Drell-Yan production at NNLO+NNLL' in GENEVA

Improving shower Monte Carlo event generators with higher-order analytical resummation.

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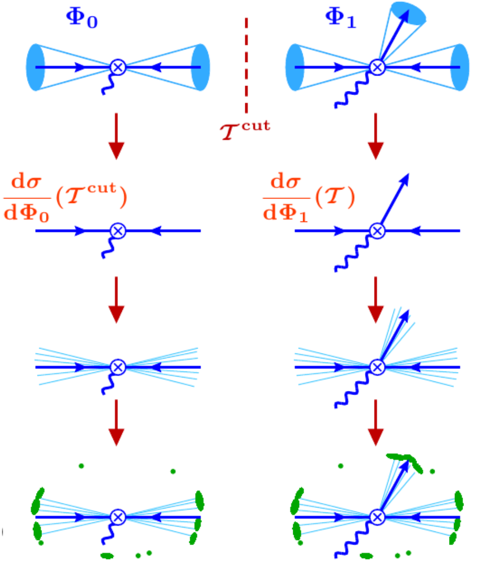
SA, C. Bauer, C. Berggren, A. Hornig, F. Tackmann, C. Vermilion, J. Walsh, S. Zuberi JHEP09(2013)120

SA, C. Bauer, C. Berggren, F. Tackmann, J. Walsh, S. Zuberi JHEP06(2014)089

SA, C. Bauer, C. Berggren, F. Tackmann, J. Walsh, Phys.Rev. D92 (2015) 9

GENEVA

1. Start from an IR-finite NLO definition of events, based on resolution parameters $\mathcal{T}_N^{\mathrm{cut}}$.
2. Associate differential cross-sections to events such that inclusive jet bins are (N)NLO accurate and jet resolution is resummed at NNLL'$_{\mathcal{T}}$
3. Shower events imposing conditions to avoid spoiling higher order logarithmic accuracy reached at step 2
4. Hadronize, add MPI and decay without restrictions



GENEVA main formulae

- For Drell-Yan at NNLO need to provide partonic formulae for up to 2 extra partons.
- $0-$jet exclusive cross section

$$\frac{d\sigma_0^{\mathsf{MC}}}{d\Phi_0}(\mathcal{T}_0^{\mathrm{cut}}) = \frac{d\sigma_0^{\mathrm{resum}}}{d\Phi_0}(\mathcal{T}_0^{\mathrm{cut}}) + \frac{d\sigma_0^{\mathrm{sing\ match}}}{d\Phi_0}(\mathcal{T}_0^{\mathrm{cut}}) + \frac{d\sigma_0^{\mathrm{nons}}}{d\Phi_0}(\mathcal{T}_0^{\mathrm{cut}})$$

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

- 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.

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$$\frac{\mathrm{d}\sigma_0^{\mathrm{sing\ match}}}{\mathrm{d}\Phi_0}(\mathcal{T}_0^{\mathrm{cut}}) = 0$$

- At NNLL' all singular contributions to $\mathcal{O}\left(\alpha_s^2\right)$ already included in $\frac{\mathrm{d}\sigma^{\mathrm{NNLL}'}}{\mathrm{d}\Phi_0}(\mathcal{T}_0^{\mathrm{cut}})$ by definition. Singular matching vanishes.
- Two-loop virtual corrections properly spread to nonzero $\mathcal{T}_0$ as resummation dictates.

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$$\frac{d\sigma_0^{\mathrm{nons}}}{d\Phi_0}(\mathcal{T}_0^{\mathrm{cut}}) = \frac{d\sigma_0^{\mathrm{NNLO}_0}}{d\Phi_0}(\mathcal{T}_0^{\mathrm{cut}}) - \left[\frac{d\sigma^{\mathrm{NNLL}'}}{d\Phi_0}(\mathcal{T}_0^{\mathrm{cut}})\right]_{\mathrm{NNLO}_0}$$

- Nonsingular matching constrained by requirement of NNLO_0 accuracy.

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GENEVA main formulae

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- $1-$jet inclusive cross section

$$\frac{d\sigma^{\mathsf{MC}}_{\geq 1}}{d\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}}) = \frac{d\sigma^{\mathrm{resum}}_{\geq 1}}{d\Phi_1}\,\theta(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}}) + \frac{d\sigma^{\mathrm{sing\,match}}_{\geq 1}}{d\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}}) + \frac{d\sigma^{\mathrm{nons}}_{\geq 1}}{d\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}})$$

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

- 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.

$$\mathcal{P}(\Phi_1) = \frac{p_{\mathrm{sp}}(z,\phi)}{\sum_{\mathrm{sp}}\int_{z_{\min}(\mathcal{T}_0)}^{z_{\max}(\mathcal{T}_0)}\mathrm{d}z\mathrm{d}\phi\, p_{\mathrm{sp}}(z,\phi)}\,\frac{\mathrm{d}\Phi_0\mathrm{d}\mathcal{T}_0\mathrm{d}z\mathrm{d}\phi}{\mathrm{d}\Phi_1}, \qquad \int\frac{\mathrm{d}\Phi_1}{\mathrm{d}\Phi_0\mathrm{d}\mathcal{T}_0}\,\mathcal{P}(\Phi_1) = 1$$

- p_{sp} are based on AP splittings for FSR, weighted by PDF ratio for ISR.

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$$\frac{d\sigma^{\mathrm{nons}}_{\geq 1}}{d\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}}) = \frac{d\sigma^{\mathrm{NLO}_1}_{\geq 1}}{d\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}}) - \left[\frac{d\sigma^{\mathrm{NNLL}'}}{d\Phi_0 d\mathcal{T}_0}\,\mathcal{P}(\Phi_1)\right]_{\mathrm{NLO}_1} \theta(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}})$$

- Singular matching vanishes again at NNLL'
- Nonsingular matching fixed by NLO_1 requirement

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GENEVA main formulae

- For Drell-Yan at NNLO need to provide partonic formulae for up to 2 extra partons.
- We also perform a Sudakov-like LL resummation of $\mathcal{T}_1^{\mathrm{cut}}$ to obtain a sensible separation between 1 and 2 jets, always enforcing unitarity.
- LL is enough to interface with the shower. At the moment we use a simple

$$U_1^{(1)}(\mathcal{T}_1^{\max}, \mathcal{T}_1) = -\frac{\alpha_s(\mathcal{T}_1^{\max})(2C_F + C_A)}{2\pi} \ln^2 \frac{\mathcal{T}_1}{\mathcal{T}_1^{\max}}$$

- Results in lengthier expressions. Need to include both the $\mathcal{T}_0$ and $\mathcal{T}_1$ resummations. See ArXiv: 1508.01475 for derivation.

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$$\frac{d\sigma_1^{\mathrm{MC}}}{d\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}}; \mathcal{T}_1^{\mathrm{cut}}) = \frac{d\sigma_1^{\mathrm{resum}}}{d\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}}; \mathcal{T}_1^{\mathrm{cut}}) + \frac{d\sigma_1^{\mathrm{match}}}{d\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}}; \mathcal{T}_1^{\mathrm{cut}})$$

$$\frac{d\sigma_{\geq 2}^{\mathrm{MC}}}{d\Phi_2}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}}, \mathcal{T}_1 > \mathcal{T}_1^{\mathrm{cut}}) = \frac{d\sigma_{\geq 2}^{\mathrm{resum}}}{d\Phi_2}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}})\, \theta(\mathcal{T}_1 > \mathcal{T}_1^{\mathrm{cut}}) + \frac{d\sigma_{\geq 2}^{\mathrm{match}}}{d\Phi_2}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}}, \mathcal{T}_1 > \mathcal{T}_1^{\mathrm{cut}})$$

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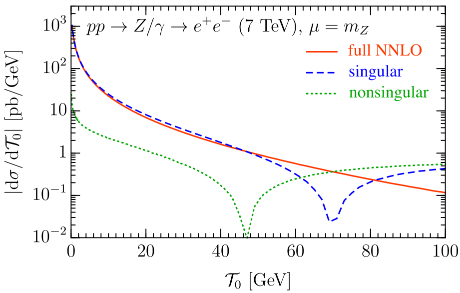
$$\frac{\mathrm{d}\sigma_1^{\rm resum}}{\mathrm{d}\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\rm cut}; \mathcal{T}_1^{\rm cut}) = \frac{\mathrm{d}\sigma_{\geq 1}^{C}}{\mathrm{d}\Phi_1} U_1(\Phi_1, \mathcal{T}_1^{\rm cut})\, \theta(\mathcal{T}_0 > \mathcal{T}_0^{\rm cut})$$

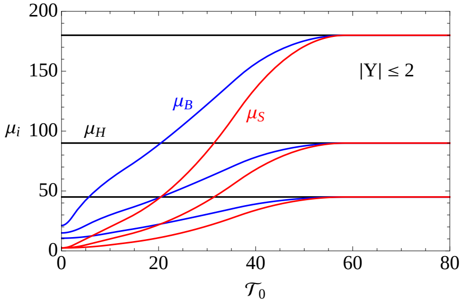
$$\frac{\mathrm{d}\sigma_{\geq 2}^{\rm resum}}{\mathrm{d}\Phi_2}(\mathcal{T}_0 > \mathcal{T}_0^{\rm cut}) = \frac{\mathrm{d}\sigma_{\geq 1}^{C}}{\mathrm{d}\Phi_1} U_1'(\Phi_1, \mathcal{T}_1)\, \theta(\mathcal{T}_0 > \mathcal{T}_0^{\rm cut})\Big|_{\Phi_1 = \Phi_1^{\mathcal{T}}(\Phi_2)} \mathcal{P}(\Phi_2)\,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

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

- The fully differential $\mathcal{T}_0$ information is contained trough $\frac{\mathrm{d}\sigma_{\geq 1}^{\rm resum}}{\mathrm{d}\Phi_1}$

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 $x \sim 1$

NNLO accuracy in GENEVA

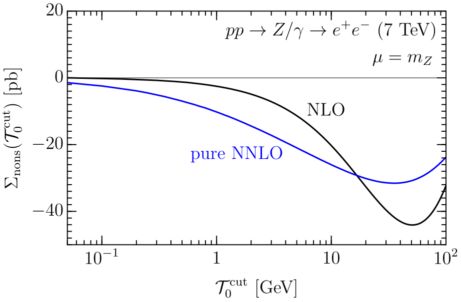
- Resum. expanded result in $\mathrm{d}\sigma^{\mathrm{nons}}_{\geq 1}/\mathrm{d}\Phi_1$ acts as a differential NNLO $\mathcal{T}_0$-subtraction

$$\frac{\mathrm{d}\sigma^{\mathrm{NLO}_1}_{\geq 1}}{\mathrm{d}\Phi_1} - \left[\frac{\mathrm{d}\sigma^{\mathrm{NNLL}'}}{\mathrm{d}\Phi_0 \mathrm{d}\mathcal{T}_0}\,\mathcal{P}(\Phi_1)\right]_{\mathrm{NLO}_1}$$

- Nonlocal cancellation in Φ_1, after averaging over $\mathrm{d}\Phi_1/\mathrm{d}\Phi_0\mathrm{d}\mathcal{T}_0$ gives finite result.
- To be local in $\mathcal{T}_0$ has to reproduce the right singular $\mathcal{T}_0$-dependence when projected onto $\mathrm{d}\mathcal{T}_0\mathrm{d}\Phi_0$.

$$\frac{\mathrm{d}\sigma^{\mathrm{nons}}_0}{\mathrm{d}\Phi_0}(\mathcal{T}_0^{\mathrm{cut}}) = \left[\alpha_{\mathrm{s}} f_1(\mathcal{T}_0^{\mathrm{cut}}, \Phi_0) + \alpha_{\mathrm{s}}^2 f_2(\mathcal{T}_0^{\mathrm{cut}}, \Phi_0)\right] \mathcal{T}_0^{\mathrm{cut}}$$

$$\Sigma_{\mathrm{nons}}(\mathcal{T}_0^{\mathrm{cut}}) = \int \mathrm{d}\Phi_0 \, \frac{\mathrm{d}\sigma^{\mathrm{nons}}_0}{\mathrm{d}\Phi_0}(\mathcal{T}_0^{\mathrm{cut}})$$



- At $\mathcal{T}_0^{\mathrm{cut}} = 1\,\mathrm{GeV}$ gives $\sim 1\%$ xsec. Small but not negligible, can be lowered further. Tradeoff with speed/stability.

- $f_1(\Phi_0, \mathcal{T}_0^{\mathrm{cut}})$ included exactly by doing NLO$_0$ on-the-fly.
- For pure NNLO$_0$, we currently neglect the Φ_0 dependence below $\mathcal{T}_0^{\mathrm{cut}}$ and include total integral via simple rescaling of $\mathrm{d}\sigma_0^{\mathrm{MC}}/\mathrm{d}\Phi_0(\mathcal{T}_0^{\mathrm{cut}})$.

Adding the parton shower.

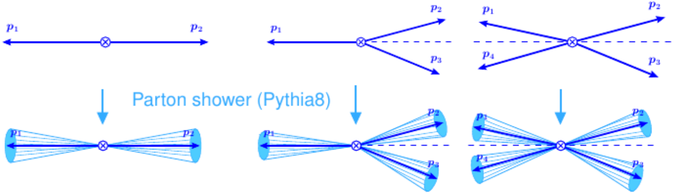
- Purpose of the parton shower is to make the partonic calculation differential in the higher multiplicities.
- Not allowed to affect jet xsec at accuracy reached at partonic level.
- $\mathcal{T}_k^{\mathrm{cut}}$ constraints must be respected.

$$\theta_{\mathcal{T}_N}(\Phi_M) \equiv \theta[\mathcal{T}_N(\Phi_M) < \mathcal{T}_N^{\mathrm{cut}}], \quad \theta_{\mathrm{map}}(\Phi_N;\Phi_{N+1}) \equiv [\Phi_{N+1} \text{ projects onto } \Phi_N]$$

- First 3 columns already for partonic calculation, last after showering

	Φ_0	Φ_1	Φ_2	Φ_N
$\mathrm{d}\sigma_0^{\mathrm{MC}}/\mathrm{d}\Phi_0$	All	$\theta_{\mathcal{T}_0}(\Phi_1)$ and $\theta_{\mathrm{map}}(\Phi_0;\Phi_1)$	$\theta_{\mathcal{T}_0}(\Phi_2)$	$\theta_{\mathcal{T}_0}(\Phi_N)$
$\mathrm{d}\sigma_1^{\mathrm{MC}}/\mathrm{d}\Phi_1$	–	$\overline{\theta}_{\mathcal{T}_0}(\Phi_1)$ or $\overline{\theta}_{\mathrm{map}}(\Phi_1)$	$\overline{\theta}_{\mathcal{T}_0}(\Phi_2)$ and $\theta_{\mathcal{T}_1}(\Phi_2)$ and $\theta_{\mathrm{map}}(\Phi_1;\Phi_2)$	$\overline{\theta}_{\mathcal{T}_0}(\Phi_N)$ and $\theta_{\mathcal{T}_1}(\Phi_N)$
$\mathrm{d}\sigma_{\geq 2}^{\mathrm{MC}}/\mathrm{d}\Phi_2$	–	–	$\overline{\theta}_{\mathcal{T}_0}(\Phi_2)$ and $\left[\overline{\theta}_{\mathcal{T}_1}(\Phi_2) \text{ or } \overline{\theta}_{\mathrm{map}}(\Phi_2)\right]$	$\overline{\theta}_{\mathcal{T}_0}(\Phi_N)$ and $\overline{\theta}_{\mathcal{T}_1}(\Phi_N)$

- Can be viewed as filling the $0-$ and $1-$jet exclusive bins with radiations and adding more to the inclusive $2-$jet bin



Adding the parton shower.

- If shower ordered in N-jettiness, $\mathcal{T}_k^{\mathrm{cut}}$ constraints are enough.
- For different ordering variable (i.e. any real shower), $\mathcal{T}_k^{\mathrm{cut}}$ constraints need to be imposed on hardest radiation (largest jet resolution scale), rather than the first. Can happen much later.
- Impose the first emission has the largest jet resolution scale, by using an LL Sudakov and the $\mathcal{T}_k$-preserving map.

$$\frac{\mathrm{d}\sigma^{\mathsf{MC}}_{N\to N}}{\mathrm{d}\Phi_N}(\mathcal{T}_N^{\mathrm{cut}};\Lambda_N) = \frac{\mathrm{d}\sigma^{\mathsf{MC}}_{N}}{\mathrm{d}\Phi_N}(\mathcal{T}_N^{\mathrm{cut}})\,U_N(\mathcal{T}_N^{\mathrm{cut}},\Lambda_N)$$

$$\frac{\mathrm{d}\sigma^{\mathsf{MC}}_{N\to N+1}}{\mathrm{d}\Phi_{N+1}}(\mathcal{T}_N > \Lambda_N, \mathcal{T}_N^{\mathrm{cut}}) = \frac{\mathrm{d}}{\mathrm{d}\mathcal{T}_N}\left[\frac{\mathrm{d}\sigma^{\mathsf{MC}}_{N\to N}}{\mathrm{d}\Phi_N}(\mathcal{T}_N^{\mathrm{cut}};\mathcal{T}_N)\right]\mathcal{P}(\Phi_{N+1})$$
$$\times\,\theta(\mathcal{T}_N^{\mathrm{cut}} > \mathcal{T}_N > \Lambda_N)$$

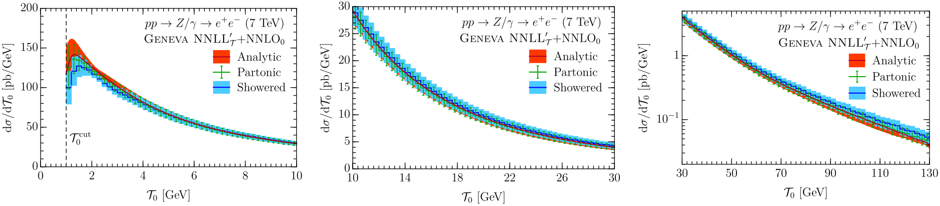
- Λ_N is shower cutoff, much lower than $\mathcal{T}_N^{\mathrm{cut}}$.

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

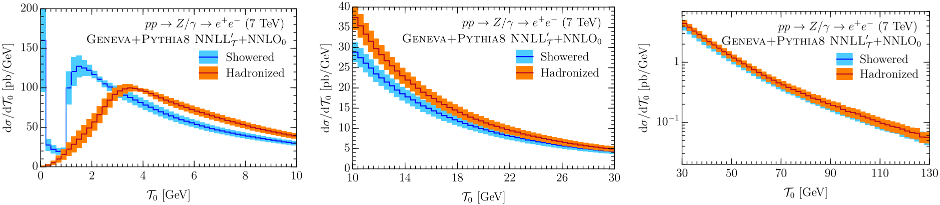
- Φ_0 events only constrained by normalization, shape given by PYTHIA
- Φ_1 events vanish for $\Lambda_1 \lesssim 100$ MeV (sub per mille ot total xsec).
- Φ_2 events: PYTHIA showering can be shown to shift $\mathcal{T}_0$ distribution at the same $\alpha_s^3/\mathcal{T}_0$ order of the dominant term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

Validation of the beam-thrust spectrum.

- Only tests correctness of implementation.
- After showering level only small changes within pert. uncertainties.



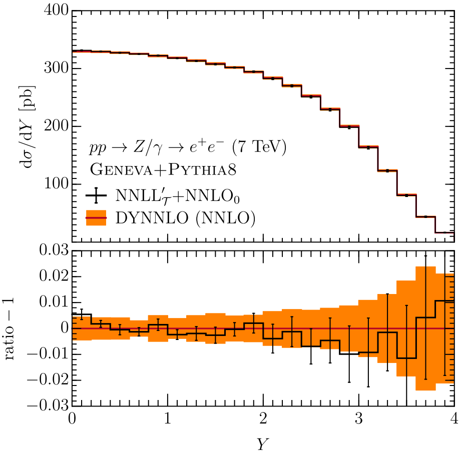
- After hadronization larger shift, as predicted by factorization.



- Benefit of GENEVA is to obtain nonperturb. corrections directly from PYTHIA8

NNLO validation

- NNLO xsec and inclusive distributions validated against DYNNLO.
  Catani, Grazzini et al. [hep-ph/0703012, 0903.2120]
  Also checked against VRAP.
  Anastasiou, Dixon et al. [hep-ph/0312266]
- Comparison for 7 TeV LHC, $\mathcal{T}_0^{\mathrm{cut}} = 1$. Very good agreement for NNLO quantities, both central scale and variations.
- Only scale variations shown as error bands, statistical fluctuations show up at large rapidities.
- Non-trivial correlations for outer scales, ad-hoc procedure to ensure exact reproducibility of fixed-order variations.



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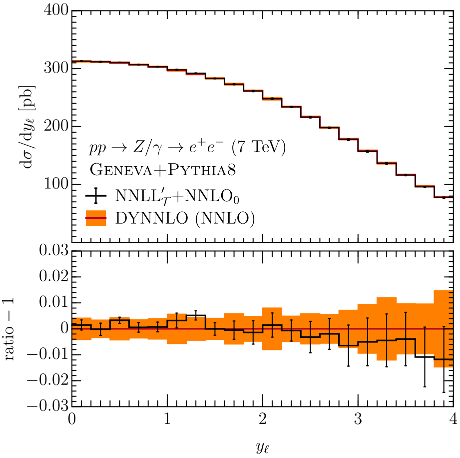

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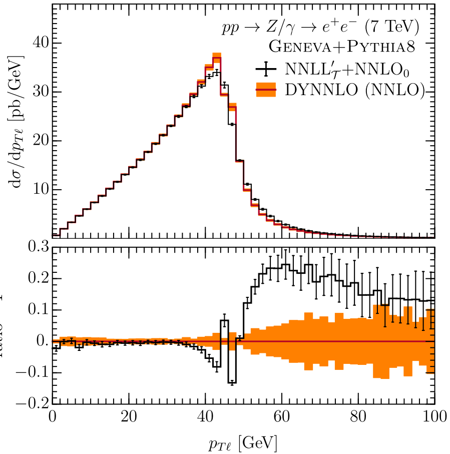
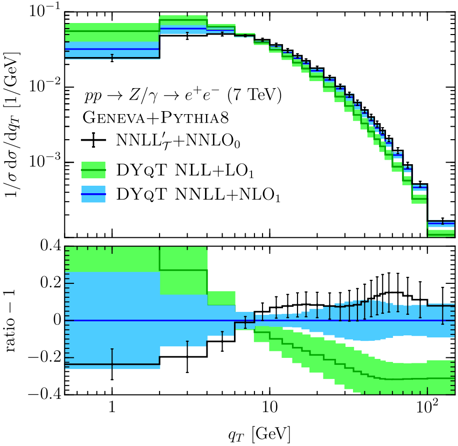
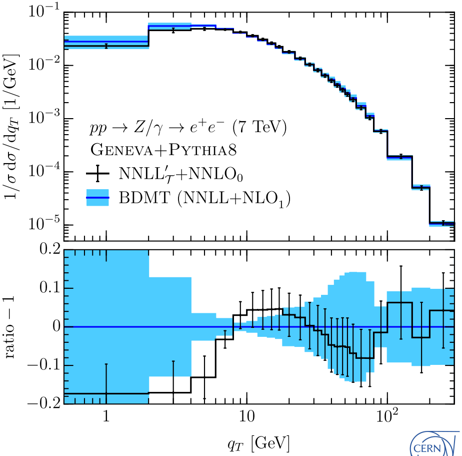


- True NNLO only for $p_{T\ell} < m_{\ell^+\ell^-}/2$. Around $m_{\ell^+\ell^-}/2$ very sensitive to Sudakov shoulder logarithms. GENEVA resumes some of these logs.
- $p_{T\ell} > m_{\ell^+\ell^-}/2$ only NLO. GENEVA results higher than NLO due to spillovers from below $m_{\ell^+\ell^-}/2$ caused by resumm. Converges back to NLO at higher $p_{T\ell}$

Predictions for other observables : q_T and ϕ^*

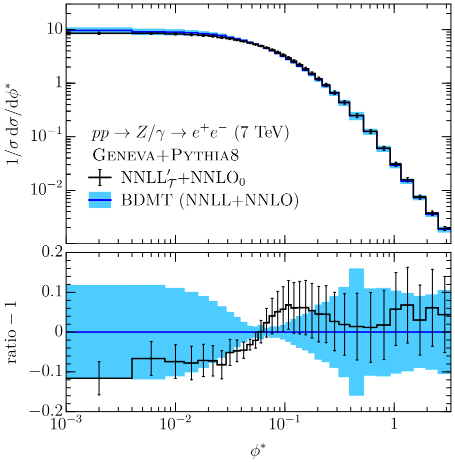
- Comparison with DYqT Bozzi et al. arXiv:1007.2351 and BDMT results Banfi et al. arXiv:1205.4760
- Inclusive cuts for DYqT, ATLAS cuts for BDMT. Each normalized to own XS.
- Analytic NNLL predictions formally higher log accuracy than GENEVA
- PYTHIA8 provides non-perturbative hadronization corrections





Predictions for other observables : q_T and ϕ^*

- Comparison with DYqT Bozzi et al. arXiv:1007.2351 and BDMT results Banfi et al. arXiv:1205.4760
- Inclusive cuts for DYqT, ATLAS cuts for BDMT. Each normalized to own XS.
- Analytic NNLL predictions formally higher log accuracy than GENEVA
- PYTHIA8 provides non-perturbative hadronization corrections



- ϕ^* strongly correlated to q_T

$$\phi^* = \tan\left(\frac{\pi - \Delta\phi}{2}\right)\sin\theta^* \approx \left|\sum_i \frac{k_{T,i}}{Q}\sin\phi_i\right|$$

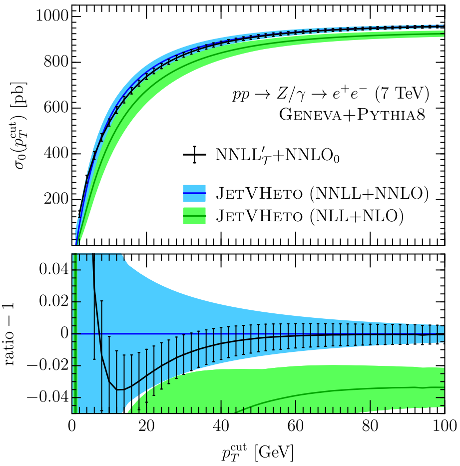
- Very low end highly sensitive to non-pertub. effects, k_T smearing.
- Smaller unc. in GENEVA there not necessarily an indication of higher precision.
- No sistematic tuning attempt, nor inclusion of shower uncert. yet.

Predictions for other observables : jet-veto acceptance

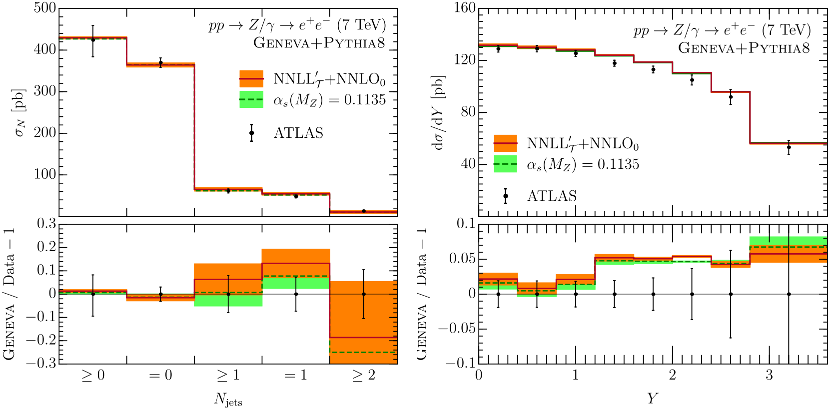
- Comparison with JetVHeto

  Banfi et al. 1308.4634

- Analytic predictions at NNLL formally higher log accuracy than GENEVA
- Correctly gets total xsec in the tail.
- Non-trivial propagation of spectrum uncertainties to cumulant result. Neglecting correlations yield much larger uncertainties.
- Imposing total XS hard variations only results in smaller uncertainties in peak region.



Comparisons with data



- Used RIVET [Buckley et al. 1003.0694] analyses to ensure full compliance with exp. selection.
- Also showing results for $\alpha_s(M_Z) = 0.1135$ in GENEVA perturbative calculation.
- Good agreement for both inclusive and exclusive jet cross sections.
- Given agreement with NNLO, Z rapidity distributions mostly driven by PDF used (CT10nnlo), same deviations observed in ATLAS and LHCb papers.

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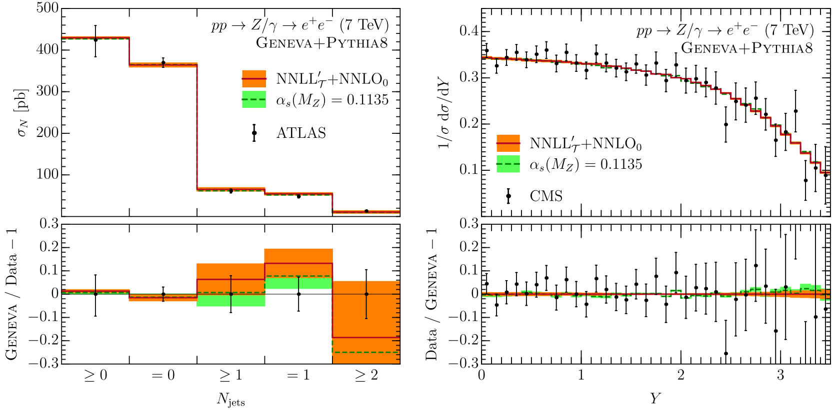

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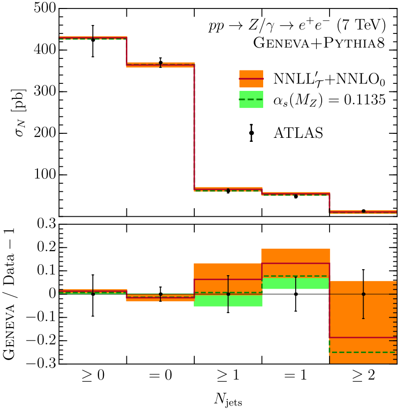

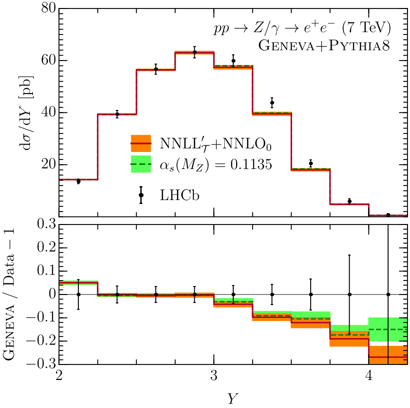

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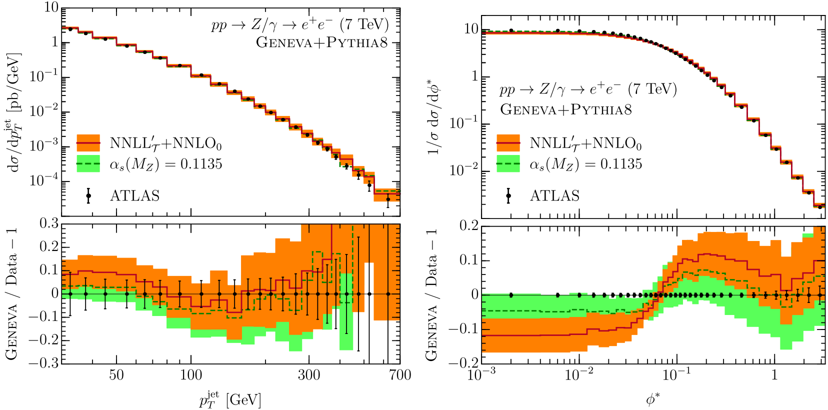
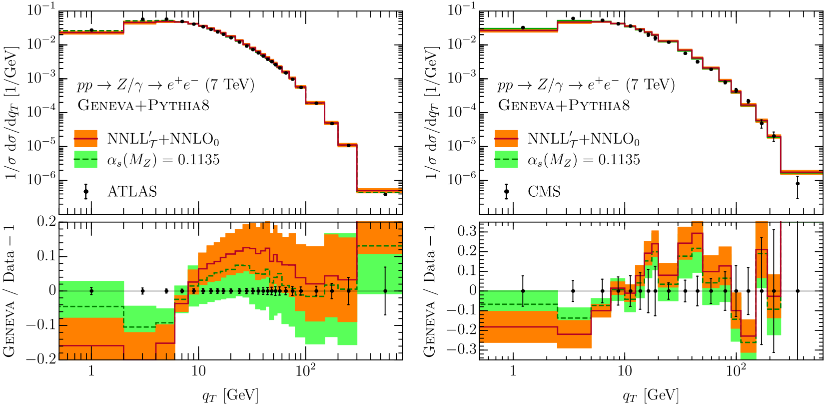


- Hardest jet only precited at NLO. At high-p_{T} larger deviations, still within unc. Improvable by using dynamical scale $\alpha_{\mathrm{s}}(p_{\mathrm{T}})$.
- ϕ^* highly sensitive to resummation, similar results reported by ATLAS comparing with BDMT. Better agreement with lower $\alpha_{\mathrm{s}}(M_Z) = 0.1135$.

Comparisons with data



- Similar trend observed in ϕ^* case. Two measurements highly correlated.
- Good agreement with ATLAS and CMS. For ATLAS also in different Z rapidity bins.
- Recent results from DYRES [Catani et al. 1507.06937] also show remarkable agreement with data.
- NNLO Zj K-factor in $[50 - 100]$ GeV region $\sim 10\%$ [Gehrmann et al. 1507.02850].

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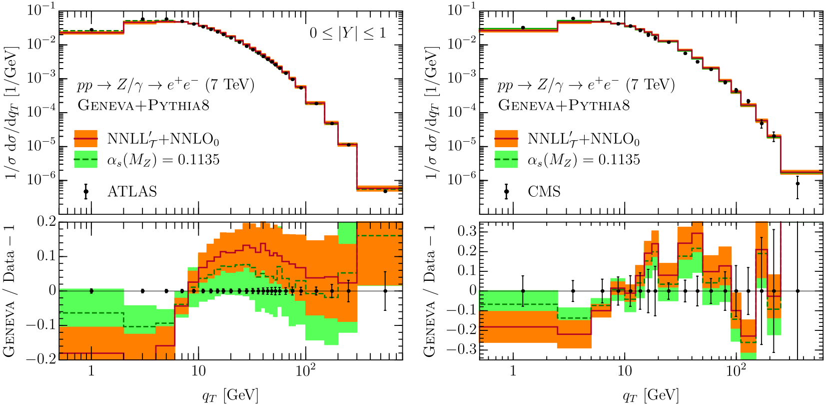

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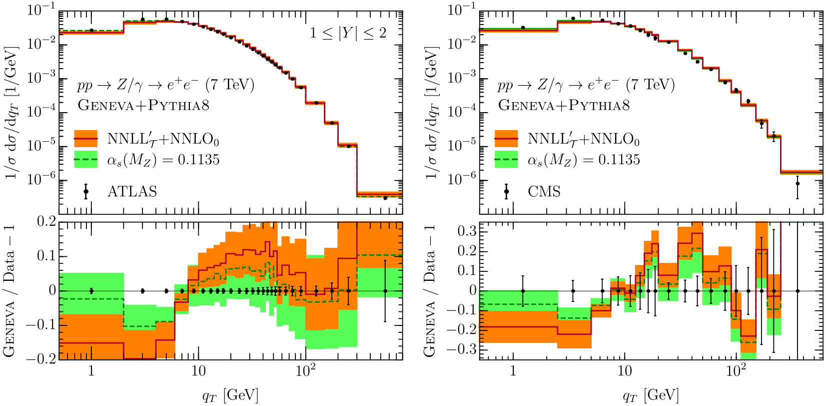

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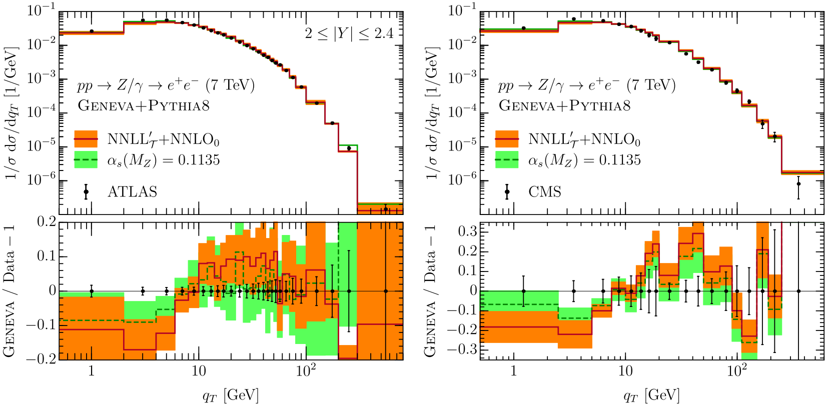

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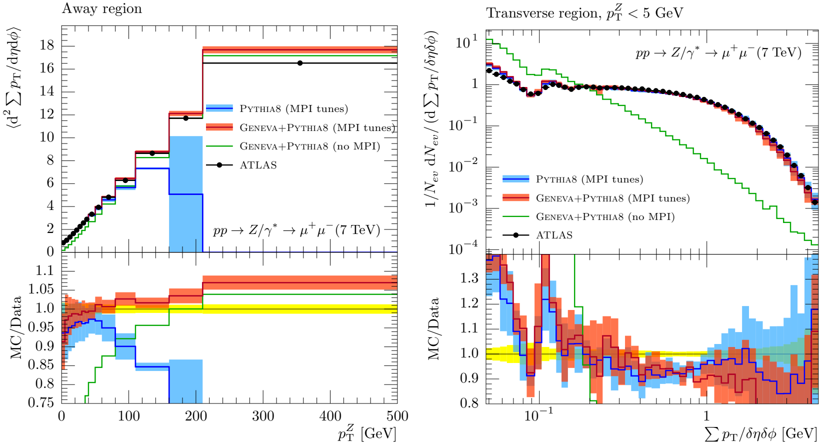
Adding MPI



- MPI effects provided by the PYTHIA8 interleaved evolution.
- We apply shower constraints independently from MPI.
- Less sensitivity to MPI tune model compared to standalone PYTHIA 8
- Good agreement with data, improves standalone PYTHIA8 in hard regions.

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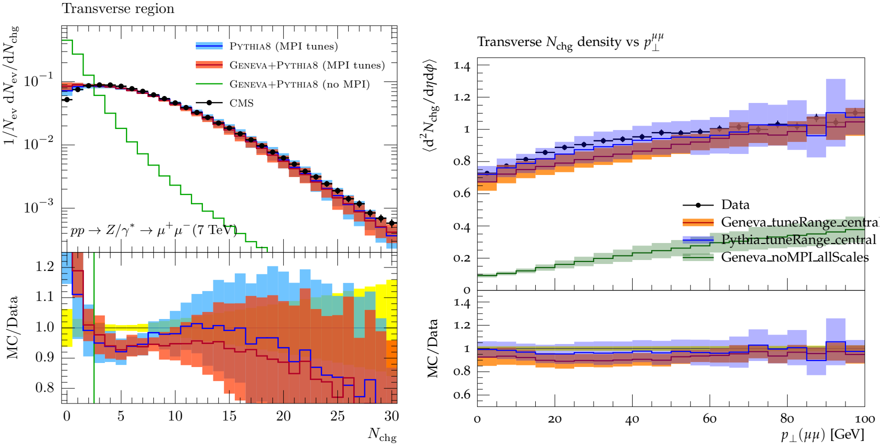

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Conclusions

GENEVA is a NNLO event generator that can be interfaced with shower/hadronization.

- Based on IR-safe, jet-like definitions of events.
- Uses a physics observable, N-jettiness, factorizable and whose resummation is known to NNLL as jet resolution parameter.
- Method tested for e^+e^- and Drell-Yan. Results extremely encouraging.
- Good agreement with analytical calculation / tools and with LHC data.
- Novel approach to NNLO+PS : competitive with MINLO-based NNLO+PS and UNNLOPS, spreading of two-loop contributions dictacted by resummation.
- Can directly take advantage of SMC's hadronization and MPI models.
- Room for improved agreement from tailored GENEVA+PYTHIA8 tuning.
- Drell-Yan production just the first example of application of the method for hadronic colliders, more to come ... stay tuned !

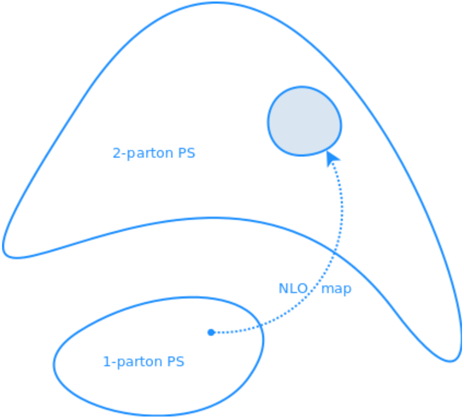
Thank you for your attention!

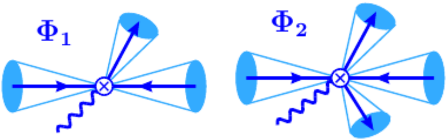
Backup

Preserving the $\mathcal{T}_0$ value in $V+1 \to V+2$ partons splittings

$$\frac{d\sigma^{\rm NLO}}{d\Phi_1}(\mathcal{T}_0) = [B_1(\Phi_1) + V_1(\Phi_1)]\,\delta(\mathcal{T}(\Phi_1) - \mathcal{T}_0) + \int \frac{d\Phi_2}{d\Phi_1} B_2(\Phi_2)\delta\left(\mathcal{T}(\Phi_1(\Phi_2)) - \mathcal{T}_0\right)$$

- When calculating NLO_1 we must preserve $d\Phi_1$. Cannot re-use existing calculations.
- Real emissions must preserve both $d^4q\;\delta(q^2 - M^2_{\ell^+\ell^-})$ and $\mathcal{T}_0 \equiv \bar{p}_{T,1}e^{-|y_V - \bar{\eta}_1|} = p_{T,1}e^{-|y_V - \eta_1|} + p_{T,2}e^{-|y_V - \eta_2|}$.

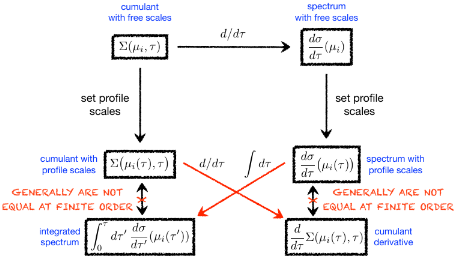




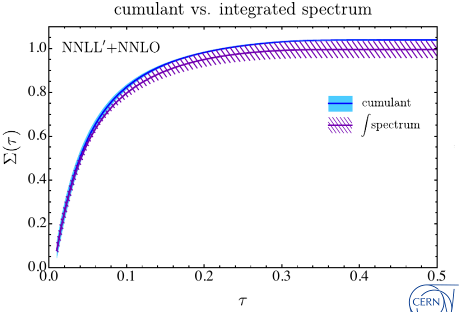
- Standard FKS or CS map don't preserve $\mathcal{T}_0$. They are designed to preserve other quantities. We had to design our own map.
- This map makes $\mathcal{T}_0$-subtraction local in $\mathcal{T}_0$. Better numerical convergence. Still averaged over $d\Omega_2$

Preserving the total cross-section

- Different advantages in resumming the cumulant (better cross-section and correlated unc.) or the spectrum (better profiles in trans and tail region and better point-by-point unc.)
- The two approaches only agree at all order. When the series is truncated results are different. Numerical problem when aiming at NNLO precision.
- Enforcing equivalence by taking derivative or integrating results in unreliable uncertainties.
- Similar problem in preserving total xsec in matched QCD resummation solved with ad-hoc smoother.
- We add higher-order term to the spectrum such that integral get closer to cumulant. Add the exact difference to central to restore it completely.
- Correlations now enforced by hand for up/down scales, automatic method to select profile scale enforcing correlations under investigation.



[slide from J. Walsh]



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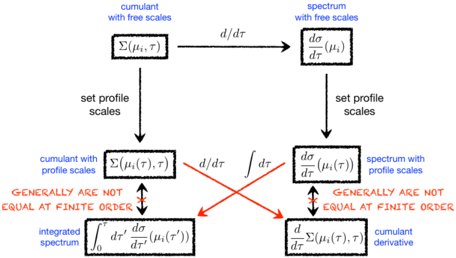

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