POWRACE

Electroweak and strong corrections to the Drell-Yan process

Davide Pagani 2nd November 2009

THE DRELL-YAN PROCESS

$$p\overset{(-)}{p} \rightarrow \gamma, Z \rightarrow l^+ l^-$$

Neutral current

Calibration of the detector

Electroweak mixing angle

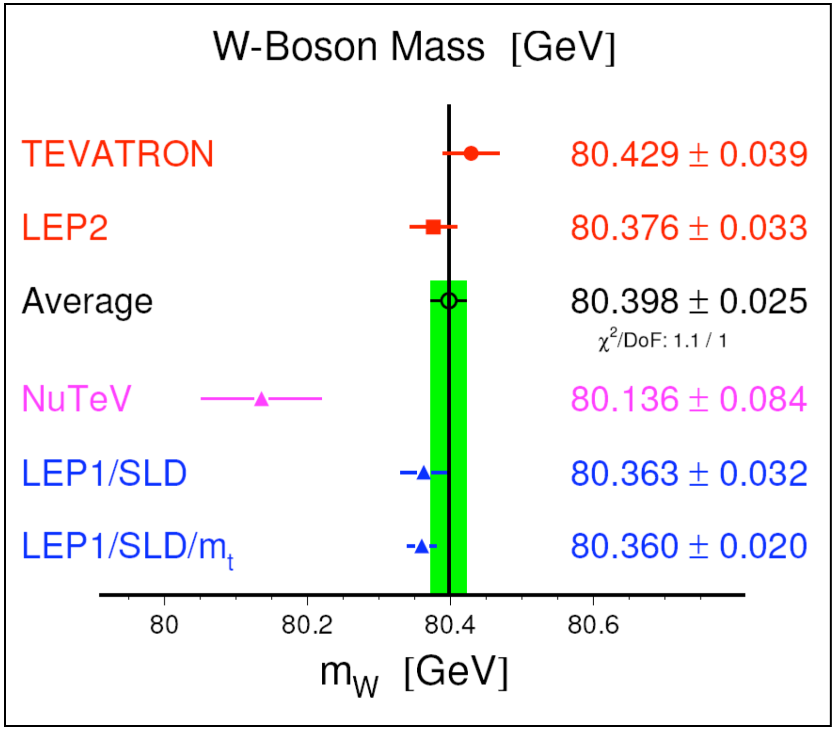
$$p\overset{(-)}{p} \rightarrow W \rightarrow l \overset{(-)}{\nu}_l$$

Charged current

Mass m_W and decay width of the W boson
(indirect bounds on m_{HIGGS})

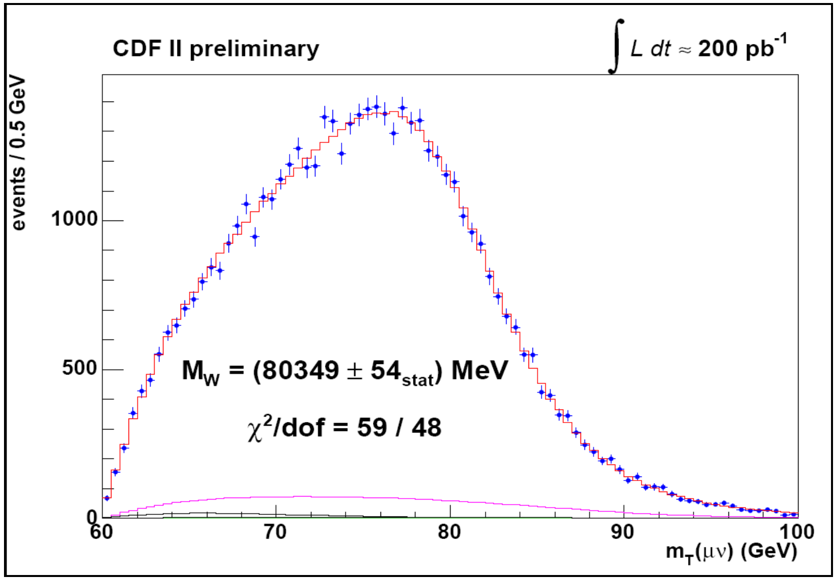
Constraints on the partonic distributions

Possible signals of new physics



$$\Delta m_W = 15 \text{ MeV}$$

EXPERIMENTAL ERROR AT LHC



Fit of the experimental data for the transverse mass

$$M_t = \sqrt{2|p_{t,\nu_l}||p_{t,l}|(1-\cos(\Delta\phi))}$$

THE EVENT GENERATOR

Energy in the hadronic C.M.F.?

Initial hadrons? Final leptons?

Experimental cuts on leptons?

Theoretical assumptions?

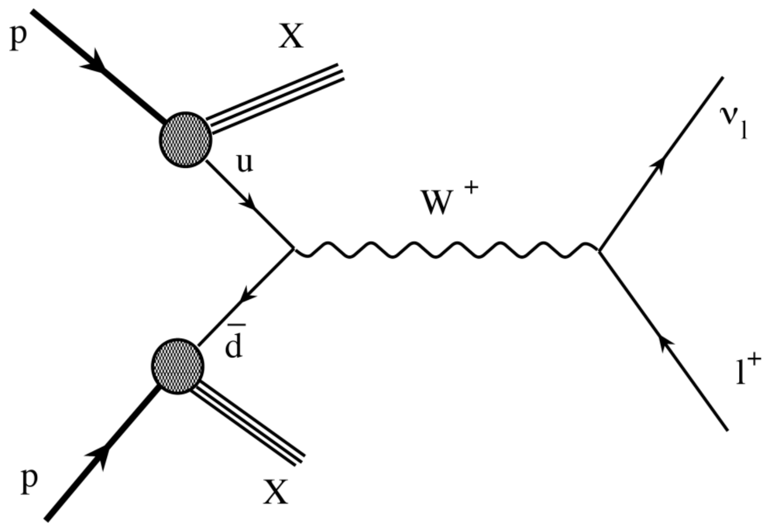
EVENTS
Simulations of the collisions, describing the partonic subprocess.
Momentum and other physical observables are listed for **every particle** involved in the process.

Accuracy of theoretical calculation

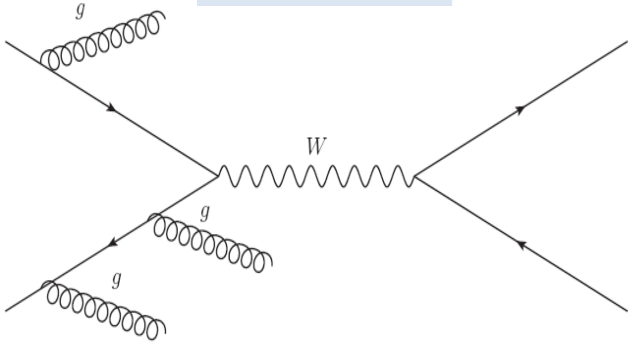
Experimental set-up

Efficiency of the generator

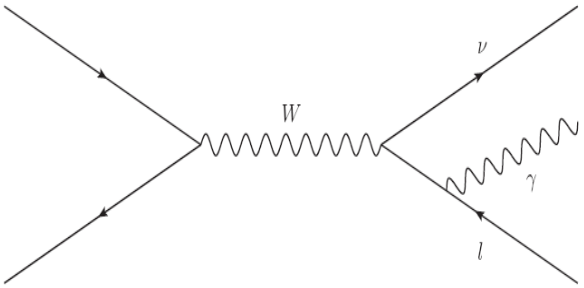
BORN HADRONIC PROCESS



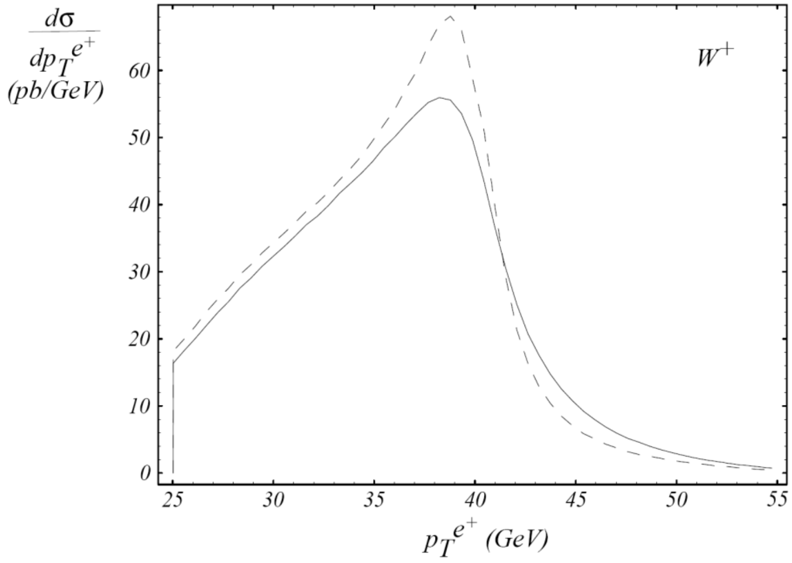
QCD



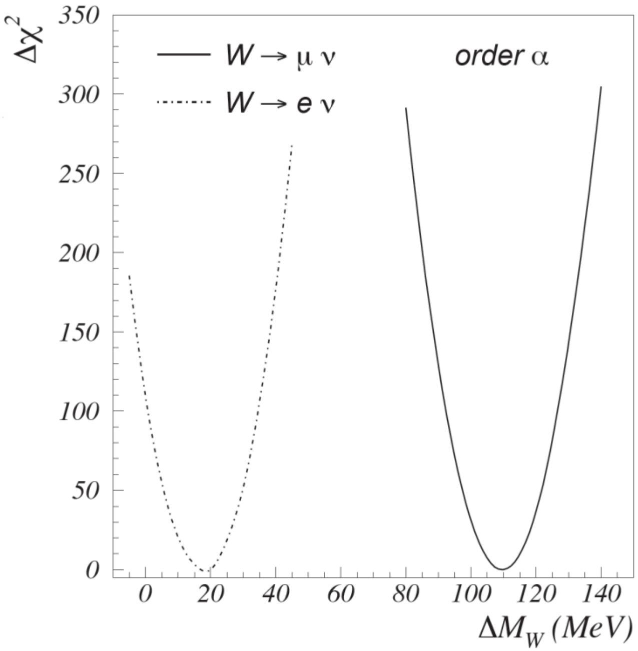
EW

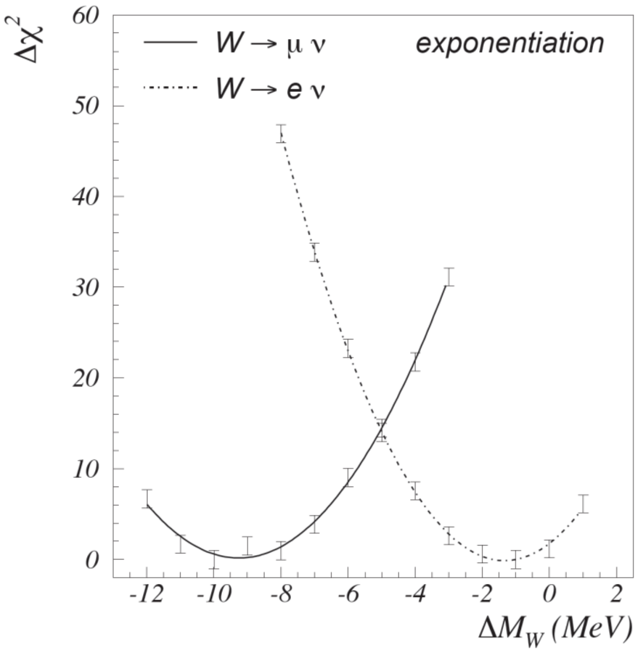


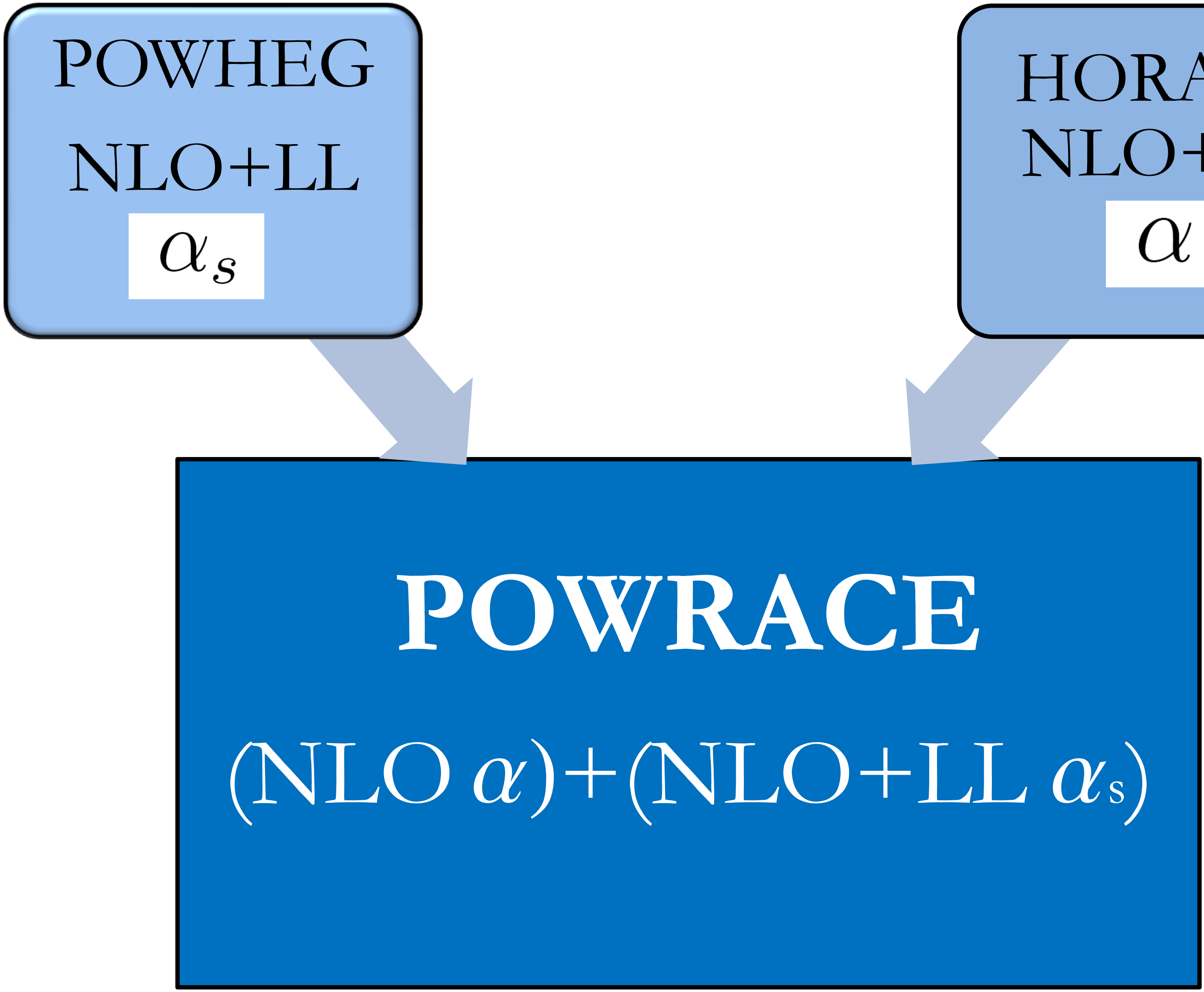
QCD EFFECTS ON LEPTON'S TRANSVERSE MOMENTUM



EW EFFECTS ON W BOSON MASS



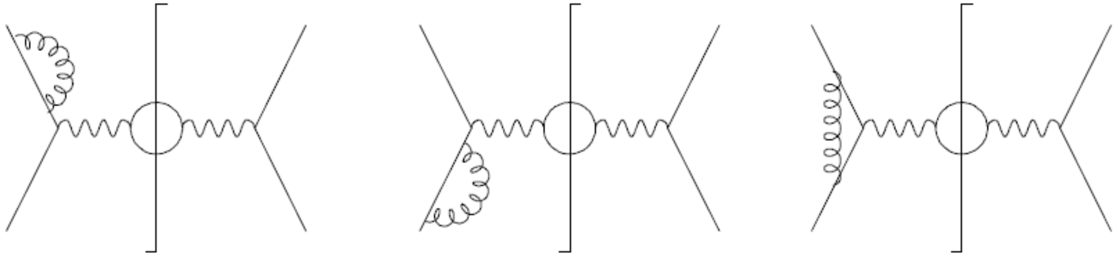



POWHEG
NLO+LL
α_s
HORACE
NLO+LL
α
POWRACE
(NLO α)+(NLO+LL α_s)

NLO in α_s

Dimensional regularization with massless partons

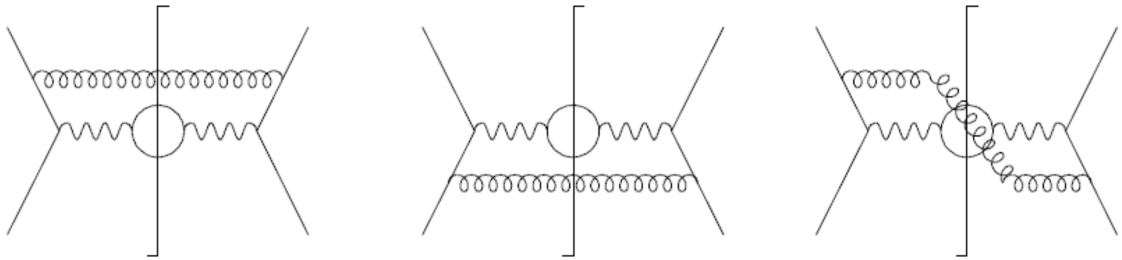
$$q\bar{q} \longrightarrow l\overset{(-)}{\nu}$$



$$2Re(\mathcal{M}_{born}\mathcal{M}^{*}_{virt})$$

NO ULTRAVIOLET divergences, but there are:
SOFT, COLLINEAR, SOFT&COLLINEAR divergences

$$q\bar{q} \longrightarrow l\overset{(-)}{\nu} + g$$



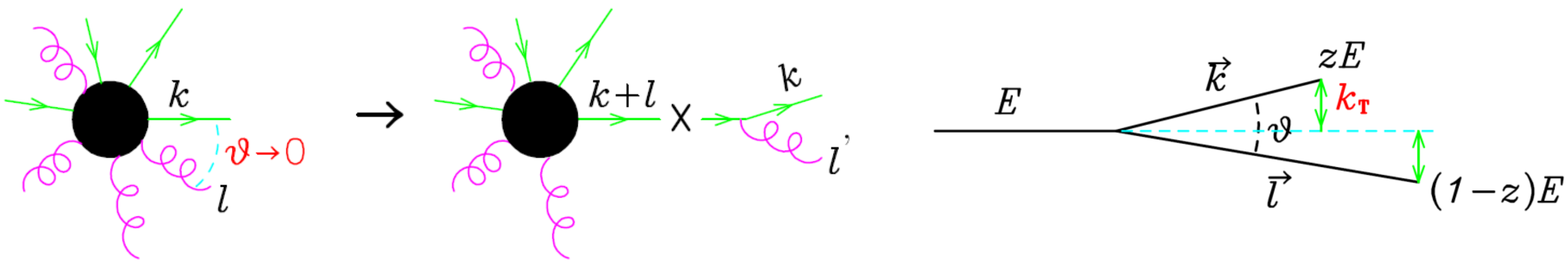
$$|\mathcal{M}_{real}|^2$$

there are:
SOFT, COLLINEAR, SOFT&COLLINEAR divergences

CANCELLATION OF THE COLLINEAR DIVERGENCES ONLY AT HADRONIC LEVEL!!

Parton Shower

In order to generate events, we need an **exclusive** description of final states, not an inclusive one

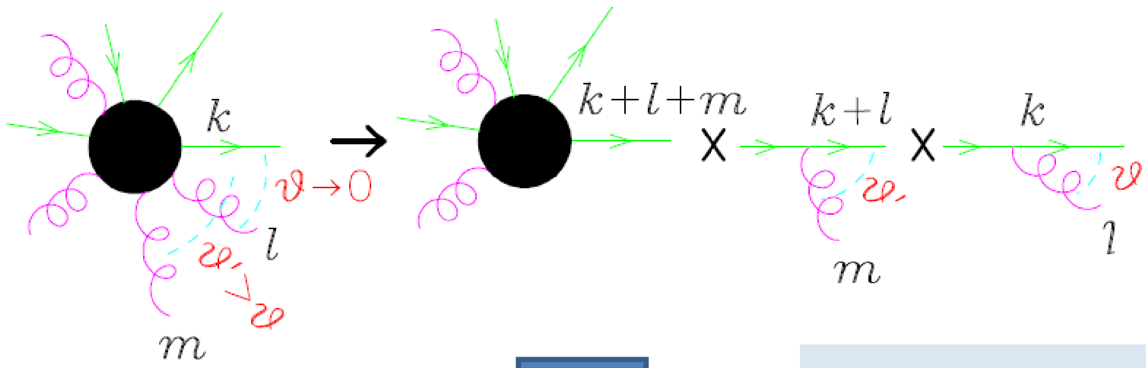


In the collinear approximation we find the leading terms

Cross section can be factorized

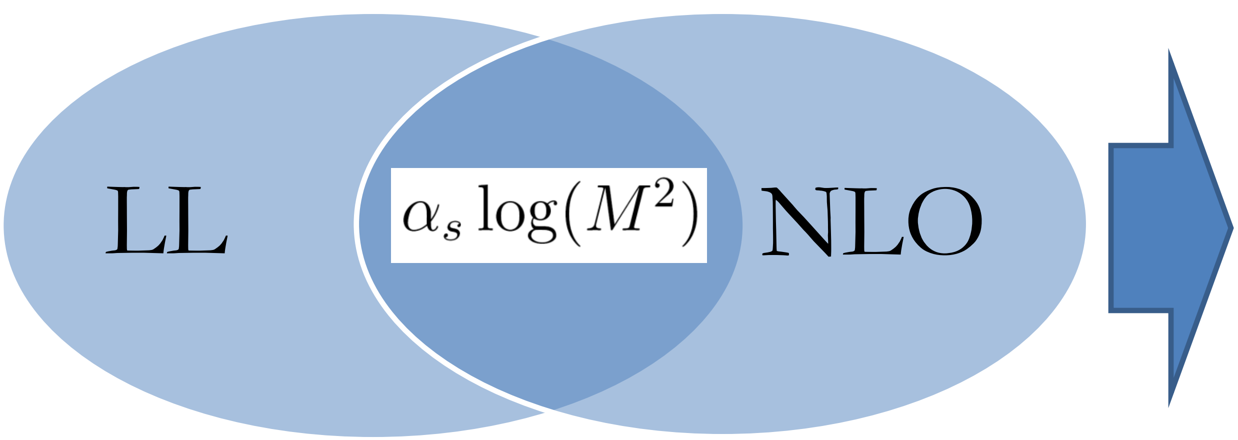
$$|M_{n+1}|^2 d\Phi_{n+1} \Rightarrow |M_n|^2 d\Phi_n \quad \frac{\alpha_S}{2\pi}\,\frac{dt}{t}\,P_{q,qg}(z)\,dz\,\frac{d\phi}{2\pi}$$

Approximation and factorization can be iterated



LL Leading Logarithms

$$\sigma_0 \alpha_S^n \int \frac{dt_1}{t_1}\frac{dt_2}{t_2}\dots\frac{dt_n}{t_n} \times \theta(Q^2 > t_1 > t_2 > \dots > t_n > \lambda^2) = \sigma_0 \frac{1}{n!}\alpha_S^n \log^n \frac{Q^2}{\lambda^2}$$



POWHEG

POWHEG

S. Alioli, P. Nason, C. Oleari, E. Re, *NLO vector-boson production matched with shower in POWHEG,* JHEP0807:060,2008, **arXiv:0805.4802**

$$d\sigma = \sum_{q\bar{q}} \underbrace{\bar{B}_{q\bar{q}}(\Phi_2)}_{\boxed{B_{q\bar{q}}(\Phi_2)+\mathcal{O}(\alpha_s)}} d\Phi_2 \left\{ \Delta_{q\bar{q}}(\Phi_2, p_t^{min}) + \Delta_{q\bar{q}}(\Phi_2, k_t(\Phi_3)) \frac{R_{q\bar{q}}(\Phi_3)}{B_{q\bar{q}}(\Phi_2)} d\Phi_{rad} \right\}_{\bar{\Phi}_2=\Phi_2}$$

$$\boxed{1+\mathcal{O}(\alpha_s)} \qquad \boxed{\mathcal{O}(\alpha_s)}$$

Probability of non emitting partons with $k_t > p_t^{min}$ + Probability that the first emitted parton has trans. momentum k_t = **1**

The Sudakov factor is defined as

$$\Delta_{q\bar{q}}(\Phi_2, p_t) = \exp\left\{ - \left[\int d\Phi_{rad} \frac{R_{q\bar{q}}(\Phi_3)}{B_{q\bar{q}}(\Phi_2)} \theta(k_t(\Phi_3) - p_t) \right]^{\bar{\Phi}_2=\Phi_2} \right\}$$

$$R_{q\bar{q}} = R_{q\bar{q},g} + R_{g\bar{q},q} + R_{gq,\bar{q}}$$

NLO ACCURACY+ EXCLUSIVE DESCRIPTION OF THE EVENTS WITH HARD PARTONS

$$k_t > p_t^{min}$$

EVENT WITH PARTONS

$$k_t < p_t^{min}$$

EVENT WITHOUT PARTONS

POWHEG MAKES THE **FIRST STEP** OF THE SHOWERING PROCESS:
IT MUST BE COMUNICATED TO **AVOID DOUBLE COUNTING**

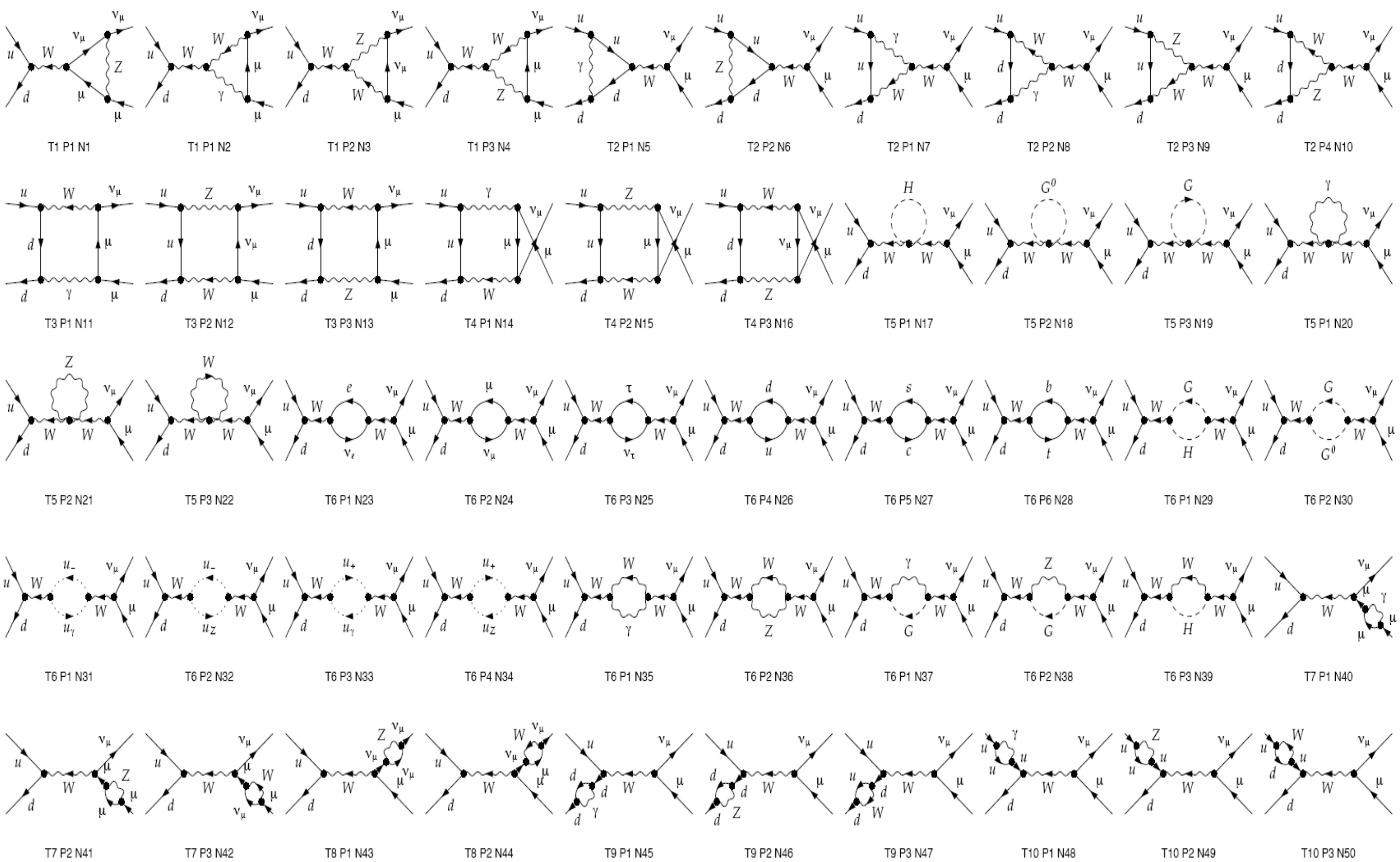
SCALUP = kt

MATCHING NLO+LL, WITHOUT DEPENDENCE ON ANY SHOWER MONTECARLO

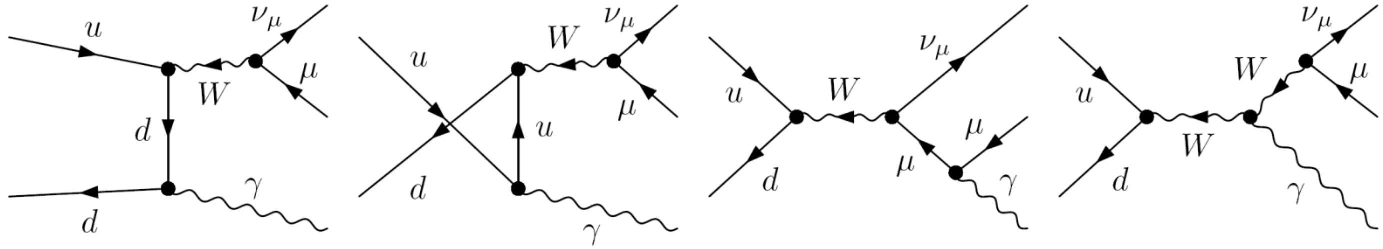
NLO in α

<u>Every</u> particle electroweakly interacts

$$\mathcal{M}^*_{virtual}$$



$\mathcal{M}_{real}$



HORACE

C.M. Carloni Calame, G. Montagna, O. Nicrosini, A. Vicini, *Precision electroweak calculation of the charged current Drell-Yan process*, JHEP 0612:016,2006, arXiv:hep-ph/0609170

$$d\sigma_{NLO} = [|\mathcal{M}_{born}|^2 + 2Re(\mathcal{M}_{born}\mathcal{M}^*_{virtual})]d\Phi_0 + |\mathcal{M}_{real}|^2 d\Phi_1$$

ULTRAVIOLET DIVERGENCES	RENORMALIZATION
INFRARED DIVERGENCES	PHOTON MASS
COLLINEAR DIVERGENCES	FERMION MASS

$\lambda < E_\gamma < \Delta E$	SOFT PHOTONS
$E_\gamma > \Delta E$	HARD PHOTONS

Cancellation of the infrared divergences

$$d\sigma_{NLO} = |\mathcal{M}_{born}|^2(1 + \delta_{soft} + \delta_{virtual})d\Phi_0 + |\mathcal{M}_{hard}|^2 d\Phi_1$$

POWRACE

$$\sigma_{NLO(\alpha_s)} + \sigma_{NLO(\alpha)} - \sigma_0 = \sigma_0 + \sigma_0 + \sigma_\alpha + \sigma_{\alpha_s} - \sigma_0 = \sigma_{NLO(\alpha_s,\alpha)}$$

Removing Born contribution from HORACE

- EVENT WITH A HARD PHOTON: The weight is computed using tree level approximation
- EVENT WITHOUT PHOTONS: The weight takes into account only soft+virtual corrections to $p\overset{(-)}{p} \to W \to l\overset{(-)}{\nu}_l$, so it could be negative

EVENT CLASSIFICATION BASED ON PHYSICAL OBSERVABLES

- EVENTS WITH A PHOTON: there is an hard photon $E_\gamma > \Delta E$ $\boxed{\mathcal{O}(\alpha)}$
- EVENTS WITHOUT A PHOTON: the photon is undetectable because $E_\gamma < \Delta E$ or there isn't really any photon $\boxed{\text{Born} + \mathcal{O}(\alpha)}$
  These events are subdivided again into:
  - EVENTS WITH AN EMITTED PARTON: jet can be seen by the detector $p_{t,jet} > p_{t,min}$ $\boxed{\mathcal{O}(\alpha_s)}$
  - EVENTS WITHOUT EMITTED PARTON: the jet is undetectable because $p_{t,jet} < p_{t,min}$ or there isn't really any emitted parton.

1 photon contribution(RACE)

$$d\sigma_{RACE} = \sum_{i,j} \int dx_1 dx_2 f_{q_i}(x_1, M^2) f_{q_j}(x_2, M^2) \left[|\tilde{\mathcal{M}}_1|^2 d\Phi_1 + d\sigma_\alpha^{sub,H} \right]$$

0 photon electroweak soft+virtual contribution

$$\sum_{i,j} \int dx_1 dx_2 f_{q_i}(x_1, M^2) f_{q_j}(x_2, M^2) F_{HOR}(\Phi_0) d\sigma_0$$

$$F_{HOR} := \left[\tilde{C}_\alpha + C_\alpha^{sub} - \left(\frac{\Delta f_{q_i}(x_1, M^2)}{f_{q_i}(x_1, M^2)} + \frac{\Delta f_{q_j}(x_2, M^2)}{f_{q_j}(x_2, M^2)} \right) \right]$$

$$d\sigma_{_{POWHEG}} = \sum_{q\bar{q}} \bar{B}_{q\bar{q}}(\Phi_2) d\Phi_2 \left\{ \Delta_{q\bar{q}}(\Phi_2, p_t^{min}) + \Delta_{q\bar{q}}(\Phi_2, k_t(\Phi_3)) \frac{R_{q\bar{q}}(\Phi_3)}{B_{q\bar{q}}(\Phi_2)} d\Phi_{rad} \right\}_{\bar{\Phi}_2 = \Phi_2}$$

$$\bar{B}_{q\bar{q}}(\Phi_2) = \sum_{q\bar{q}} \left\{ [B_{q\bar{q}}(\Phi_2) + V_{q\bar{q}}(\Phi_2)] + \ldots \right\}$$

$$\boxed{V_{q\bar{q}}(\Phi_2) \rightarrow V_{q\bar{q}}^{HOR}(\Phi_2) = V_{q\bar{q}}(\Phi_2) + B_{q\bar{q}} F_{HOR}}$$

NUMERICAL TEST, obtained results:

- Cross sections must **not depend** on ϵ.
- Soft+virtual contributions calculated by POWRACE and HORACE must be compatible.

ϵ=0.0005			
0	σ_0	(HORACE)	981.6 ± 0.9
1	$\sigma_0 + \sigma_{\alpha,SV}$	(HORACE)	767.2 ± 1.2
2	$\sigma_0 + \sigma_{\alpha_s}$	(POWRACE)	1185.7 ± 0.8
3	$\sigma_0 + \sigma_{\alpha_s} + \sigma_{\alpha,SV}$	(POWRACE)	970.4 ± 0.6
(0)-(1)=$\sigma_{\alpha,SV,HORACE}$= 214,4 $\pm$ 1.5			
(2)-(3)=$\sigma_{\alpha,SV,POWRACE}$= 215,3 $\pm$ 1			

$$\epsilon = \Delta E/E$$

ϵ=0.00001			
0	σ_0	(HORACE)	981.6 ± 0.9
1	$\sigma_0 + \sigma_{\alpha,SV}$	(HORACE)	608.4 ± 1.0
2	$\sigma_0 + \sigma_{\alpha_s}$	(POWRACE)	1185.7 ± 0.8
3	$\sigma_0 + \sigma_{\alpha_s} + \sigma_{\alpha,SV}$	(POWRACE)	810.7 ± 0.5
(0)-(1)=$\sigma_{\alpha,SV,HORACE}$= 373.2 $\pm$ 1.7			
(2)-(3)=$\sigma_{\alpha,SV,POWRACE}$= 375,0 $\pm$ 0.9			

Compatibility within numerical errors

ϵ	σ_{RACE}	σ_{POW}	$\sigma_{POWRACE}$
0.0005	269.7 ± 0.3	970.4 ± 0.6	1240.1 ± 0.7
0.00001	429.1 ± 0.6	810.7 ± 0.5	1239.9 ± 0.8

EXPERIMENTAL SET-UP SIMULATED:

TEVATRON $p\bar{p}$

$$E_{cm} = 1960 \;\; \mathrm{GeV} \qquad |y_\mu| < 1.2 \quad |p_{t,l}|, |p_{t,\nu_l}| > 25\mathrm{GeV}$$

LHC pp

$$E_{cm} = 14 \;\mathrm{TeV} \qquad |y_\mu| < 2.5 \quad |p_{t,l}|, |p_{t,\nu_l}| > 25\mathrm{GeV}$$

(a) TRANSVERSE MOMENTUM OF THE LEPTON (pb/GeV)

(b) LEPTON RAPIDITY (pb)

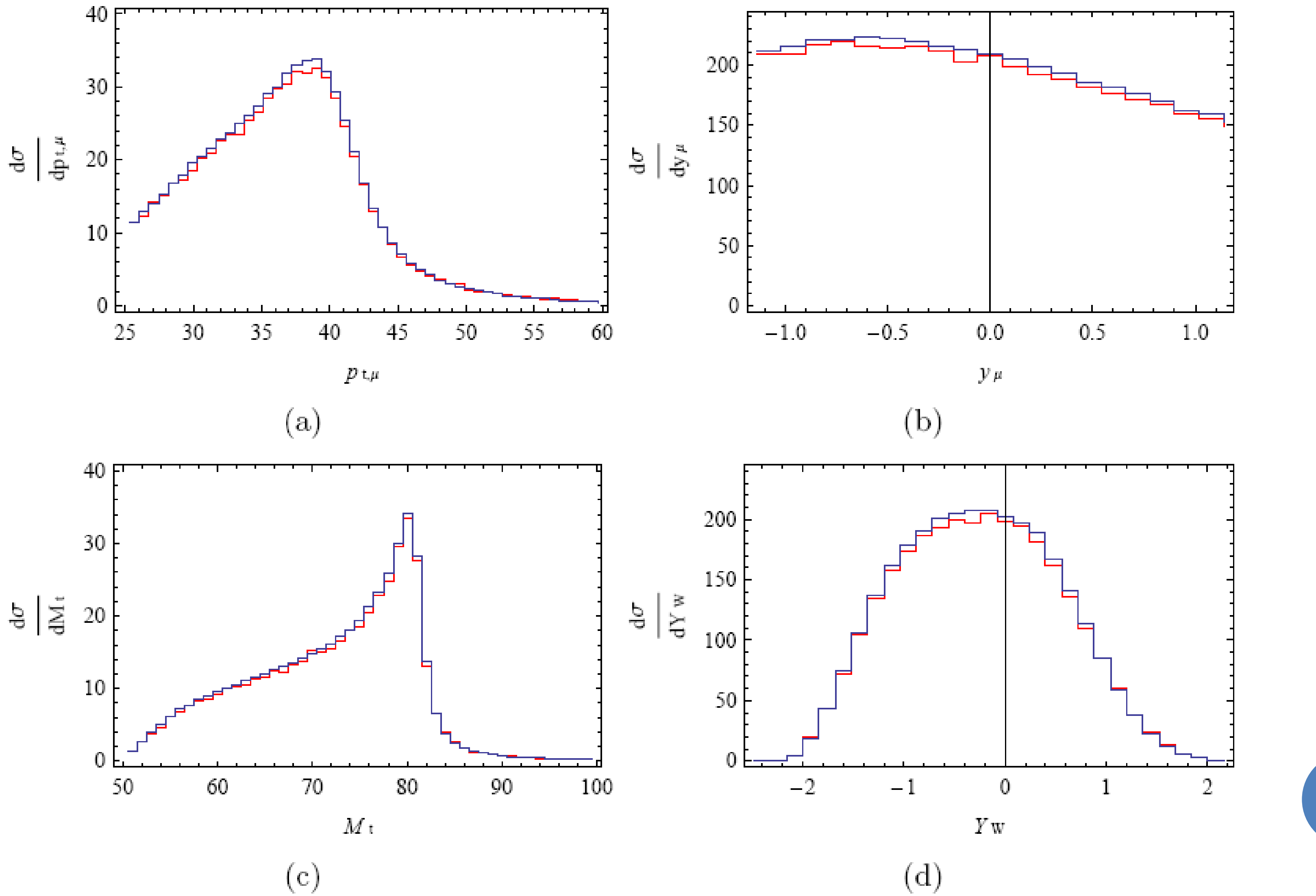
(c) TRANSVERSE MASS(pb/GeV)

(d) W BOSON RAPIDITY (pb)

Tevatron W-

Strong corrections

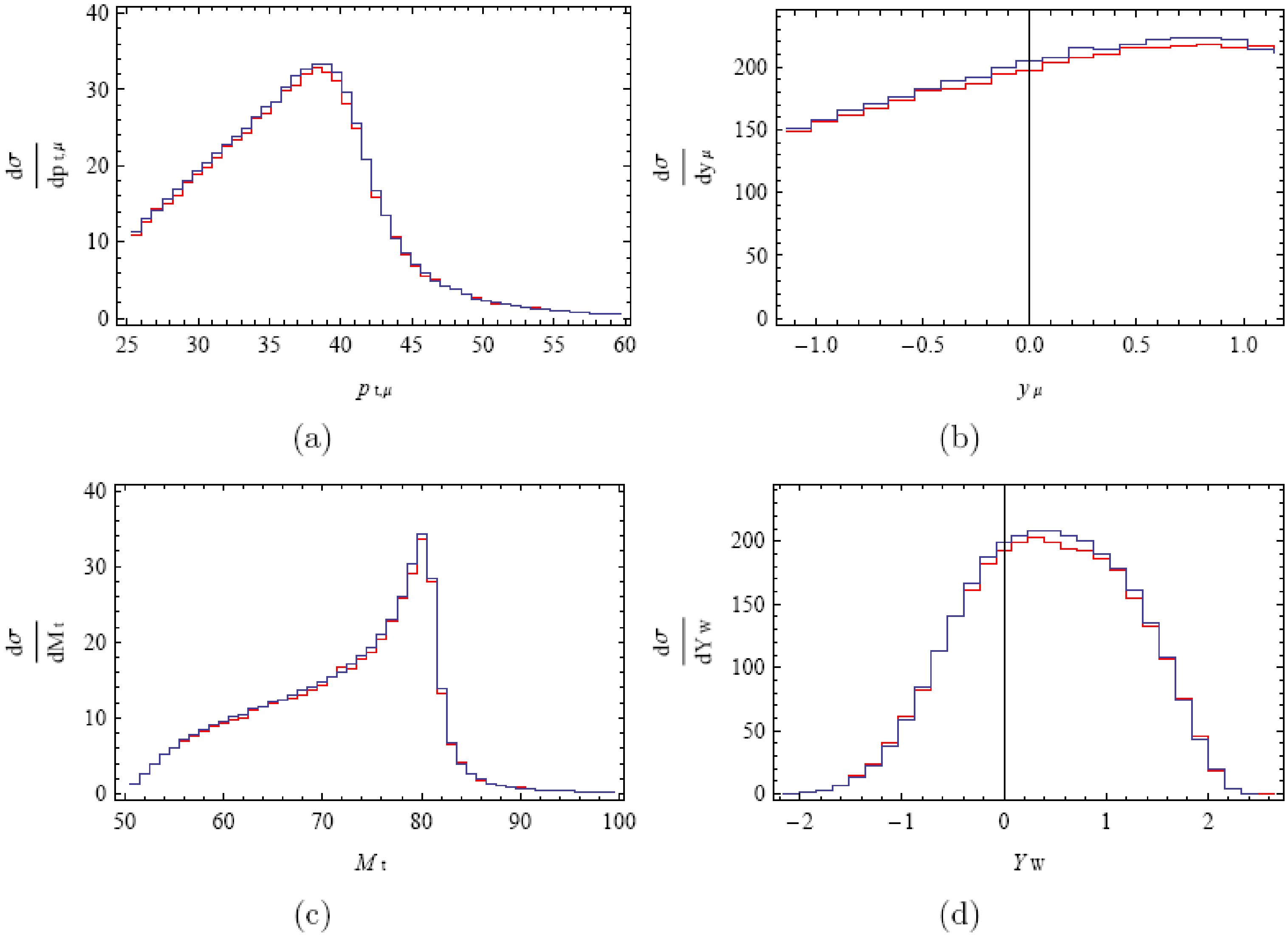
Strong and electroweak NLO corrections



Tevatron W^+

Strong corrections

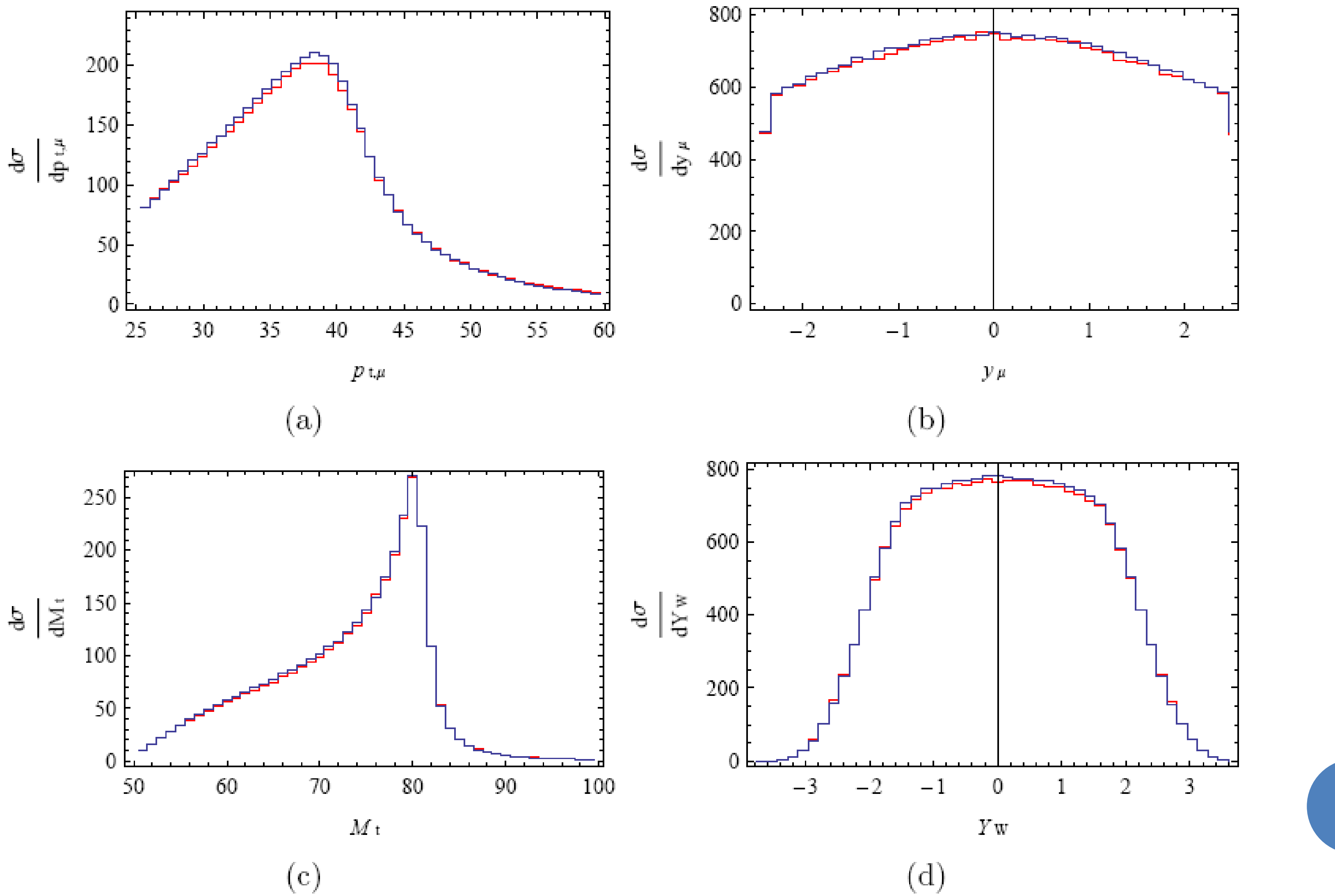
Strong and electroweak NLO corrections



LHC W⁺

Strong corrections

Strong and electroweak NLO corrections



CONCLUSION

For the first time a single generator **(POWRACE)** includes **QCD and EW NLO** corrections. Events receive **QCD LL** corrections after the showering process.

Plots are compatible with:

G. Balossini, C.M. Carloni Calame, G. Montagna, M. Moretti, O. Nicrosini, F. Piccinini, M. Treccani, A. Vicini, *Combination of electroweak and QCD corrections to single W production at the Fermilab Tevatron and the CERN LHC,* [arXiv:hep-ph/09070276]

Possible developements:

-Extension to the neutral current channel

-Inclusion of the electroweak LL approximation for multiphotonic radiation

-Complete analysis of EW and QCD combined effects

-High precision analysis of physical observables

Thank you for your attention