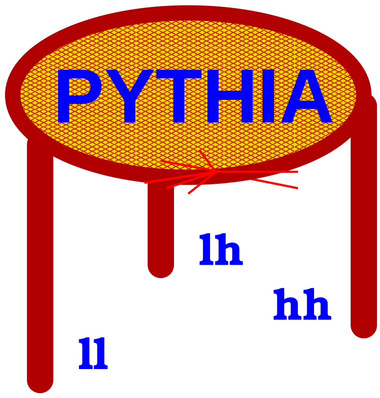
LUND UNIVERSITY

Workshop on
Monte Carlo Generator Physics
for Run II at the Tevatron,
Fermilab, April 18-20, 2001

Matching of ME with PS in PYTHIA



Torbjörn Sjöstrand

Introduction
Merging
. . . in FSR
. . . in ISR
NLO Matching I (S. Mrenna)
NLO Matching II (L. Lönnblad)
(N)LO Matching III

3 persons $\Rightarrow$ $\geq$ 4 strategies

Introduction

ME : Matrix Elements

- $+$ systematic expansion in α_{s} ('exact')
- $+$ powerful for multiparton Born level
- $+$ flexible phase space cuts
- $-$ loop calculations very tough
- $-$ negative cross section in collinear regions
  $\Rightarrow$ unpredictive jet structure
- $-$ no easy match to hadronization

PS : Parton Showers

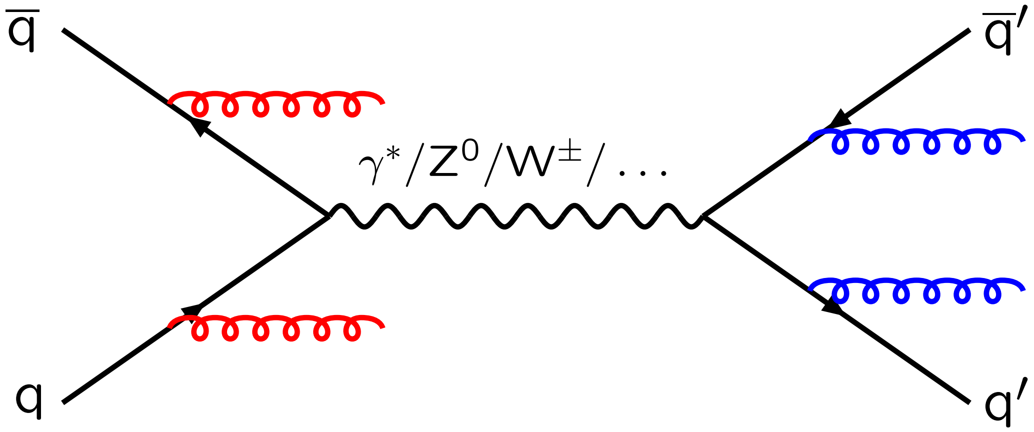
- $-$ approximate, to LL (or NLL)
- $-$ main topology not predetermined
  $\Rightarrow$ inefficient for exclusive states
- $+$ process-generic $\Rightarrow$ simple multiparton
- $+$ Sudakov form factors/resummation
  $\Rightarrow$ sensible jet structure
- $+$ easy to match to hadronization

Marriage desirable! But how?

Problems:
- gaps in coverage?
- doublecounting of radiation?
- Sudakov?
- NLO consistency?

Merging

= smooth transition ME/PS, no sharp edge.
Default strategy in PYTHIA



FSR = final-state radiation: timelike shower
forwards evolution in $Q^2 = m^2$

ISR = initial-state radiation: spacelike shower
backwards evolution in $Q^2 = -m^2$

$+$ emissions can cover full phase space
$-$ coherence not straightforward

Want shower to reproduce

$$W^{\mathrm{ME}} = \frac{1}{\sigma(\mathrm{LO})} \frac{\sigma(\mathrm{LO}+\mathrm{g})}{\mathrm{d(phasespace)}}$$

by shower generation + correction procedure

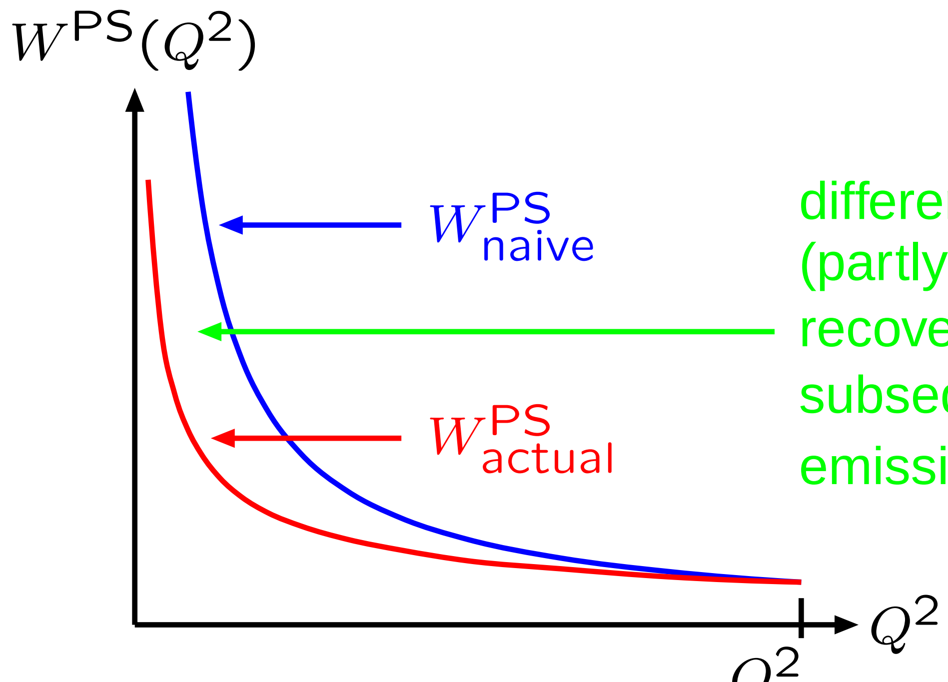
$$\overbrace{W^{\mathrm{ME}}}^{\text{wanted}} = \overbrace{W^{\mathrm{PS}}}^{\text{generated}} \; \frac{\overbrace{W^{\mathrm{ME}}}^{\text{correction}}}{W^{\mathrm{PS}}}$$

Comments:

• Do not normalize W^{ME} to $\sigma(\mathrm{NLO})$, since extra work without clear gain (expect radiation also in events added by K-factor ≥ 1)

• Shower contains Sudakov form factor

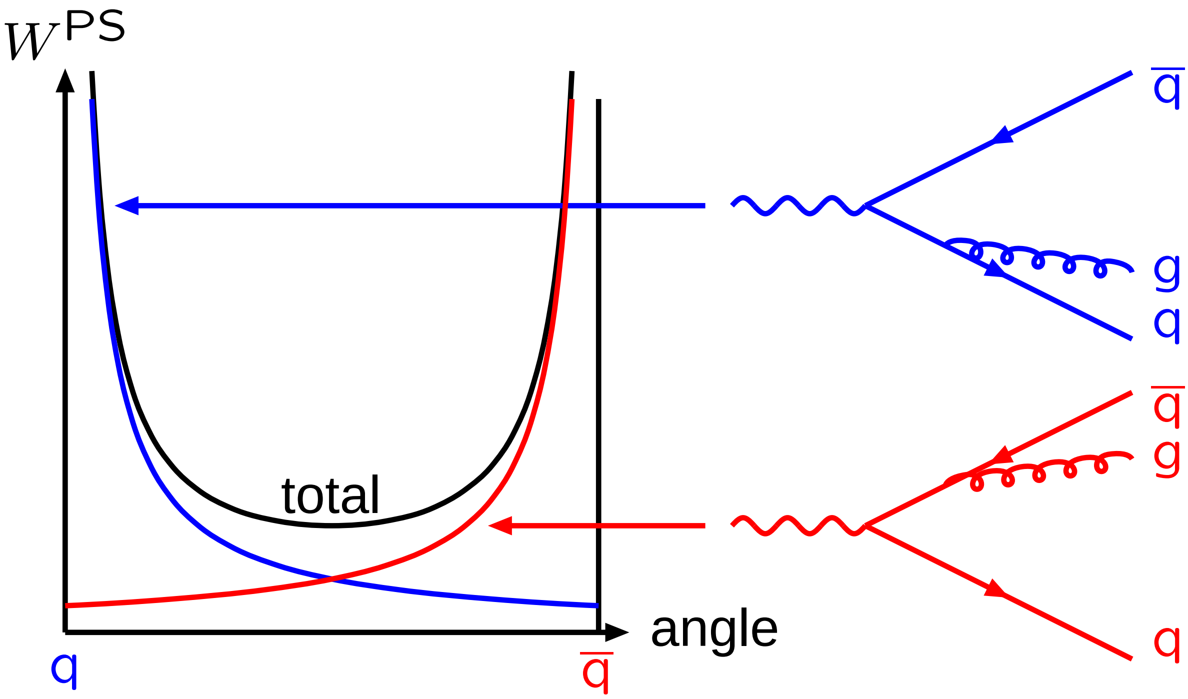
$$W^{\mathrm{PS}}_{\mathrm{actual}}(Q^2) =$$
$$W^{\mathrm{PS}}_{\mathrm{naive}}(Q^2)\,\exp\left(-\int_{Q^2}^{Q^2_{\mathrm{max}}} W^{\mathrm{PS}}_{\mathrm{naive}}(Q'^2)\,\mathrm{d}Q'^2\right)$$



merger: exponentiate ME correction

$$W^{\mathrm{PS}}_{\mathrm{actual}}(Q^2) =$$
$$W^{\mathrm{ME}}(Q^2)\,\exp\left(-\int_{Q^2}^{Q^2_{\mathrm{max}}} W^{\mathrm{ME}}(Q'^2)\,\mathrm{d}Q'^2\right)$$

• Normally several shower histories



(often ~ Feynman graphs; cf. ME amplitudes)

$$\Rightarrow W^{\text{PS}} = \sum_i W_i^{\text{PS}}; \text{ also(?) } W^{\text{ME}} = \sum_i W_i^{\text{ME}}$$

Alternative 1 (assuming $W^{\text{ME}} \leq W^{\text{PS}}$):

$$W^{\text{ME}} = W^{\text{PS}} \frac{W^{\text{ME}}}{W^{\text{PS}}} = \sum_i W_i^{\text{PS}} \frac{W^{\text{ME}}}{\sum_j W_j^{\text{PS}}}$$

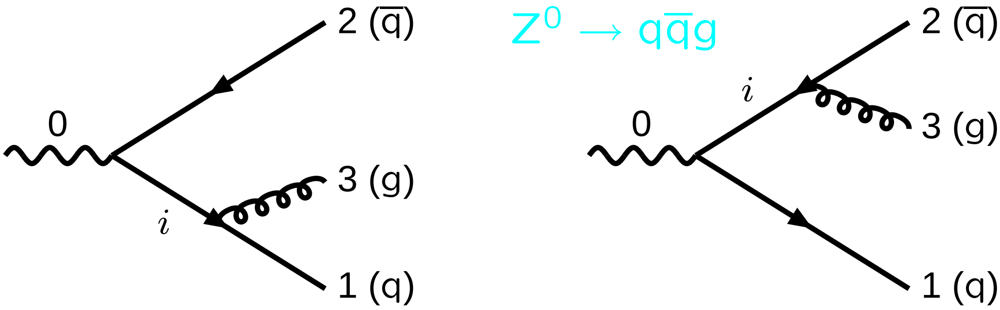
Alternative 2 (assuming $W_i^{\text{ME}} \leq W_i^{\text{PS}}$):

$$W^{\text{ME}} = \sum_i W_i^{\text{ME}} = \sum_i W_i^{\text{PS}} \frac{W_i^{\text{ME}}}{W_i^{\text{PS}}}$$

largely equivalent (some difference in Sudakov)
⇒ pick by convenience

Merging in FSR: massless case

(M. Bengtsson & TS, PLB185 (1987) 435, NPB289 (1987) 810)



$$\frac{1}{\sigma_0}\frac{d\sigma_{ME}}{dx_1\,dx_2} = \frac{\alpha_s}{2\pi} C_F \frac{\overbrace{x_1^2 + x_2^2}^{\approx 2}}{(1-x_1)(1-x_2)}$$

$$\frac{1}{\sigma_0}\frac{d\sigma_{PS}}{dQ^2\,dz} = \frac{\alpha_s}{2\pi} C_F \frac{dQ^2}{Q^2} \frac{\overbrace{1+z^2}^{\approx 2}}{1-z} dz \cdot (\text{Sudakov})$$

$$Q_1^2 = m_i^2 = (p_0 - p_2)^2 = (1-x_2)E_{CM}^2$$

$$z_1 = \frac{p_0 p_1}{p_0 p_i} = \frac{E_1}{E_i} = \frac{x_1}{x_1 + x_3} = \frac{x_1}{2 - x_2},$$

$$\Rightarrow \frac{dQ_1^2}{Q_1^2}\frac{dz_1}{1-z_1} = \frac{dx_2}{1-x_2}\frac{dx_1}{x_3}$$

$$\Rightarrow \frac{1}{\sigma_0}\frac{d\sigma_{PS}}{dx_1\,dx_2} \propto \frac{2}{(1-x_2)x_3} + \frac{2}{(1-x_1)x_3} = \frac{2}{(1-x_1)(1-x_2)}$$

$W^{ME} < W^{PS}$, i.e. good MC starting point

Merging in FSR: massive case

(E. Norrbin & TS, LUTP 00-42 [hep-ph/0010012] ⇒ NPB)

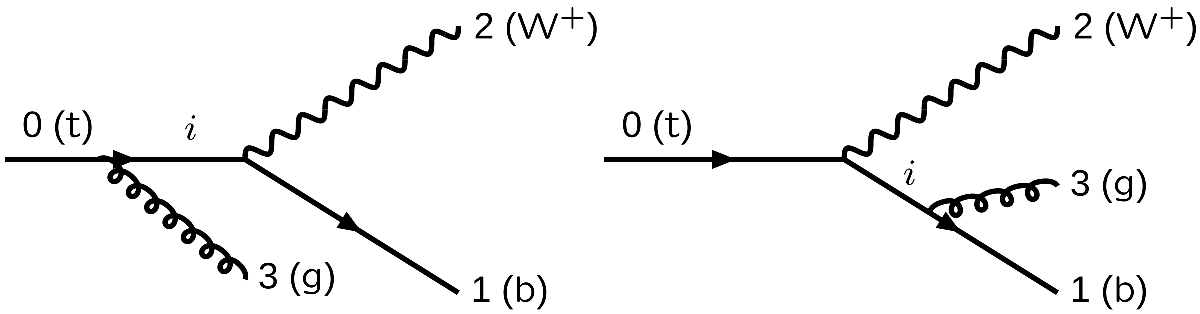
$Q_i^2 = m_i^2$ gives wrong singularity structure,
$Q_i^2 = m_i^2 - m_{i,\mathrm{onshell}}^2$ is relevant propagator;

$$\frac{1}{\sigma_0}\frac{\mathrm{d}\sigma_{\mathrm{ME}}}{\mathrm{d}x_1\,\mathrm{d}x_2} = \frac{(\ldots)}{Q_1^2 Q_2^2} - \frac{(\ldots)}{Q_1^4} - \frac{(\ldots)}{Q_2^4}$$

z now more messy but $\mathrm{d}z/(1-z) = \mathrm{d}x_1/x_3$ still

$$W_i^{\mathrm{ME}} = \frac{1/Q_i^2}{1/Q_1^2 + 1/Q_2^2}\,\frac{1}{\sigma_0}\,\frac{\mathrm{d}\sigma_{\mathrm{ME}}}{\mathrm{d}x_1\,\mathrm{d}x_2}$$

Also radiation from decaying particle:



$$Q_0^2 = |m_i^2 - m_0^2| = |(p_0 - p_3)^2 - m_0^2| = x_3 E_{\mathrm{CM}}^2$$

ME $\frac{1}{Q_0^2 Q_1^2}$ matches PS b → bg

⇒ can match PS to generic $a \to bc$g ME

subsequent branchings q → qg: also matched to ME, with reduced energy of system

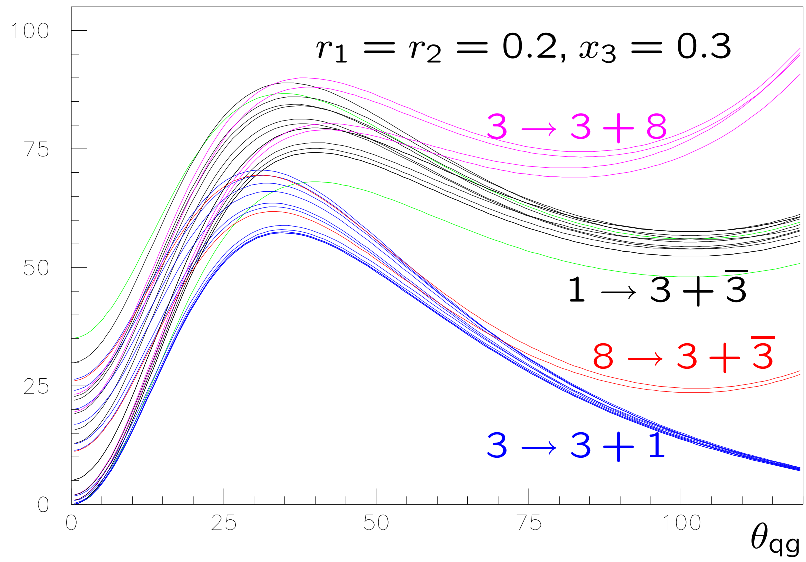
Calculate for $1 \to 2$ processes in SM + MSSM:

$$W^{ME}(x_1, x_2) = \frac{1}{\sigma(a \to bc)} \frac{d\sigma(a \to bcg)}{dx_1\, dx_2}$$

Depends on

- mass ratios $r_1 = m_b/m_a$ and $r_2 = m_c/m_a$
- colour and spin structure
- vector vs. axial vector etc. (γ_5)

colour	spin	γ_5	example
$1 \to 3 + \overline{3}$	—	—	(eikonal)
$1 \to 3 + \overline{3}$	$1 \to \frac{1}{2} + \frac{1}{2}$	$1, \gamma_5, 1 \pm \gamma_5$	$Z^0 \to q\overline{q}$
$3 \to 3 + 1$	$\frac{1}{2} \to \frac{1}{2} + 1$	$1, \gamma_5, 1 \pm \gamma_5$	$t \to bW^+$
$1 \to 3 + \overline{3}$	$0 \to \frac{1}{2} + \frac{1}{2}$	$1, \gamma_5, 1 \pm \gamma_5$	$H^0 \to q\overline{q}$
$3 \to 3 + 1$	$\frac{1}{2} \to \frac{1}{2} + 0$	$1, \gamma_5, 1 \pm \gamma_5$	$t \to bH^+$
$1 \to 3 + \overline{3}$	$1 \to 0 + 0$	1	$Z^0 \to \tilde{q}\overline{\tilde{q}}$
$3 \to 3 + 1$	$0 \to 0 + 1$	1	$\tilde{q} \to \tilde{q}'W^+$
$1 \to 3 + \overline{3}$	$0 \to 0 + 0$	1	$H^0 \to \tilde{q}\overline{\tilde{q}}$
$3 \to 3 + 1$	$0 \to 0 + 0$	1	$\tilde{q} \to \tilde{q}'H^+$
$1 \to 3 + \overline{3}$	$\frac{1}{2} \to \frac{1}{2} + 0$	$1, \gamma_5, 1 \pm \gamma_5$	$\chi \to q\overline{\tilde{q}}$
$3 \to 3 + 1$	$0 \to \frac{1}{2} + \frac{1}{2}$	$1, \gamma_5, 1 \pm \gamma_5$	$\tilde{q} \to q\chi$
$3 \to 3 + 1$	$\frac{1}{2} \to 0 + \frac{1}{2}$	$1, \gamma_5, 1 \pm \gamma_5$	$t \to \tilde{t}\chi$
$8 \to 3 + \overline{3}$	$\frac{1}{2} \to \frac{1}{2} + 0$	$1, \gamma_5, 1 \pm \gamma_5$	$\tilde{g} \to q\overline{\tilde{q}}$
$3 \to 3 + 8$	$0 \to \frac{1}{2} + \frac{1}{2}$	$1, \gamma_5, 1 \pm \gamma_5$	$\tilde{q} \to q\tilde{g}$
$3 \to 3 + 8$	$\frac{1}{2} \to 0 + \frac{1}{2}$	$1, \gamma_5, 1 \pm \gamma_5$	$t \to \tilde{t}\tilde{g}$



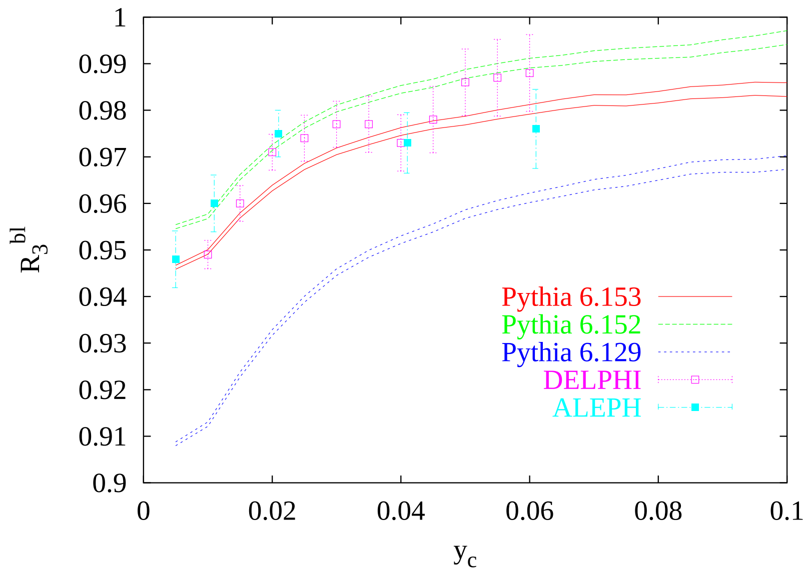
$W^{\mathsf{ME}}(x_1, x_2)$

g emission rate

for different

colour, spin and

parity structures



$R_3^{\mathsf{bl}}(y_c)$

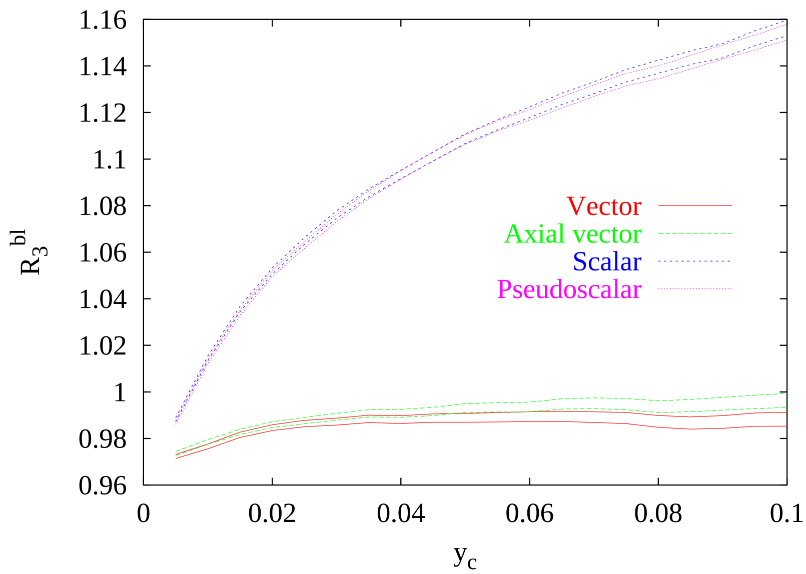
$E_{\mathsf{CM}} = 91$ GeV

$m_{\mathsf{b}} = 4.8$ GeV

ratio of 3-jets

in b and uds (=l)

events



$R_3^{\mathsf{bl}}(y_c)$

$E_{\mathsf{CM}} = m_{\mathsf{h/H/A}}$

$= 120$ GeV

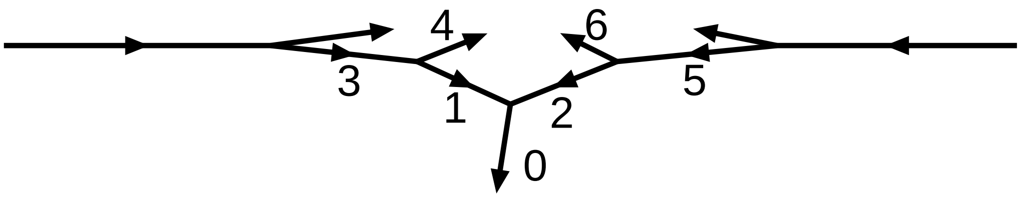
$m_{\mathsf{b}} = 4.8$ GeV

reference light q

from γ^*/Z^*

Merging in ISR: massless case

(G. Miu & TS, PLB449 (1999) 313)



$2 \to 2$ process $\mathrm{q}(3) + \overline{\mathrm{q}}'(2) \to \mathrm{g}(4) + \mathrm{W}(0)$:

$$\hat{s} = (p_3 + p_2)^2 \;=\; \frac{(p_1 + p_2)^2}{z} = \frac{m_{\mathrm{W}}^2}{z}$$

$$\hat{t} = (p_3 - p_4)^2 \;=\; p_1^2 = -Q^2$$

$$\hat{u} = m_{\mathrm{W}}^2 - \hat{s} - \hat{t} \;=\; Q^2 - \frac{1-z}{z}\, m_{\mathrm{W}}^2$$

Relate ME and PS rates:

$$\left.\frac{\mathrm{d}\hat{\sigma}}{\mathrm{d}\hat{t}}\right|_{\mathrm{ME}} = \frac{\sigma_0}{\hat{s}} \frac{\alpha_{\mathrm{s}}}{2\pi} \frac{4}{3} \frac{\hat{t}^2 + \hat{u}^2 + 2m_{\mathrm{W}}^2 \hat{s}}{\hat{t}\hat{u}}$$

$$\xrightarrow{Q^2 \to 0} \quad \sigma_0 \frac{\alpha_{\mathrm{s}}}{2\pi} \frac{4}{3} \frac{1+z^2}{1-z} \frac{1}{Q^2} = \left.\frac{\mathrm{d}\hat{\sigma}}{\mathrm{d}Q^2}\right|_{\mathrm{PS1}}$$

$$\left.\frac{\mathrm{d}\hat{\sigma}}{\mathrm{d}\hat{t}}\right|_{\mathrm{PS1}} = \frac{\sigma_0}{\hat{s}} \frac{\alpha_{\mathrm{s}}}{2\pi} \frac{4}{3} \frac{\hat{s}^2 + m_{\mathrm{W}}^4}{\hat{t}(\hat{t}+\hat{u})}$$

Add mirror $\mathrm{q}(1) + \overline{\mathrm{q}}'(5) \to \mathrm{g}(6) + \mathrm{W}(0)$:

$$\left.\frac{\mathrm{d}\hat{\sigma}}{\mathrm{d}\hat{t}}\right|_{\mathrm{PS}} = \left.\frac{\mathrm{d}\hat{\sigma}}{\mathrm{d}\hat{t}}\right|_{\mathrm{PS1}} + \left.\frac{\mathrm{d}\hat{\sigma}}{\mathrm{d}\hat{t}}\right|_{\mathrm{PS2}} = \frac{\sigma_0}{\hat{s}} \frac{\alpha_{\mathrm{s}}}{2\pi} \frac{4}{3} \frac{\hat{s}^2 + m_{\mathrm{W}}^4}{\hat{t}\hat{u}}$$

$$R_{q\overline{q}'\to gW}(\hat{s},\hat{t}) = \frac{(d\hat{\sigma}/d\hat{t})_{ME}}{(d\hat{\sigma}/d\hat{t})_{PS}} = \frac{\hat{t}^2+\hat{u}^2+2m_W^2\hat{s}}{\hat{s}^2+m_W^4}$$

$$\frac{1}{2} < R_{q\overline{q}'\to gW}(\hat{s},\hat{t}) \leq 1$$

Similarly for $q(1)+g(5)\to q'(6)+W(0)$:

$$\left.\frac{d\hat{\sigma}}{d\hat{t}}\right|_{ME} = \frac{\sigma_0}{\hat{s}}\frac{\alpha_s}{2\pi}\frac{1}{2}\frac{\hat{s}^2+\hat{u}^2+2m_W^2\hat{t}}{-\hat{s}\hat{u}}$$

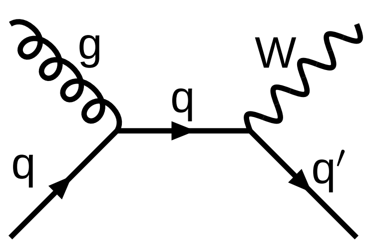
$$\stackrel{Q^2\to 0}{\longrightarrow} \quad \sigma_0\frac{\alpha_s}{2\pi}\frac{1}{2}\frac{z^2+(1-z)^2}{Q^2} = \left.\frac{d\hat{\sigma}}{dQ^2}\right|_{PS}$$

$$\left.\frac{d\hat{\sigma}}{d\hat{t}}\right|_{PS} = \frac{\sigma_0}{\hat{s}}\frac{\alpha_s}{2\pi}\frac{1}{2}\frac{\hat{s}^2+2m_W^2(\hat{t}+\hat{u})}{-\hat{s}\hat{u}}$$

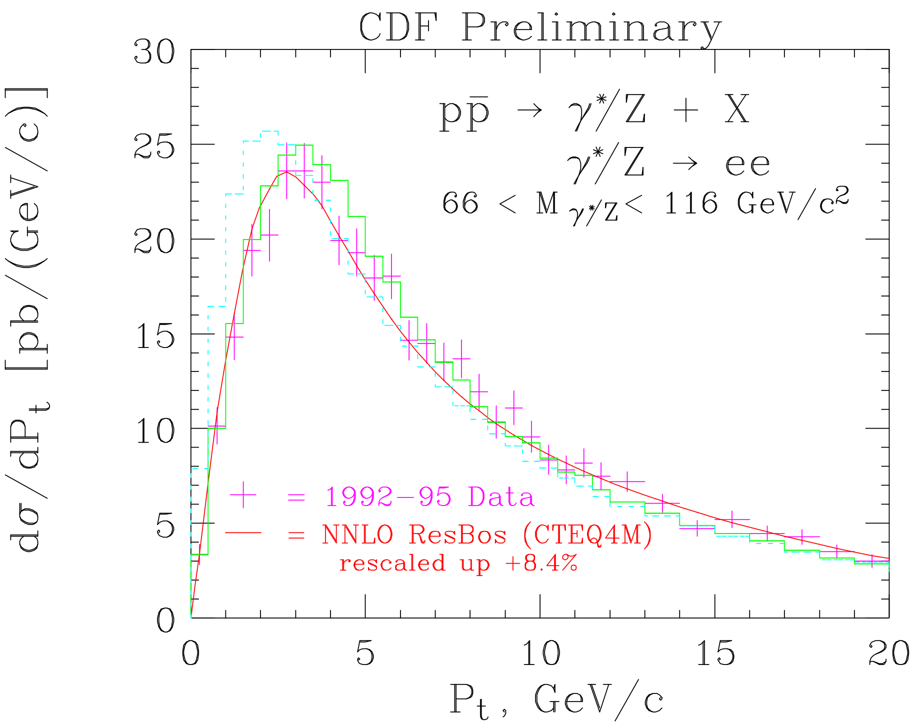
$$R_{qg\to q'W}(\hat{s},\hat{t}) = \frac{(d\hat{\sigma}/d\hat{t})_{ME}}{(d\hat{\sigma}/d\hat{t})_{PS}} = \frac{\hat{s}^2+\hat{u}^2+2m_W^2\hat{t}}{(\hat{s}-m_W^2)^2+m_W^4}$$

$$1 \leq R_{qg\to q'W}(\hat{s},\hat{t}) \leq \frac{\sqrt{5}-1}{2(\sqrt{5}-2)} < 3$$

(?) Larger R_{qg} than $R_{q\overline{q}'}$ since PS misses s-channel graph of ME:
"resonance decay",
"final-state radiation"



C. Balázs, J. Huston and I. Puljak,
PRD63 (2001) 014021



curve=ResBos

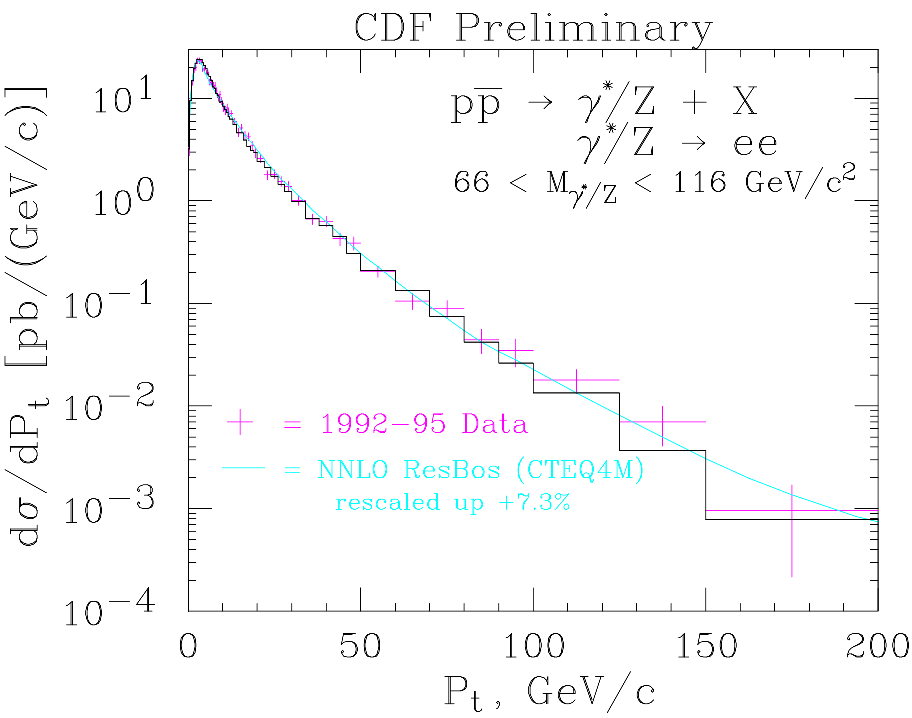
cyan=PYTHIA

($k_\perp = 0.44$ GeV)

green=PYTHIA

($k_\perp = 2.15$ GeV)

$K_{\text{PYTHIA}} = 1.4$



curve=ResBos

black=PYTHIA

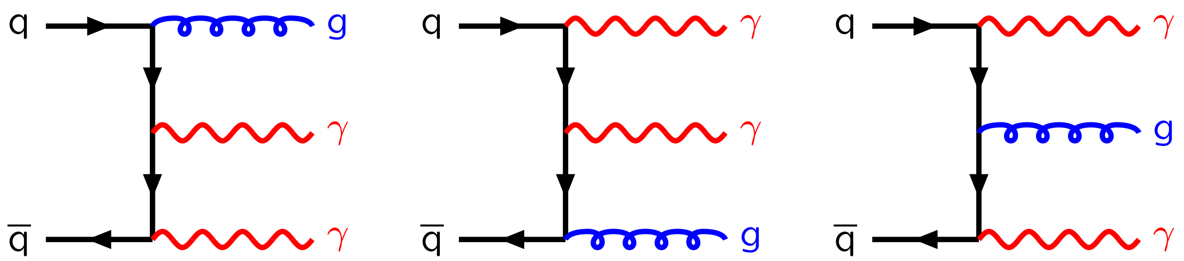
$K_{\text{PYTHIA}} = 1.4$

$Q^2_{\text{max}} = s$

Merging: much more to do!

ISR for gauge boson pairs

(S. Burby & TS, studies begun)



$q\bar{q} \to \gamma\gamma g$:

not only $(q\bar{q} \to \gamma\gamma) \oplus (q \to qg)$

but also $(q\bar{q} \to g\gamma) \oplus (q \to q\gamma)$

$\Rightarrow$ more shower histories $\approx$ divergences,

more difficult to ensure $W^{\mathrm{ME}} \leq W^{\mathrm{PS}}$

ISR in Graviton/Higgs/... production

$q\bar{q} \to G$ $\quad$ $gg \to G$

$q\bar{q} \to Gg$ $\quad$ $qg \to Gq$ $\quad$ $gg \to Gg$

also Higgs loop $\Rightarrow$ much more messy

QCD $2 \to 2$ processes, e.g. $gg \to gg$,

with consistent merging both to ISR and FSR

NLO Showering I

(S. Mrenna, UCD-99-4 [hep-ph/0010012])

ISR PS is a Q_T-resummation calculation

$$=\mathrm{e}^{-S_0^1}\otimes\mathrm{e}^{-S_1^2}\ldots\mathrm{e}^{-S_{N-1}^N}\sigma_0\mathrm{e}^{-S_{M-1}^M}\ldots\mathrm{e}^{-S_1^2}\otimes\mathrm{e}^{-S_0^1}$$

where $\mathrm{e}^{-S_i^j}=\mathrm{r}\in[0,1]$ and $\sigma_0=\sigma(q\bar{q}'\to W)$

$$S_i^j=-\int_{t_i}^{t_j}dt''\int_{\frac{x}{1-\epsilon}}^{\frac{x}{x+\epsilon}}dz\frac{\alpha_s(z,t'')}{2\pi}\widehat{P}_{a\to bc}(z)\frac{x'f_a(x',t_i)}{xf_b(x,t_i)}$$

allow all branchings $N+M=[0,\infty]$
$\Rightarrow$ generates NLL $d\sigma/dQ_T^2$, LO σ

Can Q_T-resummation generate a PS?

$$\frac{d\sigma(WX)}{dQ^2\,dQ_T^2\,dy}=\frac{d}{dQ_T^2}\widetilde{W}(Q_T,Q)+Y(Q_T,Q)$$

$$\widetilde{W}=\mathrm{e}^{-S_{Q_T}^Q}(C\otimes f)[Q_T](C\otimes f)[Q_T]\,H(Q)$$

$$S_{Q_T}^Q=\int_{Q_T^2}^{Q^2}\frac{d\bar{\mu}^2}{\bar{\mu}^2}[\ln\left(\frac{Q^2}{\bar{\mu}^2}\right)A(\alpha_s(\bar{\mu}))+B(\alpha_s(\bar{\mu}))]$$

$$(C_{jl}\otimes f_{l/h_1})(x_1,\mu) = \int_{x_1}^{1}\frac{d\xi_1}{\xi_1}C_{jl}(\frac{x_1}{\xi_1},\mu)f_{l/h_1}(\xi_1,\mu)$$

with H, A, B, C calculable in pert. theory

Ignoring Y and other kinematical dependence,

$$\frac{d\sigma(WX)}{dQ_T^2} = \sigma_1\frac{d}{dQ_T^2}\left[e^{-S_{Q_T}^{Q}}\frac{(C\otimes f)\,[Q_T]\,(C\otimes f)\,[Q_T]}{(C\otimes f)\,[Q]\,(C\otimes f)\,[Q]}\right]$$

$$\sigma_1 = \kappa\int\frac{dx_1}{x_1}(C\otimes f)\,[Q]\,(C\otimes f)\,[Q]$$

σ_1 is the higher-order cross section $(-Y)$
integral over Q_T^2 is unity

$$\sigma_0 = \kappa\int\frac{dx_1}{x_1}f(x_1,Q)f(x_2,Q) \quad (C\sim\delta(1-x))$$

Are the Sudakov's the same?

$$\int_{z_m}^{1-z_m} dz C_F\left(\frac{1+z^2}{1-z}\right) \simeq A^{(1)}\ln(Q^2/Q_T^2) + B^{(1)}$$

new PS algorithm $\Rightarrow$ use $C \otimes f$ instead of f generates higher-order rate

slightly modifies showering

What about Y?

Y corrects for soft gluon approximation

At NLO, $Y \propto$

$$|\mathcal{M}(q\bar{q}' \to Wg)|^2 + |\mathcal{M}(qg \to W\bar{q}')|^2 - \widetilde{W}|_{1/Q_T^2}$$

for $Q \geq Q_T$, the total rate is given by the hard emission processes

But Y has $+$ and $-$ weights!

(Also $\widetilde{W} < 0$ for $Q_T \sim 50$ GeV)

How to make hard correction with explicit emissions?

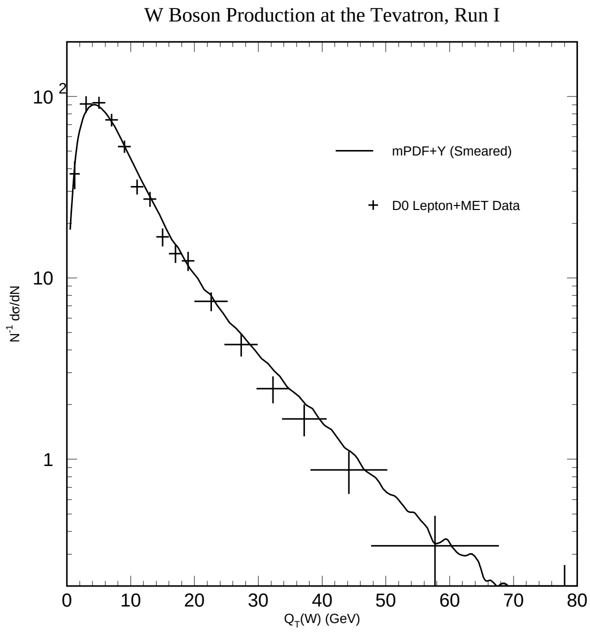
keep track of signs and cancel?

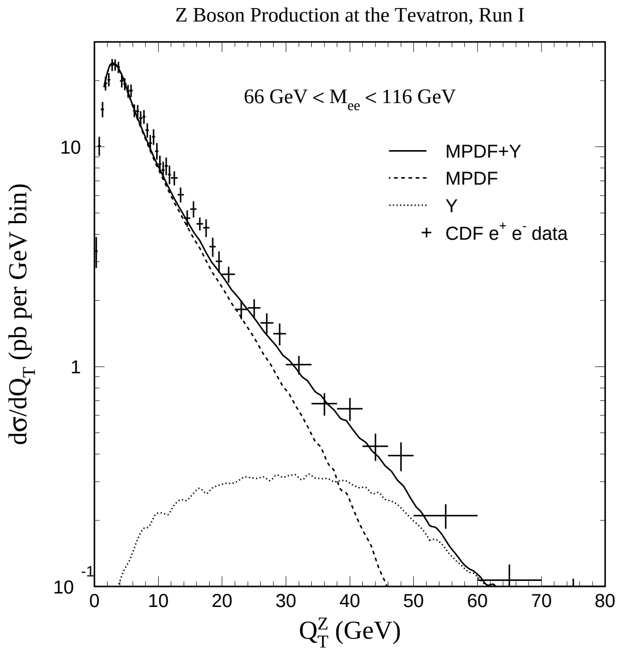
modify $\widetilde{W}$? (Promising)

for now, guarantee average behavior

$$\widetilde{W}|_{1/Q_T^2} \to (1 - f_{\text{cor}})|\mathcal{M}|^2$$

DØ P_T^W CDF P_T^Z





CTEQ4M and primordial $k_T = 2$ GeV

$Q_T < 50$ GeV

$f_{\mathrm{COR}} = \frac{1}{2}(Q_T/50)^2 \times (1 + Q_T/25)$

$Q_T \geq 50$ GeV

hard $W + g$ and $W + \bar{q}(q)$ emissions

Cut off PS at $Q_T = 50$ GeV

(where analytic resum < 0).

NLO Matching II

(L. Lönnblad, work in progress)

Current study: resonance decay
(e.g. e^+e^- annihilation)
Basic idea: add Sudakovs to tree-level α_s^2 ME
by veto procedure.

1) Pick event according to ME tree-level ($q\overline{q}$, $qg\overline{q}$, $qgg\overline{q}$ or $q\overline{q}q'\overline{q}'$), fixed (overestimated) α_{s0} and some cut-off Q_0

2) Enumerate possible shower histories, find the corresponding emission scales $k_{i\perp}^2$, estimate probabilities and pick one history accordingly.

3) Throw with probability $\Pi_i \alpha_s(k_{i\perp}^2)/\alpha_{s0}$

4a) If a 2-jet event, make a trial emission. If it is larger than Q_0 throw. Otherwise continue with emissions below Q_0.

4b) If a 3-jet event, make a trial emission from the original $q\overline{q}$. If it is larger than $k_{1\perp}^2$ throw. Otherwise make trial emission from $qg\overline{q}$. If it is larger than Q_0 throw. Otherwise continue with emissions below Q_0.

4c) If a 4-jet event, make a trial emission from the original $q\overline{q}$. If it is larger than $k^2_{1\perp}$ throw. Otherwise make trial emission from reconstructed $qg\overline{q}$. If it is larger than $k^2_{2\perp}$ throw. Otherwise continue with emissions below $k^2_{2\perp}$.

This will give emission diagrams correct to α_S^2 and leading log, and virtual diagrams correct to leading log accuracy.

Virtual diagrams could also be corrected by including the difference between the exact and leading log terms in the generation of the ME.

Is being implemented in Ariadne. Difficulties due to invariant mass cutoff in ME, but evolution in transverse momenta in dipole cascade.

(N)LO Matching III

(J. André & TS, PRD57 (1998) 5767)

1) Pick event according to ME

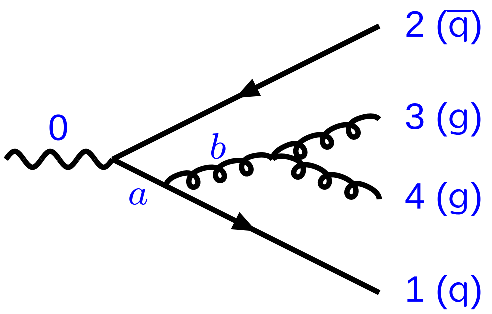
2) Enumerate possible shower histories, finding equivalent shower variables (m^2, z, φ)

3) Estimate probability for each PS history, and pick one accordingly

4) Develop shower from original parton pair, with some branchings now predetermined and the rest as normal

Currently only $\mathrm{e^+e^- \to q\overline{q}gg, q\overline{q}q'\overline{q}'}$

e.g.



$m_a^2 = (p_1 + p_3 + p_4)^2$

$z_a = E_1/E_a$

$m_b^2 = (p_3 + p_4)^2$

$z_b = E_3/E_b$

$$\mathcal{P} = \mathcal{P}_{a\to 1b}\mathcal{P}_{b\to 34} = \frac{1}{m_a^2}\,\frac{4}{3}\,\frac{1+z_a^2}{1-z_a}\,\frac{1}{m_b^2}\,3\,\frac{(1-z_b(1-z_b))^2}{z_b(1-z_b)}$$

Could be combined with NLO ME generator, by vetoing ‘normal’ shower emissions that doublecount emissions already in ME