Jets and Jet-like Correlations at RHIC

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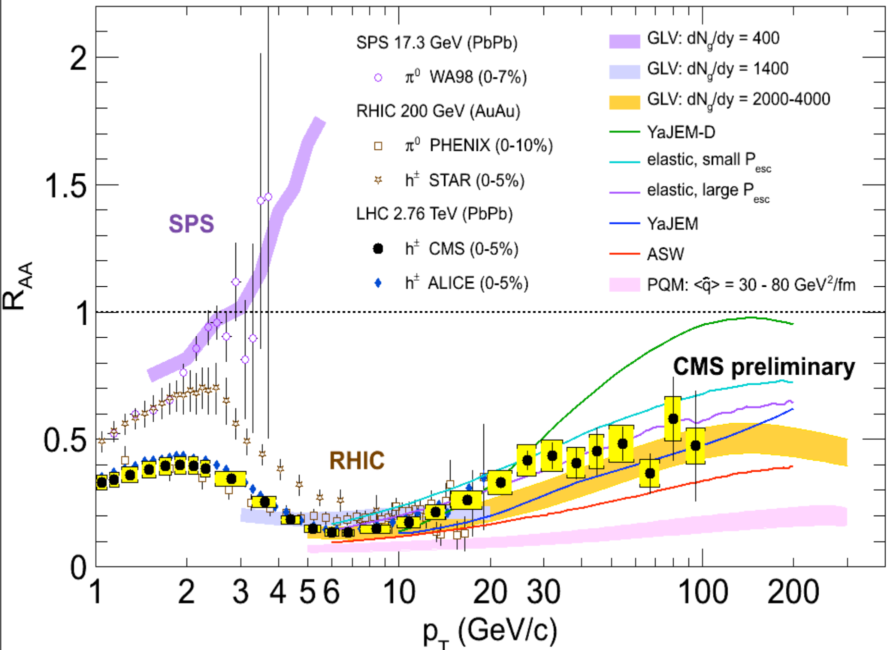
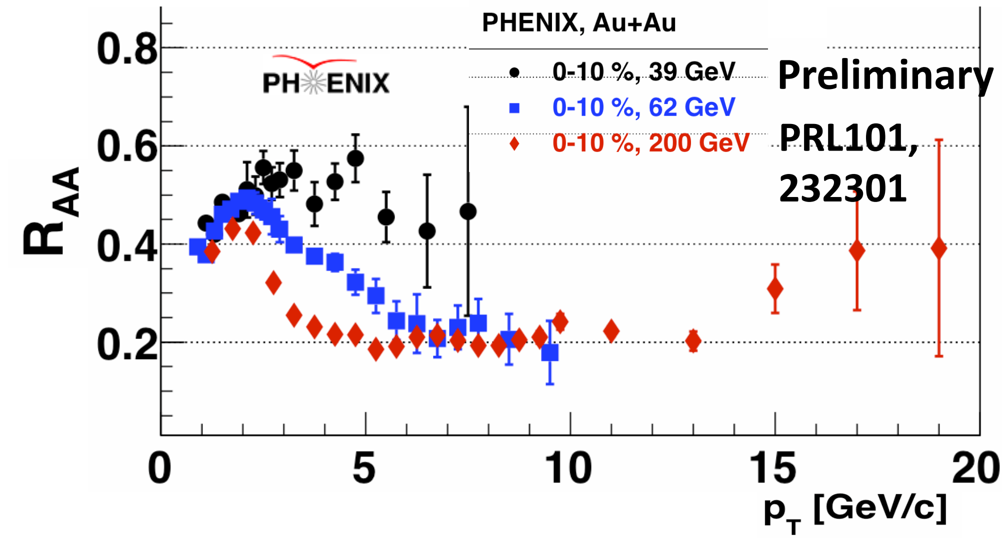
DPF - Brown University - August 2011

Outline:

Introduction
Base line measurements
Cold nuclear matter effects
Background studies for full jet reconstruction
Energy loss measures

Jet quenching - single particle R_{AA}

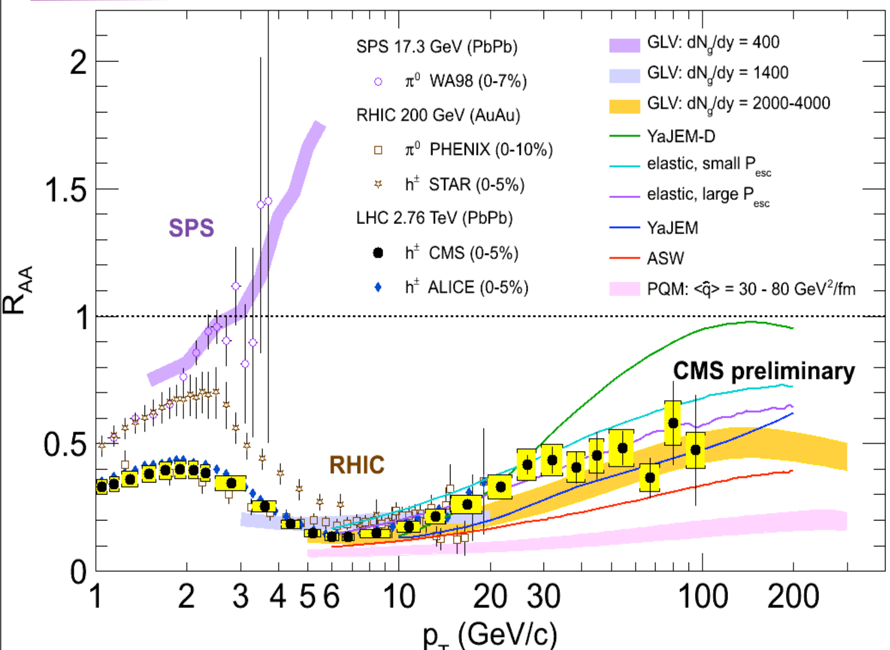


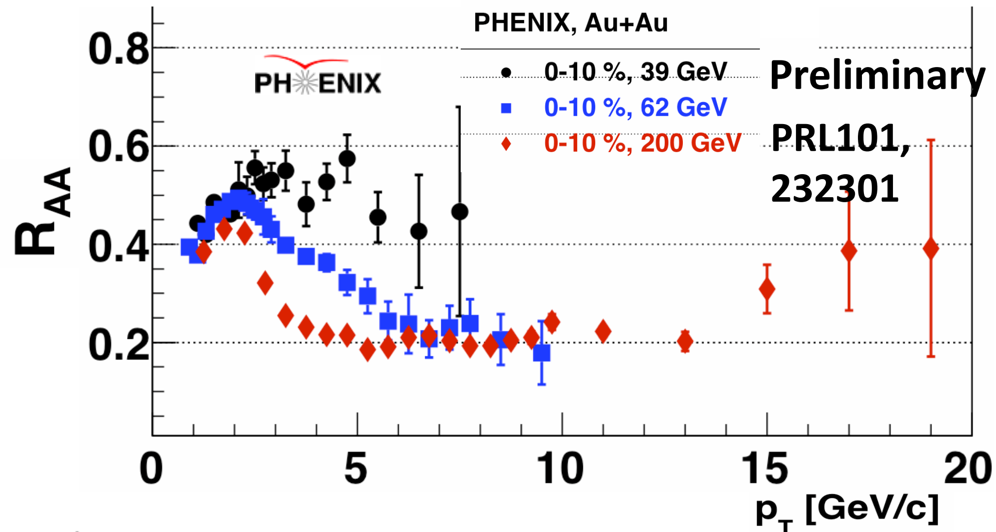


"Jet quenching" observed from 39 GeV - 2.7 TeV

At low √s: Cronin > Energy loss

Jet quenching - single particle R_{AA}

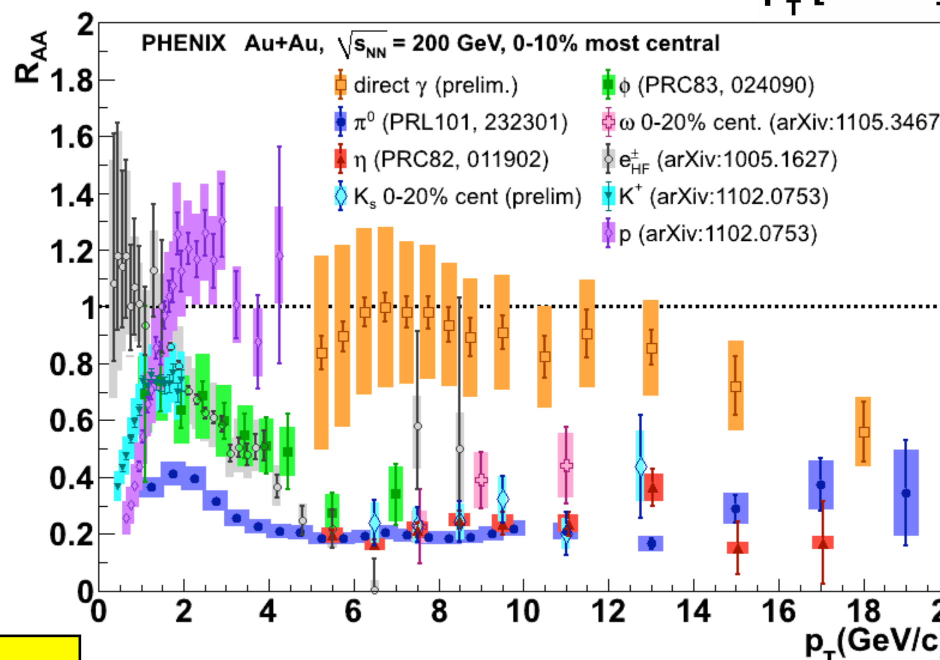




“Jet quenching” observed from 39 GeV - 2.7 TeV

At low √s: Cronin > Energy loss

At intermediate p_T: energy loss species dependent

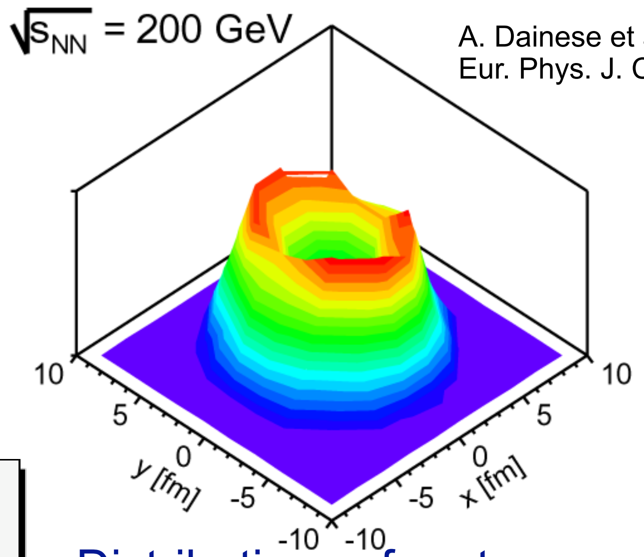


Colorless photons loose no energy

The limitations of R_{AA}

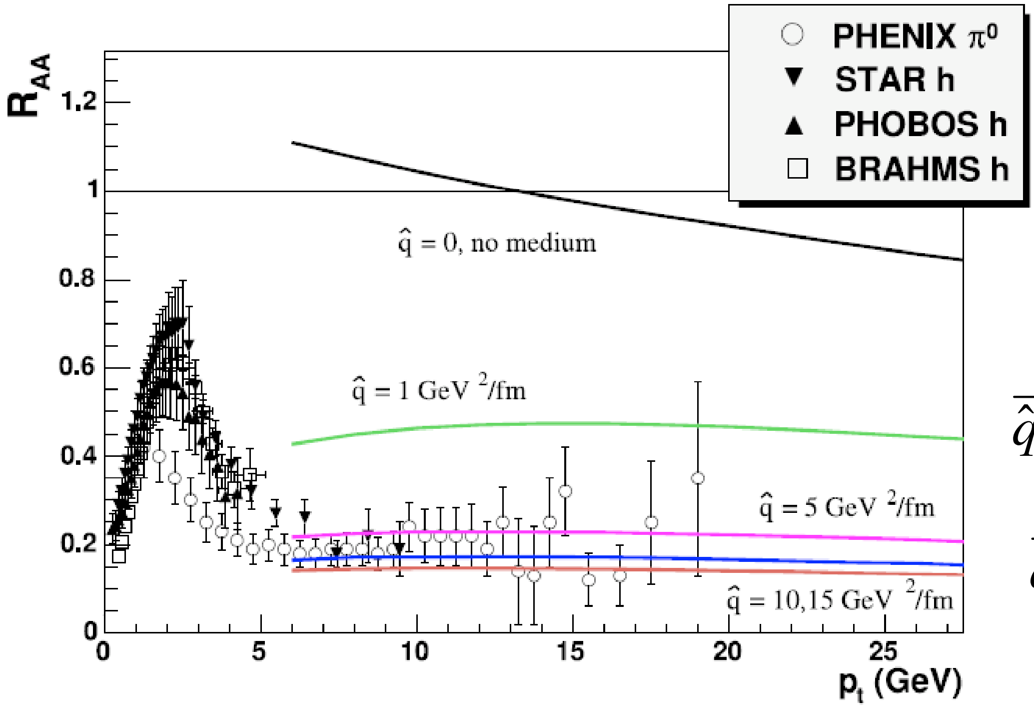
Insensitivity due to surface emission:

R_{AA} can't go to zero even for the highest densities



A. Dainese et al., Eur. Phys. J. C38(2005) 461

Distributions of parton production points in the transverse plane



[Eskola, Honkanen, Salgado, Wiedemann (2004)]

Rough correspondence:

$$\bar{\hat{q}} = 10\frac{GeV^2}{fm} \Leftrightarrow \frac{dN^g}{dy} \approx 1800$$

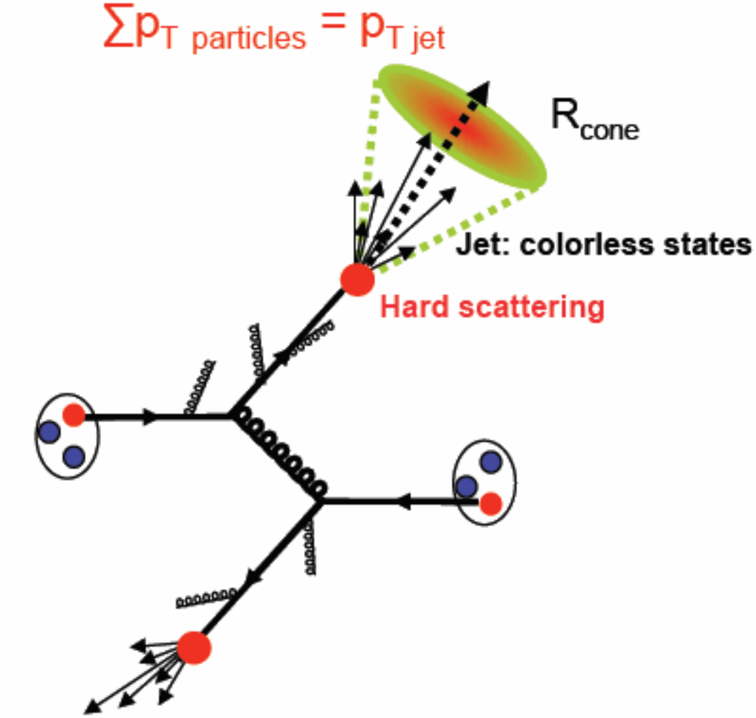
$$\bar{\hat{q}} = 5\frac{GeV^2}{fm} \Leftrightarrow \frac{dN^g}{dy} \approx 900$$

Need better tool

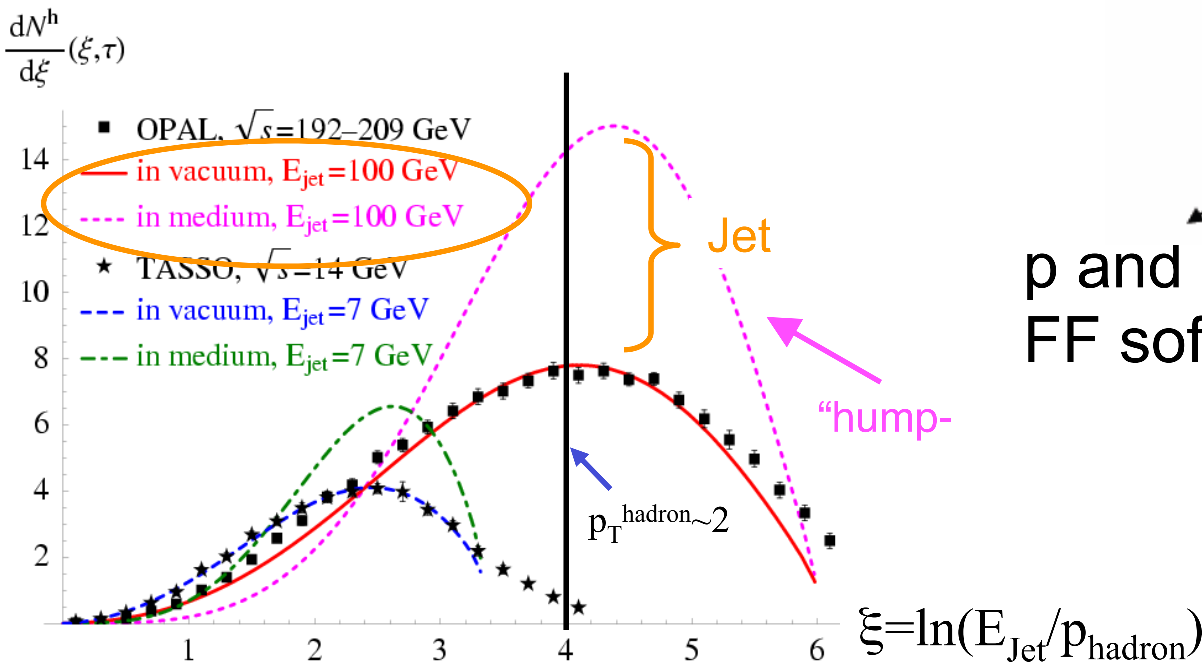
Motivation for full jet reconstruction

Jets allow reconstruction of "original" parton kinematics

Connection between theory and experiment via jet algorithms

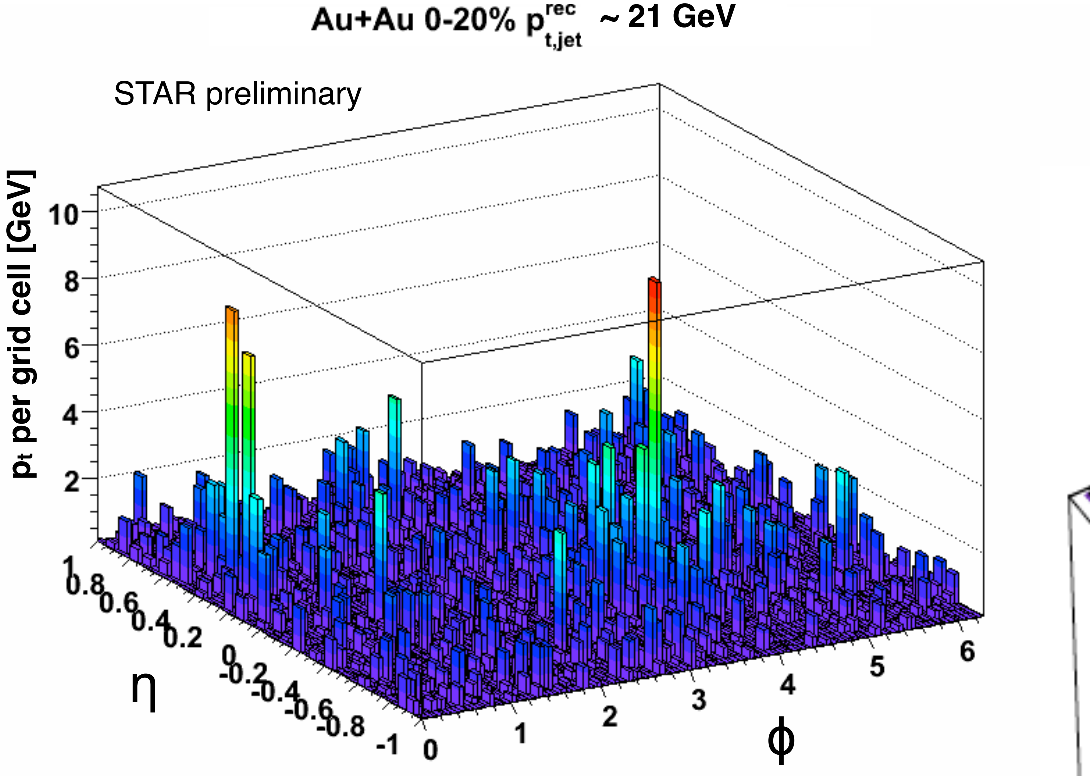


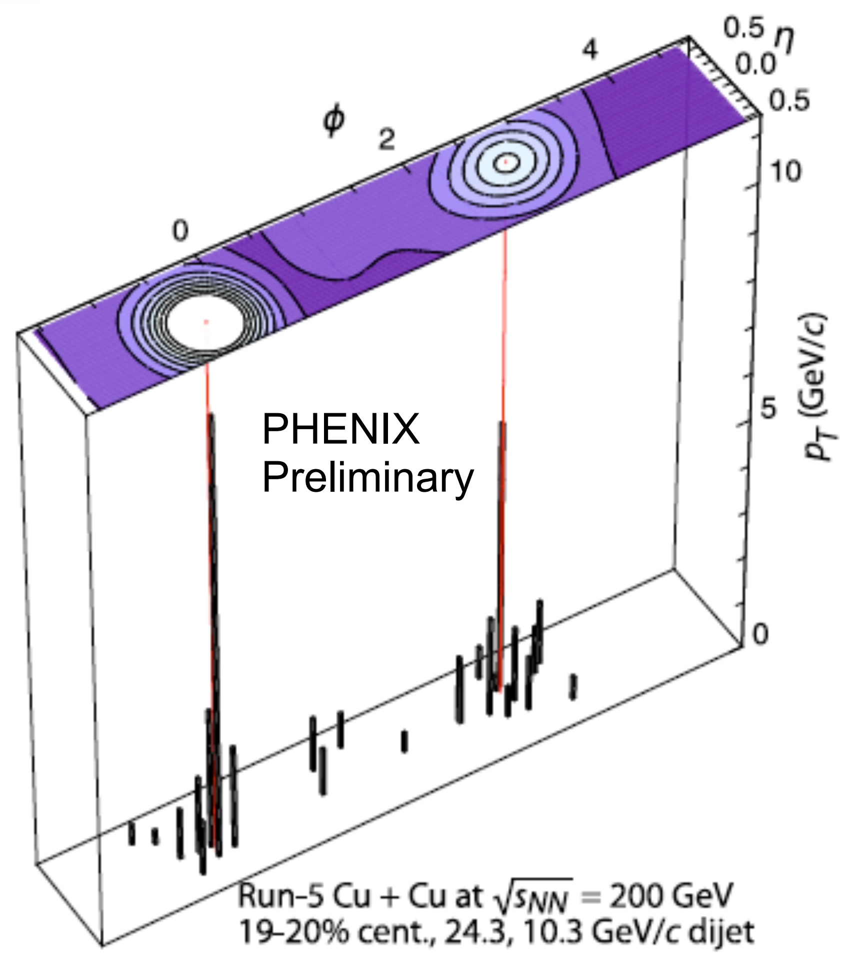
p and E must be preserved - FF softer in presence of QGP



Probe not only energy loss but energy redistribution

Jet studies in A-A collisions

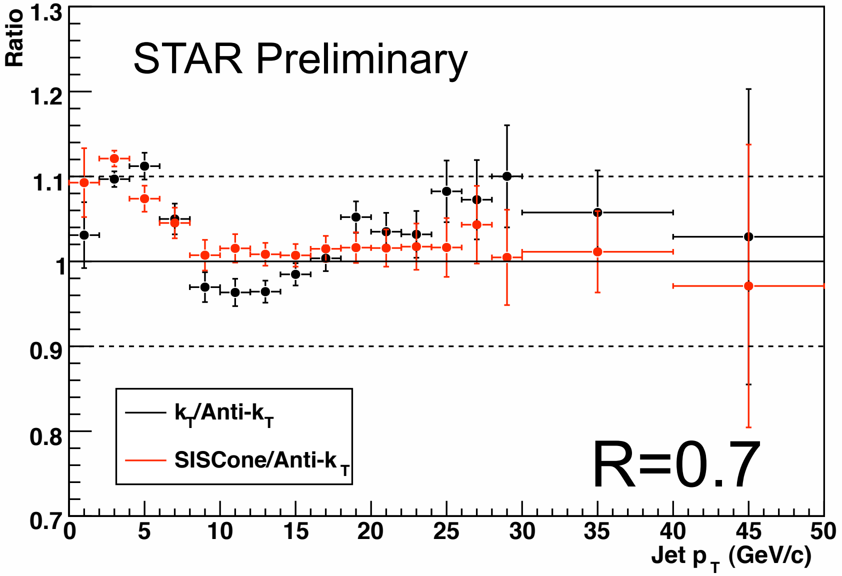




Jets can be seen by eye in A-A events

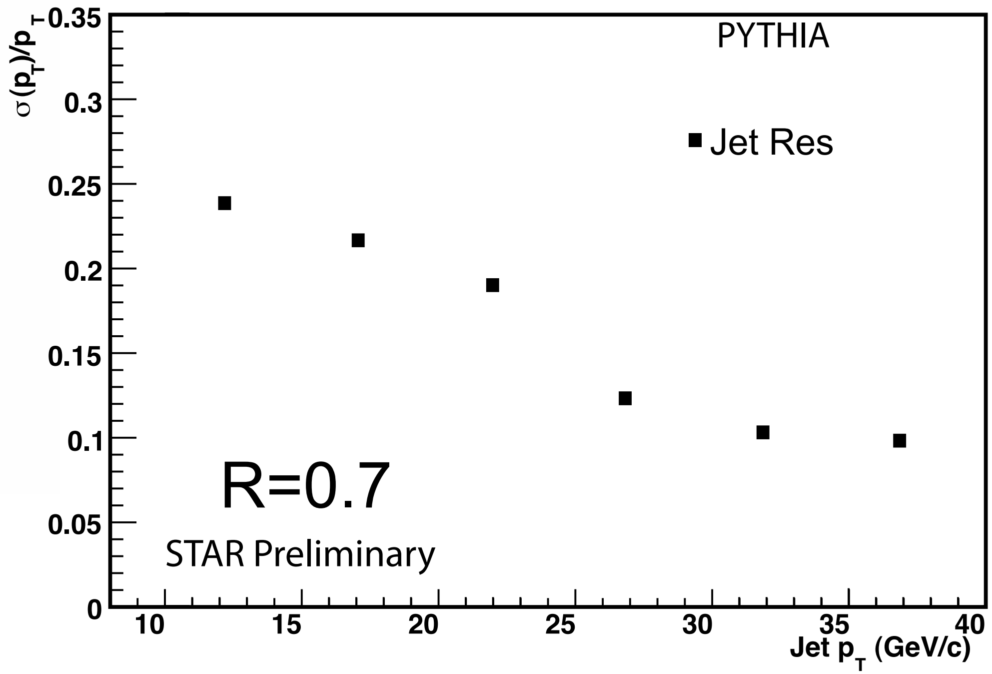
- if you can see them you can study them

p-p jet cross-section systematics



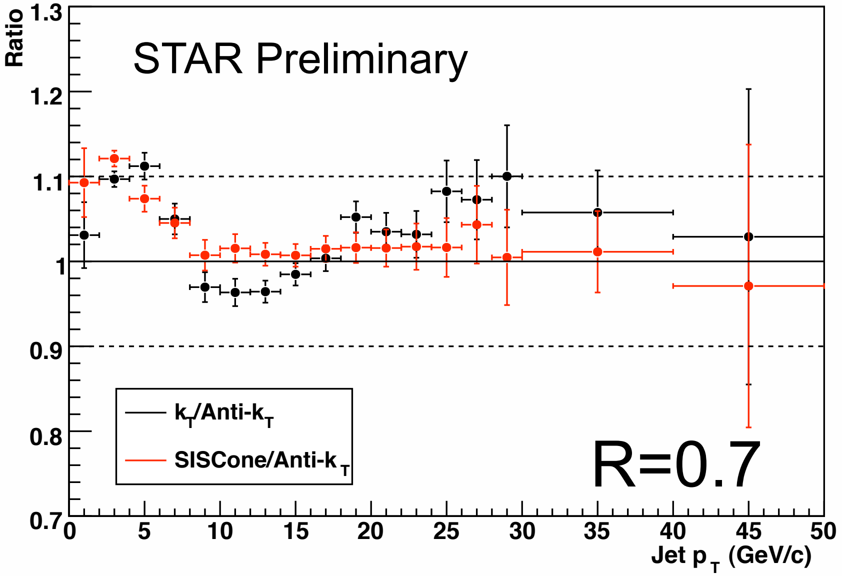
Energy resolution 10-25%

k_T, Anti-k_T, SISCone - similar behavior



Jet finders & detectors understood

p-p jet cross-section systematics



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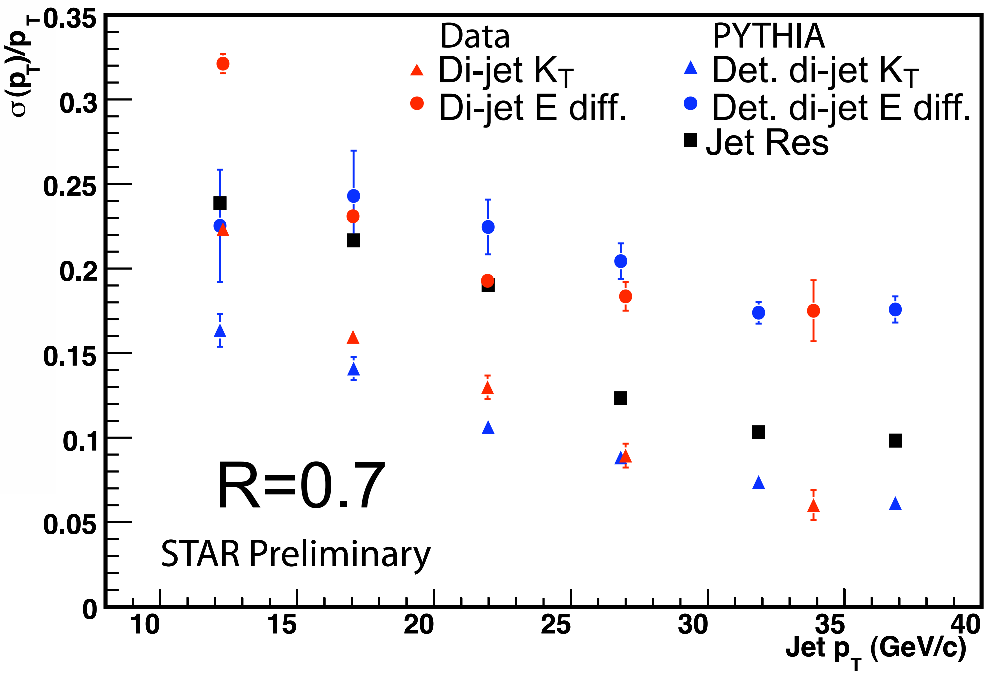

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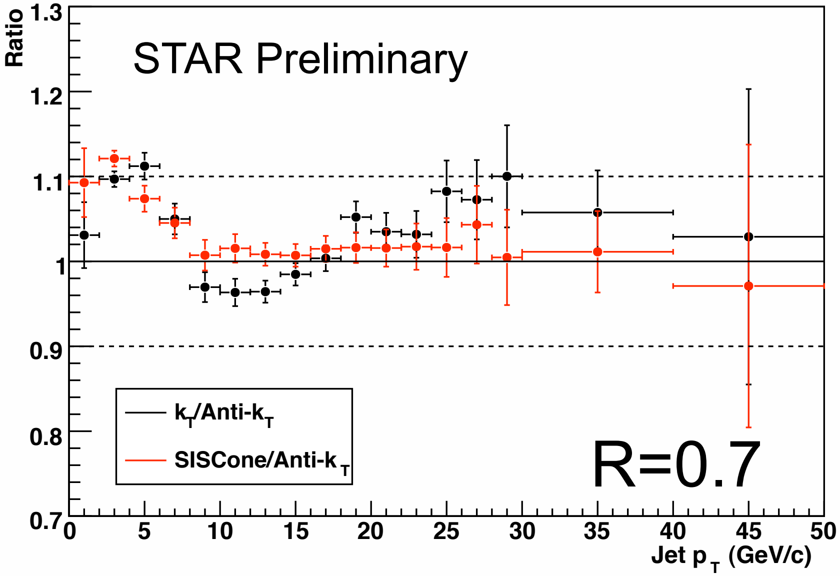

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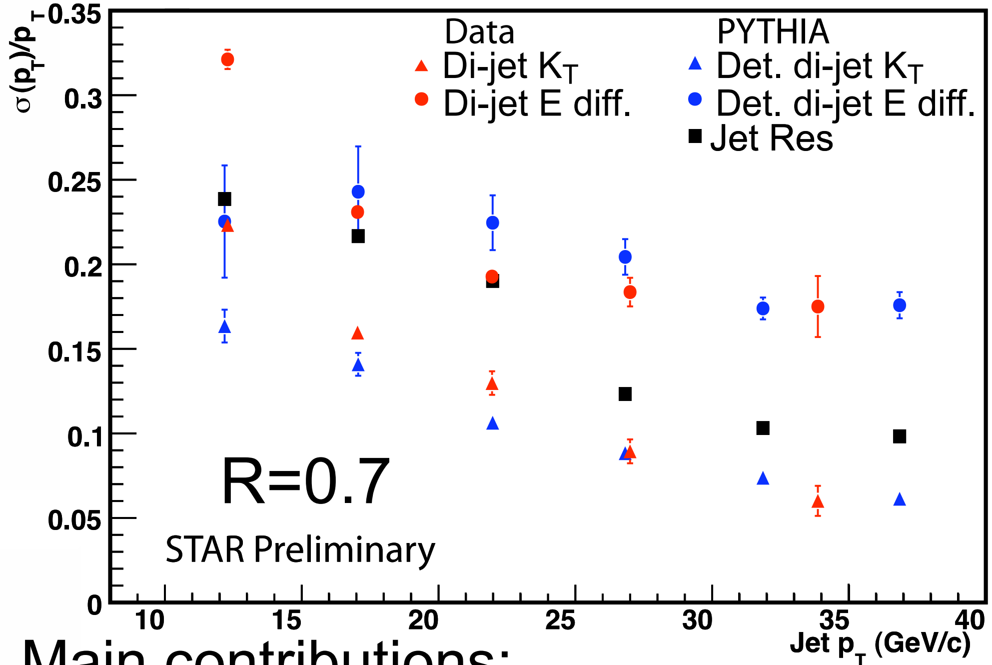

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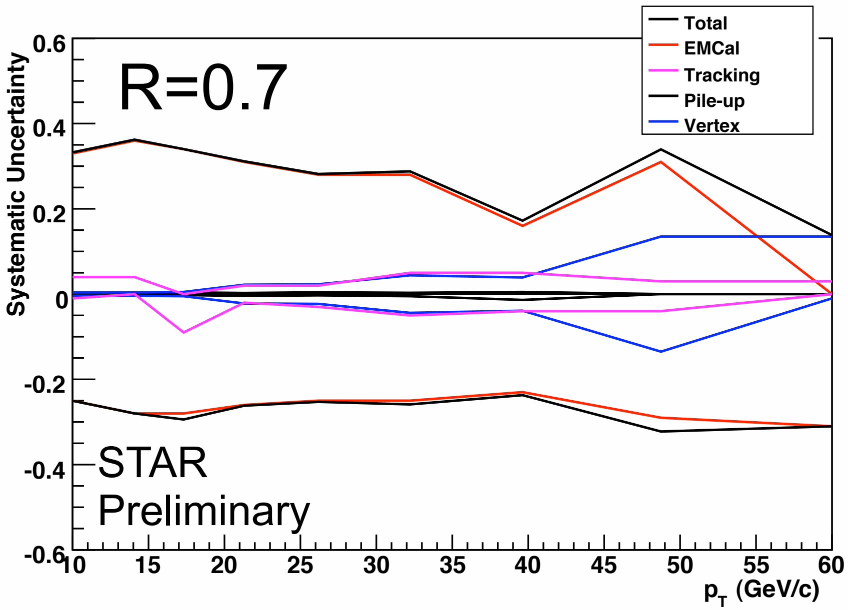


Main contributions:

EMCal calibration,Tracking effic.

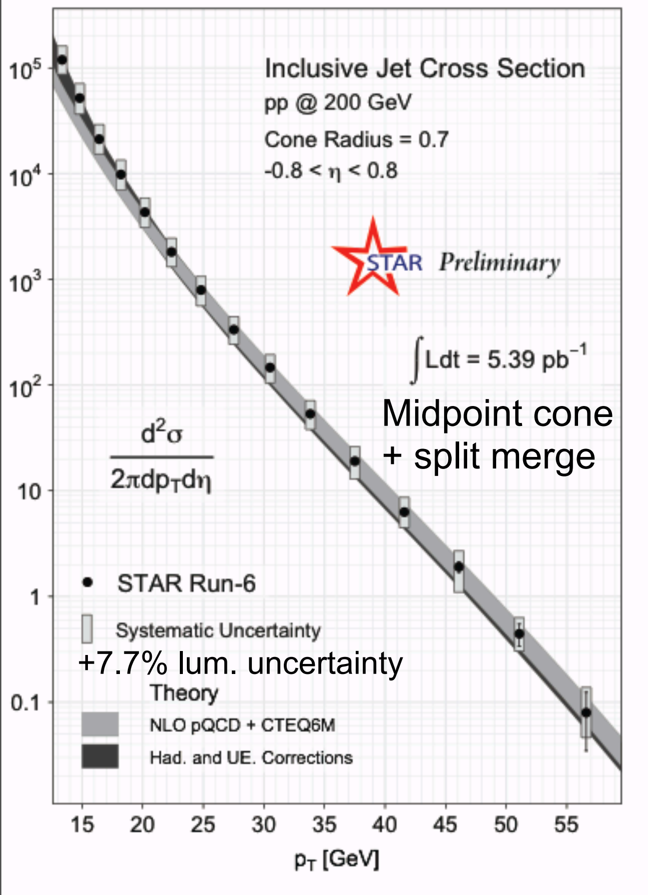
Pile-up, Vertex location selection

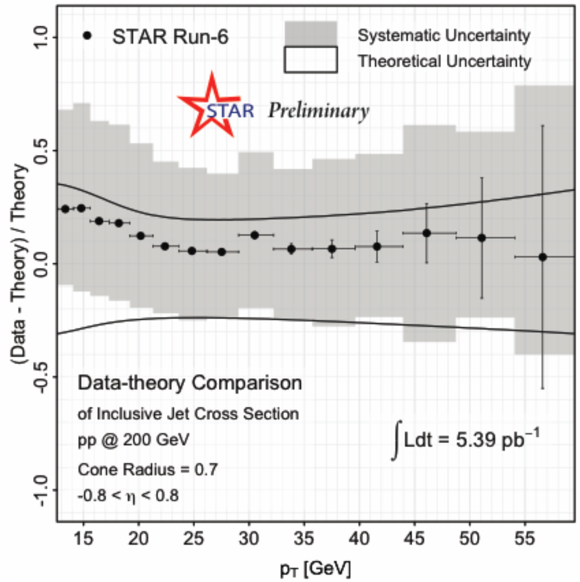
Luminosity: 7% (applied separately)

UE & hadronization (applied to theory)

Jet finders & detectors understood

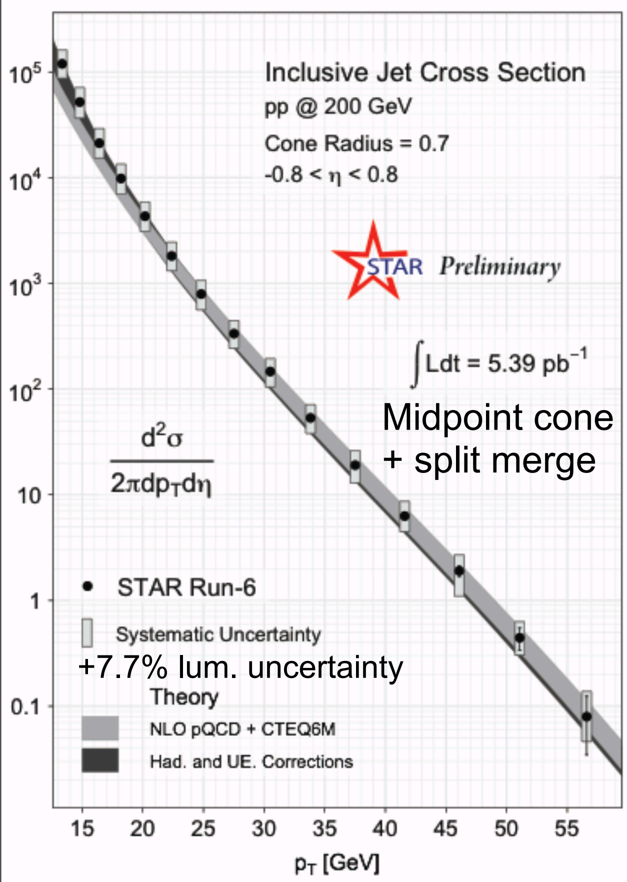
Initial conditions - p-p

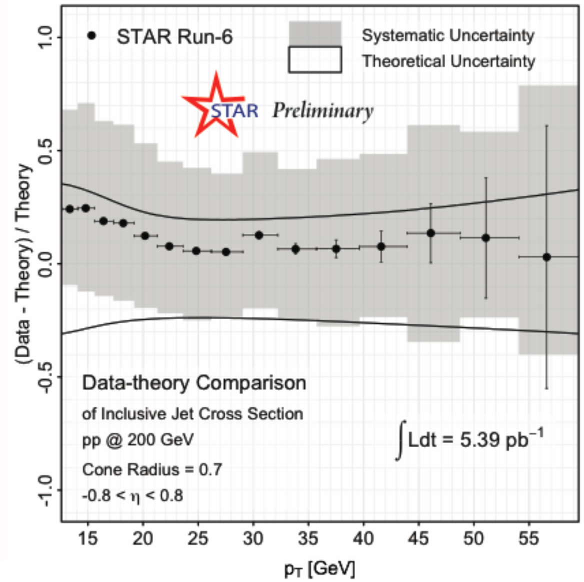


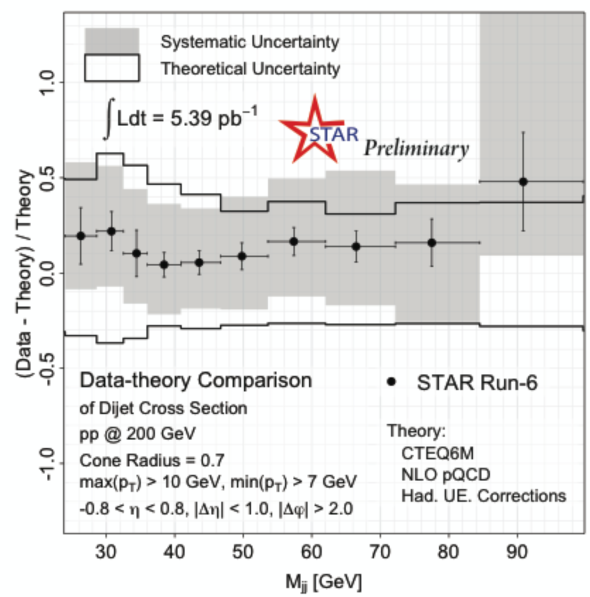


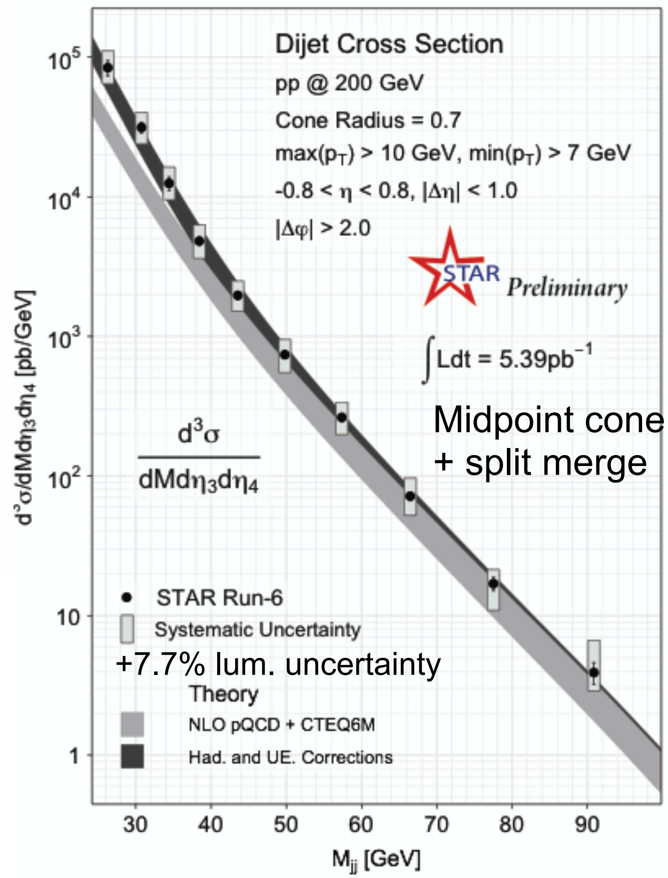
Hadronization and UE correction applied to theory

Initial conditions - p-p





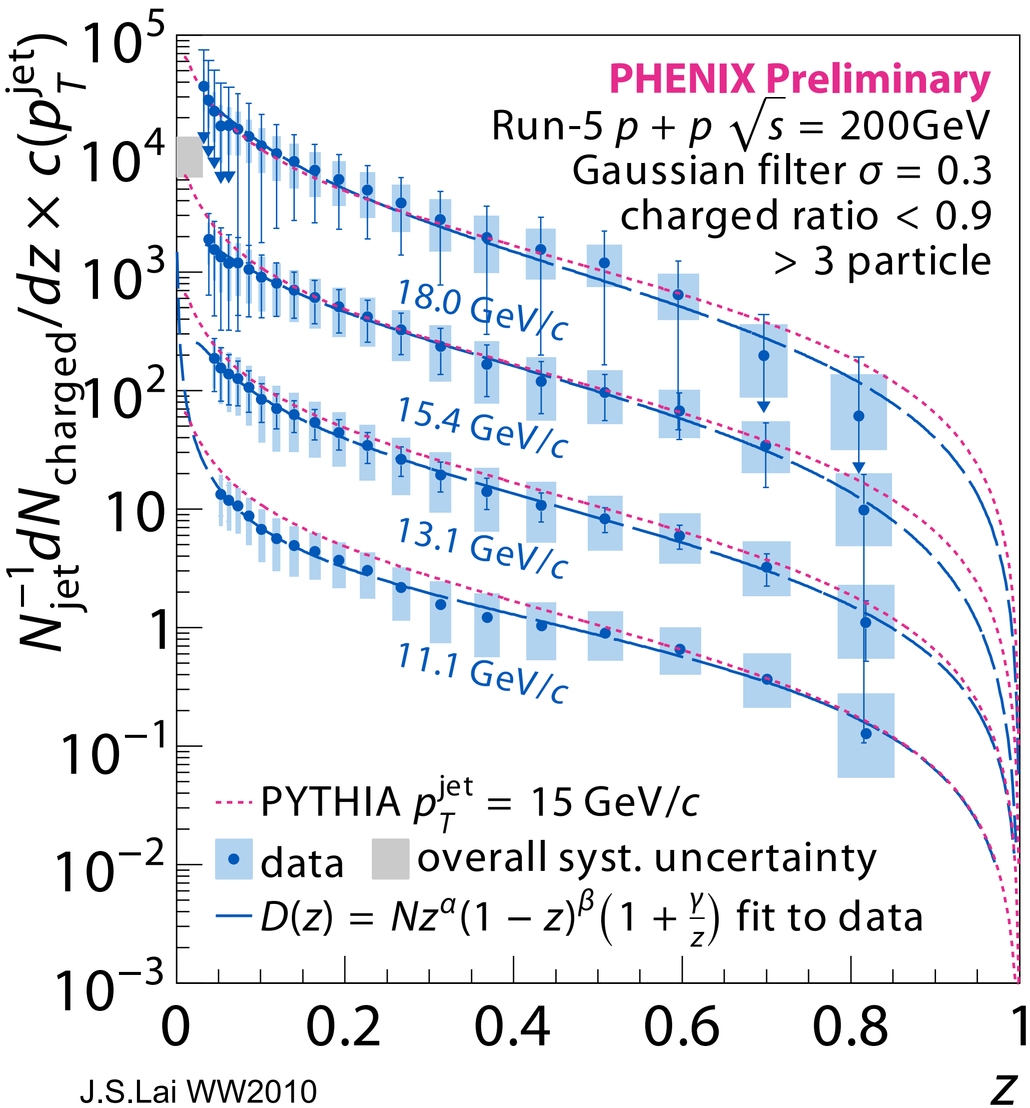




Hadronization and UE correction applied to theory

Jet and di-jet cross-section well described by NLO

Fragmentation functions for charged



Z_{max} ~ 0.81

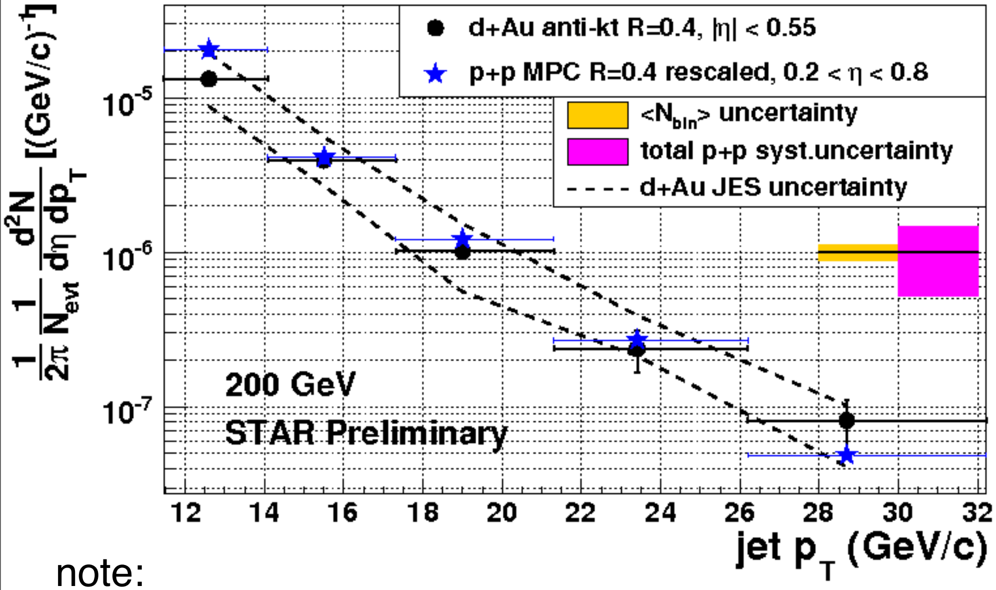
Electrons are rejected

FF scaled by successive factors of 10

Similar good agreement has been shown by STAR using R=0.4 and 0.7

Fragmentation into charged hadrons reasonably well described in PYTHIA

Binary scaling of hard processes in d-Au



Jet spectra slightly modified in central d-Au collisions

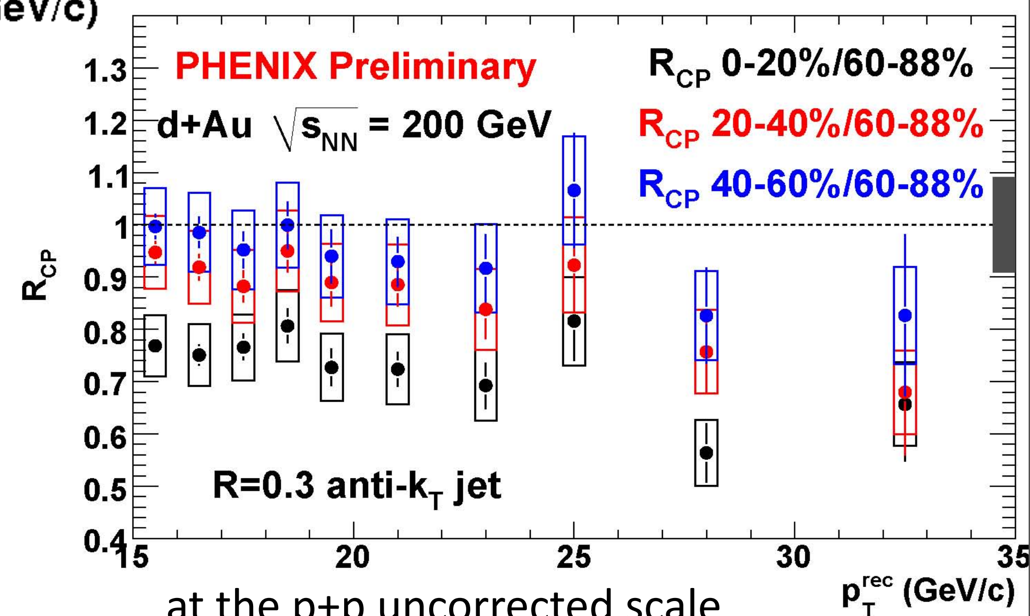
note:

different jet finding algorithms used

different η range used

Mid-rapidity results

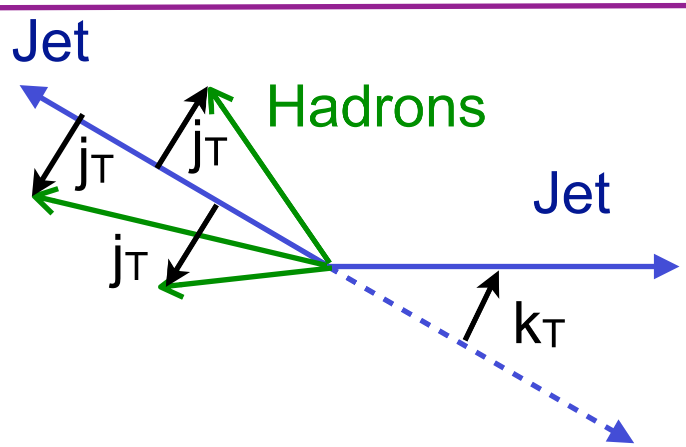
- consistent with π^0 R_{cp}
- anti-shadowing?

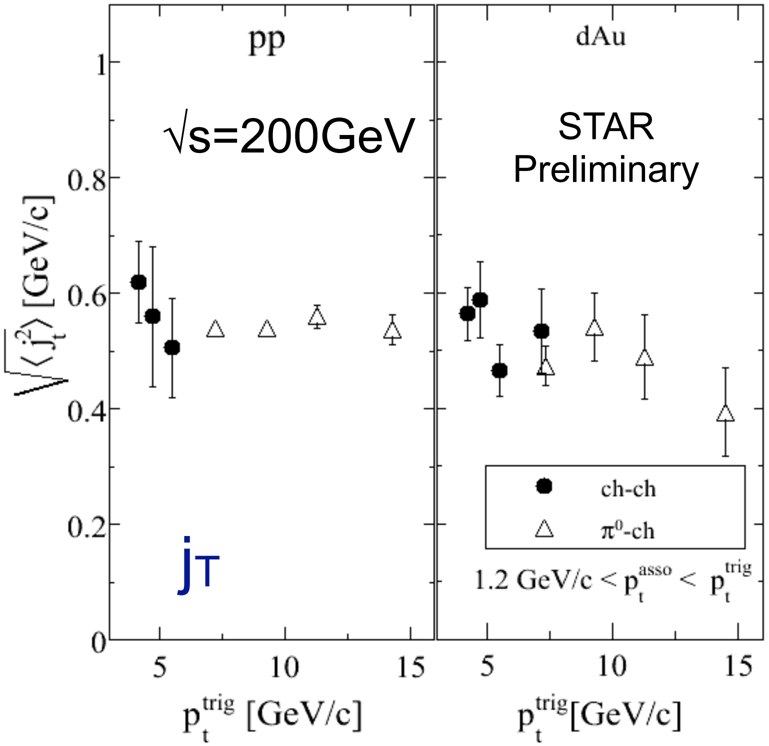


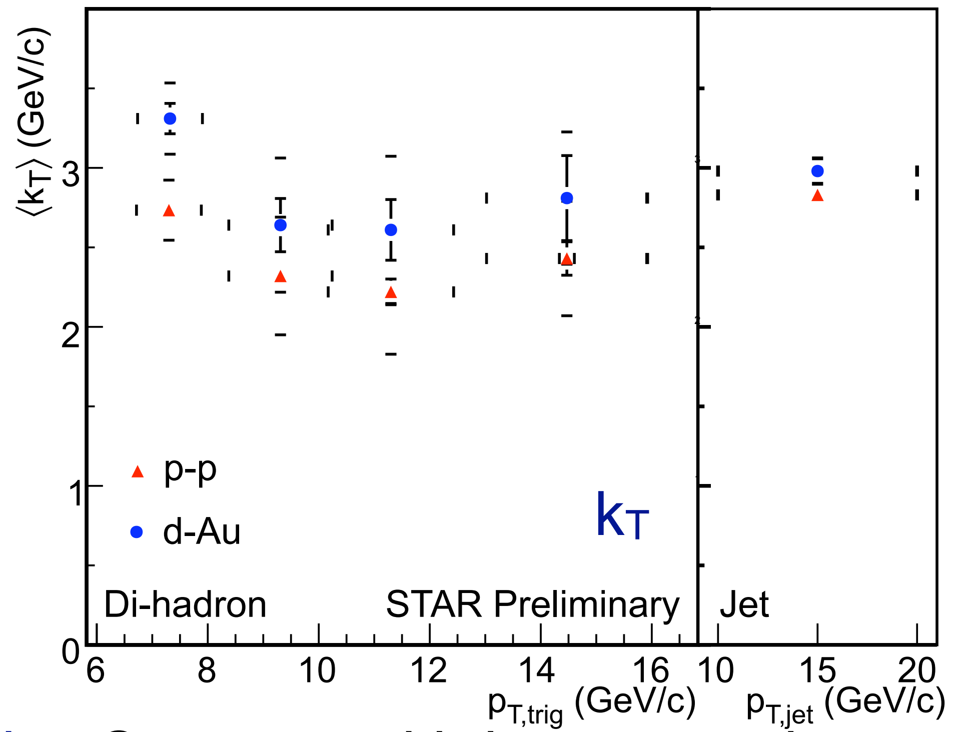
at the p+p uncorrected scale

J.Kapitan,S.Bathe,QM2011

Cold nuclear matter effects







j_T - Constant with beam species and trigger p_T

k_T - Depends on collision energy
d-Au consistently higher than p-p

CNM: small effect on partonic p_T
negligible effect on fragmentation

M.Mondal,QM2011

Underlying event in p-p and d-Au

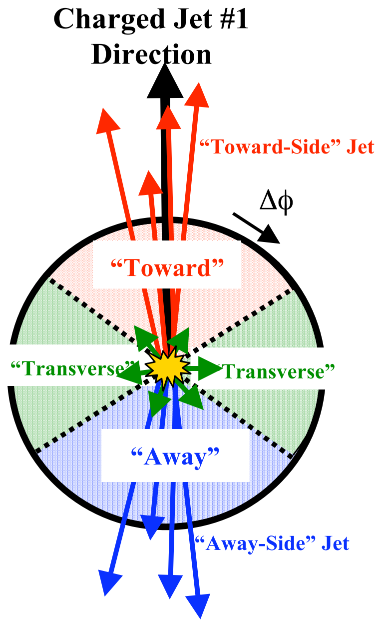
Jets:

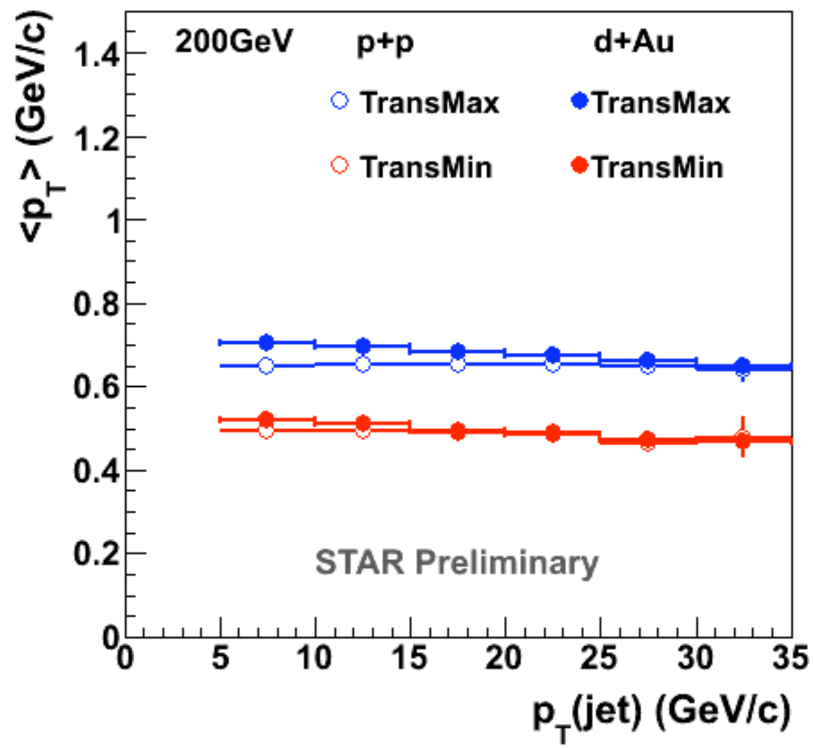
p-p = d-Au

Underlying event:

$\langle p_{T\,d\text{-}Au} \rangle \sim \langle p_{T\,p\text{-}p} \rangle$

~ 0.6 GeV/c





J.Bielcikova,QM2011

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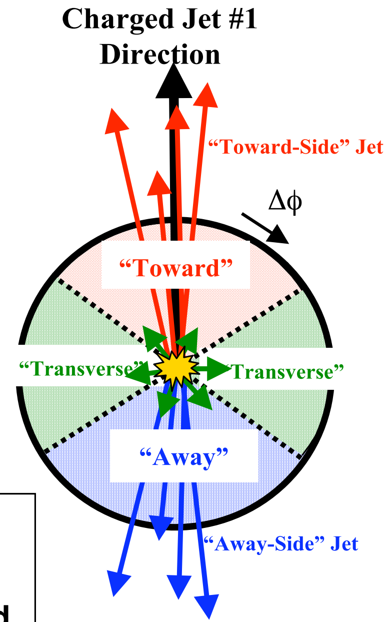
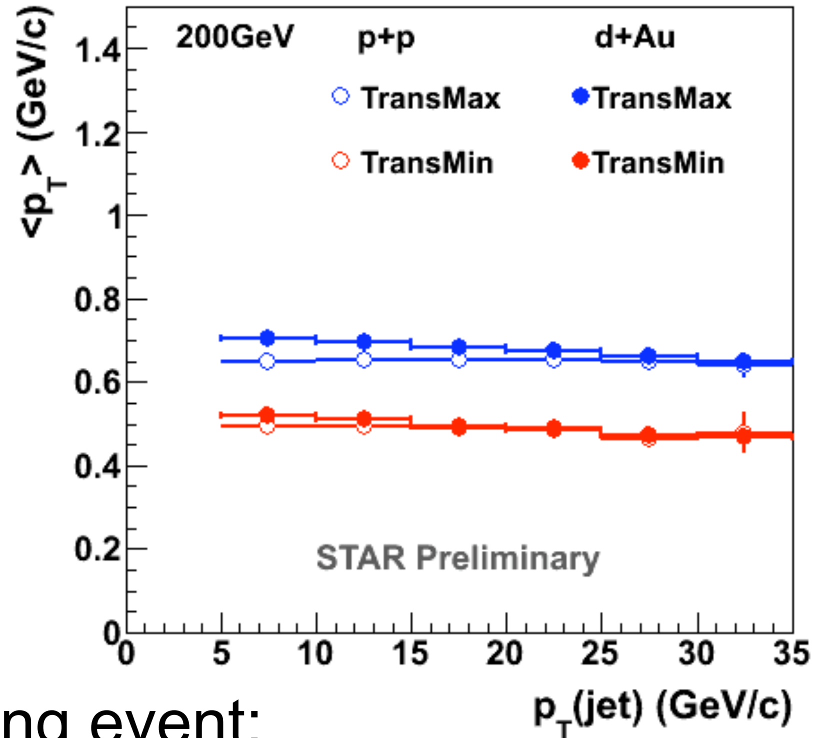
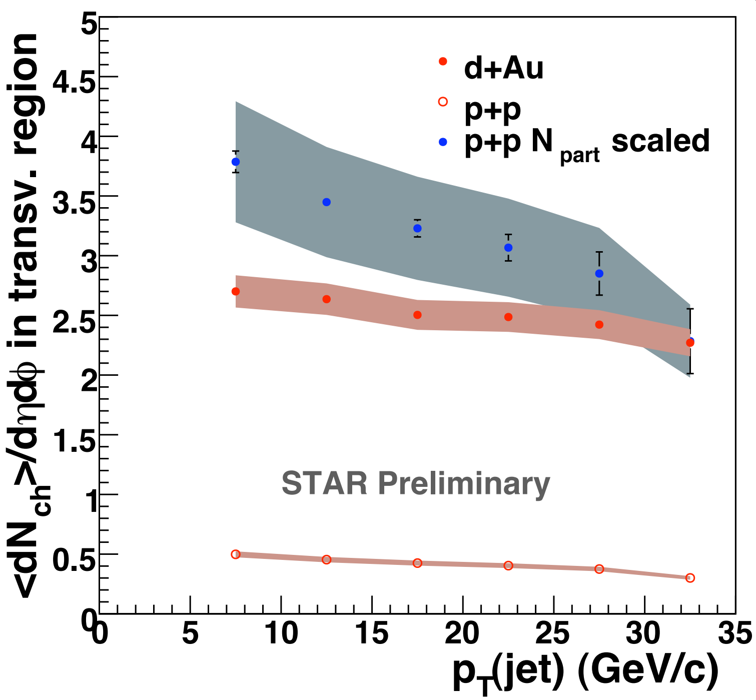






Underlying event:

$dN_{ch}/d\eta d\phi$

d-Au ~ 2.5 ~ 5 x p-p

$\sim N_{part}$ x p-p

UE multiplicity scales much slower than N_{bin}

J.Bielcikova,QM2011

Au-Au: underlying event fluctuations

Schematically Au-Au jet spectrum: $$\frac{d\sigma_{AA}}{dp_T} = \frac{d\sigma_{pp}}{dp_T} \otimes F(A, p_T)$$

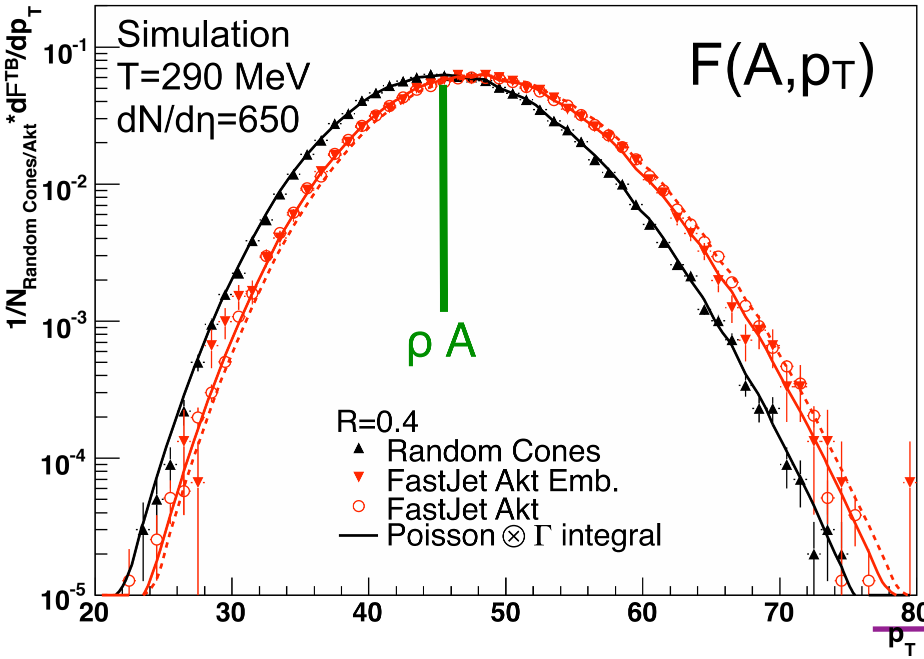
$F(A,p_T)$ - initial assumption: Gaussian distribution (a la FastJet)

If background independently distributed particles: M.Tannenbaum PLB 498 2001

number fluct ~ Poisson

$\langle p_T \rangle$ fluct (fixed M) ~ Gamma

$$F(A, p_T) = Poisson(M(A)) \otimes \Gamma(M(A), \langle p_T \rangle)$$



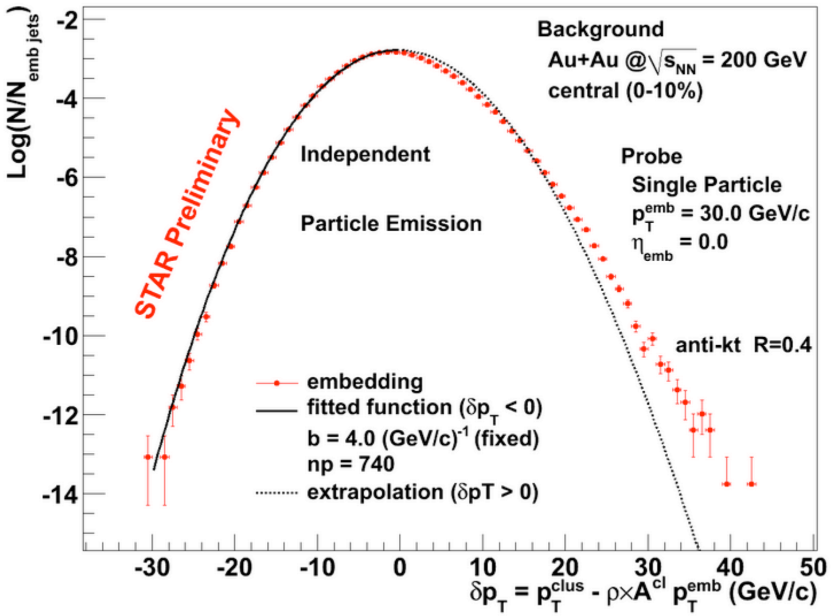
ρ A = Mean energy x Jet Area

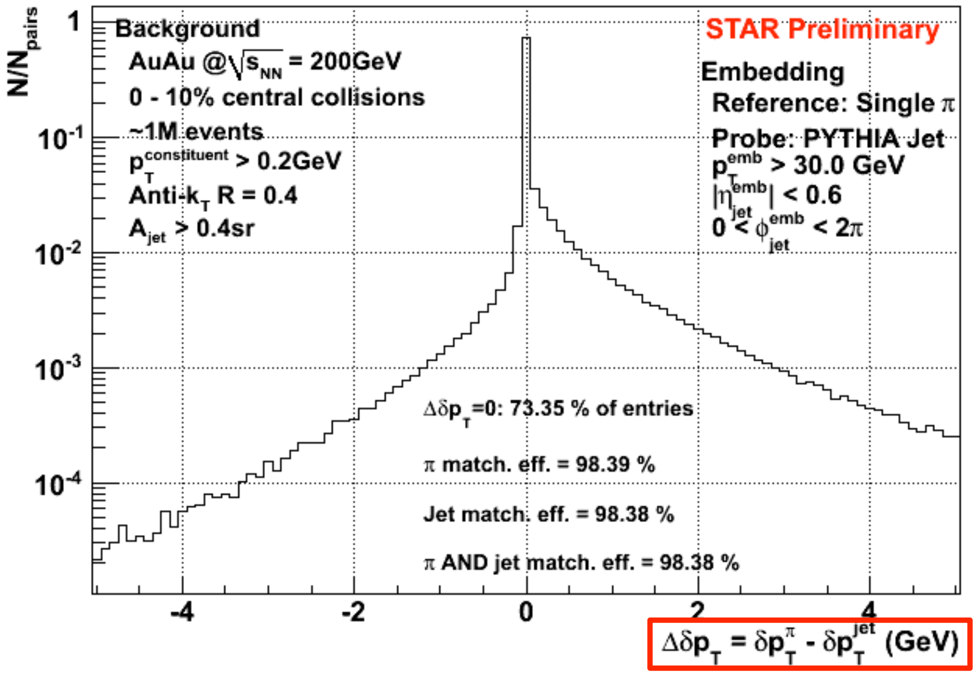
$F(A,p_T)$ closer to measurement but not exactly same - clustering occurs in non-random fashion!

Background fluctuations from data

Generalized probe embedding (GPE):

$$\delta p_T(A) = p_T^{clus} - \rho \cdot A - p_T^{emb} \rightarrow F_{Fluc}(A, p_T^{meas})$$





δp_T distribution approximately independent of fragmentation model

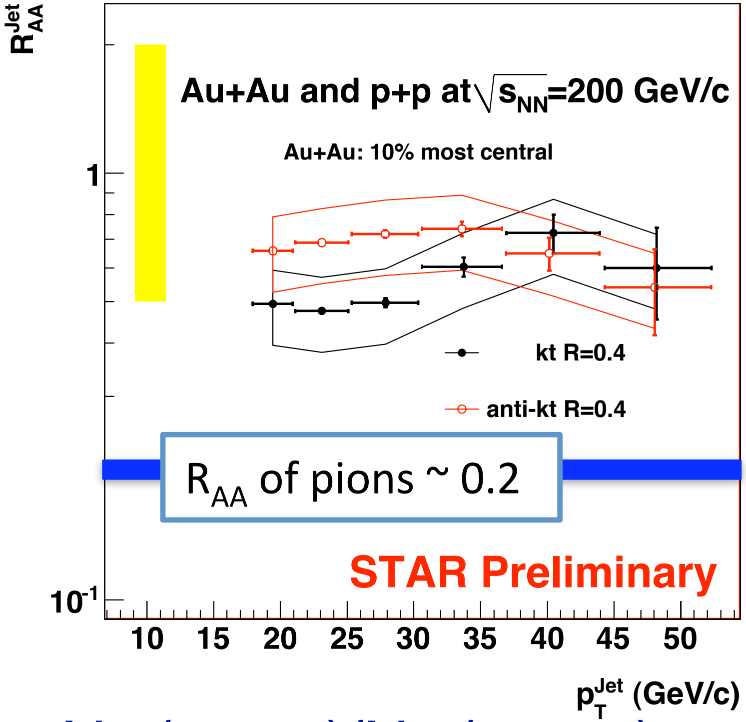
Fluctuations mapped over several orders of magnitude

→ reduction of systematic uncertainties!

Can perform BG subtraction before FF details known

G.deBarros,PANIC11

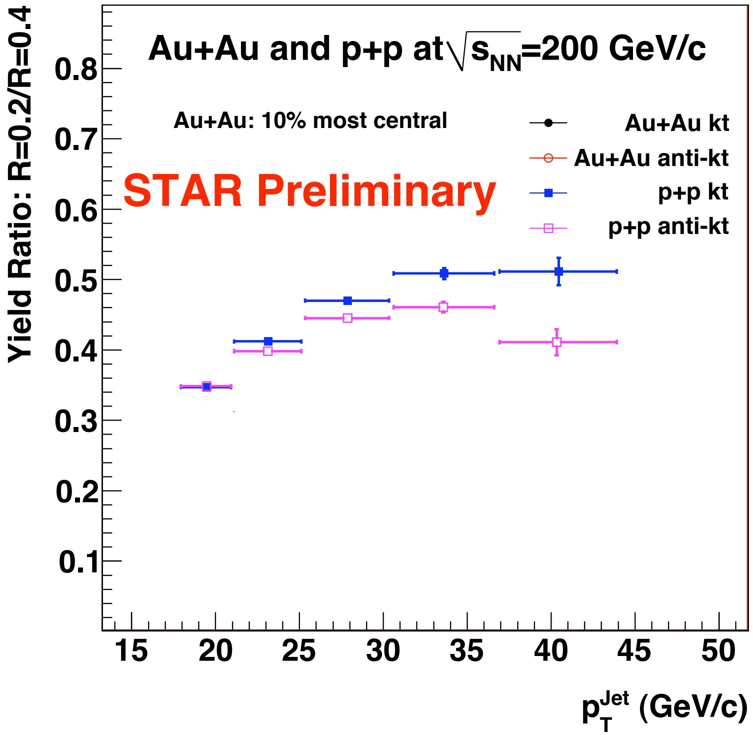
Evidence of jet broadening



k_T and Anti-k_T known to have different sensitivities to background

Jet $R_{AA} < 1$(R=0.4)

Algorithms fail to recover all jet

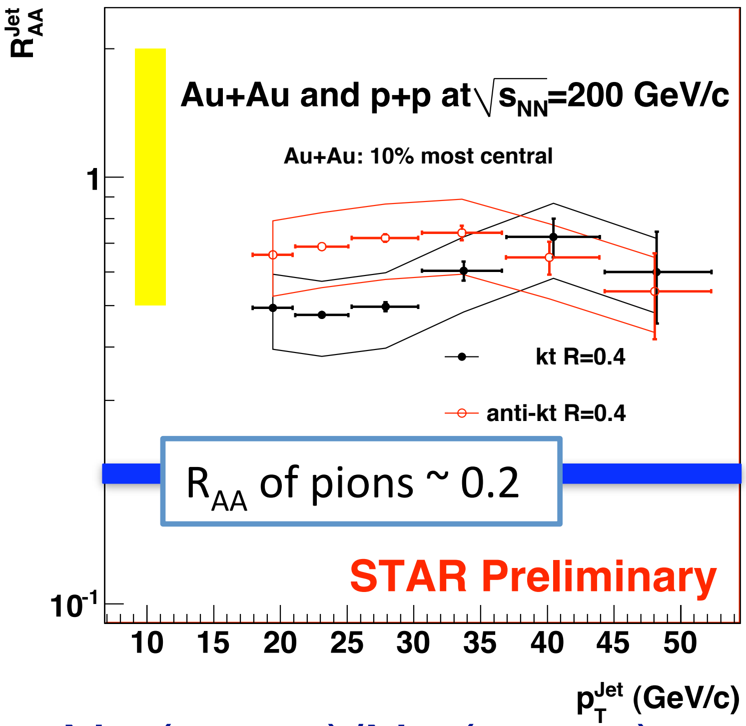


N_{jet}(R=0.2)/N_{jet}(R=0.4) vs $p_{T,jet}$

p-p:

"Focussing" of jet with jet energy

Evidence of jet broadening



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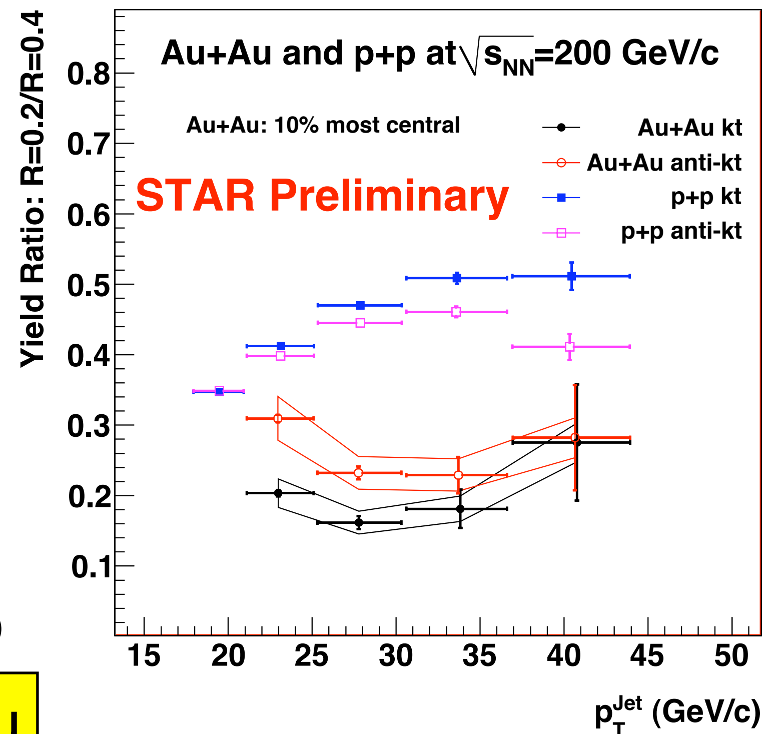


p-p:

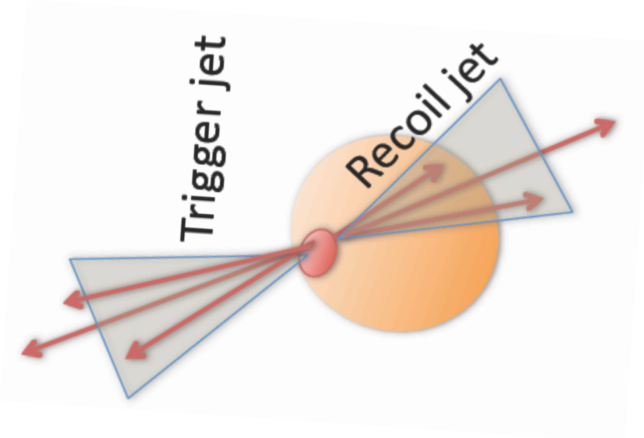
"Focussing" of jet with jet energy

Au-Au:

"Broadening" of jet compared to p-p

Jet fragmentation broader in Au-Au

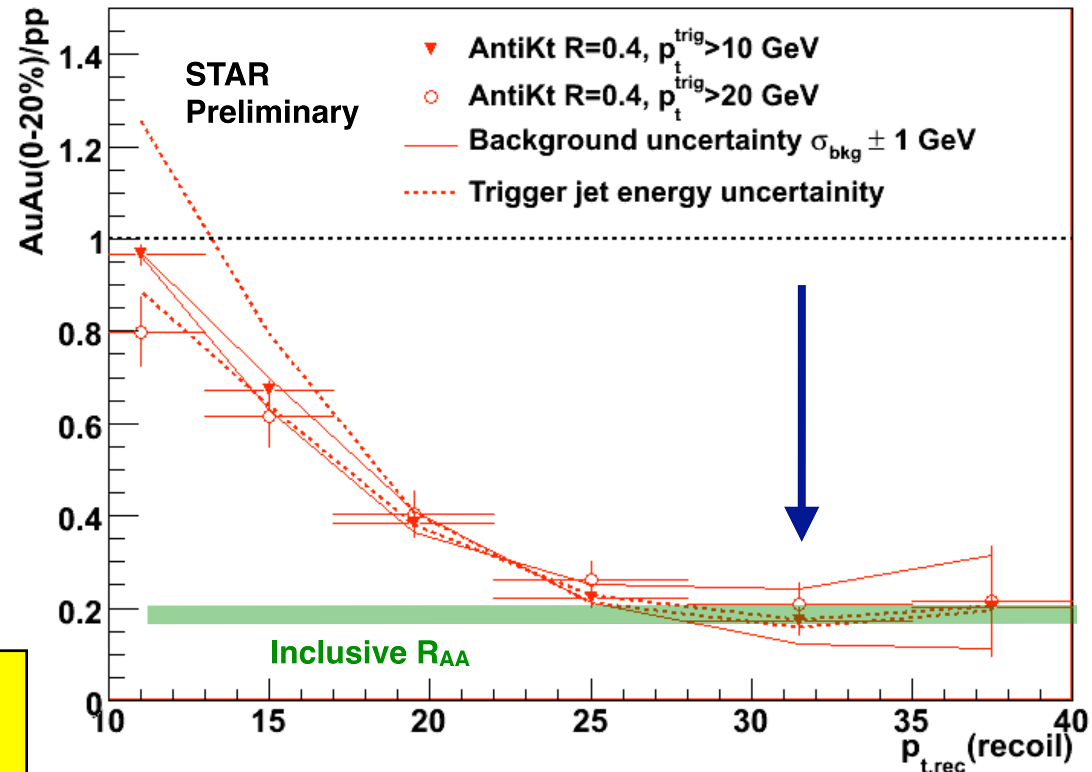
Di-jet coincidence rate



High tower trigger - single particle with high p_T

bias maximizes distance through medium recoil jet traverses

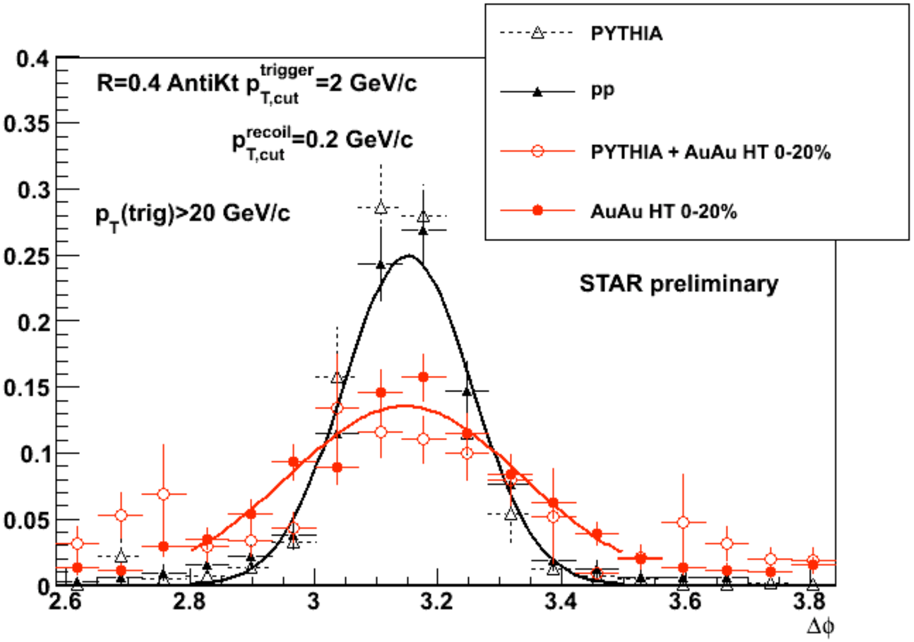
Compare yield of di-jets in p-p to Au-Au



- Significant suppression of recoil jets - close to single particle R_{AA}
- Further evidence of broadening

Larger path length results in larger suppression/broadening

Large angle di-jet scattering

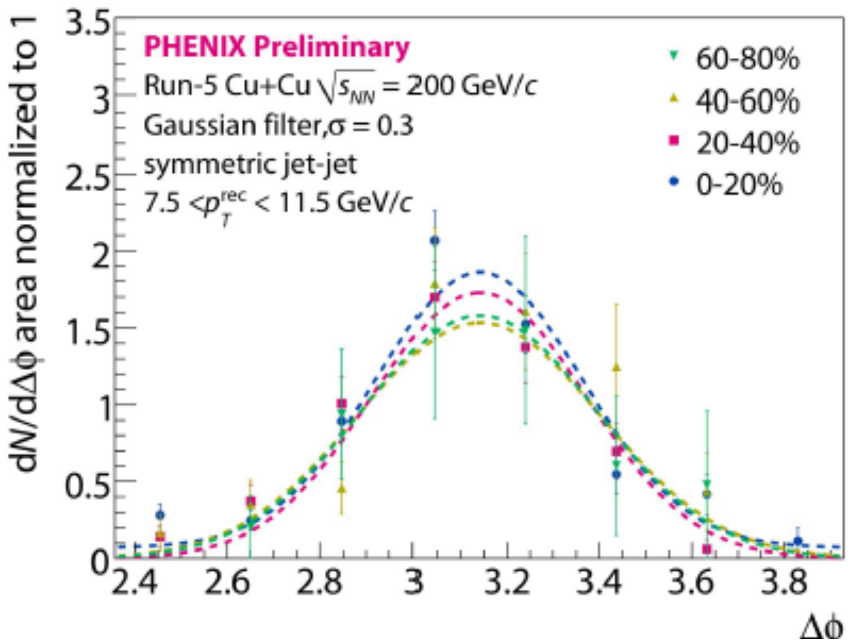


$p_{Trec,jet}$ > 20 GeV/c, $p_{Trec,dijet}$ > 10 GeV
Di-jet: highest p_T with $|\varphi_{jet}-\varphi_{dijet}|$ > 2.6

Δφ of identified di-jets

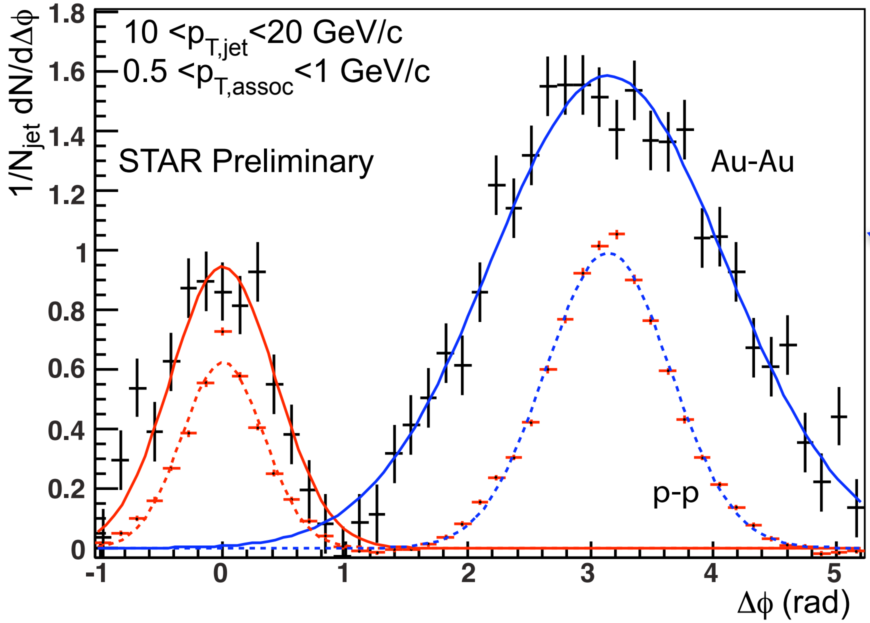
$\sigma_{Au\text{-}Au}$ ~ 0.2
$\sigma_{PYTHIA,Embed}$ ~ 0.14
$\sigma_{p\text{-}p} \sim \sigma_{PYTHIA}$ ~ 0.1

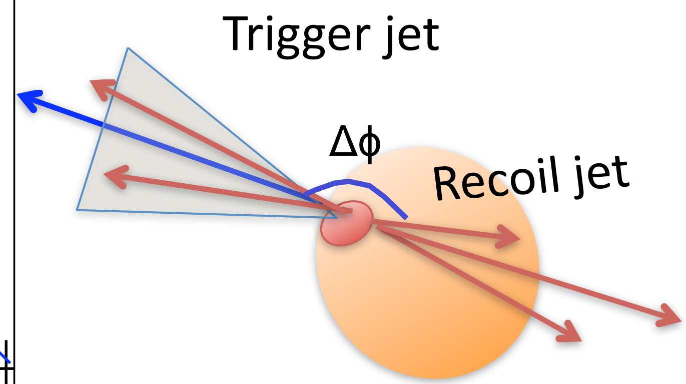
Little to no deflection of away-side jet observed in Cu-Cu and Au-Au collisions



Loss of di-jets not predominantly due to deflection to large angles

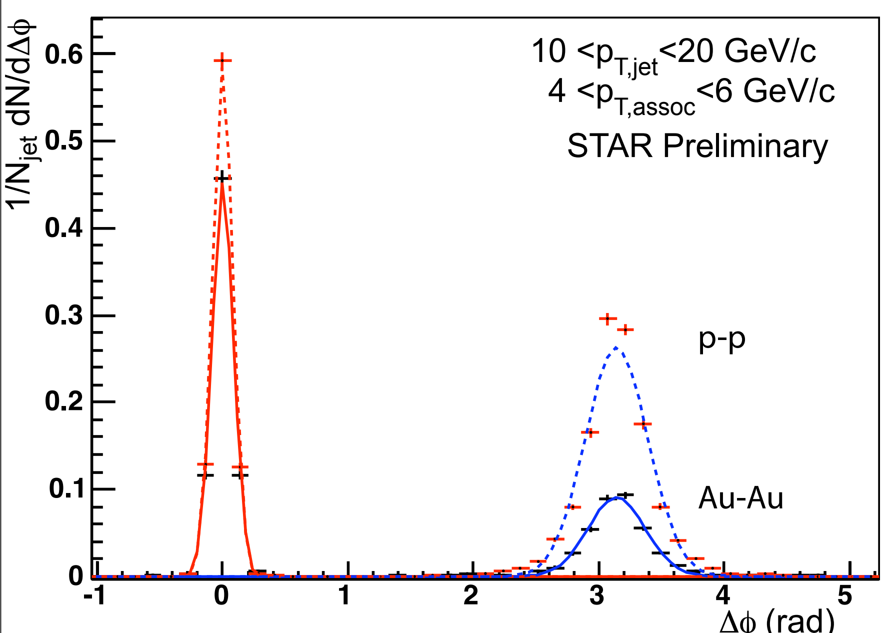
Jet-hadron correlations





Au+Au 0-20%
High Tower Trigger
1 tower
0.05x0.05 (ηxϕ)
with E_t> 5.4 GeV

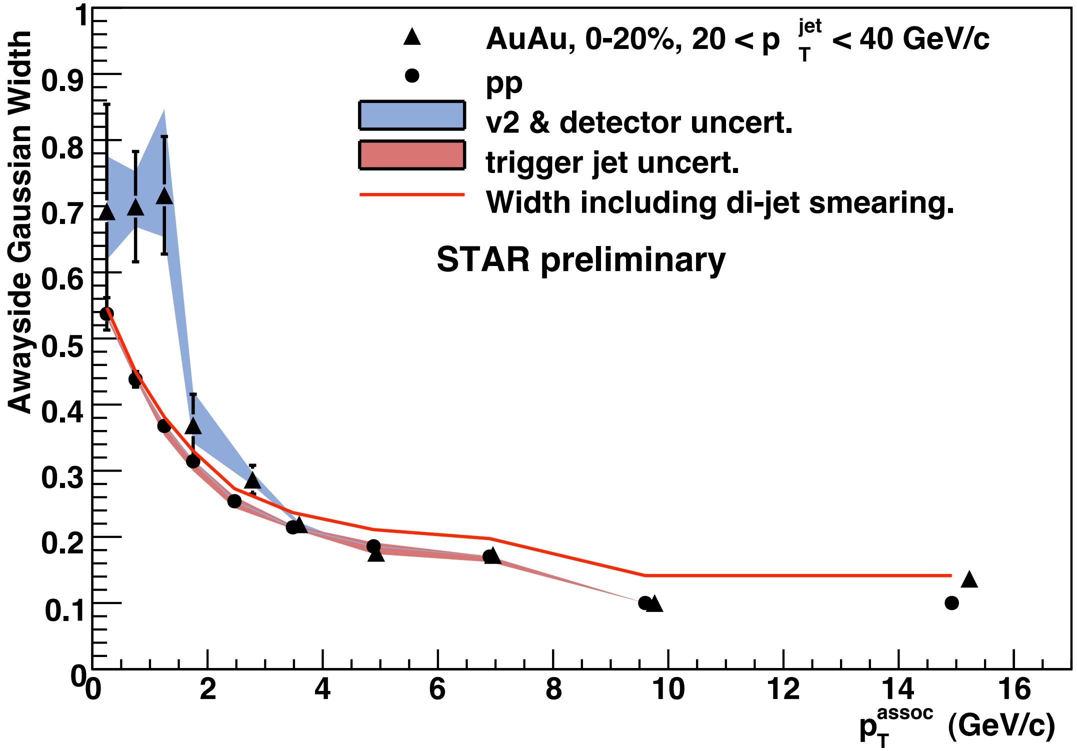
Jet trigger:
Anti-k_T,
R=0.4,
$pt_{,rec}$(jet) using
$p_{t,}$(particle)>2 GeV



Away-side: Broadening
Softening

Direct measurement of modified fragmentation due to presence of sQGP

Broadening not deflection



Majority of broadening due to fragmentation not deflection

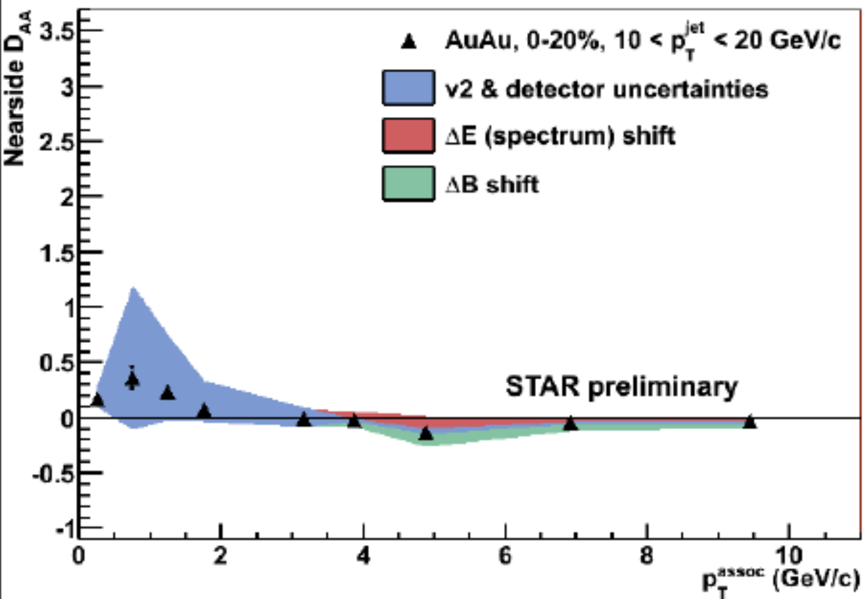
Low p_T assoc

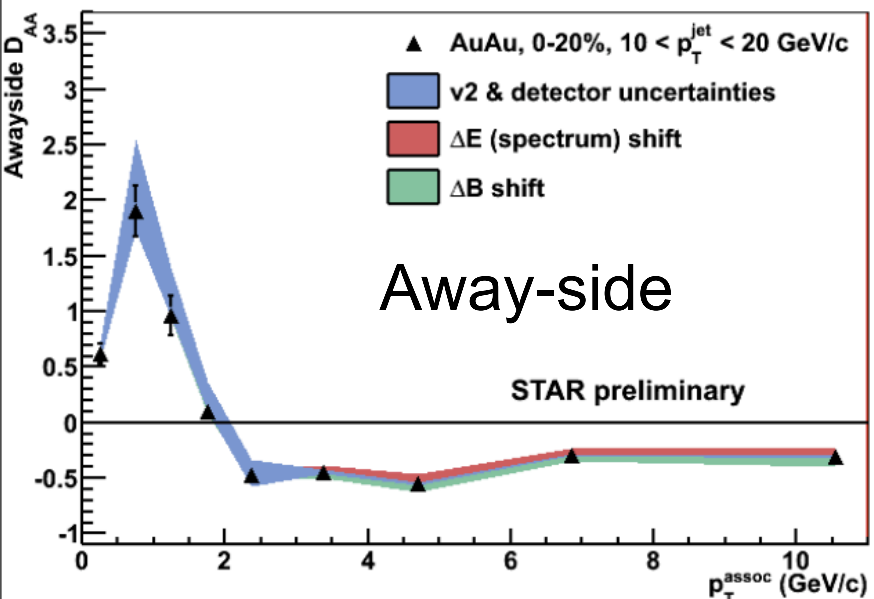
Au-Au away-side Gaussian width broader than p-p

High p_T assoc

Au-Au away-side Gaussian width same as in p-p

Jet-hadron: Energy balance





D_{AA} = Au-Au - p-p Energy difference

$$D_{AA}(p_T^{assoc}) = Y_{AA}(p_T^{assoc}) \cdot p_{T,AA}^{assoc} - Y_{pp}(p_T^{assoc}) \cdot p_{T,pp}^{assoc}$$

$$\Delta B = \int dp_T^{assoc} D_{AA}(p_T^{assoc})$$

Near-side:

$$\Delta B = 0.6 \,^{+1.9\,+\,0.5}_{-1.0\,-\,0.4}\,(\text{sys})\ \text{GeV/c}$$

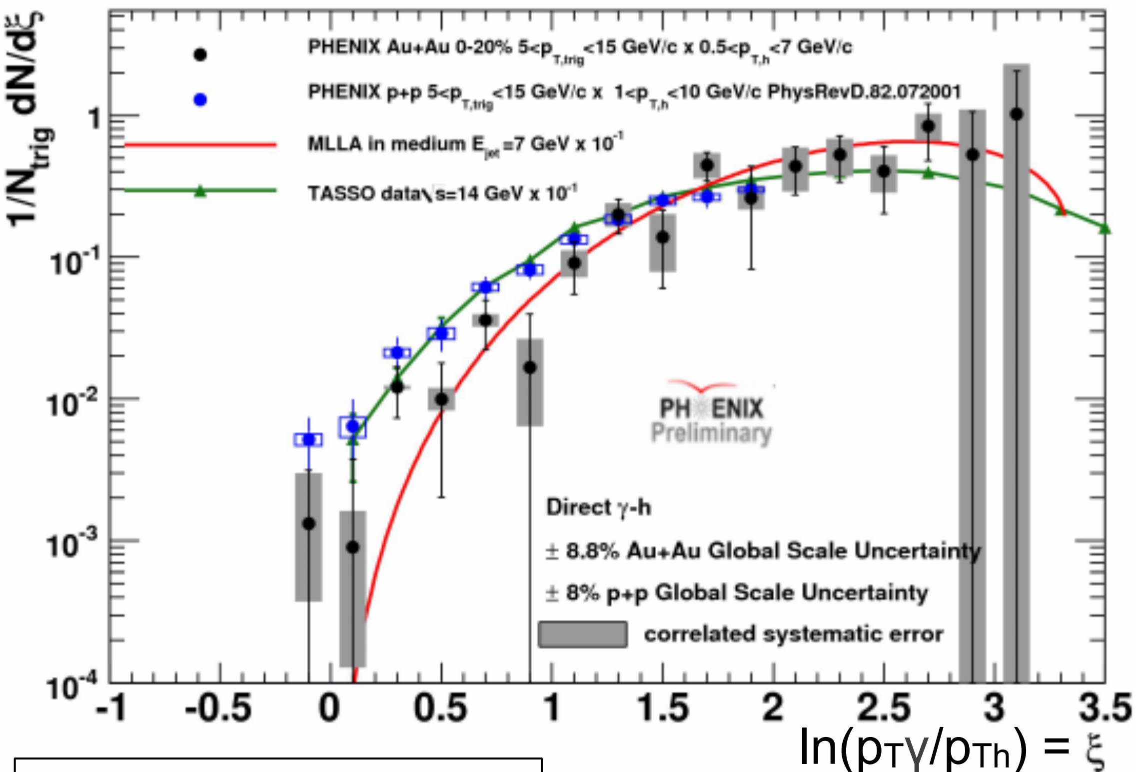
Away-side:

$$\Delta B = 1.5 \,^{+1.7\,+\,0.5}_{-0.4\,-\,0.4}\,(\text{sys})\ \text{GeV/c}$$

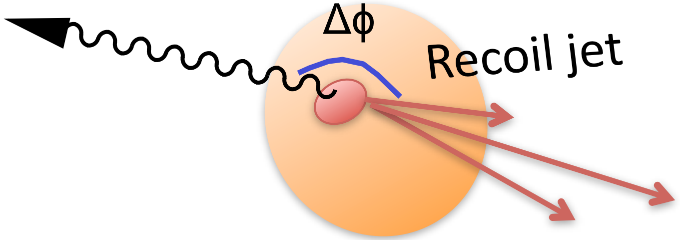
Energy lost at high p_T approximately recovered at low p_T and high R

A.Ohlson,QM2011

γ-h: Fragmentation functions



Tasso:
Braunschweig et al. , Z. Phys. 320 C47, 187
MLA:
Borghini, Wiedemann, hep-ph/0506218



Photon gives jet energy

Measure fragmentation of away-side jet

No surface bias for trigger

p-p: Consistent with e^+e^-

Au-Au: Consistent with energy loss

Fragmentation of away-side jet highly modified

N.Grau,QM2011

Summary of RHIC jet data at $\sqrt{s}$=200 GeV

Full jet reconstruction:

- p-p jet and di-jet cross-sections are well described by NLO
- d-Au jets slightly suppressed compared to binary scaled p-p data
- d-Au UE mult. shows approximate N_{part} scaling with similar $\langle p_T \rangle$
- k_T measures suggest CNM effects are small for jets
- Understanding of Au-Au background much clearer
- First clear indications of broadening of jet fragmentation in A-A
- Di-jet correlations in A-A show no significant extra deflection

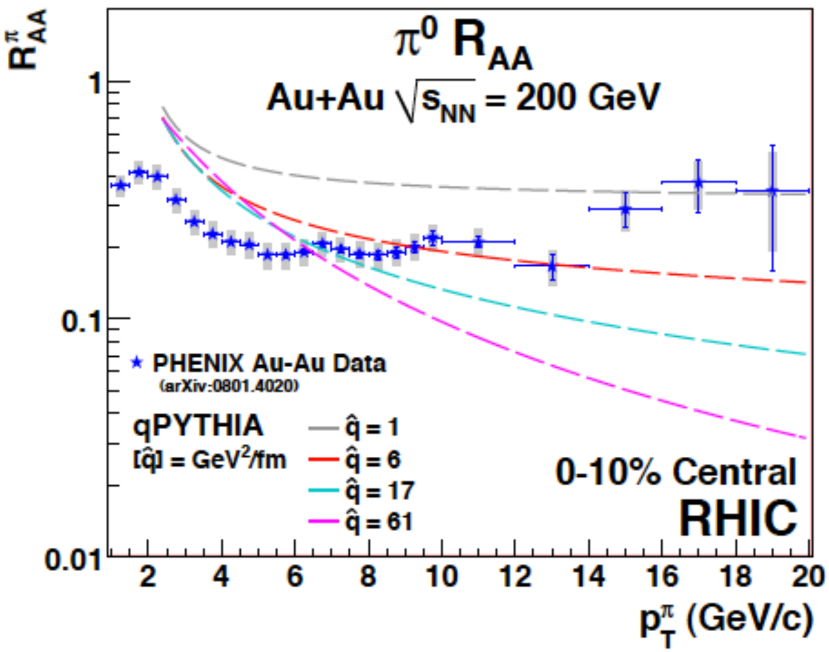
Di-hadron correlations:

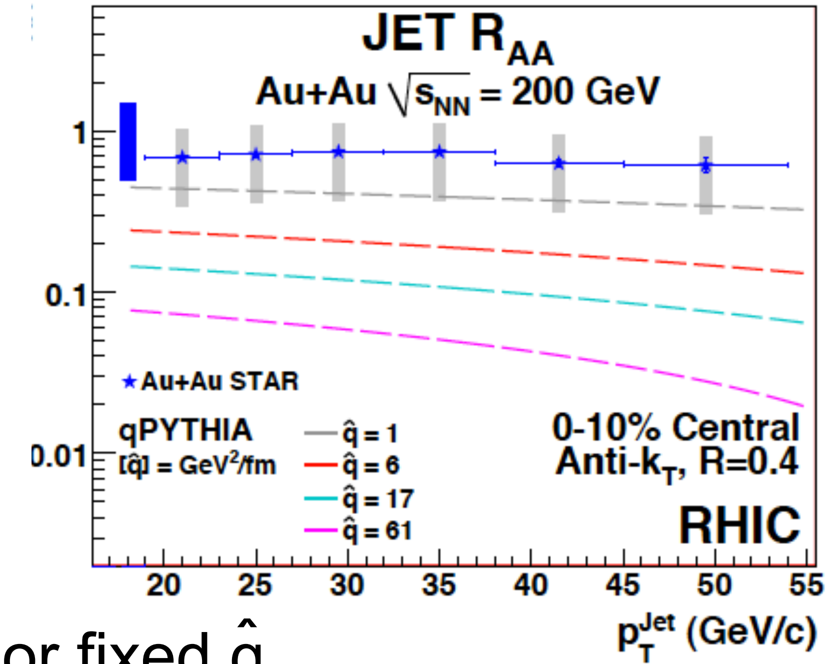
- Low-x correlations indicate significant di-jet suppression in d-Au collisions - possible indication of gluon saturation

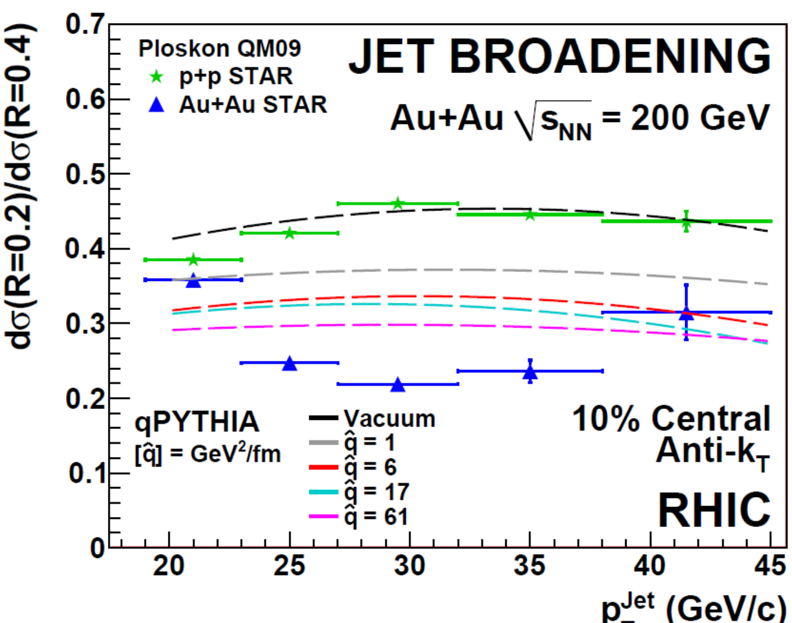
Jet-hadron correlations:

- Au-Au data indicate “lost” high p_T fragments, re-emerge as numerous low p_T particles at large cone angles

Confronting qPYTHIA with RHIC data







For fixed $\hat{q}$

- Single particle spectra OK
- Jet R_{AA} too low
- R(0.2)/R(0.4) OK for p-p
- R(0.2)/R(0.4) too high Au-Au

Jet quenching too extreme
broadening too little from 0.2 → 0.4

PID triggered correlations

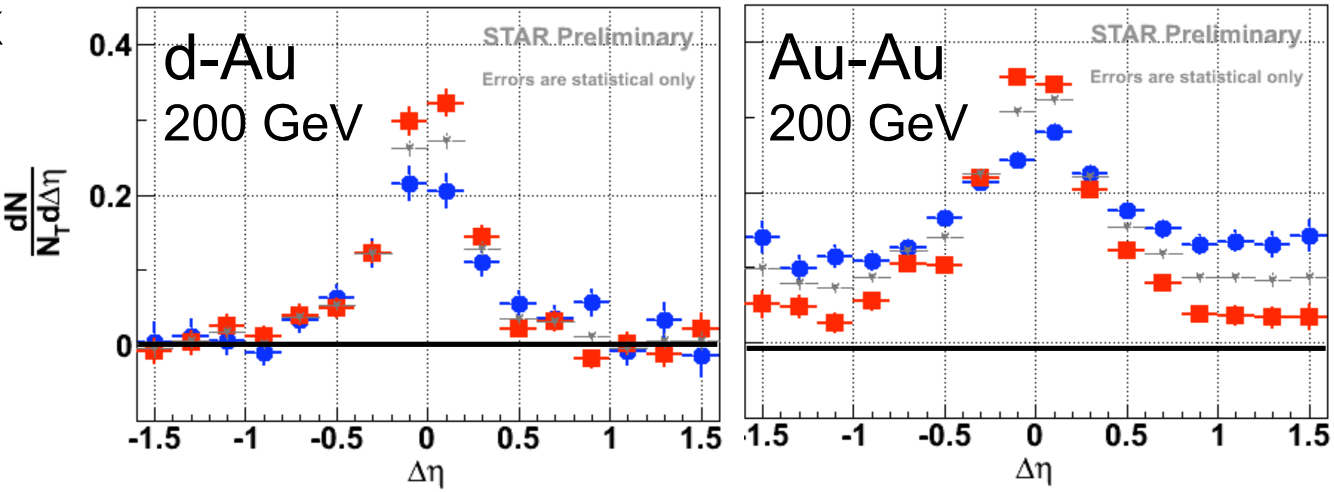
$\pi^{\pm}$, ($p^{\pm}$+$K^{\pm}$), $h^{\pm}$
via statistical dE/dx

Baselines:
d-Au MB:
$\pi = p+K$
Au-Au 0-10%:
$\pi < p+K$

Near-side Peaks:
d-Au MB:
lower for p+K
Au-Au 0-10%:
lower for p+K

Integrated Near-side yield
d-Au = Au-Au for π and p+K

$p_{T,Trig}$ = 4-6 GeV/c, $p_{T,Assoc}$>1.5 GeV/c
$|\Delta\Phi|<0.73$



p+K → enhanced ridge

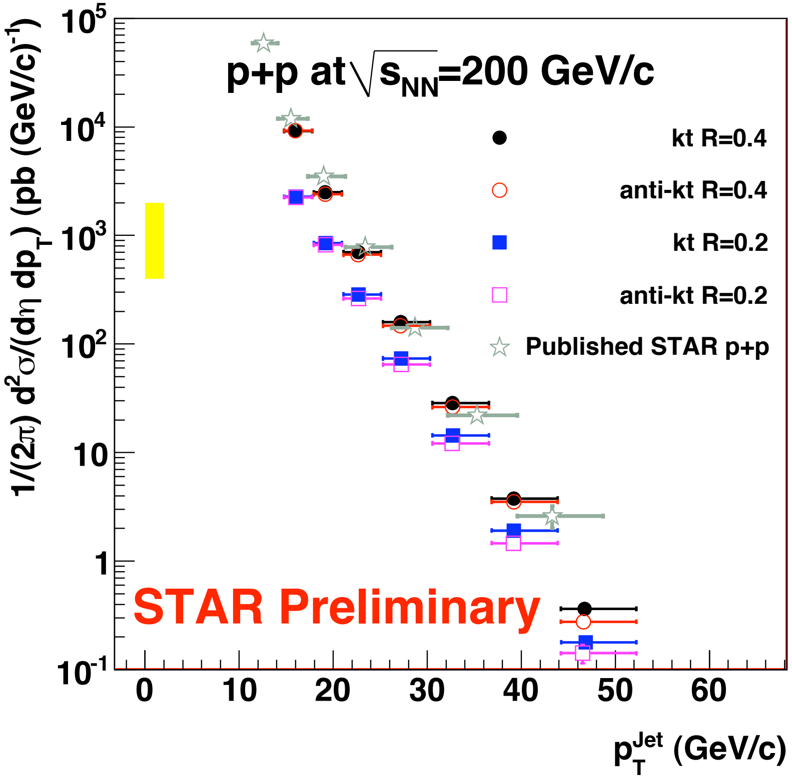
π triggers → higher jet yields

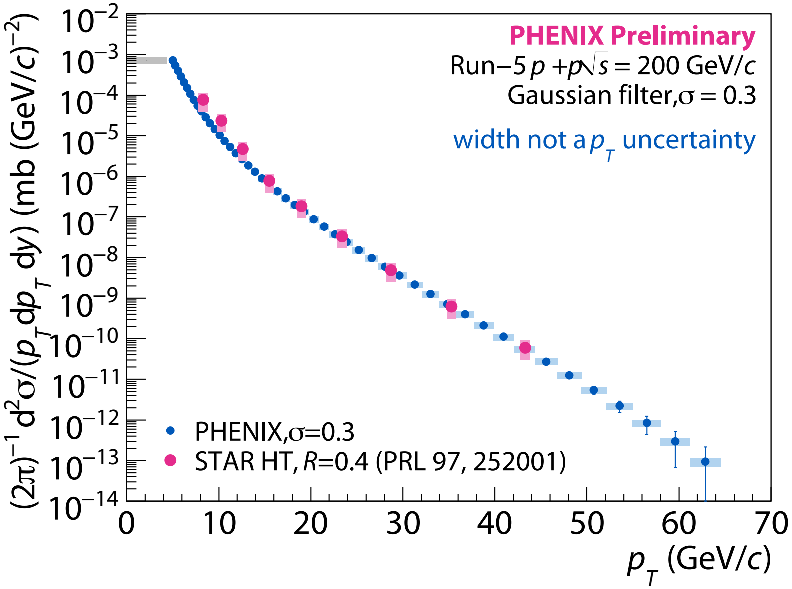
No strong dilution of near-side jet yields due to "false" triggers from recombination observed

K.Kauder,QM2011

Result depends on "question" asked

"Jet" is not a rigorous term



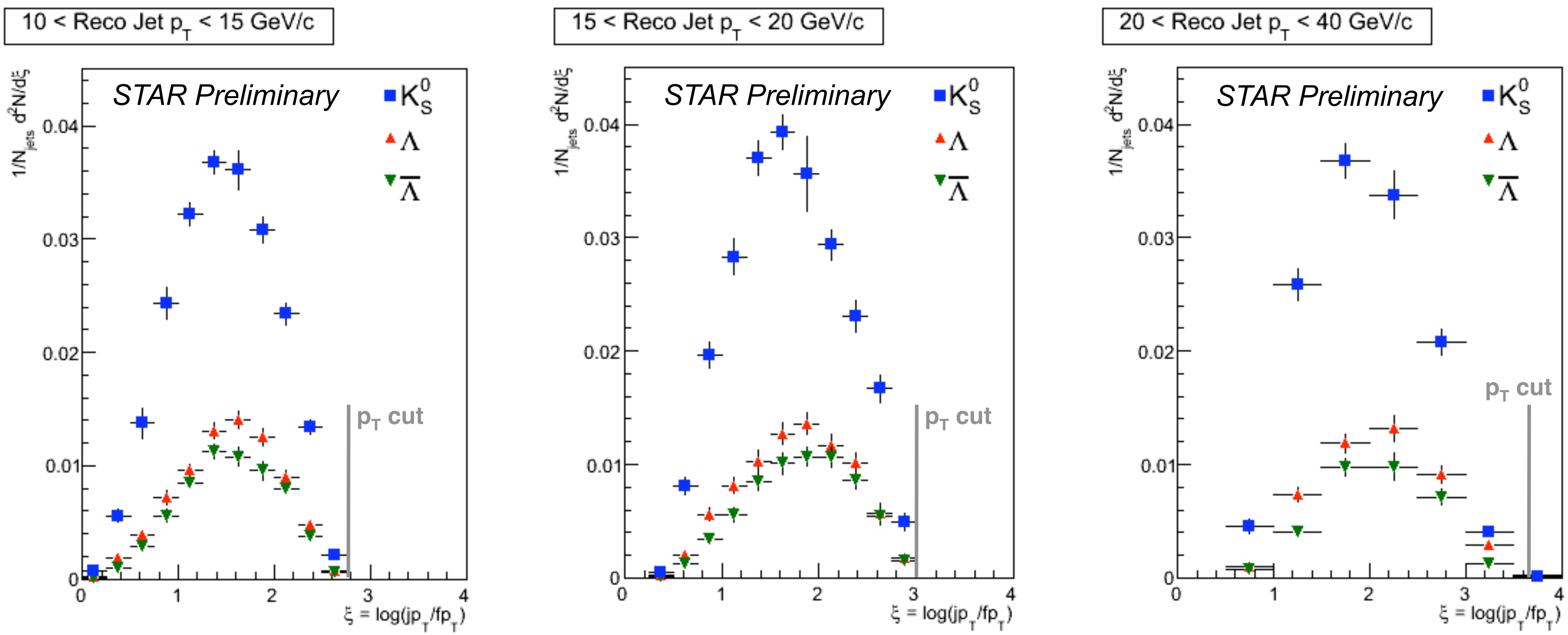


Results depend:

Strongly on resolution parameter, R
Weakly on algorithm choice

Need to be clear when discussing results exactly what was run

Strange hadron FF

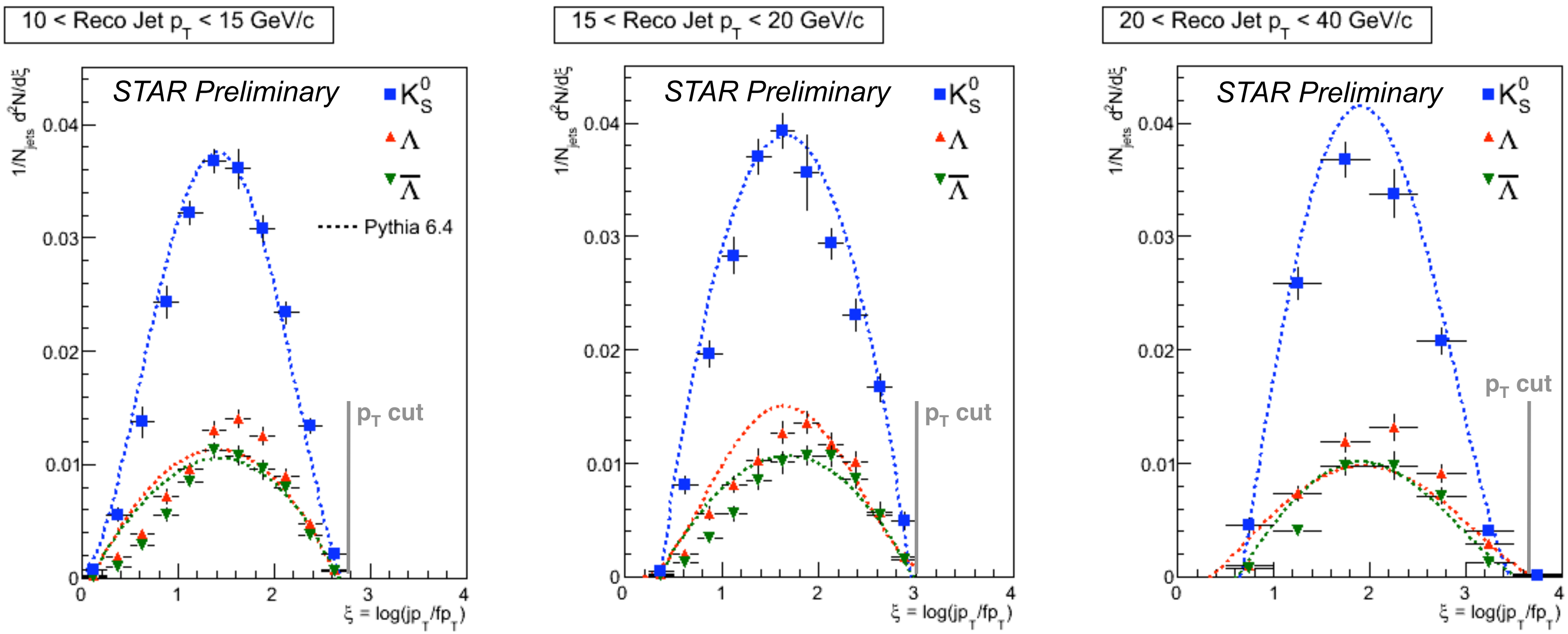


A. Timmins SQM2009

- Data presented at detector level
- Errors estimated from averaging results from k_T, anti-k_T and SISCone

V0 $p_T > 1$ GeV/c - artificial cut in distribution

Strange hadron FF



A. Timmins SQM2009

- Data presented at detector level
- Errors estimated from averaging results from k_T, anti-k_T and SISCone

PYTHIA = PYTHIA+GEANT

V0 p_T >

Description of K^0_S seems better than for Λ

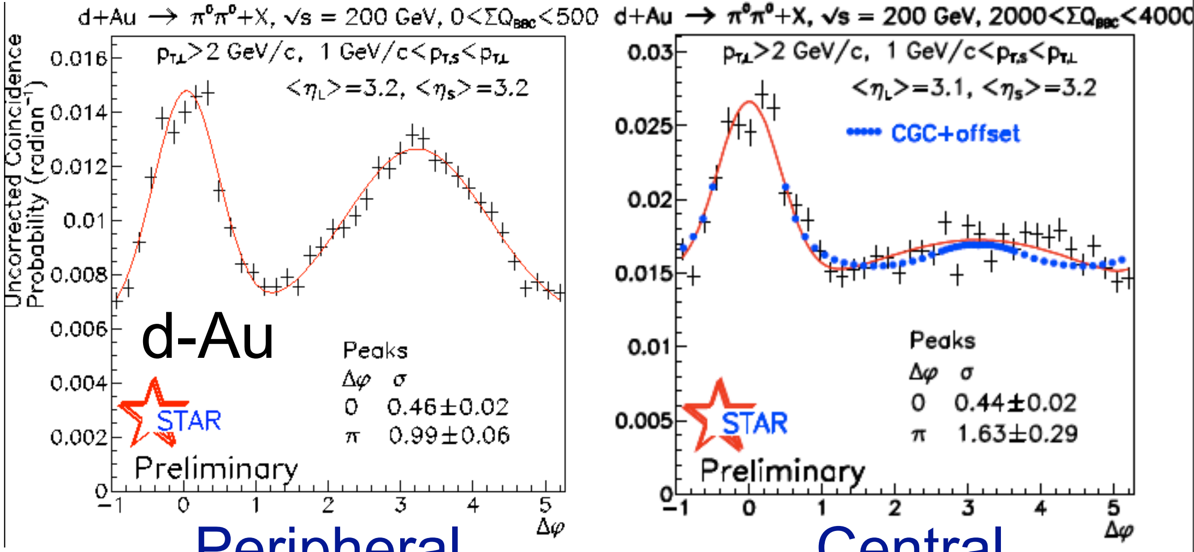
- also true for min-bias p_T distributions

Probing the initial conditions

Look at forward-forward correlations

p-p and peripheral d-Au look similar and reveal clear away-side peaks

"Mono-jets" in central d-Au forward-forward (low-x) data - CGC hint



Peripheral

Central

Suppression increases as x decreases

Important for interpreting A-A results

Probing the initial conditions

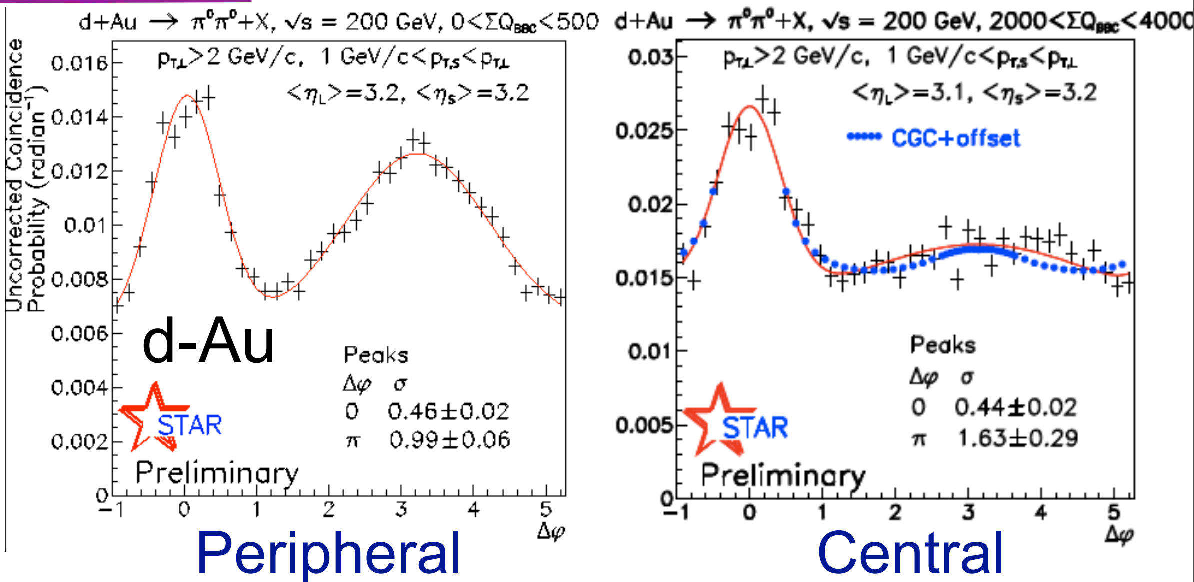
Look at forward-forward correlations

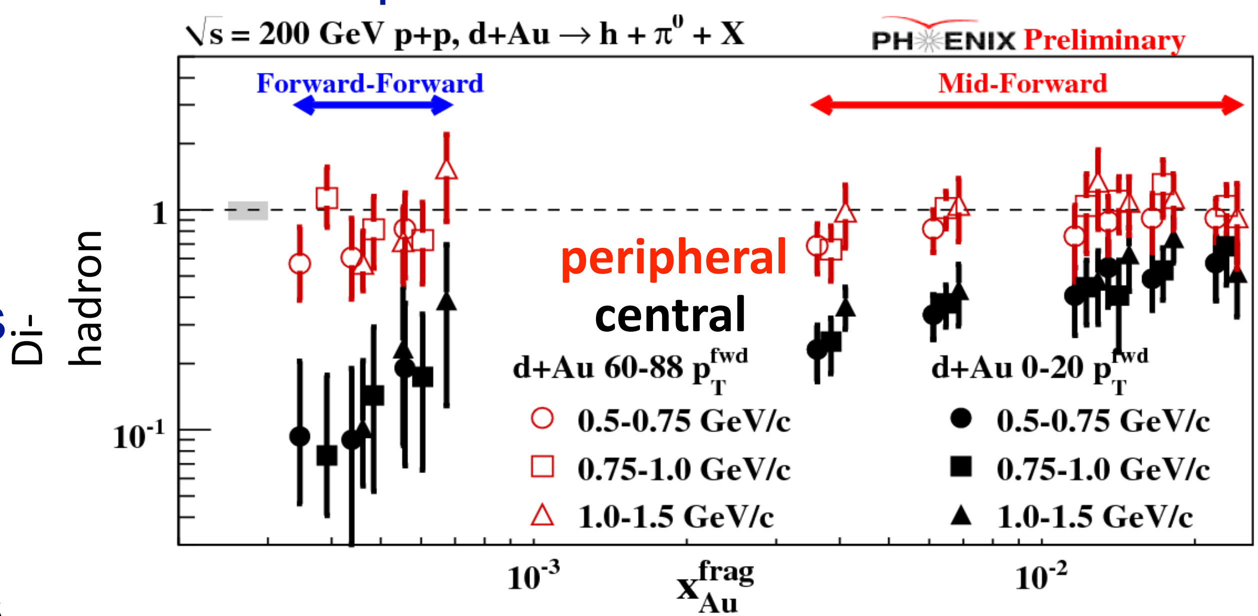
p-p and peripheral d-Au look similar and reveal clear away-side peaks

"Mono-jets" in central d-Au forward-forward (low-x) data - CGC hint

Suppression increases as x decreases

Important for interpreting A-A results





M.Chiu,QM2011,C.Perkins,DIS2011