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Event generation with SHERPA

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Game of Flavours - CMS Heavy flavour tagging workshop 2019, IUC - Dubrovnik

https://indico.cern.ch/event/795581/

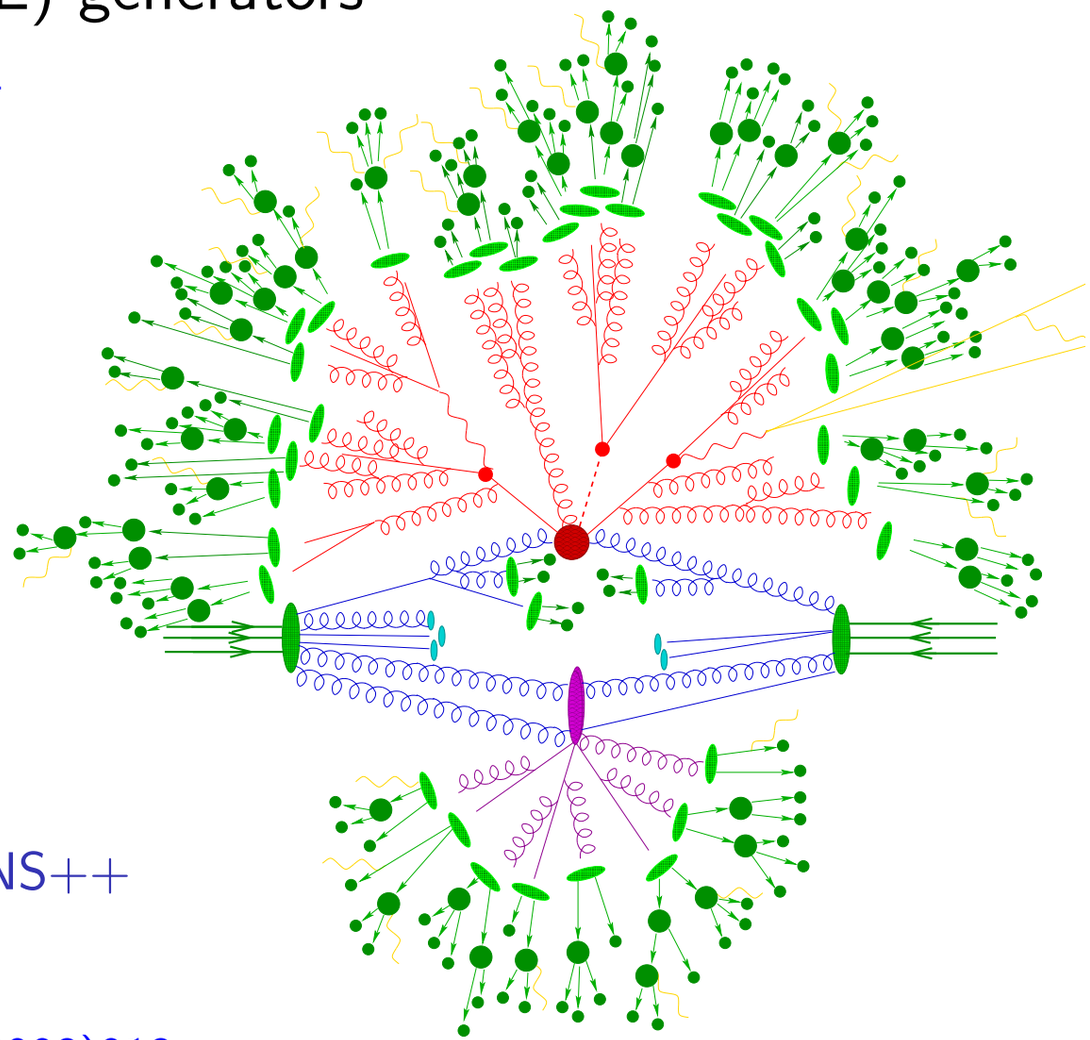
Outline

- Introduction to SHERPA
- Heavy quark mass effects in associated production
- 4 flavour vs. 5 flavour (massive) schemes
- Multijet merging, NLO EW corrections, etc.
- Status of SHERPA in CMS
- SHERPA Samples and plans

The SHERPA Event Generator Framework

JHEP02(2009)007

- Two multi-purpose Matrix Element (ME) generators
  AMEGIC++ JHEP02(2002)044, EPJC53(2008)501
  COMIX JHEP12(2008)039, PRL109(2012)042001
- Two Parton Shower (PS) generators
  CSSHOWER JHEP03(2008)038
  DIRE EPJC75(2015)461
- A multiple interaction simulation
  à la PYTHIA AMISIC++ hep-ph/0601012
- A cluster fragmentation module
  AHADIC++ EPJC36(2004)381
- A hadron and τ decay package HADRONS++
- A higher order QED generator using
  YFS-resummation PHOTONS++ JHEP12(2008)018



Sherpa's traditional strength is the perturbative part of the event

LO, NLO, NNLO, LOPS, NLOPS, NNLOPS, MEPS, MENLOPS, MEPS@NLO

Acronyms and Nomenclature

Fixed order calculations

- matrix elements only, implies fixed multiplicities
- no parton shower, no non-perturbative physics, no particle level

$\Rightarrow$ LO, NLO, NNLO

Parton shower matched calculations

- combination of fixed order calculation and parton shower for one multiplicity
- particle level predictions, no multijet observables

$\Rightarrow$ LoPs, NLoPs, NNLoPs

Multijet merged calculations

- combination of parton shower matched calculations for increasing final state multiplicities (mostly jets)
- particle level predictions, multijet observables

$\Rightarrow$ MePs(@LO), MePs@Nlo (special case MeNLoPs)

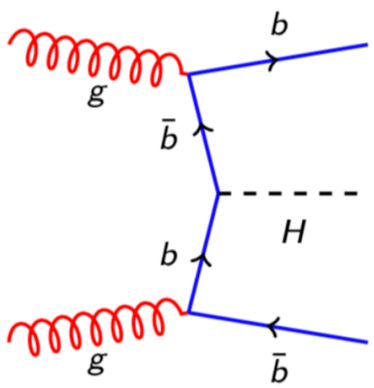
SHERPA 2.2.6

- SHERPA-2.2.6 released Jan '19
- contains bugfixes for all known bugs of SHERPA-2.2.5
- UFO support for BSM physics
- two parton showers: CSSHOWER (default), DIRE
- **on-the-fly scale and PDF variations** for ME part in
  - LO, NLO
  - LOPS, NLOPS (S-MC@NLO)
  - MEPS, MENLOPS, MEPS@NLO
- **also for** incorporation of assoc. **approx. EW corrs.** and sub-LO
  $\rightarrow$ use named weights in HEPMC (av. since HEPMC-2.06)
- full scale & PDF variations including correlated with parton shower and for NNLO/NNLOPS in SHERPA-3.0.0
- allow to force HEPMC event record into pure tree structure, lost information available through disconnected vertices
- default PDF: `NNPDF30_nnlo_as_0118`

Heavy quark mass effects in associated production

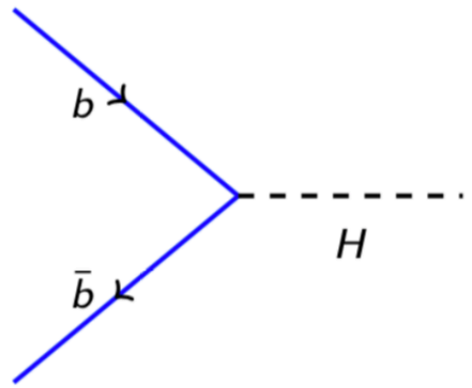
4 Flavour Scheme

- b quarks are massive, decoupled from QCD evolution, treated like light quarks
- can only be produced in the final state, through a $g \to b\bar{b}$ splitting if the gluon has enough energy.
- Fixed-order logarithms of any energy-like invariant over m_b can appear.



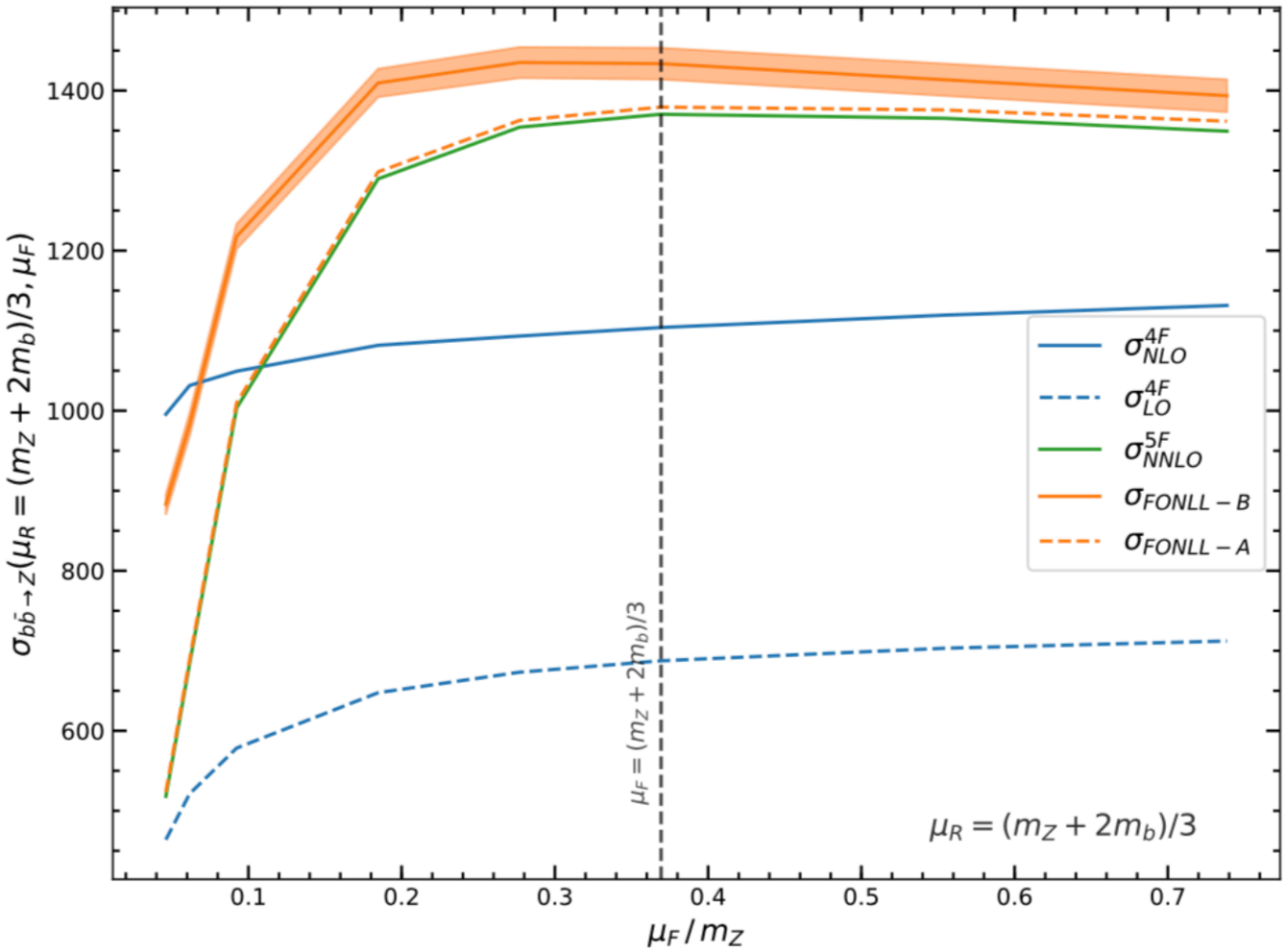
5 Flavour Scheme

- *b* quarks have zero mass, and thus participate in the QCD evolution, like all other light quarks.
- Appears in initial and final states
- *b*-mass effects, appear only as threshold effects,
- logarithms of μ_F/m_b are resummed to all order



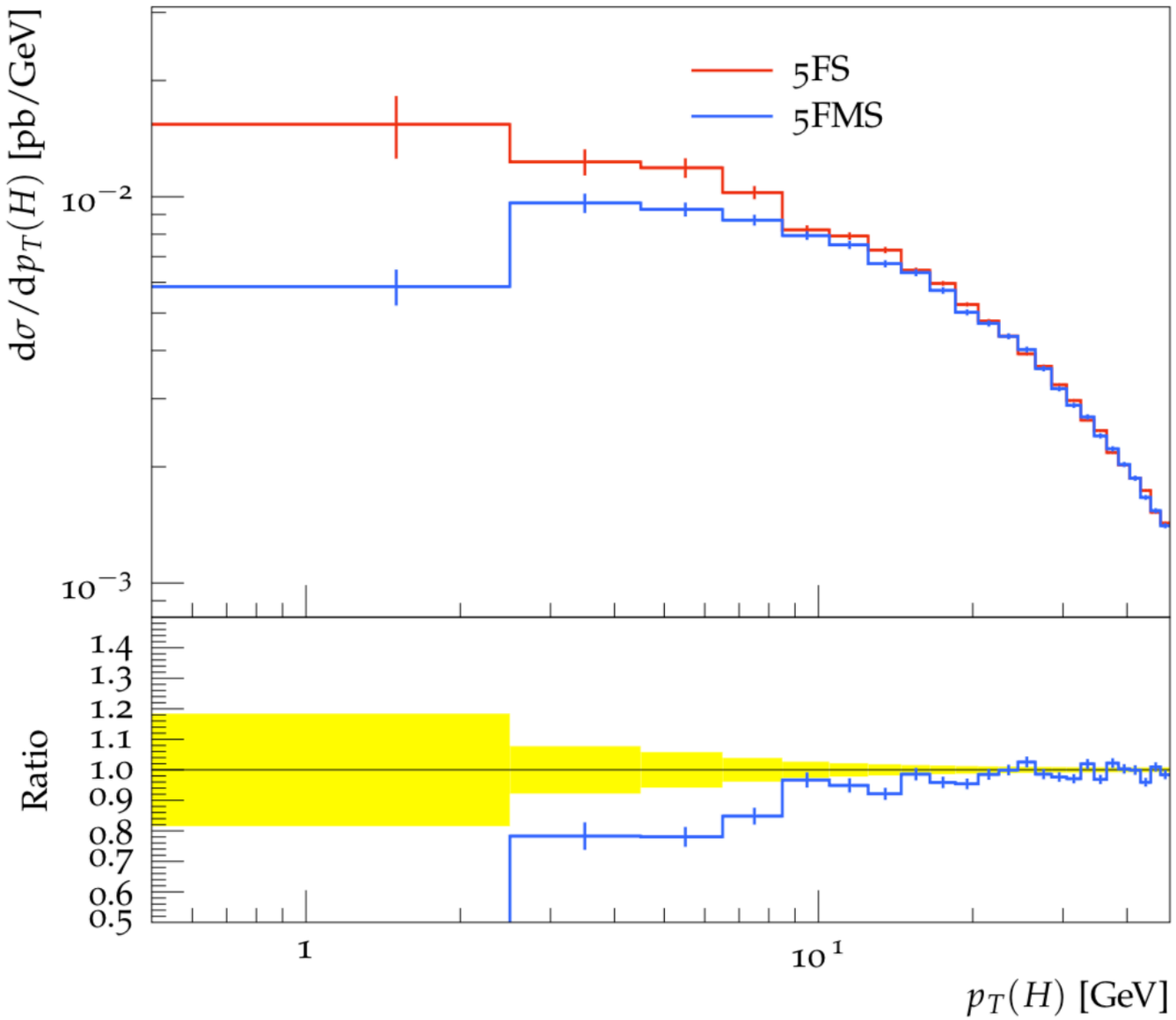
- Mainly differ by the inclusion of mass suppressed terms or in the resummation of a certain class of logarithms
- construct a matching scheme to combine the two and obtain a result which includes both fixed-order mass effects, and the resummation of large μ_F/m_b logarithms

4 flavour vs 5 flavour schemes



- matched results can give insights on what are the main contributions that make the two factorisation schemes different: mass or resummation effects
- the matched result, both with leading or next-to-leading fixed order accuracy, lies very close to the nominal 5FS, thus concluding that mass effects play a little role, with the main difference between the two schemes, coming from the resummation of large logs

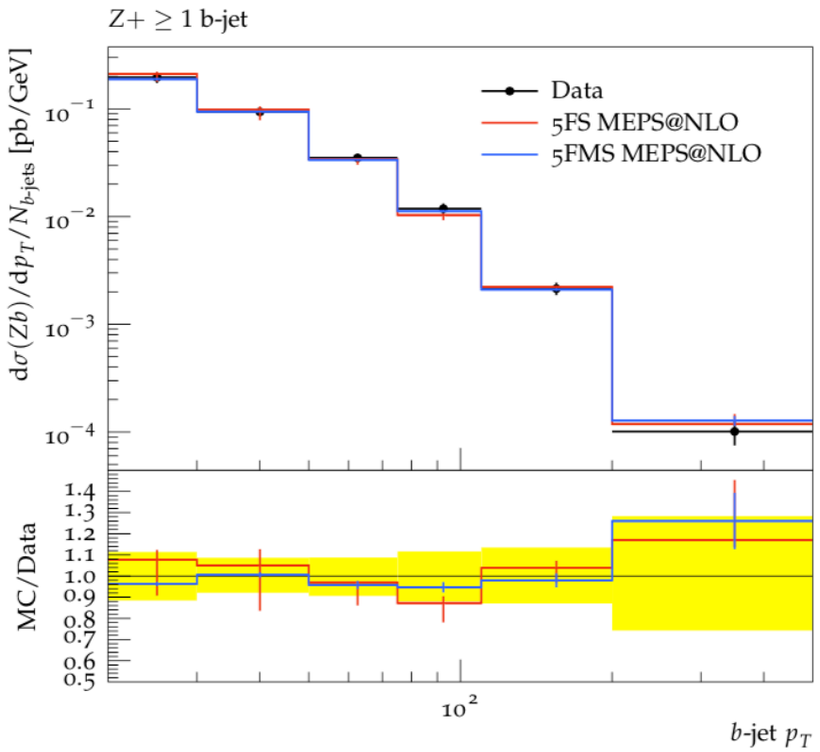
5 flavour vs 5 flavour massive schemes

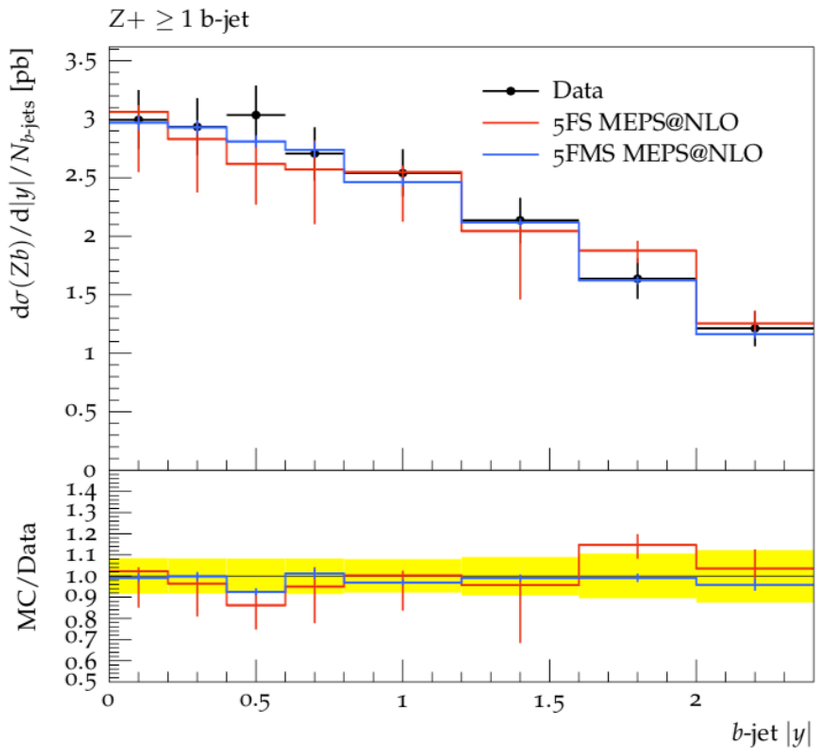


arXiv:1801.03440

- Large effect of mass at low p_T but once p_T becomes of the order of about twice the bottom mass, these effects become negligible and the massless and massive schemes converge to each other.

5 flavour vs 5 flavour massive schemes





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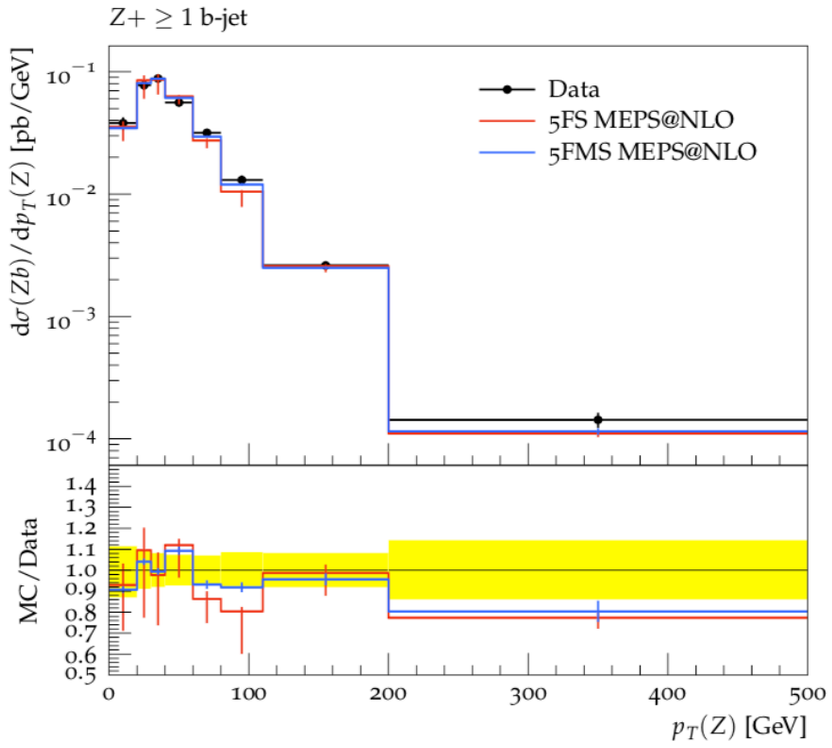
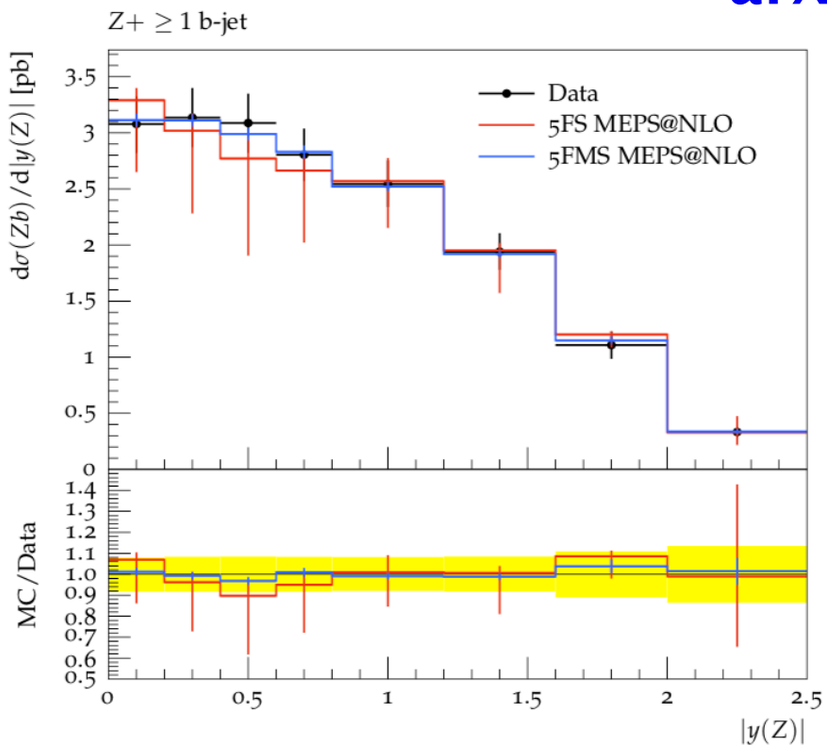




SHERPA for p_T^W and p_T^Z

Fixed order:

- NNLO QCD and NLO EW for inclusive W and Z production
- NLO QCD and NLO EW for $p_{\mathrm{T}}^{W/Z}$

Matched to parton shower:

- NNLOPS for inclusive W and Z production
- NLOPS (S-MC@NLO) for $p_{\mathrm{T}}^{W/Z}$

Multijet merged:

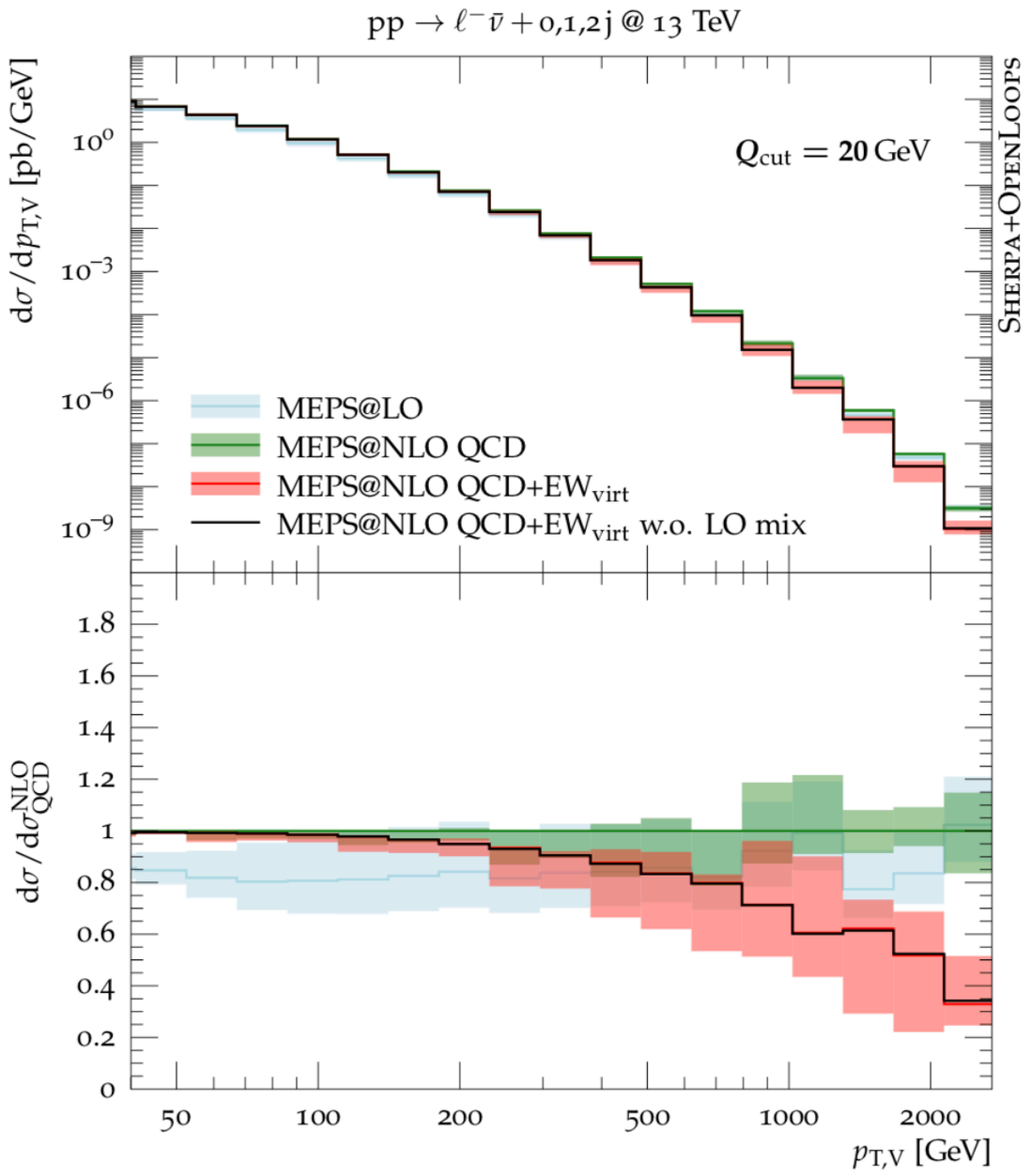
- MEPS@NLO
  $\rightarrow$ inclusive and for low $p_{\mathrm{T}}(< Q_{\mathrm{cut}})$ same as incl. NLOPS
  $\rightarrow$ for high-p_{T} benefit from NLO accuracy for multijet processes

Large p_T^W and p_T^Z

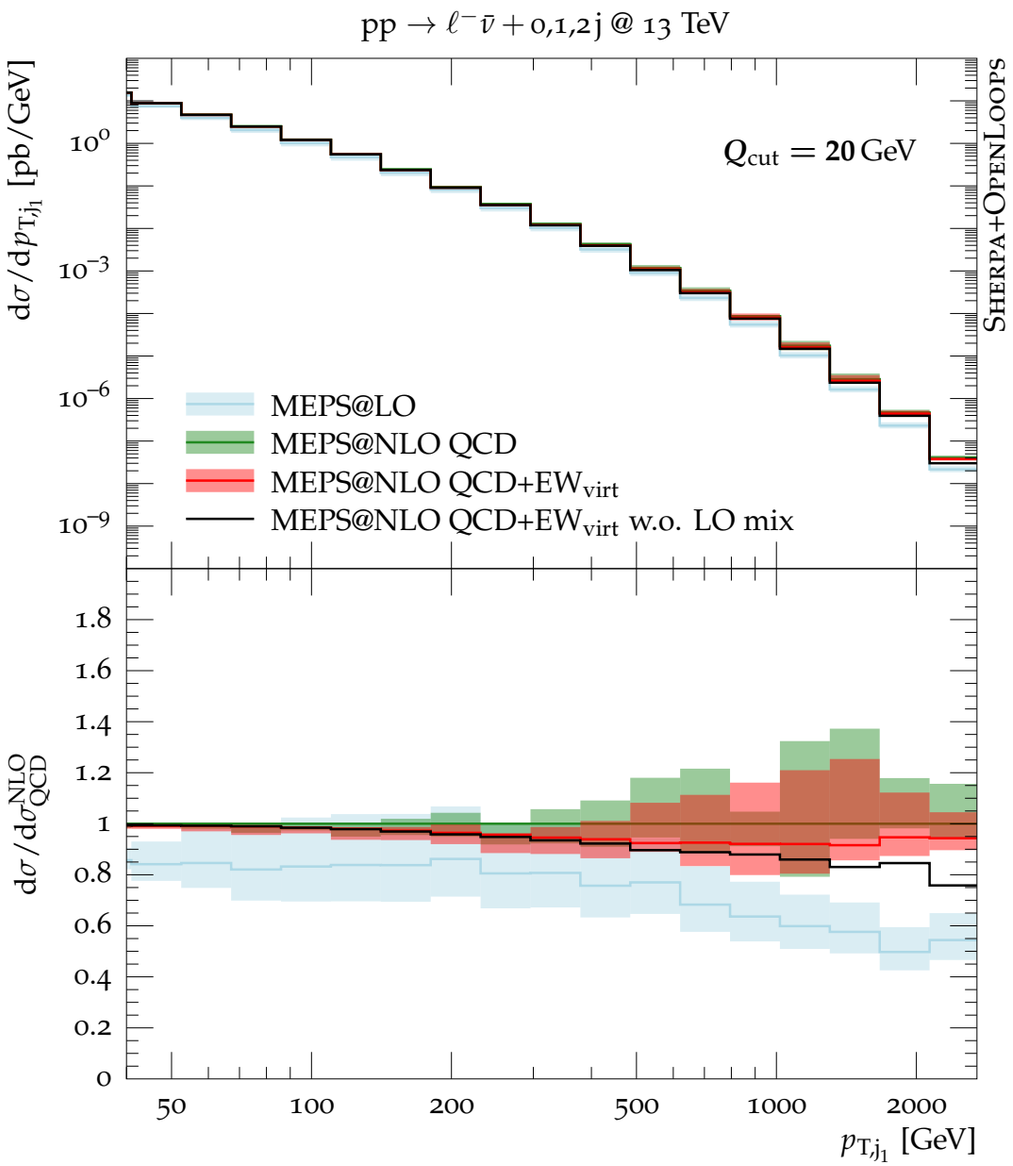
Lindert, Kallweit, Maierhöfer, Pozzorini, MS arXiv:1511.08692

MEPS@NLO QCD+EW$_{\text{virt}}$

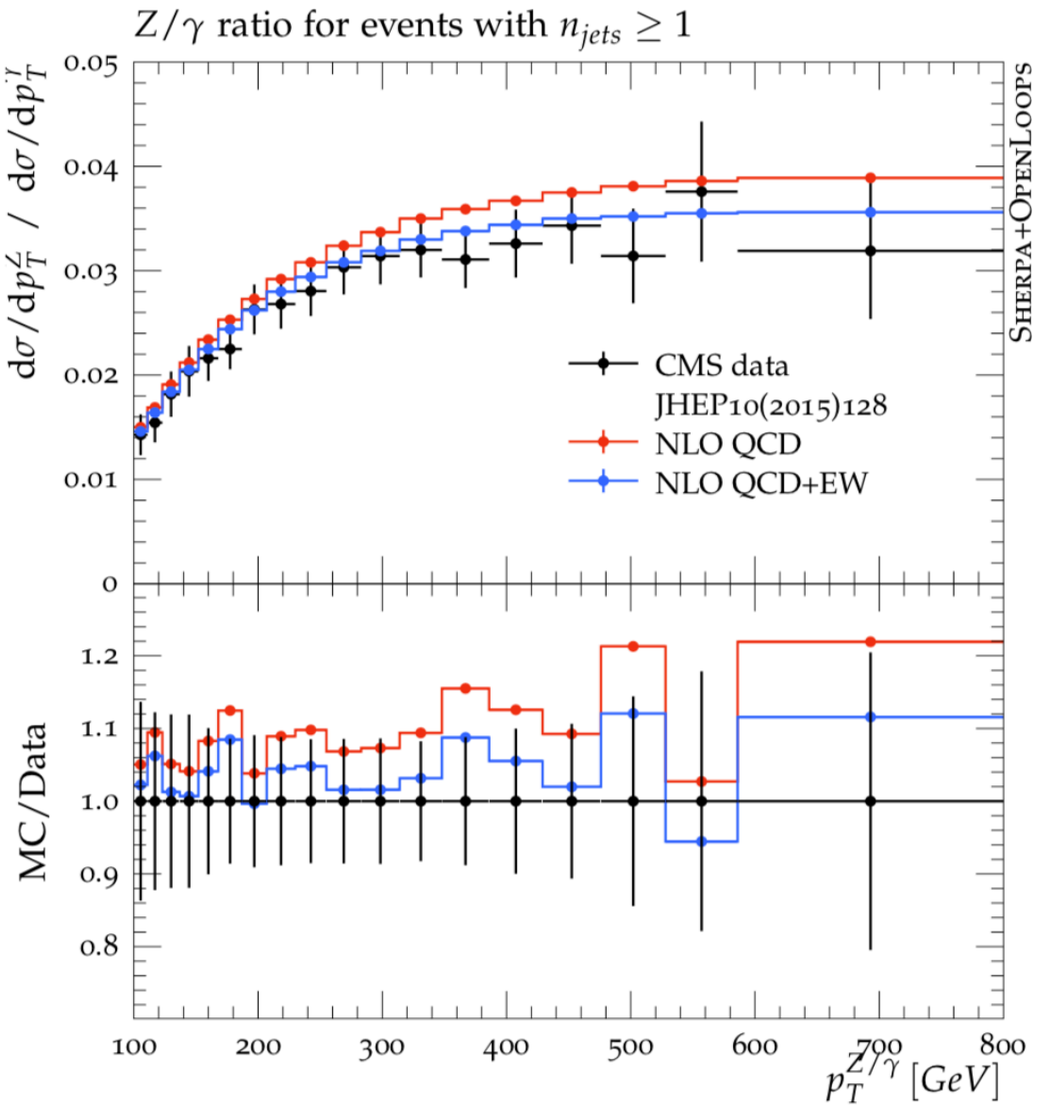
- incorporate approximate NLO EW corrections
  $\approx$ EW Sudakov approx.
  $\rightarrow$ but also includes many non-logarithmic terms that render the result closer to NLO EW
  $\rightarrow$ **recover large EW corr. at large p_T**
- also include large subleading orders
- QED FSR through YFS soft-photon resummation



Multijet merging in 2.2.6 and NLO QCD+EW correction in 3.0.0



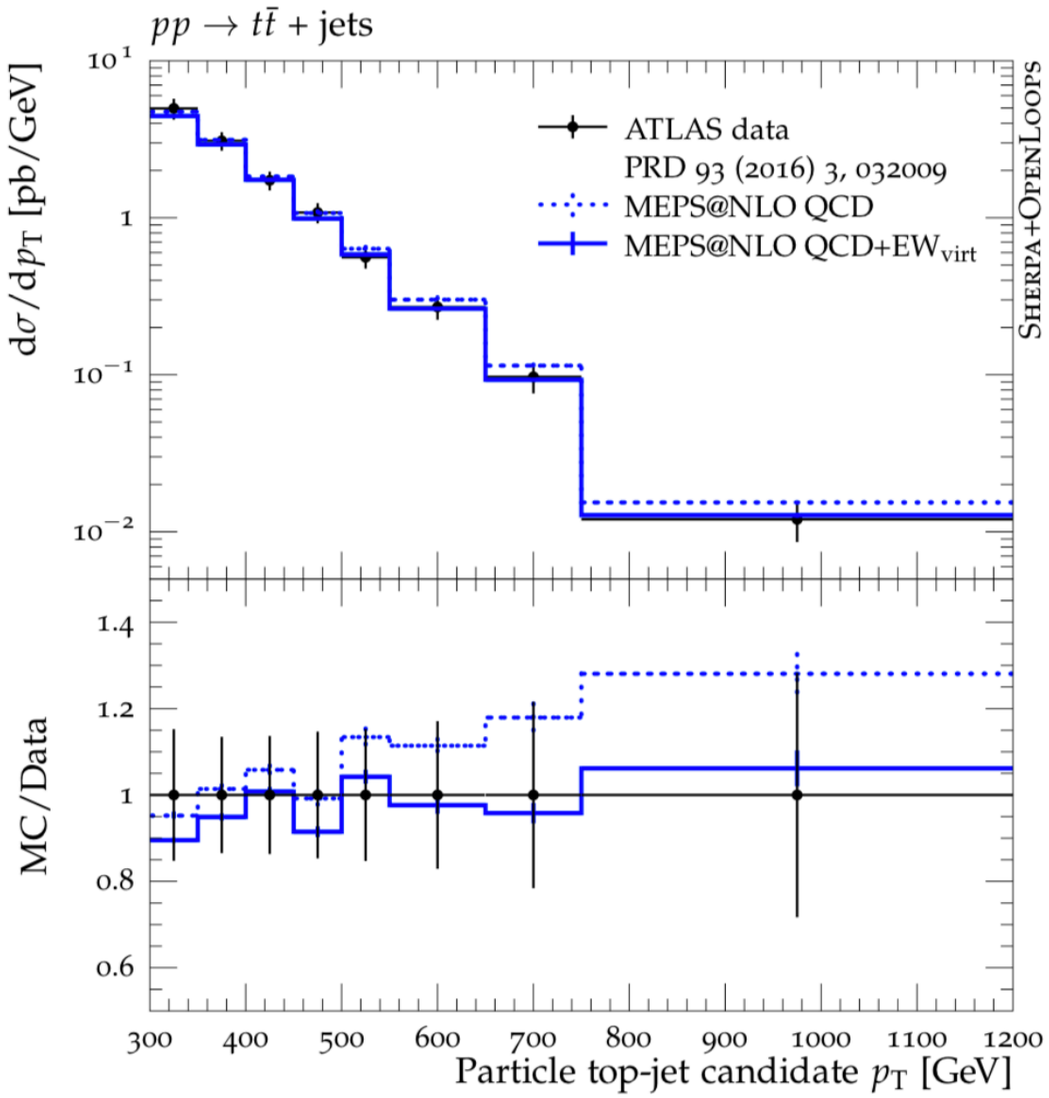
LH'15 arXiv:1605.04692



important to describt Z/γ ratio

⇒ **preview to SHERPA-3.0.0**

$t\bar{t}$ + jets production incl. approx. electroweak corrections



Gütschow, Lindert, MS arXiv:1803.00950

- $t\bar{t} + 0, 1j$@NLO QCD+EW$_{\text{virt}}$ $+ 2, 3, 4j$@LO
- include approx. virtual corrections
- additional LO multiplicities inherit electroweak corrections through MENLOPS differential K-factor

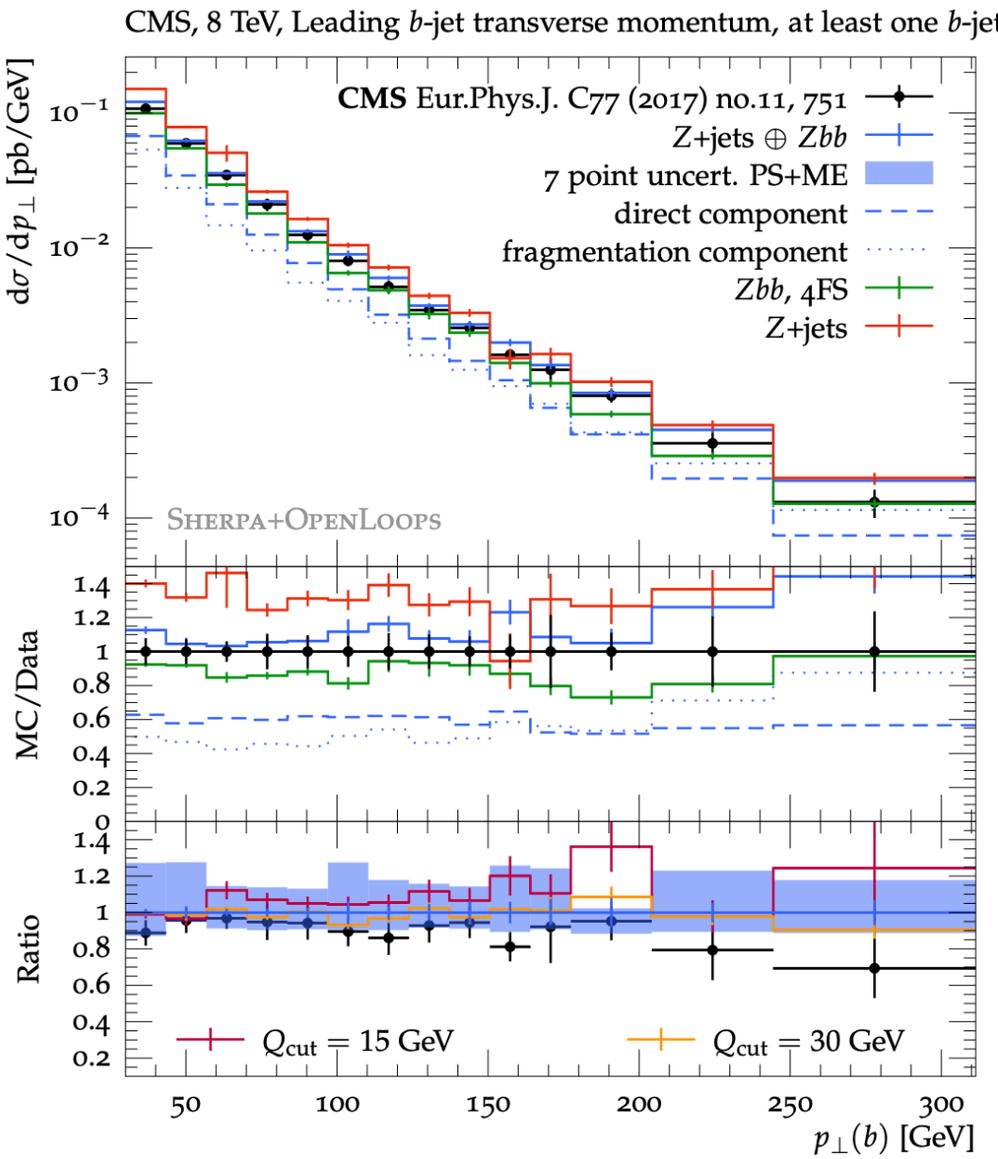
Höche, Krauss, MS, Siegert arXiv:1009.1127

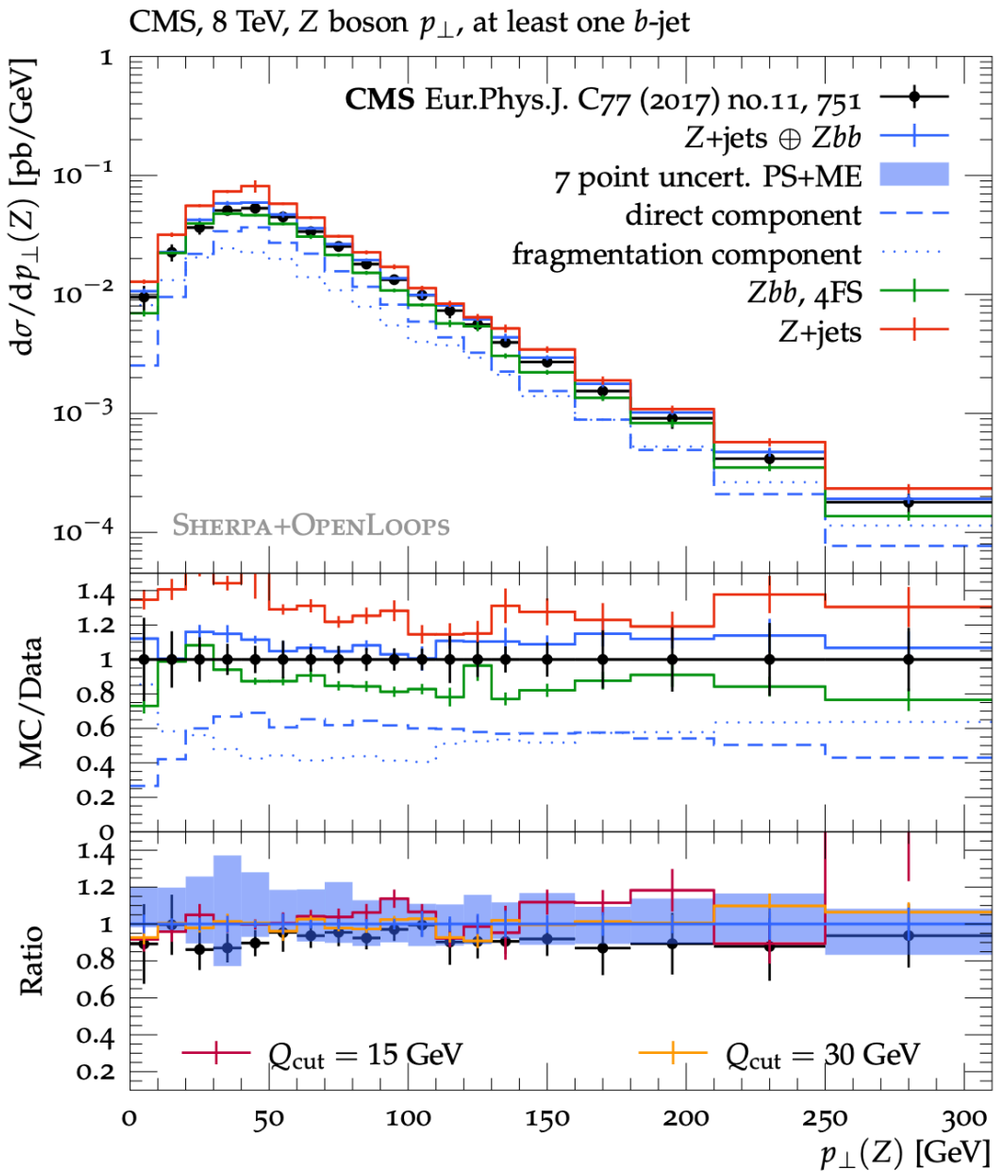
- improved description of data

Multijet merging in variable flavour number scheme

- Three main ingredients:
  - Interpreting ttbb as merged contribution
  - Overlap removal
  - Matching 4F/5F in PDFs and
- Can be applied for LO and NLO merging!

arxiv.1904.09382

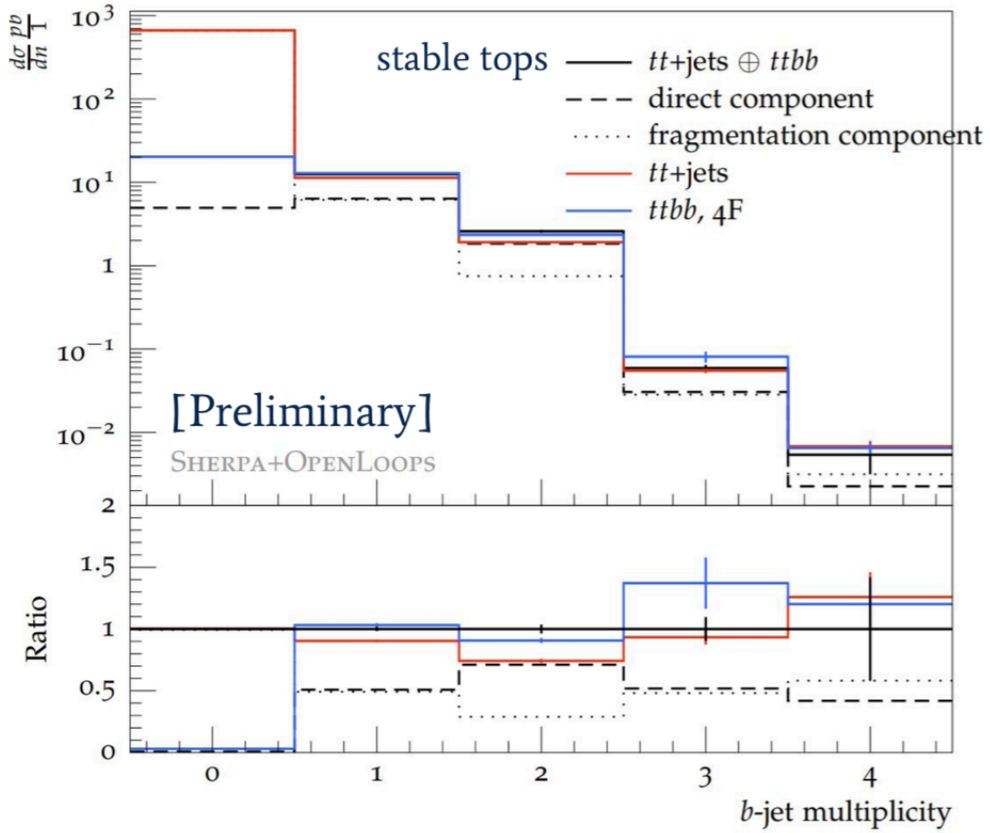


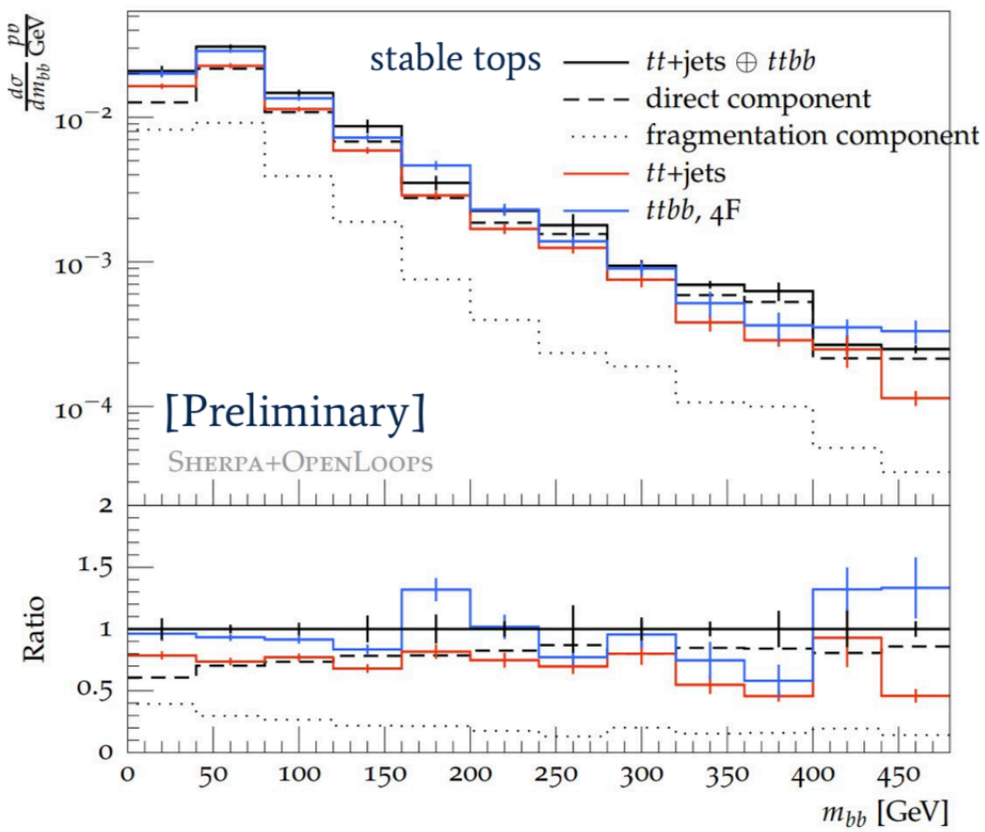


Multijet merging in variable flavour number scheme

[Katzy, Krause, Pollard, FS in prep]

- Application to fusion of MEPS@NLO tt + 0,1j@NLO + 2,3j@LO and massive ttbb@NLO
- 2-bjet production dominated by direct component, but 1-bjet observables with equal contributions from direct and fragmentation configurations!





- More information about 'Monte-Carlo modelling and uncertainties in ttbb production' is available by Frank Siegert in SM@LHC, 2019

SHERPA in CMS - I

- Sherpa is included in CMSSW as external package: https://github.com/cms-externals/sherpa
- Uses a couple of additional external packages:
  - HepMC, LHAPDF, Sqlite, FastJet, ... (used by many others)
  - BlackHat, Openloops, ... (used only by Sherpa)
- **Releases**
  - Every new release is integrated & validated in the CMS software in ~1 month
  - SHERPA is part of CMS generator validation & production infrastructure
    - Z+jets and ttbar events (100 k) are included in the RelVals
- SHERPA samples can be produced for Phase-II upgrade studies and all the data taking periods in Run-2, i.e. 2016, 2017 and 2018
- Current recommended versions: SHERPA 2.2.5 + OpenLoops.2.0.b
  - CMSSW_10_2_6 & CMSSW_10_3_0 for 2018 data
  - CMSSW_9_3_13 for 2017 data
  - CMSSW_7_1_36 for 2016 data
- **NEW**: SHERPA 2.2.6 (List of updates) and OpenLoops 2.0 are being integrated in CMSSW
  - SHERPA 2.2.7 and SHERPA 3.0.0 expected in May

SHERPA in CMS - II

- the Sherpa Interface is part of CMSSW
  - source code:

  https://github.com/cms-sw/cmssw/tree/CMSSW_9_4_X/GeneratorInterface/SherpaInterface
- purpose:
  - generate events with Sherpa
  - turn events into compliant format
  - feed output into CMSSW
- Sherpa-CMSSW workflow
  - phase-space integration and library creation
  - event generation
    - performed by interface
    - can be parallelized on grid

- **Documentation**: HEPForge is hosting the releases until 2.2.5 but SHERPA is moved to Gitlab for the future releases
- **CMS Twiki**: https://twiki.cern.ch/twiki/bin/viewauth/CMS/SherpaInterface
- **Support**: Primarily report issues at GEN hypernews: hn-cms-generators@cern.ch

SHERPA Samples

- SHERPA samples are being produced for the 10+ analyses in the standard model, top physics and Higgs physics groups
- Spreadsheet to document the Sherpa sample's usage in CMS (private and central)
- Additional work is started for:
  - Higgs+jets production in gluon fusion with finite top mass effects
  - VBF process to study the impact of parton shower uncertainties in Higgs XSection working group
  - Understand negative weight fraction in pdfs in V+jets samples
- **Suggestions for MC production of private/central samples in CMS**
  - Please always post your run cards on the official GitHub SHERPA-GEN area: https://github.com/cms-sw/genproductions/tree/master/bin/Sherpa/cards/production
  - Report the number of events/target analysis/timeline, etc. on the CMS-SHERPA-Googlesheet and GEN spreadsheets
  - for EVENT_GENERATION_MODE please use default "PartiallyUnweighted", which contrary to "Unweighted" properly treats events with weights larger than the maximum
- In addition to the SHERPA manual, several examples are available on https://gitlab.com/sherpa-team/sherpa/tree/rel-2-2-6/Examples
- To explore SHERPA in CMS, please contact Gurpreet.Singh@cern.ch

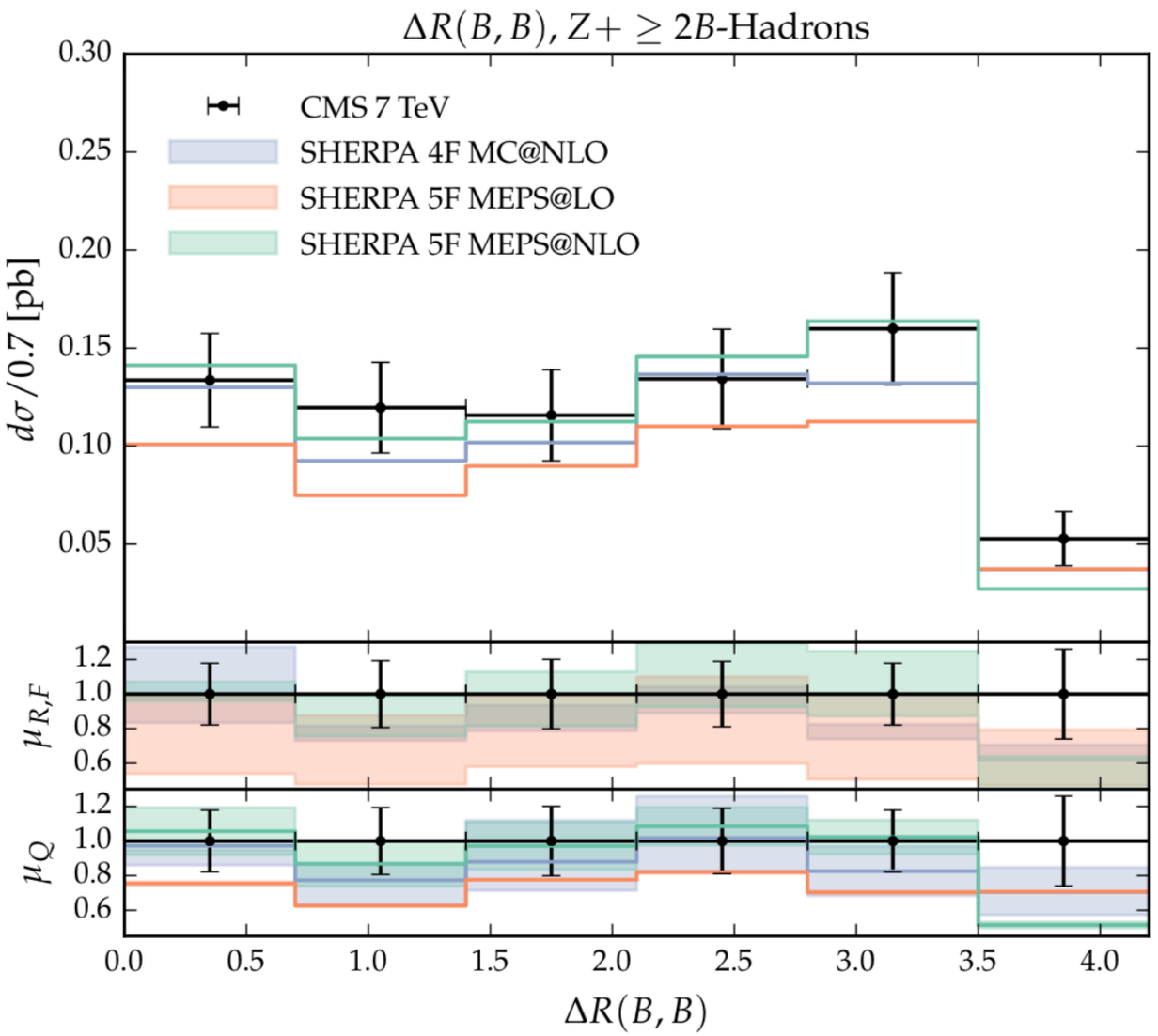
Summary

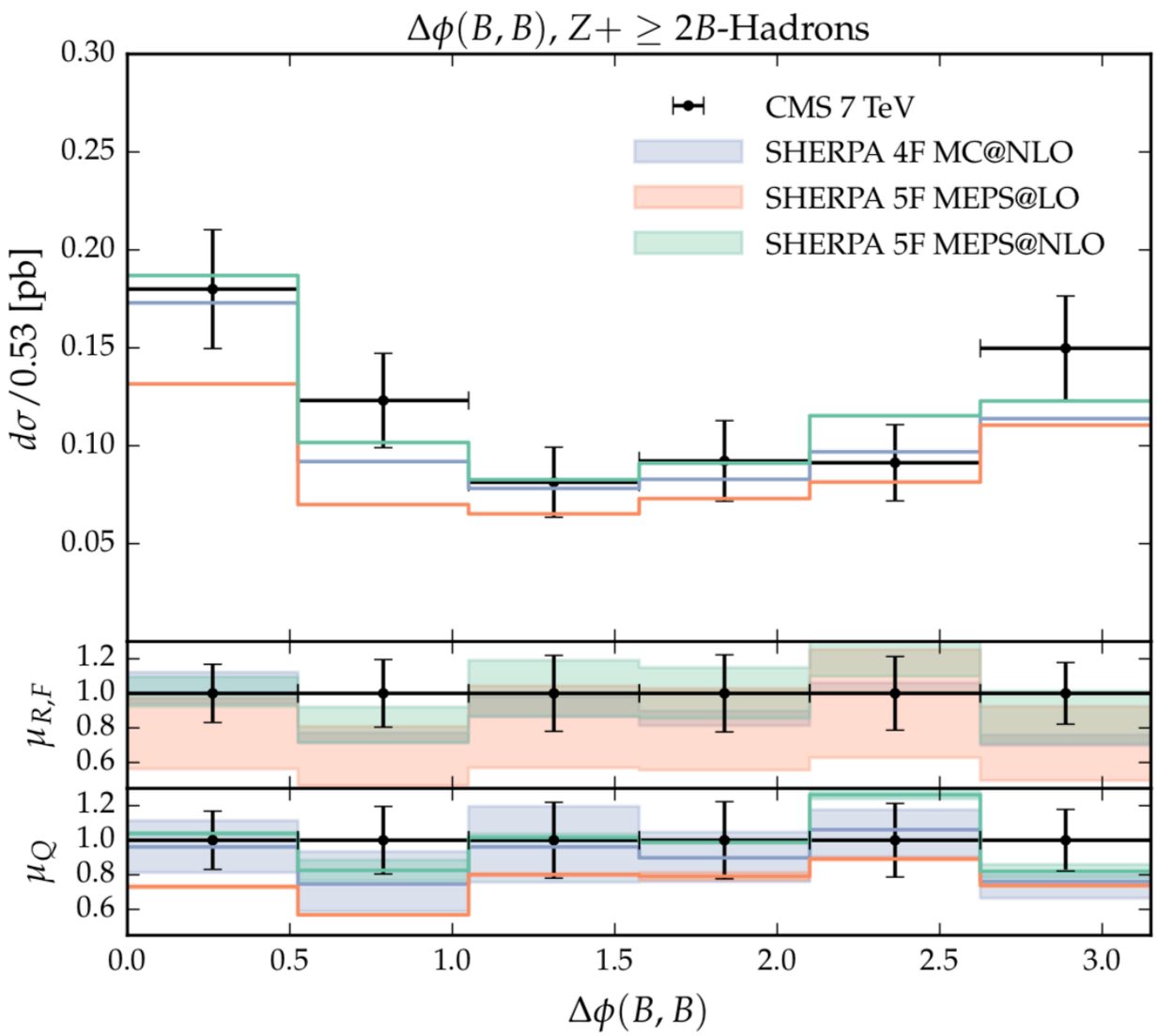
- 5FMS is recommended when the phase space is not well understood (exclusive or inclusive observables)
- Approximate NLO QCD + EW correction are available in SHERPA 2.2.6 and well tested for V+jets, ttbar+jets, VV+jets.
- SHERPA is fully compatible to produce MC samples with UFO models
- SHERPA tunes are under development
- SHERPA 2.2.6 and openloops 2.0 is being integrated in CMSSW
- Various kind of SHERPA samples can be produced in CMS
- The First CMS SHERPA workshop was organised in February 2019: https://indico.cern.ch/event/779232/
- Open to explore the possibilities to enhance heavy flavour treatment in SHERPA

Thank you very much!

Additional Slides

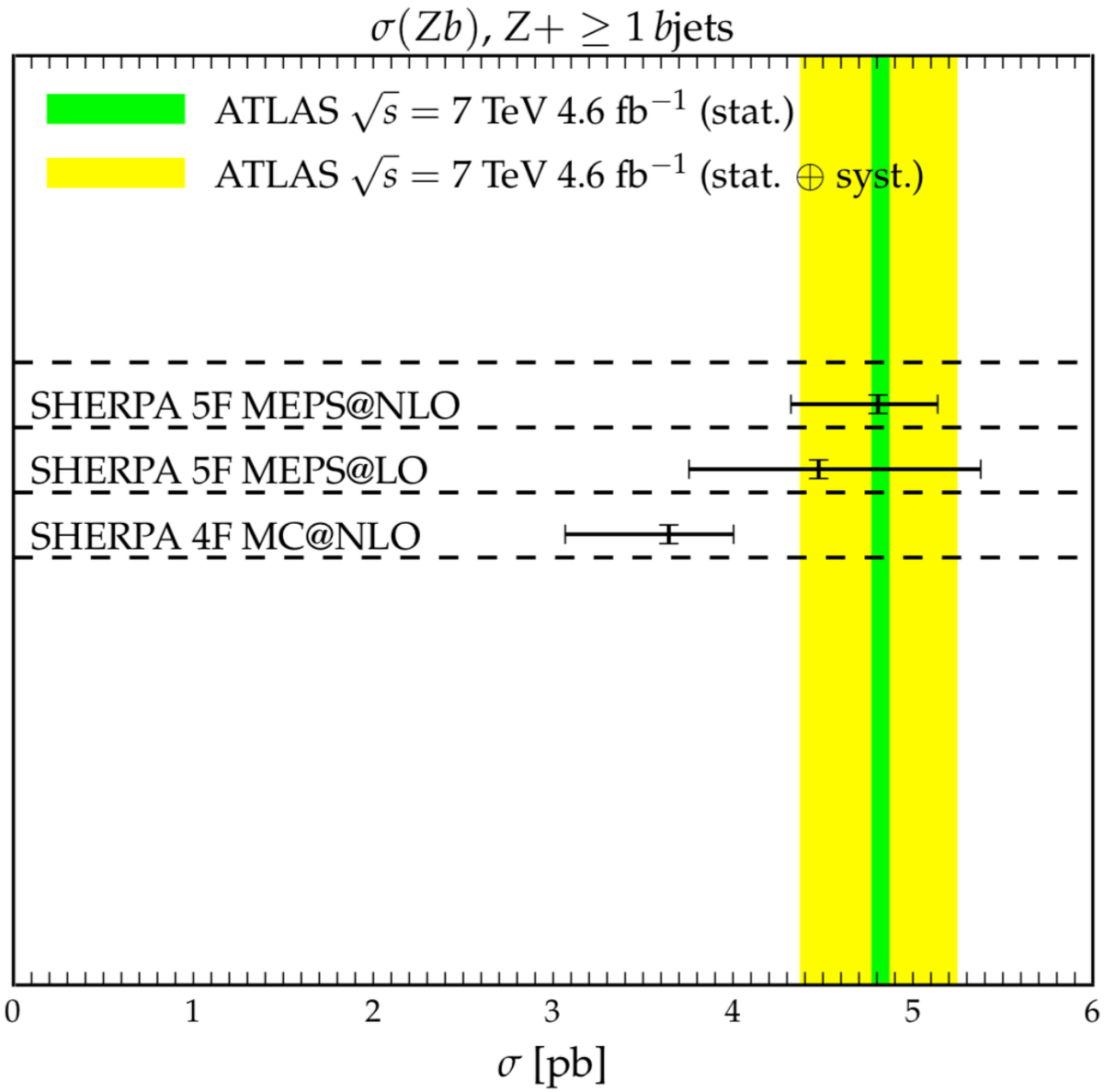
Z/H + Heavy Flavours

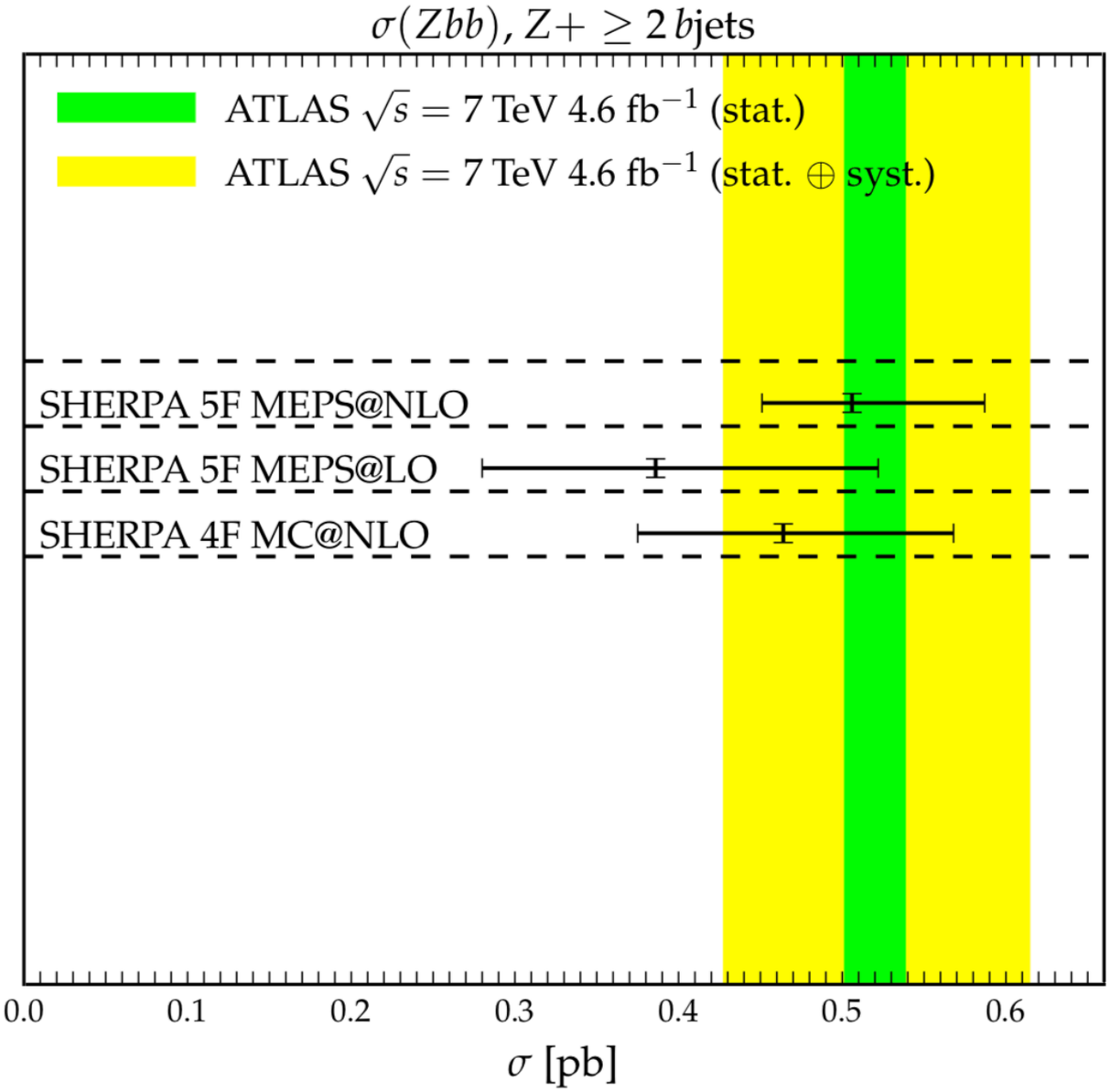




[1612.04640,1712.06832]

Z/H + Heavy Flavours





[1612.04640,1712.06832]