NLO parton shower Monte Carlo

A prototype of NLO Parton Shower for the Initial-State QCD

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This and other similar talks are here http://jadach.web.cern.ch/

Outline

Outline

The name of the game

QUESTION 1:

Can one imagine a new scheme/technique of the pQCD calculations in the Monte Carlo for LHC, which is substantially better/different from the ones based on the 1978-85 standards?

HAVING IN MIND:

1. more precise pQCD predictions within MC event generators,
2. better treatment of heavy quark masses (thresholds),
3. new method of transferring parton distributions HERA→LHC,
4. better control of parton luminosity and kT, and more...

YES! but...

The name of the game

QUESTION 2:

What is the most promising, desirable and difficult type of the MC event generator for pQCD/QED/EW/BM, for the data analysis at LHC and other colliders?

It is the MC combining both “Resummed” and “Fixed-Order” perturbative Matrix Element, featuring complete NLO in both of them.

NLO Parton Shower MC $\otimes$ NLO ME for hard process

The name of the game
QUESTION 3:

What is missing on the way to the "new brave world" of the complete NLO Monte Carlo for LHC?

Parton Shower Monte Carlo featuring complete NLO (collinear) evolution does not exists yet!

WHY?

Two bottlenecks, see next slide....

Two most important bottlenecks
on the way to NLO MC

MC technique:

The addict use of Markovian MC algorithm, "Backward Evolution" (Sjostrand 1985), narrowing options for phase space integration and forcing the use of integrated/collinear PDFs.

Theory:

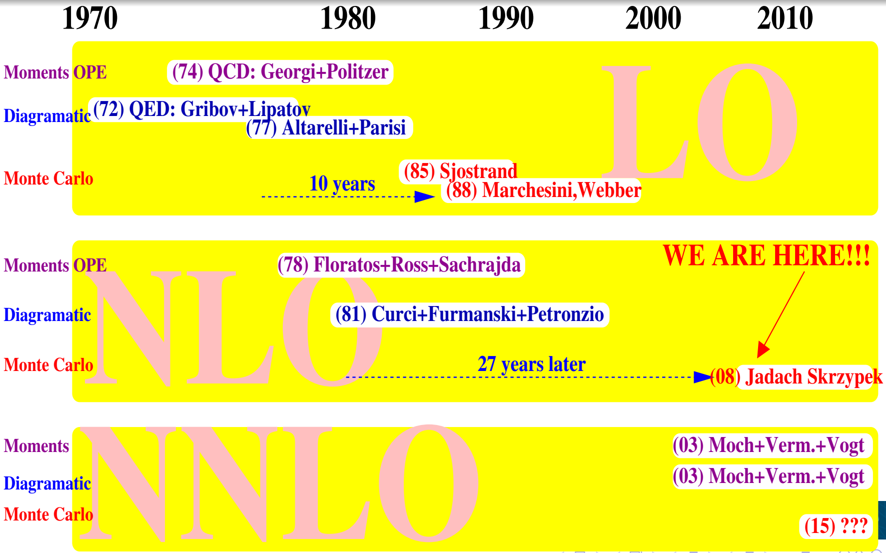
The existing collinear factorization theorems in QCD (Collins, Sterman and Soper. 1985) were never designed for the Monte Carlo.

Outline

State of art: recent partial solutions
in the right direction

- New better MC parton showers in PYTHIA and HERWIG in the improved LL approx. ISR “backward evolution"+integr.PDFs
- MC@NLO, NLO matrix element for the hard process + LL parton shower MC (piggyback). By Frixione, Webber and Nason.
- Constrained MC algorithm for ISR parton shower by Krakow group. An alternative to backward evolution. **Bottleneck 1 removed!**
- GR@PPA Monte Carlo project (GRACE@KEK), NLL parton sh.
- Nagy and Soper: General PS scheme LL class with many emitters, better phase space treatment and colour interferences.
- Collins, Rogers, Stasto: Redoing factorization theorem from the scratch (in Feynman gauge) in for suitable for the Monte Carlo!
- The other LL-class PS based MCs: CASCADE with CCFM low-x resummation, ARIADNE LL with improved soft limit, SHERPA with CKKW, tree-level QCD matrix elements + LL PS MC.
- SANC project for QCD, QED and electroweak one loop fixed order corrections, to be used in KRKMC projects.

DGLAP Collinear QCD ISR Evolution and Monte Carlo. The state of the art



Outline

So finally what we are after?

Can we construct Parton Shower Monte Carlo for QCD Initial State Radiation:

- based firmly on Feynman Diagrams (ME) and LIPS,
- based rigorously on the collinear factorization (EGMPR, CSS),
- implementing *exactly* NLO $\overline{MS}$ DGLAP evolution,
- implementing fully unintegrated PDFs (FunPDF); with NLO evolution done by MC itself, using EXClusive NLO kernels**???**

We are going to show that YES, we can do it**!**

And show first numerical implementation
– the proof of the concept.

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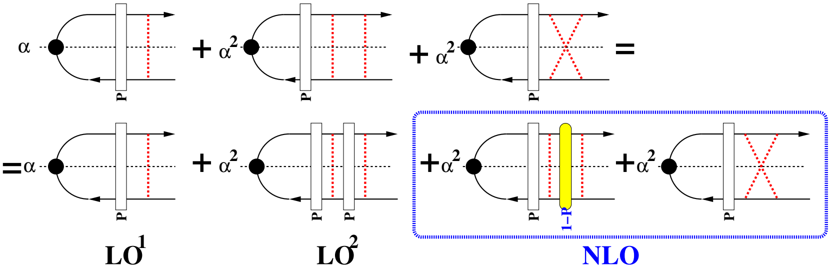
Outline

Extraction of NLO kernel from Feynman diagrams

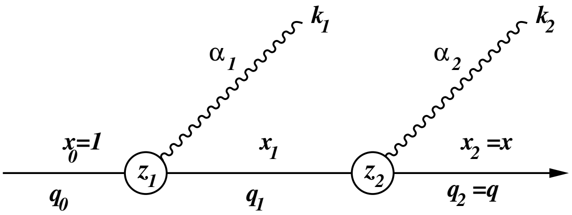
according to Curci-Furmanski-Petronzio (1980-82)



- CFP = Curci-Furmanski-Petronzio (1980-82)
- Double gluonstrahlung, only 2 diagrams, $C_F C_A$ part only.
- Axial gauge, projection operator $P = P_{spin} P_{kin.} P_{pole}$.
- LO: $\mathcal{P}(z) = \frac{1+z^2}{2(1-z)}$
- NLO: $\mathcal{P}^N(z) = \frac{1+3x^2}{16(1-x)} \ln^2(x) + \frac{2-x}{4} \ln(x) + \frac{3}{8}(1-x).$

Kinematics of double gluonstrahlung

needed to understand plots in next slides



- Initial parton $q_0^\mu = (E, 0, 0, E)$
- Emitted gluons: $k_i^\mu = (k_i^0, \mathbf{k}_i, k_i^3)$, $k_{Ti} = |\mathbf{k}_i|$.
- Lightcone plus variables: $x_i = \frac{q_i \cdot \zeta}{q_0 \cdot \zeta}$, $\alpha_i = \frac{k_i \cdot \zeta}{q_0 \cdot \zeta}$, $\zeta = (1, 0, 0, -1)$.

Unintegrated (exclusive) NLO kernel

for bremsstrahlung subset of diagrams

$$\alpha'^2 \mathcal{P}^N(x) = \frac{1}{2!} \int \frac{d^3k_2}{2k_2^0} \int \frac{d^3k_1}{2k_1^0}\; \delta_{1=\max(|\mathbf{k}_1|,|\mathbf{k}_2|)/Q}\; \delta_{1-x=\alpha_1+\alpha_2}\; b_2^N(k_1,k_2)$$

UNINTEGRATED exclusive NLO kernel directly from FEYNMAN DIAGRAMS

$$b_2^N(k_1,k_2) = \frac{(\alpha')^2}{16(2\pi)^2}\left[b^{Ladd.}(k_1,k_2) + b^{Ladd.}(k_2,k_1) + b^{XLad.}(k_1,k_2) - b^{Count.}(k_1,k_2)\right],$$

$$b^{Ladd.}(k_1,k_2) = \frac{1}{q^4(k_1,k_2)}\left\{\frac{T_1(\alpha_1,\alpha_2)}{\alpha_1\alpha_2} + \frac{T_2(\alpha_1,\alpha_2,0)}{\alpha_2^2}\frac{\mathbf{k}_2^2}{\mathbf{k}_1^2} + \frac{T_3(\alpha_1,\alpha_2)}{\alpha_2}\frac{2\mathbf{k}_1\cdot\mathbf{k}_2}{\mathbf{k}_1^2}\right\},$$

$$b^{Xlad.}(k_1,k_2) = \frac{1}{q^4(k_1,k_2)}$$

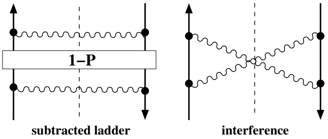
$$\times\left\{\frac{2T_1^x(\alpha_1,\alpha_2)}{\alpha_1\alpha_2} - T_{2a}^x(\alpha_1,\alpha_2)\frac{2\mathbf{k}_1\cdot\mathbf{k}_2}{\alpha_1\mathbf{k}_2^2} - T_{2b}^x(\alpha_1,\alpha_2)\frac{2\mathbf{k}_1\cdot\mathbf{k}_2}{\alpha_2\mathbf{k}_1^2} + T_3^x(\alpha_1,\alpha_2)\frac{(\mathbf{k}_1\cdot\mathbf{k}_2)^2}{\mathbf{k}_1^2\mathbf{k}_2^2}\right\},$$

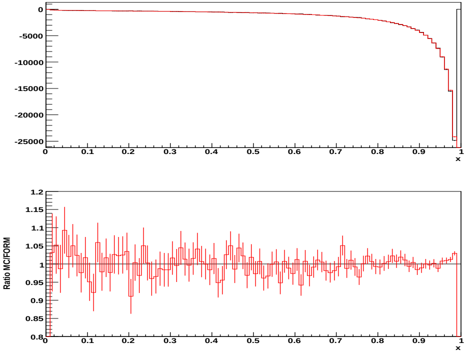
$$b^{Count.}(k_1,k_2) = \frac{\mathbf{k}_2^2}{q^4(0,k_2)}\;\frac{T_2(\alpha_1,\alpha_2,0)}{\alpha_2^2}\;\frac{1}{\mathbf{k}_1^2} = \frac{T_2(\alpha_1,\alpha_2,0)}{(1-\alpha_1)^2\mathbf{k}_1^2\mathbf{k}_2^2}.$$

$$-q^2(k_1,k_2) = \frac{1-\alpha_2}{\alpha_1}\,\mathbf{k}_1^2 + \frac{1-\alpha_1}{\alpha_2}\,\mathbf{k}_2^2 + 2\mathbf{k}_1\cdot\mathbf{k}_2.$$

For simplicity we omitted terms due to ϵ part in in the γ-trace T^2.

Reproducing Furmanski-Petronzio analytically and numerically, of course...





Comparing MC integral over exclusive NLO kernel with analytical kernel of CFP:

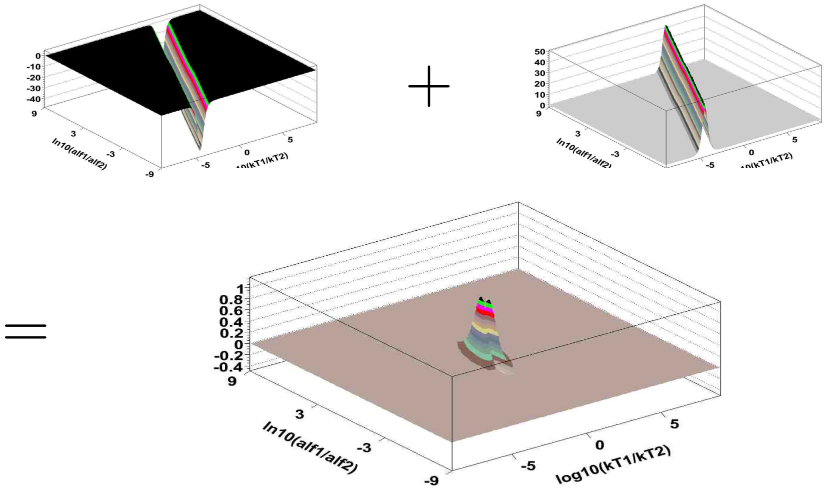
$$\mathcal{P}^N(z) = \frac{1+3x^2}{16(1-x)}\ln^2(x) + \frac{2-x}{4}\ln(x) + \frac{3}{8}(1-x)$$

$$= \frac{1}{2!}\int \frac{d^3k_2}{2k_2^0}\int \frac{d^3k_1}{2k_1^0}\,\delta_{1=\max(|\mathbf{k}_1|,|\mathbf{k}_2|)/Q}\,\delta_{1-x=\alpha_1+\alpha_2}\, b_2^N(k_1,k_2)$$

Outline

Unintegr. NLO kernel on the ($\ln k_{Ti}$, $\ln \alpha_i$) plane

obtained using FOAM



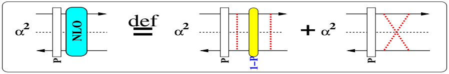
$1 - x = \alpha_1 + \alpha_2$, $y = \frac{k_{T1}}{k_{T2}}$. Bose-symmetrized. **Short-range correlations!**

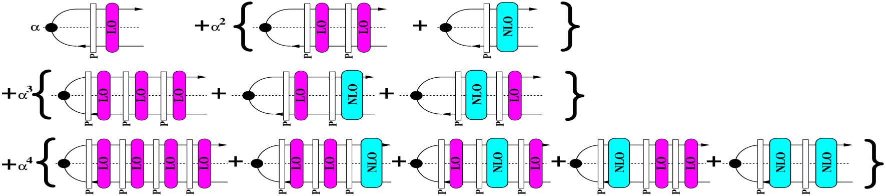
Outline

Implanting NLO UNintegrated kernels into PS MC
THE FRAMEWORK:

- Markovian MC with standard integrated LO+NLO DGLAP kernel (gluonstrahlung part)
- **Markovian MC with UNINTEGRATED LO+NLO DGLAP kernel. NEW!!!**
- Analytical integration leading to NLO DGLAP kernel following Curci-Furmanski-Petronzio (1980); Feynman diagrams $\times$ LIPS, see HERA-LHC, May 2008, and other recent talks at: http://jadach.web.cern.ch/

General scheme of exclusive NLO insertion for $n = 3, 4, ..\infty$





NLO decomposition in powers of α in factorization theorems. Example $n = 4$:

$$D_4^{L+N}(t,x) = e^{-S} \left(\prod_{i=1}^{4} \int \frac{d^3 k_i}{2k_i^0} \theta_{t_{i+1} > t_i} \right) \delta_{1-x=\sum_{i=1}^{3} \alpha_i} \; \rho_4^{L+N}(k_4, k_3, k_2, k_1),$$

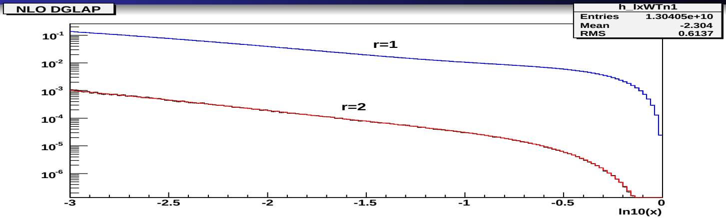
$$\begin{aligned} \rho_4^{L+N}(k_4,k_3,k_2,k_1) &= \rho^L(k_4|x_3)\ \rho^L(k_3|x_2)\ \rho^L(k_2|x_1)\ \rho^L(k_1|x_0) \\ &+ \rho^L(k_4|x_3)\ \rho^L(k_3|x_2)\ b_2^N(k_2,k_1|x_0) + \rho^L(k_4|x_3)\ b_2^N(k_3,k_2|x_1)\ \rho^L(k_1|x_0) \\ &+ b_2^N(k_4,k_3|x_2)\ \rho^L(k_2|x_1)\ \rho^L(k_1|x_0) \\ &+ b_2^N(k_4,k_3|x_2)\ b_2^N(k_2,k_1|x_0) \end{aligned}$$

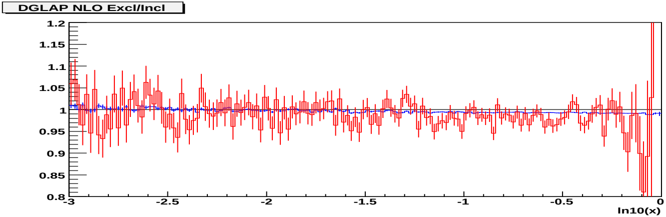
Outline

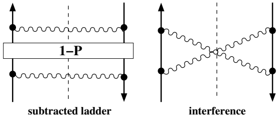
Please wake up!

Next slide shows the most important new result in this talk!

Exclus./Inclusive NLO: Slices in No. of inserts. **NO ε TERM**







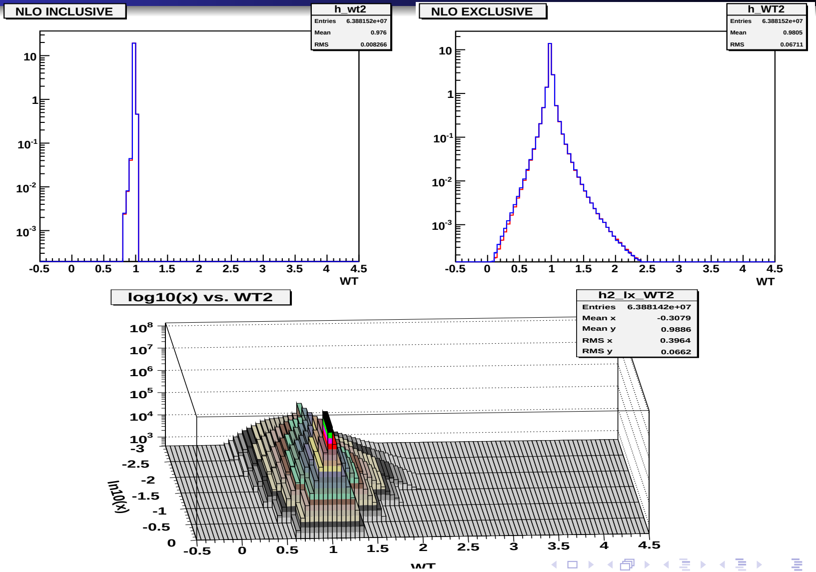
MC with Exclusive NLO kernels compared with standart DGLAP

More on what is in these plots:

- Both evolutions on top of the same Markovian LO MC. (It can be put easily on top of non-Markovian CMC.)
- MC weights positive, weight distributions very reasonable, see next slides.
- Evolution range from 10GeV to 1TeV.
- LO pre-evolution staring from $\delta(1-x)$ at 1GeV to 10GeV provides initial x-distribution for the LO+NLO continuation.
- As before only C_F^2 part of gluonstrahlung.
- Non-ruining α_S.
- Term due to ε part of γ-traces omitted. done.
- NLO virtual corrections omitted. partly done.

Outline

Excellent weight distribution!



Jump over to conclusions

Skipping all the highly nontrivial details of the NLO insertions into multiparton distributions see other talks at http://jadach.web.cern.ch/

Summary and Prospects

- First serious feasibility study of the true NLO exclusive MC parton shower is under construction, well advanced...
- What next? Workplan well defined:
- Short range aim: Complete non-singlet.
- Middle range aim: Complete singlet.
- Speed up the MC weight calculation.
- Better documentation needed on what was done.
- NLO MC for W/Z production for LHC, including SANC electroweak library.
- NLO MC for DIS@HERA and an example of BSM processes at LHC

APPENDIX: Potential gains

While retaining exact NLO DGLAP evolution, excellent starting point for extensions:

- Possible extension towards CCFM, BFKL (low x limit)
- Correct soft limit and built-in colour coherence
- More realistic description of the quark thresholds
- The use of exact amplitudes for multigluon emission, the analog of Coherent Exclusive Exponentiation in QED (Jadach,Was,Ward)
- Better connection between hard process ME and the shower parts, as compared with MC@NLO and the likes
- In particular no negative weigh events, no ambiguity of defining last emission before hard process, etc.
- Providing better tool for exploiting HERA DATA for LHC (fitting F_2 directly with MC)
- And more!!!

Diags. contributing to non-singlet kernels up to NLO