Zp_T description in GENEVA

Simone Alioli

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http://geneva.physics.lbl.gov

SA, C. Bauer, C. Berggren, A. Hornig, F. Tackmann, C. Vermilion, J. Walsh, S. Zuberi JHEP09(2013)120

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Introduction

GENEVA combines the 3 theoretical tools we use for QCD predictions into a single framework:

1) Fully differential fixed-order calculations

- up to NNLO via *N*-jettiness subtraction

2) Higher-logarithmic resummation

- up to NNLL′ via SCET (but not limited to it)

3) Parton showering, hadronization and MPI

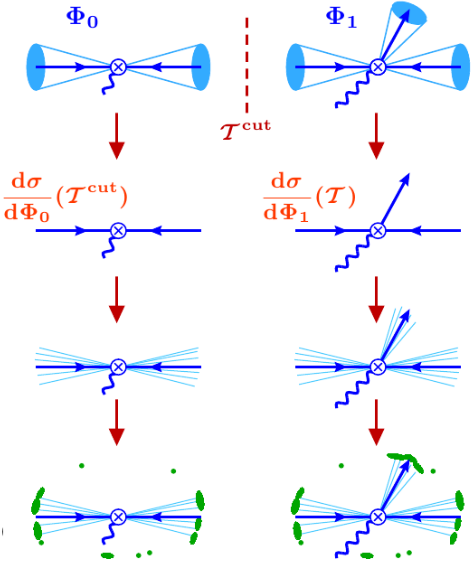
- recycling standard SMC (currently using PYTHIA8)

Resulting Monte Carlo event generator has many advantages:

- consistently improves perturbative accuracy away from FO regions
- provides event-by-event systematic estimate of theoretical perturbative uncertainties and correlations
- gives a direct interface to SMC hadronization, MPI modeling and detector simulations.

GENEVA in a nutshell: Drell-Yan production

1. Design IR-finite definition of events, based on resolution parameters $\mathcal{T}_0^{\rm cut}$.
2. Associate differential cross-sections to events such that 0-jet events are (N)NLO accurate and $\mathcal{T}_0$ is resummed at NNLL' accuracy
3. Shower events imposing conditions to avoid spoiling NNLL' accuracy reached at step 2
4. Hadronize, add multi-parton interactions (MPI) and decay without further restrictions



Combining resummation with fixed-order in GENEVA

For Drell-Yan at NNLO provide partonic formulae for up to 2 extra partons.

- $0-$jet exclusive cross section

$$\frac{d\sigma_0^{\mathrm{MC}}}{d\Phi_0}(\mathcal{T}_0^{\mathrm{cut}}) = \frac{d\sigma_0^{\mathrm{NNLL}'}}{d\Phi_0}(\mathcal{T}_0^{\mathrm{cut}}) + \frac{d\sigma_0^{\mathrm{nons}}}{d\Phi_0}(\mathcal{T}_0^{\mathrm{cut}})$$

$$\frac{d\sigma^{\mathrm{NNLL}'}}{d\Phi_0}(\mathcal{T}_0^{\mathrm{cut}}) = \int_0^{\mathcal{T}_0^{\mathrm{cut}}} d\mathcal{T}_0 \sum_{ij} \frac{d\sigma_{ij}^B}{d\Phi_0} H_{ij}(Q^2, \mu_H)\, U_H(\mu_H, \mu)$$
$$\times \left[B_i(x_a, \mu_B) \otimes U_B(\mu_B, \mu)\right] \times \left[B_j(x_b, \mu_B) \otimes U_B(\mu_B, \mu)\right]$$
$$\otimes \left[S(\mu_S) \otimes U_S(\mu_S, \mu)\right],$$

- SCET factorization: hard, beam and soft function depend on a single scale. No large logarithms present when scales are at their characteristic values:

$$\mu_H = Q, \quad \mu_B = \sqrt{Q\mathcal{T}_0}, \quad \mu_S = \mathcal{T}_0$$

- Resummation performed via RGE evolution factors U to a common scale μ.
- At NNLL' all singular contributions to $\mathcal{O}\left(\alpha_s^2\right)$ already included by definition.
- Two-loop virtual corrections properly spread to nonzero $\mathcal{T}_0$ by resummation.
- Nonsingular matching constrained by requirement of NNLO$_0$ accuracy.

Combining resummation with fixed-order in GENEVA

For Drell-Yan at NNLO provide partonic formulae for up to 2 extra partons.

- $1-$jet inclusive cross section

$$\frac{d\sigma^{\mathsf{MC}}_{\geq 1}}{d\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}}) = \frac{d\sigma^{\mathrm{NNLL}'}_{\geq 1}}{d\Phi_1}\,\theta(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}}) + \frac{d\sigma^{\mathrm{nons}}_{\geq 1}}{d\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}})$$

$$\frac{d\sigma^{\mathsf{MC}}_{\geq 1}}{d\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}}) = \frac{d\sigma^{\mathrm{NNLL}'}_{\geq 1}}{d\Phi_1}\,\theta(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}}) + \frac{d\sigma^{\mathrm{nons}}_{\geq 1}}{d\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}})$$

$$\frac{d\sigma^{\mathrm{NNLL}'}_{\geq 1}}{d\Phi_1}\,\theta(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}}) = \frac{d\sigma^{\mathrm{NNLL}'}}{d\Phi_0 d\mathcal{T}_0}\,\mathcal{P}(\Phi_1)\,\theta(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}})$$

- Resummed formula only differential in $\Phi_0, \mathcal{T}_0$. Need to make it differential in 2 more variables, e.g. energy ratio $z = E_M/E_S$ and azimuthal angle ϕ
- We use a normalized splitting probability to make the resummation differential in Φ_1.
- All singular $\mathcal{O}\left(\alpha_s^2\right)$ terms again included at NNLL' by definition.
- Nonsingular matching fixed by NLO_1 requirement

Combining resummation with fixed-order in GENEVA

For Drell-Yan at NNLO provide partonic formulae for up to 2 extra partons.

- The separation between 1 and 2 jets is determined by the NLL resummation of $\mathcal{T}_1^{\rm cut}$
  - Results in lengthier expressions. Need to include both the $\mathcal{T}_0$ and $\mathcal{T}_1$ resummations. See arXiv: 1508.01475 and arXiv: 1605.07192 for derivation.

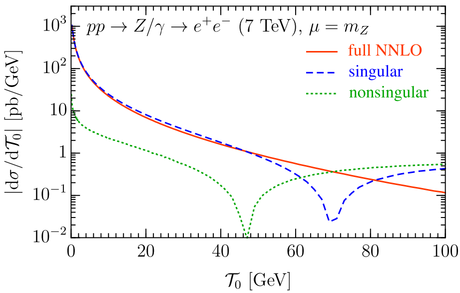
$$\frac{d\sigma_1^{\rm MC}}{d\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\rm cut}; \mathcal{T}_1^{\rm cut}) = \frac{d\sigma_{\geq 1}^{C}}{d\Phi_1} U_1(\Phi_1, \mathcal{T}_1^{\rm cut})\,\theta(\mathcal{T}_0 > \mathcal{T}_0^{\rm cut}) + \frac{d\sigma_1^{\rm match}}{d\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\rm cut}; \mathcal{T}_1^{\rm cut})$$

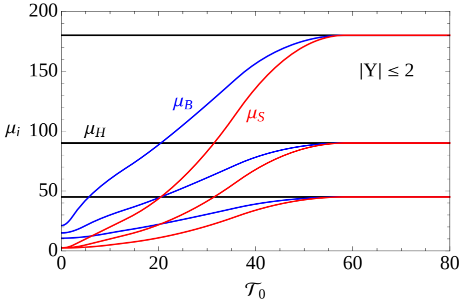
$$\frac{d\sigma_{\geq 2}^{\rm MC}}{d\Phi_2}(\mathcal{T}_0 > \mathcal{T}_0^{\rm cut}, \mathcal{T}_1 > \mathcal{T}_1^{\rm cut}) = \frac{d\sigma_{\geq 1}^{C}}{d\Phi_1} U_1'(\Phi_1, \mathcal{T}_1)\,\theta(\mathcal{T}_0 > \mathcal{T}_0^{\rm cut})\Big|_{\Phi_1 = \Phi_1^{\mathcal{T}}(\Phi_2)} \times \mathcal{P}(\Phi_2)\,\theta(\mathcal{T}_1 > \mathcal{T}_1^{\rm cut}) + \frac{d\sigma_{\geq 2}^{\rm match}}{d\Phi_2}(\mathcal{T}_0 > \mathcal{T}_0^{\rm cut}, \mathcal{T}_1 > \mathcal{T}_1^{\rm cut})$$

$$\frac{d\sigma_{\geq 1}^{C}}{d\Phi_1} = \frac{d\sigma_{\geq 1}^{\rm NNLL'}}{d\Phi_1} + (B_1 + V_1^C)(\Phi_1) - \left[\frac{d\sigma_{\geq 1}^{\rm NNLL'}}{d\Phi_1}\right]_{\rm NLO_1}$$

  - The fully differential $\mathcal{T}_0$ information is contained trough $\frac{d\sigma_{\geq 1}^{\rm NNLL'}}{d\Phi_1}$

Scale profiles and theoretical uncertainties





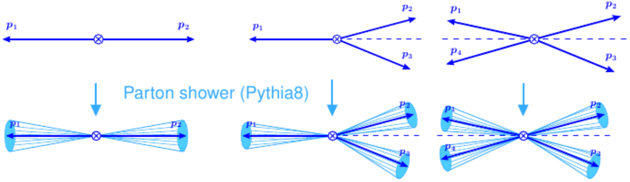
- Theoretical uncertainties in resum. are evaluated by independently varying each μ.
- Range of variations is tuned to turn off the resummation before the nonsingular dominates and to respect SCET scaling $\mu_H \gtrsim \mu_B \gtrsim \mu_S$
- FO unc. are usual $\{2\mu_H, \mu_H/2\}$ variations.
- Final results added in quadrature.

$$\mu_H = \mu_{\rm FO} = M_{\ell^+\ell^-}\,,$$
$$\mu_S(\mathcal{T}_0) = \mu_{\rm FO} f_{\rm run}(\mathcal{T}_0/Q)\,,$$
$$\mu_B(\mathcal{T}_0) = \mu_{\rm FO}\sqrt{f_{\rm run}(\mathcal{T}_0/Q)}$$

- $f_{\rm run}(x)$ common profile function: strict canonical scaling $x \to 0$ and switches off resummation $x \sim 1$

Adding the parton shower.

- Purpose of the parton shower is to fill the $0-$ and $1-$jet exclusive bins with radiation and add more emissions to the inclusive $2-$jet bin



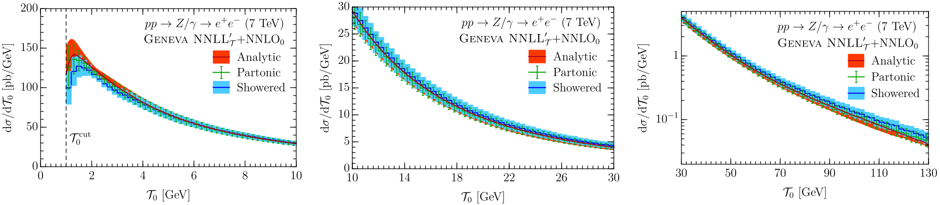
- Not allowed to change accuracy reached at partonic level.
- If shower ordered in N-jettiness setting starting scales is enough.
- For different ordering variable (i.e. any real shower), jet-boundaries constraints $\mathcal{T}_k^{\text{cut}}$ need to be imposed on hardest radiation (largest jet resolution scale)
- Impose the first emission has the largest jet resolution scale, by performing a splitting by hand using a NLL Sudakov and the $\mathcal{T}_k$-preserving map.

Showering setting starting scales $\mathcal{T}_k^{\text{cut}}$ does not spoil NNLL'+NNLO accuracy:

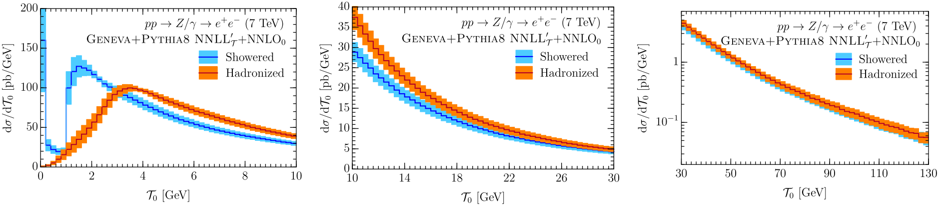
- Φ_0 events only constrained by normalization, shape given by PYTHIA
- Φ_1 events vanish forced to vanish by splitting down to $\Lambda_1 \lesssim 100$ MeV.
- Φ_2 events: PYTHIA showering can be shown to shift $\mathcal{T}_0$ distribution at the same $\alpha_s^3/\mathcal{T}_0$ order of the dominant term beyond NNLL'. Beyond claimed accuracy.

Adding hadronization and MPI

- Hadronization is left totally unconstrained by the GENEVA-PYTHIA interface
- After showering level only small changes within pert. uncertainties.



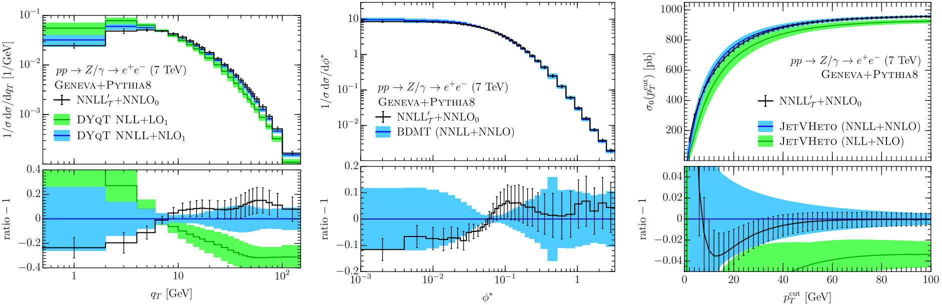
- After hadronization $\mathcal{O}(1)$ shift in peak, tail unchanged: as predicted by factorization.



- Addition of MPI complicated by PYTHIA8 interleaved evolution. Shower constraints only applied to particle arising from primary hard interaction. Secondary interactions unconstrained.

Predictions for other observables : q_T, ϕ^* and jet-veto

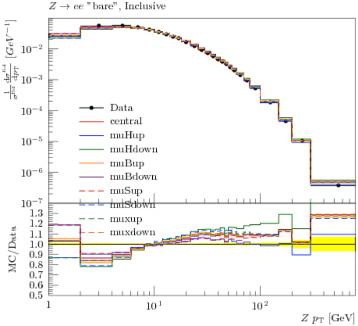
- Comparison with DYqT Bozzi et al. arXiv:1007.2351 , BDMT Banfi et al. arXiv:1205.4760 and JetVHeto Banfi et al. 1308.4634
- Analytic NNLL predictions formally higher log accuracy than GENEVA
- PYTHIA8 provides non-perturbative hadronization corrections

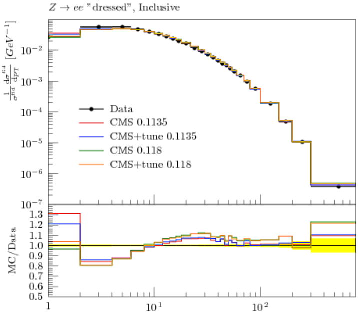


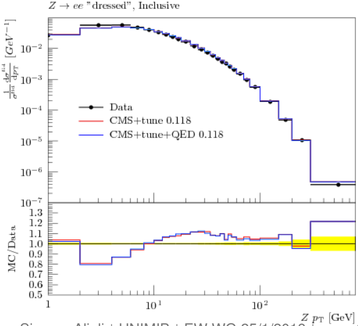
- Very low end highly sensitive to non-pertub. effects, k_T smearing.
- Smaller unc. in GENEVA there not necessarily an indication of higher precision.
- No sistematic tuning attempt, nor inclusion of shower uncertainties yet.

Results for Zp_T

- Perturbative uncertainty via different weights
- Shower uncertainty via different shower parameters
- Hadronization/MPI unc. via different tunes
- non-trivial interplay for observables which are not the resolution parameter







Thank you for your attention!