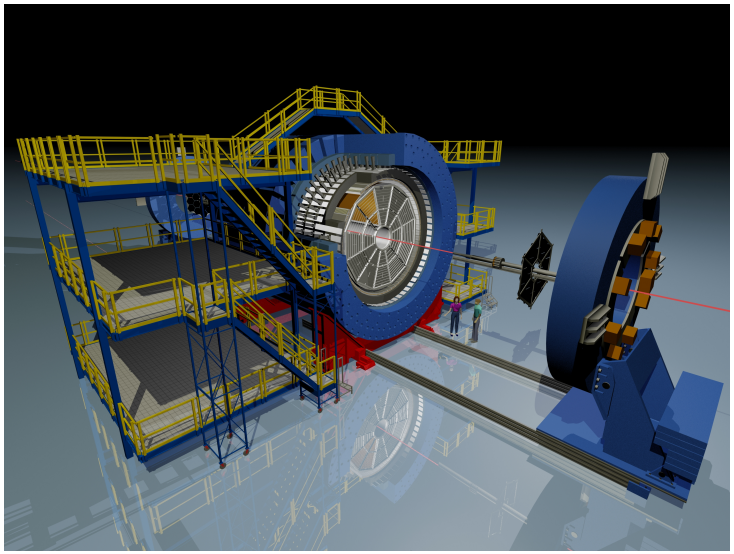
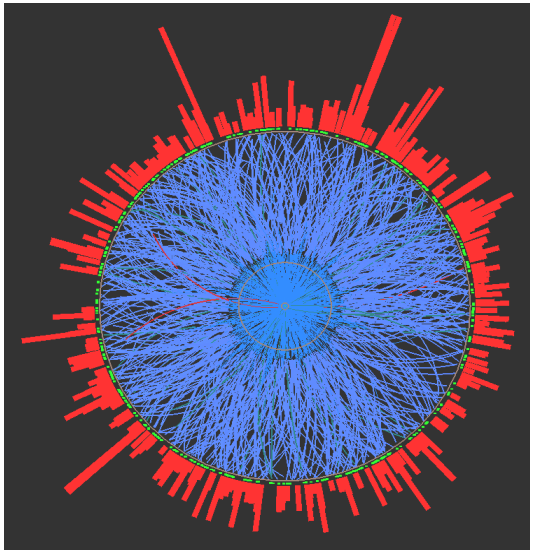
Semi-inclusive charged jet measurements in Au+Au collisions at $\sqrt{s_{NN}}$= 200 GeV

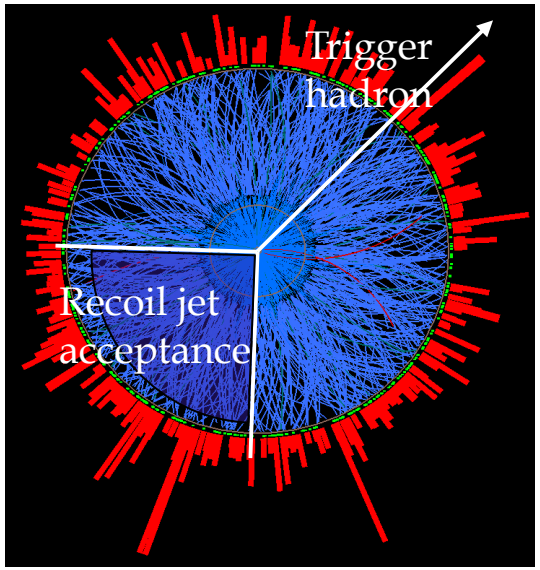
Peter Jacobs
Lawrence Berkeley National Laboratory
for the STAR Collaboration





Observable: semi-inclusive h+jet correlation

Trigger-normalized yield of jets recoiling from a high p_T hadron trigger



$$\frac{1}{N^h_{trig}}\frac{dN_{jet}}{dp_{T,jet}} = \frac{1}{\sigma^{AA\to h+X}}\frac{d\sigma^{AA\to h+jet+X}}{dp_{T,jet}}$$

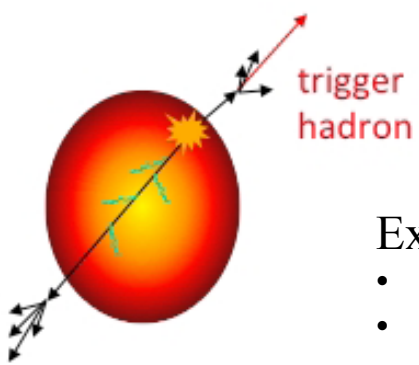
Measured Calculable in pQCD

Semi-inclusive: event selection only requires trigger hadron

- experimentally clean; trigger bias theoretically calculable

Count all recoil jet candidates:

- uncorrelated background corrected at level of ensemble-averaged distributions
- jet selection does not impose fragmentation bias



Expected geometric bias: surface, not tangential

- Large path length for recoil
- Model studies: T. Renk, PRC74, 024903; H. Zhang et al., PRL98 212301;…

Analysis details

Dataset

Year 2011 data: Au+Au, $\sqrt{s_{NN}}$=200 GeV

Minbias trigger; 500M events after cuts

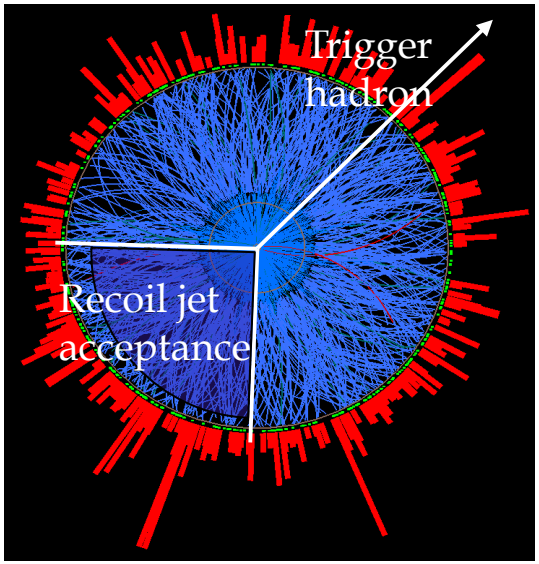
- Offline centrality selection 0-10%, 60-80% (mid-rapidity raw multiplicity)

Charged jet reconstruction

Charged tracks: $0.2<p_T^{track}<30$ GeV/c

Algorithm: anti-k_T, R=0.2, 0.3, 0.4, 0.5

- Jet centroid: $|\eta^{jet}|<1.0 - R$
- Recoil jet centroid acceptance: $[\pi-\pi/4, \pi+\pi/4]$



Hadron trigger

Charged particle, $9<p_T<30$ GeV/c

- Inclusive selection: choose one trigger particle without regard to rest of event ➔ trigger may not be highest p_T track

Uncorrelated background measured via mixed events (new method)

Correction for background fluctuations and instrumental effects

- Event-wise pedestal shift ρ*A (Fastjet prescription)
- Unfolding of ensemble averaged distribution

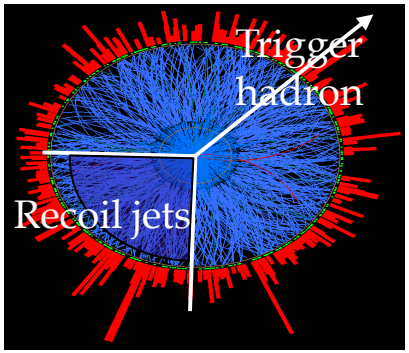
} Procedures are coupled

Corrected $p_T^{jet} > 0$

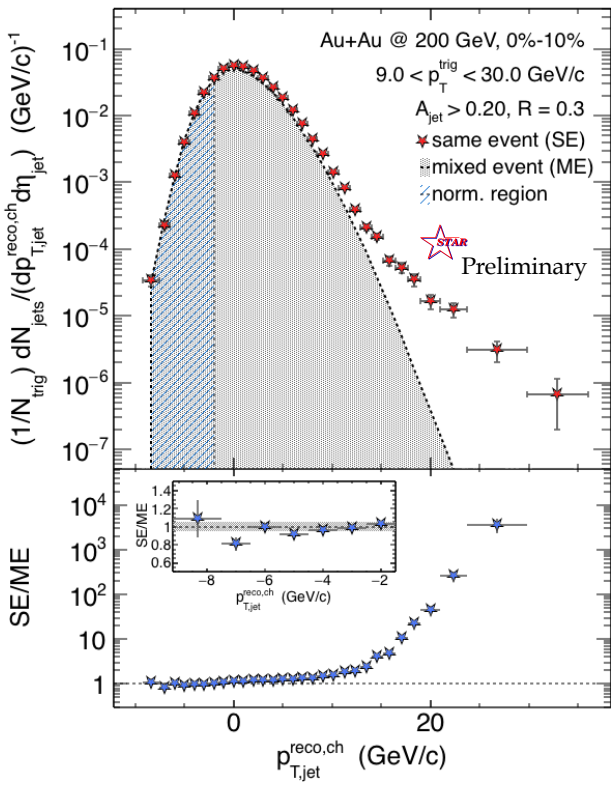
Recoil jet spectrum

$$p_{\mathrm{T,jet}}^{\mathrm{reco,ch}} = p_{\mathrm{T,jet}}^{\mathrm{raw,ch}} - \rho \cdot A$$

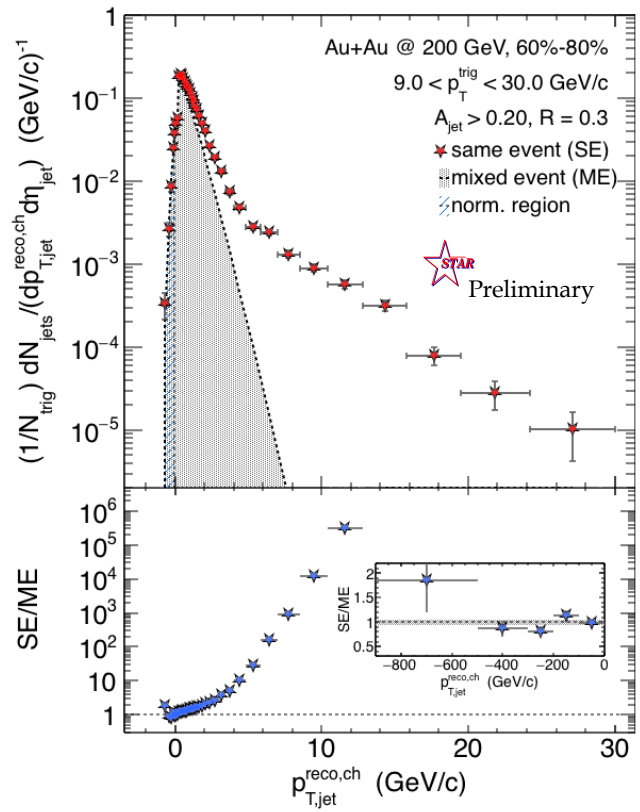
ρ = estimated background energy density



Central Au+Au

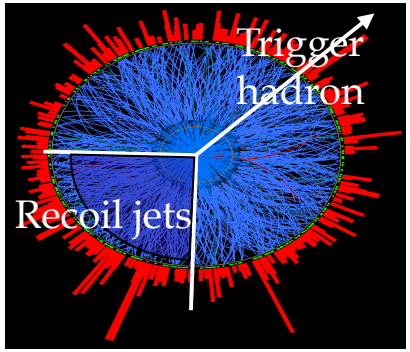


Peripheral Au+Au

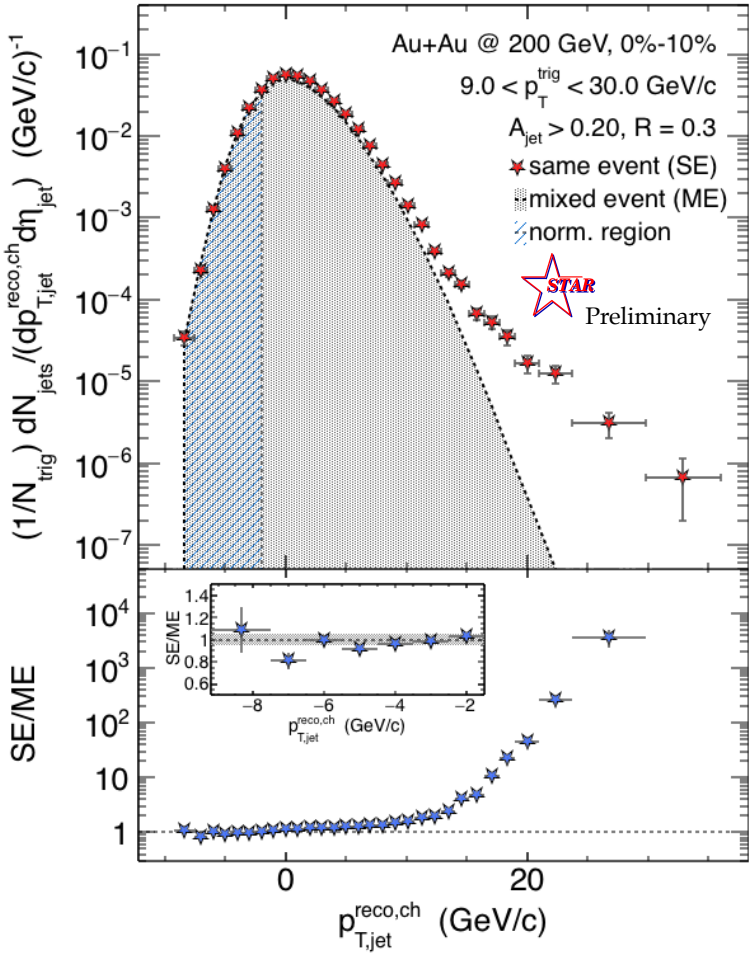


Mixed event distribution is good description of combinatorial jet background

Recoil jet spectrum: RHIC vs LHC



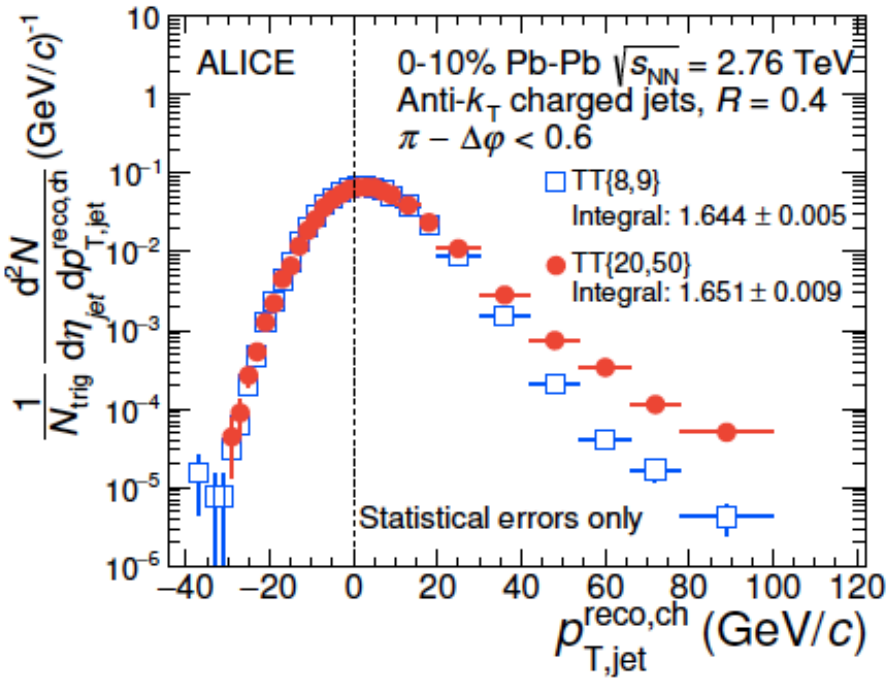
Central Au+Au, $\sqrt{s_{NN}}$=200 GeV



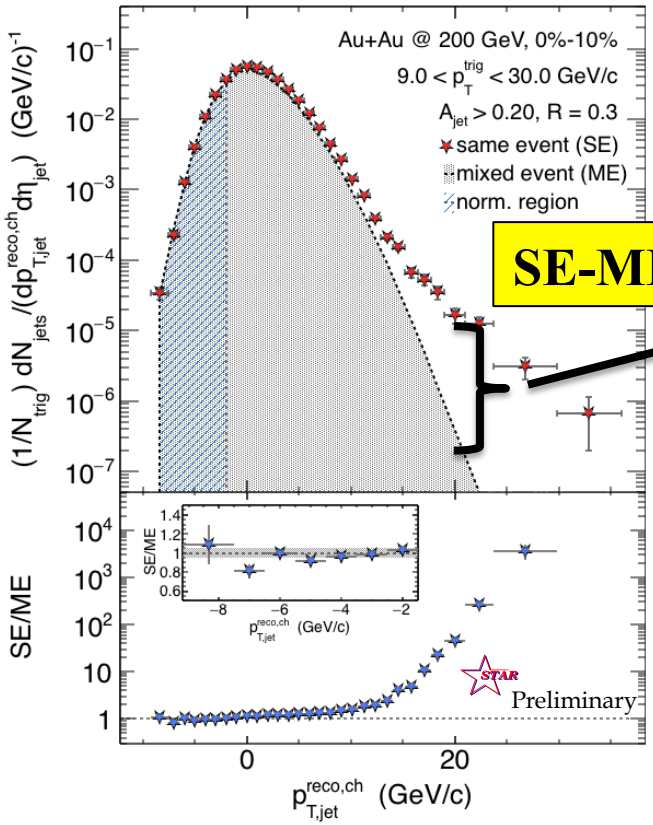
Closely related ALICE measurement

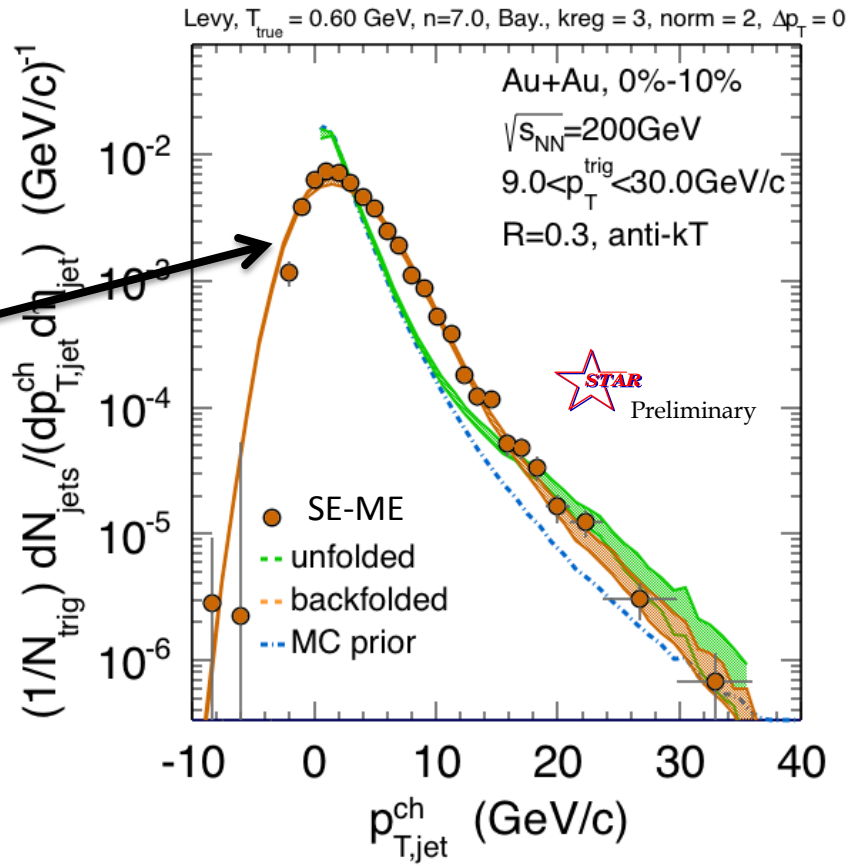
arXiv:1506.03984

Central Pb+Pb, $\sqrt{s_{NN}}$=2.76 TeV



Correction of p_T-scale via unfolding



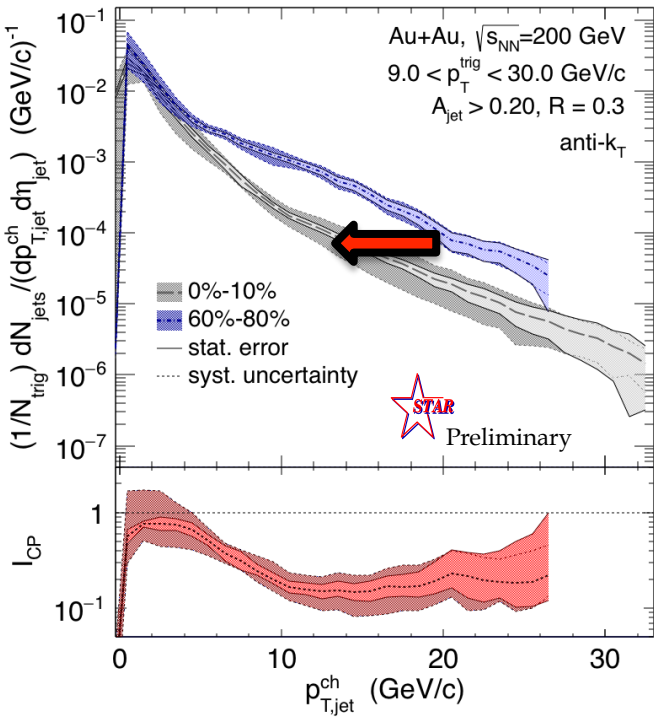


Unfolding generates large off-diagonal covariance➔ corrected distribution is unbinned

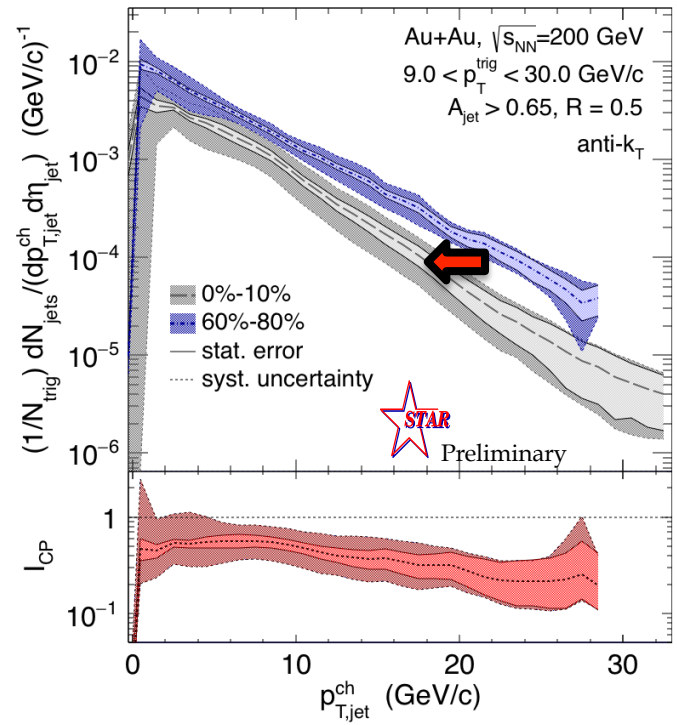
- Unfolding algorithms: SVD, Bayesian
- Systematic variations: prior, regularization, tracking efficiency, ME normalization, bkgd fluctuation distribution
- Consistency check: χ^2 of backfolding

Recoil yield suppression

R=0.3



R=0.5



Calculate spectrum shift

- requires distributions ~ exponential, ratio ~ flat

Spectrum Shift Periph/pp ➔Central			
	$p^{ch}_{T,jet}$ range [GeV]	**Shift R=0.3 [GeV]**	**Shift R=0.5 [GeV]**
Au+Au @ 200 GeV	[10,20]	**-6.3** ± 0.6 ± 0.8	**-3.8** ± 0.5 ± 1.8
Pb+Pb @ 2.76 TeV *ALICE arXiv:1506.03984*	[60,100]		**-8** ± 2

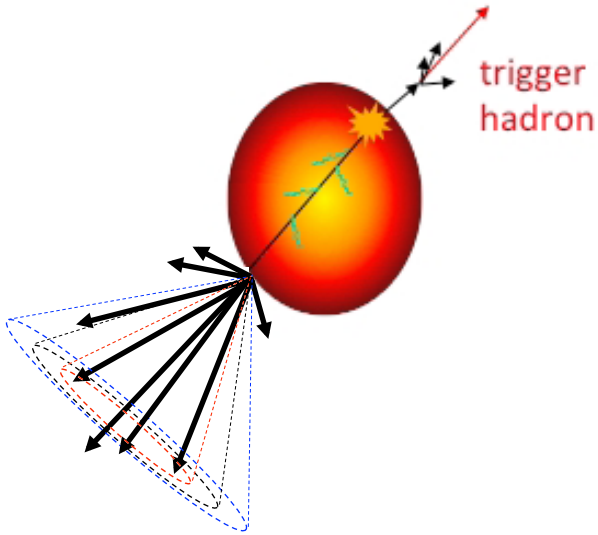
RHIC: smaller shift for larger R

R=0.5: smaller shift at RHIC than LHC

Out-of-cone energy transport ?

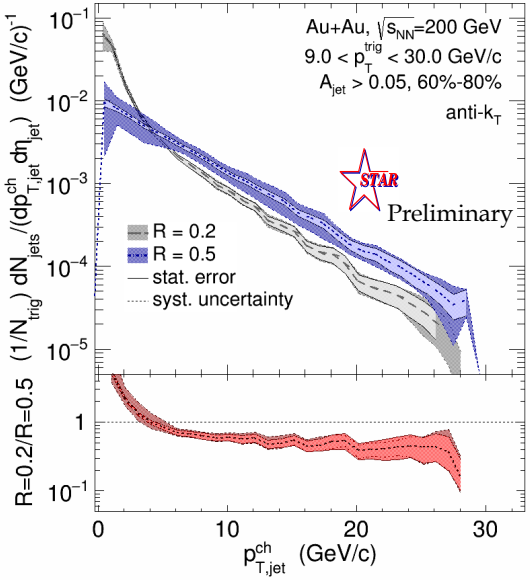
- comparison requires similar trigger bias ➔ theory calculation

Intra-jet broadening: recoil yield vs. R

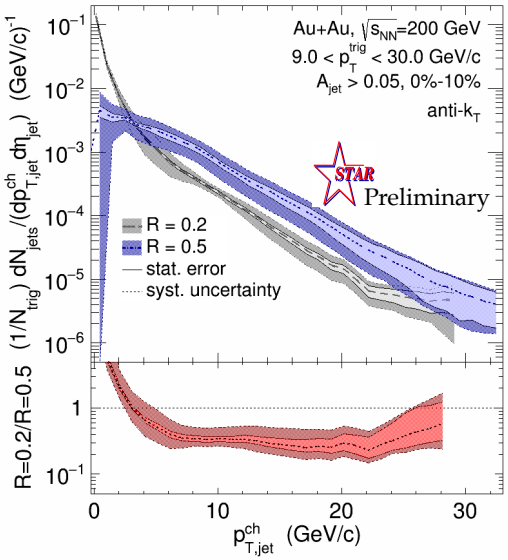


Redistribution of jet energy transverse to jet axis

Au+Au peripheral

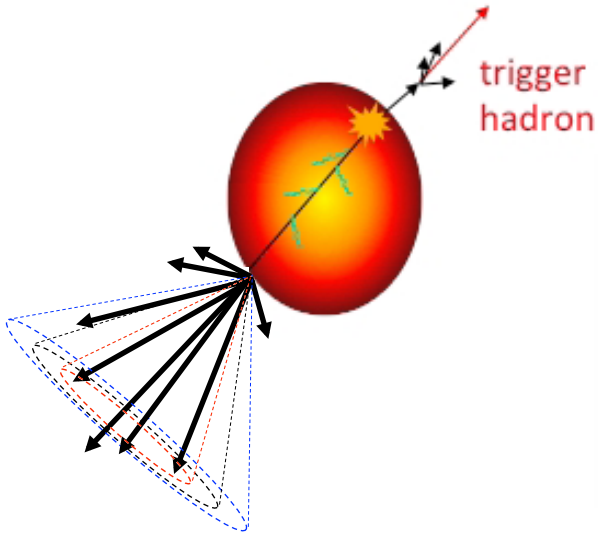


Au+Au central

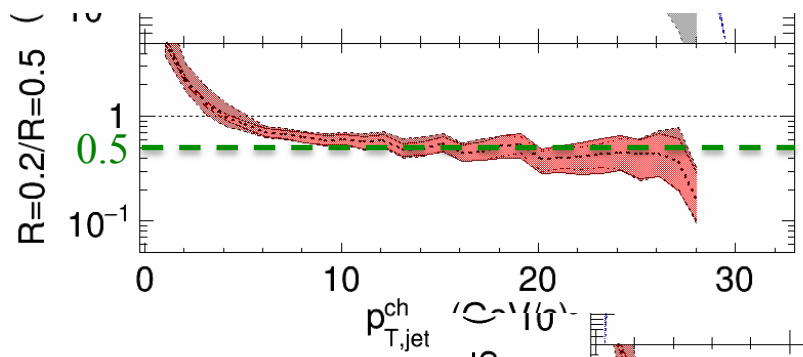


Intra-jet broadening: recoil yield vs. R

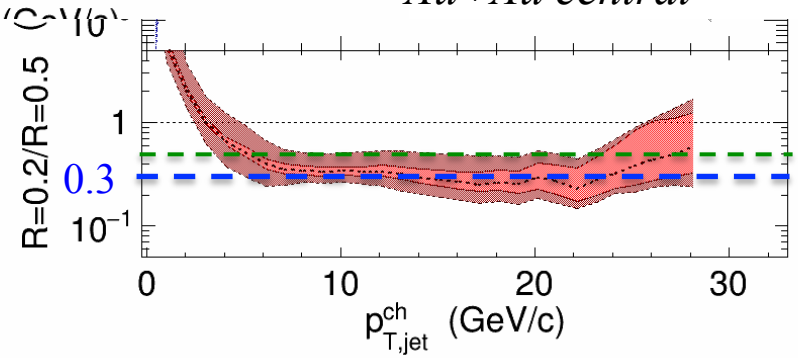
Redistribution of jet energy transverse to jet axis



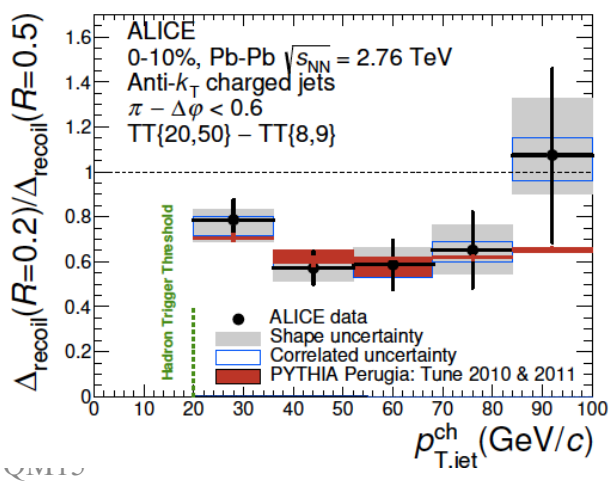
Au+Au peripheral



Au+Au central



arXiv:1506.03984



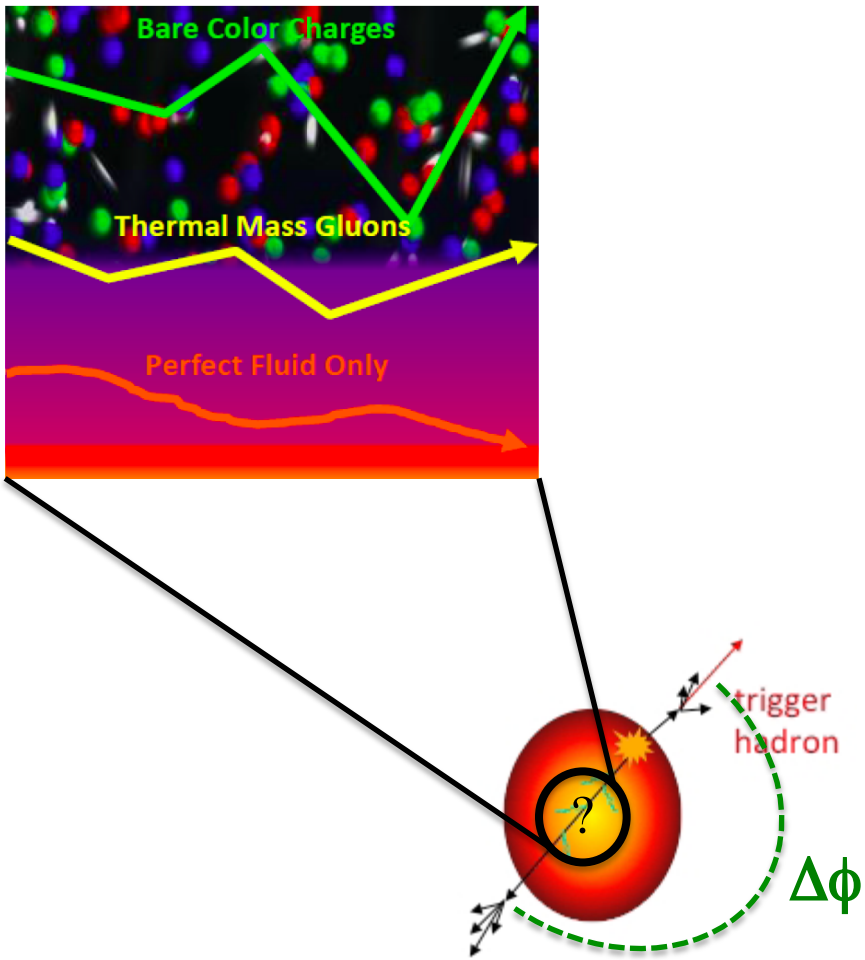
Ratios for peripheral and central are consistent within uncertainties

- compatible with some broadening within R<0.5
- future measurement (higher stats): reduce uncert.

LHC: similar picture in overlapping p_T range

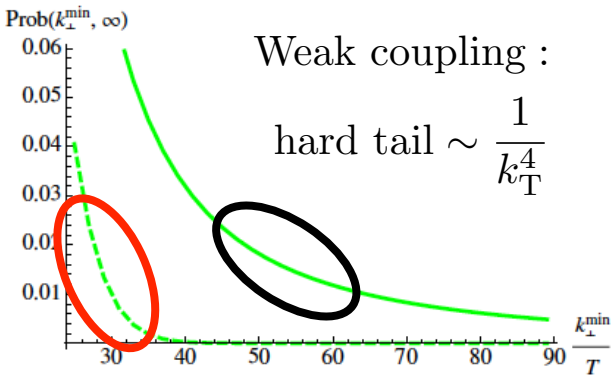
Inter-jet broadening: secondary scattering off the QGP

Discrete scattering centers or effectively continuous medium?



d'Eramo et al, arXiv:1211.1922

Distribution of momentum transfer k_T

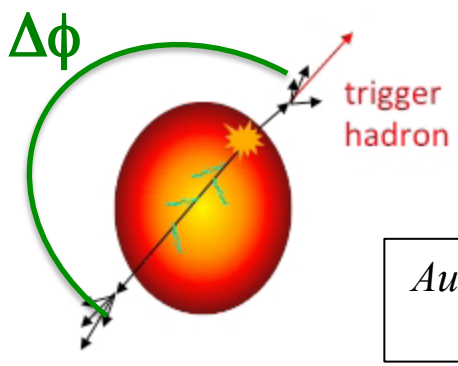


Strong coupling:
Gaussian distribution

Conjecture for weak coupling: Δϕ distribution dominated by single hard Molière scattering at "sufficiently large" Δϕ

- vacuum QCD effects fall off more rapidly
- "sufficiently large" not yet known

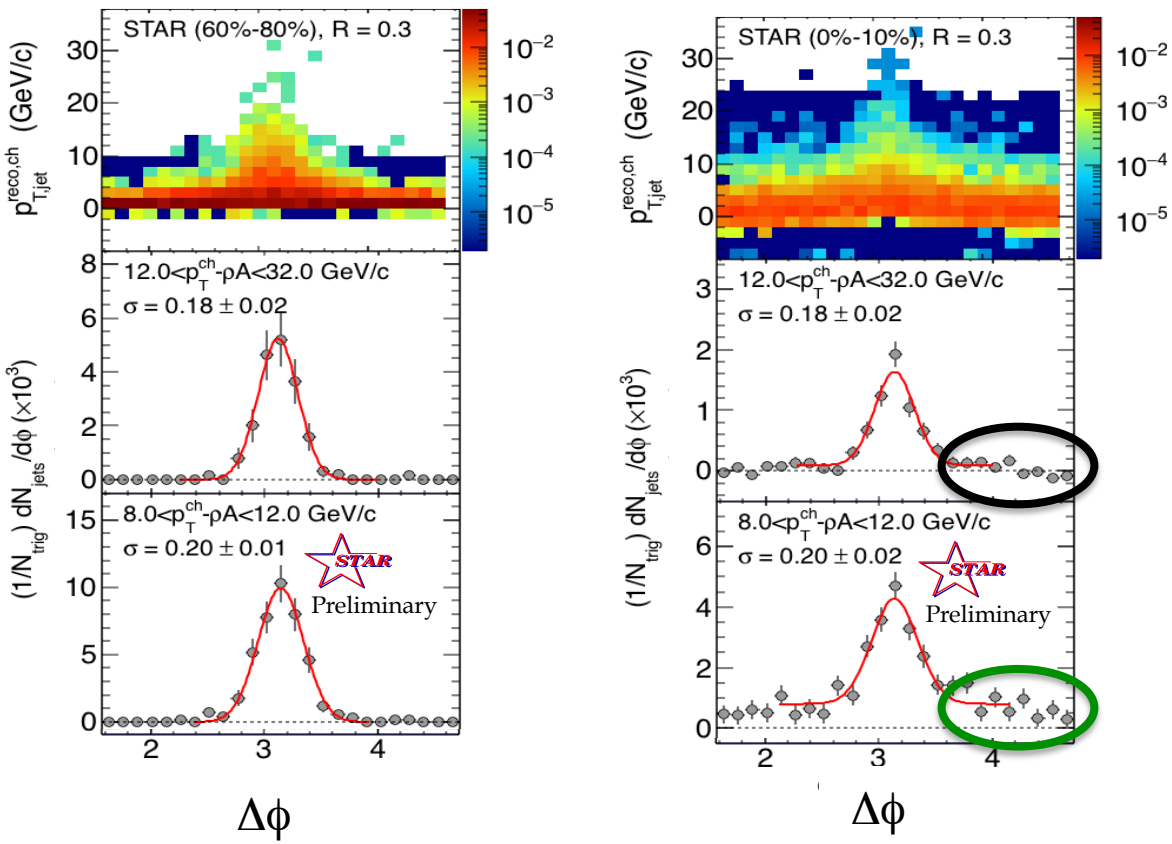
Inter-jet broadening: data



Quantitative search requires absolute normalization
➔ semi-inclusive distribution

Au+Au $\sqrt{s_{NN}}$*=200 GeV*
p_T^{trig}*>9 GeV/c*

peripheral *central*



Consistent with zero at current precision

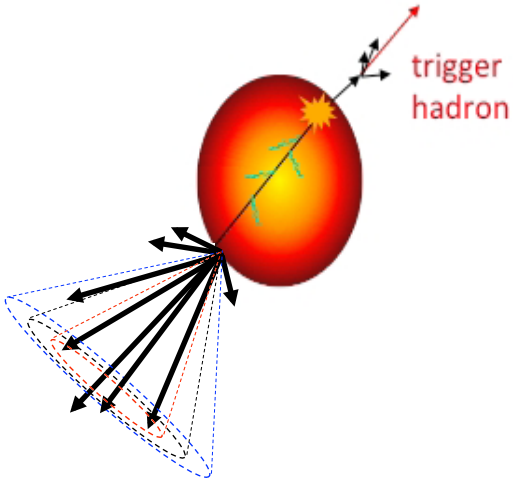
Low energies: hint of finite yield at large Δϕ yield at but not fully corrected for uncorrelated background

QCD calculation in progress (d'Eramo): will indicate integrated luminosity needed for significant measurement

Summary and Outlook

Semi-inclusive h+jet correlations:

- jet measurements with large R over full p_T range at RHIC
- comparable to similar ALICE measurement



Recoil yield is suppressed
Suggests less out-of-cone energy transport for

- large R
- central A+A collisions
- central AA @ RHIC vs. LHC

Intra-jet broadening:

- compatible with some broadening within R<0.5

Large-angle scattering: probe quasi-particle degrees of freedom in QGP

- proof of principle; low energy jets are crucial
- QCD calculation in progress ➔ future measurements at RHIC and LHC

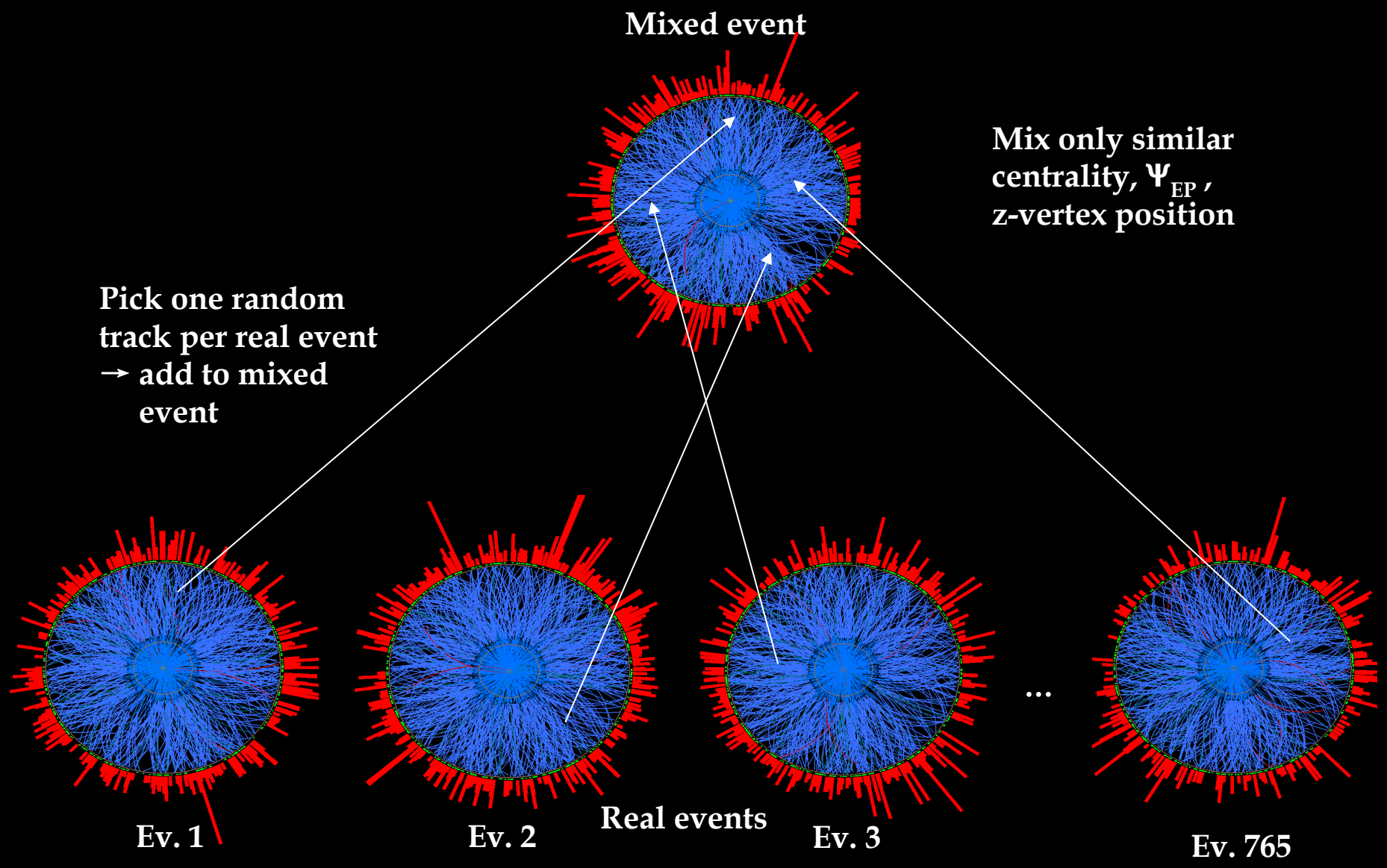
Next step: extend to fully measured jets with BEMC (higher int lumi in Year 14 data)

- reduced systematic uncertainties for all observables

Theory calculations needed to assess biases, compare RHIC/LHC

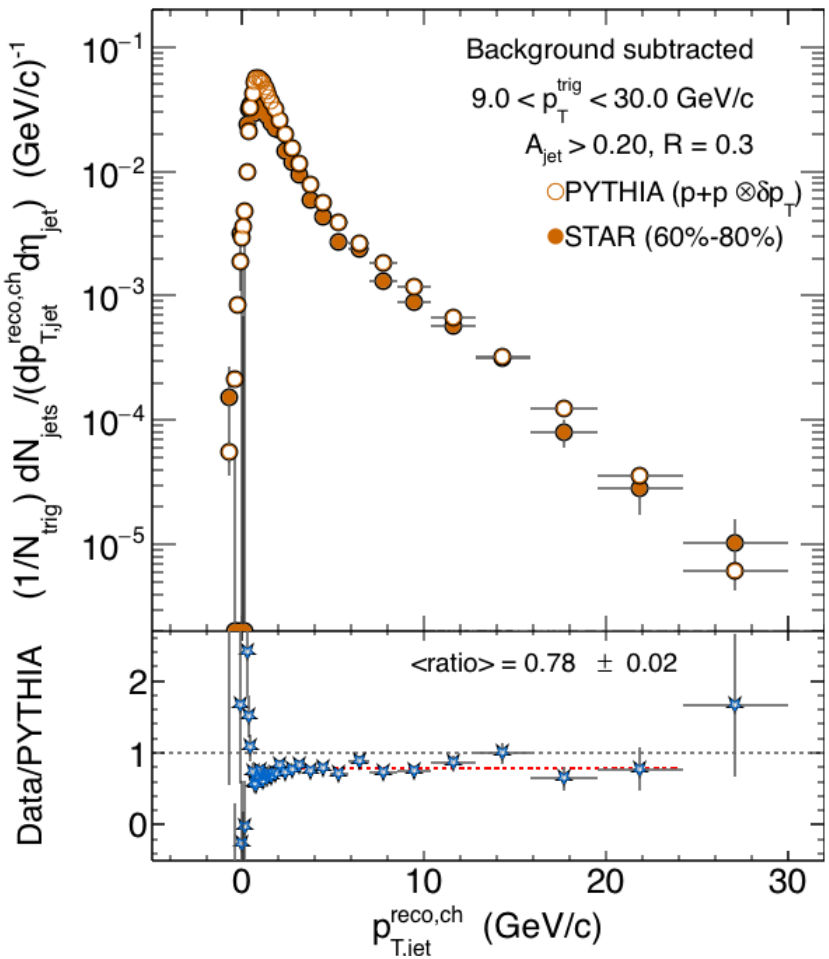
Backup slides

Uncorrelated Background: Mixed Events



Comparison of recoil jet spectra: STAR Au+Au 60-80 and PYTHIA pp

Peripheral 60-80%

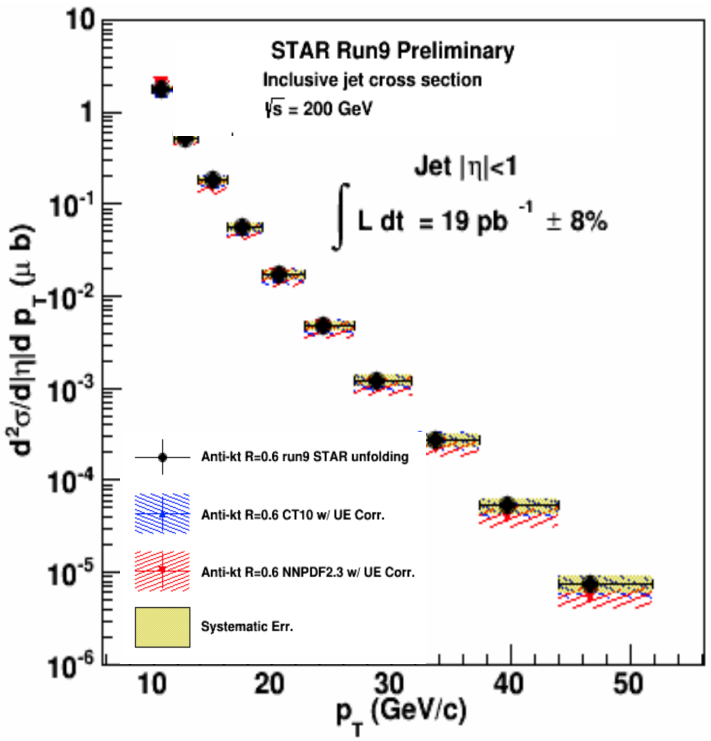


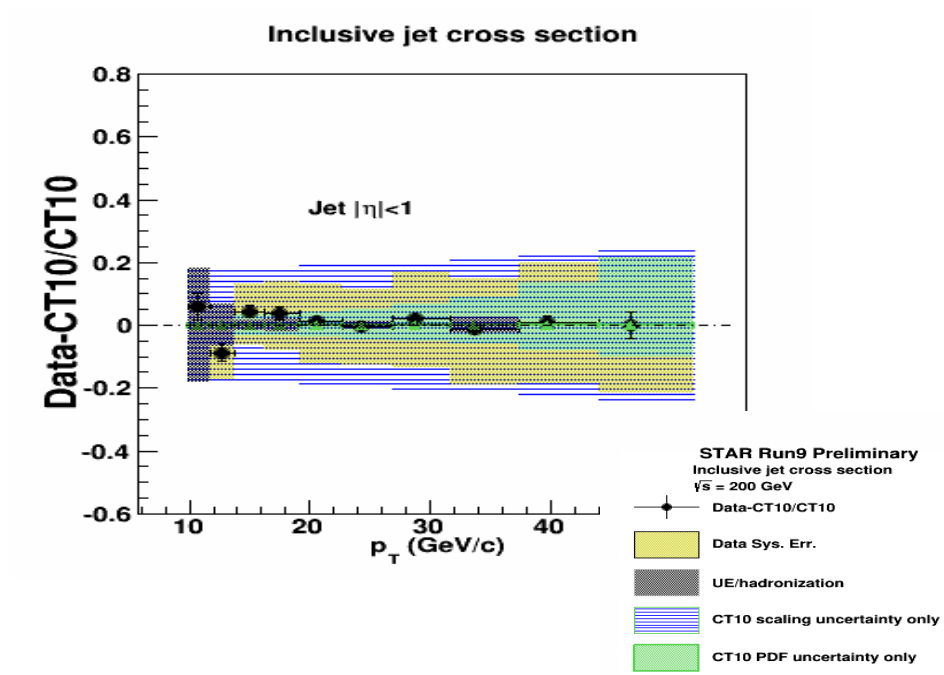
Smeared PYTHIA: convolute recoil jet spectrum from p+p@200 GeV with distribution of background fluctuations

Compare Au+Au 60-80% with smeared PYTHIA

Both shape and yield in good agreement

Jets in STAR: inclusive jet cross section in p+p collisions at √s=200 GeV



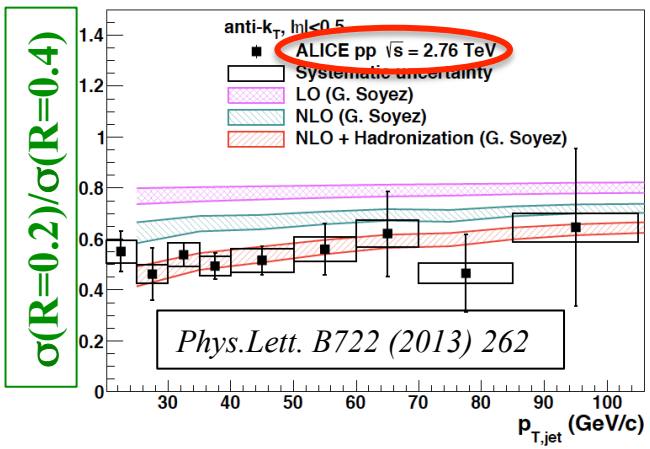


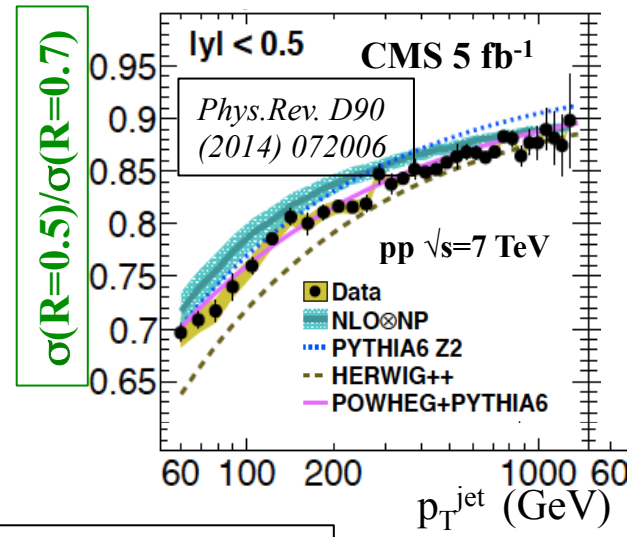
- Good and improvable systematic uncertainties over broad kinematic range
- Good agreement with NLO pQCD

Jets in heavy ion collisions: instrument is in place, need the right algorithms

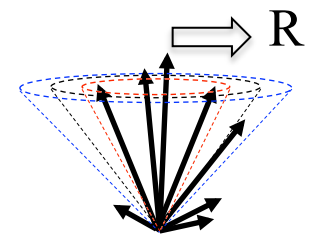
Intra-jet structure: (semi-)inclusive ratios at different R

Inclusive jets, pp √s= 2.76, 7 TeV





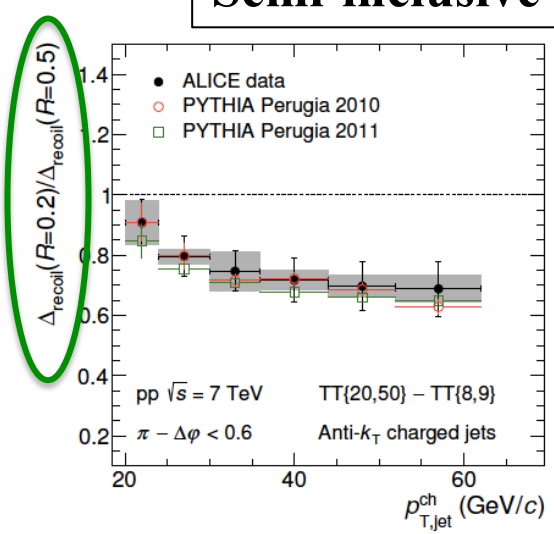
Jets with different R sensitive to different components of shower

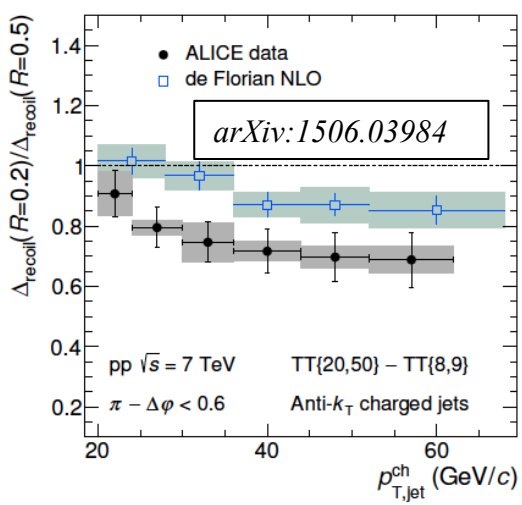


Calculable perturbatively:

- require (N)NLO + non-pert. corrections
- MC models ~OK

Semi-inclusive h+jet, pp √s=7 TeV





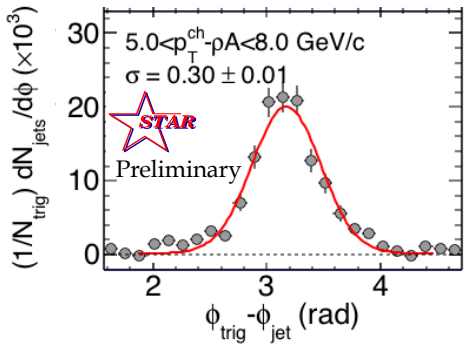
Ratios in vacuum

- sensitive to transverse jet structure
- rigorous data/theory comparison

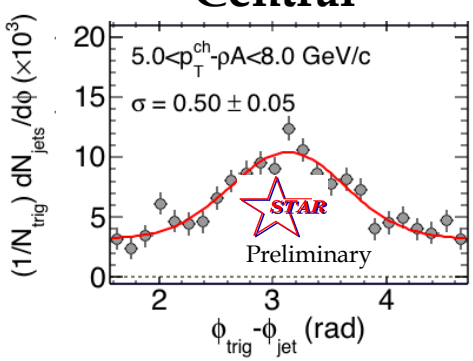
➔ Now use to measure intra-jet broadening due to quenching

Secondary scattering off the QGP: low p_T^{jet}

Peripheral



Central



- Significant difference at $5 < p_T\text{-}\rho A < 8$ GeV/c
  → Flow?
  → Φ dependent normalization needed?
  → Background from multiple interactions?
  → More studies needed!