Jet pair production with POWHEG

Emanuele Re*

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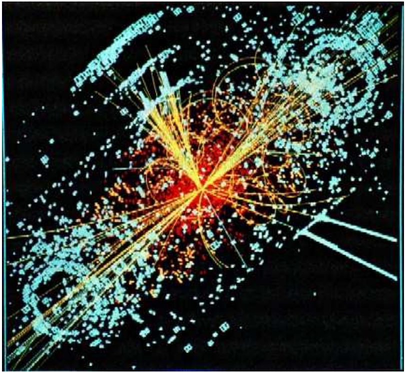
[JHEP 1104:081,2011]

Outline

- Introduction
- Jet pair production in `POWHEG`
- Results and comparison with data
- Recent developments and outlook



Introduction to POWHEG

- tools traditionally used at hadron colliders:

parton-level calculations (NLO)

- NLO accuracy: reduced scale dependence
- good description of high-p_{T} tails

$\Rightarrow$ want more: NNLO

Shower Monte Carlo (SMC)

- resummation of soft/collinear logarithms
- full simulation at the hadron level

$\Rightarrow$ multileg matching: (CKKW/MLM)

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- need accurate predictions (signal & backgrounds) $\Rightarrow$ natural to combine the 2 approaches.

- POWHEG [Nason 2004] is a method to achieve this goal consistently.

$$d\sigma_{\mathrm{POW}} = \bar{B}(\Phi_n)\, d\Phi_n \left\{ \Delta(\Phi_n; k_{\mathrm{T}}^{\mathrm{min}}) + \Delta(\Phi_n; k_{\mathrm{T}}) \frac{R(\Phi_n, \Phi_r)}{B(\Phi_n)} d\Phi_r \right\}$$

$$\bar{B}(\Phi_n) = B(\Phi_n) + V(\Phi_n) + \int R(\Phi_{n+1})\, d\Phi_r$$

$$\Delta(\Phi_n; k_{\mathrm{T}}) = \exp\left\{ - \int_{k_{\mathrm{T}}} \frac{R(\Phi_n, \Phi_r')}{B(\Phi_n)}\, d\Phi_r' \right\}$$

and to avoid double-counting the subsequent emissions are p_{T}-*vetoed*.

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- Accuracy: inclusive observables @NLO, first hard emission with full tree level ME, (N)LL resummation of collinear/soft logs, extra jets in the shower approximation.
- alternative to MC@NLO, with some advantages:
  - events are positive weighted (where the acronym originates from).
  - “independent” from the parton-shower algorithm used.

The POWHEG BOX framework

- Although it may look easy, the actual implementation of the algorithm is not straightforward. [Frixione,Nason,Oleari, JHEP 0711:070,2007]
- Our automation of the algorithm led to the POWHEG BOX package, which has been available for more than 1 year now.
- General features:
  - automation of the POWHEG algorithm using the FKS subtraction scheme.
  - all previous implementations and new ones included in a single and public framework:

    $V, H(gg$ fusion and VBF$), Q\bar{Q},$ single-top $(s, t, Wt), ZZ, V+j, jj, WWjj, Wb\bar{b}, Q\bar{Q}j$

  - it produces LHE files, ready to be showered through HERWIG or PYTHIA.
  - once needed ingredients are provided, it can be used as a "black-box", although all the details were carefully described.

[Alioli,Nason,Oleari,ER, JHEP 1006:043,2010]

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- Other features:
  - we want to keep as much as possible the original goal of independence from the parton-shower. If needed, will try to refine the interface.
  - until now effects of neglecting truncated-shower (when HERWIG is used) were found to be negligible. If needed, this is a point where there is space for improvements.
  - we will continue keeping our code completely available for interested theorists, and if you implement your process, we would be happy to include it in the repository.

http://powhegbox.mib.infn.it

Jet pair production with POWHEG

- Dijet production is by far the most frequent hard scattering in hadronic collisions.
- from the technical point of view, it is up to now the more complicated process implemented in POWHEG.
  This means also a serious test for the POWHEG BOX program.
- All ingredients have been known since the late 80's: [Ellis, Sexton], [Kunszt, Soper]
  - $2 \to 2$ and $2 \to 3$ tree-level amplitudes
  - virtual corrections
  - color-linked amplitudes
  - $2 \to 2$ amplitudes in the planar limit needed, to assign color structure

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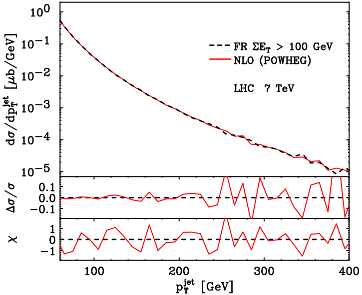
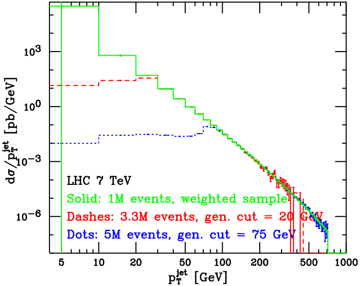
- checked NLO with Frixione-Ridolfi code + study of generation cut + weighted generation:

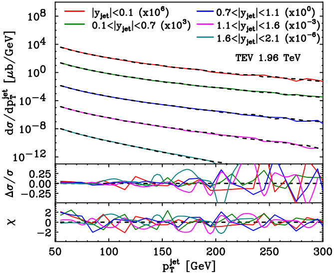




$\Rightarrow$ D0 midpoint, $R = 0.7$, $f = 0.5$

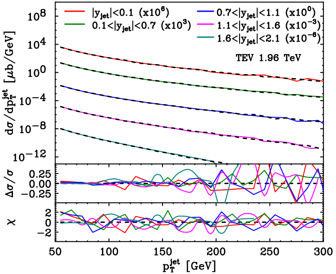
$\Rightarrow$ weighted generation using $\left(\frac{k_T^2}{k_T^2 + k_{T,\mathrm{s}}^2}\right)^3$

Jet pair production with POWHEG



$\Leftarrow$ POWHEG = first emission (colored line)

- inclusive k_T spectrum
- expected agreement between NLO and POWHEG but ...



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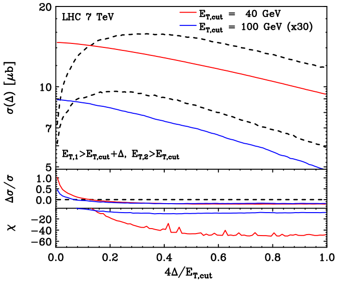
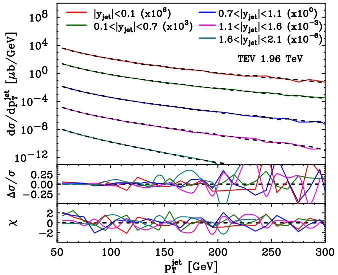


$\sigma(\Delta)$, with $E_{T,2} > E_{T,cut}$ $E_{T,1} > E_{T,cut} + \Delta$

- we expect $\sigma'(\Delta) = d\sigma/d\Delta < 0$
- NLO curve alone is “wrong”: peak and suppression at low Δ
  $\Rightarrow$ unbalanced cancellation of soft-collinear emissions close to the cut.
  [Frixione,Ridolfi], [Banfi,Dasgupta]
- Resummation performed by the shower works well (here POWHEG first emission).

Jet pair production with POWHEG



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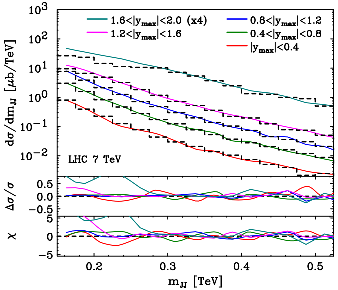
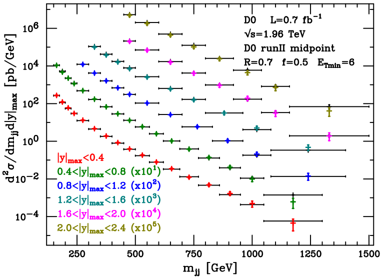


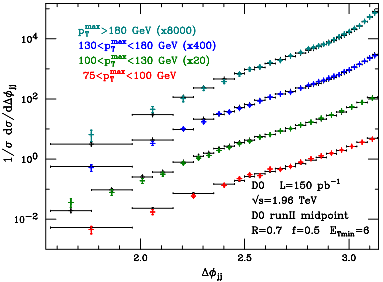
$\Leftarrow \quad |y| = \max(|y_1|, |y_2|)$

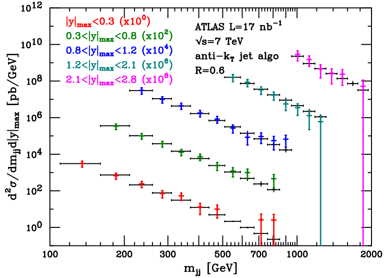
- dijet mass
- for $E_{T,cut} = 40$ GeV:

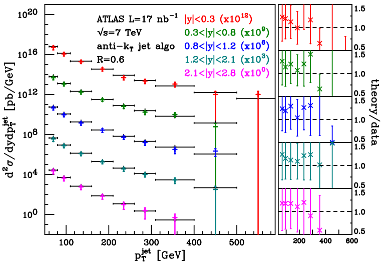
$$y \sim 1.8 \quad \Rightarrow \quad m_{jj} \sim 250 \text{ GeV}$$
$$y \sim 1.4 \quad \Rightarrow \quad m_{jj} \sim 170 \text{ GeV}$$

Comparison with Tevatron and LHC data







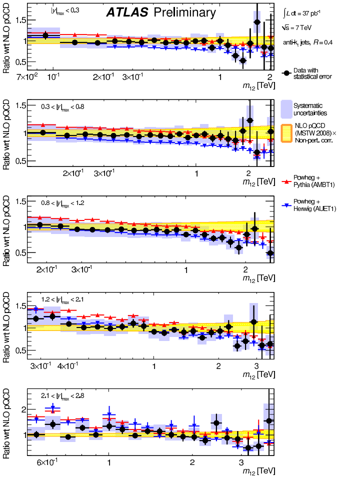


black: POWHEG+PYTHIA, Perugia tune

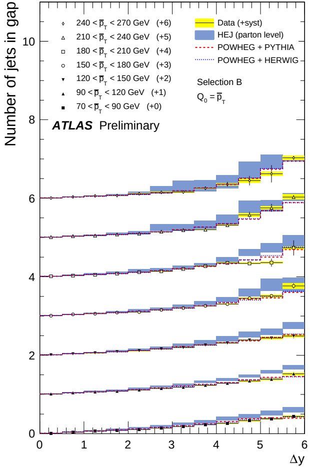
experimental cuts + direct comparison with data

Studies by ATLAS and CMS

Program already used in ATLAS-CONF-2011-038,-047,-056,-057 CMS-PAS-FWD-10-003,-006



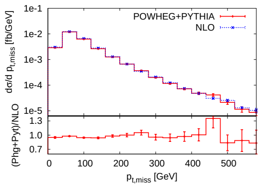
- dijet invariant mass, $R = 0.4$
- cuts: $p_T^{j1} > 30$ GeV, $p_T^{j2} > 20$ GeV, $|y^j| < 4.4$
- observed disagreement, especially when $R = 0.6$

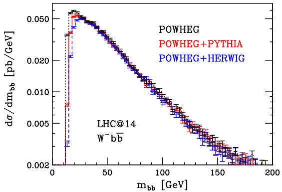


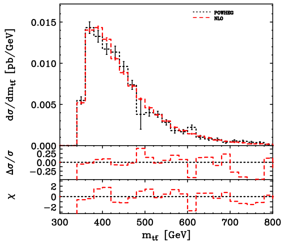
- cuts: $p_T^j > 20$ GeV, $|y^j| < 4.5$
- gap region = 2 highest-y jets, with $\bar{p}_T > 50$ GeV
- gap events $=$ no jets harder than Q_0 within the gap (here $Q_0 = \bar{p}_T$)

Conclusions and outlook

- Many $2 \rightarrow 2$ SM processes are available within the POWHEG BOX package.
- Together with other POWHEG implementations (in HERWIG++ and SHERPA) and with MC@NLO it is already possible to simulate almost all $2 \rightarrow 2$ SM processes with NLO+PS accuracy.
- $2 \rightarrow 3$ implementations are work in progress, and a $2 \rightarrow 4$ implementation was already possible.







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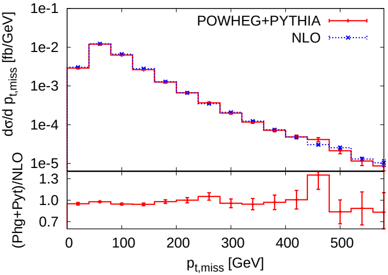
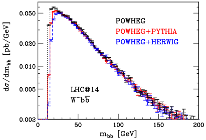
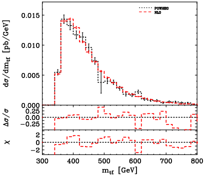


W^+W^+jj

[Melia,Nason,Rontsch,Zanderighi, arXiv:1102.4846]





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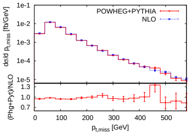

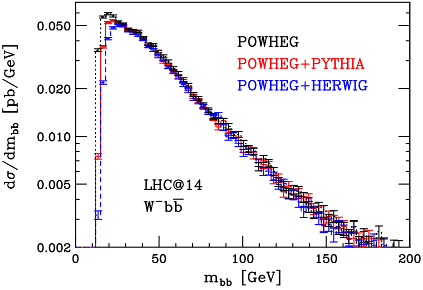

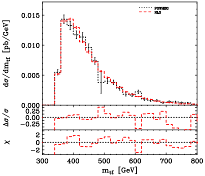

$Wb\bar{b}$

[Oleari,Reina, PRELIMINARY]

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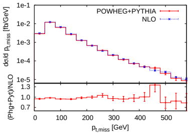

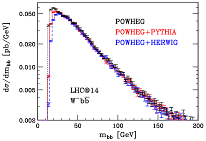

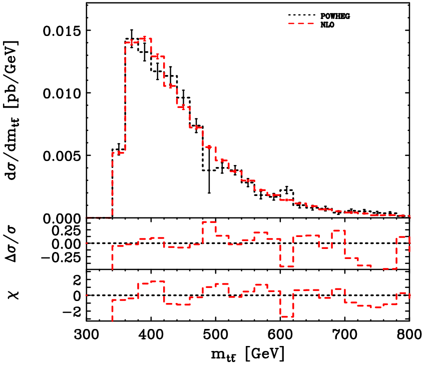

$Q\bar{Q}j$

[Kardos, Papadopoulos, Trocsanyi, arXiv:1101.2672]

[Alioli,Moch,Uwer, PRELIMINARY]

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- Understand the origin of the disagreement with ATLAS dijets data is work in progress.
- In general, the validation of the code will be demanding for more complicated processes:

  $\Rightarrow$ code running properly $\neq$ implementation fully understood
  $\Rightarrow$ this could be especially relevant for processes with multijets

Outlooks:

- Many interesting processes yet to be implemented (V+multijets, heavy flavours with jets, exact mass effects in Higgs gluon fusion, BSM).

  $\Rightarrow$ use them to do some phenomenology
  $\Rightarrow$ allow experimentalists to have accurate tools
- Interfacing to modern codes for virtual corrections.
- Further studies and improvements are possible, for example MENLOPS

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