aMCfast:
Automation of fast NLO calculations for PDF fits

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FAST NLO CALCULATIONS AND PDF ANALYSIS

NLO Calculations in PDF analyses

- **(N)NLO QCD calculations** are too CPU-time intensive to be used directly into PDF analysis
- The traditional solution, **LO supplemented by iterative bin-by-bin K-factors**, is not suitable in general to match the **precision of LHC data**
- In the recent years, various approaches have been proposed to provide **fast interfaces to NLO calculations**, that can be used directly in PDF analysis, the main ones being:
  - ☑ **APPLgrid**: interfaced to **MCFM** and **NLOJet++**
  - ☑ **FastNLO**: interfaced to **NLOJet++**
- Basic strategy: **interpolate PDFs** in a suitable basis, and **precompute the partonic cross-section** into a set of grids, reconstructing the final distributions via a **fast convolution**. The same ideas underlie most **x-space PDF evolution codes**: HOPPET, QCDNUM, APFEL, ...
- Main limitations of present tools:
  - Restricted to a **limited number of processes**, implementation and debugging of each new process is time consuming
  - Only QCD corrections, **no QED and electroweak corrections** available, important for many LHC processes
  - Only Fixed Order processes, cannot account for **Monte Carlo parton shower effects.** These are required both to **estimate non-perturbative corrections** and to account for **QCD shower resummation effects**

MadGraph5_aMCatNLO

The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations

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arxiv:1405.0301

http://amcatnlo.web.cern.ch/amcatnlo/

- **MadGraph5_aMCatNLO** provides calculations with **NLO accuracy for arbitrary processes**, their matching with **Parton Showers,** and the **merging** of exclusive NLO+PS samples of different multiplicity
- Built upon the **MadGraph** framework, it uses **MadFKS** for subtraction of soft/collinear divergences, **MadLoop** (with CutTools) for the computation of virtual corrections, **MC@NLO** method to match matrix elements with parton showers, and the **FxFx** merging of NLO+PS samples with different multiplicies
- **PDF and scale uncertainties** provided at no extra cost for each run via reweighting
- Ongoing developments include extending **loop corrections to electroweak theory** as well as to **generic renormalizable BSM Lagrangians** (via FeynRules@NLO)

Why we want a fast interface to MG5_aMC?

- **MadGraph5_aMCatNLO** provides theory predictions with **NLO accuracy for arbitrary processes**

  Available fast interfaces are restricted to a limited number of processes

  The implementation of each new process is time consuming and error-prone

  A fast interface to MadGraph5_aMCatNLO would allow to include arbitrarily complicated LHC processes into a NLO global PDF fit

- **MadGraph5_ aMCatNLO** provides an automatic matching of NLO events with **various parton showers**

  Available fast interfaces allow only fixed-order computations

  NLO+PS computations are not only more accurate, they also provide an exclusive events description, and allow a more direct data/theory comparisons with reduced extrapolations

- **MadGraph5_ aMCatNLO** will soon include not only NLO QCD but also **NLO electroweak corrections**

  QED and electroweak corrections are important to fit TeV scale data, and are not available in form of a fast interface to PDF fits. Also photon-induced effects are sizable for many EW processes

Therefore, a **fast interface to MadGraph5_ aMCatNLO** is of outmost important for **global PDF analysis**:

☑ **Increase the number of LHC processes for which fast NLO interfaces are available**, and that thus can be used to constrain PDFs.

☑ Allow to perform **PDF fits with NLO+PS accuracy**, study the stability of PDF fits wrt higher order corrections, increase the number of observables that can be used in PDF fits, and eventually provide **specific PDF sets for NLO event generators**

☑ Include consistently **electroweak corrections in PDF fits** at the matrix element level, and include QED effects that allow to perform a **precision determination of the photon PDF** from LHC data

AMCFAST:
GENERAL STRATEGY

Interpolation Strategy

- The fast interface to **MadGraph5_aMC@NLO,** which we denote by **aMCfast,** is constructed using the routines provided by the **APPLgrid** library
- The key idea is to use a generic **higher-order Lagrange interpolation**

$$F(z) = \sum_{i=0}^{s} F\left(\left(\left\lfloor \frac{z}{\delta} - \frac{s-1}{2} \right\rfloor + i\right)\delta\right) I_i^{(s)}\left(\frac{z}{\delta} - \left\lfloor \frac{z}{\delta} - \frac{s-1}{2}\right\rfloor\right)$$

$$I_i^{(s)}(u) = \frac{(-1)^{s-i}}{i!(s-i)!} \prod_{k=0,k\neq i}^{s} (u-k)$$

$$\lfloor u \rfloor \in \mathbb{Z}\,, \qquad u-1 < \lfloor u \rfloor \leq u\,, \qquad u \in \mathbb{R}$$

- We want to use this expansion to **compute a generic integral**, defined by the convolution of two terms

$$J = \int_a^b dz\, S(z)\, F(z) = \sum_{k=1}^{M} \Phi_k\, S(z_k)\, F(z_k)$$

"Slow" function, CPU-time intensive, to be precomputed only one (ie NLO cmatrix element)

"Fast" function, quick evaluation
To be expanded in Lagrange polynomials
(ie PDFs)

Interpolation Strategy

- Now we can show that the integral J can be written as

$$
\begin{aligned}
J &= \sum_{k=1}^{M} \Phi_k \, S(z_k) \sum_{j=p_\delta(z_k)}^{s+p_\delta(z_k)} F(j\delta) I^{(s)}_{j-p_\delta(z_k)} \left(\frac{z_k}{\delta} - p_\delta(z_k) \right) \\
&= \sum_{j=-\infty}^{\infty} F(j\delta) \, G_j \, ,
\end{aligned}
$$

- That is, in terms of the function **F(z)** evaluated only at a finite subset of **interpolation grid nodes,** weighted by a **factor** that depends on the **node position,** and is by

$$
G_j = \sum_{k=1}^{M} \Phi_k \, S(z_k) \, I^{(s)}_{j-p_\delta(z_k)} \left(\frac{z_k}{\delta} - p_\delta(z_k) \right) \Theta \left(p_\delta(z_k) \le j \le s + p_\delta(z_k) \right)
$$

- The idea of **aMCfast** is to extract the information on the hard-scattering matrix elements from **MadGraph5_aMC@NLO,** use this to fill the **APPLgrid** interpolating grids, and then reconstruct the original distributions a posteriori with arbitrary PDFs and scales.

- Given the automated nature of **MadGraph5_aMC@NLO,** this is a task that needs to be performed only once, and then it will be valid for a generic process

Short-distance cross-sections

- In the **FKS subtraction formalism**, a generic 2 -> n short distance cross-section is given by

$$
\begin{aligned}
d\sigma^{(\mathrm{NLO})} &\longleftrightarrow \left\{ d\sigma^{(\mathrm{NLO},\alpha)} \right\}_{\alpha=E,S,C,SC} , \\
d\sigma^{(\mathrm{NLO},\alpha)} &= f_1(x_1^{(\alpha)}, \mu_F^{(\alpha)}) f_2(x_2^{(\alpha)}, \mu_F^{(\alpha)}) W^{(\alpha)} d\chi_{Bj} d\chi_{n+1}
\end{aligned}
$$

with the contribution of the **fully resolved event** (E) and of the **soft** (S), **collinear** (C) and **soft-collinear** (SC) counterevents

The information on **partonic matrix-elements**, including scale dependence, is encoded in the functions:

$$
\begin{aligned}
W^{(\alpha)} &= g_S^{2b+2}(\mu_R^{(\alpha)}) \left[\widehat{W}_0^{(\alpha)} + \widehat{W}_F^{(\alpha)} \log\left(\frac{\mu_F^{(\alpha)}}{Q}\right)^2 + \widehat{W}_R^{(\alpha)} \log\left(\frac{\mu_R^{(\alpha)}}{Q}\right)^2 \right] \\
&+ g_S^{2b}(\mu_R^{(\alpha)}) \widehat{W}_B \delta_{\alpha S} ,
\end{aligned}
$$

where the various pieces are the **Born**, the **scale independent NLO term**, and the terms which encode the **renormalization and factorization scale dependences** of the NLO calculation

In **aMCfast,** the information on the **event-by-event** ***W*** **weights** is extracted and used to fill the **APPLgrid** interpolation grids

Short-distance cross-sections

- Skipping technicalities (see paper for full details), we can finally write the **four components of the FKS cross-section** in terms of **PDFs and strong coupling** evaluated only **at the grid nodes**, and grid weight factors which encode **all dependence on matrix elements**, and that need to be computed only once

$$
\begin{aligned}
\sigma_{O,0}^{(h)} &= \sum_{j_1,j_2,j_3,j_4} f_1(j_1\delta_1, j_3\delta_3)\, f_2(j_2\delta_2, j_3\delta_3)\, g_S^{2b+2}(j_4\delta_4)\, G_{j_1j_2j_3j_4}^{(h,0)}\,, \\
\sigma_{O,F}^{(h)} &= \sum_{j_1,j_2,j_3,j_4} f_1(j_1\delta_1, j_3\delta_3)\, f_2(j_2\delta_2, j_3\delta_3)\, g_S^{2b+2}(j_4\delta_4)\, \log\left(\frac{j_3\delta_3}{Q}\right)^2 G_{j_1j_2j_3j_4}^{(h,F)}\,, \\
\sigma_{O,R}^{(h)} &= \sum_{j_1,j_2,j_3,j_4} f_1(j_1\delta_1, j_3\delta_3)\, f_2(j_2\delta_2, j_3\delta_3)\, g_S^{2b+2}(j_4\delta_4)\, \log\left(\frac{j_4\delta_4}{Q}\right)^2 G_{j_1j_2j_3j_4}^{(h,R)}\,, \\
\sigma_{O,B}^{(h)} &= \sum_{j_1,j_2,j_3,j_4} f_1(j_1\delta_1, j_3\delta_3)\, f_2(j_2\delta_2, j_3\delta_3)\, g_S^{2b}(j_4\delta_4)\, G_{j_1j_2j_3j_4}^{(h,B)}\,,
\end{aligned}
$$

- As opposed to other NLO calculations, in the FKS formalism we require **four independent interpolation grids** rather than two, to account for the most general possible scale variations

Scale variations

- Once the APPLgrid interpolating grids have been produced with **aMCfast**, we can recompute the **original kinematical distributions** for arbitrary **PDFs, scales and value of α_S**
- We assume that scales vary wrt the central value by a **constant factor** in all phase space

$$\mu_F = \xi_F \, \mu \, , \qquad \mu_R = \xi_R \, \mu$$

- We end up with the following final expressions in terms of PDFs in the grid and node weight factors:

$$\sigma^{(h)}_{O,0} = \sum_{j_1,j_2,j_3} \sum_{l=1}^{n_l} \widehat{\mathcal{F}}^{(l)}(j_1\delta_y, j_2\delta_y, j_3\delta_\tau)\hat{g}_S^{2b+2}(j_3\delta_\tau)\, G^{(h,0,l)}_{j_1 j_2 j_3} \, ,$$

$$\sigma^{(h)}_{O,F} = \sum_{j_1,j_2,j_3} \sum_{l=1}^{n_l} \widehat{\mathcal{F}}^{(l)}(j_1\delta_y, j_2\delta_y, j_3\delta_\tau)\, \hat{g}_S^{2b+2}(j_3\delta_\tau)\; \log \xi_F^2 \, G^{(h,F,l)}_{j_1 j_2 j_3} \, ,$$

$$\sigma^{(h)}_{O,R} = \sum_{j_1,j_2,j_3} \sum_{l=1}^{n_l} \widehat{\mathcal{F}}^{(l)}(j_1\delta_y, j_2\delta_y, j_3\delta_\tau)\, \hat{g}_S^{2b+2}(j_3\delta_\tau)\; \log \xi_R^2 \, G^{(h,R,l)}_{j_1 j_2 j_3} \, ,$$

$$\sigma^{(h)}_{O,B} = \sum_{j_1,j_2,j_3} \sum_{l=1}^{n_l} \widehat{\mathcal{F}}^{(l)}(j_1\delta_y, j_2\delta_y, j_3\delta_\tau)\, \hat{g}_S^{2b}(j_3\delta_\tau)\, G^{(h,B,l)}_{j_1 j_2 j_3} \, ,$$

This is a different approach for scale variations as compared to the default **APPLgrid** method, which requires using an external code, **HOPPET**, and is valid only in the **limit of very high statistics**

The **aMCfast method is fully generic**, valid on a **event-by-event basis** and completely stand-alone. Also, if needed, it can be generalized to more complex choices of scale variations

AMCFAST: VALIDATION

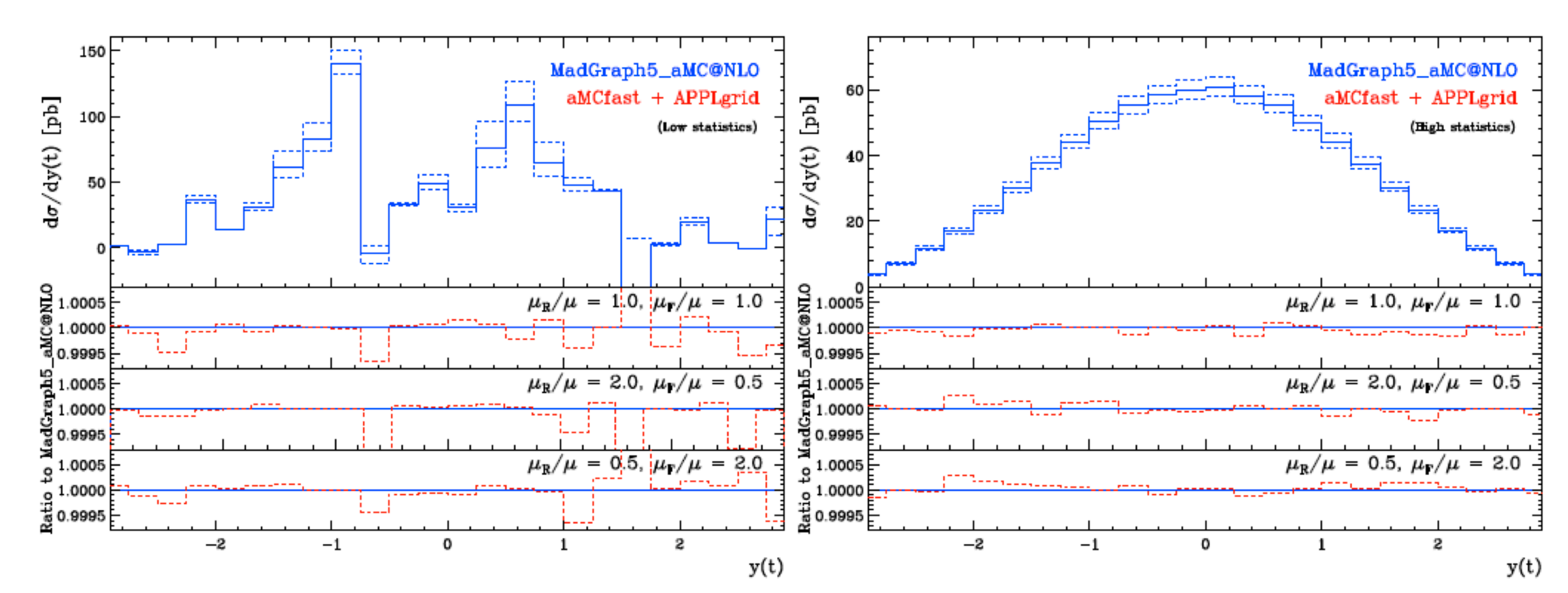
aMCfast validation

- For all the processes we have explicitly tested, the **aMCfast+APPLgrid interface** to **MadGraph5_aMC@NLO** has an accuracy well below the permille level, more than enough for any phenomenological application (and could be further increased by using a finer grid)
- This is the case both for the central scale, dynamically chosen on an event-by-event basis, and for **arbitrary scale variations**. In the examples I show we have used **H_T as central scale**
- The aMCfast interpolation is correct on a event-by-event basis: the **original MadGraph5_aMC@NLO distributions** are successfully reproduced even in very low statistics runs (of course useful only for validation purposes)
- We use **NNPDF2.3/2.1 as input PDFs**, with the number of active flavors consistent with the process under consideration

APPLgrid settings

Parameter	value	Parameter	value
κ	5	Λ	0.250 GeV
$(x_{\rm min}, x_{\rm max})$	$(2\cdot 10^{-7}, 1)$	$(\mu_{\rm min}, \mu_{\rm max})$	(10,3162) GeV
N_y	50	N_τ	30
s_y	3	s_τ	3

Top-quark pair production



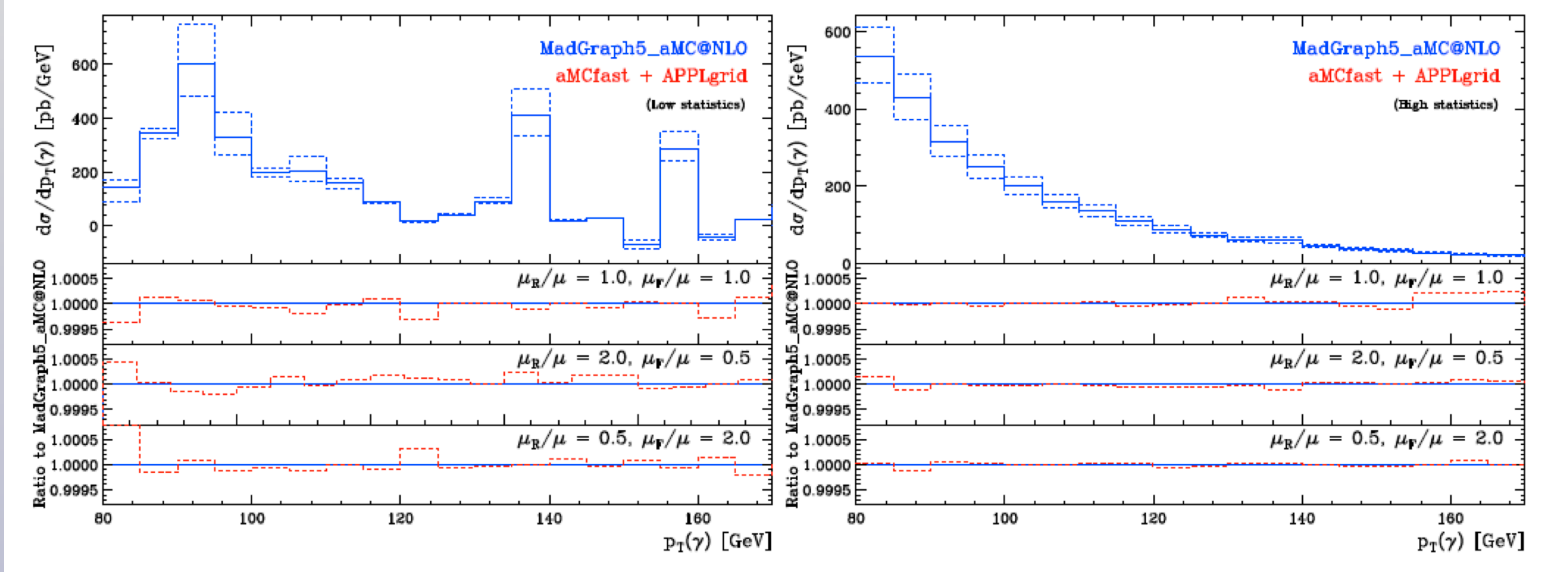

```
MG5_aMC>  import model loop_sm-no_b_mass
MG5_aMC>  define p = g u d s c b u~ d~ s~ c~ b~
```

```
MG5_aMC>  generate p p > t t~ [QCD]
```

- Useful to constrain the **gluon PDF**
- For this process, we have the contribution from 7 independent PDF luminosities. **Lumis determined automatically at run time**
- Excellent agreement with original distributions both at low and at high statistics

l	n_{rs}	(r,s)				
1	1	(g,g)				
2	5	$(\bar{b},g)$	$(\bar{c},g)$	$(\bar{s},g)$	$(\bar{u},g)$	$(\bar{d},g)$
3	5	(d,g)	(u,g)	(s,g)	(c,g)	(b,g)
4	5	$(g,\bar{b})$	$(g,\bar{c})$	$(g,\bar{s})$	$(g,\bar{u})$	$(g,\bar{d})$
5	5	(g,d)	(g,u)	(g,s)	(g,c)	(g,b)
6	5	$(d,\bar{d})$	$(u,\bar{u})$	$(s,\bar{s})$	$(c,\bar{c})$	$(b,\bar{b})$
7	5	$(\bar{b},b)$	$(\bar{c},c)$	$(\bar{s},s)$	$(\bar{u},u)$	$(\bar{d},d)$

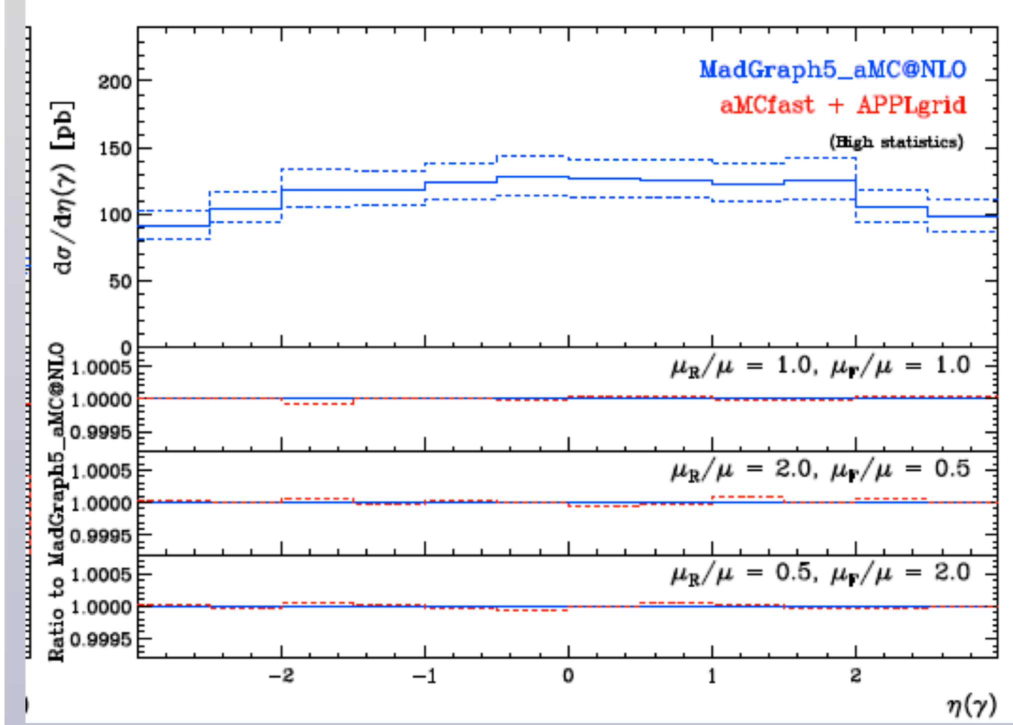
Photon+jet production




```
MG5_aMC>  define j = g u d s c b u~ d~ s~ c~ b~
MG5_aMC>  generate p p > a j [QCD]
```

- Could have PDF discrimination power if experimental measurements are precise enough
- Same generation commands as before, adding the correct jet definition for a 5-flavor scheme
- Again, **excellent agreement** for all distributions and choices of scales
- Uses the **Frixione isolation criterion** to remove the fragmentation component
- Generation-level cuts and analysis parameters (including isolation) **accessible from the run card**

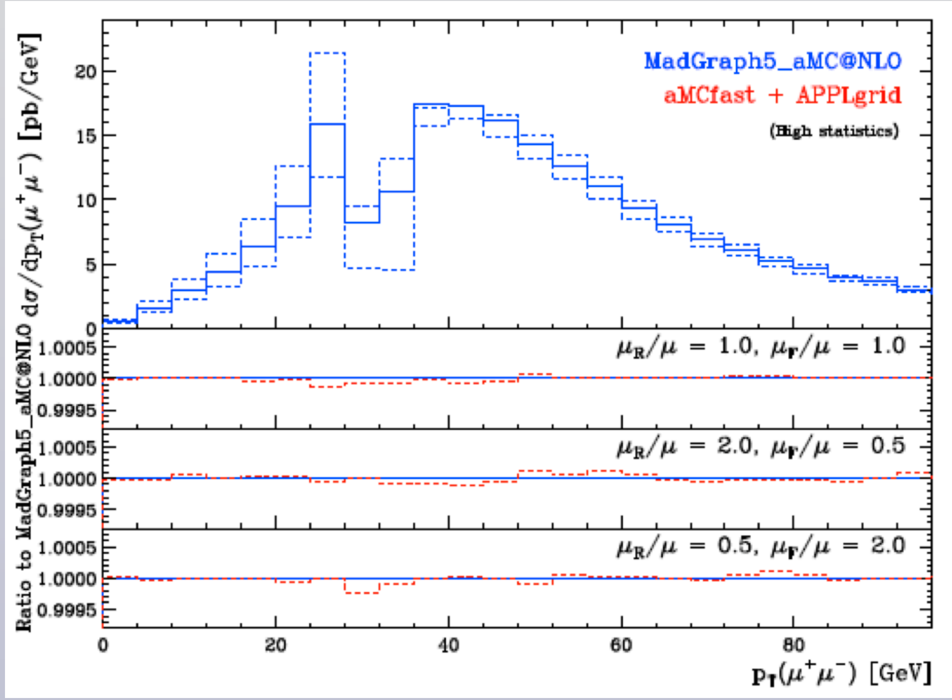
Photon+jet production

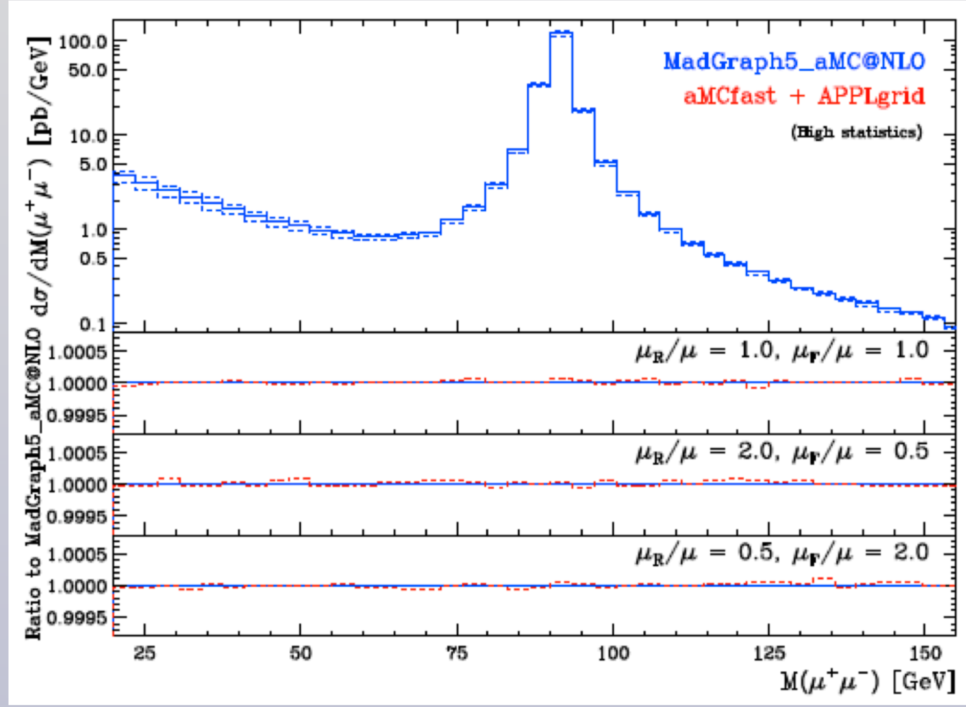


- Due to the complexity of this process, here we have **33 independent PDF luminosities**
- Determined at run time, this information is **completely transparent to the user**

l	n_{rs}	(r,s)					
1	2	(g,u)	(g,c)				
2	6	$(\bar{b},u)$	$(\bar{b},c)$	$(\bar{s},u)$	$(\bar{s},c)$	$(\bar{d},u)$	$(\bar{d},c)$
3	6	(d,u)	(d,c)	(s,u)	(s,c)	(b,u)	(b,c)
4	2	$(\bar{c},c)$	$(\bar{u},u)$				
5	2	(u,u)	(c,c)				
6	2	$(\bar{c},u)$	$(\bar{u},c)$				
7	2	(u,c)	(c,u)				
8	1	(g,g)					
9	3	(g,d)	(g,s)	(g,b)			
10	3	$(\bar{b},b)$	$(\bar{s},s)$	$(\bar{d},d)$			
11	3	(d,d)	(s,s)	(b,b)			
12	6	$(\bar{c},d)$	$(\bar{c},s)$	$(\bar{c},b)$	$(\bar{u},d)$	$(\bar{u},s)$	$(\bar{u},b)$
13	6	(u,d)	(u,s)	(u,b)	(c,d)	(c,s)	(c,b)
14	6	$(\bar{b},d)$	$(\bar{b},s)$	$(\bar{s},d)$	$(\bar{s},b)$	$(\bar{d},s)$	$(\bar{d},b)$
15	6	(d,s)	(d,b)	(s,d)	(s,b)	(b,d)	(b,s)
16	2	$(g,\bar{c})$	$(g,\bar{u})$				
17	6	$(\bar{b},\bar{c})$	$(\bar{b},\bar{u})$	$(\bar{s},\bar{c})$	$(\bar{s},\bar{u})$	$(\bar{d},\bar{c})$	$(\bar{d},\bar{u})$
18	6	$(d,\bar{c})$	$(d,\bar{u})$	$(s,\bar{c})$	$(s,\bar{u})$	$(b,\bar{c})$	$(b,\bar{u})$
19	2	$(\bar{c},\bar{c})$	$(\bar{u},\bar{u})$				
20	2	$(u,\bar{u})$	$(c,\bar{c})$				
21	2	$(\bar{c},\bar{u})$	$(\bar{u},\bar{c})$				
22	2	$(u,\bar{c})$	$(c,\bar{u})$				
23	3	$(g,\bar{b})$	$(g,\bar{s})$	$(g,\bar{d})$			
24	3	$(\bar{b},\bar{b})$	$(\bar{s},\bar{s})$	$(\bar{d},\bar{d})$			
25	3	$(d,\bar{d})$	$(s,\bar{s})$	$(b,\bar{b})$			
26	6	$(\bar{c},\bar{b})$	$(\bar{c},\bar{s})$	$(\bar{c},\bar{d})$	$(\bar{u},\bar{b})$	$(\bar{u},\bar{s})$	$(\bar{u},\bar{d})$
27	6	$(u,\bar{b})$	$(u,\bar{s})$	$(u,\bar{d})$	$(c,\bar{b})$	$(c,\bar{s})$	$(c,\bar{d})$
28	6	$(\bar{b},\bar{s})$	$(\bar{b},\bar{d})$	$(\bar{s},\bar{b})$	$(\bar{s},\bar{d})$	$(\bar{d},\bar{b})$	$(\bar{d},\bar{s})$
29	6	$(d,\bar{b})$	$(d,\bar{s})$	$(s,\bar{b})$	$(s,\bar{d})$	$(b,\bar{s})$	$(b,\bar{d})$
30	2	(u,g)	(c,g)				
31	3	(d,g)	(s,g)	(b,g)			
32	2	$(\bar{c},g)$	$(\bar{u},g)$				
33	3	$(\bar{b},g)$	$(\bar{s},g)$	$(\bar{d},g)$			

dilepton+jet production

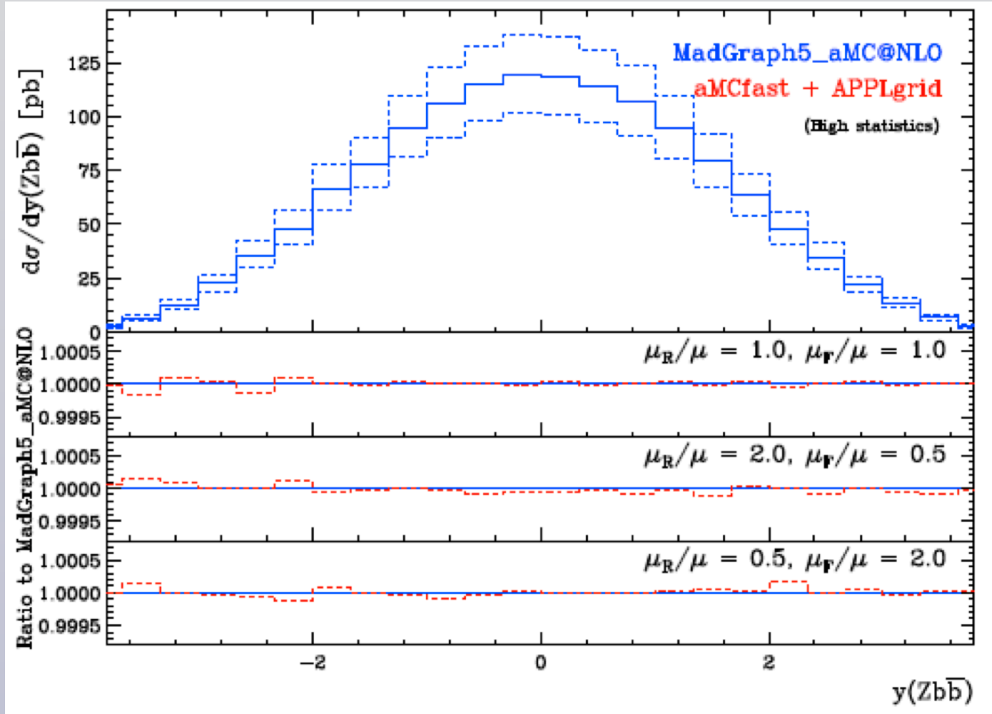


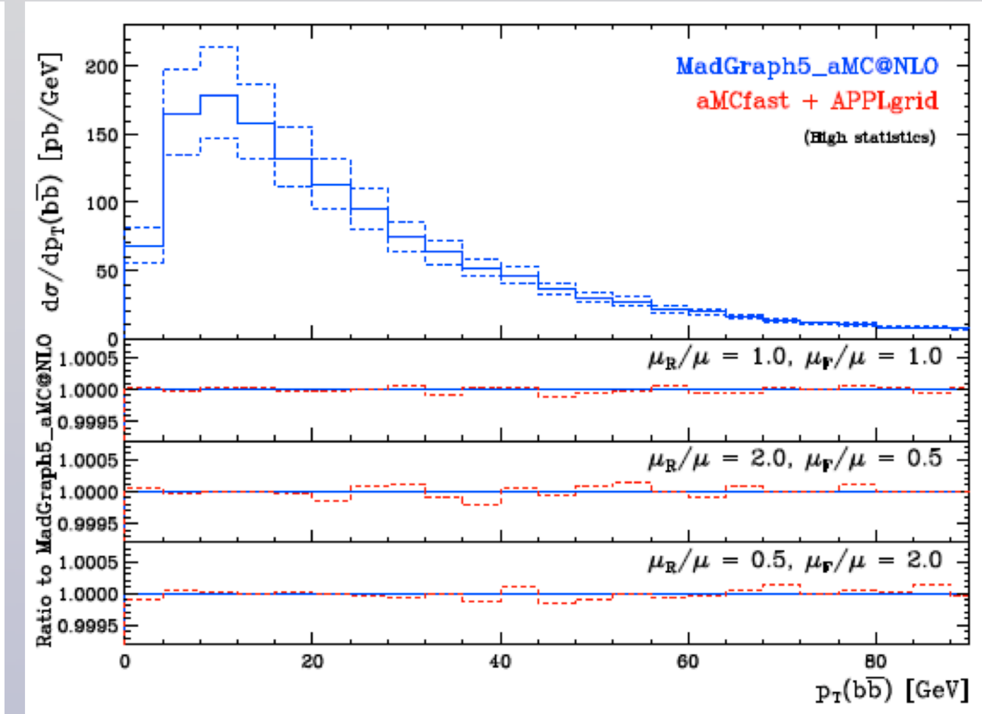



```
MG5_aMC>  generate p p > mu+ mu- j [QCD]
```

- Useful to constrain the **gluon** and the **antiquarks**
- Feature around pT = 30 GeV understood from perturbative instability in fNLO calculation, requires resummation
- Ratios of this process with W+jets could provide important information on **quark flavor separation**

Zbb production



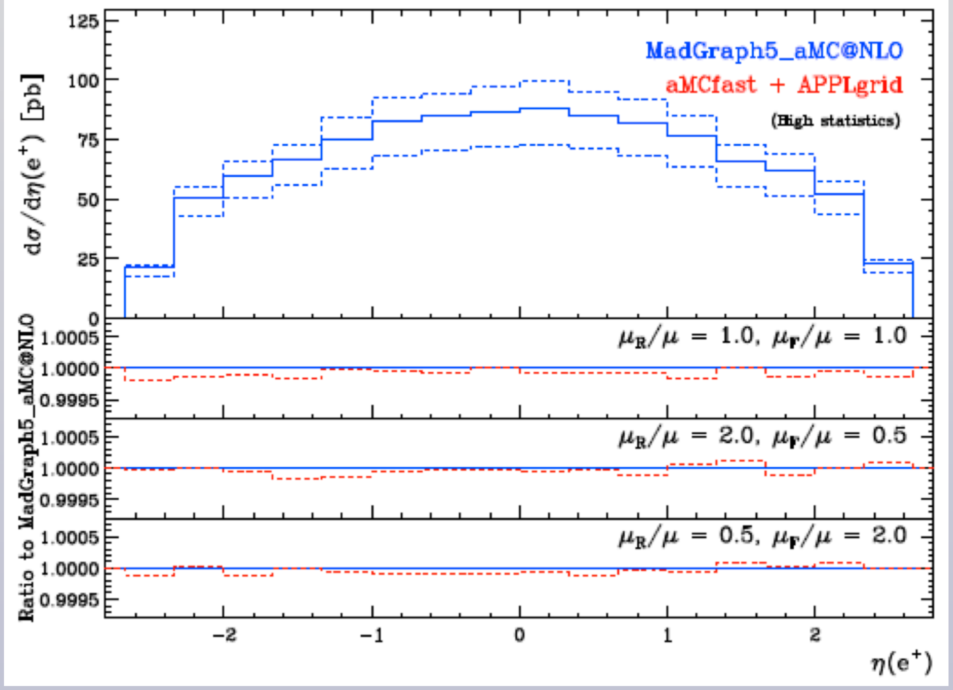


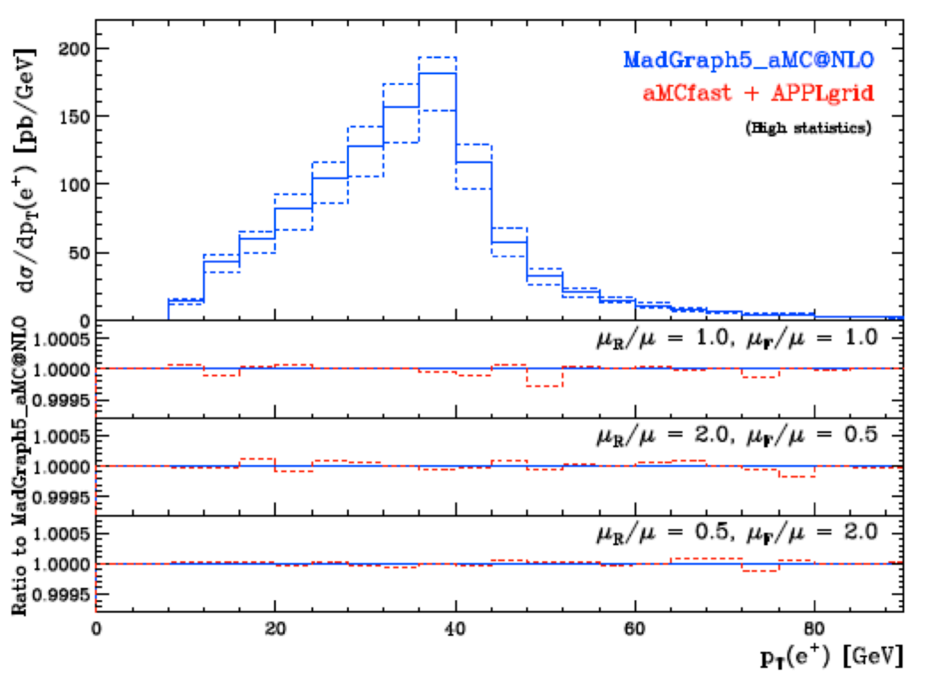

```
MG5_aMC>  generate p p > z b b~ [QCD]
```

- Example of a quite complicated final state that benefits from the complete automation of fast NLO calculations in **aMCfast**
- Calculation needs to be performed in a scheme with massive b quark
- In this case we have 13 independent PDF lumis

l	n_{rs}	(r,s)	
1	1	(g,g)	
2	2	$(\bar{s},g)$	$(\bar{d},g)$
3	2	(d,g)	(s,g)
4	2	$(\bar{c},g)$	$(\bar{u},g)$
5	2	(u,g)	(c,g)
6	2	$(g,\bar{s})$	$(g,\bar{d})$
7	2	(g,d)	(g,s)
8	2	$(g,\bar{c})$	$(g,\bar{u})$
9	2	(g,u)	(g,c)
10	2	$(u,\bar{u})$	$(c,\bar{c})$
11	2	$(d,\bar{d})$	$(s,\bar{s})$
12	2	$(\bar{c},c)$	$(\bar{u},u)$
13	2	$(\bar{s},s)$	$(\bar{d},d)$

W production in association with charm quarks






```
MG5_aMC>  import model loop_sm-c_mass
MG5_aMC>  define p = g u d s u~ d~ s~
MG5_aMC>  generate p p > e+ ve c~  [QCD]
```

- Crucial experimental data to constrain the **strange PDF**
- Illustrates that **resonance decays** can the trivially included in aMCfast
- Any **theoretical refinement of the original MadGraph5_aMC@NLO calculation**, such as the use of complex mass scheme to account for finite widths of resonances, **translates automatically into aMCfast**

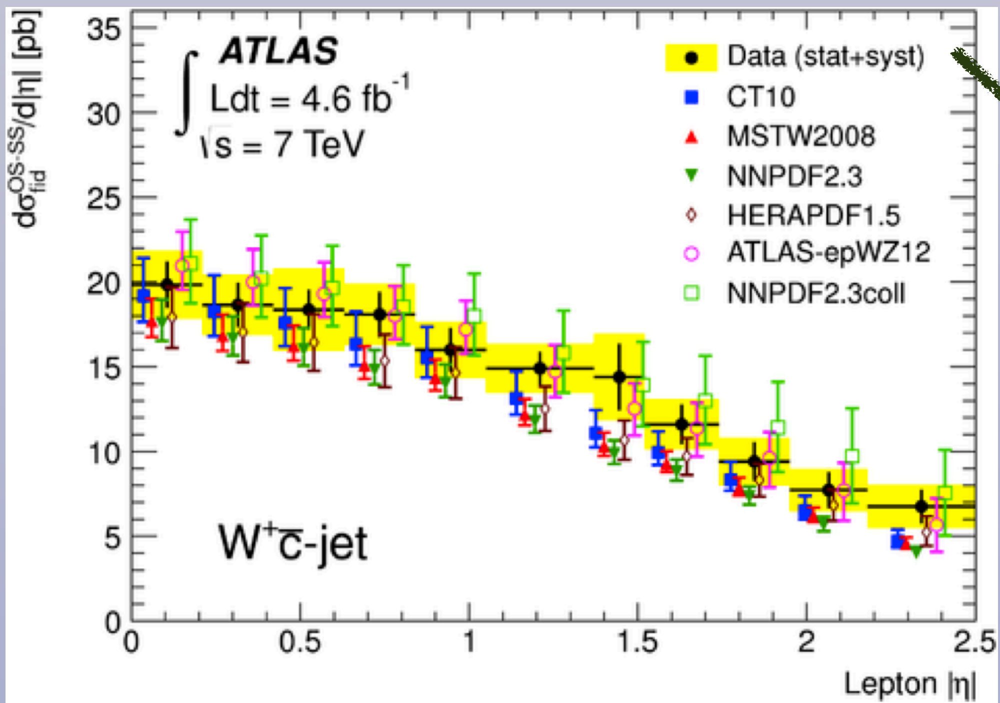
PHENOMENOLOGICAL APPLICATIONS

Just some representative examples

Huge range of interesting pheno applications to be explored

Consistent estimate of non-perturbative corrections

- Estimating **non-perturbative corrections**, for instance due to hadronization or underlying event, is required to unfold measurements from hadron level to parton level
- With **MadGraph5_aMC@NLO**, one should generate the same process in NLO and NLO+PS, with identical settings, and extract consistently the **bin-by-bin correction due to NP effects**
- Of course, this is only possible in kinematic regions where the effects of **perturbative resummation from the parton shower are small**
- This could be applied to the **ATLAS W+charm data**
  - ☑ Run MadGraph5_aMC@NLO at fNLO **with aMCfast activated**, generate the APPLgrid tables corresponding to your measurement
  - ☑ Re-run MadGraph5_aMC@NLO in the NLO+PS mode in identical settings
  - ☑ In the PDF fit, use the **fast NLO grid** calculation supplemented with the **parton-to-hadron correction**



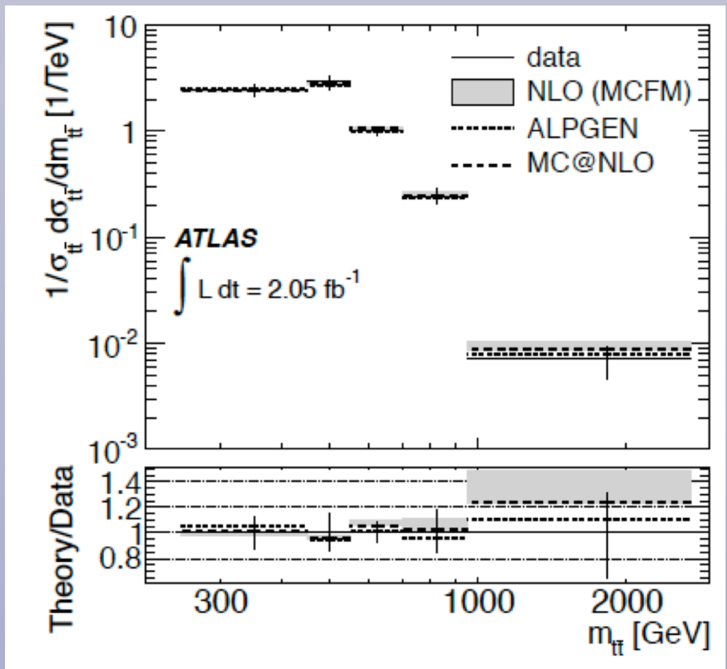
Can be included now in PDF fit thanks to MadGraph5_aMC@NLO and the aMCfast interface

Top quark data with finite width effects

- Top quark data provides useful constraints on the **large-x gluon PDF**
- Studies so far use total cross-sections, now moving towards including **top quark differential distributions** in PDF fits
- Thanks to **MadGraph5_aMC@NLO + aMCfast**, one should be able to include in the PDF fit fully differential distributions including **finite width effects of the top quark**, for example, in the fully leptonic final state

```
MG5_aMC> generate p p > l+ vl b l- vl~ b~ [QCD]
```

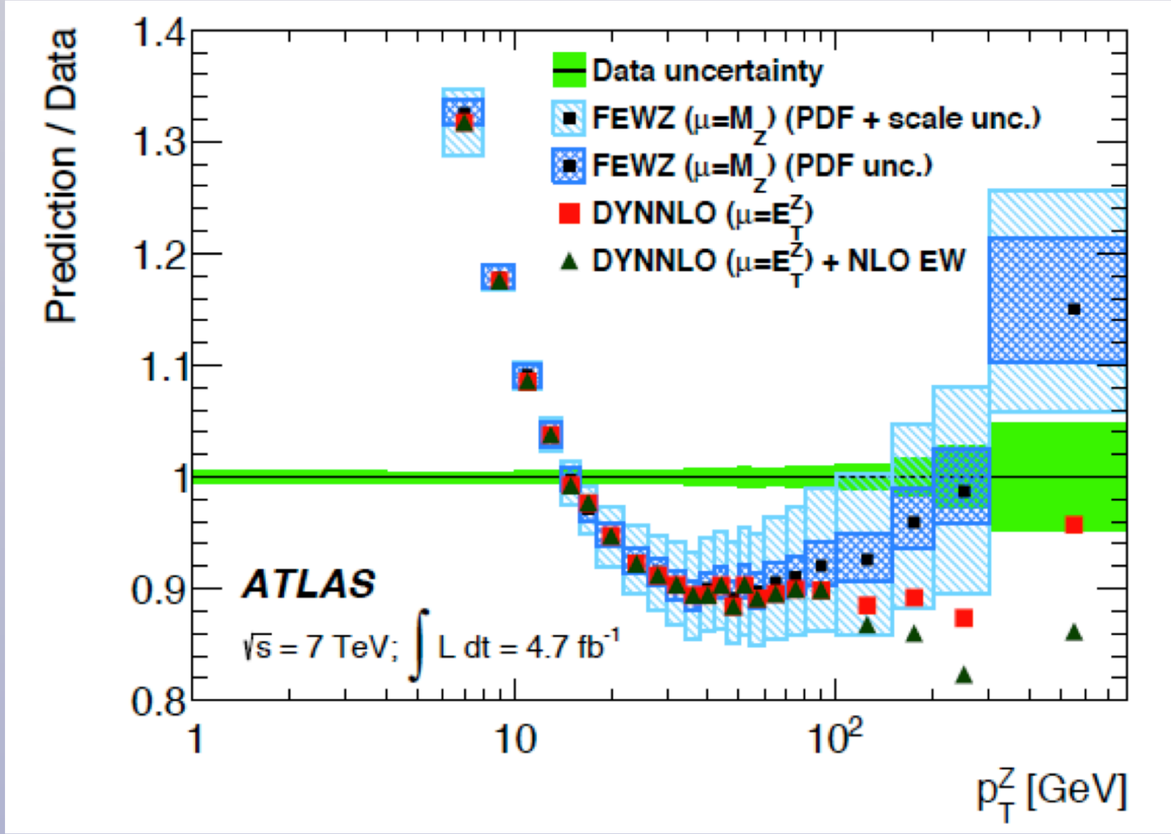
- Once the full NNLO calculation is available, c**orrect exclusive NLO calculation with a suitable K-factor** (which has very reduced PDF sensitivity)
- With the same method as for W+charm, estimating uncertainties due to shower and non-perturbative effects becomes an easy talk



PS **Absolute distributions** have greatly **improved PDF constraining** power as compared to normalized distributions

Z+jet data for PDF constraints

- The transverse momentum distribution of the Z boson is very useful to **constrain PDFs**, both gluons and antiquarks, and can be measured very precisely in terms of **leptonic variables only**
- It is crucial to identify the region of validity of fixed order QCD, and this can be studied for example running **MadGraph5_aMC@NLO** at fixed order and then matched to parton showers
- **NLO electroweak** and mixed QCD/EW corrections are important at the **highest pt**, will become available in a future release of **MadGraph5_aMC@NLO** and therefore also in **aMCfast**



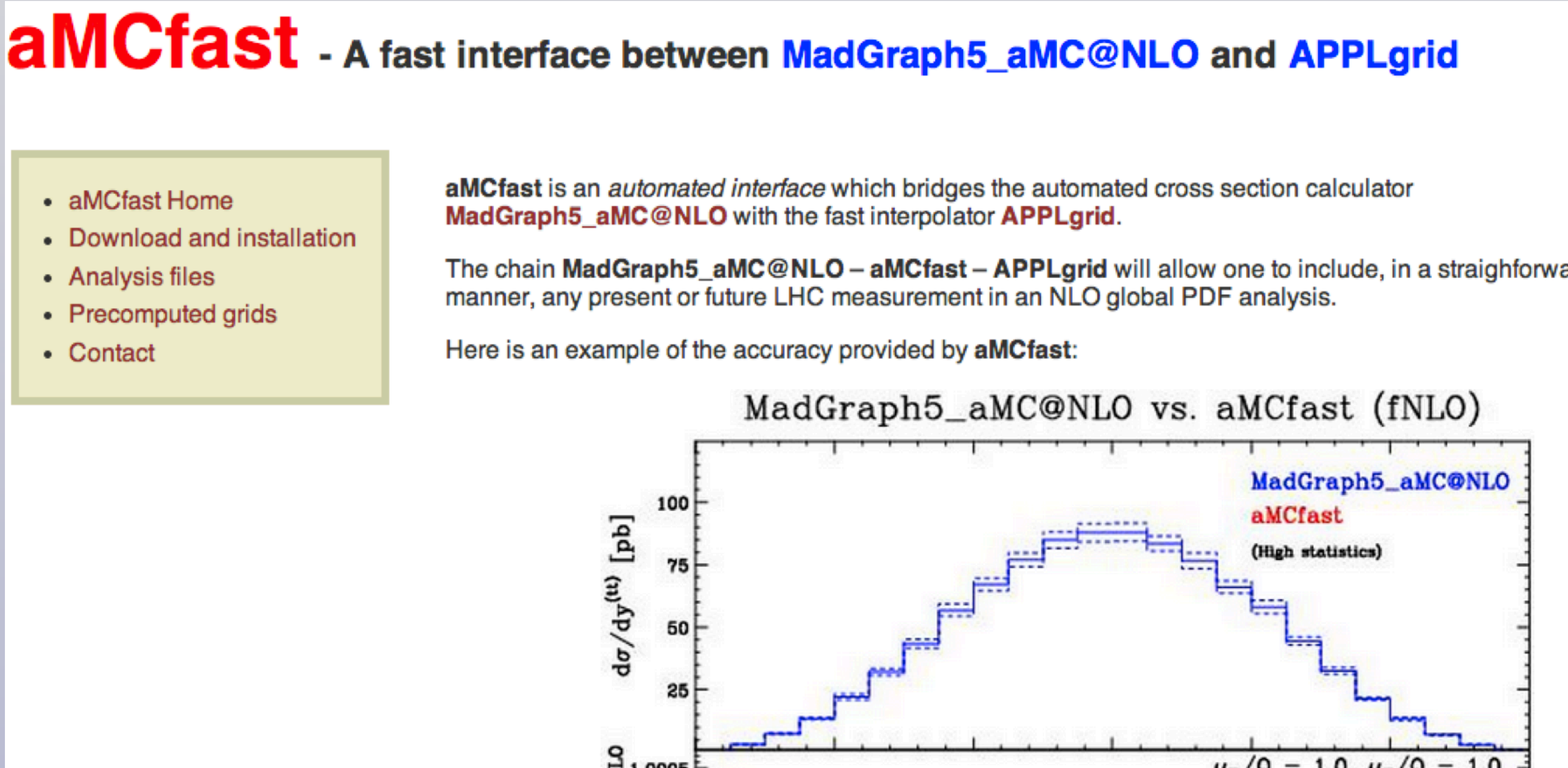
OUTLOOK and DELIVERY

Beyond NLO QCD

- The **automation of fast NLO QCD calculations needed in PDF fits for arbitrary processe**s can be considered now as **fully completed**
- Next step is to extend the **aMCfast** interface to **NLO+PS calculations.**
- While there are no conceptual problems, extra technical work is required to **extend the NLO+PS reweighting format propagating all the information** that allow to fill APPLgrids starting from showered events, and modify **LHEF/HepMC** formats
- In parallel, once the mixed QCD/EW expansion becomes available in **MadGraph5_aMC@NLO**, we will generalize **aMCfast** to processes with **both QCD and QED/EWK corrections**
- Again, no conceptual obstructions here, the generalization of the **aMCfast** formulae to a mixed expansions are trivial
- From the phenomenology point of view, once **aMCfast** with QCD/EW corrections is available it should be possible to use it to provide stringent constraints to the **photon PDF** using LHC data sensitive to **photon-initiated contributions,** and use QCD+EW corrections to fit high-ET data like jets, high mass tt, high-mass DY etc where NLO electroweak corrections are substantial

Delivery

- **aMCfast** will be make available in the next days in its **HepForge** website
- It also requires the use of the latest **APPLgrid** release



- The version of **MadGraph5_aMC@NLO** with the complete **MCfast** functionalities will be make available in one of the future releases
- In the meantime, a development version of **MadGraph5_aMC@NLO** with these functionalities is available from the authors upon request