Phenomenology of event shapes at hadron colliders

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Work done in collaboration with
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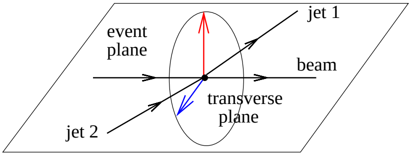
Event shapes in hadron-hadron collisions

Event shapes explore the geometry of hadronic energy-momentum flow (i.e. if hadronic events are planar, spherical, etc.)

- Two examples: transverse thrust and thrust minor

Transverse thrust

Thrust minor



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

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

- Event shapes can involve also longitudinal momenta, e.g. total and heavy-jet mass ρ_T, ρ_H, total and wide-jet broadening B_T, B_W, three-jet resolution parameter y_{23}

- All event shapes we consider vanish in the two-jet limit

Feasibility of event shapes measurements

Event shapes can be measured with very first data

- High-statistics event selection: two central jets ($|\eta_{\rm jets}| < 0.7$ at the Tevatron and $|\eta_{\rm jets}| < 1$ at the LHC) with $p_{t1} > p_{t,\rm min}$

	LO	NLO	$qq \to qq$	$qg \to qg$	$gg \to gg$
Tevatron, $p_{t1} > 50\mathrm{GeV}$	$60\mathrm{nb}$	$116\mathrm{nb}$	10%	43%	45%
Tevatron, $p_{t1} > 200\mathrm{GeV}$	$59\mathrm{pb}$	$101\mathrm{pb}$	41%	43%	12%
$14\mathrm{TeV}$ LHC, $p_{t1} > 200\mathrm{GeV}$	$13.3\mathrm{nb}$	$23.8\mathrm{nb}$	7%	40%	50%
$14\mathrm{TeV}$ LHC, $p_{t1} > 1\mathrm{TeV}$	$6.4\mathrm{pb}$	$10.5\mathrm{pb}$	31%	51%	17%

- Normalisation of event shapes gives a reduced sensitivity to detector calibration effects

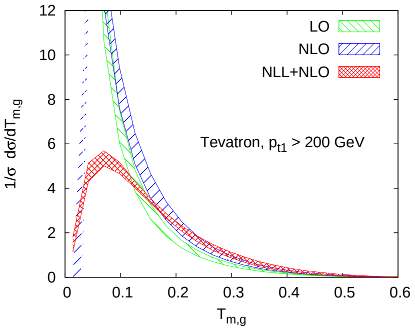
$$T_t \equiv \max_{\vec{n}_t} \frac{\sum_i |\vec{q}_{ti} \cdot \vec{n}_t|}{\sum_i q_{ti}} \qquad T_m \equiv \frac{\sum_i |\vec{q}_{ti} \times \vec{n}_t|}{\sum_i q_{ti}}$$

- Measure event-shape fractions $\Rightarrow$ no need to measure luminosity

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

Comparison of resummation and fixed order

- Fixed order predictions ($\alpha_s + \alpha_s^2$) diverge at small T_m
  [Nagy PRD **68** (2003) 094002]
- Resummation of large logarithms $\exp\{\alpha_s^n \ln^{n+1} T_m + \alpha_s^n \ln^n T_m\}$ (NLL) restores correct physical behaviour for $T_m \to 0$
  [AB Salam Zanderighi arXiv:1001.4082]

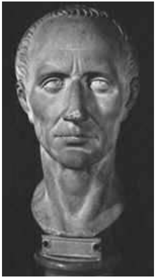


Monte Carlo event generators do resum large logarithms but with poor control over theoretical accuracy ⇒ NLL resummation needed

Computer automated resummation: CAESAR

General NLL resummation for any suitable event shape is possible with the Computer Automated Expert Semi-Analytical Resummer

[AB Salam Zanderighi JHEP **0503** (2005) 073, qcd-caesar.org]



Given a computer subroutine that computes $V(k_1, \ldots, k_n)$, CAESAR

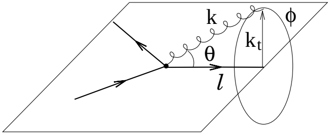
1. checks whether V is resummable within NLL accuracy
2. performs the NLL resummation using a general master formula

Conditions for NLL resummation

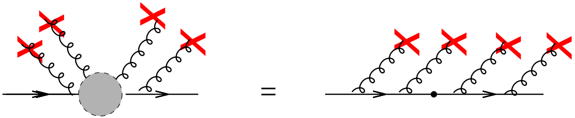
An event shape $V(k_1, \ldots, k_n)$ is resummable at NLL accuracy if

1. $V(k)$ has a specific functional dependence on a single soft and emission k collinear to a leg ℓ

$$V(k) = \left(\frac{k_t}{Q}\right)^{a_\ell} e^{-b_\ell \eta} g_\ell(\phi)$$



2. it is (continuously) global, i.e. it is sensitive to soft/collinear emissions in the whole of the phase space
3. it is recursively IRC safe, i.e. it has good scaling properties with respect to multiple emissions

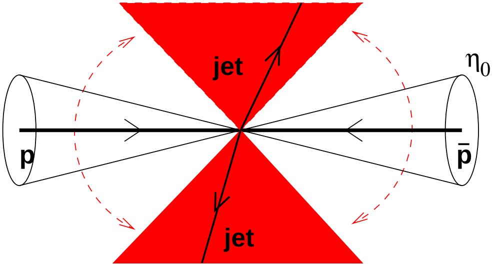


Globalness + rIRC safety + QCD coherence ⇒ angular ordered parton branching accounts for all LL and NLL contributions

Experimental setup and globalness

Experimental setup can lead to non-global observables

- Observed hadrons are usually charged particles in the central tracker region, at the LHC central region is $|\eta| < 2.5$
- Outside the central region no measurements possible in the beam pipe, at the LHC $|\eta| \gtrsim 5$

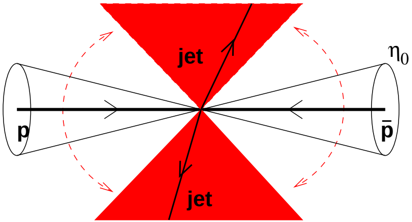


Are there any hadron-hadron event shapes that can be resummed within NLL accuracy?

Three classes of global event shapes

- Directly global: measure all hadrons up to the maximum available rapidity η_0
- Exponentially suppressed: define event shape in central region $\mathcal{C}$ and add exponentially suppressed forward term $\mathcal{E}_{\bar{\mathcal{C}}}$
- Recoil: define event shape in central region and add recoil term

$$\mathcal{E}_{\bar{\mathcal{C}}} \sim \sum_{i \notin \mathcal{C}} q_{ti}\, e^{-|\eta_i - \eta_{\mathcal{C}}|} \qquad \mathcal{R}_{t,\mathcal{C}} \sim \left| \sum_{i \in \mathcal{C}} \vec{q}_{ti} \right| = \left| \sum_{i \notin \mathcal{C}} \vec{q}_{ti} \right|$$

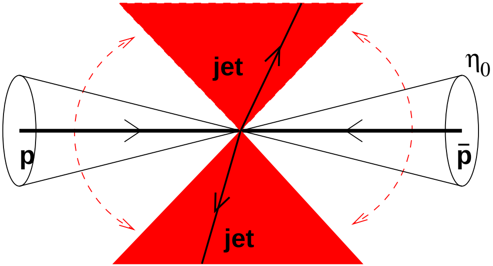


NLL resummation is valid for not too small event-shape values severe breakdown (divergence) only for recoil event shapes

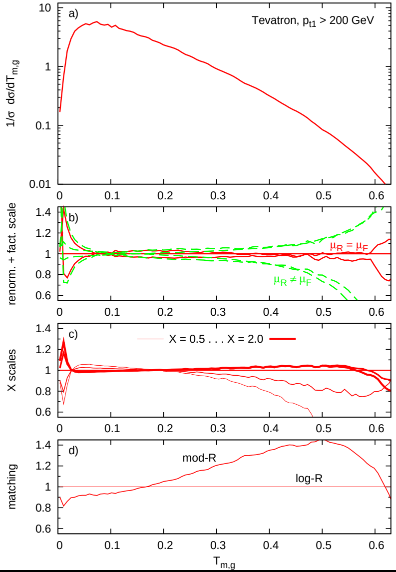
Particles vs. jets as inputs

Event shapes preferably measured with jets rather than hadrons $\Rightarrow$ two problems with globalness

1. Potential insensitivity to emissions clustered in the same jet $\Rightarrow$ use as inputs topoclusters/particle flows inside central jets + all remaining jets
2. Cutoff p_{t0} to eliminate contamination from UE $\Rightarrow$ NLL resummation sensible for $v \gg (p_{t0}/Q)^a$



Theoretical uncertainties are under control and within 20%



- Asymmetric variation of μ_R and μ_F around $p_t = (p_{t1} + p_{t2})/2$

$$p_t/2 \leq \mu_R \leq 2p_t$$

$$\mu_R/2 \leq \mu_F \leq 2\mu_R$$

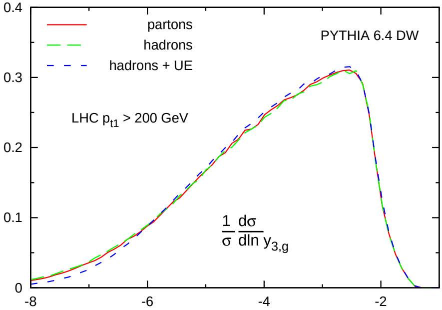
- Rescaling of the argument of the logs to estimate NNLL corrections

$$\ln T_m \to \ln(XT_m) \qquad 1/2 \leq X \leq 2$$

- Change the procedure to match NLL resummation with NLO, so as to estimate NNLO contributions

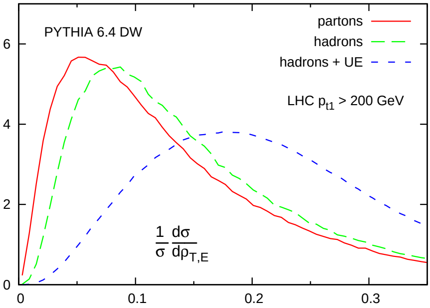
Sensitivity to hadronisation and underlying event

Three-jet fractions are hardly affected by hadronisation and UE



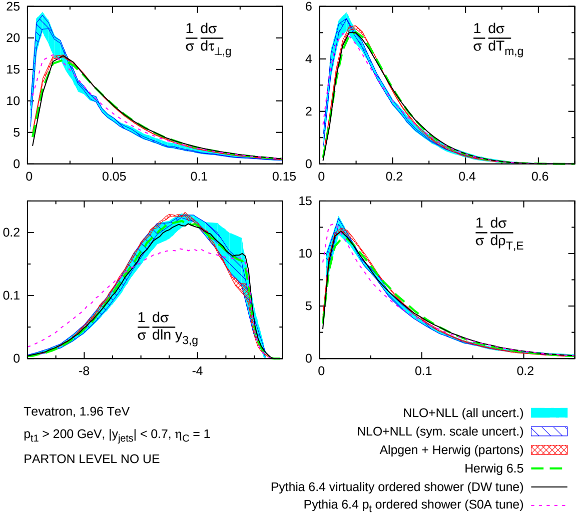
- PT predictions directly compared to data ⇒ measure α_s?
- Suitable for tunings of parton shower parameters

Event-shape distributions get large corrections from UE



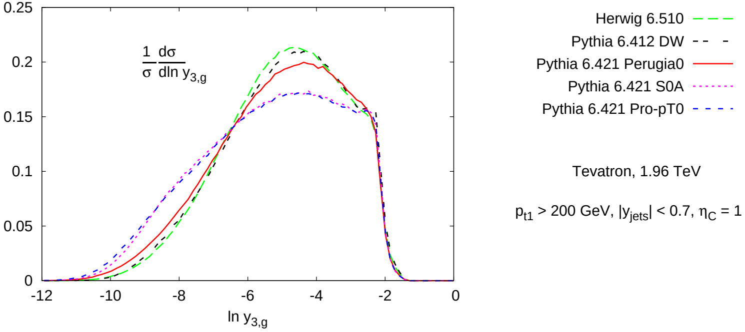
- Comparison to parton level MC for tests of parton shower
- Suitable for tests and tunings of UE models

Comparison with parton showers: Tevatron high-p_t sample



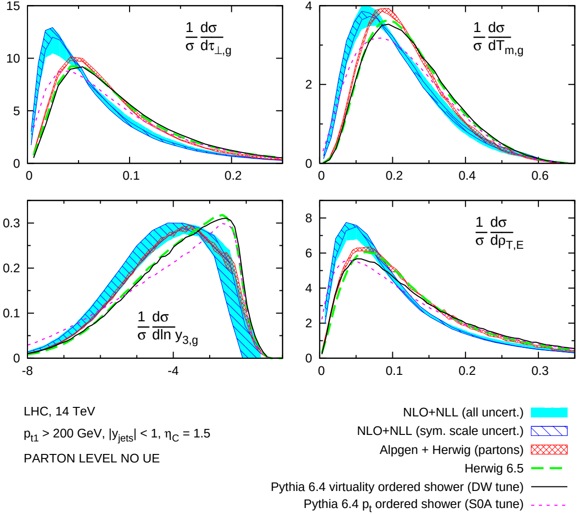
Agreement between NLL and parton level MC is good for quark-dominated samples

Sensitivity to parton shower parameters



- Herwig (angular-ordered) and Pythia DW (mass-ordered) agree with Alpgen+Herwig, but not with p_t-ordered Pythia (S0A tune)
- Sensitivity to different tunes of p_t-ordered Pythia shower

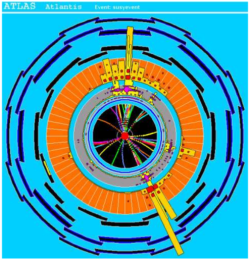
Comparison with parton showers: LHC low-p_t sample



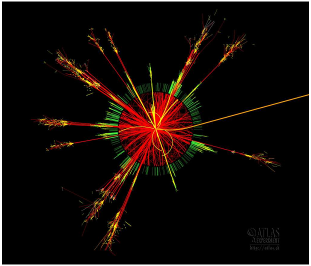
Sizeable differences in gluon dominated samples $\Rightarrow$ new tests of initial state gluon branching?

Event shapes for new physics

- New physics events are generally broader than dijet events $\Rightarrow$ Use event shapes to discriminate among different topologies?
- Event shapes discriminate between two- and multi-jet events
- IRC safe event shapes give better resolution in discriminating among different topologies in a given n-jet sample



SUSY multi-jet event



Black hole production

Event shapes for new physics

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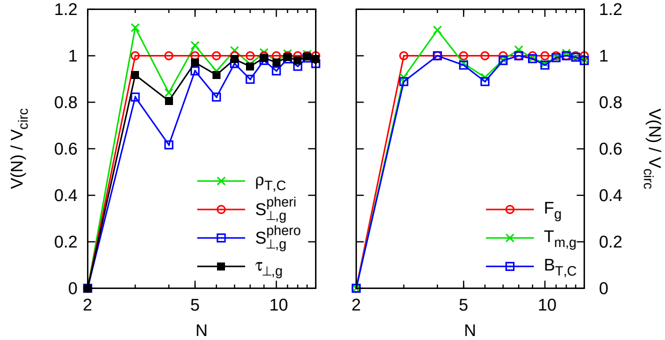

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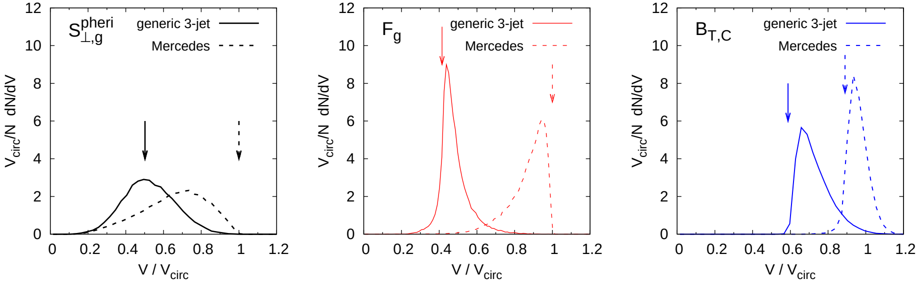

Conclusions

Phenomenology of event shapes at hadron colliders is extremely rich

- First ever NLL+NLO predictions with full theoretical uncertainties
- Event shapes are very useful for tuning of MC shower and UE

There are many more issues on event shapes, including

- a trick to extend range of validity of NLO predictions without computing the resummation
- new variable supersphero with increased sensitivity to the spherical limit

Important research direction

- Better event shapes for New Physics searches

Preliminary measurements have been performed at the Tevatron and will be performed at the LHC

We are ready for many years of Physics. . .