Overview of STAR results on correlations, jets and heavy-flavor production

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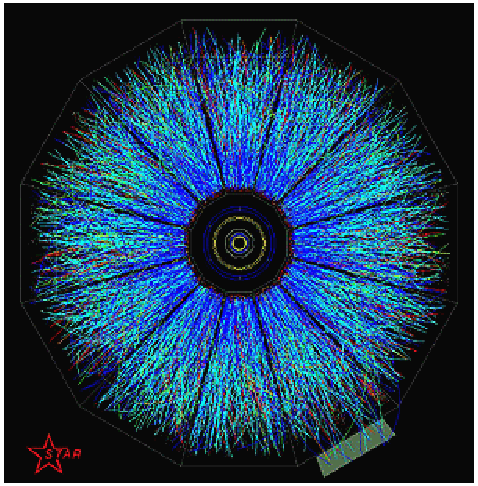
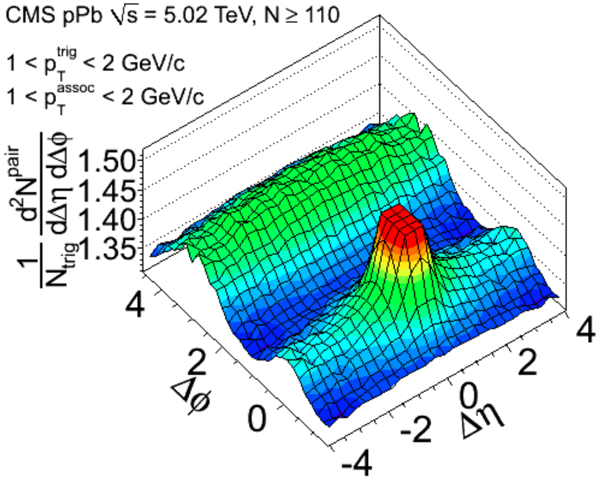


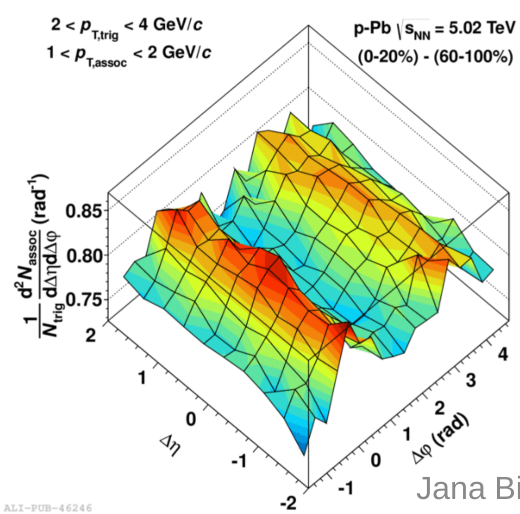
9th International Workshop on High-p_T Physics at LHC, 2013, Grenoble, France

p+p, p+Pb, d+Au (?) ridge …

CMS, PLB 718 (2012) 795

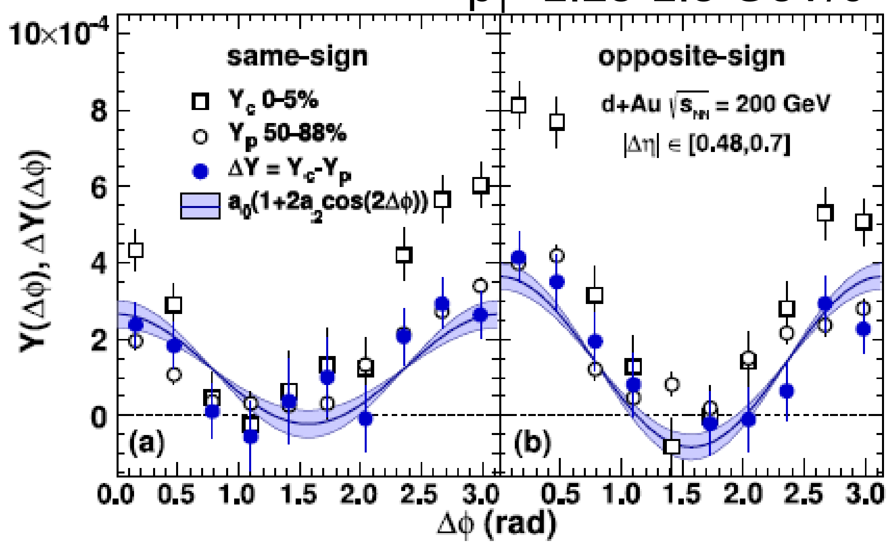


ALICE, PLB 719 (2013) 29



PHENIX, arXiv:1303.1794

p_T=1.25-1.5 GeV/c



Di-hadron correlations in d+Au collisions

d+Au @ 200 GeV

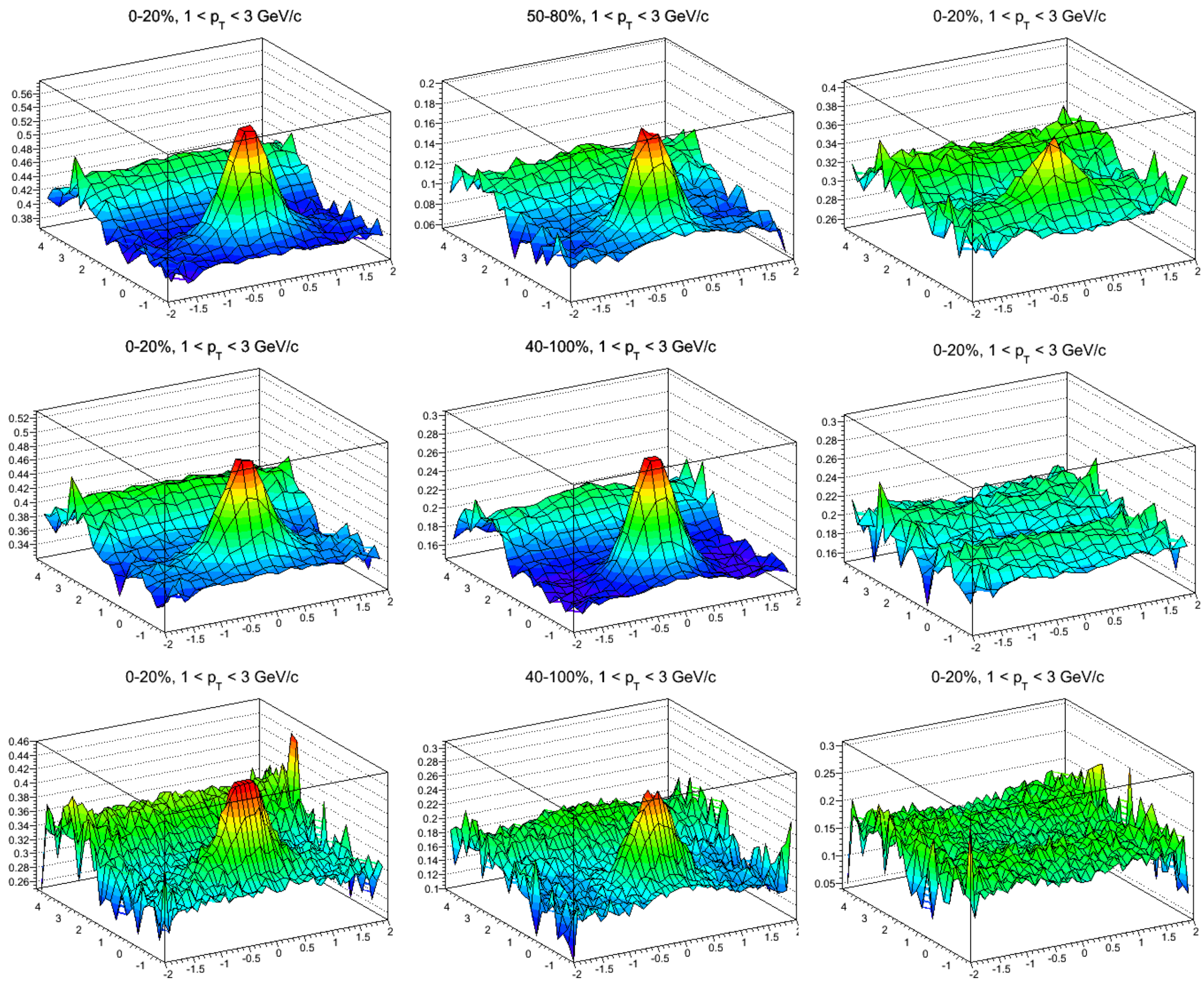
Multiplicity measurement

central | peripheral | central-peripheral

TPC multiplicity
$|\eta|<1.0$

FTPC multiplicity
$-3.8<\eta<-2.8$

ZDC-E multiplicity
Au-side



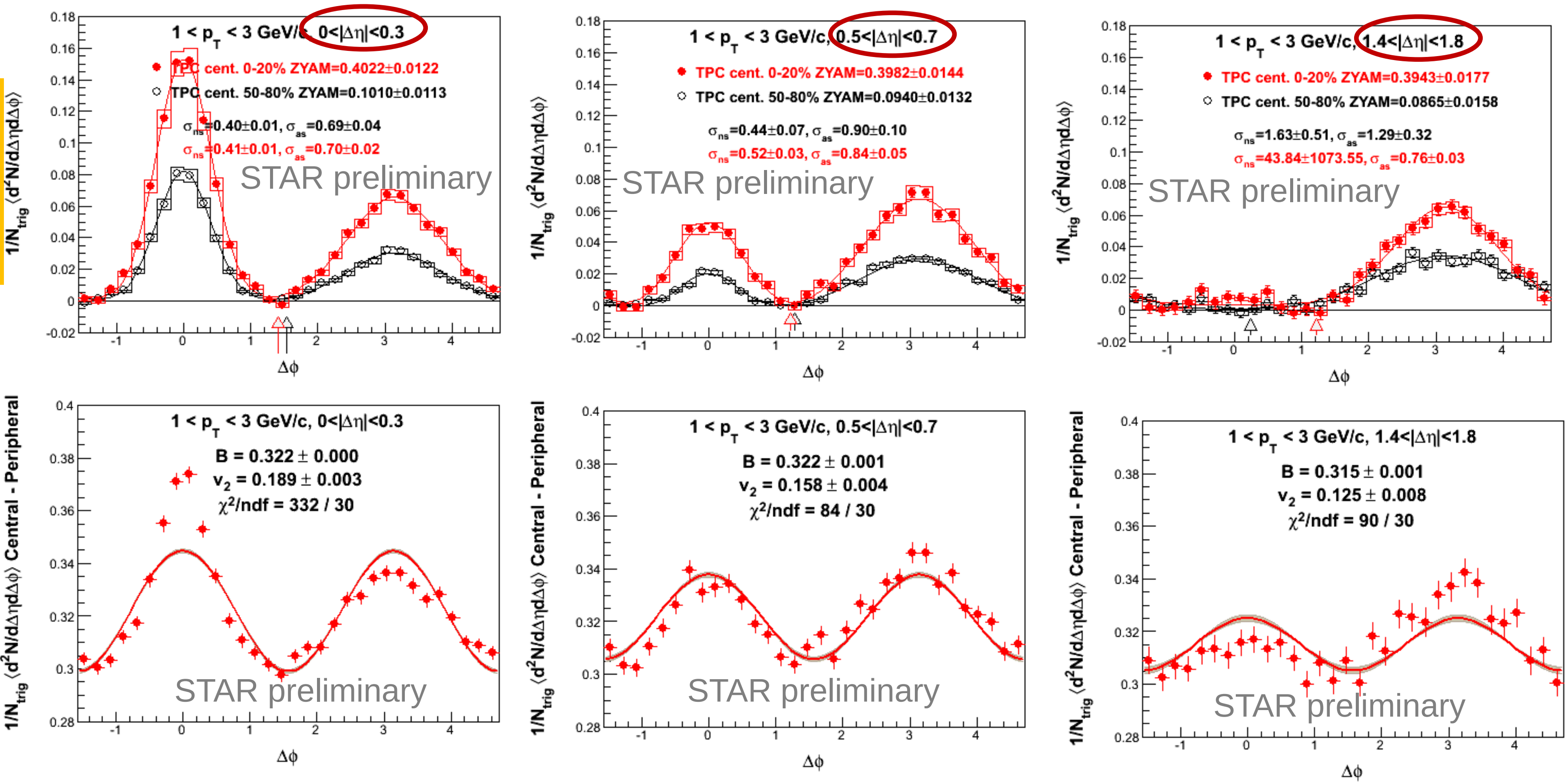
$1 < p_T < 3.0$ GeV/c

Δϕ projections in different Δη

(TPC multiplicity |η|<1 as centrality)

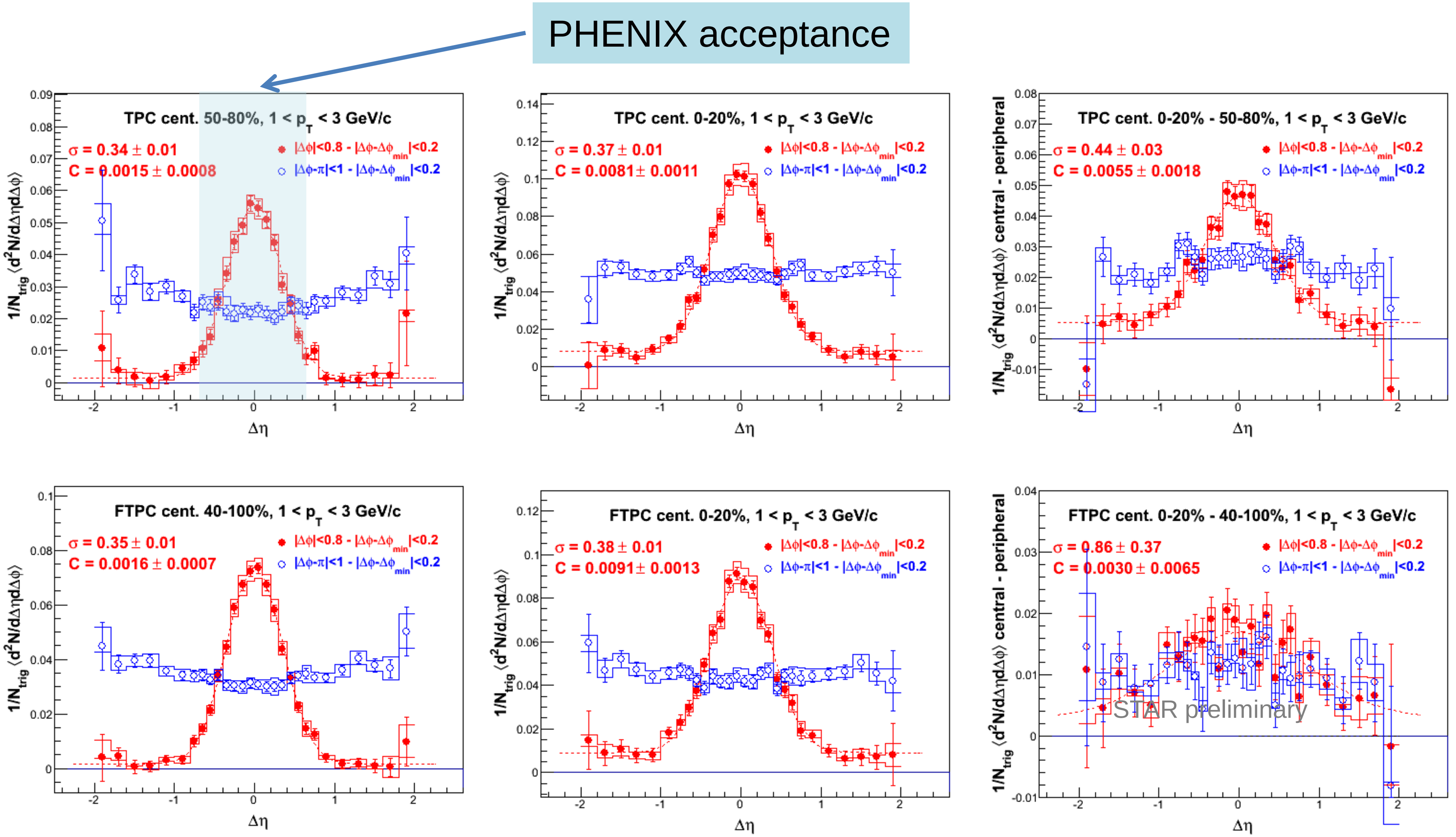
ZYAMed!

No ZYAM



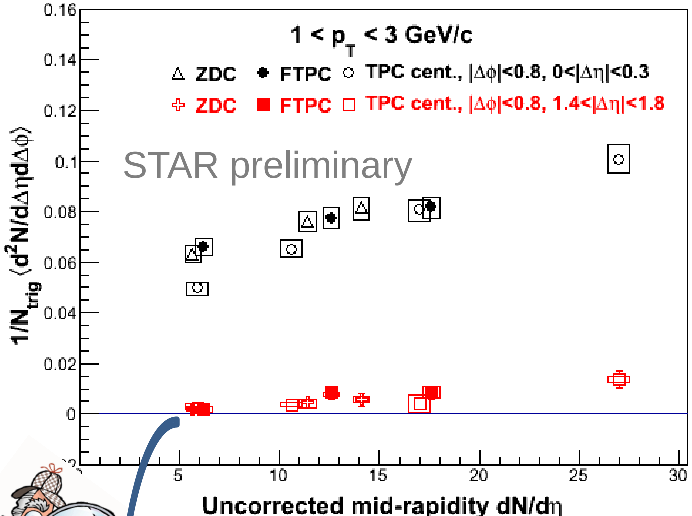
- data corrected for efficiency of associated hadrons: 85 ± 5%
- syst. error from different sizes of Δϕ region for ZYAM.

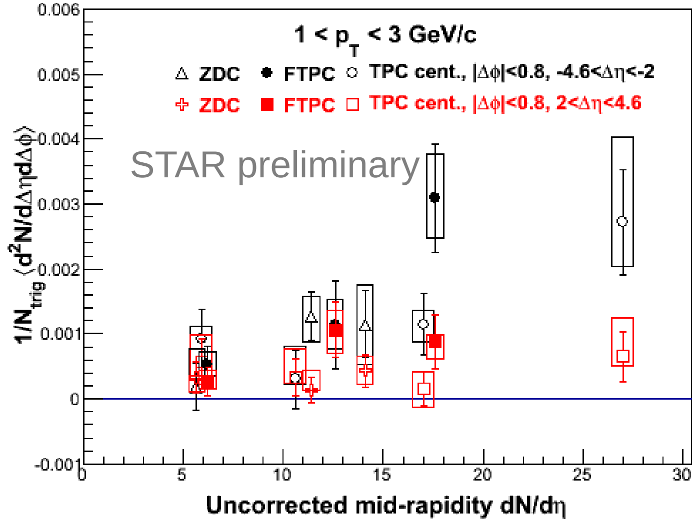
Δη projections in different Δφ

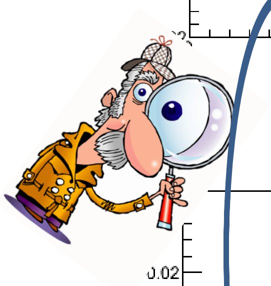


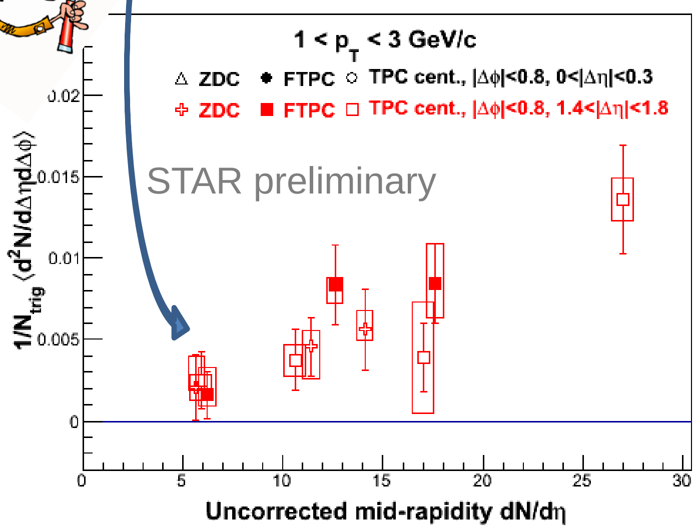
Conditional yield vs multiplicity

1 <p_T^{trig}< 3.0 GeV/c, 1<p_T^{assoc}< 3 GeV/c







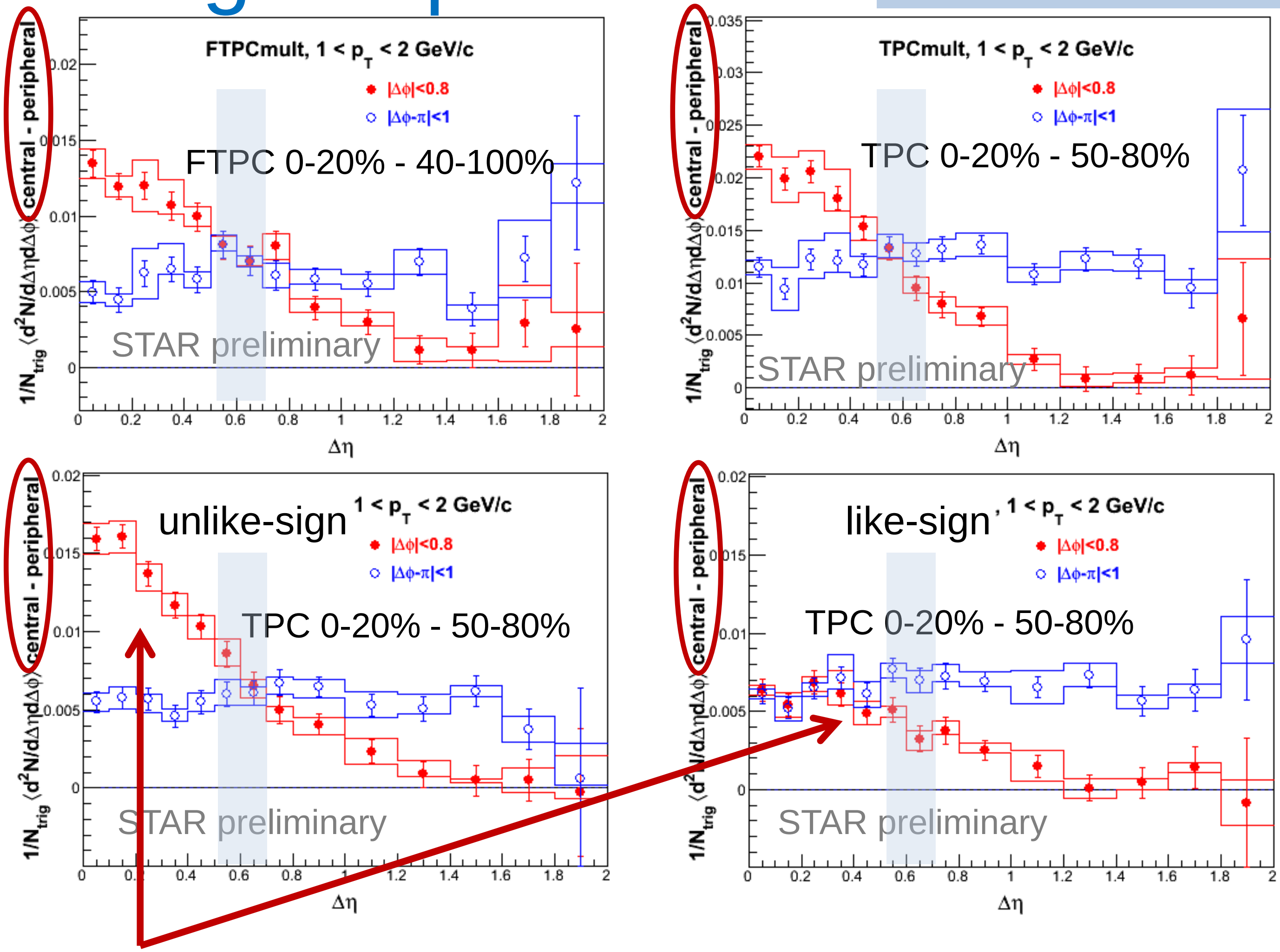


Jet-like yield is biased by multiplicity.

Small ridge yield after ZYAM at large $\Delta\eta$ present, but it is 2-3 σ effect.

Central-peripheral correlation functions, charge dependence

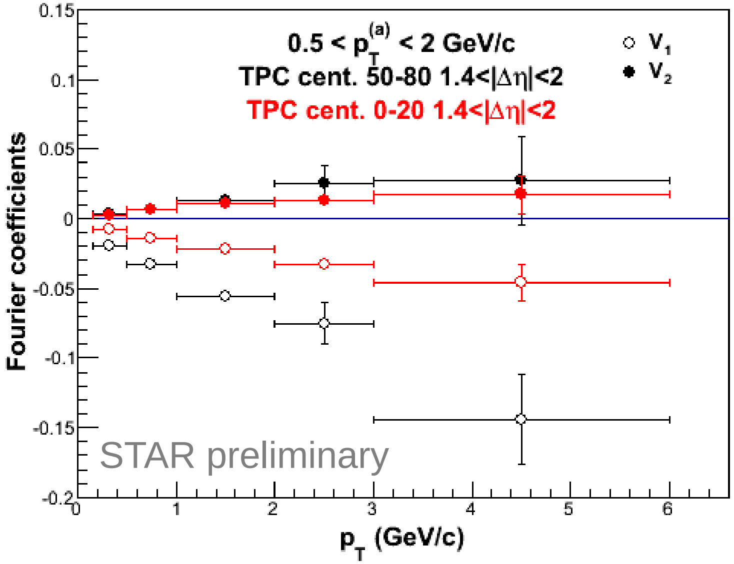
0.15 <p_T^{trig}< 3.0 GeV/c, 1<p_T^{assoc}< 2 GeV/c

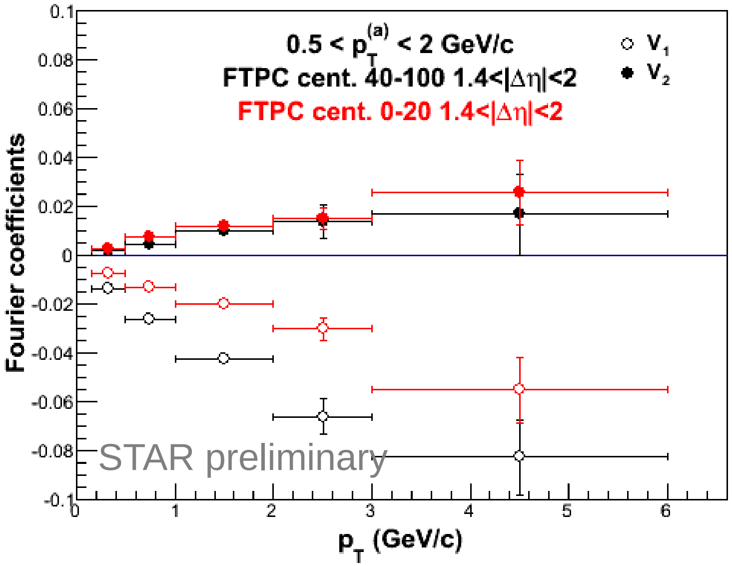


"Near-side peak" shows jet-like features of charge-ordering.

Fourier analysis of correlation functions (I)

$$V_n = \langle \cos(n\Delta\varphi) \rangle$$



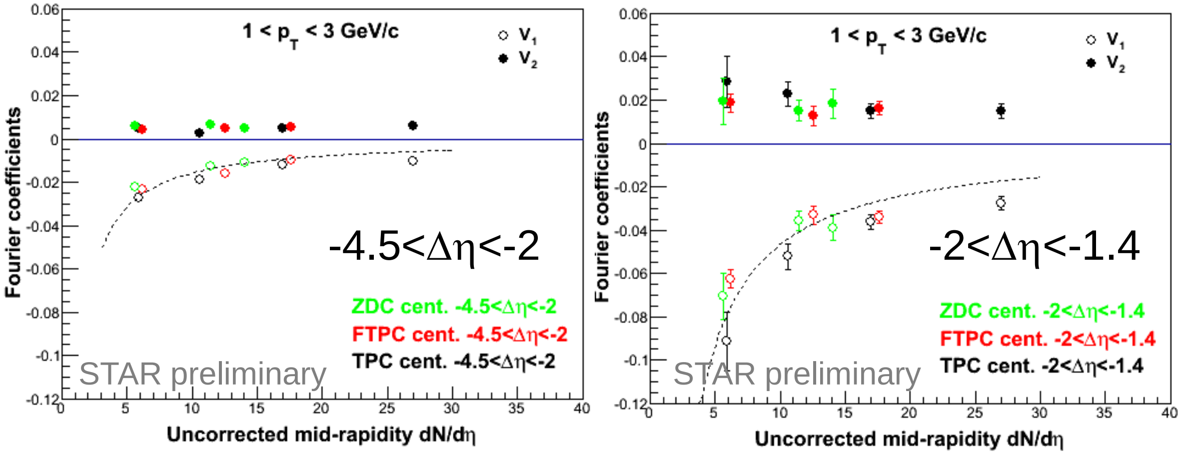


- No ZYAM
- No central-peripheral
- p_T dependence: one particle p_T is fixed to 0.5-2 GeV/*c*

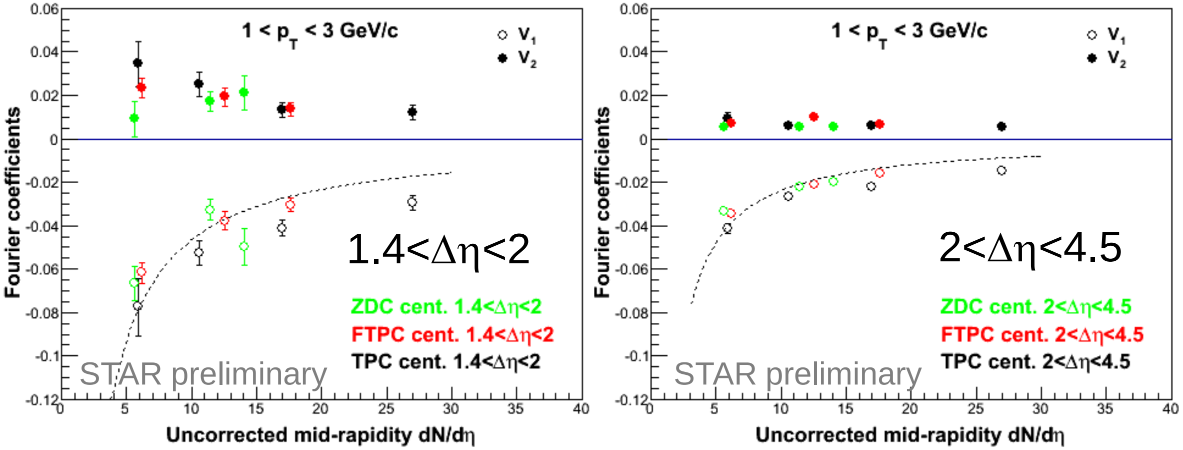
Correlations in d+Au have non-zero V_1 and V_2 components

Fourier analysis of correlation functions (II)

Au-side



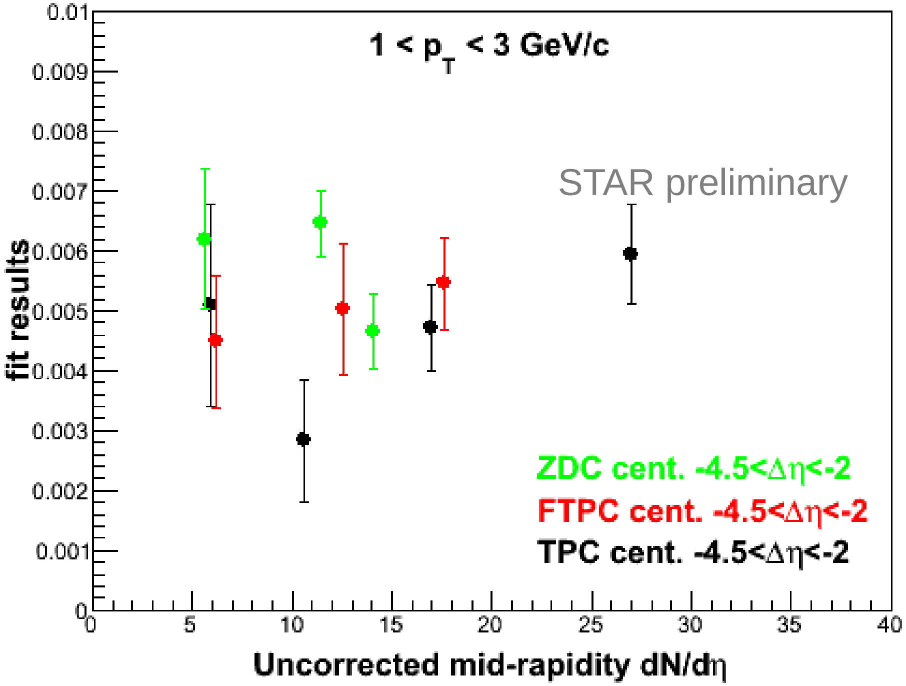
d-side

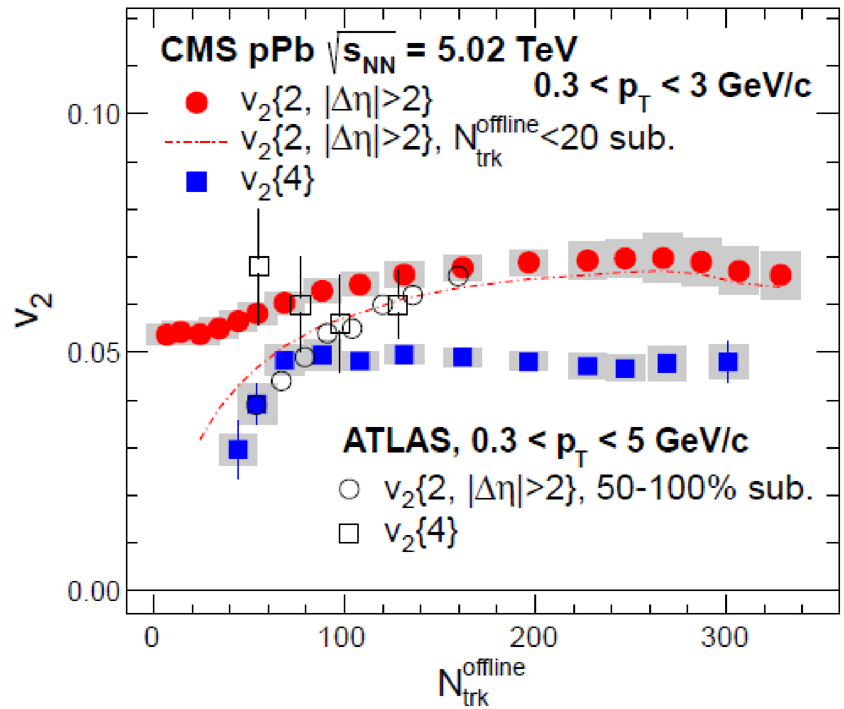


Centrality dependence:

- V_1 ~1/N
- V_2 ~ const. with multiplicity
- V_2 component is large even at very forward η (d-side)

v_2 in cold nuclear matter at RHIC vs LHC





- $v_2\{2\}$ is insensitive to multiplicity in d+Au at RHIC and p+Pb at LHC
- $v_2\{4\}$ at LHC is independent of multiplicity except for peripheral p+Pb

What is the physics origin of this v_2?

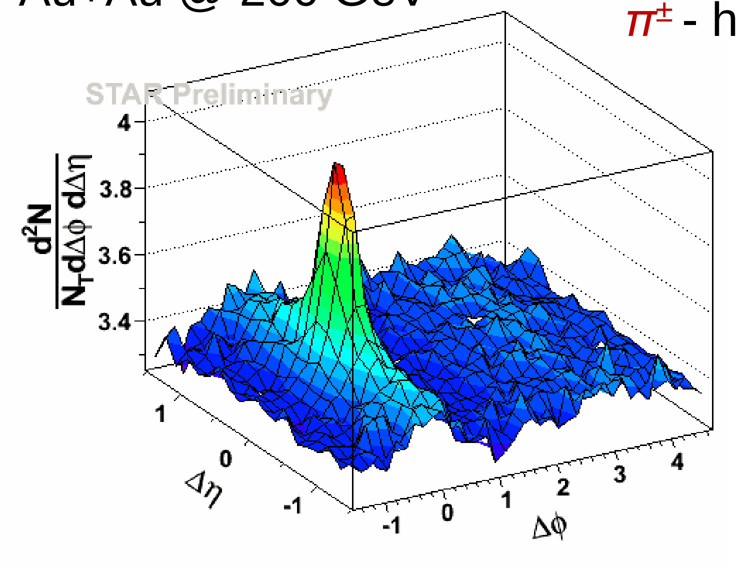
Hydrodynamic flow? *In peripheral collisions? No increase with multiplicity?*

Color Glass Condensate? *No increase with multiplicity?*

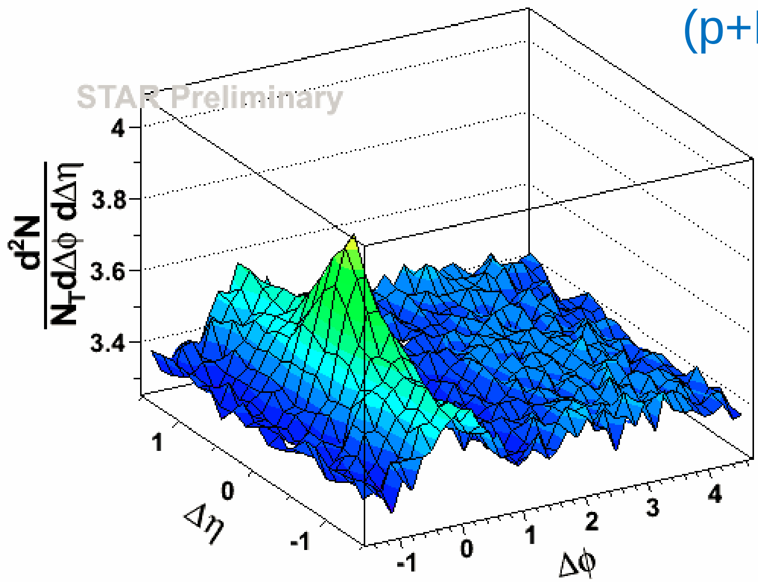
New data on PID triggered correlations

Au+Au @ 200 GeV

$\pi^{\pm}$ - h



(p+K) - h



Data set: 200 GeV Au+Au Central (Run 10)
150M events
200 GeV d+Au MinBias (Run 8)
46M events
PID: TPC dE/dx based, statistical separation

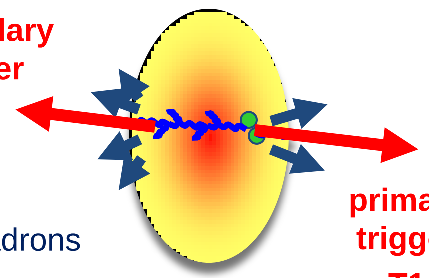
A closer look on hadronization effects and origin of the ridge …

π triggers:
large cone, small ridge
p+K triggers:
small cone, large ridge

See talk by O. Evdokimov (STAR) – Saturday, Sep. 28, 9:00

2+1 correlations: di-jet study

“Pin” the jet axis by selecting back-to-back triggers. Investigate distributions of associated hadrons with respect to both trigger hadrons.

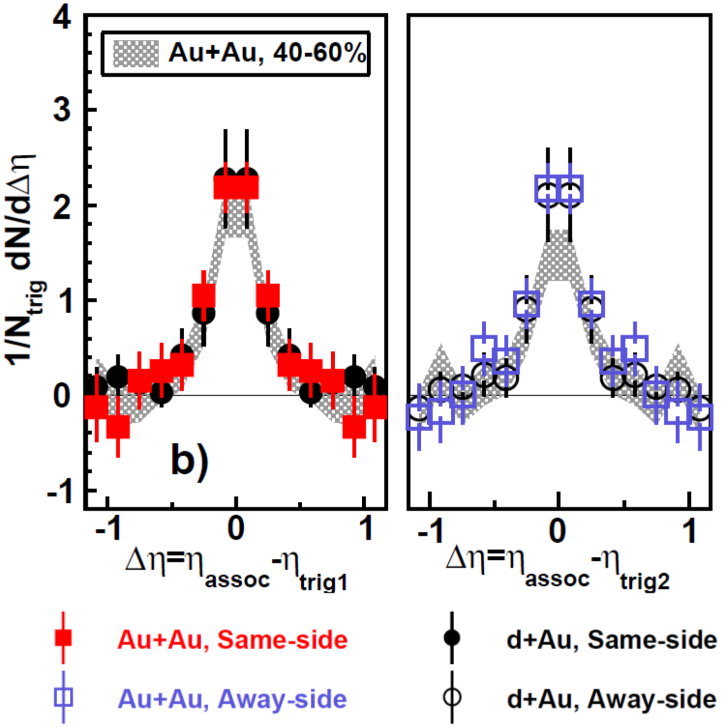


symmetric triggers (p_{T1}~p_{T2})

$5 < p_{T1} < 10$ GeV/*c*, 4 GeV/c $< p_{T2} < p_{T1}$

1.5 GeV/*c* $< p_T^{assoc} < p_{T1}$

STAR, PRC 83 (2011) 061901



Central Au+Au ~ d+Au collisions:
- no away-side suppression
- no significant shape/yield modifications
- no apparent ridge present

Sampling of surface-biased/unmodified di-jets? Di-jets where both jets lose similar amounts of energy?

Look at p_T asymmetric di-jets using elmag.calorimeter for T1

2+1 correlations: di-jet energy imbalance

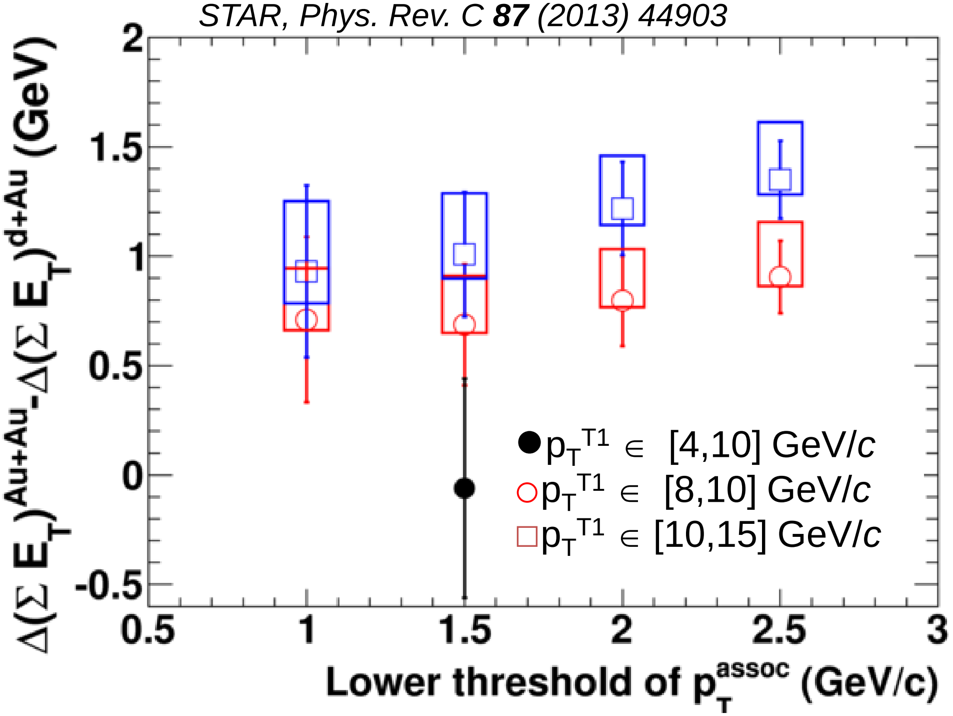
Jet energy ~ Σp_T within the 0.5x0.5 ($\Delta\eta$ x $\Delta\phi$)

Energy imbalance: $\Delta(\Sigma E_T) = (E_T^{T1} + \Sigma p_T^{assoc,near}) - (p_T^{T2} + \Sigma p_T^{assoc,away})$

→ investigate relative energy imbalance:

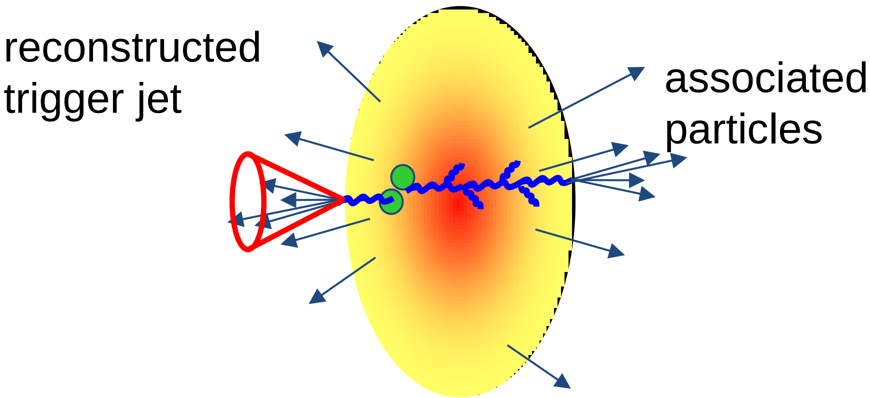
$$\Delta(\Sigma E_T)^{Au+Au} - \Delta(\Sigma E_T)^{d+Au}$$

STAR, Phys. Rev. C ***87*** *(2013) 44903*

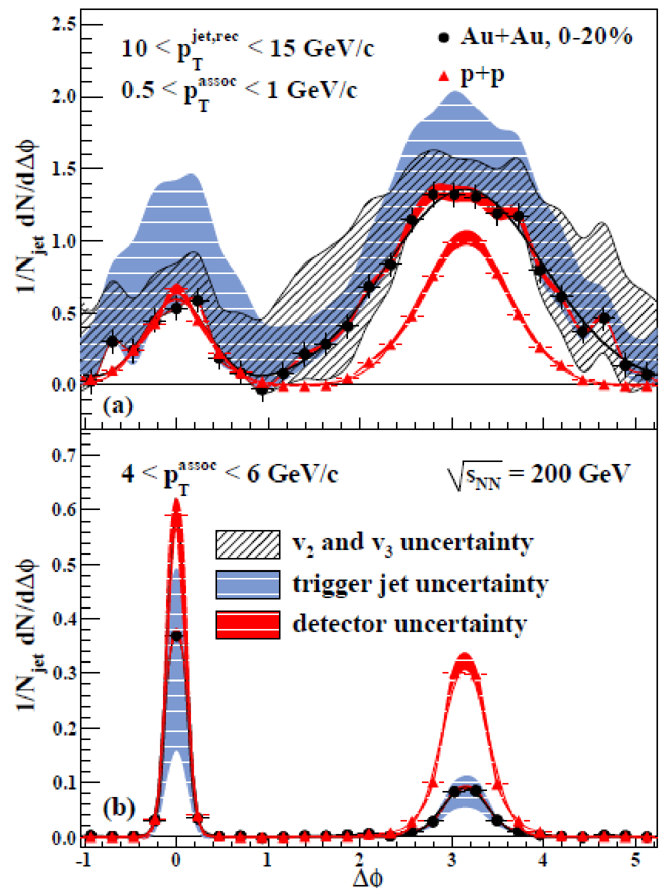


- non-zero relative energy imbalance for asymmetric triggers observed
- the imbalance increases with trigger asymmetry
- Indication of softening of fragmentation function for selected di-jets
- qualitatively consistent with longer path-lengths traversed and higher energy loss

Jet-hadron correlations



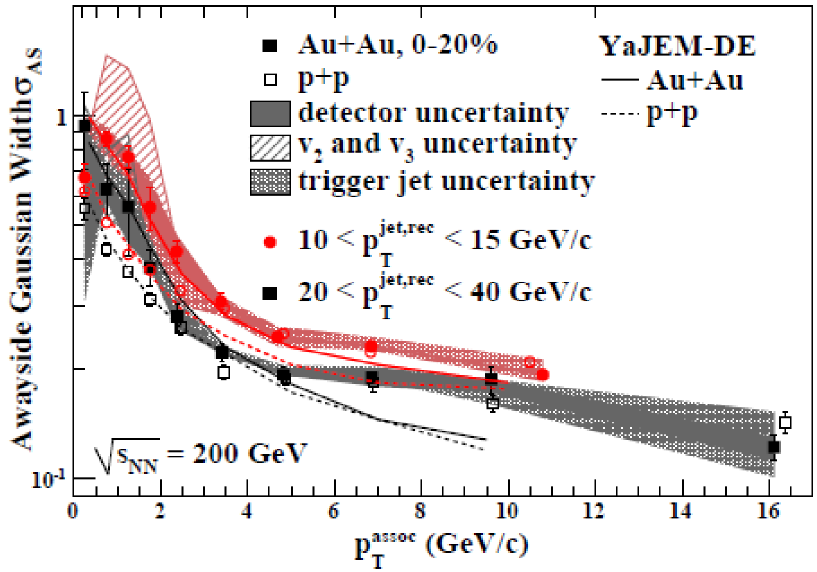
larger kinematic reach compared to di-hadron correlations

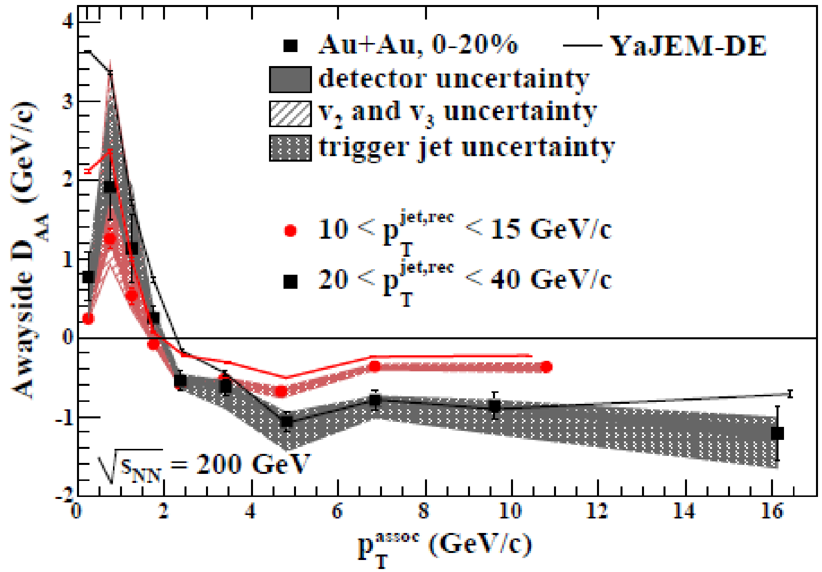


- jet reconstruction: anti-k_T algorithm (R = 0.4) with a trigger tower in BEMC with E_T > 6 GeV and constituent tracks/towers with $p_T(E_T)$>2 GeV to reduce background fluctuations (NOTE: "a highly biased jet population")
- recoil (away-side) jet fragmentation is unbiased

Quantifying properties of jet-hadron correlations

STAR, arXiv: 1302.6184 ; YaJEM-DE, T. Renk, PRC 87 (2013) 2, 024905





Away-side Gaussian width:

suggestive of medium induced broadening

BUT!

highly depends on v_3 → further information on v_2^{jet} and v_3^{jet} needed

Away-side energy balance:

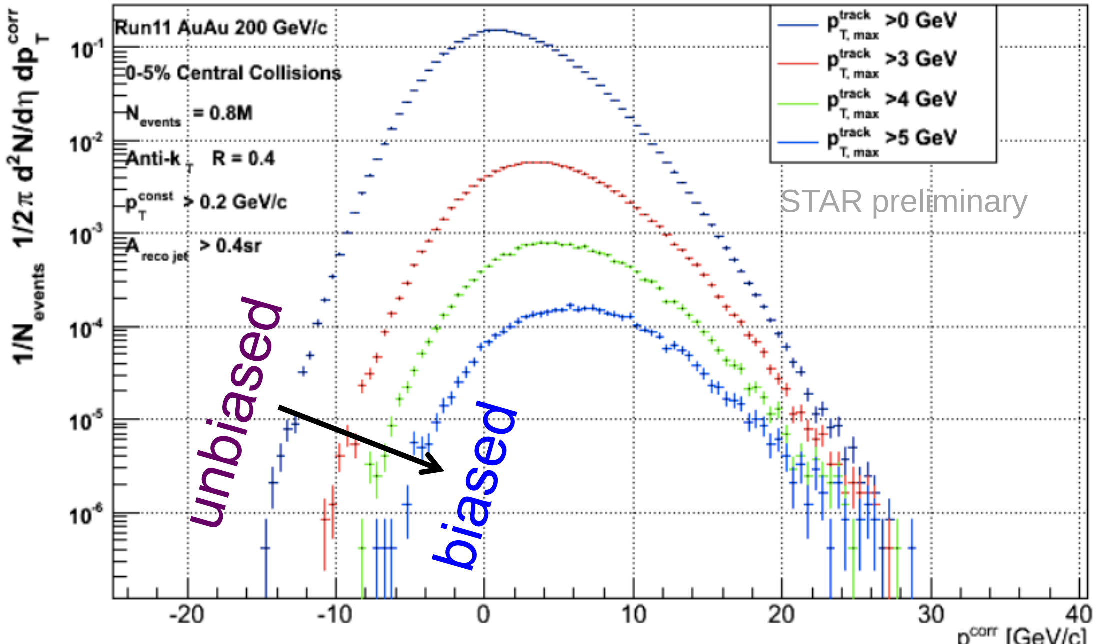
$$D_{AA}(p_T^{assoc}) = Y_{AuAu}(p_T^{assoc}) \cdot \langle p_T^{assoc} \rangle_{AuAu} - Y_{pp}(p_T^{assoc}) \cdot \langle p_T^{assoc} \rangle_{pp}$$

Suppression of high-p_T associated hadron yield ~ balanced by enhancement at low-p_T.

The redistribution of energy quantitatively consistent with YaJEM-DE model of in-medium shower modification.

Toward jet R_{AA} in Au+Au collisions

- early Quark Matter 2009 results: pioneering work on jet R_{AA}
- high statistics Run11 Au+Au data at 200 GeV under study
- jets reconstructed using IR safe anti-k_T algorithm with R=0.4
- currently only charged jets (for simplicity)
- minimum constituent cut (p_T^{const}>200 MeV/c for tracks)
- exploratory study on small fraction of data (1%)



Stable unfolding requires each jet candidate to have at least one constituent with p_T greater than a threshold value.

Unfolding of background fluctuations

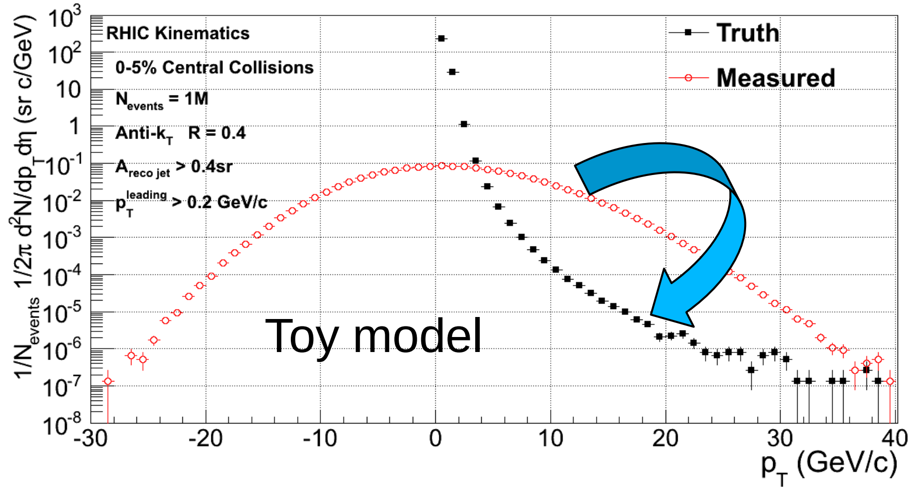
Standard methods:

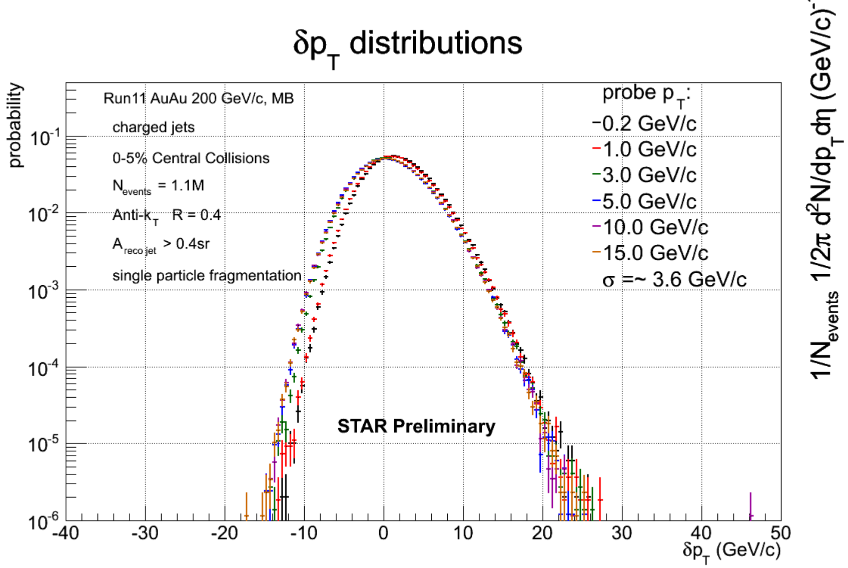
- Bayesian
- Singular Value Decomposition (SVD)

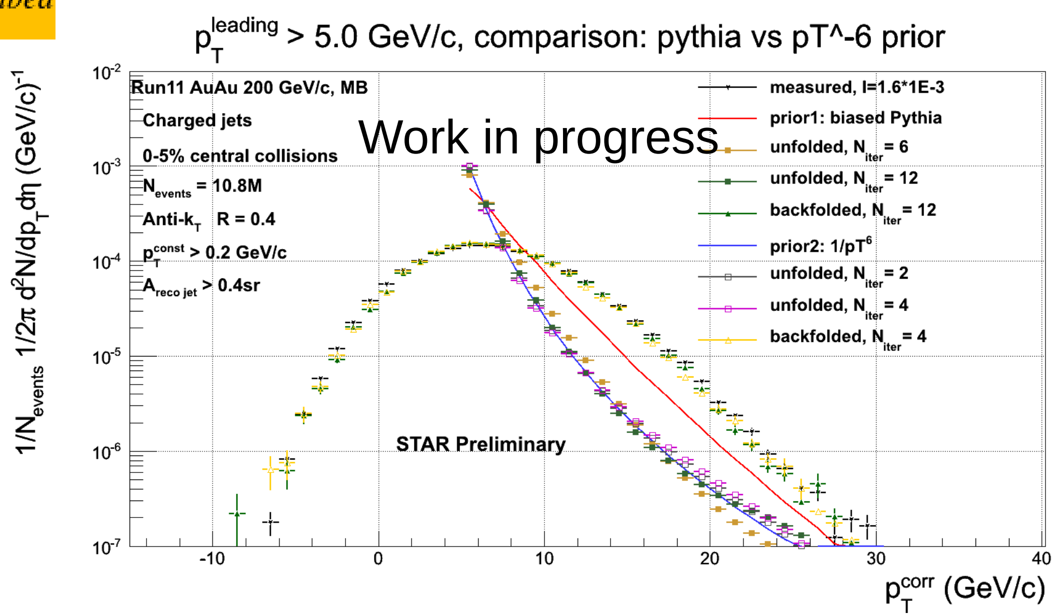
Methods tested in parallel using a “Toy model” Monte-Carlo

Response matrix measured by embedding simulated “jets” into real events → δp_T

$$\delta p_T \equiv p_T^{<corr>} - p_T^{embed} = p_T^{jet} - \rho \cdot A_{jet} - p_T^{embed}$$

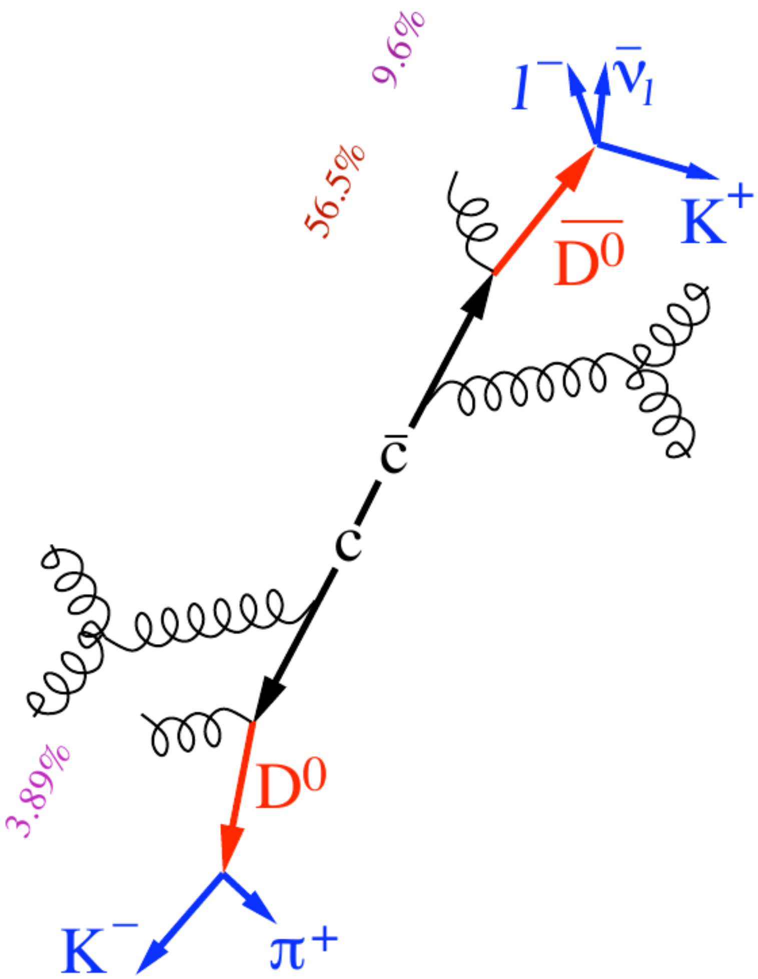






Stable convergence for $p_T^{leading}$>5 GeV/*c*, ~20% sensitivity to choice of prior.

Open heavy-flavour hadron production

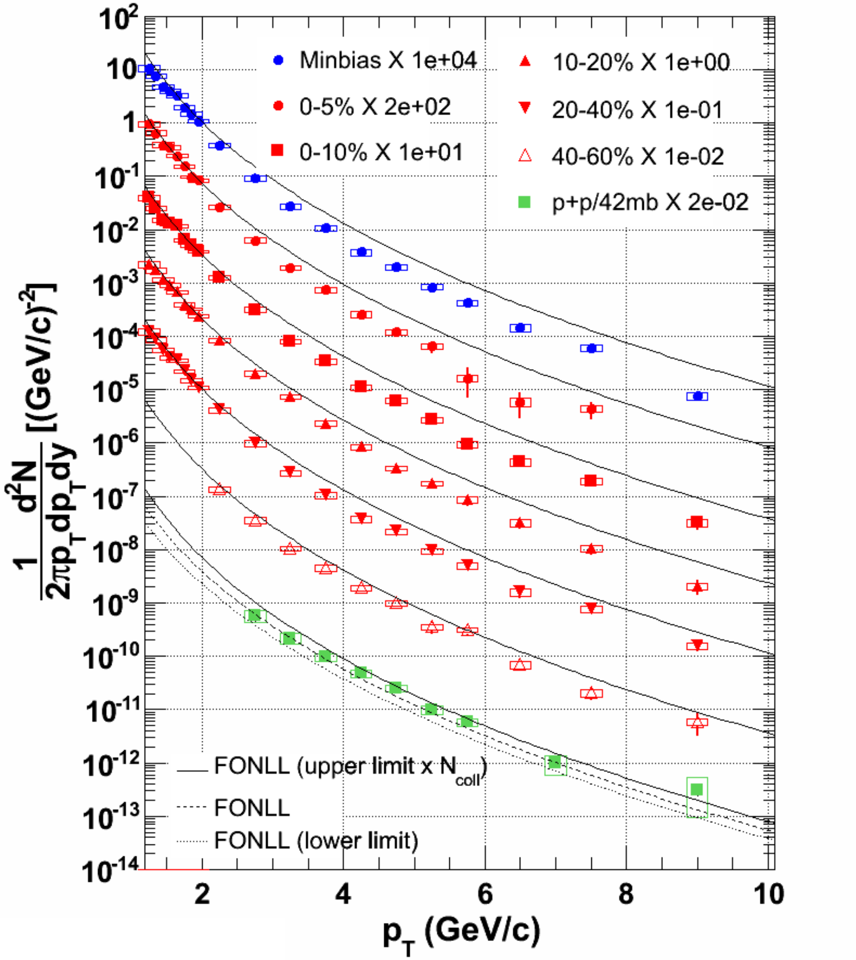


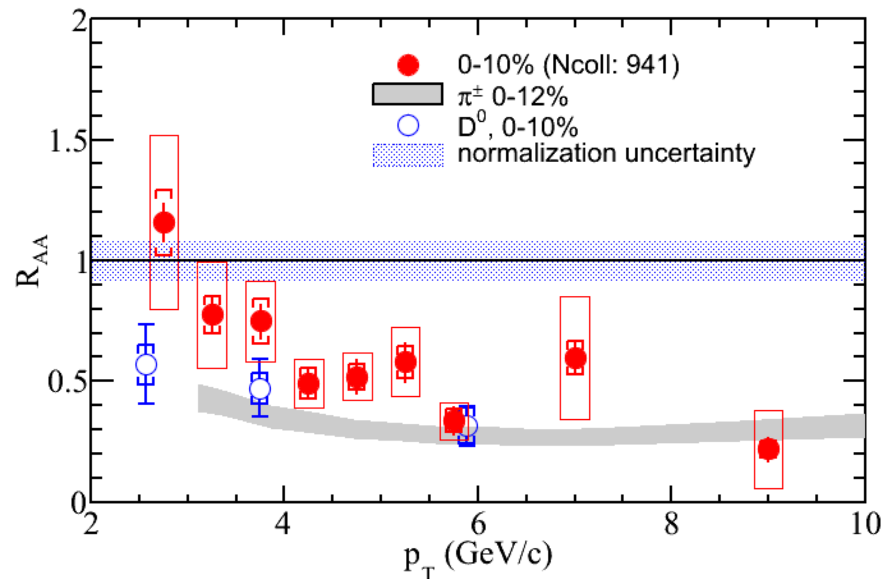
Non-photonic electrons:
(electrons from semi-leptonic heavy flavour hadron decays)

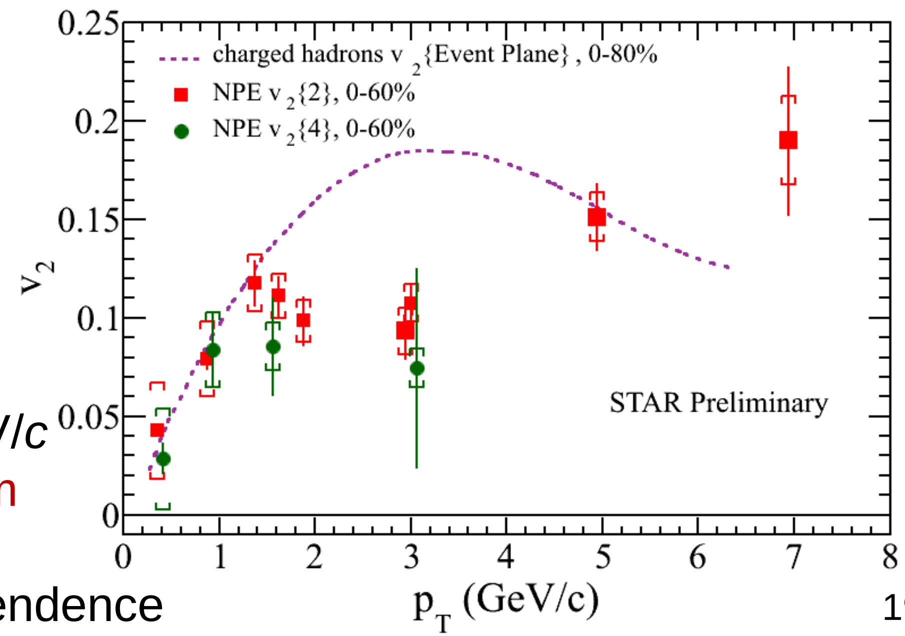
+ easy to trigger
- indirect access to heavy quark kinematics

Direct open charm reconstruction:
+ direct access to heavy quark kinematics
- requires precise vertex tracking detector to suppress background
- difficult to trigger

New high-p_T non-photonic electron data

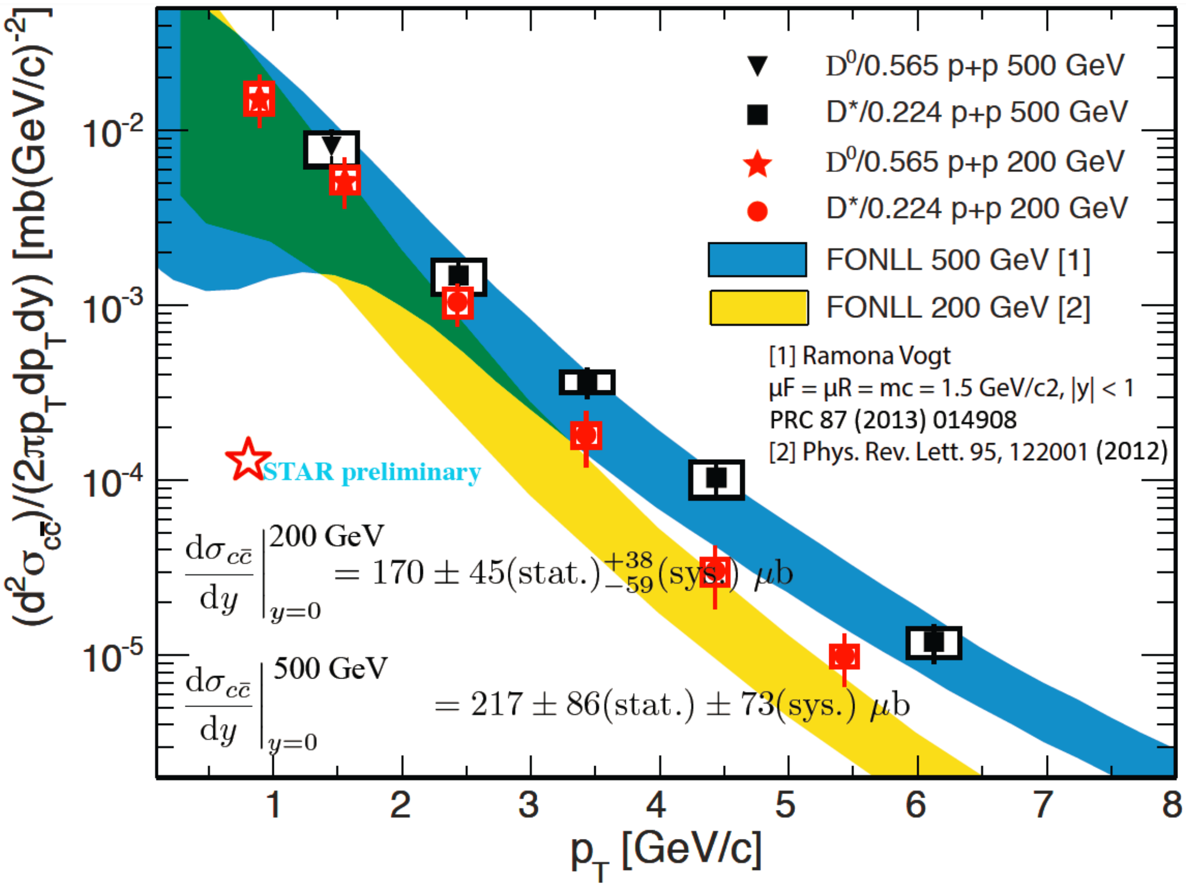






- R_{AA}(NPE) ~ R_{AA}(D) ~ R_{AA}(hadrons)
- elliptic flow v_2(NPE): finite up to p_T=7 GeV/c
  strong charm interaction with medium
- increase of v_2(NPE) with p_T : contribution from jet-like correlations, path length dependence

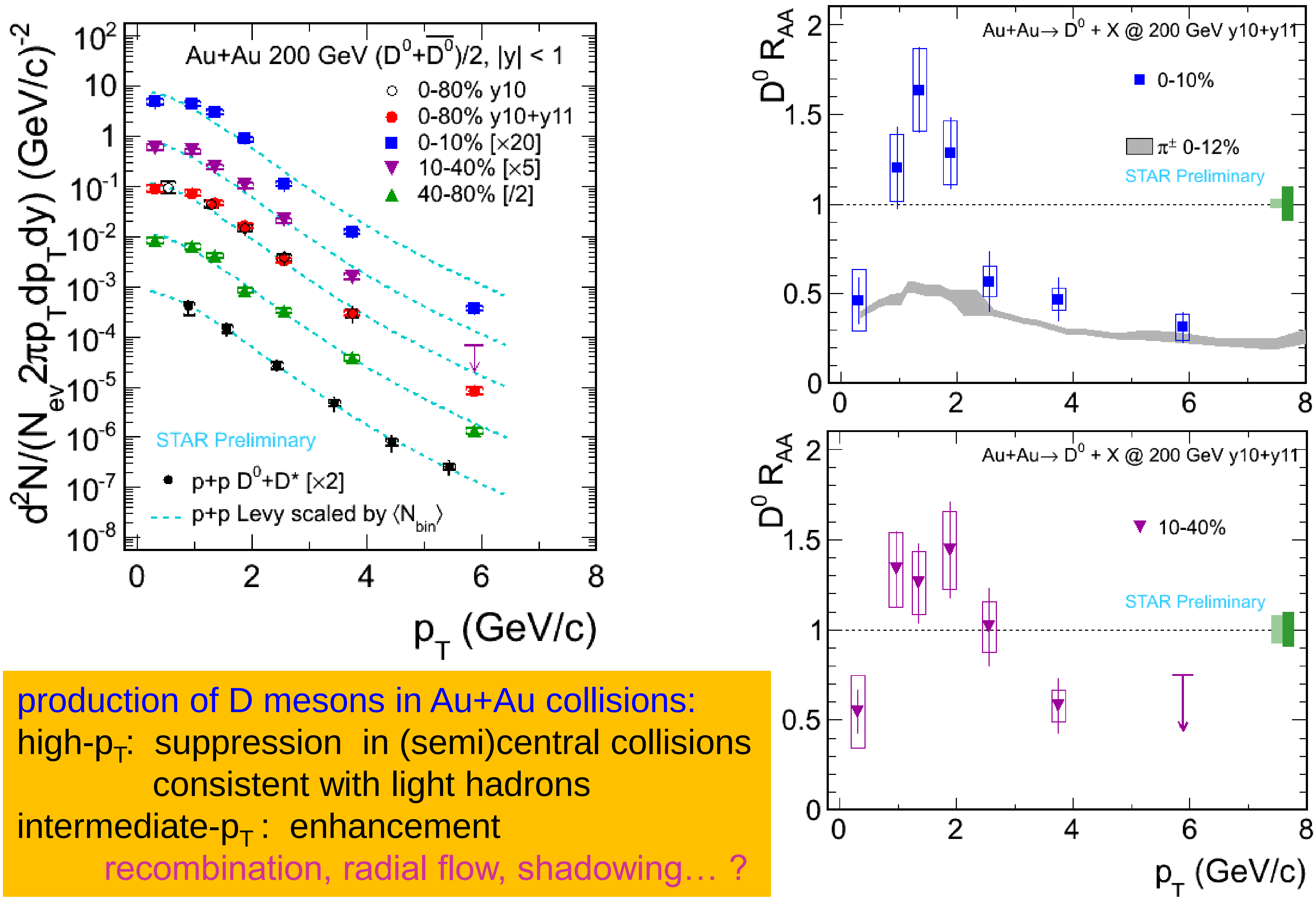
Open charm production in p+p



FONLL: Fixed Order plus Next-to-Leading Logarithm calculation, μF = μR = mc, |y| < 1,
R. Nelson, R. Vogt, A. D. Frawley, arXiv: 1210.4610

Measurements in p+p provide constraints for the pQCD calculations.
D^0 and D* cross section consistent with FONLL upper limit at 200 and 500 GeV.

Open charm production in Au+Au



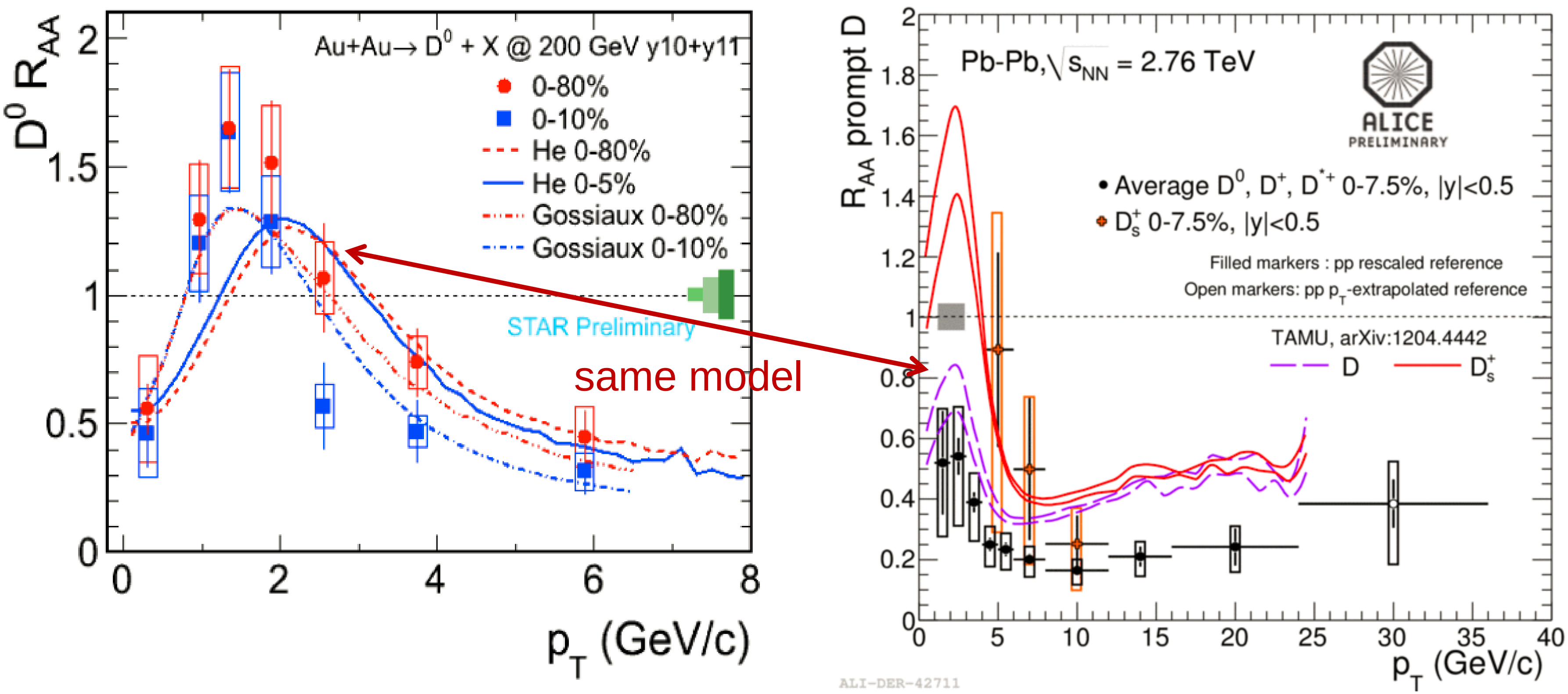
production of D mesons in Au+Au collisions:

high-p_T: suppression in (semi)central collisions
consistent with light hadrons

intermediate-p_T : enhancement
recombination, radial flow, shadowing… ?

Charm suppression at RHIC vs LHC

200 GeV 2.76 TeV

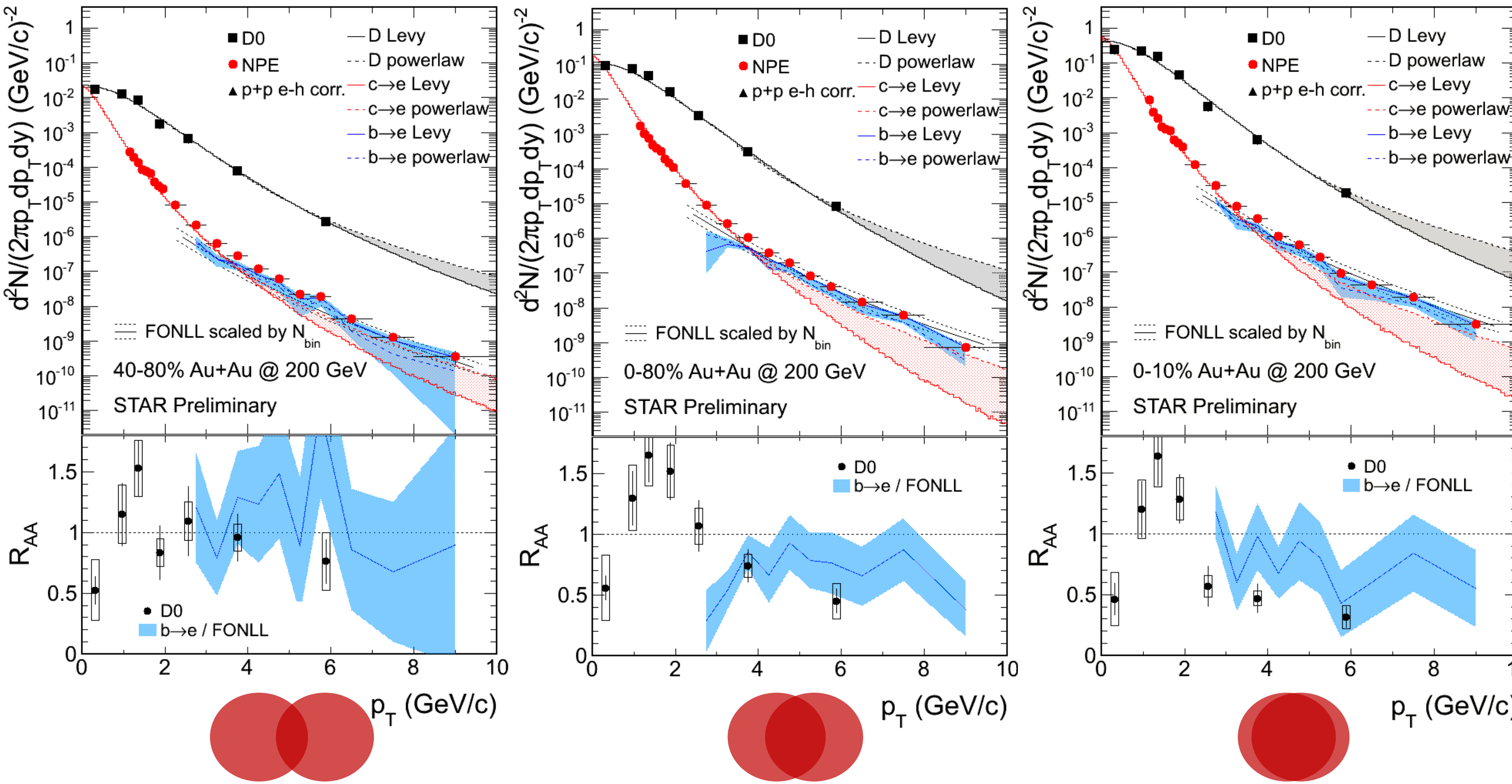


Models: He, Fries, Rapp: PRL 110 (2013) 112301
Gossiaux, Aichelin, Bluhm, Gousset, Vogel, Werner arxiv:1207.5445

Same model (He et al.) describes LHC and RHIC data.

Flow effects stronger at RHIC? Steeper initial spectrum

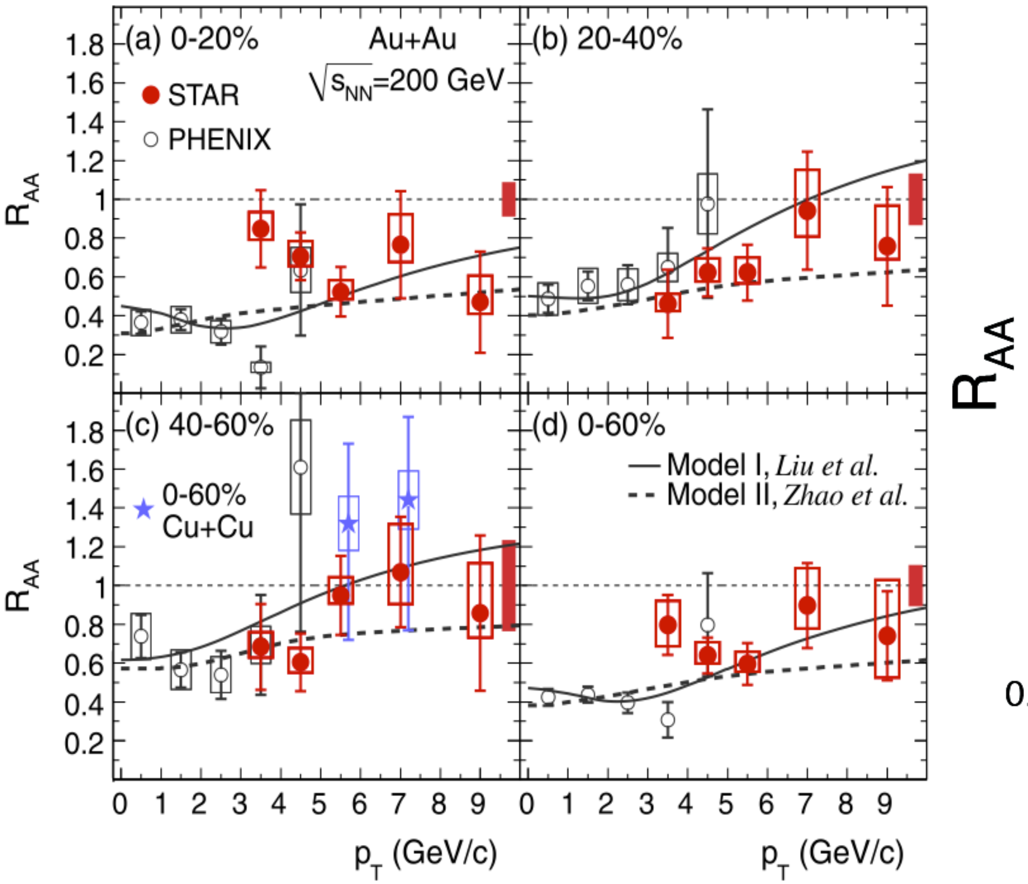
Bottom suppression at RHIC

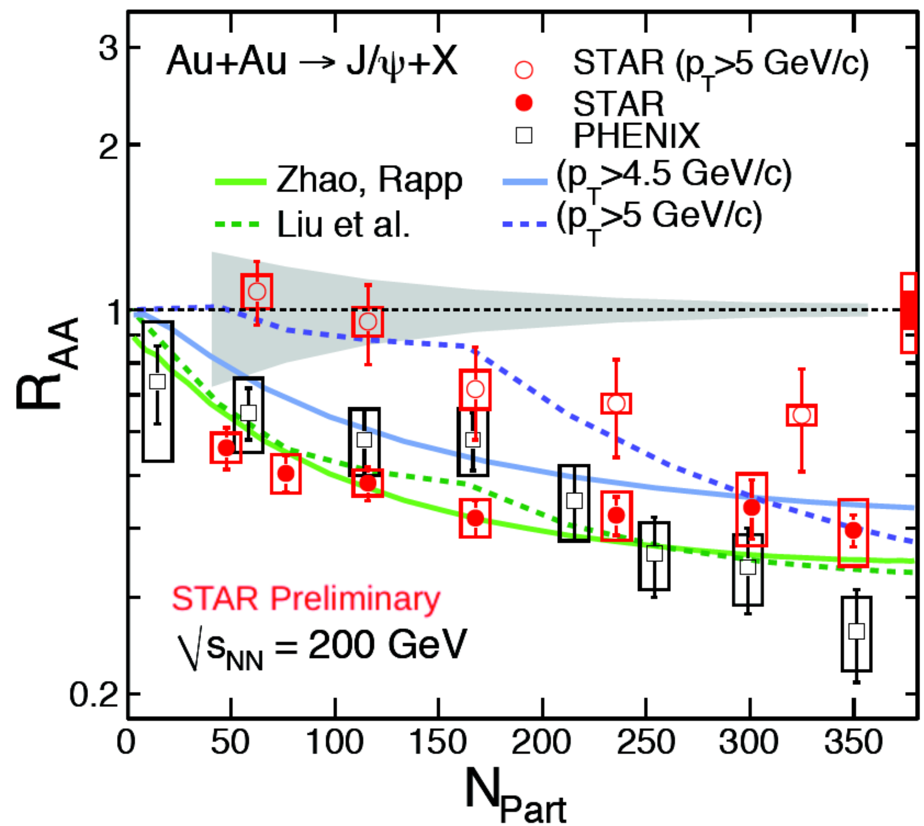


Measured D and non-photonic electron production allows to access production of b

- peripheral Au+Au collisions: consistent with no suppression.
- minimum bias and central Au+Au collisions: a hint of less suppression than for D^0

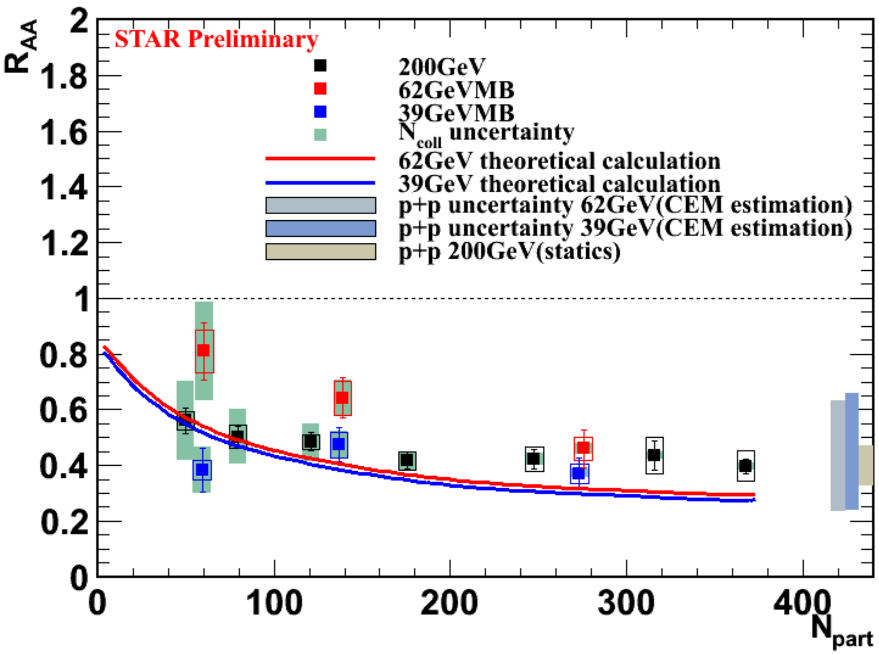
Nuclear modification factor of J/ψ



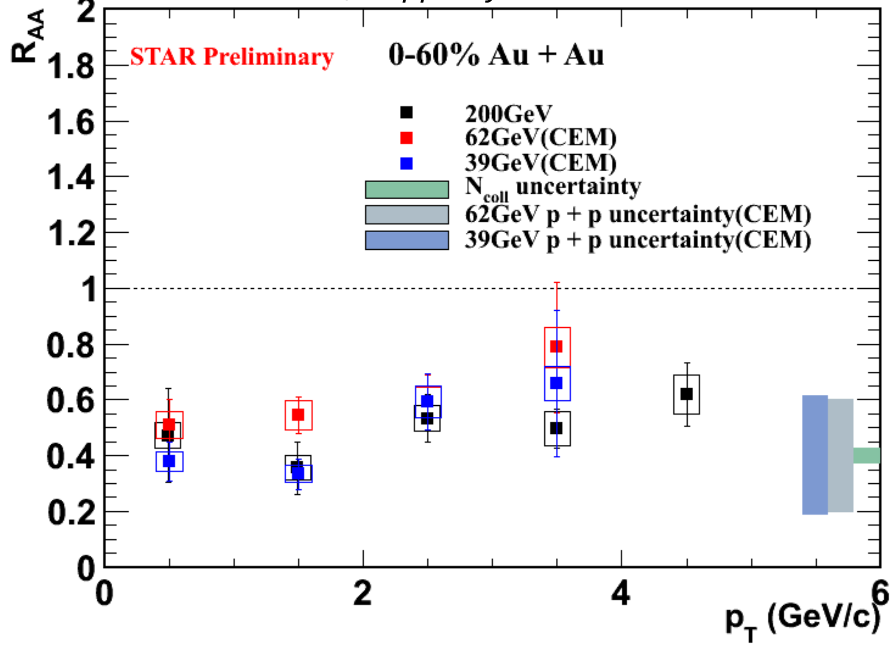


- R_{AA} decreases with p_T
- at high-p_T (p_T>5 GeV/*c*): R_{AA} ~1 in peripheral, but R_{AA} < 1 in central Au+Au
  → clearly a QGP effect
- models including regeneration and color-screening effects describe data well at low-p_T

Collision energy dependence of J/ψ production



Model: Zhao, Rapp Phys Rev C.82.064905

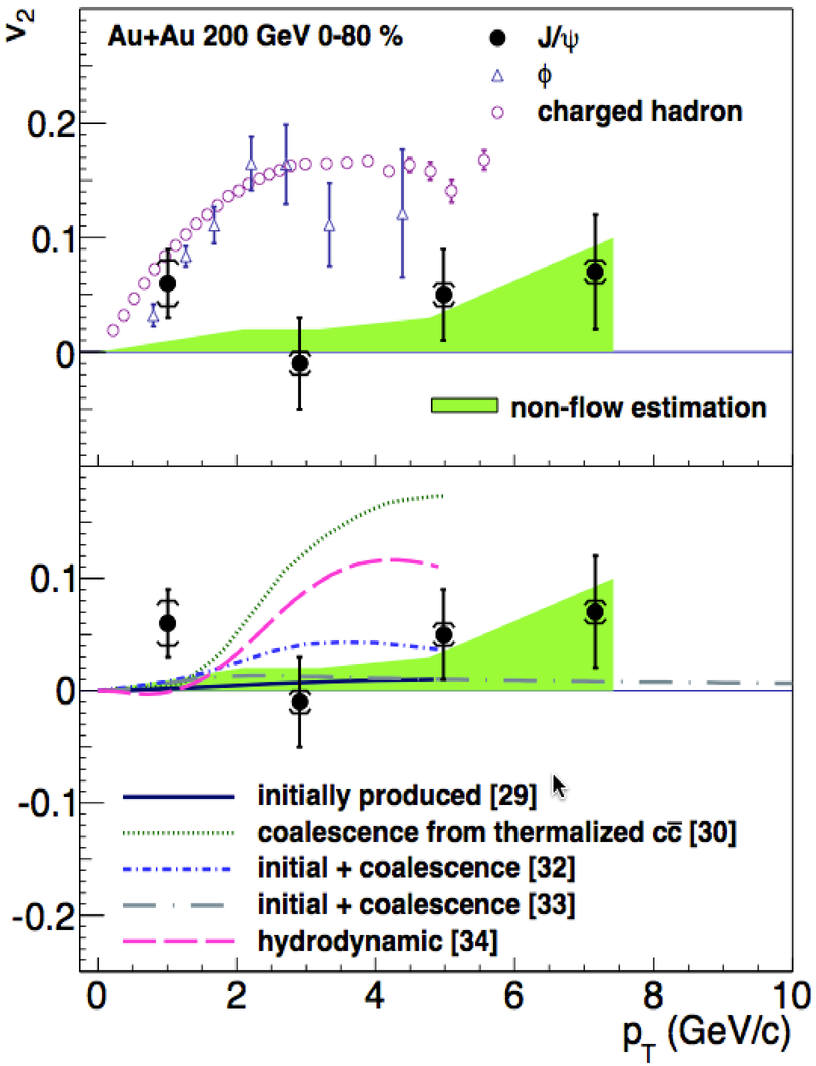


- R_{AA} suppression in Au+Au collisions at 39 and 62 GeV is similar to 200 GeV
- model with direct suppression and regeneration consistent with data

Caution! *39 and 62 GeV p+p reference not measured, instead Color Evaporation Model (CEM) used*

v_2 measurement of J/ψ

STAR, Phys. Rev. Lett. 111 (2013) 52301



v_2(J/ψ) is sensitive to production mechanisms

v_2(J/ψ) at p_T>2 GeV/*c* consistent with zero

J/ψ is not dominantly produced by coalescence from thermalized charm and anti-charm quarks.

ϒ(1S+2S+3S) in Au+Au collisions at 200 GeV

- new p+p reference based on Run9 data

Models:

Strickland et al. PRL 107,132301 (2011)

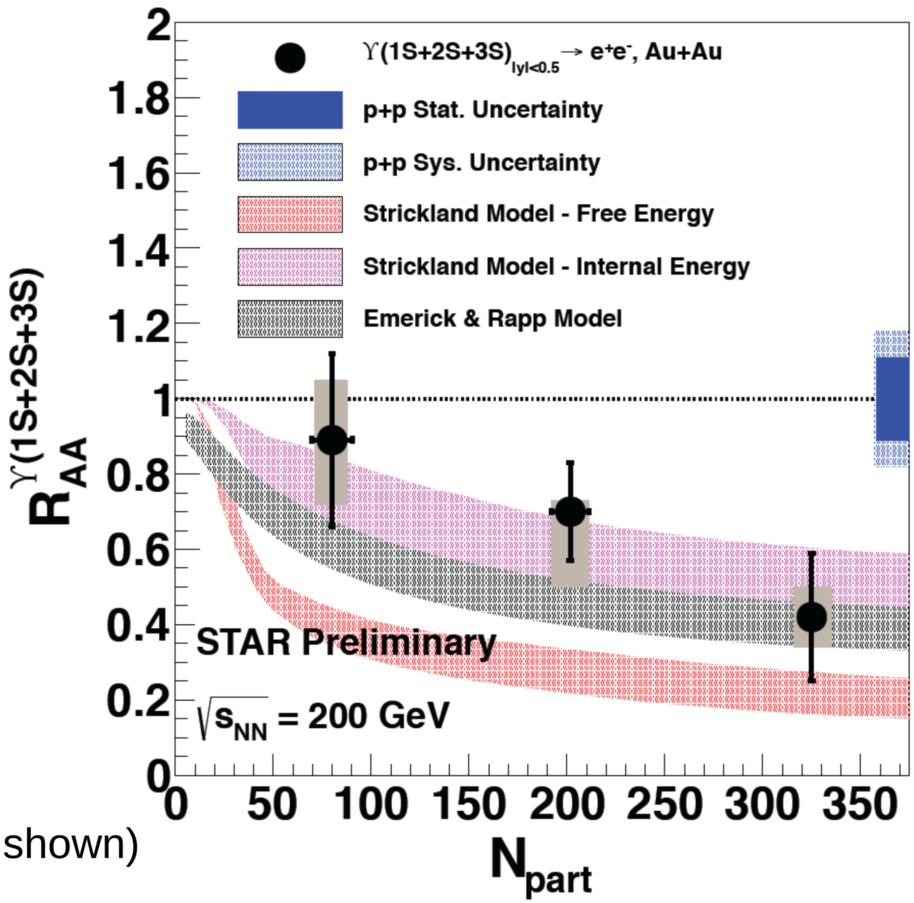
- dynamic model with fireball expansion and feed-down
- assumes T_0 of 428-442 MeV and $1/4\pi < \eta/S < 3/4\pi$

Rapp et al. EPJ A 48 (2012) 72

- kinetic rate equation approach in a thermal QGP background

2 scenarios:

- binding energy decreases with T (weak binding)
- Gluodissociation of Upsilon (strong binding, not shown)



ϒ(1S+2S+3S) suppression increases with centrality.
Data are consistent with a model with complete ϒ(2S) and ϒ(3S) state suppression.

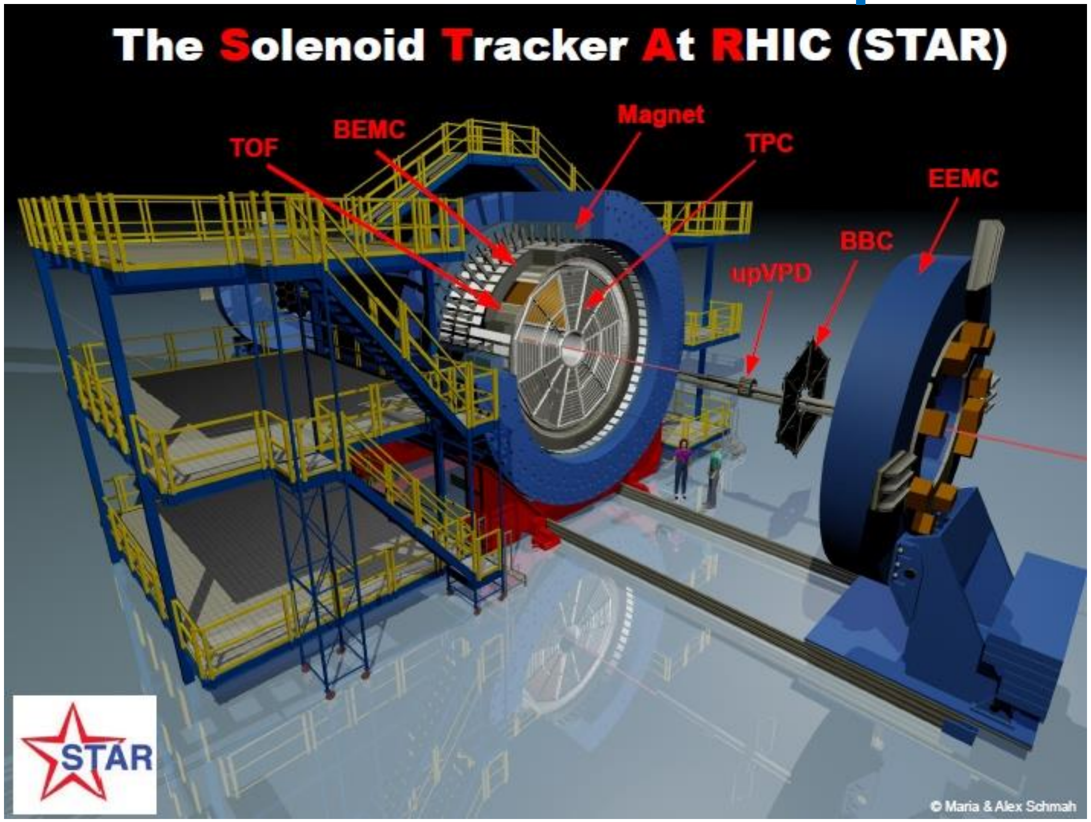
Summary

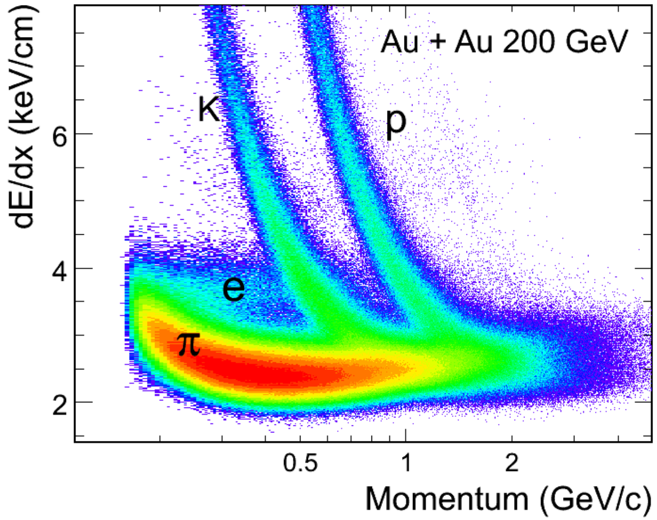
- pinning down origin of the ridge and jet-medium interaction
- work in progress on full jet reconstruction in Au+Au collisions.
  we expect ~2K jets with p_T>50 GeV/c
- strong heavy flavor (D^0 and NPE) suppression at 200 GeV
- significant J/ψ suppression at high-p_T → clear signal of QGP effects
- J/ψ suppression at lower energies (39 and 62 GeV) similar to 200 GeV
- ϒ(1S+2S+3S) suppression in Au+Au 200 GeV consistent with complete ϒ(2S) and ϒ(3S) suppression
- more quantitative results to come from STAR upgraded by Muon Telescope Detector (MTD) and Heavy Flavor Tracker (HFT) !

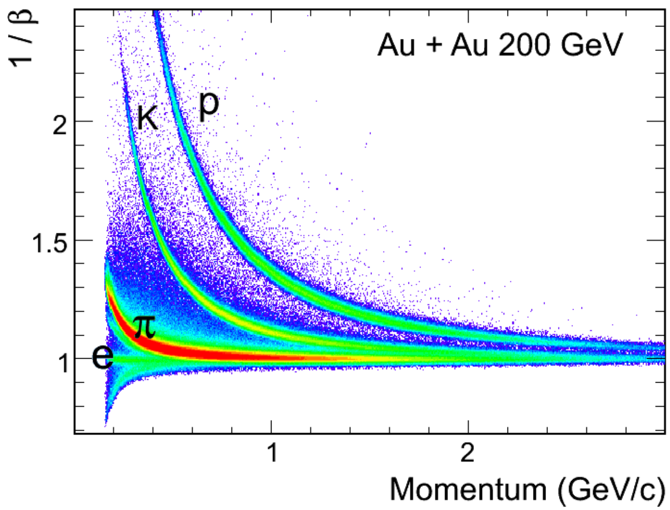
Other STAR talks at the workshop:
A. Hamed: Direct photon status at STAR experiment, Thursday 15:00
O. Evdokimov: PID-triggered correlations, Saturday 9:00

BACKUP

STAR experiment



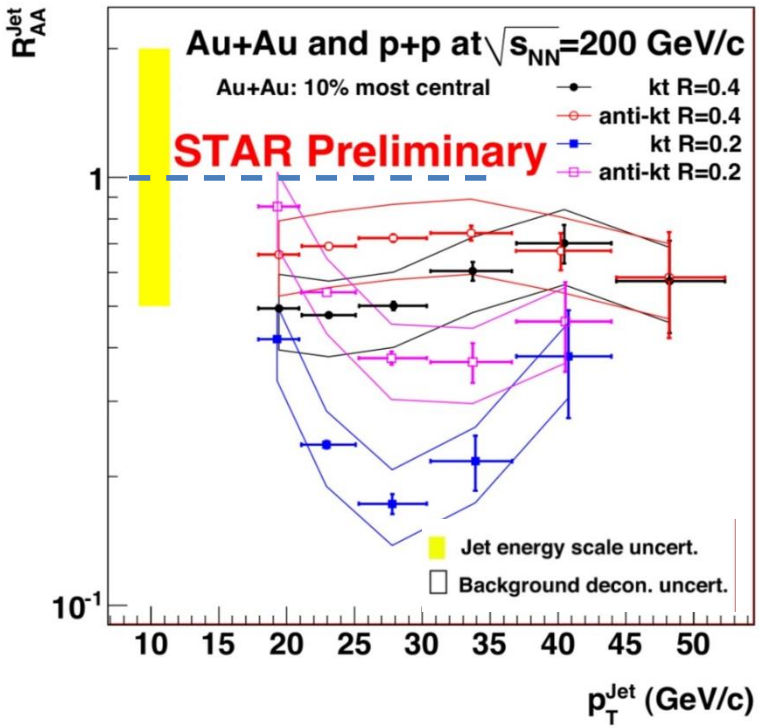


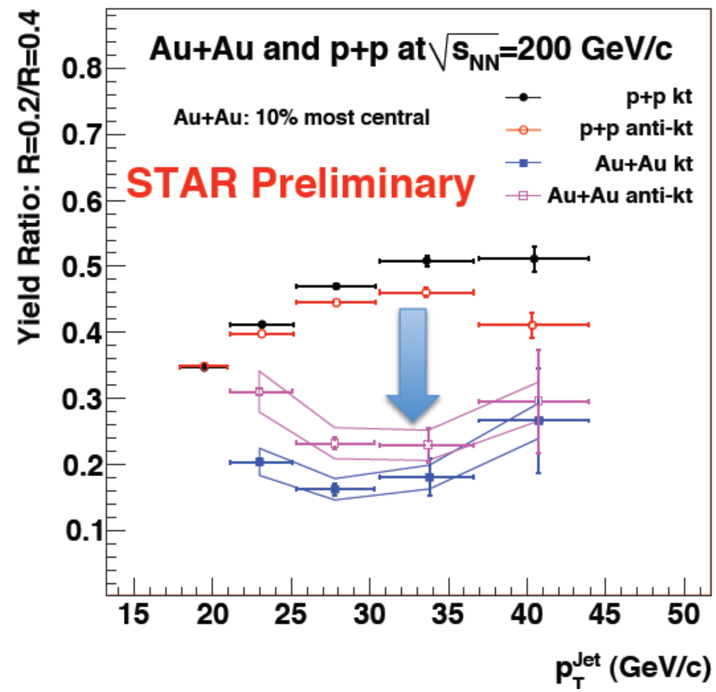


- Time Projection Chamber: *dE/dx, PID, momentum*
- Time Of Flight detector: *PID, $1/\beta$*
- Barrel ElectroMagnetic Calorimeter: *E/p, trigger*
- Endcap ElectroMagnetic Calorimeter ($1.0 \leq |\eta| < 2.0$)
- Forward Meson Spectrometer ($2.5 < |\eta| < 4.0$)
- Forward Time Projection Chambers ($2.8 < |\eta| < 3.8$)

Full azimuthal acceptance: $0<\phi<2\pi$

Pioneering work on jet reconstruction in Au+Au collisions



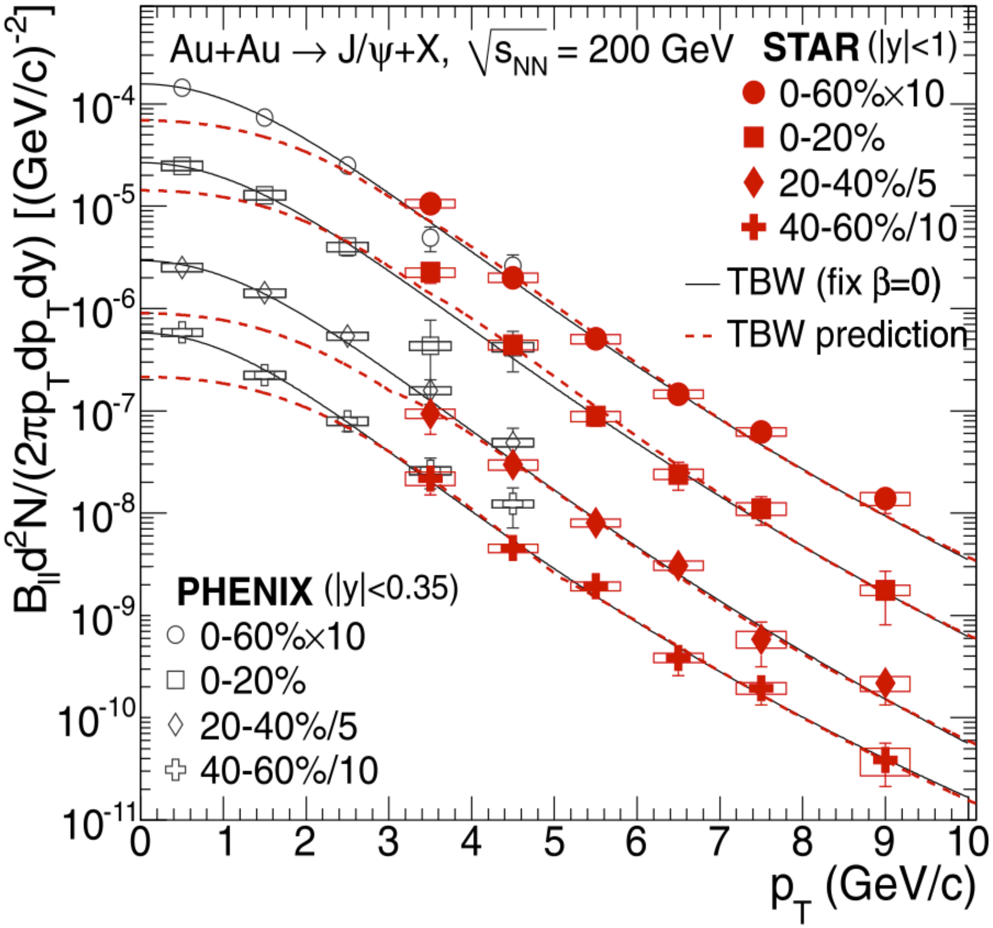


Early Quark Matter ’09 results on Run 7 Au+Au data at 200 GeV

- limited statistics, new methods developed since then

J/ψ production in Au+Au collisions at 200 GeV

STAR, Phys. Lett. B 722 (2013) 55



Tsallis Blast-Wave model:
CPL 30, 031201 (2013);
JPG 37, 085104 (2010)

- J/ψ spectra are softer than those of light hadrons

  a small radial flow?

  a significant contribution from c-quark recombination?