Jet Production at RHIC and LHC

(a selection of results)

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Quark Matter 2017
Chicago, USA

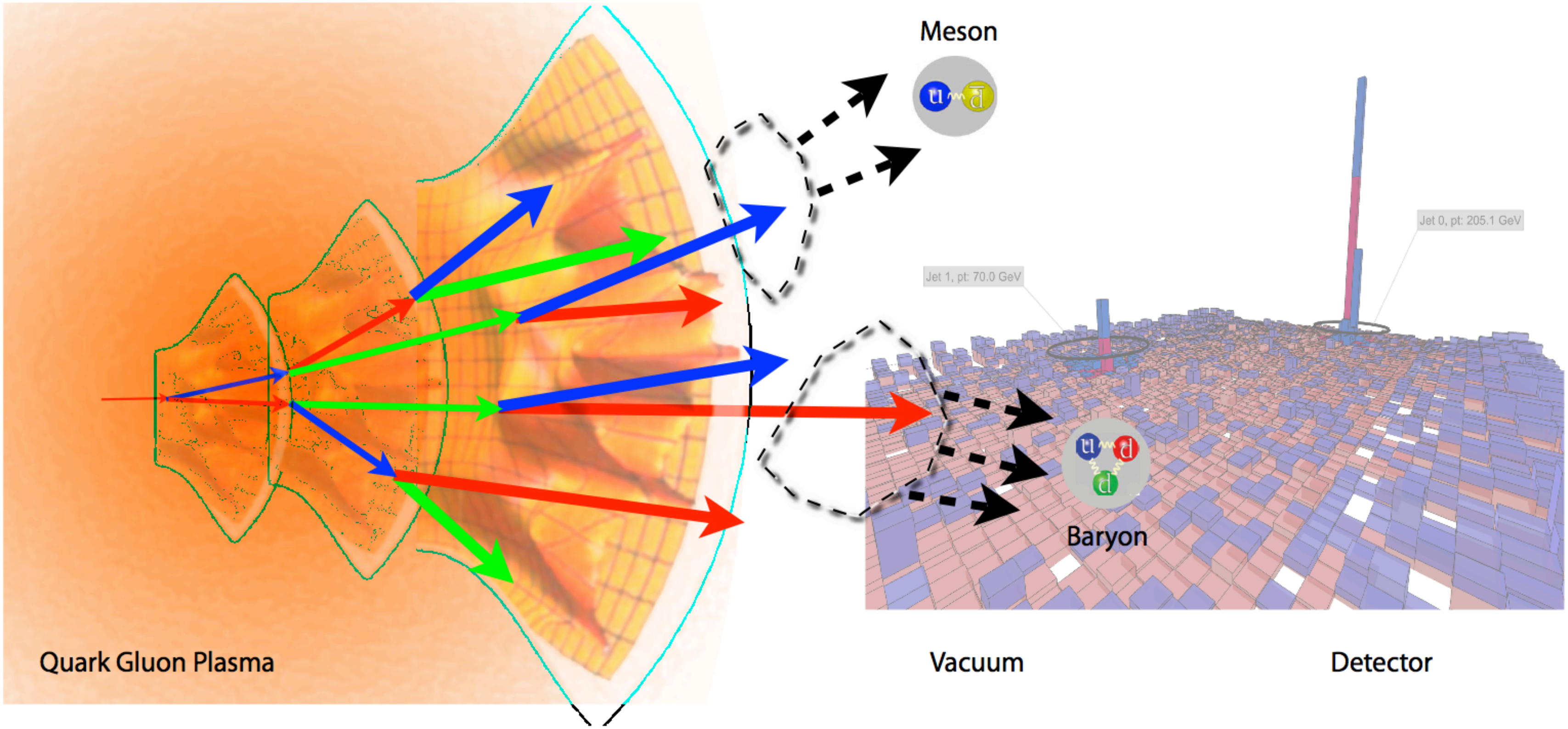
Jet Physics in Heavy Ions

How is the jet shower modified in a Heavy Ion Collision
relate observed jet modifications to parton energy loss in the medium (quenching)

Understand mechanisms of parton energy loss in medium
parton shower probes medium at different energy scales

Infer fundamental properties: color density, qhat, quasi-particle structure
clean connection to the theory, well defined observables

Jets in Heavy Ions: multi-scale problem



Hard process, scale is $O(p_T^{jet})$

- Vacuum DGLAP evolution
- Medium-induced gluon emission
- Collisional energy loss
- Large angle scattering (Moliere)

Soft exchanges of energy and momentum between jet fragments and the medium, scale is $O(T^{medium})$

- Drag forces
- Sound waves
- Heating up the plasma

Jets in Heavy Ions

Jets in heavy ions becoming a quantitative field

Well defined, fully corrected, calculable observables

Isolate key aspects of the physics by careful choice of the observables.

Examples:

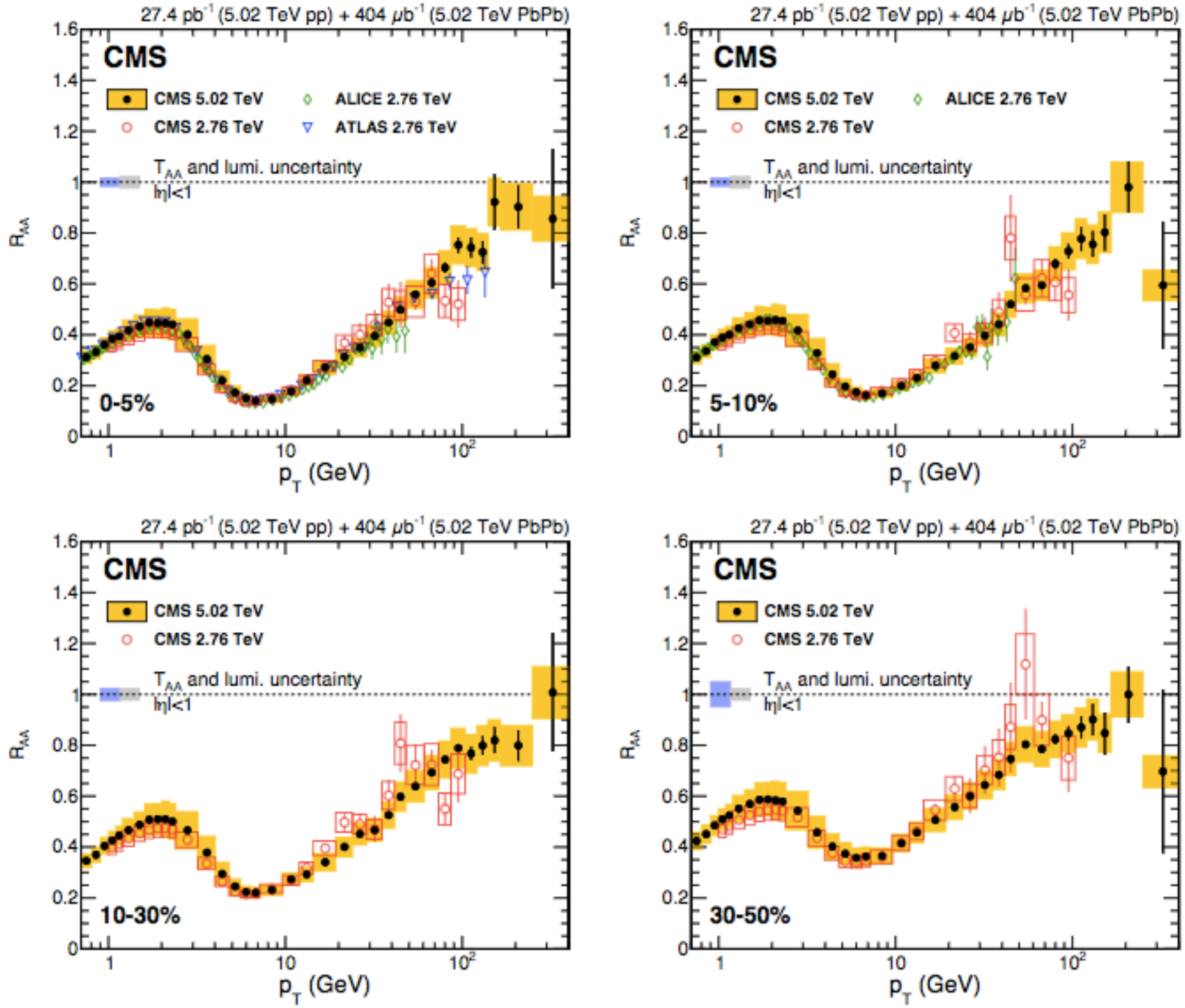
- z_g: isolate the hard splitting in the jet, gain sensitivity to semihard rare BDMPS gluons and to medium response

- angular correlations with jets at low jet p_T to be sensitive to momentum broadening

- ...

Inclusive hadron and jet suppression up to the TeV scale

Inclusive Hadron and Jet Suppression

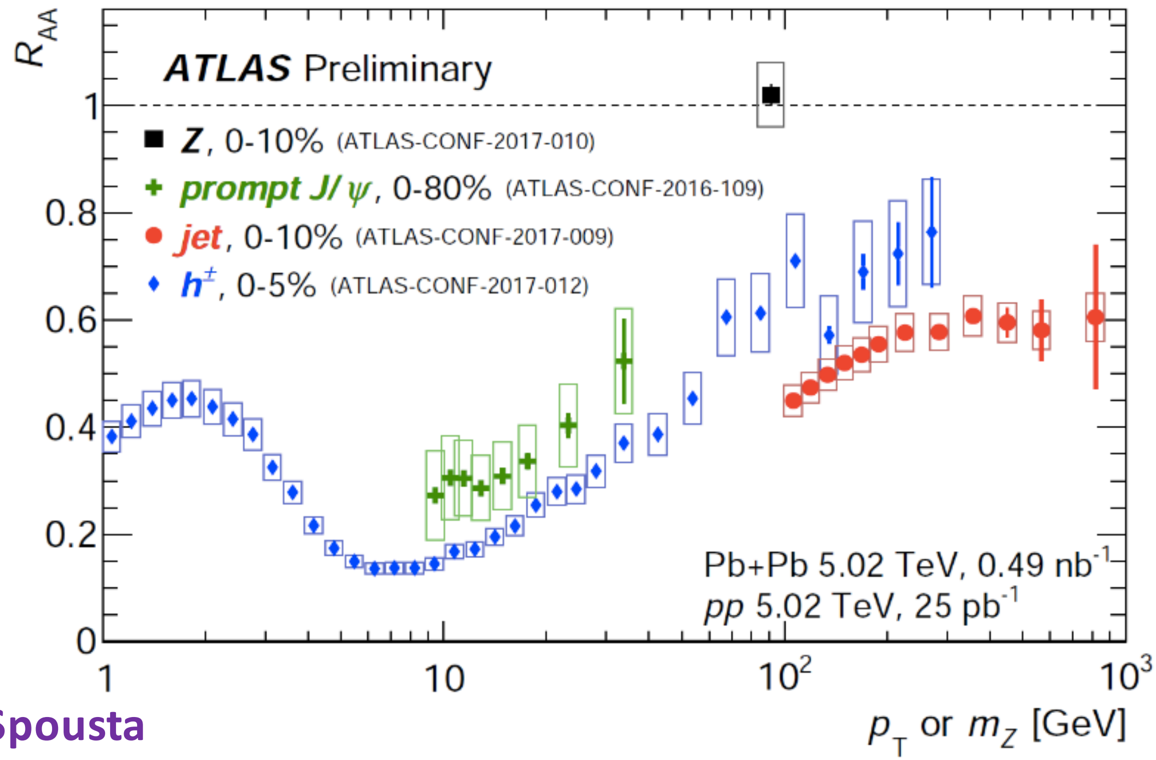


Single hadron R_{AA} is a “disappearence” measurement ->limited info on dynamics of jet quenching

No energy dependence of R_{AA}, however the production spectrum is expected to be different for the two energies

Austin Baty

Inclusive Hadron and Jet Suppression



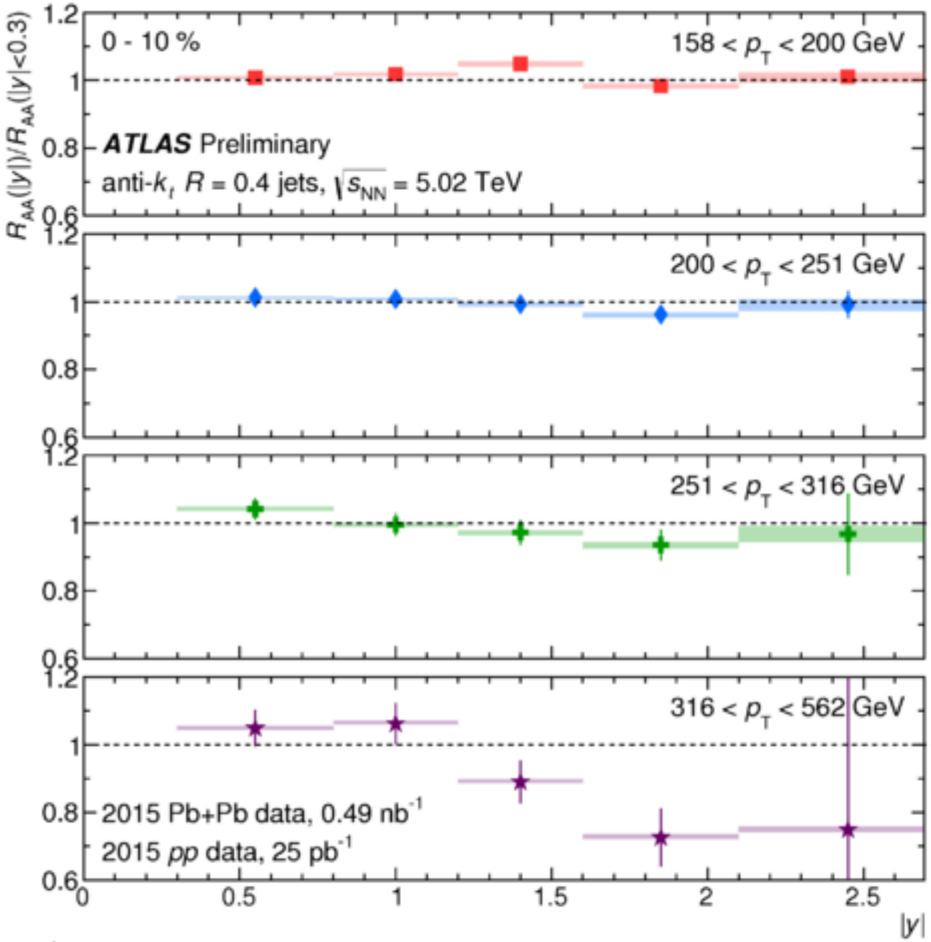
Martin Spousta

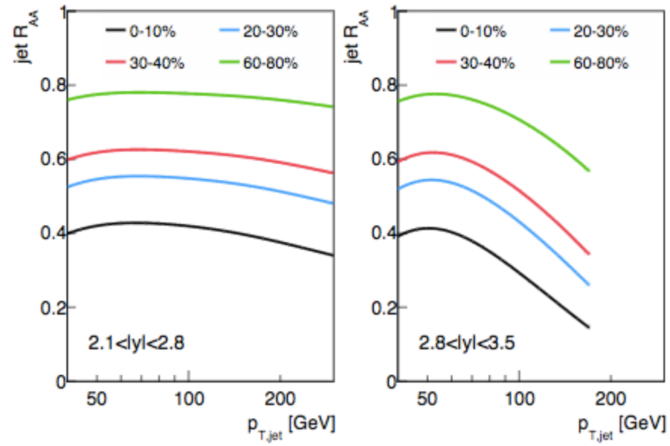
-ATLAS new measurement of jet R_{AA} up to 1 TeV (R=0.4)

-When comparing hadrons and jets note that:

A very high p_T hadron comes from a parton that fragmented very hard (low mass) and that consequently suffered less quenching

Rapidity dependence of suppression





The main features of R_{AA} and its y dependence can be explained by two ingredients:

- -increasing steepness of the spectra close to kinematic limit
- -increasing quark-jet fraction with y

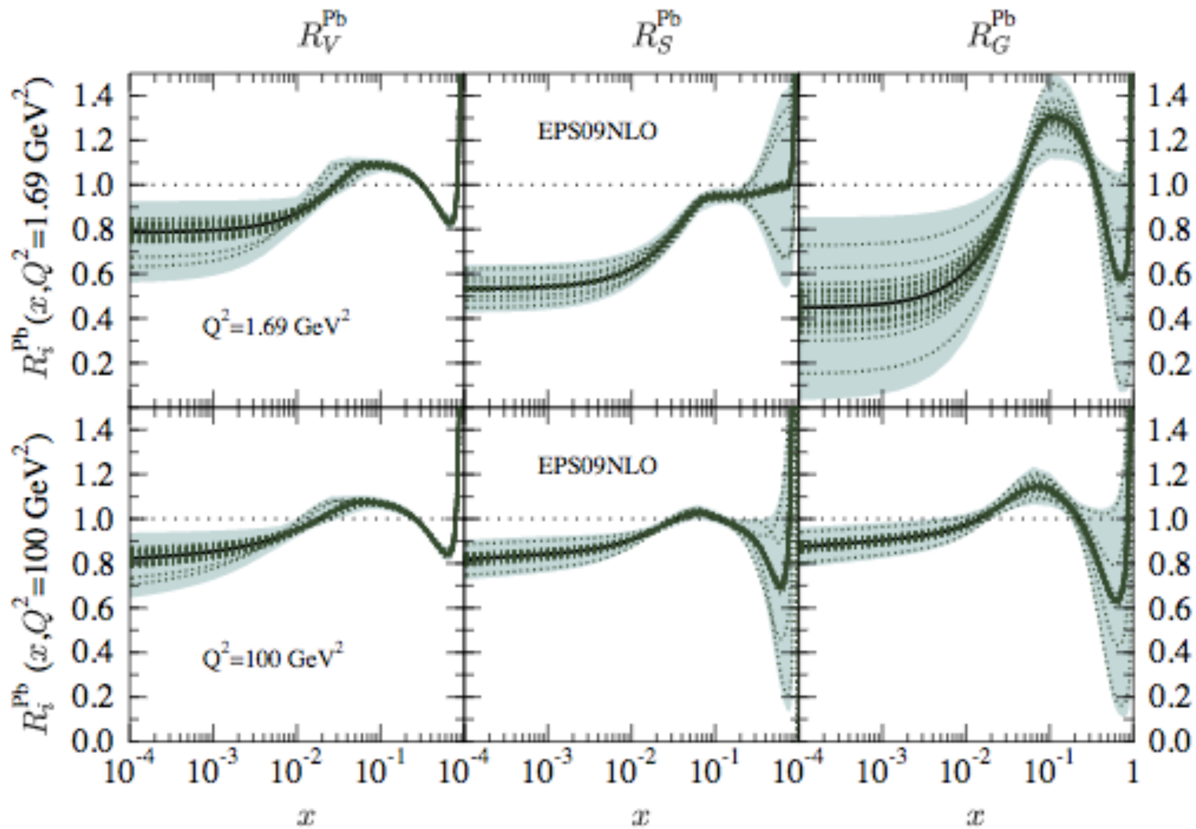
M.Spousta, B.Cole, Eur. Phys. J. C 76 (2016) no.2, 50

Martin Spousta

Interplay between y-dependent flavor composition & spectral shape

See also T.Renk arXiv:1406.6784

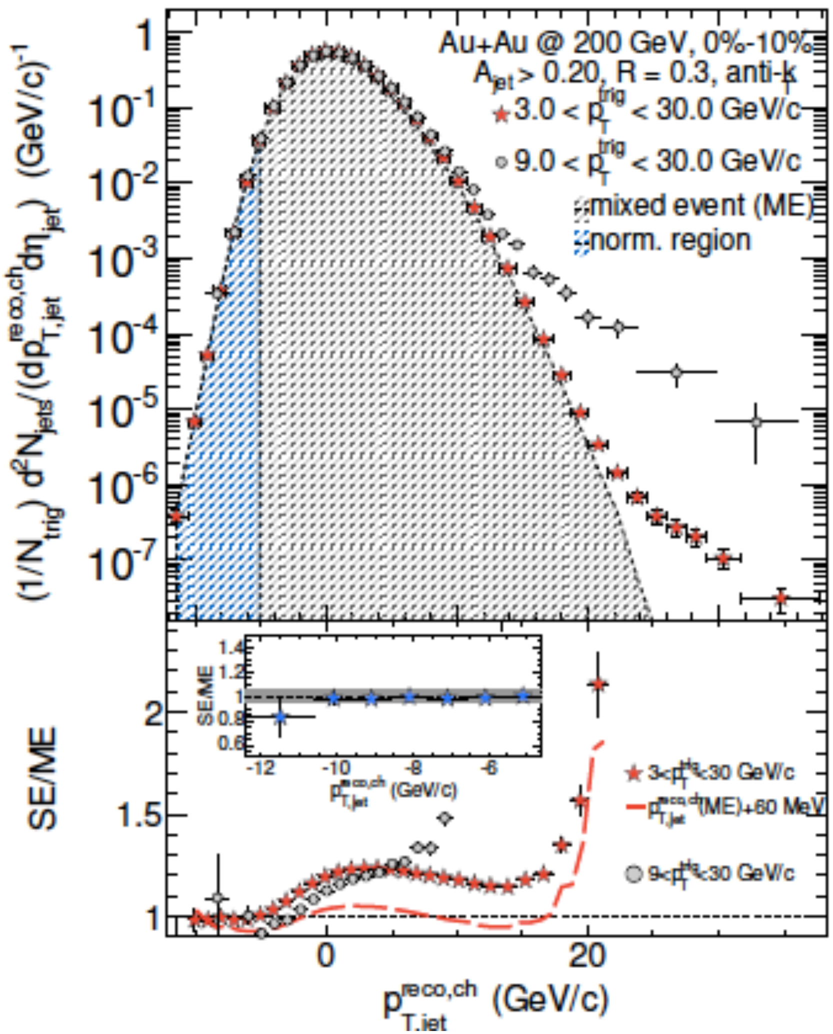
Role of nuclear effects at the TeV scale?



-At y=0, x_t=2E/sqrt(s), for E=1 TeV, x_t=0.4 at LHC@5 TeV ->EMC region

Seminclusive measurements with hadron, boson and jet triggers

Seminclusive recoil jet suppression with hadron triggers

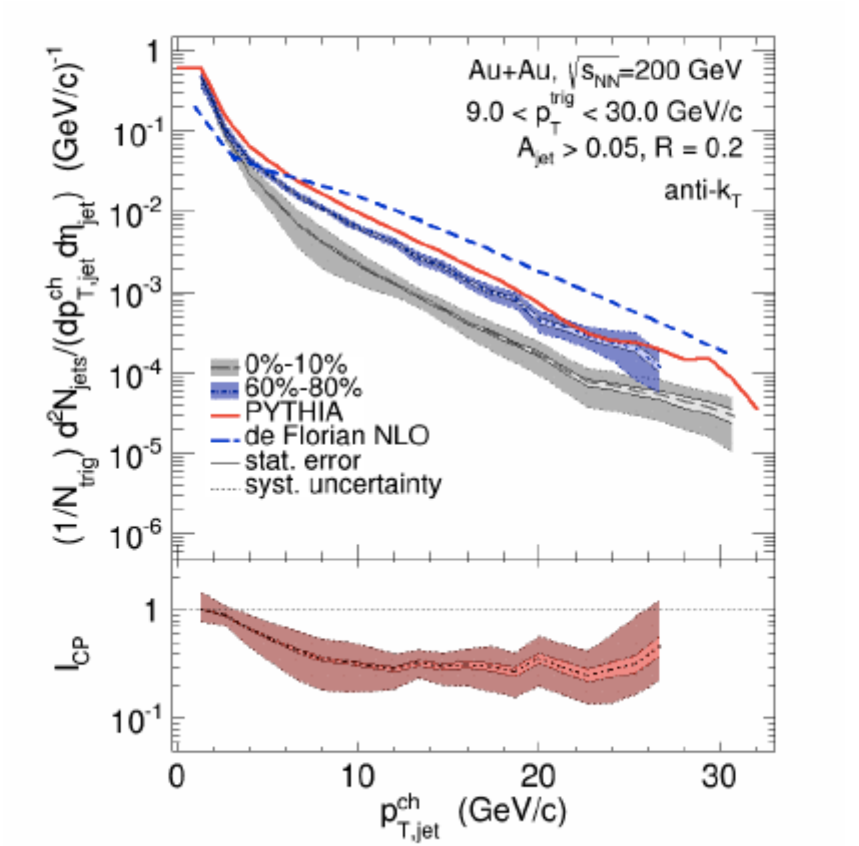


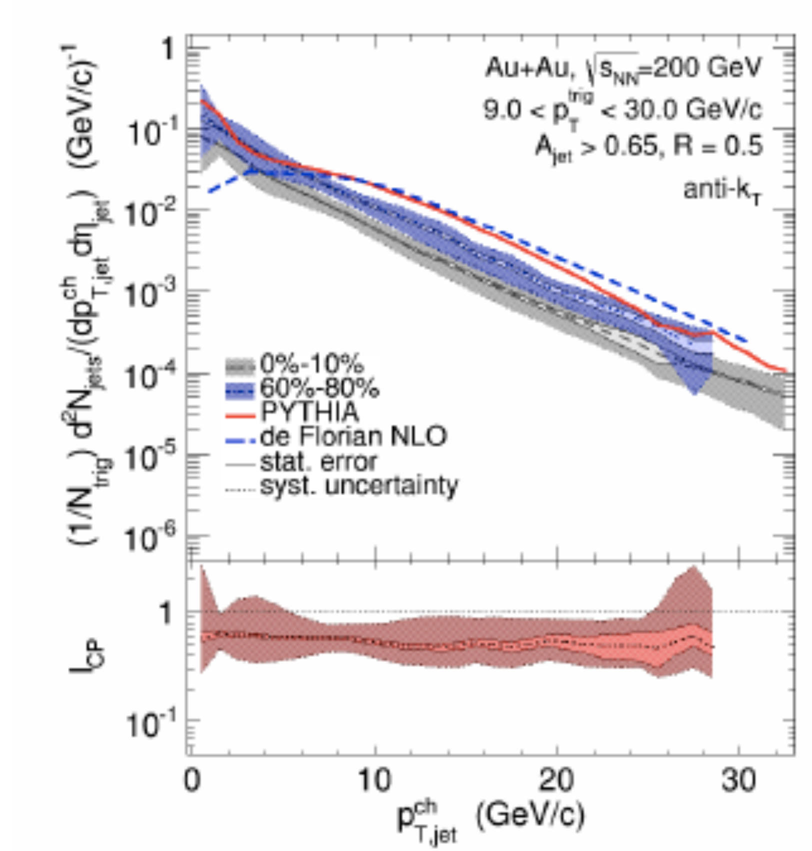
Correction for uncorrelated background at the level of ensemble averaged distributions without discrimination of signal/background on a jet-by-jet basis.

Access to low jet p_T and arbitrarily large R

STAR arXiv:1702.01108

Seminclusive recoil jet suppression with hadron triggers

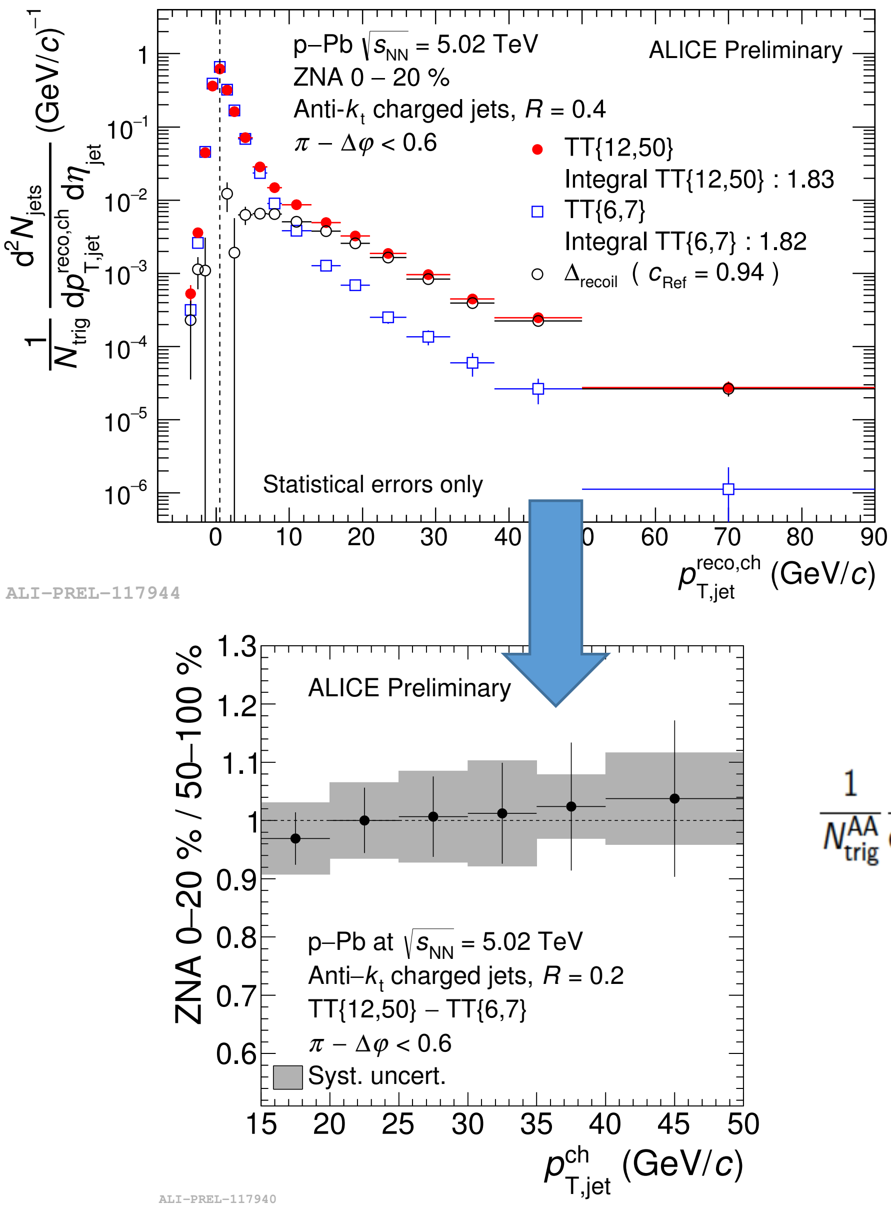




System		Au+Au $\sqrt{s_{NN}} = 200$ GeV	Pb+Pb $\sqrt{s_{NN}} = 2.76$ TeV
$p_{T,jet}^{ch}$ range (GeV/c)		[10,20]	[60,100]
		p_T-shift of $Y\left(p_{T,jet}^{ch}\right)$ (GeV/c)	
		peripheral→central	p+p→central
R	0.2	$-4.4 \pm 0.2 \pm 1.2$	
	0.3	$-5.0 \pm 0.5 \pm 1.2$	
	0.4	$-5.1 \pm 0.5 \pm 1.2$	
	0.5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

Energy shift:
RHIC ~ 4 GeV
LHC ~ 8 GeV

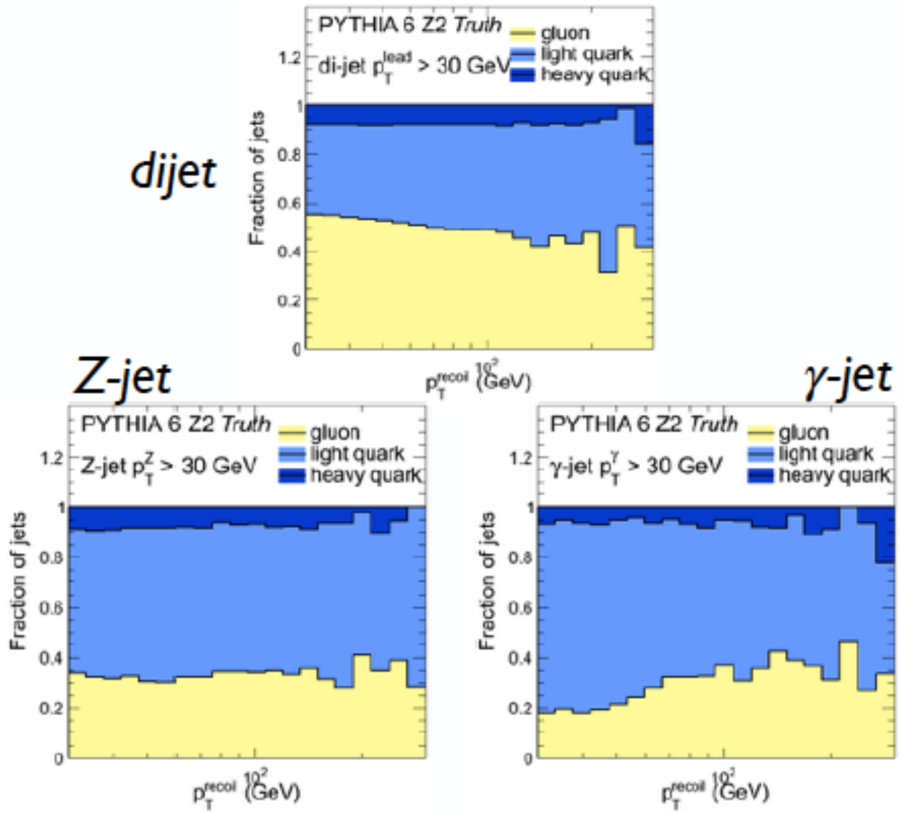
Seminclusive recoil jet suppression with hadron triggers



Seminclusive hadron-jet measurements also bring the opportunity to study hard procesess and constrain jet quenching in small system without relating event activity to geometry

$$\frac{1}{N_{trig}^{AA}} \frac{d^2 N_{jet}^{AA}}{dp_{T,jet}^{ch} d\eta_{jet}}\bigg|_{p_{T,trig}\in TT} = \left(\frac{1}{\sigma^{pp\to h+X}} \cdot \frac{d^2\sigma^{pp\to h+jet+X}}{dp_{T,jet}^{ch} d\eta_{jet}}\right)\bigg|_{p_{T,h}\in TT} \times \frac{T_{AA}}{T_{AA}}$$

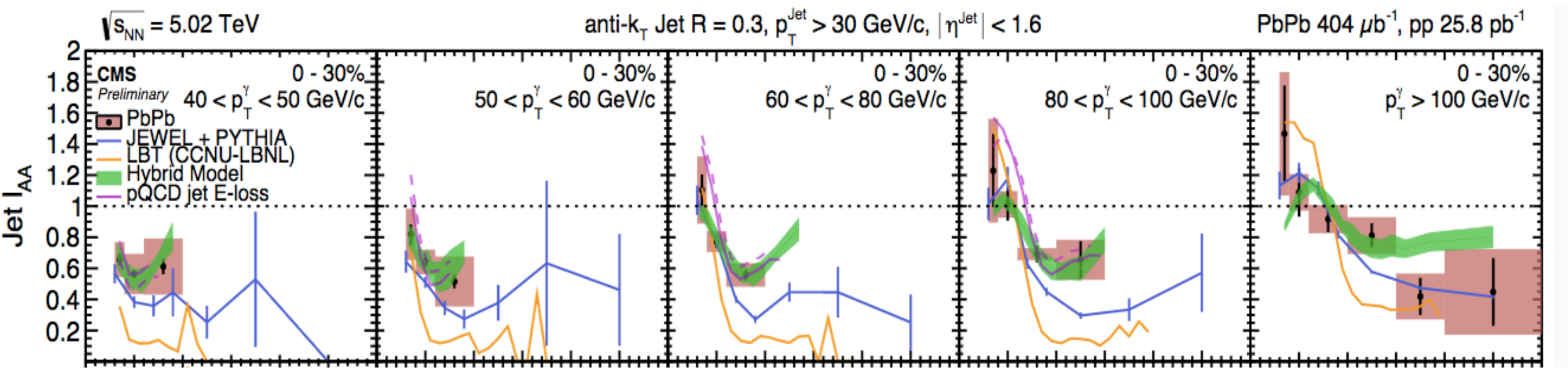
Seminclusive recoil jet suppression with boson triggers



Boson triggers bias towards more quark jets in the recoil than jet triggers
->handle on parton flavour dependence of energy loss

Plots from Doga Gulhan, Hard Probes 2016

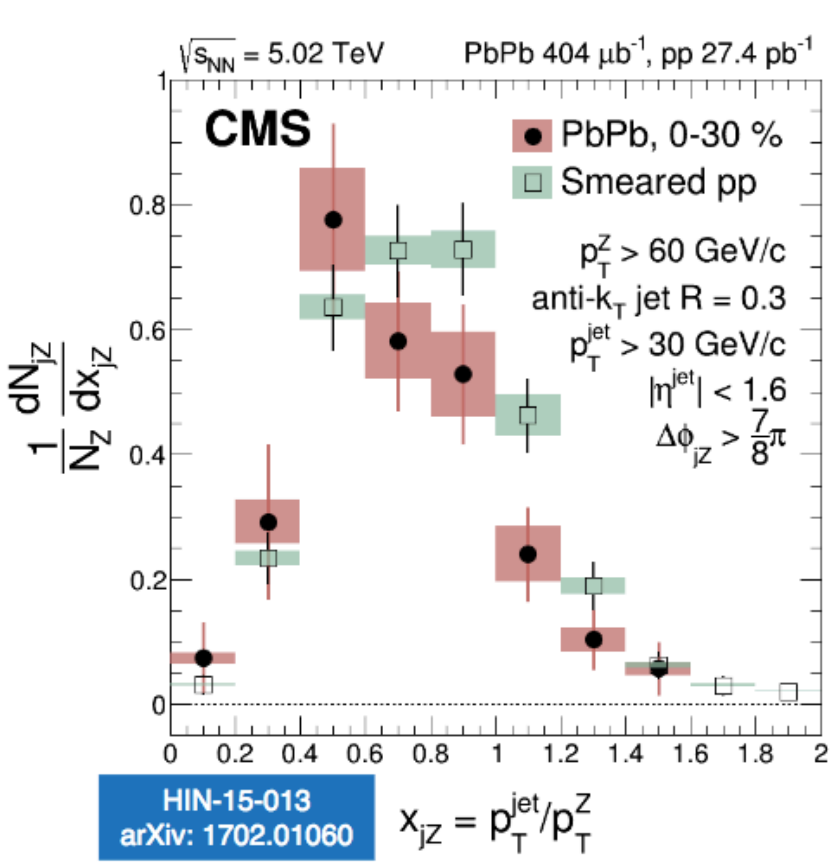
Seminclusive recoil jet suppression with γ triggers

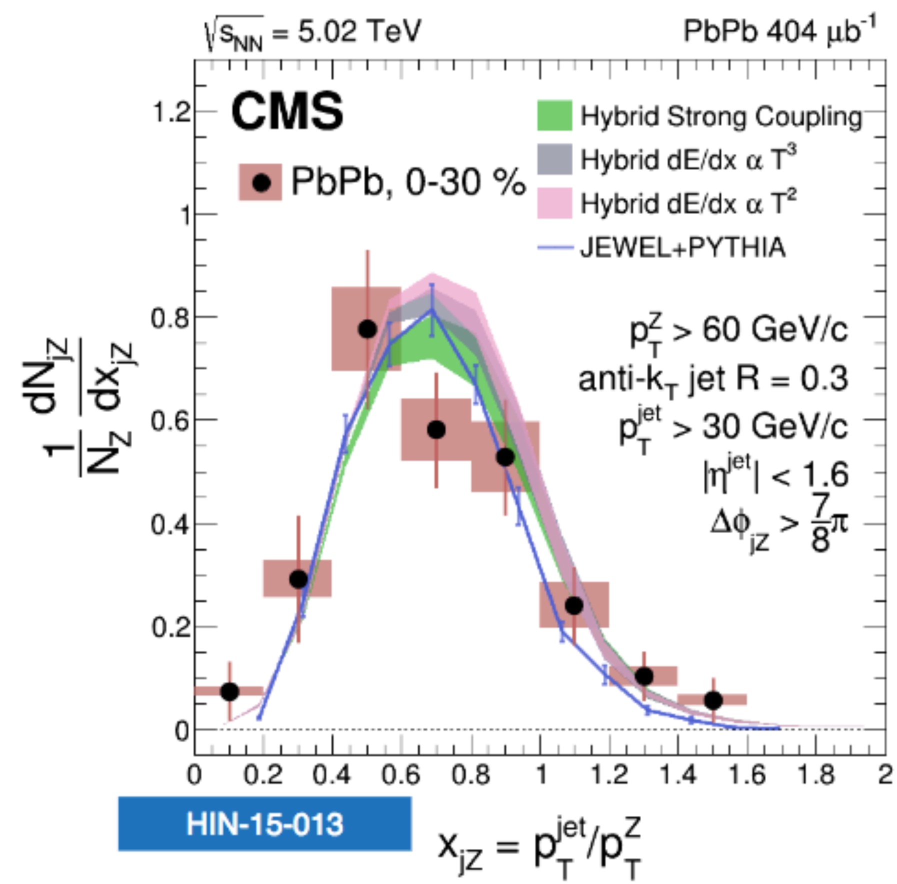


Krishna Ragajopal

Difficult to understand the contribution to the agreement of the different ingredients:
ie, what is the role of the non-perturbative effects? Can perturbative effects alone describe the data?

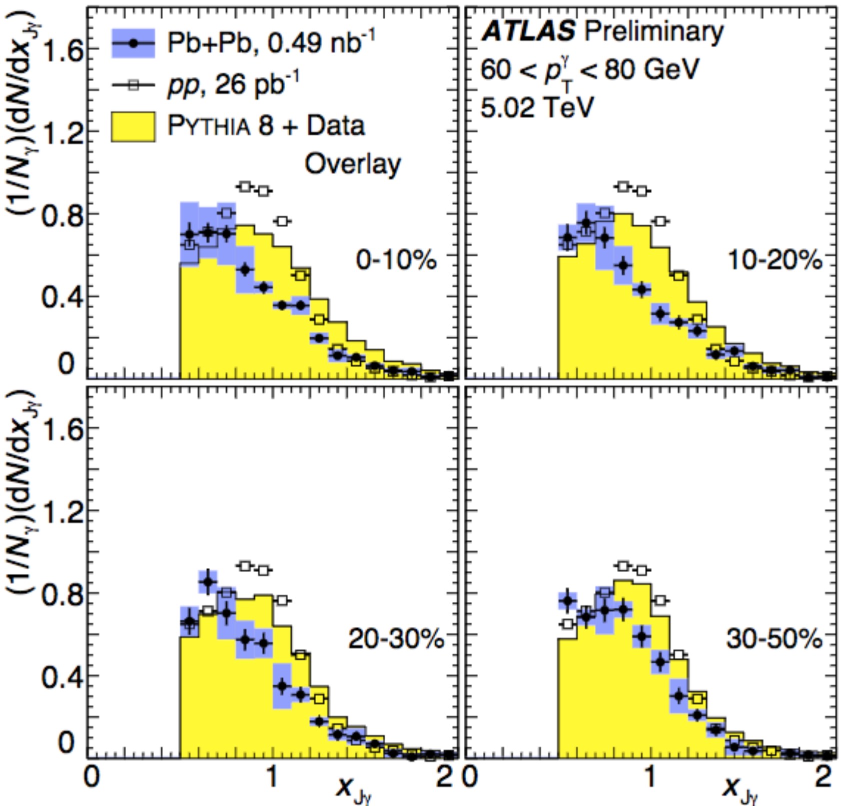
Momentum imbalance in Z+jet





Exact quantification of the energy lost out of the jet cone, boson energy is that of the parton initiating the recoil jet

Momentum imbalance in γ+jet

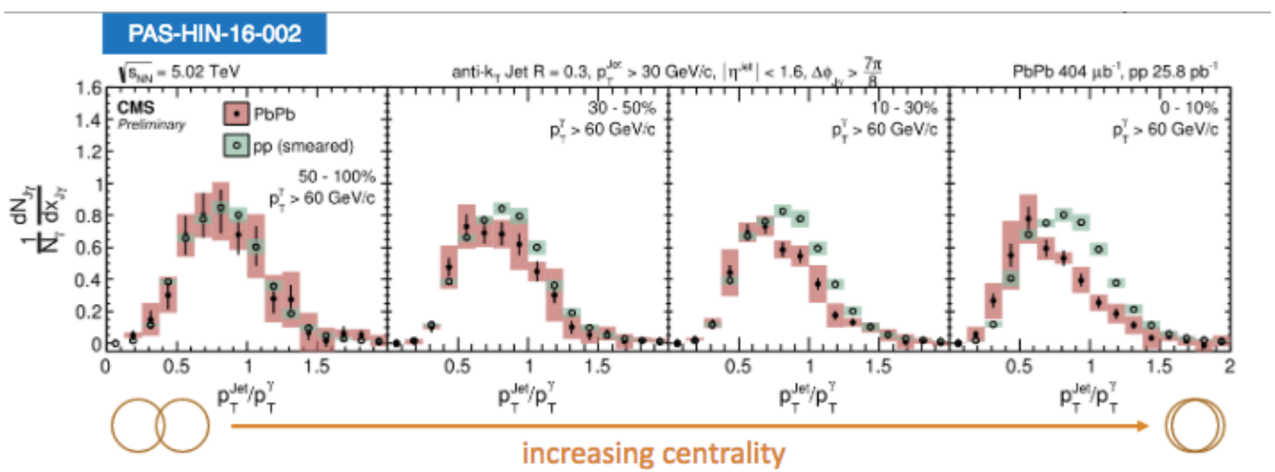


Exact quantification of the energy lost out of the jet cone, boson energy is that of the parton initiating the recoil jet

CMS and ATLAS results consistent

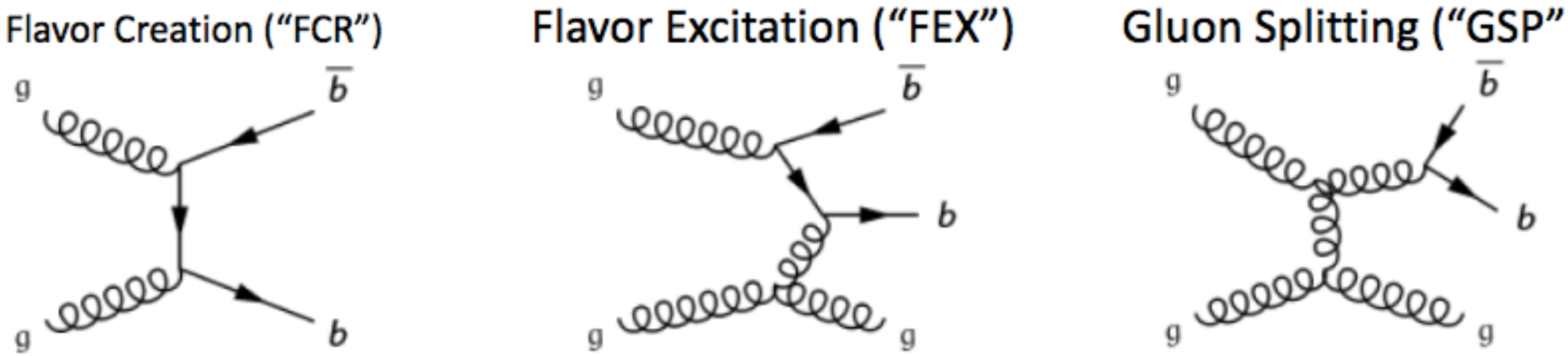
Main features of $x_{J\gamma}$ are reproduced by all models

Peter Steinberg



Ran Bi

Momentum imbalance in b-dijets

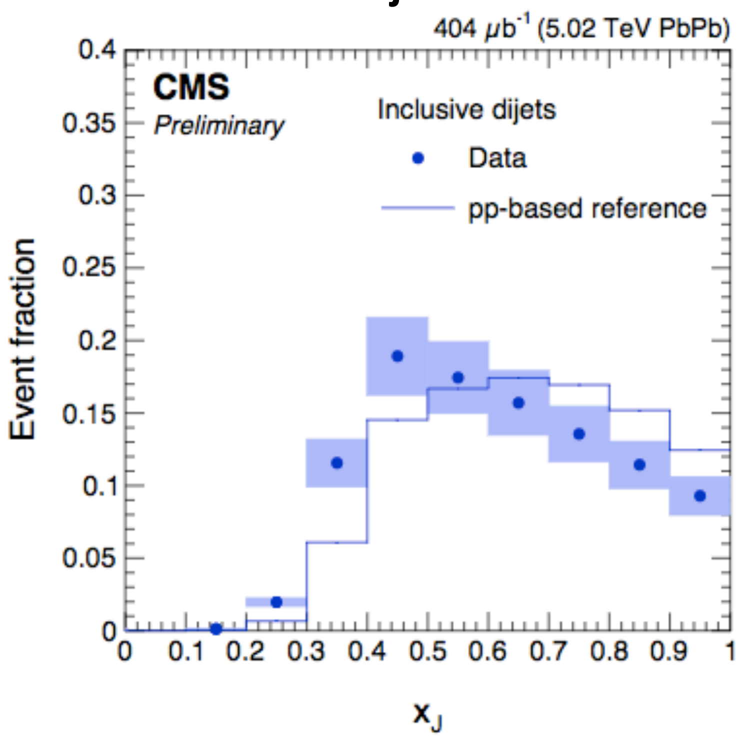


b dijets bias towards FCR processes and allow to decouple gluon splitting processes from LO

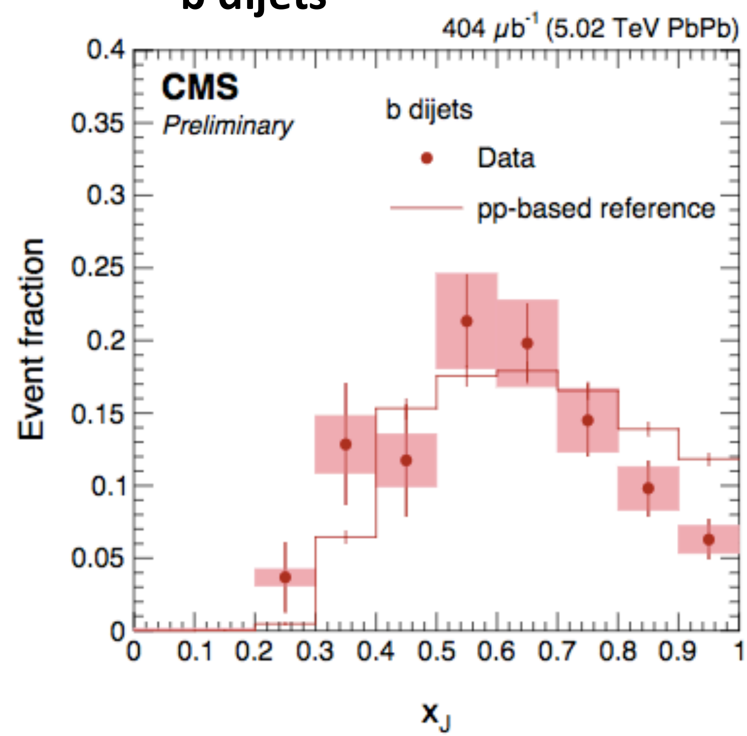
Cleaner measurement of the quark flavour than inclusive R_{AA}

Momentum imbalance in b-dijets

inclusive dijets



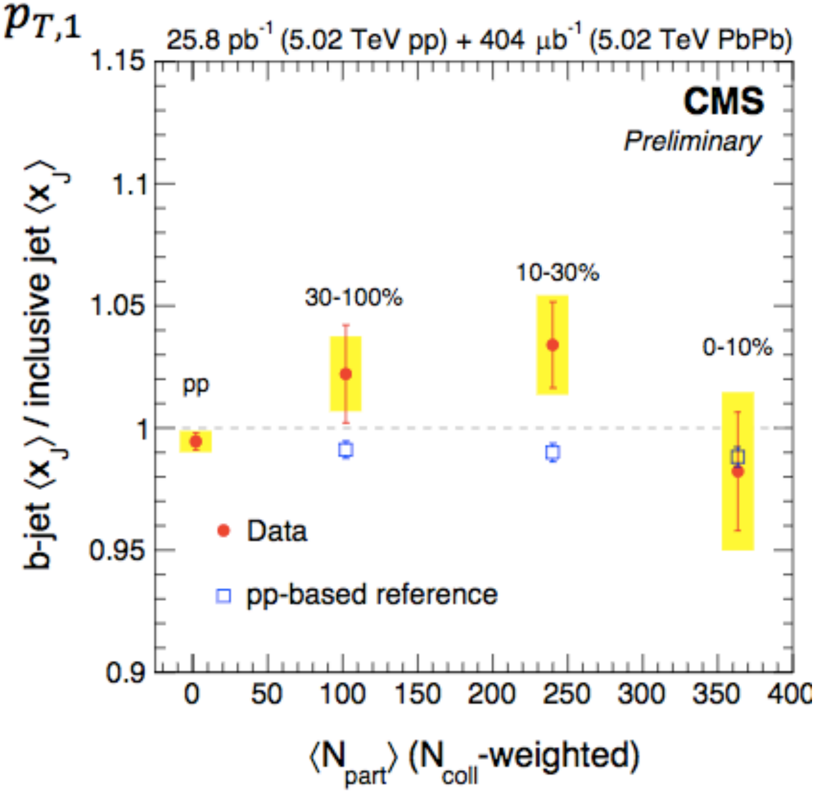
b dijets



No significant difference between inclusive and b dijet momentum imbalance

Momentum imbalance in b-dijets

$$\langle x_J \rangle = \frac{p_{T,2}}{p_{T,1}}$$



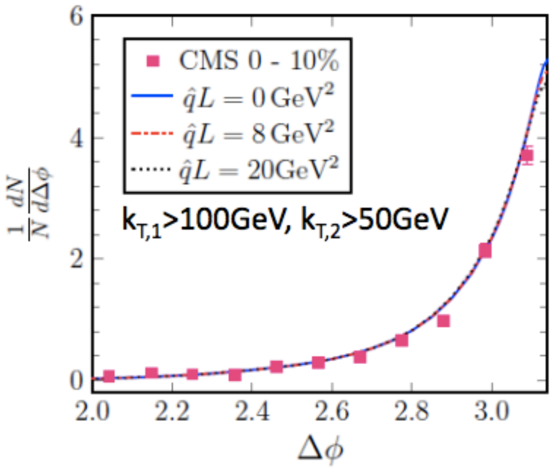
No significant difference between inclusive and b dijet momentum imbalance

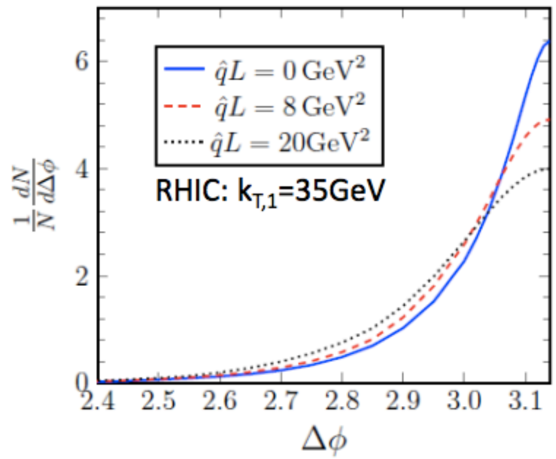
Medium induced acoplanarity

Medium-induced broadening via angular correlations

(in a purely perturbative framework)

Mueller, Wu,Xiao,Yuan PLB763 (2016)





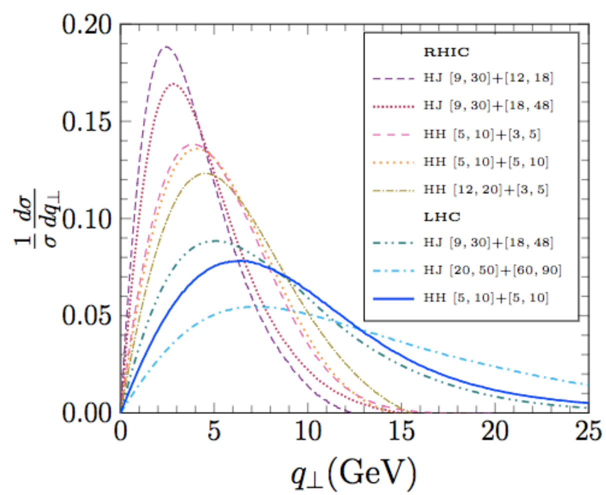
LHC: vacuum Sudakov effect overwhelms medium-induced broadening effect

=> essentially no angular decorrelation

RHIC: medium-induced broadening effect comparable to vacuum Sudakov effect

=> sizable angular decorrelation

Smaller p_T jets more effective in probing medium-induced broadening effects



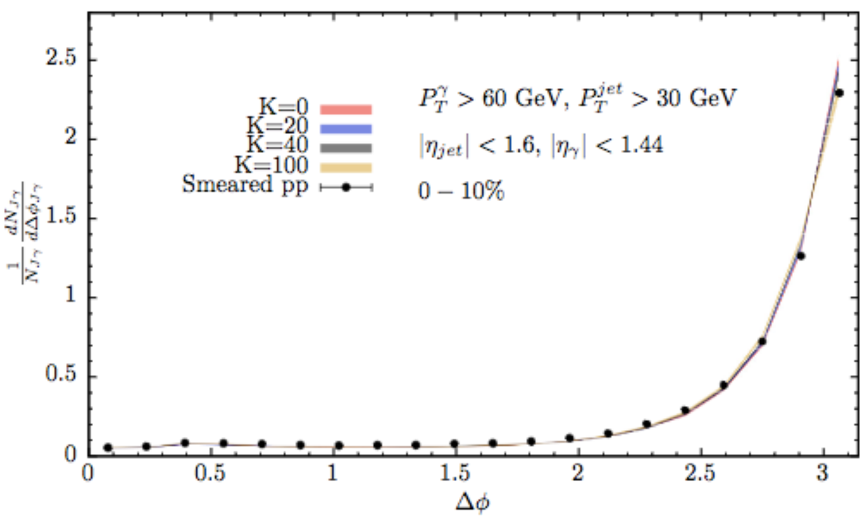
Guang-You Qin

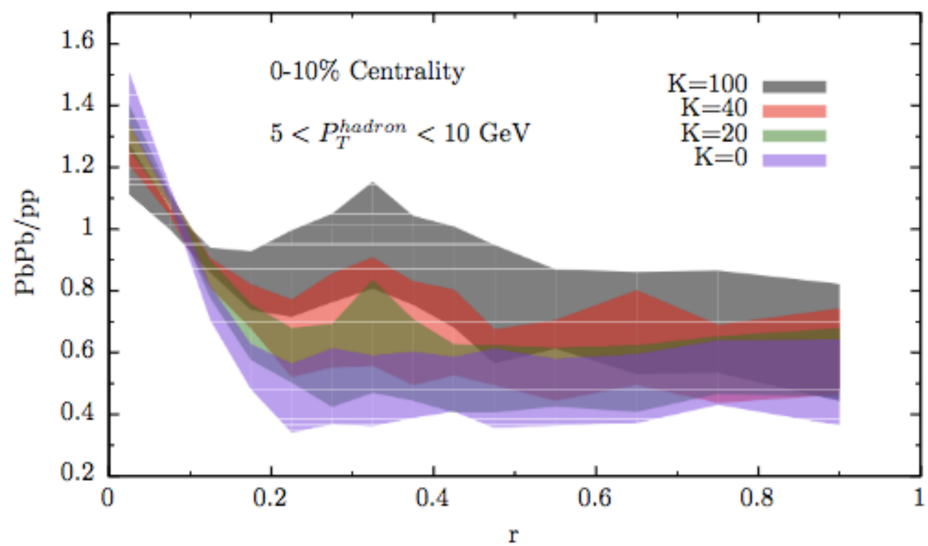
Medium-induced broadening via angular correlations

(in a non-perturbative framework)

-Coloured excitations acquire transverse momentum following a Gaussian distribution with width Q=qhatL, where qhat ~K T^3

-No dynamical relation between Eloss and broadening



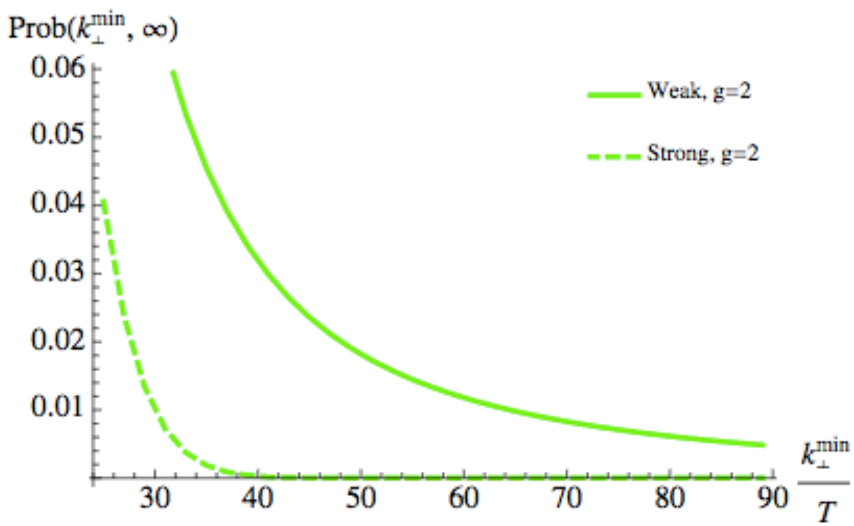


Left: Low sensitivity in the photon-jet acoplanarity to the relevant broadening parameter K

Right: Great sensitivity in the observable designed by the authors, essentially the fraction of the jet momentum carried by soft particles in a given annulus of the subleading jet

J. Casalderrey-Solana, D.C.Gulhan, G.Milhano, D.Pablos and K.Rajagopal, arXiv:1612.09238 [hep-ph]

Medium-induced broadening: rare large angle deflections



D'Eramo, Lekaveckas,Liu,Rajagopal, JHEP 1305 (2013) 0131

The equivalent of performing the Rutherford experiment in the QGP

Evolution of degrees of freedom with scale

Scale is the deflection angle of the parton in the medium

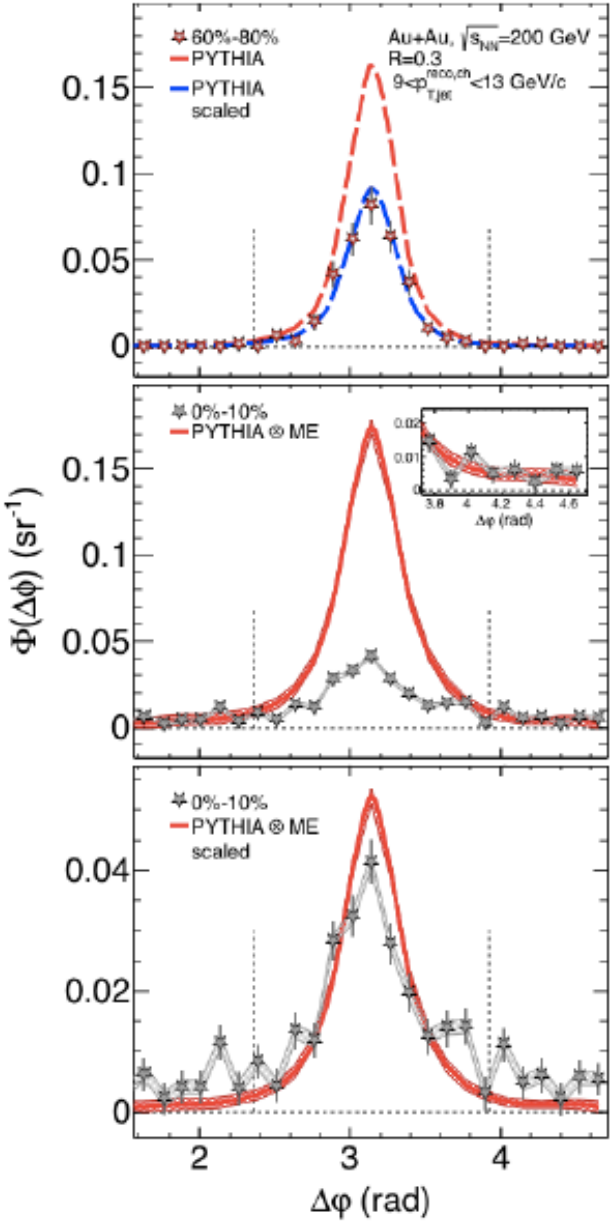
At large deflection angles ->emergence of weakly coupled degrees of freedom in the strongly coupled QGP

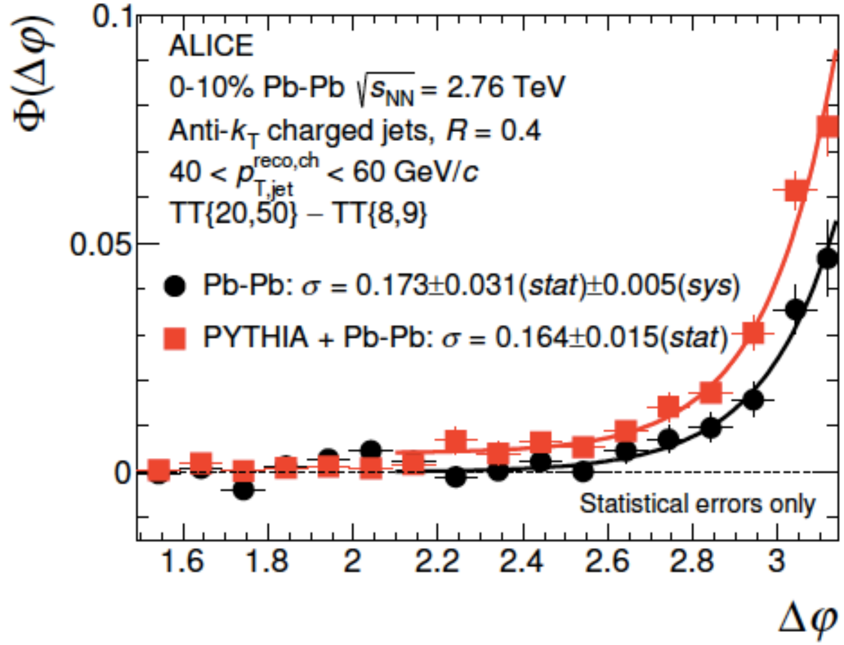
Experimentally:

- inspect the tails of the azimuthal dijet correlation at very low jet p_T
- large angle deflections of constituents within the jet ->need jet substructure large R
- statistically hungry

Need more realistic calculations including finite energy corrections etc

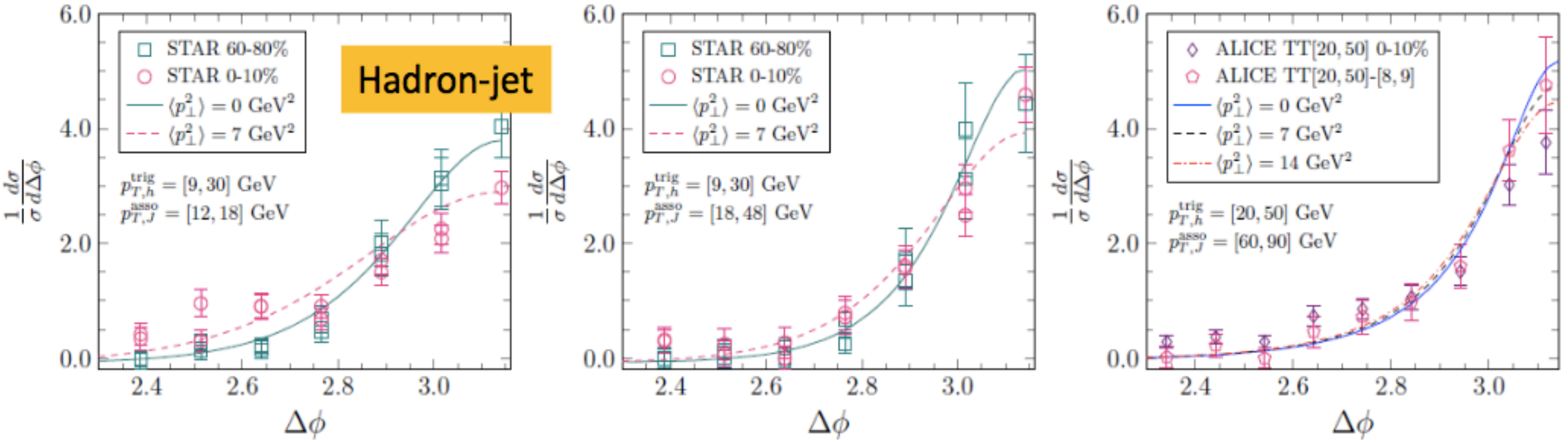
Dijet acoplanarity via h+jet





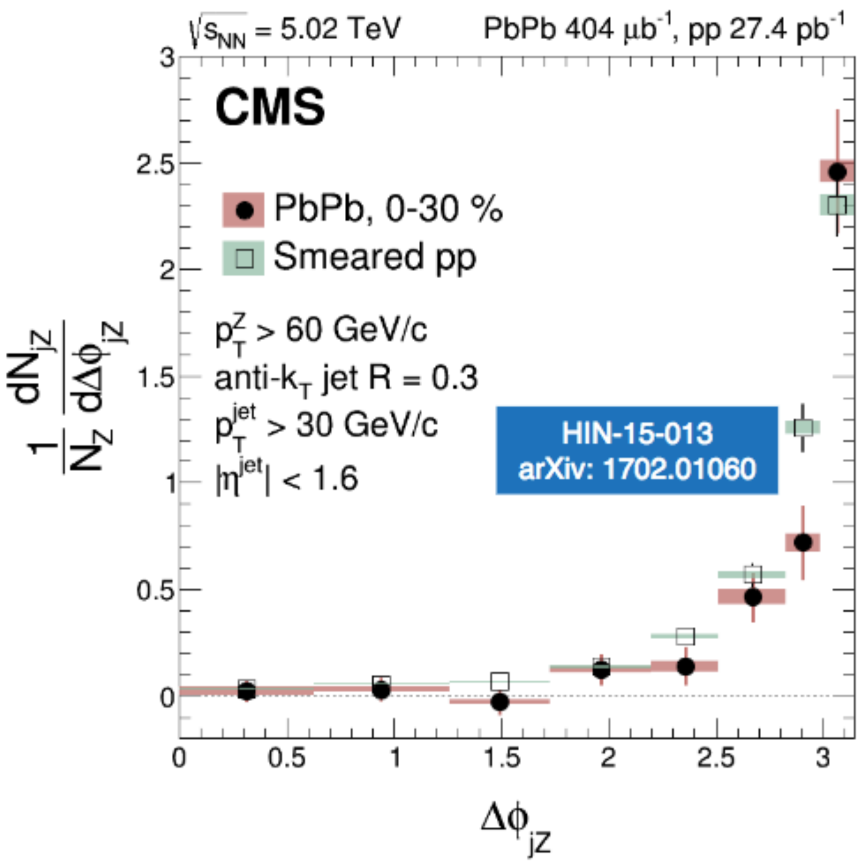
STAR arXiv:1702.01108

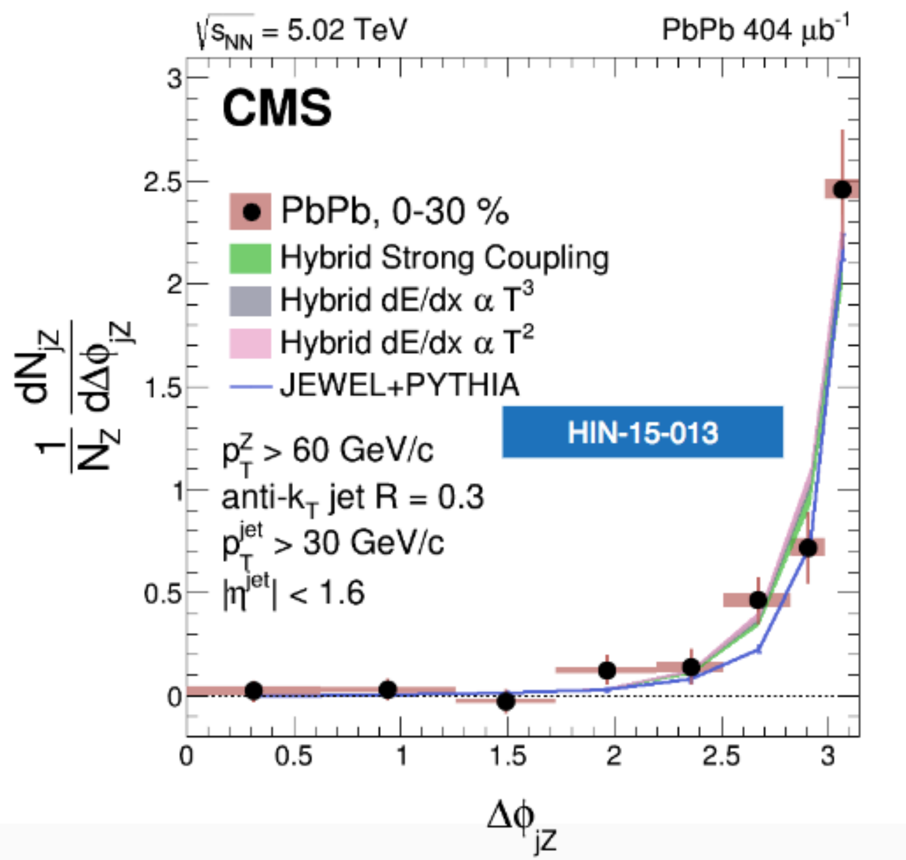
Dijet acoplanarity via h+jet



Global χ2 analysis with **RHIC** di-hadron and hadron-jet correlations give $\langle \hat{q} L \rangle = 7^{+21}_{-7}$ GeV^2

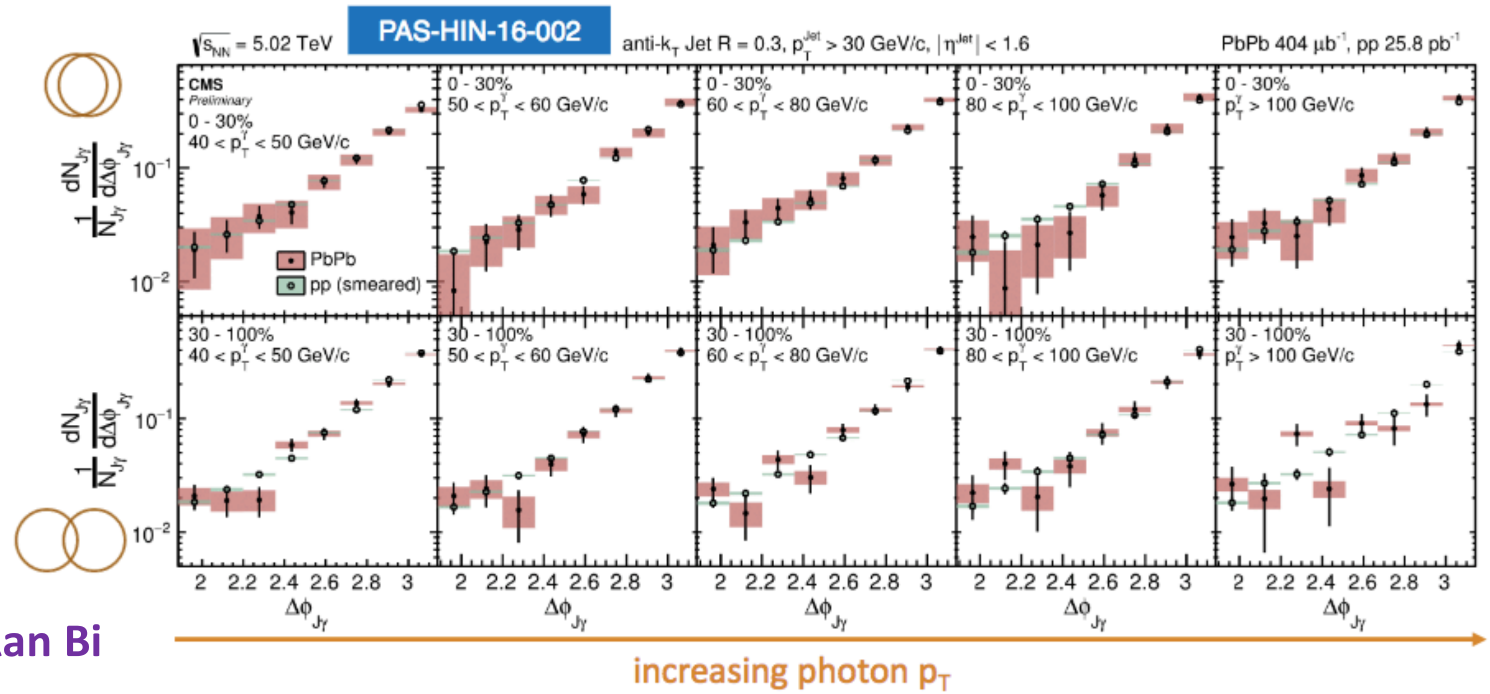
Dijet acoplanarity via Z+jet



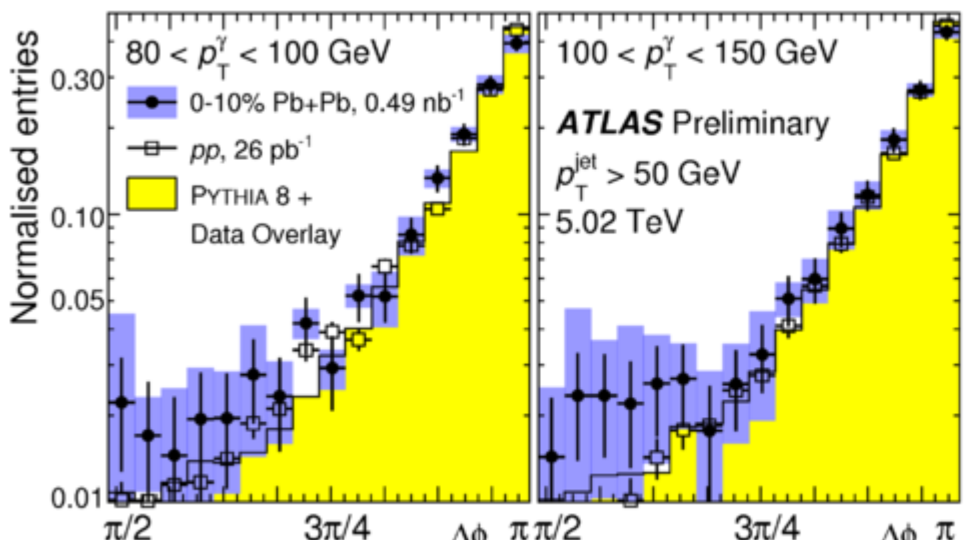


Ran Bi

Dijet acoplanarity via γ+jet



Ran Bi



Peter Steinberg

Summary

-Beautiful set of new data

-**Reached TeV sector in inclusive jet spectrum, medium still 'opaque'**

-Seminclusive measurements of jets recoiling from Z-boson and γ triggers
→access to the energy of the parton initiating the jet

-First generation of jet measurements discussed, mainly sensitive to total energy loss

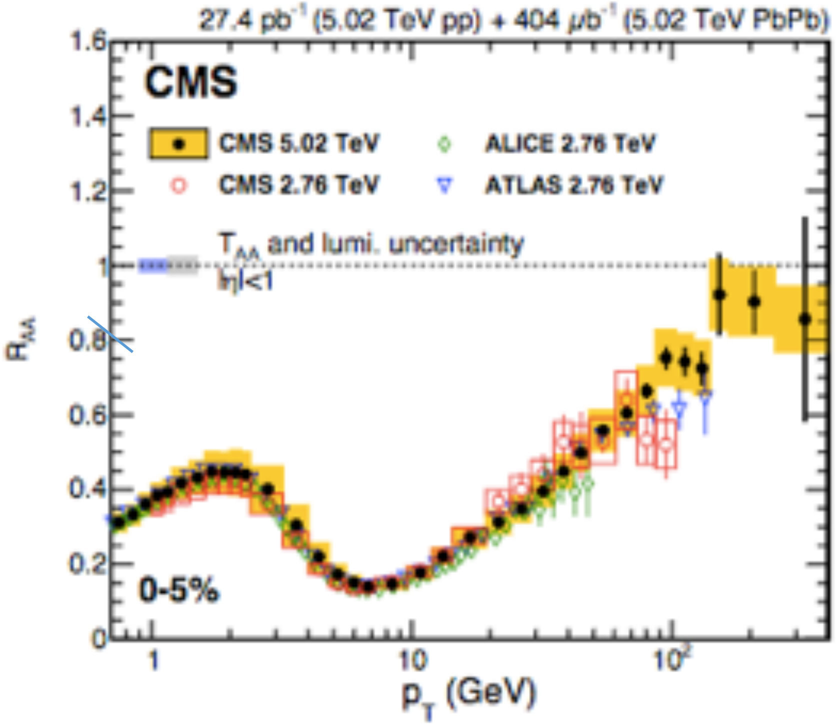
-Very different underlying physics lead to similar agreement with data (ie perturbative and strongly-coupling models lead to similar momentum imbalance in boson-jet correlations)

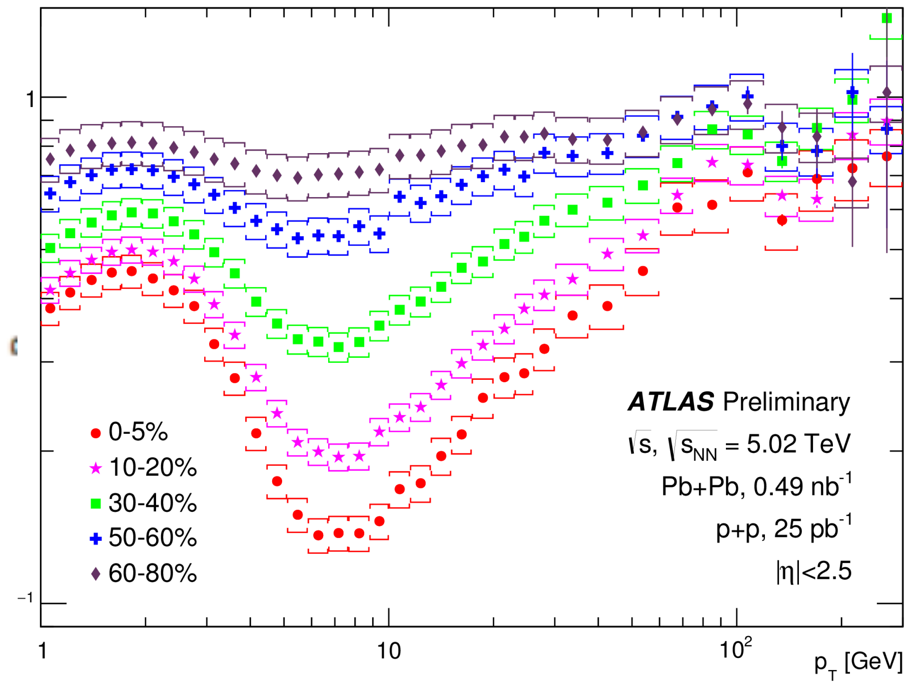
-Next: Jet substructure. Plethora of analytical tools to explore sensitivity to different dynamical aspects of jet quenching. ->See next talk!

Thank you!

and many thanks to Peter Jacobs, Marco Van Leeuwen, Andreas Morsch, Marta Verweij

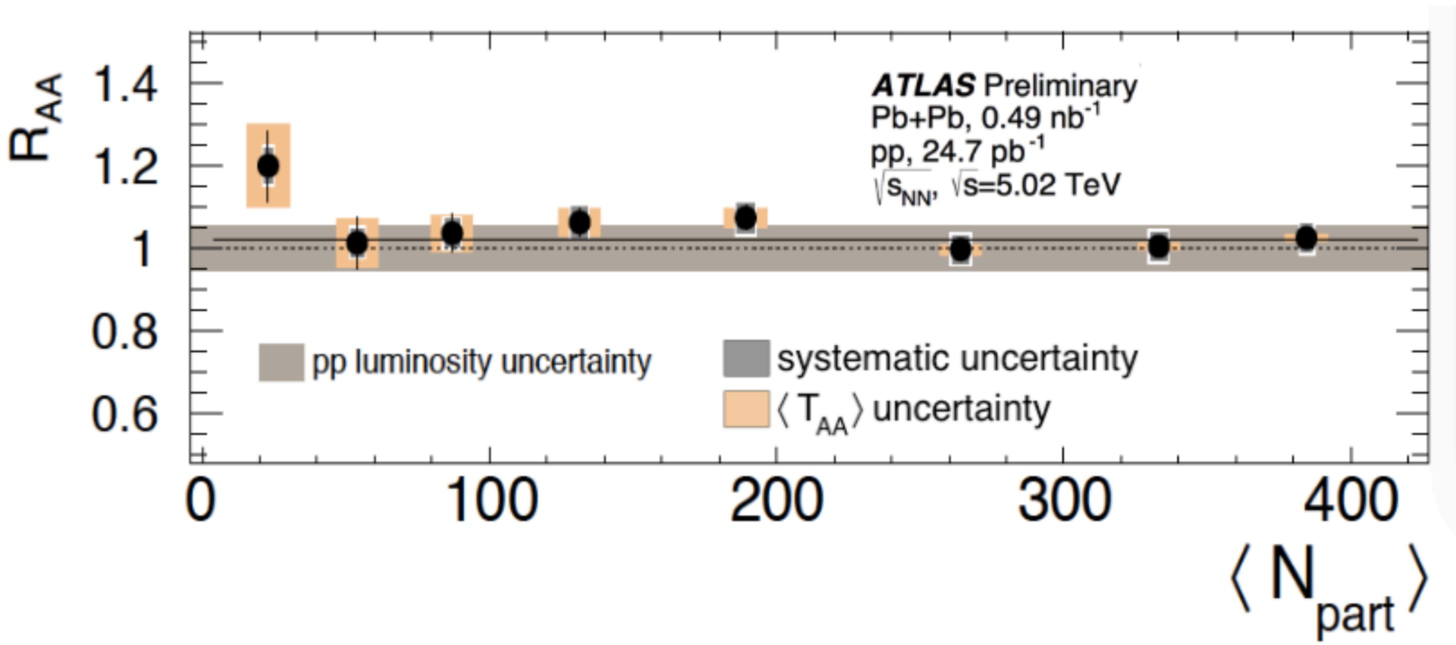
Inclusive Hadron and Jet Suppression





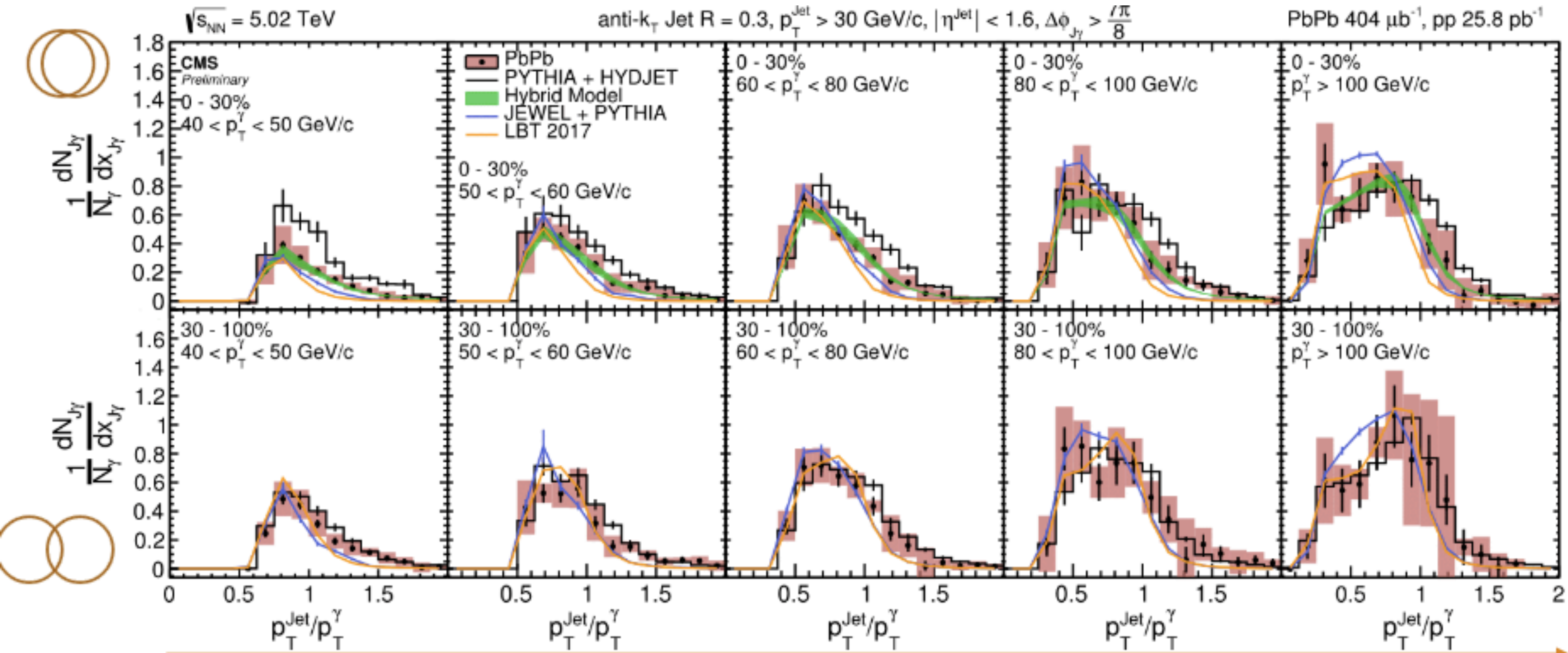
Flattening trend at high p_T more apparent in ATLAS data?

Z boson R_{AA}



High precision results

Zvi Citron



increasing photon p_T

Ran Bi