Measurement of jet production in central Pb-Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV using semi-inclusive hadron-jet distributions

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Hard Probes 2013
November 2013
StellenBosch, South Africa

Outline

Use hadron-jet correlations to explore:

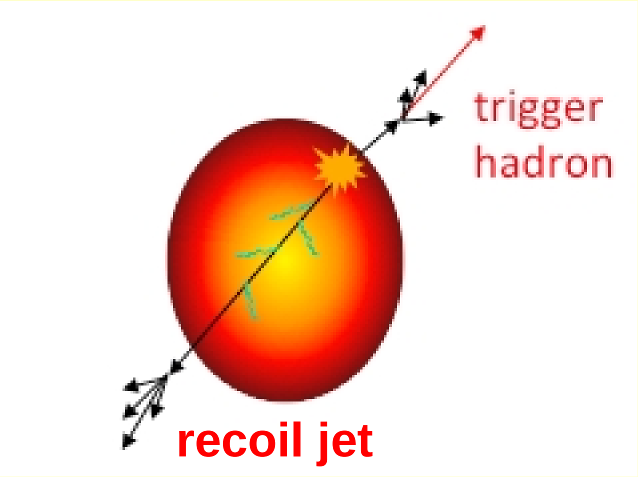
-Suppression of recoil jets:
magnitude of the suppression & p_T dependence

-Energy redistribution within recoil jets
via ratios of yields for different *R*

-Medium-induced acoplanarity
via hadron-jet azimuthal correlations

Down to low jet p_T and up to large resolution *R* =0.5 with minimal bias on jet fragmentation (IR cutoff 150 MeV/*c*)

Semi-inclusive recoil jet distribution



Inclusive trigger selection

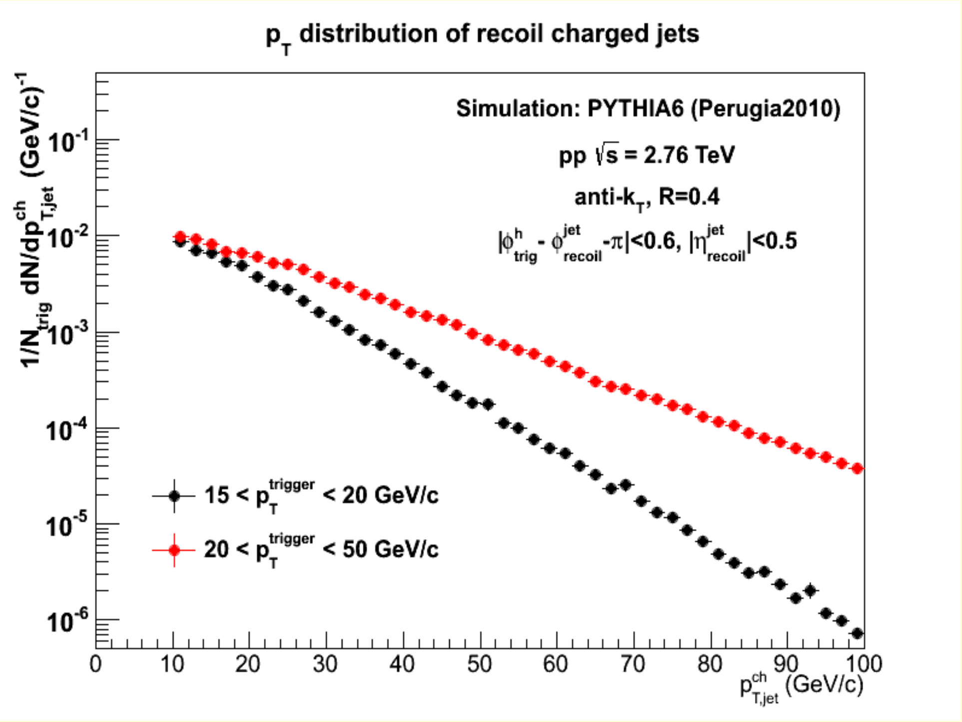
Select randomly one of the hadrons that fall in the given trigger class (T T)
→calculable in pQCD

Semi-inclusive recoil jet yield:

Count the number of jets in the recoil region and normalize by the number of triggers

$$|\varphi_{TT} - \varphi_{Recoil}^{Jet} - \pi| < 0.6$$

Jet finding is collinear safe with minimal IR cutoff



Increase hadron trigger p_T →higher Q^2 process →harden recoil jet spectrum

Charged recoil jets in Pb-Pb with ALICE

DATA SET

Pb-Pb 2011 run, $\sqrt{s_{NN}}$=2.76 TeV, 0-10% central: ~9M events

INPUT

Tracks from TPC and ITS p_T>0.15 GeV/*c*
$|\eta_{track}^{max}|=0.9$
Uniform azimuthal tracking efficiency

JET FINDING

anti-k_T algorithm from FastJet package [1]
- **boost invariant p_T recombination scheme**
- **resolution parameter *R*=0.2, *R*=0.4 and *R*=0.5**
- **jet area cuts A>0.07, A>0.4 and A>0.6**
- **jet acceptance $|\eta_{jet}|<|\eta_{track}^{max}|-R$**

MEDIAN BACKGROUND ENERGY DENSITY ρ

is estimated on an event-by-event basis using an area-based method [2]

[1] Cacciari et al. Eur.Phys.J. C72 (2012) 1896
[2] Cacciari et al. Phys.Lett.B659 (2008) 119

Charged recoil jet correction in Pb-Pb

REMOVAL OF THE COMBINATORIAL JETS (FAKES)

-Ensemble basis:
via hadron-jet correlations

DETECTOR EFFECTS AND RESIDUAL BACKGROUND FLUCTUATIONS

-Detector response is based on PYTHIA (and PYQUEN)

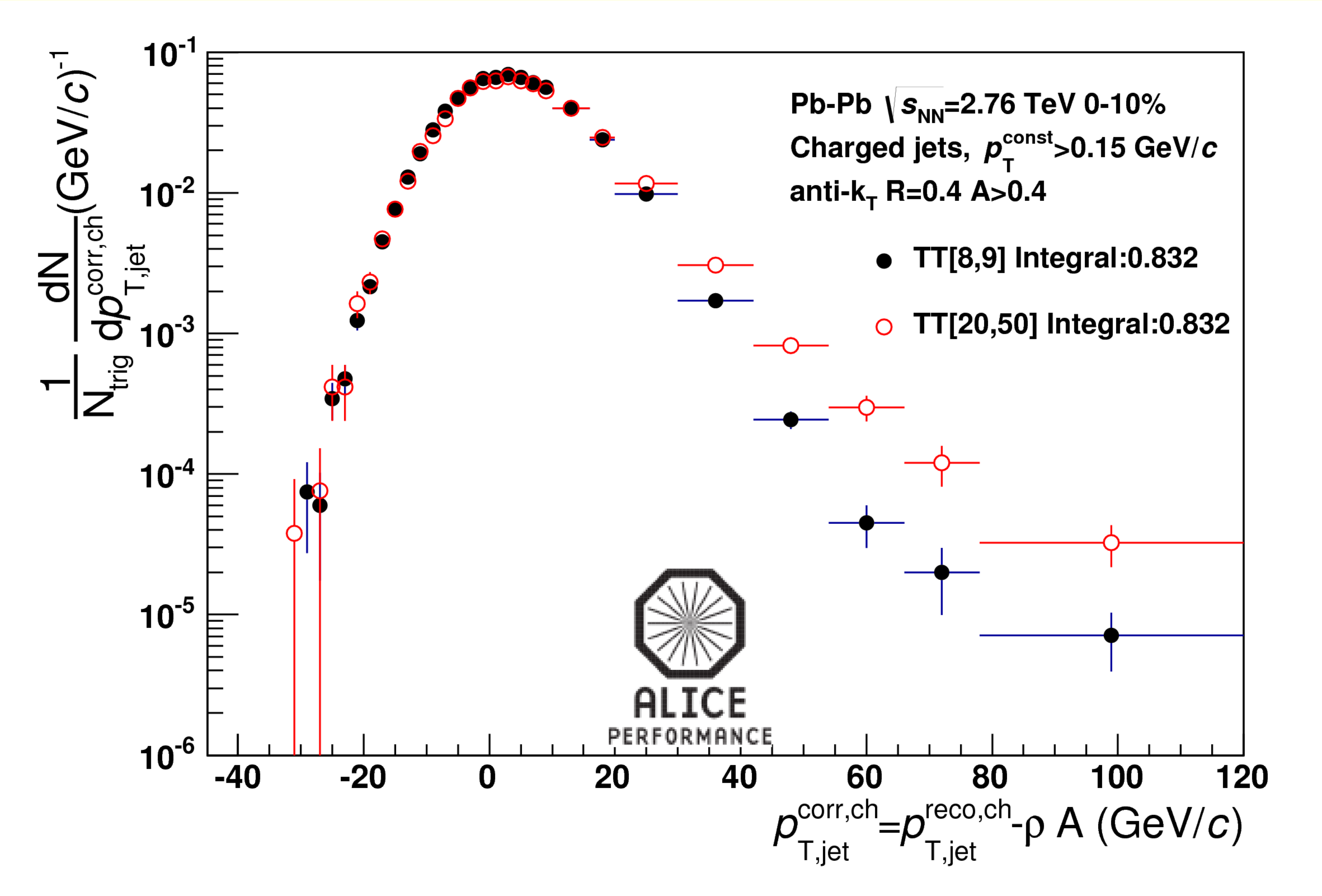
-Background response built by embedding different objects (Random Cones,single tracks, MC jets) into Pb-Pb events. Minimal dependence on fragmentation found [3]

The two effects are assumed to factorize

The combined response is built to unfold the spectra using different algorithms: Bayesian [4] and SVD [5]

[3] ALICE JHEP 1203 (2012) 053
[4] D'Agostini Nucl.Instrum.Meth.A362 (1995) 487
[5] Hoecker et al, Nucl.Instrum.Meth.A372 (1996) 469

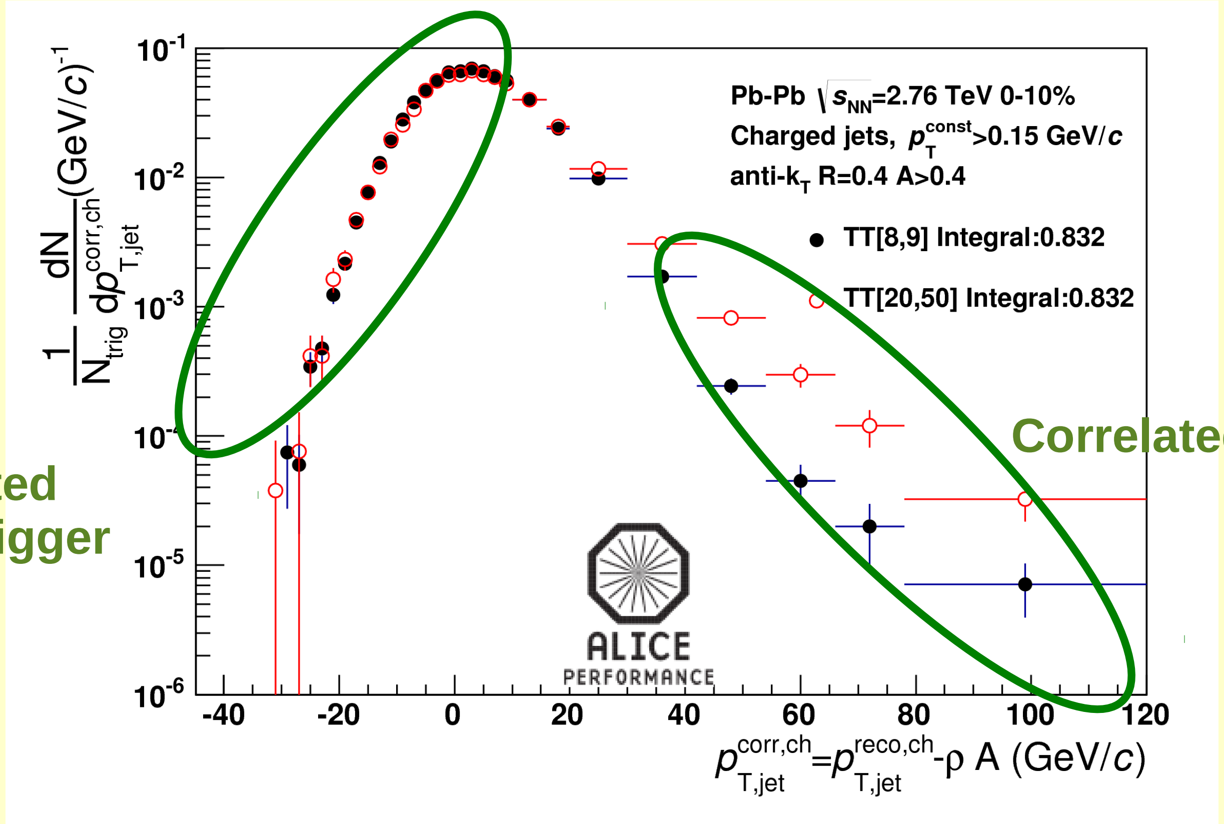
Semi-inclusive recoil jet distribution



Increase the hadron trigger p_T →higher Q^2 process →harden recoil jet spectrum

Semi-inclusive recoil jet distribution

$\Delta_{Recoil}=[(1/N_{trig})\ dN/dp_{T,jet}^{ch}]_{TT[20\text{-}50]} - [(1/N_{trig})\ dN/dp_{T,jet}^{ch}]_{TT[8\text{-}9]}$



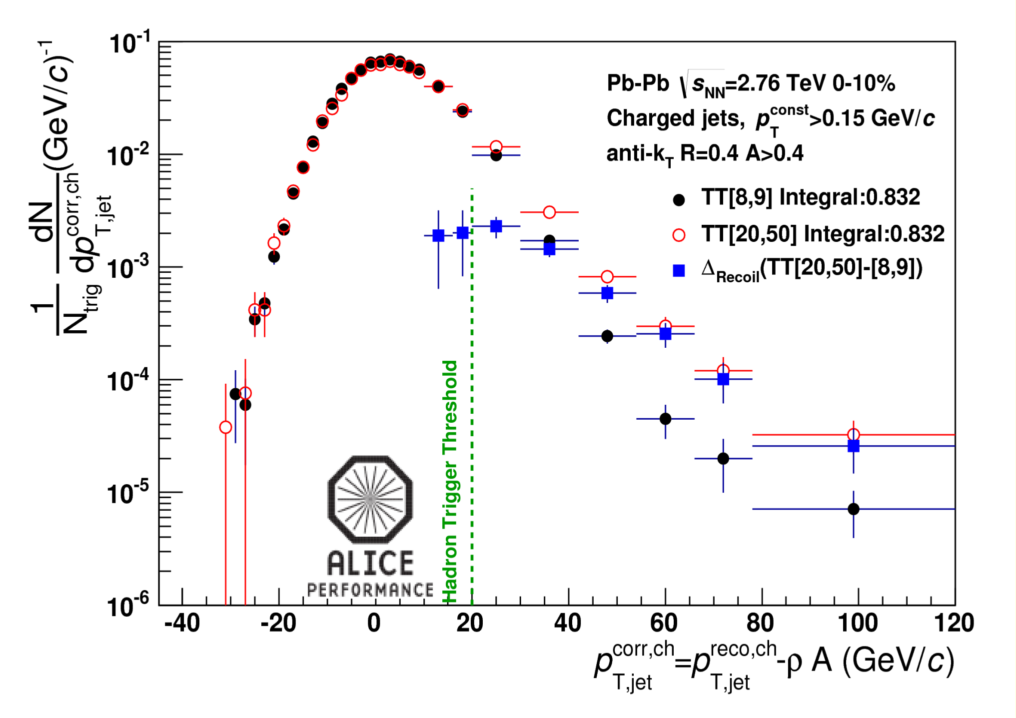
Conjecture: combinatorial jet distribution is uncorrelated with the trigger p_T

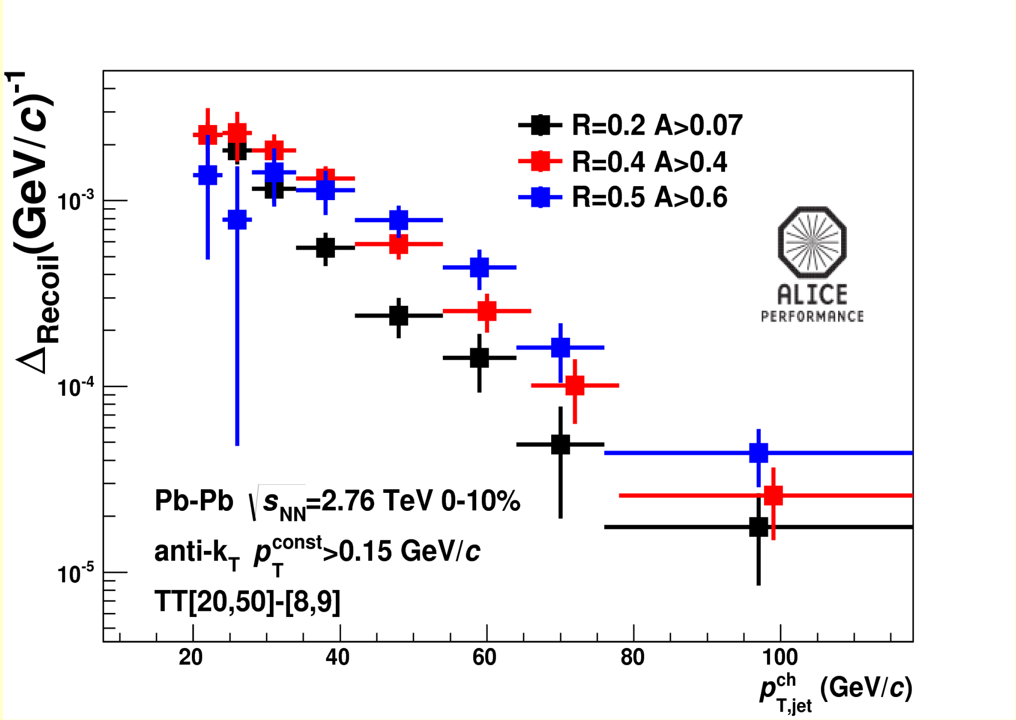
Opportunity: remove combinatorial background by considering the DIFFERENCE of the recoil jet spectra for two exclusive hadron trigger intervals, Δ_{Recoil} [6]

[6] *de Barros et al arXiv:1208.1518*

The raw Δ_{Recoil} and the kinematic threshold

$\Delta_{Recoil}=[(1/N_{trig})\, dN/dp_{T,jet}^{ch}]_{TT[20-50]} - [(1/N_{trig})\, dN/dp_{T,jet}^{ch}]_{TT[8-9]}$





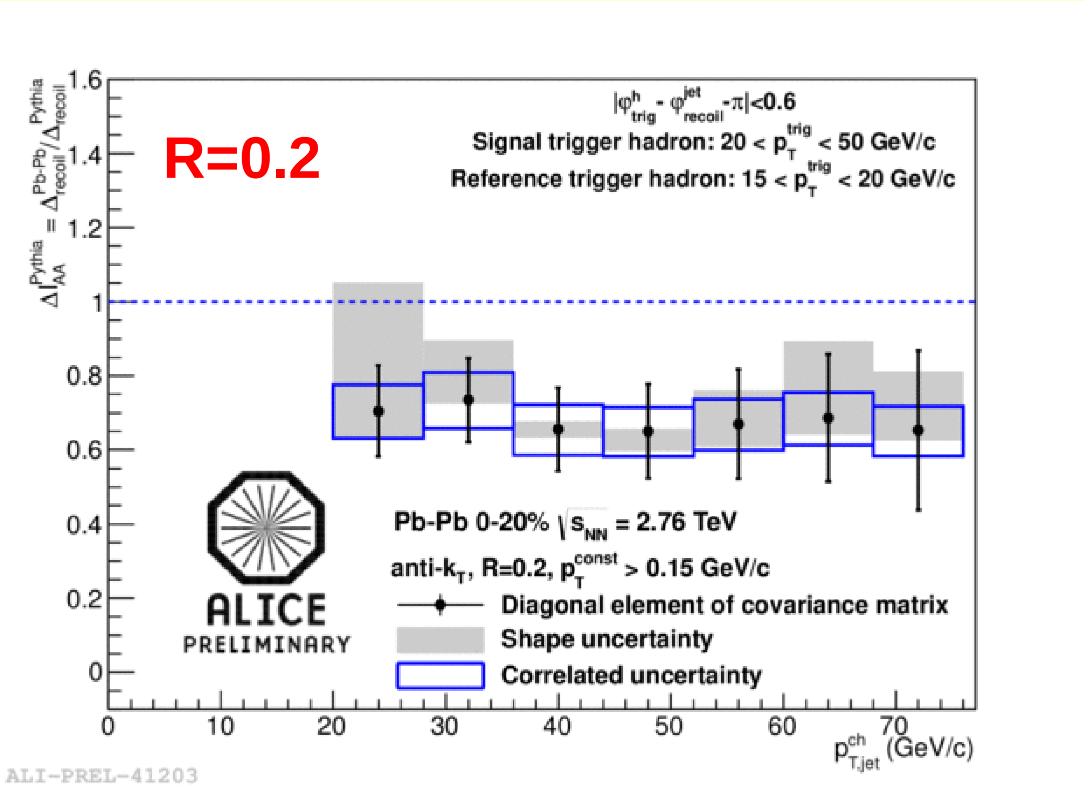
-No fragmentation bias in the jet signal beyond minimum p_T cut of 150 MeV/c on tracks

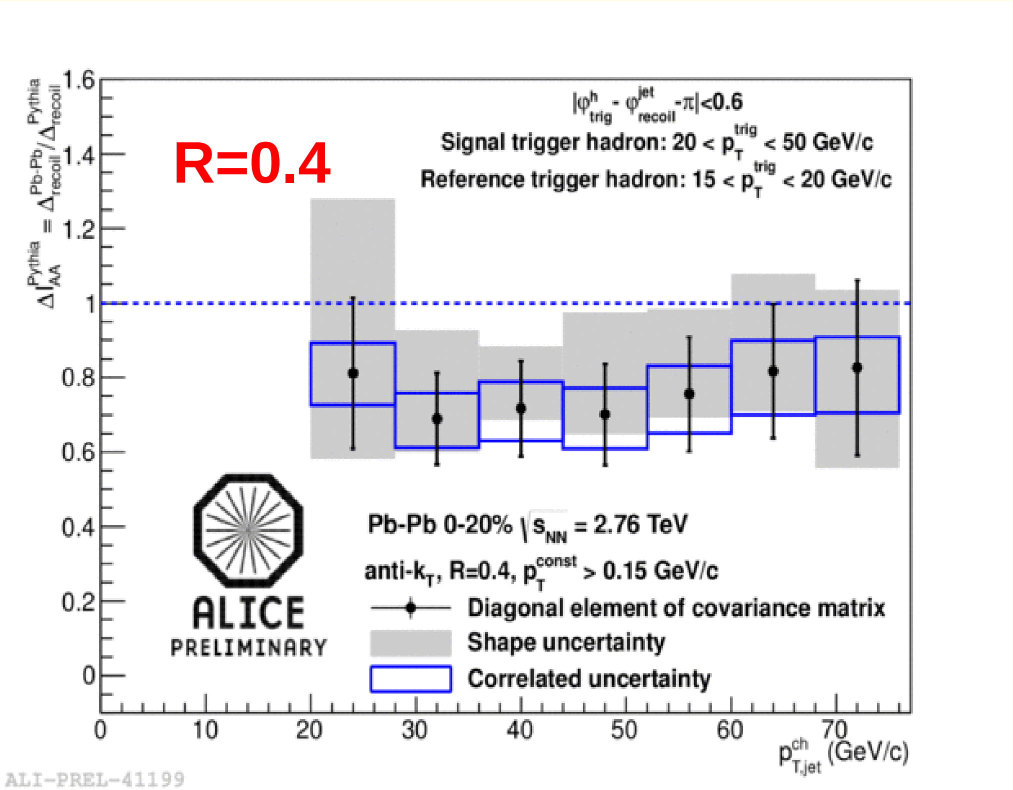
-Δ_{Recoil} is clean of combinatorial background but still has to be corrected for background smearing of the jet energy and detector effects

-Note that the trigger p_T sets a kinematic threshold: $p_{T,jet}^{recoil} > p_{T,hadron}^{trigger}$

The recoil yield suppression:

$$\Delta I_{AA}^{PYTHIA} = \Delta_{Recoil}^{Pb\text{-}Pb} / \Delta_{Recoil}^{PYTHIA}$$

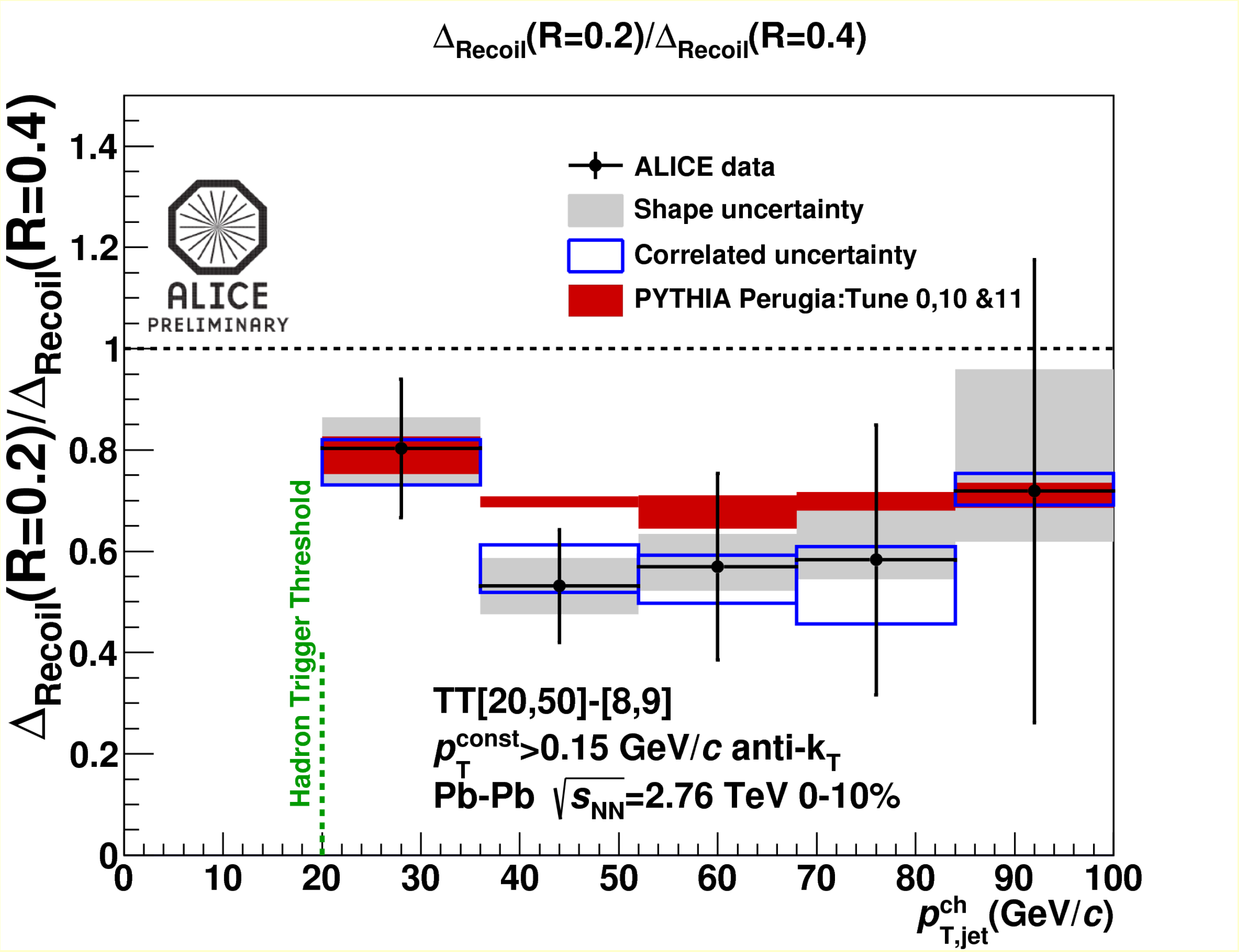




-Year 2010 data, 0-20% centrality
Trigger track selection: hardest track in the event
-PYTHIA Perugia 10 as reference
-Flat p_T dependence and no *R* dependence of the suppression within errors

Dominant uncertainties:
Shape→unfolding
Correlated→tracking efficiency

Comparison of recoil jet yield for different R



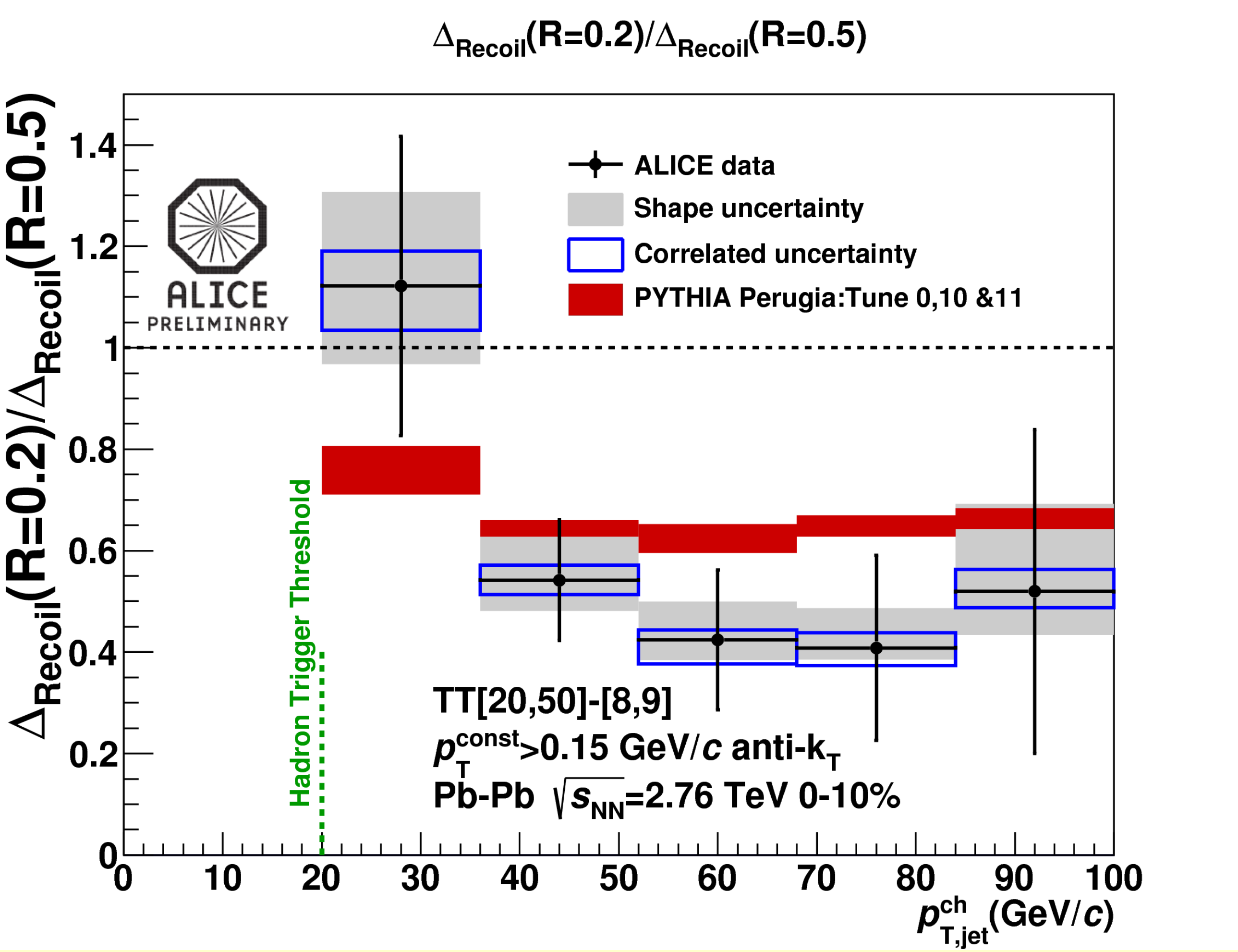
R=0.2/*R*=0.4

Y2011 data,
0-10% central

Inclusive trigger selection

-Red band: variation in observable calculated with several PYTHIA tunes
-PYTHIA calculations consistent with pp@7 TeV (analysis in progress)
-Comparison of data and PYTHIA: no evidence for significant energy redistribution within *R*=0.4

Comparison of recoil jet yield for different R



***R*=0.2/*R*=0.5**

Y2011 data, 0-10%central

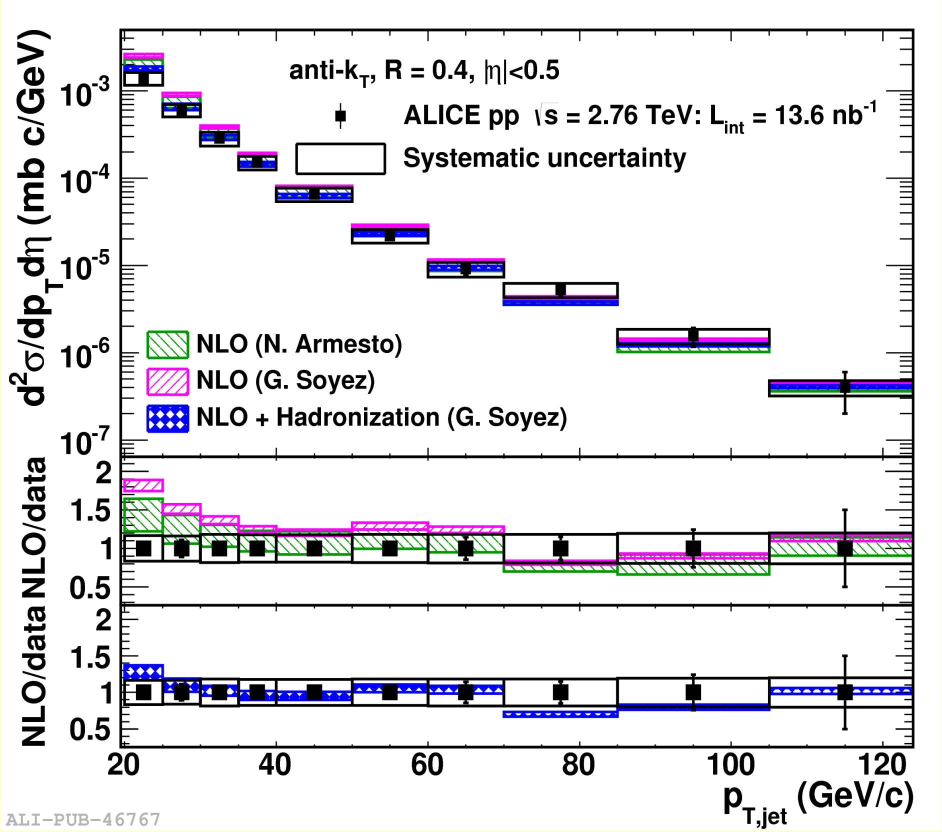
Inclusive trigger selection

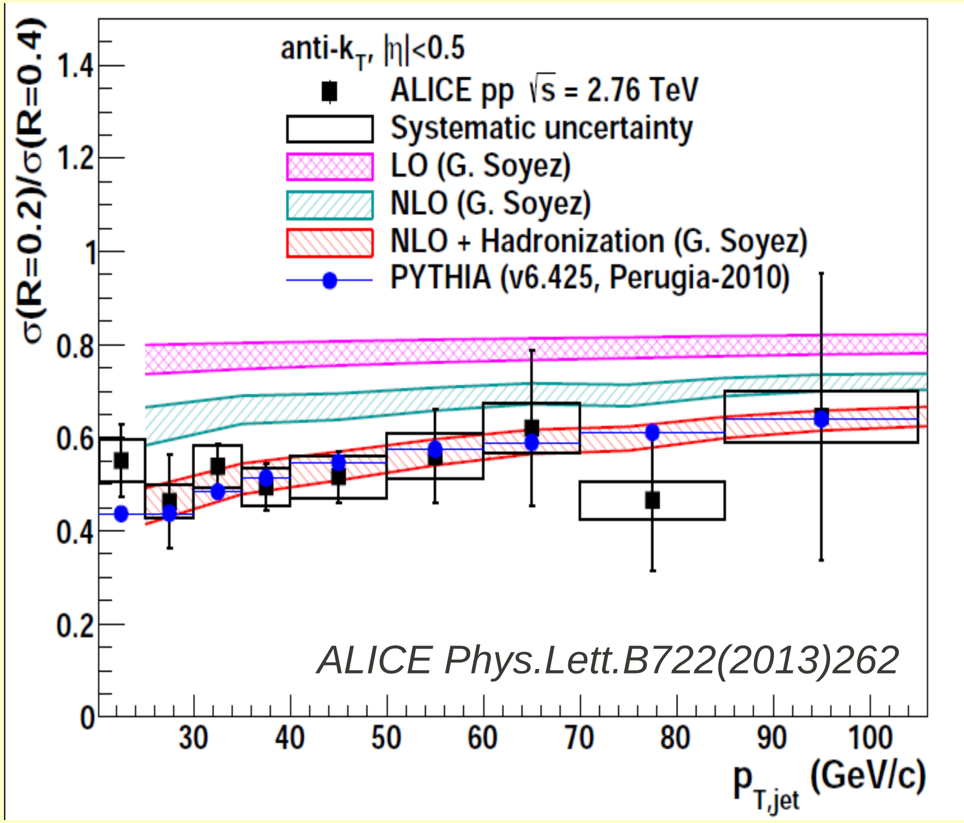
-Comparison of data and PYTHIA: no evidence of significant energy redistribution within *R*=0.5

Data systematically below PYTHIA (p_T>36 GeV/c): hint of energy redistribution?

Comparison to fixed order calculations

INCLUSIVE



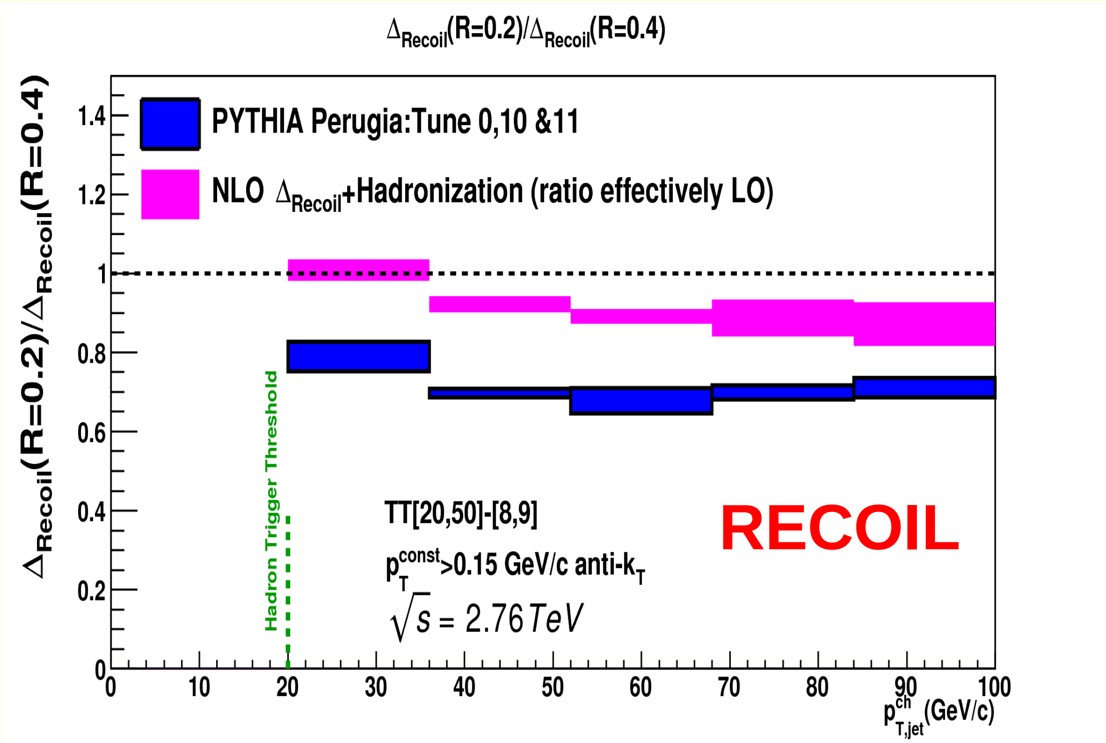


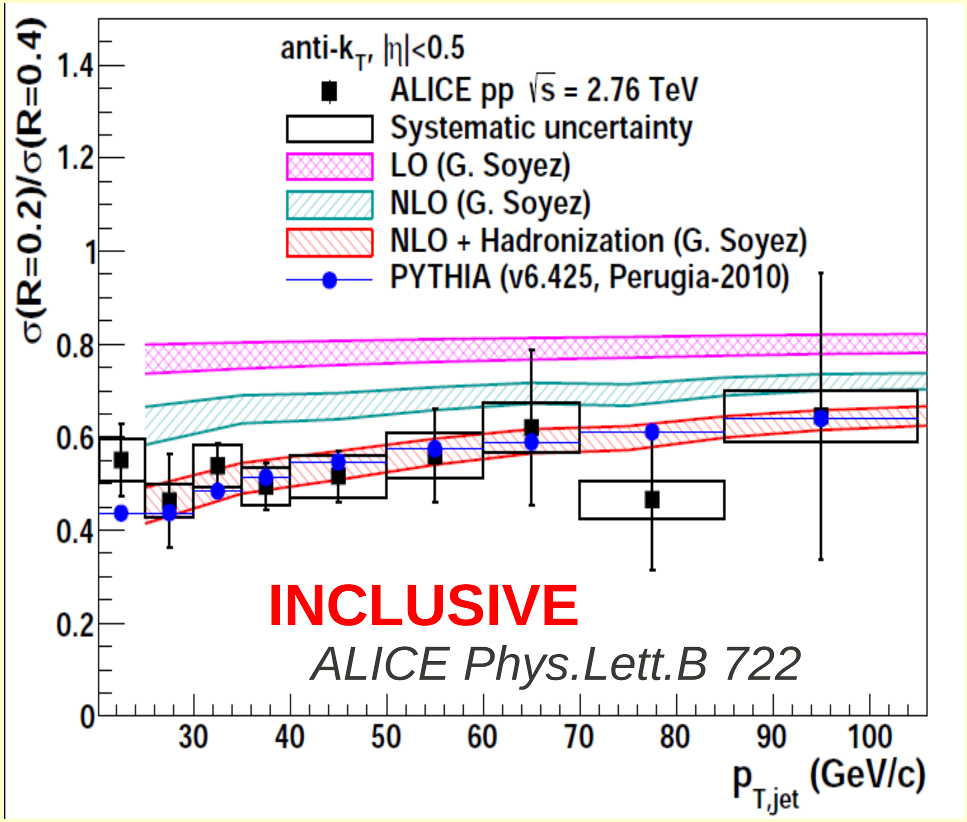
NLO+Hadronization agrees well with the inclusive spectra

NLO precision in the ratio (NNLO precision in the spectra [7]) + Hadronization is required to agree with PYTHIA (Perugia 10) and data @2.76 TeV

[7] G.Soyez, Phys.Lett.B698 (2011) 59

Comparison to fixed order calculations





New pQCD calculation for $\Delta_{Recoili}$:

NLO [8]+ Hadronization [9]
The ratio of the NLO calculation at different R -effectively LO for jet structure- differs from PYTHIA significantly

[8]De Florian arXiv:0904.443v3
[9]Salam et al. JHEP802(2008)055

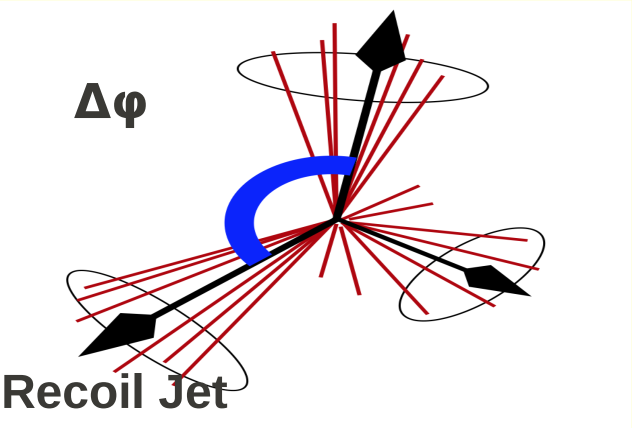
MC shower needed: all-order tree level result

Hadron-jet azimuthal correlation

Can the medium-induced radiation emitted out of cone change the jet direction?

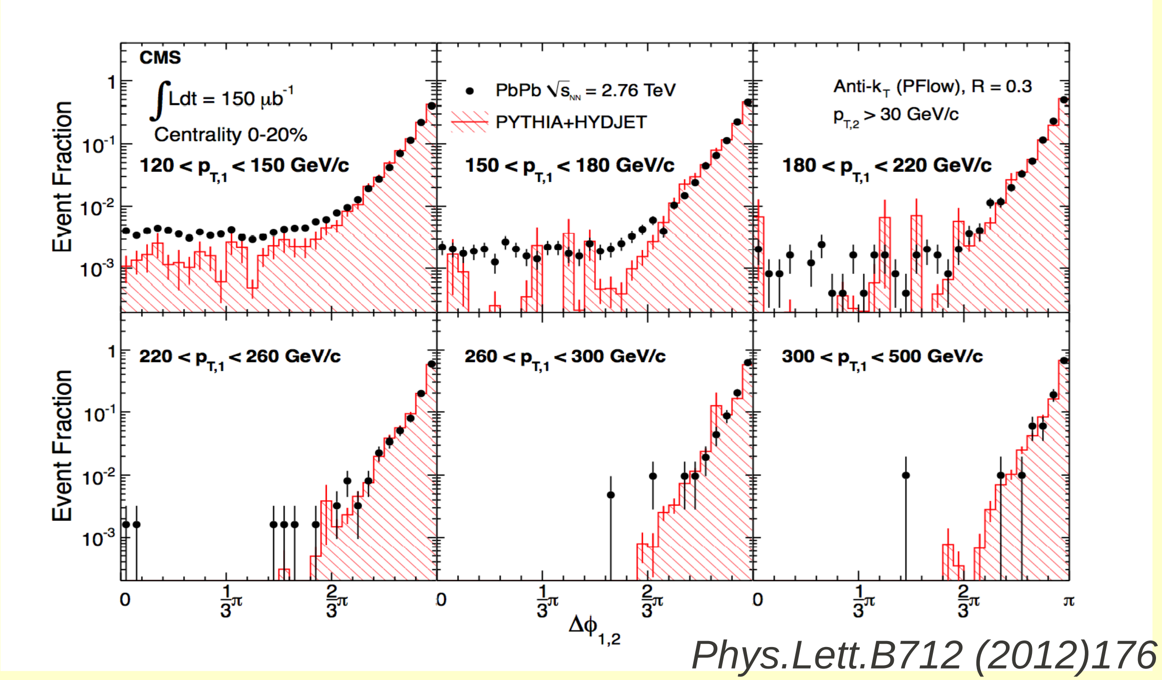
-multiple soft uncorrelated emissions→null net momentum?

-semihard (unlikely) in medium?



CMS dijets: very high Q^2 processes

Correlation peak the same in data and PYTHIA



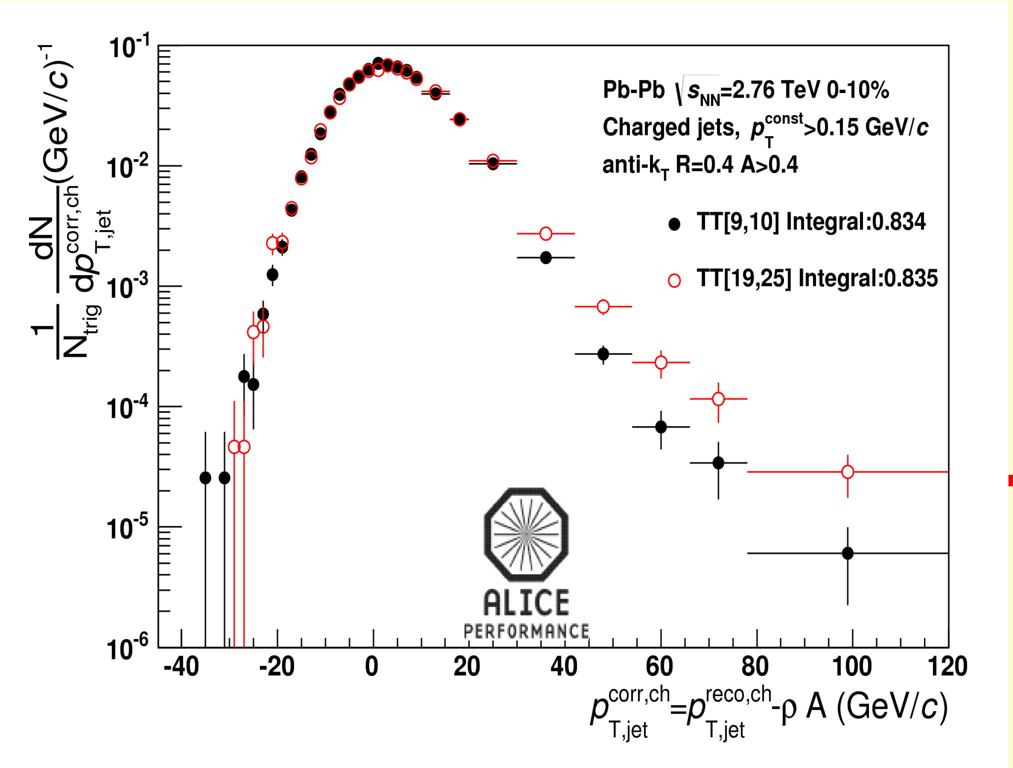
Phys.Lett.B712 (2012)176

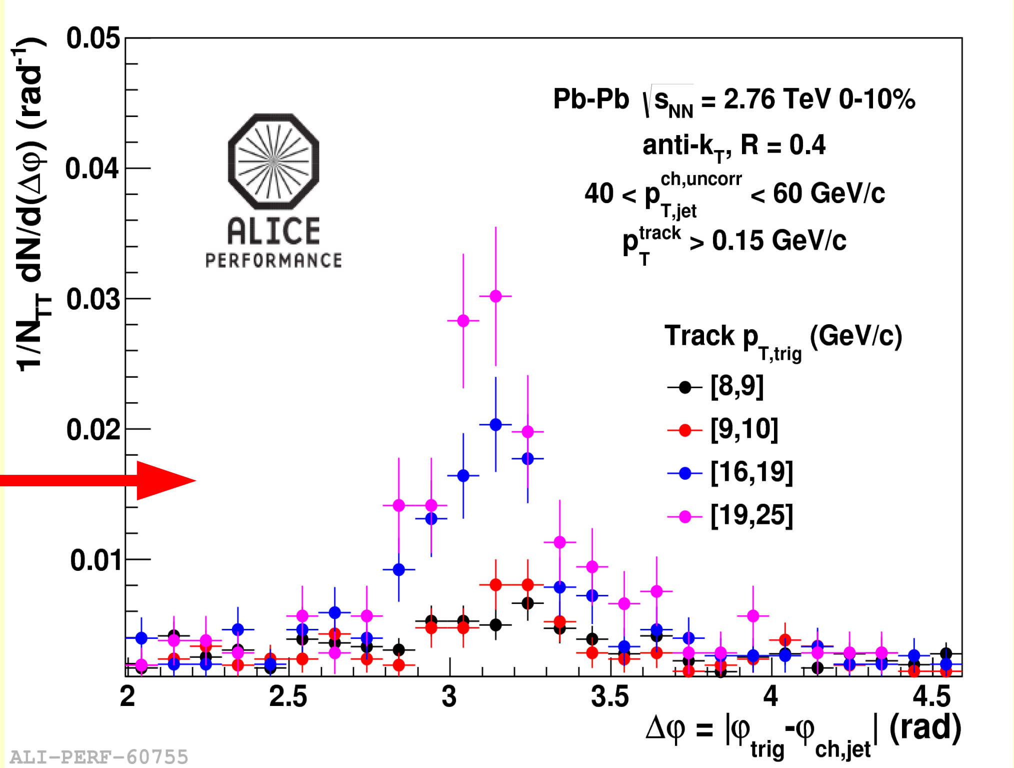
ALICE hadron-jet:

-lower Q^2 process

-minimal bias on fragmentation

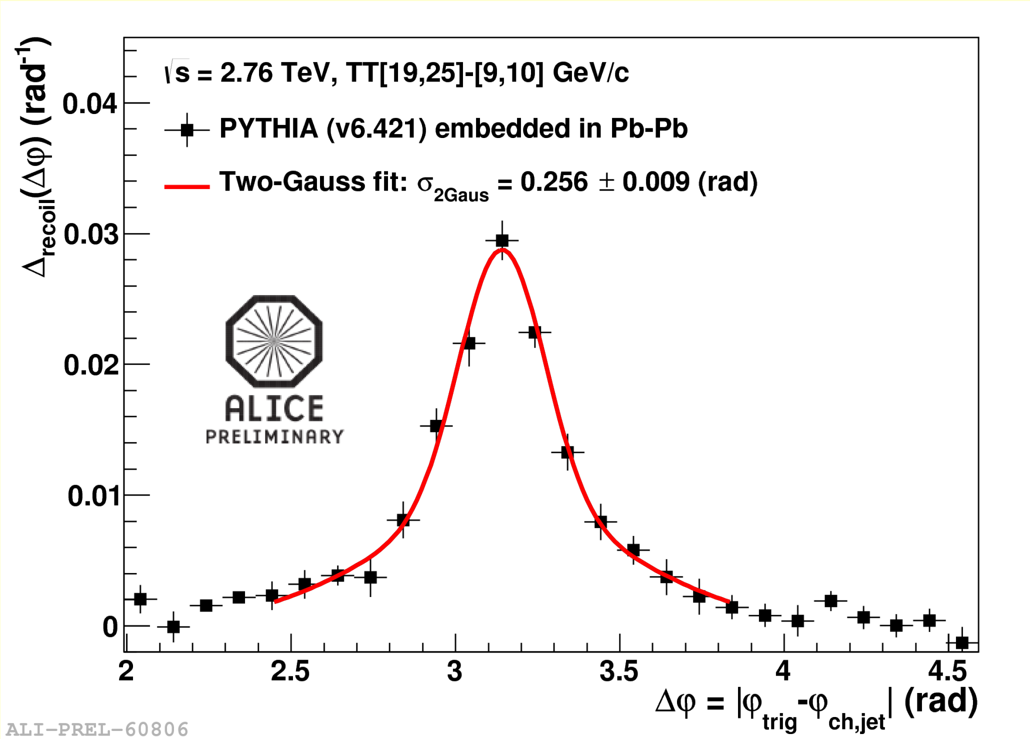
Hadron-jet azimuthal correlation

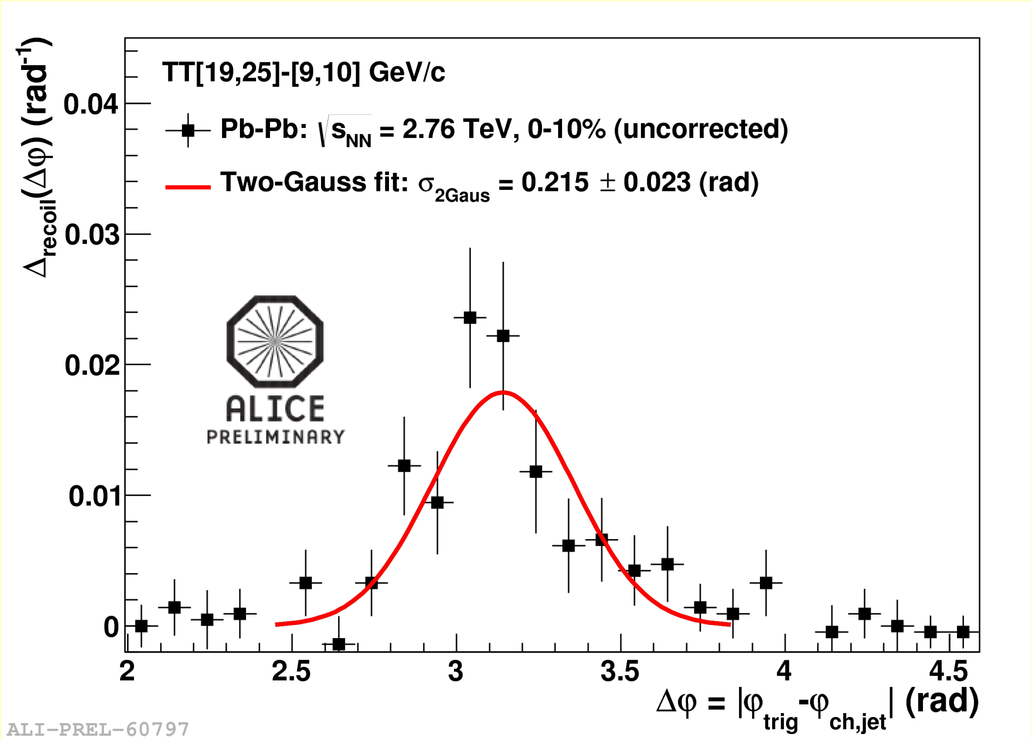




Same analysis as for the semi-inclusive differential yield, but now as function of **Δφ between trigger hadron and jet candidate**

Hadron-jet azimuthal correlation





PYTHIA is folded with the detector effects and background fluctuations

PYTHIA : σ_{2Gaus}=0.26±0.01 rad

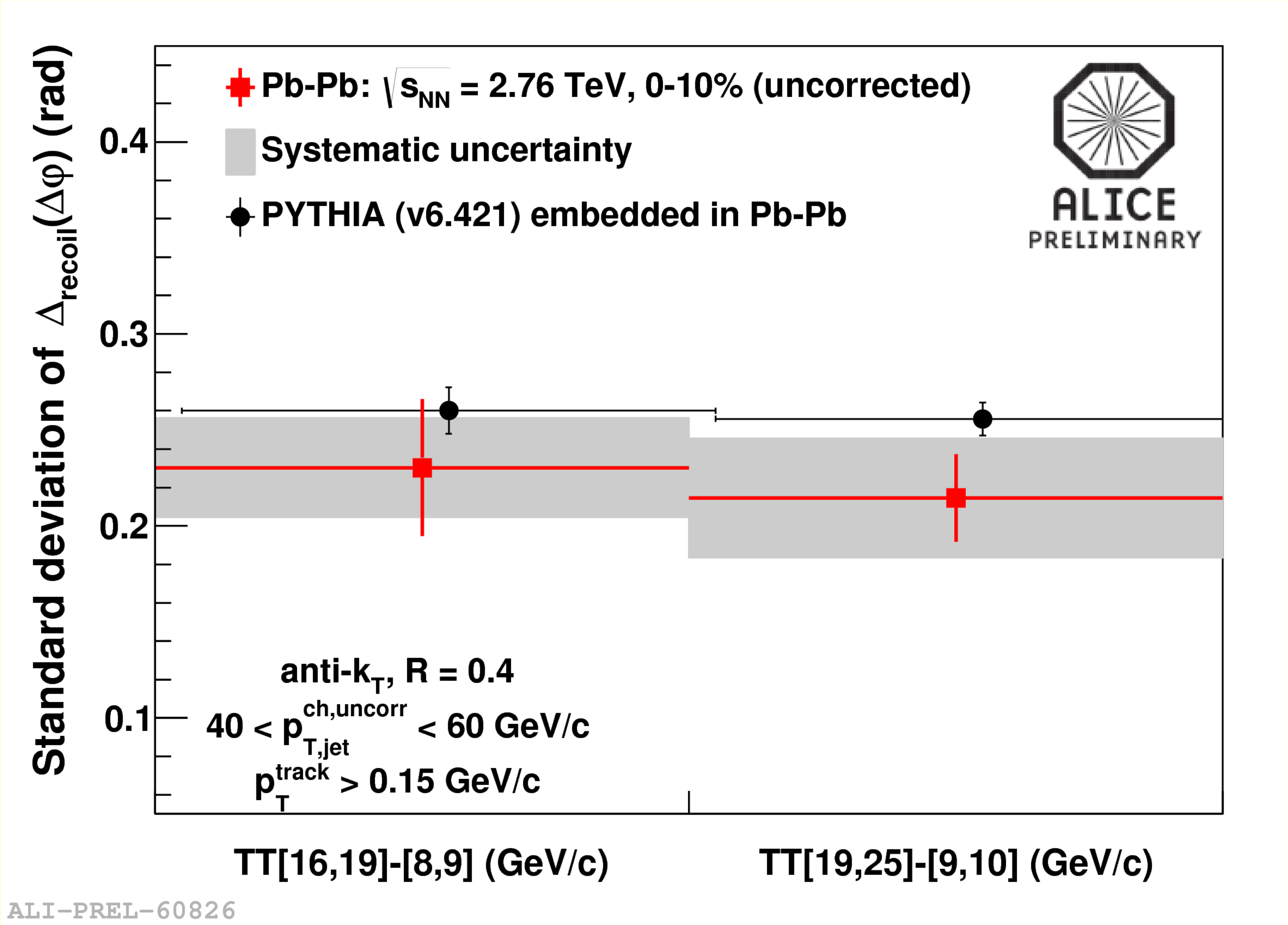
PbPb data: σ_{2Gaus}=0.22±0.02 rad

→ **Statistically compatible**

[σ_{2Gaus} is the standard deviation of the full distribution from the fit]

* 2nd gaussian in the fit accounts for non-collinear & hard radiation from the back-to-back parton

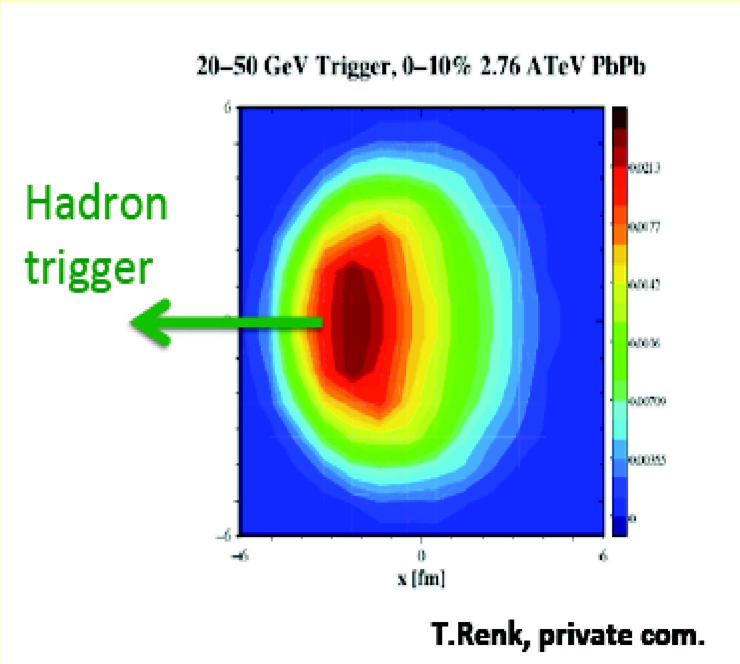
Hadron-jet azimuthal correlation



No medium-induced acoplanarity observed for the selected kinematics

Discussion

The value and p_T dependence of the suppression of the recoil jets (ΔI_{AA}) depends on several effects:

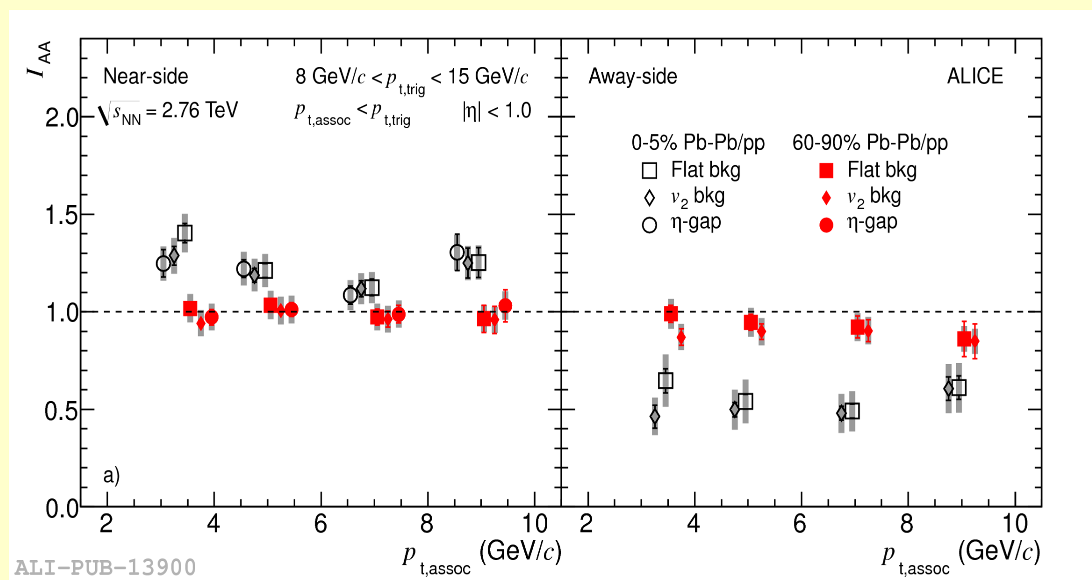


T.Renk Phys.Rev.C87 (2013) 2

1. The hadron trigger imposes a strong surface bias and **maximal medium path length** for the recoiling jets

2. Trigger track can be generated from quenched jet.
   The distribution of Q^2 of the h+jet process can therefore be harder in medium than in vacuum

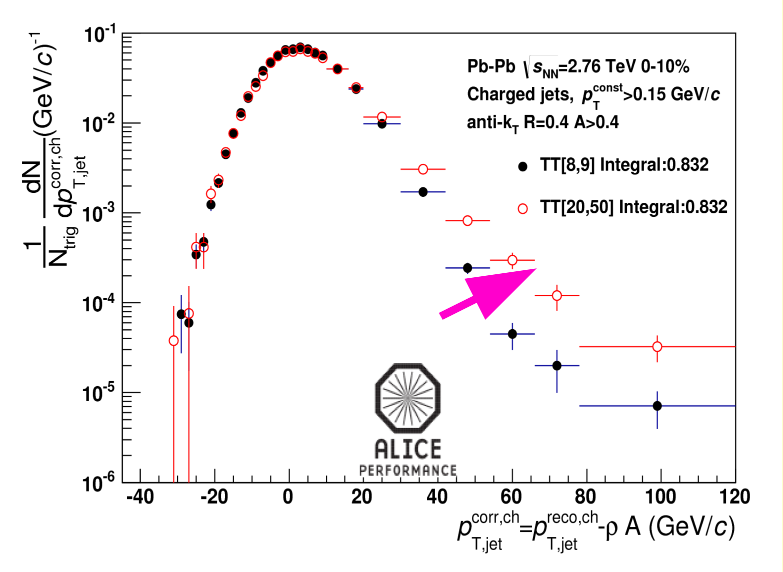
Near side single particle I_{AA}>1 also suggests larger Q^2 [10]



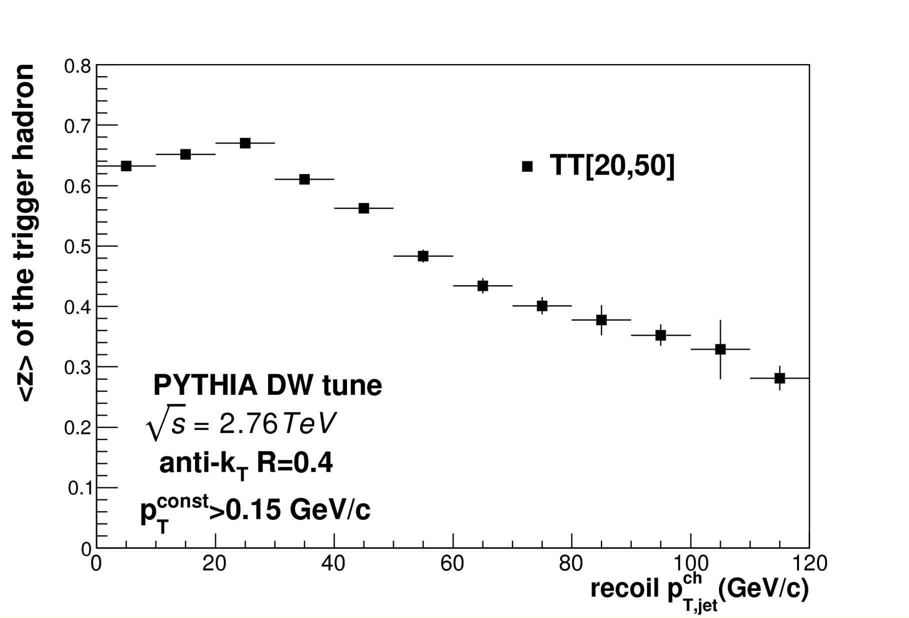
[10] ALICE Phys.Rev.Lett.108 092301 (2012)

Discussion

3. **Recoil jet spectrum is harder than the inclusive** →same energy shift due to quenching results in less suppression in ΔI_{AA} than in R_{AA}



4. For a fixed TT hadron class, increasing recoil jet p_T probes decreases hadron trigger z fraction



different surface bias for
different range in recoil jet p_T?

Summary and outlook

1. Combinatorial background subtraction techniques
   → allow to explore jet production at low p_T and large R with minimal IR cutoff

2. Recoil yield suppression:
   - ΔI_{AA}~0.75
   - Flat p_T dependence
   - ΔI_{AA} can be computed analytically

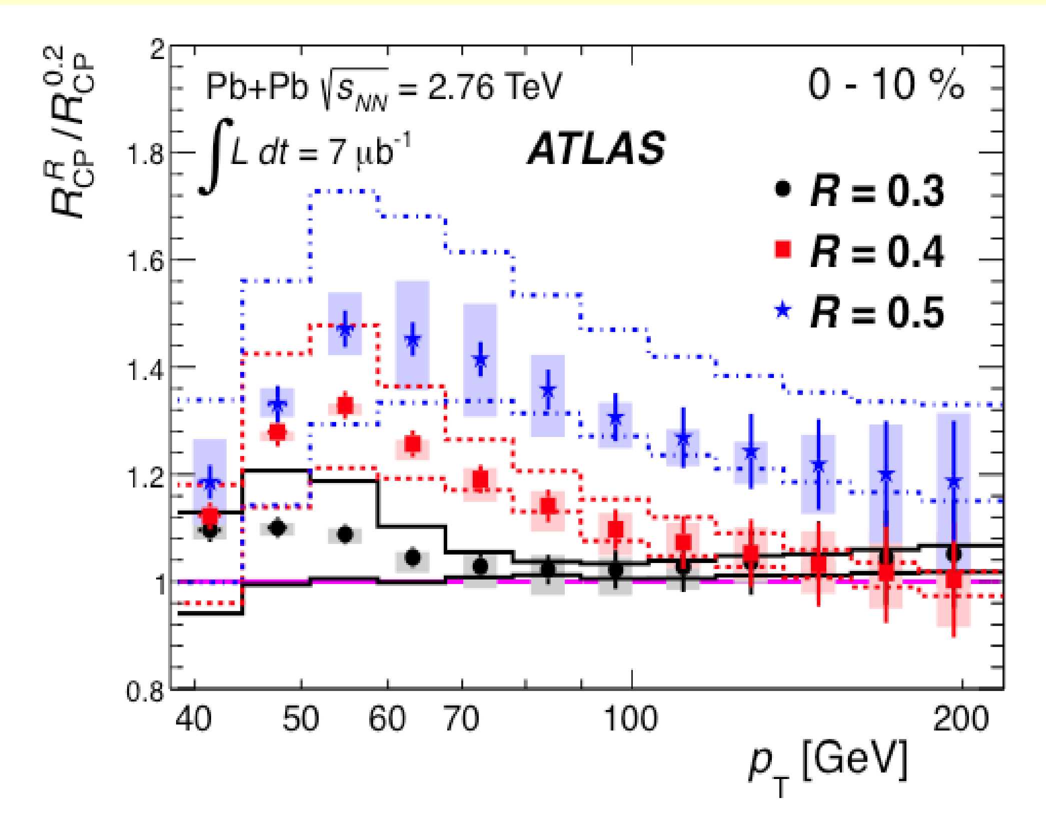
3. Energy redistribution in the recoil jets within R=0.4 and R=0.5?
   - Compatible with PYTHIA
   - Hints of effects at jet p_T~50-70 GeV/c?
   - MC shower needed: all-order tree level result for jet structure

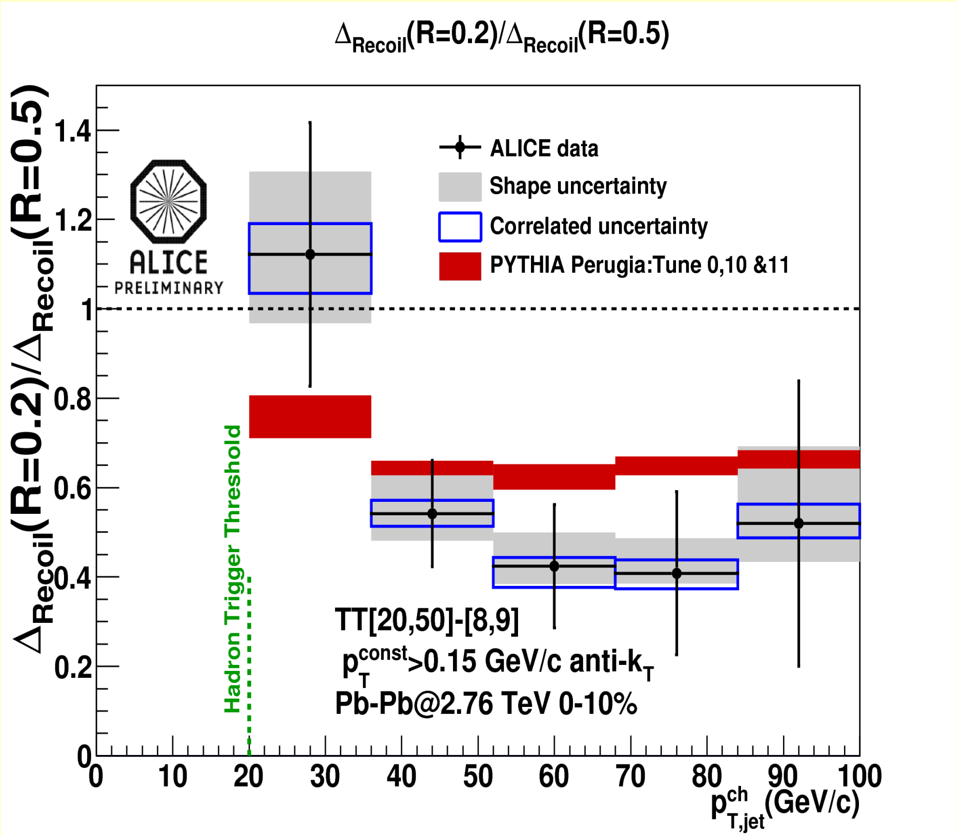
4. No indication of medium-induced acoplanarity

5. Ongoing analysis:
   - TT class vs ΔI_{AA} and p_T dependence
   - Raise the constituent cut→p_T profile of radiation within the jet cone
   - Comparison to theoretical models
   - New pp data

BACKUP

ALICE-ATLAS





ATLAS R=0.2/R=0.5: Central~0.67*Peripheral
ALICE R=0.2/R=0.5: Central~0.67*Pythia

But note only indirect comparison: different spectra(steepness): inclusive vs recoil
different constituent cut

Systematic uncertainties

Systematics for Δrecoil for R=0.4 expressed in percentage of the yield variation wrt nominal

	$\Delta^{+}(p_T^{jet}=28)$	$\Delta^{-}(p_T^{jet}=28)$	$\Delta^{+}(p_T^{jet}=76)$	$\Delta^{-}(p_T^{jet}=76)$
Iterations	3.75	0.	0	2.6
Range	1.6	0.26	0.033	0.2
p_T^{min}	0.59	0	0.25	1.8
Prior	3.37	3.9	5.6	0
Flow	0	4.5	0	9.5
Efficiency	2.8	2.9	13.76	11.78
Unf.Method	3.37	0	0.79	0
Frag. model	0	2.5	0.11	0
Binning	1.9	0	8.8	0.05
Jet Embedding	0.63	0	0	0.055

Correlated uncertainties:

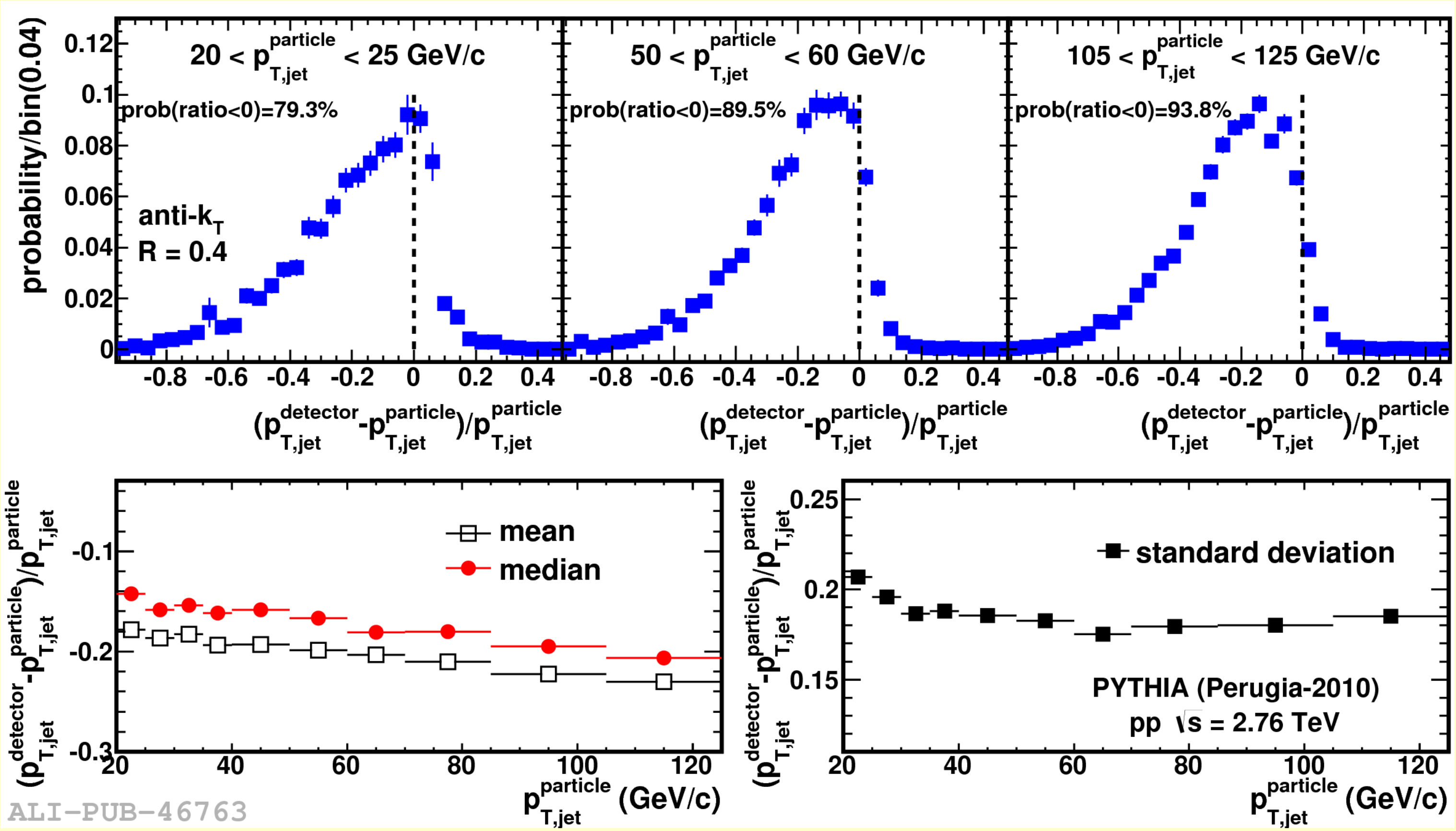
- Tracking efficiency uncertainty of 4%
- Event plane bias due to hadron trigger:Inclusive vs EP-weighted response
- Background scaling range
- Fragmentation model for detector effects

Shape uncertainties:

- Prior choice
- Regularization
- Unfolding algorithm: Bayesian vs SVD
- Binning choice measured spectrum
- Minimum p_T truncation measured spectrum
- RandomCones vs Jet embedding

Jet Energy scale uncertainty

ALICE Phys.Lett.B 722



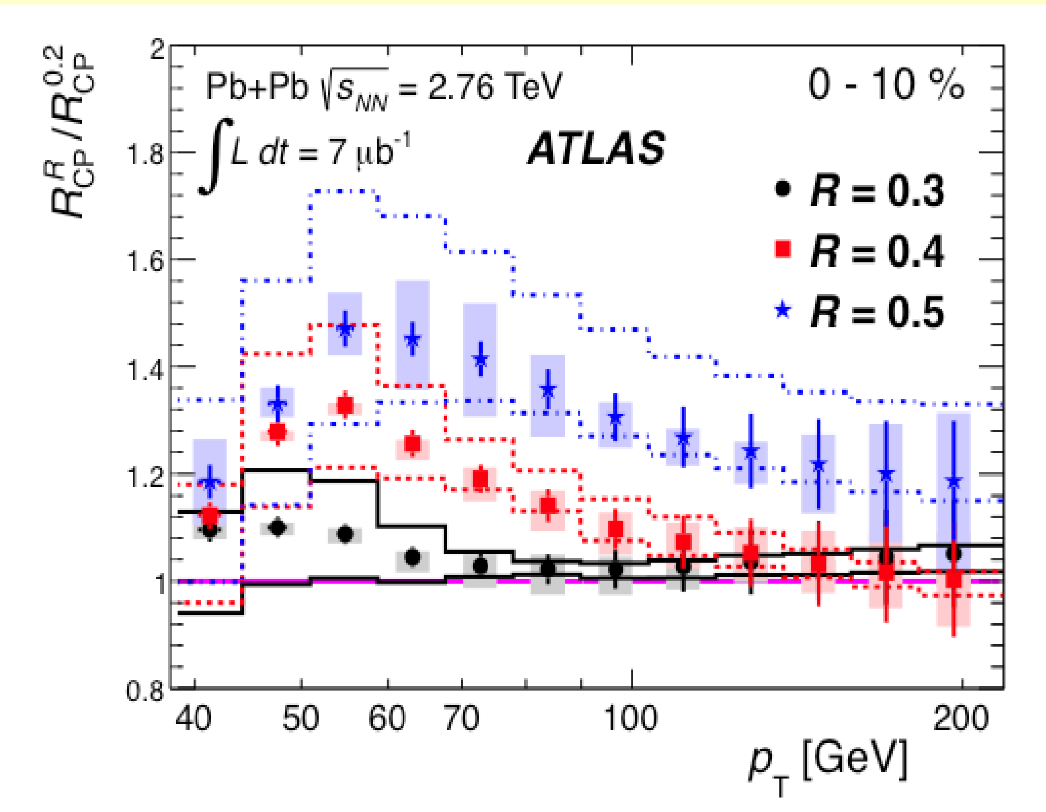
Detector effects in pp: non Gaussian response

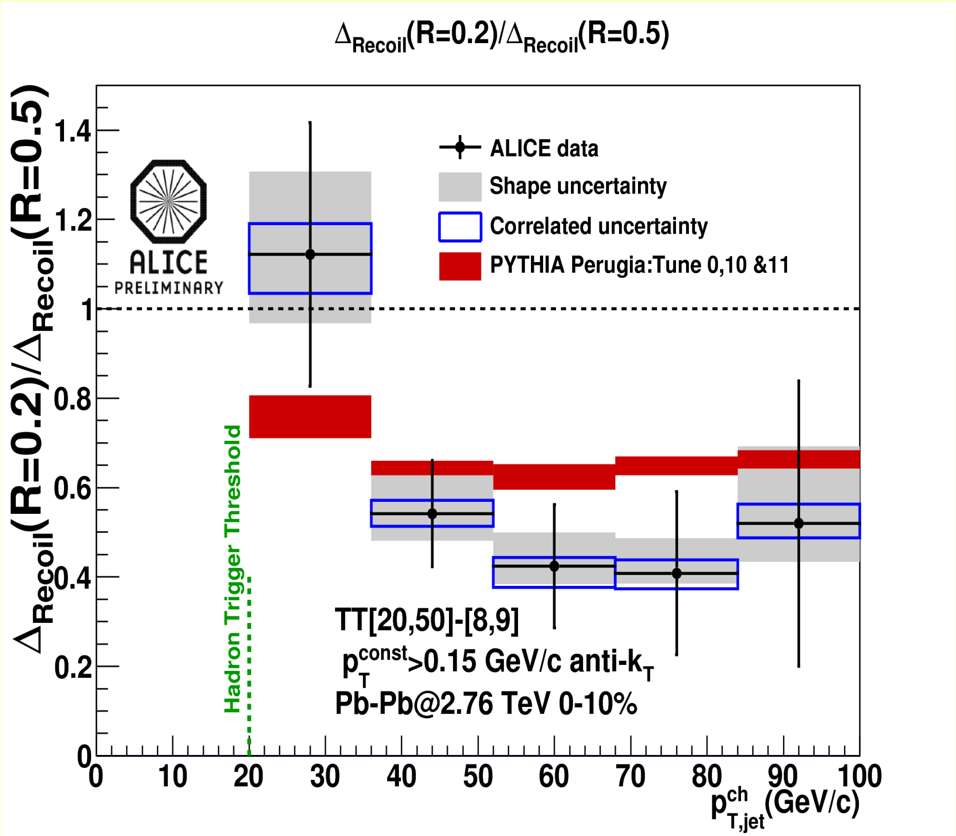
Median→20% shift in the jet energy

Uncertainties (dominantly tracking efficiency)→~2.6-3.6% JES uncertainty (5-3% in PbPb)

JES major component of total systematic uncertainty→13%-18%

ALICE-ATLAS





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