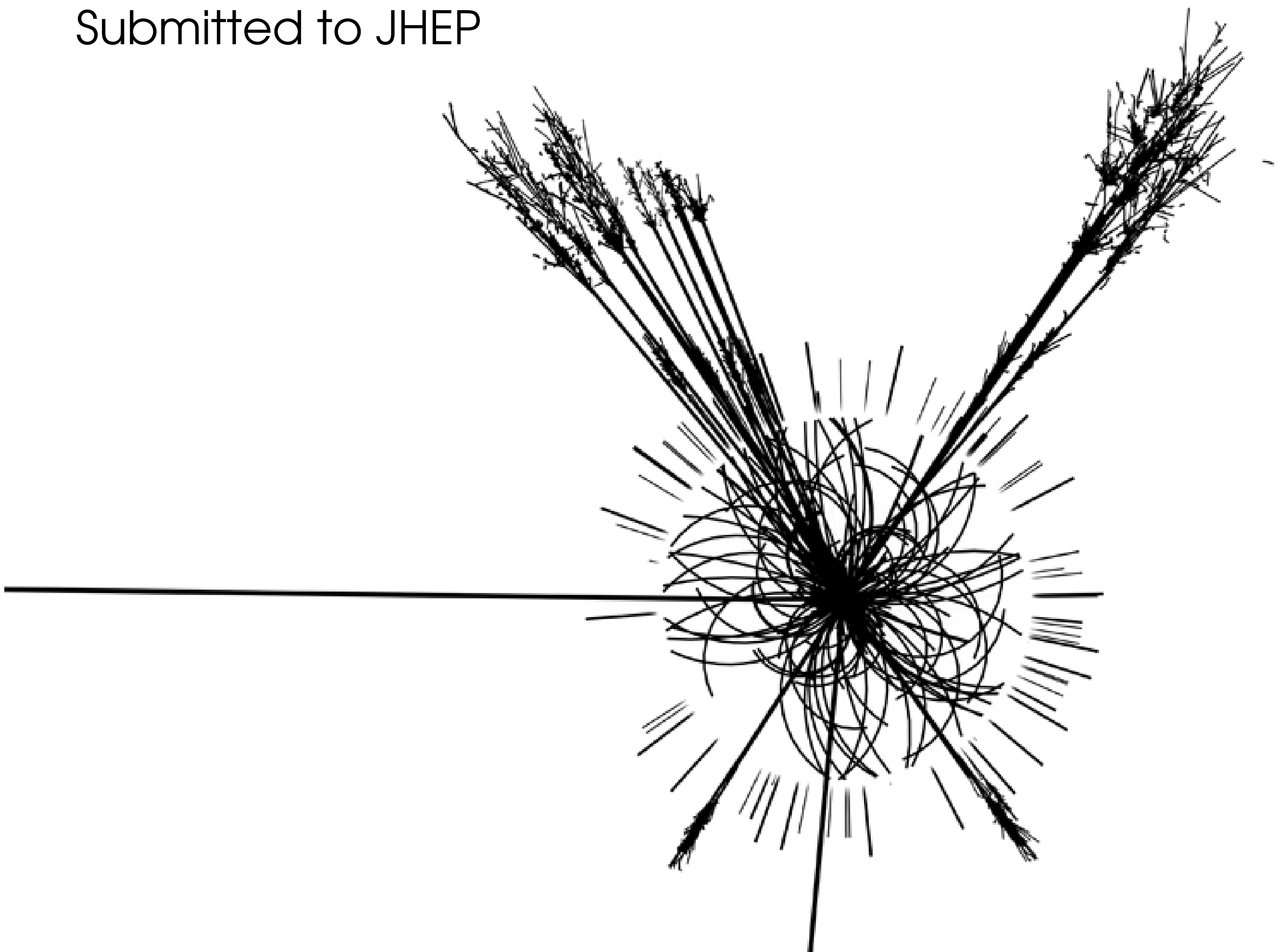
Inclusive BB cross section at 8 TeV

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/BPHY-2015-04/

arxiv:1705.03374
Submitted to JHEP



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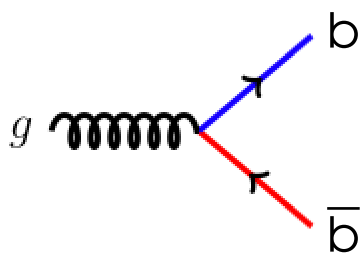
7th September 2017

Background

Aim: measure b-hadron production

- down to zero opening angle
- across a range of kinematics

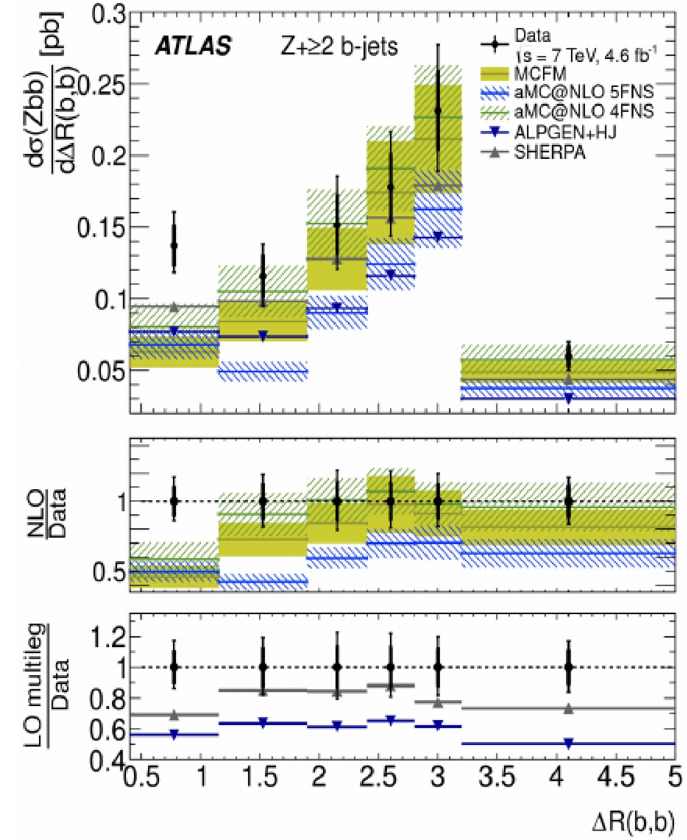


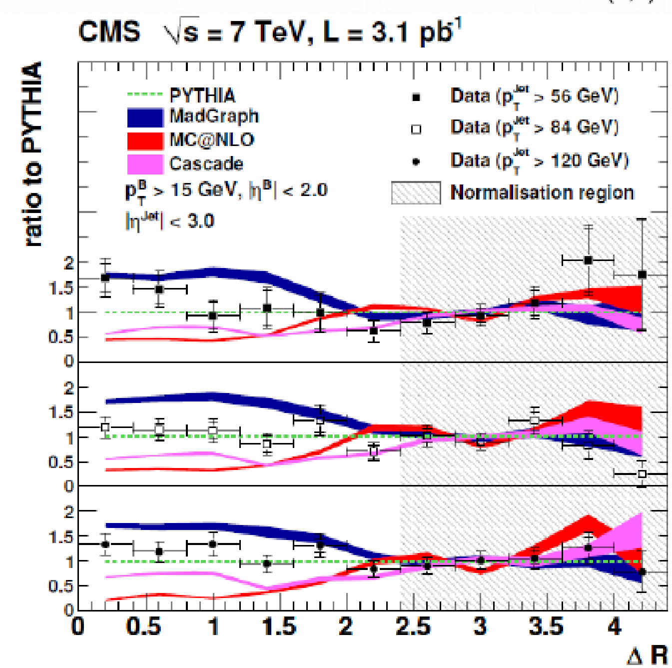
Interested in b production mechanisms

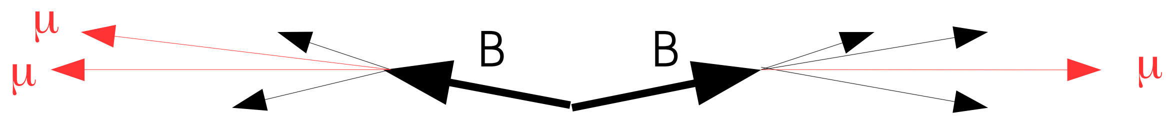
- particularly small angle g→bb
  - important background for boosted searches
    - eg boosted H→bb

Previous measurements:

- limited by b-jet radius
  - small-R jet analyses in Run 2 will go to dR~0.2
- stats & systs for inclusive vertexing







J/psi→mumu is a clean signal

- use displaced J/ψ to tag B (include feed-down)

… but low branching fraction Br(B → J/ψ → mumu) ***~0.01 x 0.06***

Use displaced muon to tag other B

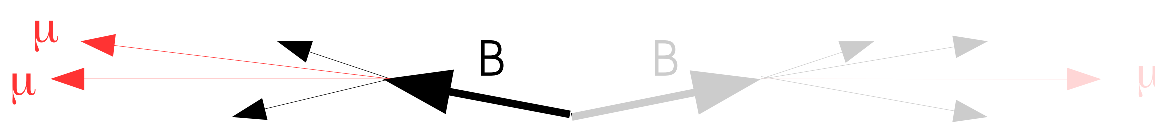
- include cascades
- *Br (B→mu + X)* ***~0.2***

Analysis is based on 3 muons

- can measure muons down to ~zero BB opening angle

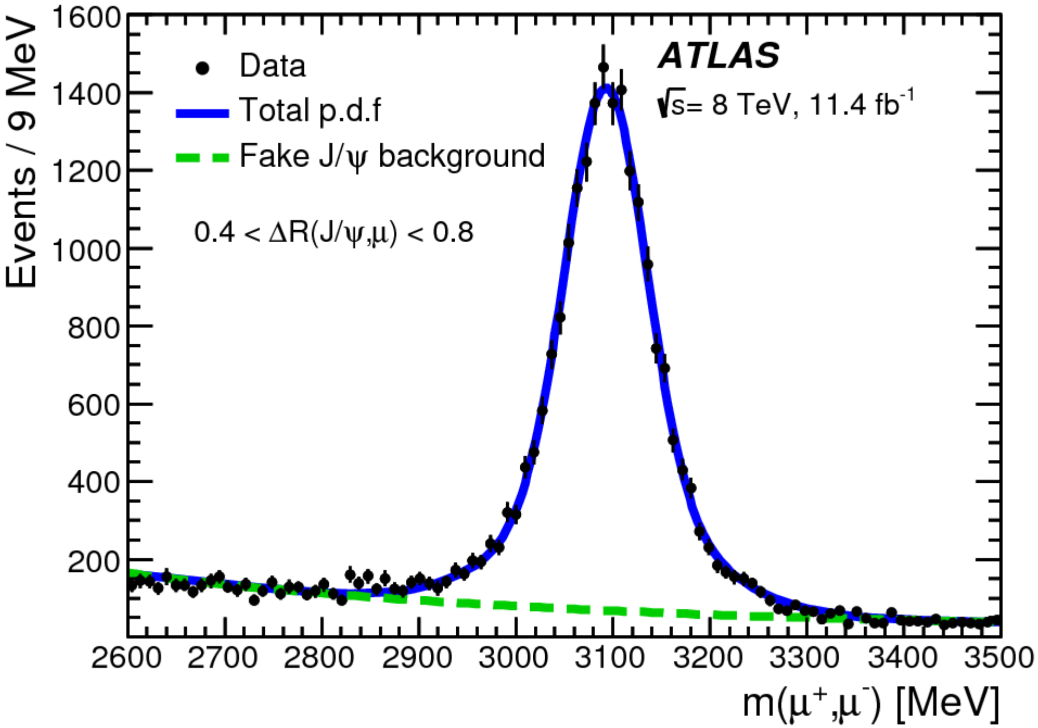
Measure differential, normalised cross sections:

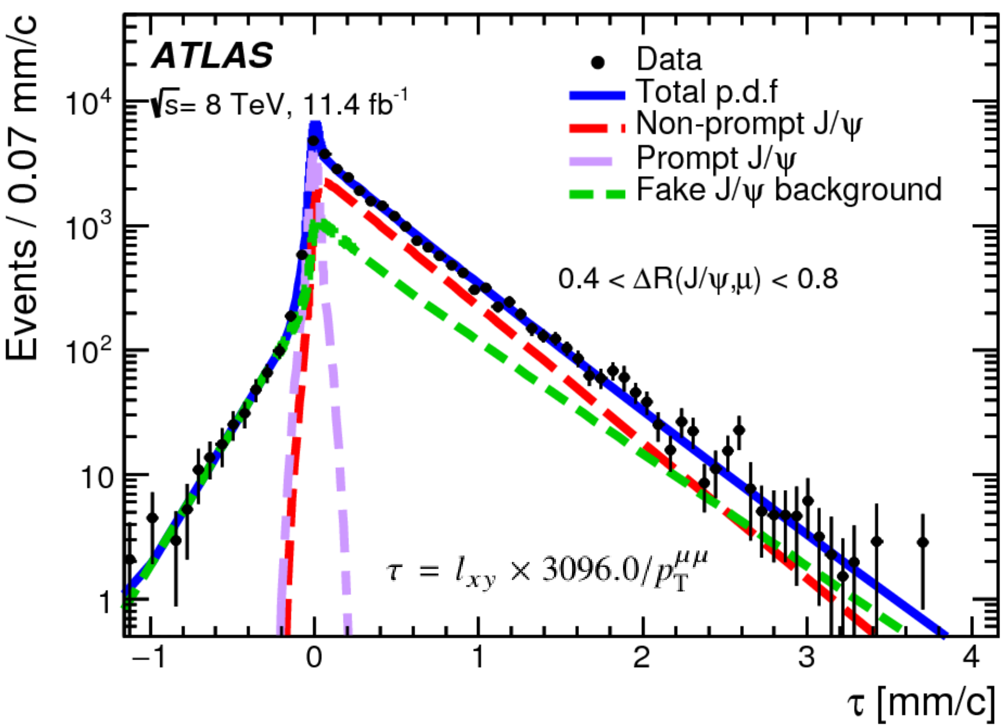
- ΔR(J/ψ, mu) inclusively, for pT(J/ψ + mu) > 20 GeV, and < 20 GeV
- Δφ(J/ψ, mu), y(J/ψ, mu)
- y_{boost}(J/ψ, mu)
- pT (J/ψ + mu), mass(J/ψ + mu)
- pT / m, and m / pT



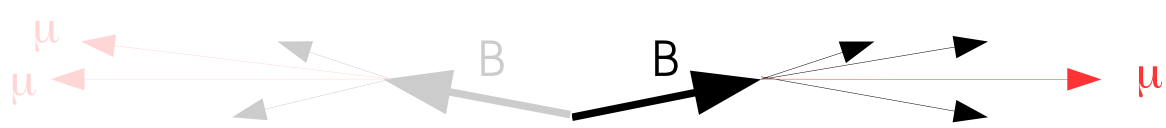
B → J/ψ + X → μμ + X :
- clean signal, use dedicated B-physics triggers (prescaled in some runs)
- efficiencies measured using tag&probe, applied as weights to data
- select muons with pT > 6 GeV, $|\eta| < 2.3$

Backgrounds are small:
- "fake J/ψ": combinatorics, fake vertices etc
- prompt J/ψ, ie not from B decay.





Third muon

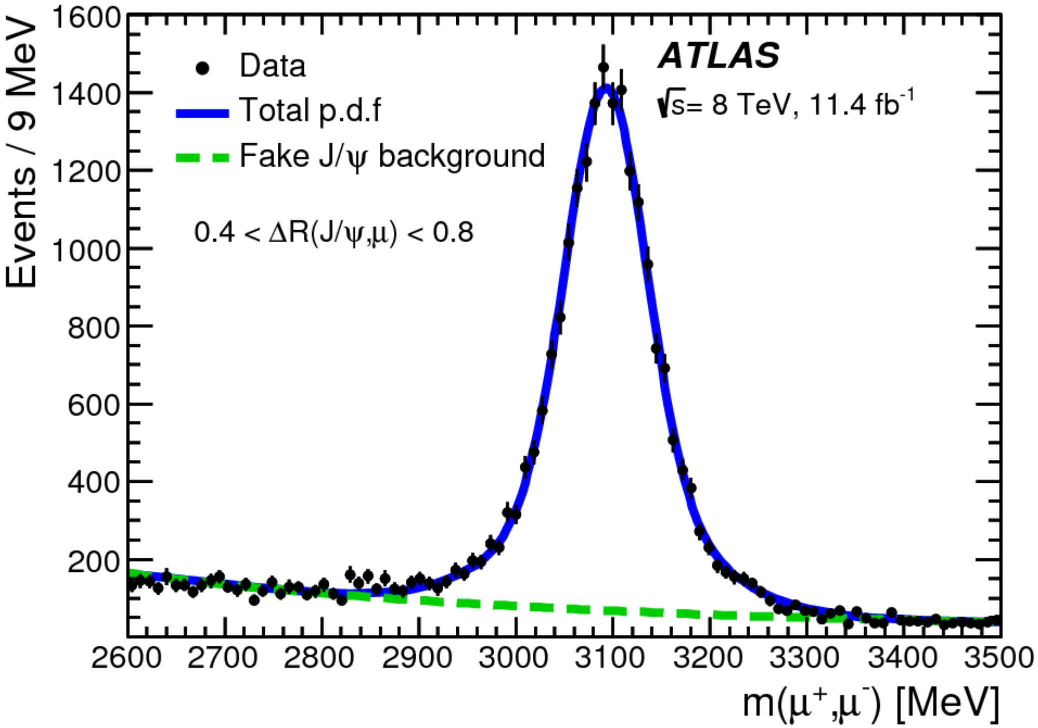


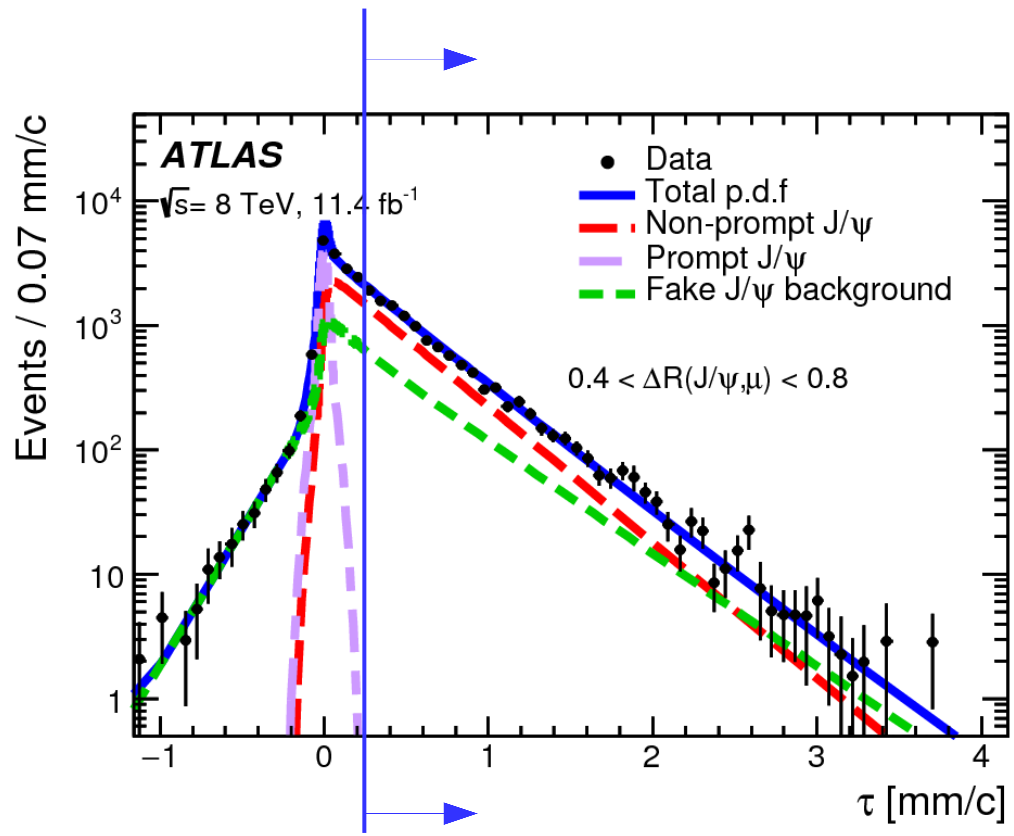
B → μ + X :

- select muon with pT > 6 GeV, |η|<2.5
- use transverse distance of closest approach to beam (d0) as discriminant

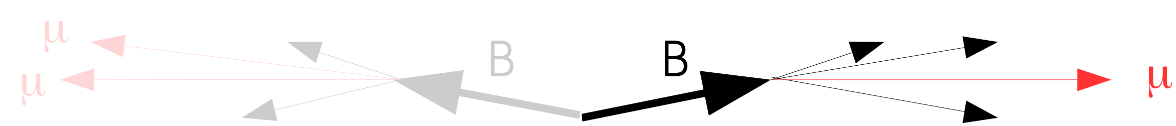
Backgrounds are significant:

- in-flight decay of π/K, punch-through, "sail-through", pile-up, prompt muons…
- simplify picture by first cutting on J/ψ τ > 0.25.





Third muon



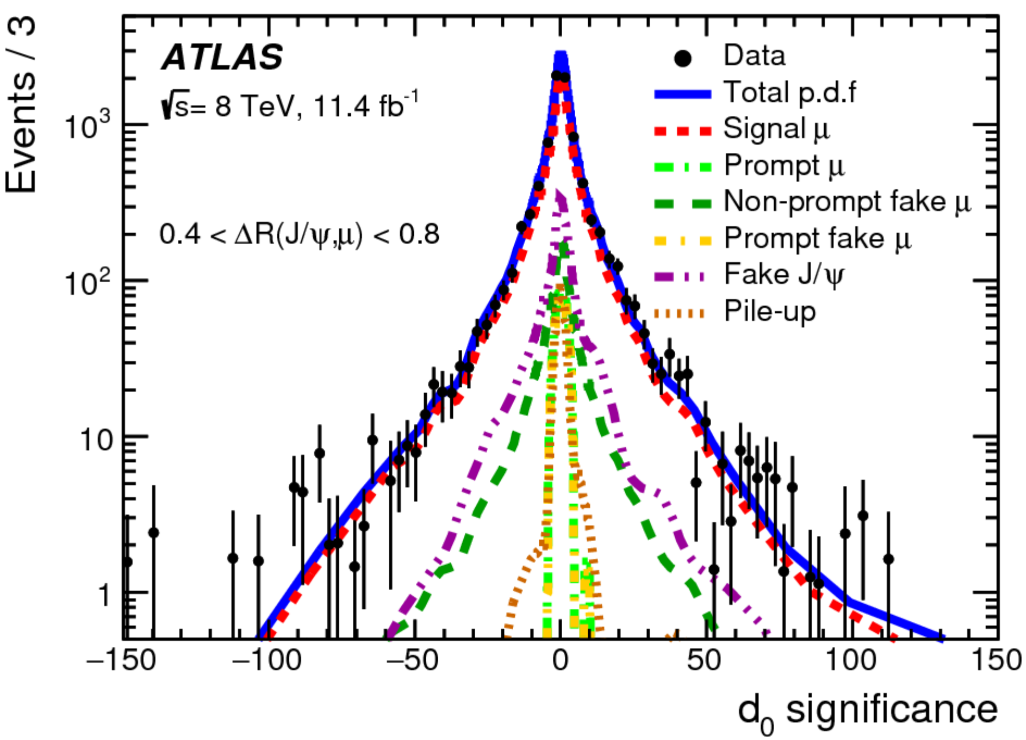
Final signal yield determined by 2D fit to 3rd muon:

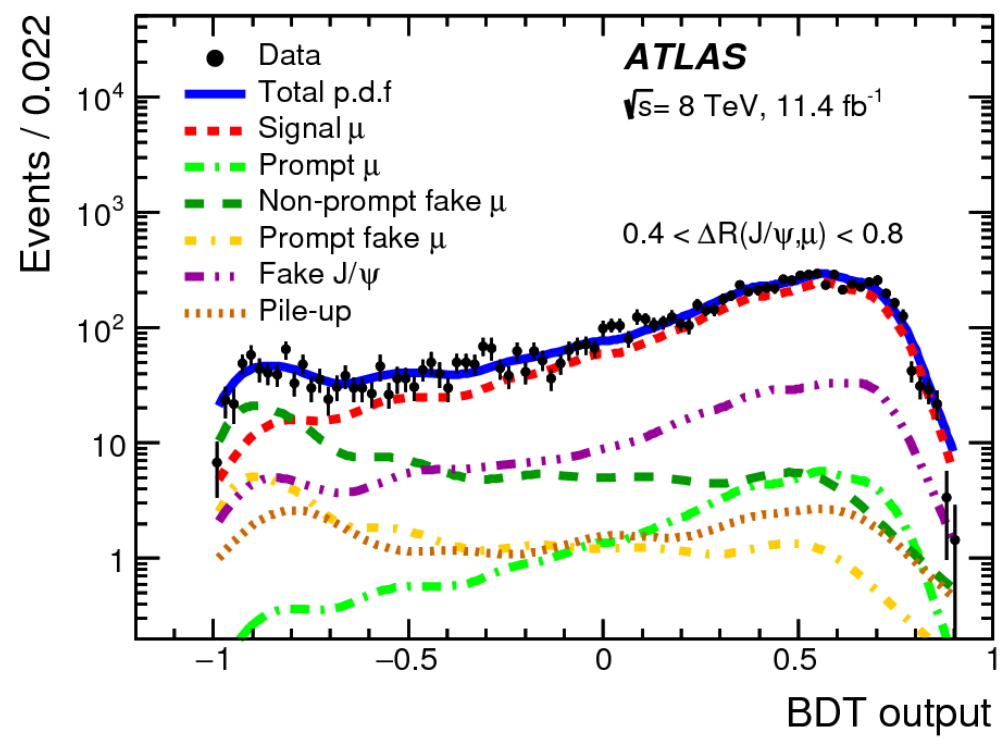
- d0 significance to separate prompt from non-prompt muons
- BDT output to separate "real" muons and "fakes": in-flight decays, punch-through

Fake J/ψ and pile-up contributions fixed in control regions

Extrapolation to full J/ψ lifetime region after 3rd muon fit

- small unfolding corrections also applied bin-by-bin



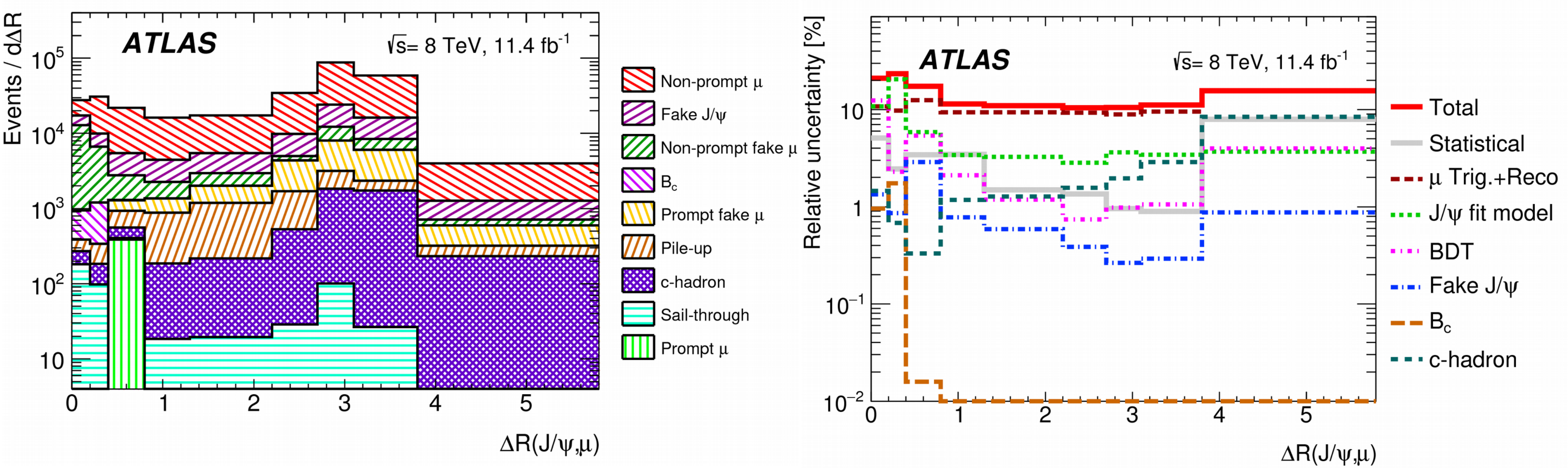


Irreducible backgrounds subtracted from the data post-fit:

- "sail-through" (eg pi/K flying out through the muon system)
  - distribution and normalisation taken from MC (~1%)

- B_c or B_s → J/ψ+mu+X
  - attempt to quantify looking for 4-muon events: B_c(→ J/psi + mu) + B(→mu + X)
  - instead take from MC (<5%, all at low ΔR)

- B(→ J/ψ + X) + D (→mu + X)
  - possible discrimination through shorter D lifetime
  - attempted to include in 3rd muon fit as separate template, struggle with stats
  - instead take from MC (~5%)



$$\sigma(B(\to J/\psi[\to \mu^+\mu^-] + X)B(\to \mu + X)) = 17.7 \pm 0.1(\text{stat}) \pm 2.0(\text{syst})\ \text{nb}.$$

Pythia 8.2, NNPDF2.3, A14 tune:

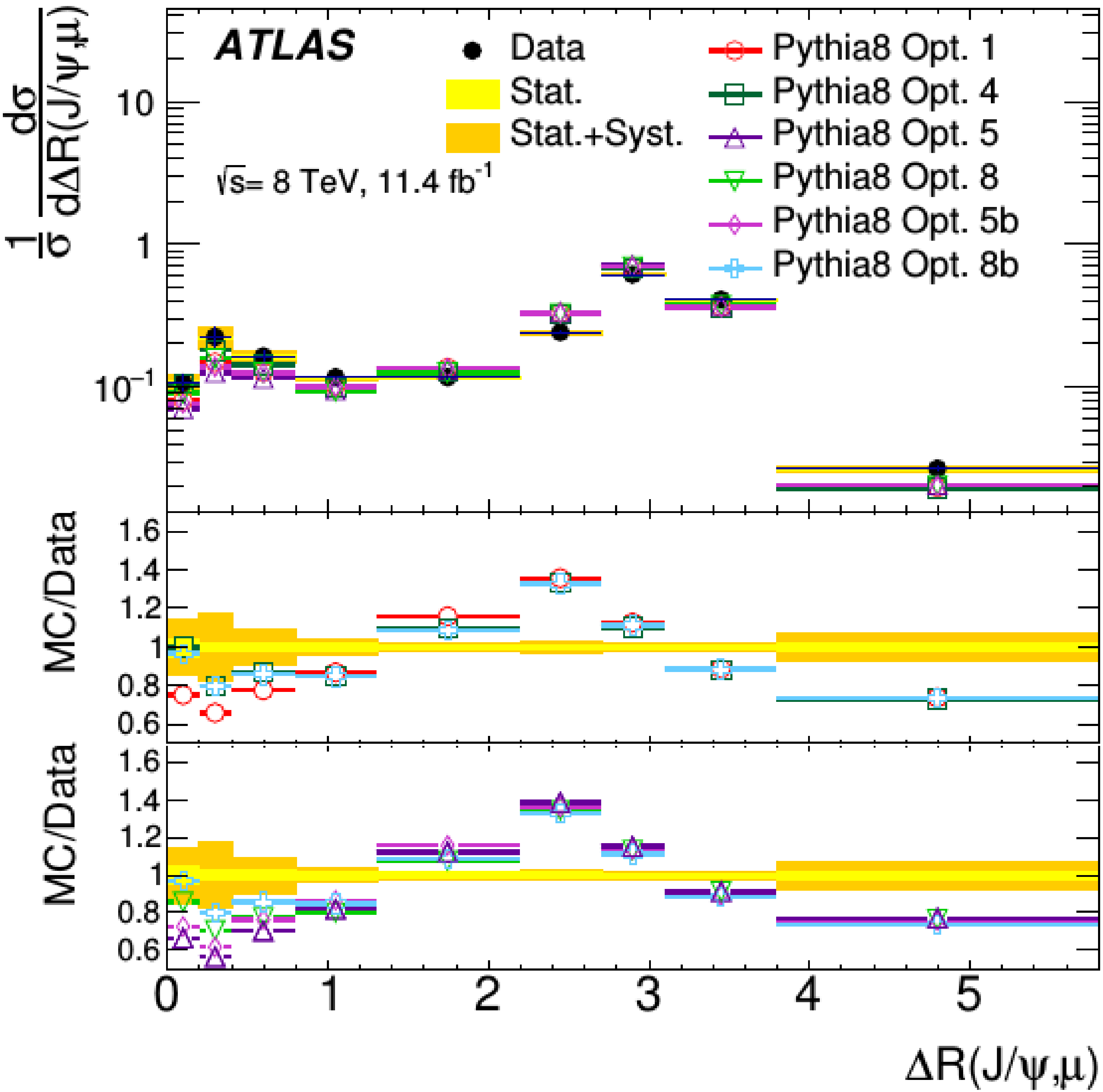
- generate fully inclusive 2→2 process with very loose cuts
  - allow b-hadrons from ME and PS
- force one b-hadron to decay to J/ψ, with J/ψ → mumu.
  - still a significant amount of CPU time…

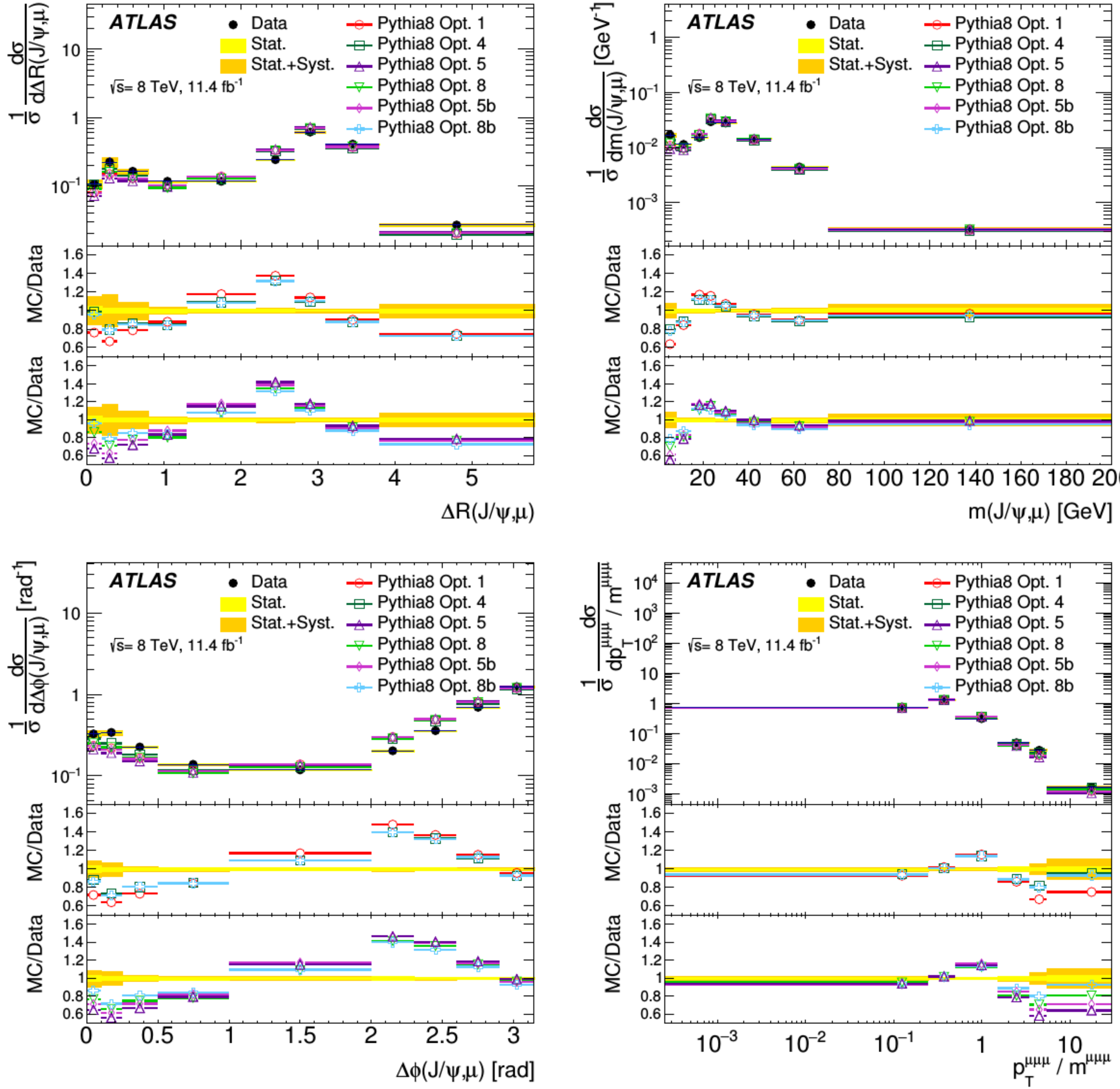
Generate samples with various settings for g→bb splitting kernel:

Option label	Descriptions
Opt. 1	The same splitting kernel, $(1/2)(z^2+(1-z)^2)$, for massive as massless quarks, only with an extra β phase-space factor. This was the default setting in PYTHIA8.1, and currently must also be used with the MC@NLO [36] method.
Opt. 4	A splitting kernel $z^2+(1-z)^2+8r_q z(1-z)$, normalised so that the z-integrated rate is $(\beta/3)(1+r/2)$, and with an additional suppression factor $(1-m_{qq}{}^2/m^2_{\text{dipole}})^3$, which reduces the rate of high-mass $q\bar{q}$ pairs. This is the default setting in PYTHIA8.2.
Opt. 5	Same as Option 1, but reweighted to an $\alpha_s(km^2_{qq})$ rather than the normal $\alpha_s(p^2_T)$, with $k=1$.
Opt. 5b	Same as Option 5, but setting $k=0.25$.
Opt. 8	Same as Option 4, but reweighted to an $\alpha_s(km^2_{qq})$ rather than the normal $\alpha_s(p^2_T)$, with $k=1$.
Opt. 8b	Same as Option 8, but setting $k=0.25$.

pT kernels + best mass kernel

mass kernels




ATLAS
Data
Stat.
Stat.+Syst.
Pythia8 Opt. 1
Pythia8 Opt. 4
Pythia8 Opt. 5
Pythia8 Opt. 8
Pythia8 Opt. 5b
Pythia8 Opt. 8b
√s= 8 TeV, 11.4 fb⁻¹
$\frac{1}{\sigma}\frac{d\sigma}{d\Delta R(J/\psi,\mu)}$
MC/Data
$\Delta R(J/\psi,\mu)$
$\frac{1}{\sigma}\frac{d\sigma}{dm(J/\psi,\mu)}$ [GeV⁻¹]
m(J/ψ,μ) [GeV]
$\frac{1}{\sigma}\frac{d\sigma}{d\Delta\phi(J/\psi,\mu)}$ [rad⁻¹]
Δφ(J/ψ,μ) [rad]
$\frac{1}{\sigma}\frac{d\sigma}{dp_T^{\mu\mu\mu}/m^{\mu\mu\mu}}$
$p_T^{\mu\mu\mu}$ / $m^{\mu\mu\mu}$

Samples using Herwig++2.7.1, CTE6L1, UE-EE-5 tune:

- again, fully inclusive 2→2 process, loose cuts
- force one b-hadron → J/ψ , with J/ψ → mumu

Madgraph5_aMC@NLO v2.2.2, CKKW-L merging @ 30 GeV, Pythia 8.186 A14 tune

- 5 and 4-flavour samples, using NNPDF3.0NLO (4fl) PDF for ME, NNPDF2.3LO for PS.
- no HFOR for 4-flavour, generate b's in ME with ~no cuts

Shepa 2.1.1, CT10 PDF, MEPS@LO, default tune

- both MG & Sherpa: generate LO samples, up to 3 partons in ME.
- was not possible* to generate 3-muon predictions

Instead derive transfer functions:

ratio of (3-muon cross section) / (2xb-hadron cross section)

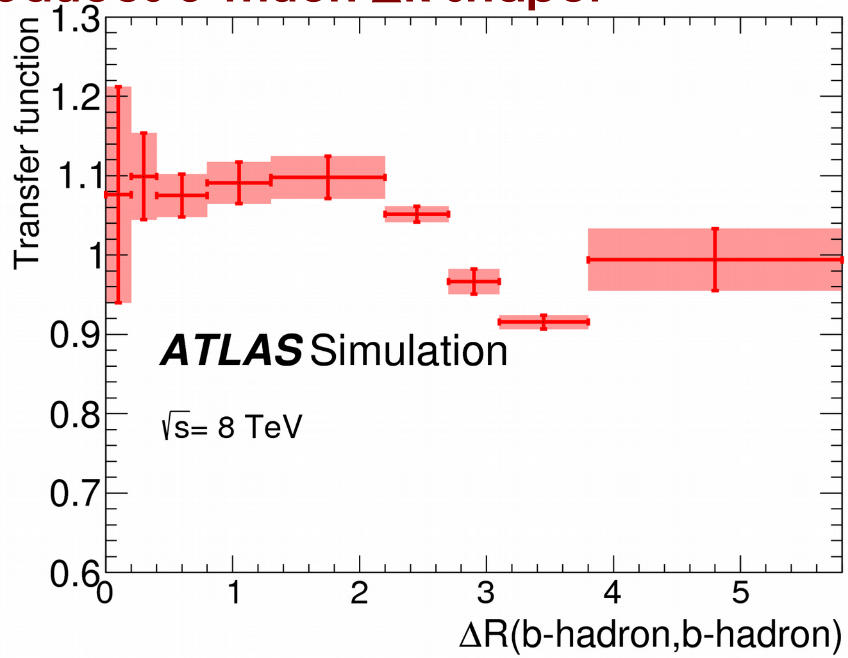
Define a 2xb-hadron fiducial volume which reproduces 3-muon ΔR shape:

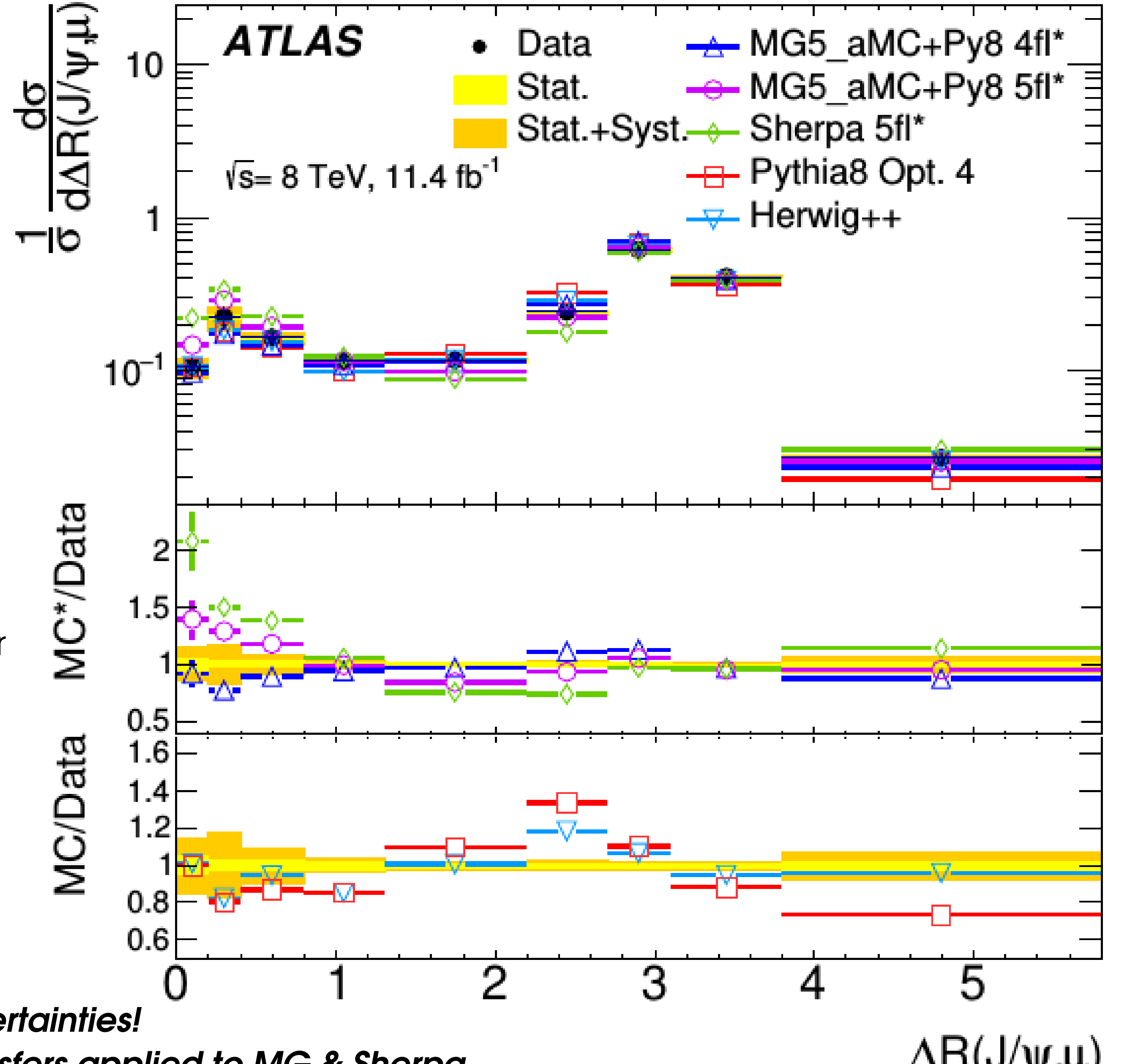
3-muon:

- muon pT>6 GeV
- two muons from J/ψ: | eta | <2.3
- 3[rd] muon from different b-hadron: | eta | < 2.5

2xb-hadron:

- b-hadron pT> 15.5 GeV
- b-hadron | eta | <2.4
- for pT and mass, scale down by 1.75

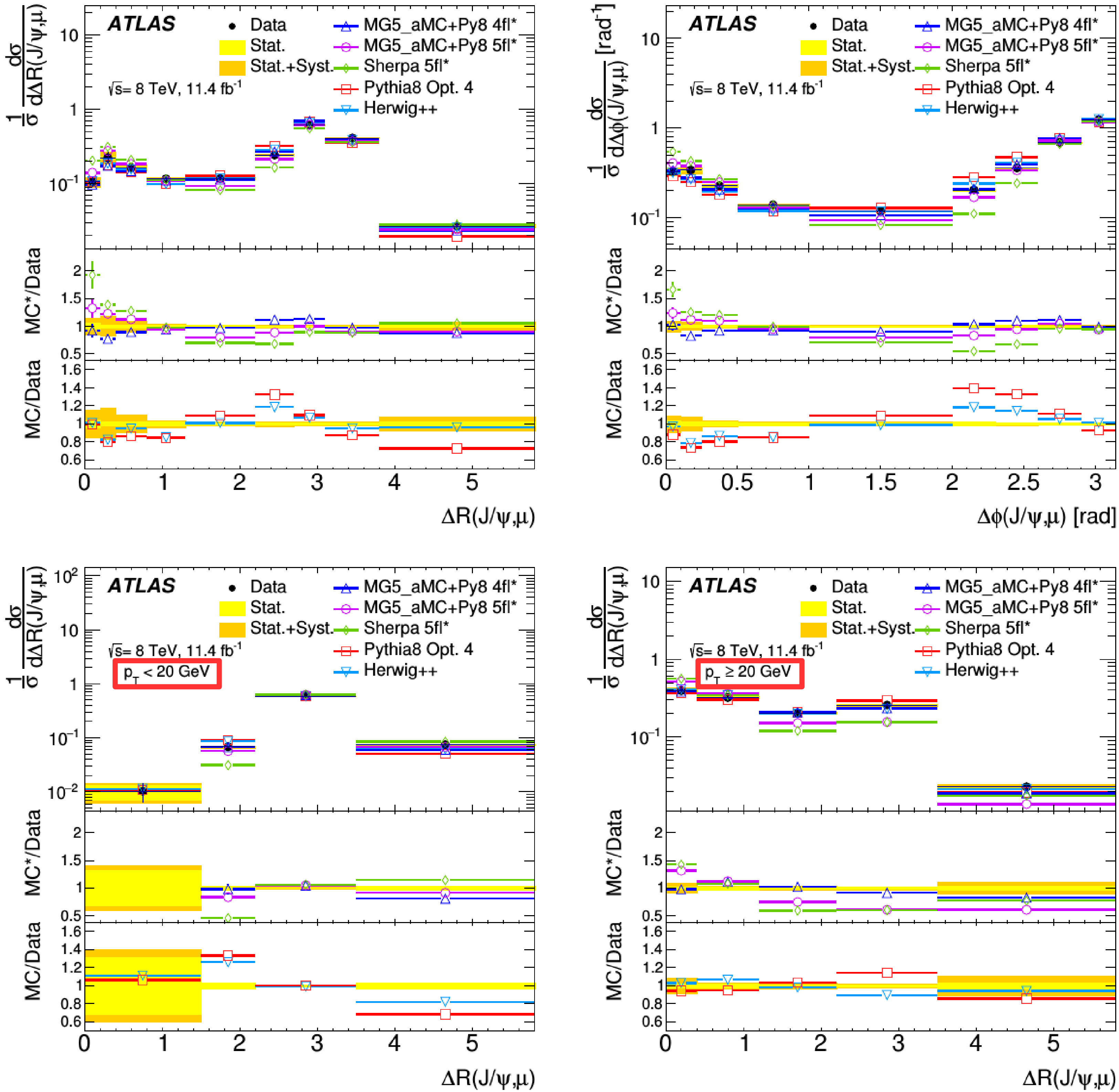


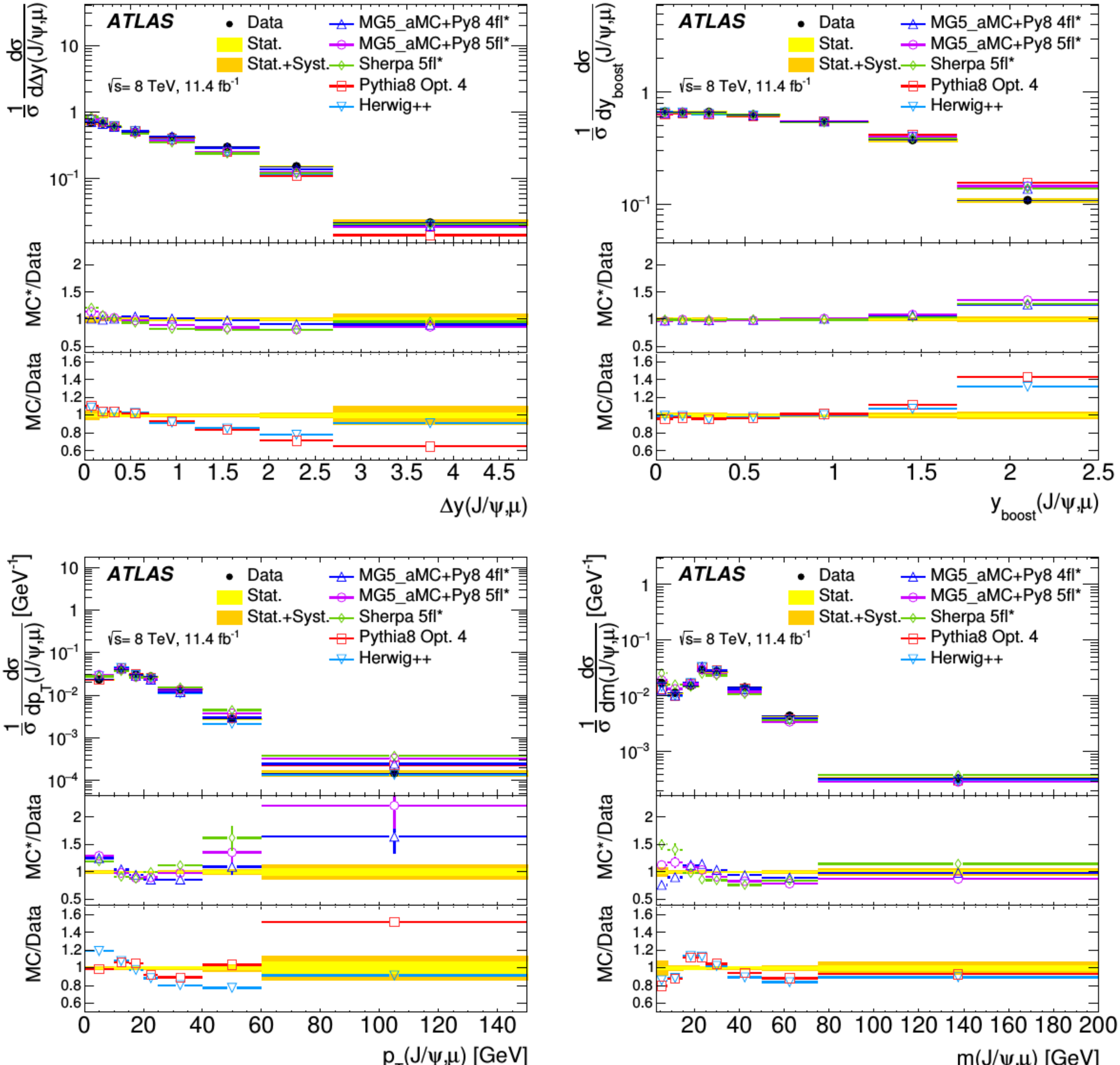


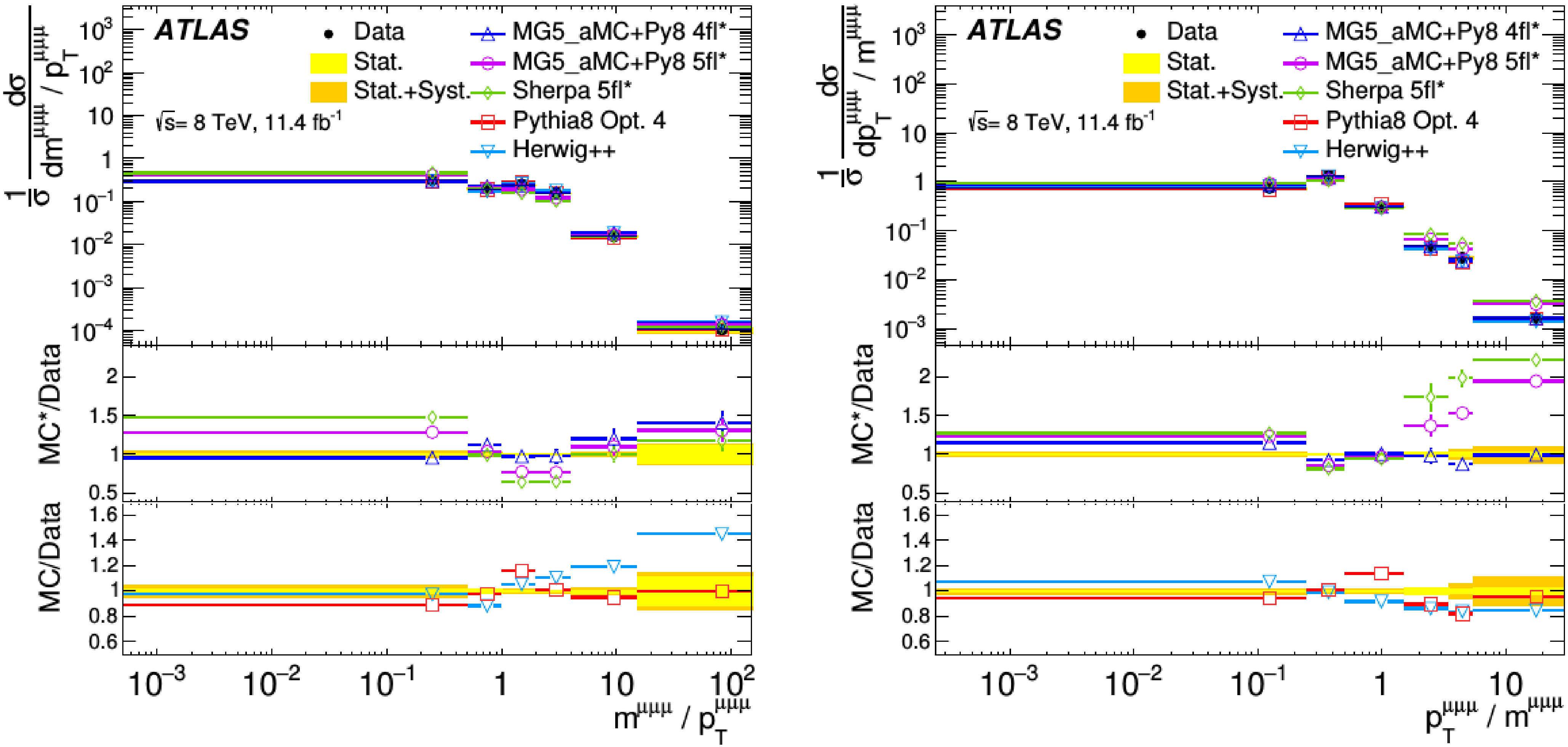
MG5 4-flavour
MG5 5-flavour
Sherpa 2.1 5-flavour

Herwig++
Pythia 8.2 opt.4
(default setting)

Note: no theory uncertainties!
Uncertainties on transfers applied to MG & Sherpa


ATLAS
Data
Stat.
Stat.+Syst.
MG5_aMC+Py8 4fl*
MG5_aMC+Py8 5fl*
Sherpa 5fl*
Pythia8 Opt. 4
Herwig++
√s= 8 TeV, 11.4 fb-1
1/σ dσ/dΔR(J/ψ,μ)
MC*/Data
MC/Data
ΔR(J/ψ,μ)
1/σ dσ/dΔφ(J/ψ,μ) [rad-1]
Δφ(J/ψ,μ) [rad]
pT < 20 GeV
pT ≥ 20 GeV


ATLAS
Data
Stat.
Stat.+Syst.
MG5_aMC+Py8 4fl*
MG5_aMC+Py8 5fl*
Sherpa 5fl*
Pythia8 Opt. 4
Herwig++
√s= 8 TeV, 11.4 fb-1
MC*/Data
MC/Data
1/σ dσ/dΔy(J/ψ,μ)
Δy(J/ψ,μ)
1/σ dσ/dy_boost(J/ψ,μ)
y_boost(J/ψ,μ)
1/σ dσ/dp_T(J/ψ,μ) [GeV-1]
p_T(J/ψ,μ) [GeV]
1/σ dσ/dm(J/ψ,μ) [GeV-1]
m(J/ψ,μ) [GeV]



ATLAS
√s= 8 TeV, 11.4 fb-1
Data
Stat.
Stat.+Syst.
MG5_aMC+Py8 4fl*
MG5_aMC+Py8 5fl*
Sherpa 5fl*
Pythia8 Opt. 4
Herwig++
MC*/Data
MC/Data
m^μμμ / p_T^μμμ
p_T^μμμ / m^μμμ

Conclusion

Measurement of b-hadron pair production

- using 3-muon final state

Measure 10 normalised differential cross sections

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/BPHY-2015-04/

arxiv:1705.03374

Rivet routine uploaded to contrib 30th August

- can be run in 3-muon mode
- or 2xb-hadron mode, with transfer functions applied.

Discussion

What are the prospects for using these results in tuning?

Update to 13 TeV should be fairly easy (if people could be found…)

- driving down uncertainties at lowest ΔR should be relatively simple.

Alternative is the CMS-style approach:

- inclusive vertex finding
- would allow, eg Z+bb measurement down to very small angles.

Which is more interesting?

- we are dominated by fairly low pT stuff
    - b-hadron pT > ~16.5 GeV
- does this really tell us about the backgrounds to boosted topologies?

Are there other kinematic variables of interest?

Third muon

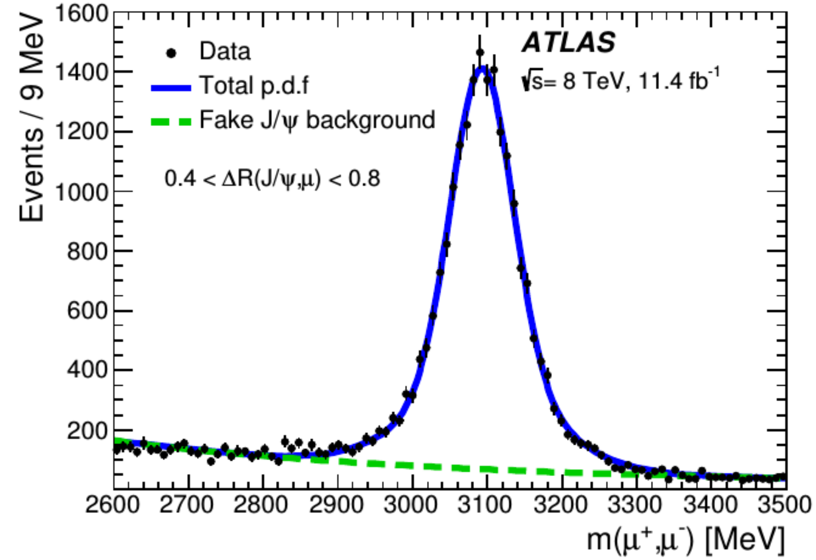
Some backgrounds are fixed in the fit:

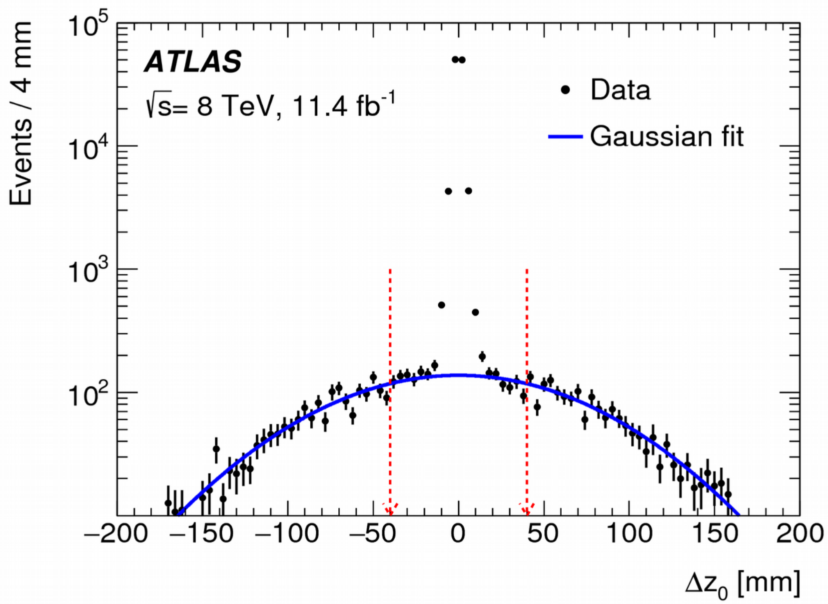
"Fake J/psi"

- determine from J/psi fit, applying tau cut

Signal region:

- 2.95 – 3.25 GeV
- Background normalisation from fit
- Background shapes from mass sidebands





Pile-up: J/psi and 3rd muon from different collisions

Determine yield by fitting Δz:

- gaussian, excluding range |Δz| < 40 mm

Signal region:

- cut |Δz| <40 mm
- pileup normalisation from gaussian
- pileup shape from sidebands