Looking for a simple method to combine “hard + 0 jet” and “hard + 1 jet” event generators

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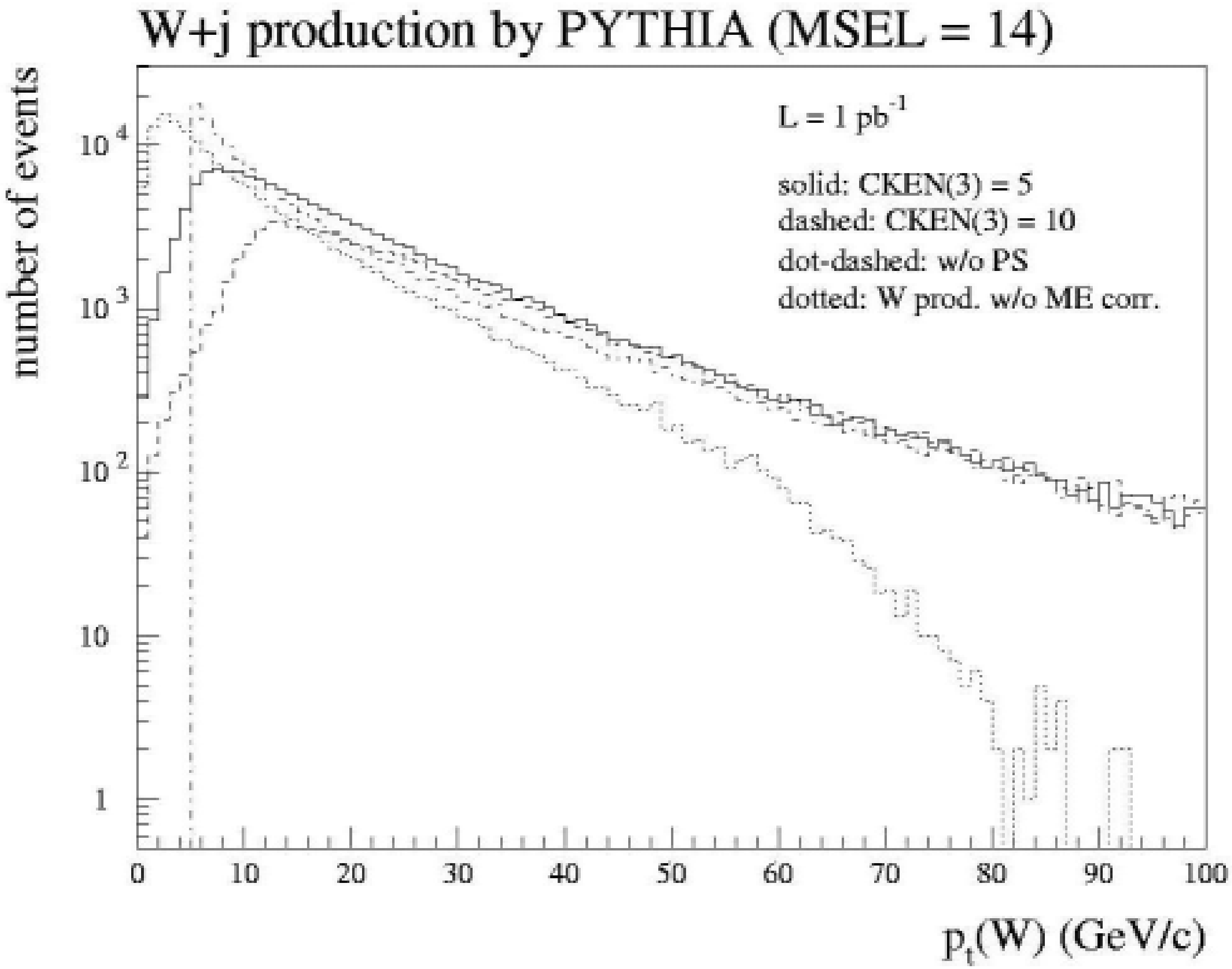
Motivation

- There are many needs to simulate "**hard interaction + 1 or 2 jet**" processes in hadron collisions, in order to estimate backgrounds and, sometimes, signals.
- We have many "hard + 1 jet" generators, but encounter an apparent **double-count problem**.
- A "hard + 0 jet" generator + PS would give us a better description for relatively soft jets; "hard +1 jet" generators should be used for hard jets.
- **There must be a consistent way to merge them**.
- There are some theoretically clear methods: *ME corrections* in PYTHIA and HERWIG, *LL-subtraction* in the NLO calculation by Kurihara et al. They are process-dependent. Is there any **process-independent** way?.
- The *CKKW method* may be a solution, but there must be a **simpler** way because we need only 1 or 2 jets.
- I started an exploration from the simplest case: "W + 0 jet" and "W + 1 jet".

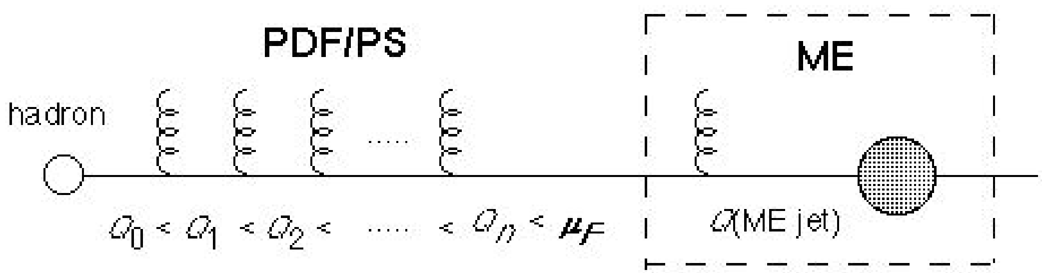

W+j production by PYTHIA (MSEL = 14)
L = 1 pb^-1
solid: CKEN(3) = 5
dashed: CKEN(3) = 10
dot-dashed: w/o PS
dotted: W prod. w/o ME corr.
number of events
10^4
10^3
10^2
10
1
0
10
20
30
40
50
60
70
80
90
100
p_t(W) (GeV/c)

Double count in "hard + 1 jet"

- Two energy scales in **ME**: a "hard" process scale and a cut for the jet.
  - Usually, we take μ_F^2 (factorization scale) = $<m_T^2> = m_W^2/2 + p_T^2$(ME) (> p_T^2(ME jet)) for "W + 1 jet".
- **PDF** or **PS** is a jet-radiation correction up to Q(jet) (≈ p_T(jet)) = μ_F.
- There is an apparent overlap in the phase space; *i.e.* a double count.
  - It may happen that p_T(ME jet) < p_T(PS jet).

⇒ We must constrain Q(ME jet) > μ_F.

This preserves a virtuality ordering.



Double count between “hard + 0 jet” and “hard + 1 jet”

- Usually, we take $\mu_F = m_W$ in “W + 0 jet”.
- If we take $p_{T,\mathrm{min}}$(ME jet) $< m_W$ in “W + 1 jet”, there is an overlap in the “jet” phase space; another double count.

⇨ We have to use a common μ_F in “hard + 0 jet” and “hard + 1 jet”.

  – It should be considered as a **boundary** between the corrections by PDF/PS and ME.

Where should we place μ_F?

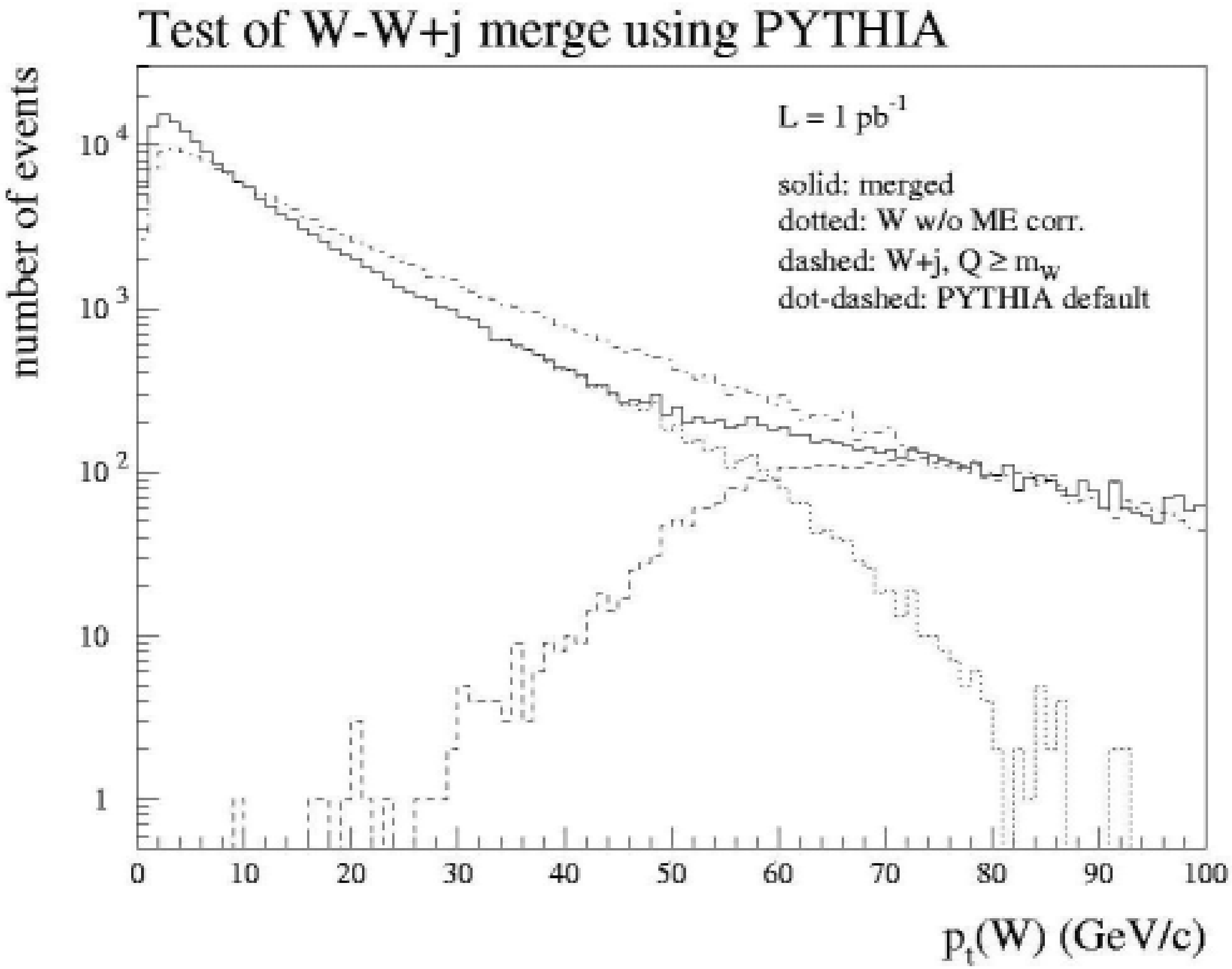
- μ_F = "hard" energy scale would be the maximum.
- It must be in a region where both the ME and the collinear approximation of PDF/PS work well.
- It should not be very small.
  - If very small, double-scale effects would become large, *i.e.*, $\alpha_s(Q^2)$ and Sudakov-factor corrections would become necessary, just like the CKKW method.

The 1st try using PYTHIA 6.2

Setup

- LHC condition
- MSEL = 12 without ME correction for "W + 0 jet"
  - $\mu_F^2 = \hat{s}$ (default); no other choice is allowed.
- MSEL = 14 for "W + 1 jet"
  - Q^2(ME jet) $\equiv \min\{|t|, |u|\} > \mu_F^2$ required.
  - $\mu_F^2 = \langle m_T^2 \rangle$ (default)

    This is not ideal but most of the double counts are avoided because of the Q(ME jet) cut.
- MSEL = 12 with ME corr. (default) is a good reference for the tests.
- Only the initial-state PS is turned on.



Test of W-W+j merge using PYTHIA
number of events
L = 1 pb-1
solid: merged
dotted: W w/o ME corr.
dashed: W+j, Q ≥ mW
dot-dashed: PYTHIA default
10^4
10^3
10^2
10
1
0
10
20
30
40
50
60
70
80
90
100
pt(W) (GeV/c)

The 1st try using PYTHIA 6.2

Result

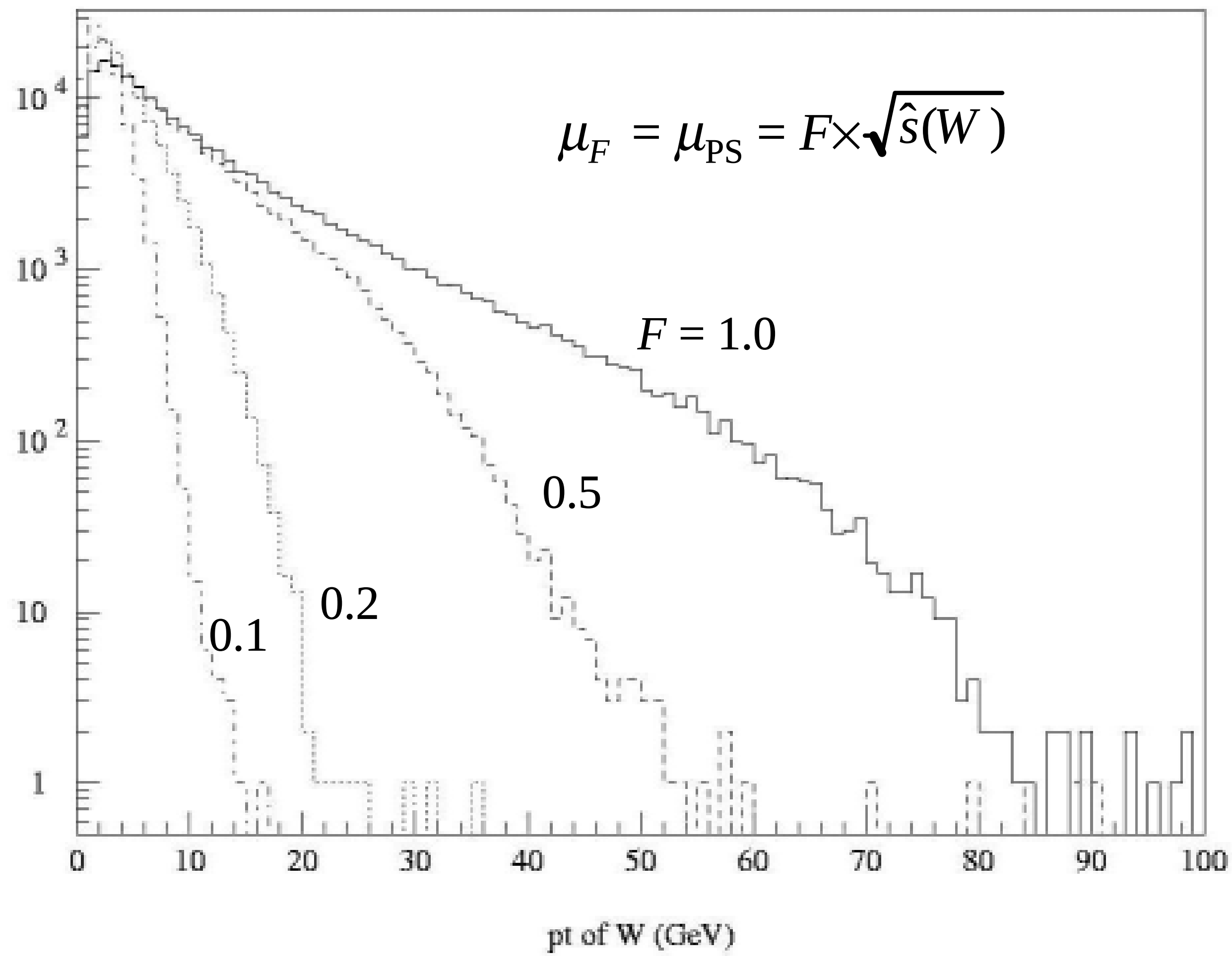
- A good shape in $p_T(W) > m_W$, where "W + 1 jet" covers.
- But a deficit below m_W where "W + 0 jet" should dominate.
  - An ambiguity in the Q(ME jet) definition (t-u mix) and a contribution of an s-channel process might be the reason; *i.e.*, PS does not simulate u- and s-channel contributions.
- These effects (over-rejection in ME or deficit in PS) will be reduced if μ_F is set smaller.

Tests using GR@PPA_All (PYTHIA6.2-embed)

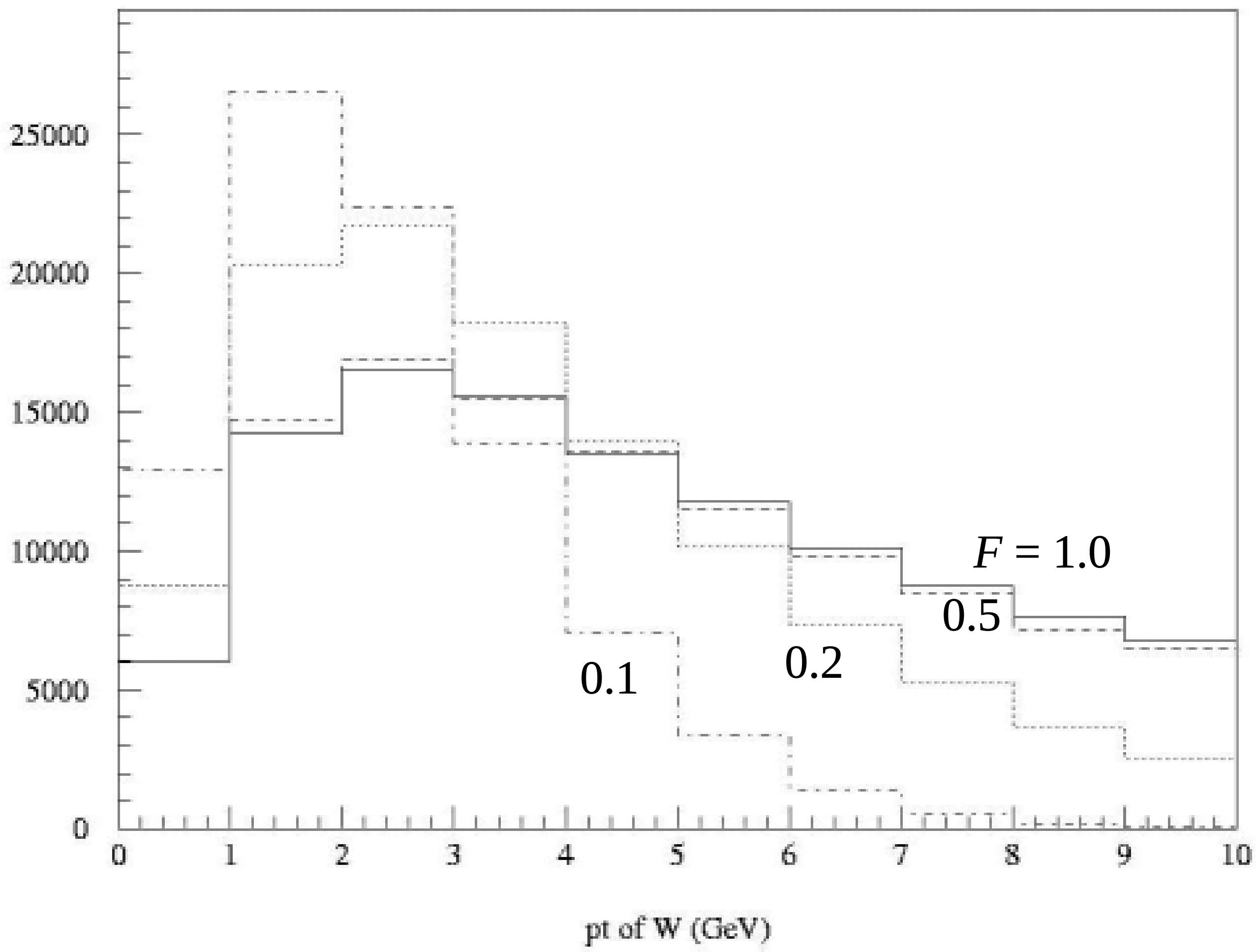
Setup

- LHC condition
- ISUB = 421 for "W + 0 jet"
- ISUB = 422, 423 for "W + 1 jet"
  - Q^2(ME jet) $\equiv \min\{|t|, |u|\} > \mu_F^2$ required
  - μ_R (renormalisation scale) = p_T(ME jet): not important now.
- Common μ_F (= μ_{PS})
  - It is passed to PYTHIA via the "energy scale" parameter in the Les Houches external generator interface, to be used as the PS energy-scale.
- $W \to e\nu$ decay only.
- Only the initial-state PS is turned on.
  - "jet = parton" assumed.
- Tests for $\mu_F = \sqrt{\hat{s}(W)}$ and $\sqrt{\hat{s}(W)}/2$

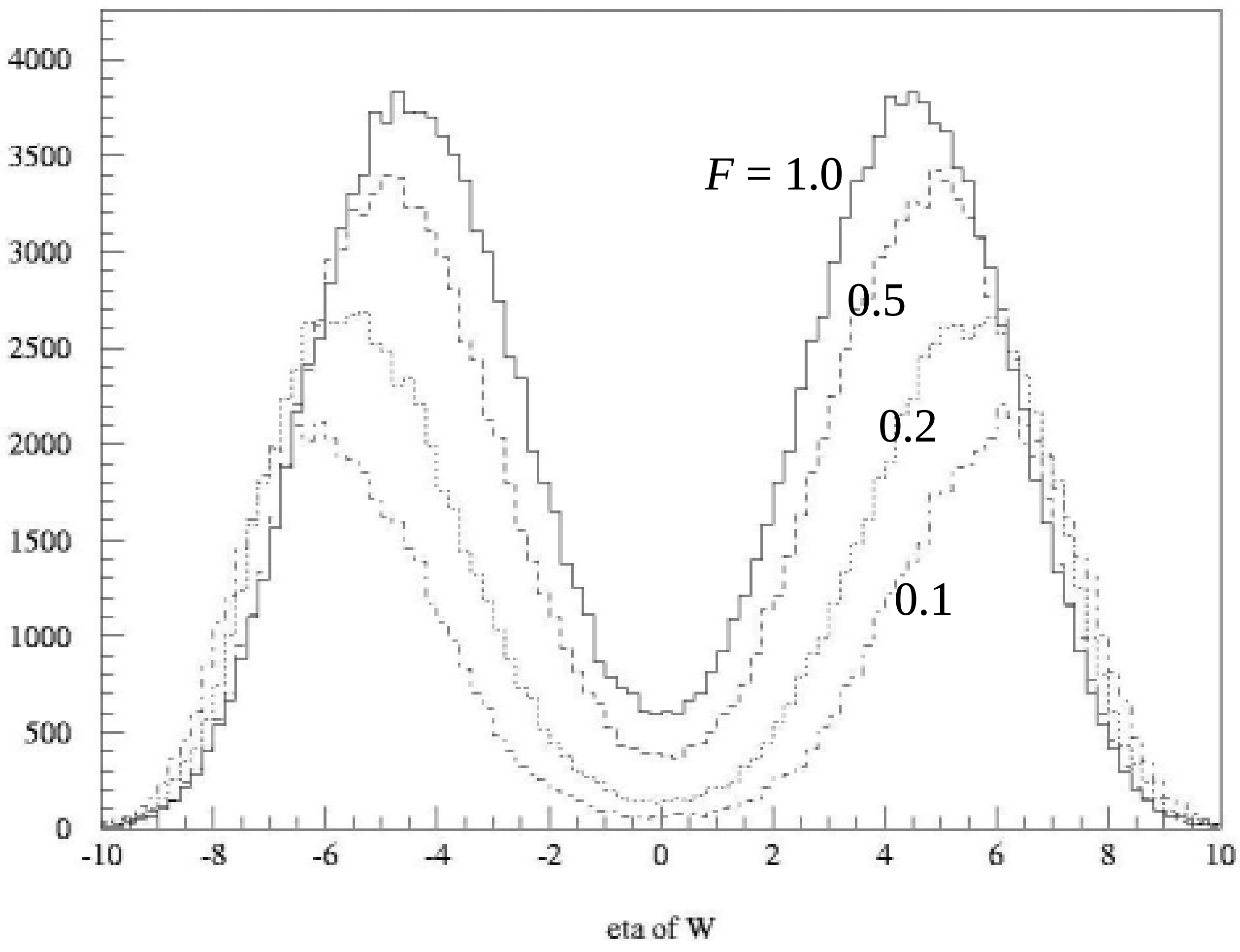
“W + 0 jet”



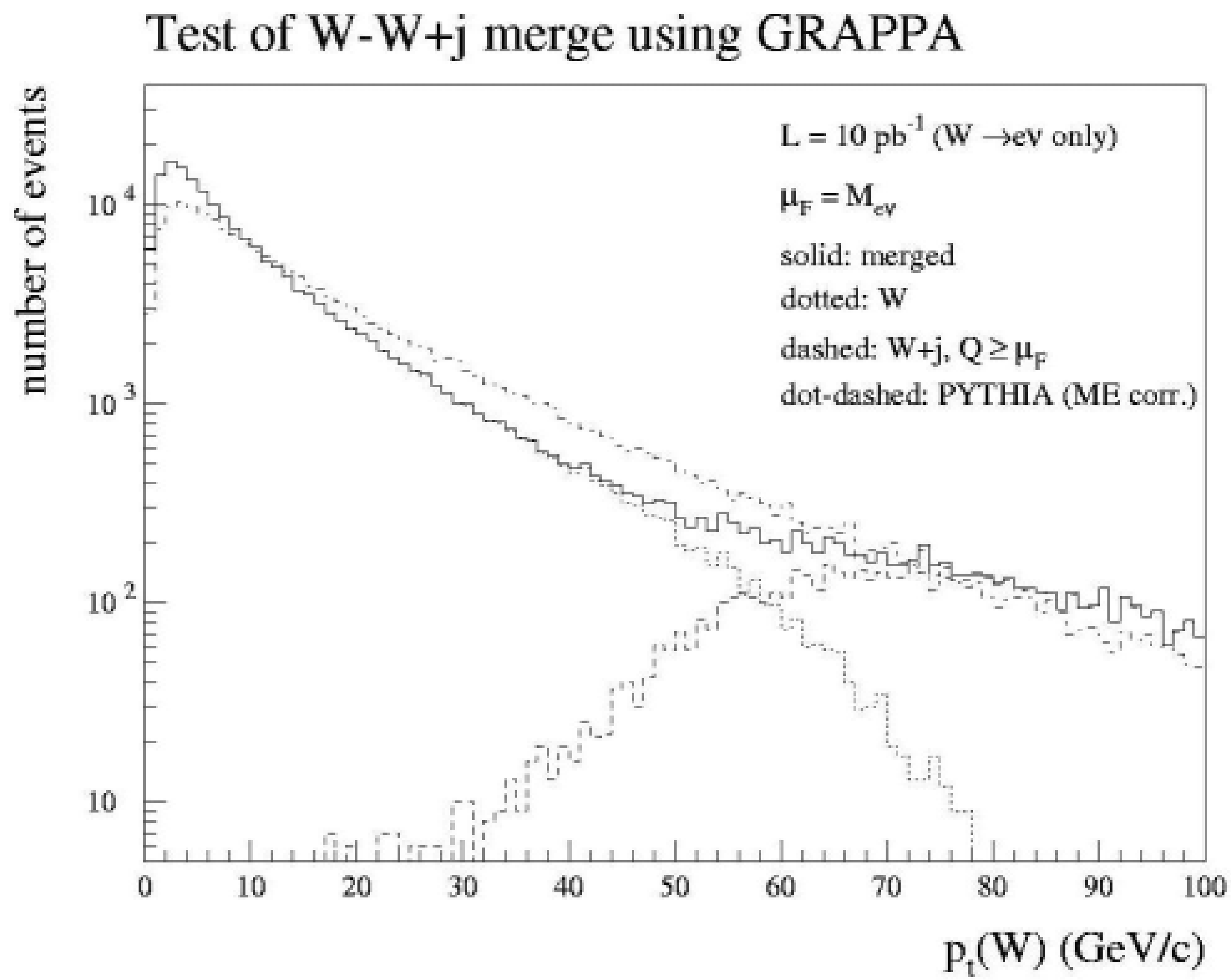
“W + 0 jet”


25000
20000
15000
10000
5000
0
0
1
2
3
4
5
6
7
8
9
10
pt of W (GeV)
F = 1.0
0.5
0.2
0.1

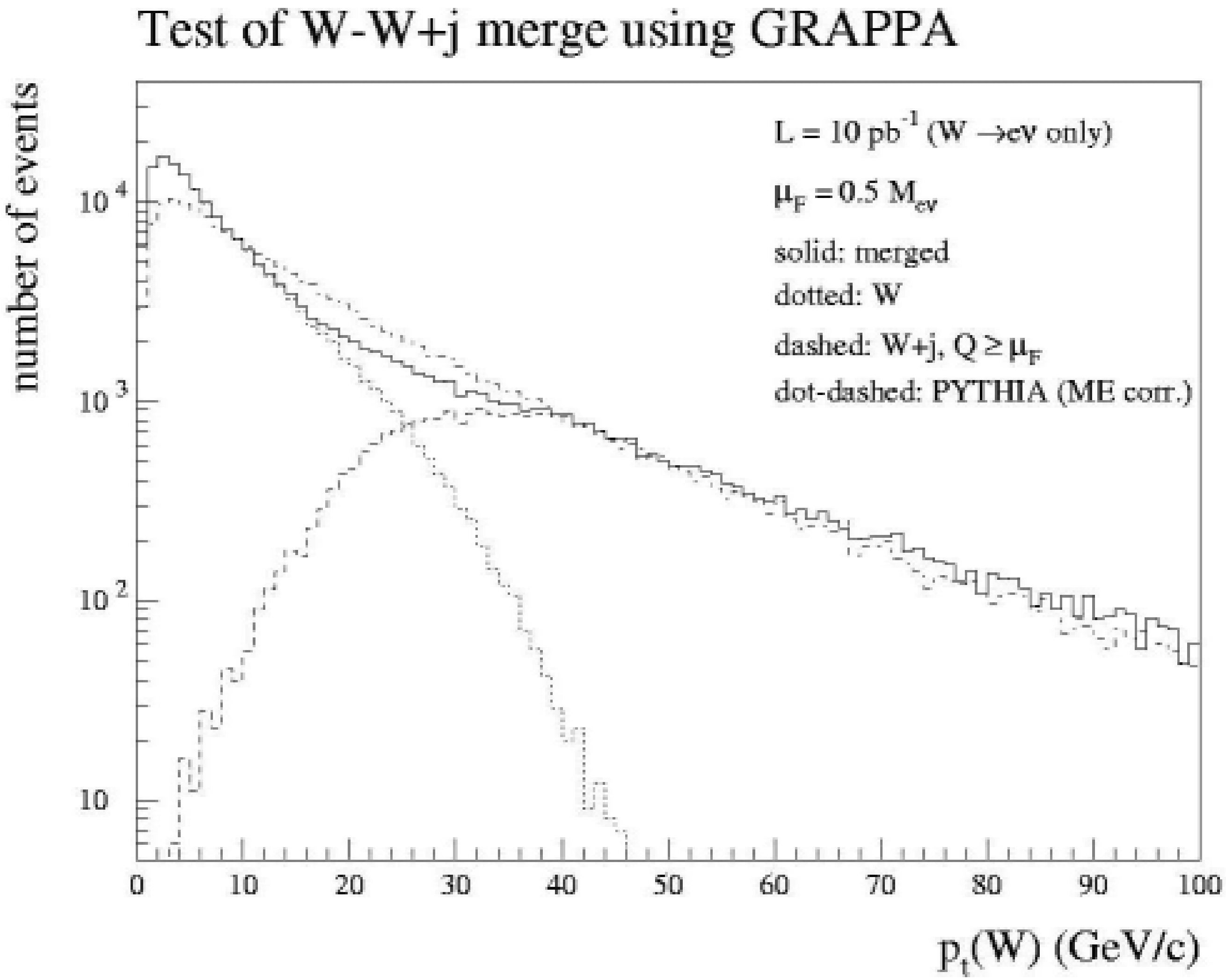
“W + 0 jet”



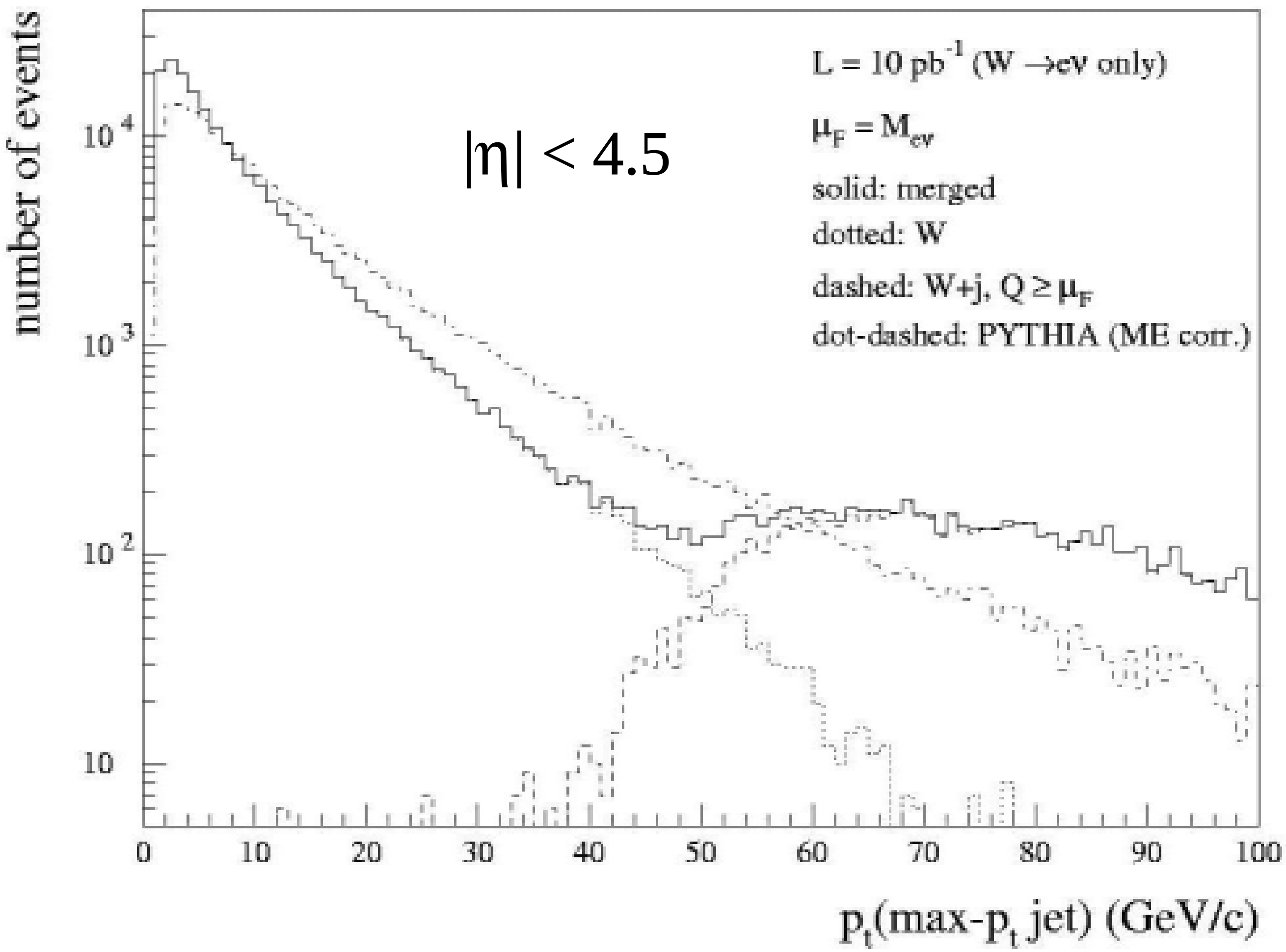
4000
3500
3000
2500
2000
1500
1000
500
0
F = 1.0
0.5
0.2
0.1
-10
-8
-6
-4
-2
0
2
4
6
8
10
eta of W

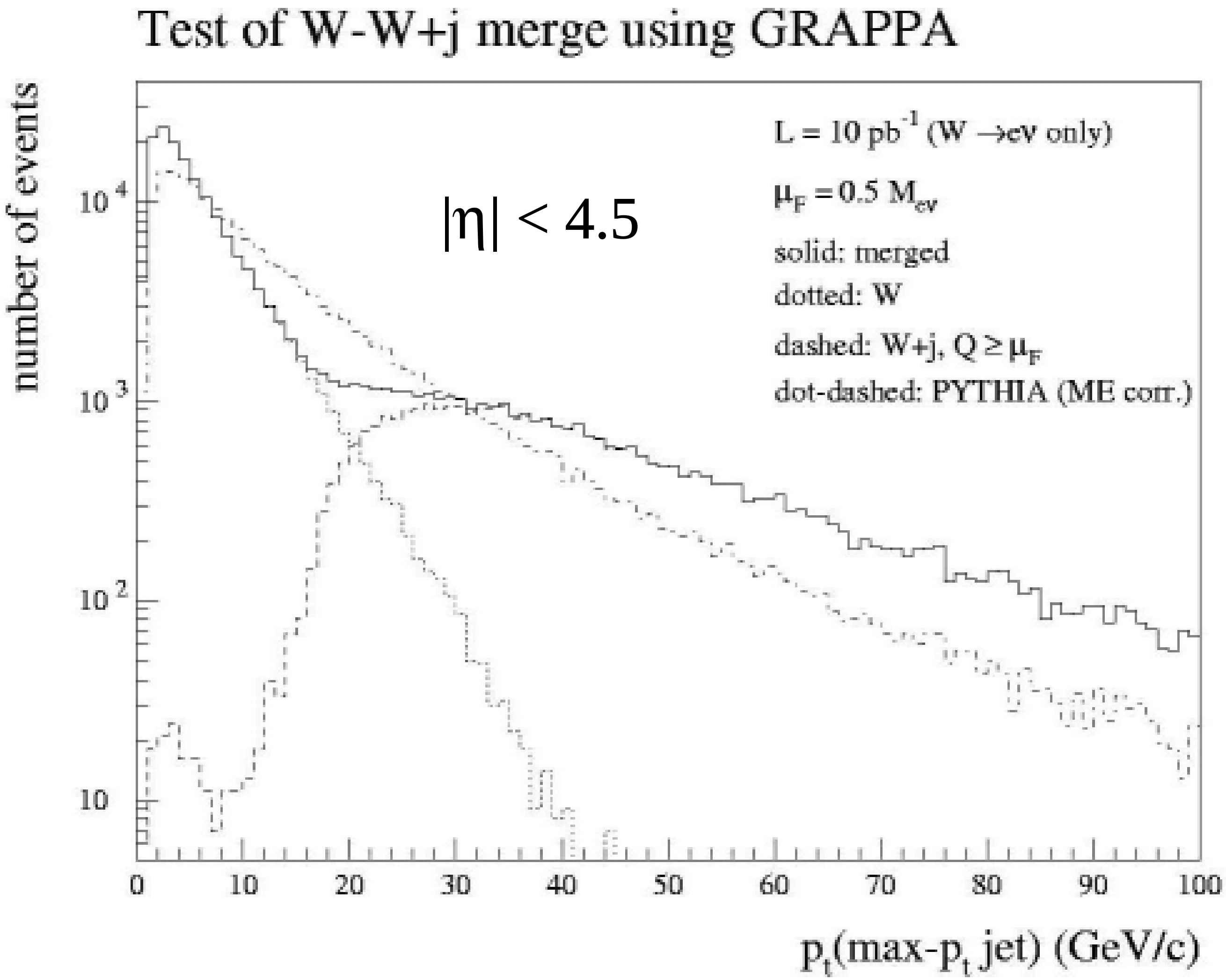


Test of W-W+j merge using GRAPPA
number of events
L = 10 pb^{-1} (W →eν only)
$\mu_F = M_{e\nu}$
solid: merged
dotted: W
dashed: W+j, Q ≥ μ_F
dot-dashed: PYTHIA (ME corr.)
10^4
10^3
10^2
10
0
10
20
30
40
50
60
70
80
90
100
p_t(W) (GeV/c)


Test of W-W+j merge using GRAPPA
number of events
L = 10 pb-1 (W →eν only)
μF = 0.5 Meν
solid: merged
dotted: W
dashed: W+j, Q ≥ μF
dot-dashed: PYTHIA (ME corr.)
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 GRAPPA




Test of W-W+j merge using GRAPPA
number of events
10^4
10^3
10^2
10
0 10 20 30 40 50 60 70 80 90 100
p_t(max-p_t jet) (GeV/c)
L = 10 pb^{-1} (W $\rightarrow e\nu$ only)
$\mu_F = 0.5\ M_{e\nu}$
solid: merged
dotted: W
dashed: W+j, $Q \geq \mu_F$
dot-dashed: PYTHIA (ME corr.)
$|\eta| < 4.5$

Tests using GR@PPA_All (PYTHIA6.2-embed)

Result

- Similar to the PYTHIA result when $\mu_F = \sqrt{\hat{s}(W)}$.
- The deficit below μ_F still exists even if $\mu_F = \sqrt{\hat{s}(W)}/2$.
- Only 1% change in the total cross section.
- Very bad connection in the p_t(max- p_t jet) distribution.
- "W + 0 jet" looks too soft; especially, the "jet" p_t .
  - Well known fact?
  - Any simple solution?

Summary

- A very naïve method based on a reconsideration of double-count problems does not show a good result.
- If no simple solution,
  - I answer to my colleagues “Wait for the CKKW!”, and go to a generalization of the LL-subtraction method.