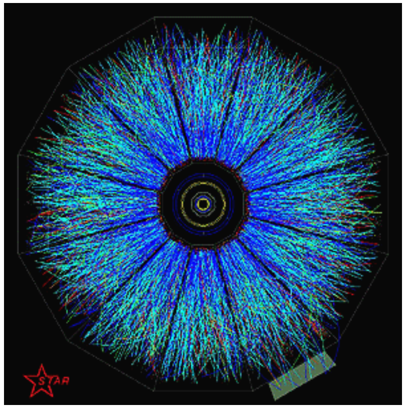
Latest results on triangular flow, correlations and jets from STAR

Jana Bielcikova

(for the STAR Collaboration)

Nuclear Physics Institute ASCR
Czech Republic

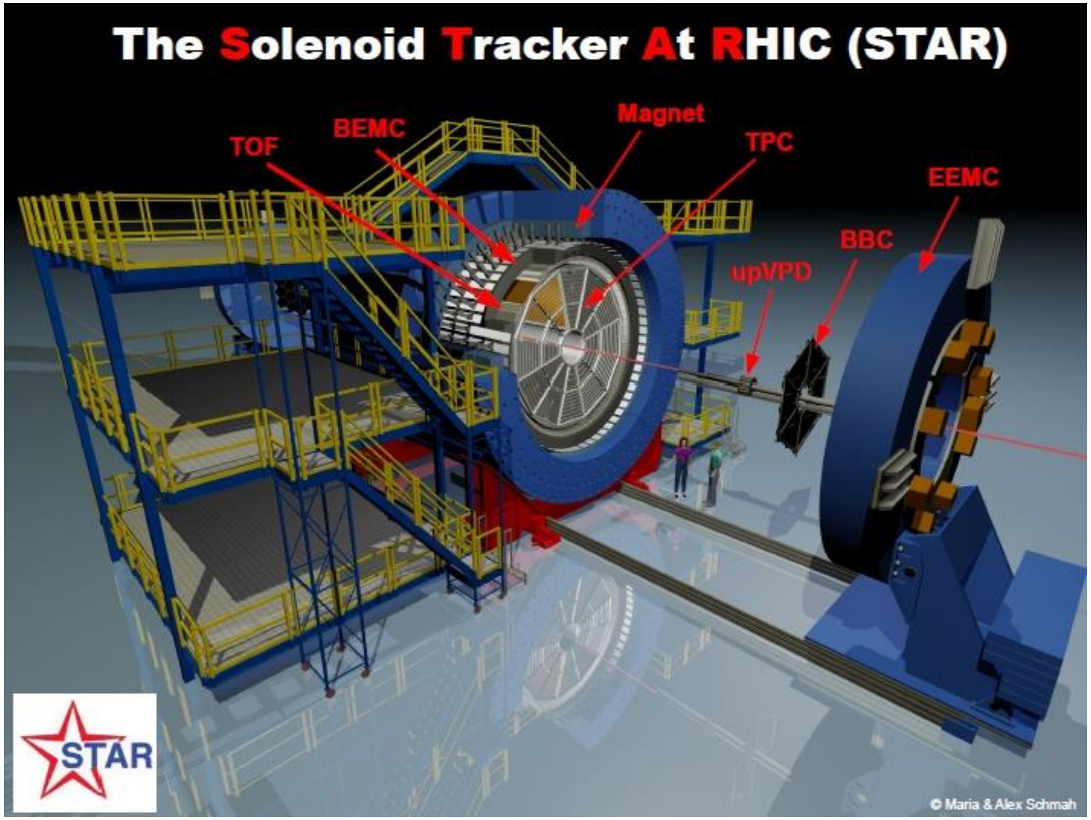


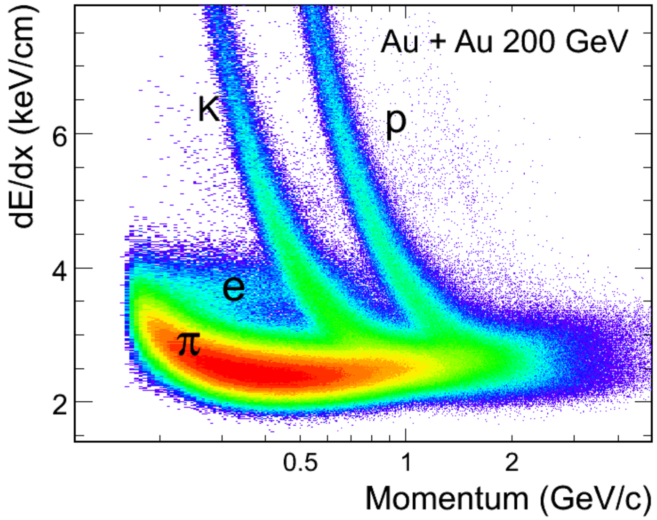
h3QCD workshop, ECT*, Trento, Italy, June 17-21, 2013

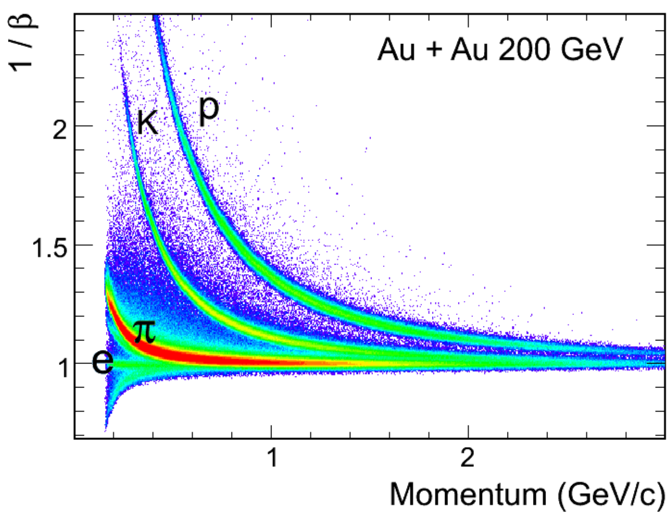
Outline

- STAR experiment at RHIC
- Measurements of triangular flow
- Ridge studies in d+Au collisions
- Forward di-hadron correlations
- Ongoing jet studies in Au+Au collisions
- Summary and outlook

STAR experiment





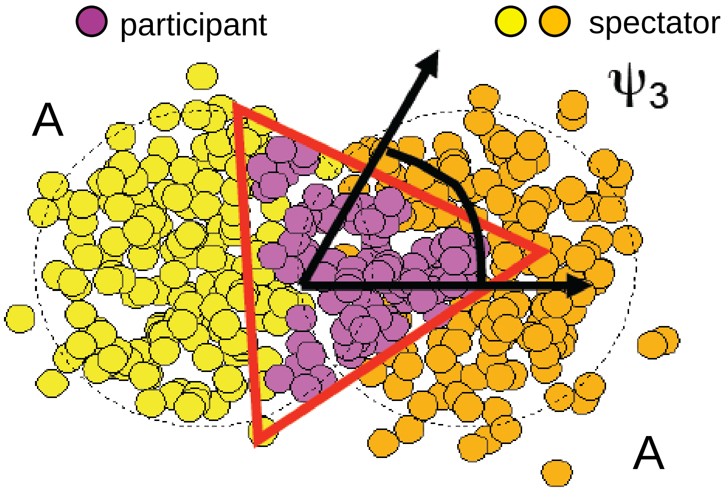


- Time Projection Chamber: *dE/dx, PID, momentum*
- Time Of Flight detector: *PID, $1/\beta$*
- Barrel ElectroMagnetic Calorimeter: *E/p, trigger*
- Endcap ElectroMagnetic Calorimeter ($1.0 \leq |\eta| < 2.0$)
- Forward Meson Spectrometer ($2.5 < |\eta| < 4.0$)
- Forward Time Projection Chambers ($2.8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

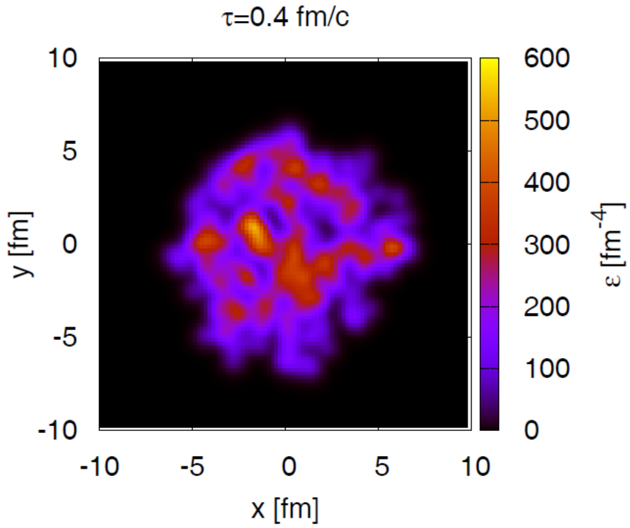
Full azimuthal acceptance:

$0<\phi<2\pi$

Triangular flow (v_3) …



B. Alver, G. Roland, PRC81 (2010) 054905



B. Schenke, S. Jeon, C. Gale PRL 106, 042301

Methods to determine v_3

- determination of v_3 from event plane method:

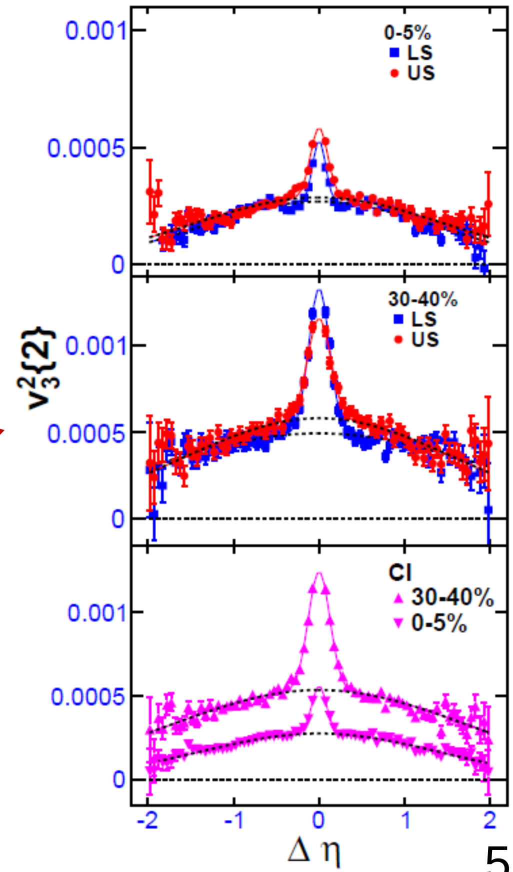
  TPC event plane: determined at mid-rapidity from TPC tracks using sub-events with a small $\Delta\eta$ gap of 0.05 reduces self-correlation

  FTPC event plane: a large $\Delta\eta$ gap between EP and TPC particles used for v_3 no self-correlation

- wide Gaussian method: $v_3^2\{2\} = \langle\cos[3(\phi_i - \phi_j]\rangle_{i \neq j}$ data are fit with a wide + narrow Gaussians (narrow Gaussian: short-range correlations: BE, resonances, Coulomb)

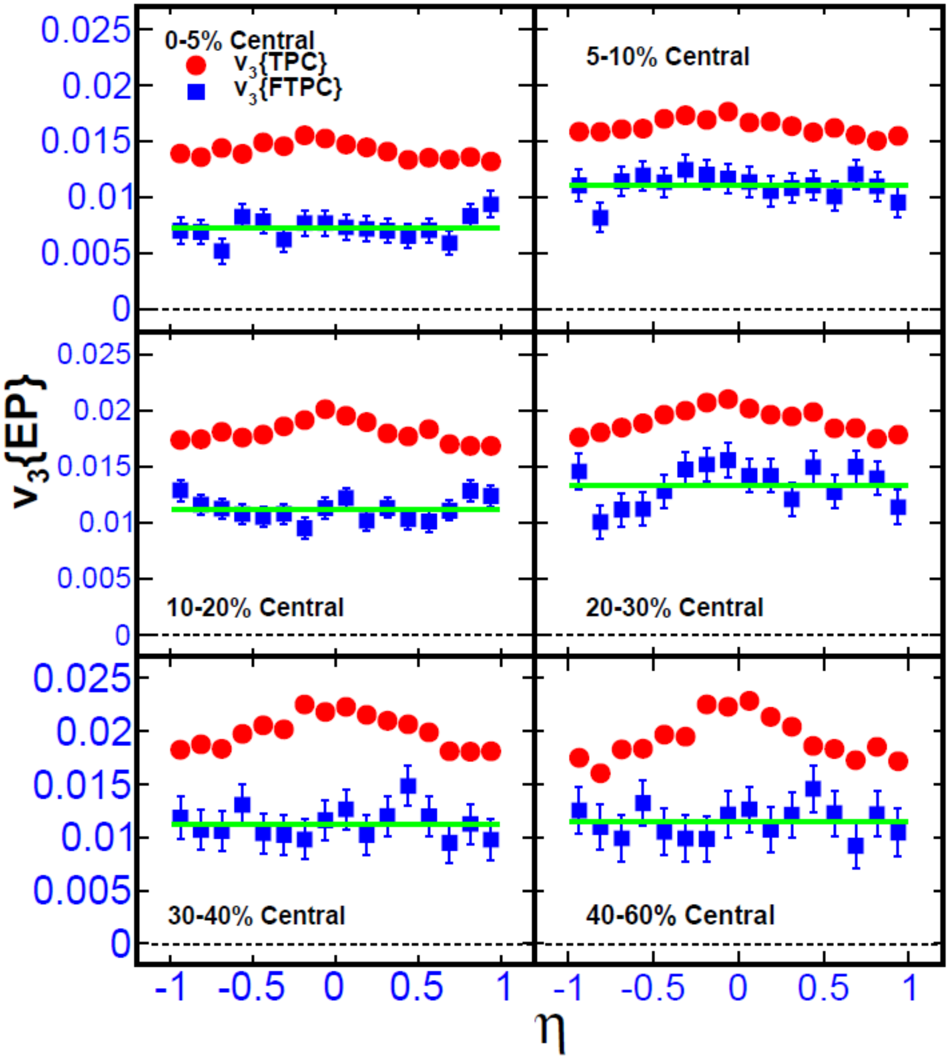
- $v_3\{2\}$ with $|\Delta\eta|>1.0$ gap

STAR, arXiv:1301.2187



η dependence of v_3 in Au+Au collisions

STAR, arXiv:1301.2187



Data: Run 4 Au+Au @ 200 GeV

Two different event plane methods used:

TPC: sub-events with a small Δη gap of 0.05 reduces self-correlation

FTPC: a large Δη gap between EP and TPC particles used for v_3 no self-correlation

- v_3\{TPC\} shows a small peak around midrapidity
- v_3\{FTPC\} is flat with pseudorapidity

Centrality dependence of v_3 in Au+Au collisions

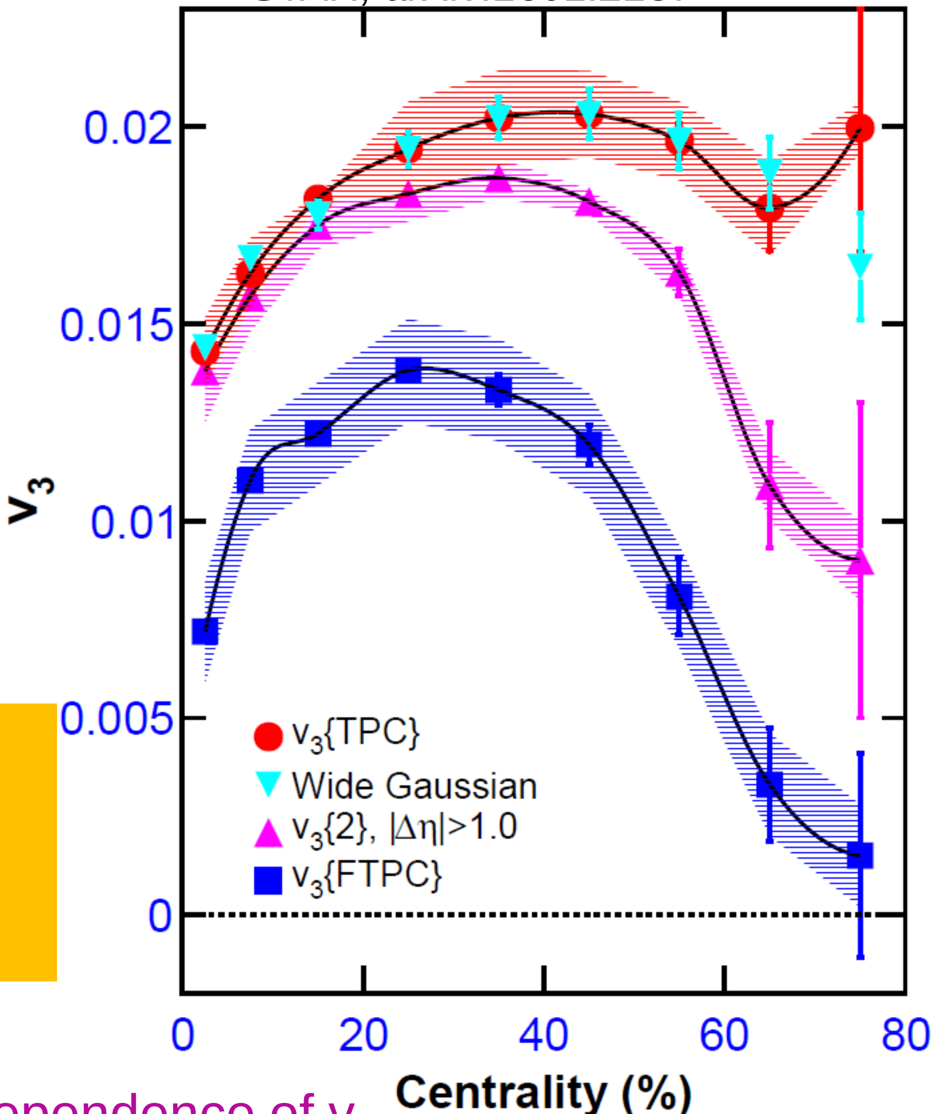
v_3 is integrated for:
$0.15<p_T<2.0$ GeV/c and $-1<\eta<1$

Large sensitivity of various v_3 analysis methods:

v_3\{wide Gaussian\} and v_3\{TPC\} are similar: the narrow Gaussian effect eliminated

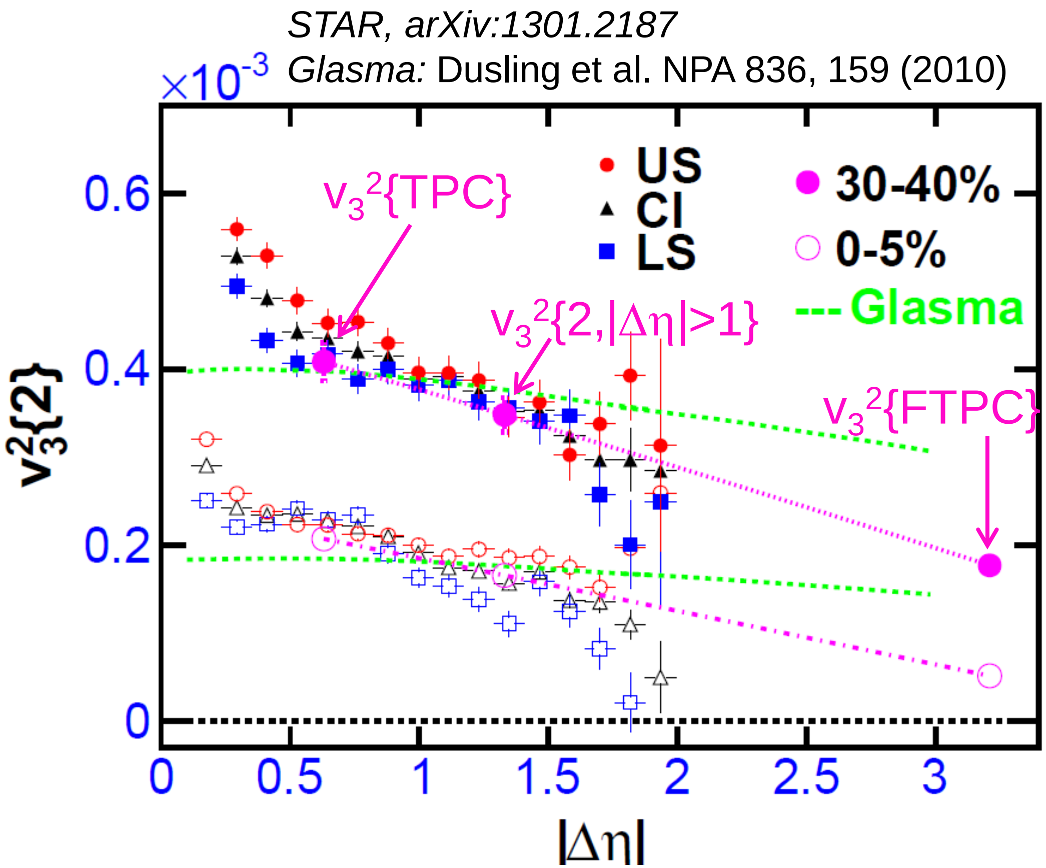
Requiring a large $\Delta\eta$
→ v_3 values decrease
This decrease is more pronounced in peripheral Au+Au collisions.

STAR, arXiv:1301.2187



Let us have a closer look at the $\Delta\eta$ dependence of v_3.

$|\Delta\eta|$ dependence of v_3 in Au+Au collisions



- $v_3^2\{2\}$ gradually decreases with $|\Delta\eta|$
- within the STAR acceptance $v_3^2\{2\}$ does not approach a constant value
- LS and US charge-sign combinations show only little difference despite different contributions from resonances, fluctuations and FS interactions
- similar decrease of $v_n^2\{2\}$ observed also by ATLAS *PRC 86 014907 (2012)*

Comparison with the Glasma model:

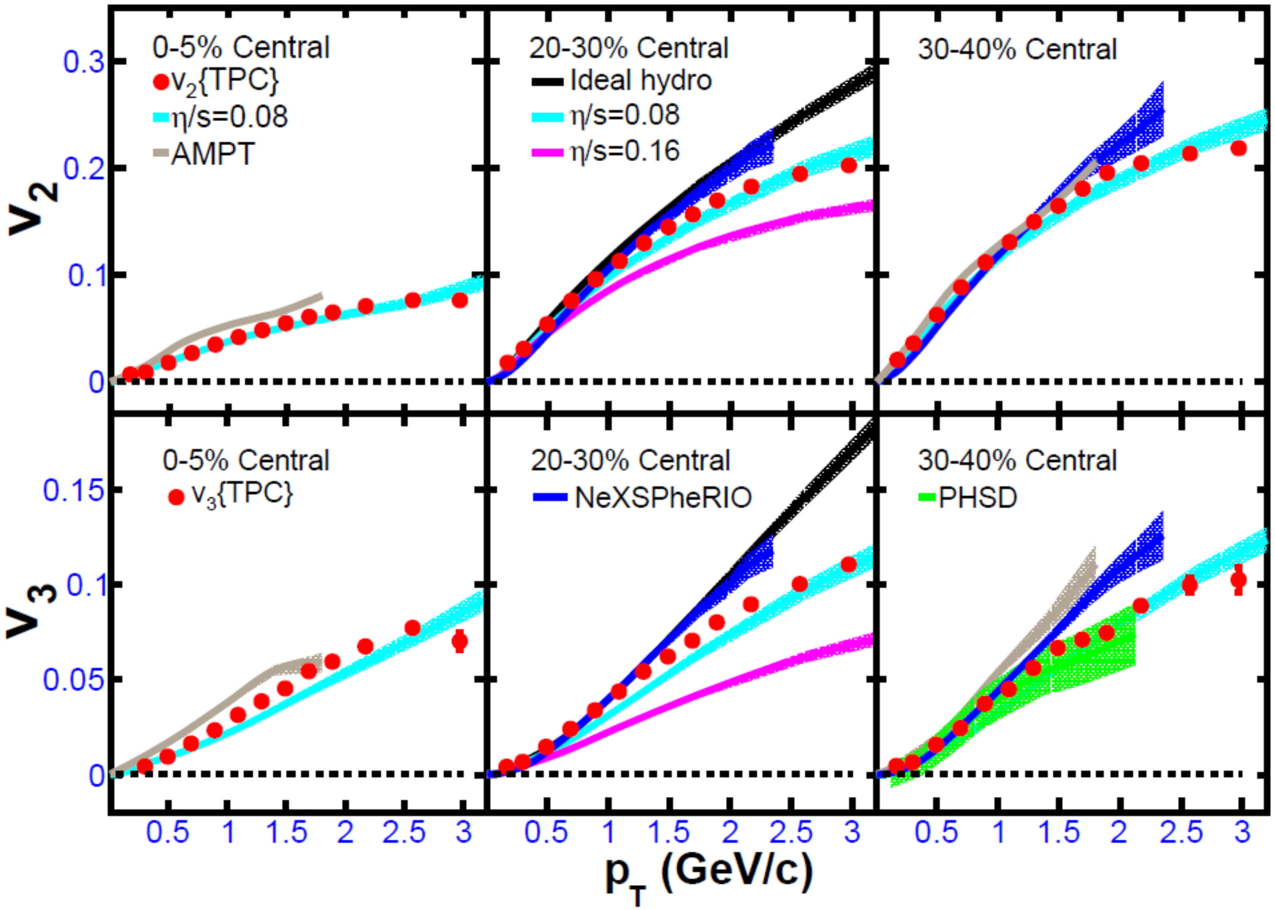
- decreasing effect of fluctuations in the model?

Glasma model is in a qualitative agreement with the data, but the data show a steeper decrease.

For each v_3 value one must always quote $\Delta\eta$ range for which it was calculated!

$v_3(p_T)$ dependence and comparison with models

v_2: STAR, PRC 72, 014904 (2005); v_3: *STAR, arXiv:1301.2187*



Good agreement:

- hydro with $\eta/s=0.08$ +Glauber initial conditions
- NeXSPheRIO for $p_T<1$ GeV/c and 20-40% centrality
- Parton-Hadron-String-Dynamics model semi-central collisions

- AMPT is a bit higher
- HIJING has negligible v_3 (not shown here)

Glasma model captures ≈ $v_3(\Delta\eta)$ + models including fluctuations describe $v_3(p_T)$
→ v_3 is likely mainly due to $\Delta\eta$ dependent fluctuations
(+ possibly non-flow contributions).

Comparison of v_3 to other experiments

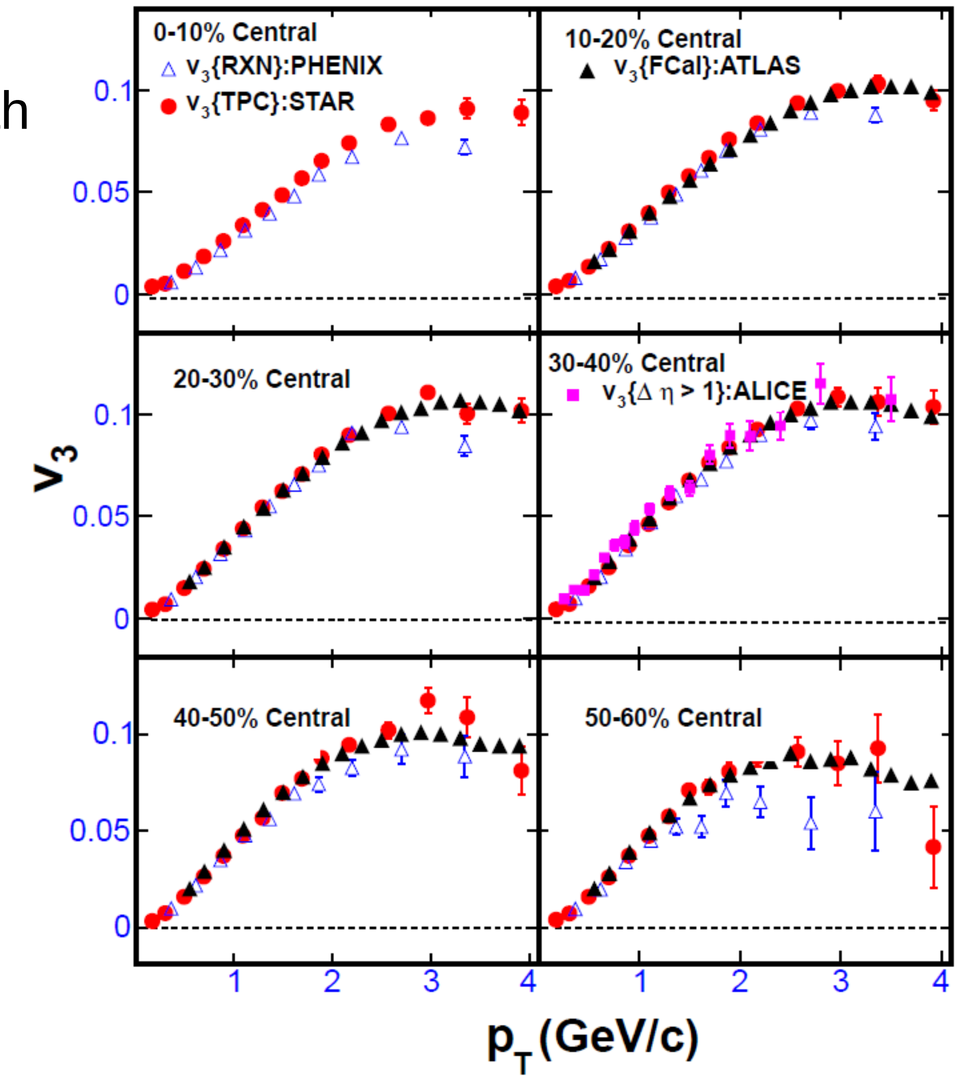
STAR, arXiv:1301.2187

STAR data for v_3\{TPC\} agree well with PHENIX v_3\{RXN\}
BUT: RXN acceptance: $1<\eta<2.8$
i.e. $<\eta>$ of RXN > TPC (?)

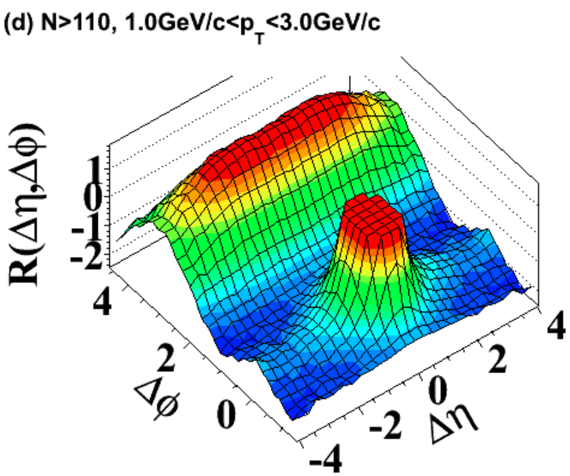
Surprisingly good agreement also with the LHC experiments (?):

ALICE v_3 for $|\eta| <0.8$ and $|\Delta\eta| >1$
ATLAS v_3 for $|\eta| <2.5$ and $|\Delta\eta| >2.5$

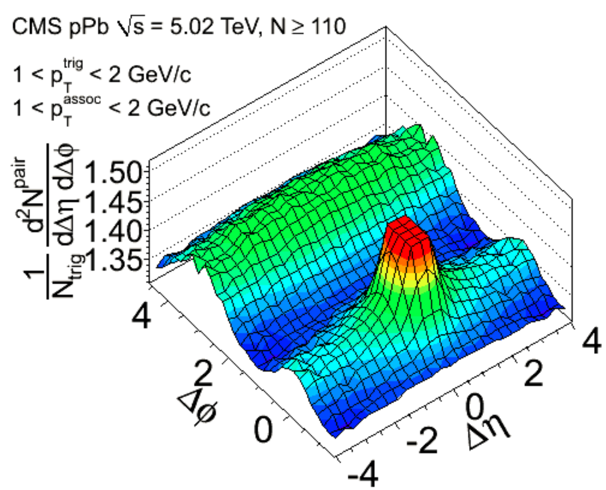
BUT: fluctuations are expected to be largely independent of collision energy ☺

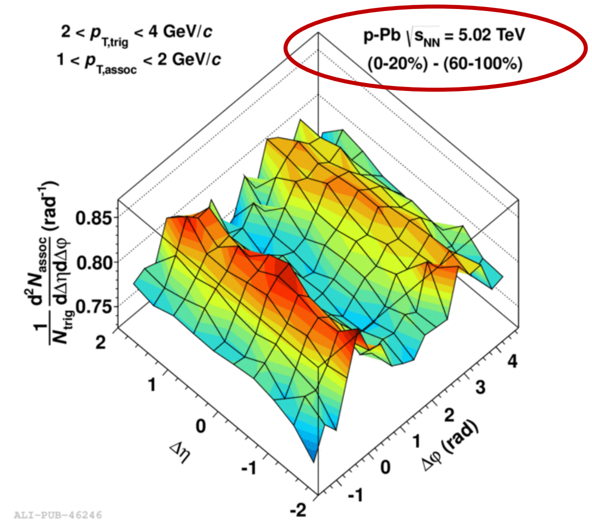


p+p, p+Pb, d+Au (?) ridge …



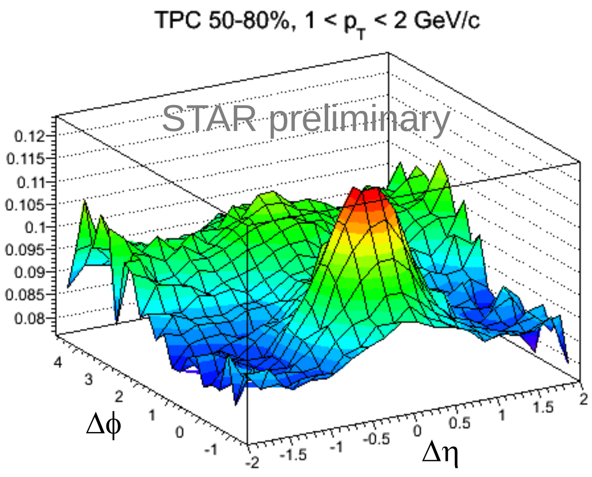
CMS, PLB 718 (2012) 795





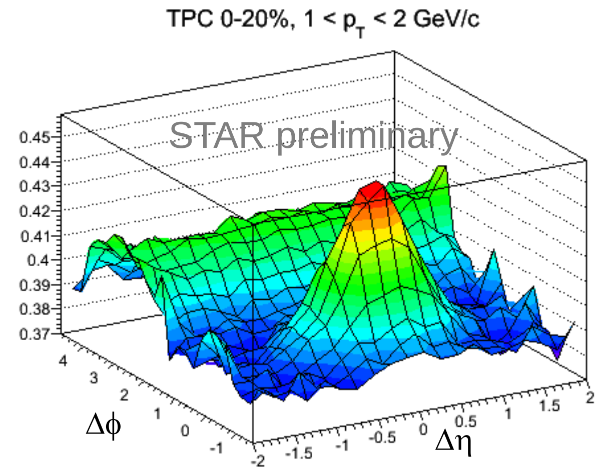
ALICE, PLB 719 (2013) 29

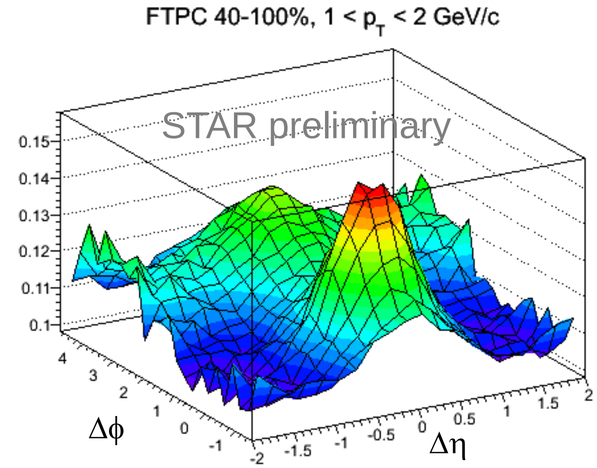
Di-hadron correlations in d+Au @ 200 GeV



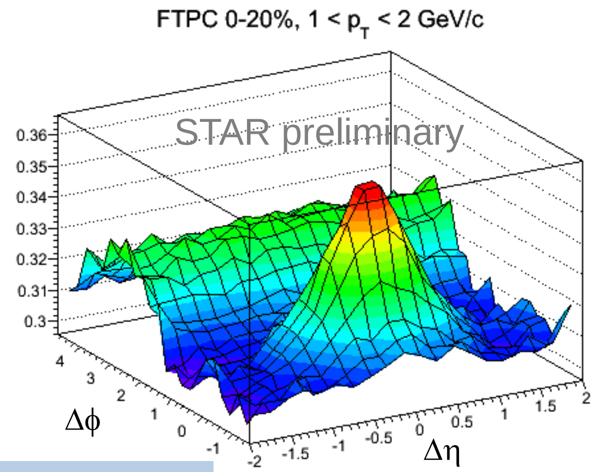
Centrality determination:

TPC multiplicity
$|\eta|<1.0$





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

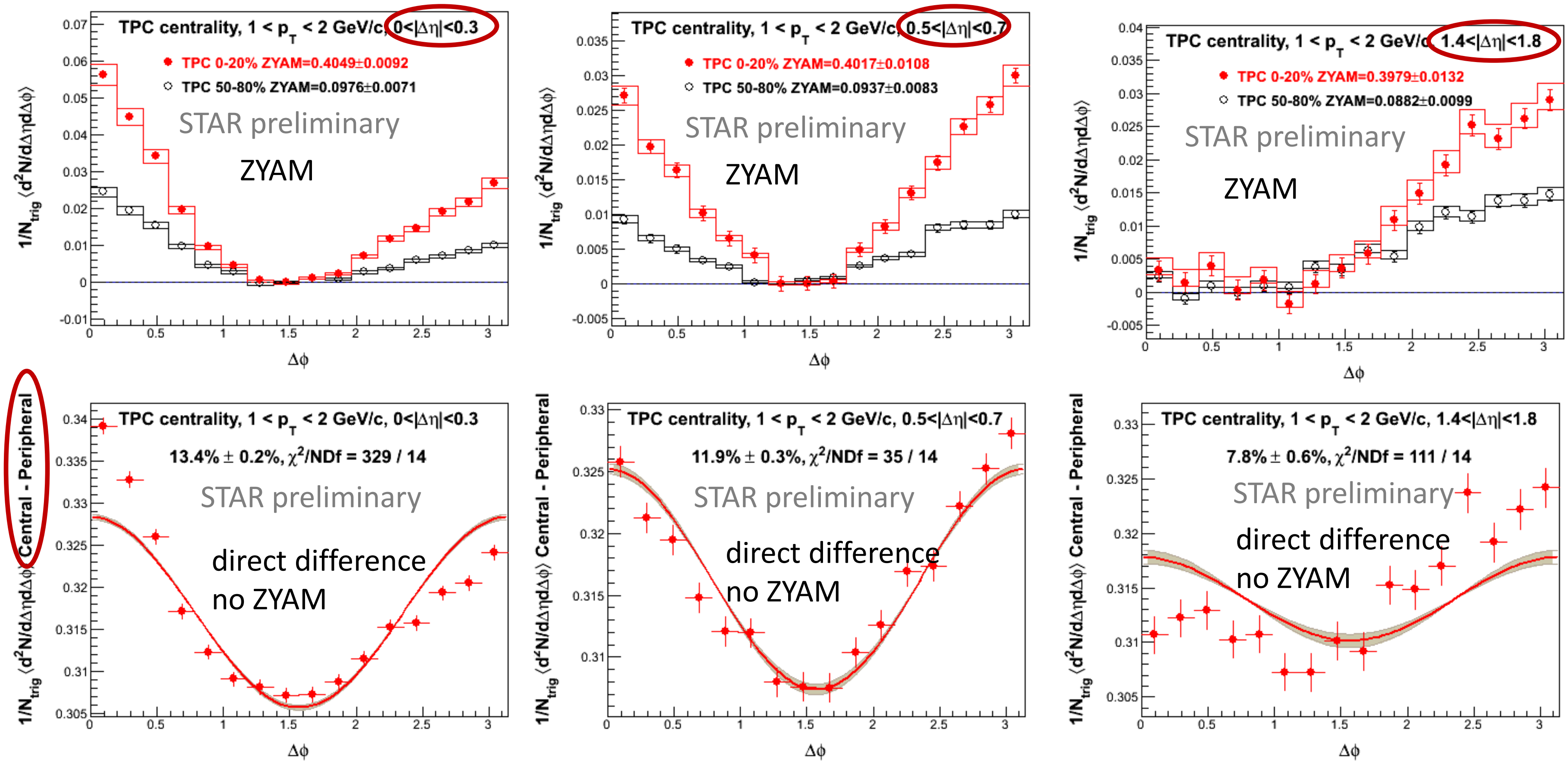


$0.15 < p_T^{trig} < 3.0$ GeV/c, $1 < p_T^{assoc} < 2$ GeV/c

Δϕ projections in different Δη

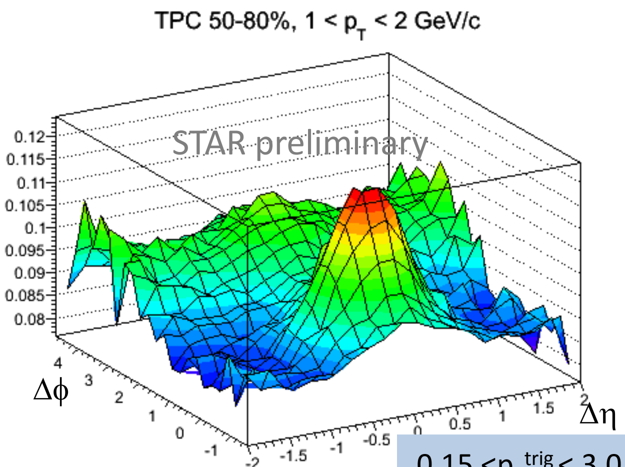
0.15 < p_T^{trig} < 3.0 GeV/c, 1< p_T^{assoc} < 2 GeV/c

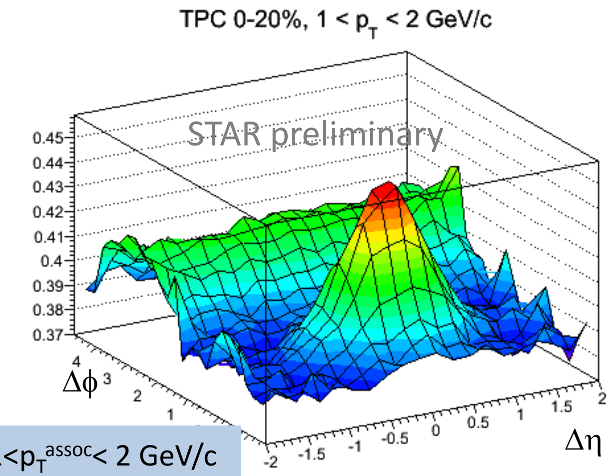
(TPC multiplicity |η|<1 as centrality)



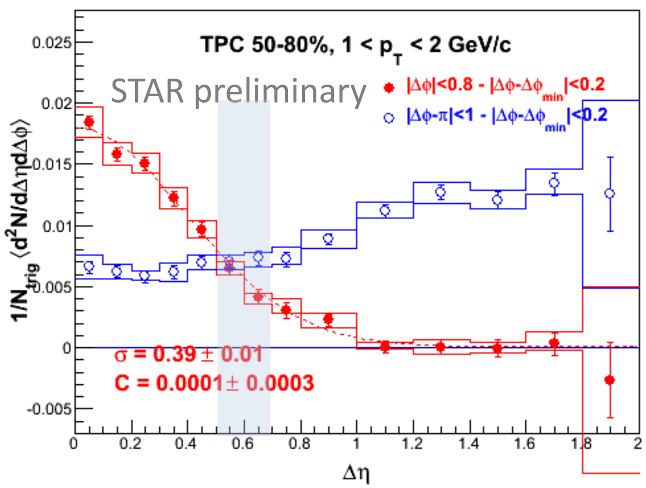
- ZYAM syst. error from different sizes of Δϕ region for ZYAM.
- efficiency corrected: 85 ± 5%

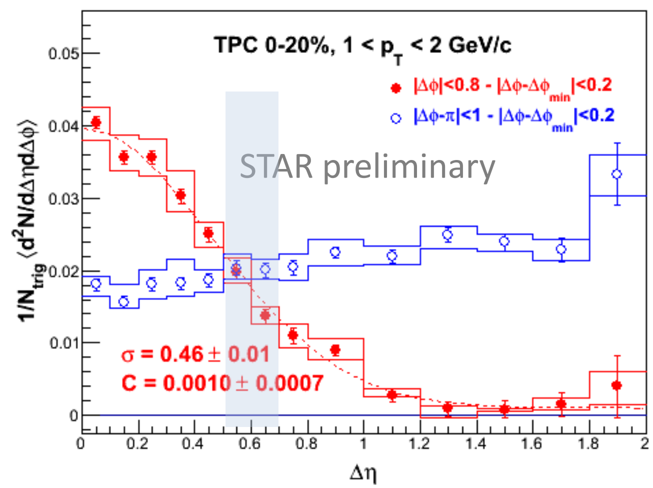
$\Delta\eta$ projections in different $\Delta\phi$
(TPC multiplicity $|\eta|<1$ as centrality)





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

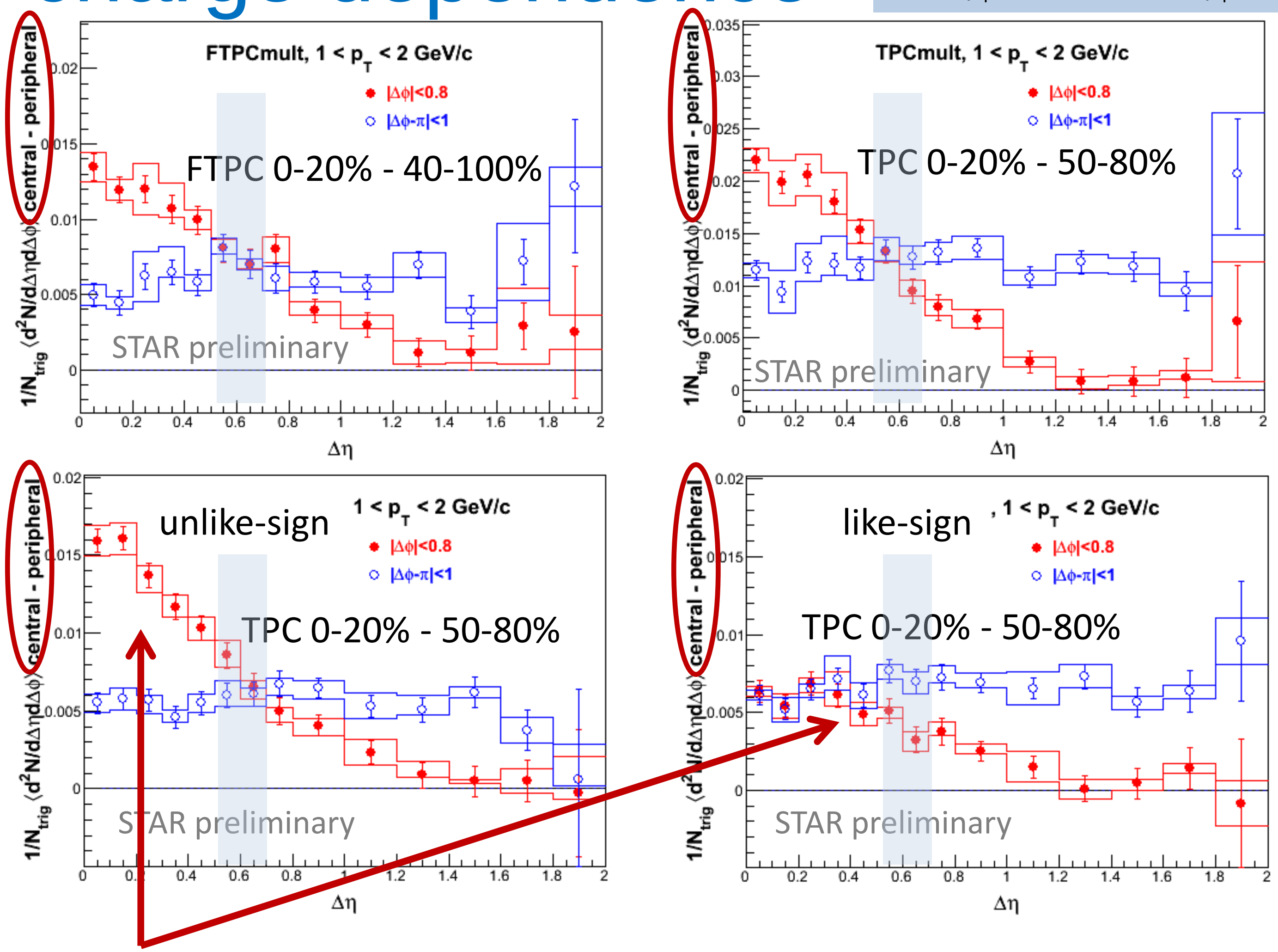




- ZYAM syst. error from different sizes of $\Delta\phi$ region for ZYAM.
- efficiency corrected: 85 ± 5%

Central-peripheral correlation functions, charge dependence

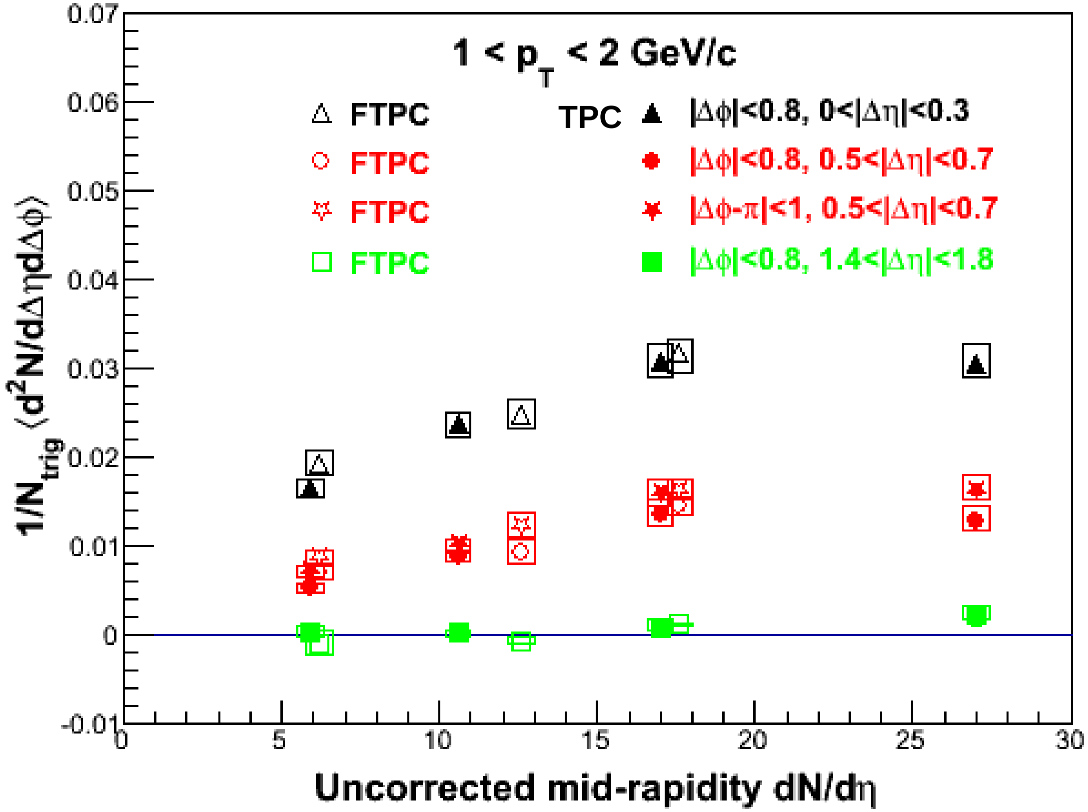
0.15 <p_T^{trig}< 3.0 GeV/c, 1<p_T^{assoc}< 2 GeV/c



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

Conditional yield vs multiplicity

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



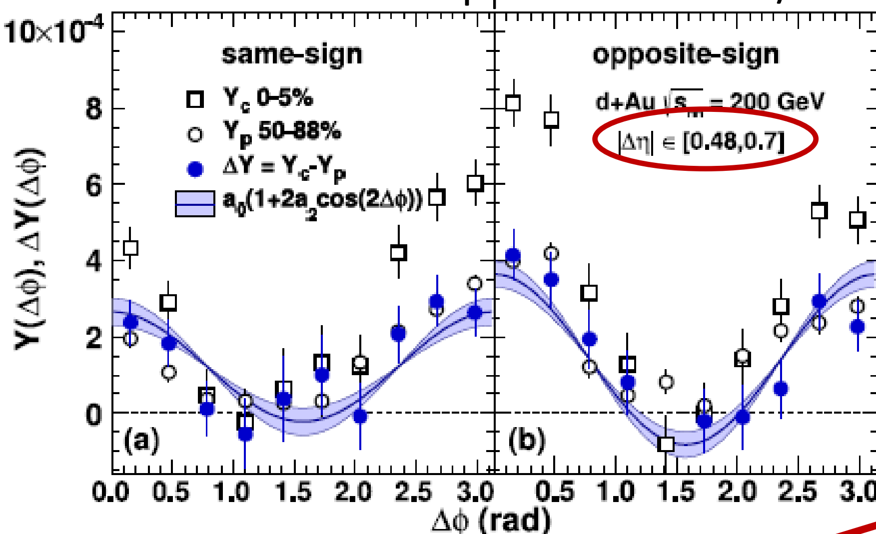
Conditional yield in d+Au is consistent with zero for 1.4 <|Δη|<1.8 as a function of centrality.

- ongoing studies of p_T dependence

Comparison with PHENIX

PHENIX, arXiv:1303.1794

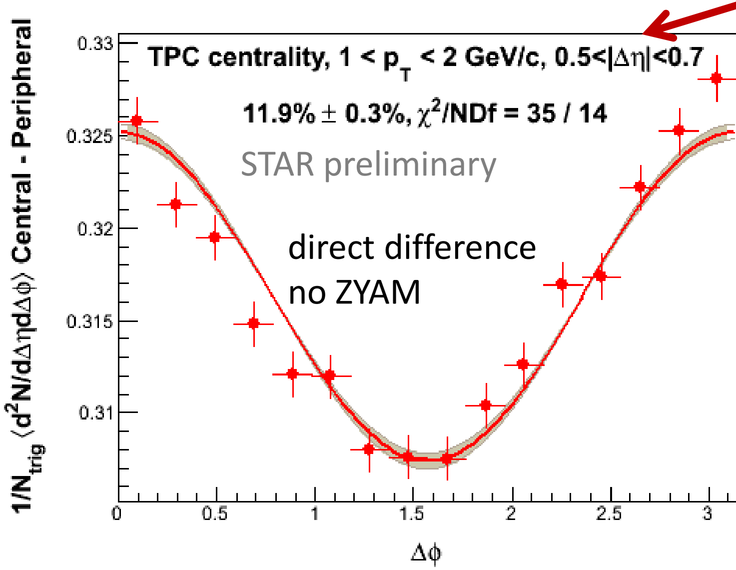
p_T=1.25-1.5 GeV/c

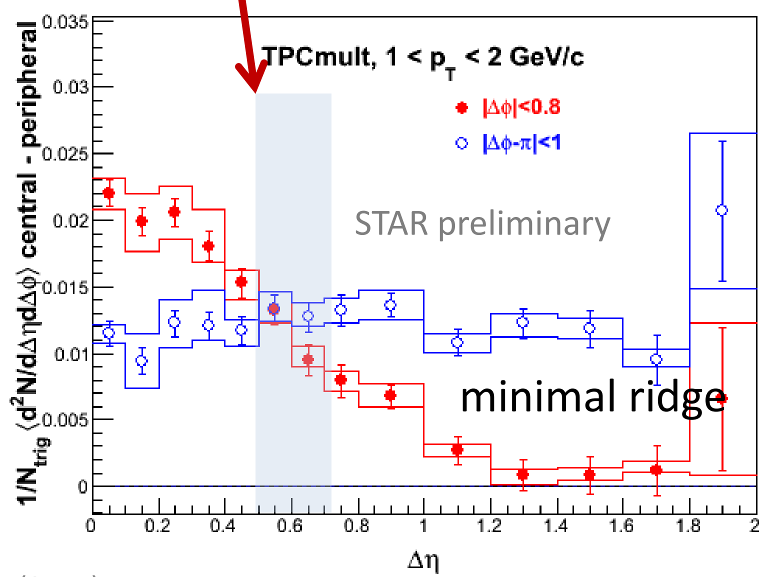


Use the same acceptance cuts as PHENIX:

- PHENIX measurement is likely contaminated by jet contribution

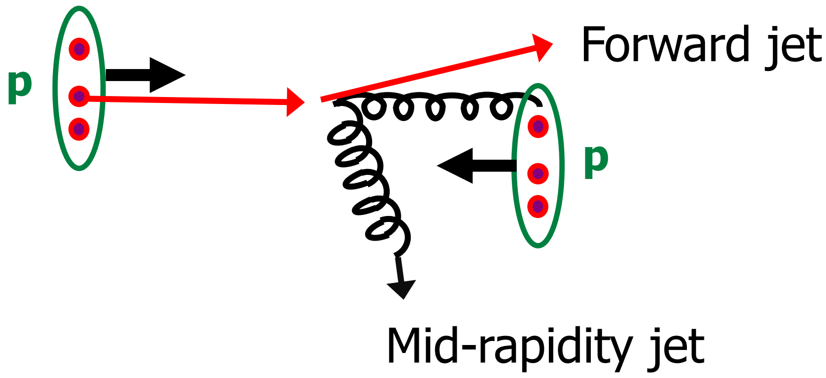
PHENIX Δη acceptance window

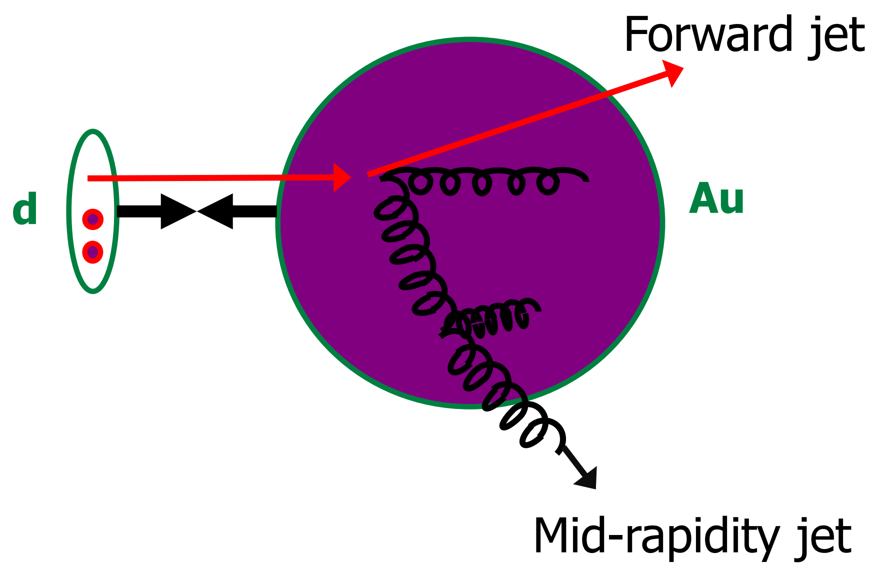




Looking forward …

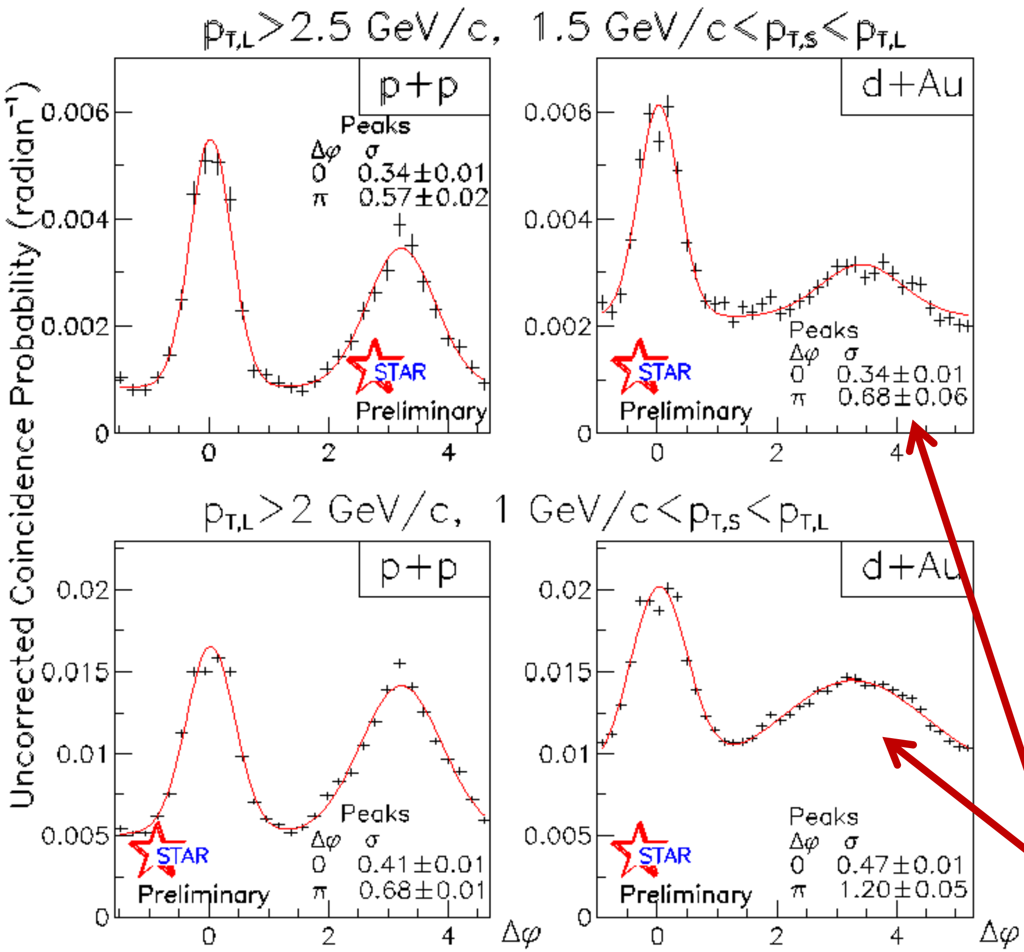
CGC ?





Forward π–π azimuthal correlations

$\langle\eta_{\pi,L}\rangle=3$, $\langle\eta_{\pi,S}\rangle=3$



STAR, arXiv:1005.2378

- forward π^0 pairs probe the lowest x

  2→2 scattering:

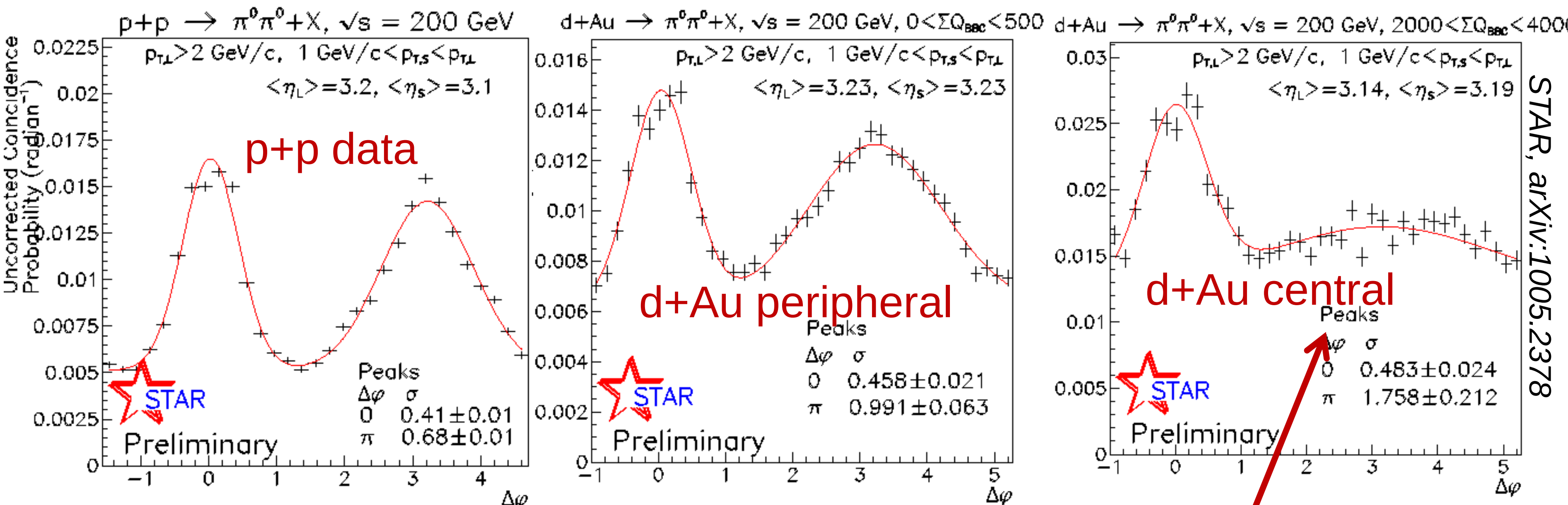
  $0.001 < x < 0.005$

- forward π^0 pairs detected via 4 γ
- jet-like correlations for p+p consistent with NLO pQCD description of inclusive forward π^0 cross section

significant broadening of away-side correlation peak observed in d+Au relative to p+p

Centrality dependence of forward π–π correlations

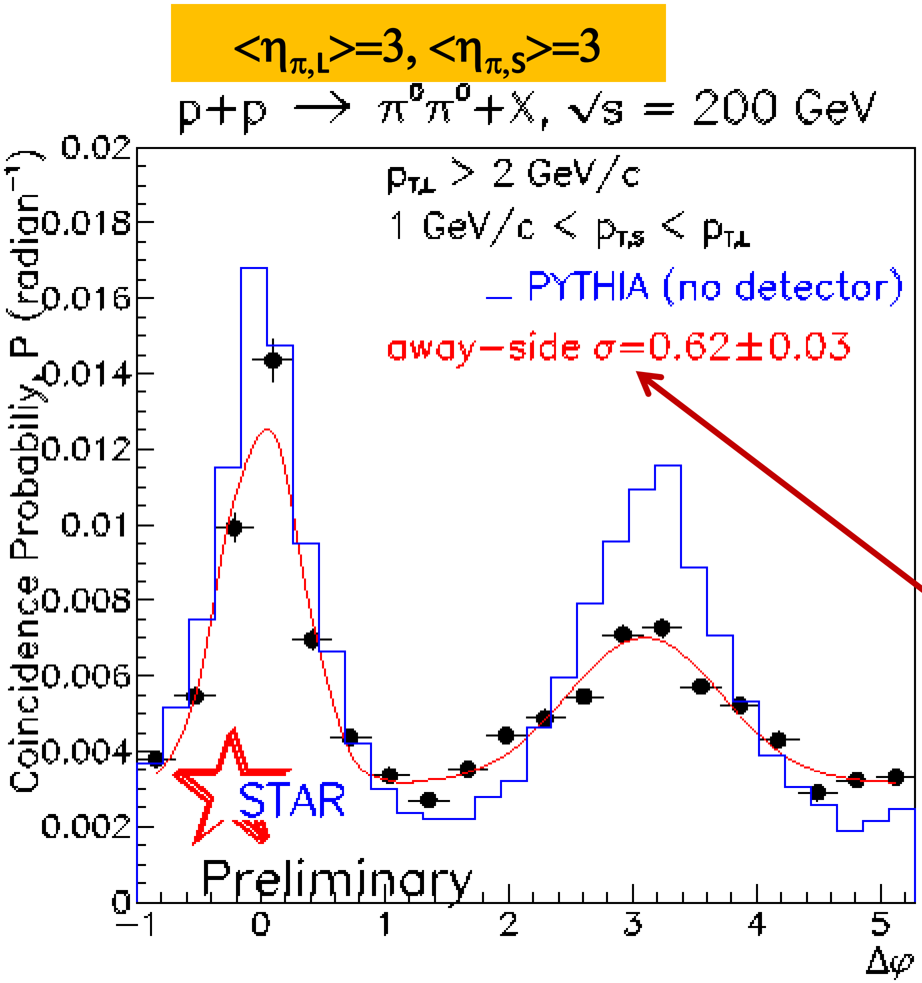
Leading p_T π^0 > 2 GeV/*c*



- *note: uncorrected coincidence probabilities*
- away-side peaks evident in p+p and peripheral d+Au
- peripheral d+Au: away-side ~ 50% wider than in p+p

Away-side peak in d+Au shows significant centrality dependence → clear azimuthal decorrelation.

Corrected p+p coincidence probability



PYTHIA 6.222

Apply off-mass-peak subtraction and efficiency correction to p+p data

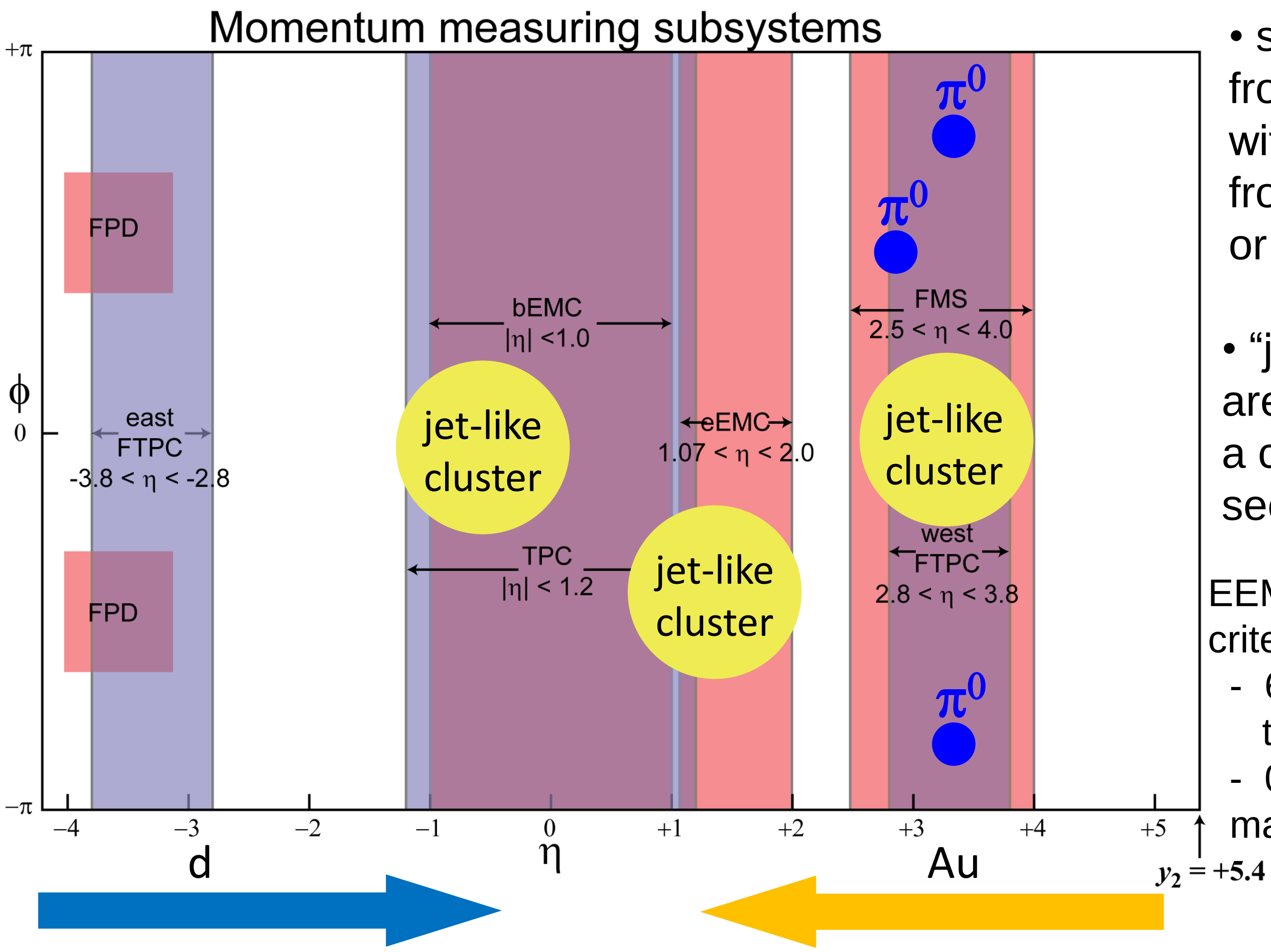
Conclusions:

- away-side peak width comparable to uncorrected azimuthal correlations

  N.B. σ (uncorr.) = 0.68±0.01
- near-side peak agrees with PYTHIA
- away-side peak broader than PYTHIA
- pedestal appears larger than PYTHIA

Pseudorapidity dependence of forward π^0+jet-like correlations

STAR



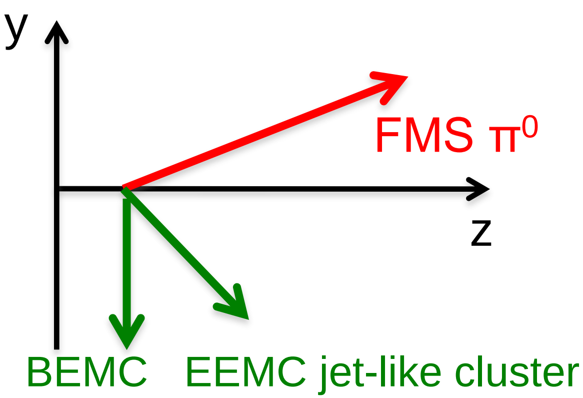
- study correlations of π^0 from FMS (η~3) with "jet-like" clusters from EEMC (η~1.5) or BEMC (η~0)

- "jet-like" clusters are reconstructed within a cone of R=0.6 with a seed from high-tower

EEMC/BEMC selection criteria:

- 600 (400) MeV tower threshold
- 0.4 (0.2) GeV/c^2 lower mass limit for jet-like cluster

FMS (π^0) - jet-like cluster correlations



- mixed event correction applied
- *caveat:* jet energy scale not fixed between different detectors, but this does not change conclusions
- p+p correlations become narrower as η increases
- d+Au correlations become broader as η increases

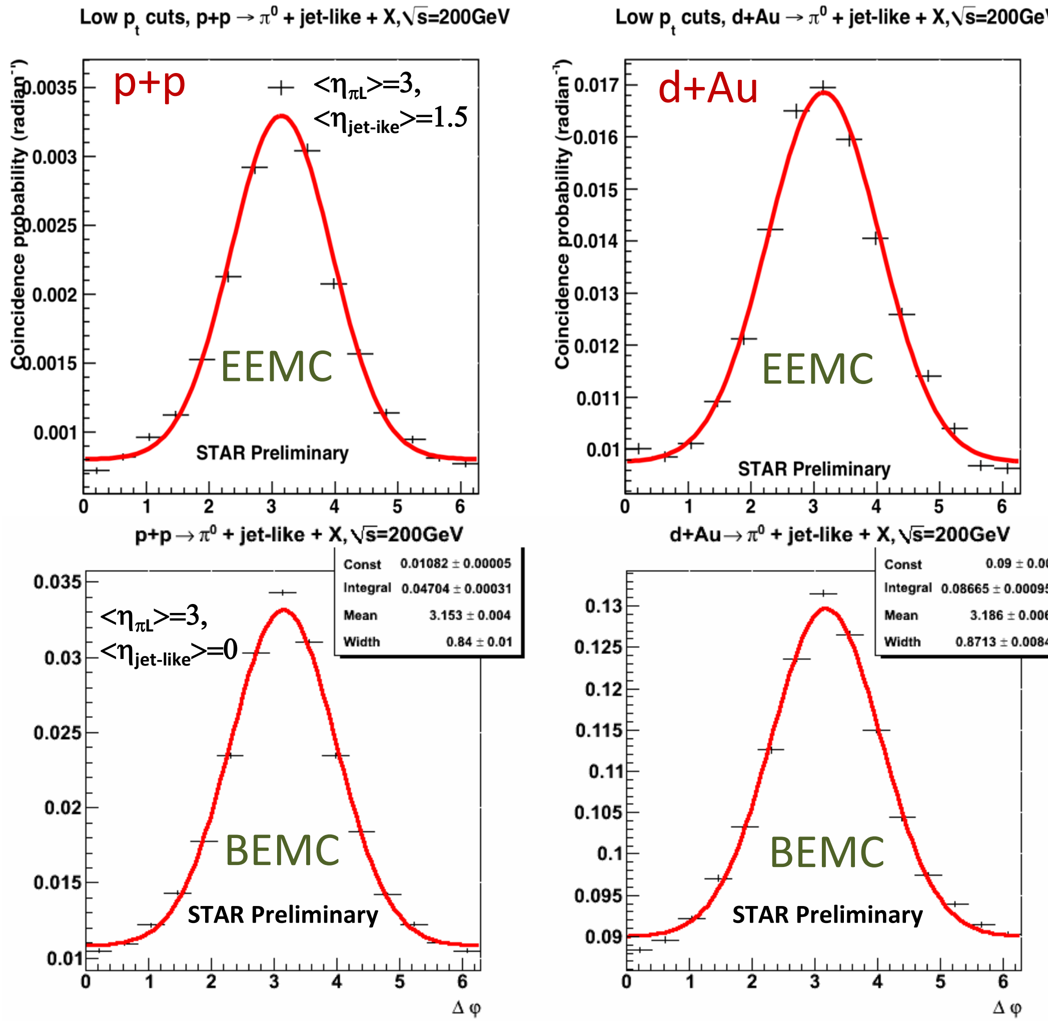
FMS-EEMC:

$$\sigma_{dAu} - \sigma_{pp} = 0.10 \pm 0.02^{+0.04}_{-0.02}$$

FMS-BEMC:

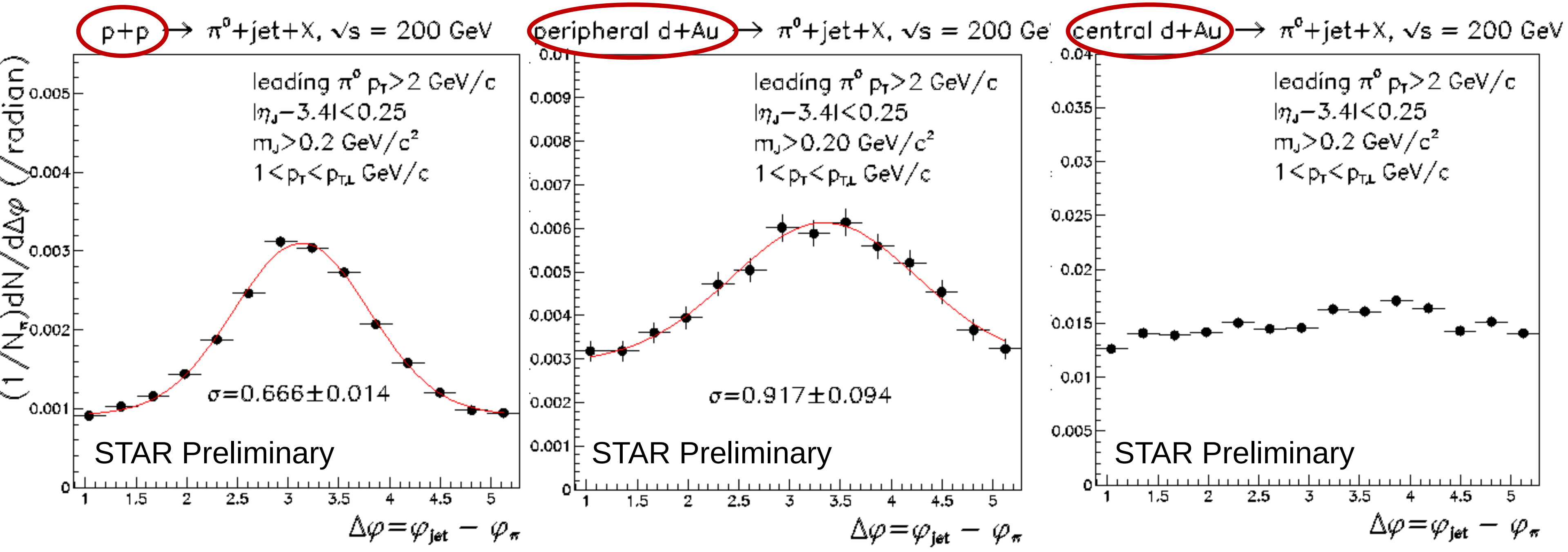
$$\sigma_{dAu} - \sigma_{pp} = 0.031 \pm 0.013$$

p_T(FMS) > 2.0 GeV/c ; 1.0 GeV/c < p_T(jet-like cluster) < p_T(FMS)



Significant broadening from p+p to d+Au for FMS-EEMC correlations observed.

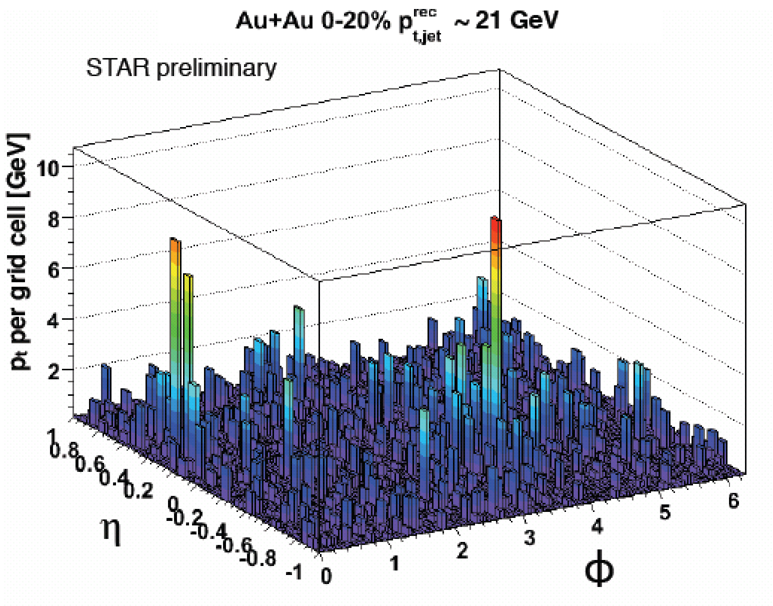
Centrality dependence of π^0+jet-like correlations

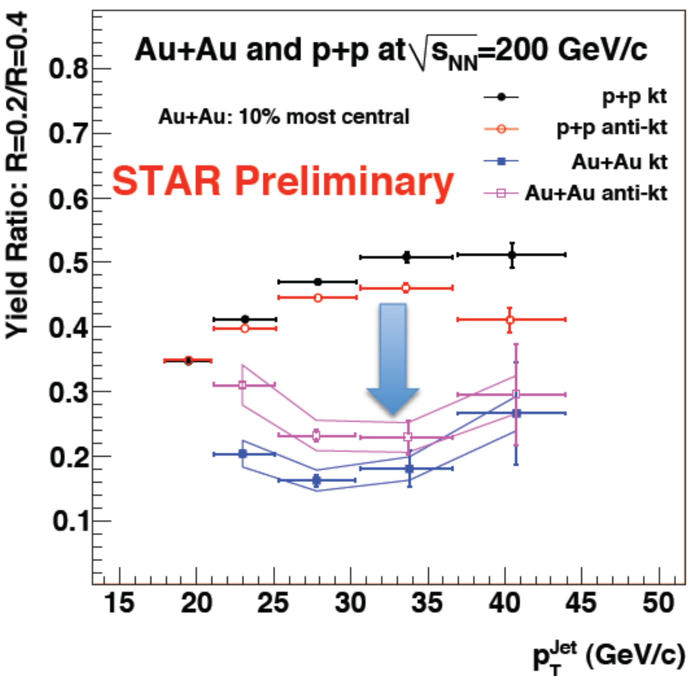


- mixed-event corrections applied, results in ~15% bin-to-bin changes
- use beam-beam counter facing Au beam to select peripheral (ΣQ<250) and central (2000<ΣQ<4000) collisions

No evidence of away-side peak for central d+Au collisions.
Pronounced cold nuclear matter effects in the forward direction.

Full jet reconstruction in Au+Au collisions …





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

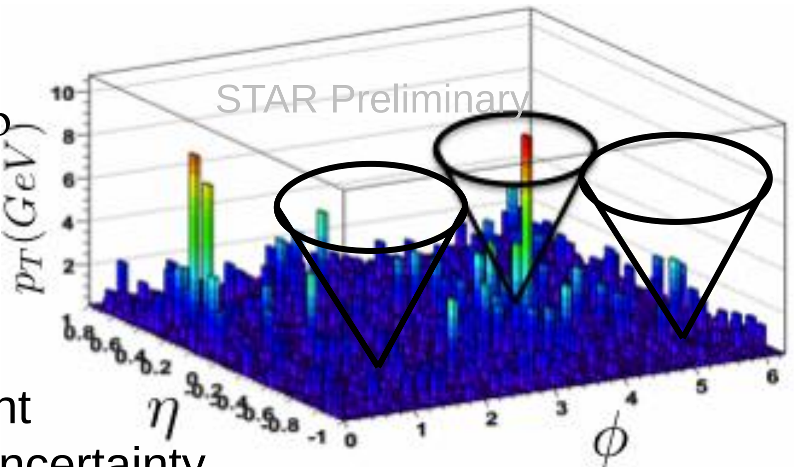
- limited statistics, new methods developed since then

Large and fluctuating background in Au+Au collisions

- event-wise estimate of background density ρ (k_t, FastJet):

$$\rho = \text{median}\{p_{T,i} / A_i^{\,jet}\}$$

A … jet area

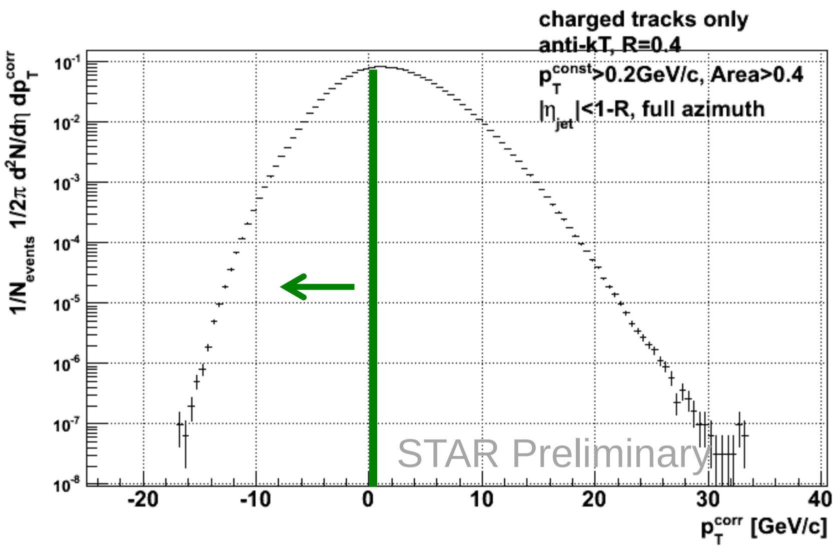


Caution: definition of ρ is not unique:

- e.g. exclude two hardest jets in event
- vary choice → contribution to syst. uncertainty

- jet candidate p_T is corrected event-wise for ρ:

$$p_{T,i}^{corr} \sim p_{T,i}^{reco} - \rho \times A_i$$



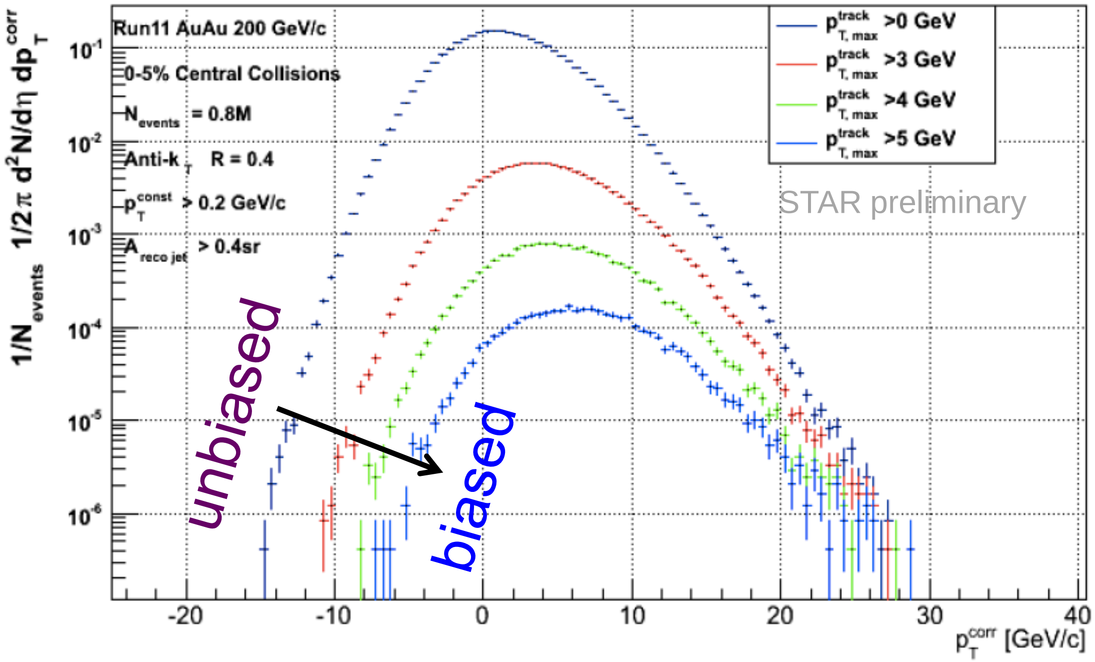
Large fraction of jet population has $p_T^{<corr>} < 0$:

- not interpretable as physical jets
- BUT this component contains crucial information about background or “combinatorial” jets

Note: it is rejected implicitly at later step by imposition of bias on jet candidates

Inclusive jet spectrum in central Au+Au

- Run11 Au+Au data at 200 GeV
- 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.

G. de Barros et al., arXiv:1208.1518

Unfolding of background fluctuations

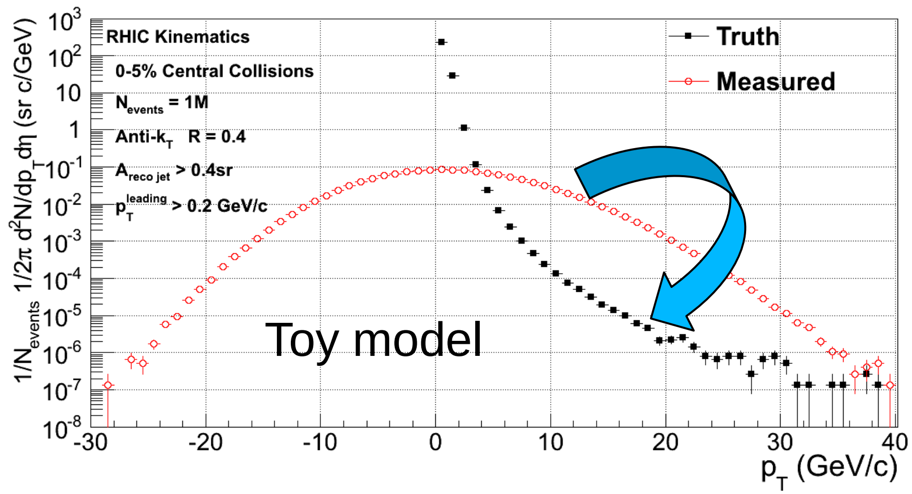
Standard methods:

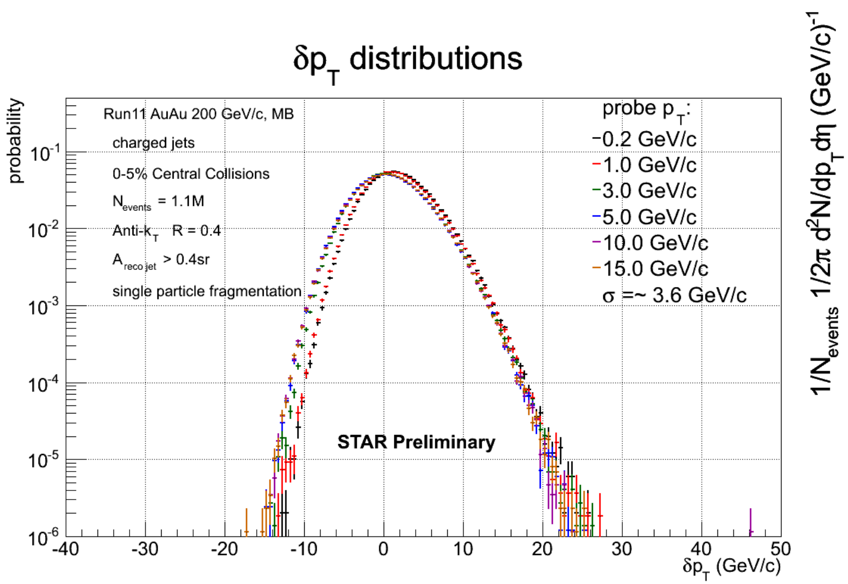
- Bayesian
- Singular Value Decomposition (SVD)

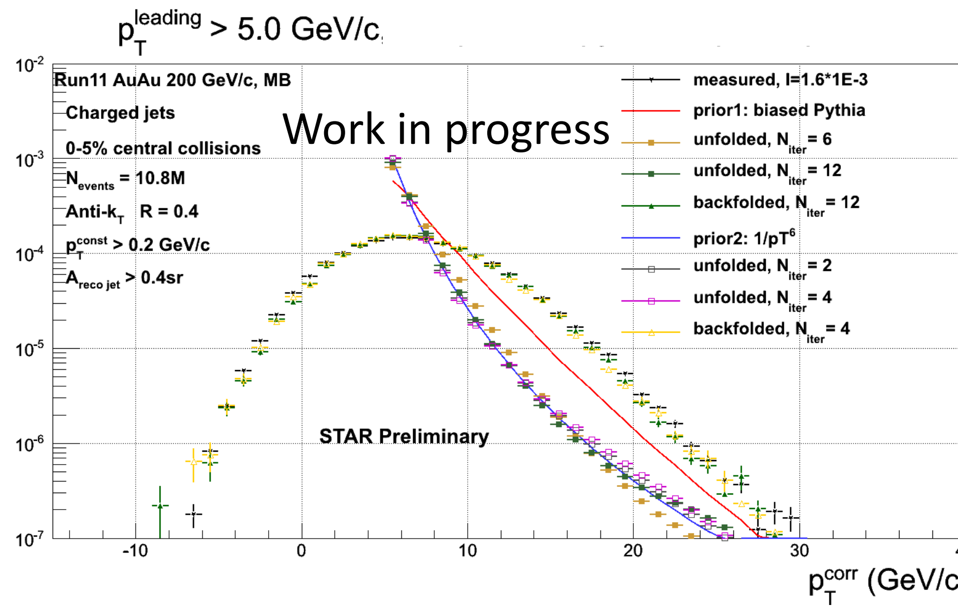
Methods tested in parallel using a “Toy model” Monte-Carlo

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

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





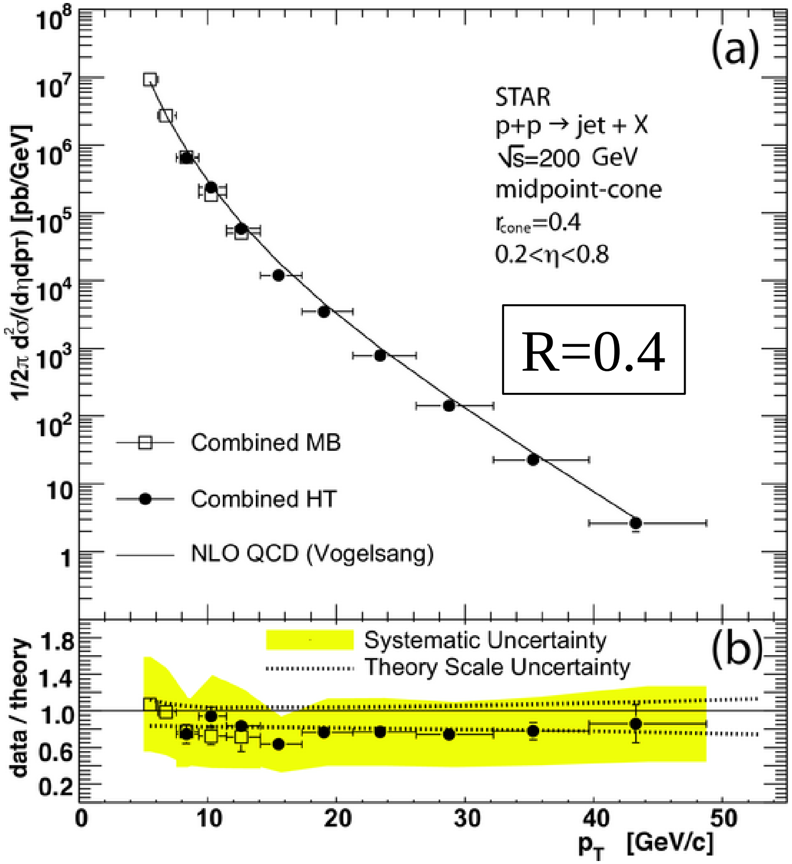


J. Rusnak (STAR)

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

Estimate of jet yields in Run11 Au+Au data

STAR, Phys. Rev. Lett. 97 (2006) 252001



Run 11 Au+Au integrated luminosity:
~ 2.8/nb

Estimate jet production yield (i.e. R_{AA}=1):

$$\sim T_{AA} \cdot \frac{d\sigma_{pp}^{jet}}{dp_T d\eta}$$

10% central Au+Au in Run11:
We expect ~2K jets with p_T>50 GeV/c.

STAY tuned ☺

Summary and outlook

- v_3 may be due to $\Delta\eta$ dependent fluctuations (e.g. a la Glasma).
- STAR data show no ridge, within measurement uncertainties, in d+Au collisions.
- Observed pronounced cold nuclear matter effects in di-hadron correlations in forward direction.
- Work in progress on full jet reconstruction in Au+Au collisions.
  methods tested, unfolding under control

More interesting results from STAR to come ☺