APPLGRID news

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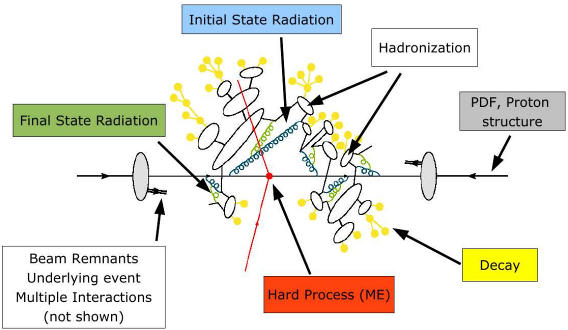
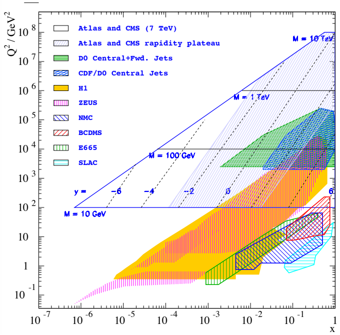
for APPLGRID developers

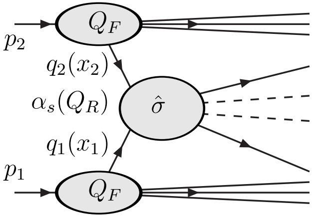
Proton-proton collision





- 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.

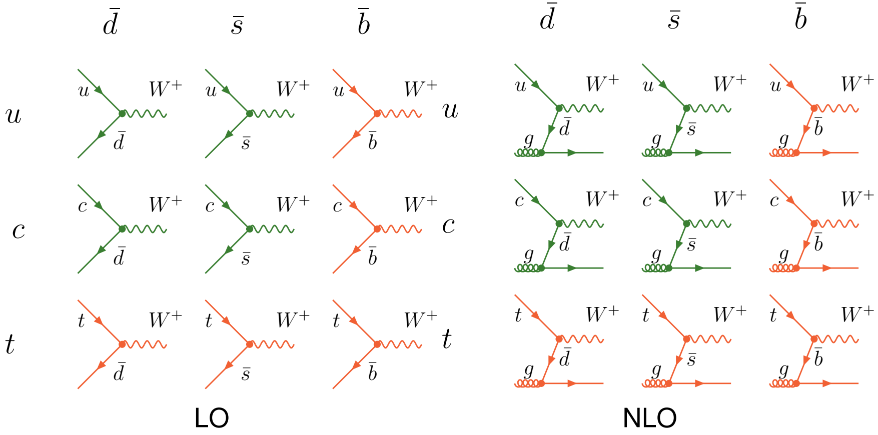
- Step 1 (long run): Collect perturbative weights to grids .
  - binning (x_1, x_2, Q^2)
  - interpolation
  - initial flavours decomposition : $13 \times 13 \rightarrow \mathcal{L}$ ($\mathcal{L} \sim 10$)

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

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

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

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)

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

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

APPLGRID subprocesses for Z^0 production II

Use is made of the generalised PDFs defined as:

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

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

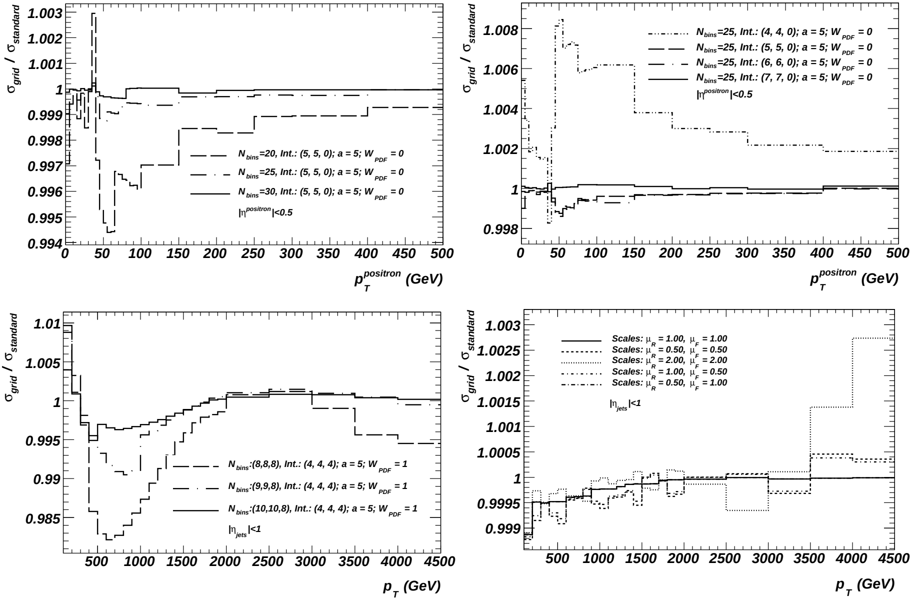
$$U_{12}(x_1, x_2) = \sum_{i=2,4,6} f_{i/H_1}\left(x_1, Q^2\right) f_{-i/H_2}\left(x_2, Q^2\right),$$

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

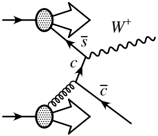
$$U_{21}(x_1, x_2) = \sum_{i=2,4,6} f_{-i/H_1}\left(x_1, Q^2\right) f_{i/H_2}\left(x_2, Q^2\right),$$

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

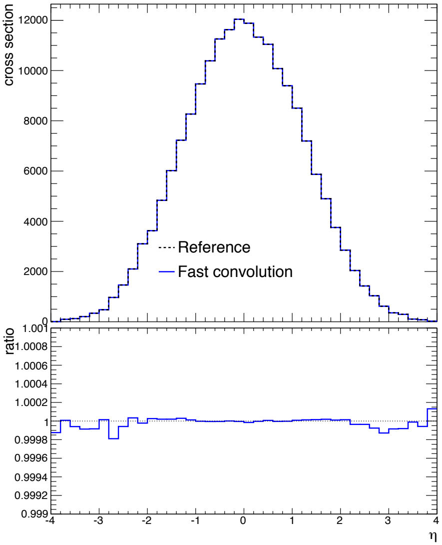
APPLGRID accuracy.

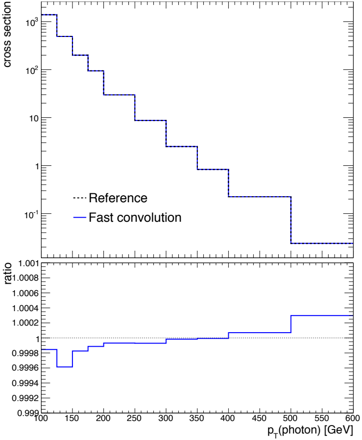


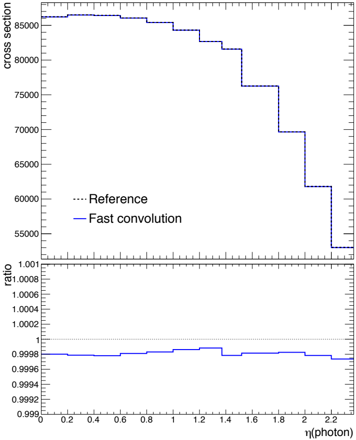
Just a selection of interesting processes ...

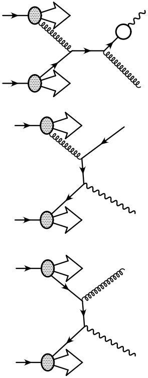


- W+charm production implemented and well tested
- Bare charm - for realistic comparison with experimental fiducial data some model of hadronisation is required





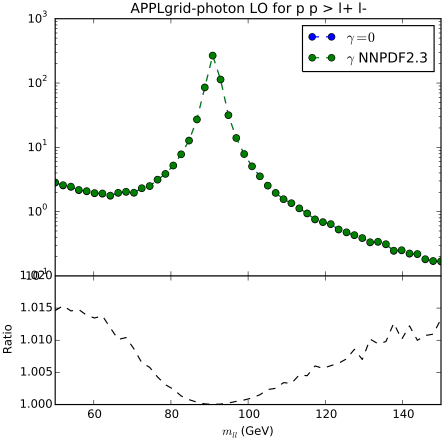




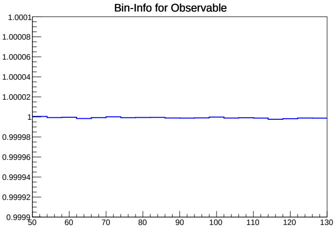
Prompt photon production (Andrey Sapronov)

- Prompt photon production at NLO + LO fragmentation process
- Small non-closure at the level of 0.02%
- Some validation underway: NLO+NLO fragmentation contribution available from JetPhox - calculating LO → NLO fragmentation k-factors

Photon PDF



- first implementation of the photon PDF weights
- possibility to store photon PDF contributions for hadronic processes
  - include data to constrain the photon PDF
  - initial developments to integrate this feature in MC codes

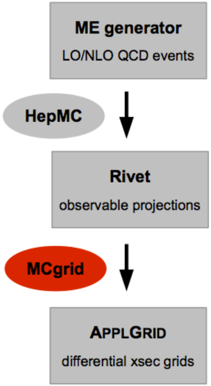


Interface to cross section calculators

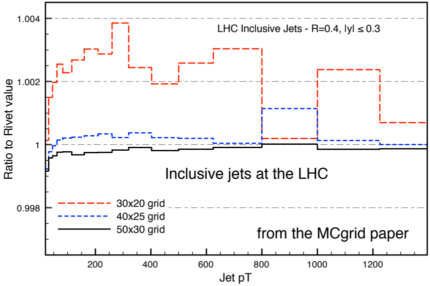
- NLOJET++ : Jet production in $pp(\bar{p})-$ and $ep-$ collisions.
  - $2 \to 2$ and $2 \to 3$ at NLO; $2 \to 4$ at LO www.desy.de/∼znagy/Site/NLOJet++.htm.
- MCFM : parton-level NLO QCD cross sections calculator for various femtobarn-level processes at hadron-hadron colliders.
  - $V, V + nJet, V + b\bar{b}, VV, Q\bar{Q}, \ldots (\sim \mathcal{O}(300))$ 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/.

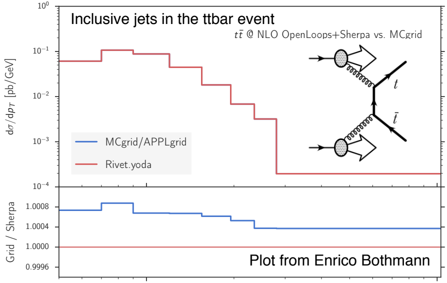
MCgrid Sherpa interface - Del Debbio et al

- Written by Del Debbio, Hartland and Schumann arXiv:1312.4460. http://mcgrid.hepforge.org
- Available for all fixed order NLO processes using the generic PDF decomposition



- MCgrid works as a Rivet plugin using the HepMC event record





aMCfast - A fast interface between MadGraph5_aMC@NLO and APPLgrid

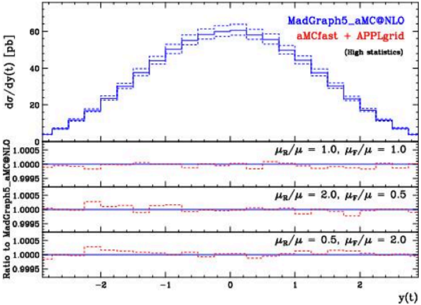
- aMCfast Home
- References
- Download and installation
- Instructions to run the code
- Analysis file examples
- Talks
- Contact

aMCfast [arXiv:1406.7693] is an *automated interface* which bridges the automated cross section calculator **MadGraph5_aMC@NLO** [arXiv:1405.0301] with the fast interpolator **APPLgrid** [arXiv:0911.2985].

The chain **MadGraph5_aMC@NLO – aMCfast – APPLgrid** will allow one to include, in a straighforward manner, any present or future LHC measurement in an NLO global PDF analysis.

The basic idea behind the use of these three codes is that of computing user-defined observables relevant to arbitrary processes, and to represent them in terms of look-up grids, which can be accessed at later times, and used to obtain predictions for such observables with any PDFs. This a-posteriori computation is both accurate and very fast. Contrary to other **APPLgrid** application, factorisation scale variation can be performed without linking to any third-party code.

The following representative figures show the rapidity of the top quark in top-pair production and the lepton-pair invariant mass in dilepton production in association with one jet at the 14 TeV LHC. For more details, please refer to the original publication.



- Valerio Bertone, Rik Frederix, Stefano Frixione, Juan Rojo, MS

Interface to NNLO cross section calculators

- DYNNLO : NNLO calculation of Drell-Yan processes at hadron colliders theory.fi.infn.it/grazzini/dy.html
  - almost there, final cross-checks are being done
- the APPLGRID and FastNLO authors are collaborating together, and with the authors of the NNLO QCD jet calculations to provide a flexible interface that can be used with either grid code (APPLGRID or FastNLO).
  - Basic interface is there,e and the work is ongoing. Usage far beyond NNLO QCD jets in future.

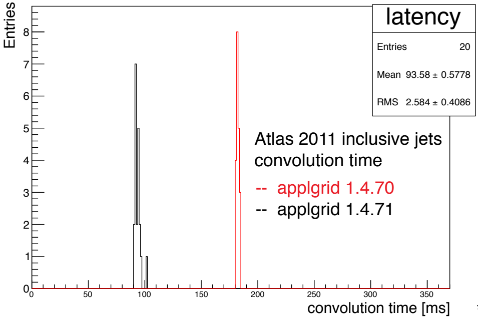
Summary

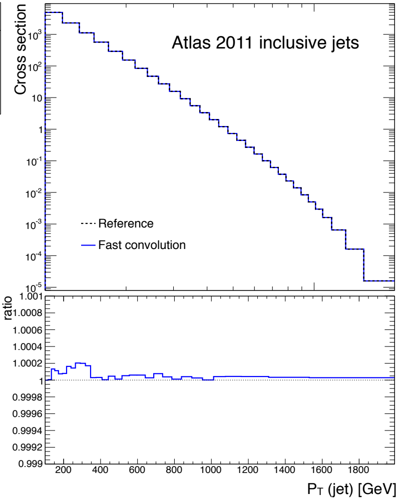
- A list of QCD and electroweak processes can be studied
  - Jet production cross sections studied using NLOJET++
  - Electroweak observables, $t\bar{t}$ or generally $Q\bar{Q}$, + many more are included using MCFM
  - A list of other processes via SHERPA, aMC@NLO
  - W/Z production at NNLO via DYNNLO (almost there)
  - NNLO QCD jets are in progress
- A posteriori evaluation of uncertainties from renormalisation and factorisation scale variations, strong coupling measurement and PDFs error sets in a very short time
  - Scales at LO/NLO (+)
  - Scales at NNLO (-) ...yet...

Discussion

- Convolution
  - Time consumption (PDFs calculation time is the limiting factor)
  - Memory issues (Observable binning, grid architecture and initial flavour decomposition are limiting factors)
  - Multi-thread convolution have been implemented in 1.4.72. For lhapdf 5 the gain in time was a factor of 2-5. Need to check with lhapdf 6. (PDF cache is the limiting factor there)
  - Grid architecture (interplay between accuracy and performance)
    - ★ can try to provide reduction constructors (grid(40,40,6)→grid(10,10,3) with PDF-shape re-weighting and reasonable accuracy)
- Grid library : Existing grids are being collected on the appgrid.hepforge.org and spectrum.web.cern.ch
  - How much effort should we put into it (ideology is to provide the code/help to our users)

Upcoming developments





- Many new developments are on their way
  - Just a taster here - significantly faster convolution implementation
  - Aspects of internal grid structure being reimplemented, new utilities
- Several new calculations being implemented, watch this space for details