Study of the jet multiplicity of W + jets process

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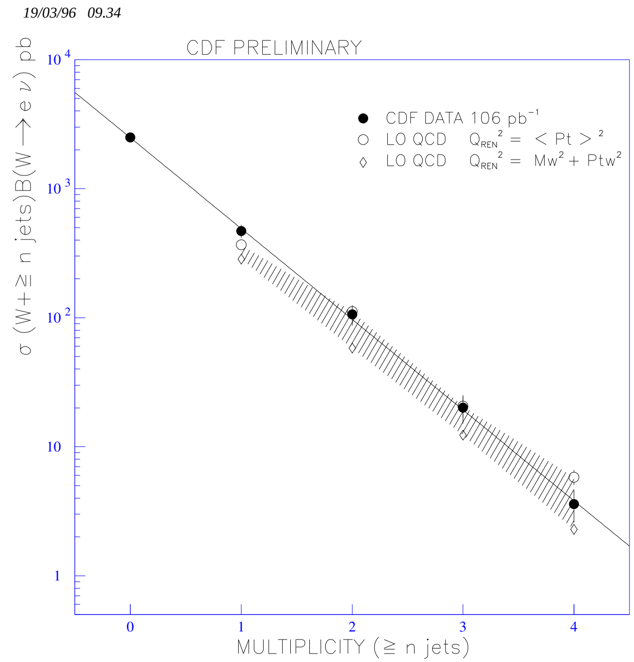
Introduction

In Tevatron RunI experiment, CDF measured the inclusive W + jets cross section ($\sigma(W+\geq n) \cdot Br(W \rightarrow e\nu)$ (n = 1,..,4)).

We had the difficulties for the N jets pQCD prediction.

- What have we learned about the LO ME ?
- What is the next toward a better understanding for RunII (LHC) experiment ?



Purpose :

1) To reproduce the RunI "**naive**" method.

$\Rightarrow$ taking considerably large variation of the choise of the energy scale.

2) To explore the effective methods to describe the jet multiplicities.

$\Rightarrow$ Especially, we concentrate looking at the fluctuations of the additional jet multiplicities from the Parton Shower depending on the choise of the factorization scale.

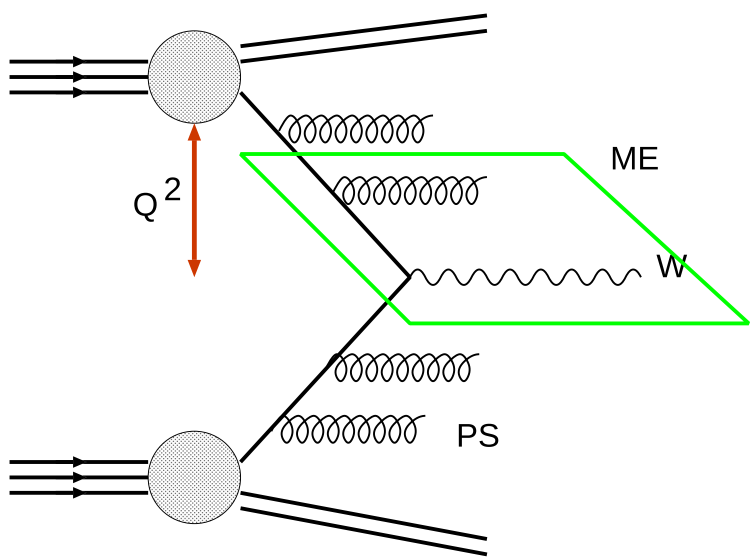
$\Rightarrow$ Some considerations about "double counting" issue.

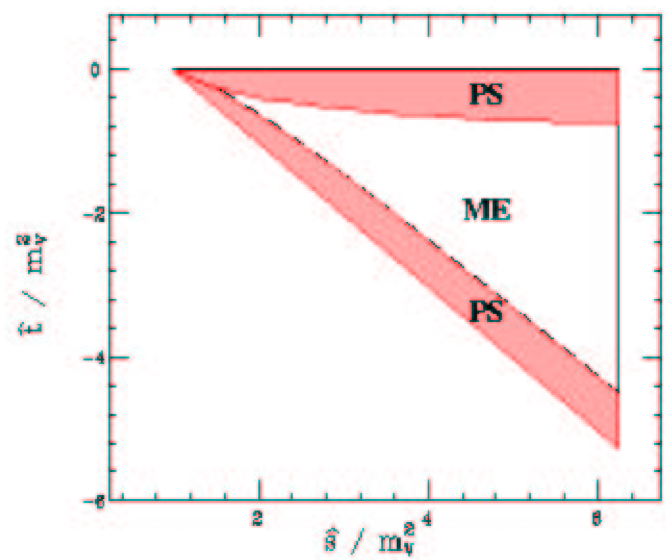
Double counting (review) :

The PDF (Parton Shower) has already described all outgoing partons with the all-order summation at LL level. But, unfortunately, it's not enough to describe the high p_t region of outgoing particles. Then, ME-based event generators have developed to compensate that high p_t region, although its calculations are order-dependent.

- $\Rightarrow$ LO-ME event generators: Alpgen, CompHep, Madgraph, GRAPPA, *etc*
- $\Rightarrow$ NLO-ME event generators: MCFM, DYRAD, and many... but process specific.

Once naively we consider the connection with PDF and ME, every QCD multi-particle event generator encounters a trouble of "double counting"!!





ref. RunII MC Workshop, Webber's talk.

How do we decide the factorization scale?

Factorization scale and Showering scale :

While the renormalization scale dependence is resolved at the higher order purturbative calculation (PMS), the factorization scale is only a connection scale of PDF to ME, that is, independent of the order of ME calculation.

In the Les Houches common block,

SCALUP : the only argument for the evolution scale of the patron shower.

- ⇒ The PS generator (PYTHIA/HERWIG/ISAJET) never knows which scale was taken in the ME calculation.
- ⇒ completely black box.

Factorization scale should be the same as the scale of the initial state radiation.

- ⇒ Showering scale (**SCALUP**) = Factorization scale

Three methods :

We tried three methods :

1) As usual,... most naive method, by varying the energy scale as same as RunI method.

2) **PYXTRA** (we call.),... taking an invariant mass with a color conected pair, proposed by S.Mrenna.

3) Rejection Method. Same as Method 1) but requiring a P_t ordering in partons from the hard-process and the parton shower.

Jet multiplicity and Factorization scale (Naive method) :

Let's consider the worst (!?) case taking a large variation of the energy scales.

Scale variation :

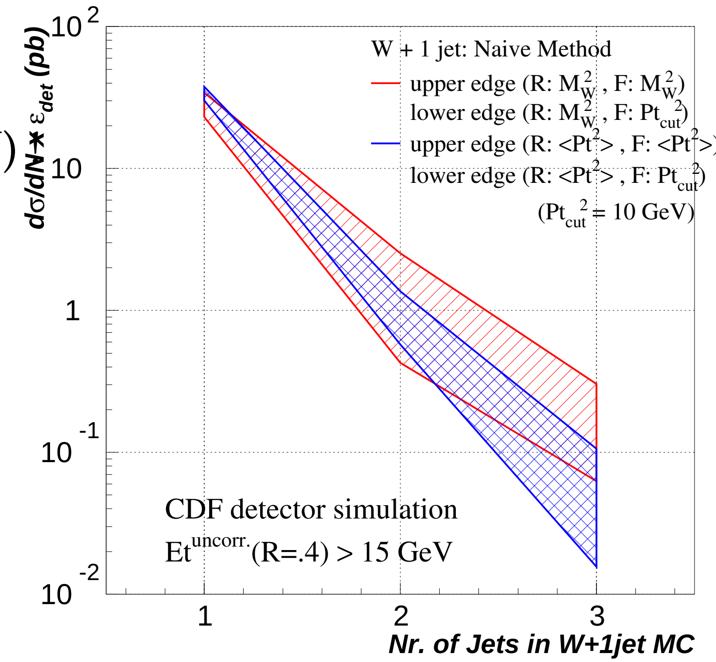
Maximum scale :

- ⇒ Definitely, collision energy (RunII=1.96 TeV) but no one take it.
- ⇒ Due to the convention, $Q^2 = M_W^2\ (+\ P_{tW}^2)$.

Minimum scale :

- ⇒ $Q^2 \approx P_{tcut}^2, Q_{cut}^2$, on the generation.
- ⇒ In RunI, $Q^2 = < P_t^2 >$ was taken.

Worst case??



Fact. scale dependency of N jets distribution in W+1jet MC.
Plot was after CDF detector simulation.

What happens in the jet multiplicity ??

- ⇒ The PS makes the additional jets.
- ⇒ very sensitive to the factorization scale.

Note that :

Larger scale (M_W^2) makes a suspicious source of the "double counting" problem.
Lower scale (P_{tcut}) may have some untruncated LL orders by PDF.

PYXTRA Method

Proposed : by S.Mrenna

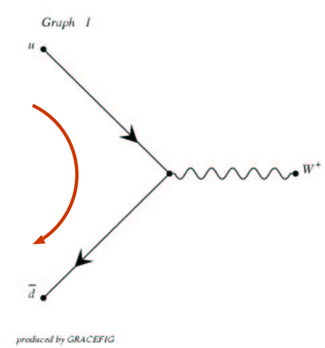
www-pat.fnal.gov/personal/mrenna/generator.html

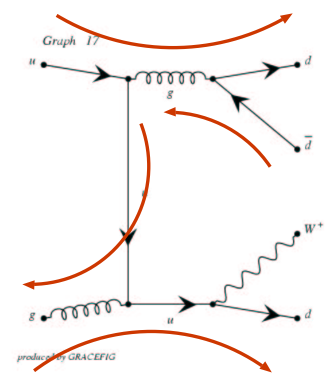
Assumptions :

Outputs the fact.(PS) scale based on a color flow.

(1) if the initial state is a color singlet, then use $\hat{s}$ for the scale.

(2) if color flows to the final state, use the minimum of the dot products of color connected pairs (times two for consistency with above).

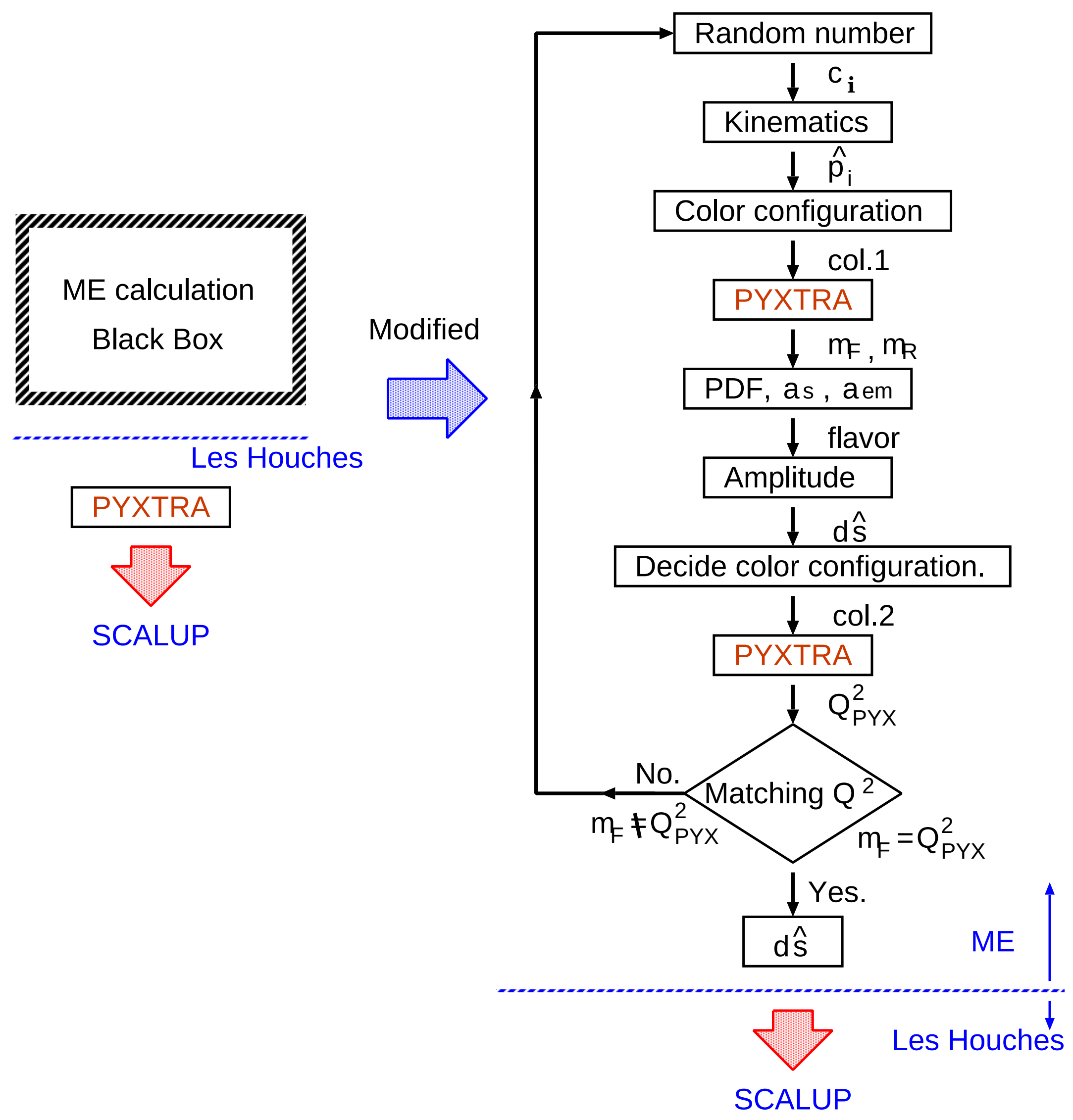




Modifications :

This program is usually used outside ME calculations. Then, its output scale differs from the the factorization scale used in ME calculations. So that shows unphysical cross sections. In order to get physical cross section, the modification was done in the ME calculation.

Schematic view

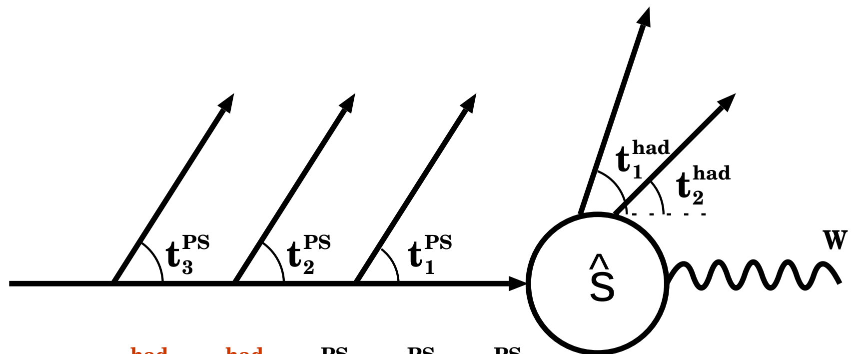


Rejection Method

In order to avoid the double couting diagrams, we propose simple "Rejection Method" from our experience of LL-subtraction method (**hep-ph/0212216, hep-ph/0207214**).

Assumptions :

Requiring the momentum ordering with "hard-partons" of ME as well as "soft-partons" from PS.



$t_1^{had} > t_2^{had} > t_1^{PS} > t_2^{PS} > t_3^{PS}$

The ordering is applied after PS.

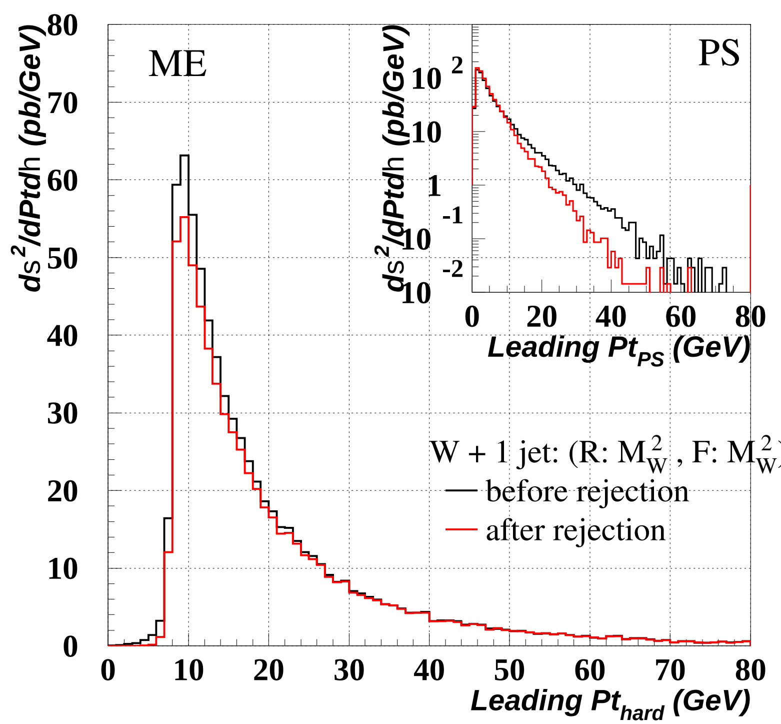
$$P_{t1}^{had.} > P_{t2}^{had.} > P_{t1}^{PS} > P_{t2}^{PS} > P_{t3}^{PS} > \ldots$$

$\Rightarrow$ If P_t^{PS} exceeds **min.**$\{P_t^{had.}\}$, then this event is rejected.

Cross section correction :

Cross section is corrected by the ratio of the rejected events only for partons from the initial state radiation.

$$\sigma^{rej} = \frac{N_{tot} - N_{rej}}{N_{tot}} \cdot \sigma$$



Note that :

This scheme needs more considerations.

Event generator — GR@PPA (GRace At Proton-Proton/Anti-proton) :

We've used GRACE based event generator for hadron collisions,

— GR@PPA (**hep-ph/0204222**).

Process : W ($\rightarrow e\nu$) + n jets (n = 1,2,3) (LO ME)

CM Energy : 1.96 TeV, $p\bar{p}$ collision (TEVATRON RunII condition)

Generation Cut :

$P_t^j > 8$ GeV , $|\eta^j| < 3.5$, $\Delta R_{jj} > 0.4$,
no cut for leptons

Choise of Renor./Fact. scales :

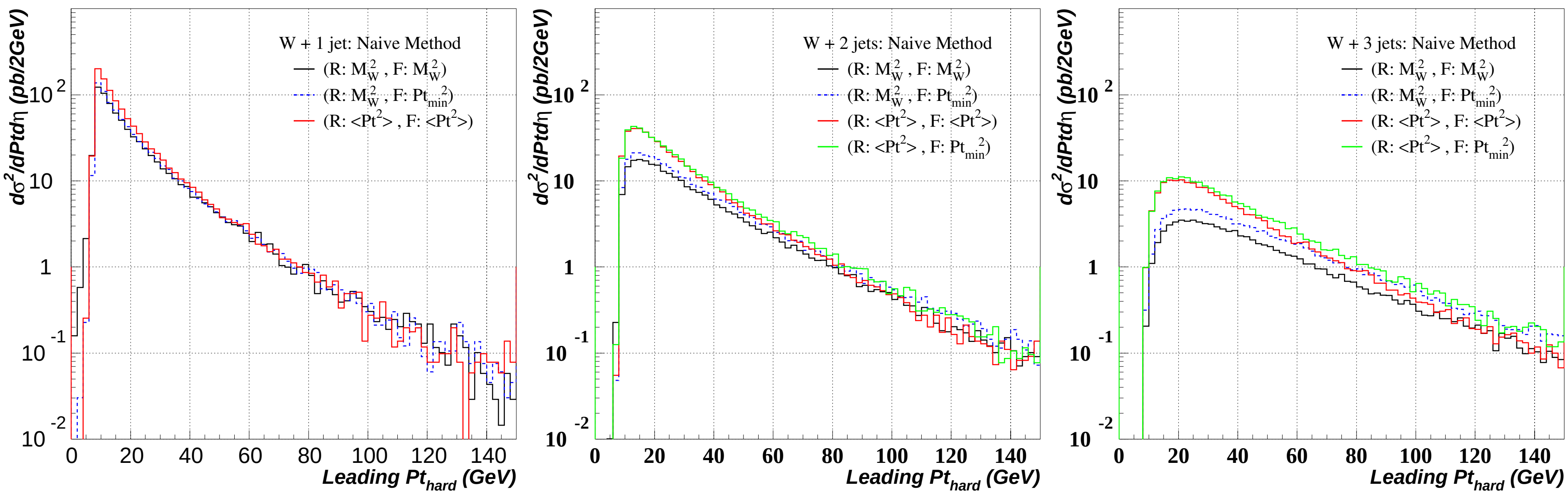
— (R: M_W^2, F: M_W^2) ,
— (R: M_W^2, F: P_{tmin}^2) ,
— (R: $< P_t^2 >$, F: $< P_t^2 >$) ,
— (R: $< P_t^2 >$, F: P_{tmin}^2)

PS/Hadronization Model : PYTHIA.6.203

Scale dependence on (LO)ME on W+jets process :

Naive Method :

Let's show the fluctuations by the variation of the renormalization/ factorization scale using the "naive" method (same as RunI method).

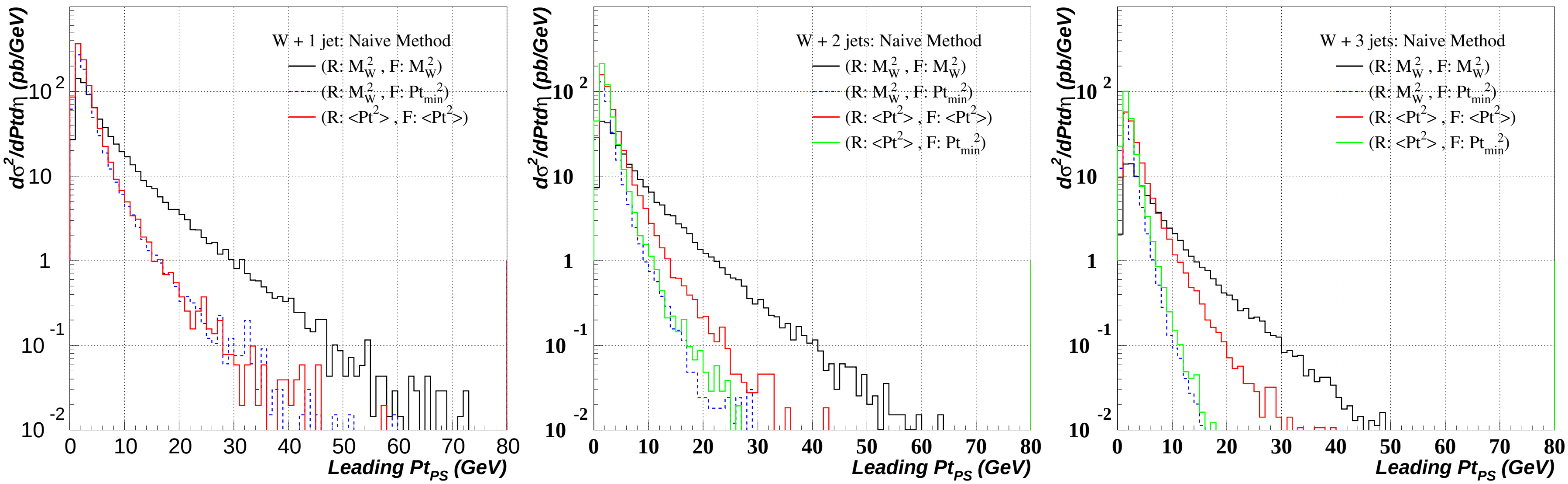


Note that :

Plots are showing the maximum transverse momentum of the final state parton, P_t, from the hard-process (ME). The distributions strongly depend on the renormalization scale, especially in the low P_t region, not the factorization scale.

Factorization scale dependence :

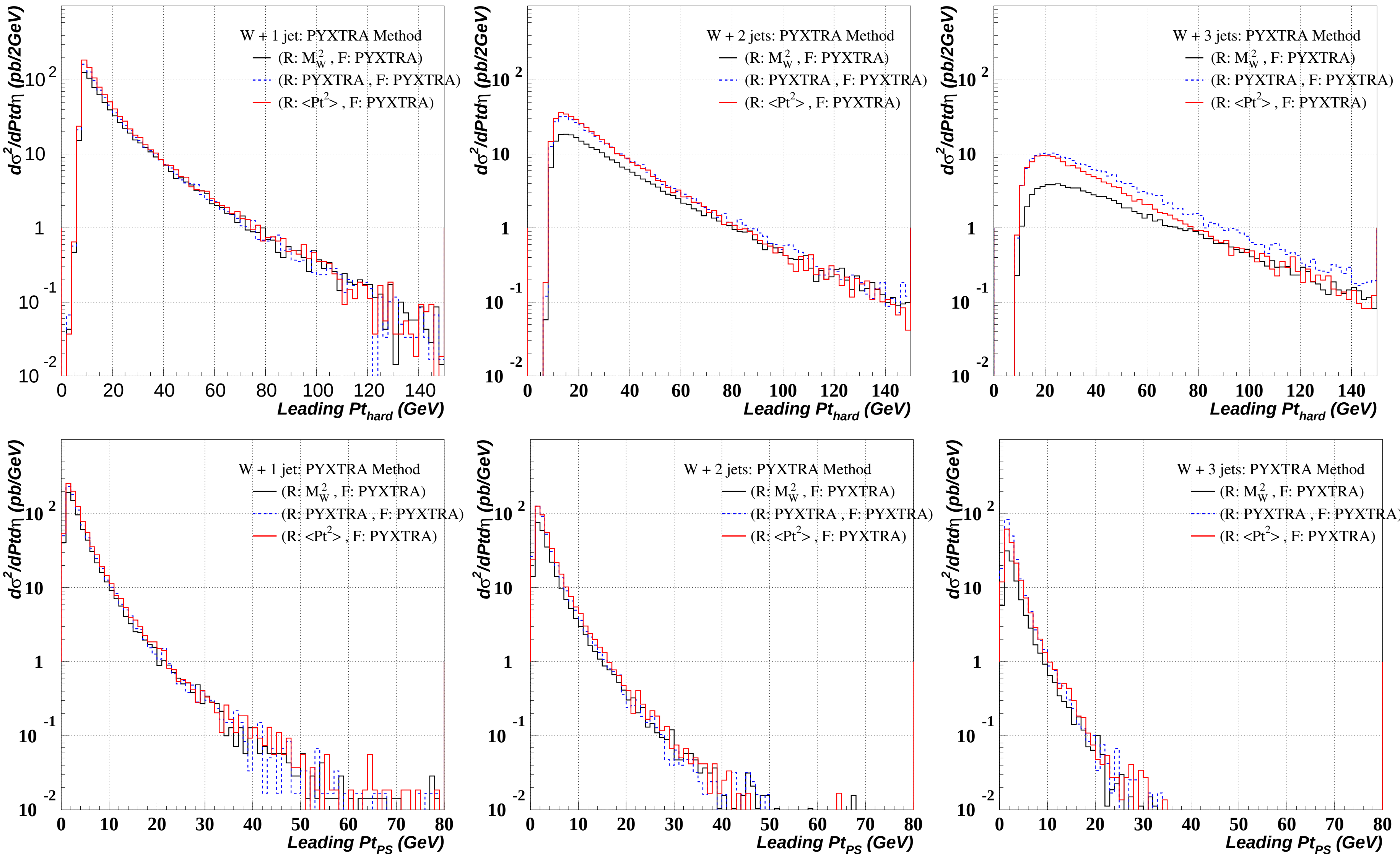
On the other hand, look at the transverse momentum from the parton shower.



Note that :

Plots are showing the maximum P_t distribution from PS. As we expects, the parton P_t of PS drastically depends on the size of the fact. scale.

Distributions (PYXTRA Method) :



Note that :

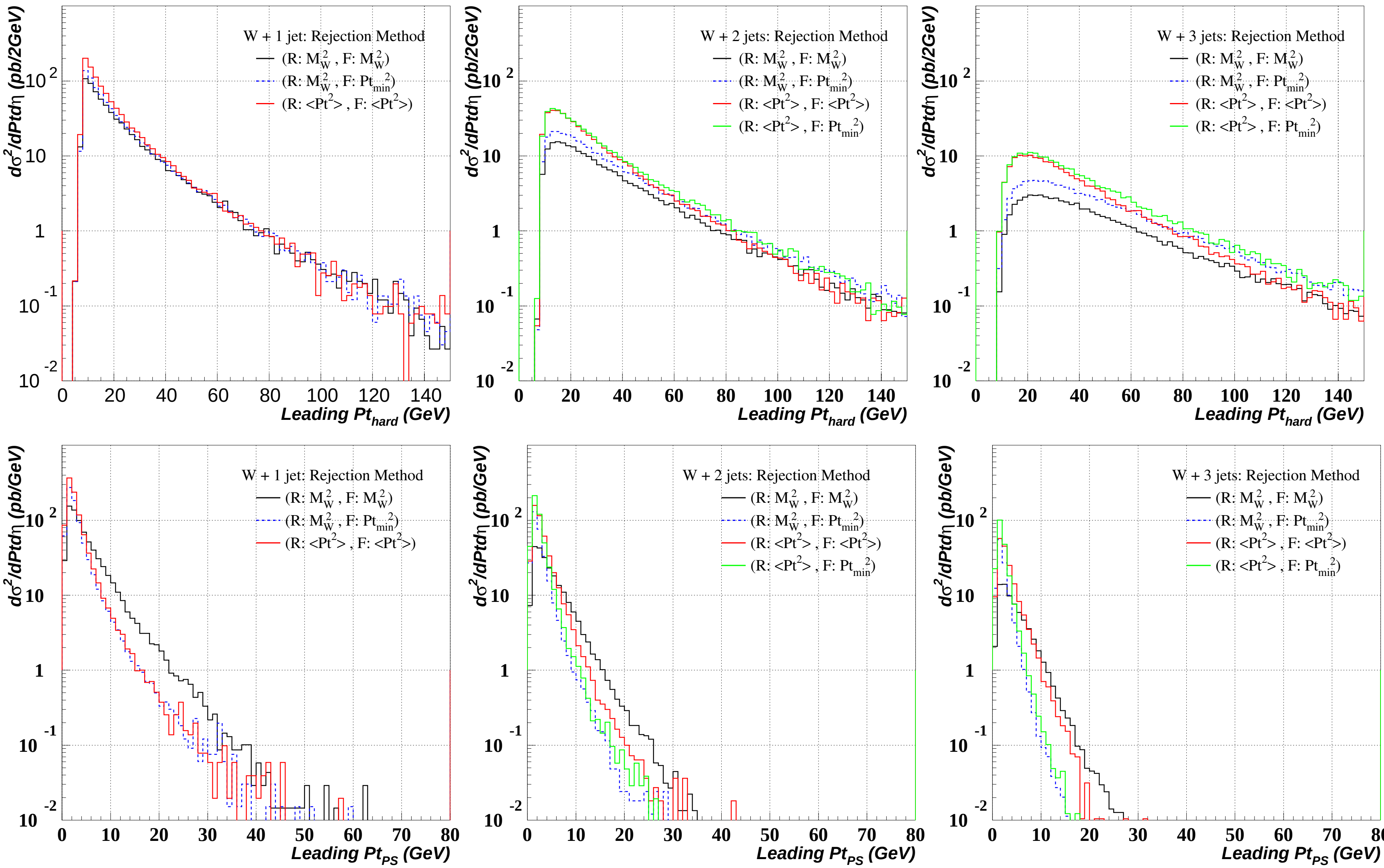
The renor. scale dependence is almost same as one of the "naive" method. Since the fact. scale is decided by **PYXTRA** identicaly, the P_t spectrum of PS does not show any big differences.

Consideration of PYXTRA Method :

Is it a better choise of the fact. scale ??

Despite the dominant contribution of the total cross section is in the on-shell W mass region, the color connected $\mathbf{min}\{Q^2_{jj}\}$ tends to be smaller than the W mass (M_W).

Distributions (Rejection Method) :



Note that :

The higher tail of the P_t distributions from PS are suppressed by the rejection algorithm. However, the renor. scale dependence increases while the fact. scale dependence is suppressed.

Detector Simulation

Jet counting is heavily depended on the jet clustering algorithm at the detector level. We use CDF-RunII detector simulation program. Basic strategy is to follow the Tevatron RunI analysis of a W+jets cross section measurement.

Selection criteria :

Electrons : CDF standard cuts.

($E_t^{ele.} > 20$ GeV , $P_t^{ele.} > 10$ GeV , $|\eta^{ele.}| < 1.1$, + some quality cuts.)

W boson : MET > 30 GeV , $M_t > 40$ GeV

Jet definition : Cone Algorithm (R=0.4) (used in RunI).

$E_t^{uncorr.} > 15$ GeV , $|\eta^{jet}| < 2.4$

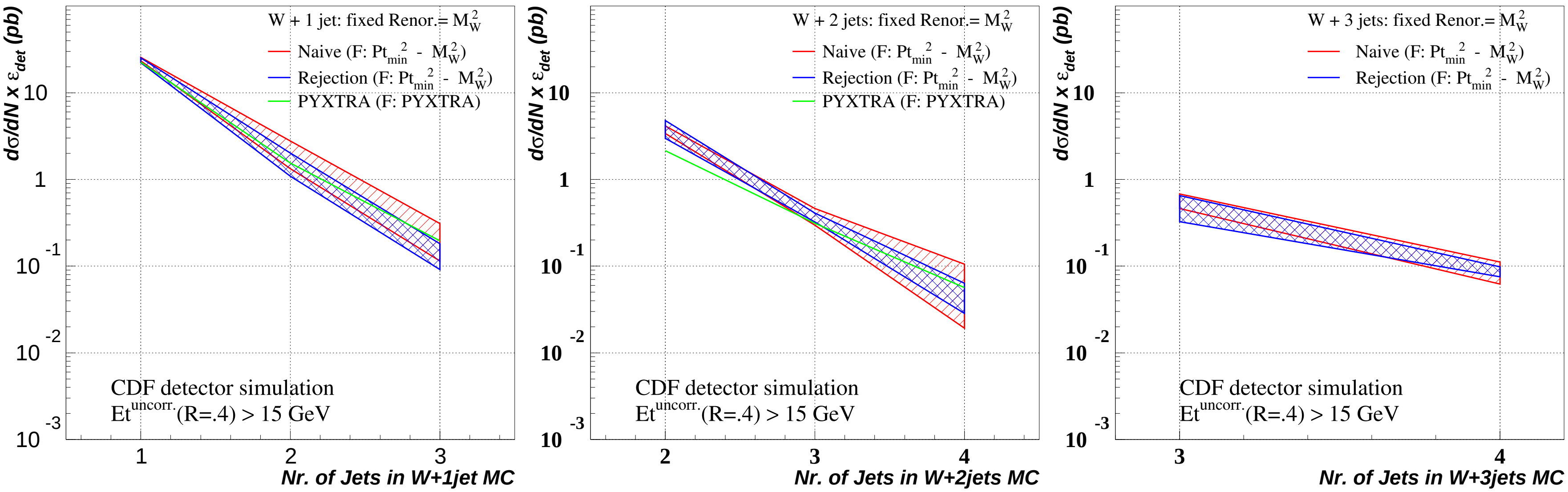
(Unfortunately, no Jet correction...)

Note : if ΔR(jet,jet) < 0.52, jets are merged as 1 jet (4-vector sum).

Matching requirement : ΔR(parton,jet) $<$ **cone size**

Factorization scale dependence :

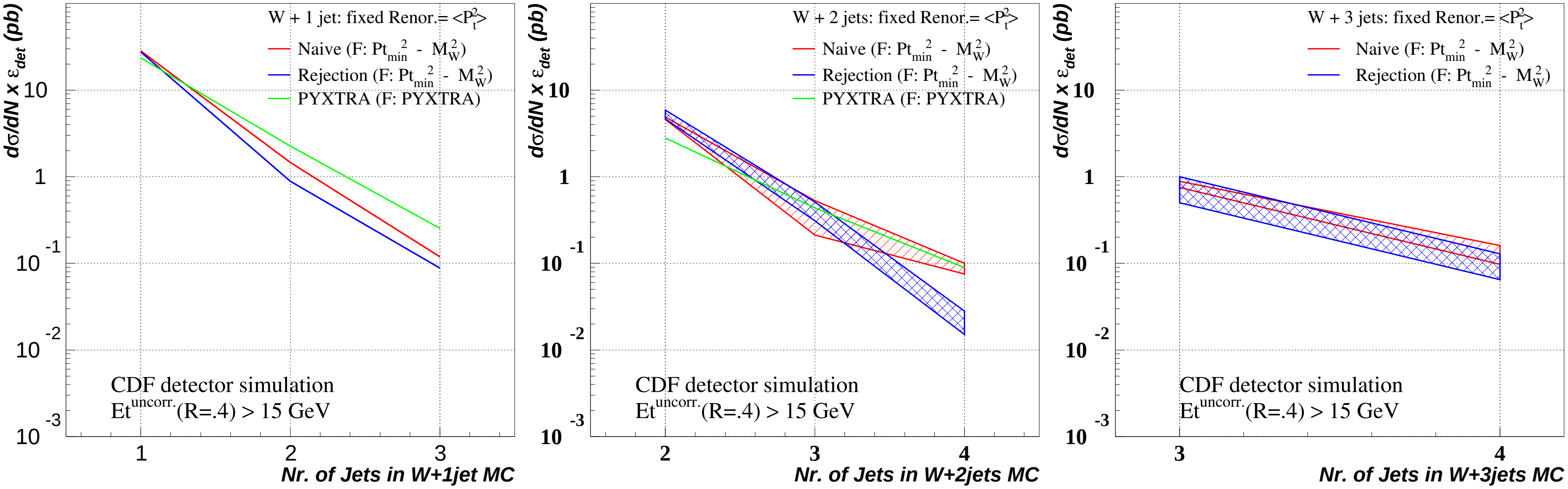
The systematic uncertainty is simply taken as the range of the fact. scale between M_W^2 and P_{tmin}^2 (F.= $M_W^2 \sim P_{tmin}^2$). But the renor. scale was fixed as the M_W^2.



Note that :

The additinal jets contribution from PS in the **Rejection** method is smaller than those of the **Naive** method. The size of systematics (we define here) is also sightly smaller than the **Naive** method.

Distributions (II) :



Renormalization scale dependence :

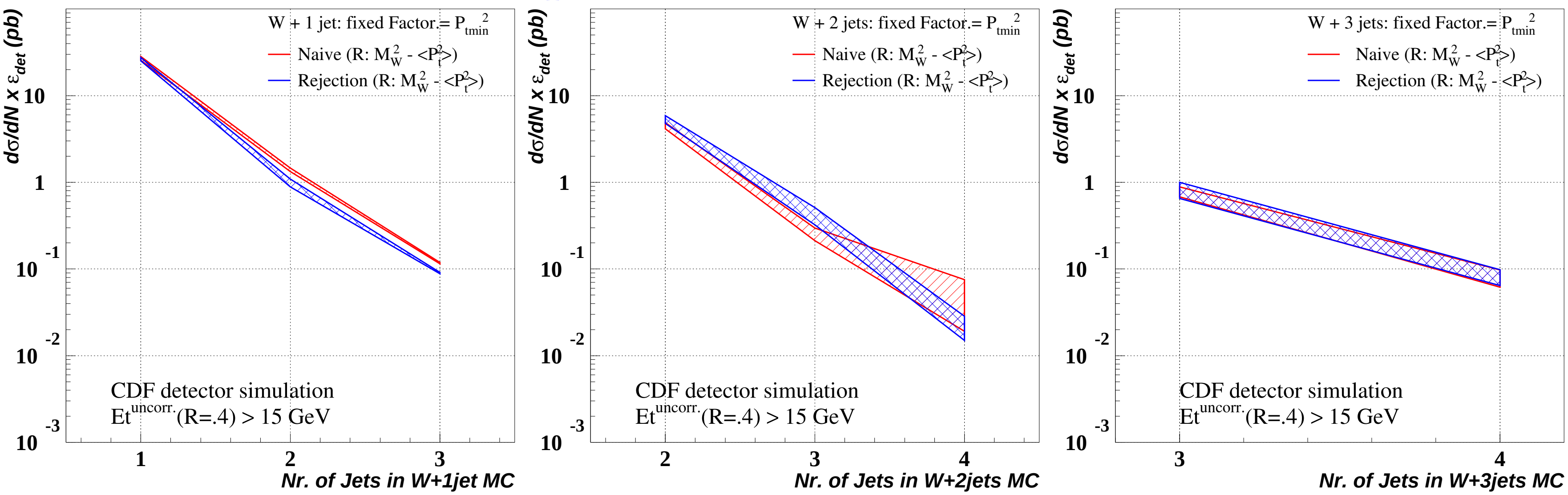


Table of cross sections :

W + 1 jet

Method	Energy Scales	σ_{tot} (pb)	$\sigma^{det.}_{1jet}$ (pb)	$\sigma^{det.}_{2jets}$ (pb)	$\sigma^{det.}_{3jets}$ (pb)	$\sigma^{det.}_{4jets}$ (pb)
Naive	(R: M_W^2 , F: M_W^2)	722.9(6)	23.3(7)	2.7(2)	0.31(8)	—
	(R: M_W^2 , F: P^2_{tmin})	755.6(6)	25.6(7)	1.3(1)	0.11(5)	—
	(R: $< P_t^2 >$, F: $< P_t^2 >$)	981.4(8)	28.3(9)	1.4(2)	0.11(5)	—
PYXTRA	(R: M_W^2 , F: **PYXTRA**)	714(1)	22.4(7)	1.5(1)	0.19(6)	—
	(R: **PYXTRA** , F: **PYXTRA**)	836(1)	23.5(7)	2.2(2)	0.25(8)	—
	(R: $< P_t^2 >$, F: **PYXTRA**)	927(2)	26.1(8)	2.2(2)	0.16(6)	—
Rejection	(R: M_W^2 , F: M_W^2)	666.1(6)	22.2(6)	2.0(2)	0.18(6)	—
	(R: M_W^2 , F: P^2_{tmin})	755.3(6)	25.2(7)	1.0(1)	0.09(4)	—
	(R: $< P_t^2 >$, F: $< P_t^2 >$)	980.9(8)	27.5(9)	0.8(1)	0.08(5)	—

W + 2 jets

Method	Energy Scales	σ_{tot} (pb)	$\sigma^{det.}_{1jet}$ (pb)	$\sigma^{det.}_{2jets}$ (pb)	$\sigma^{det.}_{3jets}$ (pb)	$\sigma^{det.}_{4jets}$ (pb)
Naive	(R: M_W^2 , F: M_W^2)	252.5(3)	—	3.3(1)	0.46(6)	0.10(2)
	(R: M_W^2 , F: P^2_{tmin})	301.3(4)	—	4.1(1)	0.29(5)	0.02(1)
	(R: $< P_t^2 >$, F: $< P_t^2 >$)	458.3(7)	—	4.5(2)	0.53(8)	0.10(3)
	(R: $< P_t^2 >$, F: P^2_{tmin})	481.2(7)	—	4.8(2)	0.21(5)	0.07(3)
PYXTRA	(R: M_W^2 , F: **PYXTRA**)	261.4(7)	—	2.1(1)	0.31(4)	0.05(2)
	(R: **PYXTRA** , F: **PYXTRA**)	399(1)	—	2.8(1)	0.43(7)	0.08(3)
	(R: $< P_t^2 >$, F: **PYXTRA**)	417(1)	—	2.3(1)	0.40(6)	0.05(2)
Rejection	(R: M_W^2 , F: M_W^2)	223.1(3)	—	2.9(1)	0.40(5)	0.06(2)
	(R: M_W^2 , F: P^2_{tmin})	301.2(4)	—	4.7(2)	0.32(5)	0.03(1)
	(R: $< P_t^2 >$, F: $< P_t^2 >$)	453.5(7)	—	4.6(2)	0.31(6)	0.03(2)
	(R: $< P_t^2 >$, F: P^2_{tmin})	480.9(7)	—	5.8(2)	0.51(8)	—

W + 3 jets

Method	Energy Scales	σ_{tot} (pb)	$\sigma^{det.}_{1jet}$ (pb)	$\sigma^{det.}_{2jets}$ (pb)	$\sigma^{det.}_{3jets}$ (pb)	$\sigma^{det.}_{4jets}$ (pb)
Naive	(R: M_W^2 , F: M_W^2)	80.6(2)	—	—	0.46(3)	0.11(1)
	(R: M_W^2 , F: P^2_{tmin})	113.0(4)	—	—	0.67(4)	0.06(1)
	(R: $< P_t^2 >$, F: $< P_t^2 >$)	177.7(6)	—	—	0.75(6)	0.16(3)
	(R: $< P_t^2 >$, F: P^2_{tmin})	203(1)	—	—	0.88(7)	0.09(2)
PYXTRA	not yet...	—	—	—	—	—
Rejection	(R: M_W^2 , F: M_W^2)	70.2(2)	—	—	0.32(2)	0.07(1)
	(R: M_W^2 , F: P^2_{tmin})	112.9(4)	—	—	0.65(4)	0.09(1)
	(R: $< P_t^2 >$, F: $< P_t^2 >$)	174.3(6)	—	—	0.49(5)	0.12(2)
	(R: $< P_t^2 >$, F: P^2_{tmin})	202(1)	—	—	1.00(8)	0.06(2)

Summary

The dependence of the renor./fact. scale on W + jets process was studied. For a better treatment of the fact. scale, we've tried two attempts : **PYXTRA** and **Rejection** method. The jet multiplicities from the additional jets from PS drastically depended on the size of the fact. scale. The **Rejection** method showed slightly smaller fluctuations of fact. scale to be compared with the **Naive** method. (This is the first attempt. $\Rightarrow$ needed more study.)