Recent Jet Measurements in Heavy-ion Collisions at STAR in a Nutshell

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2017 RHIC & AGS Annual Users' Meeting

Recent jet measurements in Heavy-Ion collisions

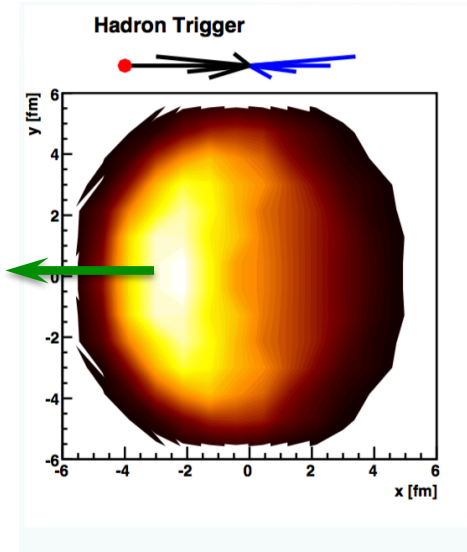
- Jet-like correlation
  - γ+hadron and π^0+hadron [PLB 760 (2016) 689]
- Semi-inclusive recoil charged jet
  - $h^{\pm}$+jet [arXiv:1702.01108]
  - γ+jet and π^0+jet [ongoing work: preliminary results:QM2017]
- Di-jet
  - A_J measurement (momentum imbalance) [accepted in PRL, arXiv:1609.03878]
  - Di-jet+hadron correlations [preliminary results:QM2017]
  - Di-jet z_g (Splitting function) [ongoing work: preliminary results:QM2017 and HP2016]

- Jet-like correlation
  - γ+hadron and π^0+hadron [PLB 760 (2016) 689]

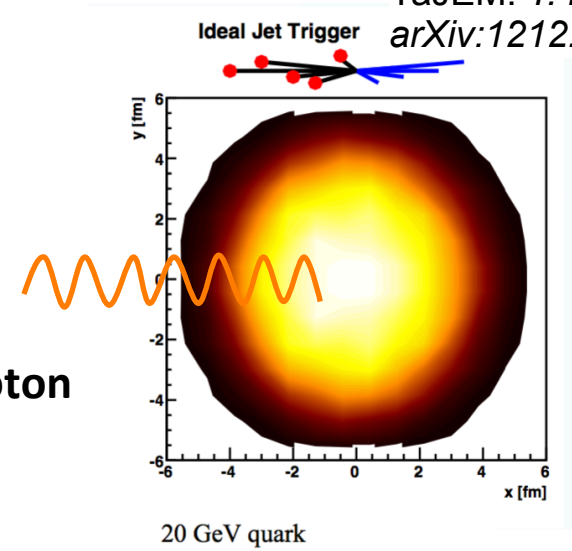
γ-hadrons and π^0-hadrons correlations

YaJEM: *T. Renk*
arXiv:1212.0646

Hadron (π^0)



Ideal jet/
Direct-photon



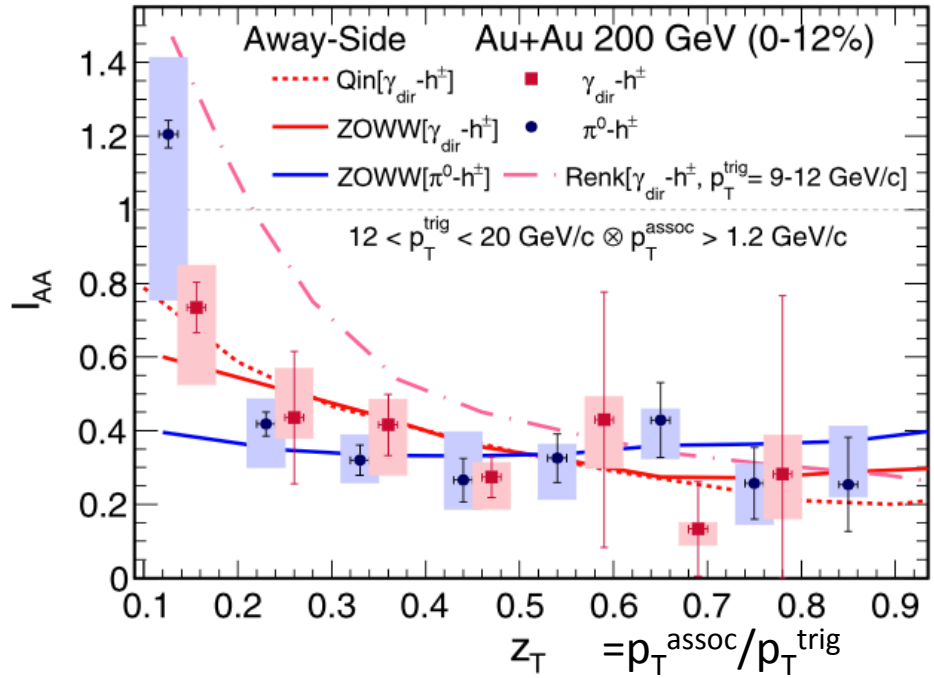
- On ave. γ-triggered parton (jet) loses less energy than that of π^0-trigger
  - due to path length (surface biased of π^0-trigger)

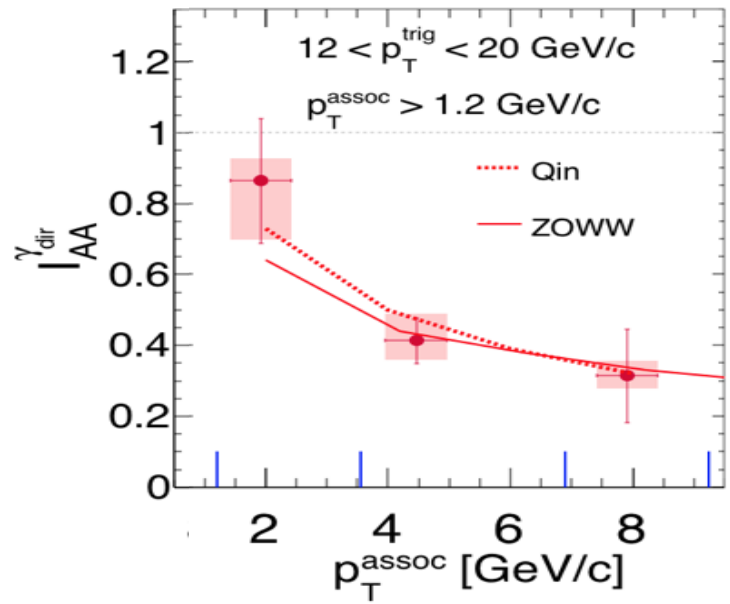
- γ-triggered parton (jet) loses less energy than π^0-trigger recoil
  - due to color factor ($C_A/C_F = 9/4$)
    (dominant γ production: qg ->qγ)

Jet-like correlation: γ+hadron and π^0+hadron

STAR: PLB 760 (2016) 689

$$I_{AA}(x) = \frac{Y^{Au+Au}(x)}{Y^{p+p}(x)}$$





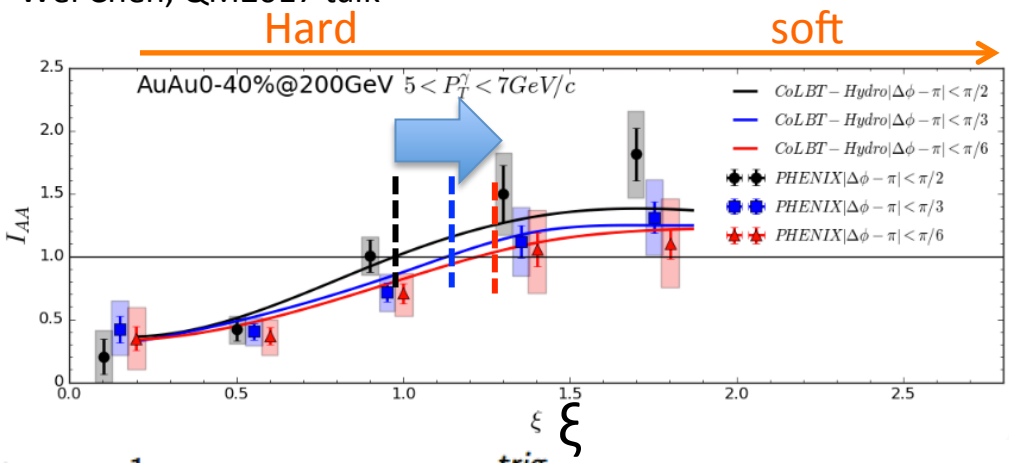
- Large suppression at high z_T and p_T^{assoc}
- Within large uncertainty, no clear signature of color factor and path length dependence of energy loss
- Precision measurements, like γ+jet and π^0+jet, are needed for better understanding (different method and also higher statistics)

Jet-like correlation: γ+hadron

W. Chen, et al. arxiv:1704.03648

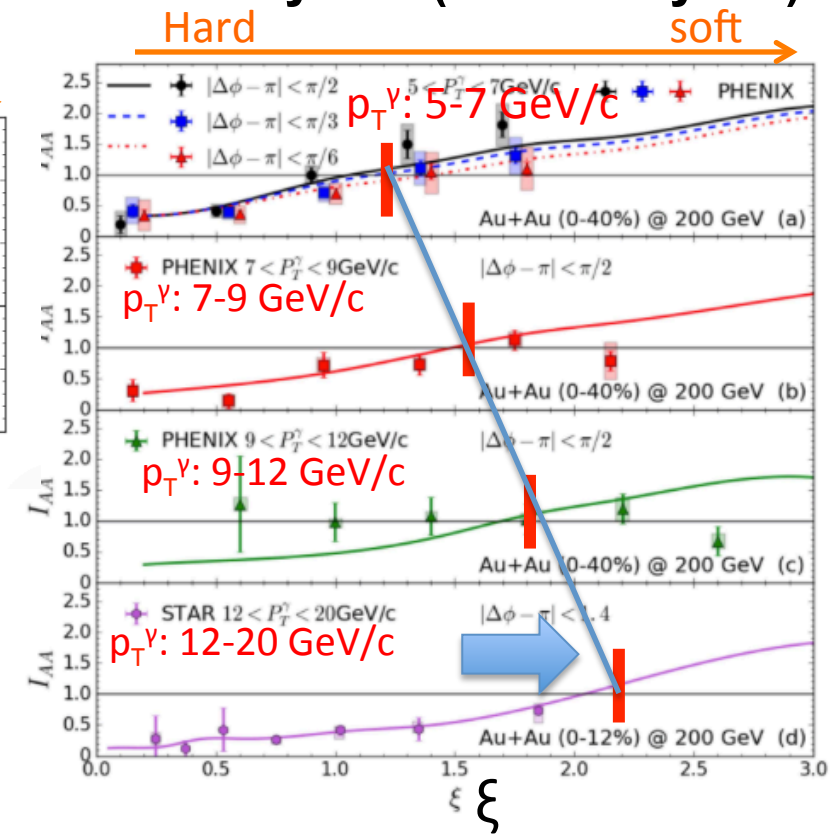
Coupled linear Boltzmann Transport and 3+1D hydro (CoLBT-hydro)

Wei Chen, QM2017 talk



$$\xi = ln\frac{1}{z_T} \qquad z_T \equiv p_T^{assoc}/p_T^{trig}$$

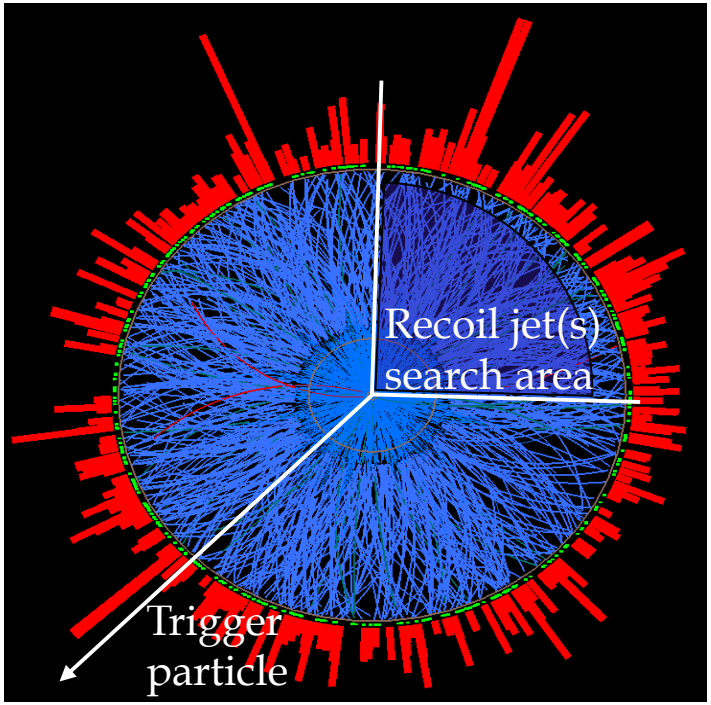
- enhancement of soft hadrons due to jet-induced medium excitation
- medium enhances production of soft particles in parton fragmentation, relative to pp, preferentially at large angles



Similar effect from low to high p_T^γ ?

- Semi-inclusive recoil charged jet
  - $h^{\pm}$+jet [arXiv:1702.01108]
  - γ+jet and π^0+jet [ongoing work: preliminary results:QM2017]

Semi-inclusive hadron+jet



Courtesy of Alex Schmah

Semi-inclusive yield of jets* recoiling from a high p_T hadron trigger

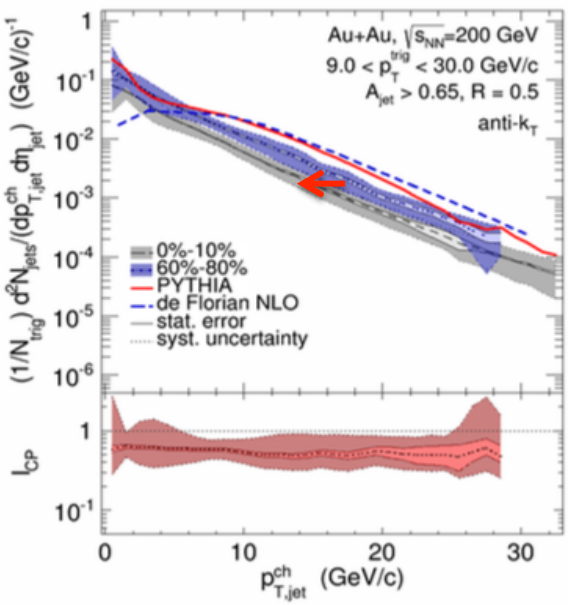
$$\frac{1}{N^h_{trig}}\frac{dN_{jet}}{dp_{T,jet}} = \frac{1}{\sigma^{pp\to h+X}}\frac{d\sigma^{pp\to h+jet+X}}{dp_{T,jet}}$$

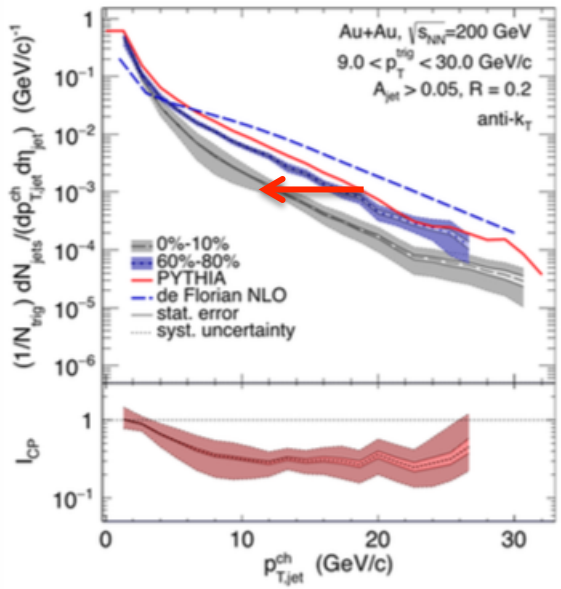
Measured Calculable in fixed-order pQCD

- Use all jet candidates on the other azimuthal hemisphere within +/- 45 degree
  - no fragmentation bias on recoil side
- Mixed event correction for uncorrelated background jets in HIC
  - allow to reach low jet p_T

[arXiv:1702.01108]

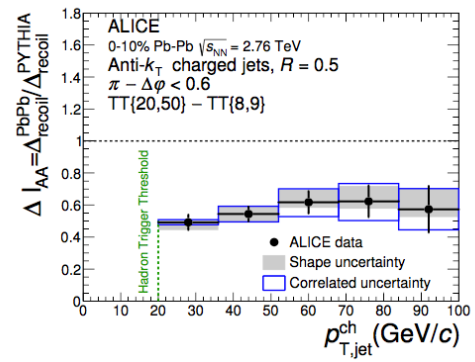
h+Jet yield suppression





[h+jet: arXiv:1702.01108]

ALICE: JHEP09(2015)170



System		Au+Au $\sqrt{s_{NN}}$ = 200 GeV	Pb+Pb $\sqrt{s_{NN}}$ = 2.76 TeV
$p_{T,jet}^{ch}$ range (GeV/c)		[10,20]	[60,100]
		p_T-shift of $Y\left(p_{T,jet}^{ch}\right)$ (GeV/c)	
		peripheral→central	p+p→central
R	0.2	$-4.4 \pm 0.2 \pm 1.2$	
	0.3	$-5.0 \pm 0.5 \pm 1.2$	
	0.4	$-5.1 \pm 0.5 \pm 1.2$	
	0.5	$-2.8 \pm 0.2 \pm 1.5$	-8 ± 2

Note: PYTHIA p+p in ALICE *vs.* Peripheral Au+Au in STAR

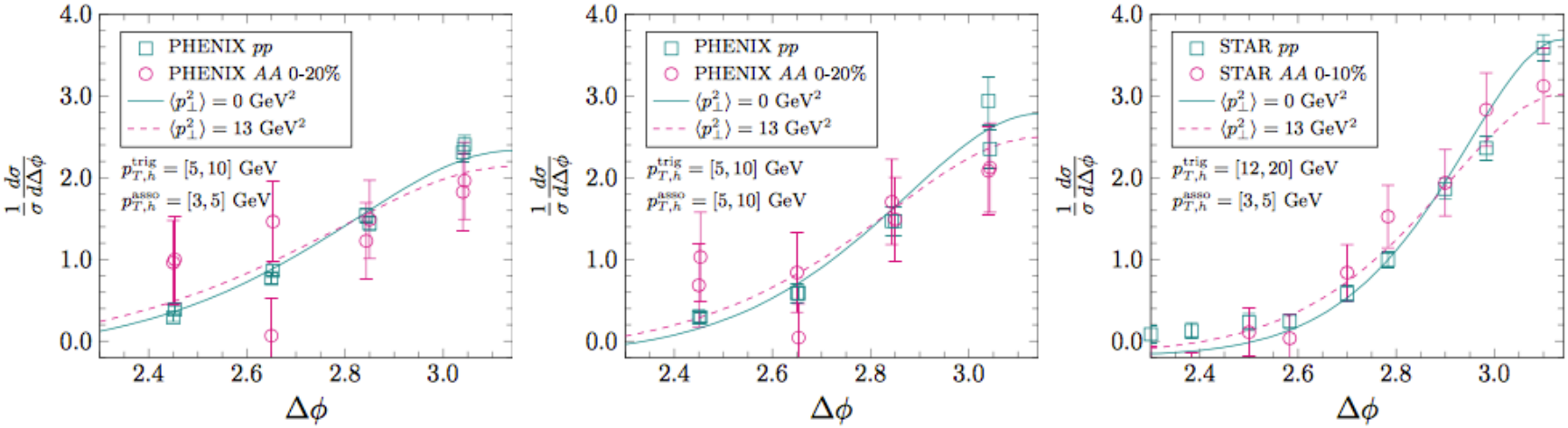
- Energy transported to larger jet R ➔ interaction of jet with the medium
- Medium-induced energy transport to large angles➔lesser at RHIC than LHC

Transverse Momentum Broadening in HIC

Lin Chen, et. al, arXiv:1607.01932

STAR: **h+jet, π^0+hadron**
PHENIX: **charge dihadrons**

Vacuum soft gluon radiation + medium induced p_T broadening

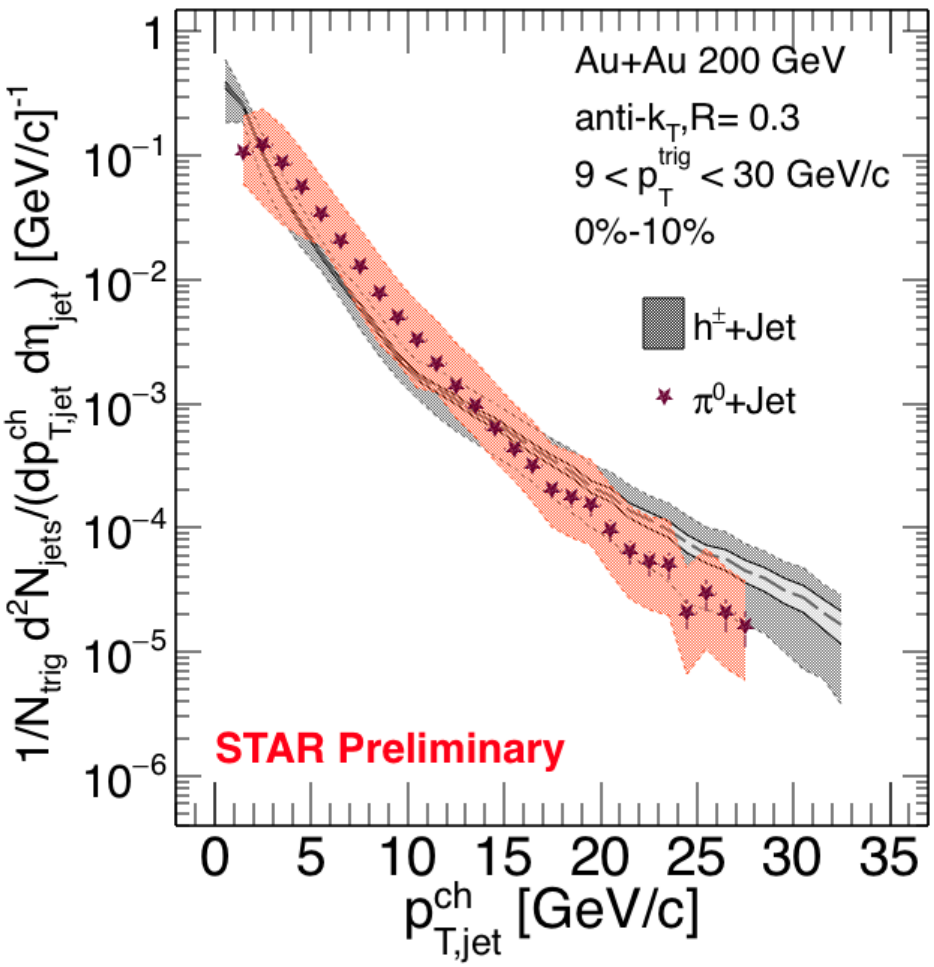


- For a quark jet: the amount of medium-induced p_T broadening $< p_\perp^2 > \sim 13\ \mathrm{GeV}^2$ describes the Au+Au central collisions from RHIC data.(Using global χ^2 analysis)

- Higher statistics and low beam energy (e.g, 62.4 GeV) helpful for better insight of p_T broadening

π^0+jet vs. $h^{\pm}$+jet

N. Sahoo[QM2017 talk]



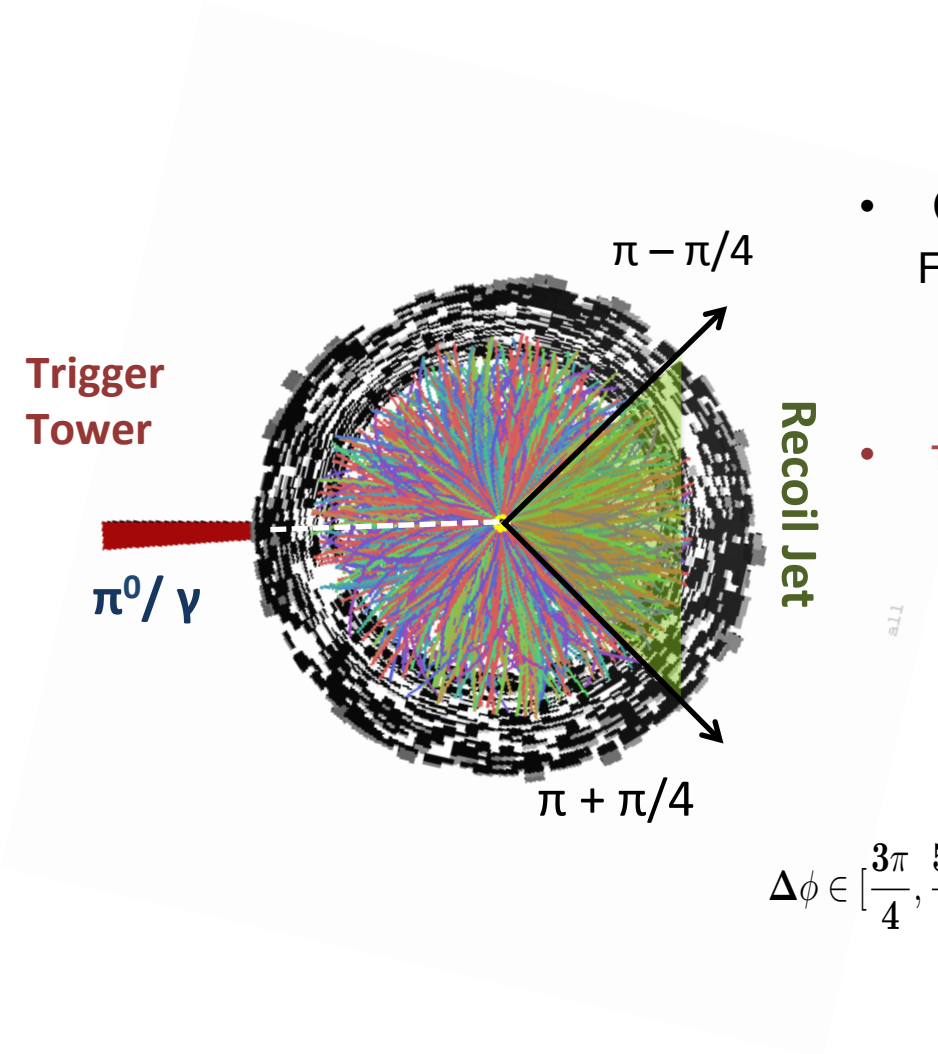
- Applying correction due to detector and background fluctuations effects
  - Singular value decomposition (SVD) method for unfolding
- Taking into account systematic effects, π^0 +jet and $h^{\pm}$+jet show agreement within uncertainties

  ($h^{\pm}$+jet: arXiv:1702.01108)
- Any new information ?
  - I_{cp}, I_{AA},
  - Different hadron trigger

(Ongoing analysis)

What about comparison between γ+jet and π^0 +jet ?

Semi-inclusive γ+jet and π^0+jet



$$\Delta\phi \in [\frac{3\pi}{4}, \frac{5\pi}{4}]$$

- Charged jet reconstruction (using FastJet3.0.6)
  - k_t algorithm for background subtraction
  - Anti-k_t algorithm for jet reconstruction
- π^0/γ discrimination in heavy-ion experiment
  - STAR barrel electromagnetic calorimeter (BEMC) and shower maximum detector (BSMD)
  - Transverse shower profile (TSP) method

π^0 +jet vs. γ+jet

N. Sahoo[QM2017 talk]

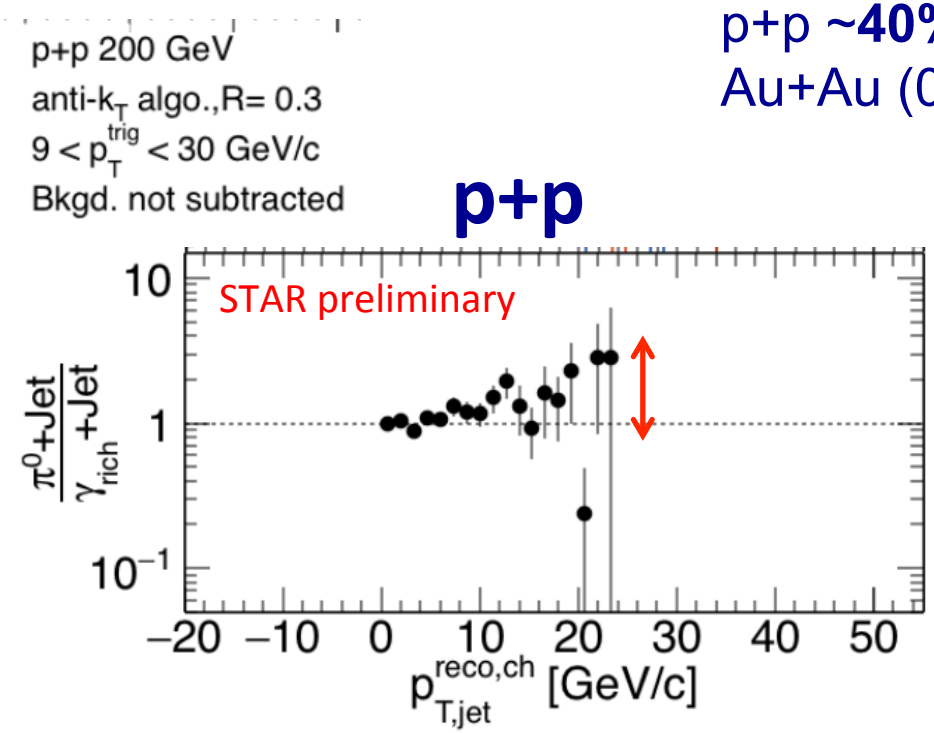
Raw Jet p_T without background and detector effect correction

Purity of γ_{dir} :

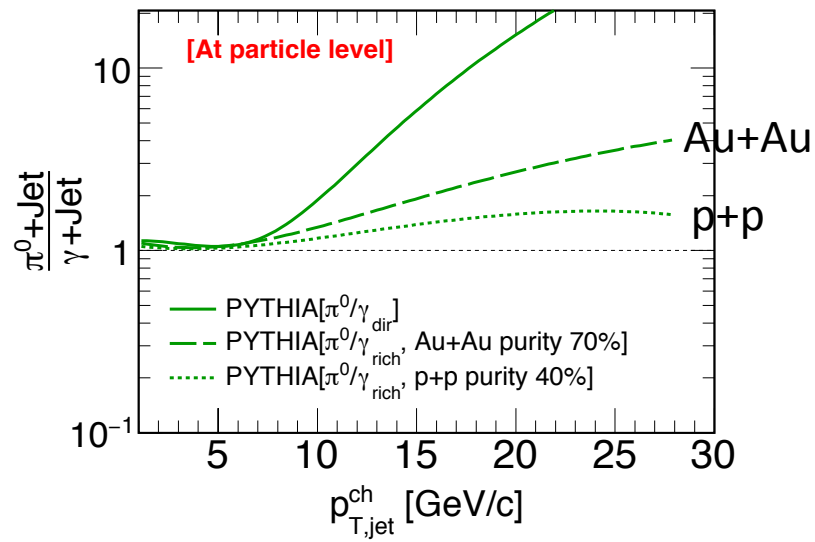
p+p **~40%**

Au+Au (0-10%) **~70%**

[STAR:PLB 760 (2016) 689]



PYTHIA expectation(for different purity of γ_{dir})



(Ongoing analysis)

- PYTHIA predicts larger jet yield for π^0 trigger than γ_{dir}
  (π^0 carries ~85% energy of near side parton, STAR:PLB 760 (2016) 689)
- In p+p, reasonable agreement with standalone PYTHIA considering purity of γ_{dir}

π^0 +jet vs. γ+jet

N. Sahoo[QM2017 talk]

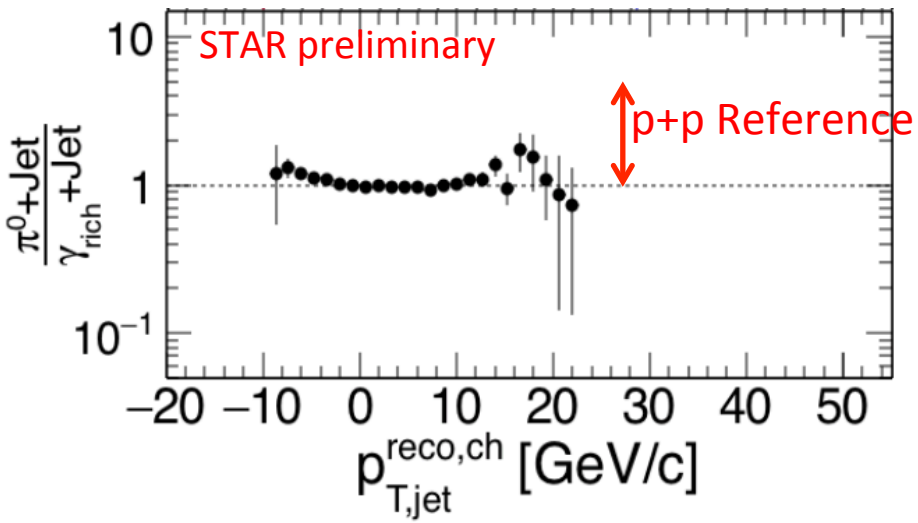
Raw Jet p_T without background and detector effect correction

Au+Au 200 GeV
anti-k_T,R= 0.3
$9 < p_T^{trig} < 30$ GeV/c
0%-10%
Bkgd. not subtracted

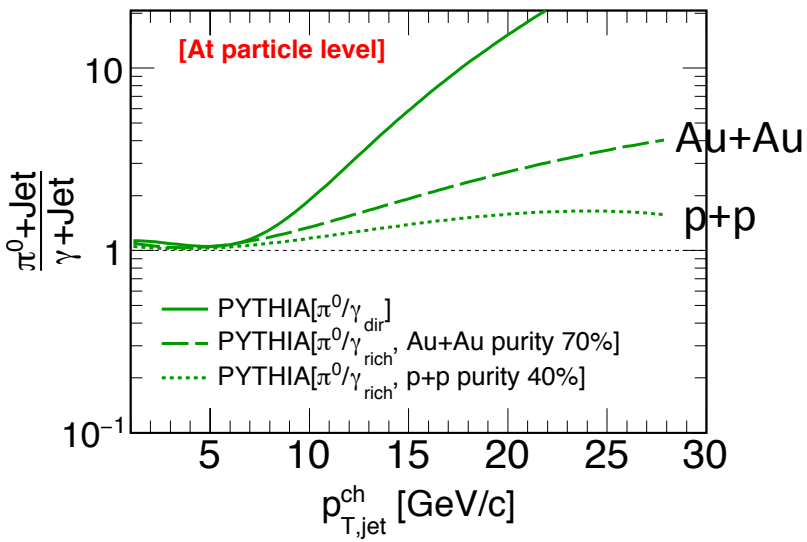
Purity of γ_{dir} :
p+p **~40%**
Au+Au (0-10%) **~70%**

[STAR:PLB 760 (2016) 689]

Au+Au



PYTHIA expectation(for different purity of γ_{dir})



(Ongoing analysis)

- Medium effect ? (Color factor and/or path length effect)
- To extract medium effect for π^0 +jet vs. γ+jet, need full corrections, detailed study and large statistics

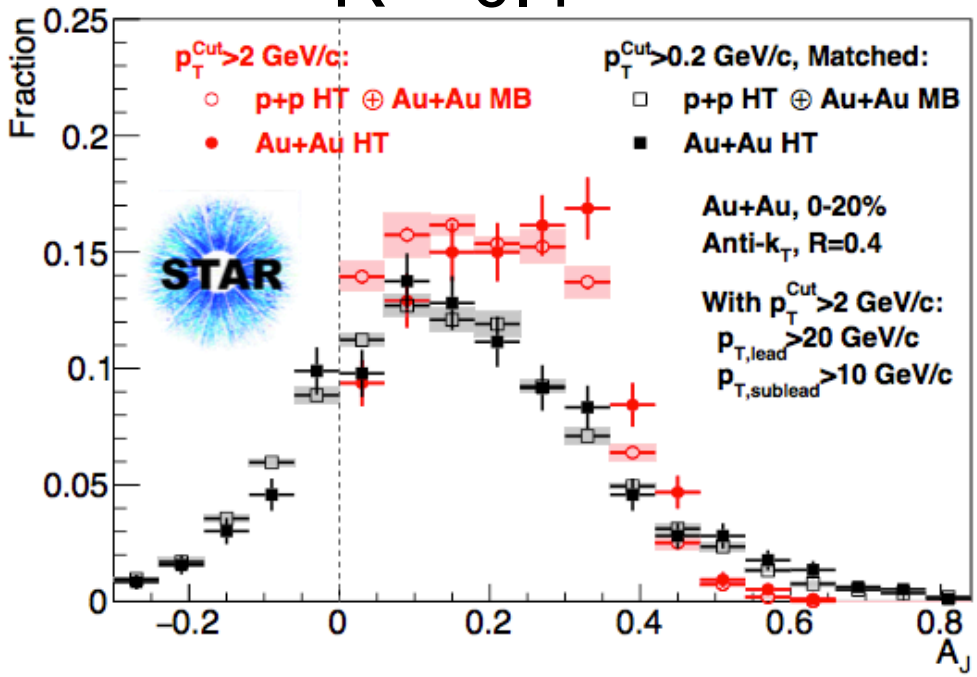
- Di-jet
  - A_J measurements [accepted in PRL, arXiv:1609.03878]
  - Di-jet+hadron correlation [preliminary results:QM2017]

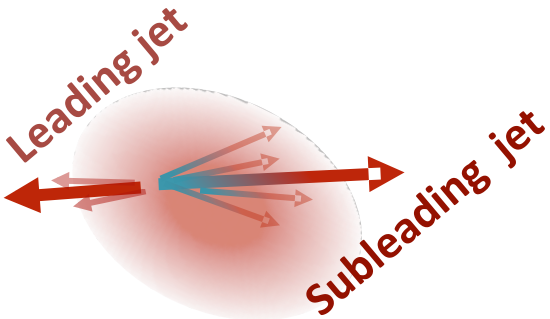
- Di-jet z_g (Groomed Momentum Sharing z_g)

Di-jet imbalance

Accepted by PRL
arXiv:1609.03878

R = 0.4





Charged + neutral constituents
"Hard Core:"
High Tower (HT) trigger E_T>5.4 GeV
p_T^{Cut} = 2 GeV/*c*

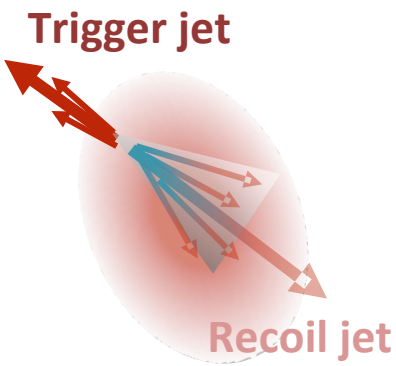
$$A_J = \frac{p_T^{\mathrm{Lead}} - p_T^{\mathrm{SubLead}}}{p_T^{\mathrm{Lead}} + p_T^{\mathrm{SubLead}}}$$

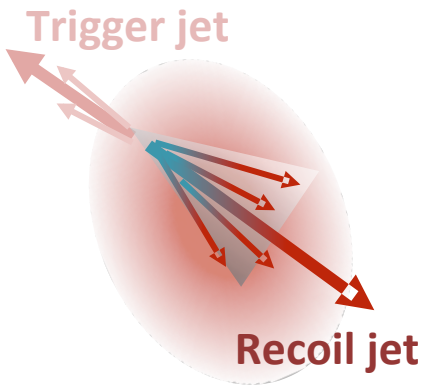
- Stronger di-jet Imbalance in AuAu for p_T^{Cut} > 2 GeV for hard core selection
- But pp balance recovered for p_T^{Cut} > 0.2 GeV for R=0.4 (Not for R=0.2!)

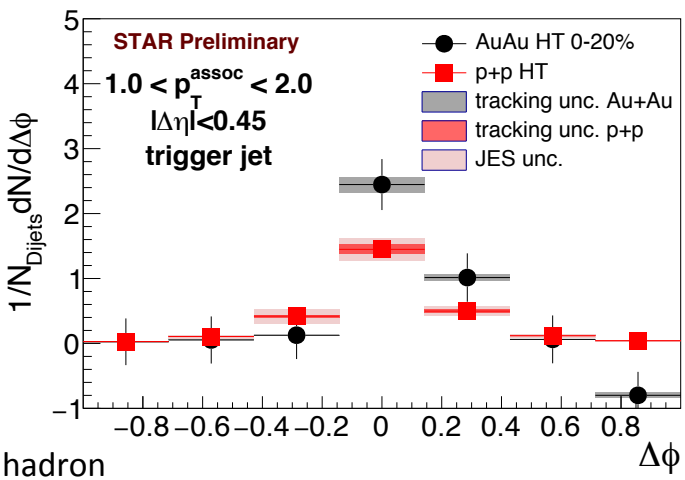
How do we understand the redistribution of energy within each jets ?

Dijet+hadron correlation

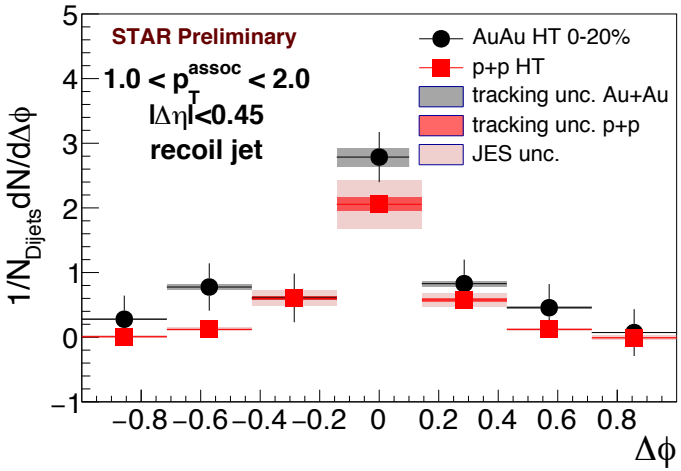
Updated Hard Core selection:
p_T^{Cut} = 2 GeV/*c*
and Jet p_T^{Lead}>20 GeV/c
Jet $p_T^{SubLead}$>10 GeV/*c*
Trigger Jet contains HT with
E_T>6 GeV







$\Delta\phi = \phi^{trig} - \phi^{hadron}$



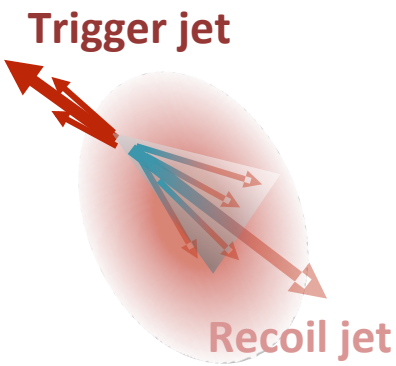
$\Delta\phi = \phi^{recoil} - \phi^{hadron}$

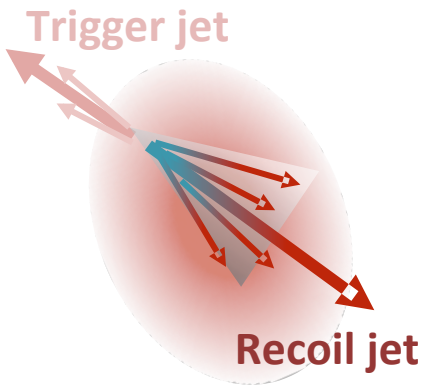
Similar observation in Δη correlation.

Nick Elsey
QM2017 poster

Jet yields in Au+Au and p+p collisions

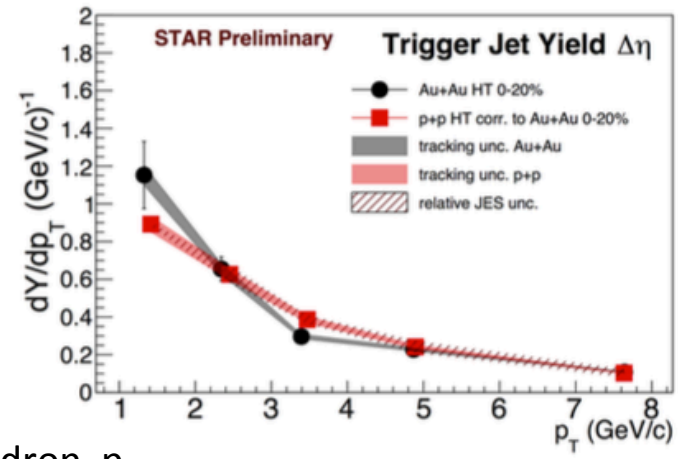
Updated Hard Core selection:
p_T^{Cut} = 2 GeV/*c*
and Jet p_T^{Lead}>20 GeV/c
Jet $p_T^{SubLead}$>10 GeV/*c*
Trigger Jet contains HT with
E_T>6 GeV

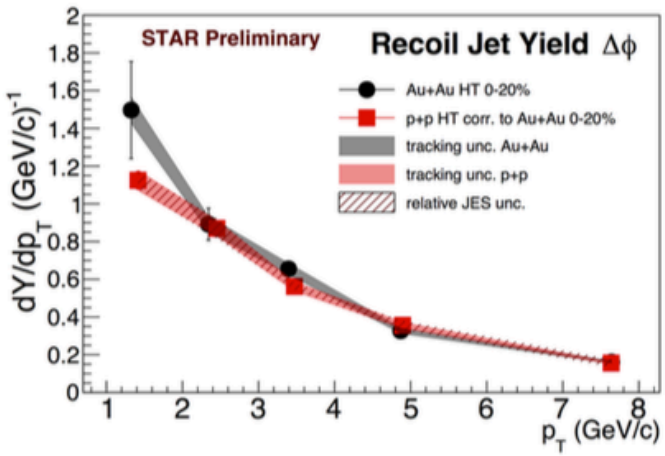




N. Sahoo
[QM2017 talk]

Nick Elsey
QM2017 poster





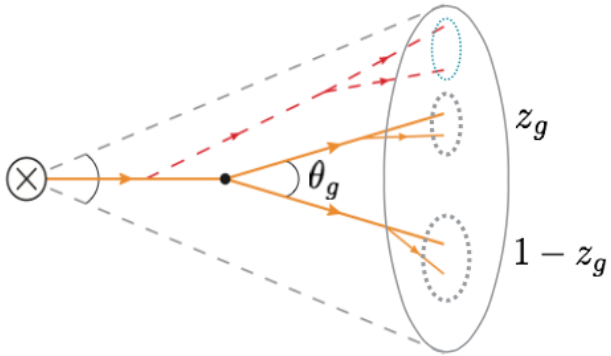
Associated hadron p_T

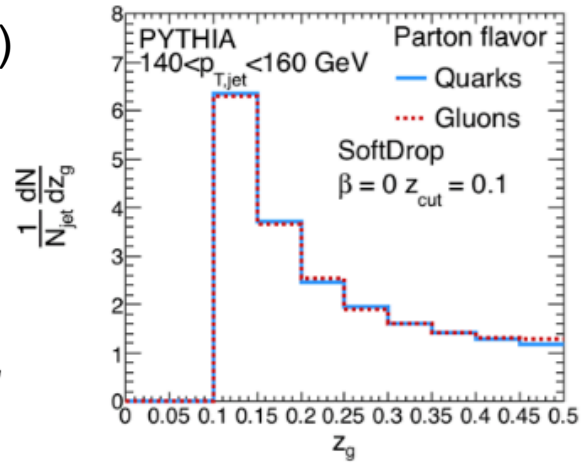
- Trigger jet +hadron: no significant difference (Surface biased)
- Recoil jet +hadron: hints of excess yields at low hadron p_T < 2 GeV/c
- Expecting excess yields in Au+Au than p+p, but hints of balanced dijets (because no A_J cut is used)

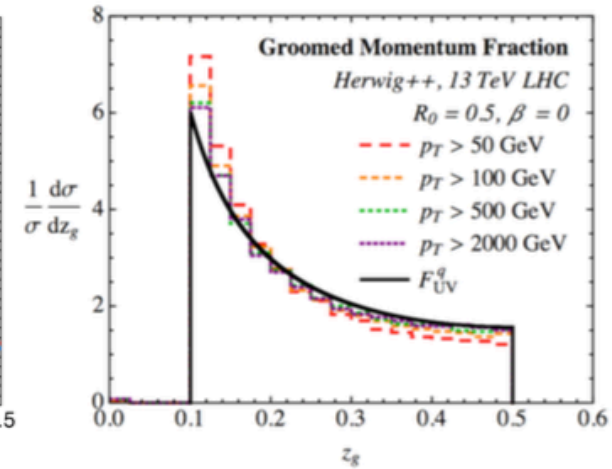
Jet grooming

Removes soft divergences and uncorrelated backgrounds in a jet

Shared momentum fraction (z_g)







JHEP 1405 (2014) 146

Soft drop condition

$z > z_{cut}\,\theta^{\beta}$

$$z_g = \frac{\min(p_{T1}, p_{T2})}{p_{T1} + p_{T2}}$$

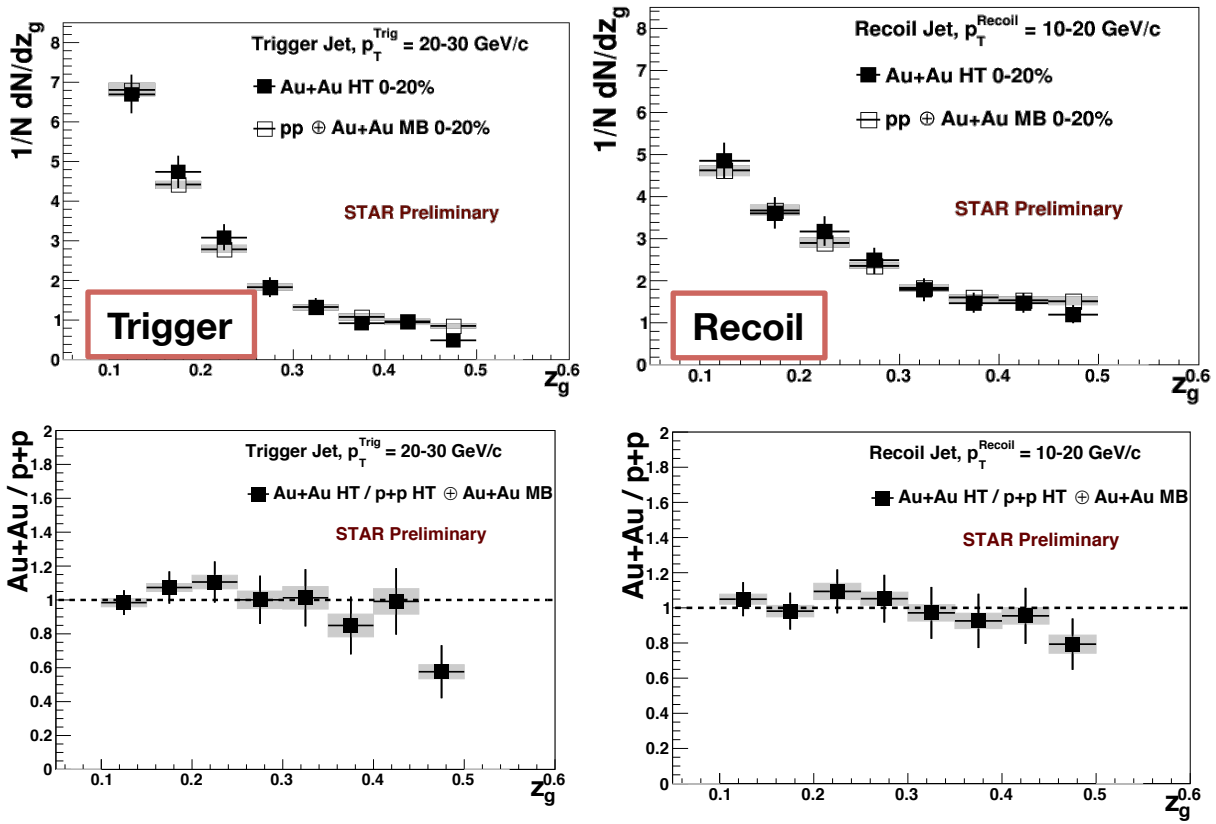
Momentum fraction carried by the subleading branch

No flavor and (weak) jet p_T dependence

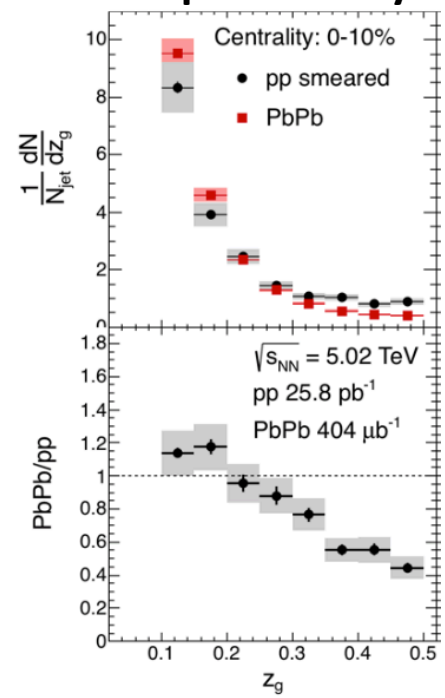
Marta Verweij
QM2017 talk

Di-jet z_g in Au+Au and p+p

K. Kauder[QM2017 talk]



CMS preliminary



$$z_g = \frac{\min(p_{T1}, p_{T2})}{p_{T1} + p_{T2}}$$

- No significant splitting modification on near- or away-side (with hard-core jet selection but A_J is modified!)
- Contrast to LHC (Note:No dijet selection)

What we learned so far ?

- **Jet-like correlation** **(γ+hadron and π^0+hadron)**
  - Precision measurements to understand color factor and path length effect
  - CoLBT-Hydro: jet-induced medium excitation and soft particle emission at large opening angle
  - Extracting of medium induced p_T broadening
- **Semi-inclusive recoil charged jet** **($h^{\pm}$+jet /γ+jet)**
  - Energy transported to larger jet cone R due to interaction of jet with the medium
  - Lesser medium-induced energy transport to large angles at RHIC than LHC (Lower RHIC energy, i.e. 62.4 GeV, may give more info)
  - π^0+jet *vs.* γ+jet: hints of medium effect ? Ongoing work…
- **Di-jet**
  - "Lost" energy contained within R=0.4
  - Splitting via z_g not modified

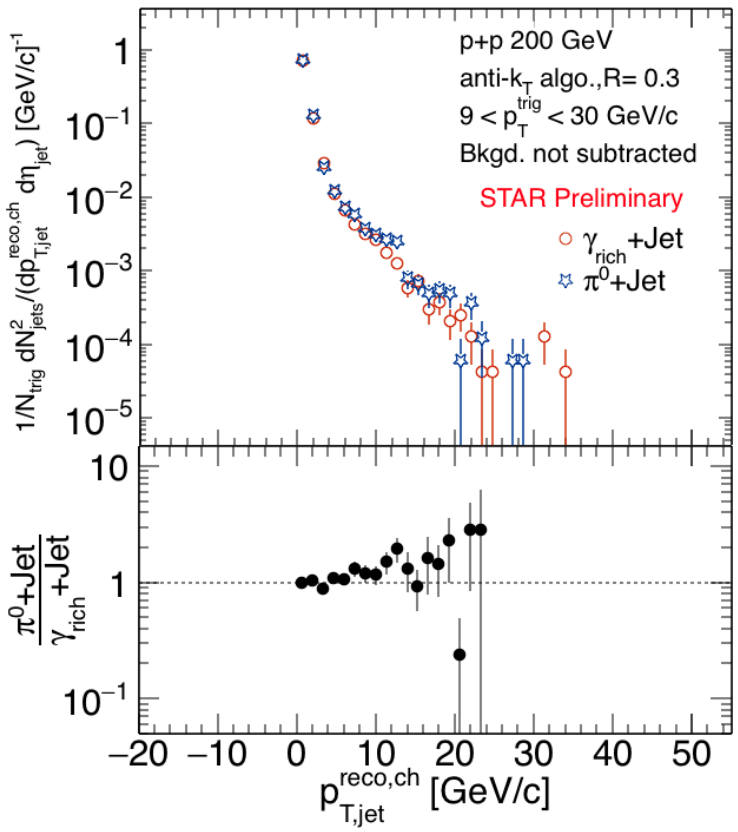
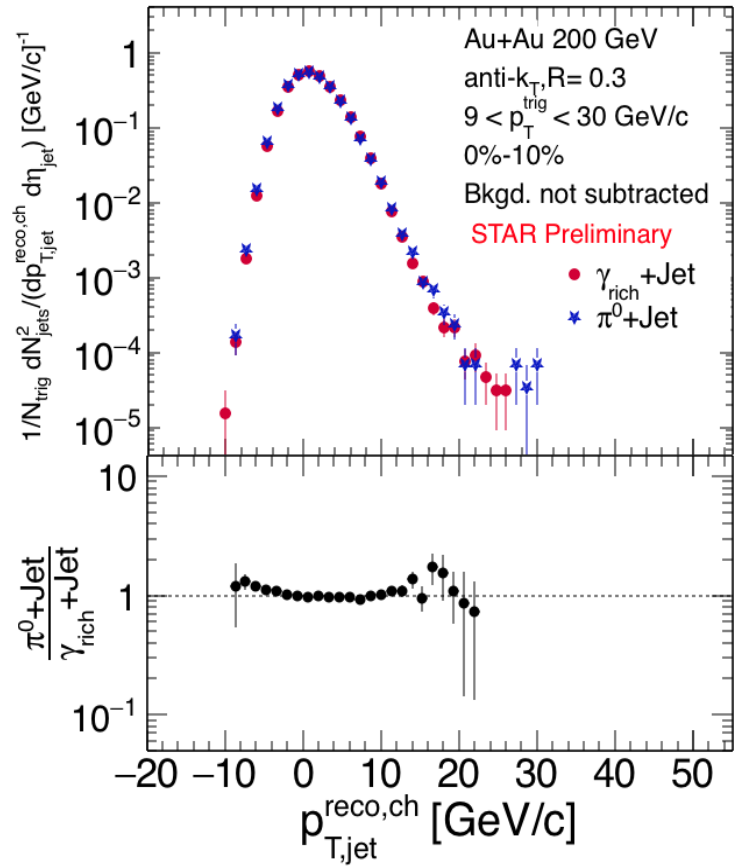
Stay tuned….

Back Up

π^0 +jet vs. γ+jet

Raw Jet p_T without background and detector effect correction

p+p



Au+Au