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Jet Reconstruction in Heavy Ion collisions

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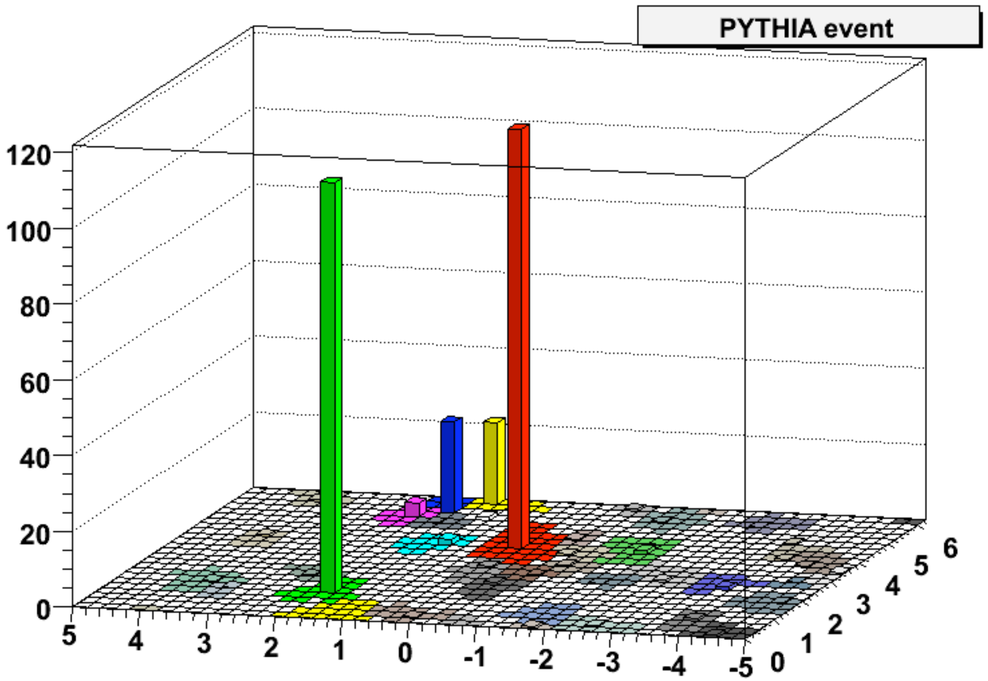
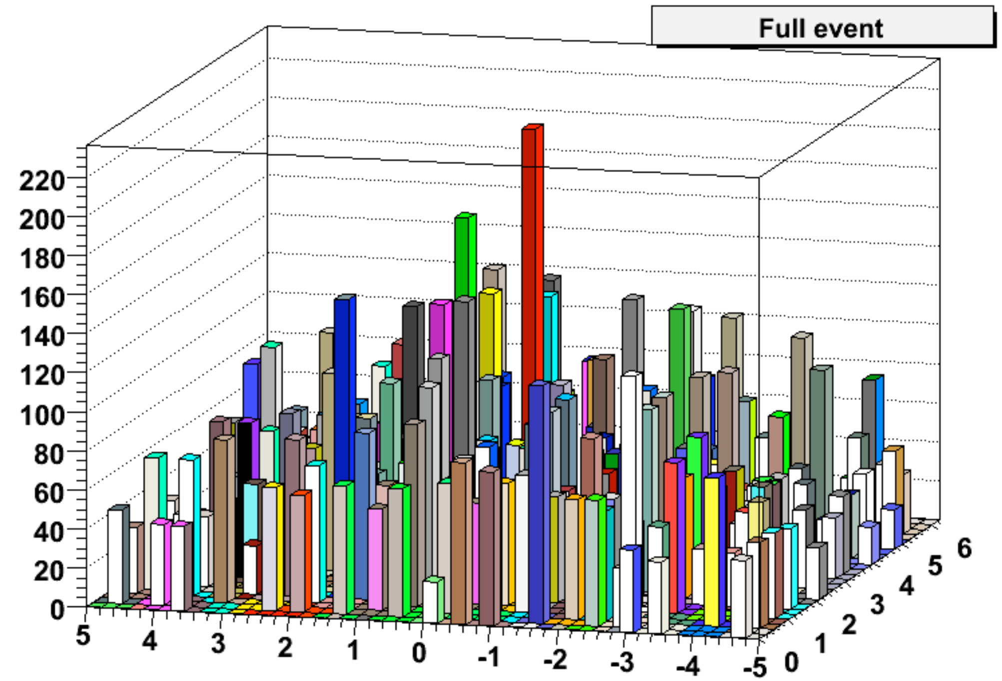
Paper in collaboration with J. Rojo, G. Salam and G. Soyez
To appear soon

NB. Some of the numbers will likely be slightly different in the paper.
Qualitative behaviour and conclusions will however be the same

Hard jets and background





Hard jets
(pp collisions)

Hard jets + background
(AA collisions)

Can we 'reconstruct' the hard jets?

We apply the jet area/median method

(MC, Salam, arXiv:0707.1378)

How are the hard jets modified by the background?

Susceptibility (how much bkgd gets picked up)

Resiliency (how much the original jet changes)

Hard jets and background

MC, Salam, arXiv:0707.1378
MC, Salam, Soyez, arXiv:0802.1188

Modifications of the hard jet

$$p_{t,jet}^{AA} = p_{t,jet}^{pp} + \boxed{\rho A_{jet} \pm \sigma\sqrt{A_{jet}}} + \boxed{\Delta p_t^{BR}}$$

hard jet

background

'susceptibility'

back-reaction

'resiliency'

Reconstruct the momentum the hard jet would have without the background:

MC, Salam, arXiv:0707.1378

$$p^{sub}_{\mu,jet} \equiv p_{\mu,jet} - \rho A_{\mu,jet}$$

(subtracts background,
fluctuations and back-reaction remain)

Quality measures

Offset $$\langle \Delta p_t \rangle \equiv \langle p_t^{AA,sub} - p_t^{pp,sub} \rangle$$

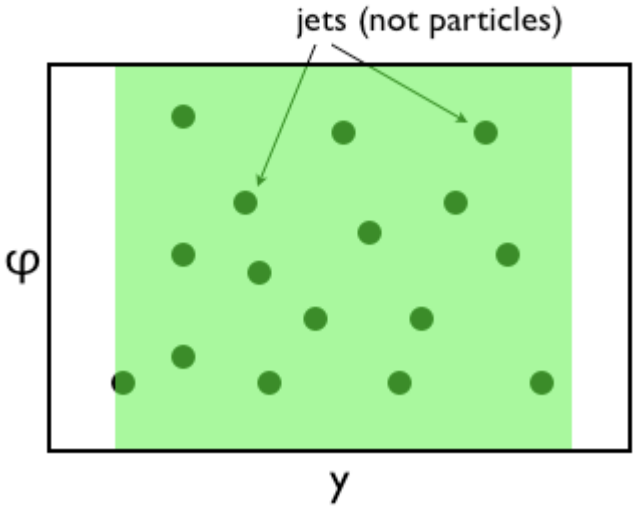
Dispersion $$\sigma_{\Delta p_t} \equiv \sqrt{\langle \Delta p_t^2 \rangle - \langle \Delta p_t \rangle^2}$$

Small offset and dispersion will indicate a good reconstruction

Background determination

In order to subtract the background, one must first determine it

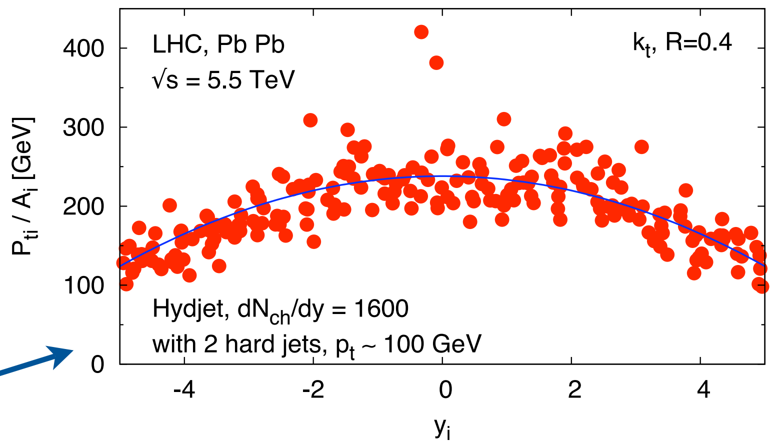
Proposal in 2007 paper (MC, Salam, arXiv:0707.1378)



- either, choose a region in rapidity-azimuth plane where the background is uniform
  - calculate ρ (p_t per unit area) as

$$\rho \equiv \text{median}\left[\left\{\frac{p_t^{jet}}{\text{Area}_{jet}}\right\}\right]$$

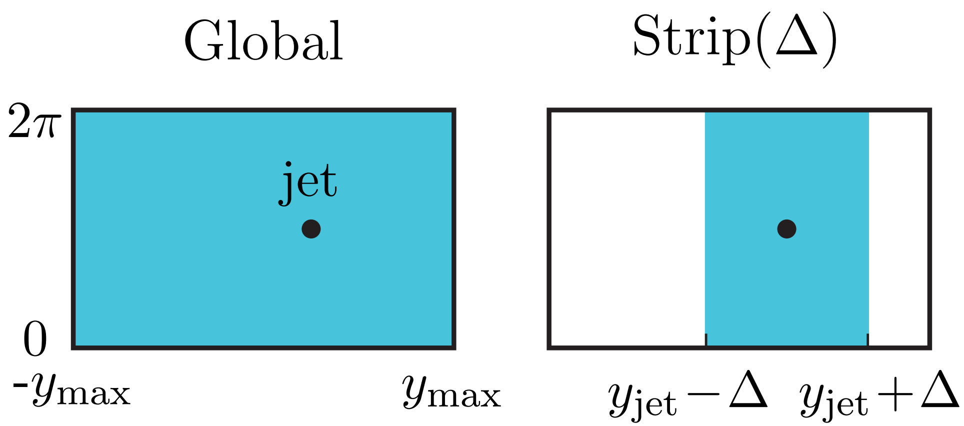
- or, account for rapidity dependence of background by fitting a quadratic function to $p_{t,jet}/\text{Area}_{jet}$ distribution



This way to account for rapidity dependence of background turns out to be insufficiently accurate ⇒ Adapt the median method to a varying background

Background determination: the ranges

Ranges can now be *fixed*, or *local* (tied to a jet's position)



Choose a range **such that you expect the background to be uniform within it,** place it **where you need it.**

Use median operation within each local range of interest

A range should be ***not too large*** (to avoid non-uniformity of background) ***nor too small*** (to have sufficient statistics for the median operation).

We find $\text{Area}_{\text{range}} \geq 25R^2$ to be a reasonable lower limit

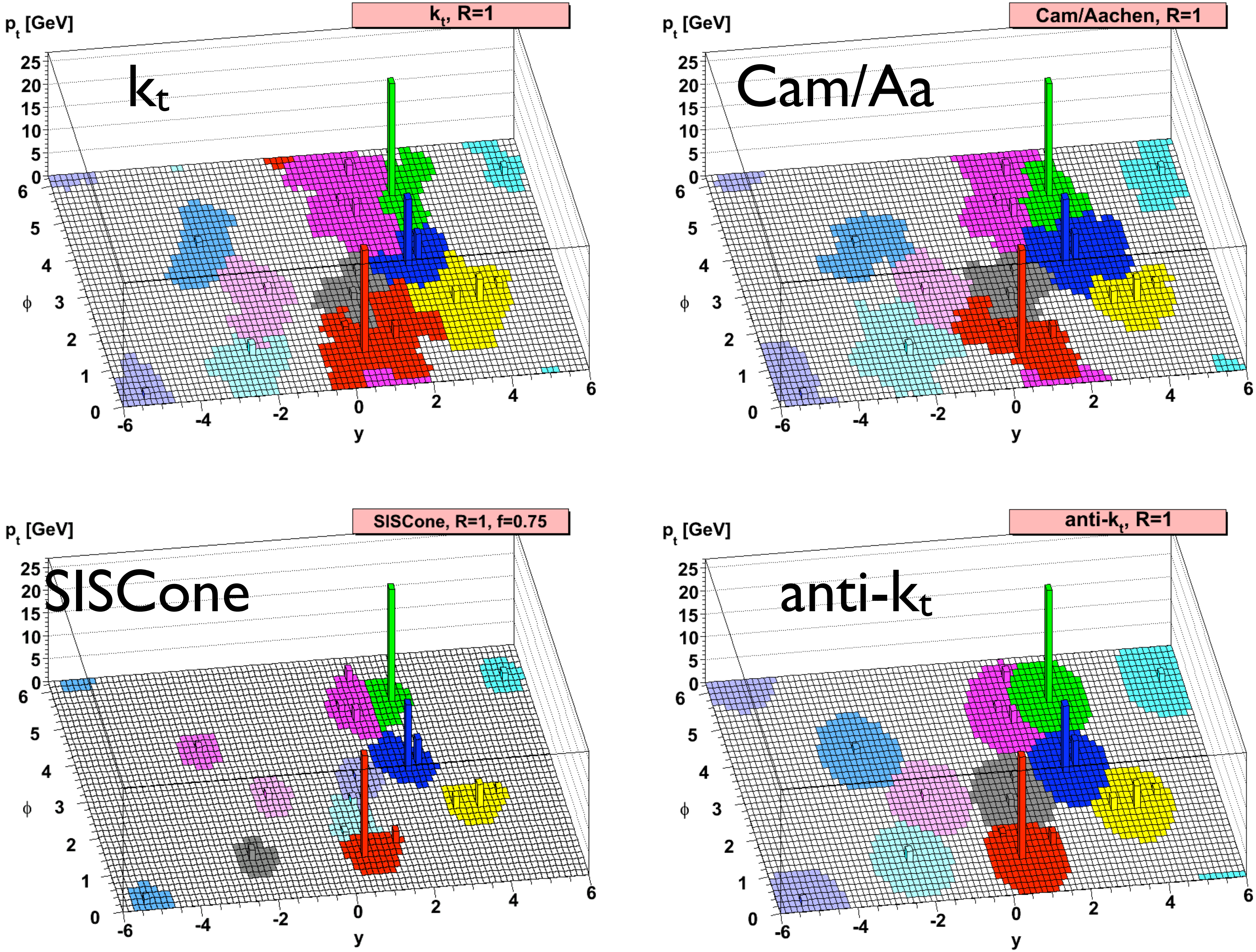
The IRC safe jet algorithms

k_t	SR $d_{ij} = \min(k_{ti}^2, k_{tj}^2)\Delta R_{ij}^2/R^2$ hierarchical in rel p_t	Catani et al '91 Ellis, Soper '93	NlnN
Cambridge/Aachen	SR $d_{ij} = \Delta R_{ij}^2/R^2$ hierarchical in angle	Dokshitzer et al '97 Wengler, Wobish '98	NlnN
anti-k_t	SR $d_{ij} = \min(k_{ti}^{-2}, k_{tj}^{-2})\Delta R_{ij}^2/R^2$ gives perfectly conical hard jets	MC, Salam, Soyez '08 (Delsart, Loch)	$N^{3/2}$
SISCone	Seedless iterative cone with split-merge gives 'economical' jets	Salam, Soyez '07	$N^2 \ln N$

We call these algs 'second-generation' ones

All are available in FastJet, http://fastjet.fr

(As well as many IRC unsafe ones)


k_t, R=1
k_t
Cam/Aachen, R=1
Cam/Aa
SISCone, R=1, f=0.75
SISCone
anti-k_t, R=1
anti-k_t
p_t [GeV]
ϕ
y

Cover of EPJ C

Cambridge/Aachen with filtering

Butterworth, Davison, Rubin, Salam, arXiv:0802.2470

An example of a **third-generation** jet algorithm

- Cluster with C/A and a given R
- Undo the clustering of each jet down to subjets with radius $\mathbf{x_{filt}R}$
- Retain only the $\mathbf{n_{filt}}$ hardest subjets

Idea: filter out soft background, retain hard core

(for this work we'll be using $x_{filt} = 0.5$, $n_{filt} = 2$)

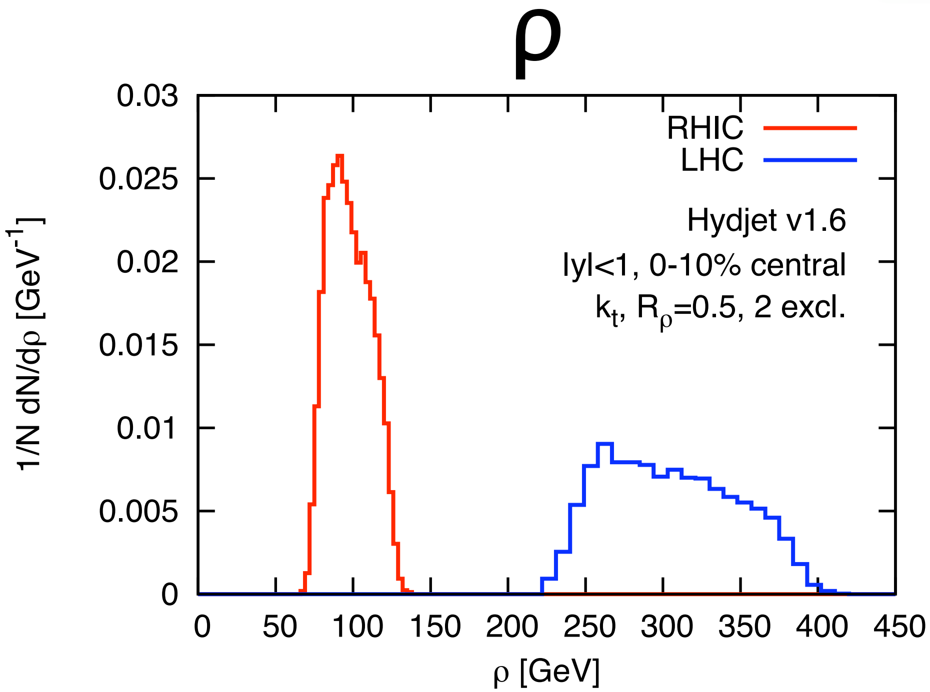
Background determination: the median

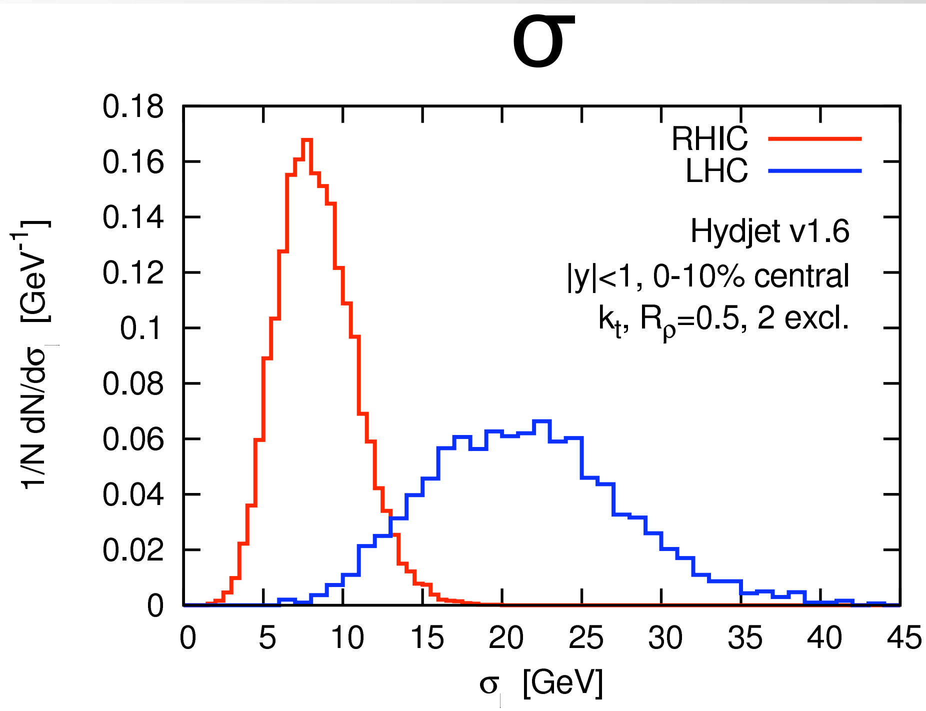
MC, Salam, arXiv:0707.1378

$$\rho \equiv \underset{jet \in range}{\text{median}} \left[\left\{ \frac{p_t^{jet}}{\text{Area}_{jet}} \right\} \right]$$

- Should be used only with algorithms like k_t or Cambridge/Aachen (but the subtraction can then be performed on jets of any algorithm)
- Works on **an event-by-event basis** (this removes many fluctuations)
- One can also explicitly remove the hard(est) jet(s) before taking the median, to reduce a potential bias from the hard jets in the event

The background





Typical values (depend on model):

Hydjet v1.6	$dN_{ch}/d\eta\|_{\eta=0}$	ρ (GeV) (y=0, 0-10%)	σ (GeV)
RHIC	658 (0-6%)	100	8
LHC 5.5 TeV	1570 (0-10%)	310	21

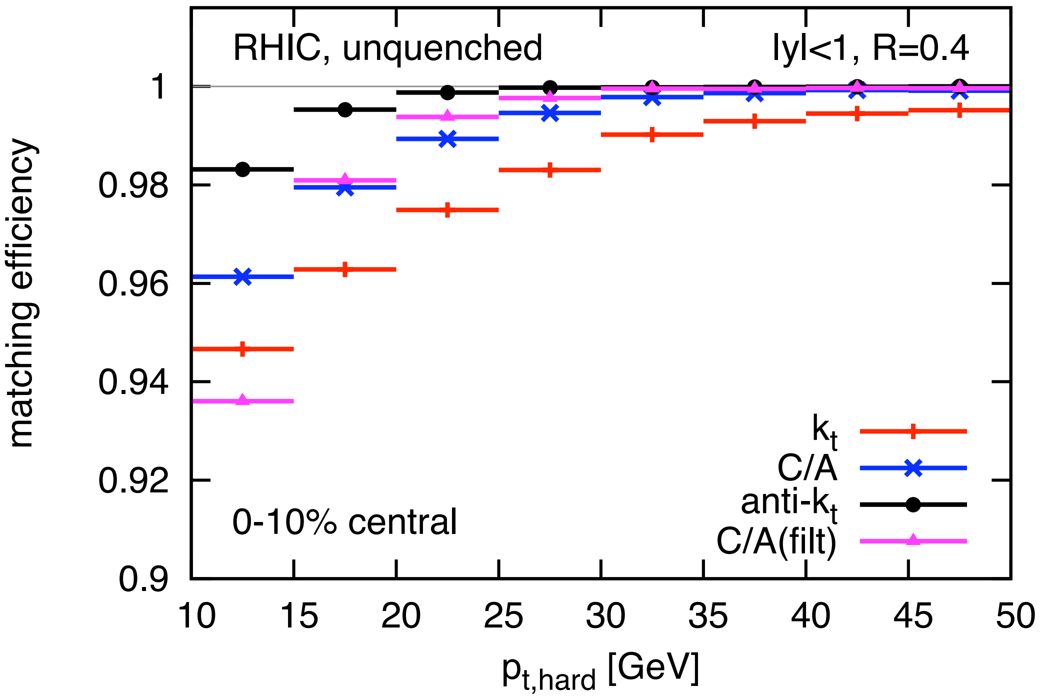
How do the different algorithms fare in jet reconstruction?

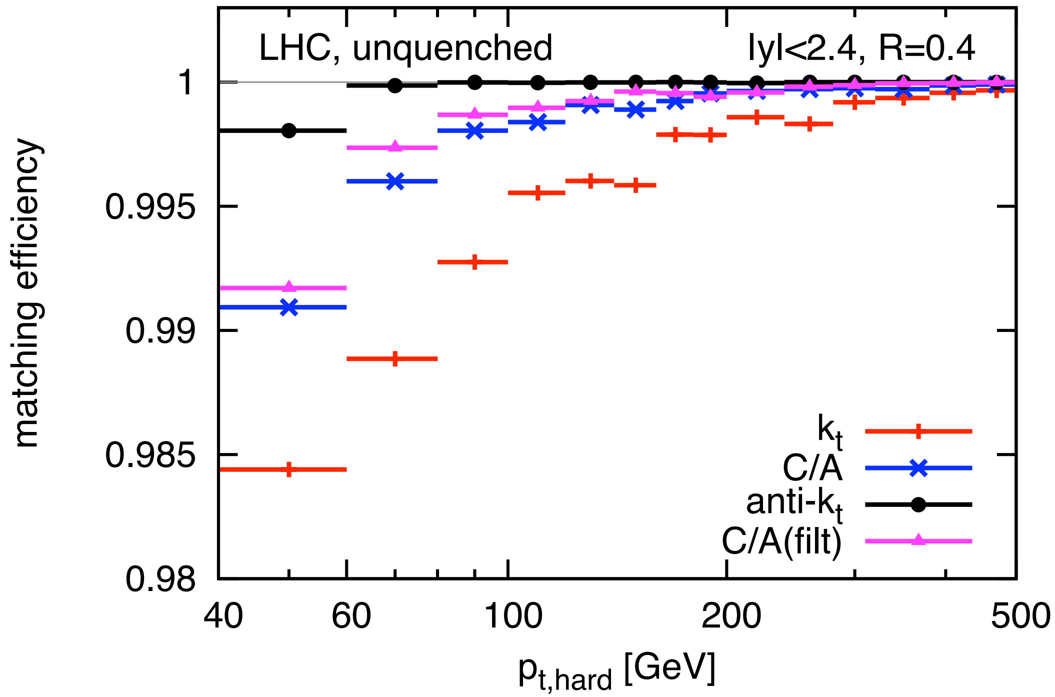
Offset $$\langle \Delta p_t \rangle \equiv \langle p_t^{AA,sub} - p_t^{pp,sub} \rangle$$

Dispersion $$\sigma_{\Delta p_t} \equiv \sqrt{\langle \Delta p_t^2 \rangle - \langle \Delta p_t \rangle^2}$$

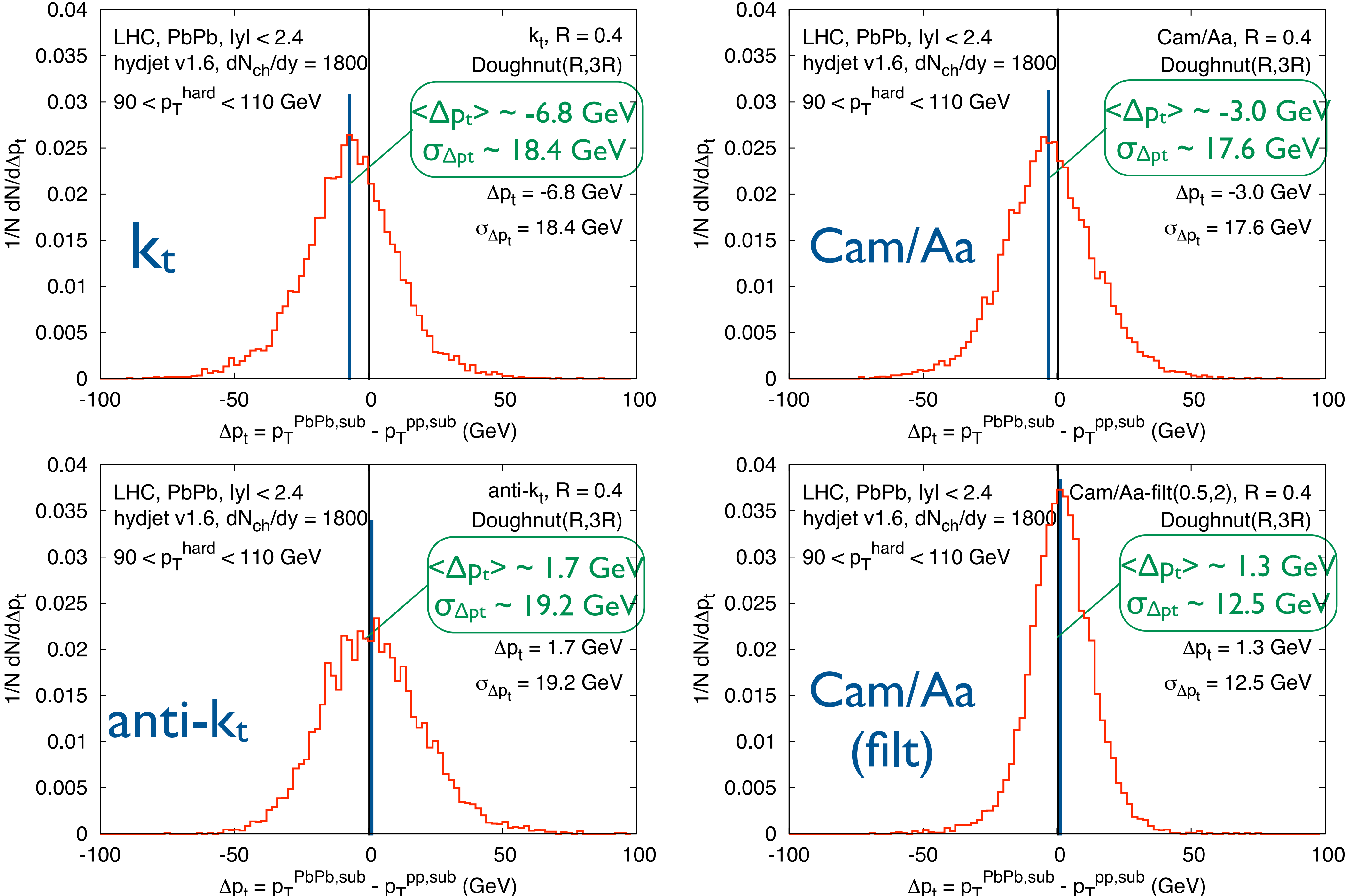
Reconstruction efficiency

A jet reconstructed in the full event is considered **matched** to a hard jet *if the constituents common to both the hard and the full jet make up at least 50% of the transverse momentum of the constituents of the hard jet*

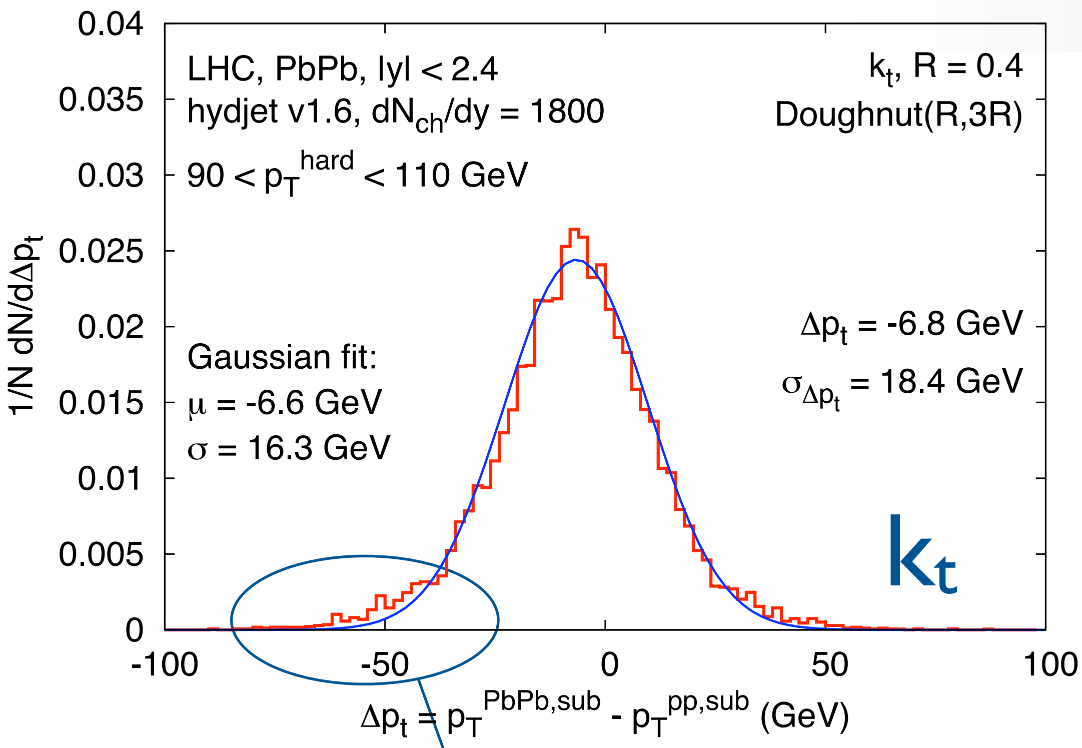




Δp_t distributions in PbPb at LHC

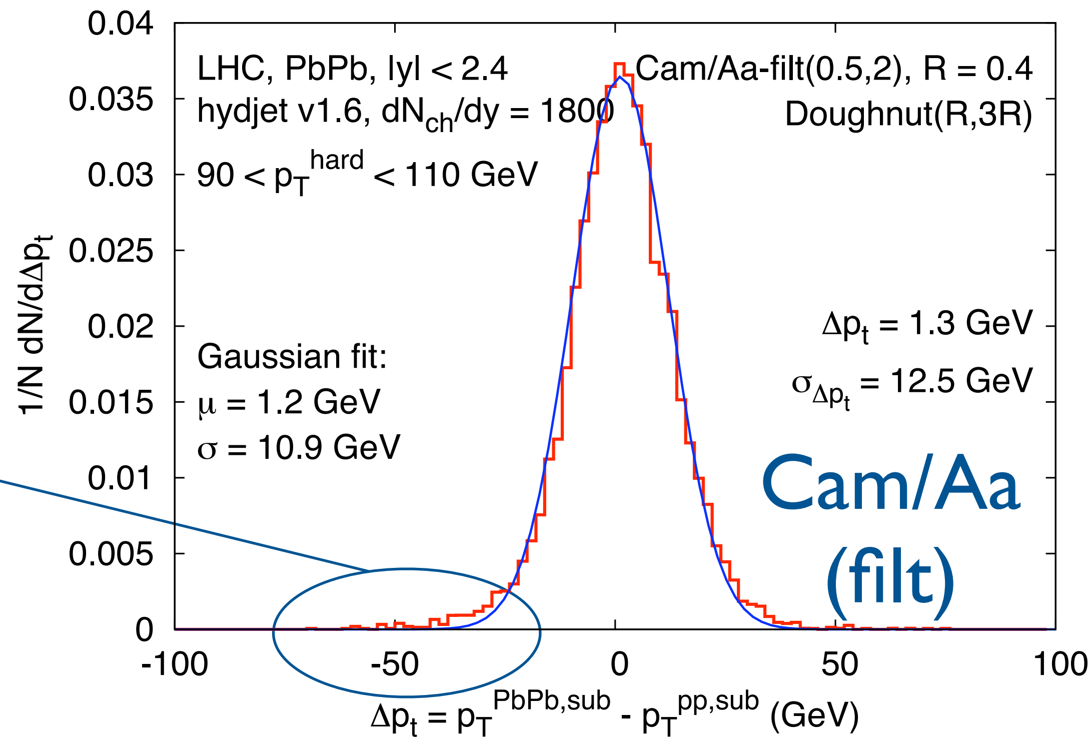


Gaussianity of Δp_t



Distributions of Δp_t quite well described by a gaussian

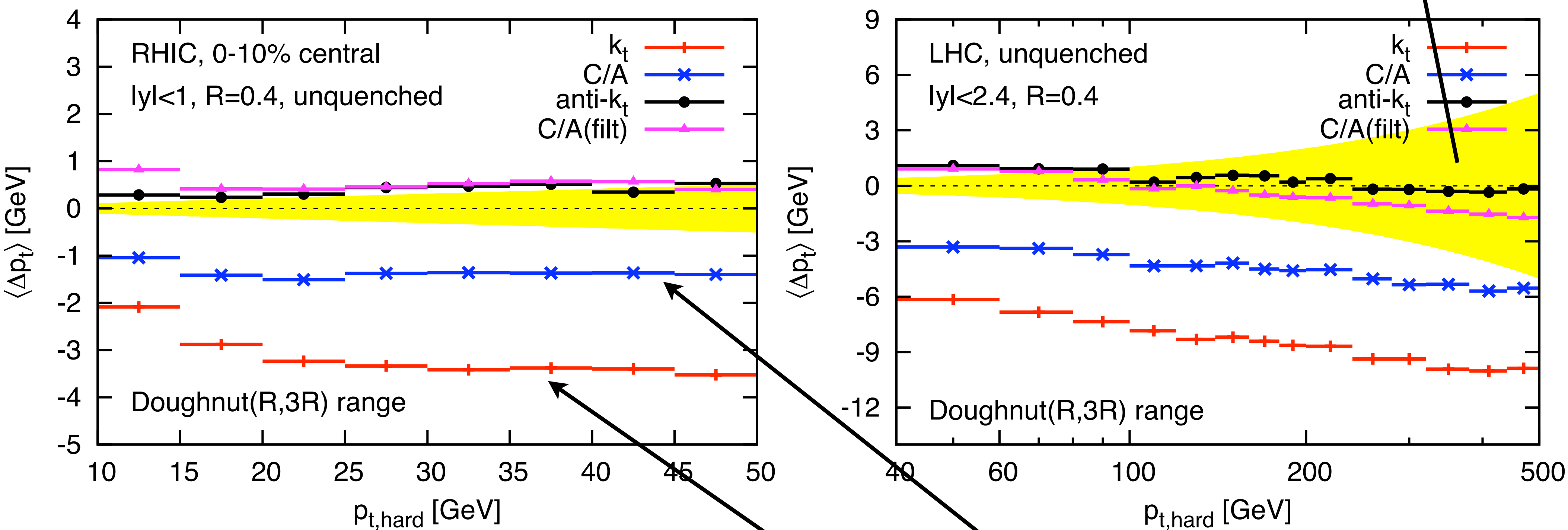
Slight tendency to 'fat tails'



anti-k_t and C/A(filt) fare best

(Results are fairly independent of p_t)

Yellow band:
1% accuracy

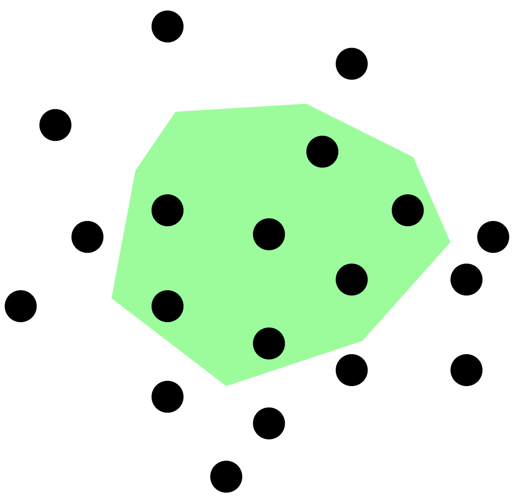


The residual offset of k_t and C/A can be interpreted as an effect of the **back-reaction**

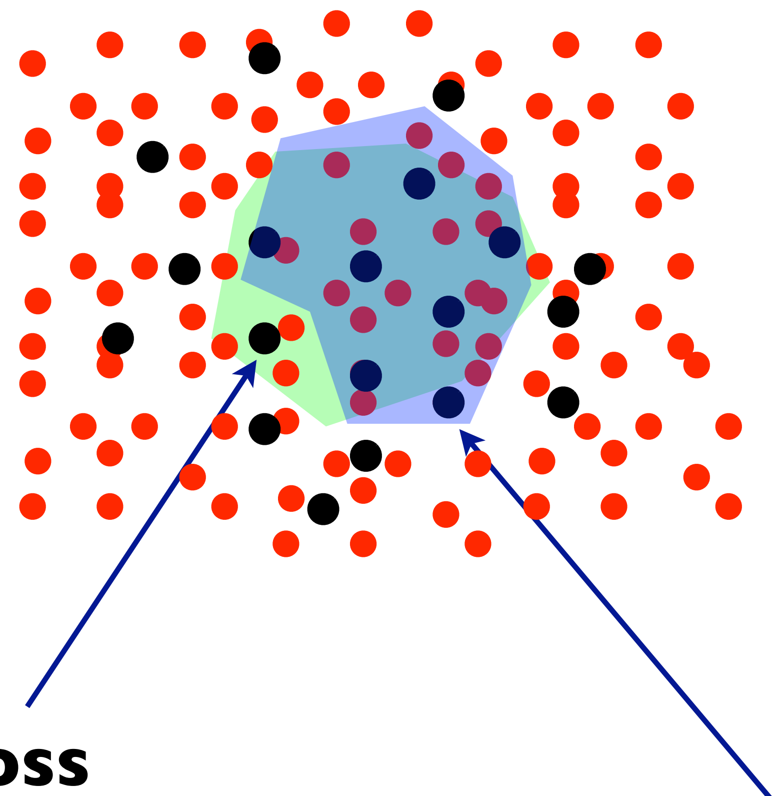
Back-reaction

“How (much) a jet changes when immersed in a background”

Without background



With background

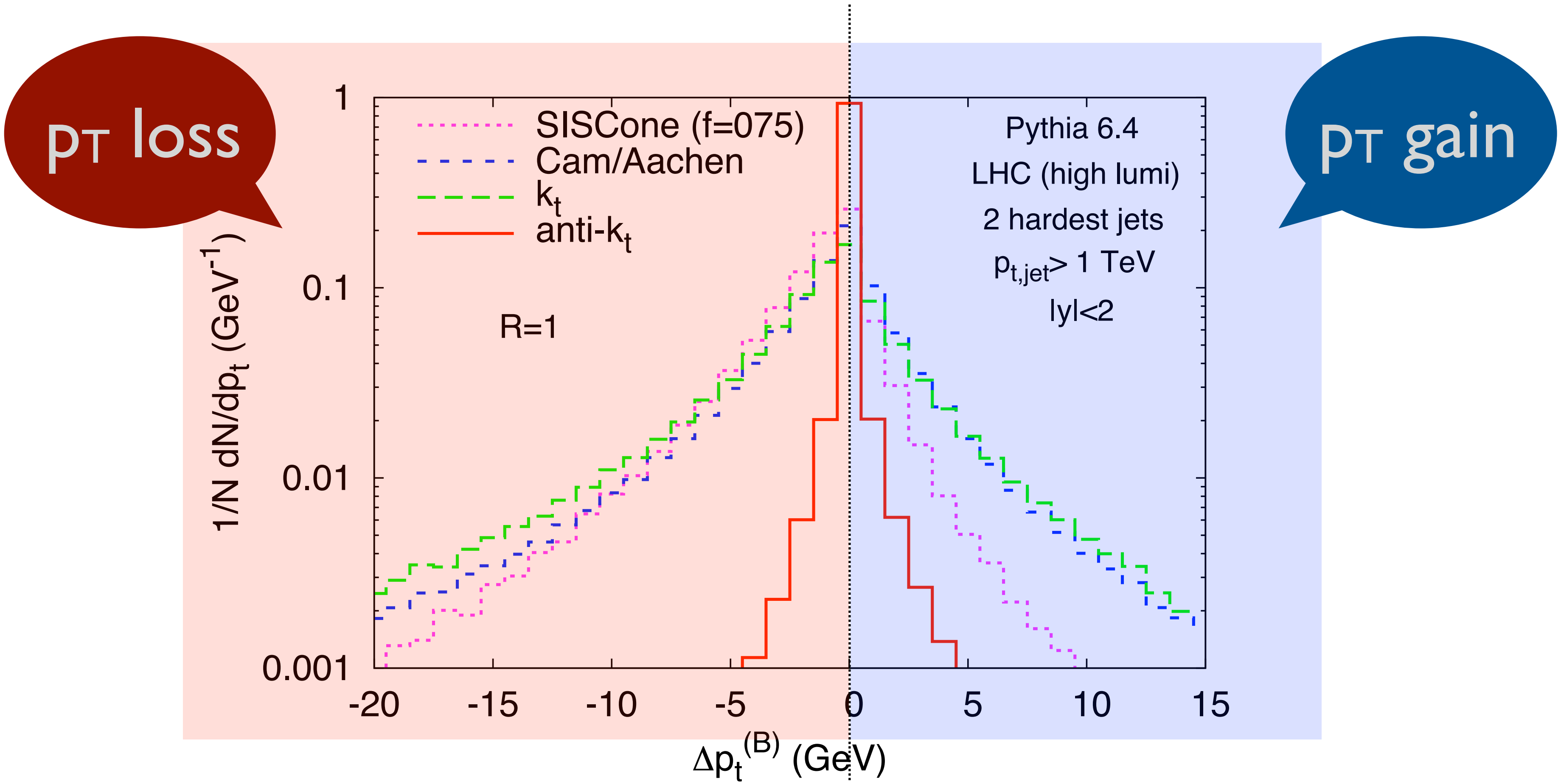


Back-reaction **loss**

Back-reaction **gain**

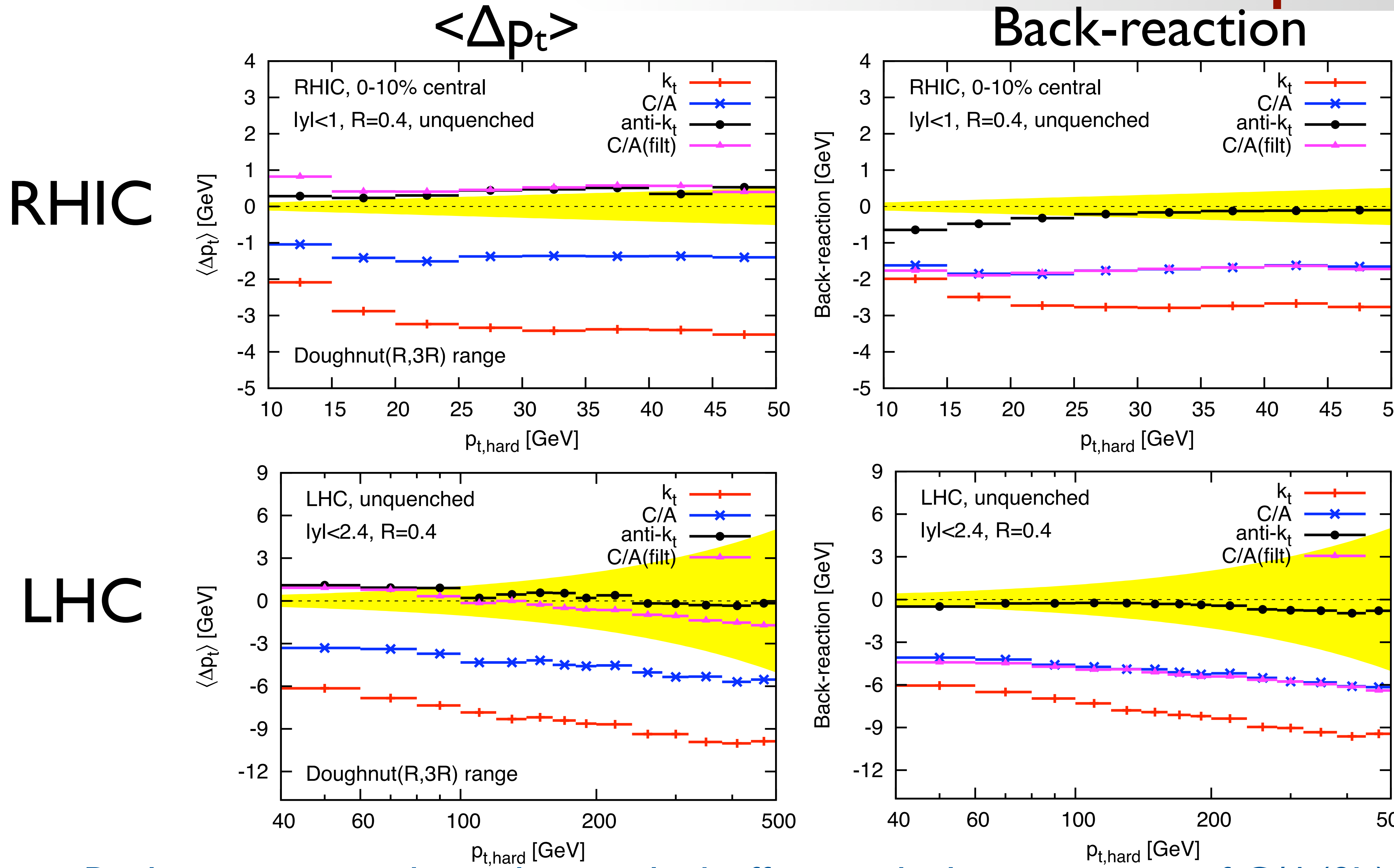
Back-reaction

MC, Salam, Soyez, arXiv:0802.1188



Anti-k_t jets are much more resilient to changes from background immersion

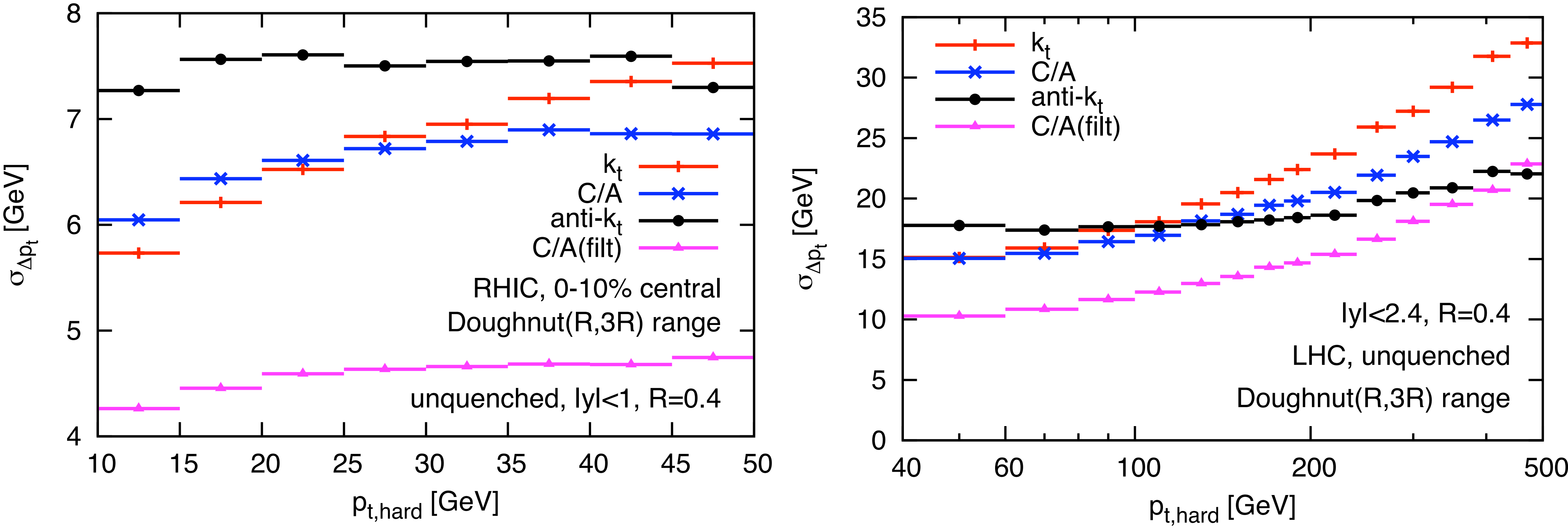
Back-reaction contribution to $\langle \Delta p_t \rangle$



Back-reaction explains the residual offset, with the exception of C/A(filt)

(accidental compensation of back-reaction and positive offset)

Dispersion of Δp_t



- C/A(filt) markedly better, as a consequence of its smaller effective area
- Dispersions increase at large p_t, probably as a consequence of a larger dispersion of back-reaction
- anti-k_t remains fairly constant ('resiliency'), and eventually becomes better at large p_t

Robustness

Centrality

No significant changes in other classes or non-central events
(dispersion of course decreases with decreasing background)

Quenching

Using PYQUEN and Q-PYTHIA we observe a degradation of the $<\Delta p_t>$ offset for C/A(filt) at large p_t at the LHC (but still only a 2% effect at 500 GeV)

Note however that the results for quenching my depend significantly on the simulation used.

Conclusions

- Jet area/median method for background determination and subtraction successfully applied to heavy ion collisions at RHIC and LHC: *high efficiency, small or almost zero* $<\Delta p_t>$ *offset*

- Each different jet algorithm has characteristics which affect the subtraction in specific ways (e.g. back-reaction)

- Irreducible dispersions are left, and may of course play an important role in measurements like the inclusive cross section (fakes rate). Their size also depends on the algorithm used.

- anti-k_t turns out to have the safest smallest offset, filtering algorithms have the smallest dispersion (but may be more affected by quenching)

Extra material

Caveats

While jet clustering is a deterministic procedure (though one must still choose a jet definition), background subtraction is less well-determined

A number of not fully clear-cut choices must be made:

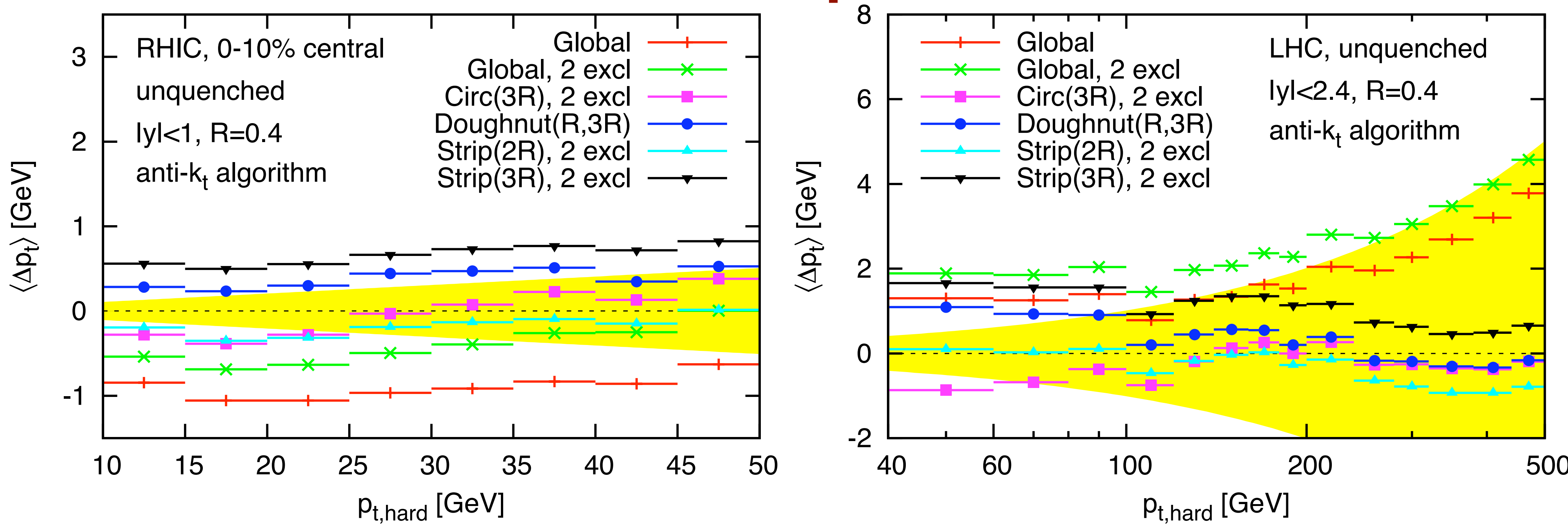
- **Where** to estimate the background (i.e. which range)
- **How** to estimate it (for instance, subtract hard jets?)
- **Which jet algorithm** to use (privilege small bias or small dispersion?)

Making the "proper" choice is as much a matter of art (i.e. experience) as of science, and depends on what you want to do

Having many algorithms and techniques at one's disposal will allow better tuning of procedure with aim

Ranges

<Δp$_t$>



Intrinsic ambiguity mostly of order 1-2 GeV on Δp$_t$

The local ranges perform similarly, the exclusion of hardest jets helps a little,
the global range also performs fairly well here thanks to the limited rapidity coverage

The IRC safe algorithms

	Speed	Regularity	UE	Backreaction	Hierarchical substructure
k_t	☺ ☺ ☺	☂	☂☂	☁☁	☺ ☺
Cambridge /Aachen	☺ ☺ ☺	☂	☂	☁☁	☺ ☺ ☺
anti-k_t	☺ ☺ ☺	☺ ☺	☁/ ☺	☺ ☺	✗
SISCone	☺	☁	☺ ☺	☁	✗