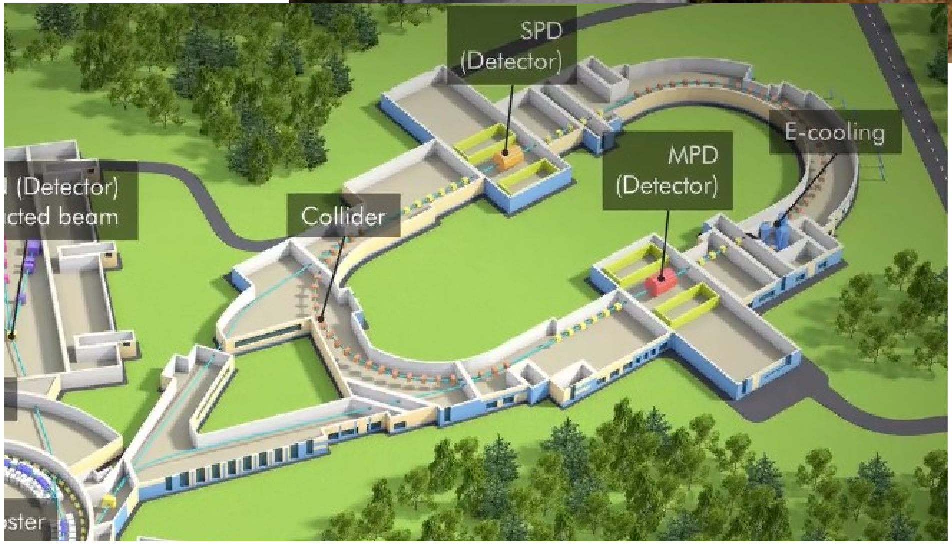
The possibility for the experimental distinction of the different EoS at NICA energies

HMEC
17.09.2019
Dubna

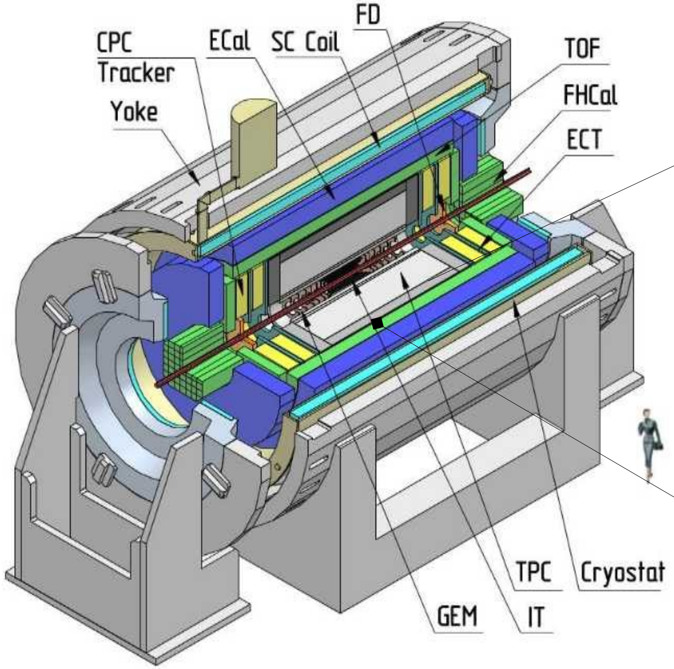
Rogachevsky O.
JINR

NICA site


09-16-2019 Mon 13:28:57

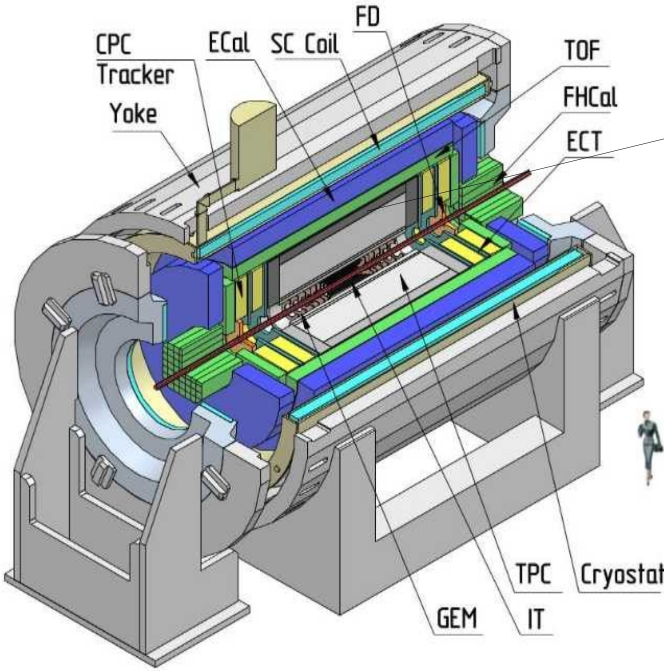

SPD
(Detector)
E-cooling
MPD
(Detector)
Collider

MPD TPC

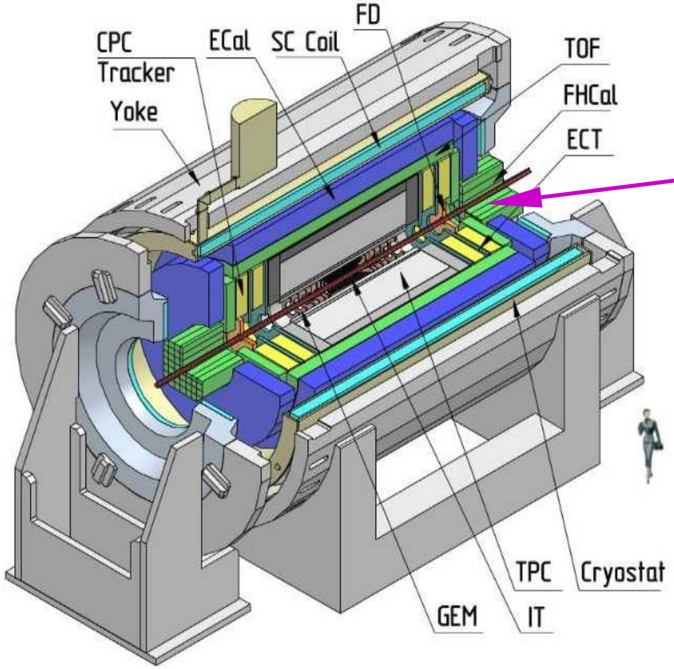


TPC outer walls
& membrane

MPD TOF


CPC
Tracker
Yoke
ECal
SC Coil
FD
TOF
FHCal
ECT
TPC
Cryostat
GEM
IT

MPD FHCal



CPC
Tracker
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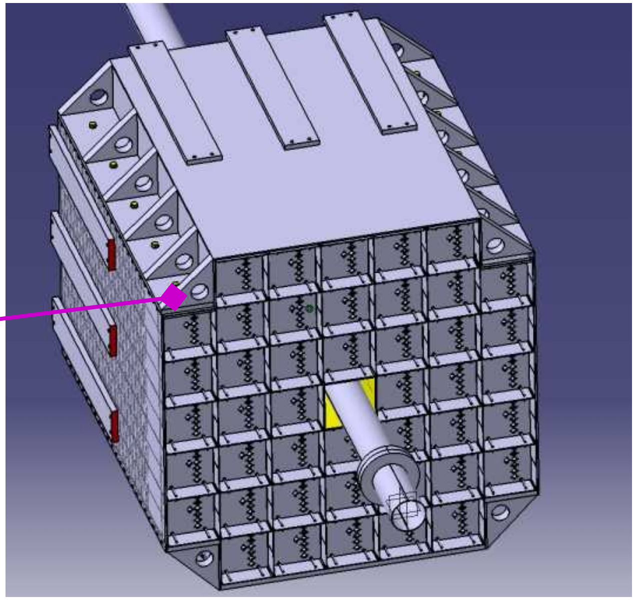
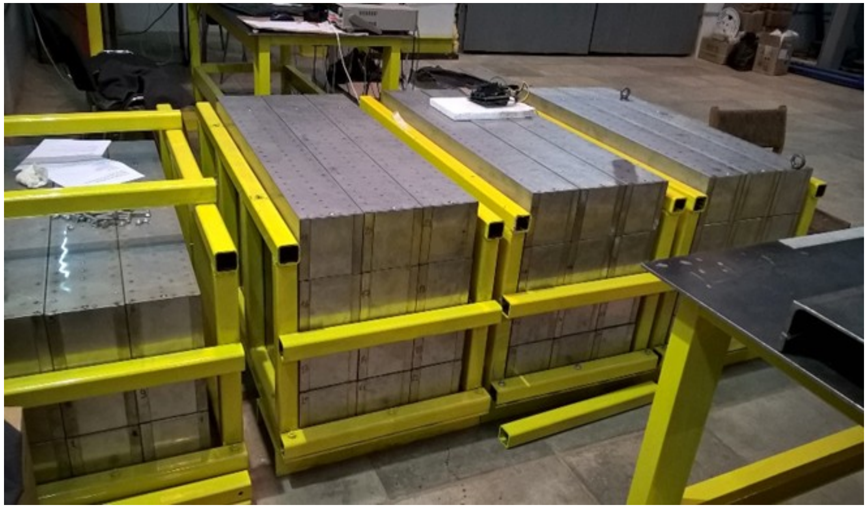
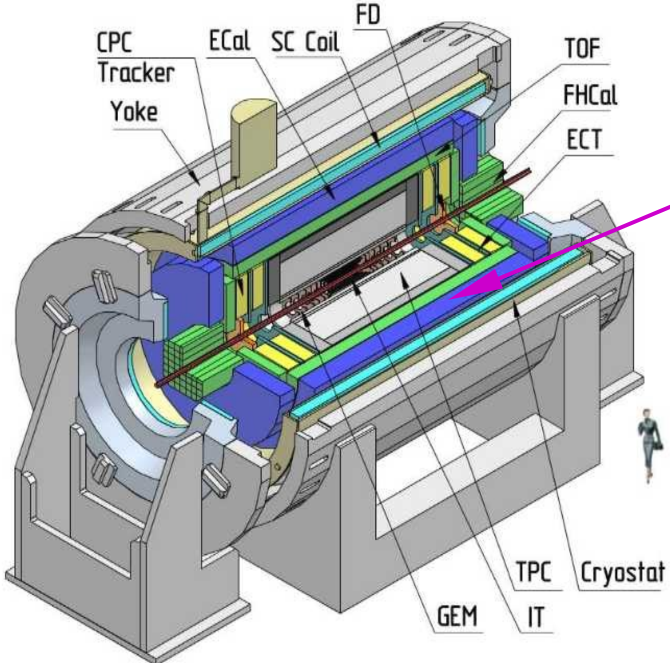
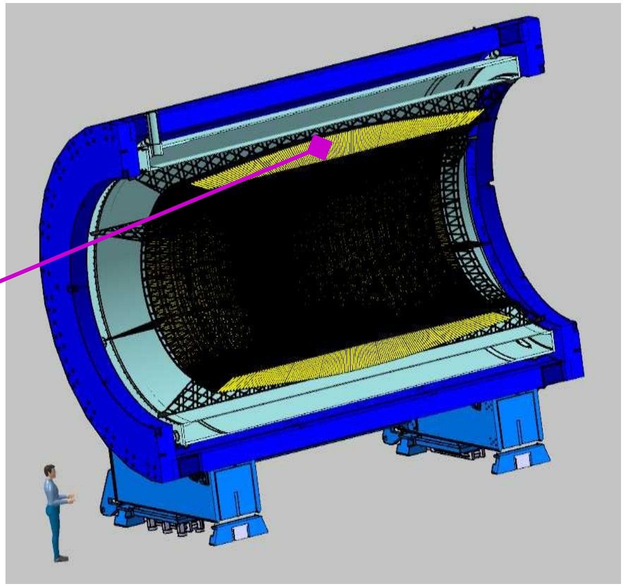


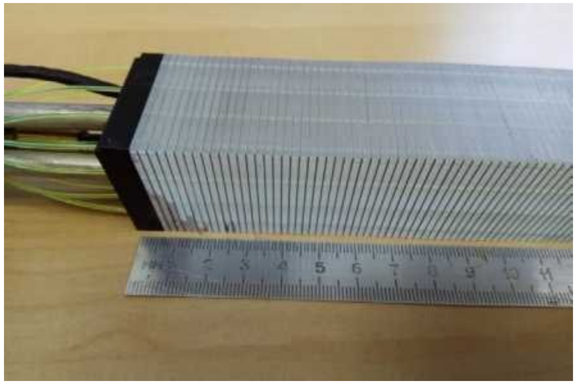


MPD ECal

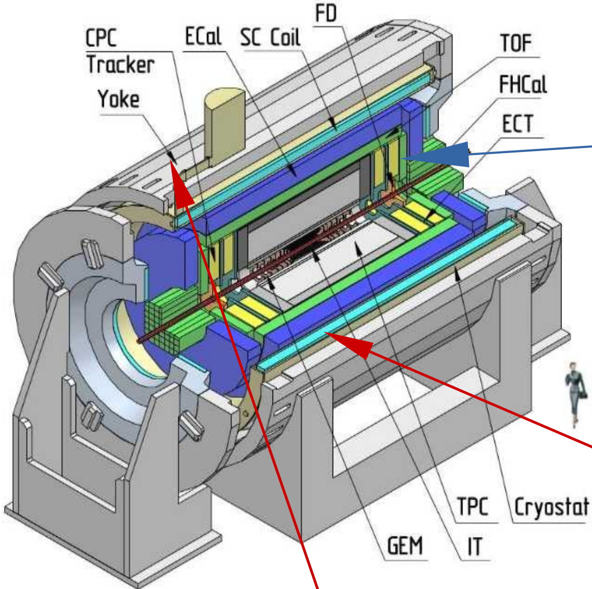




~ <u>*43000*</u> ***ECAL modules***



MPD magnets



trim coil

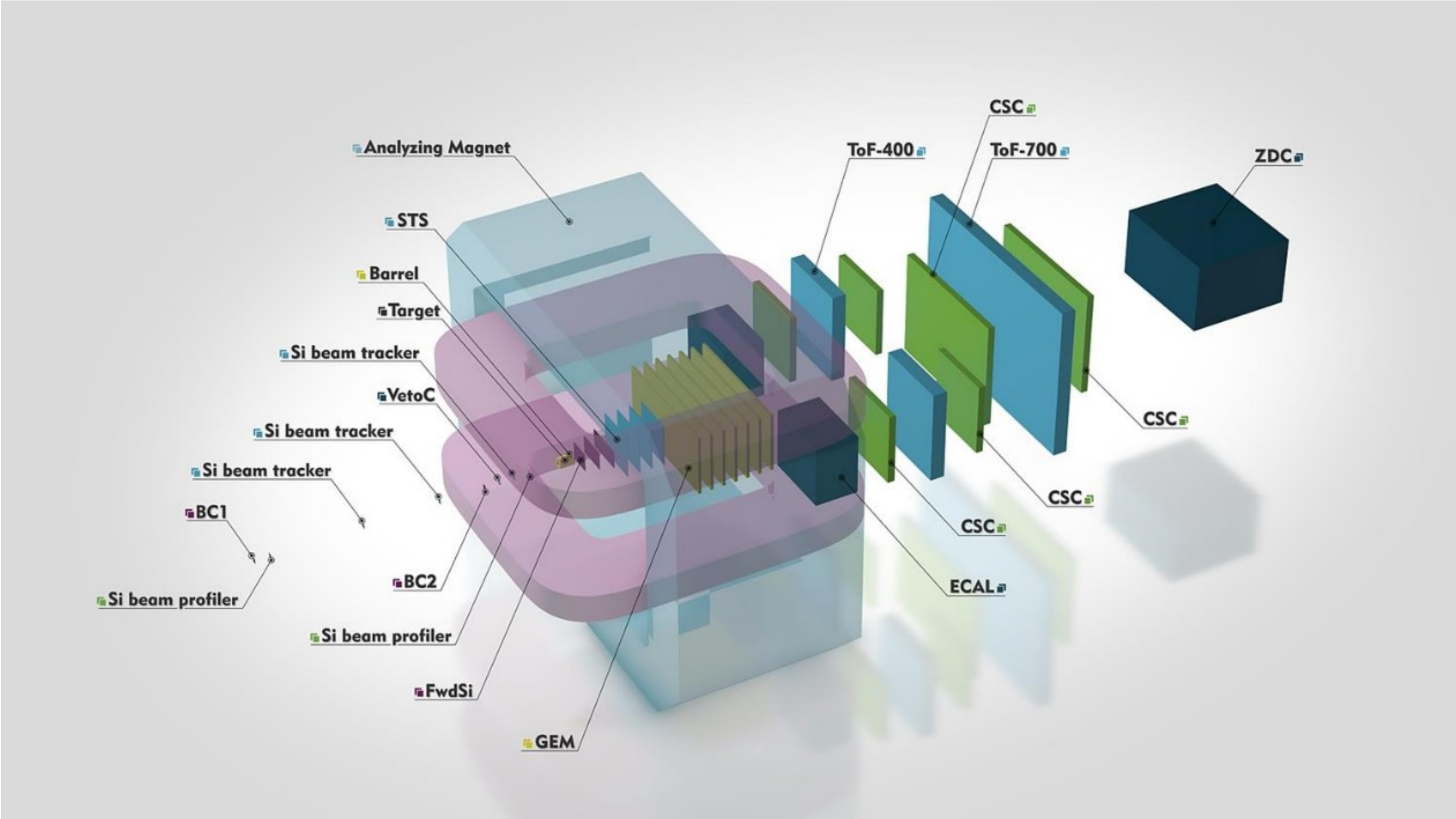
yoke assembly at HM Vitkovice

Solenoid assembling

Booster

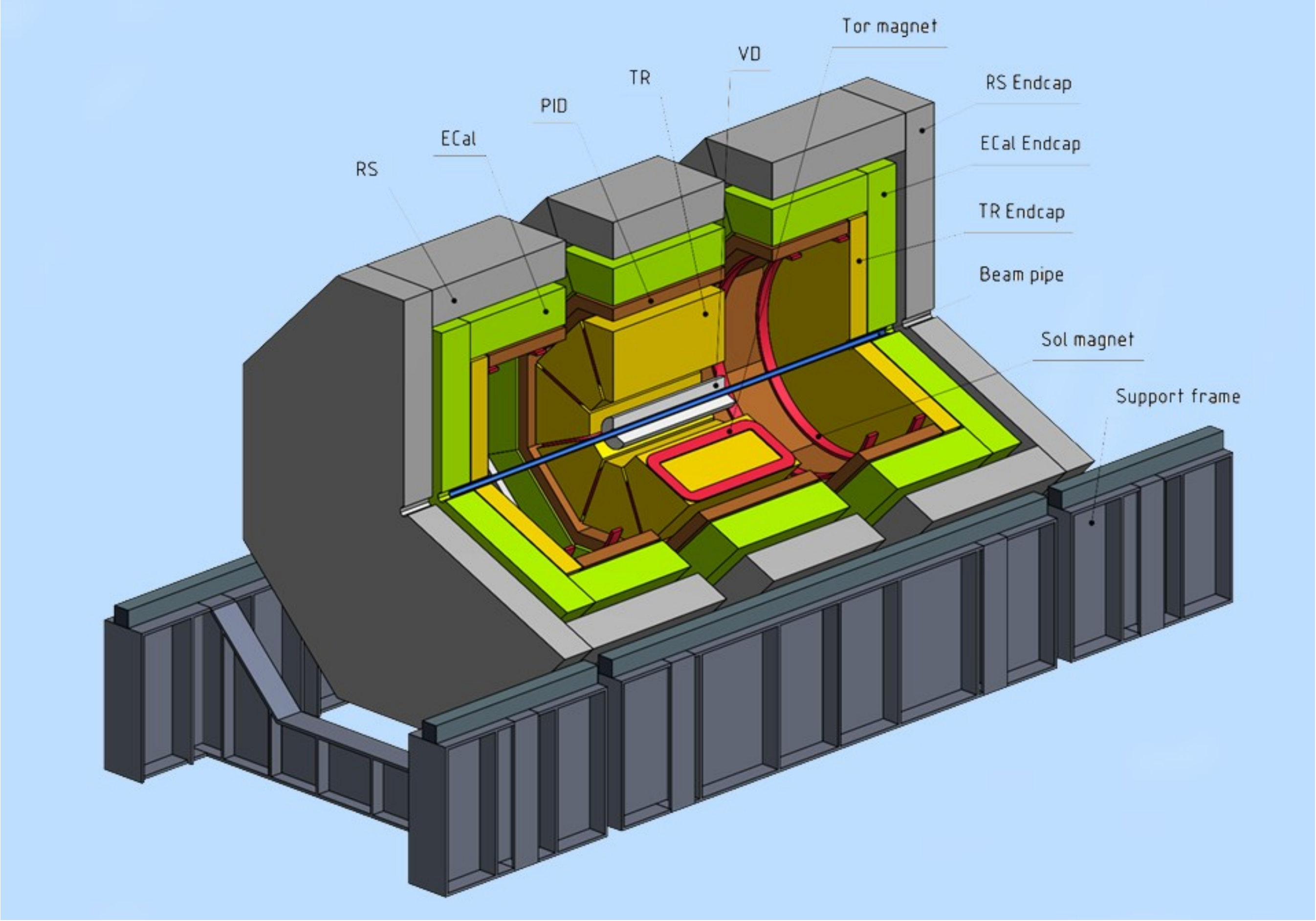
BM@N

Next run (2020?)



SPD

Collaboration, Letter of intent, CDR, detectors development are started



MC generators:

- **UrQMD** Prog. Part. Nucl. Phys. 41 (1998) 225
- **HIJING:** Phys. Rev. D 44 (1991) 3501
- **AMPT:** Phys. Rev. C 72 (2005) 064901
- **Hybrid UrQMD:** Phys. Rev. C 78 (2008) 044901
- **PHSD:** Nucl. Phys. A 856 (2011) 162
- **VHLLE:** Comput. Phys. Commun. 185 (2014) 3016
- **DC-QGSM:** will be published soon
- **3 Fluid Dynamics:** Phys. Rev. C 73 (2006) 044904
- **Theseus:** Phys. Rev. C 94 (2016) 044917

What is the QGP ?

Strangeness enhancement

Flow

CME

Jet quenching

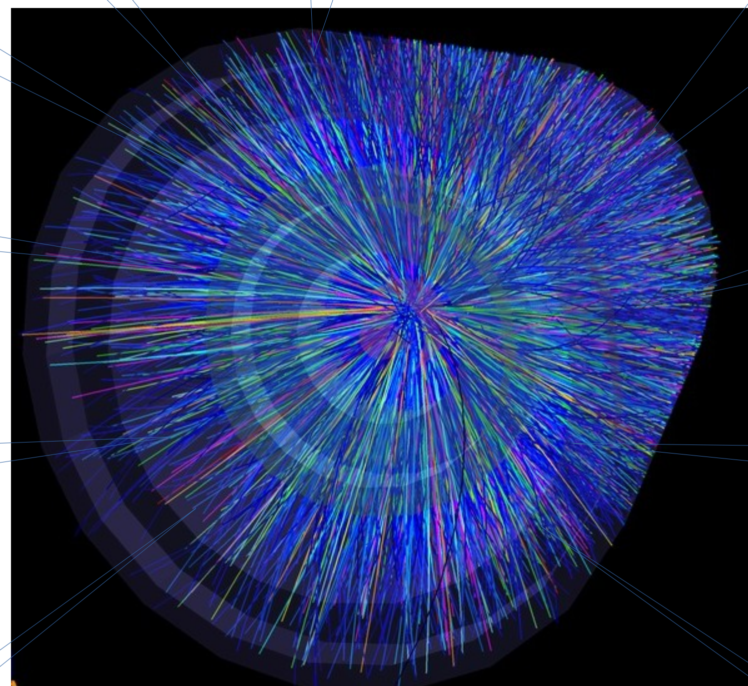
High p_T suppression

Femtoscopy

Horn

Baryon stopping power

Fluctuations

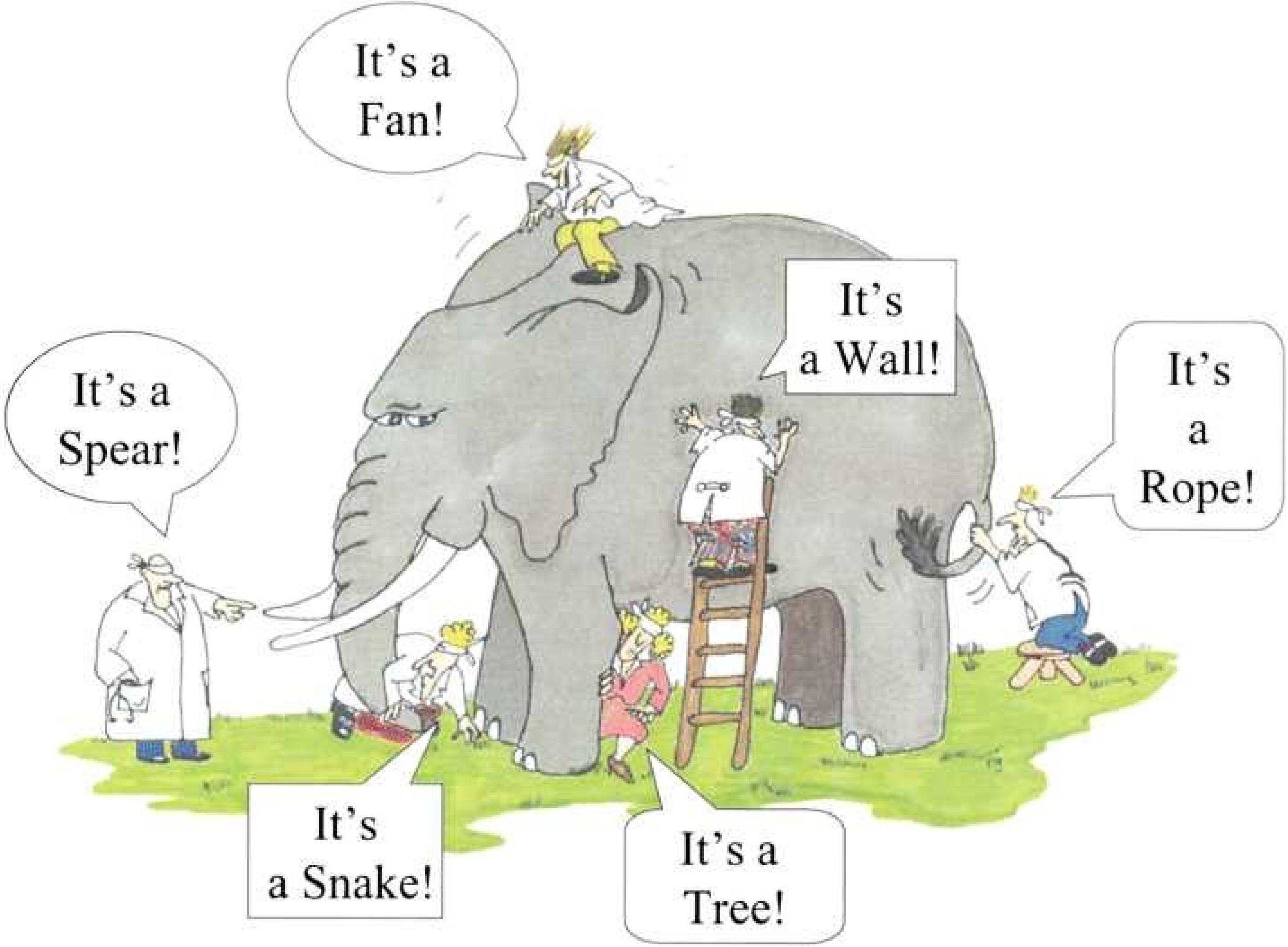


Ridge

N_{cq} scaling

CVE

What is the elephant ?

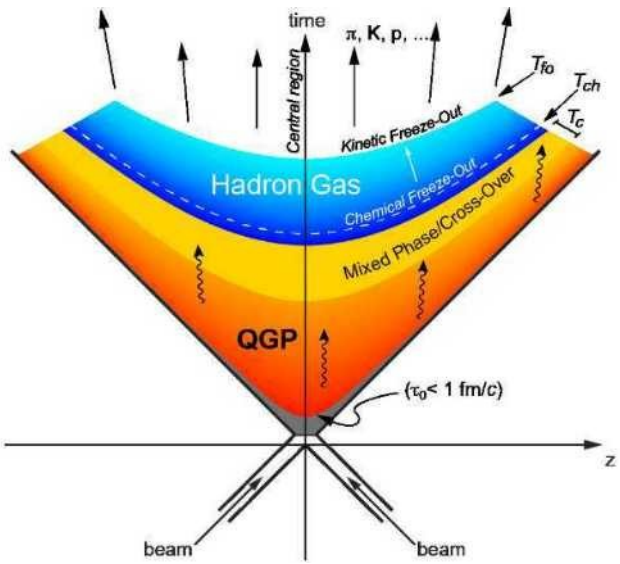


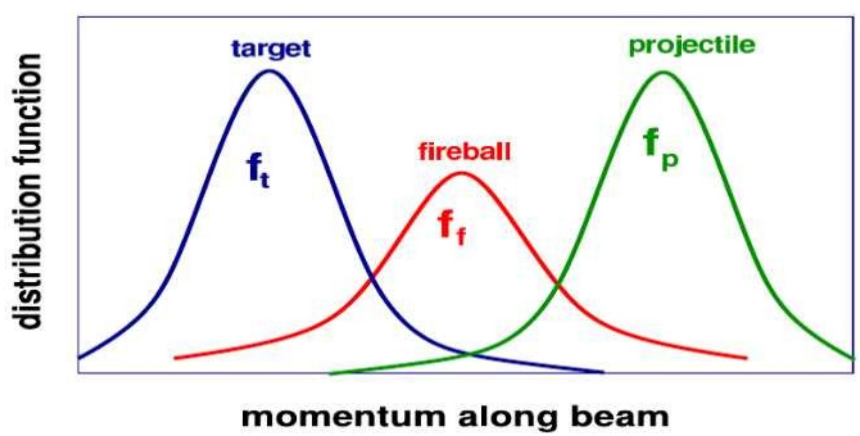
3FD model

- Distributions are separated in momentum space
  ⇒ different fluids
- Leading particles carry baryon charge
  ⇒ 2 baryon-rich fluids: projectile-like and target-like

At high incident energies ($E_{lab} \gtrapprox 10A$ GeV)

- Produced particles populate mid-rapidity
  ⇒ fireball fluid





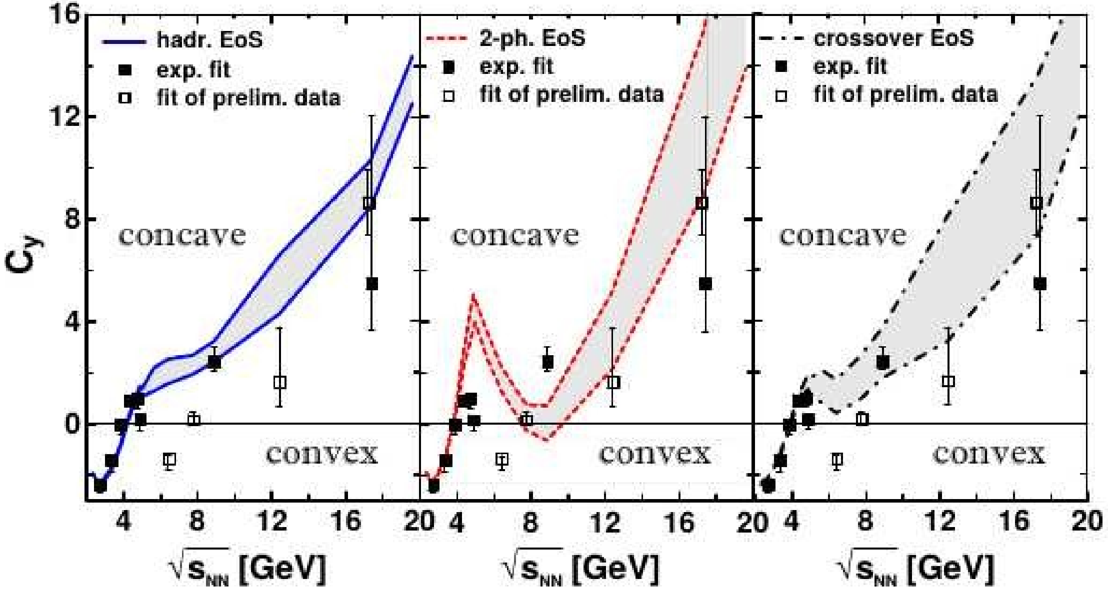
3FD: hydro model with different EOS

To quantify the "peak-dip-peak-dip" irregularity, net-proton rapidity distributions are fitted by (a, y_s and w_s are parameters of the fit)

$$\frac{dN}{dy} = a\left(\exp\{-(1/w_s)\cosh(y - y_{cm} - y_s)\} + \exp\{-(1/w_s)\cosh(y - y_{cm} + y_s)\}\right)$$

A reduced curvature of the spectrum at midrapidity

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



Ivanov, Yu.
Baryon Stopping in Heavy-Ion Collisions at E_{lab}= 2--160 GeV/nucleon. Physics Letters B. 690. 358-362, 2010.

THESEUS: hydro model with different EOS and particlization

Three-fluid Hydrodynamics-based Event Simulator Extended by UrQMD final State interactions

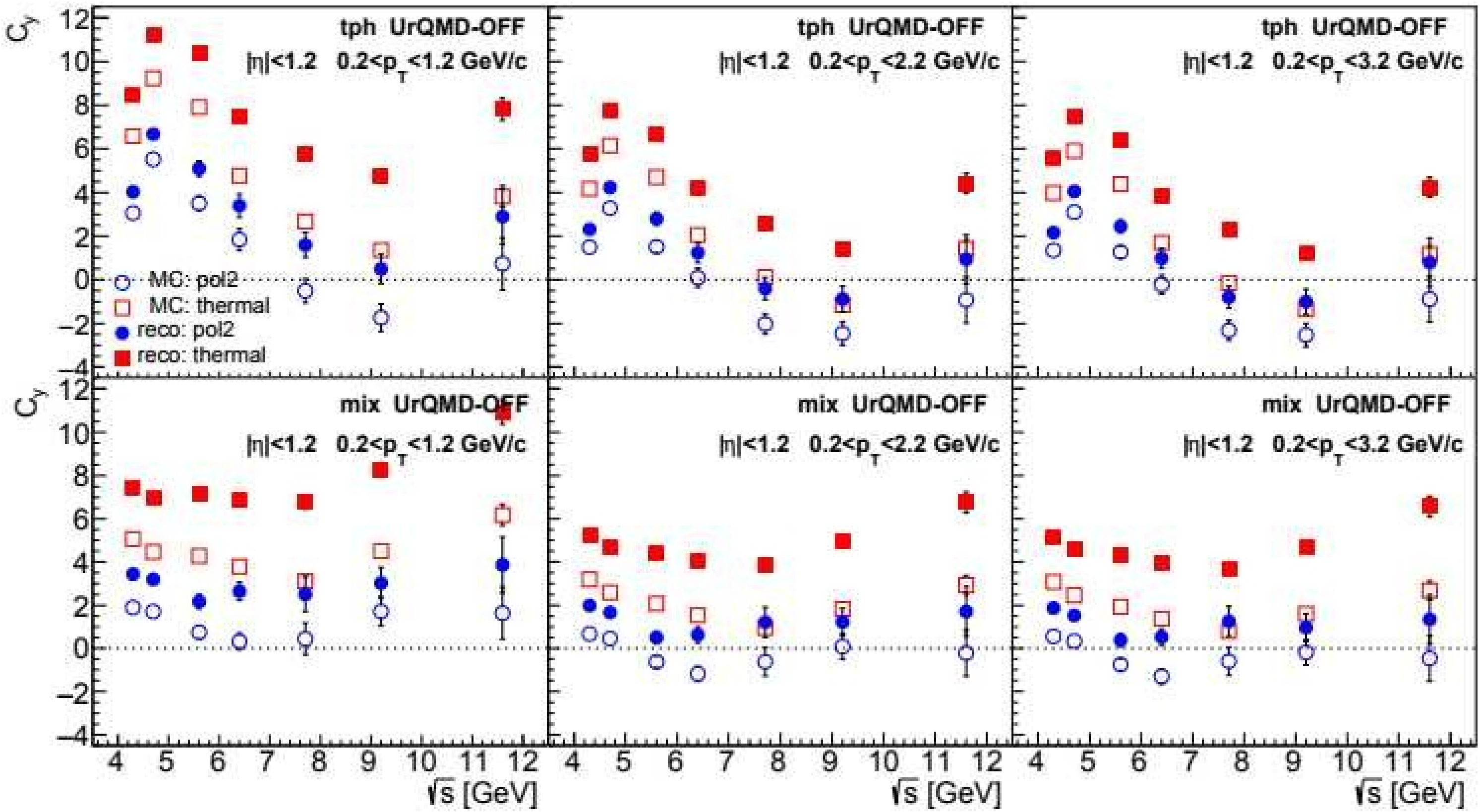
Event simulation based on three-fluid hydrodynamics for collisions at energies available at the Dubna Nuclotron-based Ion Collider Facility and at the Facility for Antiproton and Ion Research in Darmstadt

P. Batyuk, D. Blaschke, M. Bleicher, Yu. B. Ivanov, Iu. Karpenko, S. Merts, M. Nahrgang, H. Petersen, and O. Rogachevsky

Phys. Rev. C 94, 044917 – Published 28 October 2016

Int.	*AuAu*								
√s (GeV)	*4.3*	*4.7*	*5.6*	*6.4*	*7.7*	*11.5*	*19.6*	*27*	*39*
EoS	*hadron, 2 phase, crossover*								
b(Fm)	*2, 6, 11*								

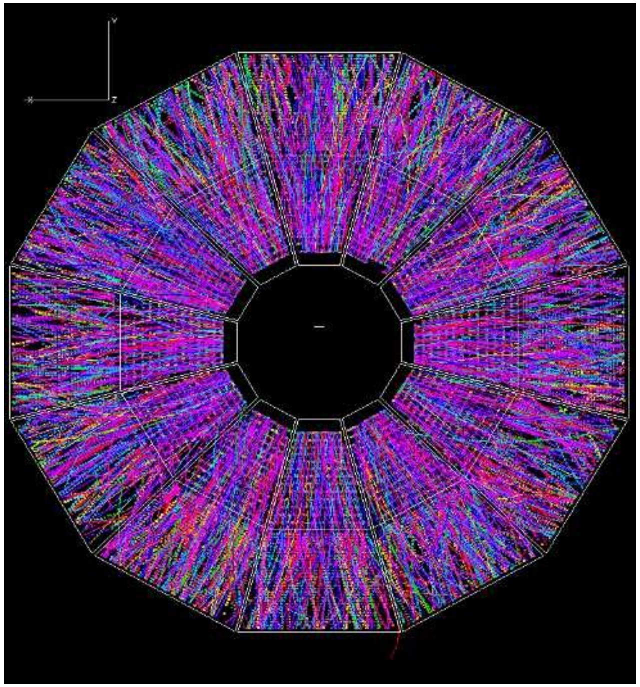
C_y with THESEUS implementation



Can be distinguishable with MPD at NICA

Deterministic chaos

Collections of small entities (particles or whatever) behave haphazardly, even though physical laws govern the particles individually



STAR AuAu $\sqrt{s}$=200 GeV

A system may be perfectly deterministic in principle but its behavior is completely unpredictable in practice. This phenomenon was called **deterministic chaos**.

Deterministic chaos - chaos results from deterministic process

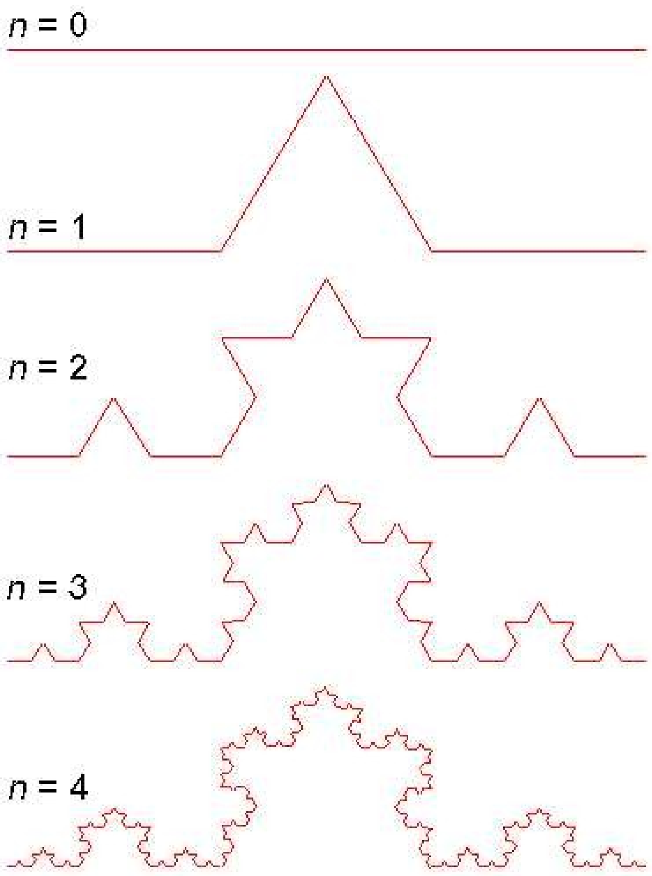
R. Hagedorn
"Remarks on the Thermodynamical Model of Strong Interactions"
Nucl. Phys. B (1970).

A firebal is
a statistical equilibrium of undetermined numbers of fireballs, each of which, in turn, is considered to be ...

= selfsimilarity

Fractal dimension

Koch's arc



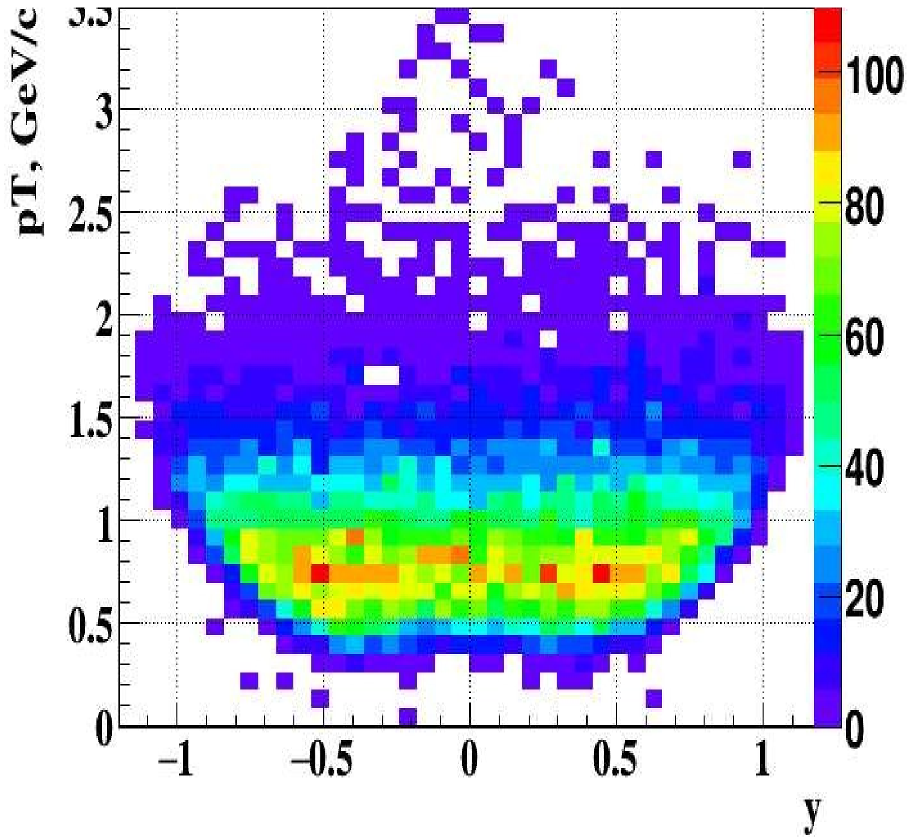
The **fractal dimension** of sets observed in the dynamics can be used as quantitative measure of the chaoticity

$$\boldsymbol{D} = \lim_{r \to 0} \frac{\log \boldsymbol{N}(\boldsymbol{r})}{\log (1/\boldsymbol{r})}$$

r - scale
N(r) - number of elements in fractal at given scale

$$\boldsymbol{D}^{Koch's\ arc} = \lim_{n \to \infty} \frac{\log 4^n}{\log 3^n} = \frac{\log 4}{\log 3} = 1.261\ldots$$

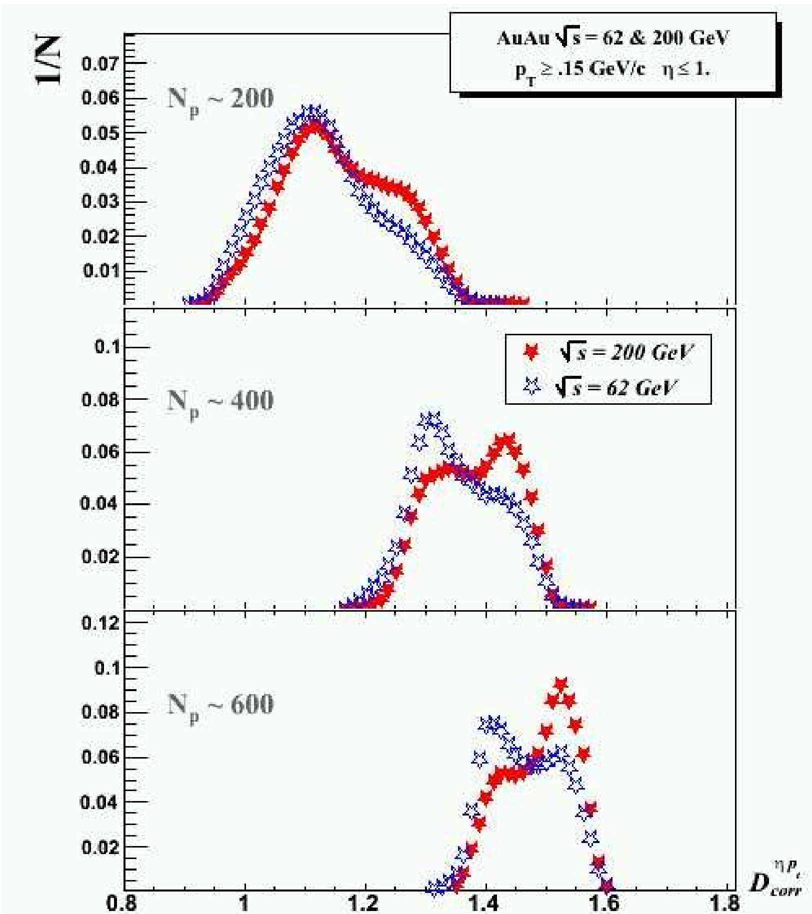
Box counting

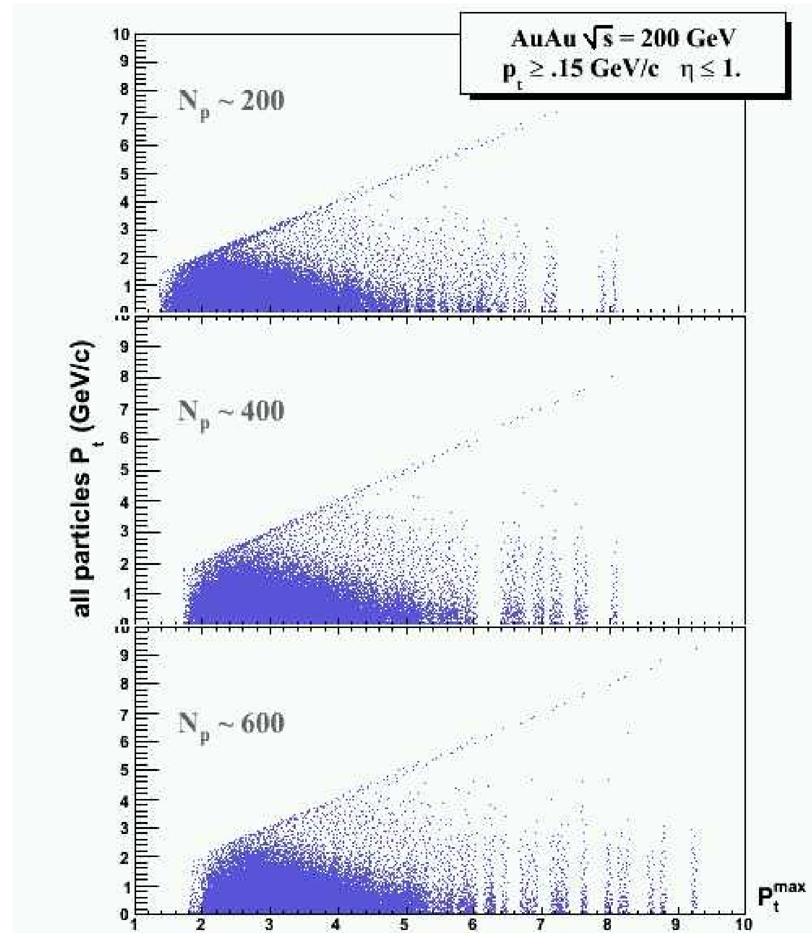


$$D = \lim_{\epsilon \to 0} \frac{\log N(\epsilon)}{\log \frac{1}{\epsilon}}$$

N(ε) is the number of boxes of side length ε required to cover the set.

STAR AuAu ηP_T space @ $\sqrt{s}$=200 GeV

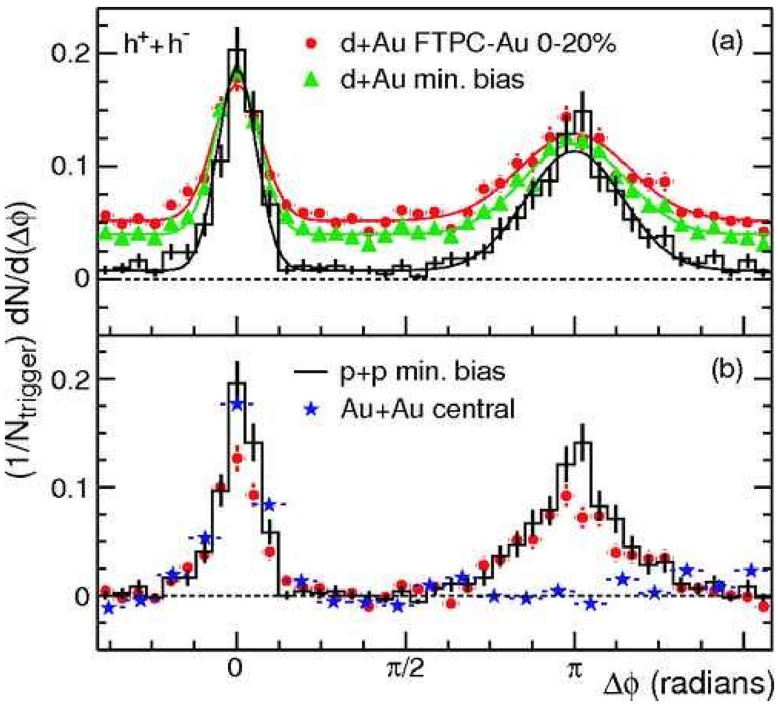




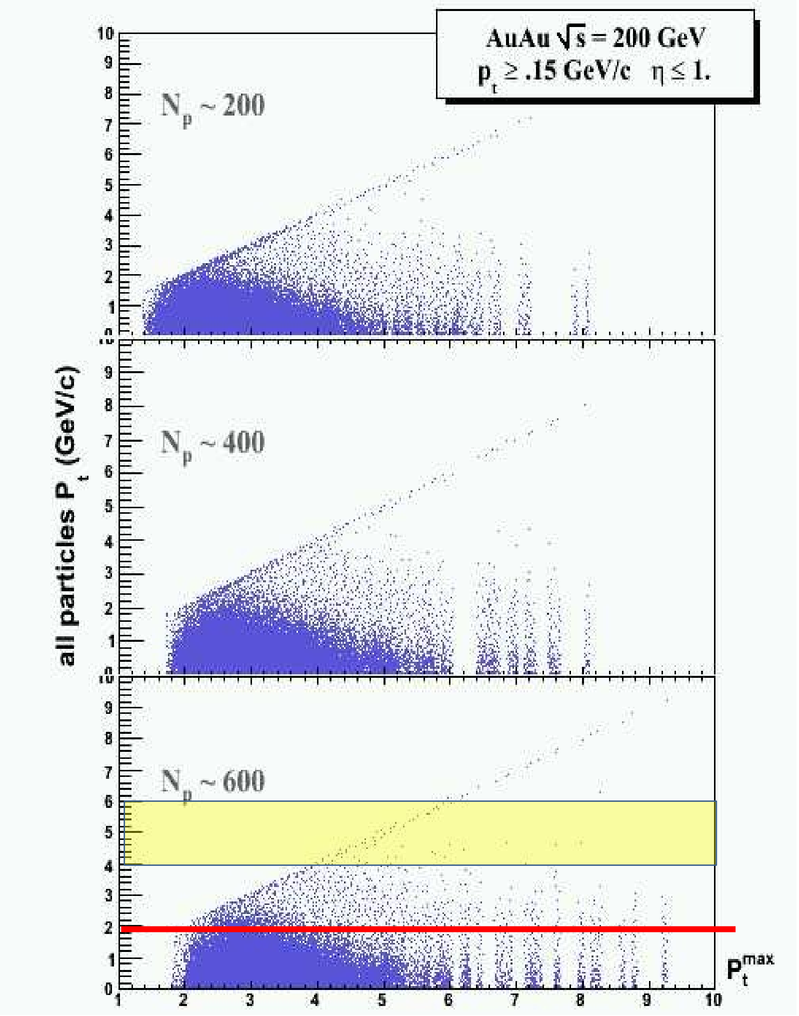
Fractal dimension in ηp_T space (R.O. ICHEP 2006)

Disappearance of away side jet

Phys. Rev. Lett. 91, 072304 (2003).



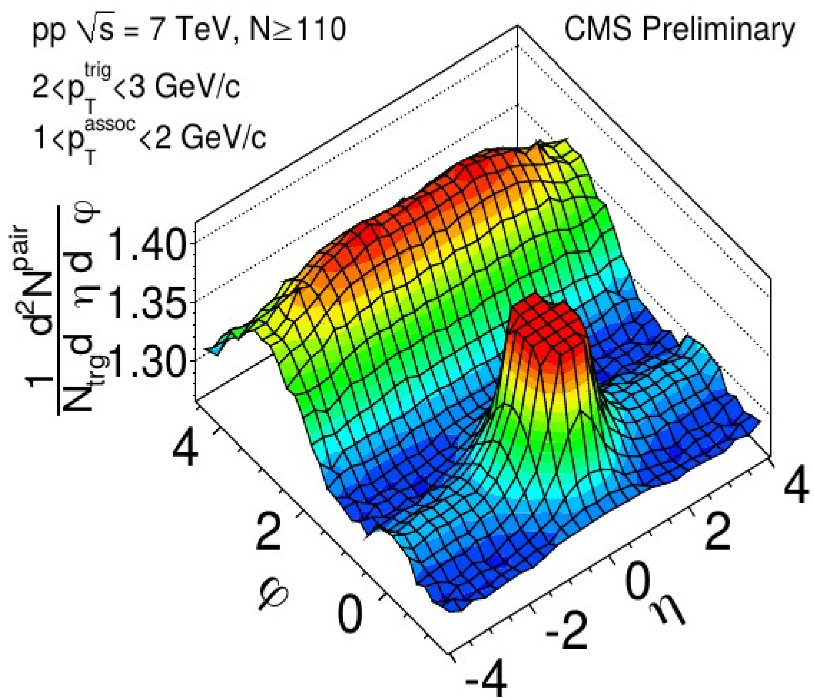
$|\eta| < 0.7$
4 GeV/c < p^{trig}_T < 6 GeV/c
2 GeV/c < $p_T^{associated}$ < p_T^{trig}

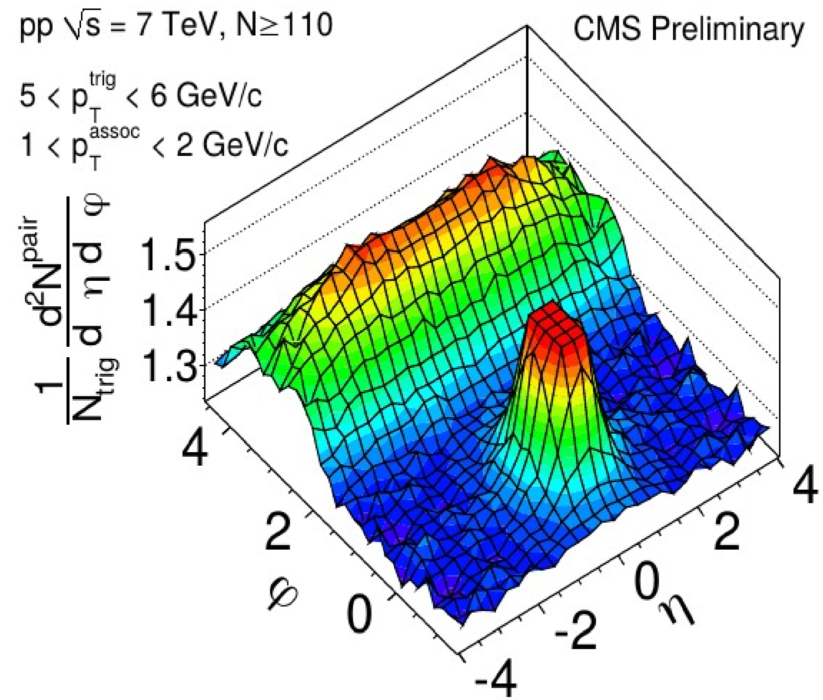


Ridge @ LHC pp & 7 TeV

Ridge correlation structure in high multiplicity pp collisions with CMS

arXiv:1107.2196





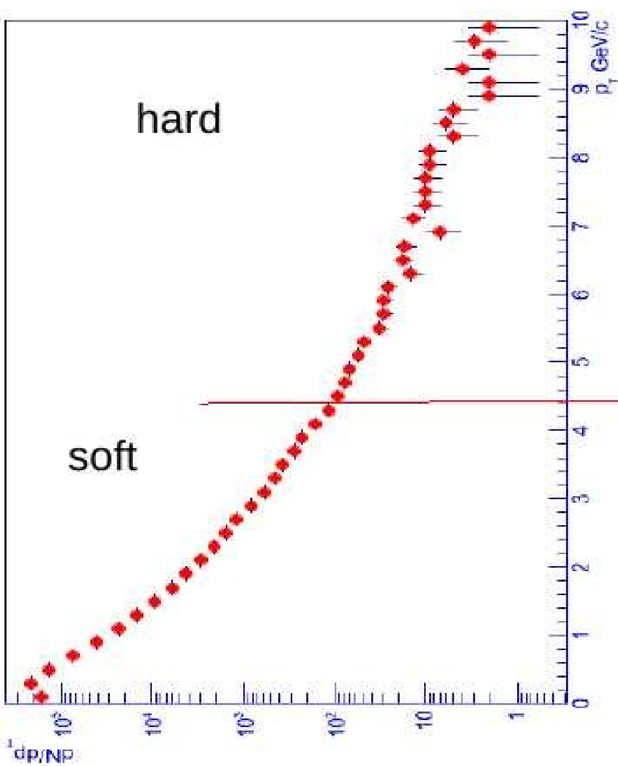
Two-dimensional (2-D) per-trigger-particle associated yield of charged hadrons as a function of Δη and Δφ with jet peak cutoff for better demonstration of the ridge from high multiplicity (N ≥ 110) pp collisions at √s = 7 TeV, for:

$2 < p_T^{trig} < 3$ GeV/c and $1 < p_T^{assoc} < 2$ GeV/c

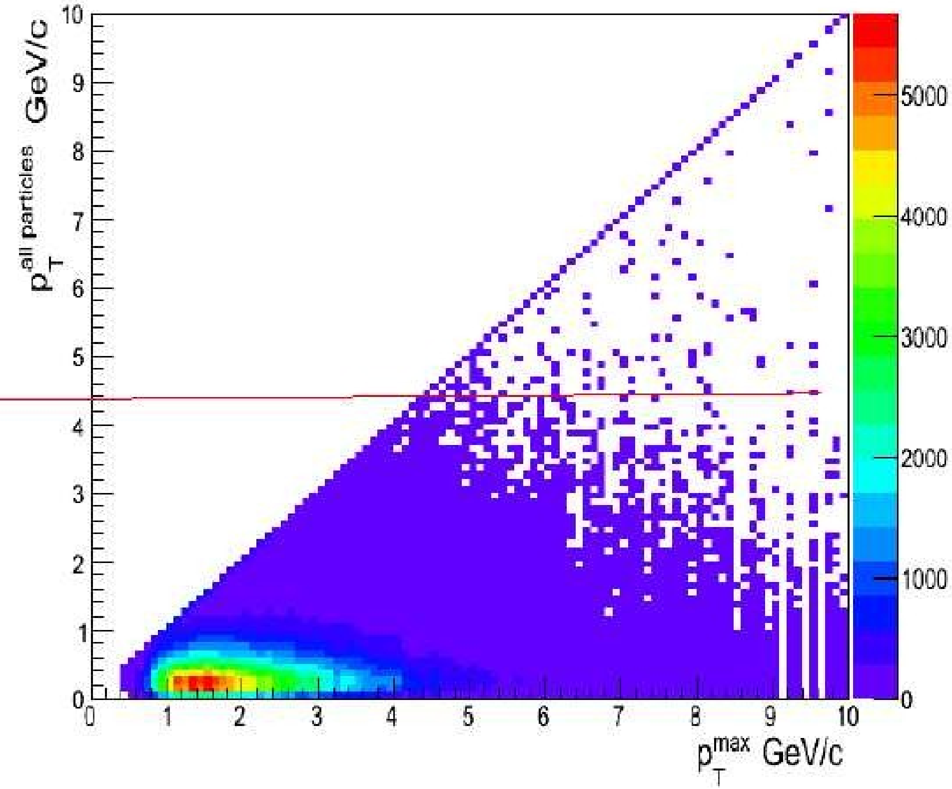
$5 < p_T^{trig} < 6$ GeV/c and $1 < p_T^{assoc} < 2$ GeV/c

Inflection point

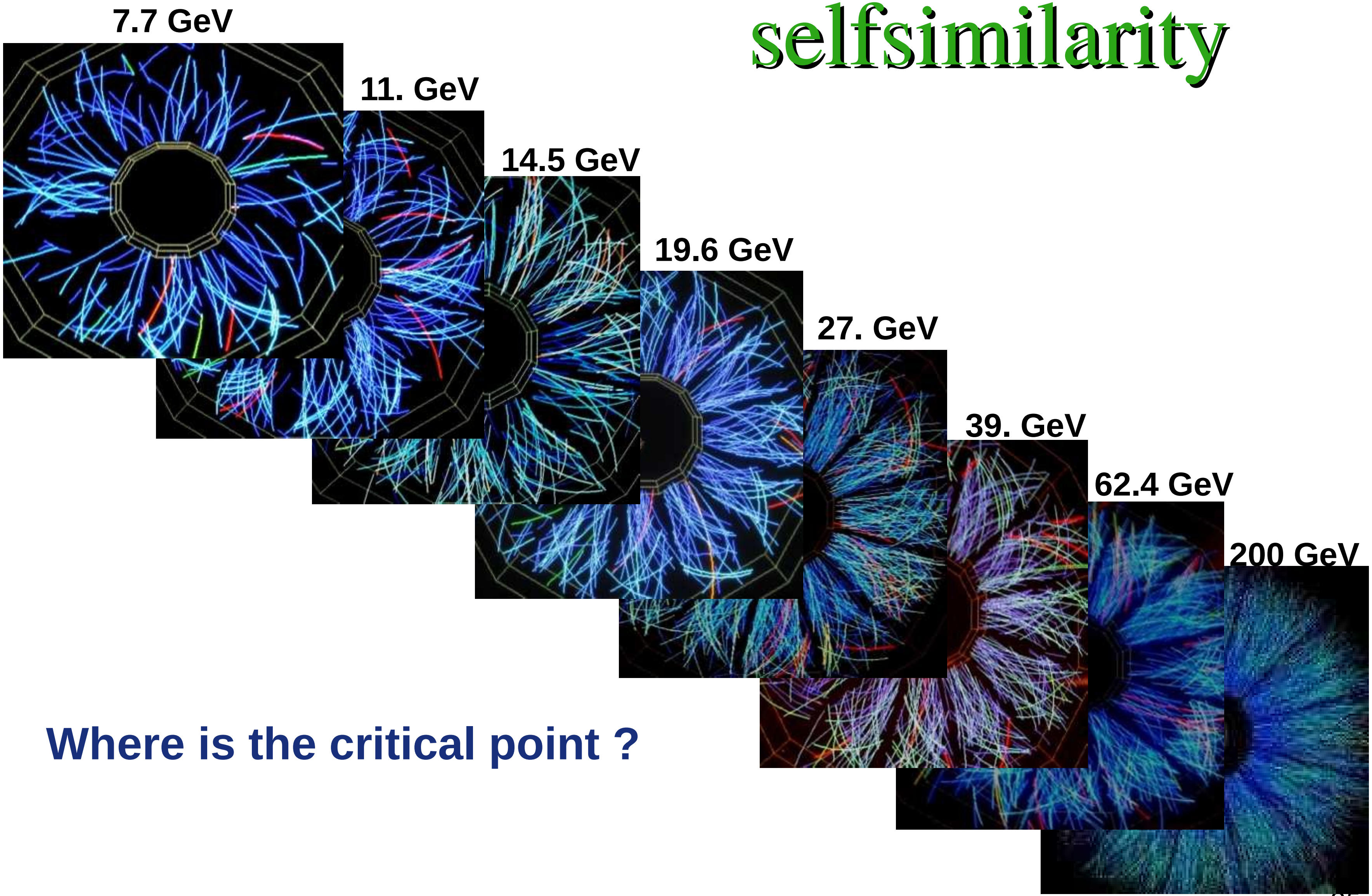
Pythia v.6-424



10K events √s =7 TeV
All charged particles

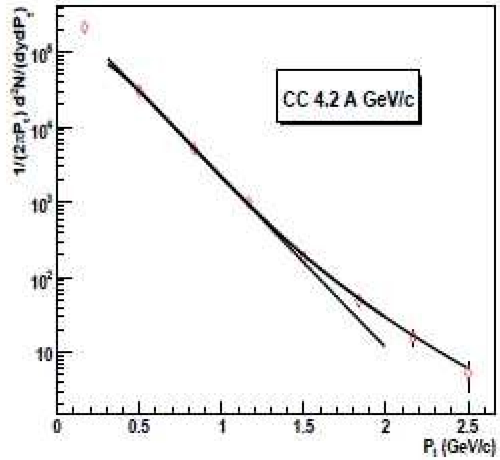


STAR beam energy scan: selfsimilarity

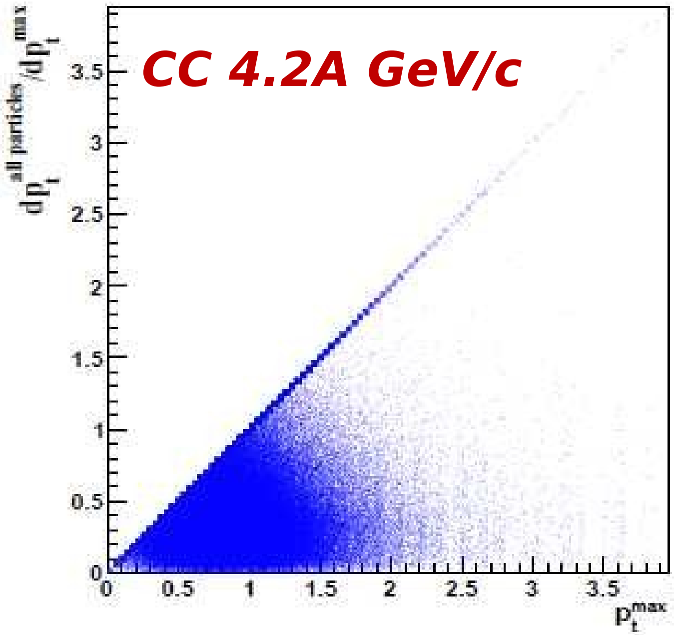


Where is the critical point ?

PC, dC, aC, CC @ 4.2AGeV/c



Interaction	Number of events
pC	5722
dC	3826
αC	9643
CC	15842



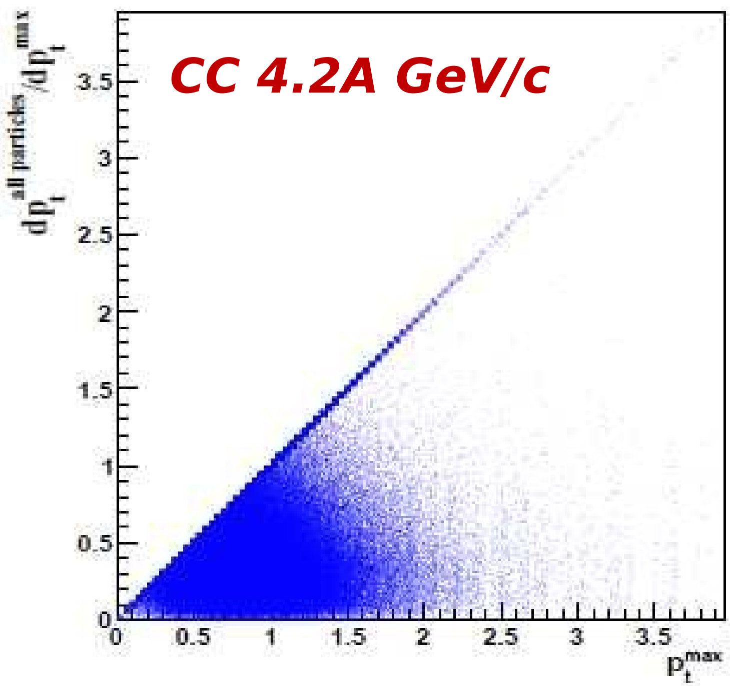
Levy distribution

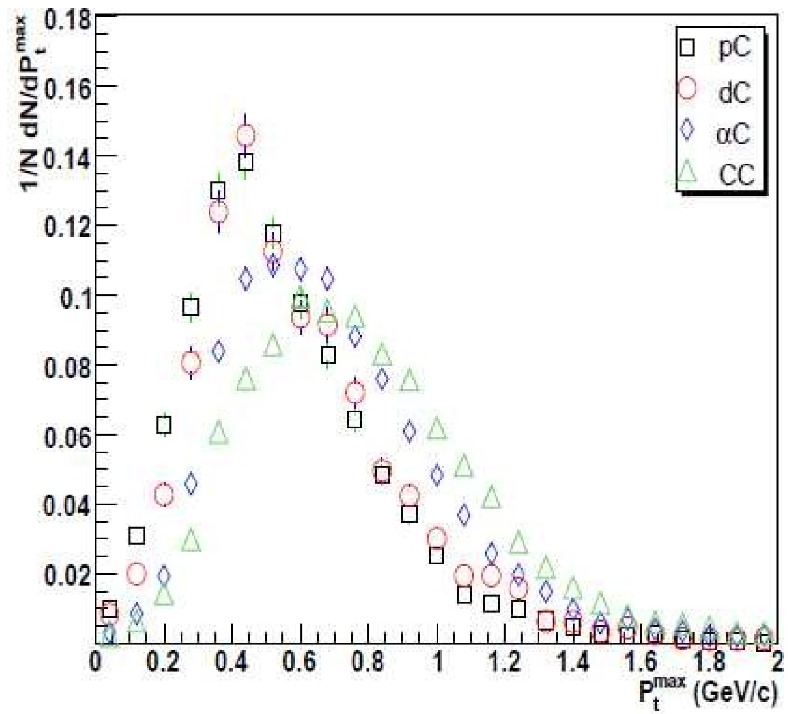
$$\frac{d^2N}{2\pi p_t dp_t dy} = \frac{B}{(1+(m_t - m_0)/nT)^n}$$

	parameter value			
	n	T	B	χ^2/ndf
pC	7.45 ± 1.22	6.86e-02 ± 6.04e-03	2.29e+04 ± 2.40e+03	0.19
dC	6.68 ± 1.10	6.63e-02 ± 6.78e-03	1.85e+04 ± 2.31e+03	0.19
αC	6.59 ± 0.57	7.08e-02 ± 3.66e-03	6.10e+04 ± 3.70e+03	1.20
CC	6.84 ± 0.39	7.69e-02 ± 2.39e-03	1.30e+05 ± 4.55e+03	3.20

cite

P_t^{max} distributions





- Shifts with A
- Broadening with A

Higuchi's estimation of fractal dimension

Approach to an irregular time series on the basis of the fractal theory
T.Higuchi Physica D 31 (1988) 277-283

We now consider a finite set of time series observations taken at a regular interval:

$$X(1),\ X(2),\ X(3), \ldots, X(N).$$

From given time series, we first construct a new time series, X_k^m, defined as follows:

$$X_k^m;\ X(m),\ X(m+k),\ X(m+2k), \ldots, X\left(m + \left[\frac{N-m}{k}\right] \cdot k\right) \quad (m = 1, 2, \ldots, k),$$

where [ ] denotes the Gauss' notation and both k and m are integers. m and k indicate the initial time and the interval time, respectively. For a time interval equal to k, we get k sets of new time series. In the case of $k = 3$ and $N = 100$, three time series obtained by the above process are described as follows:

$$X_3^1;\ X(1),\ X(4),\ X(7), \ldots, X(97),\ X(100),$$

$$X_3^2;\ X(2),\ X(5),\ X(8), \ldots, X(98),$$

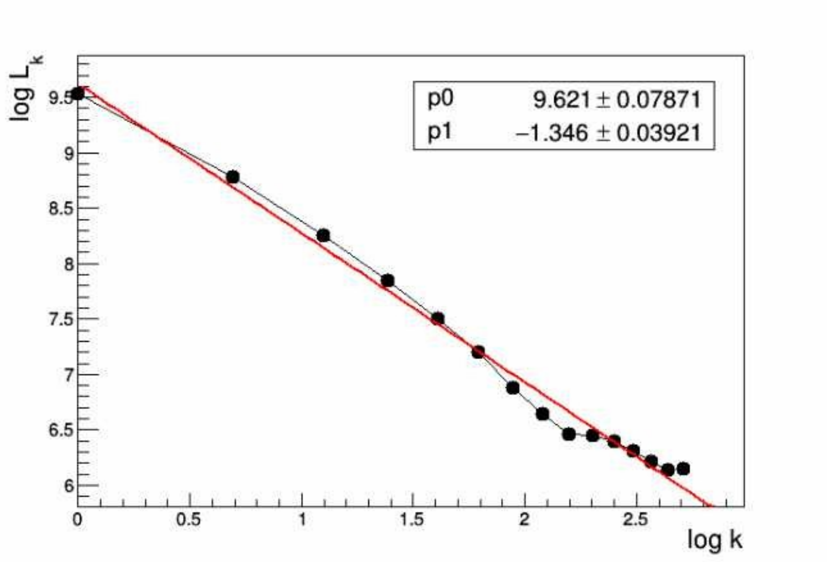
$$X_3^3;\ X(3),\ X(6),\ X(9), \ldots, X(99).$$

Higuchi's method

We define the length of the curve, X_k^m, as follows:

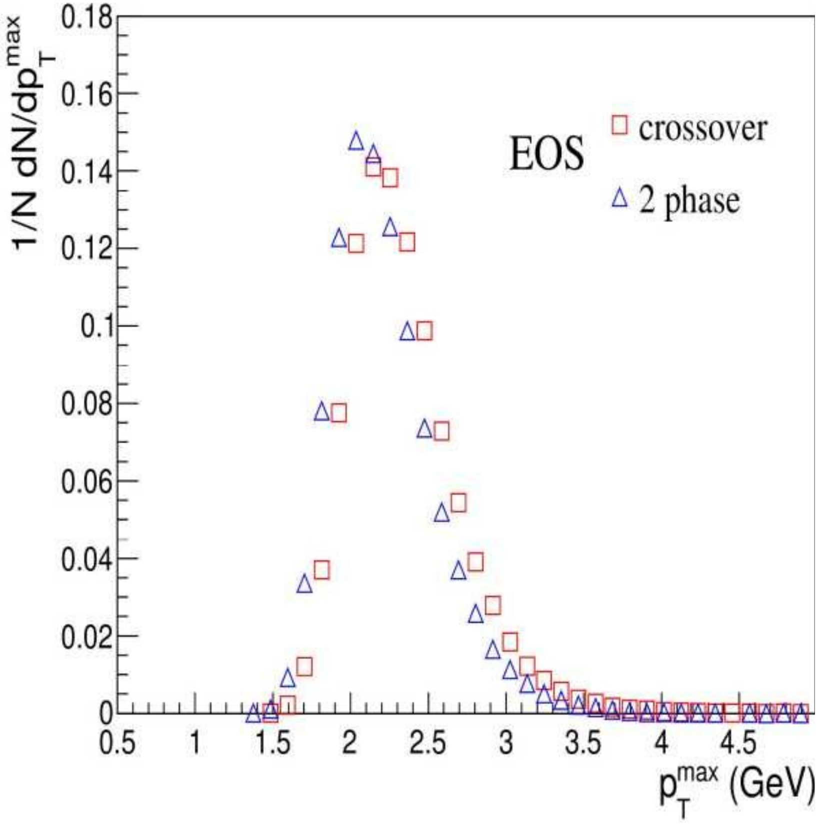
$$L_m(k) = \left\{ \left(\sum_{i=1}^{\left[\frac{N-m}{k}\right]} |X(m+ik) - X(m+(i-1)\cdot k)| \right) \frac{N-1}{\left[\frac{N-m}{k}\right]\cdot k} \right\} \Bigg/ k.$$

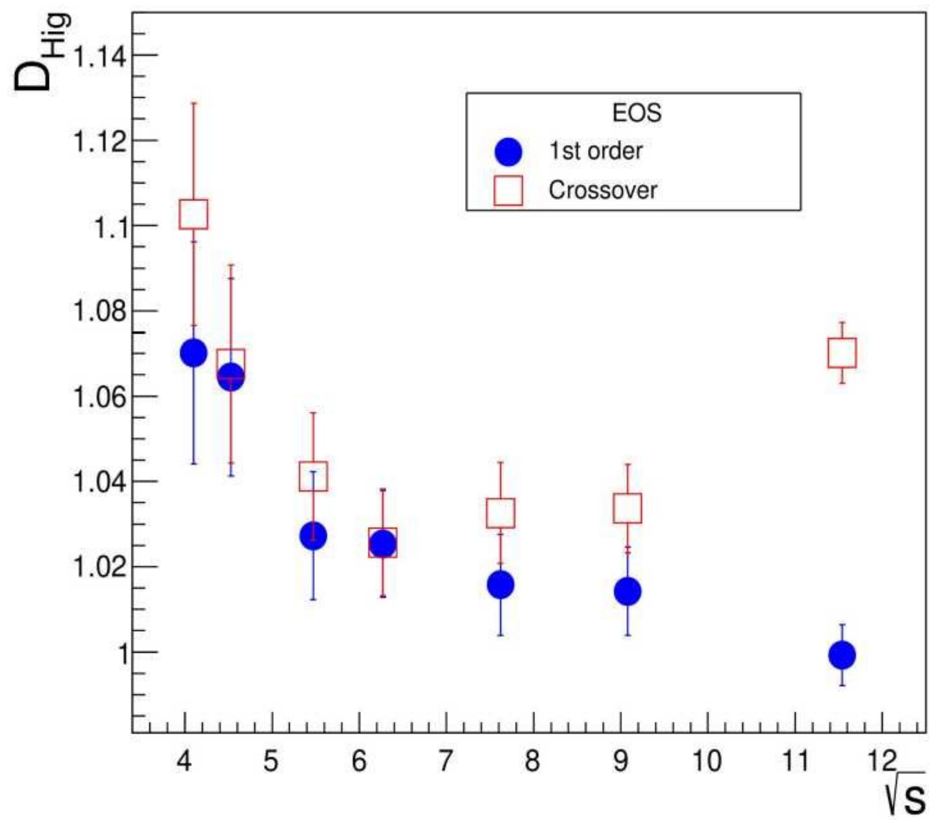
The term, $N-1/[(N-m)/k]\cdot k$ represents the normalization factor for the curve length of subset time series. We define the length of the curve for the time interval k, $\langle L(k)\rangle$, as the average value over k sets of $L_m(k)$. If $\langle L(k)\rangle \propto k^{-D}$, then the curve is fractal with the dimension D.



Yet another signature of EOS with THESEUS

AuAu √s = 11.5 GeV





Summary

- *Reduced curvature of net-proton rapidity distribution can be used as the signuture of different EoS for nuclear matter*
- *Fractal dimension for the multiparticle events is sensitive to the global structure of these events*
- *Fractal dimension analysis is useful to understand features in events*

STAR BES I results

S. Jowzaee,
Quark Matter 2017

Ridge effect