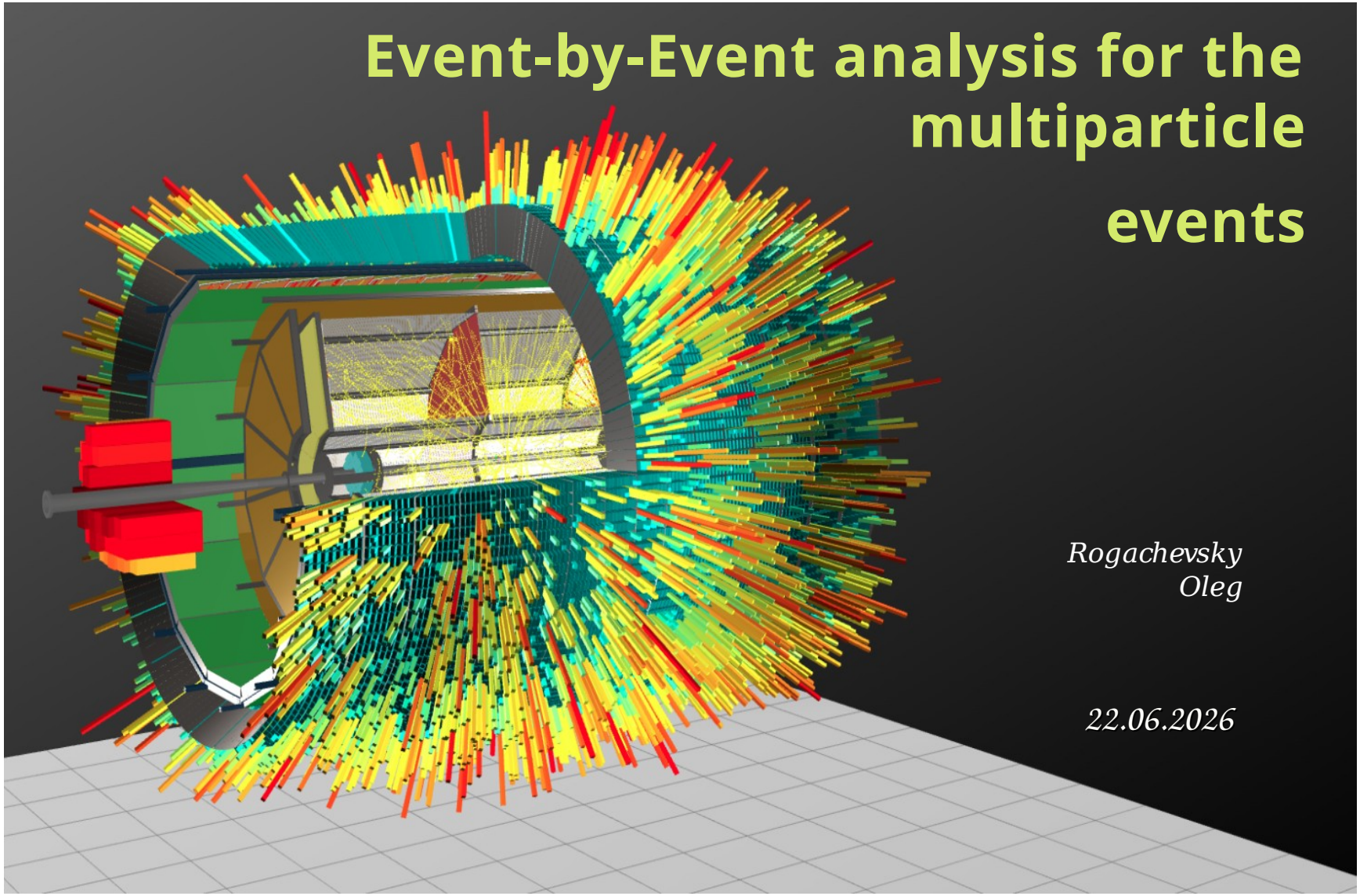
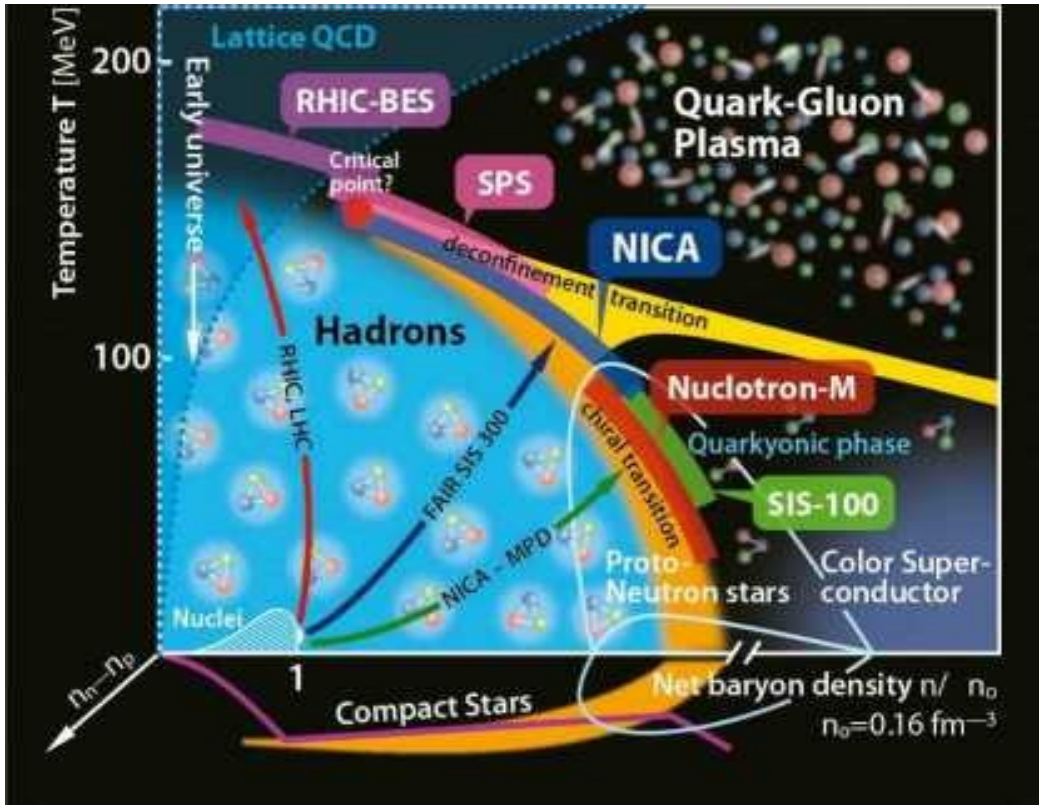
Event-by-Event analysis for the multiparticle events

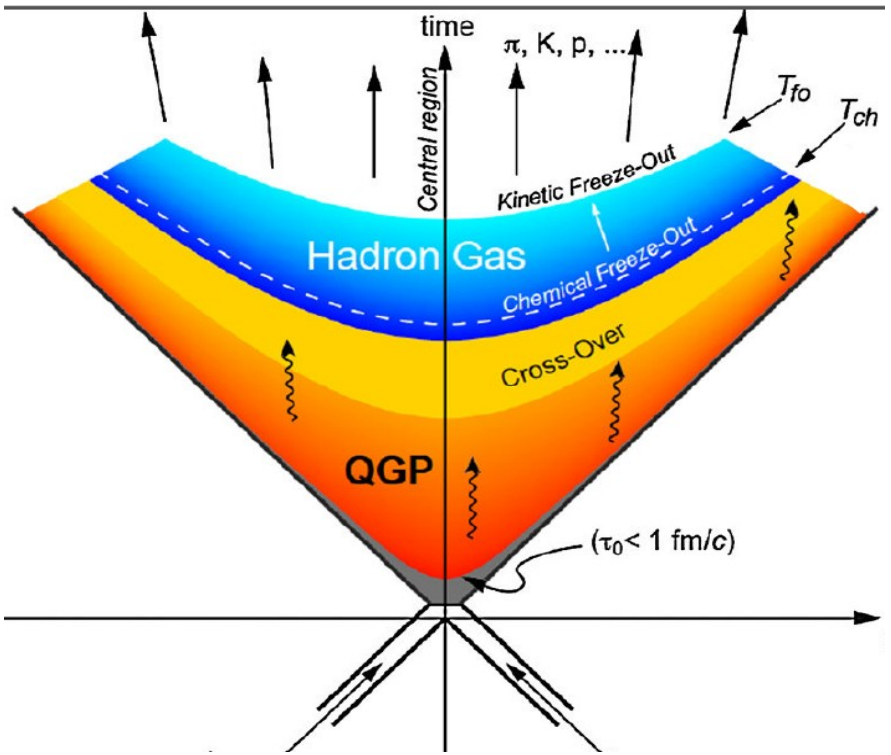


Rogachevsky Oleg

22.06.2026

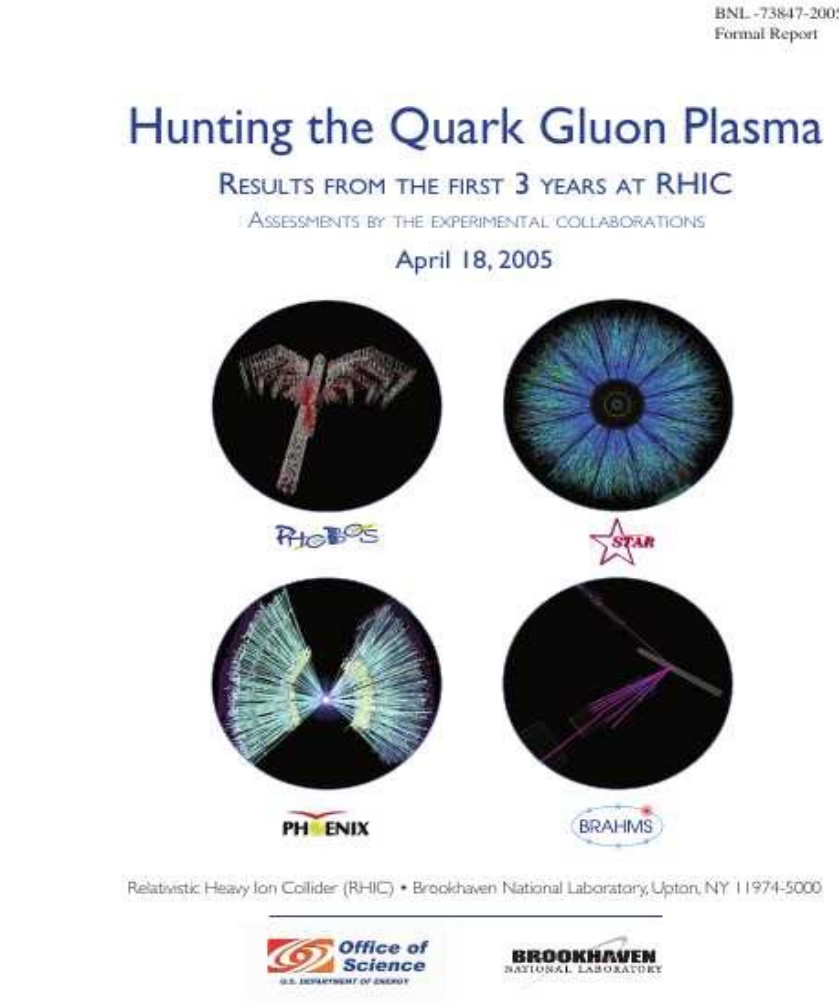
QCD phase diagram





Quark–gluon plasma (QGP) is an interacting localized assembly of quarks and gluons at thermal (local kinetic) and (close to) chemical (abundance) equilibrium. In normal matter quarks are confined; in the QGP quarks are deconfined. Quark–gluon plasma occurs at energy densities high enough to melt the protons and neutrons that make up the nuclei of normal matter. It is a very low viscosity liquid composed of the elementary particles, quarks and gluons, a new state of matter.

The Quark-Gluon-Plasma is Found at RHIC 2005



BNL -73847-2005
Formal Report

Hunting the Quark Gluon Plasma

RESULTS FROM THE FIRST 3 YEARS AT RHIC

ASSESSMENTS BY THE EXPERIMENTAL COLLABORATIONS

April 18, 2005

PHOBOS STAR PHENIX BRAHMS

Relativistic Heavy Ion Collider (RHIC) • Brookhaven National Laboratory, Upton, NY 11974-5000

Office of Science U.S. DEPARTMENT OF ENERGY

BROOKHAVEN NATIONAL LABORATORY

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Experimental and Theoretical Challenges in the Search for the
Quark Gluon Plasma: The STAR Collaboration's Critical Assessment
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The early measurements have revealed compelling evidence for the existence of a new form of nuclear matter at extremely high density and temperature – a medium in which the predictions of QCD can be tested, and new phenomena explored, under conditions where the relevant degrees of freedom, over nuclear volumes, are expected to be those of quarks and gluons, rather than of hadrons. This is the realm of the quark gluon plasma, the predicted state of matter whose existence and properties are now being explored by the RHIC experiments.

Nuclotron based Ion Collider fAcility

Beams – p,d(h)..$^{197}Au^{79+}$

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

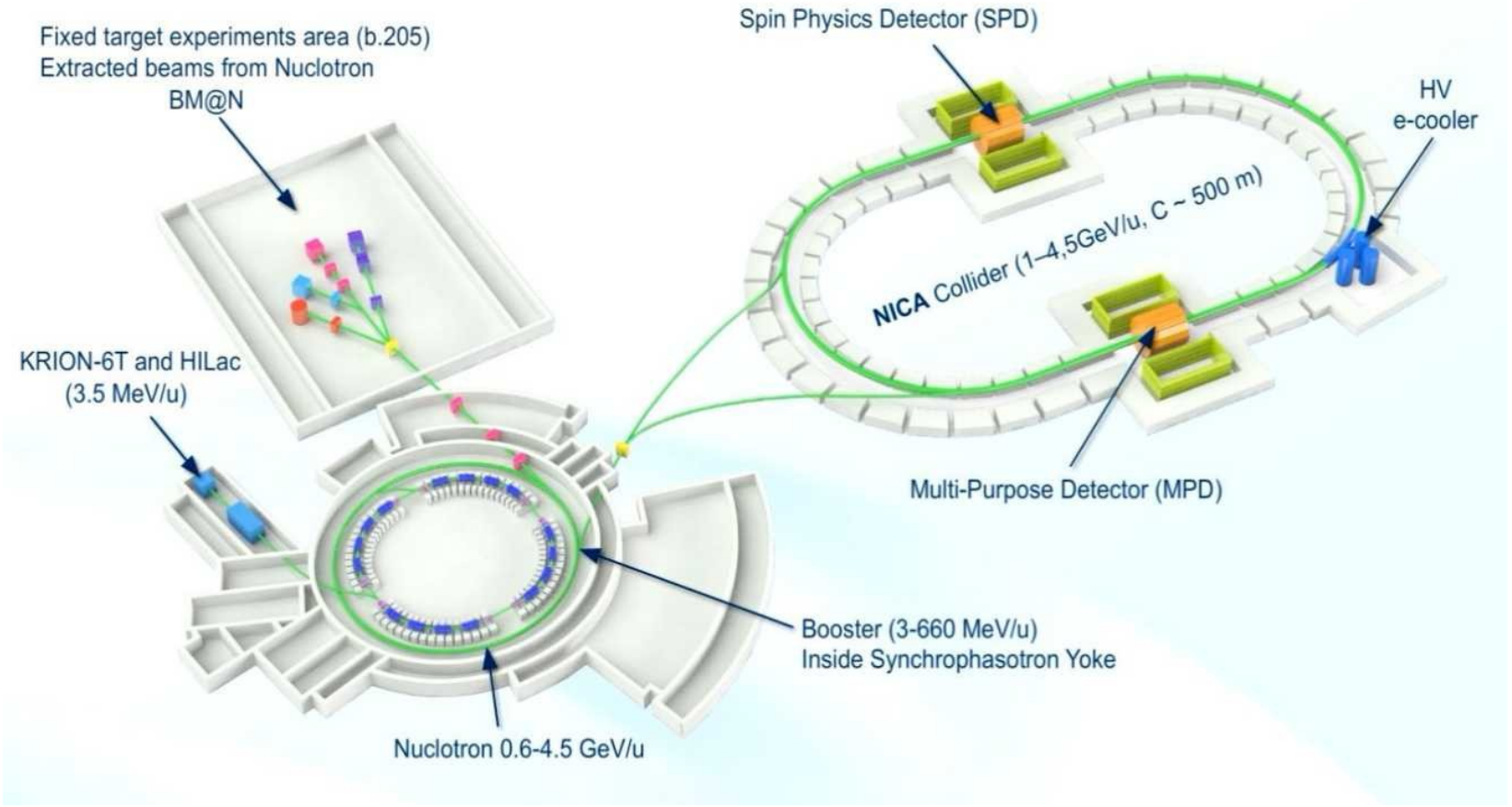
Beam energy (fixed target) - **1-6** GeV/u

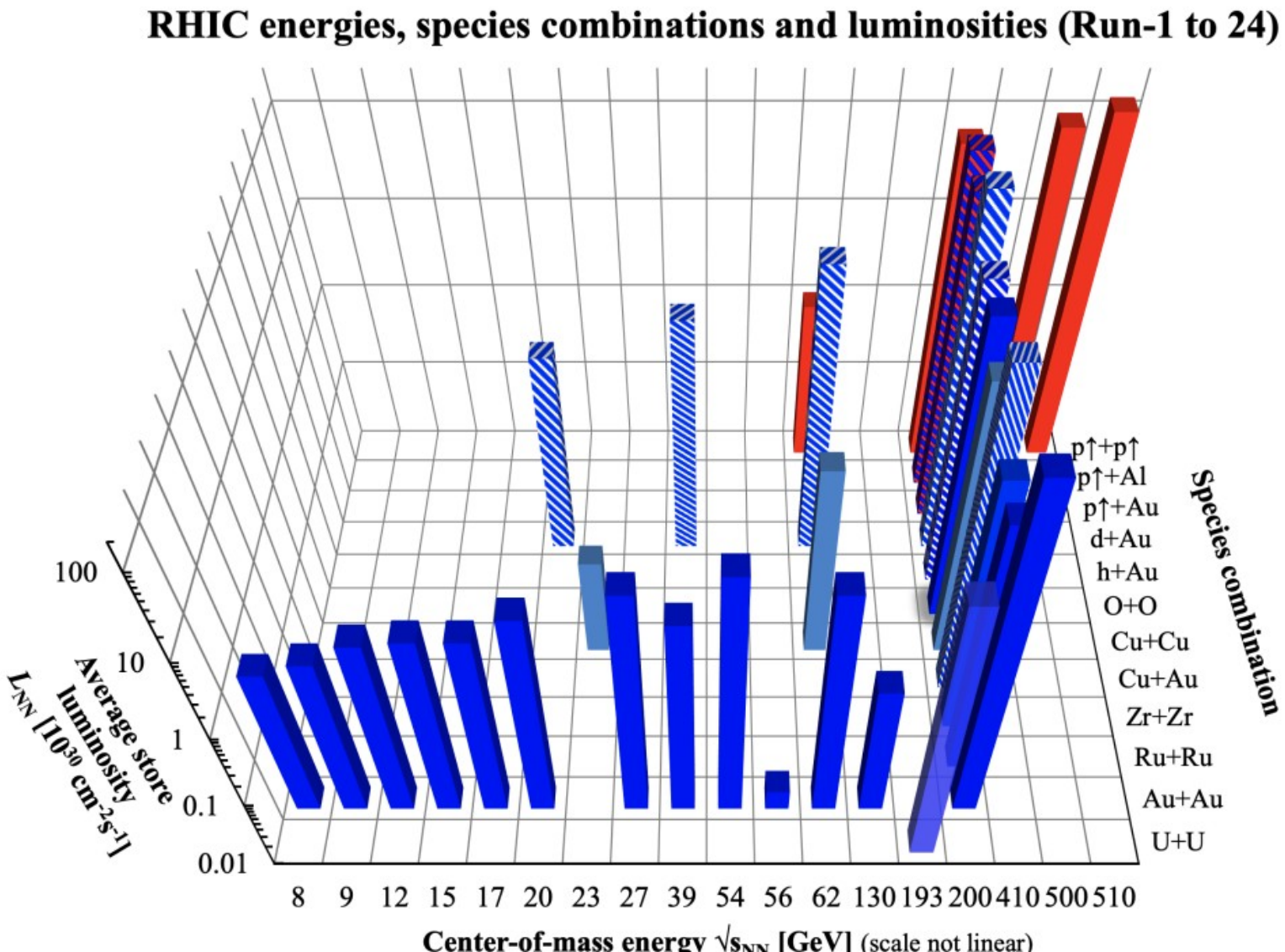
Luminosity: 10^{27} $cm^{-2}s^{-1}$(Au), 10^{32} (p)

Experiments:

2 Interaction points – **MPD** and SPD

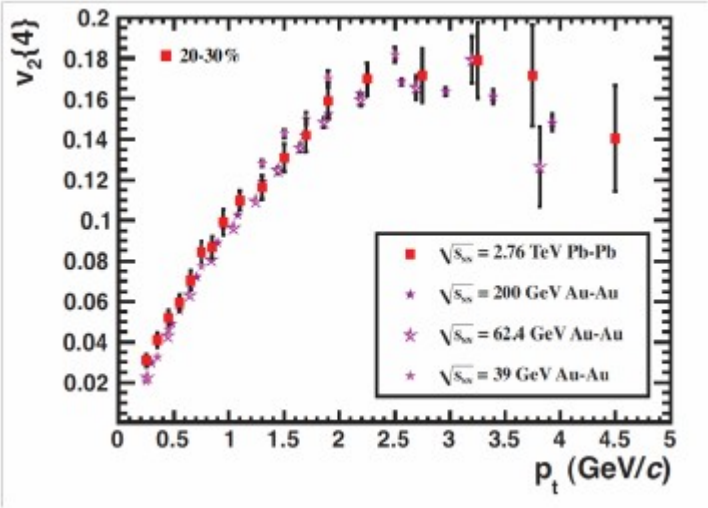
Fixed target experiment **BM@N**




RHIC energies, species combinations and luminosities (Run-1 to 24)
Average store luminosity L_{NN} [10^{30} cm^{-2}s^{-1}]
100
10
1
0.1
0.01
p↑+p↑
p↑+Al
p↑+Au
d+Au
h+Au
O+O
Cu+Cu
Cu+Au
Zr+Zr
Ru+Ru
Au+Au
U+U
Species combination
8 9 12 15 17 20 23 27 39 54 56 62 130 193 200 410 500 510
Center-of-mass energy $\sqrt{s_{NN}}$ [GeV] (scale not linear)

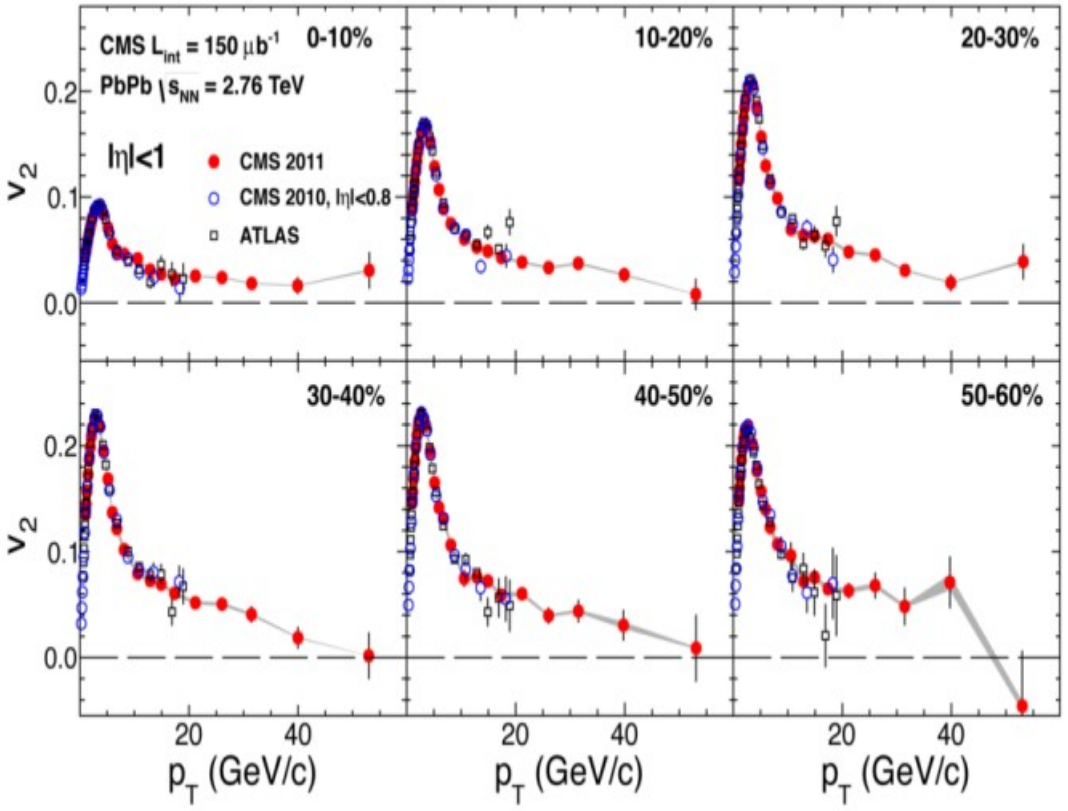
Flow analyses

Nucl. Phys. A 862, 125 (2011)



The v_2 (p_T) measured in 20−30% central Au+Au (Pb+Pb) collisions over the collision energies $\sqrt{s_{NN}}$ from 39 GeV to 2.76 TeV. The fact that the data all follow the same curve is indicative of elliptic flow that is driven by hydrodynamic expansion of a fireball with the initial geometric shape of the nuclear overlap associated with the impact parameter window

Nuclear Physics A 904–905 (2013) 98–105



Phase transition and fluctuations

Event-by-event (EbyE) analysis in physics, particularly in high-energy heavy-ion collisions, is a technique that examines individual collision events to measure fluctuations and correlations, rather than averaging over the entire dataset. It is essential for studying the QCD phase boundary, quark-gluon plasma formation, and initial-state spatial anisotropies

- Order of the QCD phase transition
- Density, rapidity, temperature and other fluctuations

Multiplicity fluctuations in relativistic heavy-ion collisions

- Charged particle production in pp and pp reactions
- Fluctuations in the participant model
- Fluctuations in the thermal model
- Centrality dependence and degree of thermalization
- Enhanced fluctuations in first-order phase transitions

Correlations between total and net charge, baryon number or strangeness

- General analysis of fluctuations and correlations
- Charge fluctuations in a thermal hadron gas
- Charge fluctuations in a quark-gluon plasma
- Total charge conservation

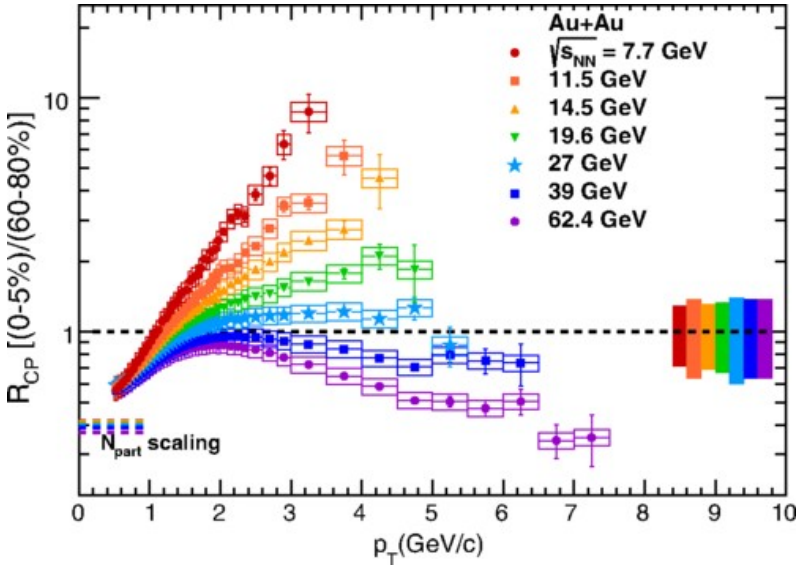
Fluctuations in particle ratios

- π^+/π^- ratio and entropy production
- K/π ratio and strangeness enhancement
- $\pi^0/\pi^\pm$ ratio and chiral symmetry restoration
- J/ψ multiplicity correlations and absorption mechanisms
- Photon fluctuations: thermal emission vs. $\pi^0 \rightarrow 2\,\gamma$
- Transverse momentum fluctuations

High p_T suppressions

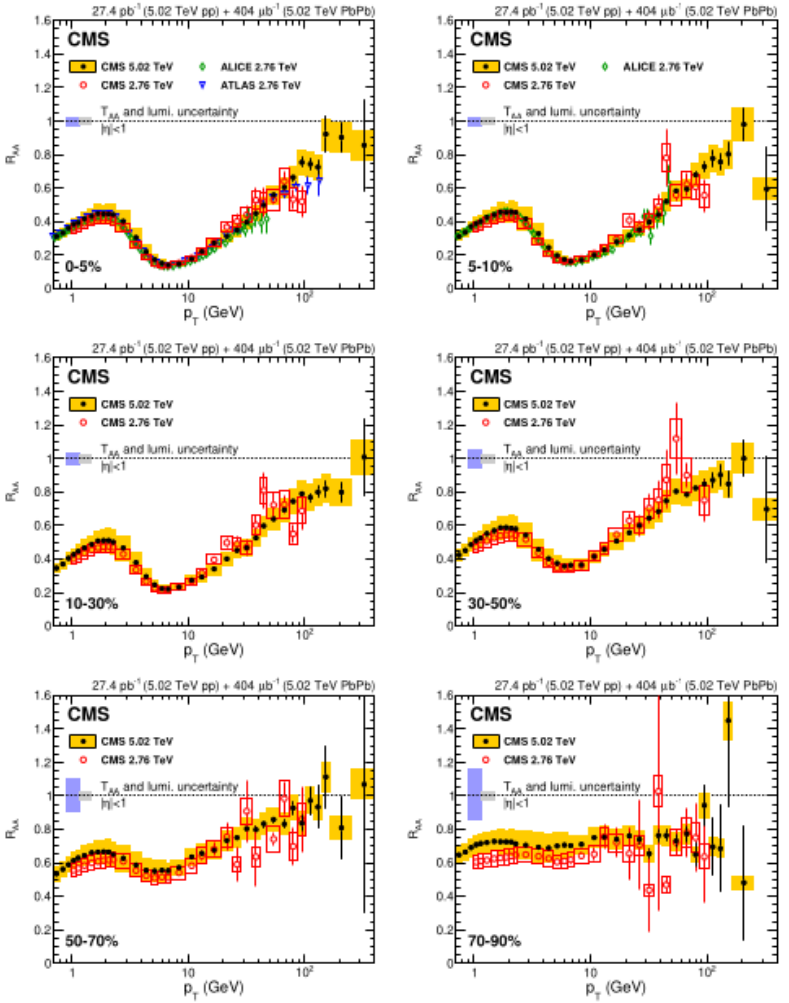
Beam Energy Dependence of Jet-Quenching Effects in Au+Au Collisions at √sNN=7.7, 11.5, 14.5, 19.6, 27, 39, and 62.4 GeV

L. Adamczyk et al. (STAR Collaboration)
Phys. Rev. Lett. 121, 032301



Identified particle RCP for RHIC BES energies. The colored shaded boxes describe the point-to-point systematic uncertainties. The uncertainty bands at unity on the right side of the plot correspond to the p_T-independent uncertainty in N_{coll} scaling with the color in the band corresponding to the color of the data points for that energy

arXiv:1611.01664v2 [nucl-ex] 11 Apr 2017

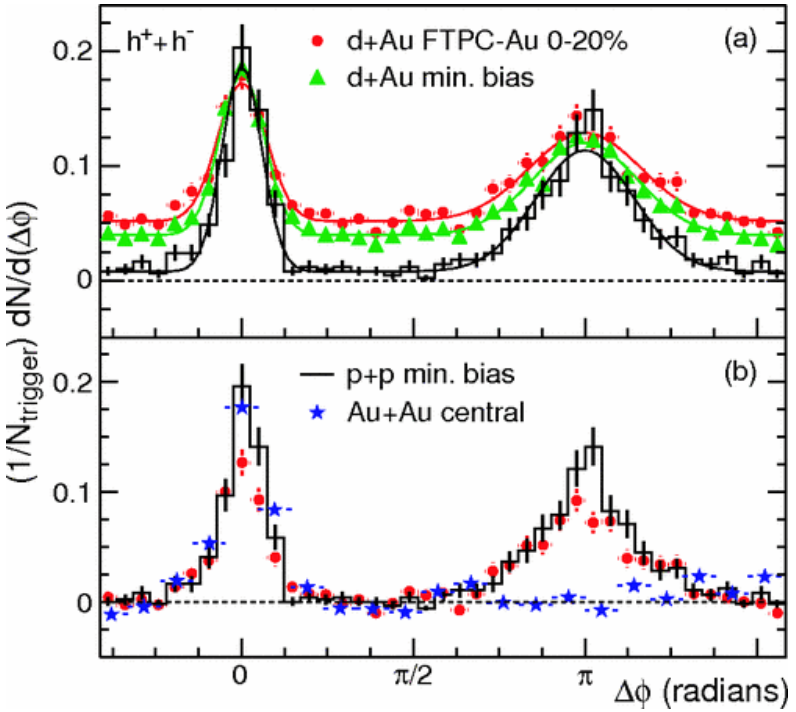


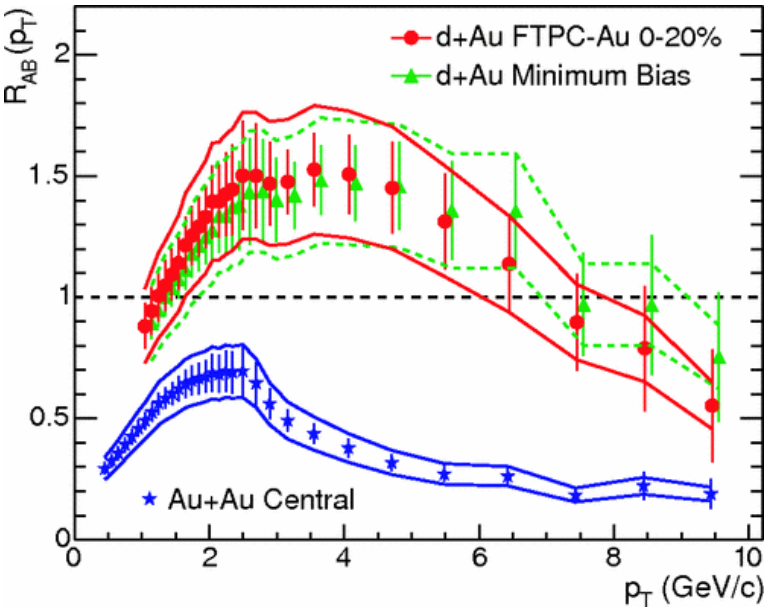
Charged-particle RAA measured in six different centrality ranges at √sNN = 5.02 TeV compared to results at sNN = 2.76 TeV from CMS (all centrality bins), ALICE (in the 0–5% and 5–10% centrality ranges), and ATLAS (in the 0–5% centrality range)

Jet quenching

Evidence from d+Au Measurements for Final-State Suppression of High-pT Hadrons in Au+Au Collisions at RHIC

Phys.Rev.Lett. 91 072304, 2003





4 GeV/c < p_T^{trig} < 6 GeV/c

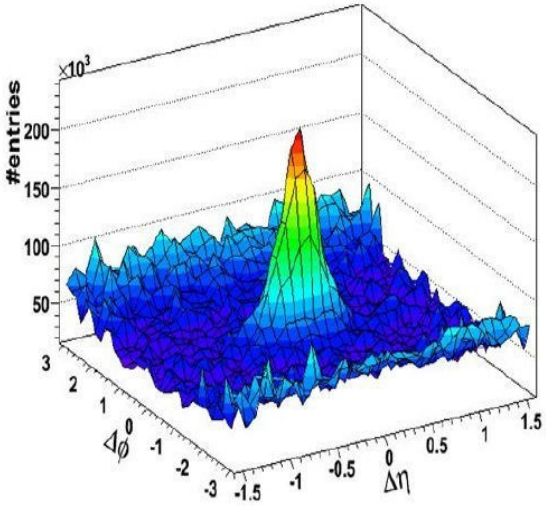
2 GeV/c < p_T^{assoc} < p_T^{trig}

Ridge @ RHIC

Long range rapidity correlations and jet production in high energy nuclear collisions

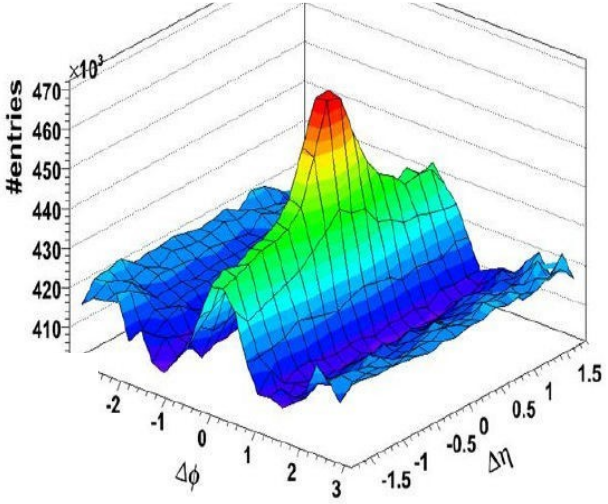
B. Abelev et al., Phys. Rev. C80, 064912 (2009).

d–Au

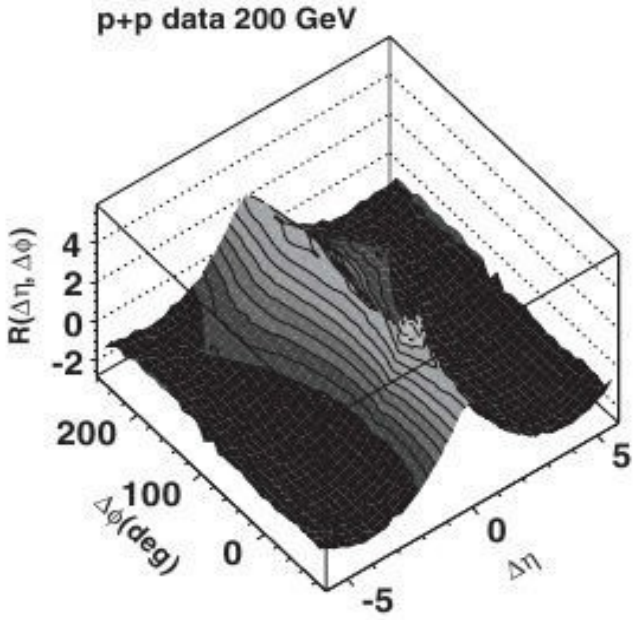


Two particle correlation function at 200 GeV/N from STAR experiment

Au–Au central



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



Cover an acceptance
of $3 < |\eta| < 4.5$ and
$-180^\circ < \varphi < 180^\circ$
5×10^5 200-GeV Au+Au
8×10^5 410 GeV p+p
$|z_{vtx}| < 10$ cm

$3\ \text{GeV/c} < p_T^{\text{trig}} < 4\ \text{GeV/c}$
$2\ \text{GeV/c} < p_T^{\text{assoc}} < p_T^{\text{trig}}$

Cuts for jet quenching & ridge

Ridge

RHIC AuAu

3 GeV/c < p_T^{trig} < 4 GeV/c

2 GeV/c < p_T^{assoc} < p_T^{trig}

0.1 GeV/c < … < p_T < … < 5. GeV/c

Multiplicity N > 110

Jet Quenching

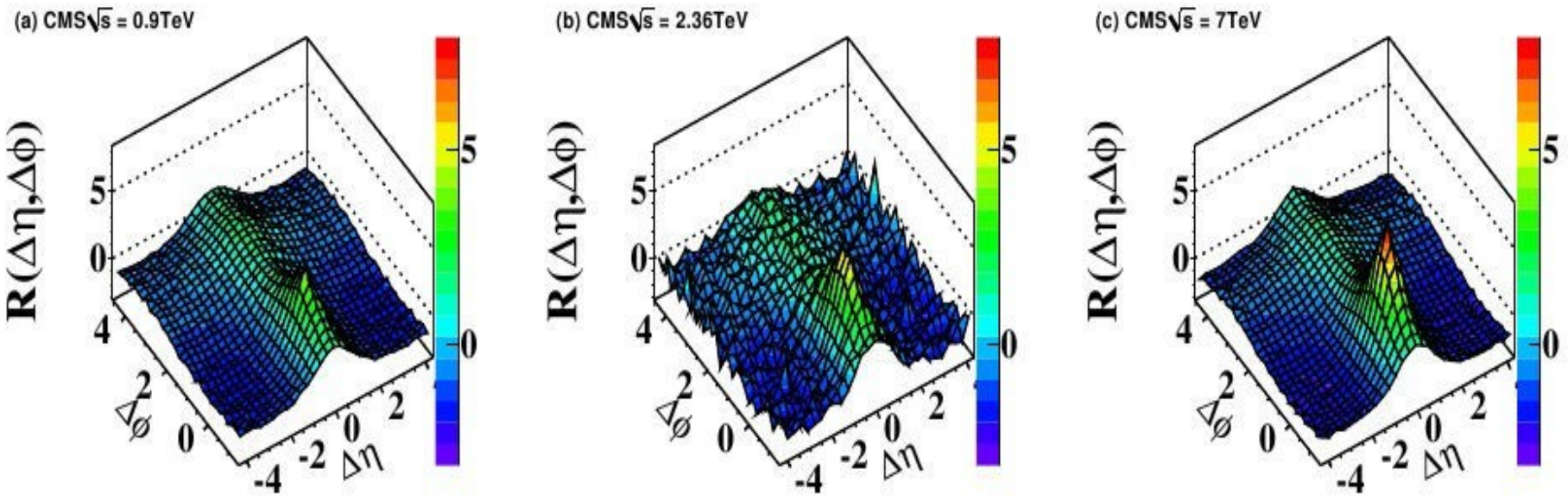
RHIC AuAu

4 GeV/c < p_T^{trig} < 6 GeV/c

2 GeV/c < p_T^{assoc} < p_T^{trig}

CMS jet + ridge

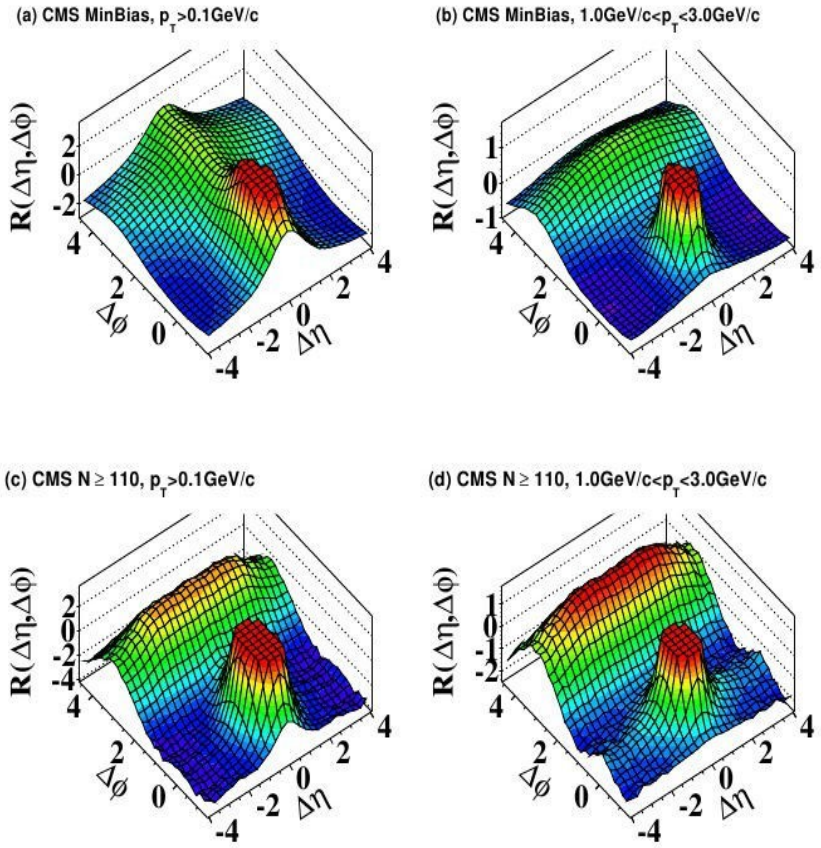
arXiv:1009.4122

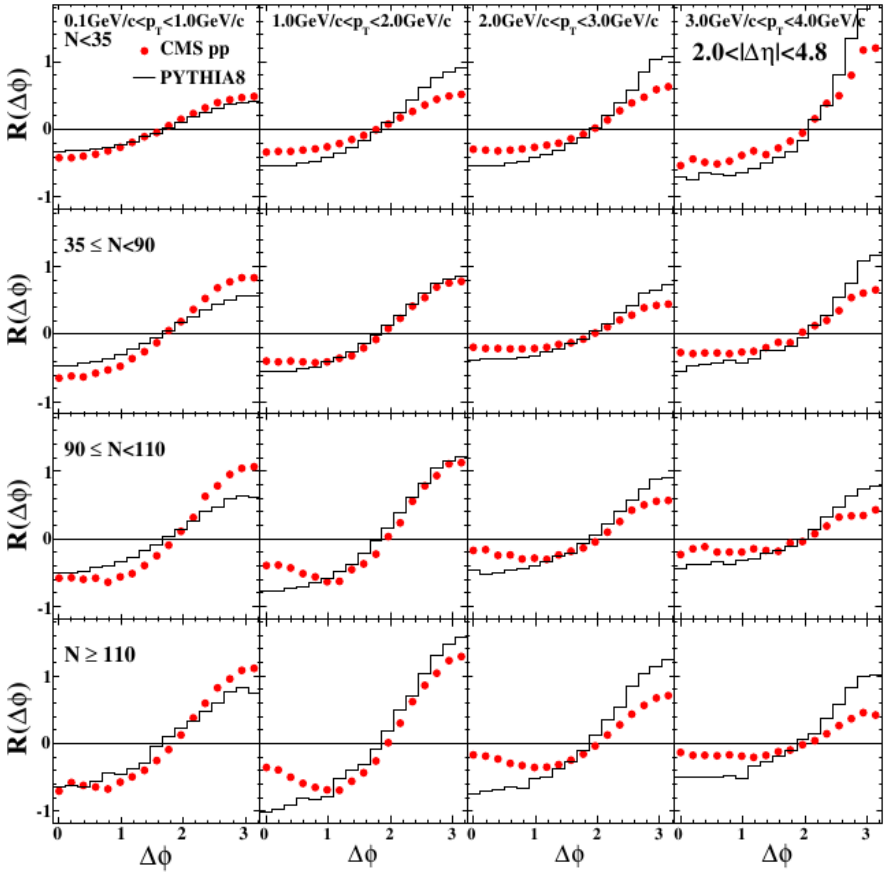


Two-particle correlation functions versus Δη and Δφ in pp collisions

CMS vs Pythia

pp @ 7 TeV

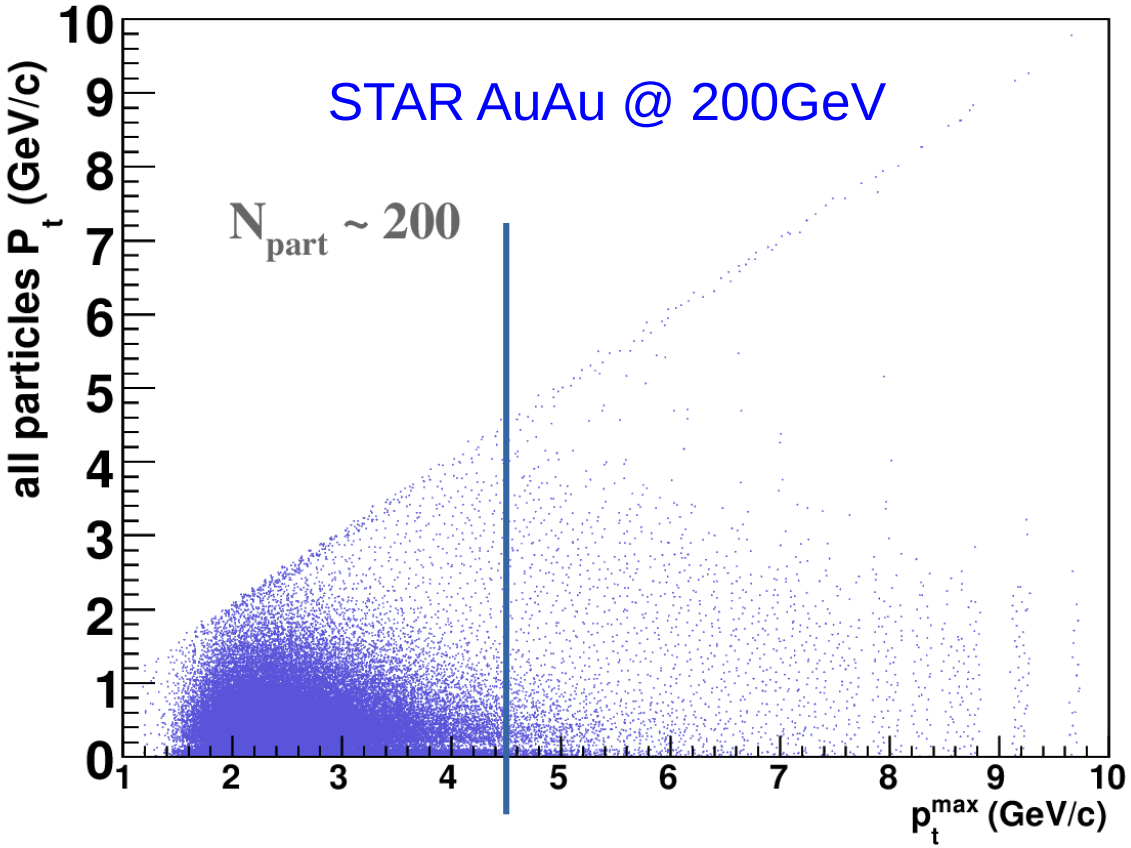




Universal events structure with p_T^{max}

R.O. ICHEP 2006 v.2 p.443
Scale dependent analysis approach for STAR events

~$2 \cdot 10^6$ event



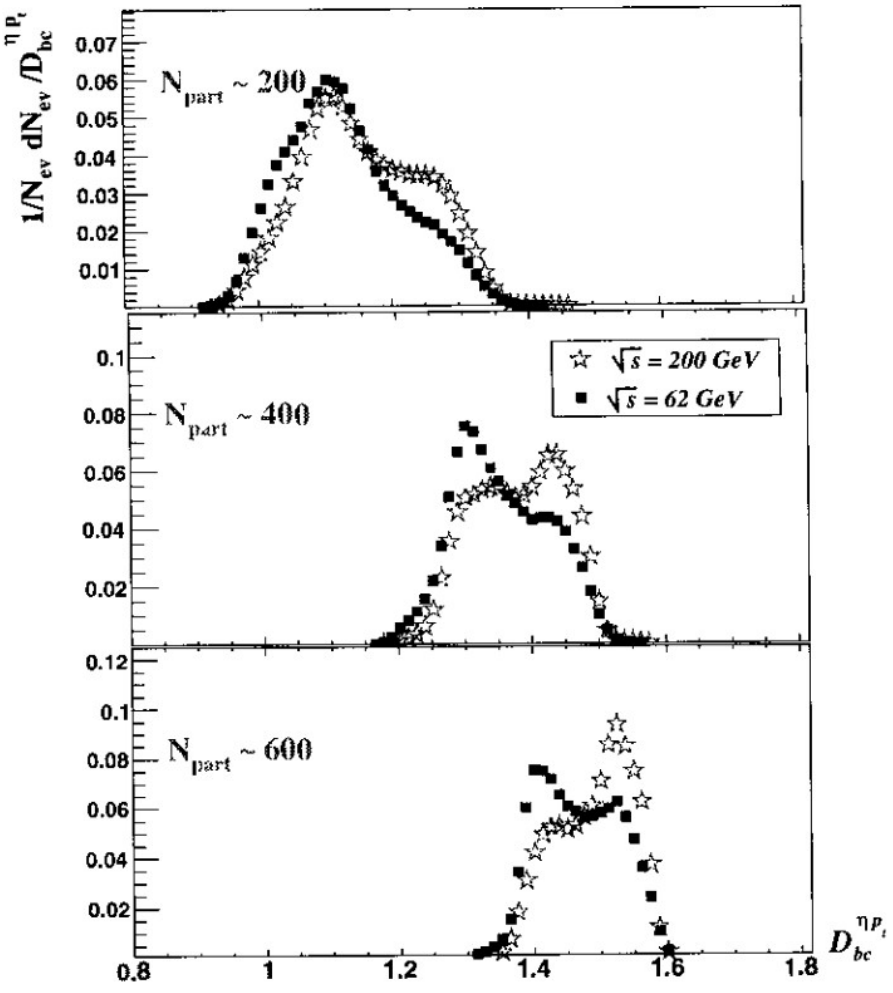
One event

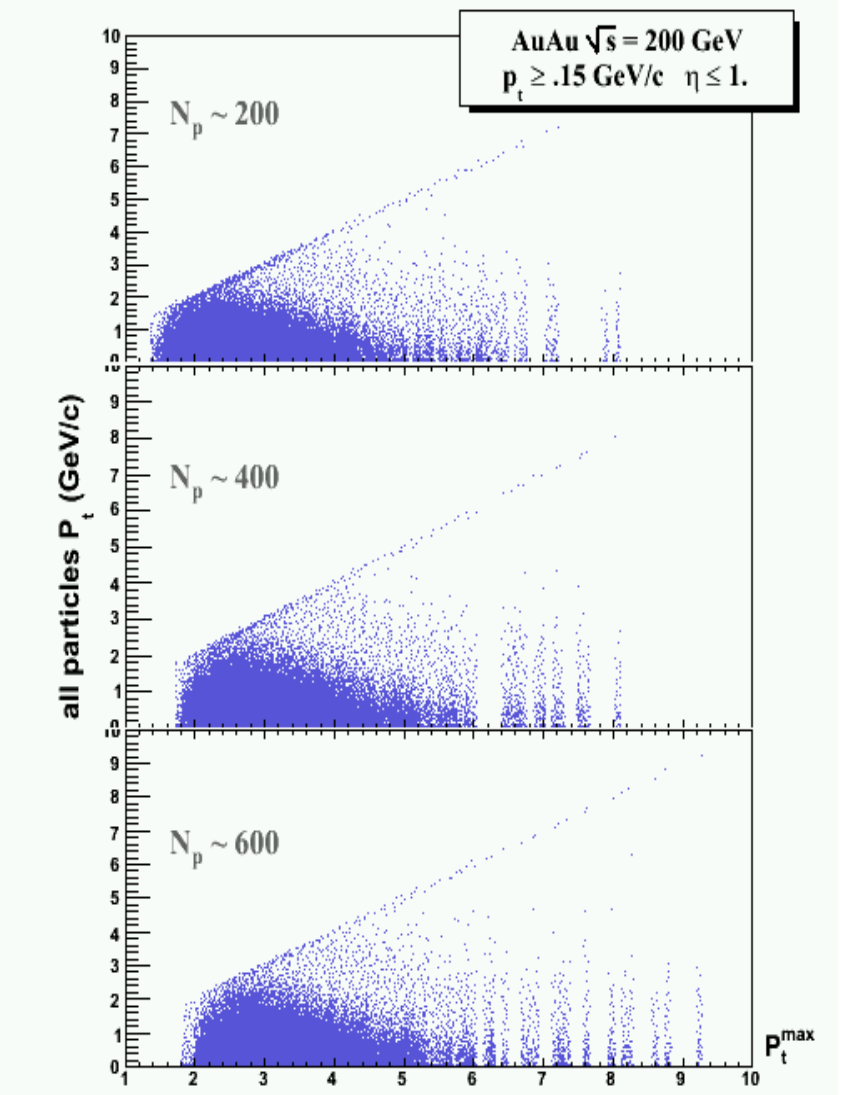
Structure does not depend on:

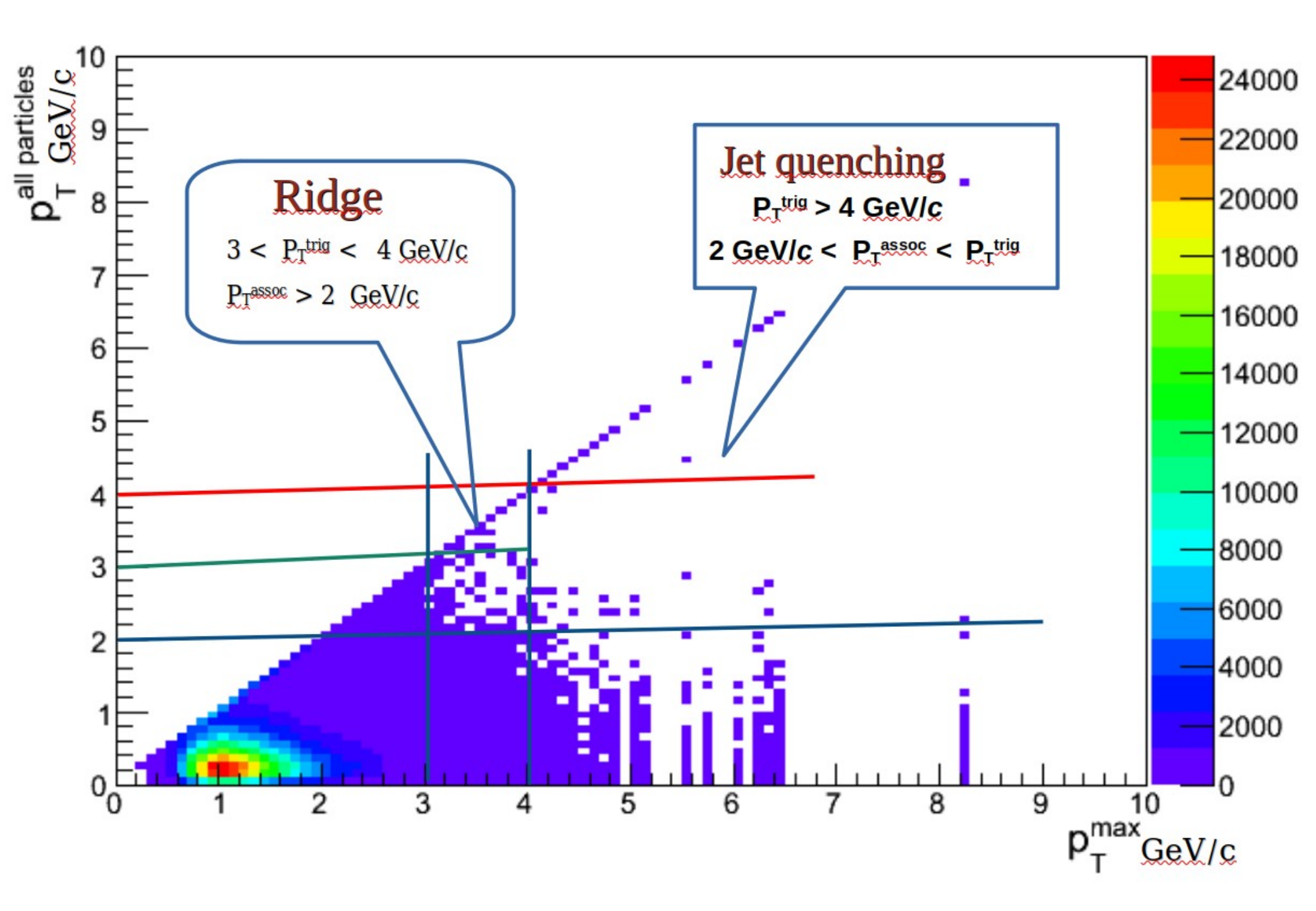
- Multiplicity
- Collision energy
- Colliding particles
- Produced particles

Universal events structure with p_T^{max}

Scale dependent analysis approach for STAR events. R.O. ICHEP 2006 v.2 p.443



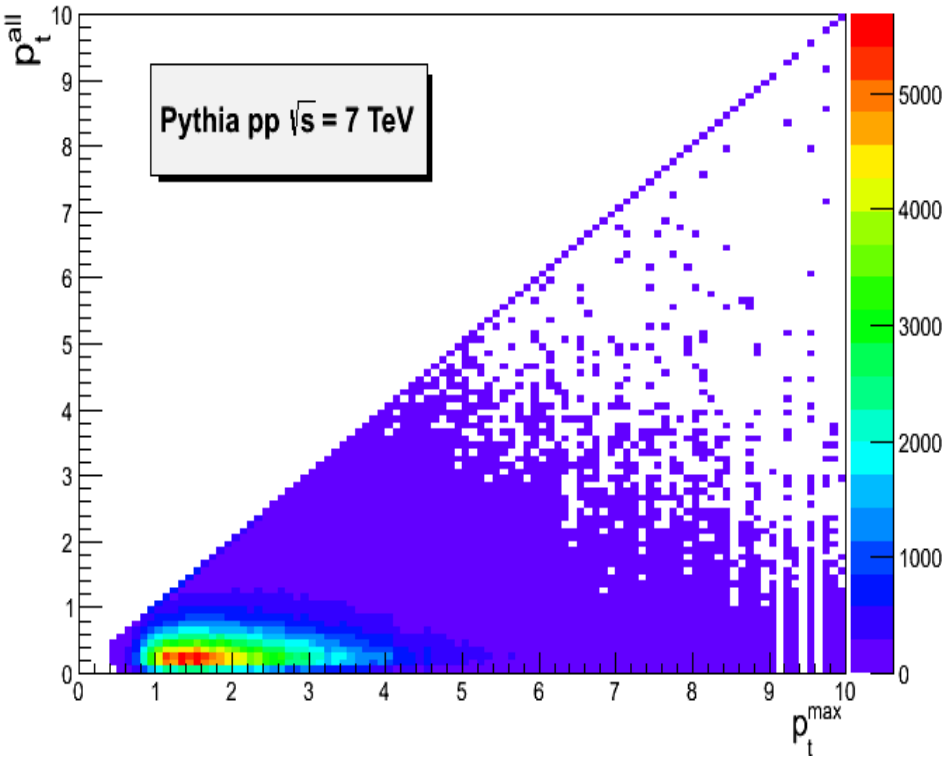



Ridge
3 < P_T^{trig} < 4 GeV/c
P_T^{assoc} > 2 GeV/c
Jet quenching
P_T^{trig} > 4 GeV/c
2 GeV/c < P_T^{assoc} < P_T^{trig}
$p_T^{all\ particles}$ GeV/c
p_T^{max} GeV/c
0
1
2
3
4
5
6
7
8
9
10
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
22000
24000

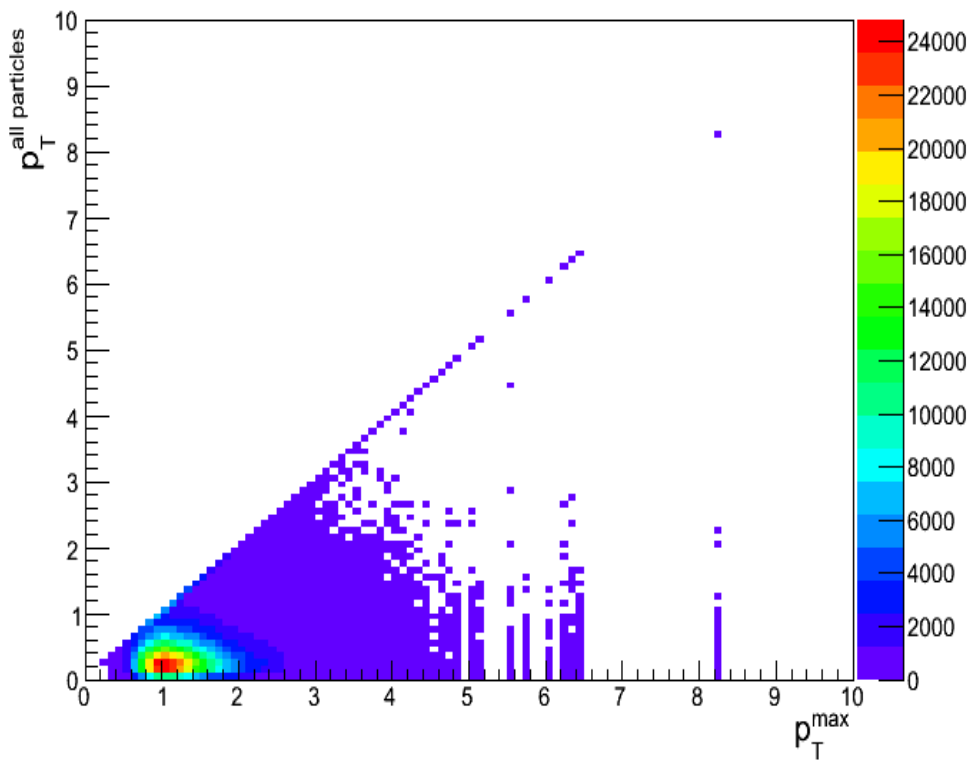
Structure @ high energy collisions

All charged particles

Pythia pp √s =7 TeV



STAR AuAu √s =200 GeV




Thanks
for your
attention