New MC for QCD initial state radiation

CAMTOPH-Krakow collaboration,

status report for MC4LHC Workshop, CERN, July 17-26, 2006

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CAMTOPH-Krakow project

QCD ISR MC 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.

Other LHC related MC projects:

TAUOLA, PHOTOS, WINHAC.

Single QCD Evolution in Cracow using MC, 05/06

QCD Evolution programs/exercises for single hadron:

- The long term aim: a high quality MC for QCD ISR in the W/Z production at LHC. (High quality EW/QED. DIS in the scope etc).
- Main emphasis on **CMC**= **C**onstrained **M**onte **C**arlo
- Also **MMC** programs = **M**arkovian**M**onte **C**arlos developed in parallel and used as calibration tool for testing MMCs.
- MMC programs implement presently:
  - DGLAP LL/NLL (xchecked with QCDnum16 and APCHEB to within 0.2%),
  - CCFM 1-loop LL evolution with options: $\alpha_S(q(1-z))$, $\epsilon_{IR} = q_0/q$, $q_{stop} = x_0 q_{max}$, Quark-Gluon transitions.
- **CMC** programs feature presently:
  - DGLAP LL (xchecked with MMC and QCDnum16), Q-G transitions.
  - CCFM 1-loop LL evol. (xchecked with MMC), options: $\alpha_S(q(1-z))$, $\epsilon_{IR} = q_0/q$, Q-G transitions! And more... see next slides.

Double evolution in rapidity – NEW June 06

Emitted particle momenta in terms of 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":

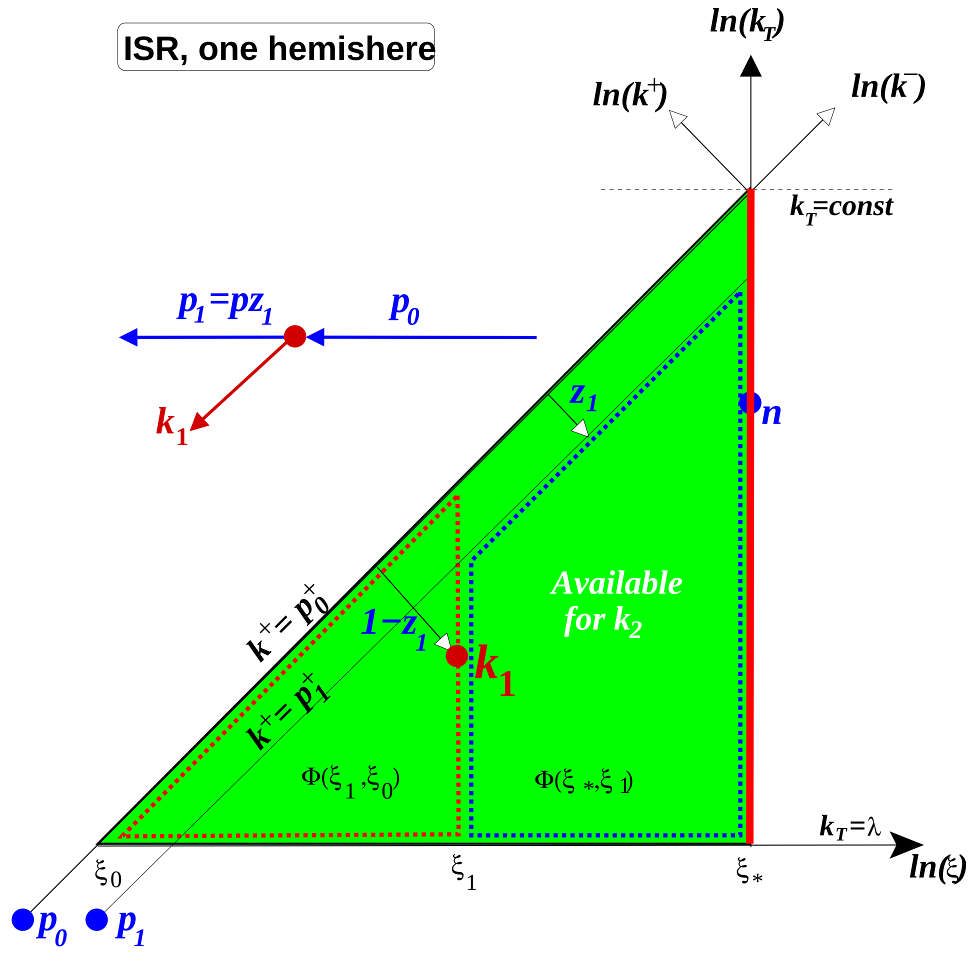
$$\frac{d^3 k_i}{2k_i^0} \frac{1}{k_i^- k_i^+} = \frac{d\xi_i dk_i^+ d\varphi_i}{\xi_i k_i^+}$$

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

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

The choice of the evolution time variable: $q_i = p_0^+ \sqrt{\xi_i}$, where $p_0 = (p_0^+, 0, 0, 0)$ is the primary emitter, before the evolution starts.
We chose rapidity as the evolution time!!!!
Also equal to maximum k_T of the next emission.

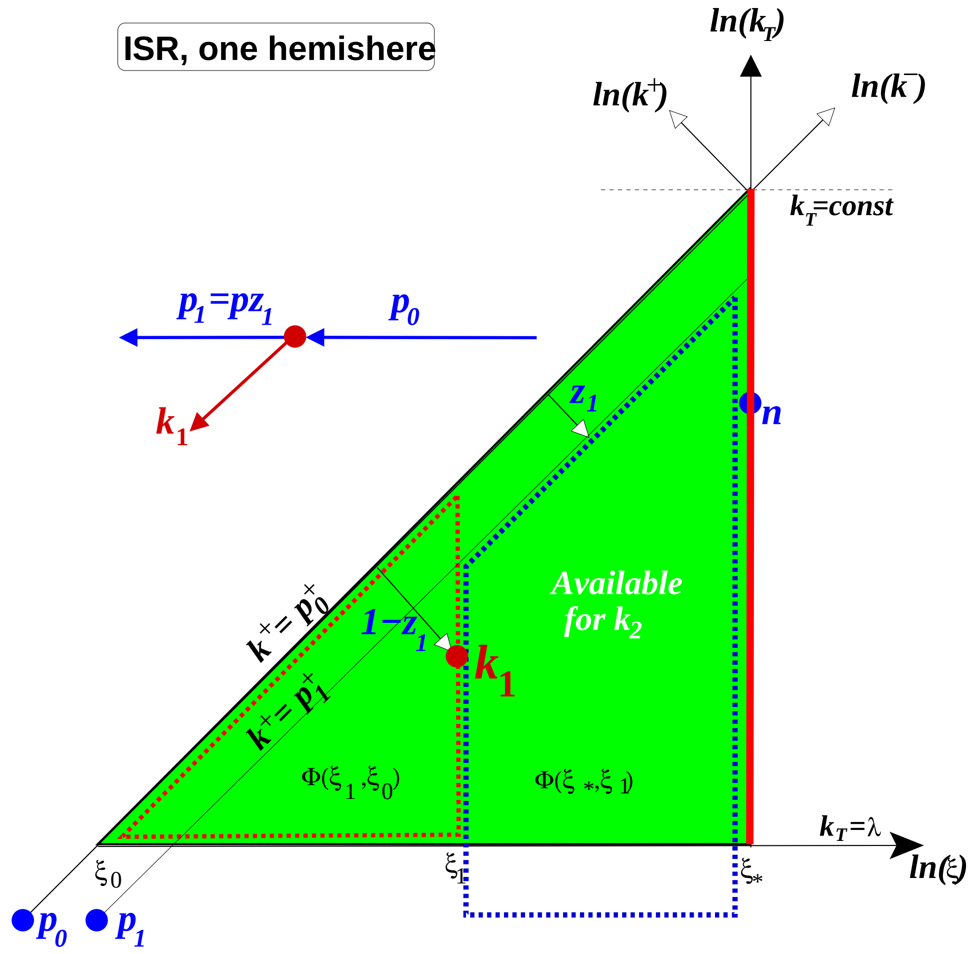
Rapidity – log(kT) plane: Single gluon emission example



Phase space limits and distribution. Integration domains of $\Phi_f(\xi|\xi_1,x)$ and $\Phi_f(\xi_1|\xi_0,x_0)$ are triangle and trapezoid:

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

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

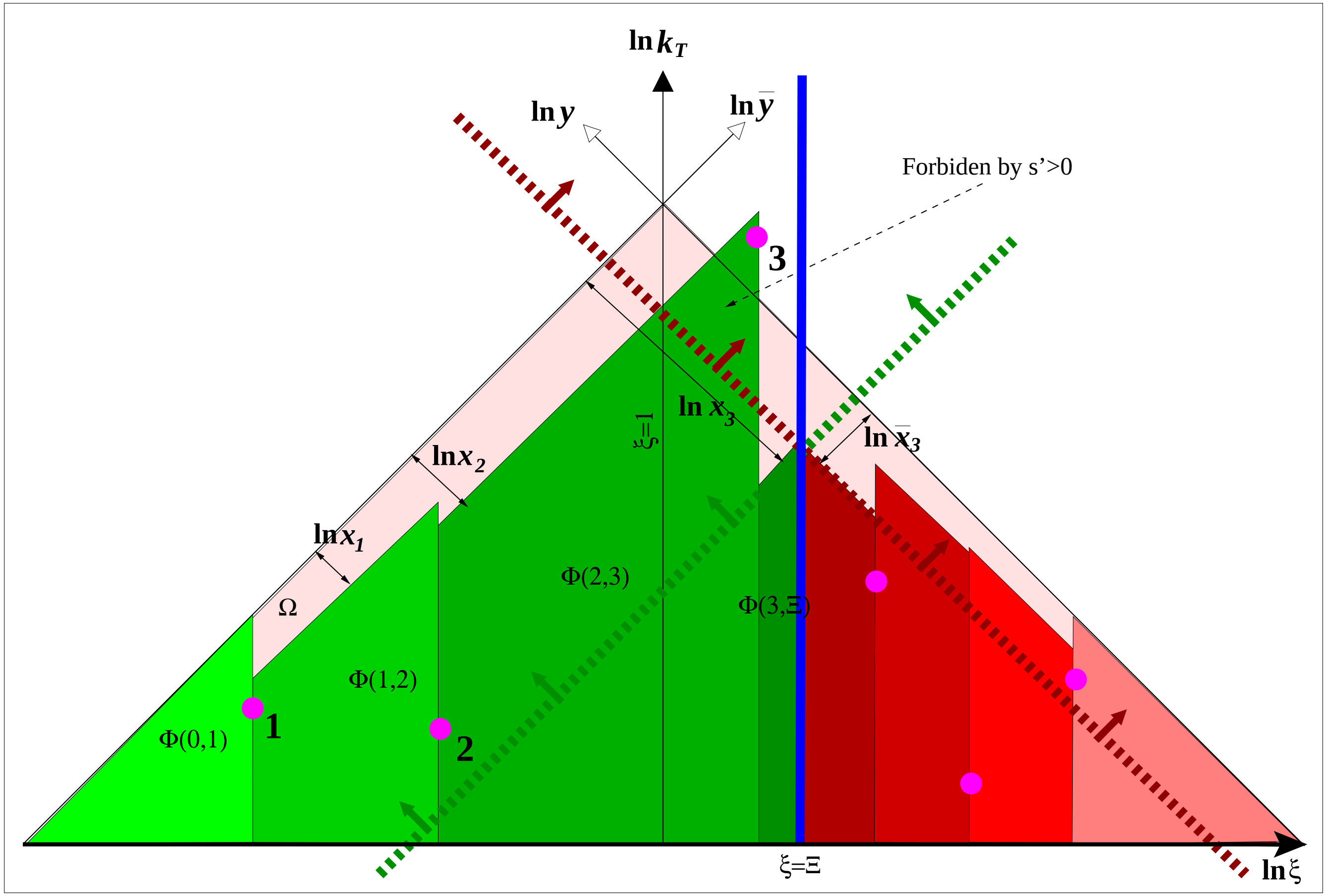


First stage (June 05): IR boundary in CMC was $1 - z_i > \frac{\lambda}{p_0^+ \sqrt{\xi_i}}$ instead of $k_i^T > \lambda$.

Blue line defines phase space of the 2nd emission.

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

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.

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)

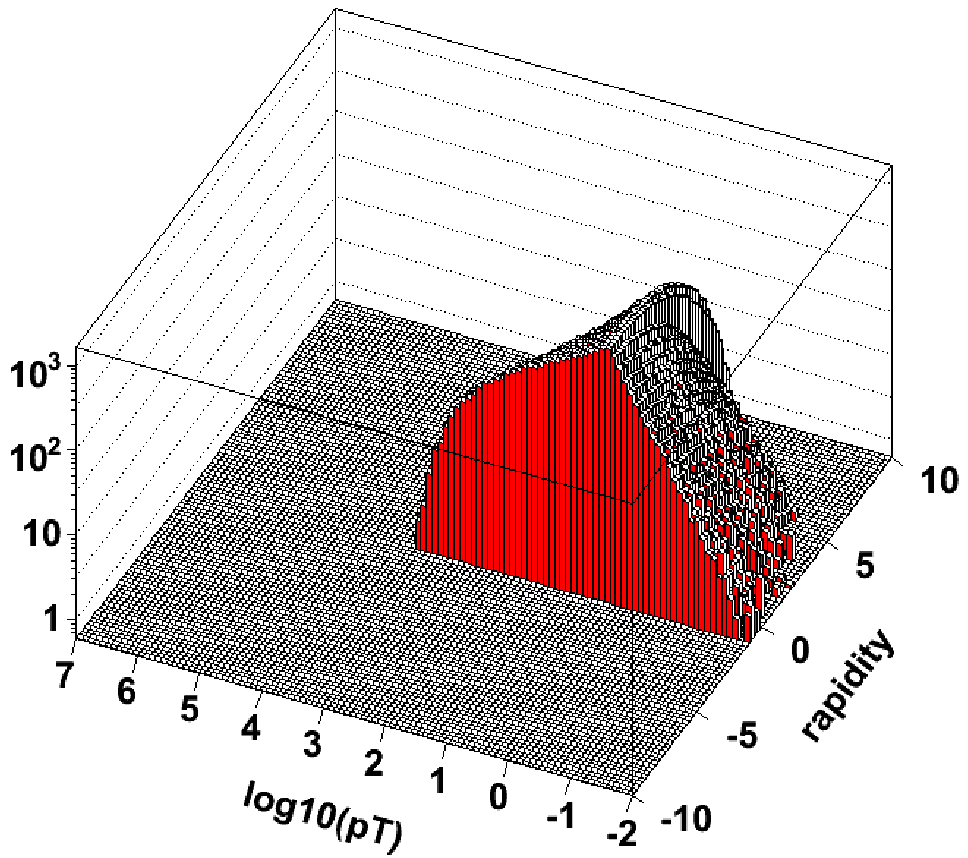
Replaces complicated constraint on $\hat{s}$ with a simplified one.

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. lighcone variables.

Two "intermediate step" CMCs glued together, June 06



- 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) :-(

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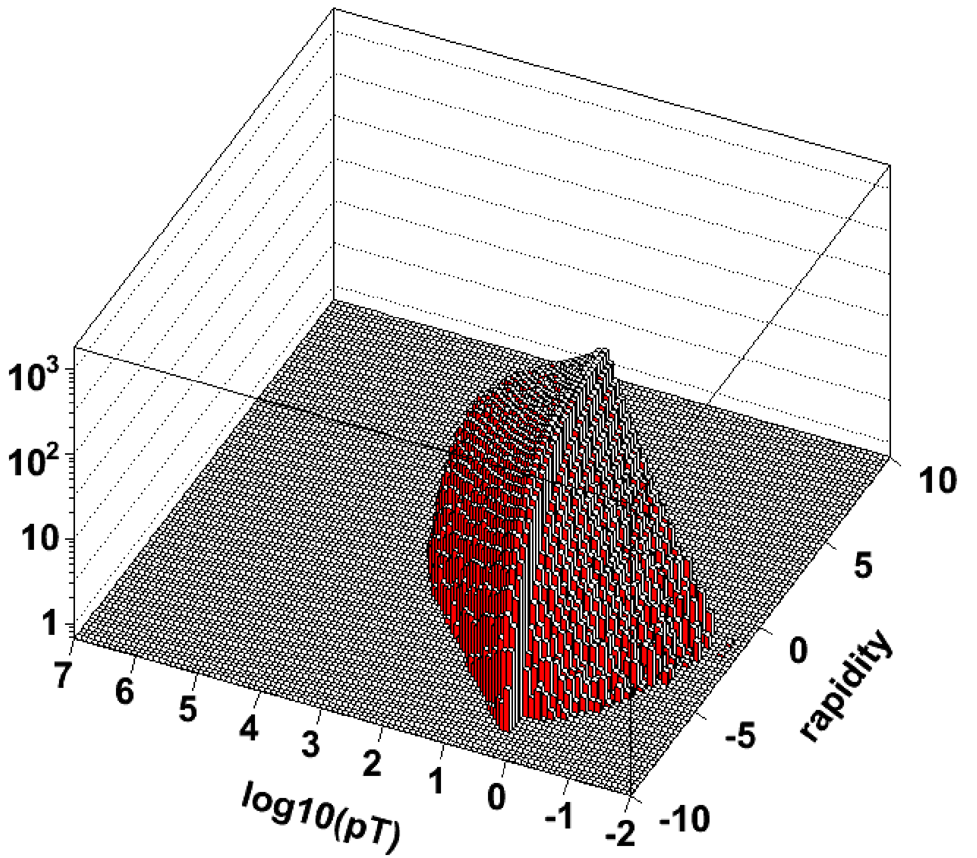

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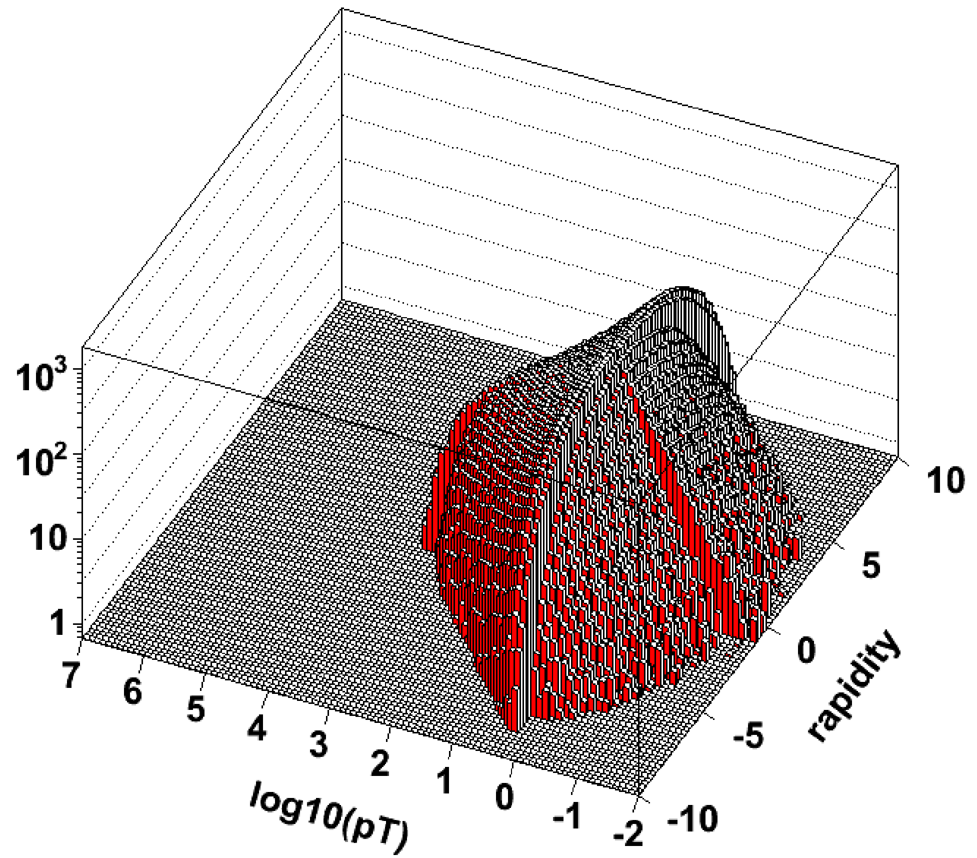

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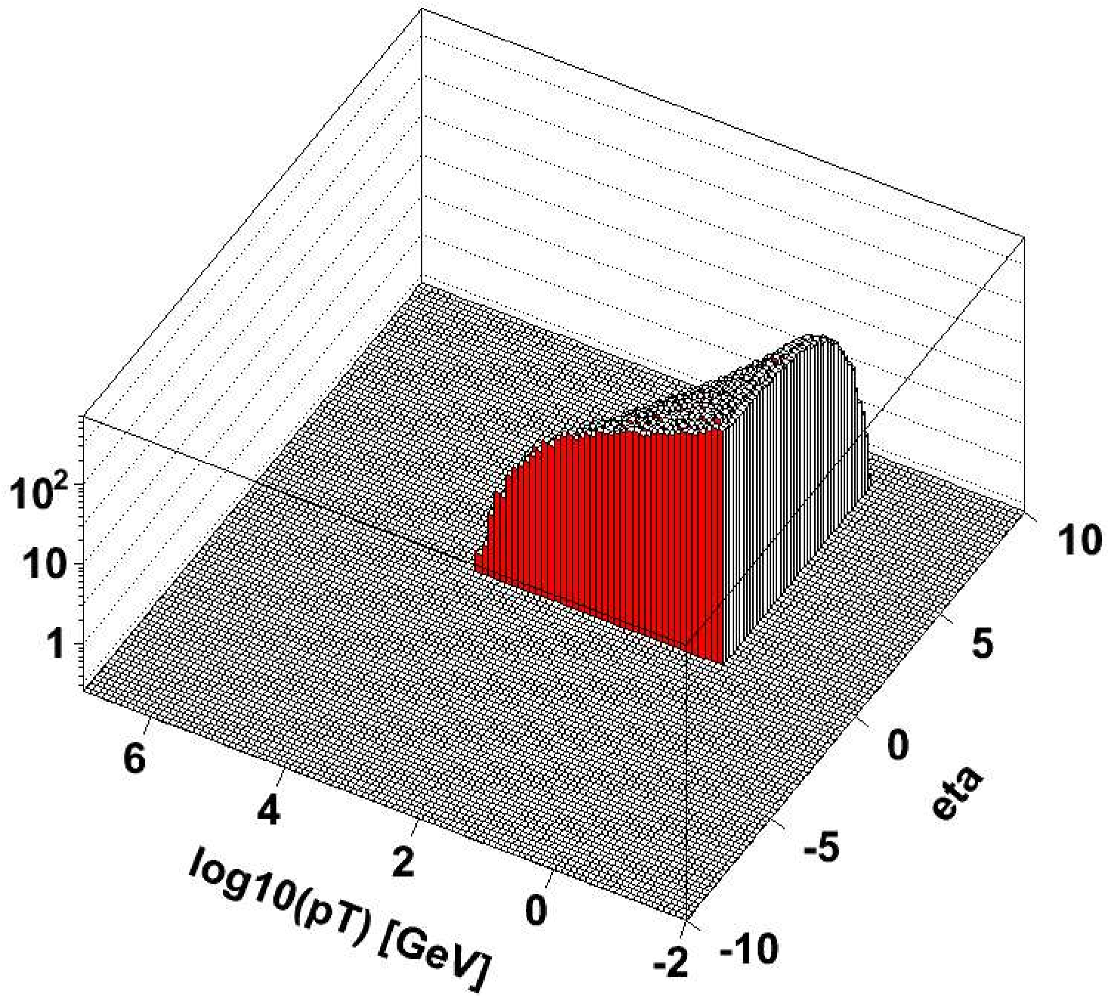
NEW!!! July 06: Maximum rapidity and minimum kT, single hemisp.



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

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

Joining 2 hemispheres – debugging stage.

Recent developments and plans

Recent activity:

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

Plans:

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

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:

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