A Strategy
for the ME-PDF/PS Matching
in Jet-associate Events

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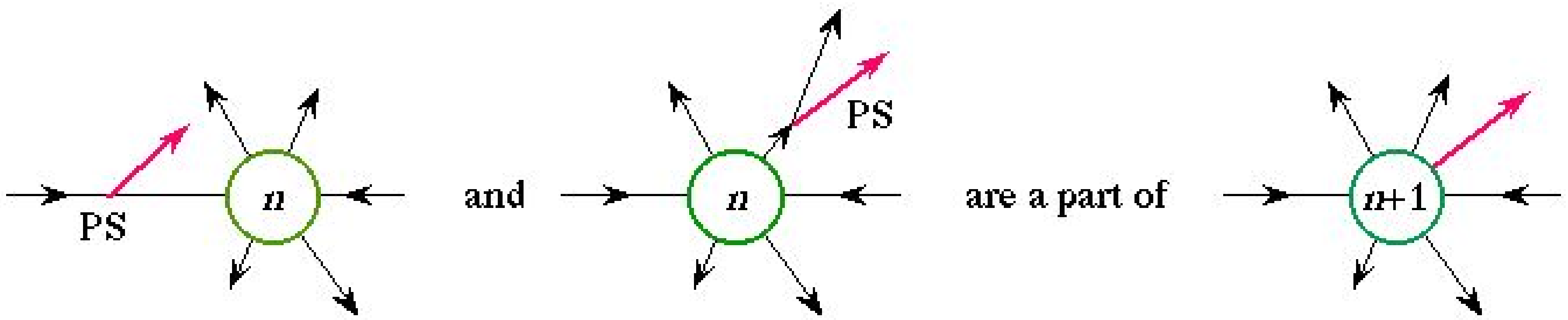
ME-PDF/PS Matching Problem

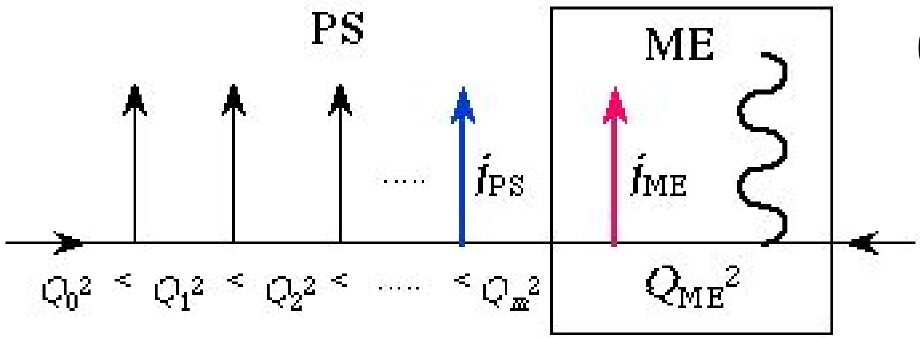
- We encounter serious problems when we try to simulate jet-associate processes (*e.g.*, $W/Z/H$ + jets).
  - When we want an n-jet sample, we have to run an n-jet generator and, maybe, at least (n-1)-jet and (n+1)-jet generators since jets in ME do not necessarily correspond to jets to be observed.
  - We need to use a PDF for hadron collision simulations, and need to apply initial and final-state PSs to obtain realistic events.
  - Then, we encounter a problem that we cannot find reasonable cuts in the event generation, and other problems when we try to combine the results.
- Problems in this simulation: double count between the generators, violation of Q^2 ordering at the junction between PS and ME, and the double-scale problem in ME.
- These problems are correlated. A rational guiding principle is necessary to solve them.

Double-count problem



We cannot simply add the results from an *n*-jet ME and an (*n*+1)-jet ME when a PS is applied.

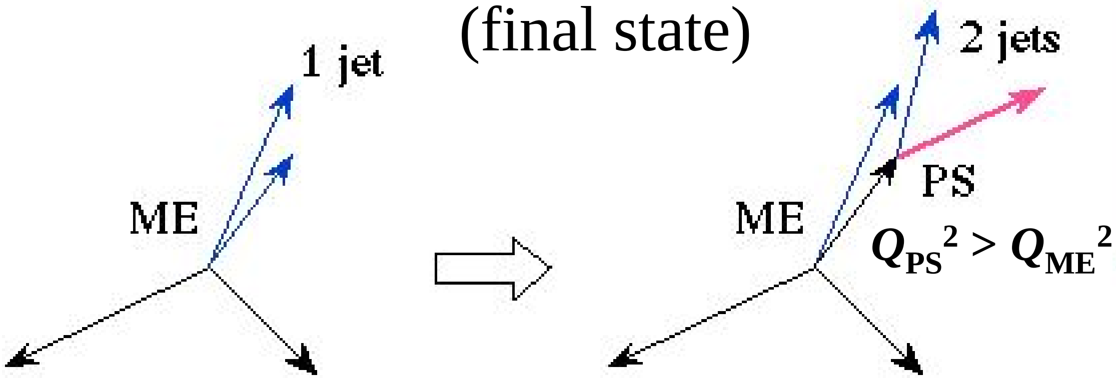
Violation of Q^2 ordering



(initial state)

Q_{ME}^2 may be smaller than Q_m^2.
If smaller, i_{PS} is likely to be harder than i_{ME}.

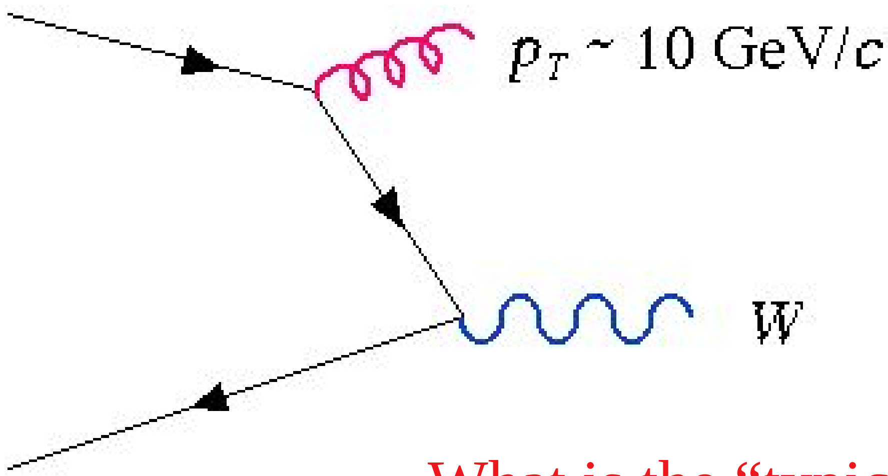
(final state)



Those events which should be rejected at the ME level may be accepted after the PS is applied.

Forbidden in the collinear approximation, while non-collinear terms are allowed to violate.

Double-scale problem in ME



What is the "typical" energy scale?

Source of all the problems

$\mu_{PS} > p_T \Longrightarrow$ Double count, violation of Q^2 ordering

$\mu_{PS} \sim p_T \Longrightarrow$ Large effect of higher p_T radiation (Sudakov suppression in coll. approx.)

Energy Scales

- μ_R: renormalisation scale in the matrix elements (ME)
  - I will not discuss about this.
- μ_F: factorisation scale in the PDF
  - Maximum hardness of the radiation to be integrated in PDF
  - People say that this should be equal to the "typical" energy of the interaction.
- μ_{PS}: energy scale of the parton shower (PS)
  - Maximum hardness of the partons that the PS can radiate.
    - The definition of the "hardness" (Q^2) depends on the actual implementation of PS; identical at the collinear limit, but may be different at large p_T.
  - The scale may be different for the initial state and the final state.
  - It would be natural to take μ_{PS} of the initial state equal to μ_F in order to preserve the PS-PDF matching.

CKKW

- Force the factorisation and PS scales to be very small; minimize the role of the evolution by PDF/PS.
- Map each ME generated event to a PS picture.
- Reweight the event according to the Sudakov factor and the QCD coupling strength determined in the PS language.

No double count, no divergence, less ambiguity (freedom) in the renormalisation, factorisation and PS scales.

The smallness of the factorisation/PS scales leads to a necessity of the inclusion of multi-jet MEs (up to 5 jets ?), even if we want only 1 or 2-jet events.

I'm not fully satisfied with the principal assumption.
Alternatives are desired for justification.

Another possibility

Use PDF/PS up to the "hard" energy scale of the process; ~ m_W for W + jets events.

A direction opposite to CKKW

The role of larger jet-multiplicity MEs would become less important.

Phase-space slice

- Separate PS and ME with μ_F to avoid the double count; *i.e.*, $\mu_{PS} = \mu_F$, and $Q^2(\text{jets}) > \mu_F^2$ in ME
  - Same concept as CKKW to avoid the double count
- Large μ_F (~ hard interaction scale) to avoid the double-scale problem
  - Thus, no reweighting

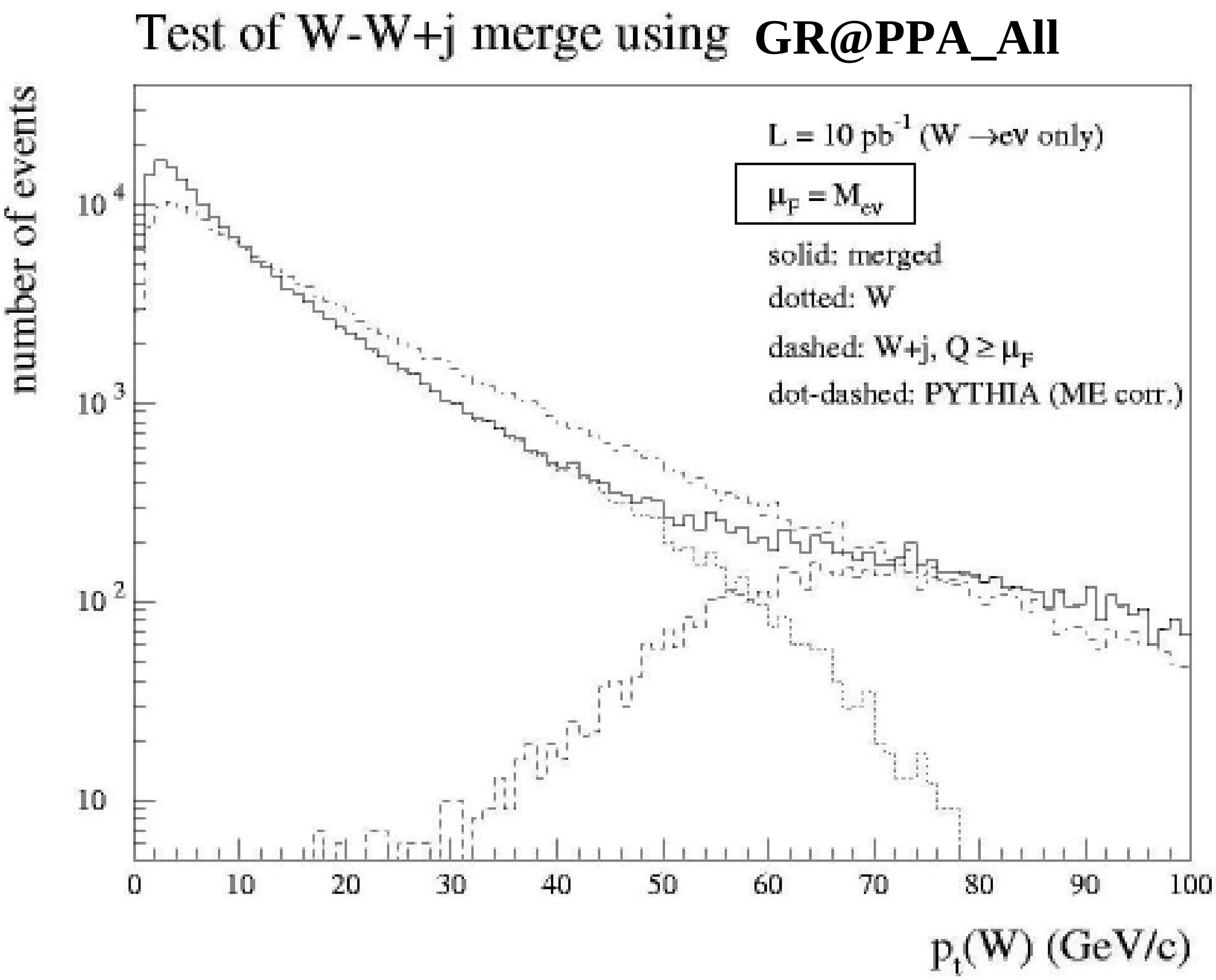
The boundary μ_F must be placed in a region where PS jet spectra matches with ME; *i.e.*, the single radiation dominates in PS and the collinear terms dominate in ME.

Is there such a region?

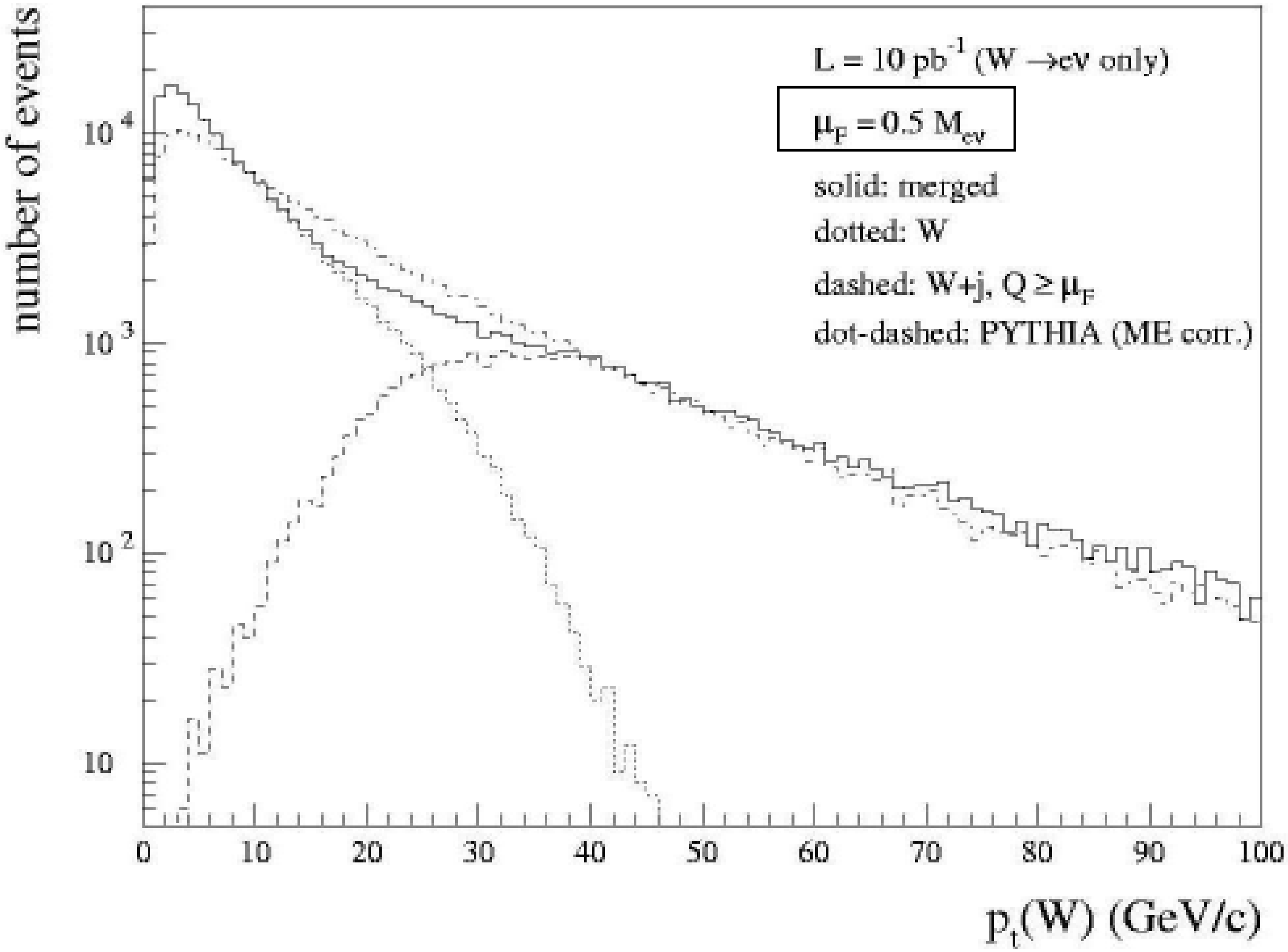
Try to combine "W + 0 jet" and "W + 1 jet"

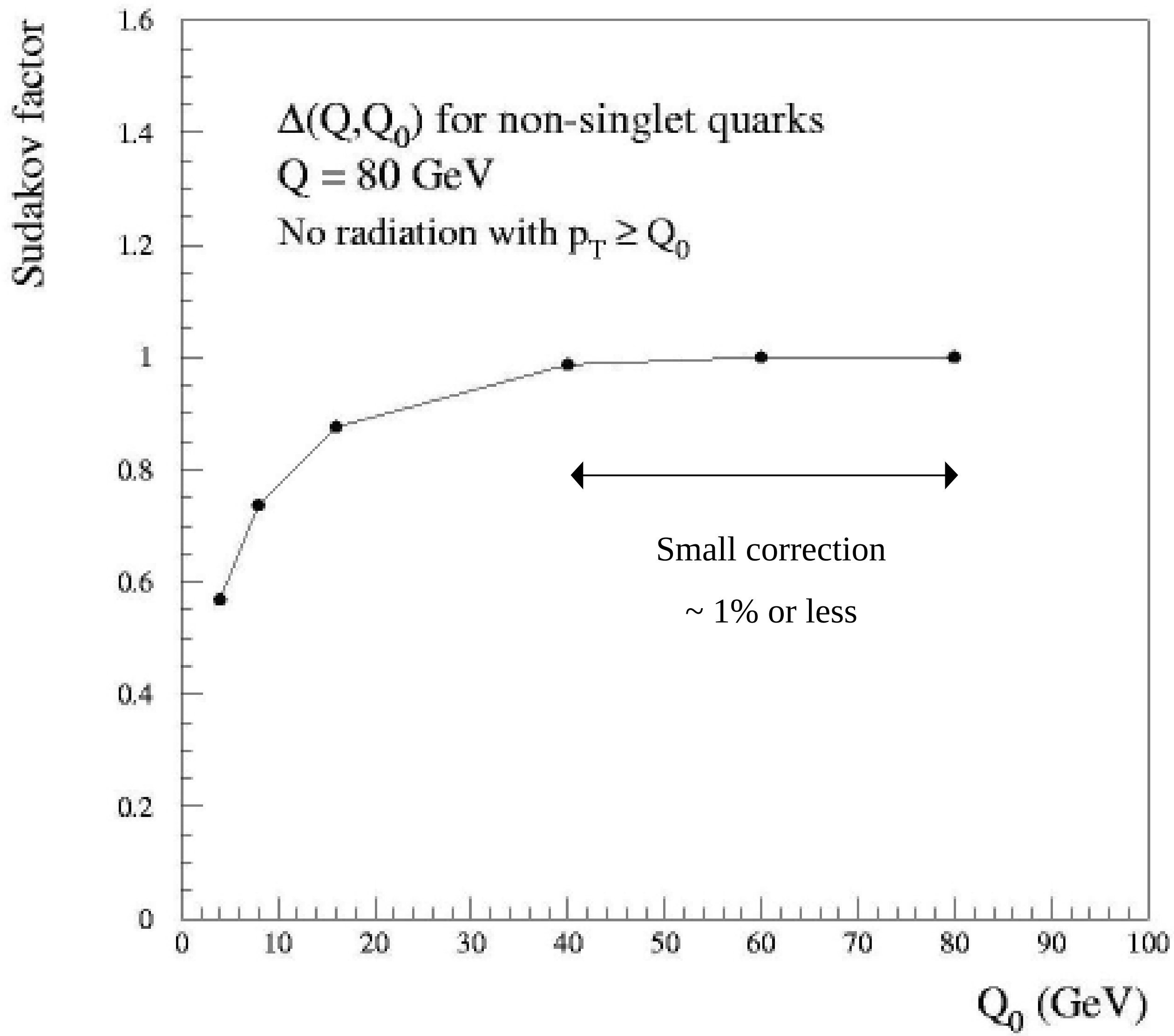
GR@PPA_All + PYTHIA-PS

$|t|, |u| > \mu_F^2$ for the "W + 1 jet" ME


Test of W-W+j merge using GR@PPA_All
L = 10 pb-1 (W →eν only)
μF = Meν
solid: merged
dotted: W
dashed: W+j, Q ≥ μF
dot-dashed: PYTHIA (ME corr.)
number of events
10 4
10 3
10 2
10
0
10
20
30
40
50
60
70
80
90
100
pt(W) (GeV/c)

Test of W-W+j merge using **GR@PPA_All**



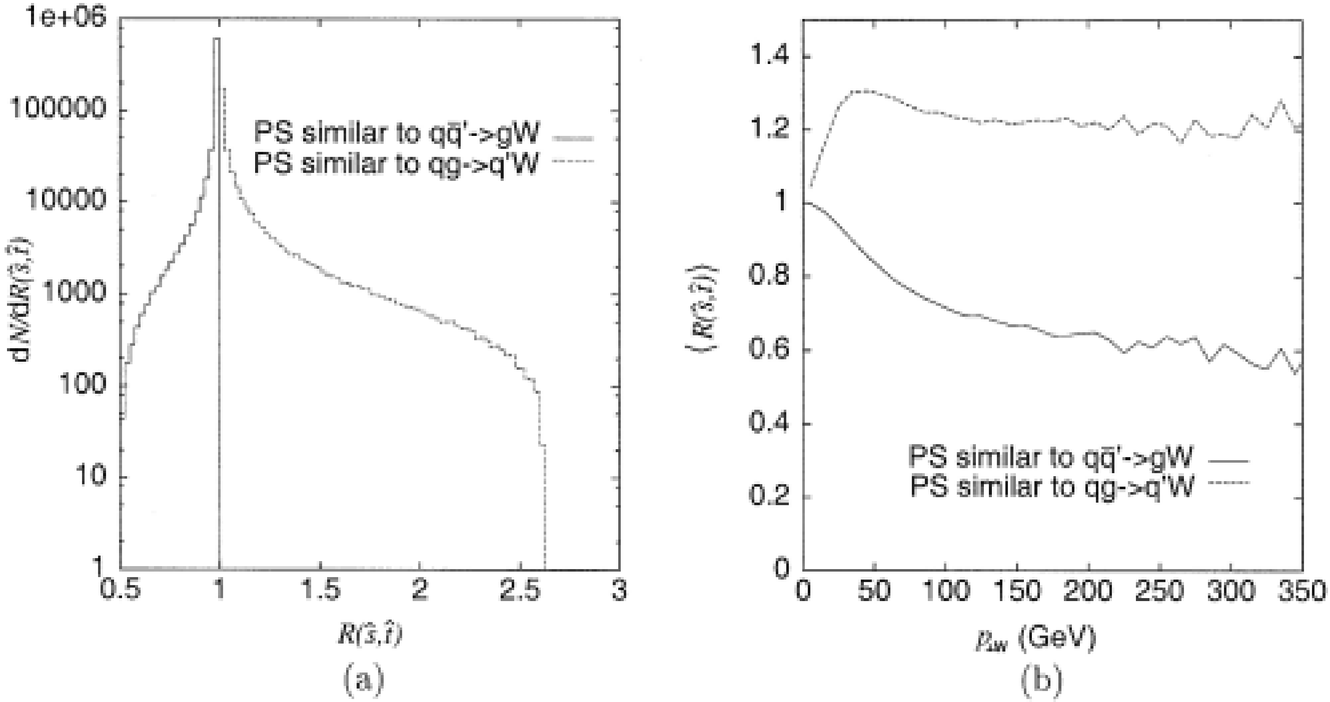


Sudakov factor
$\Delta(Q,Q_0)$ for non-singlet quarks
Q = 80 GeV
No radiation with $p_T \geq Q_0$
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
10
20
30
40
50
60
70
80
90
100
Q_0 (GeV)
Small correction
~ 1% or less

Non-collinear is sizable even at small p_Ts.

G. Miu and T. Sjöstrand, Phys. Lett. B 449 (1999) 313

$$R = \frac{d\sigma / d\Phi(\text{exact})}{d\sigma / d\Phi(\text{collinear})}$$



Simple phase-space slice is not satisfactory!

- The contribution of non-collinear terms is not negligible down to small p_Ts.
- Namely, no suitable region to place μ_F.

OK, we can add non-collinear terms.

$\Rightarrow$ Log-term subtraction

or Leading-Log (LL) subtraction

Leading-Log (LL) subtraction

- Subtract collinear divergent (LL) terms from ME numerically. They are to be included in PDF/PS. This avoids the double count.
- Already applied to the initial-state radiation in the NLO DY and *W*-production generators by Kurihara.

Leading-Log (LL) subtraction

$$d\hat{\sigma}_n(\mathrm{ME}) = \sum_{i,j} d\hat{\sigma}_{n-1} P(i,j;Q^2 < \mu^2)$$ (n–1)-body ME + PS

$$+\sum_{i,j} d\hat{\sigma}_{n-1} P(i,j;Q^2 > \mu^2) + d\hat{\sigma}_n(\mathrm{NC})$$ Subtracted *n*-body ME

i = all final-state partons

j = all initial and final-state partons

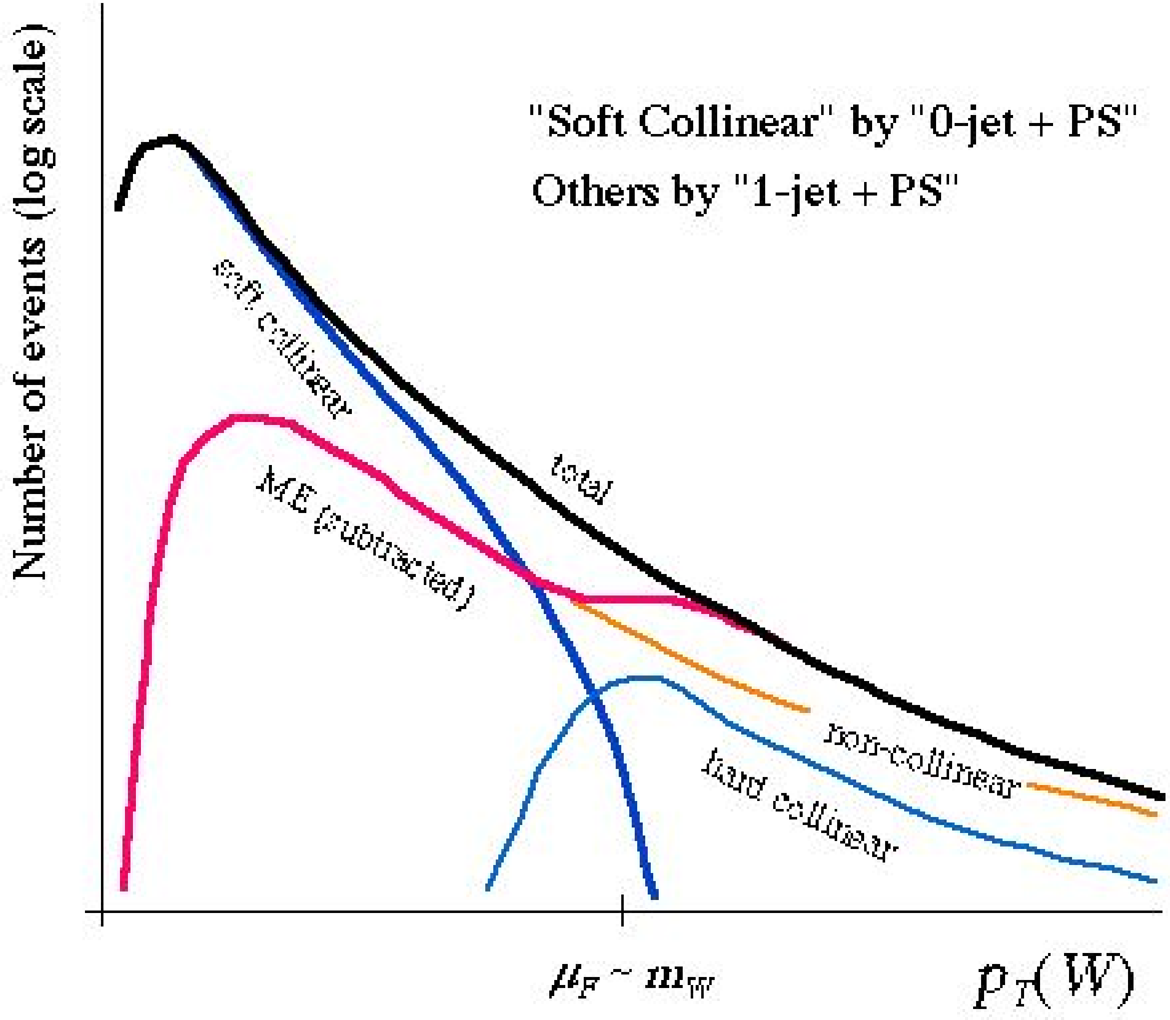
$P(i,j) = P(j \to i,k)$ for the initial state

$P(k \to i,j)$ for the final state

$\hat{\sigma}_{n-1}$: from (*n*–1)-body ME where a pair of particles *i* and *j* are replaced with *k*.

No divergence in the subtracted ME !

Image of the merging of "*W*+0-jet" and "*W*+1-jet"



Plans/Prospects

- Demonstrate the method with *W* + 1 jet.
- Extend it to the final-state radiation.
  - It has to be done anyway in order to construct NLO *W* + jet(s) generators.
- A careful treatment is necessary to define the (*m*–1)-body state within the generated *m*-body state.
  - The actual implementation of PS has to be exactly reversed.
- It would be possible to compose an *n*-jet event sample using 0-jet, 1-jet, , , *n*-jet MEs.
- We will have some negative-weight events, but it would not be a serious problem.

The phase-space slice with $\mu_F = m_W/2$ may not be so bad.

It can be applied without any modification to existing event generators, at least using GR@PPA_All.

Visit the following URL to see the activities of the NLO Working Group at KEK: GR@PPA, GRACE/NLO, NLL-PS etc.

http://atlas.kek.jp/physics/nlo-wg/index.html