

aMCfast

A fast interface between MG5_aMC@NLO and APPLgrid

[arXiv:1406.7693]

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CERN



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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 the PDFs themselves).
 - Time-consuming 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:
 - **MadGrp5_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

The Interpolating Grids

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

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

Normalization factor

Random points in the interval [a,b]

Fast NLO Computations

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*Fast function
(PDFs)*

*Slow function
(Partonic cross sections)*

Fast NLO Computations

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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-dimensional) interpolation grid:
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:

$$d\sigma^{(\text{NLO})} \longleftrightarrow \left\{ d\sigma^{(\text{NLO},\alpha)} \right\}_{\alpha=E,S,C,SC} \leftarrow \text{Event \& Counterevents}$$

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

PDFs

Partonic cross section

Fast NLO Computations

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

NLO term

Born term

Fast NLO Computations

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Fast NLO Computations

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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-dimensional interpolation grids needed.

Fast NLO Computations

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- But assuming $\mu_F \propto \mu_R \Rightarrow$ **3-dimensional** 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

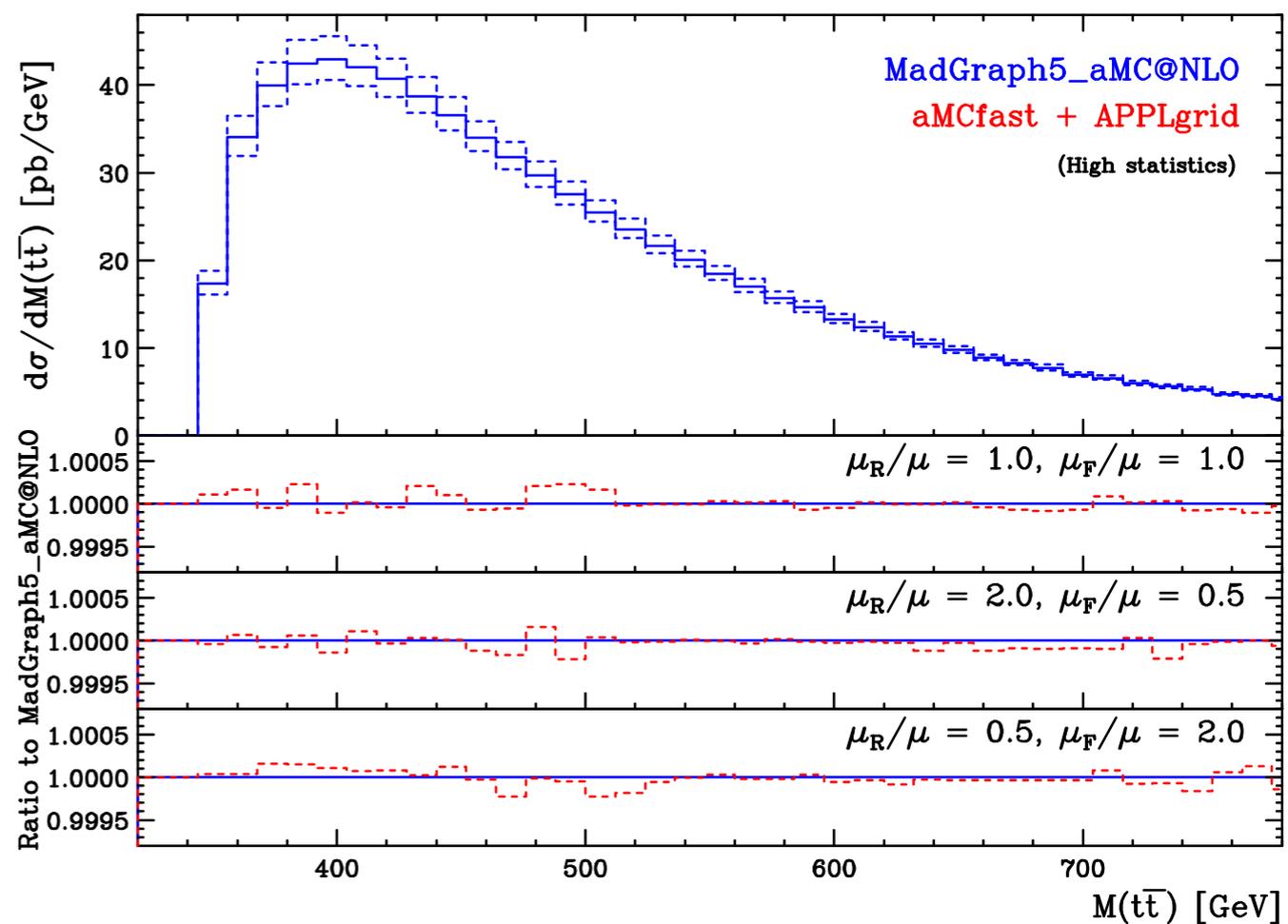
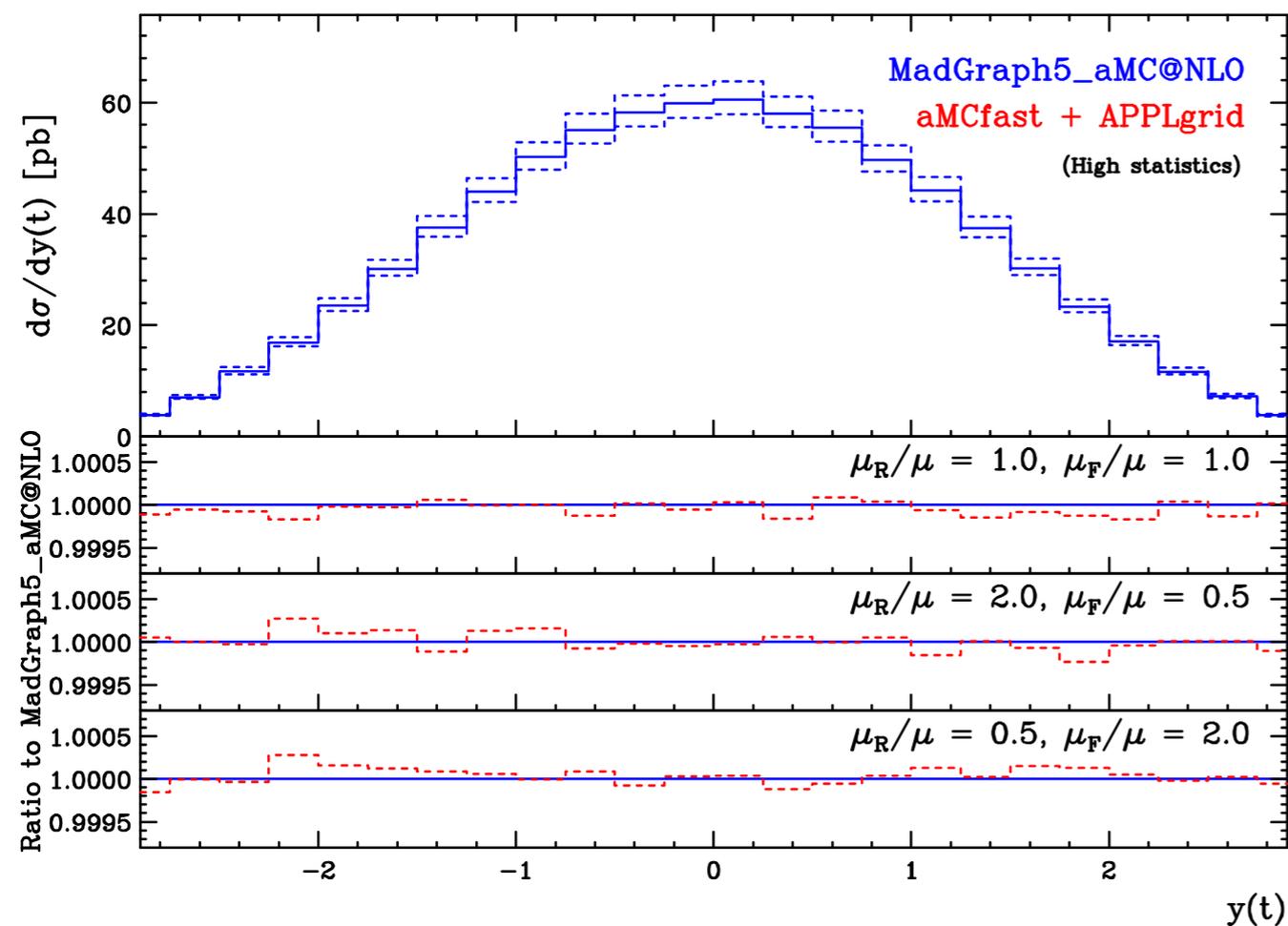
Validation: The Setup

- Given a process and an observable O , 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**, for testing we choose (4-grids approach):
 - 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

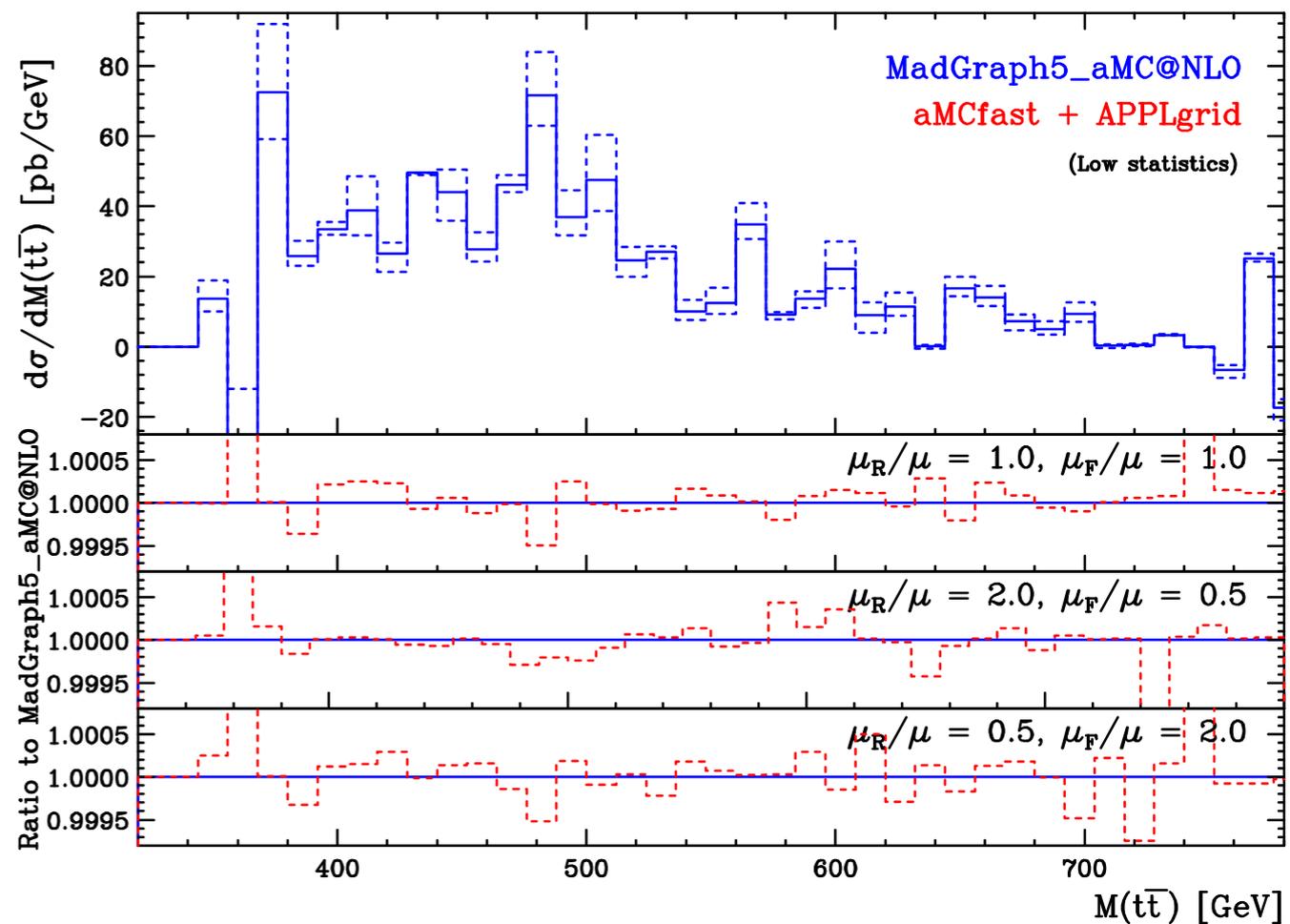
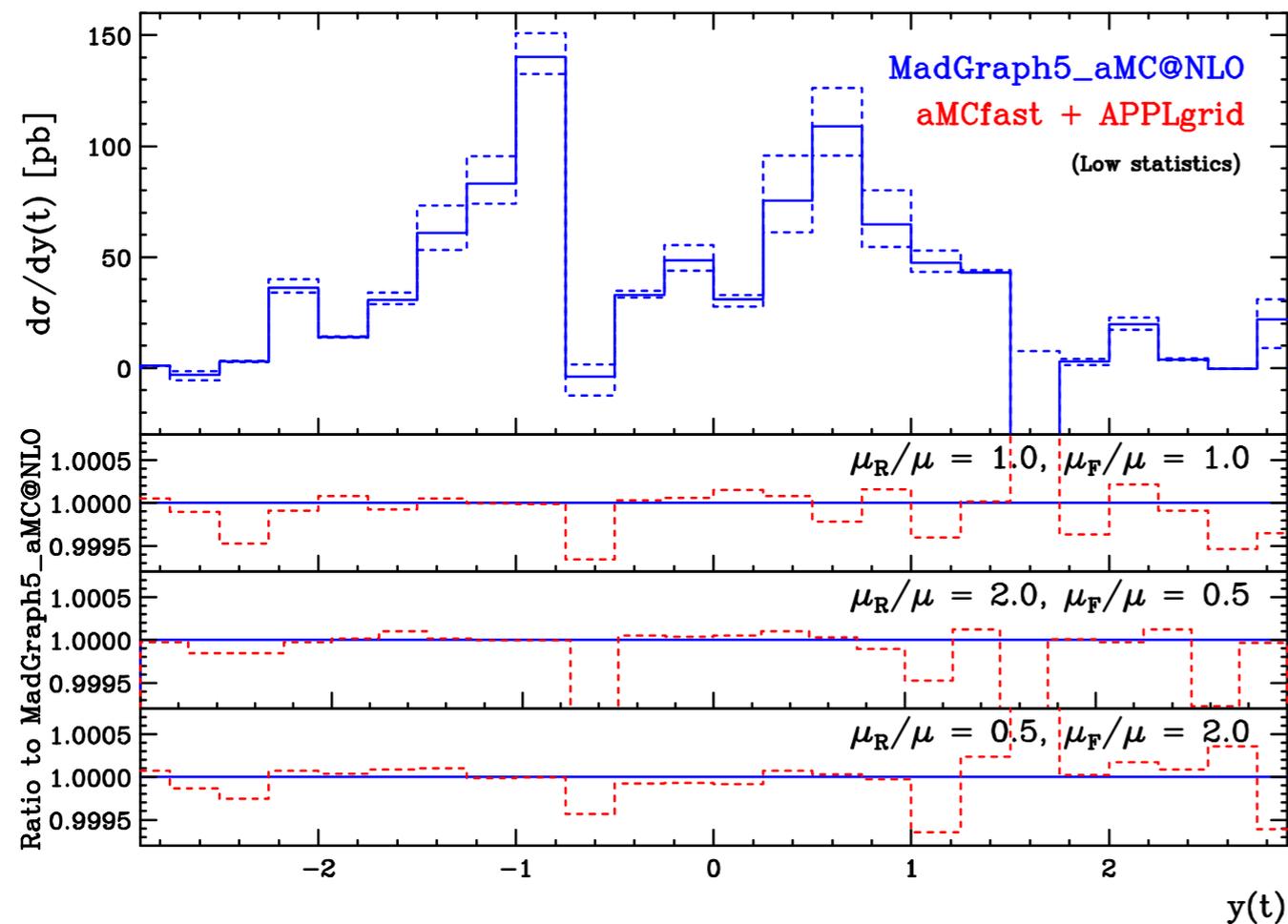
- Important for constraining the large- x gluon.
- We looked at the following observables:
 - the rapidity distribution of the top quark (left),
 - the invariant mass distribution of the top pair (right).
- High statistics plots:



The aMCfast Interface

Validation: Top-Quark Pair Production

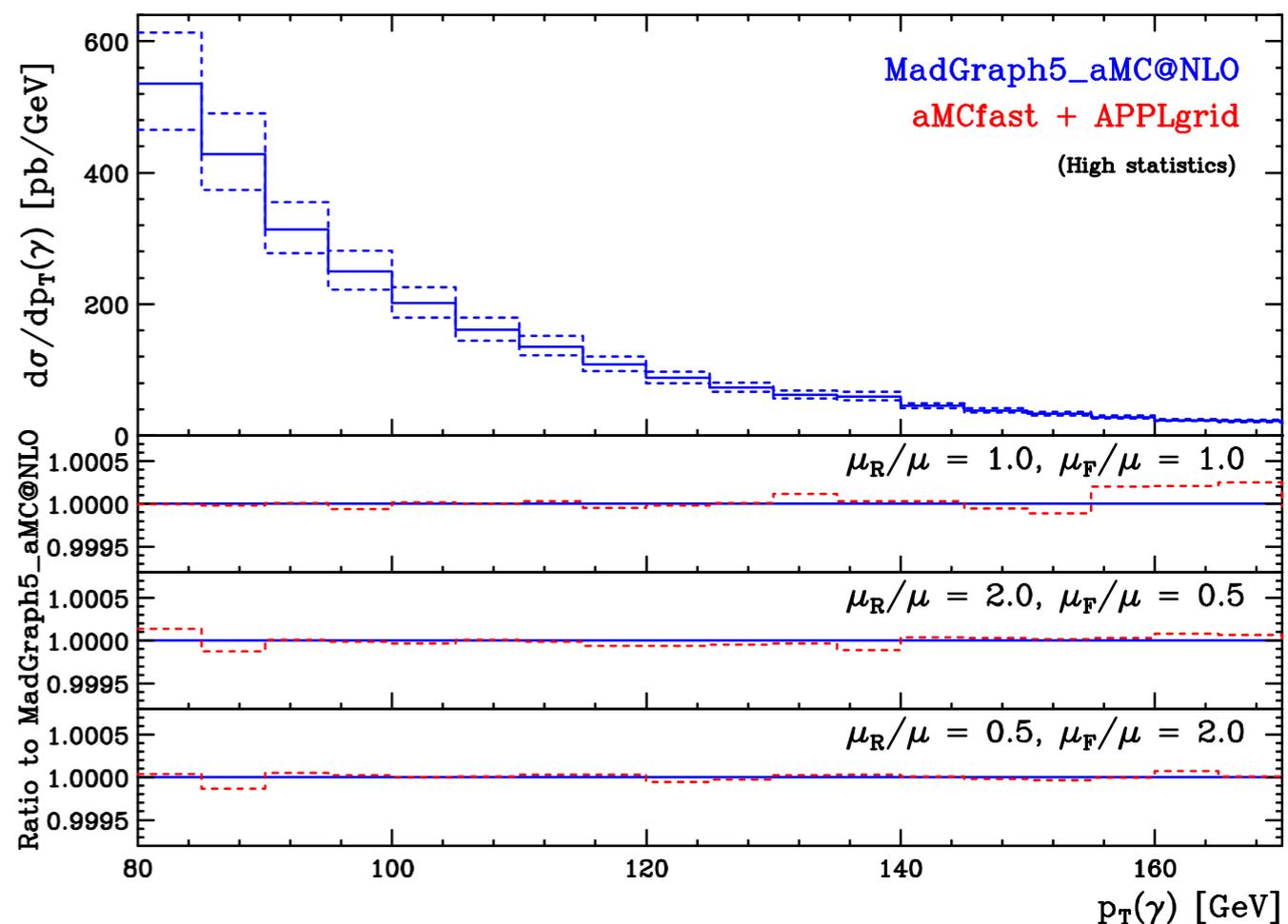
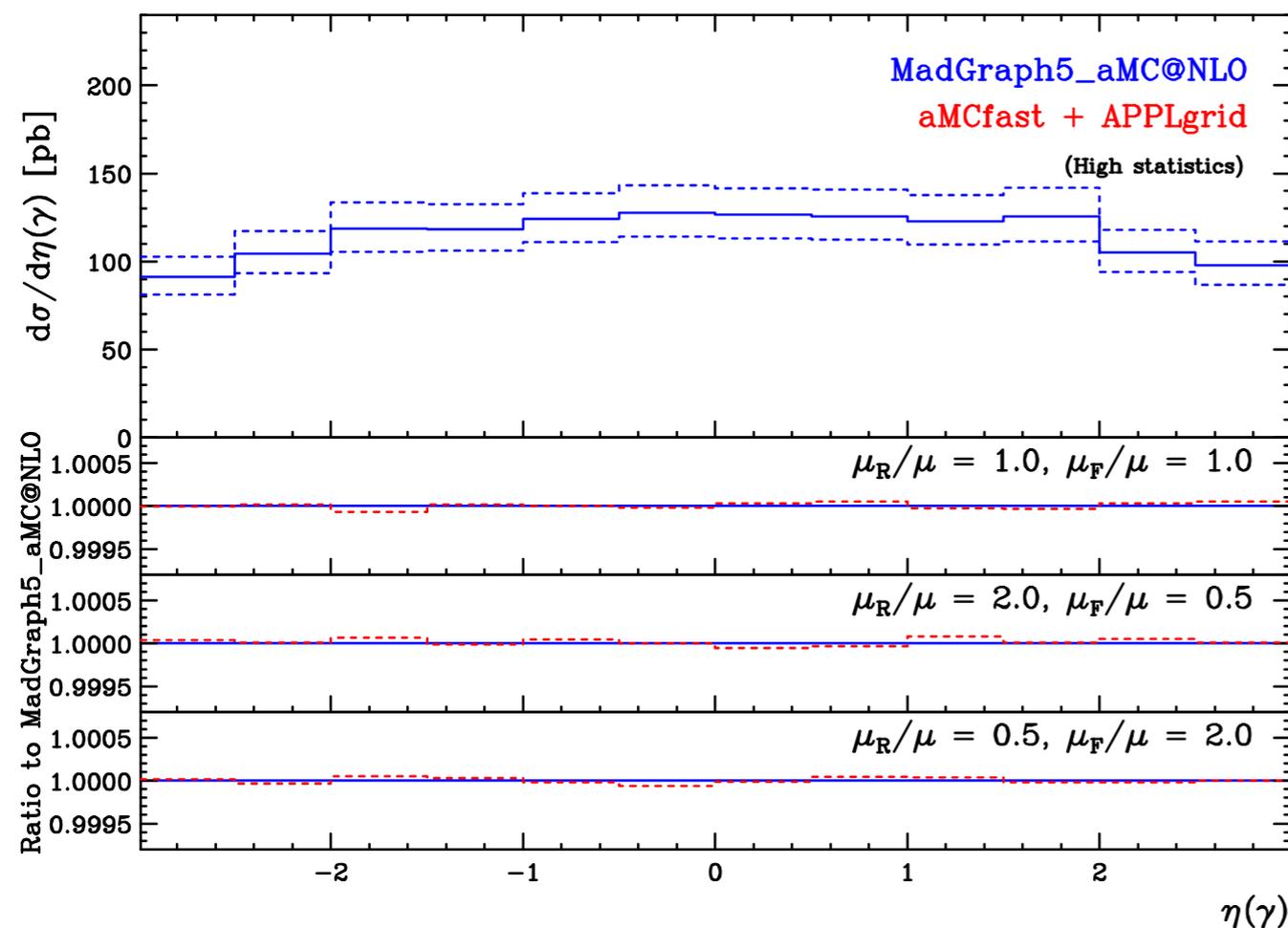
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The aMCfast Interface

Validation: Photon Production with one Jet

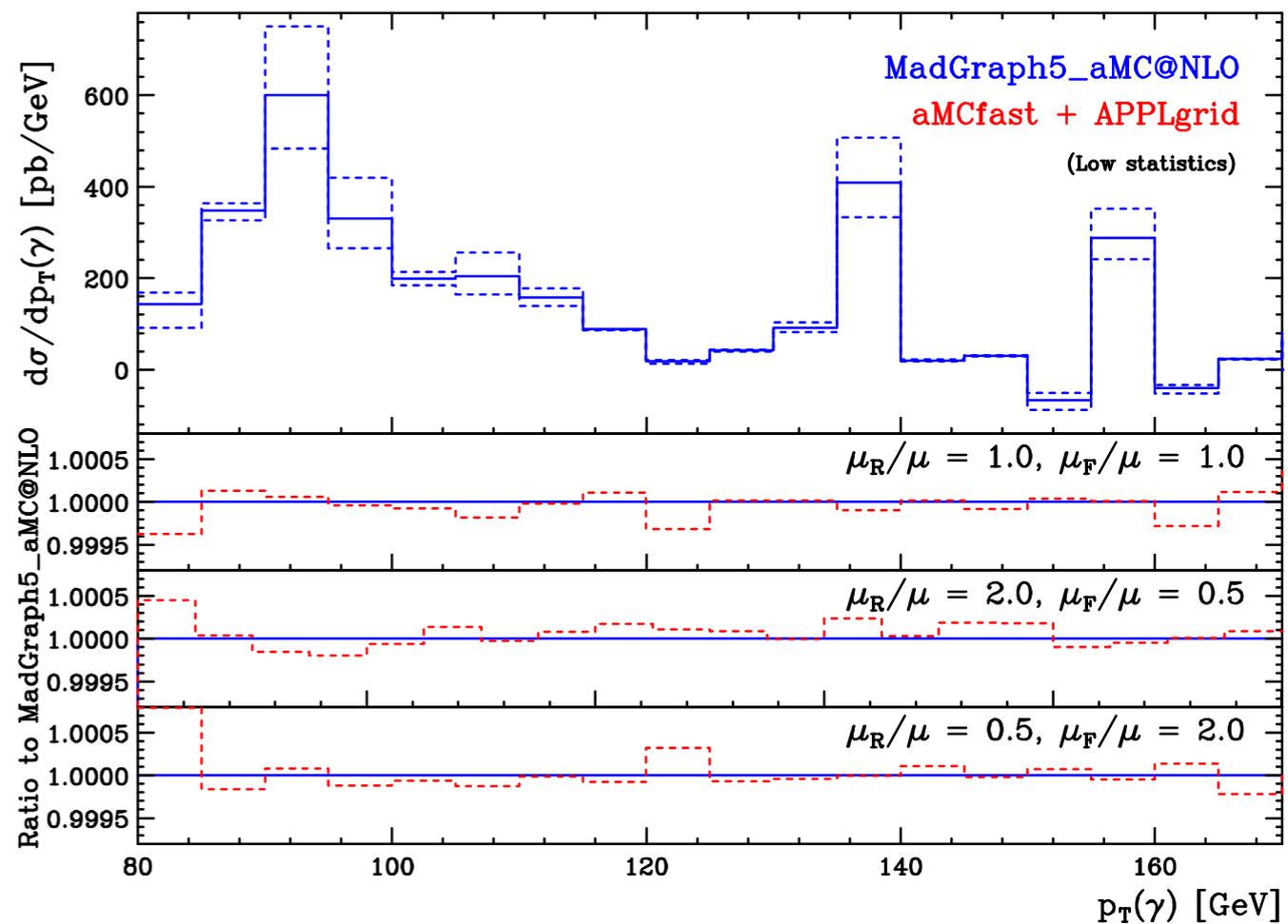
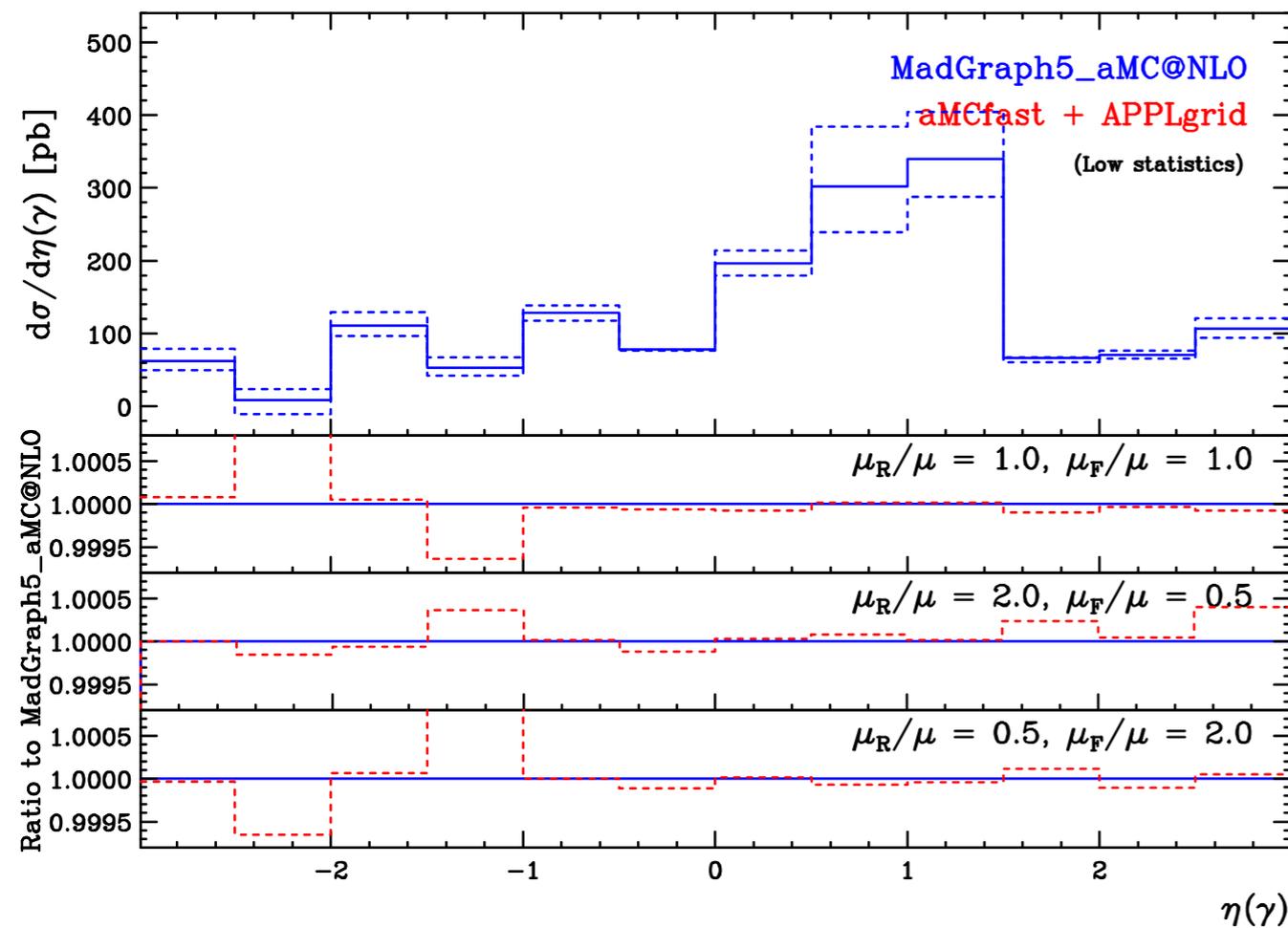
- Important for the gluon in the region relevant for Higgs production in gluon fusion.
- We looked at the following observables:
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- High statistics plots:



The aMCfast Interface

Validation: Photon Production with one Jet

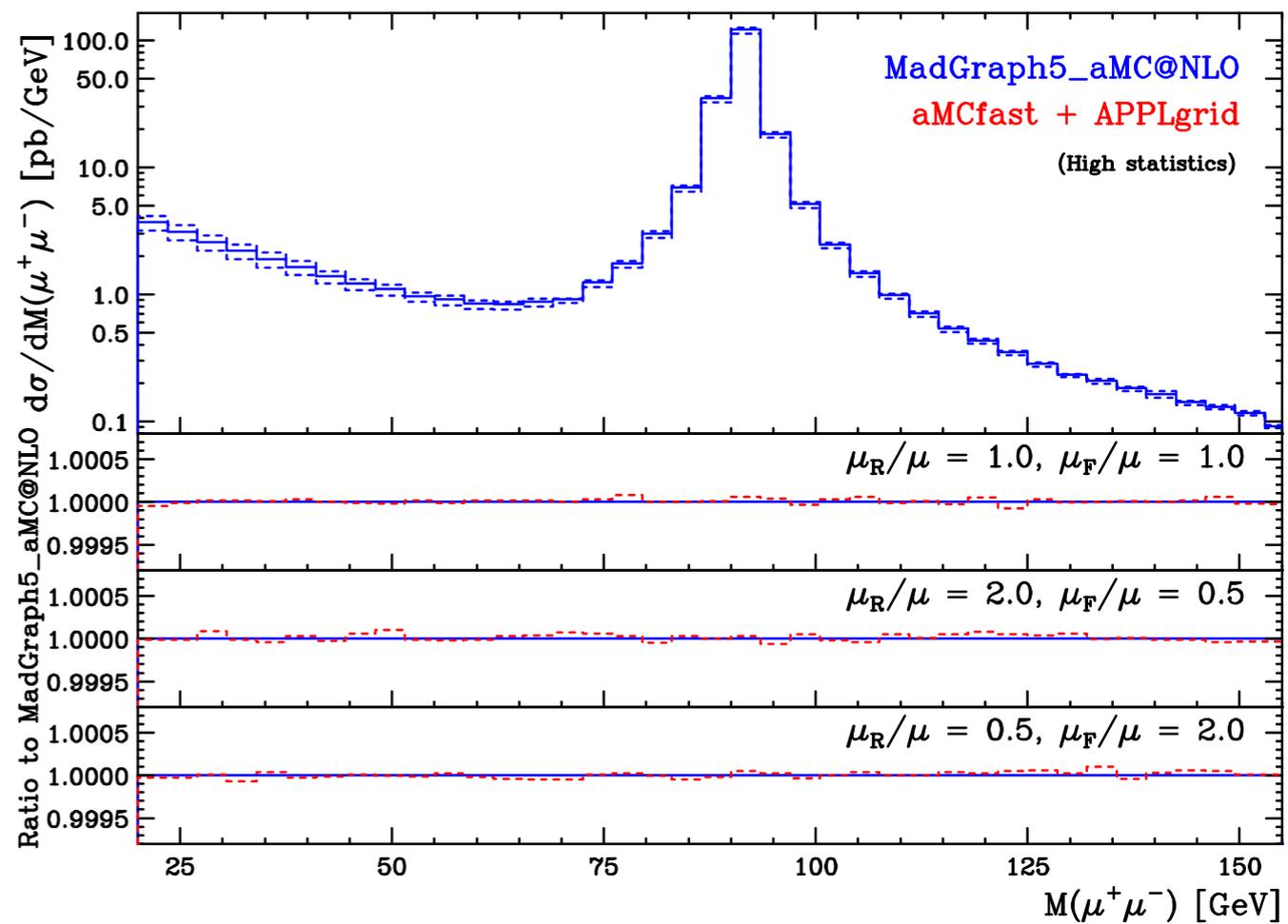
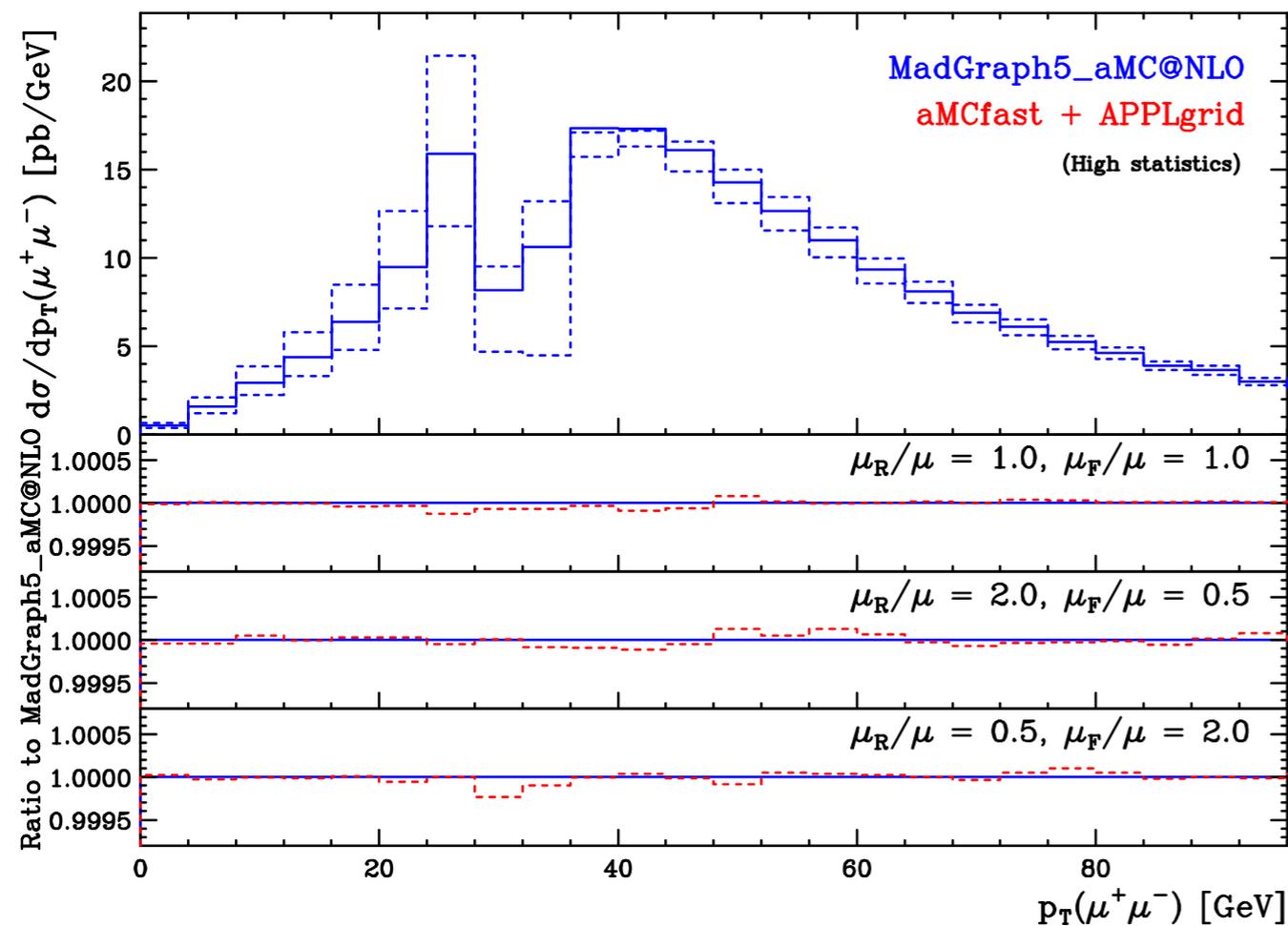
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The aMCfast Interface

Validation: Dilepton Production with one Jet

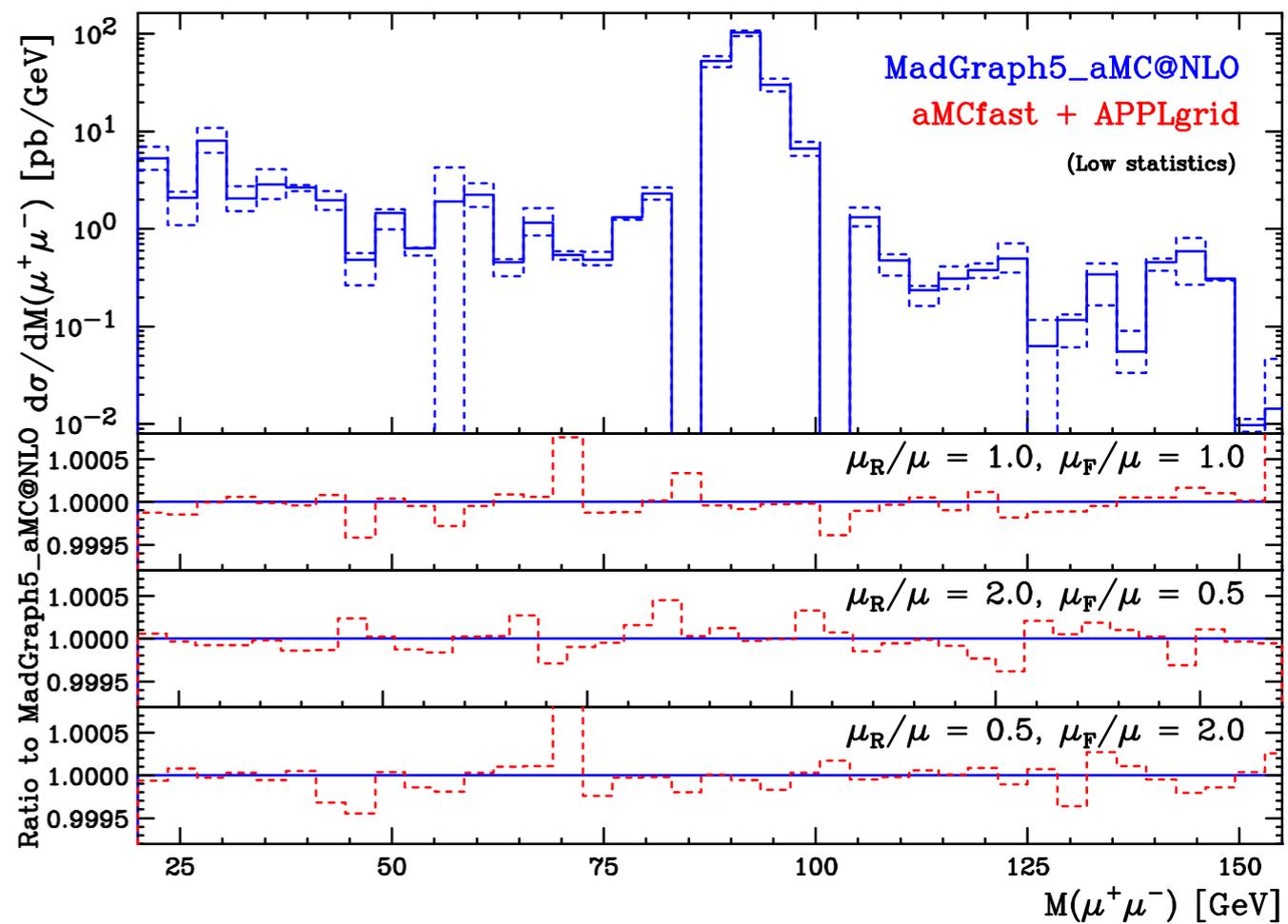
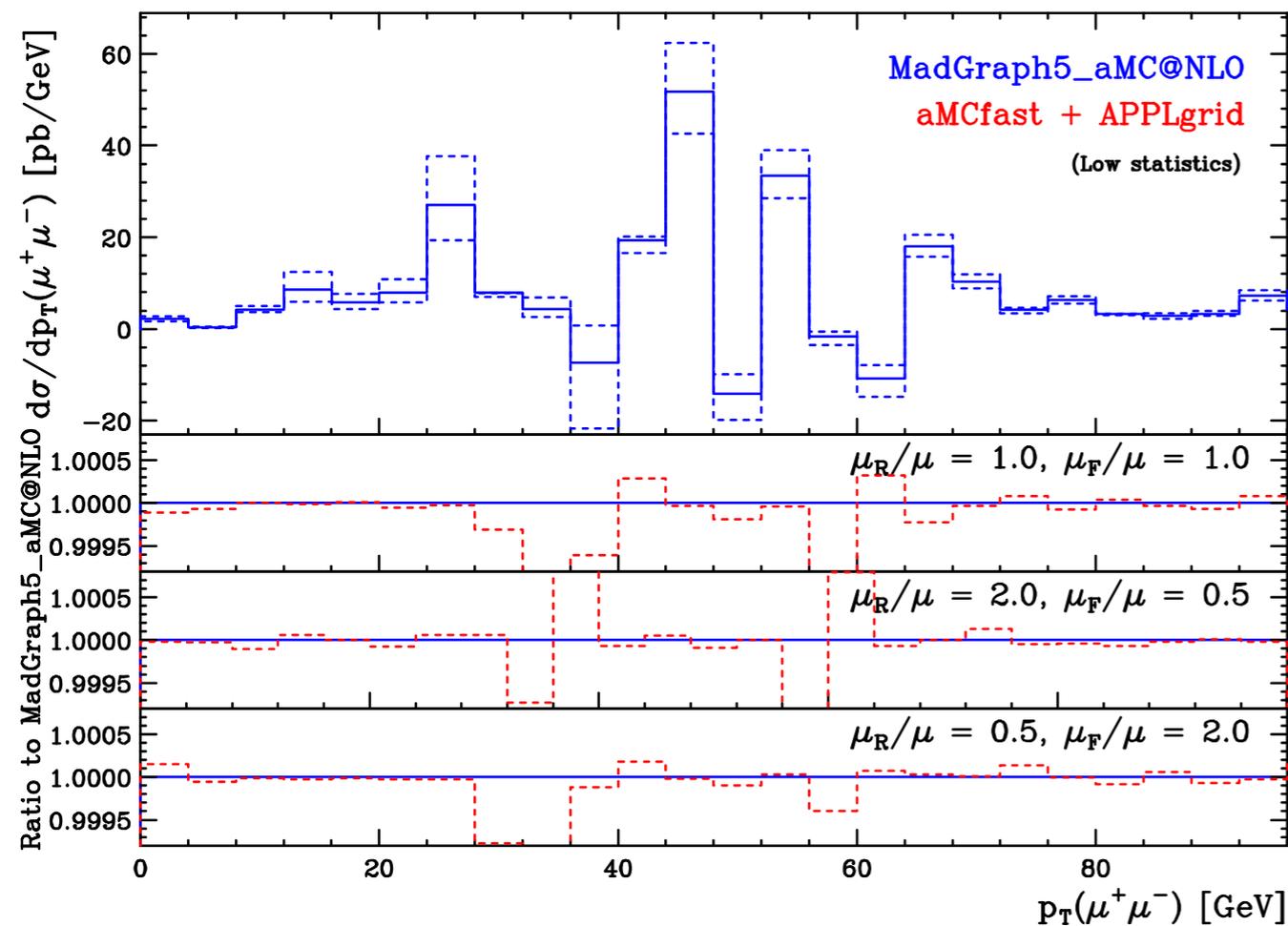
- Relevant for quarks and antiquarks in the large- x region.
- We looked at the following observables:
 - the transverse momentum distribution of the lepton pair (left),
 - the invariant mass distribution of the lepton pair (right).
- High statistics plots:



The aMCfast Interface

Validation: Dilepton Production with one Jet

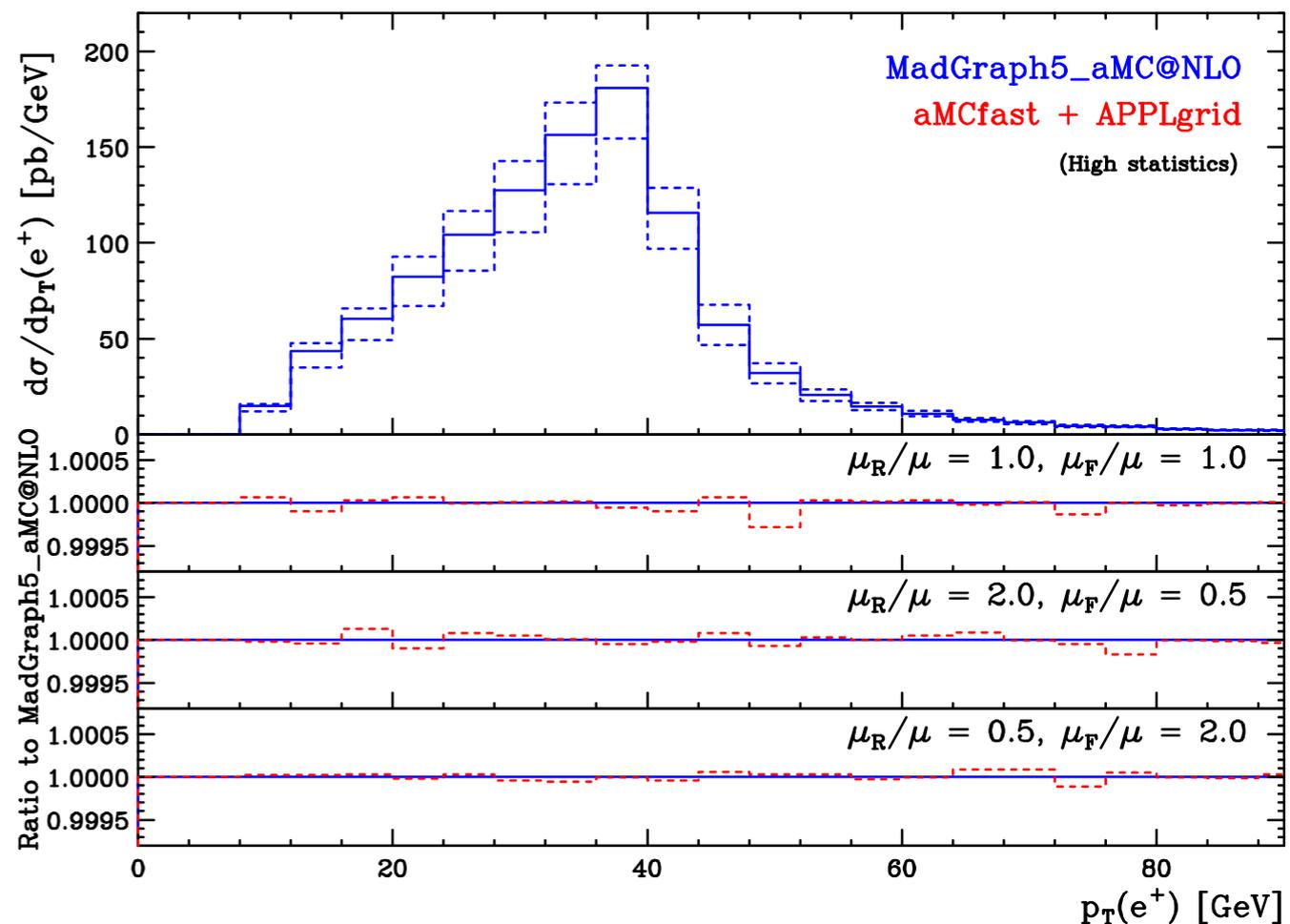
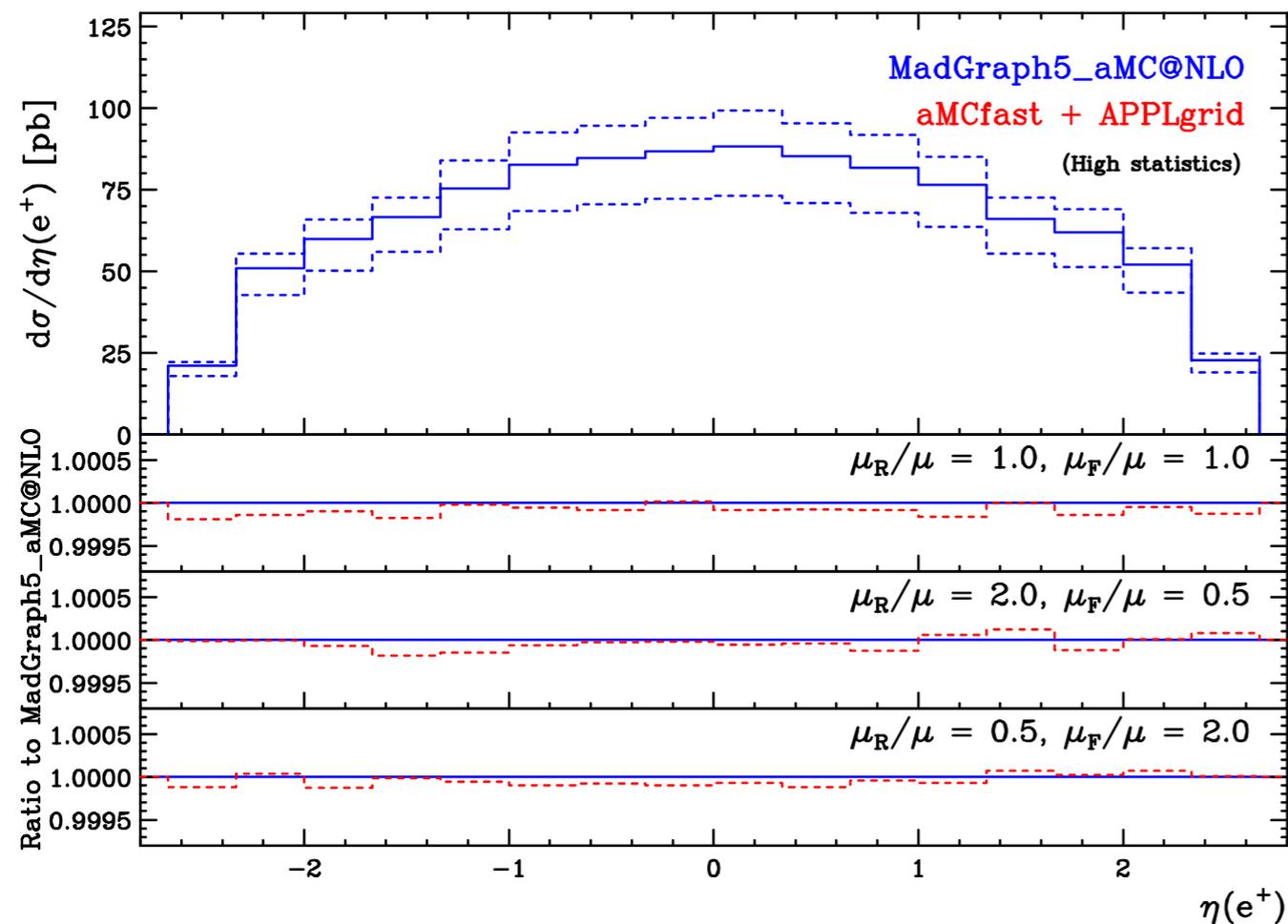
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The aMCfast Interface

Validation: $W + c$ Production

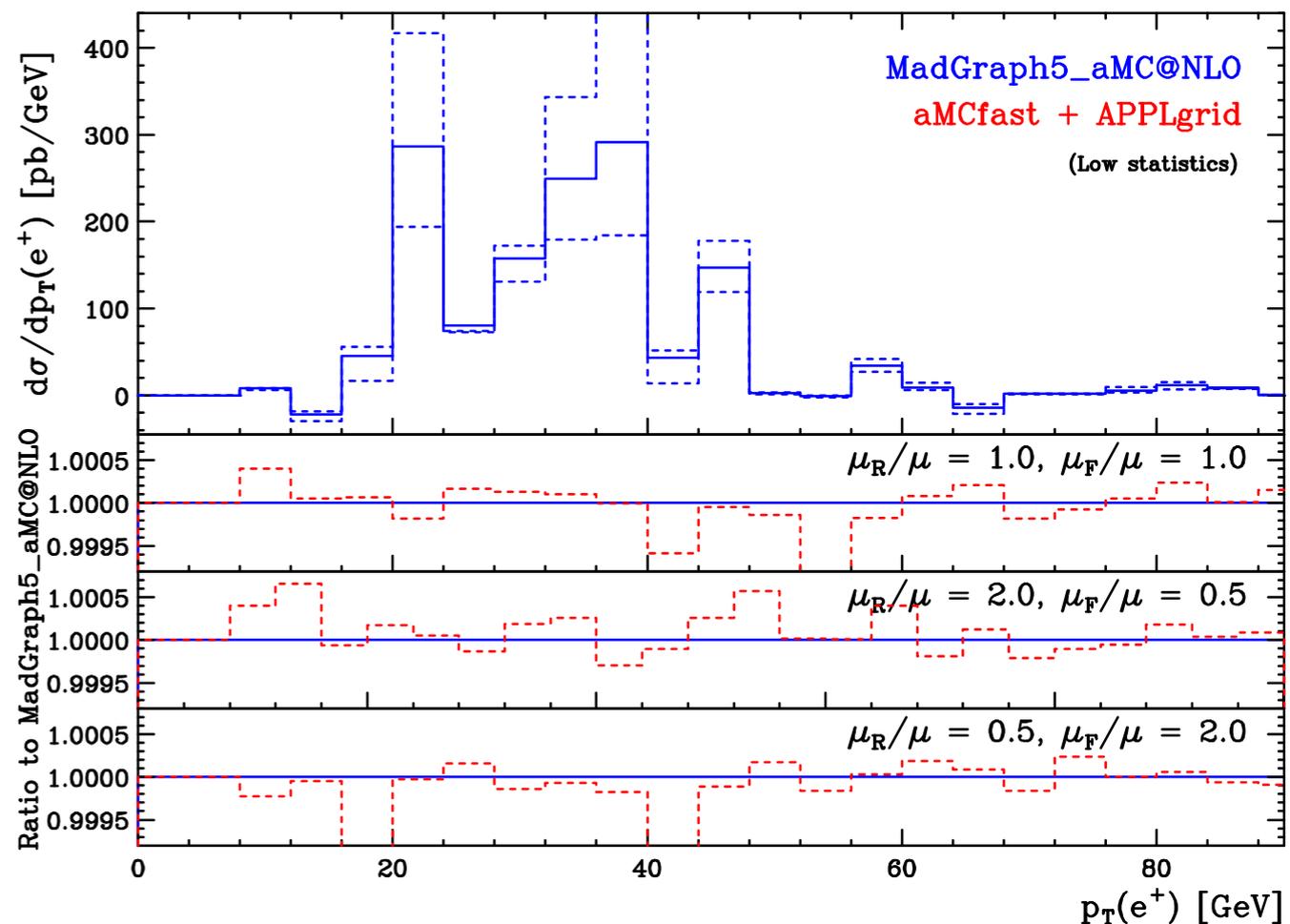
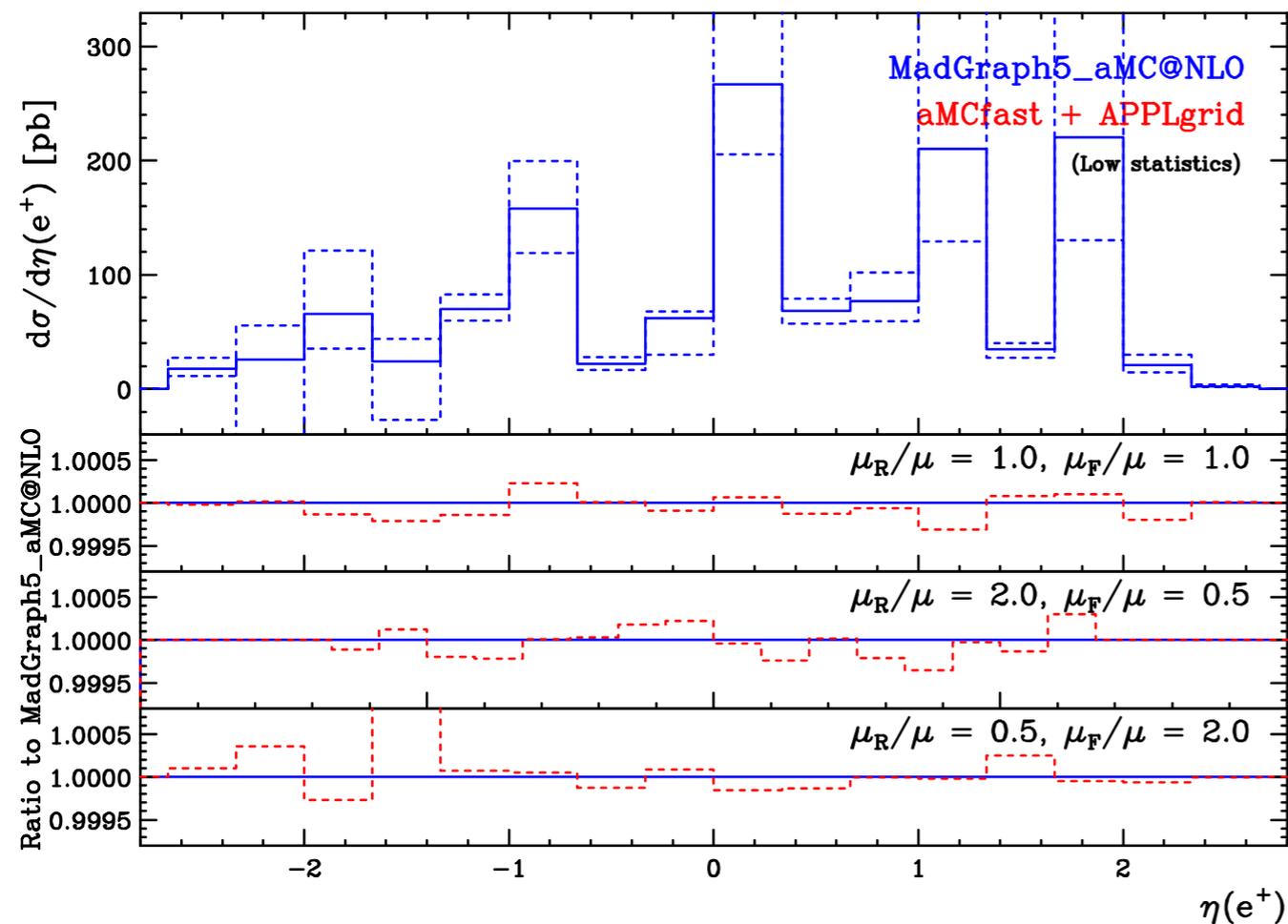
- Important for constraining the strange-quark PDFs.
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The aMCfast Interface

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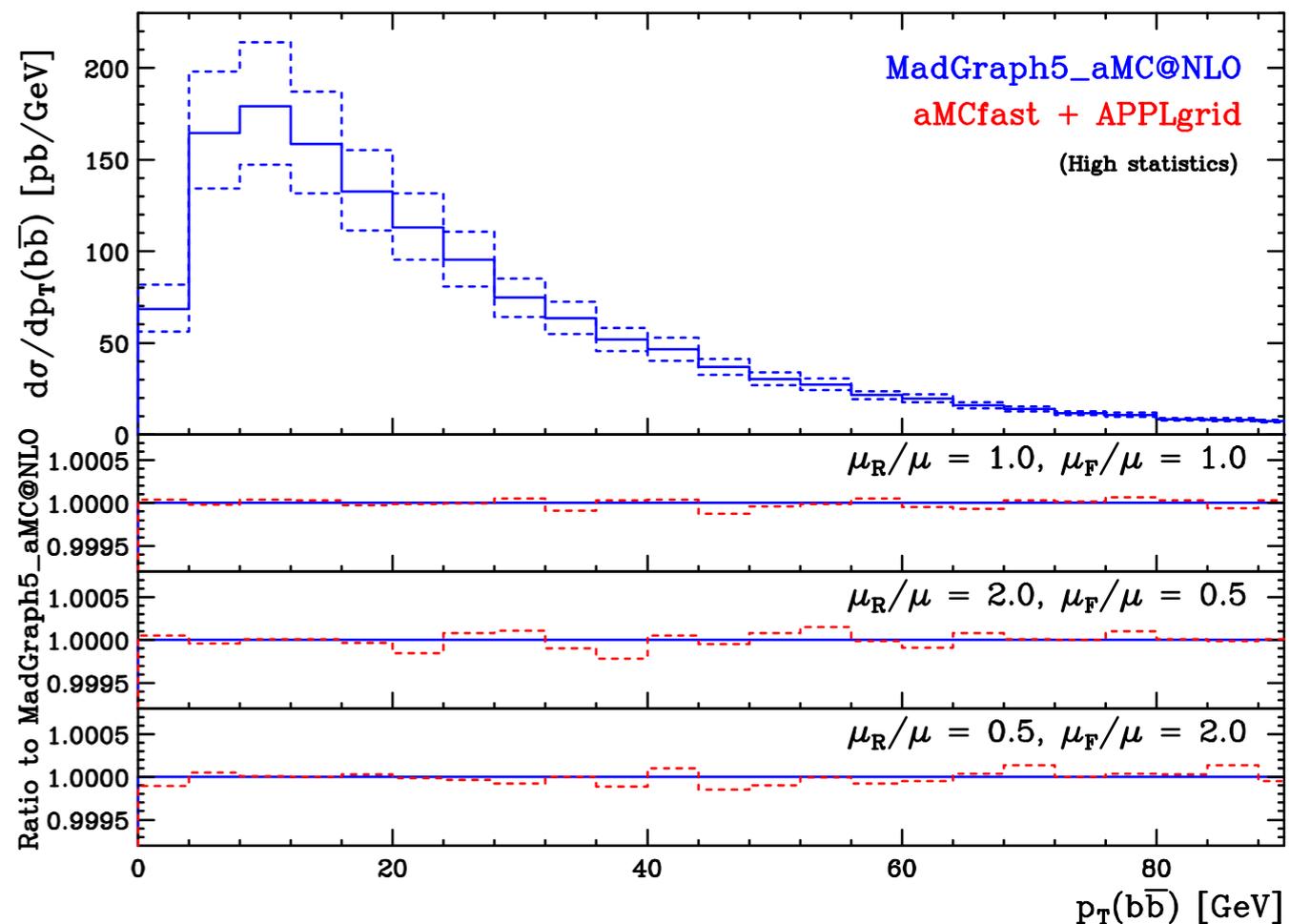
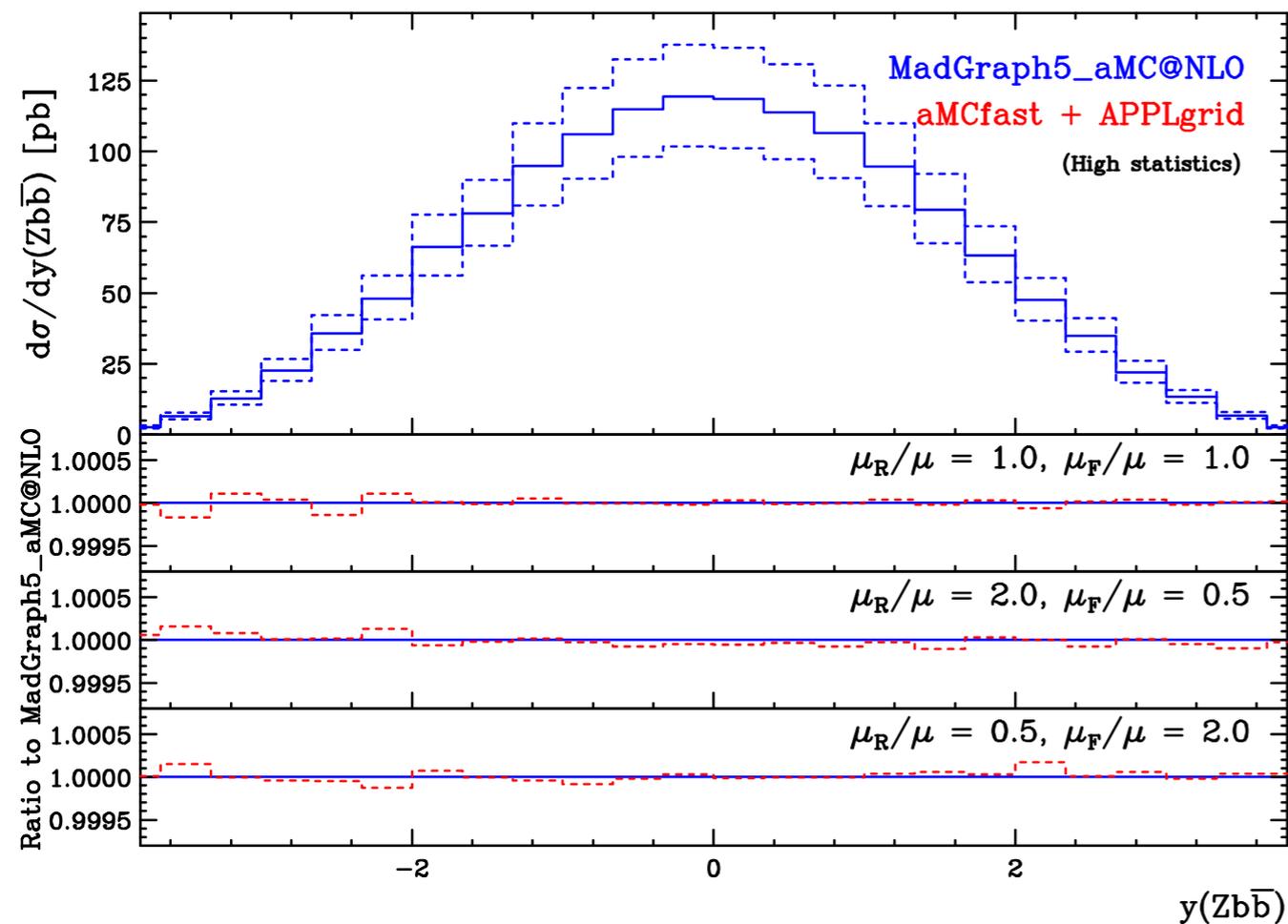
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The aMCfast Interface

Validation: $Z + bb$ Production

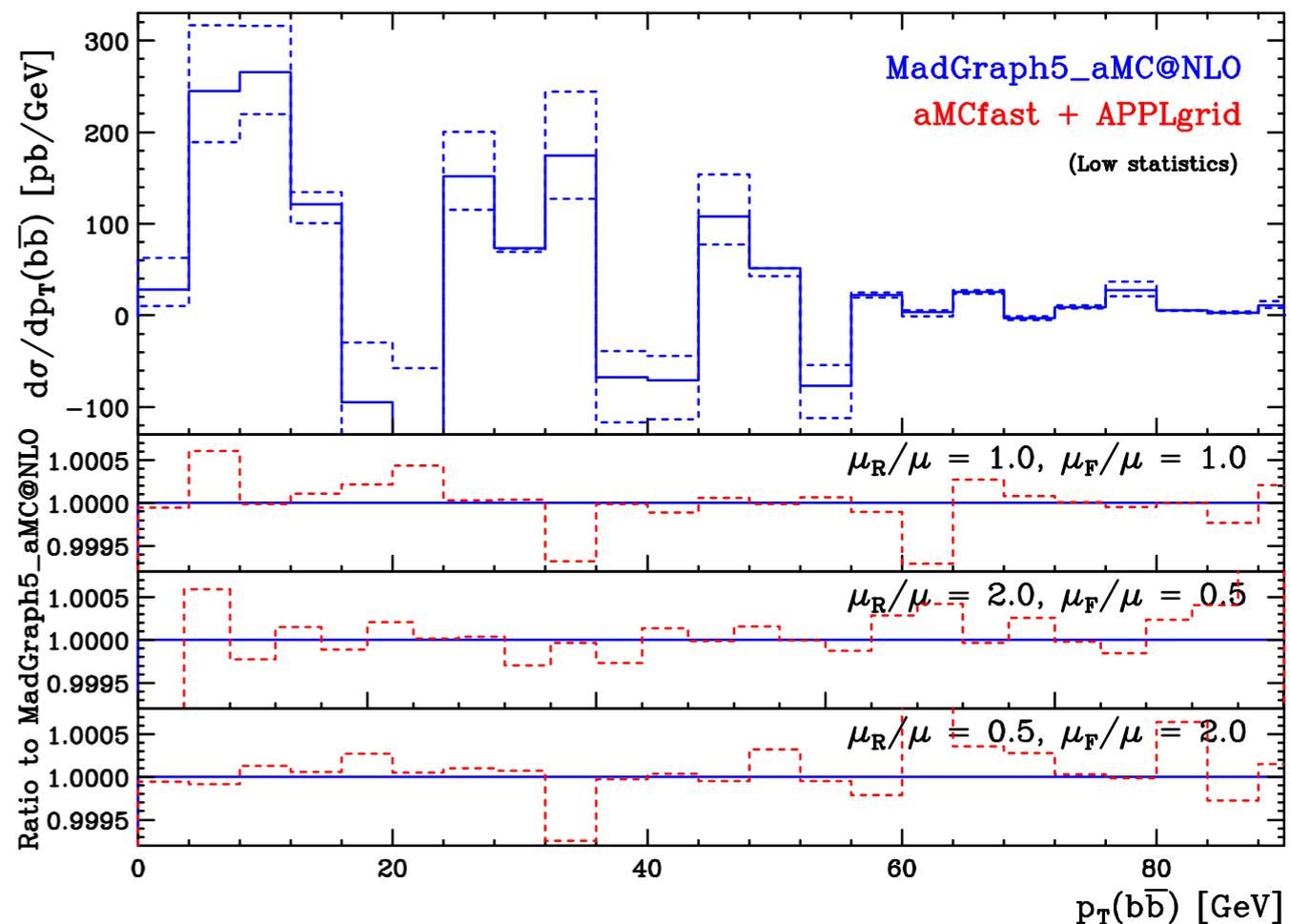
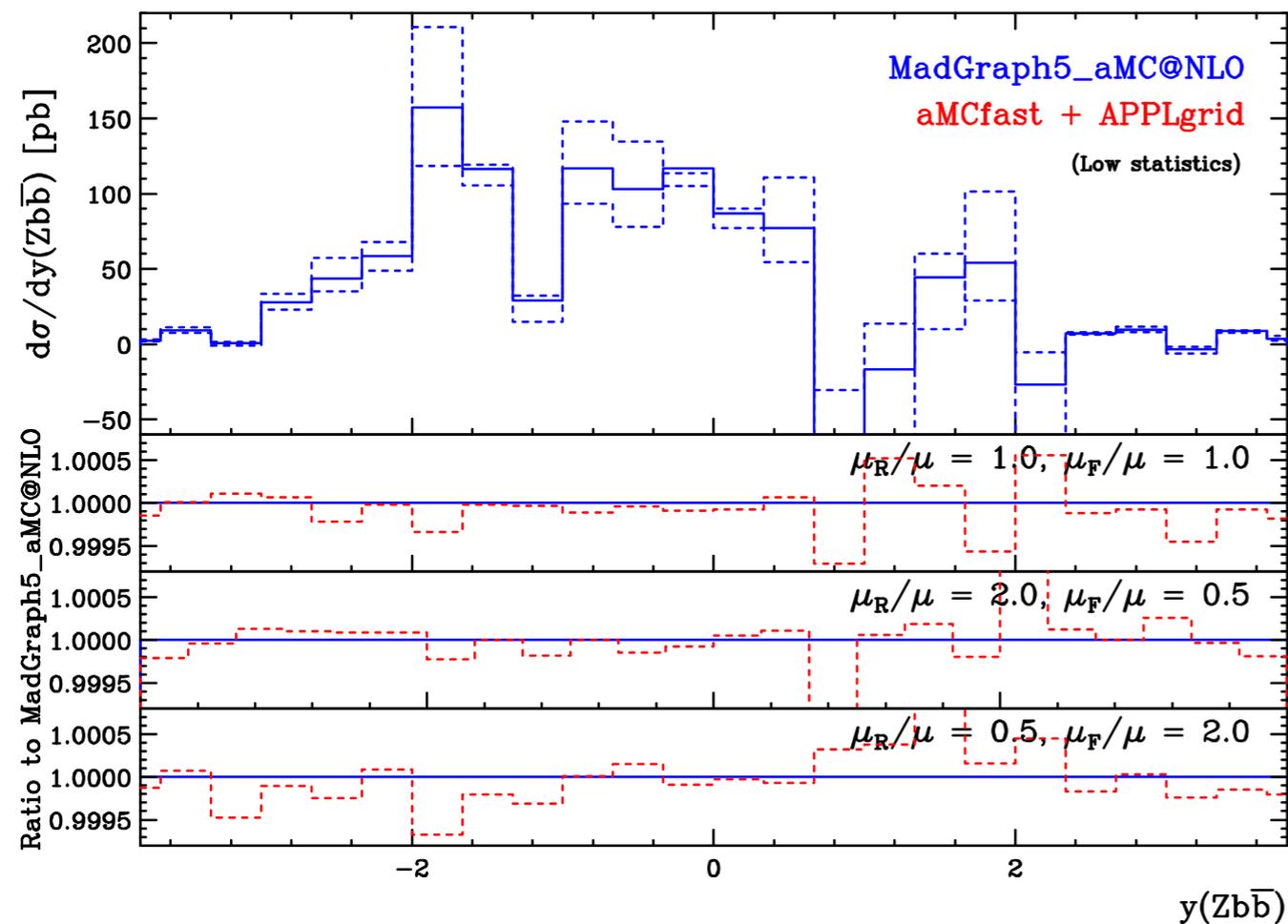
- This is just an example of complicated process.
- We looked at the following observables:
 - the rapidity distribution of the Zbb system (left),
 - the transverse momentum distribution of the Zbb system (right).
- High statistics plots:



The aMCfast Interface

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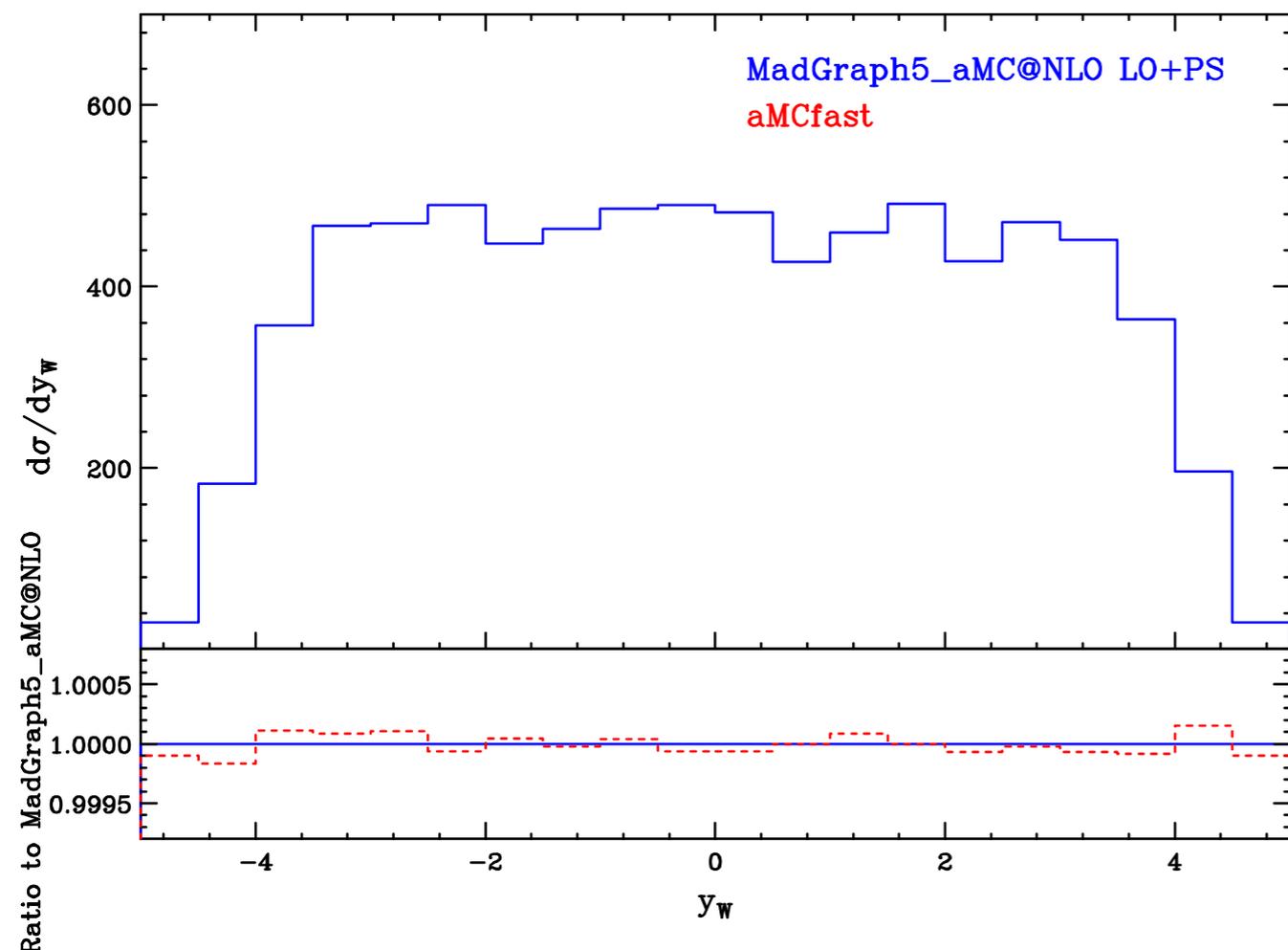


The aMCfast Interface

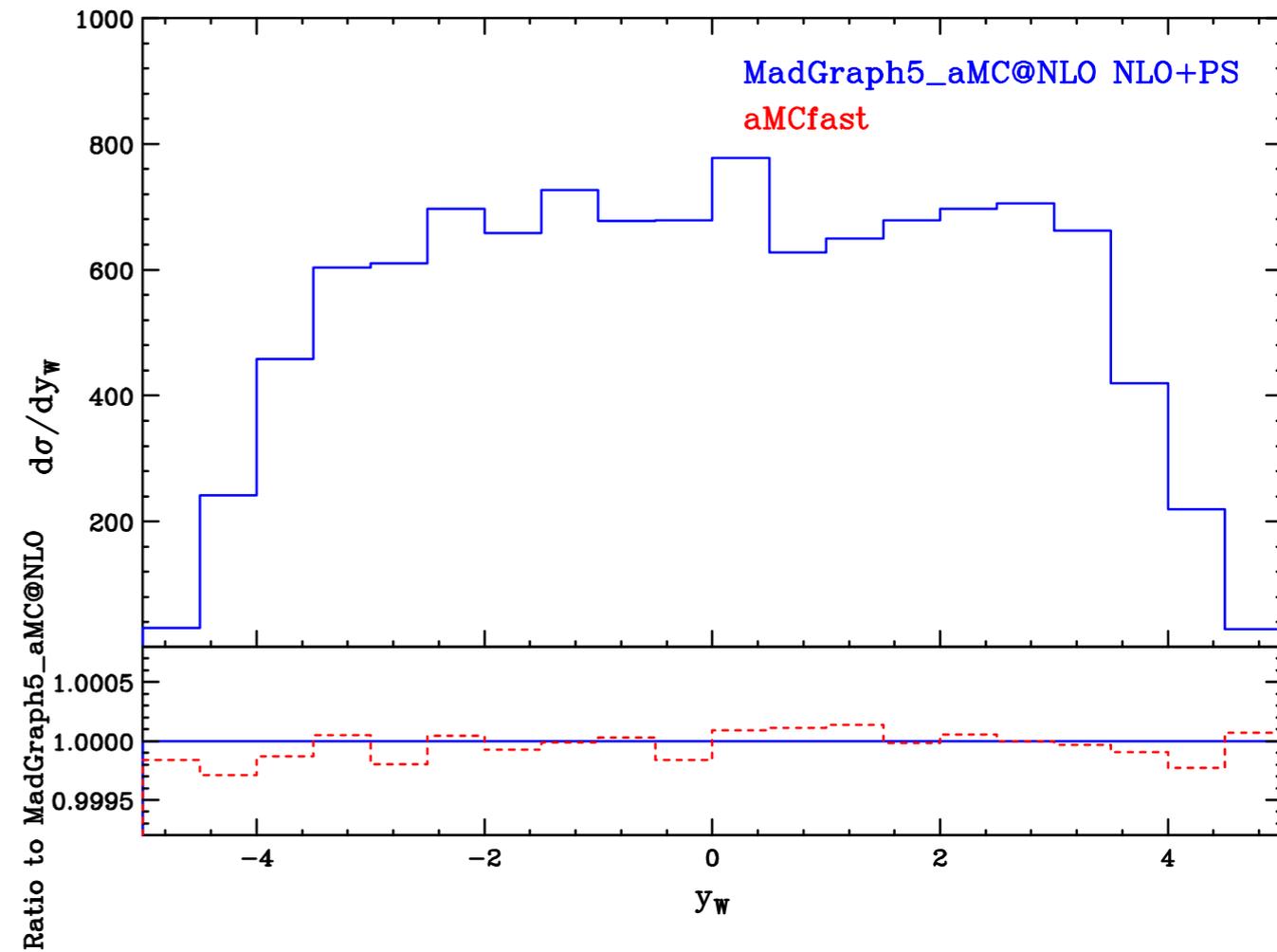
The NLO + PS Case: Preliminary Results

- We are presently working on extending aMCfast to the (N)LO +PS mode of MadGraph5_aMC@NLO.
- Preliminary results are already available (see plots below):
 - perfect agreement between reference and reconstructed histograms also in the low statistics regime, as in the fixed-order case.

MadGraph5_aMC@NLO vs. aMCfast (LO+PS)



MadGraph5_aMC@NLO vs. aMCfast (NLO+PS)



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 extremely 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/>