Jets at LHCb

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CERN, Princeton & LPTHE/CNRS (Paris)

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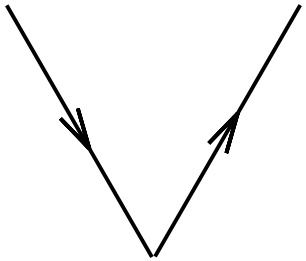
Any process that involves final-state partons gives jets

Examples of physics with jets where b-tagging and/or "forward" detection may be crucial:

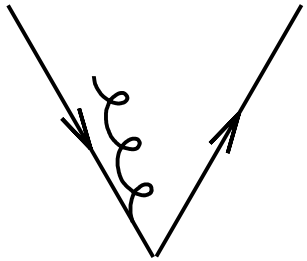
- forward jets: unusual mixture of high-x PDFs on low-x PDFs
- $t\bar{t}$ FB asymmetry: only at high rapidities is there a substantial $q\bar{q}$ initial-state asymmetry
- SUSY Higgs: $pp \to b\bar{b}H \to 4b$

Jet finding

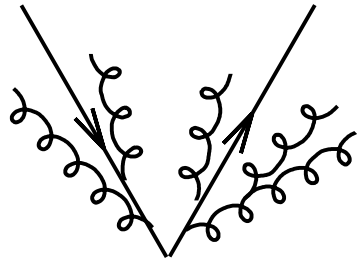
Jets made systematic: jet definitions



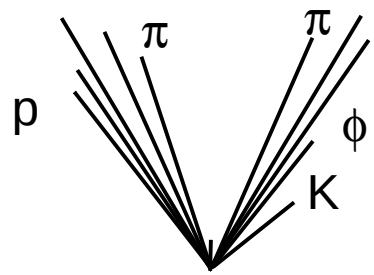
LO partons



NLO partons



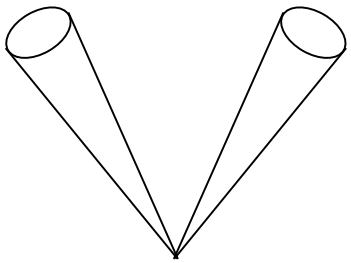
parton shower



hadron level

Jet Def^n ↓

jet 1 jet 2



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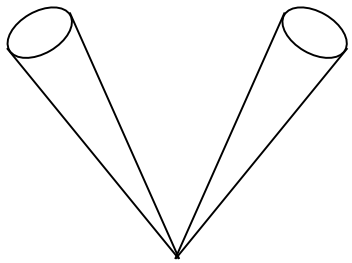

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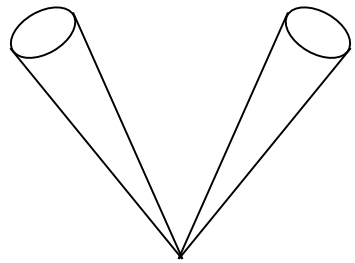

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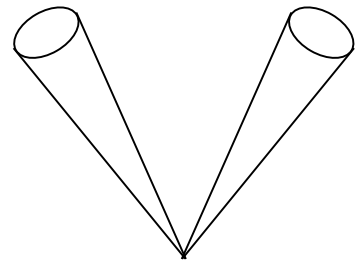


LHC events may be discussed in terms of quarks, quarks+gluon, or hadrons

A **jet definition** provides common representation of different "levels" of event complexity.

Sequential recombination algorithms

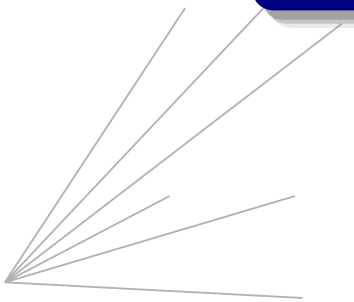
k_t algorithm — Catani, Dokshizter, Olsson, Seymour, Turnock, Webber '91–'93; Ellis, Soper '93

- Find smallest of all $d_{ij} = \min(k_{ti}^2, k_{tj}^2)\Delta R_{ij}^2/R^2$ and $d_{iB} = k_i^2$
- Recombine i–j (if iB $\ldots$ jet)
- Repeat

Bottom-up jets:

Sequential recombination

(attempt to invert QCD branching)



ariables

$+ (y_i - y_j)^2$

- rapidity $y_i = \frac{1}{2} \ln \frac{E_i + p_{zi}}{E_i - p_{zi}}$
- ΔR_{ij} is boost invariant angle

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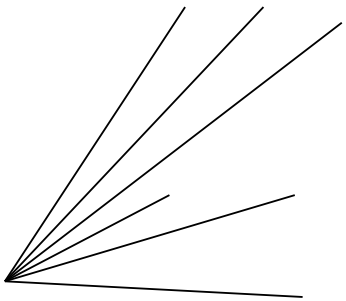

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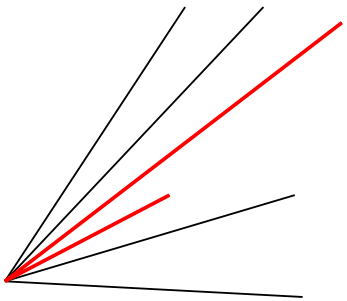

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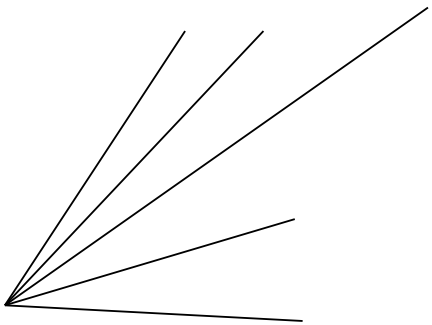

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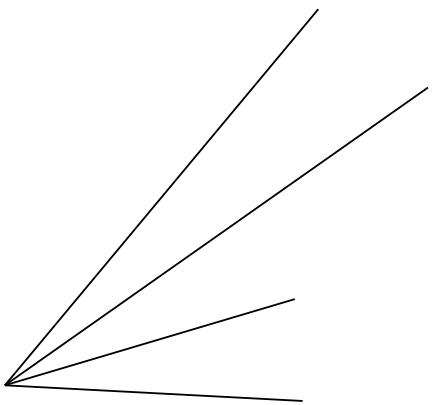

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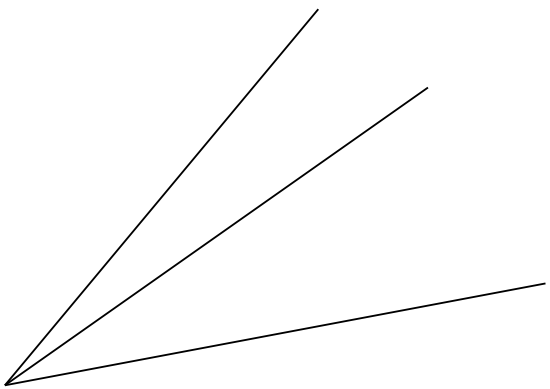

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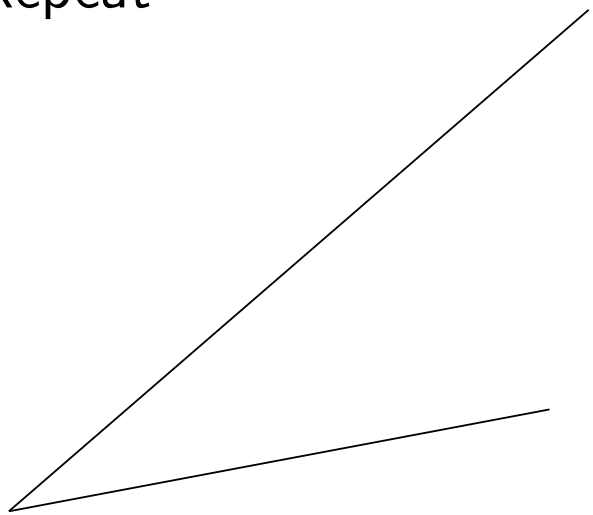

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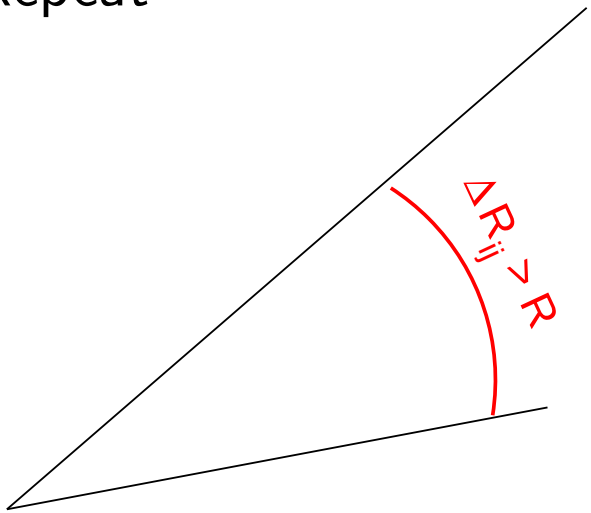

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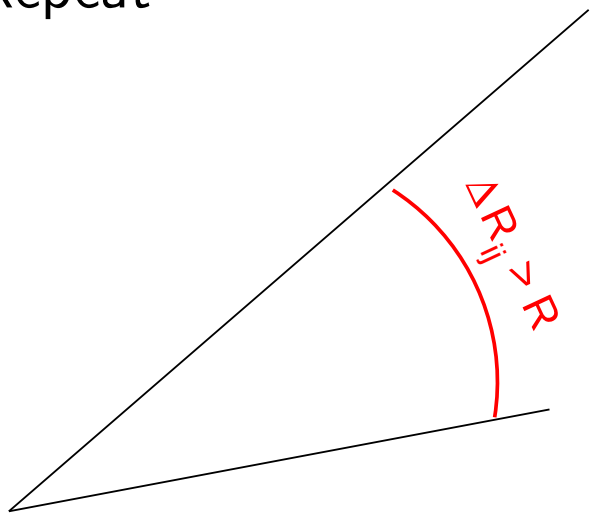

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NB: d_{ij} distance $\leftrightarrow$ QCD branching probability $\sim \alpha_s \dfrac{dk_{tj}^2 dR_{ij}^2}{d_{ij}}$

A full set of IRC-safe jet algorithms

Generalise inclusive-type sequential recombination with

$$d_{ij} = \min(k_{ti}^{2\mathbf{p}}, k_{tj}^{2\mathbf{p}})\Delta R_{ij}^2/R^2 \qquad d_{iB} = k_{ti}^{2\mathbf{p}}$$

	Alg. name	Comment	time
$p = 1$	k_t CDOSTW '91-93; ES '93	Hierarchical in rel. k_t	$N \ln N$ exp.
$p = 0$	Cambridge/Aachen Dok, Leder, Moretti, Webber '97 Wengler, Wobisch '98	Hierarchical in angle Scan multiple R at once $\leftrightarrow$ QCD angular ordering	$N \ln N$
$p = -1$	anti-k_t Cacciari, GPS, Soyez '08 $\sim$ reverse-k_t Delsart	Hierarchy meaningless, jets like CMS cone (IC-PR)	$N^{3/2}$
SC-SM	SISCone GPS Soyez '07 + Tevatron run II '00	Replaces JetClu, ATLAS MidPoint (xC-SM) cones	$N^2 \ln N$ exp.

All these algorithms [& much more] coded in (efficient) C++ at
`http://fastjet.fr/` (Cacciari, GPS & Soyez '05-'11)

A 3-year old general-purpose jet algorithm

anti-k_t: repeatedly recombine pair of objects with smallest $d_{ij} = \dfrac{\Delta R_{ij}^2}{\max(k_{ti}^2, k_{tj}^2)}$

Hard stuff clusters with nearest neighbour

Cacciari, GPS & Soyez '08

[included in FastJet]

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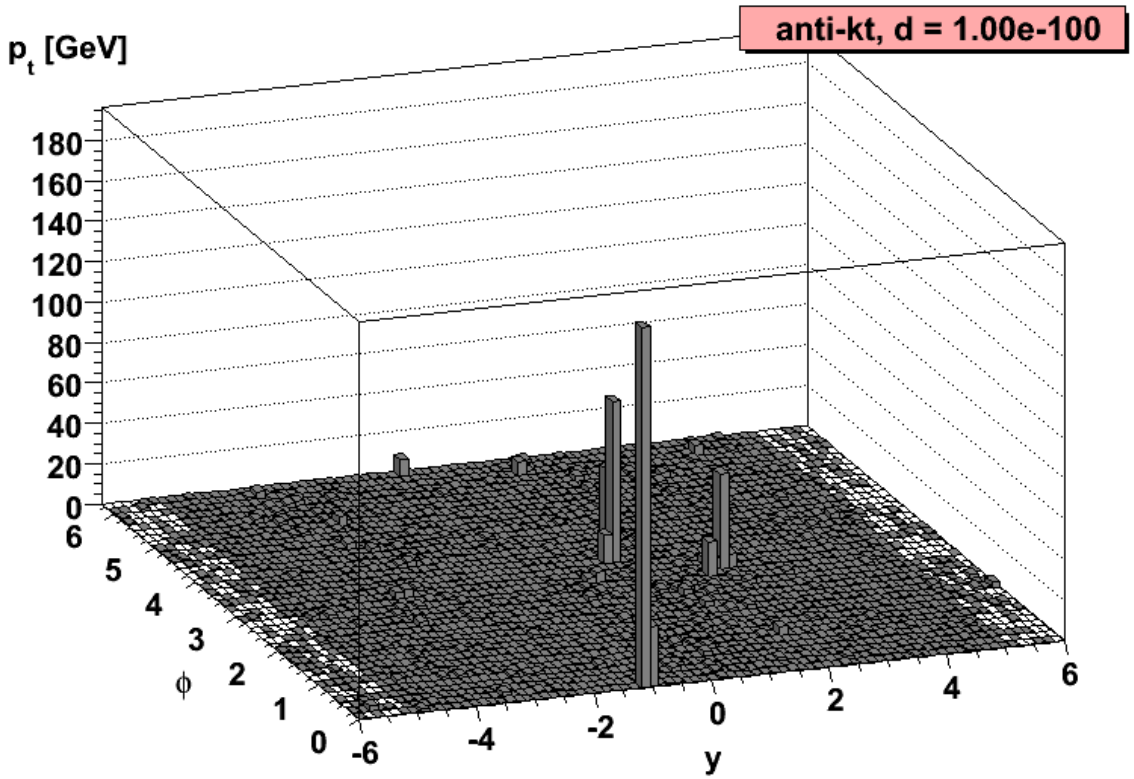

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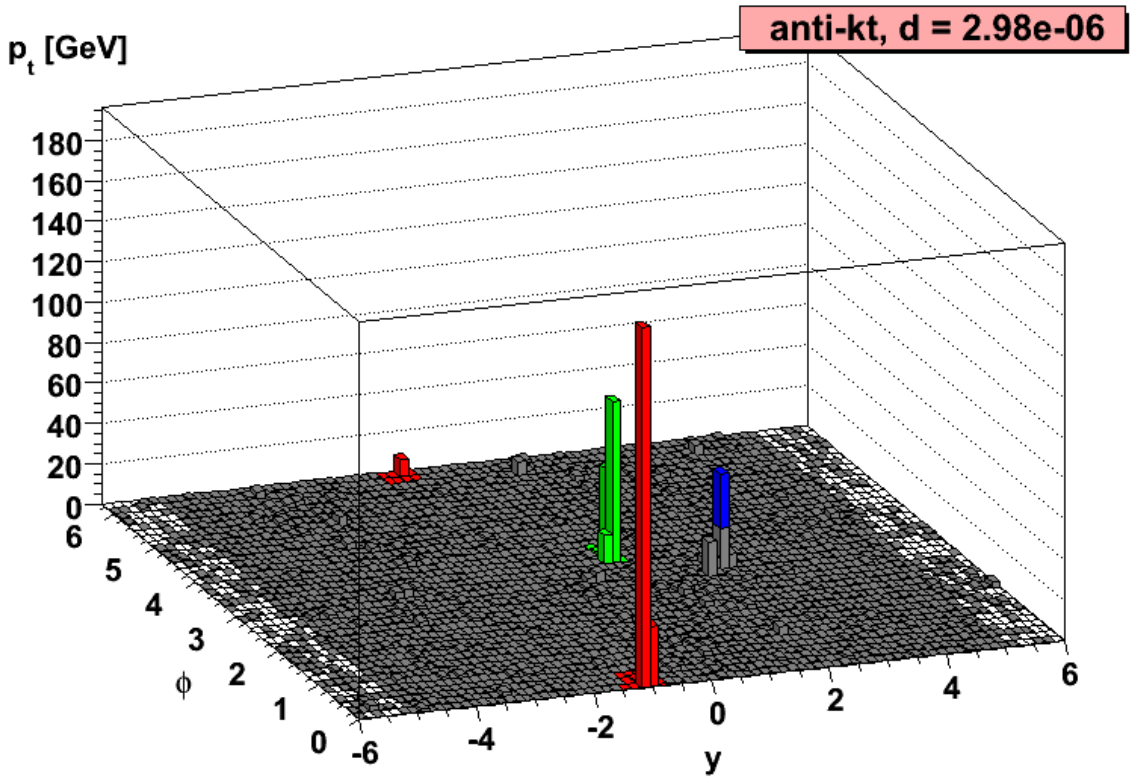

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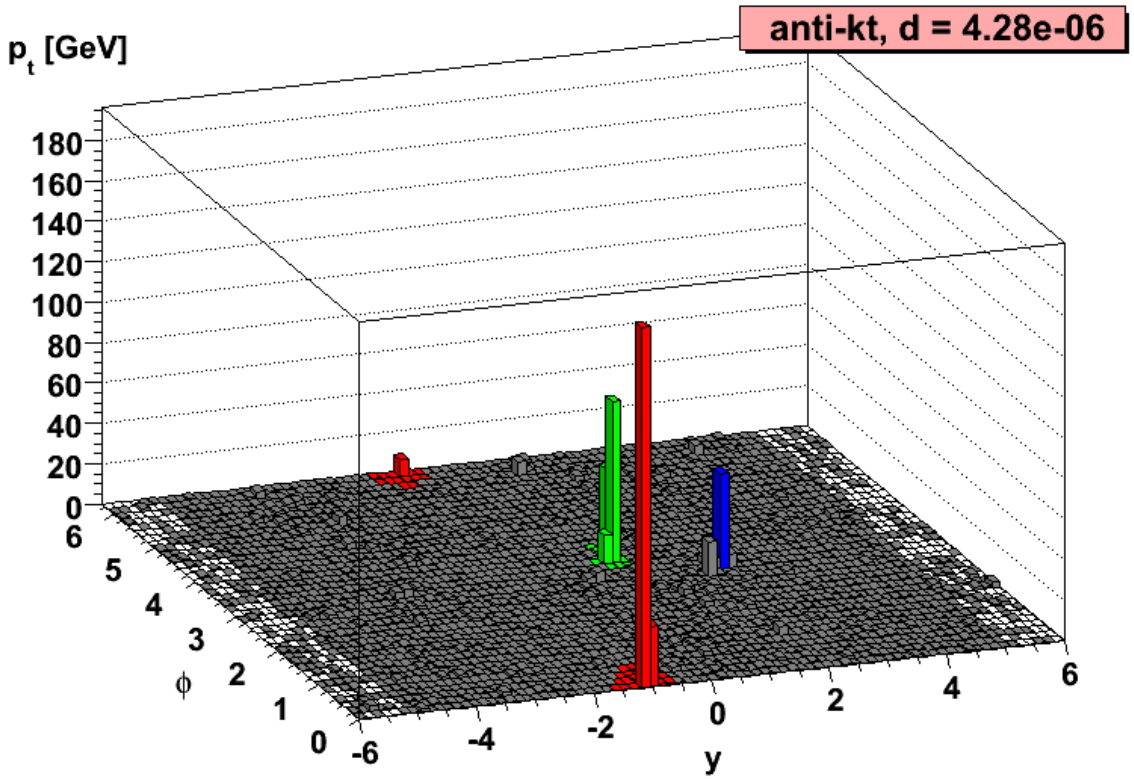

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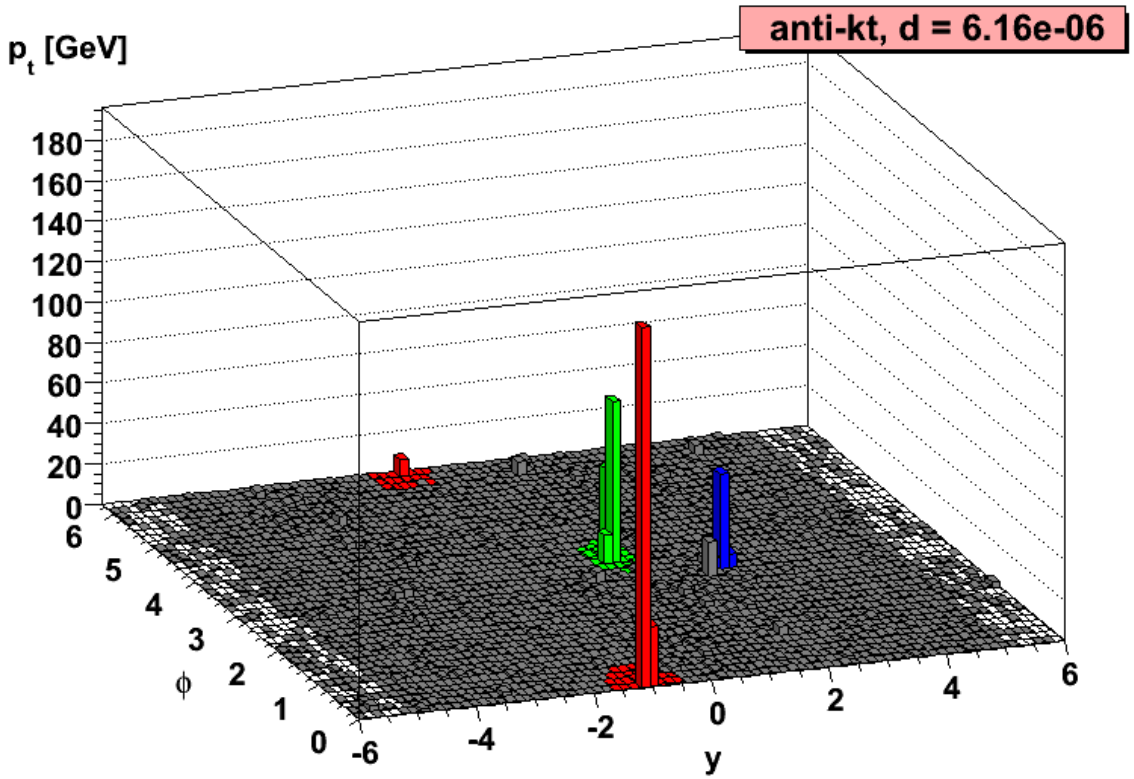

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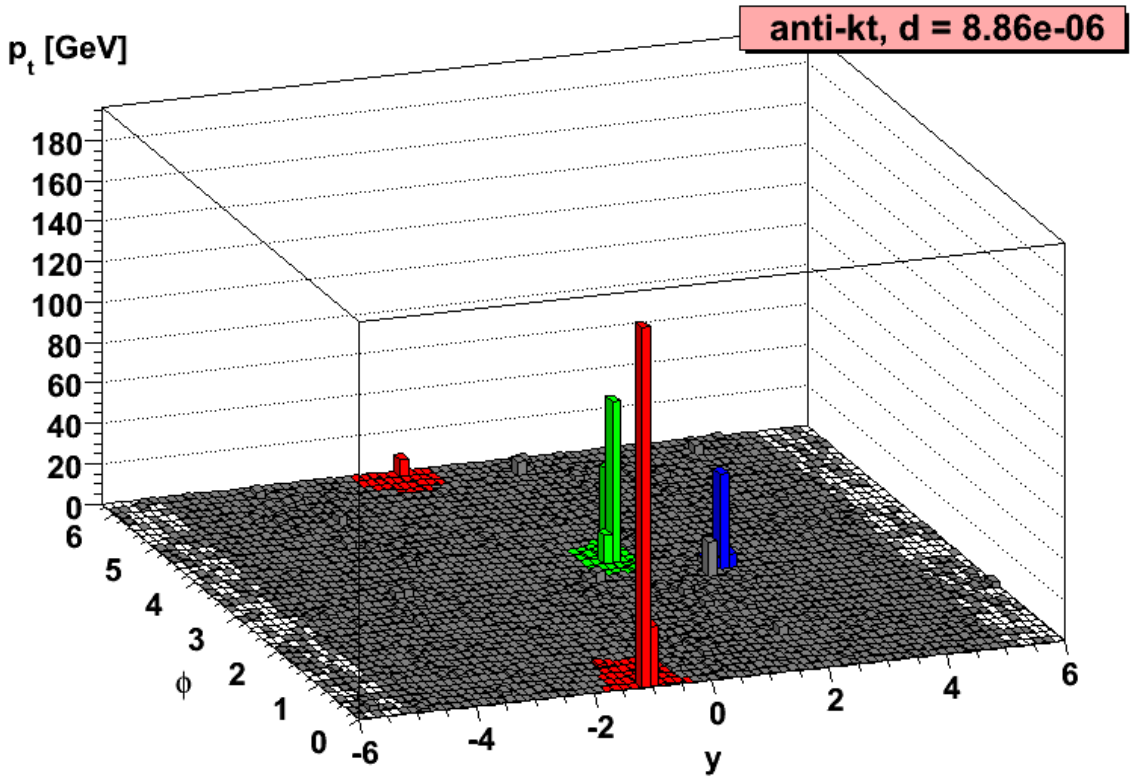

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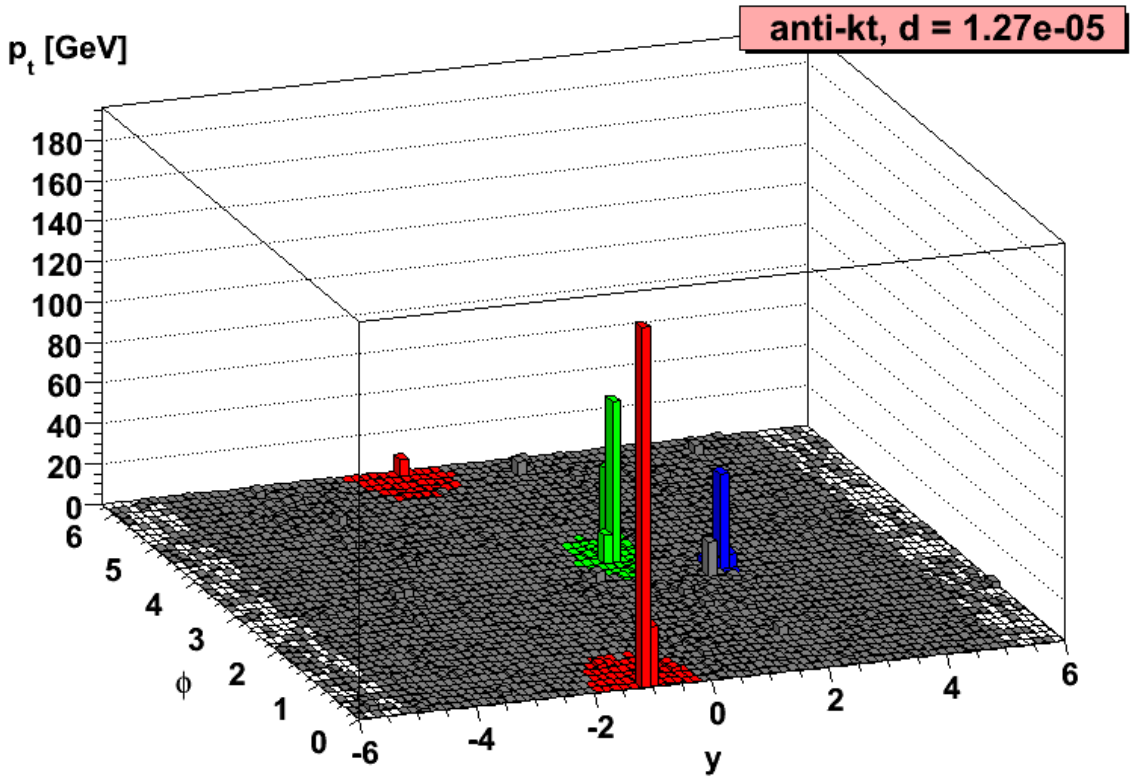

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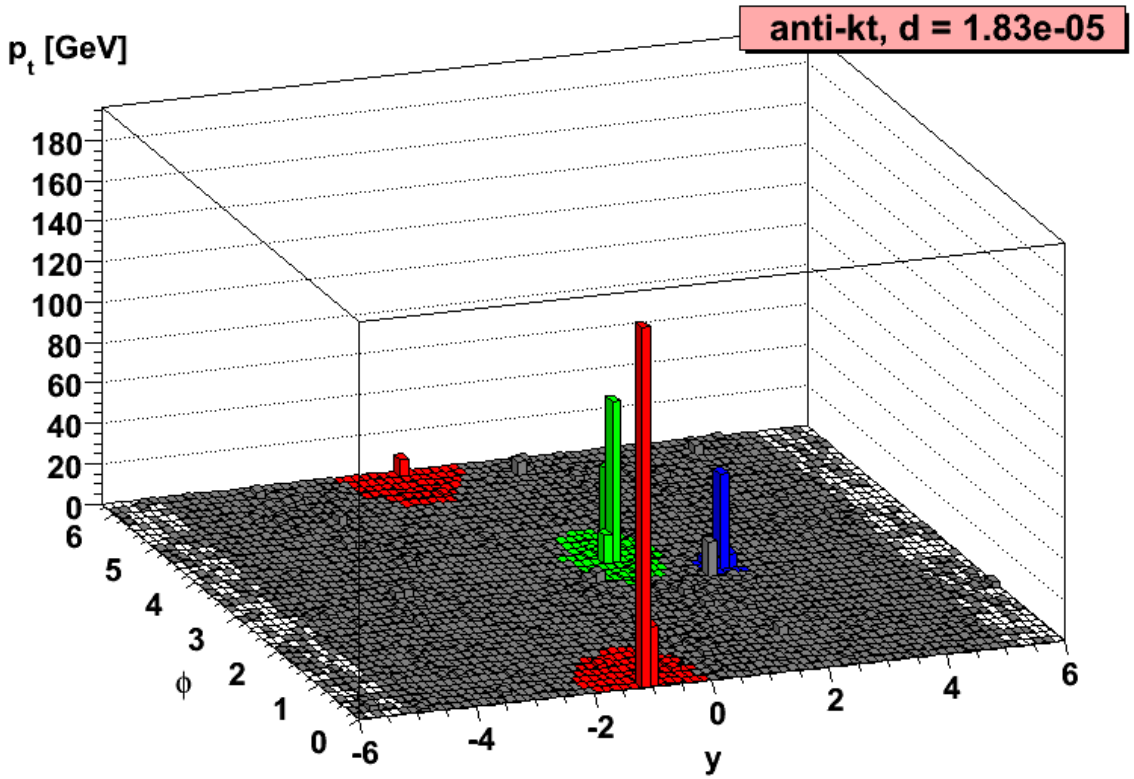

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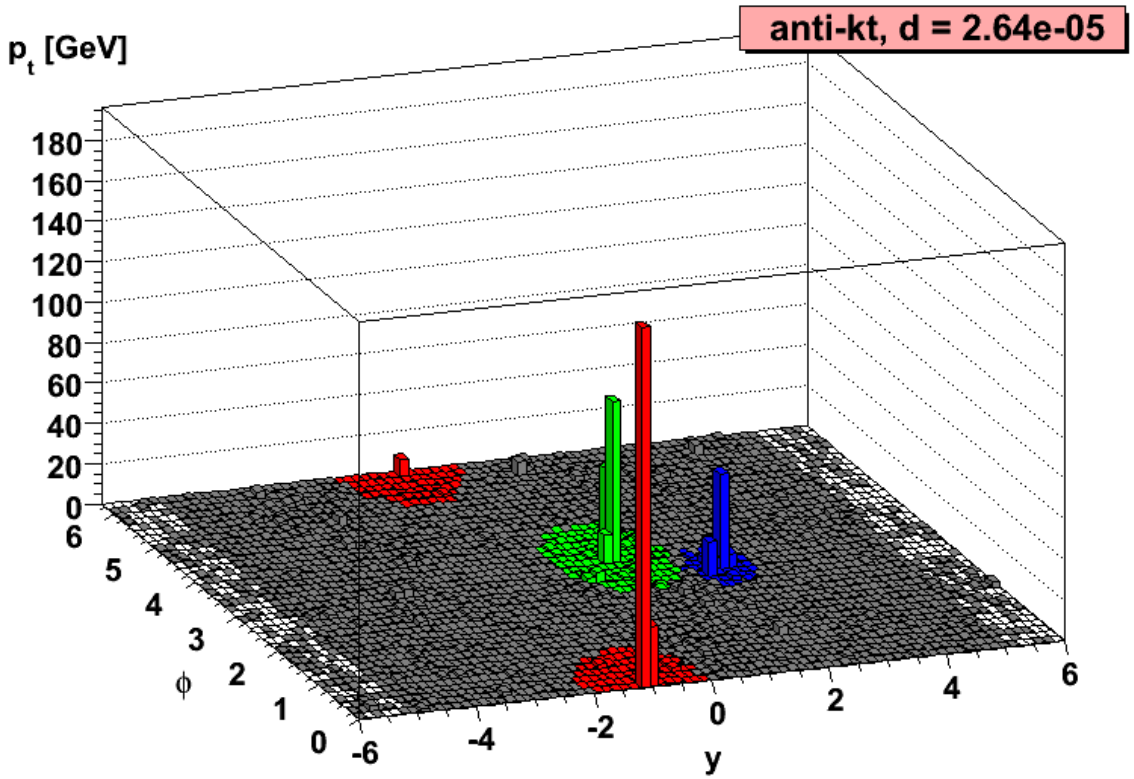

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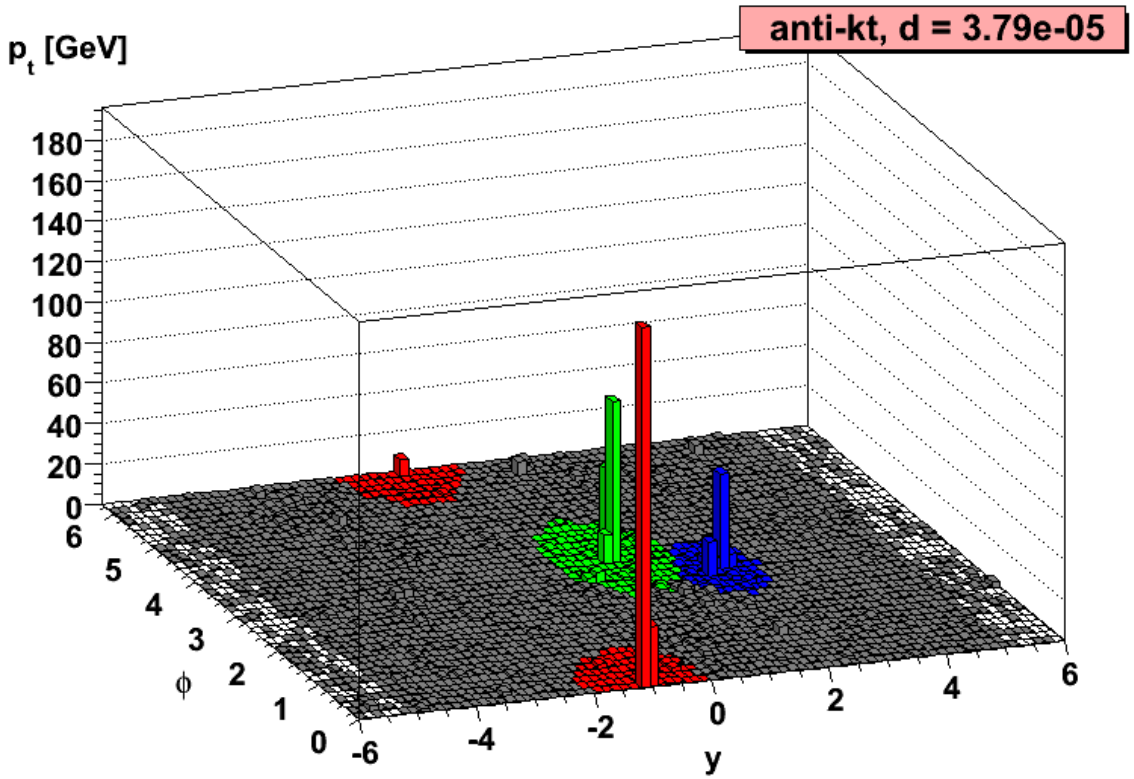

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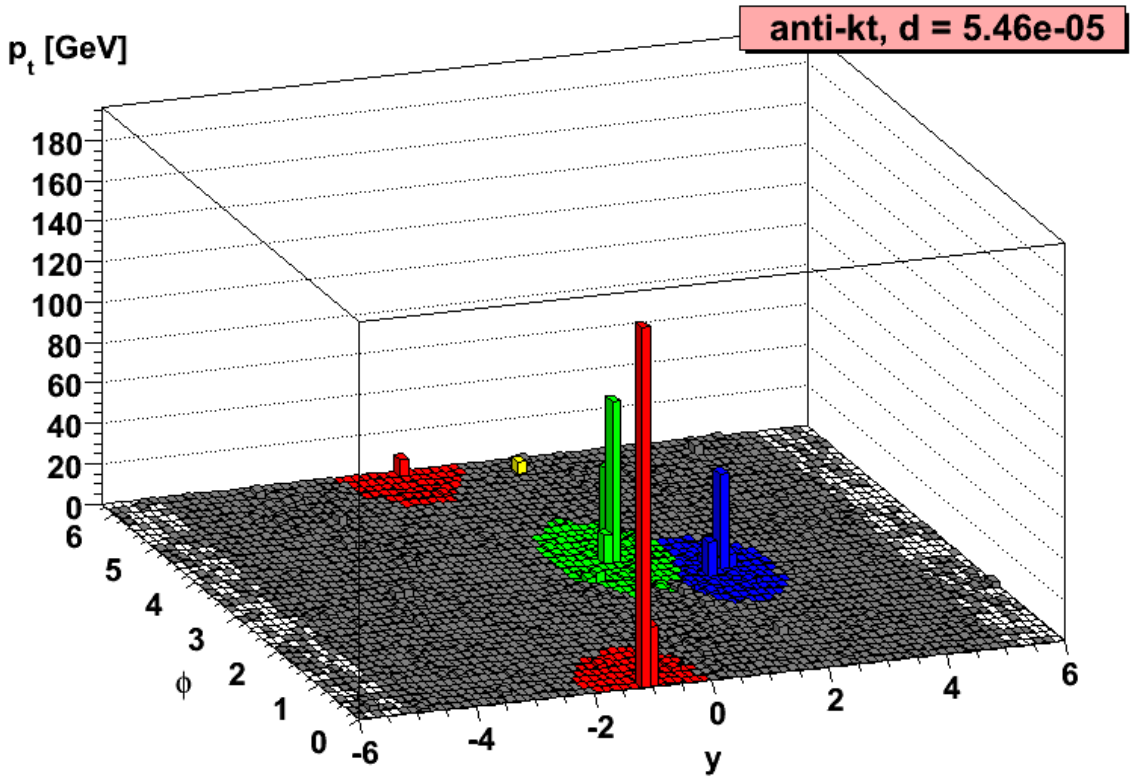

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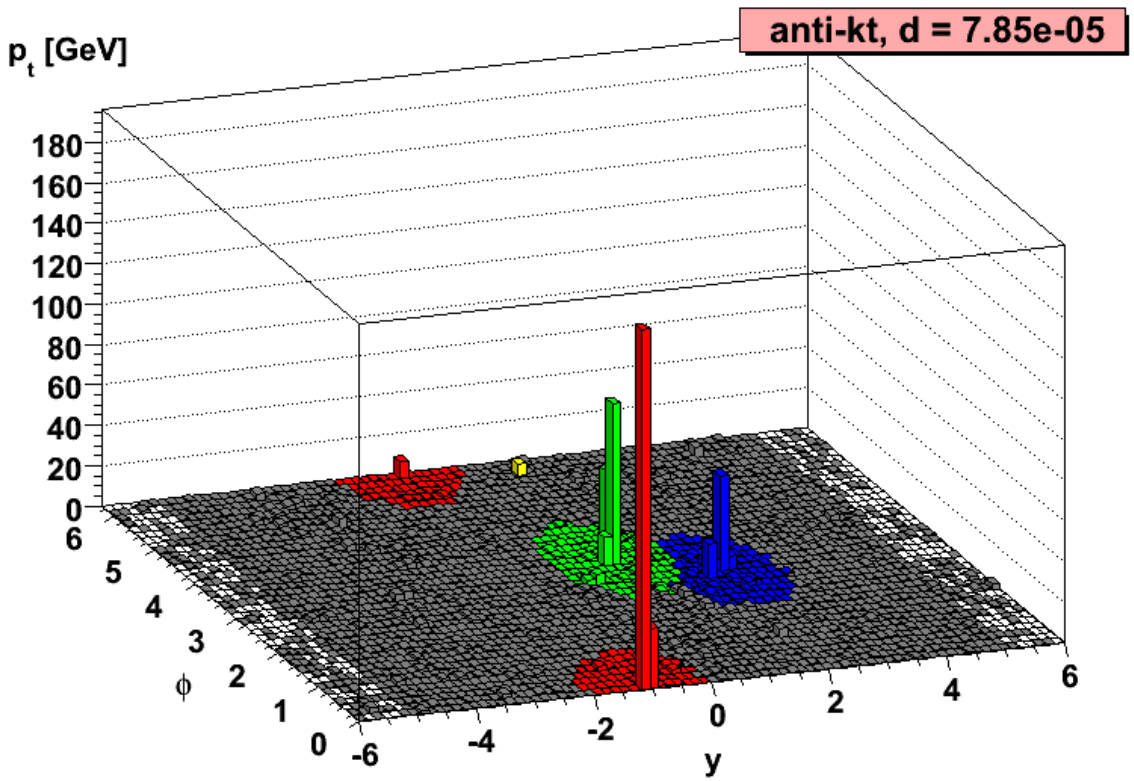


anti-k_t gives cone-like jets without using cones

And is infrared & collinear safe

Which jet algorithm to use?

For generic jet-finding, use anti-k_t algorithm.

not just because I'm biased; but also because it works well;
and it has become the standard

Which R value(s) to use?

ATLAS: 0.4 and 0.6

CMS: 0.5 and 0.7

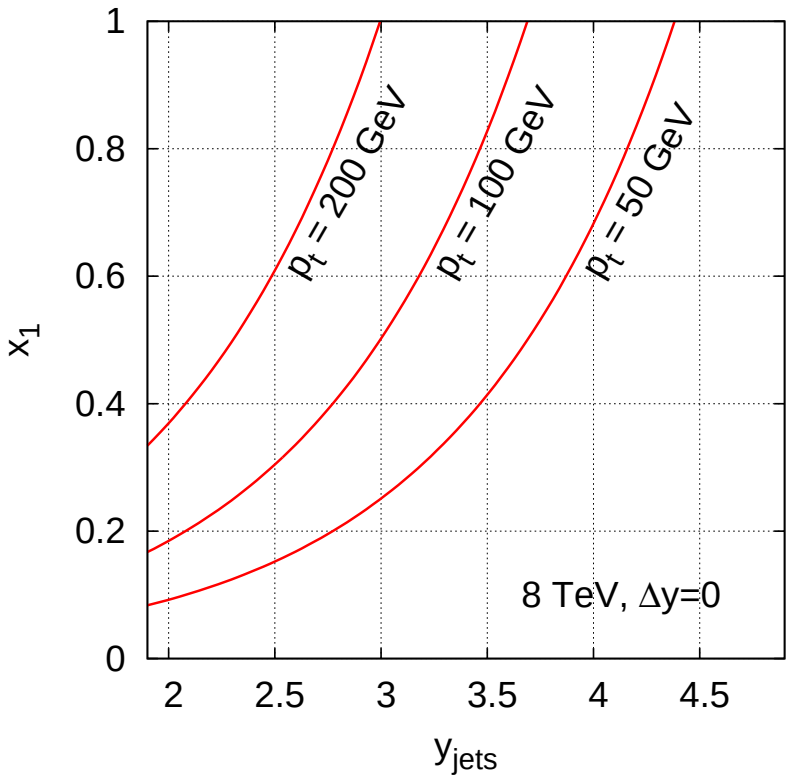
"Best" choice depends on the physics;
having two values provides powerful check on systematics

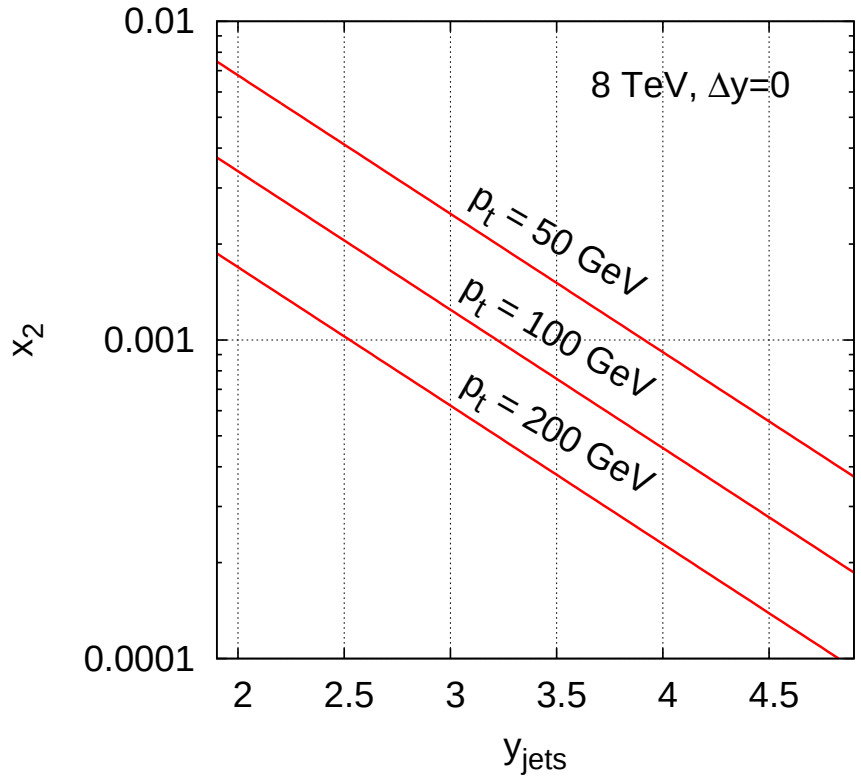
Forward Jets and PDFs

Jets going forwards

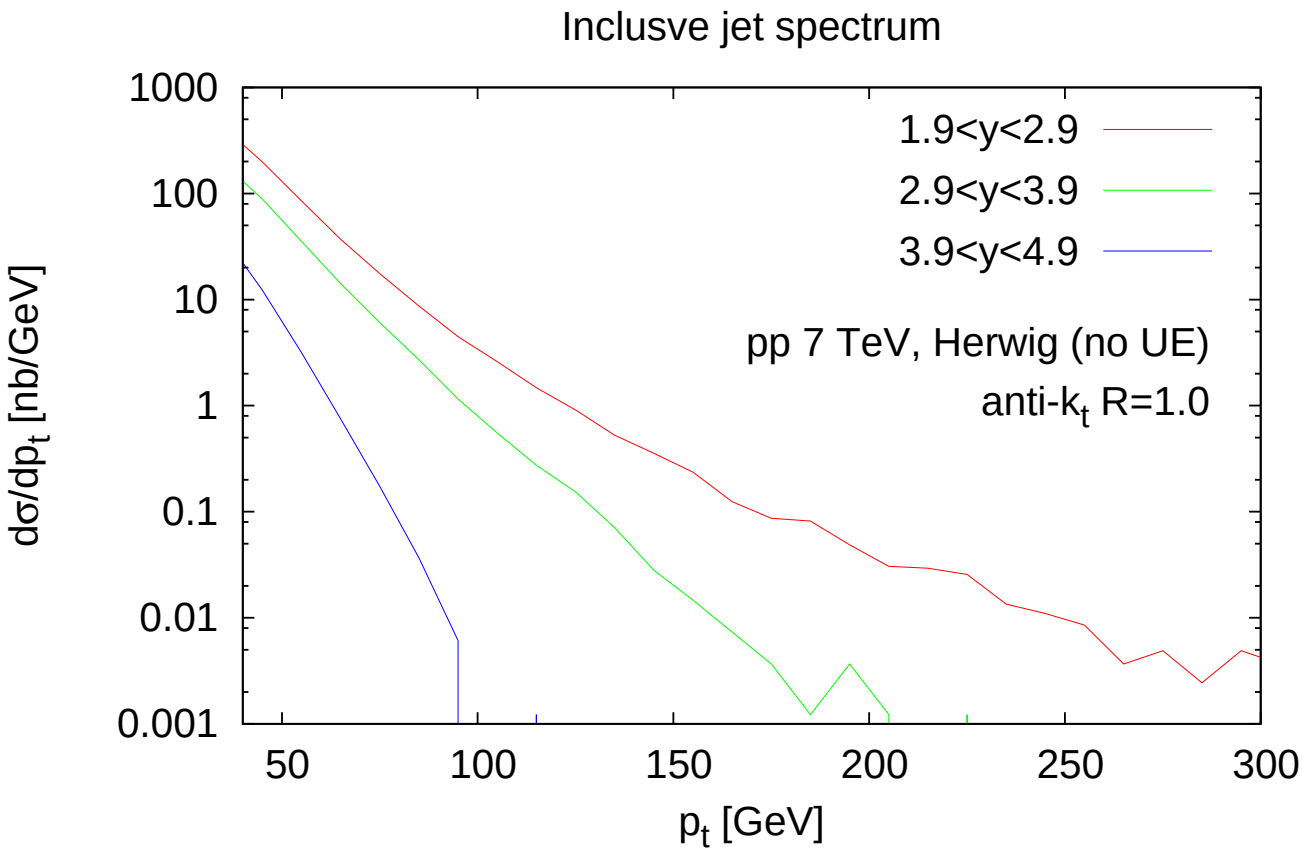
LHCb probes region with interesting mix of high-x and low-x PDFs:

$$x_{1,2} \simeq \frac{2p_t}{\sqrt{s}} e^{\pm y} \cosh \frac{\Delta y}{2}$$





Large cross sections



Use of $R = 1$ is arbitrary

Going forwards, you get large x without paying the price of tiny cross sections caused by $\mathcal{O}$(TeV) momentum transfers

b jets

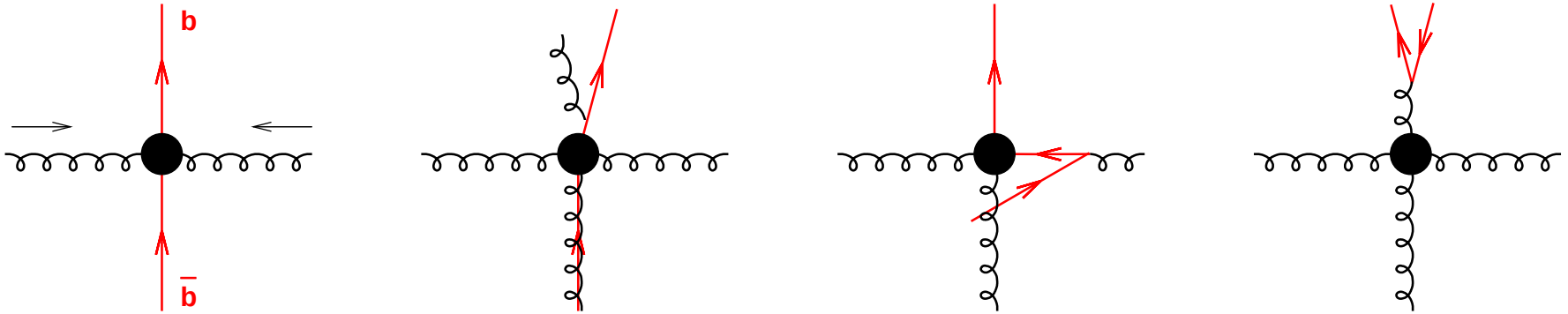
E.g. identify the direction of each b

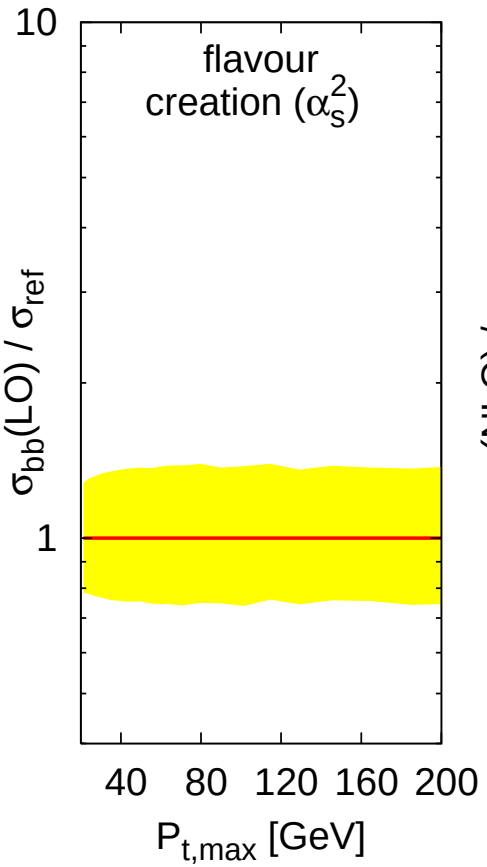
Label the calorimeter-tower in that direction as a b-tower

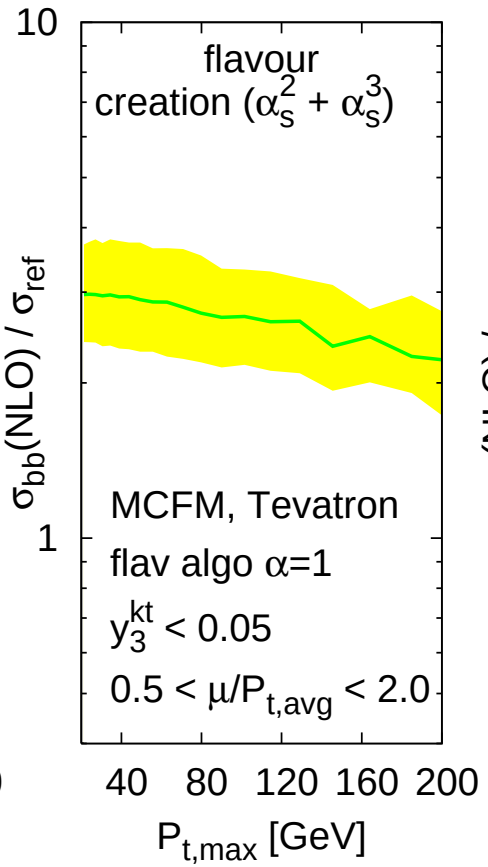
A b-jet is one that contained b-tower

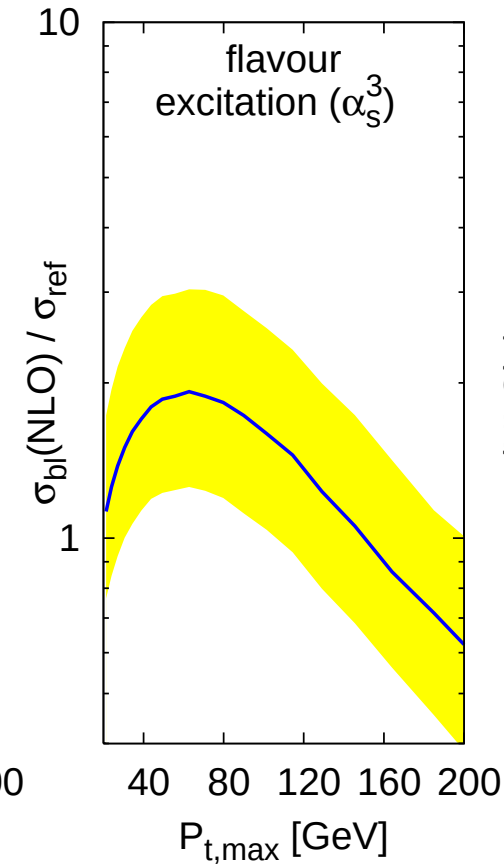
[one of several ways of assigning flavour to jets]

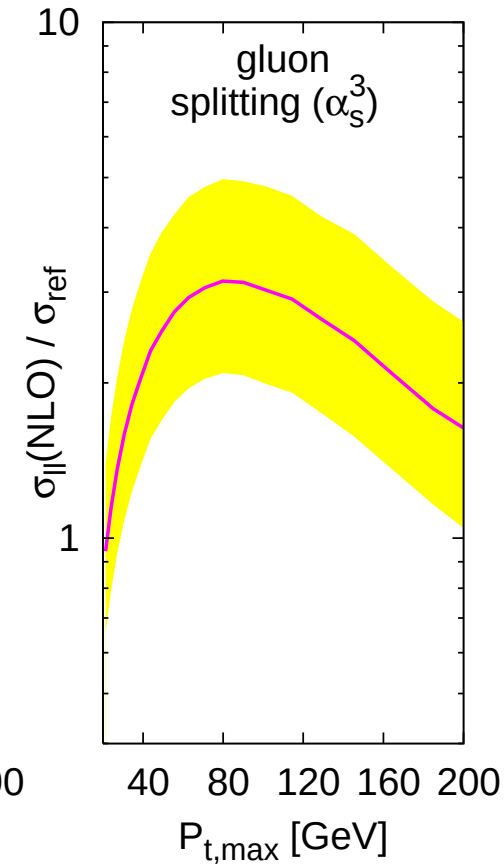
b-production sub-processes



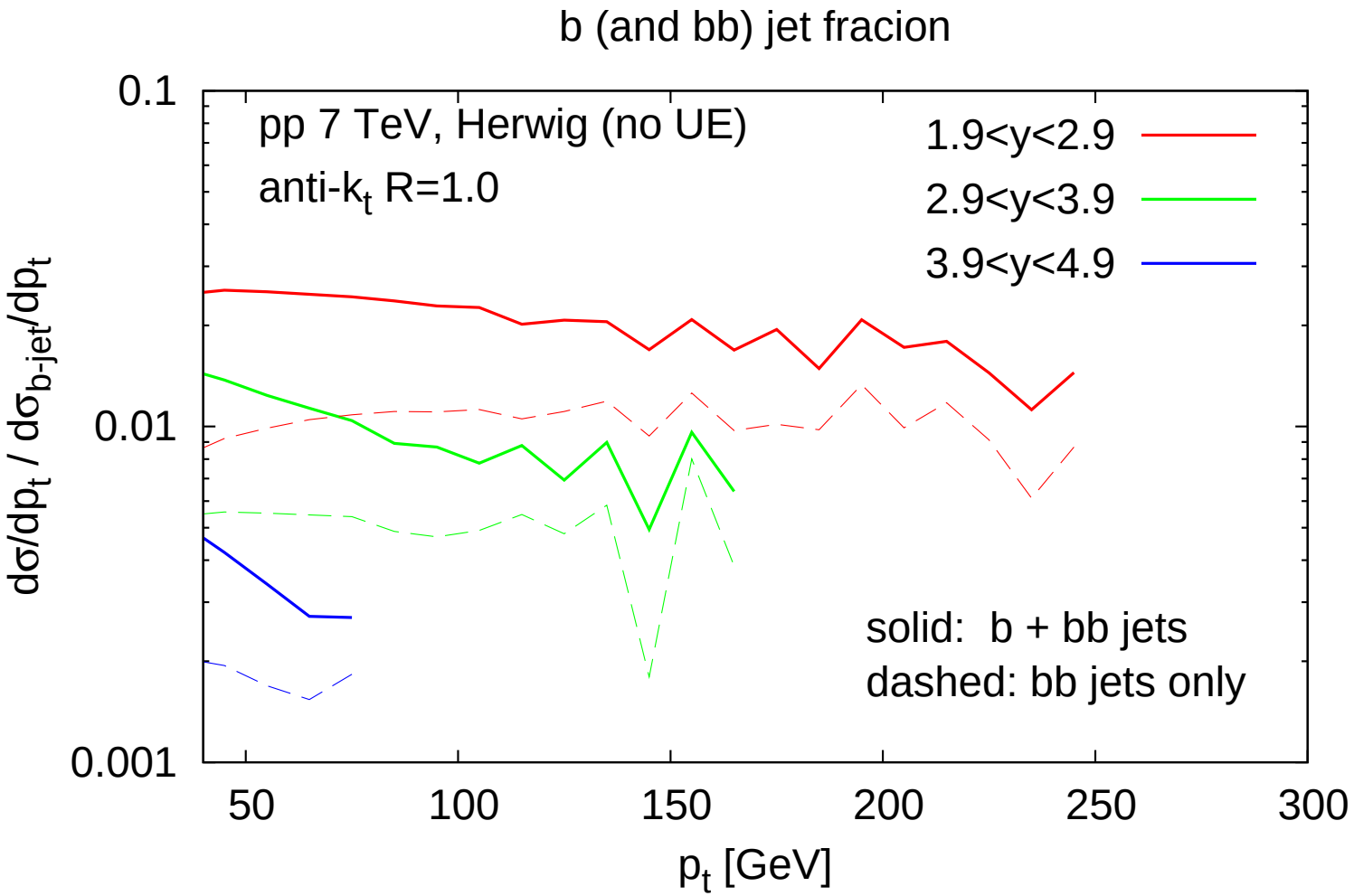








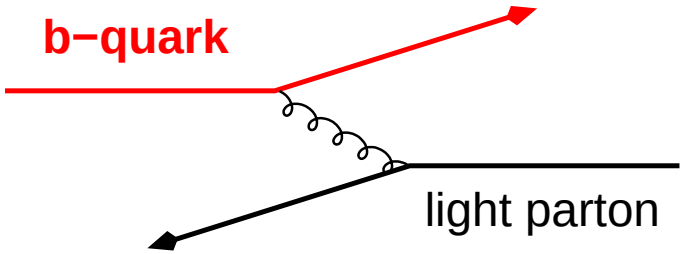
b-jet fractions for LHCb

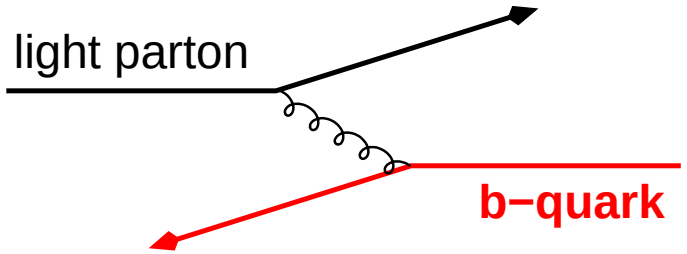


Can you experimentally separate b-jets from $b\bar{b}$ jets?

b-light dijet systems

Outgoing b jet follows direction of incoming b-quark.





If b is the more forward jet, it's more likely to come from large-x proton rather than small-x proton

Depending on accuracy of measurements & calculations, this could provide an interesting constraint on PDFs.

Also on gluons, since b-PDF comes from $g \to b\bar{b}$

Conclusions

LHCb's ability to do forward jets shared with ATLAS/CMS

Its ability to do b-tagged forward jets is unique

It was beyond the scope of this talk to do full study of what physics is possible with jets at LHCb.

PDFs certainly of interest.

Double v. single-b jets — probing origin of heavy-flavour in jets.

Maybe also top ($t\bar{t}$ asymmetry), Higgs, etc.

I'll be happy to discuss further and try to point you in the direction of people who know more about specific topics.