NLO corrections in the initial state parton shower Monte Carlo

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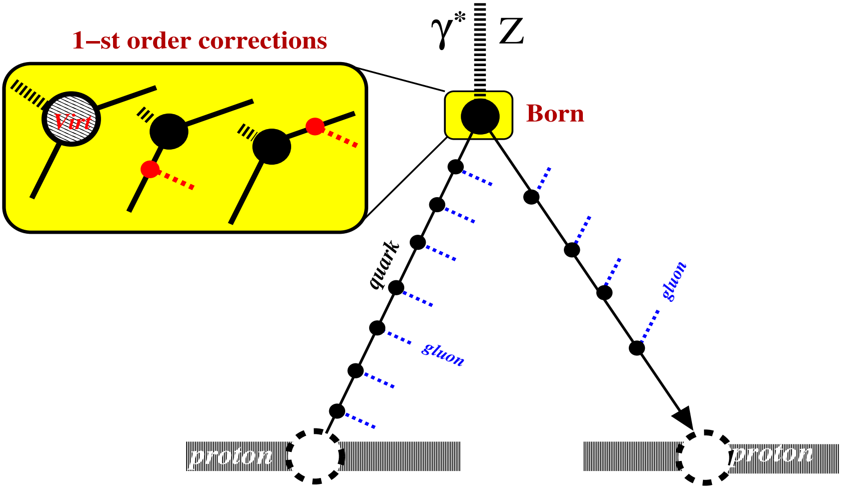
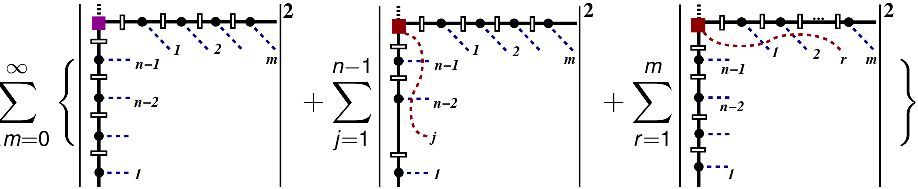
Outline

- NLO corrections to hard process
  (an alternative to MCatNLO and/or POWHEG)
- NLO corrections in the ladder
  (for NLO parton shower MC + NNLO hard process)

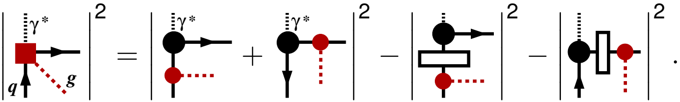
NLO correcting HARD process



The essence of our NLO methodology:



NLO real/virtual distributions (subtracted) from Feynman diags



free of any double/single collinear/soft singularities.

MC weight with NLO corrs. to DY hard proc.

NLO correction introduced using simple positive MC weight:

$$W_{MC}^{NLO} = 1 + \Delta_{S+V} + \sum_{j\in F} \frac{\tilde{\beta}_1(\hat{s}, \hat{p}_F, \hat{p}_B; a_j, z_{Fj})}{\bar{P}(z_{Fj})\; d\sigma_B(\hat{s}, \hat{\theta})/d\Omega} + \sum_{j\in B} \frac{\tilde{\beta}_1(\hat{s}, \hat{p}_F, \hat{p}_B; a_j, z_{Bj})}{\bar{P}(z_{Bj})\; d\sigma_B(\hat{s}, \hat{\theta})/d\Omega},$$

$\bar{P}(z) \equiv \frac{1+z^2}{2}$. **The IR/Col.-finite real emission part is**

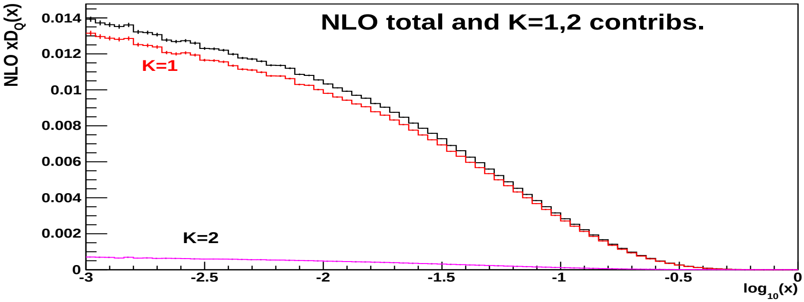
$$\tilde{\beta}_1(\hat{p}_F, \hat{p}_B; q_1, q_2, k) = \left[\frac{(1-\alpha)^2}{2}\frac{d\sigma_B}{d\Omega_q}(\hat{s}, \theta_{F1}) + \frac{(1-\beta)^2}{2}\frac{d\sigma_B}{d\Omega_q}(\hat{s}, \theta_{B2})\right]$$
$$-\theta_{\alpha>\beta}\frac{1+(1-\alpha-\beta)^2}{2}\frac{d\sigma_B}{d\Omega_q}(\hat{s}, \hat{\theta}) - \theta_{\alpha<\beta}\frac{1+(1-\alpha-\beta)^2}{2}\frac{d\sigma_B}{d\Omega_q}(\hat{s}, \hat{\theta}),$$

the kinematics independent virtual+soft correction is

$$\Delta_{V+S} = \frac{C_F\alpha_s}{\pi}\left(\frac{1}{3}\pi^2 - 4\right) + \frac{C_F\alpha_s}{\pi}\frac{1}{2}$$

Terms like $\left(\frac{f(z)}{1-z}\right)_+$ **in virt. corrs completely absent!**
Thanks to transforming MS-bar PDFs to MC Fact scheme,
(see also Martin+Ryskin 2013)

Only one single term dominates sum in W^{NLO}_{MC}

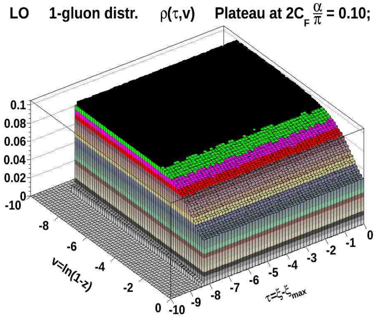


The (-)NLO contributions from $K = 1, 2$ single gluons,
the one with maximum and another one with next-to-max. kT,
in the *x*-distribution of quark entering W boson.

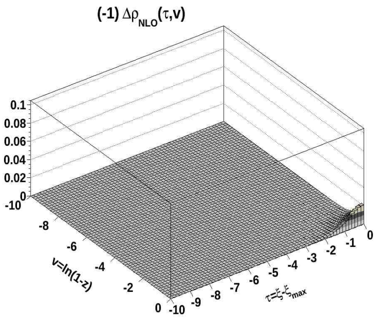
POWHEG exploits the above. We do it differently, without vetoed/truncated gluons, see next slides...

Location and size of the (real) NLO correction on the Sudakov plane (rapidity, ln(1-z))

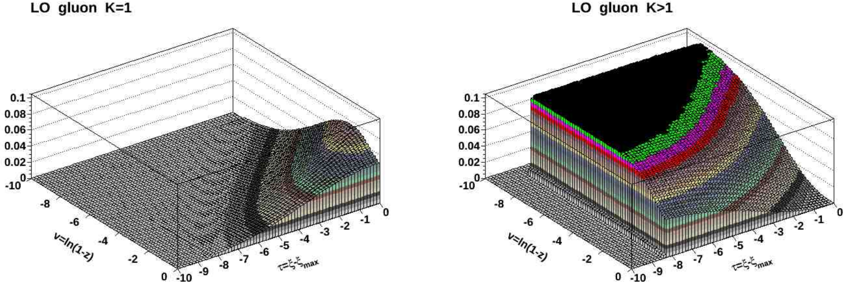
LO inclusive



pure NLO



Gluons generated in angular ordering and re-ordered in kT



Sudakov suppression for the highest kT gluon (K=1)!

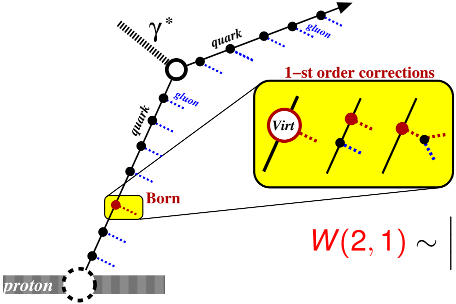
Our NLO weight with summation is ignorant about the above kT (re-)ordering.

The summation (or max. kT-selection) takes care of picking up correctly the hardest gluon, for NLO-completness.

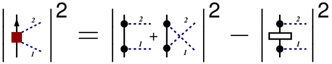
No need of truncated/vetoed gluon showers.

Exclusive NLO-corrections to the middle-of-the-ladder kernels for NLO Monte Carlo parton shower

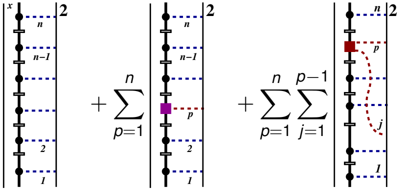
NLO-corrected middle-of-the-ladder kernel, C_F^2



$$W(2,1) \sim$$

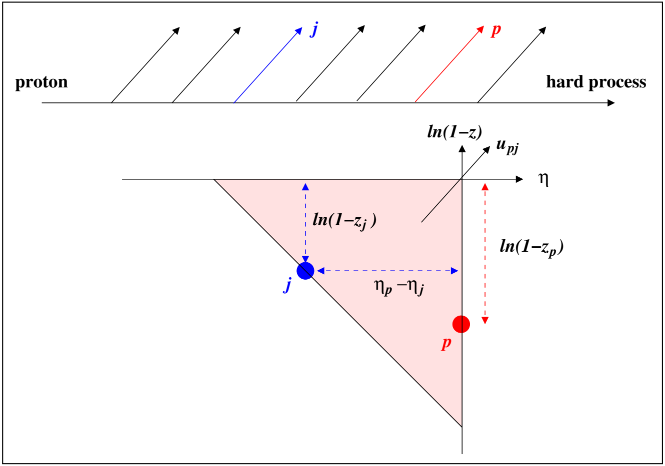


$$\bar{D}_B^{[1]}(x,Q) = e^{-S_{ISR}} \sum_{n=0}^{\infty} \Big\{ \quad + \sum_{p=1}^{n} \quad + \sum_{p=1}^{n}\sum_{j=1}^{p-1} \quad \Big\} = e^{-S_{ISR}} \Big\{ \delta_{x=1} +$$



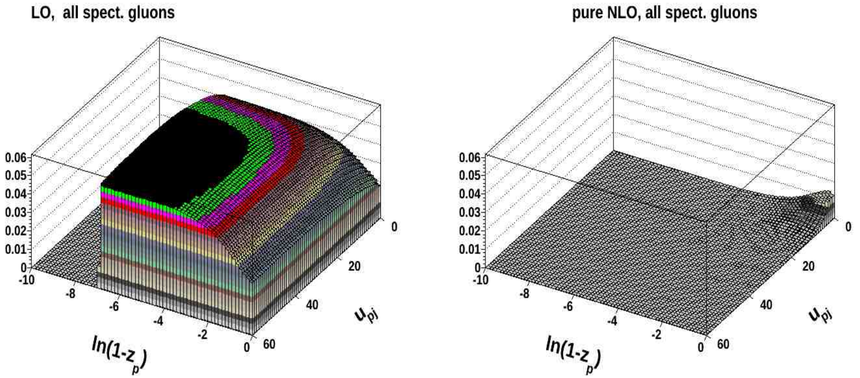
$$+ \sum_{n=1}^{\infty} \Big(\prod_{i=1}^{n} \int_{Q>a_i>a_{i-1}} d^3\eta_i \, \rho_{1B}^{(1)}(k_i) \Big) \Big[1 + \sum_{p=1}^{n} \beta_0^{(1)}(z_p) + \sum_{p=1}^{n}\sum_{j=1}^{p-1} W(\tilde{k}_p, \tilde{k}_j) \Big] \delta_{x=\prod_{j=1}^{n} x_j} \Big\}.$$

Define variable $\mathbf{u}_{pj}$ for "u-ordering" in the middle of the ladder



$u_{pj} = |\eta_p - \eta_j| + \lambda \ln(1 - z_j), \quad \lambda \sim 1 - 2.$
Variable η is rapitity, z is conventional lightcone variable.

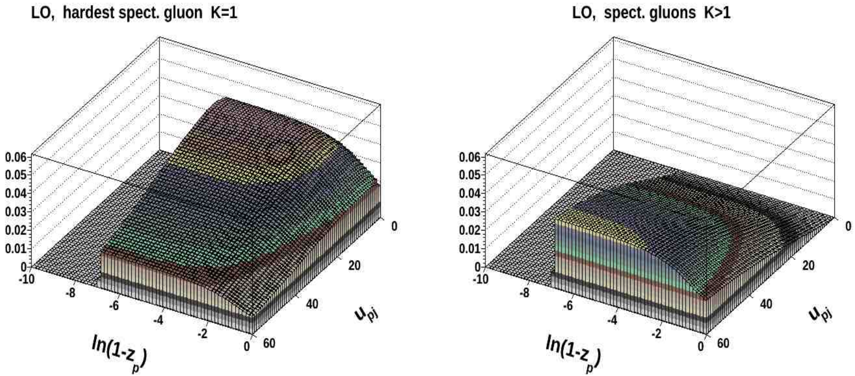
Location and size of the (real) NLO correction in the ladder on the Sudakov log space



LO inclusive distribution features triple-log IR/coll. singularity, seen as a plateau in 2-dim. projection.

NLO correction IR/coll. finite, nonzero in the corner of the size ~ 1.

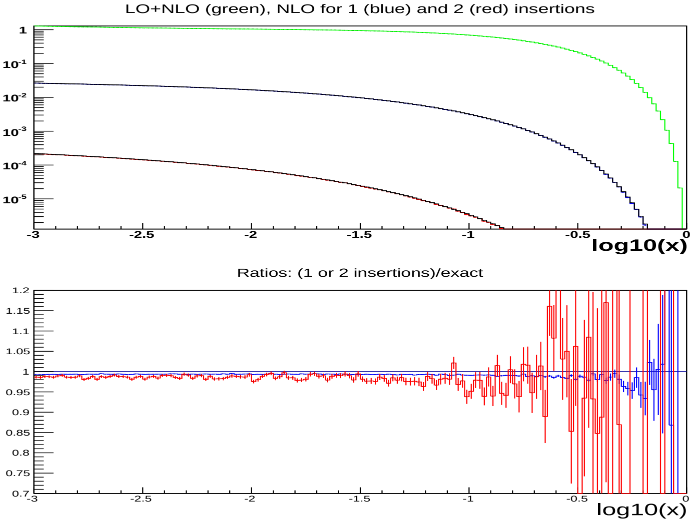
Split of inclusive LO distribution of gluons into contr. from the u-hardest one and the rest



Distribution of the hardest (in u_{pj}) LO spectator gluon approximates well the total distribution in small corner where NLO is non-zero.

Repetition of test for NLO-corrected ladder

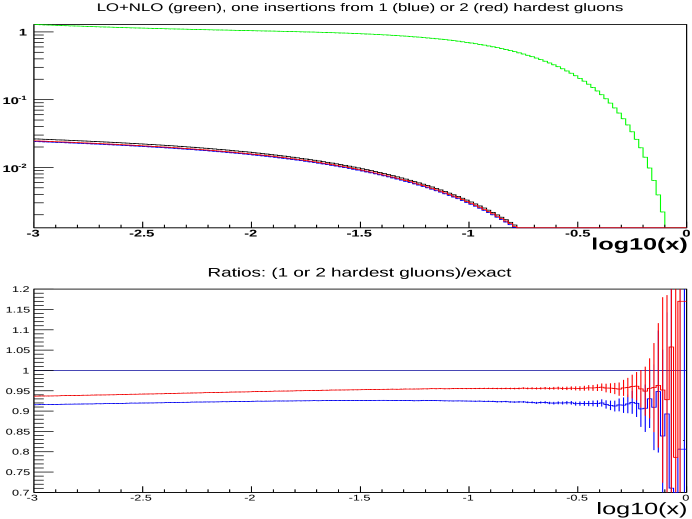
OLD: NLO MC vs. analyt. NLO kernels. Perfect agreement



Single ladder, 1GeV-1TeV, 1 or 2 kernels NLO-corrected. (Slow in CPU time).

Repetition of test for NLO-corrected ladder

NEW: NLO contrib. to 1 kernel, 1 and 2 gluons with max. kT



This difference $\sim 15\%$ is formally the NNLO/NLO class. (Faster in CPU time).

Summary

- **An alternative (to MC@NLO or POWHEG) scenario for NLO-corrected hard proc. and LO PSMC is proposed.**
- **Parton shower MC implementing complete NLO DGLAP in the ladders in exclusive way is feasible.**
- Long term: NLO ladder + NNLO hard process,
  (but LO ladder + NLO hard proc. to be optimized first!)
- Most likely application: high quality QCD+EW+QED MC with hard process like $W/Z/H$ boson production.
- Potential gains from new QCD methods are:
  – reducing uncertainties due to PDFs
  – easier implementation of NLO and NNLO corrections to hard process.
  Due to better treatment of "trivial" (albeit numerically sizeable) soft gluon corrections,
  – better environment for low x resumm. (BFKL, CCFM),
  – and more...