New simpler methods of matching NLO corrections with parton shower Monte Carlo

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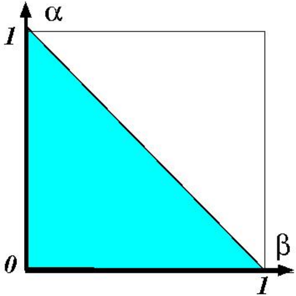
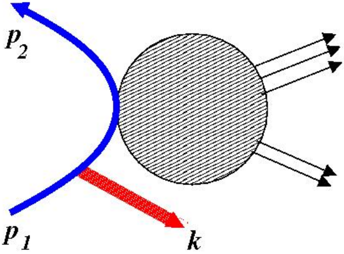
NLO corrections to hard process, KrkNLO method

1. Methodology of the KrkNLO for DY process was defined in Ustron 2011 Proc., but without numerical test:
   Acta Phys.Polon. B42 (2011) 2433 , [arXiv:1111.5368]
2. Numerical validation of KrkNLO on top of Double-CMC toy model PS MC next shown in:
   Acta Phys.Polon. B43 (2012) 2067 , [arXiv:1209.4291]
3. Complete theoretical discussion of the KrkNLO scheme, with introduction PDFs in the MC factorization scheme, provided in:
   Phys.Rev. D87 (2013) 3, 034029 , [arXiv:1103.5015],
   but MC implementation still on top of not so realistic Double-CMC PS.
4. First realistic implementation of top of SHERPA and HERWIG in *JHEP 1510 (2015) 052* [arXiv:1503.06849], including also comparisons of KrkNLO numerical results with NLO calculations of MCFM (fixed order), MC@NLO and POWHEG, all that for Drell-Yan process.
5. NEW in this presentation: (i) Mature definition of PDFs in the MC factorization scheme (ii) more on universality, (iii) application to Higgs production process.

Sudakov variables in DY

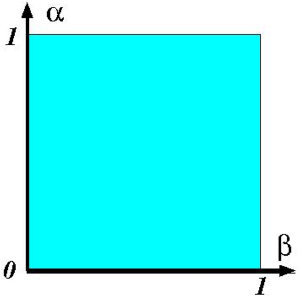


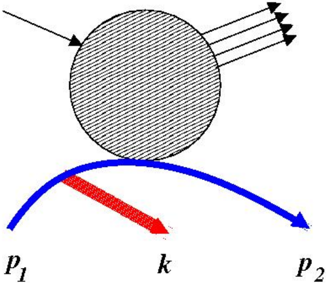


$$\alpha = \frac{(kp_1)}{(p_1p_2)}, \quad \beta = \frac{(kp_2)}{(p_1p_2)},$$

$$\alpha + \beta \le 1, \quad \alpha \ge 0,\ \beta \ge 0.$$

Sudakov variables in DIS





$$\alpha = \frac{(kp_1)}{(p_1 p_2) + (kp_1)}, \quad \beta = \frac{(kp_2)}{(p_1 p_2) + (kp_1)},$$

$$\max(\alpha,\beta) \le 1, \quad \alpha \ge 0,\ \beta \ge 0.$$

Recipe of the KrkNLO method is unbelievably simple:

Spin zero Higgs production

Take event generated by the LO parton shower MC as is and apply simple positive well behaved weight:

- $g+g \longrightarrow H, H+g$:

$$W^{\rm MC}_{gg}(\alpha,\beta) = \frac{1+z^4+\alpha^4+\beta^4}{1+z^4+(1-z)^4}(1+\Delta^{\rm MC}_{VS}),$$

$$\Delta^{\rm MC}_{VS} = \frac{\alpha_s}{2\pi}\,2C_A\left[\frac{473}{72}+\frac{2\pi^2}{3}-\frac{T_f}{C_A}\frac{59}{36}\right].$$

- $g+q \longrightarrow H+q$:

$$W^{\rm MC}_{gq}(\alpha,\beta) = \frac{1+\beta^2}{1+(1-z)^2} \quad \leq 1,$$

The above recipe is dramatically simpler than POWHEG or MC&NLO. However, several nontrivial conditions has to be met before it works.
Most important are:
(1) the use of PDFs in the physical MC factorization scheme,
(2) certain minimum quality of the PS MC, see next slides.

Recipe of the KrkNLO method is extremely simple:

$pp \to Z/\gamma^*$, DY

Take event generated by the LO parton shower MC as is and apply simple positive well behaved weight:

- $q + \bar{q} \longrightarrow Z, Z + g$

$$W^{MC}_{q\bar{q}}(\alpha,\beta) = \left\langle \frac{|\mathcal{M}^{NLO}_{q\bar{q}\to Zg}|^2}{|\mathcal{M}^{MC}_{q\bar{q}\to Zg}|^2} \right\rangle_{\text{Z decay}} = \left(1 - \frac{2\alpha\beta}{1+z^2}\right)(1 + \Delta^{MC}_{VS}),$$

$$\Delta^{MC}_{VS} = \frac{\alpha_s}{2\pi}\left(\frac{4\pi^2}{3} + \frac{1}{2}\right).$$

- $q + g \longrightarrow Z + q$:

$$W^{MC}_{qg}(\alpha,\beta) = \left\langle \frac{|\mathcal{M}^{NLO}_{qg\to Zq}|^2}{|\mathcal{M}^{MC}_{qg\to Zq}|^2} \right\rangle_{\text{Z deday}} = 1 + \frac{\alpha(\alpha+2z)}{z^2 + (1-z)^2}.$$

Without averaging over Z decay MC weight is also quite simple, see next slide.

Immediate question: Which α, β? Which parton?
Answer: of the parton with maximum kT

- For PSMC with kT-ordering, the 1-st parton in the backward evolution.
- For angular ordering parton with maximum kT to be found in MC event.
- Alternatively, one may use formula with "democratic" sum over all gluons. An example of multiple gluon emission in DY:

$$d\sigma_n^{\rm NLO} = \Big(1 + \Delta_{VS} + \sum_{i=1}^{n} W_{q\bar{q}}^{[1]}(\alpha_i, \beta_i)\Big) d\sigma_n^{\rm LO},$$

$$W_{q\bar{q}}^{[1]} = \frac{d^5\bar{\beta}_{q\bar{q}}}{d^5\sigma_{q\bar{q}}^{\rm LO}} = \frac{d^5\sigma_{q\bar{q}}^{\rm NLO} - d^5\sigma_{q\bar{q}}^{\rm LO}}{d^5\sigma_{q\bar{q}}^{\rm LO}}, \qquad \Delta_{VS}^{q\bar{q}} = \frac{\alpha_s}{2\pi} C_F \left[\frac{4}{3}\pi^2 - \frac{5}{2}\right],$$

$$d^5\sigma_{q\bar{q}}^{NLO}(\alpha, \beta, \Omega) = \frac{C_F\alpha_s}{\pi} \frac{d\alpha d\beta}{\alpha\beta} \frac{d\varphi}{2\pi} d\Omega \left[\frac{d\sigma_0(\hat{s}, \theta_F)}{d\Omega} \frac{(1-\beta)^2}{2} + \frac{d\sigma_0(\hat{s}, \theta_B)}{d\Omega} \frac{(1-\alpha)^2}{2}\right],$$

$$d^5\sigma_{q\bar{q}}^{\rm LO}(\alpha, \beta, \Omega) = d^5\sigma_{q\bar{q}}^F + d^5\sigma_{q\bar{q}}^B = \frac{C_F\alpha_s}{\pi} \frac{d\alpha d\beta}{\alpha\beta} \frac{d\varphi}{2\pi} d\Omega \frac{1 + (1-\alpha-\beta)^2}{2} \frac{d\sigma_0}{d\Omega}(\hat{s}, \hat{\theta}),$$

- This exploits Sudakov suppression as in POWHEG, but no need of truncated shower for angular ordering.

List of conditions for KrkNLO methodology to work

and other issues to be clarified

- **PDFs in MC factorization scheme – an absolute must!**
- **LO PSMC reproduces precisely all collinear and soft singularities of the NLO** ***(nontrivial for LO processes with*** ≥ 3 ***coloured legs)*** **and covers the entire NLO phase space**
- **The question of universality of the MC factorization scheme. Does it work for** ≥ 3 **coloured emitters at LO?**

Definition of LO PDFs in MC factorization scheme

in terms of PDFs in $\overline{MS}$ scheme

$$\begin{bmatrix} q(x,Q^2) \\ \bar{q}(x,Q^2) \\ G(x,Q^2) \end{bmatrix}_{\rm MC} = \int dzdy \begin{bmatrix} K^{\rm MC}_{qq}(z) & 0 & K^{\rm MC}_{qG}(z) \\ 0 & K^{\rm MC}_{\bar{q}\bar{q}}(z) & K^{\rm MC}_{\bar{q}G}(z) \\ K^{\rm MC}_{Gq}(z) & K^{\rm MC}_{G\bar{q}}(z) & K^{\rm MC}_{GG}(z) \end{bmatrix} \begin{bmatrix} q(y,Q^2) \\ \bar{q}(y,Q^2) \\ G(y,Q^2) \end{bmatrix}_{\overline{MS}} \delta(x-yz)$$

where

$$K^{\rm MC}_{Gq}(z) = \frac{\alpha_s}{2\pi}\, C_F \left\{ \frac{1+(1-z)^2}{z} \ln \frac{(1-z)^2}{z} + z \right\},$$

$$K^{\rm MC}_{GG}(z) = \frac{\alpha_s}{2\pi}\, C_A \left\{ 4\left[\frac{\ln(1-z)}{1-z}\right]_+ + 2\left[\frac{1}{z} - 2 + z(1-z)\right] \ln\frac{(1-z)^2}{z} - 2\frac{\ln z}{1-z} - \delta(1-z)\left(\frac{\pi^2}{3} + \frac{341}{72} - \frac{59}{36}\frac{T_f}{C_A}\right)\right.,$$

$$K^{\rm MC}_{qq}(z) = \frac{\alpha_s}{2\pi}\, C_F \left\{ 4\left[\frac{\ln(1-z)}{1-z}\right]_+ - (1+z)\ln\frac{(1-z)^2}{z} - 2\frac{\ln z}{1-z} + 1 - z - \delta(1-z)\left(\frac{\pi^2}{3} + \frac{17}{4}\right) \right\},$$

$$K^{\rm MC}_{qG}(z) = \frac{\alpha_s}{2\pi}\, T_R \left\{ \left[z^2 + (1-z)^2\right] \ln\frac{(1-z)^2}{z} + 2z(1-z) \right\}.$$

All virtual parts $\sim \delta(1-z)$ adjusted using momentum sum rules.
Direct fitting PDFs to DIS data requires MC-scheme coeff. functions, see below...

Fitting MC-scheme PDFs (LO) directly to DIS data

requires MC-scheme NLO coefficient functions

$$C^{\rm MC}_{2,qq}(z) = \frac{\alpha_s}{2\pi}\, C_F \left\{ \left[-\frac{1+z^2}{1-z} \ln(1-z) - \frac{3}{2}\frac{1}{1-z} + 3z + 2 \right]_+ + \frac{3}{2}\,\delta(1-z) \right\},$$

instead of $C^{\overline{MS}}_{2,qq}(z) = \frac{\alpha_s}{2\pi}\, C_F \left[\frac{1+z^2}{1-z} \ln \frac{1-z}{z} - \frac{3}{2}\frac{1}{1-z} + 2z + 3 \right]_+$ and

$$C^{\rm MC}_{2,qG}(z) = \frac{\alpha_s}{2\pi}\, T_R \left\{ -\left[z^2 + (1-z)^2\right] \ln(1-z) + 6z(1-z) - 1 \right\}$$

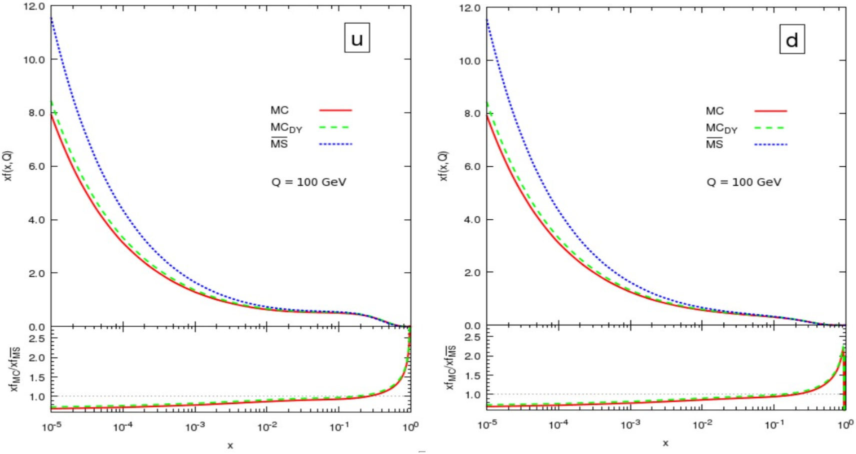
instead of $C^{\overline{MS}}_{2,qG}(z) = \frac{\alpha_s}{2\pi}\, T_R \left\{ \left[z^2 + (1-z)^2\right] \ln \frac{1-z}{z} + 8z(1-z) - 1 \right\}$.

MC factorization scheme

- What is the purpose of MC fact.scheme?
  – It is defined such that $\Sigma(z)\delta(k_T)$ terms due to emission from initial partons disappear completely from exclusive NLO corrections (even before PSMC gets involved!).
- Why the above is vital in the KrkNLO scheme?
  – Without eliminating them it is not possible to include NLO correction with a regular MC weights on top of the PSMC distributions.
- How to determine elements of the transition matrix $K_{ab}^{\rm MC}$?
  – Obtained from inspecting NLO corrs. to two processes with quarks and gluons in the LO hard process: Z and Higgs boson production.
- Will the same PDFs eliminate $\sim \delta(k_T)$ terms for other processes?
  It was shown already in *Phys.Rev. D87 (2013)* that for DIS it works.
- For any other process may work,
  provided PSMC distribution obeys certain extra conditions.
- This is a question about *universality* of the MC fact.scheme.

MC factorization scheme

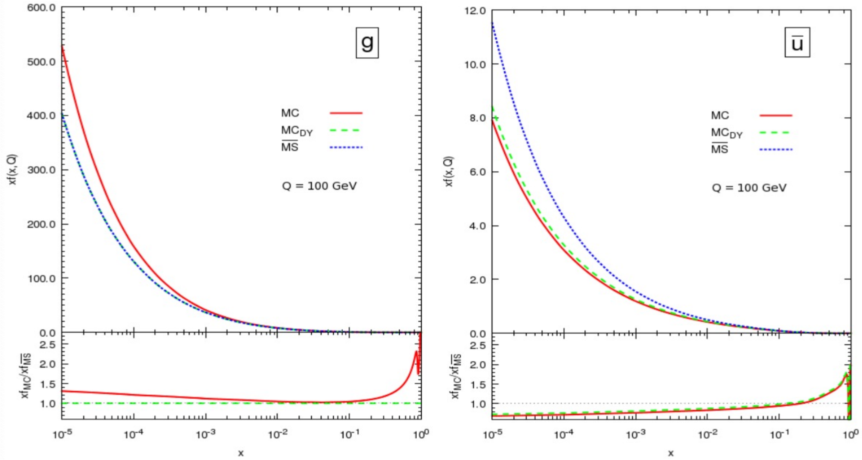
Numerical examples of PDFs in the MC scheme



- Change with respect to $\overline{MS}$ PDFs is noticeable.
- Version labeled MC is complete MC scheme.
- Version MC_{DY} neglects certain $\mathcal{O}(\alpha_s^2)$ terms, limited to DY process.

MC factorization scheme

Numerical examples of PDFs in the MC scheme



- Change with respect to $\overline{MS}$ PDFs is noticeable.
- Version labeled MC is complete MC scheme.
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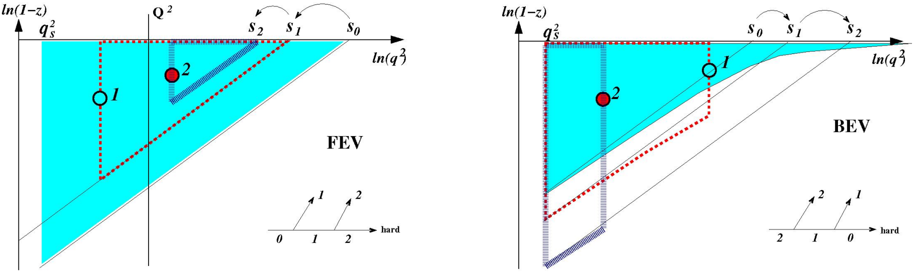
Parton shower MC related issues:

Full coverage of the hard gluon phase space by LO PSMC is essential for KrkNLO!

Phase space limits in forward (FEV) and backward (BEV) evolution for up to 2 emissions. BEV looks more complicated:



Luckily in modern LO PS MCs like Sherpa and Herwig full phase space coverage is implemented, in spite of the above complication, thanks to combination of veto and BEV algorithms.

See *JHEP 1510 (2015) 052* [arXiv:1503.06849] for more details.

Another Parton shower MC related issue:

Compatibility of forward (FEV) and backward (BEV) distribs. up to NLO

Forward evol.

$$\sigma^{LO}_{MC} = \int dx_F dx_B d\Omega \sum_{n_F=0}^{\infty} \sum_{n_B=0}^{\infty} \int d\sigma^{LO}_{n_F n_B},$$

$$d\sigma^{LO}_{n_F n_B} = \prod_{i=1}^{n_F} \prod_{j=1}^{n_B} \Big\{ \int d^3\rho^F_i \theta_{q^2_{i-1}>q^2_i>q^2_s} e^{-S_F(q^2_{i-1},q^2_i)} \Big\} \Big\{ \int d^3\rho^B_j \theta_{q^2_{j-1}>q^2_j>q^2_s} e^{-S_B(q^2_{j-1},q^2_j)} \Big\}$$
$$\times e^{-S_F(q^2_{n_F},q^2_s)} e^{-S_B(q^2_{n_B},q^2_s)} \frac{d\sigma}{d\Omega}(sx_F x_B,\hat\theta) \frac{1}{Z_{n_F}} D^F_{MC}\Big(q^2_s, \frac{x_F}{Z^F_{n_F}}\Big) \frac{1}{Z_{n_B}} D^B_{MC}\Big(q^2_s, \frac{x_B}{Z^B_{n_B}}\Big),$$

$$d^3\rho^F_i = d^3\rho^F_i(s_{ij}) = \frac{d\tilde\beta_i d\tilde\alpha_i}{\tilde\beta_i(\tilde\alpha_i+\tilde\beta_i)} \frac{d\phi_i}{2\pi} \bar{\mathcal{P}}(1-\tilde\alpha_i-\tilde\beta_i)\, \theta_{\tilde\alpha_i>0}\, \theta_{\tilde\alpha_i+\tilde\beta_i<1}$$
$$= \frac{dq^2_i dz_i}{q^2_i} \frac{d\phi_i}{2\pi} \theta_{(1-z_i)^2 s_{ij}>q^2_i} \mathcal{P}(z_i) = \frac{dq^2_i}{q^2_i} \frac{d\phi_i}{2\pi} dz_i \frac{\bar{\mathcal{P}}(z_i)}{1-z_i} \theta_{(1-z_i)^2 s_{ij}>q^2_i},$$

$$S_F(q^2_b,q^2_a) = S_F(s_{ij}|q^2_b,q^2_a) \equiv \int_{q^2_a<q^2_i<q^2_b} d^3\rho^F_i(s_{ij}),$$

Backward evolution

$$d\sigma^{LO}_{n_F n_B} = \frac{d\sigma}{d\Omega}(sx_F x_B,\hat\theta) \prod_{i=1}^{n_F} \Big\{ d^3\omega^F_i\; \theta_{q^2_{i-1}>q^2_i} \Big\} \prod_{j=1}^{n_B} \Big\{ d^3\omega^B_j\; \theta_{q^2_{j-1}>q^2_j} \Big\}$$
$$\times e^{-\Delta_F(x^F_{n_F}|q^2_{n_F},q^2_s)} e^{-\Delta_B(x^B_{n_B}|q^2_{n_B},q^2_s)} D^F(\hat s, x_F)\, D^B(\hat s, x_B)\, dx_F dx_B d\Omega,$$
$$x^F_i = x_F/Z^F_i,\; x^B_j = x_B/Z^B_j,\; \hat s = s x_F x_B,$$

$$d^3\omega^H_i = \frac{dq^2_i dz_i}{q^2_i} \frac{d\phi_i}{2\pi} \mathbb{K}_{MC}(x_{i-1}|z_i,q^2_i)\, e^{-\Delta_{MC}(x_{i-1}|q^2_i,q^2_{i-1})},$$

$$\mathbb{K}_{MC}(x^*|z,q^2) \equiv \mathcal{P}(z)\, \theta_{(1-z)^2 sx^*/z>q^2} \frac{\overline{D}_{MC}(sx^*/z|q^2, x^*/z)}{\overline{D}_{MC}(sx^*|q^2,x^*)},$$

$$\Delta_{MC}(x^*|q^2_{j-1},q^2_j) \equiv \int_{q^2_j}^{q^2_{j-1}} \frac{dq^2}{q^2} \int_{x^*}^{1} \frac{dz}{z} \mathbb{K}_{MC}(x^*|z,q^2),$$

Formal algebraic proof of NLO-compatibility between FEV and BEV is based on 2 elements:

1. Multiple use of identity eliminating/introducing BEV form-factor and ratios of PDFs:

$$e^{-S_{MC}(\hat s|q^2_b,q^2_a)} = e^{-\Delta_{MC}(x|q^2_b,q^2_a)} \frac{\overline{D}_{MC}(\hat s|q^2_b,x)}{\overline{D}_{MC}(\hat s|q^2_a,x)}.$$

2. And introduction of auxiliary PDFs with its own evolution equation $\bar D(Q^2,x)$, for which equality between FEV and BEV ditribs. holds *exactly*.

Final elimination of $\bar D(Q^2,x)$ provides also precise definition of PDFs in MC factoriz. scheme.

See *JHEP 1510 (2015) 052* [arXiv:1503.06849] for more details.

Universality of the KrkNLO method

Preliminary study provides positive answer (unpublished)

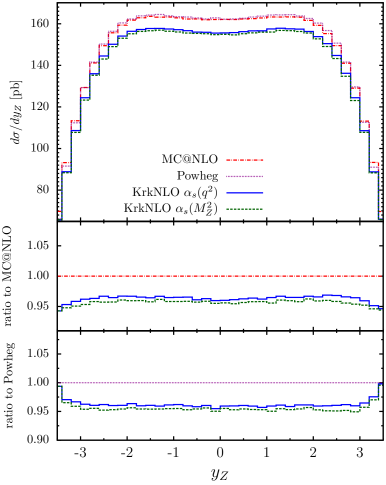
- Process-wise it was checked that KrkNLO method works, with **the same PDFs** in the MC factorization scheme, for DY ($q\bar{q} \to Z$) Higgs ($GG \to H$) and DIS ($eq \to eq$).
- Preliminary study within Catani-Seymour (CS) subtraction scheme shows that the same is true for any other process (any number of colored legs) provided that:
  1. Distribution from LO PS MC agree (for initial partons) with CS soft-collinear counterterms (SCC) up to NLO,
  2. CS soft-collinear counterterms are slightly redefined for "dipoles" with one initial and one final parton: $z = 1 - \max(\alpha, \beta)$ instead of Bjorken variable $z = 1 - \alpha$.
- Luckily, distributions of PS MC like modern versions of Herwig, Sherpa (Pythia?) are identical with "CS dipoles" for simple processes – this may be more problematic for more coloured legs... **New! Preliminary! Unpublished!**

Numerical results

DY: Comparison of the rapidity distribution

between two versions of KrkNLO and MC@NLO or POWHEG.

8 TeV: $q\bar{q}$ **and** qg **channels** (full parton shower)

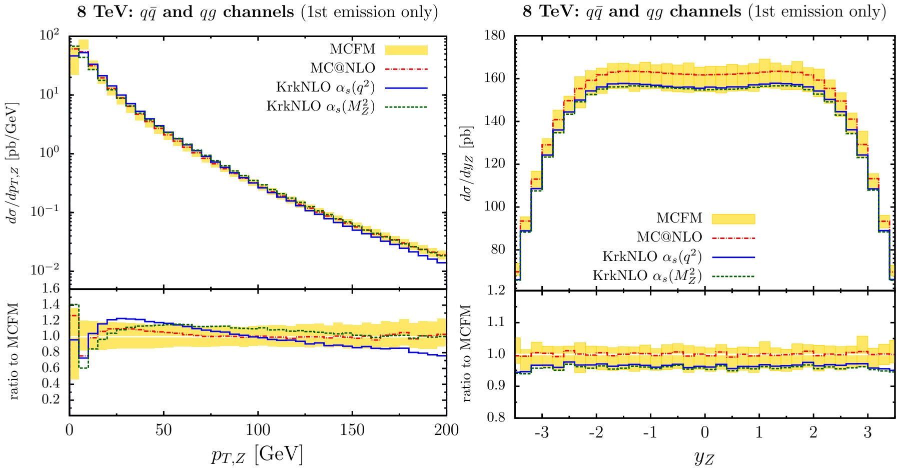


	$\sigma_{\text{tot}}^{q\bar{q}+qg}$ [pb]
MCFM	1086.5 ± 0.1
MC@NLO	1086.5 ± 0.1
POWHEG	1084.2 ± 0.6
KrkNLO $\alpha_s(q^2)$	1045.4 ± 0.1
KrkNLO $\alpha_s(M_Z^2)$	1039.0 ± 0.1

Differences in rapidity distr. normalization the same as in table of total xsect.

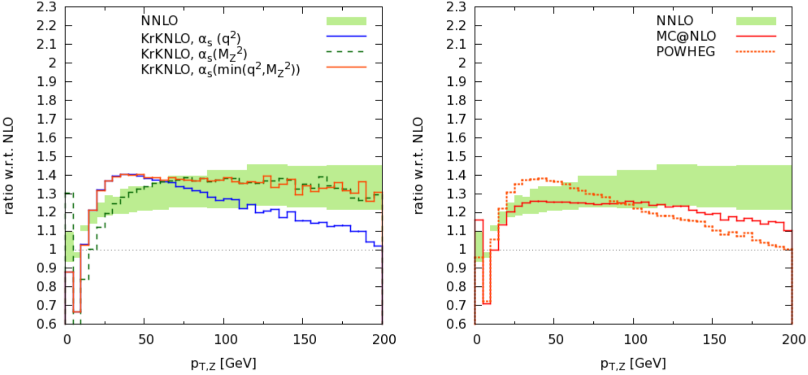
DY: Transverse momentum and rapidity distributions

from MCFM, MC@NLO and two versions of KrkNLO.



- Factorization and renormalization scale varied by 2 and 1/2 (independently).
- 10-20% differences well within uncertainty band typical for NLO.

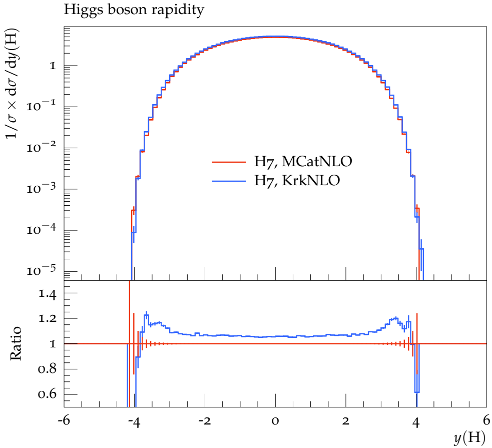
DY: Good agreement of KrkNLO with NNLO fixed order



- The Z-boson transverse-momentum distributions from KrkNLO compared with the fixed-order NNLO result from the DYNNLO (left).
- Similar comparisons for POWHEG and MCatNLO are also shown (right).
- All distributions are divided by the NLO results from MCFM.
- KrkNLO closer to NNLO than POWHEG and MCatNLO.

NEW! $pp \to H$: rapidity distrib. PRELIMINARY!

KrkNLO on top of Herwig 7 compared with MC@NLO

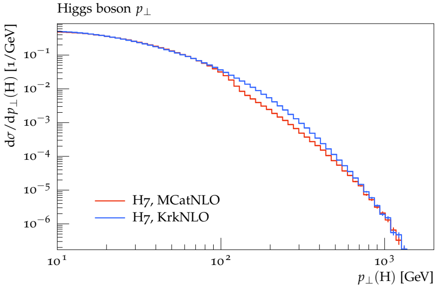


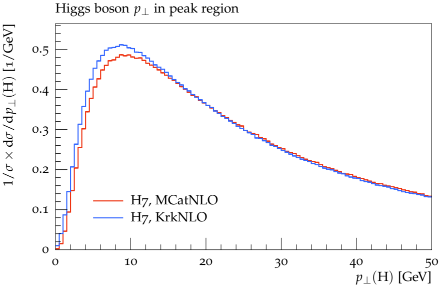
	$\sigma_{tot}[pb]$
MC@NLO	1.88 ± 0.02
KrkNLO	2.00 ± 0.02

- $\leq$ 20% differences, well within uncertainty typical for NLO.

NEW! $pp \to H$: Transverse momentum distrib. PRELIMINARY!

KrkNLO on top of Herwig 7 compared with MC@NLO





- $\leq$ 20% differences for $p_T \leq$ 100GeV, well within uncertainty typical for NLO and
- $\sim$ 200% differences for higher k_T, also well known in comparisons between POWHEG and MCatNLO for this process.

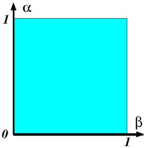
Outlook

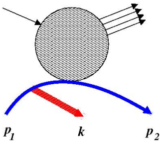
- **KrkNLO is a simple scenario for NLO-corrected PSMC – alternative to MC@NLO or POWHEG.**
- Potential gains from new QCD methods are:
  – reducing h.o. QCD uncertainties
  – easier implementation of NLO and possibly NNLO corrections to hard process. – and more...
- Next applications: high quality QCD+EW+QED MC with hard process like $W/Z/H$ boson production at high luminosity LHC.
- Other fronts: Parton shower MC implementing complete NLO DGLAP in the ladders in exclusive way is shown to be possible... see Appendix.
- Longer term: N+NLO: NLO ladder + NNLO hard process.

APPENDIX

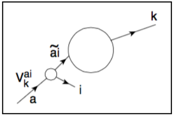
More on “universality” of the KrkNLO method

Preliminary study based on Catani-Seymour scheme





Consider In the CS scheme $\mathcal{D}_k^{ai}(p_1, p_2; p_a) =$, where $i = 2$ is emitted gluon, a is initial quark and $k = 1$ is spectator final-state quark.
The corresponding CS soft-collinear counterterm reads:



$\longrightarrow$

$$\mathcal{V}^{a,ai}(x;\epsilon) = \Theta(x)\Theta(1-x)\left(\frac{1}{1-x}\right)^{\epsilon} \int_0^1 \frac{du_i}{u_i}\,(u_i(1-u_i))^{-\epsilon}\,\frac{n_s(\widetilde{ai})}{n_s(a)}\,\frac{<\boldsymbol{V}_k^{ai}(x;u_i)>}{8\pi\alpha_S\mu^{2\epsilon}}\,. \quad (5.74)$$

In our notation, $z = x_{ik,a} = 1-\alpha,\;\; u_i = \beta$ and for $m_+ = \frac{\alpha}{\alpha+\beta}$ it reads

$$\mathcal{V}^{qq,G}(z,\varepsilon) = (1-z)^{\varepsilon} \int_0^1 d\alpha \int_0^1 d\beta\; \beta^{\varepsilon}(1-\beta)^{\varepsilon}\; C_F\left[\frac{2}{\alpha\beta}m_+ - \frac{(1+z)}{\beta} - \varepsilon\frac{(1-z)}{\beta}\right]\delta(1-z-\alpha)$$

In our MC modeling of DIS in Phys.Rev.D87 we used $\bar{m}_+ = \theta(\alpha-\beta)$ and $1-z = \max(\alpha,\beta)$, getting the same integrated MC counterterm as for DY.
The above original CS choice features extra term $\sim \ln(1+\alpha) = \ln(2-z)$.
Six possible choices of m_+ and z are analyzed in next slide...

More on "universality" of the KrkNLO method

- Six possible choices of m_+ and z are analyzed in the following table, where we indicate the presence/absence of extra term for DIS with respect to DY, in the integrated soft-collinear counterterm:

Type of $x \in (0,1)$	m_+	$\bar{m}_+$
$1-x=\alpha$	$\sim \ln(2-z)$	0
$1-x=\max(\alpha,\beta)$	0	0
$1-x=\alpha+\beta-\alpha\beta$	$\sim \ln z$	$\sim \ln z$

- We conclude/conjecture that Catani-Seymour counterterm for any initial emitter and final spectator should adopt $1-x=\max(\alpha,\beta)$, for any "soft partition factors" $m_+ + m_- = 1$, $m_+(\alpha,\beta) = m_-(\beta,\alpha)$, in order that PDFs in the MC scheme do their job of eliminating all $\delta(k_T)\Sigma(z)$ terms in the exclusive NLO corrections.

- Thanks to generality of the Catani-Seymour scheme, the above statement is valid for any process, hence opens way to "universality" of the KrkNLO method.

Other activities: from DGLAP to parton shower MC

- Early activity (2004-06) on Patron Shower Monte Carlo and NLO QCD started with solving exactly LO and NLO DGLAP evolution eqs. using Markovian methods, MMC programs:
  – *Acta Phys.Polon.B37:1785*, [arXiv:hep-ph/0603031]
  – *Acta Phys.Polon.B38:115*, [arXiv:0704.3344]
  – *Comput.Phys.Commun.181:393*,[arXiv:0812.3299]
- These MMCs were also capable to evolve CCFM evol. + DGLAP
- MMCs were used to xcheck CMC series of programs (2005-07).
  – *Comput.Phys.Commun.175:511*, [arXiv:hep-ph/0504263]
  – *Comput.Phys.Commun.180:6753*,[arXiv:hep-ph/0703281]
- CMCs implement the same evolution with constrained/predefined final x, an alternative to backward evolution in the PS MC, aiming at better control (NLO) of the distribs. generated by LO PS MC.
- CMCs were for single ladder/shower, without hard process, with exclusive LO kernels, optionally inclusive NLO kernels.

Other activity fronts: from DGLAP to parton shower MC

- Two CMC modules and hard process ME were combined into complete PSMC for Drell-Yan process, see for example:
  – *Acta Phys.Polon.B38(2007)2305*,
  – *Acta Phys.Polon.B43(2012)2067* ,
  unfortunately not upgraded with realistic PDFs and kinematic.
- However, this kind of PS MC has been instrumental in testing new ideas on implementing:
  1. NLO corrections in the exclusive evolution kernels in the initial state ladders/showers many times,
  2. NLO corrections to hard process just once (a simpler alternative to MC@NLO and POWHEG)

  thanks to perfect numerical and algebraic control over LO distributions.
- ...see next slides.

Other activity fronts: NLO corrections to PS MC

- The problem of including NLO corrs. in exclusive form into evolution (kernels) in the (initial state) ladder/shower was never addressed before.
- Except of statements that it is for sure unfeasible:)
- First solution, albeit limited to non-singlet evol. kernels, was proposed and tested numerically in:
  – *Acta Phys.Polon. B40(2009)2071*, [arXiv:0905.1399],
  – *Proc. of RADDCOR 2009, [arXiv:1002.0010]*
- ... using NLO kernels in exclusive form calculated from the scratch in the Curci-Furmanski-Petronzio (CFP) framework. Non-singlet 2-real kernels were presented in:
  – *JHEP 1108(2011)012*, [arXiv:1102.5083]
- Simplified and faster scheme reported (numerical tests) in:
  – *Nucl.Phys.Proc.Suppl. 205-206(2010)295* , [arXiv:1007.2437]

Most advanced front: NLO corrections to PS MC

- Even simpler and faster scheme of NLO-correcting PS MC (single initial state ladder) reported in Ustron 2013 Proceedings:
  – *Acta Phys.Polon. B44 (2013) 11, 2179-2187*, [arXiv:1310.6090]
- Also singlet evolution kernels are now almost complete (unpublished).
- It is a major problem to include consistently virtual corrections to exclusive kernels starting from CFP scheme.
- First solution was formulated (unpublished) exploiting recalculated virtual corrections in CFP scheme to non-singlet kernels:
  – *Acta Phys.Polon. B44 (2013) 11, 2197* , [arXiv:1310.7537]
- The above breakthrough is important but points to:
  (i) need of better understanding of the MC distributions in the PS MC,
  (ii)especially their kinematics, definition of the evolution variable etc.
- For the time being this area of the development is not very active:(