Two-particle correlations with STAR

Marek Bombara for the STAR Collaboration

University of Birmingham

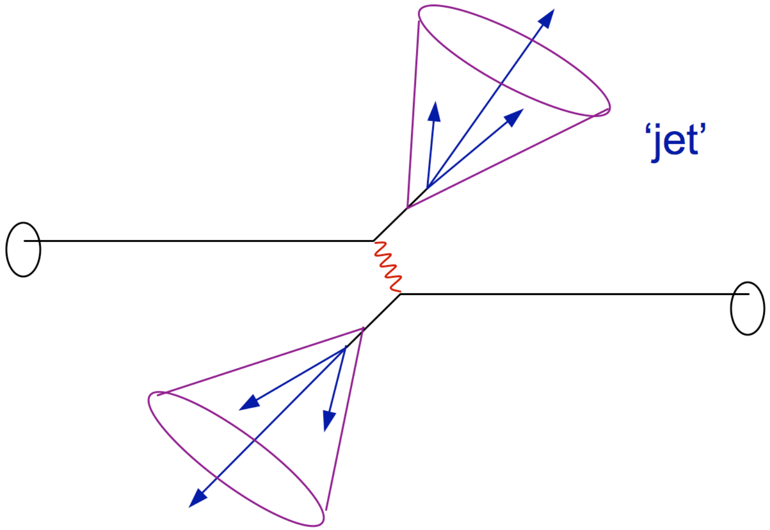
The 2007 Europhysics Conference on High Energy Physics, Manchester, UK, 19 July

Outline

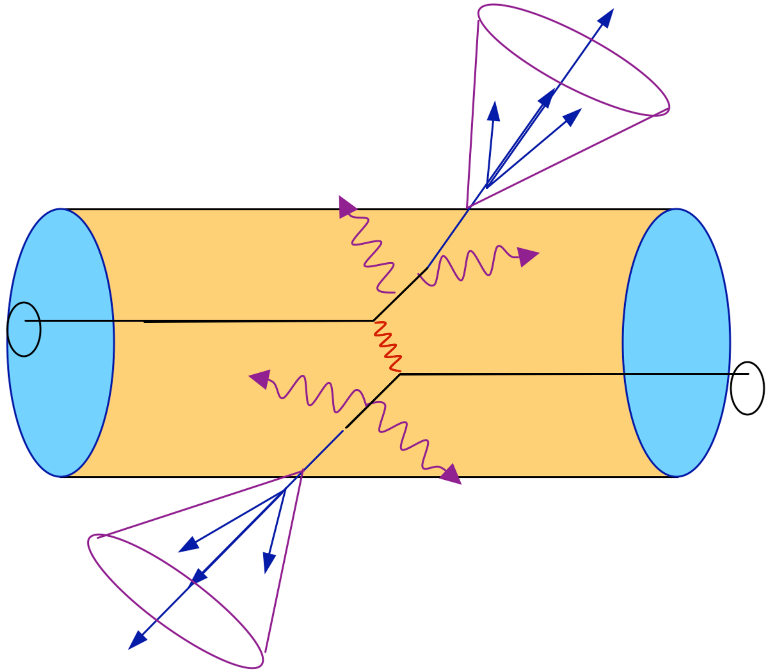
- Introduction
- Correlation technique
- Unidentified particle correlations
- Identified particle correlations
- Summary

Introduction

p+p collisions



Au+Au collisions



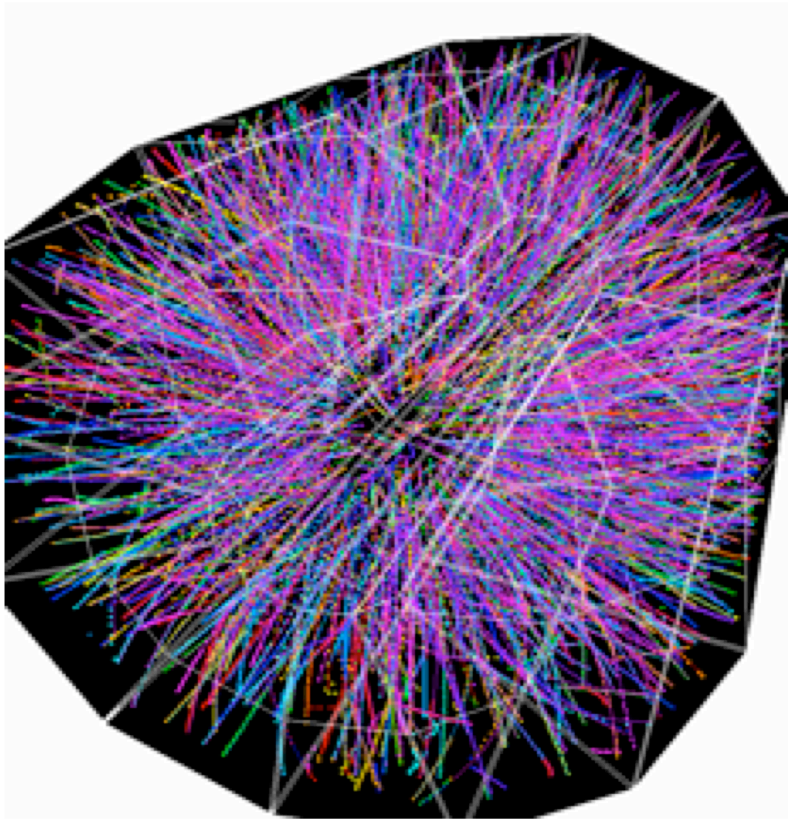
- Hard scattering of partons followed by fragmentation

- Initial state similar to p+p
- Scattered partons interact with the dense partonic medium

Jet tomography: use high energy parton to measure medium properties

Analysis technique: Two-particle correlations

Why two-particle correlations?

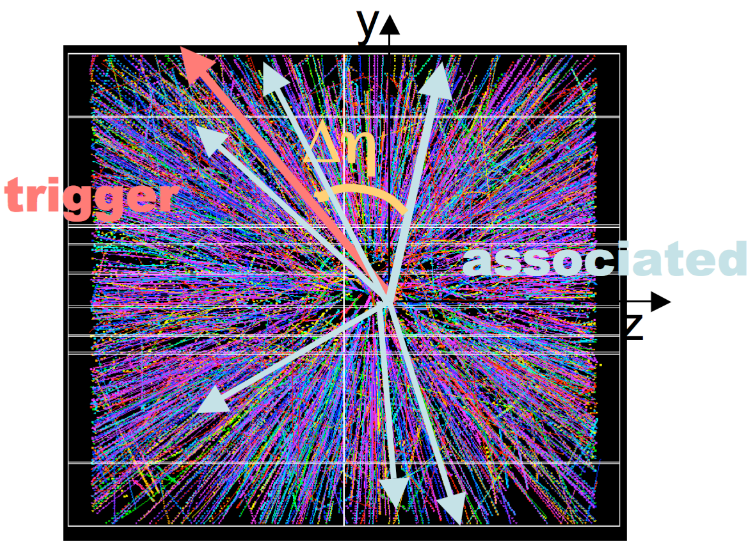


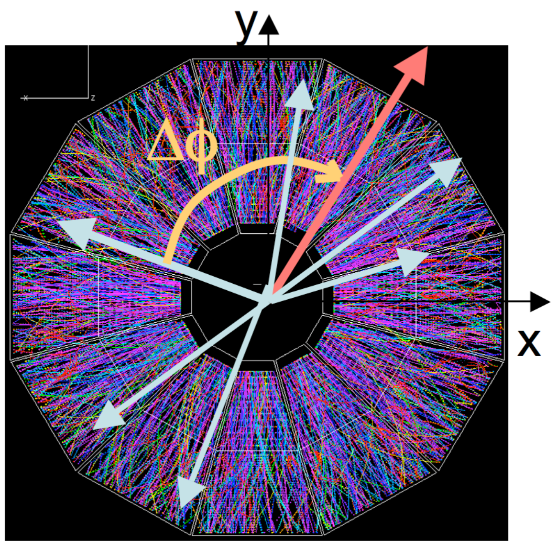
Example of Au+Au event in TPC

- No jet finding algorithm for Au+Au events
- Must use statistical approach for studying jets
  - Two-particle angular correlations
  - Triggering for jet leading particle candidate
  - Summing over millions of events is needed for this analysis

Triggered correlations - HOWTO

1) Find a particle in event with highest momentum in specific p_t range (trigger particle) - we assume that the particle is related to jet leading particle
2) Find particles from the same event with p_t: $p_{t,min} < p_{t,assoc} < p_{t,trig}$ (associated particle)
3) Calculate angular (azimuthal, $\Delta\phi$ and polar, $\sim\Delta\eta$) correlations

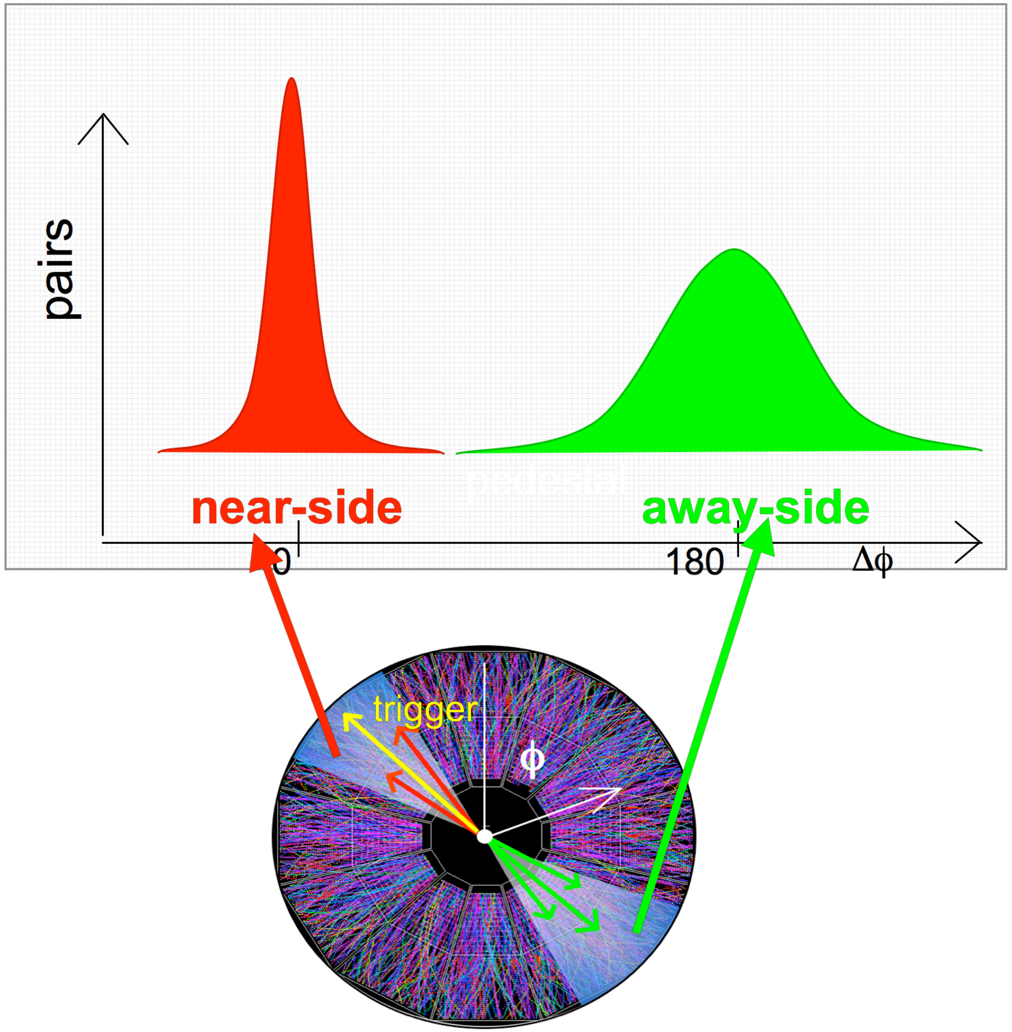




$\Delta\eta = \eta(\text{assoc}) - \eta(\text{trig})$

$\Delta\phi = \phi(\text{assoc}) - \phi(\text{trig})$

Triggered correlations with unidentified particles

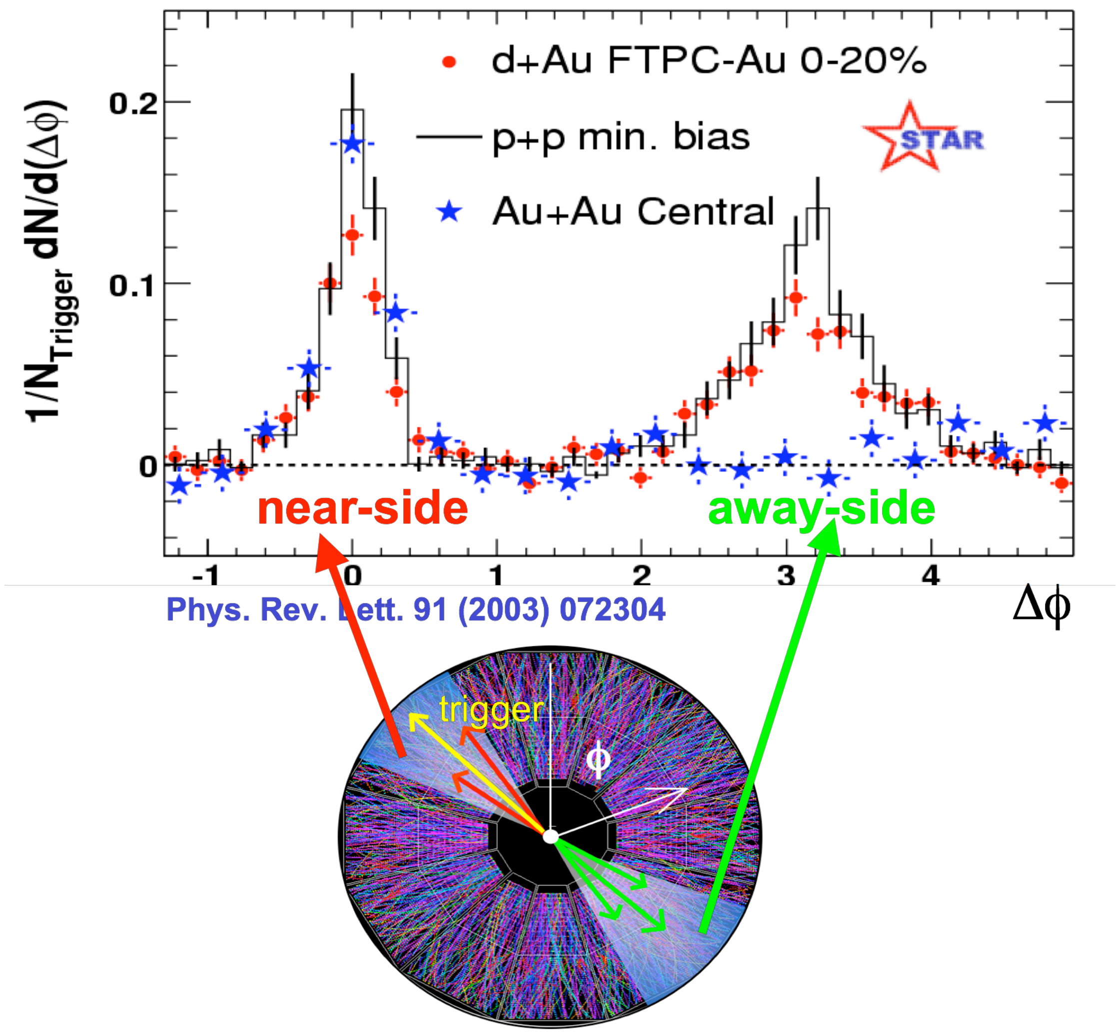


Correlations corrected for:

- Pair-wise detector acceptance
- Single particle reconstruction efficiency
- Combinatorial background modulated by elliptic flow

Triggered correlations with unidentified particles

$4<p_{t,trig}<6$ GeV/c $\quad 2<p_{t,assoc}<p_{t,trig}$



Correlations corrected for:

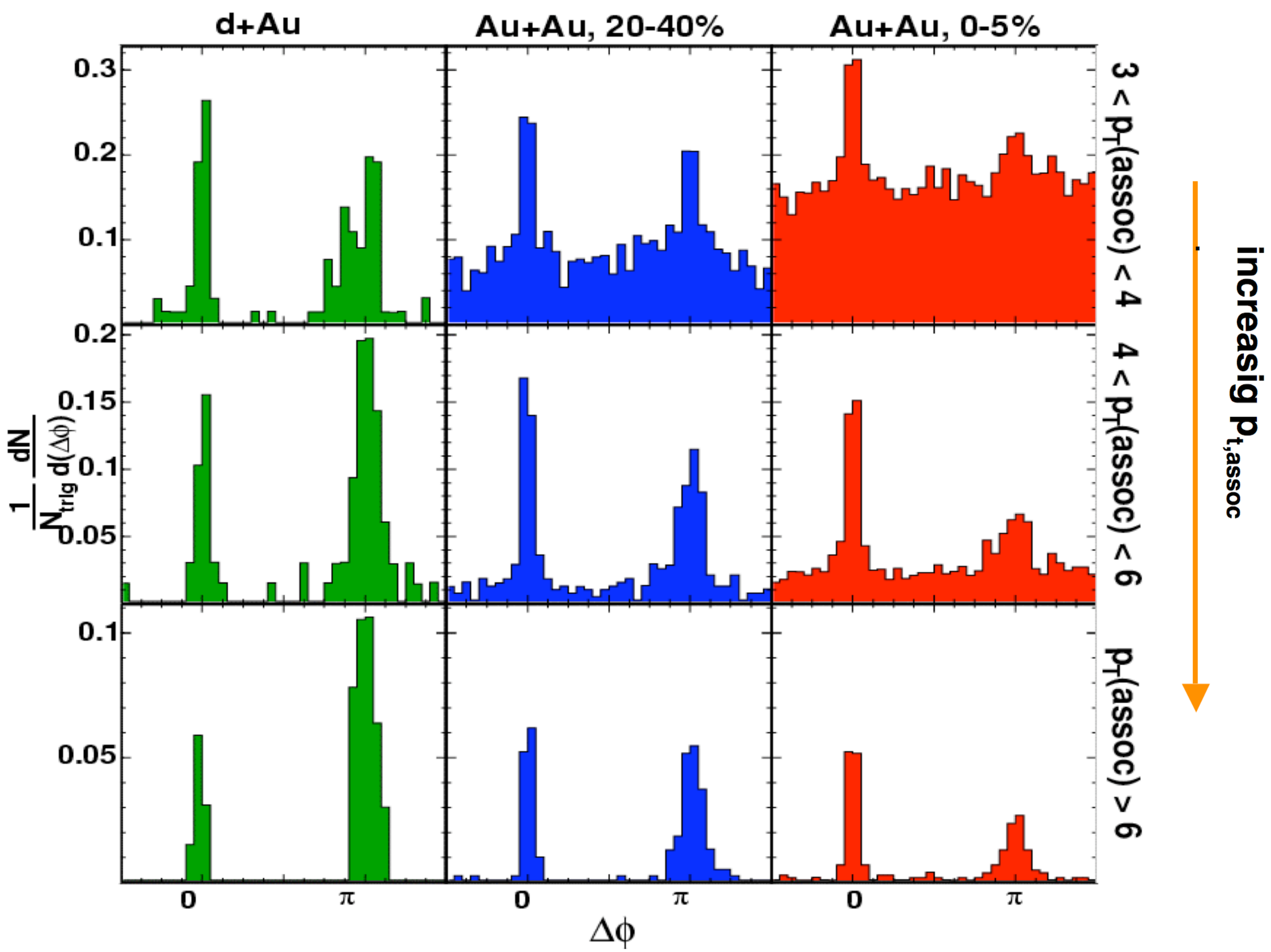
- Pair-wise detector acceptance
- Single particle reconstruction efficiency
- Combinatorial background modulated by elliptic flow

In p+p and d+Au - we see clear di-jet structure

In Au+Au - away-side jet is missing (jet quenching)

Away-side study

Phys. Rev. Lett. 97 (2006) 162301



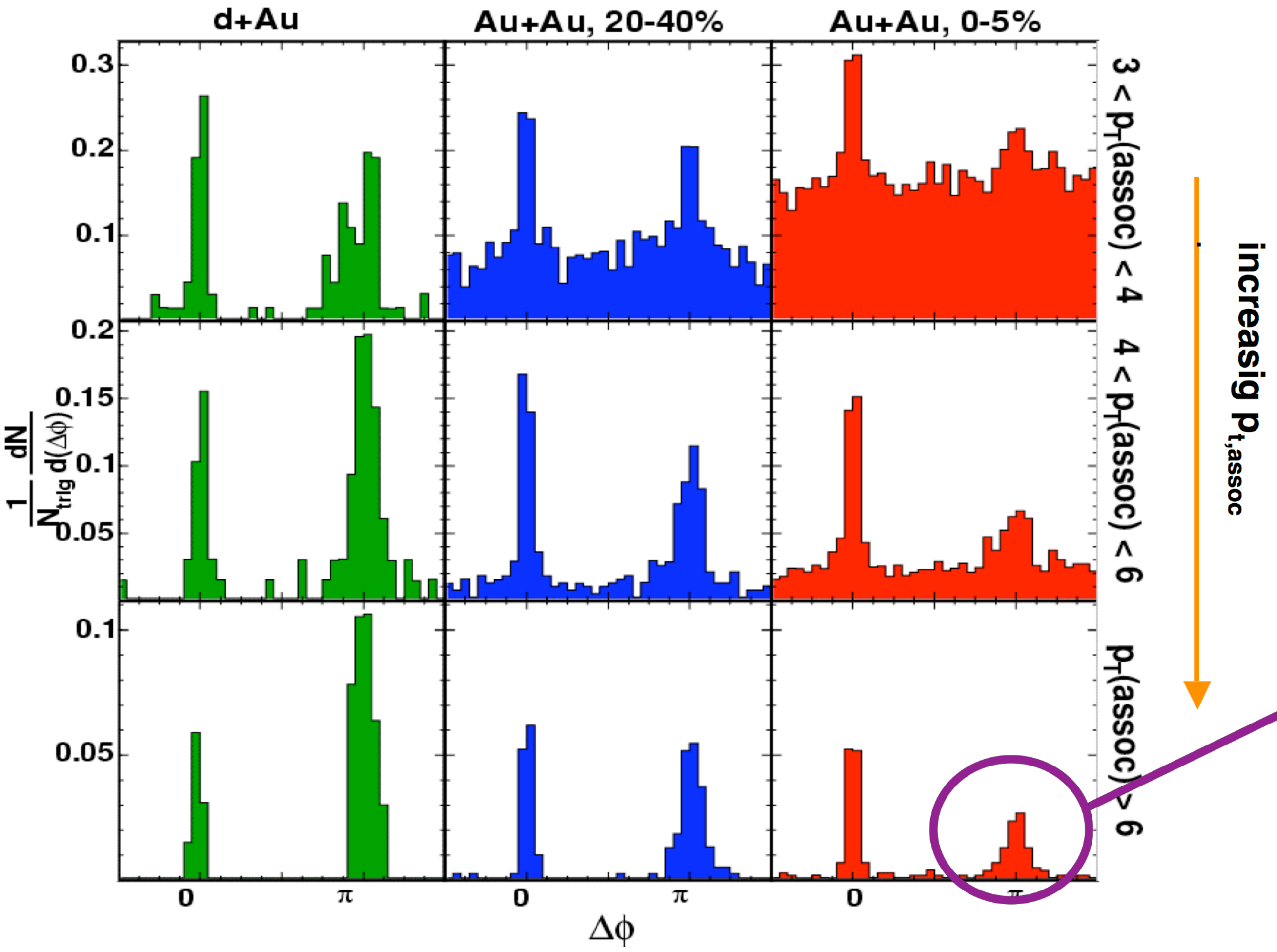
High p_t triggers:

$8 < p_{t,trig} < 15$ GeV/c

- Away-side peak in central Au+Au much smaller than in d+Au - parton energy loss before fragmentation?

Away-side study

Phys. Rev. Lett. 97 (2006) 162301



High p_t triggers:

$8 < p_{t,trig} < 15$ GeV/c

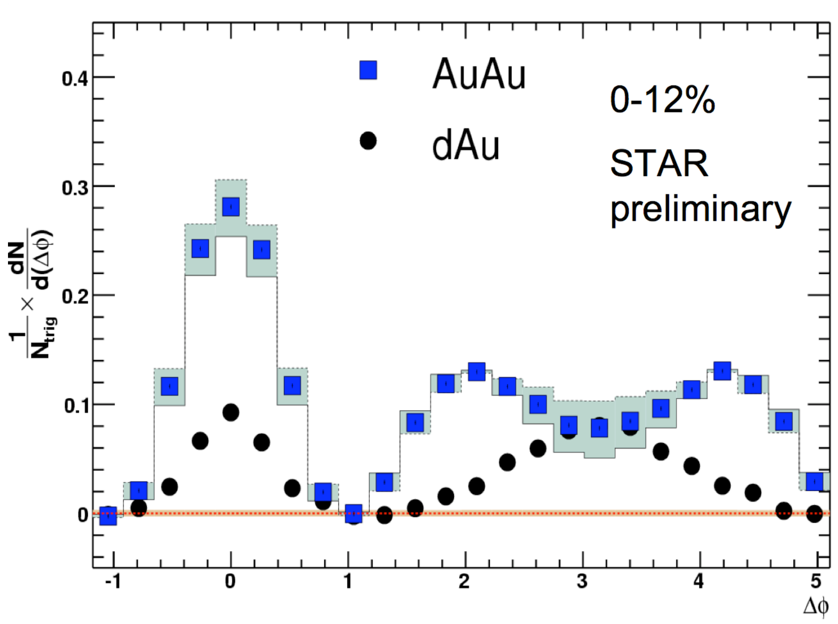
Reappearance of back-to-back jet in central Au+Au collisions for high $p_{t,assoc}$

- Away-side peak in central Au+Au much smaller than in d+Au - parton energy loss before fragmentation?

Discovery of modified away-side at lower p_t

$3<p_{t,trig}<4$ GeV/c

$1.3<p_{t,assoc}<1.8$ GeV/c

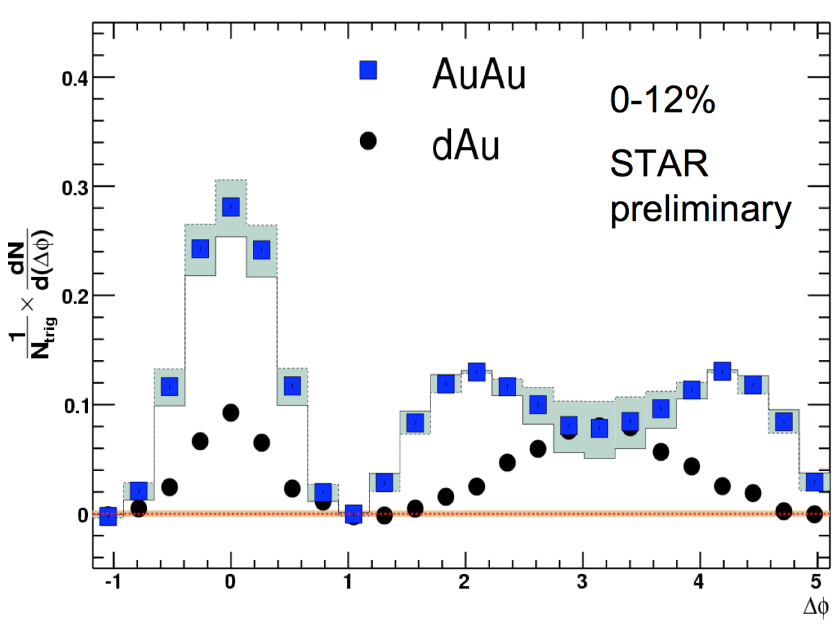


- Near-side enhanced in comparison to d+Au
- Away-side enhanced as well and doubly bumped
- Origin of bumps - source of many speculations (Mach cone, Jet deflection, Cherenkov radiation, …)
- More appropriate analysis technique for investigation of bumps origin: 3-particle correlations

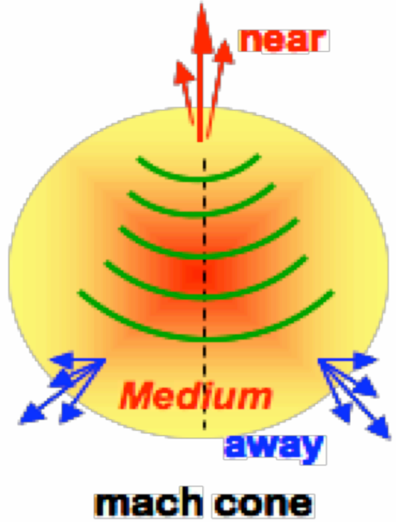
Discovery of modified away-side at lower p_t

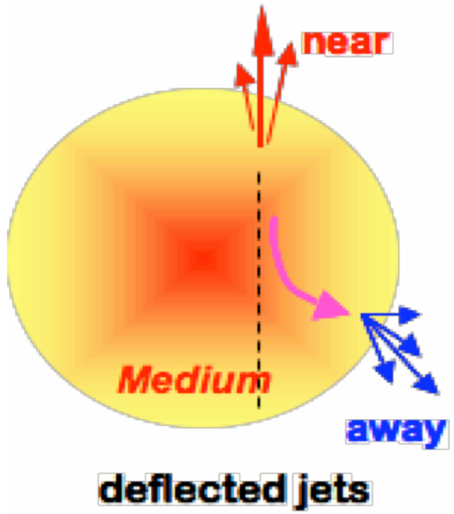
$3<p_{t,trig}<4$ GeV/c

$1.3<p_{t,assoc}<1.8$ GeV/c



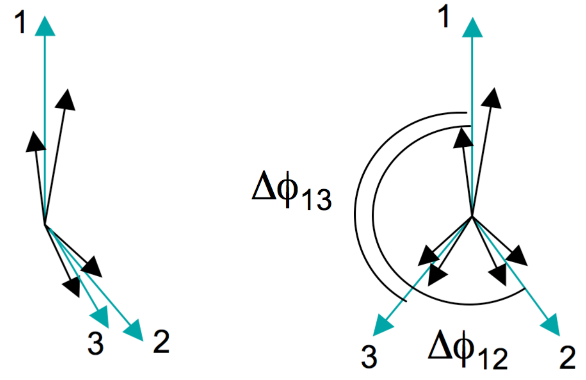
?





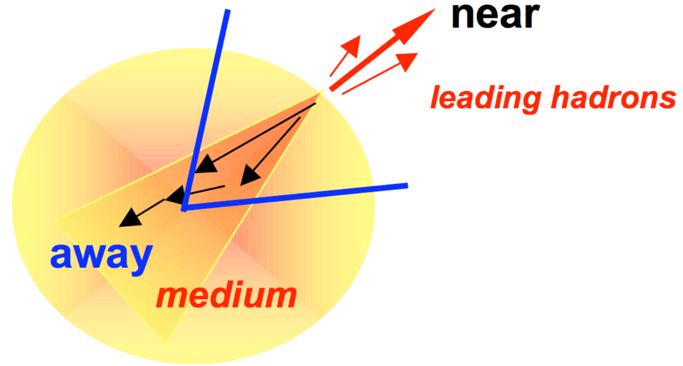
- Near-side enhanced in comparison to d+Au
- Away-side enhanced as well and doubly bumped
- Origin of bumps - source of many speculations (Mach cone, Jet deflection, Cherenkov radiation, …)
- More appropriate analysis technique for investigation of bumps origin: 3-particle correlations

3-particle correlations analysis

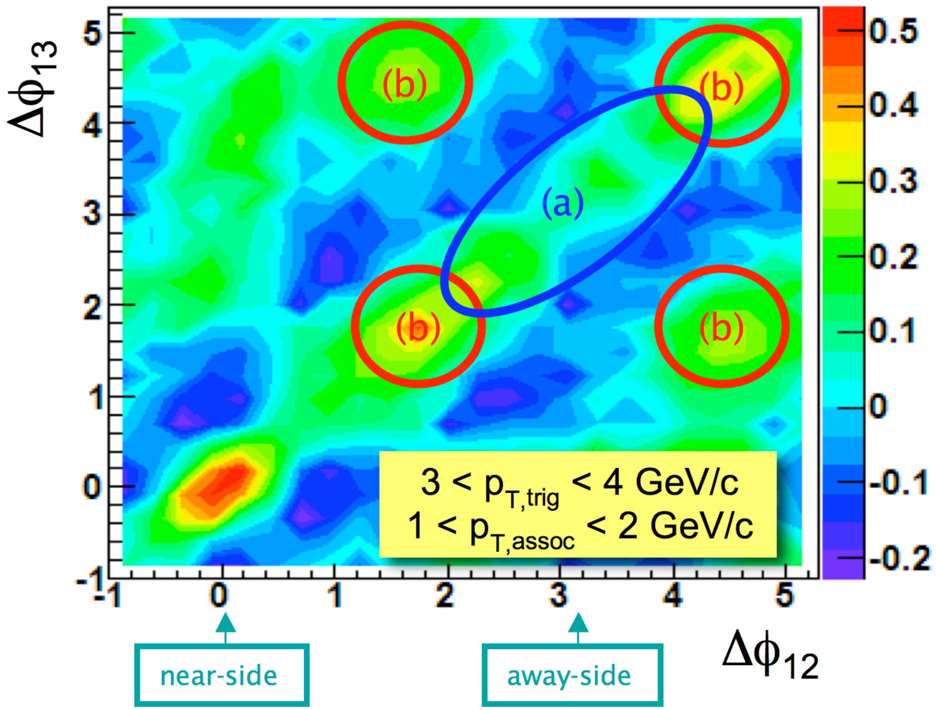


1 - trigger

2,3 - associated



(a) Deflected jets (b) Conical emission



Possible shock waves and mach cones?

Renk and Ruppert, Phys. Rev. C 73 (2006) 011901

Two methods:

(i) Cummulant

Unambiguous evidence for 3-particle correlations, although not definitive about conical emission.

(ii) Jet-flow background (shown)

Model dependent analysis.

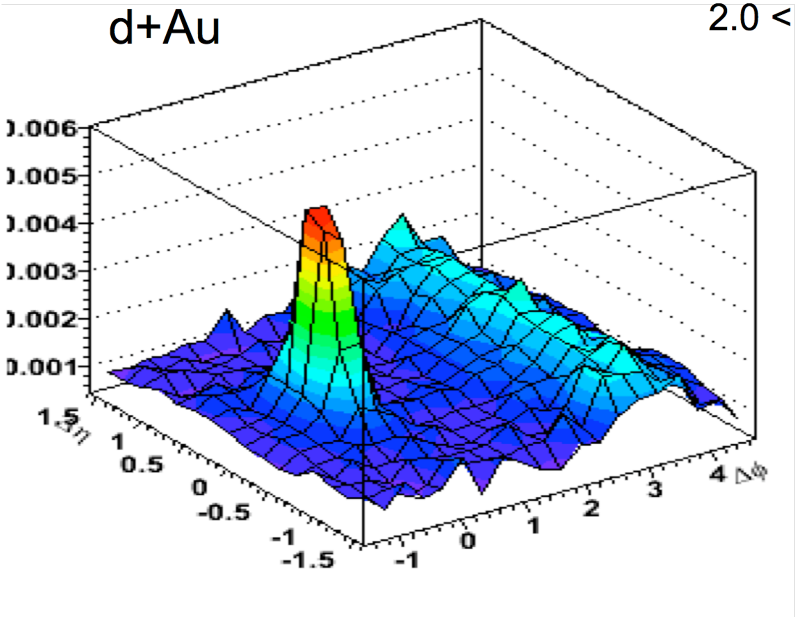
Evidence for conical emission.

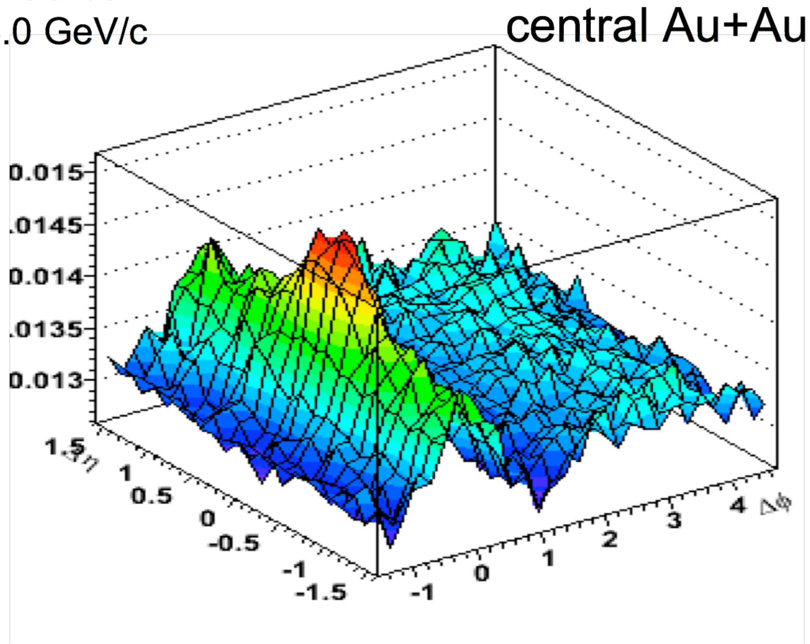
Note: Large and complicated backgrounds.

Near-side study

What we have seen in unidentified 2D h-h correlations:

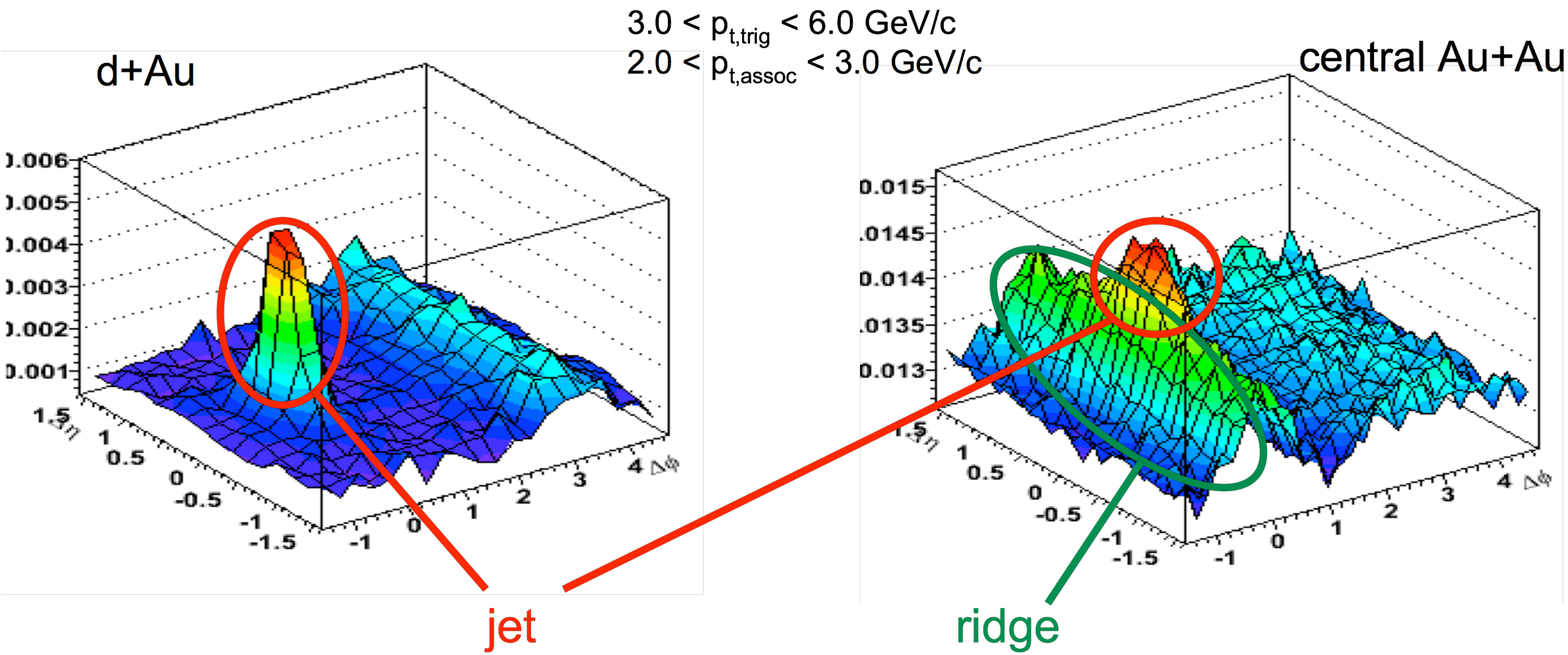
$3.0 < p_{t,trig} < 6.0$ GeV/c
$2.0 < p_{t,assoc} < 3.0$ GeV/c





Near-side study

What we have seen in unidentified 2D h-h correlations:



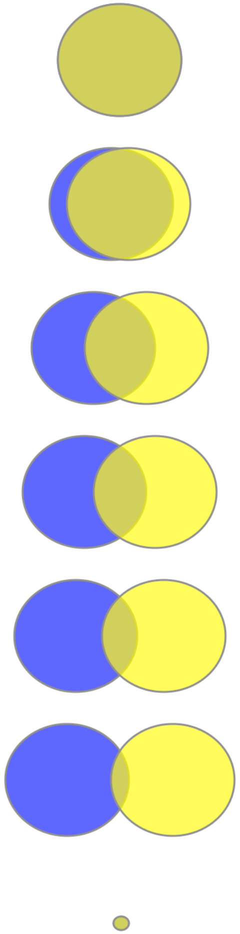
Near-side peak broader in $\Delta\eta$ and peak sits atop a ridge!

Centrality dependence

central

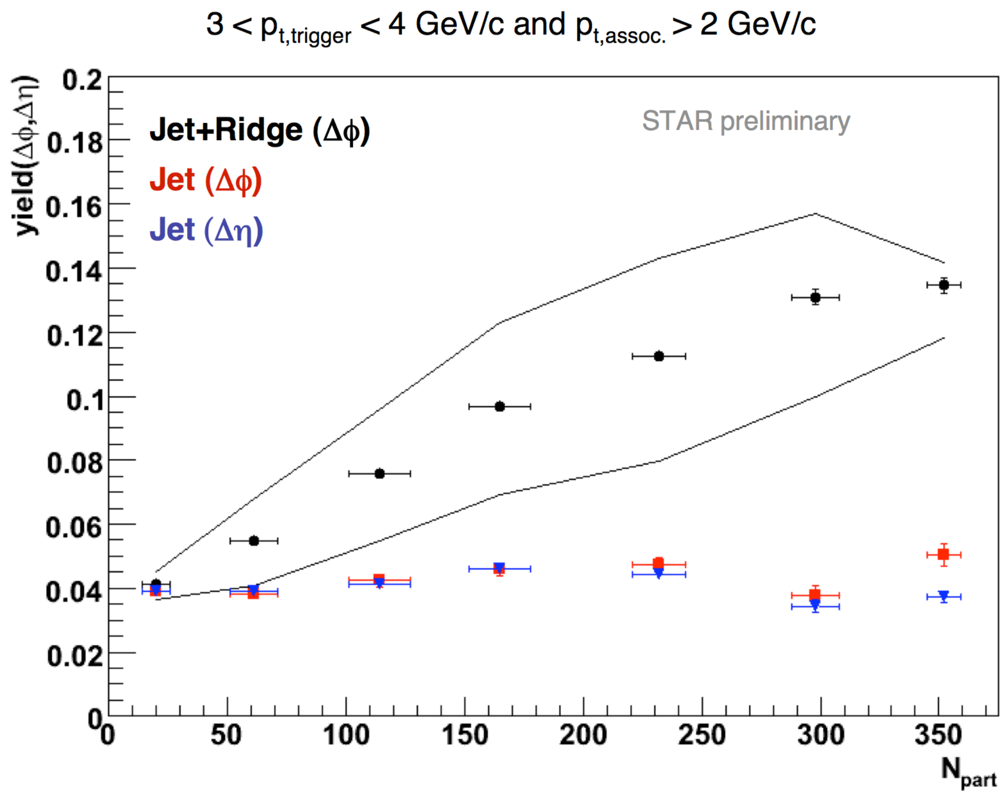
peripheral

pp



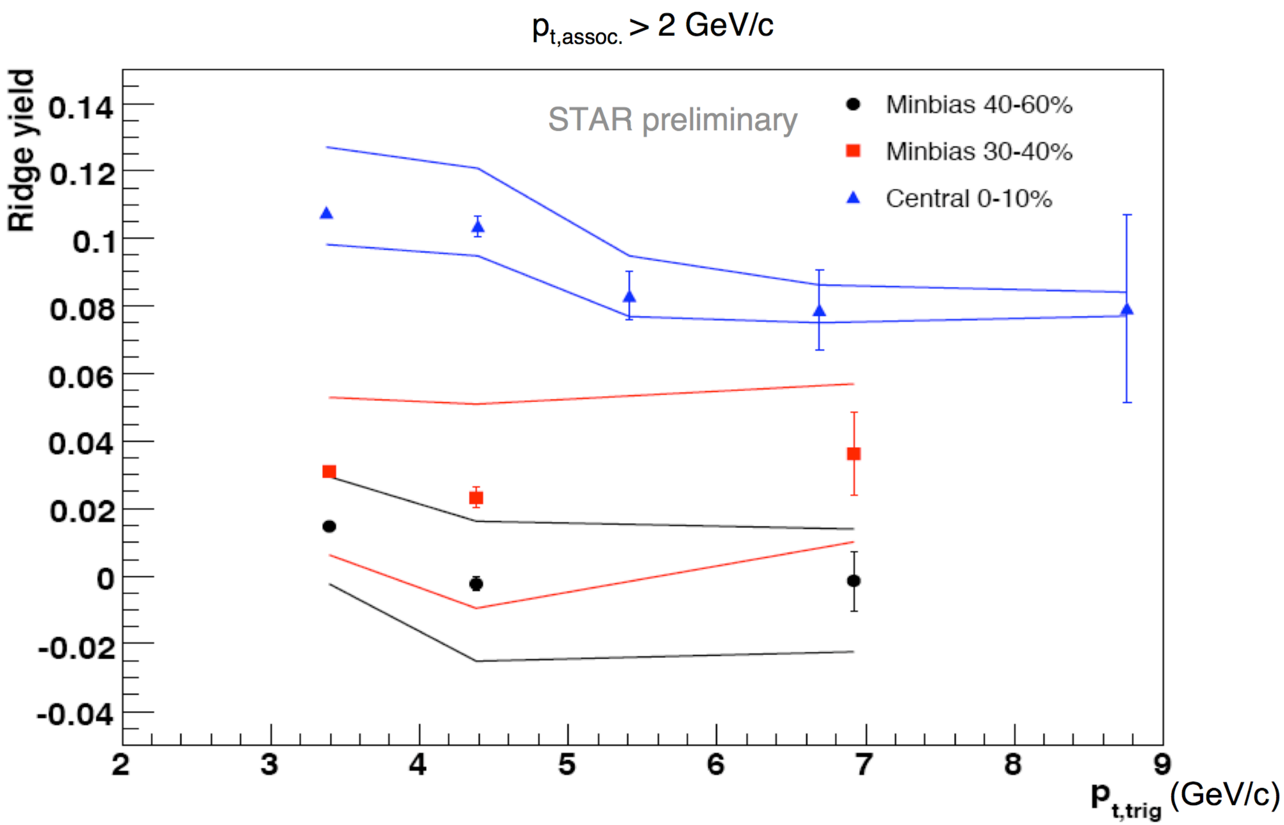
	N_{part}
0-5%	352
5-10%	299
10-20%	235
20-30%	167
30-40%	116
40-60%	62
60-80%	21
pp	2

N_{part} = number of particles that participate in the reaction



- Jet yield doesn't depend on centrality and comparable to d+Au
- Ridge yield increases with centrality

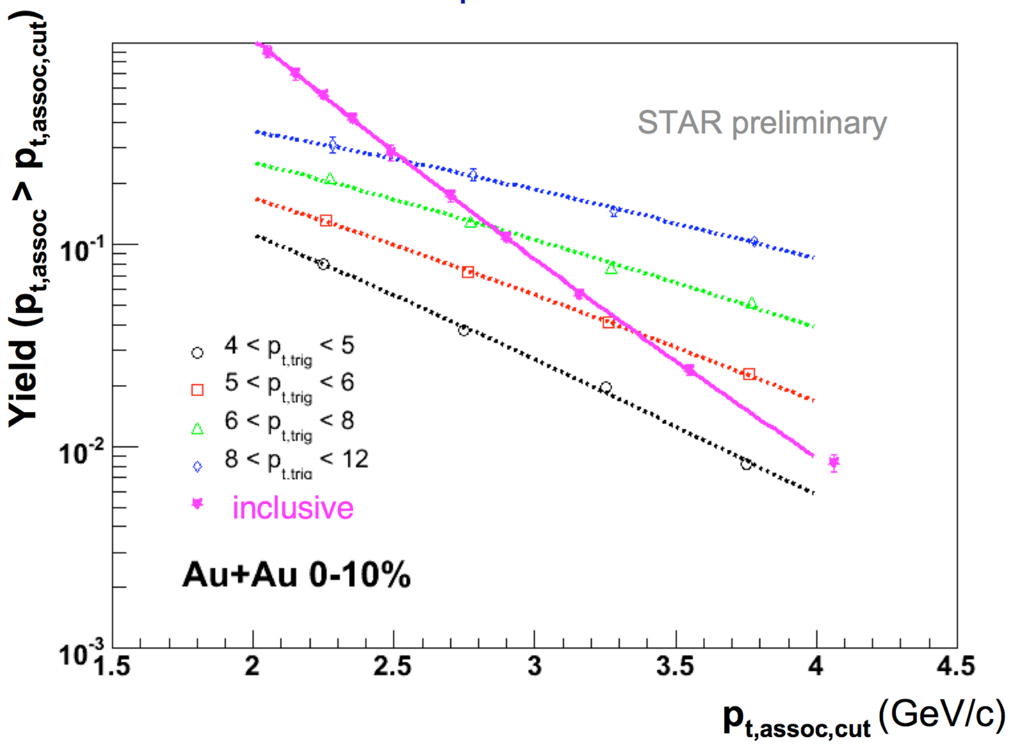
Ridge $p_{t,trig}$ dependence



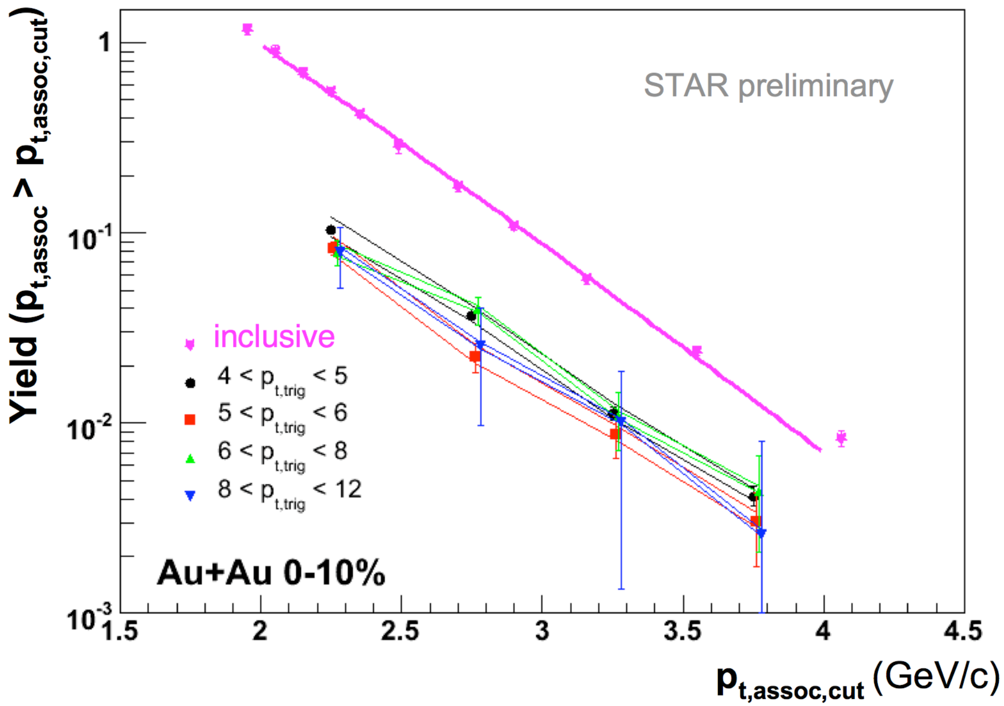
- Ridge seen only in Au+Au
- Ridge yield persists to highest $p_{t,trig}$ - correlation with jet production?

$P_{t,assoc}$ distributions

Jet spectra

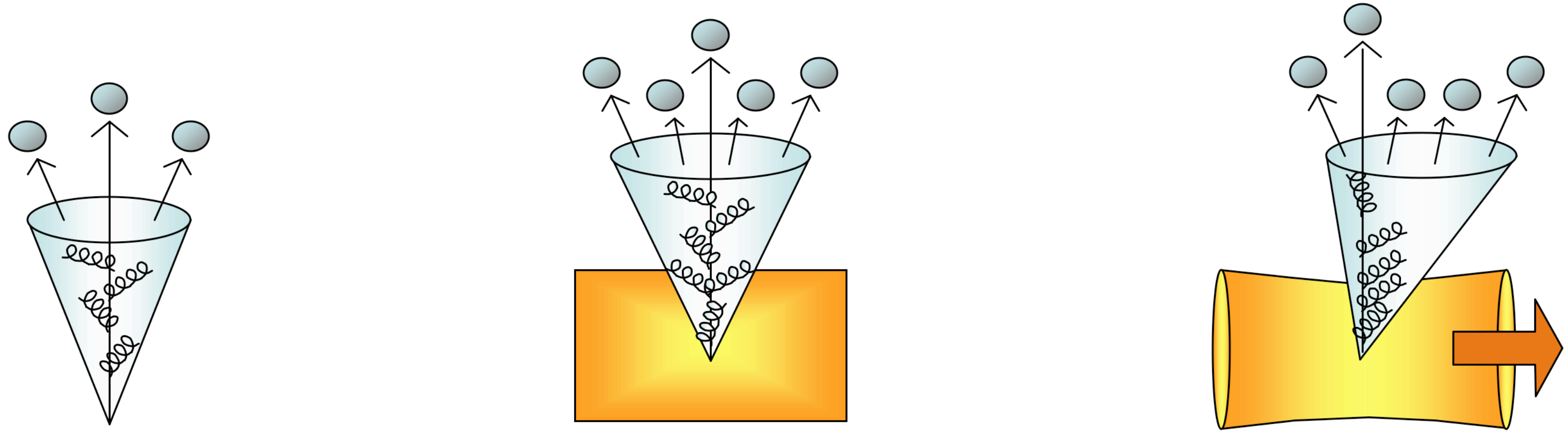


Ridge spectra



- Momenta of particles in the jet are harder than in the bulk
- Ridge momentum distributions similar to the bulk and no strong dependence of $p_{t,trig}$

What causes the ridge and jet broadening?



In vacuo (pp) fragmentation | static medium broadening | flowing medium anisotropic shape

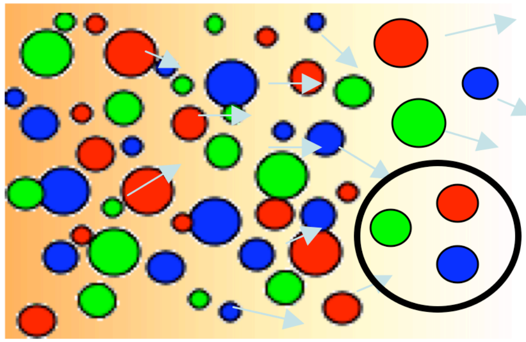
- Radiated gluons, broadened by
  - Longitudinal flow (N. Armesto, C.A. Salgado, U.A. Wiedemann, PRL 93, 2004)
  - QCD magnetic fields (A. Majumder, B. Mueller, S.A.Bass, hep-ph/0611135)
  - Anisotropic QGP (P. Romatschke, Phys.Rev. C 75, 014901, 2007)
- Medium heating + recombination

  (C.B. Chiu, R.C. Hwa, Phys. Rev. C 72, 2005)
- Radial flow + trigger bias

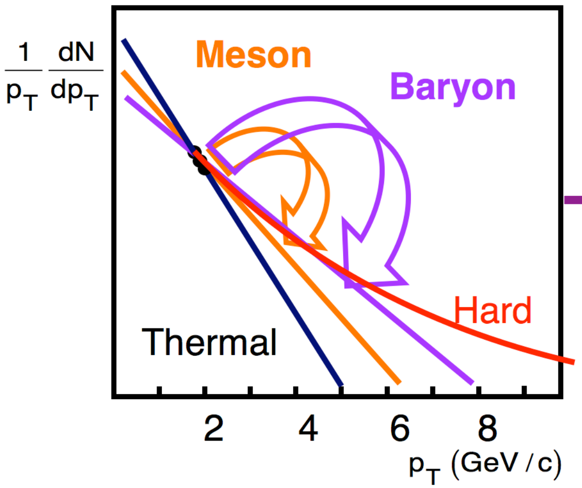
  (S.A. Voloshin, Nucl. Phys. A749, 2005)

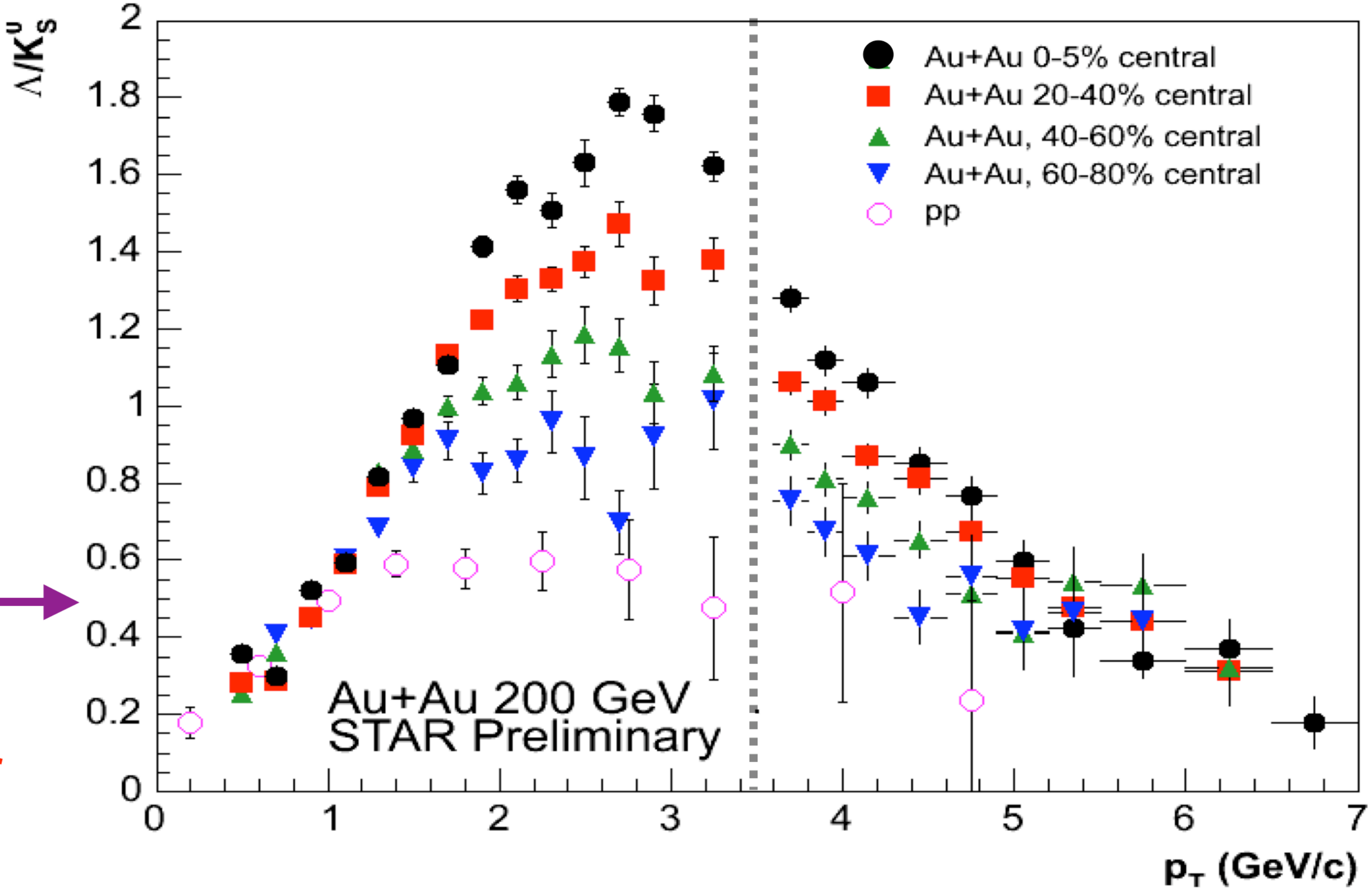
Triggered correlations with identified particles

Particle production mechanism at intermediate p_t - quark recombination



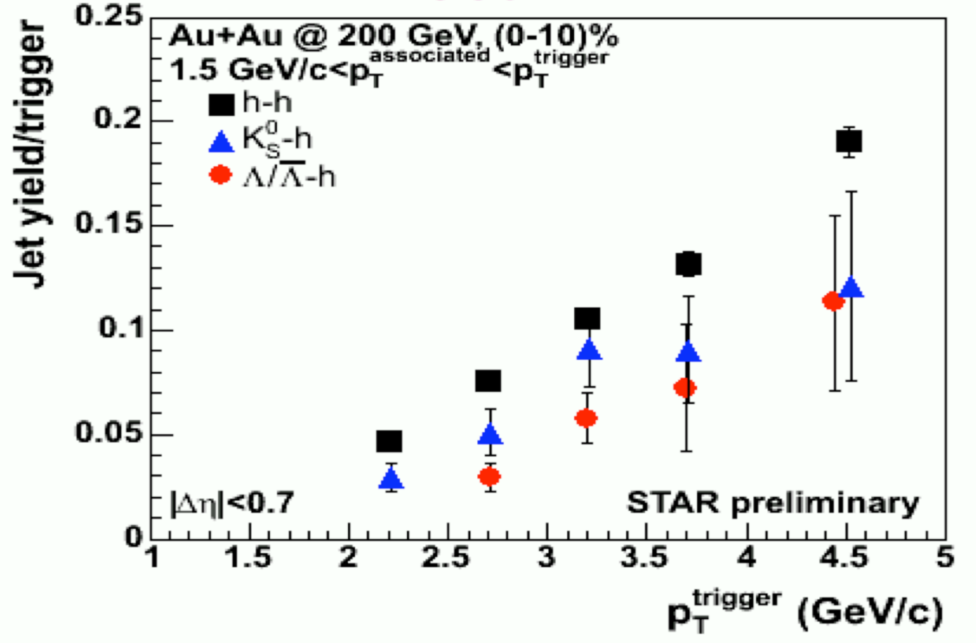
Quark recombination



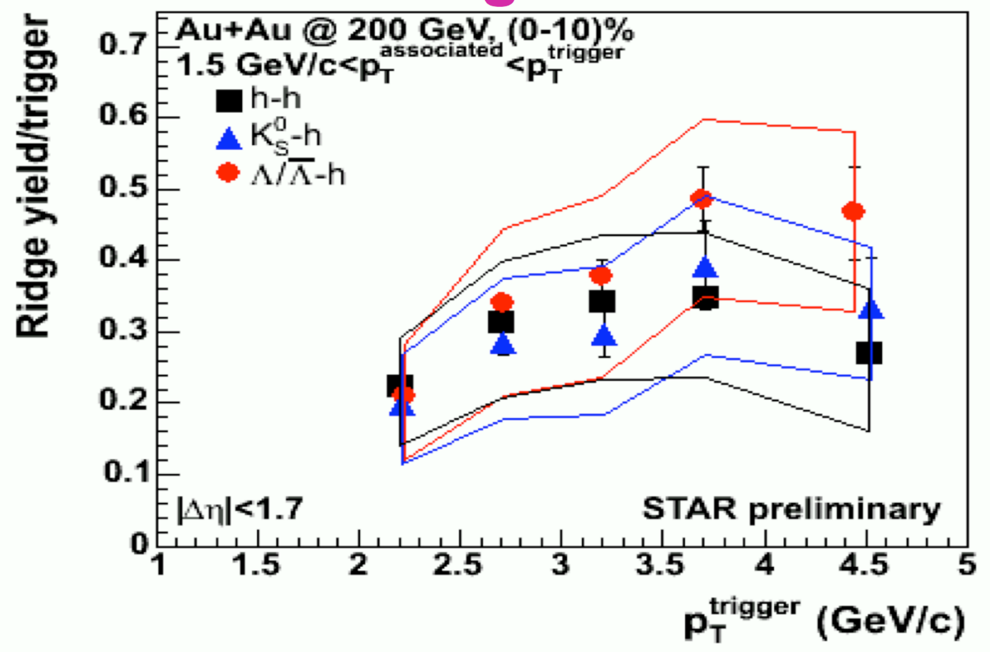


Jet/Ridge study with PID

Jet



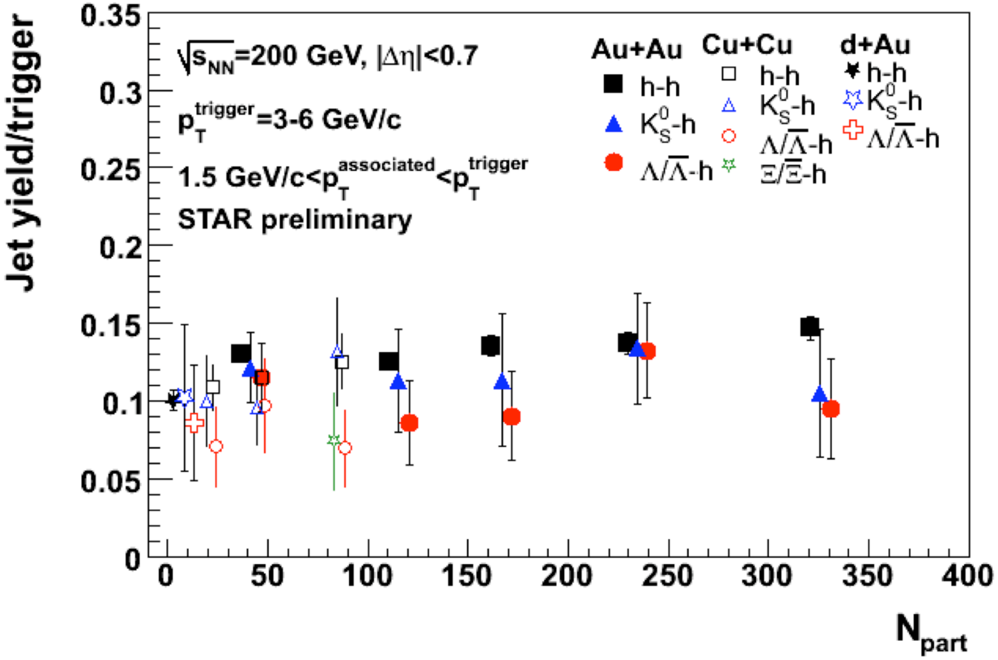
Ridge



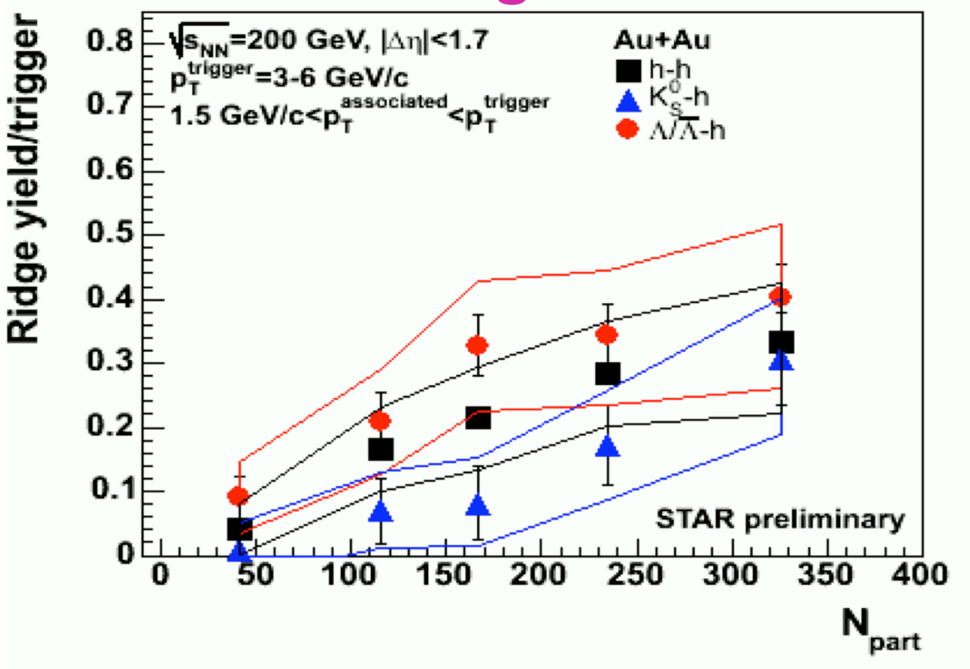
- Jet yield is increasing with p_{Ttrig}
- Ridge yield dependence?
- No trigger species dependence

System size

Jet

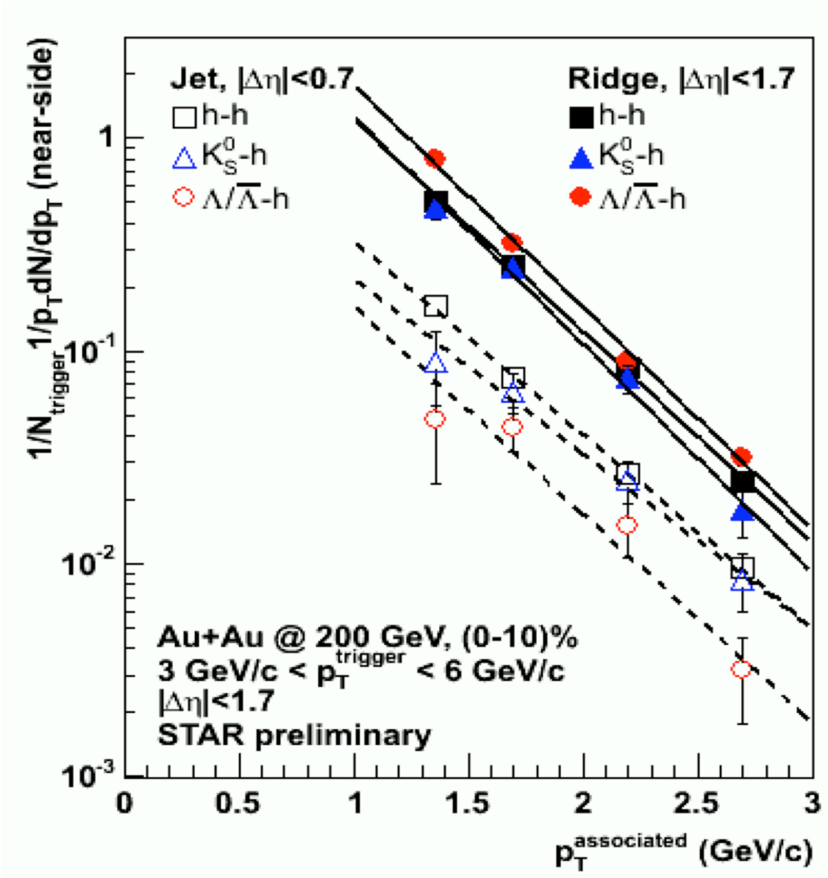


Ridge



- Jet yield for strange triggers also independent of centrality
- Ridge yield increases with centrality
- Apparent trigger species dependence for ridge yield

P_T distribution of associated particles



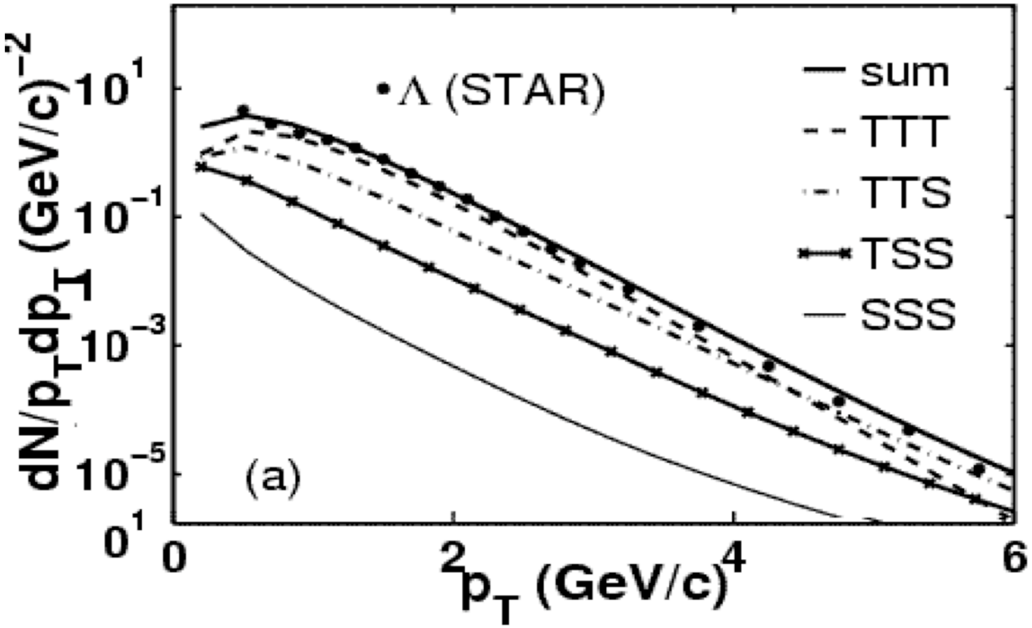
Trigger particle	T(ridge) MeV	T (jet) MeV
$h^{+/-}$	438 ± 4 (stat.)	478 ± 8
K^0_S	406 ± 20 (stat.)	530 ± 61
Λ	416 ± 11 (stat.)	445 ± 49

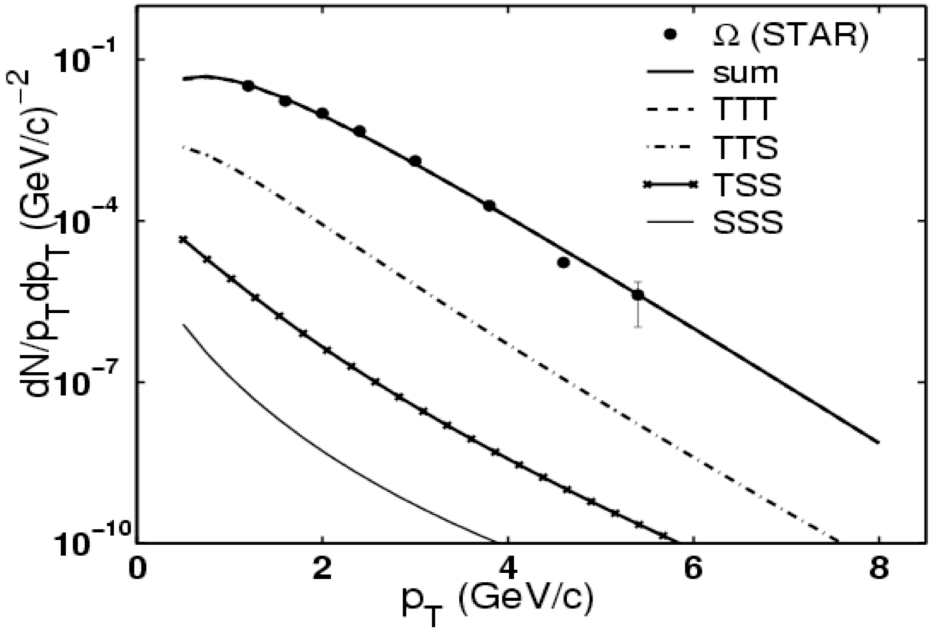
- Same as in unidentified correlations
- Ridge p_T distribution similar to medium in the same p_T range
- Jet distribution harder

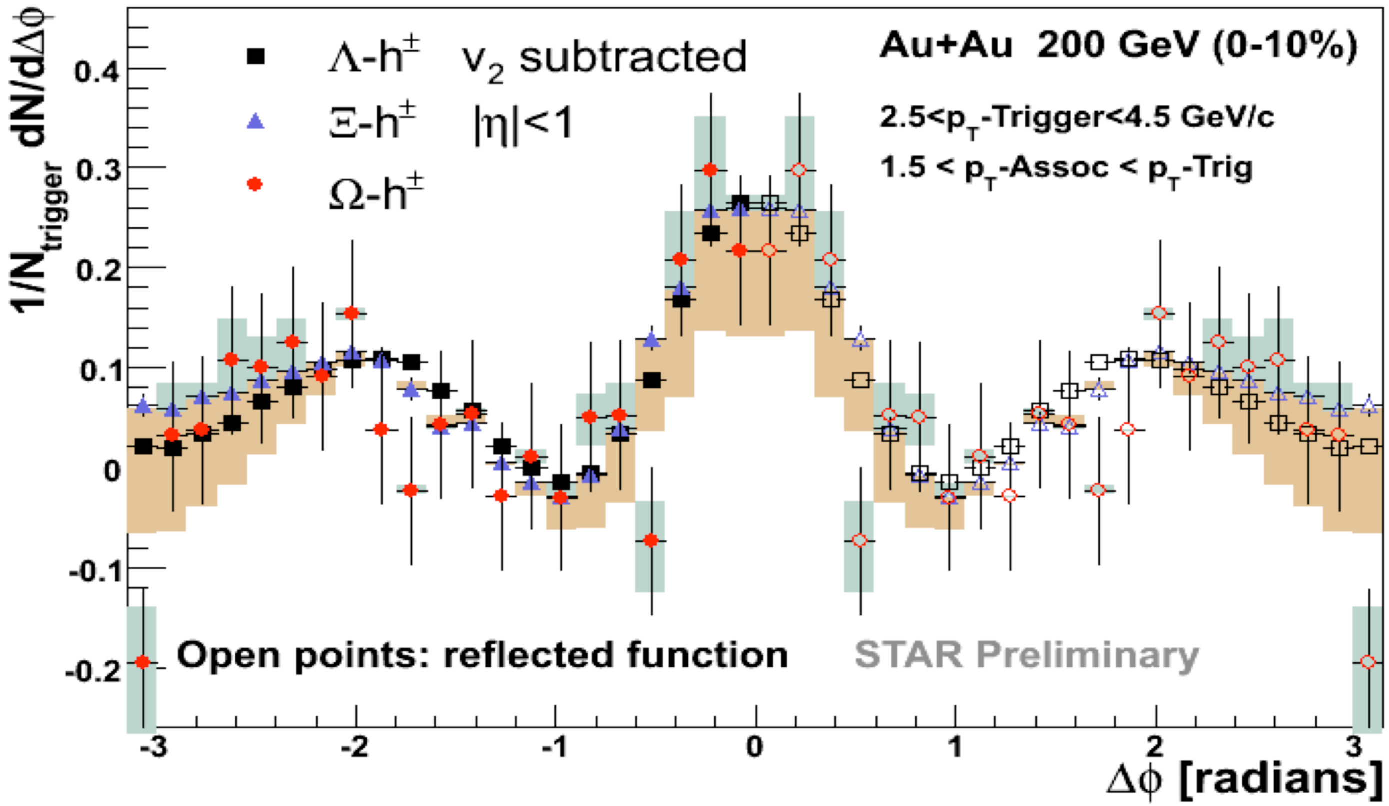
Multi-strange correlations

Recombination model: multi-strange particle production dominated by thermal recombination

R.C Hwa & C.B. Yang nucl-th/0602024

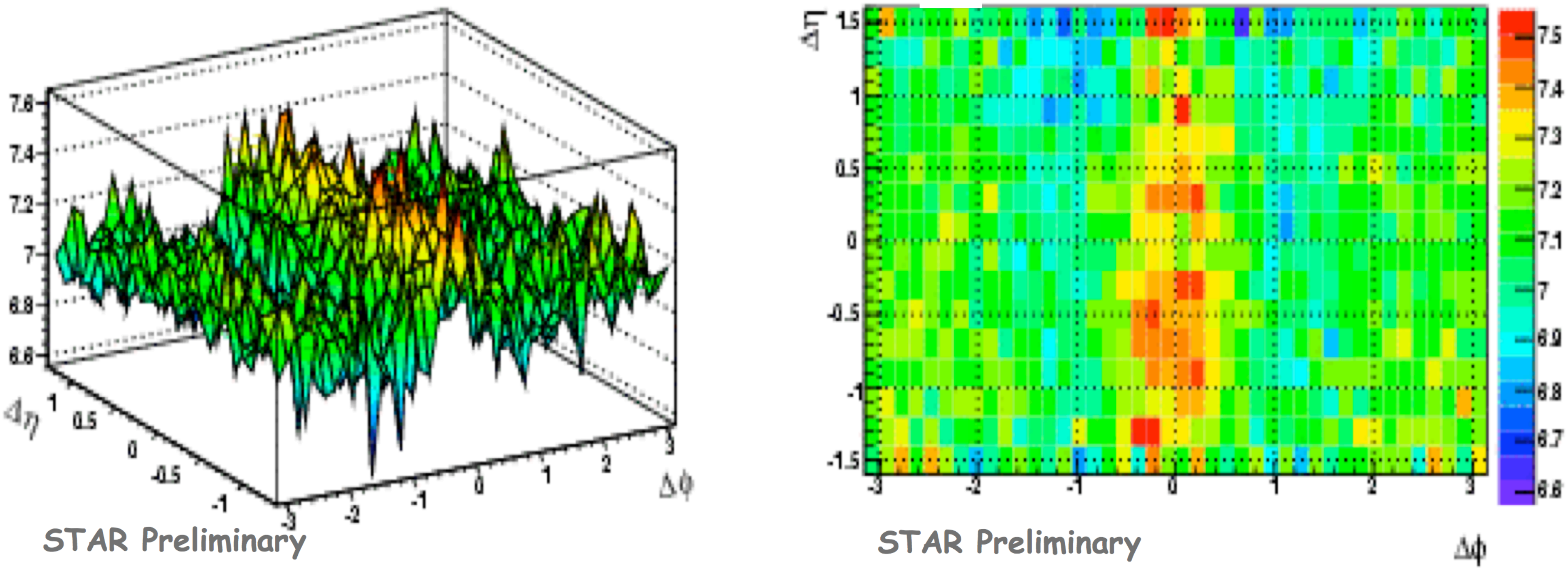






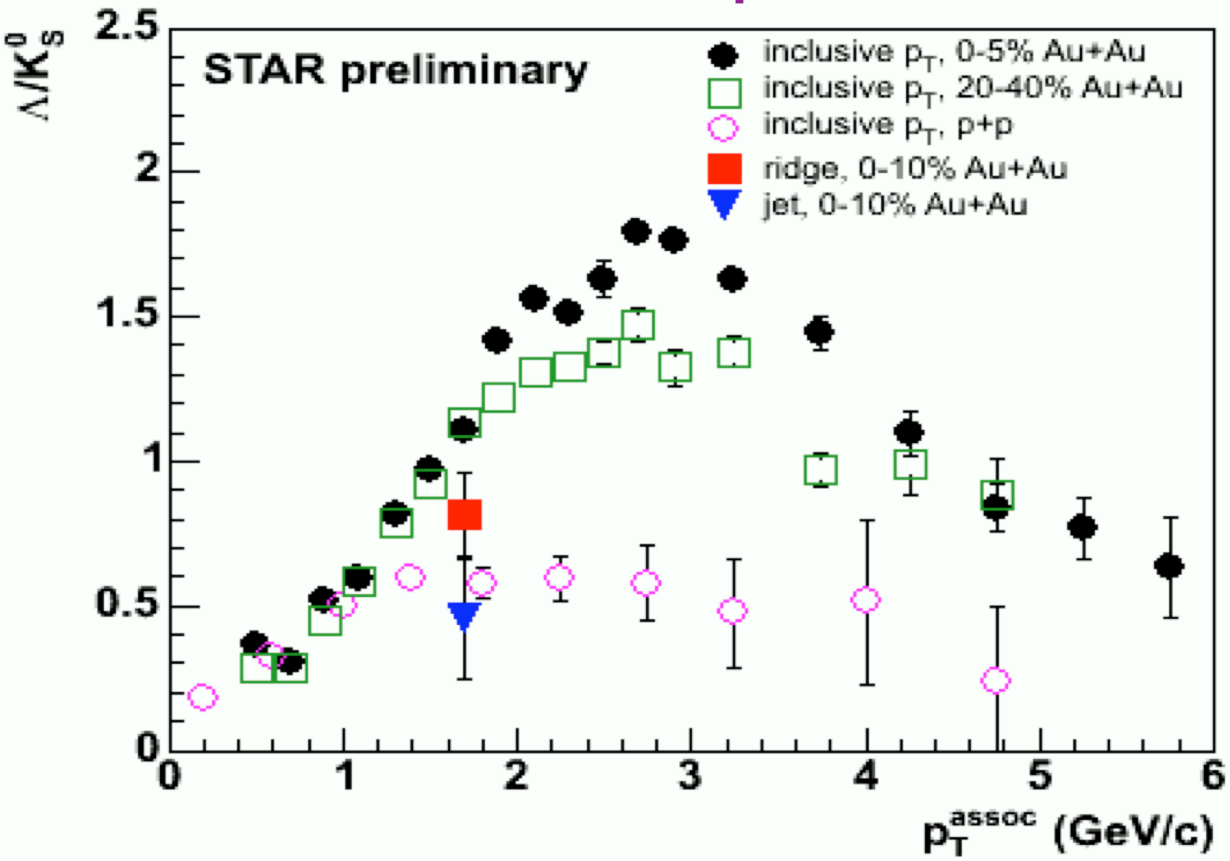
- Observation of near-side peak with multi-strange trigger particles
- The near-side yield independent of s-content
- Ω near-side peak clearly present
- Do we see ridge only?

Ξ-h correlations



- Observation of near-side peak with multi-strange trigger particles
- The near-side yield independent of s-content
- Ω near-side peak clearly present
- Do we see ridge only?

Particle composition of Jet/Ridge - identified associated particles



Baryon/meson ratio study:

Particle production in jet: fragmentation

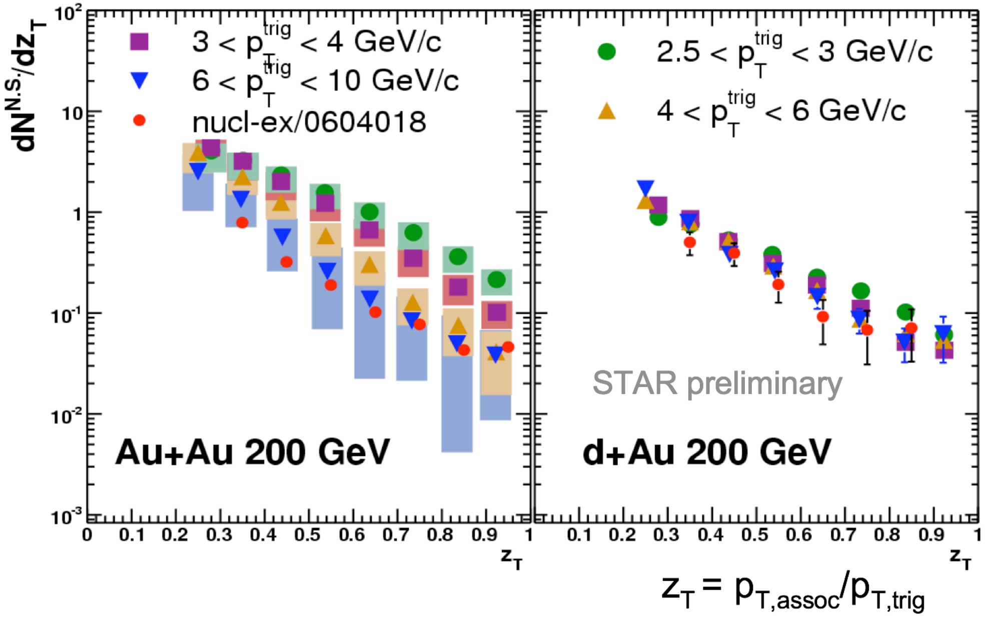
Particle production in ridge: recombination

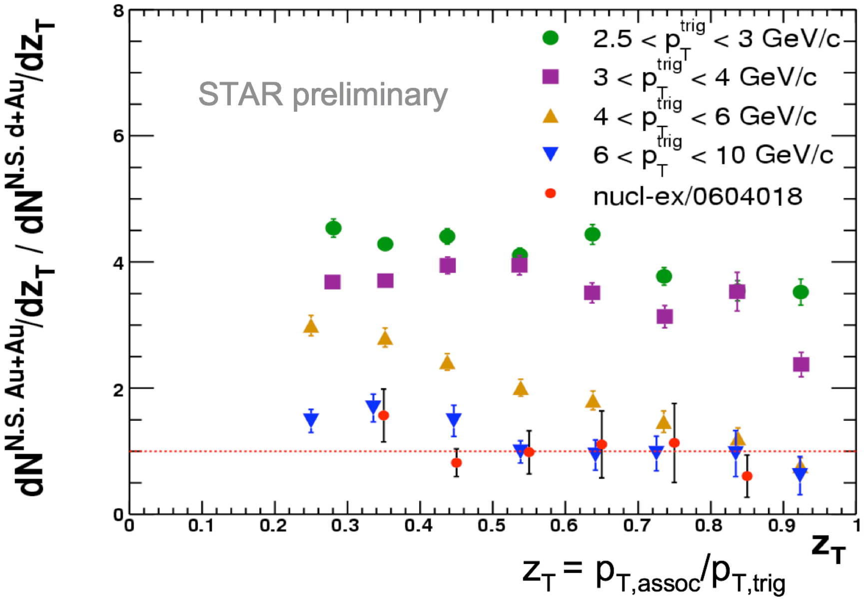
Summary

- We can study jets and the medium response on hard parton energy loss with two-particle correlations
- For triggered correlations with unidentified particles we observe:
  - Modification of the away-side
  - Doubly peaked distributions for low $p_{t,assoc}$ (Mach cone, deflected jets, Cherenkov radiaton,..?)
  - Long ranged $\Delta\eta$ correlation on near-side aka ridge (radiated gluons broadened by longitudinal flow,…?)
- For triggered correlations with identified particle we observe:
  - No clear trigger particle species dependence in jet/ridge
  - Associated particles in ridge - recombination origin, in jet - fragmentation origin
  - Correlations for multi-strange triggers

Backup slides

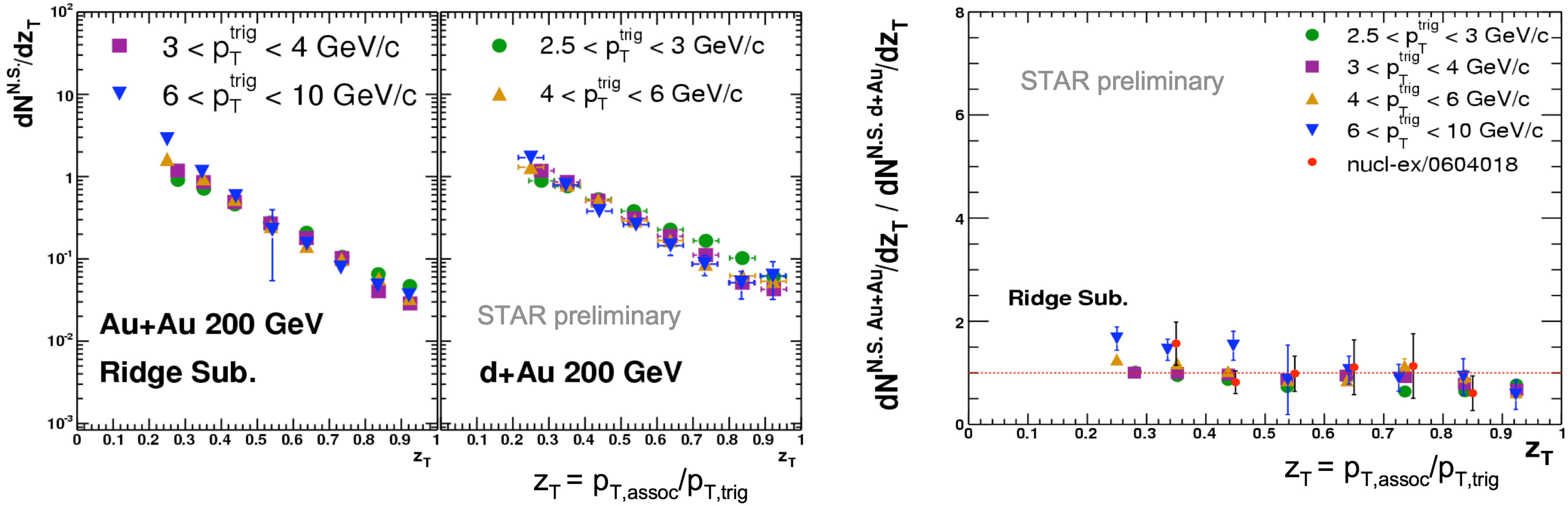
Subtracting the ridge





- Subtraction of the ridge recovers centrality independent jet yield
- Vacuum fragmentation after energy loss?

Subtracting the ridge



- Subtraction of the ridge recovers centrality independent jet yield
- Vacuum fragmentation after energy loss?