Di-jet measurements in heavy-ion collisions at STAR

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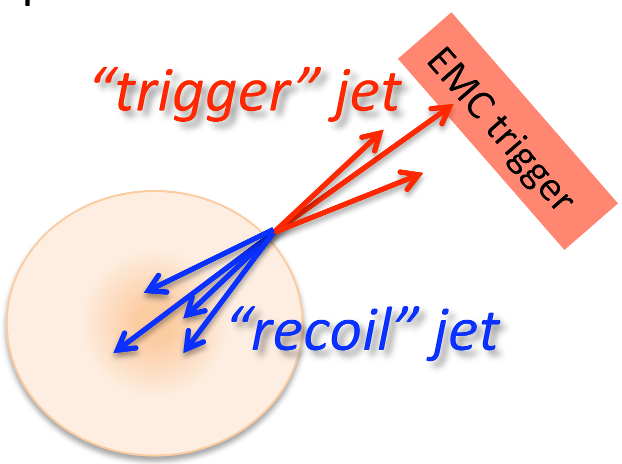
Outline

- How to reconstruct and why look at di-jets?
- Di-jet coincidence rates
- Broadening scenario in di-jet measurements
- Jet-hadron correlations: towards a consistent picture of quenching

- Summary
- To-do: towards quantitative measurements of energy loss via di-jets

Di-Jets at STAR

- TPC tracks for charged particles
- Barrel EMC for neutral energy
- $\Delta\phi=2\pi$ of TPC and BEMC
- $-1 \leq \eta \leq 1$



Data Sets:
p+p Run 2006
Au+Au Run 2007

Triggers:
High Tower (HT) in EMC
E_T>5.4 GeV in one tower
$\Delta\eta \times \Delta\phi = 0.05 \times 0.05$

Jet Algorithms:
Anti-k_T
R= resolution parameter. R=0.2, 0.4
$p_{t,cut}$=0.2 GeV/c, 2 GeV/c
$|\eta_{jet}|<0.6$

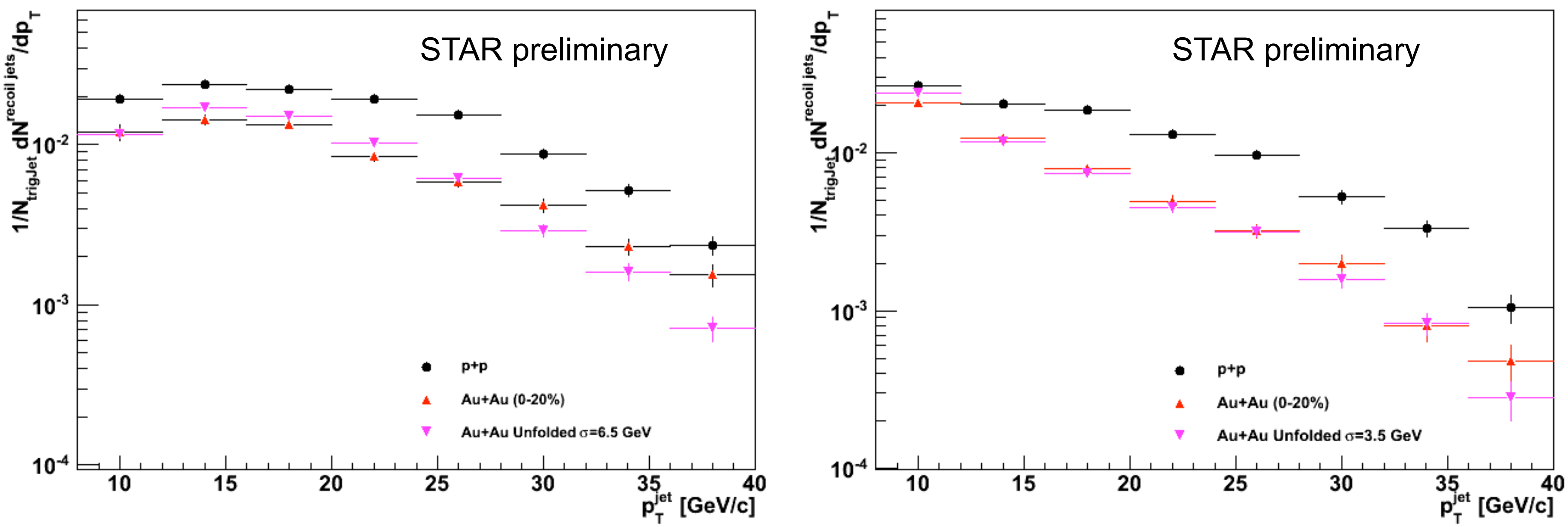
Trigger jets are selected to be biased towards the surface.
Recoil jets are exposed to a maximum path-length in the medium. Large energy loss expected.

Unfolding background fluctuations

recoil jets, $p_{T,cut}$=0.2 GeV/c

R=0.4, p_T(trig)>20 GeV
σ=6.5 GeV

R=0.2, p_T(trig)>20 GeV
σ=3.5 GeV



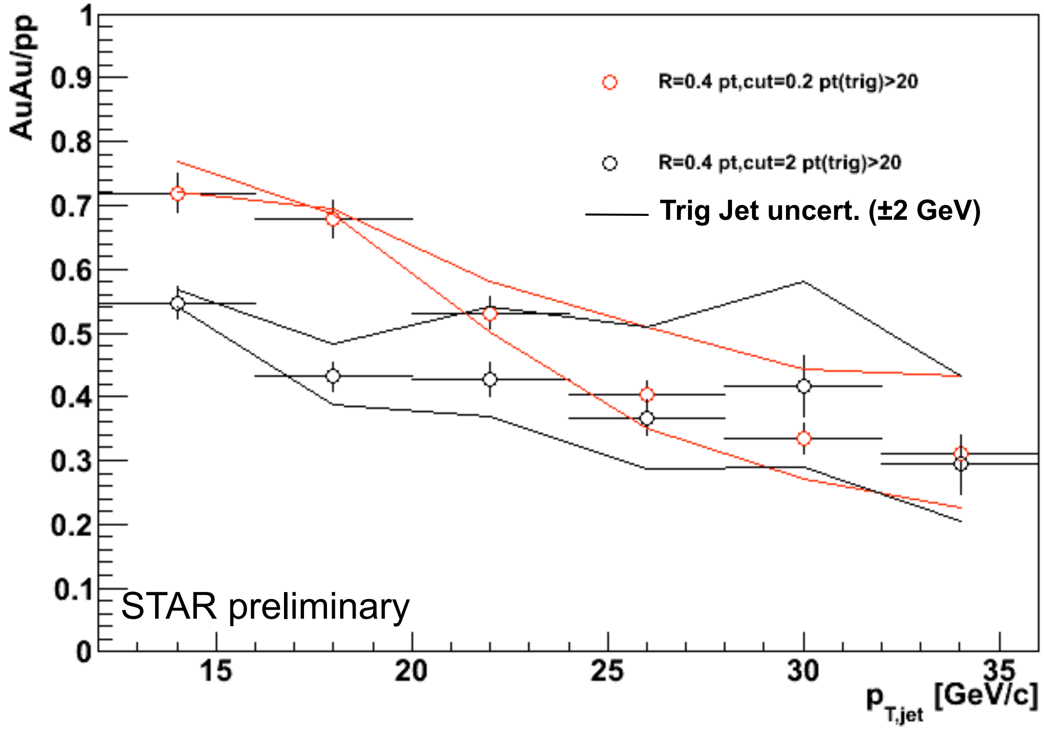
Tight selection of trigger jets → Flatter spectrum of recoil jets

Same approach for $p_{T,cut}$=2 GeV (σ=1.5 GeV for R=0.4)

Work in progress: characterization of the shape of background fluctuations

Effect of $p_{T,cut}$ on di-jet coincidence rate

Recoil Jet: R=0.4, p_{Tcut}=2 GeV/c vs p_{Tcut}=0.2 GeV/c
Trigger Jet: p_{Tcut}=2 GeV/c, p_T(trig)>20 GeV/c



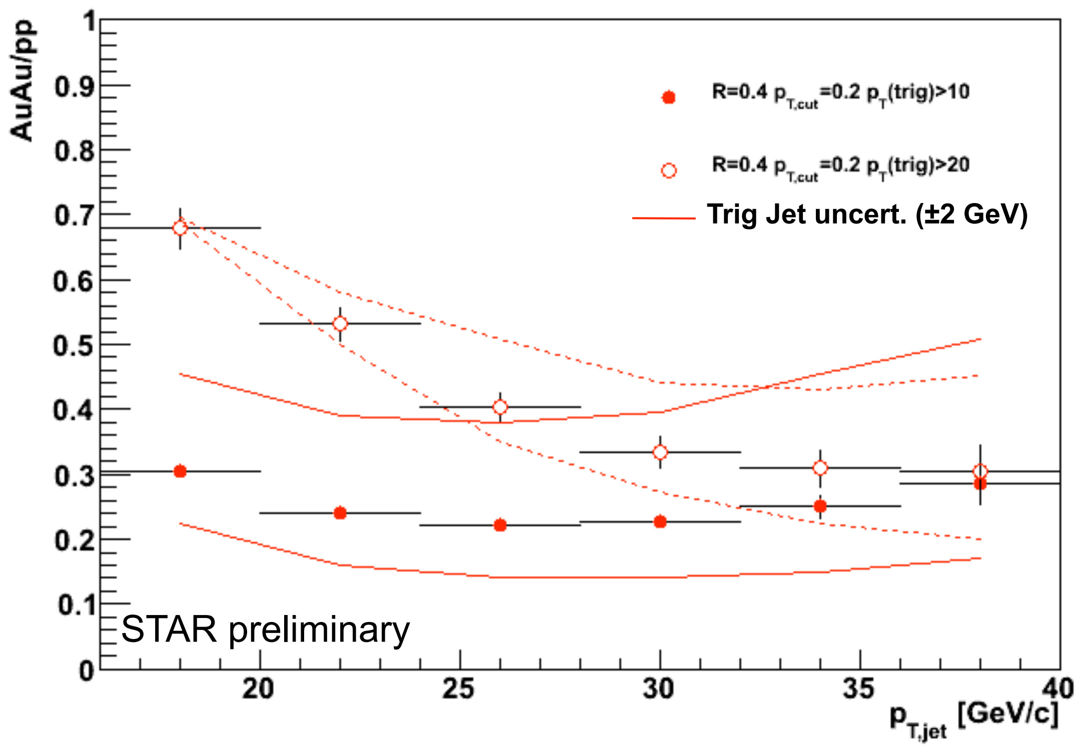
$p_{T,cut}$ allows similar trigger jet population in p+p and Au+Au

Recoil jets measured per trigger jet → coincidence rate

p_{Tcut}=2 GeV/c similar suppression as p_{Tcut}=0.2 GeV/c
→ broadening and/or absorption?

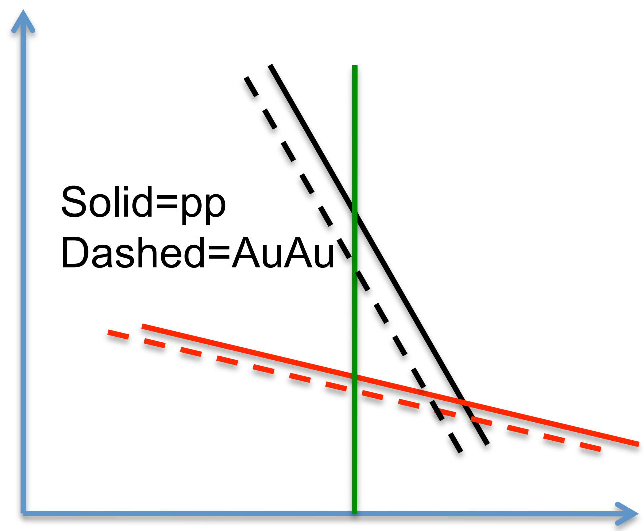
Effect of Trigger jet selection on di-jet rate

Recoil Jet: R=0.4, p_{Tcut}=0.2 GeV/c
Trigger Jet: p_{Tcut}=2 GeV/c, p_T(trig)>10 GeV/c vs 20 GeV/c

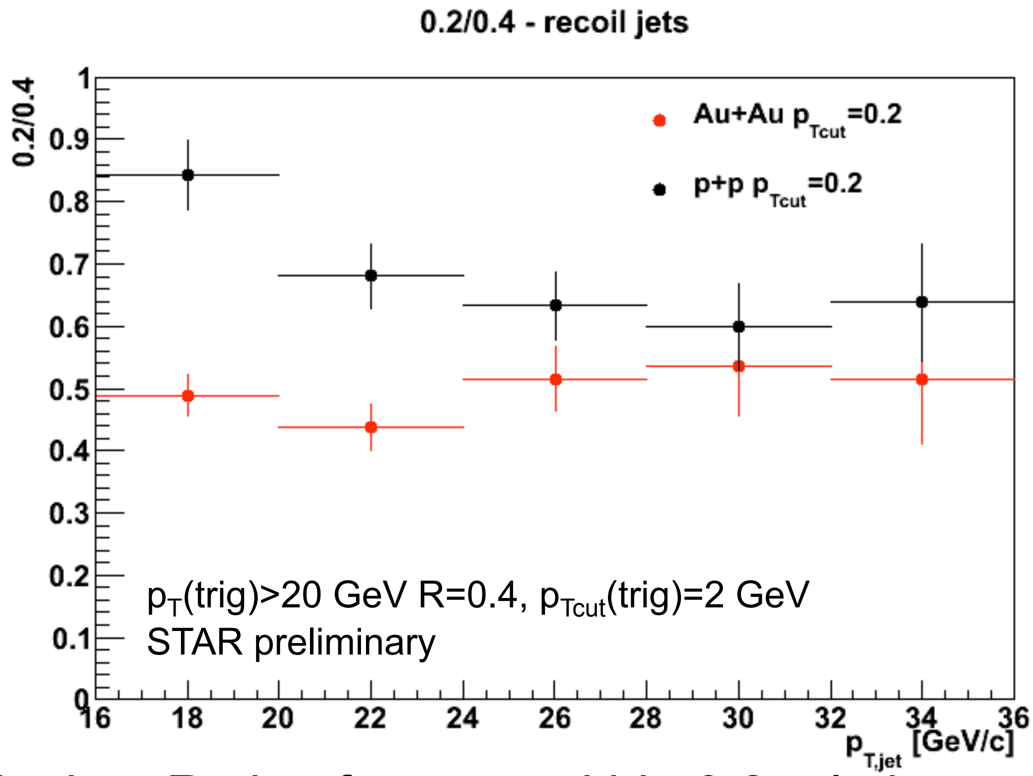


p_T(trig)>20 is flat above ~ 25 GeV.
→ trigger threshold

p_T(trig)>20 above pt(trig)>10
→ flatter spectrum for p_T(trig)>20



Recoil Jet Energy Profile: R=0.2 vs R=0.4



From inclusive jet spectrum

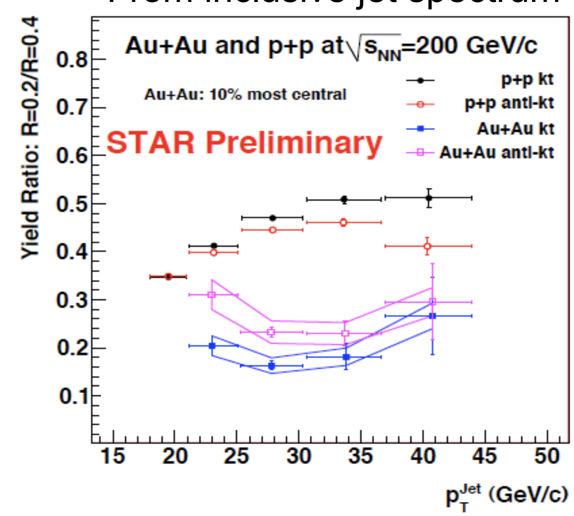
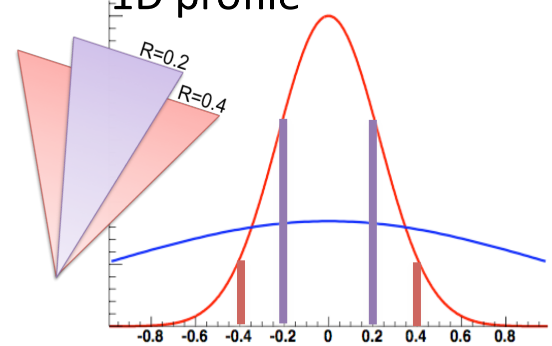


Illustration: Gaussian 1D profile



If broadening: Ratio of energy within 0.2 relative to energy in 0.4 smaller in AuAu than pp

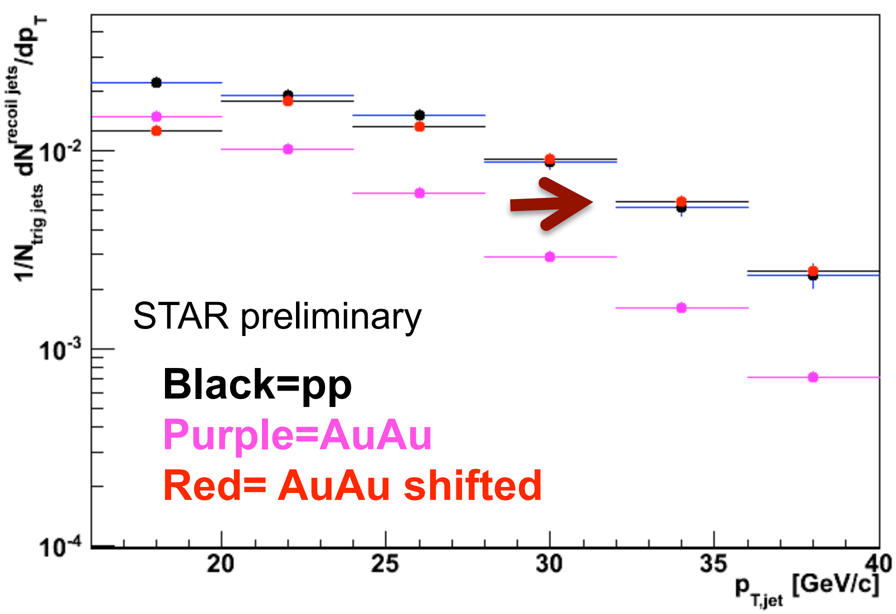
Recoil jets: Au+Au only slightly suppressed w.r.t. p+p
Selection bias → Flatter spectra of recoil jets

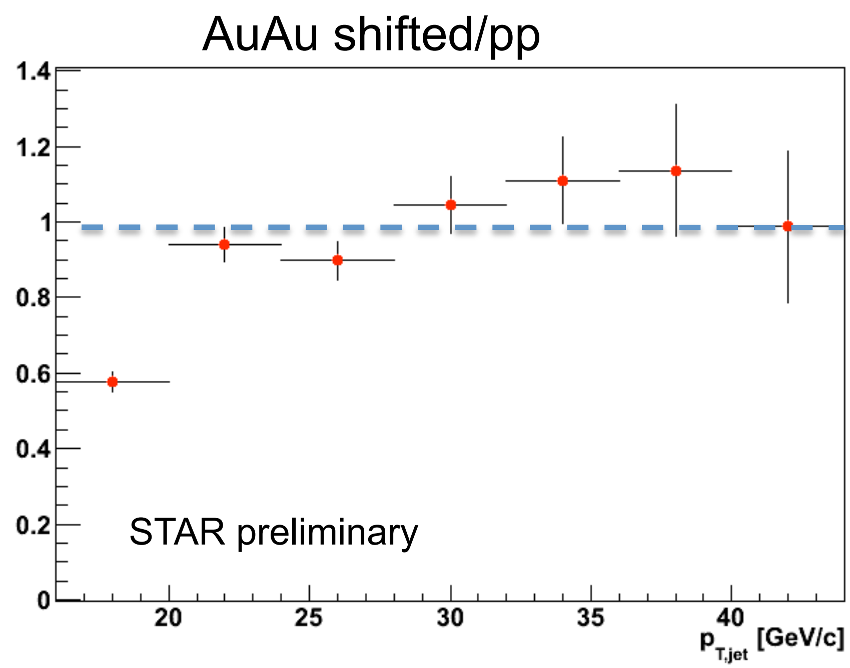
Red: p-p
Blue: Au-Au

Broadening scenario for R=0.4

possible interpretation of di-jet suppression

How much would the AuAu spectra need to be shifted in order to match pp?
(assuming constant shift of the spectra, i.e. constant energy loss)



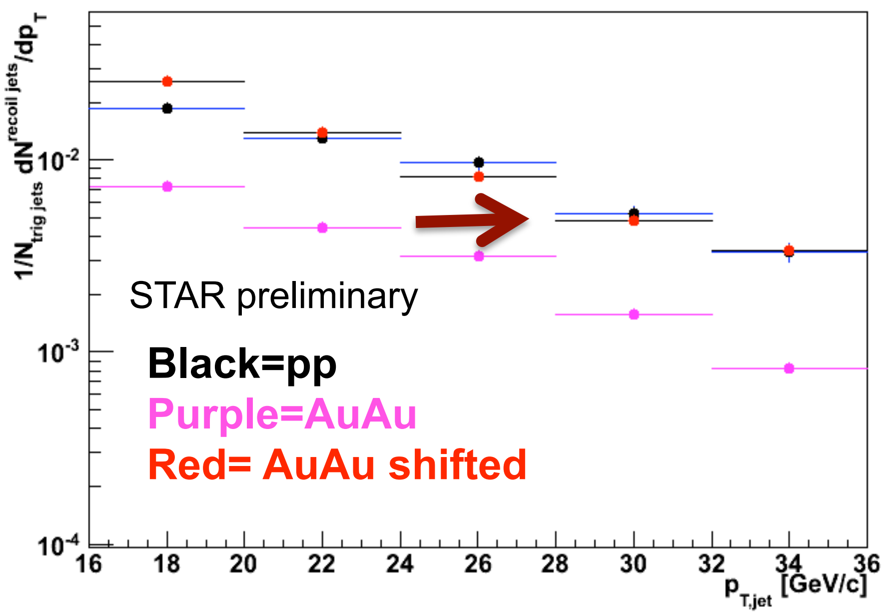


Compatible with a p_T shift Δ = 7-8 GeV

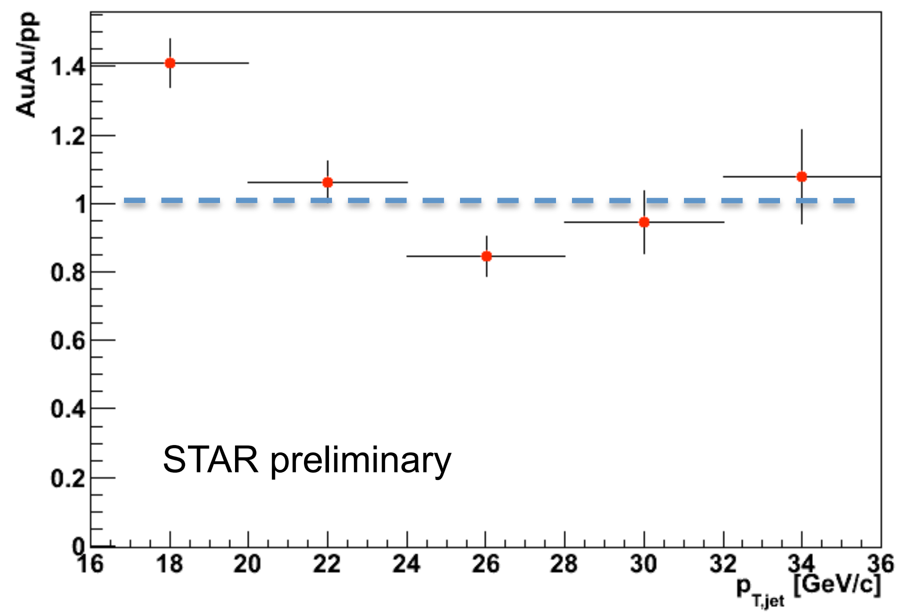
Broadening scenario for R=0.2

possible interpretation of di-jet suppression

How much would the AuAu spectra need to be shifted in order to match pp?
(assuming constant shift of the spectra, i.e. constant energy loss)



AuAu shifted/pp



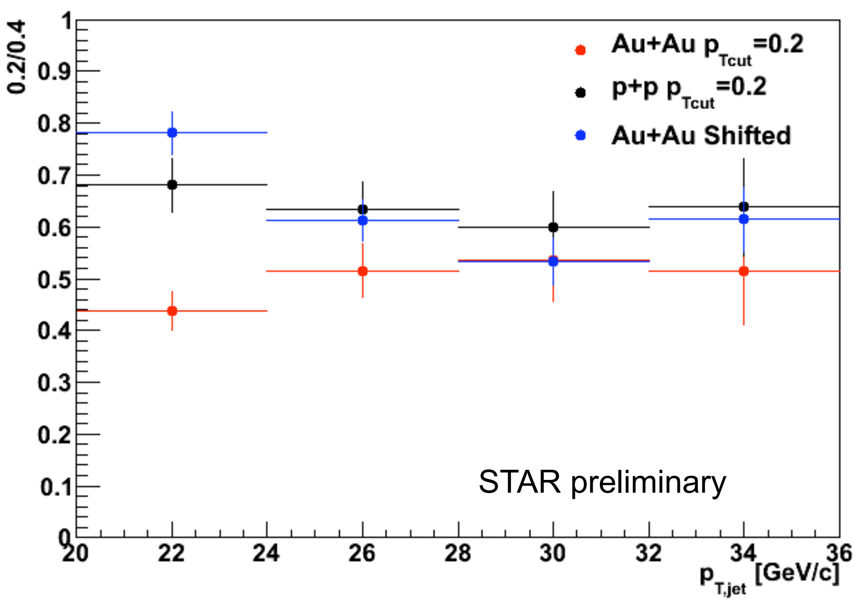
Compatible with a p_T shift Δ = 8-9 GeV

Recoil Jet Energy Profile (1)

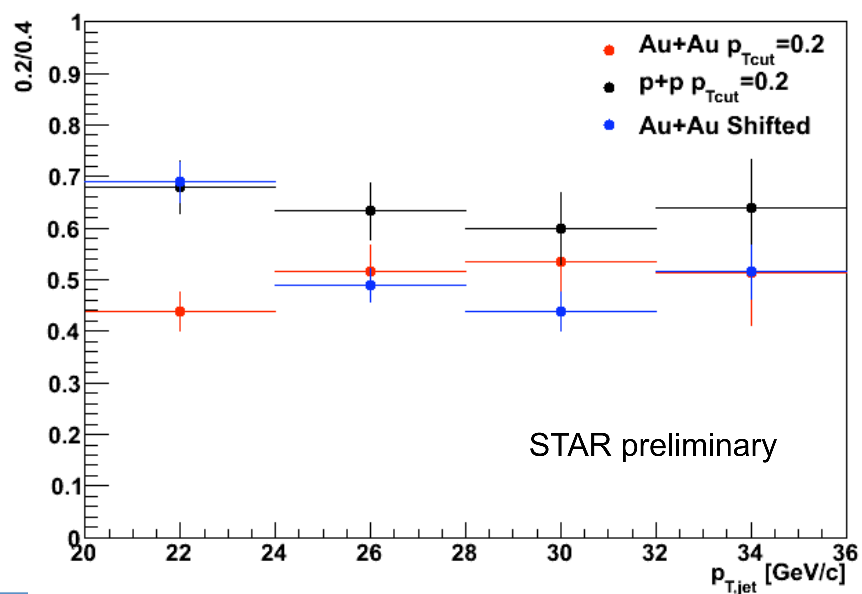
(assuming broadening scenario)

Shift AuAu to reproduce Energy loss. Constant shift in this toy example

Shift AuAu R=0.2 by Δ=7 GeV
Shift AuAu R=0.4 by Δ=9 GeV



Shift AuAu R=0.2 by Δ=8 GeV
Shift AuAu R=0.4 by Δ=8 GeV



Not excluded large angle (out of R=0.4) radiation when parton is exposed to a maximum in-medium path

Measured ratio in qualitative agreement with broadening scenario (within error bars)

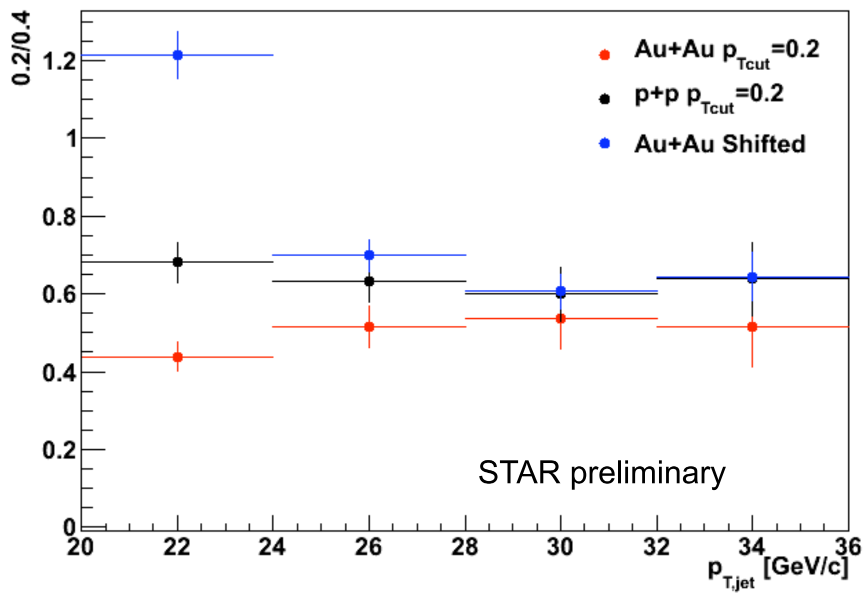
Recoil Jet Energy Profile (2)

(assuming broadening scenario)

Shift AuAu to reproduce Energy loss. Constant shift in this toy example

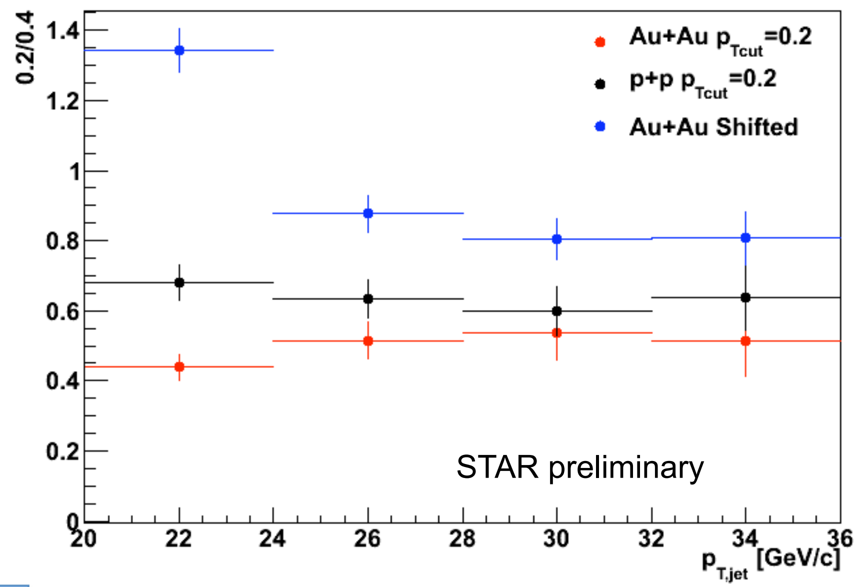
Shift AuAu R=0.2 by Δ=11 GeV

Shift AuAu R=0.4 by Δ=8 GeV



Shift pp w/ R=0.2 by Δ=12 GeV

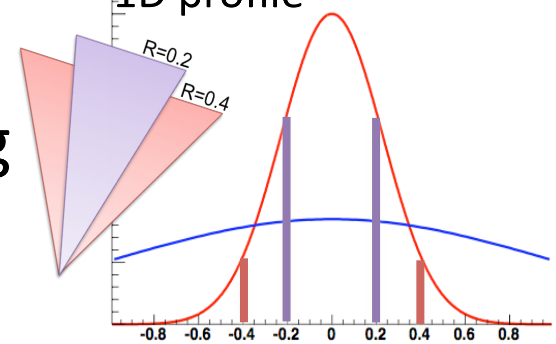
Shift pp w/ R=0.4 by Δ=7 GeV



Larger shift for R=0.2 → lower limit in the ratio

What we learned so far from di-jets

Illustration: Gaussian 1D profile



Red: p-p
Blue: Au-Au

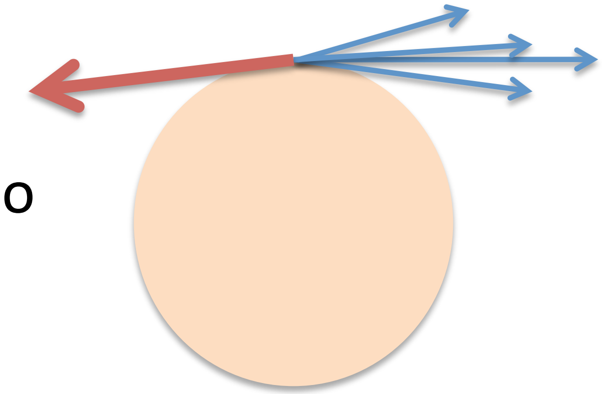
- Jet Energy profile: measured ratio in qualitative agreement with broadening scenario outside of R=0.4

- Di-jet coincidence rate: significant suppression of recoil jets, also with large bias due to $p_{T,cut}$=2 GeV

→ Are jets w/ p_{Tcut}=2 GeV less interacting? (surface bias or broadening?) ⇨ **Jet-Hadron correlations**

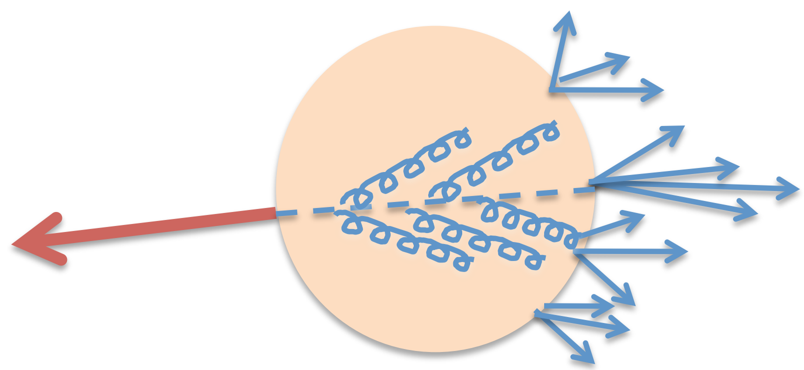
Expectations from Jet-hadron correlations

If tangential (halo) emission:



→ Away side yield in Au+Au similar to p+p, also for low $p_{t,assoc}$

If energy loss:



→ Decrease of high-$p_{t,assoc}$ particles

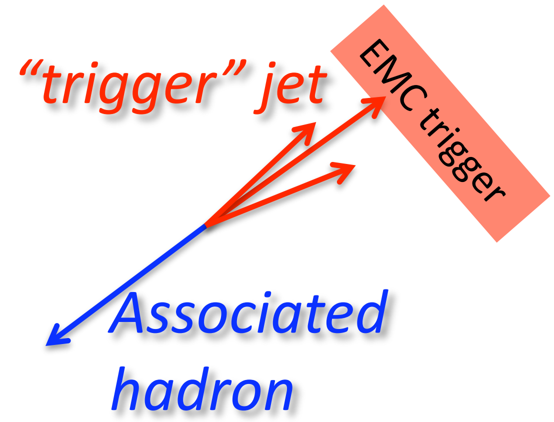
→ Strong enhancement of low $p_{t,assoc}$

→ Broadening

Method

<u>Trigger Jet:</u>

- Anti-kt R=0.4
- p_T(trig)>20 GeV, p_{Tcut}=2 GeV
- |η|<0.6



Make Jet-hadron correlation when a recoil jet is found

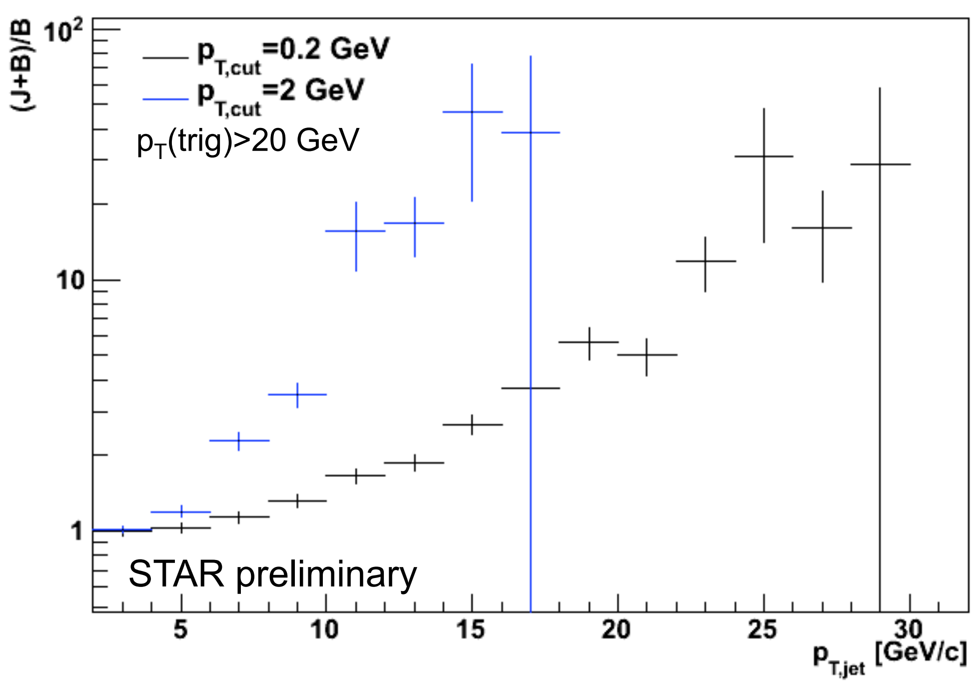
<u>Recoil Jet:</u>

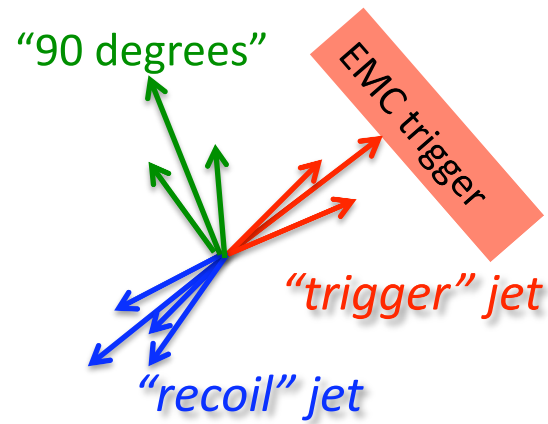
- $p_{T,cut}$=0.2 GeV vs $p_{T,cut}$=2 GeV for recoil
- |η|<0.6
- Different selections on p_T(recoil):
- p_T(recoil)>10 GeV, all

Background jet rate

Background jet spectrum (B) = Jets at 90° = fake jets + 2nd hard scattering

Jet spectrum at 180° (J+B) = di-jets + Background jets

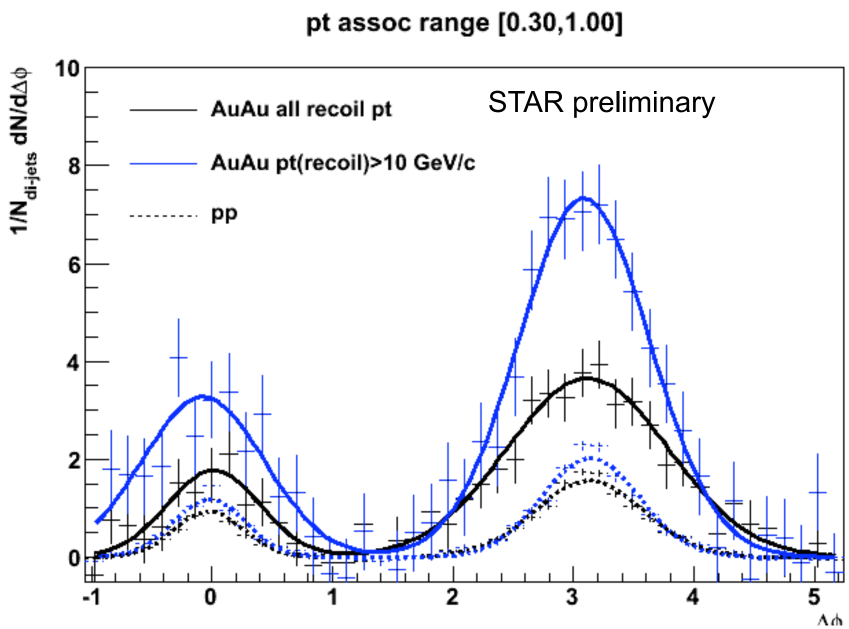


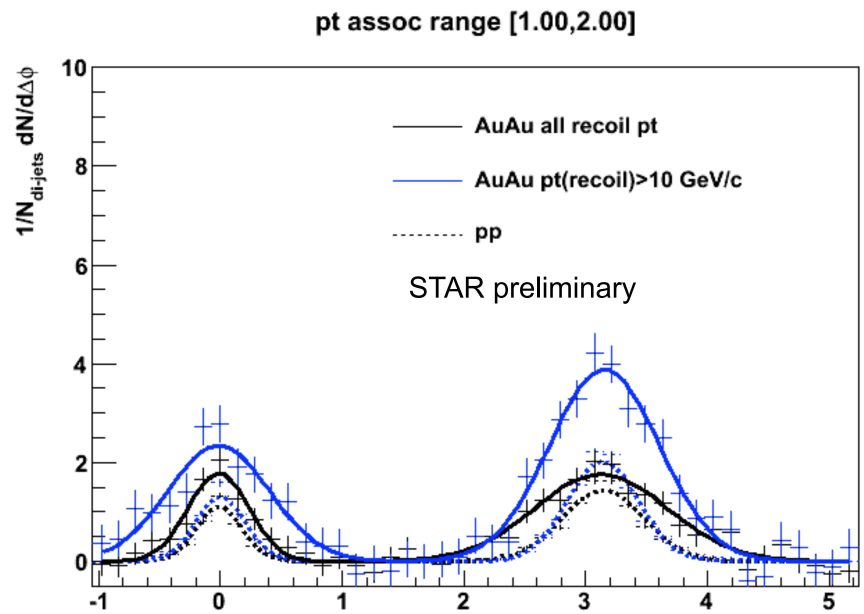


$p_{T,cut}$=0.2 GeV →J+B/B~3 (p_T>10 GeV)
$p_{T,cut}$=2 GeV→J+B/B~30 (p_T>10 GeV)

Correction to be done.
Expected to be small for $p_{T,cut}$=2 GeV.

First look at Jet-hadron with recoil jet (1)

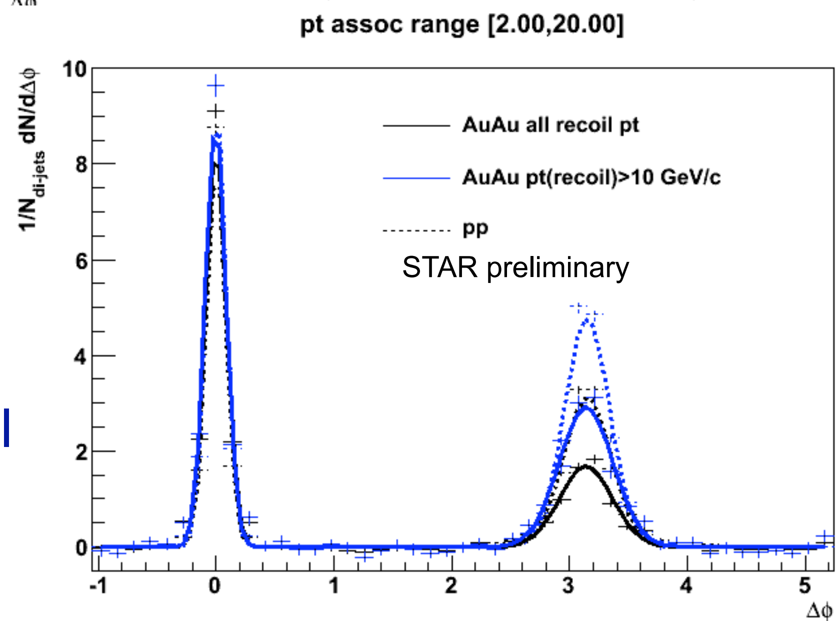




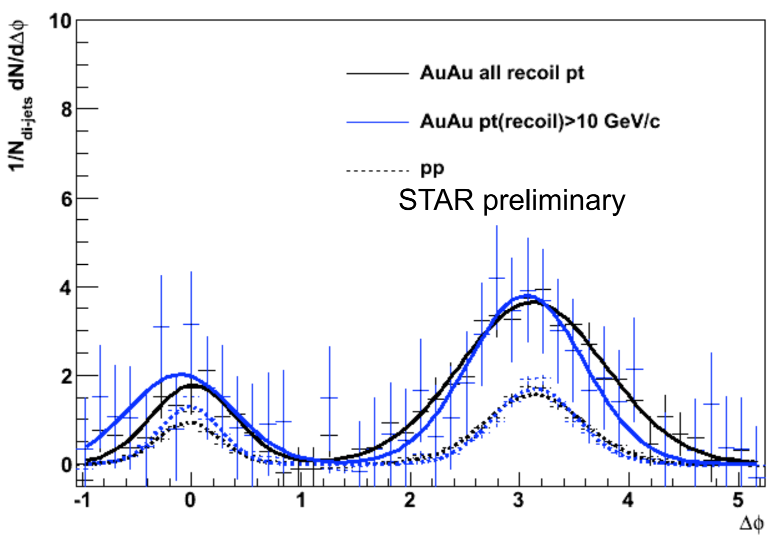
2 Gaussian + flat pedestal fit.

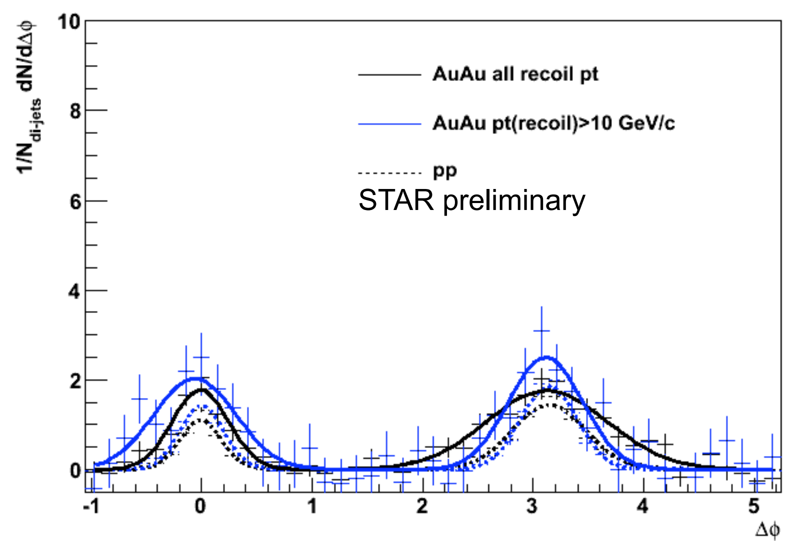
$p_{T,cut}$=0.2 GeV

Significant softening of the recoil side

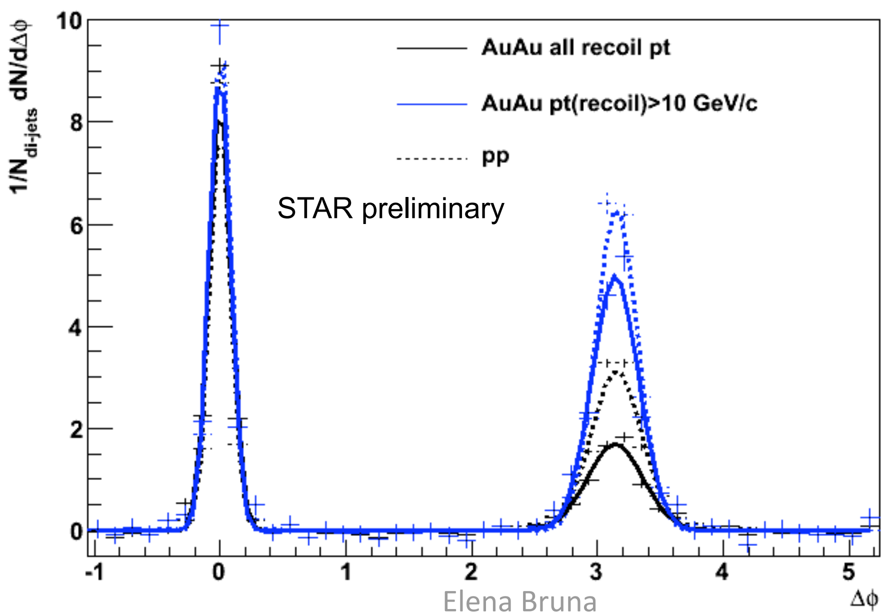


First look at Jet-hadron with recoil jet (2)





$p_{T,cut}$=2 GeV



Broadening/softening observed also for $p_{T,cut}$=2 GeV

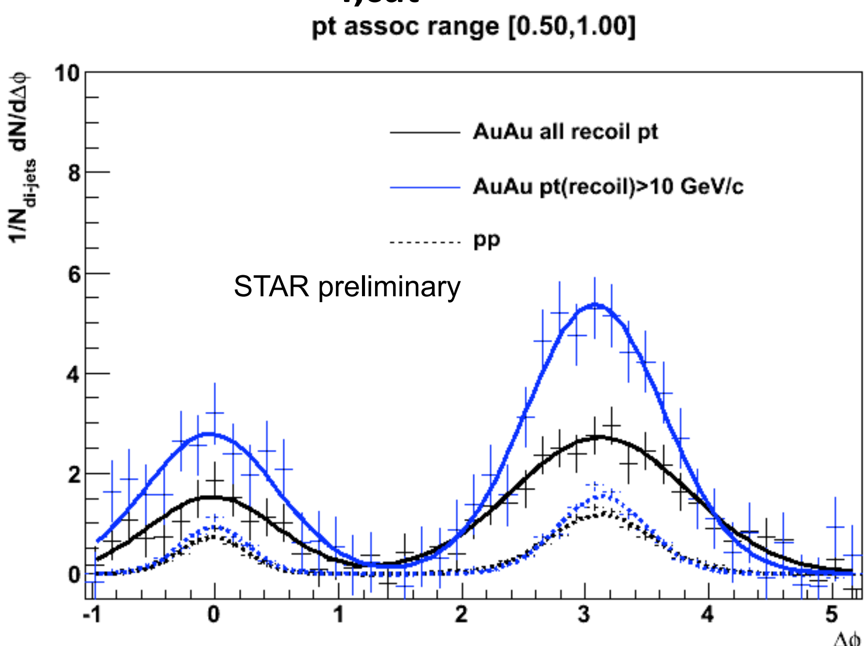
CAVEAT: quantitative measurement of out-of-cone energy requires taking into account fake jet rate, trigger bias, tracking efficiency

Background jets in di-jet analysis

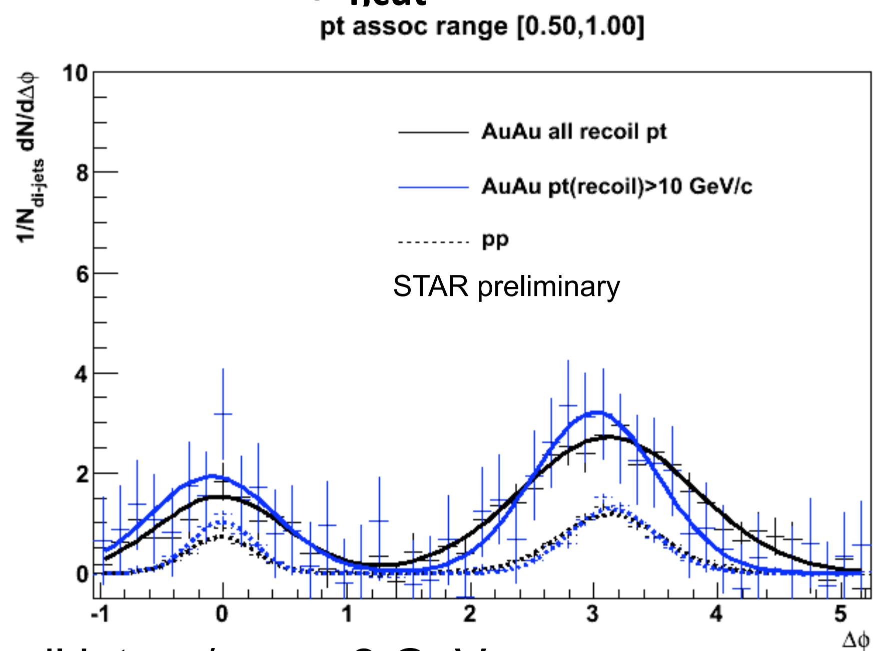
Background jets:

1) artificially raise normalization ($N_{di\text{-}jets}$). Correction enhances the away side for AuAu. To be done
2) might be correlated to the trigger jet because of the bias in the selection → look at $p_{t,assoc}$>0.5 GeV to reduce background particles clustered in fake jets. Done below

$p_{T,cut}$=0.2 GeV



$p_{T,cut}$=2 GeV



Away side Yield AuAu/pp is lower for recoil jets w/ $p_{T,cut}$=2 GeV,
Suggests that those jets are less interacting, as expected.

Summary

- Di-jet analysis:
  - Measured di-jet coincidence rate for R=0.4, w/ $p_{T,cut}$=0.2 vs $p_{T,cut}$=2 GeV and two different selection on trigger jets
  - Measured ratio of recoil spectra R=0.2/R=0.4. The ratio in qualitative agreement with broadening scenario.
- Jet-Hadron analysis:
  - Required a reconstructed recoil jet
  - Addresses biases in jet-finding
  - Different values of $p_{T,cut}$ on recoil jet helps understanding the broadening/absorption scenario

Outlook

Quantitative estimate of out-of-cone energy loss via jet-hadron with recoil jets needs taking care of:

- background subtraction, including v2
- fake jet correction
- trigger bias

→ Is the estimate from jet-hadron correlations compatible with the results from di-hadron correlations?

Use models (i.e. qPythia, YaJEM, …) to compare the expected missed energy out-of-cone with the measured one.

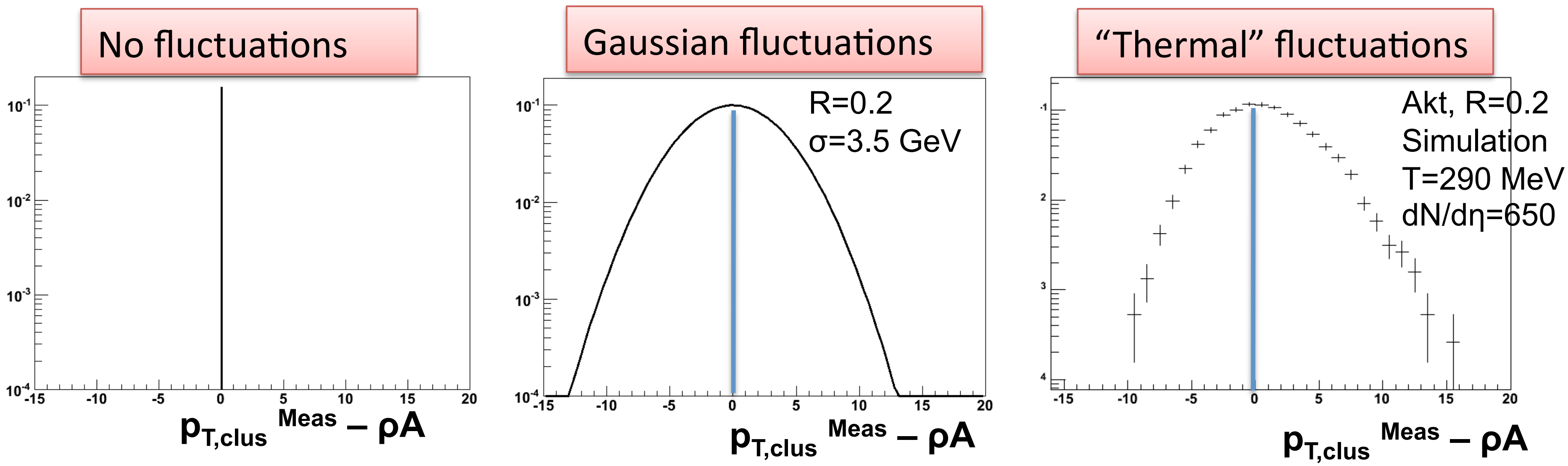
→ Same experimental conditions (extreme in medium path-length) need to be set in the models

Back-up slides

Assessing background fluctuations

$f\,(p_{T,clus}{}^{Meas} - \rho A)$

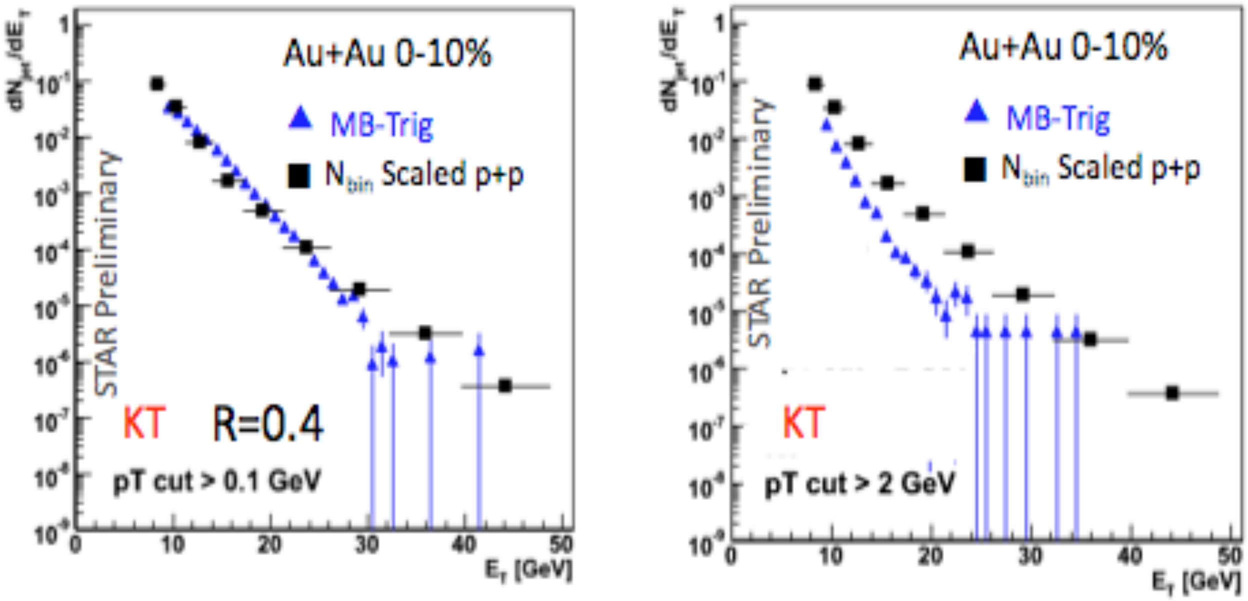
$p_{T,clus}$ for only background jets



How to characterize the full shape of the bkg fluctuations?

Biases due to $p_{T,cut}$ on particles

Lesson learned from Au+Au MB jet inclusive spectra



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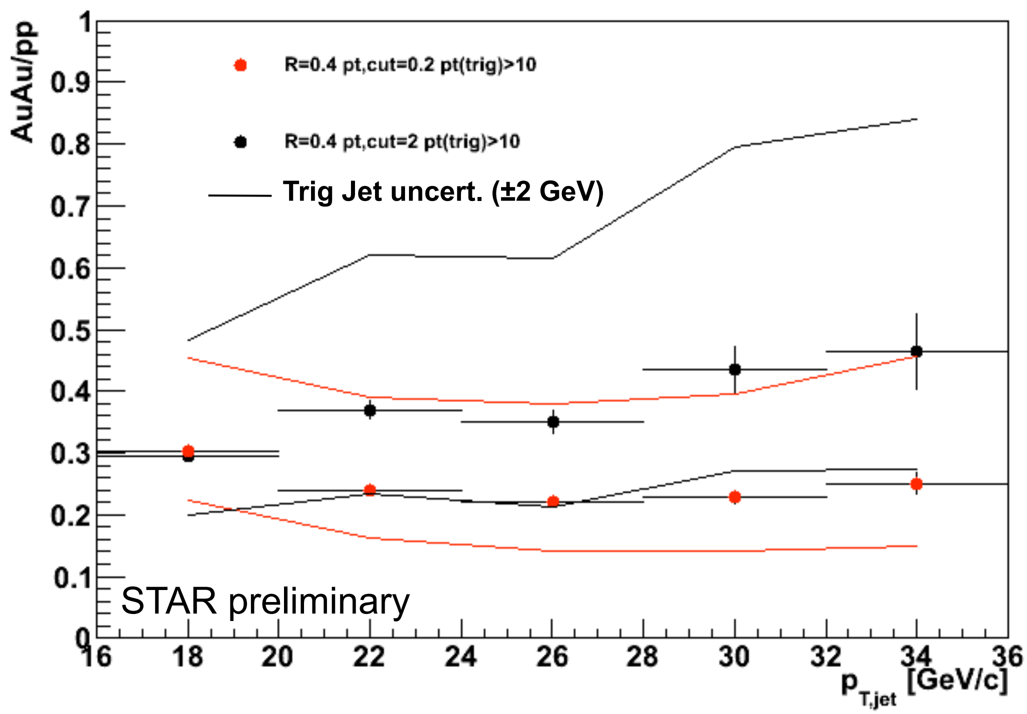
triggering on high p_T particles ⇒ bias towards non-interacting jets

p_T cut reduces background ⇒ bias towards non-interacting jets

Effect of $p_{T,cut}$ on di-jet coincidence rate

Recoil Jet: R=0.4, p_{Tcut}=2 GeV/c vs p_{Tcut}=0.2 GeV/c
Trigger Jet: p_{Tcut}=2 GeV/c, p_T(trig)>10 GeV/c



$p_{T,cut}$ allows similar trigger jet population in p+p and Au+Au

Recoil jets measured per trigger jet → coincidence rate

(i) p_{Tcut}=2 GeV/c less suppressed than p_{Tcut}=0.2 GeV/c, above a given p_T(recoil)

→ broadening or absorption?

→ trigger bias to be assessed