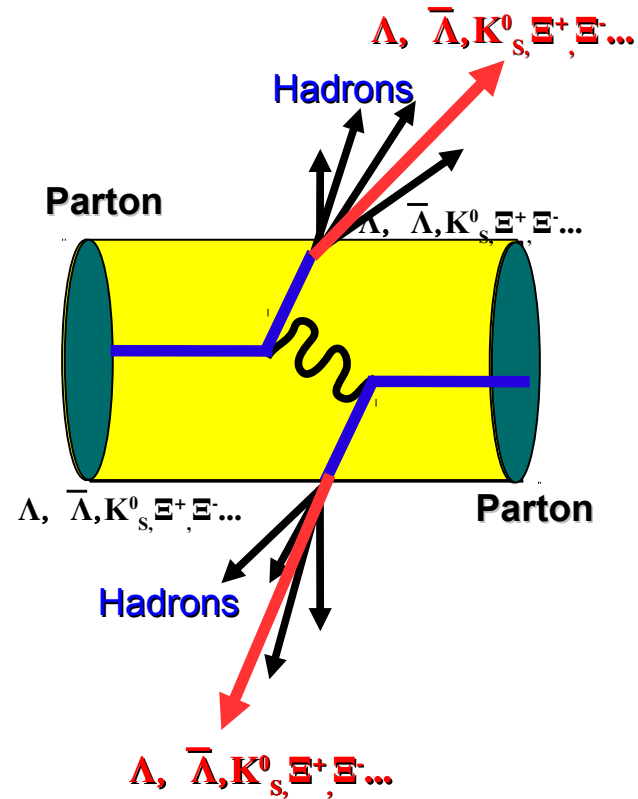


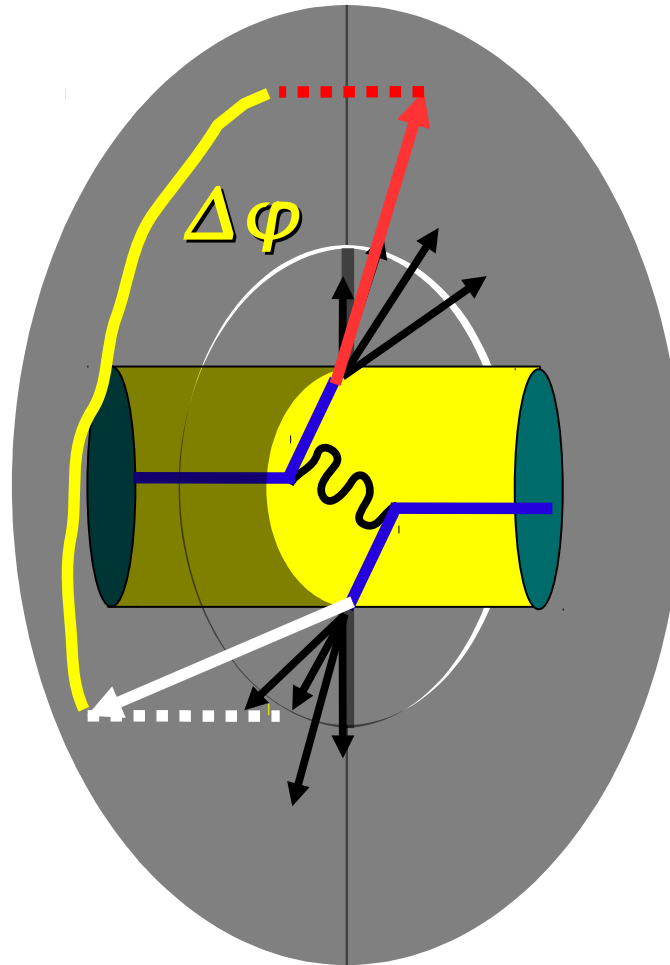


Christine Nattrass
University of Tennessee at Knoxville

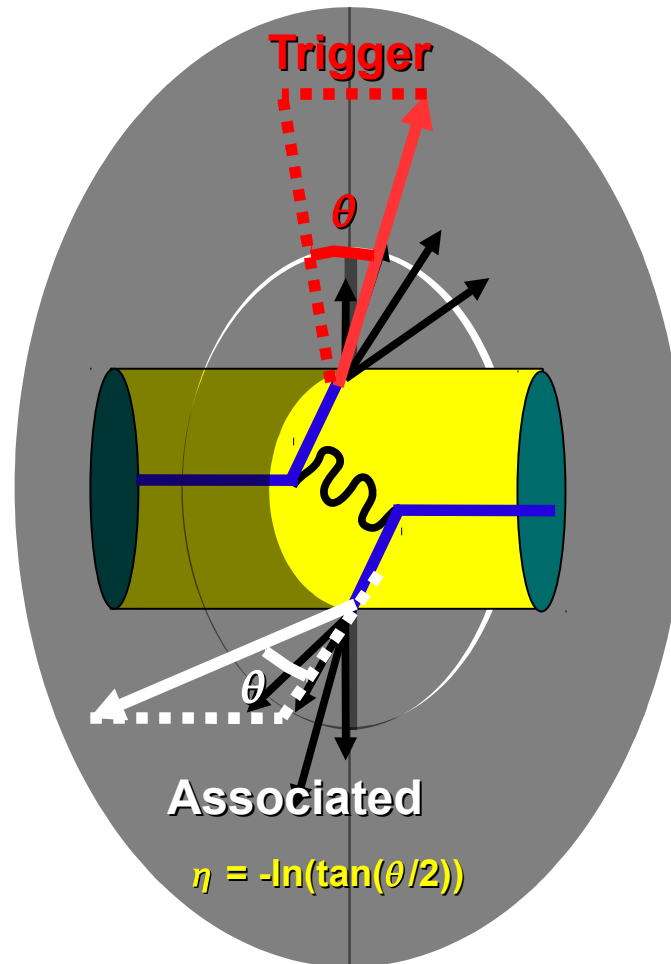
Di-hadron correlations



Di-hadron correlations



Di-hadron correlations



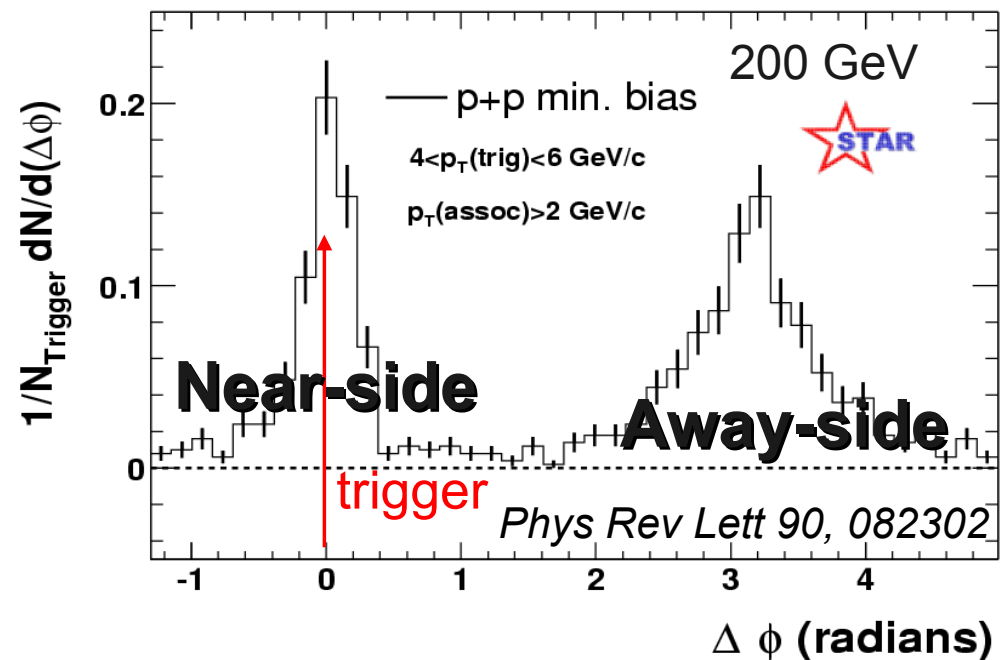
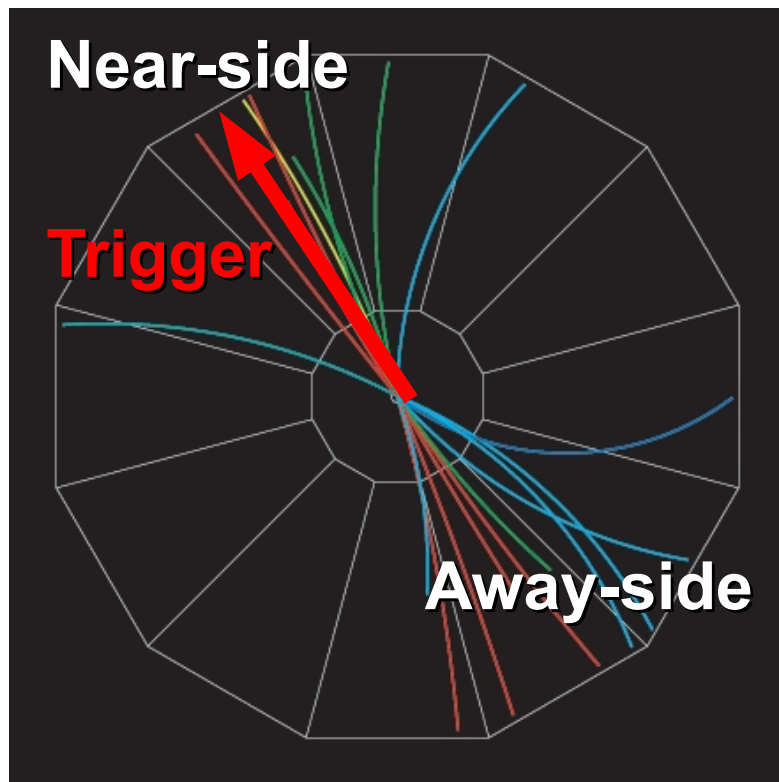
Jets – azimuthal correlations

At RHIC energies, jets are dominantly produced as di-jets

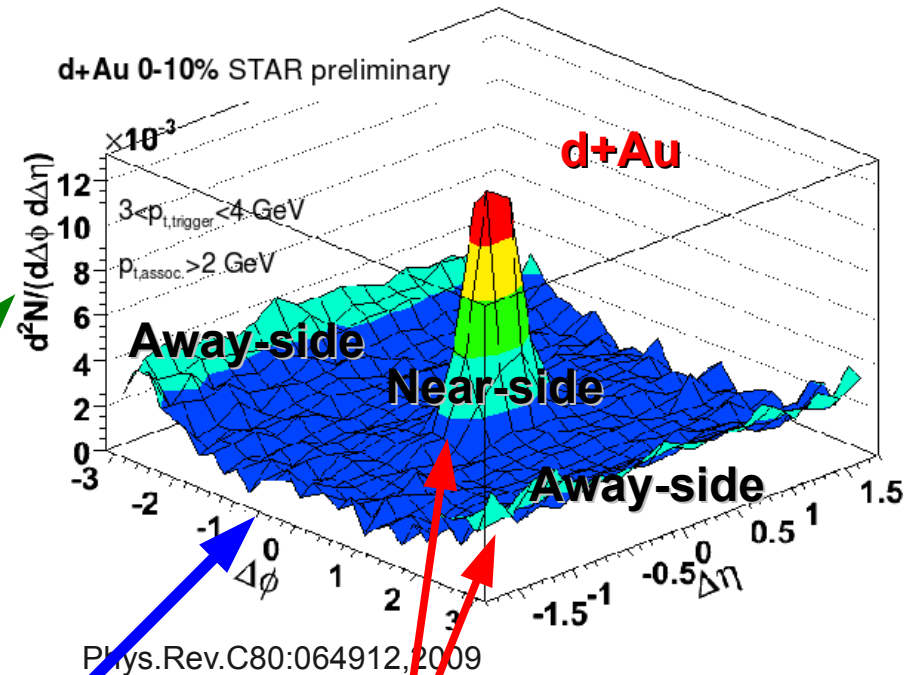
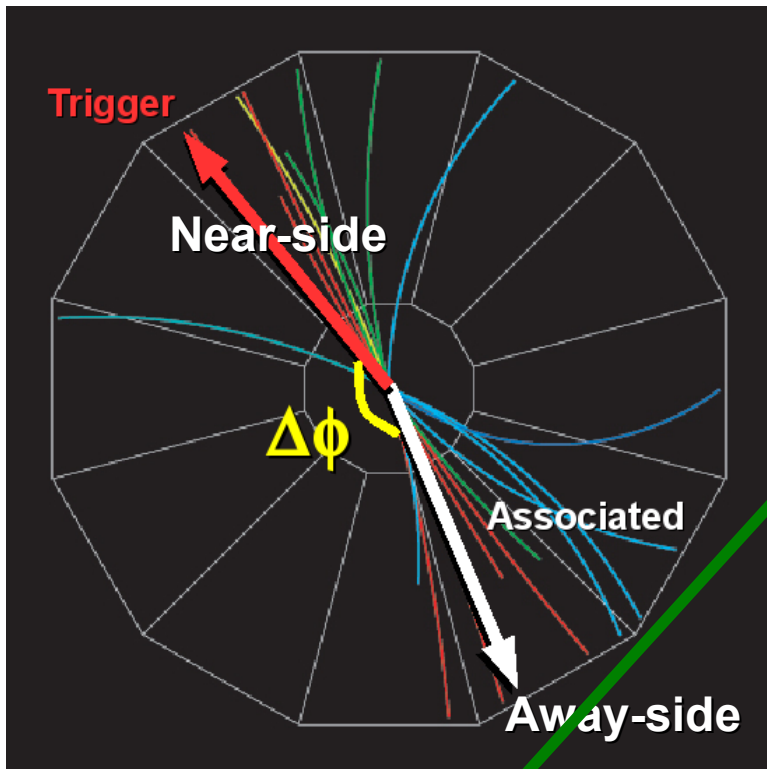
Assume that a high- p_T trigger particle comes from a jet

Look at distribution of high- p_T associated particles relative to trigger

p+p → dijet



$d+Au$

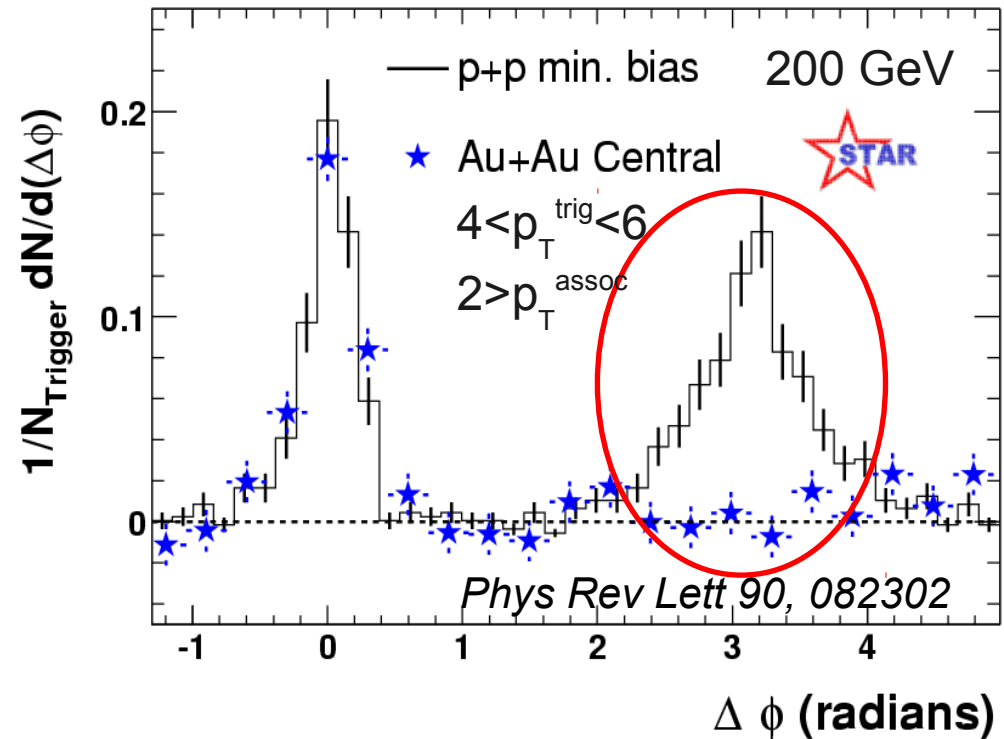
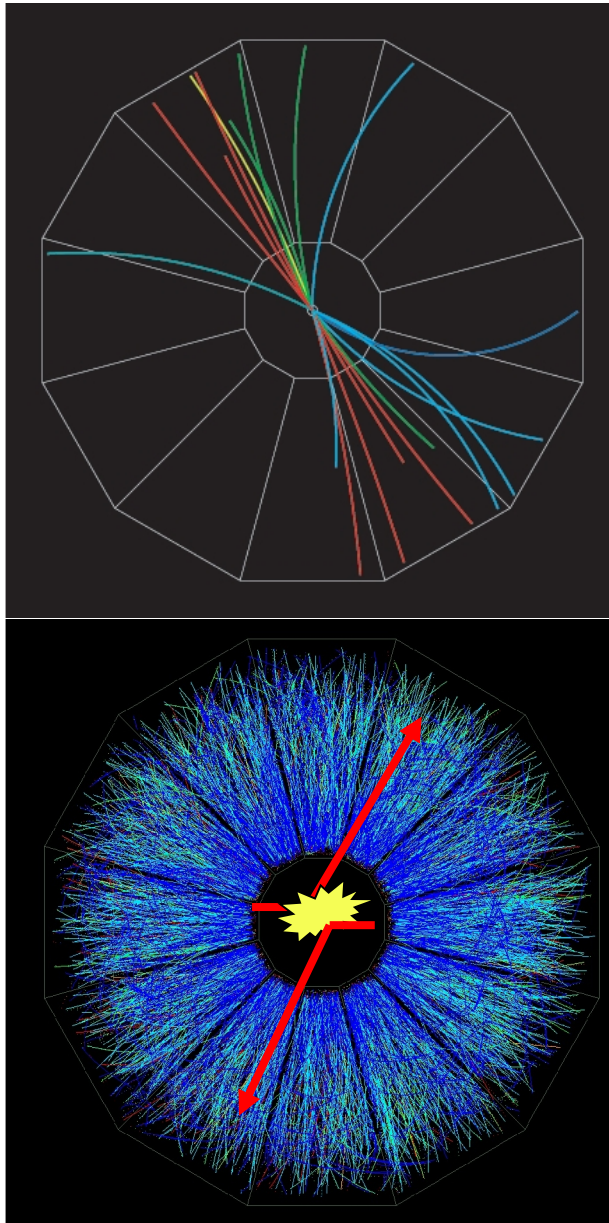


Combinatorial background

Jets/mini-jets
Multi-parton interactions

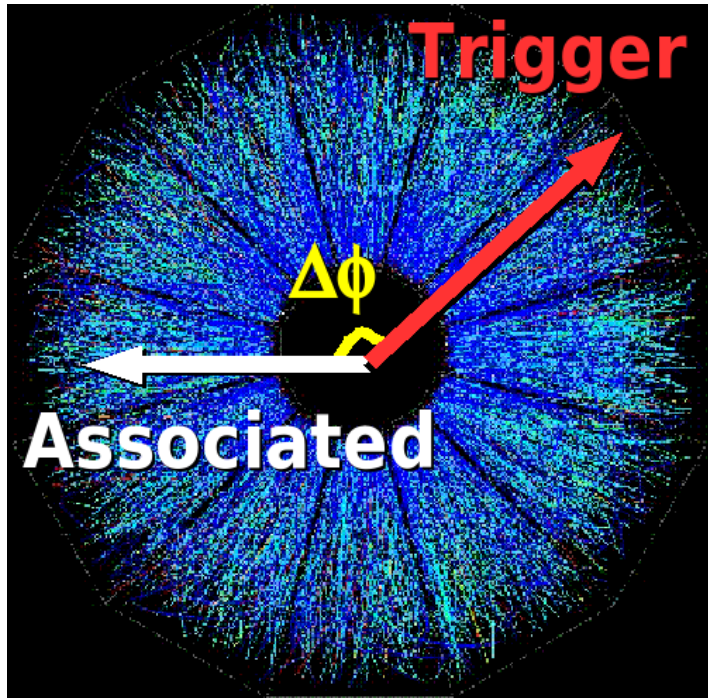
Normalization different in different measurements, may have different offset

Jets – azimuthal correlations

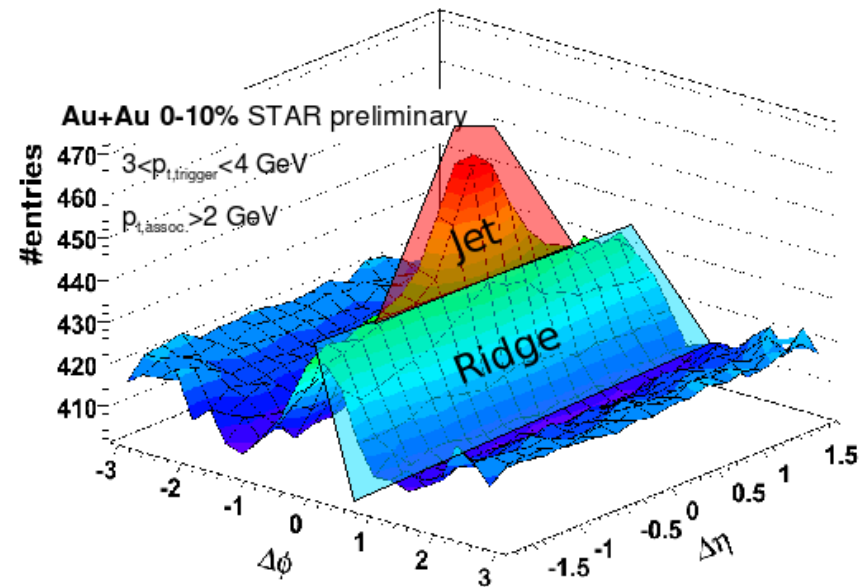


The away-side jet is quenched in Au+Au collisions

In two dimensions in Au+Au



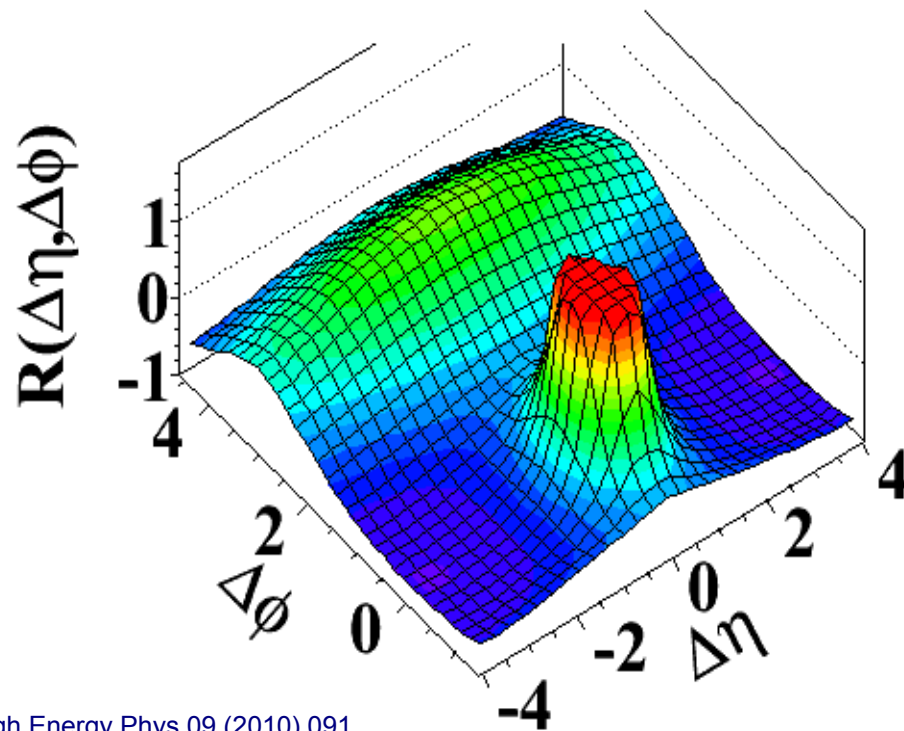
nucl-ex/0701074



CMS results: $p+p$ collisions at $\sqrt{s}=7$ TeV

Minimum Bias
no cut on multiplicity

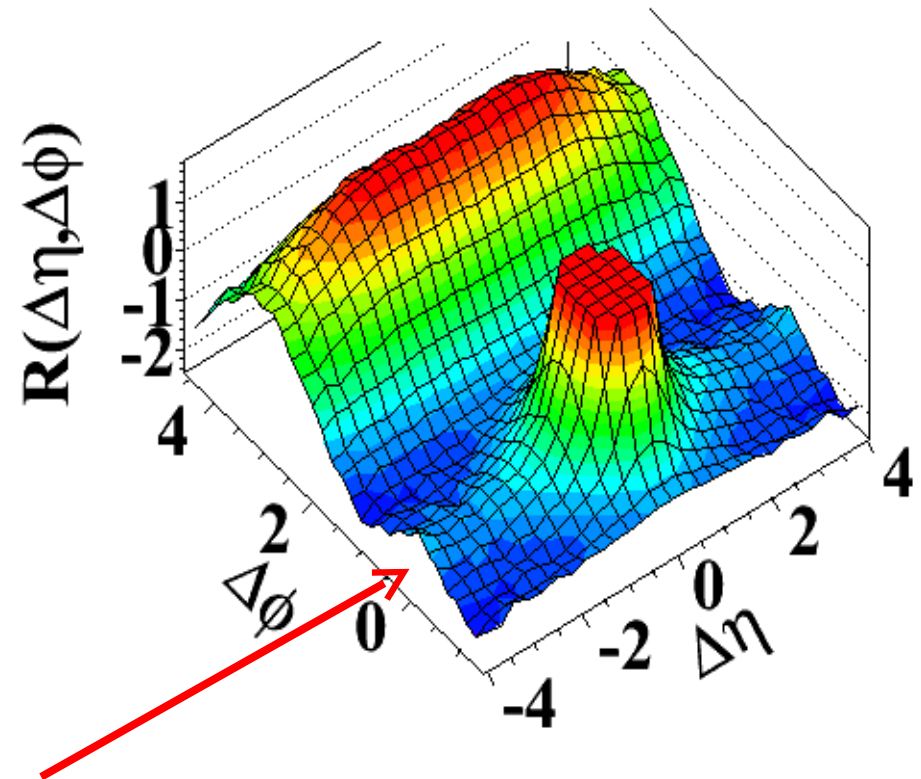
(b) MinBias, $1.0\text{GeV}/c < p_T < 3.0\text{GeV}/c$



J. High Energy Phys.09 (2010) 091

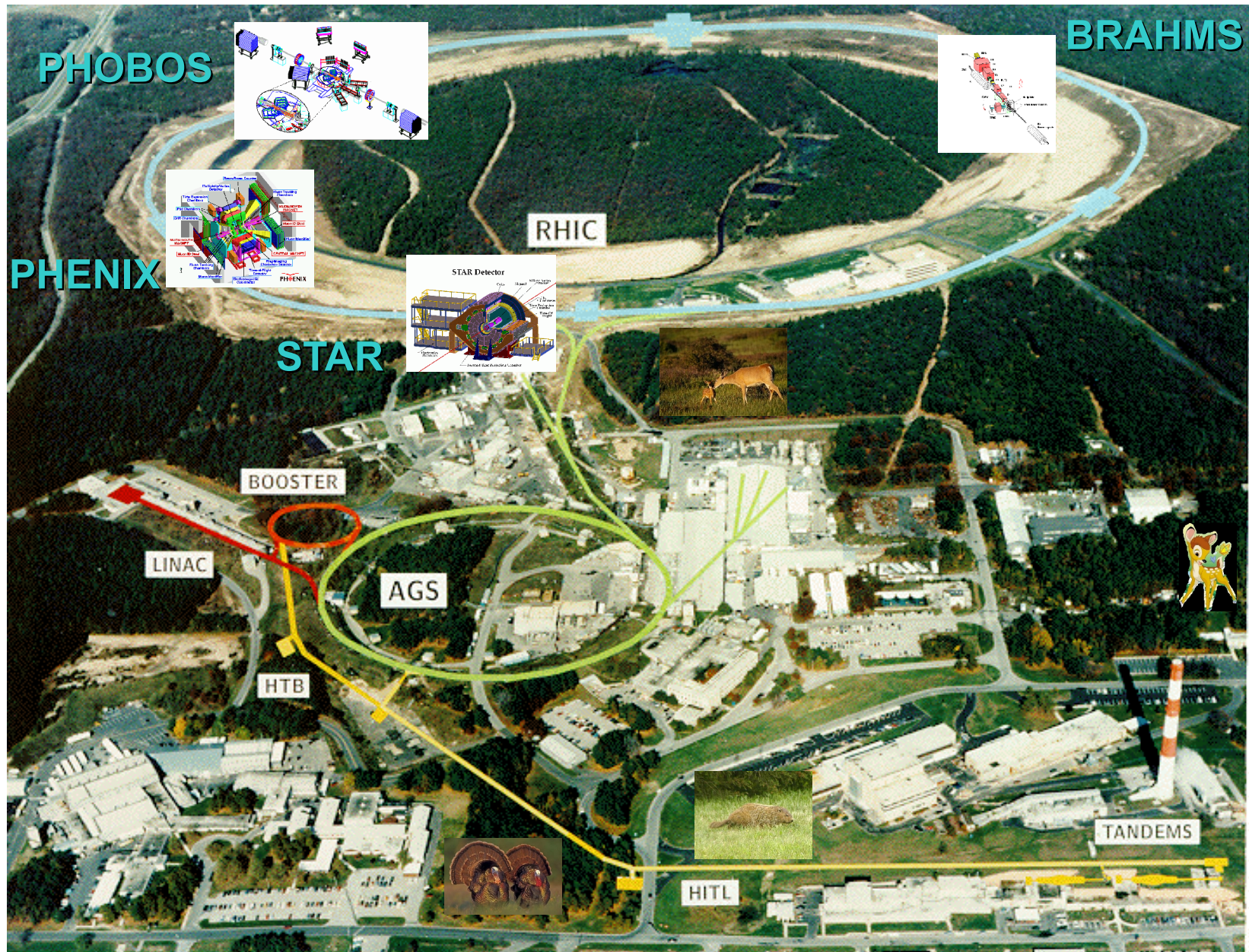
High multiplicity data set
and $N > 110$

(d) $N > 110$, $1.0\text{GeV}/c < p_T < 3.0\text{GeV}/c$



New “ridge-like” structure extending to large $\Delta\eta$ at $\Delta\phi \sim 0$

Relativistic Heavy Ion Collider



PHOBOS

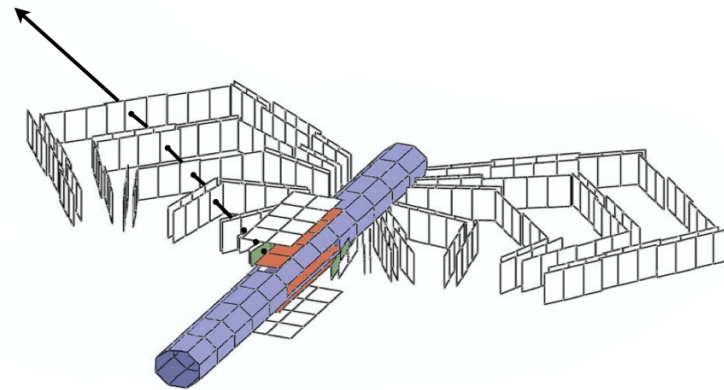
- Coverage:

With tracking:

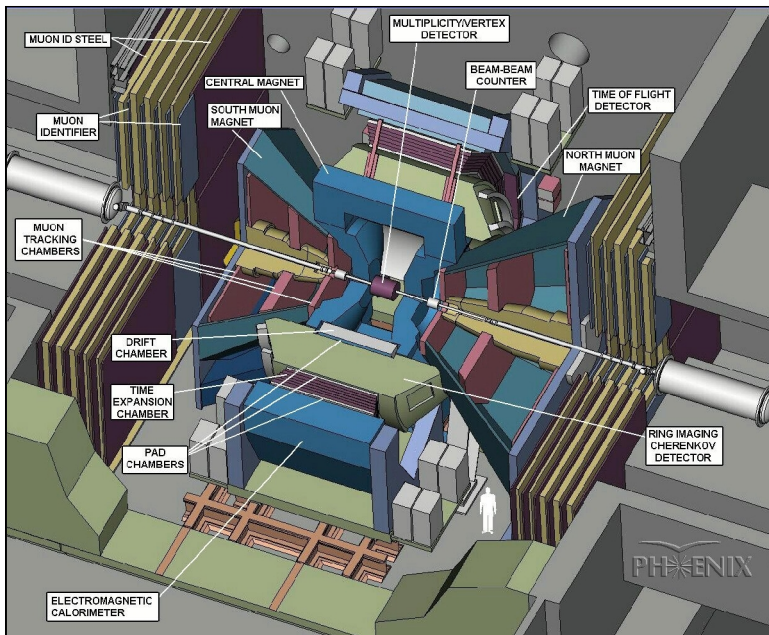
$$2x (0 < \phi < 0.2); 0 < \eta < 1.5$$

Without tracking:

$$0 < \phi < 2\pi; -3 < \eta < 3$$



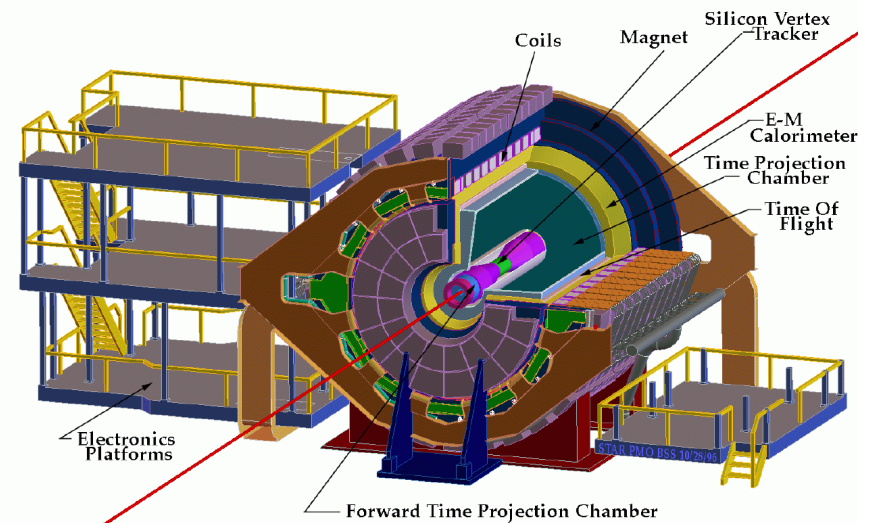
PHENIX



Coverage:

$$2x(0 < \phi < \pi/2); -0.35 < \eta < 0.35$$

STAR

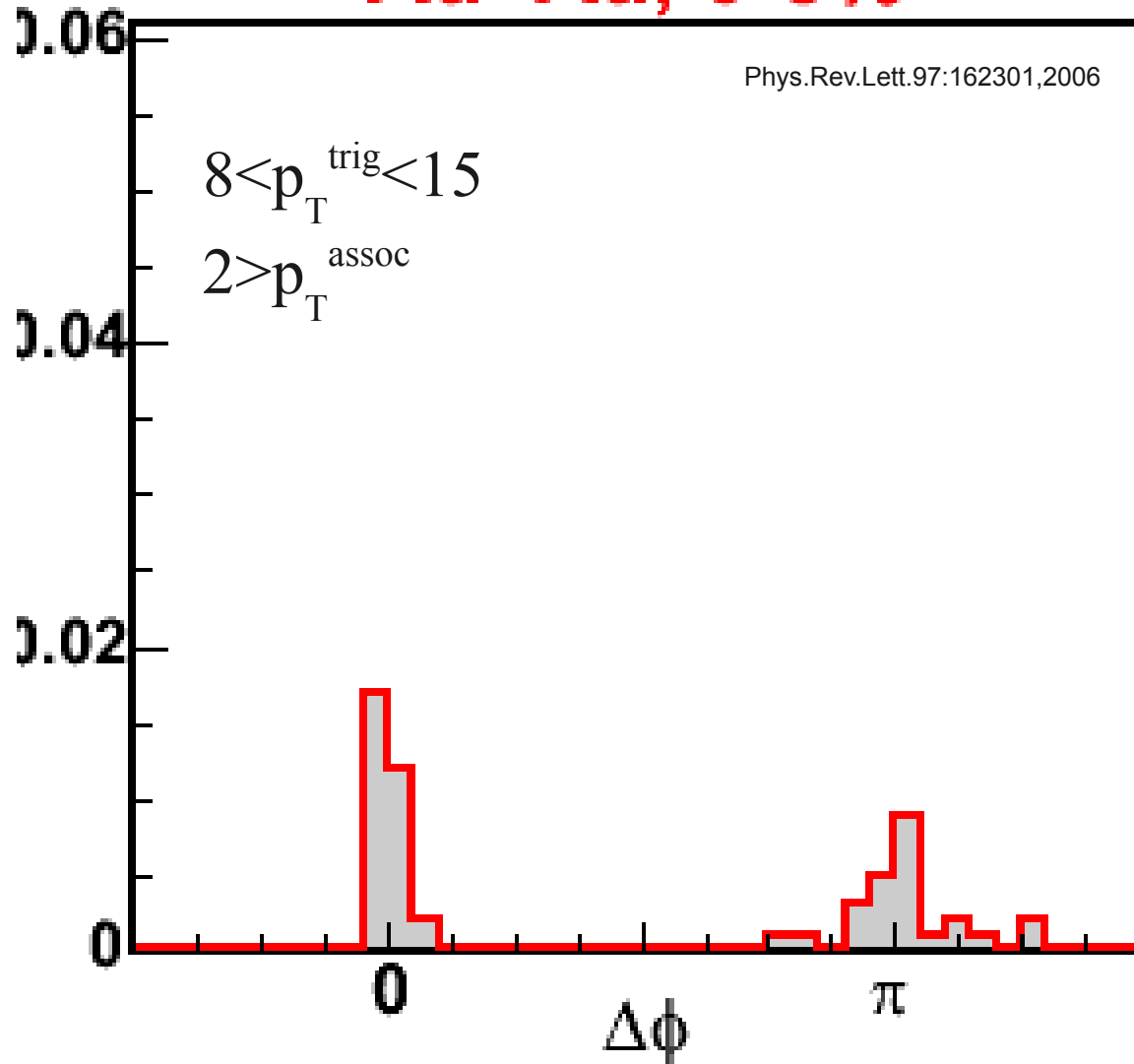


- Coverage:

$$0 < \phi < 2\pi; -1 < \eta < 1$$

At higher p_T ...

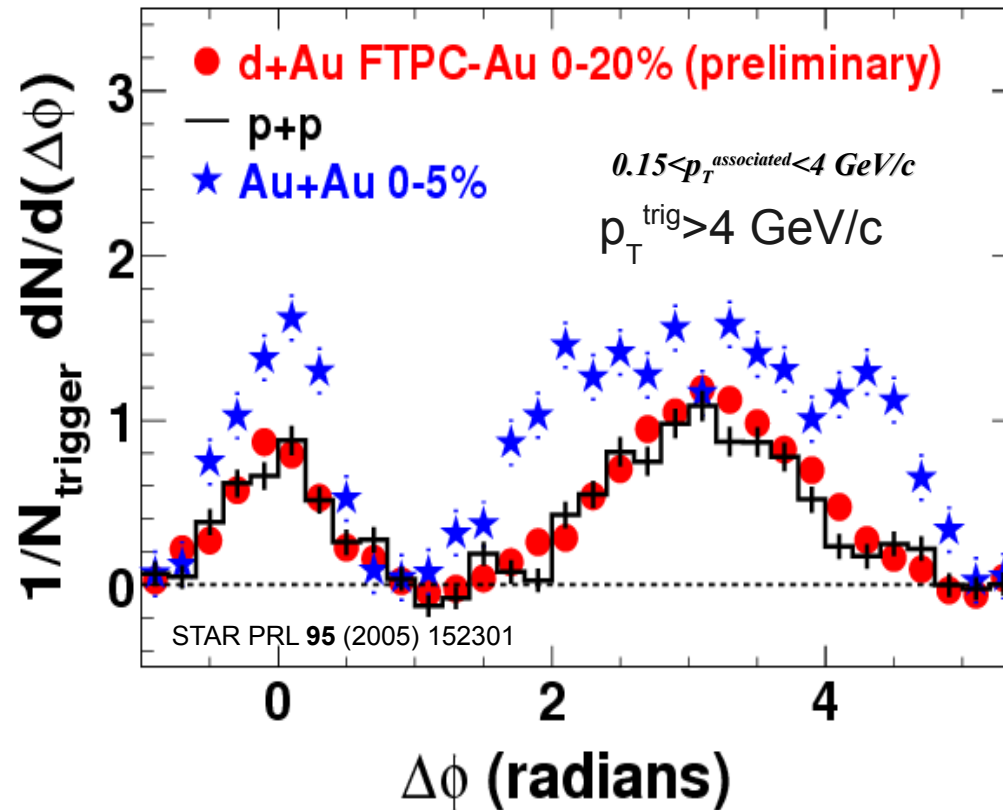
Au+Au, 0-5%



The away-side jet punches through the medium

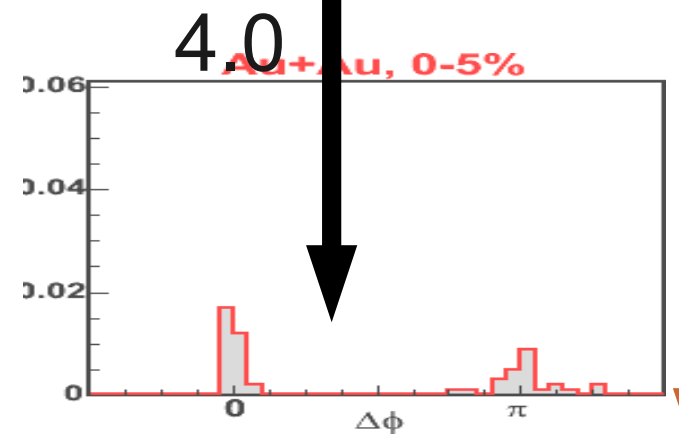
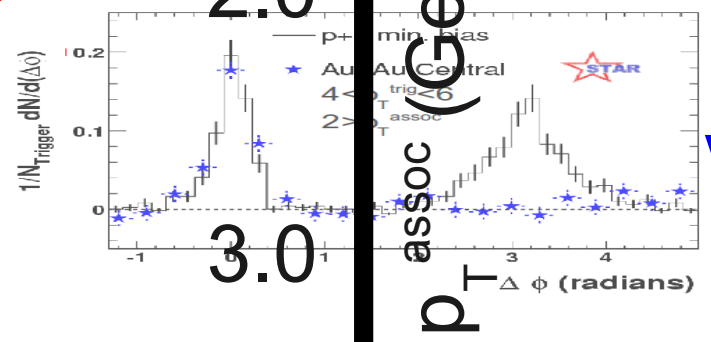
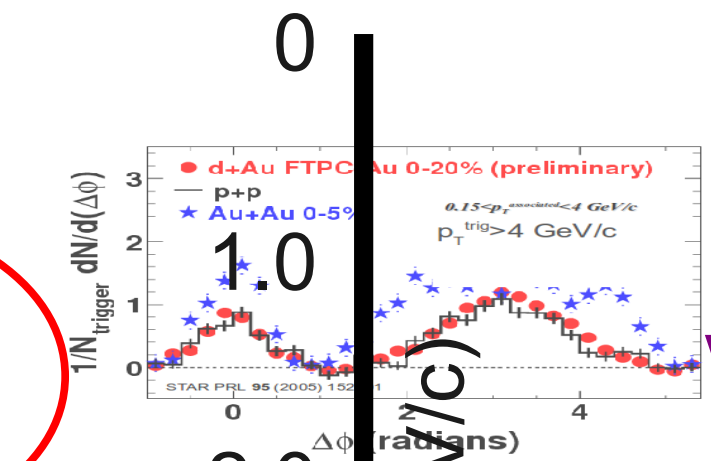
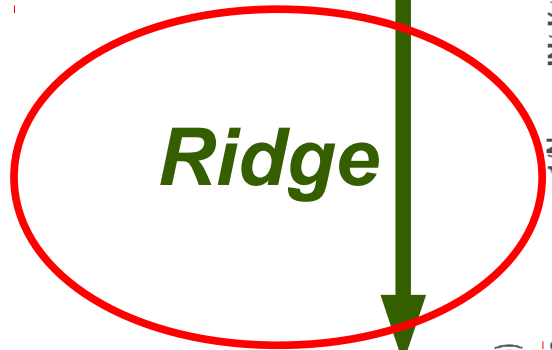
But at lower p_T ...

Near-side, away-side: excess yield in Au+Au relative to p+p



Near-side

Away-side



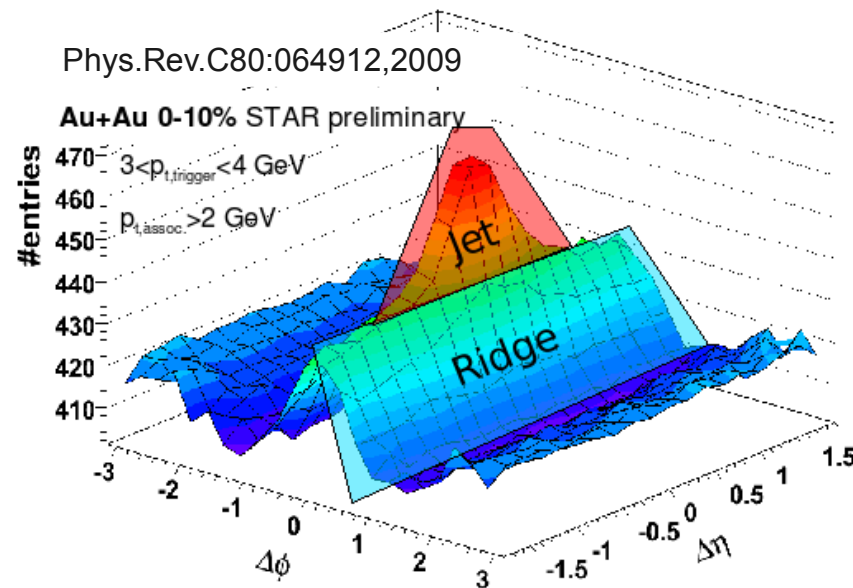
Mach Cone

Quenching

Punch Through

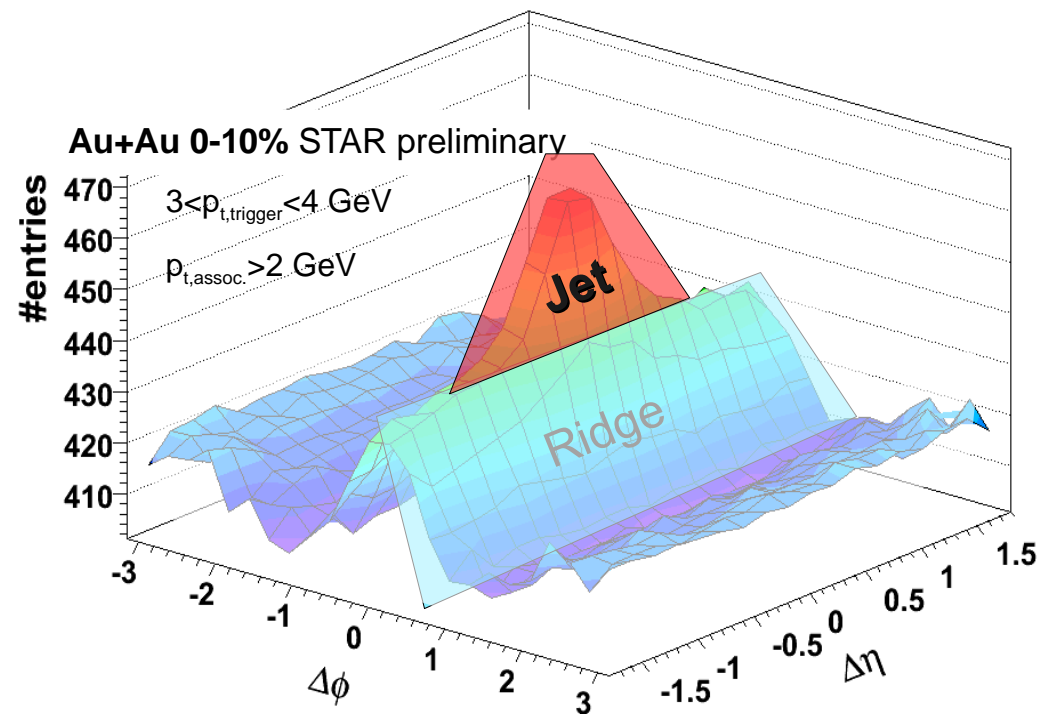
Minimally modified fragmentation

Simple picture

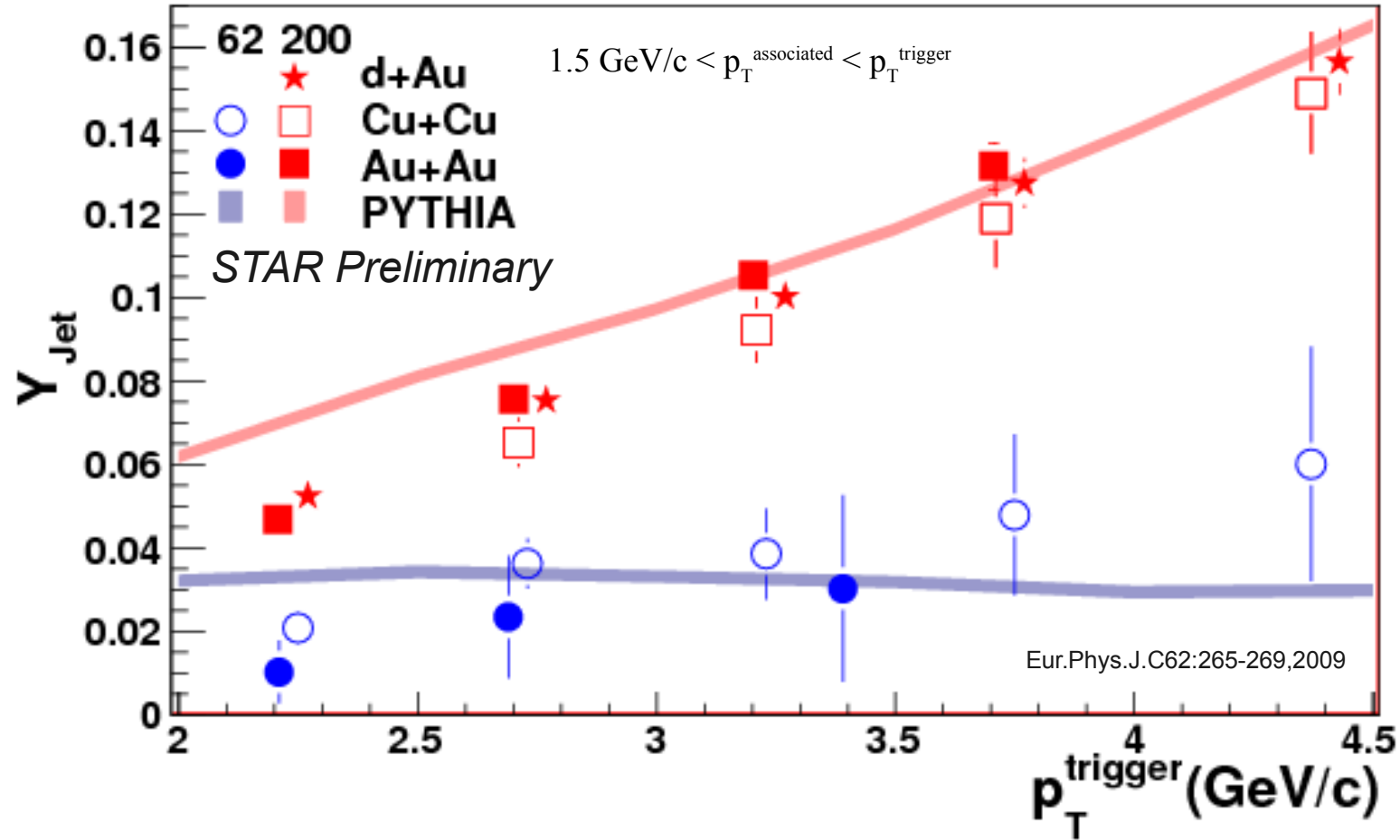


- Jet-like correlation: Dominantly produced by fragmentation
- Ridge:
 - Part of the signal: created by hard parton interaction with the medium
 - Part of the background: some extra correlation we didn't realize was there

The Jet



Jet-like yield: p_T^{trigger} dependence

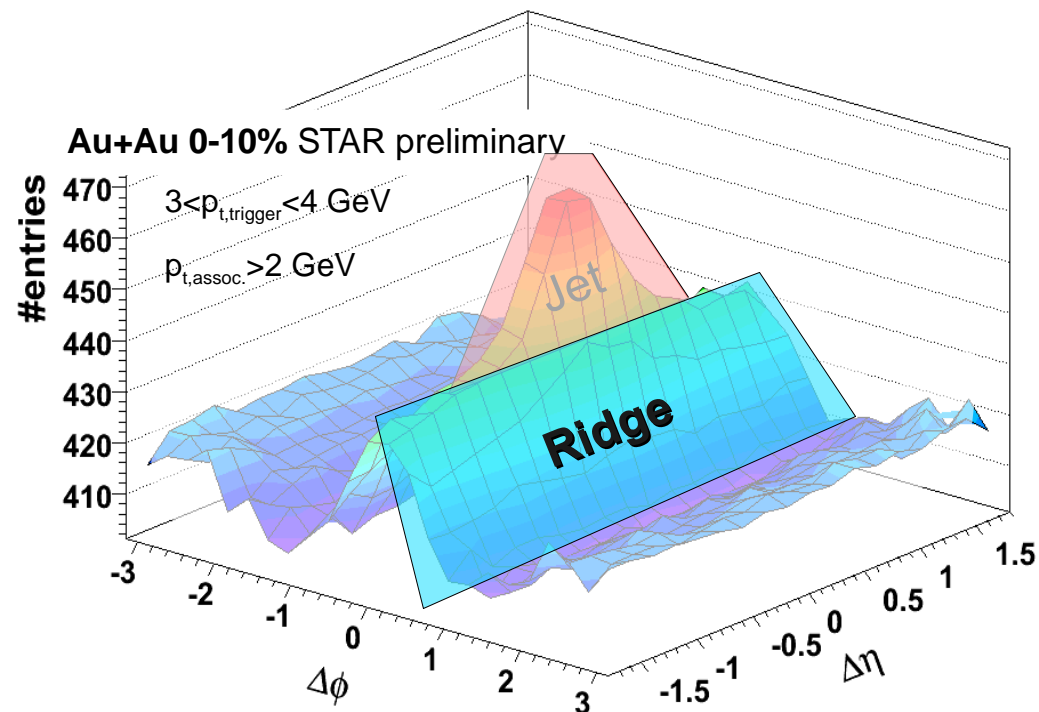


Yield increases with p_T^{trigger}

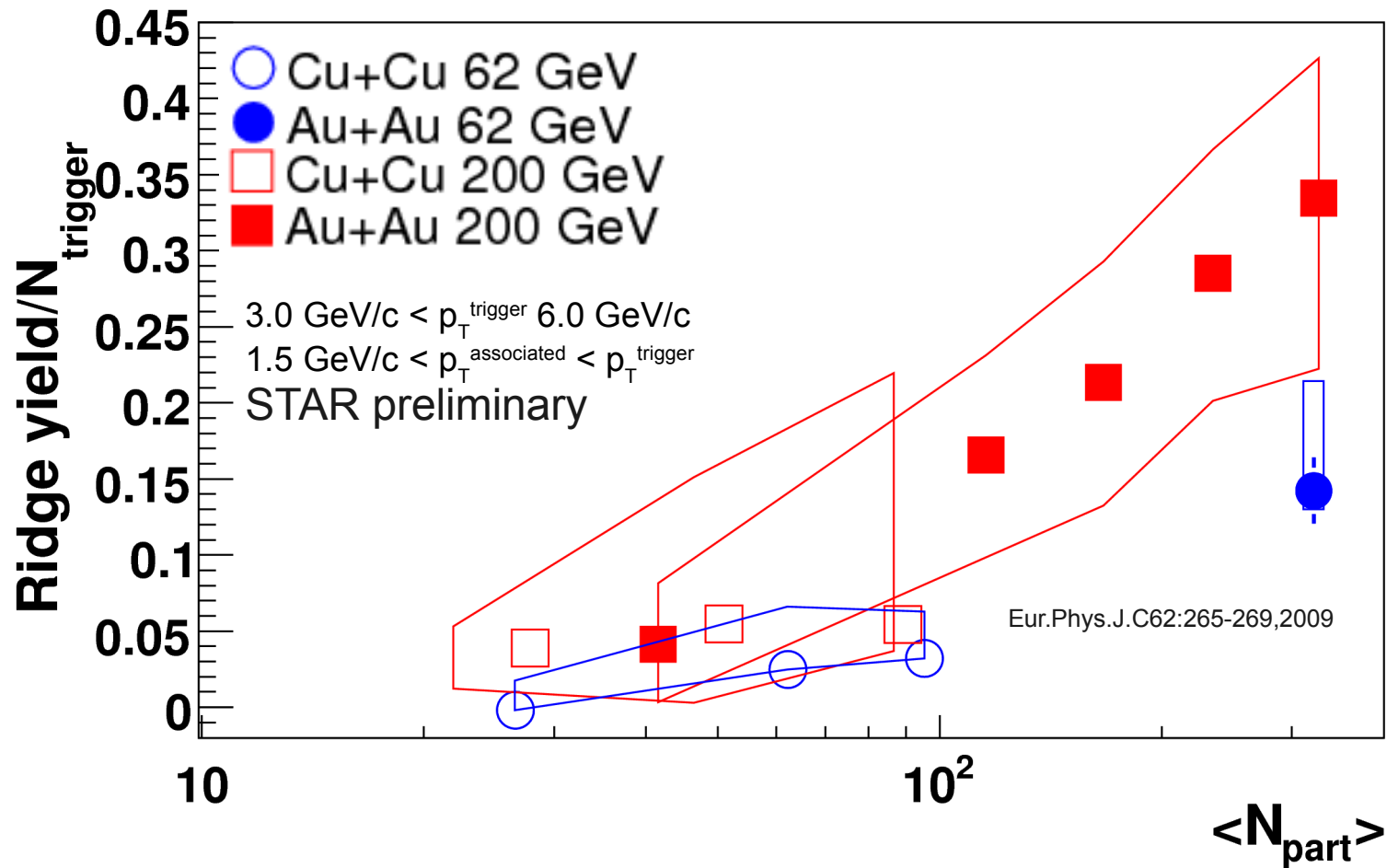
No collision system dependence

PYTHIA 6.4.10 Tune A— Monte Carlo p+p event generator tuned to data and incorporating many features of pQCD

The Ridge

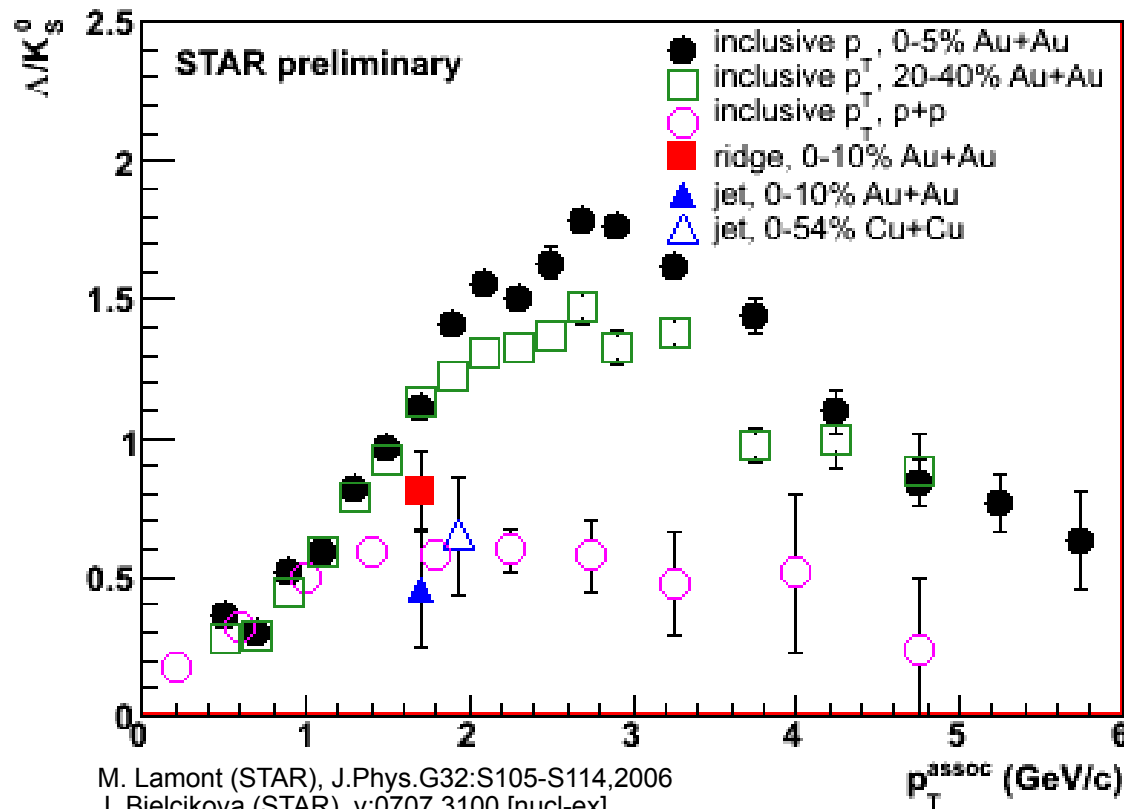


Ridge vs N_{part}

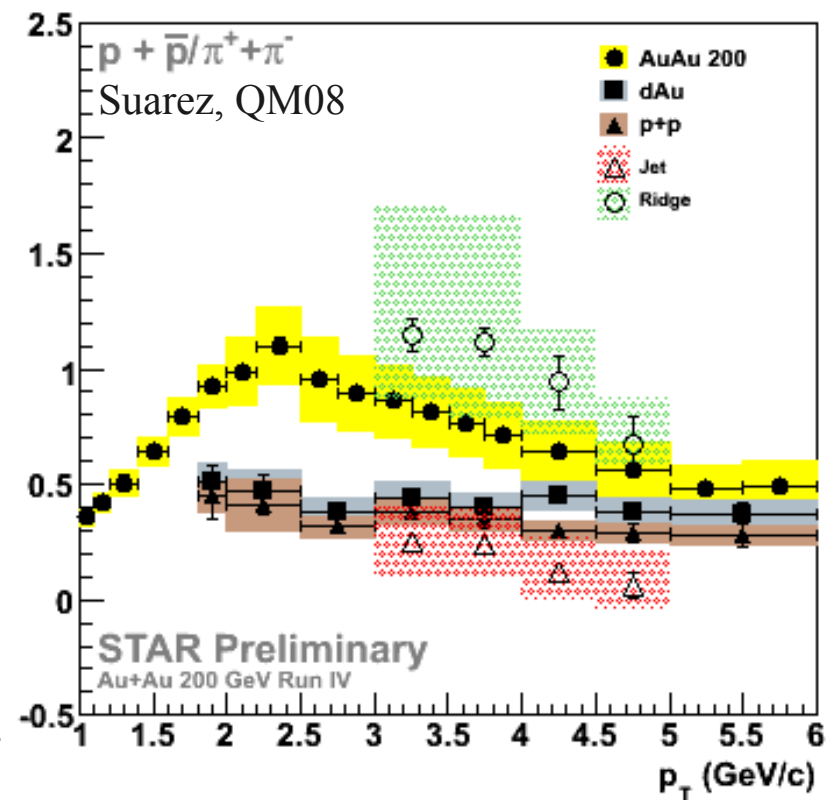


No system dependence at given N_{part}

Jet-like correlation composition

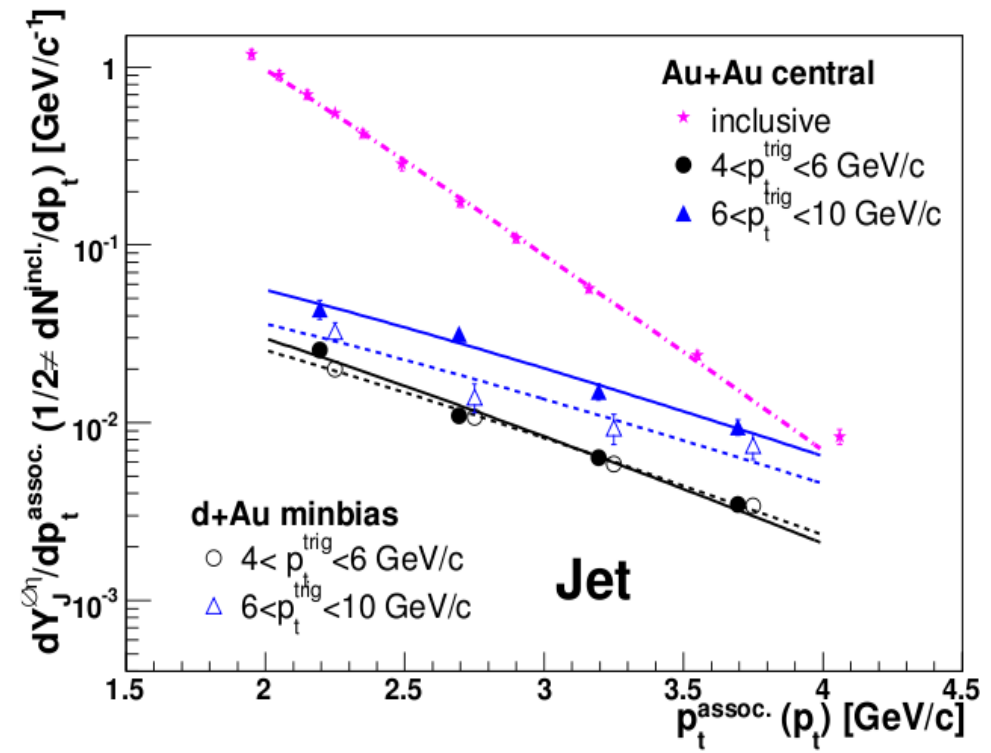
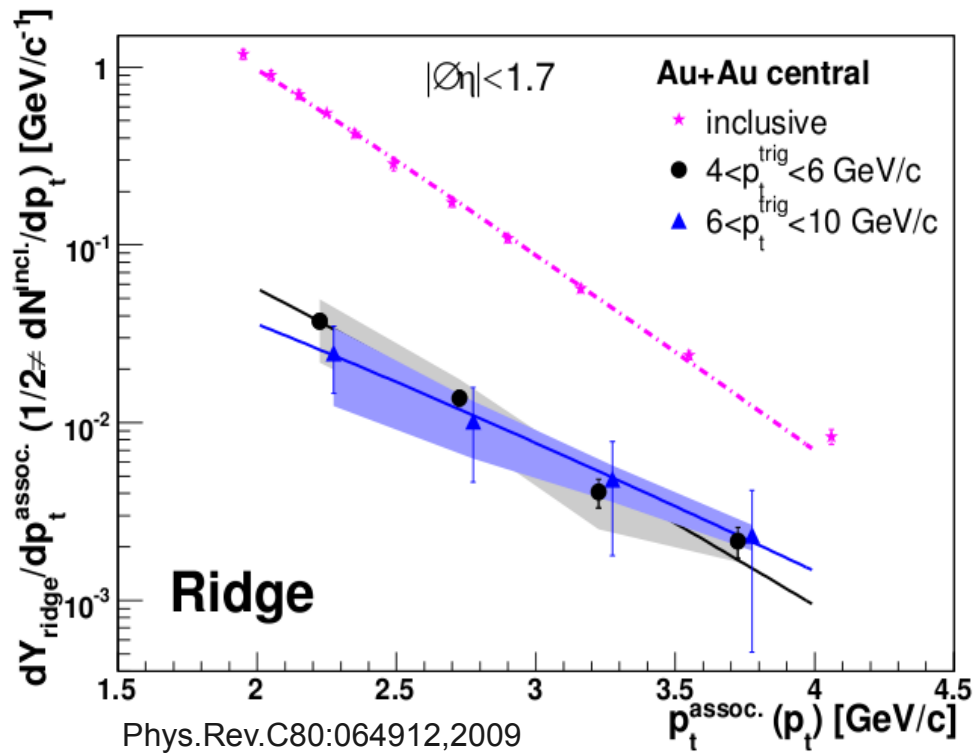


M. Lamont (STAR), J.Phys.G32:S105-S114,2006
 J. Bielcikova (STAR), v:0707.3100 [nucl-ex]
 C. Nattrass (STAR), arXiv:0804.4683/nucl-ex



- Baryon/meson ratios in jet-like correlation in Cu+Cu and Au+Au similar to p+p for both strange and non-strange particles
- Baryon/meson ratios in ridge similar to bulk for both strange and non-strange particles

Jet-like correlation is like $p+p$, ridge is like bulk

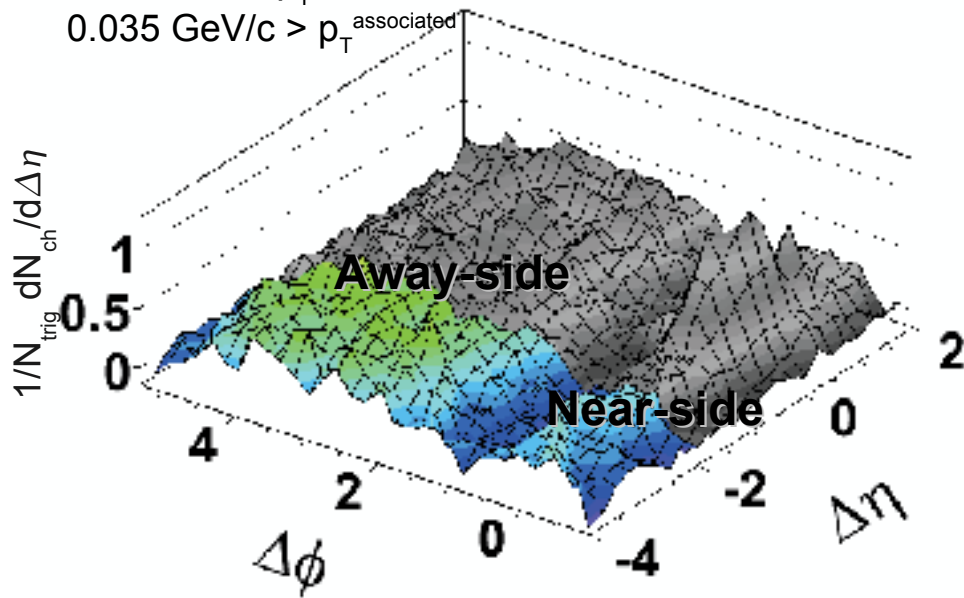


Spectra of particles associated with ridge similar to inclusive
 Spectra of particles associated with jet-like correlation harder

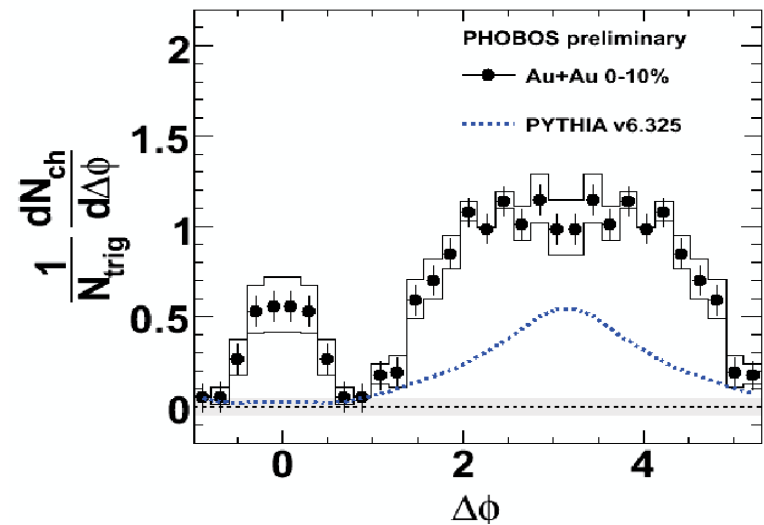
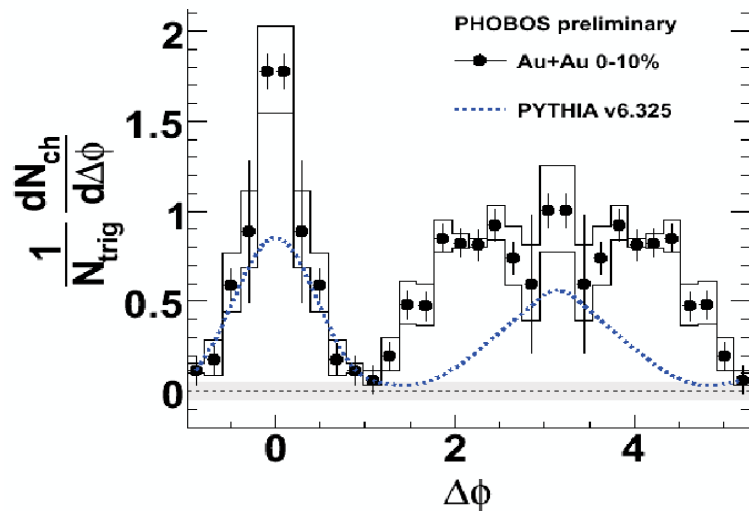
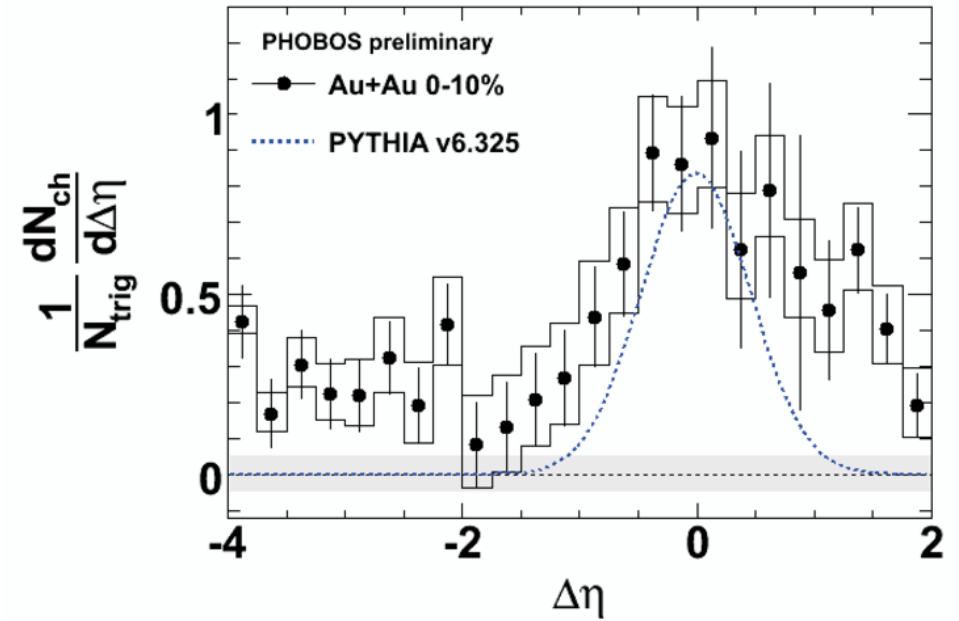
Extent of ridge in $\Delta\eta$

Au+Au 0-30% central

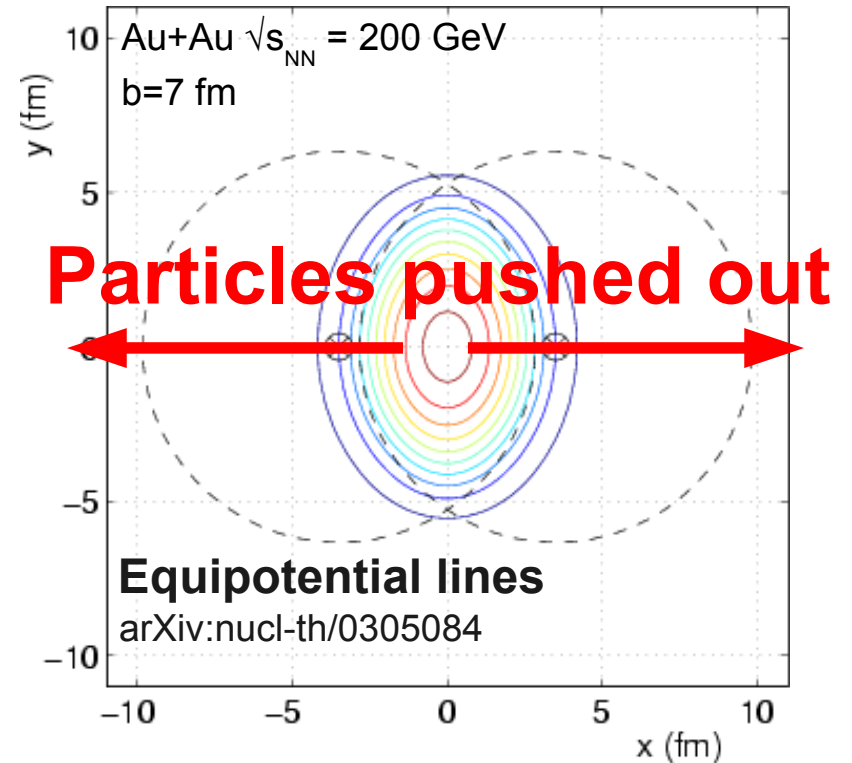
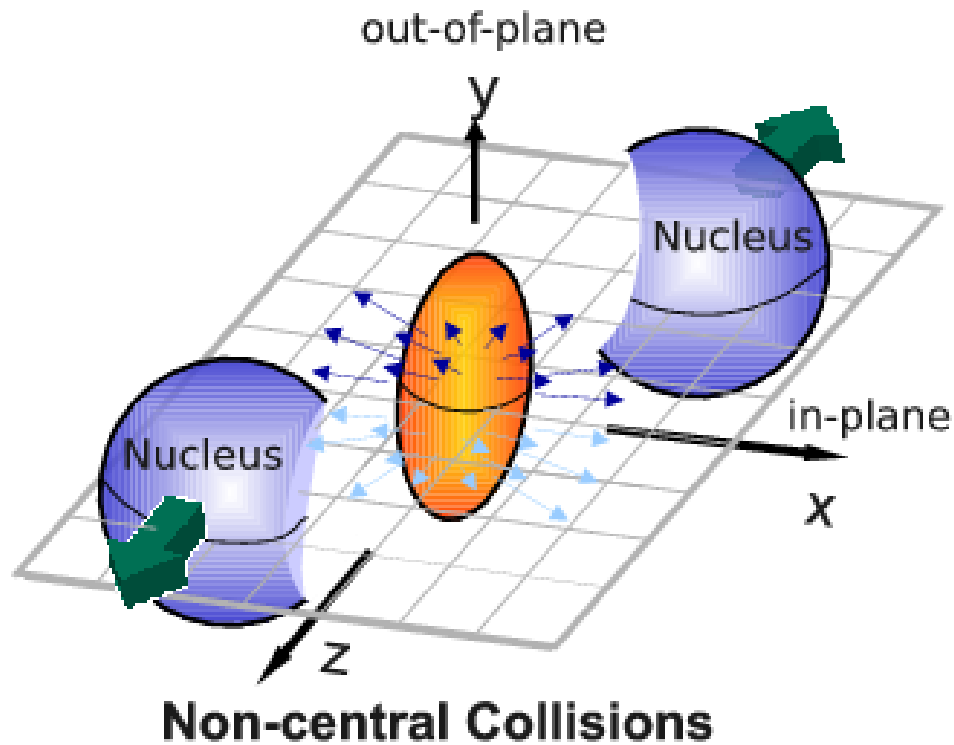
$2.5 \text{ GeV}/c > p_T^{\text{trigger}}$
 $0.035 \text{ GeV}/c > p_T^{\text{associated}}$



Phys. Rev. Lett. 104, 062301 (2010)



Hydrodynamical flow



- When nuclei collide, the overlap region is roughly elliptical
- If we have a fluid when we collide nuclei, there will be pressure gradients, pushing particles out
- We have measured this – and the liquid is made of quarks and gluons

ZYAM and the two-component model

- Two component model:

Di-hadron correlations are composed of

- Correlations arising from jet fragmentation
- Correlations arising from elliptic flow (v_2)

Assume jets are not correlated with background

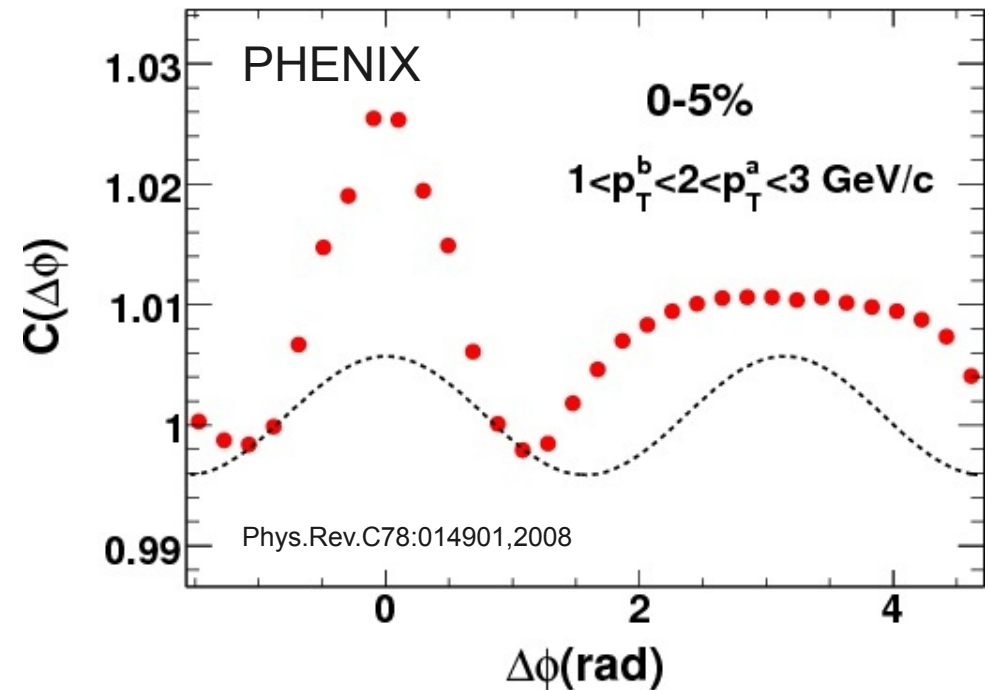
The background is then

$$B(1 + 2 v_2^{\text{trig}} v_2^{\text{assoc}} \cos(2\Delta\Phi))$$

Phys.Rev. C69 (2004) 021901

- Zero-Yield-At-Minimum (ZYAM)

- Assumes there is a region where there is no signal
- Fix B in this region assuming two component model
- Use v_2 from independent measurements



Models

- Radiated gluons broadened in pseudorapidity

Longitudinal flow, Armesto et al, PRL 93 (2004)
 QCD magnetic fields, Majumder et al, Phys.Rev.Lett.99:042301,2007
 Anisotropic plasma, P. Romatschke, PRC,75014901 (2007)

So far unable to make enough ridge

- Interaction of jet+medium

Momentum kick from jet, C.-Y. Wong, Phys.Rev.C76:054908,2007
 Medium heating + recombination, Chiu & Hwa, PRC72, 034903

Agrees with data but lots of fits to the data

- Hydrodynamical flow

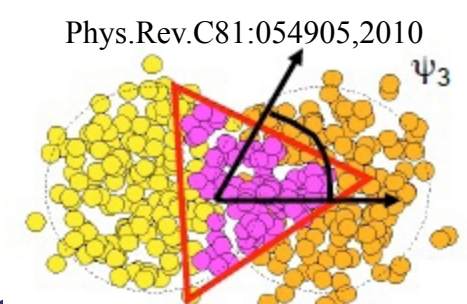
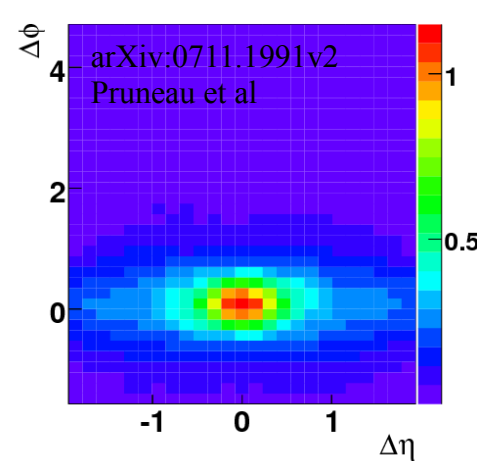
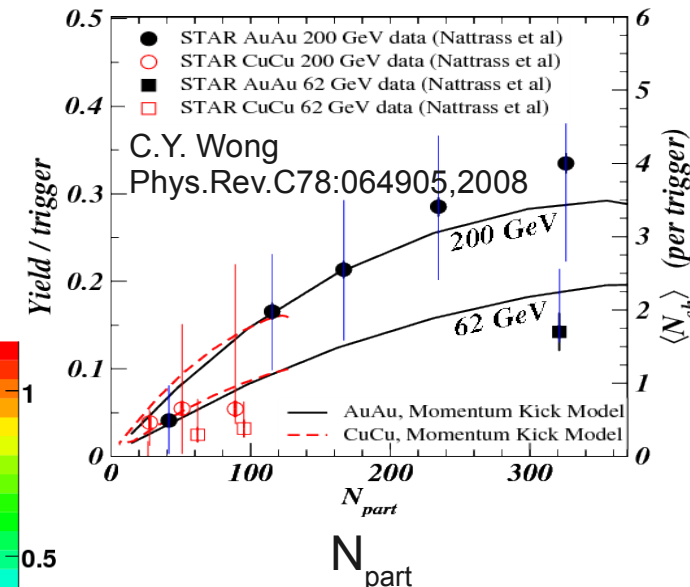
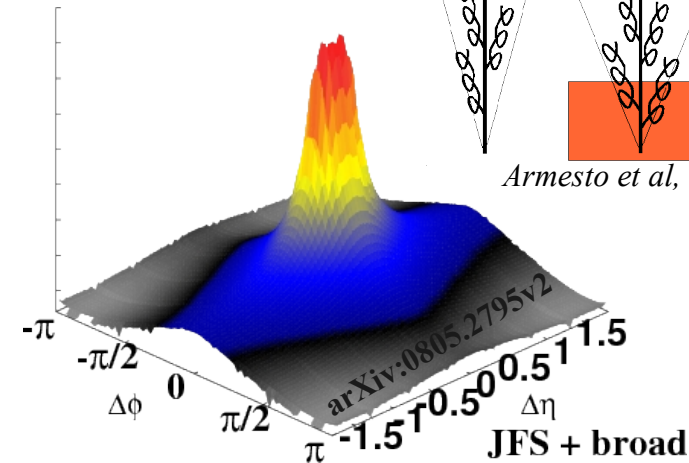
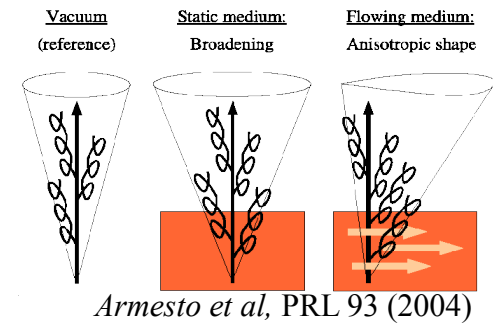
Radial flow+trigger bias

S. Voloshin, nucl-th/0312065, Nucl. Phys. A749, 287
 C.. Pruneau, S. Gavin, S. Voloshin, arXiv:0711.1991v2
 E. Shuryak, Phys.Rev.C76:047901,2007

Triangular flow (v_3)

B.Alver, G.Roland, Phys.Rev.C81:054905,2010
 P. Sorensen, arXiv:1002.4878v1

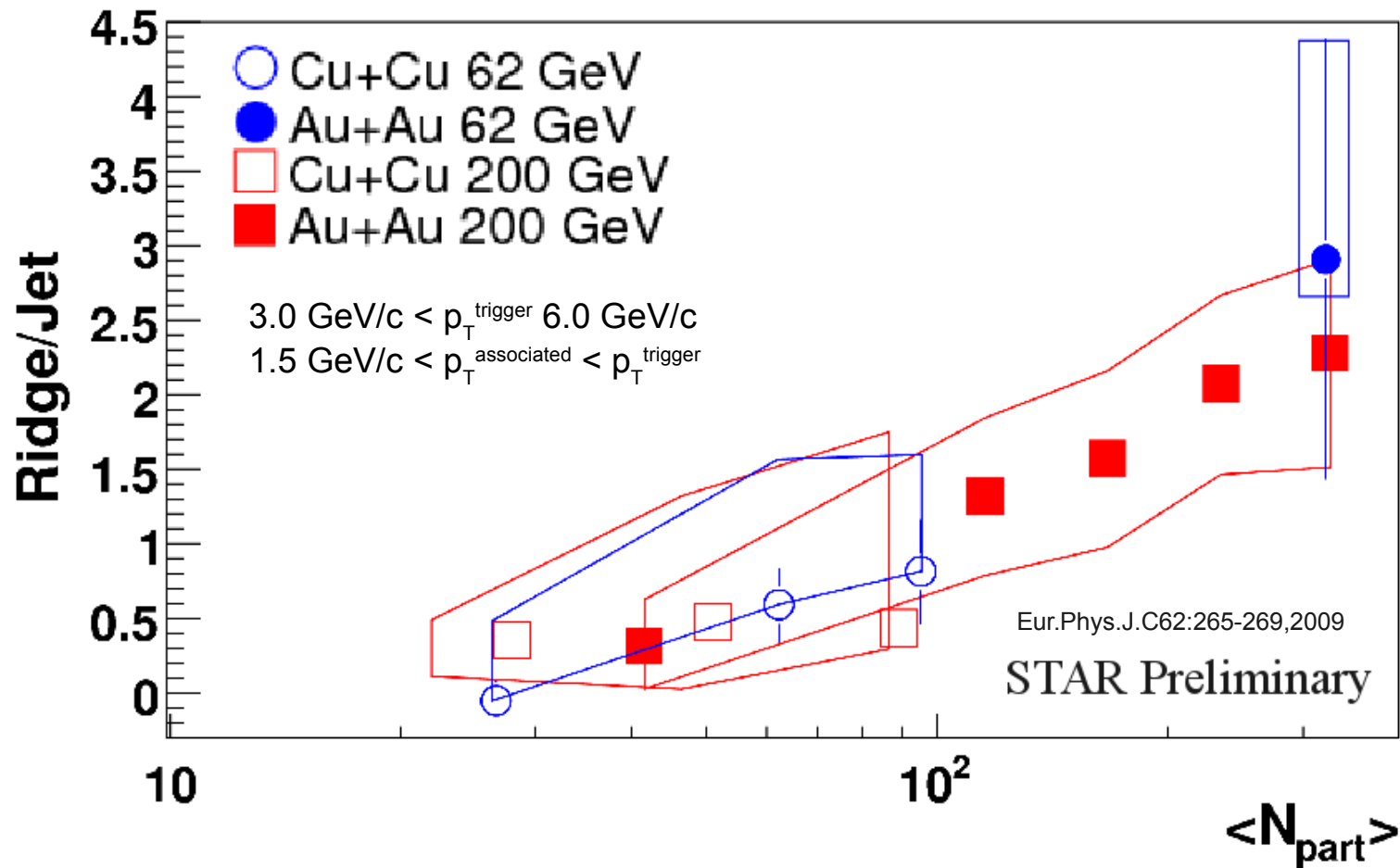
As an added bonus, these describe the away-side



Conclusions

- Most models for the ridge imply QGP formation or a relativistic hydrodynamic fluid
- Since the CMS result, some models have appeared to form a ridge without a QGP
 - Flux tubes in a Color Glass Condensate
- Stay tuned...

Ridge vs N_{part}



No system dependence at given N_{part}

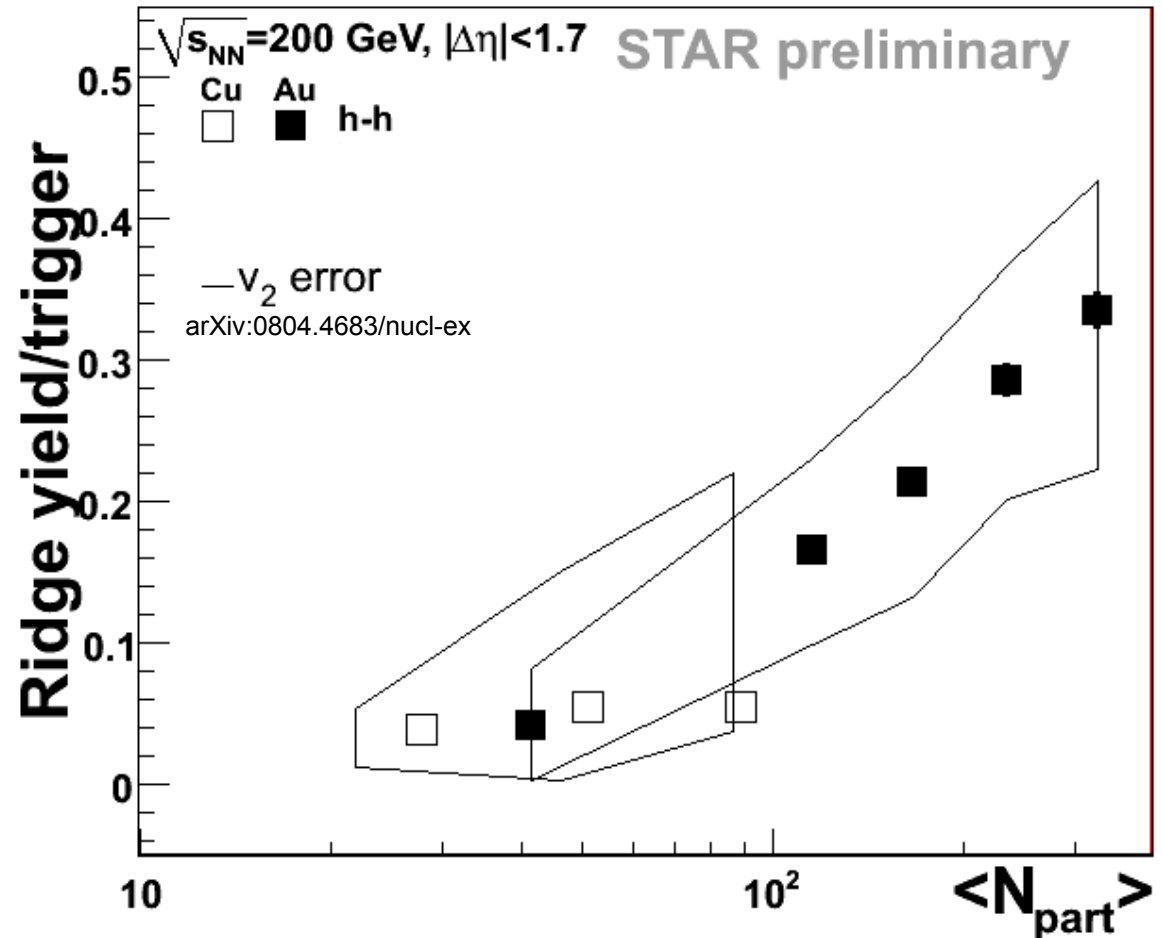
Ridge/jet-like yield independent of energy*

*Comparing these two energies in this kinematic region

Identified trigger: Near-side Yield vs N_{part}

$$3.0 \text{ GeV}/c < p_T^{\text{trigger}} < 6.0 \text{ GeV}/c; 1.5 \text{ GeV}/c < p_T^{\text{associated}} < p_T^{\text{trigger}}$$

Ridge yield -
No trigger type
dependence

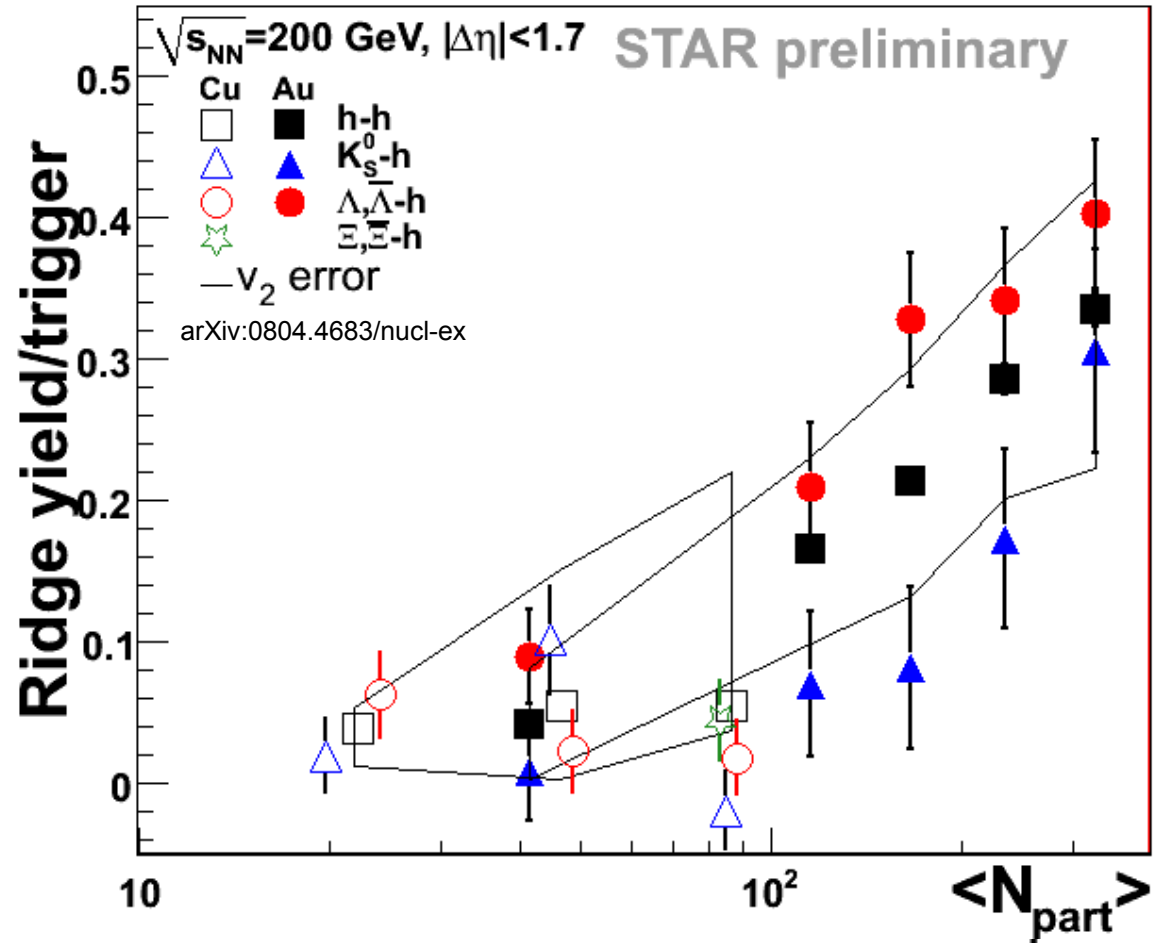


Au+Au $\sqrt{s_{NN}}=200 \text{ GeV}$ from nucl-ex/0701047
Cu+Cu $\sqrt{s_{NN}}=200 \text{ GeV}$ from SQM2007
Data points at same N_{part} offset for visibility

Identified trigger: Near-side Yield vs N_{part}

$3.0 \text{ GeV}/c < p_T^{\text{trigger}} < 6.0 \text{ GeV}/c$; $1.5 \text{ GeV}/c < p_T^{\text{associated}} < p_T^{\text{trigger}}$

Ridge yield -
No trigger type
dependence

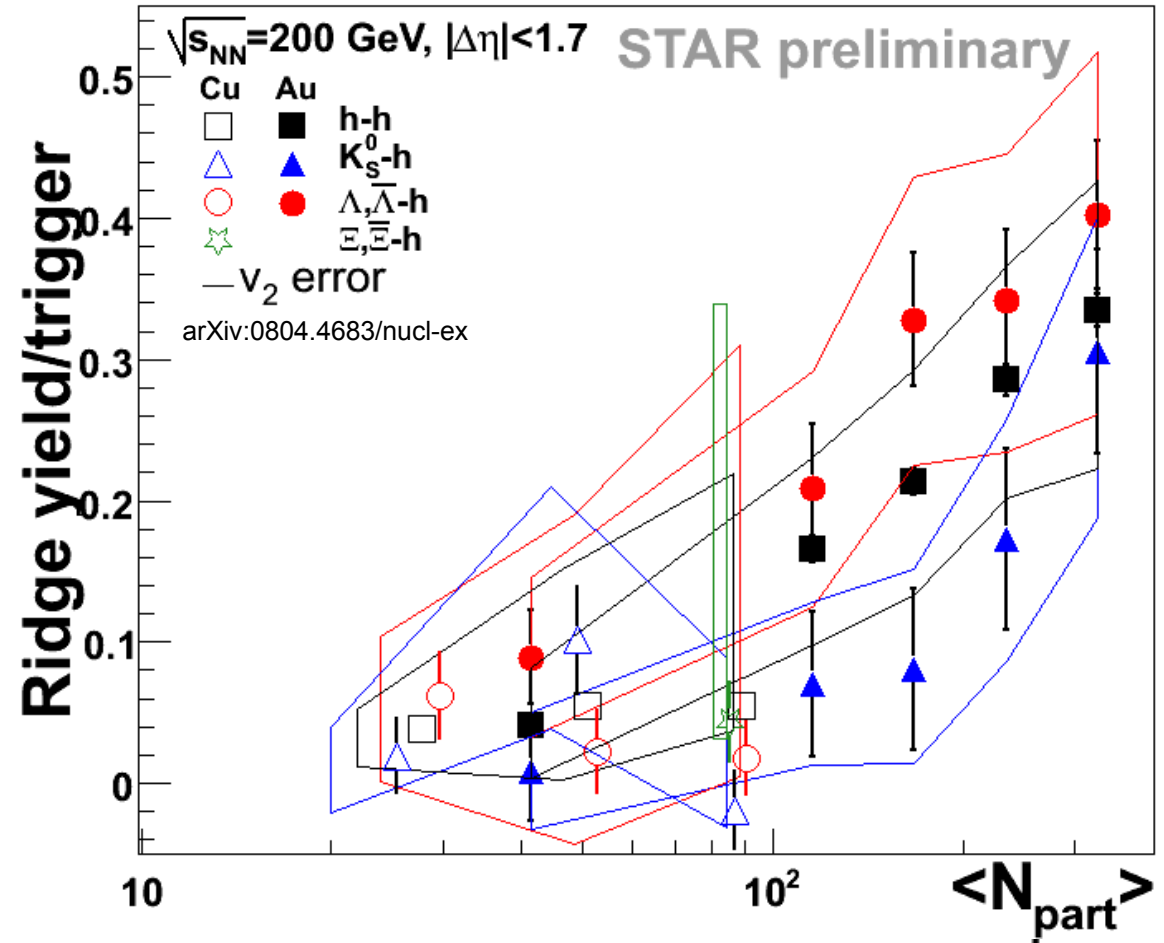


Au+Au $\sqrt{s_{NN}} = 200 \text{ GeV}$ from nucl-ex/0701047
 Cu+Cu $\sqrt{s_{NN}} = 200 \text{ GeV}$ from SQM2007
 Data points at same N_{part} offset for visibility

Identified trigger: Near-side Yield vs N_{part}

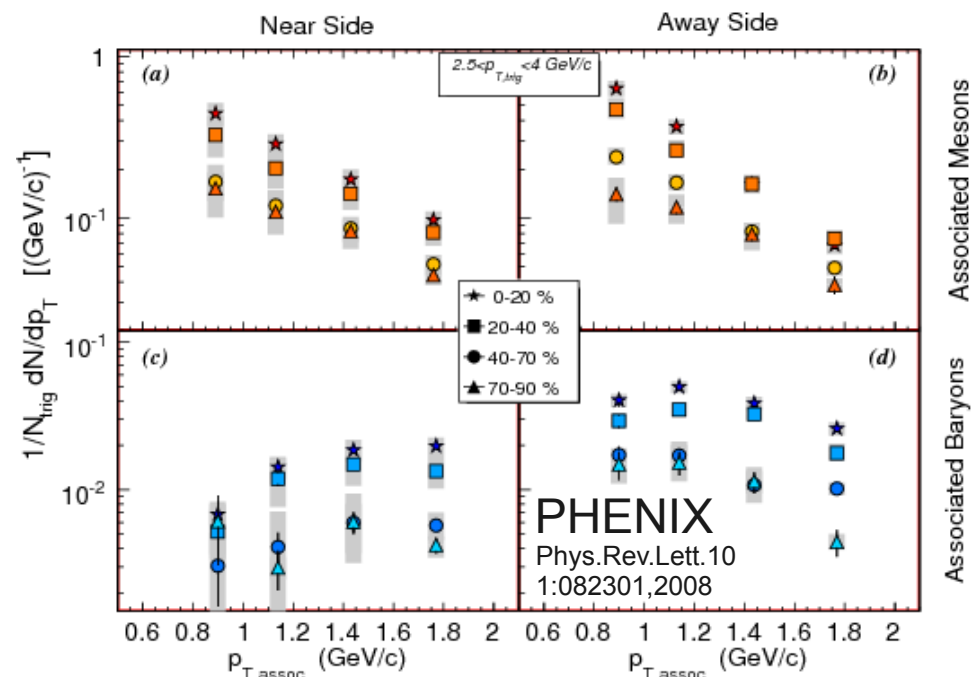
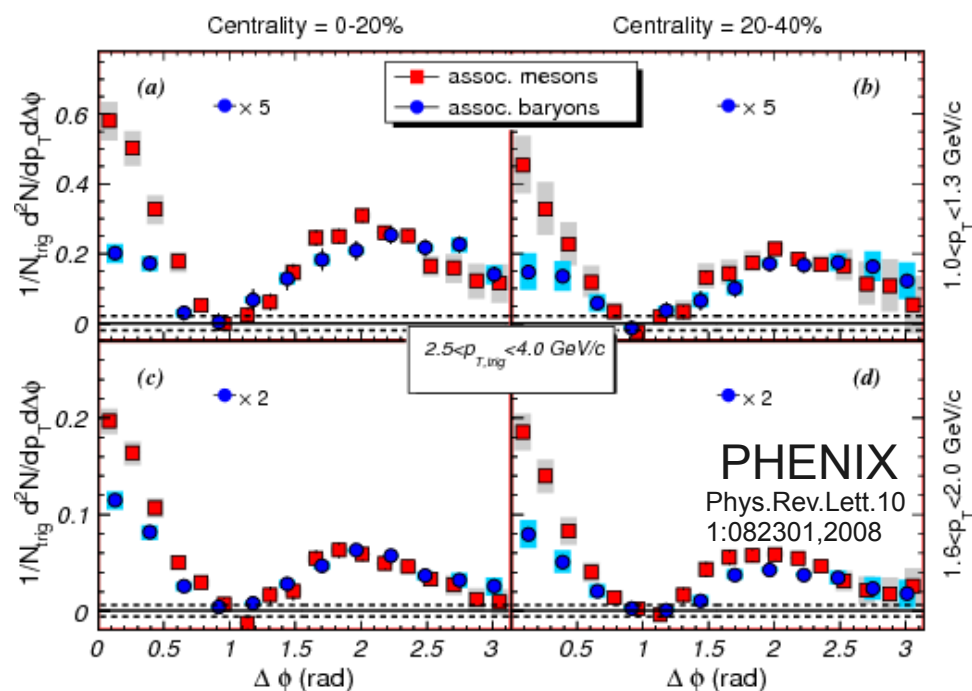
$3.0 \text{ GeV}/c < p_T^{\text{trigger}} < 6.0 \text{ GeV}/c$; $1.5 \text{ GeV}/c < p_T^{\text{associated}} < p_T^{\text{trigger}}$

Ridge yield -
No trigger type
dependence



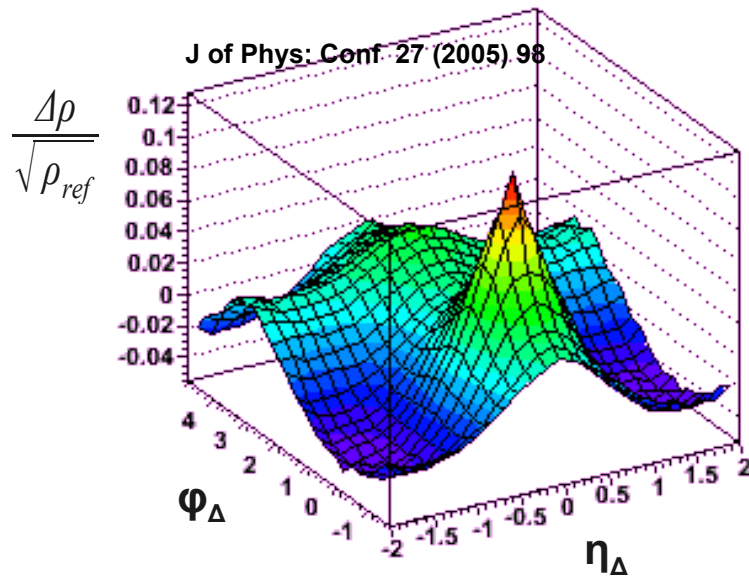
Au+Au $\sqrt{s_{NN}} = 200 \text{ GeV}$ from nucl-ex/0701047
 Cu+Cu $\sqrt{s_{NN}} = 200 \text{ GeV}$ from SQM2007
 Data points at same N_{part} offset for visibility

Baryon/meson ratios

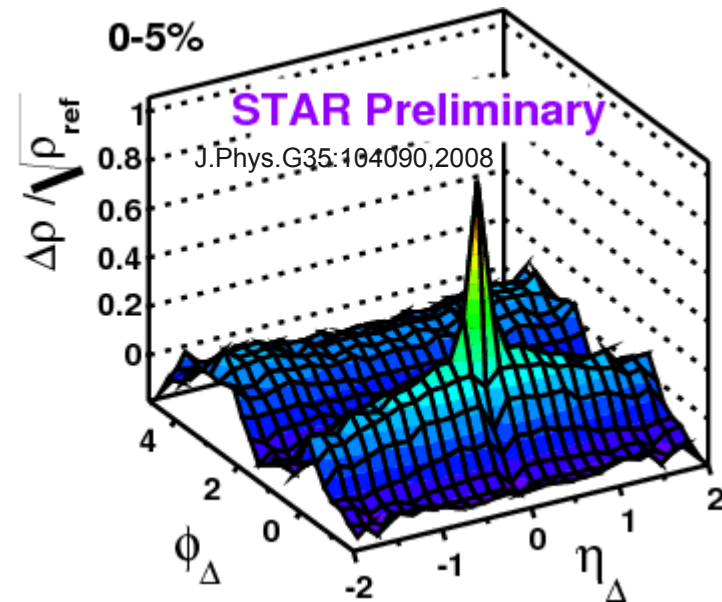


- Clear evidence of different behavior for baryons and mesons
- For this kinematic region, baryon/meson ratio in bulk changing rapidly

The soft ridge



p+p 200 GeV

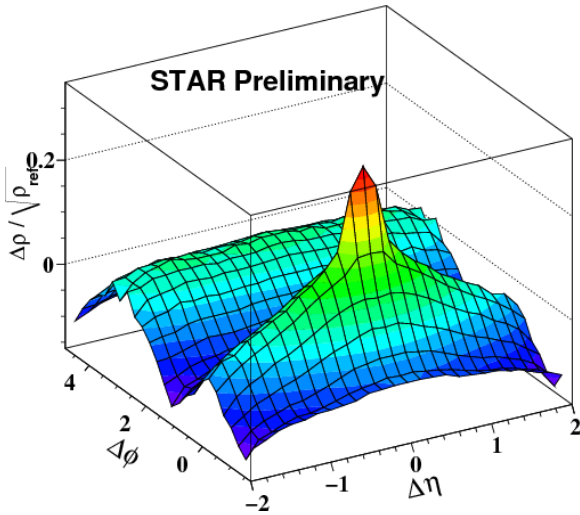


Au+Au 200 GeV

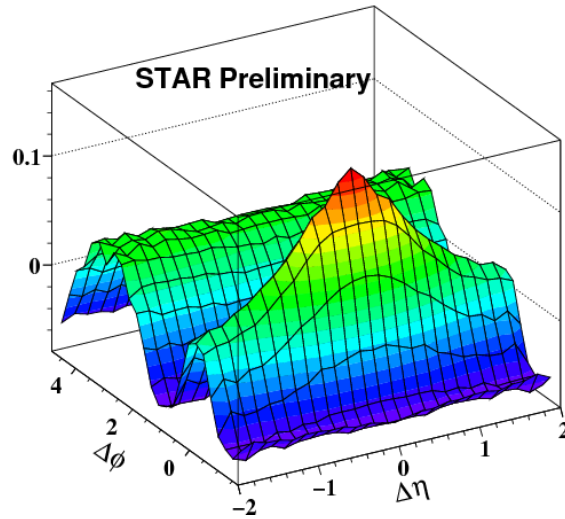
- Untriggered di-hadron correlations – no p_T cuts
- Similar structure on the near-side - “Soft Ridge”
- Are soft and hard ridge the same?

The soft ridge

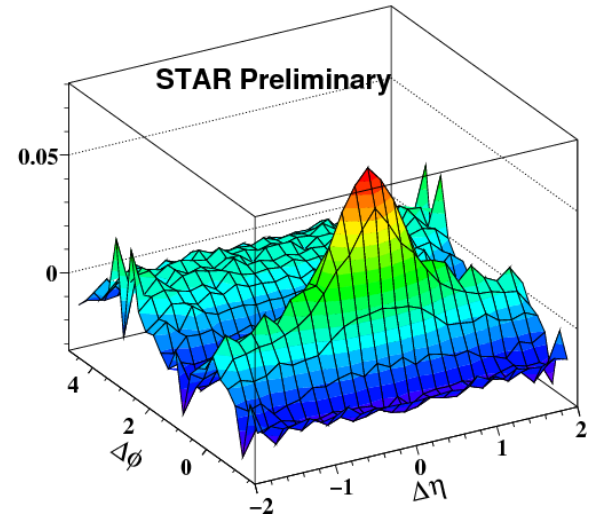
$p_T \geq 150 \text{ MeV}/c$



$p_T \geq 700 \text{ MeV}/c$



$p_T \geq 1500 \text{ MeV}/c$



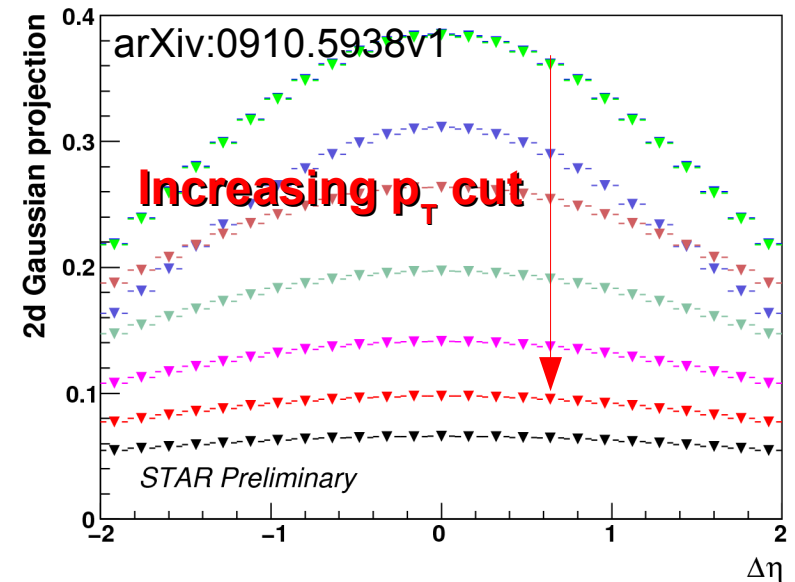
arXiv:0910.5938v1

Cu+Cu 200 GeV

Increasing p_T cut



- Soft ridge \rightarrow hard ridge with increasing p_T
- Most likely two structures are the same



*Note the different normalizations for the hard and soft ridge

Conclusions

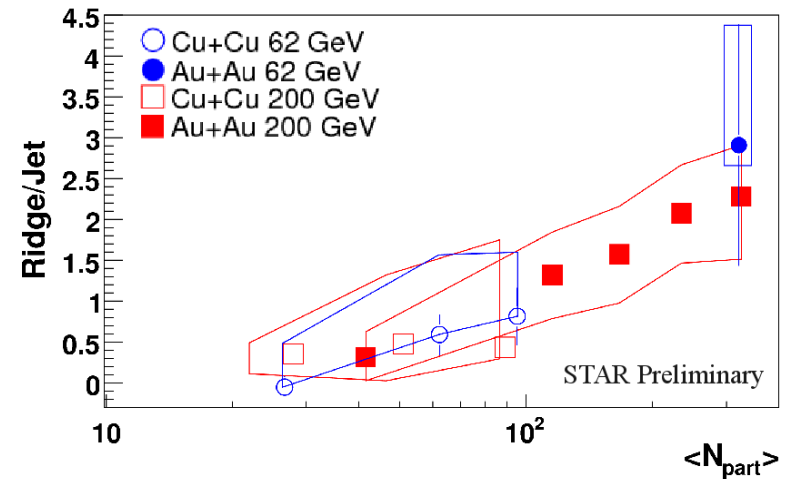
- Lots of data
 - Jet-like correlation dominated by fragmentation
 - Ridge is bulk-like. From the bulk?
 - Hard and soft ridge most likely the same phenomenon

Conclusions

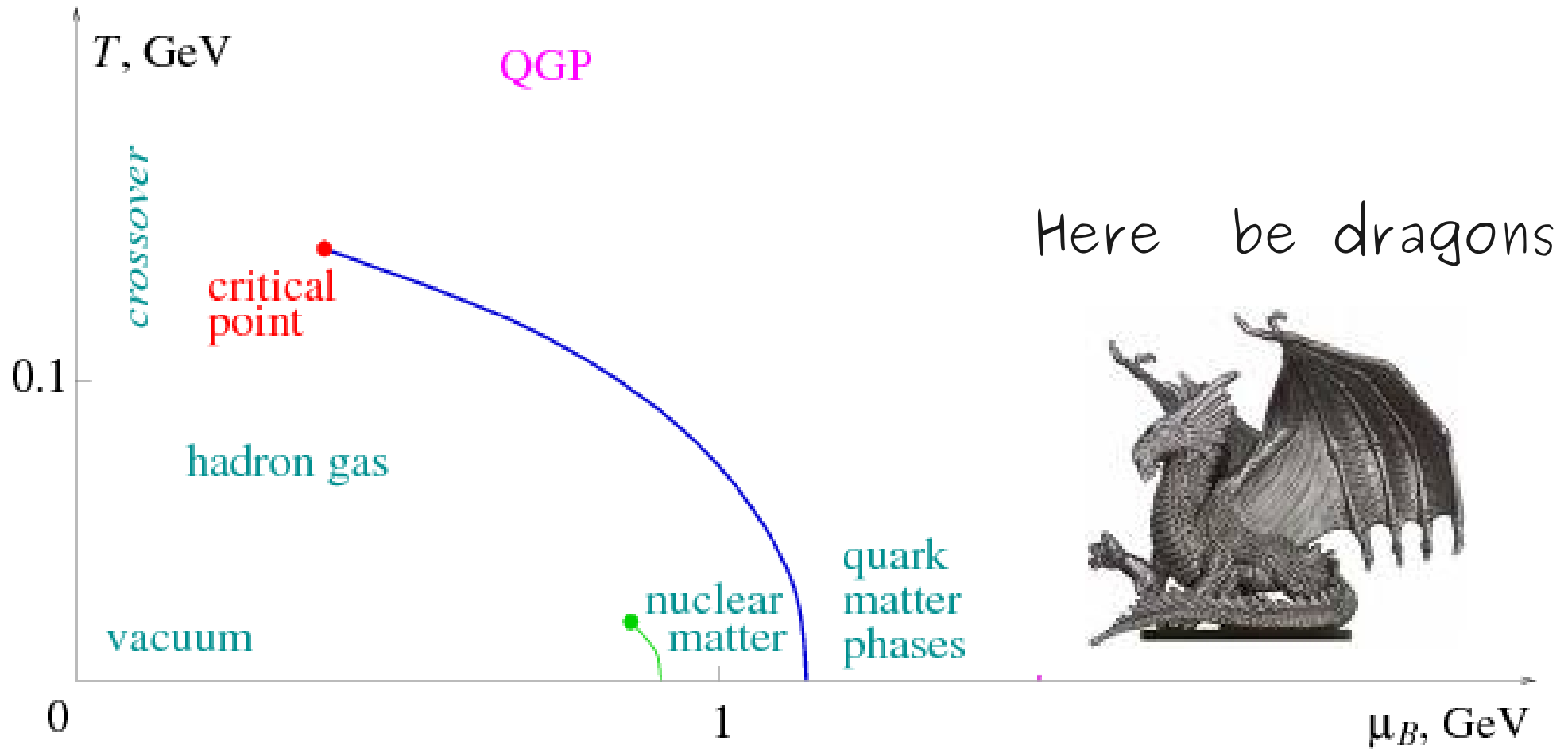
- Lots of data
 - Jet-like correlation dominated by fragmentation
 - Ridge is bulk-like. From the bulk?
 - Hard and soft ridge most likely the same phenomenon
- Theories
 - Causal: Have some difficulty reproducing the data
 - Non-causal/Hydrodynamical models: Good candidates

Outlook

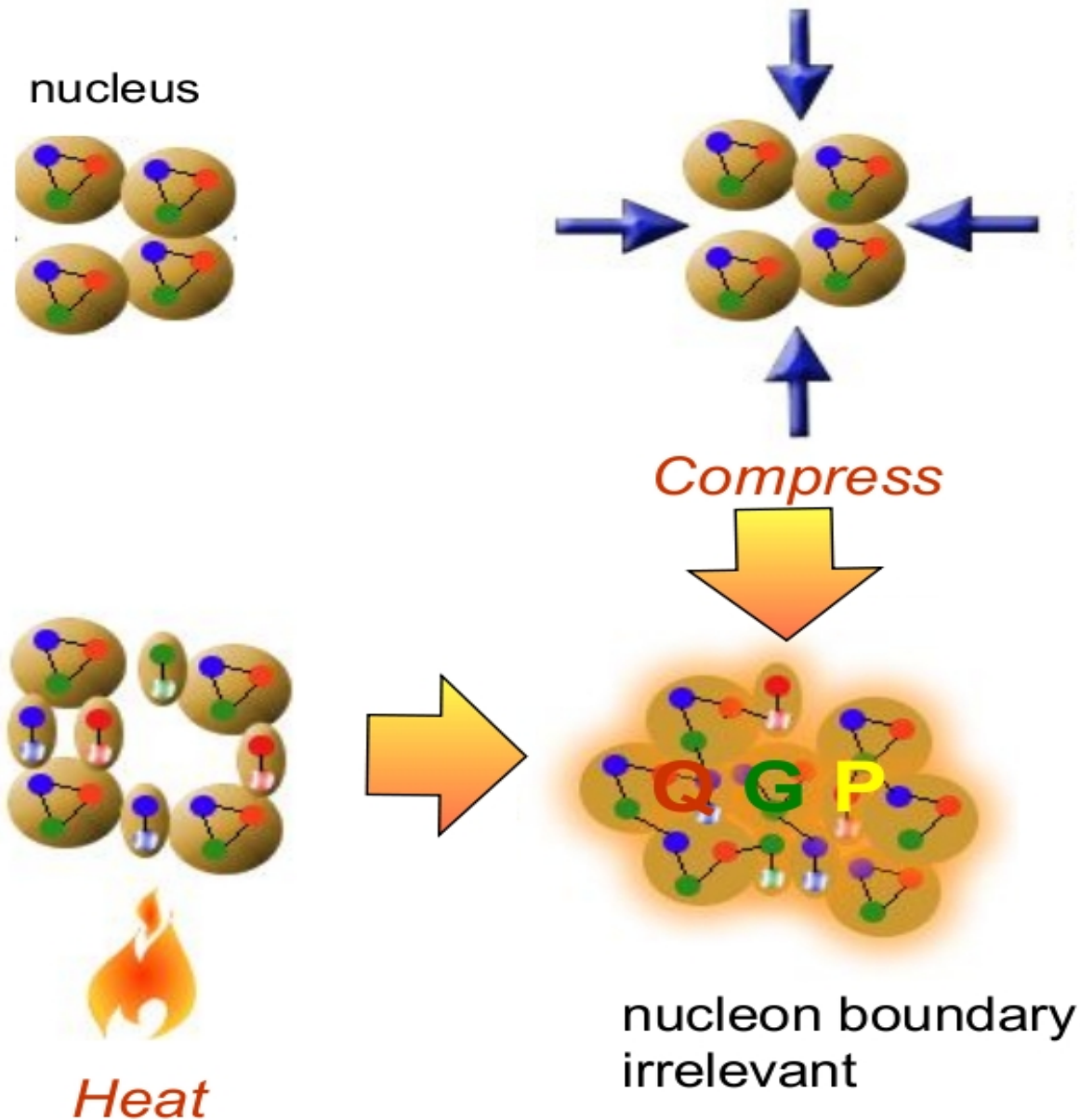
- My prediction: There will be a ridge at the LHC
 - Hydro is mass dependent → need better mass dependent measurements
- Need to understand the ridge to understand fully reconstructed jets
 - Is it background? Is it signal?
- If the ridge isn't from jets, can we use it to learn something else?



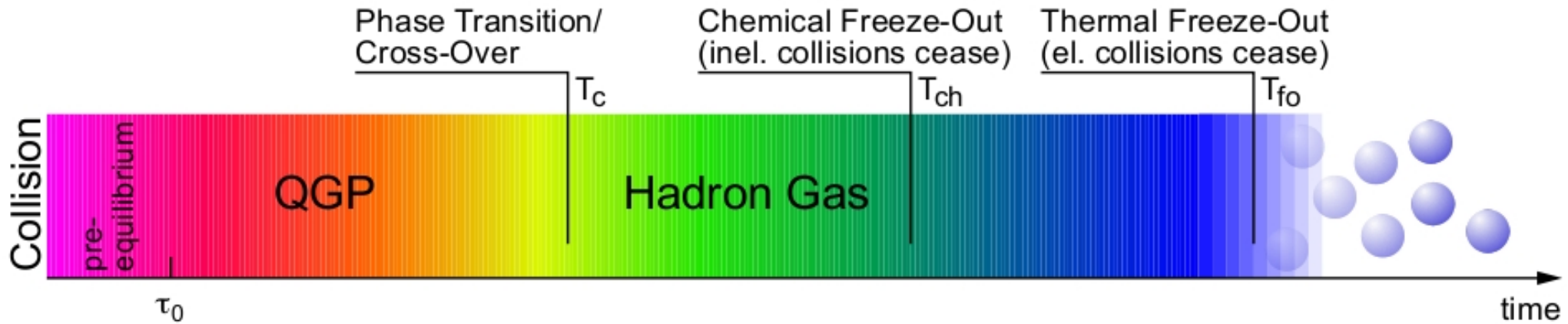
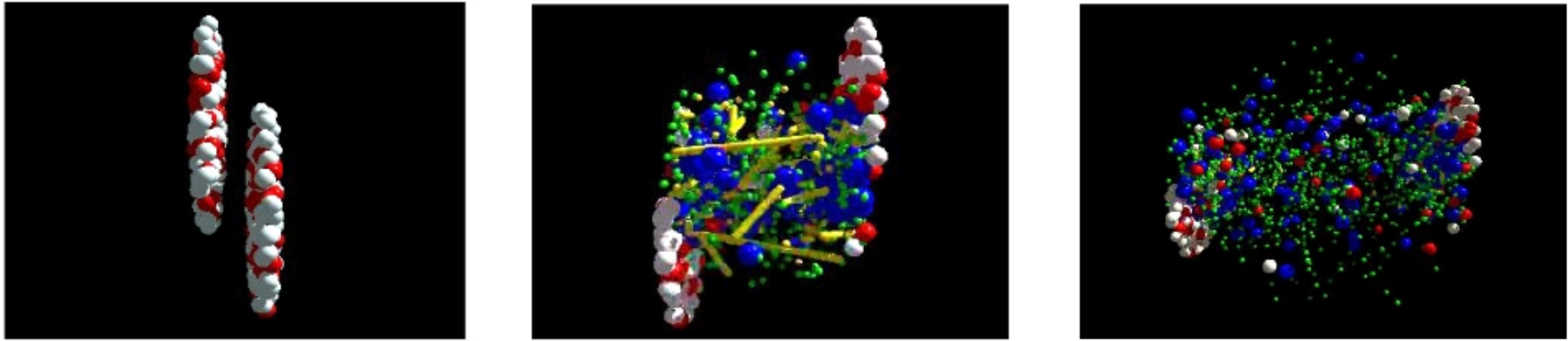
Phase diagram of nuclear matter

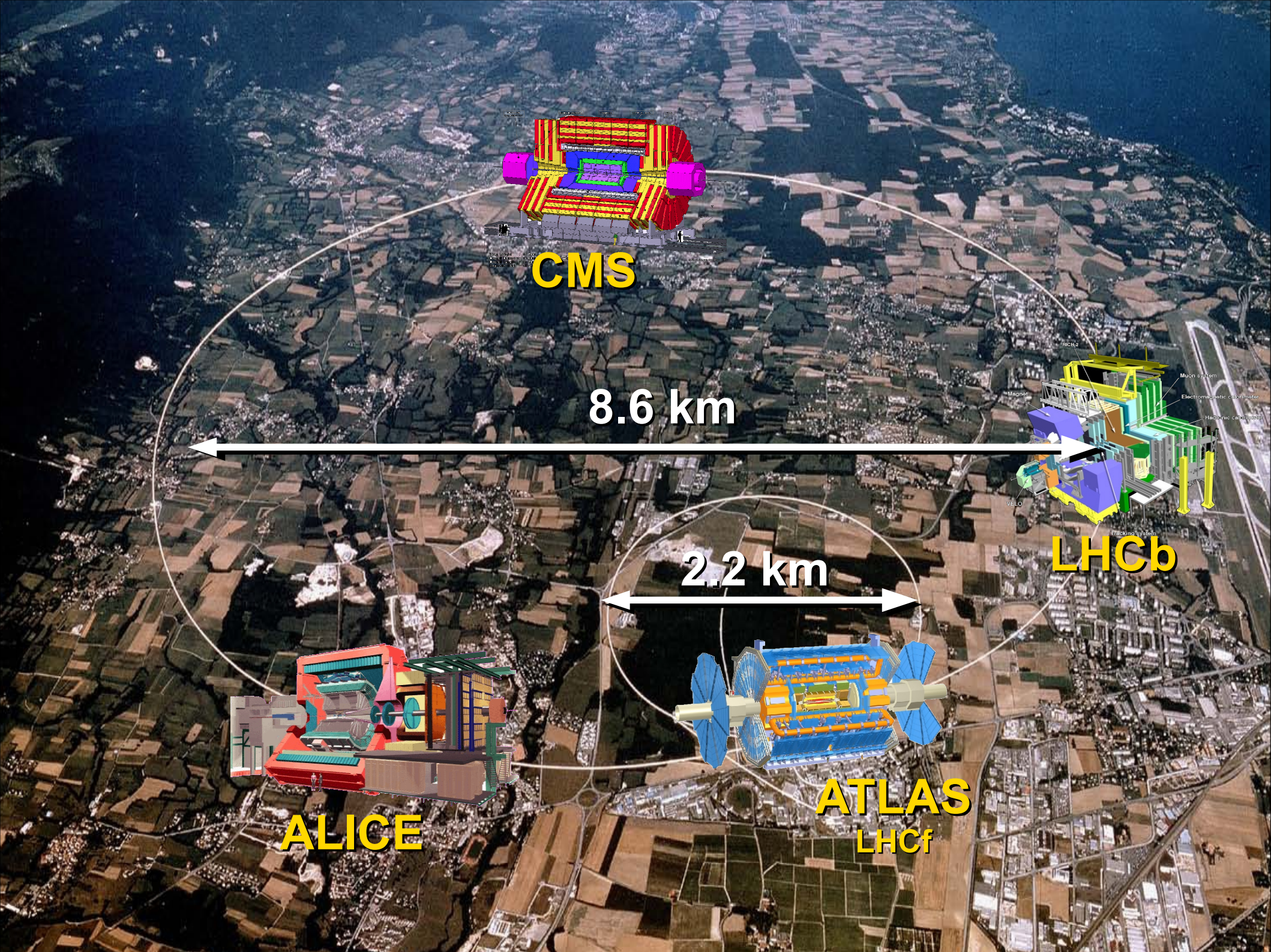


How to make a Quark Gluon Plasma



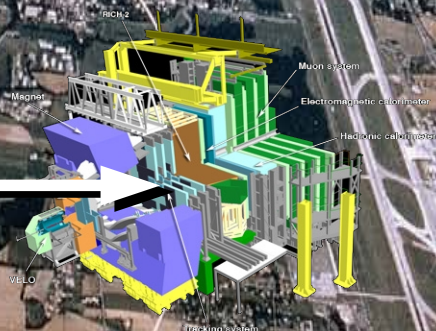
The phase transition in the laboratory





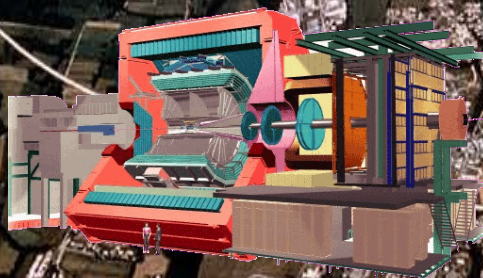
CMS

8.6 km

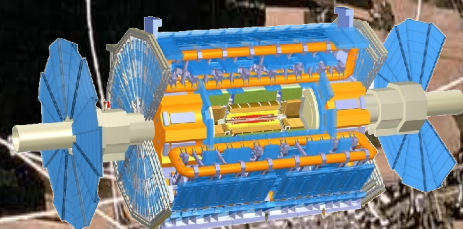


LHCb

2.2 km



ALICE



**ATLAS
LHCf**