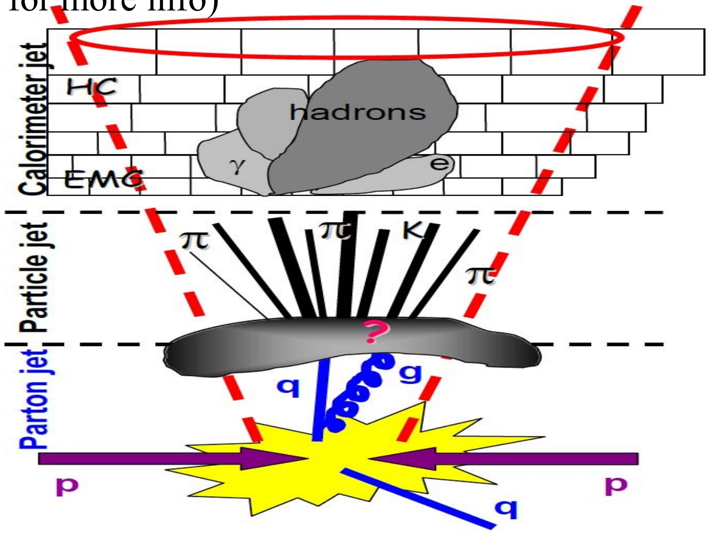
Inclusive and heavy flavor jet production in pp and p-Pb collisions and search for jet quenching effects with the ALICE experiment at the LHC

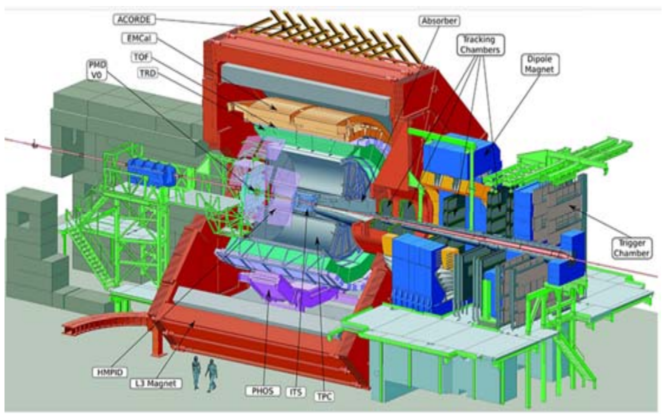
Alexandre SHABETAI (for the ALICE Collaboration)

CNRS/IN2P3 - SUBATECH (Nantes - FRANCE)

Motivations

Jet Constituents : Charged tracks (from our TPC and ITS) clustered into charged particle jets or calorimeter clusters from the EMCAL/DCAL to measure full jets (see backup for more info)





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,…

We use jets as well calibrated hard probes to
- Use robust, well defined & experimentally accessible observables
- Test and/or constrain theory - allowing access to first principles - or models

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

● We will discuss:

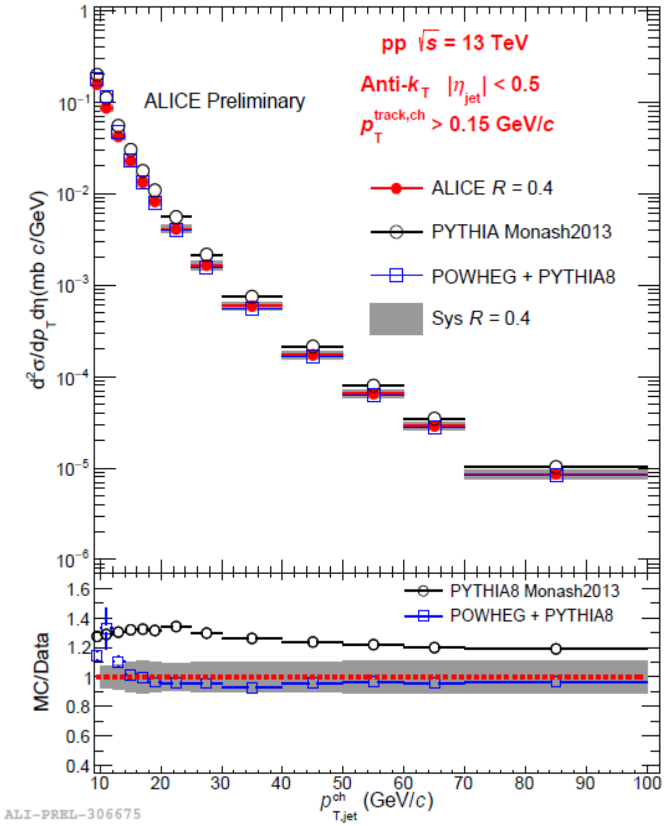
-Global observables: e.g. jet production as well as more differential ones: jet structure
Measurements (made using standard or ML mehods) will include: jet production, jet fragmentation, groomed and un-grommed (sub)jet substrucutre, h+jet …

Recent results: jet cross section in pp and Pb-Pb collisions

Phys Rev C.101.034911

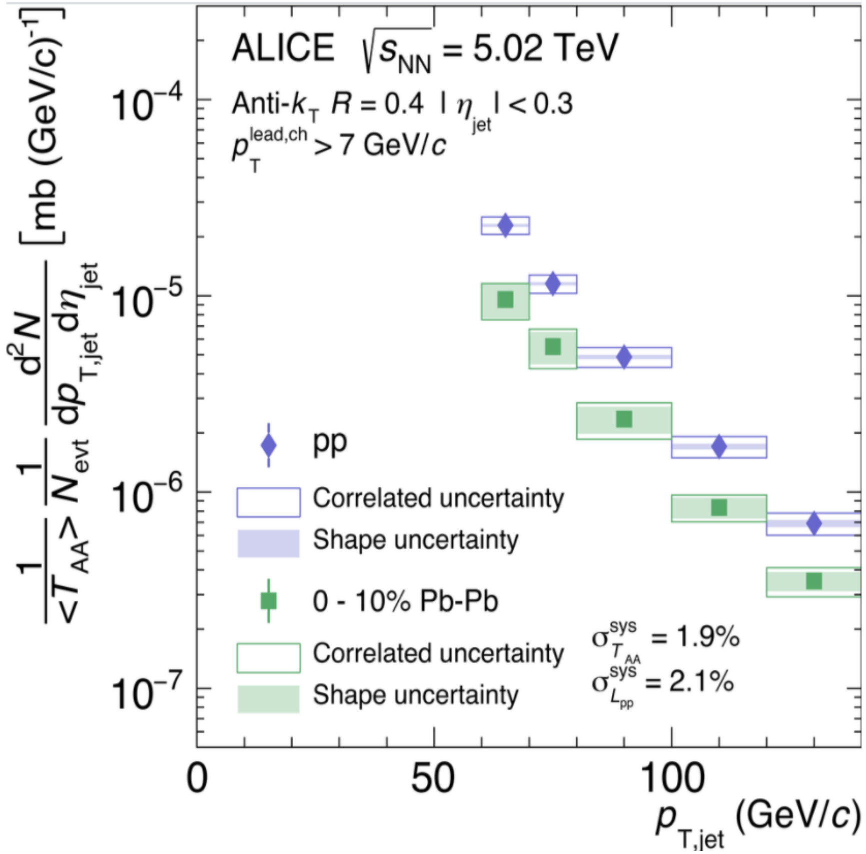
Charged jets, pp $\sqrt{s}$ = 5.02 TeV & $\sqrt{s}$ = 13 TeV

R=0.4 Min-Bias



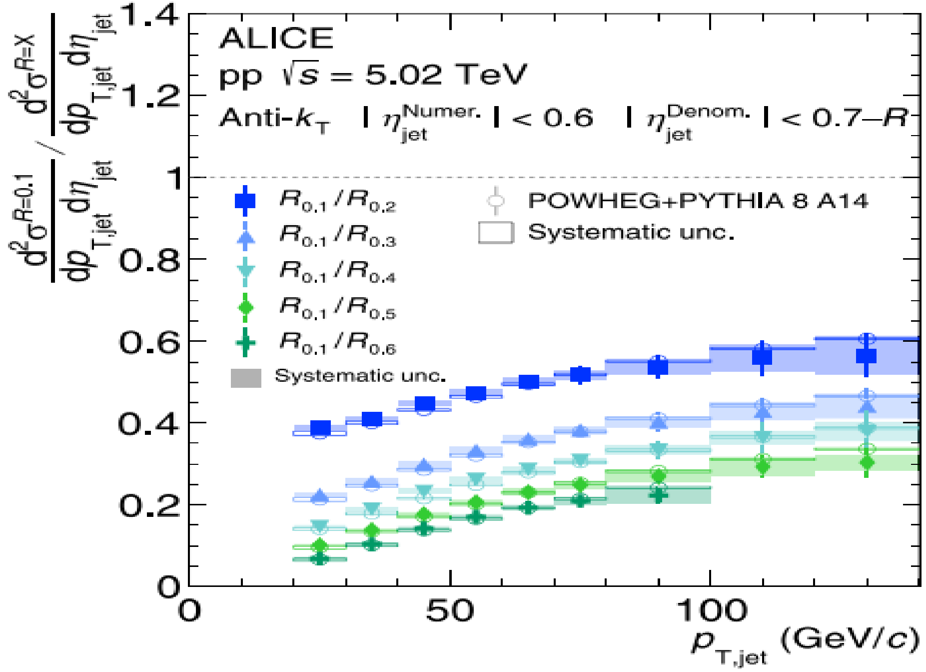
Full jets, pp & Pb-Pb $\sqrt{s_{NN}}$ = 5.02

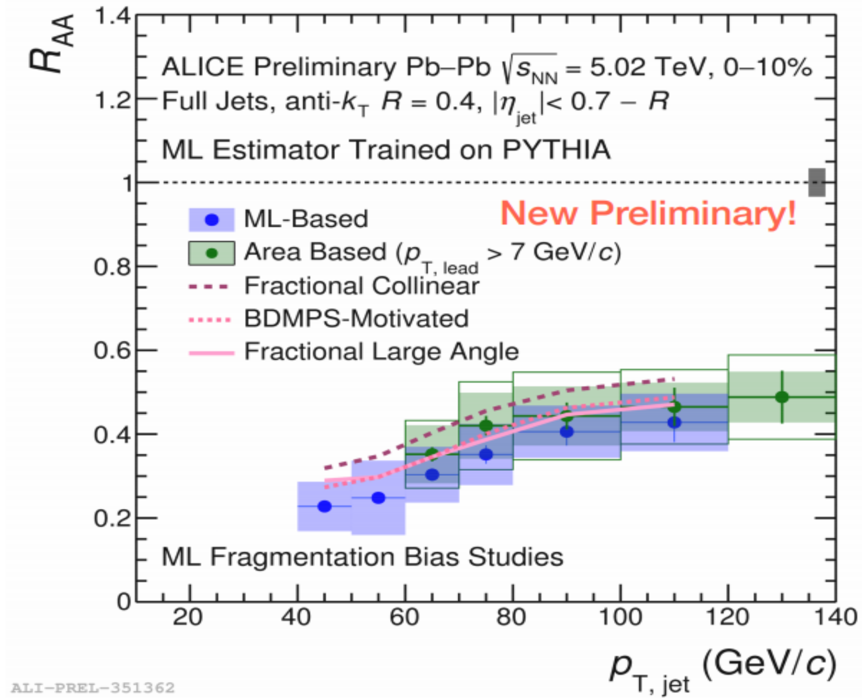
R=0.4 EMCal



Recent results: jet cross section ratios in pp and Pb-Pb collisions & Raa

Phys Rev C.101.034911





* Full jets in pp: Cross section ratios (for R=0.1 to R=0.6):

- increase with jet p_T ➔ collimation
- In good agreement with POWHEG + PYTHIA 8

* Full jets R_{AA} : area based vs ML (lower pt reach at the price of biasing fragmentation)

- Fair agreement with Fast MC (fractional energy loss)

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

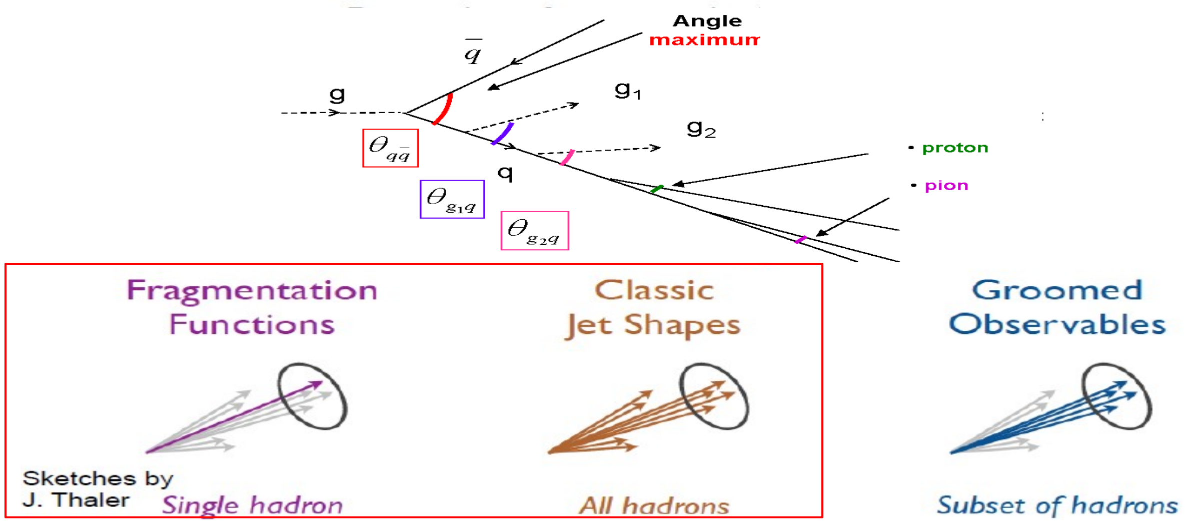
Jet shapes can be divided in 2 categories:

a) Those which use a function of the constituents
b) Those which use 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.

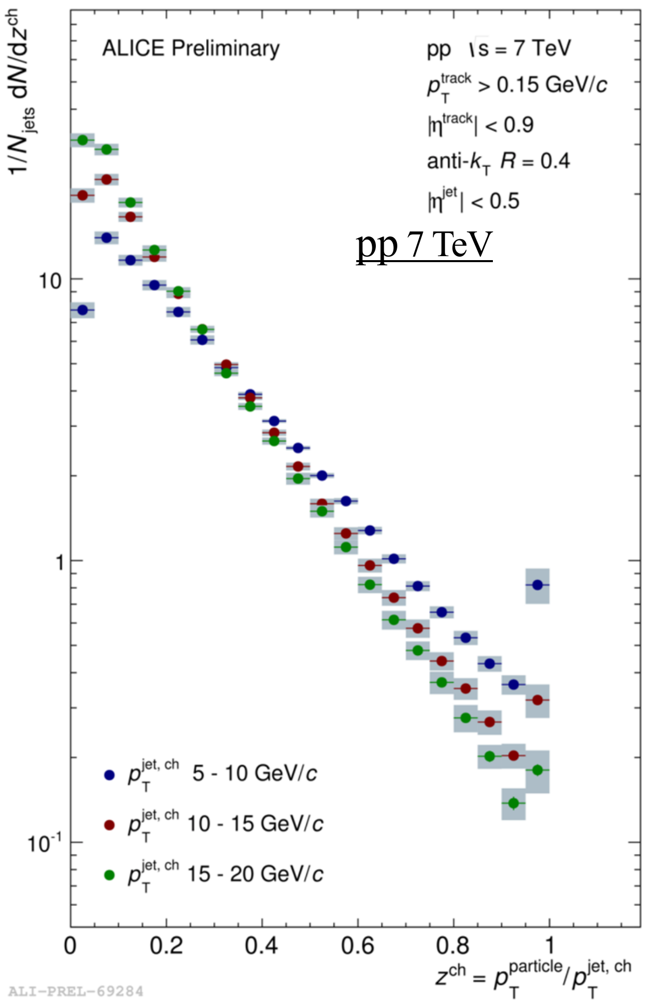
Jet shapes

Parton shower evol

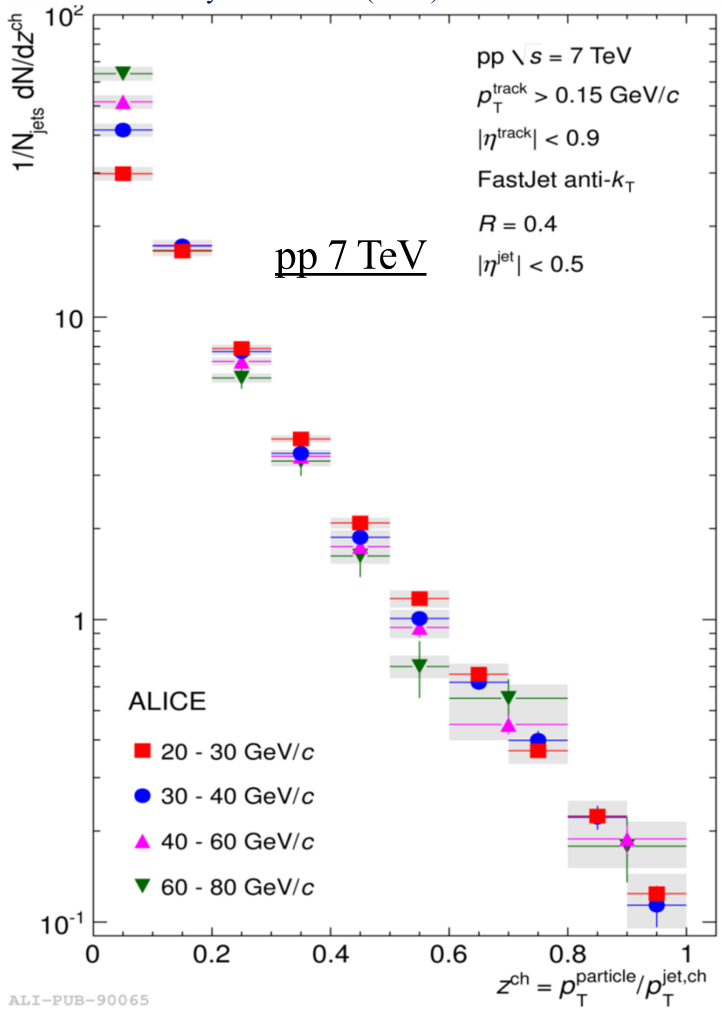


Longitudinal jet fragmentation $1/N_{jet}\, dN/dz$

Phys. Rev. D 99, 012016



Phys. Rev. D 91 (2015) 112012

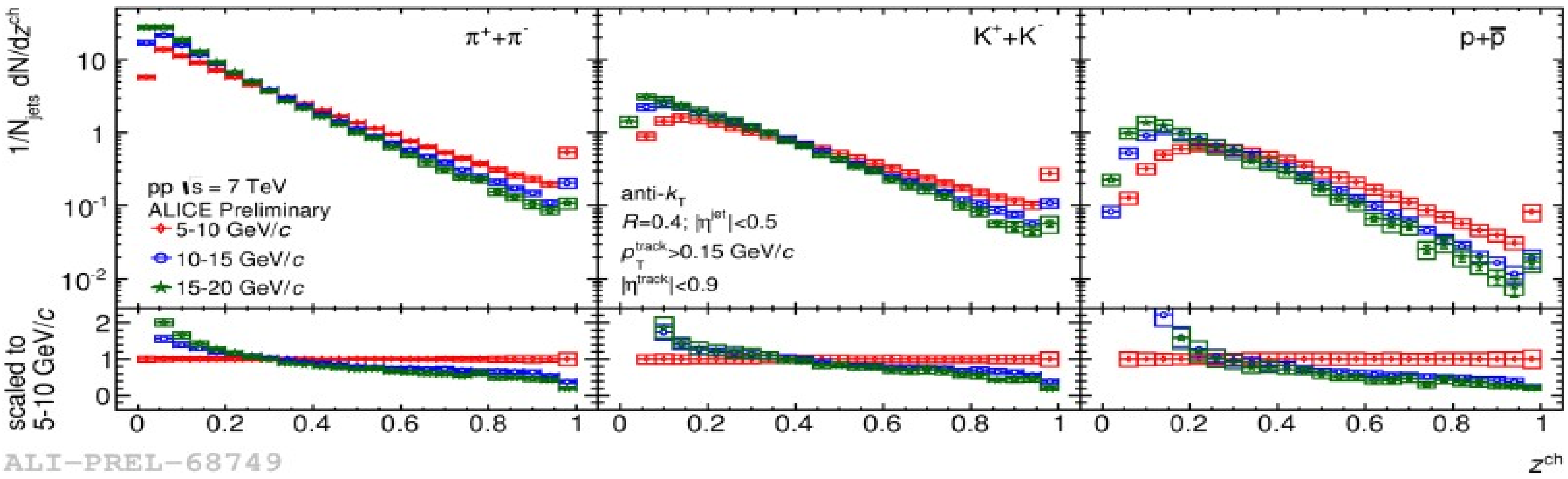


For $z_{ch} > 0.1$ for highest p_T bins, the distributions are consistent within **uncertainties**, indicating a **scaling** of charged jet **fragmentation** with charged jet $\boldsymbol{p_T}$.

$z = \boldsymbol{p_T}\,\text{track}/\,\boldsymbol{p_T}\text{jet}$

Identified Longitudinal jet fragmentation $1/N_{jet}\ dN/dz$

pp 7 TeV

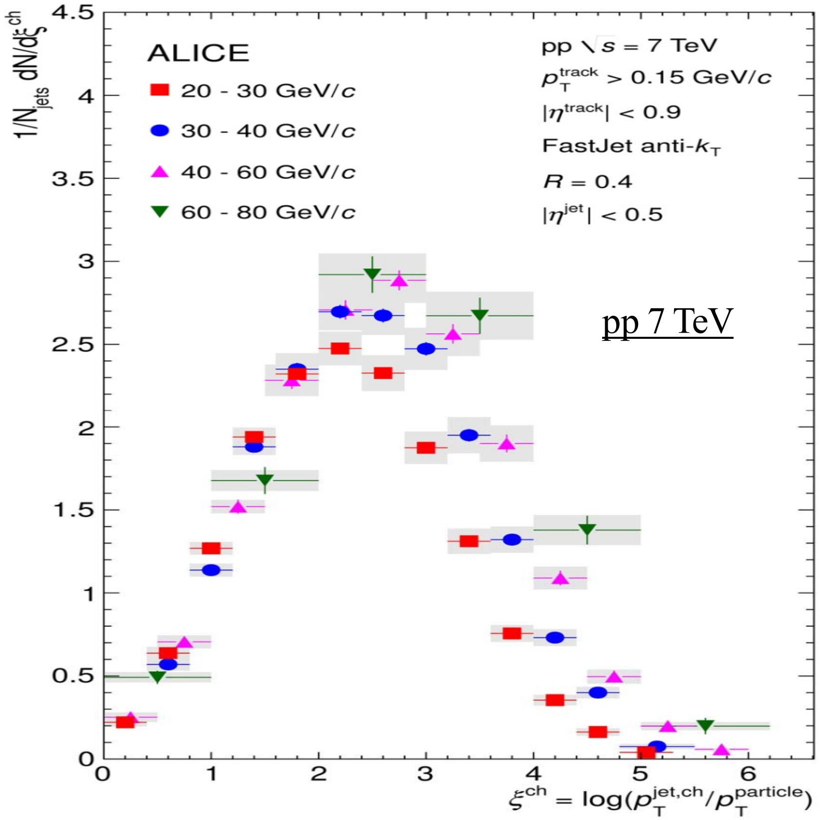


Particle Identified fragmentation (PID in jets computed on a statistical basis using fits by dE/dx templates

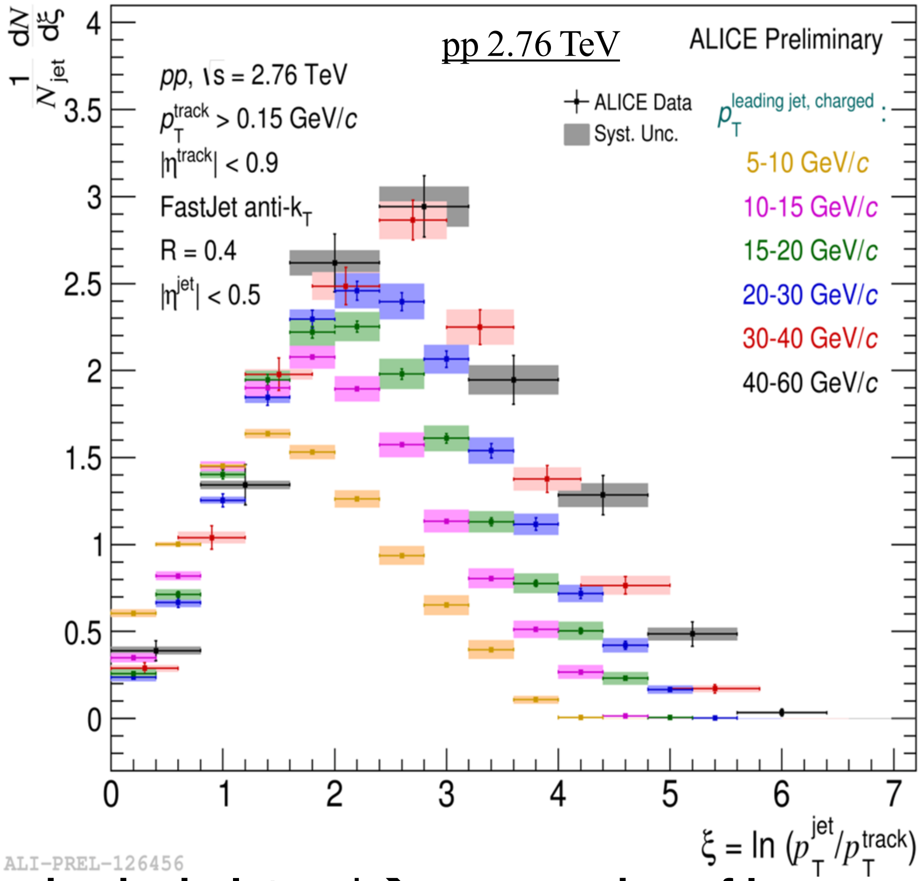
For z_{ch} > 0.2 for highest p_T bins, **scaling** of charged jet **fragmentation** with charged jet $\boldsymbol{p_T}$.

Longitudinal jet fragmentation $1/N_{jet}\, dN/d\xi$

Phys. Rev. D 91 (2015) 112012



M.Wang PhD



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**

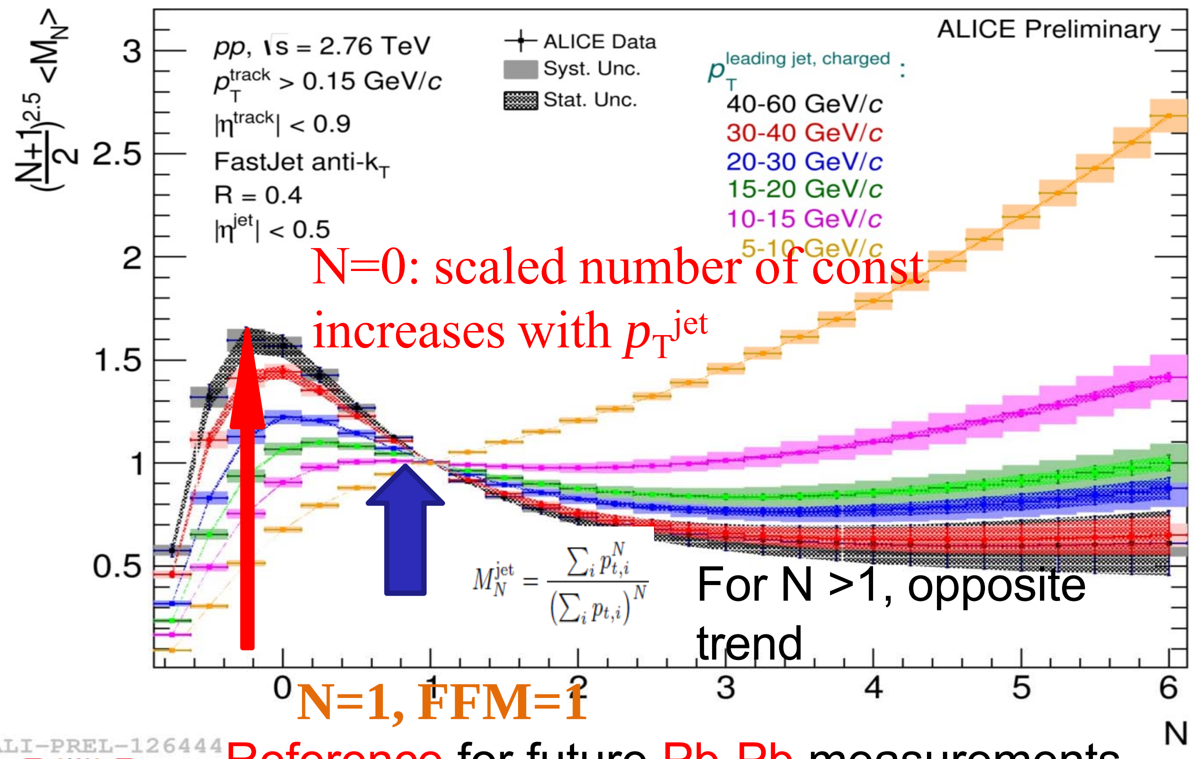
Fragmentation function moments

Cacciari et al Eur.Phys.J. C73 (2013) 2319

First measurement of the jet fragmentation fu moments

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

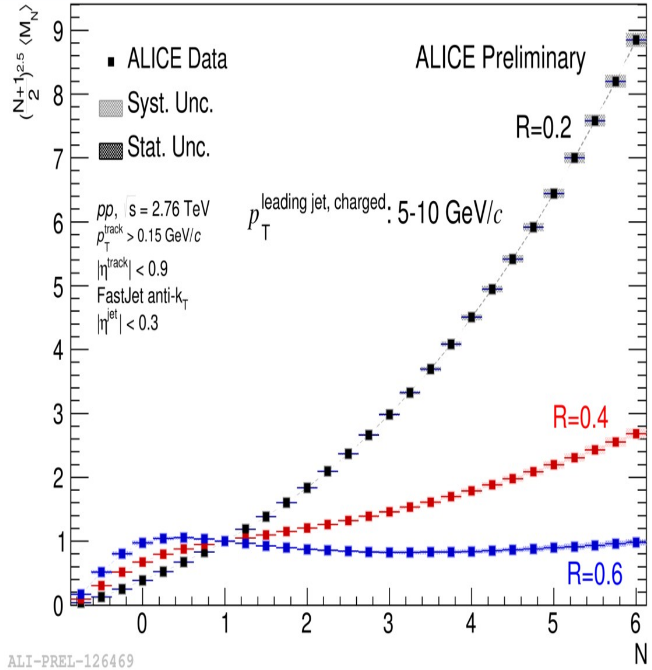
$$M_N = \frac{1}{N_{\text{jet}}} \int_0^1 z^N \frac{dN_{\text{hadron}}}{dz} dz\,, \qquad z = \frac{p_T^{\text{hadron}}}{p_T^{\text{jet}}}$$



N=0: scaled number of const increases with p_T^{jet}

For N >1, opposite trend

N=1, FFM=1



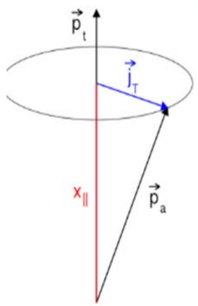
Good agreement between data and PYTHIA Perugia 11

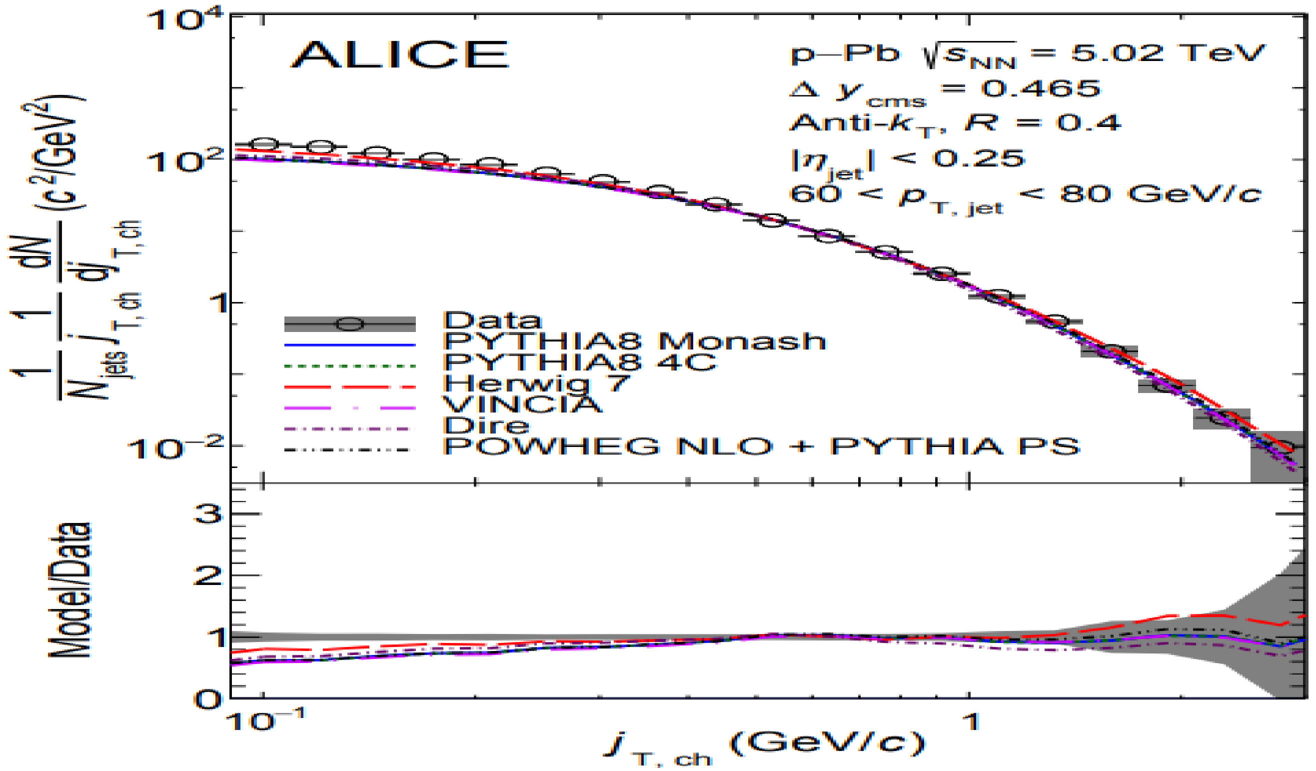
Strong dependence of the FFM distribution vs R

Reference for future Pb-Pb measurements

Transverse Fragmentation (j_T)

arxiv::2011.05904

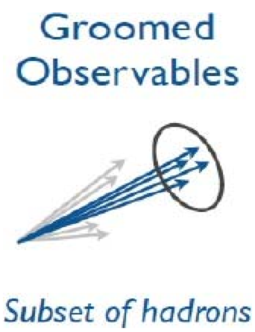




j_T distribution in p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV for jets with $60 < p_T < 80$ GeV/c compared to various generators

The data agrees well with MC generators for j_T > 0.5 GeV/c (especialy with HERWIG (underestimating the data by 20% at low)

Groomed Subjets: z_g



Grooming allows to isolate perturbative processes in the shower evolution

Procedure:

1) reconstruct anti-kt jets
2) recluster the contituents with C/A algo
3) unwind clustering history
4) search for hard split which fulfills soft drop (SD) condition

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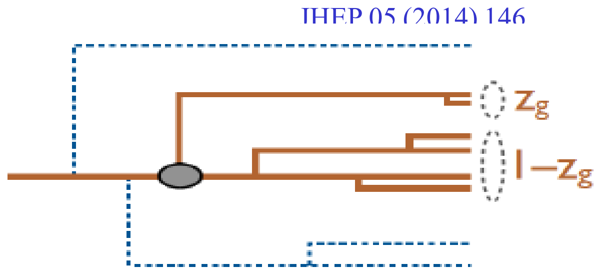


z_g Transverse Momentum balance of the two hard subjet

Observable connected to the hardest splitting (splitting function)

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

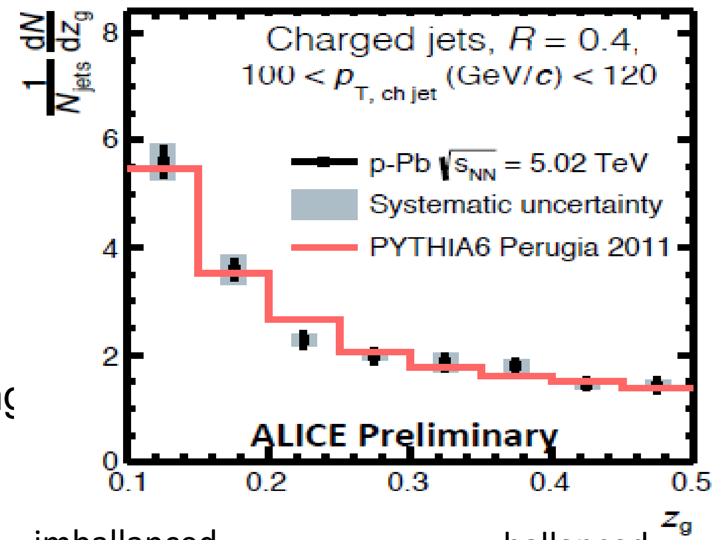
SD condition

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

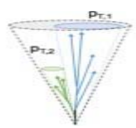
Zg: first split that fulfills SD

measurement of z_g in pPb

Search for cold nuclear matter effects in hard splitting using SoftDrop method (FastJet)



imballanced



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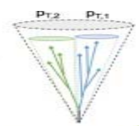
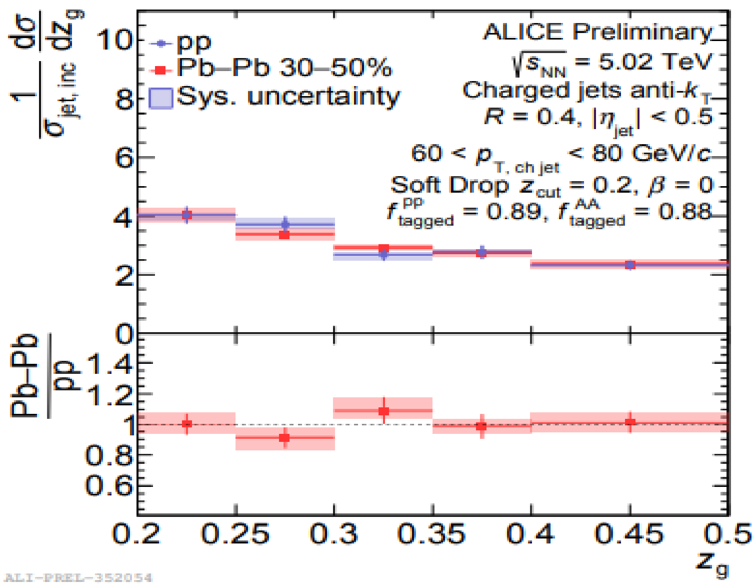
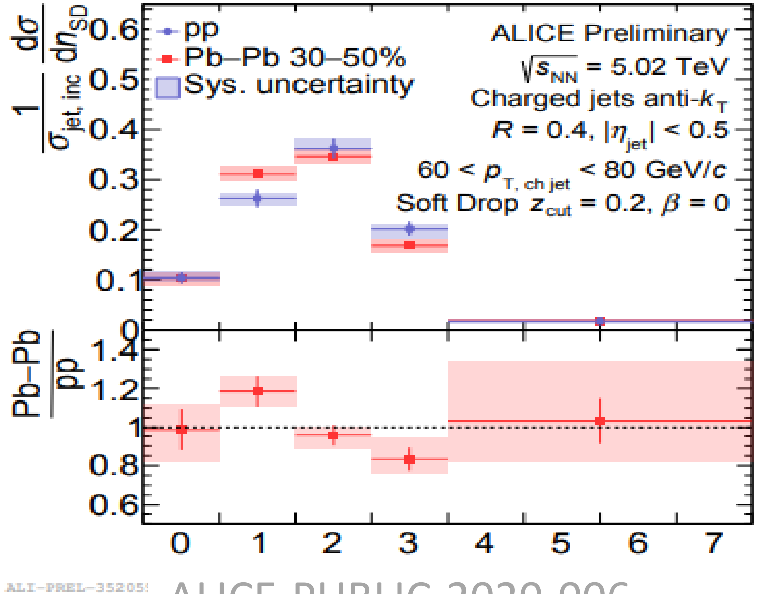


Agreement between **data** and **PYTHIA Perugia 11**

pp & Pb-Pb measurement also available (see next slide)

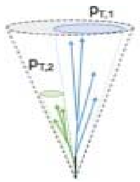
Zg & n_{SD} pp & semi central Pb-Pb @ 5 TeV)





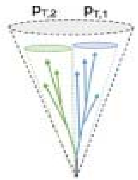
ALICE-PUBLIC-2020-006

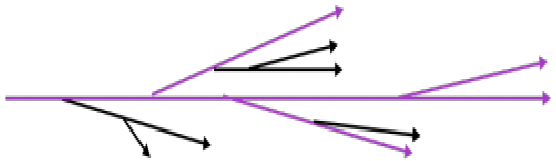
Imballanced



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

balanced



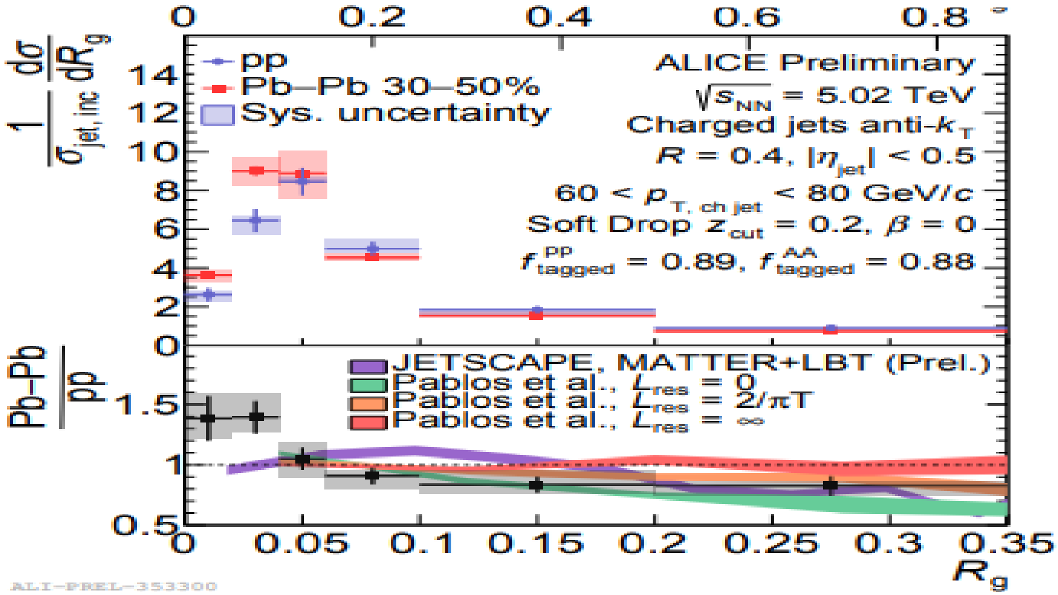


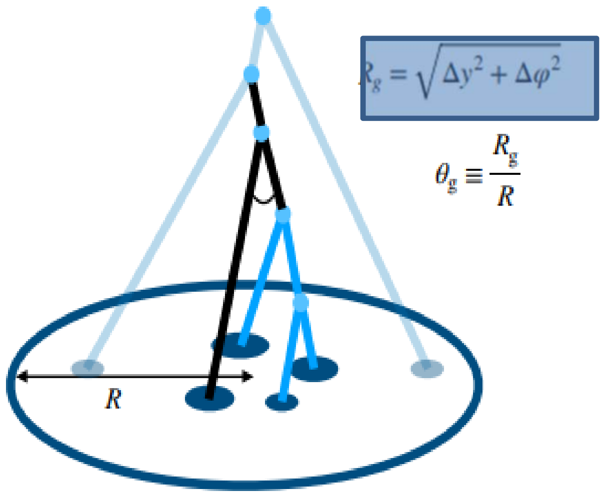
For 60 < $p_{T,ch,jet}$< 80 GeV/c, z_g measured in Pb–Pb collisions compared to pp collisions for z_{cut} = 0.2.

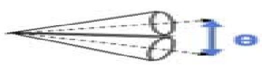
z_g and n_{SD} are consistent with no modification within exp uncertianties

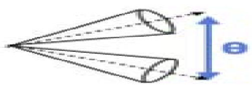
Rg (pp & semi-central Pb-Pb @ 5 TeV)

ALICE-PUBLIC-2020-006





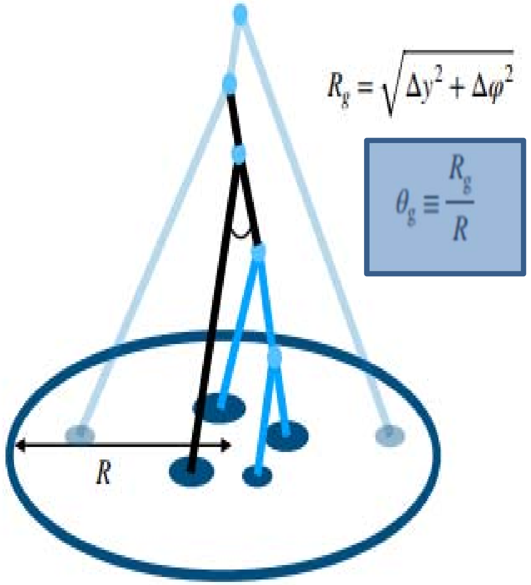


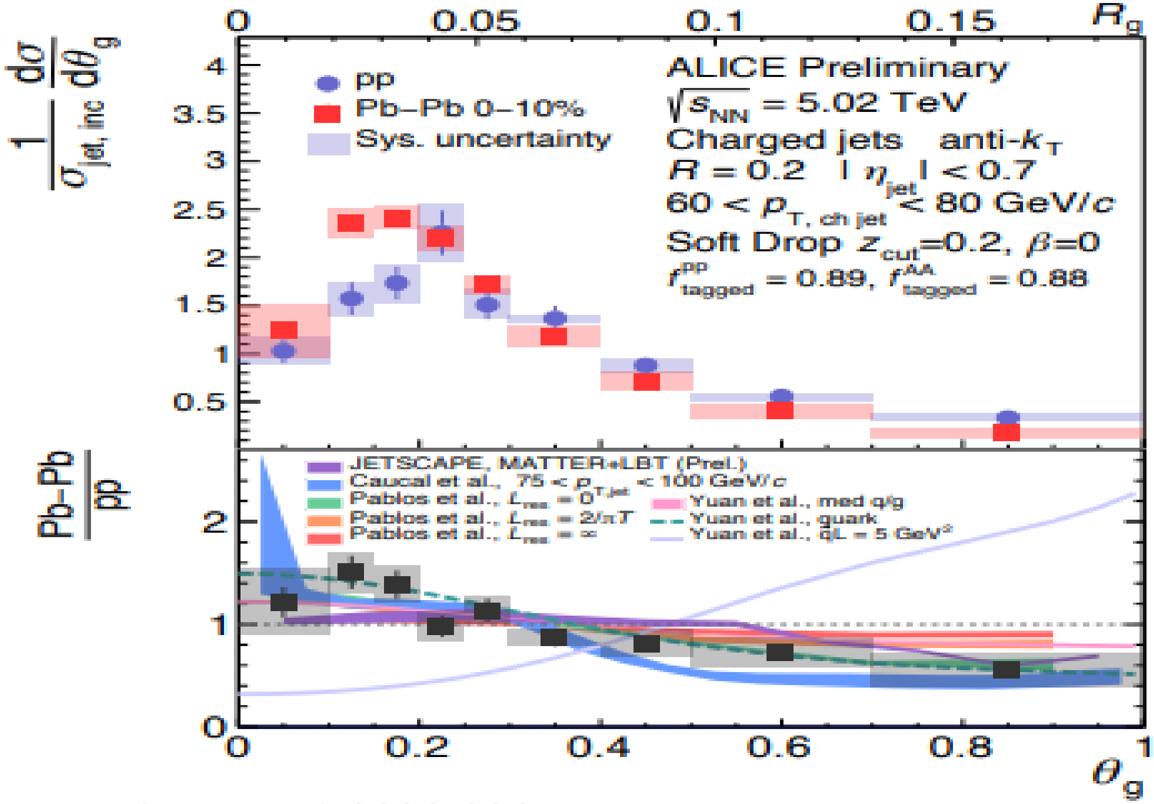


R_g separates wider and narrower angle splittings which have different formation times with wide splittings forming earlier and narrow splittings forming later. The earlier emissions could see more of the medium and experience more modification.

➔ Suppression of large angles and enhancement of small angles for both z_{cut} (0.2 and 0.4)

Θg Central pbpb





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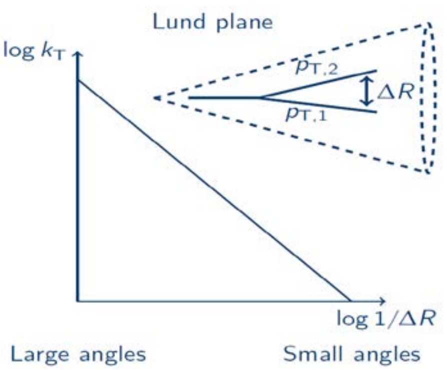
The cores of jets are narrower in Pb-Pb collisions and wider in pp collisions
Sensitive to the QGP resolution length

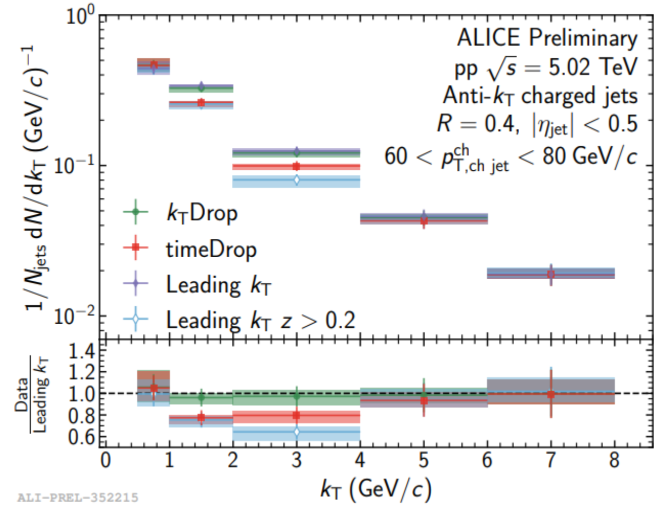
Lund plane / kT

PhysRevD 101 034004

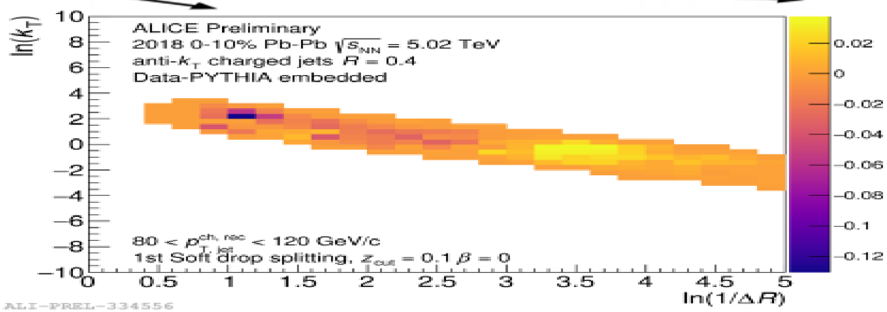


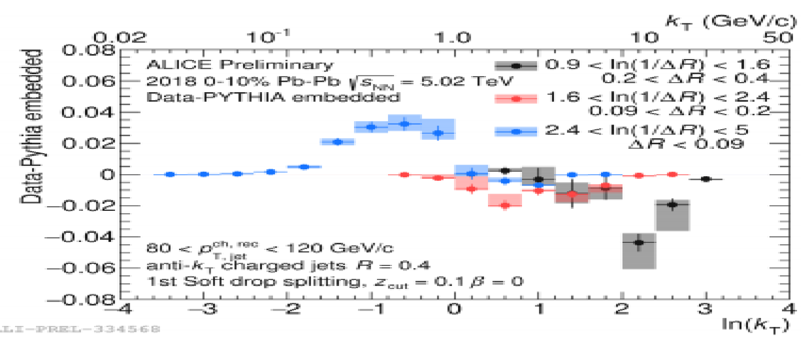
Large R jets can constrain the medium properties.
The search for large transverse momentum kicks which may indicate the presence of point-like scatters within the QGP.
Measured hardest kT splittings in pp collisions at √s = 5.02 TeV

. • Grooming methods converge at high k_T.
- PYTHIA broadly consistent with data.



$$\Delta R = \sqrt{(\eta_1 - \eta_2)^2 + (\phi_1 - \phi_2)^2} \qquad k_T = p_T^{\text{sublead}} * \sin \Delta R$$





Lund-Maps for data and embedded PYTHIA filled with first splitting
Difference between Lund-Maps ==> removes background contributions
differences ➔ quenching effetcs
Supression of wide splittings and enhancement of narrow splittings

Projection in bins of splitting angle
Non-perturbative (narrow splittings) are enhanced
More perturbative (wide splittings) supressed
Large angle splittings are formed at earlier times – interact with more of the medium - Coherence effects?

A suppression is seen at large ΔR (or small ln 1/ΔR) with a corresponding enhancement at small ΔR

First measurement of the dead cone efect in pp@13 TeV (iterative declustering)

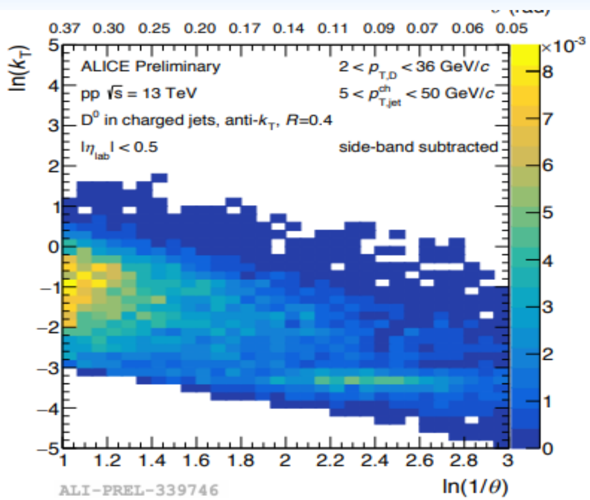
The dead-cone is a universal property of all radiative theories

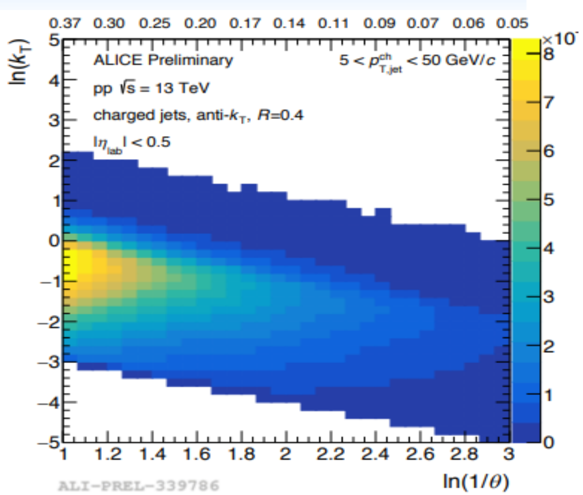
It predicts a suppression of emissions from a radiator (quark) within $\theta < \frac{Mq}{Eq}$

In QCD this leads to a change in the expectec fragmentation of heavy and light quarks:

- Gluons radiated with a small k_T are restricted
- Fragmentation functions of heavy quark peak at larger values

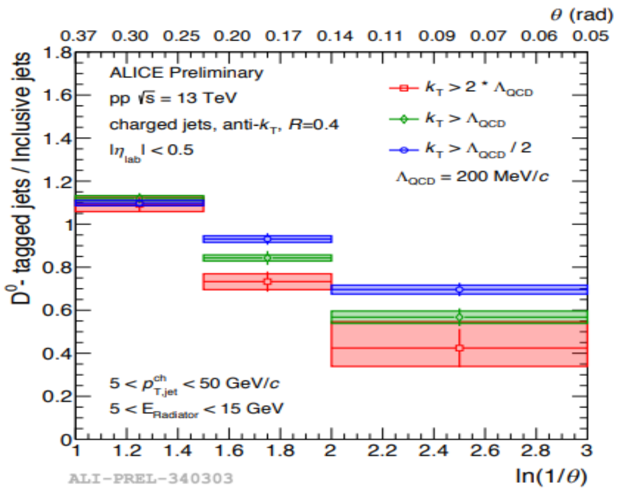
Never been directly measured at colliders





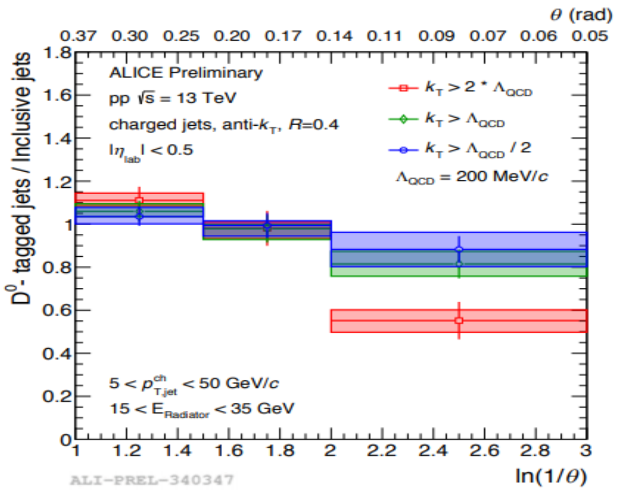
➢ The Lund-Maps for the D^0 and inclusive jets show a hint of suppression of splittings at small angles in the former compared to the latter

$5 < E_{Radiator} < 15$ GeV



Smaller angles

$15 < E_{Radiator} < 35$ GeV



Ratio of angular projections of D^0 and inclusive jet splittings are made

Suppression of splittings at small angles in heavy flavour jets due to the dead-cone effect

The magnitude of suppression increases at smaller angles

Summary

A large number of new jet measurements from ALICE are available in pp and p-Pb and Pb-Pb
They constrain fixed-order calculations in the regime of low jet $p_{T.}$

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

New data (RUN2) at $\sqrt{s}$ = 5.02 TeV allow more precise and more differential measurements. New measurements and more differential studies were shown with focus on jet substructre

Heavy flavor jets are a new classes of exciting observables under study
The first observation of the dead cone effect in pp collision was discussed;

Outlook:

With the addition of the new ALICE DCAL calorimeter (and trigger) jet correlations measurements may become accessible.

In the near future (starting for RUN3) the continous readout will allow making measurements with Higher statistics (reducing stat/syst uncertenties and improving the jet p_T reach).

Backup