Properties of the matter created in heavy ion collisions results from the PHOBOS experiment at RHIC

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INSTITUTE OF NUCLEAR PHYSICS PAN

for the PHOBOS Collaboration

EPS - HEP 2009

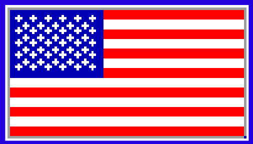
16-22 July 2009, Kraków, Poland

Outline

- The PHOBOS detector - a brief description
- Evidences for creation of a new state of nuclear matter
- Particle production in heavy ion collisions - recent results
  - correlations with a high p_T trigger particle
  - two particle correlations - particle production in clusters
- Predictions for LHC

PHOBOS Collaboration





Burak Alver, Birger Back, Mark Baker, Maarten Ballintijn, Donald Barton, Russell Betts, Richard Bindel, Wit Busza (Spokesperson), Vasundhara Chetluru, Edmundo García, Tomasz Gburek, Joshua Hamblen, Conor Henderson, David Hofman, Richard Hollis, Roman Hołyński, Burt Holzman, Aneta Iordanova, Chia Ming Kuo, Wei Li, Willis Lin, Constantin Loizides, Steven Manly, Alice Mignerey, Gerrit van Nieuwenhuizen, Rachid Nouicer, Andrzej Olszewski, Robert Pak, Corey Reed, Christof Roland, Gunther Roland, Joe Sagerer, Peter Steinberg, George Stephans, Andrei Sukhanov, Marguerite Belt Tonjes, Adam Trzupek, Sergei Vaurynovich, Robin Verdier, Gábor Veres, Peter Walters, Edward Wenger, Frank Wolfs, Barbara Wosiek, Krzysztof Woźniak, Bolek Wysłouch

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PHOBOS detector - trigger system & TOF

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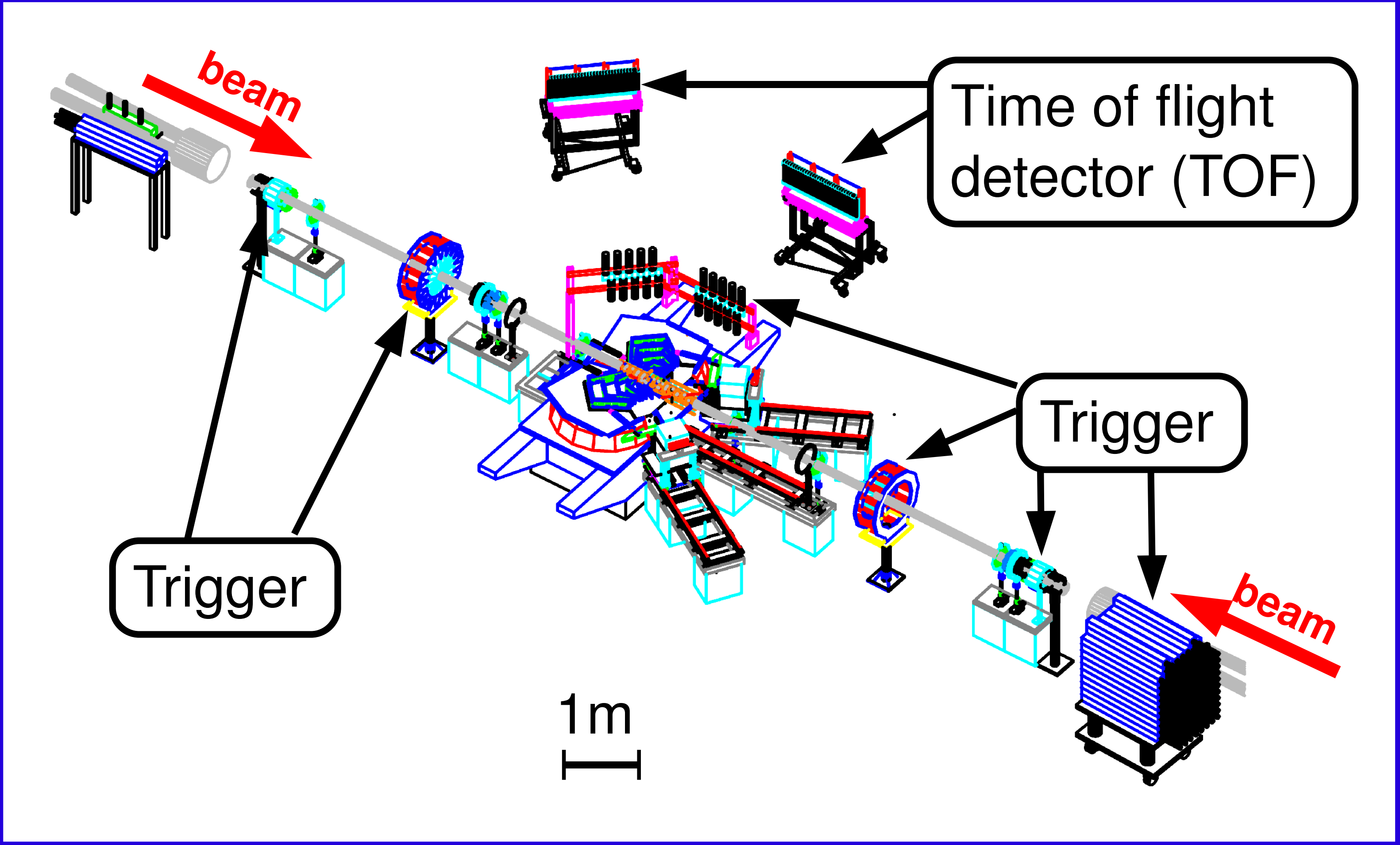
Properties of the matter created in heavy ion collisions ...

Trigger counter



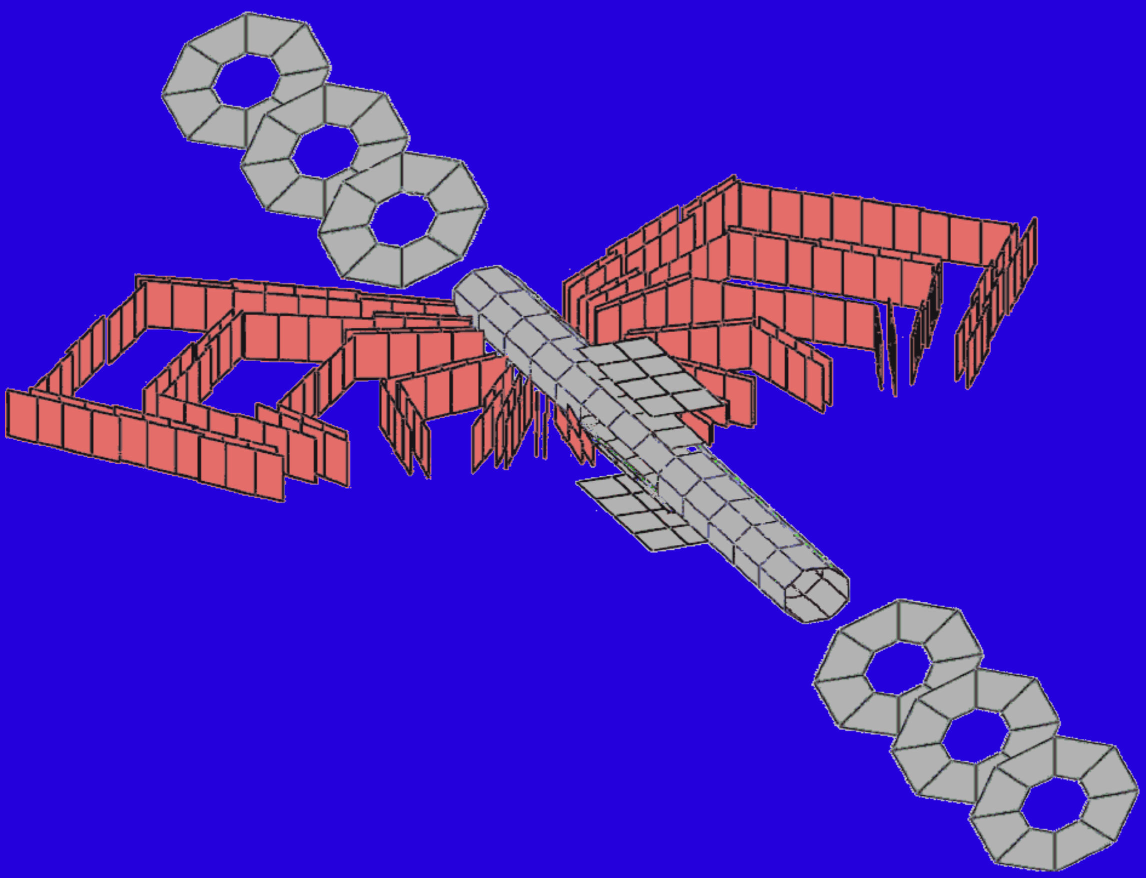
PHOBOS detector - spectrometer

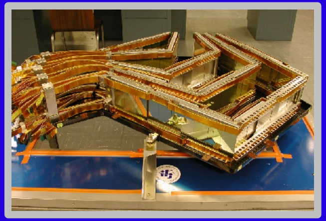
Spectrometer:

two arms
16 layers of silicon sensors
2 Tesla magnetic field

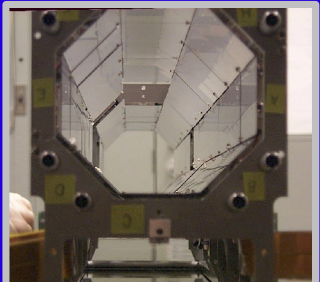
$0 < \eta < 2$

p_T from 30 MeV/c (reconstructed)





Spectrometer



Octagon

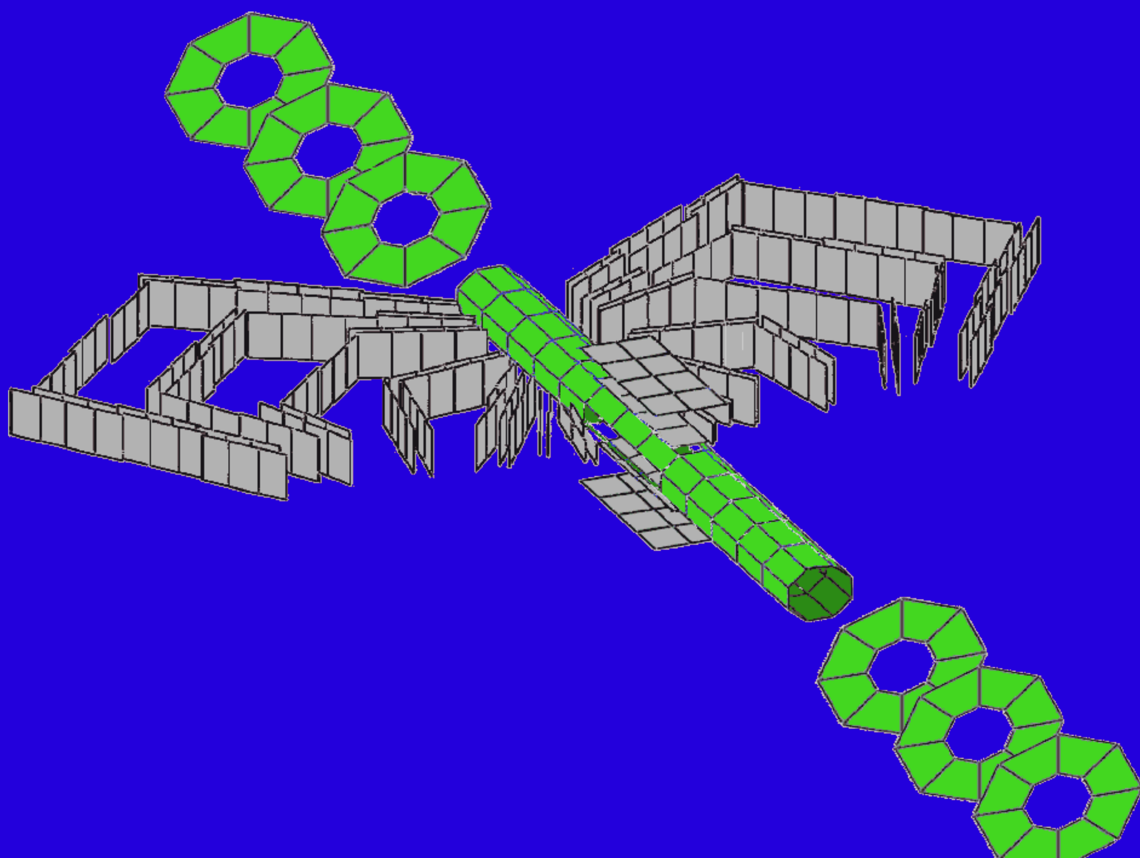
PHOBOS detector - multiplicity detector

Multiplicity detector:

octagon and 6 rings
single layer of silicon sensors
no magnetic field

$|\eta| < 5.4$

p_T from 7-35 MeV/c



Suppression of particles with high p_T

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Properties of the matter created in heavy ion collisions ...

PHOBOS Experiment

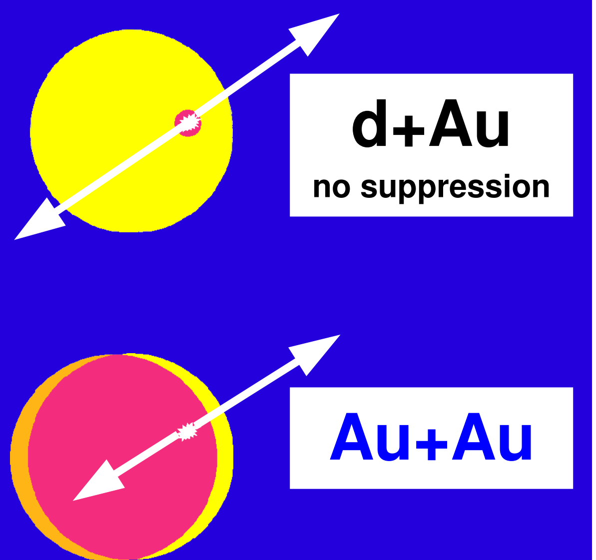
New state of matter

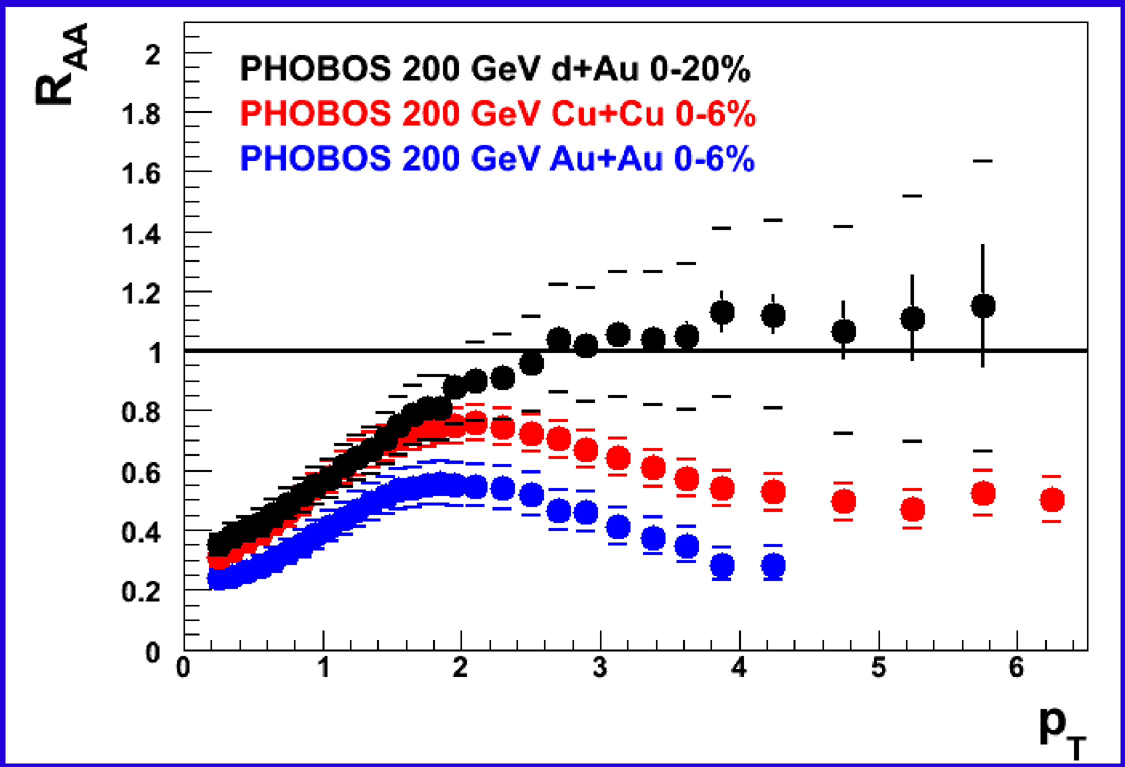
Recent results

Predictions for LHC

Production of particles with high transverse momentum is strongly suppressed in central Au+Au collisions.

This effect is caused by strong interactions of partons traversing the dense matter created in the A+A collisions.





PHOBOS
PRL **91** (2003) 072302
PRL **94** (2005) 082304
PRL **96** (2006) 212301

$$R_{AA} = \frac{\sigma^{inel}_{p\bar{p}}}{N_{coll}} \frac{d^2 N_{AA} / dp_T\, d\eta}{d^2 \sigma_{p\bar{p}} / dp_T\, d\eta}$$

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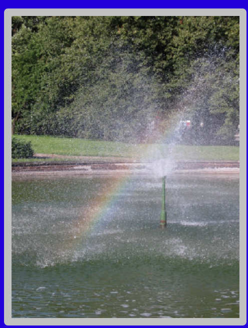
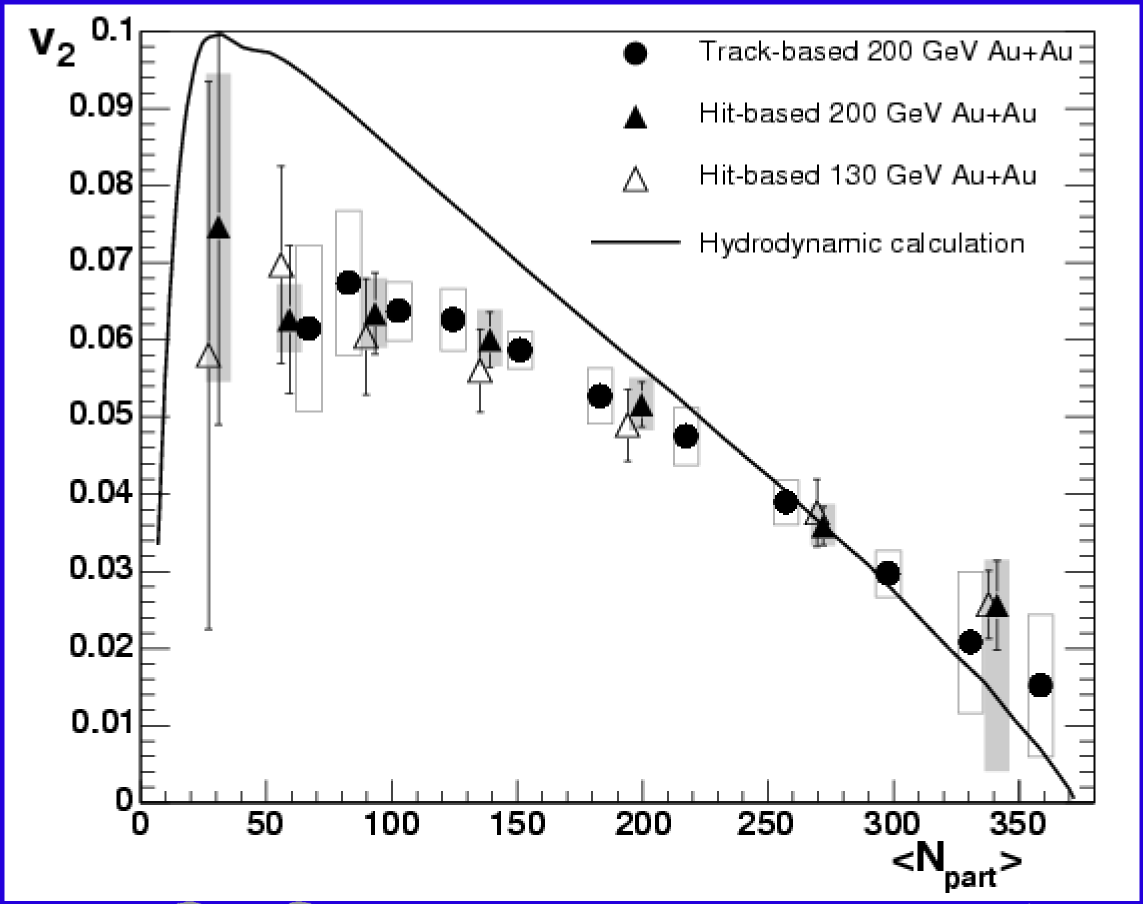
Large elliptic flow

Geometrical anisotropy of the interaction area is reflected in the momenta of produced particles.

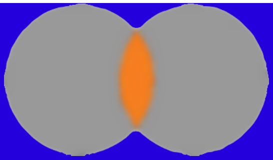
Elliptic flow is close to results of calculations in hydrodynamical models for a perfect fluid.

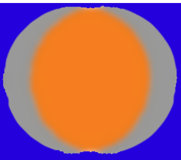


Flow



PHOBOS
PRL **98** (2007) 242302
PRC **72** (2005) 051901
PRL **94** (2005) 122303

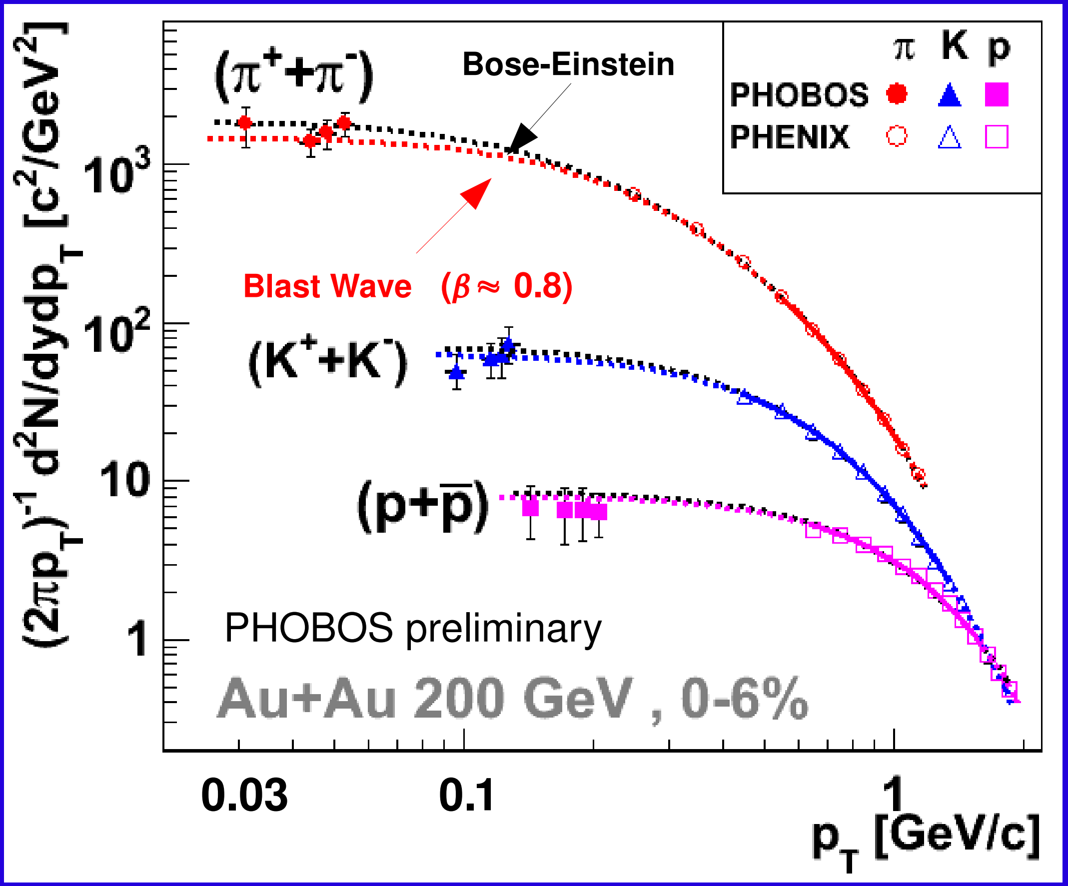




Very low p_T particles production

No anomalous enhancement in production of particles with very low p_T (expected for weakly interacting quark-gluon plasma).

Parameterization fitted at higher p_T and extrapolated to low p_T



PHOBOS
arXiv:0804.4270v1 [nucl-ex]

Correlations with a high p_T trigger particle

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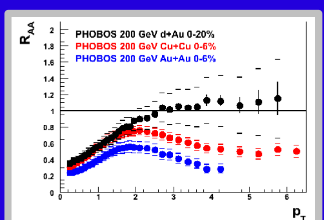
Properties of the matter created in heavy ion collisions ...



Question:

what happens to partons stopped in the dense matter in central Au+Au collisions

Trigger particle:

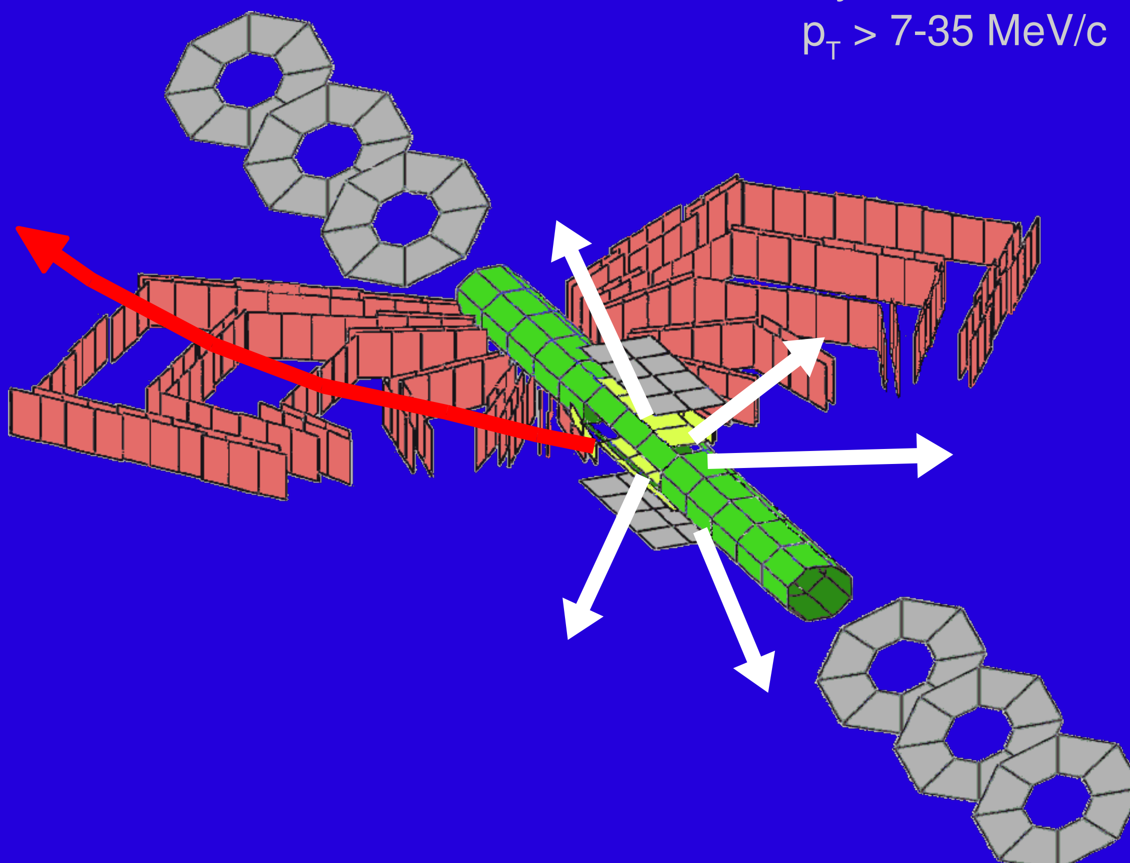
measured in spectrometer

p_T > 2.5 GeV/c

Other particles:

measured in a single layer of octagon, or first layer of vertex detetector or spectrometer

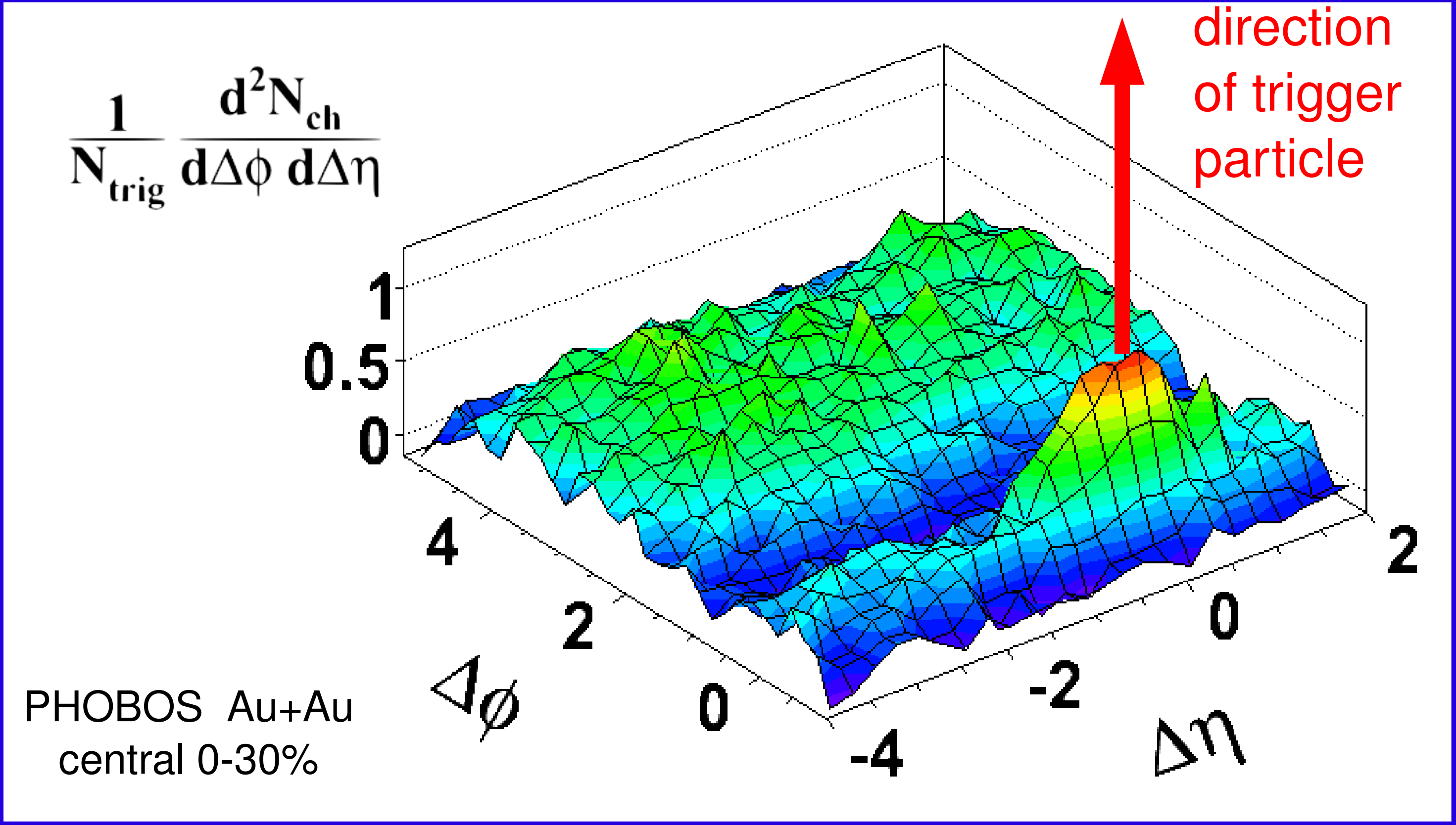
p_T > 7-35 MeV/c



Correlations with a high p_T trigger particle

PHOBOS Au+Au 200 GeV

p_T^{trig} > 2.5 GeV/c
p_T^{assoc} > 7 - 35 MeV/c ($\pi^{\pm}$)



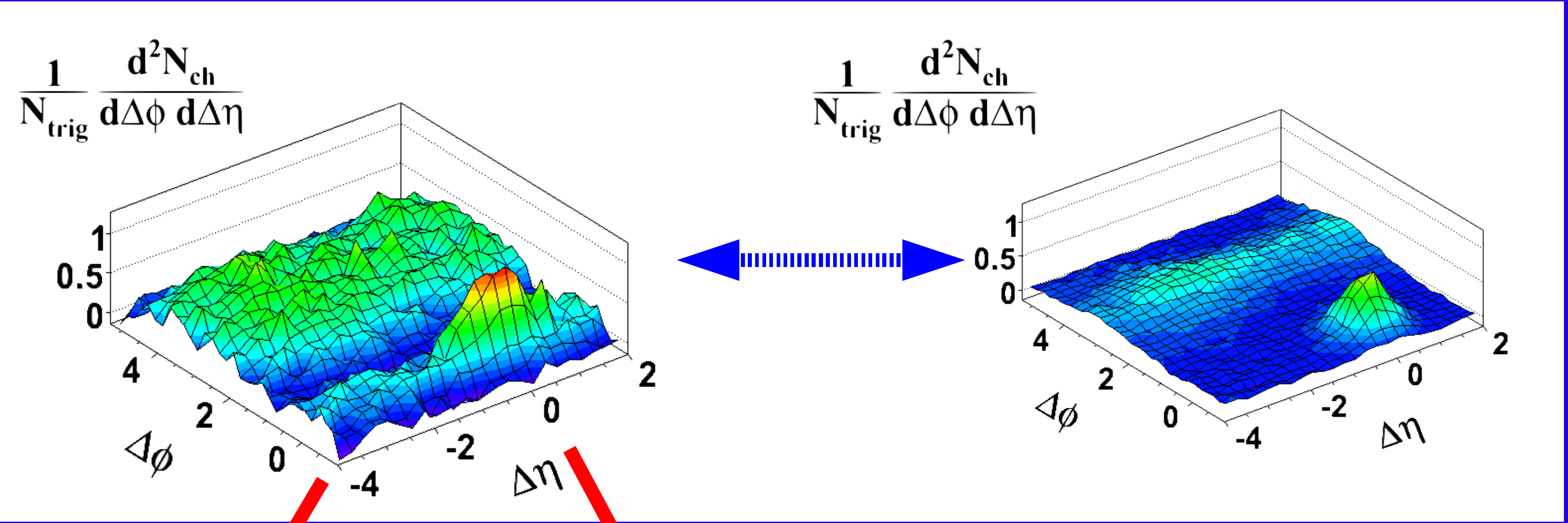
PHOBOS
arXiv: 0903.2311 [nucl-ex]

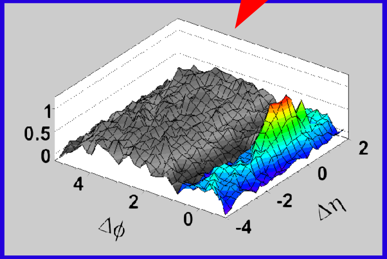
Correlations with a high p_T particle

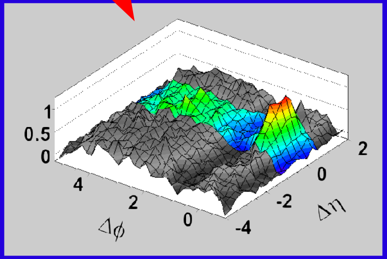
More quantitative analysis and comparisons

Au+Au (PHOBOS)

p+p (PYTHIA)







dependence on $\Delta\eta$

dependence on $\Delta\phi$

Near-side correlations with a high p_T particle

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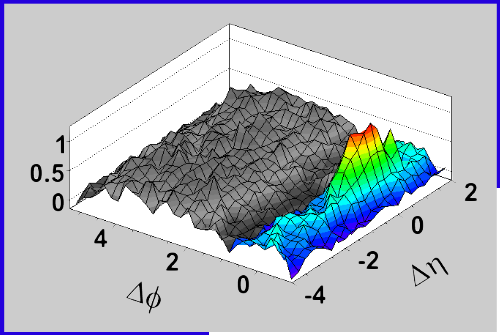
Properties of the matter created in heavy ion collisions ...

- PHOBOS Experiment
- New state of matter
- **Recent results**
- Predictions for LHC

Kraków
St Andrew's Church

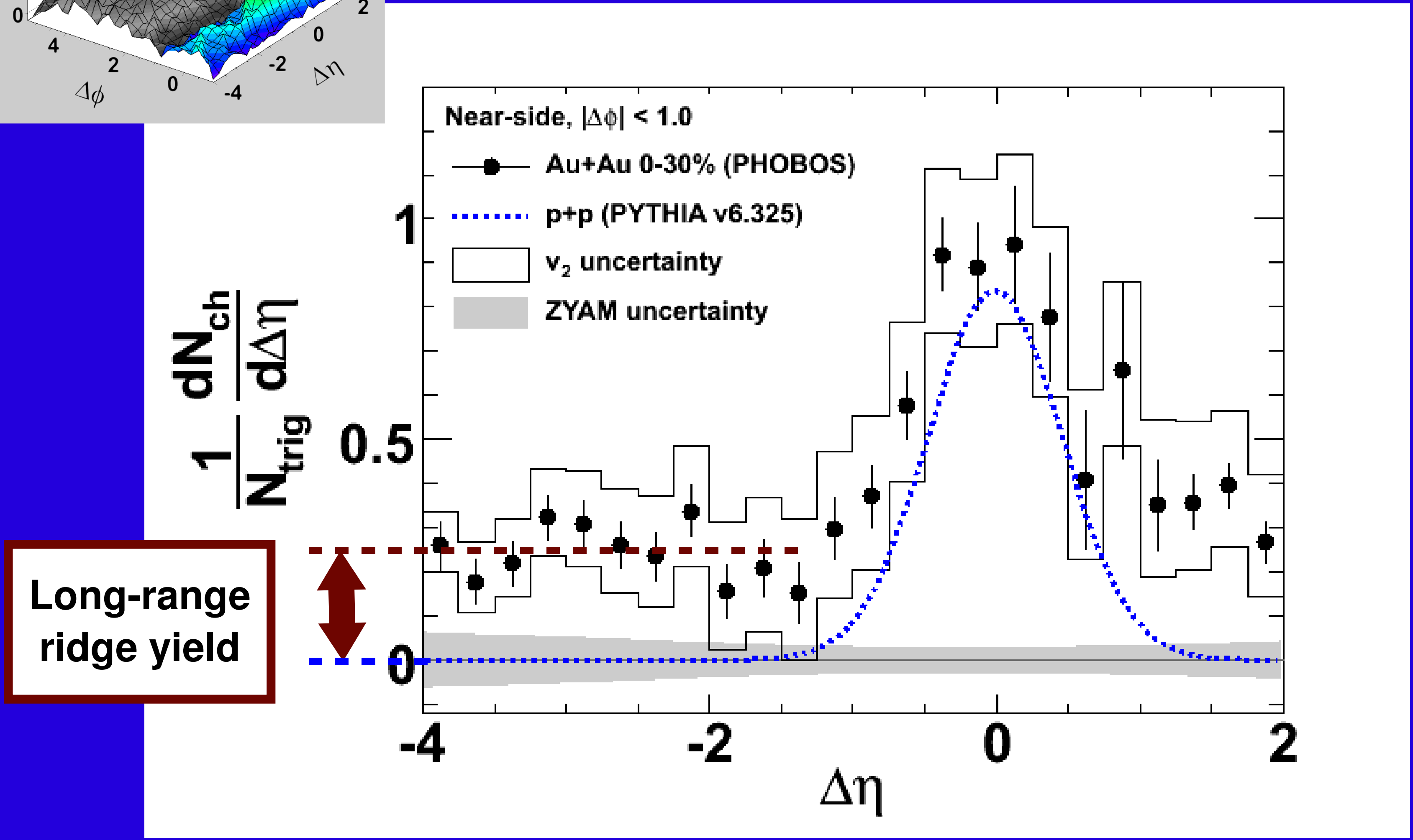
HEP 2009

Kraków, Poland



Near-side correlations, $\Delta\phi \approx 0^\circ$:

Au+Au @ 200 GeV, 0-30%



PHOBOS
arXiv: 0903.2311 [nucl-ex]

Near-side correlations with a high p_T particle

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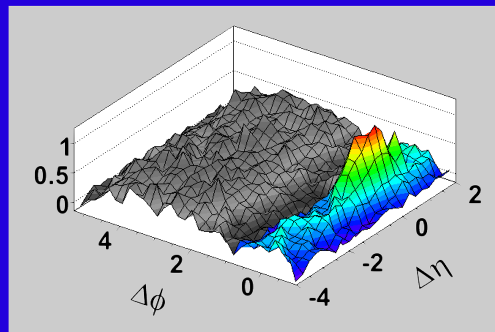
Properties of the matter created in heavy ion collisions ...



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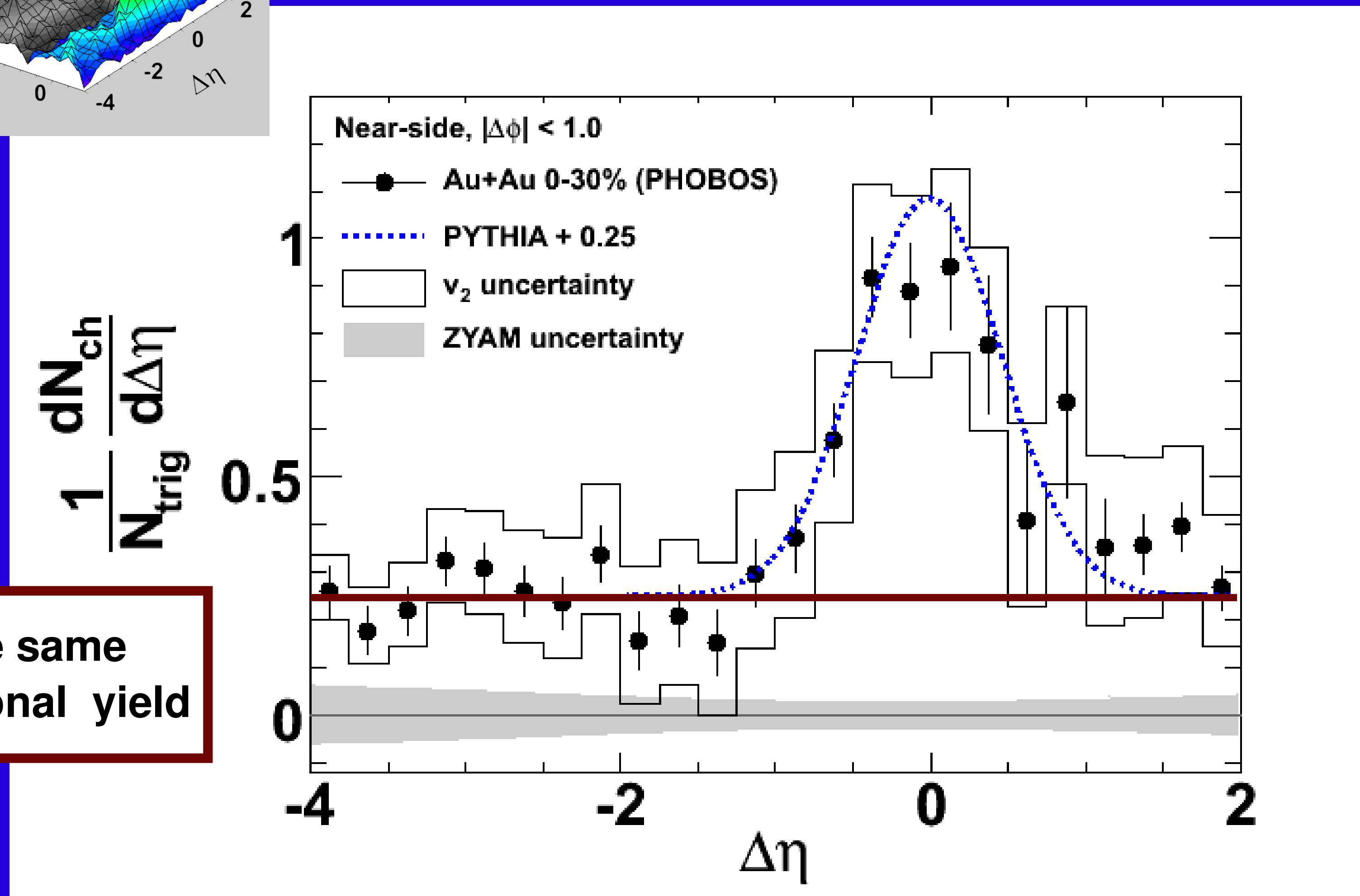

The same additional yield

PHOBOS
arXiv: 0903.2311 [nucl-ex]

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Properties of the matter created in heavy ion collisions ...

- PHOBOS Experiment
- New state of matter
- **Recent results**
- Predictions for LHC

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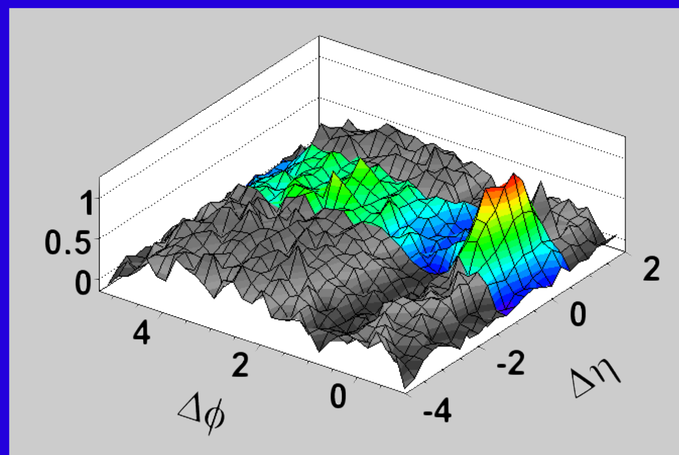
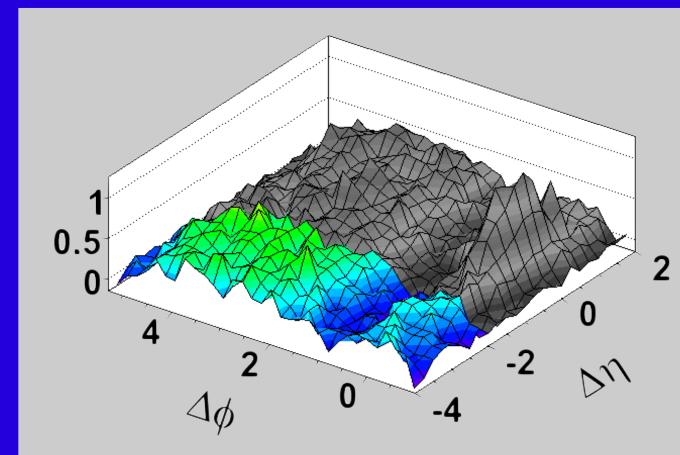
Correlations with a high p_T particle

Dependence on $\Delta\phi$ in selected $\Delta\eta$ ranges

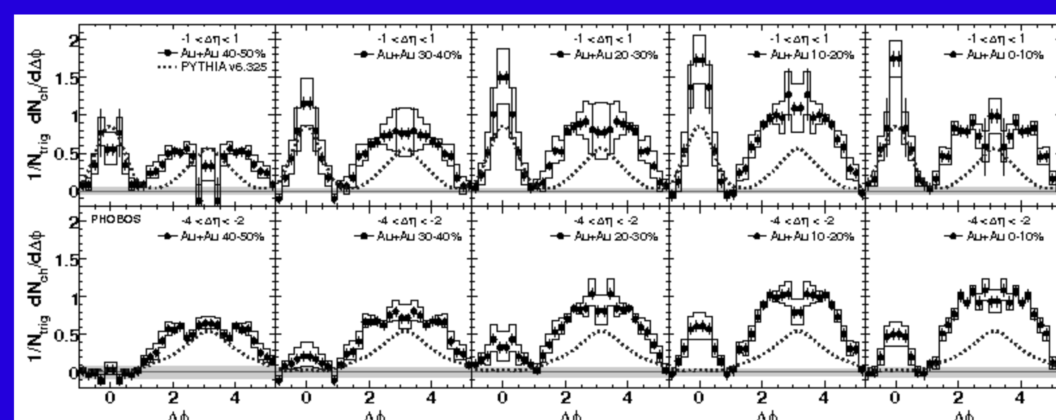
short range: $|\Delta\eta| < 1$



long range: $-4 < \Delta\eta < -2$



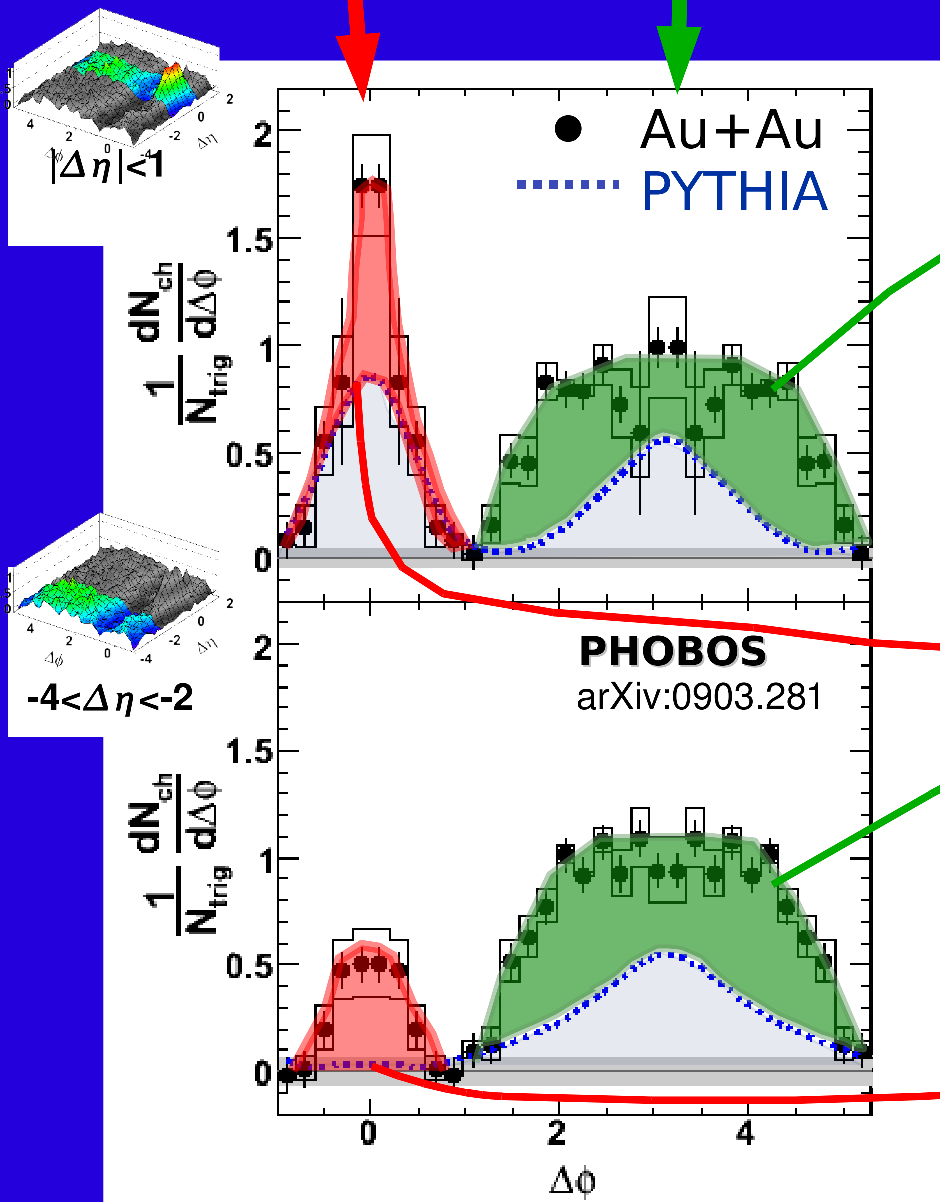
Centrality dependence

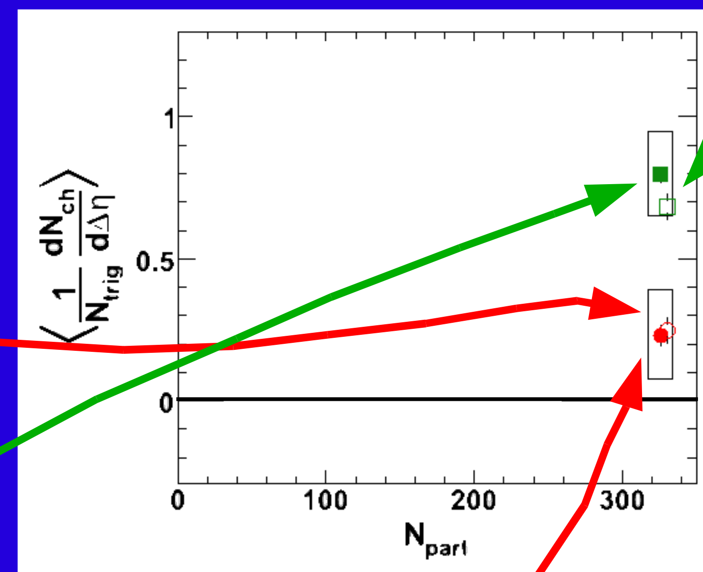


PHOBOS
arXiv: 0903.2311 [nucl-ex]

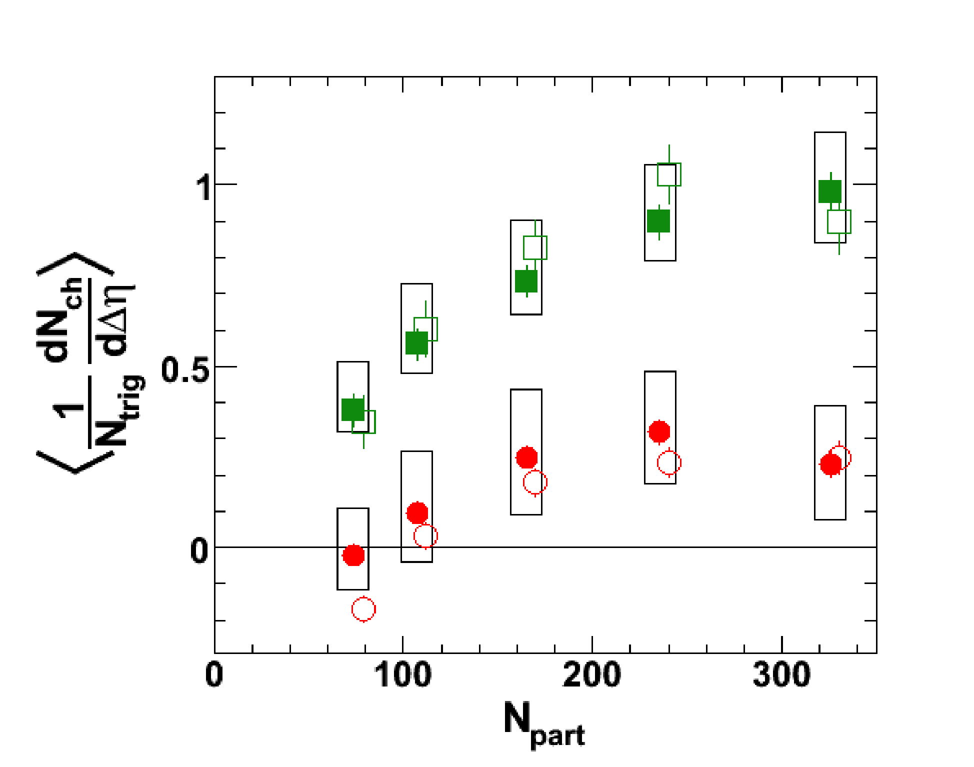
Correlations with a high p_T particle

Near-side and away-side $\Delta\phi$: subtraction of p+p yields





After subtraction of p+p yield ...



NEAR side: $\Delta\phi \approx 0^\circ$

- short-range minus PYTHIA
- long-range (PYTHIA≈0)

AWAY side: $\Delta\phi \approx 180^\circ$

- short-range
- long-range

both minus PYTHIA

The near side ridge extends to at least $|\Delta\eta| \approx 4$

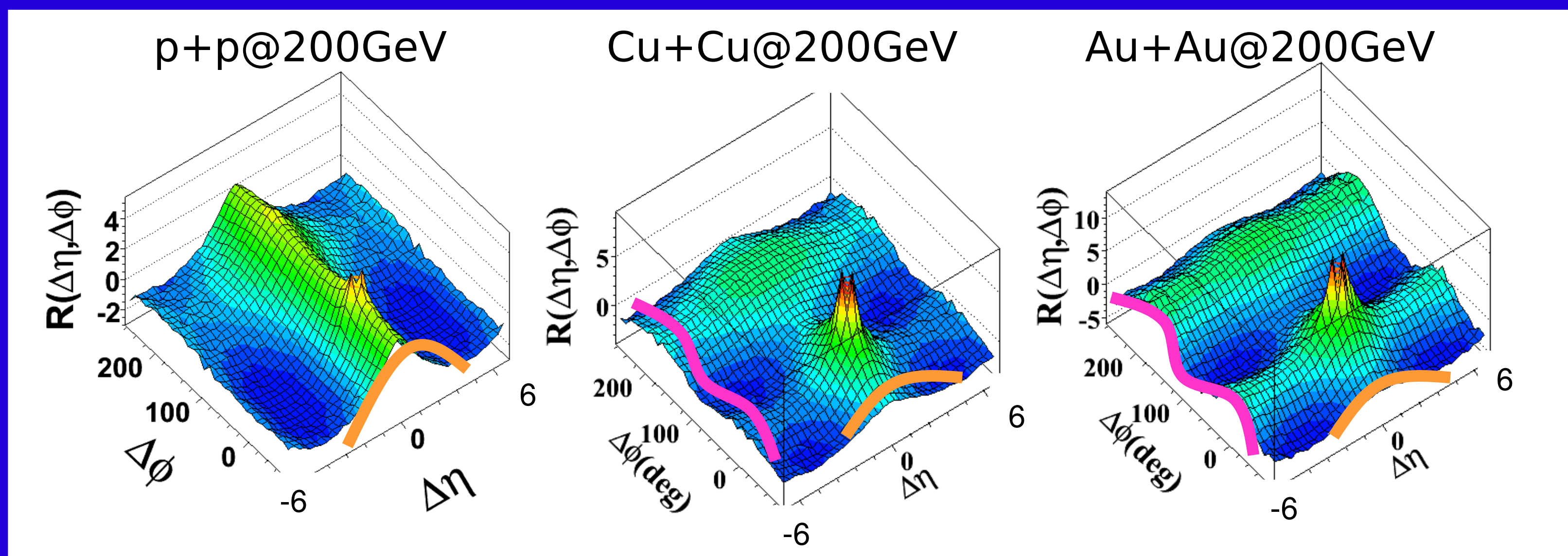
It disappears for peripheral Au+Au collisions at $N_{part} < 80$

The additional yield in Au+Au collisions (in excess of that in p+p) decreases for peripheral collisions

PHOBOS
arXiv: 0903.2311 [nucl-ex]

Two-particle correlations

Correlations measured as a function of $\Delta\phi$ and $\Delta\eta$ in the very wide pseudorapidity interval $|\eta| < 3$



PHOBOS
Phys. Rev. C75 (2007) 054913 (p+p)
arXiv: 0812.1172 [nucl-ex] (Cu+Cu, Au+Au)

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Properties of the matter created in heavy ion collisions ...

A cluster of lamps

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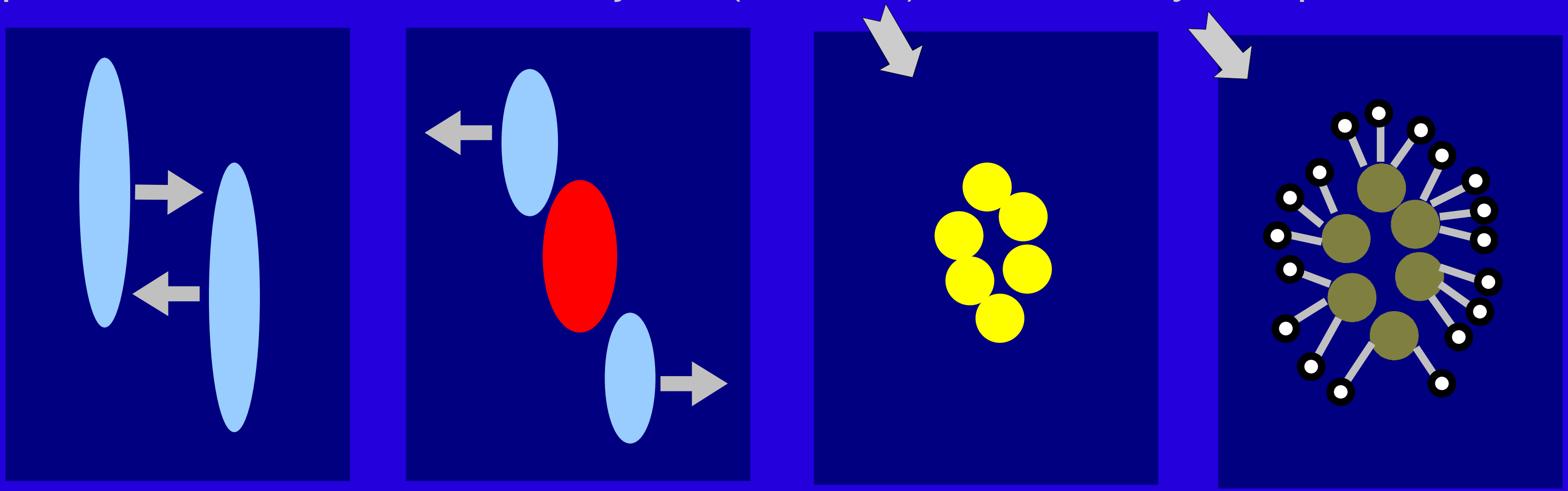
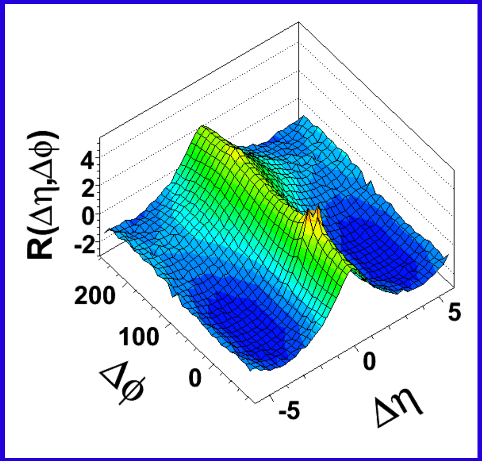
Cluster model & two-particle correlations

Possible explanation of correlations:

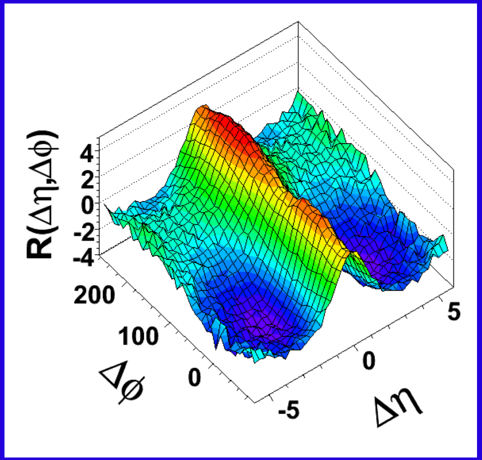
production of intermediate objects (clusters) which decay into particles



PHOBOS p+p@200GeV



Cluster model

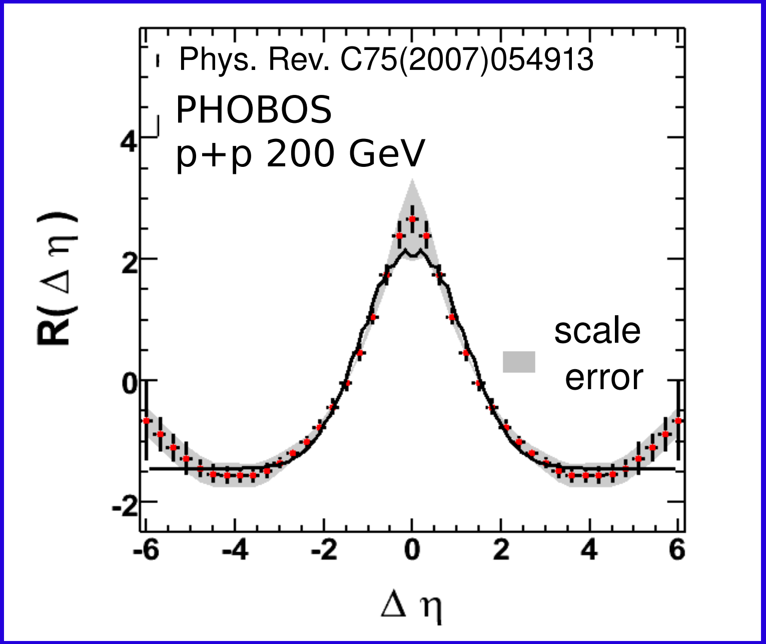


Two-particle correlations & cluster model

Cluster parameters can be extracted from the data using correlation function integrated over $\Delta\phi$

k_{eff} - efective cluster size

δ - RMS of the two particle distance in η characterizing cluster width



Parameters are obtained by fitting the function:

$$R(\Delta\eta) = (k_{eff} - 1)\left(\frac{G(\Delta\eta)}{B(\Delta\eta)} - 1\right)$$

where:

$$G(\Delta\eta) \simeq \exp\left(\frac{-(\Delta\eta)^2}{4\delta^2}\right)$$

$$B(\Delta\eta) \quad - \quad background$$

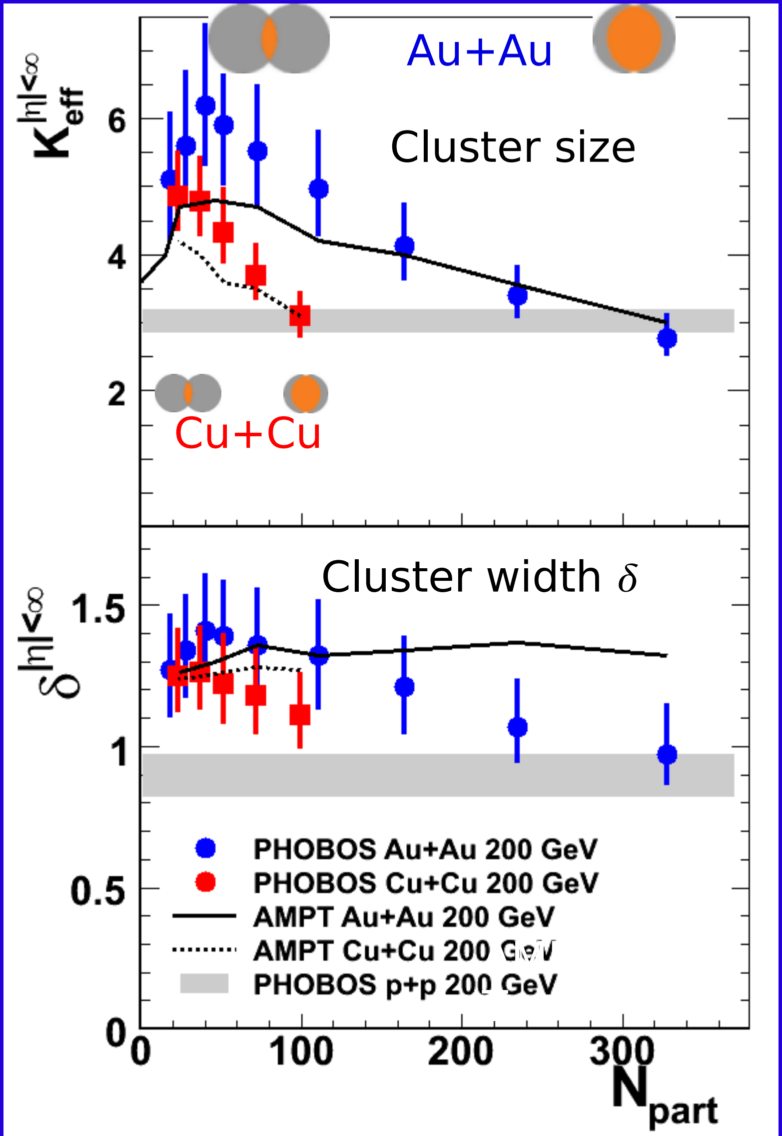
Note: even if particles from very wide range ($|\eta| < 3$) are used, acceptance corrections are large

Two-particle correlations & cluster model

Multiplicity of the clusters is large (up to 6 charged particles - more than for known resonances)

Cluster width exceeds that for isotropic decay at rest

Cluster parameters are similar for p+p and central Au+Au collisions, maximal difference is observed for semi-peripheral collisions



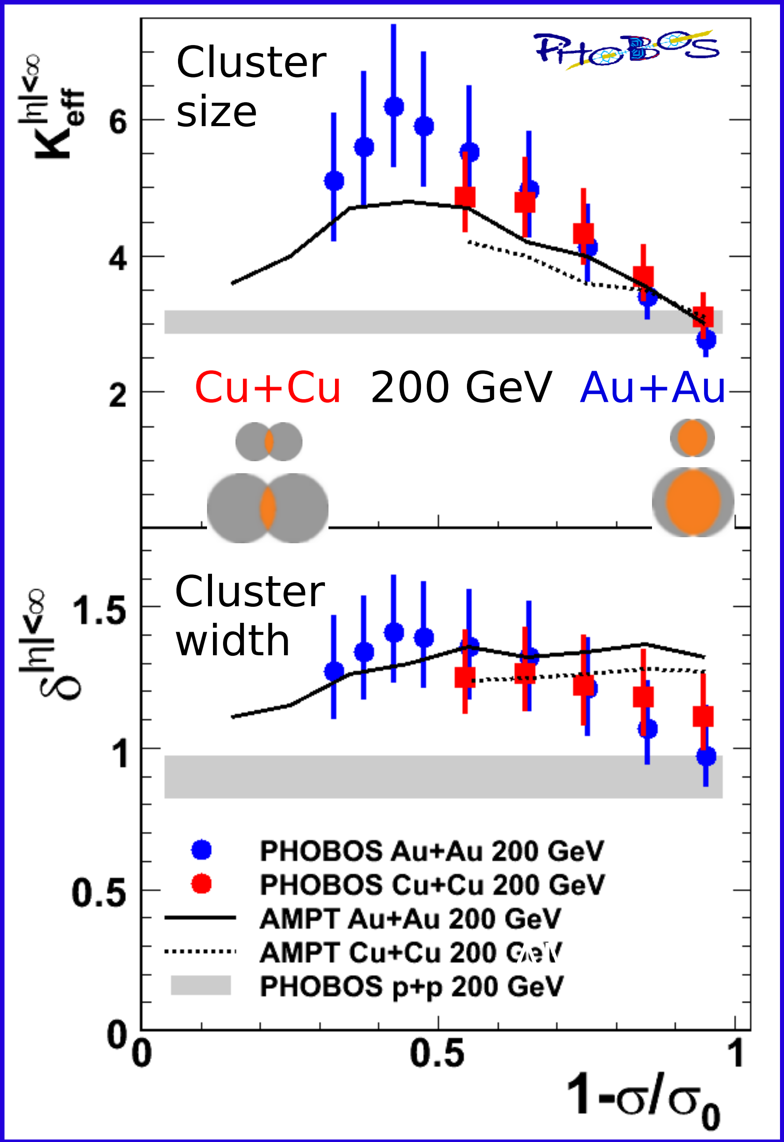
PHOBOS
Phys. Rev. C75 (2007) 054913 (p+p)
arXiv: 0812.1172 [nucl-ex] (Cu+Cu, Au+Au)
Peripheral Au+Au data - preliminary

Note: acceptance corrections were applied

Two-particle correlations & cluster model

Centrality expressed by the fractional cross-section allows to compare similar geometry of the collisions.

Cluster parameters scale with fractional cross-section

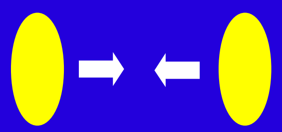


PHOBOS
Phys. Rev. C75 (2007) 054913 (p+p)
arXiv: 0812.1172 [nucl-ex] (Cu+Cu, Au+Au)
Peripheral Au+Au data - preliminary

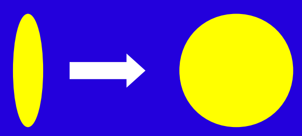
Note: acceptance corrections were applied

Extrapolations to LHC energies

In the collider experiments the laboratory frame coincides with the center of mass of the nuclei. In this frame energy dependence of many observables is complicated .



Alternatively, the rest frame of one of the nuclei involved in the collision may be used.

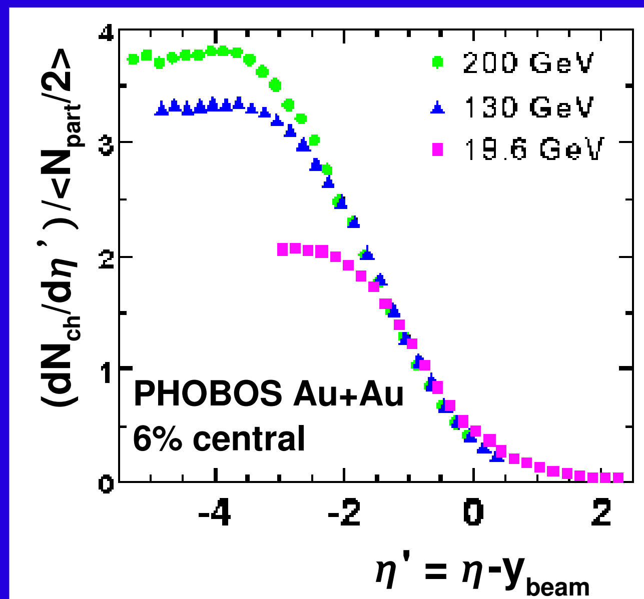


After transformation to the rest frame of one of the nuclei, the **“extended longitudinal scaling”** of pseudorapidity distributions of **charged particles density dN/dη** and the **elliptic flow** are observed.

CERN

Extrapolations to LHC energies: dN/dη

PHOBOS data 19.6-200 GeV
PRL 91 (2003) 052303



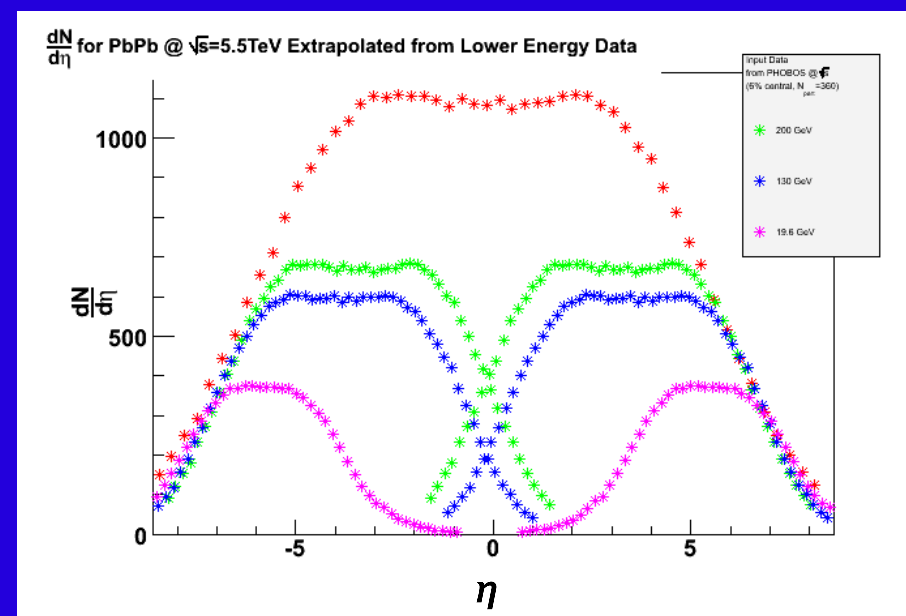
Transformation to the rest frame of one of the nuclei:

$y' = y - y_{beam}$

and, approximately:

$\eta' = \eta - y_{beam}$

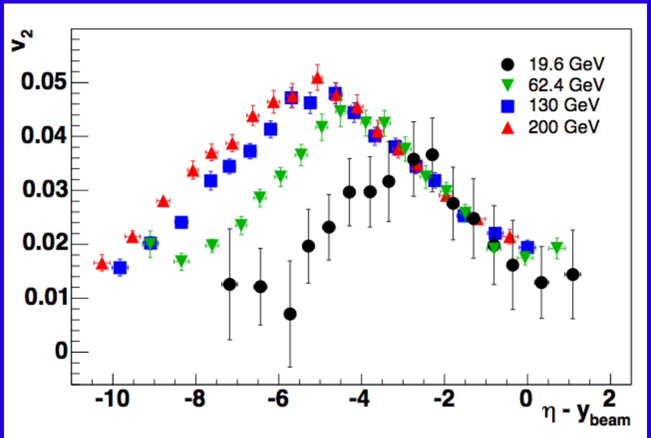
Extrapolation of PHOBOS data based on extended longitudinal scaling allows to obtain prediction for **dN/dη** at 5.5 TeV



W. Busza, J. Phys. G 35 (2008) 044040

Extrapolations to LHC energies: elliptic flow

PHOBOS data 19.6-200 GeV
PRL 91 (2003) 052303



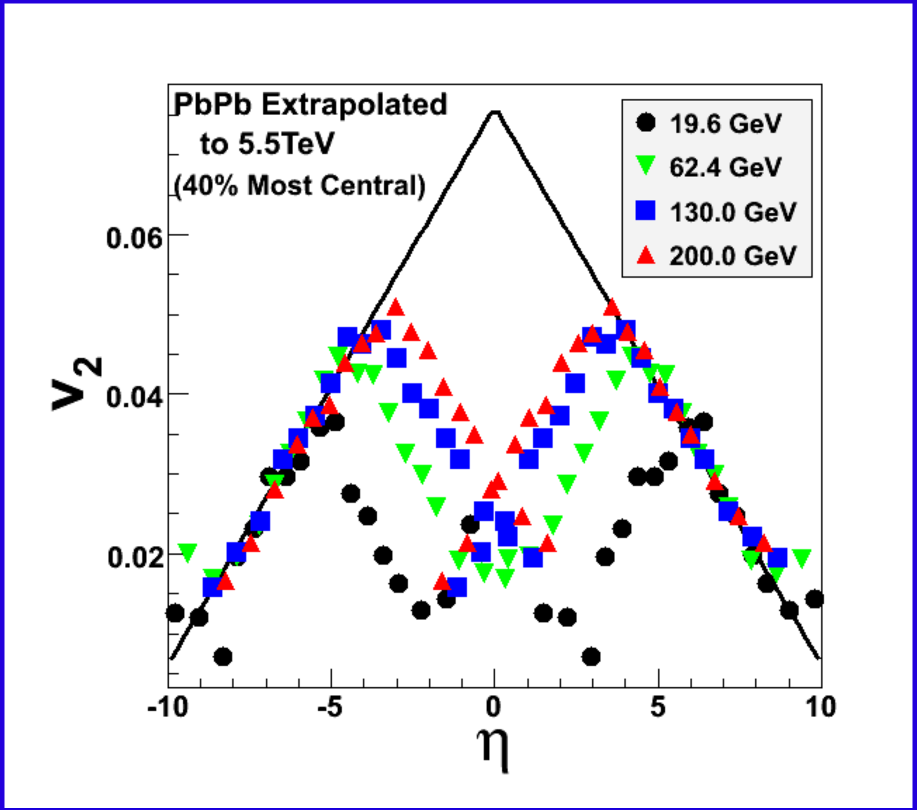
Similar extrapolation of v_2 measured by PHOBOS gives predictions for **elliptic flow** distribution at 5.5 TeV

Transformation to the rest frame of one of the nuclei:

$y' = y - y_{beam}$

and, approximately:

$\eta' = \eta - y_{beam}$



W. Busza, J. Phys. G 35 (2008) 044040

Summary

- PHOBOS experiment contributed to the discovery of the new phase of nuclear matter (sQGP) and studied its properties using unique features of the detector: very large angular acceptance and reconstruction of low p_T particles.

- Recent analysis of particle production reveals strong long-range correlations with a high p_T trigger particle and emission of particles in large clusters

- Extended longitudinal scaling (limiting fragmentation) allows to give reliable predictions for heavy ion collisions at LHC

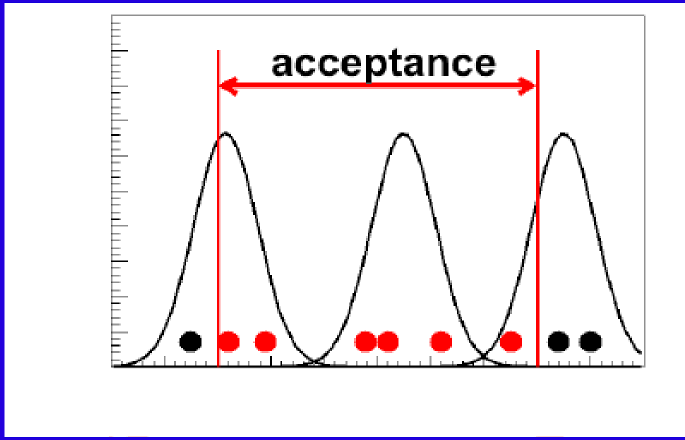
Welcome to Kraków

Krzysztof Woźniak

Properties
of the matter
created in heavy
ion collisions ...

Two-particle correlations & cluster model

Importance of acceptance corrections



Uncorrected results for the same events analyzed in different η ranges