Evidence of conical emission from three-particle azimuthal correlation at STAR

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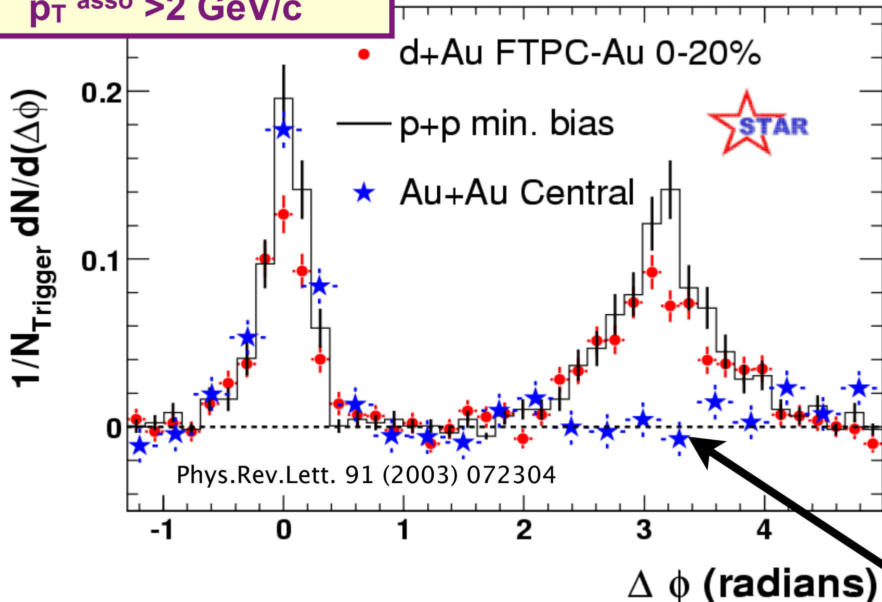
OUTLINE

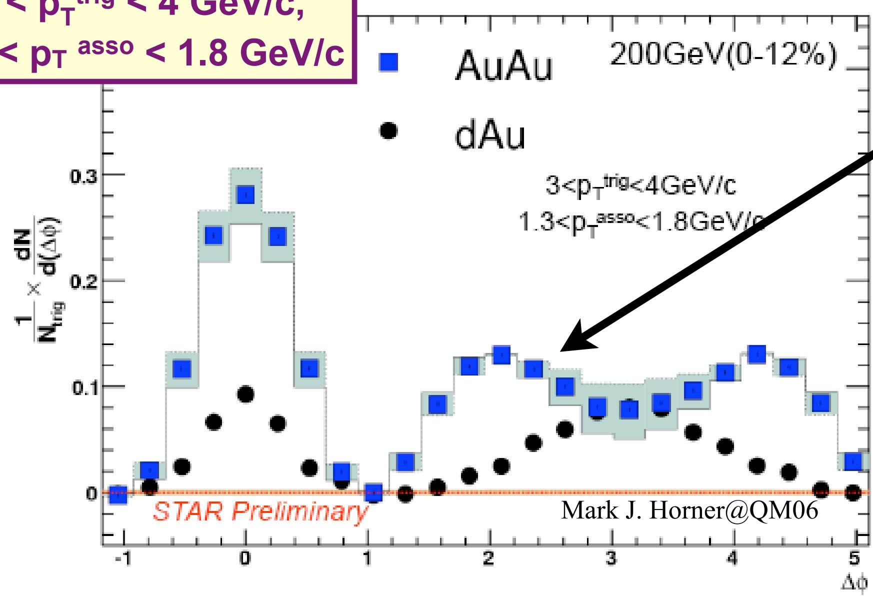
- Motivation
- Analysis technique
- Results
  - system size (centrality) dependence
  - associated pT dependence
  - trigger pT dependence
  - PID three-particle correlation
- Conclusions

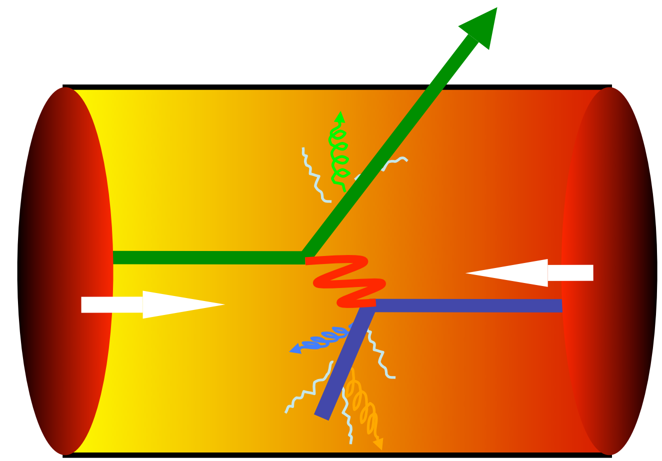
MOTIVATION

$4 < p_T^{trig} < 6$ GeV/c, $p_T^{asso} > 2$ GeV/c



$3 < p_T^{trig} < 4$ GeV/c, $1.3 < p_T^{asso} < 1.8$ GeV/c



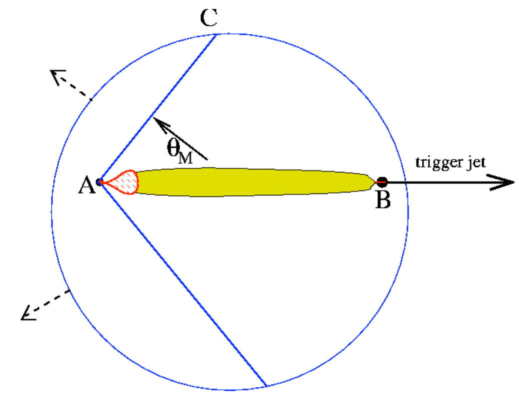


For away side in di-hadron correlation in central Au+Au collisions at RHIC:

- Suppression due to jet quenching.
- Double-peak:
  - ❑ **Mach-cone** (to be discussed)
  - ❑ **Čerenkov gluon radiation** (to be discussed)
  - ❑ **Large angle gluon radiation**
    I. Vitev, PLB 630, 78 (2005)
    A. D. Polosa et al. ,PRC 75, 041901(2007)
  - ❑ **Jet deflection**
    Armesto, PRC 72, 064910 (2005)
    Charles B. Chiu et al., PRC 74, 064909 (2005)
  - ❑ ...

CONICAL EMISSION THEORIES

- **Mach-cone**:
  - Shock waves excited by a supersonic parton.
  - Can be produced in different theories:
    - **Hydrodynamics**
      - H. Stöcker et al. (Nucl.Phys.A750:121,2005)
      - J. Casalderra-Solana et. al. (J.Phys.Conf.Ser. 27:22,2005)
      - T. Renk & J. Ruppert (Phys.Rev.C73:011901,2006)
    - **Colored plasma**
      - J. Ruppert & B. Müller (Phys.Lett.B618:123,2005)
    - **AdS/CFT**
      - S. Gubser, S. Pufu, A. Yarom. (arXiv:0706.4307, 2007)

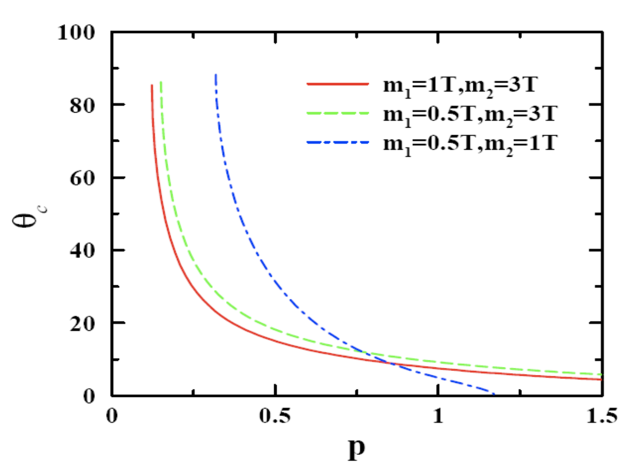


$$\cos \theta_M = C_s$$

$$C_s^2 = \frac{\partial p}{\partial \varepsilon}$$

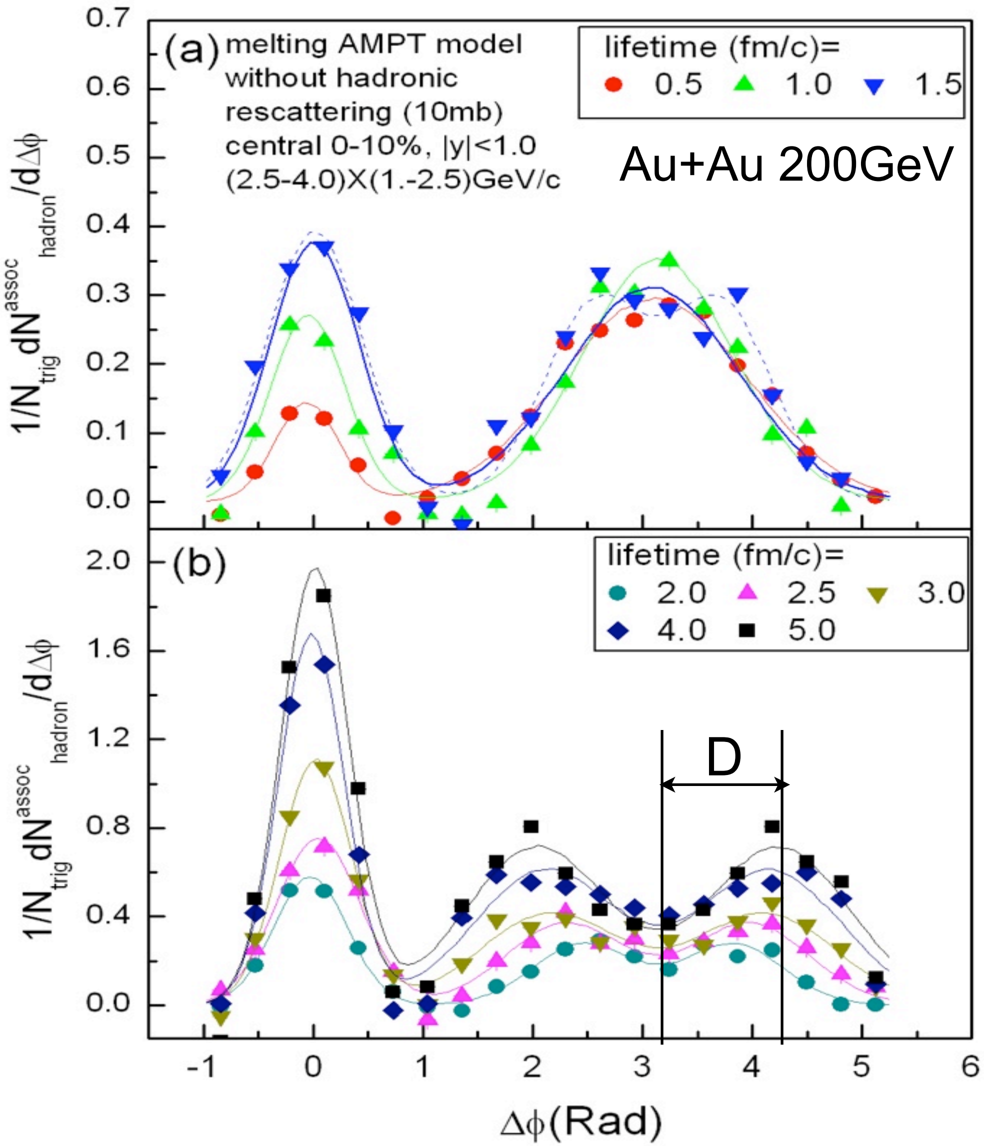
- **Čerenkov Gluon Radiation**:
  - Radiation of gluons by a superluminal parton.
    - I.M. Dremin (Nucl. Phys. A750: 233, 2006)
    - V. Koch, A. Majumder, Xin-Nian Wang (Phys. ReV. Lett. 96, 172302, 2006)

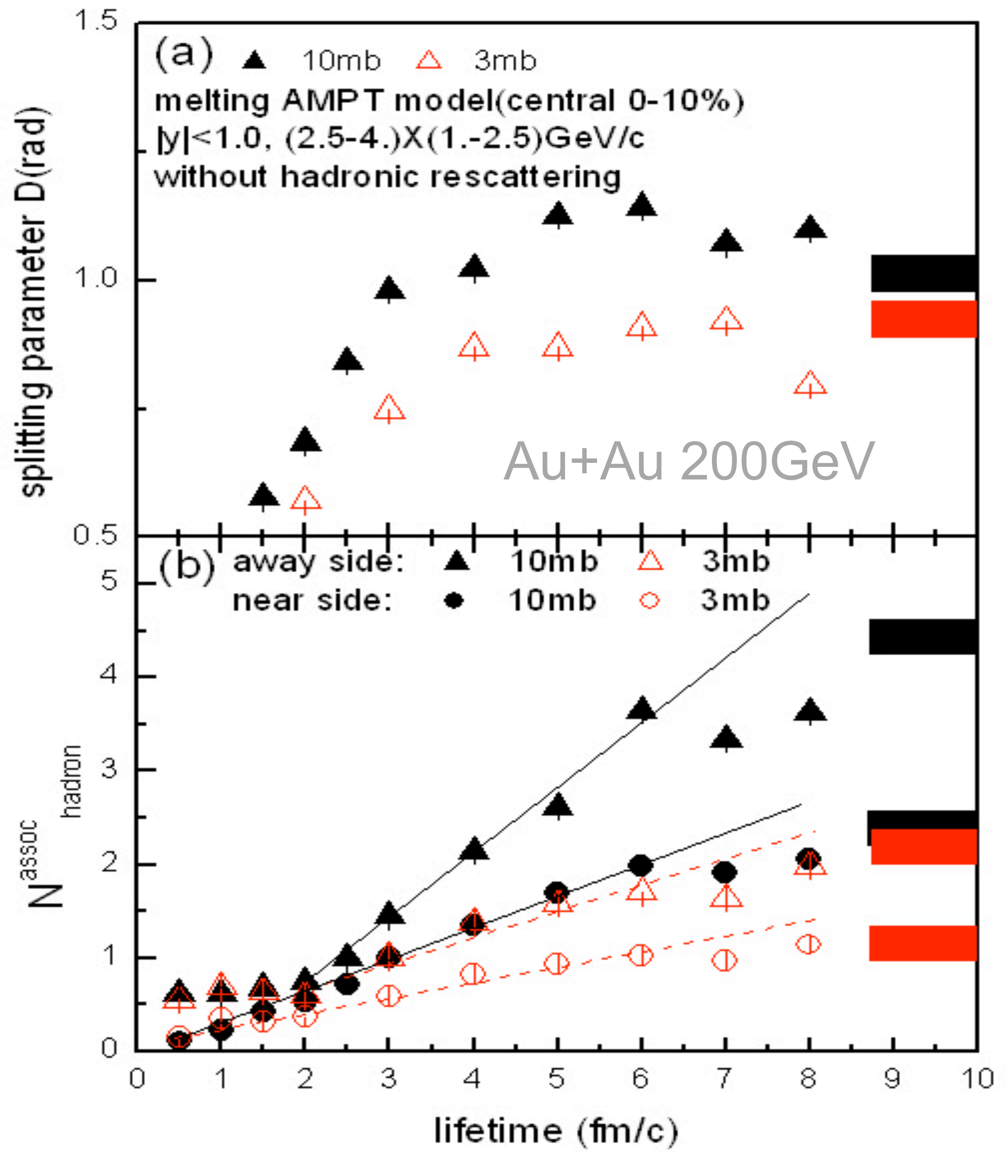
$$\cos \theta_C = 1/n(p)$$



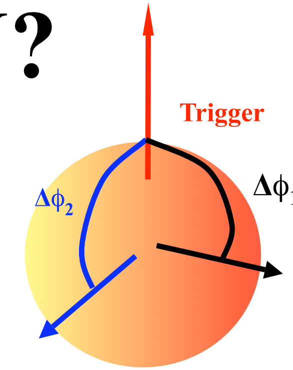
- **Parton Cascade**
  - from string-melting AMPT model

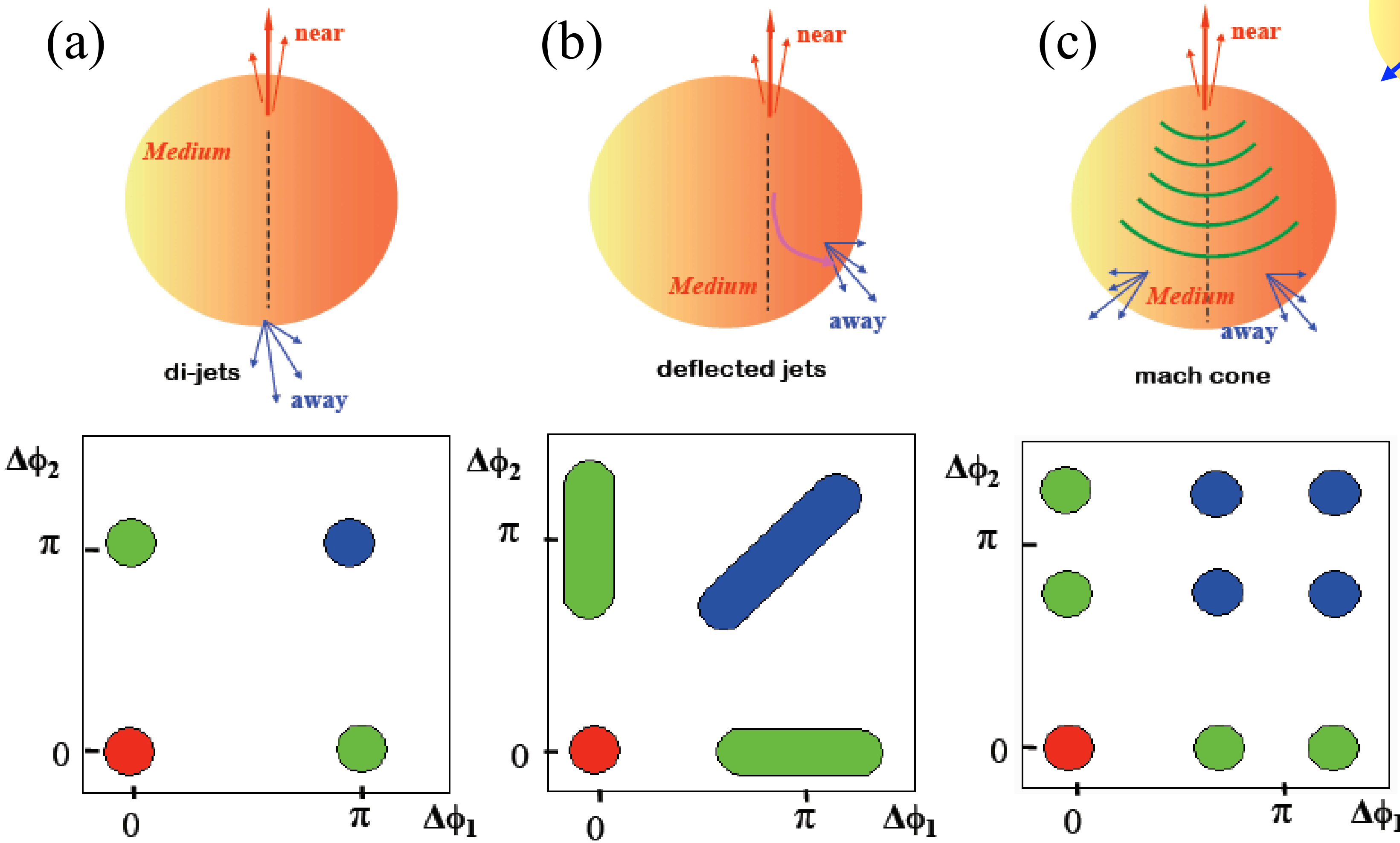
G. L. Ma, S. Zhang and Y. G. Ma et al., PLB 641, 362 (2006); PLB 647, 122, (2007); nucl-th/0610088.





WHY 3-PARTICLE CORRELATION?

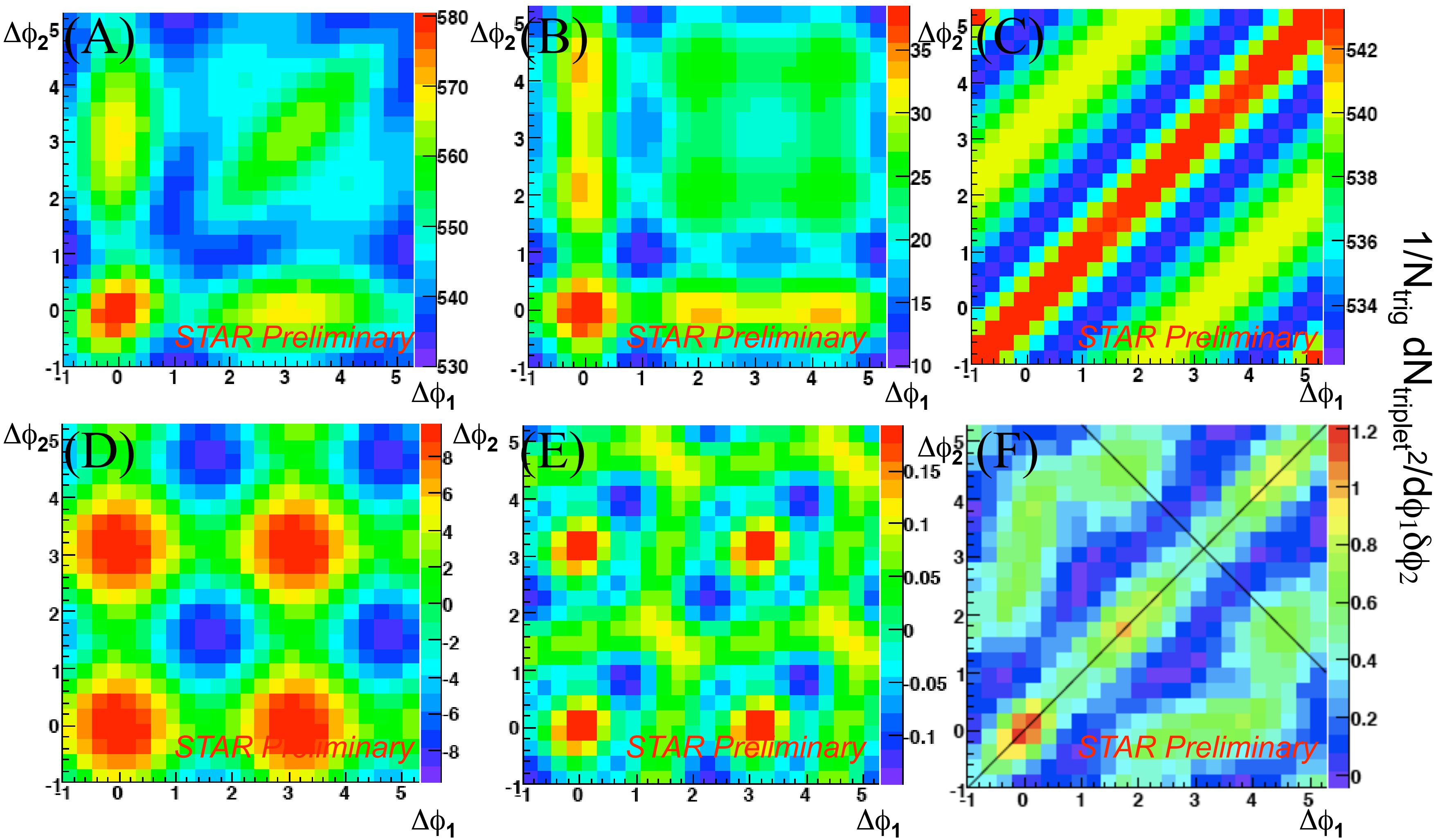




BACKGROUND SUBTRACTION

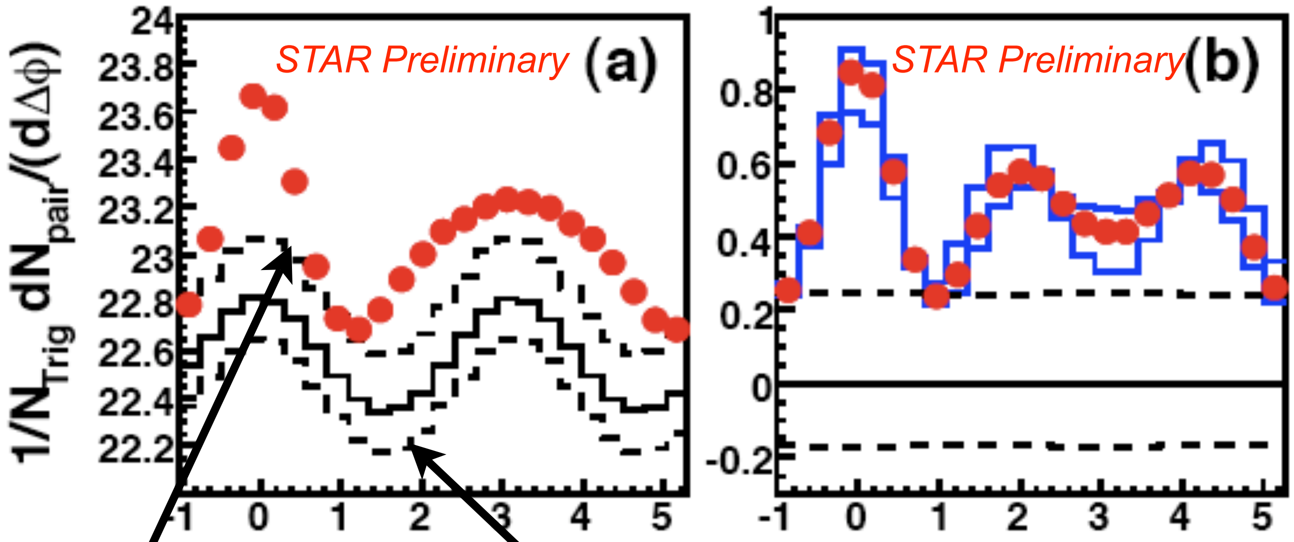
An example: Au+Au 200 GeV (0-12%),

$3 < p_T^{Trig} < 4$ GeV/c and $1 < p_T^{Asso} < 2$ GeV/c



(A): raw signal; (B): hard-soft background; (C): soft-soft background; (D): flow (v2) background; (E): flow (v4) background; (F): final signal.

SYSTEMATIC UNCERTAINTIES



A normalization factor is obtained by 3-particle ZYAM (Zero Yield At Minimum), i.e. the average of the lowest 10% data-points is required to be zero.

Systematic uncertainty from the normalization factor:

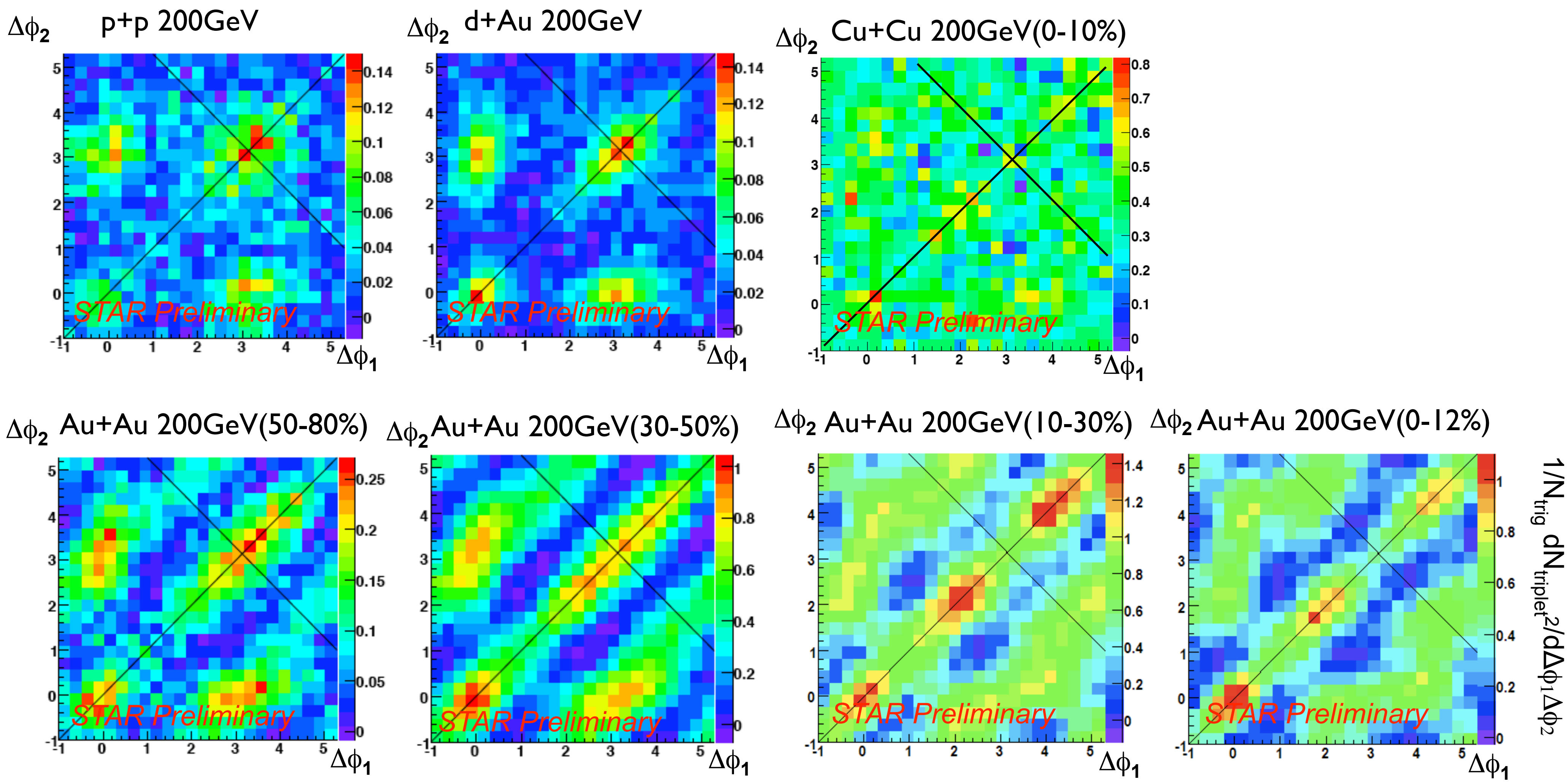
One end from 2-particle ZYAM, **the other end** from 3-particle ZYAM at only one lowest data-point.

Other systematic uncertainties:

Flow correction, multiplicity fluctuation etc.

STAR RESULTS: SYSTEM DEPENDENCE

$(3 < p_T^{Trig} < 4$ GeV/c and $1 < p_T^{Asso} < 2$ GeV/c)

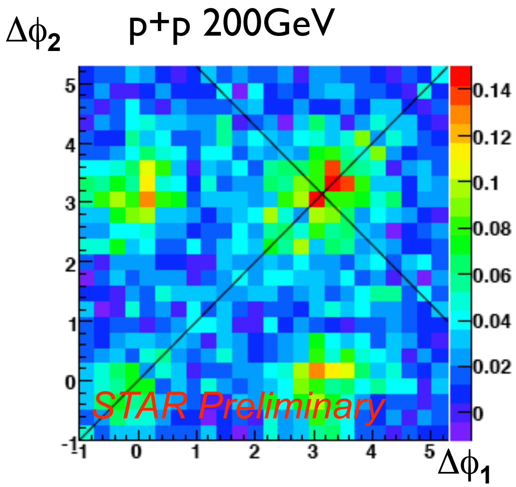


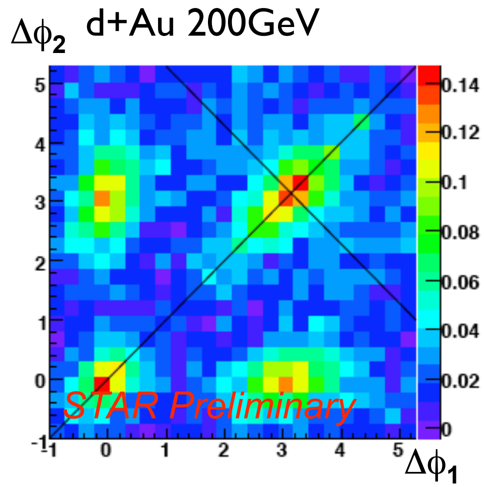
J. Ulery @ QM08

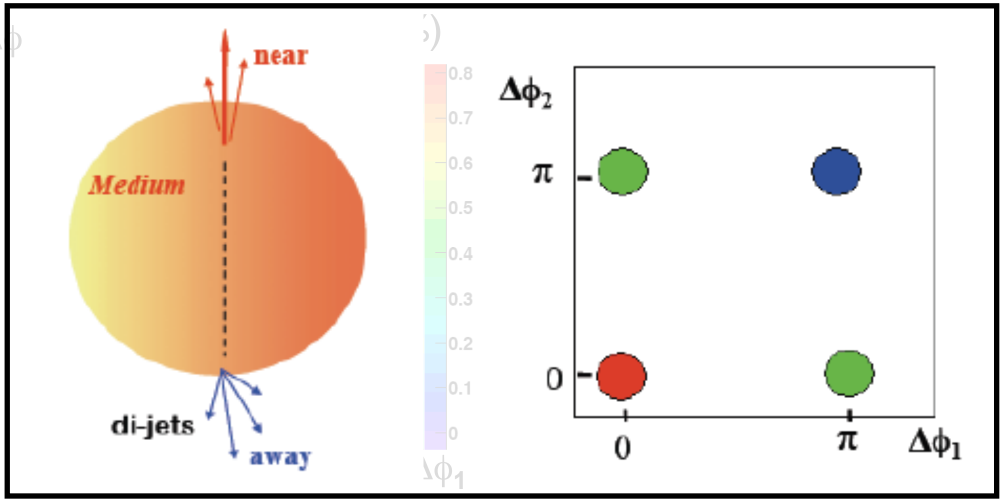
arXiv:0805.0622

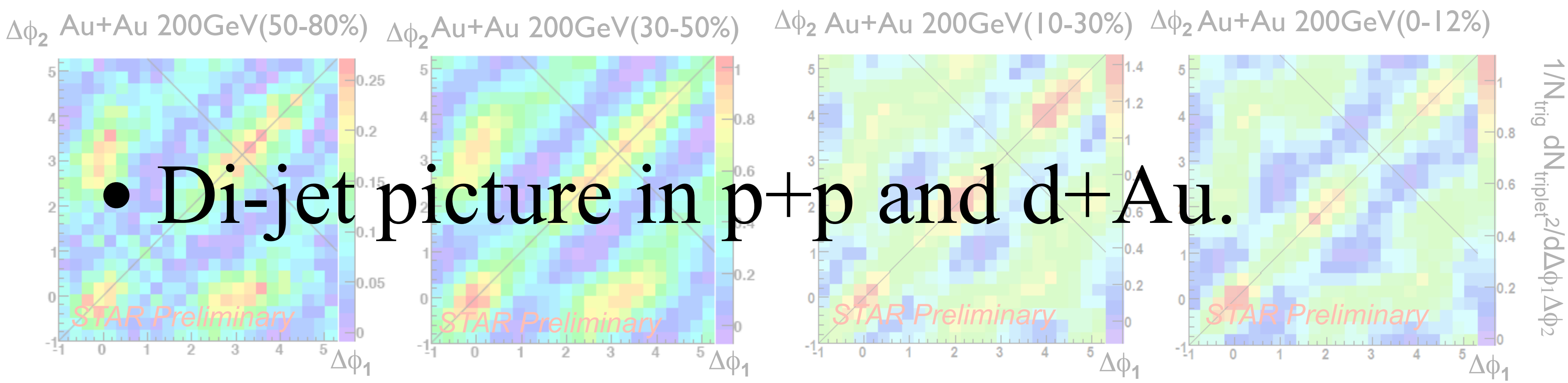
RESULTS: SYSTEM DEPENDENCE

(3 < p_T^{Trig} < 4 GeV/c and 1 < p_T^{Asso} < 2 GeV/c)





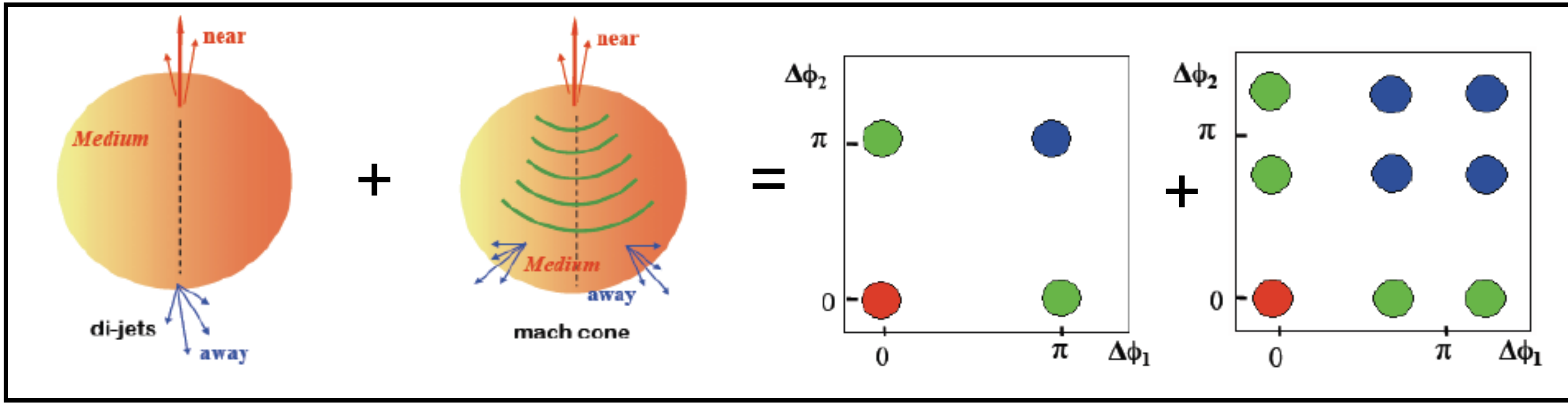


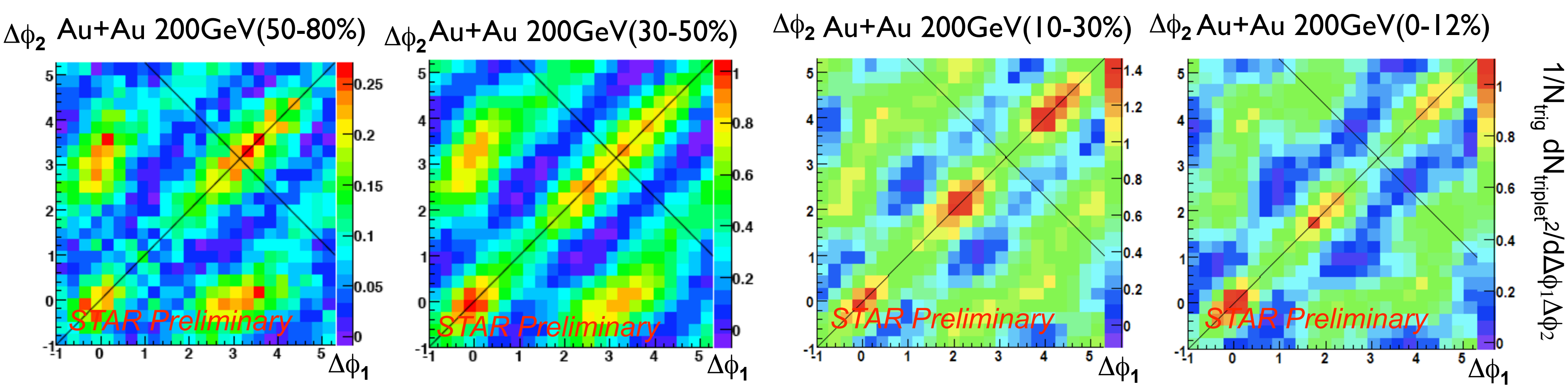


- Di-jet picture in p+p and d+Au.

RESULTS: SYSTEM DEPENDENCE

$(3 < p_T^{Trig} < 4$ GeV/c and $1 < p_T^{Asso} < 2$ GeV/c$)$

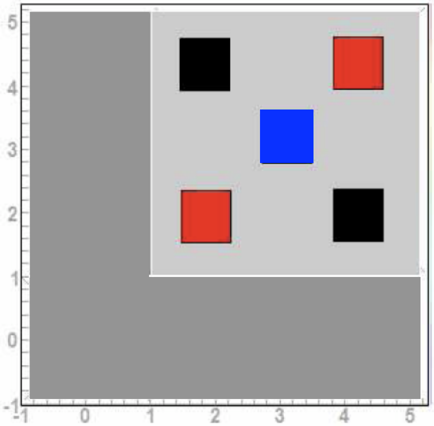


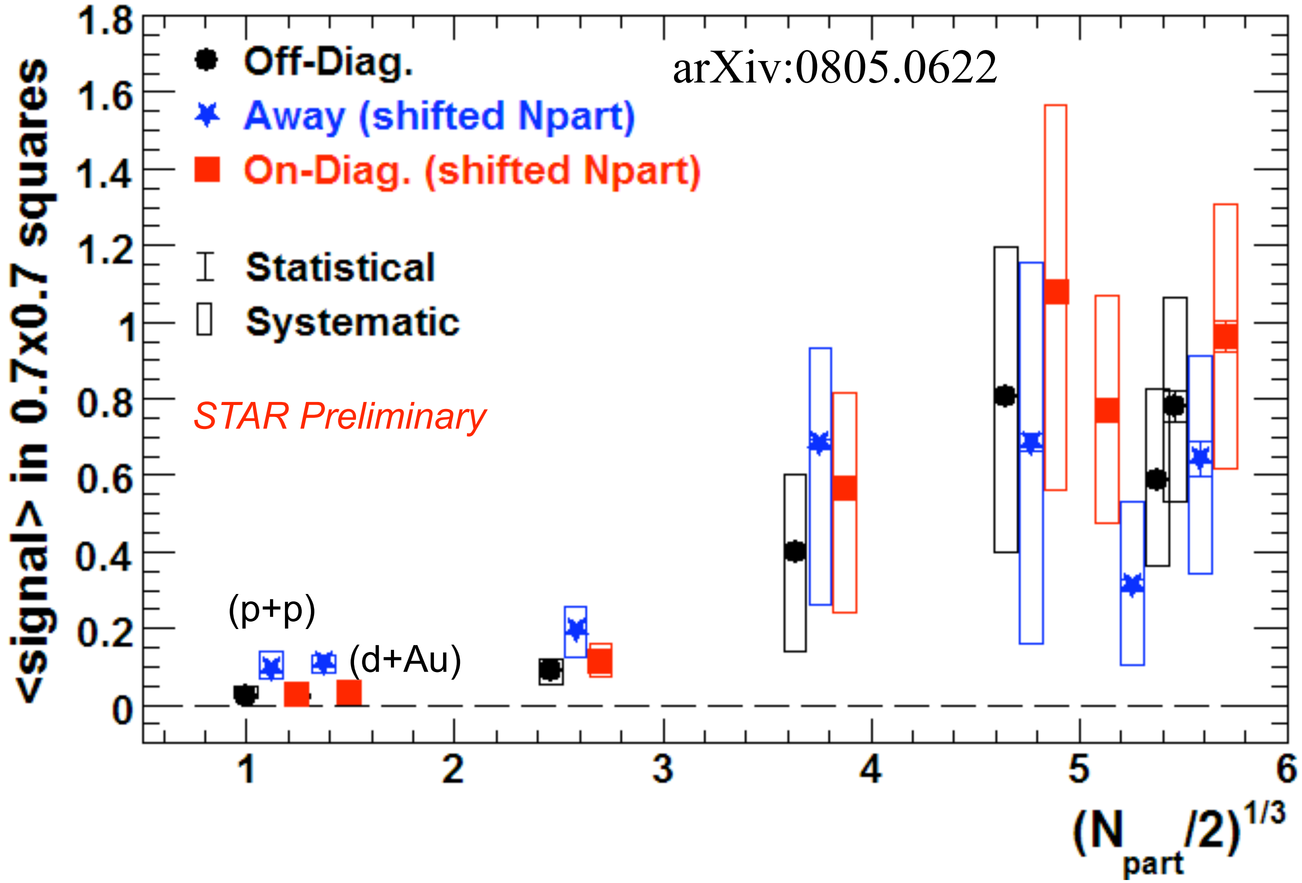


- Di-jet + conical emission in Au+Au.

CENTRALITY DEPENDENCE of average yield from different regions

$(3 < p_T^{Trig} < 4$ GeV/c and $1 < p_T^{Asso} < 2$ GeV/c)

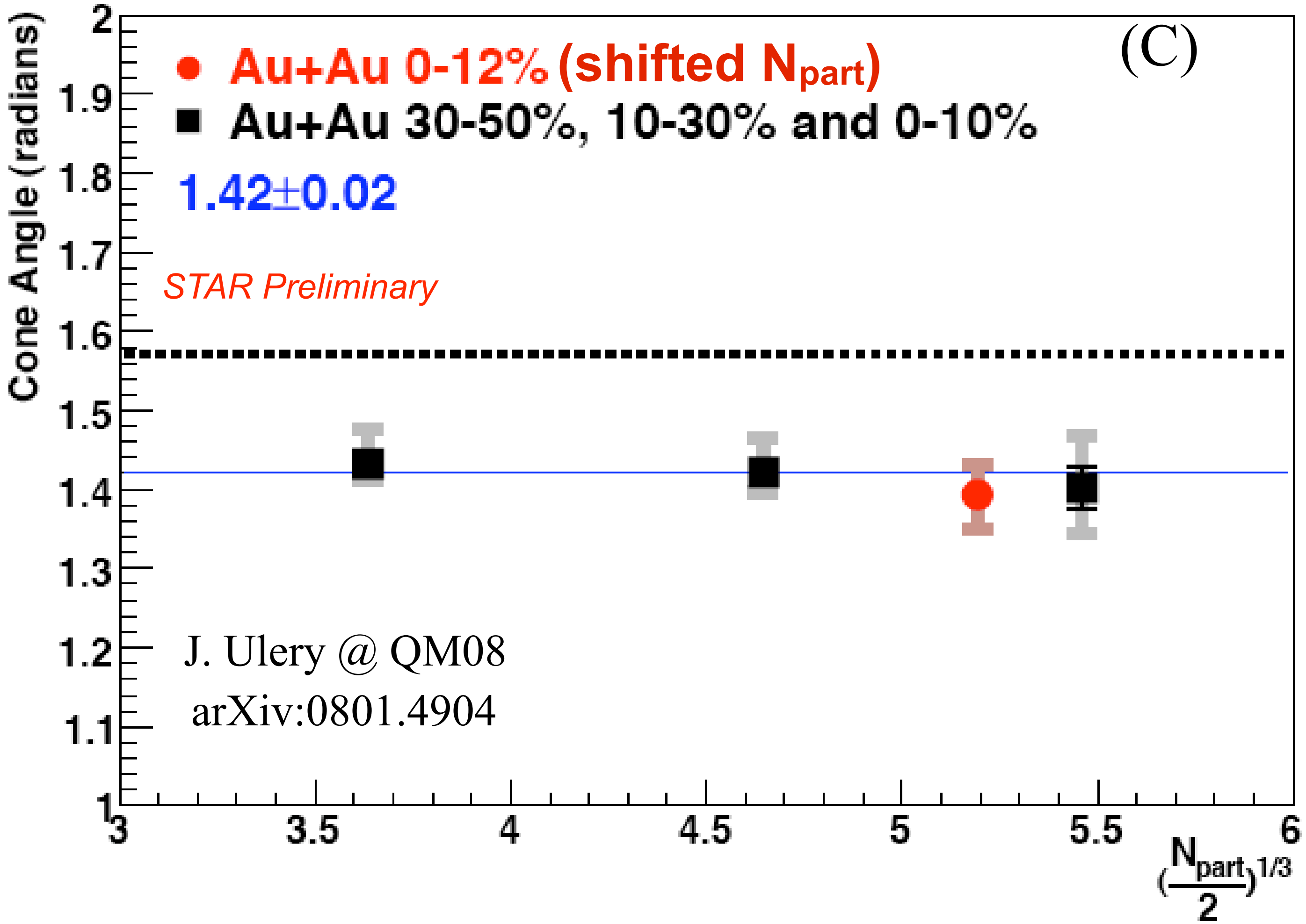




- Signals increase with N_{part} in different areas.
- On- and off- diagonal signals exist in A+A.

CENTRALITY DEPENDENCE of emission angle

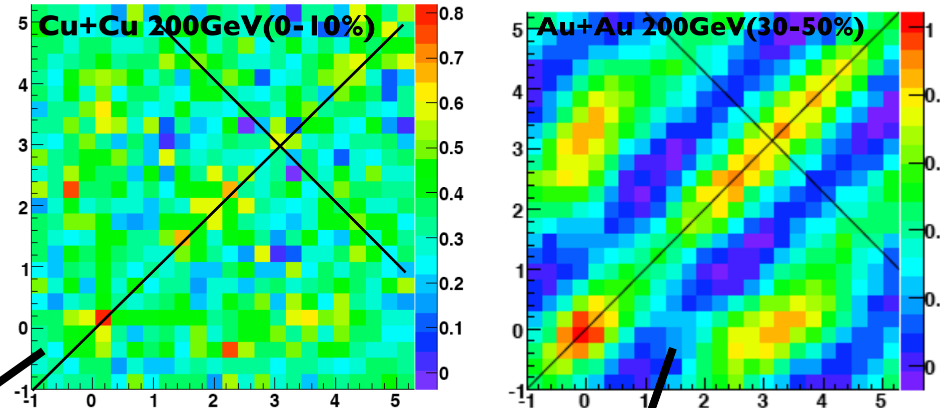
($3 < p_T^{Trig} < 4$ GeV/c and $1 < p_T^{Asso} < 2$ GeV/c)

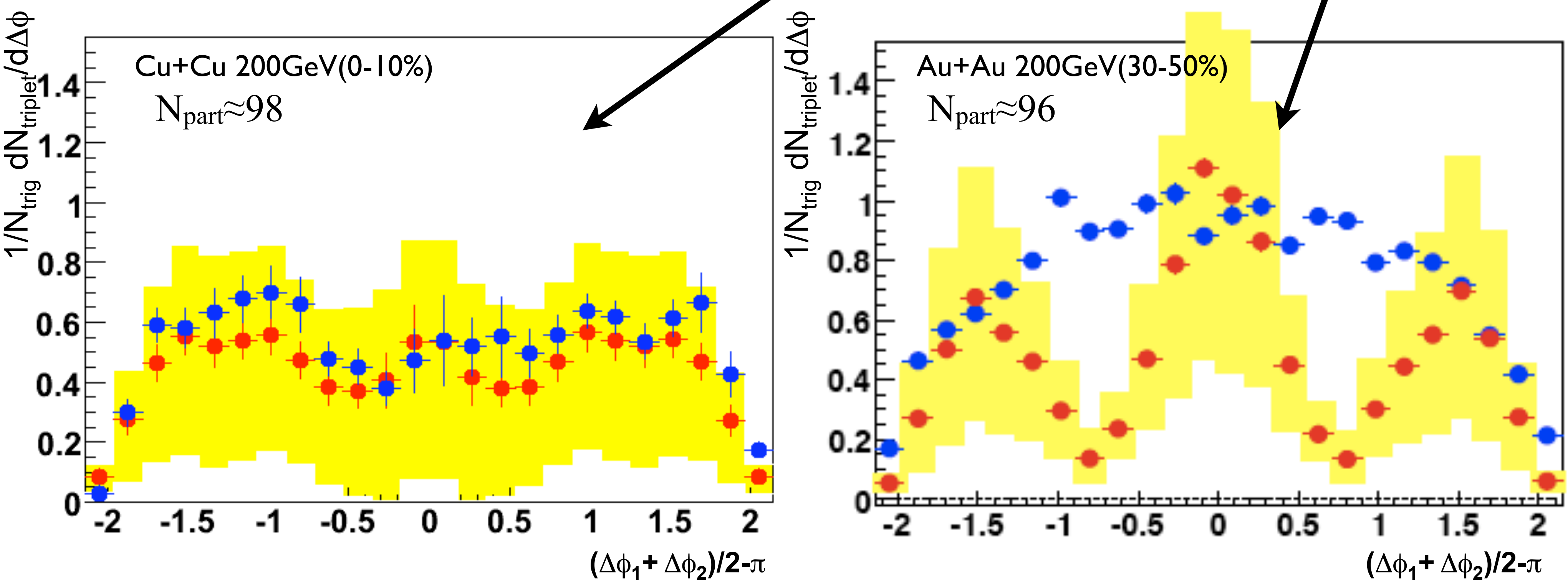


- constant dependence of cone angle on system size.

Cu+Cu vs Au+Au

(3 < p_T^{Trig} < 4 GeV/c and 1 < p_T^{Asso} < 2 GeV/c)





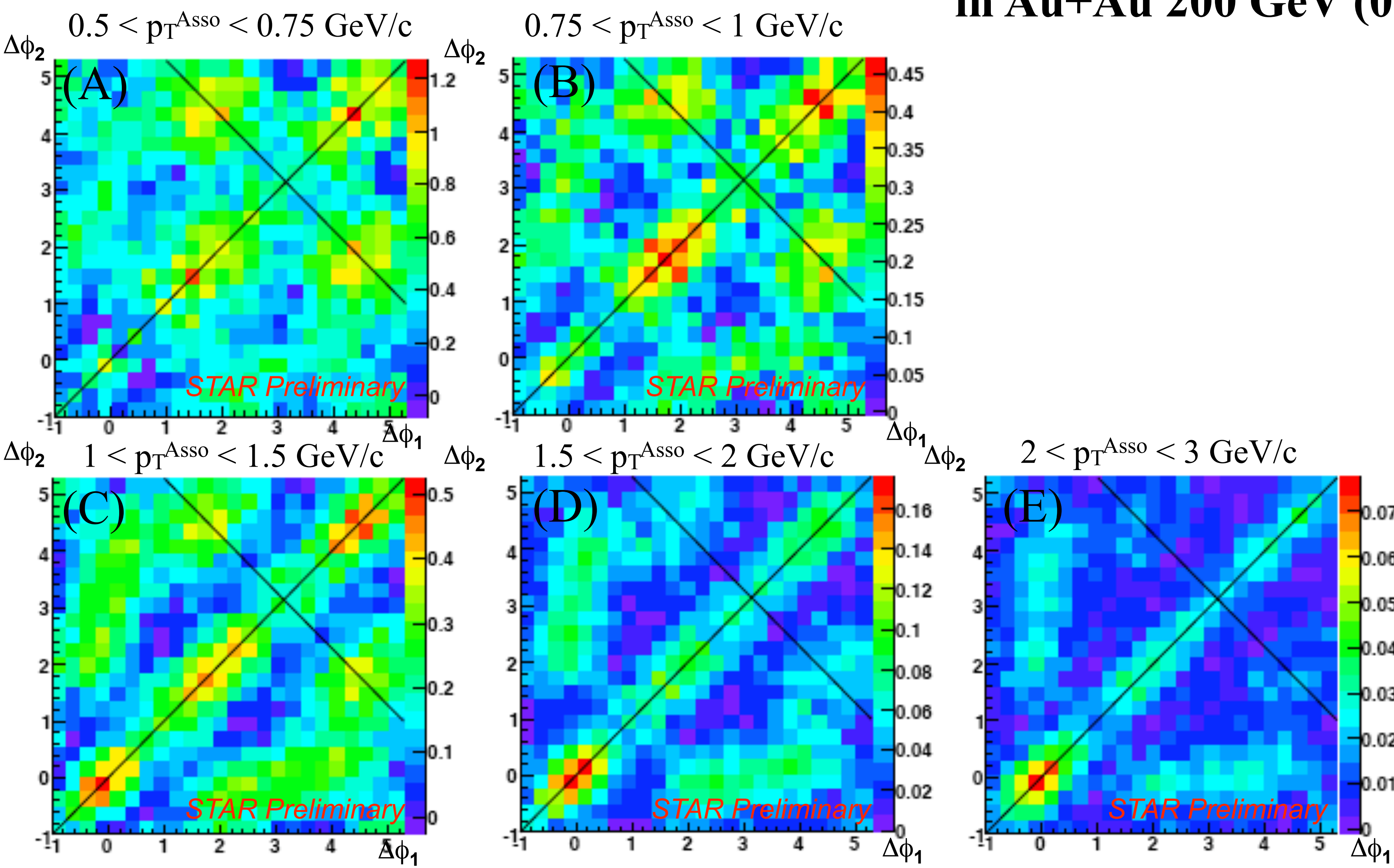
the off-diagonal projection

the diagonal projection

There seems some difference between Cu+Cu and Au+Au, which needs more further studies.

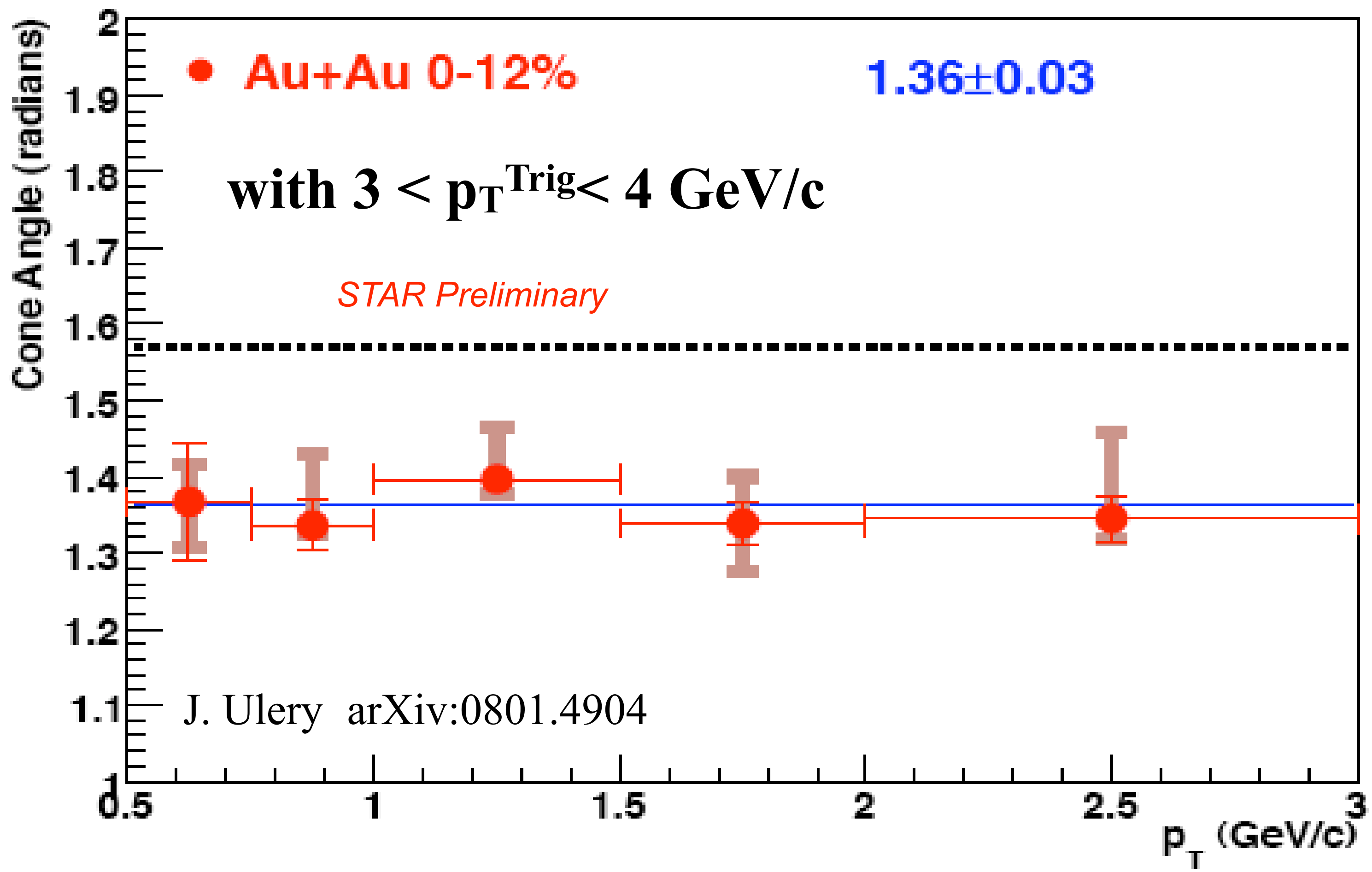
(2) p_T^{asso} DEPENDENCE

with $3 < p_T^{Trig} < 4$ GeV/c in Au+Au 200 GeV (0-12%)



J. Ulery arXiv:0801.4904

p_T^{Asso} DEPENDENCE of emission angle

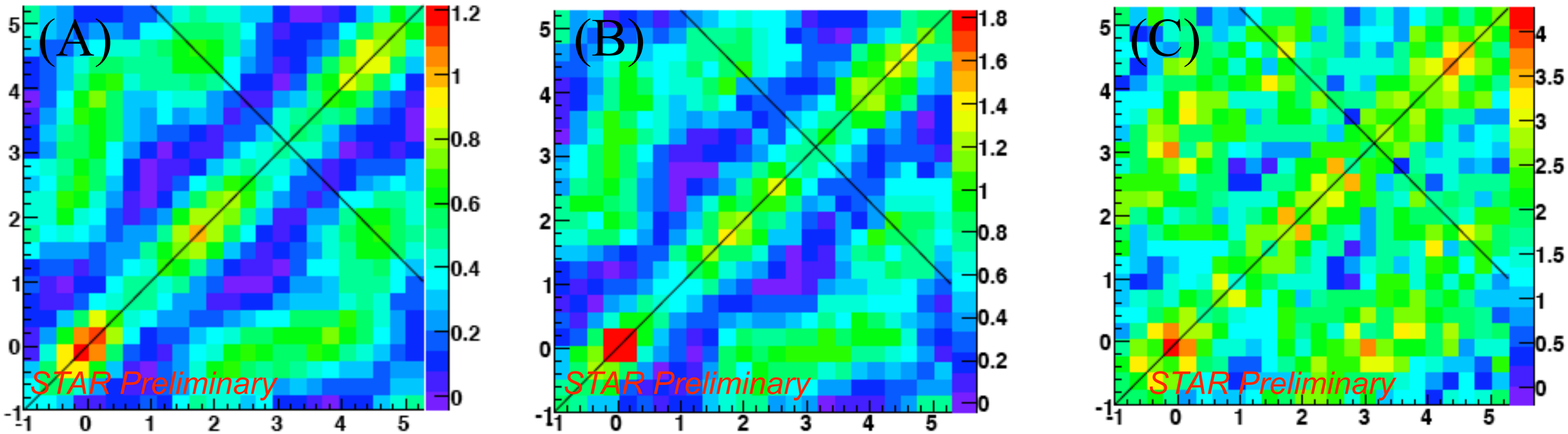


- p_T^{Asso}-independent cone angle, consistent the prediction of Mach-cone, and inconsistent with that of Čerenkov.

(3) p_T^{Trig} DEPENDENCE

with $1 < p_T^{Asso} < 2$ GeV/c

$3 < p_T^{Trig} < 4$ GeV/c | $4 < p_T^{Trig} < 6$ GeV/c | $6 < p_T^{Trig} < 10$ GeV/c

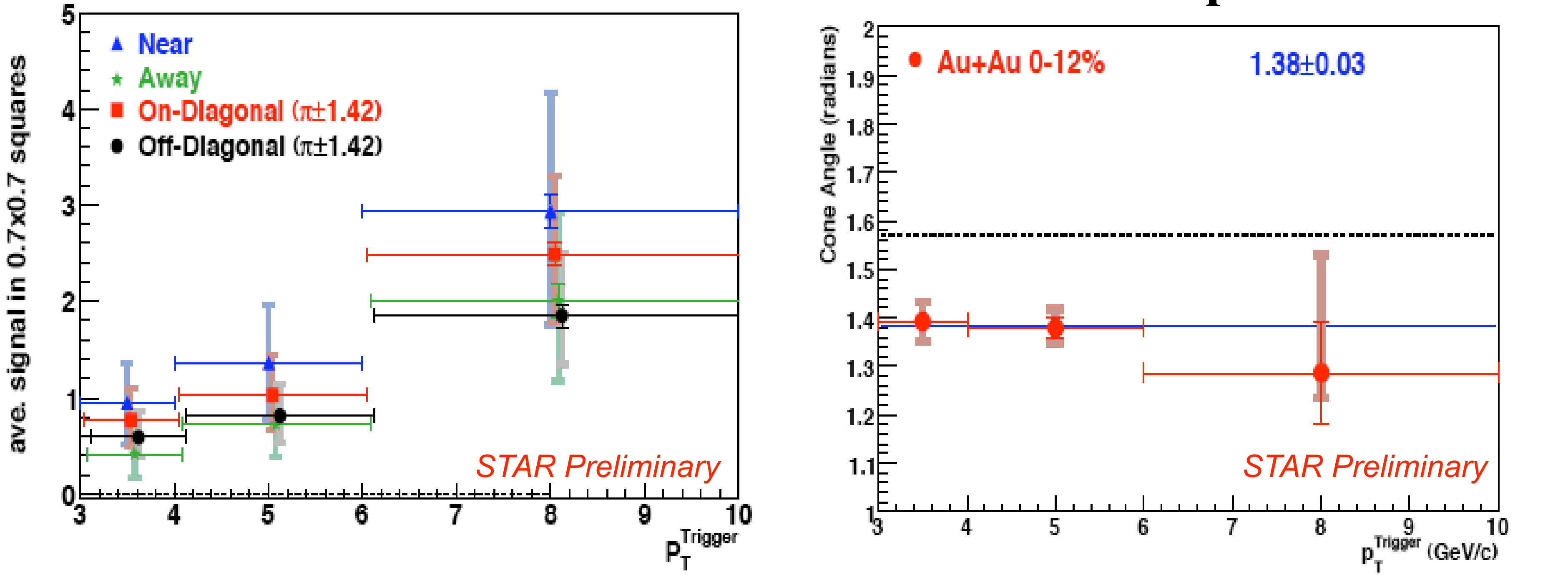


J. Ulery arXiv:0801.4904

- Three-particle correlations with trigger particles of $3 < p_T^{Trig} < 4$ (A), $4 < p_T^{Trig} < 6$ (B) and $6 < p_T^{Trig} < 10$ (C) and associated particles of $1 < p_T^{Asso} < 2$ GeV/c for Au+Au collisions (0-12%) at $\sqrt{s_{NN}} = 200$ GeV/c;

p_T^{Trig} DEPENDENCES of average yield from different regions and emmision angle

with $1 < p_T^{Asso} < 2$ GeV/c

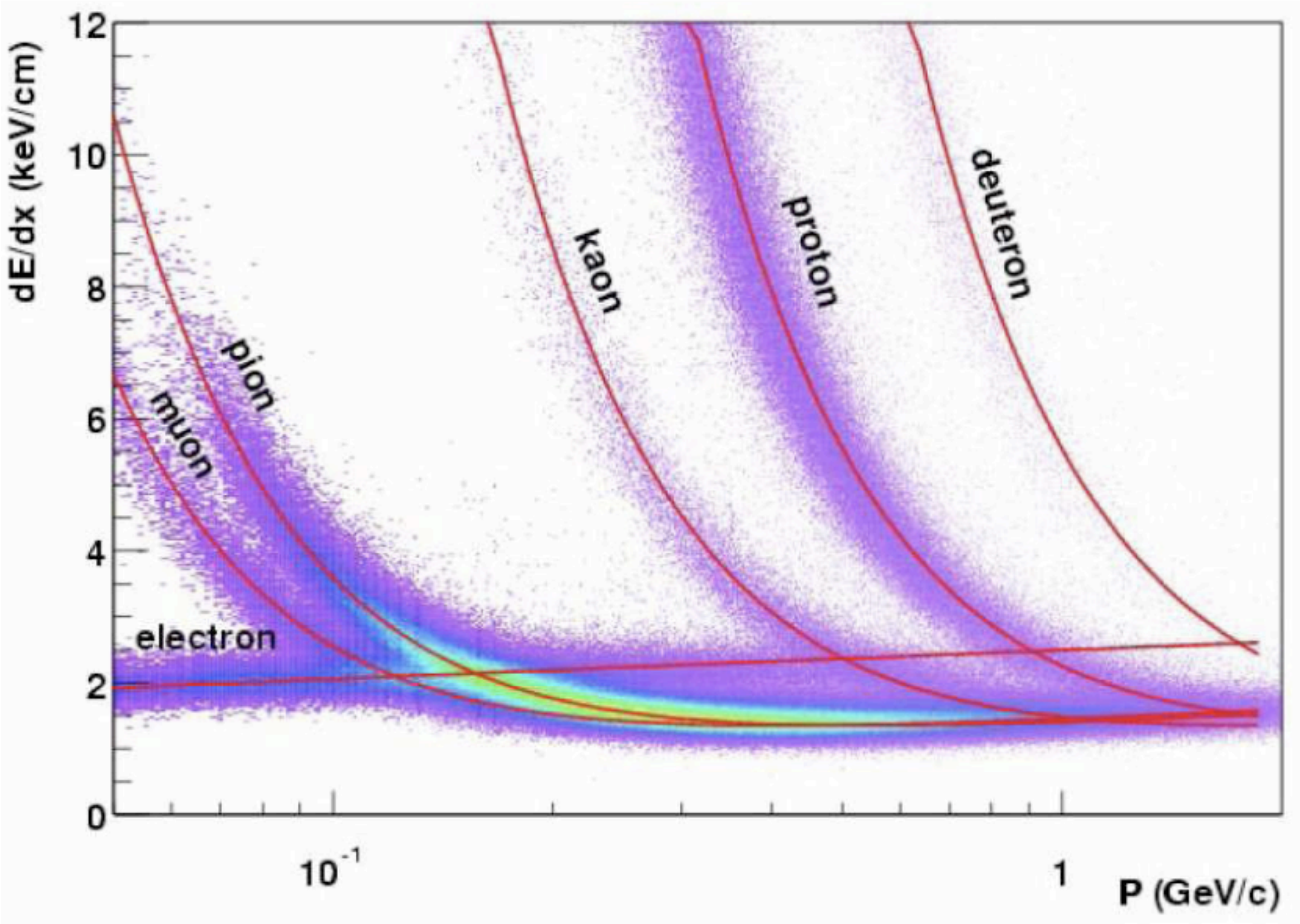


J. Ulery arXiv:0801.4904

- Signals increase with p_T^{Trig} in different areas.
- p_T^{Trig}-indpendent cone angle.

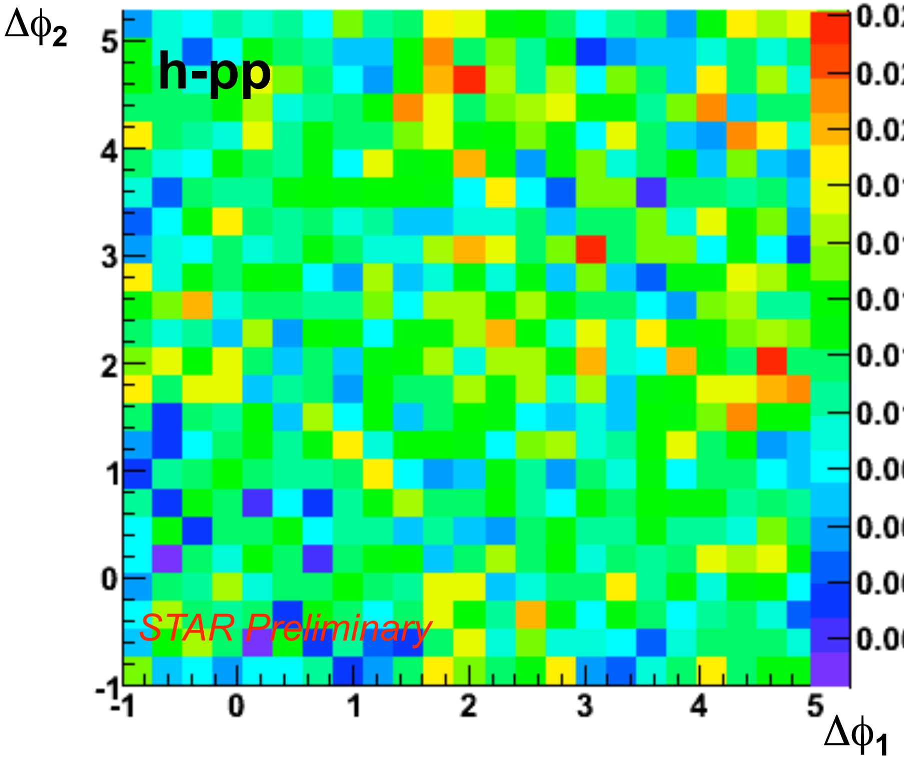
PARTICLE IDENTIFICATION

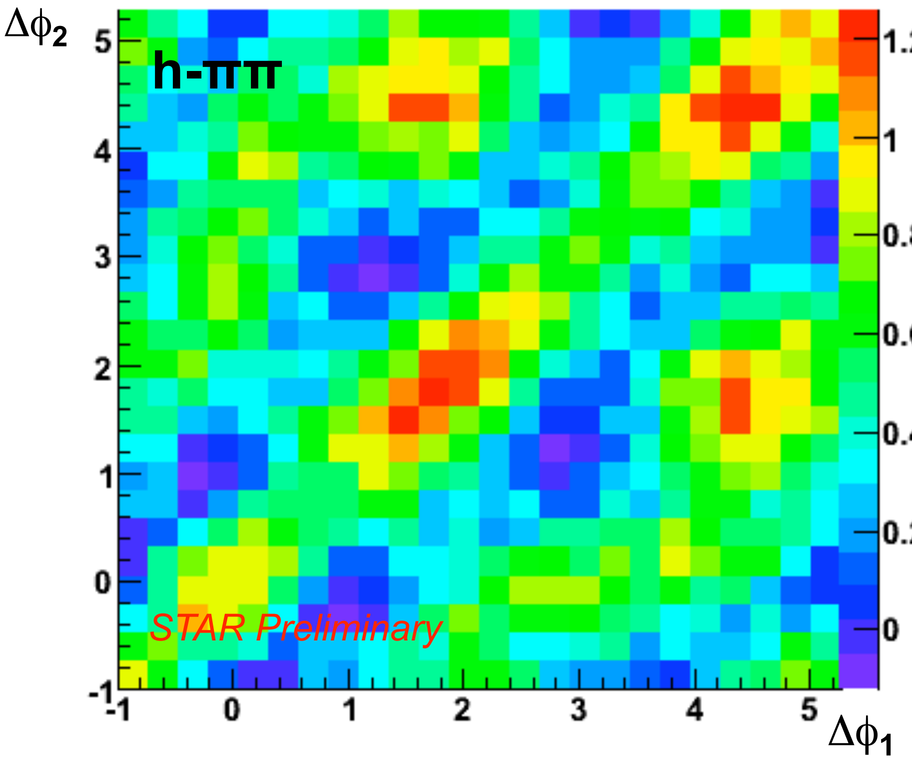
—— for PID 3-particle correlation



PID 3-PARTICLE CORRELATIONS

—— h-pp and h-ππ

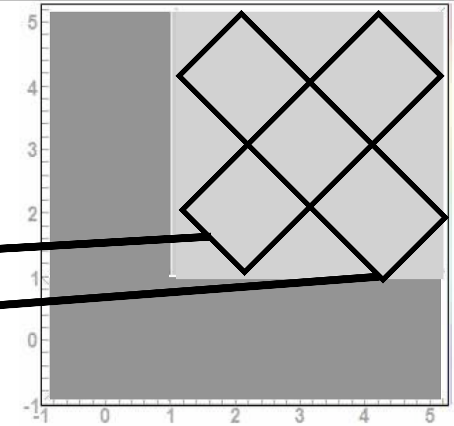




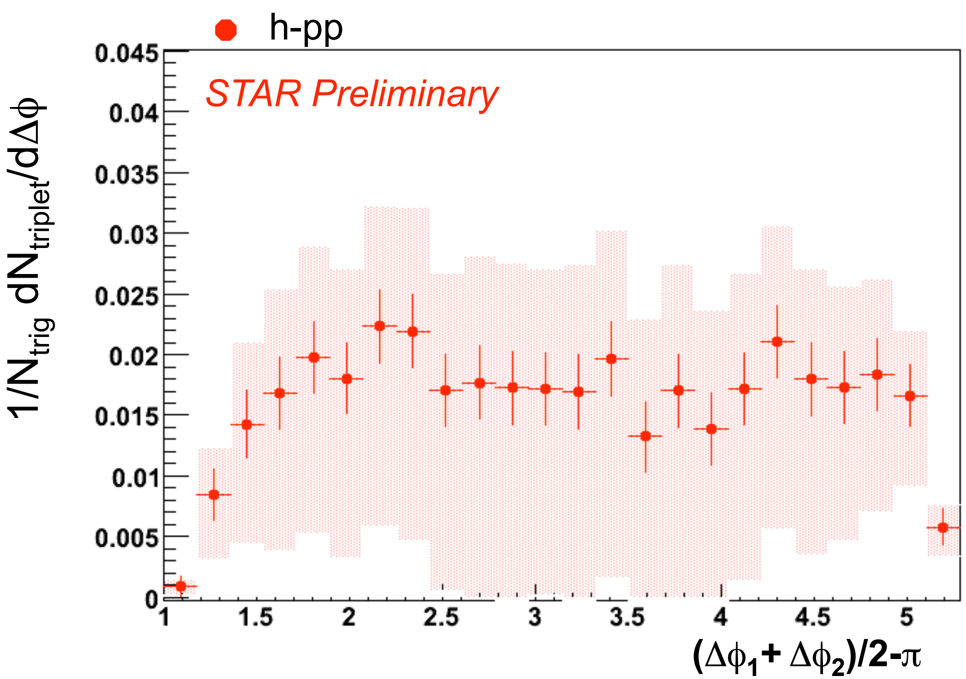
- $2.5 < p_T^{Trig} < 10$ GeV/c and $0.7 < p_T^{asso} < 1.4$ GeV/c in Au +Au collisions (0-12%) at $\sqrt{s_{NN}}$ =200GeV.
- More statics needed.

PID 3-PARTICLE CORRELATIONS

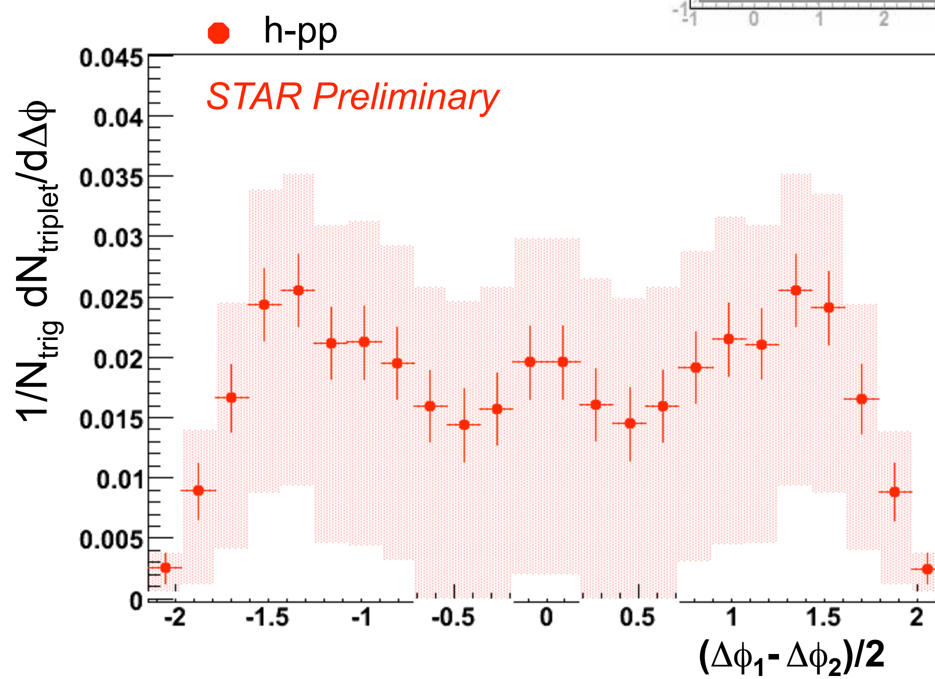
diagonal and off-diagonal projections



diagonal:



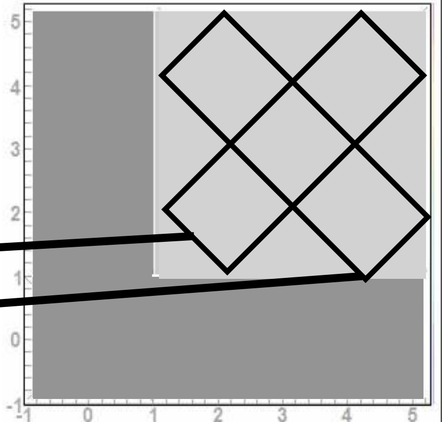
off-diagonal:



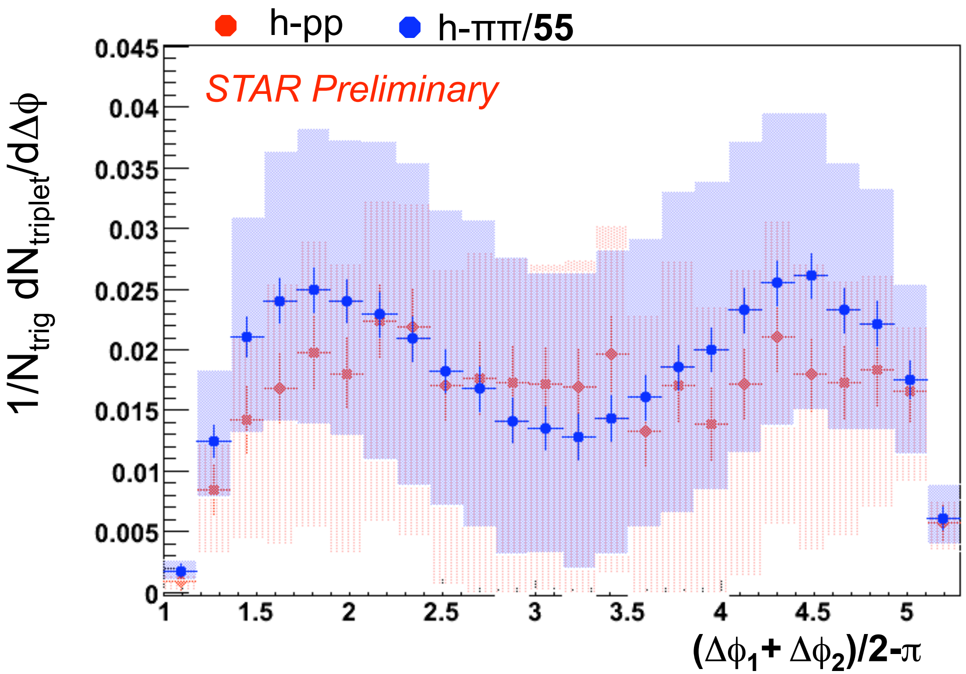
the diagonal and off-diagonal projections of ‘h-pp’

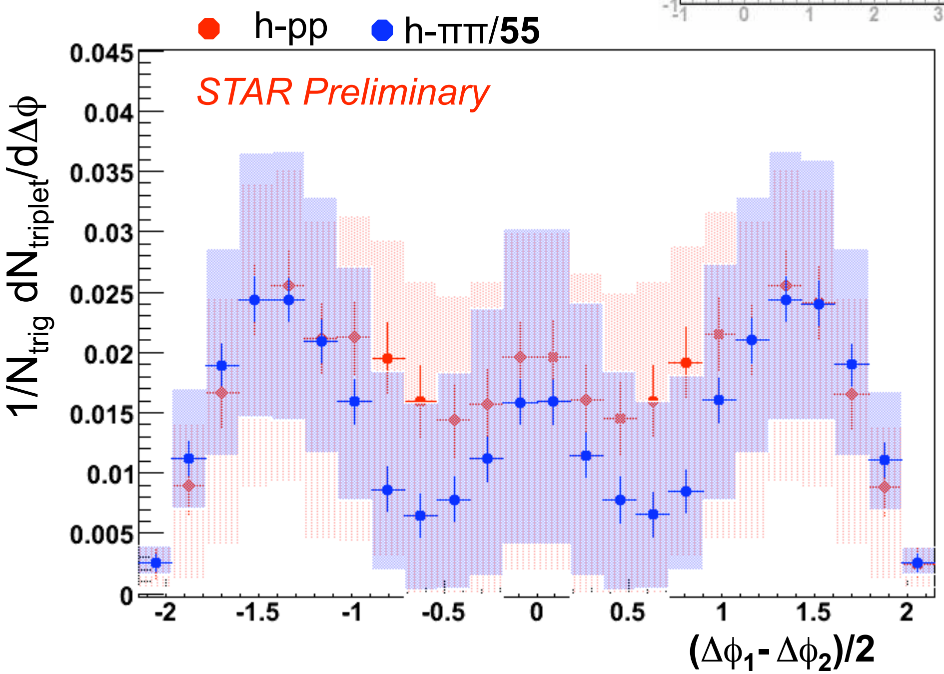
PID 3-PARTICLE CORRELATIONS

diagonal and off-diagonal projections



diagonal: **off-diagonal:**



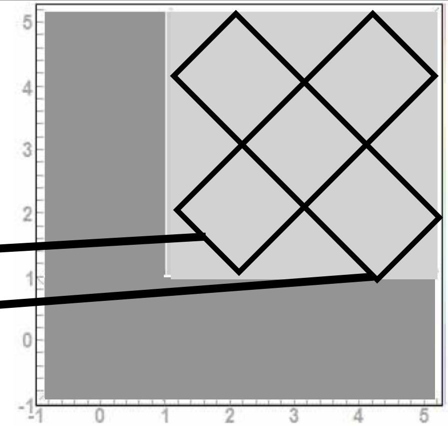


the diagonal and off-diagonal projections of 'h-pp'

the diagonal and off-diagonal projections of 'h-ππ' (scaled by **1/55**)

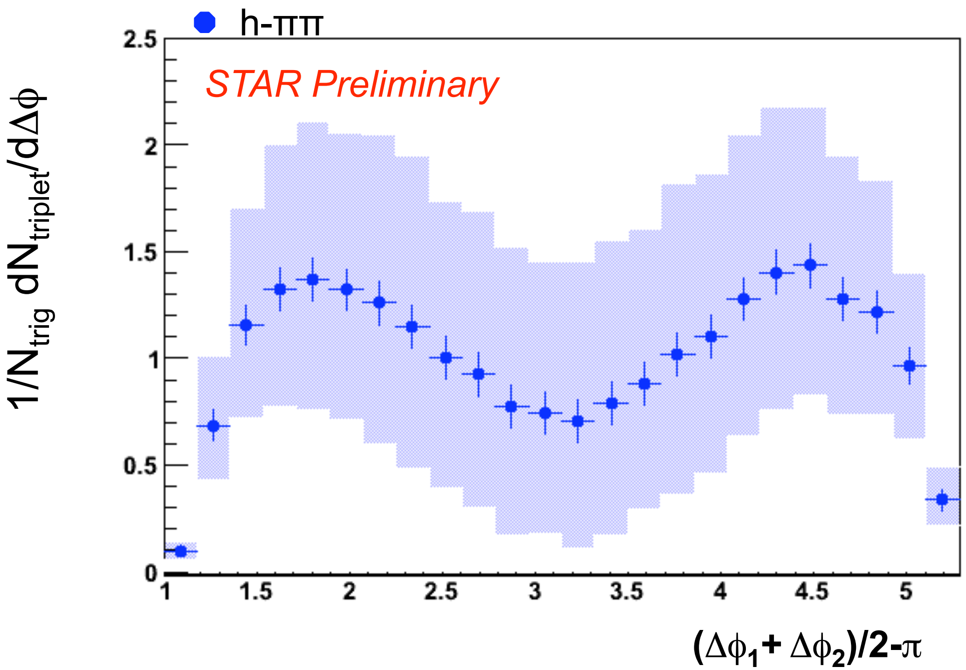
➡Needs more statistics.

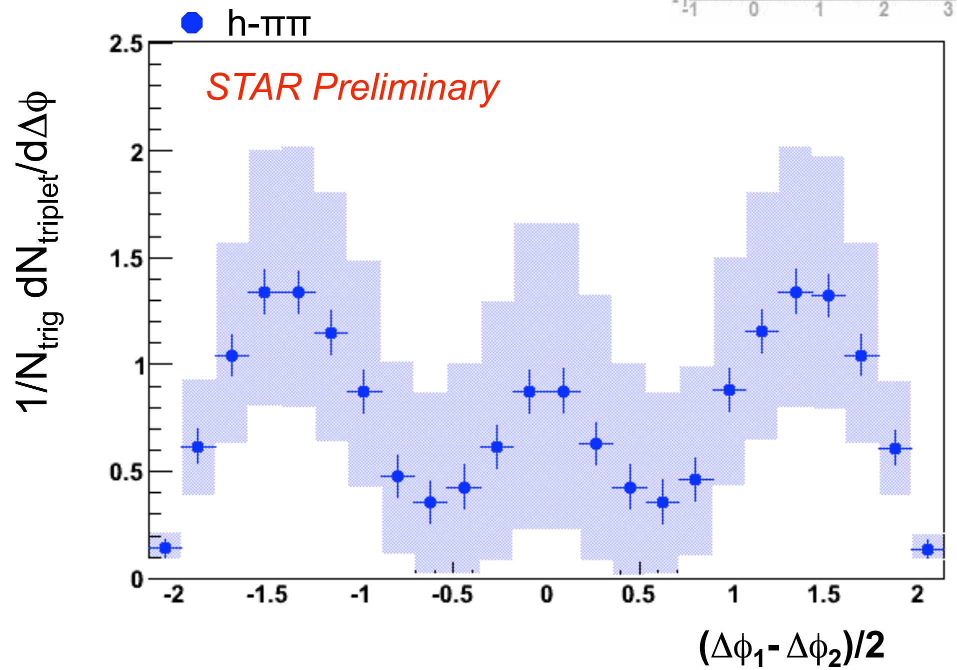
PID 3-PARTICLE CORRELATIONS



diagonal and off-diagonal projections

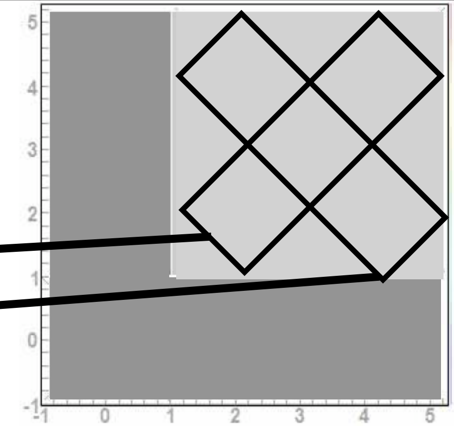
diagonal: **off-diagonal:**





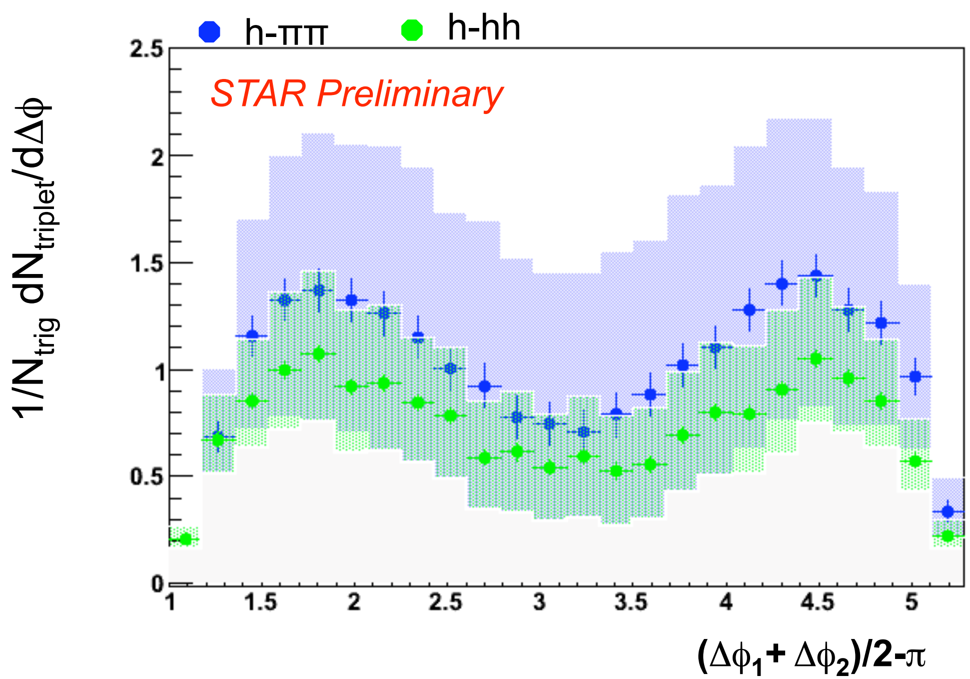
the diagonal and off-diagonal projections of ‘ h-ππ’ ($2.5 < p_T^{Trig} < 10$ GeV/c and $0.7 < p_T^{Asso} < 1.4$ GeV/c)

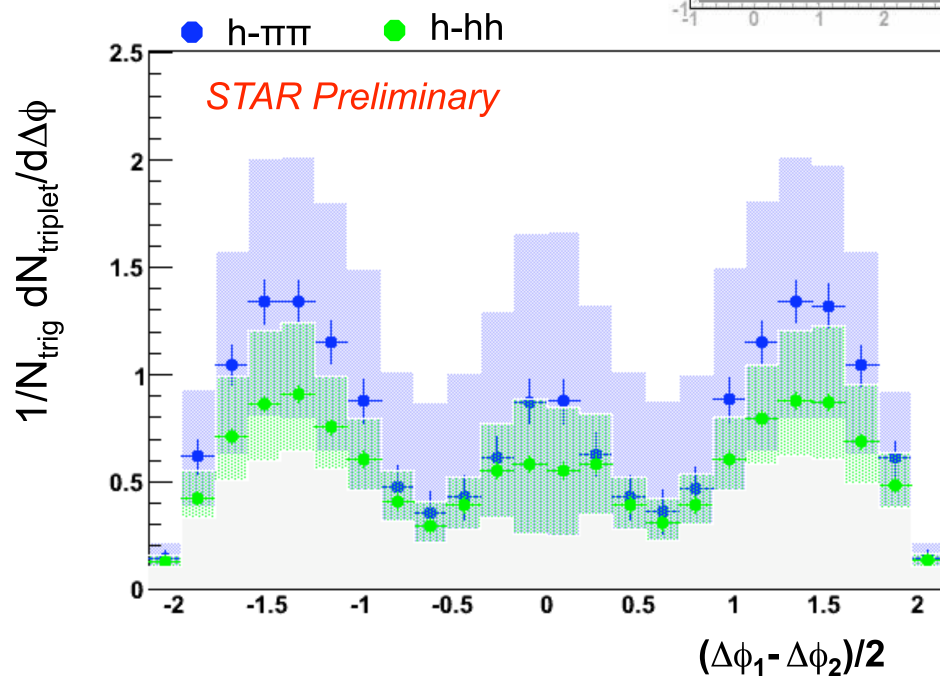
STAR PID 3-PARTICLE CORRELATIONS



diagonal and off-diagonal projections

diagonal: **off-diagonal:**





- the diagonal and off-diagonal projections of ' h-ππ' ($2.5 < p_T^{Trig} < 10$ GeV/c and $0.7 < p_T^{Asso} < 1.4$ GeV/c)
- the diagonal and off-diagonal projections of 'h-hh' ($3 < p_T^{Trig} < 4$ GeV/c and $0.75 < p_T^{Asso} < 1.0$ GeV/c + $1.0 < p_T^{Asso} < 1.5$ GeV/c)

3-PARTICLE CORRELATION AT LHC

- rich statistics of very high p_T trigger particles
- three-particle correlation with high p_T associated PID particles
- three-particle correlation with charm and bottom trigger particles
- ...

CONCLUSIONS

(1) A systematic study of three-particle correlation vs system (size), p_T^{Asso}, and $p_T^{Trig.}$

(2) p_T^{Asso}-independent cone angle consistent with Mach-cone emission, inconsistent with Čerenkov radiation.

(3) New data from Cu+Cu, and identified 'h-pp' and 'h-ππ' in central Au+Au.

(4) No significant difference observed between 'h-pp' and 'h-ππ' in shape within systematic error.

(5) More chances at LHC for three-particle correlation.

Thanks!

Back up

Speed of sound in different phases

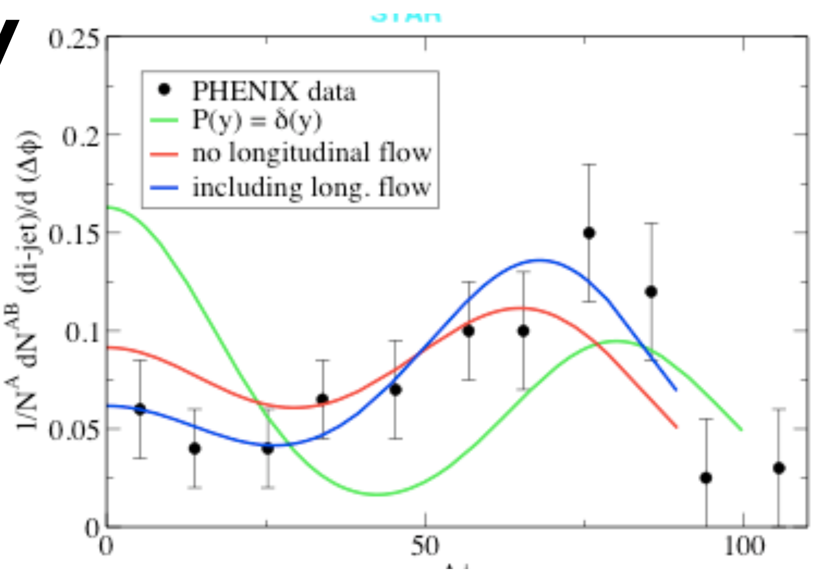
Phase	Speed of Sound
QGP	$1/\sqrt{3}$ c=0.58 c
Mixed Phase	0
Resonance Gas	0.47 c
Exp. Data *	0.15 c

*Note: If θ^M=1.42 rad and $\cos(\theta^M)=c_s/c$, then c_s=0.15c

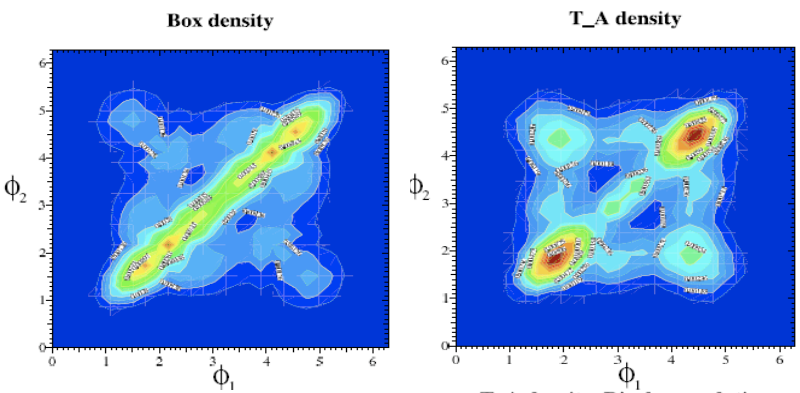
STAR

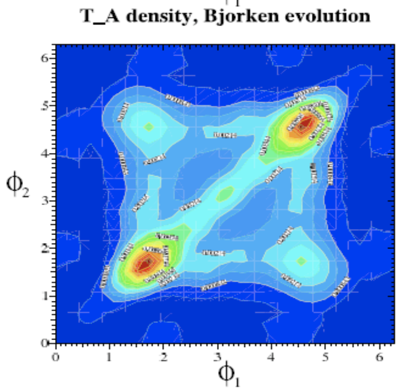
Mach-cone and flow

Renk, Ruppert,
Phys. Lett. **B646** 19 (2007)



- Rapidity distribution and longitudinal flow affects the observed angle and width.
- Transverse flow affects shape of 3-particle correlation.
  - signal at ~1 GeV/c ~9x larger if flow and shockwave aligned than if perpendicular.

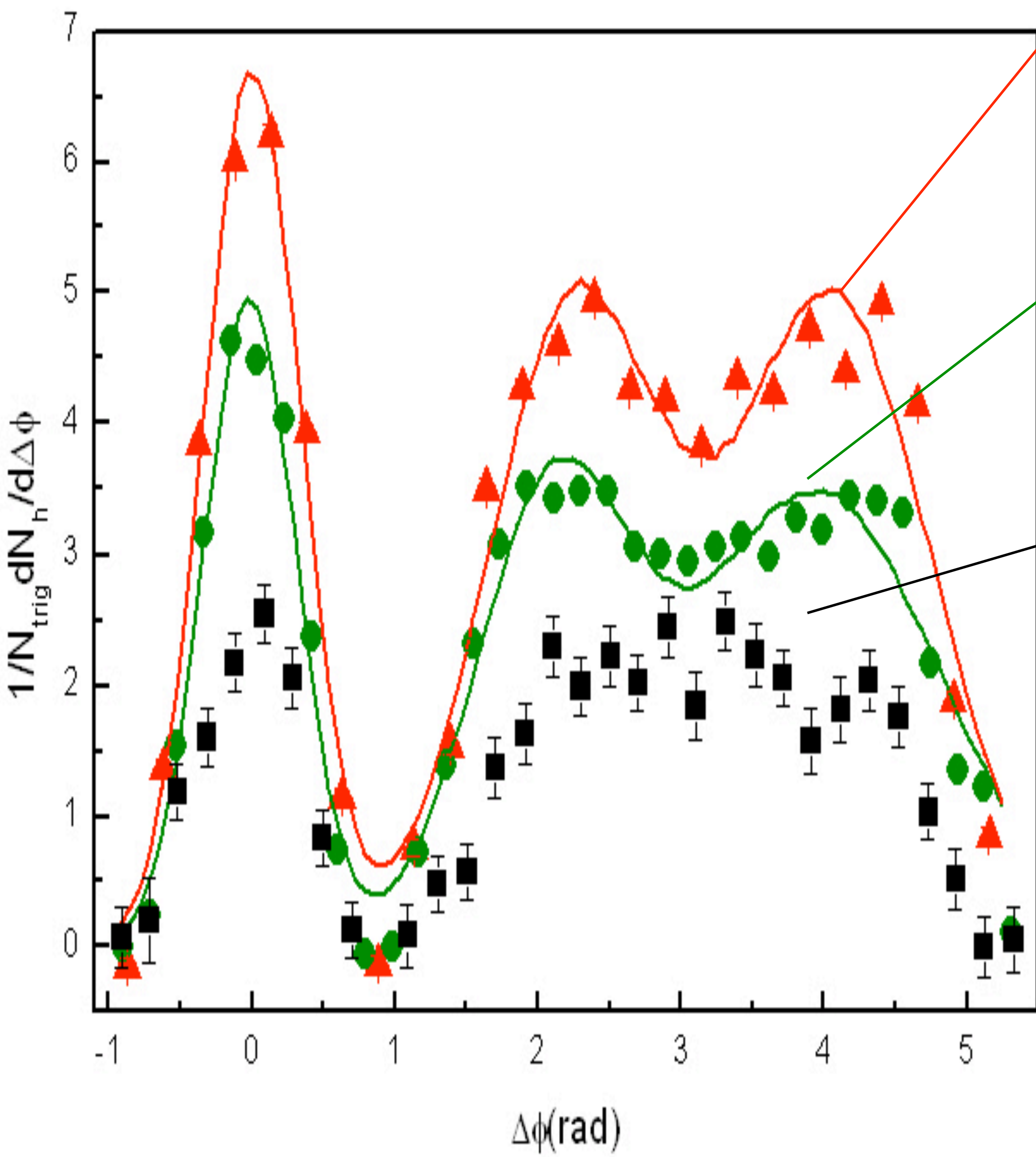




$$E\frac{d^3N}{d^3p} = \frac{g}{(2\pi)^3}\int d\sigma_\mu p^\mu \exp\left[\frac{p^\mu\left(u_\mu^{\text{flow}} + u_\mu^{\text{shock}}\right) - \mu_i}{T_f}\right]$$

Renk, Ruppert,
Phys. Rev. **C76**, 014908 (2007)

$\Delta\phi$ correlations from AMPT
$(3 < p_T^{trigger} < 6 GeV/c, 0.15 < p_T^{assoc} < 3 GeV/c)$



▲ melting version with hadronic rescattering (10mb)

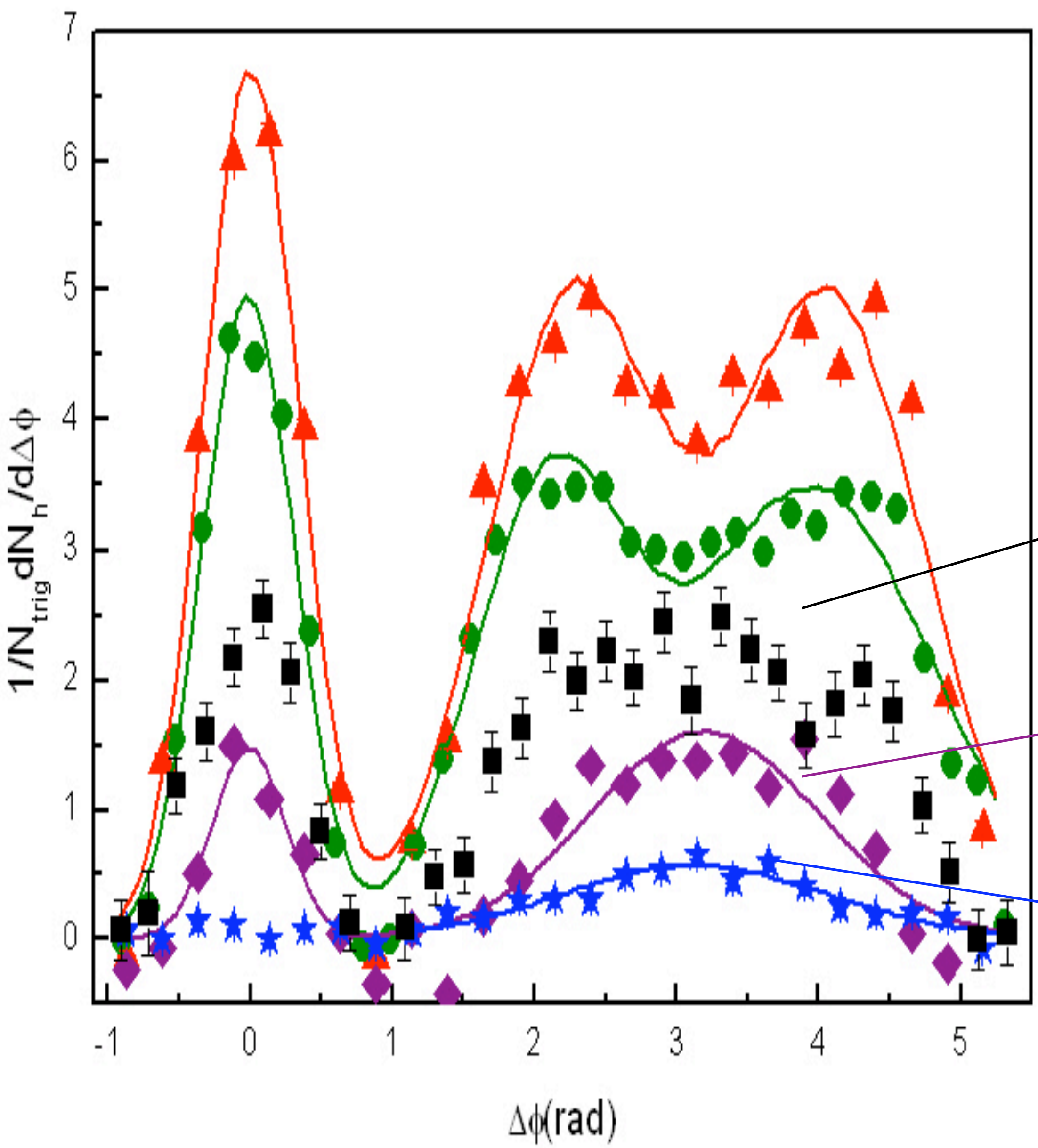
● melting version without hadronic rescattering (10mb)

■ ***STAR data***
0-5% (4-6)x(0.15-4)GeV/c

- ***Mach-like structure is born in strong parton cascade process, and furthermore developed in hadronic rescattering process.***
- ***The problem of excessive correlation magnitude.***

PLB 641, 362 (2006) G. L. Ma et al.

Δφ correlations from AMPT
$(3<p_T^{trigger}<6GeV/c\ ,0.15<p_T^{assoc}<3GeV/c)$



- ***No splitting is seen on away side under the soft p_T cut in default version (only with hadronic resacttering)!***

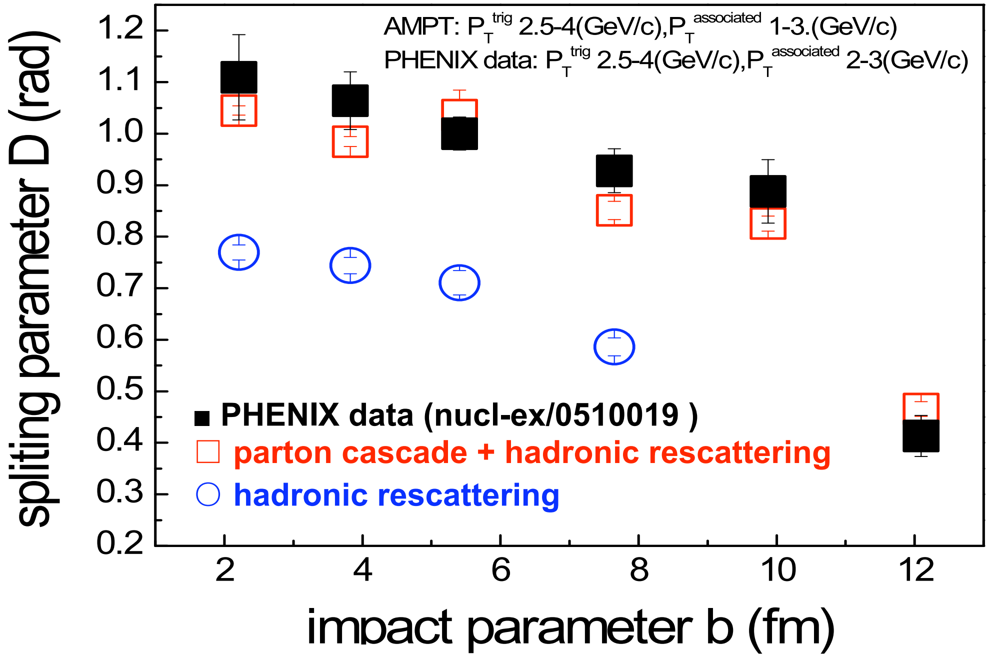
■ ***STAR data***
0-5% (4-6)x(0.15-4)GeV/c

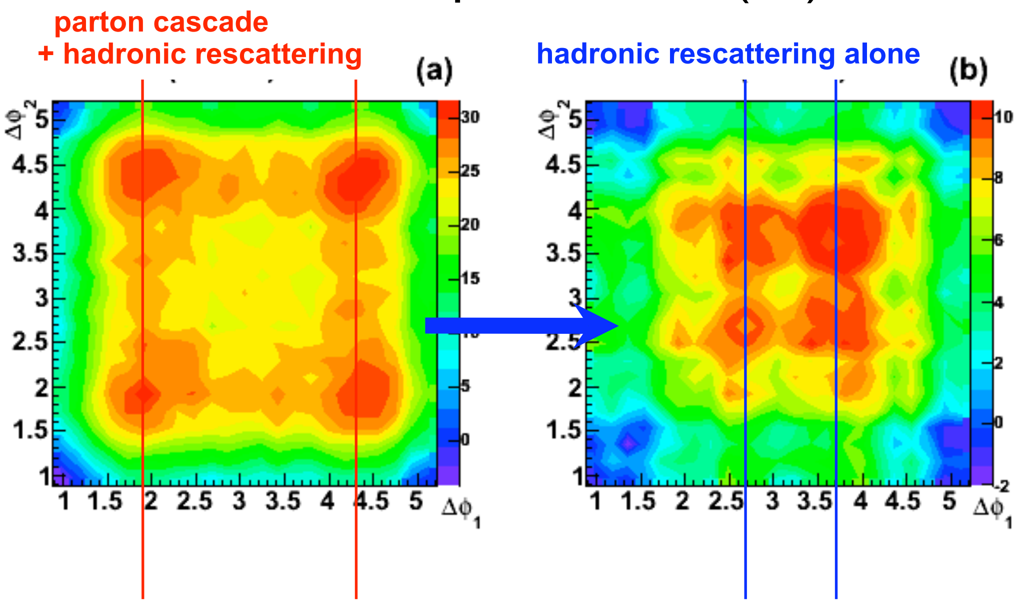
◆ **default version with hadronic rescattering**

★ **default version without hadronic rescattering**

PLB 641, 362 (2006) G. L. Ma et al.

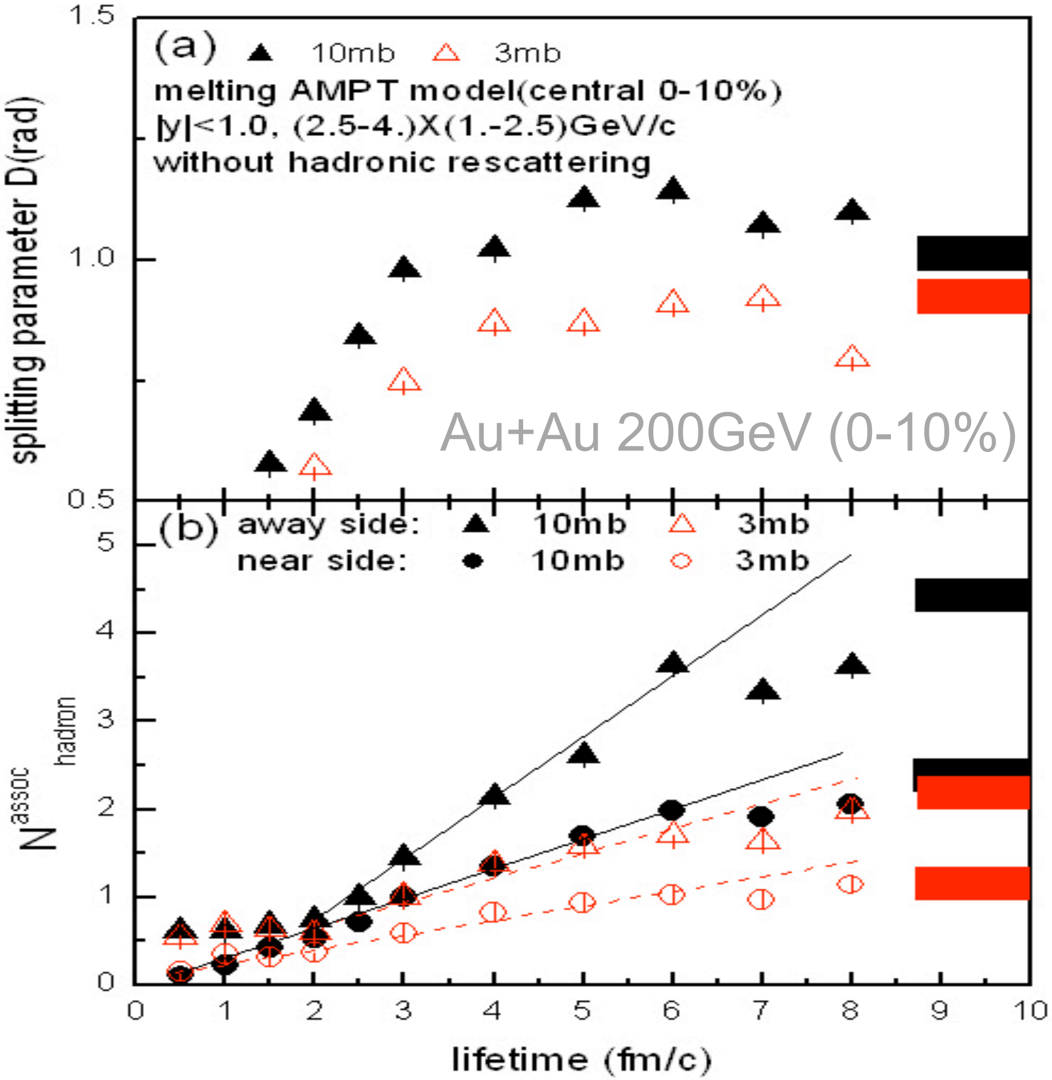
Parton cascade effect on 2- and 3-particle correlations

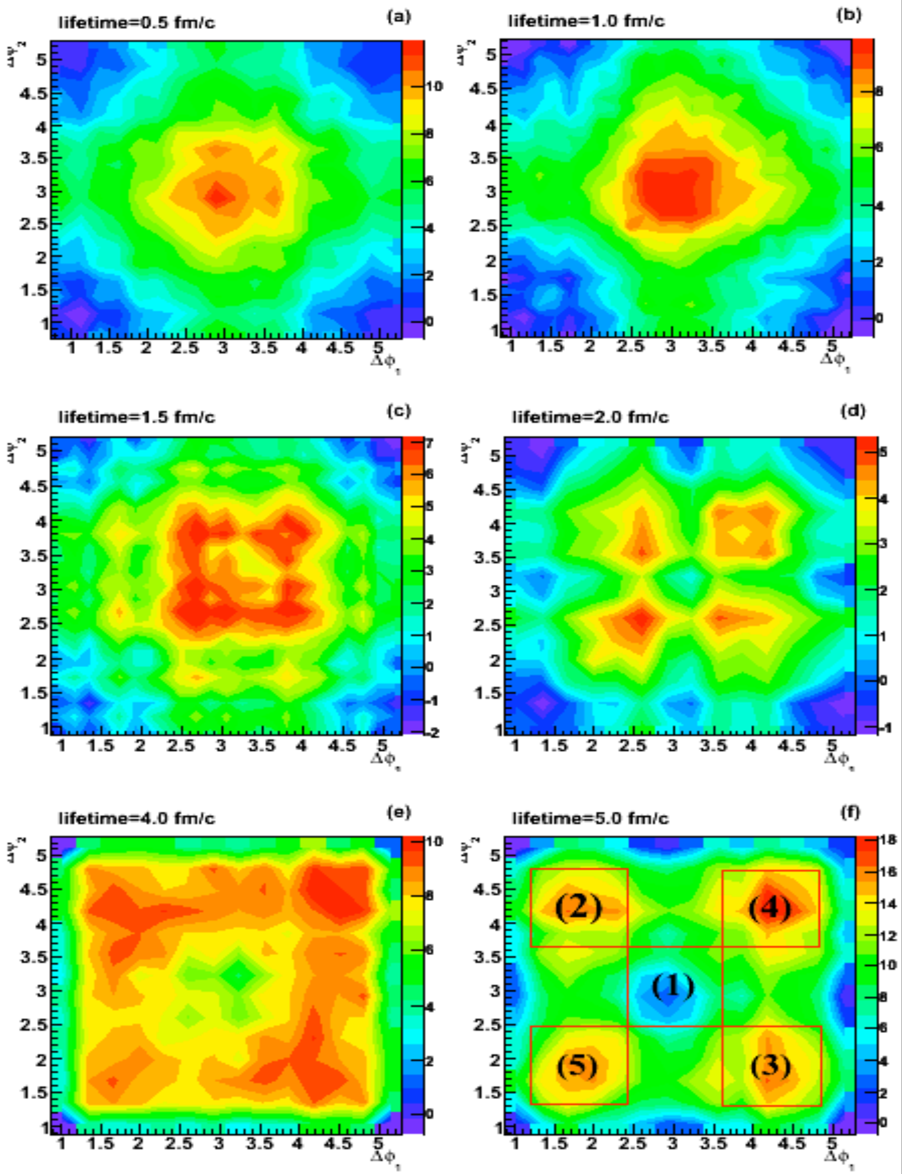




1) ***Hadronic rescattering mechanism alone can not give big enough splitting parameters and correlation areas.***
2) ***Parton cascade mechanism is essential for describing the splitting amplitude of experimental Mach-like structure.***
3) ***Large energy loss in dense partonic medium.***

Partonic Mach-like Shock Wave





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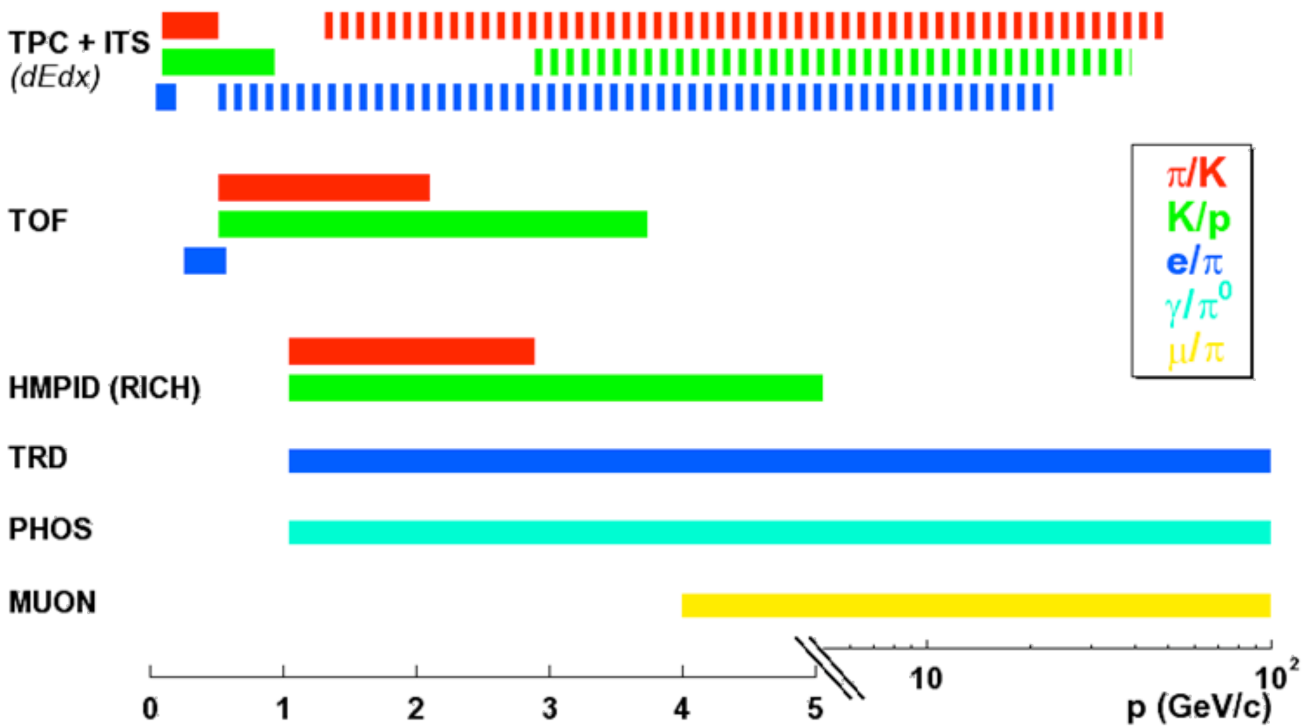
Particle Identification in ALICE



- 'stable' hadrons (π, K, p): 100 MeV/c < p < 5 GeV/c; (π and p with ~ 80 % purity to ~ 60 GeV/c)
  - dE/dx in silicon (ITS) and gas (TPC) + time-of-flight (TOF) + Cherenkov (RICH)
- decay topologies (K^0, K^+, K^-, Λ, D)
  - K and L decays beyond 10 GeV/c
- leptons (e,μ), photons, π^0
  - electrons TRD: p > 1 GeV/c, muons: p > 5 GeV/c, π^0 in PHOS: 1 < p < 80 GeV/c

- excellent particle ID up to ~ 50 to 60 GeV/c