Angular structure of jet quenching within a hybrid strong/weak coupling model

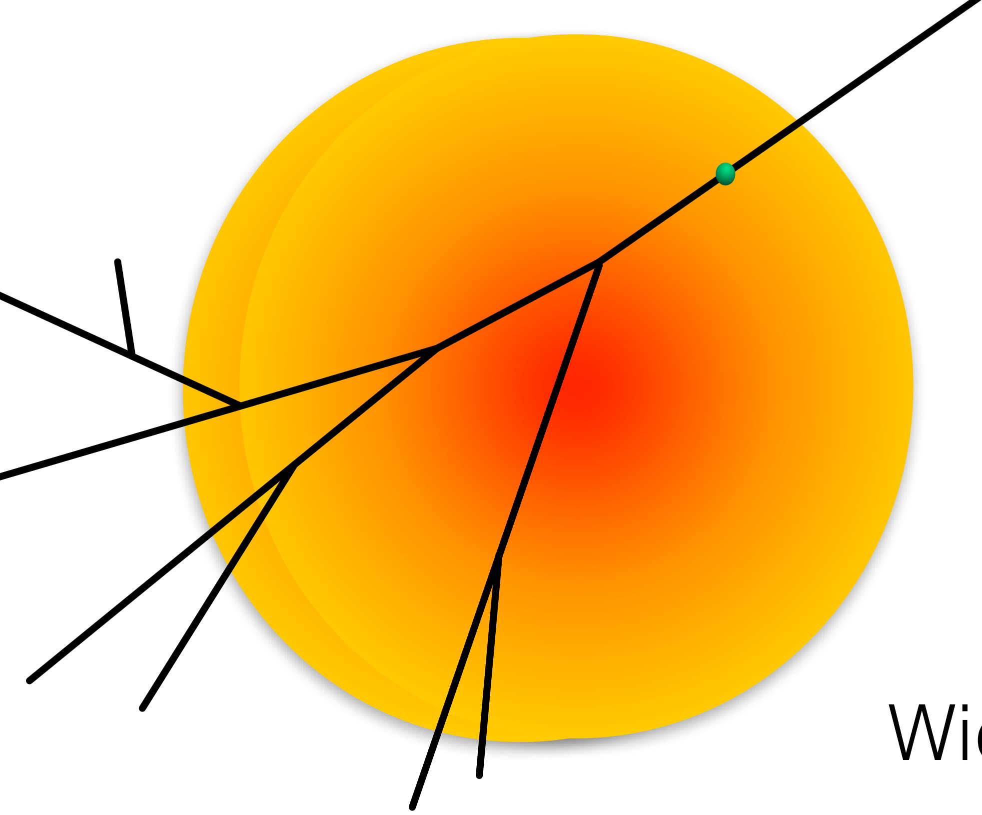
J. Casalderrey-Solana, D. Gulhan, G. Milhano, DP, K. Rajagopal, arXiv:1609.05842

Daniel Pablos Alfonso

24th September 2016
Hard Probes

UNIVERSITAT DE BARCELONA

EXCELENCIA MARÍA DE MAEZTU



A Hybrid Model: Motivation

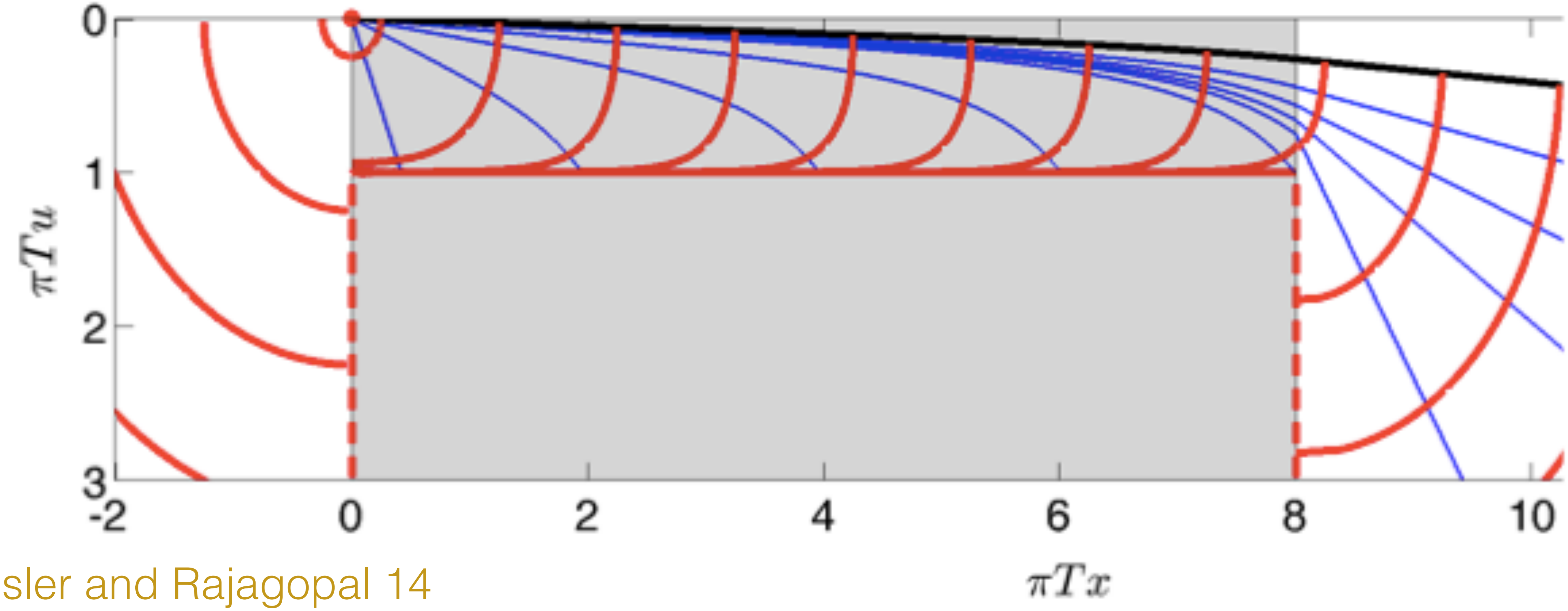
Wide hierarchy of scales in (HE) jet dynamics:

- Production and branching perturbative
- Interaction with QGP non-perturbative

Approached through simple and phenomenological model:

- Vacuum like production and showering
- Differential energy loss rate from holography
- Neglect medium induced modification of splittings (for now)

Strongly Coupled Energy Loss

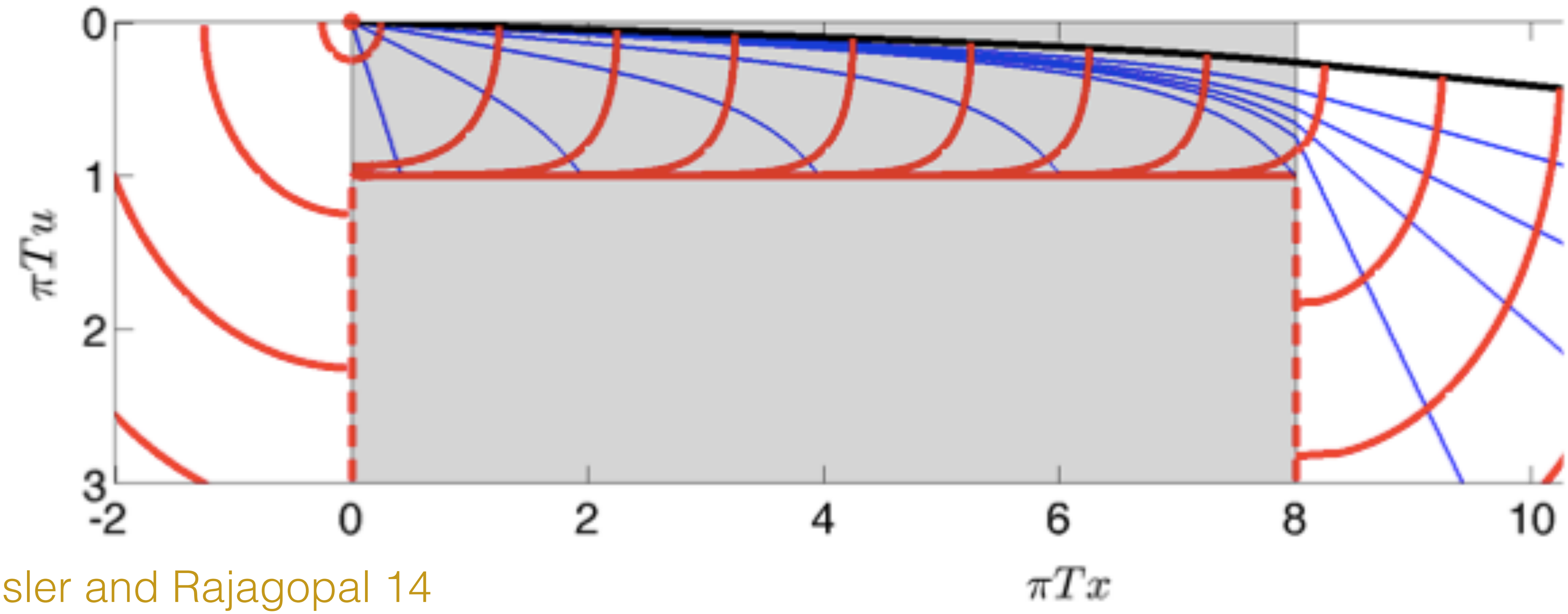


Chesler and Rajagopal 14

Long-lived light quark are
approximately null strings

Classical in the limit of
large 't Hooft coupling

Strongly Coupled Energy Loss



Chesler and Rajagopal 14

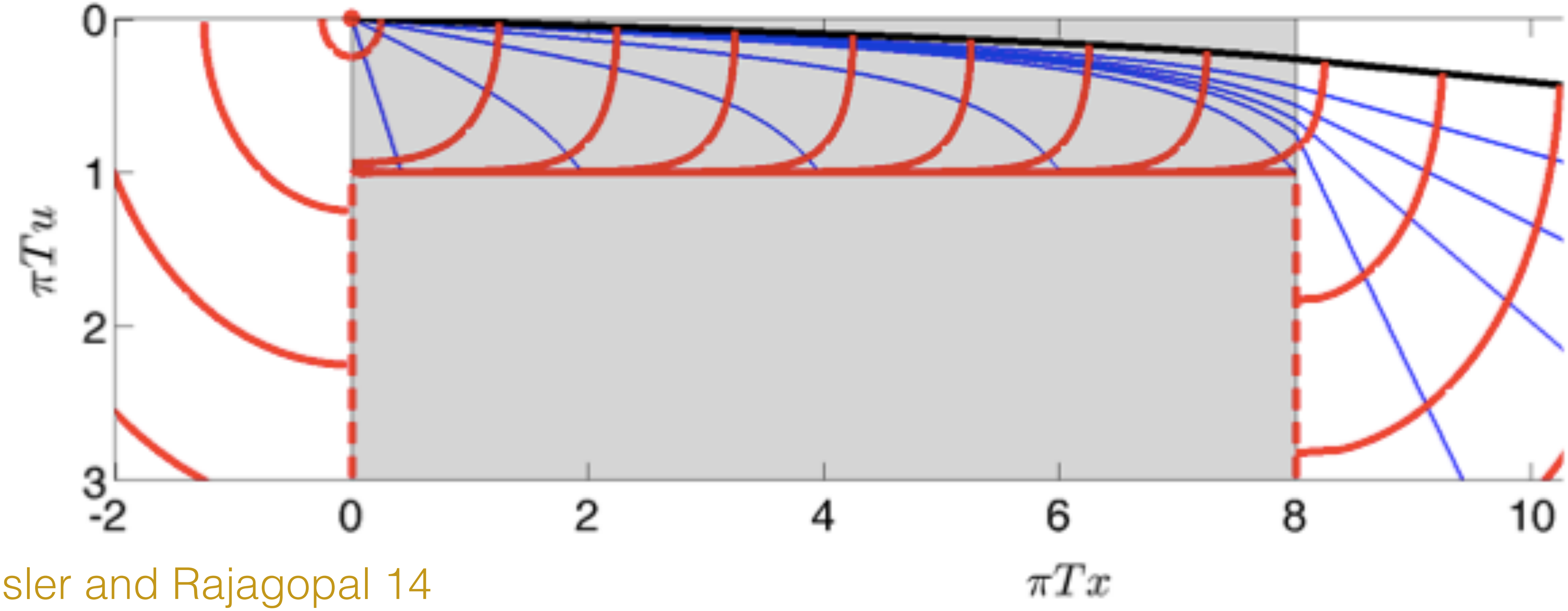
Long-lived light quark are approximately null strings

Classical in the limit of large ’t Hooft coupling

Expand around degenerate null configuration

String profile determines the amount of thermalised energy

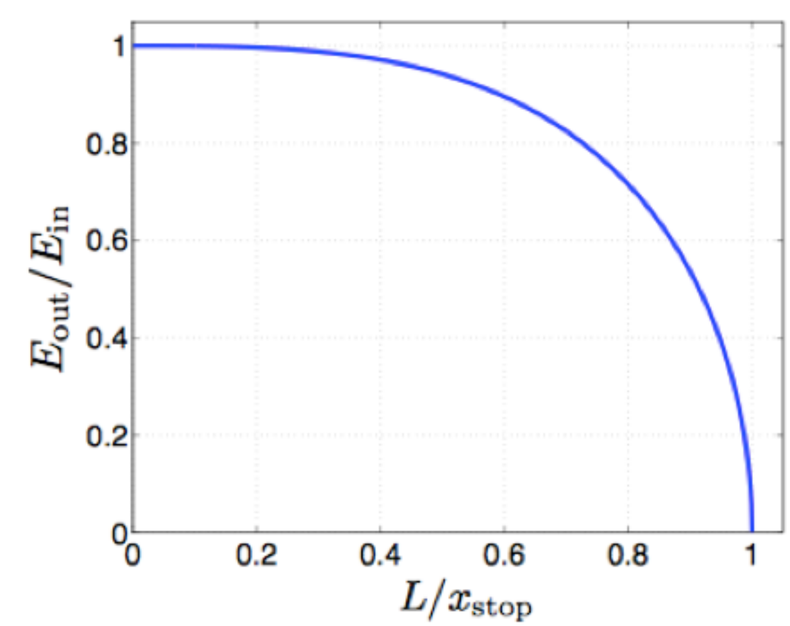
Strongly Coupled Energy Loss



Chesler and Rajagopal 14

$$\frac{1}{E_{\text{in}}}\frac{dE}{dx} = -\frac{4}{\pi}\frac{x^2}{x_{\text{stop}}^2}\frac{1}{\sqrt{x_{\text{stop}}^2 - x^2}}$$

$$x_{\text{stop}} = \frac{1}{2\,\kappa_{\text{sc}}}\frac{E_{\text{in}}^{1/3}}{T^{4/3}}$$



Value of κ_{sc} different in different setups

$\lambda \equiv g^2 N_c$

$$\kappa_{sc} \sim \lambda^{1/6}$$

String computations

Gubser et al 08, Chesler et al 08, Ficnar and Gubser 13, Chesler and Rajagopal 14

$$\kappa_{sc} \sim \lambda^{0}$$

U(1) field decays

Hatta, Iancu and Mueller 08, Arnold and Vaman 10

$$\lambda \sim 10 \rightarrow \kappa_{sc} \sim \mathcal{O}(1)$$

We'll use κ_{sc} as our fitting parameter

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expect it to be smaller in QCD than in N=4 SYM

We'll use κ_{sc} as our fitting parameter

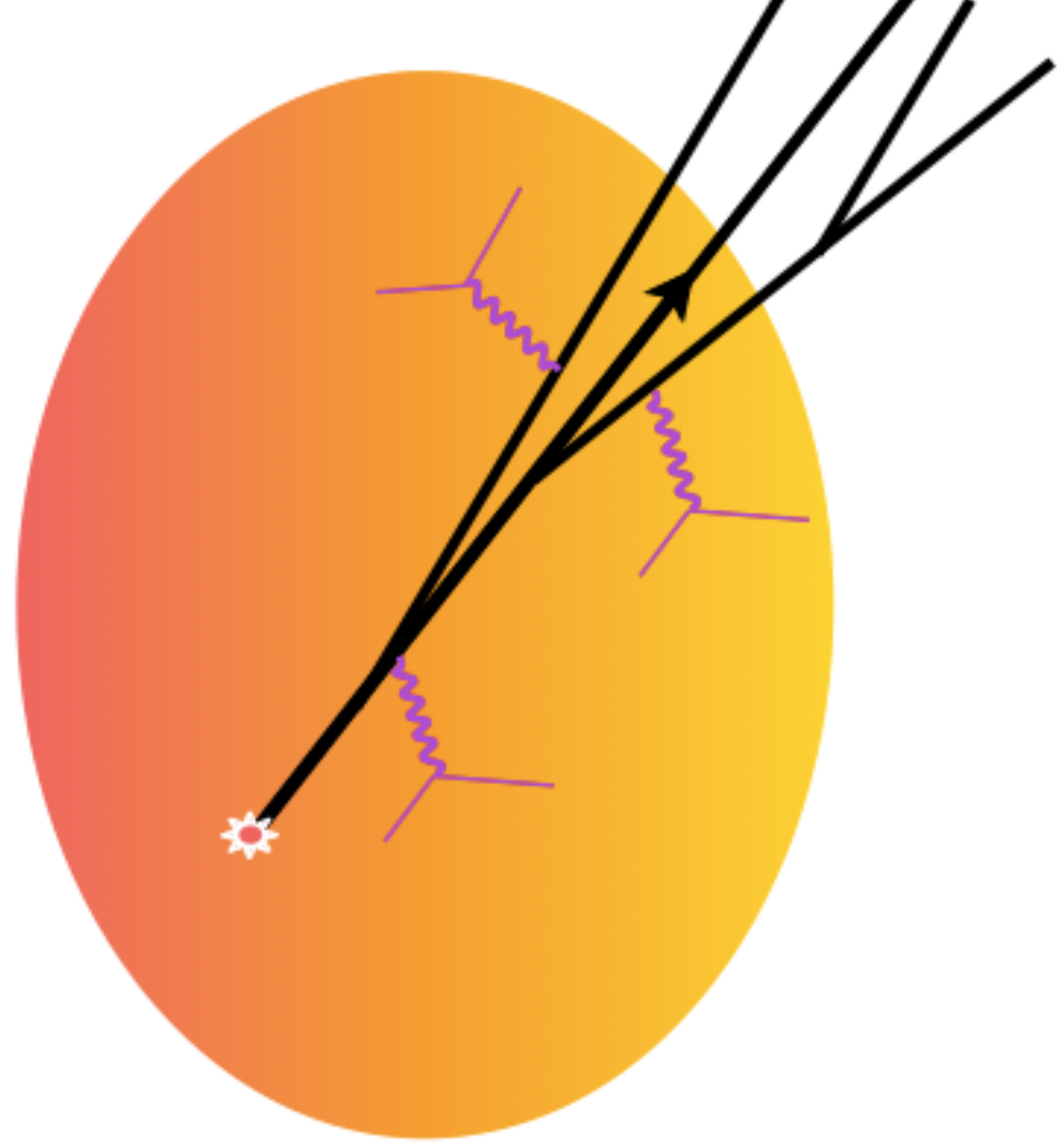
What about gluons?

$$x^{G}_{stop}(E) = x^{Q}_{stop}(E/2)$$

$$\kappa^{G}_{sc} = \kappa^{Q}_{sc}\left(\frac{C_A}{C_F}\right)^{1/3}$$

Chesler et al 08

Monte Carlo Implementation



Jet production and evolution in PYTHIA

Assign spacetime description to parton shower (formation time argument) $\tau_f = \frac{2E}{Q^2}$

Embed the system into a hydrodynamic background (2+1 hydro code from Heinz and Shen)

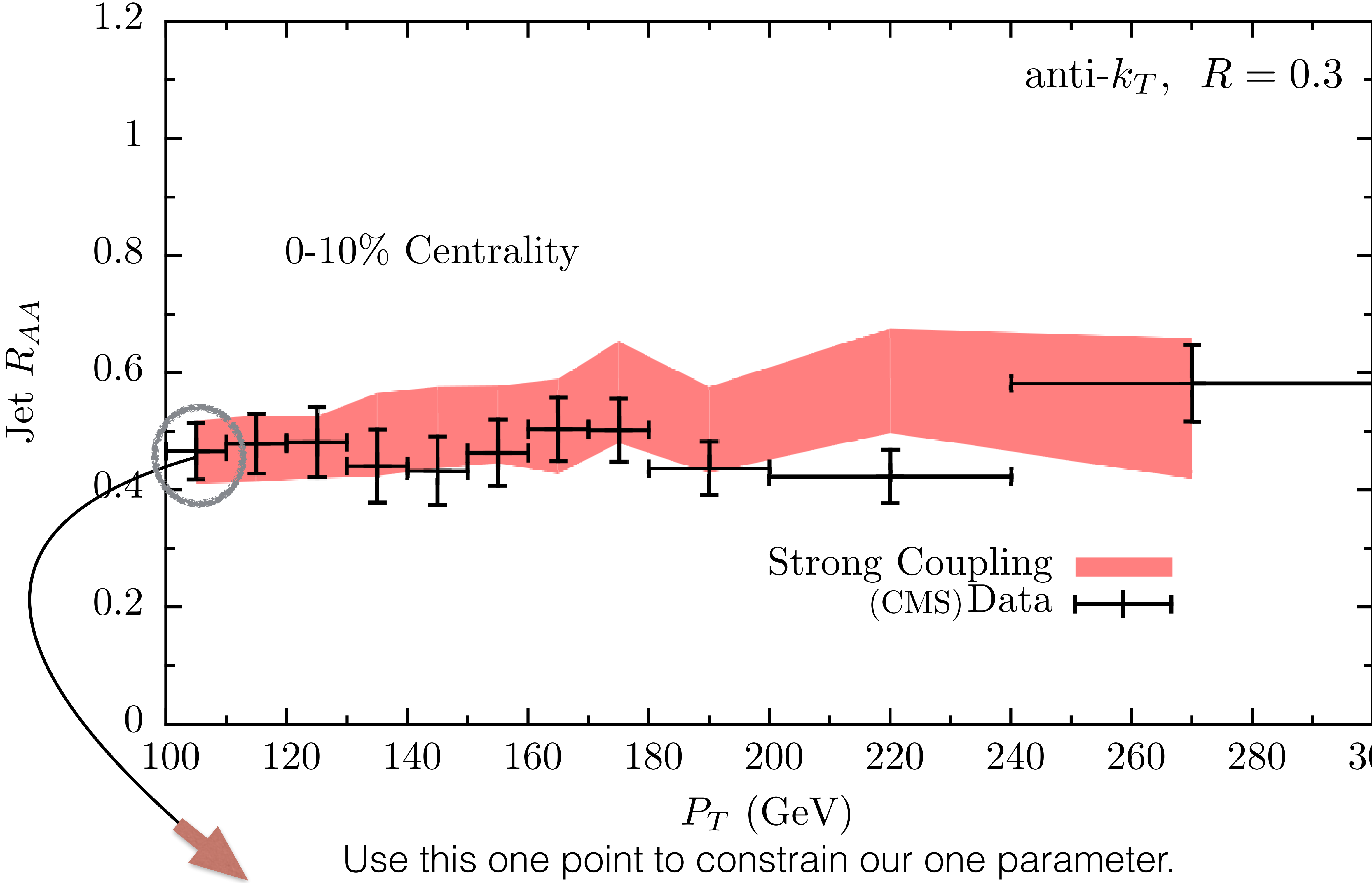
Between splittings, partons in the shower interact with QGP, lose energy

Turn off energy loss below a T_c that we vary over $145 < T_c < 170\,\mathrm{MeV}$

Extract jet observables from parton shower

more details in
MCs Round Table today

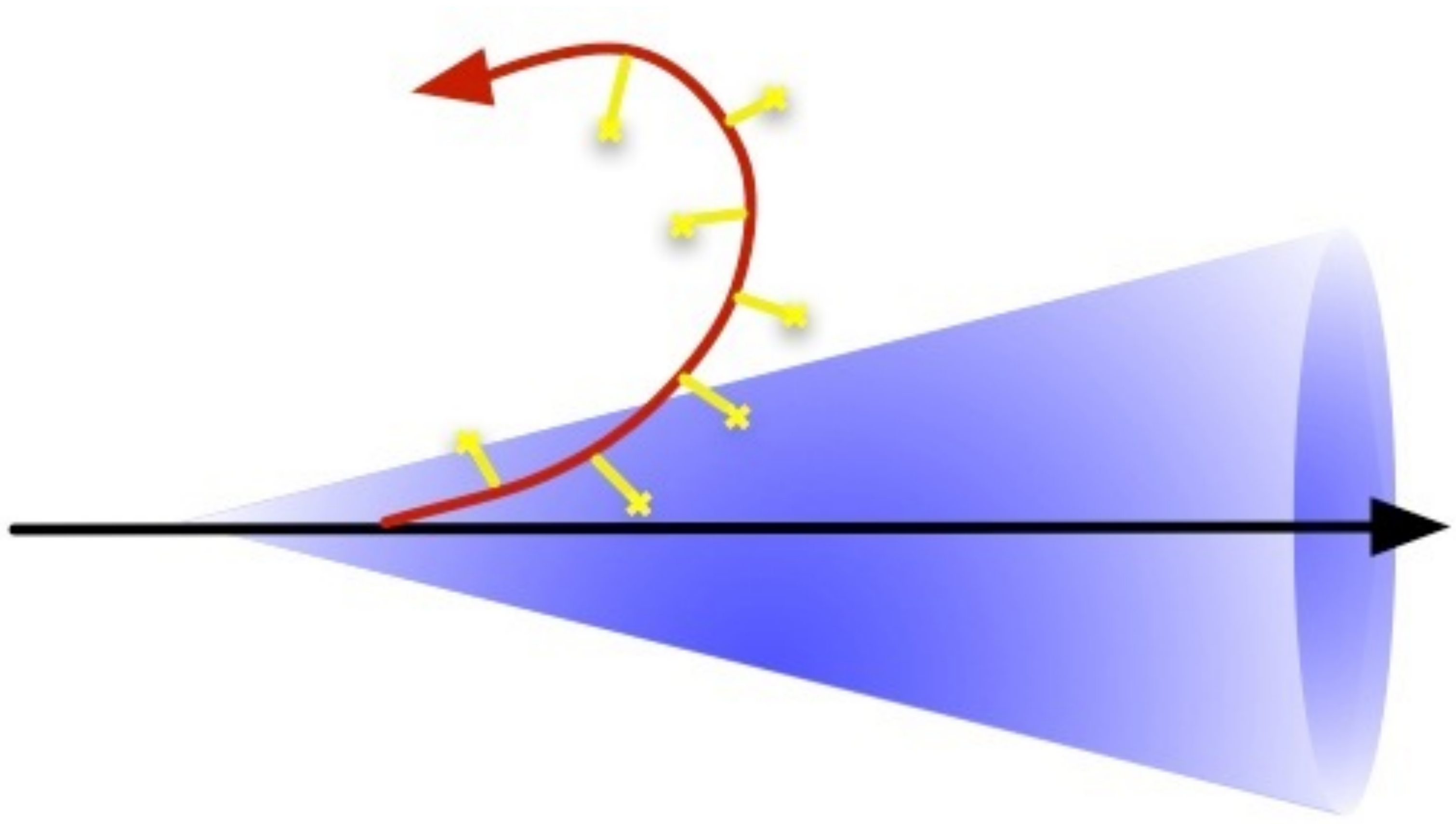
R_{AA}



Use this one point to constrain our one parameter.

Bands come from experimental uncertainty on this point plus varying T_c over $145 < T_c < 170\,\mathrm{MeV}$

Broadening



Partons receive transverse kicks according to a gaussian distribution

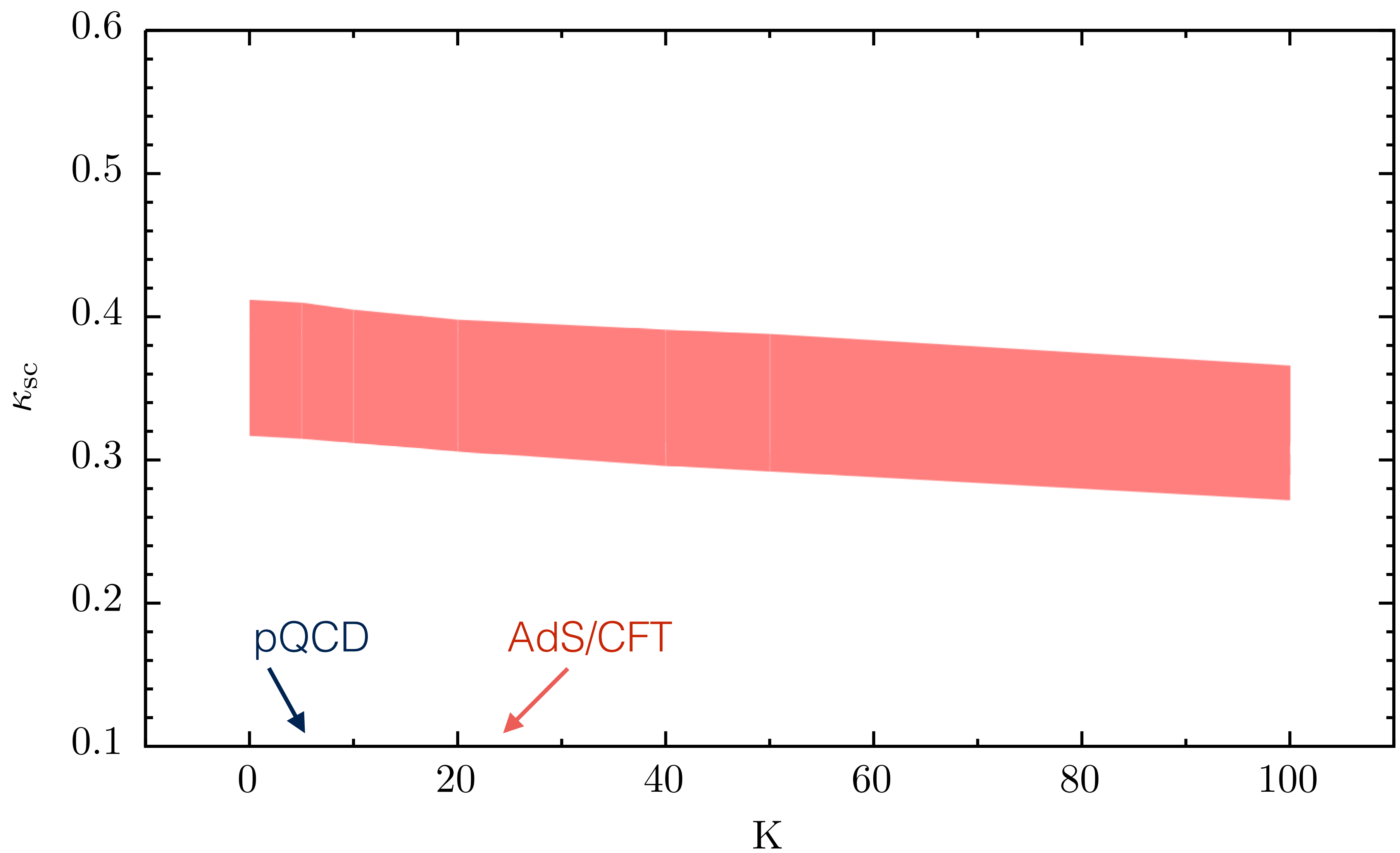
The width of the gaussian is $(\Delta k_T)^2 = \hat{q}\, dx$

Such mechanism introduces a new parameter $K = \frac{\hat{q}}{T^3}$

Transverse kicks can broaden the jet and kick particles out of the jet

more details in
MCs Round Table today

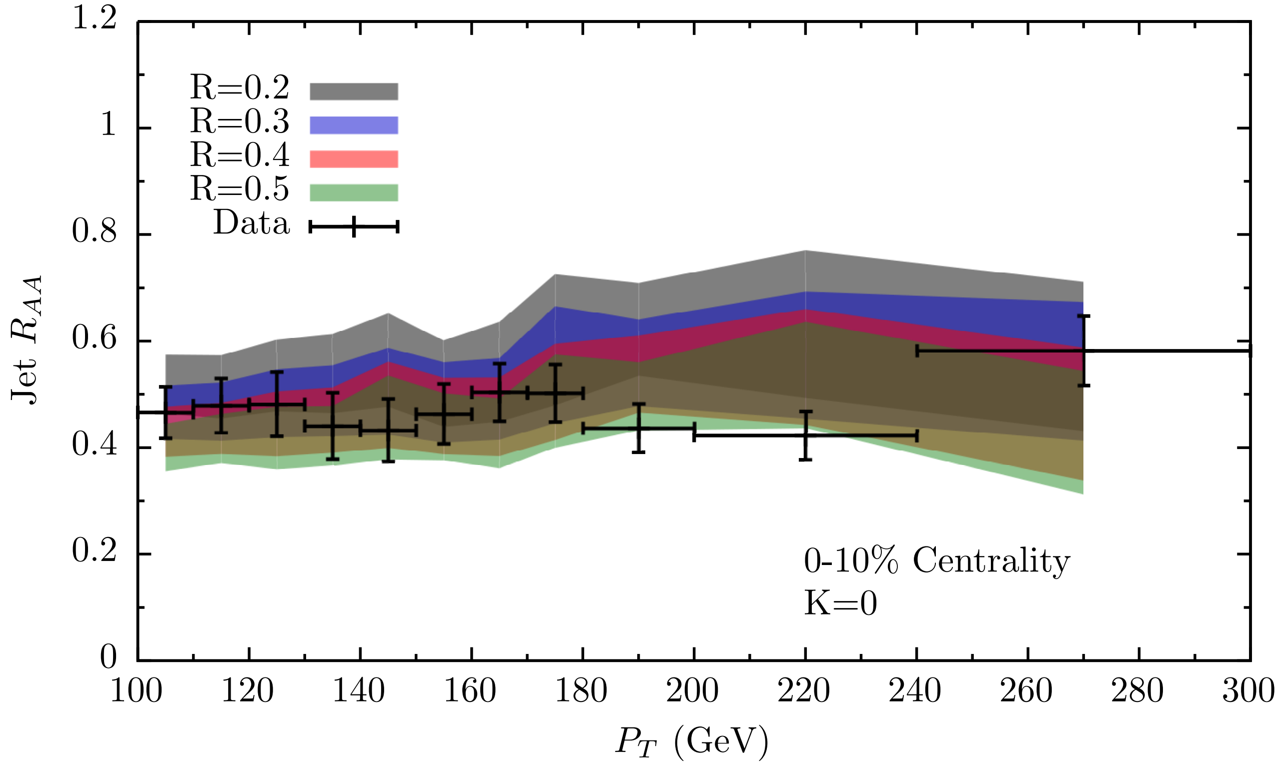
Broadening



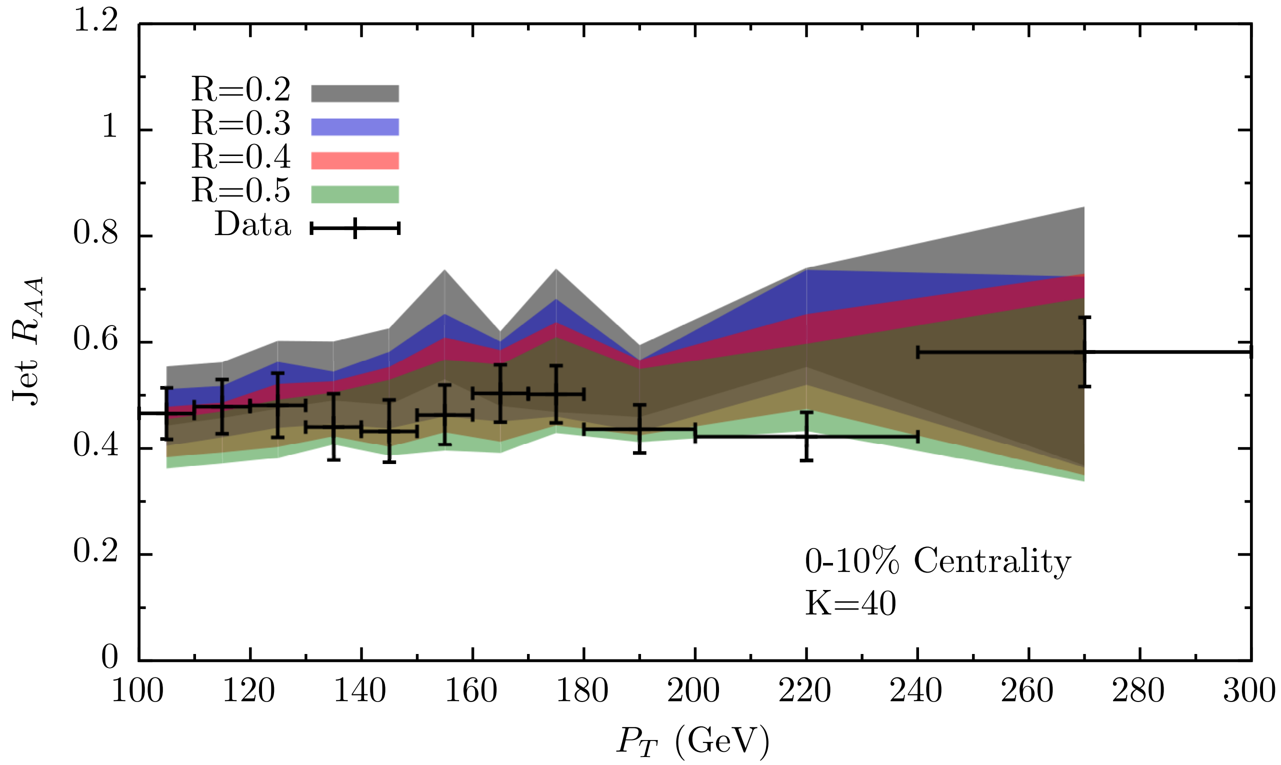
Need to refit stopping distance due to broadening effect: few percent level

Strong quenching mechanism reduces the importance of broadening energy loss

Broadening: RAA vs R

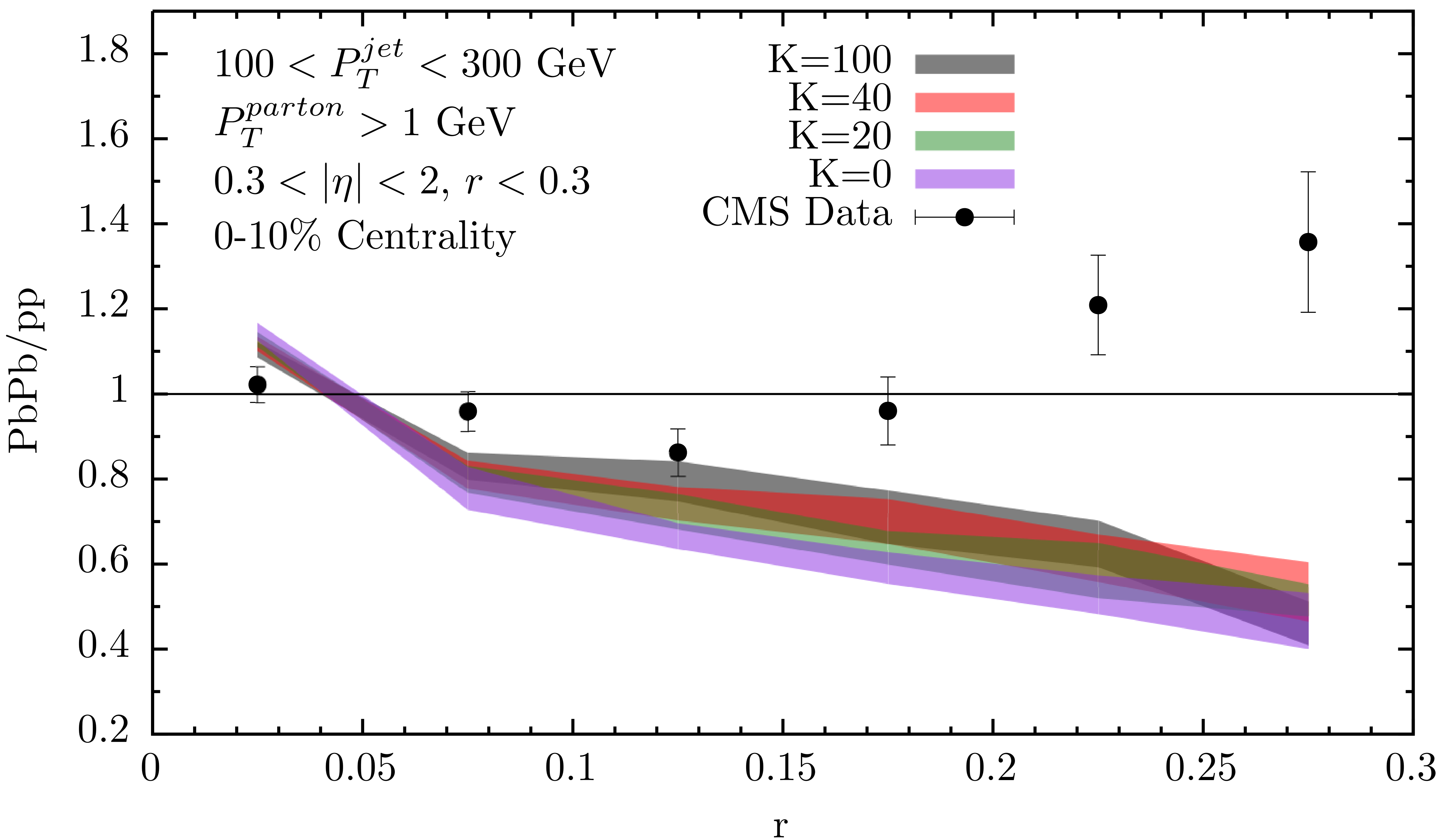


Wider jets slightly more suppressed
due to higher number of energy loss sources



Small effect on quenching due to broadening
translates into small energy recovery
by opening the jet radius

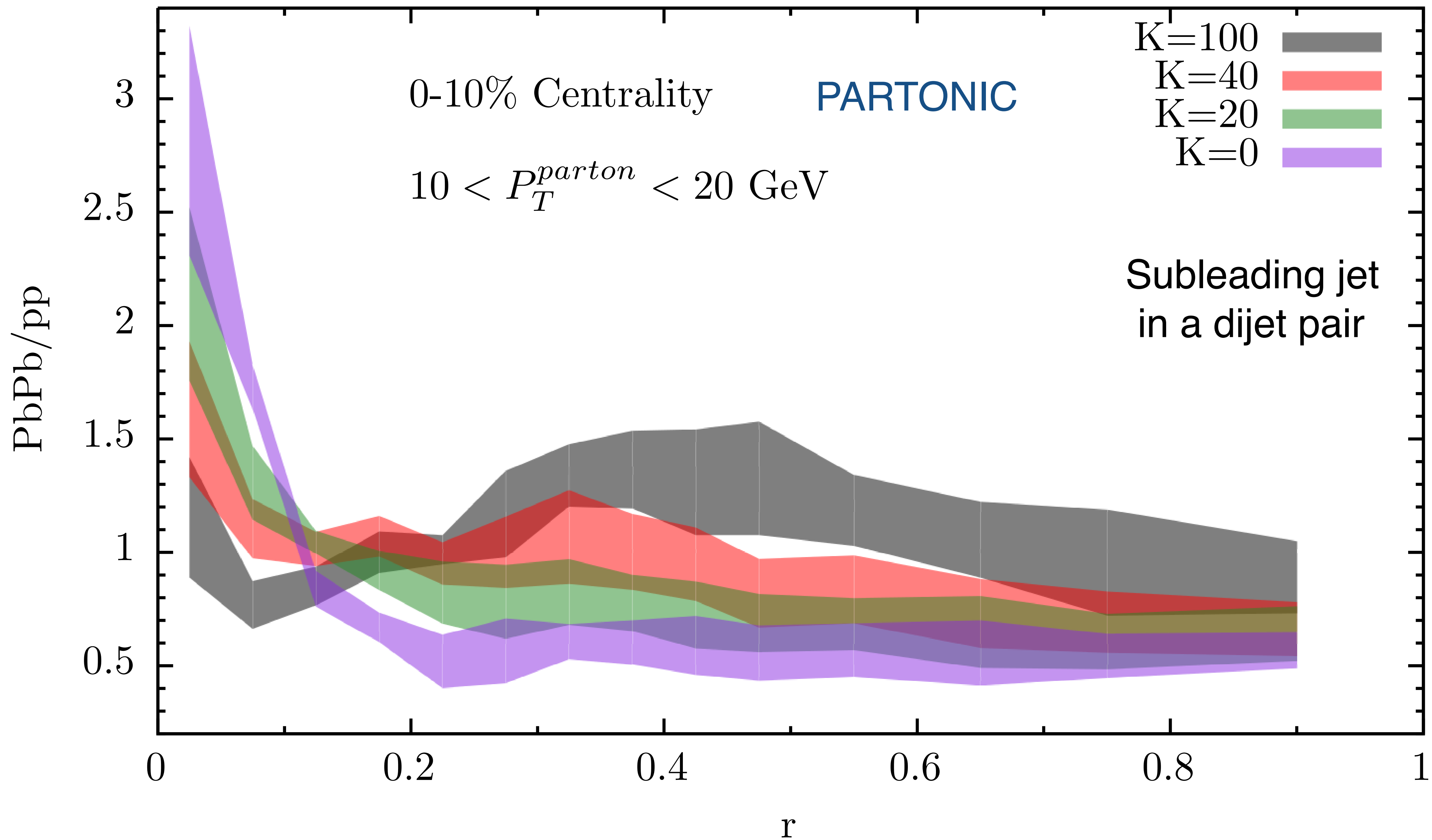
Small sensitivity of standard jet shapes to broadening



Small sensitivity of jet shapes to broadening:

- strong quenching removes soft fragments that appear early
- remaining soft tracks fragment late

A New Observable, Sensitive to Broadening

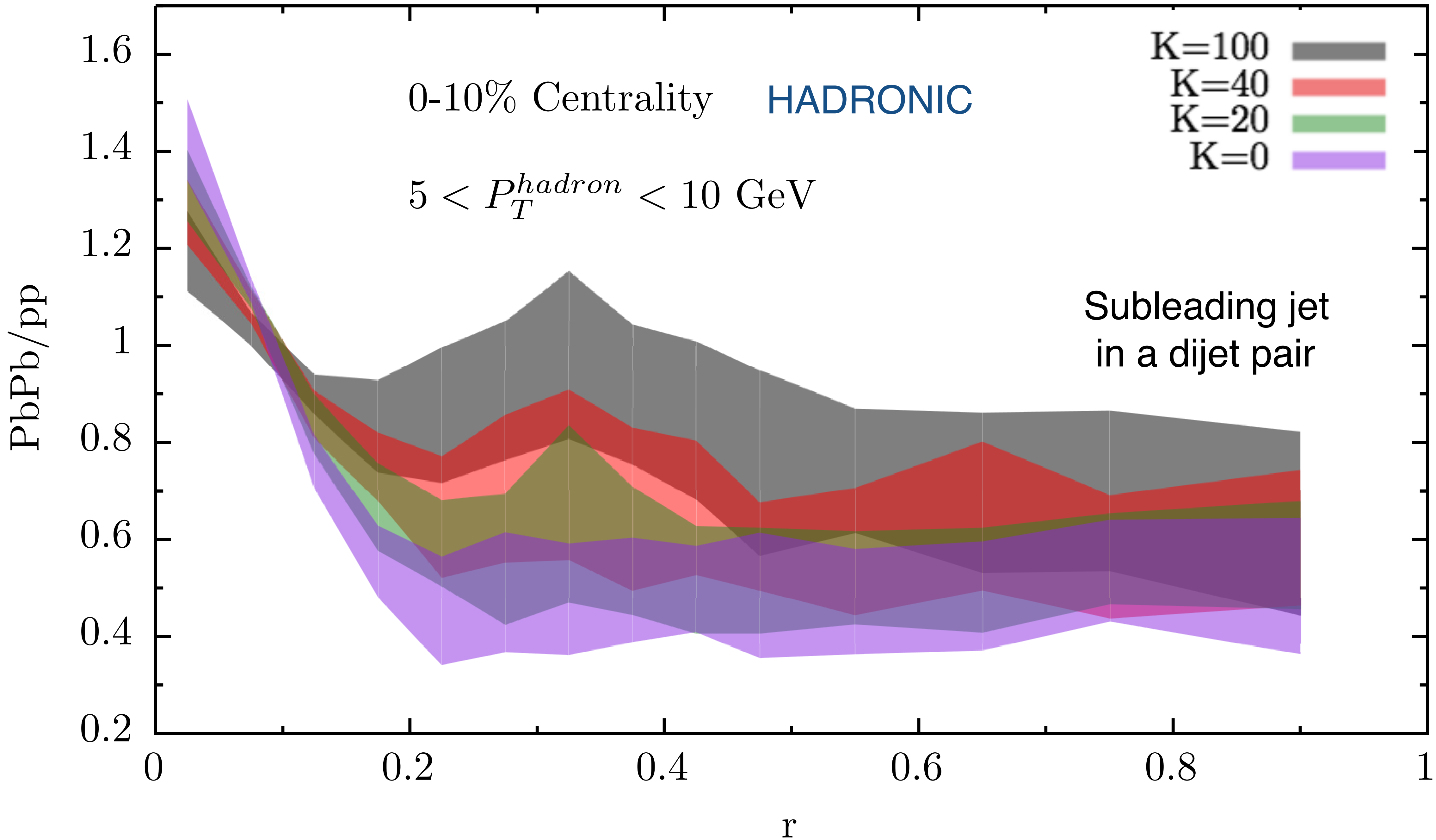


Kinematical cuts for partons chosen such that:

- there is no effect from background (soft tracks)
- we focus on jets without unfragmented cores (hard tracks)

A New Observable, Sensitive to Broadening

motivated by CMS analysis CMS-HIN-15-011



Hadrons with a given range of momenta
originate from partons with a wider range of momenta

Direct experimental determination of Gaussian broadening strength

A New Observable, Sensitive to Broadening

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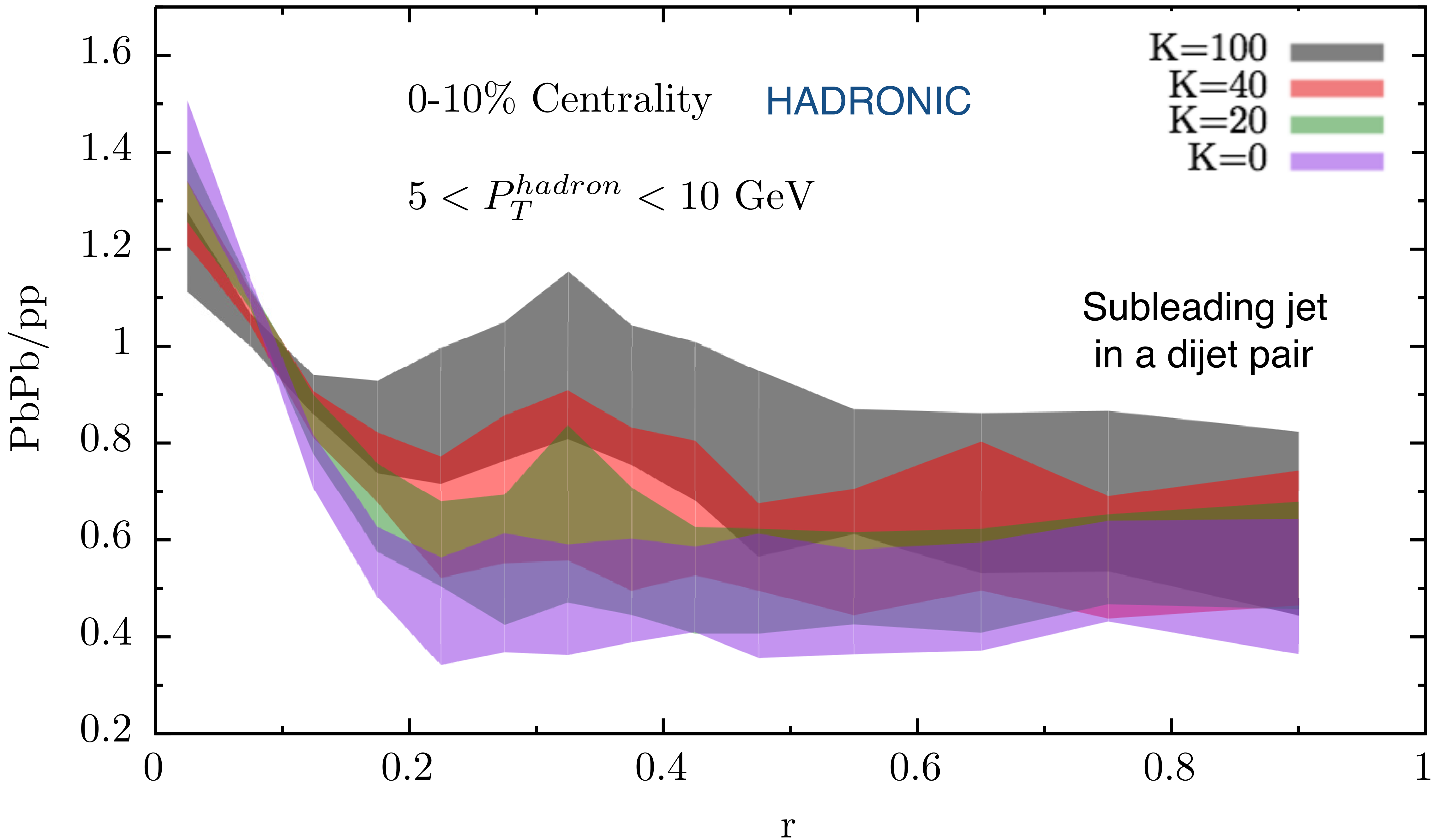
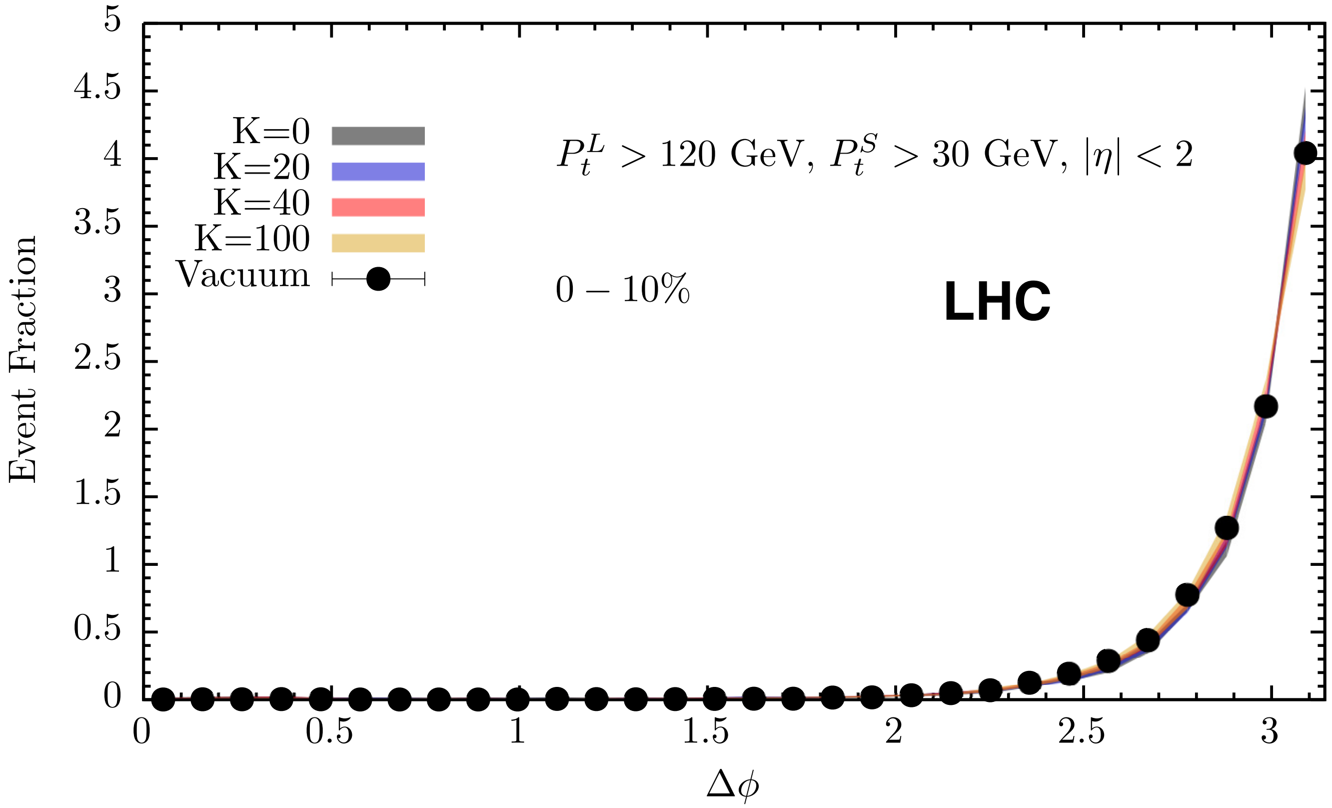
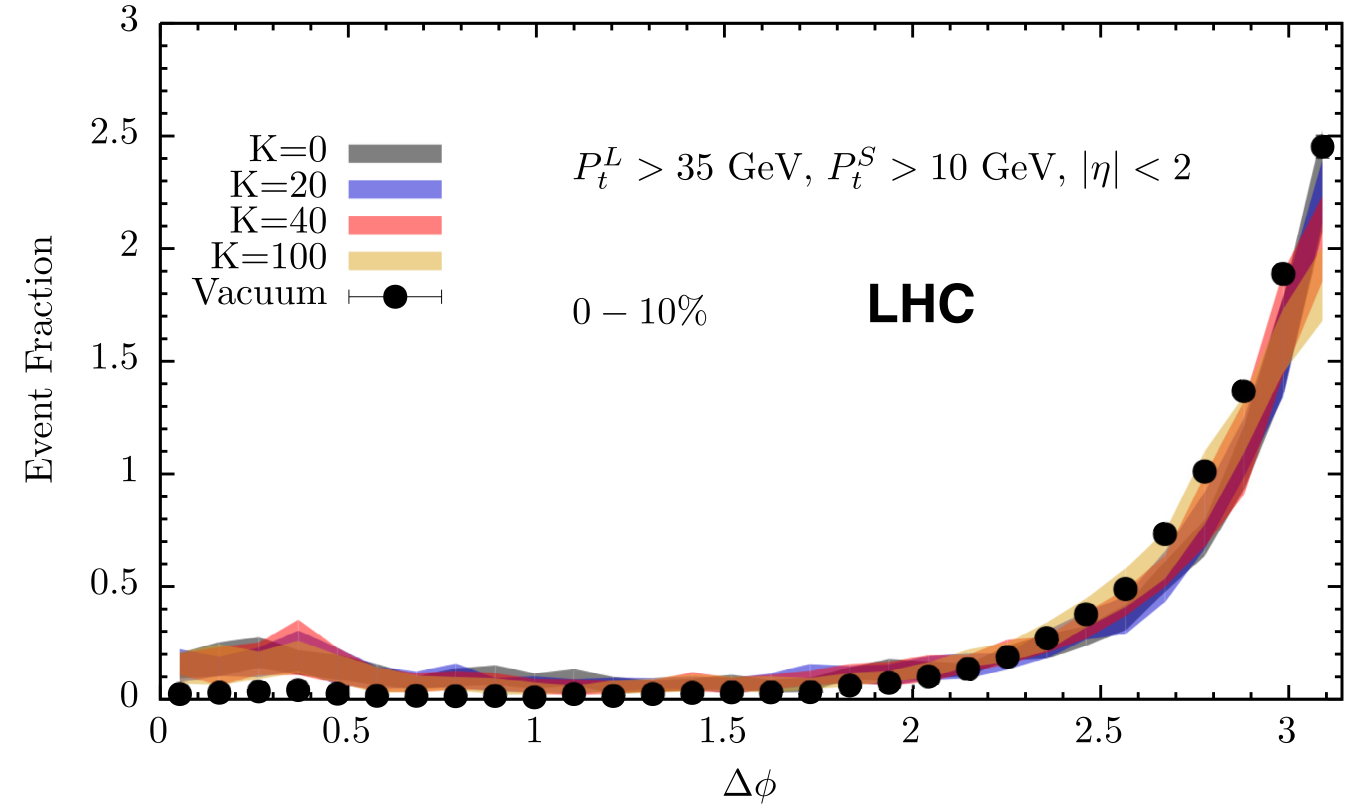
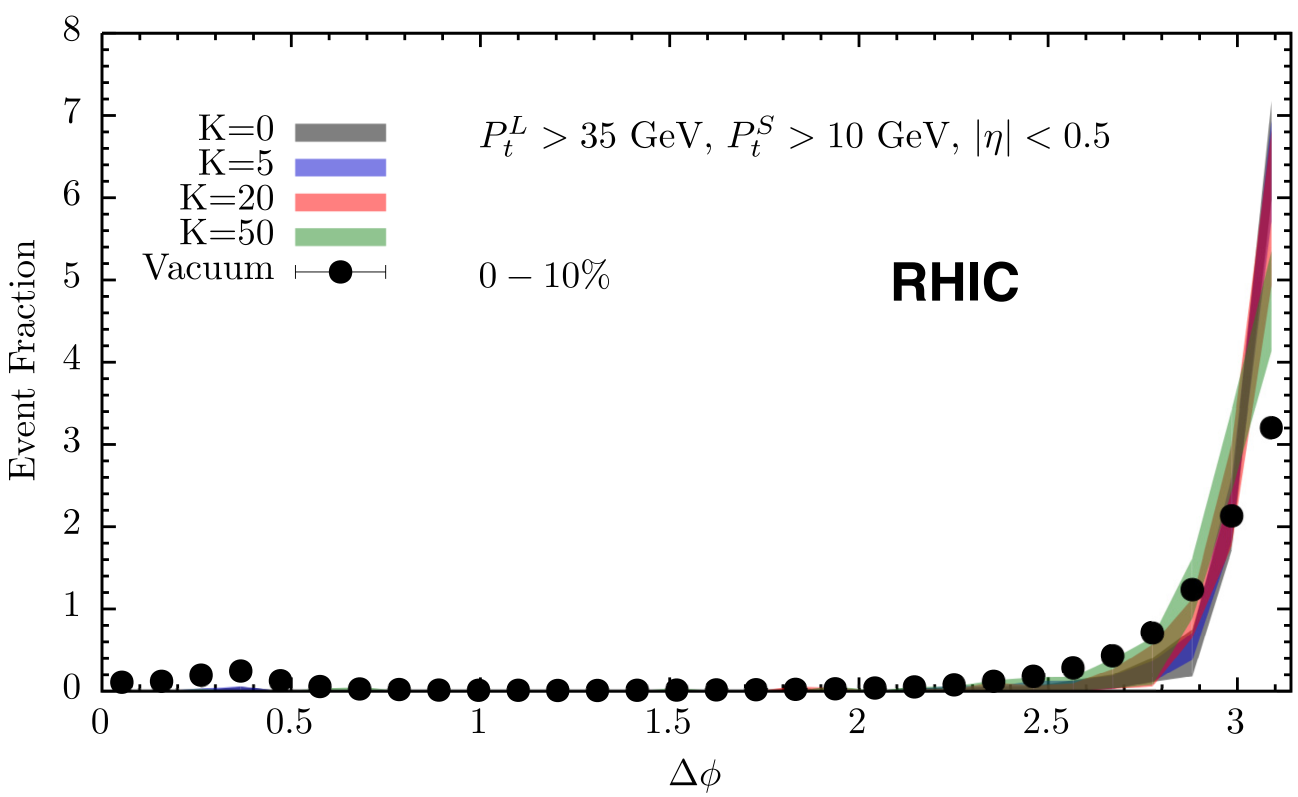


After constraining the Gaussian broadening strength,
the longer term goal will be to look for the *rare hard momentum scatterings*
given by the *short distance quasiparticles* in the soup

Dijet Acoplanarities





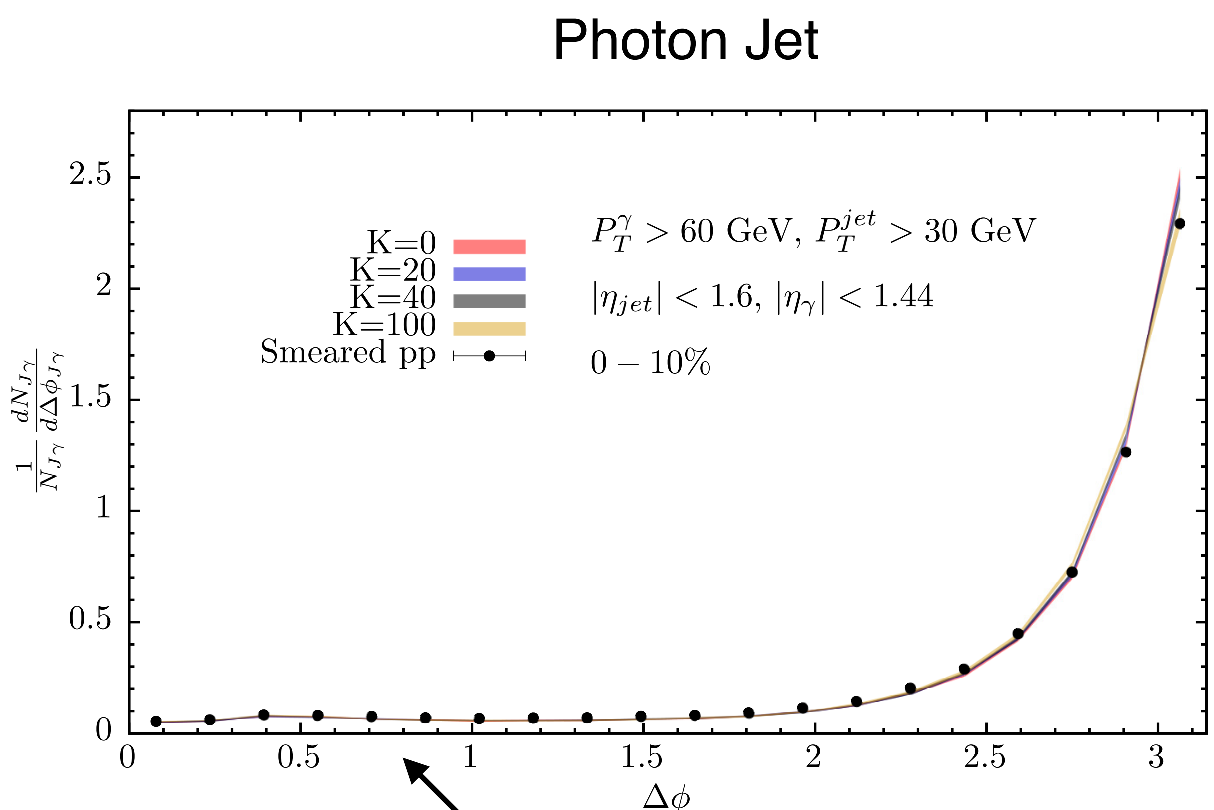


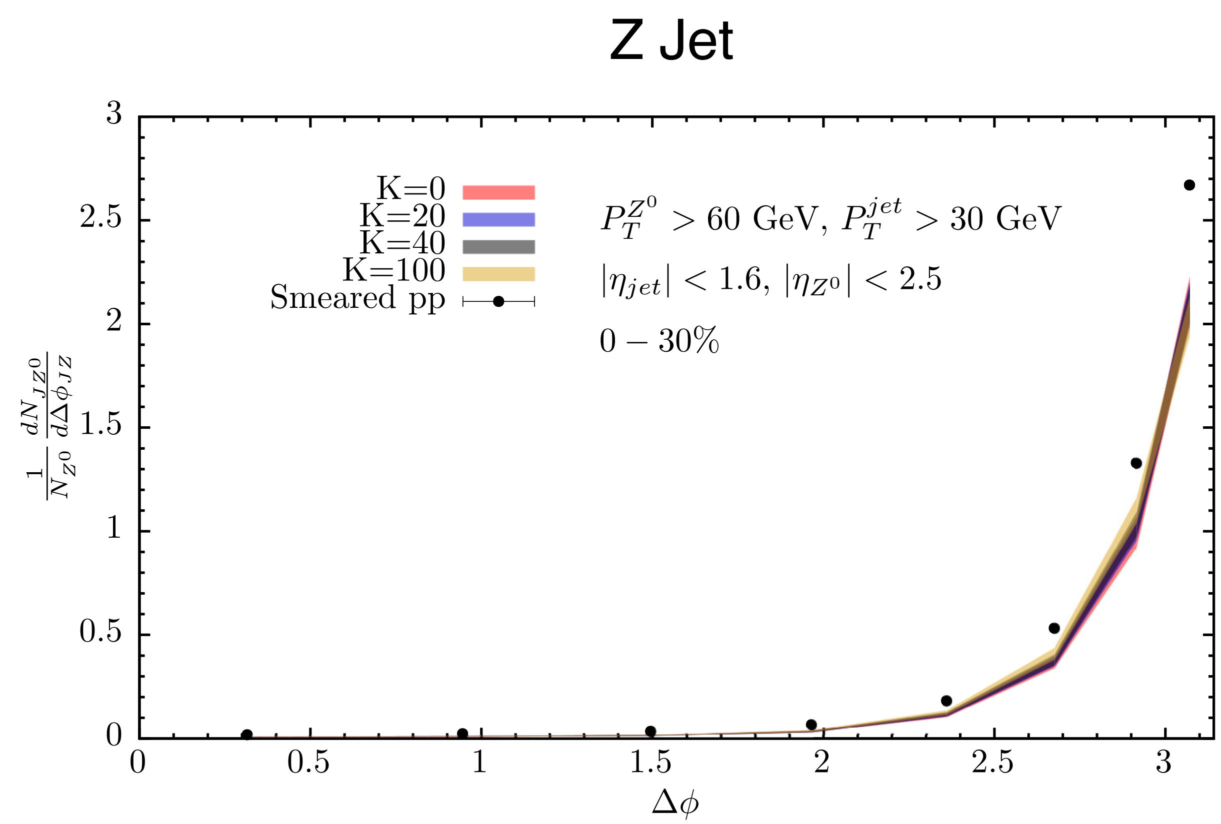
Higher energy jets are narrower: less acoplanar

Energy loss narrows the distributions, while broadening widens them back

Effects strongest for lower energies due to more steeply falling spectrum

Boson Jet Acoplanarities





frag. photon contamination

different normalisation

Photon Jet: over the number of photon jet pairs

Z Jet: over the number of Zs

more on Boson Jet observables in the Backup

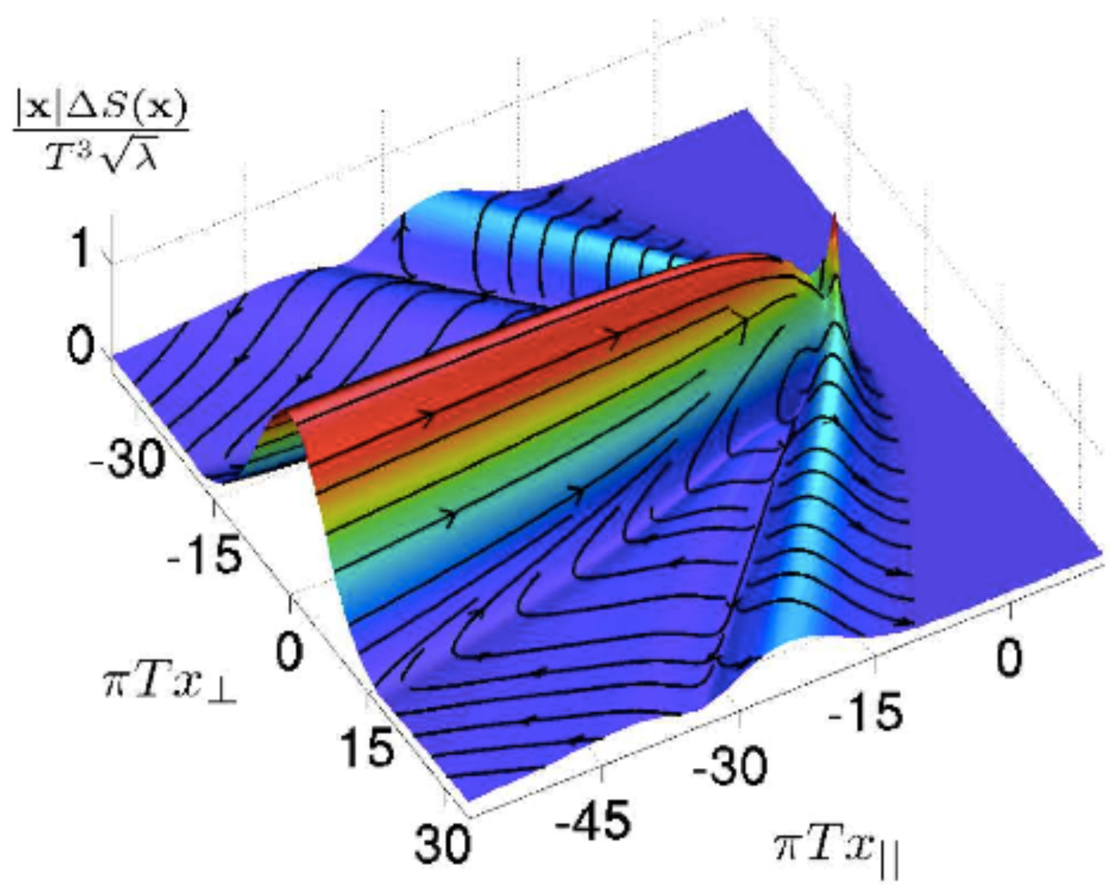
An Estimate of Backreaction

Hydro response to jet passage:

Assumption: small perturbation of hydro

Consequence:

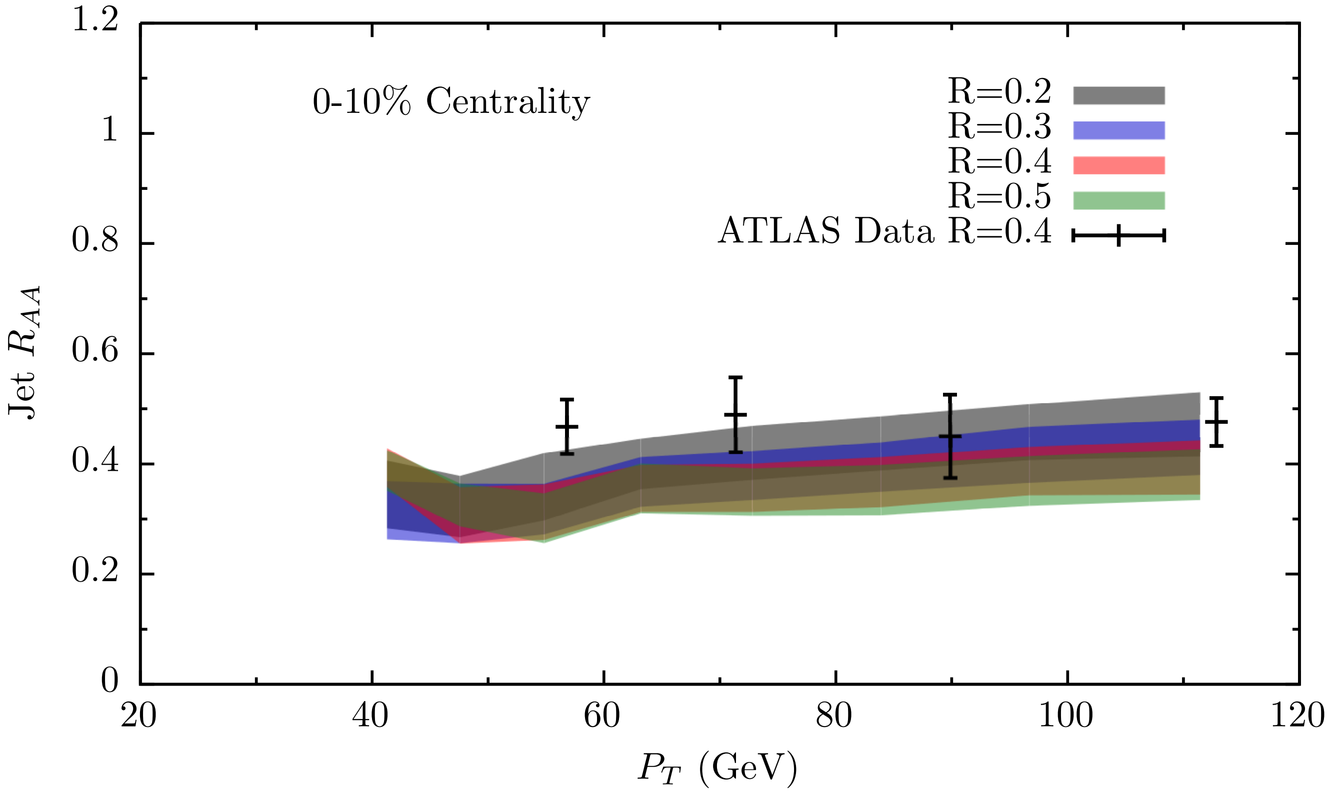
- no details on the perturbation are needed
- distribution fully constrained by **energy-momentum conservation**
- no additional parameters

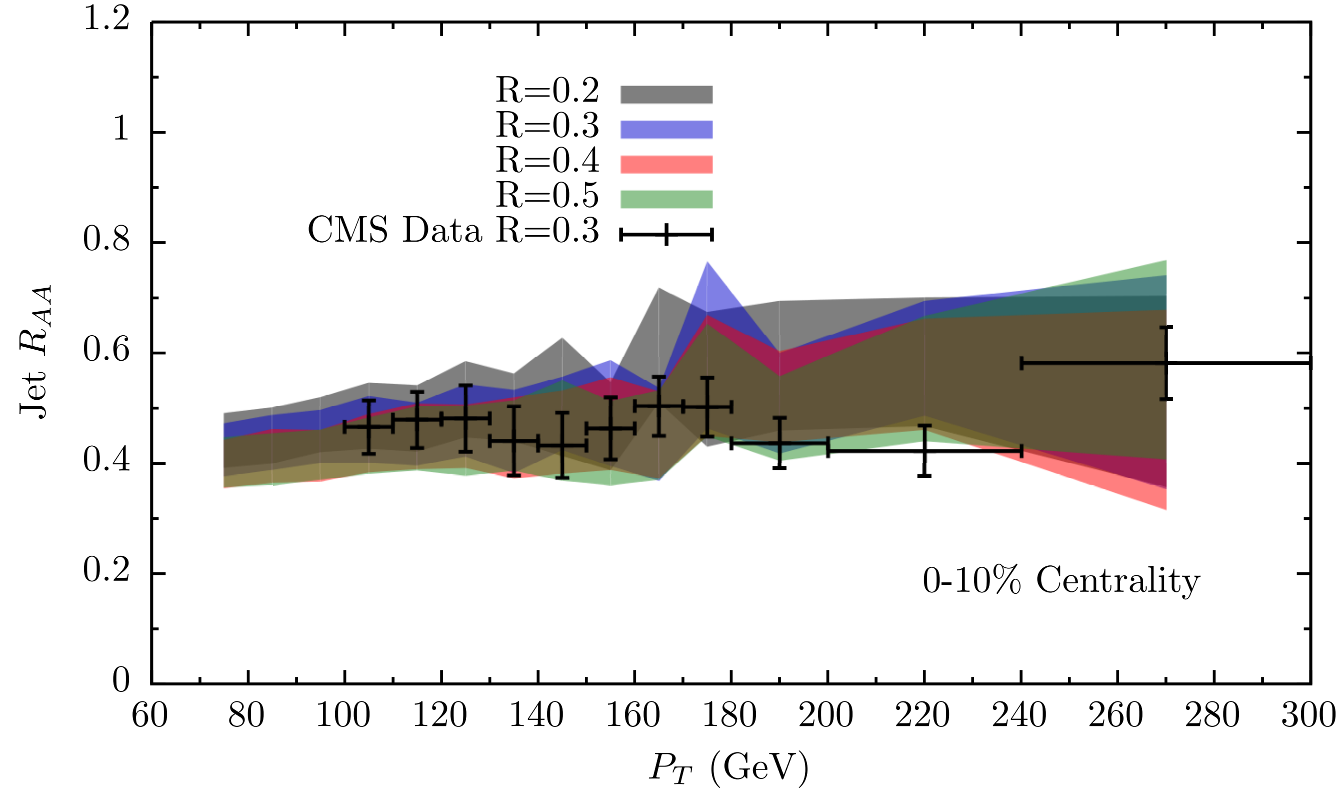


more details in
MCs Round Table today

Chester and Yaffe 0712.0050

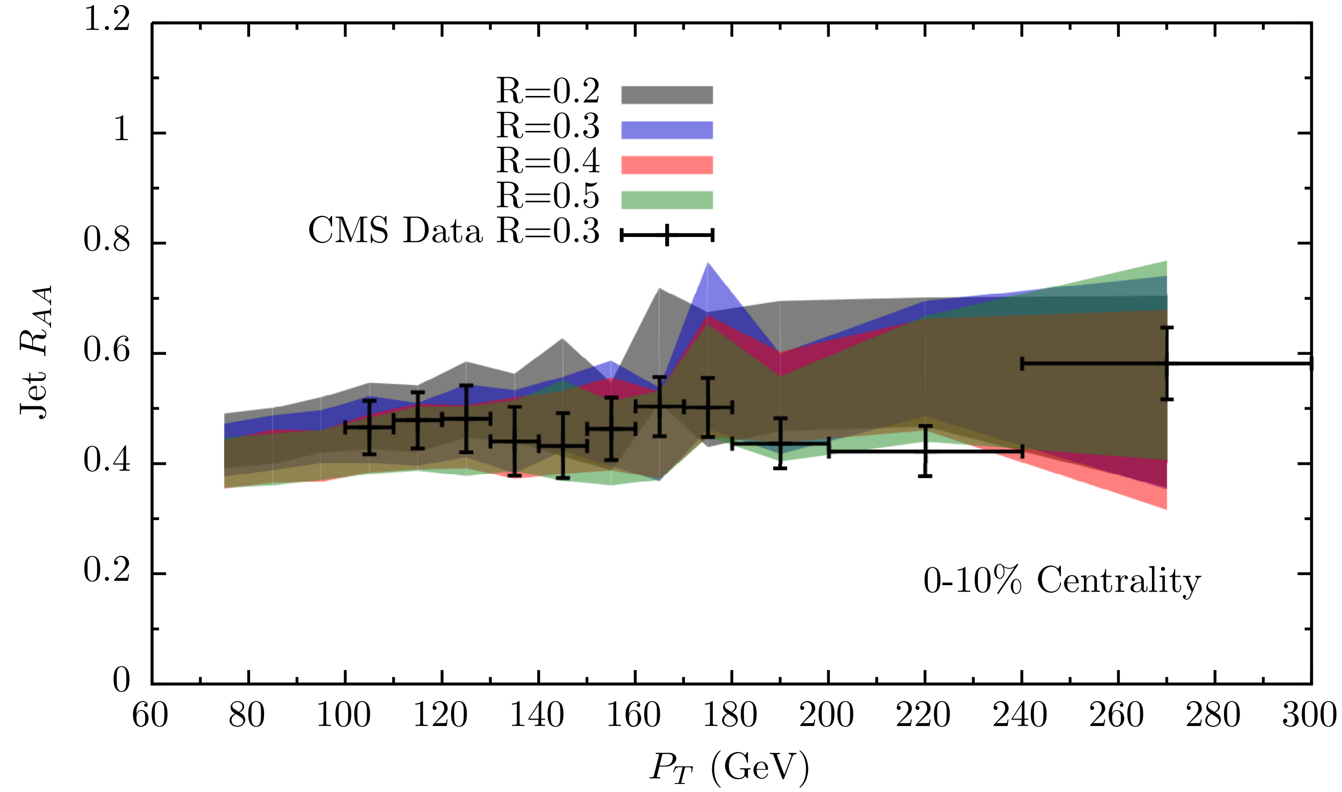
R_{AA} vs R



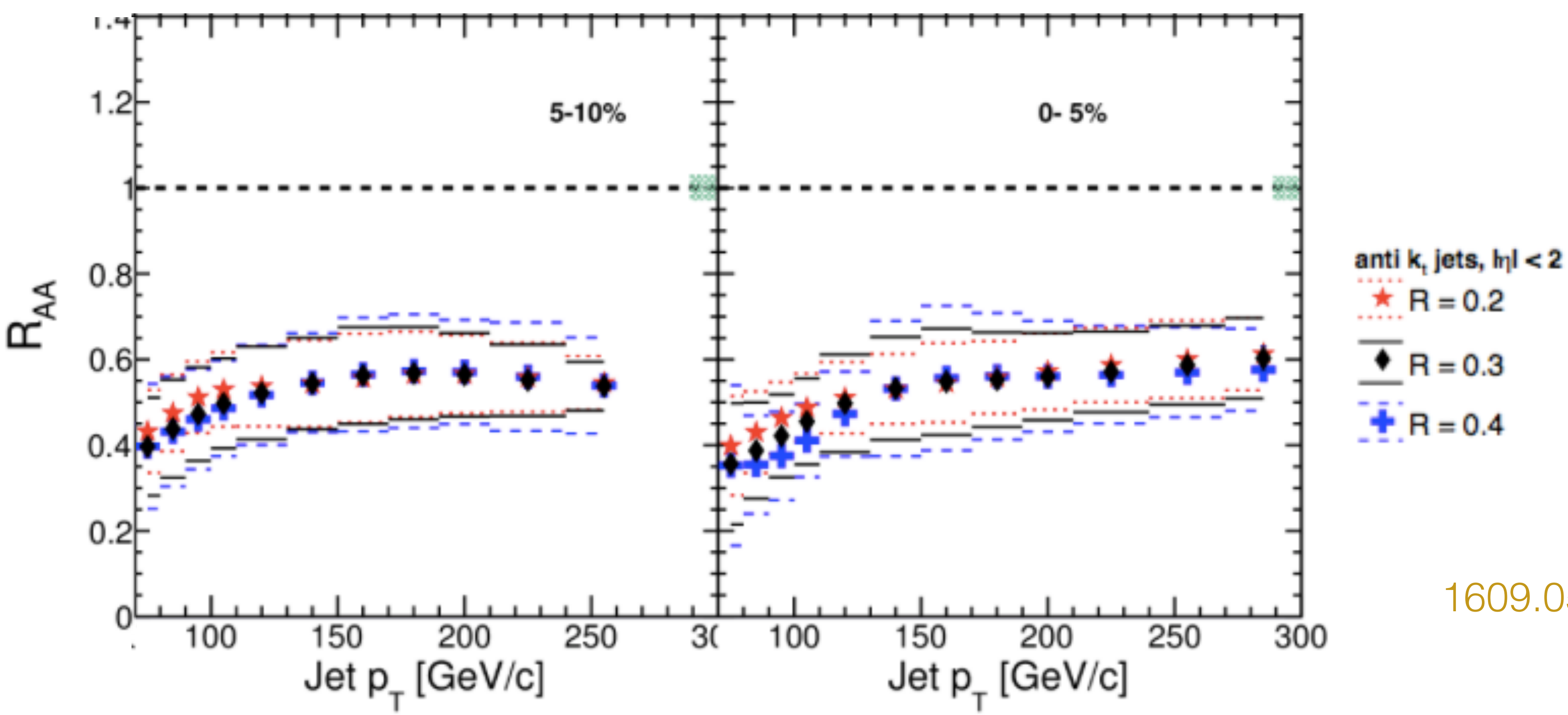


- Had to retune fitting parameter (only at percent level)
- Wider jets are (slightly) more suppressed than narrow ones
- Energy is recovered at wider angles

R_{AA} vs R



Consistent with the trend hinted in experiments (?)



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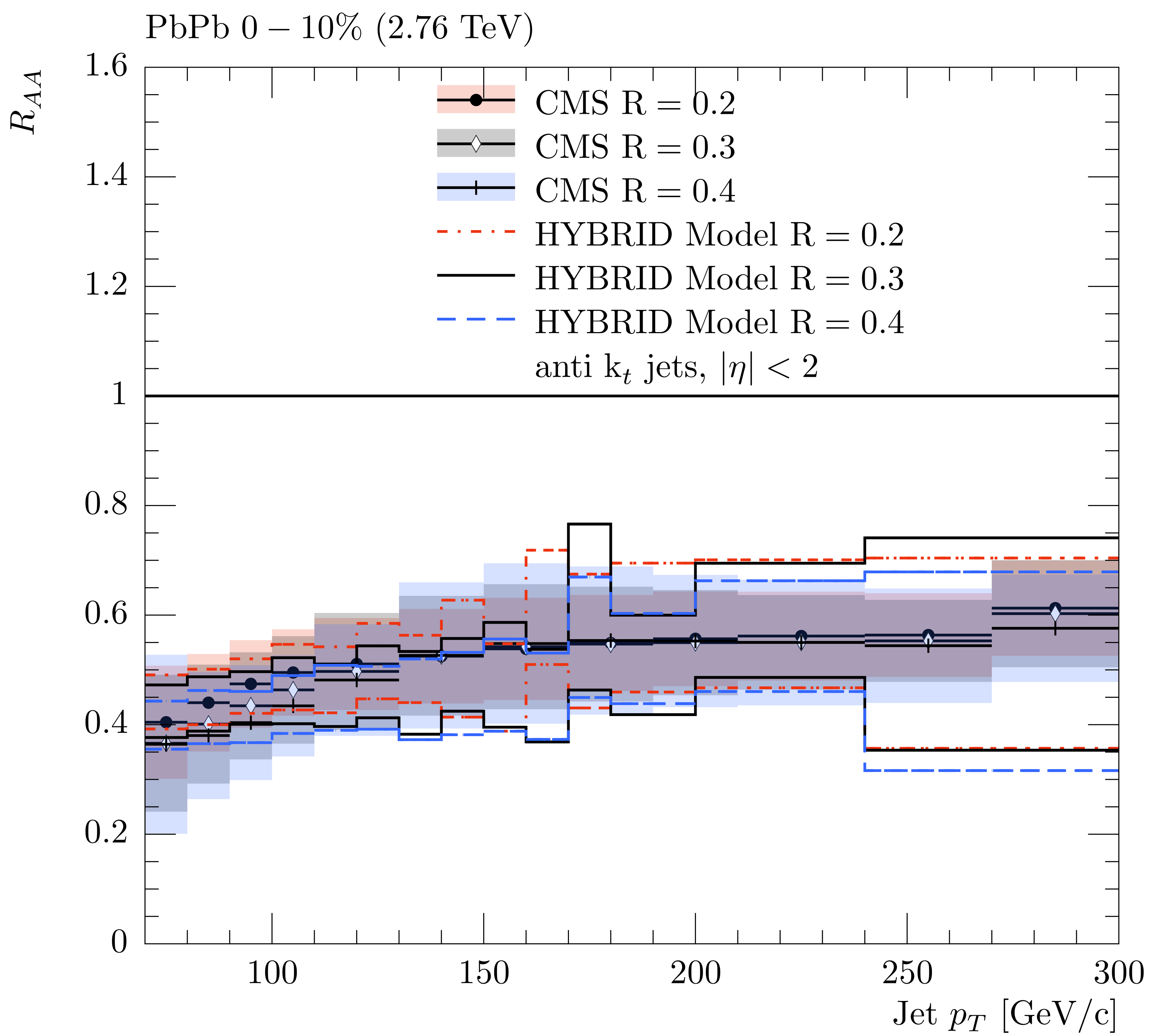
R_{AA} vs R

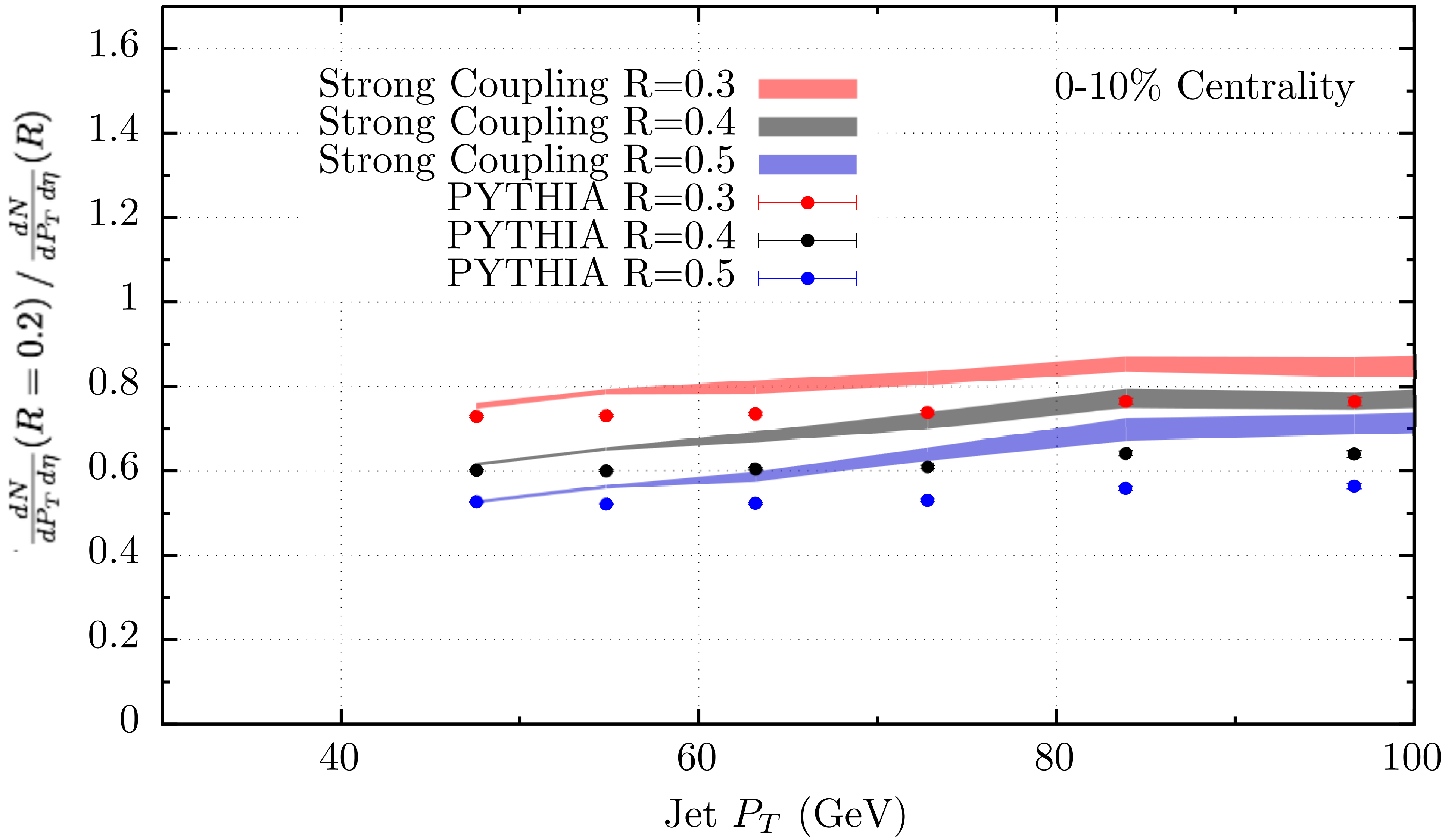


courtesy of Raghav

Improved precision on such measurements will greatly constrain medium response / gluon re-scattering assumptions

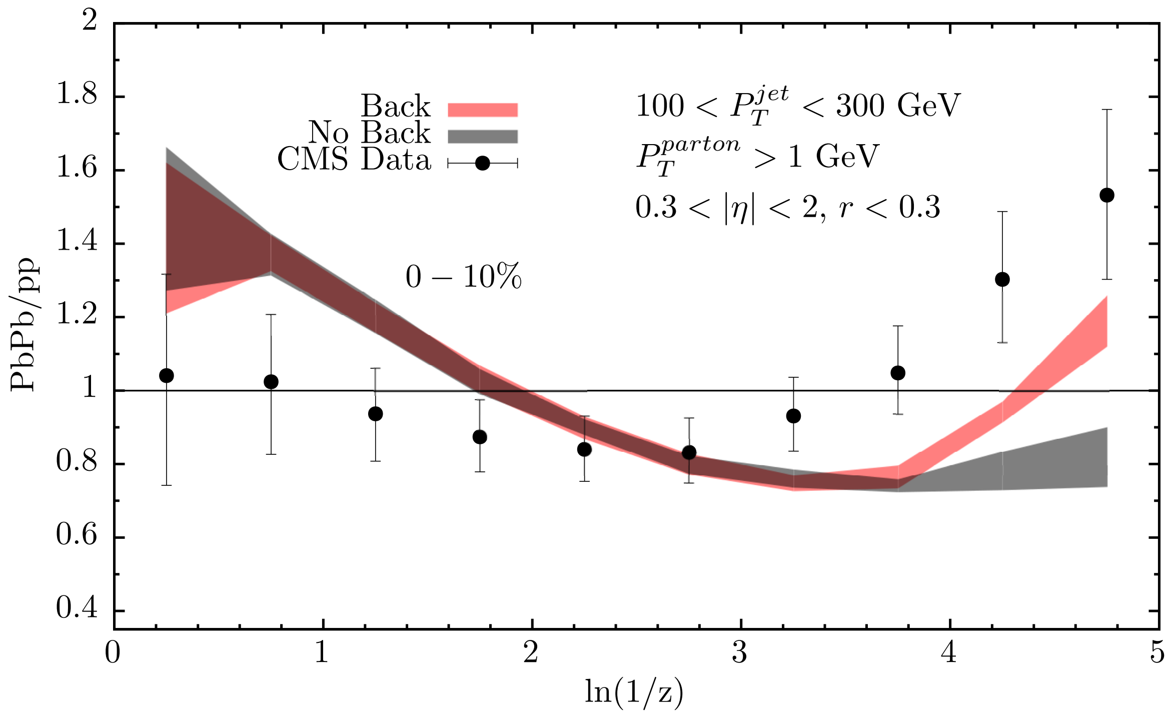
Jet Spectra Ratios

motivated by ALICE analysis arXiv:1506.03984

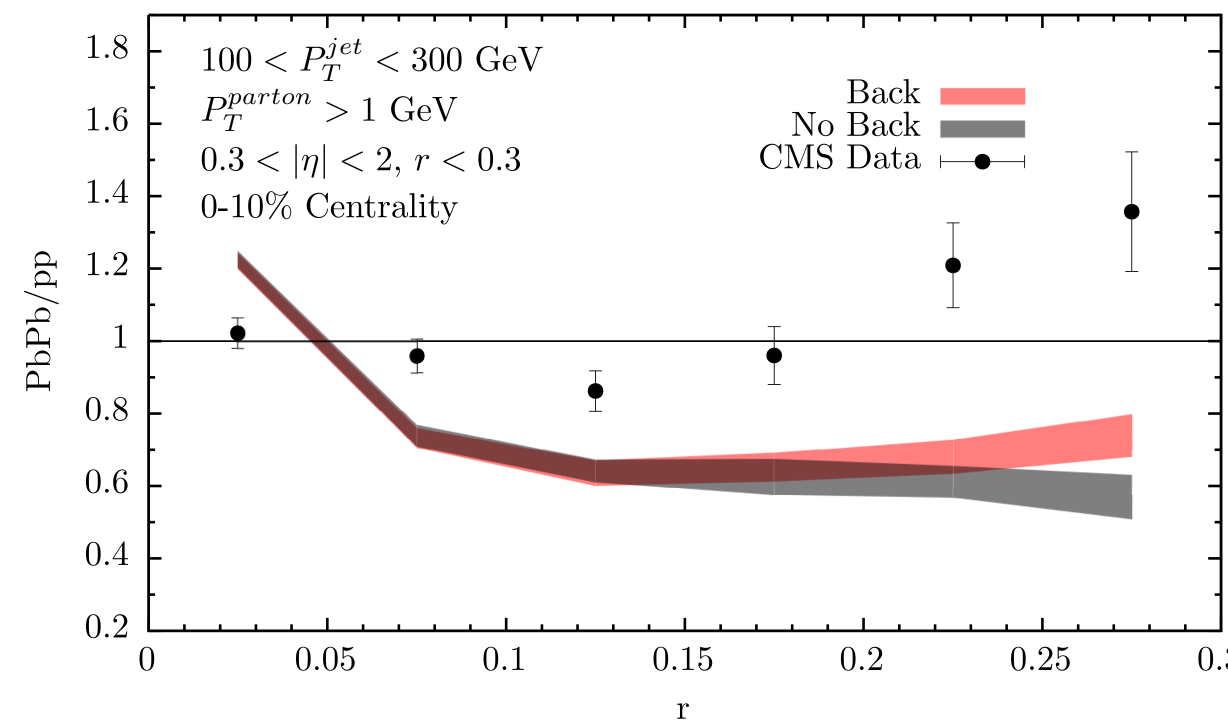


- Higher Pt jets tend to be narrower — increase of ratios with Pt
- Wider jets more suppressed — PbPb ratios always above pp ones
- <#Tracks> increases with Pt — PbPb vs pp separation increases with Pt

Backreaction on Intra-Jet Observables



Fragmentation Functions

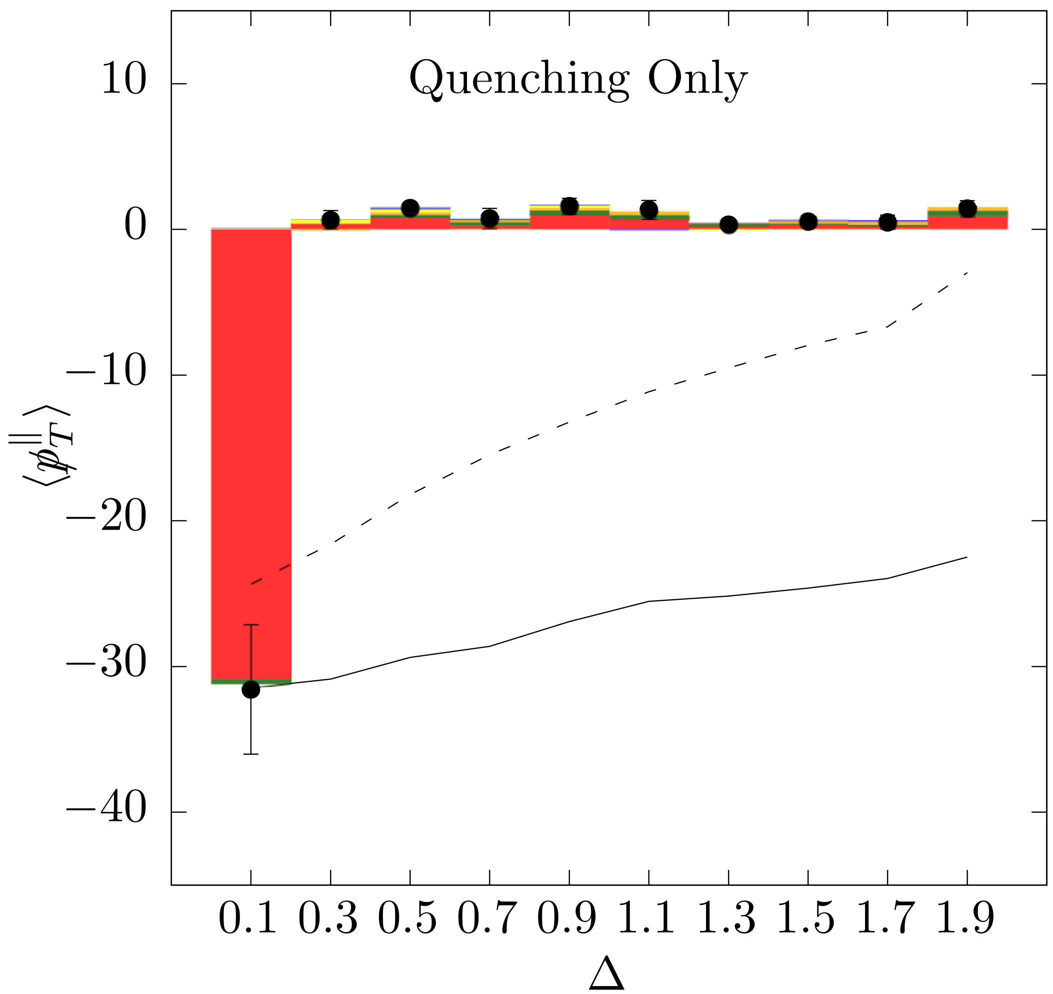


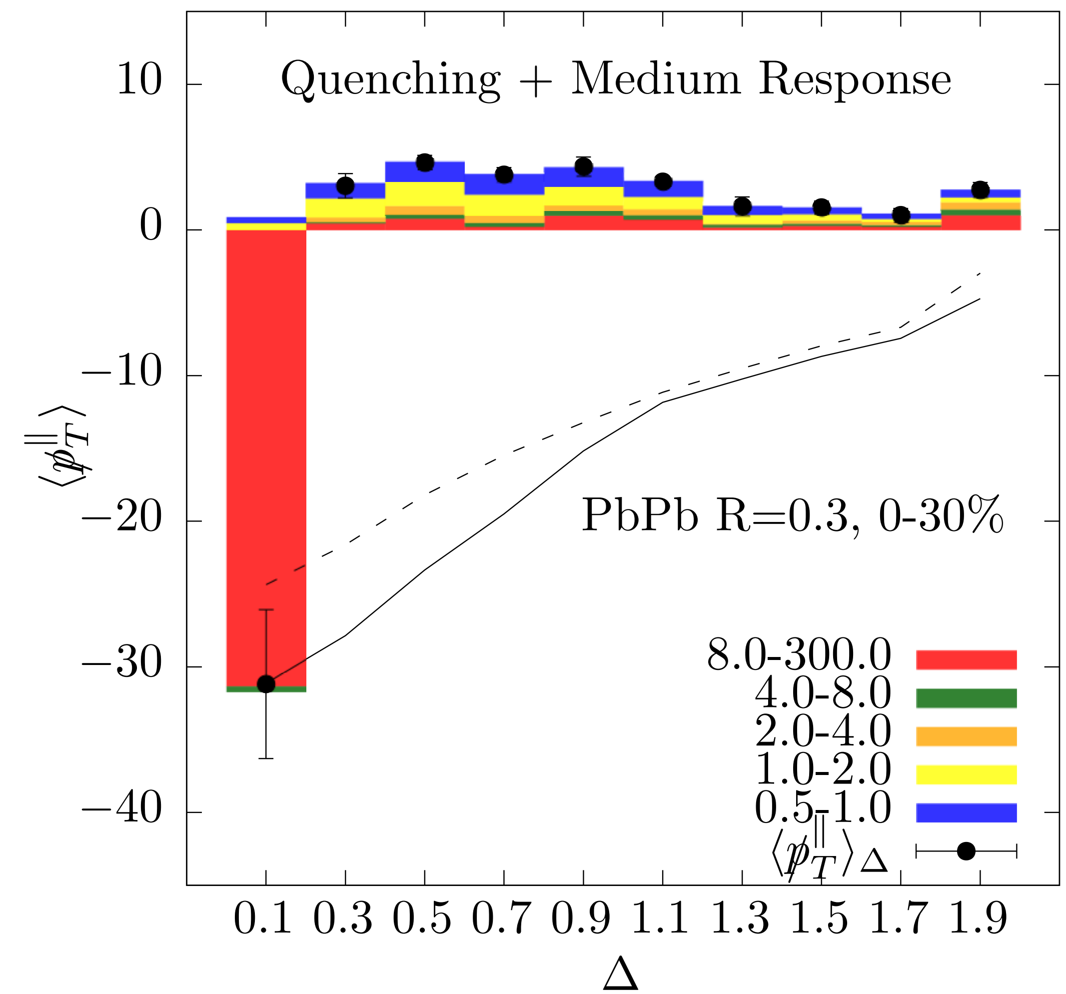
Jet Shapes

- The effect goes in the right direction
- Clearly not enough to explain angular structure

- Oversimplified backreaction?
- Hadronization uncertainties? (medium *and* vacuum)
- Finite resolution effects?

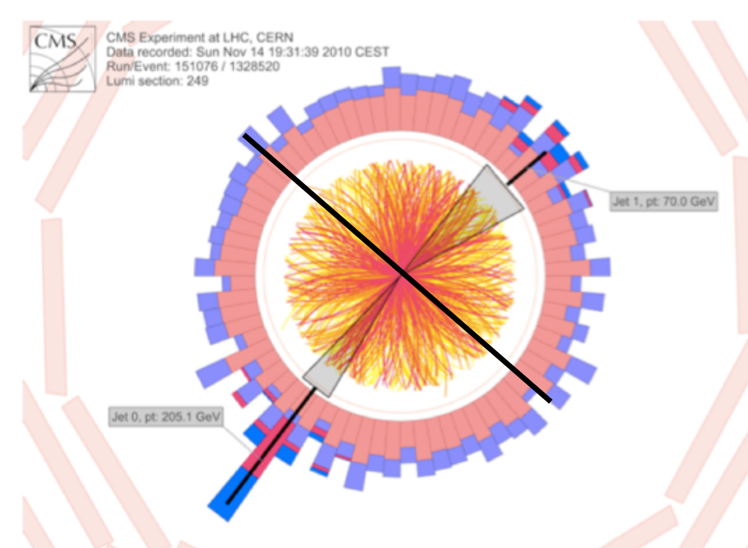
Recovering Lost Energy: Missing Pt





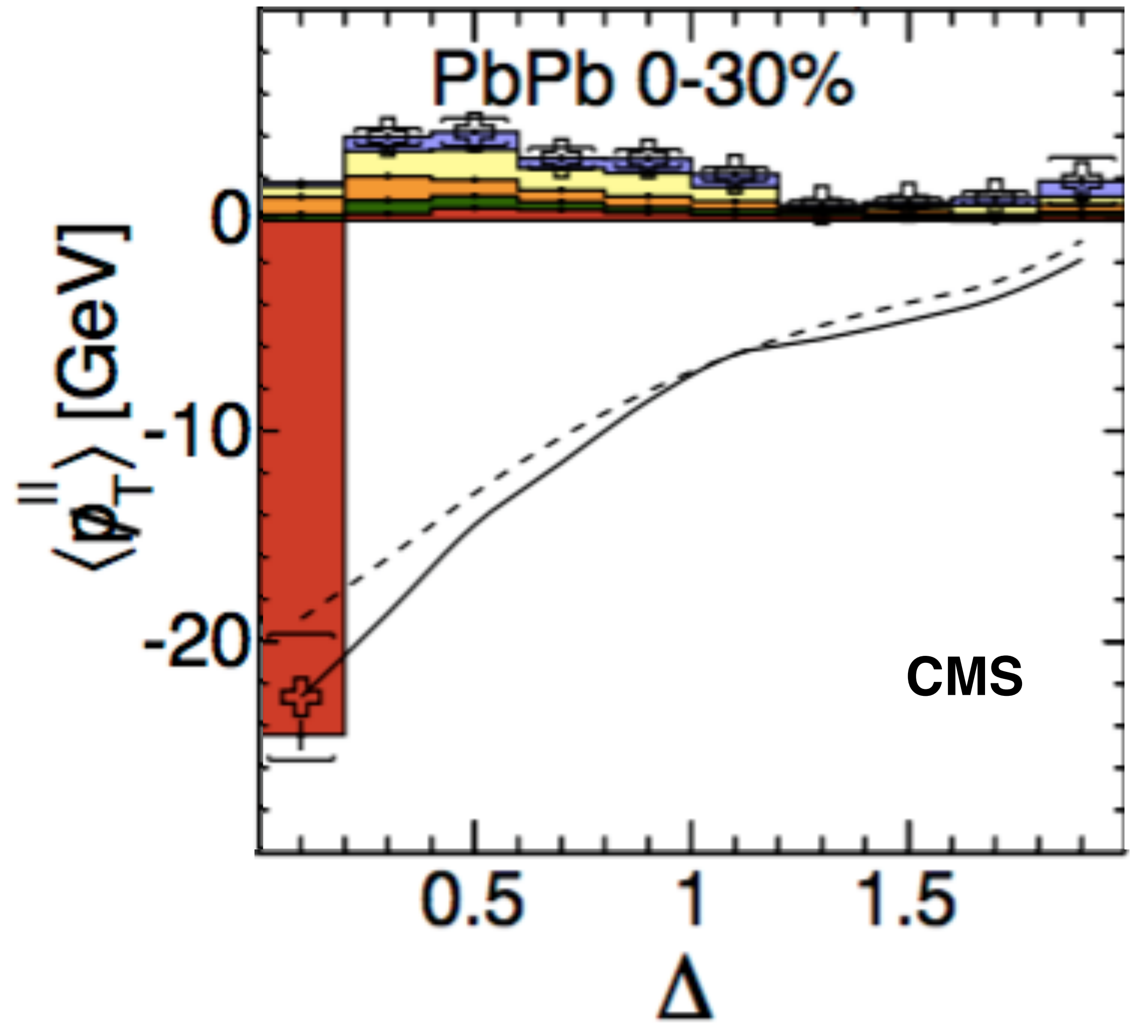
- Energy is recovered at large angles in the form of soft particles

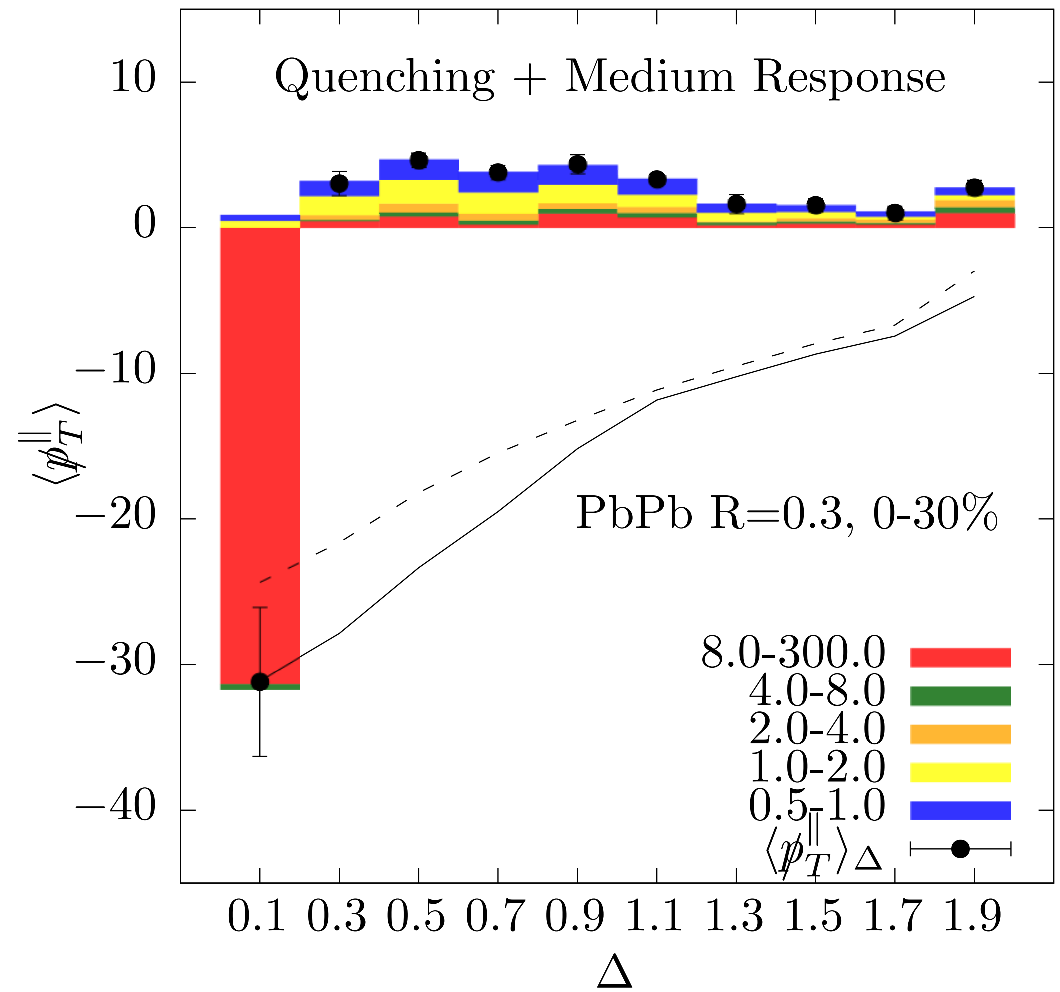
- Adding medium response is essential for a full understanding of jet quenching



Recovering Lost Energy: Missing Pt

CMS-HIN-14-010





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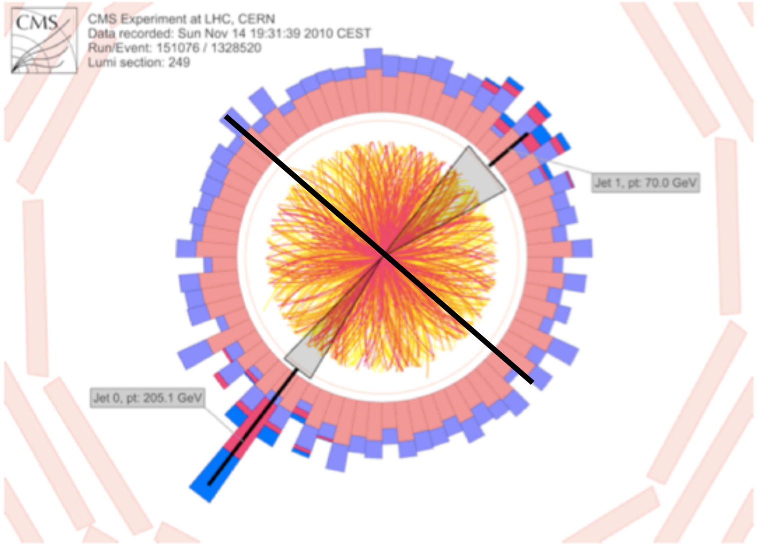

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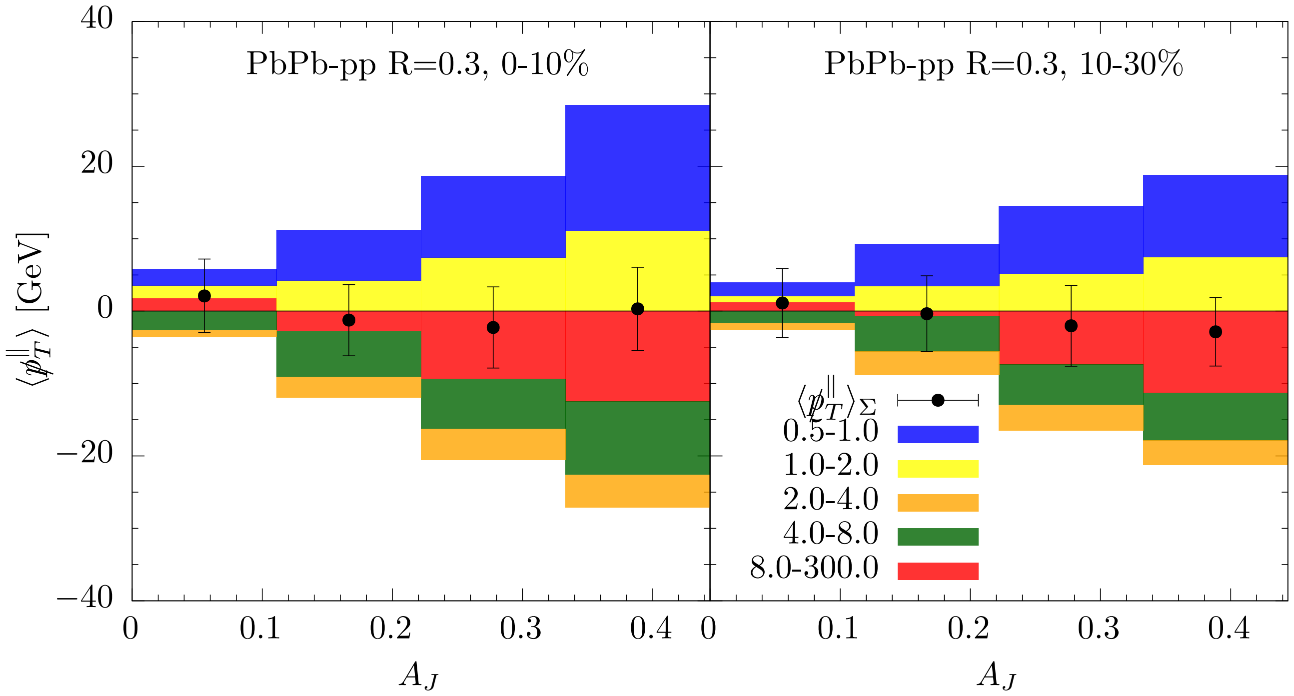
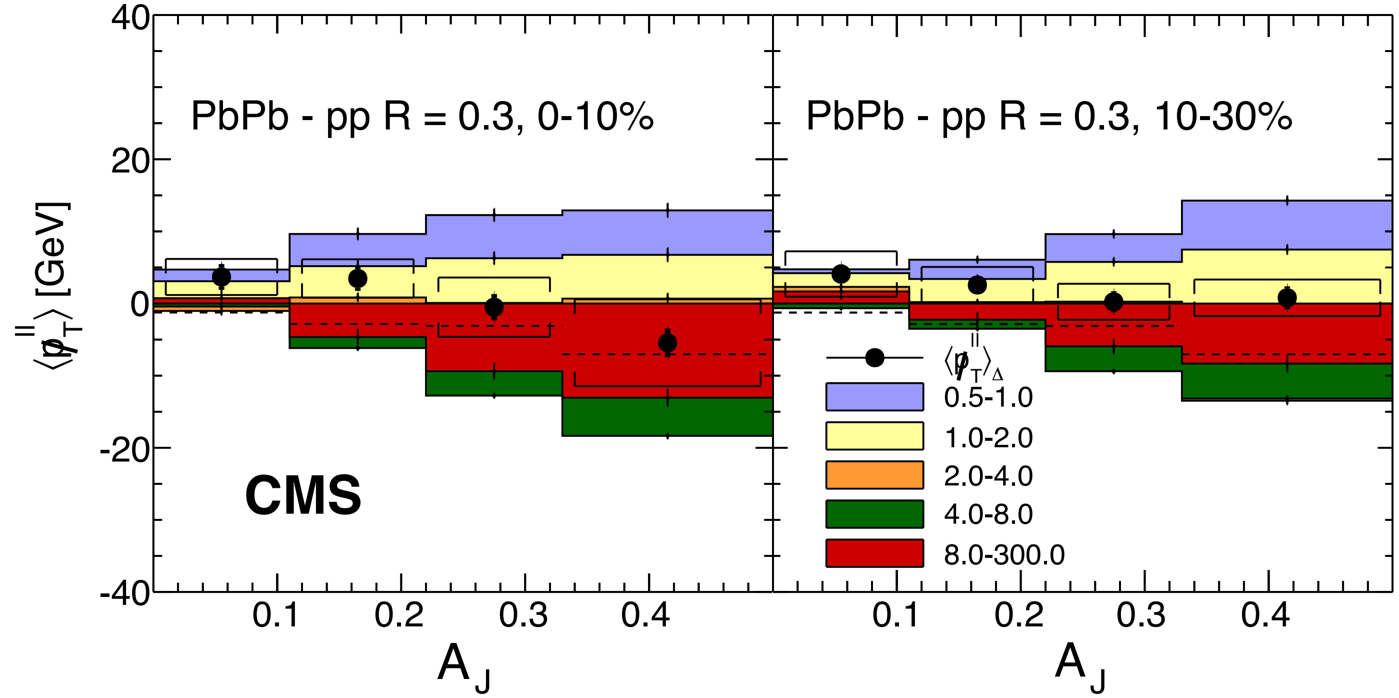
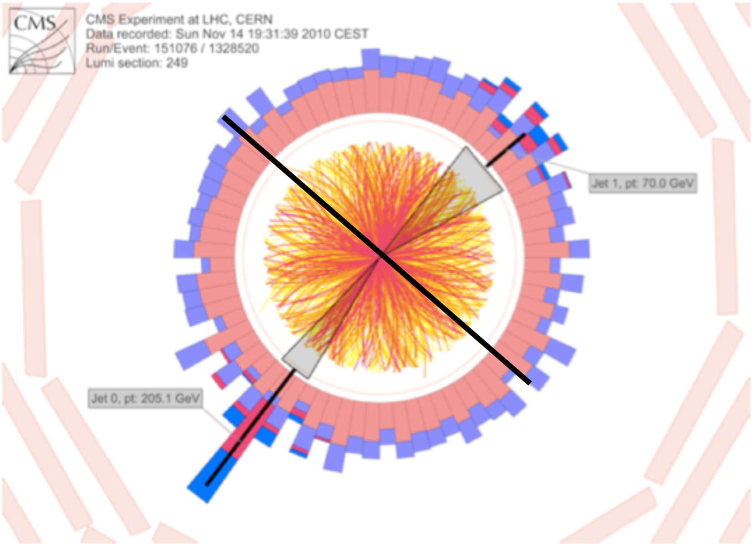


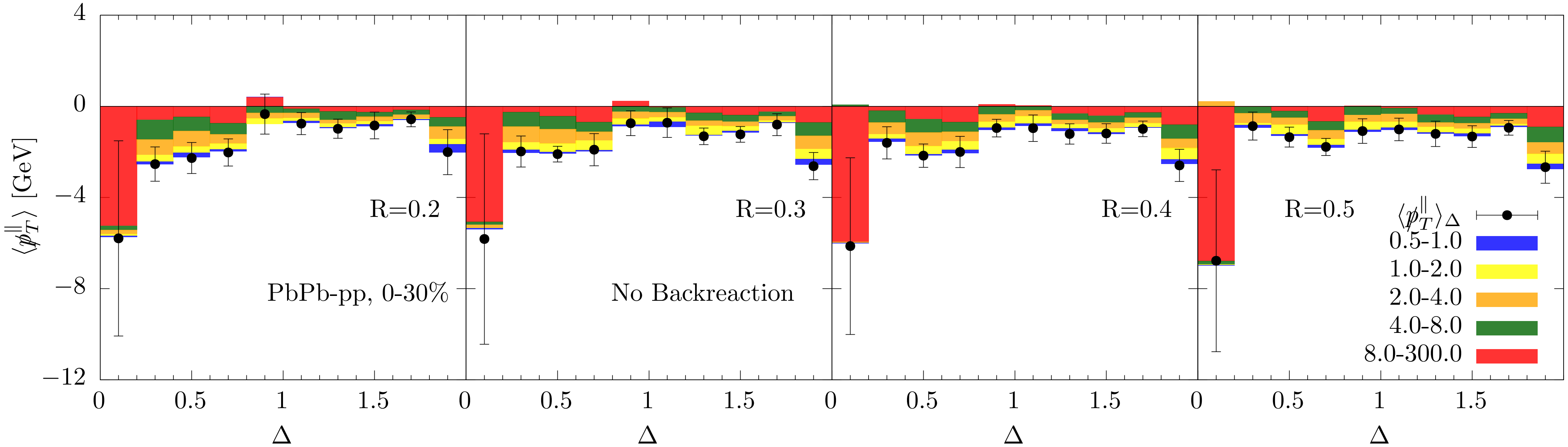


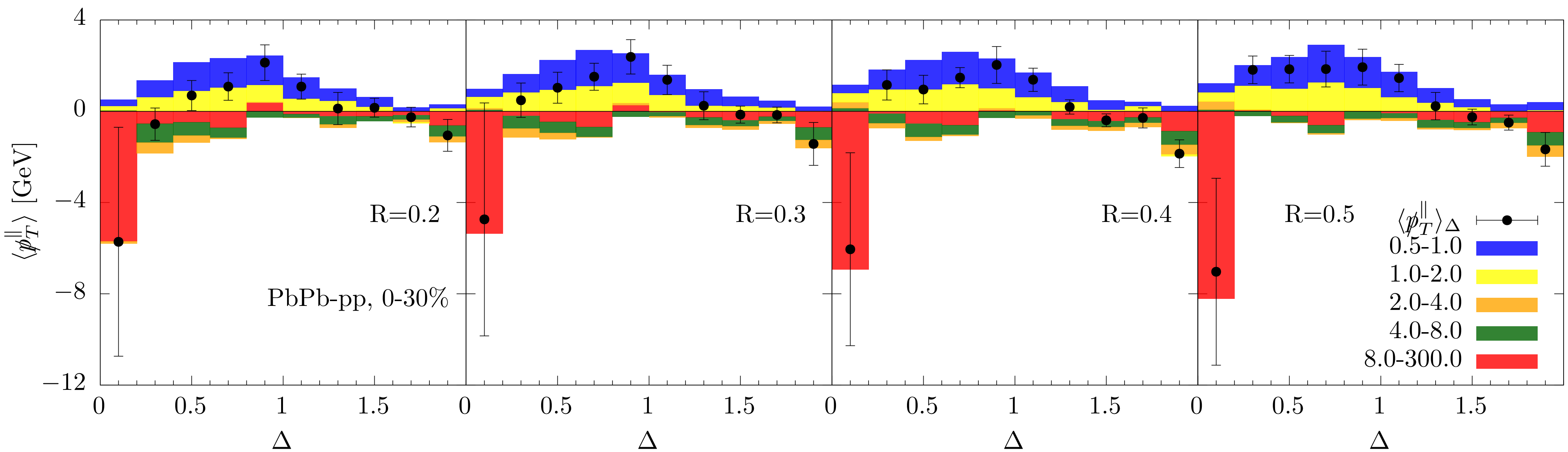
- In PbPb, more asymmetric dijet events are dominated by soft tracks in the subleading jet side

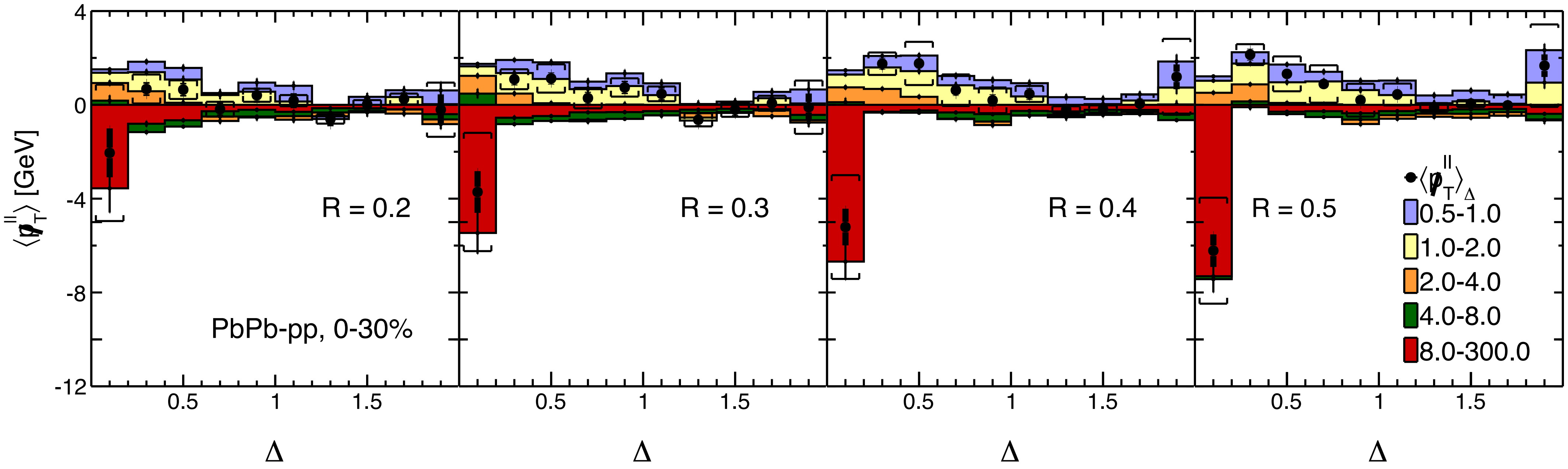
- Discrepancies w.r.t. data in the semi-hard regime motivate improvements to our model



Jet radius dependence of Missing Pt







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A. Oversimplified backreaction?
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C. Finite resolution effects?

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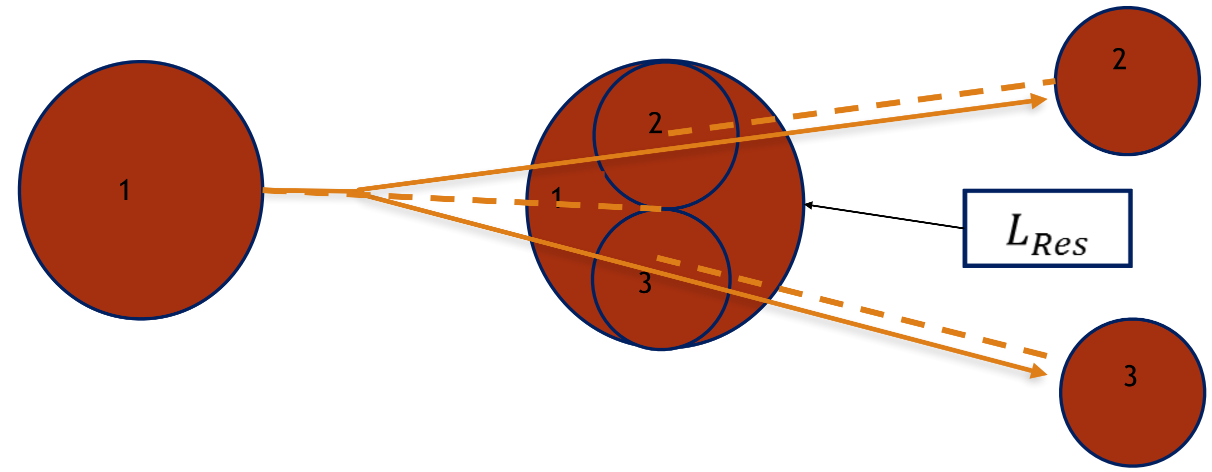
謝謝！

Backup Slides

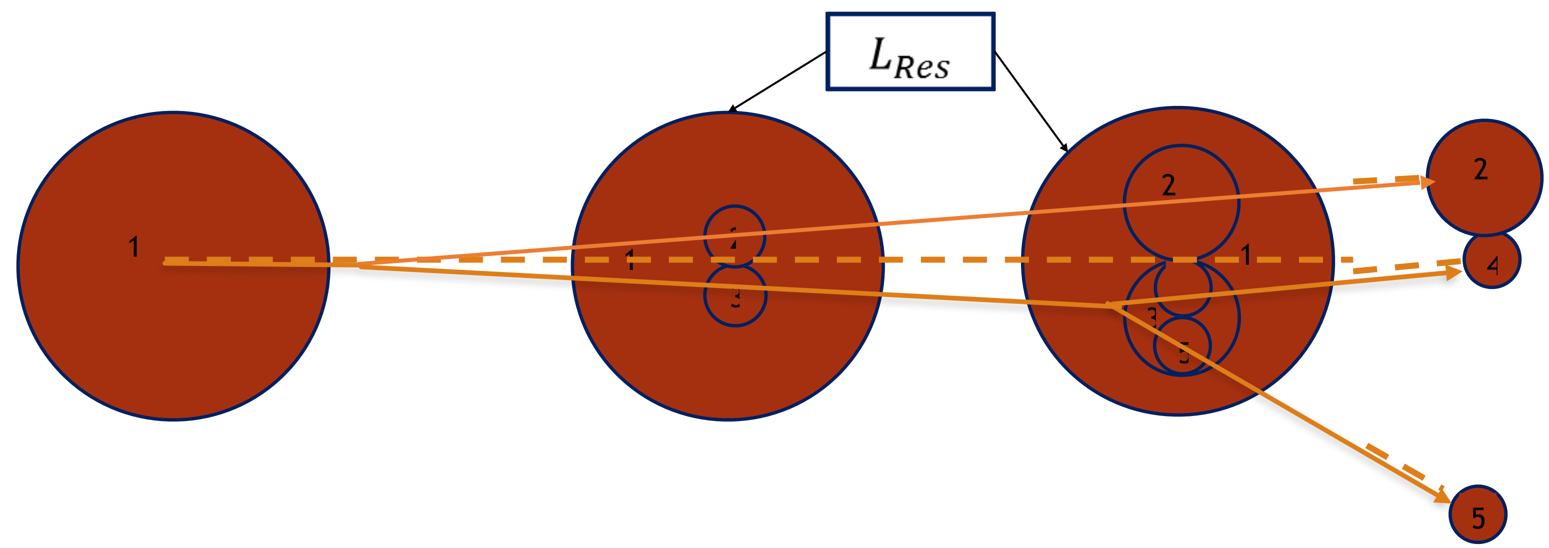
Z. Hulcher, DP,
K. Rajagopal, in progress

Finite Resolution Effects

The QGP cannot resolve sister partons until they are separated a certain distance L_{Res}



If a member of the offspring of a certain parton resolves, then color correlations break and such parton resolves as well



Expect L_{Res} to be comparable to the plasma screening length λ_D

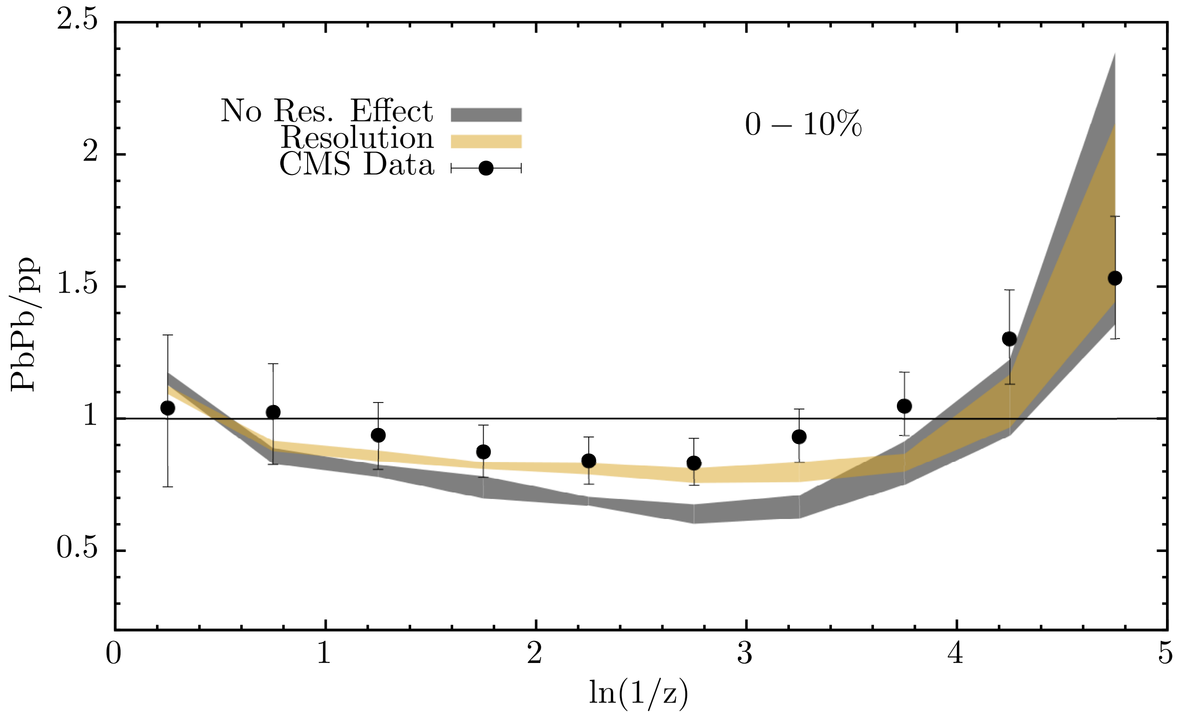
Both weak and strong coupling give approximately $\lambda_D \simeq \dfrac{1}{\pi T}$

Z. Hulcher, DP,
K. Rajagopal, in progress

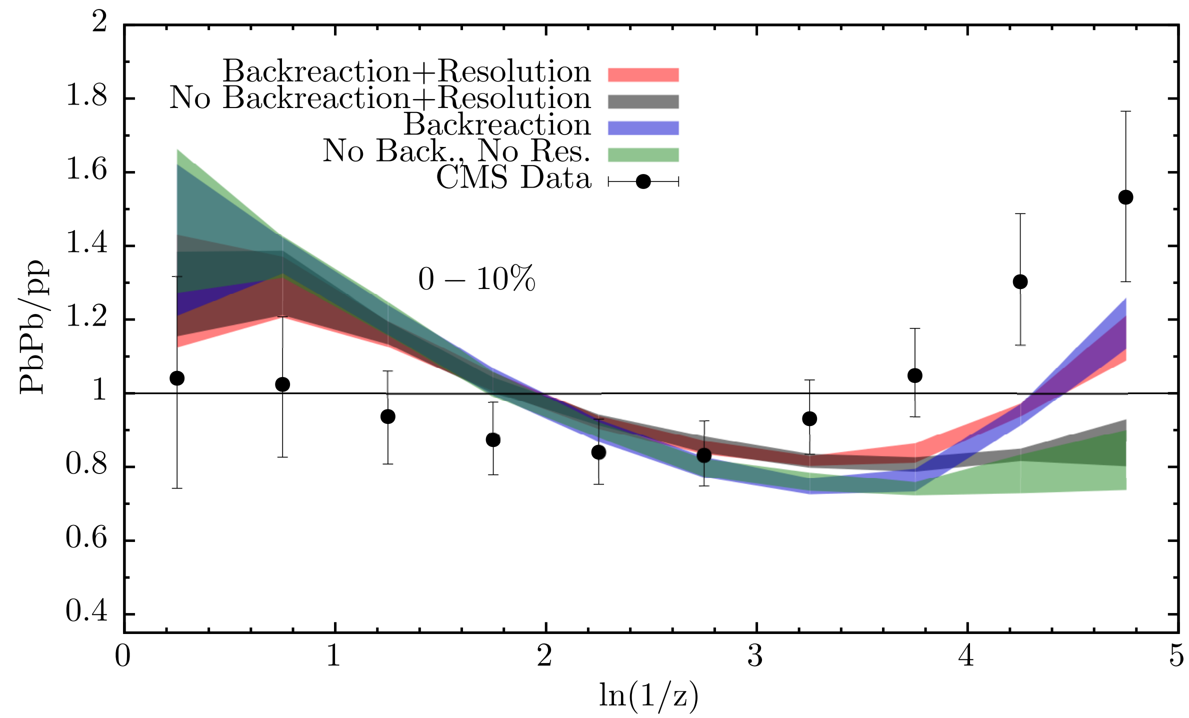
Finite Resolution Effects

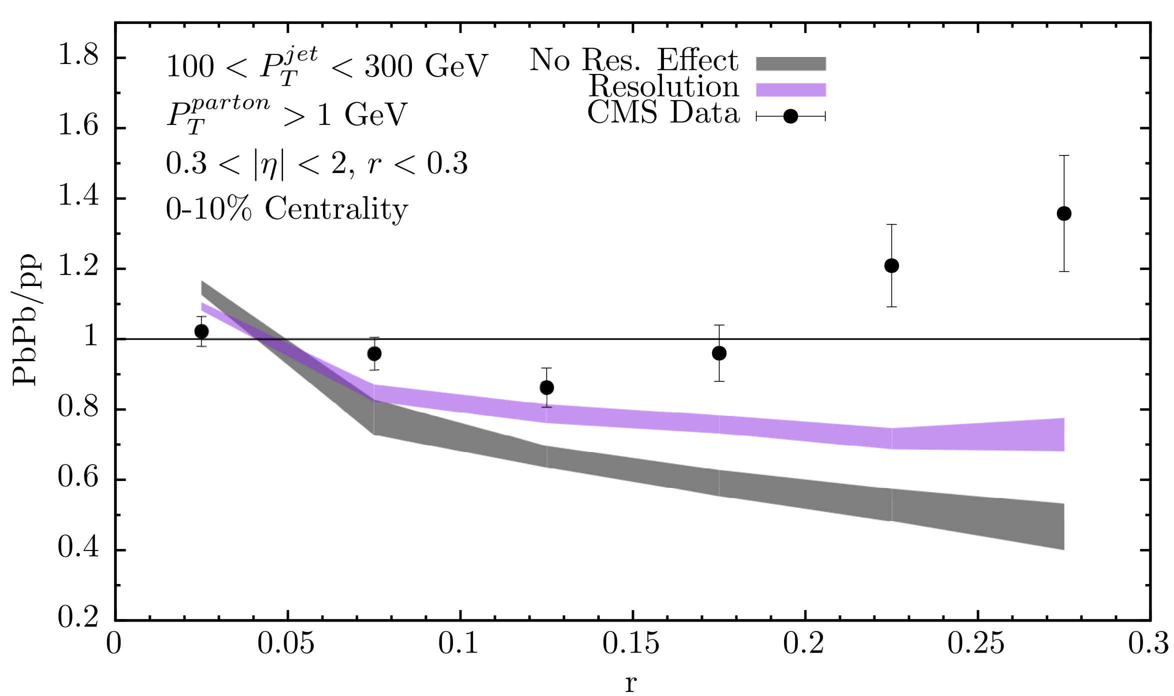
PRELIMINARY

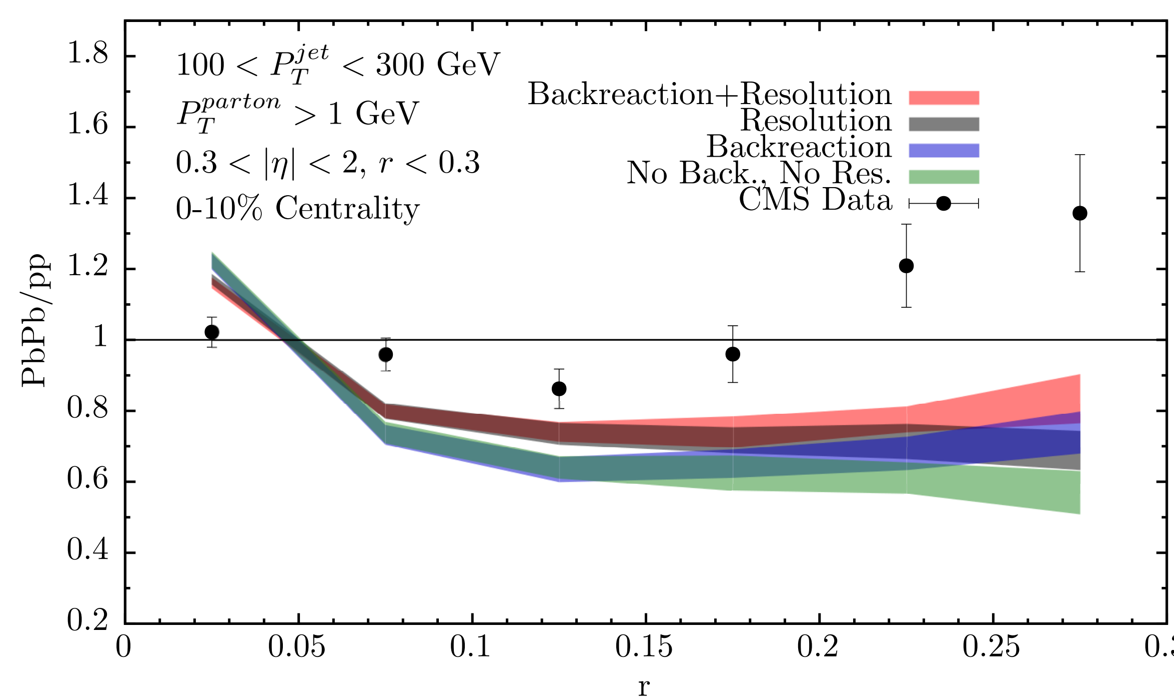
Partonic



Hadronic + Backreaction



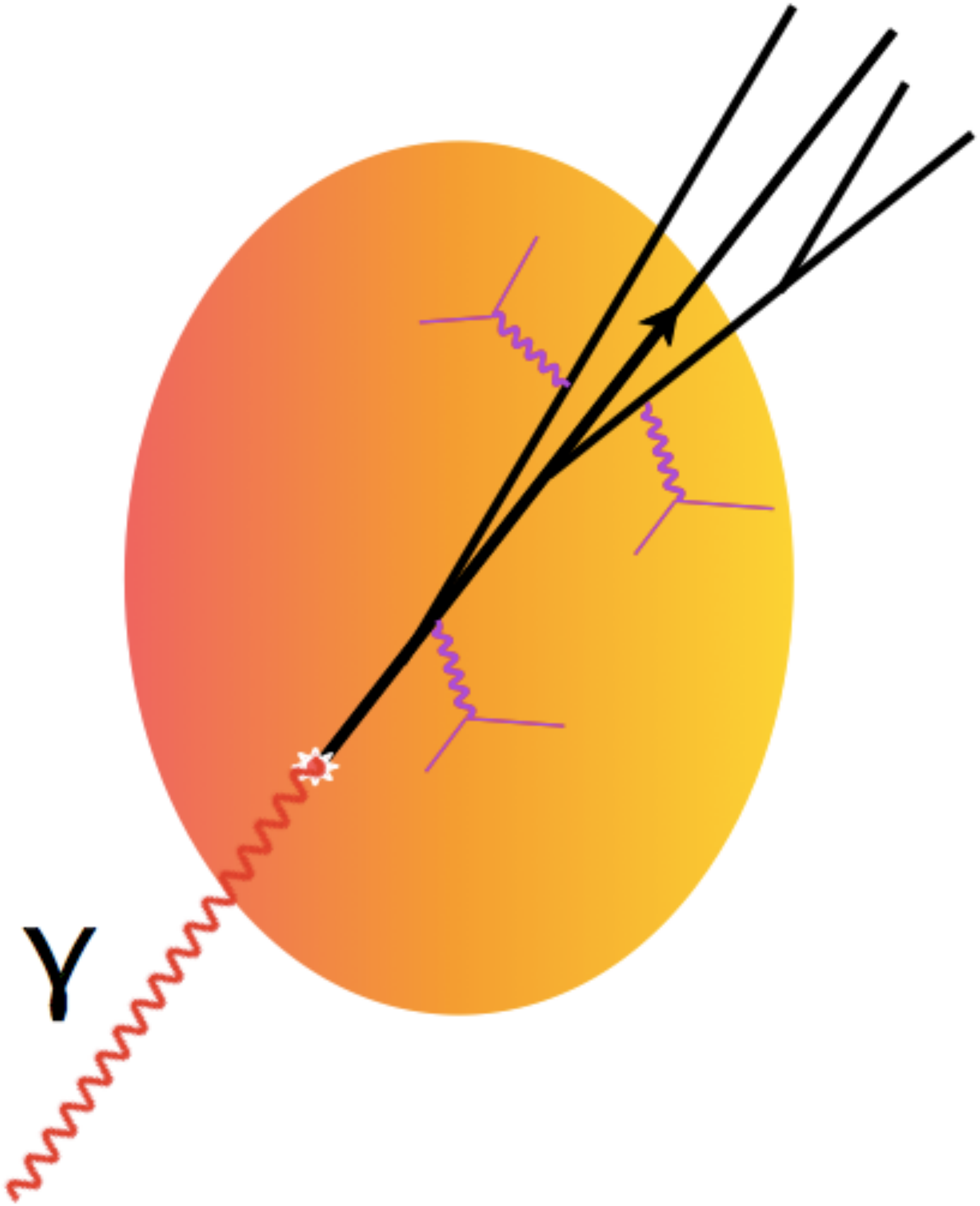




$$L_{\text{Res}} = \frac{1}{\pi T}$$

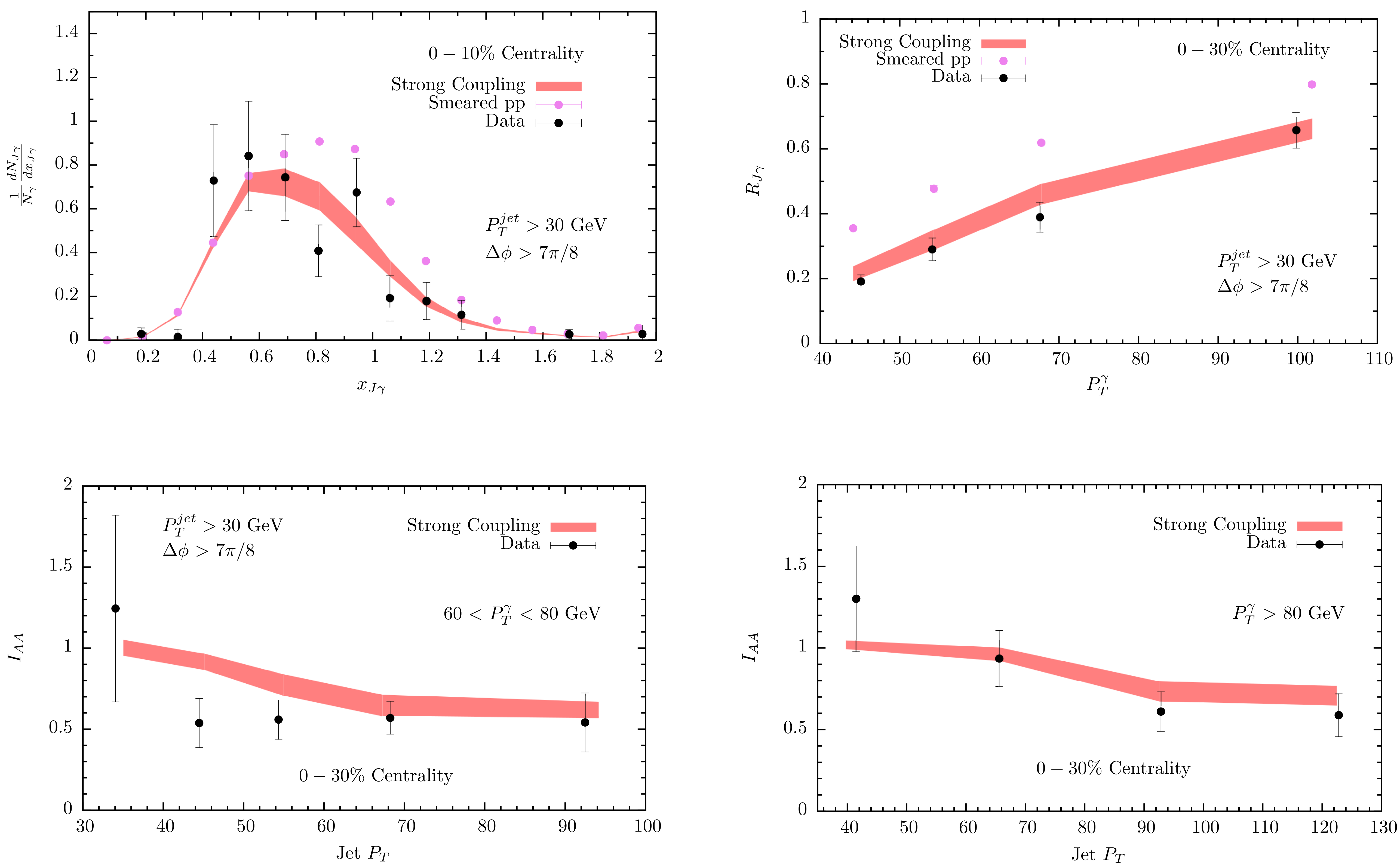
(had to refit κ_{sc} to the10% level)

Photon Jet



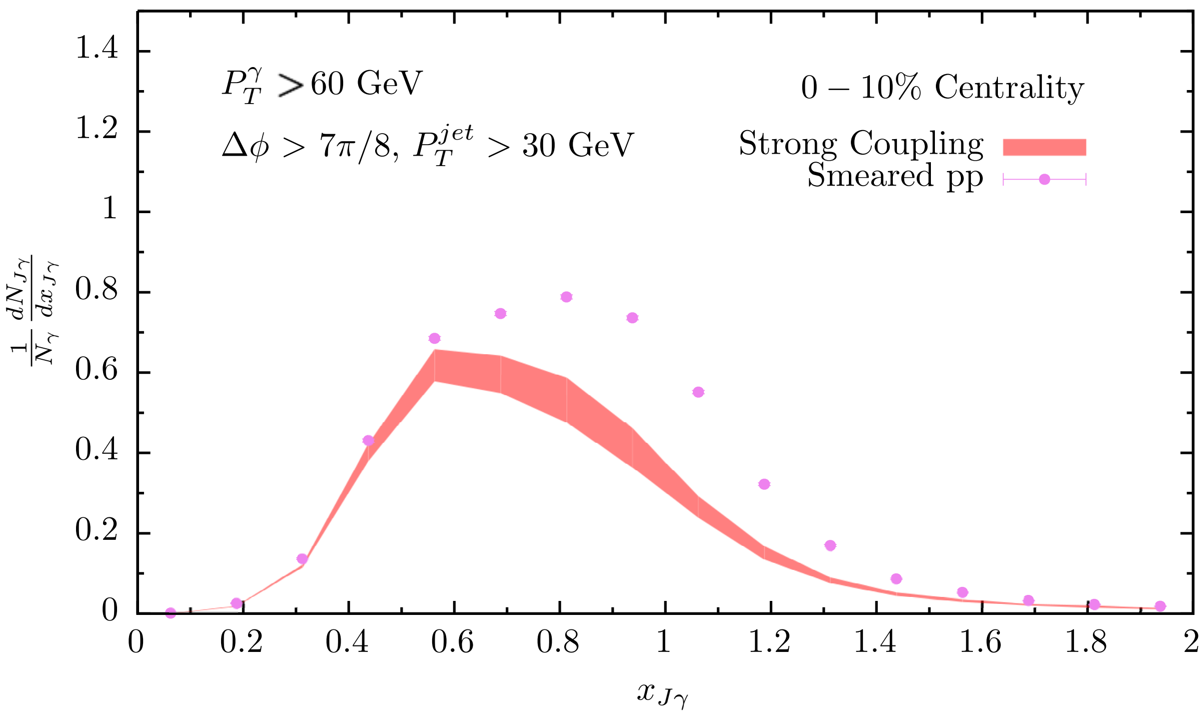
- Photons do not interact with plasma
- Look for associated jet
  - -Different geometric sampling
  - -Different species composition
  - -E_γ proxy for E_{jet}

Photon Jet @ 2.76 TeV

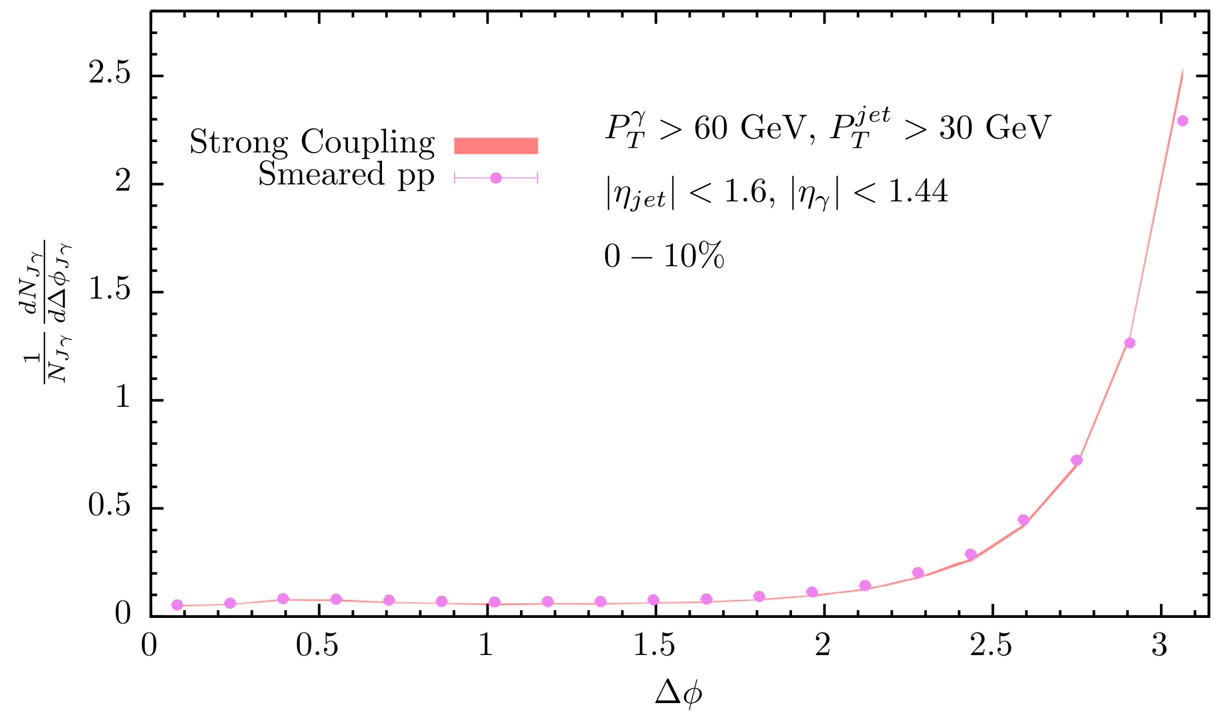


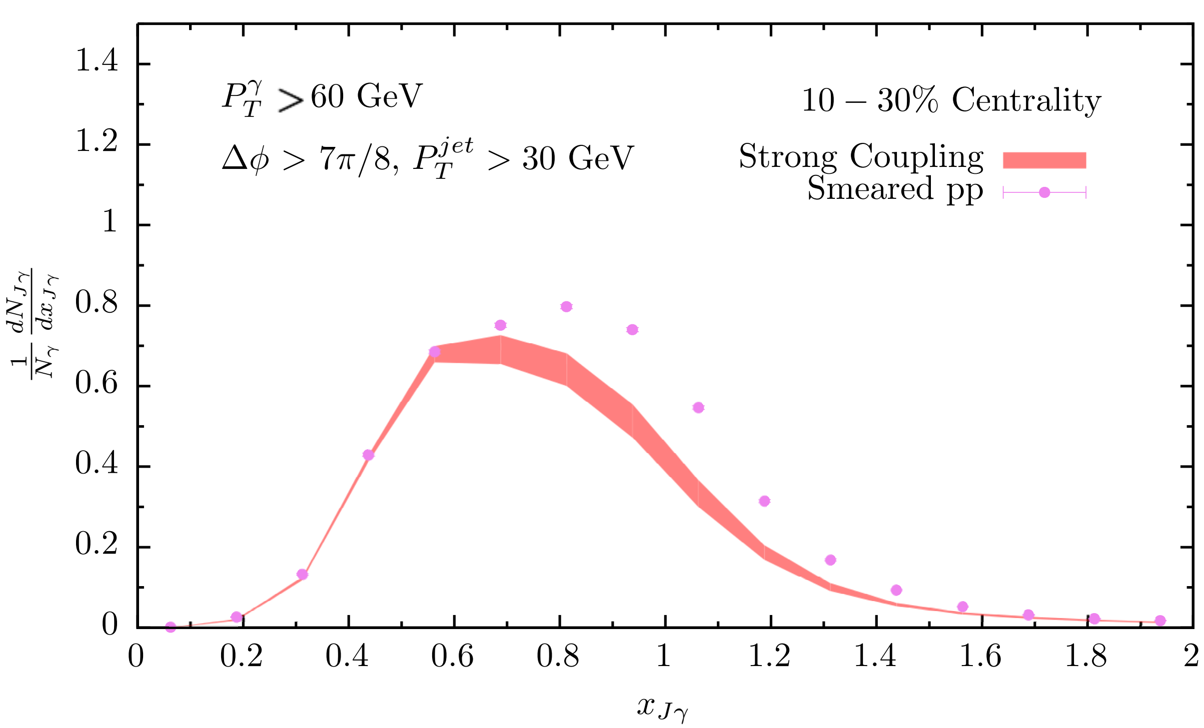
Photon Jet @ 5.02 TeV

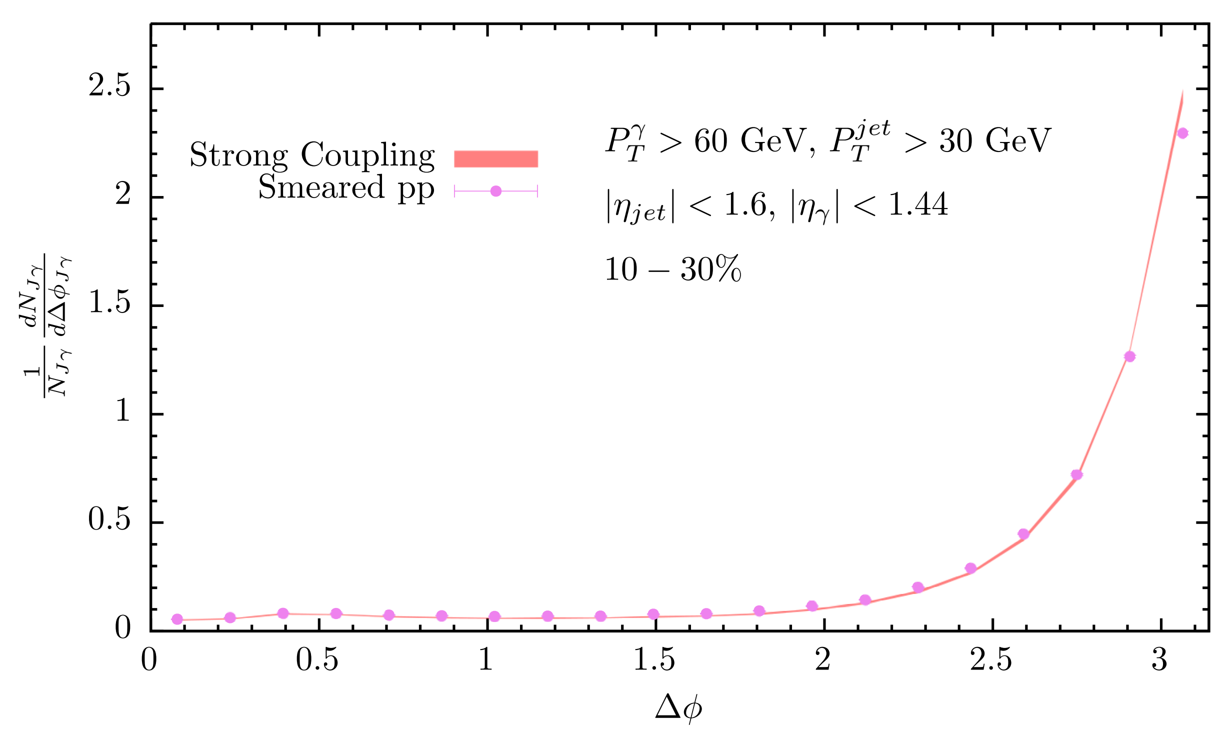
Imbalance



Acoplanarity





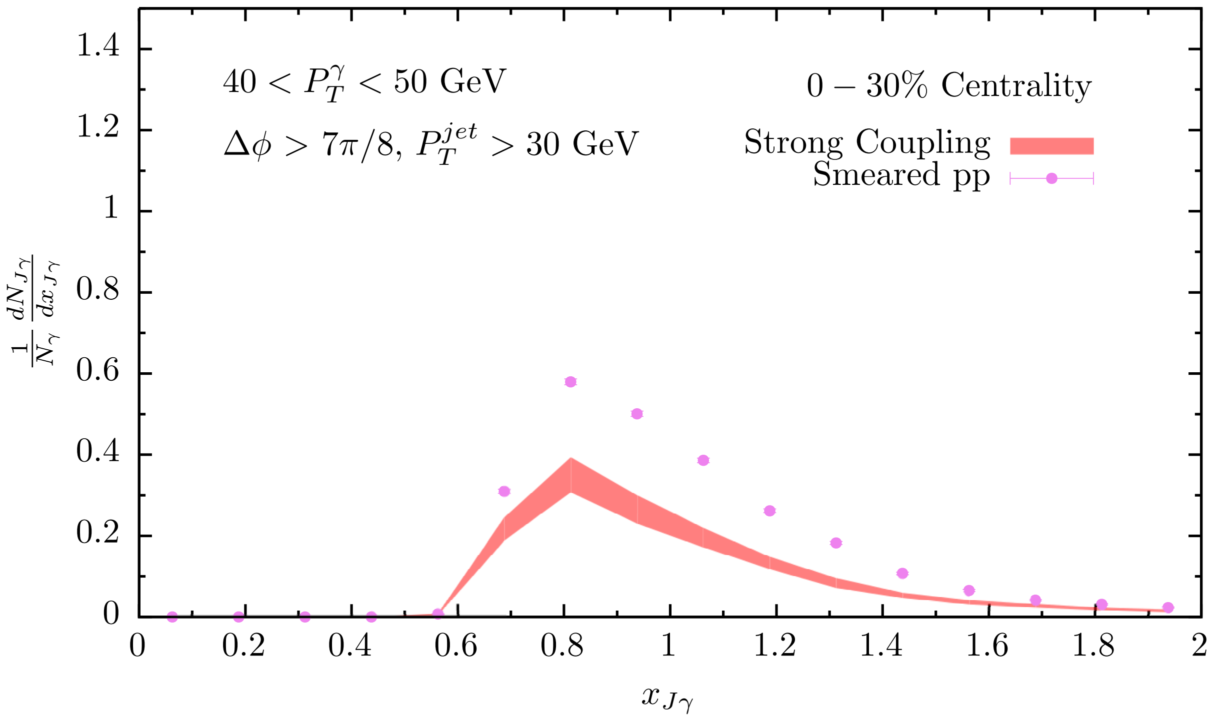


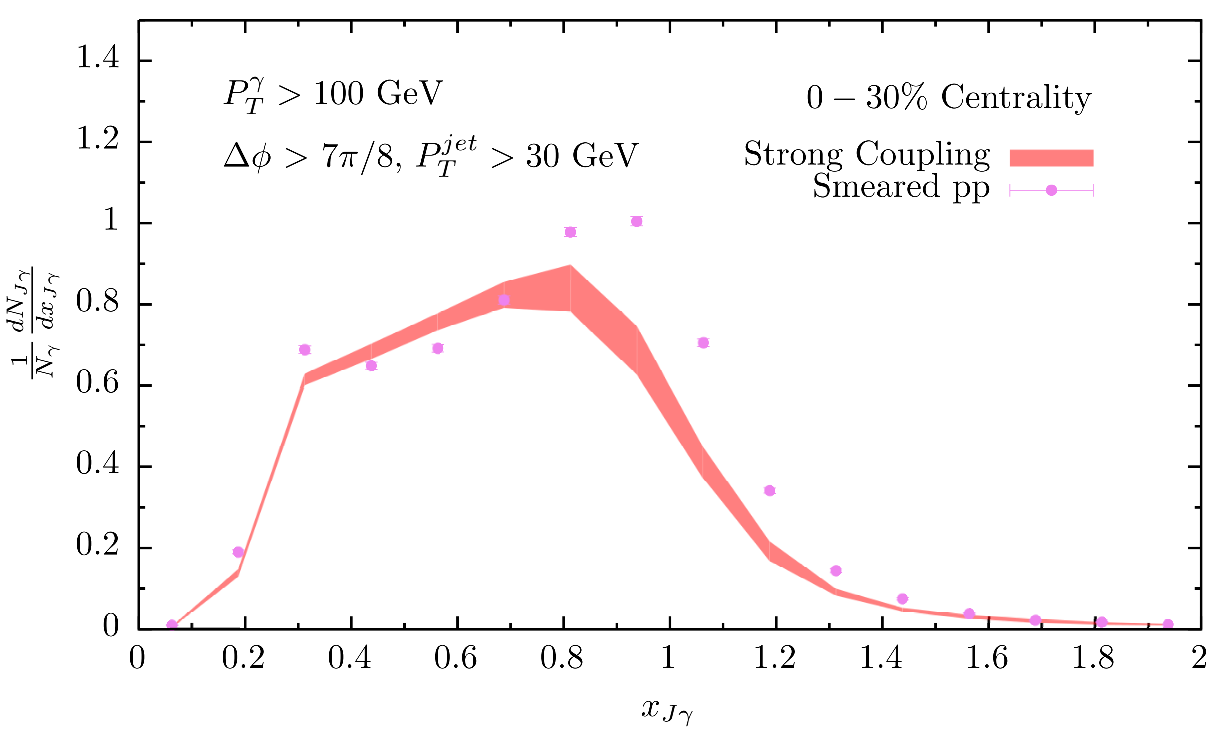
Sliced in Centrality

see Chris Mc Ginn's talk

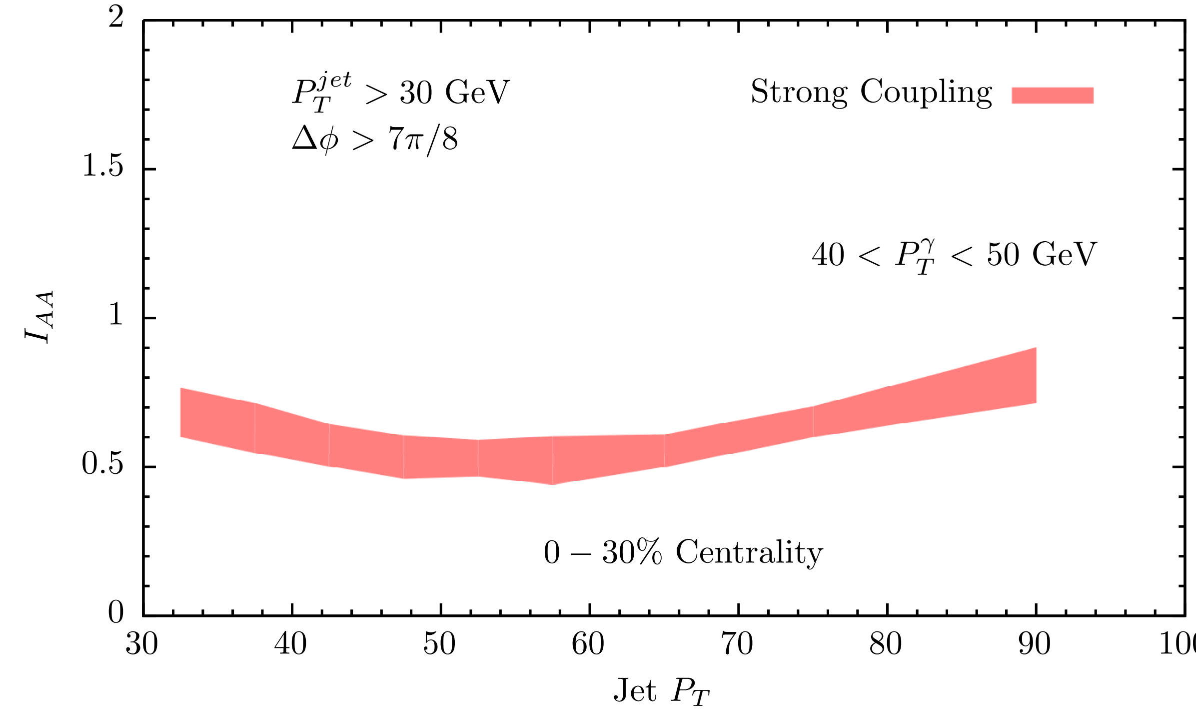
Photon Jet @ 5.02 TeV

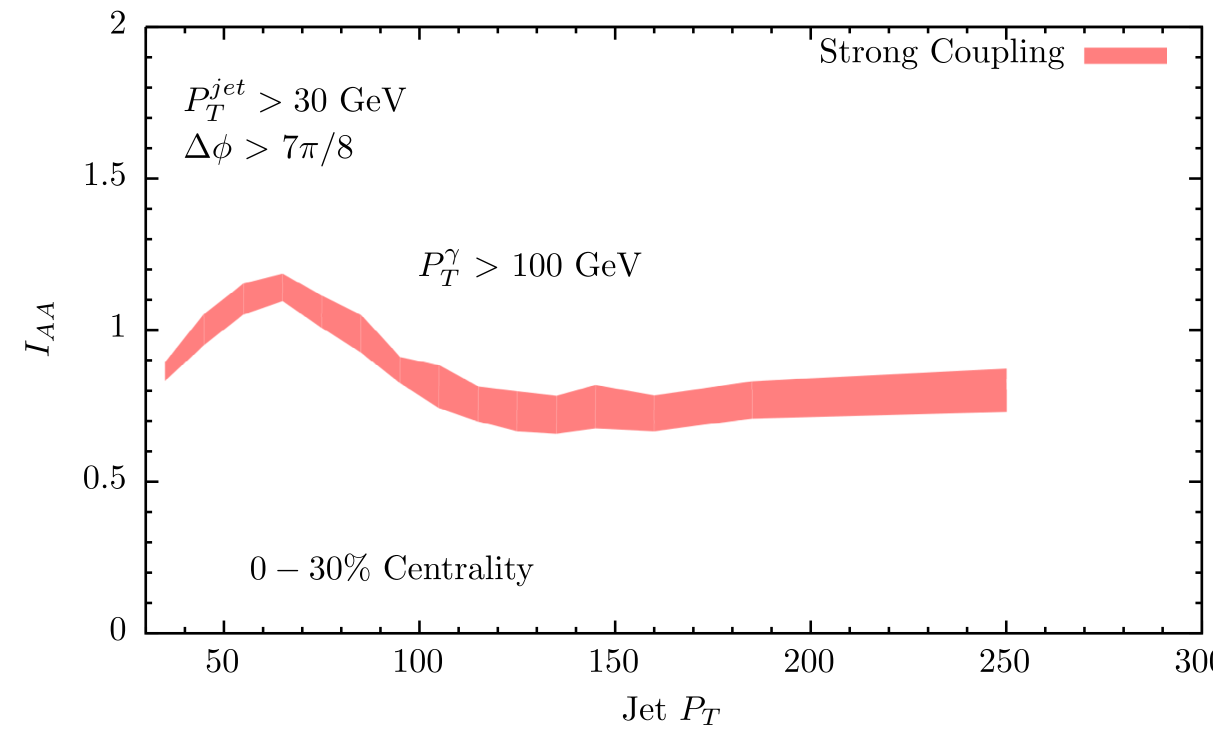
Imbalance





Associated Jet Spectrum

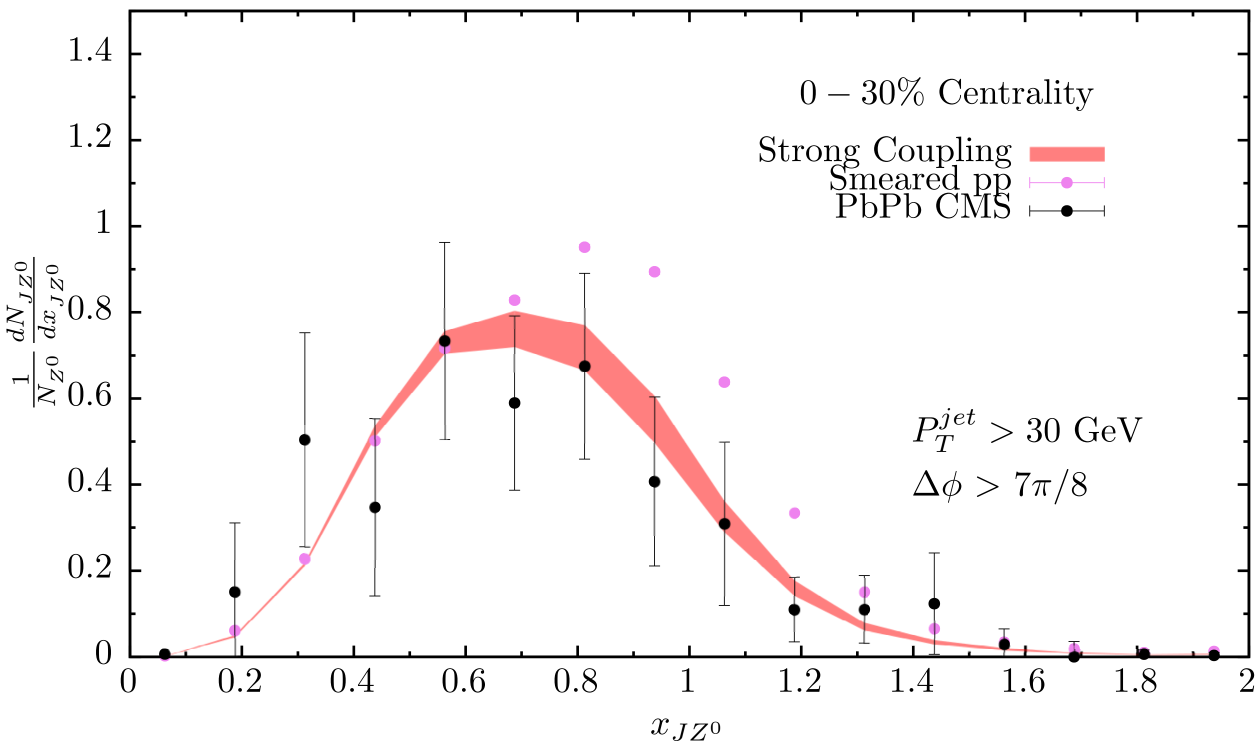


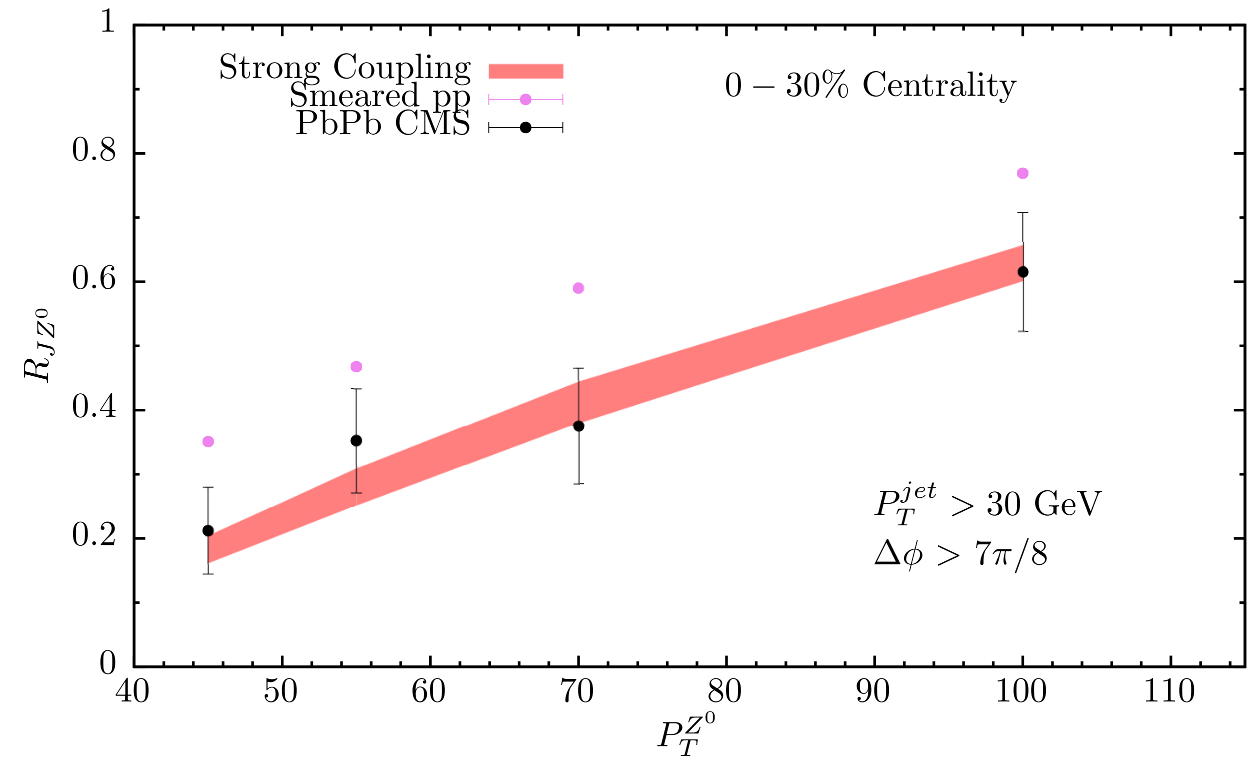


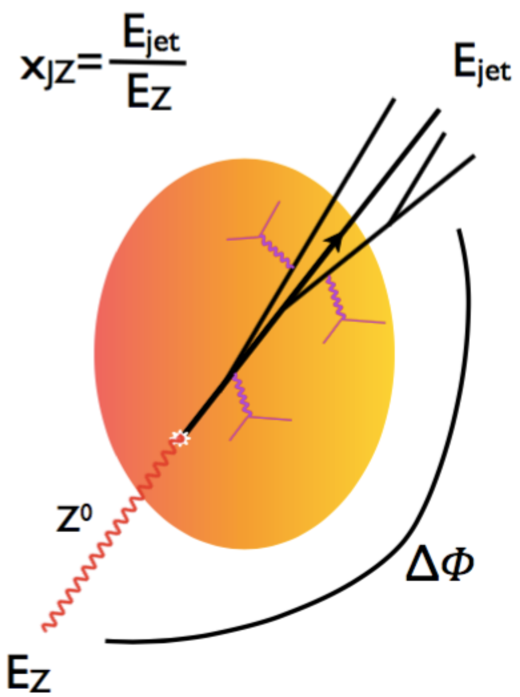
Sliced in Photon Pt

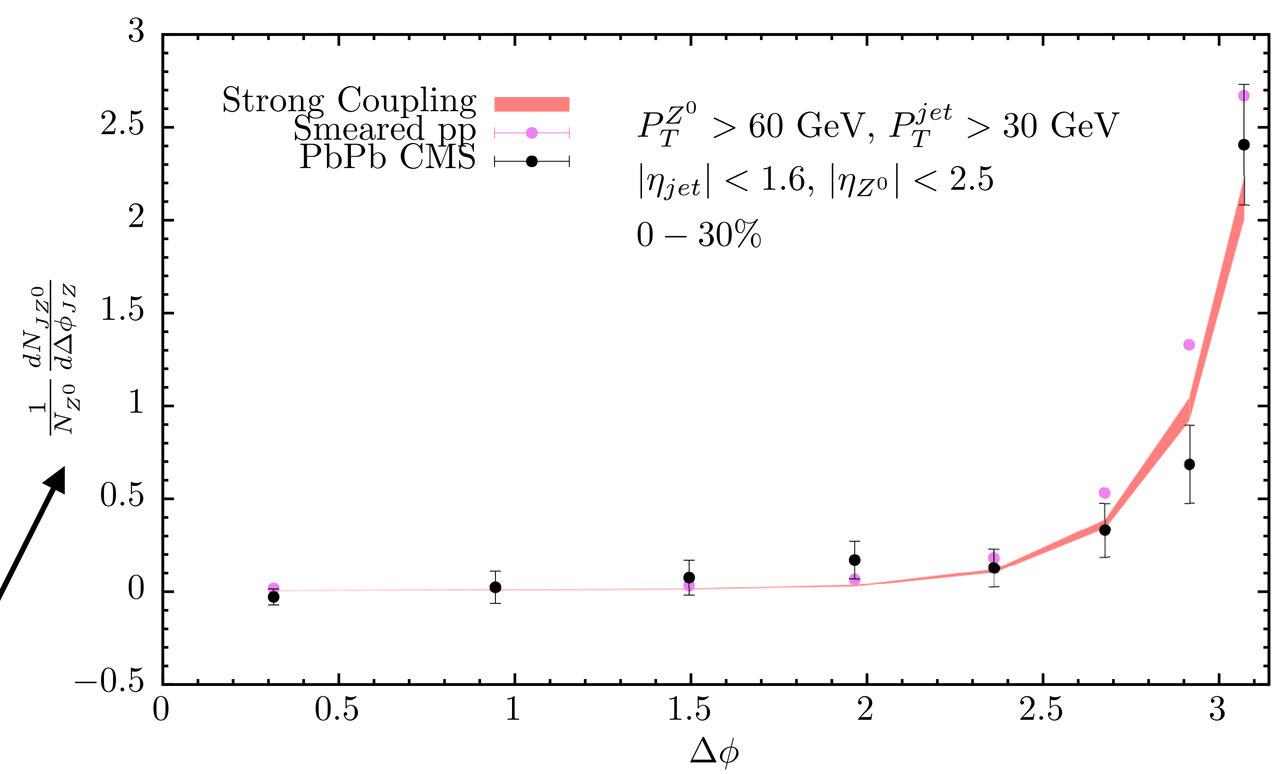
see Chris Mc Ginn's talk

Z Jet @ 5.02 TeV







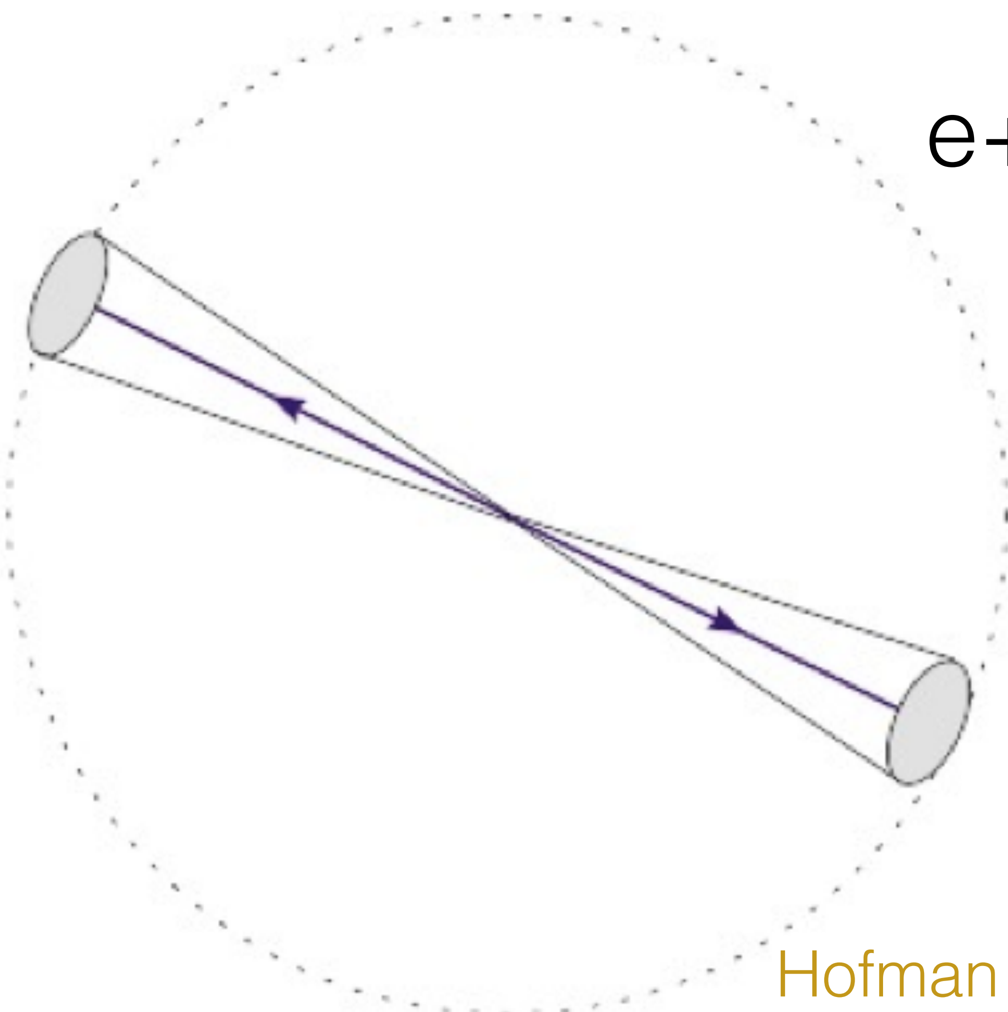


Normalised over the number of Zs

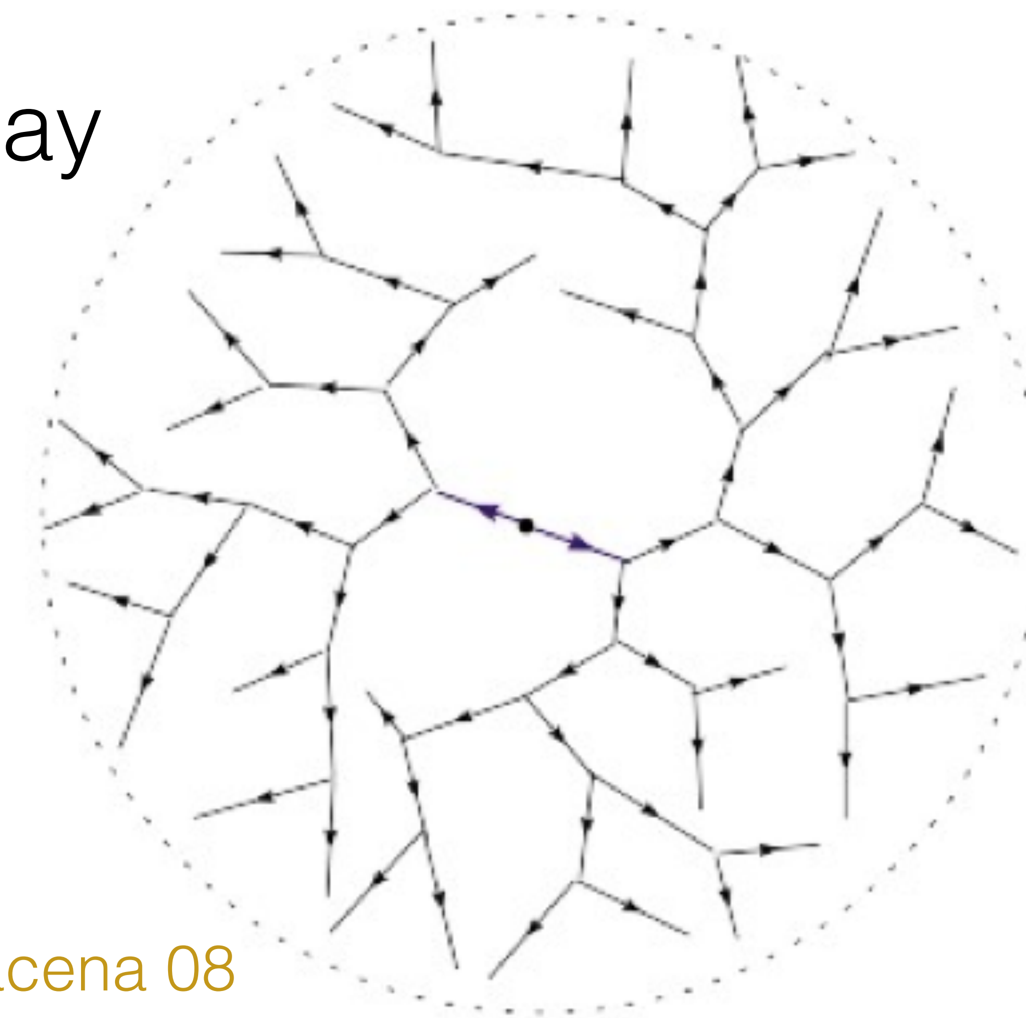
see Kaya Tatar's talk

Strong Coupling

There are no jets in N=4 SYM at strong coupling



e+e- decay



Hofman and Maldacena 08
Hatta, Iancu, Mueller 08

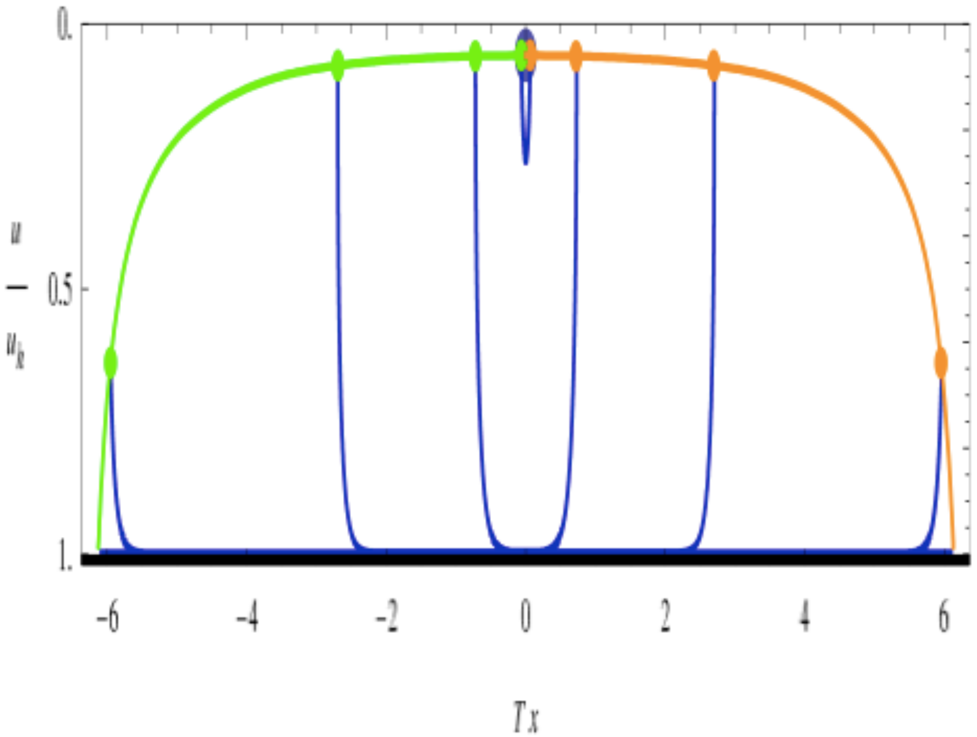
Weak

Strong

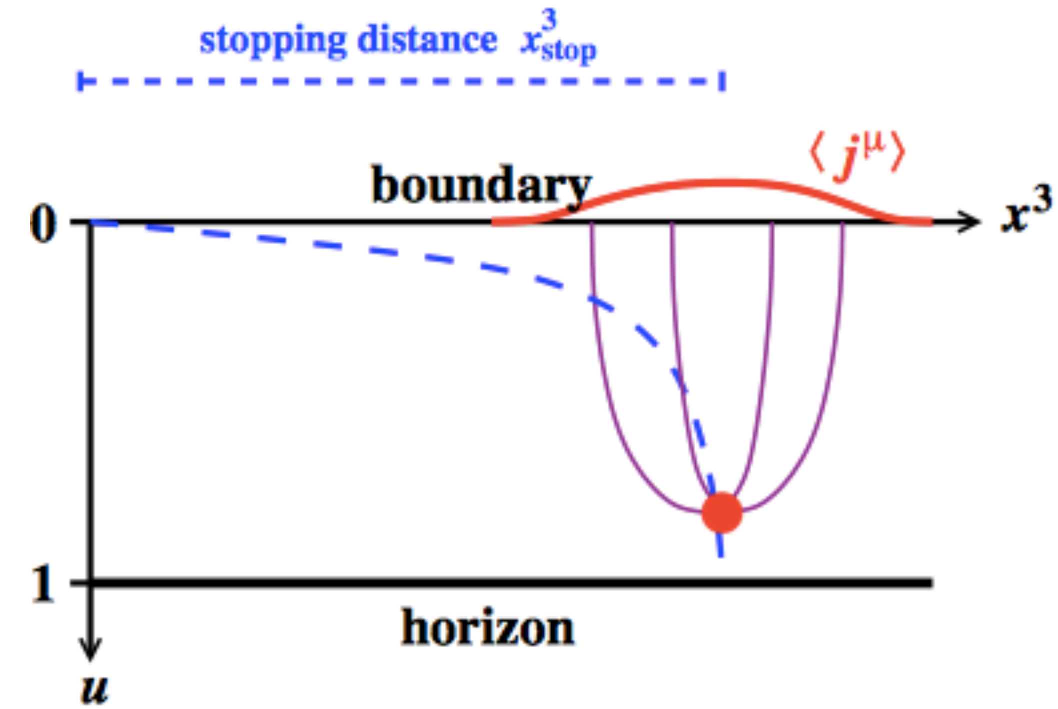
Problem for hard probes

Energetic Excitations

Classical string



Boosted virtual photon



$$x_{\text{stop}} = \frac{1}{2\,\kappa_{\text{sc}}} \frac{E_{\text{in}}^{1/3}}{T^{4/3}}$$

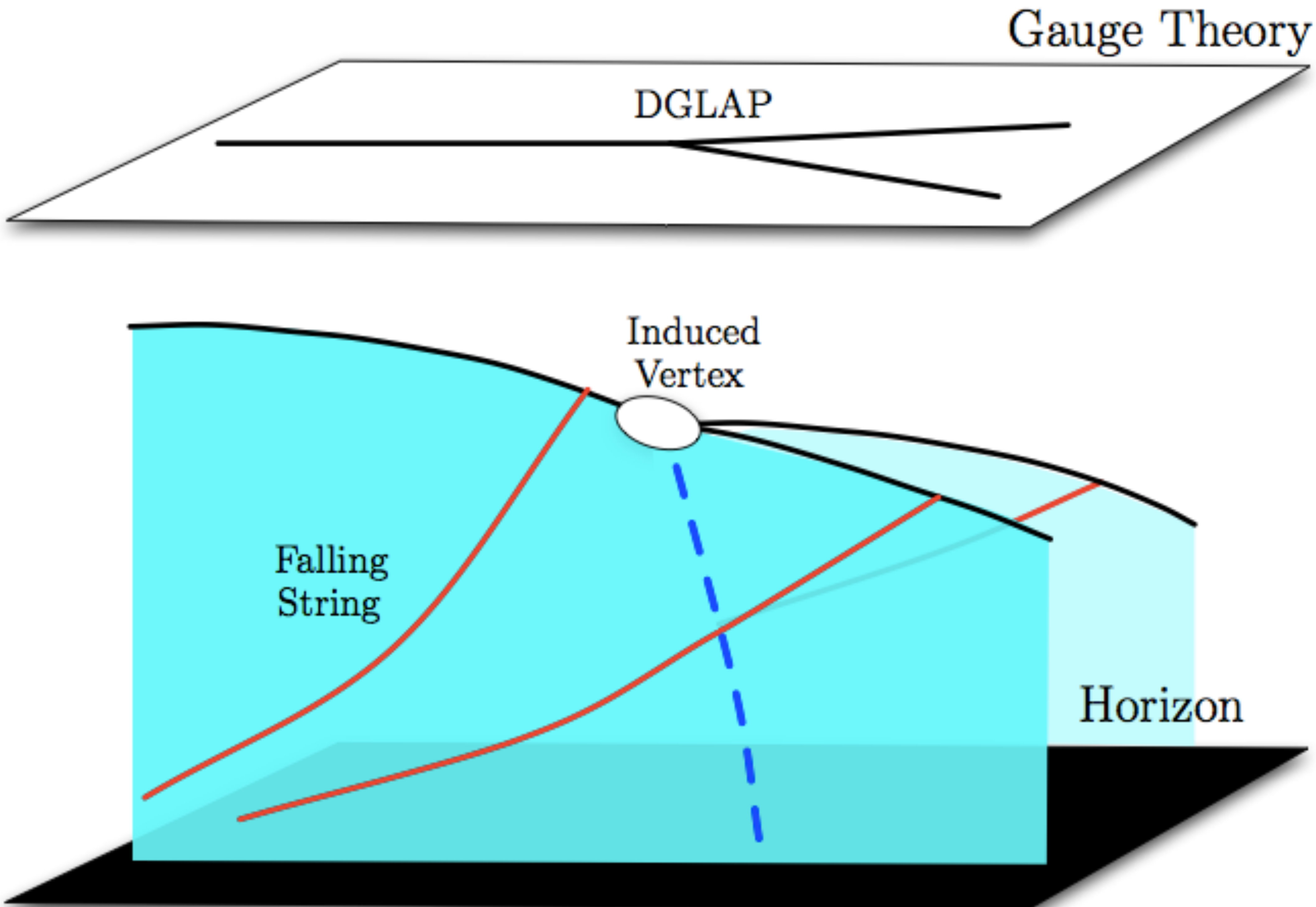
$$\kappa_{\text{sc}} = 1.05\,\lambda^{1/6}$$

$$\kappa_{\text{SC}} \propto \lambda^0$$

Chesler, Jensen, Karch, Yaffe 08

Arnold and Vaman 10

A Heuristic Picture



Parameters

Parameter	HHN hydro without flow effects		HHN hydro with flow effects		SH Hydro with flow effects	
	T_c range		T_c range		T_c range	
	180 MeV	200 MeV	180 MeV	200 MeV	145 MeV	170 MeV
$\kappa_{\rm sc}$	$0.26-0.31$	$0.30-0.35$	$0.39-0.46$	$0.45-0.53$	$0.32-0.37$	$0.35-0.41$
$\kappa_{\rm rad}$	$0.81-1.2$	$1.0-1.6$	$1.6-2.4$	$2.1-3.3$	$0.97-1.5$	$1.2-1.8$
$\kappa_{\rm coll}$	$2.5-3.5$	$2.9-4.2$	$2.5-3.5$	$2.9-4.2$	$1.8-2.6$	$2.2-3.0$

$$x_{\rm stop} = \frac{1}{2\,\kappa_{\rm sc}} \frac{E_{\rm in}^{1/3}}{T^{4/3}}$$

Strong Coupling

Parameter is of order one as expected

$$x_{stop} \sim (3-4)\, x_{stop}^{\mathcal{N}=4}$$ (via semiclassical strings)

(smaller number of degrees of freedom!)

- All the difference between N=4 and QCD leads to an order one modification of the stopping distance

$\mathcal{N}=4$ SYM at $T \neq 0$ *vs* QCD at $T > T_c$

$$N_c \to \infty, \;\; \lambda \to \infty$$

1101.0618

- Confinement scale and chiral condensate scale play no role above critical temperature
- Regime above T_c in colliders strongly coupled ($\frac{1}{\lambda}$ corrections)
- Different degrees of freedom (how do observables depend on this?)
- $N_c \to \infty$ ($\frac{1}{N_c}$ corrections)
- $0 < N_f \ll N_c$ or $N_f = 0$, but contributions from fundamental representations are important for thermodynamics above T_c
- QCD running of the coupling constant significantly non-conformal just above T_c (but increasingly conformal with higher T)