Study of high-p_{T} hadron–jet correlations in ALICE

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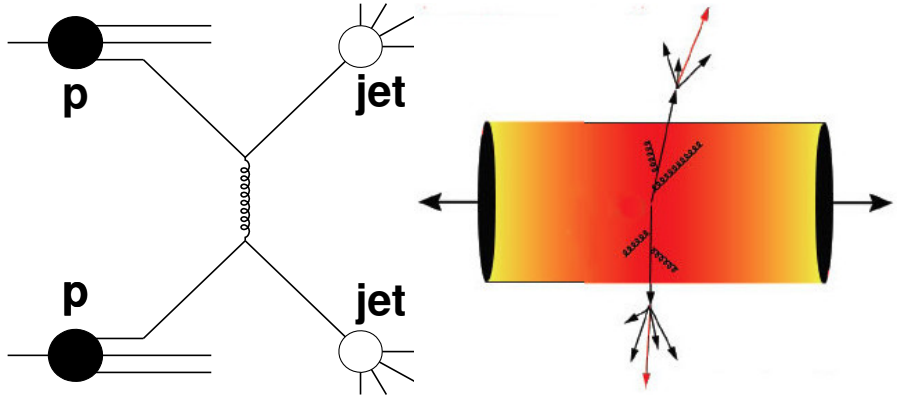
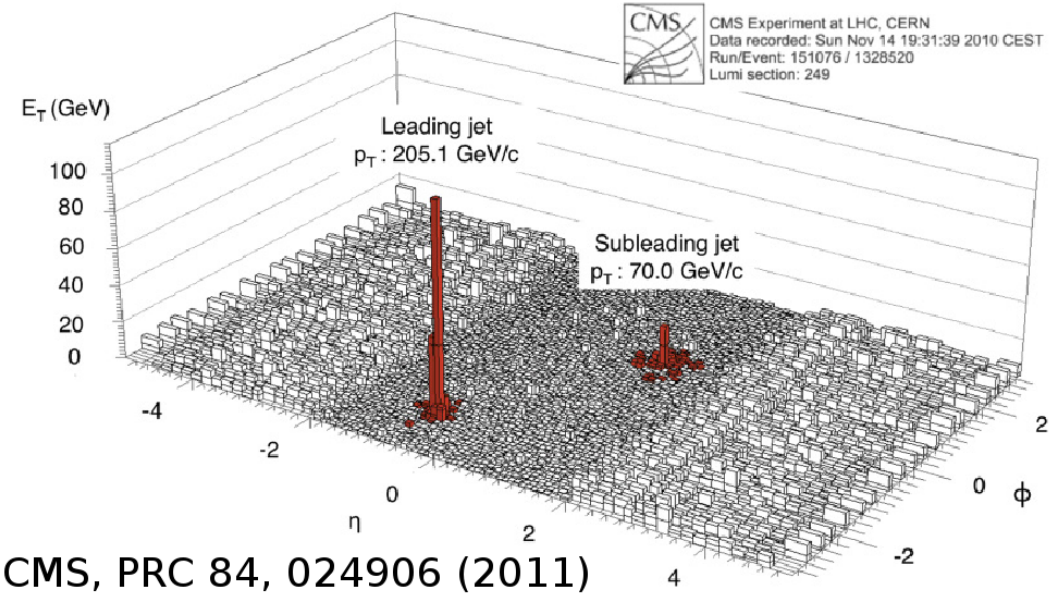
INVESTICE DO ROZVOJE VZDĚLÁVÁNÍ

Hard scattering in heavy-ion collisions

- Hard scattering occurs in early stages of heavy-ion collision
- Reasonably understood theoretically in pQCD in pp
- Jet quenching produces asymmetric di-jets
- CMS has shown [1] transverse momentum balance recovered when including
  (i) wide angle
  (ii) soft radiation
  ($p_T < 2$ GeV/c)

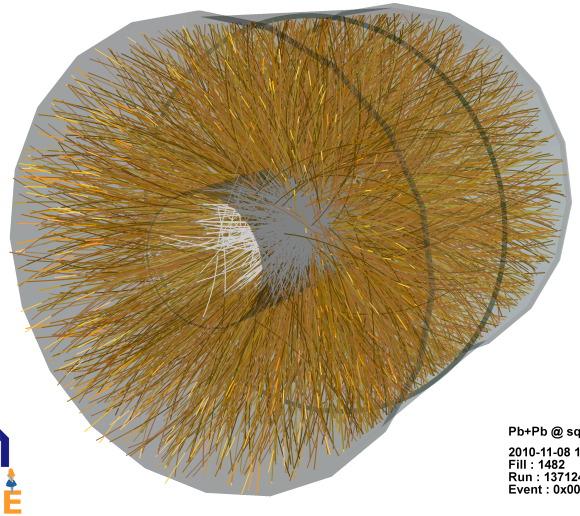


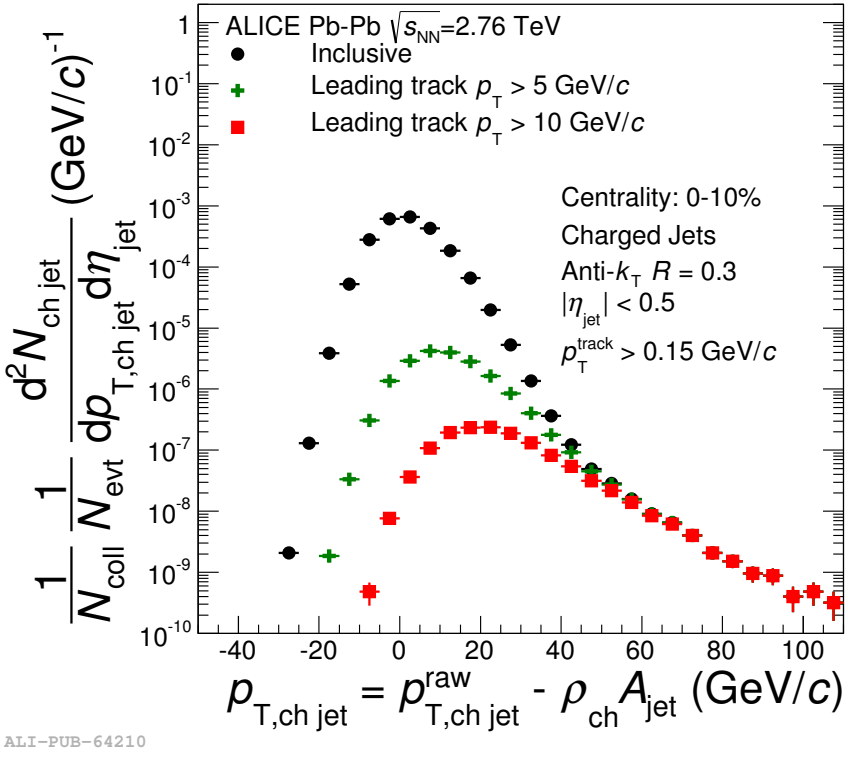


CMS, PRC 84, 024906 (2011)

[1] CMS, PRC 84, 024906 (2011)

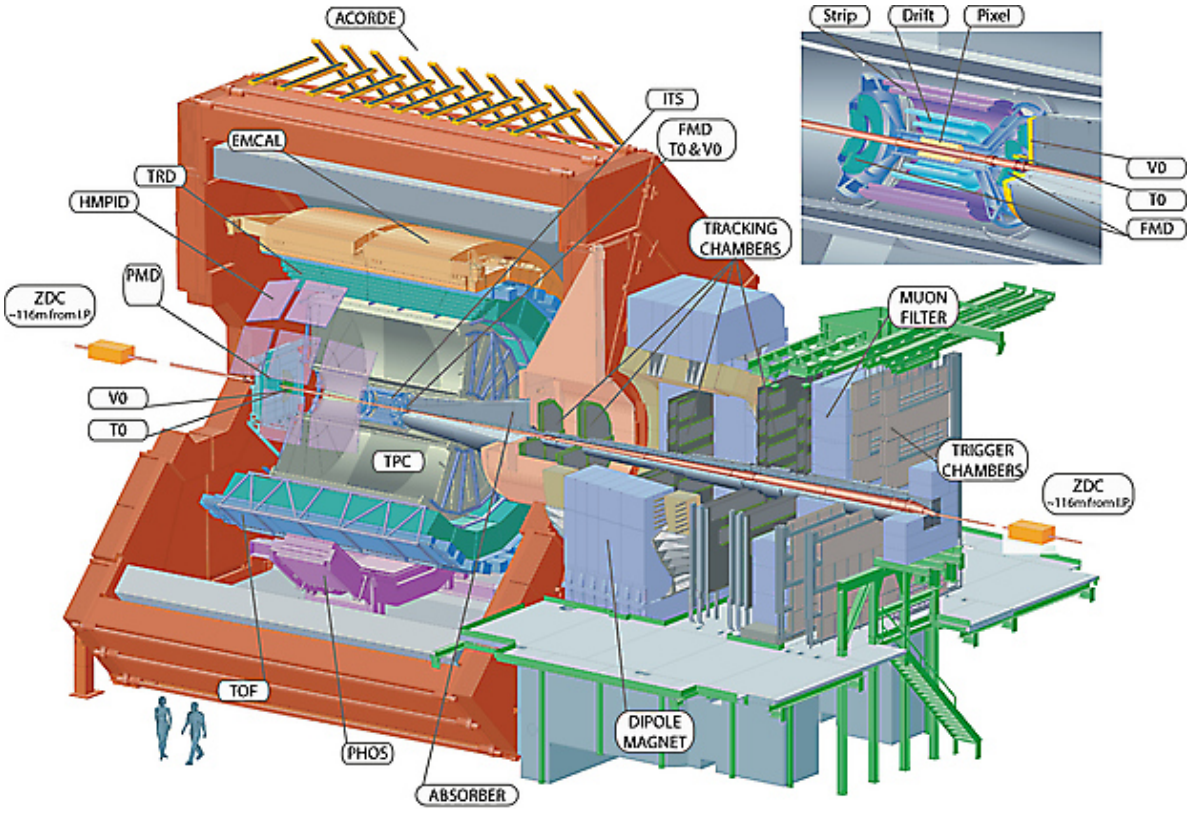
Jets in heavy-ion collisions





- Hard scattering, rare process hidden in huge, soft, fluctuating bg
- Spectrum of reconstructed jets dominated by combinatorial jets
- Suppression of comb. jets by high-p_T track requirement results in fragmentation bias on quenched jets
- Hadron-jet coincidence measurements

A Large Ion Collider Experiment (ALICE)



L3 magnet 0.5 T

Tracking:
ITS, TPC

PID:
TPC+ITS (dE/dx),
TOF
TRD (trans. rad.)
HMPID (Cherenkov)
EMCal+PHOS (calo.)
Muon arm

Input data

- Pb–Pb, $\sqrt{s_{NN}} = 2.76$ TeV 2011 (0-10% central 9 M events)
  2010 (0-20% central 3 M events)
- Track selection: $p_{T,\,track} > 150$ MeV/c ; $|\eta_{track}| < 0.9$
- Jet reconstruction: anti-k_T algorithm FastJet package [1]
  - charged track jets
  - boost invariant p_T recombination scheme
  - resolution parameter $R = 0.2$, $R = 0.4$, $R = 0.5$
  - jet area cuts $A > 0.07$, $A > 0.4$, $A > 0.6$
  - jet acceptance $|\eta_{jet}| < 0.9 - R$
- Background energy density ρ estimated by area-based method [2]

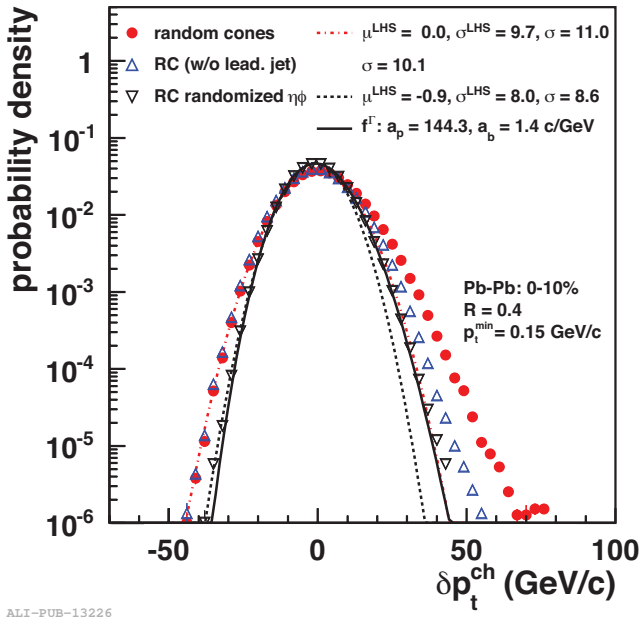
  $\rho = \text{median}_{k_T\,\text{jets}} \{p_{T,jet}/A\}$

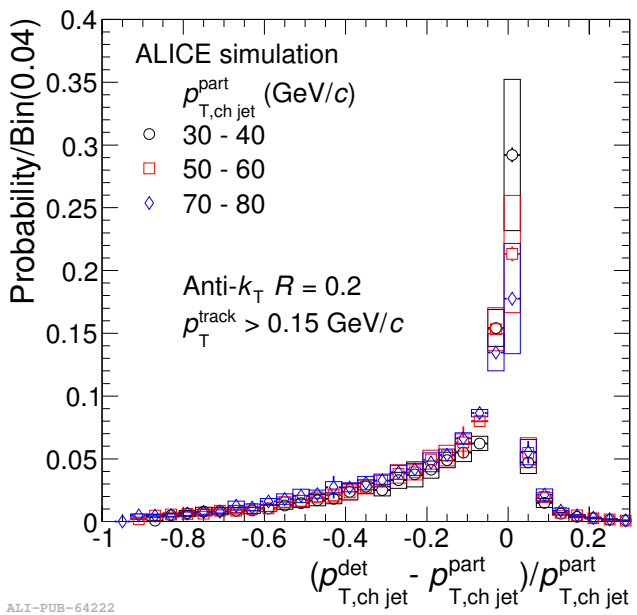
  event by event $p_{T,jet}^{corr} = p_{T,jet} - \rho \times A$

[1] Cacciari et al., Eur. Phys. J. C 72 (2012) 1896. [2] Cacciari et al., Phys. Lett. B 659 (2008) 119.

Corrections of raw jet spectra

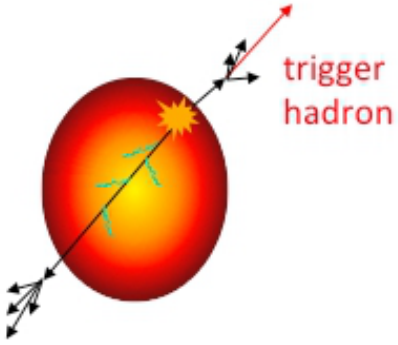
- Background fluctuations:
  embedding MC jets or random cones [1]
  $\delta p_{\mathrm{t}} = \sum_i p_{t,i} - A \cdot \rho$
- Detector response:
  based on GEANT + PYTHIA
- Response matrix:
  two effects are assumed to factorize
  $$R_{\mathrm{full}}\left(p^{\mathrm{rec}}_{\mathrm{T,jet}}, p^{\mathrm{part}}_{\mathrm{T,jet}}\right) = \delta p_{\mathrm{t}}\left(p^{\mathrm{rec}}_{\mathrm{T,jet}}, p^{\mathrm{det}}_{\mathrm{T,jet}}\right) \otimes R_{\mathrm{instr}}\left(p^{\mathrm{det}}_{\mathrm{T,jet}}, p^{\mathrm{part}}_{\mathrm{T,jet}}\right)$$
- R^{-1}_{full} obtained with Bayesian [2] and SVD [3] unfolding with RooUnfold [4]

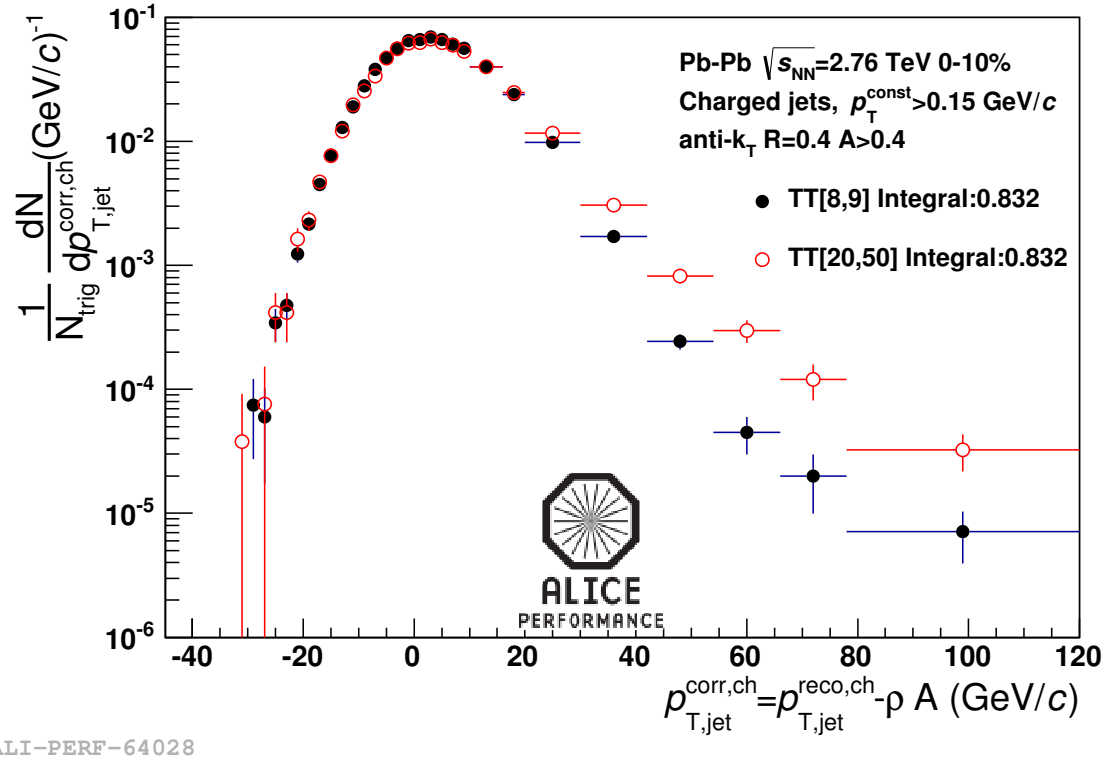




[1] ALICE collab., JHEP 1203 (2012) 053
[2] D'Agostini, Nucl.Instrum.Meth.A362 (1995) 487
[3] Höcker and Kartvelishvili, Nucl.Instrum.Meth.A372 (1996) 469
[4] http://hepunx.rl.ac.uk/ãdye/software/unfold/RooUnfold.html

Hadron+jet coincidence measurement





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

[2] T. Renk, Phys. Rev. C87 (2013) 2

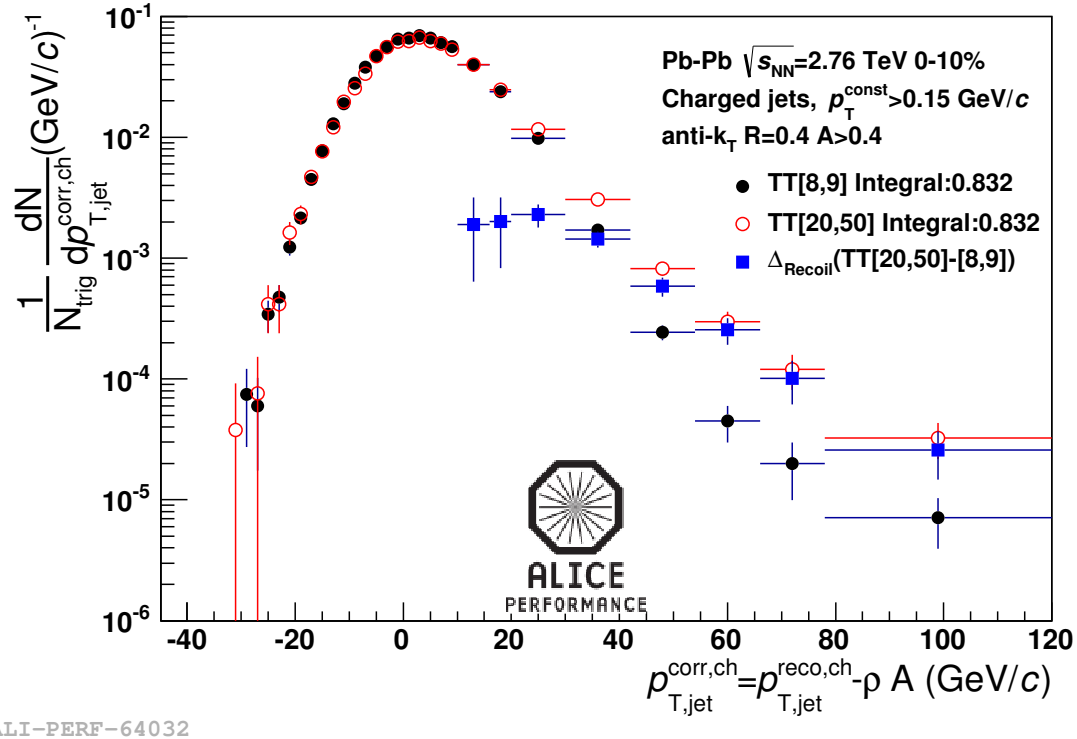
- Jets back to back in azimuth w.r.t. a high-p_T trigger hadron [1]

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

- High-p_T hadron imposes surface bias on the trigger side jet [2] $\Rightarrow$ on average larger path length of the recoil jet through medium
- Combinatorial jets are independent of trigger p_T

Definition of Δ_{recoil} observable

$$\Delta_{\text{recoil}} = \frac{1}{N_{\text{trig}}} \frac{\mathrm{d}N_{\text{jet}}}{\mathrm{d}p_{\text{T}}}\bigg|_{p_{\text{T,trig}} \in \text{TT}_{\text{Sig}}} - \frac{1}{N_{\text{trig}}} \frac{\mathrm{d}N_{\text{jet}}}{\mathrm{d}p_{\text{T}}}\bigg|_{p_{\text{T,trig}} \in \text{TT}_{\text{Ref}}}$$



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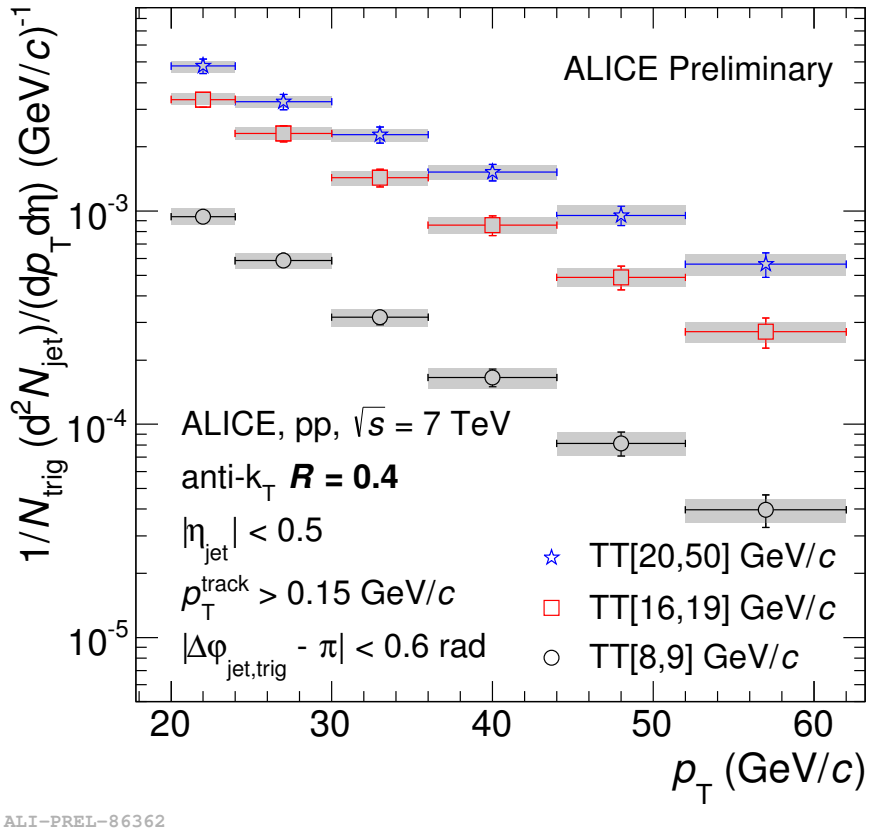
- Disjoint trigger hadron p_{T} bins $\text{TT}_{\text{Sig}} > \text{TT}_{\text{Ref}}$ (here 20-50 and 8-9 GeV/c)
- No bias on the recoil jet fragmentation
- Δ_{recoil} needs to be corrected for bg smearing of the jet energy + detector effects

Medium effects $\Delta I_{AA} = \Delta_{\text{recoil}}^{\text{Pb-Pb}} / \Delta_{\text{recoil}}^{\text{pp}}$ $\Rightarrow$ need pp ref. at the same $\sqrt{s}$

p_T spectra of recoil jets in pp at $\sqrt{s} = 7$ TeV

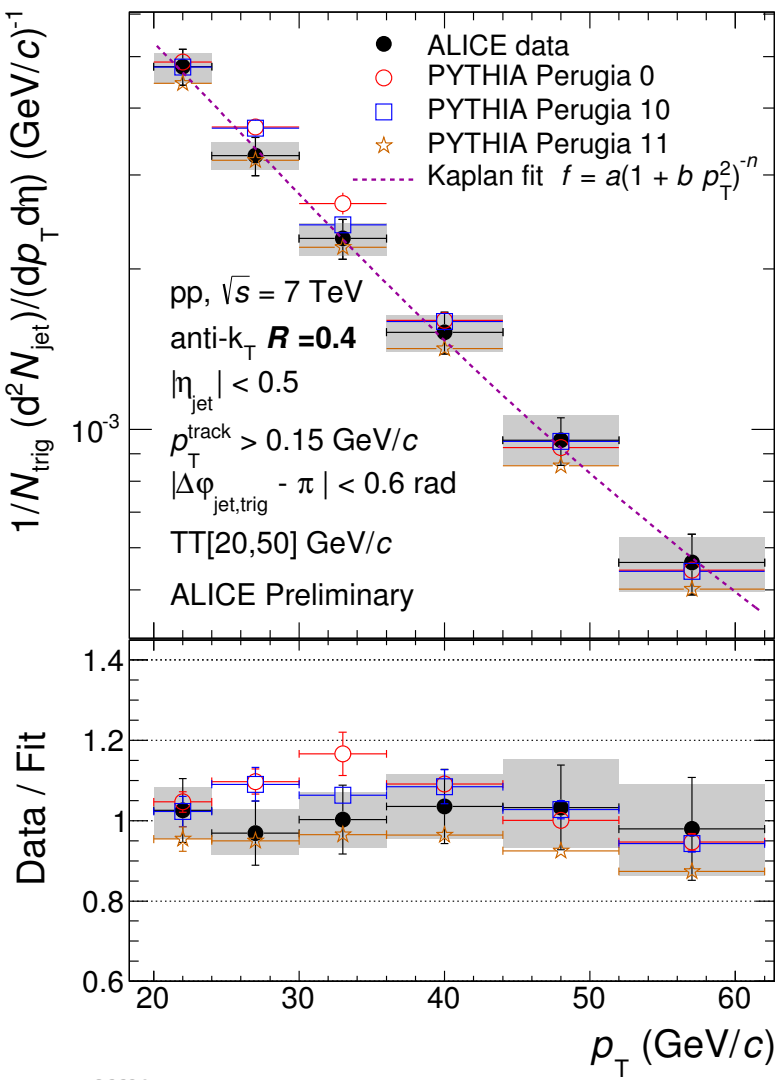
anti-k_T jets with $R = 0.4$



- Cross-check of PYTHIA Perugia ref.
- 168 M min. bias events of pp at $\sqrt{s}$ =7 TeV data from 2010
- Single inclusive trigger $p_{T,trig} \in [8, 9]$, $[16, 19]$, $[20, 50]$ GeV/c.
- Charged track anti-k_T jets $R = 0.2$, 0.4 and 0.5
- $|\varphi_{trig} - \varphi_{jet} - \pi| < 0.6$ rad $|\eta_{jet}| < 0.9 - R$
- ρ from cone perp. to leading jet in φ
- SVD unfolded
- Gray boxes - syst. uncert. resulting from detector effects and unfolding

Data for $R = 0.2$ and $R = 0.5$ see backup.

p_T spectra of recoil jets in pp at $\sqrt{s} = 7$ TeV



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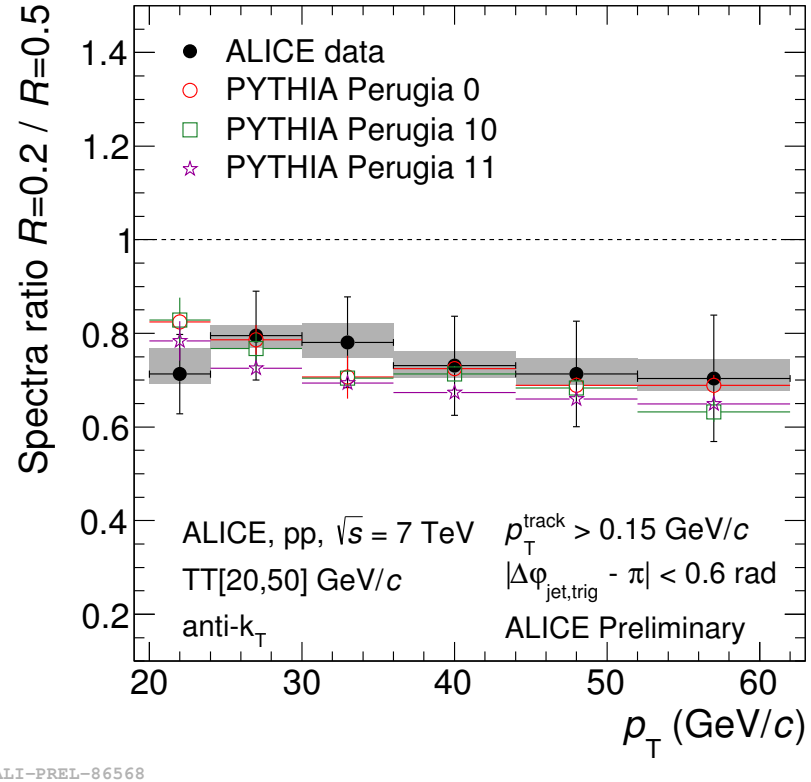
- PYTHIA comparison
  - Perugia 10 is compatible with the data
  - Perugia 11 has w.r.t. Perugia 10 [1]
    - larger underlying event
    - softer LEP fragmentation functions
  - More plots are in backup.
- Bottom panel shows the variation w.r.t. smooth fit of ALICE data

[1] P. Skands, arXiv:1005.3457v5 [hep-ph]

Ratios of recoil jet spectra in pp at $\sqrt{s} = 7$ TeV



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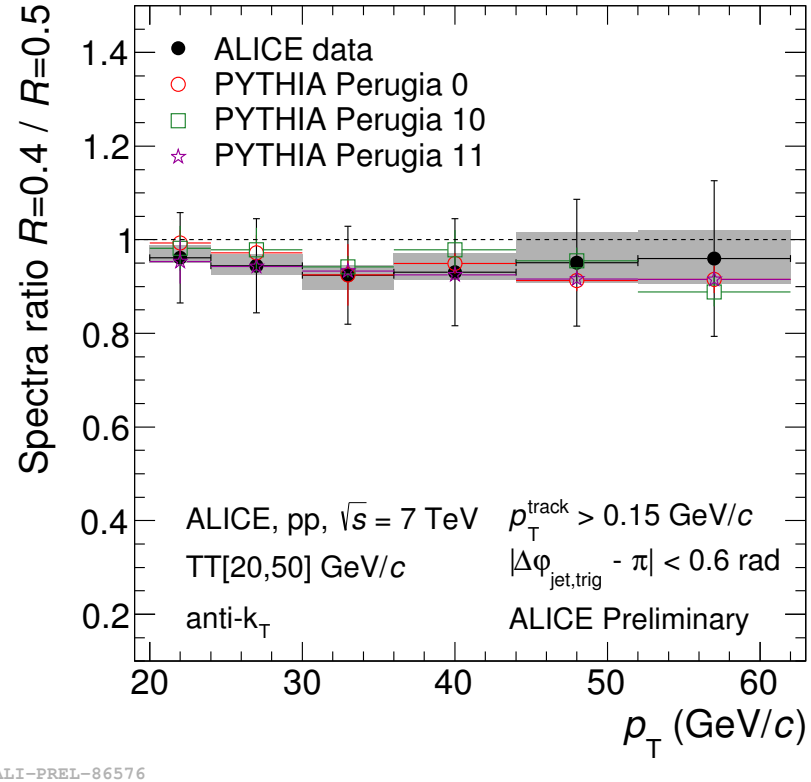

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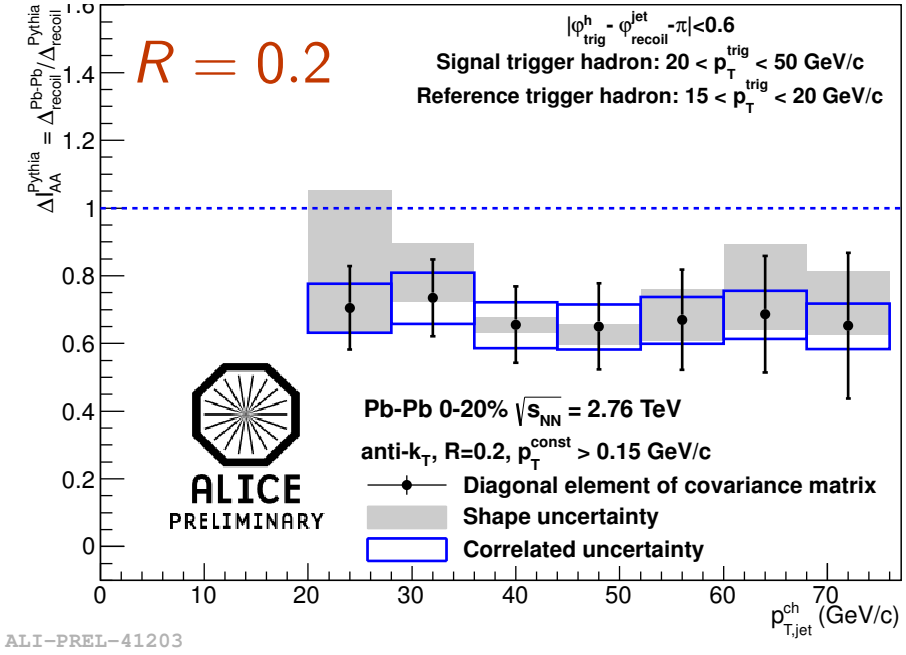
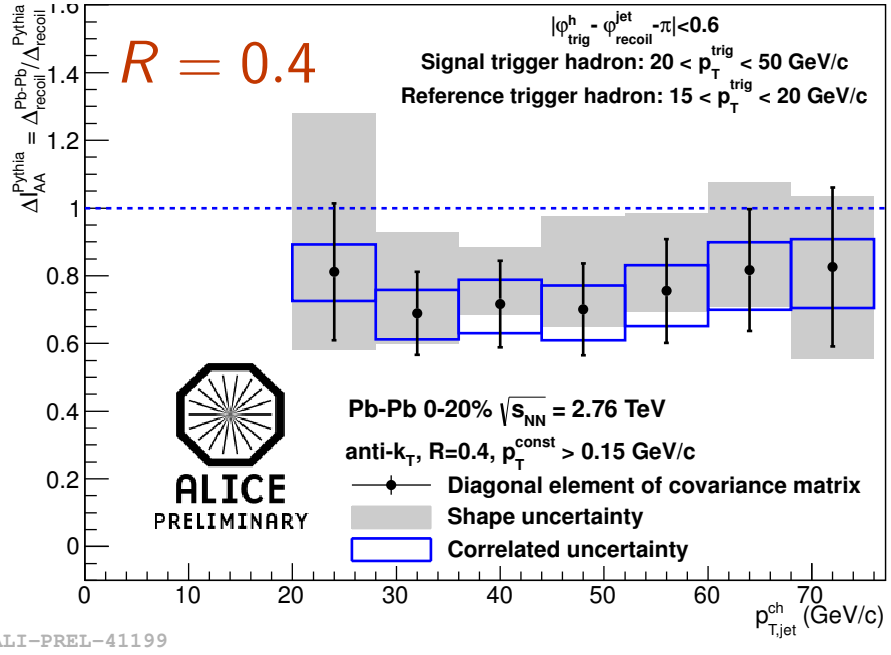
$$\text{ratio}\Big|_{R_1<R_2} = \frac{\frac{1}{N_{trig}}\frac{d^2N_{jet}}{dp_T\,d\eta}\Big|_{R_1}}{\frac{1}{N_{trig}}\frac{d^2N_{jet}}{dp_T\,d\eta}\Big|_{R_2}}$$

- Indirect measure of jet structure
- PYTHIA Perugia tunes describe well the ratios in pp at $\sqrt{s}$ =7 TeV
- More plots with ratios are in backup

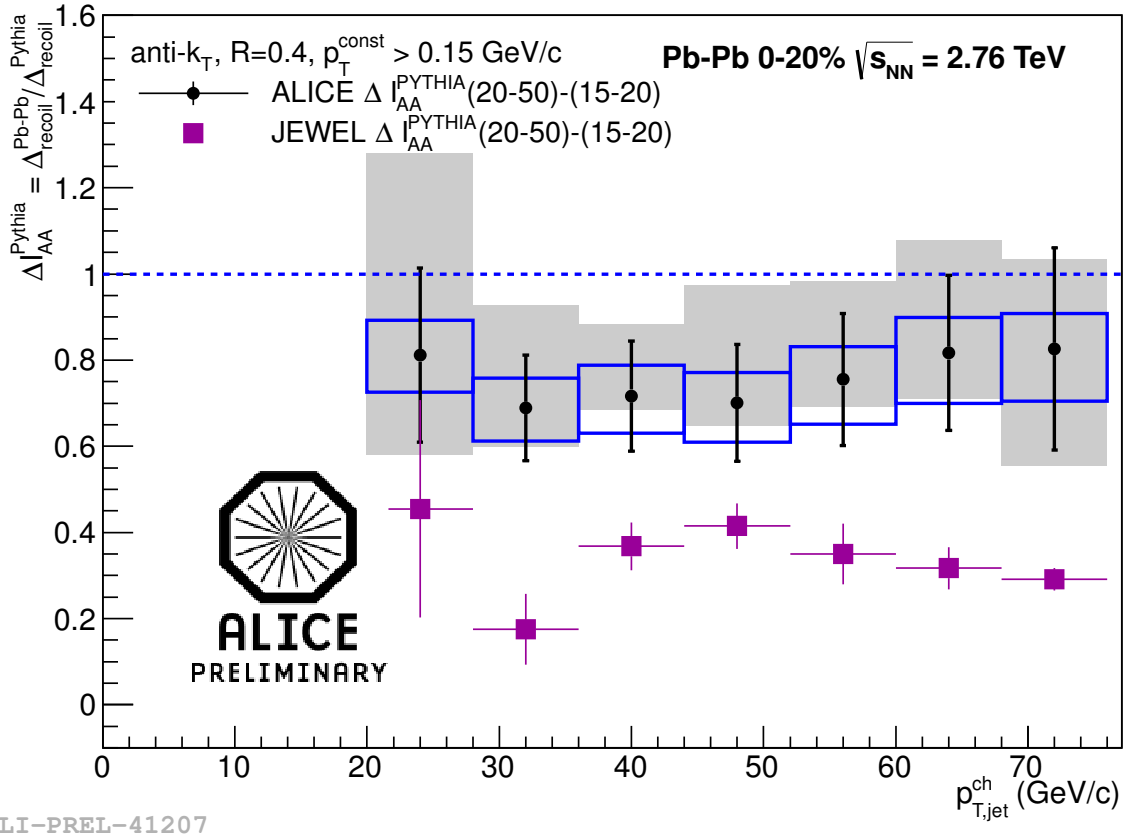
$\Delta I_{AA}^{\text{Pythia}} = \Delta_{\text{recoil}}^{\text{Pb-Pb}} / \Delta_{\text{recoil}}^{\text{Pythia}}$





- Pb–Pb at $\sqrt{s_{\text{NN}}} = 2.76$ TeV from 2010 (0-20% centrality)
- Trigger track selection : hardest track in the event
- Reference $\Delta_{\text{recoil}}^{\text{Pythia}}$ from PYTHIA Perugia 10
- Suppression in recoil jet yield
- Flat $p_{\text{T,jet}}$ dependence and no R dependence of the suppression within errors

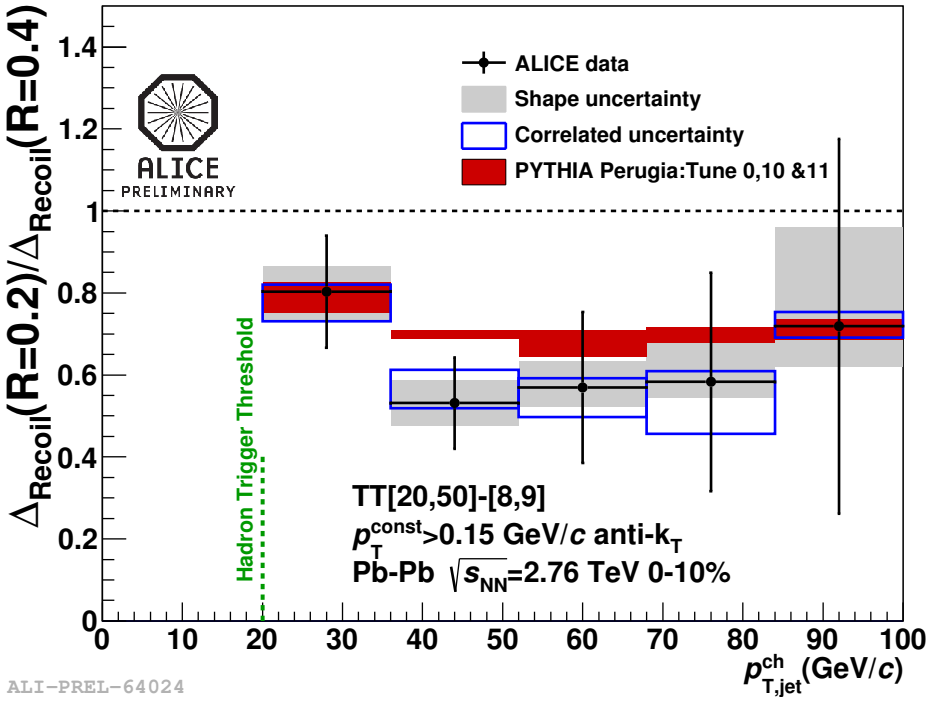
$\Delta I_{AA}^{\text{Pythia}}$ compared to JEWEL

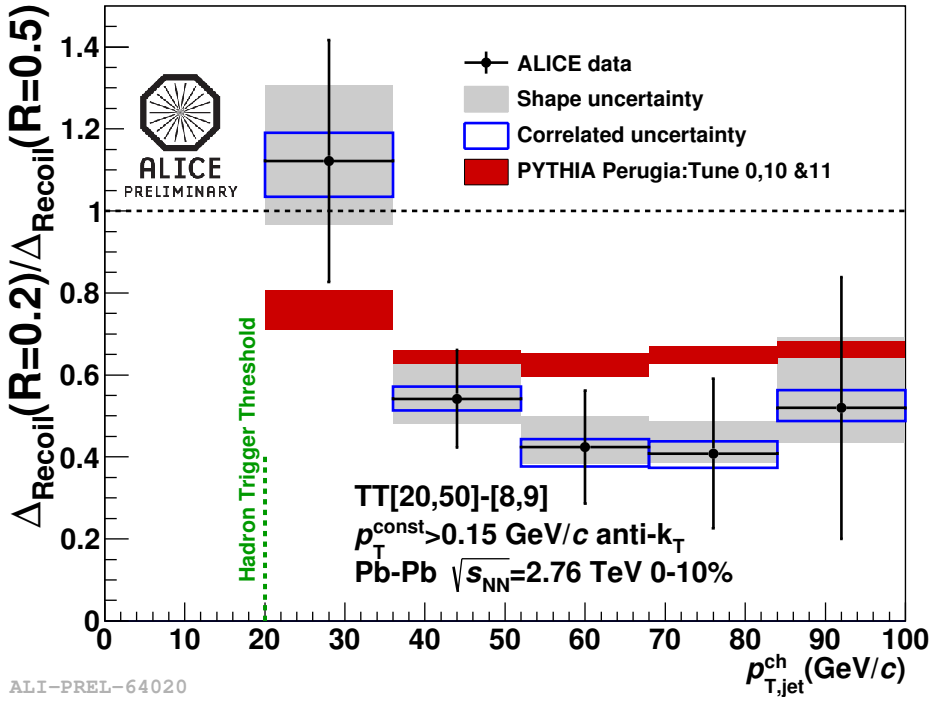


JEWEL [1] - Parton shower in the presence of a medium (coll. + rad. energy loss)
- Tuned on inclusive hadron R_{AA}
- "Recoils-off" configuration - jets do not have a correlated component originating from background partons interacting with the jet

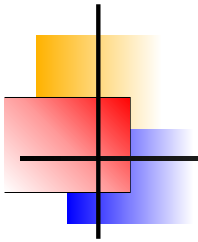
[1] JEWEL: Zapp et al., Eur.Phys.J.C69 (2009) 617

Ratios of recoil jet yields obtained with different R



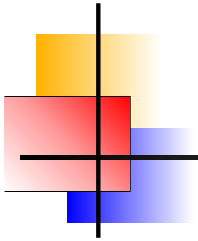


- Pb–Pb $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV data from 2011, centrality 0-10 %
- Single inclusive trigger
- Red band: variation in observable calculated using PYTHIA tunes
- No evidence for significant energy redistribution w.r.t. PYTHIA
- No evidence for intra-jet broadening within $R = 0.5$



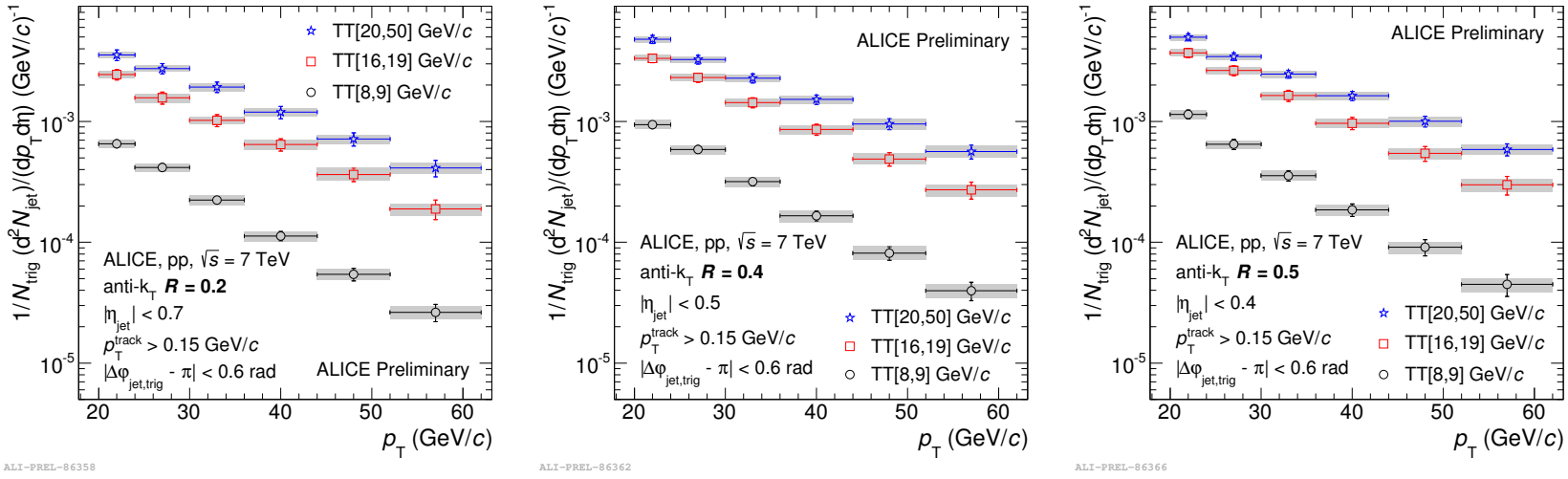
Summary

- 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
- Comparison to PYTHIA: Perugia tunes model p_T spectra of recoil jets in pp at $\sqrt{s} = 7$ TeV well
- Suppression of recoil jet yield observed ($\Delta I_{AA} \approx 0.75$),
  - not well modeled by the "recoils-off" mode of JEWEL
- No evidence of intra-jet broadening of energy profile out to $R = 0.5$



Backup slides

p_T spectra of recoil jets in pp at $\sqrt{s} = 7$ TeV



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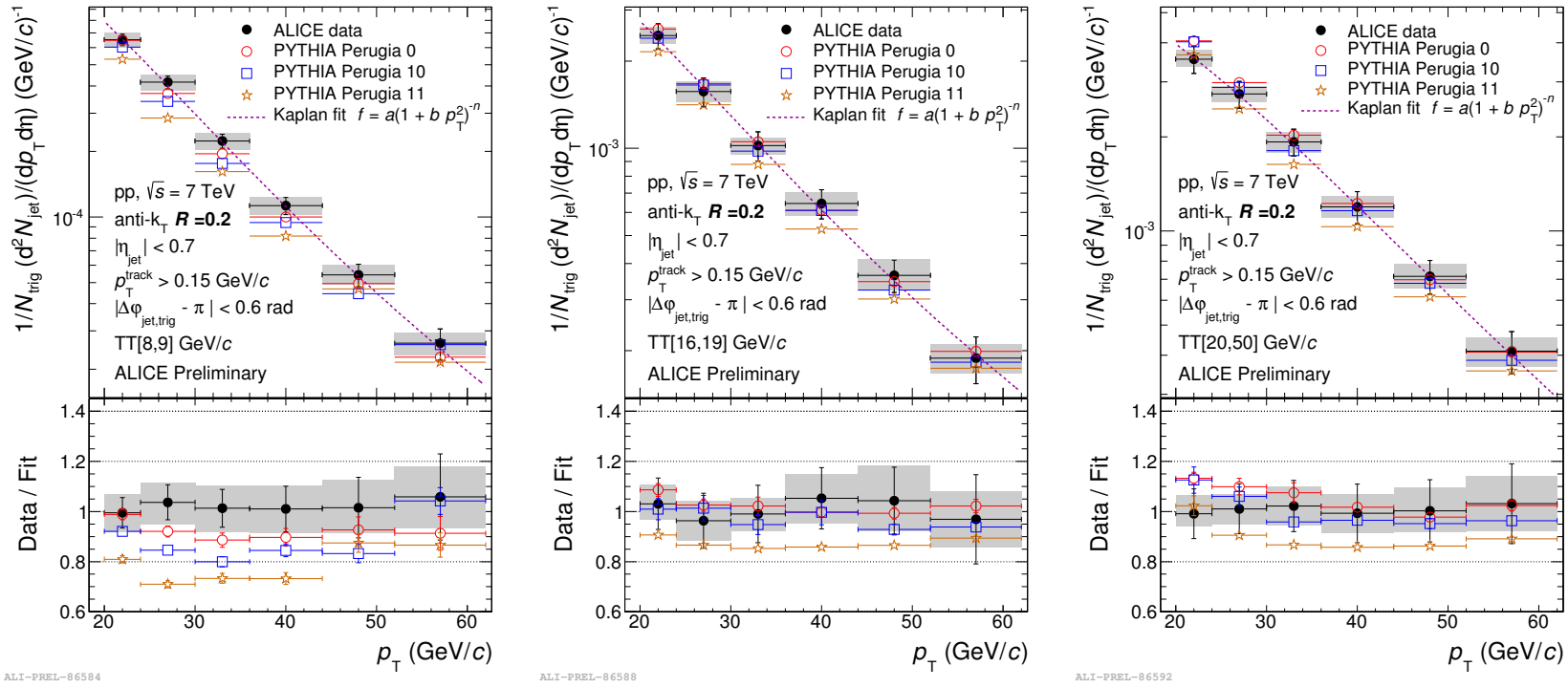
- ρ estimated in cone perp. to leading jet in azimuth
- SVD unfolded
- Gray boxes - syst. uncert. resulting from detector effects and unfolding

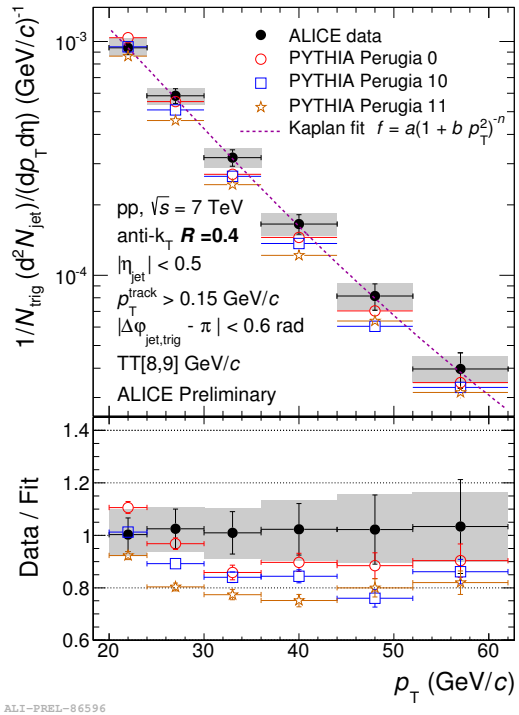
p_T spectra of recoil jets in pp at $\sqrt{s} = 7$ TeV

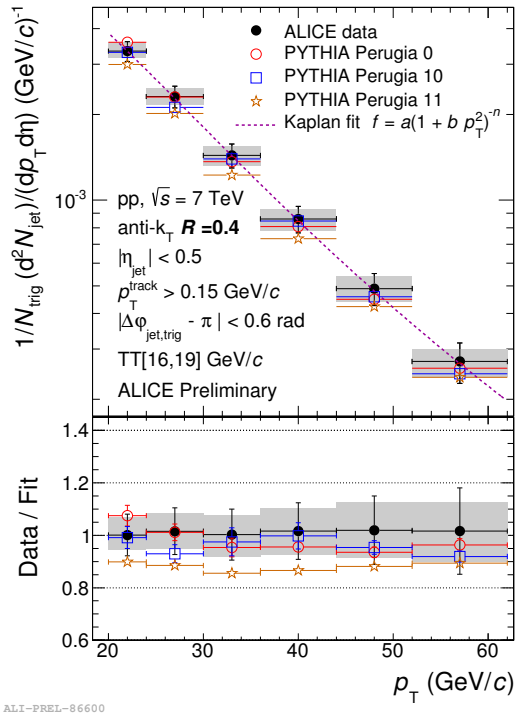
anti-k_T jets with $R = 0.2$

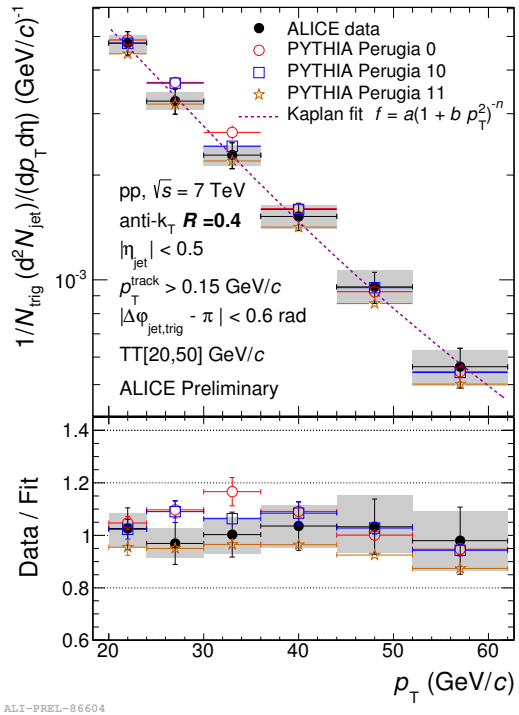


p_T spectra of recoil jets in pp at $\sqrt{s} = 7$ TeV

anti-k_T jets with $R = 0.4$

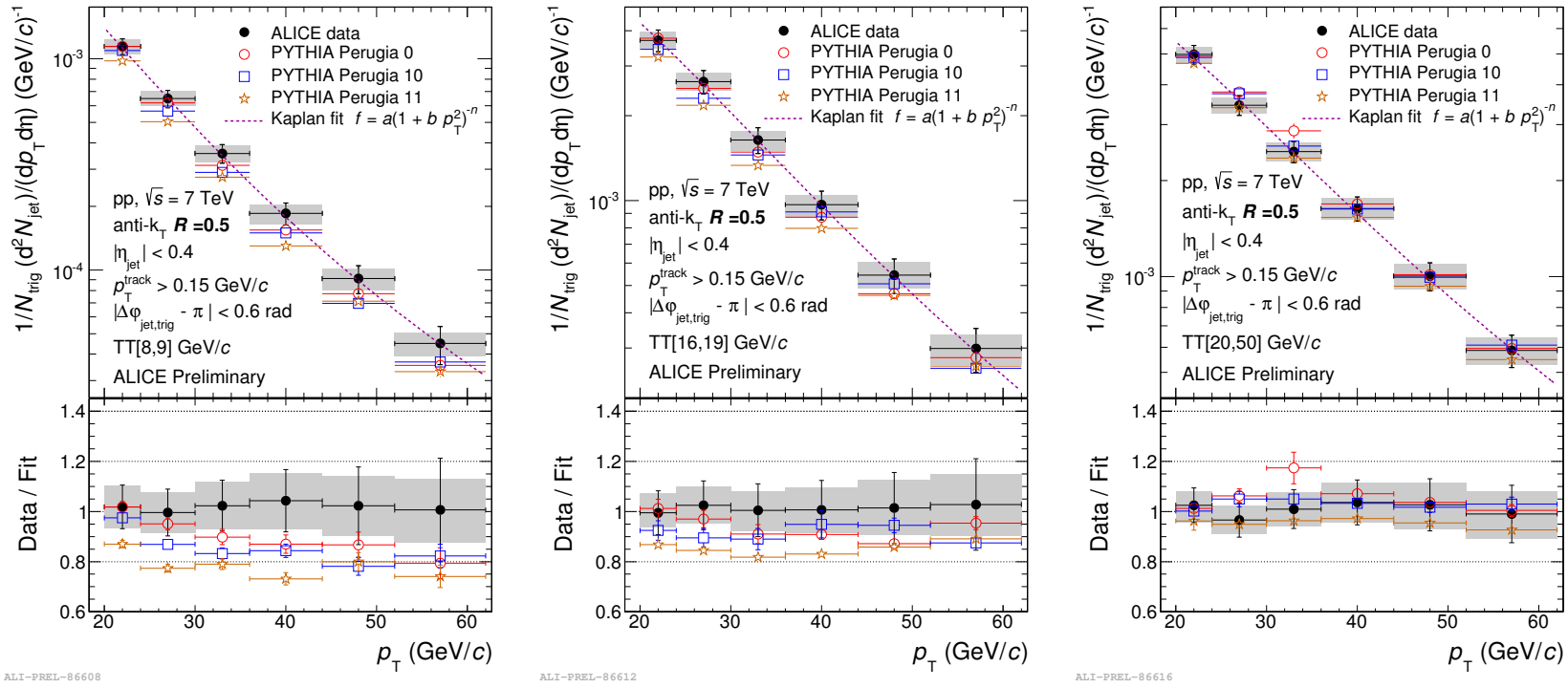




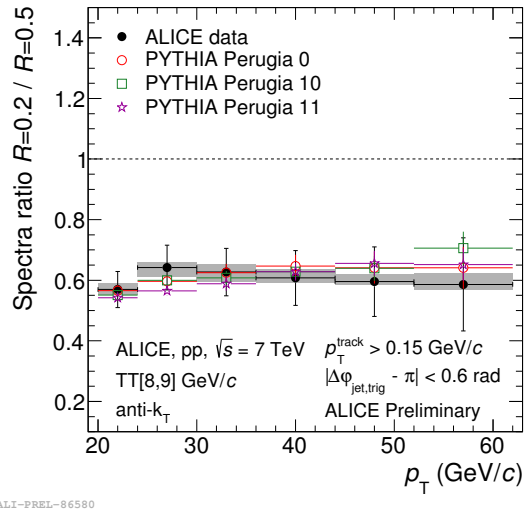


p_T spectra of recoil jets in pp at $\sqrt{s} = 7$ TeV

anti-k_T jets with $R = 0.5$



Ratios of recoil jet spectra in pp at $\sqrt{s} = 7$ TeV



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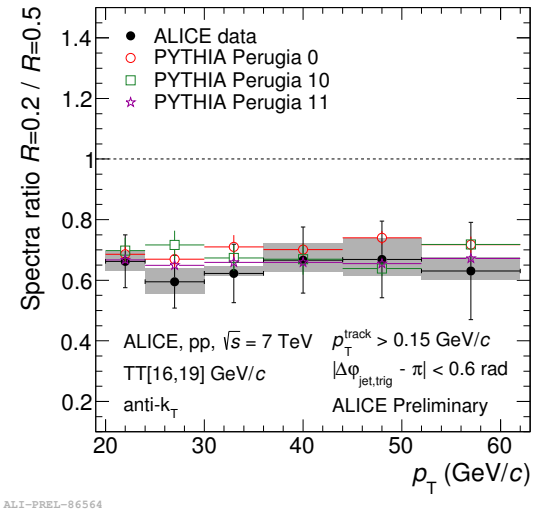

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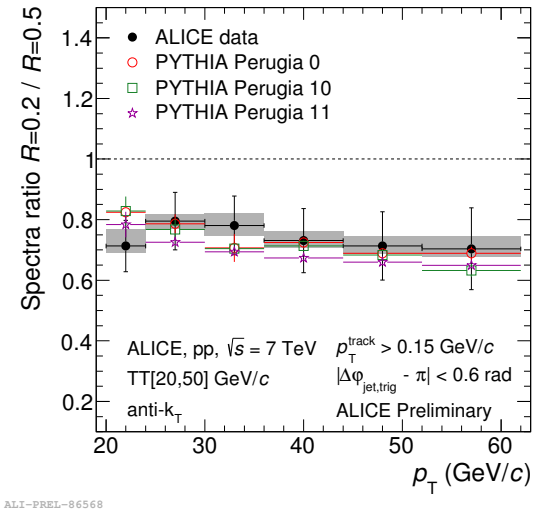

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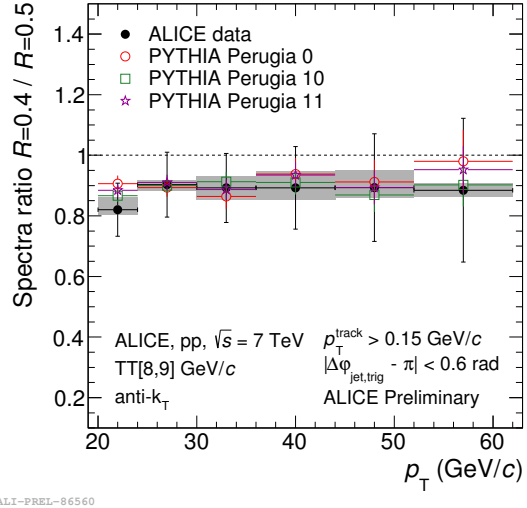

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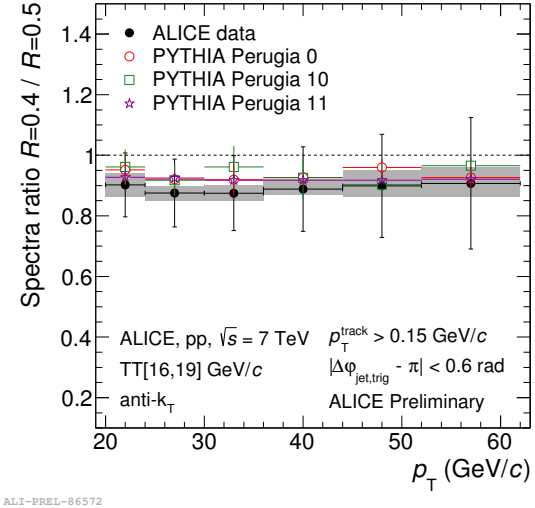

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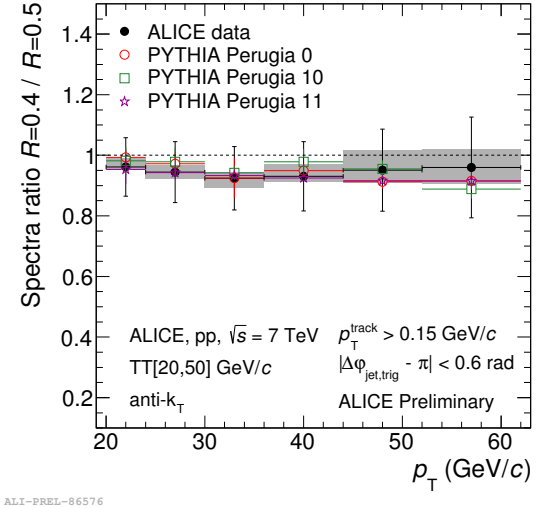

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