News from POWHEG

Emanuele Re*
IPPP, Durham University

Vector boson plus jets workshop

Durham, 09 September 2010

---

*in collaboration with S. Alioli, P. Nason and C. Oleari

Outline

- The POWHEG method and the POWHEG-BOX framework
- Current status: new results for V+jets with POWHEG
- What to do now...
- Conclusions and outlooks

The POWHEG method

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

NLO	PS
✓ reduced scale dependence	✓ Sudakov suppression in collinear regions
✓ better description of high-p_T tails	✓ parton → hadron corrections not needed

- In a nutshell, the method can be summarized by the following *master* formula:

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

- General comments:
  - 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:
    - if only interested in multijet shapes → ME+PS (CKKW, MLM)
      if only interested in inclusive quantities → NNLO
    - ✓ however, in both cases, it is still better than standalone SMC...
    - ✓ and new ideas to improve in this direction emerged. [→Keith's MENLOPS talk]
  - Main differences with respect to MC@NLO:
    - ✓ Events are positive weighted.
    - ✓ It does not depend from the parton-shower algorithm used.
  - only when used with angular-ordered PS, a truncated shower should be included too.

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 $2 \to 2$ and some $2 \to 3$ processes [Nason et al.]
  - within HERWIG++ (also with truncated shower): DY, $gg \to H$, HV
    (+ others almost finished) [Hamilton et al.]
  - very recently also within SHERPA [→Marek's talk]
- From February, the POWHEG-BOX package is available. Features:
  - automation of the POWHEG algorithm using the FKS subtraction scheme.
  - all previous implementations included in a single and already public framework.
  - it produces LHE file, ready to be showered.
  - structure: main directory + process folders.
  - it was originally builded to implement V+j !

$\Downarrow$

Now the results...

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 $2 \to 2$ and some $2 \to 3$ processes [Nason et al.]
  - within HERWIG++ (also with truncated shower): DY, $gg \to H$, HV
    (+ others almost finished) [Hamilton et al.]
  - very recently also within SHERPA [→Marek's talk]
- From February, the POWHEG-BOX package is available. Features:
  - automation of the POWHEG algorithm using the FKS subtraction scheme.
  - all previous implementations included in a single and already public framework.
  - it produces LHE file, ready to be showered.
  - structure: main directory + process folders.
  - it was originally builded to implement V+j !

$\Downarrow$

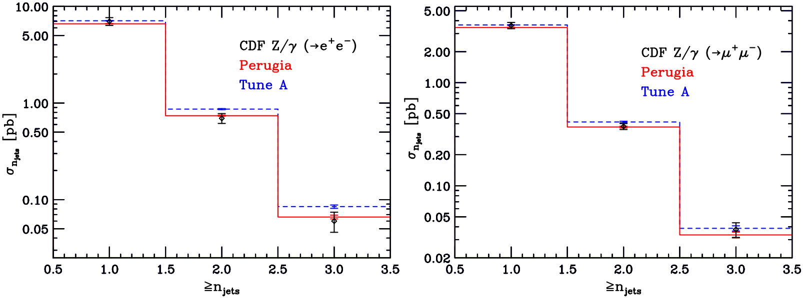
Now the results...

WARNING !

- V+j is the first POWHEG implementation with a "divergent" Born (i.e. finite *only after* jet-defining algorithm).
- Several theoretical and technical issues are connected to this feature. More details will appear in a forthcoming publication.
- Only Z+j results will be shown. Code for W+j also finished.

Results for Z+jets: comparison with CDF data

- 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_{T}-ordered) and Tune A (Q^2-ordered).

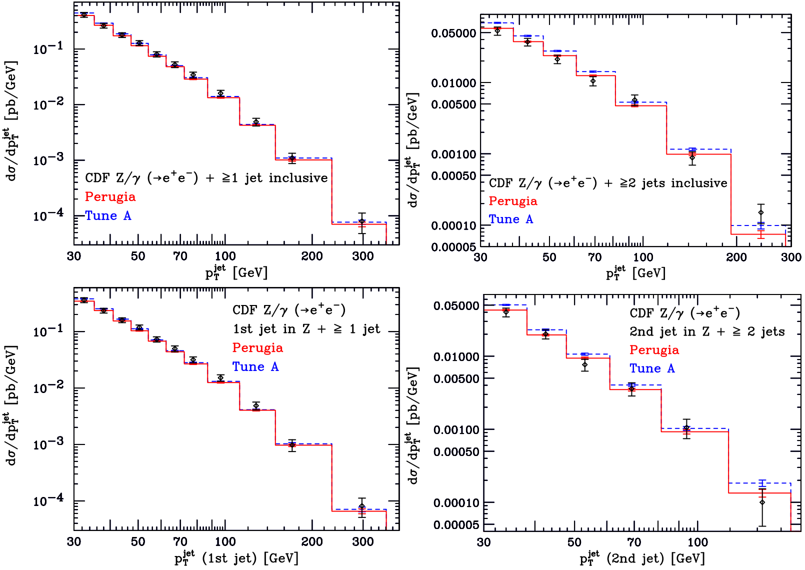


Comments:

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

Results for Z+jets: comparison with CDF data

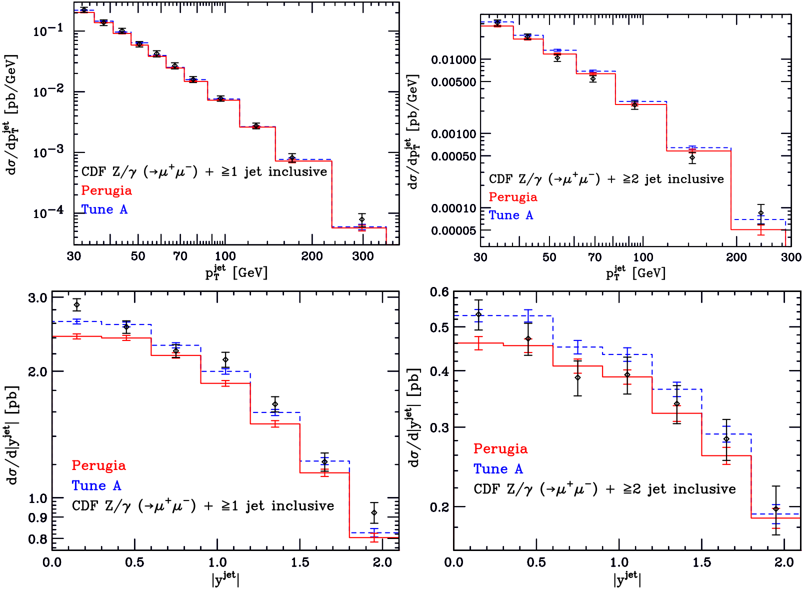
Upper panel: PRL (1.7 fb^{-1}). Lower panel: blessed data from CDF webpage (2.5 fb^{-1}).



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

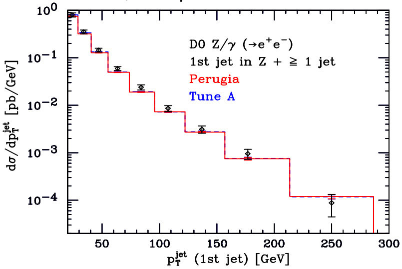
Results for Z+jets: comparison with CDF data

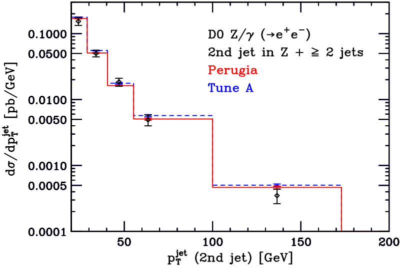
Blessed plots from CDF webpage (2.37 fb^{-1}).



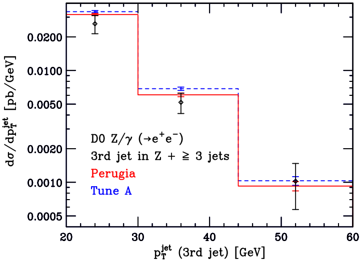
Results for Z+jets: comparison with D0 data

- 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.





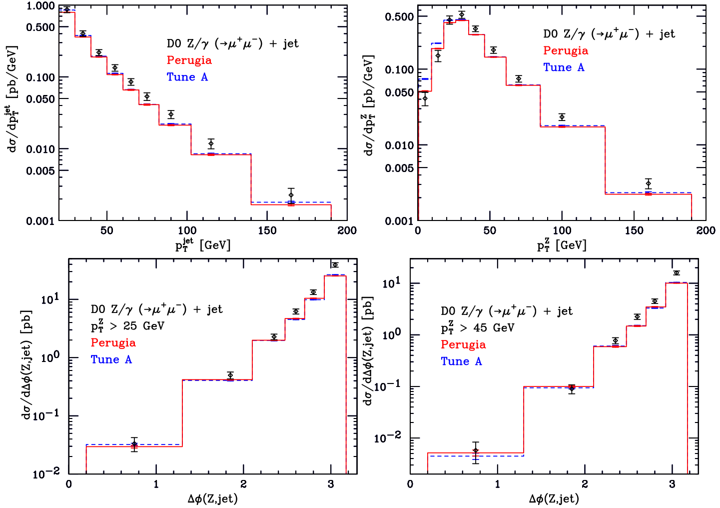
PLB 678 (1.0 fb^{-1})



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

Results for Z+jets: comparison with D0 data [2/2]

Upper panel: PLB 669 (1.0 fb^{-1}). Lower panel: PLB 682 (1.0 fb^{-1}).



- No rescaling needed (total inclusive cross section available).
- Agreement good, but not as good as with CDF data.
  Th. uncertainty band not included, (and disagreement at low p_T^Z already noticed in D0 publication).

Comments

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

Now the tool is available!

- 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

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

Now the tool is available!

- 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?)
- 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.
- Ex: in some cases, more infos on data would be welcomed (absolute values, when possible).
- Th challenges (NOT easy):
  - Check whether merging Z and Z+j brings significant improvements.
  - `MENLOPS`.
- Th/Ex: study other observables for this process (giant K-factors in H_T [Salam et al.], N_j vs Δy [Andersen et al.]).
  Data for these observables (?).

Conclusions and outlooks

Conclusions:

- POWHEG is now a well-established method to merge NLO calculations and PS's.
- Since February, the POWHEG-BOX package has been public. It contains W, Z, heavy flavours, H via gluon and vector boson fusion, single-top (s-, t- and Wt-channel) and V+j.
- Shown results for Z+j. Code will be available very soon within POWHEG-BOX, together with W+j.
- For the first time, processes with jets at LO are simulated with NLO+PS accuracy.

Outlooks:

- Understand which of the comments in the previous slide are the more important/interesting.

  $\hookrightarrow$ need of help/feedback from Ex. community.

- Merge events from Z and $Z + j$, to produce a single sample that covers properly "all" the kinematic range.
- Other processes relevant for early LHC data will also be available soon.

Conclusions and outlooks

Conclusions:

- POWHEG is now a well-established method to merge NLO calculations and PS's.
- Since February, the POWHEG-BOX package has been public. It contains W, Z, heavy flavours, H via gluon and vector boson fusion, single-top (s-, t- and Wt-channel) and V+j.
- Shown results for Z+j. Code will be available very soon within POWHEG-BOX, together with W+j.
- For the first time, processes with jets at LO are simulated with NLO+PS accuracy.

Outlooks:

- Understand which of the comments in the previous slide are the more important/interesting.

  $\hookrightarrow$ need of help/feedback from Ex. community.

- Merge events from Z and $Z + j$, to produce a single sample that covers properly "all" the kinematic range.
- Other processes relevant for early LHC data will also be available soon.

Comments/proposals/new ideas from this WS welcomed...

Conclusions and outlooks

Conclusions:

- POWHEG is now a well-established method to merge NLO calculations and PS's.
- Since February, the POWHEG-BOX package has been public. It contains W, Z, heavy flavours, H via gluon and vector boson fusion, single-top (s-, t- and Wt-channel) and V+j.
- Shown results for Z+j. Code will be available very soon within POWHEG-BOX, together with W+j.
- For the first time, processes with jets at LO are simulated with NLO+PS accuracy.

Outlooks:

- Understand which of the comments in the previous slide are the more important/interesting.

  $\hookrightarrow$ need of help/feedback from Ex. community.
- Merge events from Z and $Z + j$, to produce a single sample that covers properly "all" the kinematic range.
- Other processes relevant for early LHC data will also be available soon.

Comments/proposals/new ideas from this WS welcomed...

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 $\sim 10\%$)

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

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

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

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 $\sim 5\%$)

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

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

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