
http://qm2014.gsi.de/

# Measurement of hadron composition in charged jets from pp collisions with the ALICE experiment

Xianguo Lu

Physikalisches Institut, Universität Heidelberg

for the ALICE Collaboration

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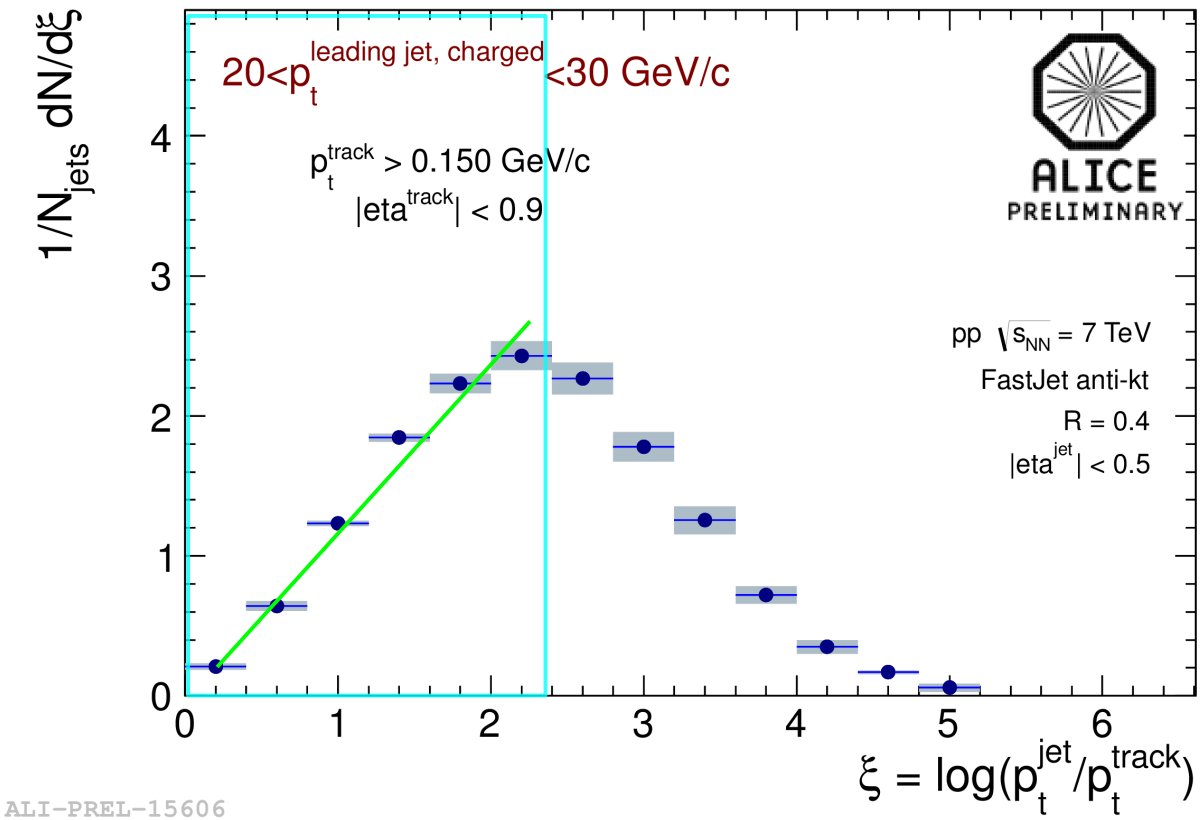
# Motivation

- Jets are phenomenological objects constructed to represent partons originating from hard scattering processes.
- Inclusive charged jet fragmentation in pp collisions measured by ALICE

  → Above $p_T^{jet}$ 20 GeV/$c$, jet $p_T$ scaling for $z=p_T^{track}/p_T^{jet}$ >0.1 ( $\xi$ = -log $z$ < 2.3 )



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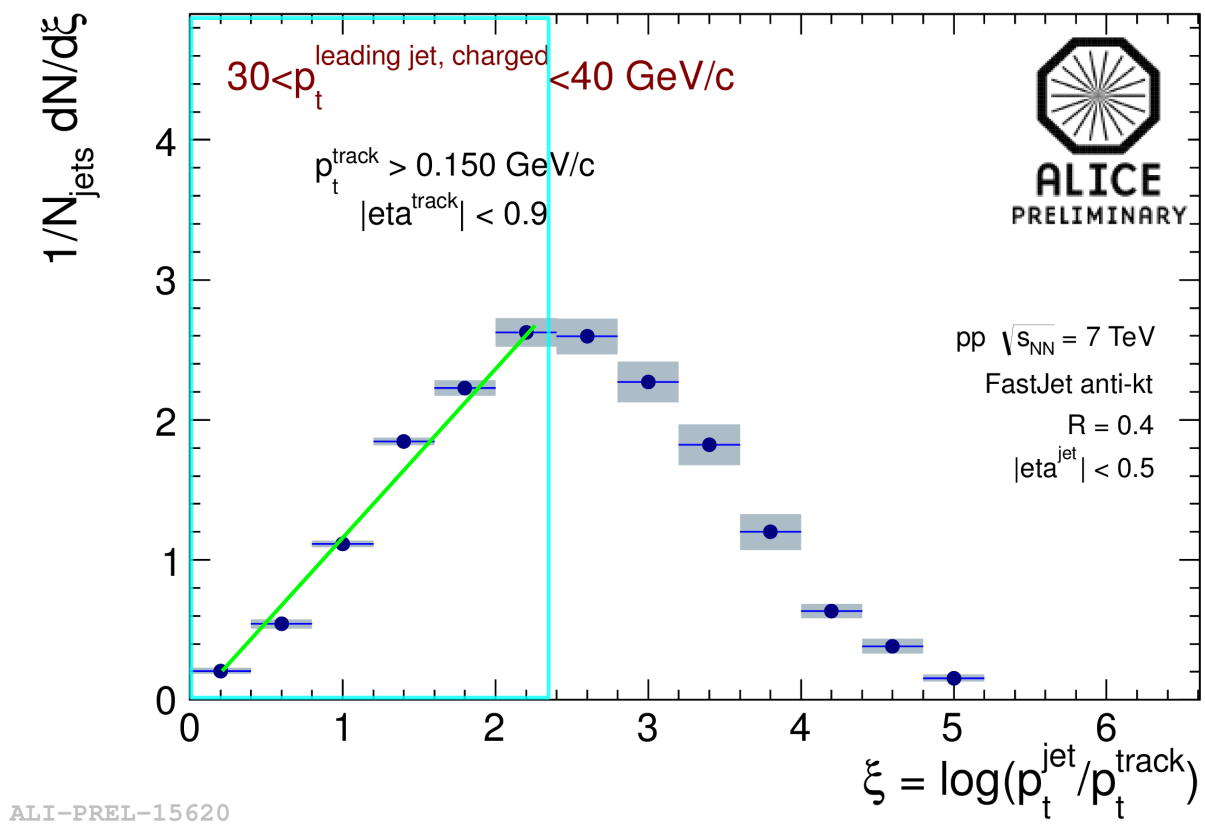

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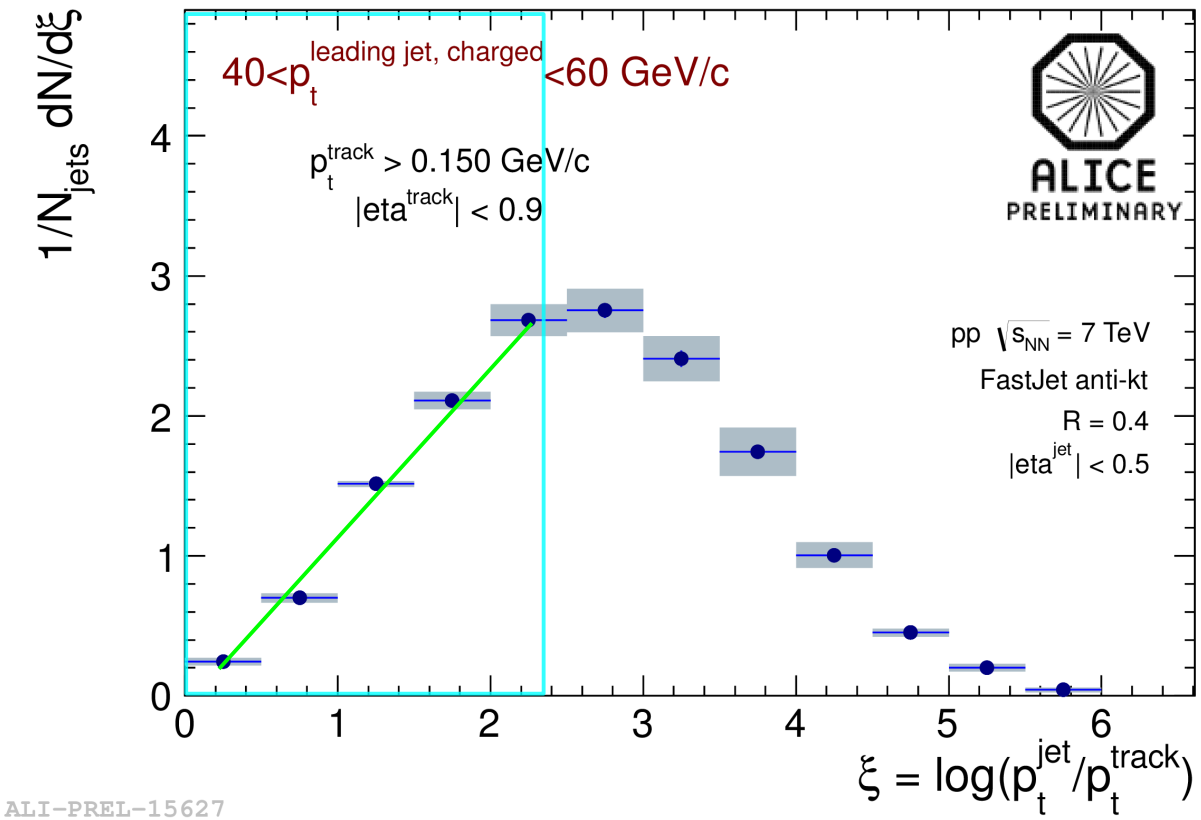
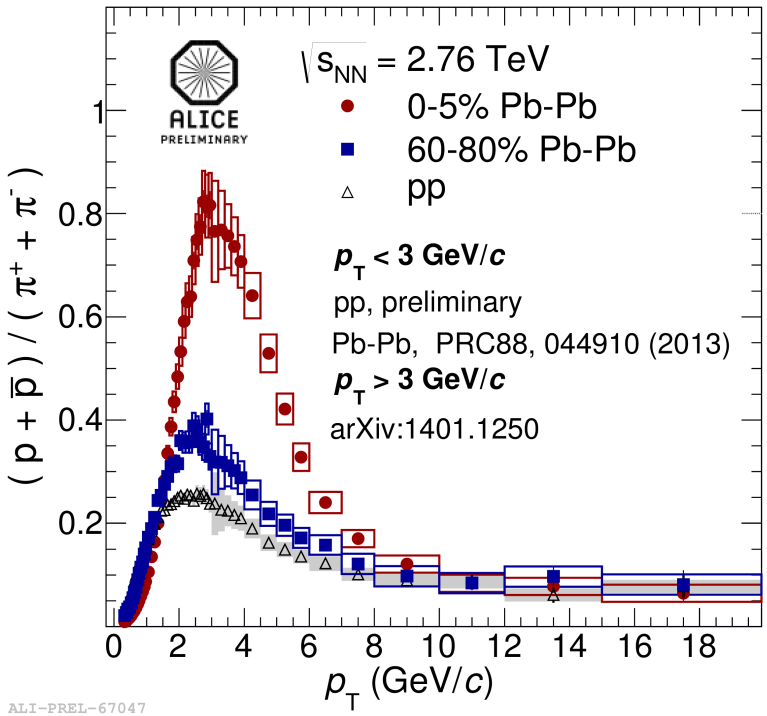


# Motivation

- Identified particle spectra in pp and Pb-Pb collisions measured by ALICE

  → large p/π in intermediate $p_T$




- ALICE Particle IDentification capability allows to identify particle types in jets

  → ***first measurement of particle type dependent jet fragmentation at hadron colliders***

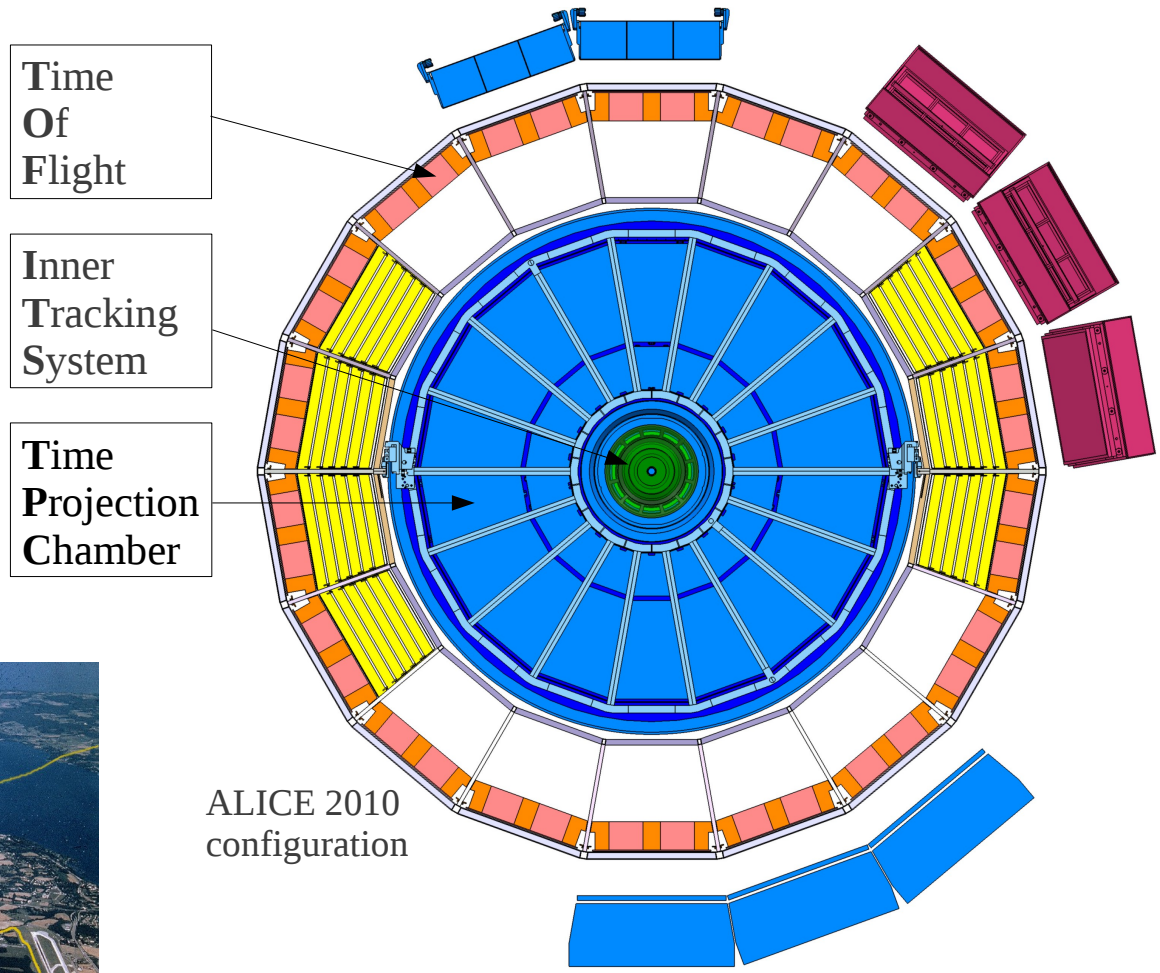
  → unique measurement to provide constraint on fragmentation models

  → baseline technique for PID in jets from Pb-Pb collisions

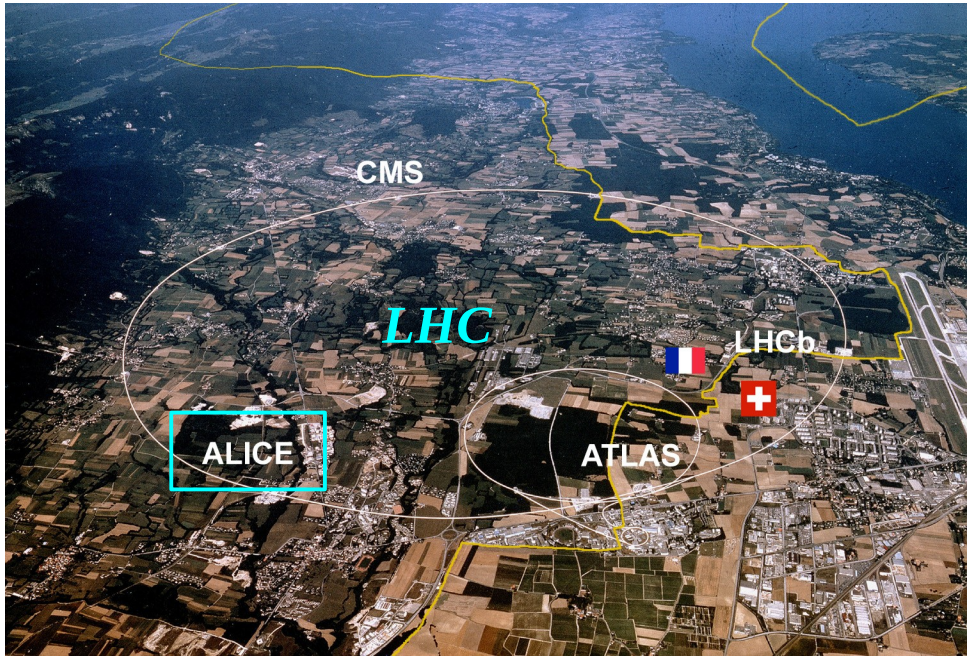
# The ALICE Experiment

ALICE: A Large Ion Collider Experiment

- High multiplicity environment
  - High granularity
- Very low $p_T$ cut-off ~ 100 MeV/$c$
  - Very low material budget ~10%$X_0$
  - Moderate B-field 0.5 T
- PID: large momentum range
  - d$E$/d$x$, Transition Radiation, TOF, Cherenkov ...




ALICE 2010 configuration

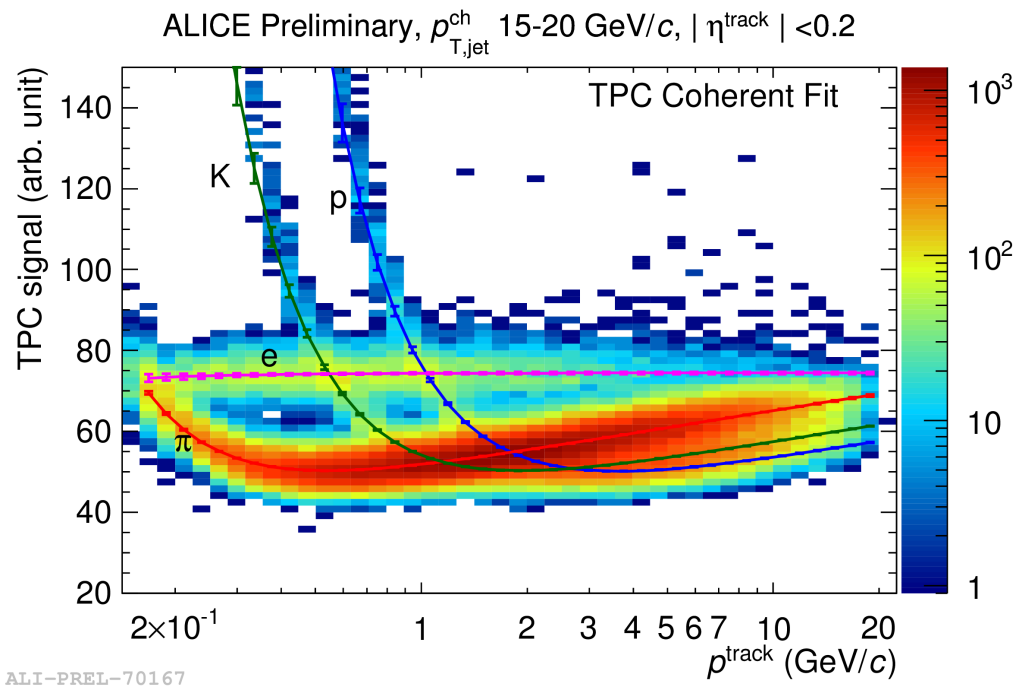



http://www.jamin86.com/cern/

π/K/p yields in charged jets from pp collision at 7 TeV

- FastJet anti-$k_T$ with $R$=0.4
- $p_T^{jet}$ 5-10, 10-15, 15-20 GeV/$c$
- Advanced statistical PID methods (next slides):
  - TPC Coherent Fit
  - TPC Multi-Template Fit

# PID in jets – TPC Coherent Fit




- Most abundant particle types: π, K, p, e
- Gaussian signal shape (d$E$/d$x$ truncated mean)
- Continuous signal mean and width → models
- Continuous particle fractions
  - Allowing only statistical deviation from neighbor interpolation

Maximum likelihood estimation

$$l = l_{\text{stat}} + l_{\text{reg}}$$

1 distribution
1 regularized likelihood function

1 optimization

Calibration of TPC signal
Particle yield extraction

Likelihood function built from signal models and fractions –
***Coherence:***
***full-range constraint on dE/dx model***

***feedback***

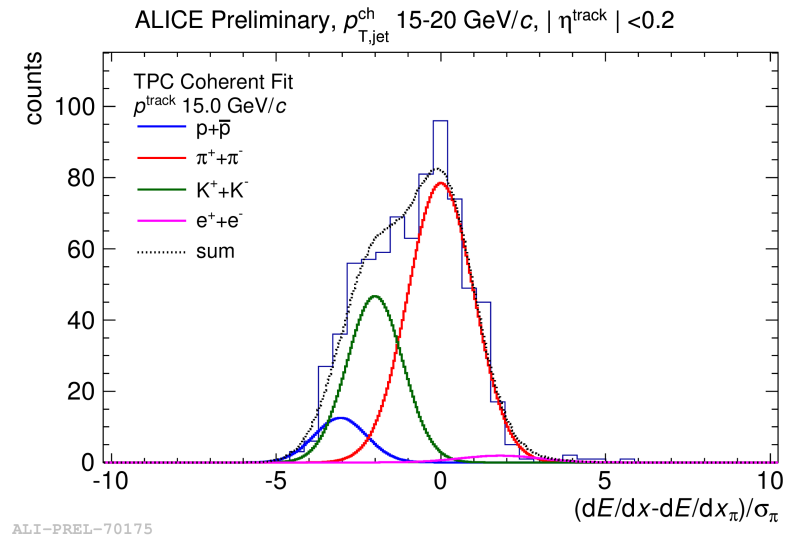
***constraint on fractions***

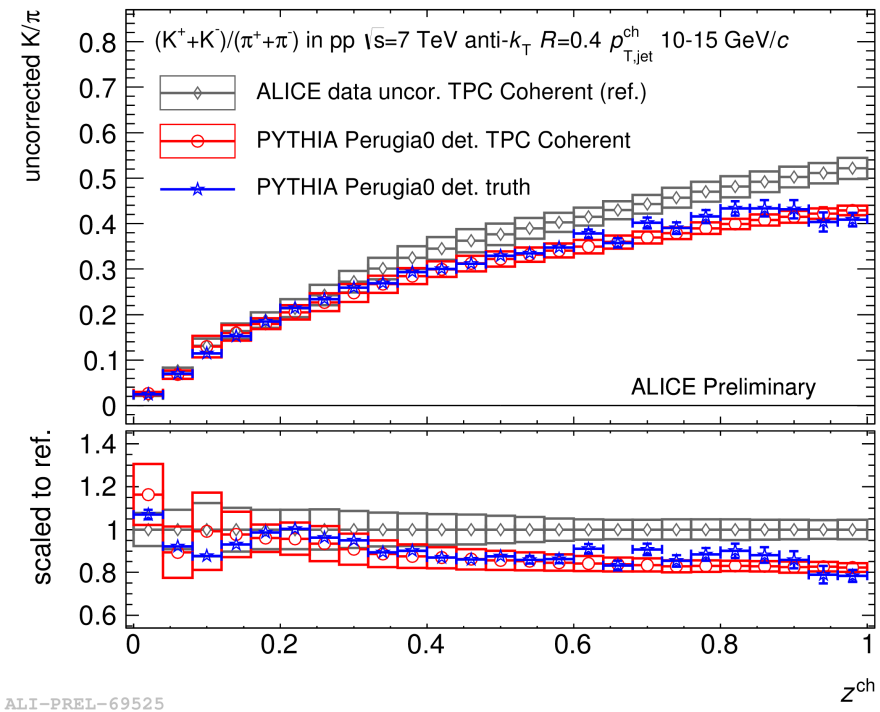
Regularization on continuity condition of particle fractions: maximal use of information

Origin: X.-G. Lu, Doctoral dissertation, University of Heidelberg (2013).
http://archiv.ub.uni-heidelberg.de/volltextserver/15651/

# PID in jets – TPC Coherent Fit

- Particle fraction at high $p_T$ (>4 GeV/$c$) very sensitive to d$E$/d$x$ mean
  - 5% d$E$/d$x$ K-p separation
    - 1 per mil d$E$/d$x$ bias
      - → 0.1%/5% = 2% fraction bias
- Major systematics on PID in jets
  - TPC d$E$/d$x$ model uncertainty
  - Change of TPC d$E$/d$x$ quality
  - Particle type dependence of d$E$/d$x$
    - Negligible: -0.1±0.3%
  - ***Jet $p_T$ dependence of dE/dx***
    - Critical: 0.3% d$E$/d$x$ increase per 5 GeV/$c$ $p_T^{jet}$ increase due to enhanced track density
    - ***Automatically taken into account***



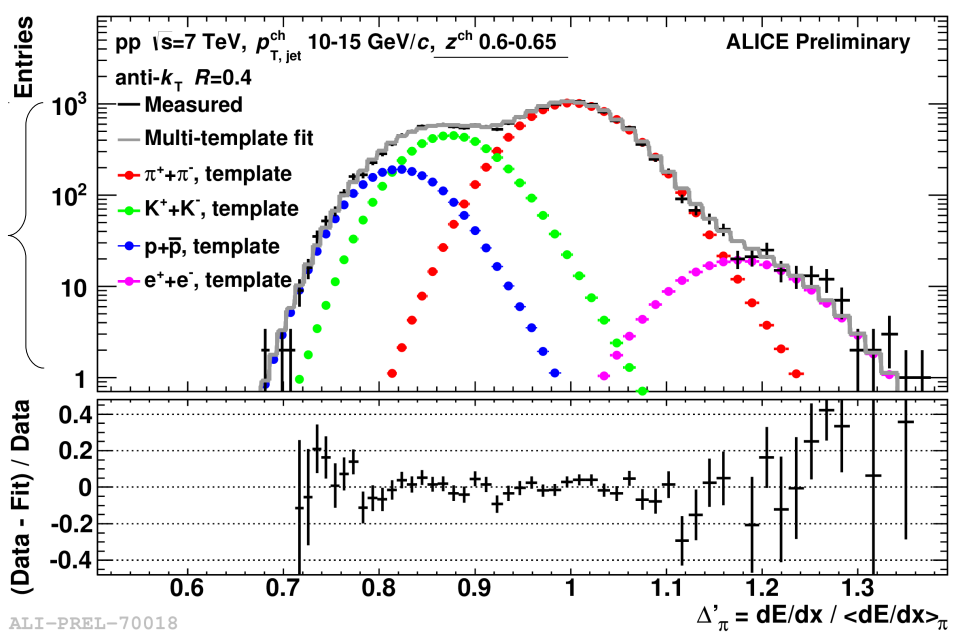



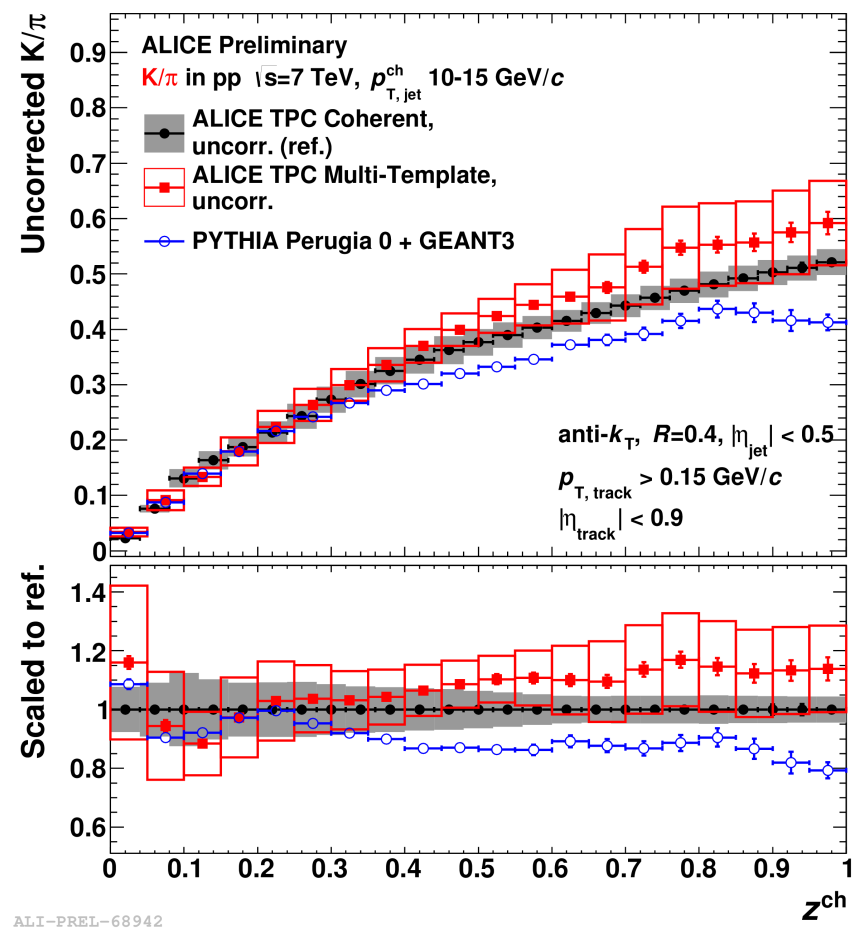
# TPC Multi-template Fit
# (Poster: Benjamin Andreas HESS, 20/5 14:30)

- Model TPC d*E*/d*x* response in detail (function of number of ionization clusters, track phase space, etc.) with pure particle samples selected via
  - TPC d*E*/d*x*, TOF and V0 daughters ($K^0$s/ Λ decays, γ conversions)
- High $p_T$ d*E*/d*x* determined by d*E*/d*x* model fit to clean samples
- Generate TPC d*E*/d*x* templates for a given track sample and for each particle species with parametrized yield fractions - ***done directly in z bins***
- Minimize template-data difference

***Two independent methods with different systematics give consistent results.***

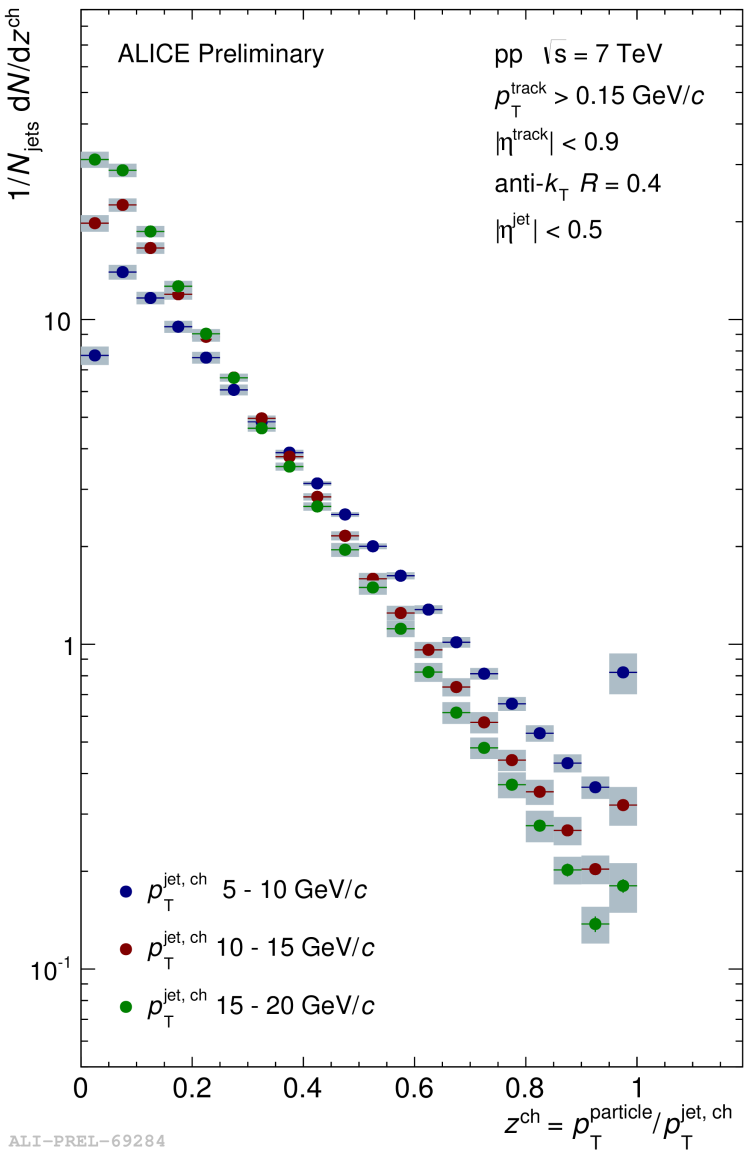
3 orders of mag.



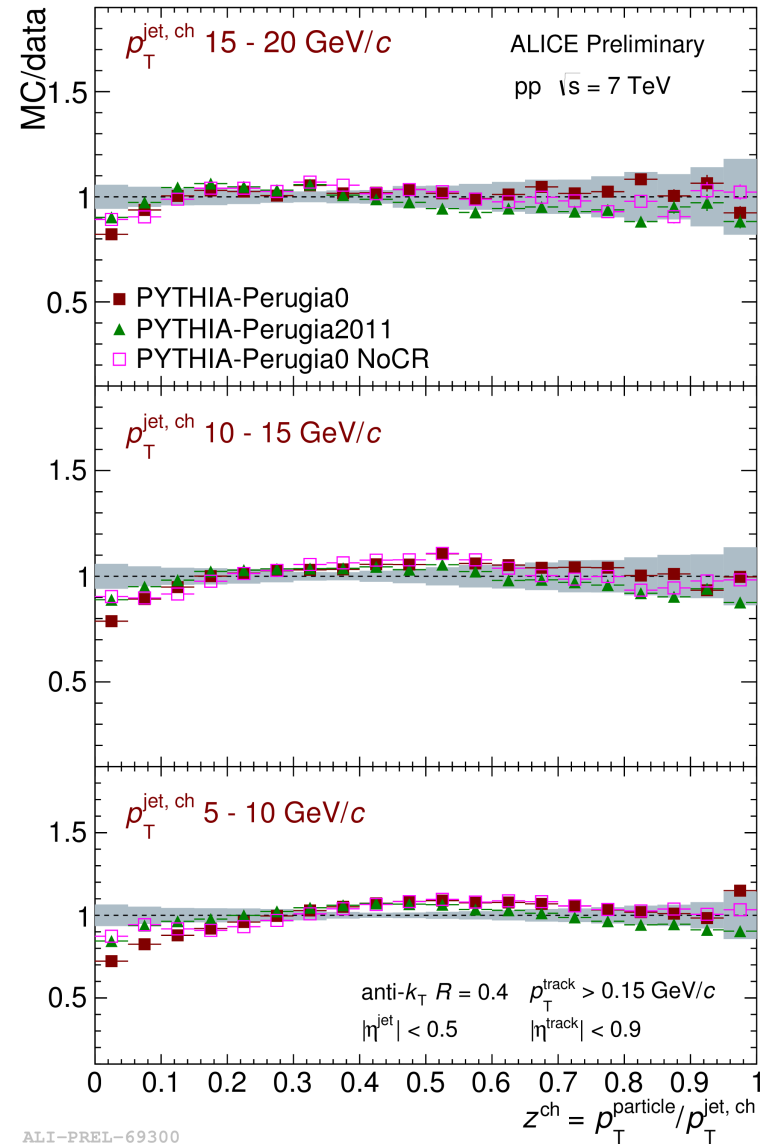



***The following results are shown for the first time in conferences.***

# Jet constituent spectra – all charged particles



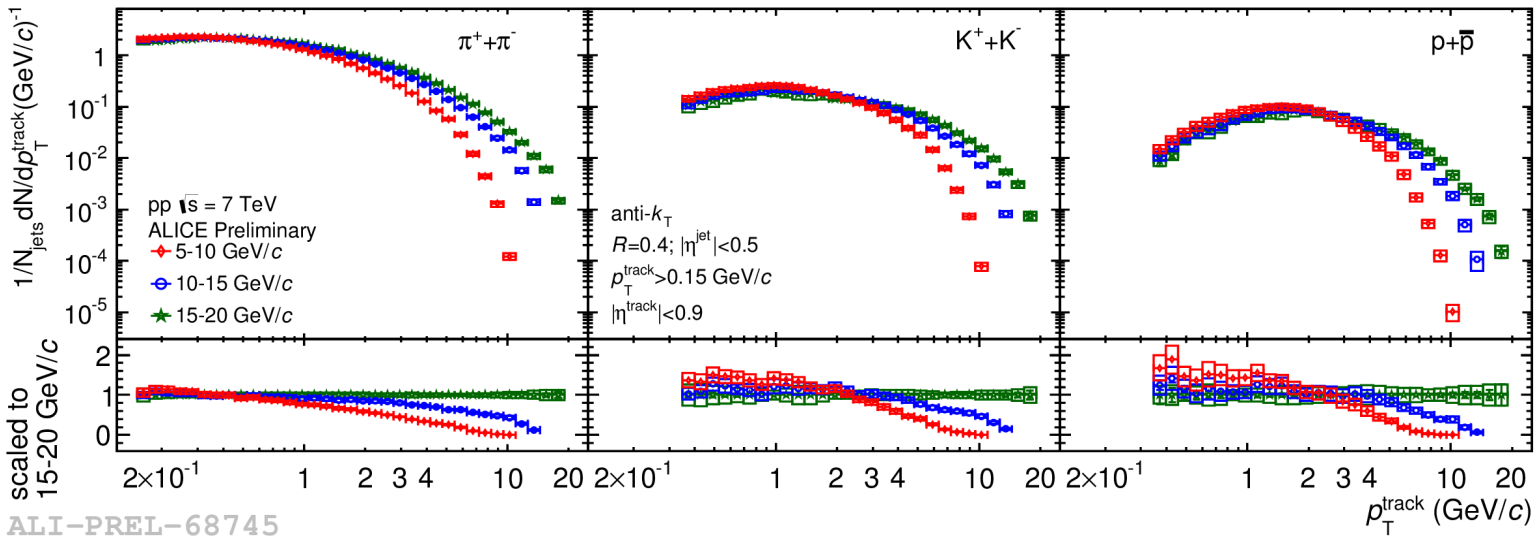

*disappearance of scaling at lowest jet $p_T$*




*description improves with jet and particle $p_T$*

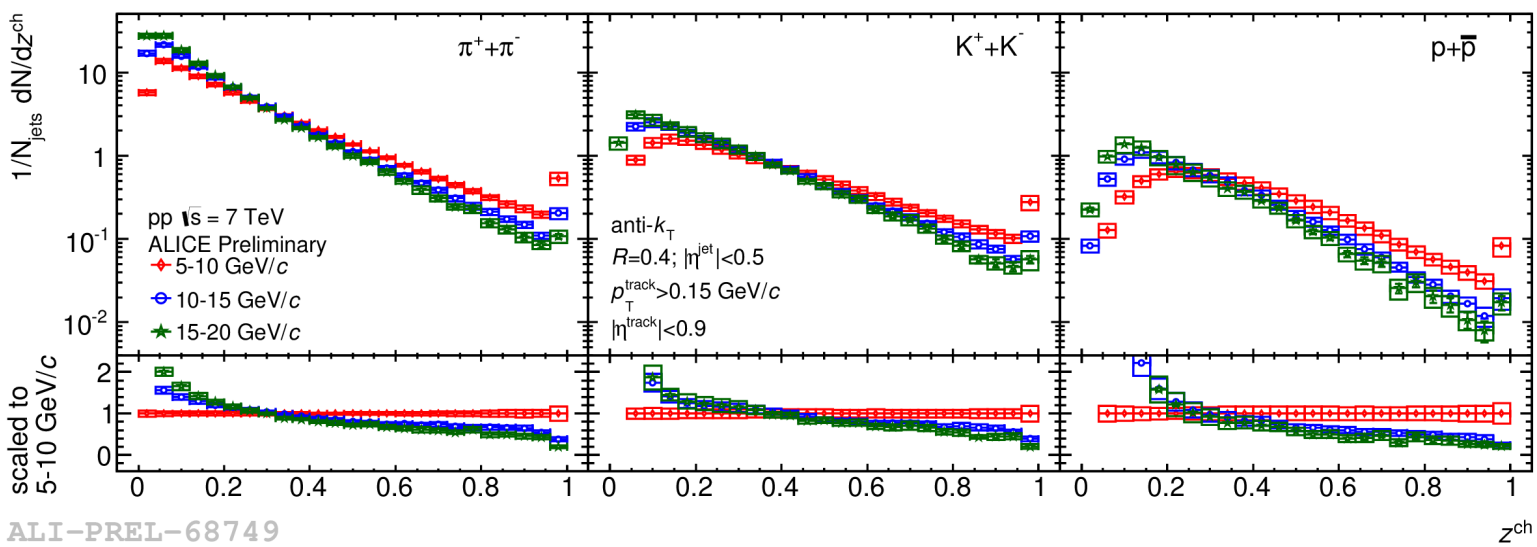
# π/K/p yields in charged jets from pp collisions at 7 TeV

**PID up to $p_T$ = 20 GeV/*c***




$p_T$ dependence

- Span 3-4 orders of mag.
- Harder spectra at high jet $p_T$
- Crossing at $p_T$ 0.4 (2) GeV/*c* for π (K,p)
- ln(N) parabolic in ln($p_T$)
  - ξ-spectra Gaussian shape

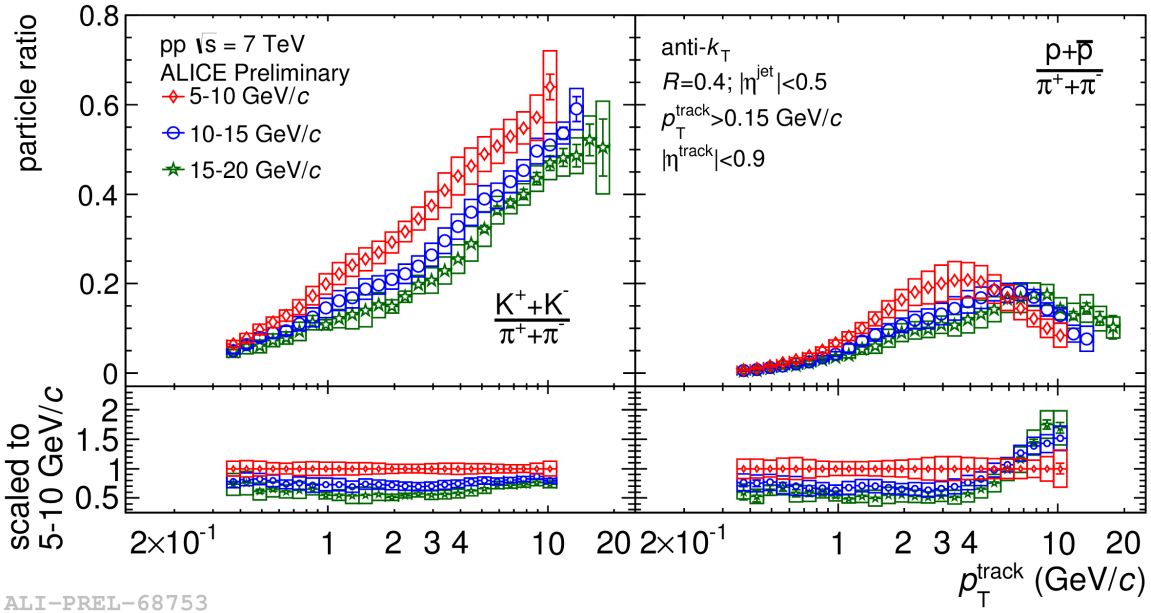



*z* dependence

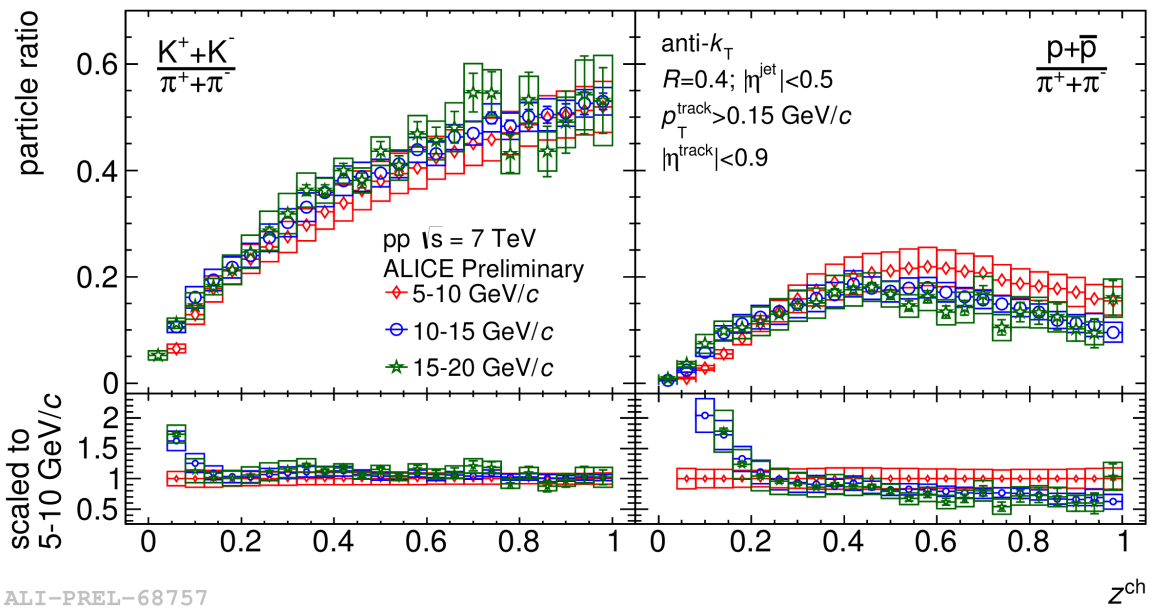
- Span 1-2 orders of mag.
- Jet $p_T$ ordering opposite
- Crossing at *z* 0.3-0.4
- Exponential especially for light hadron

→ ***disappearance of scaling at lowest jet $p_T$***

# K/π and p/π in charged jets from pp collisions at 7 TeV




- No scaling with particle $p_T$ observed

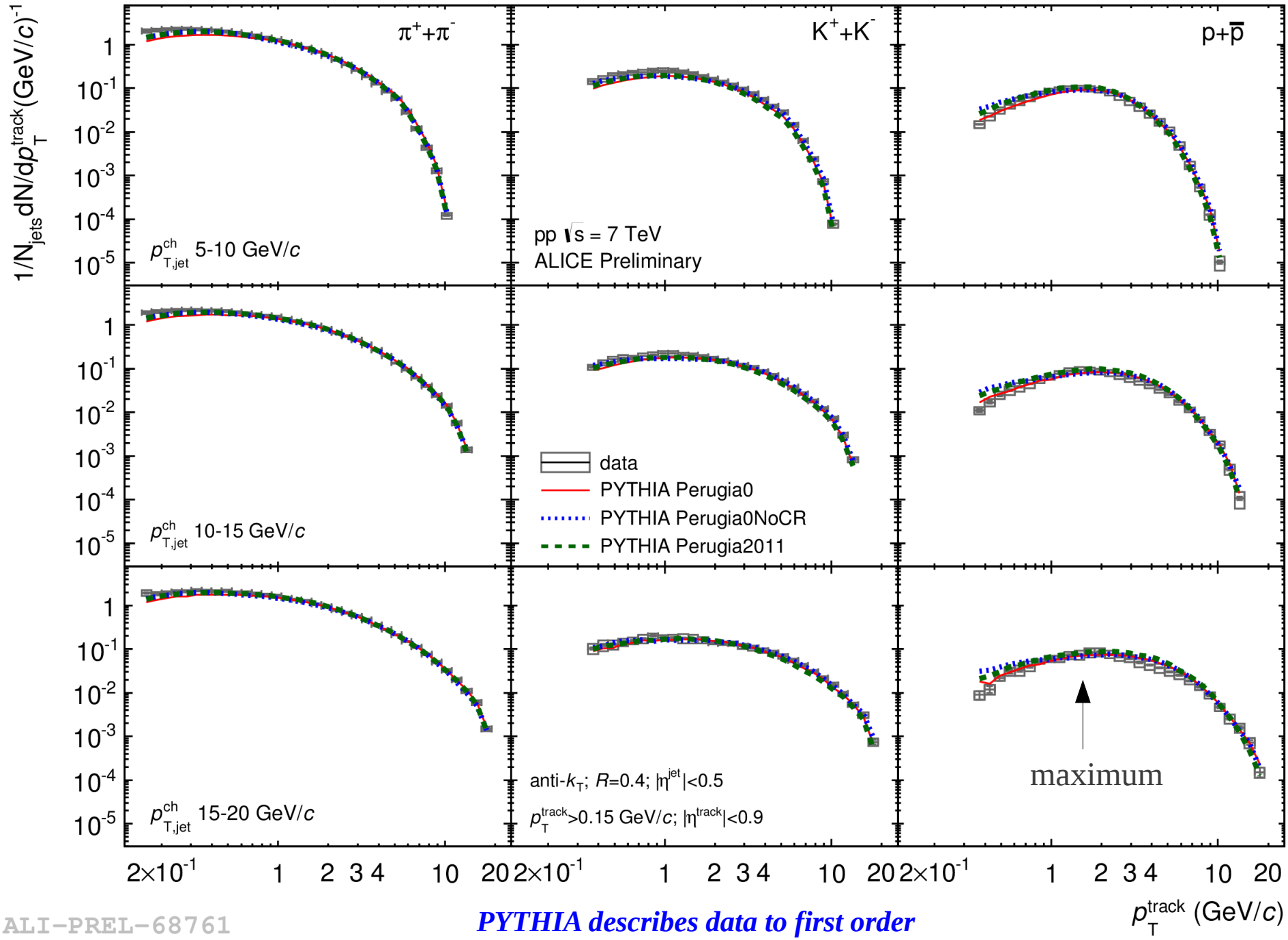



- ***Scaling at z>0.2***
  - Kaon 5-10, 10-15, 15-20 GeV/*c* jet
  - Proton 10-15, 15-20 GeV/*c* jet

*Monotonic increase to 0.5-0.6*
***strangeness fraction increases with z***

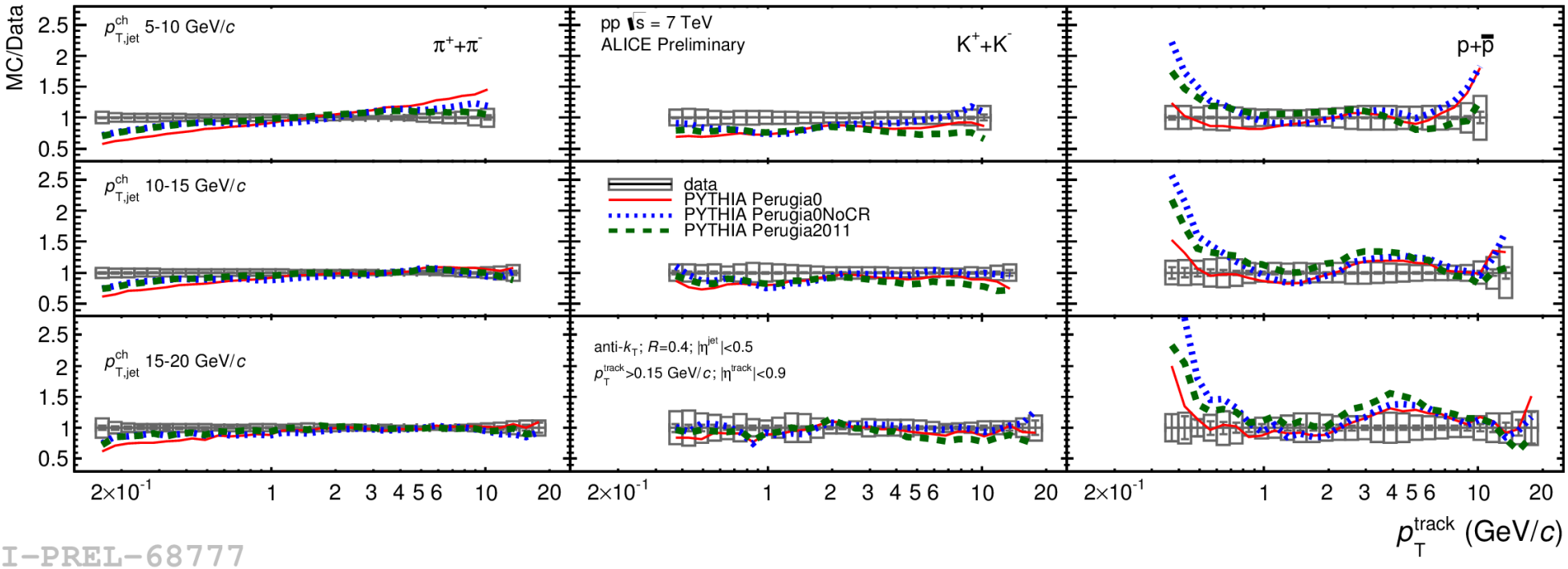
*Maximum 0.15-0.2 at z 0.5-0.6*
***z → 1: Leading baryons suppressed***

# Comparison of π/K/p $p_T$ spectra with PYTHIA




***PYTHIA describes data to first order***

# PYTHIA/data $p_T$ spectra

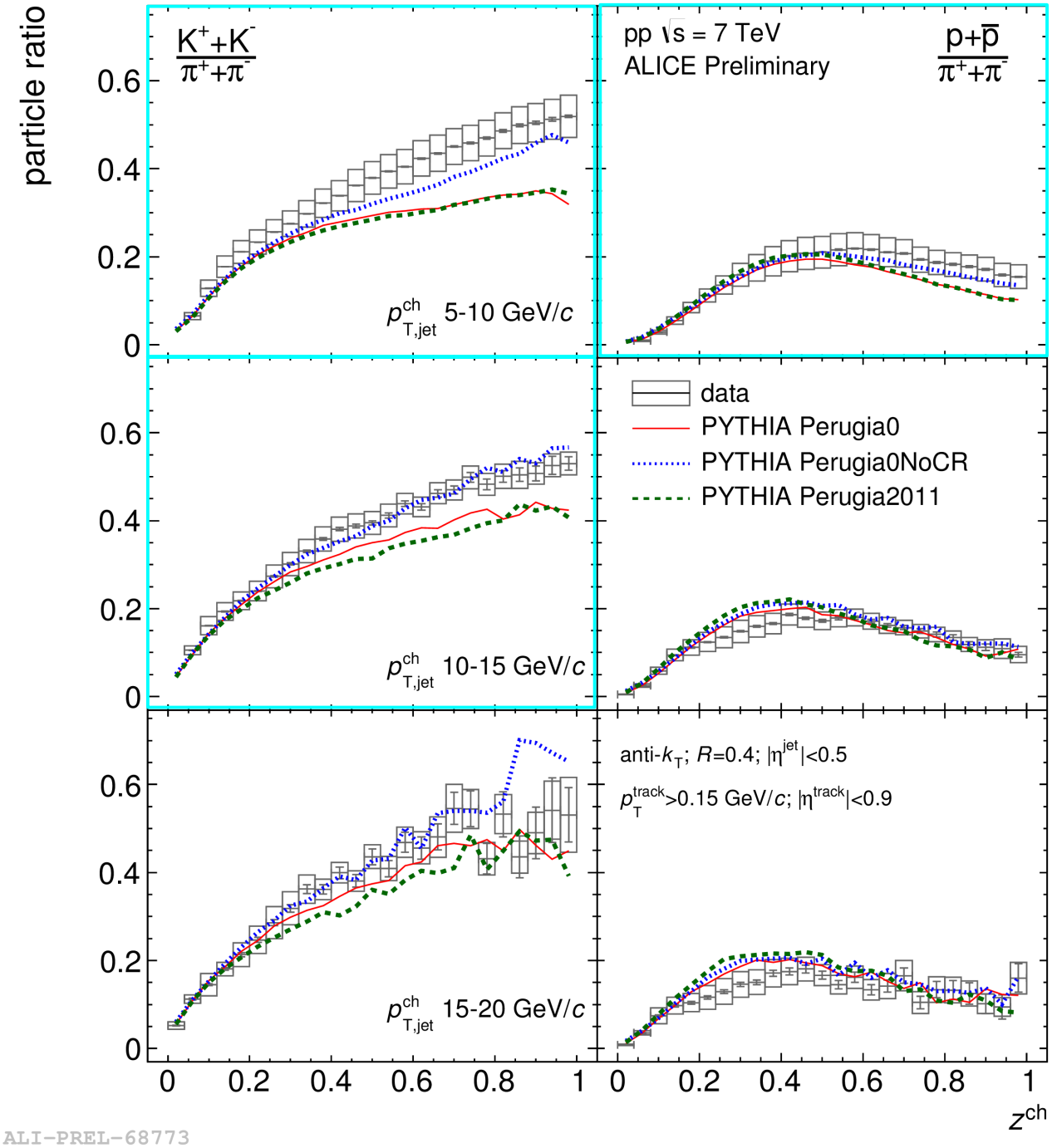



ALI-PREL-68777

- Largest deviation at lowest $p_T$ jet (5-10 GeV/$c$) and particle $p_T$
  Low $p_T$ PYTHIA undershoots pions, consistent with kaons but overshoots protons.
- Better agreement at high jet $p_T$ and particle $p_T$
- ***PYTHIA reproduces the proton maximum, but fails to describe the width and high $p_T$ slope***

# Comparison of K/π and p/π $p_T$ with PYTHIA

- Kaons favor *PerugiaNoCR* (tune ID 324: no color reconnection, re-tuned to pre-LHC data)
- strangeness fraction increases with *z* and leading baryon suppression at high *z*
  - ***trends described by PYTHIA***



# Summary

***First measurement of identified jet fragmentation at hadron colliders***

- Particle yields and ratios as functions of $p_T$, $z$ of primary hadrons (π/K/p) in jets of $p_T$ 5-20 GeV/$c$ with advanced PID techniques
- Disappearance of scaling at lowest jet $p_T$
- Strangeness fraction increases with $z$ and leading baryon suppression at high $z$
  - trends described by PYTHIA
- Compared to PYTHIA, challenges:
  - low jet $p_T$
  - pions and protons at low particle $p_T$

**Poster: Benjamin Andreas HESS, 20/5/2014 14:30 – 18:30**
Particle identification techniques for measuring the hadron composition in charged jets from pp collisions with the ALICE experiment

**Talk: Xiaoming ZHANG, 20/5/2014 15:20 – 15:40**
Production of strange particles in charged jets and underlying event in p–Pb collisions with ALICE

# BACKUP

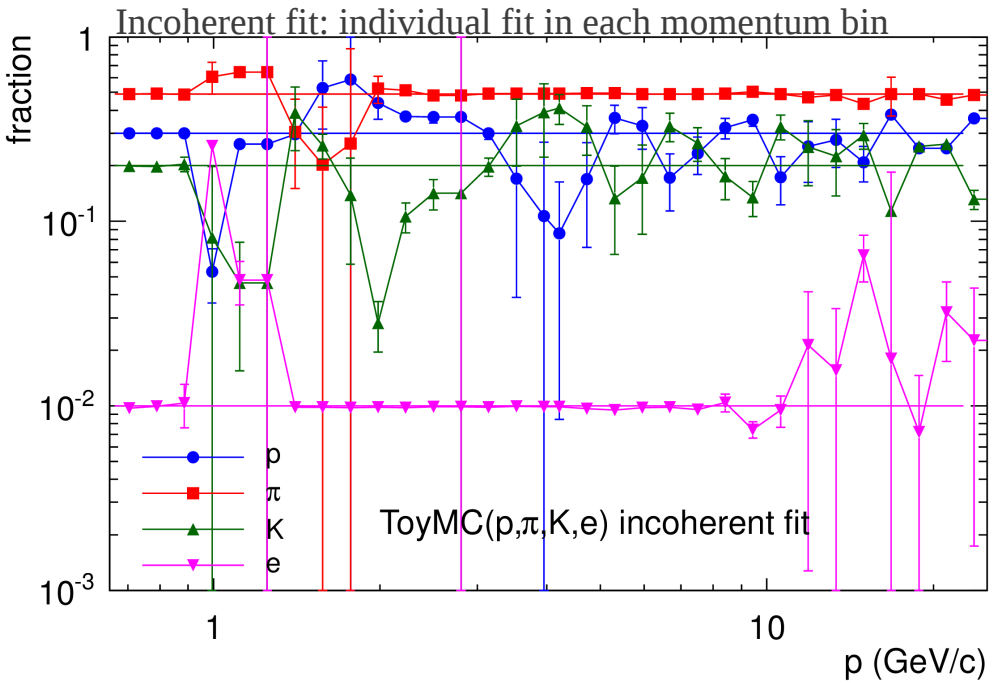
# Analysis details

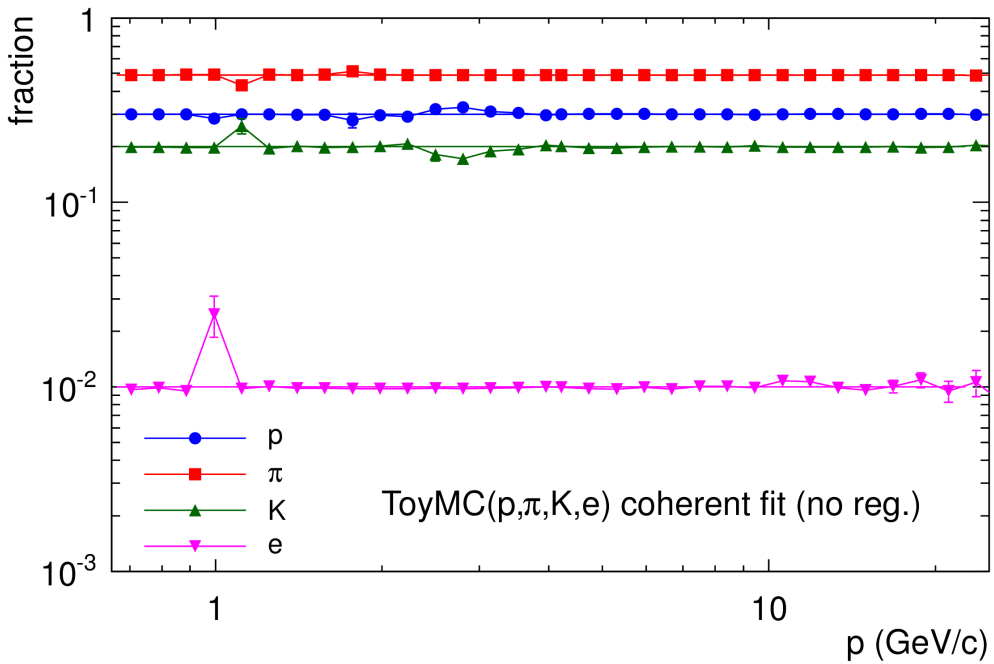
- $\pi$/K/p yields in charged jets from pp collision at 7 TeV
  - 200M minimum bias events
  - FastJet anti-$k_T$ with $R$=0.4, $|\eta^{jet}| < 0.5$, $|\eta^{track}| < 0.9$
  - $p_T^{jet}$ 5-10, 10-15, 15-20 GeV/$c$, $p_T^{track} > 0.15$ GeV/$c$
  - Corrected to the particle level

Weighted mean

$$
\begin{aligned}
f_k(u) &= \frac{\sum_i N_k(p_i;u)}{\sum_j N_{\mathrm{all}}(p_j;u)},\ u = p_{\mathrm{T}}, z, \\
&= \frac{\sum_i N_{\mathrm{all}}(p_i;u) f_k(p_i;u)}{\sum_j N_{\mathrm{all}}(p_j;u)} \\
&= \sum_i w(p_i;u) f_k(p_i;u) \\
&\simeq \sum_i w(p_i;u) f_k(p_i),
\end{aligned}
$$

# TPC Coherent Fit – coherence and regularization




Coherence:

- Global constraint to d$E$/d$x$ model
- d$E$/d$x$ model constraint fed back to fraction constraint

Regularization:

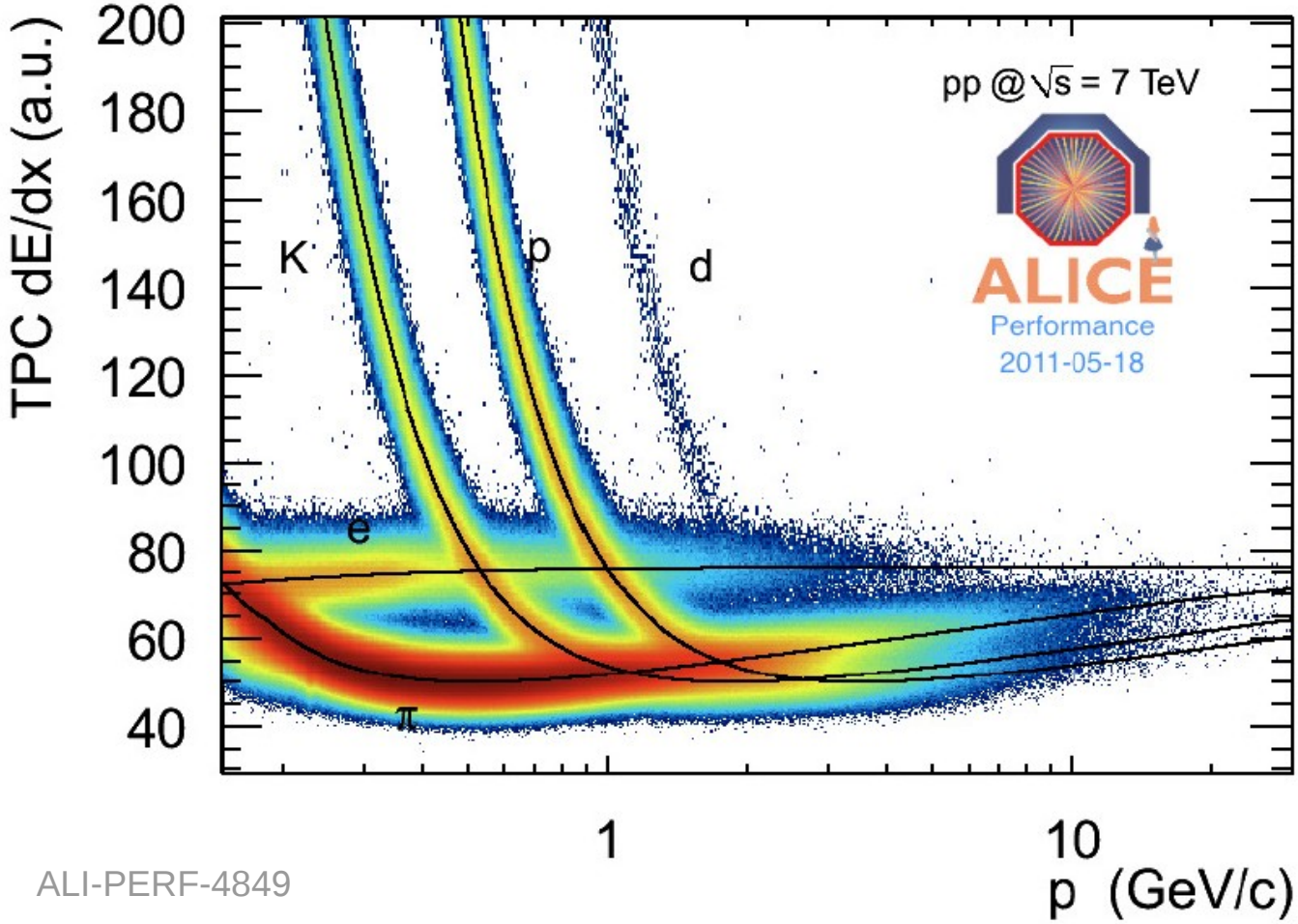
- Maximal use of information – continuity condition


X.-G. Lu, Doctoral dissertation, University of Heidelberg (2013).
http://archiv.ub.uni-heidelberg.de/volltextserver/15651/

# PID in jets – TPC Multi-template Fit – Overview

- Model TPC d*E*/d*x* response in detail:
  momentum *p*, mass, pseudorapidity η, d*E*/d*x*, $N_{PID\ cluster}$, *shape asymmetry*

- Determine response from pure track samples selected via
  → TPC d*E*/d*x*, *Time of flight (TOF)*
  → *track topology ($K^0_s$ / Λ decays, γ conversions)*

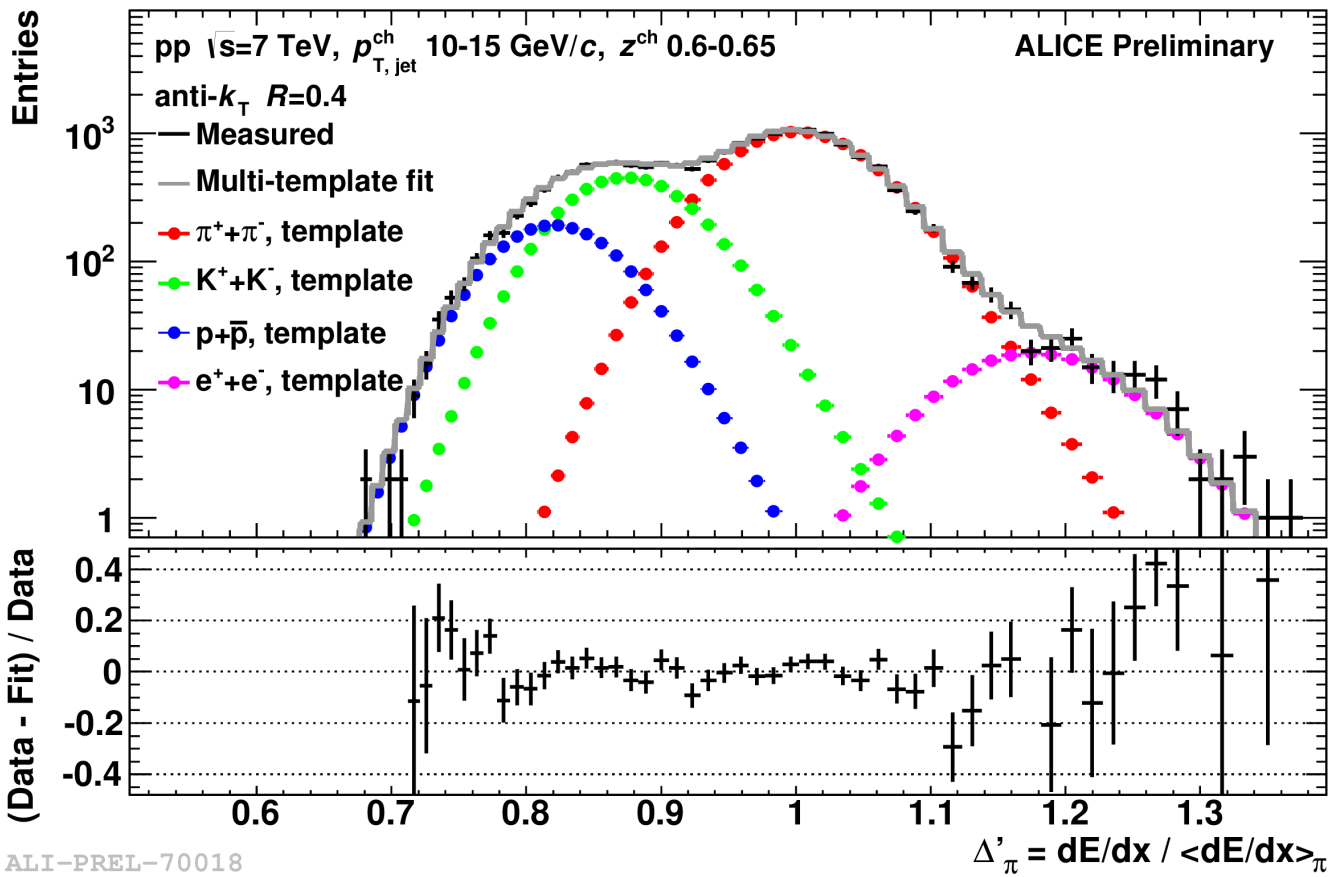



ALI-PERF-4849

# PID cross-check – TPC Multi-template Fit – Overview

- *Binned log-likelihood fit*:
  Minimize difference between measured $dE/dx$ distribution and template sum weighted by species fractions is
  → Fit parameters: Particle fractions as function of (jet $p_T$, track $p_T$ / z)

- Regularisation:
  Ensure continuity of fractions versus $\ln(p_T)$ / z




- Excellent description of data over 2-3 orders of magnitude

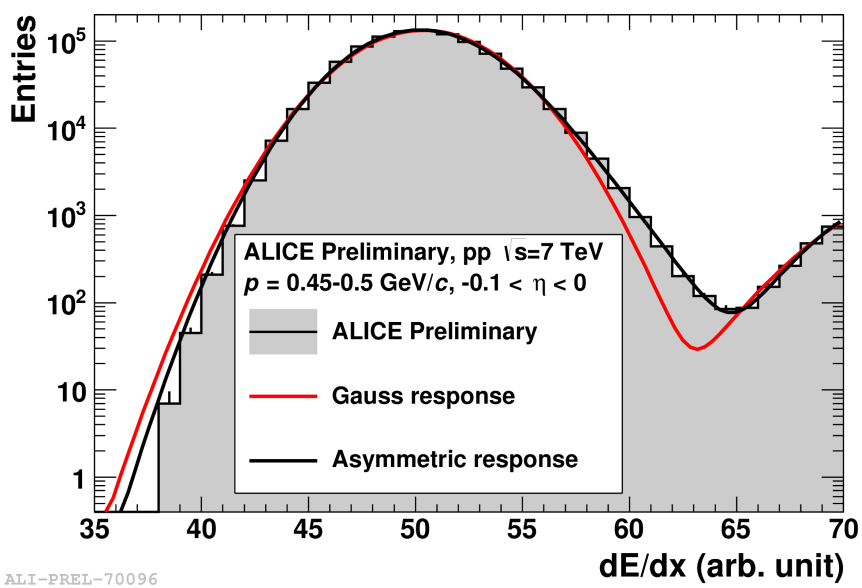
# PID in jets – TPC Multi-template Fit – Modelling the TPC d*E*/d*x* Response

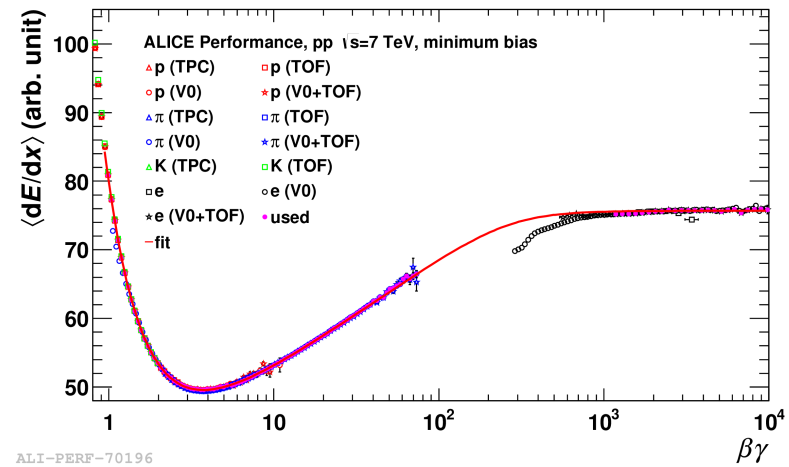
TPC d*E*/d*x* of track depends on: momentum, mass, θ, d*E*/d*x*, #PID clusters, shape asymmetry

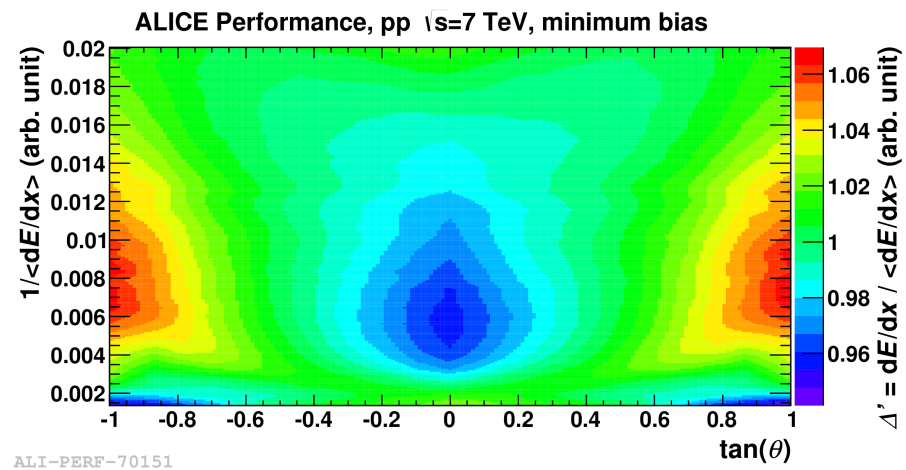
Extract dependencies with data driven methods:

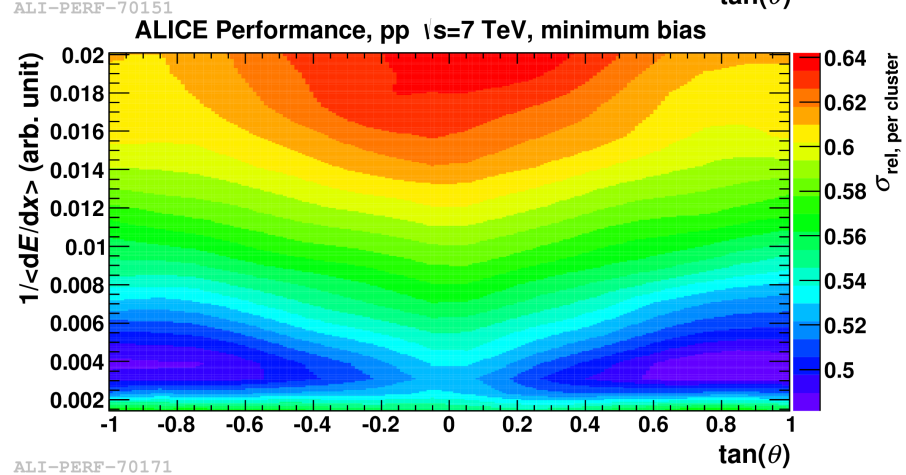
- Clean samples from TPC, TOF and V0's
- Fit <d*E*/d*x*> ($\theta$ averaged) with Bethe-Bloch model
- Extract dependence on $\theta$ (vs. 1/<d*E*/d*x*>)
- (Rel.) resolution map in ($\theta$, 1/<d*E*/d*x*>)-bins as function of #PID cluster
- Parametrise asymmetric shape

Track parameters from sample of TPC tracks at given $p_T$ to generate templates for each species



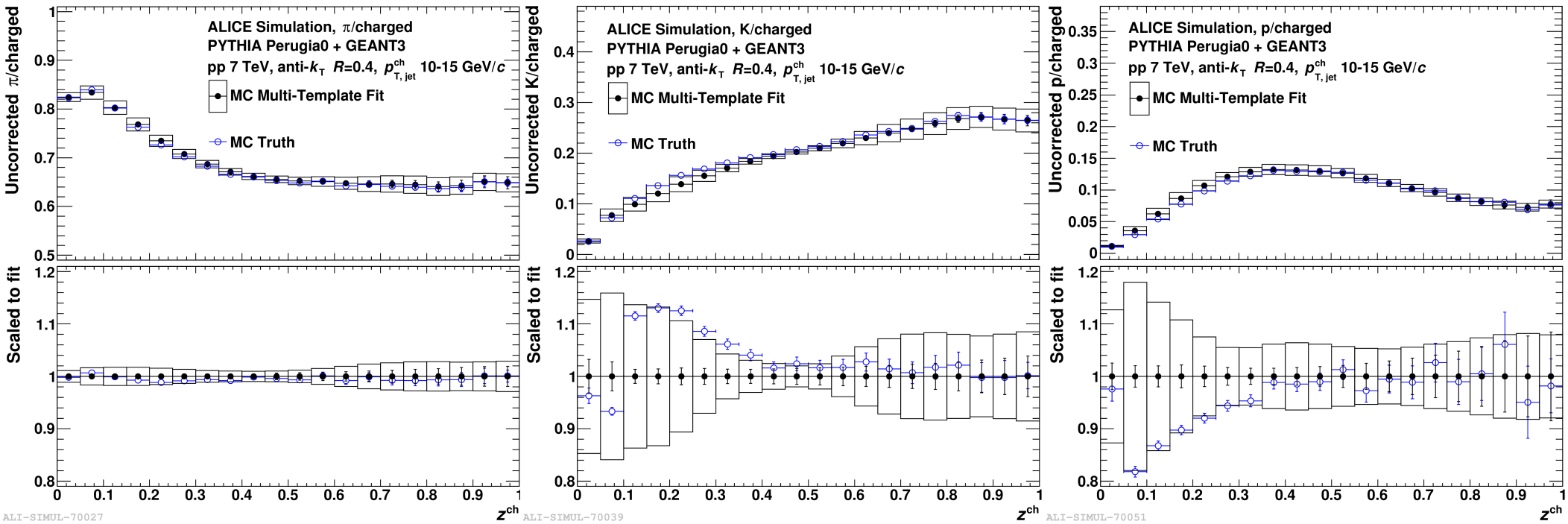



# PID in jets – TPC Multi-template Fit – MC Semi-Blind Test

**Goal**: Confirm method with MC
- Take same uncertainties as in data, vary templates
- Do not use any MC information for the fit => “blind” as in data
- Use PDG instead of pure samples to extract splines and maps (“semi-blind”)




- **MC truth reproduced** within typically 10%
- **Sys. errors confirmed**: follow size of deviations between truth and fit

# PID in jets – TPC Multi-template Fit – Systematic Uncertainties: Raw Fractions

- Uncertainties of dEdx response change template shapes
- Propagate uncertainties to fractions by varying shape with systematic error and assigning sigma of resulting fractions as systematic error
- Sum up all error sources in quadrature

| Template input | Variations |
|---|---|
| Mean $dE/dx$ (Splines) | $\pm 0.2\%$ for $\beta\gamma \lesssim 50$<br>$+1.3\%$ and $-0.6\%$ for $\beta\gamma \gtrsim 50$ |
| $\sigma(dE/dx)$ | $\pm 3\%$ for $dE/dx \lesssim 250$<br>$\pm 50\%$ for $dE/dx \gtrsim 250$ |
| $\eta$-dependence of mean $dE/dx$ | $\pm 3\%$ for $p \lesssim 0.45$ GeV/$c$<br>$\pm 0.5\%$ for $p \gtrsim 0.45$ GeV/$c$ |
| PID weighting | Default: Combined PID from ITS, TPC, TOF with default priors<br>Flat |
| Shape of detector response | Default: Asymmetric shape<br>Pure Gaussian |

- First 3 variations:
  - Global scaling with corresponding percentage
  - Uncertainties estimated from clean sample + dE/dx model comparison (high pT)
- Note: Possible jet Pt dependence of splines as estimated by coherent fit covered by variations

# Corrections

- Efficiency, acceptance and $p_T^{jet}$ , $p_T^{track}$ resolution
- Secondary particle contamination
- Muon contamination (species cannot be separated with given d$E$/d$x$ resolution)

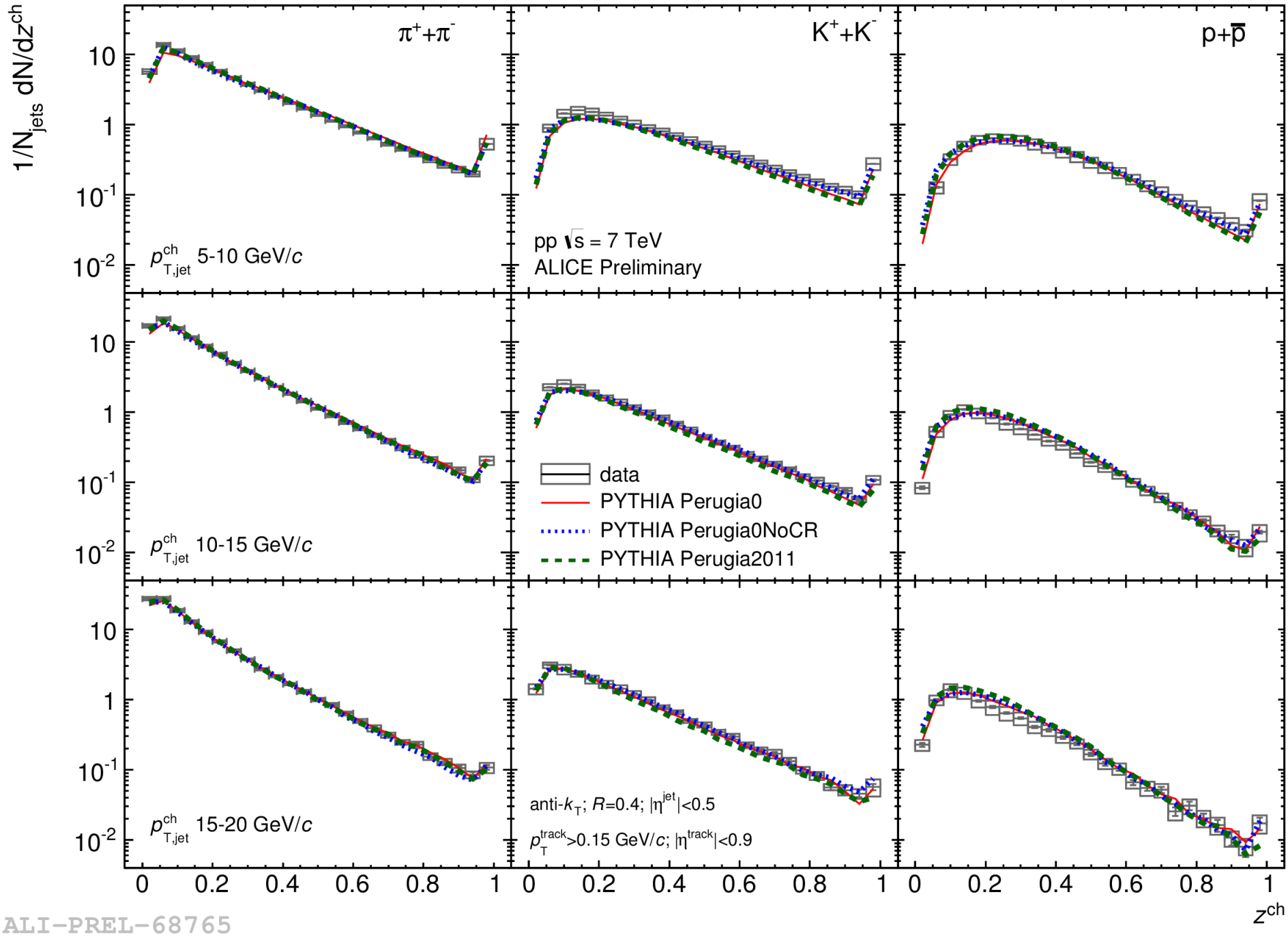
| jet $p_T$ (GeV/c) | 5–10 | 10–15 | 15–20 | jet $p_T$ (GeV/c) | 5–10 | 10–15 | 15–20 |
|---|---|---|---|---|---|---|---|
| $\pi$ | 1.8 | 1.8 | 2.4 | $\pi$ | 1.9 | 1.5 | 1.7 |
| K | 8.5 | 8.6 | 13 | K | 8.8 | 5.8 | 8.5 |
| p | 12 | 12 | 16 | p | 13 | 11 | 18 |

**Table 1:** Averaged systematic errors in % of raw particle yields as functions of $p_T$ (left) and $z$ (right).

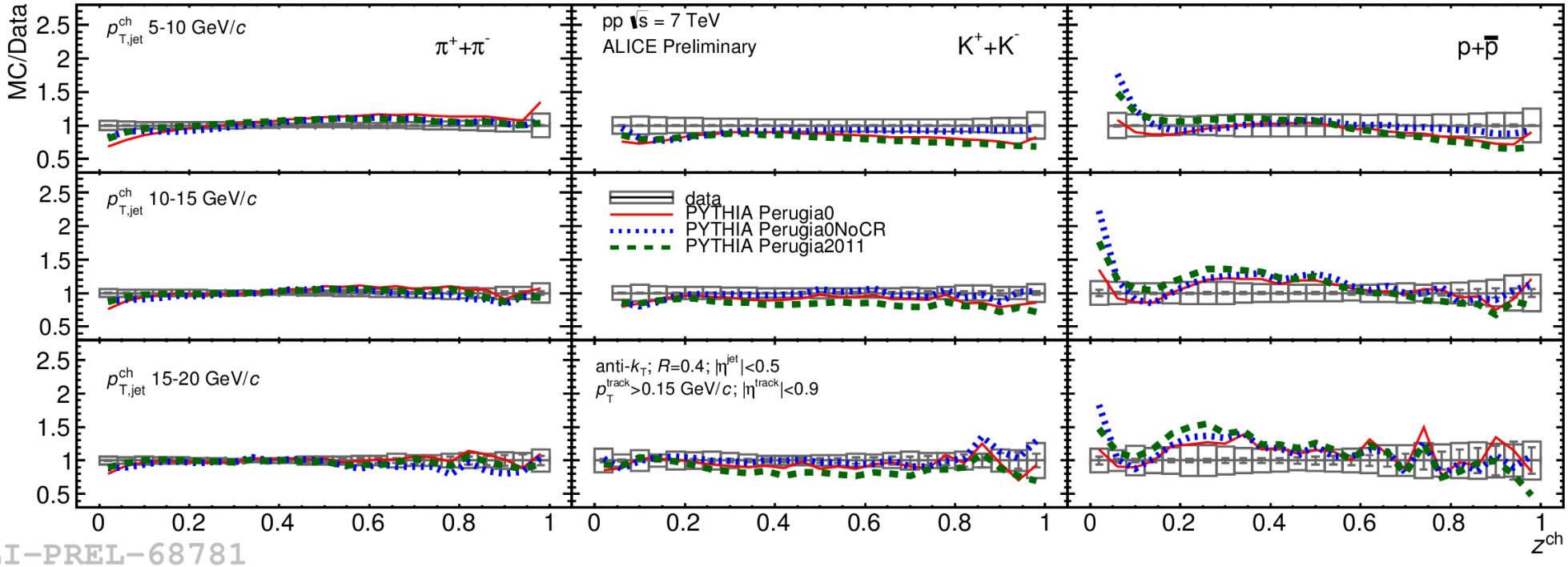
| jet $p_T$ (GeV/c) | 5–10 | 10–15 | 15–20 | jet $p_T$ (GeV/c) | 5–10 | 10–15 | 15–20 |
|---|---|---|---|---|---|---|---|
| $\pi$ | 5.8 | 5.6 | 6.3 | $\pi$ | 5.6 | 5.9 | 7.0 |
| K | 10 | 11 | 15 | K | 11 | 8.7 | 12 |
| p | 18 | 18 | 21 | p | 17 | 16 | 21 |

**Table 2:** Averaged systematic errors in % of corrected particle yields as functions of $p_T$ (left) and $z$ (right).

# Model comparison – z spectra direct comparison



# Model comparison – MC/Data z spectra

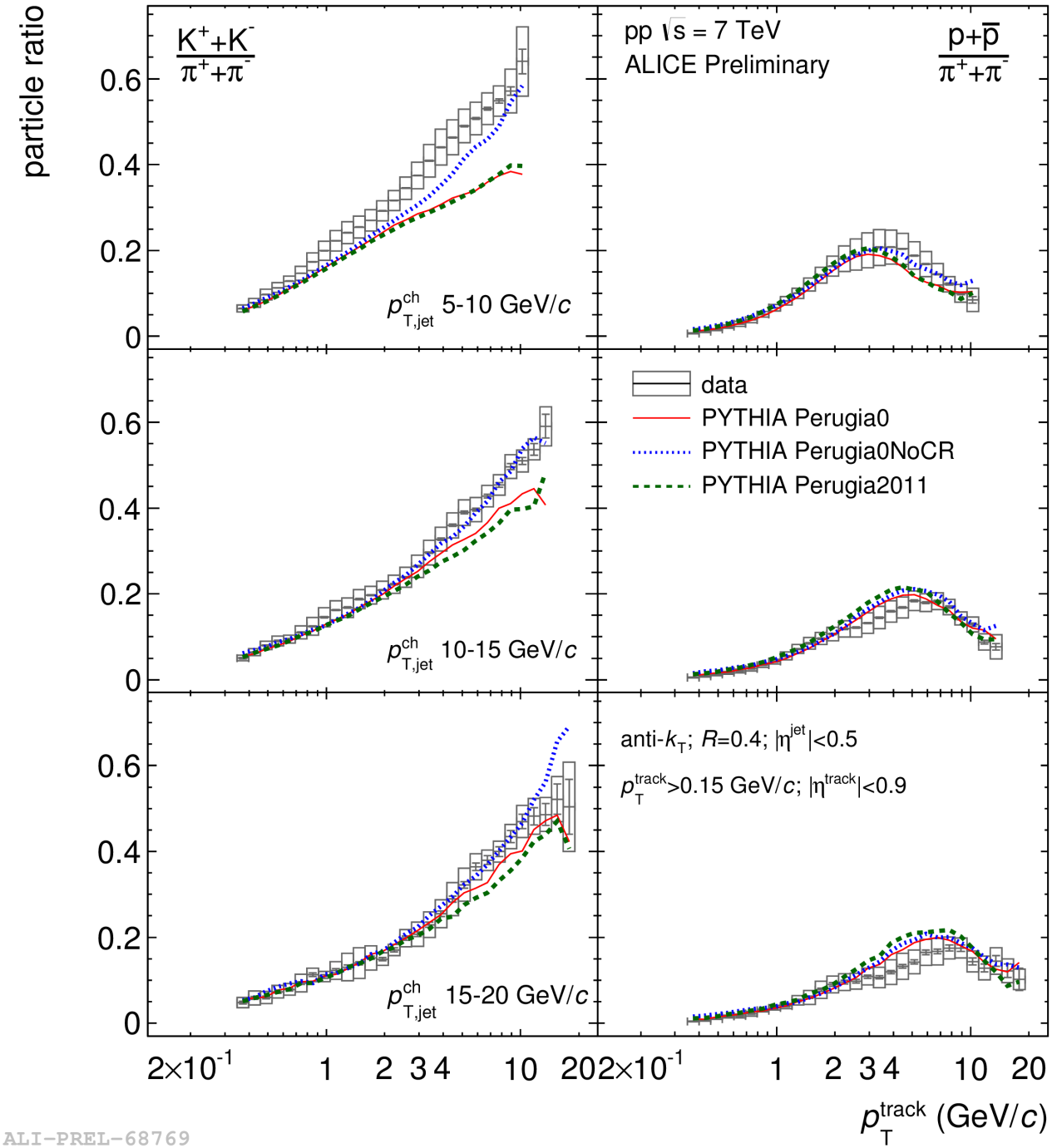



Largest deviation at 5-10 GeV/c jet low z
Better agreement at high jet $p_T$ and z

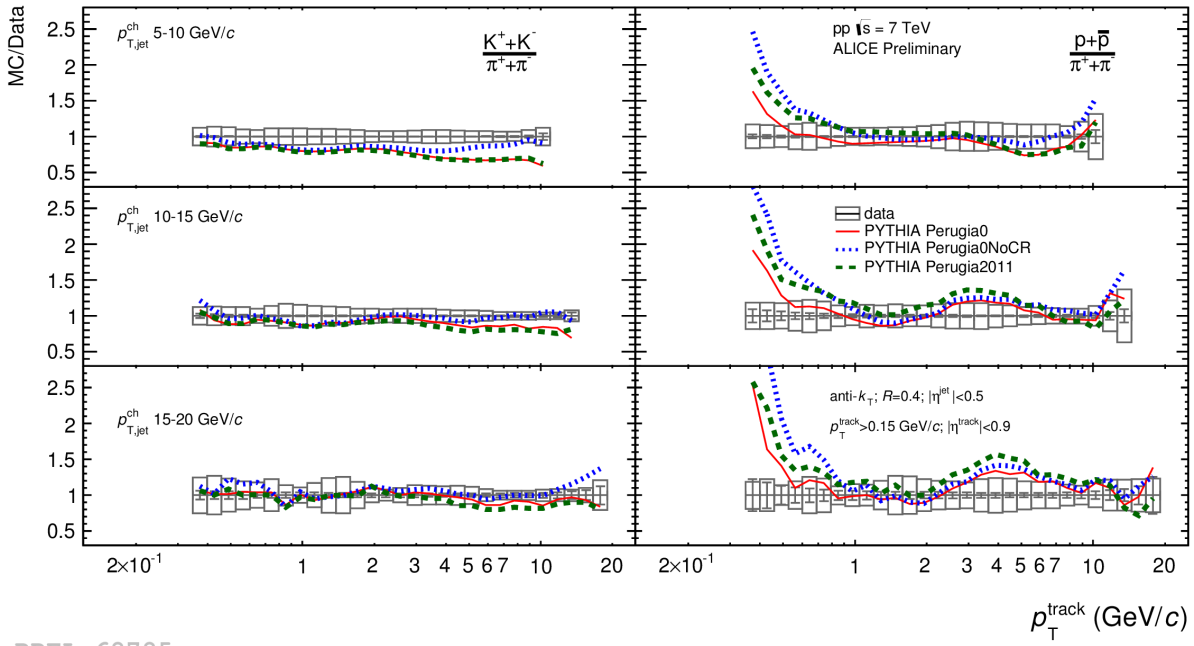
Kaons favor *PerugiaNoCR* (pre LHC tune, no color reconnection)

Models *reproduce the proton maximum and its position*,
but *fail to describe the width and high z slope*

# Model comparison – K/π, p/π direct comparison



# Model comparison – K/π, p/π MC/Data

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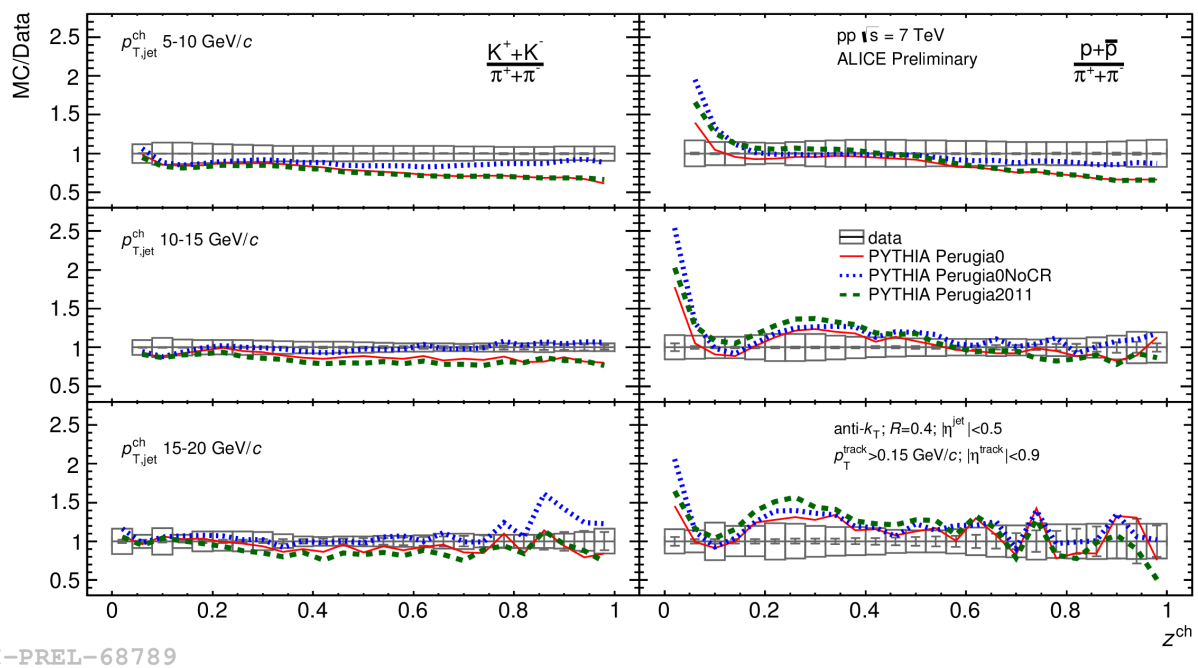


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Consistency pattern similar to particle yields, especially for high jet $p_T$ due to good consistency for pions

# END