Recent developments and results with POWHEG-BOX

Emanuele Re
IPPP, Durham University

MCnet meeting

Cambridge, 23 September 2010

The POWHEG method

- POWHEG is a method to merge NLO calculations with Parton Showers:

NLO
- ✓ reduced scale dependence
- ✓ better description of high-p_T tails

PS
- ✓ Sudakov suppression in collinear regions
- ✓ parton → hadron corrections not needed

- It works generating the hardest-radiation according to:

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

where

$$\bar{B}(\Phi_n) = B(\Phi_n) + V(\Phi_n) + \int \left[R(\Phi_{n+1}) - C(\Phi_{n+1}) \right] d\Phi_r$$

$$\Delta(\Phi_n; k_T) = \exp\left\{ - \int \frac{R(\Phi_n, \Phi_r')}{B(\Phi_n)} \theta(k_T' - k_T)\, d\Phi_r' \right\}$$

and by *p_T-vetoing subsequent emissions*, to avoid double-counting.

- Accuracy: inclusive observables @NLO, first hard emission with full tree level ME, LL resummation of collinear/soft logs, extra jets in the shower approximation.
- Formally it has the same accuracy of MC@NLO. Main differences:
  - ✓ Events are positive weighted.
  - ✓ It does not depend from the parton-shower algorithm used.
- when used with angular-ordered PS, a truncated shower should be included too.

Automation: the POWHEG-BOX framework

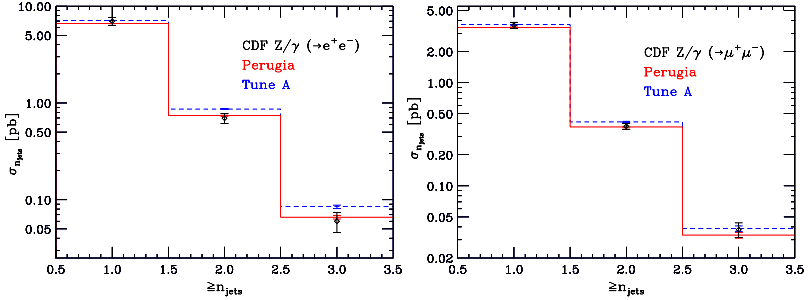
- Although it may look easy, the actual implementation of the algorithm is not straightforward.
- Until now processes (for hadron colliders) have been implemented:
  - as standalone codes: several SM $2 \to 2$ processes [Nason et al.]
  - within HERWIG++ (also with truncated shower): DY, V', $gg \to H$, HV, VV (+ others almost finished) [Hamilton, Richardson et al.]
  - very recently also within SHERPA [Krauss et al.]
- From February, the POWHEG-BOX package is available. Features:
  - automation of the POWHEG algorithm using the FKS subtraction scheme.
  - to include new processes, the needed inputs are:

    $$d\Phi_n, \ B, \ V, \ R, \ B_{jk}, \ B^{\mu\nu}$$

    and the list of partonic subprocesses.
    - They are typical inputs of a NLO calculation.
    - Almost all can be obtained with other programs, like MadGraph.
    - It is likely that the standard way to include V will be the Binoth-LesHouches procedure.
  - all previous implementations included in a single and already public framework, namely W, Z, heavy flavours, H via gluon and vector boson fusion, single-top (s-, t- and Wt-channel).
  - it produces LHE files, ready to be showered.
  - structure: main directory + process folders.
  - it was originally built to implement V+j !

[Alioli,Nason,Oleari,ER, in preparation]

- Samples of $\sim$ 1.3 million of positive weighted events.
- Direct comparison with CDF data (PRL 100:102001 (2008) - blessed data from CDF-QCD webpage): no K-factors, no parton-to-hadron corrections (not needed).
- Showered with `PYTHIA 6.4.21`, with Perugia 0 ($p_{\rm T}$-ordered) and Tune A (Q^2-ordered).

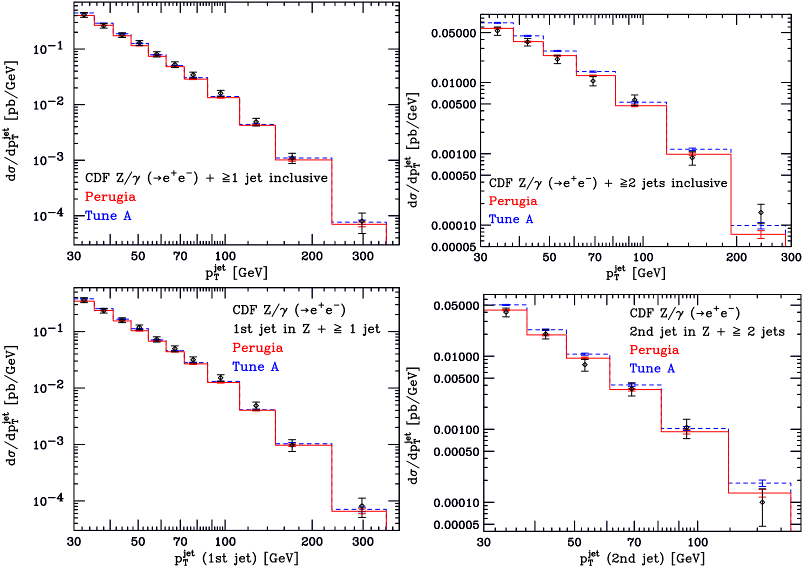


Comments:

- very good agreement.
- tune effect sizeable (and $p_{\rm T}$-ordering gives better results).

Results for Z+jets: comparison with CDF data

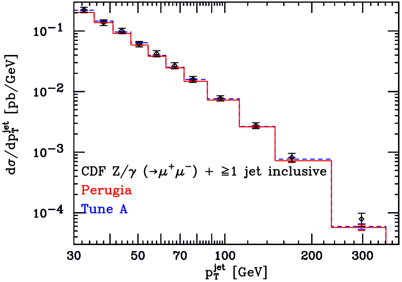
Upper panel: PRL (1.7 fb^{-1}). Lower panel: blessed data from CDF webpage (2.5 fb^{-1}).

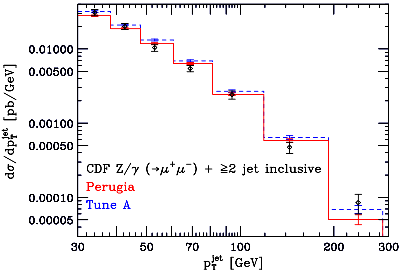


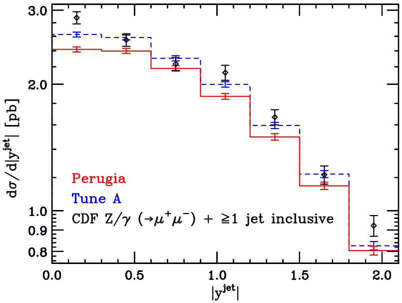
- 1st jet has full NLO+PS accuracy, 2nd jet has tree-level full ME accuracy.

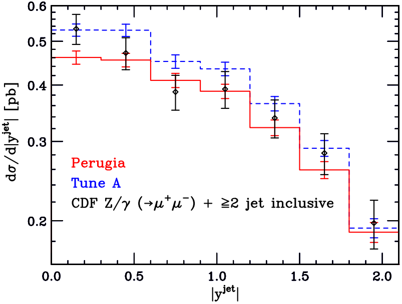
Results for Z+jets: comparison with CDF data

Blessed plots from CDF webpage (2.37 fb^{-1}).



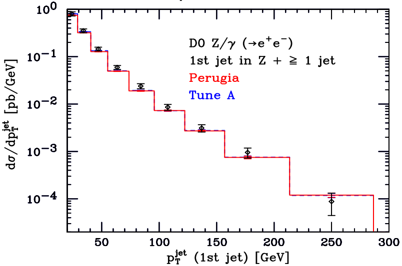


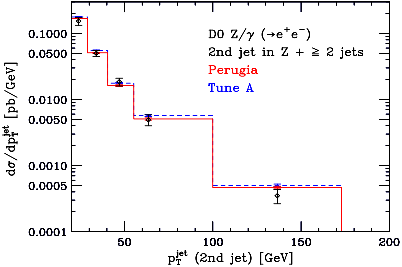




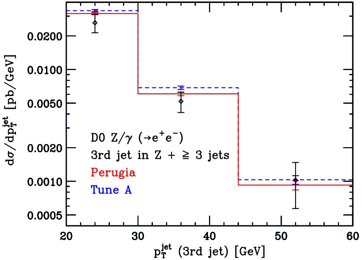
Results for Z+jets: comparison with D0 data

- Samples of $\sim$ 1.3 million of positive weighted events.
- Direct comparison with D0 data (PLB 669:278 (2008) - PLB 678:45 (2009) - PLB 682:370 (2010)): no K-factors, no parton-to-hadron corrections (not needed).
- With D0 cuts, non-perturbative corrections are smaller.





PLB 678 (1.0 fb^{-1})



- Data available only as ratios to Z fully-inclusive cross section.
- Rescaled with total measured inclusive cross section obtained for $Z \to \mu^+\mu^-$.
- 3rd jet always generated by the PS only.

Comments

- V+j is the first POWHEG implementation with a “divergent” Born (i.e. finite *only after* jet-defining algorithm).
- Theoretical and technical issues are connected to this feature: effect of a generation cut in this context, behaviour of the program at small p_{T}^{Z}, folded integration...
  More details in a forthcoming publication.

Aim of this study: validate, to some extent, the implementation.
$\hookrightarrow$ a more thorough analysis should be performed with/by the experimental collaborations.

- Scale choice: we choose $\mu = p_{\mathrm{T}}^{Z}$ (UB kinematics). It seems the natural choice given the method we use.
- Scale uncertainty: varying $\mu \to \mu/2$ or $\mu \to 2\mu$ can be easily done.
- PDFs uncertainty: full study is feasible.
  - Quantify the effect of PDFs used in the PS is also possible. (useful?)

Comments

- V+j is the first POWHEG implementation with a "divergent" Born (i.e. finite *only after* jet-defining algorithm).
- Theoretical and technical issues are connected to this feature: effect of a generation cut in this context, behaviour of the program at small p_{T}^{Z}, folded integration...
  More details in a forthcoming publication.

Aim of this study: validate, to some extent, the implementation.
$\hookrightarrow$ a more thorough analysis should be performed with/by the experimental collaborations.

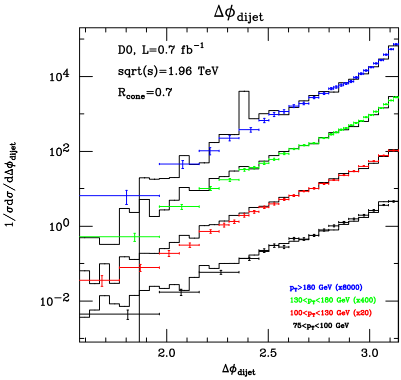
- Scale choice: we choose $\mu = p_{\mathrm{T}}^{Z}$ (UB kinematics). It seems the natural choice given the method we use.
- Scale uncertainty: varying $\mu \rightarrow \mu/2$ or $\mu \rightarrow 2\mu$ can be easily done.
- PDFs uncertainty: full study is feasible.
  - Quantify the effect of PDFs used in the PS is also possible. (useful?)
- Th/Ex: Showers: comparison among different showers is easy, because of the method (and because a LHE file is available).
  - We will start using the PYTHIA 8 and HERWIG++ showers (improved features and more support with respect to fortran versions).
  - Need of a dedicated tune when POWHEG is used?
- Th: when using HERWIG(++), study truncated shower effects.

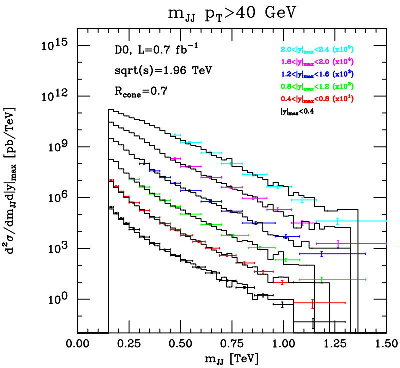
We would like to improve the communication between POWHEG and PS programs. Important for more complicated processes ?

Results for dijets (PRELIMINARY)

[Alioli,Hamilton,Nason,Oleari,ER, preliminary]

- Dijets is the most complicated among the processes implemented until now.
- There are some technical aspects still to be understood...it is work in progress.
- Direct comparison with data: no K-factors, no parton-to-hadron corrections (not needed).
- Showered with PYTHIA.





Comments:

- although results are preliminary, and no effort at all to understand tuning effects has been done, very good agreement.
- recent interest in ATLAS: a public pre-release of the code is already available.

Conclusions and outlooks

Conclusions:

- POWHEG is now a well-established method to merge NLO calculations and PS's.
- Since February, the POWHEG-BOX package is available at

  `http://virgilio.mib.infn.it/~nason/POWHEG`

  It contains the old processes, new ones, and some technical improvements (mainly related to Exp requests and new implementations).
- Z+j is finished, tested and ready to be released. Code for W+j is also (almost) ready. Dijets is work in progress.
- For the first time, processes with jets at LO are simulated with NLO+PS accuracy.

Outlooks:

- We would like to improve the communication with PS programs.
  This can become important for specific issues (and likely also for more complicated processes).
- Merge events from Z and $Z + j$, to produce a single sample that covers properly "all" the kinematic range.
- MENLOPS. [Marek's talk]
- Other interesting processes...

Conclusions and outlooks

Conclusions:

- POWHEG is now a well-established method to merge NLO calculations and PS's.
- Since February, the POWHEG-BOX package is available at

  http://virgilio.mib.infn.it/~nason/POWHEG

  It contains the old processes, new ones, and some technical improvements (mainly related to Exp requests and new implementations).
- Z+j is finished, tested and ready to be released. Code for W+j is also (almost) ready. Dijets is work in progress.
- For the first time, processes with jets at LO are simulated with NLO+PS accuracy.

Outlooks:

- We would like to improve the communication with PS programs.
  This can become important for specific issues (and likely also for more complicated processes).
- Merge events from Z and $Z + j$, to produce a single sample that covers properly "all" the kinematic range.
- MENLOPS. [Marek's talk]
- Other interesting processes...

Thanks for your attention!

Backup

POWHEG generation cut: 5 GeV. PDF set: CTEQ6M.

CDF

Midpoint algo, cone radius $R = 0.7$, merging/splitting fraction 0.75.

- $Z(\to e^+ e^-) + j$: (h/p $\sim 10\%$)

$$66\ \text{GeV} < M_{ee} < 116\ \text{GeV}, \quad p_T^e > 25\ \text{GeV}, \quad |\eta^{e1}| < 1.0, \quad |\eta^{e2}| < 1.0 \text{ or } 1.2 < |\eta^{e2}| < 2.8,$$
$$|y^{\text{jet}}| < 2.1, \quad p_T^{\text{jet}} > 30\ \text{GeV}, \quad \Delta R_{e,\,\text{jet}} > 0.7\,.$$

- $Z(\to \mu^+ \mu^-) + j$

$$66\ \text{GeV} < M_{\mu\mu} < 116\ \text{GeV}, \quad p_T^\mu > 25\ \text{GeV}, \quad |\eta^\mu| < 1.0,$$
$$|y^{\text{jet}}| < 2.1, \quad p_T^{\text{jet}} > 30\ \text{GeV}, \quad \Delta R_{\mu,\,\text{jet}} > 0.7\,.$$

D0

D0 Run II iterative seed-based cone algo, cone radius $R = 0.5$, merging/splitting fraction 0.5.

- $Z(\to e^+ e^-) + j$: (h/p $\sim 5\%$)

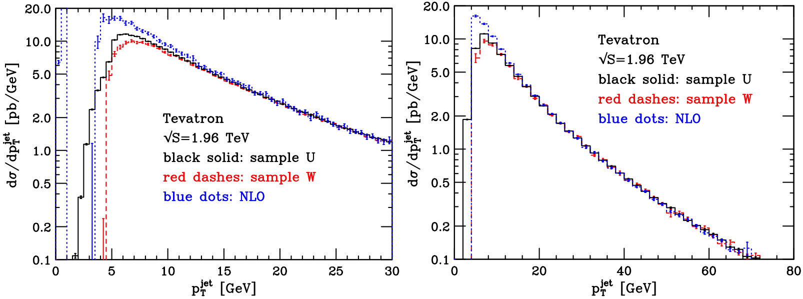
$$65\ \text{GeV} < M_{ee} < 115\ \text{GeV}, \quad p_T^e > 25\ \text{GeV}, \quad |\eta^e| < 1.1 \text{ or } 1.5 < |\eta^e| < 2.5,$$
$$|y^{\text{jet}}| < 2.5, \quad p_T^{\text{jet}} > 20\ \text{GeV}\,.$$

- $Z(\to \mu^+ \mu^-) + j$: (h/p $< 4\%$)

$$65\ \text{GeV} < M_{\mu\mu} < 115\ \text{GeV}, \quad p_T^\mu > 15\ \text{GeV}, \quad |\eta^\mu| < 1.7,$$
$$|y^{\text{jet}}| < 2.8, \quad p_T^{\text{jet}} > 20\ \text{GeV}, \quad \Delta R_{\mu,\,\text{jet}} > 0.5\,.$$

Backup

Z+j: generation cut, folding.



U: generation cut, unweighted events.

W: suppression factor, weighted events.

Backup

Dijets: coherence plot.