Status of the GENEVA MC event generator

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based on

(S. Alioli, A. Broggio, AG, S. Kallweit, M. A. Lim, R. Nagar, D. Napoletano, L. Rottoli JHEP 04 (2021) 254)

(S. Alioli, A. Broggio, AG, S. Kallweit, M. A. Lim, R. Nagar, D. Napoletano, L. Rottoli JHEP 04 (2021) 041)

(S. Alioli, C. W. Bauer, A. Broggio, AG, S. Kallweit, M. A. Lim, R. Nagar, D. Napoletano, L. Rottoli 2102.08390 [hep-ph])

(S. Alioli, A. Broggio, AG, S. Kallweit, M. A. Lim, R. Nagar, D. Napoletano Phys.Lett.B 818 (2021) 136380)

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The GENEVA framework

GENEVA is an automated event generator that provides

- Fully differential **events** up to **NNLO QCD**
- **NNLL′ resummation** of the 0/1 jet resolution variable (the zero-jettiness $\mathcal{T}_0$ or the transverse momentum q_{T} for the case of color singlet production)
- **NLL resummation** of the 1/2 jet resolution variable (the one-jettiness $\mathcal{T}_1$ for the case of color singlet production)
- Matching to a **parton shower**

$\mathcal{T}_0$ and q_{T} as resolution variables

Given a process of production of a color singlet accompanied by one jet

$$pp \to \mathrm{CS} + \mathrm{jet}$$

the phase space region where the matrix elements present infrared divergences can be equivalently identified as those with

- Small transverse momentum q_{T} of the color singlet
- Small zero-jettiness $\mathcal{T}_0 = \min\left(\hat{p}^0 - \hat{p}^3, \hat{p}^0 + \hat{p}^3\right)$

0/1 parton resolution variable

The color singlet transverse momentum q_{T} and the zero-jettiness $\mathcal{T}_0$ are two valid **resolution variables** for distinguishing between events with 0 and 1 final-state resolved partons

The resolution variable: N-jettiness

Given a configuration with n final-state massless partons of momenta p_1, ..., p_n we define the ***N*-jettiness** as

$$\mathcal{T}_N = \sum_{i=1}^{n} \min_{\substack{q_1,\ldots,q_N \\ \text{lightlike with } q_i^0 = 1}} \left(q_a \cdot \hat{p}_i, q_b \cdot \hat{p}_i, q_1 \cdot \hat{p}_i, \ldots, q_N \cdot \hat{p}_i \right)$$

- $q_a = (1, 0, 0, 1)$ and $q_b = (1, 0, 0, -1)$ are the beam directions.
- q_1, ..., q_N are any lightlike vectors with $q_i^0 = 1$.
- $\hat{p}_1$, ..., $\hat{p}_n$ are the momenta of the partons after a longitudinal boost from the laboratory to the frame where the color singlet has zero rapidity.

The resolution variable: N-jettiness

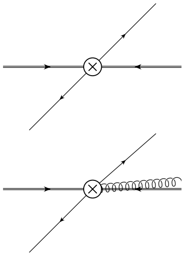
Given a configuration with n final-state massless partons of momenta p_1, ..., p_n we define the ***N*-jettiness** as

$$\mathcal{T}_N = \sum_{i=1}^{n} \min_{\substack{q_1,\ldots,q_N \\ \text{lightlike with } q_i^0 = 1}} \left(q_a \cdot \hat{p}_i, q_b \cdot \hat{p}_i, q_1 \cdot \hat{p}_i, \ldots, q_N \cdot \hat{p}_i \right)$$

- Lorentz invariant.
- A configuration with N final-state partons or less has $\mathcal{T}_N = 0$.
- The N-jettiness of a configuration with $N + 1$ final-state partons close to its soft or collinear limit tends to 0.

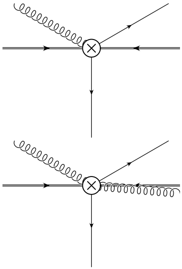
Generation of the events

$\mathcal{T}_0 < \mathcal{T}_0^{\mathrm{cut}}$



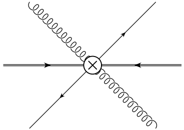
No resolved partons in the final state

$\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}}$
$\mathcal{T}_1 < \mathcal{T}_1^{\mathrm{cut}}$



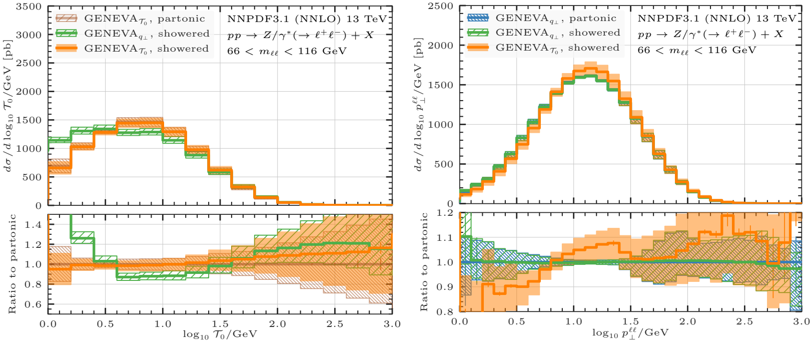
One resolved parton in the final state

$\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}}$
$\mathcal{T}_1 > \mathcal{T}_1^{\mathrm{cut}}$



Two resolved partons in the final state

$\mathcal{T}_0$ and q_T resummation



Comparison between $\mathcal{T}_0$ and q_T resummation in the $\mathcal{T}_0$ and q_T spectrum for Drell-Yan production

Processes available in GENEVA

- NC and CC Drell-Yan production ($pp \to \ell^+\ell^-$ and $pp \to \ell\nu_\ell$)

  (S. Alioli, C. W. Bauer, A. Broggio, C. Berggren, F. J. Tackmann, J. R. Walsh Phys.Rev.D 92 (2015) 9, 094020)

  (S. Alioli, C. W. Bauer, A. Broggio, AG, S. Kallweit, M. A. Lim, R. Nagar, D. Napoletano, L. Rottoli 2102.08390 [hep-ph])

- Higgsstrahlung ($pp \to \ell^+\ell^- H$)

  (S. Alioli, A. Broggio, S. Kallweit, M. A. Lim, L. Rottoli Phys.Rev.D 100 (2019) 9, 096016)

- $H \to gg$ and $H \to b\bar{b}$ decay

  (S. Alioli, A. Broggio, AG, S. Kallweit, M. A. Lim, R. Nagar, D. Napoletano, L. Rottoli JHEP 04 (2021) 254)

- Photon pair production ($pp \to \gamma\gamma$)

  (S. Alioli, A. Broggio, AG, S. Kallweit, M. A. Lim, R. Nagar, D. Napoletano, L. Rottoli JHEP 04 (2021) 041)

- Z boson pair production ($pp \to \ell_1^+\ell_1^-\ell_2^+\ell_2^-$)

  (S. Alioli, A. Broggio, AG, S. Kallweit, M. A. Lim, R. Nagar, D. Napoletano Phys.Lett.B 818 (2021) 136380)

- $W\gamma$ production ($pp \to \ell\nu_\ell\gamma$)

  (T. Cridge, M. A. Lim, R. Nagar 2105.13214 [hep-ph])

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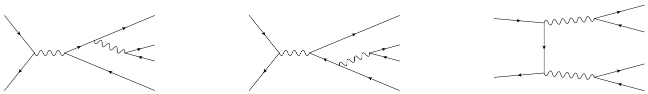
ZZ production

We consider proton-proton scattering processes at the LHC with four charged massless leptons in the final state

$$p\,p \to e^+\,e^-\,\mu^+\,\mu^- + X$$



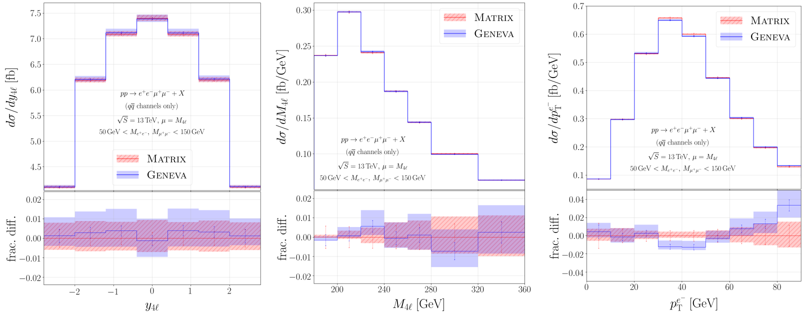
- Diagrams up to $\mathcal{O}(\alpha_s^2)$: NNLO for quark-initiated diagrams, LO for gluon-initiated diagrams
- 0- and 1-loop matrix elements taken from OpenLoops2 (`ppllll`, `ppllllj` and `ppllll2` packages)

  (Buccioni, Lang, Lindert, Maierhöfer, Pozzorini, Zhang, Zoller Eur.Phys.J.C 79 (2019) 10, 866)
- Two-loop virtual implemented starting from the `qqvvamp` code

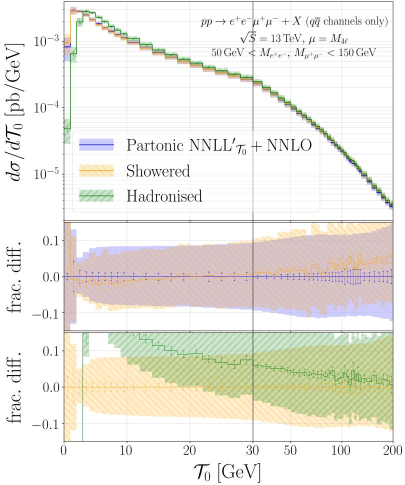
  (Gehrmann, von Manteuffel, Tancredi JHEP09(2015)128)

Validation of the code

We compare the GENEVA results at partonic level with those obtained from the fixed-order (NNLO) calculation implemented in MATRIX. The bands represent the theory uncertainty estimated through a 3-point scale variation, while the vertical bars are the statistical errors from the Monte Carlo integration.



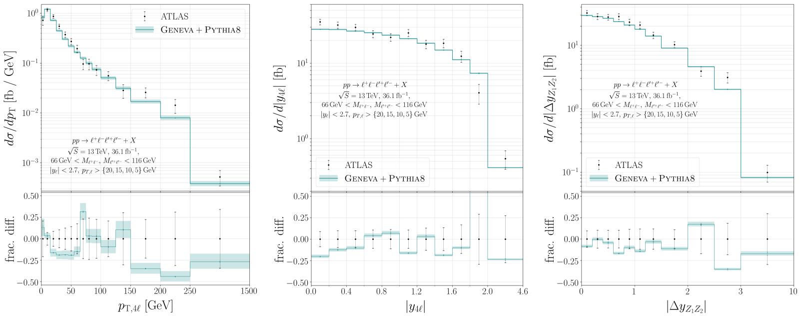
Parton shower and hadronization



Effects of the PYTHIA8 parton shower and hadronization on the $\mathcal{T}_0$ distribution

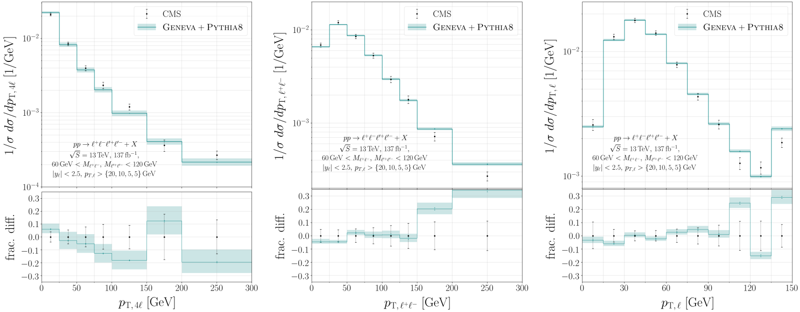
- The parton shower effects are $\mathcal{O}(2\%)$ on most of the $\mathcal{T}_0$ range
- The hadronization effect is large for small values of $\mathcal{T}_0$

Phenomenological results (ATLAS)



ATLAS measurements at 13 TeV from Phys. Rev. D 97, 032005 (2018)

Phenomenological results (CMS)



CMS measurements at 13 TeV from Eur. Phys. J. C 81 (2021) 200

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Photon pair production

We consider proton-proton scattering processes at the LHC with two on-shell photons in the final state

$$p\,p \to \gamma\,\gamma + X$$

- Diagrams up to $\mathcal{O}\left(\alpha_{\mathrm{S}}^{2}\right)$: NNLO for quark-initiated diagrams, LO for gluon-initiated diagrams
- 0- and 1-loop matrix elements taken from OpenLoops2 (`ppvv`, `ppvvj` and `ppvv2` packages)

  (Buccioni, Lang, Lindert, Maierhöfer, Pozzorini, Zhang, Zoller Eur.Phys.J.C 79 (2019) 10, 866)
- Two-loop virtual implemented analytically

  (Anastasiou, Glover, Tejeda-Yeomans Nucl.Phys.B 629 (2002) 255-289)

Phase space cuts and photon isolation criterion

In order to make the **cross section well defined** we need to apply several cuts at generation level

- Three hard **phase space cuts** on the momenta of the photons

$$p_{\mathrm{T}\gamma_1} > p_{\mathrm{T}\gamma_1}^{\mathrm{min}} \qquad p_{\mathrm{T}\gamma_2} > p_{\mathrm{T}\gamma_2}^{\mathrm{min}} \qquad m_{\gamma\gamma} > m_{\gamma\gamma}^{\mathrm{min}}$$

- **Frixione isolation algorithm** (Frixione Phys.Lett.B 429 (1998) 369-374)
  A phase space point with n_{part} final partons is rejected unless, for every photon γ and every angular distance R

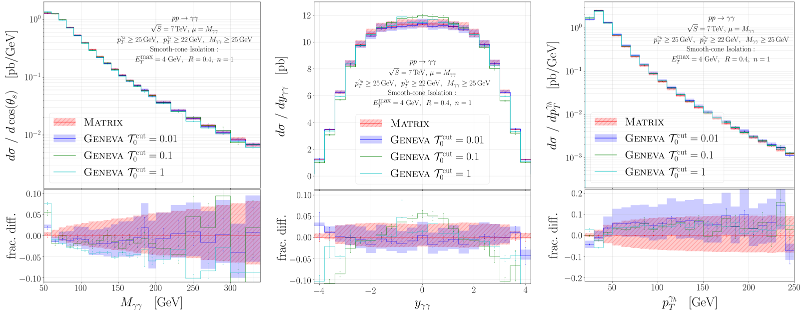
$$\sum_{i=1}^{n_{\mathrm{part}}} p_{\mathrm{T}i}\, \theta(R - R_{i\gamma}) < E_{\mathrm{T}}^{\mathrm{max}} \left(\frac{1 - \cos R}{1 - \cos R_{\mathrm{iso}}} \right)^n$$

where

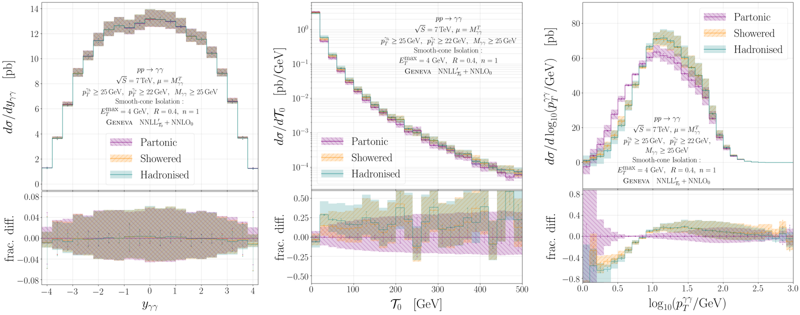
$$R_{i\gamma} = \sqrt{(\eta_i - \eta_\gamma)^2 + (\phi_i - \phi_\gamma)^2}$$

Validation of the code

Comparison of the GENEVA results at partonic level with the distributions obtained from the fixed-order (NNLO) calculation implemented in MATRIX. The bands represent the theory uncertainty estimated through a 3-point scale variation, while the vertical bars are the statistical errors from the Monte Carlo integration.

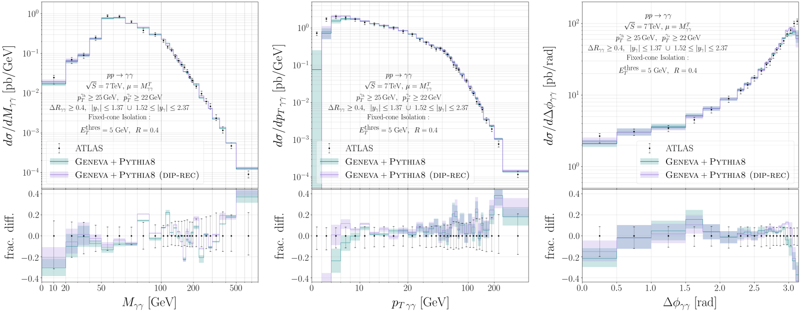


Parton shower and hadronization



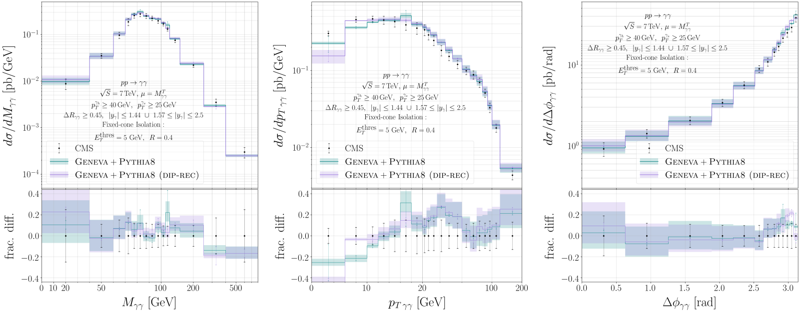
Effects of the matching with parton shower and hadronization

Phenomenological results (ATLAS)



ATLAS measurements at 7 TeV from JHEP01(2013)086

Phenomenological results (CMS)



CMS measurements at 7 TeV from Eur. Phys. J. C 74 (2014) 3129

Thanks for your attention!