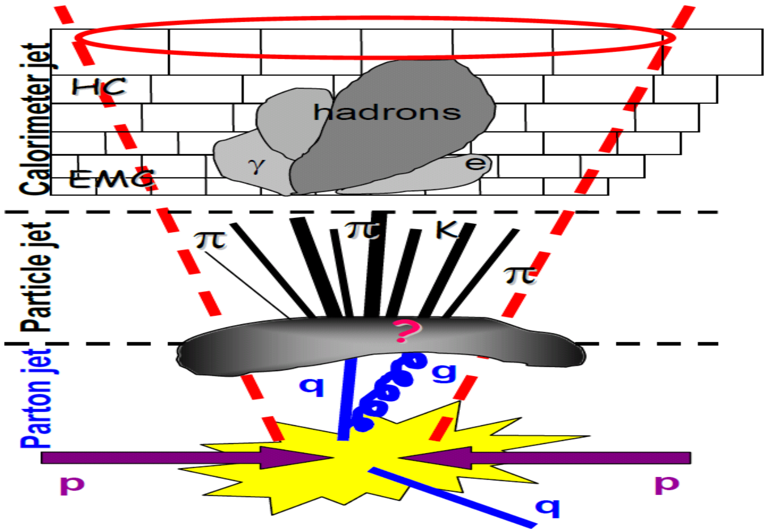
Jet production in pp & p-Pb collisions with the ALICE experiment at the LHC

Alexandre SHABETAI (for the ALICE Collaboration)

CNRS/IN2P3 - SUBATECH (Nantes - FRANCE)

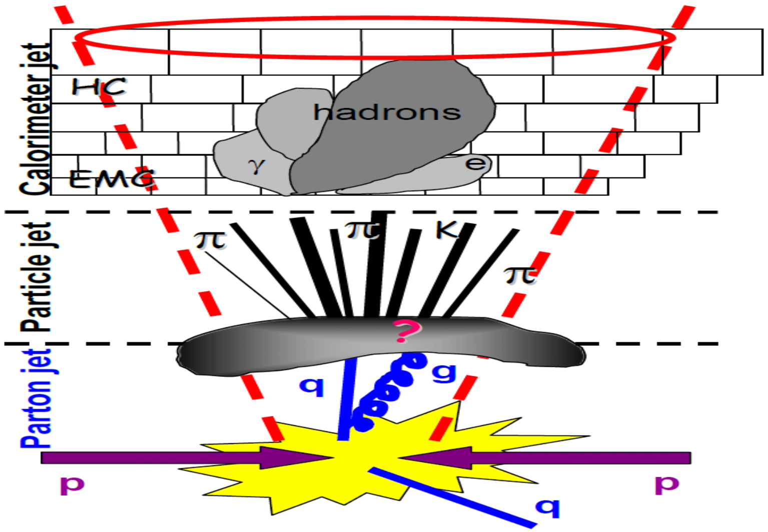
Motivations

Jet Constituents : Charged tracks for charged jets (+ calorimeter clusters for full jets)



Motivations

Jet Constituents : Charged tracks for charged jets (+ calorimeter clusters for full jets)



We use jets as well calibrated hard probes

Goal: Make a given measurement:

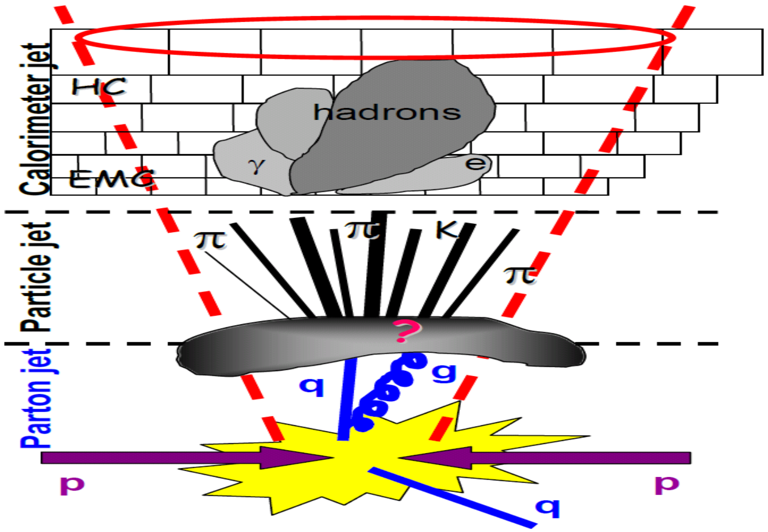
-Test / constrain theory / models

➔Use well defined observables

- Experimentally accessible & robust
- Theory point of view: calculable from first principles

Motivations

Jet Constituents : Charged tracks for charged jets (+ calorimeter clusters for full jets)



At LHC measurements are available in 3 collision systems:
- pp: “vacuum” case: test (or better constrain) pQCD, hadronization models,…
Also used as a reference for HI collisions
- p-Pb : Are jets affected by Cold Nuclear Mater effects ?
- Pb-Pb : Study in medium energy loss,…

● Focus in the talk on measurements in pp, and p-Pb

We will discuss:
-Global observables: e.g. jet production (Cross-section)
- as well as more differential ones: e.g jet structure

We use jets as well calibrated hard probes
Goal: Make a given measurement:
-Test / constrain theory / models
➔Use well defined observables
- Experimentally accessible & robust
- Theory point of view: calculable from first principles

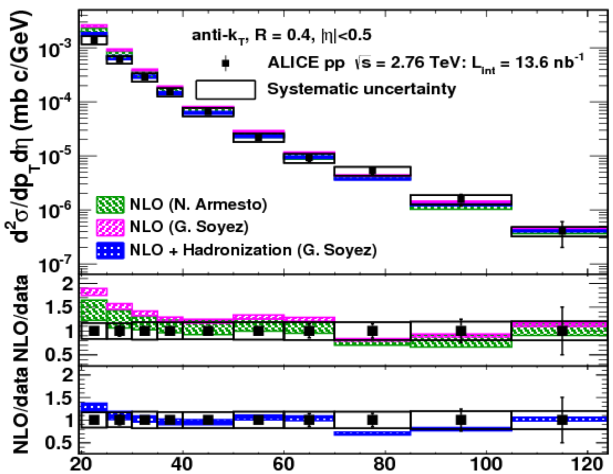
See talk by C. Nattrass focussing on Pb-Pb

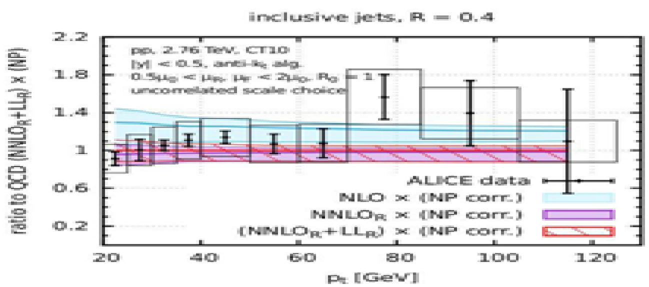
jet cross section in pp collisions

Full jets, $\sqrt{s}$ = 2.76 TeV

Phys. Lett. B 722 (2013) 262

R=0.4
EMCAL L0

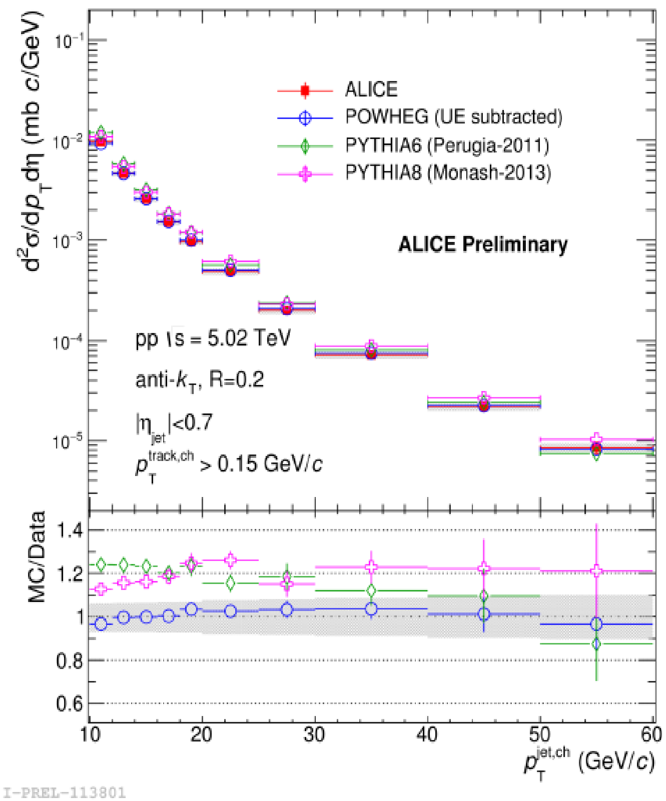




M. Dasgupta et a
JHEP 1606 (201
057

Charged jets, $\sqrt{s}$ = 5.02 TeV

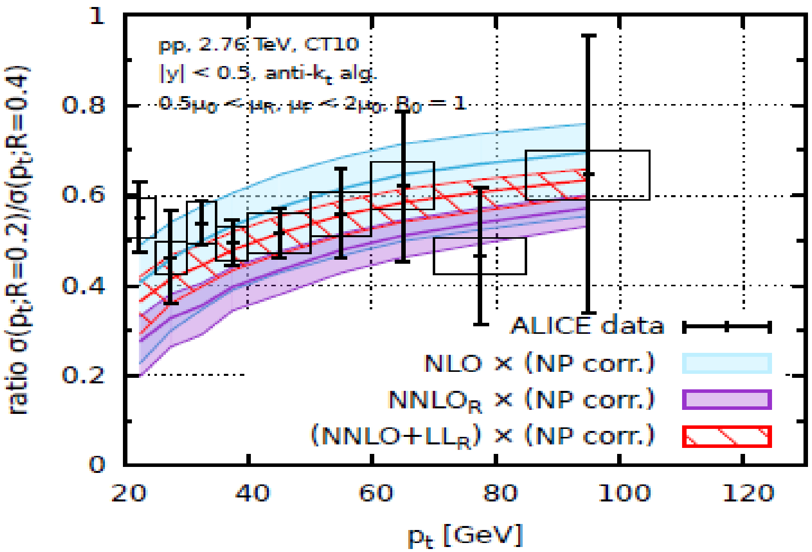
R=0.2
Min-Bias



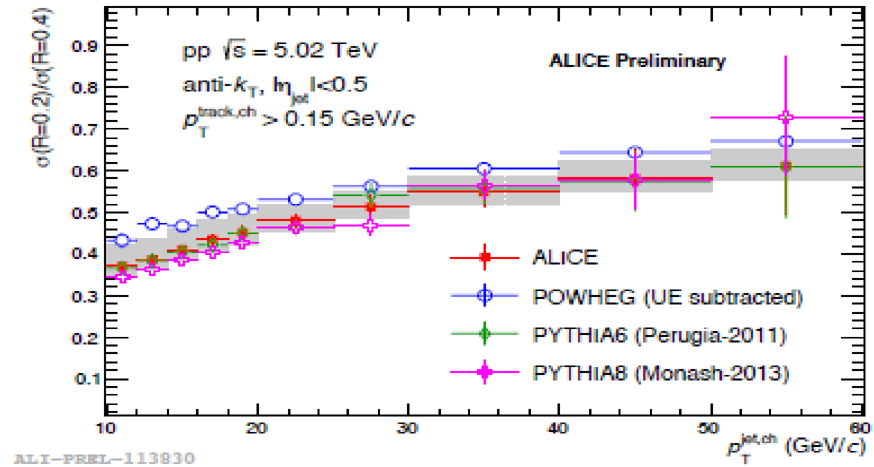
Good agreement between data and NLO calculations (+hadronization). Recent calculations based on $NNLO+LL_R$ including UE and hadronization effects are in even better agreement than just NNLO calculations.

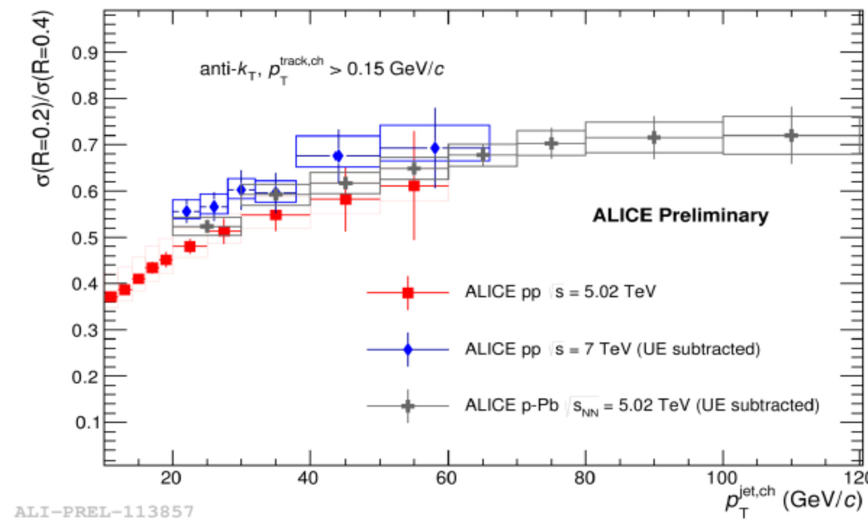
Recent results at $\sqrt{s}$ = 5.02 TeV (RUN 2) are in good agreement with POWHEG + PYTHIA 8 NLO calculations .

Jet cross section ratios



M. Dasgupta et al. JHEP 1606 (2016) 057

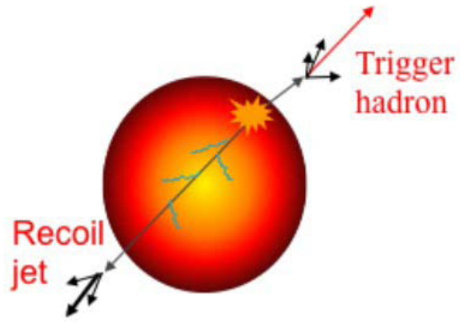




Cross section ratios (R=0.2/R=0.4):
- consistent across different systems (pp and pA) & Energies (5.02 and 7 TeV)
-increase with jet p_T ➔ collimation

-In good agreement with NLO / NNLO calculations

Measurements at lower jet p_T (from 5 GeV/c) are ongoing



Surface bias effect: the parton producing the jet is biased towards higher in-medium path length
Trigger Hadron: close to the surface

Hadron-jet Azimuthal Correlations

Motivated by HI collisions where recoil jet measurement provides us with a good handle on the combinatorial background and allows to go to larger R

Bonus: **No fragmentation bias on recoil side**

Hadron-jet correlations

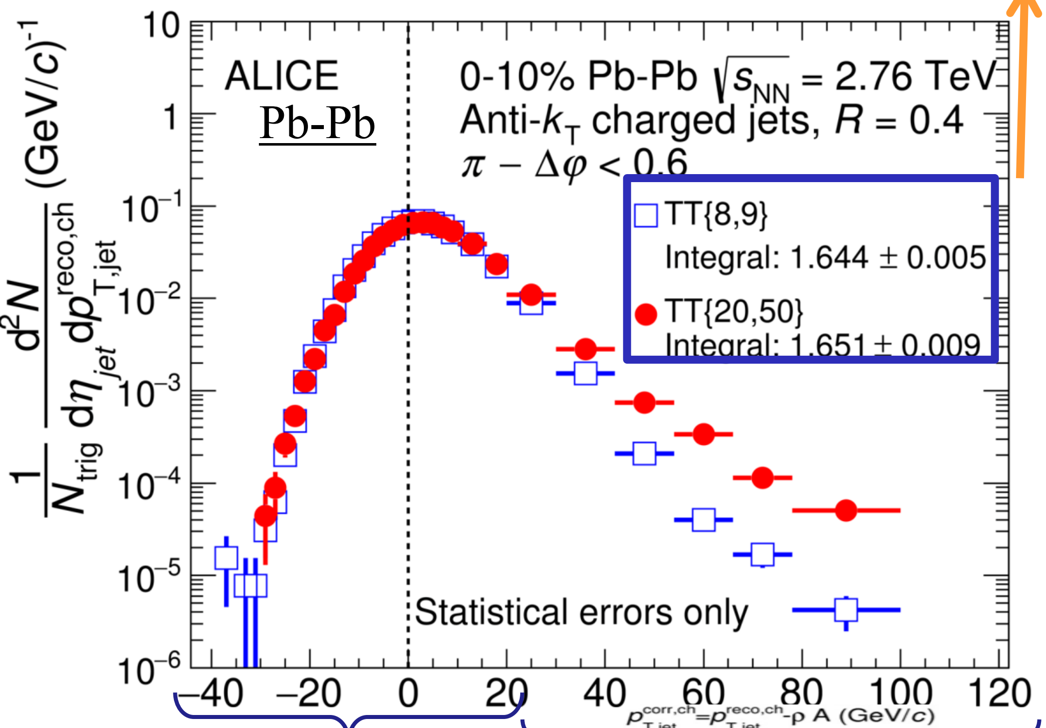
Low $p_{T,trig}$ (TT*[8, 9]) trigger recoil jet spectrum as a reference (dominated by combinatorial jet).

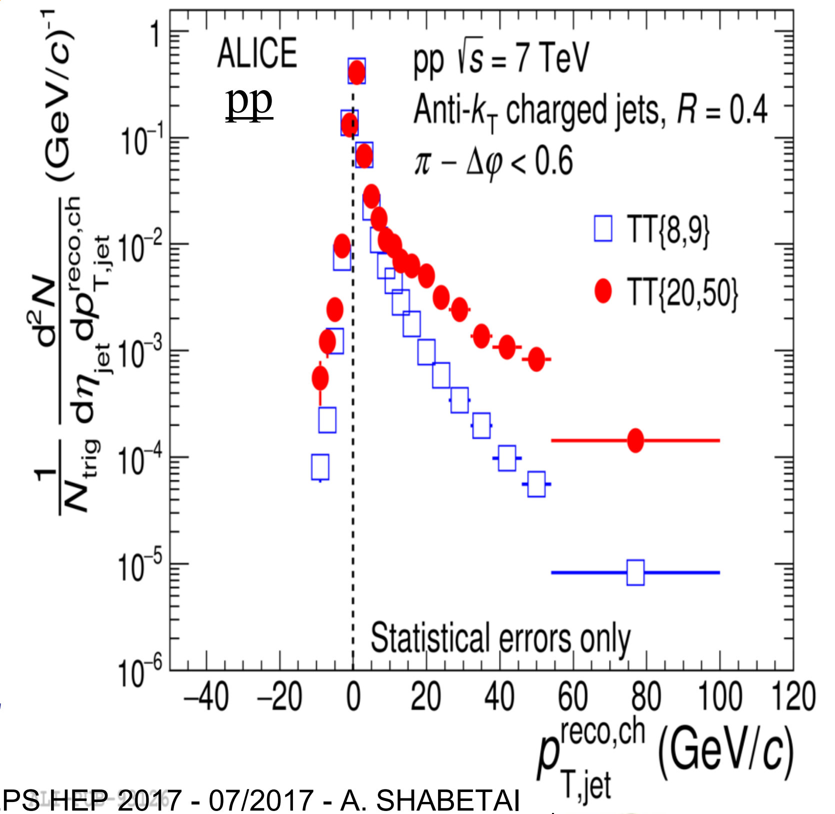
High $p_{T,trig}$ (TT[20, 50]) trigger recoil jet spectrum mainly from hard (high Q^2) process (signal).

Δ_{Recoil} Is defined as the difference of these two spectra to remove the uncorrelated bkg component

* TT for triggered track

JHEP 09 (2015) 170



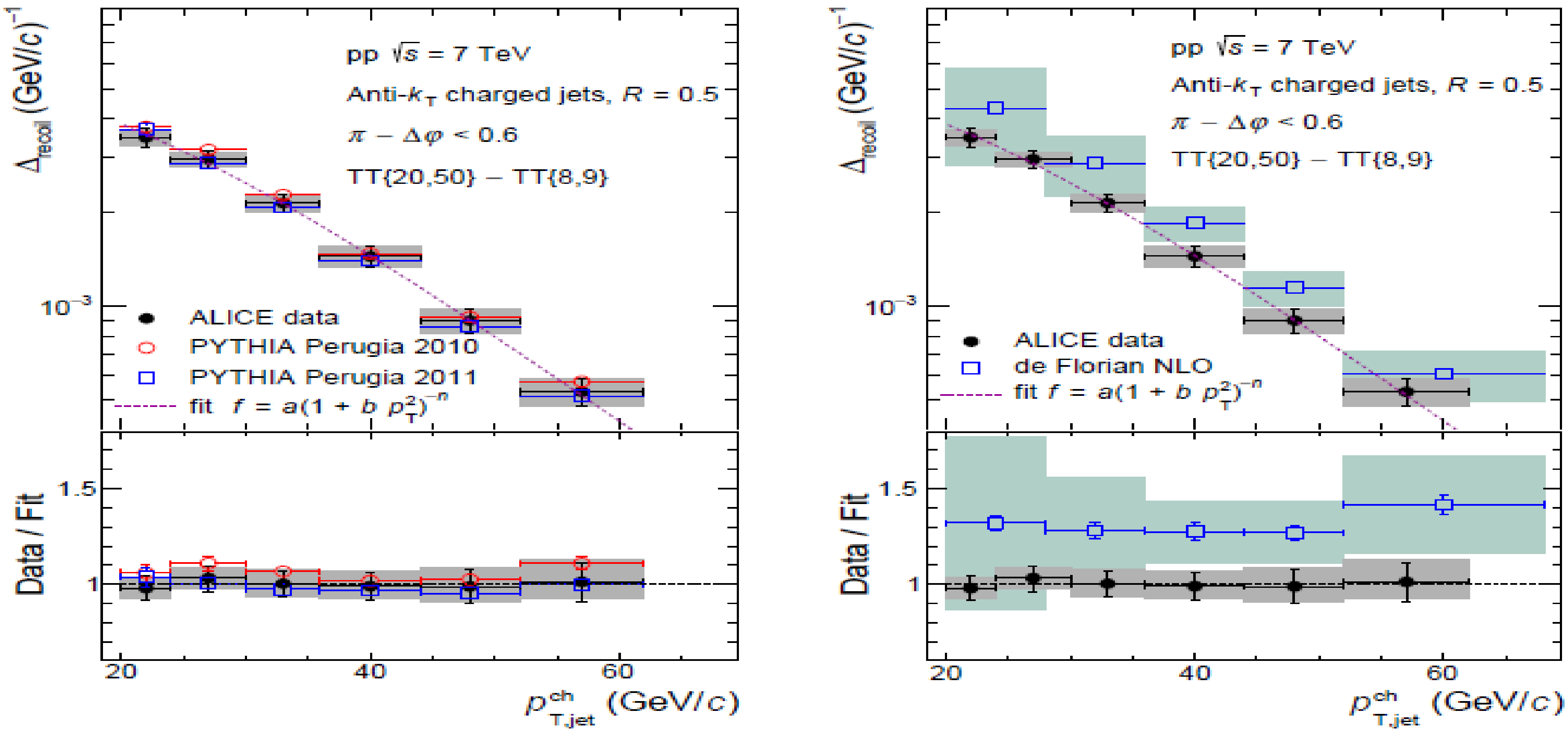


$p_{T,jet}$ < 20 GeV/c:
Shape does not change with $p_{T,trig}$
➔ Combinatorial background

$p_{T,jet}$ > 20 GeV/c:
Recoil jet spectrum evolves with $p_{T,trig}$

Semiinclusive recoil jet yields

JHEP 09 (2015) 170



Perugia tunes provide predictions that are compatible with the measured data within statistical and systematic uncertainties.

Improved agreement between the NLO calculation and data may therefore be achievable using resummation techniques

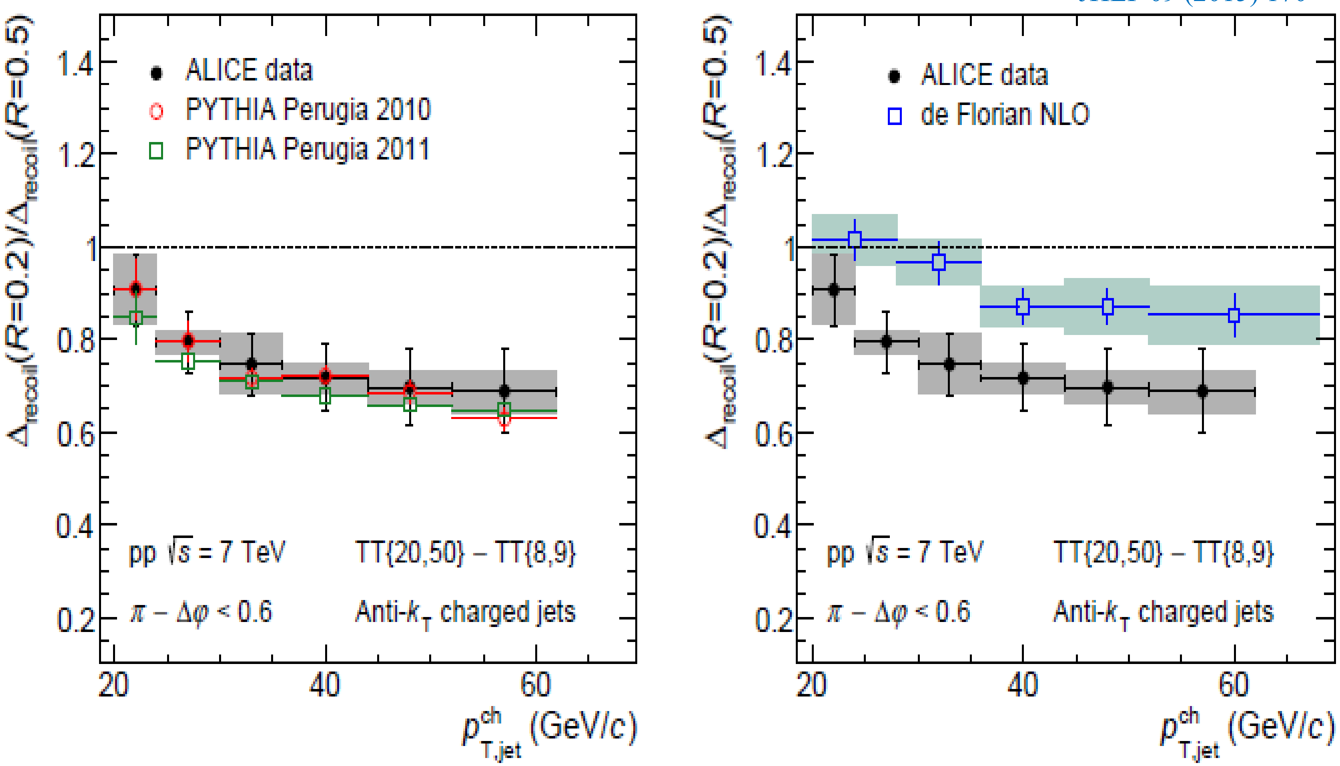
Ratios of recoiled jet yields with different R

ALI-PREL-86568

$$\text{ratio}\Big|_{R_1<R_2} = \frac{\left.\frac{1}{N_{\text{trig}}}\frac{d^2N_{\text{jet}}}{dp_{\text{T}}\,d\eta}\right|_{R_1}}{\left.\frac{1}{N_{\text{trig}}}\frac{d^2N_{\text{jet}}}{dp_{\text{T}}\,d\eta}\right|_{R_2}}$$

Indirect measure of jet structure
PYTHIA perugia tunes describe well the rations in pp at 7 TeV
NLO (fixed order) generates larger ratios ➔
Higher order needed (as for the cross-section)

JHEP 09 (2015) 170



Dynamics of particles inside jets
2 scales: angular and momentum space

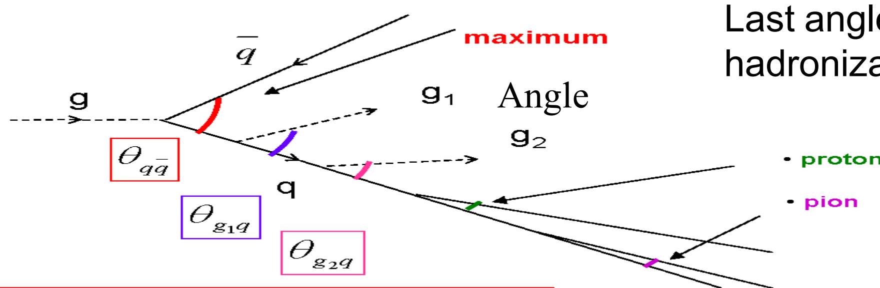
Jet shapes can be divided in 2 categories:

a) Those which computes a function of the constituents
b) Those which uses the clustering history.

ALICE jet substructure program in pp is conceived primarily as a reference for the Pb-Pb measurements and to constrain pQCD in a regime of low jet $p_{T,}$ while exploring a wide range of resolution parameters R.

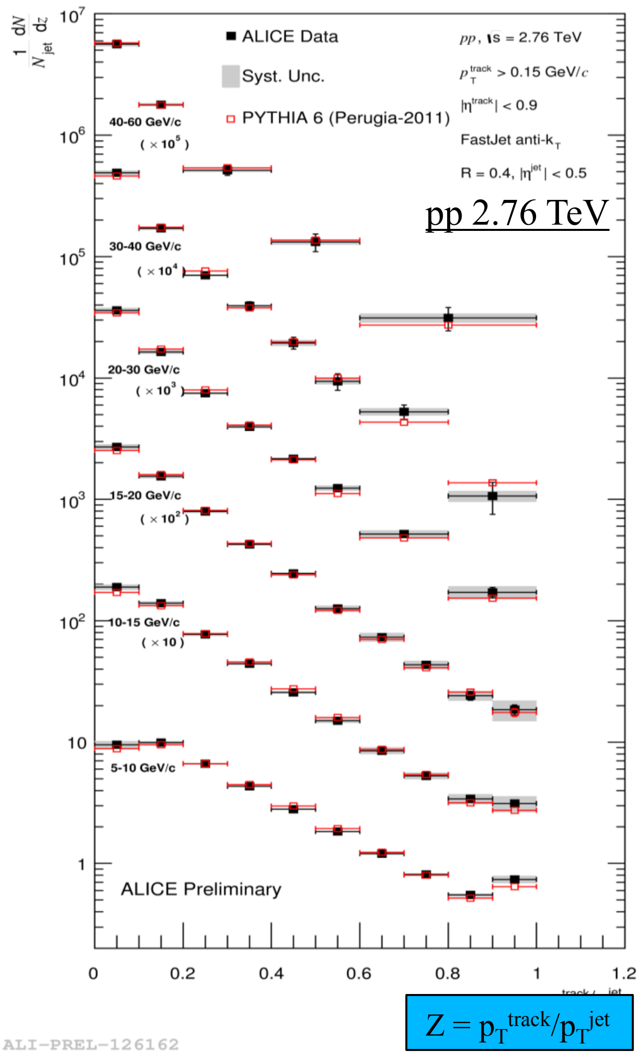
Jet shapes

Parton shower evolution:



Last angle before hadronization in:

$1/N_{jet}\, dN/dz$



$Z = p_T^{track}/p_T^{jet}$

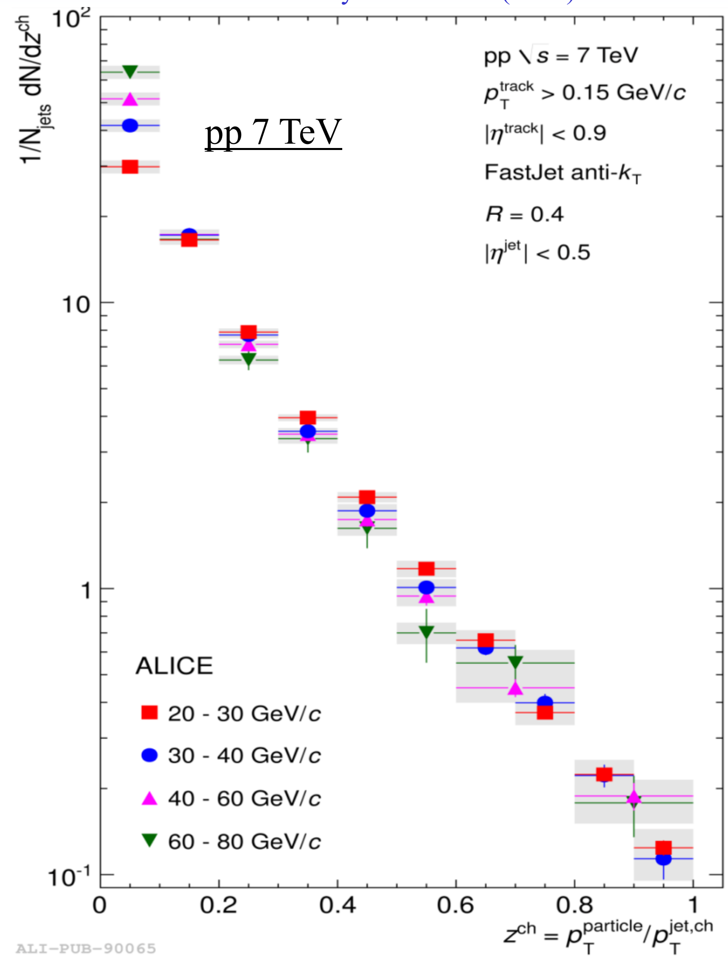
jet fragmentation functions

√s = 2.76 TeV. Charged jets, 5 < pT < 60 GeV/c

R=0.2.R=0.4, R=0.6

$1/N_{jet}\, dN/dz$

Phys. Rev. D 91 (2015) 112012

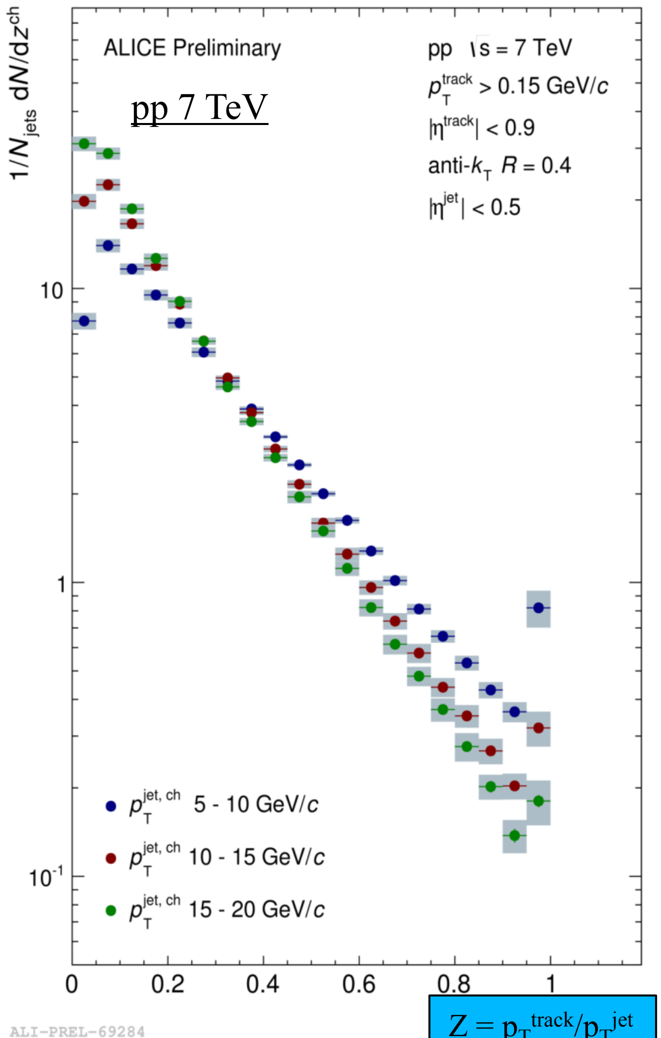


$Z = p_T^{track}/p_T^{jet}$

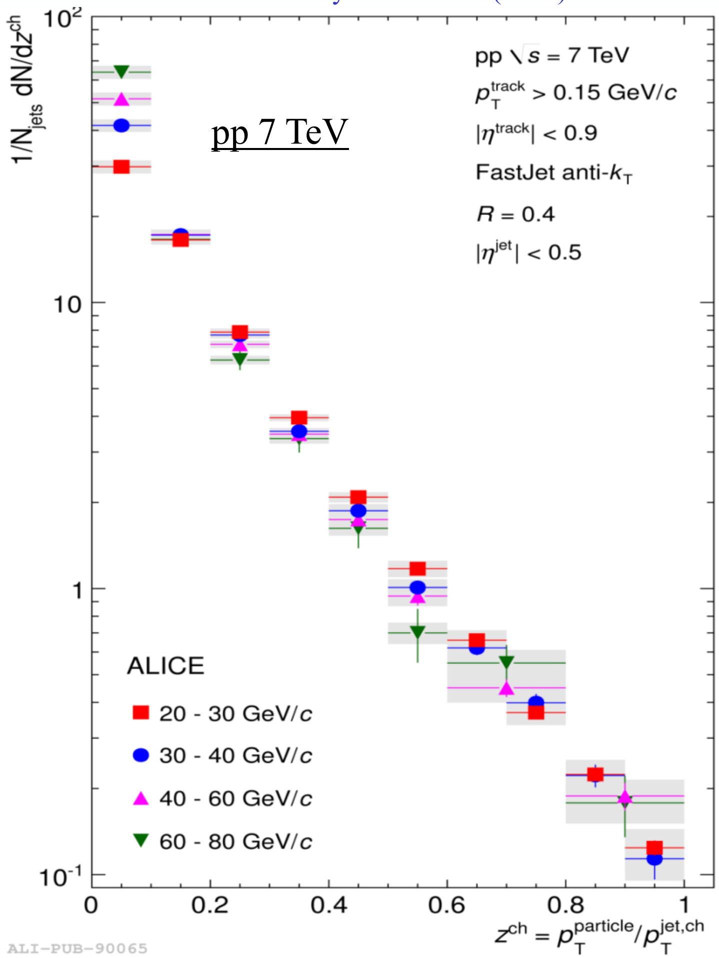
For z_{ch} > 0.1 all measured distributions are consistent within **uncertainties**, indicating a **scaling** of charged jet **fragmentation** with charged jet $\boldsymbol{p_T}$.

$1/N_{jet}\, dN/dz$

Phys. Rev. D 91 (2015) 112012



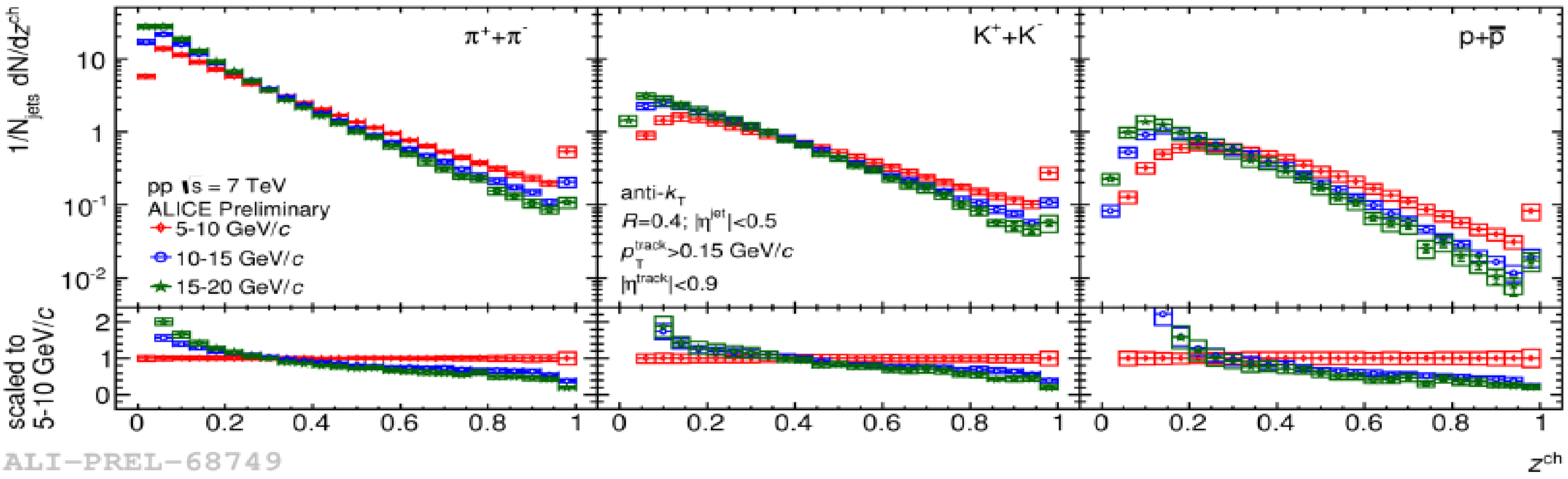
$Z = p_T^{track}/p_T^{jet}$



For z_{ch} > 0.1 for highest p_T bins, the distributions are consistent within **uncertainties**, indicating a **scaling** of charged jet **fragmentation** with charged jet p_T.

$1/N_{jet}\, dN/dz$

pp 7 TeV

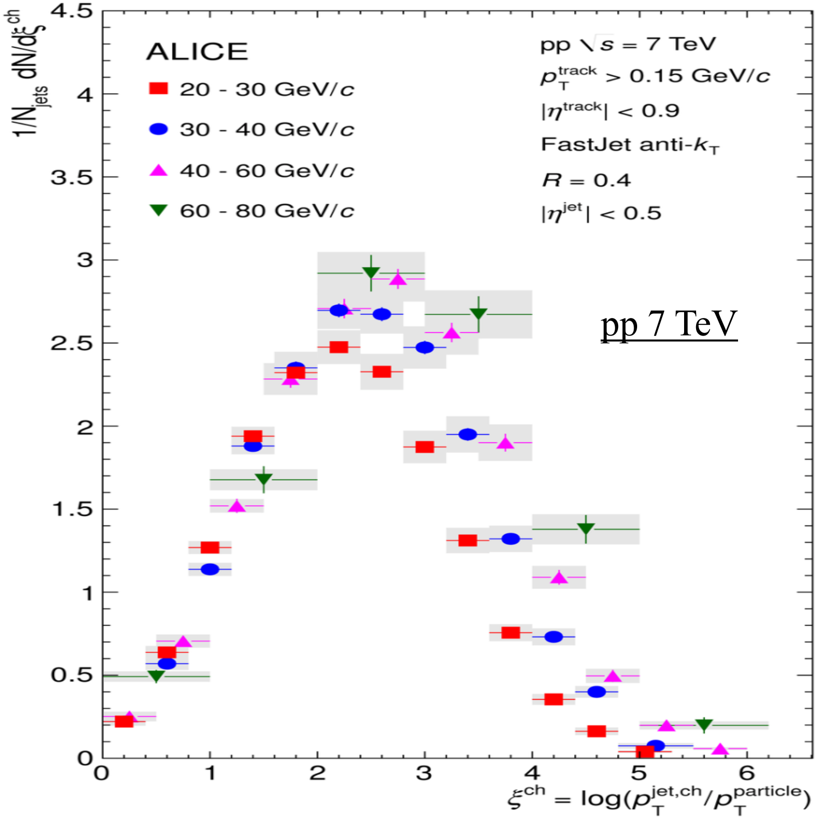


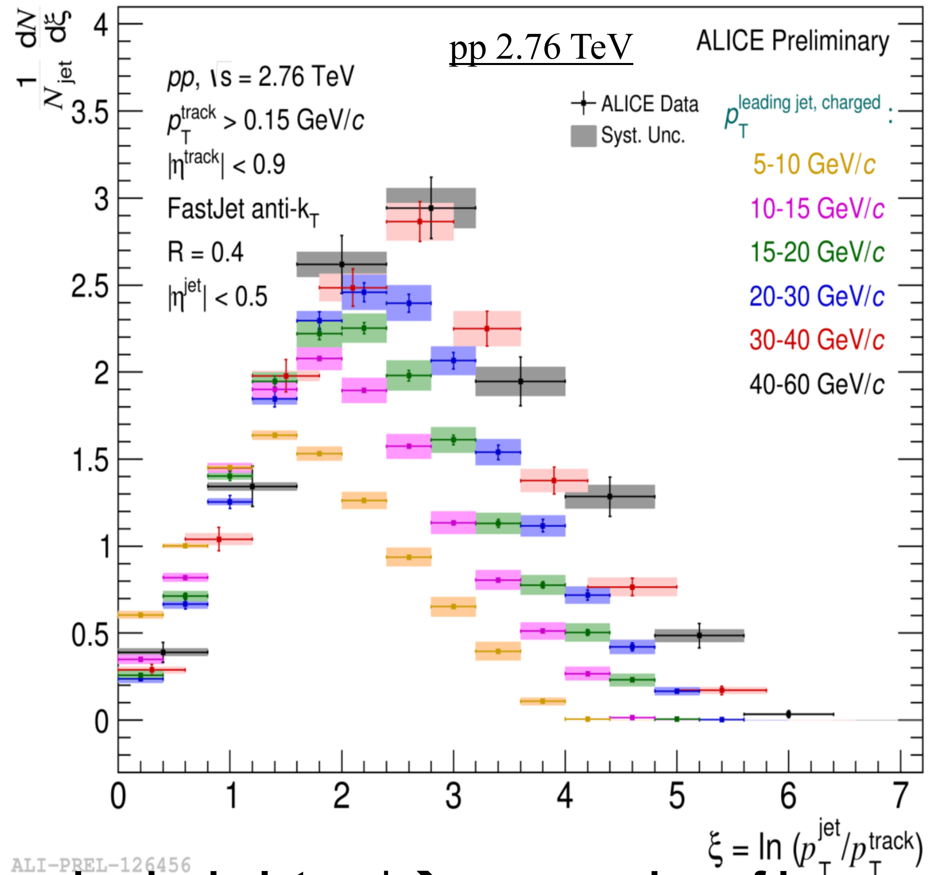
Particle Identified fragmentation (PID in jets using 2 consistent methods TPC Coherent fit or muti-template fit)

For z_{ch} > 0.2 for highest p_T bins, **scaling** of charged jet **fragmentation** with charged jet $\boldsymbol{p_T}$.

$1/N_{jet}\ dN/d\xi$

Phys. Rev. D 91 (2015) 112012





For ξ **< 2 same scaling** as for z.

At higher ξ (small z), maximum :'**hump-backed plateau**' ➔ **suppression of low momentum particle** production by QCD coherence

With **increasing jet p_T,** the **area** of the distributions **increases** (**higher** particle **multiplicity** in jets), maximum shifts to higher values of ξ

This observation is in qualitative agreement with **MLLA**

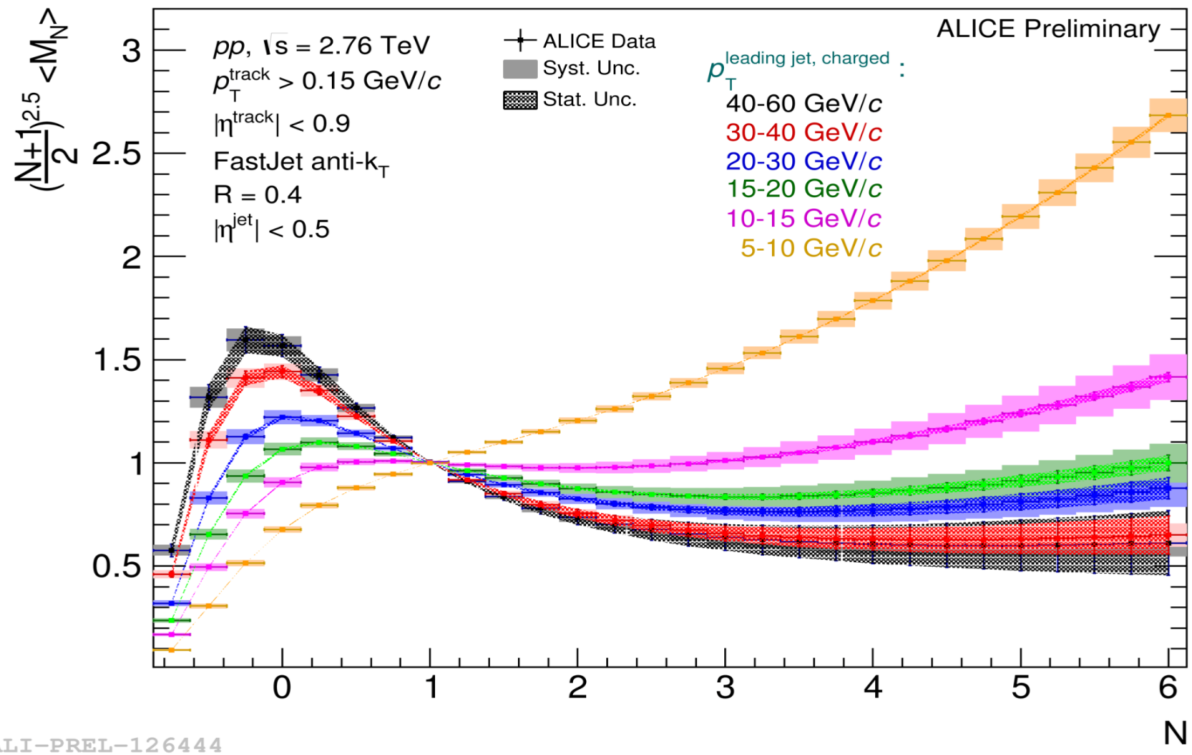
Fragmentation function moments

First measurement of the jet fragmentation function moments

√s = 2.76 TeV. Charged jets, 5 < pT < 60 GeV/c R=0.2.R=0.4, R=0.6

Cacciari et al Eur.Phys.J. C73 (2013) 2319 (arxiv:1209.6086), "Jet fragmentation function moments in heavy ion collisions

$$M_N = \frac{1}{N_{\rm jet}} \int_0^1 z^N \frac{dN_{\rm hadron}}{dz} dz \,, \qquad z = \frac{p_T^{\rm hadron}}{p_T^{\rm jet}}$$



Advocated to facilitate the correction of background effect (via subtraction and deconvolution) that are known to be large in HI.

Good agreement between data and PYTHIA Perugia 11

Reference for future Pb-Pb measurements

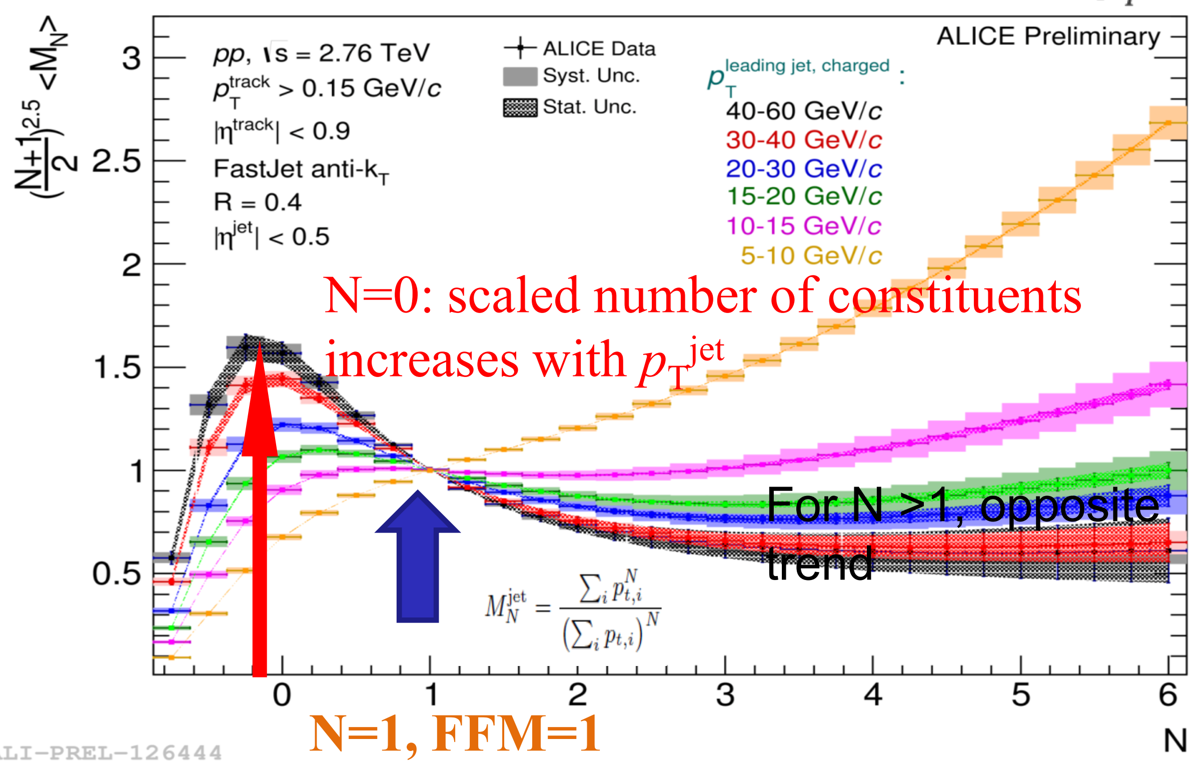
Fragmentation function moments

First measurement of the jet fragmentation function moments

$\sqrt{s}$ = 2.76 TeV. Charged jets, 5 < pT < 60 GeV/c R=0.2.R=0.4, R=0.6

Cacciari et al Eur.Phys.J. C73 (2013) 2319 (arxiv:1209.6086), "Jet fragmentation function moments in heavy ion collisions

$$M_N = \frac{1}{N_{\rm jet}} \int_0^1 z^N \frac{dN_{\rm hadron}}{dz} dz \,, \qquad z = \frac{p_T^{\rm hadron}}{p_T^{\rm jet}}$$



Advocated to facilitate the correction of background effect (via subtraction and deconvolution) that are known to be large in HI.

Good agreement between data and PYTHIA Perugia 11

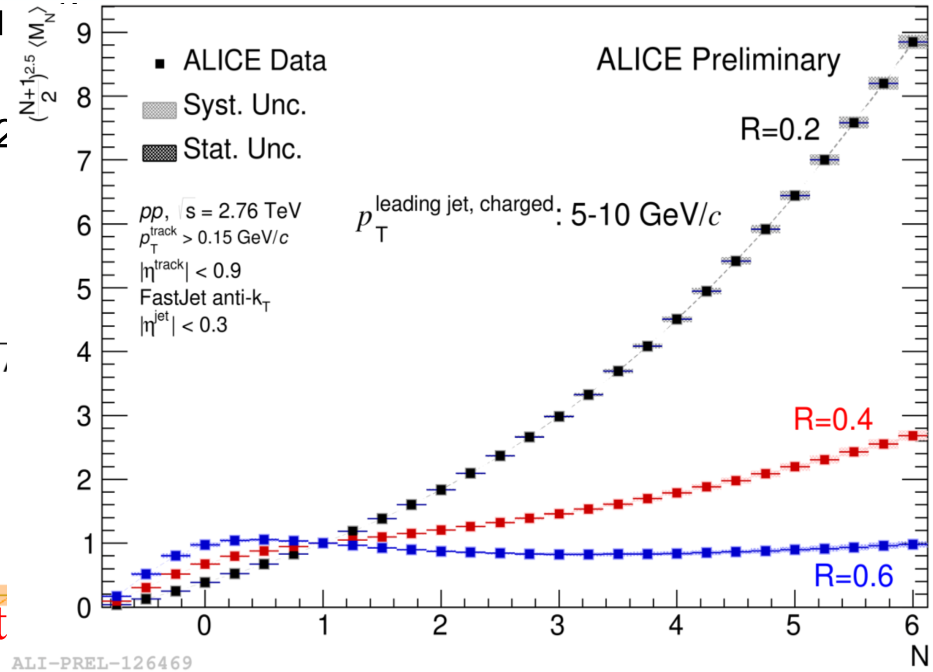
Reference for future Pb-Pb measurements

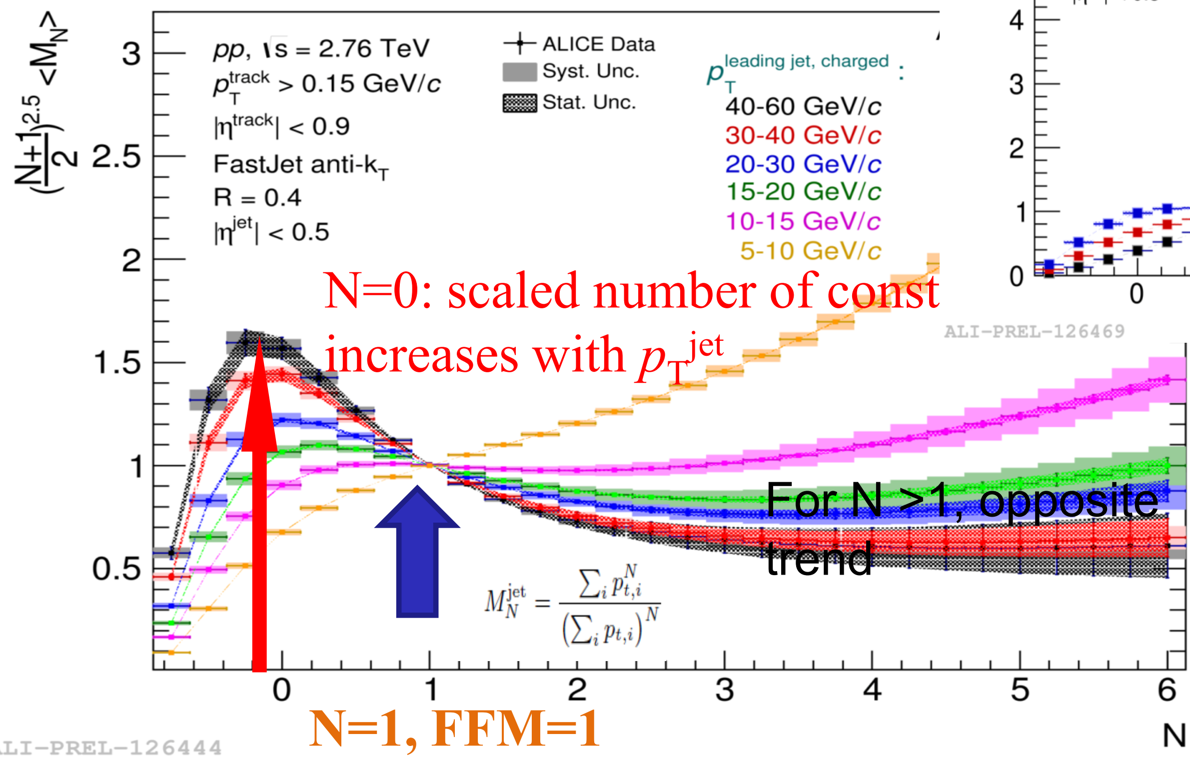
Fragmentation function moments

First measurement of the jet fragmentation fu... moments

$\sqrt{s}$ = 2.76 TeV. Charged jets, 5 < pT < 60 GeV/c R=0.2...

$$M_N = \frac{1}{N_{\text{jet}}} \int_0^1 z^N \frac{dN_{\text{hadron}}}{dz} dz\,,$$





Good agreement between data and PYTHIA Perugia 11

Strong dependence of the FFM distribution vs R

N=1, FFM=1

Reference for future Pb-Pb measurements

p_TD, g, LeSub

$$p_T D = \frac{\sqrt{\sum_i p_{T,i}^2}}{\sum_i p_{T,i}}$$

Longitudinal dispersion

momentum re-distribution of jet constituents.

$$g = \sum_{i \in \text{jet}} \frac{p_T^i}{p_T^{jet}} |r_i|$$

Radiat moment (« grith ») g

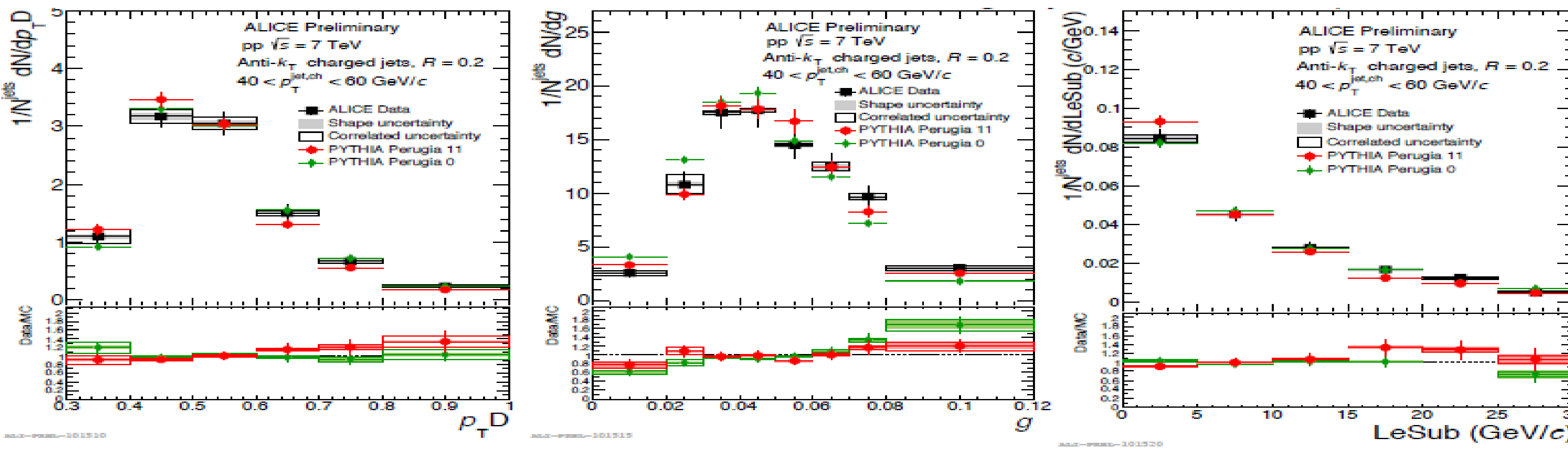
momentum re-distribution of jet constituents weighted by their distance from the jet axis

$$\text{LeSub} = p_T^{lead,track} - p_T^{sublead,track}$$

Transverse momentum Difference between the hardest and second hardest constituents of the jet

not IRC safe but background invariant, ➔ interesting for Pb-Pb

$\sqrt{s}$ = 7 TeV. Charged jets, R = 0.2, 40 < p_T < 60 GeV/c



Jet shapes corrected to particle level.

Reasonable agreement between data and PYTHIA calculations

Jet mass in p-Pb

$$M = \sqrt{p^2 - p_T^2 - p_z^2} \qquad p = \sum_{i=1}^{n} p_{T_i} \cosh \eta_i \qquad p_z = \sum_{i=1}^{n} p_{T_i} \sinh \eta_i$$

Difference of the momentum of the jets and the energy of its constituents weighted by their pseudo rapidity

Releated to the virtuality of the parton traversing the medium

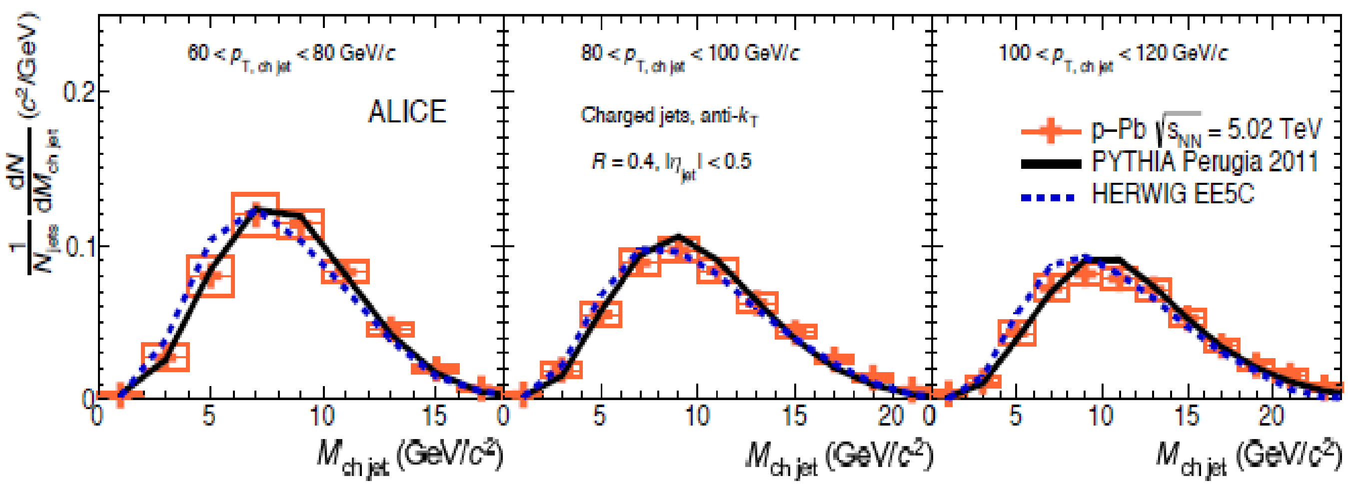
- small mass collimated jet small number of constituents → low virtuality
- large mass: broad jet large number of constituents → high virtuality

p-Pb: Reasonable agreement between data and PYTHIA calculations for jet mass within 10-20%, some tensions in the tails.

Slightly worse agreement with HERWIG, in particular the low mass tails.

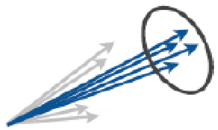
$\sqrt{s}$ = 5.02 TeV Charged jets, R = 0.4, 60 < p_T < 120 GeV/c

arXiv:1702.00804 submitted to PLB



Groomed Subjets: z_g in p-Pb

Groomed Observables



Subset of hadrons

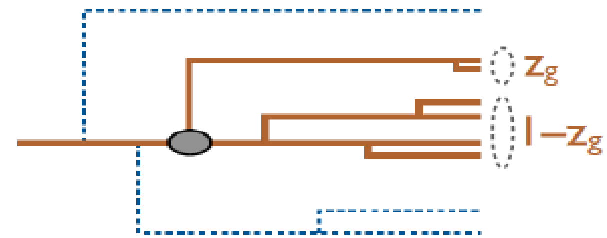
Transverse Momentum balance of the two hard subjets
Observable connected to the hardest splitting (splitting function)

C/A recombination

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

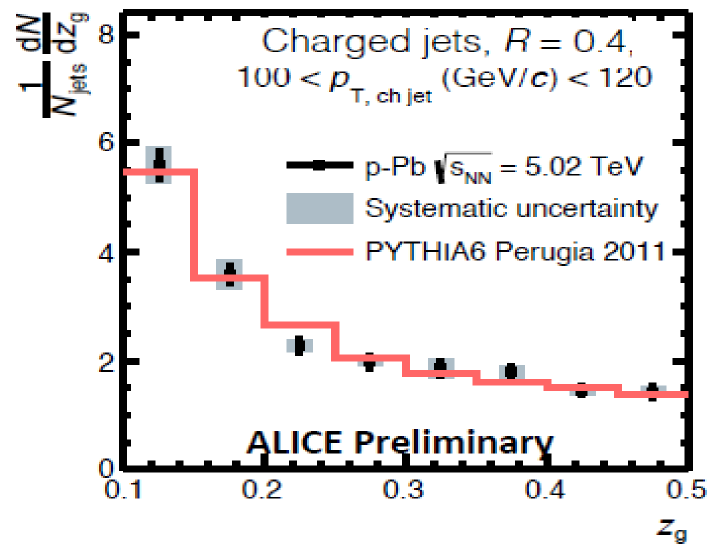
$$z_g = \frac{\min(p_{T,1}, p_{T,2})}{p_{T,1} + p_{T,2}},$$

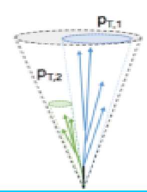
JHEP 05 (2014) 146



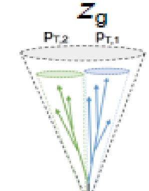
First measurement of z_g in p-Pb collisions
Search for cold nuclear matter effects in hard splitting using SoftDrop method (FastJet)

Agreement between **data** and **PYTHIA Perugia 11**
Reference for future Pb-Pb measurement in ALICE



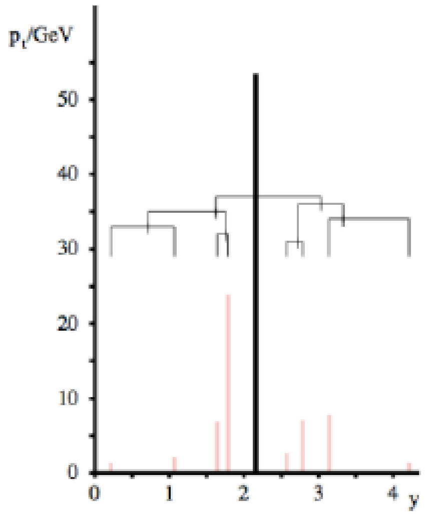


$$z_g = \frac{\min(p_{T,1}, p_{T,2})}{p_{T,1} + p_{T,2}}$$



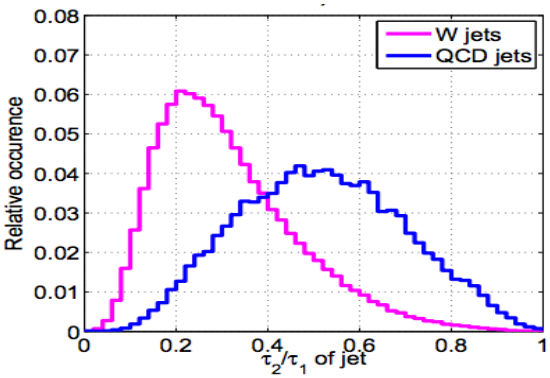
N-Subjettiness

Plots by G. Salam



Undo last step

J.Thaler et al,JHEP 1103:015,2011



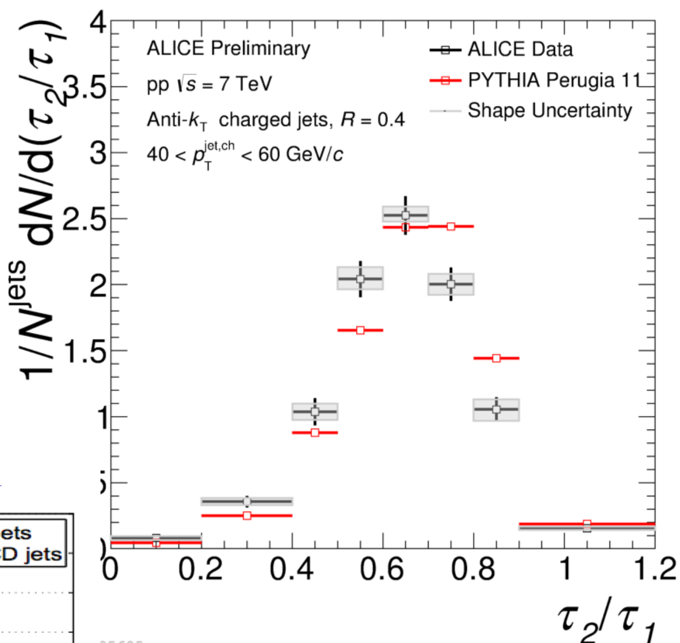
Test for *coherence effects* *via subjet structure*

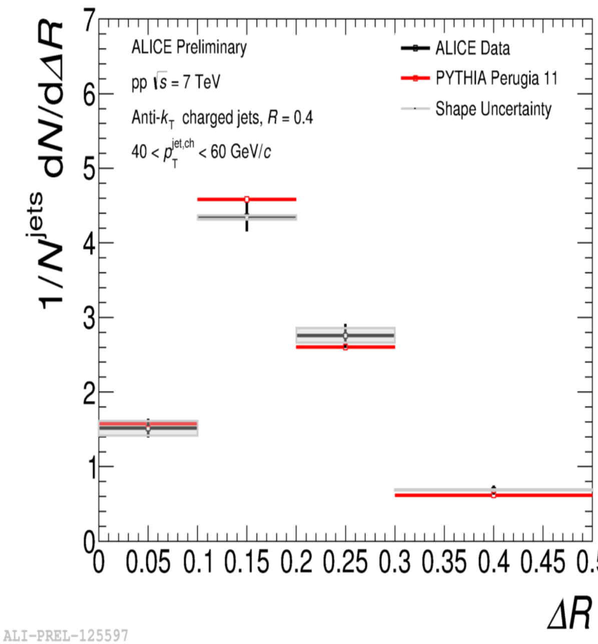
Recluster Jet constituents with k_T algorithm with 2 subjets:

- The two axes are the axes of the two subjets combined in the last reclustering step
- Measure jet shapes relative to these axes:

- *ΔR*: *η-φ* distance between axes.

- *τ2/τ1:* observable that measues how well the jet constituents are aligned w.r.t. the two axes (two prongness of the jet. i.e. *τ2/τ1* → 0 Jet is 2 pronged





ΔR well described by PYTHIA.
Small shift of τ2/τ1 comparing pp and PYTHIA

Summary

A large number of new jet measurements from ALICE are available in pp and p-Pb.

They constrain fixed-order calculations in the regime of low jet $p_{T.}$

In p-Pb measurements are compatible with the absence of hint from cold nuclear matter effect(s).

Outlook:

New data at $\sqrt{s}$ = 5.02 TeV will allow more precise and more differential measurements.
New measurements and more differential studies (R, p_T jet) are ongoing with focus on jet substructre

Heavy flavor jets are a new classes of exciting observables under study.

With the addition of the new ALICE DCAL calorimeter (and trigger) for RUN 2, jet correlations measurements will become accessible

Backup