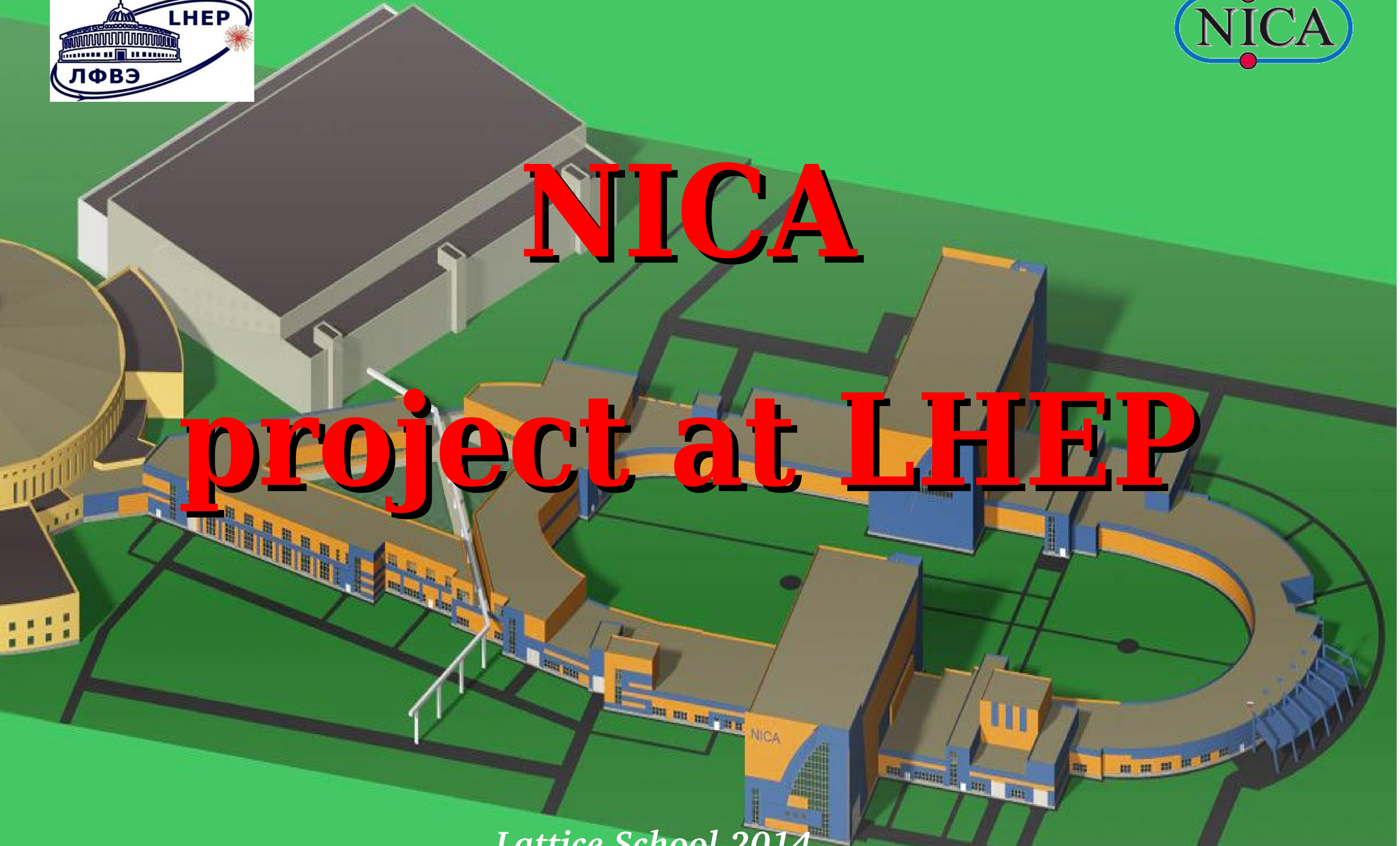
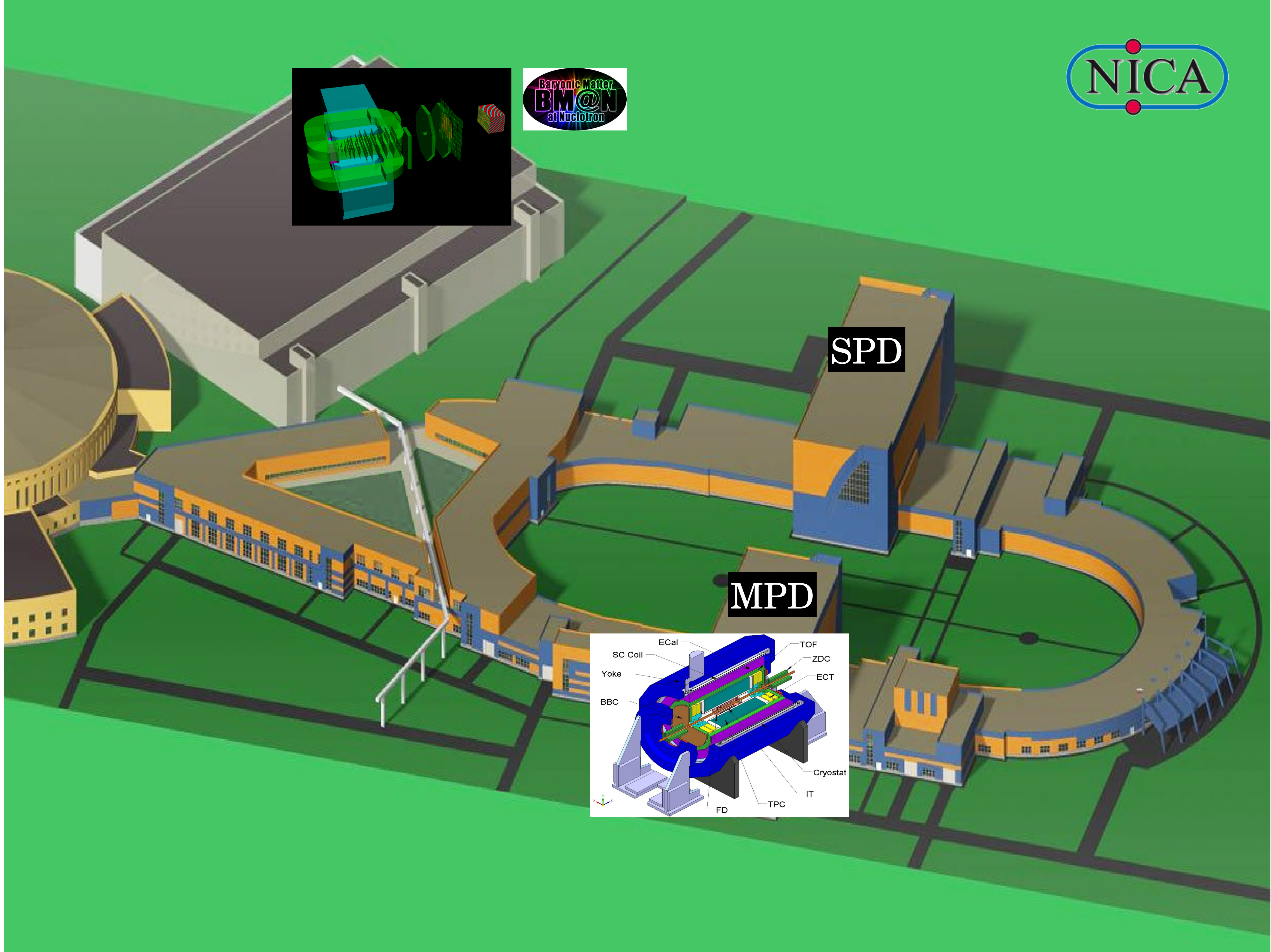
NICA project at LHEP



Lattice School 2014
Dubna
26.08.2014

Rogachevsky Oleg
for MPD/BM@N team


NICA
Baryonic Matter
BM@N
at Nuclotron
SPD
MPD
ECal
SC Coil
Yoke
BBC
TOF
ZDC
ECT
Cryostat
IT
TPC
FD

History

Order parameter

QUARK–GLUON PLASMA

From Big Bang to Little Bang

(i) Recipe for QGP at high T (Fig. 1.5(a)). We assume that the QCD vacuum is heated in a box. At low temperature, hadrons, such as pions, kaons, etc., are thermally excited from the vacuum. Note that only the color-white particles can be excited by the confinement at low energies. Because the hadrons are all roughly the same size (about 1 fm), they start to overlap with each other at a certain critical temperature, T_c. Above this temperature, the hadronic system dissolves into a system of quarks and gluons (QGP). Note that in the QGP thus produced the number of quarks, n_q, is equal to that of anti-quarks, $n_{\bar{q}}$. The various model calculations and the Monte Carlo lattice QCD simulations yield $T_c = 150 \sim 200$ MeV (**Chapters 3** and **5**). Although this is extremely high in comparison with (for example) the temperature at the center of the Sun, 1.5×10^7 K $= 1.3$ keV, it is

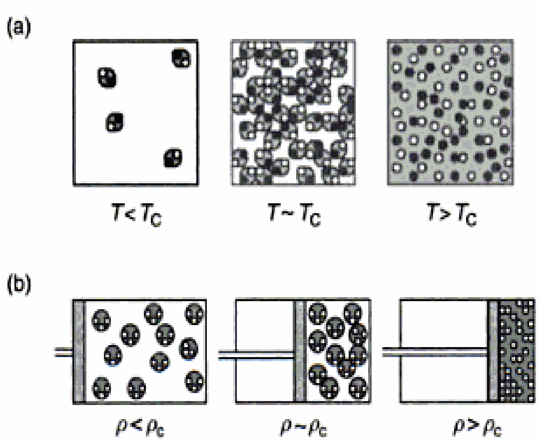


Fig. 1.5. Formation of QGP (a) at high temperature (T) and (b) at high baryon density (ρ).

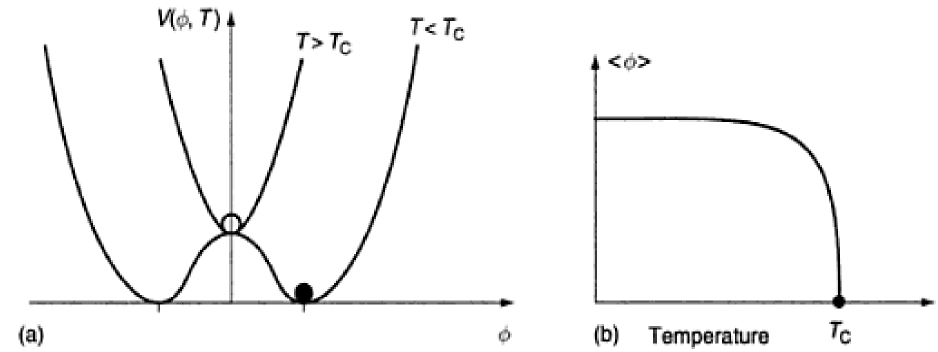


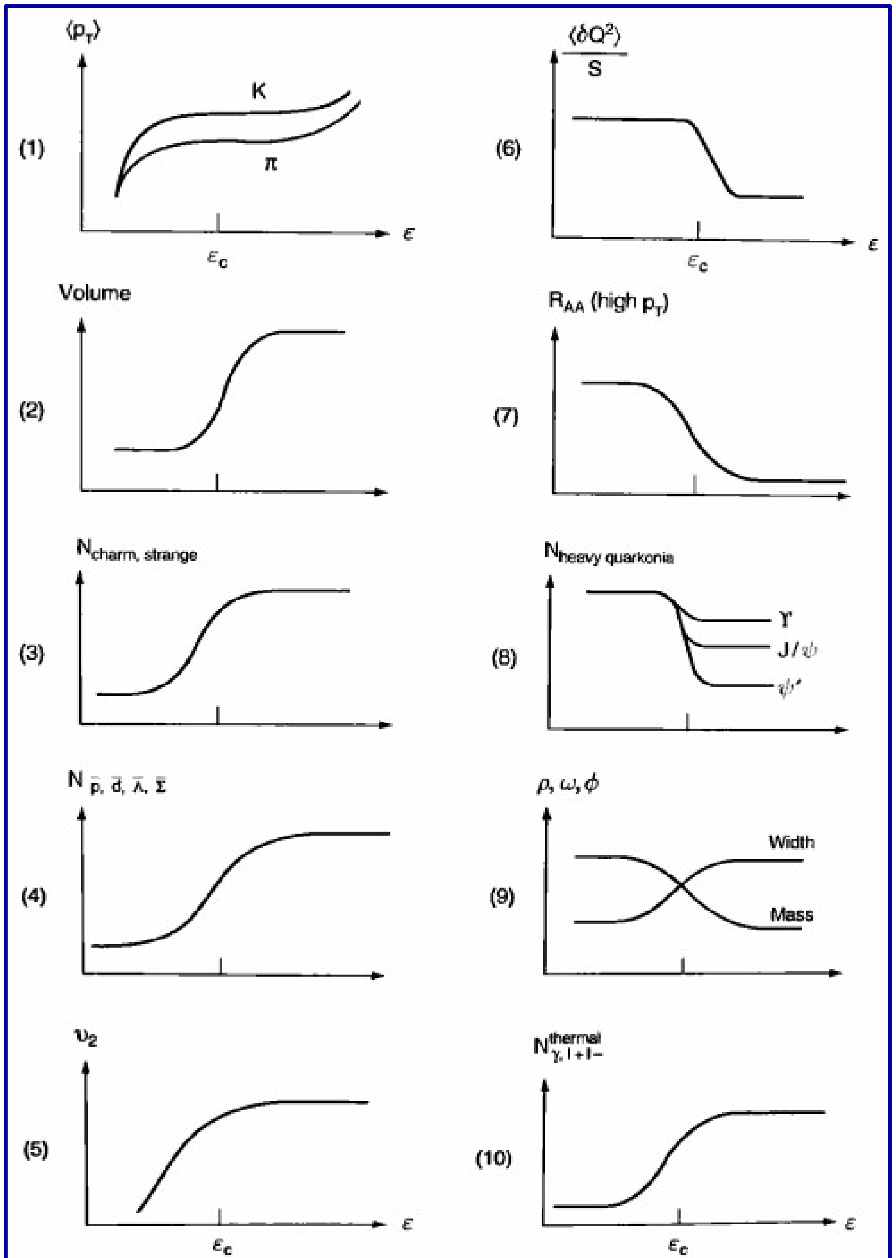
Fig. 1.6. (a) The Ginzburg–Landau potential, $V(\phi, T)$, showing the second order phase transition at $T = T_c$. (b) Behavior of the order parameter, $< \phi >$, as a function of T.

a typical energy scale of hadronic interactions and can be attained in laboratories (**Chapter 10**).

The finite T QCD phase transition may also be described by the order parameter and the corresponding Ginzburg–Landau (GL) potential (or the Landau function) if dynamical symmetry breaking and its restoration are involved. We will see such examples for center symmetry of the color SU(3) gauge group (**Chapter 5**) and global chiral symmetry of quarks (**Chapter 6**). Figure 1.6 is an illustration of the GL potential, V, as a function of an order parameter, ϕ; it also shows the behavior of the minimum of V as a function of T for the second order phase transition.

(ii) Recipe for QGP at high ρ (Fig. 1.5(b)). Let us put a large number of baryons into a cylinder with a piston and compress the system adiabatically, keeping $T \sim 0$. The baryons start to overlap at a certain critical baryon density, ρ_c, and dissolve into a system of degenerate quark matter. The quark matter thus produced is of high baryon density with $n_q \gg n_{\bar{q}}$. Model calculations show that $\rho_c =$ (several) $\times \rho_{nm}$, where $\rho_{nm} = 0.16\,\mathrm{fm}^{-3}$ is the baryon number density of normal nuclear matter (**Chapter 9**).

QGP signatures



QUARK–GLUON PLASMA

From Big Bang to Little Bang

(1) A second rise in the average transverse momentum of hadrons due to a jump in entropy density at the phase transition.

(2) Measurement of the size. of the fireboll by particle interferometry with identical hadrons (Hanbury-Brown and Twiss effect).

(3) Enhanced production of strangeness and charm from QGP.

(4) Enhanced production of anti-particles in QGP.

(5) An increase of an elliptic flow of hadrons from early thermalization of an anisotropic initial configuration.

(6) Suppression of the event-by-event fluctuations of conserved charges

(7) Suppression of high-p_T hadrons due to the energy loss of a parton in QGP

(8) Modification of the properties of heavy mesons (J/Ψ, Ψ', ϒ, ϒ'} due to the color Debye screening in QGP.

(9) Modifications of the mass and width of the light vector mesons due to chiral symmetry restoration.

(10) Enhancement of thermal photons and diieptons due to the emission from deconfined QCD plasma

Theoretical studies

-1950: E. Fermi

statistical hadron production at $T = T_f \approx s_{NN}^{1/4}$

Prog. Theor. Phys. 5, 570 (1950)

-1951: I. Pomeranchuk

freeze-out at $T_{FO} \approx m_{\pi}$

Dokl. Akad. Nauk Ser. Fiz. 78, 889 (1951)

-1953: L.D. Landau

hydrodynamical expansion from T_f to T_{FO}

Izv. Akad. Nauk Ser. Fiz. 17, 51 (1953)

Theoretical studies

~1965: R. Hagedorn

statistical hadron production at $T_C = T_H \approx 160$ MeV

R. Hagedorn, Nuovo Cimento , LII A, 4 (1967)

~1978: E. Shuryak

QCD quark-gluon plasma ($T \approx 500$ MeV)

E. Shuryak, Phys. Lett. B78, 150 (1978), Sov. J. Nucl. Phys. 28, 408 (1978), Yad. Fiz. 28, 796 (1978).

~1980: R. Hagedorn, J. Rafelski

$T_C = T_H \approx 160$ MeV

~1980: J. Rafelski, B. Mueller, T. Matsui, H. Satz

QCD-inspired models of QGP signals, strangeness enhancement and J/ψ suppression

R. Hagedorn

IL NUOVO CIMENTO Vol. LII A, N. 4 21 Dicembre 1967

On the Hadronic Mass Spectrum.

R. Hagedorn
CERN - Geneva

(ricevuto il 10 Ottobre 1967)

A fireball is

(T) → a statistical equilibrium of an undetermined number of all kinds of fireballs, each of which, in turn, is considered to be —

(3) $$\varrho(m) \underset{m\to\infty}{\Rightarrow} \frac{\text{const}}{m^{\frac{5}{2}}} \exp[m/T_0] \ (^*) .$$

It follows that T_0 *is the highest possible temperature*—a kind of « boiling point of hadronic matter » in whose vicinity particle creation becomes so vehement that the temperature cannot increase anymore, no matter how much energy is fed in.

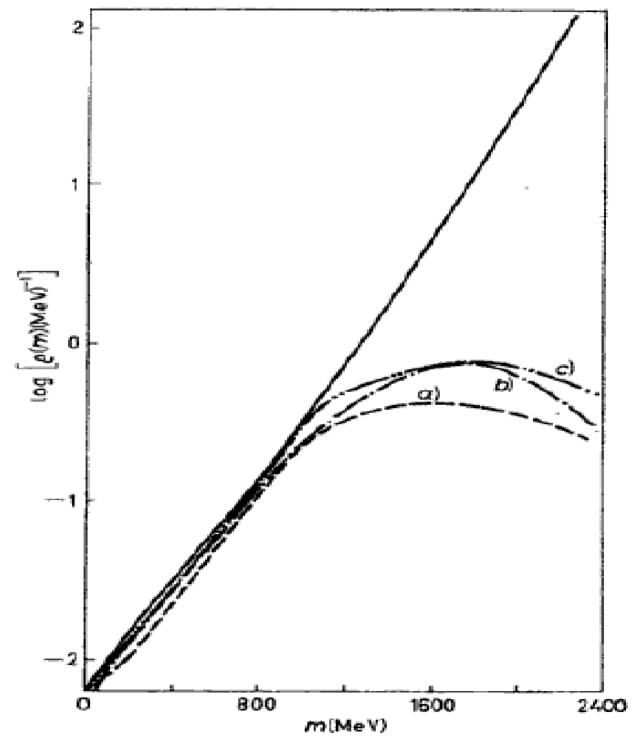
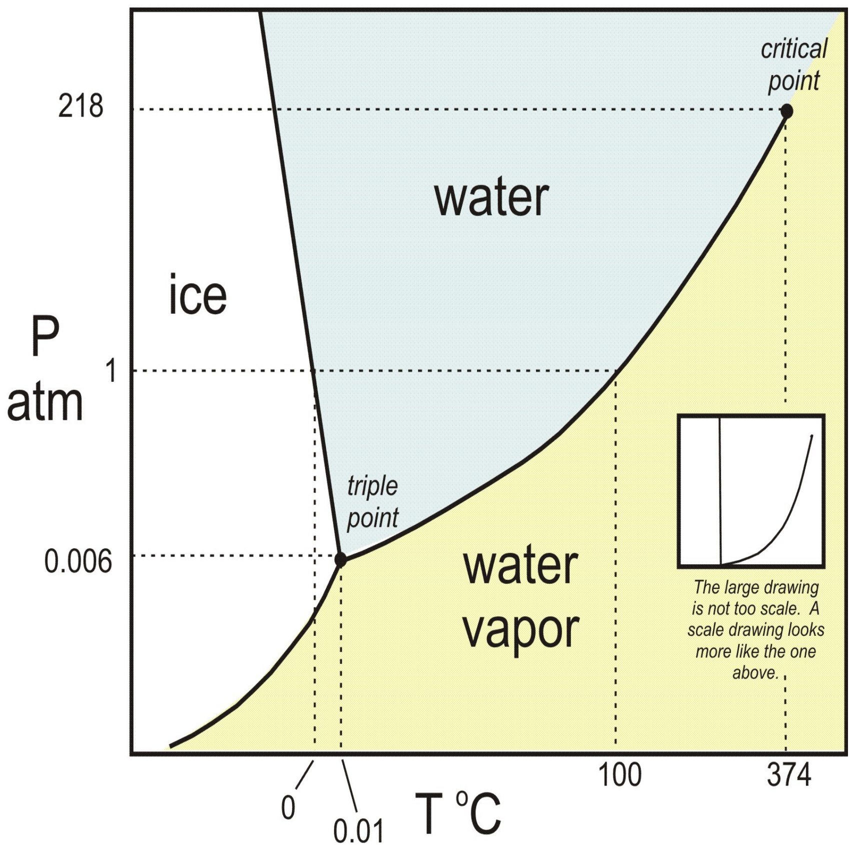


Fig. 1. – The experimental mass spectrum smoothed by Gauss functions (dashed lines) and a fit by a simple function with the asymptotic behaviour required by eq. (3). The constant a is a free parameter (with a value suggested by *a priori* considerations). $a = 2.53 \cdot 10^4\,(\text{MeV})^{\frac{3}{2}}$, $m_0 = 500$ MeV, $T_0 = 160$ MeV. *a*) October 1964 (600 states); *b*) April 1966 (971 states), *c*) January 1967 (1432 states). A particle or resonance is counted with its statistical weight $z = (2J+1)(2I+1)\cdot 2^{\alpha}$ [$\alpha = 1$ if particle ≠ antiparticle, $\alpha = 0$ if particle = antiparticle], and then represented by a Gauss function normalized to z with width 200 MeV.

Phase diagram

water

Nadronic matter



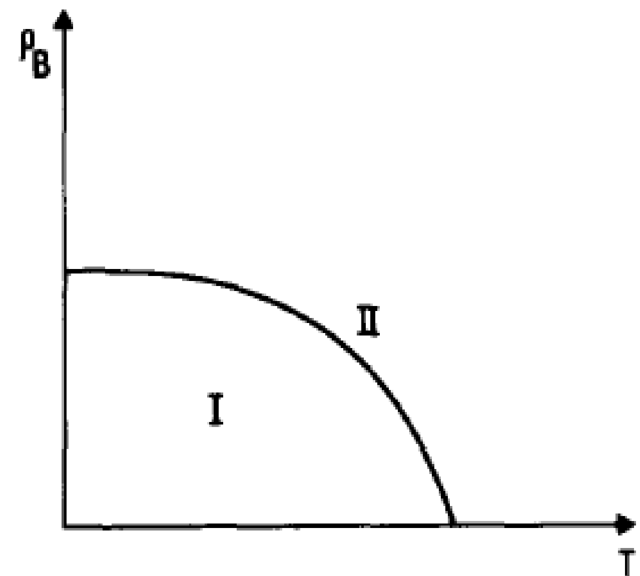
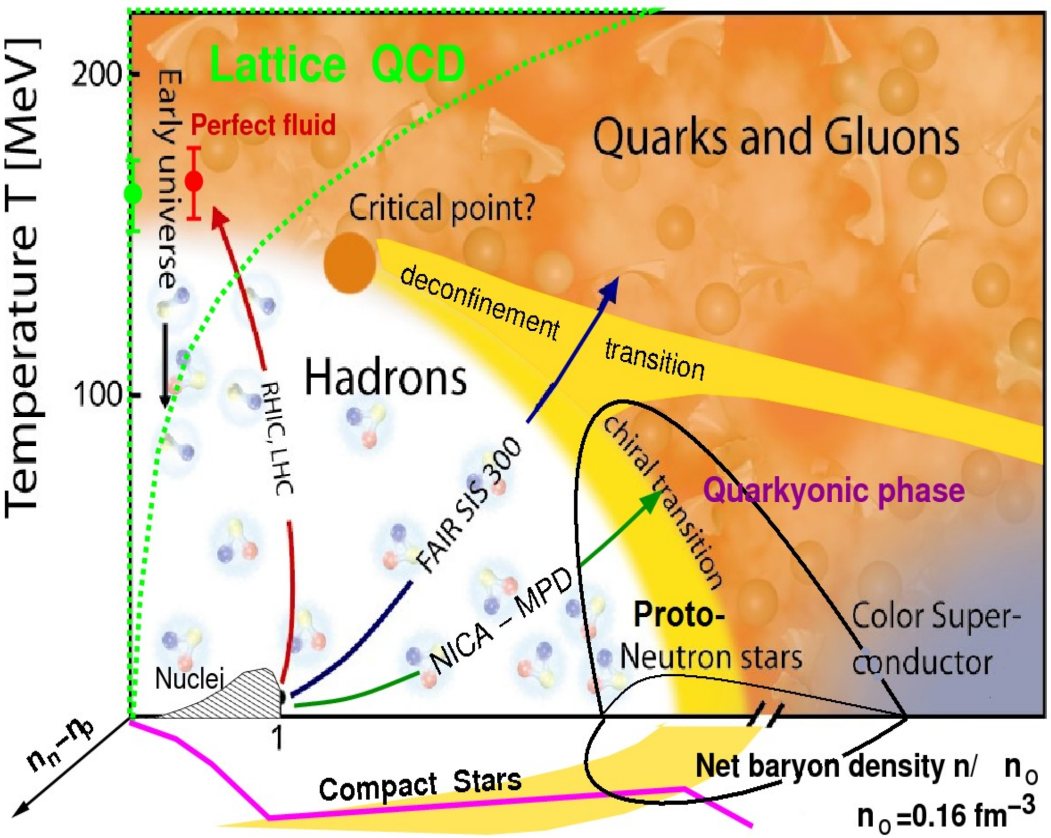


Fig. 1. Schematic phase diagram of hadronic matter. ρ_B is the density of baryonic number. Quarks are confined in phase I and unconfined in phase II.

EXPONENTIAL HADRONIC SPECTRUM AND QUARK LIBERATIONN.
CABIBBO G. PARISI Phys.Lett. 59B p.67 1975

QGP phase diagram



The collision of two heavy nuclei which approach and smash against each other with almost the speed of light. According to Einstein's theory of special relativity they look like thin pancakes. This "Little Bang" creates in the laboratory the primordial state of matter, called Quark-Gluon Plasma (QGP). The QGP expands like a fireball, cools and finally turns into ordinary matter.

. The thousands of particles produced will be recorded by detectors. The tracks that those particles leave in the detectors will be analysed by modern powerful software tools.

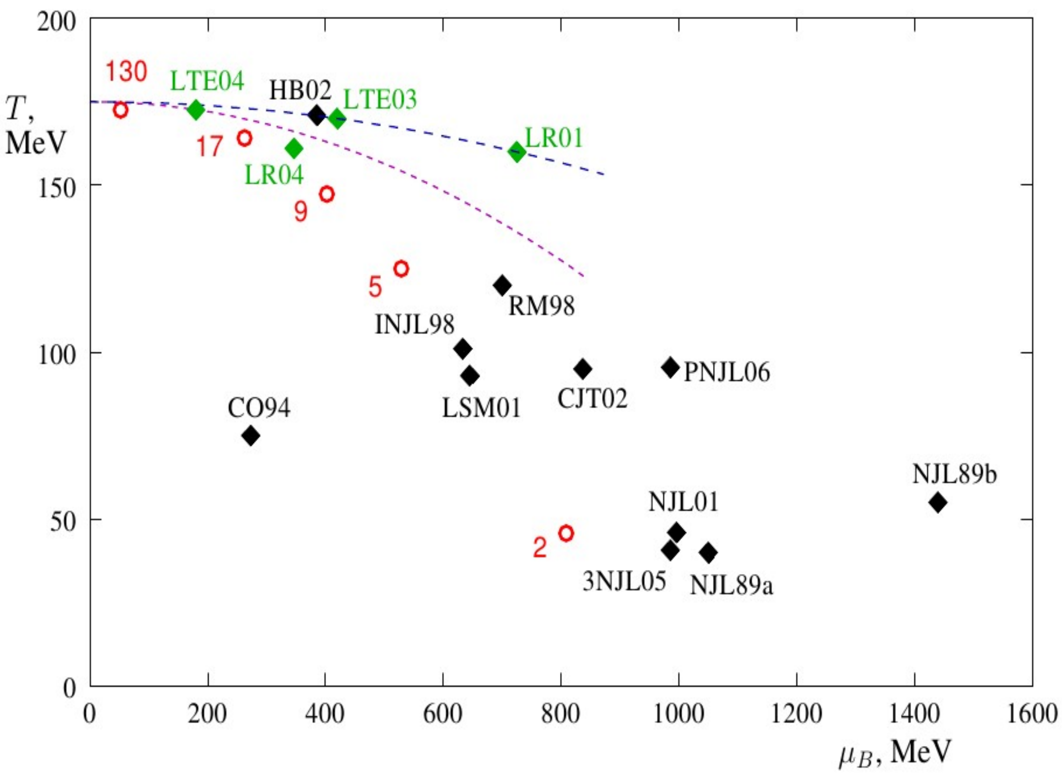
The challenge is to infer the properties of the QGP state of matter by studying the different particles that arrive in the detectors.

QCD Critical point quest

M. Stephanov

XXIV International Symposium on Lattice Field Theory
July 23-28 2006
Tucson Arizona, US

Comparison of predictions for the location of the QCD critical point on the phase diagram. Black points are model predictions: NJLa89, NJLb89 – [12], CO94 – [13, 14], INJL98 – [15], RM98 – [16], LSM01, NJL01 – [17], HB02 – [18], CJT02 – [19], 3NJL05 – [20], PNJL06 – [21]. Green points are lattice predictions: LR01, LR04 – [22], LTE03 – [23], LTE04 – [24]. The two dashed lines are parabolas with slopes corresponding to lattice predictions of the slope $dT/d\mu_B^2$ of the transition line at $\mu_B = 0$ [23, 25]. The red circles are locations of the freezeout points for heavy ion collisions at corresponding center of mass energies per nucleon (indicated by labels in GeV)



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[25] P. de Forcrand and O. Philipsen, arXiv:hep-ph/0301209; Nucl. Phys. B 673 (2003) 170
[arXiv:hep-lat/0307020]; Nucl. Phys. Proc. Suppl. 129, 521 (2004) [arXiv:hep-lat/0309109].

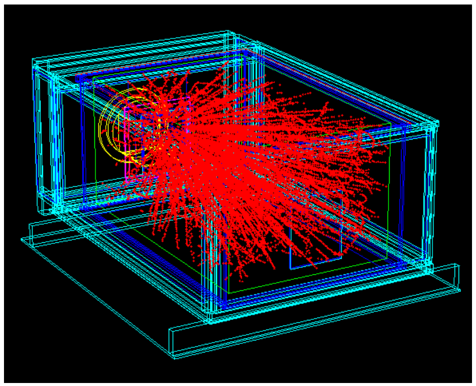
Experiments

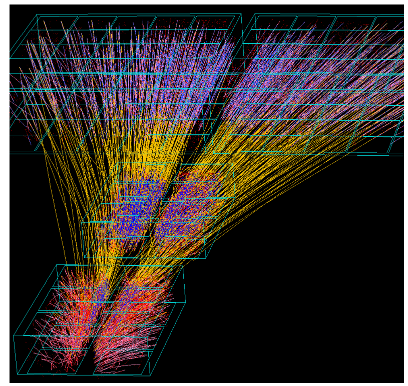
Pioneering ideas/experiments:

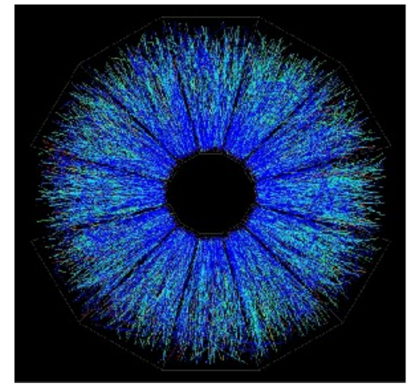
- 1980/00: AGS/SPS experiments with heavy ions discovery of strongly interacting matter (large volume, in ≈ equilibrium)
- 2000: M.Gazdzicki, M. Gorenstein statistical model predictions of the phase transition at the SPS energies
- 2000: NA49 at the CERN SPS discovery of phase transition of strongly interacting matter
- 2000-...: RHIC experiments study the properties of QGP

Experiments

AGS → SPS → RHIC







	Experiments	E_{beam} (A GeV)	$\sqrt{s_{nn}}$ (GeV)	System	Particles
AGS	E802, E866, E877, E891, E895, E917	2-10.7	2.7-4.9	Au+Au	π, K, p, Λ
SPS	NA45, NA49, NA57, (NA44, WA98)	20-158	6.3-17.3	Pb+Pb	π, K, p, ϕ, Λ, Ξ, Ω,...
RHIC	STAR, PHENIX, BRAHMS, PHOBOS	-	20.0-200.0	Au+Au	π, K, p, ϕ, Λ, Ξ, Ω, ...

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

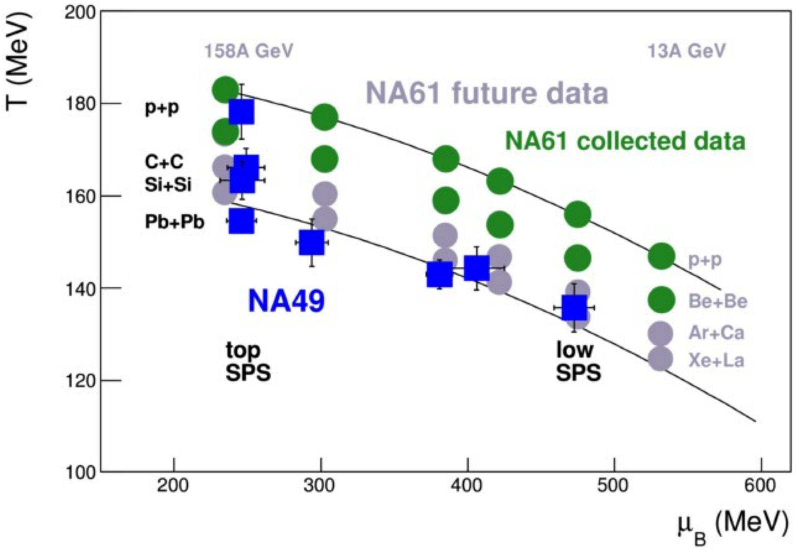
A common assessment of the collected data leads us to conclude that we now have compelling evidence that a new state of matter has indeed been created, at energy densities which had never been reached over appreciable volumes in laboratory experiments before and which exceed by more than a factor 20 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.

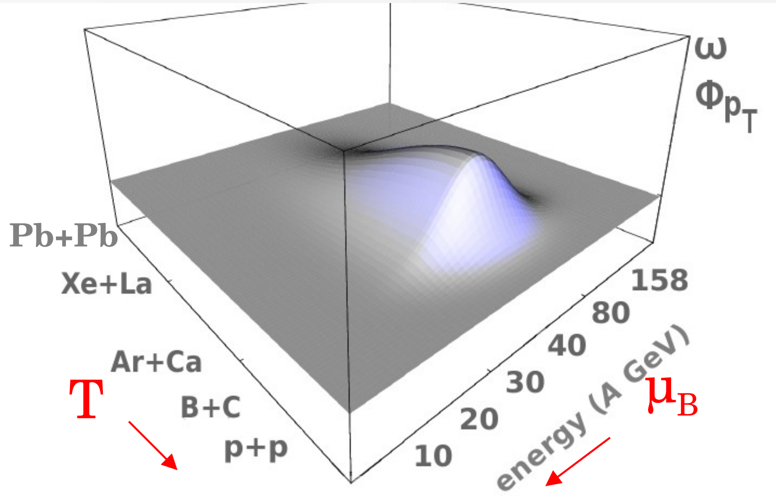
arXiv:nucl-th/0002042v1 16 Feb 2000

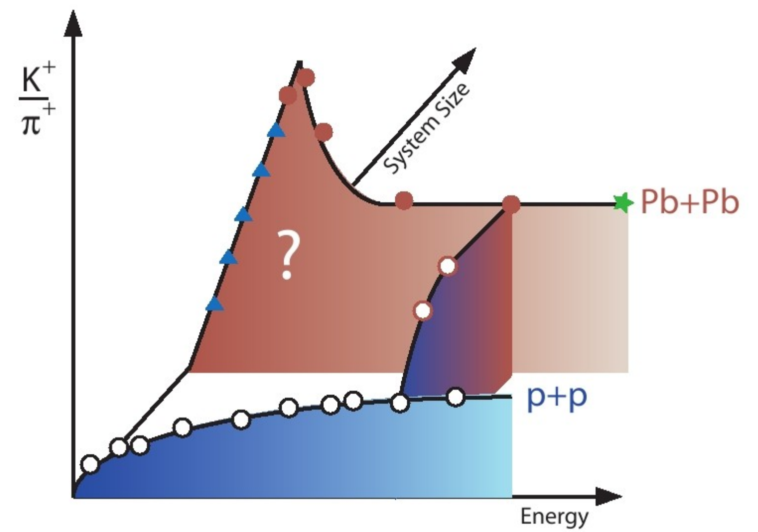
NA61 scan in energy and system size

Comprehensive scan in the whole SPS energy range (13A-158A GeV) with light and intermediate mass nuclei

search for hill of fluctuations as signature of critical point

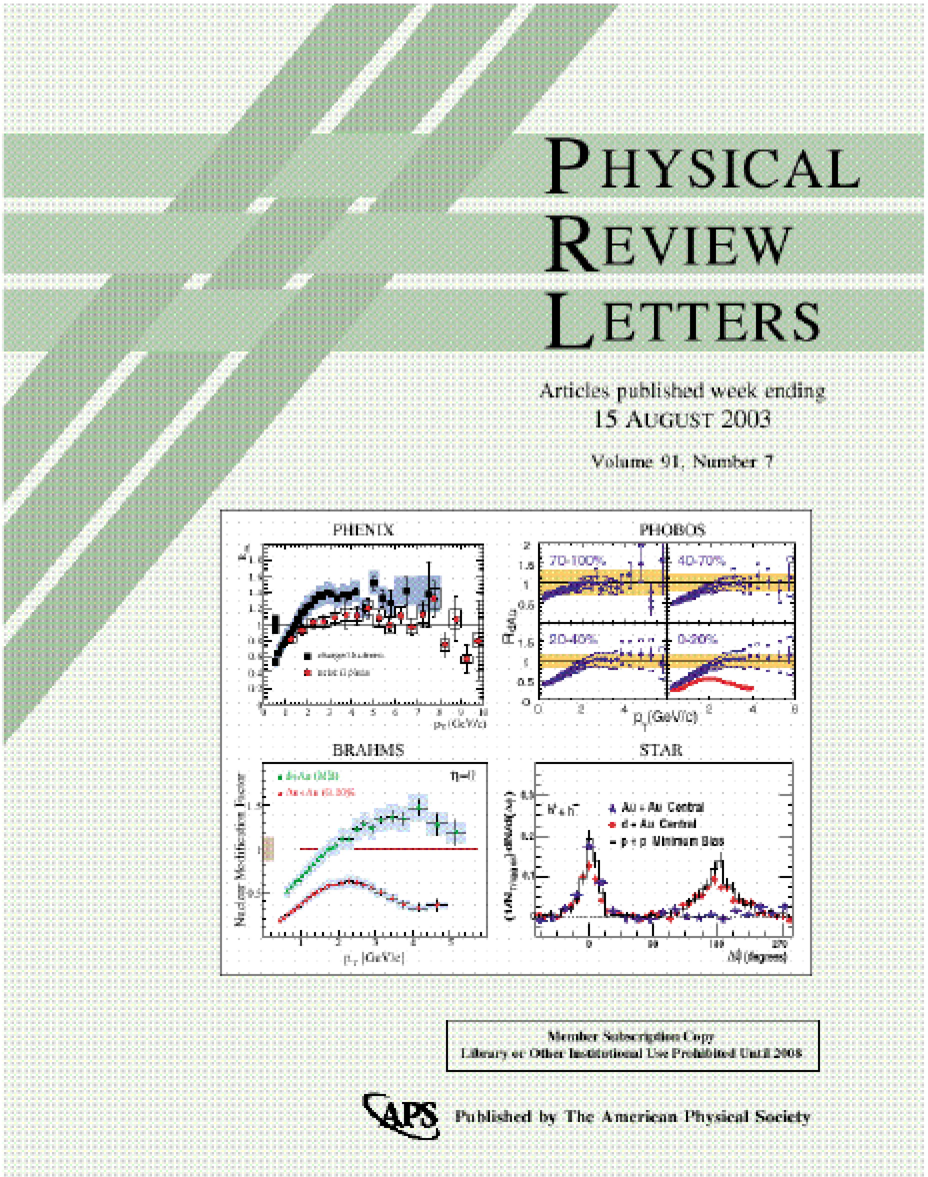






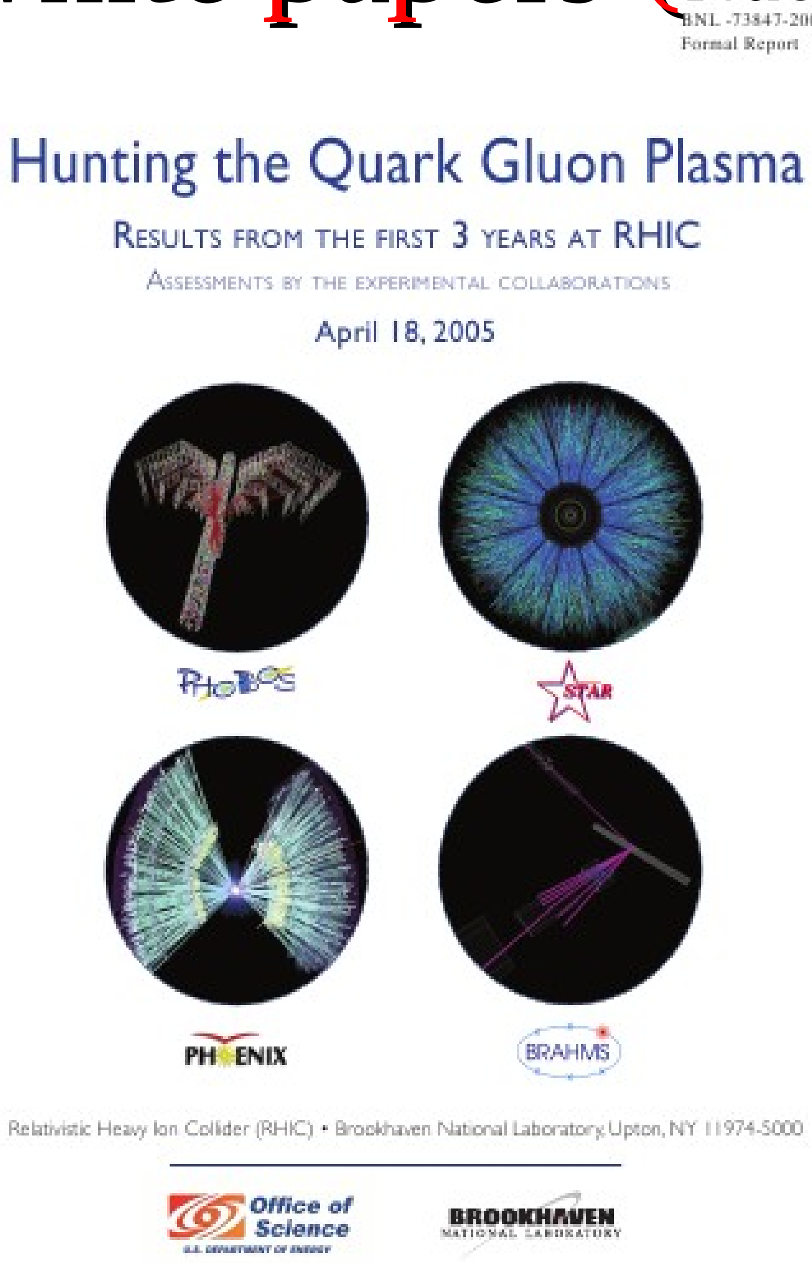
study onset of deconfinement: disappearance of horn etc.

The Quark-Gluon-Plasma is Found at RHIC



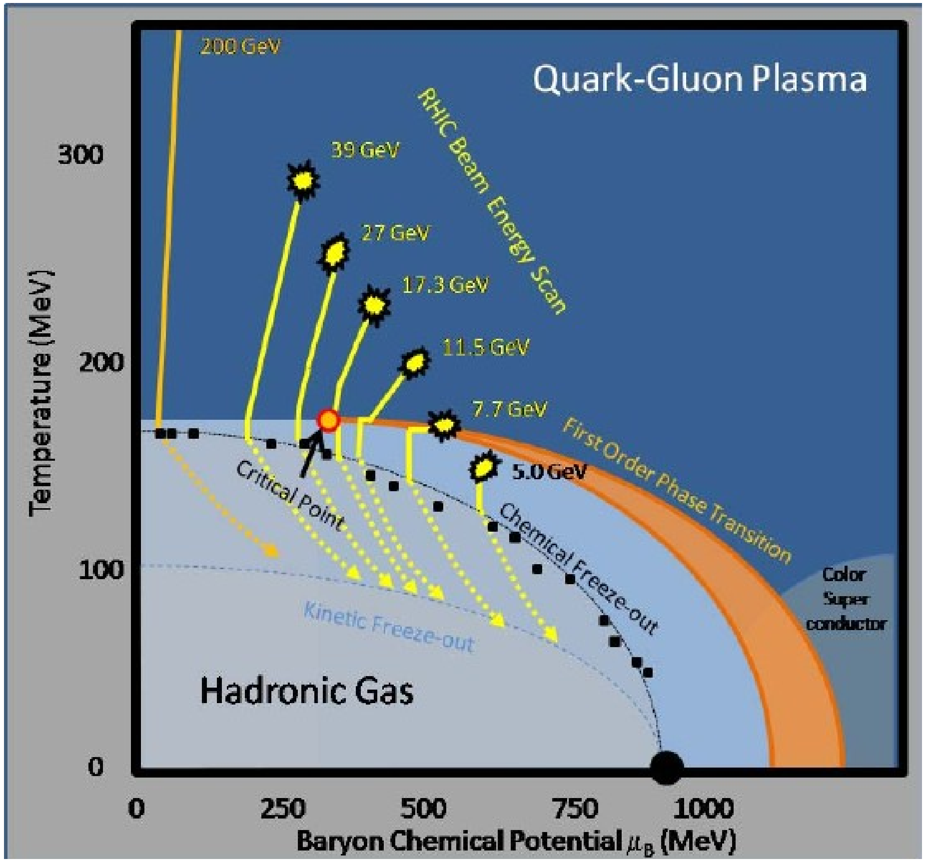
3rd RHIC Milestone

White papers (Nuclear Physics A 757 (2005))



CONTENTS

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):

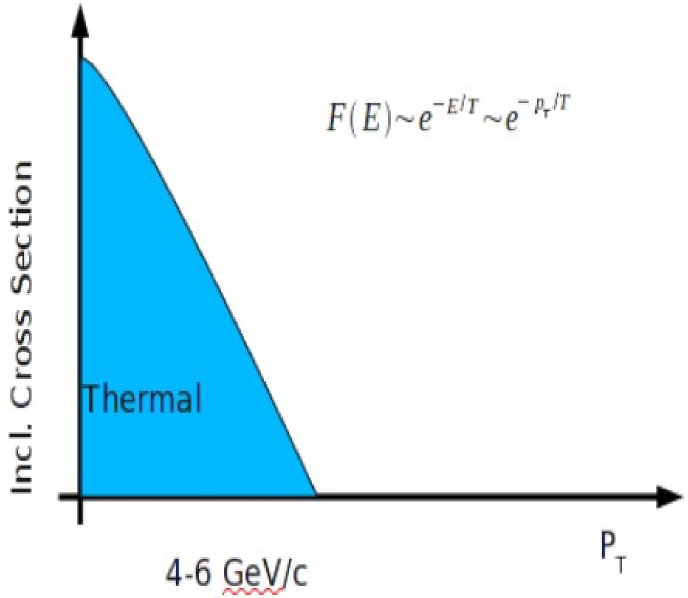
A. A search for turn-off of new phenomena already established at higher RHIC energies; QGP signatures are the most obvious example, but we define this category more broadly. If our current understanding of RHIC physics and these signatures is correct, a turn-off must be observed in several signatures, 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.

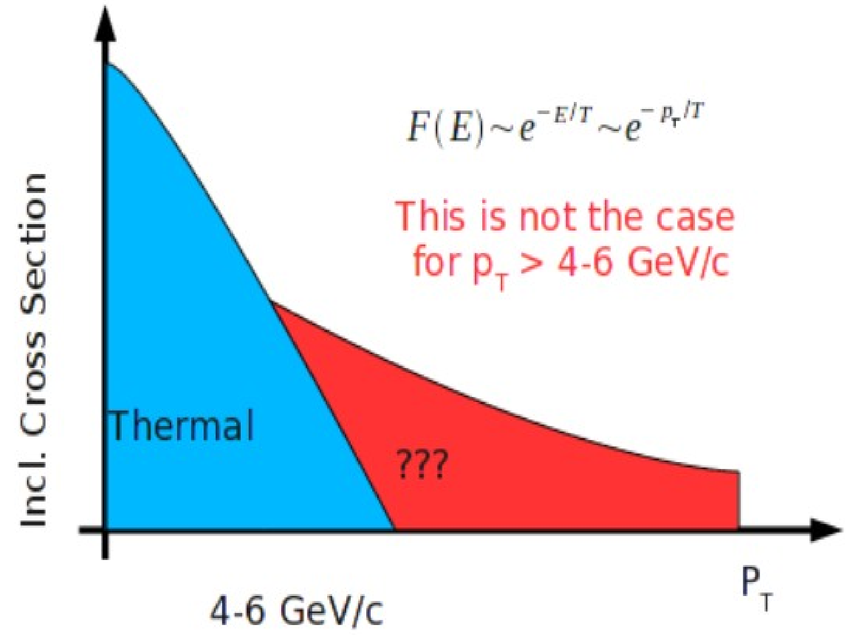
Physics

Boltzmann-Gibbs and ...

- Thermalised system: spectra follow Boltzmann-Gibbs



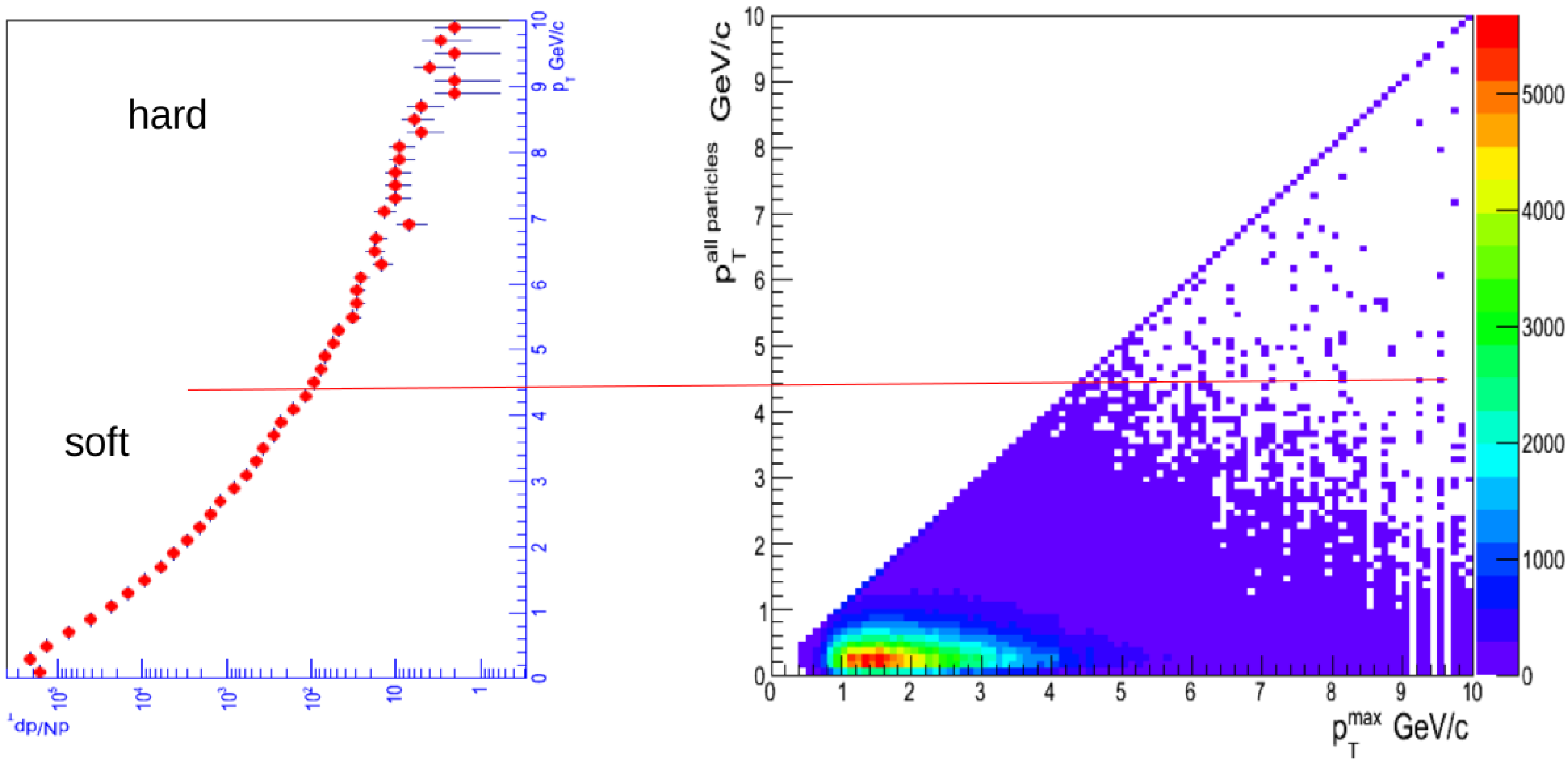
- But in HIC this is quite different...



Hard and soft physics

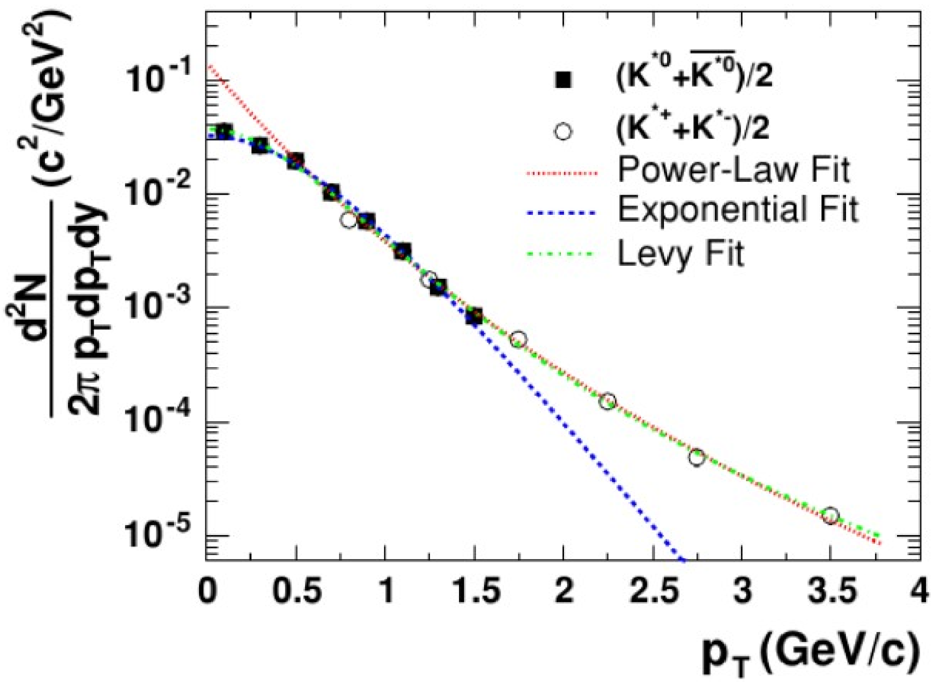
Pythia v.6-424

10K events √s =7 TeV
All charged particles



Particles spectra

Phys.Rev. C 71, 064902 (2005) STAR



exp

$$\frac{1}{2\pi m_T}\frac{d^2N}{dy\,dm_T}=\frac{dN}{dy}\frac{1}{2\pi T(m_0+T)}\exp\left(\frac{-(m_T-m_0)}{T}\right)$$

Power law

$$\frac{1}{2\pi p_T}\frac{d^2N}{dy\,dp_T}=\frac{dN}{dy}\frac{2(n-1)(n-2)}{\pi(n-3)^2\langle p_T\rangle^2}\times\left(1+\frac{p_T}{\langle p_T\rangle(n-3)/2}\right)^{-n}$$

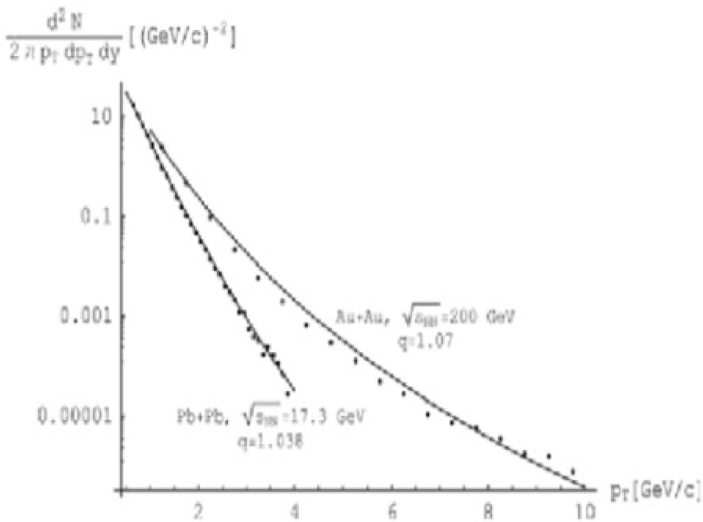
Levy

$$\frac{1}{2\pi p_T}\frac{d^2N}{dy dp_T}=\frac{dN}{dy}\frac{(n-1)(n-2)}{2\pi nT[nT+m_0(n-2)]}\times\left(1+\frac{\sqrt{p_T^2+m_0^2}-m_0}{nT}\right)^{-n}$$

The invariant yields for both (K ∗0 + K ∗0)/2 and (K ∗+ + K ∗−)/2 as a function of pT for |y| < 0.5 in minimum bias p + p interactions. The dotted curve is the fit to the power-law function for pT > 0.5 GeV/c and extended to lower values of pT . The dashed curve is the K ∗0 spectrum fit to the exponential function and extended to higher values of pT . The dashed-dotted curve is the fit to the Levy function for pT < 4 GeV/c. Errors are statistical only.

Tsallis statistics

Eur. Phys. J. A 40, 313 (2009)

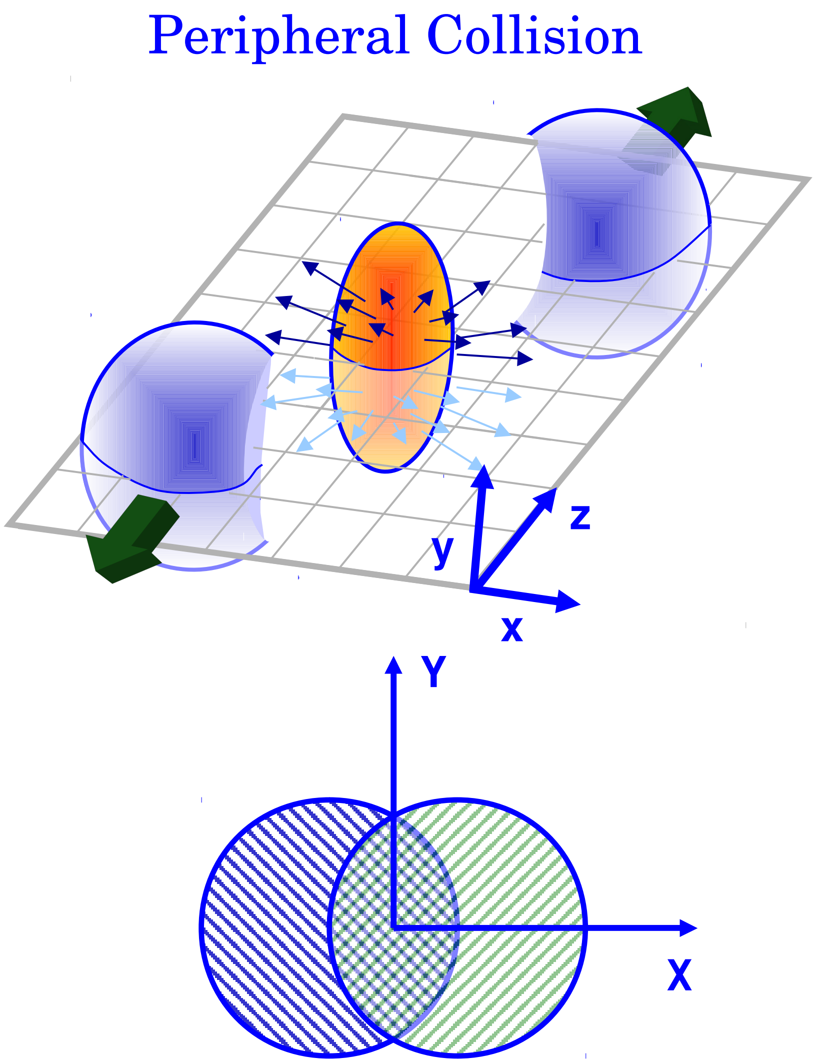


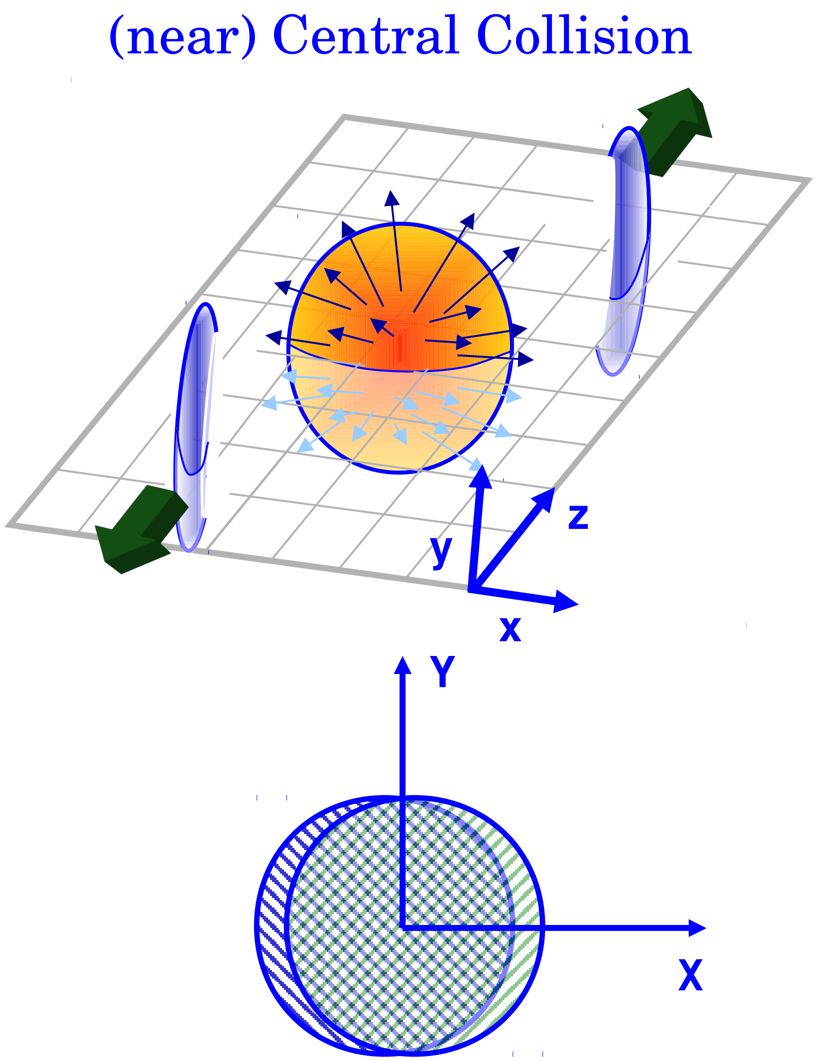
Experimental neutral pion invariant yields in central Pb+Pb collisions at $\sqrt{s_{NN}}$ = 17.3 GeV and in central Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV compared with the modified thermal distribution shape by using non-extensive statistics

(q = 1.038 for Pb+Pb and q = 1.07 for Au+Au collisions.)

$$\frac{\mathrm{d}^2 N}{2\pi p_\perp \mathrm{d}p_\perp \mathrm{d}y} = C\, m_\perp \left[1 - (1-q)\frac{m_\perp}{T}\right]^{1/(1-q)}$$

Collectivity



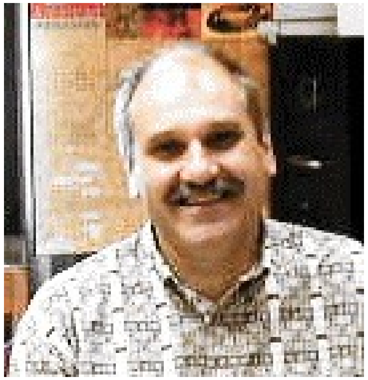


Flows

First to use Fourier harmonics:

$$1 + 2v_1 \cos(\phi - \Psi_{RP}) + 2v_2 \cos[2(\phi - \Psi_{RP})] + \cdots$$

$$v_n = \langle \cos[n(\phi_i - \Psi_{RP})] \rangle$$



Voloshin

Event plane resolution correction made for each harmonic

Unfiltered theory can be compared to experiment!

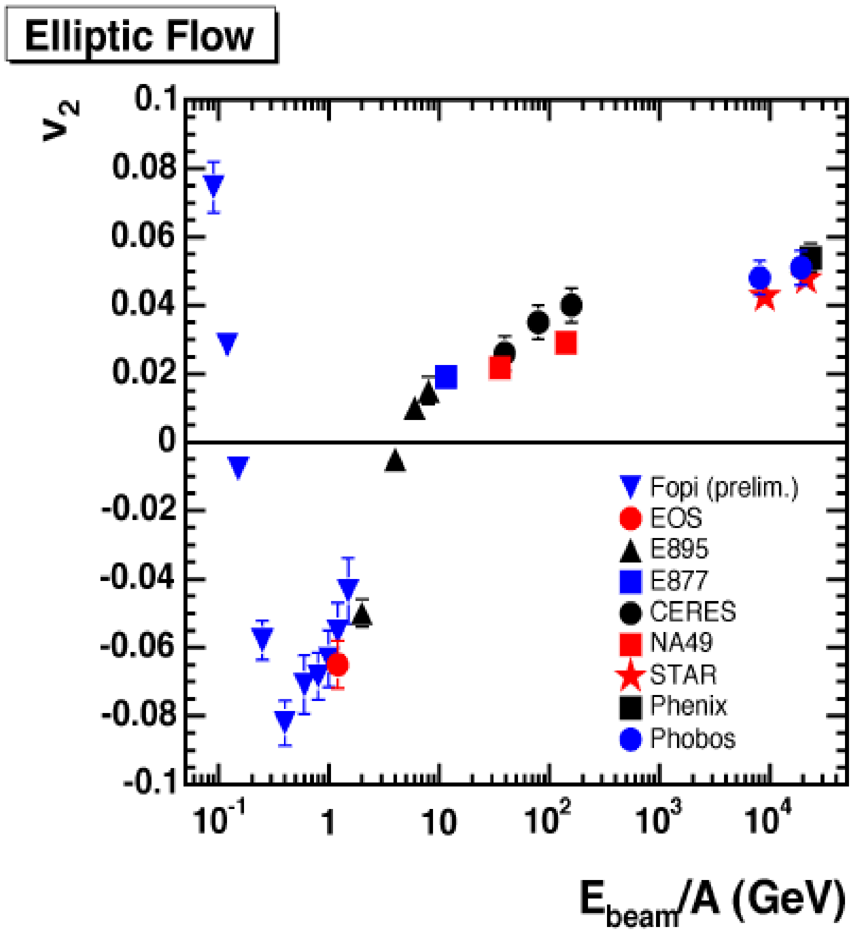
First to use mixed harmonics

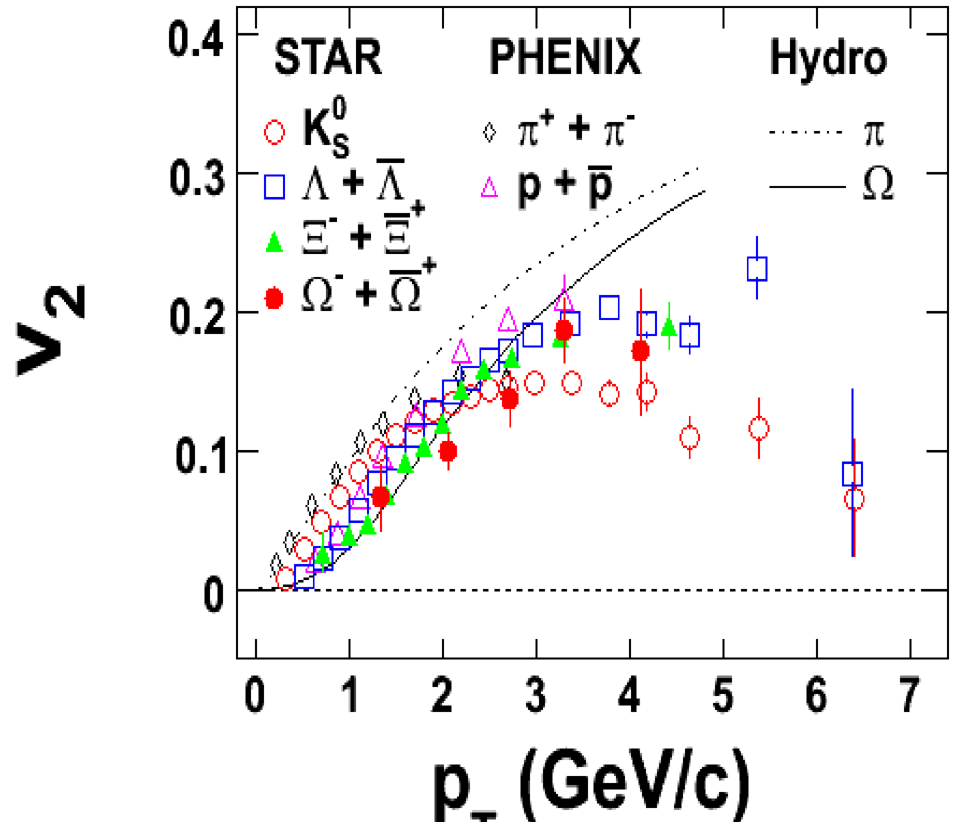
First to use the terms directed and elliptic flow for v_1 and v_2

S. Voloshin and Y. Zhang, hep-ph/940782; Z. Phys. C **70**, 665 (1996)

See also, J.-Y. Ollitrault, arXiv nucl-ex/9711003 (1997)
and J.-Y. Ollitrault, Nucl. Phys. **A590**, 561c (1995)

Elliptic flow energy scan



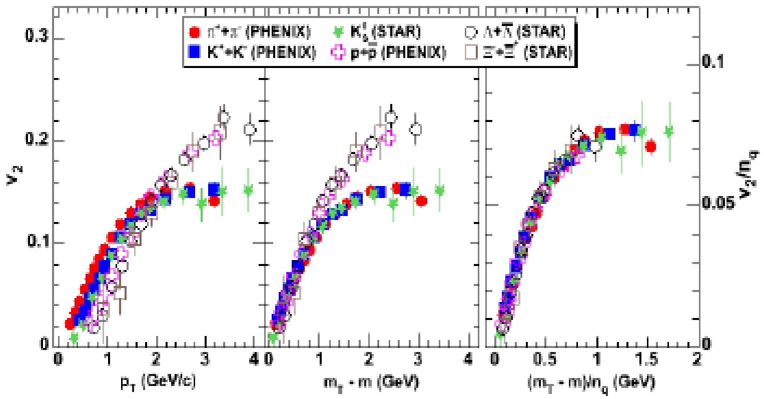


Elliptic Flow:disappearance of partonic collectivity ?

NCQ scaling of v_2

Indication for partonic flow

Au+Au at $\sqrt{s_{NN}}$ = 200 GeV:

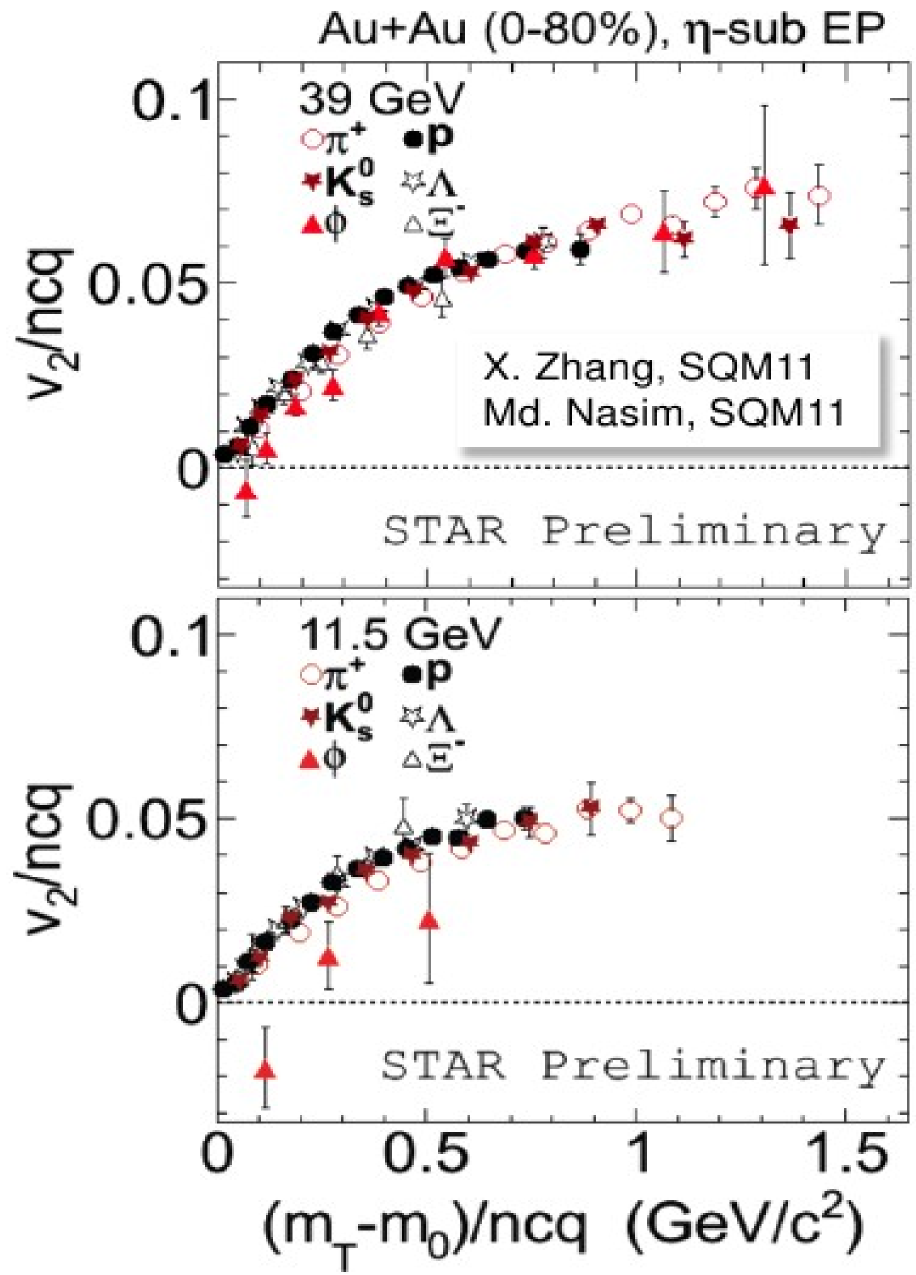


ϕ Meson seems to deviate at low energies

Scaling still ok at $\sqrt{s_{NN}}$ = 39 GeV

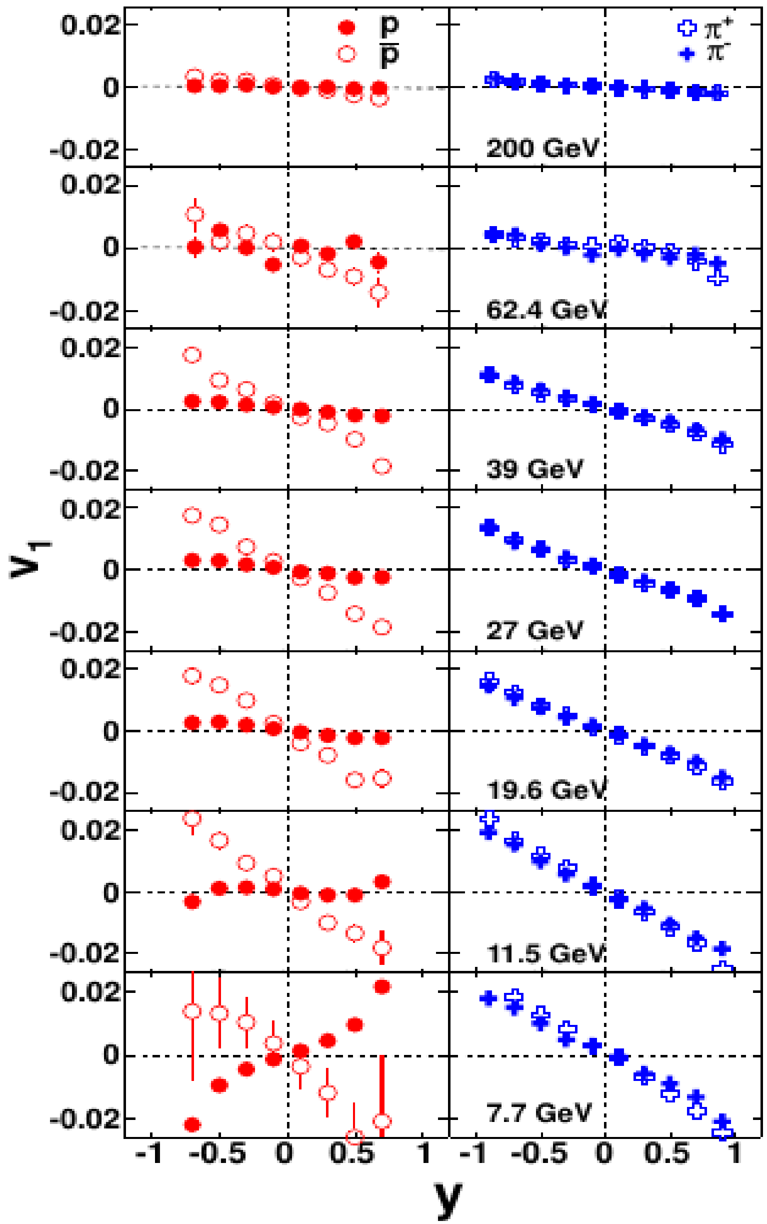
Low hadronic cross section of ϕ → less partonic flow seen ?

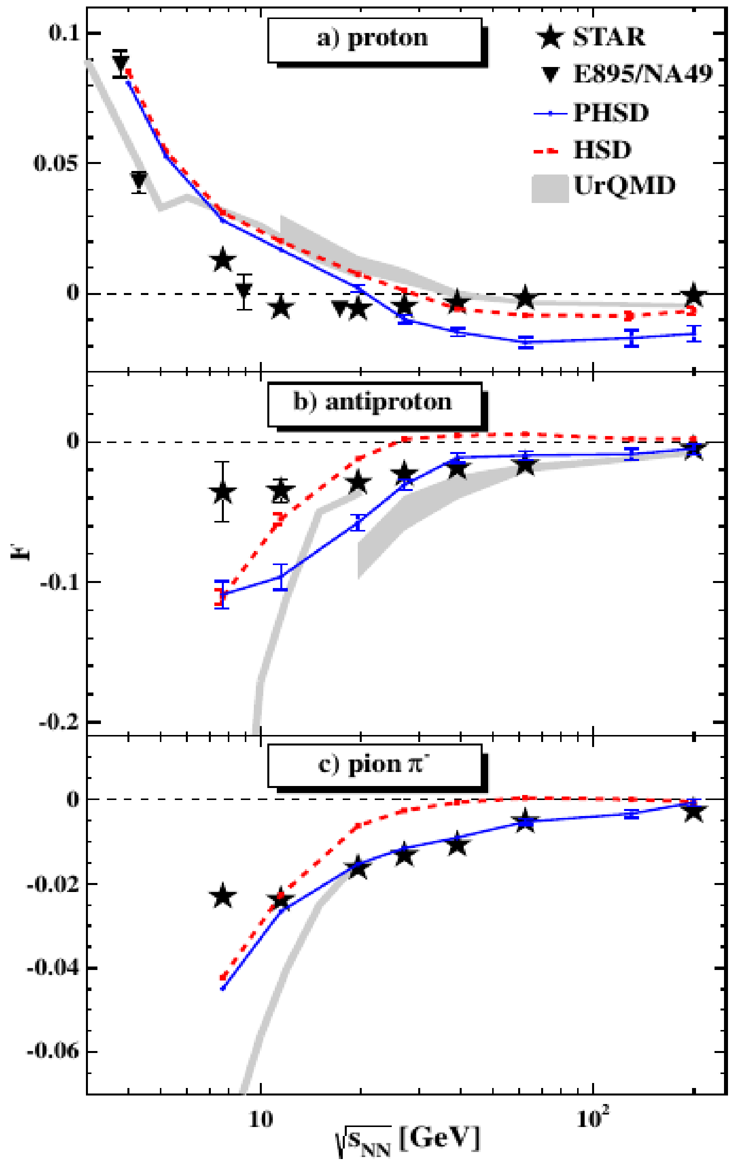
Breaking of NCQ scaling?



Direct flow energy scan

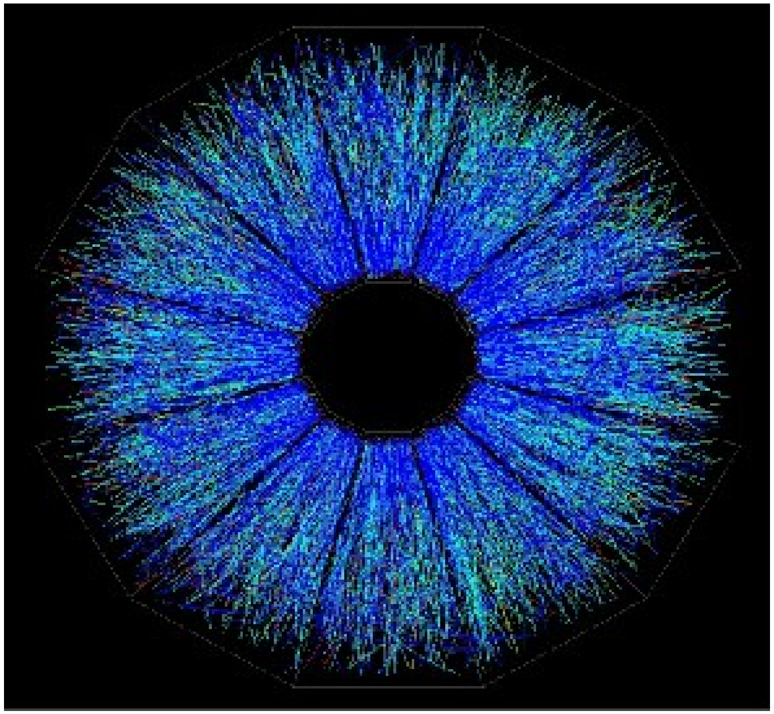
L. Adamczyk, et al. (STAR Collaboration),
Phys. Rev.Lett. 112, 162301 (2014).

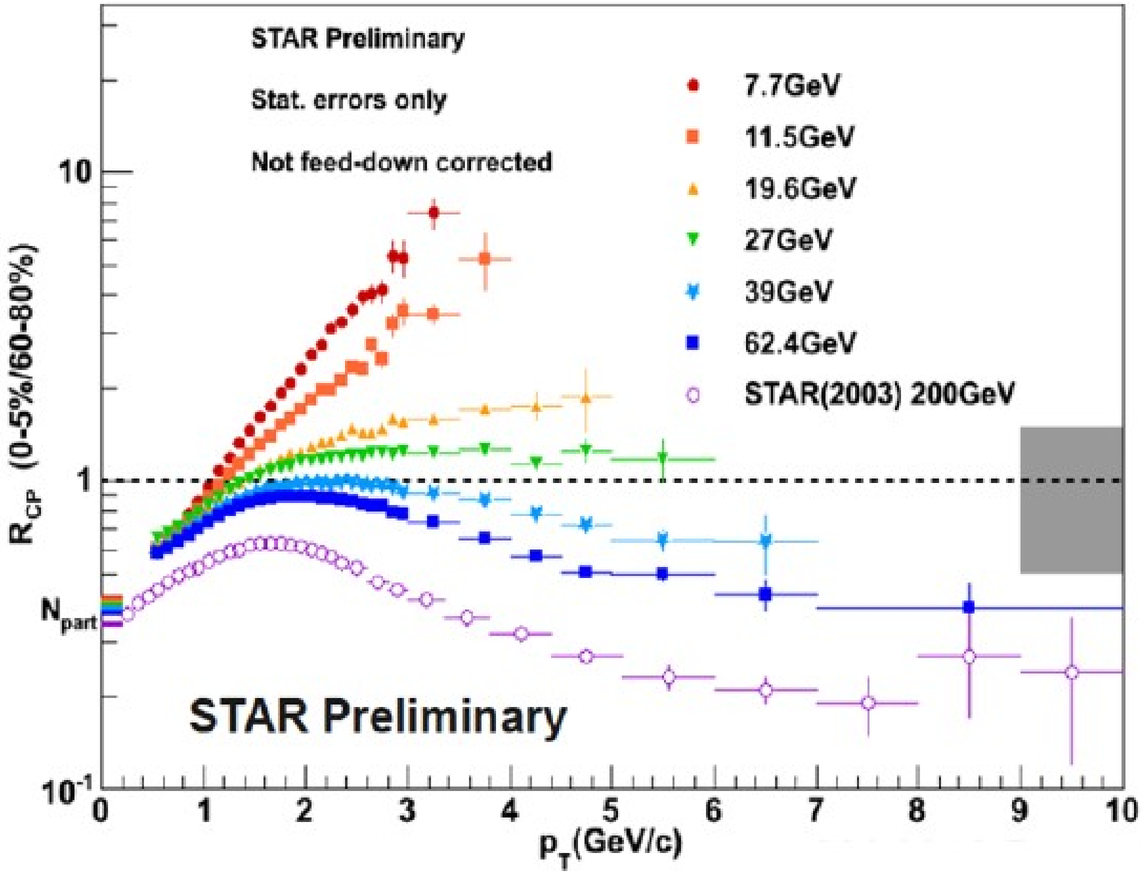




intermediate-centrality (10-40%)
Au+Au collisions

High p_T suppression





Yield in A+A

$$R_{AA}(p_T) = \frac{d^2N_{AA}/dp_T dy}{T_{AA}\left(d^2\sigma_{NN}/dp_T dy\right)}$$

Area density of p+p coll's in A+A

Cross section in p+p coll's

Without nuclear effects:

$R_{AA} = 1$.

$$R_{CP} = \frac{d^2N_{(0-5)\%}/dp_T d\eta \,/\langle N_{bin}\rangle_{(0\text{-}5)\%}}{d^2N_{(60-80)\%}/dp_T d\eta \,/\langle N_{bin}\rangle_{(60\text{-}80)\%}}$$

Statistical Model of the Early Stage

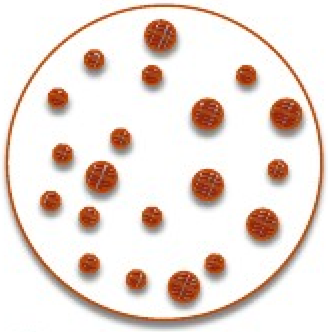
$$\langle N_i \rangle = -T\frac{\partial \ln Z_i}{\partial \mu} = \frac{g_i V}{2\pi^2}\int_0^\infty p^2 dp\, e^{-\frac{\sqrt{p^2+m^2}}{T}}$$ Boltzmann limit

hadron gas

$$m/T \to \infty, \quad \sqrt{p^2+m^2} \approx \frac{p^2}{2m}+m, \quad \langle N \rangle \propto T^{3/2} e^{-m/T}$$

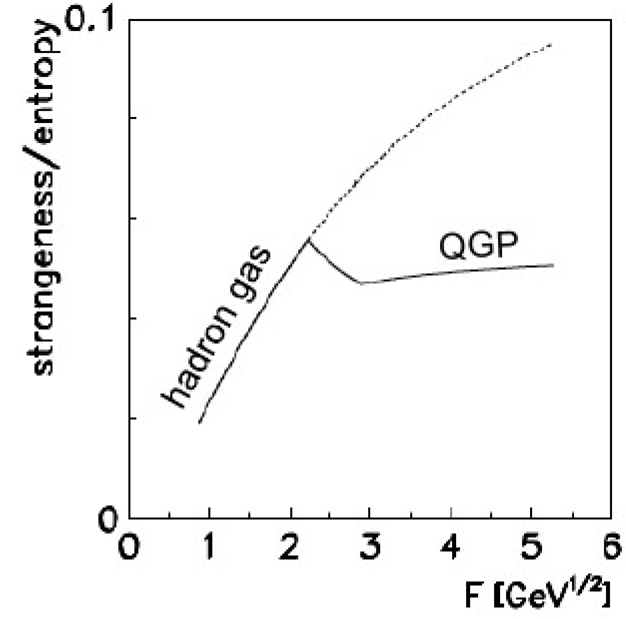
$$\frac{\text{strangeness}}{\text{entropy}} \propto T^{-3/2} e^{-m/T}$$

QGP



$$m/T \to 0, \quad \langle N_i \rangle \propto T^3$$

$$\frac{\text{strangeness}}{\text{entropy}} = \text{const}$$



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

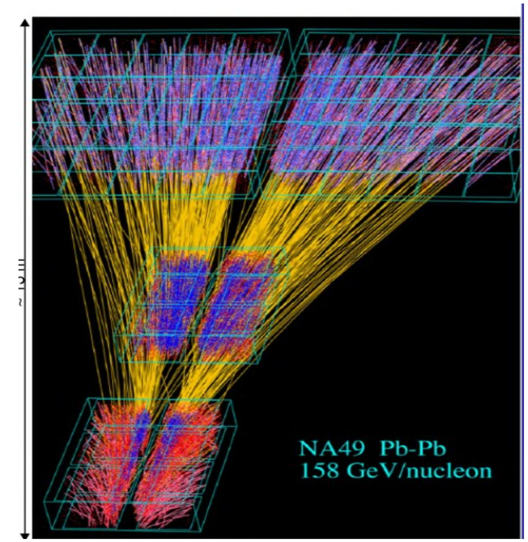
Gazdzicki, Z. Phys. C 71 (1996) 55

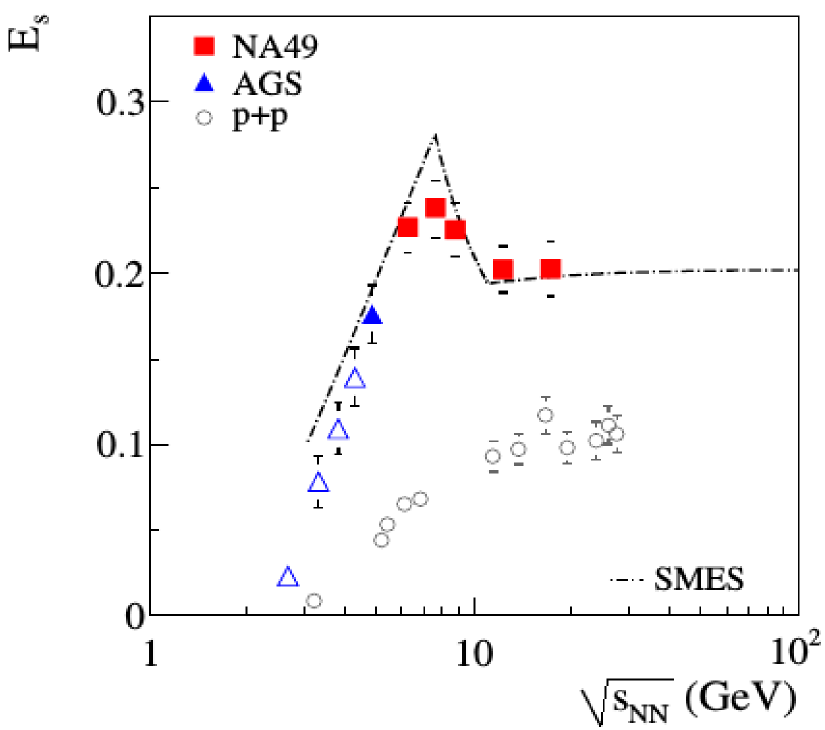
Horn

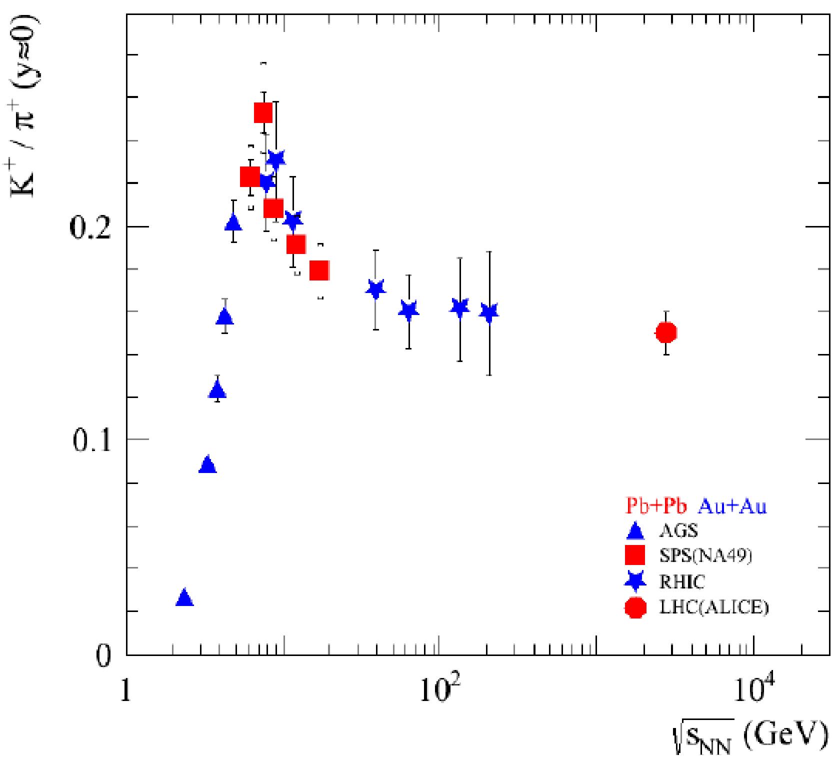
Statistical Model of the Early Stage

M. Gazdzicki and M. I. Gorenstein,
Acta Phys. Polon. B 30, 2705 (1999)

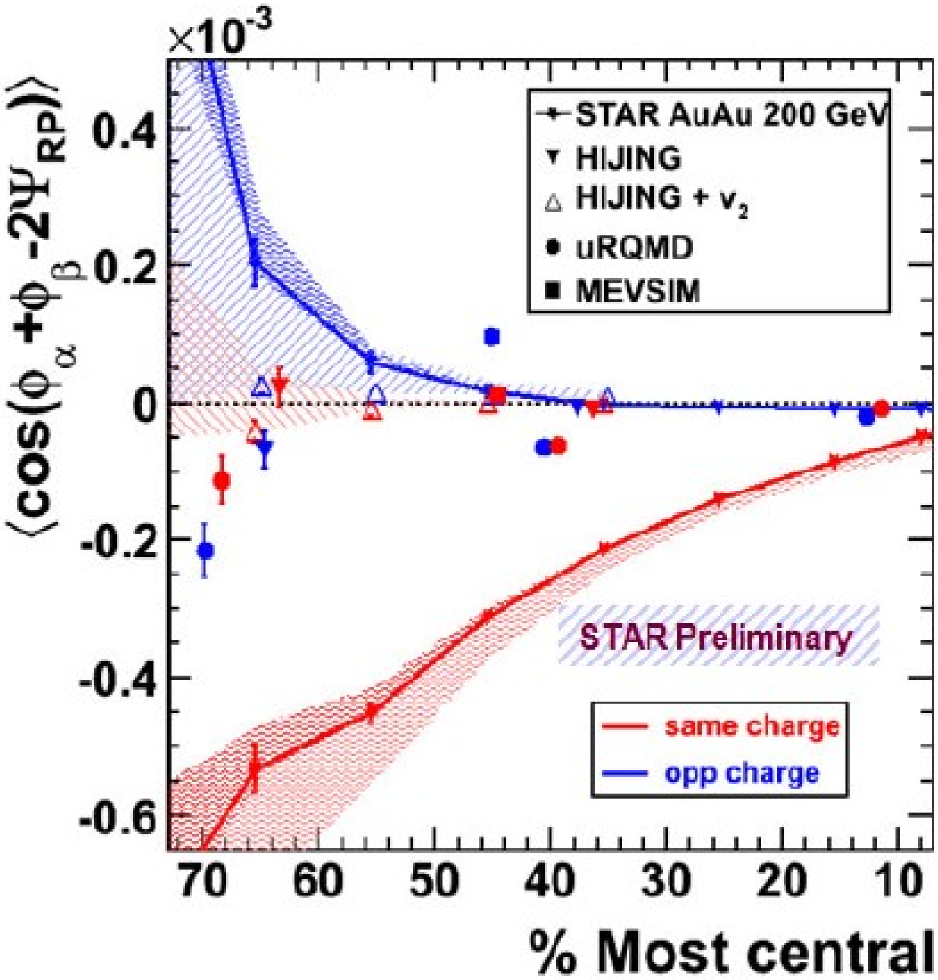
$$E_S = \frac{\langle \Lambda \rangle + \langle K + \overline{K} \rangle}{\langle \pi \rangle}$$







Local parity violation (CME effect)

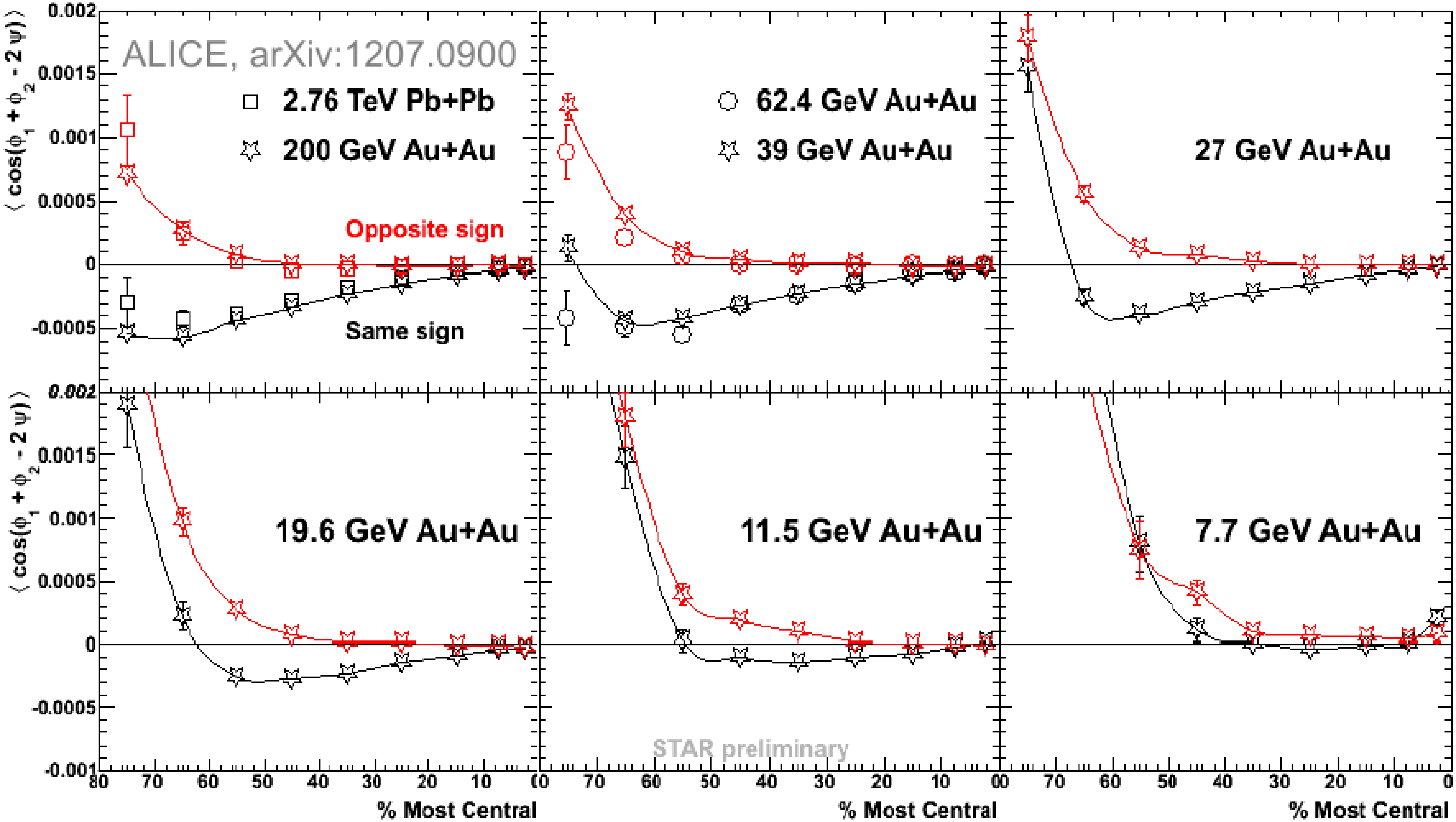


$$\frac{dN_{\pm}}{d\phi} \propto 1 + 2a_{\pm}\sin(\phi - \Psi_{RP}) + \ldots$$

the coefficient a represents the size of the parity-violating signal, and the remaining terms (not shown explicitly) are the familiar ones with coefficients vn for directed and elliptic flow, etc.
However, the coefficient a averages to zero when integrated over many parity-violating domains in many events.
If parity violation takes place, a non-zero average signal can be obtained.

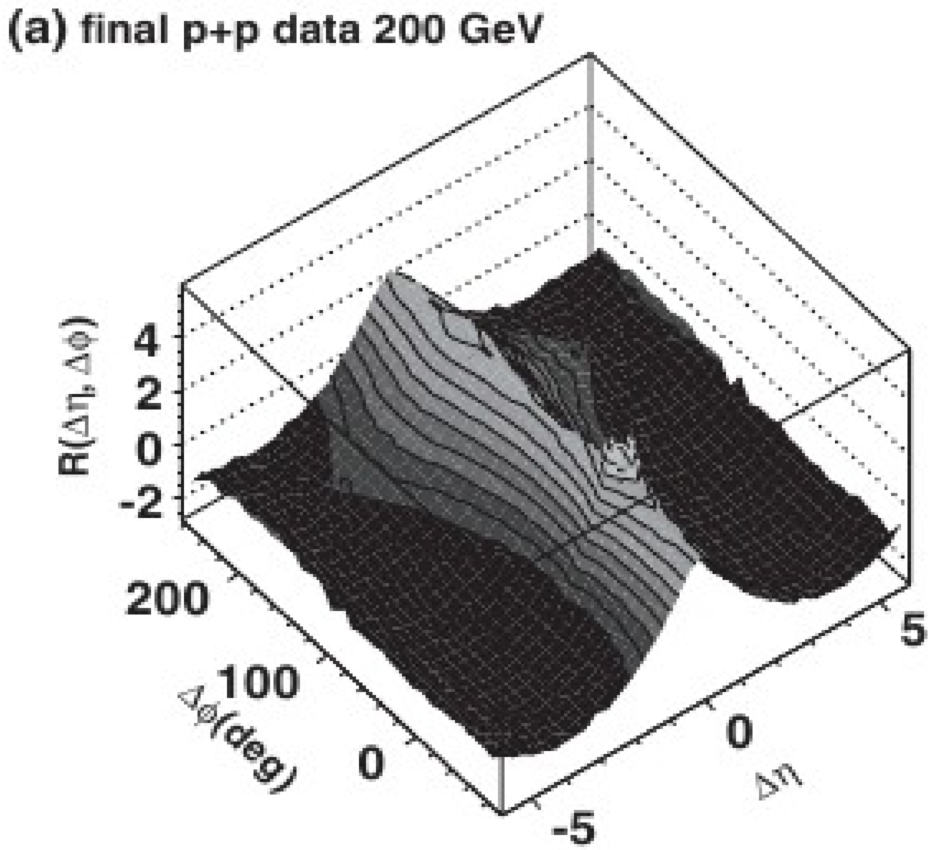
CME energy scan

Gang Wang QM12

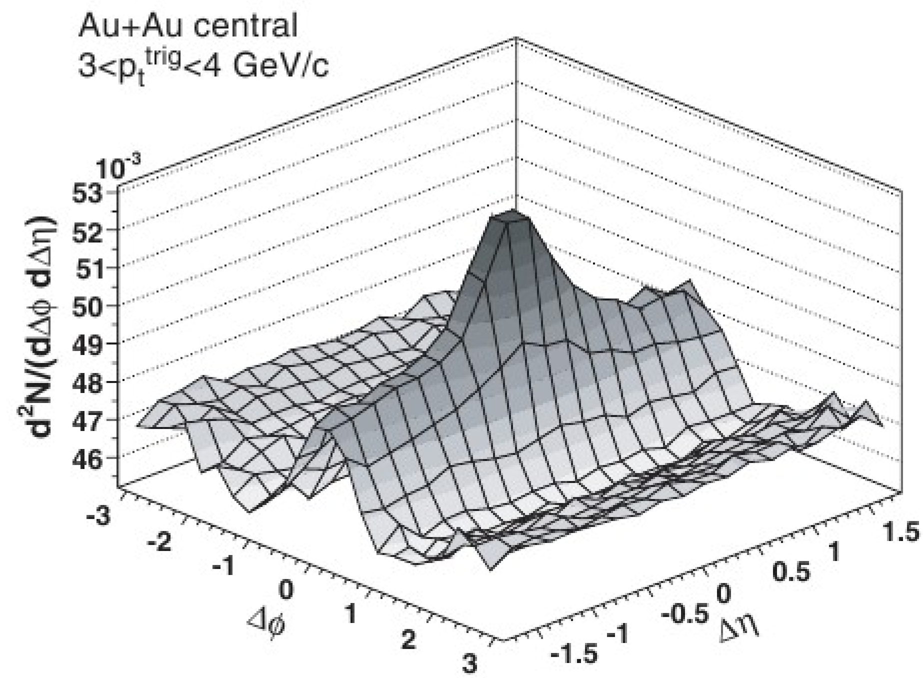


Ridge @ 200 GeV

PHYSICAL REVIEW C **75**, 054913 (2007)



PHYSICAL REVIEW C **80**, 064912 (2009)



$3 < |\eta| < 4.5$

$-180^\circ < \varphi < 180^\circ$

5×10^5 200-GeV and 8×10^5 410-GeV p+p events

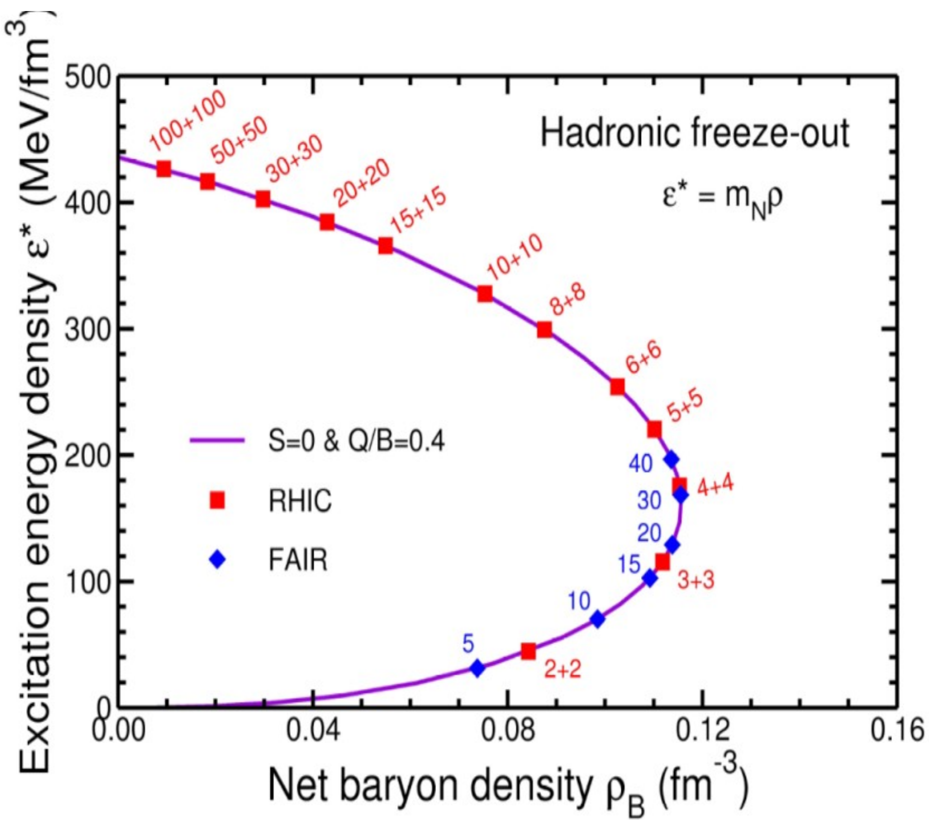
$|z_{vtx}| < 10$ cm along the beam axis.

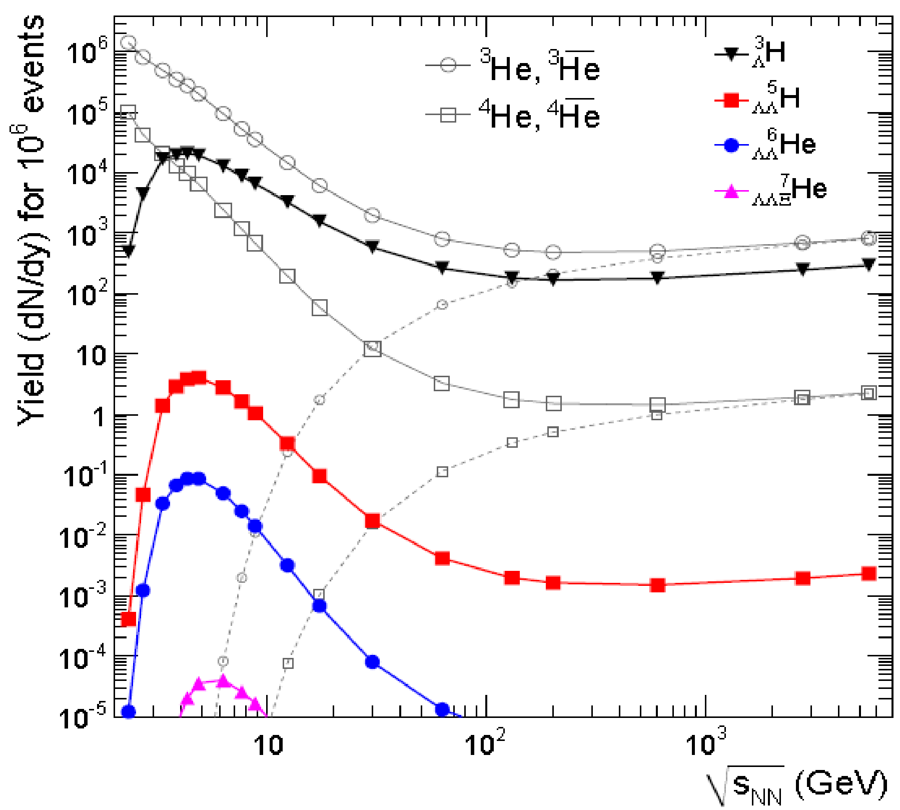
$2\ \mathrm{GeV}/c < p_T^{assoc} < p_T^{trig}$

Barion density & hypernuclei production

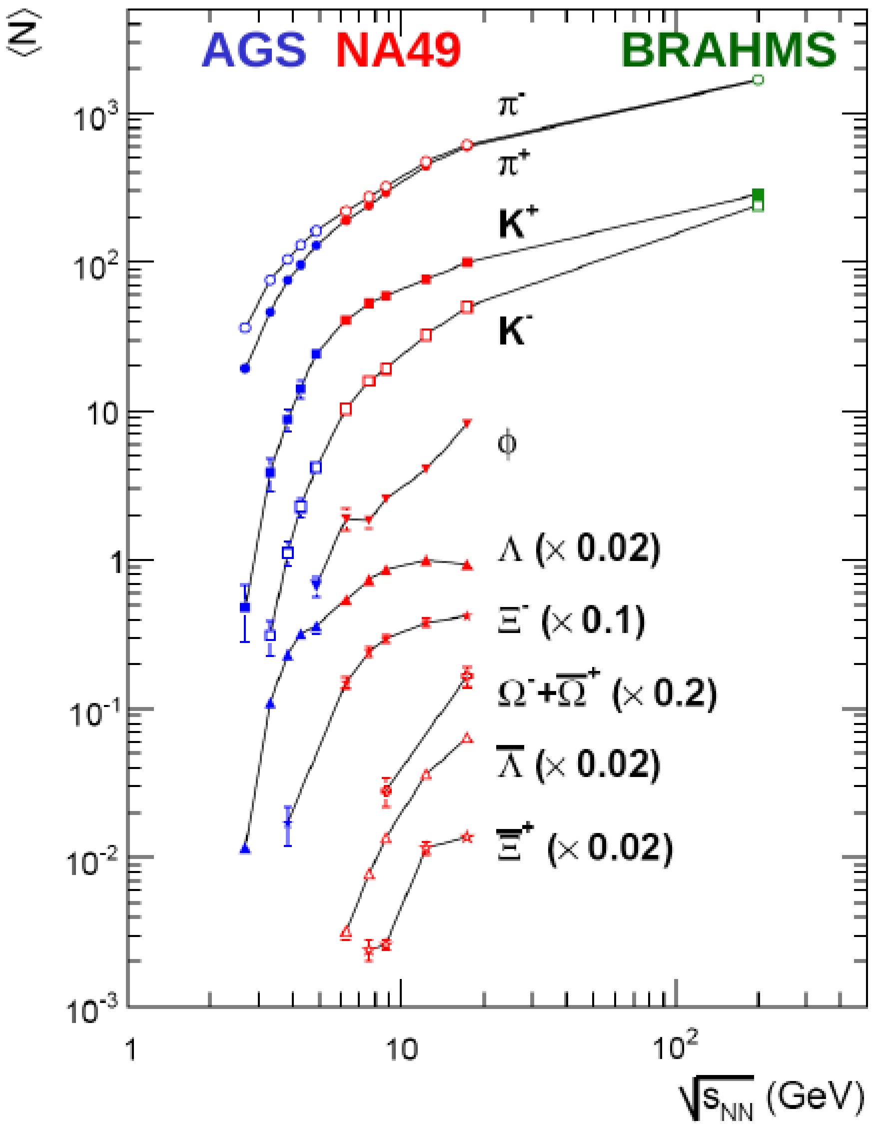
A.Andronic, P.Braun-Munzinger, J.Stachel, H.Stocker

Hypernuclei production enhanced at high baryon densities (NICA)





Particles yield



NICA physics

http://theor.jinr.ru/twiki-cgi/view/NICA/WebHome

NICA

Draft v 10.01
January 24, 2014

SEARCHING for a QCD MIXED PHASE at the
NUCLOTRON-BASED ION COLLIDER FACILITY
(NICA White Paper)

Contents

MPD physics

http://nica.jinr.ru

Version 1.4

The MultiPurpose Detector – MPD

to study Heavy Ion Collisions at NICA
(Conceptual Design Report)

Project leaders: **A.N. Sissakian,** **A.S. Sorin, V.D. Kekelidze**

The MPD Collaboration:[1]

Kh.U.Abraamyan, S.V.Afanasiev, V.S.Alfeev, N.Anfimov, D.Arkhipkin, P.Zh.Aslanyan, V.A.Babkin, S.N.Bazylev, D.Blaschke, D.N.Bogoslovsky, I.V.Boguslavski, A.V.Butenko, V.V.Chalyshev, S.P.Chernenko, V.F.Chepurnov, Vl.F.Chepurnov, G.A.Cheremukhina, I.E.Chirikov-Zorin, D.E.Donetz, K.Davkov, V.Davkov, D.K.Dryablov, D.Drnojan, V.B.Dunin, L.G.Efimov, A.A.Efremov, E.Egorov, D.D.Emelyanov, O.V.Fateev, Yu.I.Fedotov, A.V.Friesen, O.P.Gavrischuk, K.V.Gertsenberger, V.M.Golovatyuk, I.N.Goncharov, N.V.Gorbunov, Yu.A.Gornushkin, N.Grigalashvili, A.V.Guskov, A.Yu.Isupov, V.N.Jejer, M.G.Kadykov, M.Kapishin, A.O.Kechechyan, V.D.Kekelidze, G.D.Kekelidze, H.G.Khodzhibagiyan, Yu.T.Kiryushin, V.I.Kolesnikov, A.D.Kovalenko, N.Krahotin, Z.V.Krumshtein, N.A.Kuz'min, R.Lednicky, A.G.Litvinenko, E.I.Litvinenko, Yu.Yu.Lobanov, S.P.Lobastov, V.M.Lysan, L.Lytkin, J.Lukstins, V.M.Lucenko, D.T.Madigozhin, A.I.Malakhov, I.N.Meshkov, V.V.Mialkovski, I.I.Migulina, N.A.Molokanova, S.A.Movchan, Yu.A.Murin, G.J.Musulmanbekov, D.Nikitin, V.A.Nikitin, A.G.Olshevski, V.F.Peresedov, D.V.Peshekhonov, V.D.Peshekhonov, I.A.Polenkevich, Yu.K.Potrebenikov, V.S.Pronskikh, A.M.Raportirenko, S.V.Razin, O.V.Rogachevsky, A.B.Sadovsky, Z.Sadygov, R.A.Salmin, A.A.Savenkov, W. Scheinast, S.V.Sergeev, B.G.Shchinov, A.V.Shabunov, A.O.Sidorin, I.V.Slepnev, V.M.Slepnev, I.P.Slepov, A.S.Sorin, O.V.Teryaev, V.V.Tichomirov, V.D.Toneev, N.D.Topilin, G.V.Trubnikov, I.A.Tyapkin, N.M.Vladimirova, A.S.Vodop'yanov, S.V.Volgin, A.S.Yukaev, V.I.Yurevich, Yu.V.Zanevsky, A.I.Zinchenko, V.N.Zrjuev, Yu.R.Zulkarneeva
Joint Institute for Nuclear Research, Dubna, RF

V.A.Matveev, M.B.Golubeva, F.F.Guber, A.P.Ivashkin, L.V.Kravchuck, A.B.Kurepin, T.L.Karavicheva, A.I.Maevskaya, A.I.Reshetin, E.A.Usenko
Institute for Nuclear Research, RAS, Troitsk, RF

[1]The list of participating Institutes is currently a subject of update.

Contents

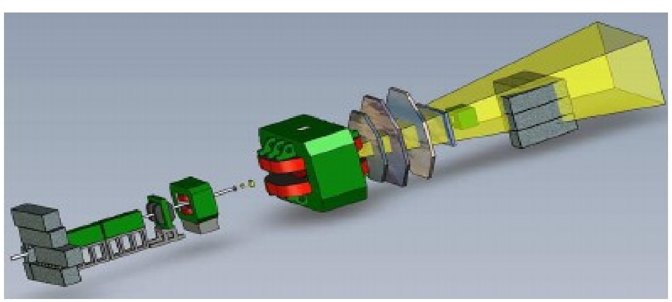
BM@N physics

http://nica.jinr.ru

Conceptual Design Report

BM@N — Baryonic Matter at Nuclotron

Study of Strange Matter Production in Heavy-Ion Collisions at the Nuclotron



Contents

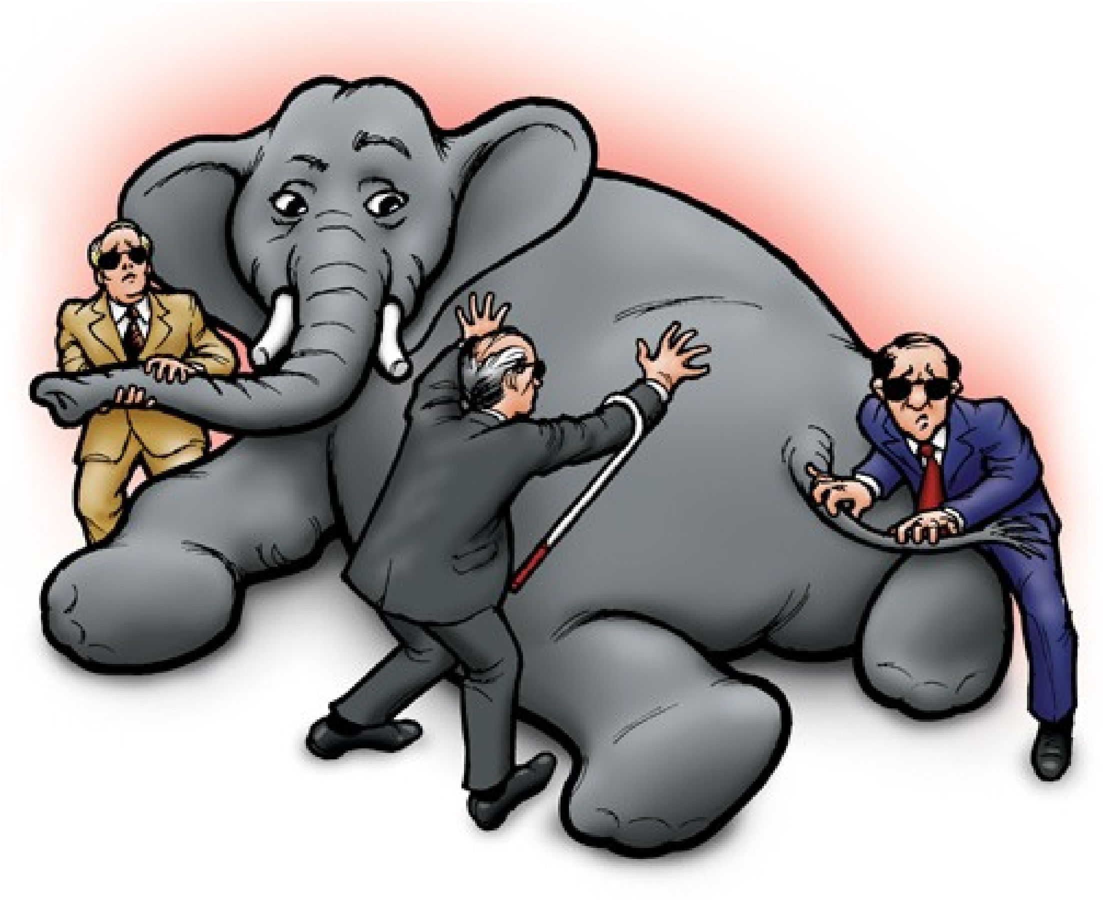
Current & future experiments

Facility	SPS	RHIC BES	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	**2019**	**2017/18**	**2009**
CMC energy GeV/(N+N)	5.1 – 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
GD — onset of deconfinement, mixed phase, 1st order phase transition
HDM — hadrons in dense matter
PDM — properties of deconfined matter

NICA experiments

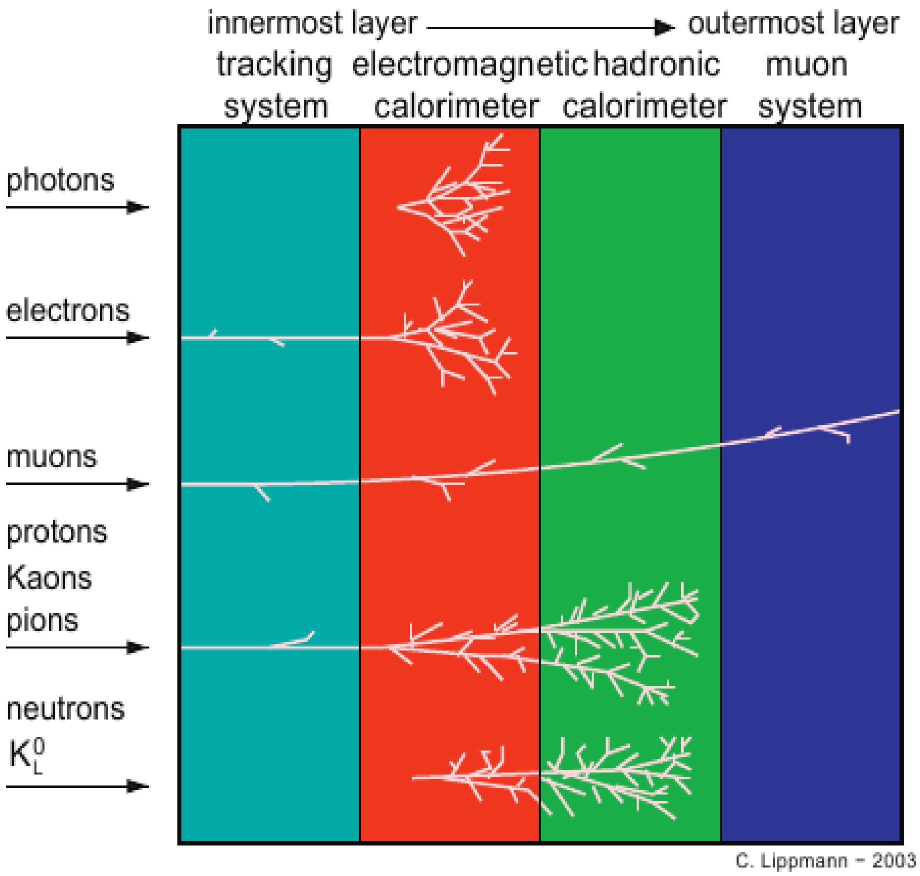
What is QGP ?



“The 6 blind wise men think the elephant is a set of components consisting of a mountain, rope, tree, fan, spear and snake … “

The legend of “The Blind Men and the the Elephant”, written by John Godfrey Saxe in the late 1800s

Perfect Detector



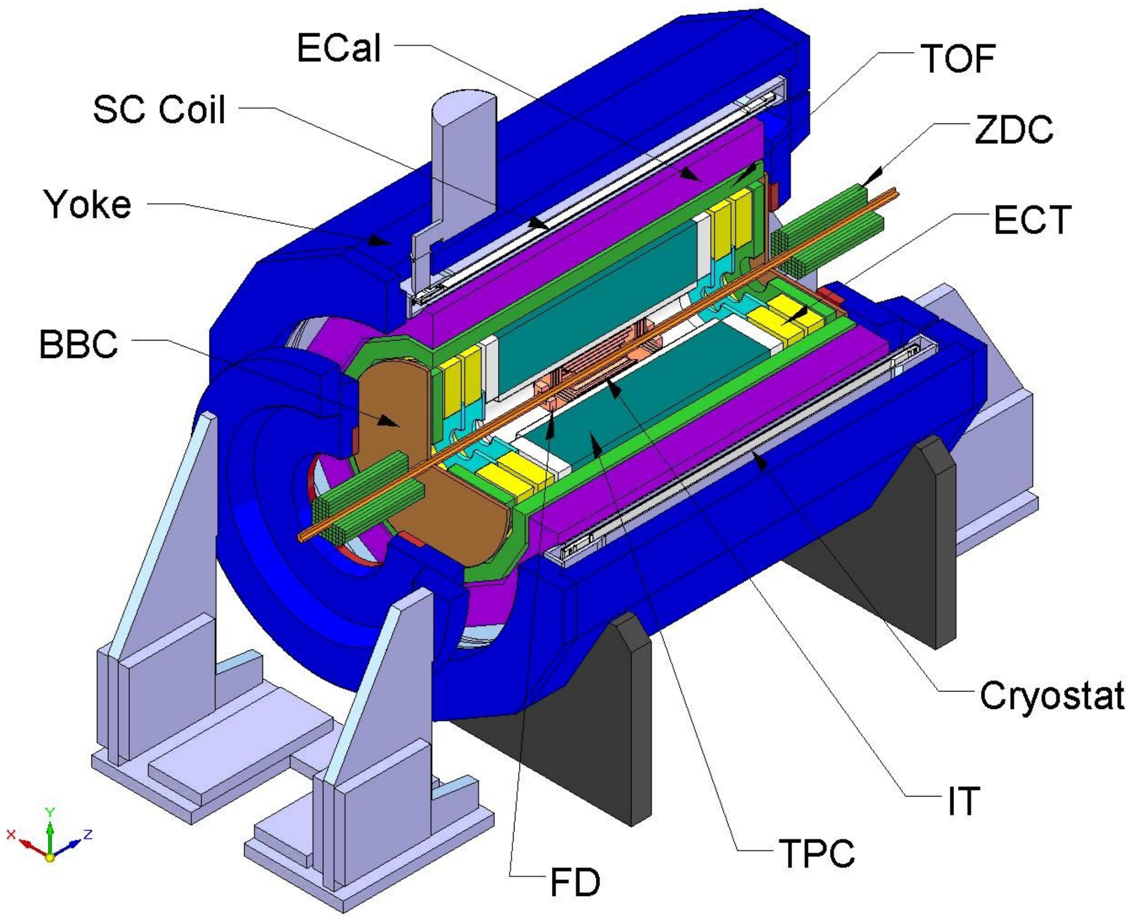
Photons react via photo-Effect, Compton-scattering and pair-production

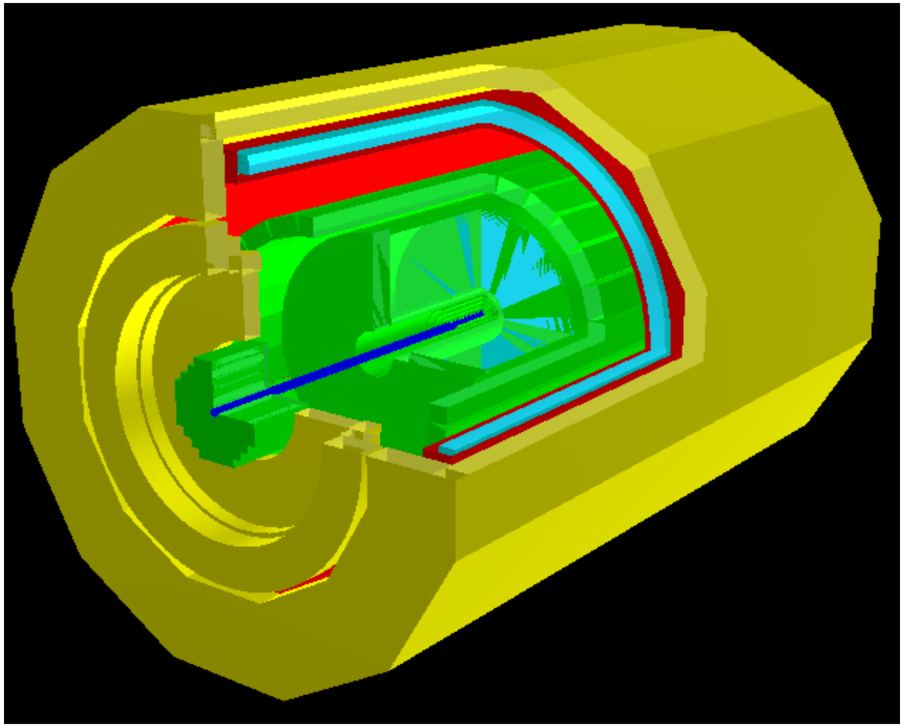
charged particles (e.g. $e^{\pm}$, $\mu^{\pm}$,p, $\pi^{\pm}$, etc.) interact mainly by scattering (unwanted), ionization, excitation, but also by bremsstrahlung, transition radiation and Cherenkov radiation

hadrons (charged and neutral) in addition, interact strongly through inelastic interaction (e.g. induced fission, neutron capture, etc.)

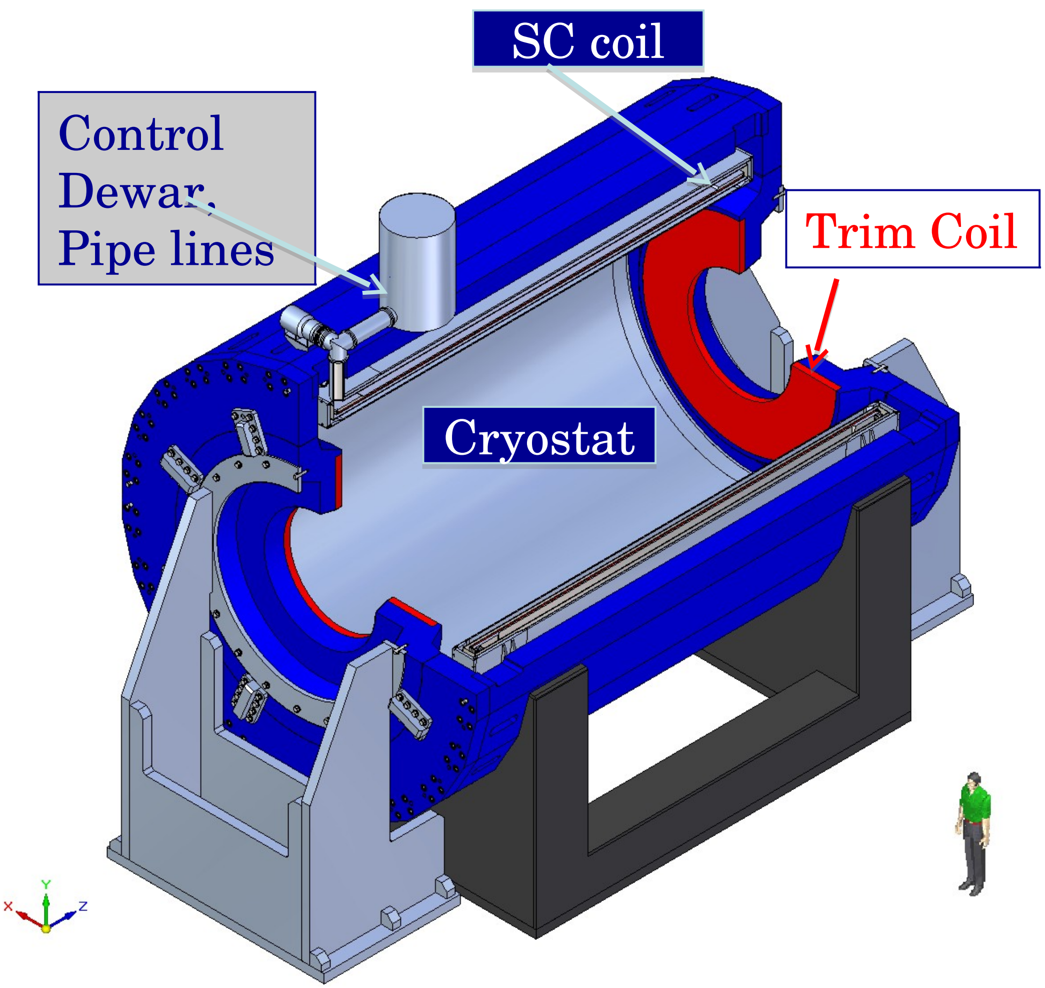
neutrinos only interact weakly, meaning they statistically do not interact in the 'light mass' HEP detectors and their signature is 'non-interaction', manifesting itself as 'Missing Energy'.

Multi Purpose Detector

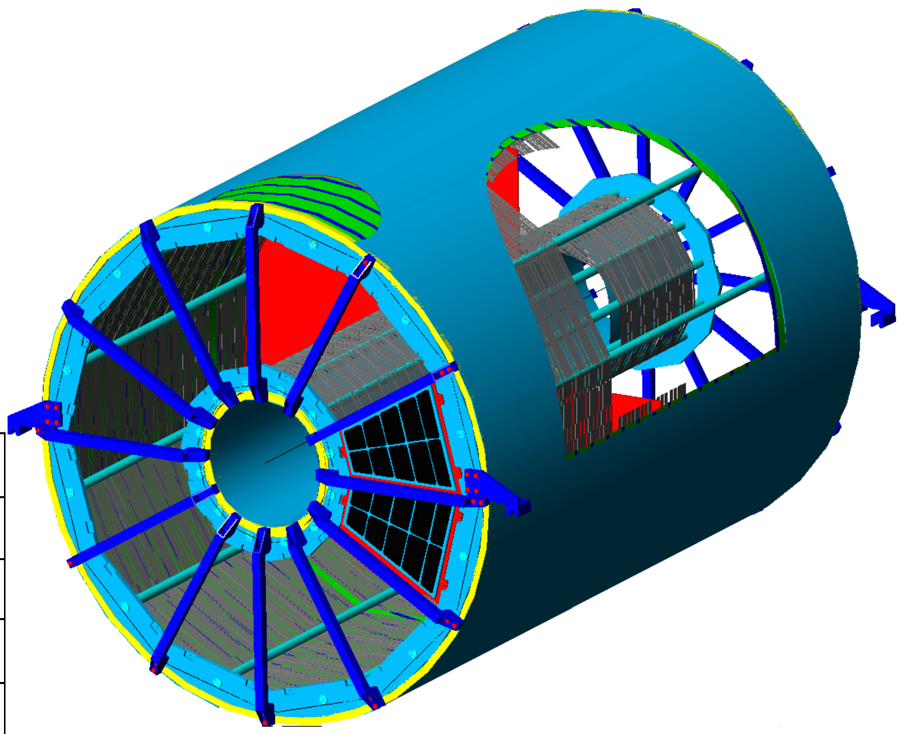




MPD solenoid

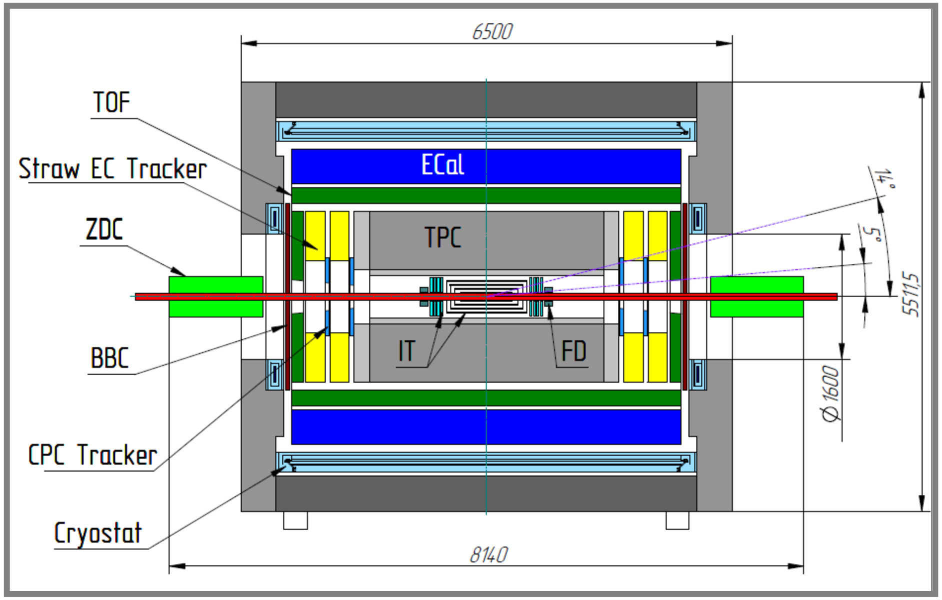


MPD TPC

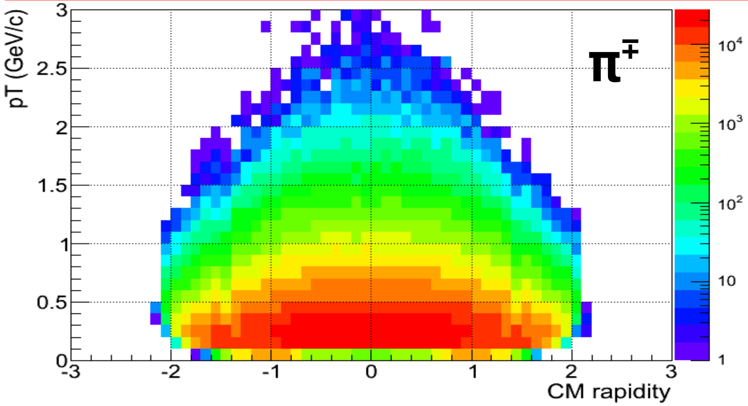


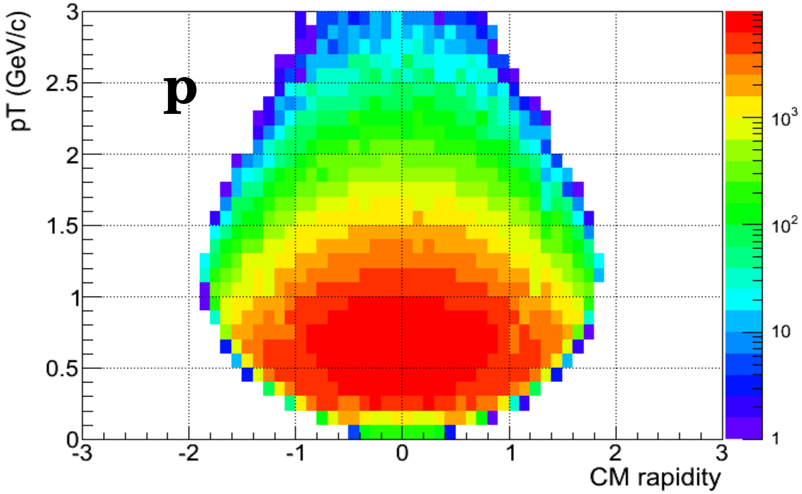
Length of the TPC	340 cm | Full length : 400cm
Outer radius of vessel	140cm
Inner radius of vessel	27 cm
Length of the drift volume	170cm (of each half)
Magnetic field strength	0,5 Tesla
Electric field strength	~140V/cm;
Drift gas	90% Ar+10% Methane, Atmospheric pres. + 2 mbar
Gas amplification factor	~ 10^4
Drift velocity	5,45 cm/μs;
Drift time	≤ 31μs
Temperature stability	< 0.1°C
Pad size	$4x12mm^2$ and $5x18mm^2$
Number of pads	~ 110 000
Pad raw numbers	53
Maximal event rate	≤ 5 kHz (Lum. 10^{27})
Signal to noise ratio	30:1

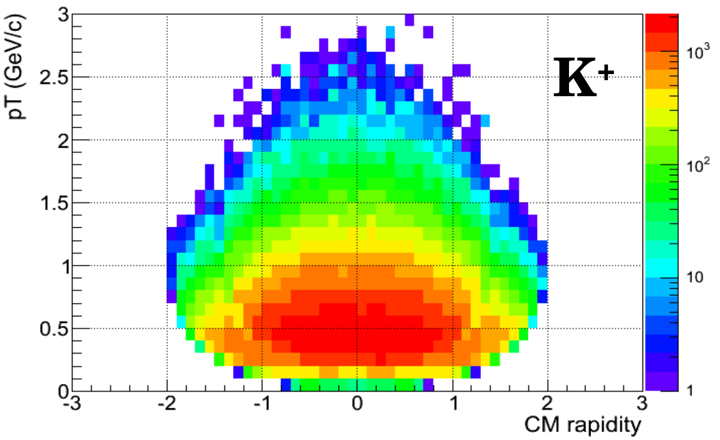
Phase space



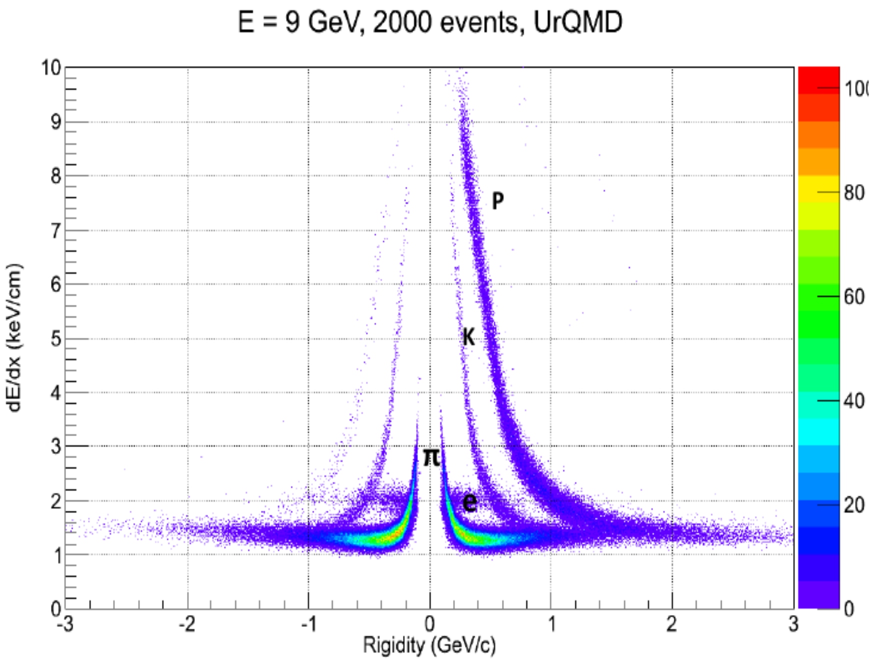
MPD registers on average :
~380 charged pions
~85 protons
~30 K+
in an event (central Au+Au at 8 GeV)







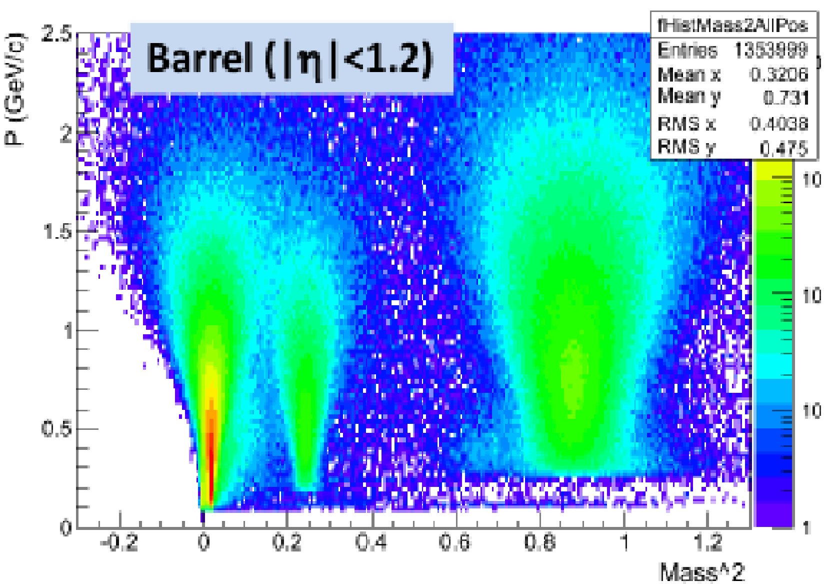
Charged Particle ID

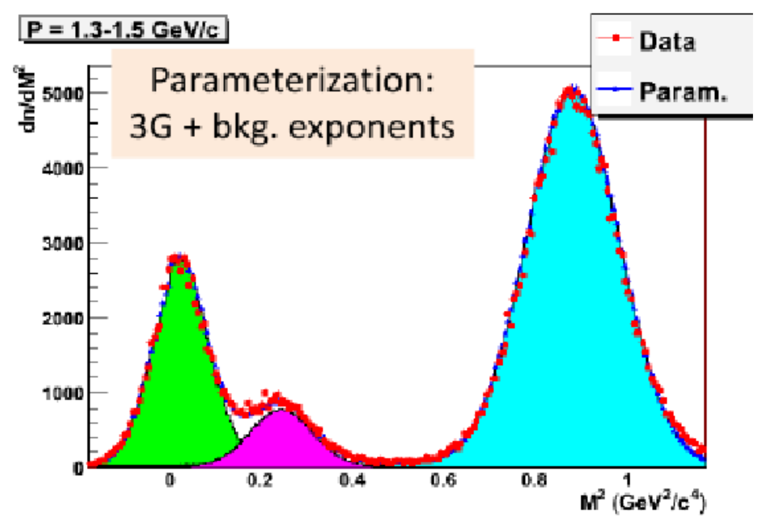


TPC
PID: Ionization loss (dE/dx) Separation:
e/h – 1.3..3 GeV/c
π/K – 0.1..0.6 GeV/c
K/p – 0.1..1.2 GeV/c

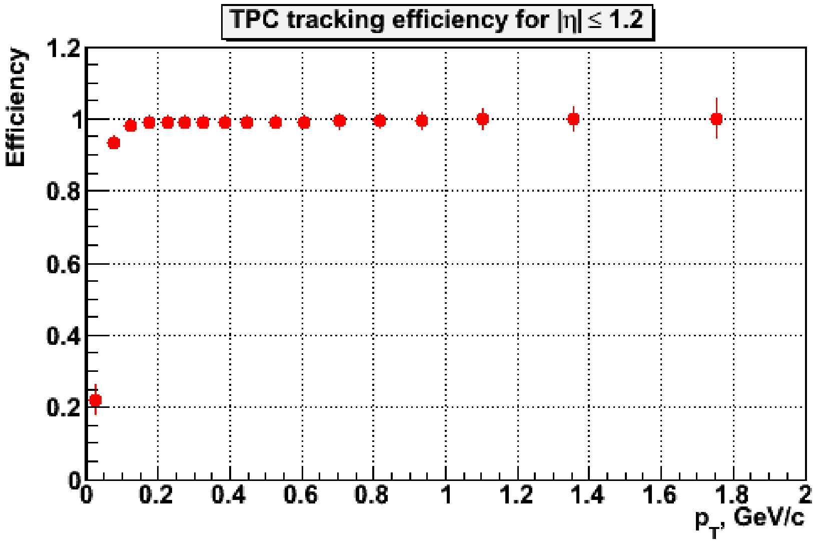
MPD PID (TOF):

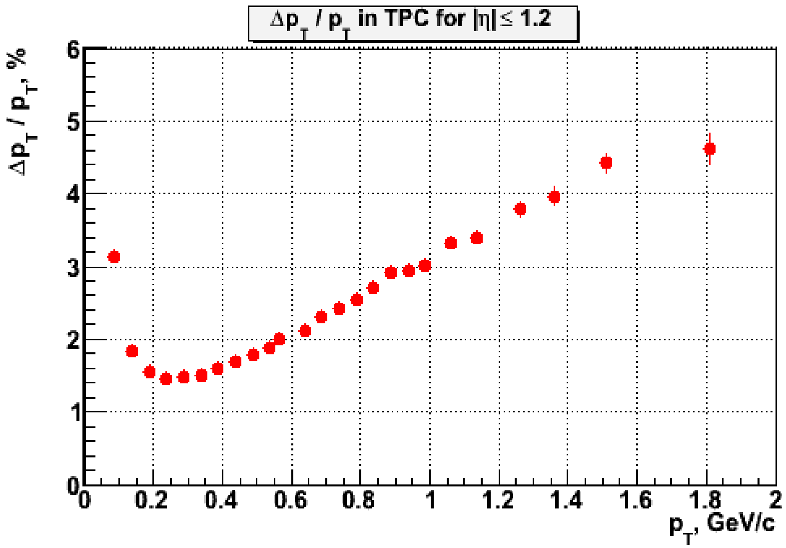
- π/K separation up to p=1.7 GeV/c, above 2 GeV/c - extrapolating the fitted 3G parameters
- Protons up to 3 GeV/c
- dE/dx provide extra PID capability for electrons and low momentum hadrons



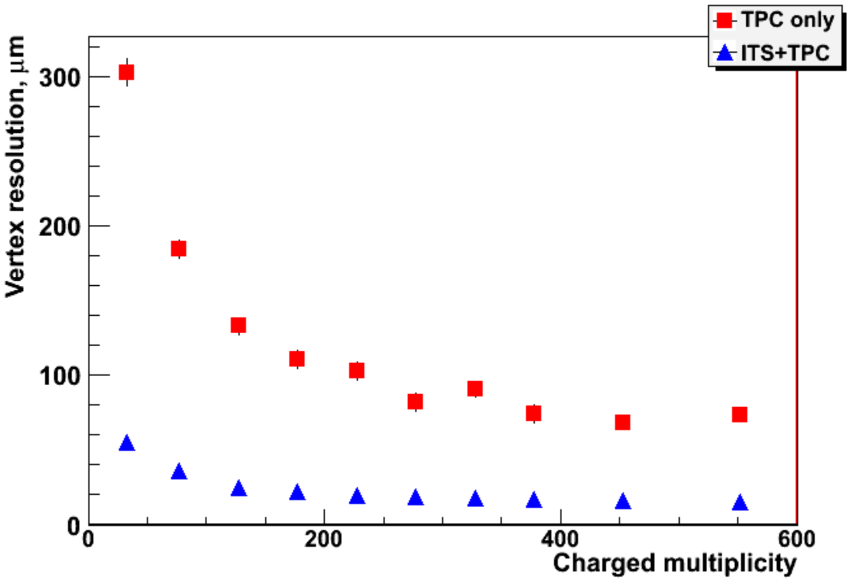


Tracking

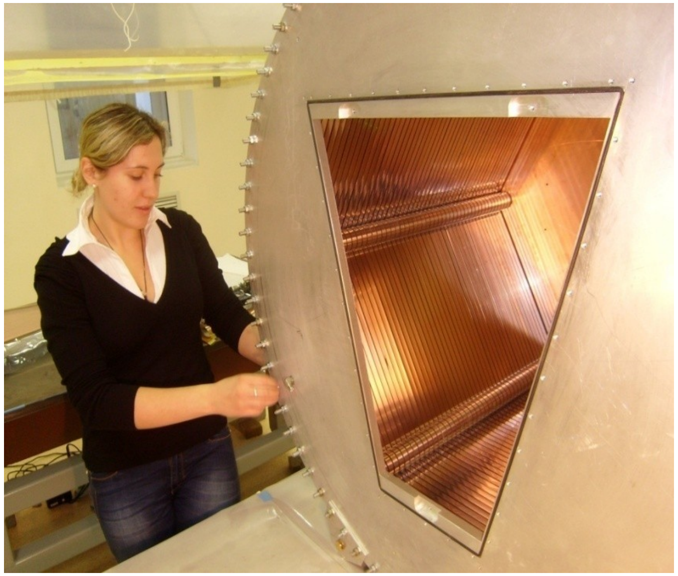




Low-p cutoff ~ **100 MeV**
for a **0.5 T** magnetic field



TPC prototype

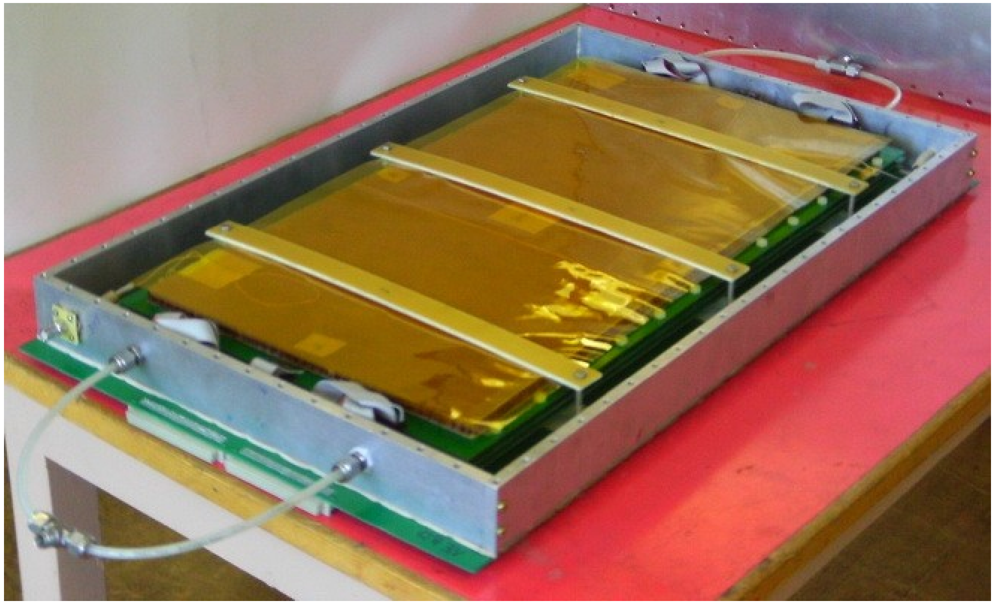


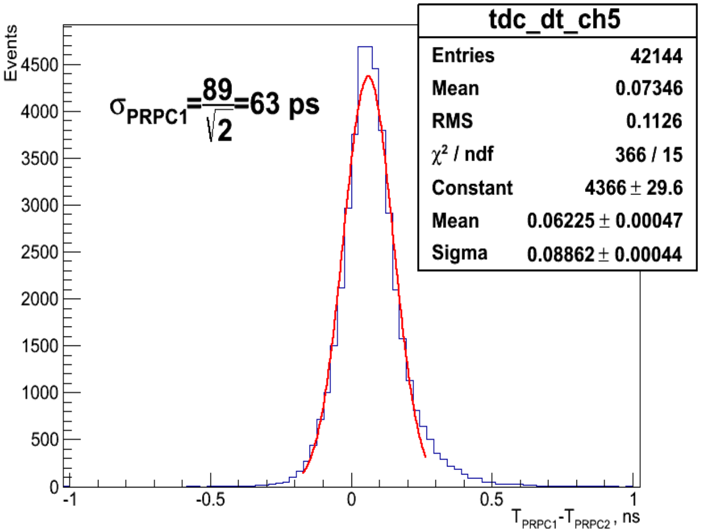
Test with laser beam

Field cage

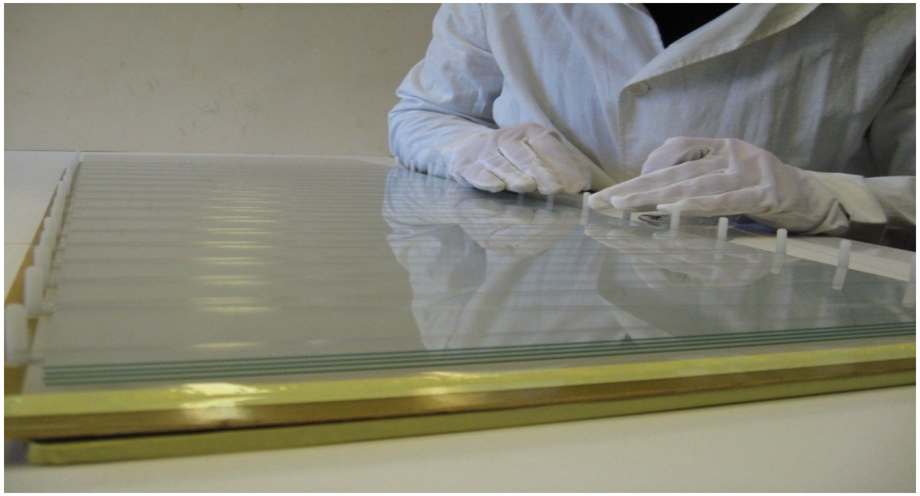
Time of Flight detector

mRPC prototype with a strip





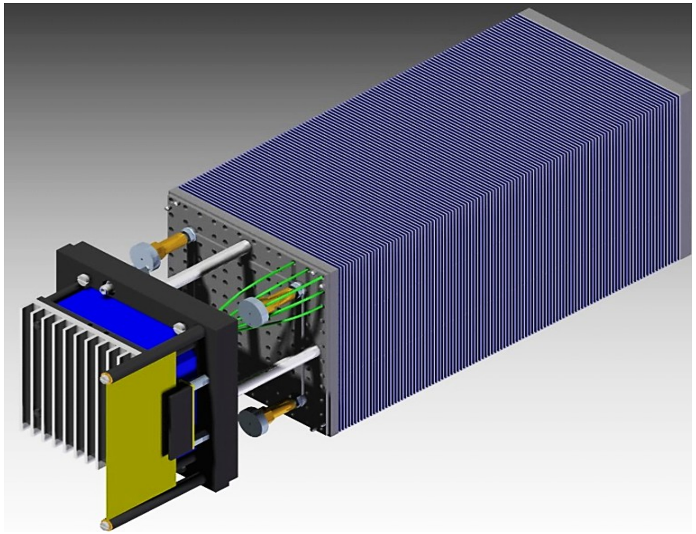
(T1 - T2) for two mRPCs



Full scale mRPC prototype with a strip

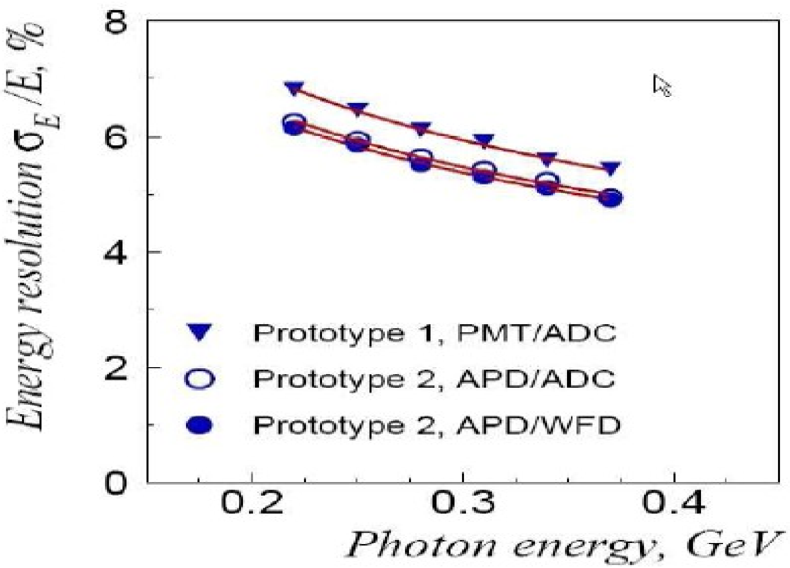
Electromagnetic calorimeter

Design of the ECAL module.



Pb(0.35 mm)+Scint.(1.5 mm)
4x4 cm², L ~35 cm (~ 14 X_0)
read-out: WLS fibers + MAPD

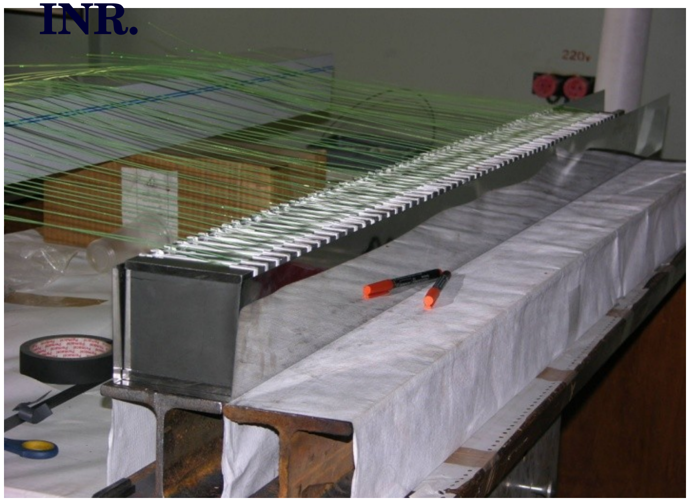
Setup for testing ECAL prototypes

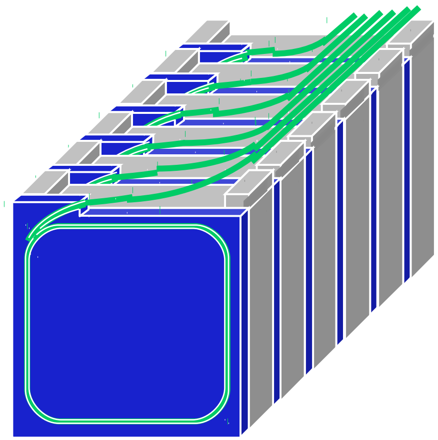


Energy resolution

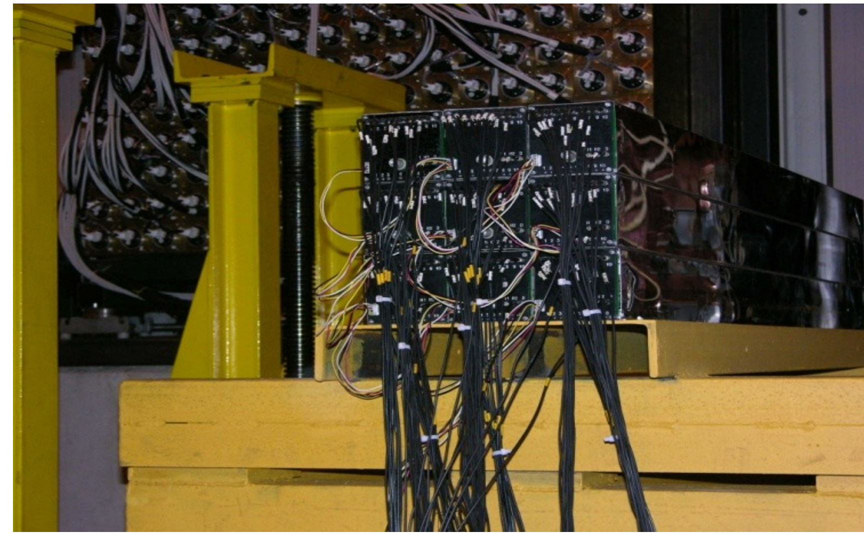
Zero Degree Calorimeter

Module assembling at INR.

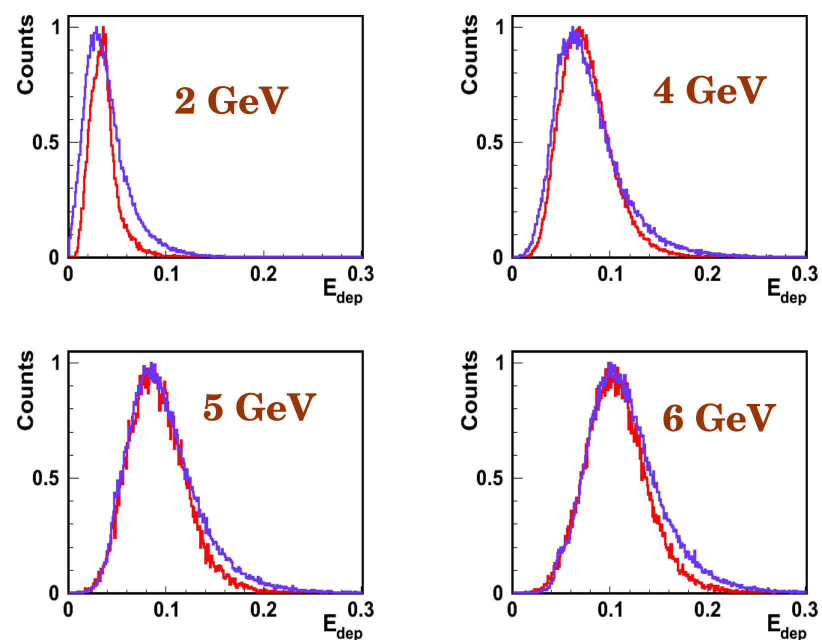




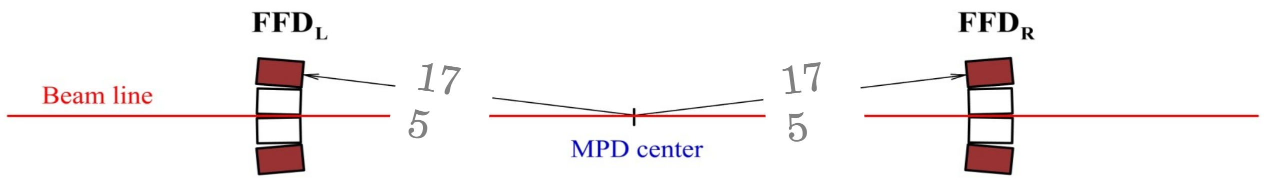
Transverse size 10x10 cm², length~160 cm, weight ~120 kg.
60 lead/scintillator sandwiches.
6 fiber/MAPD
10 MAPDs/module

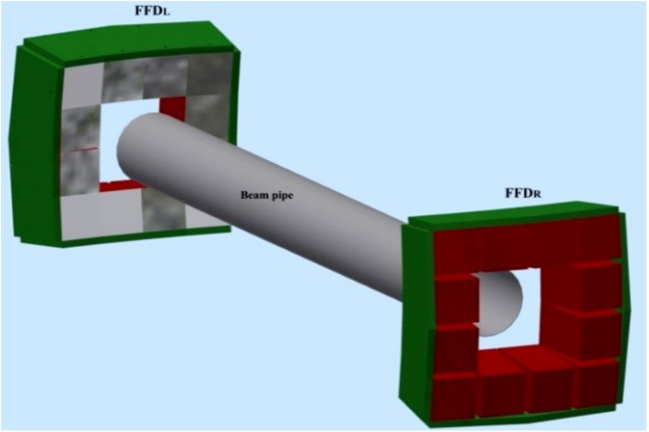


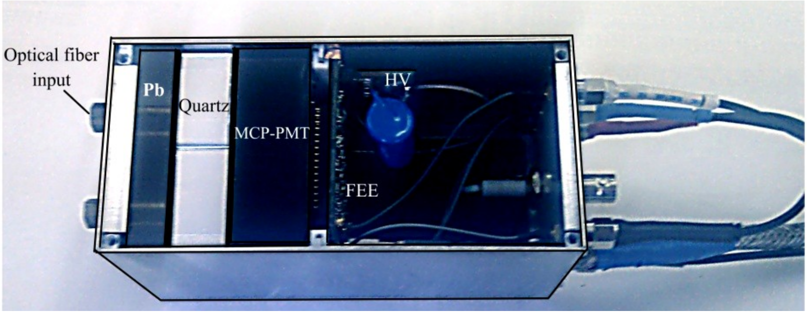
Beam test at *CERN*



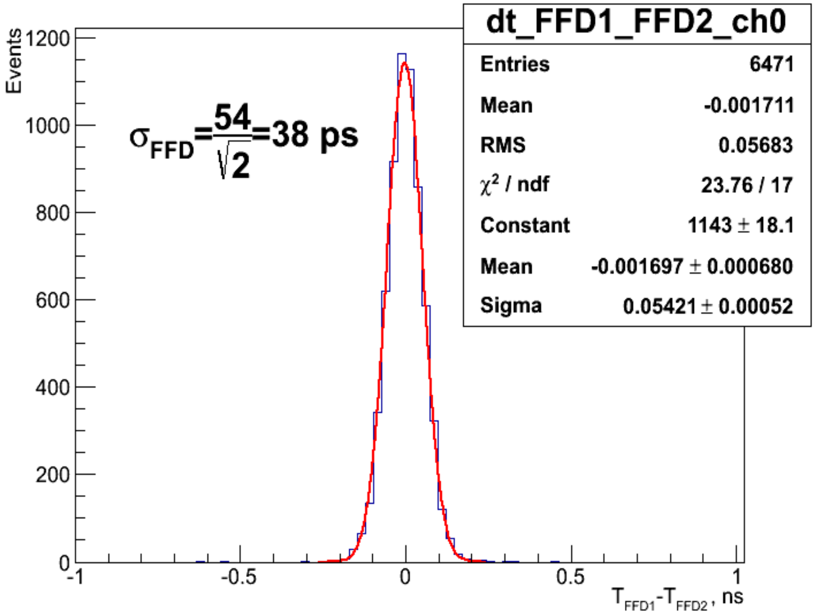
Fast Forward Detector (FFD)



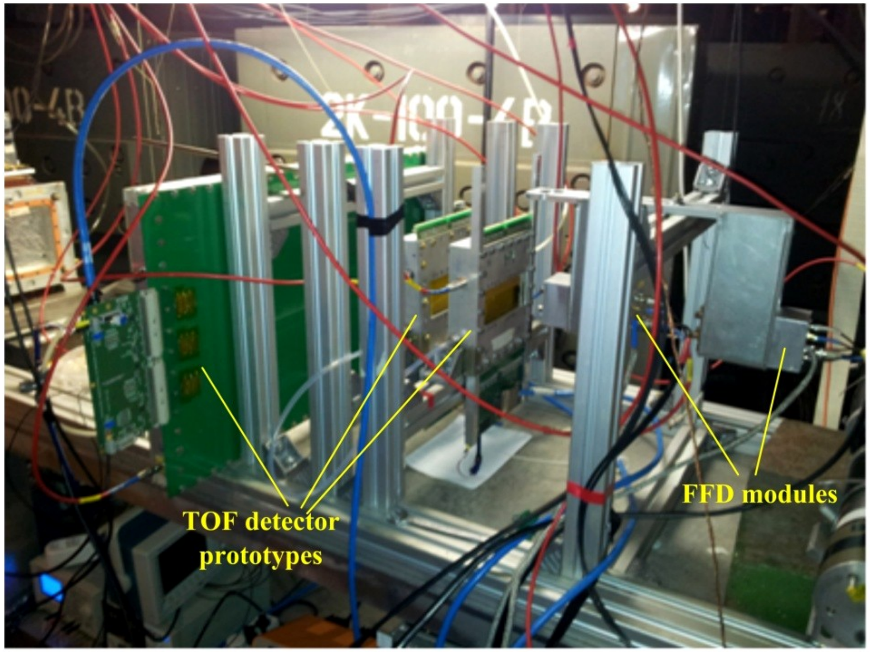




FFD prototype module



Time difference (T1-T2) for 2 FFD modules measured in Dec'12



Test facility at Nucltron

Observables

I stage: ***: mid rapidity region*** *(good performance)*

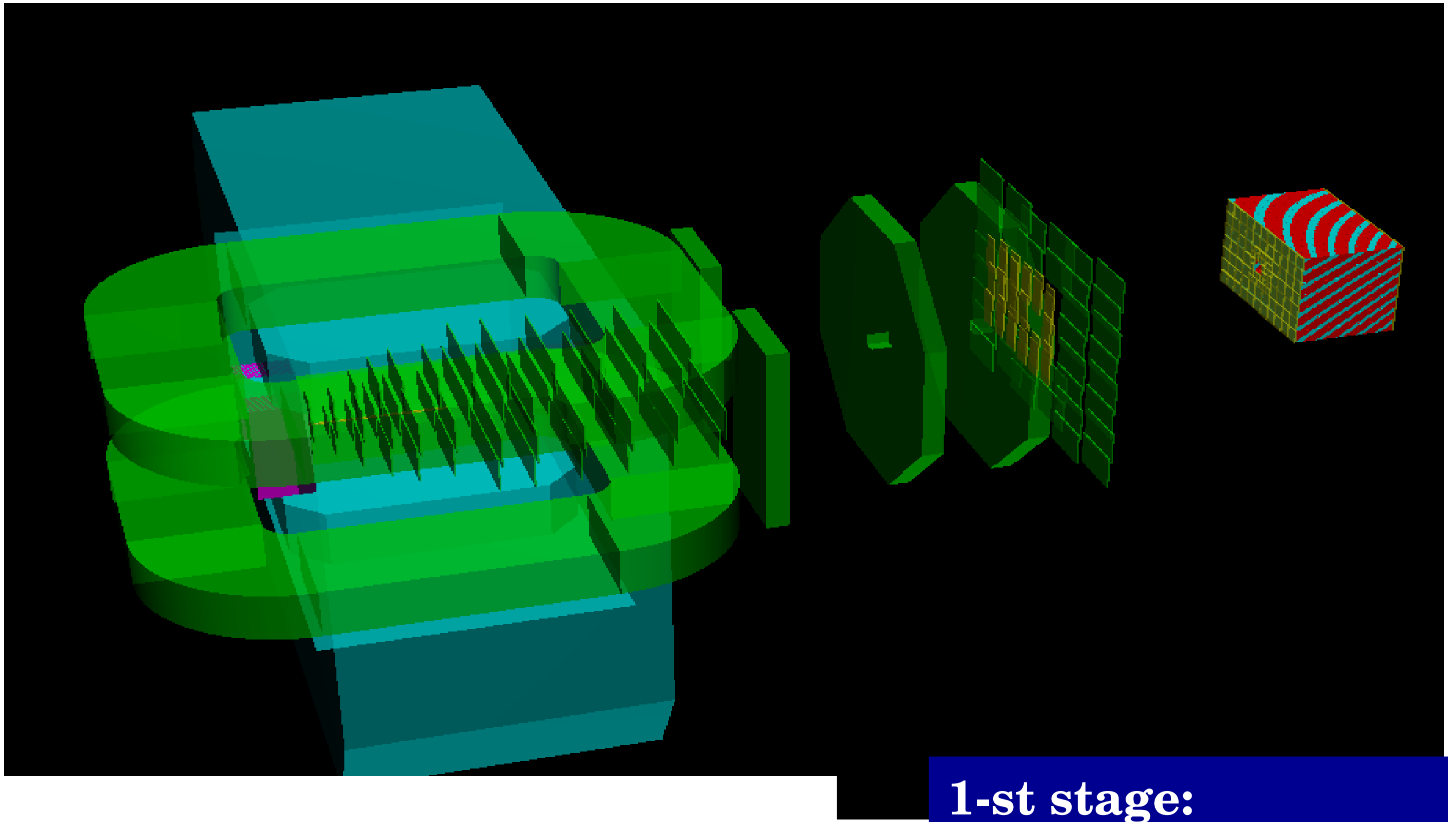
- ***Particle yields and spectra (π,K,p,clusters,Λ, Ξ ,Ω)***
- ***Event-by-event fluctuations***
- ***Femtoscopy involving π, K, p, Λ***
- ***Collective flow for identified hadron species***
- ***Electromagnetic probes (electrons, gammas)***

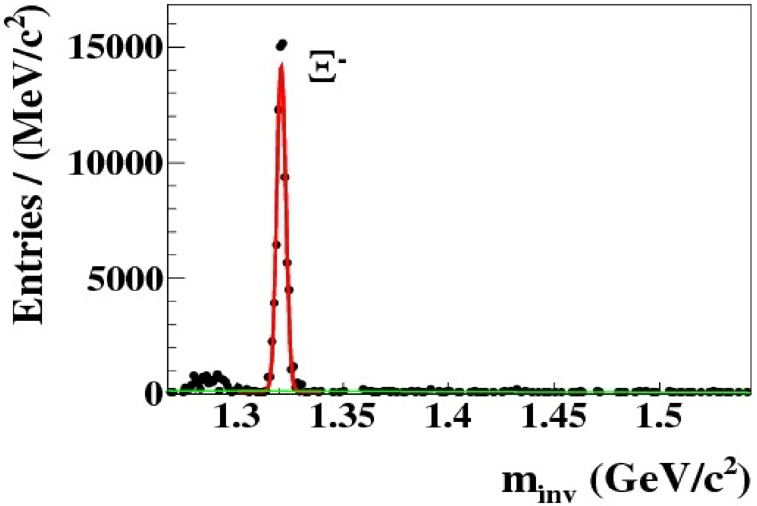
II stage: ***: extended rapidity + ITS***

- ***Total particle multiplicities***
- ***Asymmetries study*** *(better reaction plane determination)*
- ***Di-Lepton precise study*** *(Endcap Calorimeter)*
- ***Charm***
- ***Exotics (soft photons, hypernuclei)***

Measurements regarded as complementary to RHIC/BES and CERN/NA61,
However, higher statistics & (close to) the total yields for rare probes at MPD
No boost invariance at NICA – more accurate source parameters fit without rapidity cut
Rapidity dependence of the fireball thermal parameters will be possible at NICA

Barionic Matter at Nuclotron





1-st stage:

- ***flows & azhimuthal correlations***
- ***femtoscopy***

2-nd stage :

(sub)threshold production of cascades – to obtain the information on EOS

BM@N cave

BM@N drift chambers

International Cooperation
@ Nuclotron-M / NICA experiments

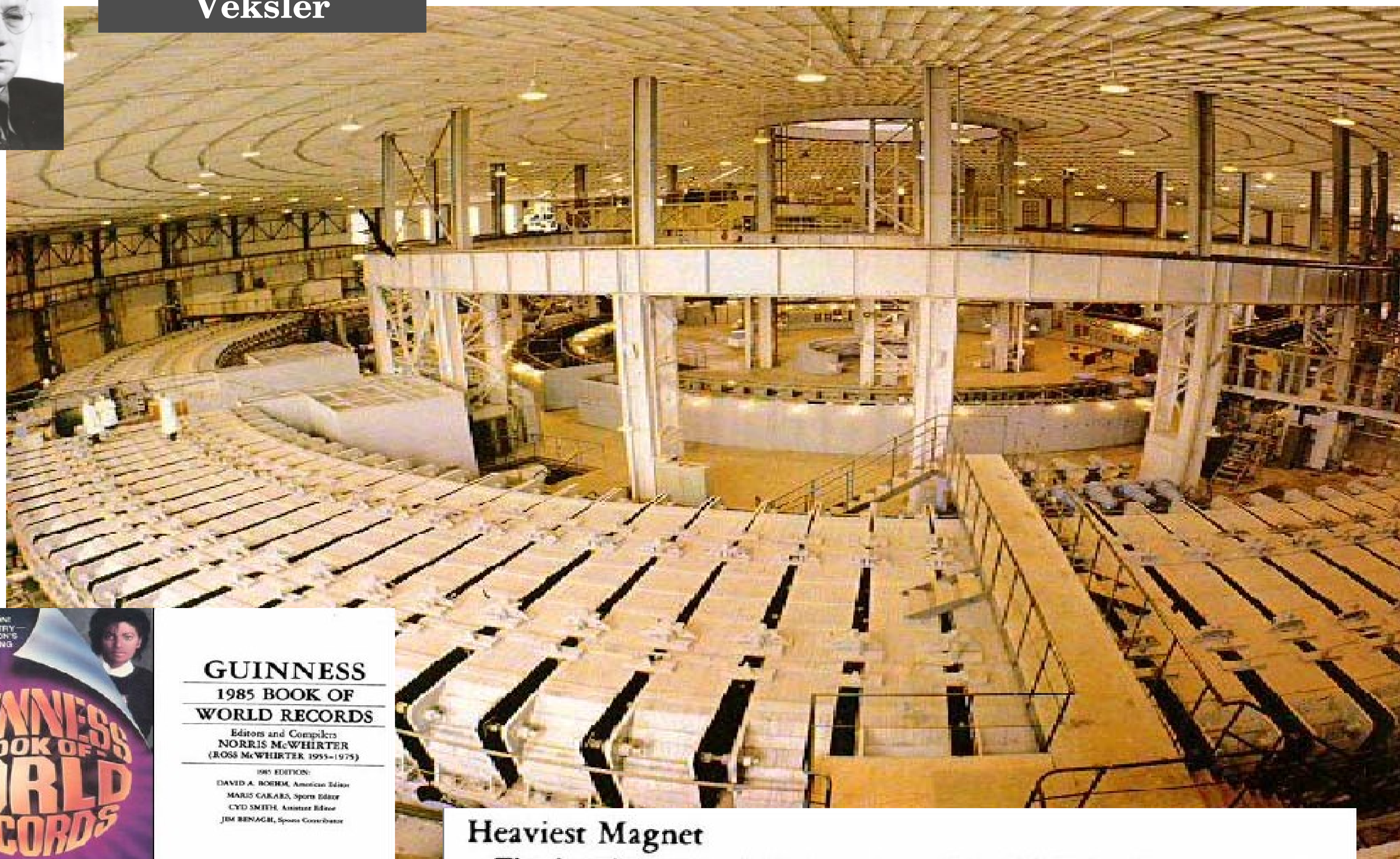
- **Joint Institute for Nuclear Research**
- The University of Sidney, **Australia**
- Physics Institute Az.AS, **Azerbaijan**
- Particle Physics Center of Belarusian State University, **Belarus**
- Institute for Nuclear Research & Nuclear Energy BAS, Sofia, **Bulgaria**
- Hilendarski University of Plovdiv, **Bulgaria**
- Blagoevgrad University, Blagoevgrad**, Bulgaria**
- University of Science and Technology of China, Hefei, **China**
- Department of Engineering Physics, Tsinghua University, Beijing, **China**
- Osaka University, **Japan**
- RIKEN, **Japan**
- GSI, Darmstadt, **Germany**
- Aristotel University of Thessaloniki, **Greece**
- Institute of Applied Physics, AS, **Moldova**
- Institute of Physics & Technology of MAS, University of **Mongolia**
- Warsaw Technological University, Warsaw**, Poland**
- Institute for Nuclear Research, RAS, **RF**
- Nuclear Physics Institute of MSU, **RF**
- St.Petersburg State University, **RF**
- Institute Theoretical & Experimental Physics, **RF**
- University of Cape Town, **RSA**
- Bogolyubov Institute for Theoretical Physics, NAS, **Ukraine**
- Institute for Scintillation Materials, Kharkov, **Ukraine**
- State Enterprise Science & Tech. Research Design Institute, Kharkov, **Ukraine**
- TJNAF (Jefferson Laboratory), **USA**

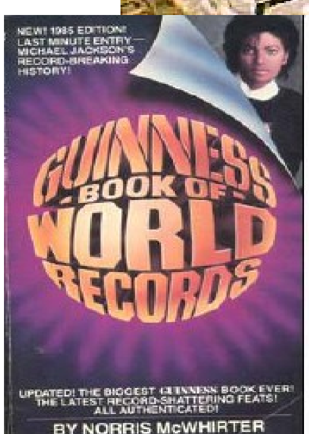
Thank you for attention

Back up

From synchrophasotron (1957-2002)

Vladimir I. Veksler





GUINNESS
1985 BOOK OF
WORLD RECORDS

Editors and Compilers
NORRIS McWHIRTER
(ROSS McWHIRTER 1955–1975)

1985 EDITION:
DAVID A. BOEHM, American Editor
MARIS CAKARS, Sports Editor
CYD SMITH, Assistant Editor
JIM BENAGH, Sports Contributor

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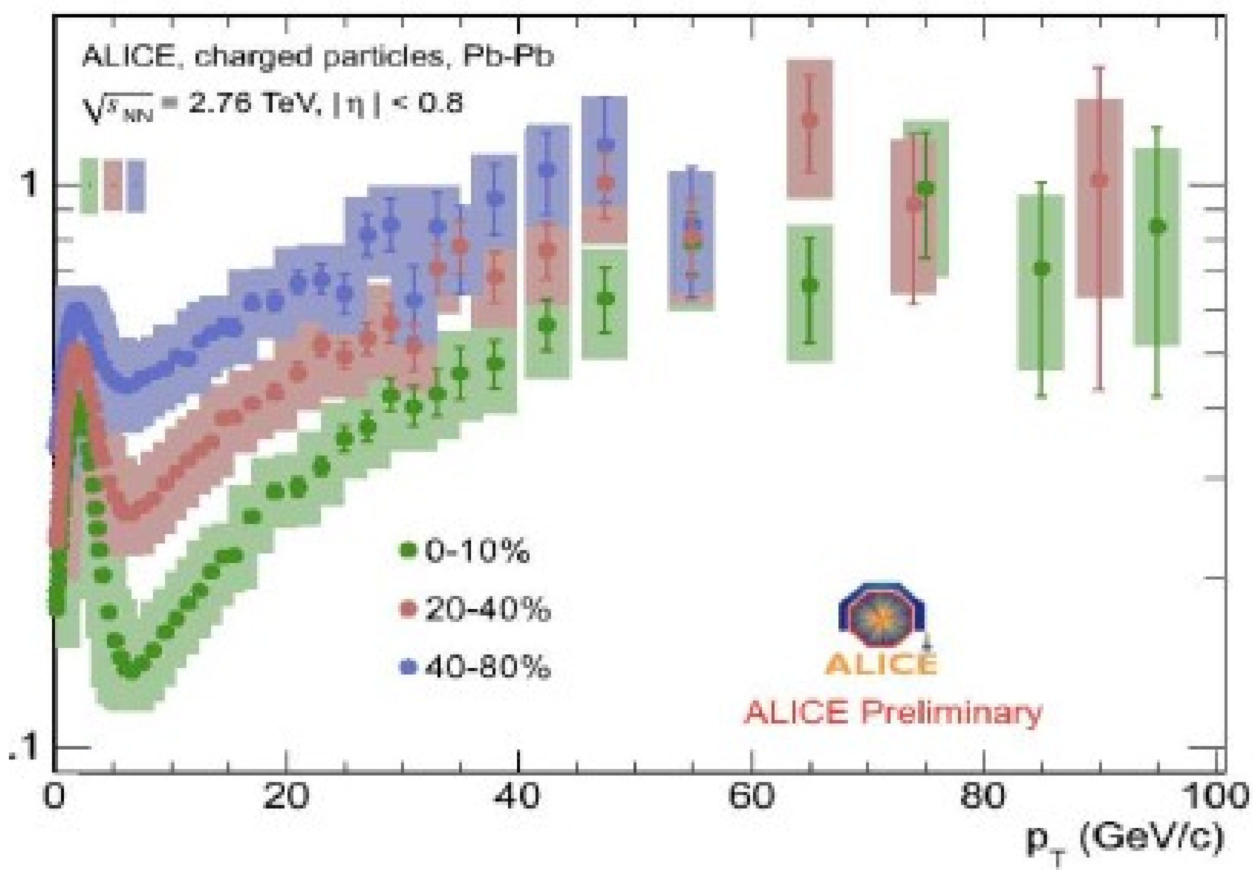
Heaviest Magnet

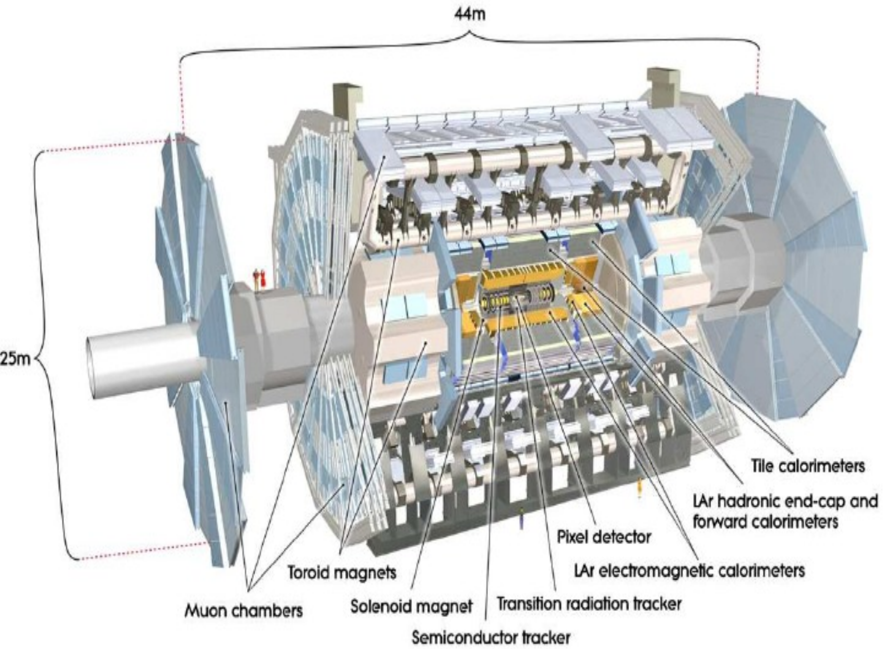
The heaviest magnet is one measuring 196 ft in diameter, with a weight of 40,000 tons, for the 10 GeV synchrophasotron in the Joint Institute for Nuclear Research at Dubna, near Moscow.

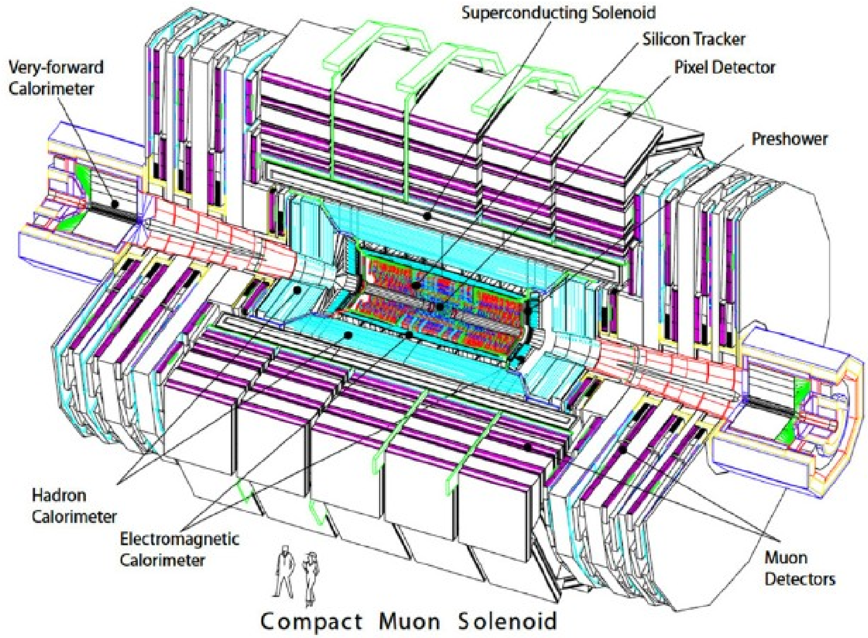
High P_T Hadron Suppression @ LHC

François Arleo
QM 2011

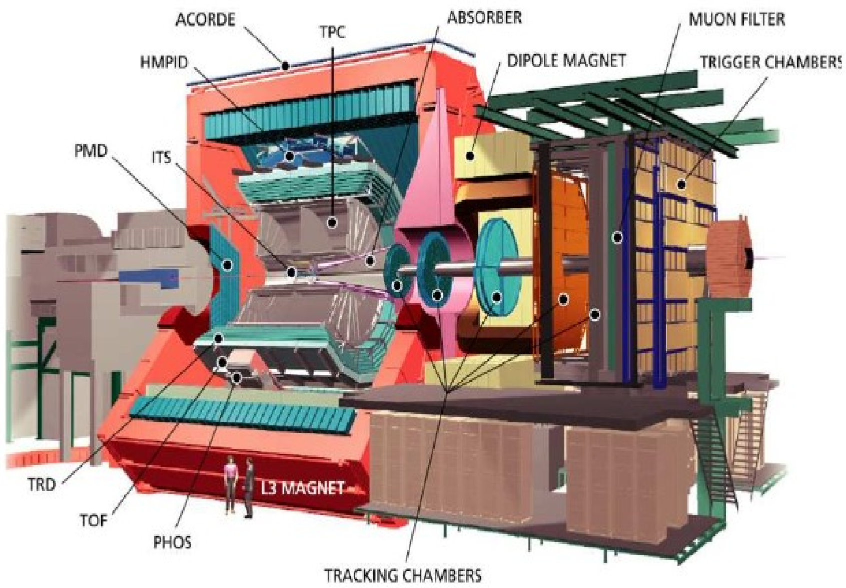


LHC

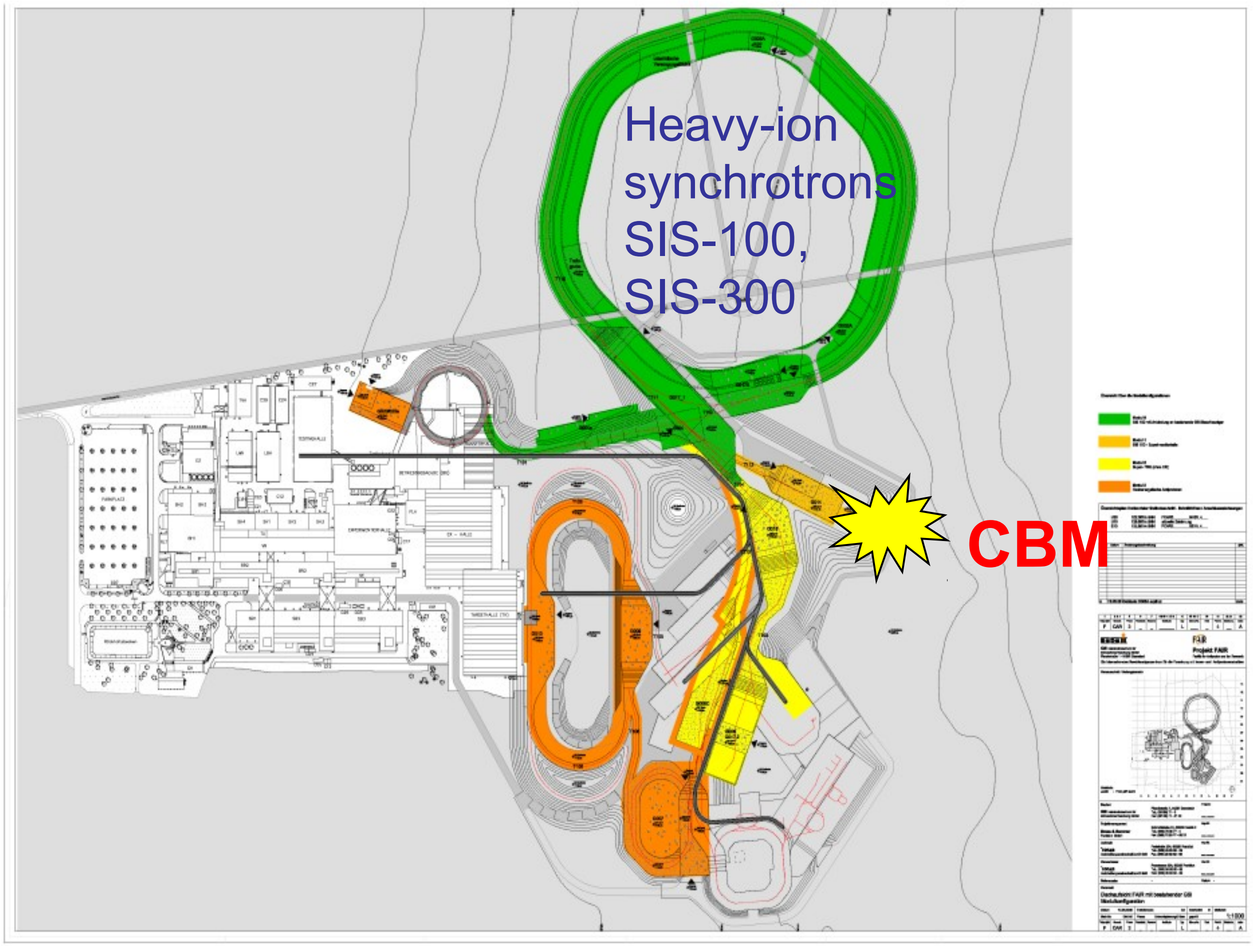




ATLAS: 46 m long, 25 m high and 25 m wide; 7 000 tonnes
CMS: 21.6 m long, 15 m diameter; 12 500 tonnes
ALICE: 26 m long, 16 m diameter; 10 000 tonnes



Facility for **A**ntiproton and **I**on **R**esearch

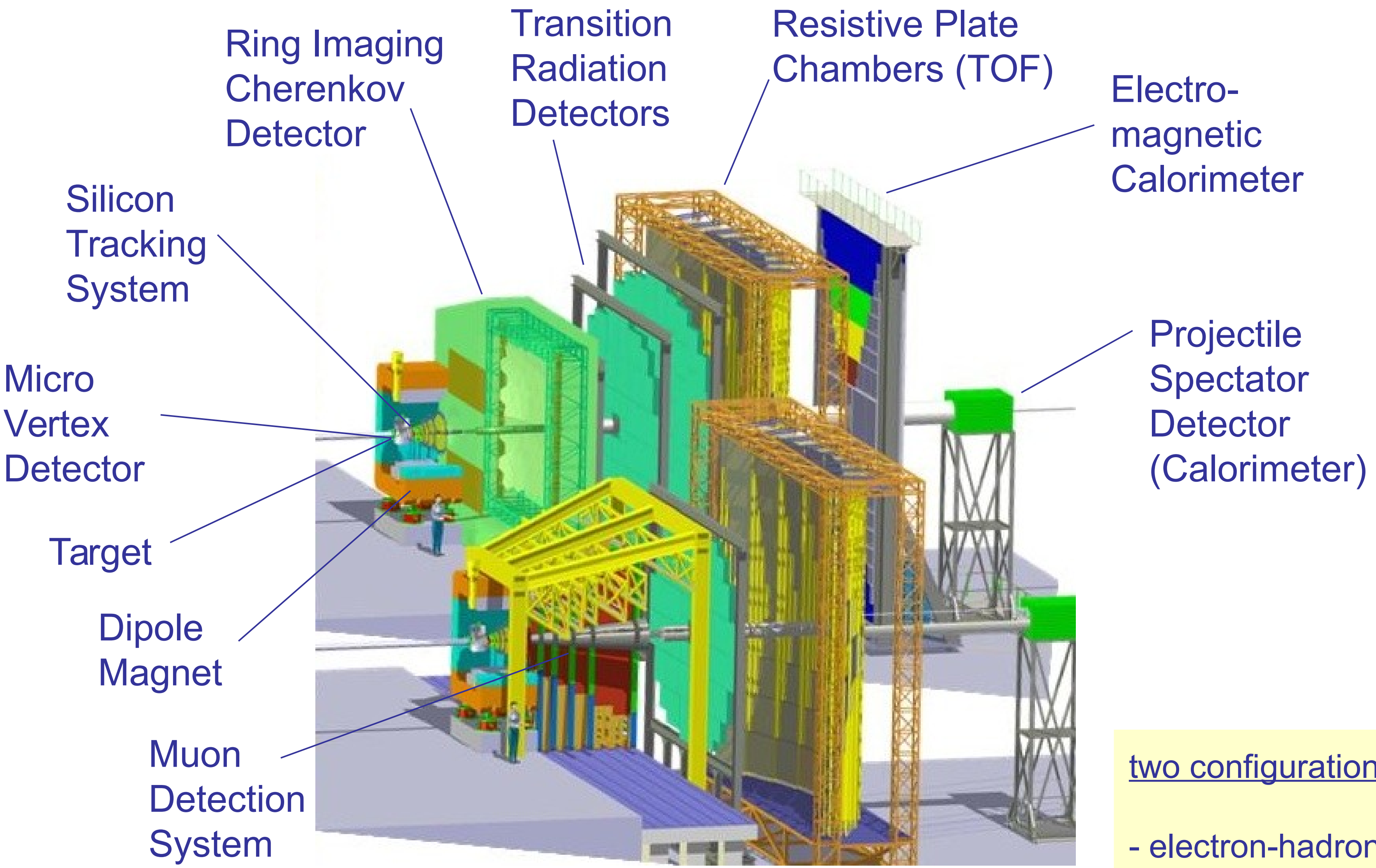


- **CBM is one of the four scientific pillars at FAIR**
- **Civil construction of FAIR has started**

SIS-100 / SIS-300:

- ***protons:***
  2 - 29/89 GeV
- ***ions:***
  2 - 14/44 AGeV,
  $\sqrt{s_{NN}}$= 1.9 - 4.5/
  4.2 - 9 GeV
- ***intensities:***
  up to 109 ions per second at CBM

The CBM experiment



two configurations:

- electron-hadron
- and muon setup

from Nuclotron (1993) ...

– superconducting accelerator for ions and polarized particle
– physics of ultrarelativistic heavy ions, high energy spin physics

Nuclotron provides now performance of experiments on accelerated proton and ion beams (up to *Xe42+, A=124*) with energies up to 6 AGeV (Z/A = 1/2)

To NICA ...