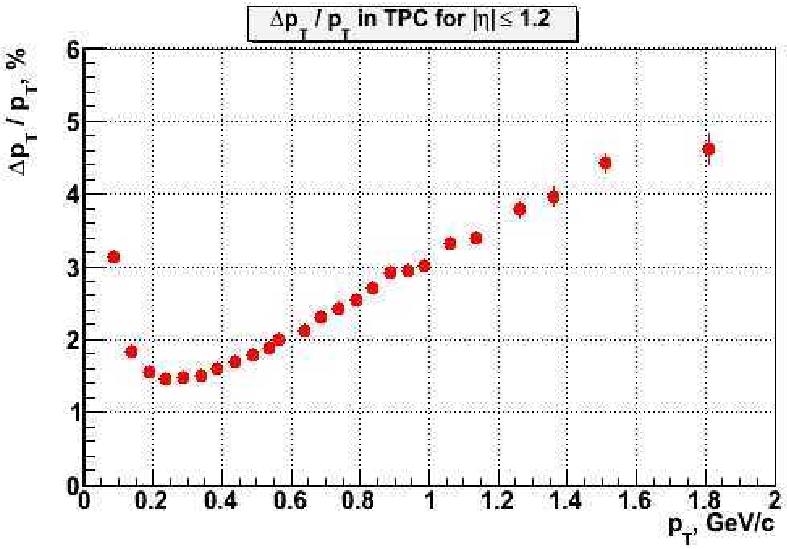
- π/K separation up to p=1.7 GeV/c, above 2 GeV/c - extrapolating the fitted 3G parameters
- Protons up to 3 GeV/c
- dE/dx provide extra PID capability for electrons and low momentum hadrons





Tracking





Low-p cutoff ~ **100 MeV** for a **0.5 T** magnetic field