Fast re-evaluation of the W/Z differential cross-section at the NNLO using APPLGRID interface to DYNNLO framework

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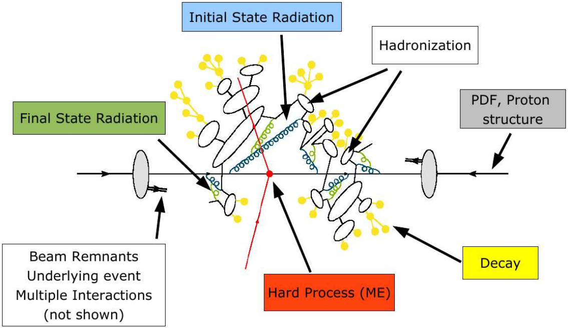
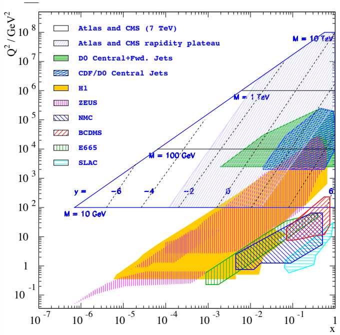
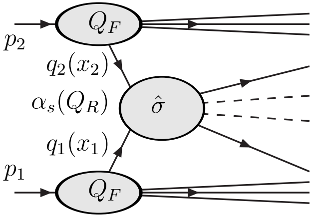
Proton-proton collision





- hard scattering can be calculated to NLO(NNLO) precision
- description of showers and non-perturbative effects comes from MC
- PDFs and strong coupling are determined from precision data (LEP, HERA, TEVATRON, . . .).

NNLO QCD cross section



$$\frac{d\sigma}{dX} \sim \sum_{(i,j,p)} \int d\Gamma \alpha_s^p(Q_R^2)\, q_i(x_1, Q_F^2) q_j(x_2, Q_F^2)\, \frac{d\hat{\sigma}^{ij}_{(p)}}{dX}(x_1, x_2, Q_F^2, Q_R^2;\; S)$$

- Coupling and parton density functions are non-perturbative inputs to calculation (extracted from data)
- Perturbative coefficients are essentially independent from PDF functions due to factorisation theorem

Calculating NLO/NNLO cross-sections
takes a long time ($\sim$ *days*)

$\Longrightarrow$ we can split calculation into two parts

APPLGRID method

Eur.Phys.J.C66:503-524,2010.

- Step 1 (long run): Collect perturbative weights to grids .
  - binning (x_1, x_2, Q^2)
  - interpolation
  - initial flavours decomposition : $13 \times 13 \to \mathcal{L}$ ($\mathcal{L} \sim 10$)

$$\frac{d\hat{\sigma}^{ij}_{(p)}}{dX}(x_1, x_2, Q_F^2, Q_R^2;\ S) \xrightarrow{3D-grid} w^{(p)(l)}(x_1^m, x_2^n, Q^{2^k})\ (Q_R^2 \equiv Q_F^2)$$

- Step 2 ($\sim$ 10–100 ms): Convolute grid with PDF's .
  - integral $\to$ sum
  - any coupling, PDF

$$\frac{d\sigma}{dX} = \sum_p \sum_{l=0}^{L} \sum_{m,n,k} w_{m,n,k}^{(p)(l)} \left(\frac{\alpha_s(Q_k^2)}{2\pi} \right)^{p_l} F^{(l)}\left(x_{1\,m}, x_{2\,n}, Q_k^2\right)$$

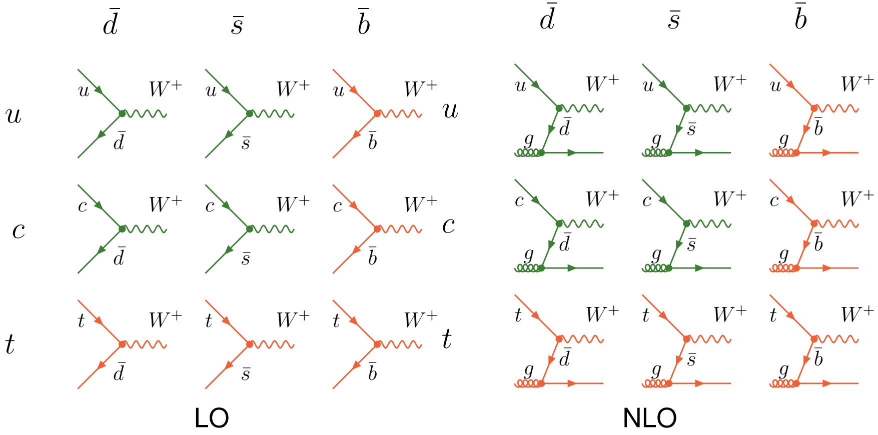
Interface to cross section calculators

- NLOJET++ : Jet production in $pp(\bar{p})-$ and $ep-$ collisions.
  - $2 \to 2$ and $2 \to 3$ at NLO; $2 \to 4$ at LO
    www.desy.de/∼znagy/Site/NLOJet++.htm.
- MCFM : parton-level NLO QCD cross sections calculator for various femtobarn-level processes at hadron-hadron colliders.
  - $V, V + nJet, V + b\bar{b}, VV, Q\bar{Q}, \ldots (\sim \mathcal{O}(300))$ mcfm.fnal.gov/
- SHERPA : Simulation of High-Energy Reactions of PArticles in lepton-lepton, lepton-photon, photon-photon, lepton-hadron and hadron-hadron collisions.
  - A huge amount of scattering processes sherpa.hepforge.org.
- aMC@NLO : A framework for the computation of hard events at the NLO or LO, to be subsequently showered (infrared-safe observables at the NLO or LO).
  - Matrix elements calculations from Madgraph 5
    amcatnlo.web.cern.ch/amcatnlo/; madgraph.phys.ucl.ac.be/.
- DYNNLO : NNLO calculation of Drell-Yan processes at hadron colliders theory.fi.infn.it/grazzini/dy.html

Observable definition

- $W^{\pm}$-boson : $\frac{d\sigma}{dy_\ell}$
  - $M_T > 40$ GeV
  - $p_T^\ell > 25$ GeV
  - $E_T^{miss} > 25$GeV
- $\frac{d\sigma}{dy_{Z^0}}$
  - $66 < M_{\ell\ell} < 116$ GeV
  - $|\eta_\ell| < 2.5$

APPLGRID subprocesses for $W^{\pm}$ production (I)



APPLGRID subprocesses for Z^0 production

We can introduce 12 sub-processes in Z production (calculated using MCFM)

We separate $u\bar{u}$ from $\bar{u}u$ contributions to include γ/Z interference

$$
\begin{aligned}
U\bar{U}: &\quad F^{(0)}\left(x_1, x_2, Q^2\right) = U_{12}(x_1, x_2) \\
D\bar{D}: &\quad F^{(1)}\left(x_1, x_2, Q^2\right) = D_{12}(x_1, x_2) \\
\bar{U}U: &\quad F^{(2)}\left(x_1, x_2, Q^2\right) = U_{21}(x_1, x_2) \\
\bar{D}D: &\quad F^{(3)}\left(x_1, x_2, Q^2\right) = D_{21}(x_1, x_2) \\
gU: &\quad F^{(4)}\left(x_1, x_2, Q^2\right) = G_1(x_1)U_2(x_2) \\
g\bar{U}: &\quad F^{(5)}\left(x_1, x_2, Q^2\right) = G_1(x_1)\overline{U}_2(x_2) \\
gD: &\quad F^{(6)}\left(x_1, x_2, Q^2\right) = G_1(x_1)D_2(x_2) \\
g\bar{D}: &\quad F^{(7)}\left(x_1, x_2, Q^2\right) = G_1(x_1)\overline{D}_2(x_2) \\
Ug: &\quad F^{(8)}\left(x_1, x_2, Q^2\right) = U_1(x_1)G_2(x_2) \\
\bar{U}g: &\quad F^{(9)}\left(x_1, x_2, Q^2\right) = \overline{U}_1(x_1)G_2(x_2) \\
Dg: &\quad F^{(10)}\left(x_1, x_2, Q^2\right) = D_1(x_1)G_2(x_2) \\
\bar{D}g: &\quad F^{(11)}\left(x_1, x_2, Q^2\right) = \overline{D}_1(x_1)G_2(x_2)
\end{aligned}
$$

APPLGRID subprocesses for Z^0 production II

Use is made of the generalised PDFs defined as:

$$U_H(x) = \sum_{i=2,4,6} f_{i/H}\left(x, Q^2\right), \qquad \overline{U}_H(x) = \sum_{i=2,4,6} f_{-i/H}\left(x, Q^2\right),$$

$$D_H(x) = \sum_{i=1,3,5} f_{i/H}\left(x, Q^2\right), \qquad \overline{D}_H(x) = \sum_{i=1,3,5} f_{-i/H}\left(x, Q^2\right),$$

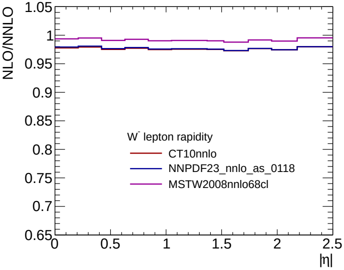
$$U_{12}(x_1, x_2) = \sum_{i=2,4,6} f_{i/H_1}\left(x_1, Q^2\right) f_{-i/H_2}\left(x_2, Q^2\right),$$

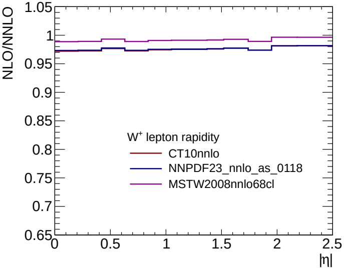
$$D_{12}(x_1, x_2) = \sum_{i=1,3,5} f_{i/H_1}\left(x_1, Q^2\right) f_{-i/H_2}\left(x_2, Q^2\right),$$

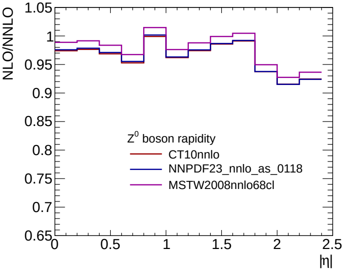
$$U_{21}(x_1, x_2) = \sum_{i=2,4,6} f_{-i/H_1}\left(x_1, Q^2\right) f_{i/H_2}\left(x_2, Q^2\right),$$

$$D_{21}(x_1, x_2) = \sum_{i=1,3,5} f_{-i/H_1}\left(x_1, Q^2\right) f_{i/H_2}\left(x_2, Q^2\right),$$

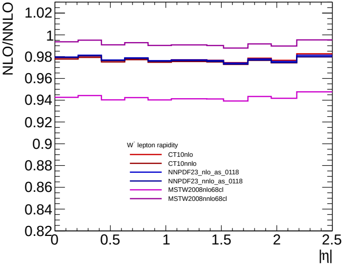
k-factors (NNLO PDFs)

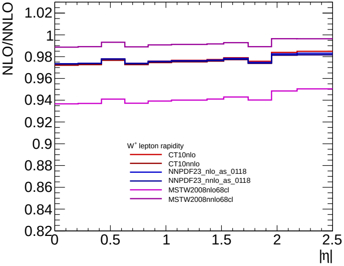


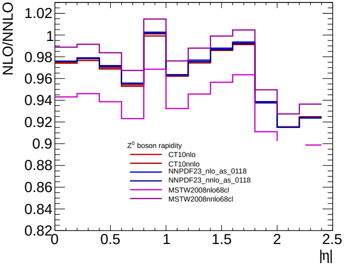




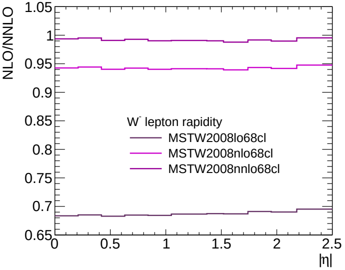
k-factors (NLO/NNLO PDFs)

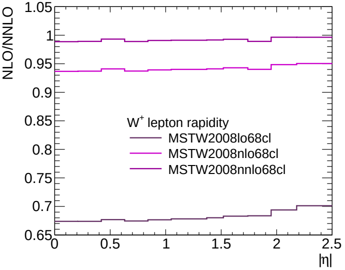


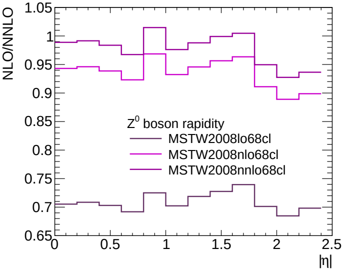




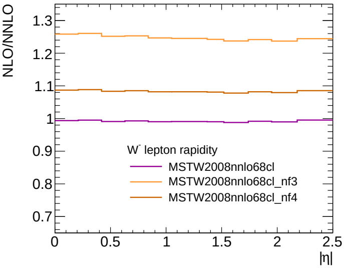
k-factors (LO/NLO/NNLO PDFs)

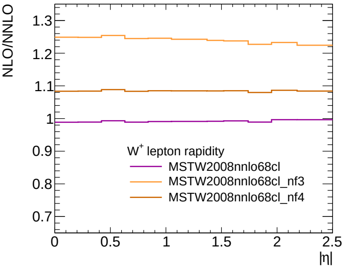


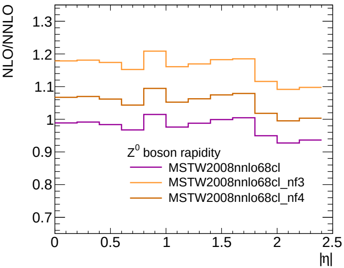




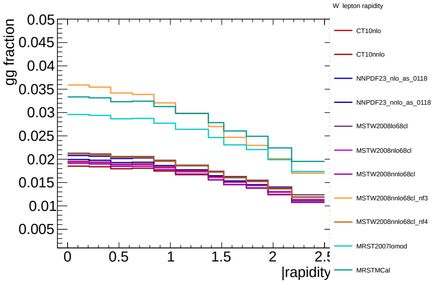
k-factors (FF PDFs)

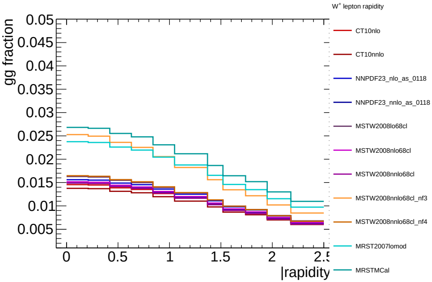


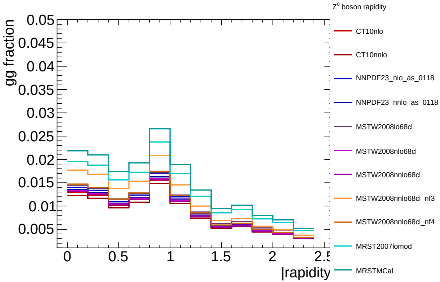




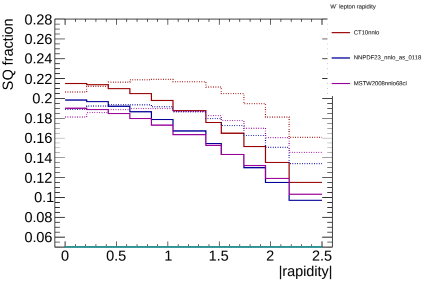
gg contribution

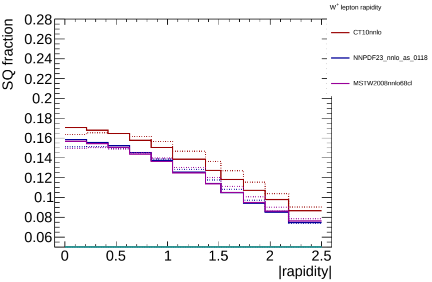


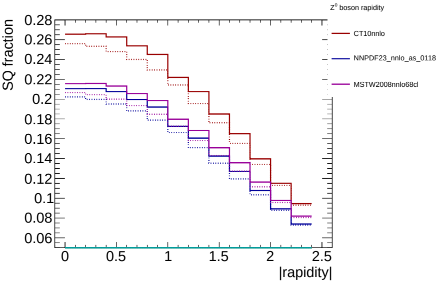




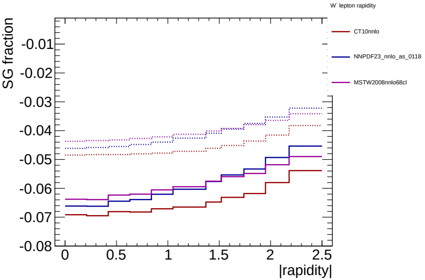
Strange-Quark contribution

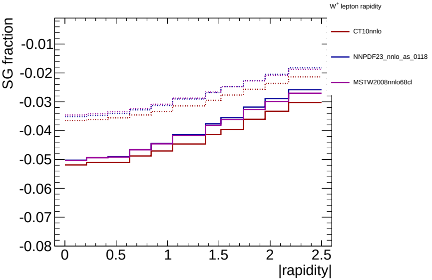


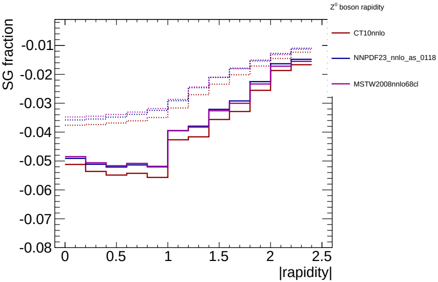




Strange-gluon contribution







Summary

Precision measurements of QCD processes can improve knowledge of proton parton density functions and strong coupling constant and facilitate discoveries at LHC. We need fast tools to interpret data.

- APPLGrid is an open project:https://projects.hepforge.org/applgrid
- A posteriori evaluation of uncertainties from renormalisation and factorisation scale variations, strong coupling measurement and PDFs error sets in a very short time
- Allows rigorous inclusion of jet and electroweak cross sections in PDF fit.
- Other functionality, such as a posteriori $\sqrt{S}$ rescaling
- A list of QCD and electroweak processes can be studied
  - Jet production cross sections studied using NLOJET++
  - Electroweak observables included using MCFM
  - Many other processes via SHERPA, aMC@NLO
  - W/Z production at NNLO via DYNNLO

APPLGRID accuracy.