Correlations and flavors in jets in ALICE

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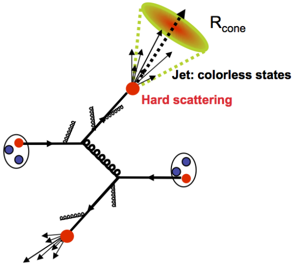
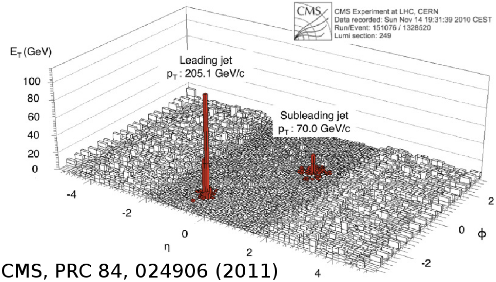
Outline

- $\pi/K/p$ yields in charged jets in pp
- $(\Lambda + \bar{\Lambda})/2K^0_S$ ratio in charged jets in Pb–Pb and p–Pb
- h-jet correlation measurements in Pb–Pb and pp
  (Submitted to JHEP, http://arxiv.org/abs/1506.03984)

Hard scattering in heavy-ion collisions

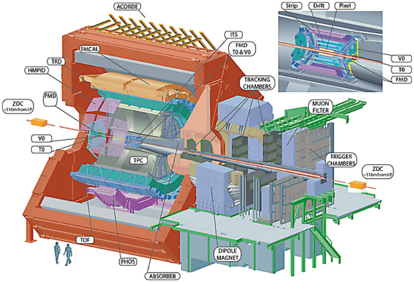
- Hard scattered partons produce collimated sprays of particles
- Jet is a phenomenological object defined via algorithm
- Reasonably understood theoretically in pQCD in pp
- Hard scattering occurs in early stages of heavy-ion collision
- Jet quenching produces asymmetric di-jets

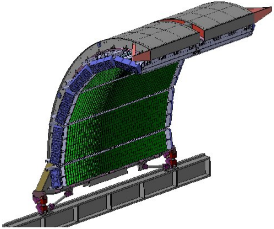




CMS, PRC 84, 024906 (2011)

Jets in ALICE





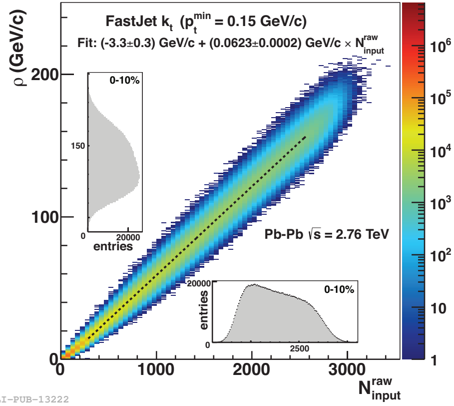
EMCal

- Charged jets (tracks $|\eta| < 0.9$, $0^\circ < \varphi < 360^\circ$, $p_T^{const} > 150$ MeV/c)
- Full jets (tracks + EMCAL clusters $|\eta| < 0.7$, $80^\circ < \varphi < 180^\circ$)
- Jet reconstruction: anti-k_T algorithm (FastJet package [1])
  Given jet R, charged jet acceptance is $|\eta_{jet}| < 0.9 - R$

[1] Cacciari et al., Eur. Phys. J. C 72 (2012) 1896.

Mean background density correction

ALICE, JHEP03 (2012) 053



- Background energy density ρ estimated by area-based method [1]

  $\rho = \text{median}_{k_T \text{ jets}} \{p_{T,\text{jet}} / A_{\text{jet}}\}$

  event by event $p_{T,\text{jet}}^{\text{corr}} = p_{T,\text{jet}} - \rho \times A_{\text{jet}}$

[1] Cacciari et al., Phys. Lett. B 659 (2008) 119.

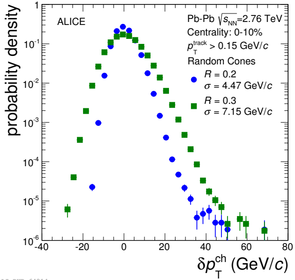
Corrections of raw jet spectra

- Background fluctuations:
  embedding MC jets or random cones [1]
  $\delta p_t = \sum_i p_{t,i} - A \cdot \rho$

- Detector response:
  based on GEANT + PYTHIA

- Response matrix:
  two effects are assumed to factorize
  $$R_{\text{full}}\left(p_{\text{T,jet}}^{\text{rec}}, p_{\text{T,jet}}^{\text{part}}\right) = \delta p_t\left(p_{\text{T,jet}}^{\text{rec}}, p_{\text{T,jet}}^{\text{det}}\right) \otimes R_{\text{instr}}\left(p_{\text{T,jet}}^{\text{det}}, p_{\text{T,jet}}^{\text{part}}\right)$$

- R_{full}^{-1} obtained with Bayesian [2] and SVD [3] unfolding with RooUnfold [4]



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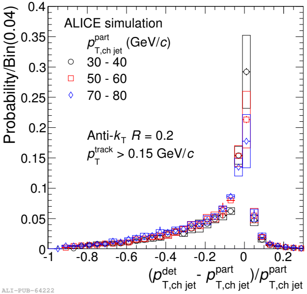
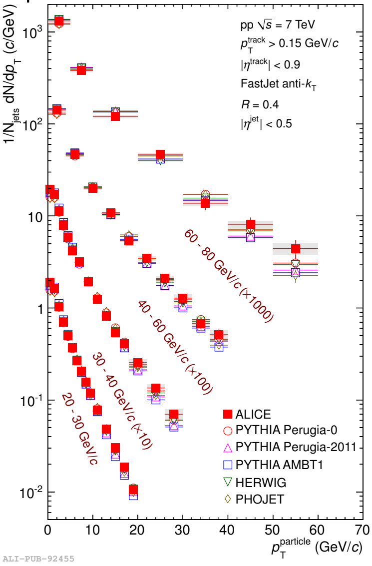
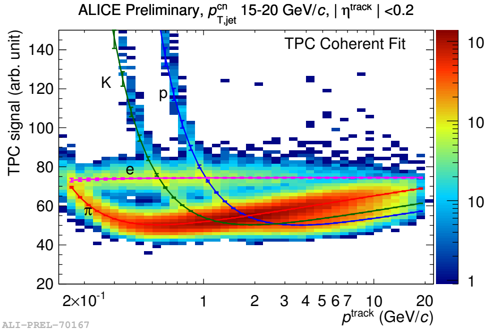


ALI-PUB-64222

[1] ALICE collab., JHEP 1203 (2012) 053
[2] D'Agostini, Nucl.Instrum.Meth.A362 (1995) 487
[3] Höcker and Kartvelishvili, Nucl.Instrum.Meth.A372 (1996) 469
[4] http://hepunx.rl.ac.uk/~adye/software/unfold/RooUnfold.html

Jet constituent spectra in pp at $\sqrt{s} = 7$ TeV

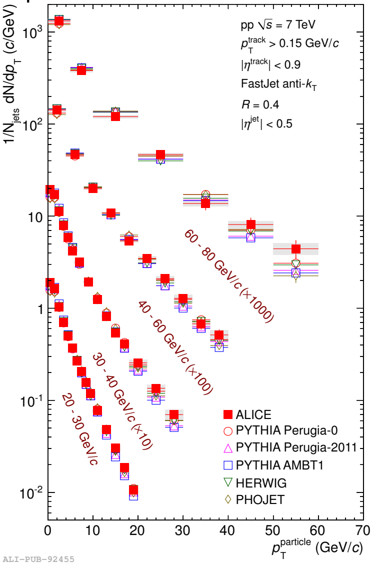


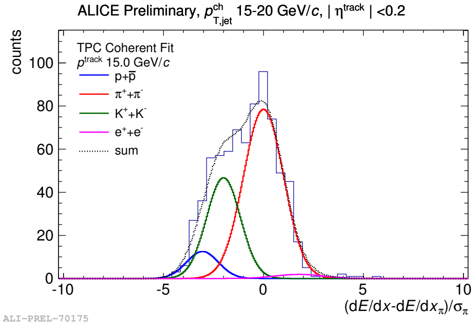


- Charged anti-k_t $R = 0.4$ jets
- dE/dx measured by TPC
- Coherent fit
- Multiple template fit

[1] ALICE, arXiv:1411.4969

Jet constituent spectra in pp at $\sqrt{s} = 7$ TeV





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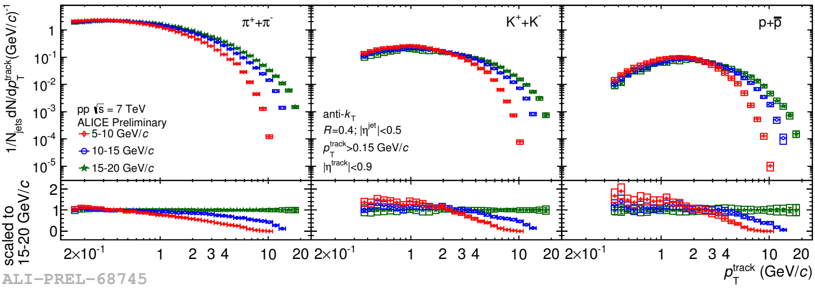
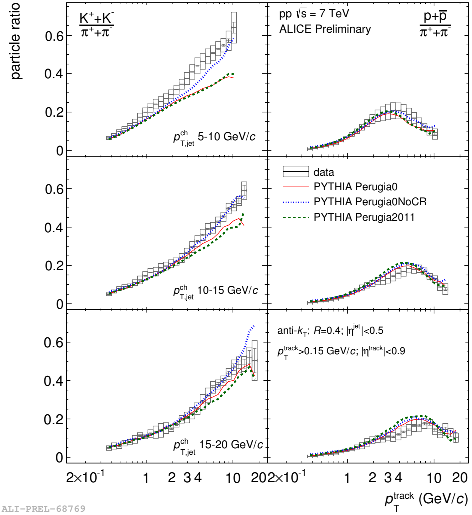
$\pi/K/p$ *yields in charged jets in* pp *at* $\sqrt{s} = 7$ *TeV*

- Corrected for tracking efficiency, acceptance, momentum smearing, contamination by secondary tracks and muons
- First measurement of particle type dependent jet fragmentation at the LHC



K/π *and* p/π *ratios in* pp *at* $\sqrt{s} = 7$ *TeV*

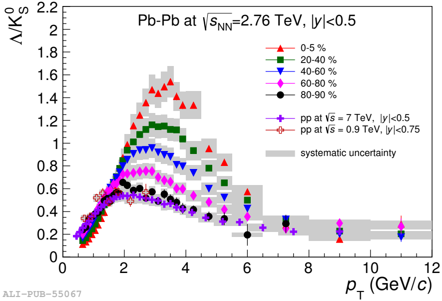


- Increase of strangeness with z^{ch}

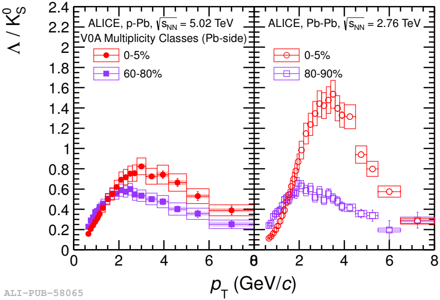
$$z^{ch} = \frac{p_{T,track}}{p_{T,jet}^{ch}}$$

- Leading baryon suppression at high z^{ch}
- Trends described by PYTHIA
- Kaons favor PerugiaNoCR (tune ID 324: no color reconnection, retuned to pre-LHC data)

Baryon anomaly



ALICE PRL 111, 222301 (2013)

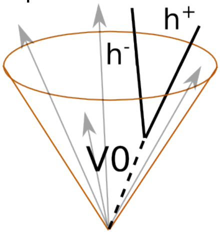


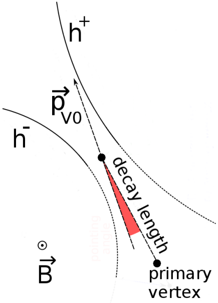
ALICE, Phys. Lett. B 728 (2014) 25-38

- Enhancement of baryon/meson ratio $p_T \in (2, 5)$ GeV/c [*]
- Seen also in p–Pb
- Λ, K^0_S PID at higher p_T
- Does the enhancement come from bulk only or do jets also contribute?

[*] PHENIX, PRL 91, 172301 (2003); STAR, PRL 108, 072301 (2012)

V0 *and jet selection*

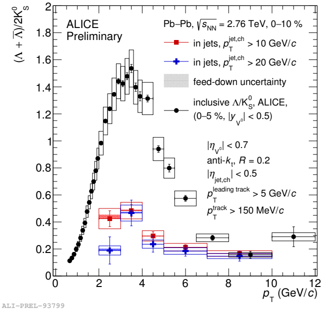




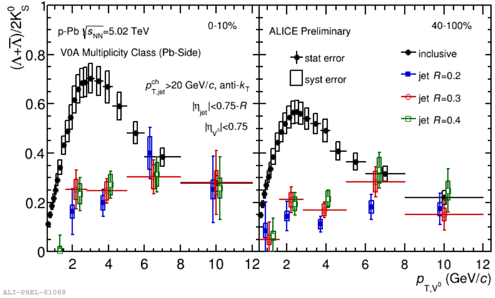
- Jet reconstruction:
  - Charged anti-k_T jets $R = 0.2,\ 0.3,\ 0.4$
  - $p_T^{\text{leading track}} > 5\ \text{GeV}/c$
- V0 reconstruction: $K^0_S \rightarrow \pi^+ + \pi^-$
  $\Lambda^0 \rightarrow p + \pi^-$
  - V0 selected by topological cuts
  - V0 in jet $\sqrt{\Delta\varphi^2_{\text{jet,V0}} + \Delta\eta^2_{\text{jet,V0}}} < R$
  - V0 yield in jet corrected for UE
  - V0 yields corrected for reconstruction efficiency
  - Feed-down correction of Λ and $\bar{\Lambda}$ yield

$(\Lambda + \bar{\Lambda})/2K^0_S$ *in jets in* Pb–Pb *and* p–Pb

Pb–Pb $\sqrt{s_{NN}} = 2.76$ TeV

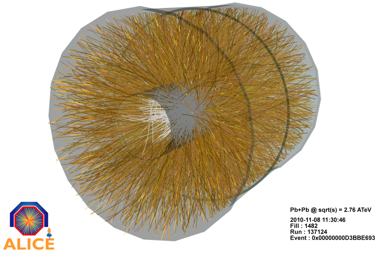


p–Pb $\sqrt{s_{NN}} = 5.02$ TeV



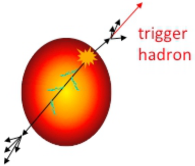
- $(\Lambda + \bar{\Lambda})/2K^0_S$ is in jets in central Pb–Pb collisions significantly lower than for inclusive particles
- Baryon/meson ratio in jets significantly below inclusive one $\Rightarrow$ baryon anomaly arises from bulk

Selection of jets using fragmentation bias

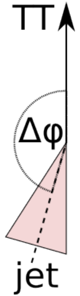


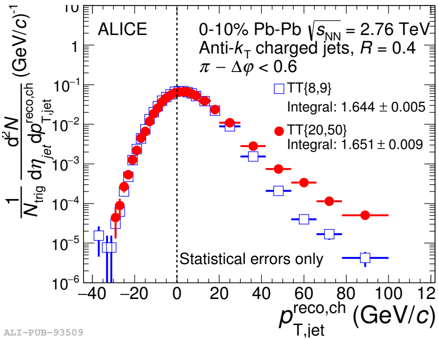
- Hard scattering, rare process embedded in huge background
- Spectrum of reconstructed jets dominated by combinatorial jets
- Suppression of combinatorial jets by high-p_T track requirement results in fragmentation bias on quenched jets

Hadron-jet coincidence measurement



[1] de Barros et al., arXiv:1208.1518





- ◇ h-jet correlation allows to suppress combinatorial bg jets including MPI without imposing fragmentation bias
- ◇ Data driven approach allows to measure jets with large R and low p_T
- ◇ In events with a high-p_T trigger hadron analyze recoiling away side jets [1]

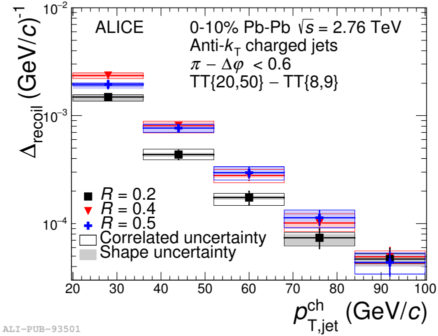
$$|\varphi_{trig} - \varphi_{jet} - \pi| < 0.6 \text{ rad}$$

- ◇ Combinatorial jets are independent of trigger p_T

Δ_{recoil} in Pb–Pb at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV

$$\Delta_{\mathrm{recoil}} = \frac{1}{N_{\mathrm{trig}}} \frac{\mathrm{d}^2 N_{\mathrm{jet}}}{\mathrm{d}p_{\mathrm{T,jet}}^{\mathrm{ch}} \mathrm{d}\eta}\Bigg|_{p_{\mathrm{T,trig}} \in \mathrm{TT}\{20,50\}} - \frac{1}{N_{\mathrm{trig}}} \frac{\mathrm{d}^2 N_{\mathrm{jet}}}{\mathrm{d}p_{\mathrm{T,jet}}^{\mathrm{ch}} \mathrm{d}\eta}\Bigg|_{p_{\mathrm{T,trig}} \in \mathrm{TT}\{8,9\}}$$

◇ Link to theory $$\frac{1}{N_{\mathrm{trig}}^{\mathrm{AA}}} \frac{\mathrm{d}^2 N_{\mathrm{jet}}^{\mathrm{AA}}}{\mathrm{d}p_{\mathrm{T,jet}}^{\mathrm{ch}} \mathrm{d}\eta_{\mathrm{jet}}}\Bigg|_{p_{\mathrm{T,trig}} \in \mathrm{TT}} = \left(\frac{1}{\sigma^{\mathrm{AA}\to \mathrm{h}+X}} \cdot \frac{\mathrm{d}^2 \sigma^{\mathrm{AA}\to \mathrm{h+jet}+X}}{\mathrm{d}p_{\mathrm{T,jet}}^{\mathrm{ch}} \mathrm{d}\eta_{\mathrm{jet}}} \right)\Bigg|_{p_{\mathrm{T,h}} \in \mathrm{TT}}$$

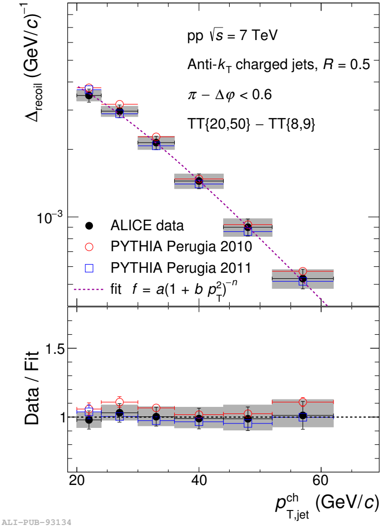


- Δ_{recoil} corrected for bg smearing of jet p_{T} + detector effects
- Medium effects

$$\Delta I_{\mathrm{AA}} = \Delta_{\mathrm{recoil}}^{\mathrm{Pb\text{-}Pb}} / \Delta_{\mathrm{recoil}}^{\mathrm{pp}}$$

Need pp reference at the same $\sqrt{s}$

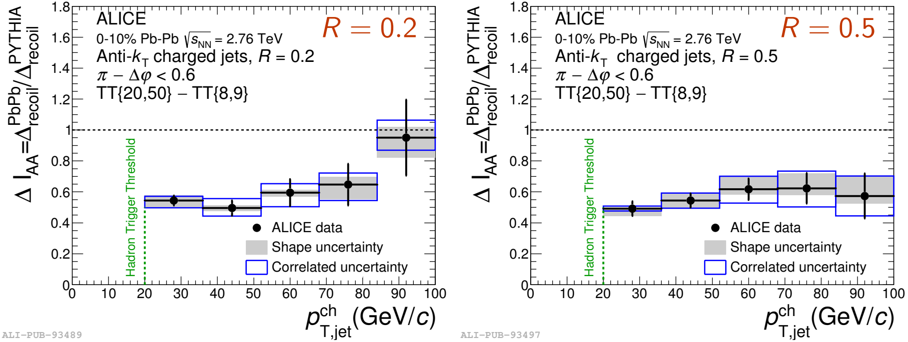
Δ_{recoil} *spectra in* pp *at* $\sqrt{s} = 7$ *TeV*



- pp analysis similar to Pb–Pb
- Gray boxes - syst. uncert. resulting from detector effects and unfolding
- PYTHIA comparison
  - Perugia 10 and 11 are compatible with the data
  - Supports the use Perugia 10 calculation as a reference for Pb–Pb at $\sqrt{s_{NN}} = 2.76$ TeV
- Bottom panel shows variation w.r.t. the smooth fit of ALICE data

More details in http://arxiv.org/abs/1506.03984

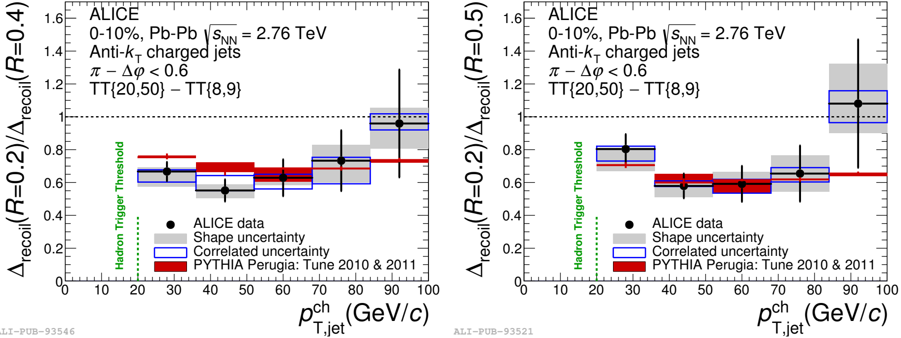
$\Delta I_{AA}^{Pythia} = \Delta_{recoil}^{Pb\text{-}Pb} / \Delta_{recoil}^{Pythia}$ *in* Pb–Pb *at* $\sqrt{s_{NN}} = 2.76$ *TeV*



- Reference Δ_{recoil}^{Pythia} from PYTHIA Perugia 10
- Suppression in recoil jet yield
- Magnitude of the suppression is similar for different R

More details in http://arxiv.org/abs/1506.03984

Ratios of recoil jet yields obtained with different R



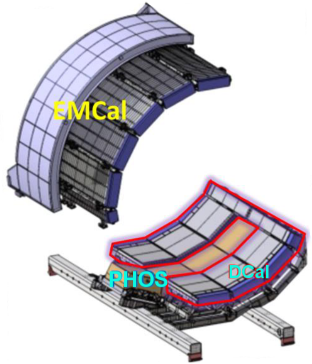
- Red band: variation in observable calculated using PYTHIA tunes
- No evidence for significant energy redistribution w.r.t. PYTHIA
- No evidence for intra-jet broadening up to $R = 0.5$

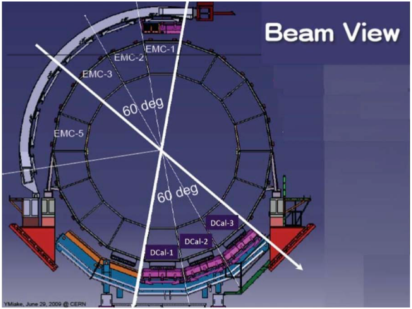
More details in http://arxiv.org/abs/1506.03984

Summary

- First measurement of particle type dependent jet fragmentation at the LHC
- Baryon anomaly arises from bulk
- Hadron-jet correlation observables in heavy-ion collisions
  - no fragmentation bias in jet selection (unique to this technique)
  - allow to study jets with low p_{T} and large R with minimal IR cutoff
    - Δ_{recoil} calculated with PYTHIA Perugia tunes consistent with measurement in pp at $\sqrt{s} = 7$ TeV
    - Suppression of recoil jet yield in Pb–Pb at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV ($\Delta I_{\mathrm{AA}} \approx 0.6$)
    - No evidence of intra-jet broadening of energy profile out to $R = 0.5$

Outlook for Run2





- Extending acceptance for full jet reconstruction with DCal (Di-Jet Calorimeter), $|\eta| < 0.7$ and azimuth 60°
- New PHOS module
- More statistics in Run2 (jet shapes, sub-jets, γ/h-jets,...)

Backup slides

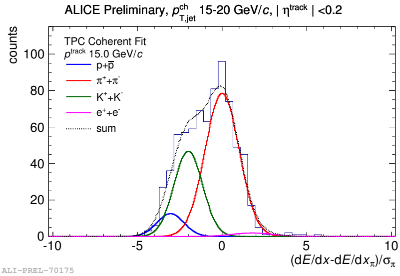
PID in jets – TPC Coherent Fit

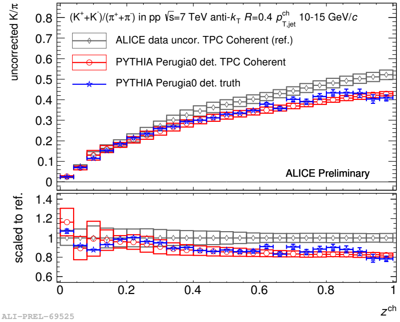
- Most abundant particle types π, K, p, e
- Gaussian signal shape
- Continuous mean, width - parameterized by model $\vec{\theta} = \vec{\theta}(p_{\mathrm{T}})$
- Continuous particle fractions $\vec{f} = \vec{f}(p_{\mathrm{T}})$ within stat. uncertainty
- Maximum likelihood fit with regularization to get $\vec{\theta}$ and $\vec{f}$

$$\mathcal{L} = \sum_{i \in p_{\mathrm{T}}\,\mathrm{bins}} \mathcal{L}\left(\vec{\theta}_i, \vec{f}_i\right) + \mathcal{L}_{reg}\left(\vec{f}_i\right)$$

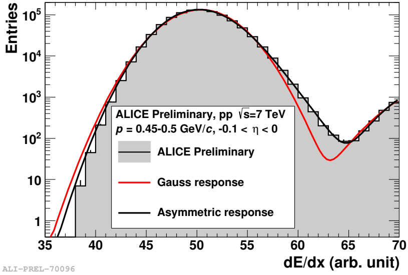
X.-G. Lu, Ph.D. thesis

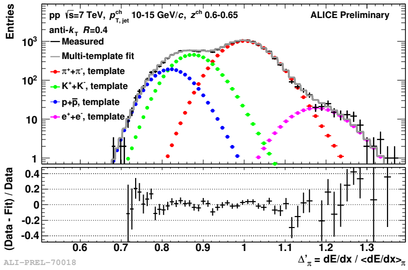
http://archiv.ub.uni-heidelberg.de/volltextserver/15651/





PID in jets – Multiple Template Fit





- Most abundant particle types π, K, p, e
- dE/dx template for given particle specie obtained from real data
- Maximum likelihood fit