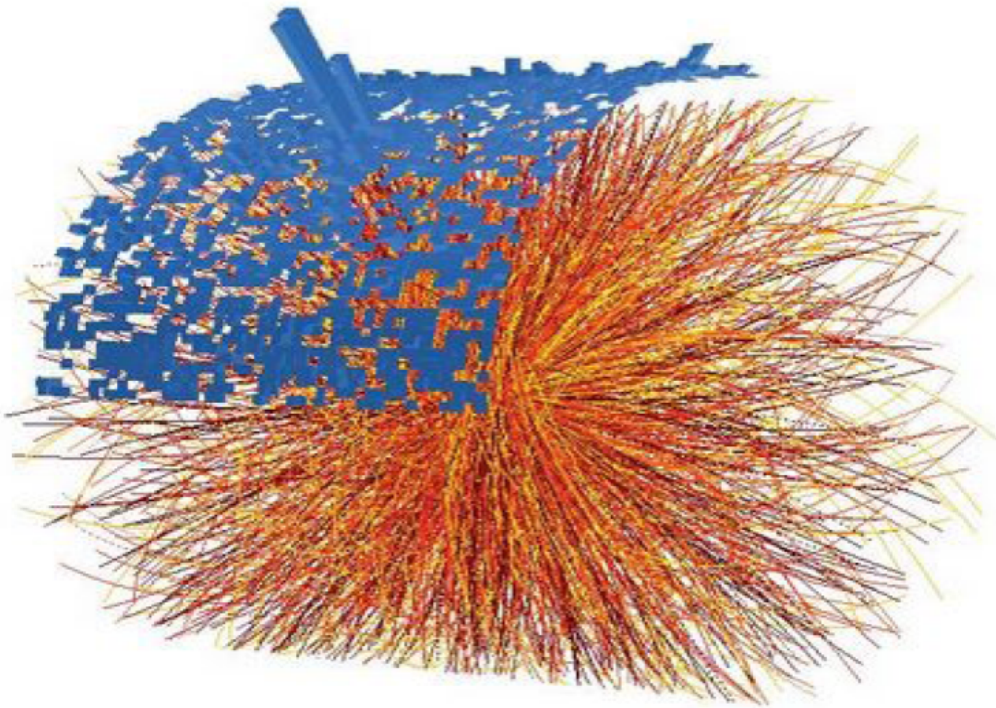
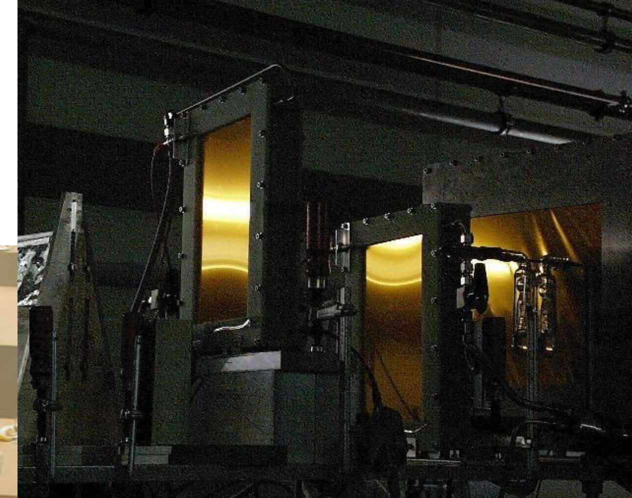


Jet Physics at ALICE

Oliver Busch

University of Tsukuba
Heidelberg University


Outline

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- Introduction
- Results from pp collisions
- Identified jet fragmentation in pp
- Jets in heavy-ion collisions
- Jet shapes in Pb-Pb collisions

Introduction

Jets: seeing quarks and gluons

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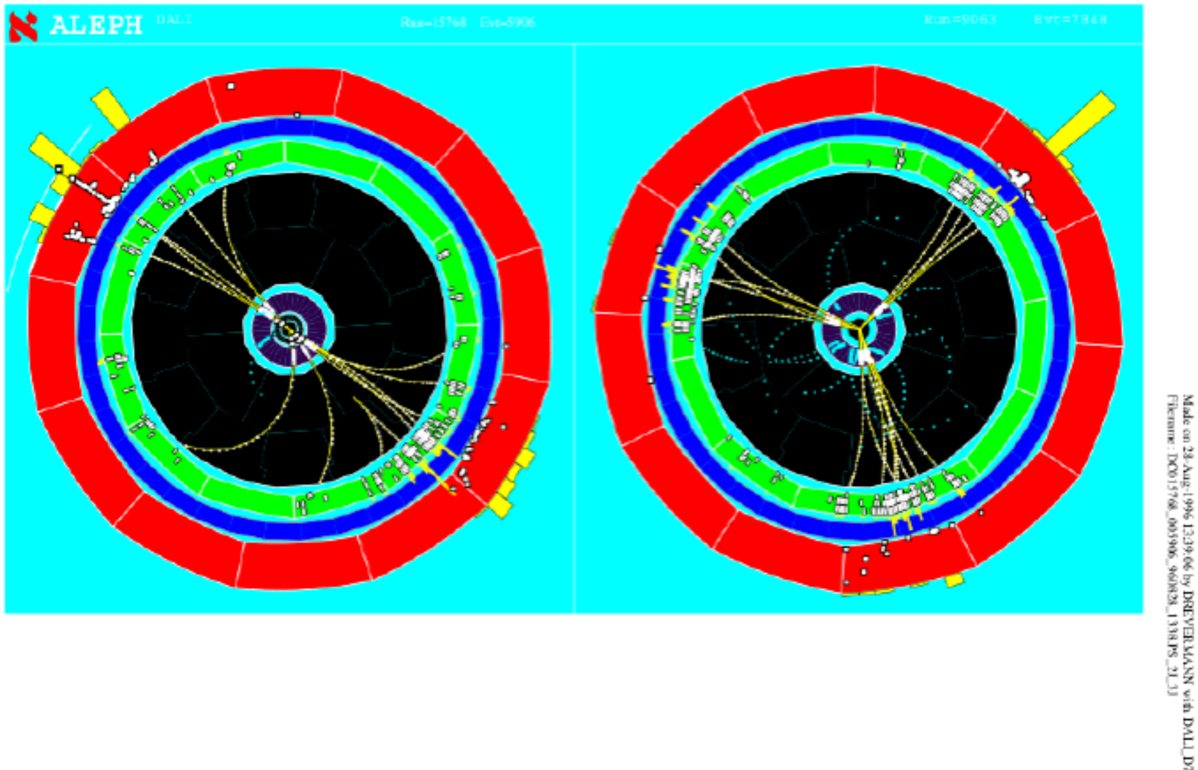
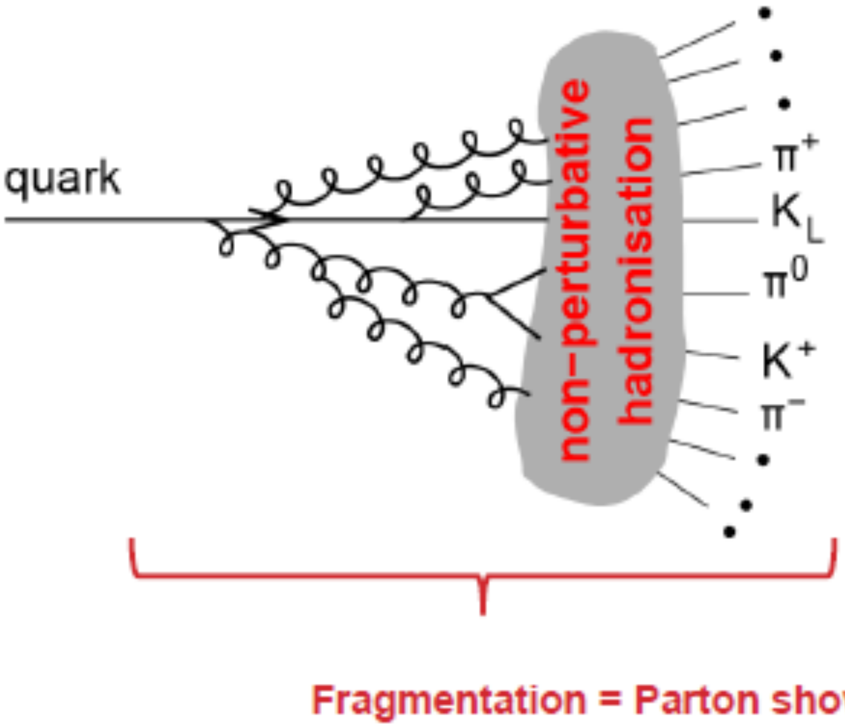


- jet: collimated bunch of hadrons
- quasi-free parton scattering at high Q^2:
  the best available experimental equivalent to quarks and gluons

Jet fragmentation

- initial hard scattering: high-p_T partons
- cascade of gluons: parton shower
- at soft scale ($o(\Lambda_{QCD})$): hadronization

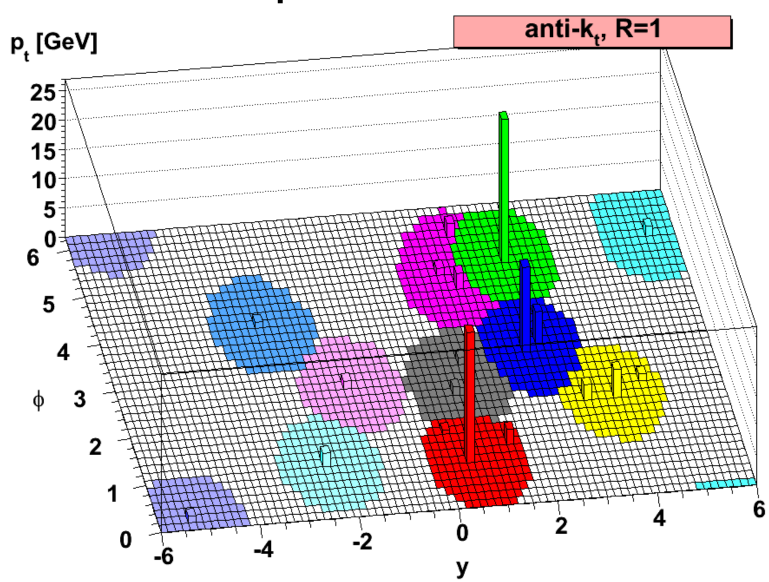


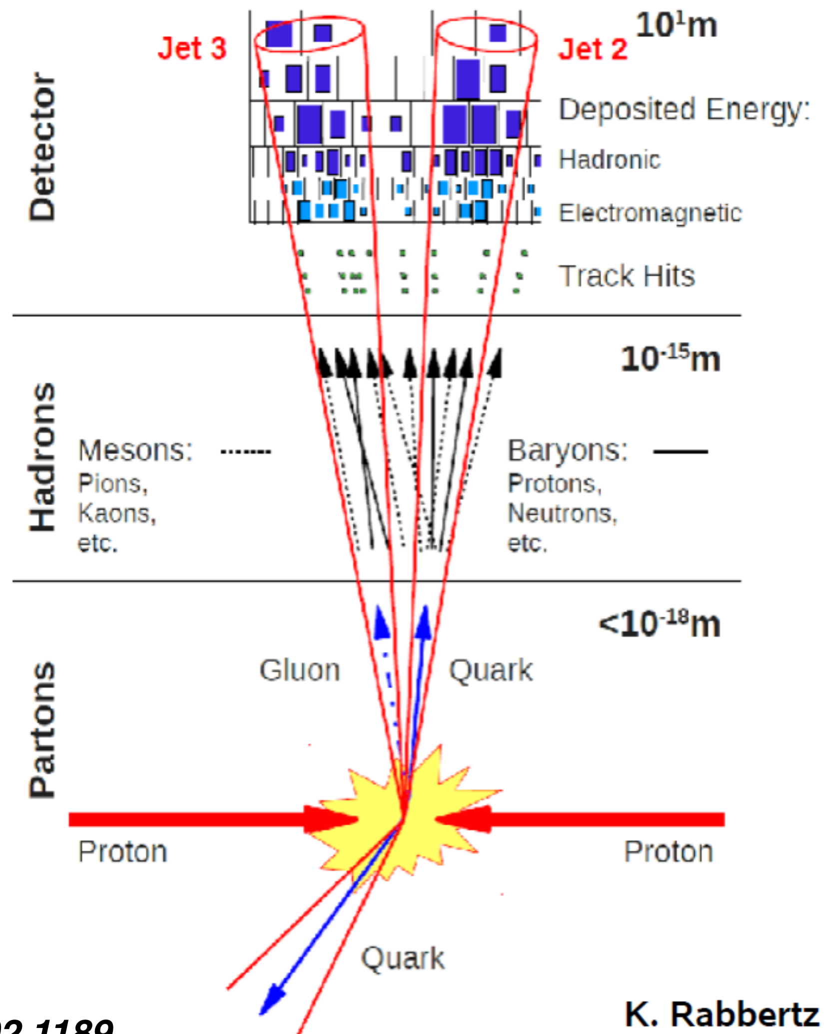
Jet reconstruction

- Establish correspondence between detector measurements / final state particles / partons

- two types of jet finder:
  - iterative cone
  - sequential recombination (e.g. anti-k_T)

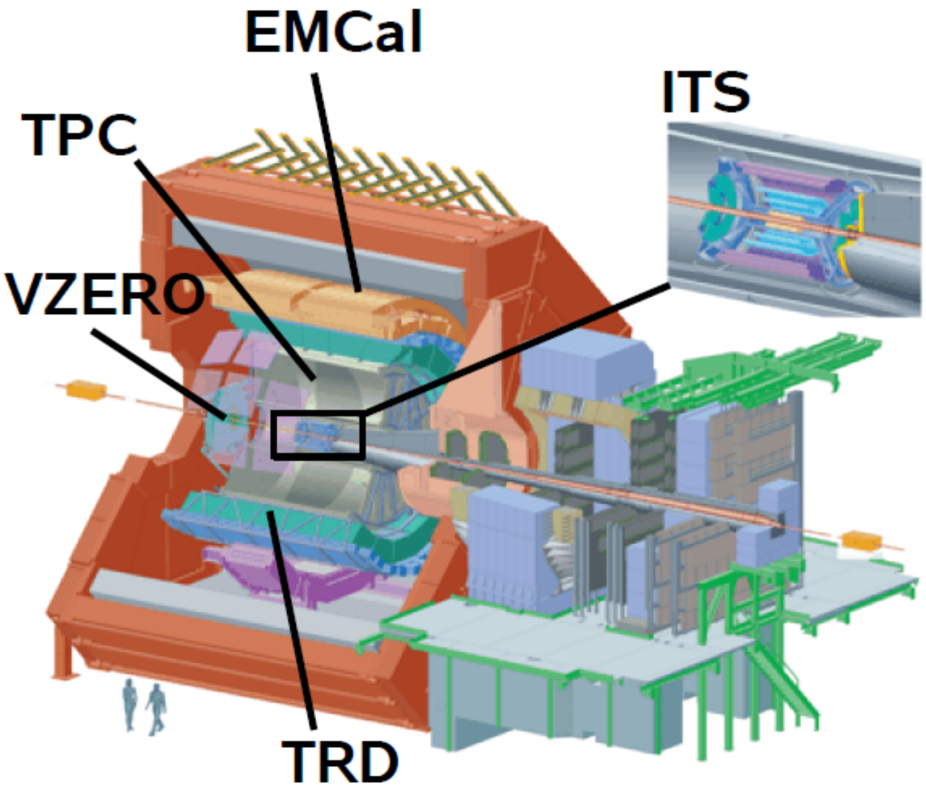
- resolution parameter R





hep-ph/0802.1189

Jets at ALICE (LHC run 1)



- charged particle tracking:
  - Inner Tracking System (ITS)
  - Time Projection Chamber
  - full azimuth, $|\eta| < 0.9$
    $p_T > 150$ MeV/c

- EMCal :
  - neutral particles
  - $\Delta\varphi = 107°$, $|\eta|<0.7$
    cluster $E_T > 300$ MeV

- jet trigger with EMCal and TRD
- ‘charged’ (tracking) jets and ‘full’ jets
- full jets from charged particle tracking and EM energy: conceptually different and complementary to traditional approach

Results from pp collisions

Full jets in pp at $\sqrt{s}$ = 2.76 TeV

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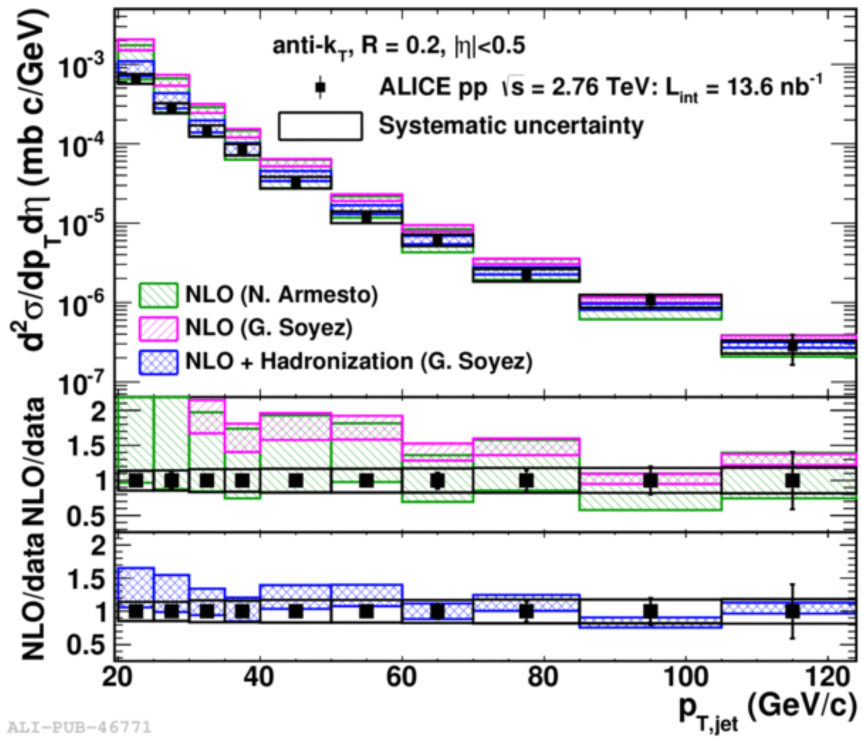
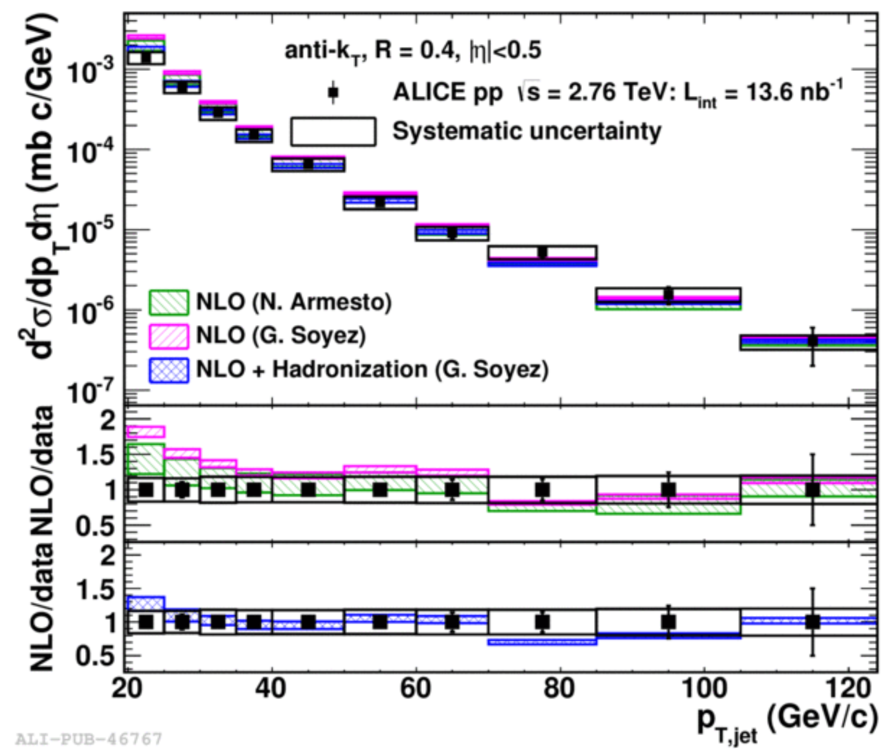
- good agreement with NLO calculations for R = 0.2 and R = 0.4
- reference for Pb-Pb at same energy

R = 0.2



R = 0.4



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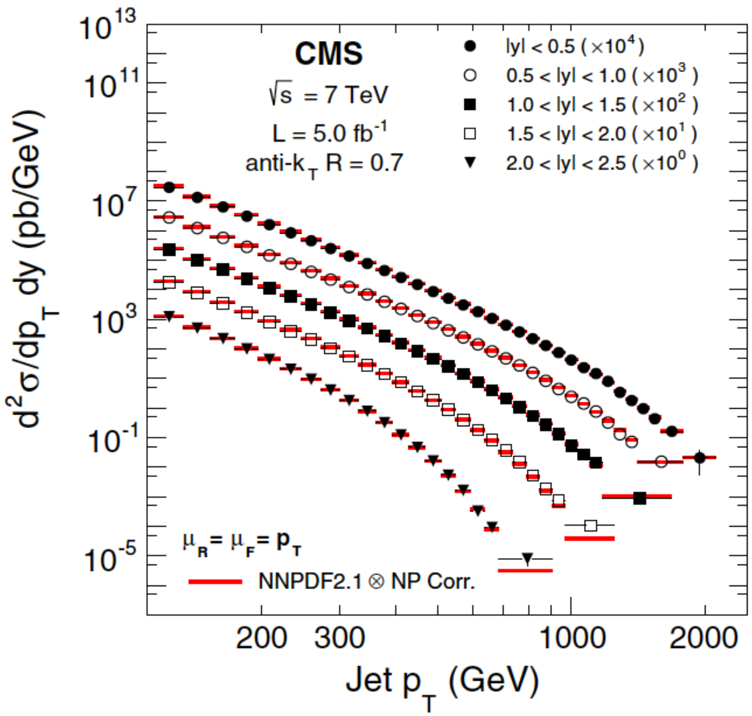
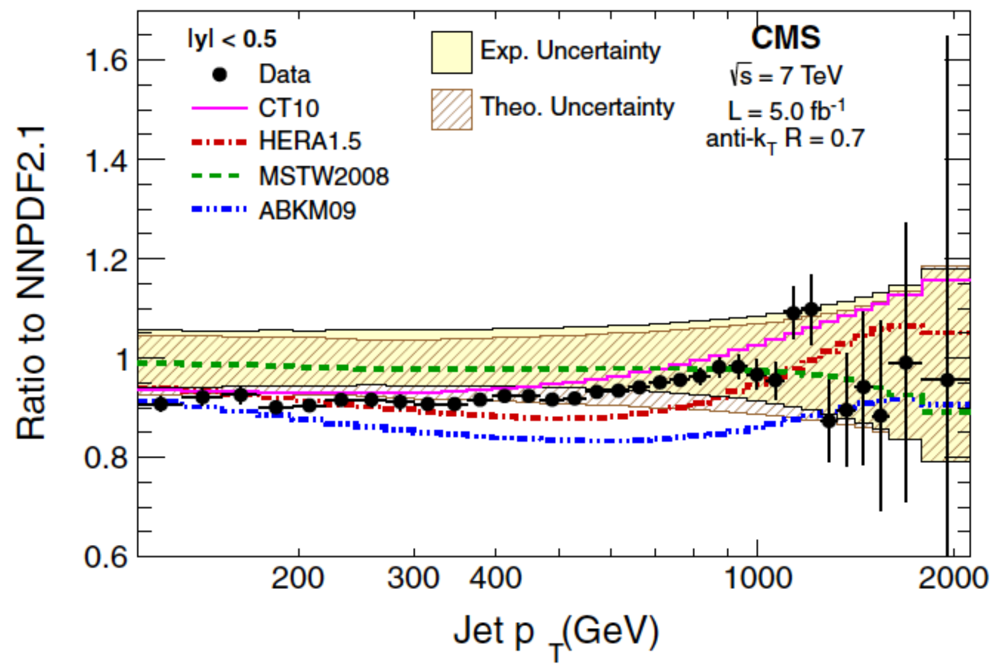
CMS jets at $\sqrt{s}$ = 7 TeV

- single inclusive jet cross sections compared to NLO: agreement over 14 orders of magnitude
- comparable theoretical and experimental uncertainties
- complementary jet p_T reach

PRD 87 (2012) 112002





pp jet fragmentation at $\sqrt{s}$ = 7 TeV

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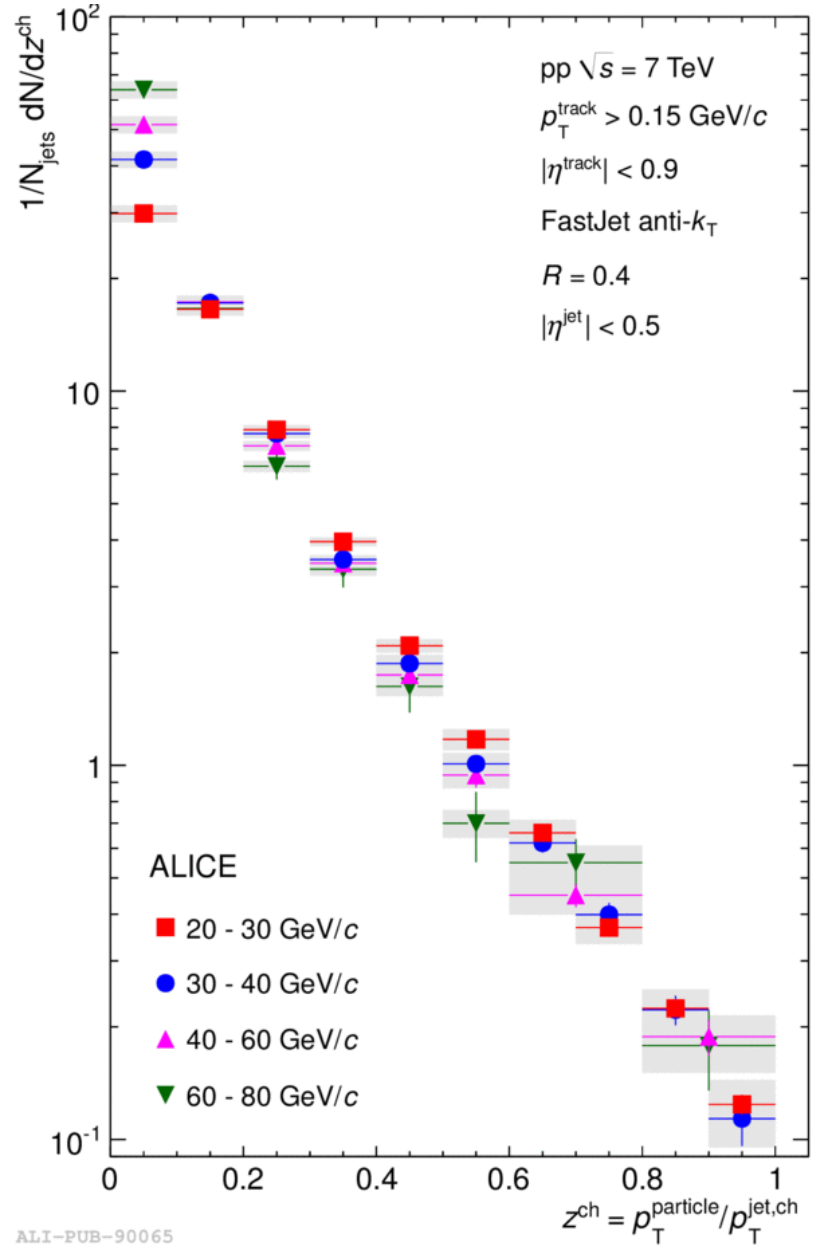
- $z^{ch} = p_{\mathrm{T}}^{\mathrm{particle}} / p_{\mathrm{T}}^{\mathrm{jet,ch}}$ distributions of charged particles in charged jets

- for z > 0.2 distributions consistent for all jet p_{T}: 'scaling'

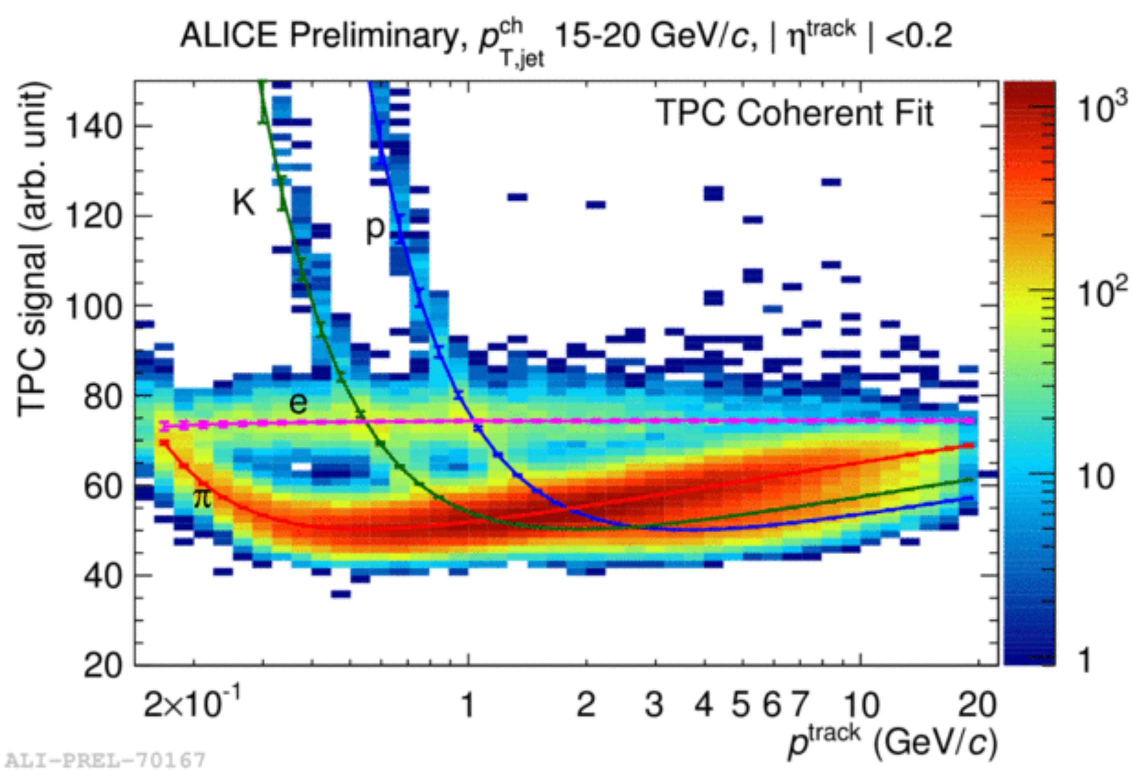
- bulk production at low z: ~ 5-10 charged particles per jet

PRD 91, 112012



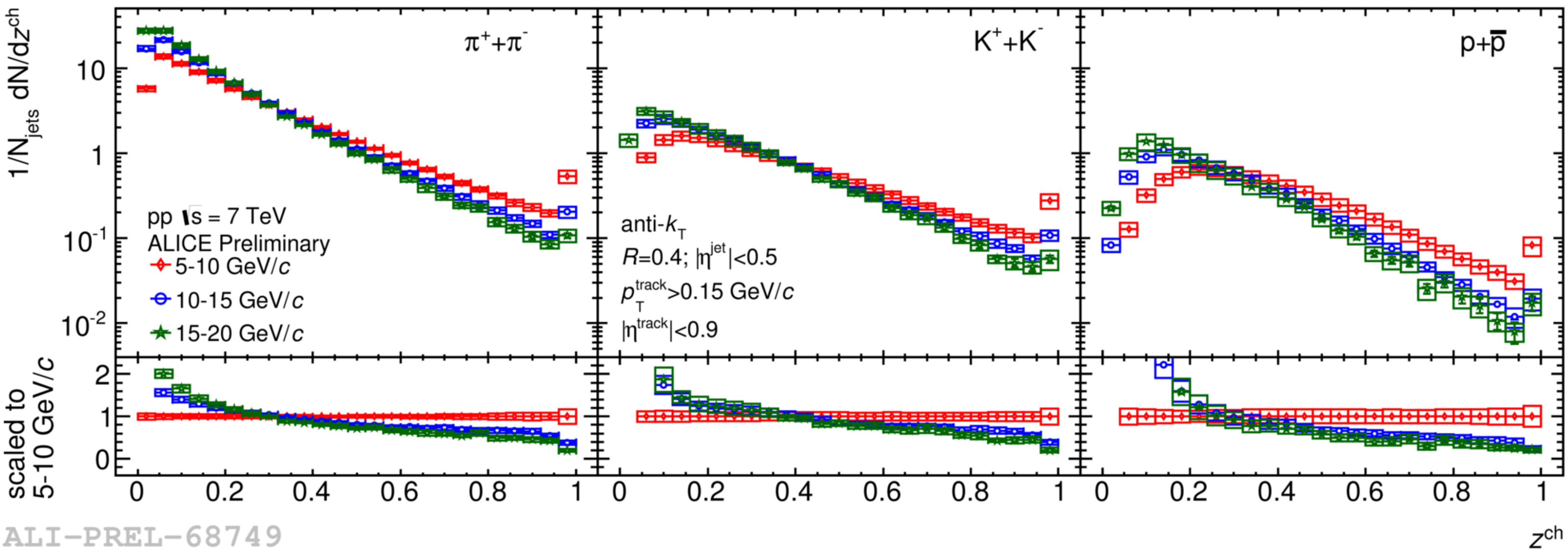
PID in jets : `TPC coherent fit’

- particle identification via specific ionisation in TPC ('dE/dx'):
- TPC coherent fit:
  use energy loss model parameterisation as input, adjust model parameters and particle fractions `on the fly’ during fit
- regularisation requiring continuity of particle fractions
- complementary and consistent: multi-template fit



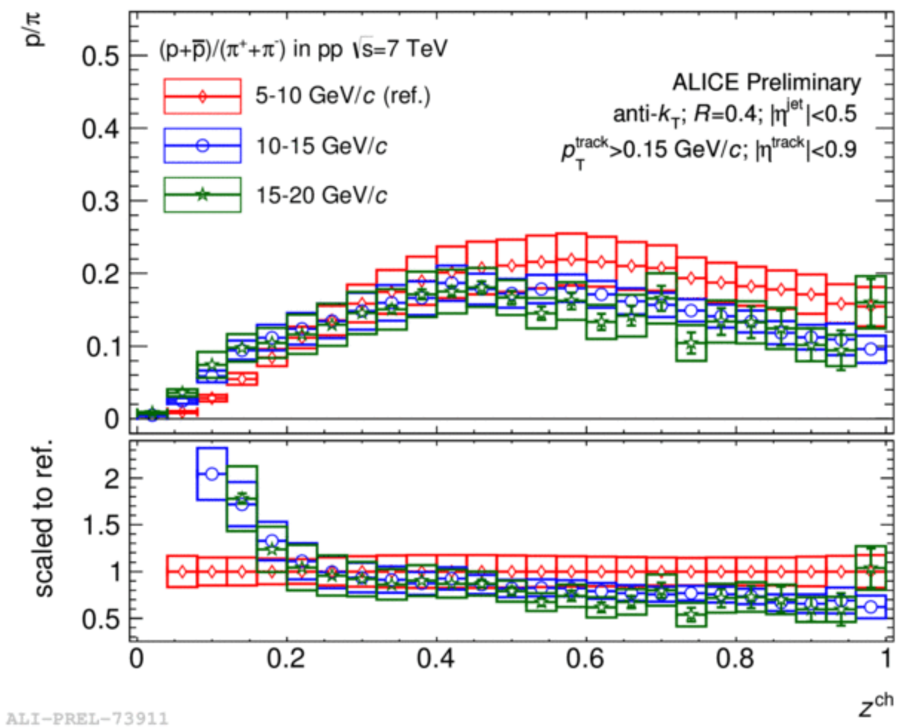
Particle identified fragmentation

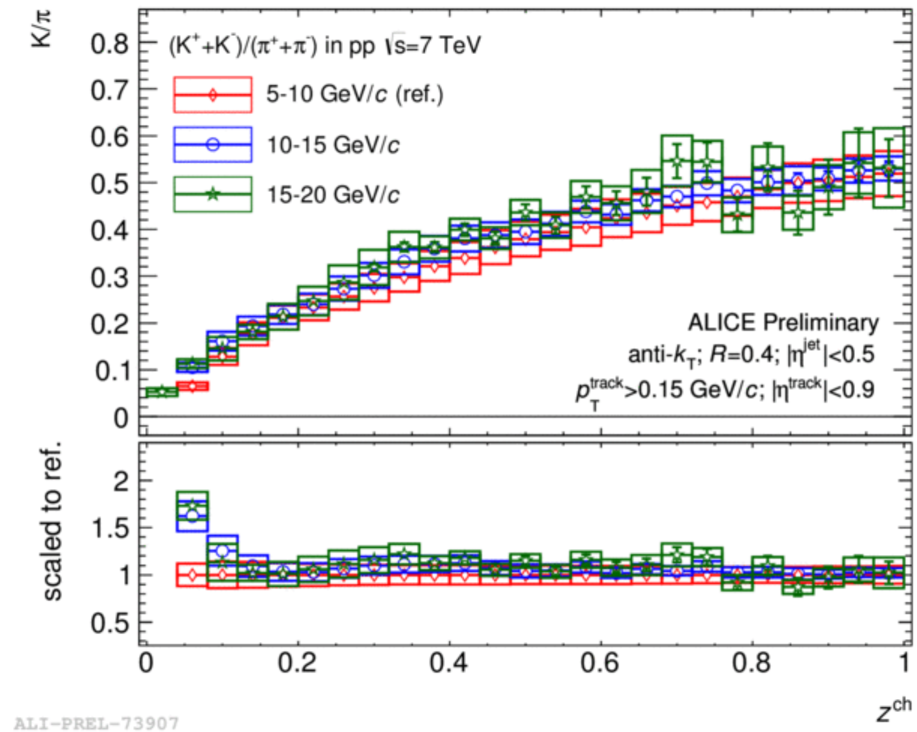
- identified charged hadrons in charged jets at $\sqrt{s}$ = 7 TeV
- π, K, p, 5 < $p_T^{ch\ jet}$ < 20 GeV/c
- scaling for z^{ch} > 0.2 for higher jet p_T bins



Particle ratios in jets

- leading baryons suppressed
- strangeness content strongly enhanced for $z^{ch} \rightarrow 1$





Event generator comparison

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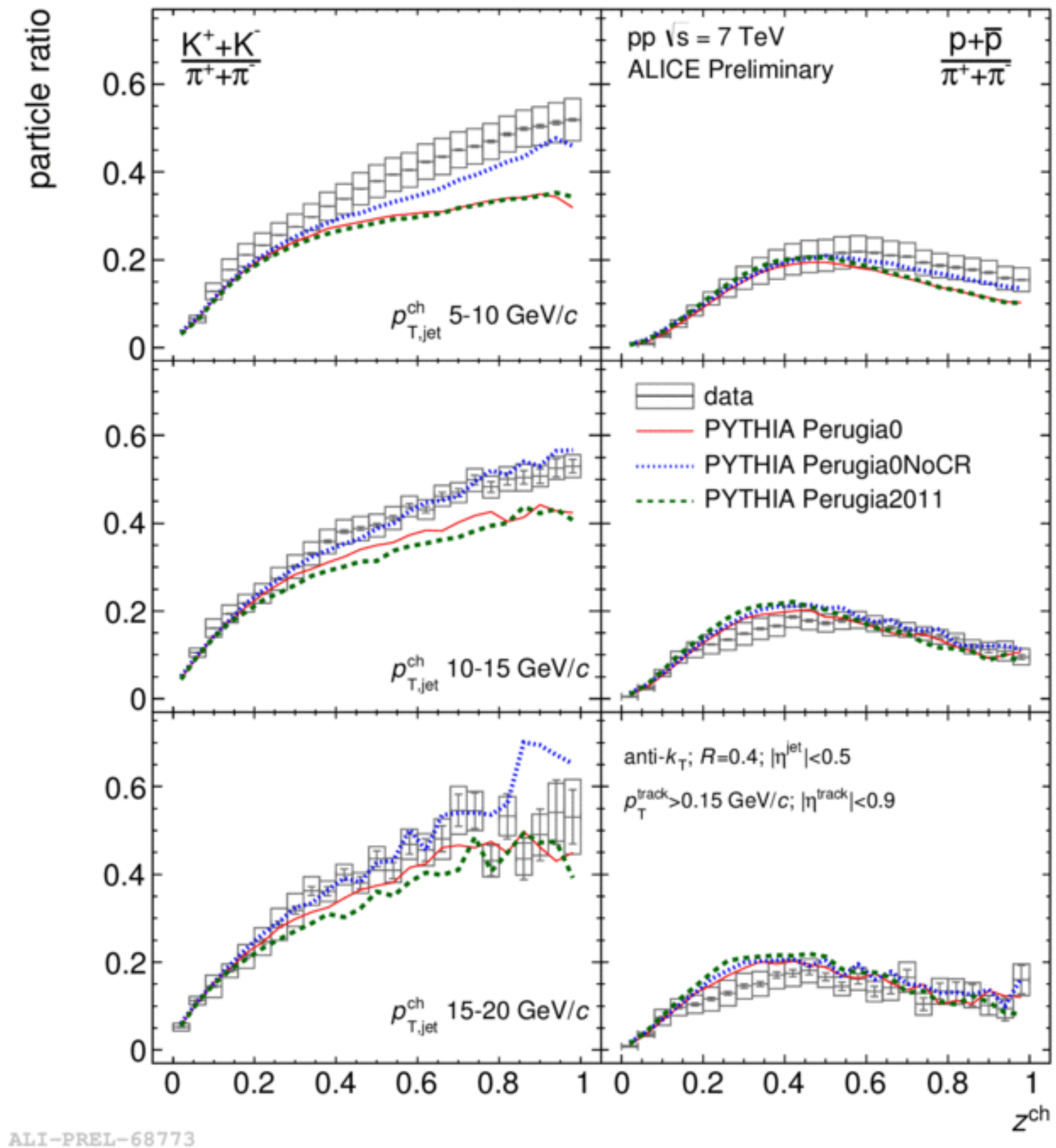
- comparison to PYTHIA (p_T ordered parton shower, Lund string fragmentation)
- data reasonably well described
- best reproduced by Perugia tune without color reconnections



Jets and Quark-Gluon Plasma

Hadrons in heavy-ion collisions

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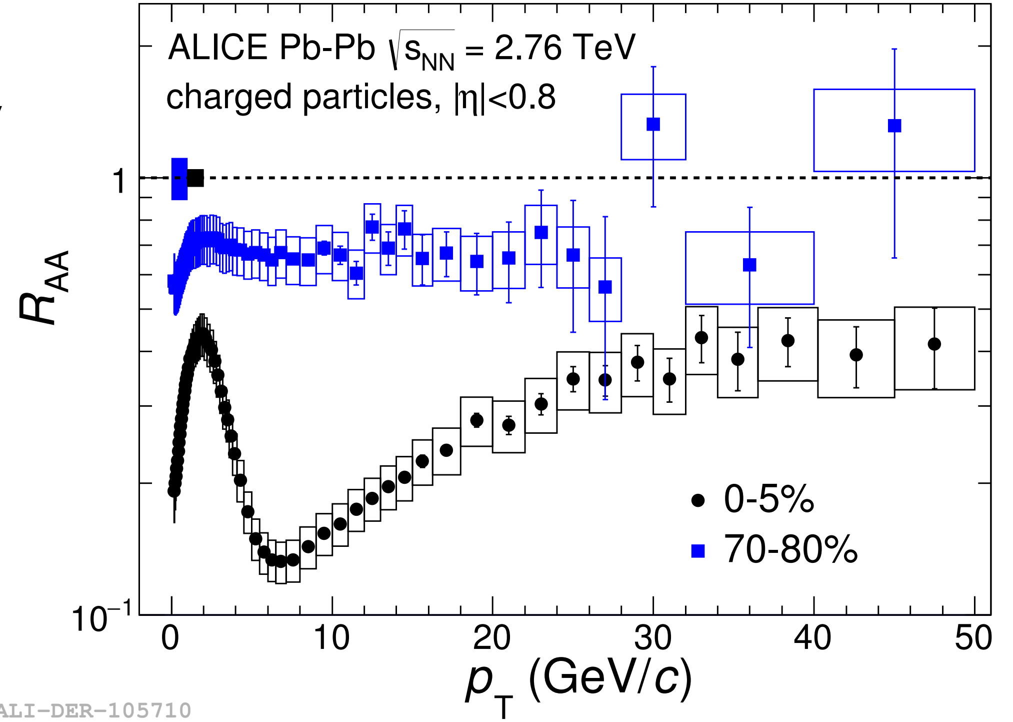
- hard partons are produced early and traverse the hot and dense QGP
- expect enhanced parton energy loss, (mostly) due to medium-induced gluon radiation: 'jet quenching'
- high-p_T hadrons 'proxy' for jet
- jet quenching for charged hadrons, Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV
- measure R_{AA} for fully reconstructed jets to mitigate fragmentation bias and assess parton kinematics

$$R_{AA}(p_T) = \frac{1}{T_{AA}} \frac{\mathrm{d}^2 N_{\mathrm{ch}}/\mathrm{d}\eta\,\mathrm{d}p_T}{d^2\sigma^{\mathrm{pp}}_{\mathrm{ch}}/d\eta\,\mathrm{d}p_T}$$

PLB 720 (2013) 250

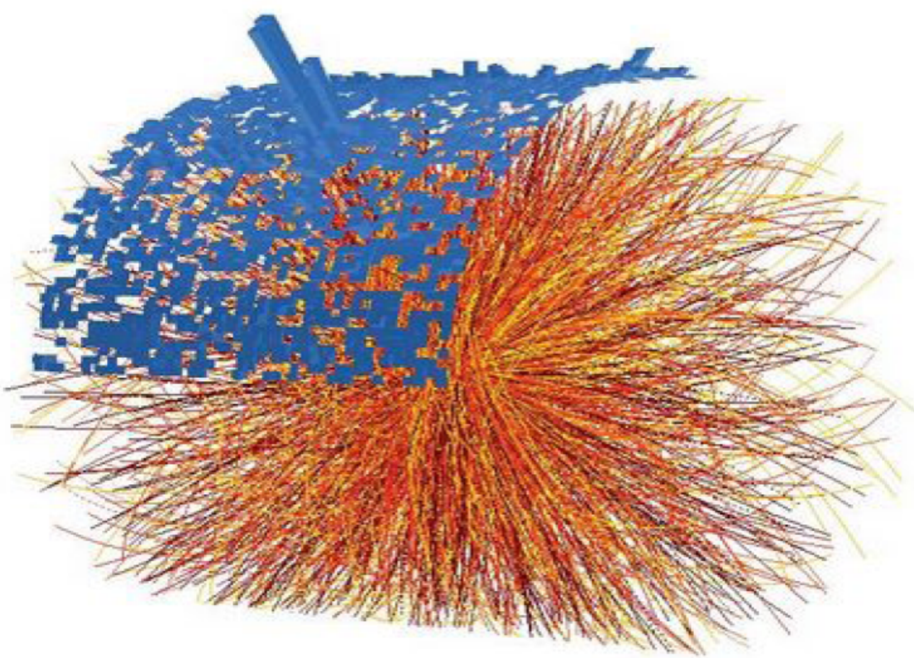


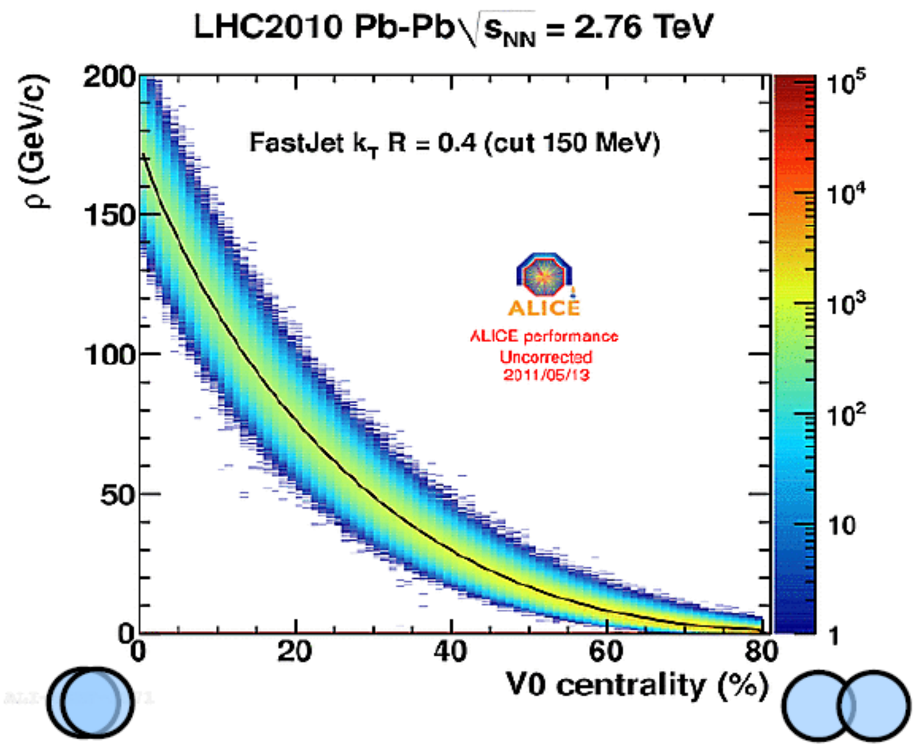
Underlying event in heavy-ion collisions

- jet reconstruction in heavy-ion collisions :
  high underlying event background
  not related to hard scattering

- background is dominant at low jet and constituent p_T

- background fluctuations are important



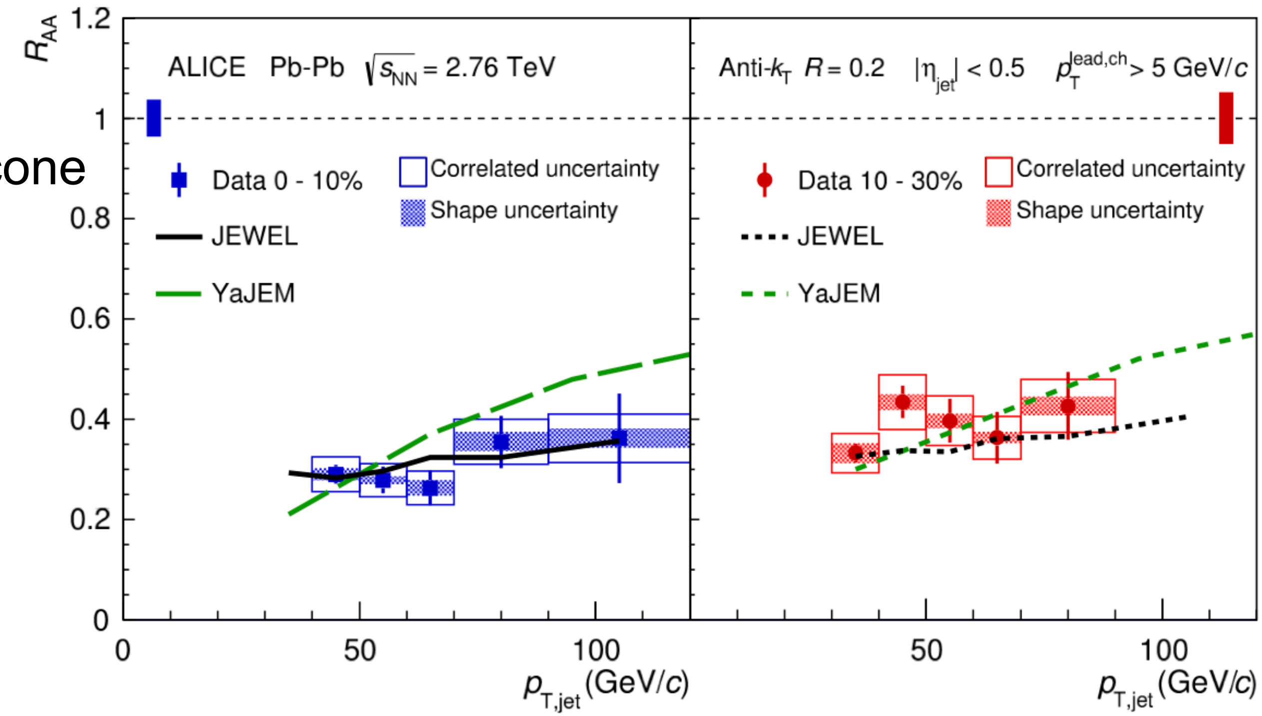


jet area ~ 0.5 (R = 0.4)

central *peripheral*

Jet nuclear modification factor

- strong suppression, similar to hadron RAA
  → parton energy not recovered inside jet cone



- increase of suppression with centrality, weak p_T dependence

- JEWEL:
  - microscopic pQCD parton shower + gluon induced emissions

- YaJEM:
  - detailed fireball model
  - parameterisation of radiative and collisional energy loss

Phys.Lett. B746 (2015) 1

JEWEL: PLB 735 (2014)

YaJEM:PRC 88 (2013) 014905

- different models reproduce observed jet suppression
  → study jet quenching through more differential measurements

Jet shapes

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- radial moment 'girth' g, longitudinal dispersion $p_T D$, difference leading - subleading p_T LeSub

- shapes in Pb-Pb as probe of quenching of low-p_T jets: characterise fragment distributions, sensitive to medium induced changes of intra-jet momentum flow

- 'event-by-event' measure, sensitive to fluctuations

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

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

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

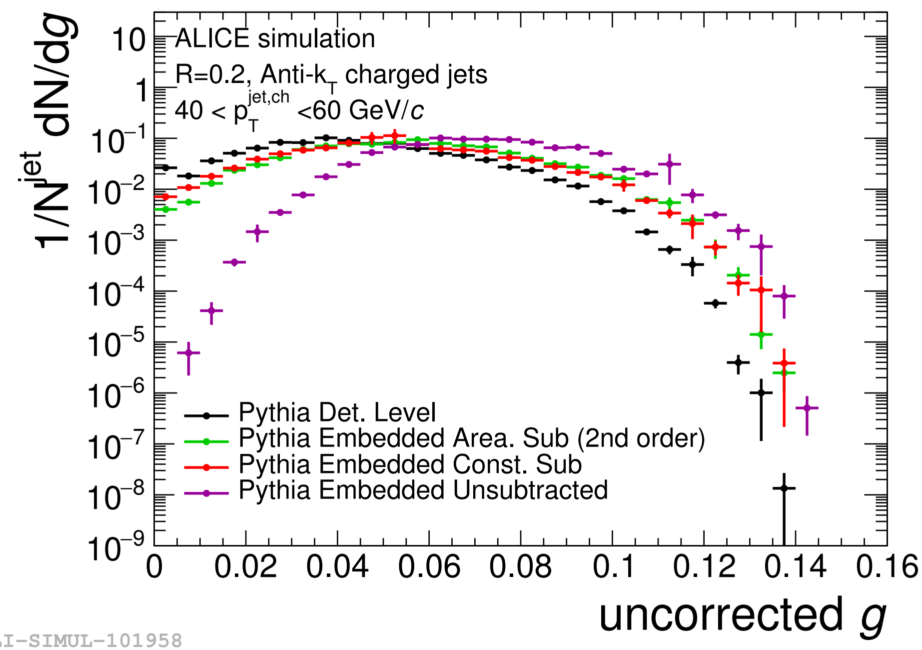
Analysis details

- charged jets from charged particle tracks, $p_T^{const} > 150$ MeV/c in pp MinB at 7 TeV and Pb-Pb 10% central at 2.76 TeV

- R=0.2, $40 < p_T^{jet} < 60$ GeV/c, no leading constituent cut

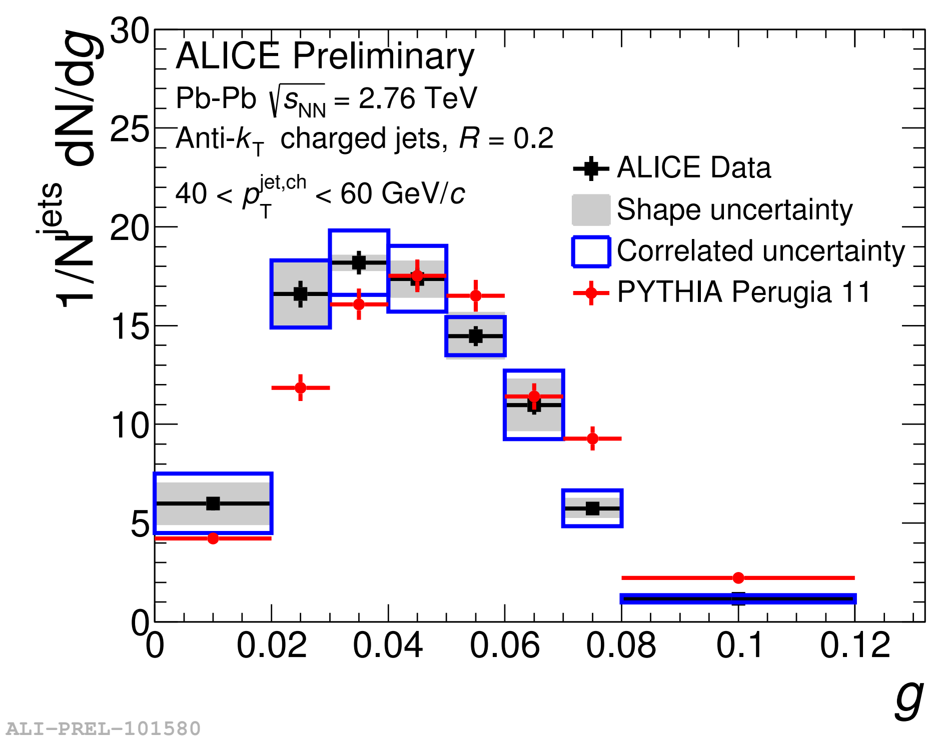
- novel background subtraction methods (Pb-Pb)
  - area subtraction (*G. Soyez et al, Phys. Rev. Lett 110 (2013) 16*)
  - constituent subtraction (*P. Berta et al, JHEP 1406 (2014) 092*)

- 2D unfolding to correct for background fluctuations and detector effects



Jet shapes in Pb-Pb

- fully corrected to charged particle level
- compare to PYTHIA reference, validated with results from pp collisions
- g shifted to smaller values → indicates more collimated jet core

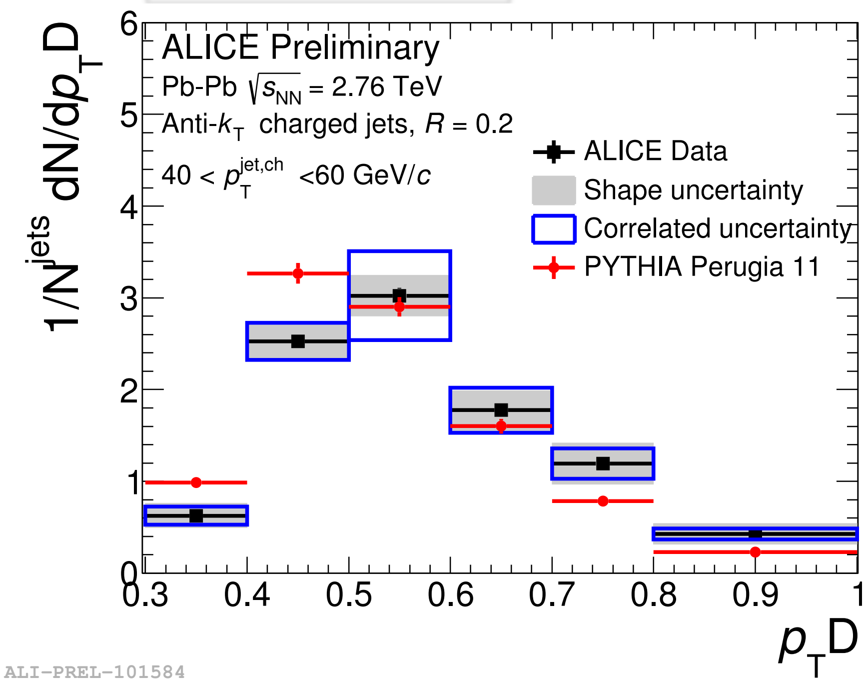


$$g = \sum_{i \in \text{jet}} \frac{p_T^i}{p_T^{jet}} |r_i|$$

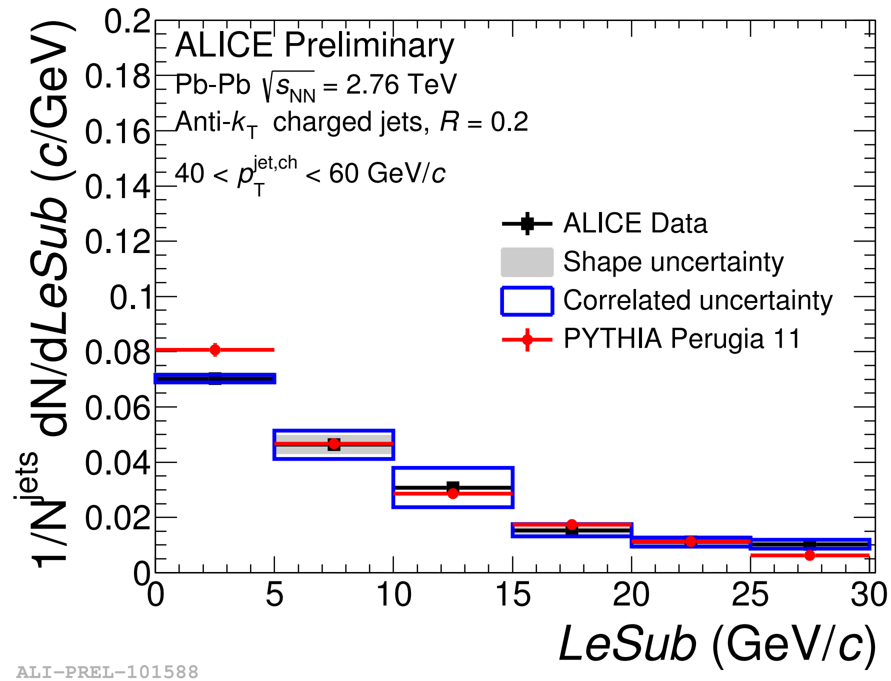
- larger $p_T D$ in Pb-Pb compared to PYTHIA
  → indicates fewer constituents in quenched jets

- LeSub in Pb-Pb in good agreement with Pb-Pb:
  → hardest splittings likely unaffected

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

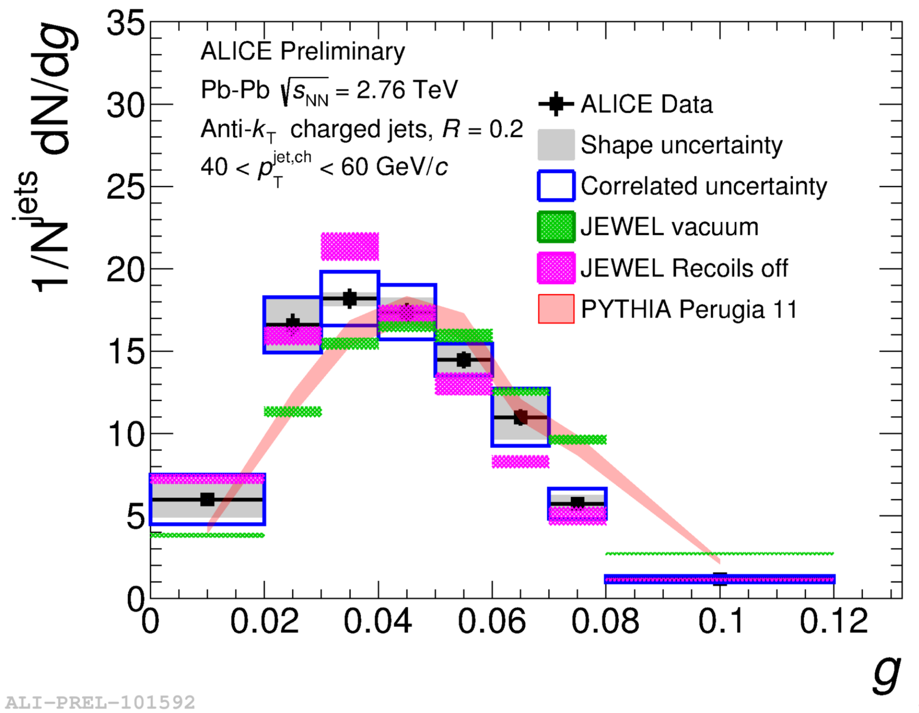


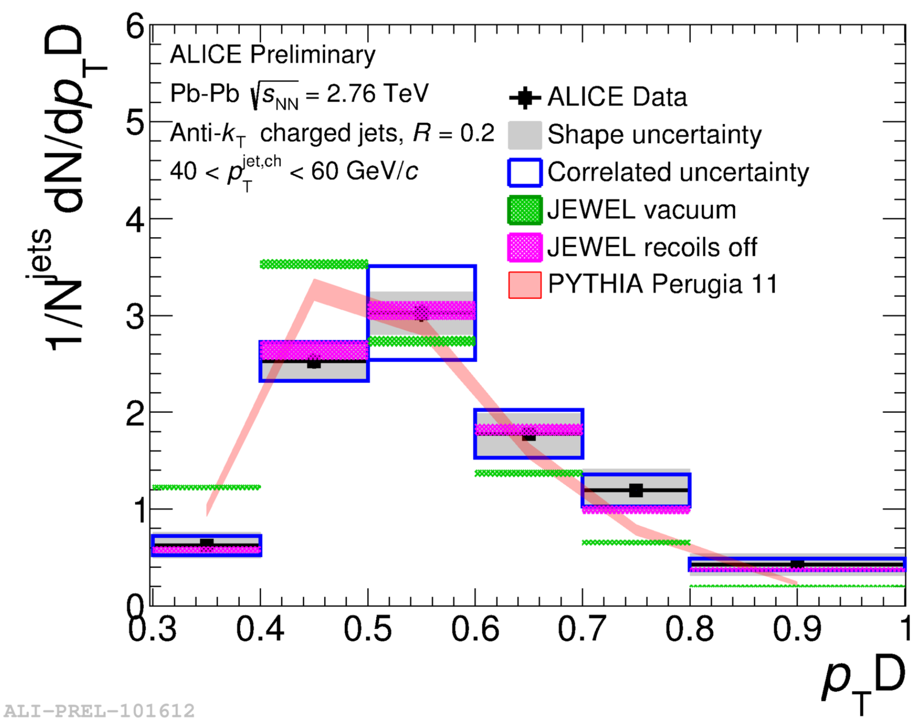
$$\text{LeSub} = p_T^{\text{lead,track}} - p_T^{\text{sublead,track}}$$



Jet shapes: model comparison

- trends reproduced by JEWEL jet quenching model: collimation through emission of soft particles at large angles





JEWEL: K.C. Zapp, F. Kraus, U.A. Wiedemann, JHEP 1303 (2013) 080

Summary

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- Jets at ALICE: a rich and interesting Physics programme !
  - jet cross sections and properties studied with ALICE in pp collisions
  - identified jet fragmentation distributions in pp collisions
  - jet nuclear modification factor
  - jet shapes in Pb-Pb

… and much more that wasn't shown today !

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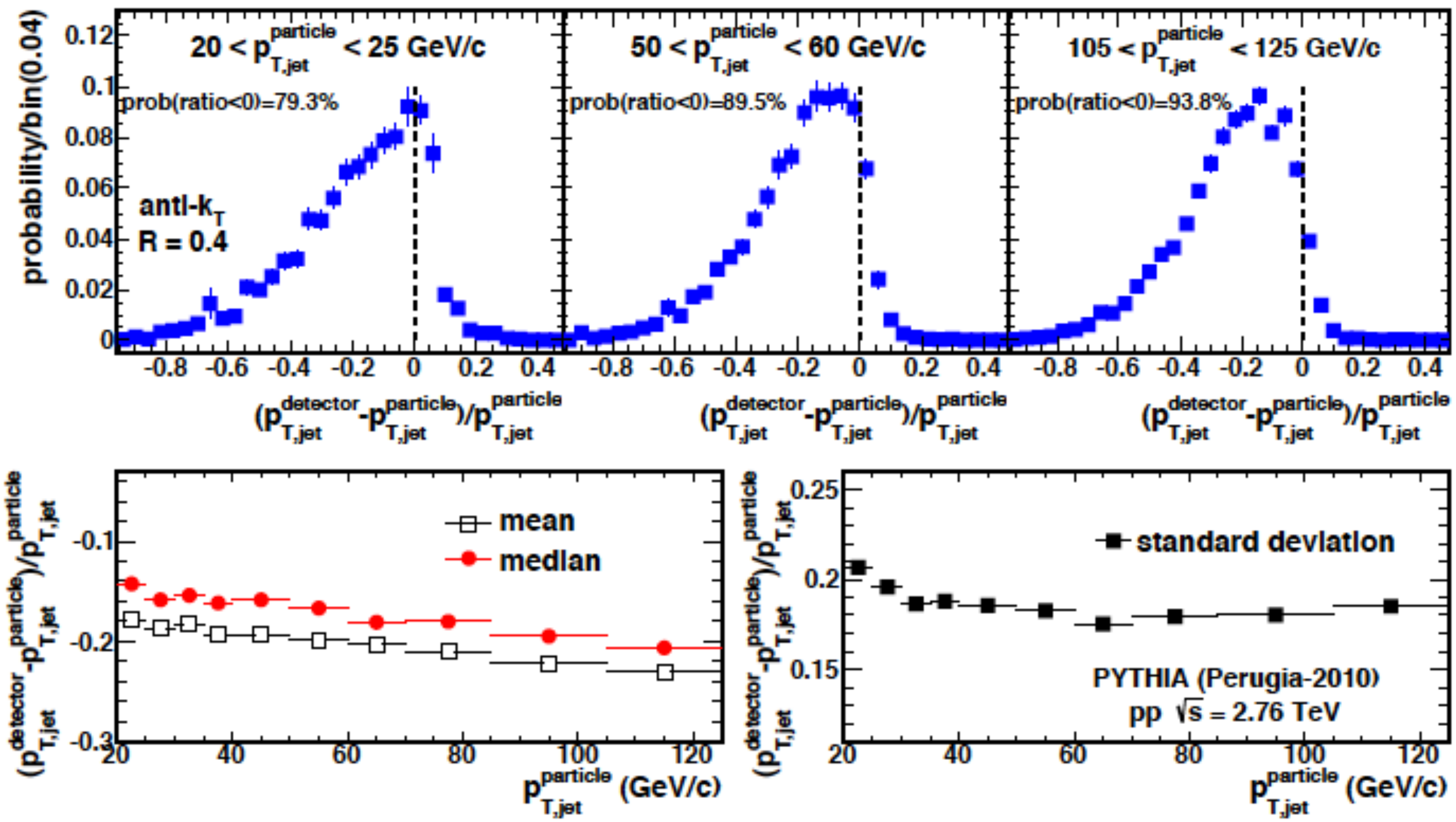
Happy Birthday !

- Backup -

ALICE jet response (pp)

- full jets: JE correction ~ 20%, ‘resolution’ ~18%
- JES uncertainty ~3.6%



pp charged jet cross-sections

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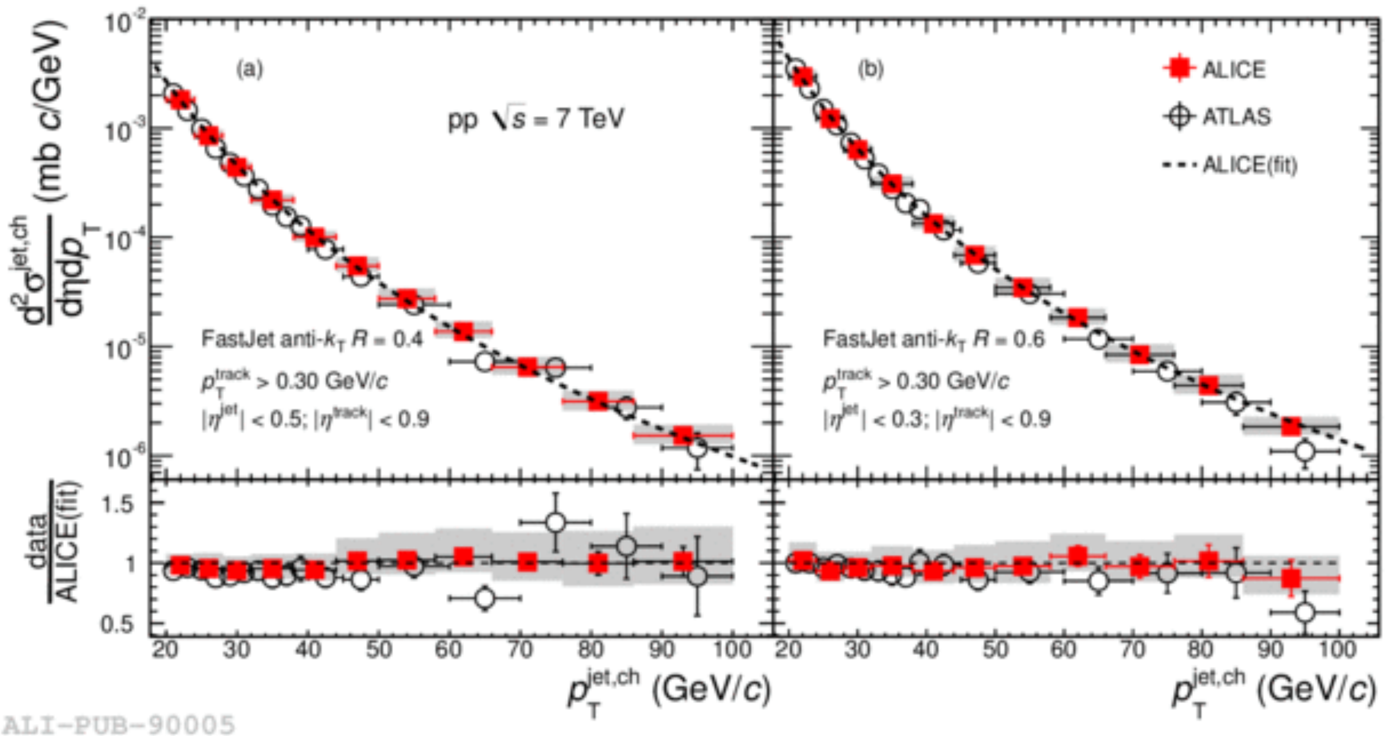
- measured in minimum bias collisions at $\sqrt{s}$ = 7 TeV
- good agreement with ATLAS charged jet measurements (despite slightly different acceptance and track p_{T} range)

R = 0.4 **R = 0.6**

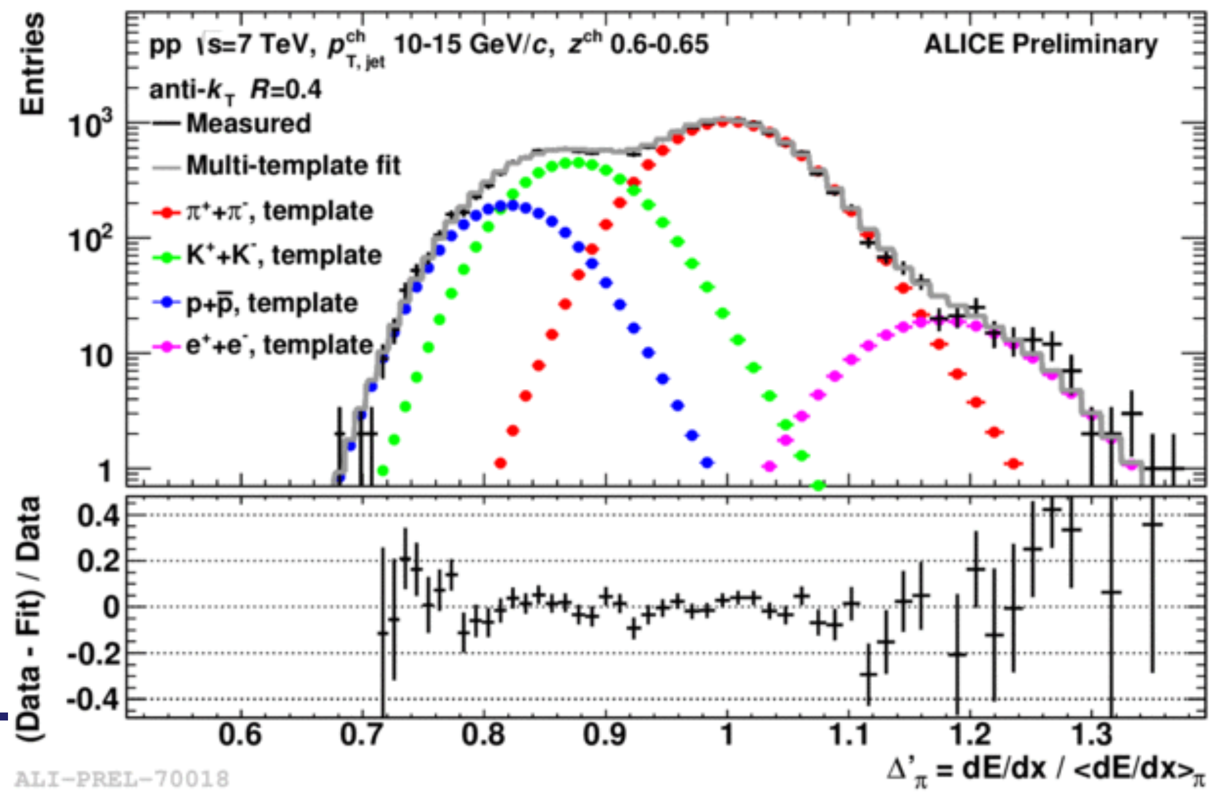


PRD 91 (2015) 112012

Multi Template Fit

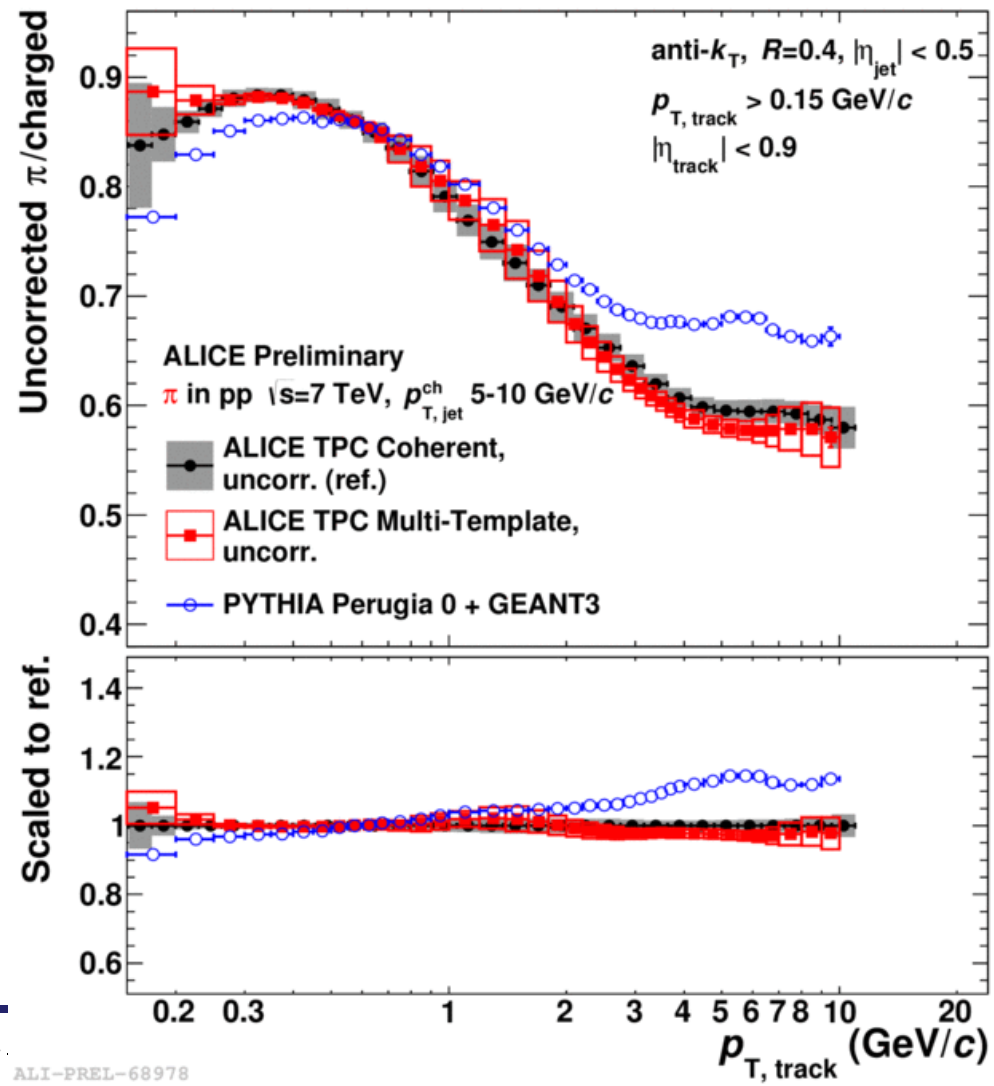
- TPC multi-template fit
  - best possible description of dE/dx from external reference
  - parametrize dependences on η, TPC nClusters
  - templates in transverse momentum (z, xi) slices

- dE/dx in one z slice (0.6 < z < 0.65), 10-15 GeV/c fitted with 4 templates



Method comparison

- uncorrected hadron fractions from Multi-Template Fit and TPC Coherent Fit
- 2 complementary methods obtain consistent results



Hard probes and medium properties

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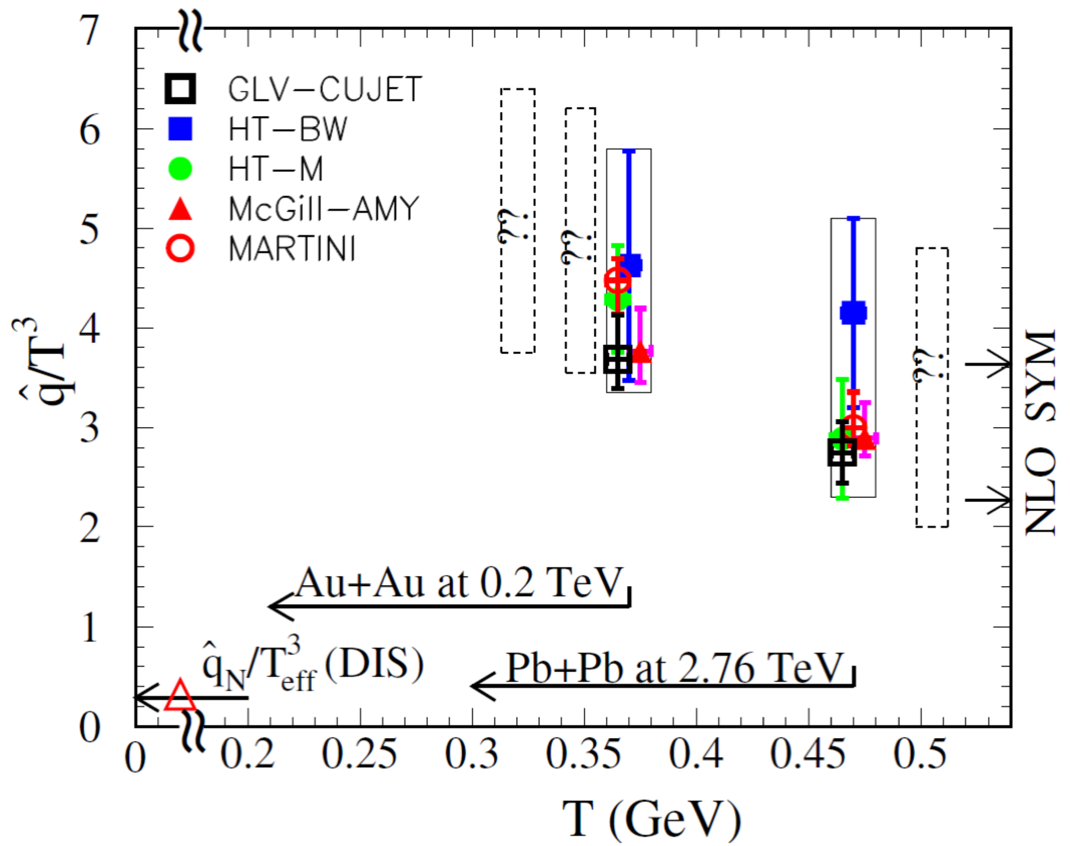
- jet quenching sensitive to properties of the medium (energy density, $\hat{q}$, mean free path, coupling ...)
- ... but also jet-medium interaction not trivial (strong / weak coupling, parton mass / type, fireball dynamics ...)

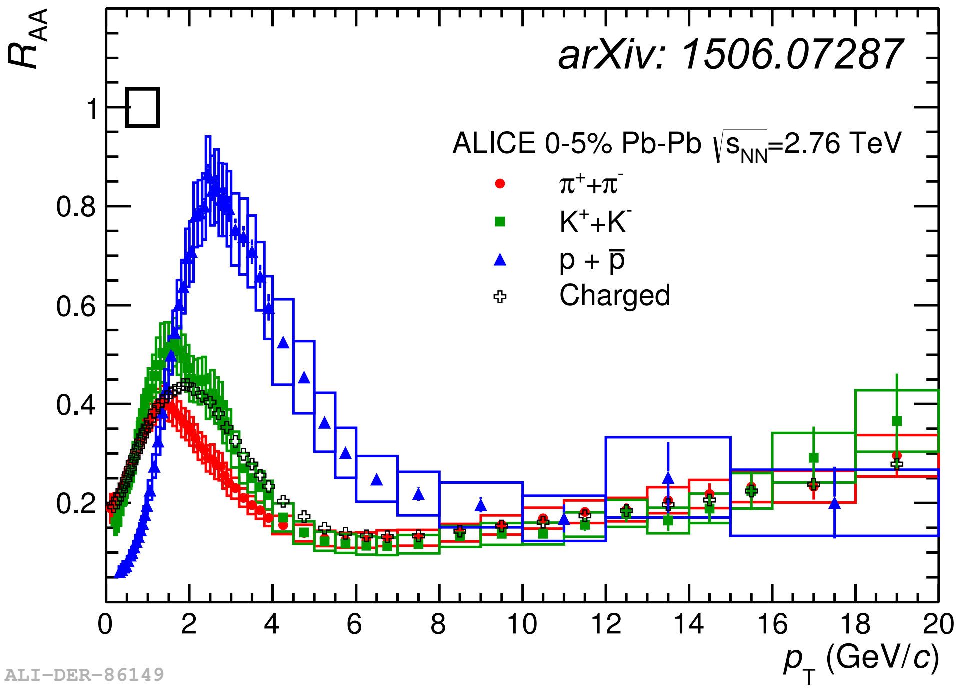


JET collaboration, Phys. Rev. C 90, 014909 (2014)

Identified hadrons in heavy-ion collisions

- baryons / meson R_{AA} a probe of gluon / quark energy loss?

- would expect stronger radiative energy loss for gluons than for quarks
  - subtle cancellations?
  - hadron observable biased towards hard fragmentation?



- study jets to improve our understanding of parton energy loss:
  - PID in reconstructed jets mitigates fragmentation biases
  - enhanced sensitivity to medium effects measuring soft particles in jets

- note: medium effects likely strongest at scales of ~ medium Temperature
  (*J.G. Milhano, K. C. Zapp, hep-ph/1512.0819, T. Renk, Phys. Rev. C 81, 014906, B. Mueller, hep-ph/1010.4258*)