aMCfast

A fast interface between MG5_aMC@NLO and APPLgrid

[arXiv:1406.7693]

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Nature of the Problem

- Main goal:
  - constraining **Parton Distribution Functions** (PDFs) by including as many data as possible from the LHC with the highest accuracy possible.
- Problem:
  - presently, hadronic NLO(+PS) calculations are too **time-consuming** to be directly employed in a PDF fit.
- The common solution adopted is:
  - **interpolating the PDFs** (and α_s) on the (x,Q^2)-plane with some suitable polynomial basis on a finite number of nodes.
  - **Precomputing the hadronic cross section** by using the basis members as input (rather than PDFs themselves).
    - Time-cosuming step that must be done only once.
  - **Reconstructing the original calculation** by means of the numerical convolution of the precomputed cross sections with an arbitrary PDF set.
    - Very fast $\Rightarrow$ suitable for PDF fits.

Nature of the Problem

- The objective of our work is:
  - to solve this problem once and for all in a **general manner**.
  - This is actually possible thanks to the fact that NLO(+PS) calculations can now be routinely done by means of **automated codes**.
- The ingredients here are:
  - **MadGrap5_aMC@NLO** [arXiv:1405.0301]
    - an automated cross section calculator that contains all the ingredients relevant to the computation of LO and NLO cross sections, with or without matching to parton showers.
  - **APPLgrid** [arXiv:0911.2985]
    - a framework that implements the strategy for the fast computation of cross sections outlined in the previous slide.
- The result is:
  - **aMCfast** [arXiv:1406.7693]:
    - an automated interface which bridges MadGraph5_aMC@NLO with APPLgrid.

Fast NLO Computations
The Interpolating Grids

- The basic idea is that of a Lagrange-polynomial expansion:

$$F(z) = \sum_i F(z_i) I_i^{(s)}(z)$$

Grid nodes

Interpolation functions

Fast NLO Computations

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- Suppose you want to compute numerically the following integral, *e.g.* by Monte Carlo methods:

Normalization factor

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

Random points in the interval [a,b]

Fast NLO Computations

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Fast function (PDFs)

Slow function (Partonic cross sections)

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- Using the interpolation formula:

$$J = \sum_i F(z_i) G_i \quad \text{with} \quad G_i = \sum_{k=1}^{M} \Phi_k S(z_k) I_i^{(s)}(z_k)$$

(1-dimentional) interpolation grid independent of $F(z)$: precomputed and stored

Fast NLO Computations

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- Once G_i has been precomputed, the *a posteriori* computation of J with any function $F(z)$ will be extremely fast.

Fast NLO Computations

The Hard Cross Sections in aMC@NLO at NLO

- The generalization of this procedure to the realistic case of a hard NLO cross section is straightforward, considering that:

$$d\sigma^{(\mathrm{NLO})} \quad \longleftrightarrow \quad \left\{ d\sigma^{(\mathrm{NLO},\alpha)} \right\}_{\alpha=E,S,C,SC}$$

Event & Counterevents

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$$d\sigma^{(\mathrm{NLO},\alpha)} \quad = \quad f_1(x_1^{(\alpha)}, \mu_F^{(\alpha)}) f_2(x_2^{(\alpha)}, \mu_F^{(\alpha)}) W^{(\alpha)} d\chi_{Bj} d\chi_{n+1}$$

PDFs → $f_1(x_1^{(\alpha)}, \mu_F^{(\alpha)}) f_2(x_2^{(\alpha)}, \mu_F^{(\alpha)})$

Partonic cross section → $W^{(\alpha)}$

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$$\begin{aligned} W^{(\alpha)} \quad &= \quad \alpha_s^{b+1}(\mu_R^{(\alpha)}) \left[W_0^{(\alpha)} + W_F^{(\alpha)} \ln\left(\frac{\mu_F^{(\alpha)}}{Q}\right) + W_R^{(\alpha)} \ln\left(\frac{\mu_R^{(\alpha)}}{Q}\right)\right] \\ &+ \quad \alpha_s^b(\mu_R^{(\alpha)}) W_B \delta_{\alpha S} \end{aligned}$$

NLO term

Born term

Fast NLO Computations

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Slow functions

Fast functions

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$$W^{(\alpha)} = \alpha_s^{b+1}(\mu_R^{(\alpha)})\left[W_0^{(\alpha)} + W_F^{(\alpha)}\ln\left(\frac{\mu_F^{(\alpha)}}{Q}\right) + W_R^{(\alpha)}\ln\left(\frac{\mu_R^{(\alpha)}}{Q}\right)\right] + \alpha_s^b(\mu_R^{(\alpha)})W_B\delta_{\alpha S}$$

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- 4 **slow functions** $\Rightarrow$ **4 interpolation grids**.

- The **fast functions** are functions of 4 independent variables (x_1, x_2, μ_F, μ_R) $\Rightarrow$ 4-dimentional interpolation grids needed.

Fast NLO Computations
The Hard Cross Sections in aMC@NLO at NLO

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- 4 **slow functions** $\Rightarrow$ **4 interpolation grids**.
- The **fast functions** are functions of 4 independent variables $(x_1, x_2, \mu_F, \mu_R) \Rightarrow$ 4-dimentional interpolation grids needed.
- But assuming $\mu_F \propto \mu_R \Rightarrow$ **3-dimentional** interpolation grids.

The aMCfast Interface

The NLO Case: a Short Description

- The **aMCfast** interface proceeds through three phases:
  - **Initialisation phase:** aMCfast provides APPLgrid with:
    - the total number of grids needed (equal to the sum over all observables of the number of bins of each observable, times four).
    - the grid spacings, the interpolation orders, and the interpolation ranges (this information is under the user's control).
  - **Running phase:**
    - aMCfast gets all the needed information (kinematics and weight functions W) event-by-event from MadGraph5_aMC@NLO.
    - This information is then fed to APPLgrid, whose grid-filling internal routines iteratively construct the interpolation grids.
  - **Termination phase:**
    - The grids are finally written to file in the APPLgrid format.

The aMCfast Interface

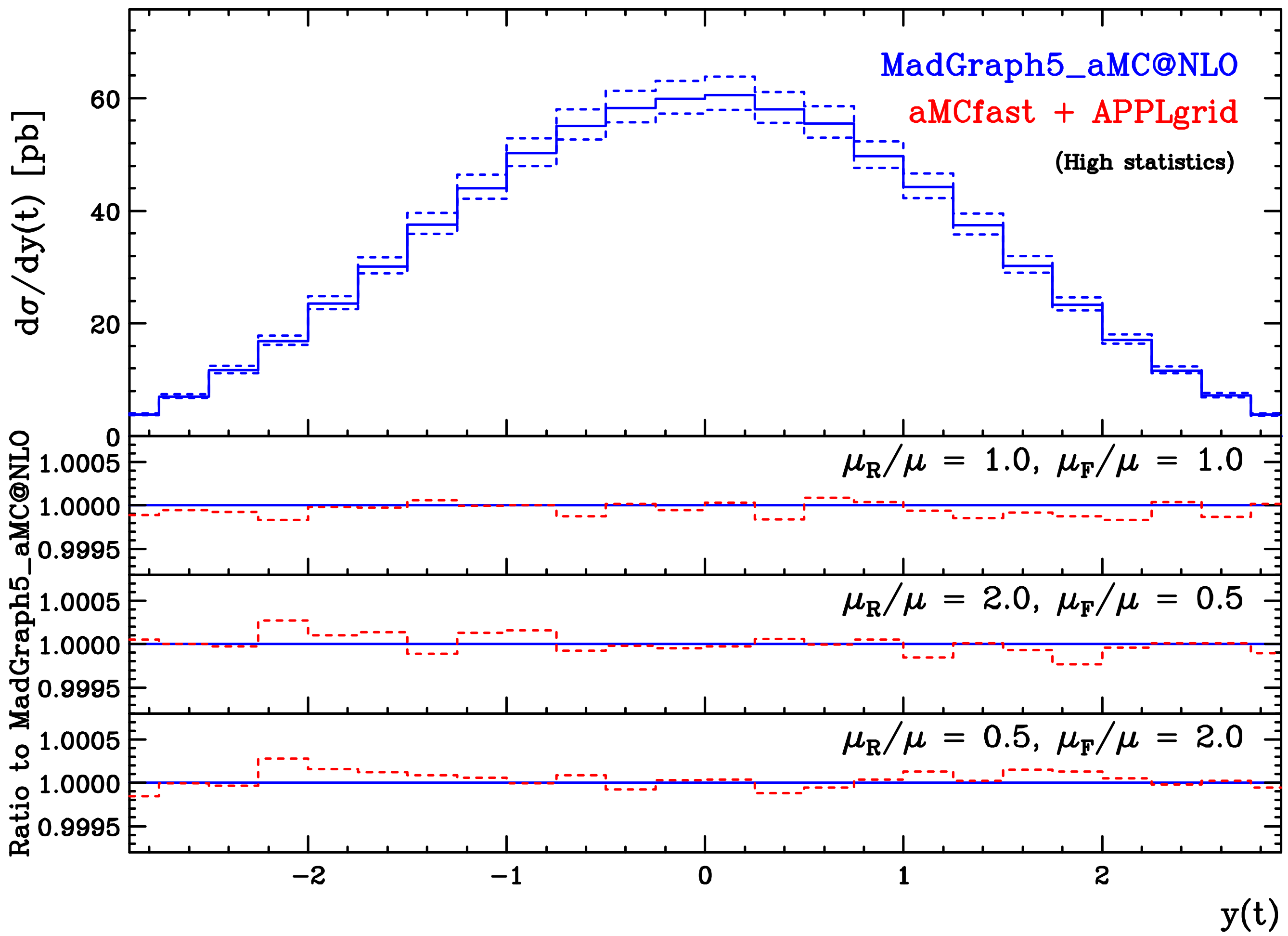
Validation: The Setup

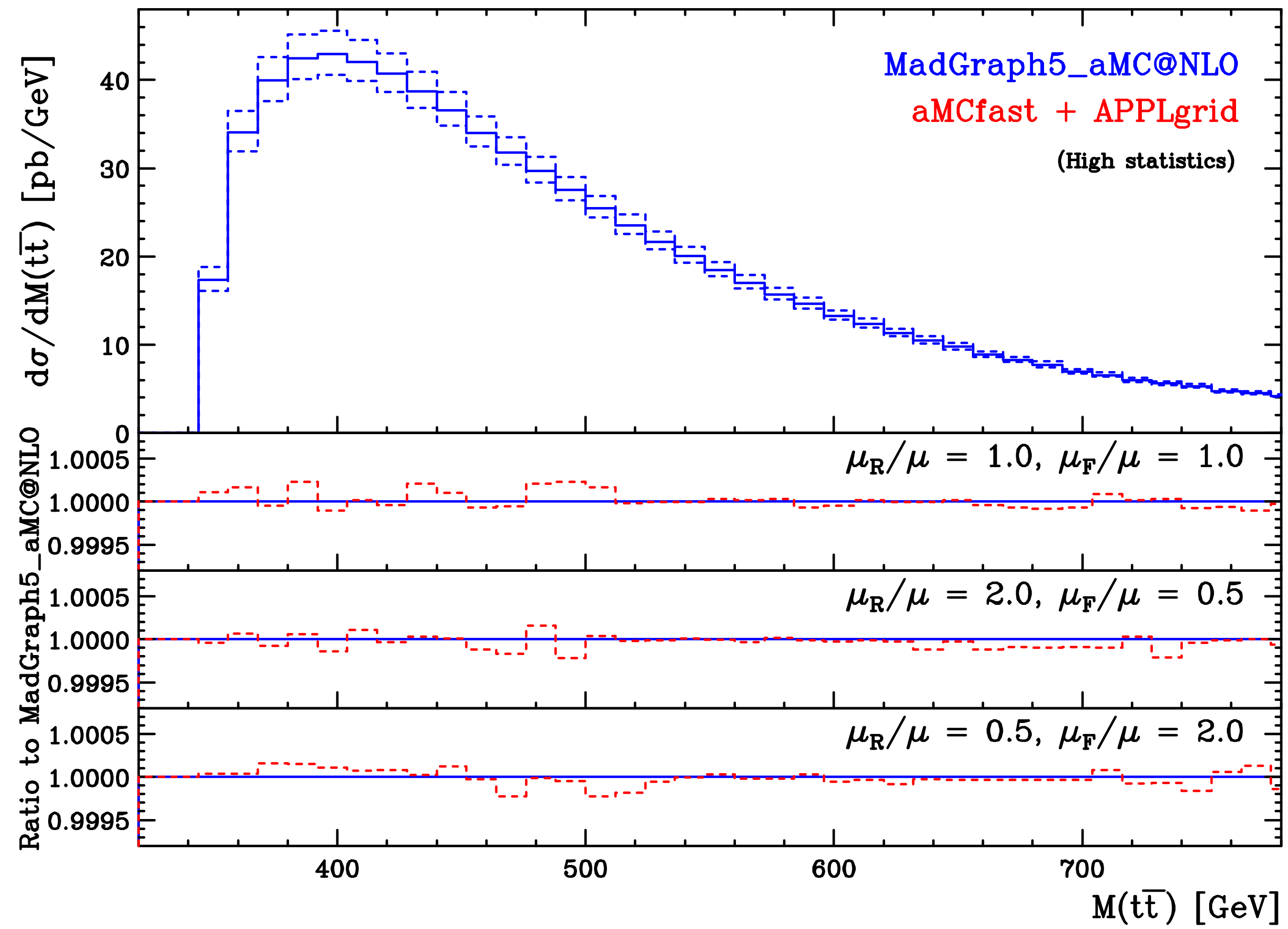
- Given a process and an observable, we compute the respective differential distribution in two different ways:
  - directly, by means of MadGraph5_aMC@NLO (**Reference**),
  - a posteriori, convoluting the grids constructed with aMCfast (**Reconstructed**).
- In our approach, the distributions must be in agreement for:
  - **any statistics** (4-grids approach), for testing we choose:
    - low ($\sim 10^3$ phase space points per integration channel),
    - high ($\sim 10^6$ phase space points per integration channel),
  - **any scale combination**, for testing we choose:
    - $\mu_F = \mu \quad \mu_R = \mu$,
    - $\mu_F = 2\mu \quad \mu_R = \mu/2$,
    - $\mu_F = \mu/2 \quad \mu_R = 2\mu$.
- No PDF variation considered here.

The aMCfast Interface

Validation: Top-Quark Pair Production

- Important for constraining the large-*x* gluon.
- We looked at the following observables:
  - the rapidity distribution of the top quark (left),
  - the invariant mass distribution of the top pair (right).
- High statistics plots:





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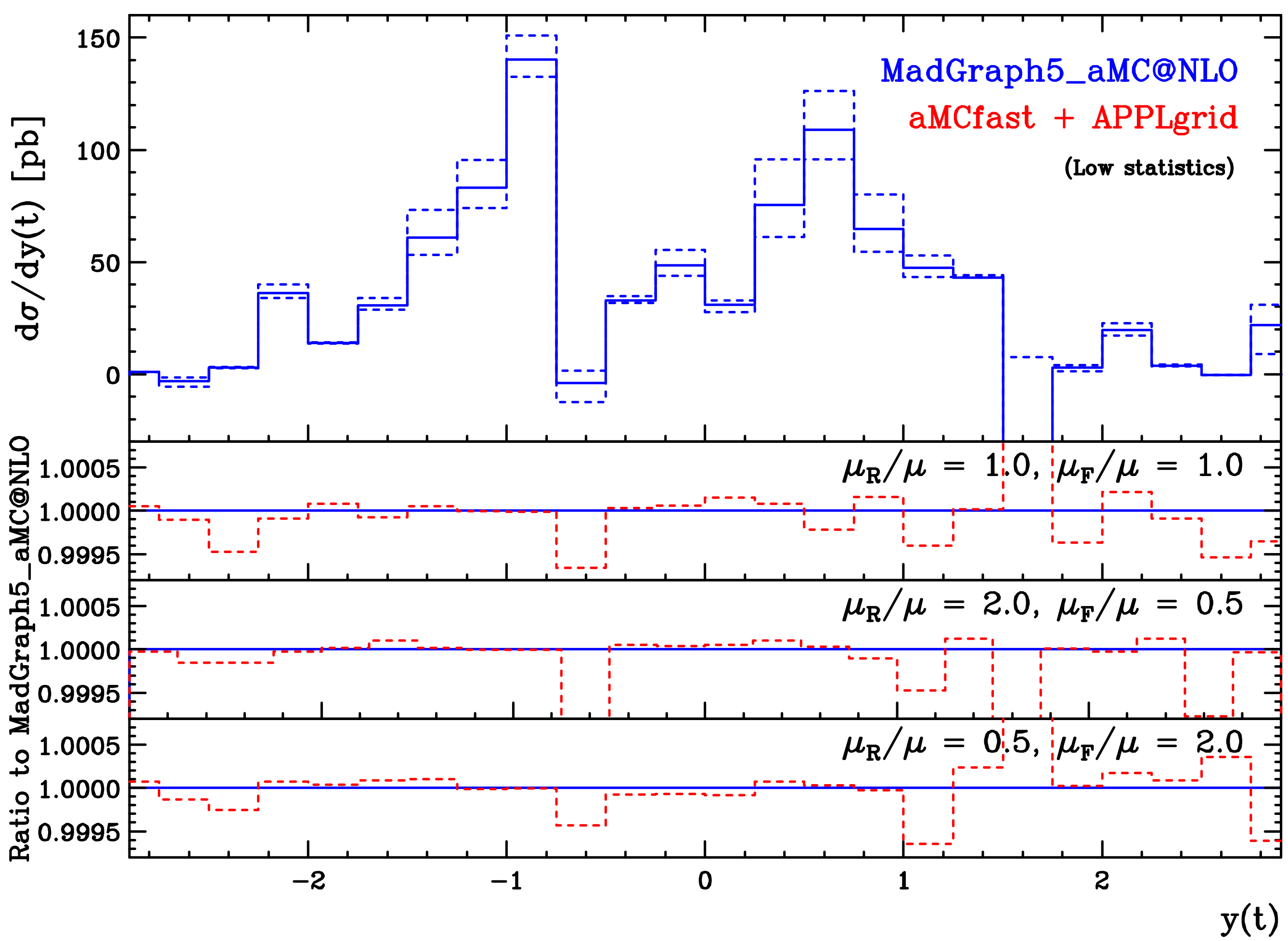

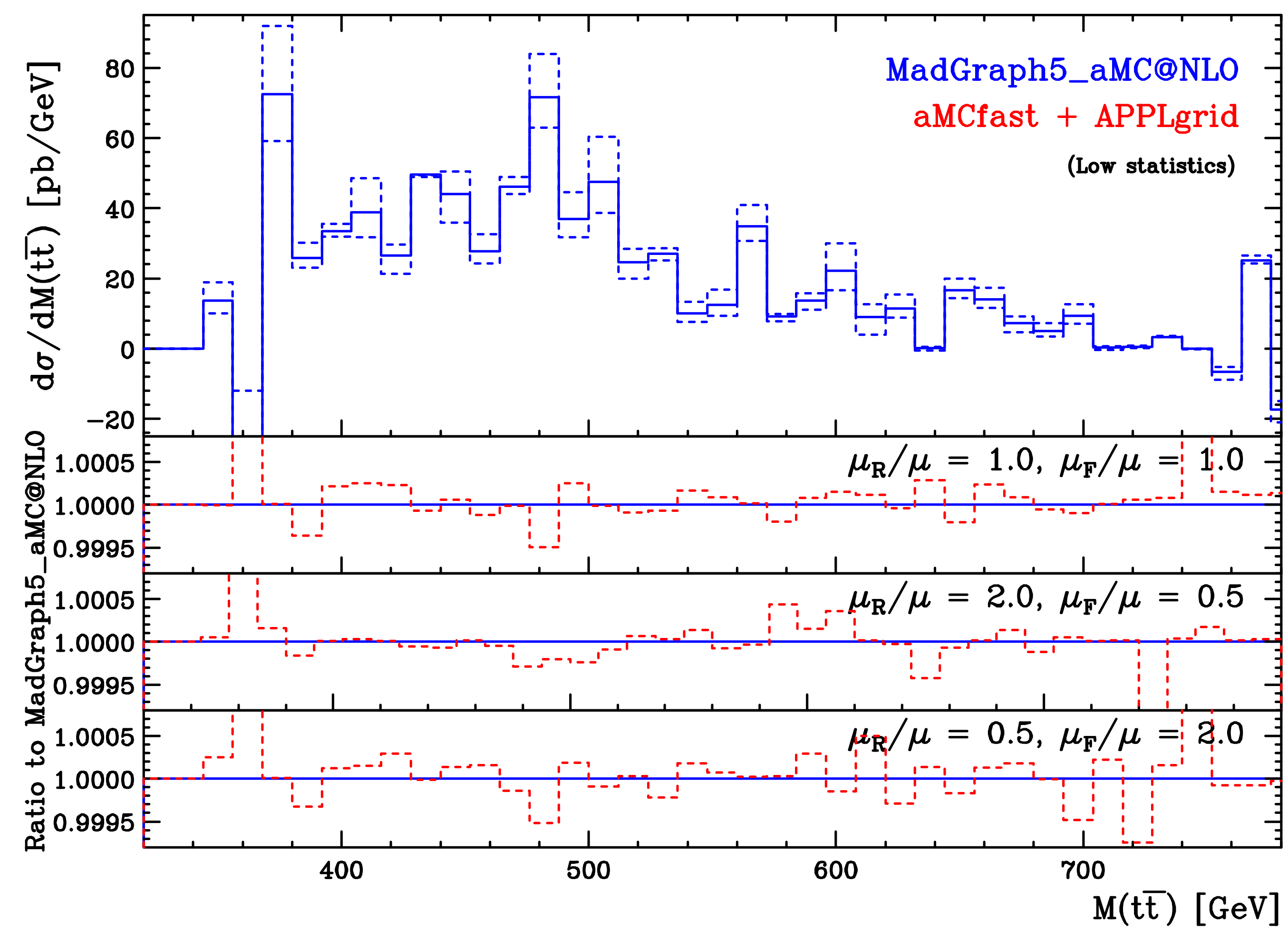

The aMCfast Interface

Validation: Photon Production with one Jet

- Important for the gluon in the region relevant for Higgs production in gluon fusion.
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  - the pseudo-rapidity distribution of the photon (left),
  - the tranverse momentum distribution of the photon (right).
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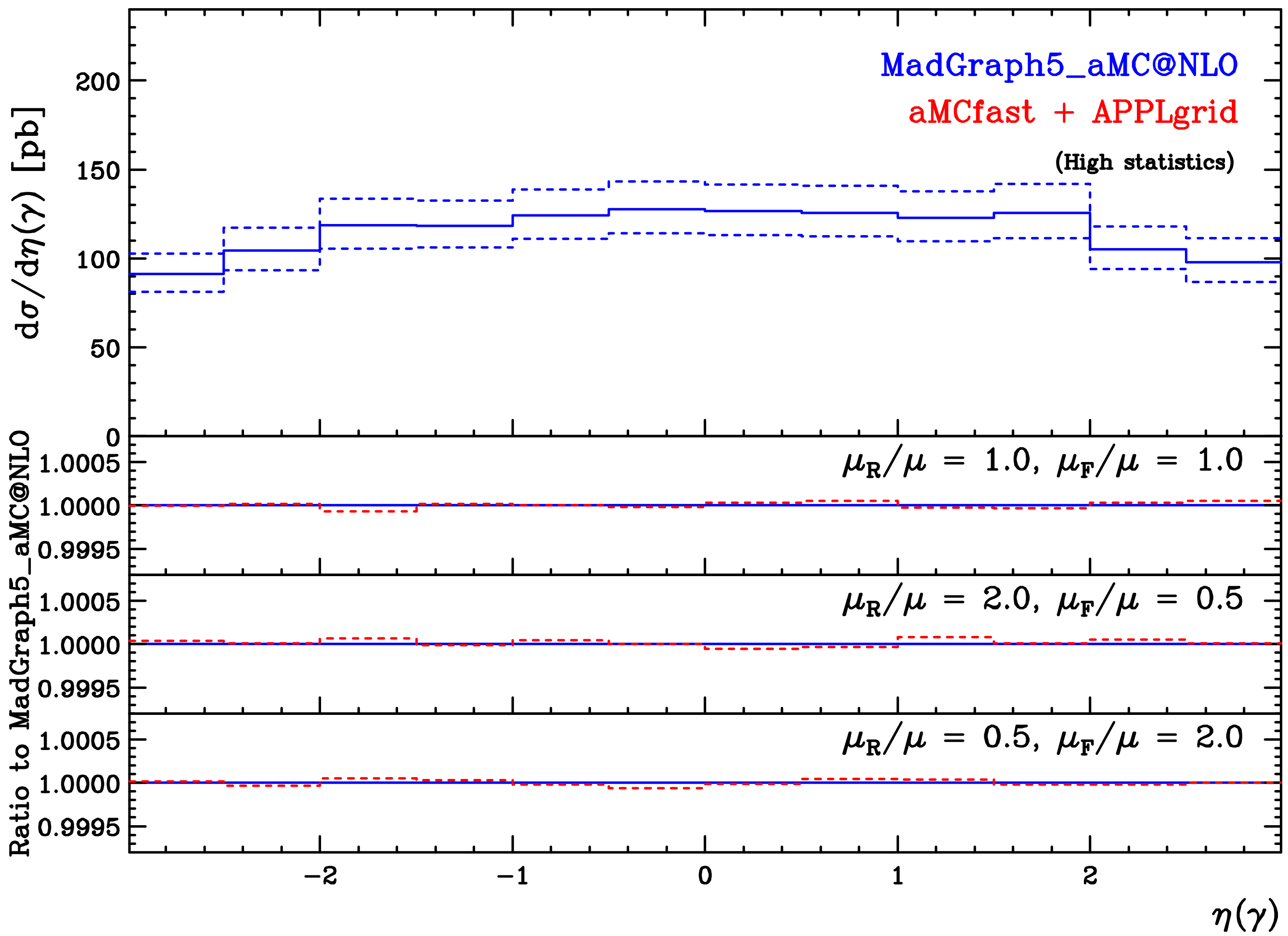

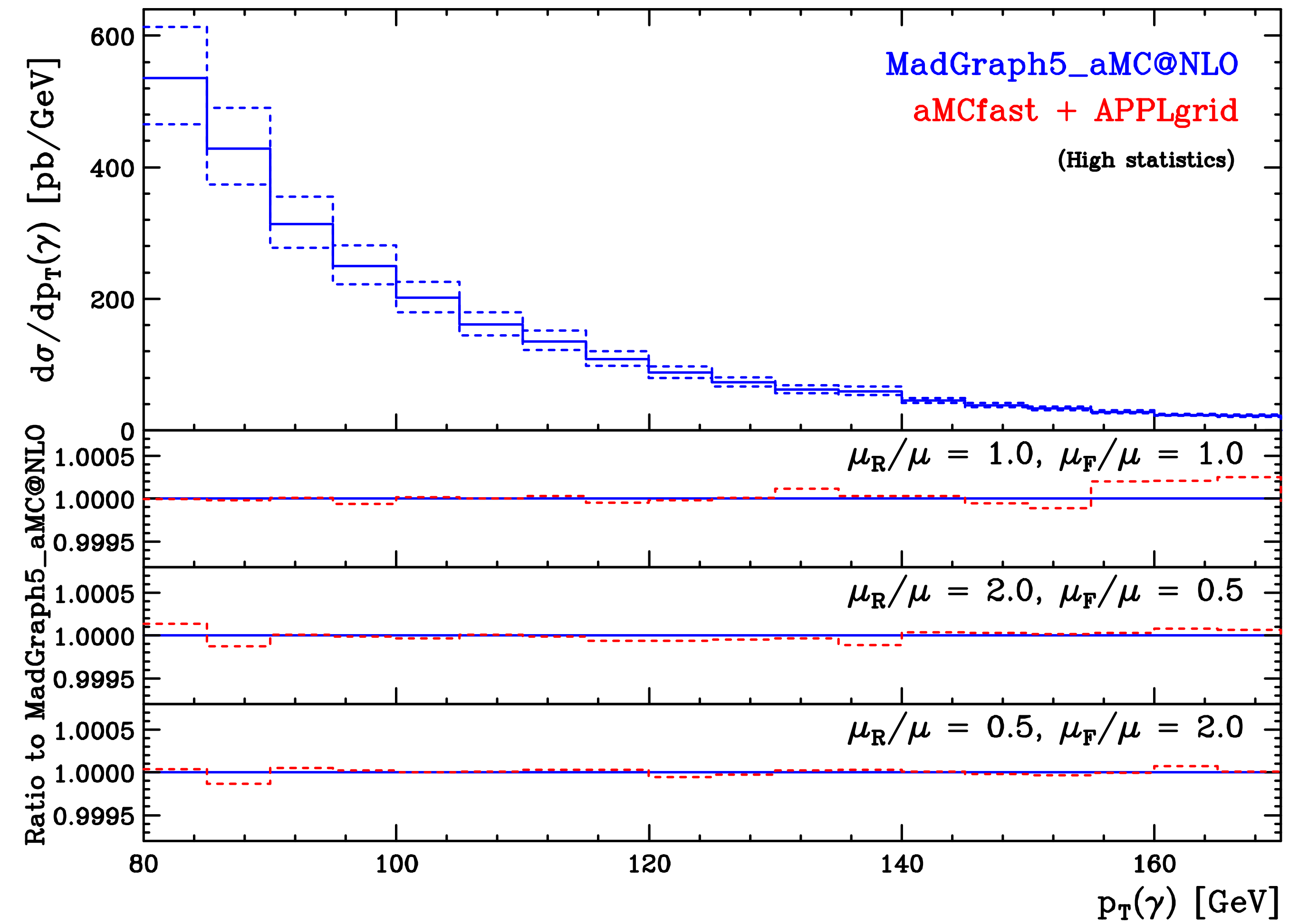

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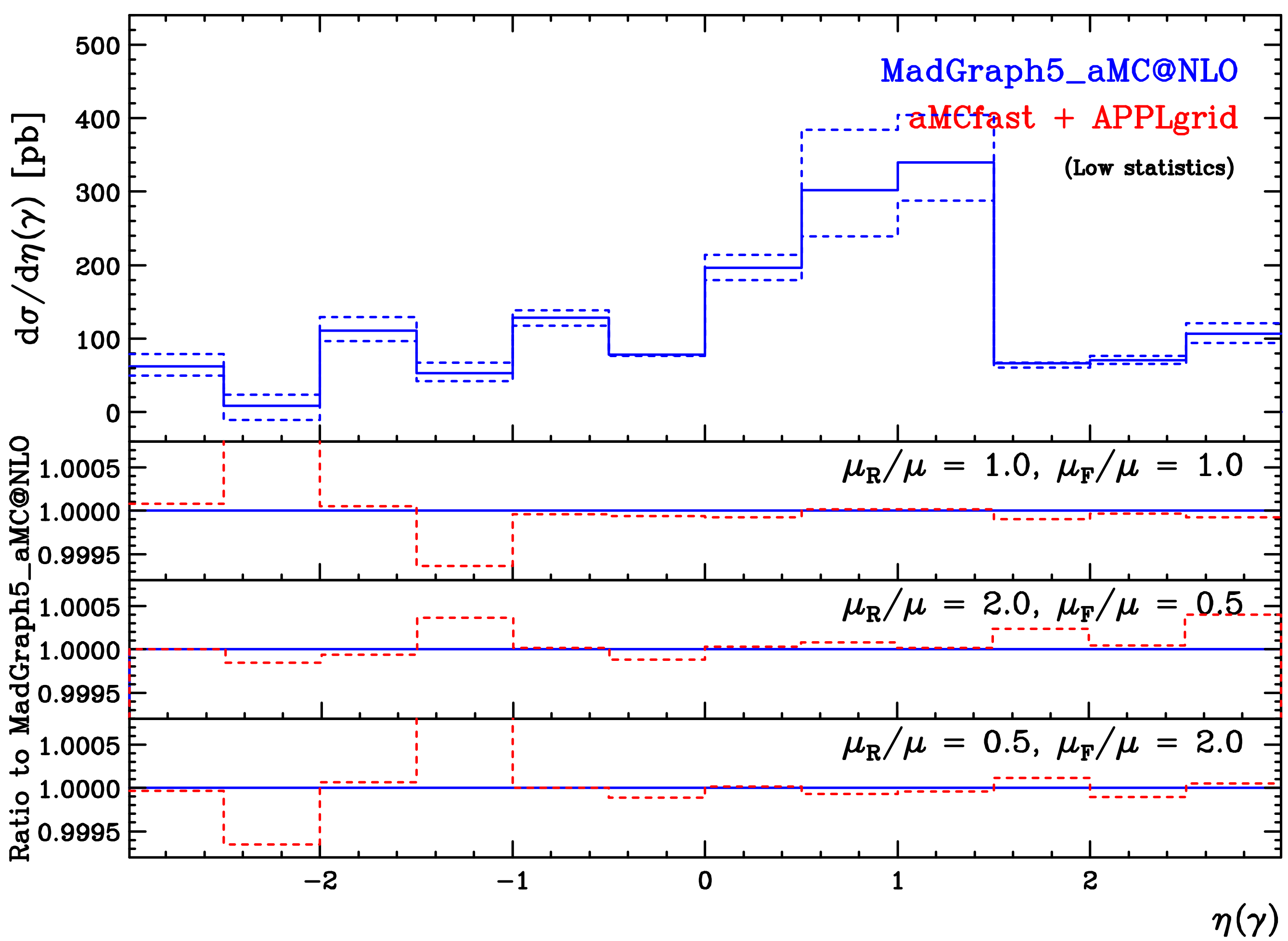

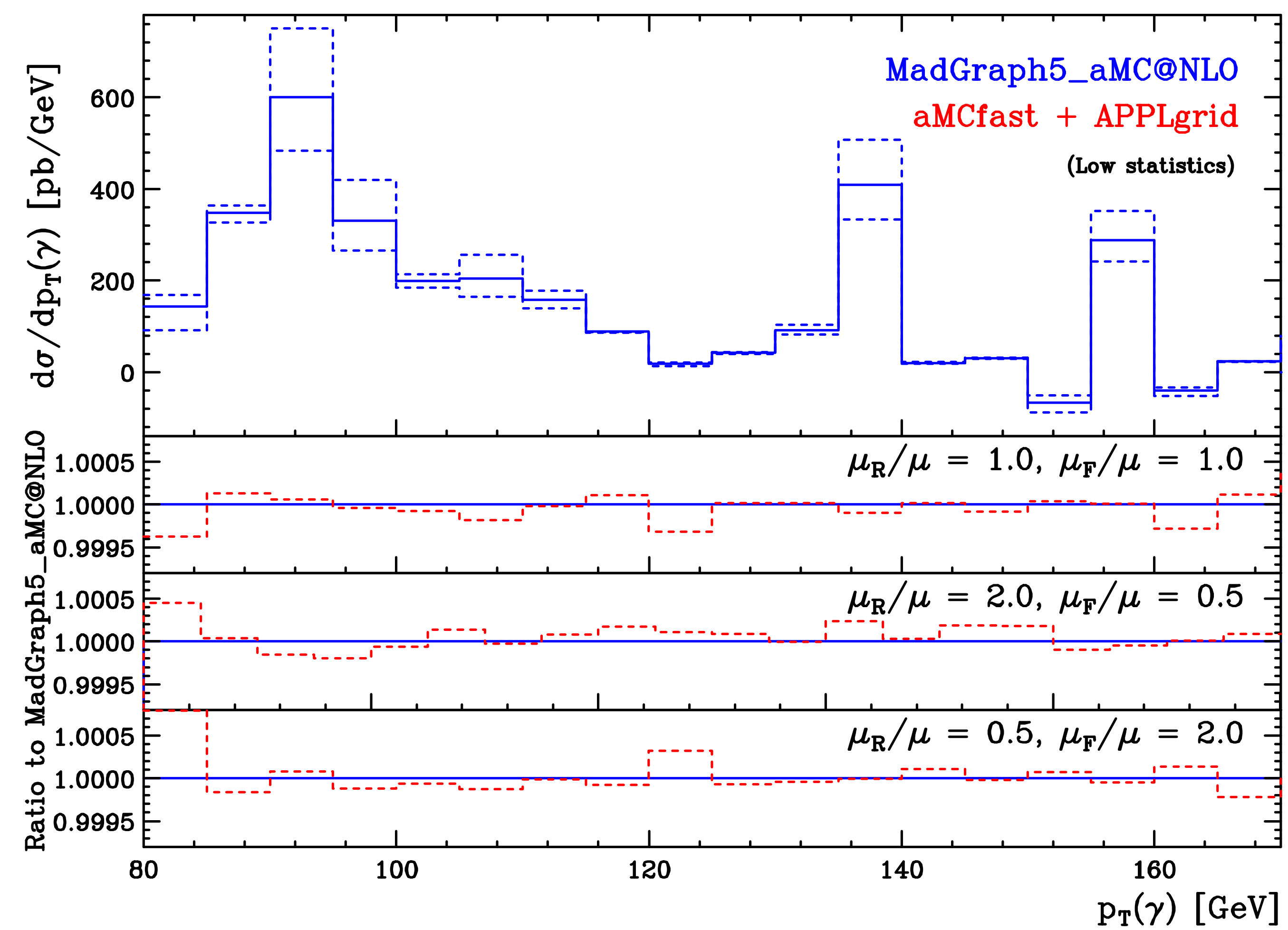

The aMCfast Interface

Validation: Dilepton Production with one Jet

- Relevant for quarks and antiquarks in the large-x region.
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  - the invariant mass distribution of the lepton pair (right).
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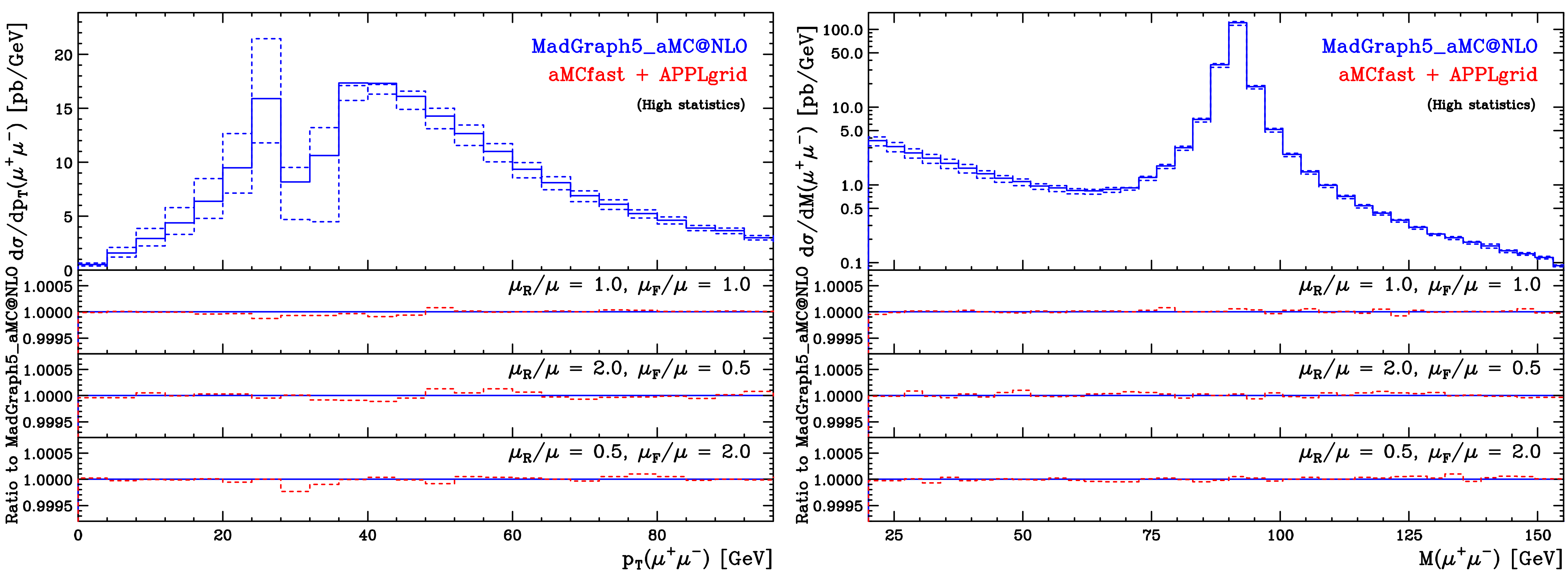

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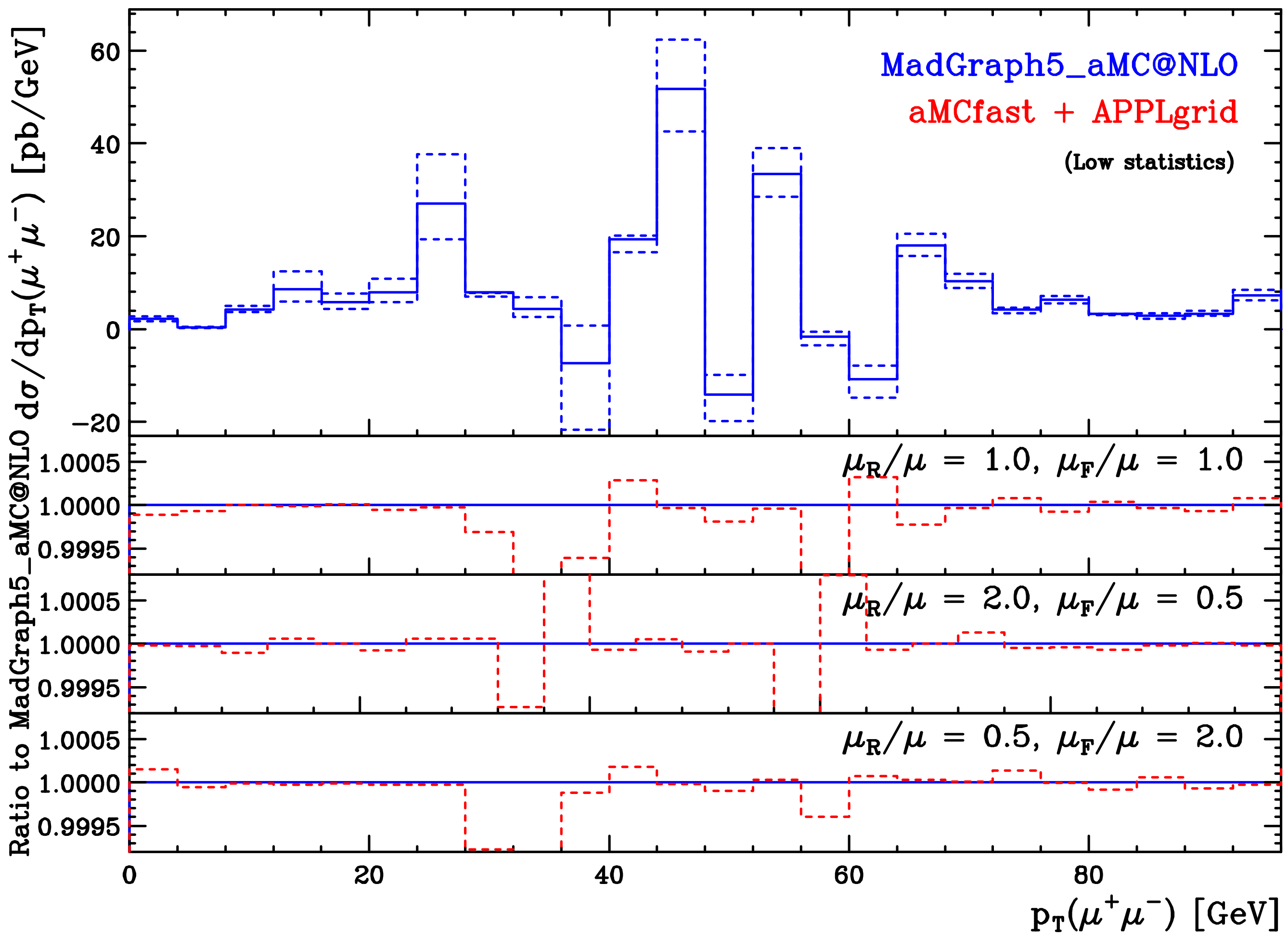

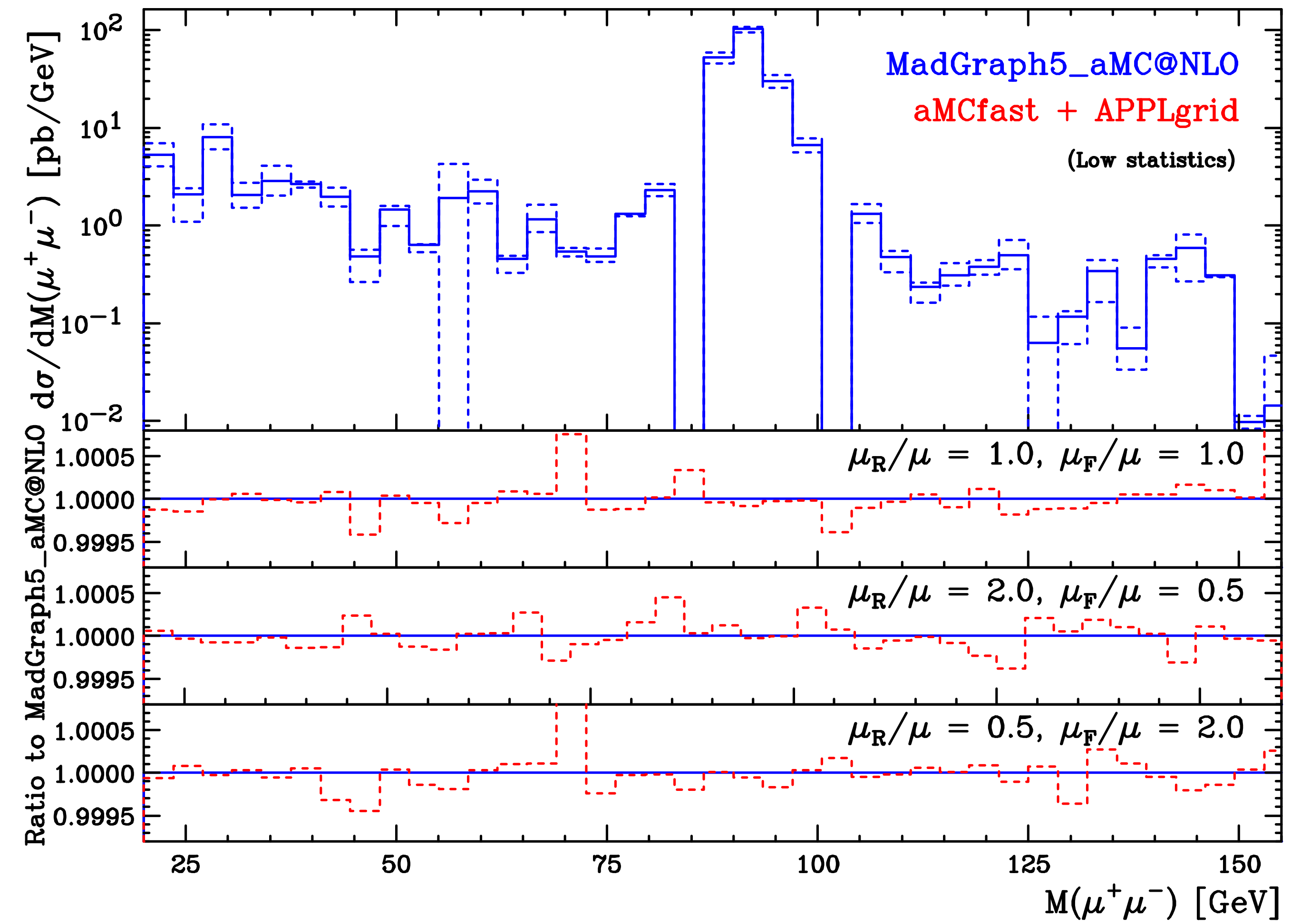

The aMCfast Interface

Validation: W + c Production

- Important for constraining the strange-quark PDFs.
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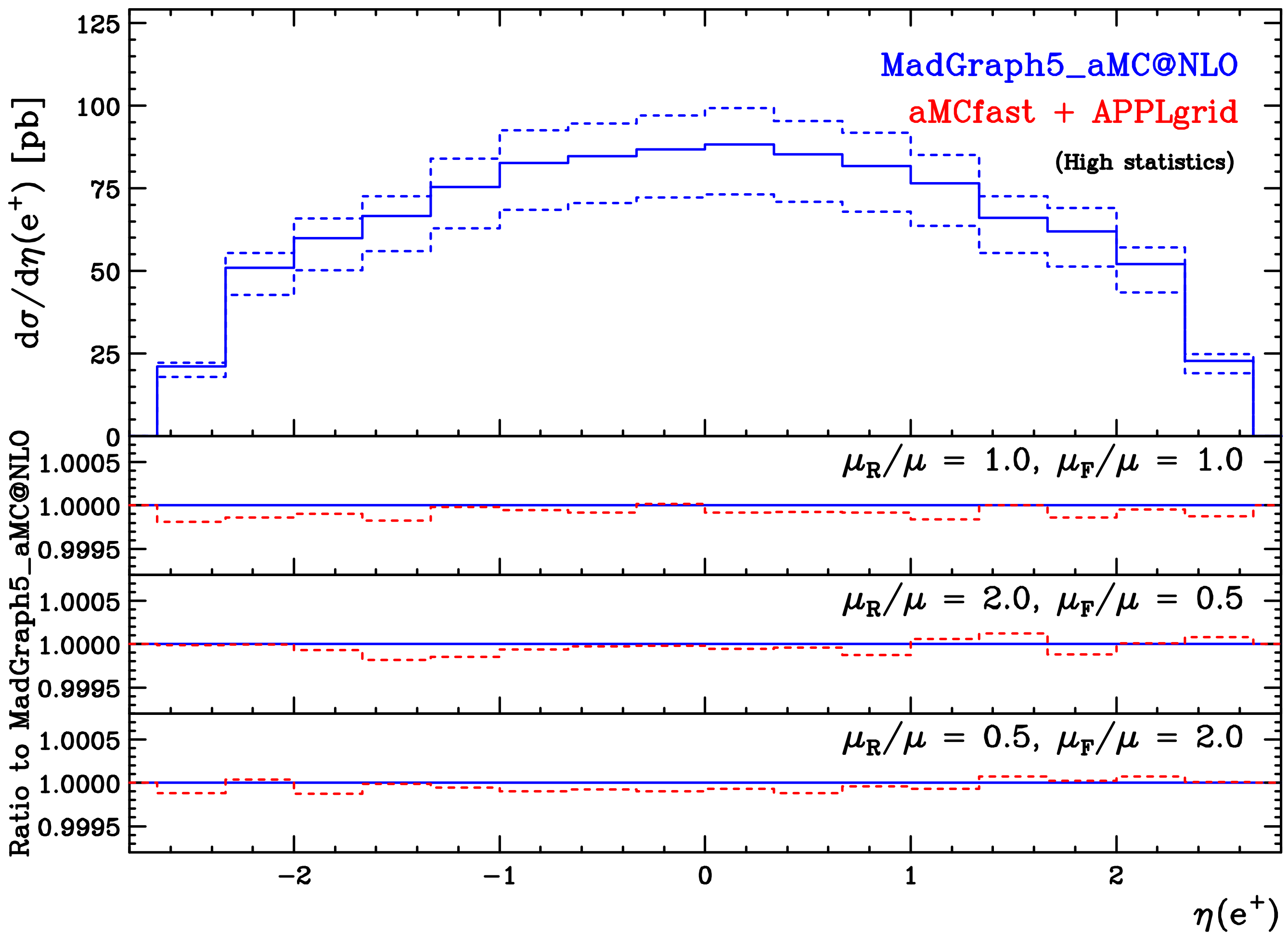

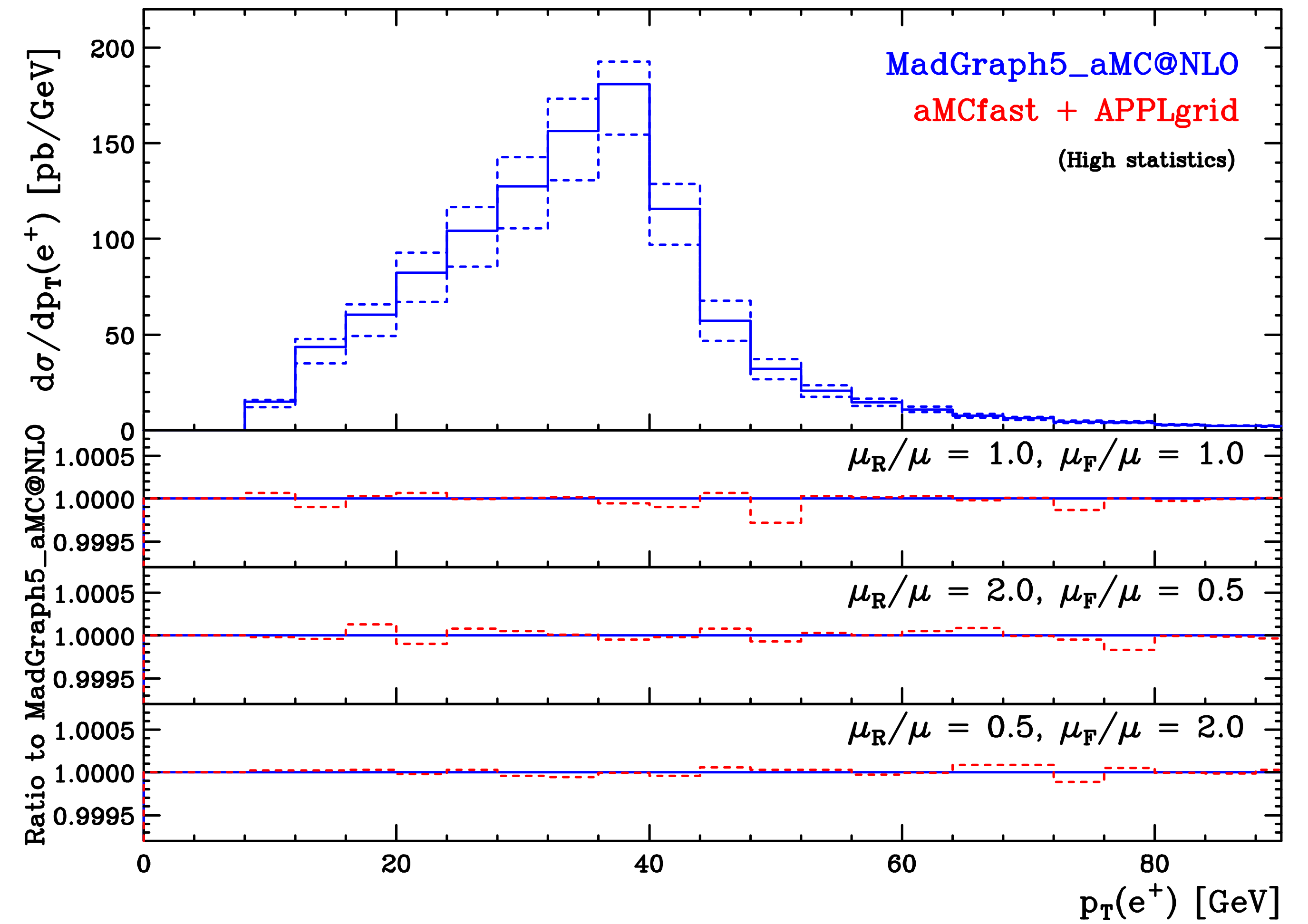

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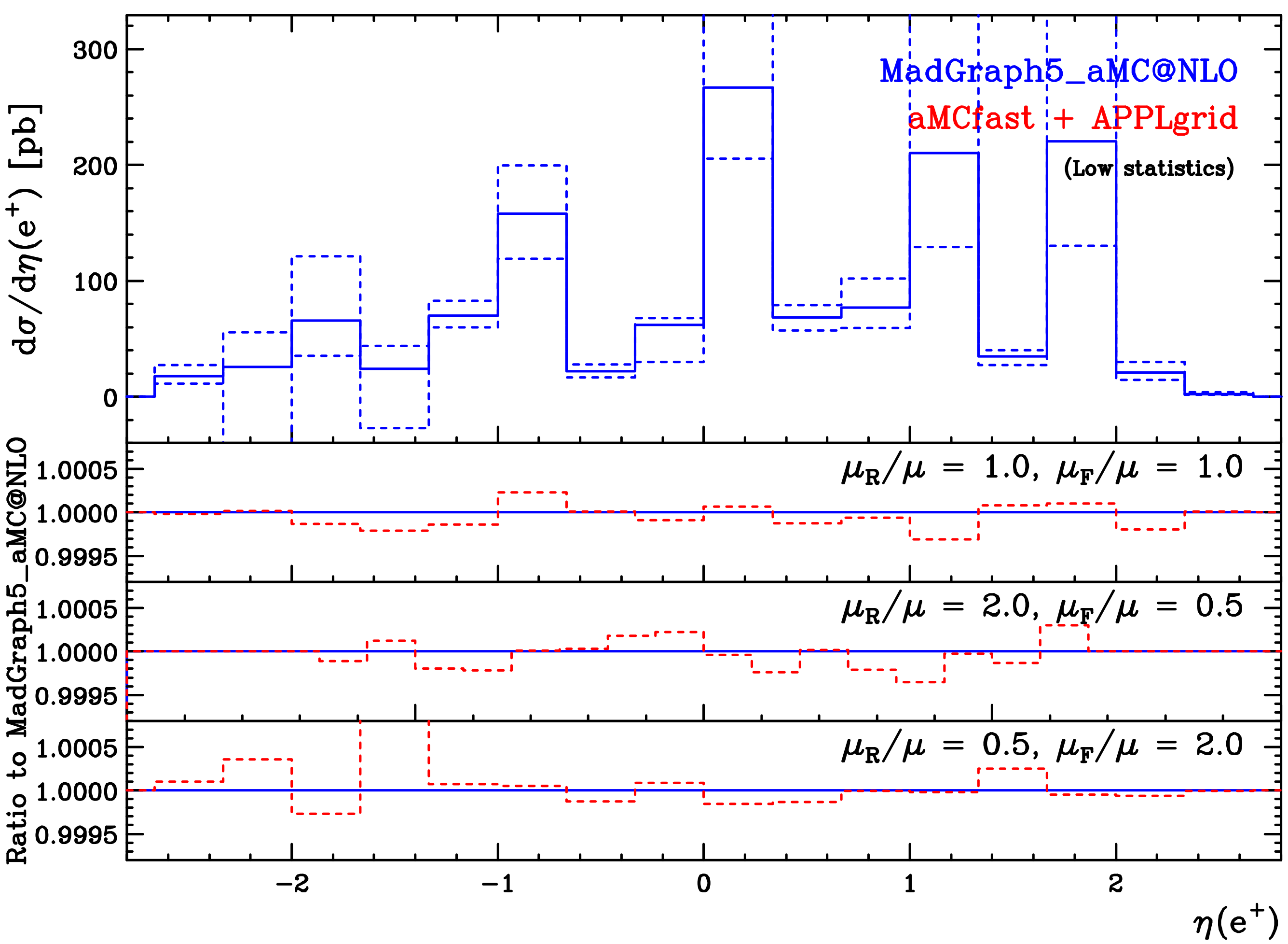

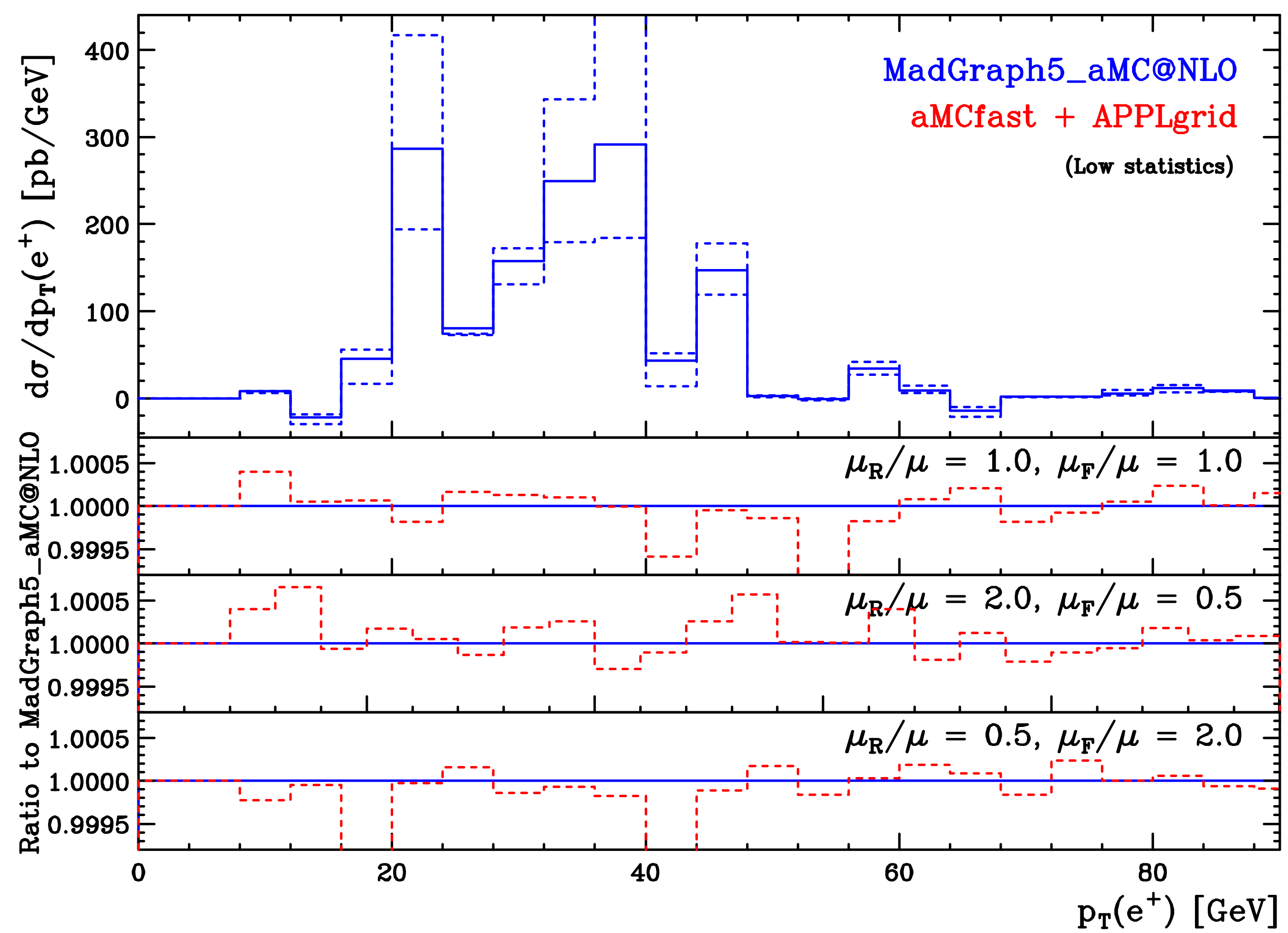

The aMCfast Interface

Validation: Z + bb Production

- This is just an example of complicated process.
- We looked at the following observables:
  - the rapidity distribution of the *Zbb* system (left),
  - the transverse momentum distribution of the *Zbb* system (right).
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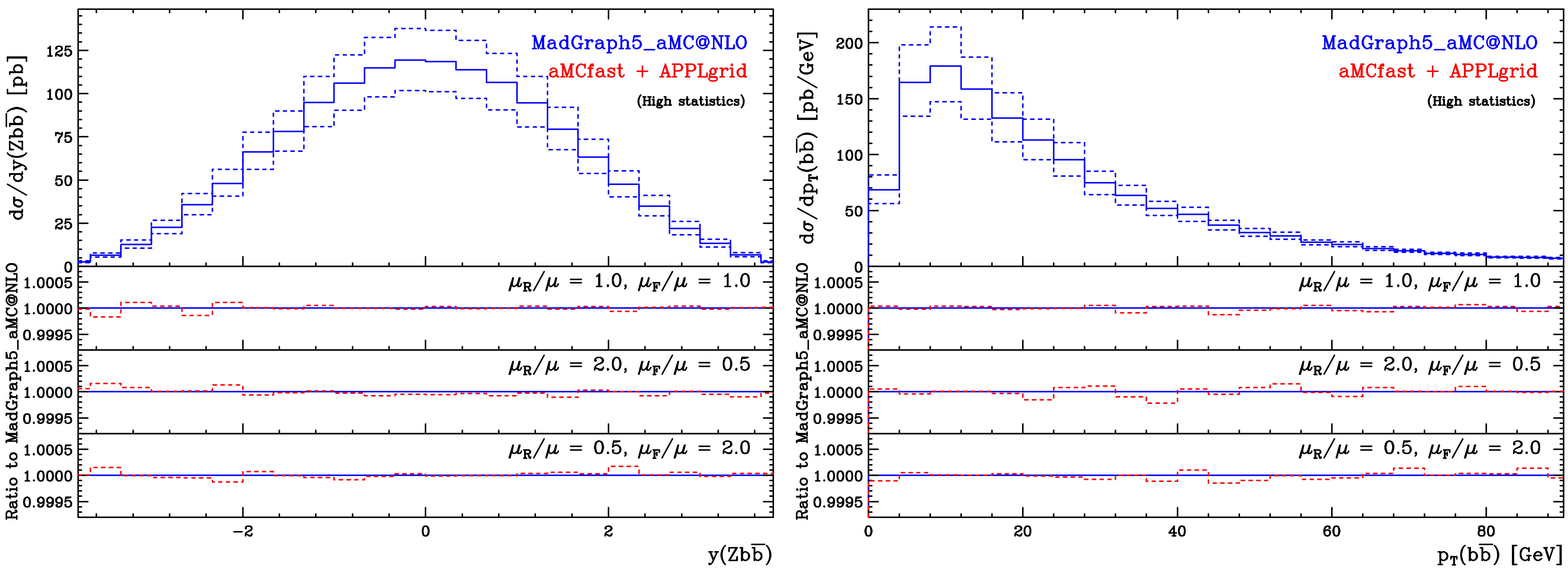

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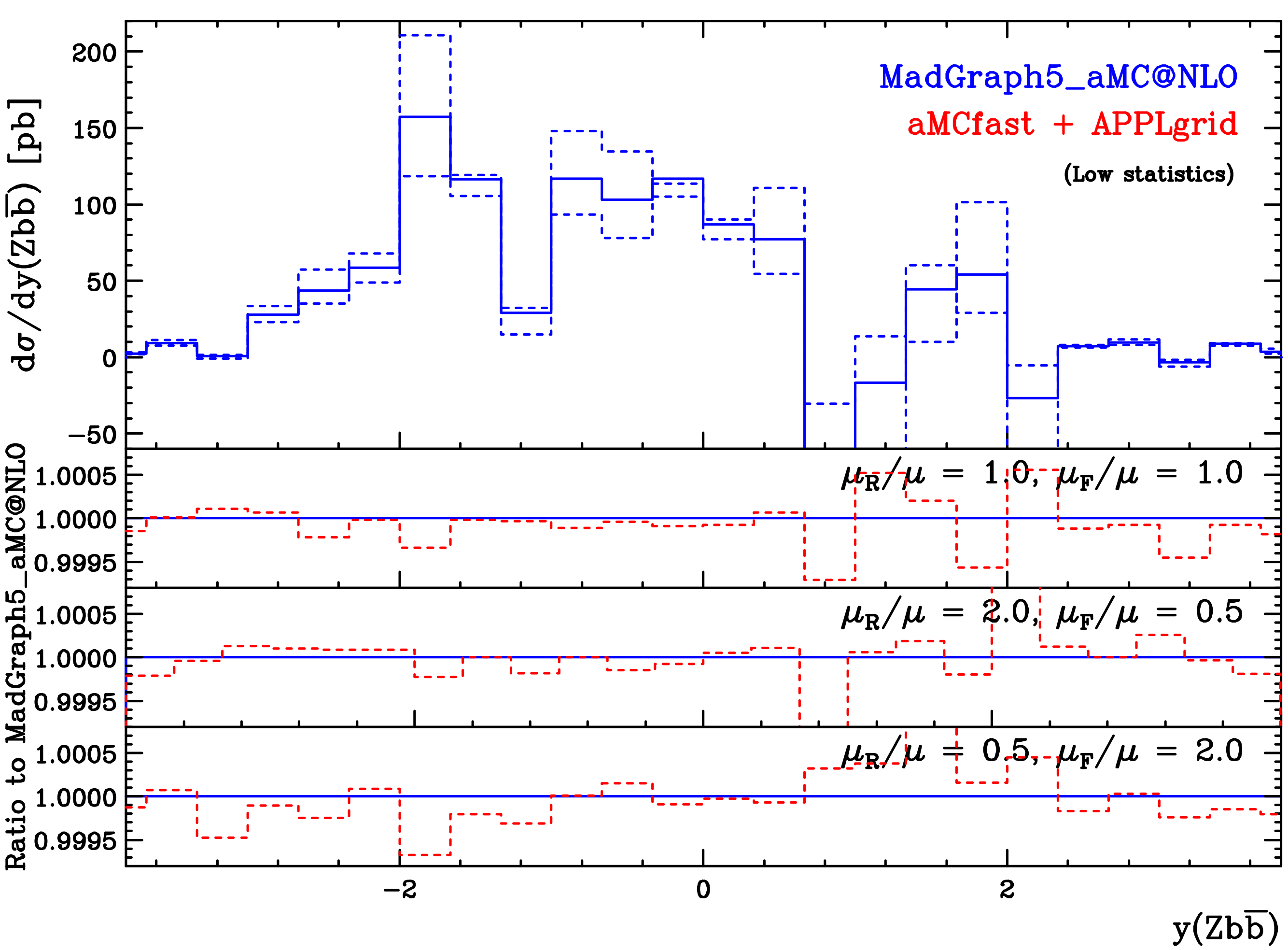
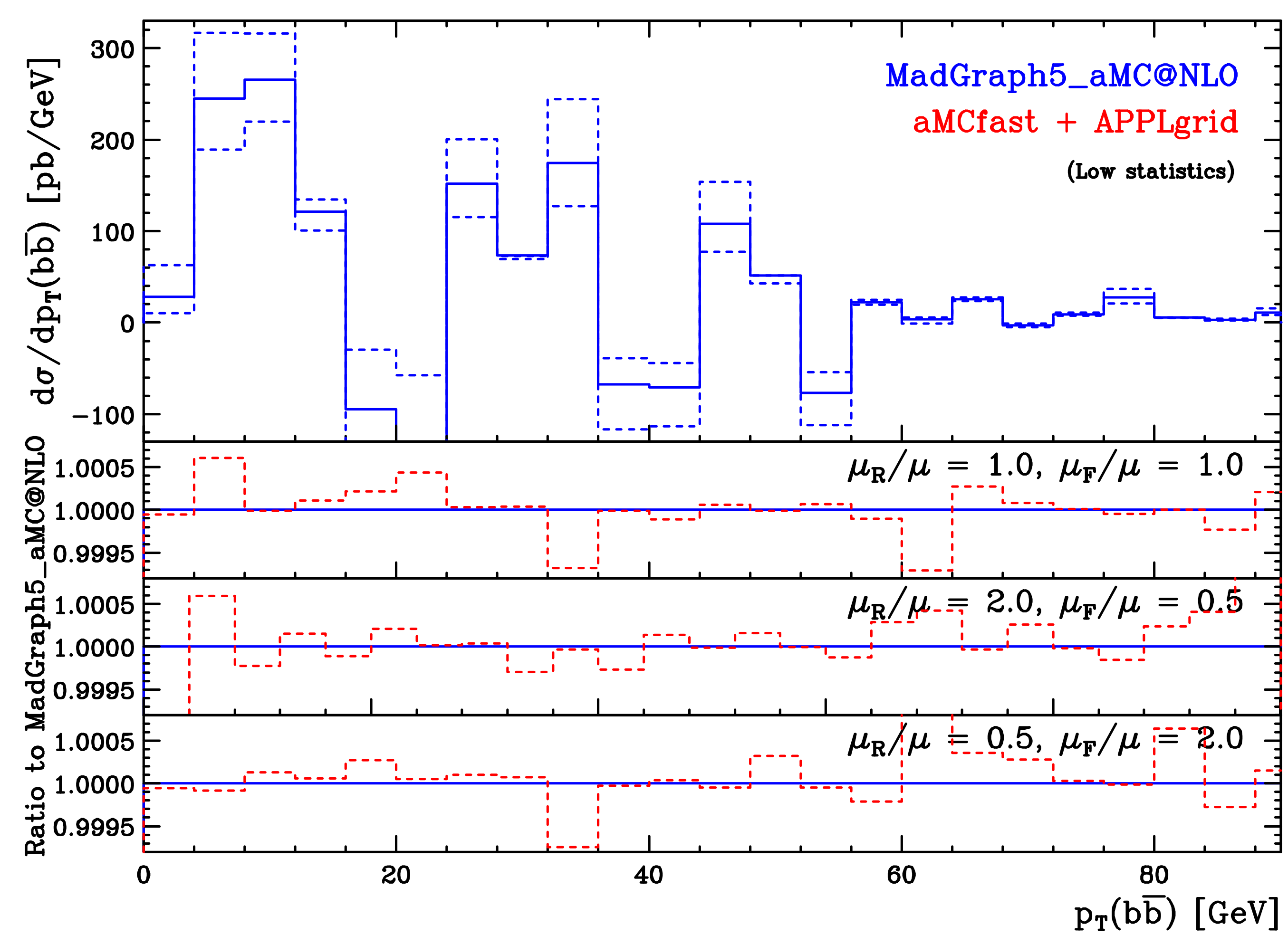


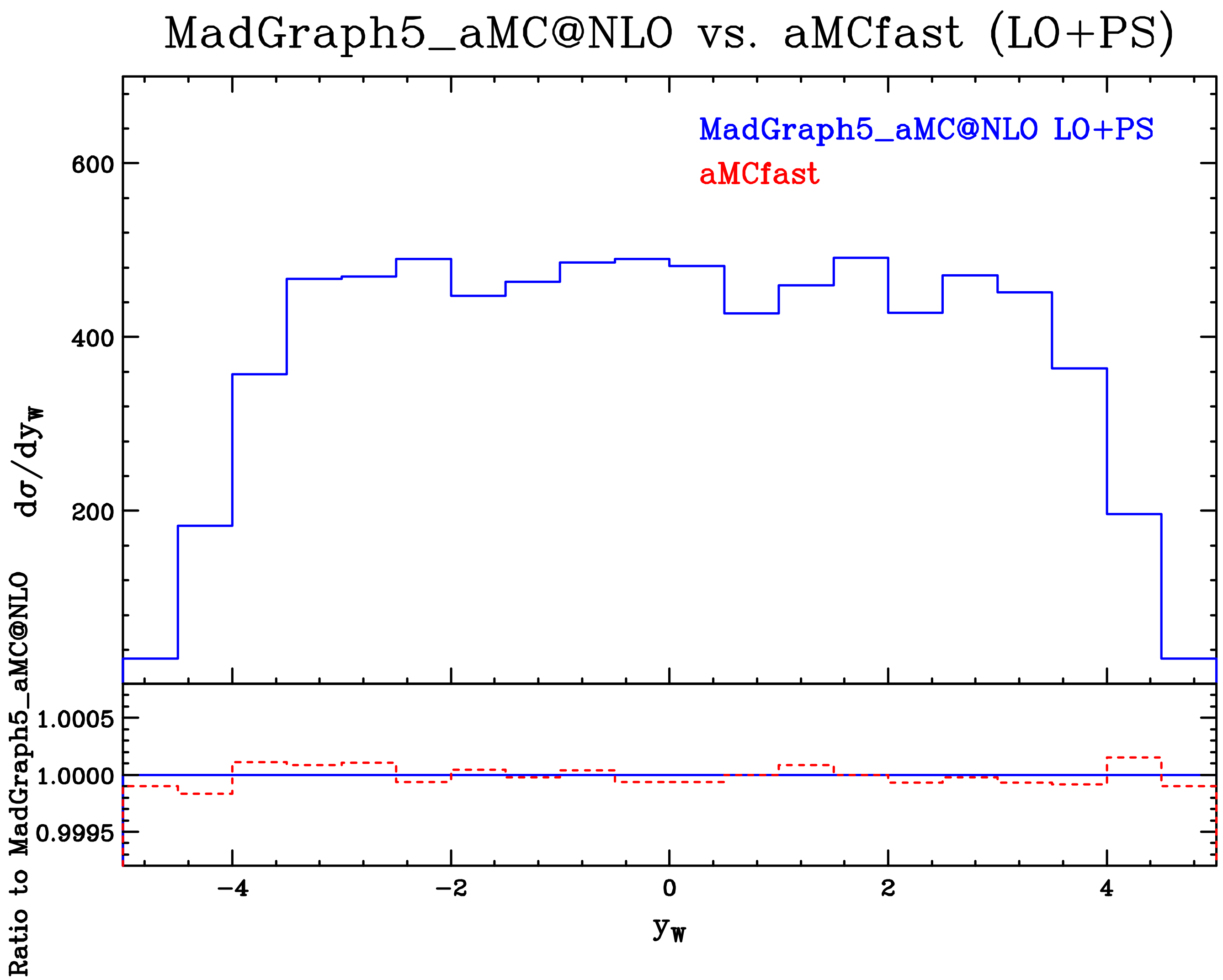


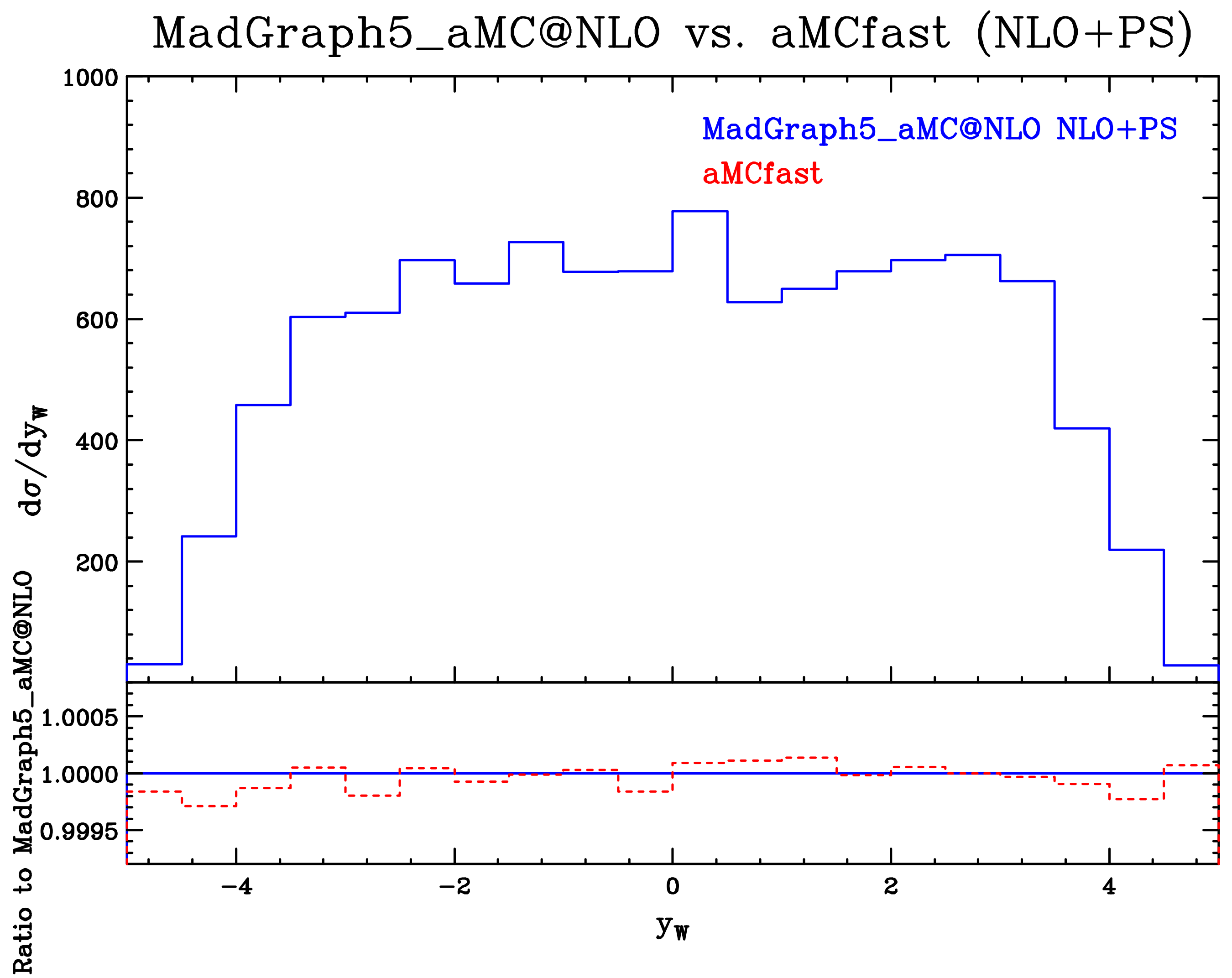
The aMCfast Interface

The NLO + PS Case: Preliminary Results

- We are presently working on extending aMCfast to the (N)LO+PS mode of MadGraph5_aMC@NLO.

- Preliminary results are already available ($e^+\nu$ + Herwig6):





- Perfect agreement between reference and reconstructed histograms also in the low statistics regime, as in the fixed-order case.

The aMCfast Interface

The NLO + PS Case: Preliminary Results

- The production of interpolation grids in the presence of PS poses more **conceptual questions** as compared to the fixed-order case.

- There are **two main issues**:

  1) Dependence on PDFs of the **backward PS evolution** cannot be disentangled:

     - expeted to be small as it appears as a ratio of PDFs at the same x but different Q^2.

  2) Dependence on PDFs of the **PS evolution** as a results of different kinematic configurations at the **matrix element** (ME) level when the latter is computed with different PDF sets cannot be removed.

- Need to explicitly check that interpolation grids including PS do not have a (strong) depencence on the PDFs used for the production.

The aMCfast Interface

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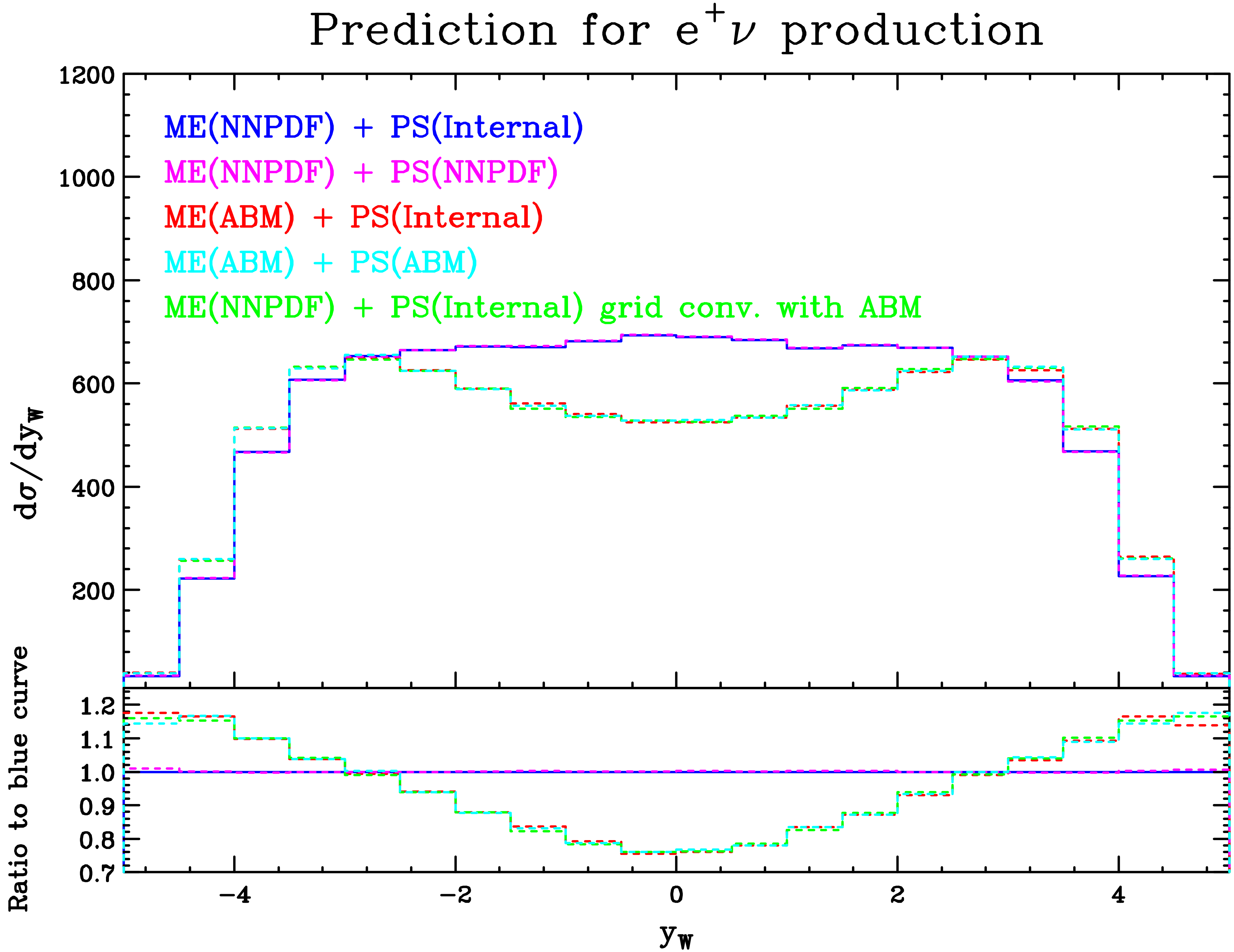

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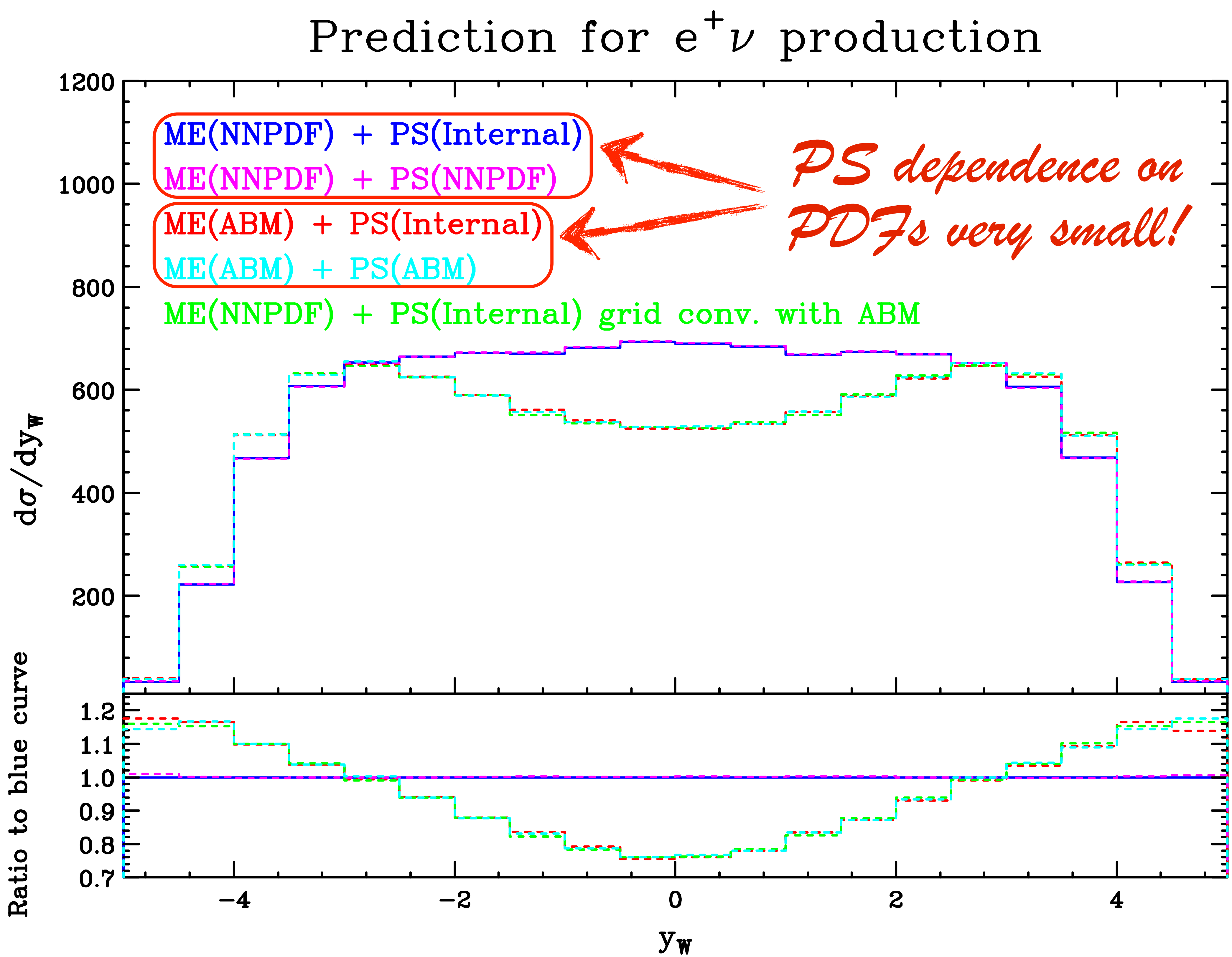

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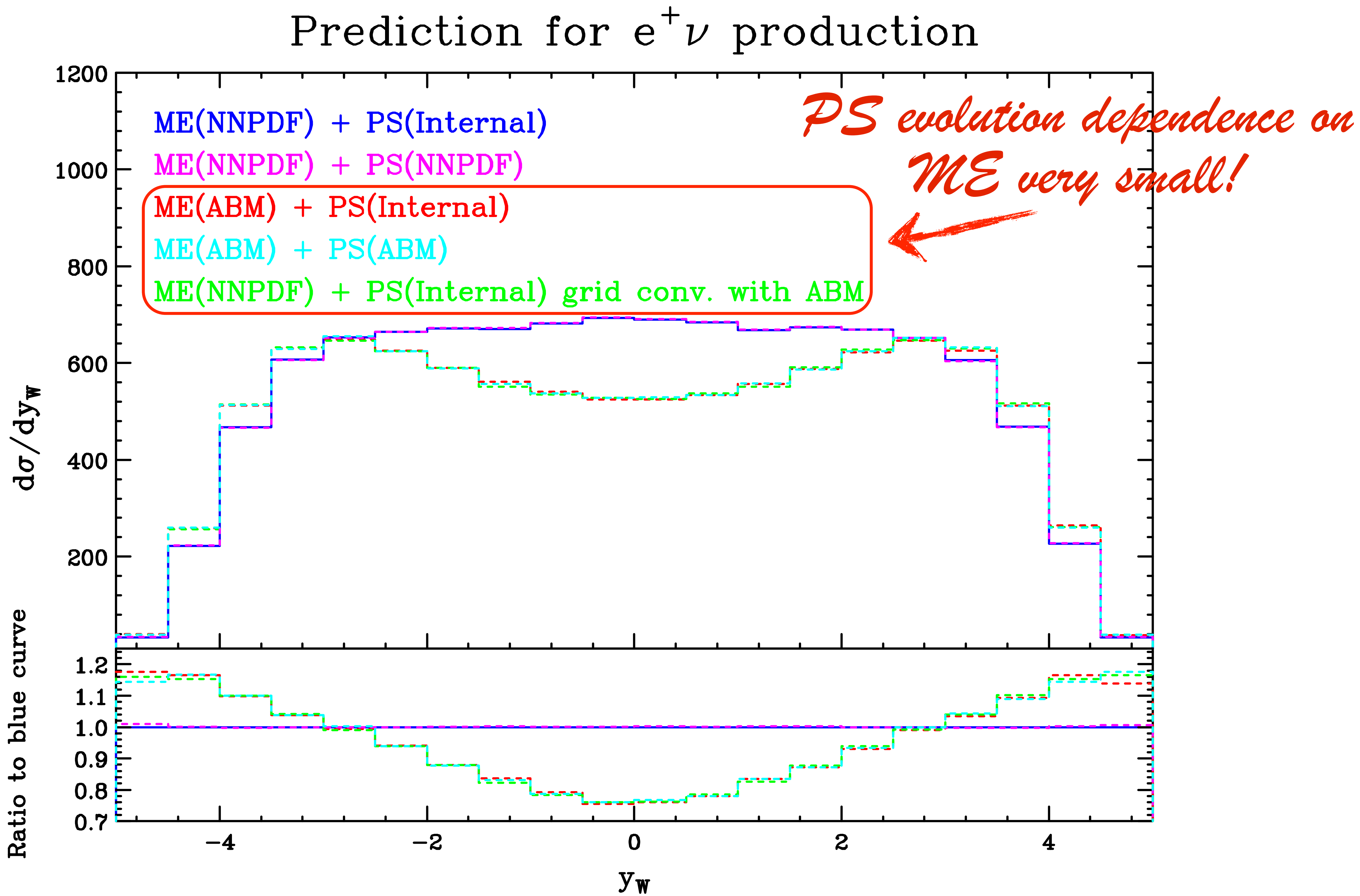

Summary and Outlook

- Summary:
  - **aMCfast** is an automated interface which bridges **APPLgrid** and **MadGraph5_aMC@NLO**.
  - It allows the user to produce fast interpolation grids for any possible hadronic process up to NLO (in the SM for the time being).
  - It ensures a very high accuracy for any statistics and **any scale** choice.
  - **aMCfast** will make extremly simple the inclusion of new data coming from the LHC in any future PDF fit.
- Outlook:
  - We are presently working on aMCfast in order to interface APPLgrid with Madgraph5_aMC@NLO when running in the (N)LO+PS mode.
  - Encouraging **preliminary** results.
- For more details on how to install and use **aMCfast**, you can visit our web page:

http://amcfast.hepforge.org/