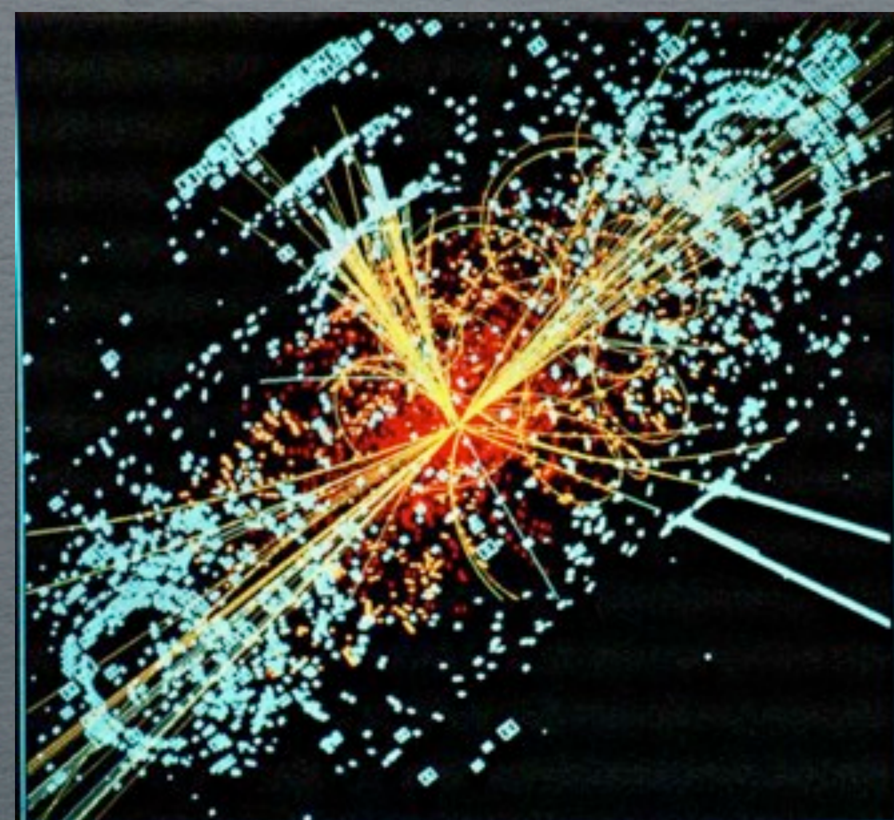
Event shapes in hadronic collisions

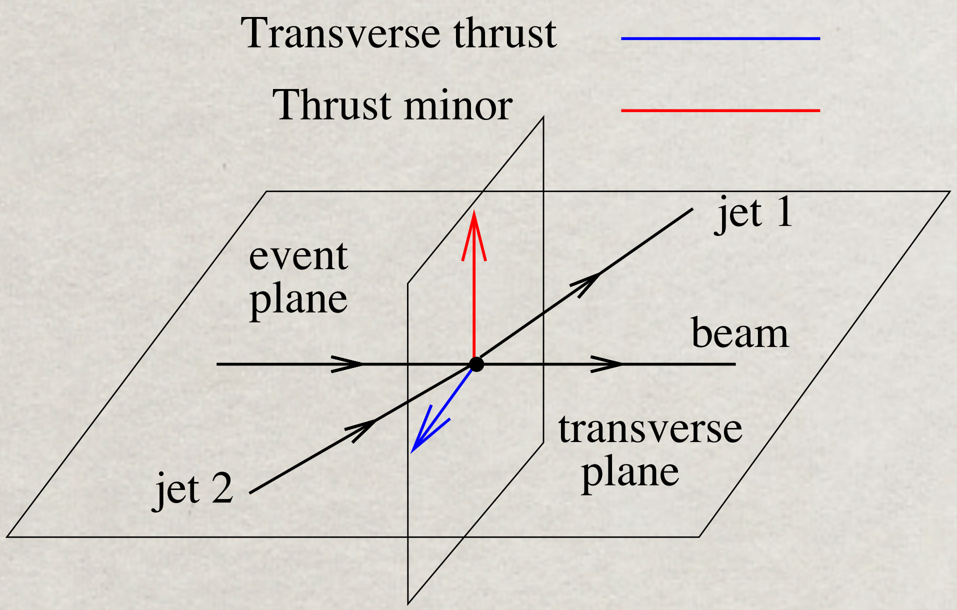


Andrea Banfi
ETH Zürich

SM@LHC - Durham - 12 April 2011

Event shapes at hadron colliders

Event shapes are combinations of hadron momenta in a number related to the geometry of an event



$$T_t \equiv \max_{\vec{n}_t} \frac{\sum_i |\vec{q}_{ti} \cdot \vec{n}_t|}{\sum_i q_{ti}}$$

$$T_m \equiv \frac{\sum_i |\vec{q}_{ti} \times \vec{n}_t|}{\sum_i q_{ti}}$$

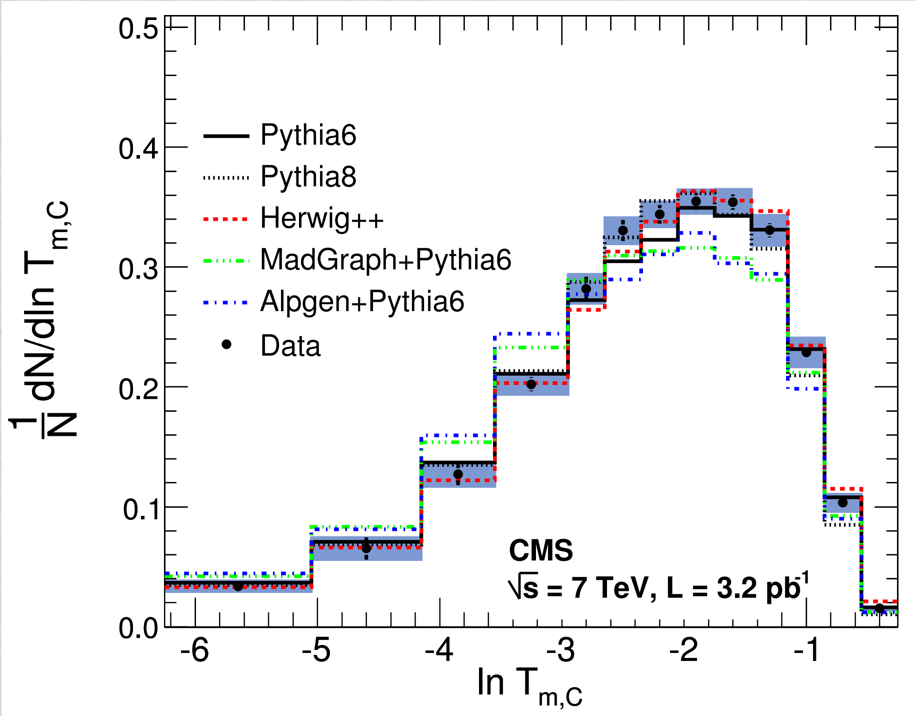
Event shapes can be measured with very first data

- Definitions involve ratios of momenta $\Rightarrow$ reduced experimental uncertainties (jet energy scale)
- Differential distributions do not require knowledge of luminosity

$$\frac{1}{\sigma}\frac{d\sigma}{dT_m} = \frac{1}{N}\frac{dN}{dT_m}$$

Event shapes at hadron colliders

Event shapes are combinations of hadron momenta in a number that gives insight on the geometry of an event



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Event shapes have been already measured at the LHC

[CMS coll. '11]

EVENT SHAPE STUDIES

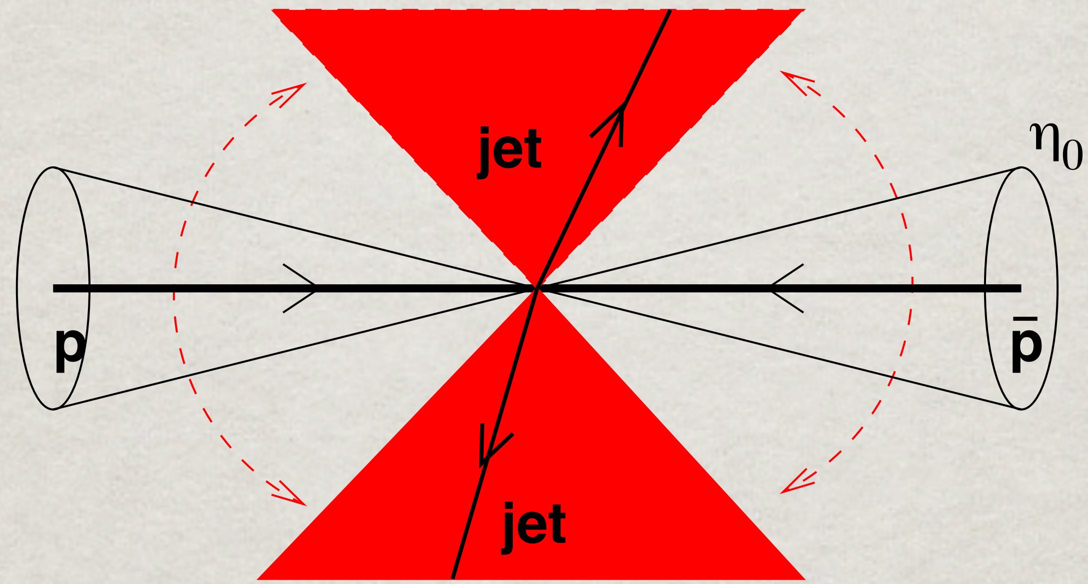
There are many event shapes with different sensitivities to properties of QCD radiation: transverse thrust, thrust minor, F-parameter, jet masses and broadenings, jet resolution parameters (see qcd-caesar.org)

They have widespread applications:

- tests of QCD and measurements of the running coupling and colour factors
- tuning of Monte Carlo event generators and tests of models for hadronisation and underlying event
- discriminatory tools between Standard Model and New Physics events

Classification of shape variables

Event shapes are classified according to the observed region



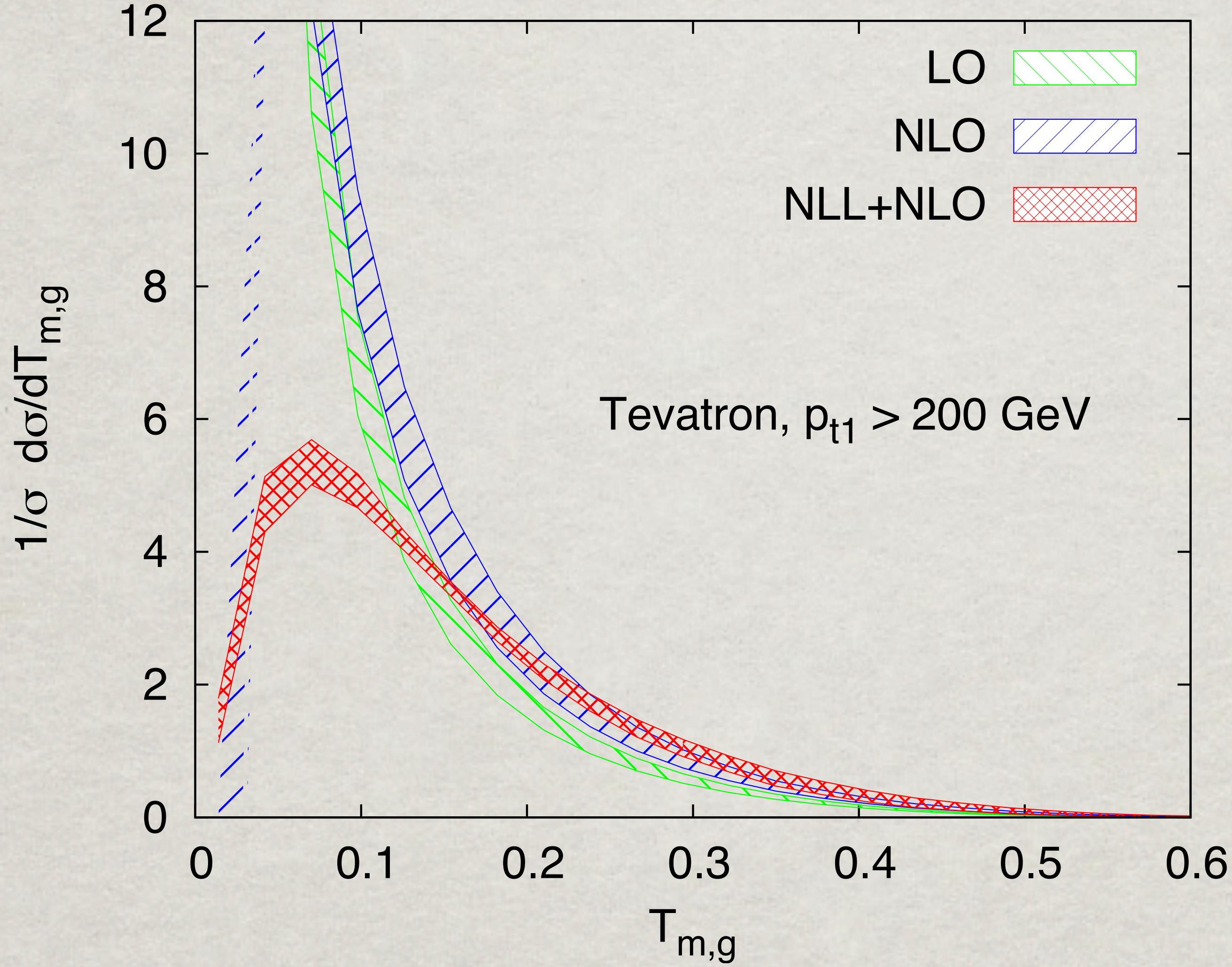
- global: sensitive to hadrons everywhere
- non-global, for instance
  - central: only hadrons in central region
  - jet-shapes: only hadrons inside a single jet

It is always possible to promote central event shapes to global

[AB Salam Zanderighi '04]

Event shapes we consider require the selection of a QCD hard di-jet event and vanish in the limit of two narrow jets

Event-shape distributions in QCD



PT QCD description of event-shape distributions

- Fixed order (3jets@NLO) unreliable close to the peak
- All order resummation of multiple soft-collinear emissions is required to describe the peak region

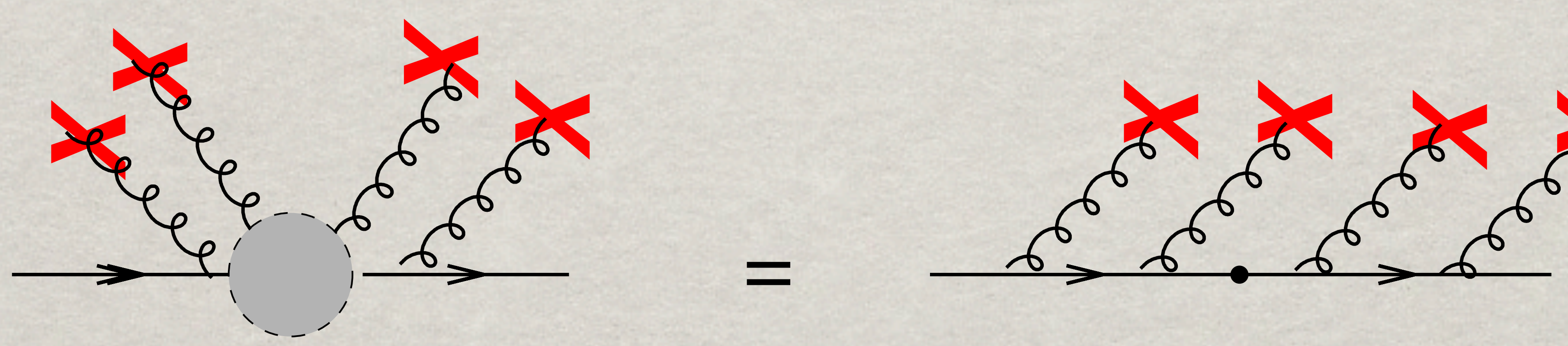
In the peak region $\alpha_s \ln T_m \sim 1 \Rightarrow$ NLL accuracy

Automated NLL resummation

Principles of NLL resummation for suitable event shapes are embedded in the Computer Automated Expert Semi-Analytical Resummer (CAESAR) [AB Salam Zanderighi '05]

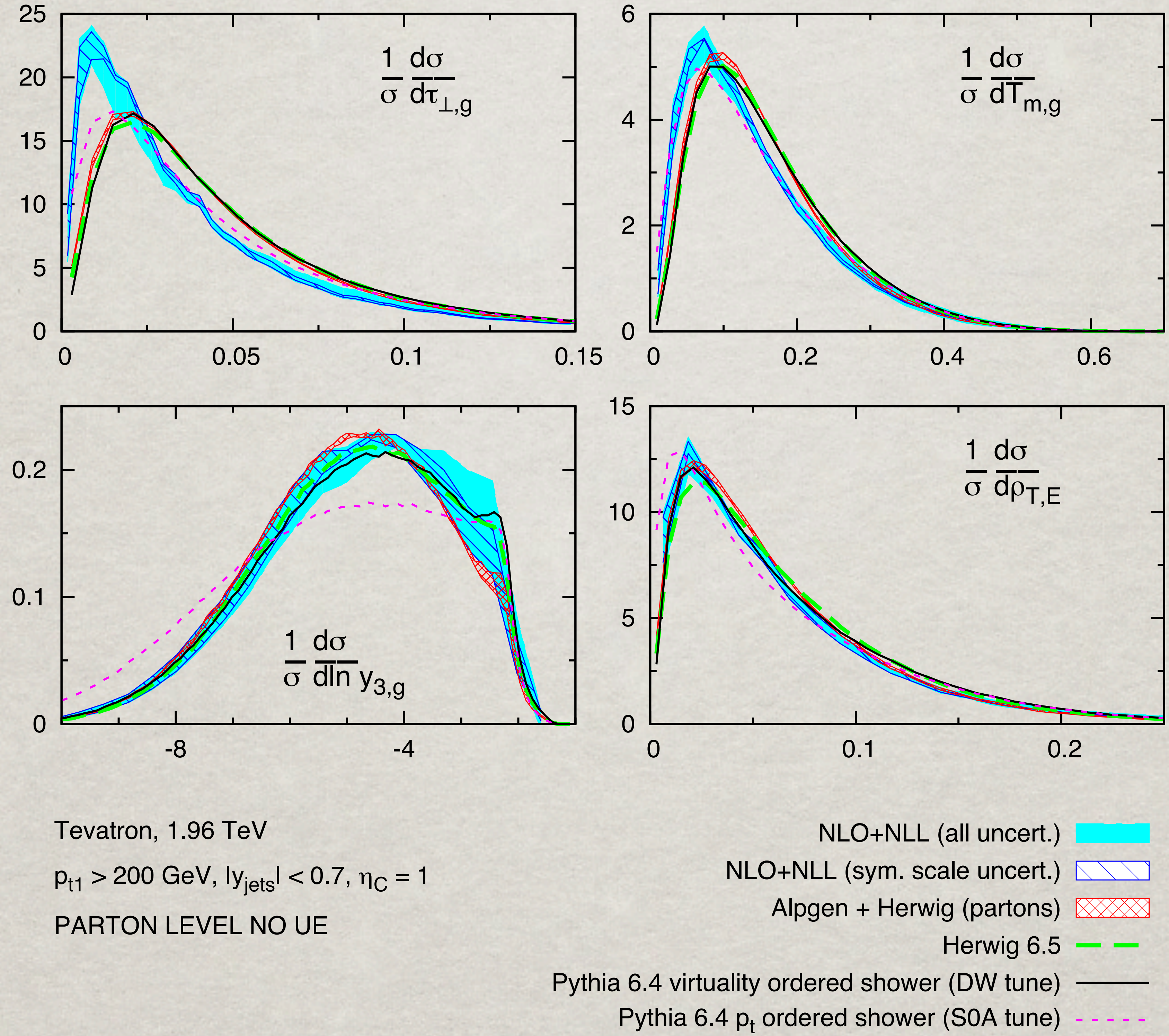
Conditions for NLL resummability

- Recursive infrared and collinear safety $\Rightarrow$ double logarithms exponentiate in a Sudakov form factor
- Continuous globalness $\Rightarrow$ multiple soft/collinear gluons independently emitted with angular ordered branching



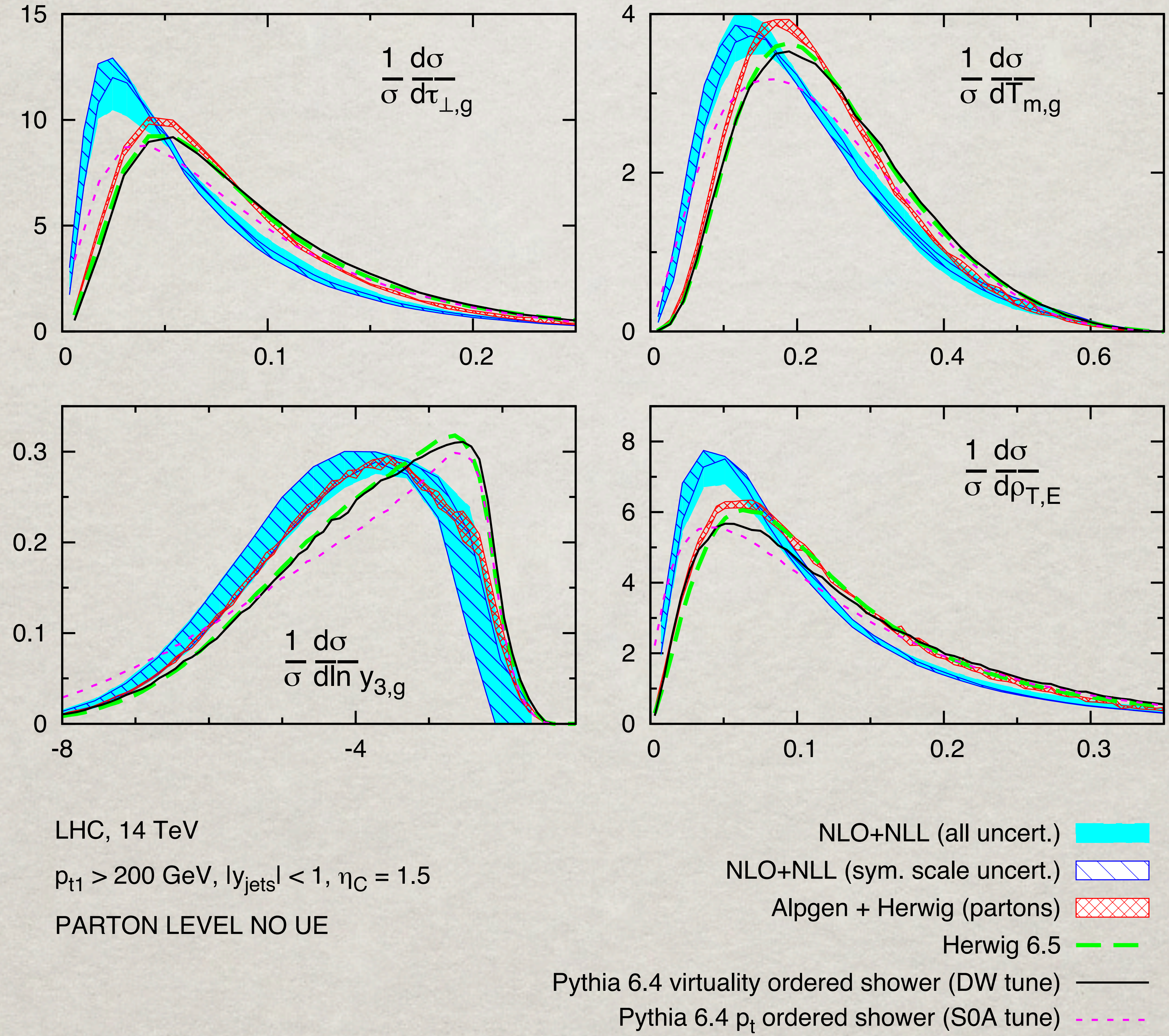
The Physics of NLL resummation should be contained in parton shower event generators $\Rightarrow$ validation tests

Resummation vs MC: Tevatron



Agreement is good for quark-dominated samples (problem revealed in Pythia S0A tune)

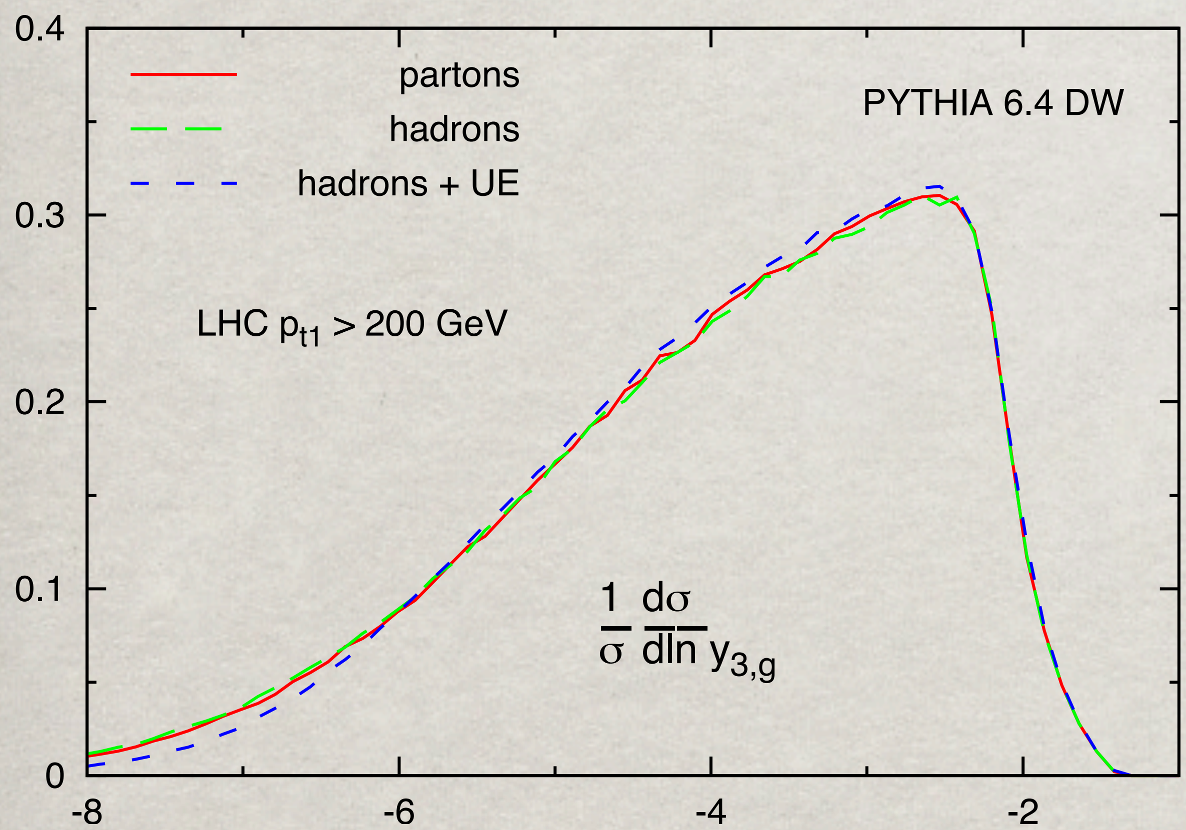
Resummation vs MC: LHC 14 TeV



Sizable disagreement in gluon-dominated samples (possibility of tuning initial-state shower)

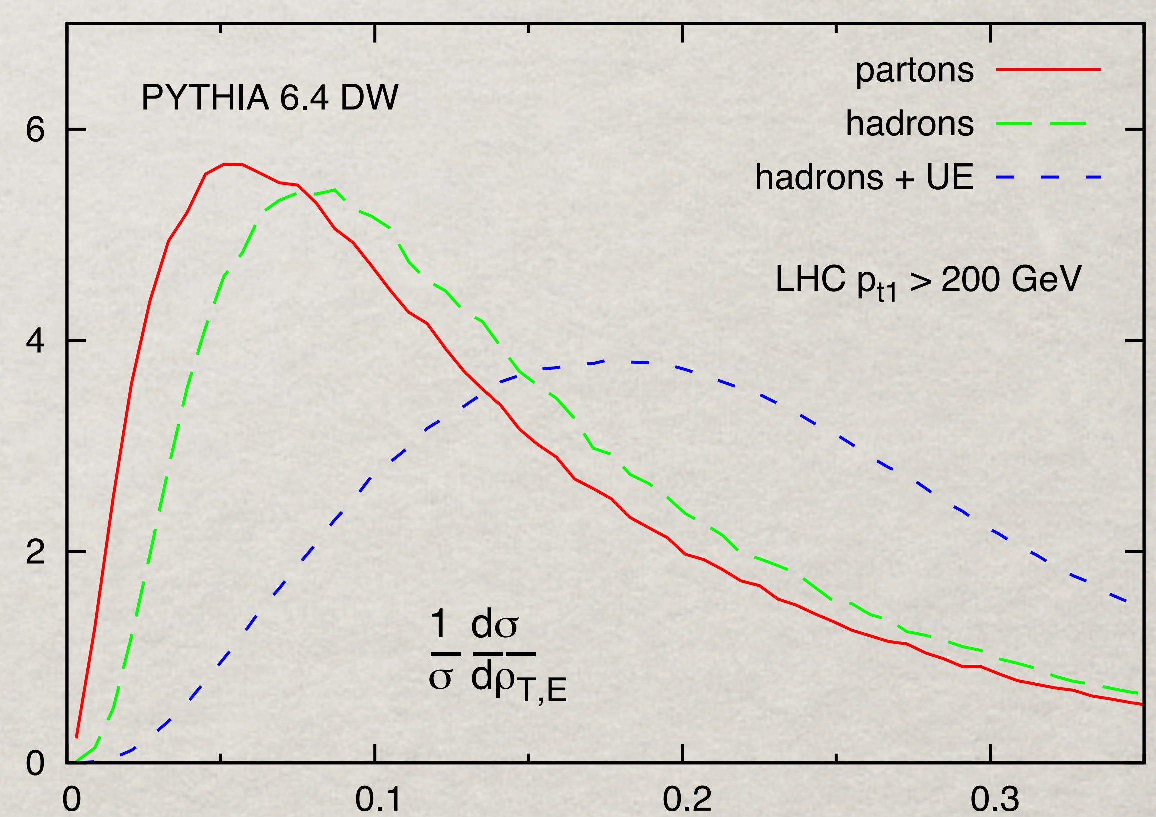
Sensitivity to NP effects

Three-jet fractions are hardly affected by hadronisation and underlying event



- PT predictions can be directly compared to data
- Suitable for tunings of parton shower parameters

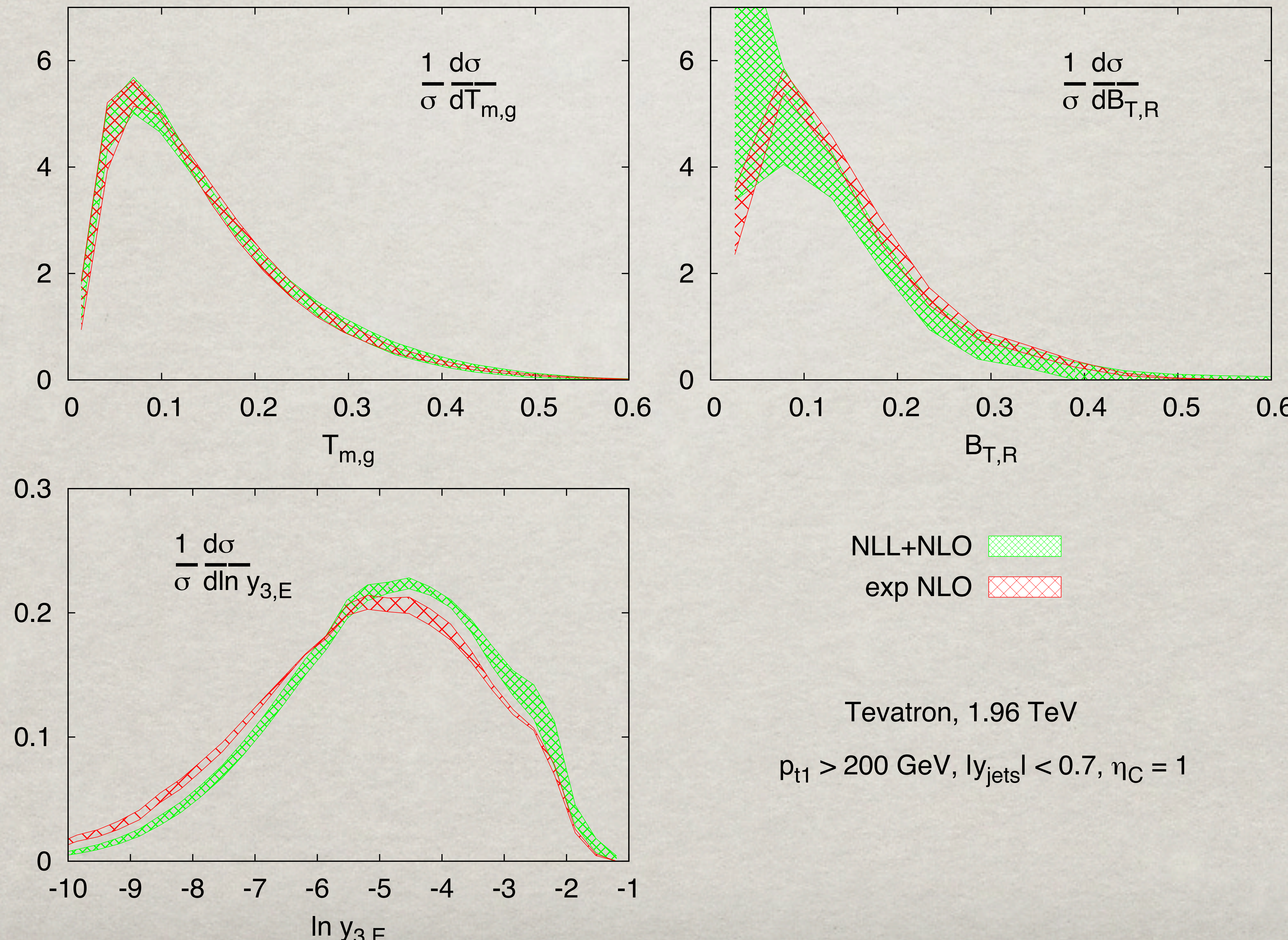
Event-shape distributions are heavily distorted by NP effects (hadronisation + UE)



- Comparison to parton level MC for parton shower tests
- Suitable for tests and tunings of models for UE

An alternative to MC: ExpNLO

It is possible to mimic resummation effects by suitably exponentiating NLO event-shape distributions



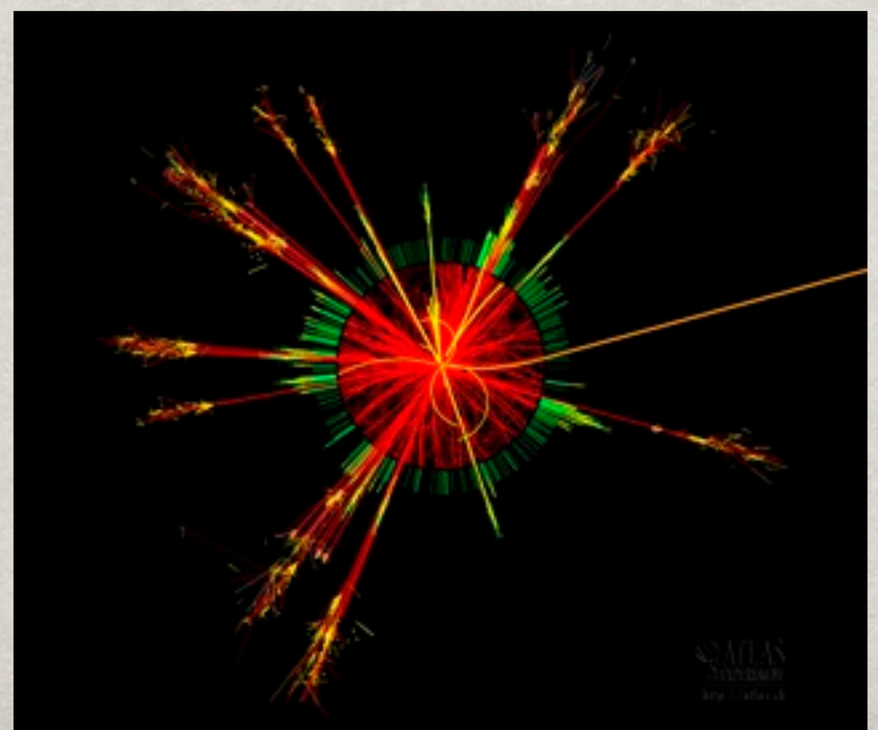
Shape variables and New Physics

Inclusive searches $p_t \lesssim M$

$\Downarrow$

global and central event shapes

- upper bound on a global event shape as a jet-veto condition
- lower bound on a central event shape to select spherical events

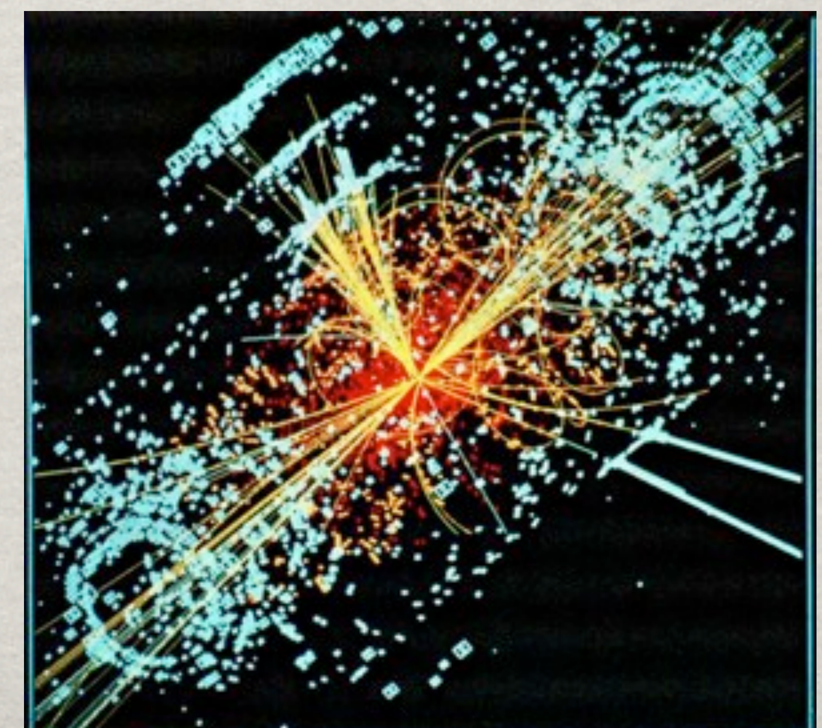


Boosted objects $p_t \gg M$

$\Downarrow$

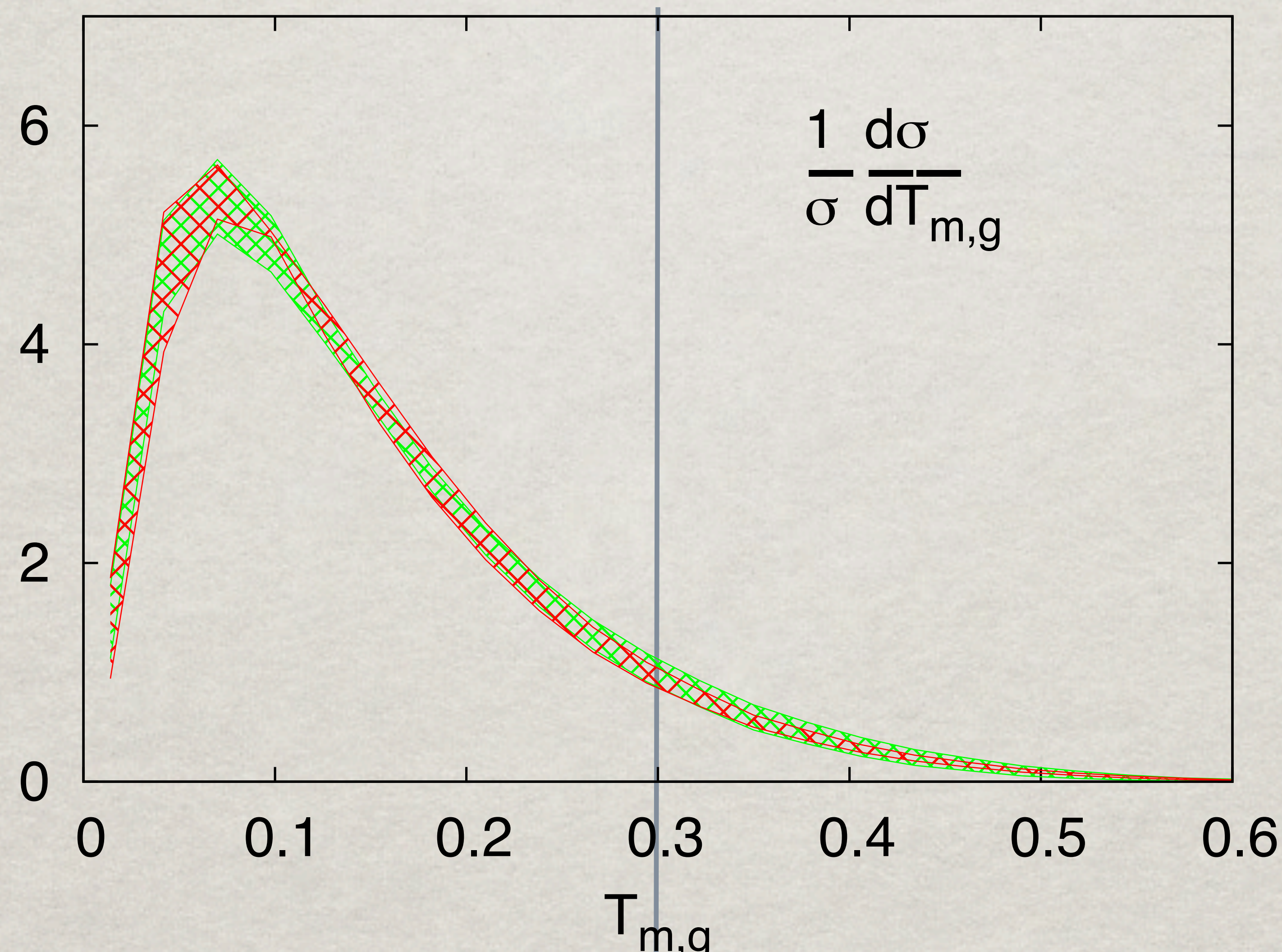
non-global jet shapes

- select a window in the invariant mass of a jet $\Leftrightarrow$ jet mass distribution
- jet substructure $\Leftrightarrow$ event shape inside a fat jet
- veto on an extra jet



Event shapes for New Physics

Event shapes (global or non-global) are properties of the whole event $\Rightarrow$ useful for inclusive searches



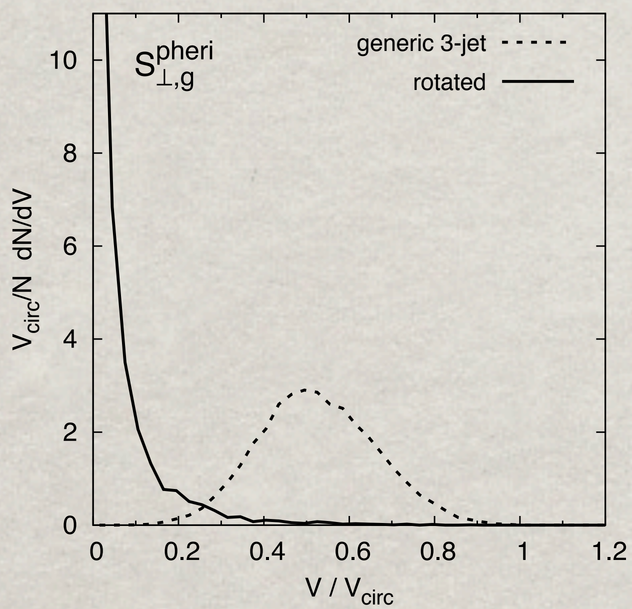
dijet events $\Downarrow$ veto on an extra jet ← | → multi-jet & spherical events $\Downarrow$ SUSY, black holes, etc.

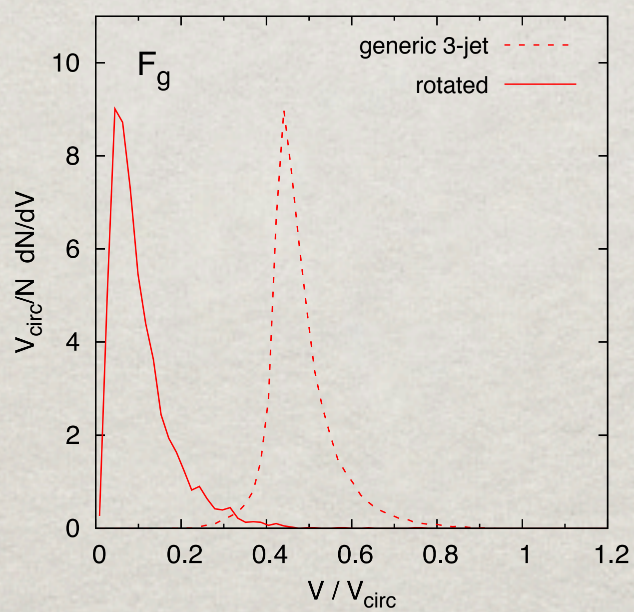
Cuts on event shapes are to be combined with signal-specific cuts

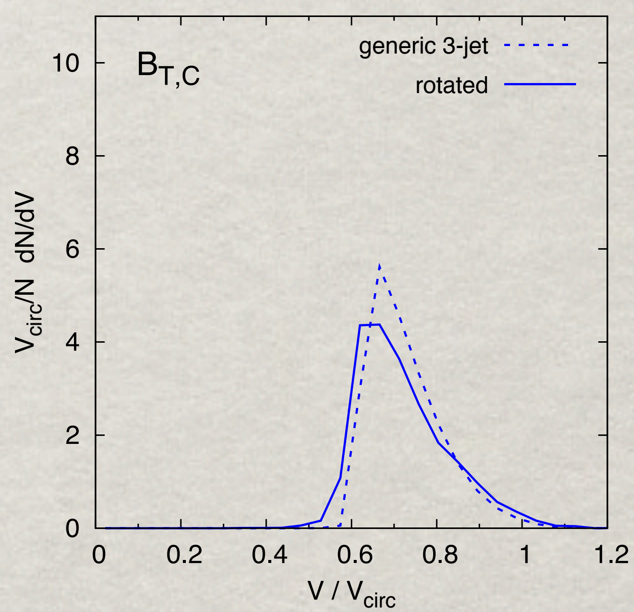
Selection of spherical events

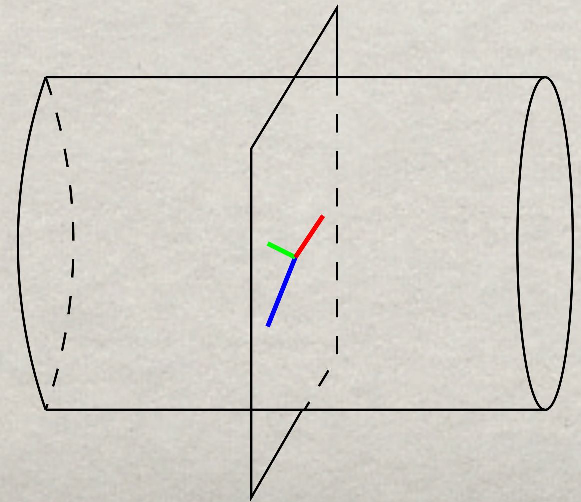
We have already event shapes that can be used in multivariate analyses for inclusive searches

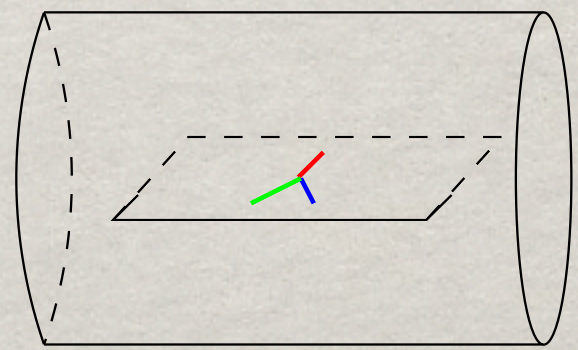
- Robust under multiple QCD emissions
- Insensitive to rotations of event plane









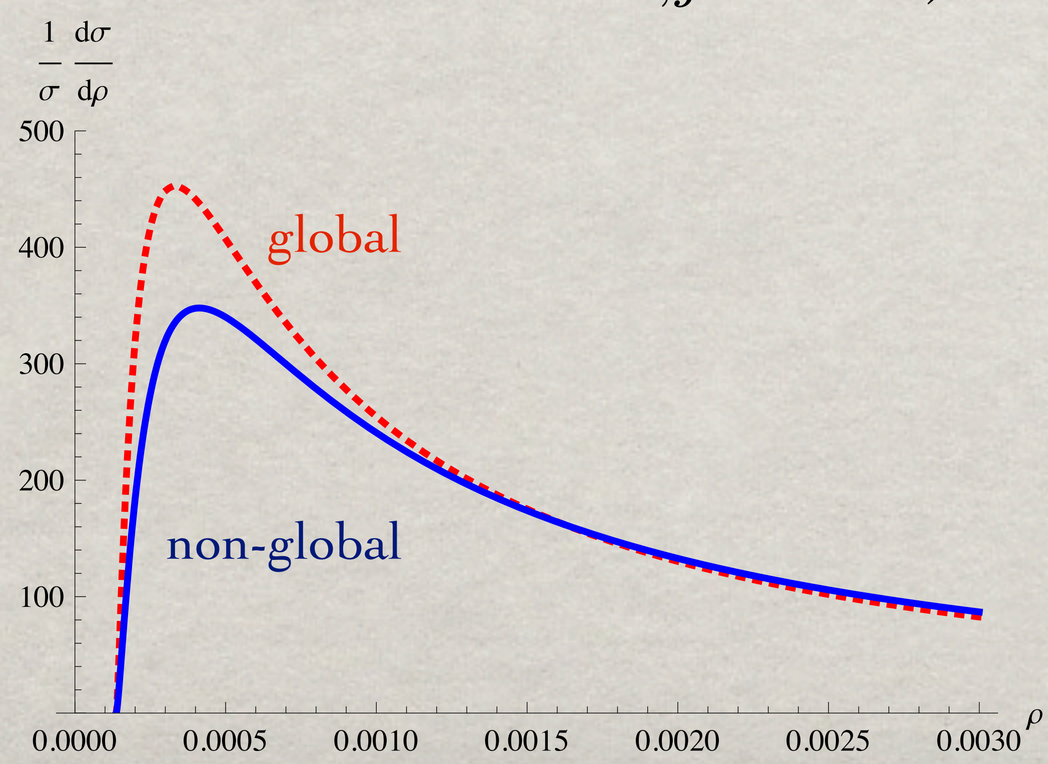


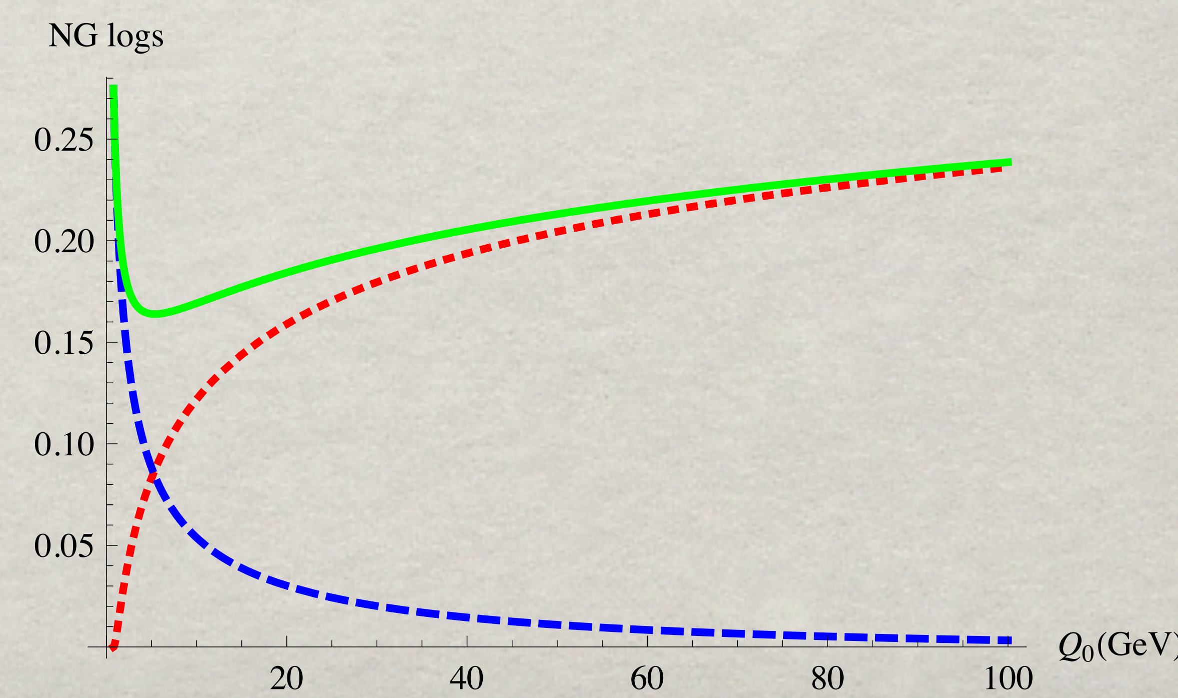
The invariant mass of narrow jets

Single-jet mass is a non-global observable $\Rightarrow$ new NLL contributions, namely non-global and clustering logs

[AB Dasgupta Khelifa-Kerfa Marzani '10]

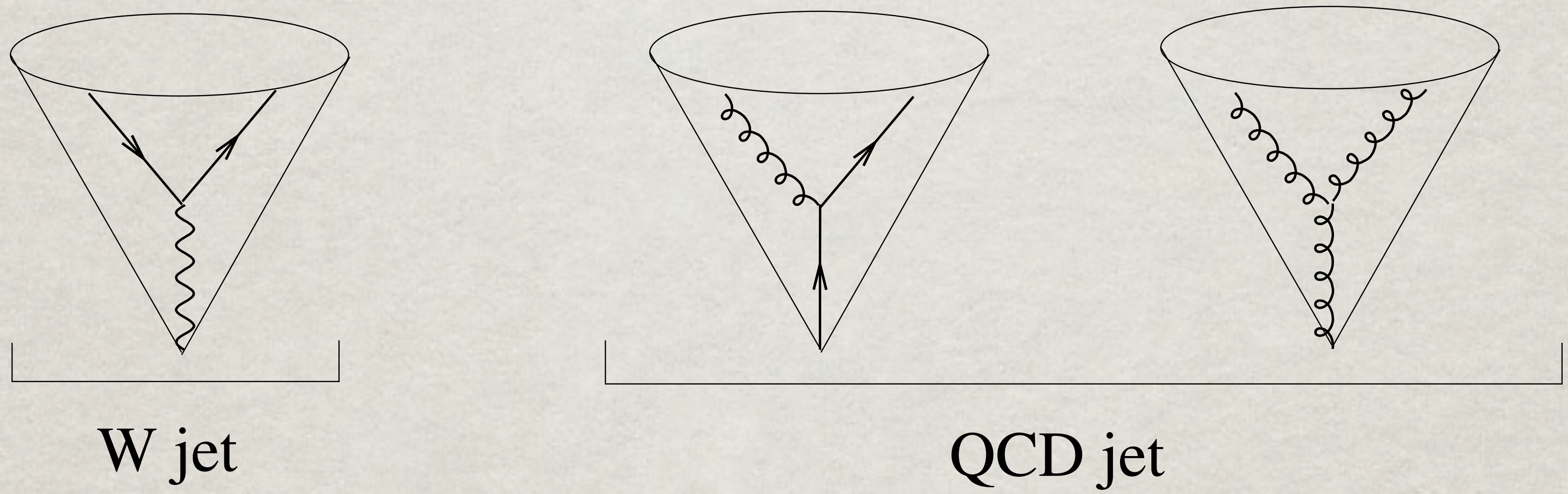
- Clustering logarithms are absent for anti-k_t jets
- For widely separated jets non-global logs arise from the boundary of the observed jet $\Rightarrow$ universality
- Non-global logs cannot be eliminated by introducing an extra-jet veto condition (e.g. requiring exclusive N-jet events with $p_{t,j} > Q_0$)





Event shapes inside a fat jet

Basic question: difference between a QCD jet and one containing the decay products of a boosted heavy object



- Use event shapes inside the fat jet to probe the colour charge of the constituent subjets
- CAESAR can automatically predict the position of the peaks of event shape distributions
- If needed, matching should require 4jets@NLO!

NB: only CAESAR can give analytical answers for jet resolution parameters!

Conclusions

Event shapes in dijet events provide valuable tests of our knowledge of QCD dynamics at the LHC

- Test and inspiration for new parton shower algorithms
- Jet rates can be directly compared to LHC data

The use of event shapes for New Physics searches requires some extensions of the CAESAR framework

- Arbitrary multi-jet process (including New Physics)
- Non-global observables (jet masses, jet shapes)

We are working on the release of a public version of CAESAR, so please stay tuned ...

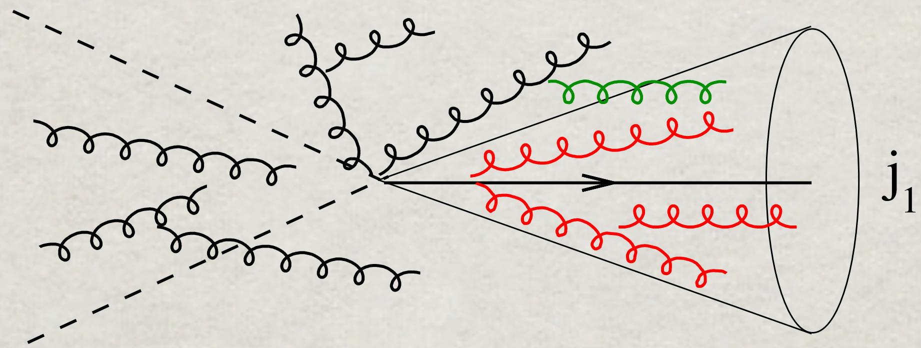
Backup slides

NLL effects on high-pt jet mass

Single-jet mass is a non-global observable ⇒ new NLL contributions appear, non-global and clustering logs

- Non-global logarithms: partons outside the jet coherently emitting a softer parton inside

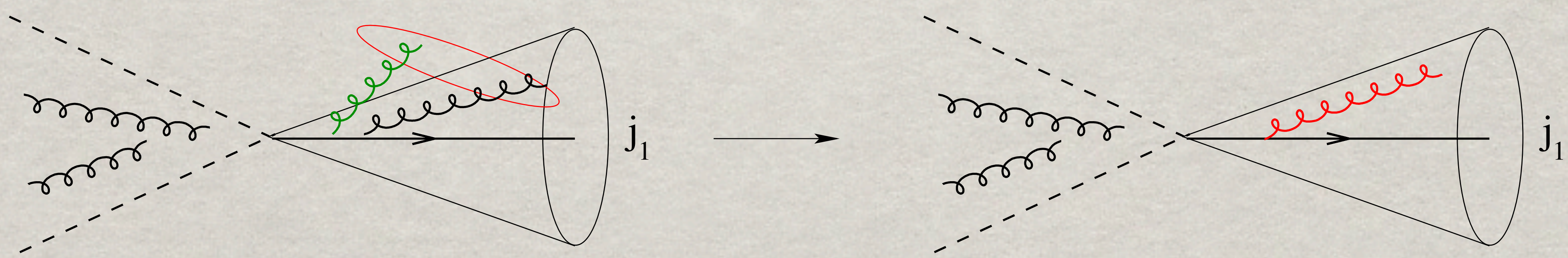
[Dasgupta Salam '01]



Considerably reduced for jet-clustering algorithms (k_t, CA)

[Appleby Seymour '02]

- Clustering logarithms: a softer parton independently emitted outside the jet is recombined with the jet [AB Dasgupta '05]



Absent for anti-kt algorithm, but non-global logs maximised