Towards new MC(QCD+EW) for W/Z@LHC and DIS

CAMTOPH-Krakow collaboration,

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CAMTOPH-Krakow project

- **People involved:**
  K. Golec-Biernat*, A. van Hameren, S. Jadach*, M. Jeżabek, G. Nanava, W. Płaczek*, E. Richter-Wąs, M. Skrzypek*, P. Sawicki, P. Stephens, Z. Wąs*
- **Papers* on QCD MC evolution and new parton shower MCs:**
  hep-ph/0312355, NP Proc. 135:138(04), hep-ph/0504205, hep-ph/0509178, hep-ph/0504263, hep-ph/0603031, NP Proc. 157:241(06), more in preparation.
- **EW corrections to be taken from SANC group (Dubna)**
- **Other LHC related MC projects at IFJ-PAN:**
  TAUOLA, PHOTOS, WINHAC.

Single hadron QCD Evolution in Cracow using MC, 2005/06

- Towards high quality MC for QCD ISR (+EW) in the W/Z production at LHC. DIS in the scope.
- Main emphasis on **CMC**= **C**onstrained **M**onte **C**arlo
- **MMC**s = **M**arkovian**M**onte **C**arlos developed for testing MMCs.
- MMC programs implement presently:
  - DGLAP LL/NLL (xchecked with QCDnum16 and APCHEB to within 0.2%),
  - CCFM-like $\alpha_S(q(1-z))$, $\epsilon_{IR} = q_0/q$, with Q-G transitions.
  - CCFM all-loop, $\alpha_S(k^T)$, $k^T > \lambda$, with Q-G transitions.
- **CMC**s feature presently:
  - DGLAP LL (xchecked with MMC and QCDnum16), Q-G transitions.
  - CCFM-like $\alpha_S(q(1-z))$, $\epsilon_{IR} = q_0/q$, Q-G trans., tested with MMC
  - CCFM all-loop, $\alpha_S(k^T)$, $k^T > \lambda$, agrees with MMC, without Q-G transitions yet (coming soon).

QCD ISR: Double evolution in rapidity – June 06

Emitted particle 4-moms in lightcone $\pm$ variables and rapidities:

$$k_i = (k_i^+, k_i^-, \vec{k}_{Ti}), \quad \vec{k}_{Ti}^2 = k_i^+ k_i^-, \quad e^{2\eta_i} = \xi_i = \frac{k_i^-}{k_i^+} = \frac{\vec{k}_{Ti}^2}{s k_i^{+2}}$$

Parametrization of the"eikonal phase space element":

$$\frac{d^3 k_i}{2k_i^0} \frac{1}{k_i^- k_i^+} = \frac{d\xi_i dk_i^+ d\varphi_i}{\xi_i k_i^+}$$

The IR boundary on k_i^T (alternatively on $x_{i-1} k_i^T$):

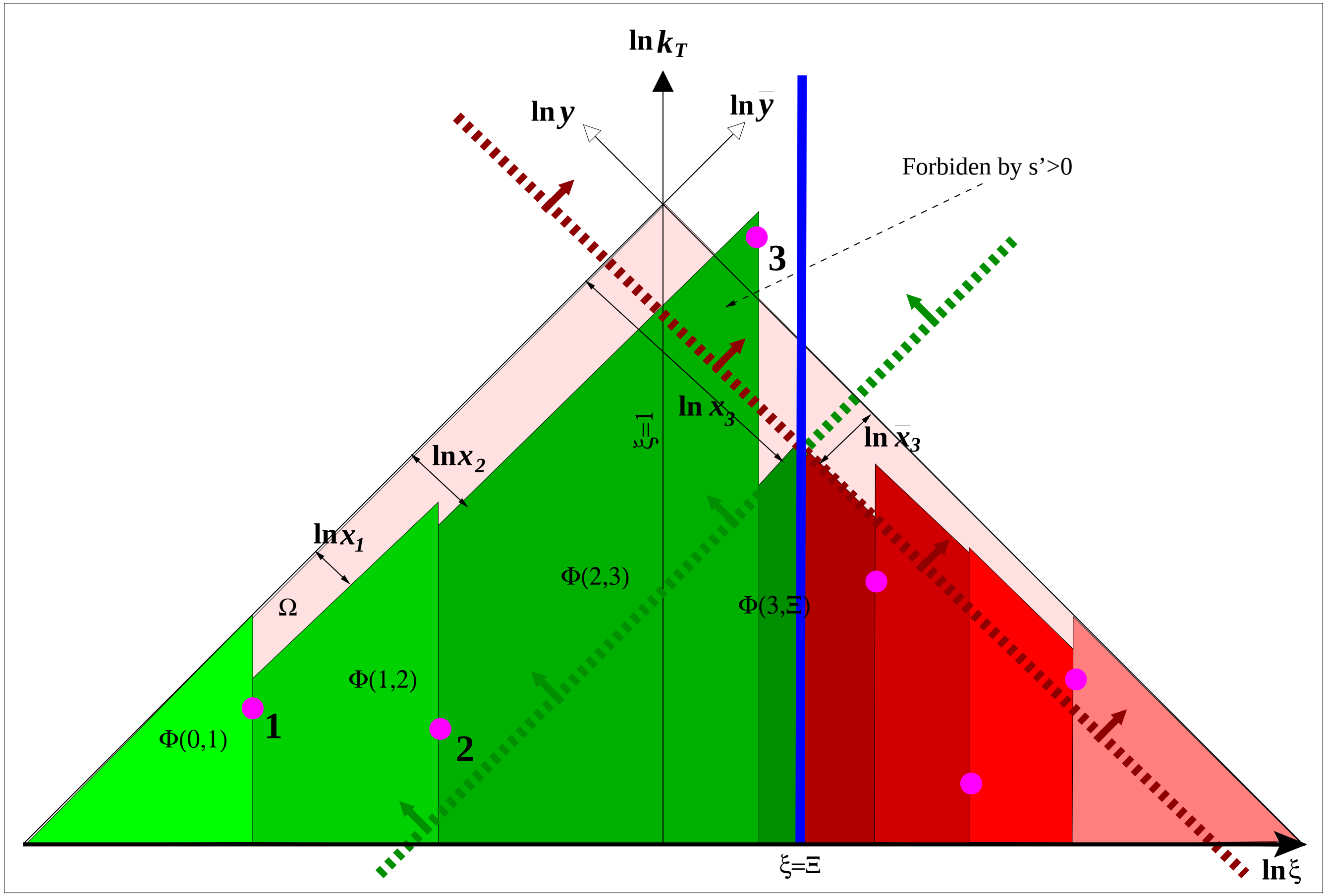
$$k_{Ti}^2 = k_i^+ k_i^- = k_i^{+2} \xi_i > \lambda^2, \quad k_i^+ = p_0^+ (1 - z_i) x_{i-1} > \frac{\lambda}{\sqrt{\xi_i}},$$

We chose rapidity as the evolution time (CCFM)

It is: $q_i = p_0^+ \sqrt{\xi_i}$, where $p_0 = (p_0^+, 0, 0, 0)$ is the primary emitter.

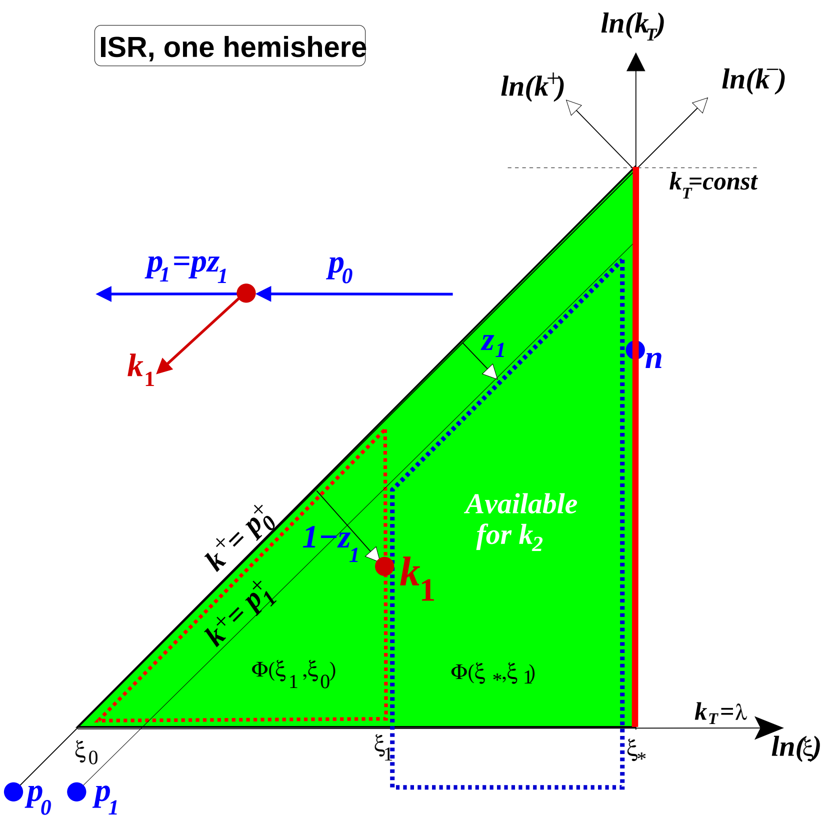
(Also $q_i =$ maximum k_T of the next emission.)

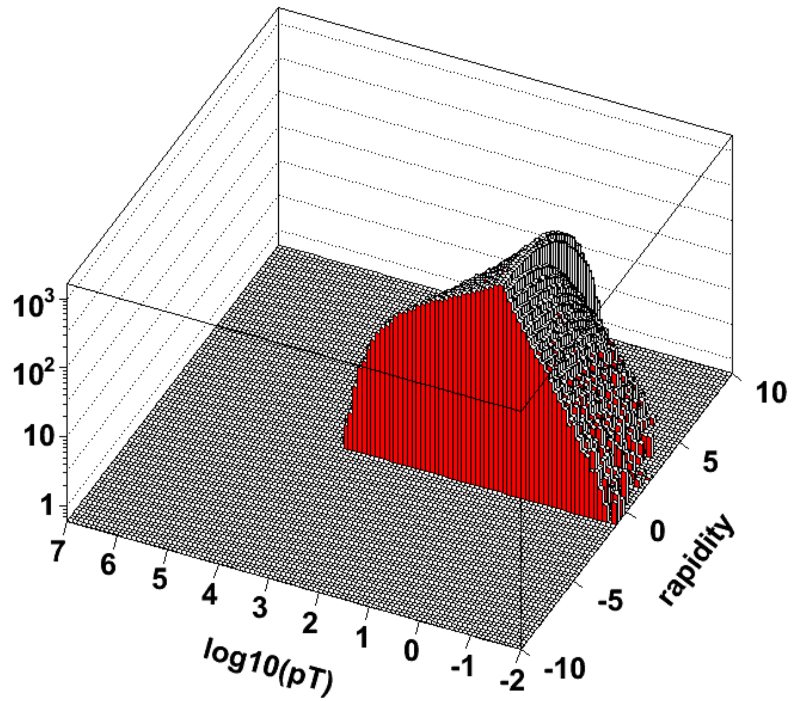
Rapidity – log(kT) plane: Multiple emission in 2 hemispheres



Using twice CMC for single evolution (`with the strict maximum rapidity phase space limit`) we cover smoothly the entire phase space of the emitted gluons **without any gaps or overlaps**.
The boundary blue line in rapidity should coincide with rapidity of the W/Z boson. Its actual position is unimportant for the soft gluon distributions.

Intermediate step CMC (June 05), $Q(1-z)$ instead of k^T





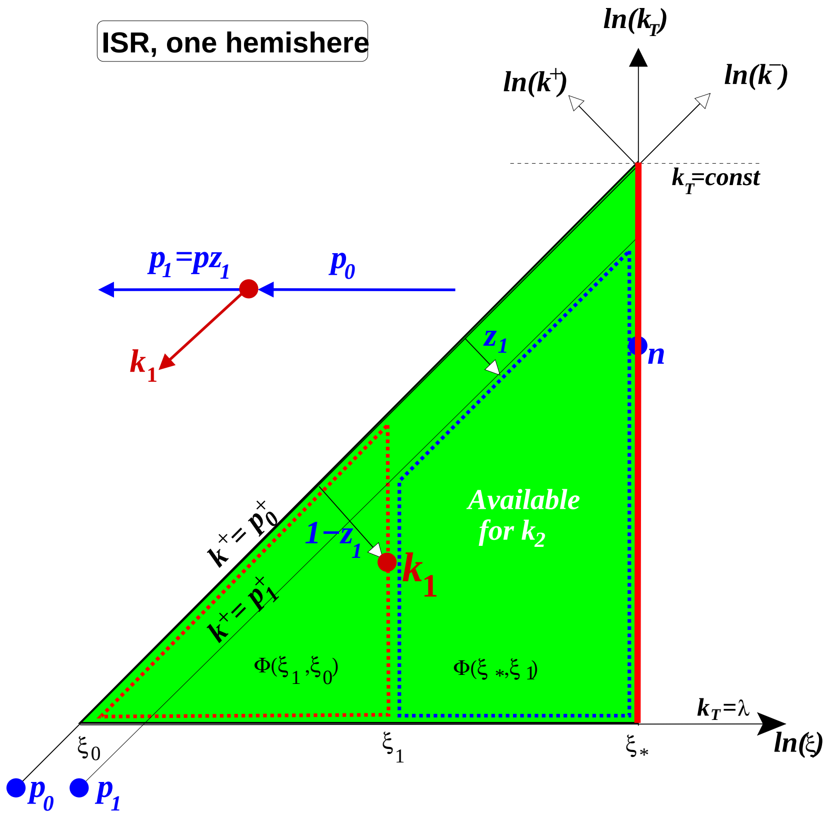
IR boundary in CMC (CCFM-like)

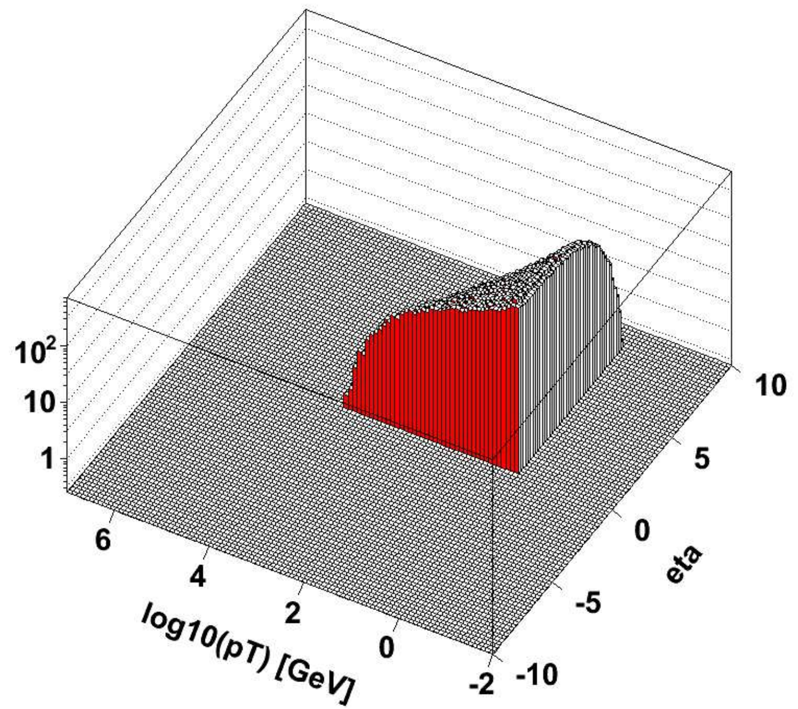
was $1 - z_i > \frac{\lambda}{p_0^+ \sqrt{\xi_i}}$ instead of $k_i^T > \lambda$.

Spurious $k_i^T < \lambda$ gluons and simplified $\alpha_S(Q(1-z))$.

Blue line defines phase space of the 2nd emission.

New! CMC compatible with all-loop CCFM





Full $\alpha(p^T) = \alpha(e^t x(1-z)/z)$ dependence!

No gluons below $p^T = p^T_{\min} = 1GeV$

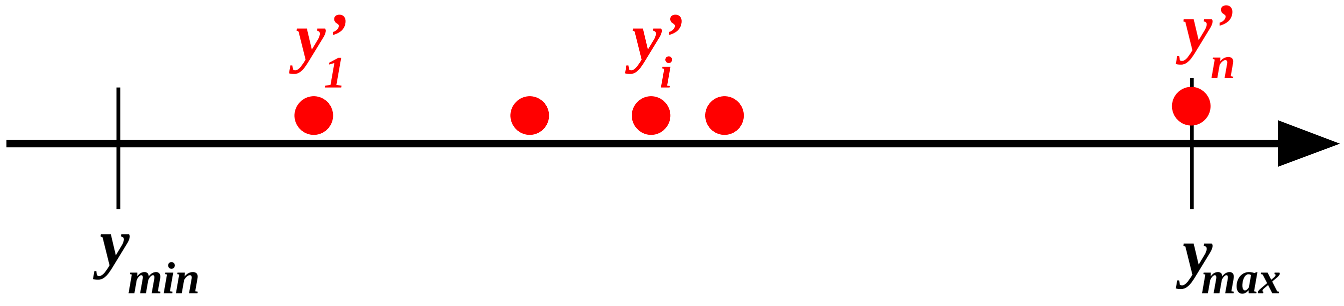
NB. Integration domains for Sudakov ffactors $\Phi_f(\xi|\xi_1,x)$ and $\Phi_f(\xi_1|\xi_0,x_0)$ are triangle and trapezoid in the 1-gluon distr.:

$$\tilde{D}_f(\xi,x)_{n=1} = \int_{\xi_0}^{\xi} \frac{d\xi_1}{\xi_1} \int_{\lambda/\sqrt{\xi_1}}^{p_0^+} \frac{dk_1^+}{k_1^+} \int \frac{d\varphi_1}{2\pi} e^{-\Phi_f(\xi|\xi_1,x)} \tilde{\mathbf{P}}_{ff}(k_1,z_1) e^{-\Phi_f(\xi_1|\xi_0,x_0)} \delta_{x=z_1}$$

CMC in a nutshell

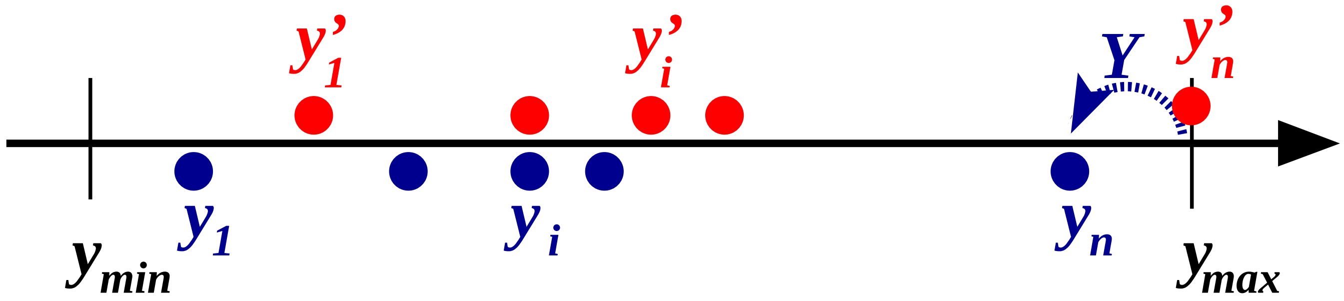
- **Mapping of evolution time $t_i \to s_i$ and $u_i = x_i - x_{i-1} \to y_i$, such that Jacobian eliminates completely the (simplified) kernel $zP_{ff}(z,t)$**
- **Ordering in s_i temporarily removed**
- **The constraint $\delta(x - \sum u_i)$ is eliminated/fulfilled by means of the parallel shift $y_i \to y_i - Y$ (for DGLAP.**
- **Quark-Gluon transitions modeled with “brute force” method using general purpose FOAM simulator.**
- **Appropriate correcting MC weights applied at the end.**
- **For more details see my talks in previous HERA-LHC and other places, http://jadach.web.cern.ch/jadach/ and http://arxiv.org/abs/hep-ph/0504263**
- **Such algorithm is now implemented in CMC (and tested with MMC) for all-loop CCFM (unpublished).**

Linear shift: $y'_i \to y_i = y'_i - Y$



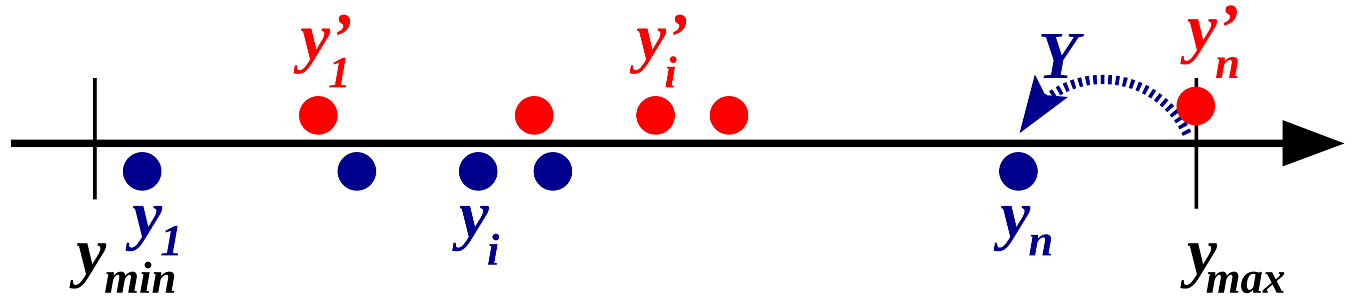
- Begin with y'_i such that one of them $y_n \equiv y_{\max}$

Linear shift: $y_i' \to y_i = y_i' - Y$



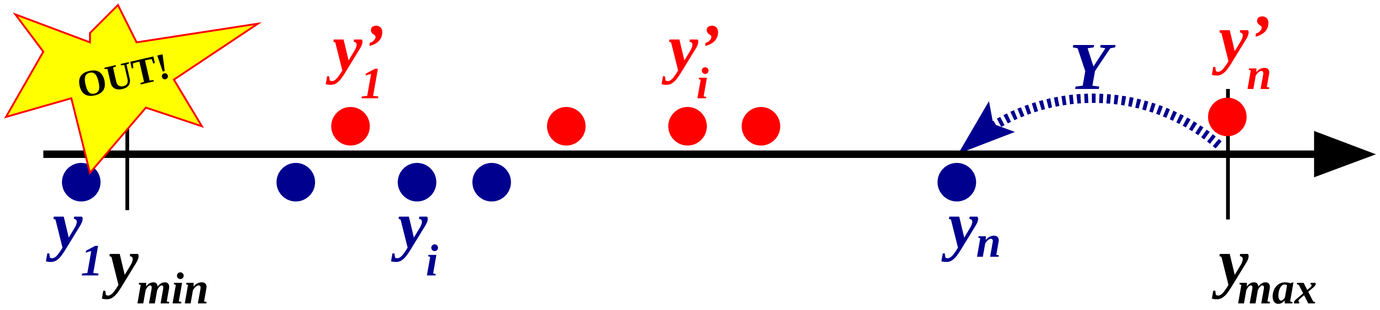
- Begin with y_i' such that one of them $y_n \equiv y_{\max}$
- Shift $y_i' \to y_i$ by Y, where Y solves constraint condition $x = \sum u_i = x$

Linear shift: $y'_i \to y_i = y'_i - Y(y'_1, y'_2, ..., y'_n)$



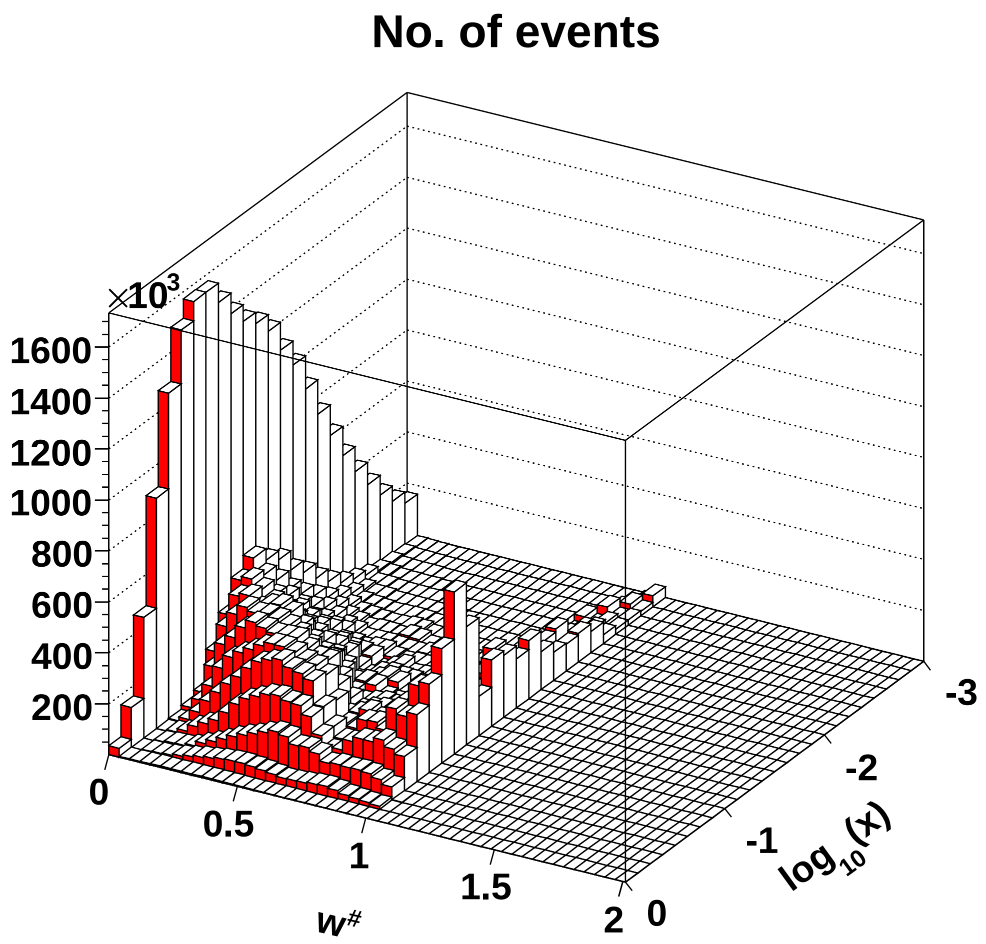
- Begin with y'_i such that one of them $y_n \equiv y_{\rm max}$
- Shift $y'_i \to y_i$ by Y, where Y solves constraint condition $x = \sum u_i = x$
- Y is therefore complicated function of all y'_i

Linear shift: $y'_i \to y_i = y'_i - Y(y'_1, y'_2, ..., y'_n)$



- Begin with y'_i such that one of them $y_n \equiv y_{\max}$
- Shift $y'_i \to y_i$ by Y, where Y solves constraint condition $x = \sum u_i = x$
- Y is therefore complicated function of all y'_i
- Sometimes the smallest y'_i is shifted OUT of the phase space, below IR the limit $y_{\min}$. Such an event gets MC weight $w = 0$

NEW! weight distribution for CMC(CCFM)



This is weight distribution, as a function of x, for quark emitter.

It looks OK. For Gluon emitter seems to be worse, under investigation.

HERA-LHC June 06: Joining smoothly two evolutions of 2 hemispheres

IMPORTANT PROBLEM to be solved:

In the existing CMC for single evolution the constraint is on the $\sum_F p_i^+$ of all gluons in the forward hemisphere and separately on the $\sum_B p_i^-$ in the backward one.

In reality we need the constraint on the effective mass $\hat{s}$ of the W/Z boson involving also $\sum_F p_i^-$, $\sum_B p_i^+$ and all transverse momenta.

Can we impose constraint on $\hat{s}$? Yes!

Example solution based on rescaling of 4-momenta (June 06)

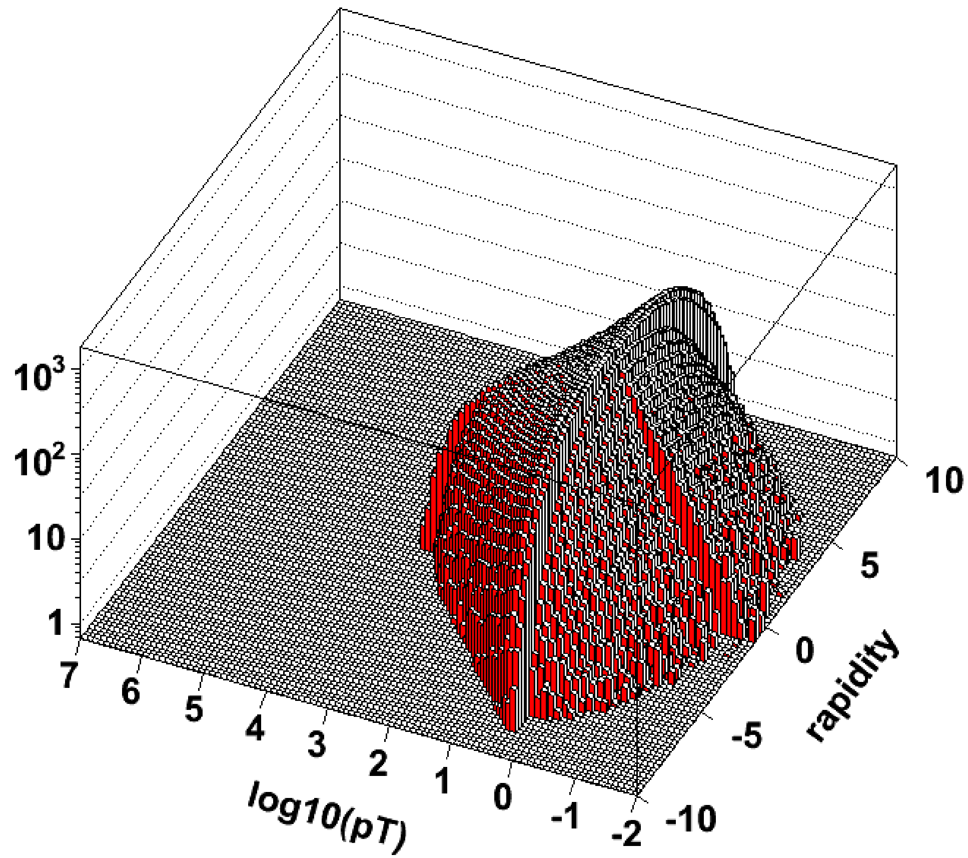
Replaces complicated constraint on $\hat{s}$ with a simplified one.

Additional requirement – Total control on the overall normalization: Normalization corrected rigorously by compensating MC weight W_{MC}.

$$\delta\left(sx - (p_{0F} + p_{0B} - K_F - K_B)^2\right) \;\longrightarrow\; \delta(sx - s_0 \hat{Z}_F \hat{Z}_B)\, W_{MC}$$

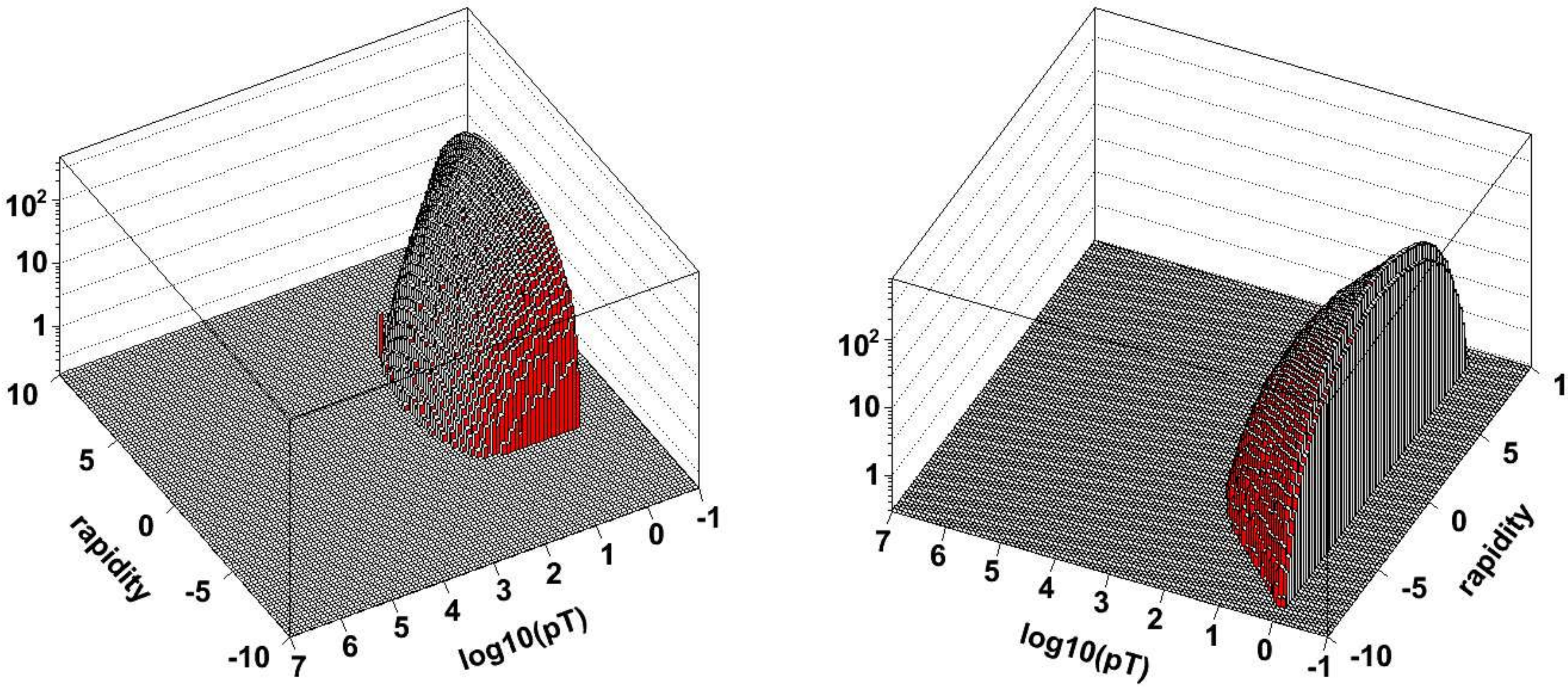
where $K_F = \sum_F k_{iF}$ and $K_B = \sum_B k_{iB}$ are total momenta of emitted gluons in the Forw./Backward hemispheres and $\hat{Z}_{F,B} = 1 - \sum x^+_{iF,B}$ are 1-hemis. lightcone variables.

June-July 06: Two simplified CMCs glued together



- Full coverage of 2 hemispheres, no overlap, no gaps :-)
- Visible gluons below k^T_{min}=1GeV (temporarily) and discontinuities due to $\alpha_S(Q(1-z))$:-(
- No L-R symmetry because rapitity of W is fixed at non-zero value (for this exercise) :-(

NEW!!! 2 hemispheres: Matched rapidity and minimum kT,



Joining 2 hemispheres – looks OK, more tests required.

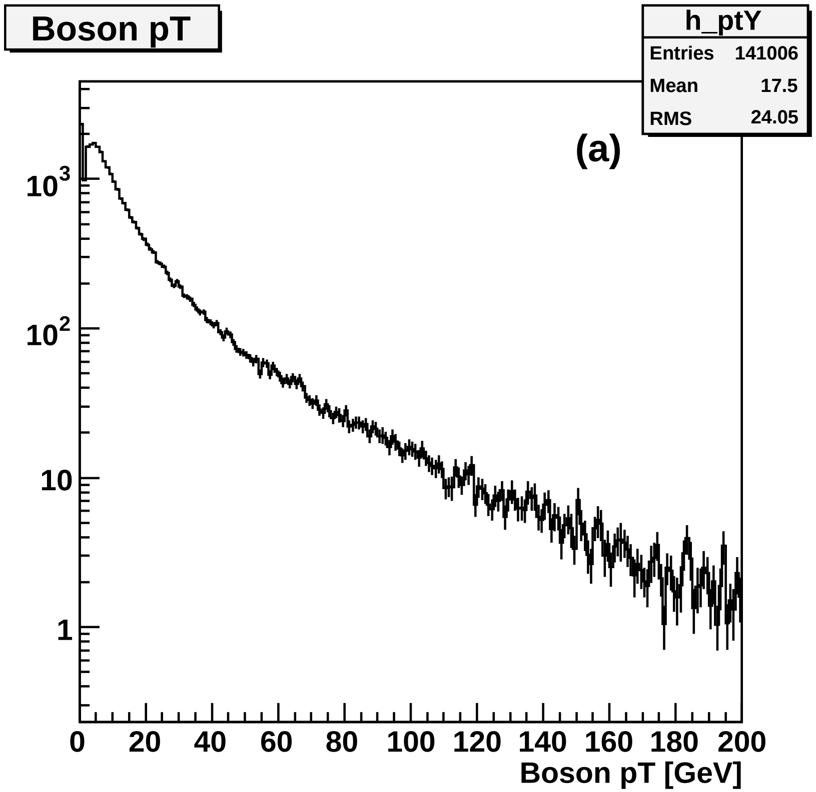
Full $\alpha(p^T) = \alpha(e^t x(1-z)/z)$ dependence!

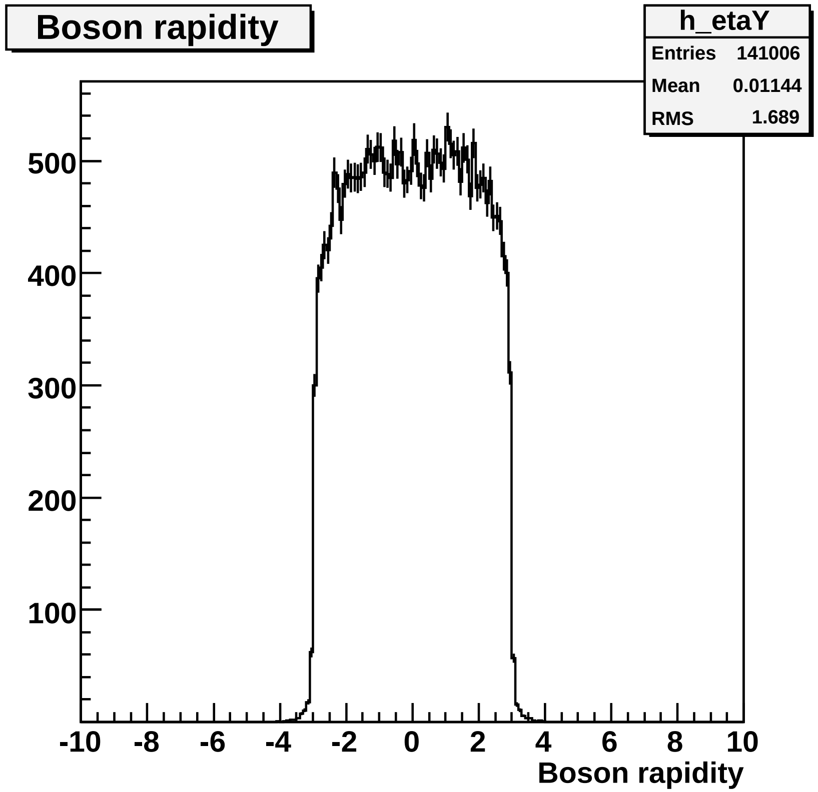
No gluons below $p^T = p^T_{\min} = 1GeV$

Fig. left: 1-hemisphere, with W rapidity fixed, emitted gluons.

Fig. right: 2 hemispheres, emitted gluons.

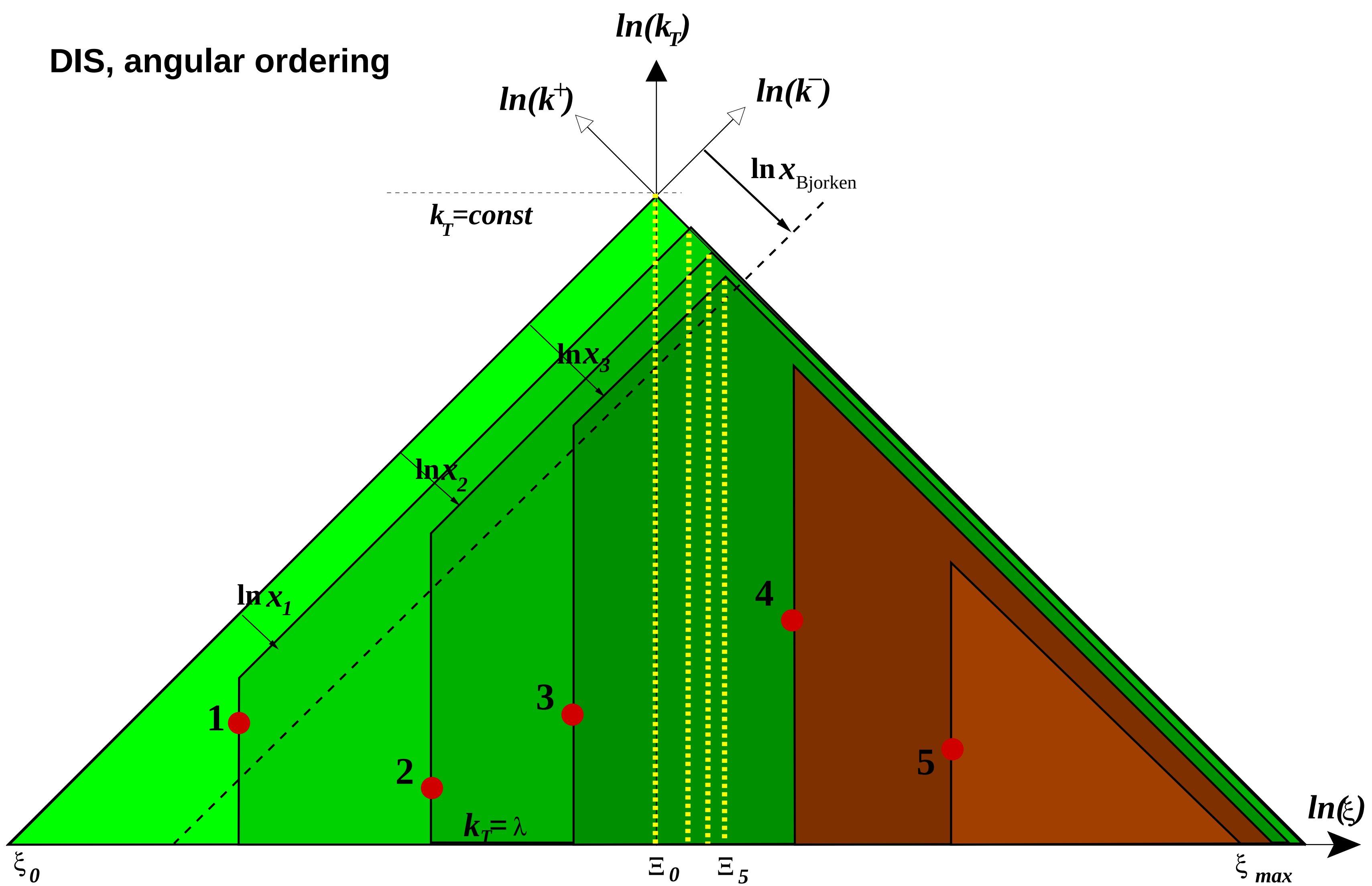
EW boson transverse momentum and rapitity distributions





Transverse momentum and rapidity distribution of the EW boson (mass 100GeV). Matrix element is maximally simplifi ed (only Breit-Wigner).
This was shown in June 06. Next round of tests/upgrades soon.

What about MC for DIS?



We are going for DIS MC towards scenario depicted above, with angular ordering and coverage of the FSR part of the phase space.
Part of that has to be done soon, as it is also needed for QCD ISR for W/Z@LHC.

Recent developments and plans

Recent activity:

- In progress: 2 single evolutions into one MC for W/Z production at LHC, more testing!
- HERA-LHC, June 06: First rudimentary distributions of W/Z rapidity and kT, towards more realistic distributions.

Plans:

- Quark-gluon transitions in CMC (CCFM)
- Better EW +QED FSR matrix element, from WINHAC/SANC
- xchecks with uPDFs of CASCADE/SMALLX?
- CMC/MMC for DIS process, fitting F_2
- QCD NLO in hard process (easy?)
- QCD NLO for evolution (difficult?)

Appendix

Three extra reserve slides follow.

- Vocabulary
- Master equation for single hemisphere gluonstrahlung
- Master equation, cont.

Vocabulary

Evolution types and solution methods:

- **Evolution: Common forward, unconstrained, (ISR, FSR):**
  - **Method of solving: straightforward Markovian MC algorithm (MMC)**
- **Evolution: Constrained (ISR):**
  - **Method: Constrained MC algorithm, non-Markovian (CMC)**
  - **Method: "Backward evolution" MC algorithm, Markovian (PYTHIA, HERWIG,...)**

Terminology:

"Markovian MC'': Emission multiplicity generated as last variable in the MC,

"Non-Markovian MC": Emission multiplicity generated as first variable (or 2nd).

"Constrained evolution": Final parton type and energy fraction x in the evolution are predefined, fixed. However, all the distribution can be identical as in the forward evolution (Markovian style).

Master eq. for single hemisphere gluonstrahlung

Master formula for ISR gluonstrahlung out of parton f with the angular ordering:

$$
\begin{aligned}
\tilde{D}_f(\xi,x) &= e^{-\Phi_f(\xi,\xi_0)}\delta(1-x) + \\
&+ \sum_{n=0}^{\infty} e^{-\Phi_f(\xi|\xi_n,x)} \left(\prod_{i=1}^{n} \int_{\xi_{i-1}}^{\xi} \frac{d\xi_i}{\xi_i} \int_{\lambda/\sqrt{\xi_i}}^{p_0^+ x_{i-1}} \frac{dk_i^+}{k_i^+} \int \frac{d\varphi_i}{2\pi} \right) \\
&\times \left(\prod_{i=1}^{n} \tilde{\mathbf{P}}_{ff}(k_i,z_i) e^{-\Phi_f(\xi_i|\xi_{i-1},x_{i-1})} \right) \delta_{x=\prod_{i=1}^{n} z_i} \\
1-z_i &= \frac{k_i^+}{p_0^+ - k_1^+ - k_2^+ \ldots . - k_{i-1}^+} = \frac{k_i^+}{p_0^+ x_{i-1}}, p_0^+ x_{i-1} = p_0^+ - \sum_{j=0}^{i-1} k_j^+,
\end{aligned}
$$

where, $\xi_0 = \lambda$, kernel $\tilde{\mathbf{P}}_{ff}(k,z) = z(1-z)\mathbf{P}_{ff}(k,z,x)$ includes α_S

$$
\mathbf{P}_{ff}(k,z,x) = \frac{\alpha_S(k)}{\pi} P_{ff}(\xi,z,x) = \frac{\alpha_S(k)}{\pi} \frac{B_{ff}}{z(1-z)} \chi_f(\xi,z),
$$

Master equation, cont.

Sudakov formfactor explicitly reads:

$$\Phi_f(\xi_i|\xi_{i-1},x_{i-1}) = \int\limits_{\xi_{i-1}}^{\xi_i} \frac{d\xi'}{\xi'} \int\limits_{\lambda/\sqrt{\xi'}}^{p_0^+ x_{i-1}} \frac{dk'^+}{k'^+} \tilde{\mathbf{P}}_{ff}(k',x_{i-1})$$

$$= \int\limits_{\xi_{i-1}}^{\xi_i} \frac{d\xi'}{\xi'} \int\limits_{0}^{1-\lambda/(p_0^+ x_{i-1}\sqrt{\xi_i})} \frac{dz'}{1-z'} \tilde{\mathbf{P}}_{ff}(z',x_{i-1})$$

Distribution of parton energy $\tilde{D}_f(\xi,x)$ obeys an evolution equation:

$$\partial_\xi \tilde{D}_f(\xi,x) = \int_0^1 \frac{dz}{1-z} dx P_{ff}(\xi,z,x')\tilde{D}_f(\xi,x')\delta_{x=zx'}$$