

Discriminating the heavy jet production mechanisms in associated Z + heavy flavor events at the LHC

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in collaboration with

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Outline

1. Motivation
2. Theoretical framework
3. Numerical results
4. Conclusion

Motivation

- $Z + \text{heavy jet}$ production provides a good test for TMD based calculations and MC generators (CASCADE3, PEGASUS);
- The process can allow to study some „rare“ and „exotic“ contributions (double parton scattering, DPS, and intrinsic charm, IC);
- The process allows to study the origin of heavy flavor jets („prompt“ and „non-prompt“ jets).

Theoretical framework: *PEGASUS calculations*

- $g^*g^*\rightarrow ZQ\bar{Q}$ in k_T -factorization:

$$d\sigma = \int \frac{dx_1}{x_1} f_g(x_1, \mathbf{k}_{1T}^2, \mu^2) d\mathbf{k}_{1T}^2 \frac{d\phi_1}{2\pi} \int \frac{dx_2}{x_2} f_g(x_2, \mathbf{k}_{2T}^2, \mu^2) d\mathbf{k}_{2T}^2 \frac{d\phi_2}{2\pi} d\hat{\sigma}(g^*g^* \rightarrow ZQ\bar{Q})$$

- $q\bar{q}\rightarrow ZQ\bar{Q}$ and $qQ\rightarrow ZqQ$ in collinear factorization;
then parton showers are added with PYTHIA8.

PEGASUS

- parton level Monte-Carlo event generator for pp and $p\bar{p}$ processes with simple user-friendly graphical interface;
- can work with both TMD and collinear PDFs;
- a lot of implemented processes (heavy quarks, quarkonia, etc.);
- can generate an event record according to the Les Houches Event (*.lhe) format (with weighted or unweighted events);
- an easy way to implement various kinematical restrictions;
- compatible with HEPData repository <https://www.hepdata.net>;
- built-in plotting tool PEGASUS Plotter

A.V. Lipatov, M.A. Malyshev, S.P. Baranov, Eur. Phys. J. **C80**, 4, 330 (2020);
<https://theory.sinp.msu.ru/doku.php/pegasus/overview>

Theoretical framework: *CASCADE3 calculations*

- based on Parton Branching (PB) approach
[F. Hautmann et al., Phys. Lett. **B772**, 446 (2017); JHEP **01**, 070 (2018)]
- on-shell matrix elements are combined with PB TMD parton distributions;
- $Z+jet$ sample is produced at NLO in MadGraph5_aMC@NLO with HERWIG6 subtraction terms and then processed with CASCADE3.

TMDs

1. CCFM-based unintegrated distributions

Numerical solutions of Catani-Ciafaloni-Fiorani-Marchesini evolution equation. The starting distribution is chosen to satisfy data on proton structure functions $F_2(x, \mu^2)$ and $F_2^c(x, \mu^2)$ (JH2013-set-2).

[H. Jung, hep-ph/0411287, F. Hautmann, H. Jung, Nucl. Phys. **B883** (2014) 1].

2. PB TMD distributions

Obtained from a fit to precise HERA DIS data. Two sets were obtained, which differ by the choice of the scale in α_s . In this work PB-NLO-HERAII-2018-set-2 is used.

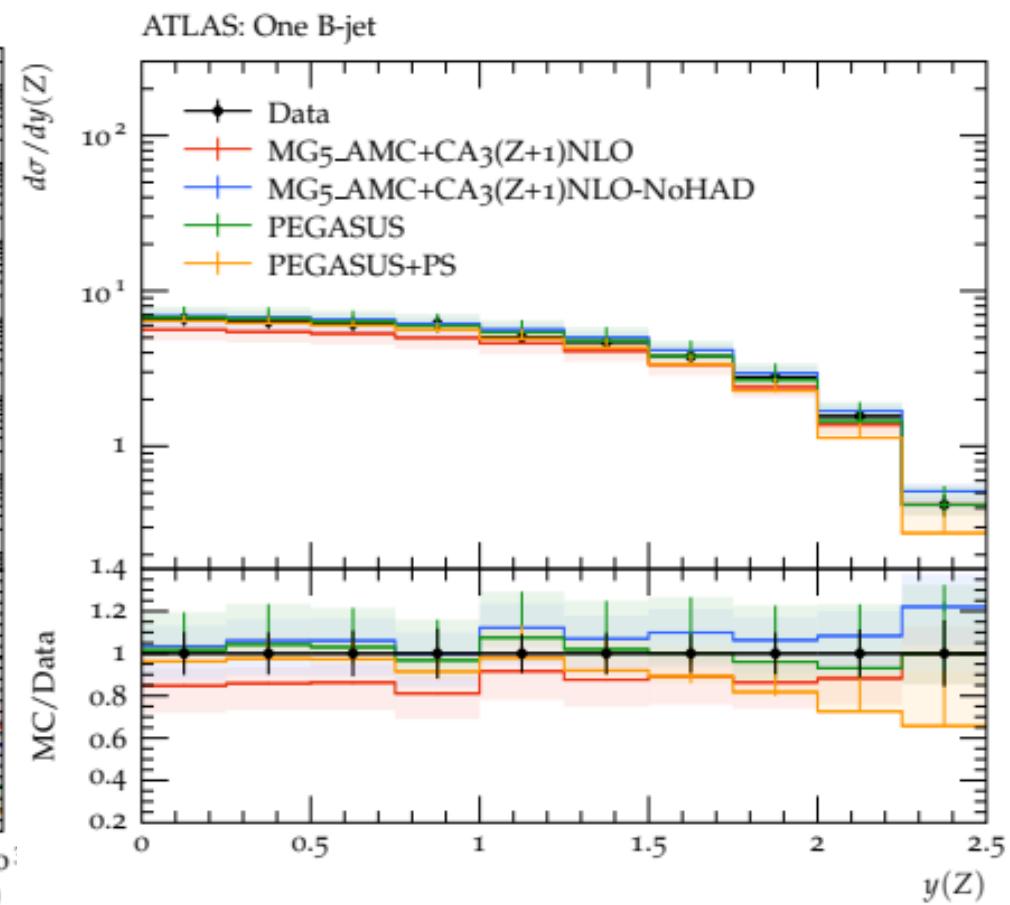
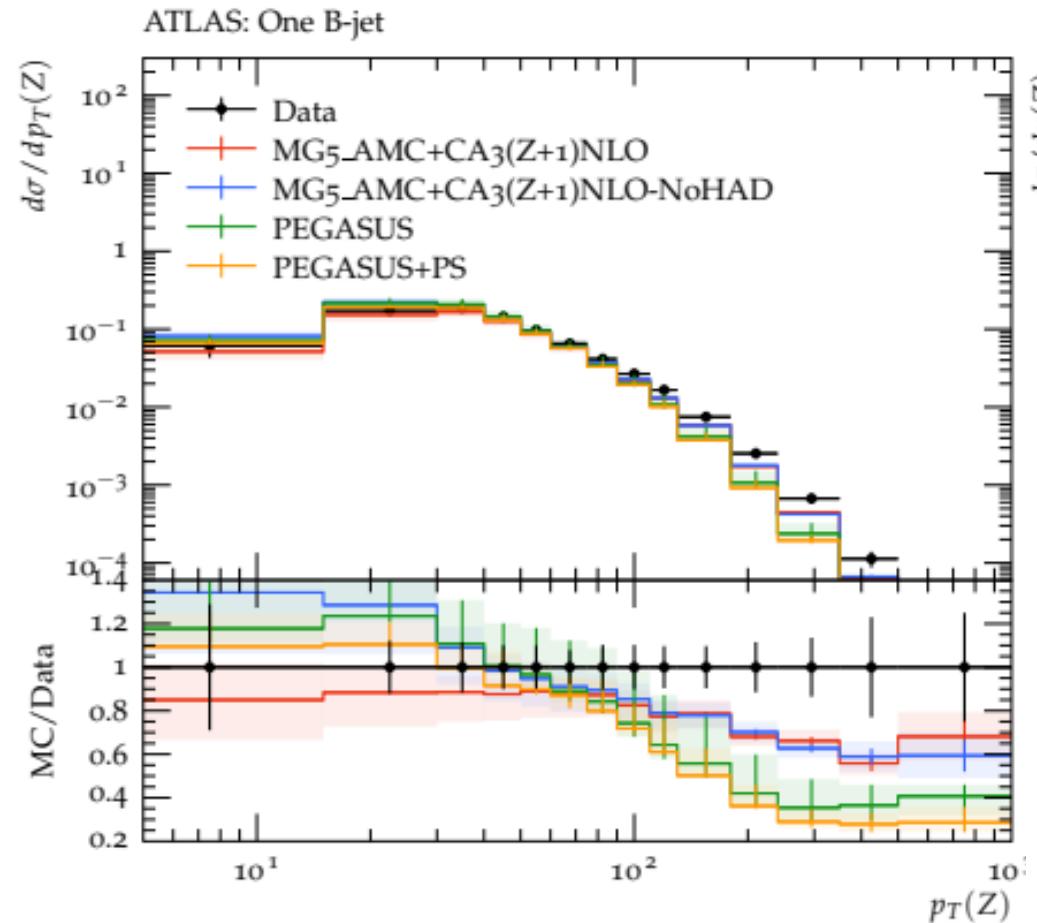
[A. Bermudez Martinez et al., Phys. Rev. **D99**, 074008 (2019)].

Parameters

- Theoretical uncertainties are connected with the choice of the factorization and renormalization scales. In PEGASUS calculation we took $\mu_R = m_Z$ and $\mu_F^2 = (s + \mathbf{Q}_T^2)$, where s and \mathbf{Q}_T^2 are the energy of scattering subprocess and transverse momentum of the incoming off-shell gluon pair, respectively. Auxilliary „+“ and „-“ distributions were used to estimate theoretical uncertainties. In CASCADE3 calculations we took $\mu_R^2 = \mu_F^2 = \Sigma(m_i^2 + p_{Ti}^2)$.
- We use 2-loop formula for the strong coupling constant $\alpha_s(\mu^2)$ with $n_f = 5$ active quark flavors at $\Lambda_{\text{QCD}} = 200$ (118) MeV in PEGASUS (CASCADE3).
- Jets are formed with FastJet in PEGASUS calculations.
- As collinear PDFs in PEGASUS NNPDF 4.0 (LO) distributions are taken.

Numerical results

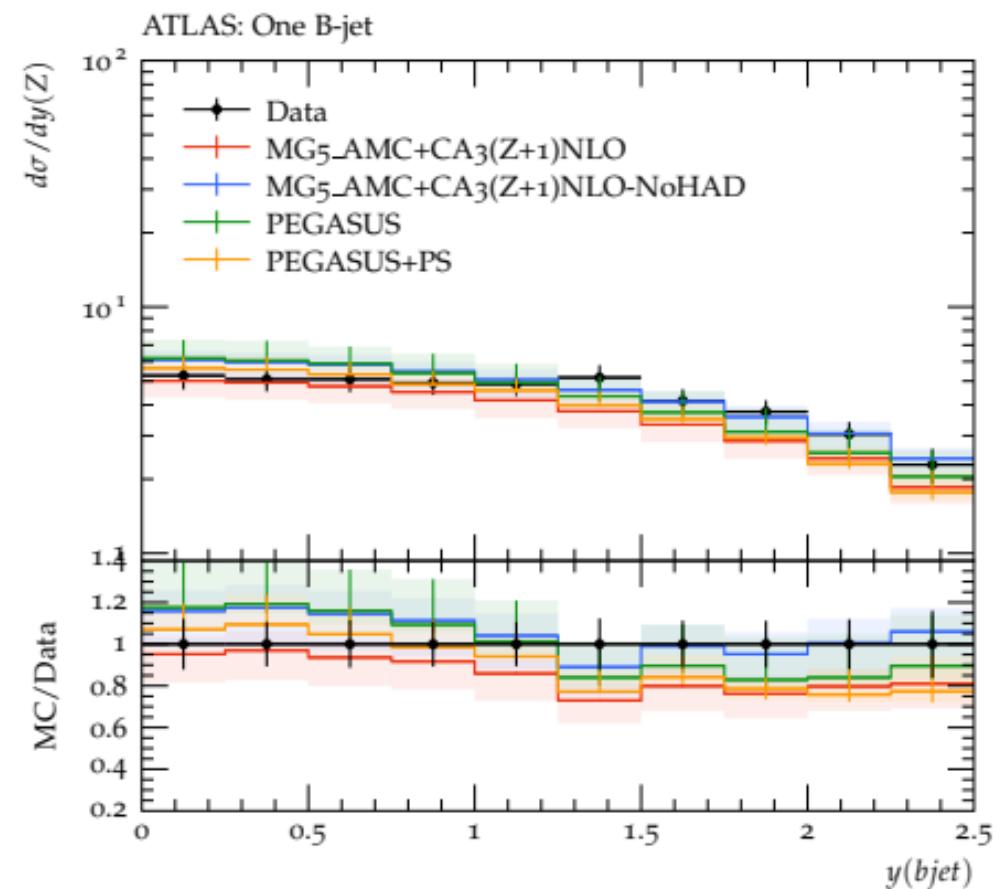
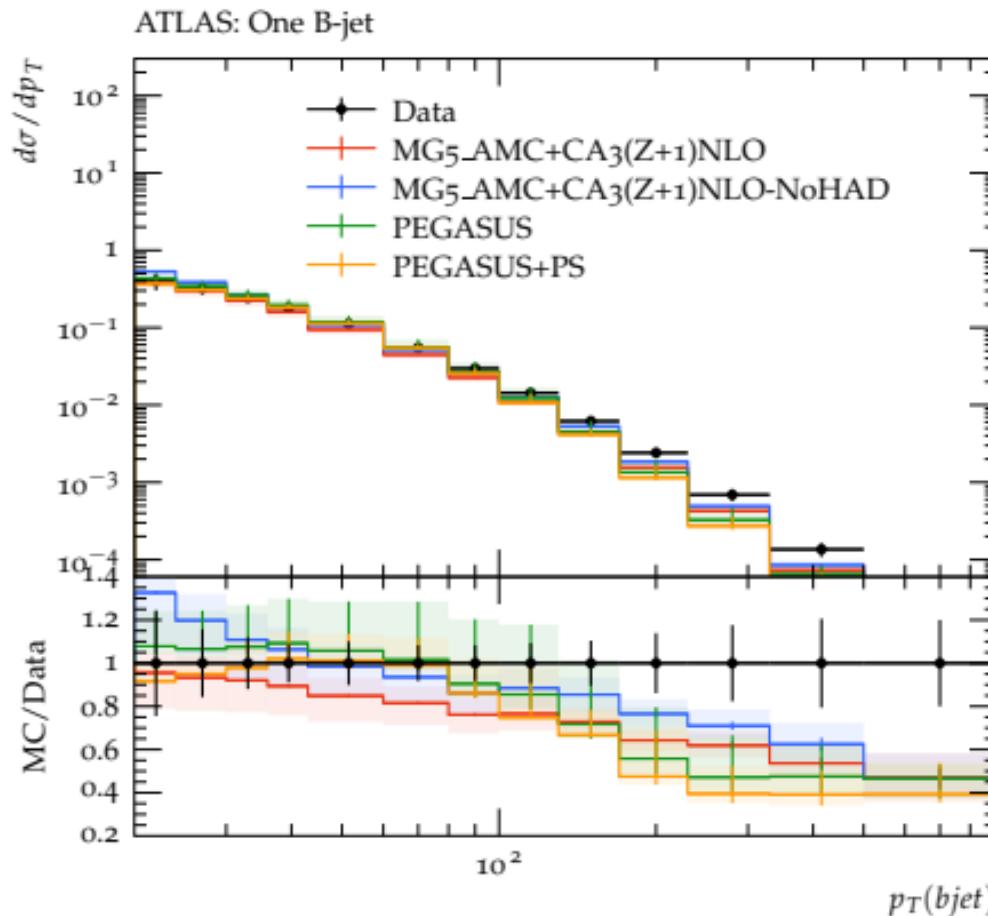
$Z+b$



$\sqrt{S}=13 \text{ TeV}$

Numerical results

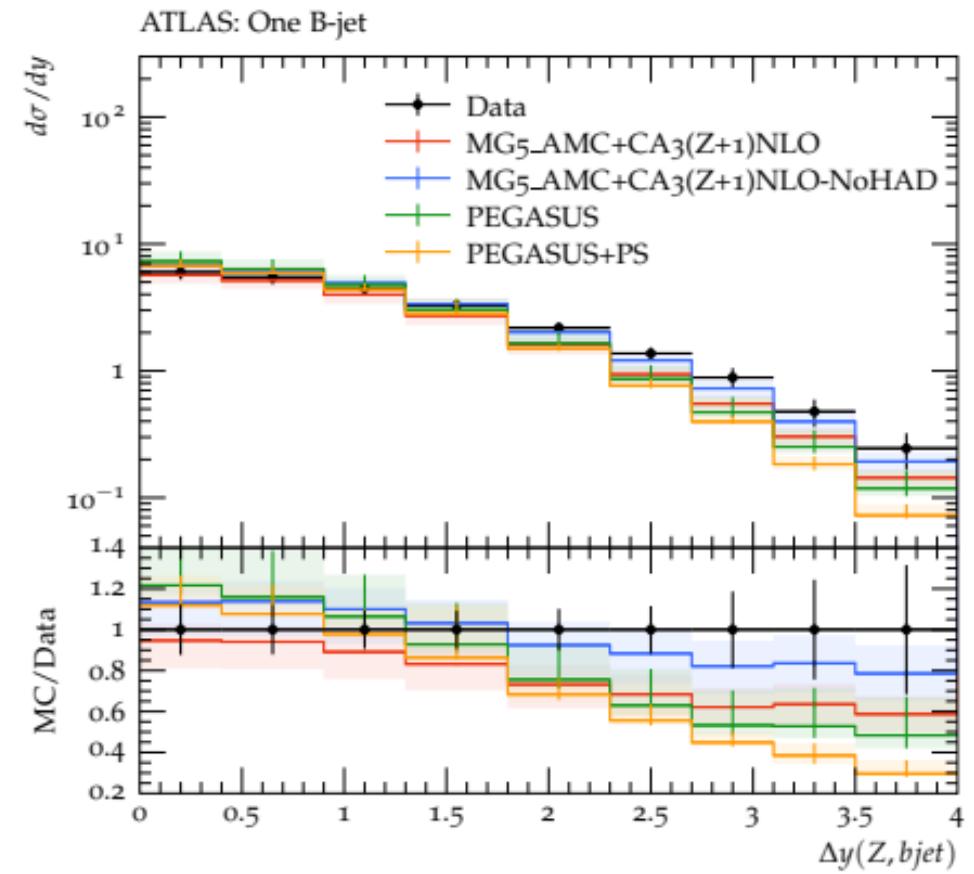
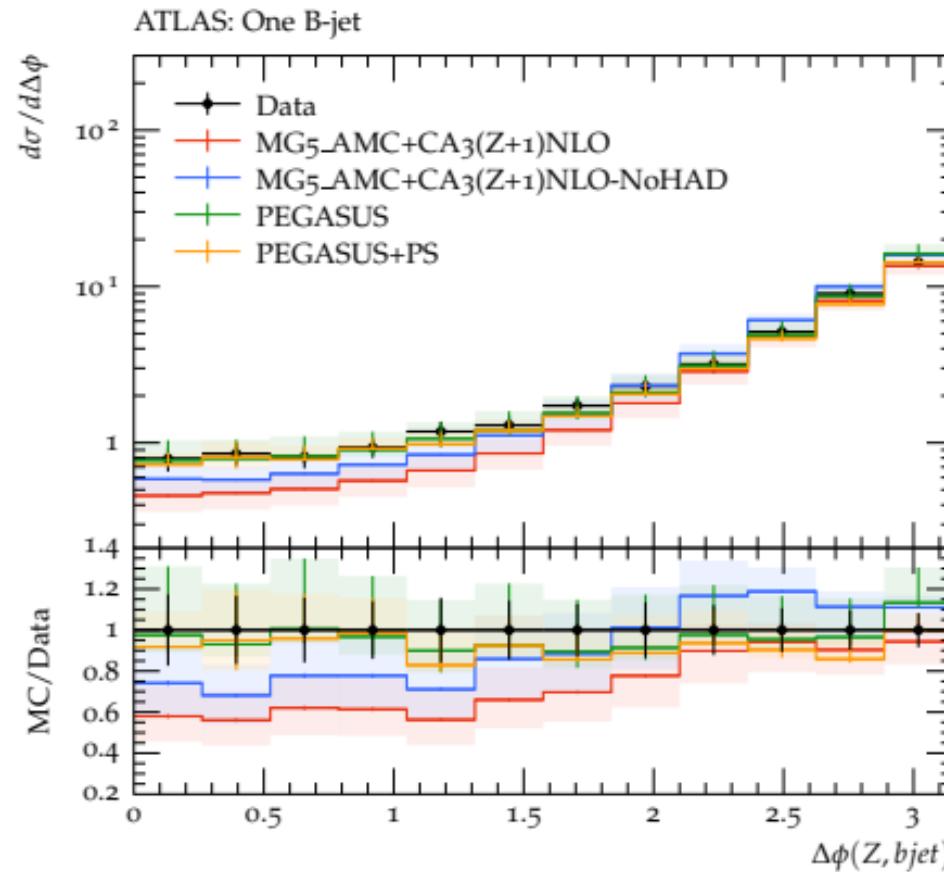
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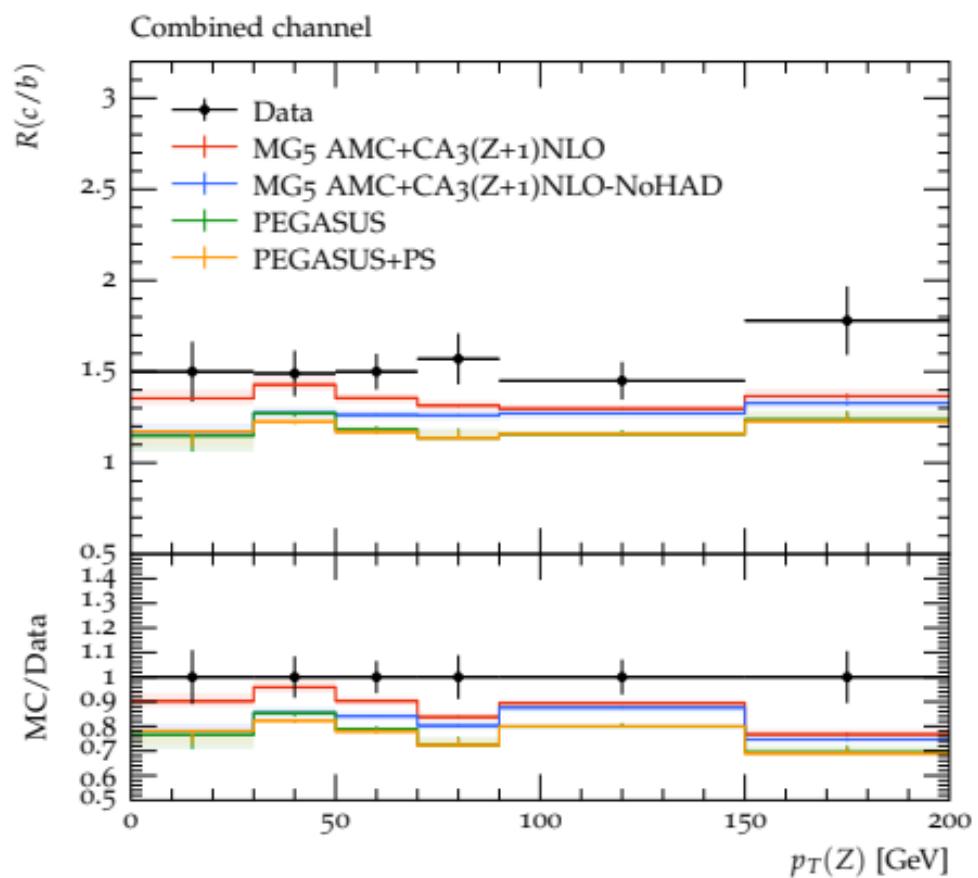
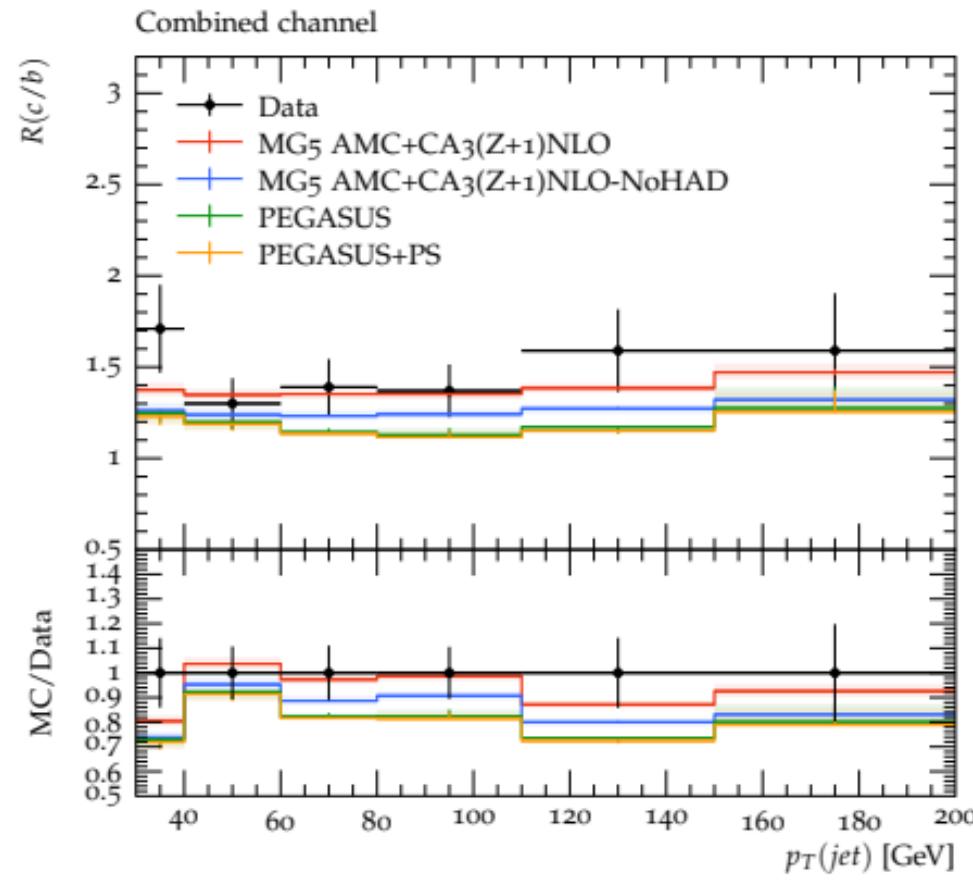
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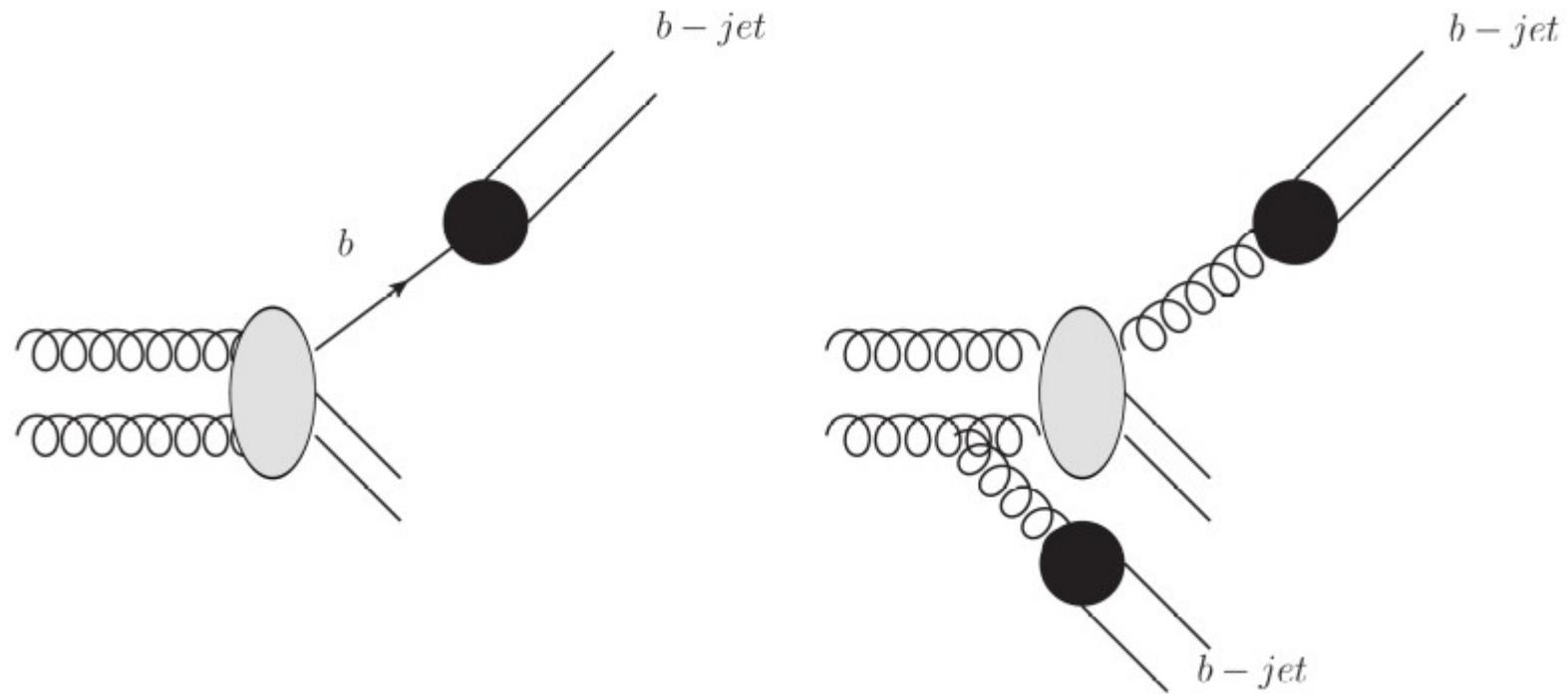
Numerical results

$Z+b$

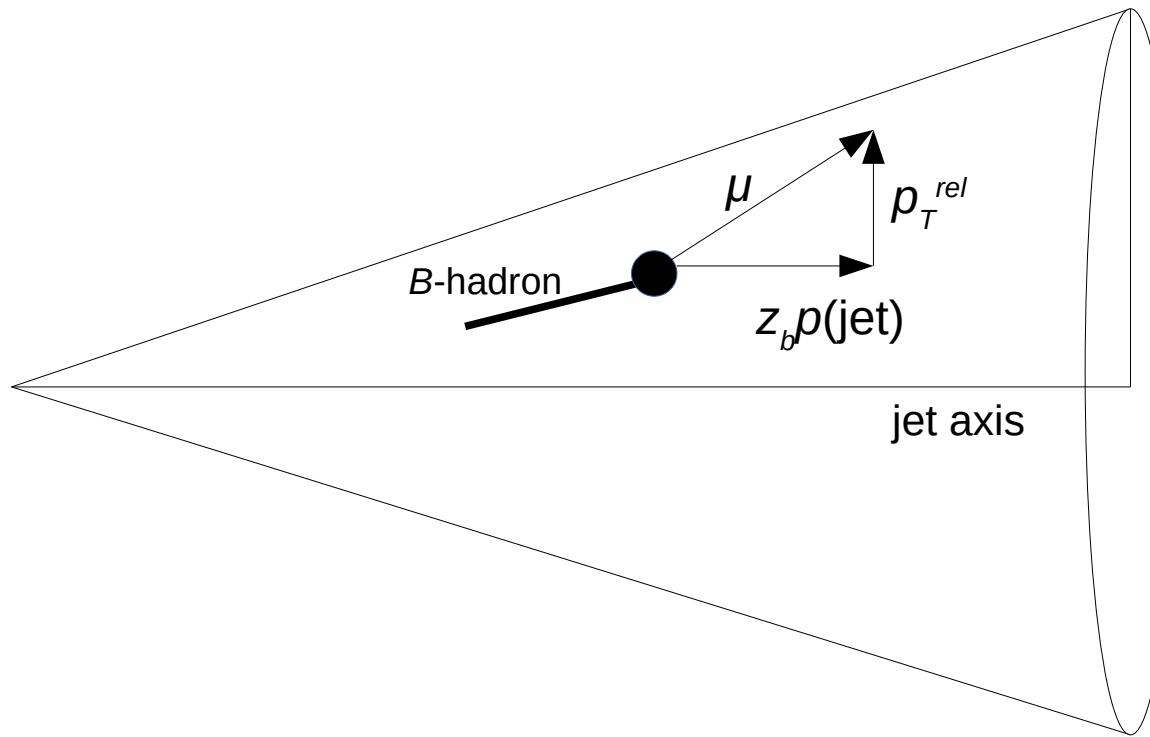


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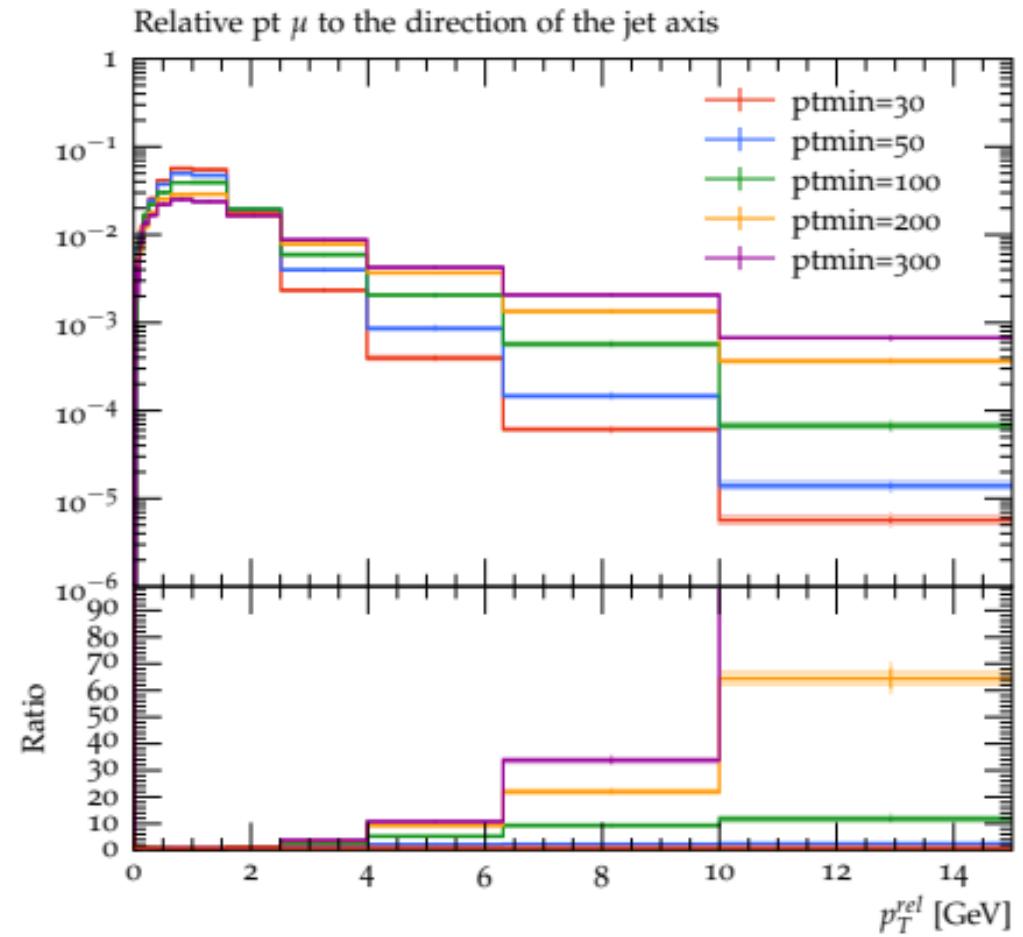
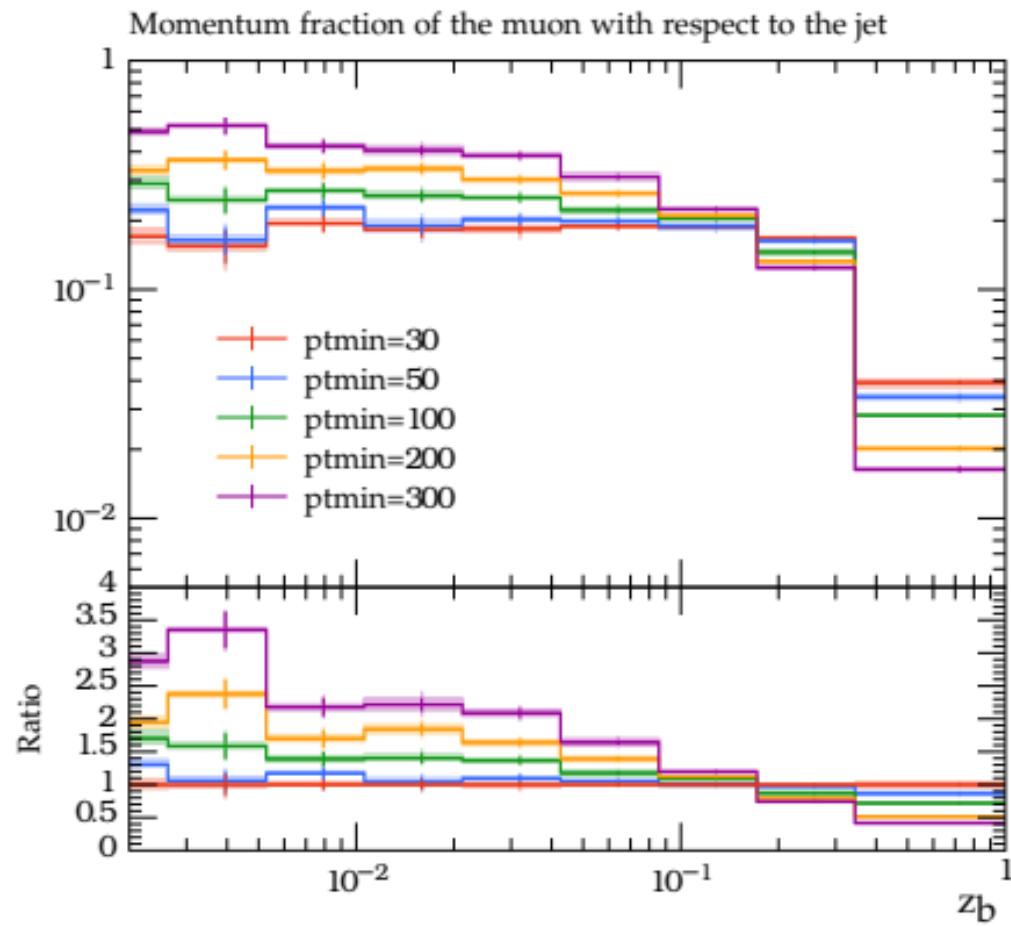
„Prompt“ and „non-prompt“ b -jets



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- non-prompt B -hadrons have smaller z_b and larger p_T^{rel}
- the fraction of non-prompt b -jets increases as the cut on the p_T of the jet becomes larger

Conclusion

*Associated Z+ heavy quark jet production at LHC
($\sqrt{s}=13$ TeV) has been considered.*

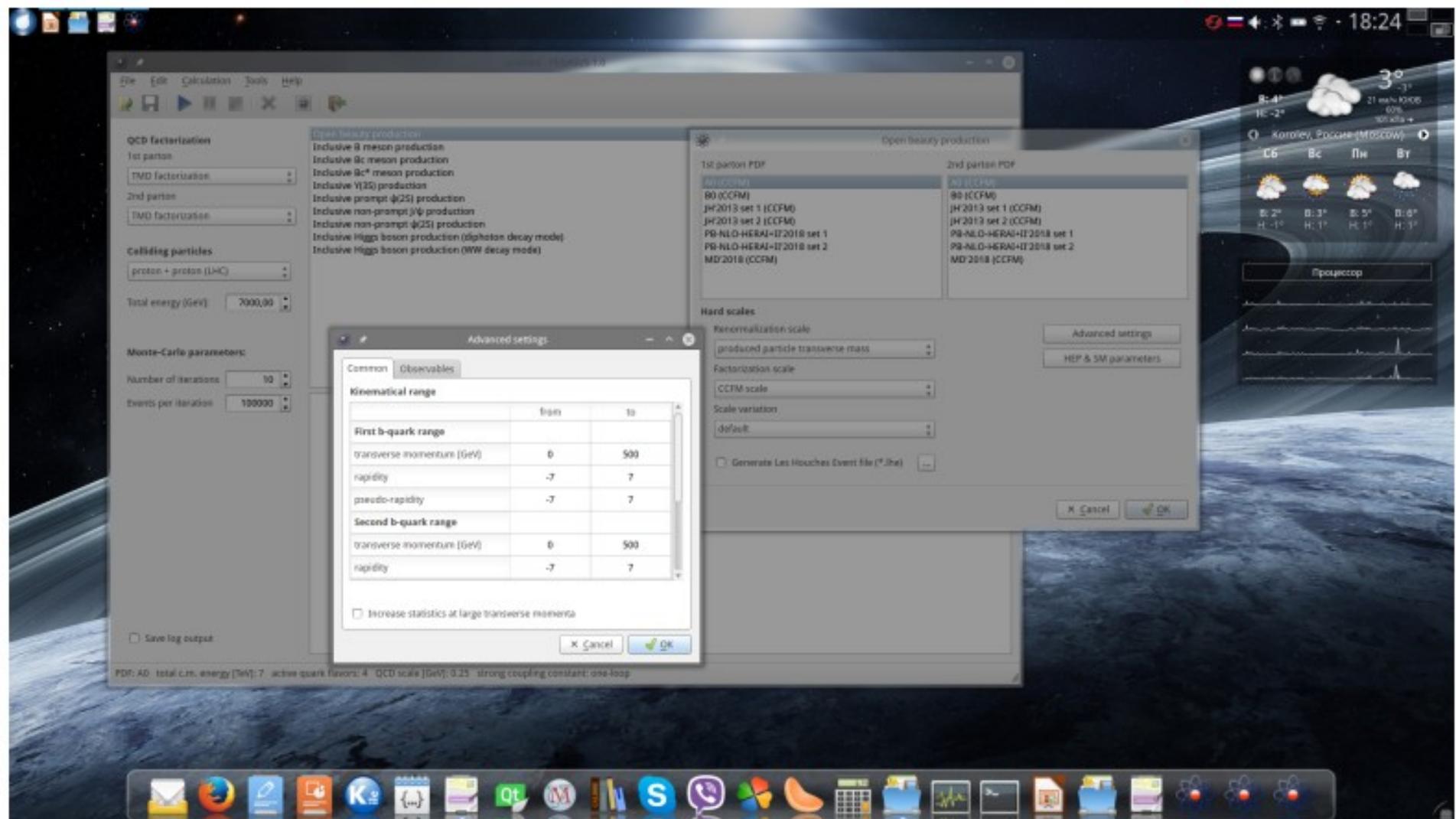
- Reasonable description of ATLAS and CMS data is obtained.
- The process is sensitive to the choice of TMDs.
- One is able to distinguish „prompt“ and „non-prompt“ jets using simple intuitive variables z_b and p_T^{rel} .

Back up

Off-shell gluon polarization sum

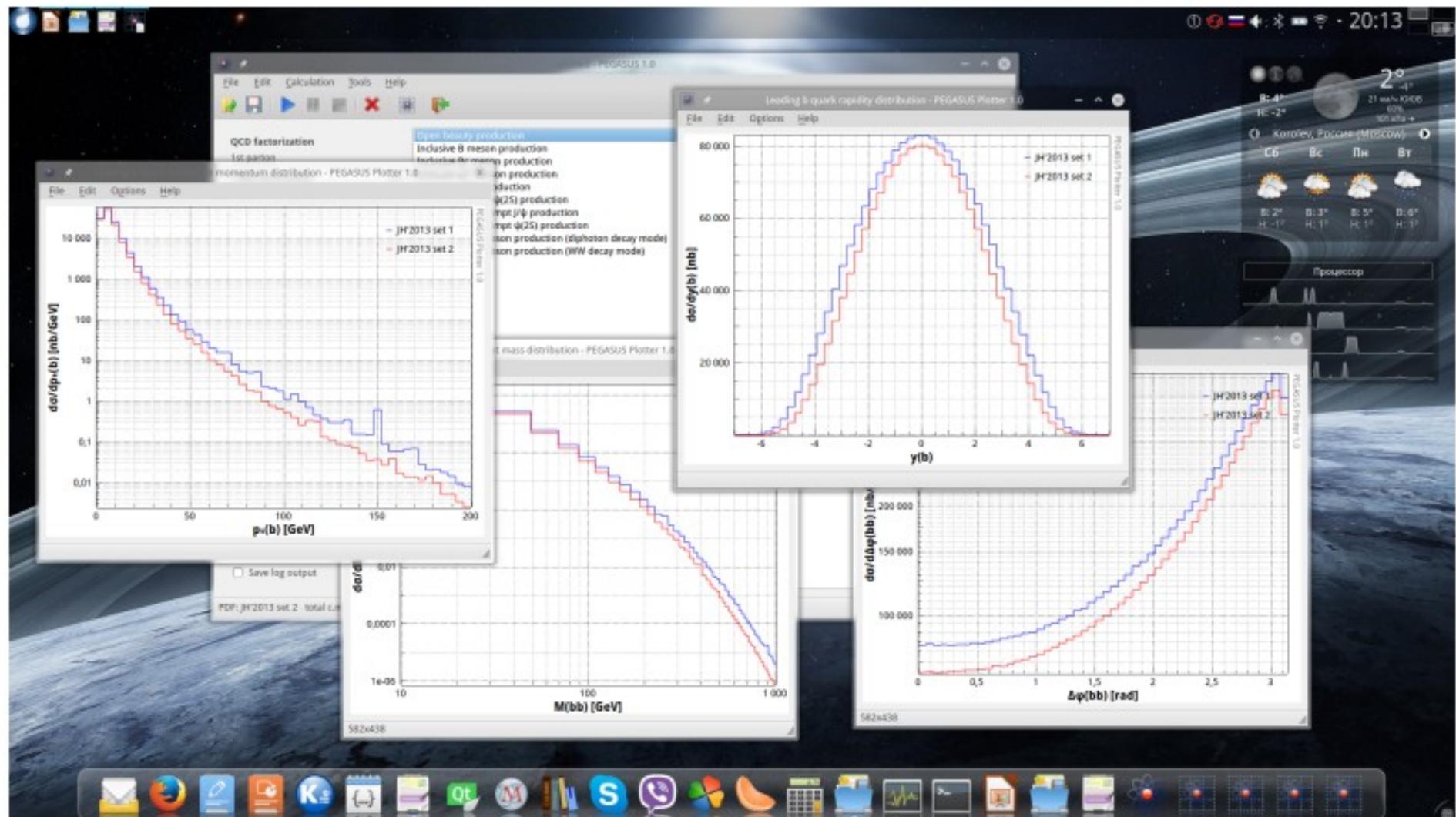
$$\epsilon_\mu \epsilon_\nu^* = \frac{k_T^\mu k_T^\nu}{\mathbf{k}_T^2}$$

PEGASUS Particle Event Generator: A Simple-in-Use System



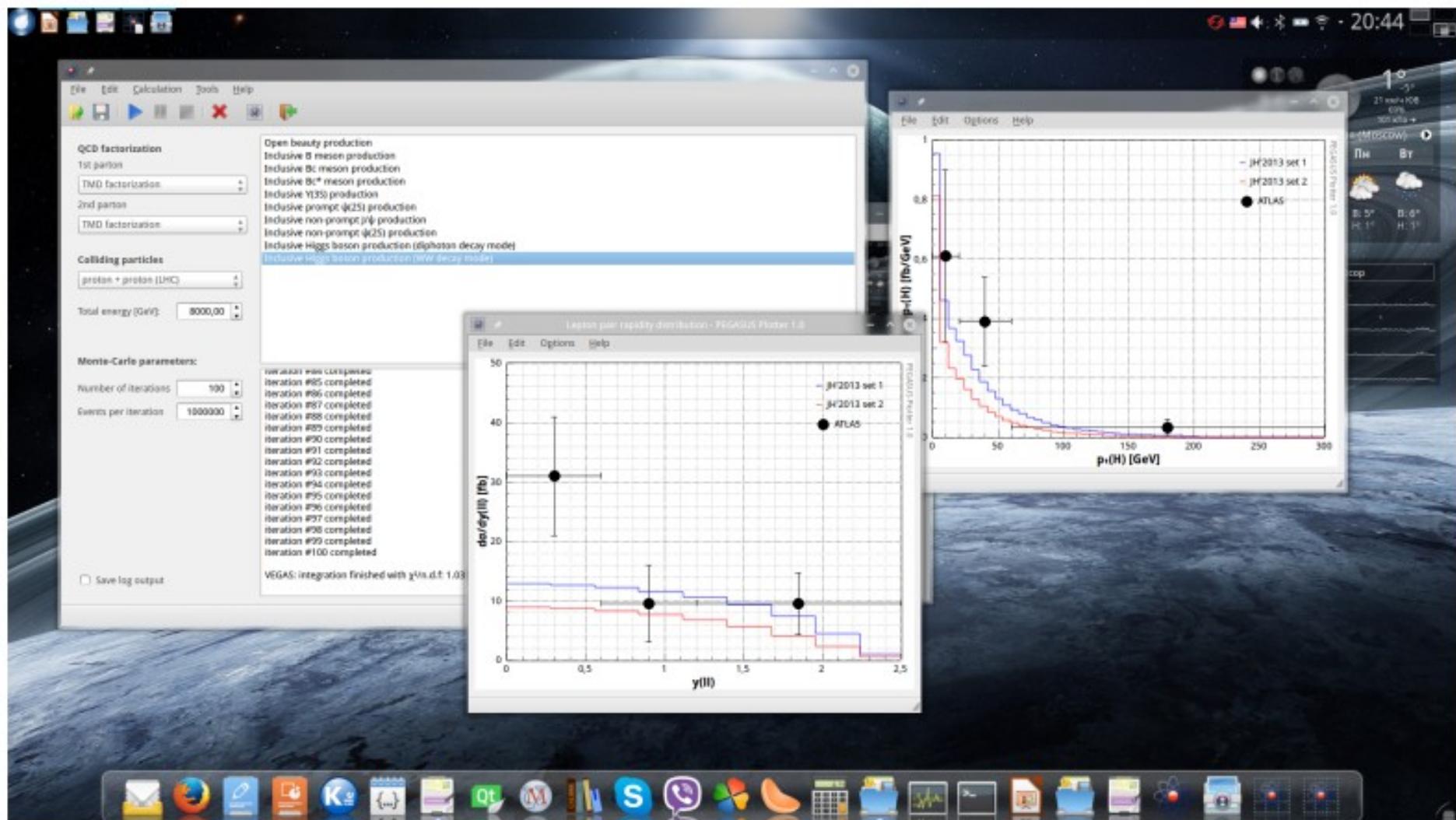
A.V. Lipatov, S.P. Baranov, M.A. Malyshev, in preparation (2019)

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