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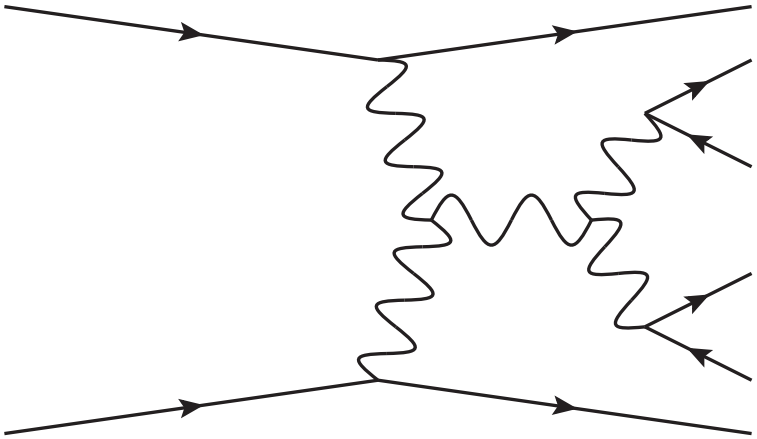


Parton-Shower Effects in Electroweak W^+Zjj-Production at NLO QCD

KIT-NEP '19 · Karlsruhe

09.10.2019, Johannes Scheller*

*In cooperation with Barbara Jäger and Alexander Karlberg; Eur. Phys. J. C (2019) 79: 226

Outline

- Vector Boson Scattering
- Process Definition
- Overview of Related Work
- Implementation and Setup
- Phenomenology
- Outlook: Options for BSM Physics

Vector Boson Scattering

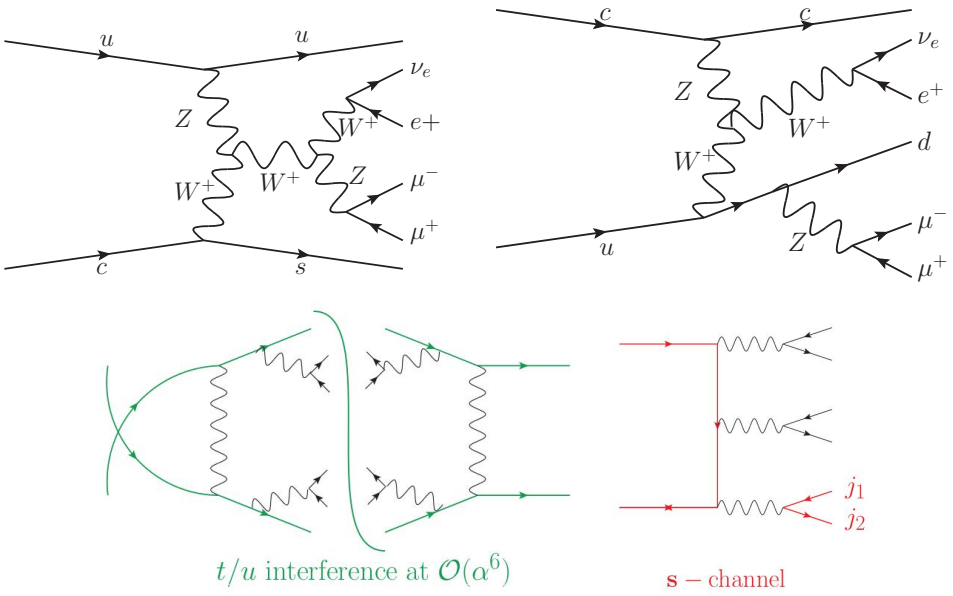
- EW process of the form $pp \to VVjj$ or $pp \to HHjj$ in t- and u-channel
- containing VVV, VVVV and VVH vertices
- offers insights into the gauge structure and the symmetry breaking of the EW sector of the SM
- experimentally: distinct signature $\Rightarrow$ relatively good signal/background ratio with appropriate cuts

Process Definition: VBS W^+Z

- include decays (here: fully leptonic) $\rightarrow \mathcal{O}(\alpha^6)$

$\Rightarrow$ $pp \rightarrow \mu^+\mu^- e^+\nu_e jj$

- t- and u-channel contributions, but no interference of t- with u-channel diagrams; no s-channel induced production modes



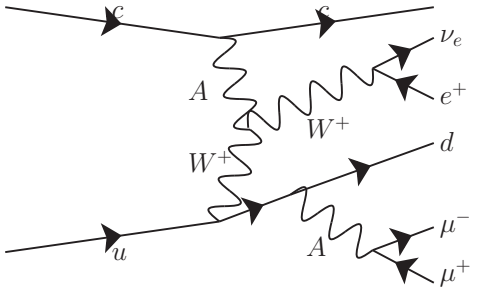
Colored diagrams taken from [Pellen, 2018], original source by [Pelliccioli]

Related Work

- NLO-QCD included in multi-purpose Monte Carlo program `VBFNLO`, publication from 2007 *[Baglio et al.; Arnold et al. '08-'14]*
- similar `POWHEG-BOX` implementations for W^+W^+jj, W^+W^-jj and $ZZjj$ *[Jäger et al., 2011-2013]*
- 13 TeV results from ATLAS *[ATLAS-CONF-2018-033]* and CMS *[CMS-PAS-SMP-18-001]* in 2018
- Les Houches comparison of various LO and LO+PS implementations in 2017 *[Bendavid, Long et al., 2017]*
- full NLO QCD and EW corrections published in 2019 *[Denner, Dittmaier et al., 2019]*

Setup and Implementation

- generation cuts on photon virtuality in t-channel, $Q^2_{min} = 4\,\text{GeV}^2$ and on mass of same-type lepton pair, $m_{\mu^+\mu^-} > 0.5\,\text{GeV}$

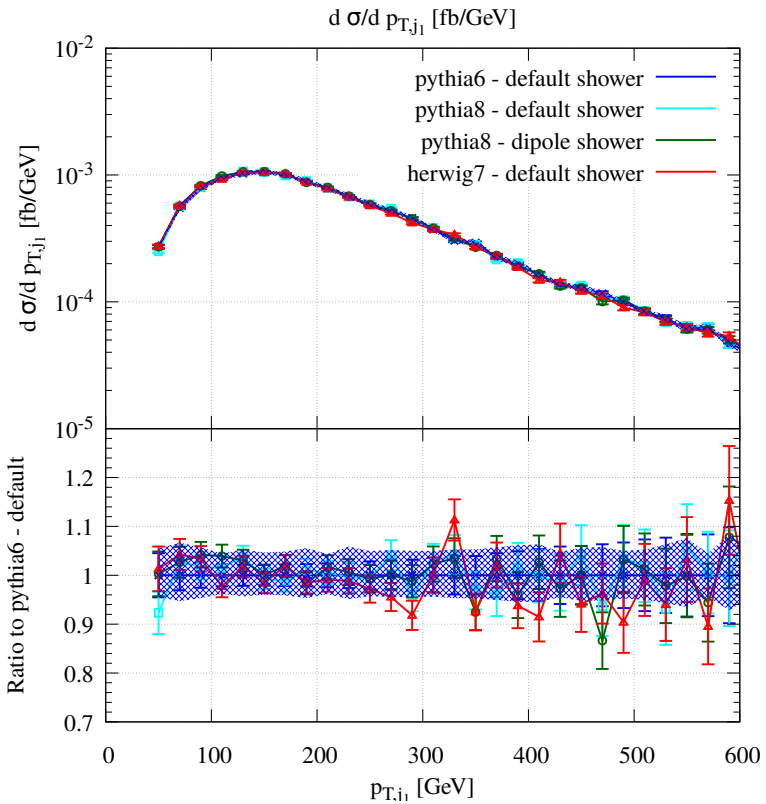


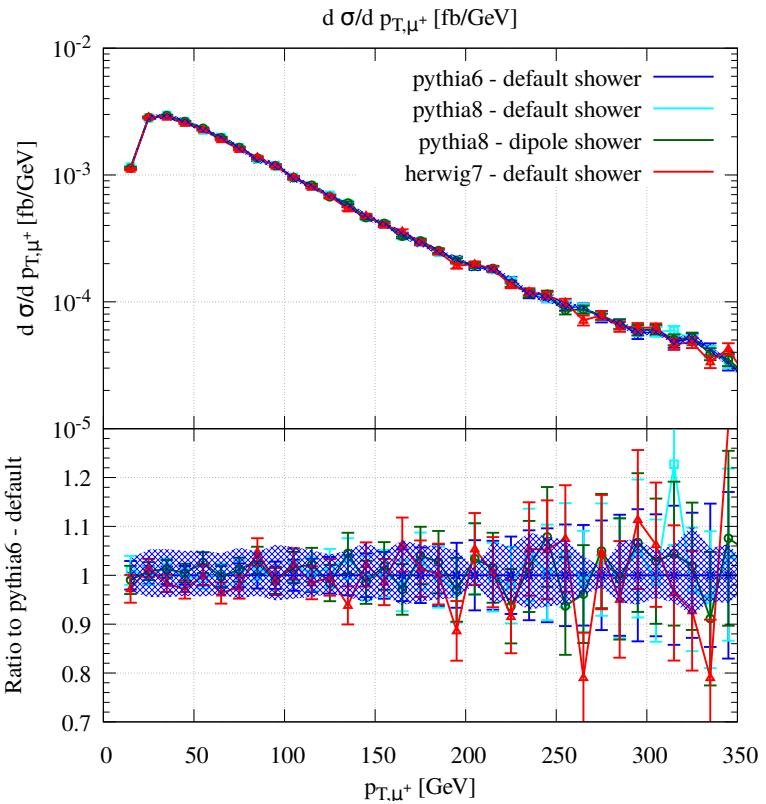
- Born-suppression factor $F(\Phi_N) = \left(\frac{p^2_{T,1}}{p^2_{T,1}+\Lambda^2}\right)^2 \left(\frac{p^2_{T,2}}{p^2_{T,2}+\Lambda^2}\right)^2$
- parton shower programs: PYTHIA6, PYTHIA8 (dipole & default recoil), HERWIG7
- analysis cut set inspired by CMS analysis (paper: also ATLAS-inspired cut set, less tight)

Cuts inspired by CMS (tight cuts)

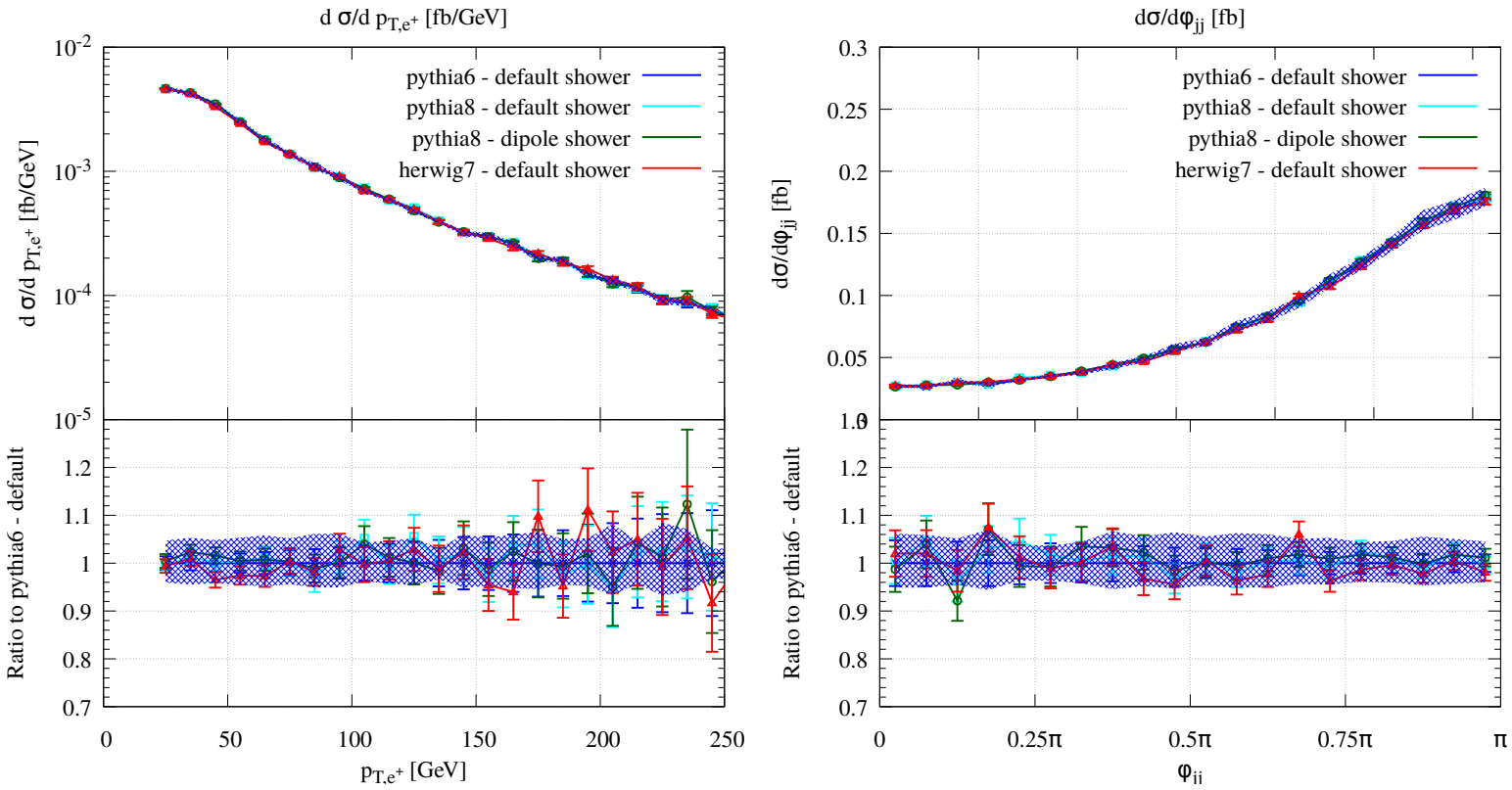
- min. 2 jets with:
  $p_{T,j} > 50$ GeV , $|y_j| < 4.7$
- $m_{j_1 j_2} > 150$ GeV ,
  $|\Delta y_{j_1,j_2}| = |y_{j_1} - y_{j_2}| > 2.5$
- $\Delta R_{\ell\ell} > 0.2$, $\Delta R_{j\ell} > 0.4$
- $p_{T,\mu_1} > 25$ GeV , $p_{T,\mu_2} > 15$ GeV
- $p_{T,e} > 20$ GeV , $p_T^{\text{miss}} > 30$ GeV
- $|\eta_\mu| < 2.4$, $|\eta_e| < 2.4$
- $m_{\mu^+\mu^-} > 4$ GeV ,
  $m_{e^+\mu^+\mu^-} > 10$ GeV
- $|\eta_{3\ell} - \frac{\eta_{j_1} - \eta_{j_2}}{2}| < 2.5$

Leptons And Tagging Jets I





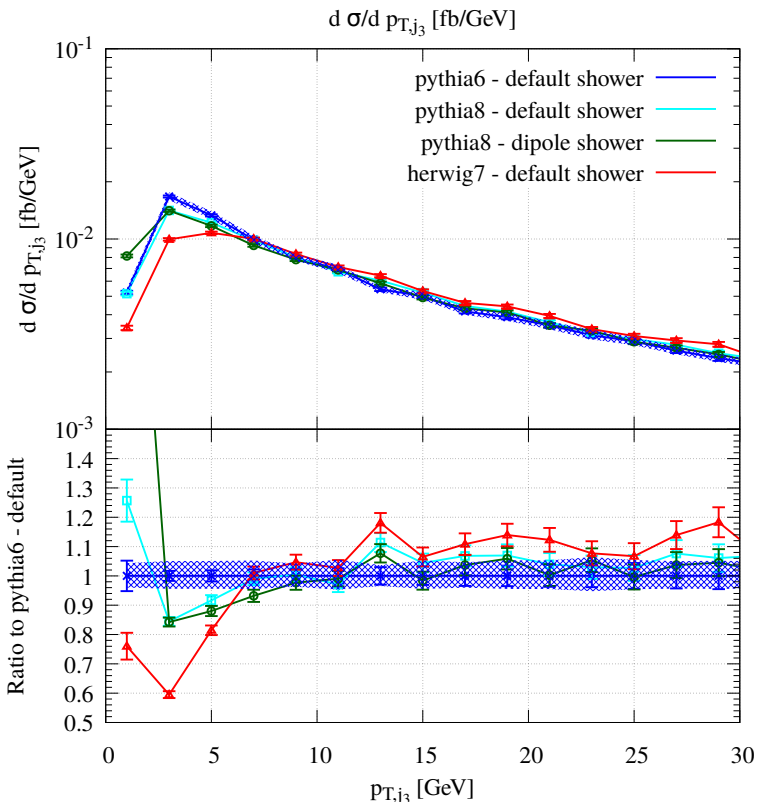
Leptons And Tagging Jets II

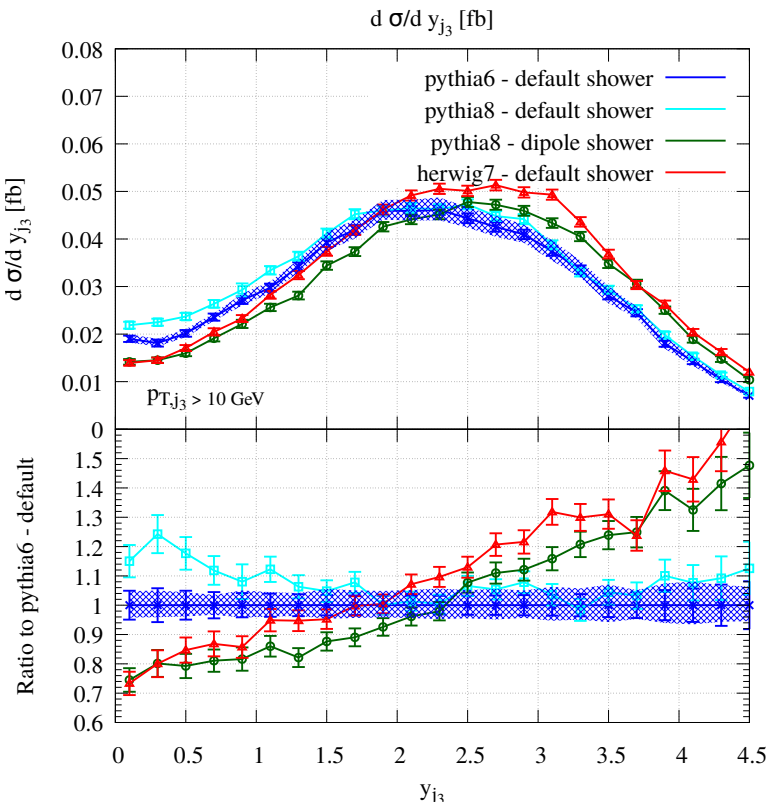


Results with cut set inspired by CMS analysis

→ barely affected by parton shower

Additional Jets



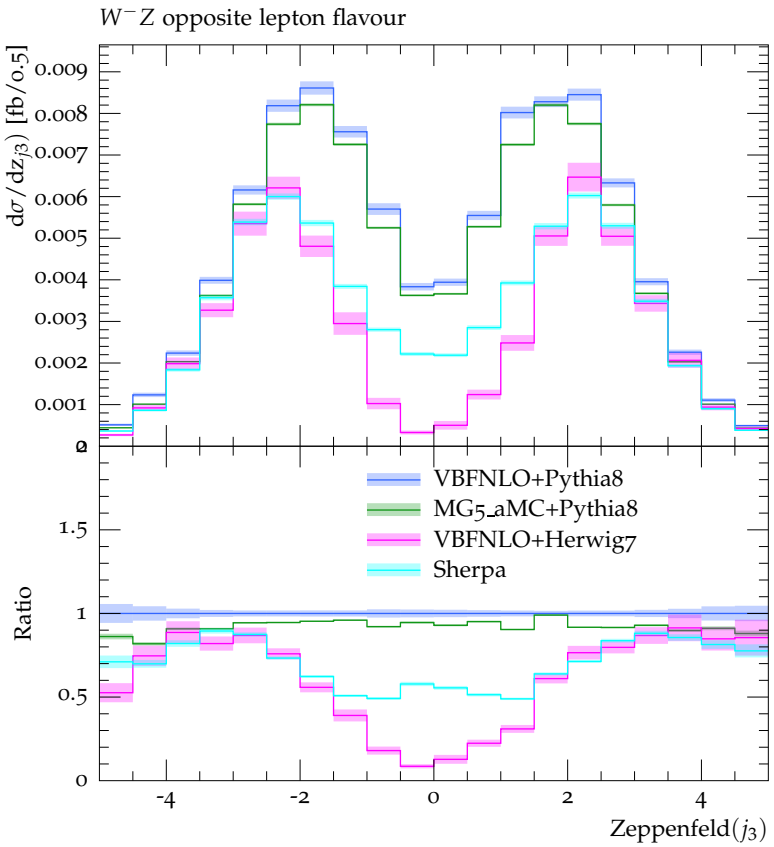


Results with cut set inspired by CMS analysis

→ less stable results, effects relevant for veto techniques

Zeppenfeld Variable

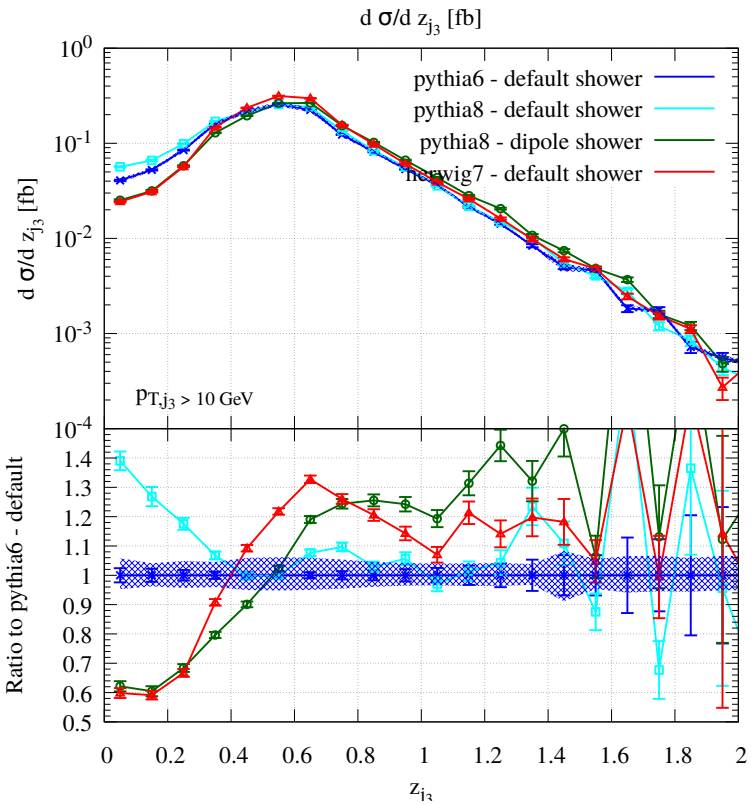
$$z_{j_3} = \frac{y_{j_3} - \frac{y_{j_1} + y_{j_2}}{2}}{\left|\Delta y_{j_1, j_2}\right|}$$



[Bendavid et al., 2017]

Zeppenfeld Variable

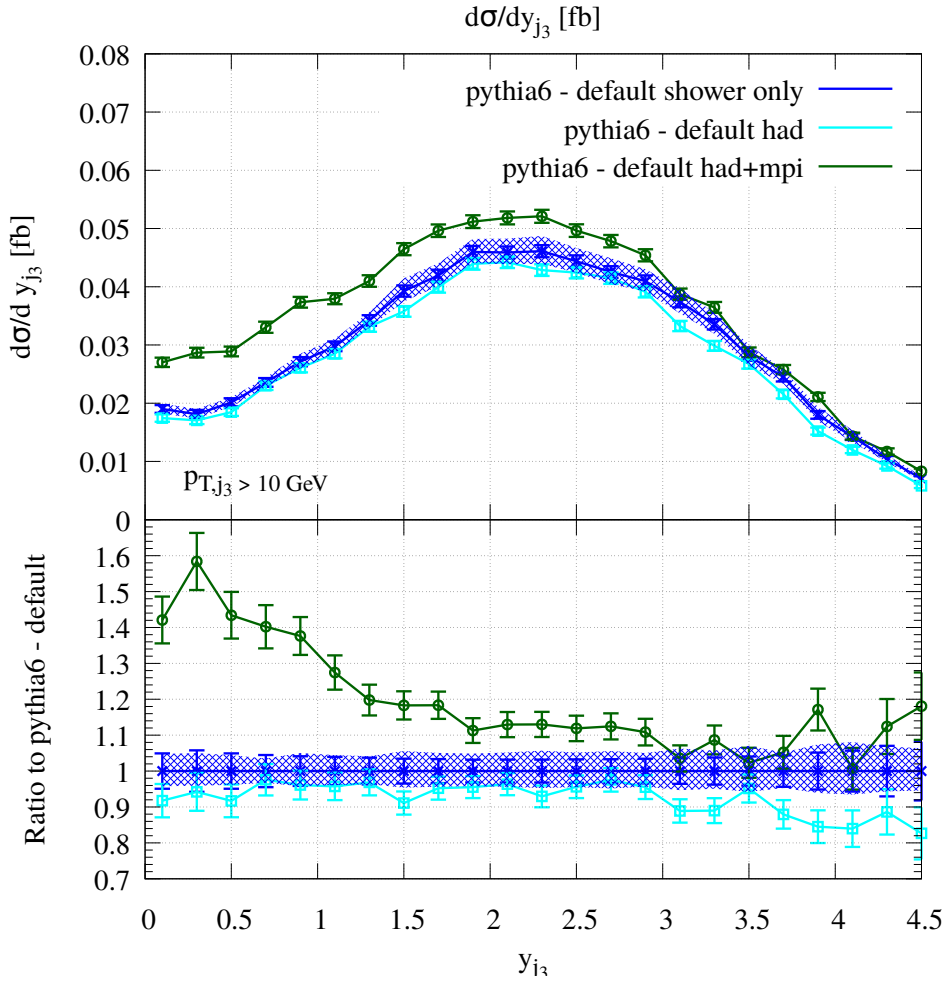
$$z_{j_3} = \frac{y_{j_3} - \frac{y_{j_1} + y_{j_2}}{2}}{\left|\Delta y_{j_1,j_2}\right|}$$



Results with cut set inspired by CMS analysis

→ improvements in central rapidity region

MPI And Hadronization



Outlook: Anomalous Couplings

- VBS very sensitive to BSM physics in the EW sector
- easily accessible in framework of anomalous gauge couplings
  $\Rightarrow$ can be implemented in `POWHEG-BOX` code
- also suitable for various other ways of implementing new physics in EW sector

Conclusion

- first public NLO+PS implementation of VBS-W^+Z
  available at svn://powhegbox.mib.infn.it/trunk/User-Processes-V2/VBF_WZ
- results very stable for leptons and tagging jets
- significant parton shower effects on 3rd jet distributions remains
- strong improvement compared to LO+PS
- important for jet veto
- confirmed by results within ATLAS cut set
- possibility to include anomalous couplings in future

Questions?

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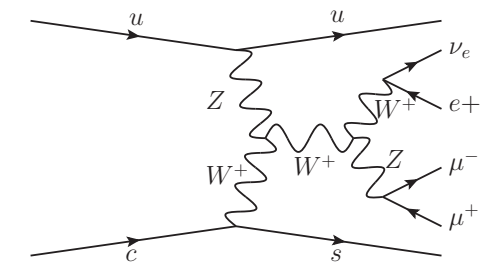
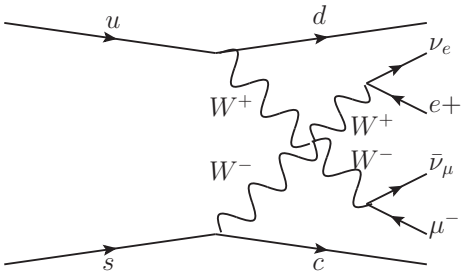
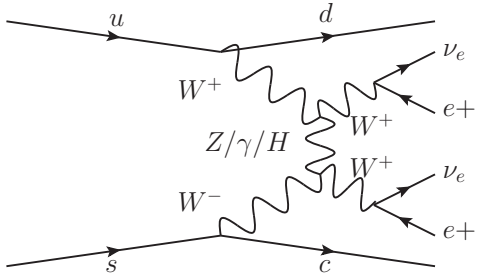
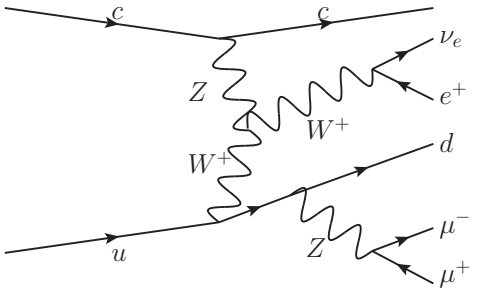
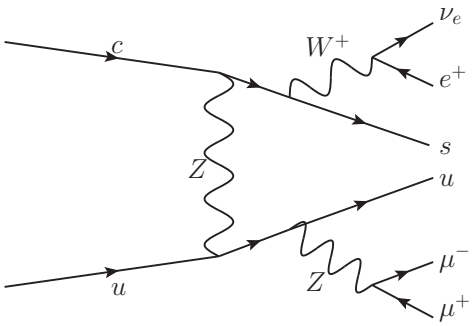
Backup: Subprocesses/Topologies

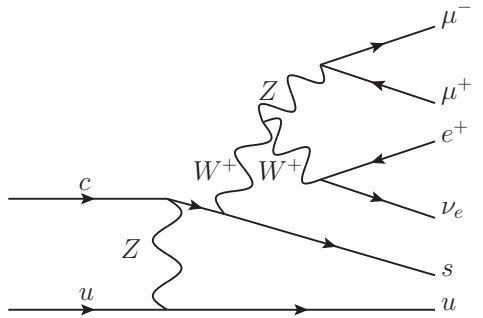












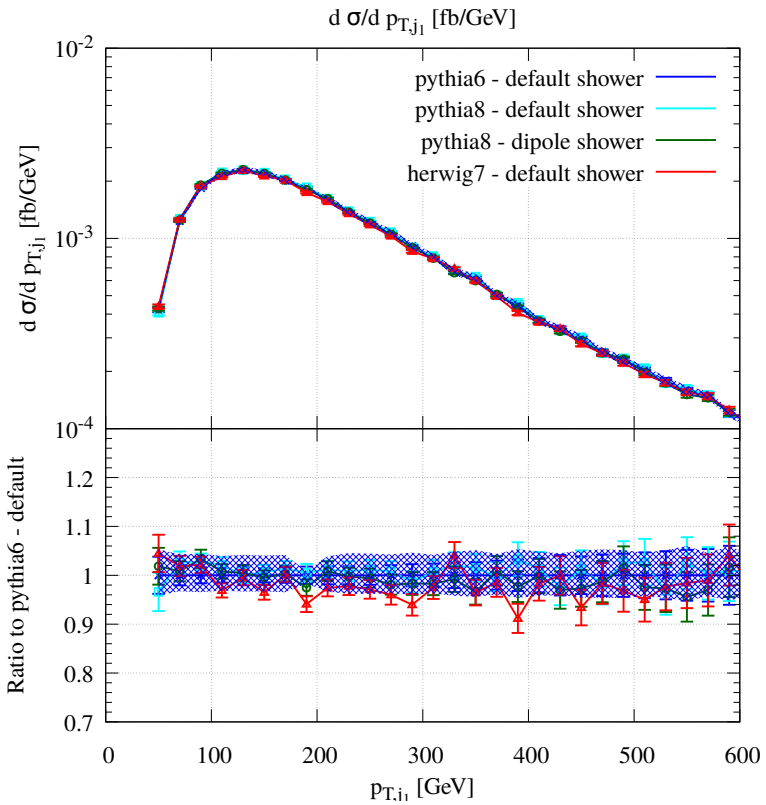
Backup: POWHEG

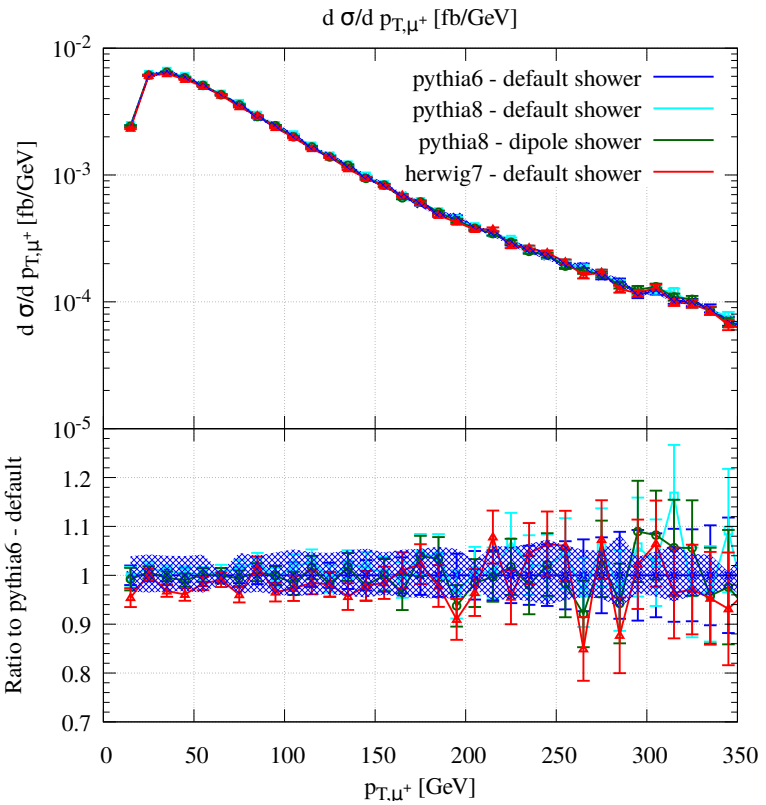
- uses FKS substraction method
- input needed
  - phase space parametrization
  - definition of flavour structures
  - Born, virtual & real matrix elements squared
  - color & spin correlated Born amplitudes
  - color information about the Born process
- `POWHEG` master formula:
  $\sigma = \int \mathrm{d}\Phi_n \tilde{\mathcal{B}}_n \Delta\left(p_T^{\min}\right) + \int \mathrm{d}\Phi_{n+1} \tilde{\mathcal{B}}_n \Delta\left(p_T^{\min}\right) \frac{\mathcal{R}_{n+1}}{\mathcal{B}_n} \Theta\left(p_T^n - p_T^{n+1}\right)$

Backup: ATLAS Cuts

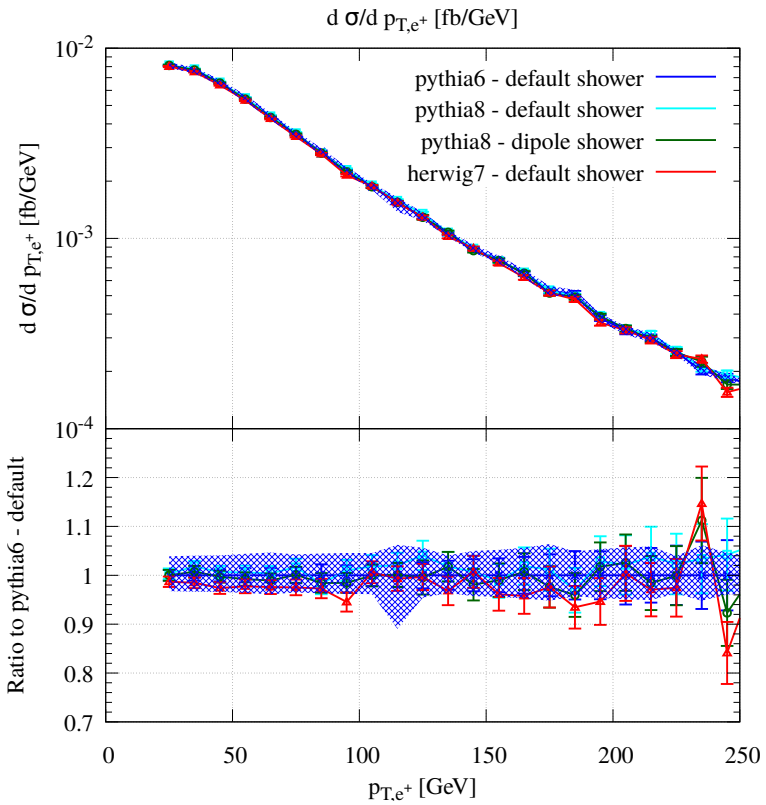
- min. 2 jets with:
  $p_{T,j} > 40$ GeV , $|y_j| < 4.5$
- $m_{j_1 j_2} > 150$ GeV
- $|y_\ell| < 2.5$,
  $\Delta R_{\ell\ell} > 0.2$, $\Delta R_{j\ell} > 0.2$
- $|m_Z - m_{\mu^+\mu^-}| < 10$ GeV ,
  $p_{T,\mu} > 15$ GeV
- $p_{T,e} > 20$ GeV

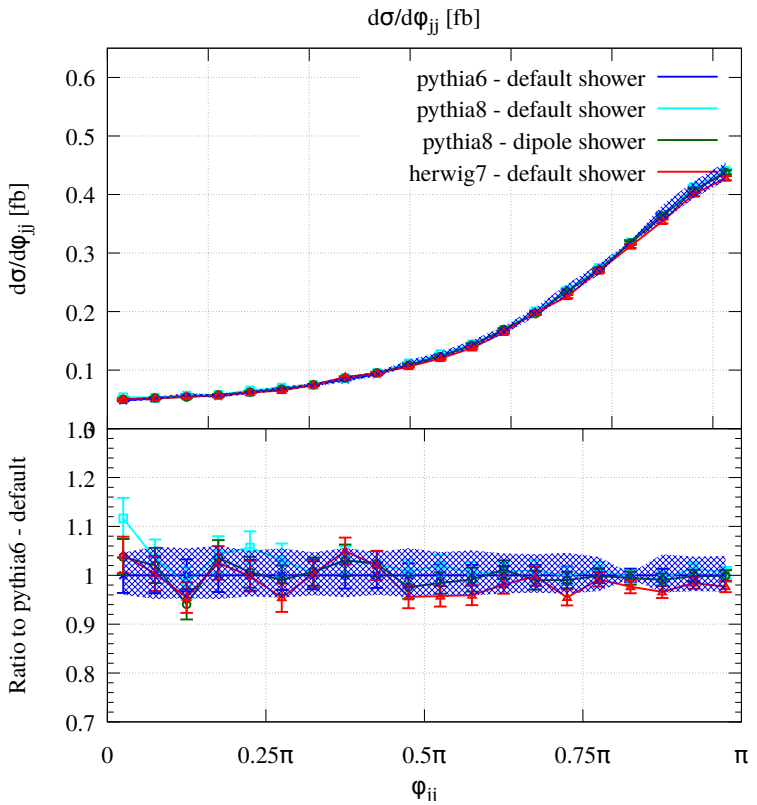
Backup: ATLAS I



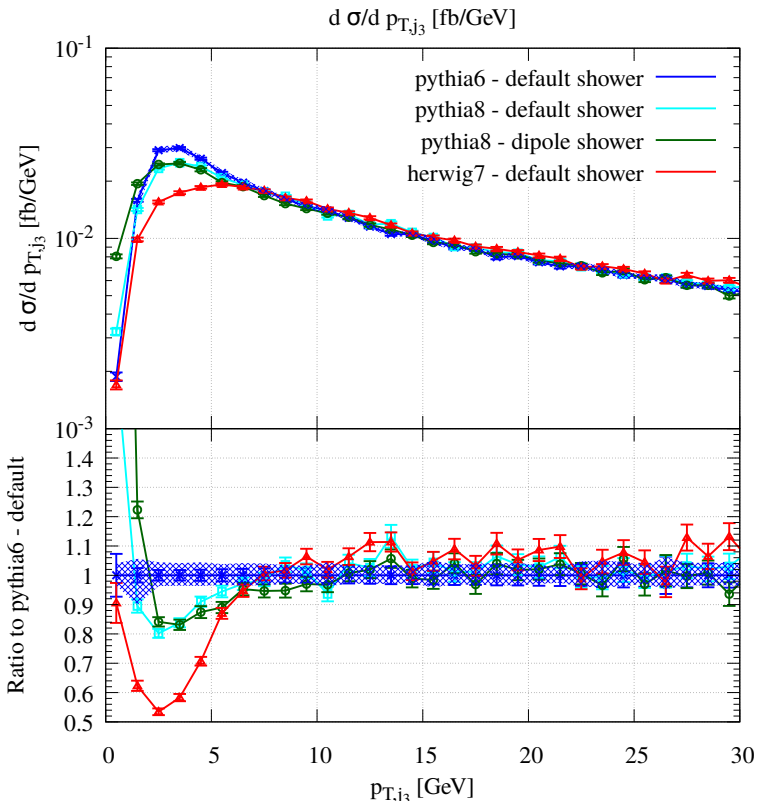


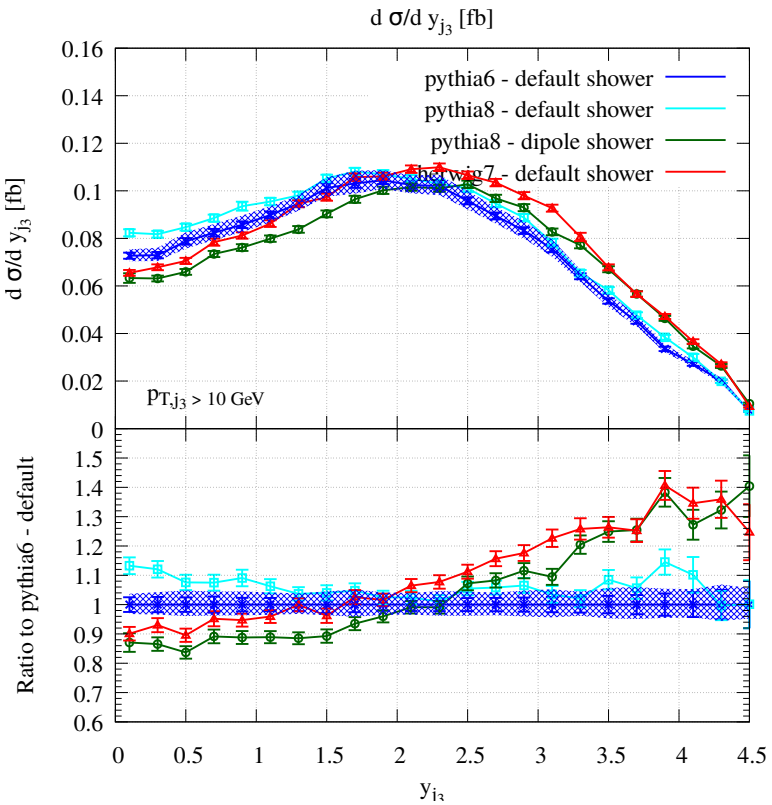
Backup: ATLAS II





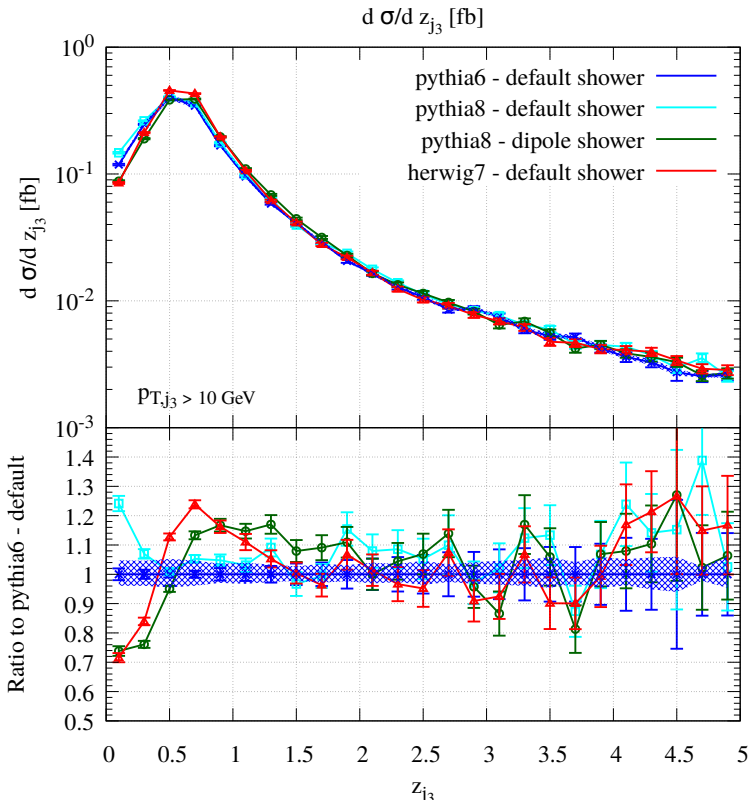
Backup: ATLAS III





Backup: ATLAS IV

$$z_{j_3} = \frac{y_{j_3} - \frac{y_{j_1} + y_{j_2}}{2}}{\left|\Delta y_{j_1, j_2}\right|}$$



Backup: ATLAS V