Infrared safe definition of jet flavour

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LPTHE, Universities of Paris VI and VII and CNRS

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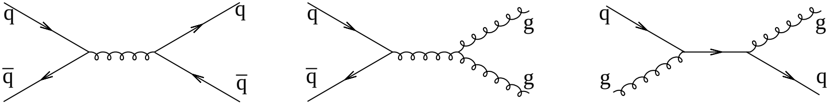
20 April 2006

Subprocess decomposition

QCD processes at hadron colliders involve many possible subprocesses.
E.g. dijet production:



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Want to be able to discuss decomposition into subprocesses, beyond LO

- To attribute more physical meaning to higher-order calculations
  e.g. which subprocesses get largest corrections
- To know relative numbers of quark v. gluon jets
  e.g. for multiplicity studies, Monte Carlo tuning
- When matching multi-leg calculations with Monte Carlo showering
  e.g. CKKW, Nagy-Soper NLO+showers
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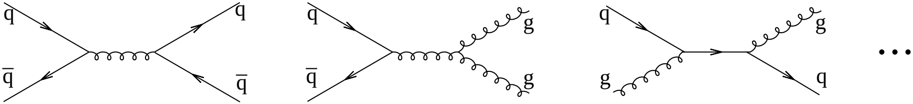

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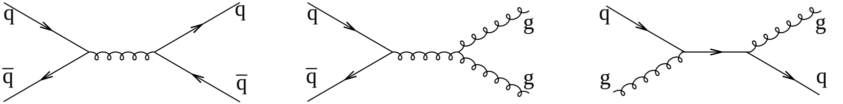

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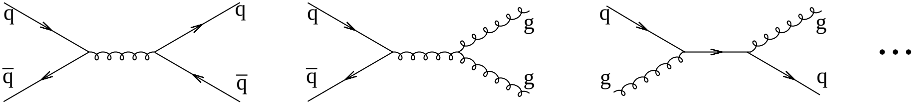

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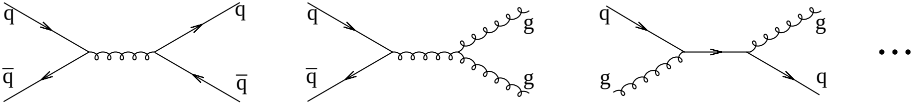

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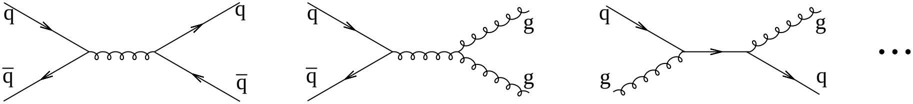

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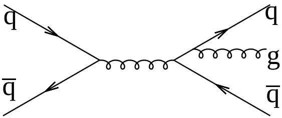
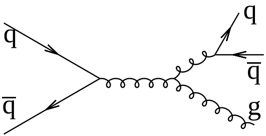
Problem: at higher orders, decomposition into the original LO 'flavour channels' is ambiguous:



Correction to $q\bar{q} \to q\bar{q}$?



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I.e. assignment to unique $2 \to 2$ channel is *impossible* (*e.g.* the two diagrams interfere in squared amplitude).

Need a *convention to define channel* beyond LO:

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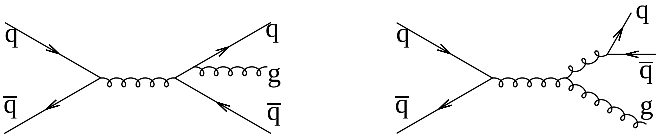

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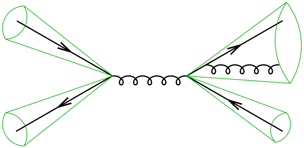

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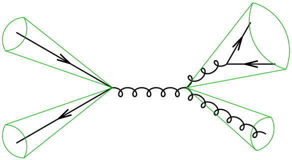

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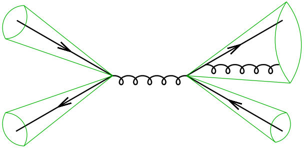

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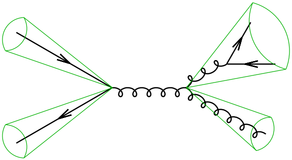

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376 papers with 'quark/gluon jet' in title

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Jet flavour and infrared safety

Physical meaning of quark or gluon jet (jet *flavour*) is "obvious".

[one initiated by a hard quark resp. gluon]

But with normal jet algorithms (k_t, cone), sum of flavours of partons in jet is *infrared unsafe:*

- Soft gluon $\longrightarrow$ large angle $q\bar{q}$ is clustered into different jets and *contaminates* jet flavour.

Can the jet flavour be made infrared safe?

Feynman alleged to have said "no" (but we haven't found ref.)

∃ hints of problems in reconciling IR safety and flavour: *e.g.* Nagy & Soper '05

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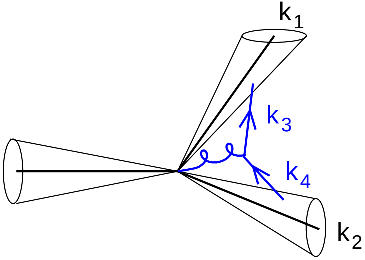

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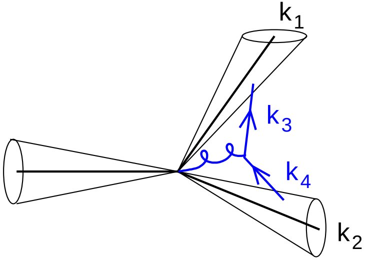

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Logic behind k_t clustering

k_t algorithm clusters closest pair of particles, next closest pair, etc.

cf. talk by Cacciari

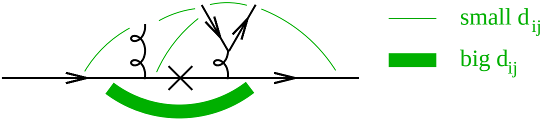
Key issue is *distance measure:*

$$d_{ij}^{(k_t)} = 2\min(E_i^2, E_j^2)\,(1 - \cos\theta_{ij})\,,$$

This is a logical generic choice because of structure of divergences in gluon emission:

$$[dk_j]|M^2_{g\to g_i g_j}(k_j)| \simeq \frac{\alpha_s C_A}{\pi}\frac{dE_j}{\min(E_i, E_j)}\frac{d\theta_{ij}^2}{\theta_{ij}^2}\,, \qquad (E_j \ll E_i\,,\ \theta_{ij} \ll 1)\,.$$

For each divergent limit, $E_j \to 0$, $\theta_{ij} \to 0$, distance vanishes ($y_{ij} \to 0$).



k_t distance and quarks

Quark production only has collinear divergence, but no soft divergence

$$[dk_j]|M^2_{g\to q_i\bar{q}_j}(k_j)| \simeq \frac{\alpha_s T_R}{2\pi}\frac{dE_j}{\max(E_i,E_j)}\frac{d\theta_{ij}^2}{\theta_{ij}^2}\,, \qquad (E_j \ll E_i\,,\ \theta_{ij}\ll 1)\,,$$

- k_t distance does not match divergence structure for quark emission
- *fatal* for jet flavour studies because soft large-angle $q, \bar{q}$ from soft gluon are deemed similarly close to all particles in event

Solution: modify distance measure for quarks to reflect divergences

[Banfi, GPS & Zanderighi, hep-ph/0601139]

$$d_{ij}^{(F)} = 2(1-\cos\theta_{ij}) \times \begin{cases} \max(E_i^2, E_j^2)\,, & \text{softer of } i,j \text{ is quark-like,} \\ \min(E_i^2, E_j^2)\,, & \text{softer of } i,j \text{ is gluon-like,} \end{cases}$$

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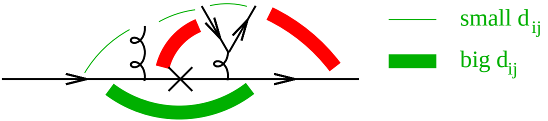
Solution: modify distance measure for quarks to reflect divergences

[Banfi, GPS & Zanderighi, hep-ph/0601139]

$$d_{ij}^{(F)} = 2(1-\cos\theta_{ij}) \times \begin{cases} \max(E_i^2, E_j^2)\,, & \text{softer of } i,j \text{ is quark-like,} \\ \min(E_i^2, E_j^2)\,, & \text{softer of } i,j \text{ is gluon-like,} \end{cases}$$



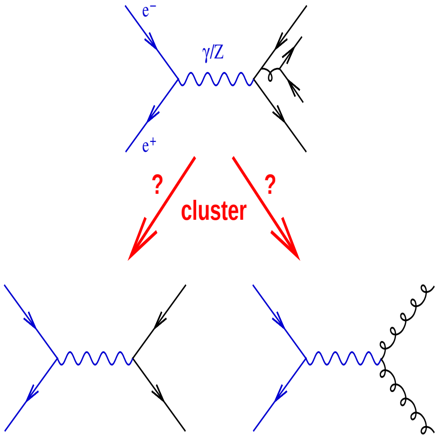
Testing IR safety (e^+e^-)

Analytical demonstration of IR safety is *straightforward*.

Can also illustrate it numerically:

- Take $e^+e^- \to 2$ jets (has known flavour structure)
- Calculate 3 and 4-parton configurations (with EVENT2)
- Cluster to 2 jets
- As function of y_3 (measure of event hardness) *examine σ for events with mis-flavoured jets* (gluonic, multi-flavoured)

NB: ∃ class of flavour algos.
That shown earlier is $\alpha = 2$



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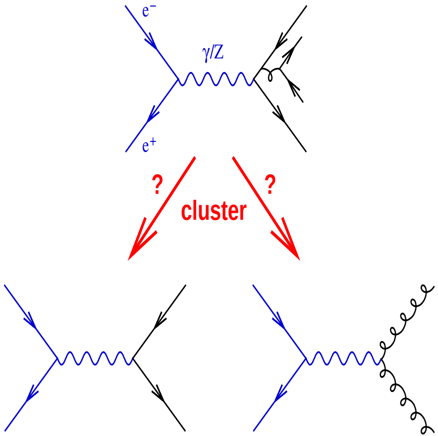

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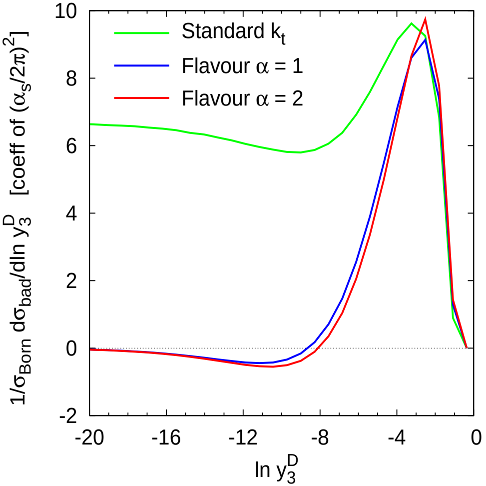

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Jet flavour at hadron colliders

Extension from e^+e^- to hadron-collisions requires extra ingredient: *beam hardness* $k_{tB}(\eta)$ ≡ estimate of DGLAP evolution scale at a given rapidity.

$$d_{iB}^{(F)} = \begin{cases} \max(k_{ti}^2, k_{tB}^2(\eta_i))\,, & i \text{ is quark-like,} \\ \min(k_{ti}^2, k_{tB}^2(\eta_i))\,, & i \text{ is gluon-like.} \end{cases}$$

How can we test it?

- NLO progs for DIS and pp *do not provide flavour info*

  A great shame. . .

- Instead, stress-test algo. with *parton-shower* events
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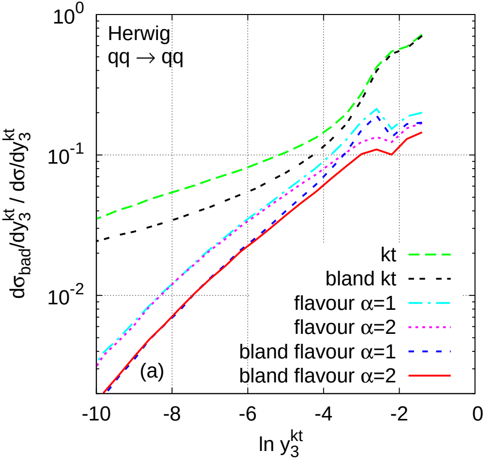

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- It is possible to define the parton-level jet-flavour in an IR safe way
- Key new idea is different clustering for quarks and gluons

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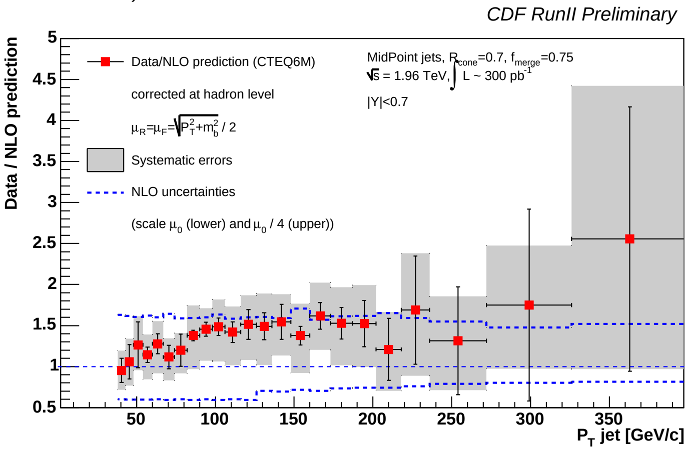
Current B-jet measurements

An important motivation for studying *b*-jets was to reduce theory uncertainties. Frixione & Mangano '96

But in practice NLO uncertainties are very large, $\sim 40-60\%$ ($10-20\%$ is more usual for NLO).



Heavy-flavour jets

Use new jet-flav. algo., but treat only the b-hadrons as quark-like

Must identify all b-hadrons in event — feasible, cf. CDF '04

- Gives physical definition of various b-production channels (flavour excitation, flavour creation, ...) *i.e.* measurable in data, calculable at NLO
- flavour b-jet cross sections are *free of any* $\ln E_\perp/m_b$ *enhancements*

  except those resummed in b PDFs

Theorem: in the calculation of any IRC safe quantity, quark masses can be neglected (modulo corrections suppressed by powers of m_Q/E_T).

➥ Can set $m_b = 0$ in NLO calculations — *i.e. any light-flavour NLO program could be used to predict b-jet cross sections*

➥ Can perhaps reduce PT uncertainties from current 40 – 60% (heavy b-jet calcs), down to 10 – 20% (standard light-jet calcs).

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Beam Scale

$$k_{tB}(\eta) = \sum_i k_{ti} \left(\Theta(\eta_i - \eta) + \Theta(\eta - \eta_i) e^{\eta_i - \eta}\right) ,$$

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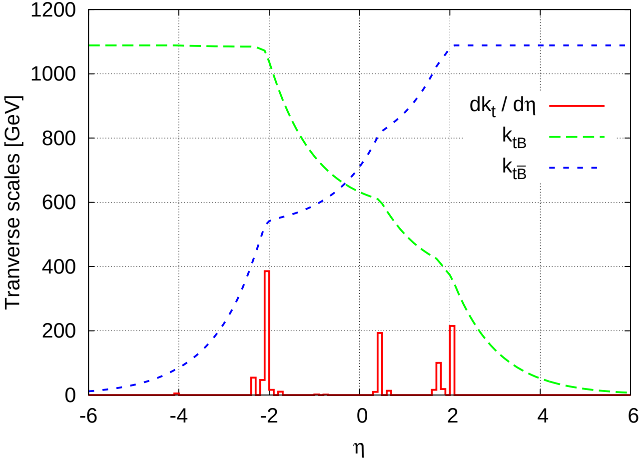

b-production sub-processes (preliminary)