Polarized charm and bottom quark production in proton-proton collisions at the LHC

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Aim of this work is research into electro-weak (EW) production of charm and beauty quarks in proton-proton scattering at the LHC energies.

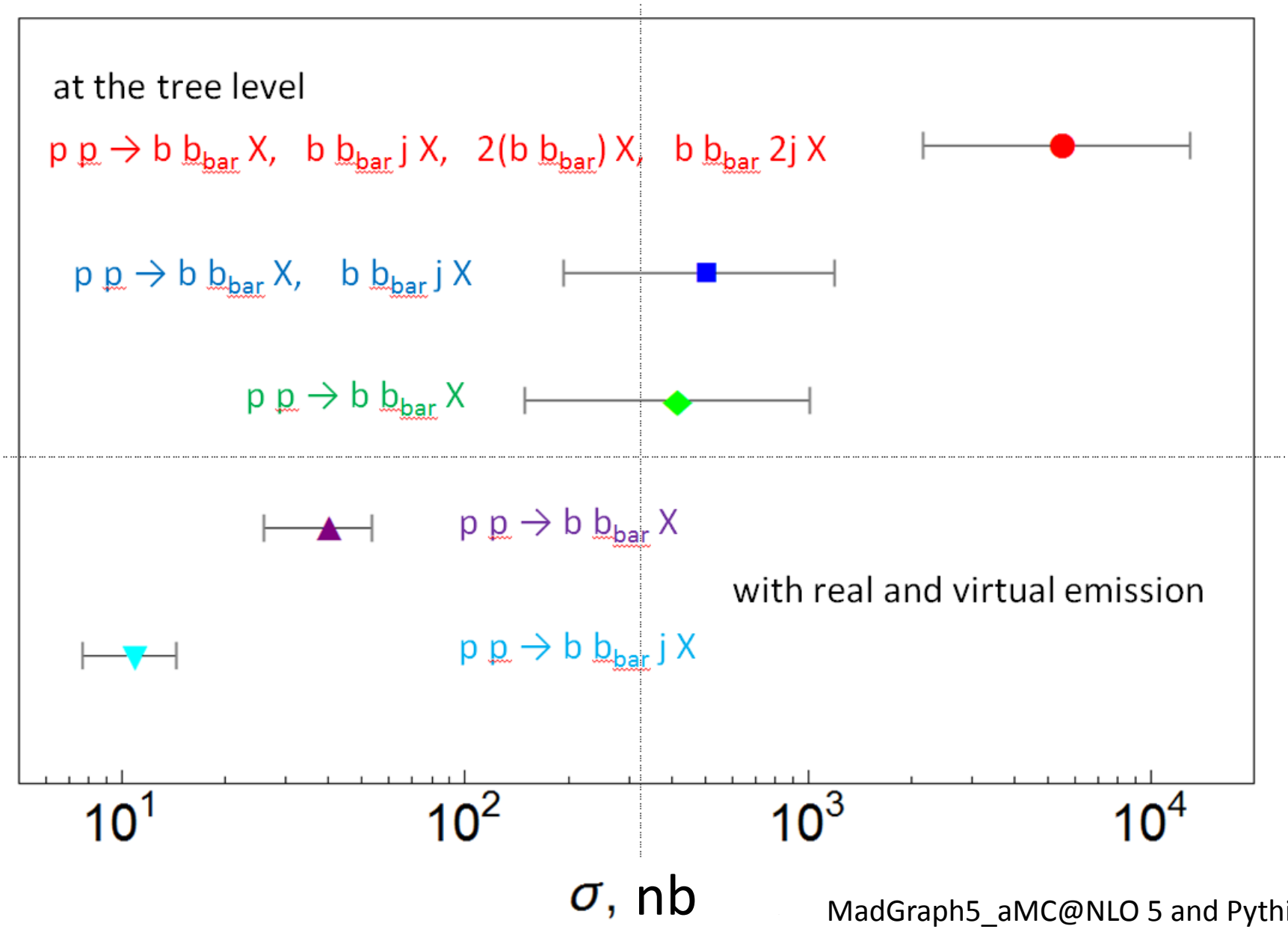
With this end partonic processes are simulated at the tree approximation with **MadGraph5_aMC@NLO** interfaced with **Pythia 8** to include showers and multiparton interaction.

The cross sections for processes with **heavy quark, W, and light jets** in the final states are computed. Final states with 2 ... 5 particles are considered.

Calculated helicity asymmetries take on values from -1 to +0.2
for quark rapidities in interval $0<y<5$.

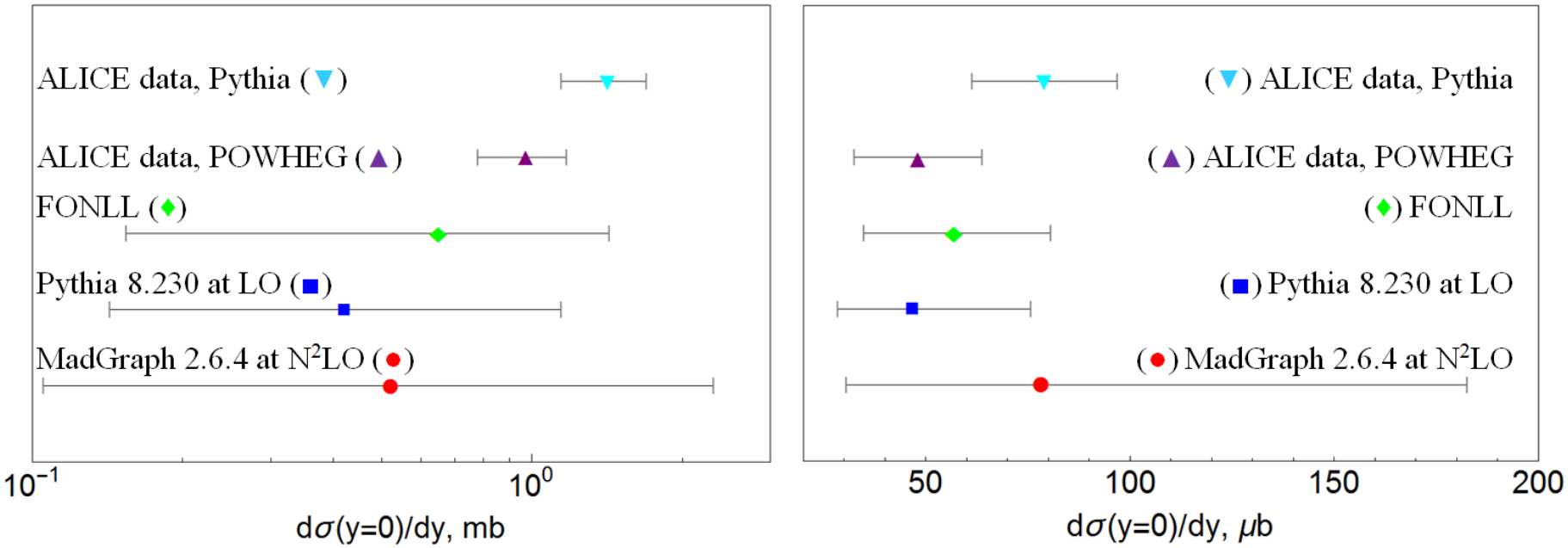
Cross sections for EW and QCD processes are compared.

Beauty Quark Anti-Quark Pair Production at 13 TeV



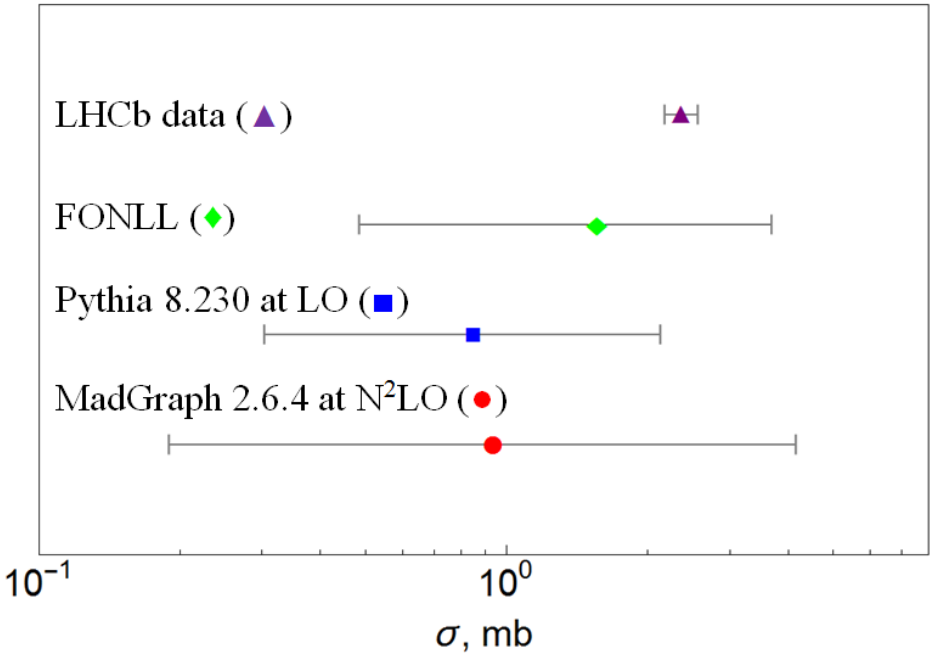
MadGraph5_aMC@NLO 5 and Pythia 8

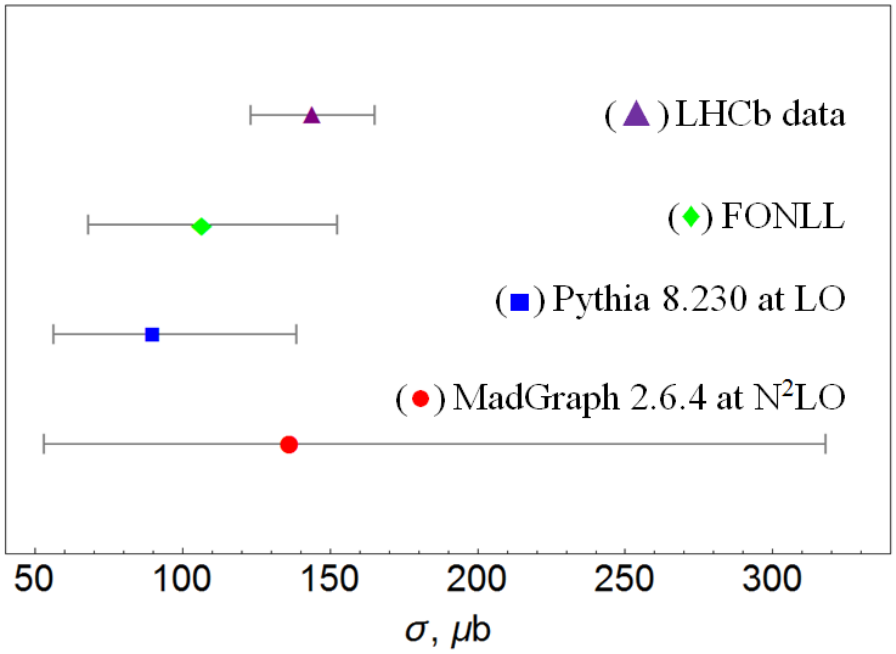
Differential cross sections of $c\bar{c}$ and $b\bar{b}$ production at zero rapidity in pp scattering at 13 TeV



The ALICE data are from S. Acharya et al., Phys. Lett. B. **788**, 505 (2018).

Integral cross sections of $c\bar{c}$ and $b\bar{b}$ production in pp scattering at 13 TeV



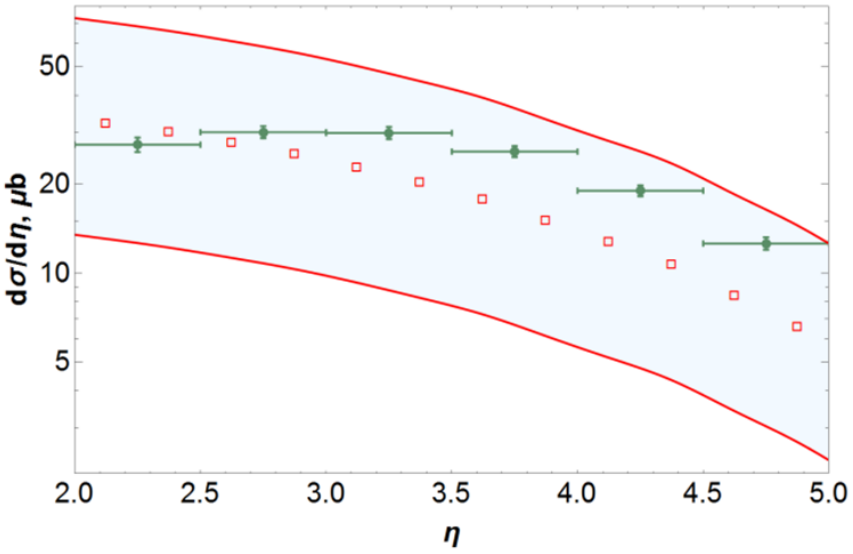


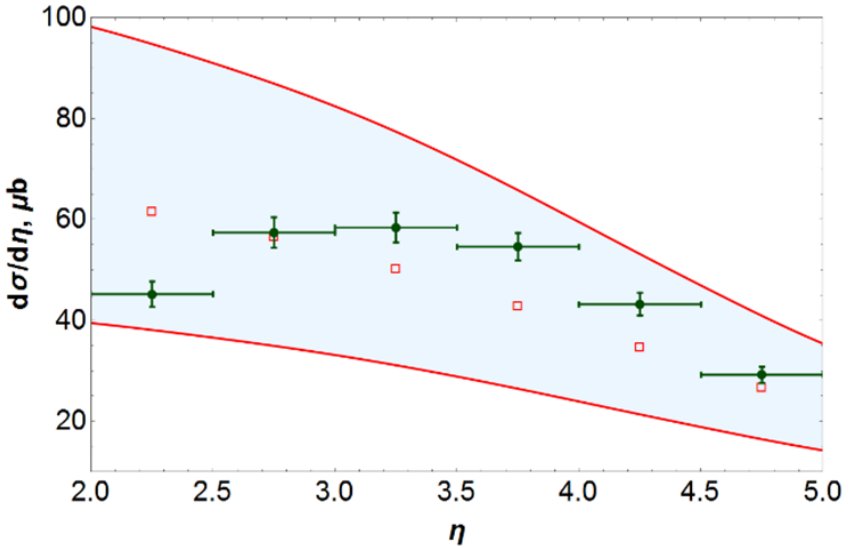
The LHCb data are from

R. Aaij et al. , J. High Energy Phys. **1603,** 159 (2016),
Erratum: J. High Energy Phys. **1609**, 013 (2016), J. High Energy Phys. **1705**, 074 (2017)

R. Aaij et al., Phys. Rev. Lett. **118**, 052002 (2017),
Erratum: Phys. Rev. Lett. **119**, 169901 (2017).

Differential cross sections of $b\bar{b}$ production in pp scattering at 7 and 13 TeV





Calculations with MadGraph and Pythia are shown by the squares, the scale uncertainties - by the band.

The LHCb data are from
R. Aaij et al., Phys. Rev. Lett. **118**, 052002 (2017),
Erratum: Phys. Rev. Lett. **119**, 169901 (2017).

MadGraph5_aMC@NLO 5 and Pythia 8

Results for the cross sections obtained with MadGraph5_aMC@NLO in junction with Pythia 8 at N^2LO are in agreement with the ALICE and LHCb data **within the band of uncertainties** due to renormalization and factorization scale variations.

At the same time, the *b* differential cross sections at 7 and 13 TeV as functions of pseudorapidity differ in shape from ones measured by the LHCb. Comparison of the computed cross sections with the ALICE and LHCb data demonstrates that for all measurements the **experimental uncertainties are smaller than theoretical ones**.

Below we discuss **EW Production** of

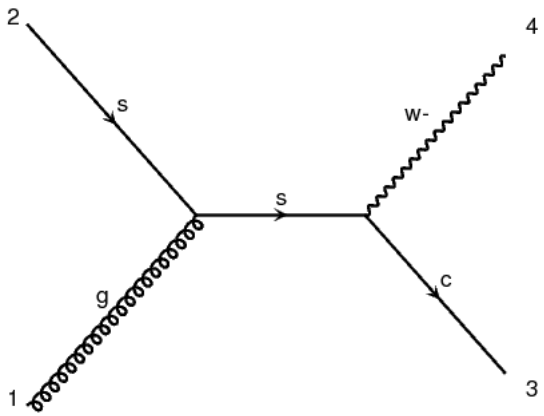
Single heavy quark in junction with light jest,

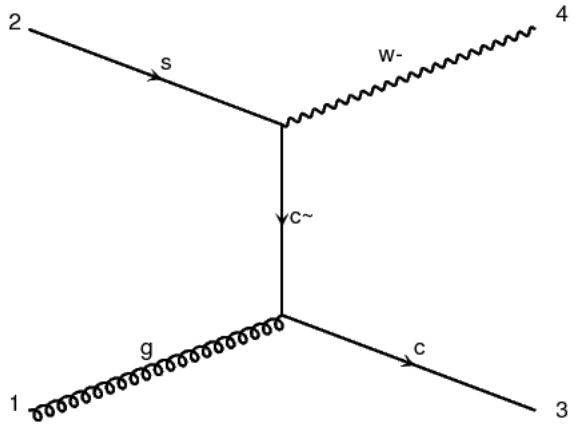
Heavy quark, W boson, and light jets (QWj)

Processes with charm and beauty quarks are considered.

Q W jet Single Heavy Quark Production

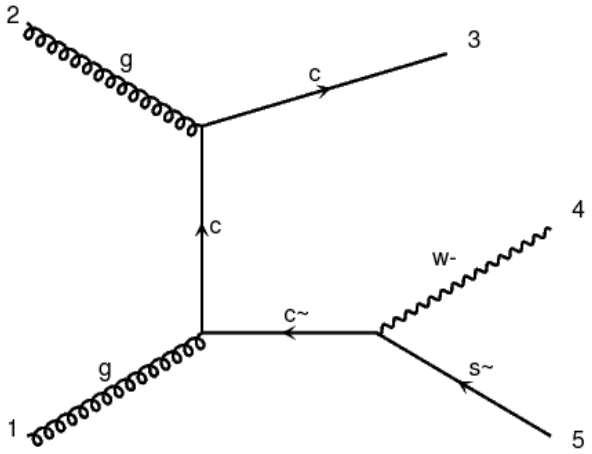
n=0

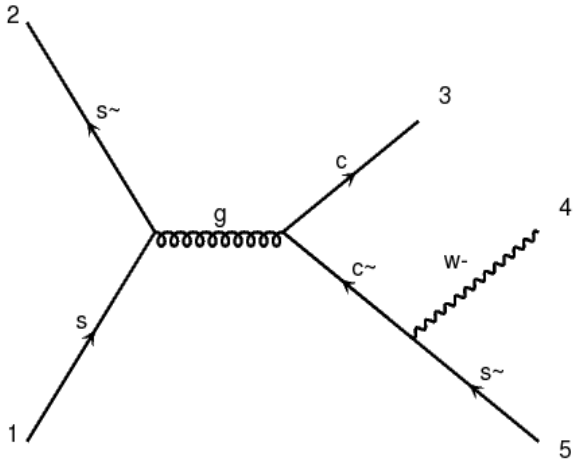




n(EW)=1

n=1

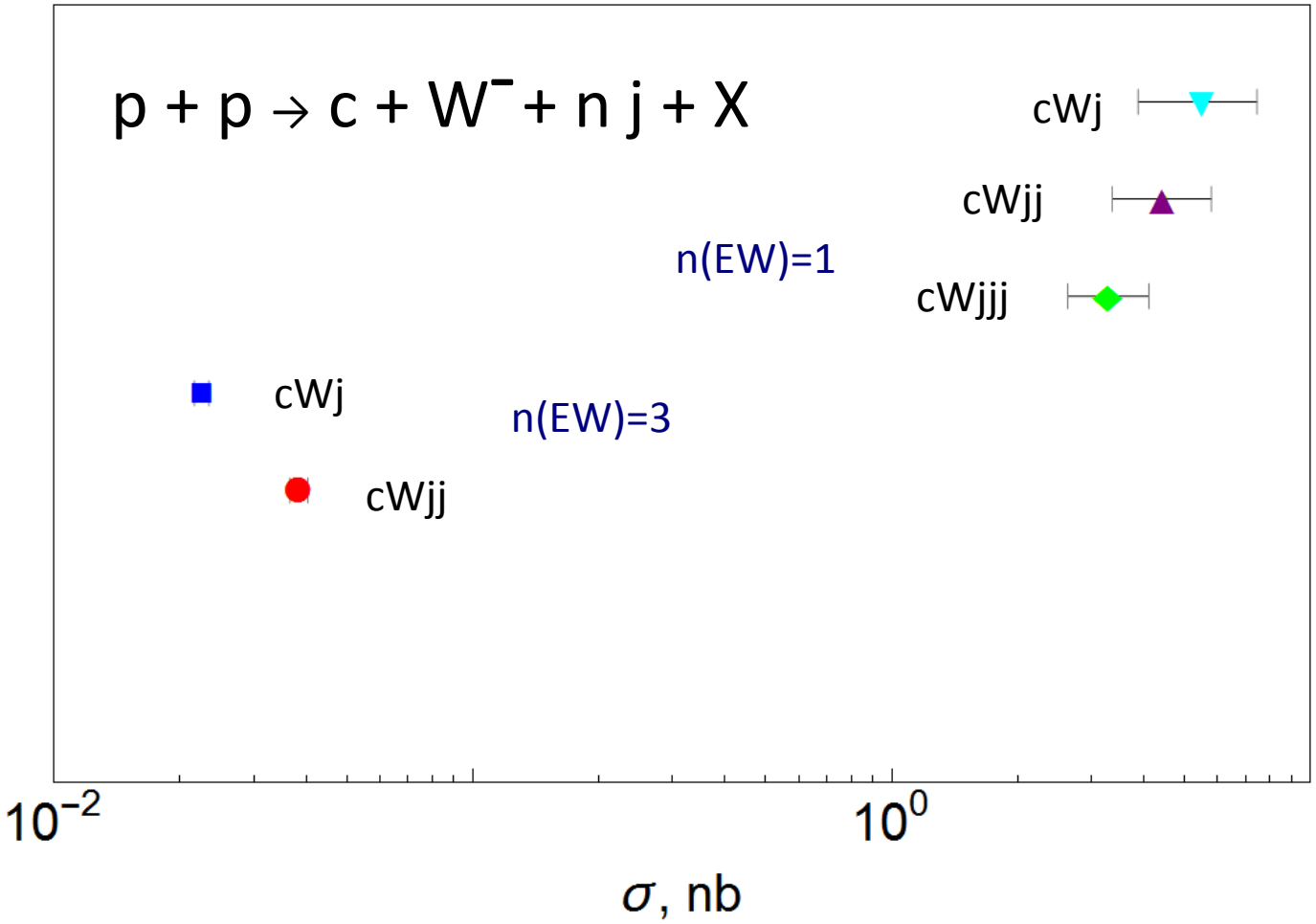




Heavy **Q**uark anti-**Q**uark pair production g → **Q** $\mathbf{Q_{bar}}$
followed by the transition $(\mathbf{Q_{bar}})^{*}$ → W q_{bar}

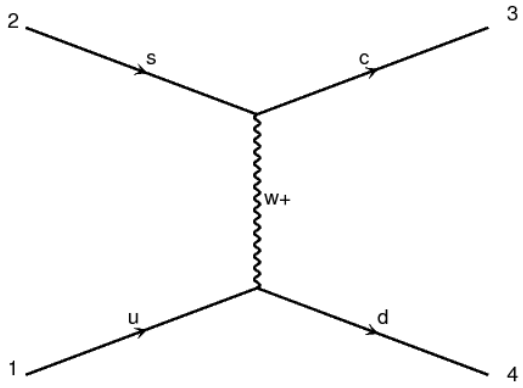
p + p → Q + W + n jet with n=0,1,2, and 3 includes
2, 36, 340, and 4424 diagrams at the tree level.

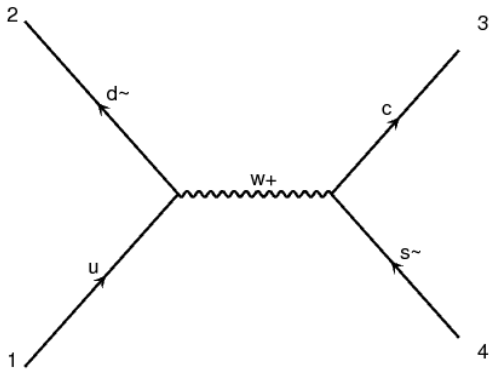
Q W jet Single Charm Quark Production at 13 TeV



MadGraph5_aMC@NLO 5 and Pythia 8

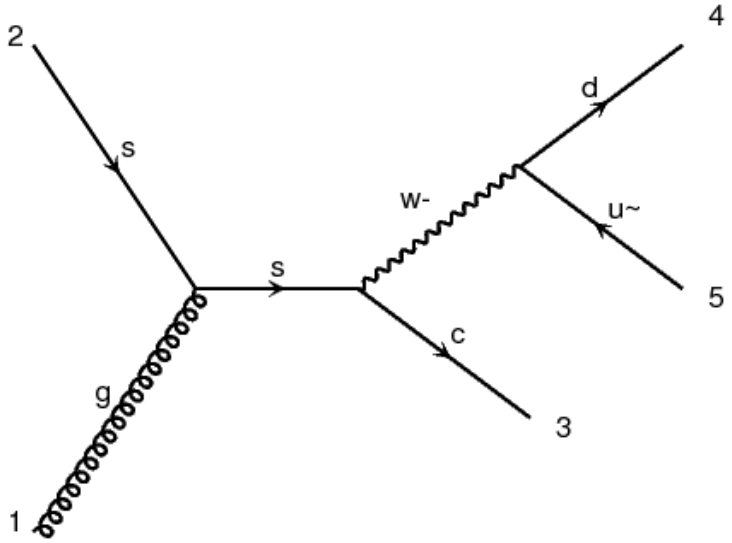
Q jet Single Heavy Quark Production

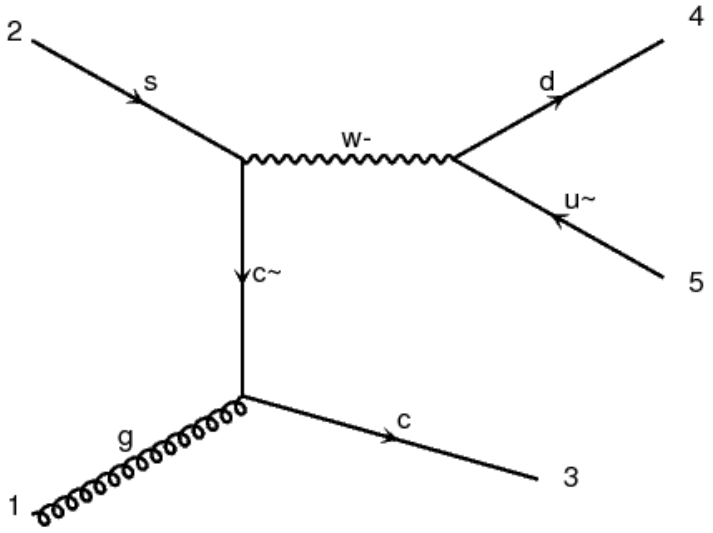




n=1

n(EW)=2

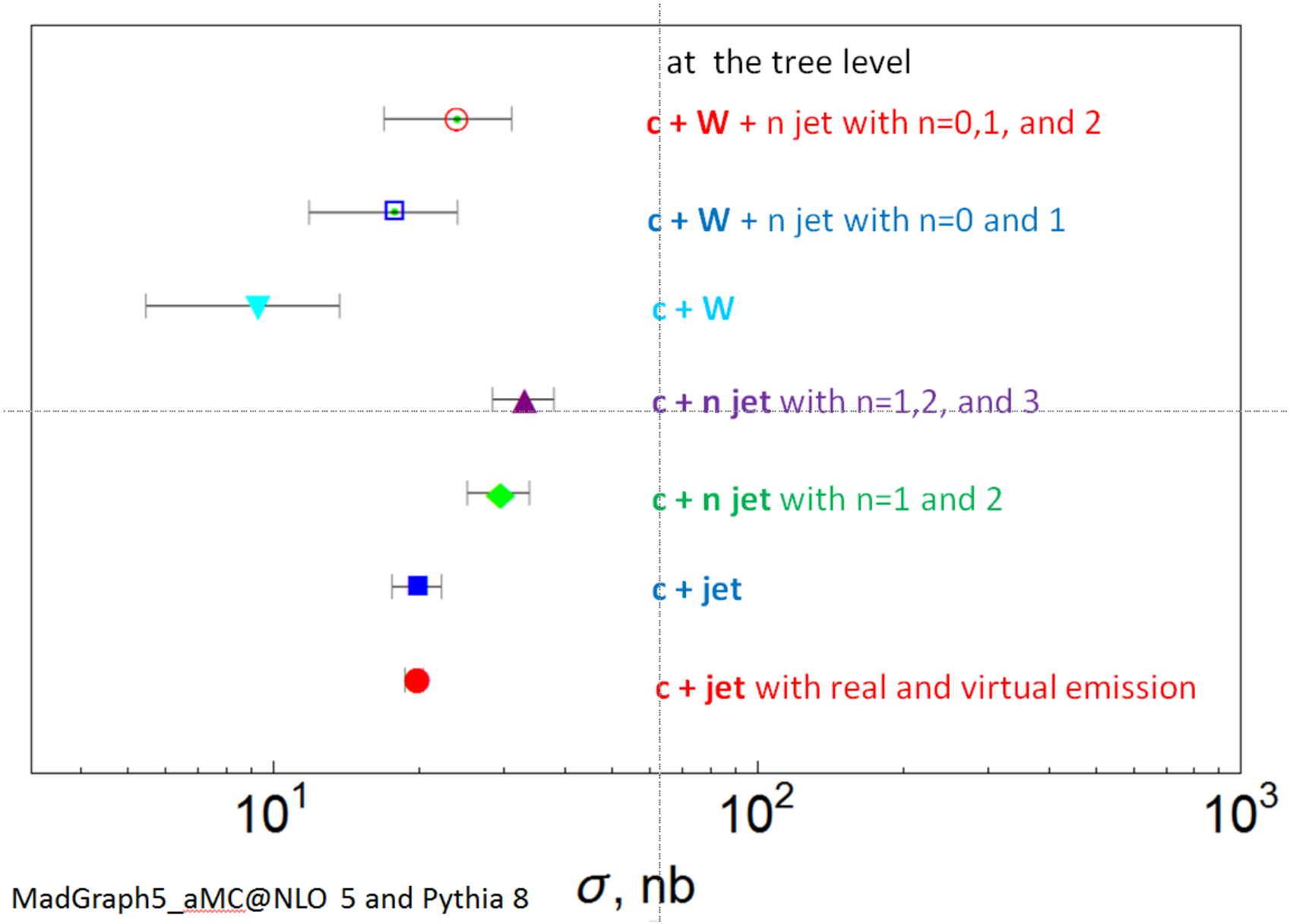




n=2

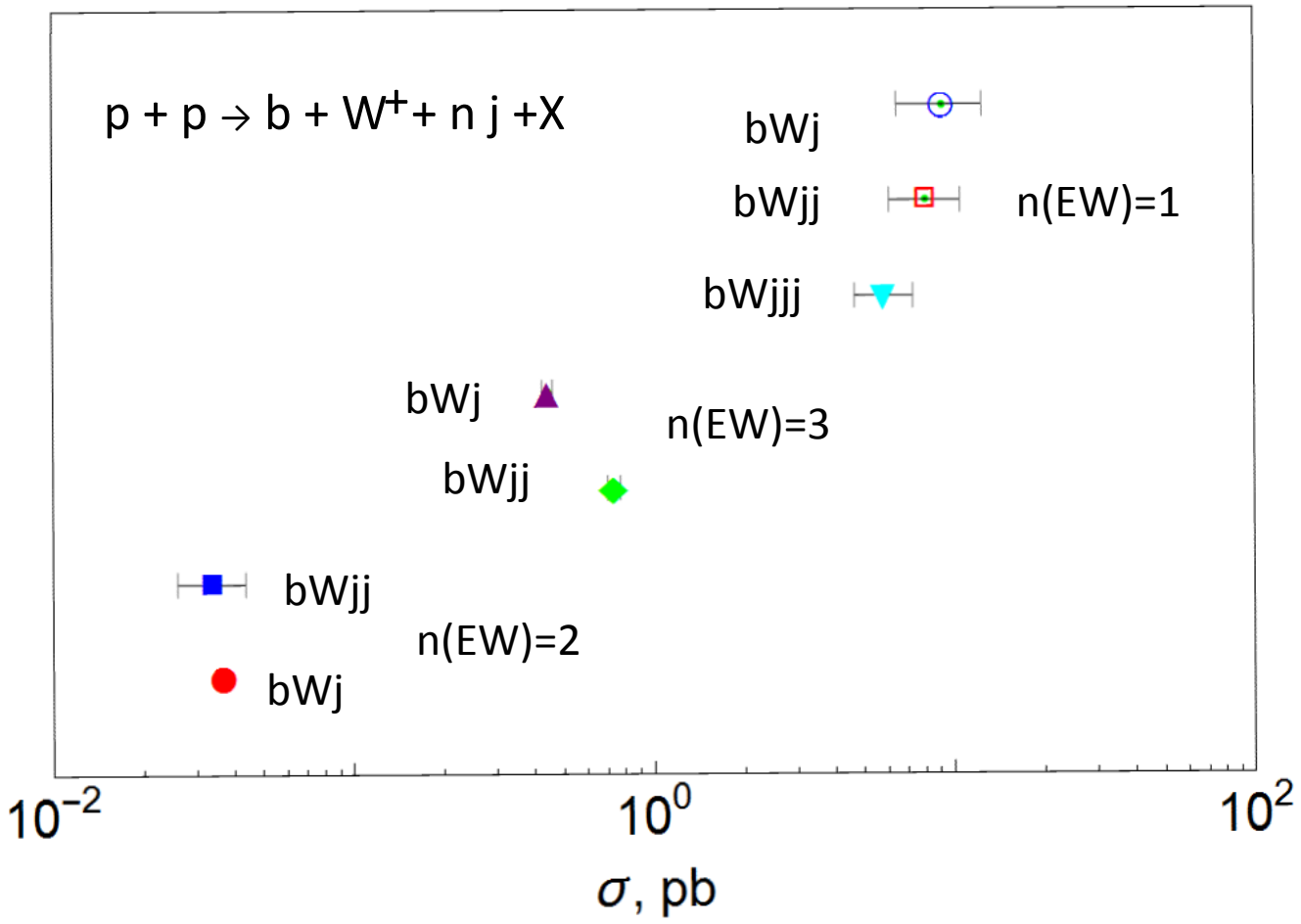
p + p → Q + n jet with n=1,2, and 3 result in 678 diagrams at the tree level.

Q W jet and Q jet Single Charm Quark Production at 13 TeV



MadGraph5_aMC@NLO 5 and Pythia 8

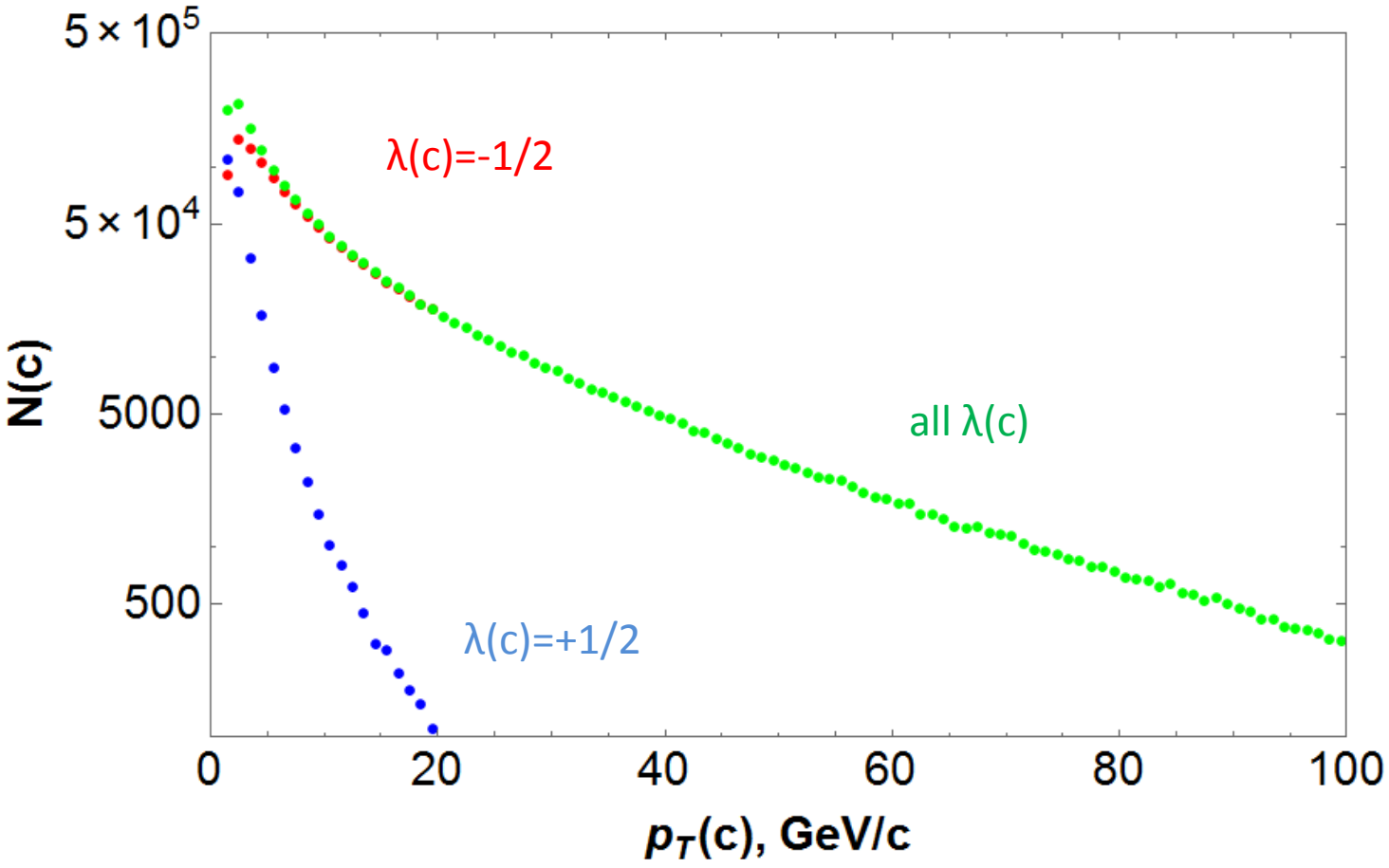
Q W jet Single Beauty Quark Production at 13 TeV



To compare:
Integral cross sections in beauty quark anti-quark pair production at 13 TeV are $4*10^4$ ... $6*10^6$ pb.

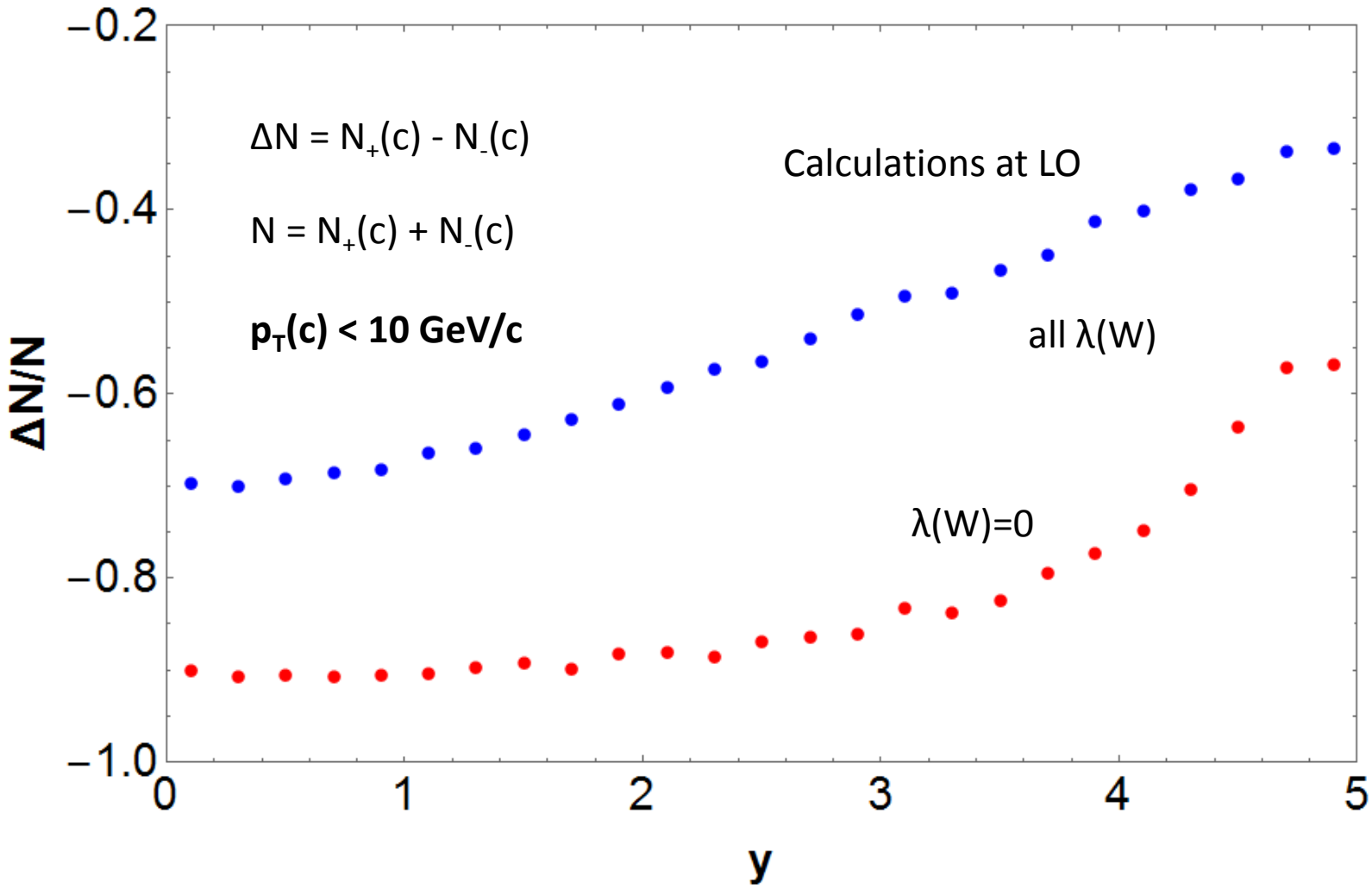
Calculations with MadGraph5_aMC@NLO

Q W jet Single Charm Quark Production at 13 TeV



MadGraph5_aMC@NLO 5 and Pythia 8

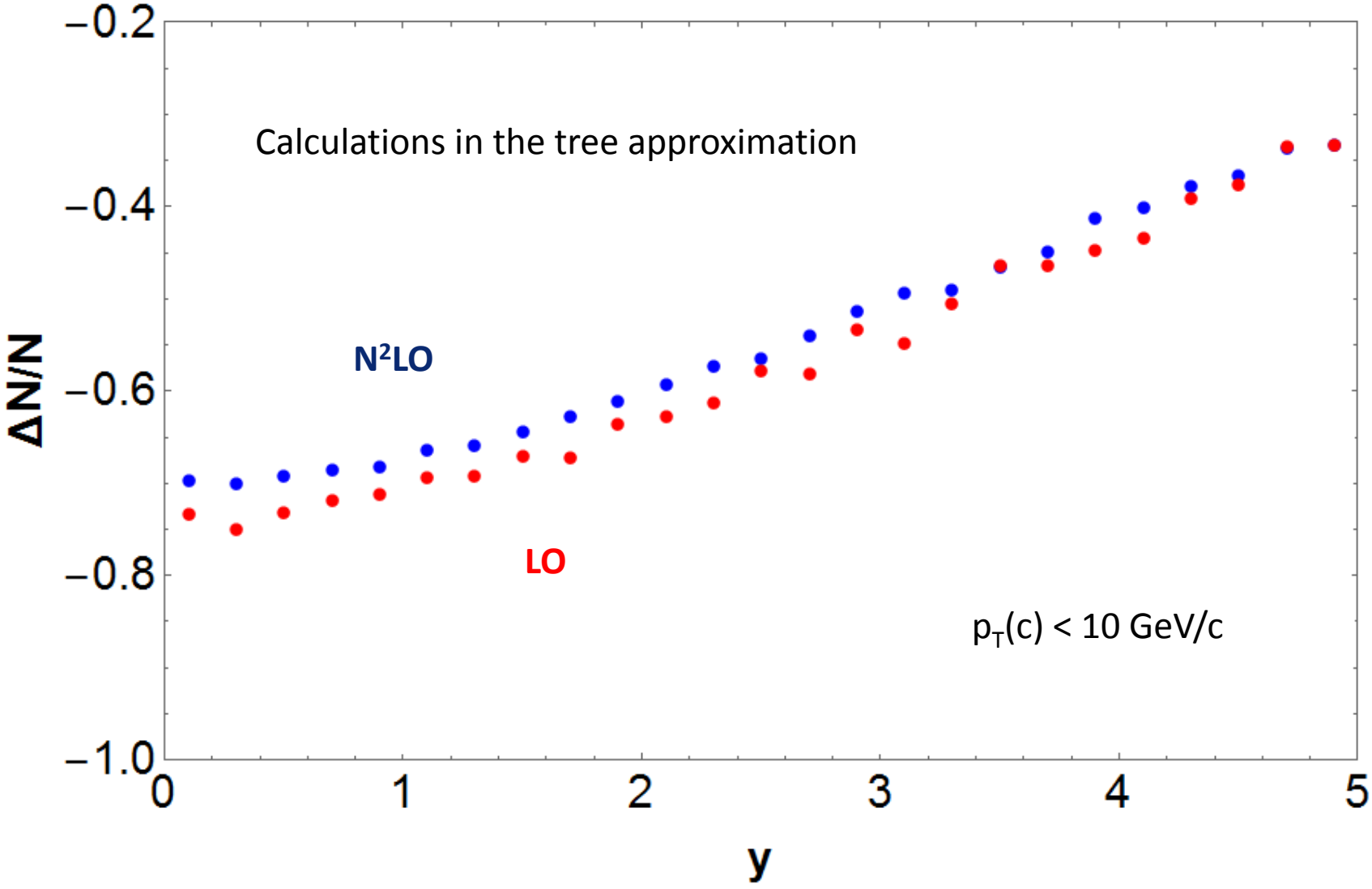
Helicity Asymmetry in
Q W jet Single Charm Quark Production at 13 TeV



$y = (1/2)\ \ln((E+p_z)/(E-p_z))$

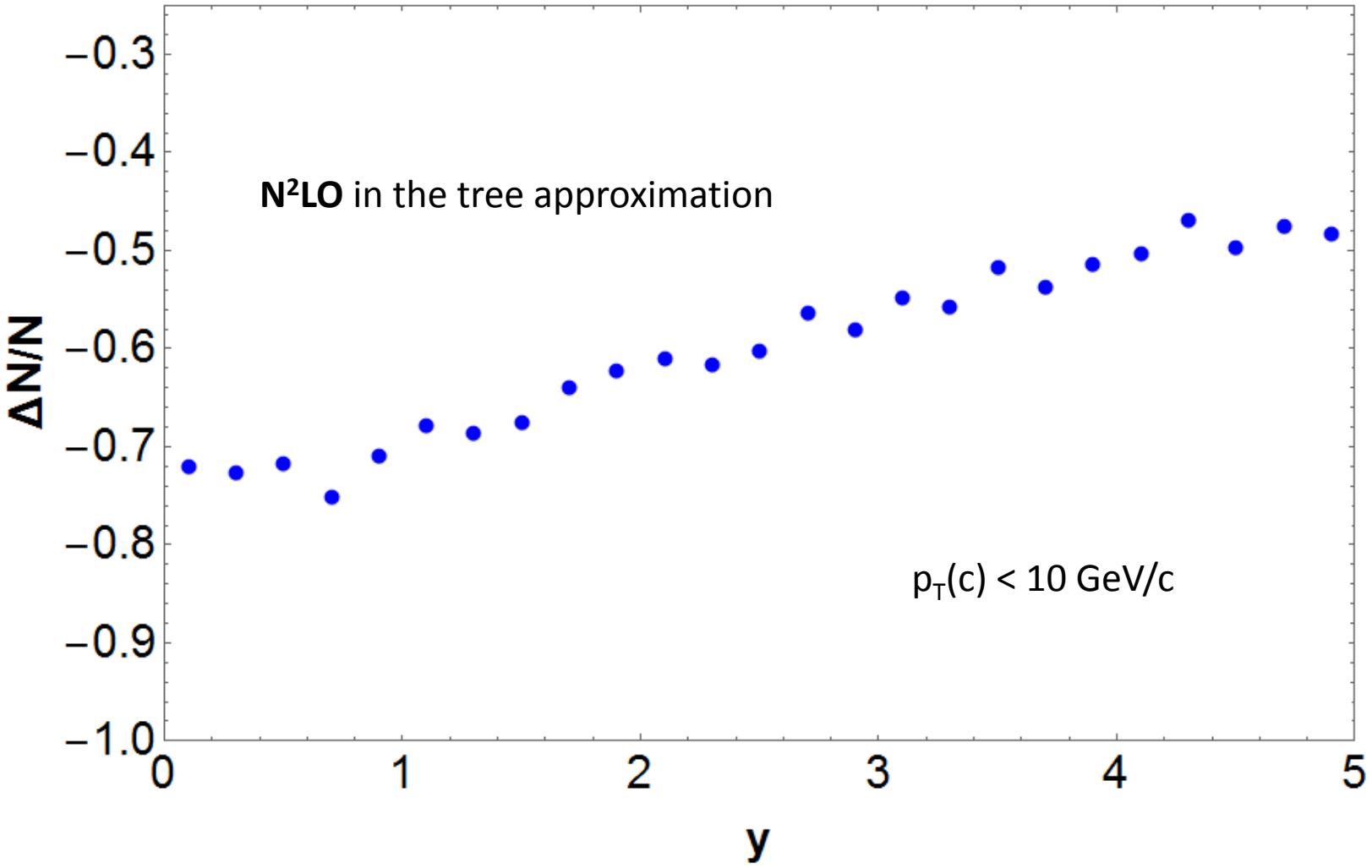
MadGraph5_aMC@NLO 5 and Pythia 8

Helicity Asymmetry in
Q W jet Single Charm Quark Production at 13 TeV



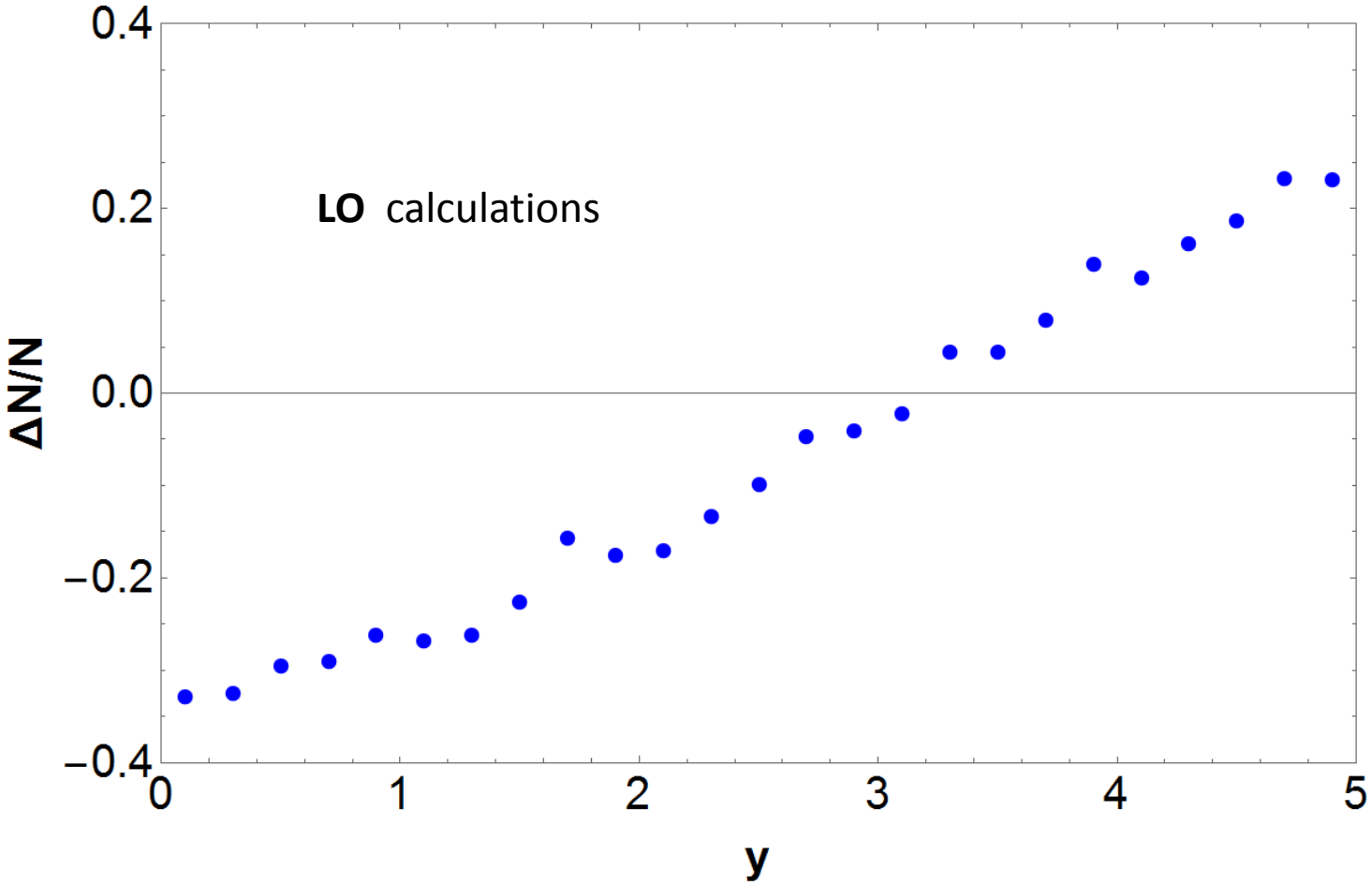
MadGraph5_aMC@NLO 5 and Pythia 8

Helicity Asymmetry in
Q jet Single Charm Quark Production at 13 TeV



MadGraph5_aMC@NLO 5 and Pythia 8

Helicity Asymmetry in
Q W jet Single Beauty Quark Production at 13 TeV



MadGraph5_aMC@NLO 5 and Pythia 8

Conclusions

Charm and beauty quark EW production is simulated.

The cross sections and helicity asymmetries are computed.
The asymmetries are demonstrated to differ visibly from -1.

The uncertainties in the cross section calculations, arising from renormalization and factorization scale variations, are shown to decrease essentially for the EW process cross sections and, in particular, for the asymmetries.

" … the collision is only incompletely described by giving the colliding and the separating particles, together with their momenta, that the complete description of the initial and of the final states includes **the dependence on the spins** or, more modernly, helicities. However, one is often inclined to disregard this dependence, or at least to postpone its consideration to some indefinite future. It was good, therefore, to learn that **a beautiful theory** of this dependence has been developed and, even more important, that **a wealth of experimental material** has been created to be interpreted by that theory."

Eugene Paul Wigner

Summary of Third International Symposium
Polarization Phenomena in Nuclear Reactions
(**1970**, University of Wisconsin)
Poceedings. Edited by H. H. Barschall and W. Haeberli.
University of Wisconsin Press, Madison 1971, pp.389-395