Jets in pp and p-Pb Collisions measured with ALICE

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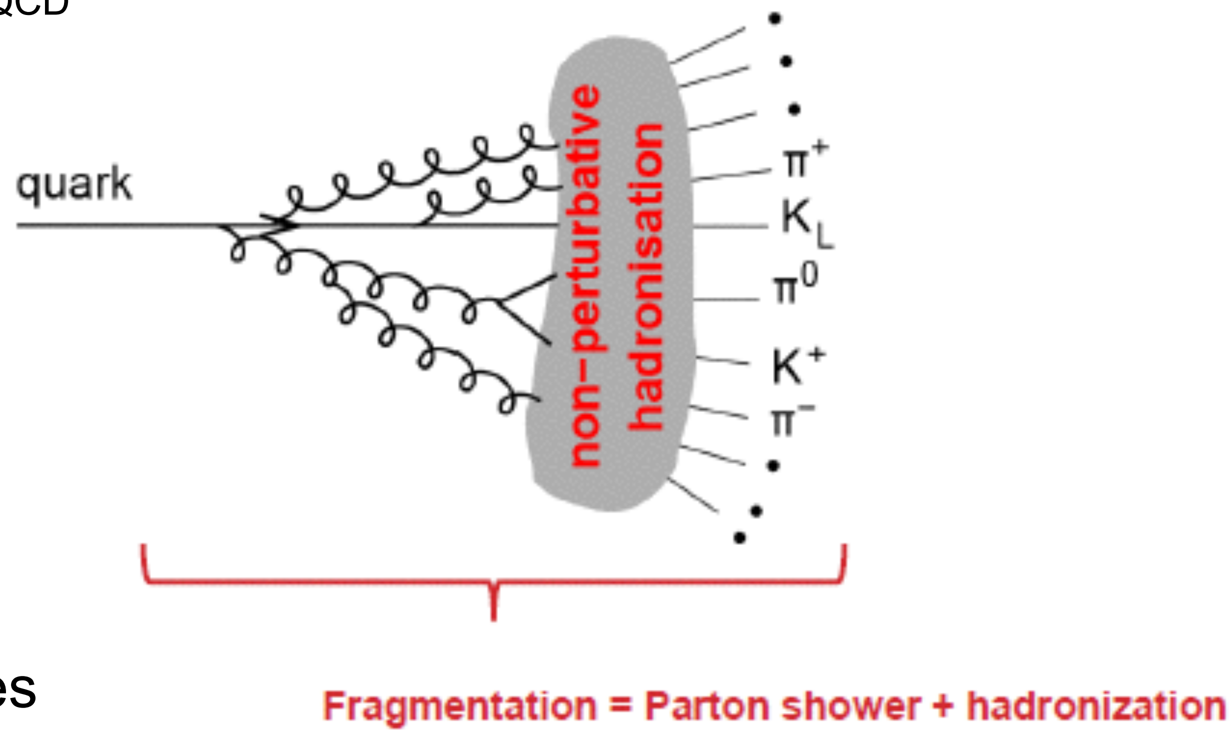
Outline

- introduction
- jet fragmentation in pp collisions
- PID in jets in pp
- jets in p-Pb collisions
- jet Q_{pPb}
- strangeness in jets in p-Pb

Introduction

Jet Fragmentation

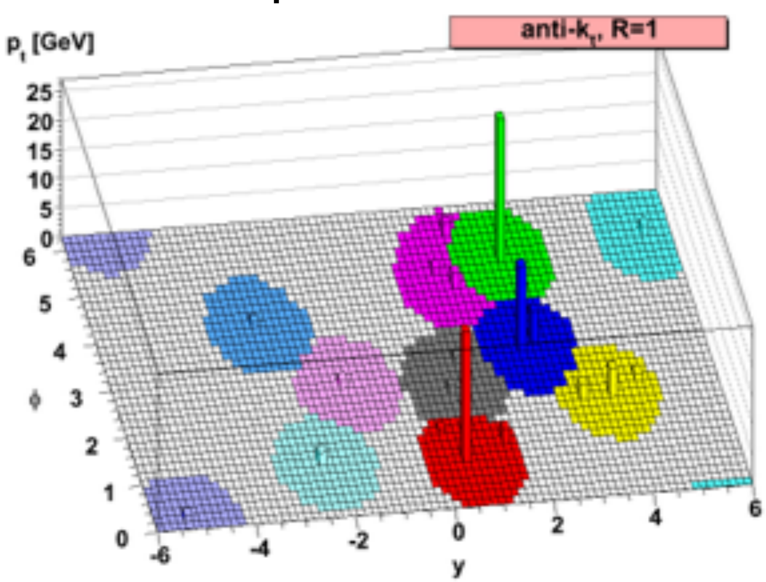
- initial hard (high Q^2) scattering: high-$p_{T,}$ quasi-free partons
- Q^2 evolution: parton shower, gluon cascade
- hadronization at $\sim\Lambda_{QCD}$



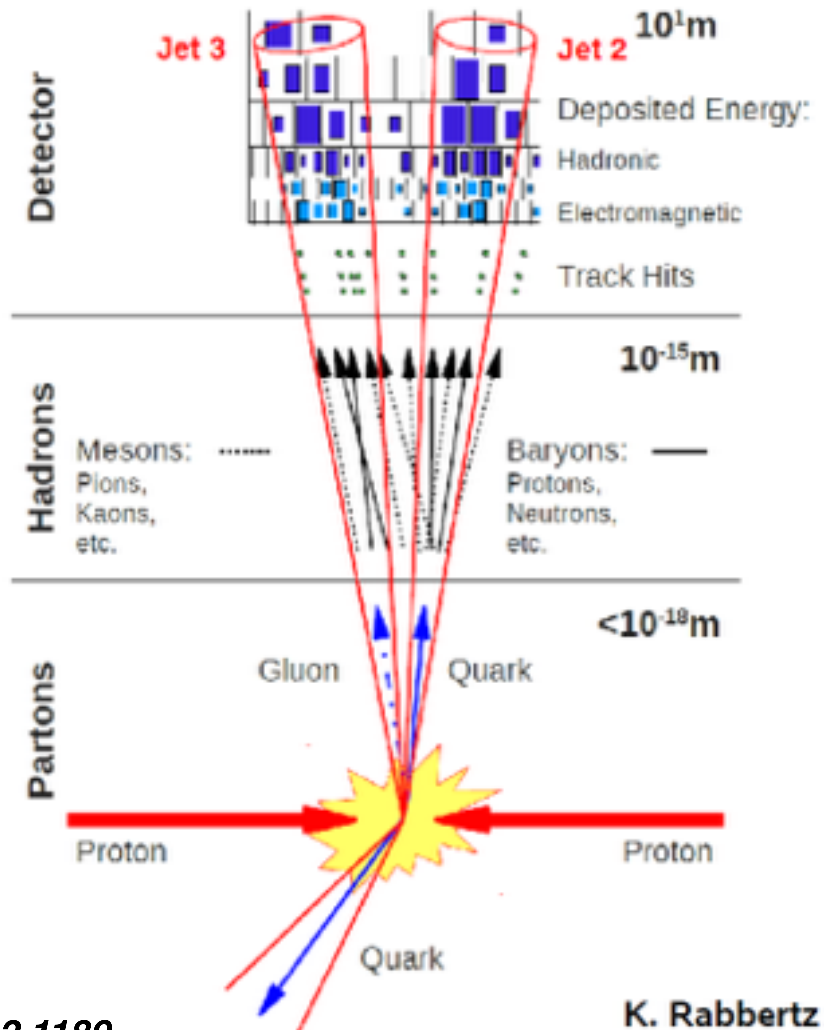
- jets allow to study QCD at various scales

Jet Reconstruction

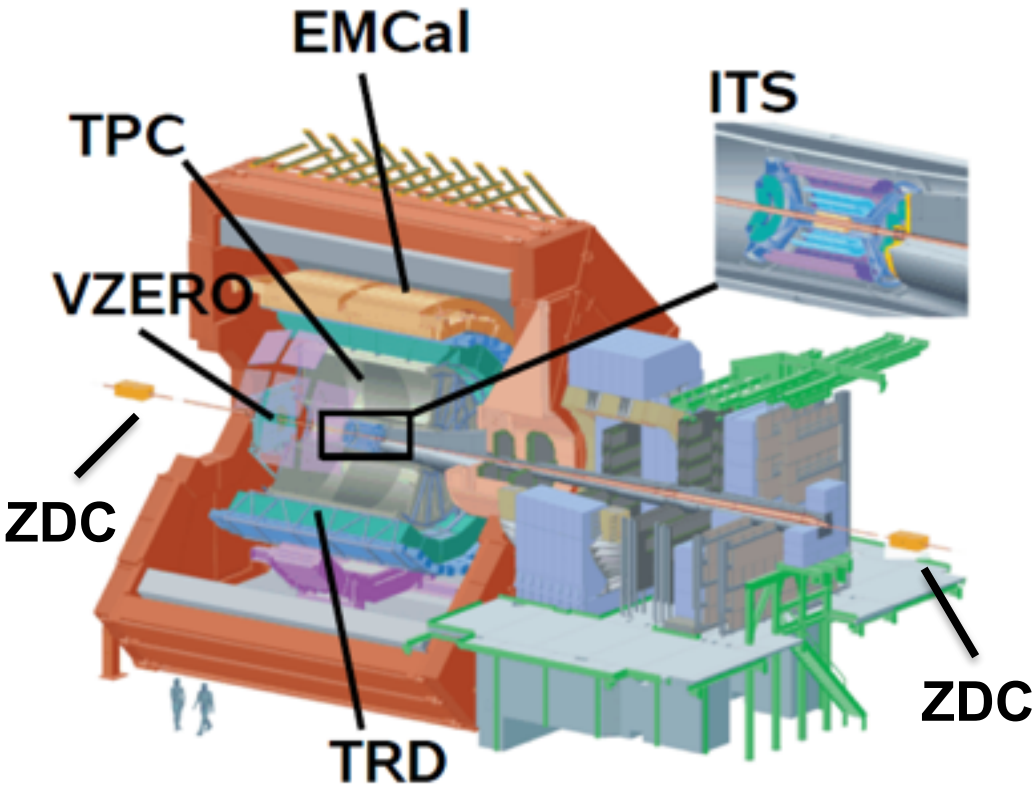
- establish correspondence between detector measurements / final state particles / partons
- two types of jet finder:
  - iterative cone
  - sequential recombination (e.g. anti-k_T)
- resolution parameter R



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

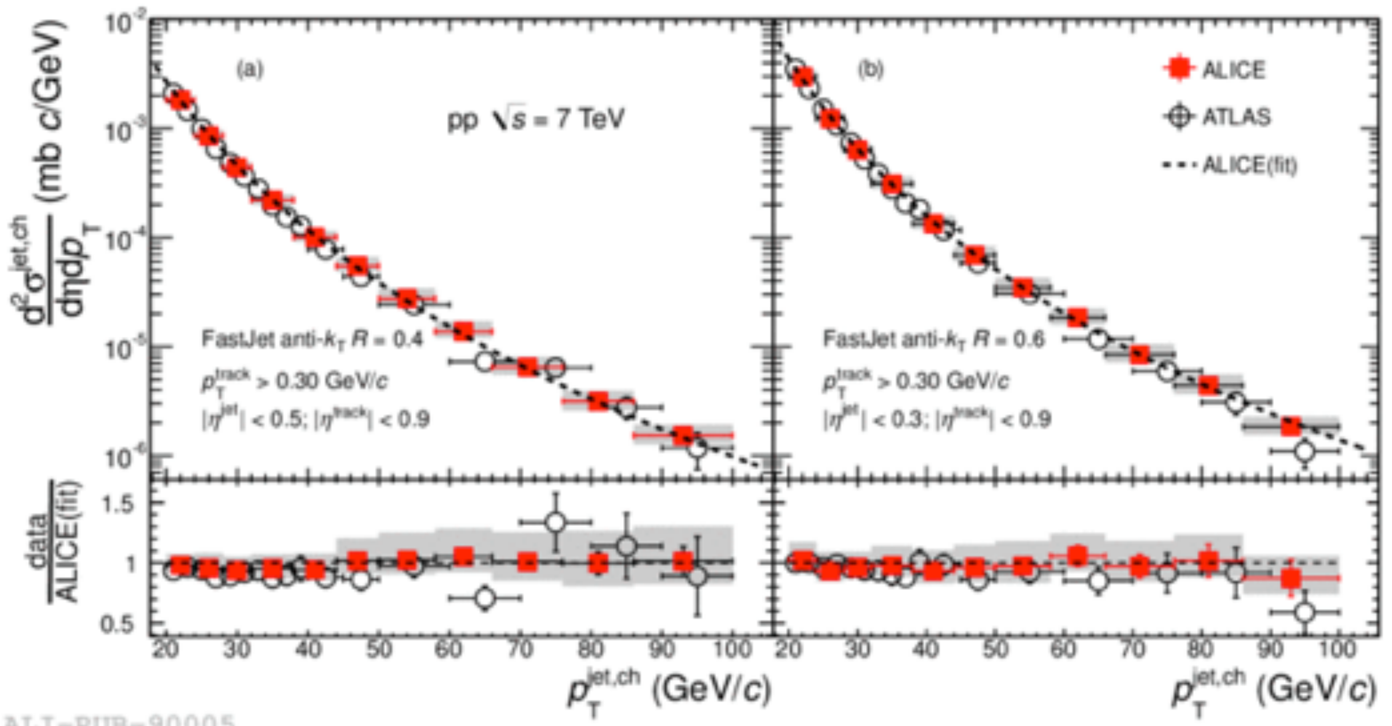
- jet trigger with EMCal and TRD
- \`charged' (tracking) jets and \`full' jets
- tracking jets: suitable especially under harsh pile-up conditions

Results from pp Collisions

pp Charged Jet Cross Sections

- 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**

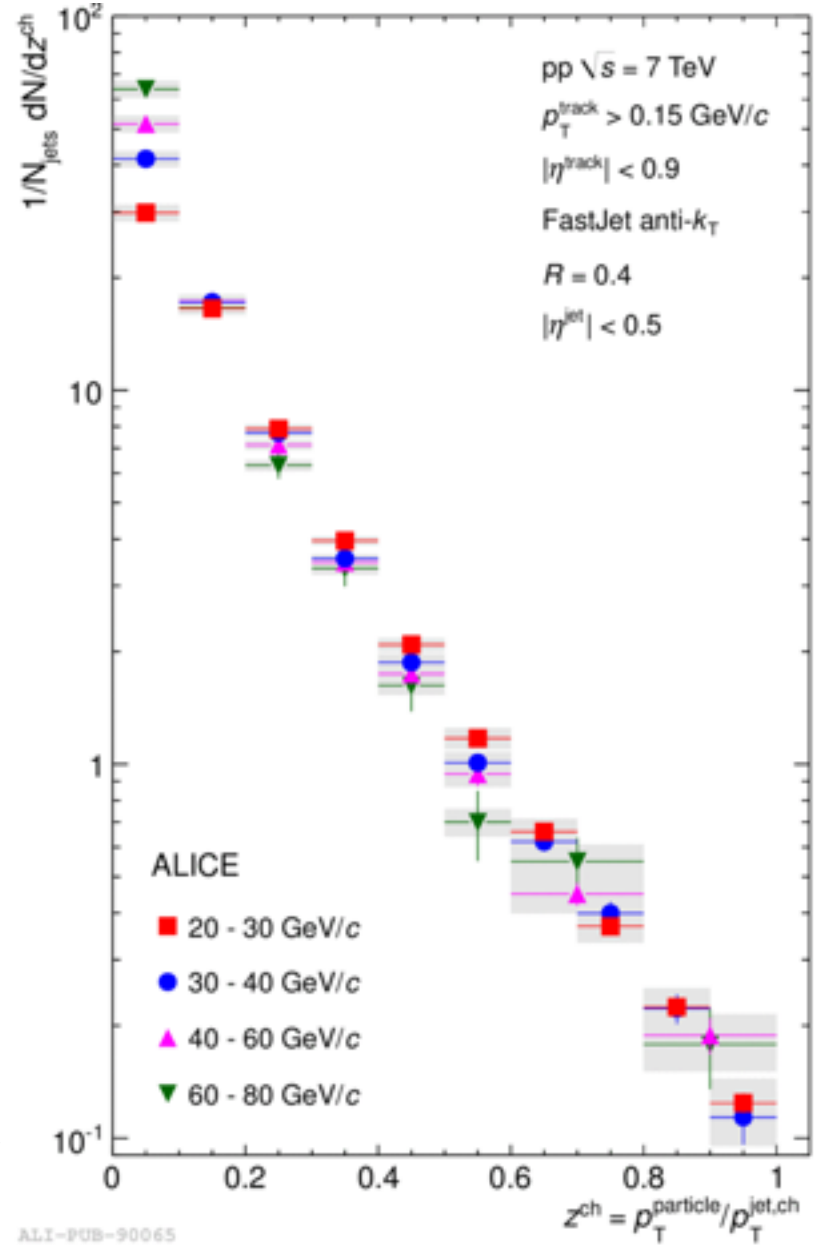


PRD 91 (2015) 112012

pp Jet Fragmentation at 7 TeV

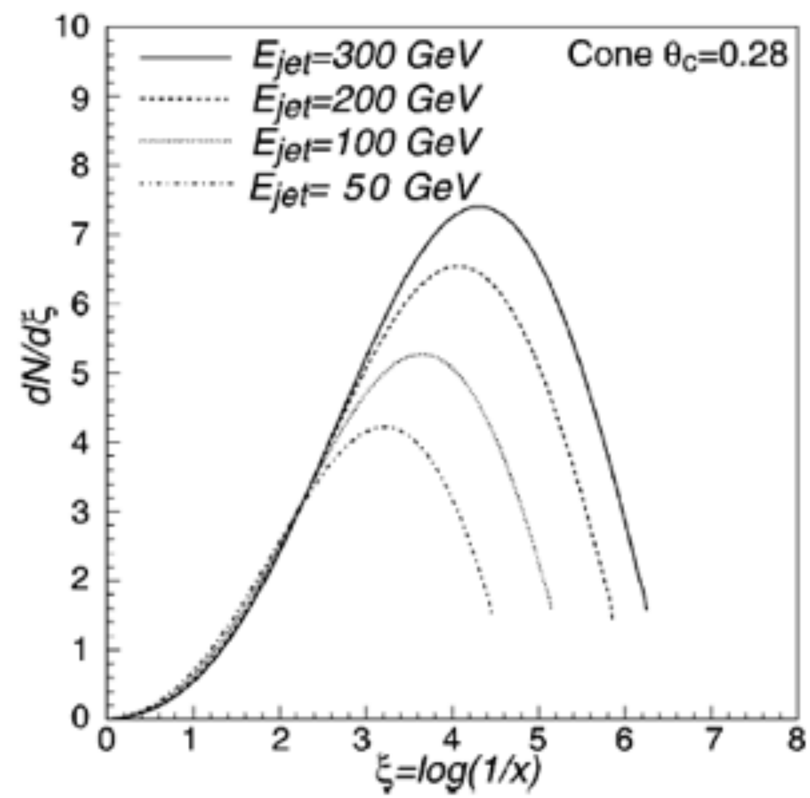
- $z^{ch} = p_{\mathrm{T}}^{\mathrm{particle}} / p_{\mathrm{T}}^{\mathrm{jet,ch}}$ distributions of charged particles in charged jets at $\sqrt{s}$ = 7 TeV
- bulk production at low z: ~ 5-10 charged particles per jet
- for z > 0.2 distributions consistent for all jet p_{T}: 'scaling'

ALICE, PRD 91, 112012



z Scaling in QCD

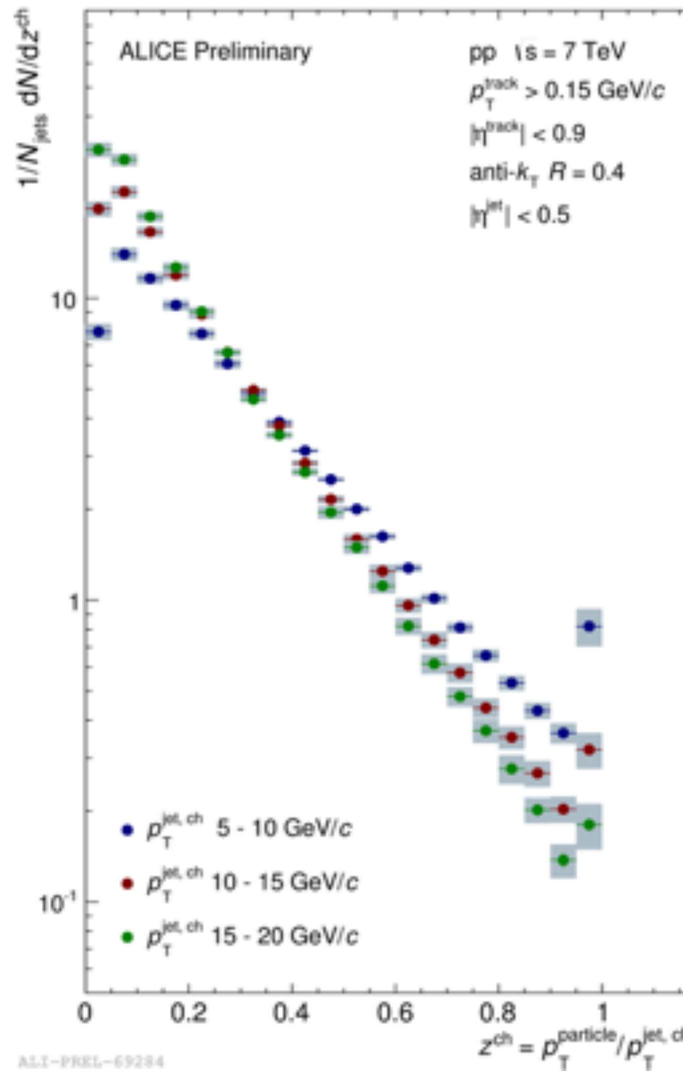
- MLLA: analytic parton shower calculation, NLL resummation
- hadronization not explicitly included
- low-ξ (approximate) scaling a feature of parton shower (with some caveats about validity as ξ-> 0)
- down to which jet p_T will this work ?



CDF, PRD 68 (2003) 012003

z Scaling: Low-p_T Jets

- …. down to 10 GeV/c charged jet p_T !
- deviations for 5-10 GeV/c jets
- low-p_T jets and their properties important in the context of pp UE studies (high-multiplicity pp)
- do we see increasing influence of non-perturbative effects on essentially free partons, or non-perturbative objects (e.g. UE 'fake jet' clusters) ?

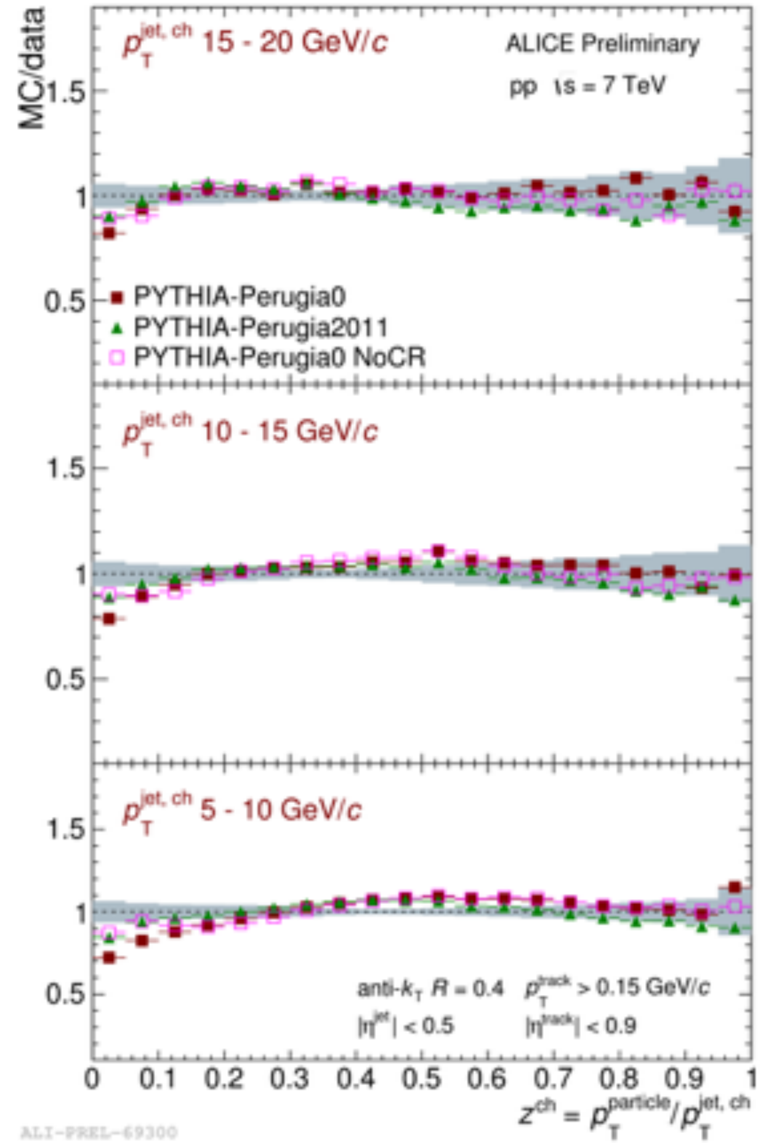


Event Generator Comparison

- low-p_T jets rather well described by PYTHIA
  (p_T ordered parton shower, Lund string fragmentation)

- Perugia2010NoCR OK, no need to evoke MPI coherence

- 5 GeV/c hadron clusters look 'jetty' and can be described by single hard scattering + fragmentation, however non-perturbative effects are important (even at high z ?!)

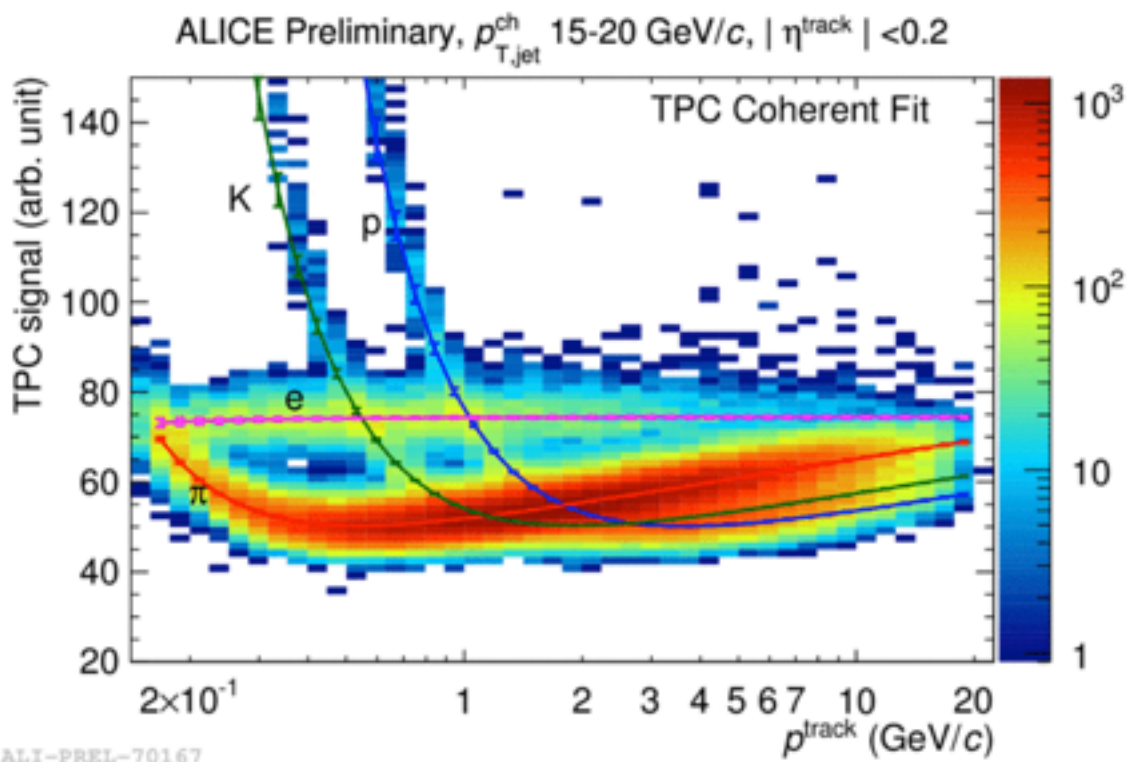


PID in Jets : `TPC Coherent Fit'

- particle identification via specific ionization in TPC ('dE/dx'):

- TPC coherent fit:
  use energy loss model parameterization as input,
  adjust model parameters and particle fractions `on the fly' during fit

- regularization requiring continuity of particle fractions

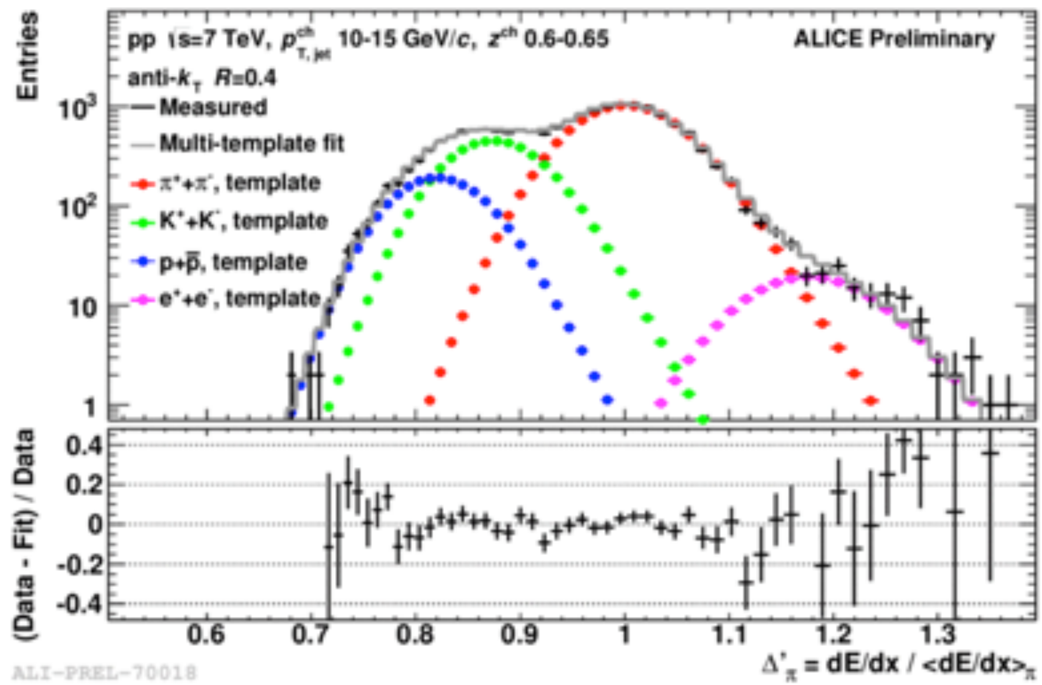


Multi Template Fit

- 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

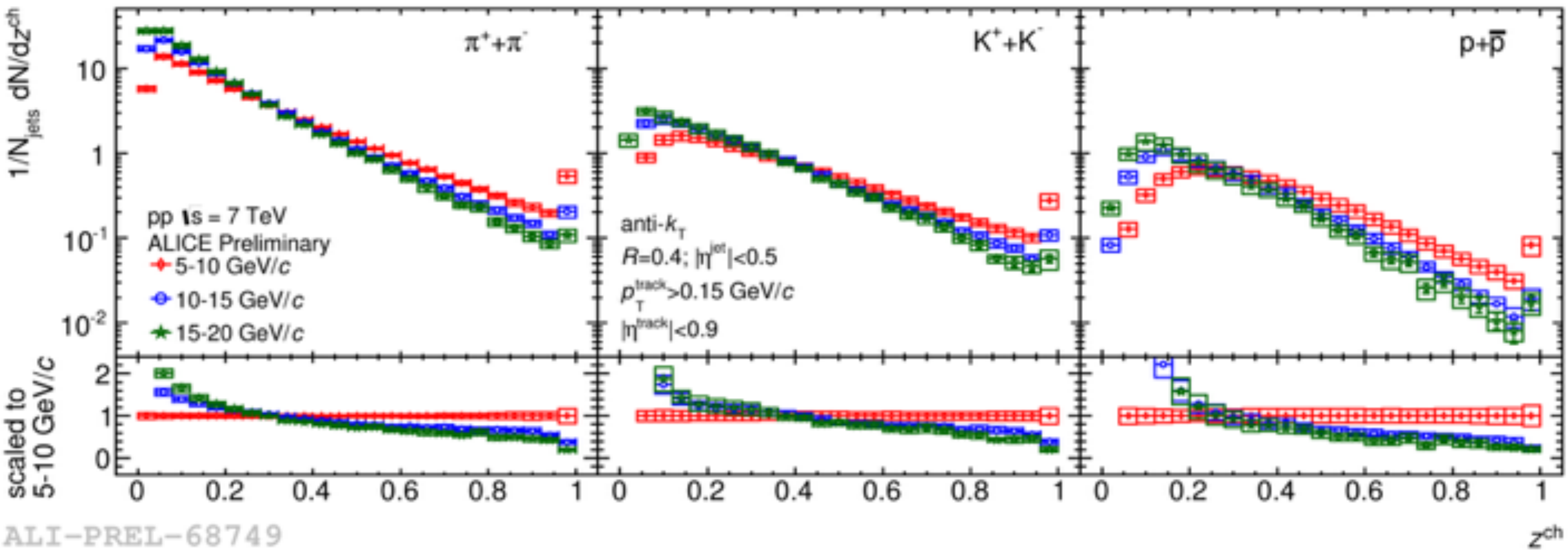
- dE/dx in one z slice (0.6 < z < 0.65), 10-15 GeV/c fitted with 4 templates

- complementary and consistent with TCF



Particle Identified Fragmentation

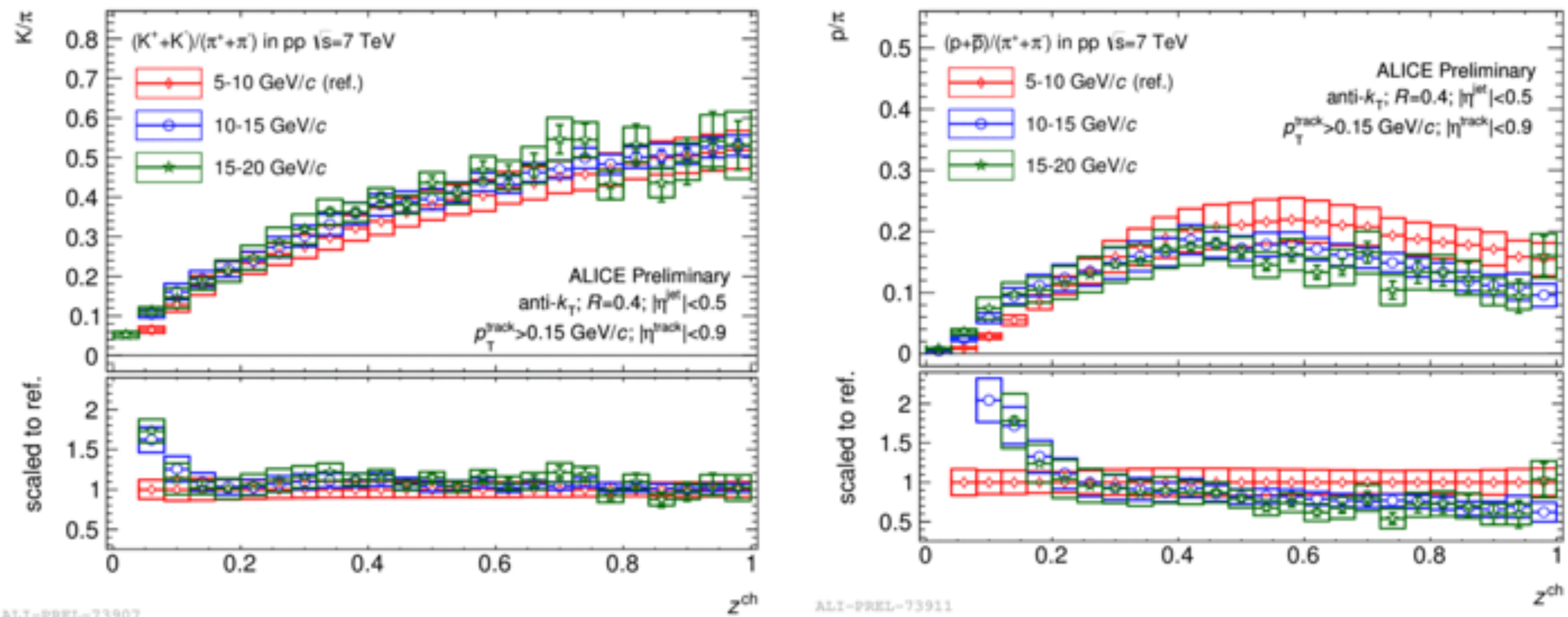
- identified charged hadrons in charged jets at $\sqrt{s}$ = 7 TeV
- π, K, p, 5 < $p_T^{ch\ jet}$ < 20 GeV/c
- z scaling for all species: no strong hadronization effects



Particle Ratios in Jets

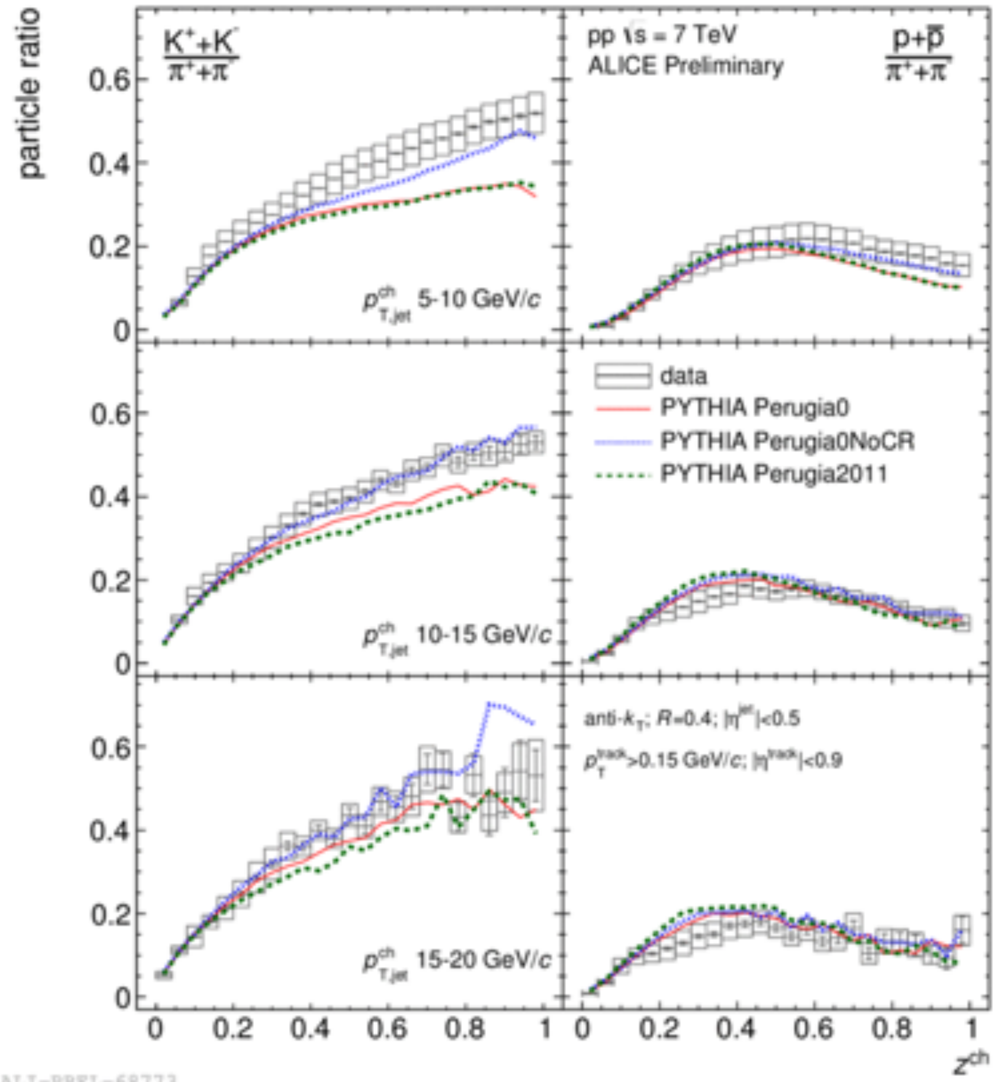
- strangeness content strongly enhanced for $z^{ch} \rightarrow 1$

- leading baryons suppressed



Event Generator Comparison

- comparison to PYTHIA6 (p_T ordered parton shower, Lund string fragmentation)
- data reasonably well described
- well reproduced by Perugia0 NoCR tune without color reconnections



Results from p-Pb Collisions

Jets in p-Pb Collisions

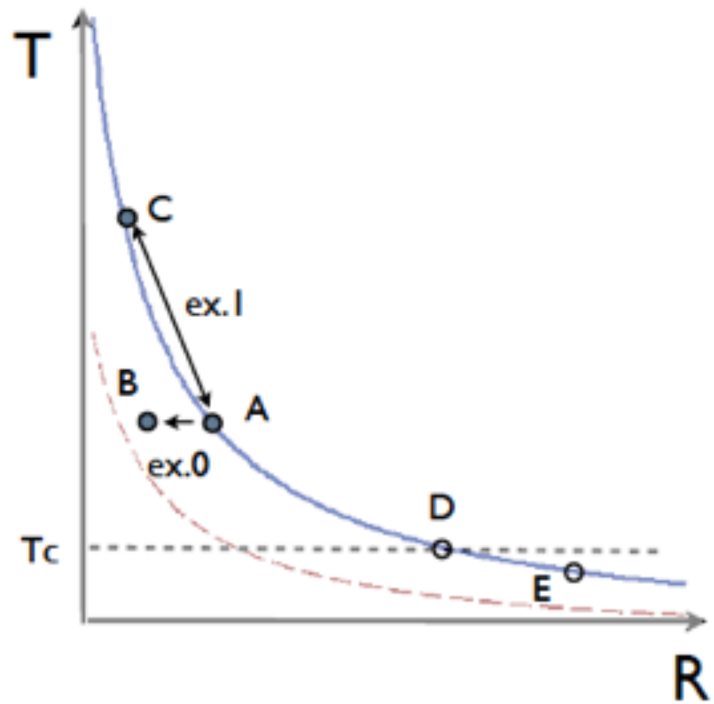
- sensitive to cold-nuclear matter effects :
  - nuclear modification of the parton distribution
  - k_T broadening and energy loss in cold nuclear matter

- in p-Pb collisions at LHC, onset of collectivity observed in high-multiplicity events

- hydro in small systems:
  high initial Temperature ?

- $\hat{q} \sim T^3$

- jet quenching in p-Pb ?
  -> jet spectra a.f.o. centrality



E. Shuryak ,I. Zahed, Phys.Rev. C88 (2013) 4

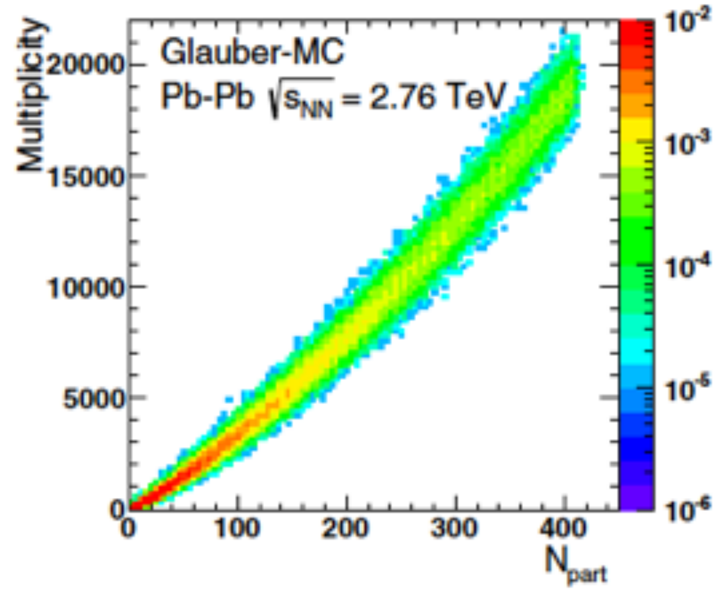
Centrality in p-Pb Collisions

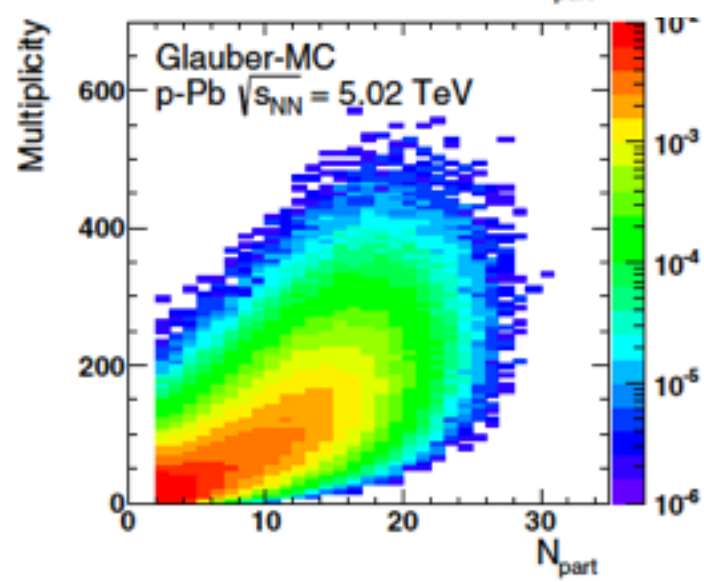
- ‘centrality’ related to collision geometry

- in Pb-Pb:
  - Glauber MC + NBD fit to
    measured multiplicity distribution
  - strong correlation multiplicity - N_{part} - b

- distance between 2 nuclei in Pb nucleus:
  $(1 / 0.17\ \mathrm{fm}^{-3})^{1/3} \sim 1.8\ \mathrm{fm} \sim 2 \times r_{Proton}$
  -> in p-Pb, correlation
  multiplicity - b much worse

- $N^{Part} \sim 7$, small !
  -> weak correlation multiplicity - N_{part}
  -> hard processes can easily bias
  multiplicity selection





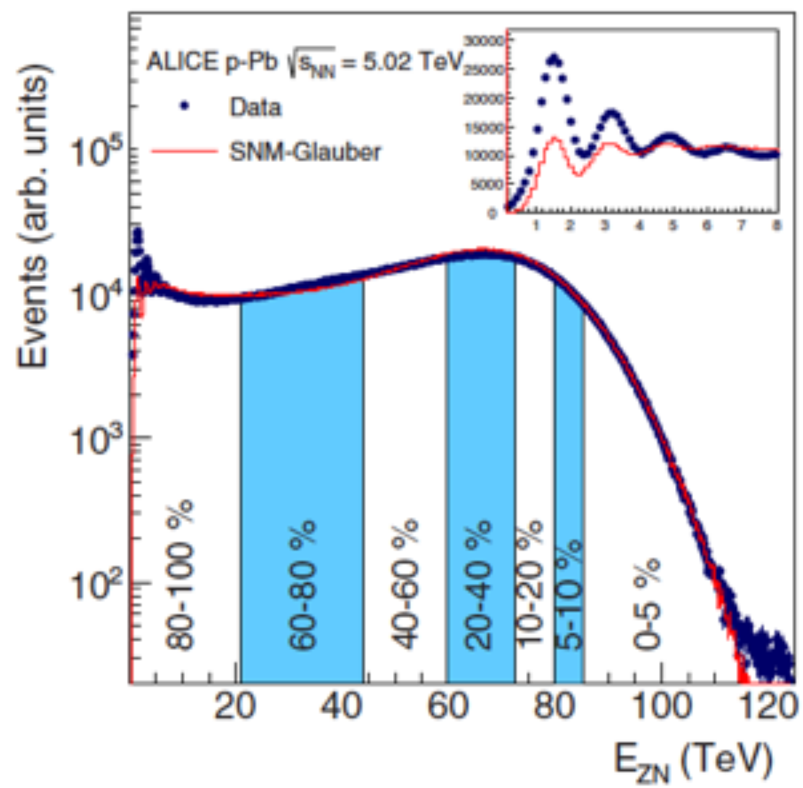
ALICE, Phys. Rev. C 91 (2015), 064905

Hybrid Model

- determine event classes from energy in zero-degree calorimeter (115 m from interaction point - no multiplicity bias)

- calculate N_{coll} from signal in V0A forward-scintillator

- $N_{coll,\ Pb\text{-}side}$: assume charged particle multiplicity is proportional to N_{part} - 1 = N_{coll}



ALICE, Phys. Rev. C 91 (2015), 064905

Jet Background Subtraction

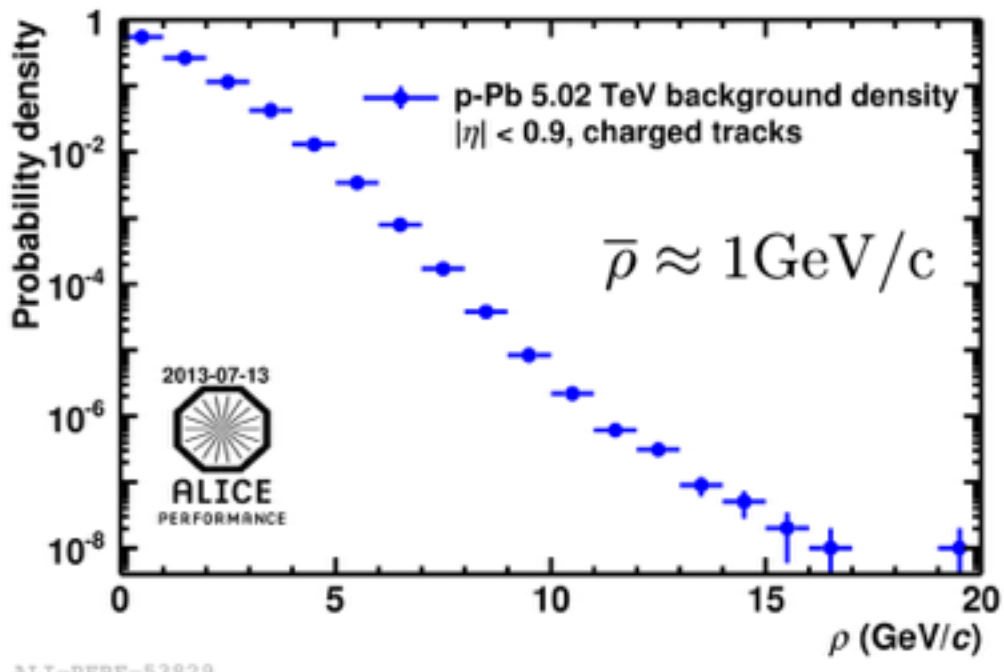
- jet reconstruction in p-Pb: background from underlying event not related to hard parton fragmentation

- estimate average background density from k_T clusters and subtract jet-by-jet

$$\rho = \text{median}\left\{\frac{p_{\mathrm{T},i}}{A_i}\right\}_i \cdot C$$

A_i : jet area
C: occupancy correction

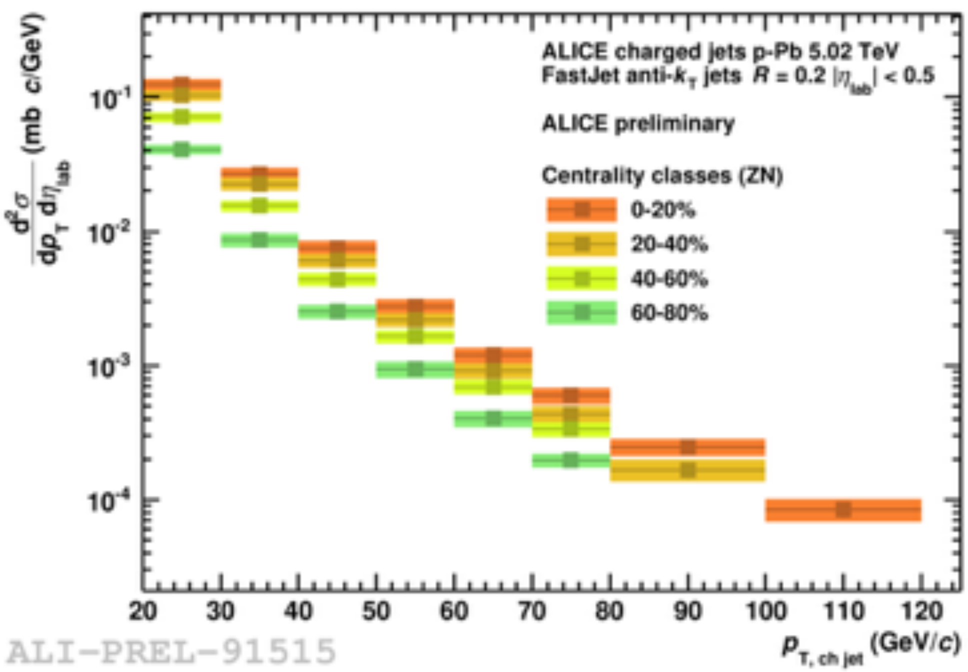
- background fluctuations and detector effects corrected through unfolding

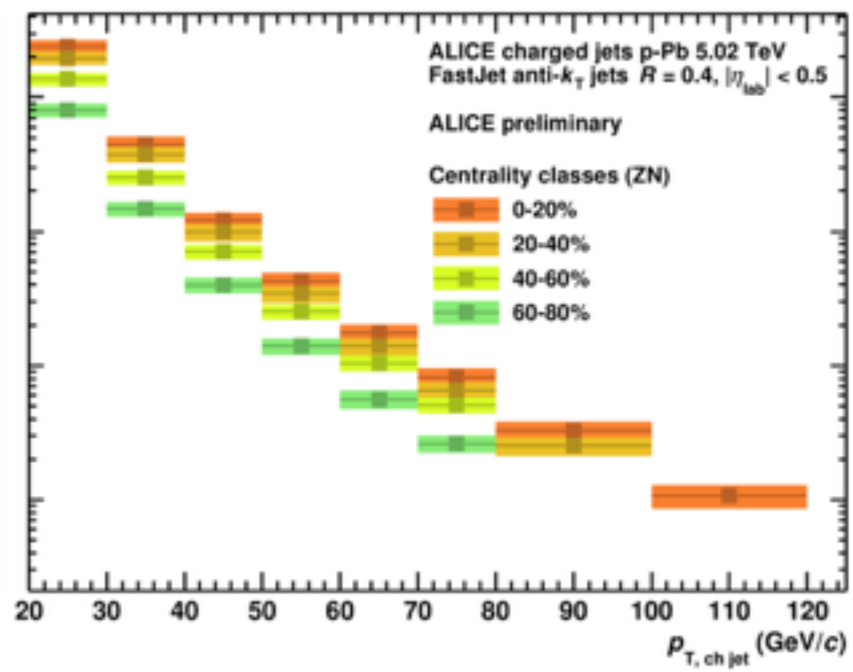


Charged Jet Cross Section

- 4 centrality bins

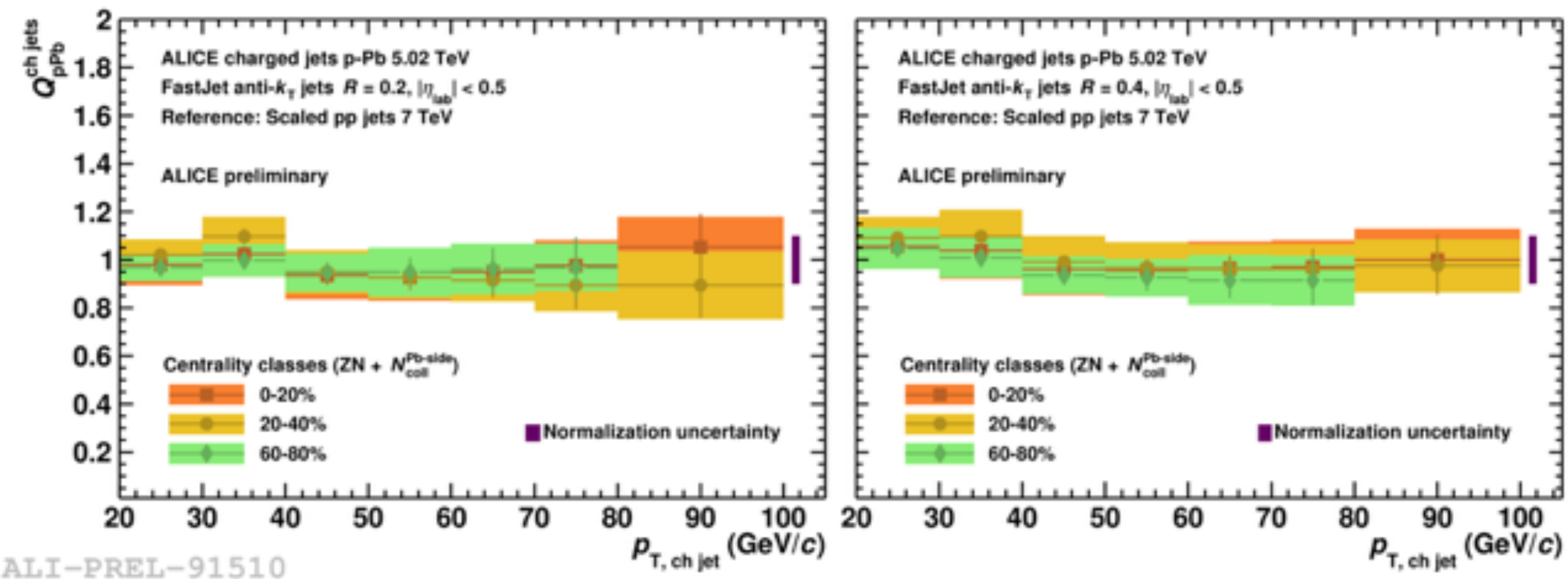
R = 0.2 **R = 0.4**





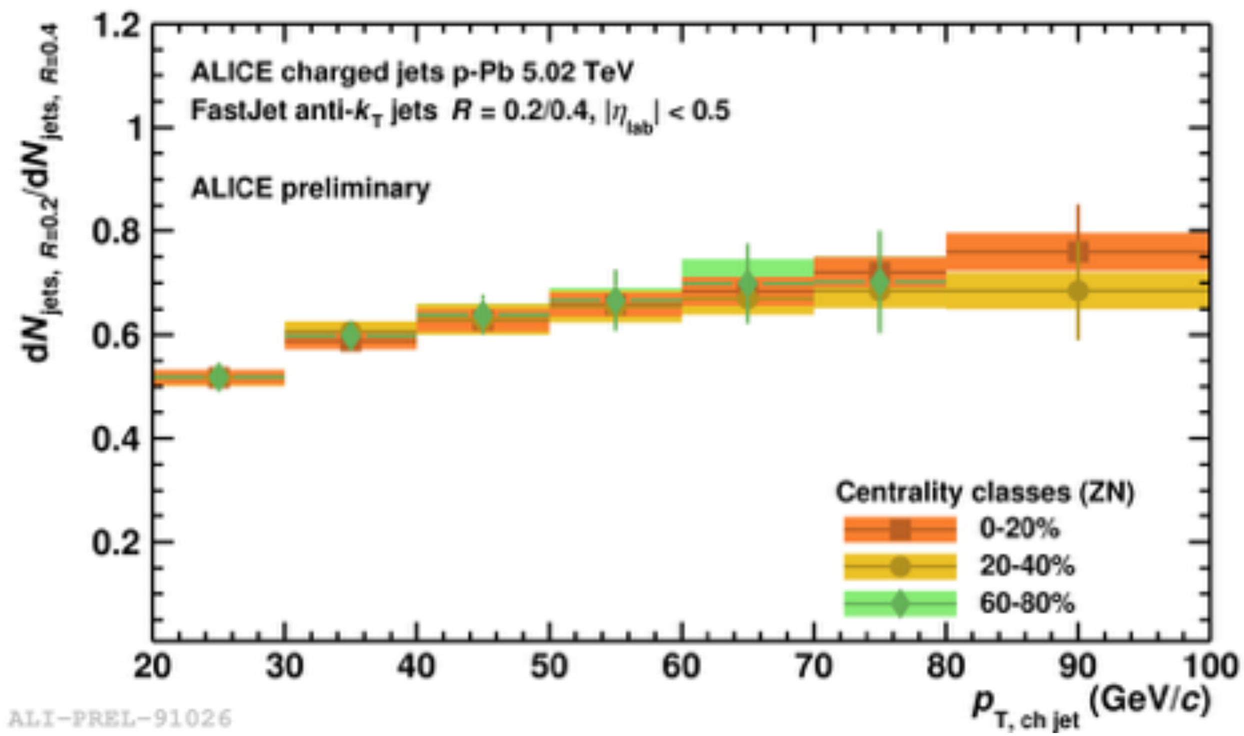
Nuclear Modification Factor

- $$Q_{\mathrm{pPb}} = \frac{\text{p-Pb yield}}{\text{pp x-section}} \cdot \frac{1}{T_{\mathrm{pPb}}}$$
- $\langle T_{\mathrm{pPb}} \rangle$: nuclear overlap function from Glauber Calculation using $N_{\text{coll, Pb side}}$
- no significant nuclear modification observed



Cross Section Ratio

- spectral ratio R = 0.2 / R = 0.4 sensitive to radial jet structure
- no significant centrality dependence



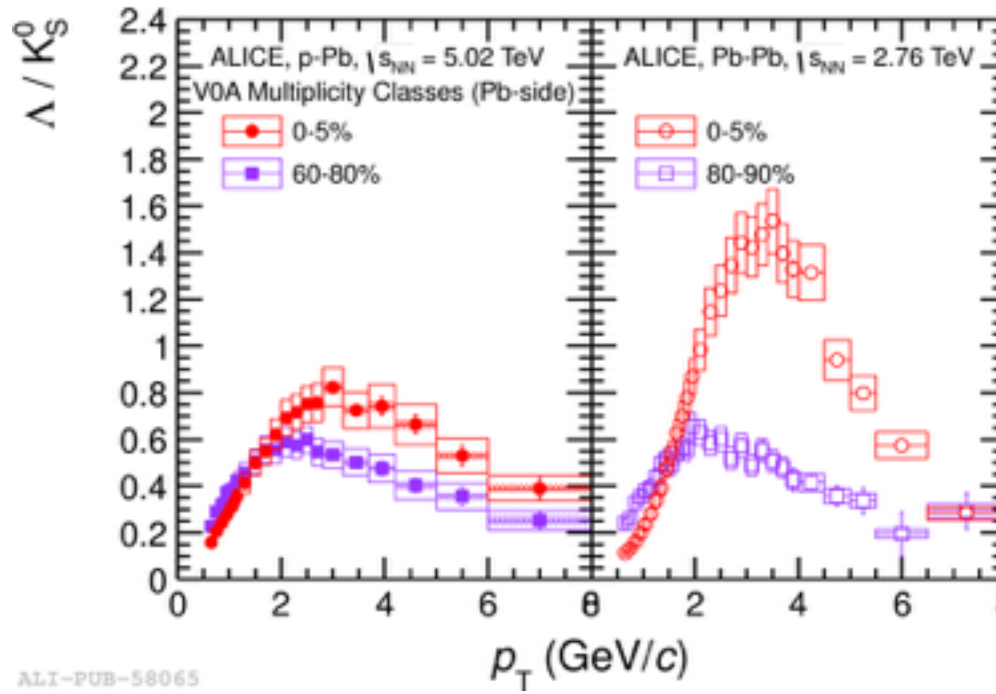
Strangeness Production in p-Pb

- inclusive strangeness production in central Pb-Pb collisions: strong enhancement of Λ/K^0_S ratio at intermediate p_T

- involving several phenomena:
  - flow
  - hadronization through recombination ?
  - jet fragmentation

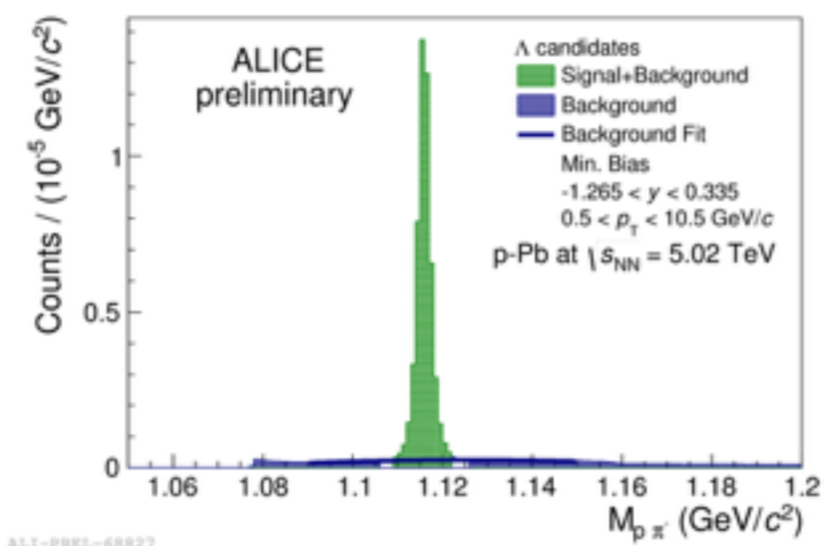
- qualitatively similar observation in p-Pb

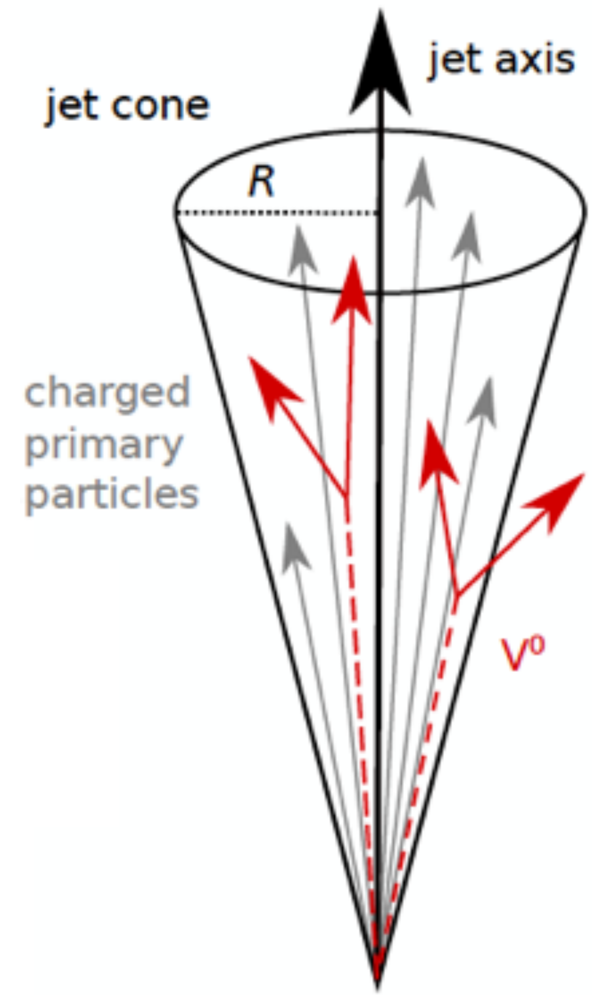
- strangeness in jets in p-Pb: separate soft and hard processes



Strangeness in Jets in p-Pb

- K^0_S and Λ identication via decay topology ('V^0')
- reconstruct V^0s and jets independently
- match V^0s to jet cone: $R(V^0, jet) < R_{jet}$
- signal extraction via invariant mass, subtraction of combinatorial background



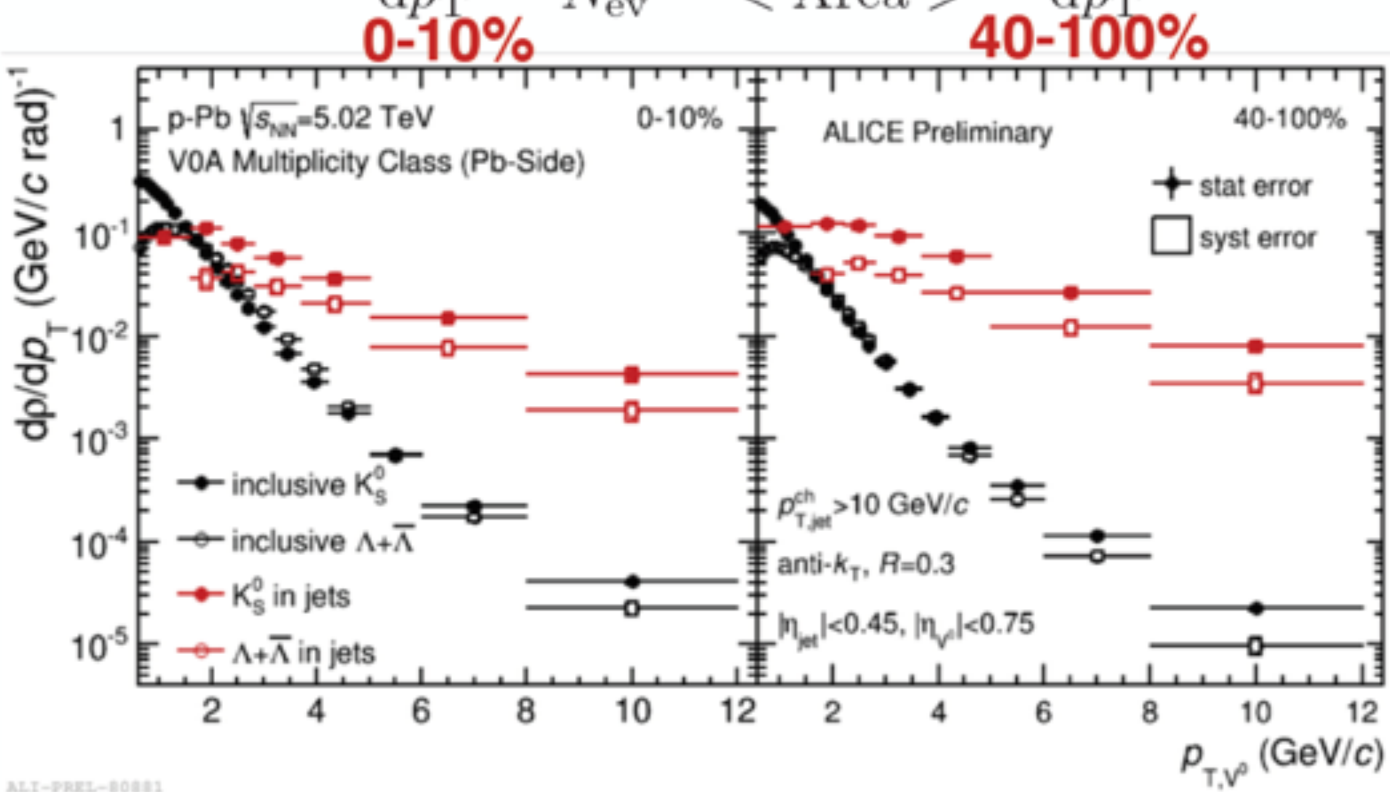


p_T Spectra

- transverse momentum spectra of K^0_S and Λ in charged jets with $p_{T,jet} > 10$ GeV/c

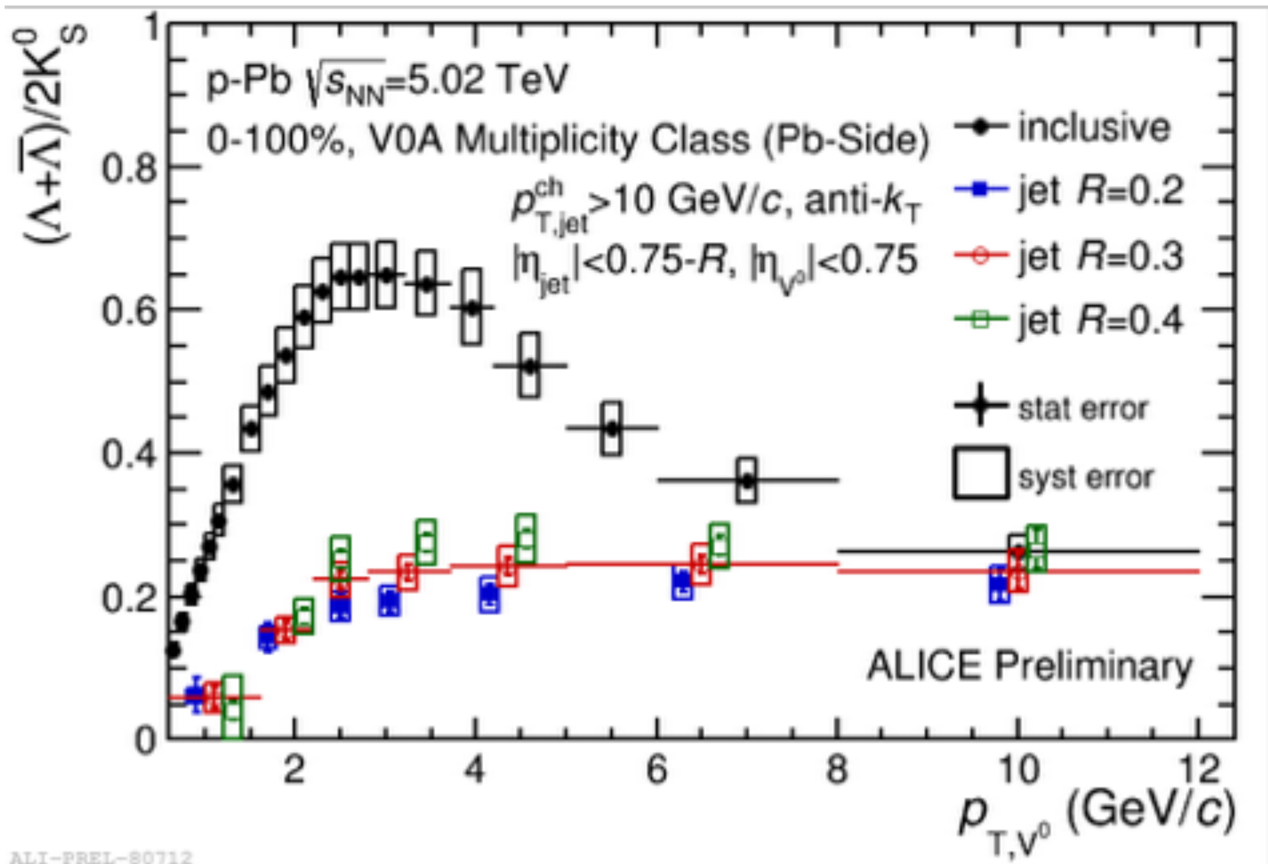
- normalized per event and unit acceptance ($\Delta\eta\Delta\phi$)

$$\frac{d\rho}{dp_T} = \frac{1}{N_{ev}} \times \frac{1}{< \mathrm{Area} >} \times \frac{dN}{dp_T}$$



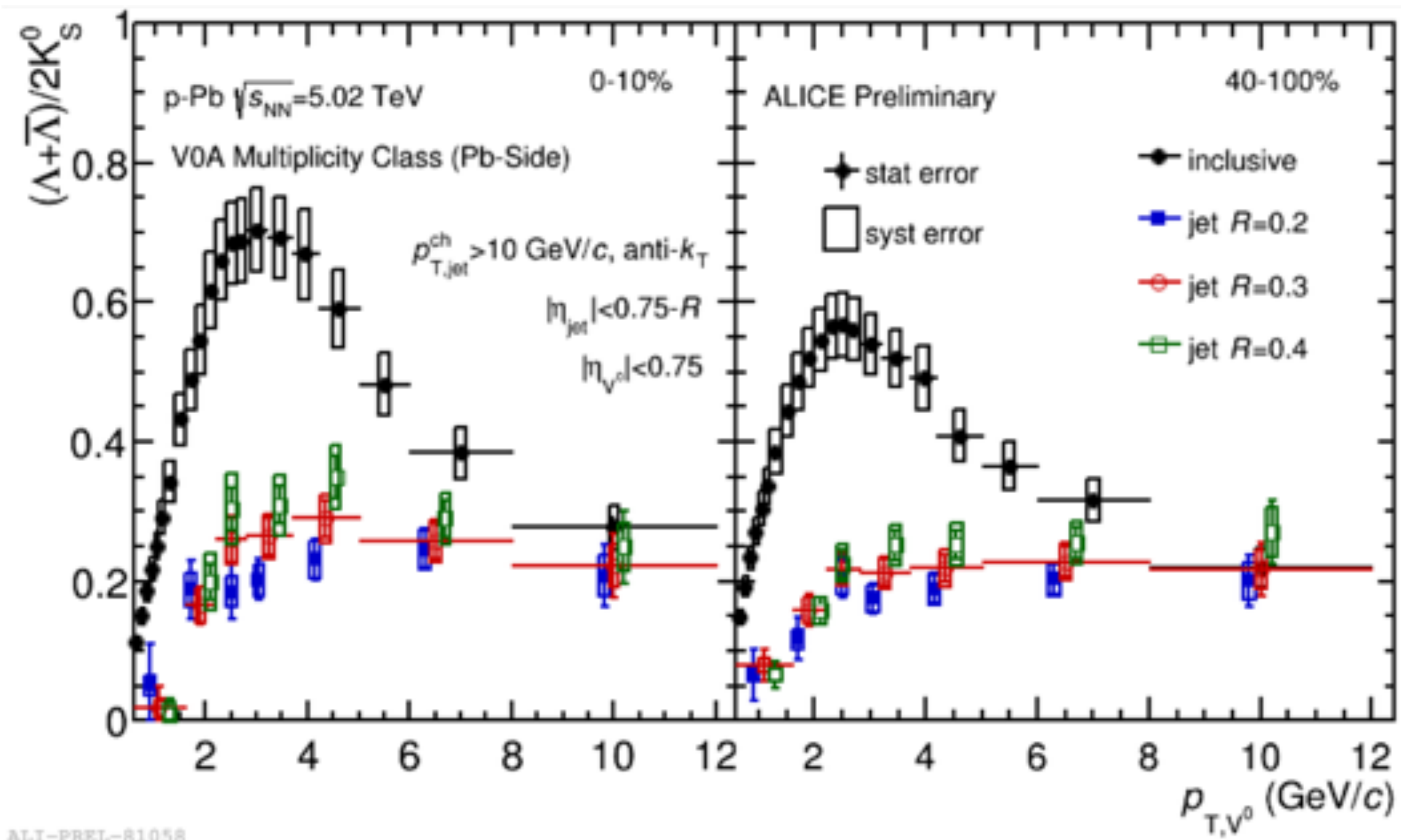
Λ / K^0_S Ratio

- Λ / K^0_S ratio in jets in Minimum Bias collisions
- significantly lower than inclusive ratio



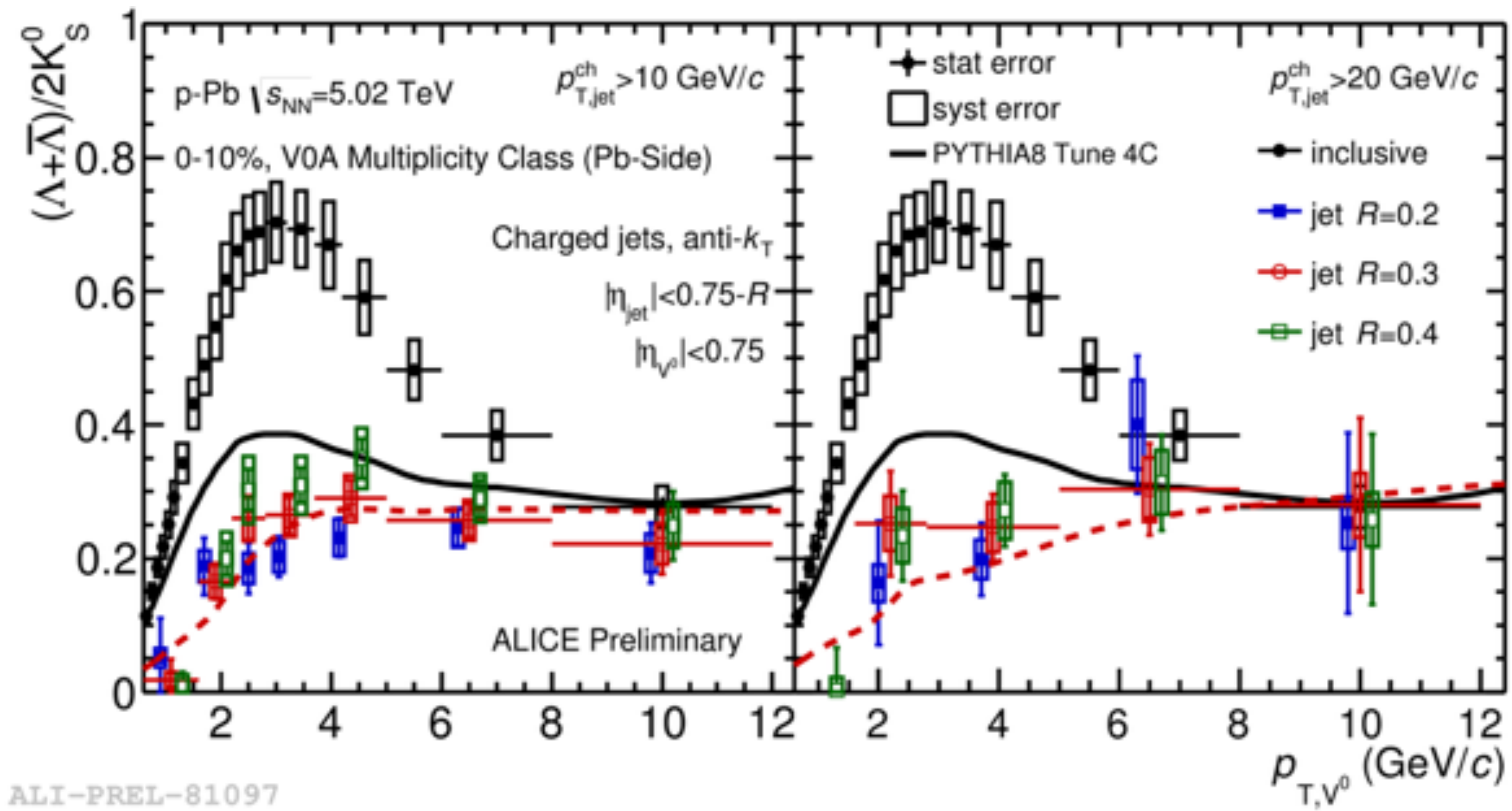
Event Multiplicity Dependence

- results for 2 V0A multiplicity classes
- no significant dependence on multiplicity



PYTHIA Comparison

- PYTHIA8 pp : Λ / K^0_S ratio in jets similar to inclusive
- simulations describe strangeness in jets, but not inclusive production



Summary

- charged jet fragmentation:
  dN/dz scaling in low-p_T jets

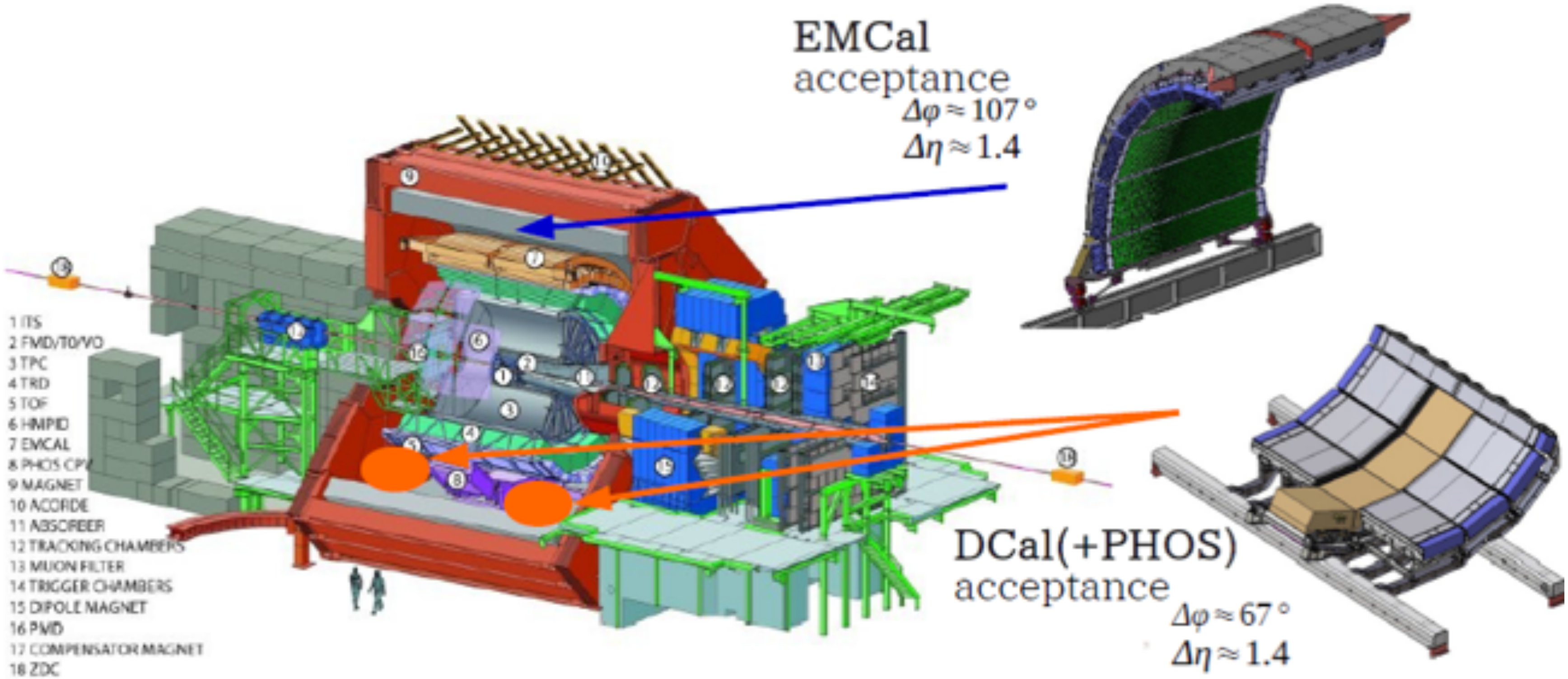
- identified kaons, protons and charged pions in jets
  well described by PYTHIA 6 simulations without CR

- charged jets in p-Pb collisions:
  no nuclear modification observed for central collisions

- strangeness in p-Pb:
  strange baryon/meson ratio smaller than inclusive production, no event multiplicity dependence

- Backup -

ALICE in run 2: DCal

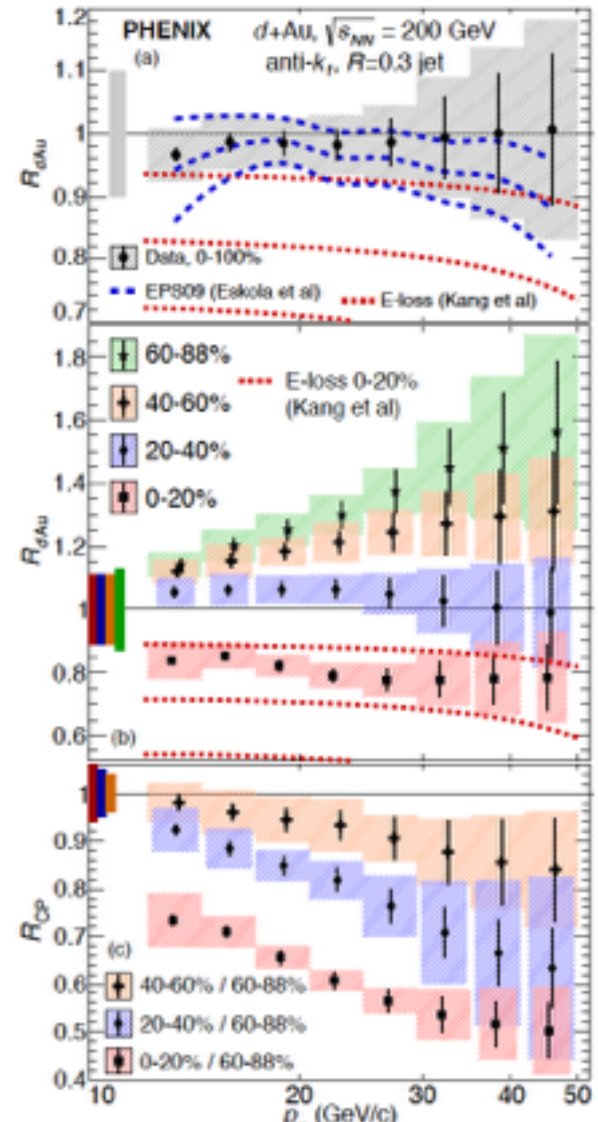


- run 2: DCal upgrade
  - significantly extended jet acceptance
  - back-to-back in azimuth (di-jet topology)

PHENIX jet R_{dAu}

- PHENIX d-Au:
  - suppression in central events
  - enhancement in peripheral events

- can not be explained by trivial multiplicity bias

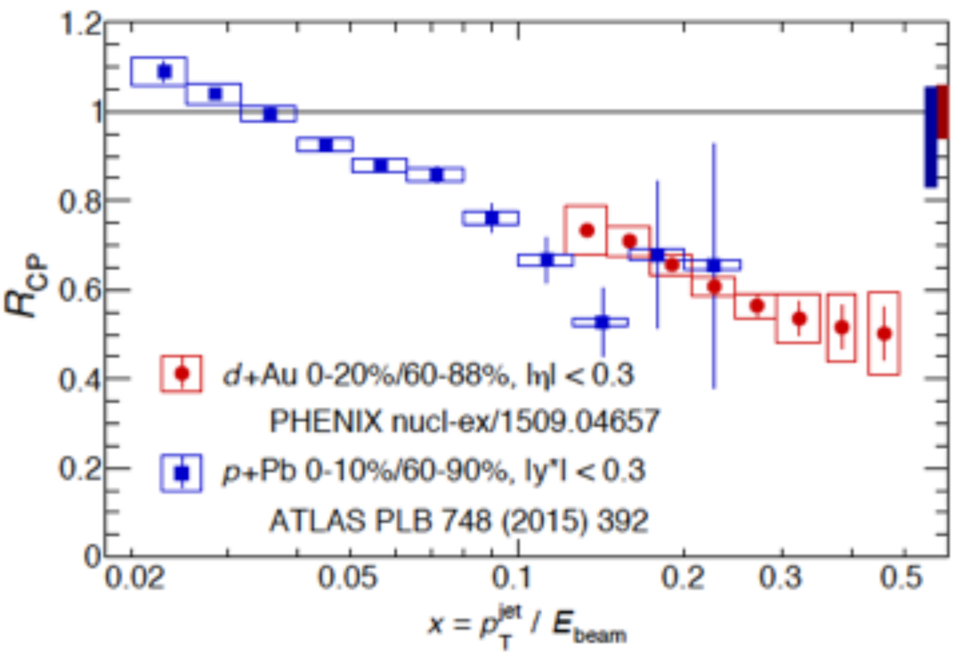


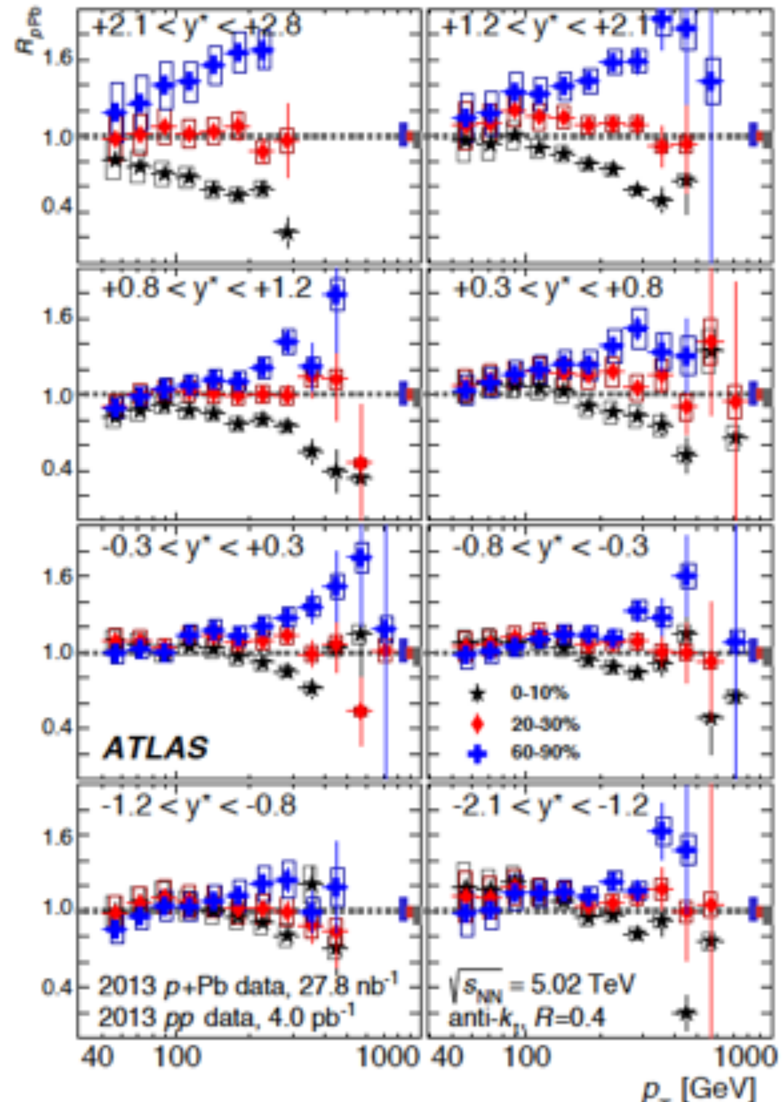
arXiv: 1509.04657 [nucl-ex]

PHENIX and ATLAS

ATLAS, 1412.4092 [nucl-ex]

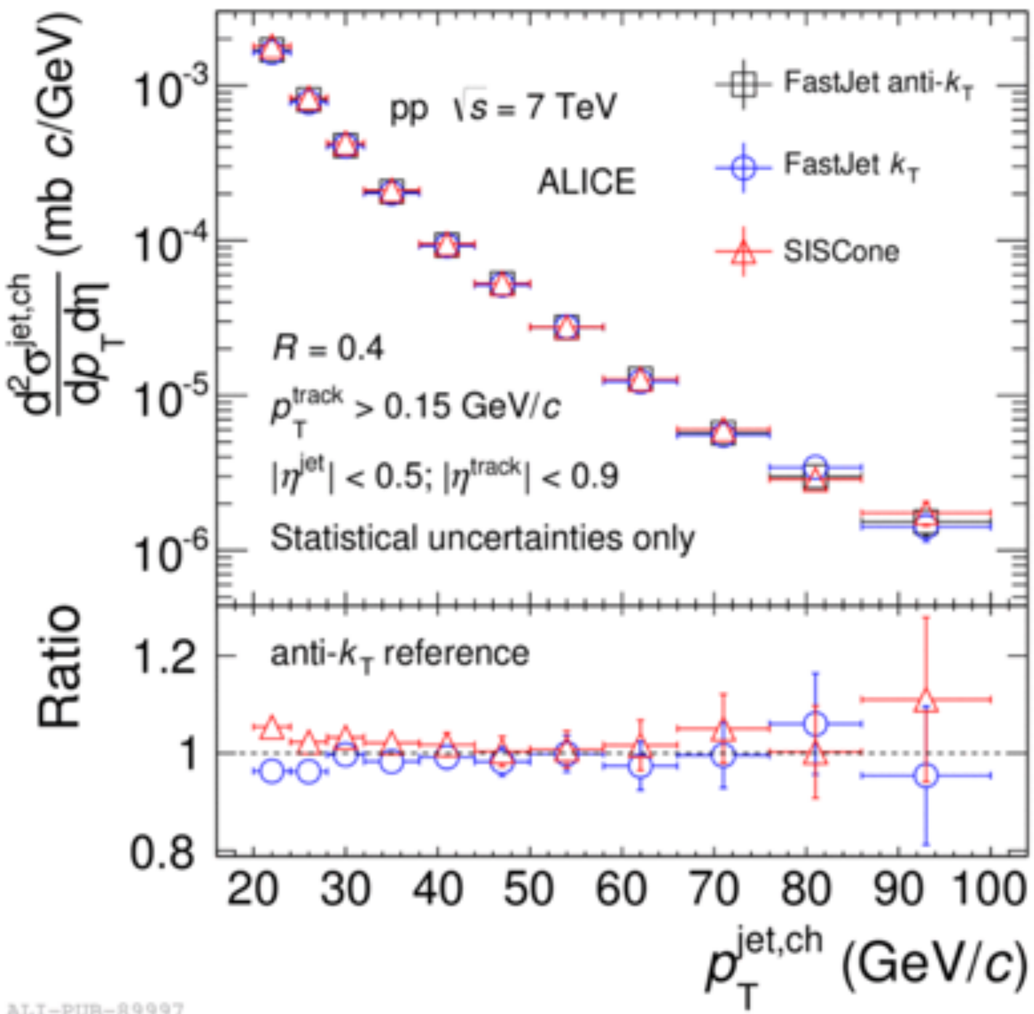
- similar observation by ATLAS
- initial state effect scaling with x ?





A. Hanks, QM 15

Jet finder comparison

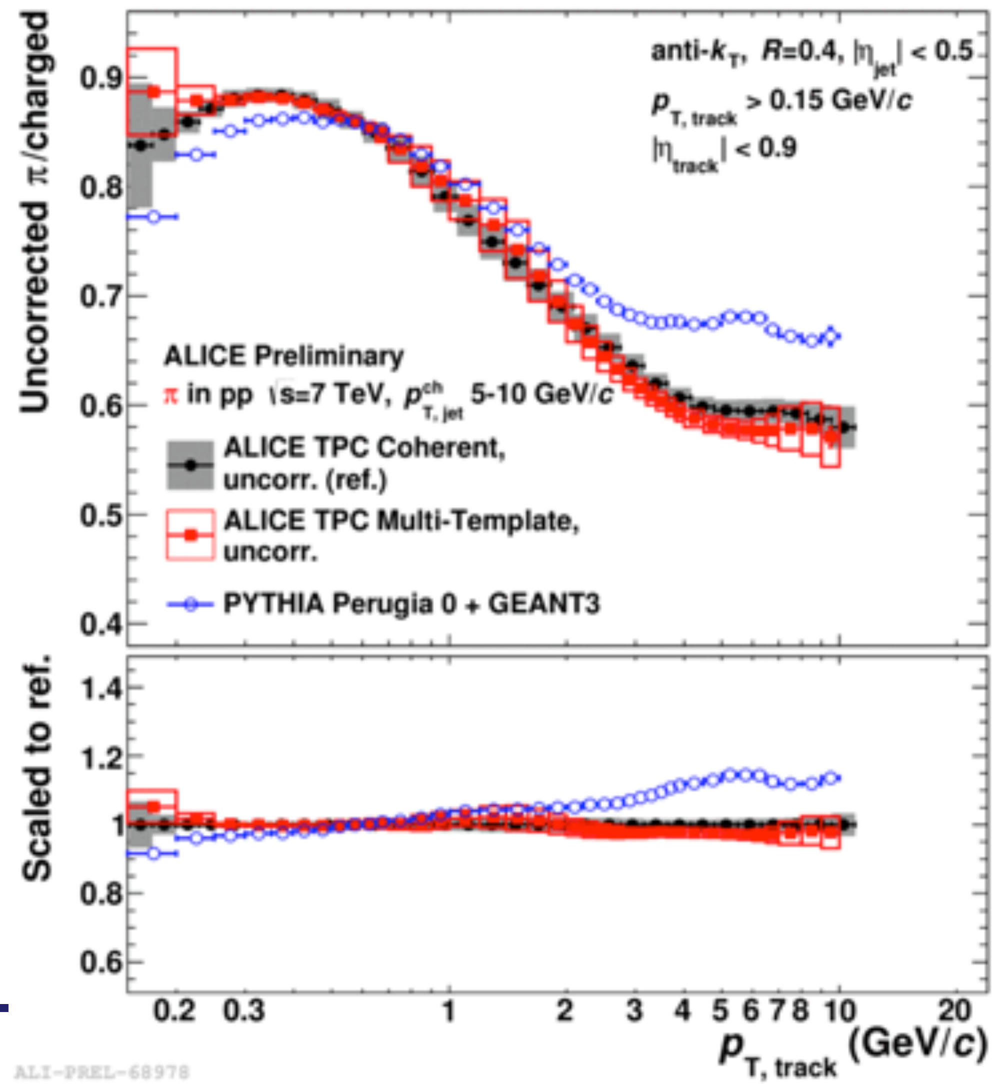


- kT: sequential recombination
- SISCone: cone algorithm

nucl-ex/1411.4969

Method comparison

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



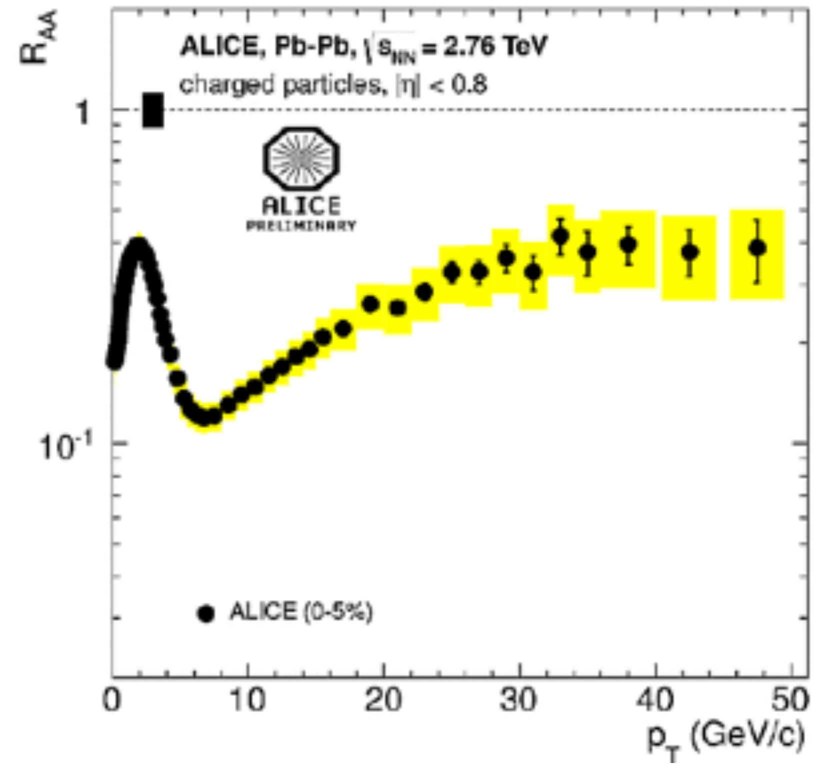
Hadrons in heavy-ion collisions

PLB 720 (2013) 250

- high- p_T hadrons `proxy' for jet
- jet quenching for charged hadrons, Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV

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

- hadron observables biased towards leading fragment



→ study the effect for fully reconstructed jets

Jet nuclear modification factor

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

Phys.Lett. B746 (2015) 1

- increase of suppression with centrality

JEWEL: PLB 735 (2014)

YaJEM:PRC 88 (2013) 014905

- weak p_T dependence

- JEWEL and YaJEM jet quenching models reproduce suppression