Jets in noisy environments

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Krakow — November 28-30 2011

Plan

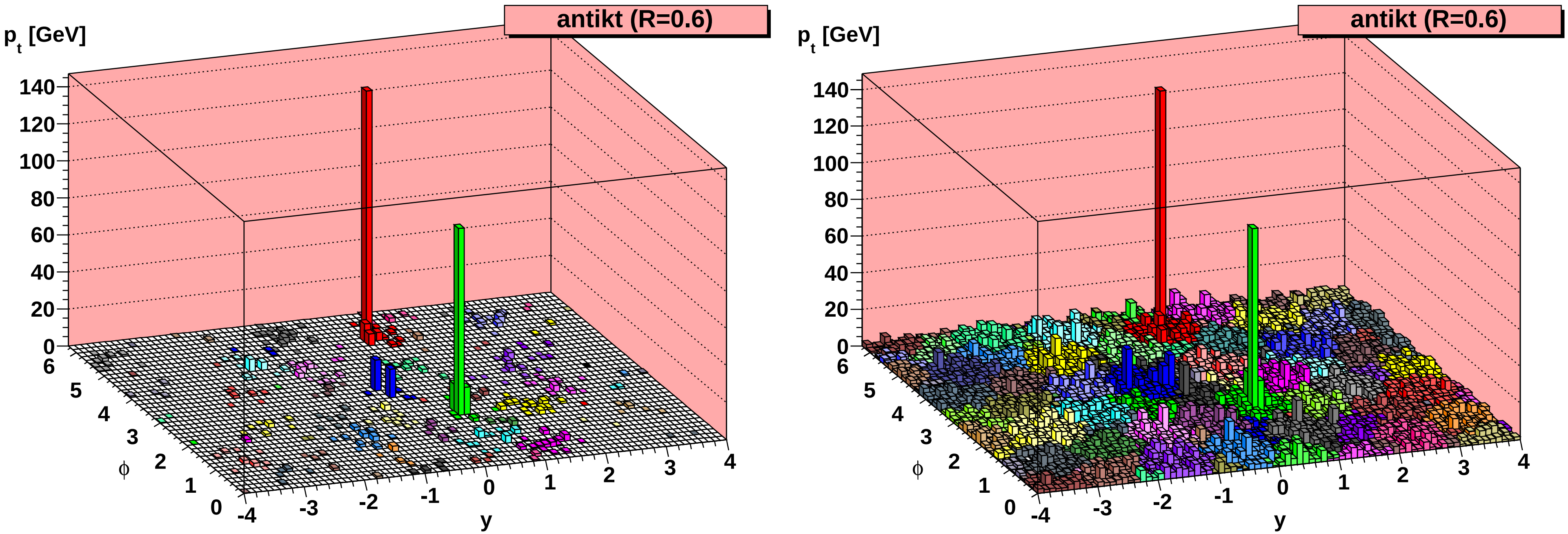
- Introduction: background effects on jets
- Jet reconstruction methods: how to subtract the background?
  - Jet-area based subtraction: our proposed method
  - Performance tests: how well do we do?
- A case study in HI:
  dijet asymmetry, what room for quenching?

Introduction

The challenge

Best illustrated with an example (dijet, $p_t > 100GeV$)

From “clean” pp... ...to busy AA



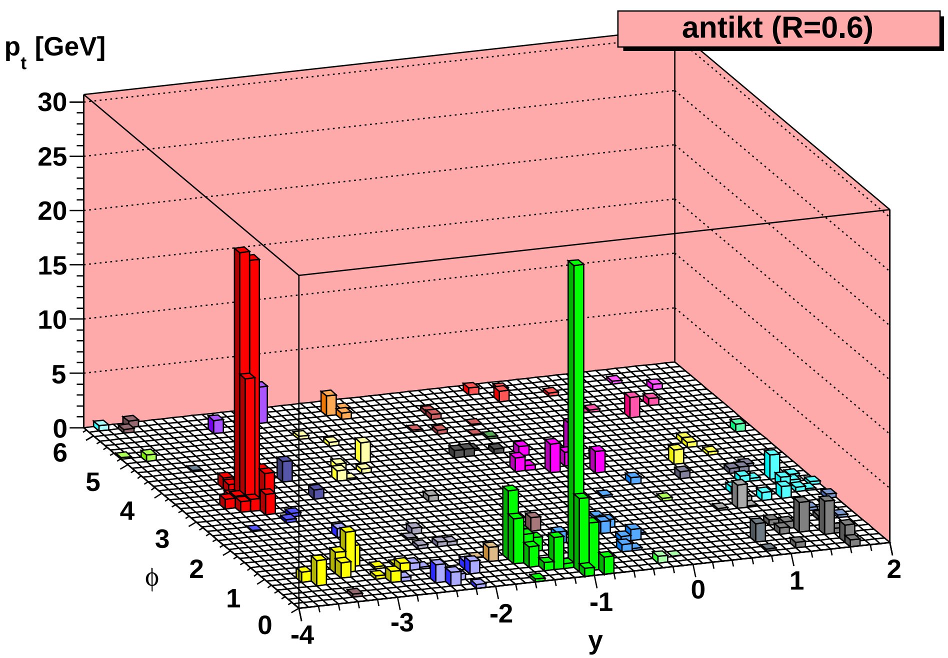
- p_t shift (net contamination)
- resolution degradation (fluctuations in and across events)

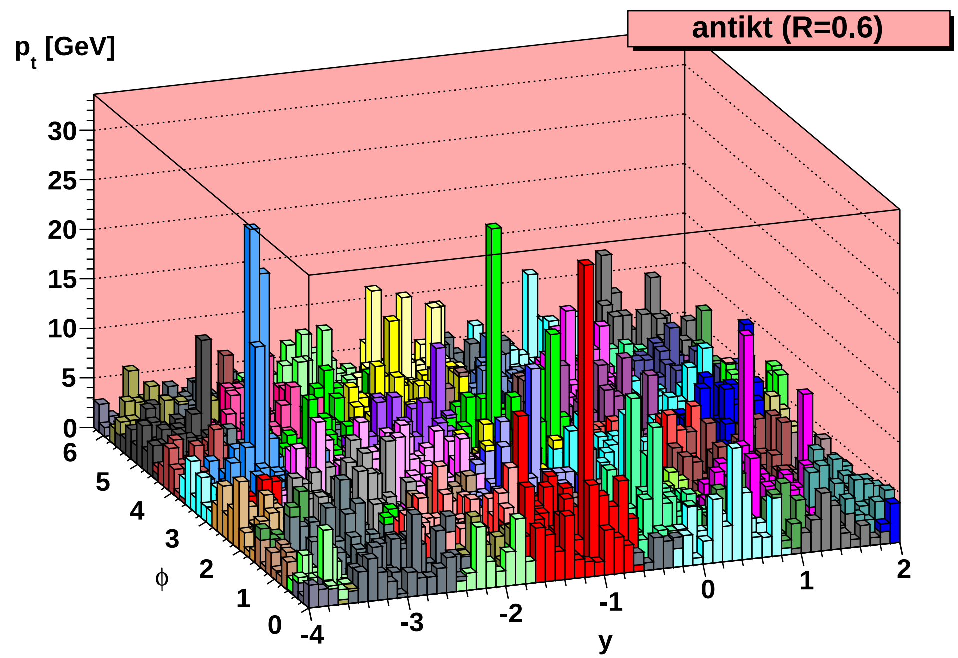
The challenge

Best illustrated with an example (dijet, $p_t > 100GeV$)

From "clean" pp...

...to busy AA





And it can get worse!!!

Effects

- Background added to the jet: (inside an event!)

$$\boxed{p_{t,\mathrm{jet}}^{\mathrm{hard}} \to p_{t,\mathrm{jet}} = p_{t,\mathrm{jet}}^{\mathrm{hard}} + \rho A_{\mathrm{jet}} \pm \sigma\sqrt{A_{\mathrm{jet}}}}$$

  - $A \equiv$ jet area (for each jet)
  - $\rho \equiv$ background density (for each event)
  - $\sigma \equiv$ background fluctuations (for each event)

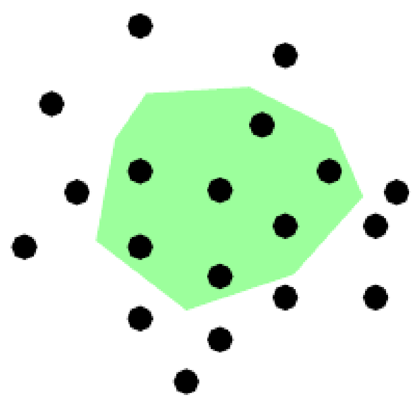
Effects

- Background added to the jet: (inside an event!)

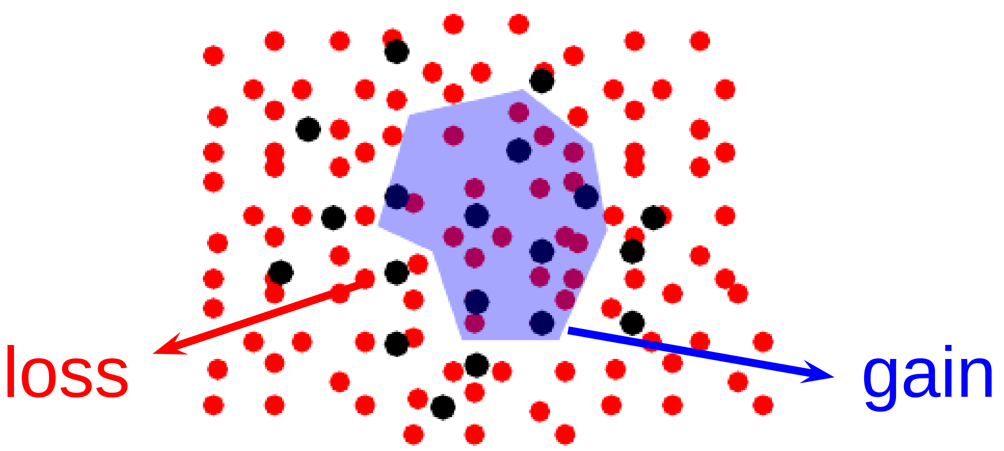
$$\boxed{p_{t,\text{jet}}^{\text{hard}} \to p_{t,\text{jet}} = p_{t,\text{jet}}^{\text{hard}} + \rho A_{\text{jet}} \pm \sigma\sqrt{A_{\text{jet}}}}$$

- Back-reaction:

No background



With background



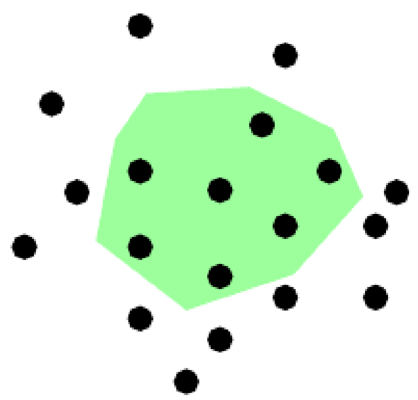
Effects

- Background added to the jet: (inside an event!)

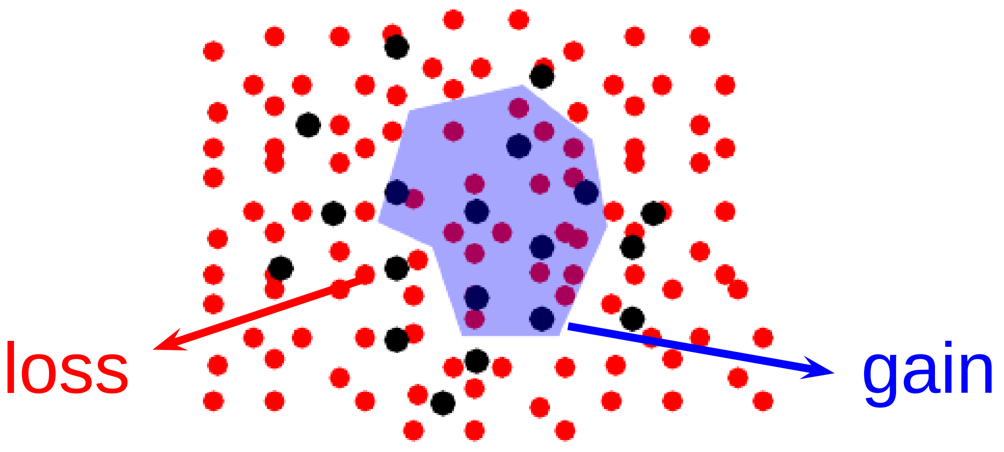
$$\boxed{p_{t,\text{jet}}^{\text{hard}} \to p_{t,\text{jet}} = p_{t,\text{jet}}^{\text{hard}} + \rho A_{\text{jet}} \pm \sigma\sqrt{A_{\text{jet}}}}$$

- Back-reaction:

No background



With background



This talk: "subtracting ρ, discussing the effects of σ"

Typical numbers

Default: anti-k_t jets $R = 0.4$, $0 - 10$% centrality

Estimates	LHC, PU	RHIC, AA	LHC, AA
ρ	15 GeV	90 GeV	200 GeV
${\sigma_\rho}^{(1)}$	4 GeV	15 GeV	40 GeV
σ	5 GeV	8 GeV	20 GeV $^{(2)}$
A_{jet}	0.5	0.5	0.5
$\delta p_{t,\mathrm{jet}}$	7.5 GeV	50 GeV	100 GeV
σ_{jet}	3.5 GeV	7 GeV	16 GeV $^{(2)}$

Notes:

1. $\sigma_\rho \equiv$ fluctuations of ρ across different events.
   Importance of a event-by-event subtraction
2. to be discussed later on!

Background subtraction

Jet-area-based subtraction

$$p_{t,\mathrm{jet}}^{(\mathrm{sub})} = p_{t,\mathrm{jet}} - \rho_{\mathrm{bkg}} A_{\mathrm{jet}}$$

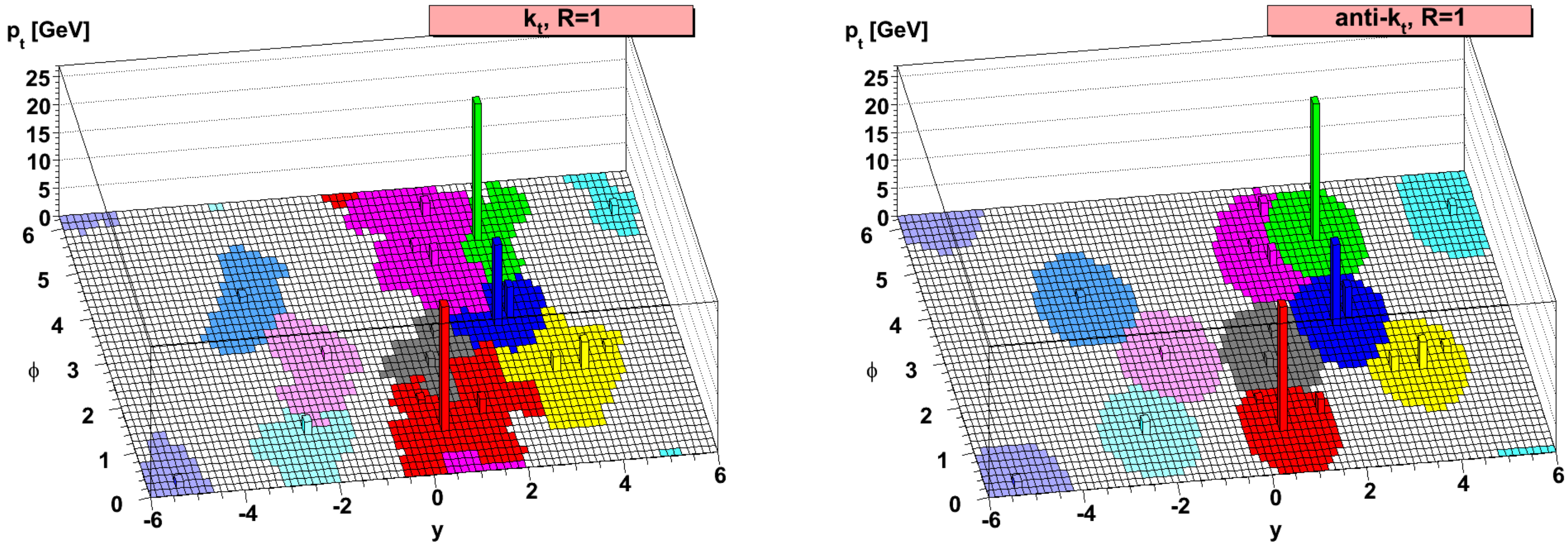
Jet area A_{jet}: per jet

Bkg density ρ_{bkg}: (typically) per event

Jet-area-based subtraction

$$p_{t,\mathrm{jet}}^{(\mathrm{sub})} = p_{t,\mathrm{jet}} - \rho_{\mathrm{bkg}} A_{\mathrm{jet}}$$

- jet area: throw *ghosts particles* (area quanta) in the event
  - defined to mimic the reaction to the background
  - implemented in FastJet
  - analytic handle

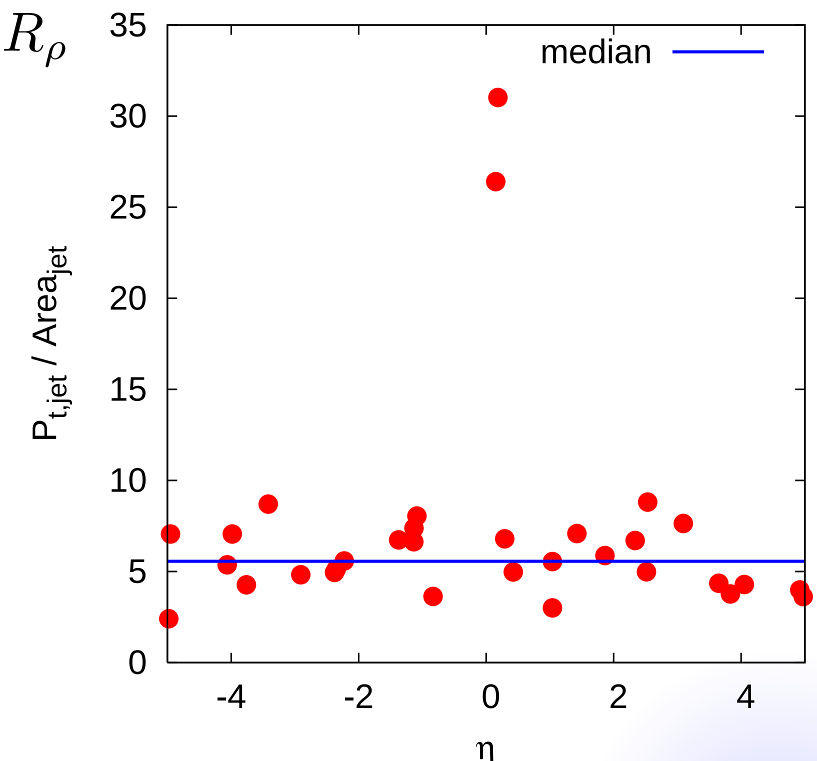


Jet-area-based subtraction

$$p_{t,\text{jet}}^{(\text{sub})} = p_{t,\text{jet}} - \rho_{\text{bkg}} A_{\text{jet}}$$

- jet area: throw *ghosts particles* (area quanta) in the event
- ρ_{bkg}, the background p_t density per unit area
  - Cluster with k_t of C/A with “radius” R_ρ
  - Estimate ρ_{bkg} using

$$\boxed{\rho_{\text{bkg}} = \underset{j\in\text{jets}}{\text{median}} \left\{ \frac{p_{t,j}}{A_j} \right\}}$$



Subtraction uncertainties (1/2)

1. Background fluctuations: (inside an event!)

$$p_{t,\rm jet} = p_{t,\rm jet}^{\rm hard} + \rho_{\rm bkg} A_{\rm jet} \pm \sigma_{\rm bkg}\sqrt{A_{\rm jet}}$$

   Hint: *e.g.* using filtering (beyond this talk)

2. Back-reaction:

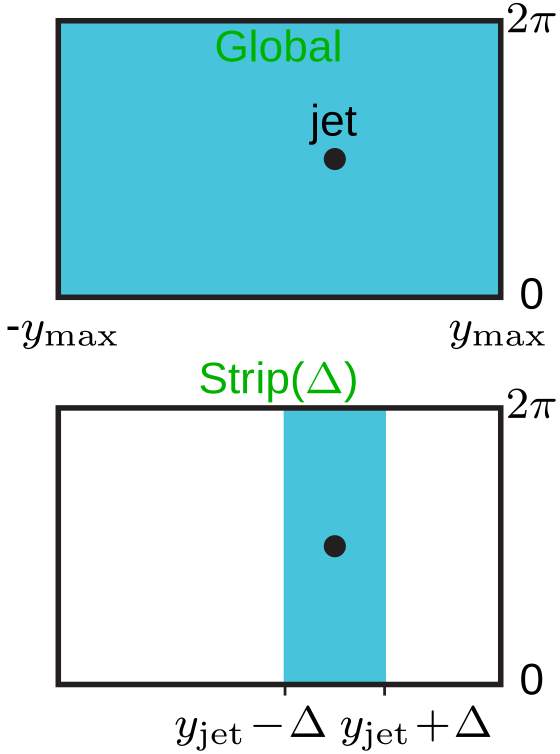
   anti-k_t $\approx$ circlular jets (rigidity!)
   $\Rightarrow$ no back-reaction

Subtraction uncertainties (2/2)

3 Background non-uniform (*e.g.* rap dependence)

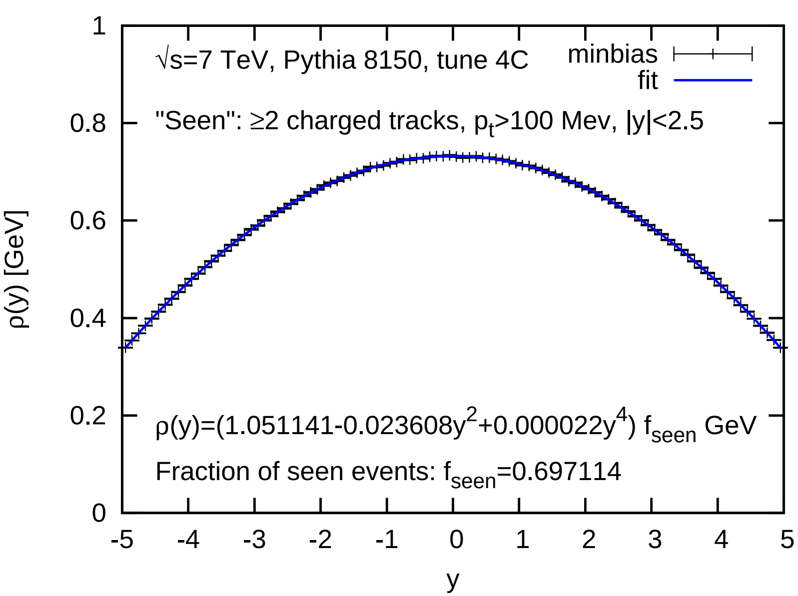
local range $\mathcal{R}$

$$\rho(j) = \underset{j' \in \mathcal{R}(j)}{\text{median}} \left\{ \frac{p_{t,j'}}{A_{j'}} \right\}$$



rapidity rescaling

$$\rho(j) = f(y_j) \underset{\text{all} j'}{\text{median}} \left\{ \frac{p_{t,j'}}{A_{j'} \, f(y_{j'})} \right\}$$

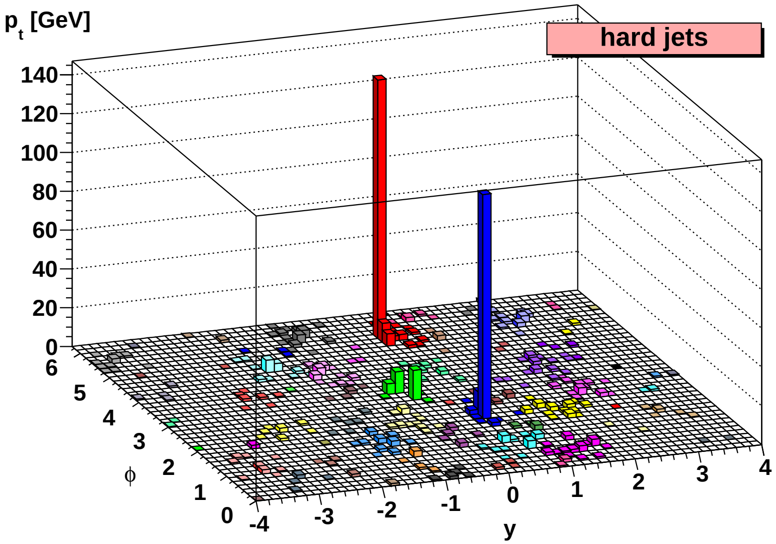


f from minbias

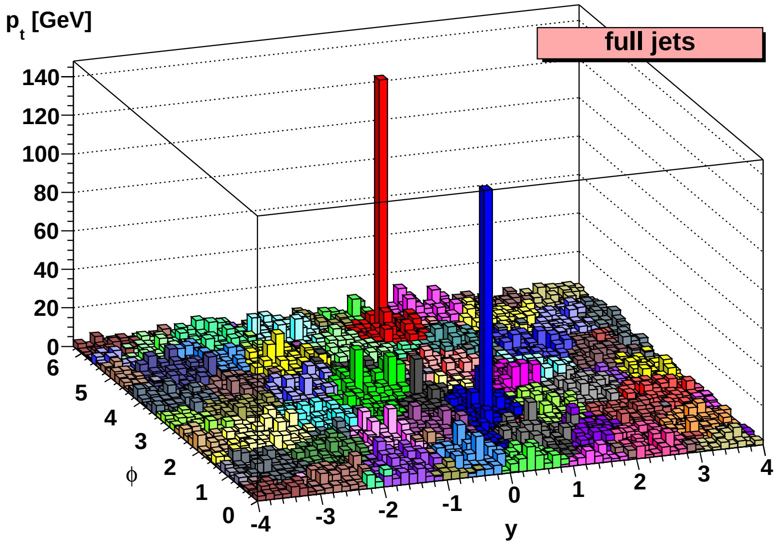
Subtraction performances

Framework for study: embedding

Hard (Pythia) event



... embedded in background

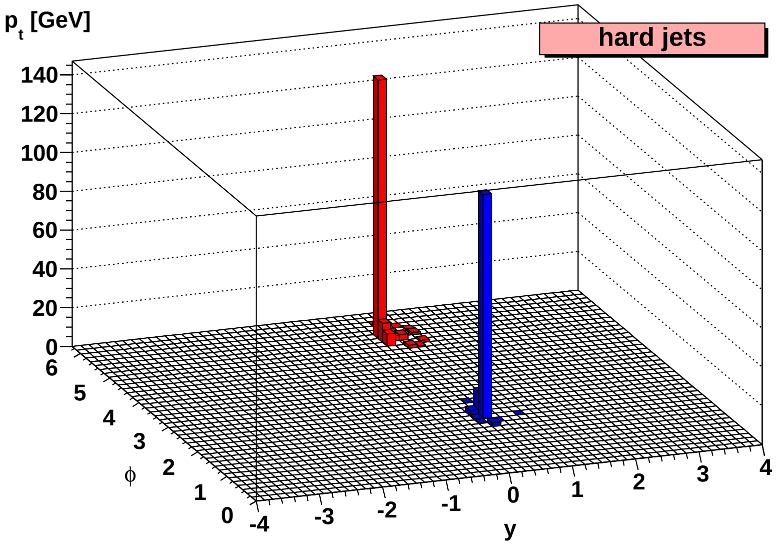


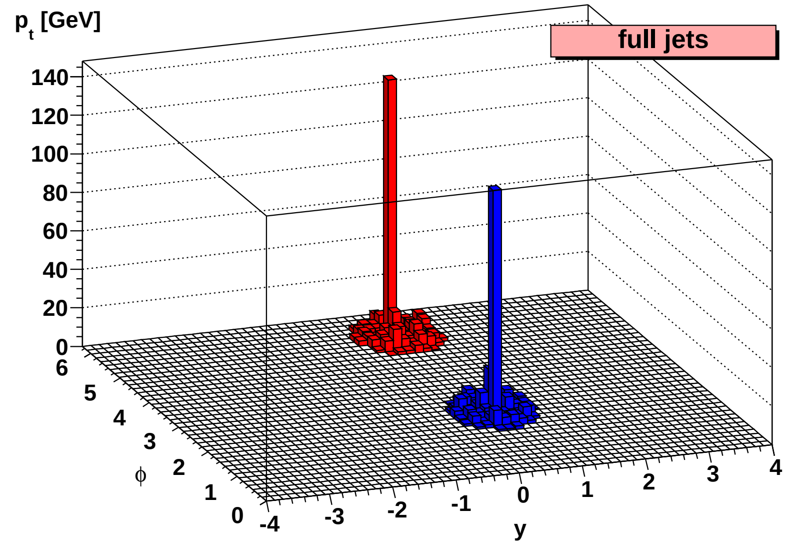
- Get the jets and apply subtraction in both cases ($R = 0.4$)

  test different methods for ρ estimation

Framework for study: embedding

Hard (Pythia) event ... embedded in background





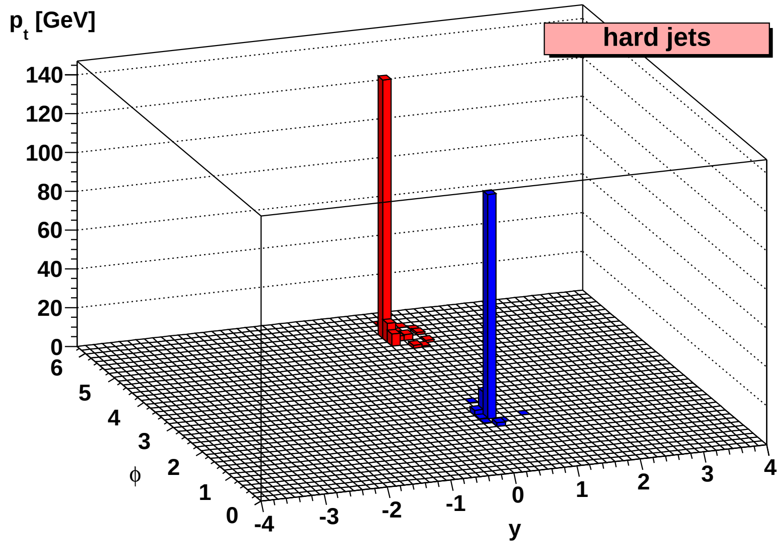
- Get the jets and apply subtraction in both cases ($R = 0.4$)
- Match the 2 hardest jets

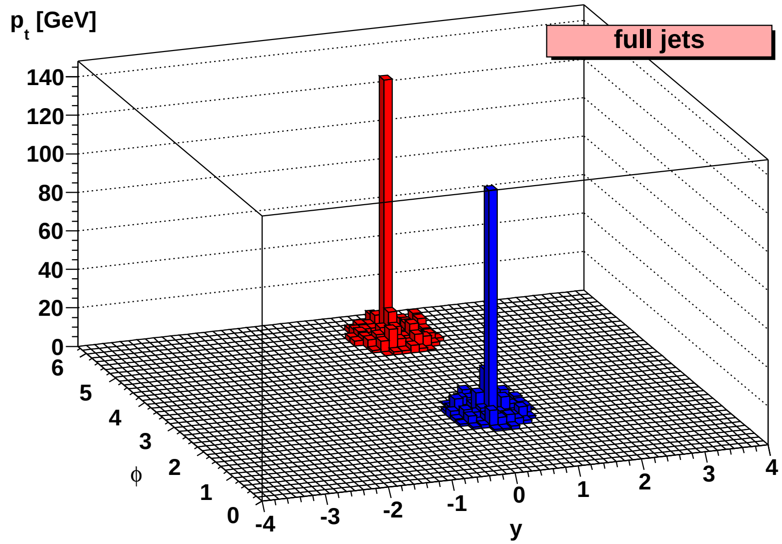
  at least 50% of the hard contents recovered after embedding

  Efficiencies $\geq$ 95%

Framework for study: embedding

Hard (Pythia) event ... embedded in background

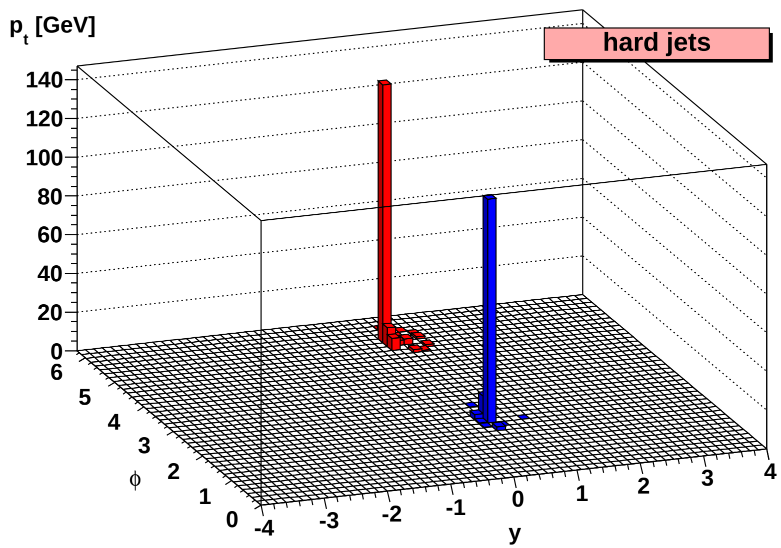




- Get the jets and apply subtraction in both cases ($R = 0.4$)
- Match the 2 hardest jets
- Subtraction quality: $\Delta p_t = p_t^{\text{hard+bkg,sub}} - p_t^{\text{hard,sub}}$
- Study $\langle \Delta p_t \rangle$ and $\sigma_{\Delta p_t}$

Framework for study: embedding

Hard (Pythia) event



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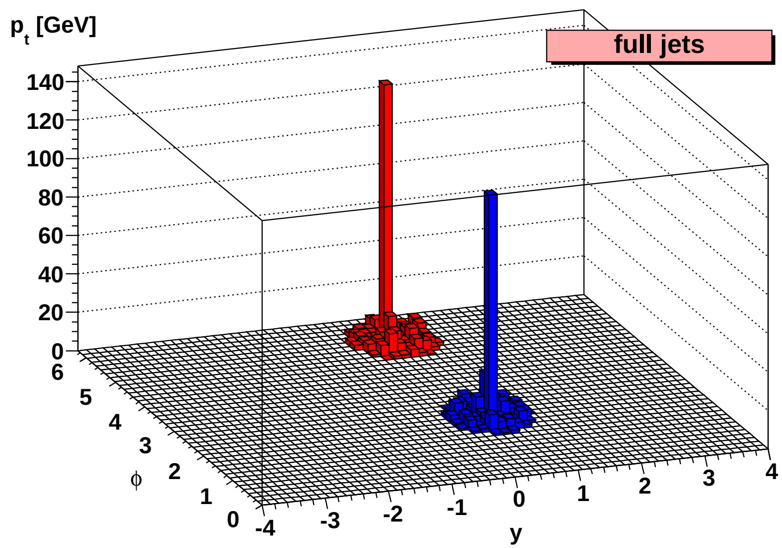


- Get the jets and apply subtraction in both cases ($R = 0.4$)
- Match the 2 hardest jets
- Subtraction quality: $\Delta p_t = p_t^{\mathrm{hard+bkg,sub}} - p_t^{\mathrm{hard,sub}}$
- Study $\langle \Delta p_t \rangle$ and $\sigma_{\Delta p_t}$
- Flexible: vary jet definition, subtraction range, Monte-Carlo, ...

  Can even use real minbias data for the background

Disclaimer

Many possible plots:

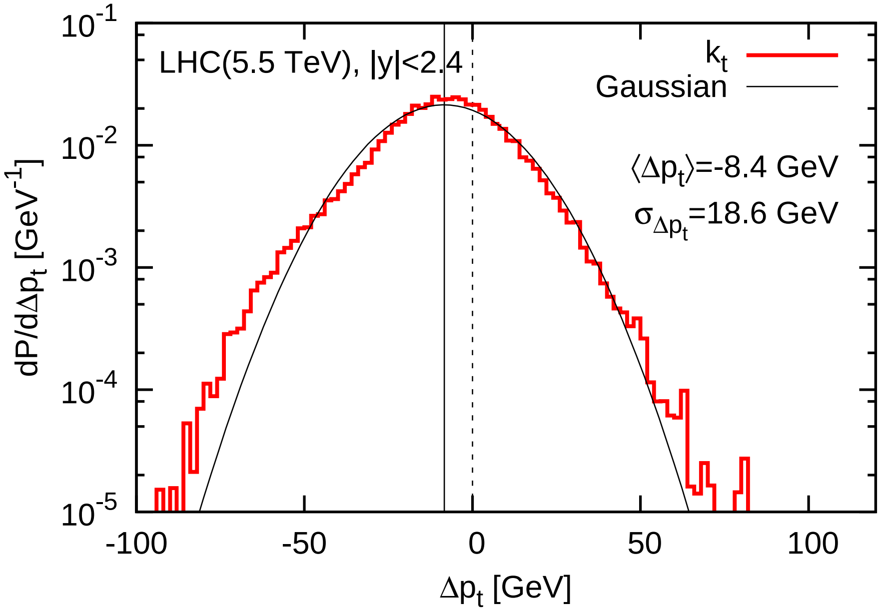
- as a function of y, $p_{t,jet}$, n_{PU}
- LHC $pp + PU$, RHIC $AuAu$, LHC $PbPb$
- Monte-Carlo variations
- HI: quenching, centrality
- Details of the subtraction (jet def, range, ...)

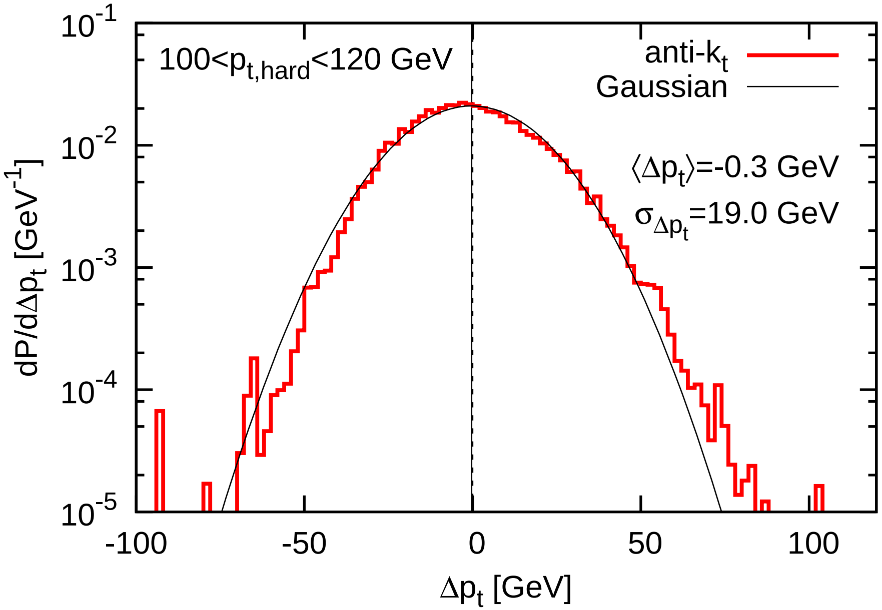
Only a minimalistic (hopefully representative) shown!

Δp_t *distributions*

Direct measurement of the residual subtraction error for each individual jet:

Example for $PbPb$ collisions at LHC(5.5 TeV)

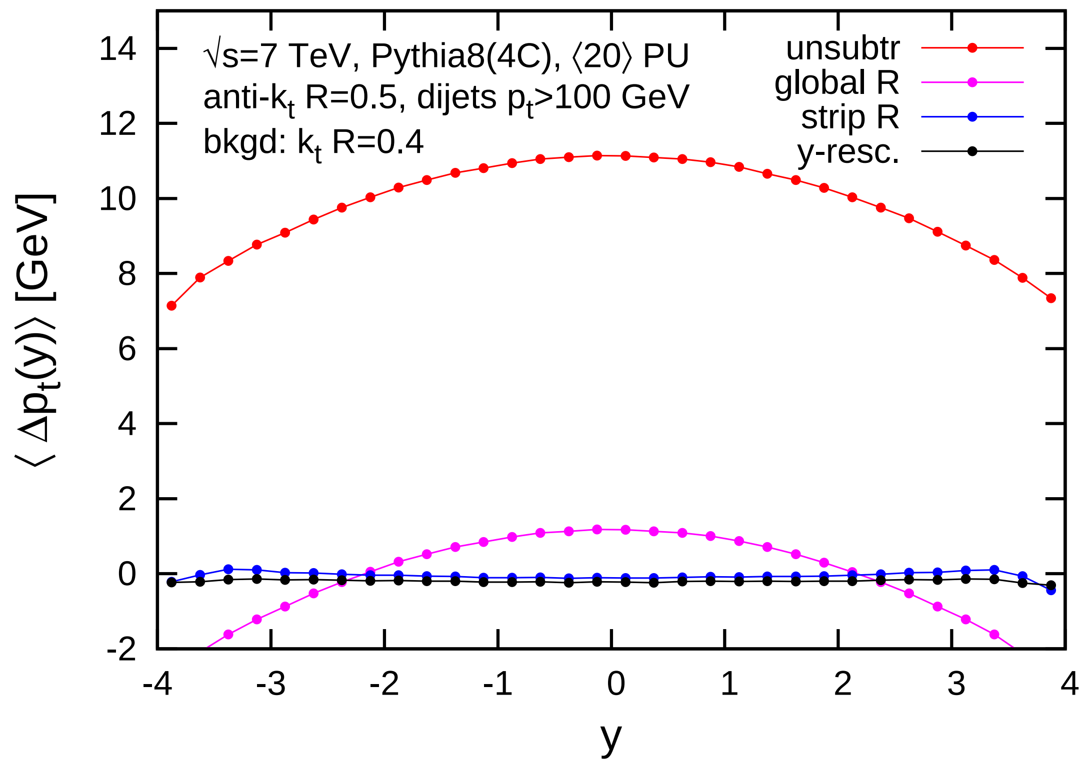




From now on, focus on $\langle \Delta p_t \rangle$ and $\sigma_{\Delta p_t}$

Subtraction benchmarks: rapidity dependence

Average shift vs. rapidity: LHC, anti-$k_t(R = 0.5)$ jets + $\langle 20 \rangle$ PU events

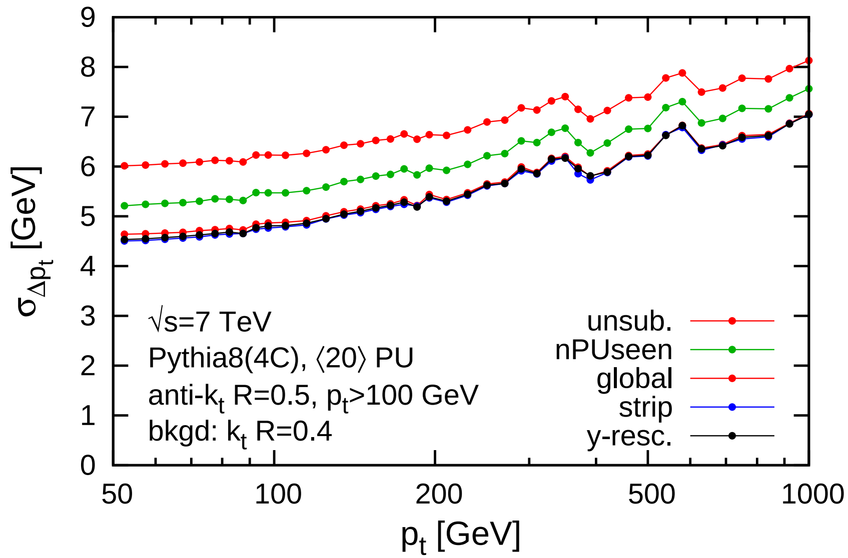


- local range & y-rescaling help
- typical 100-200 MeV average precision for PU
- HI: a few 100 MeV, no bias due to quenching or non-central

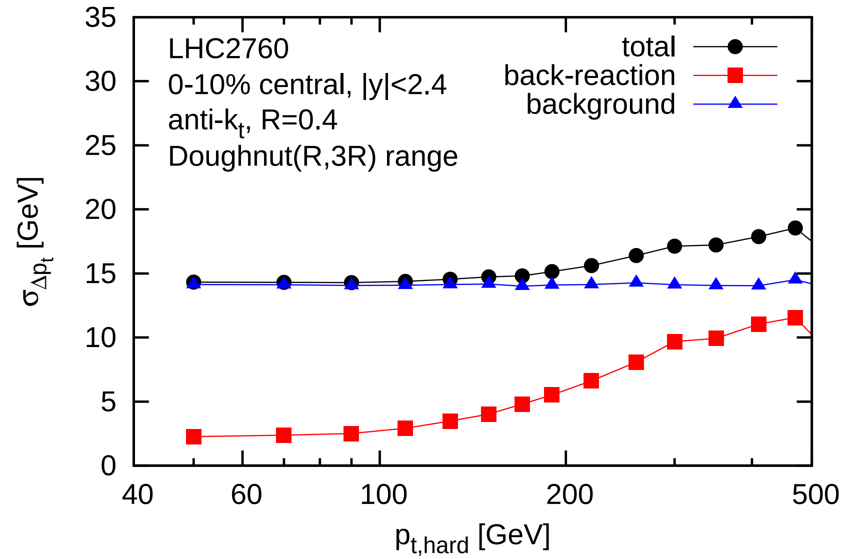
Subtraction benchmarks: dispersion

Residual resolution effect:

pp+$\langle 20\rangle$ PU, anti-$k_t(R=0.5)$ jets



PbPb, anti-$k_t(R=0.4)$ jets



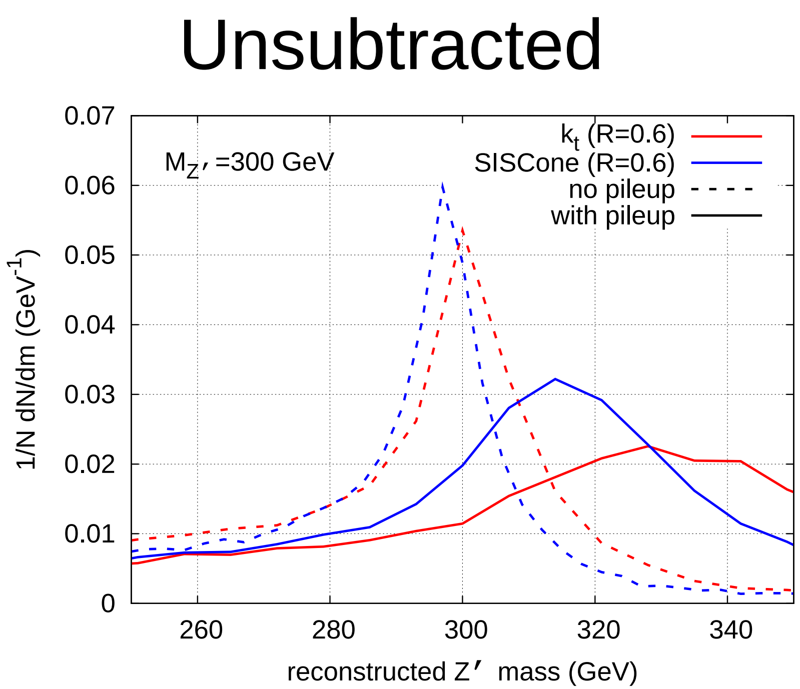
- improvement compared to “no subtraction”: no sensitivity to σ_ρ
- improvement compared to “naive subtraction”: no sensitivity to σ_ρ

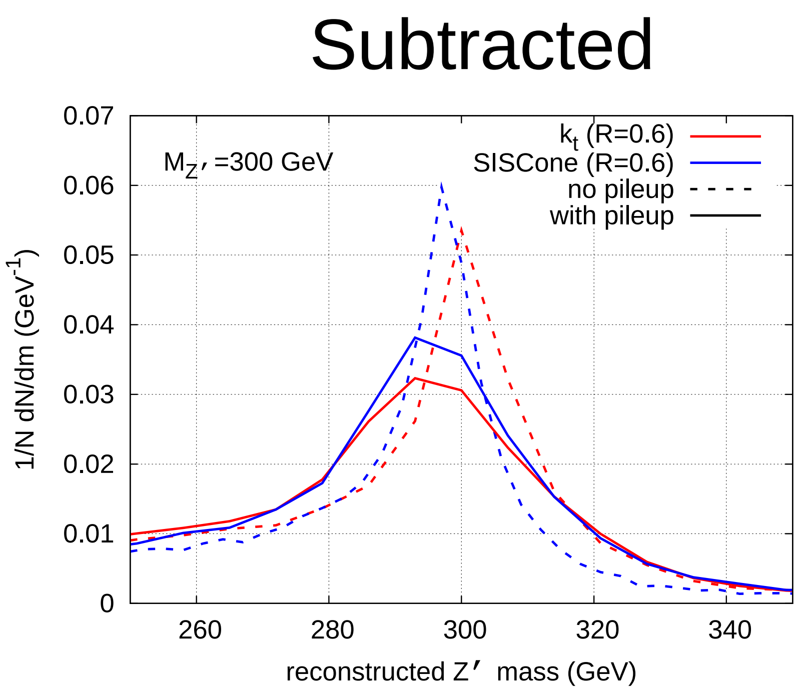
  $p_{t,\mathrm{sub}} = p_t - n_{PU}.$(constant ρ) A_{jet}
- Can reach large resolution effects from intra-event flucts. in HI
- (effect $\propto \sqrt{p_t}$ from back-reaction)

Application: pp Dijet resonnance reconstruction

Massive resonance $Z' \to qq$

Z' in the dijet mass spectrum (here $M_{Z'} = 300$ GeV)



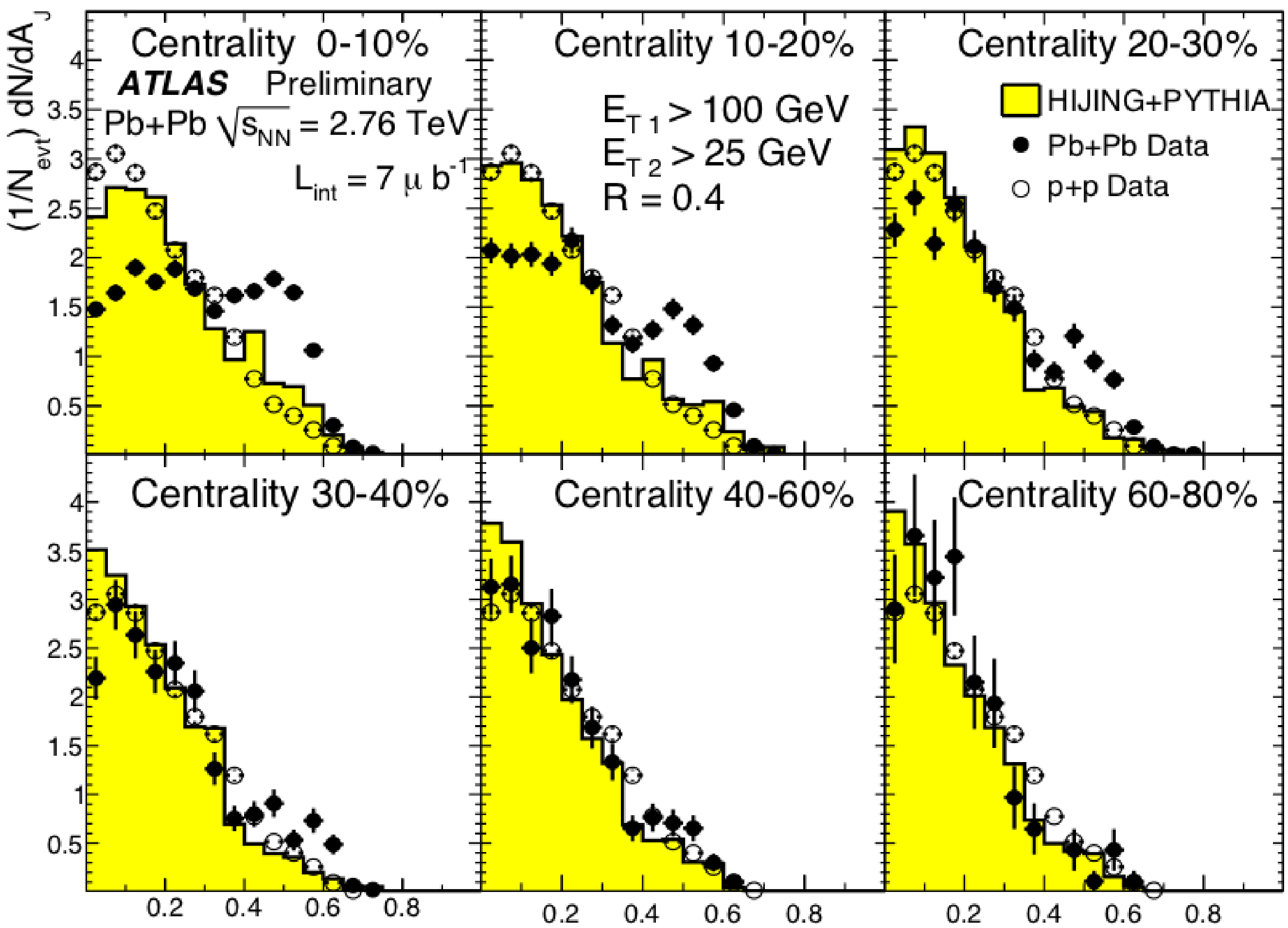


- Peak position corrected ($\langle \Delta p_t \rangle \approx 0$)
- Less smearing effects (no effect from σ_ρ)

Application: HI Dijet Asymmetry

As observed by ATLAS

[ATLAS, QM2011]



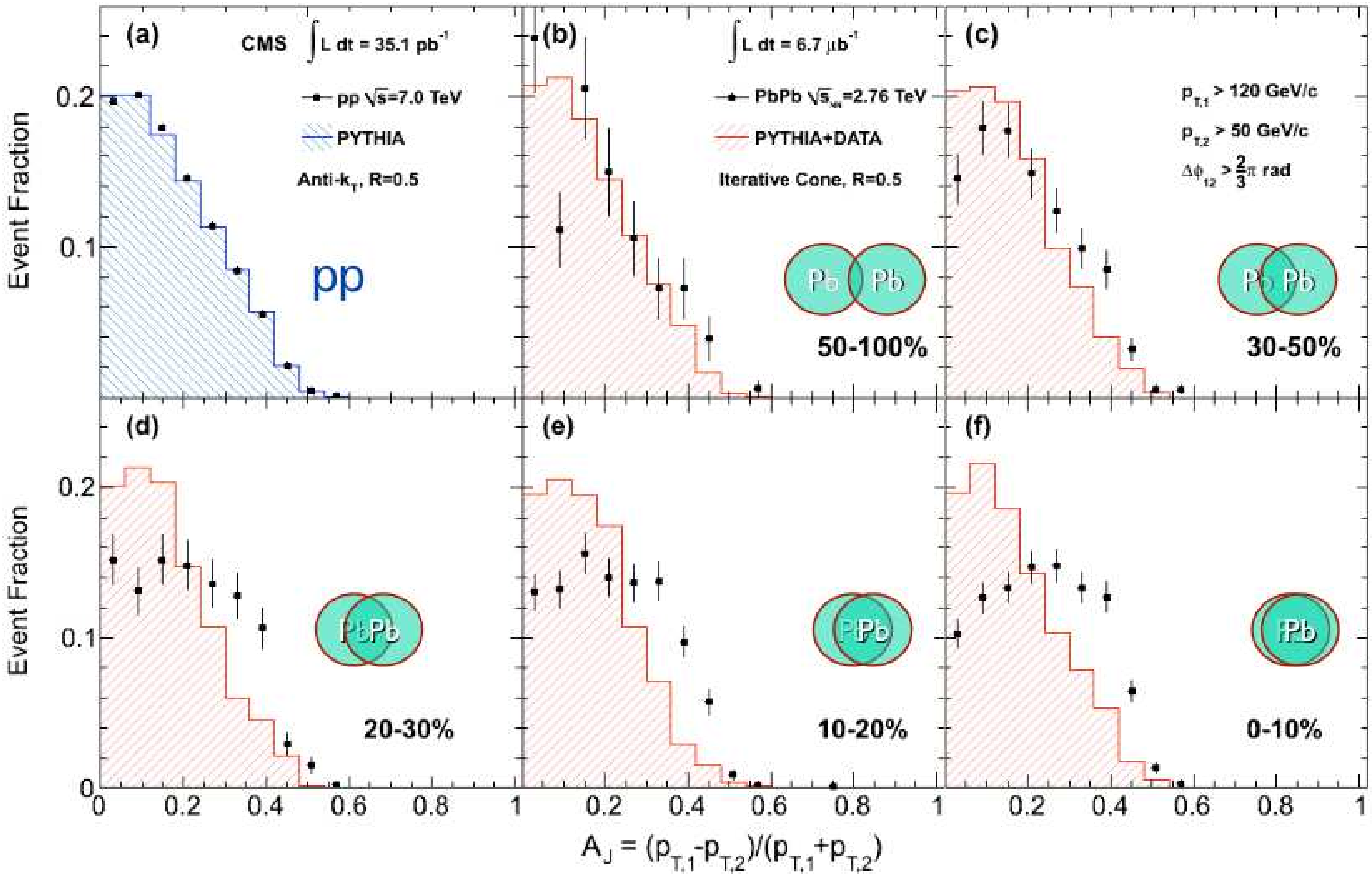
$$A_J = \frac{E_{T,1} - E_{T,2}}{E_{T,1} + E_{T,2}}$$

Interpretation:

A_J increasing from pp to AA as a consequence of *quenching*

As observed by CMS

Same kind of story for CMS... [CMS, QM2011]



Main question

How is this measurement influenced by the fluctuations of the HI background?

- Example: take a “typical” pp asymmetry:
  $p_{t,1} = 100$ GeV, $p_{t,2} = 67$ GeV $\Rightarrow A_J = 0.2$,
  Flucts: $p_{t,1} + 16$ GeV, $p_{t,2} - 16$ GeV $\Rightarrow A_J \sim 0.4$
  Fluctuations can mimic quenching

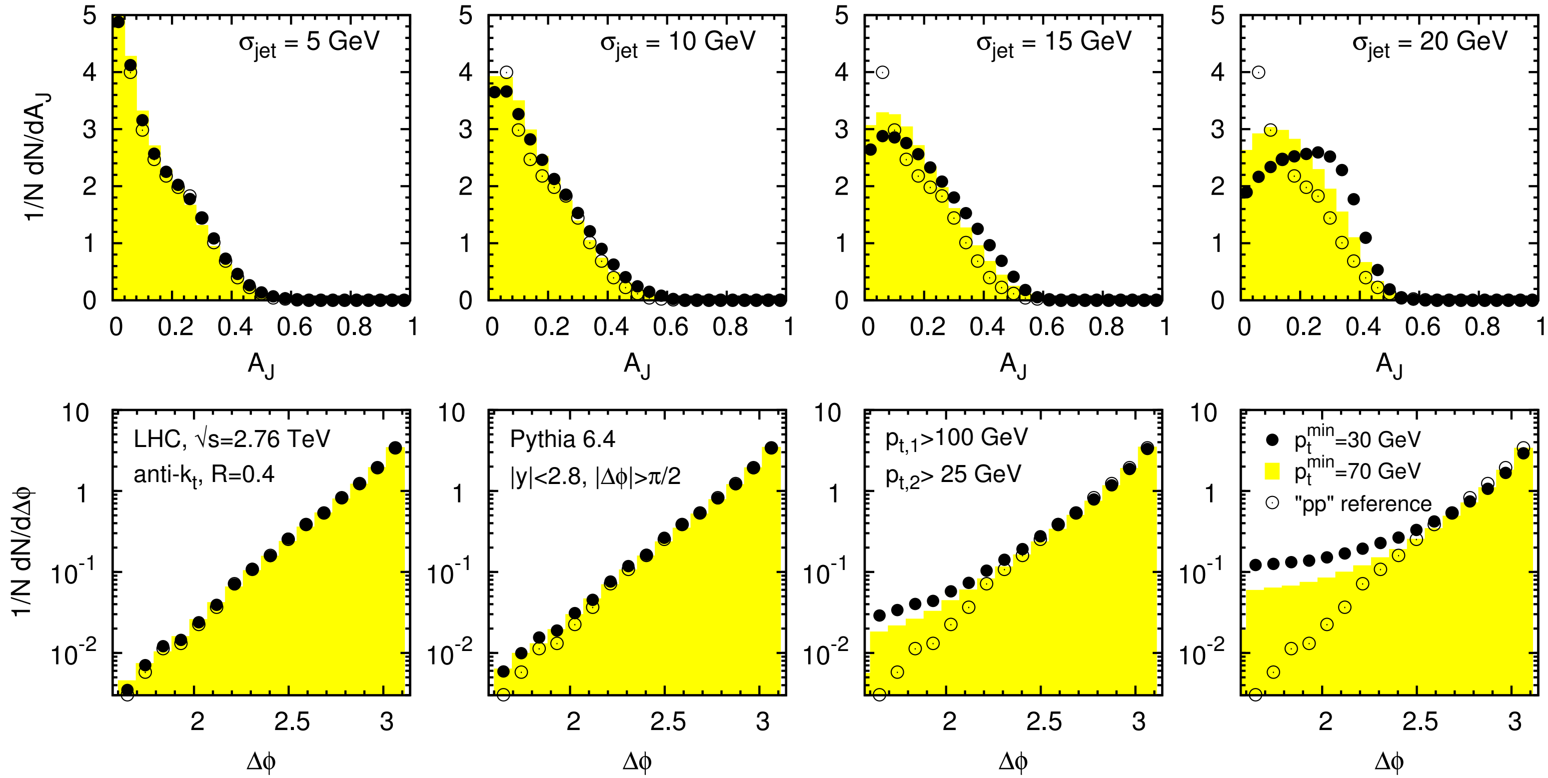
- Potential worry: Neglecting the fluctuations could lead to over-estimating the quenching
  (or misunderstanding its mechanisms)!

Setup

Try to stay close to the ATLAS setup:

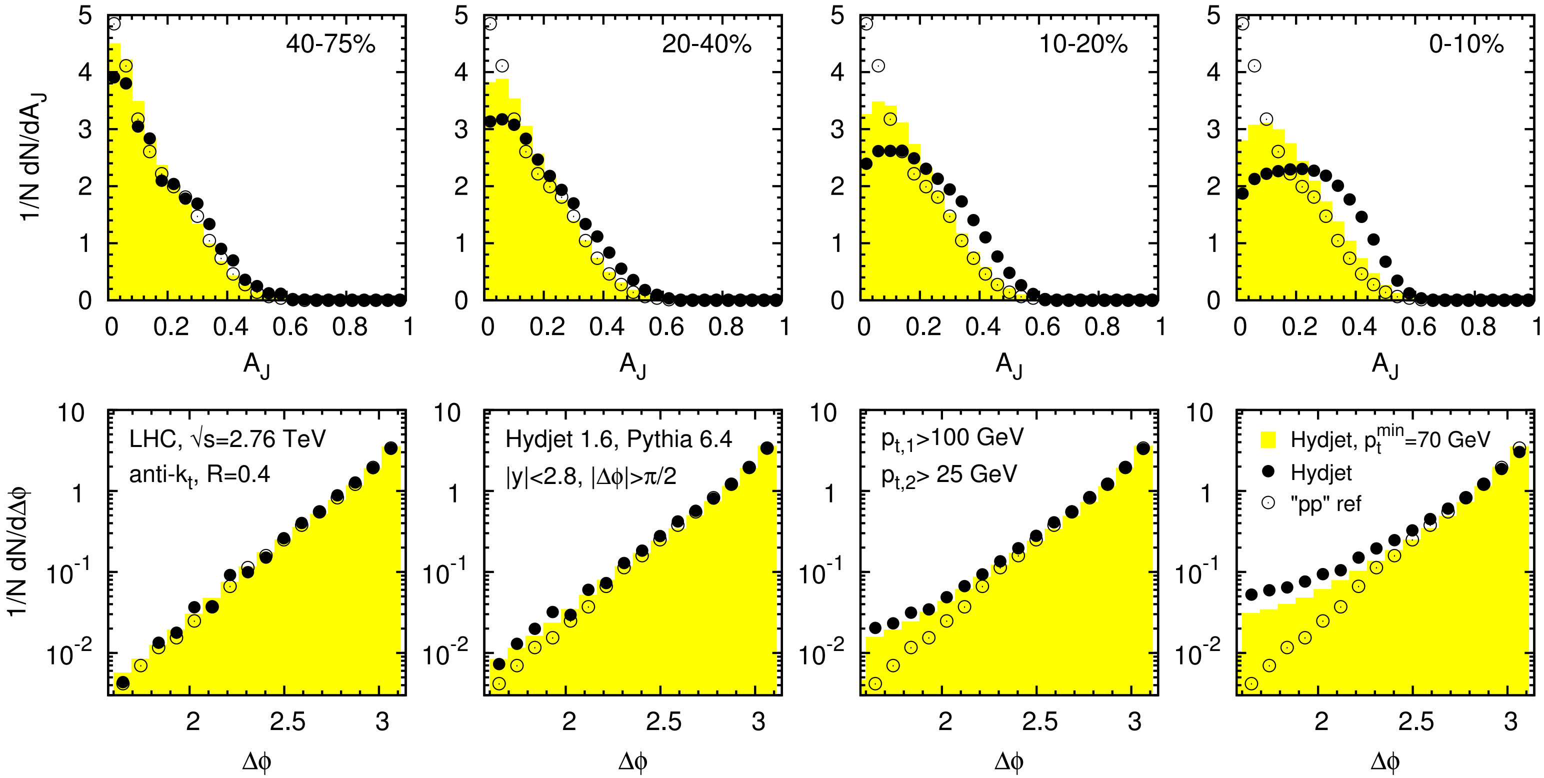
- Pythia dijets with basic cuts
  - $p_{t,1} > 100$ GeV, $p_{t,2} > 25$ GeV
  - $|\delta\phi| > \pi/2$, $|y| < 2.8$
- Option 1: naive Gaussian smearing of each jet with a Gaussian of avg 0 and stddev $\sigma_{\rm jet} \equiv \sigma_{\Delta p_t}$
- Option 2: Monte-Carlo background
  - embedded in (unquenched) Hydjet
  - calorimeter simulation
  - subtraction using a jet-area-based method
- Side question: Pythia dijets generated above a $p_{t,\min}$ threshold. How small does this have to be?

Results — Gaussian smearing



- fluctuation effects increase the dijet asymmetry
- depends on $\sigma_{\rm jet}$ $\Rightarrow$ important to constrain $\sigma_{\rm jet}$
- too low $p_{t,\min}$ may miss the effect in the MC

Results — Hydjet

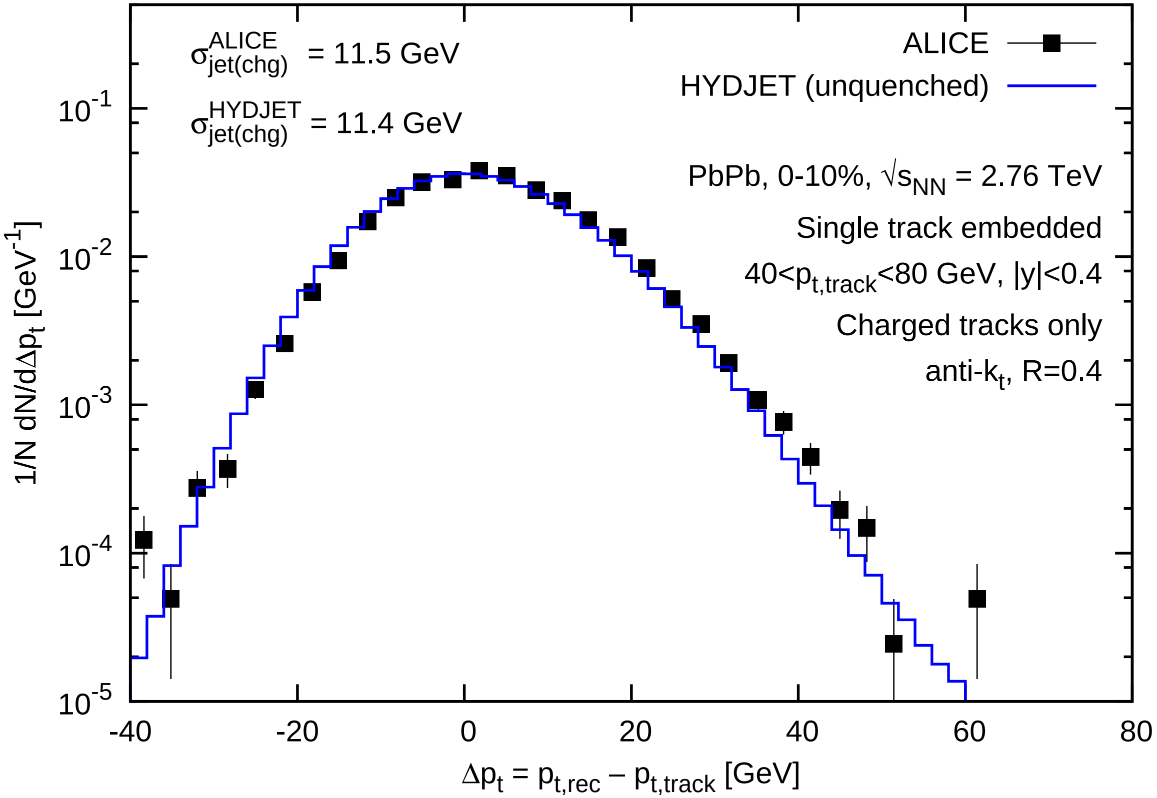


- Same concl.: fluctuations may matter quantitatively
- Most central, $\sigma_{\rm jet} \approx 17$ GeV
  similar to Gaussian with $\sigma_{\rm jet} = 20$ GeV
  $\Rightarrow$ non-Gaussianities play a role too.

ALICE flucts. measurement

Frequent "complaint" that $\sigma_{\rm jet}$ of 20 GeV is way too large and HYDJET has too much fluctuations!

That is not what ALICE sees:



track→jet, charged→all, calorimeter $\longrightarrow \sigma_{\rm jet} \sim 17$ GeV

Conclusions

- Jet-area-based background subtraction:
  - removes average and event-to-event flucts.
  - corrections for rapidity/positional dependence
  - subtraction performance ~ 100 MeV
  - independent of calo
  - left with intra-event fluctuations
- Applications:
  - Pileup subtraction in pp collisions
  - Heavy-ion underlying-event subtraction
    (watch out for the flucts.)

FastJet 3

FastJet 3.0.1 just released together with the manual [arXiv:1111.6097]

- Interface: a jet knows about its structure, *e.g.*
  `clust_seq.constituents(jet);`
  $\rightarrow$ `jet.constituents();`
- Generic additional info in PseudoJet: `jet.extra_info()`
- Improved bkgd subtraction: (*e.g.* local ranges, rescaling, ...)
  - `JetMedianBackgroundEstimator`
  - `GridMedianBackgroundEstimator`
  - `Subtractor`
- FastJet substructure tools *e.g.* `Filter` + taggers

Check out `http://www.fastjet.fr` (feedback welcome)

Backup slides

Alternative subtraction schemes

ATLAS

- cluster the jets
- in each calo rapidity strip compute average cell E_t
- exclude jets with $E_T^{\max}/\langle E_T \rangle > D_{\text{cut}} (= 5)$
- recompute average cell E_t
- iterate cut
- subtract that average from the jets

CMS

- in each calo rapidity strip compute $\langle E_t \rangle$ and σ_{E_T}
- subtract $\langle E_t \rangle + \sigma_{E_T}$
- from each cell
- cluster the jets
- exclude jets with $E_T > 10$ GeV
- iterate

Noise removal

Alternative subtraction schemes

ATLAS

- cluster the jets
- in each calo rapidity strip compute average cell E_t
- exclude jets with $E_T^{\max}/\langle E_T\rangle > D_{\rm cut}(=5)$
- recompute average cell E_t
- iterate cut
- subtract that average from the jets

Similar to jet-area-based

CMS

- in each calo rapidity strip compute $\langle E_t\rangle$ and σ_{E_T}
- subtract $\langle E_t\rangle + \sigma_{E_T}$
- from each cell
- cluster the jets
- exclude jets with $E_T > 10$ GeV
- iterate

Noise removal

less flucts. but potential bias

requires a calorimeter/grid input

Noise removal from CMS subtraction

Subtracting $\langle E_T^{\rm tower}\rangle + \sigma_{\rm tower}$ implies (roughly):

- Keeping "background cells" above the threshold

$$\langle \delta p_{t,\rm jet}^{\rm noise}\rangle \simeq 0.0833\,\sigma_{\rm tower}\,N_{\rm tower} \simeq 8 - 16 \text{ GeV}$$

- Throwing away part of the jet ($f \equiv$ occupancy)

$$\langle \delta p_{t,\rm jet}^{\rm hard}\rangle \simeq -f\,\sigma_{\rm tower}\,N_{\rm tower}$$

  Vacuum QCD: $f \simeq 0.1$ *i.e.* cancels the one above

Consequences:

- Noise reduction: $\sigma_{\rm jet}^{\rm noise-suppr.} \simeq 0.26\sigma_{\rm tower}\sqrt{N_{\rm tower}}$ vs. $\sigma_{\rm jet} \simeq \sigma_{\rm tower}\sqrt{N_{\rm tower}}$
- potential bias, especially, f for quenched jets?

But...

Q: Not all jets should be smeared!

A: Yes, they should! Smearing should be proportional to $\sqrt{A_{\text{jet}}}$ but we checked it has no influence

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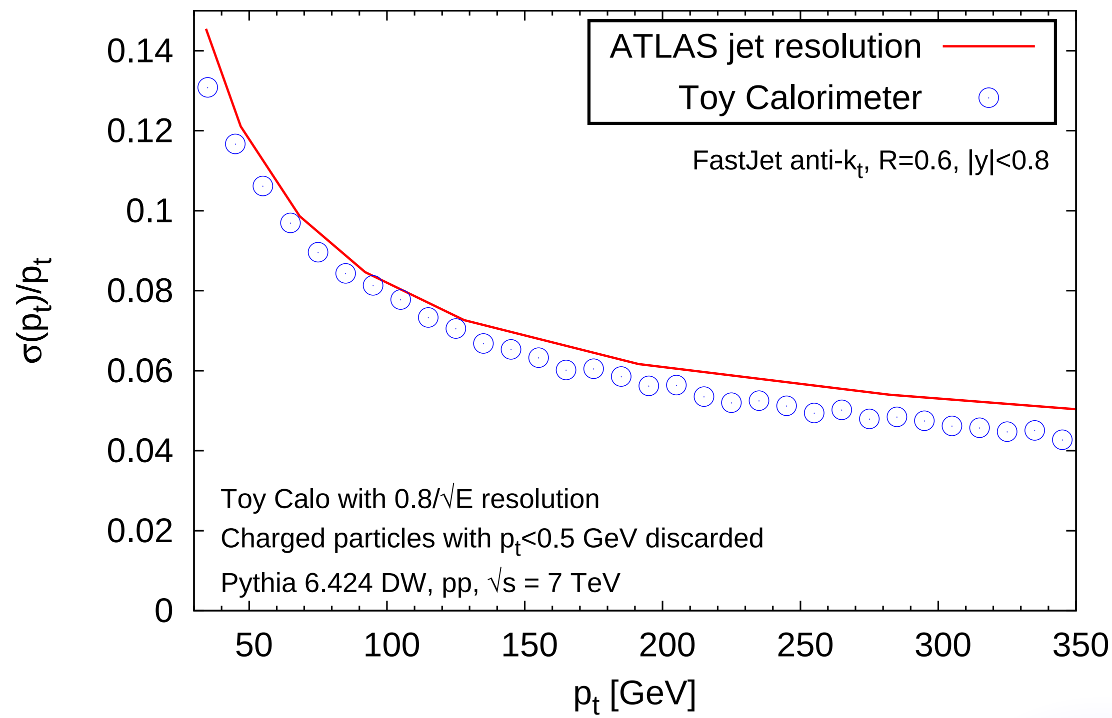
A: Yes, they should! Smearing should be proportional to $\sqrt{A_{\rm jet}}$ but we checked it has no influence

Q: Your toy calorimeter is too noisy and unlike ours!

A: Is it?

Note: extrapolation of tower fluctuations measured by ATLAS gives $\sigma_{\rm jet} \simeq 8.5$ GeV. However, this, and the $PbPb$ jet resolution, are quoted at EM scale *i.e.* not easily extrapolated to the full answer



But...

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A: Is it?

Q: Other measurements like the jet core fraction and the R dependence of A_J go in the opposite direction as expected from fluctuations!

A: Sure. These likely indicate some genuine quenching effects. But quantitative understanding would benefit from characterising the fluctuations.

Last but not least

Q: $\sigma_{\rm jet}$ of 20 GeV is way too large and HYDJET has too much fluctuations!

A: That is not what ALICE sees:

- ALICE: single track embedded in 0-10% LHC
- MC: single track embedded in 0-10% HYDJET
- reconstruct and subtract (jet-area based)
- look at $\Delta p_t = p_{t,\rm rec} - p_{t,\rm track}$
- same cuts and subtraction details

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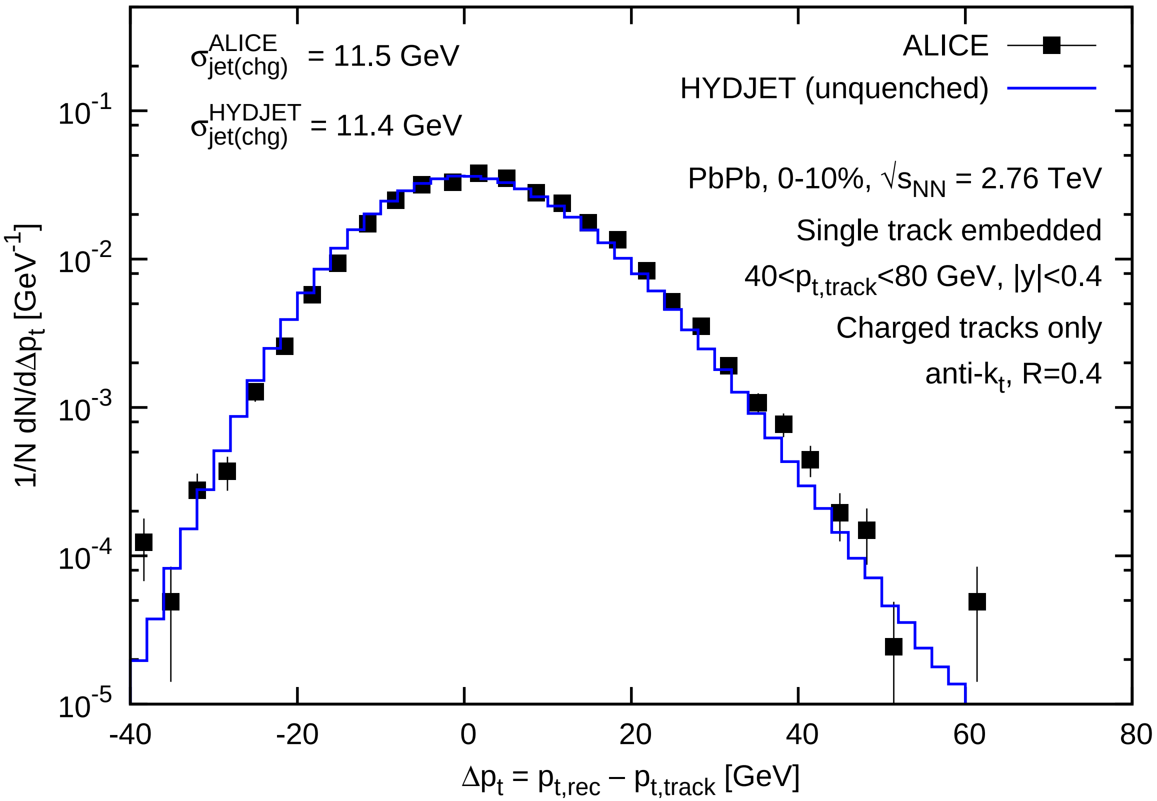

Nearly-perfect agreement!

Last but not least

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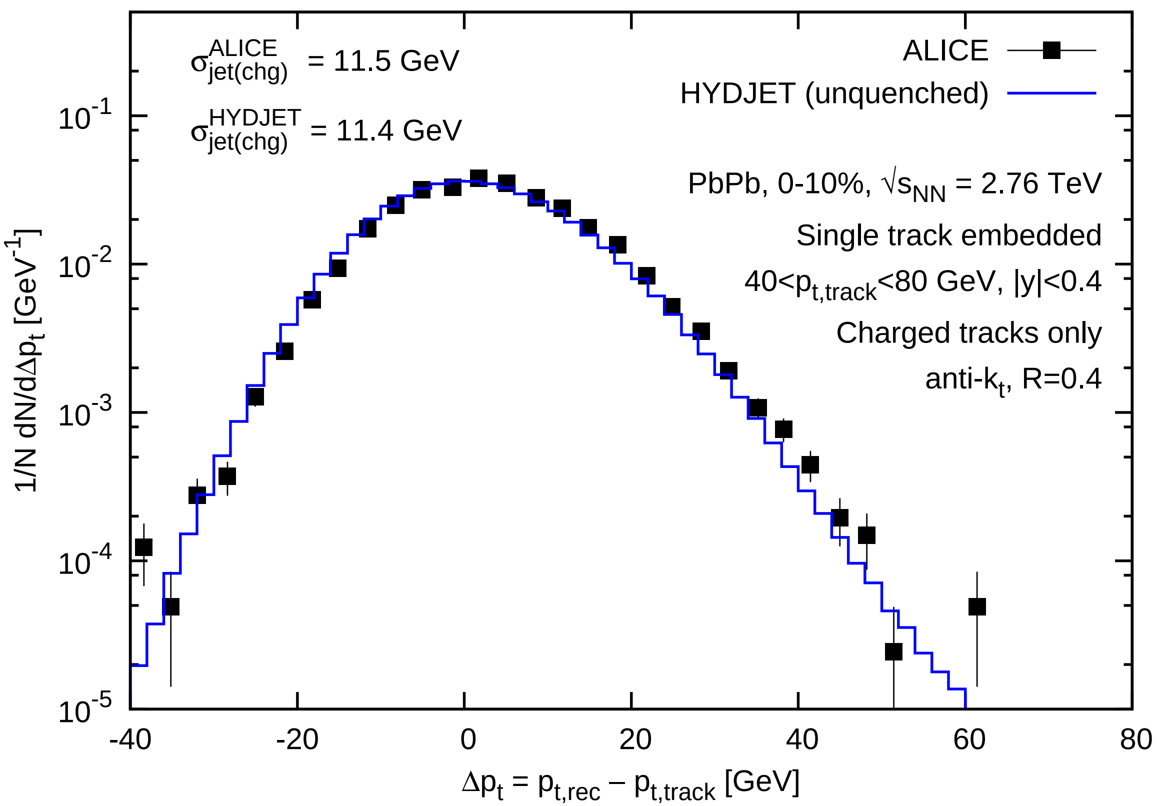

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At the end of the day

- **Fluctuations can significantly affect the measured $A_J \Rightarrow$ quantify fluctuations important to quantify quenching**

- ALICE produced the first measurement of flucts
  - agrees with flucts having significant impact
  - first step towards understanding flucts
  - Could a calorimetry upgrade help?