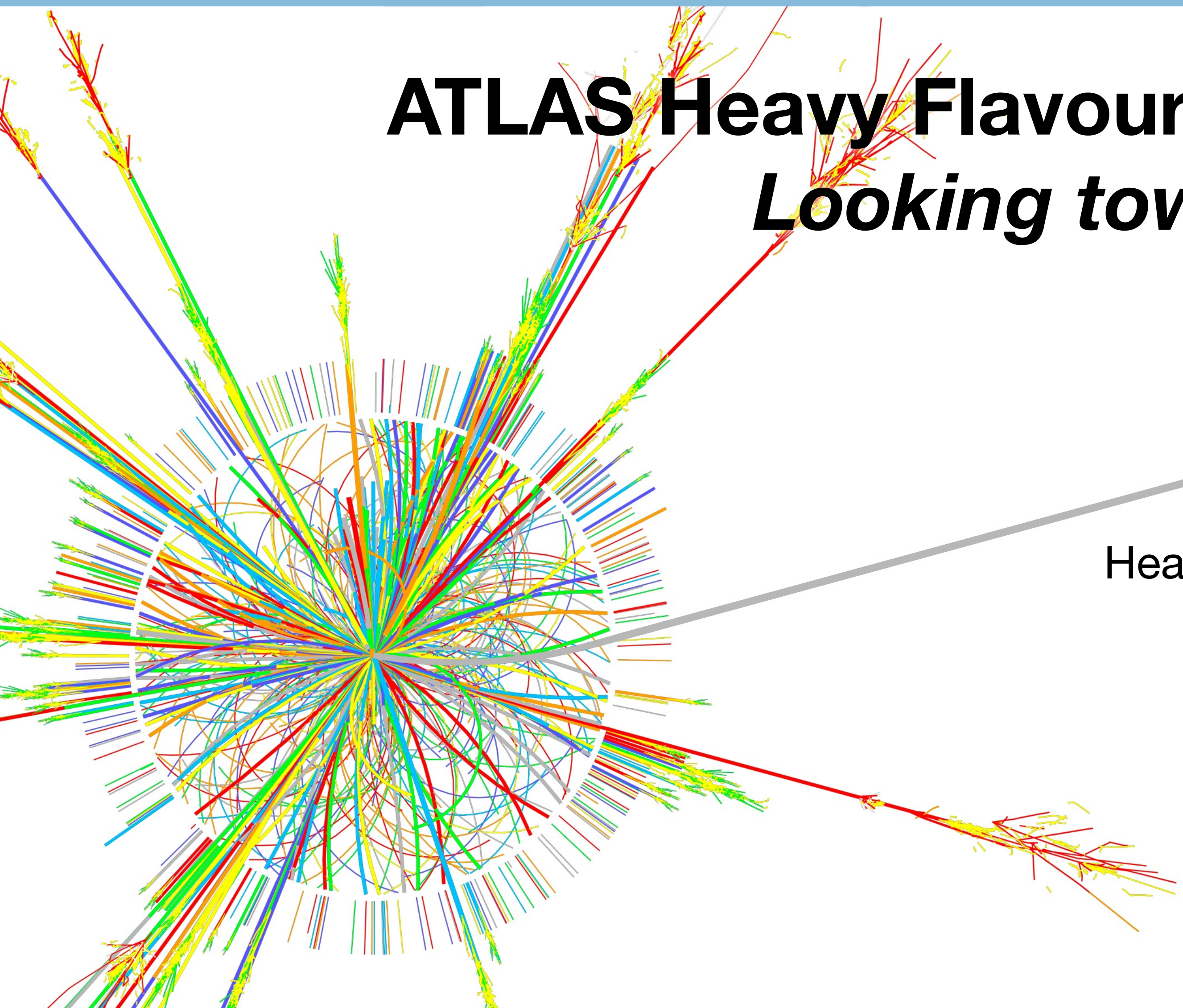
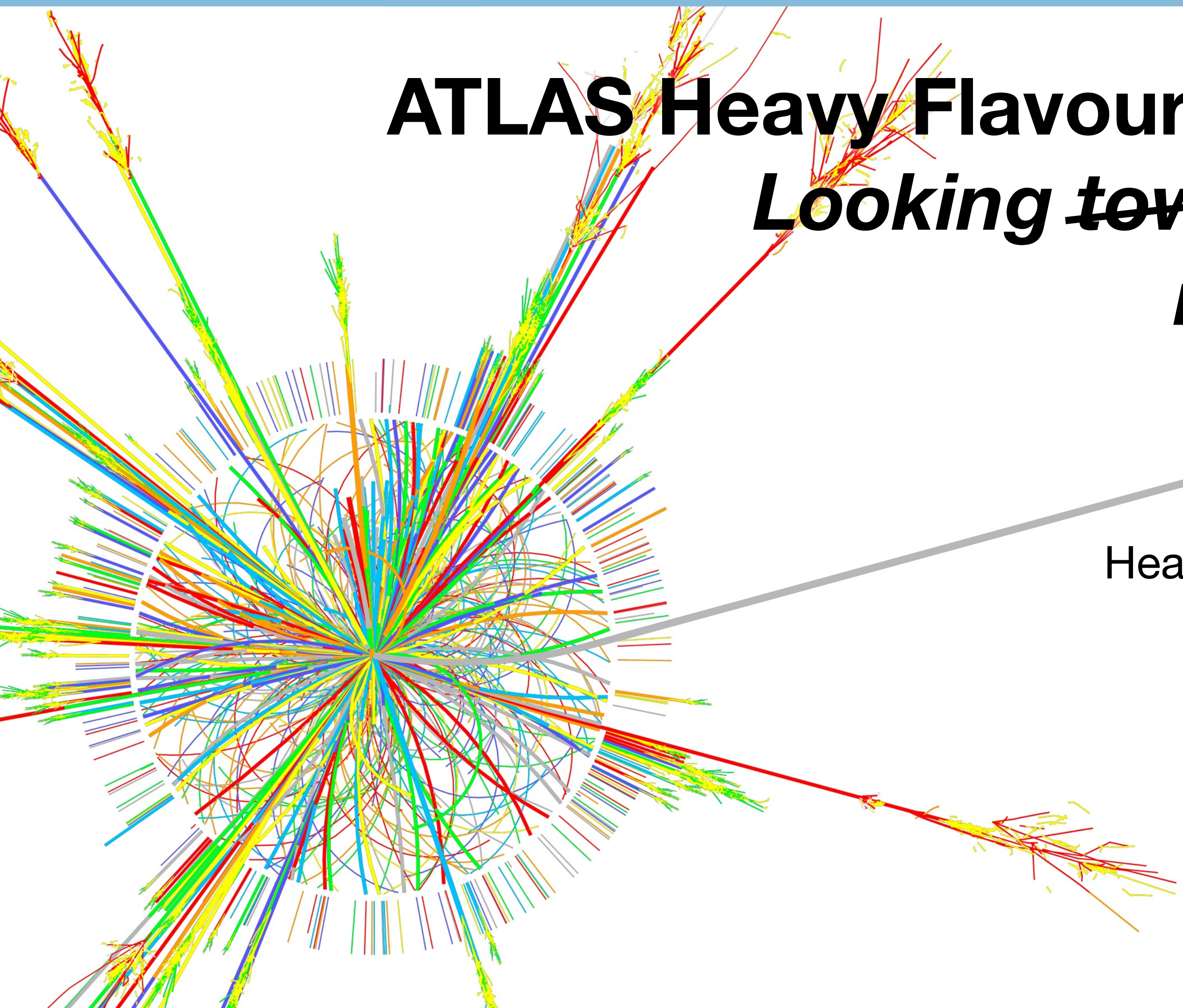


ATLAS Heavy Flavour production
Looking towards Run 2

Heavy Flavour at the LHC
IPPP Durham
21/4/2016

Josh McFayden

ATLAS Heavy Flavour production
Looking ~~towards~~ Run 2 into



Heavy Flavour at the LHC
IPPP Durham
21/4/2016

Josh McFayden

Overview

- Chiara already showed some of the Run 1 results and HF-related issues that were discovered.

- I will show a few more recent results and prospects as we get further into Run 2:

  - A new Run 1 measurement on inclusive di-bjet production

  - MC generator setups for Run 2

  - Some early Run 2 results that are affected by HF production

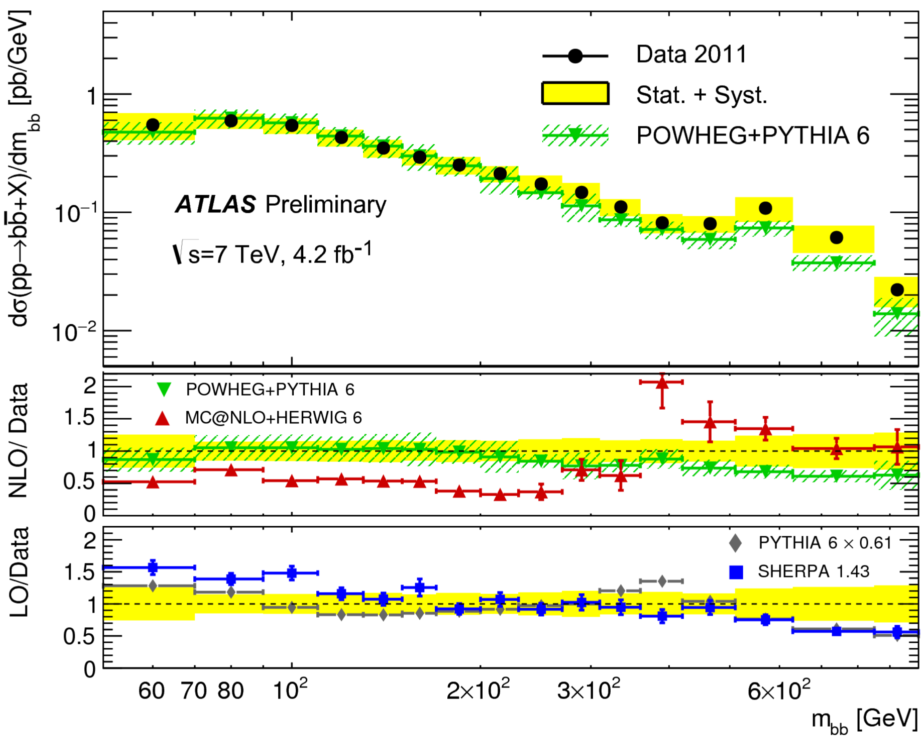
  - Prospects for better HF production measurements in the future

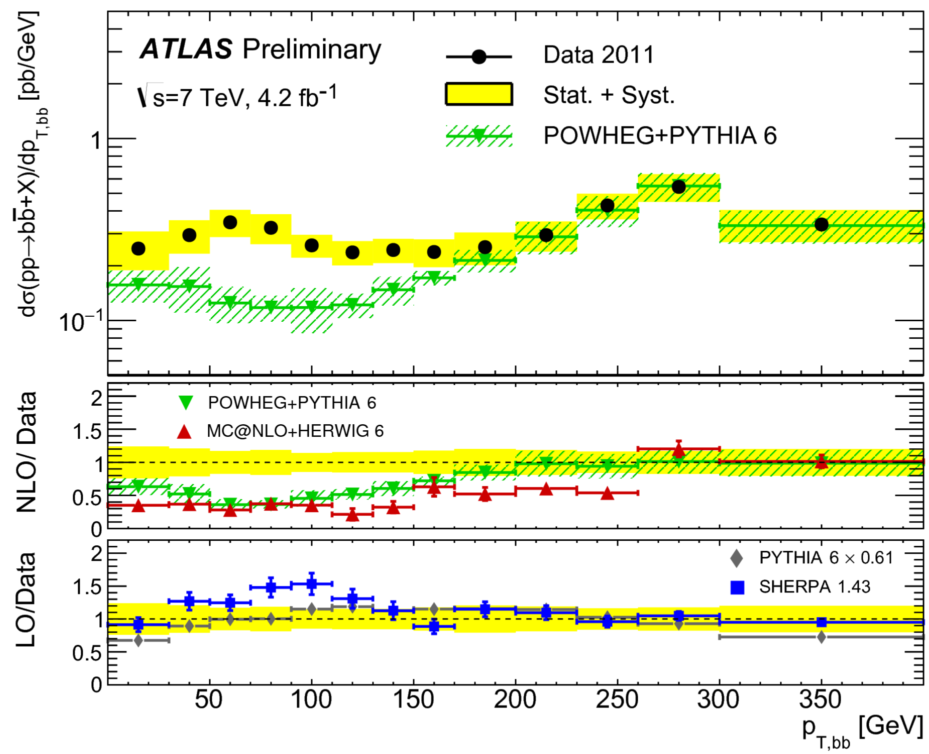
Hot off the press

7 TeV bb di-jet cross section

- **New** 7 TeV ATLAS result on di-b-jet production.
  - One jet with $p_T > 270$ GeV required due to trigger.
  - b-jets with $p_T > 20$ GeV and $\Delta R = 0.4$.
  - Template fit used to extract true b-b contribution.
- m_{bb} step at ~500 GeV due to “turn-on” of flavour creation.

STDM-2013-03





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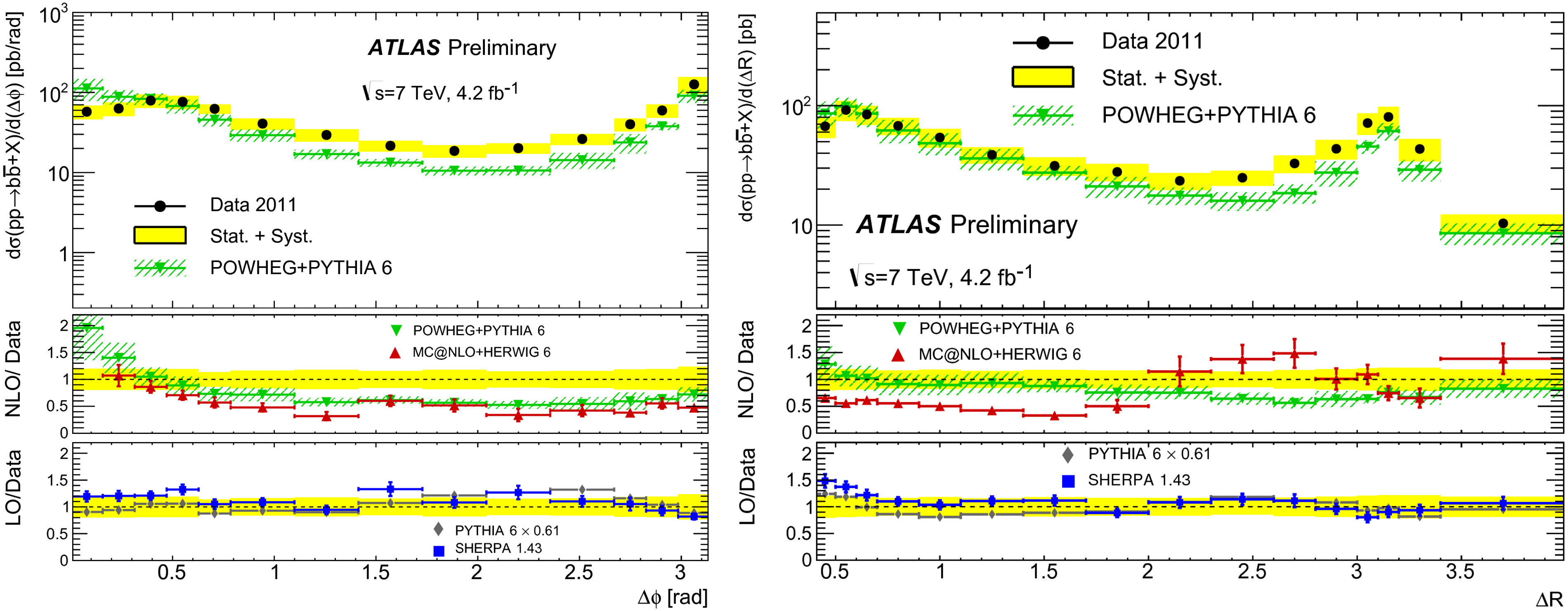
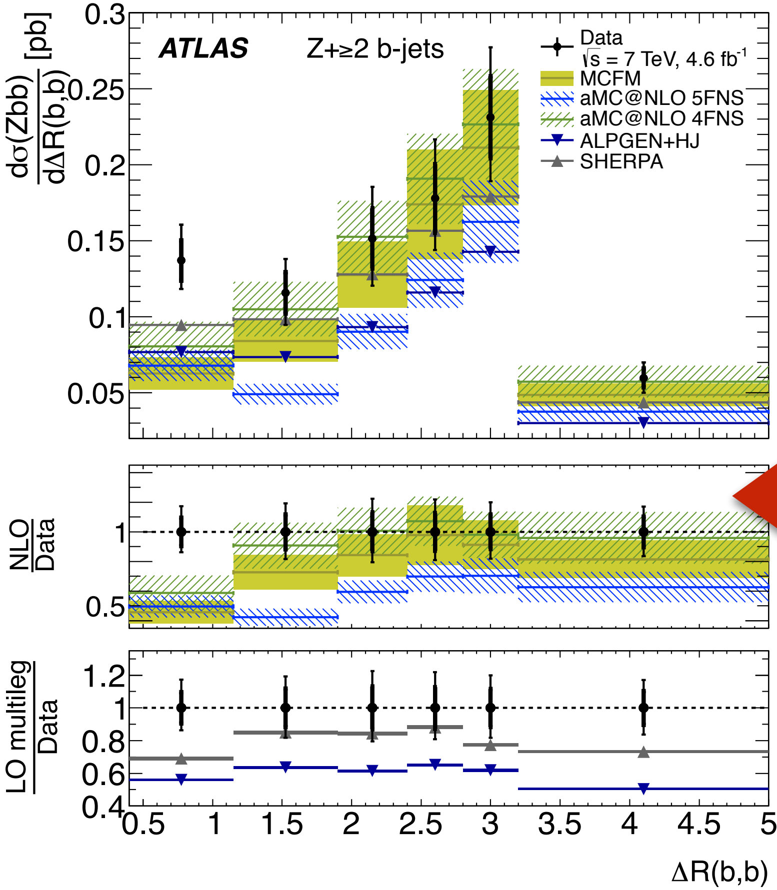
  - One jet with $p_T > 270$ GeV required due to trigger.
  - b-jets with $p_T > 20$ GeV and $\Delta R = 0.4$.
  - Template fit used to extract true b-b contribution.
- Large ΔΦ region is dominated by flavour creation and underestimated by NLO predictions.

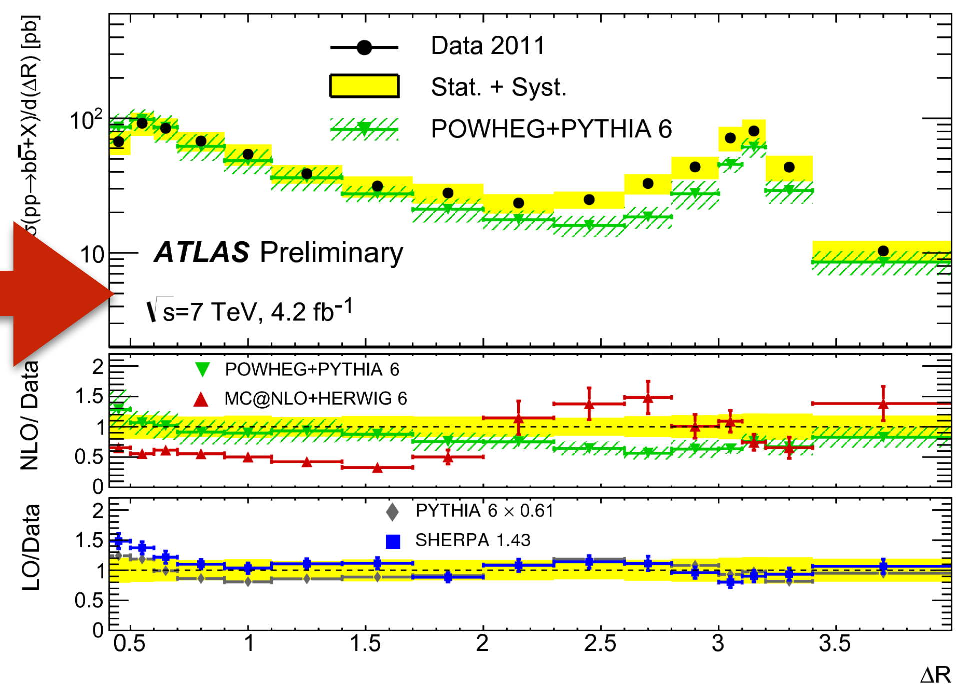
STDM-2013-03



What does it tell us?

- These results use the same dataset…
  - How much do we learn about V+HF from inclusive di-b-jets?
    - Seems like trends might be different?
  - Is the large leading jet requirement good/bad?





Generator setups for Run 2

Generators for Run 2

Generator	Matrix Element	Flavour number scheme	Slicing / filtering	Comments
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Sherpa2.2	NLO@2j LO@4j	5fl	pT(V) & HF	Improvement in low pT large η jets
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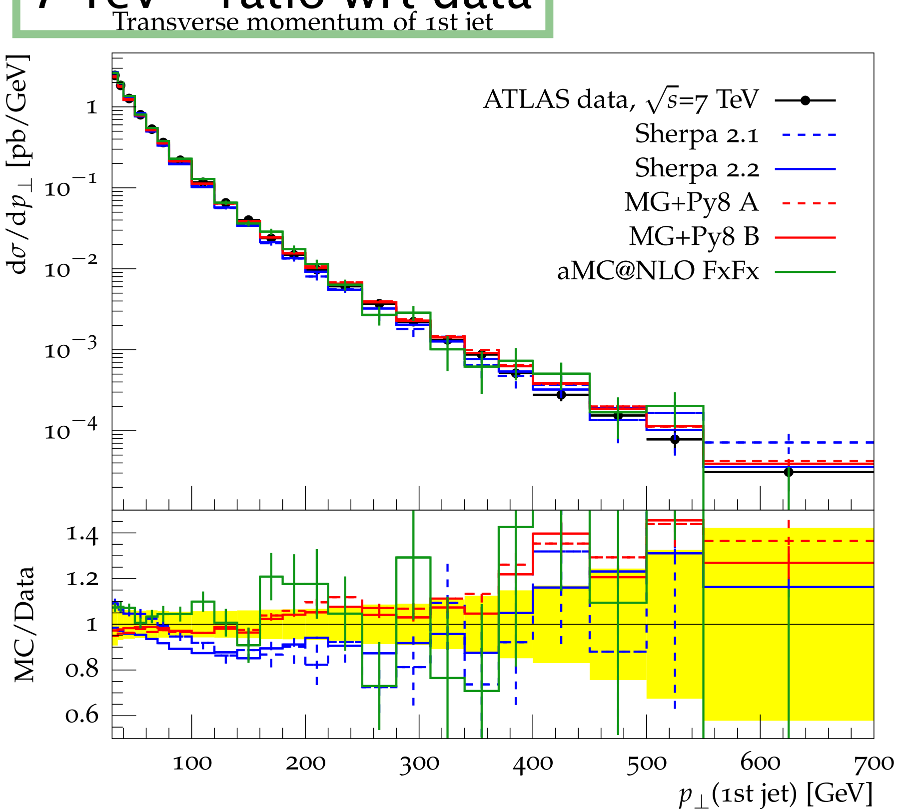
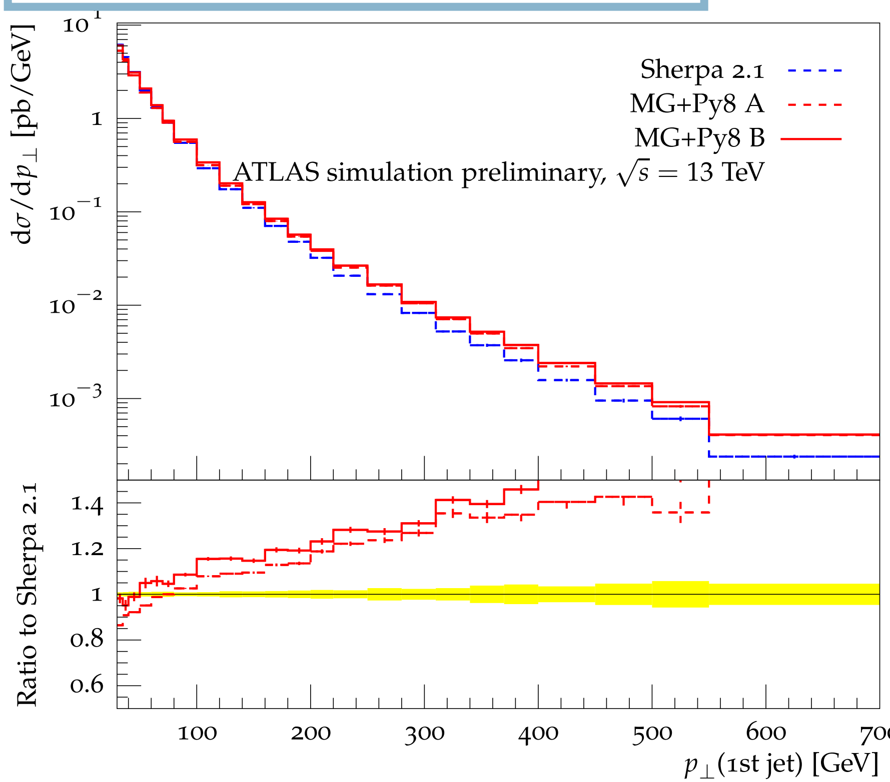
MG+Py8 B	LO@4j	5fl	HT & HF	NLO PDF, different shower settings. (still too hard)
MG5_aMC+Py8 FxFx	NLO@2j	5fl	TBD	Very promising – some N-jets mismodelling
Alpgen	LO@5j	4fl	N-parton & b/c/light	The new old! HFOR can be problematic.

- What appears to be ~small slope at 7 TeV seems to becomes much more significant at 13 TeV.
  - Important to make new measurements at 13 TeV.

7 TeV – ratio wrt data



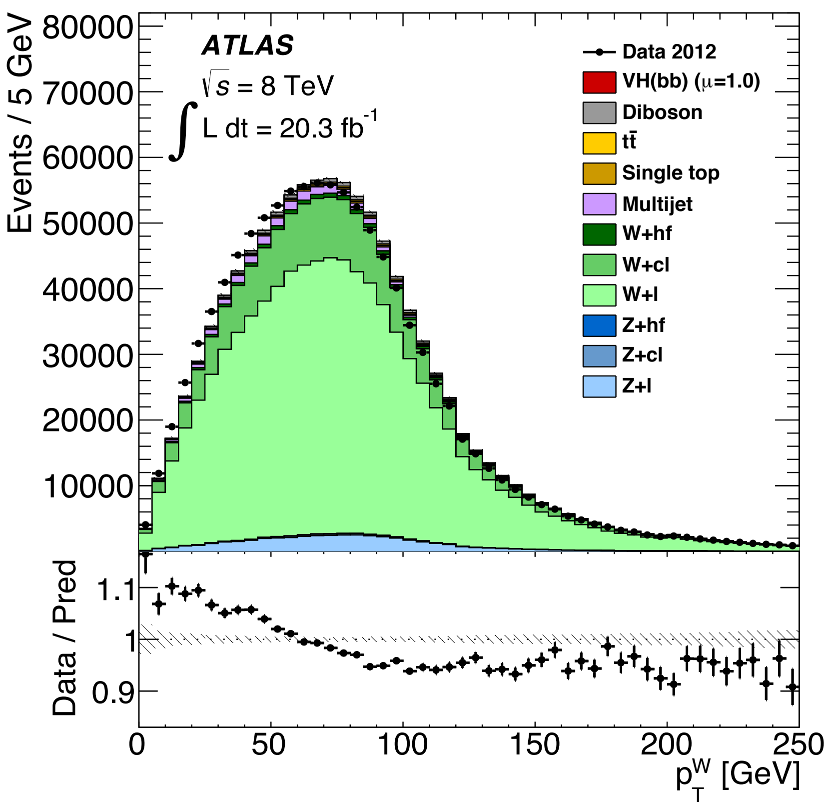
13 TeV – ratio wrt Sherpa2.1

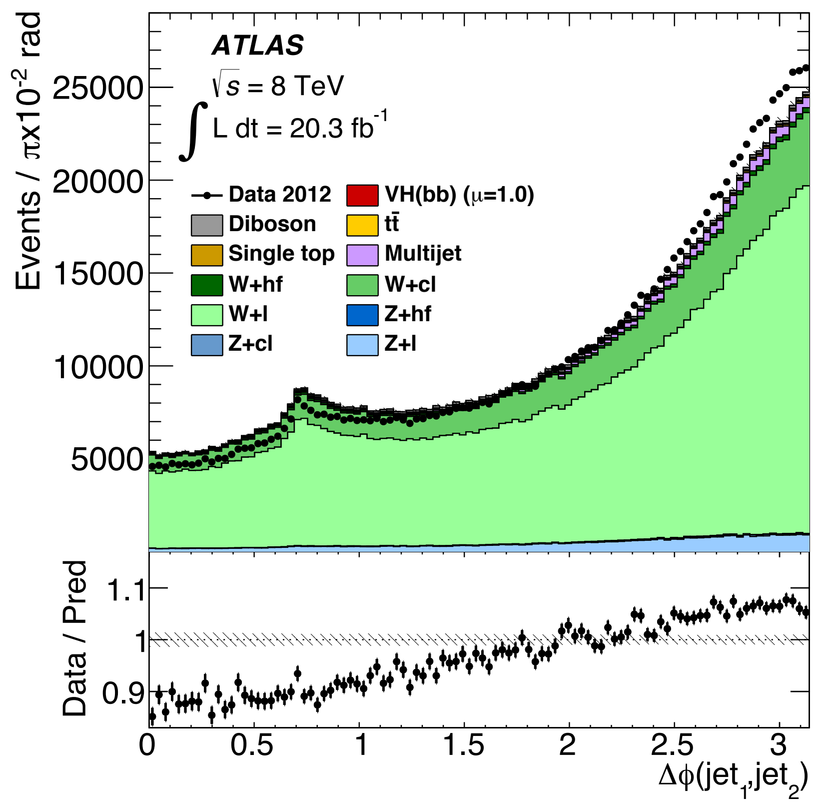


ATL-PHYS-PUB-2016-003

Looking back…

- 7 TeV VH(→bb) analysis saw large mismodelling of Δϕ(j,j) and discrepancies between generators in m(j,j).
  - Difference between Sherpa and Alpgen
- Are in a better position with our Run 2 generators setups?

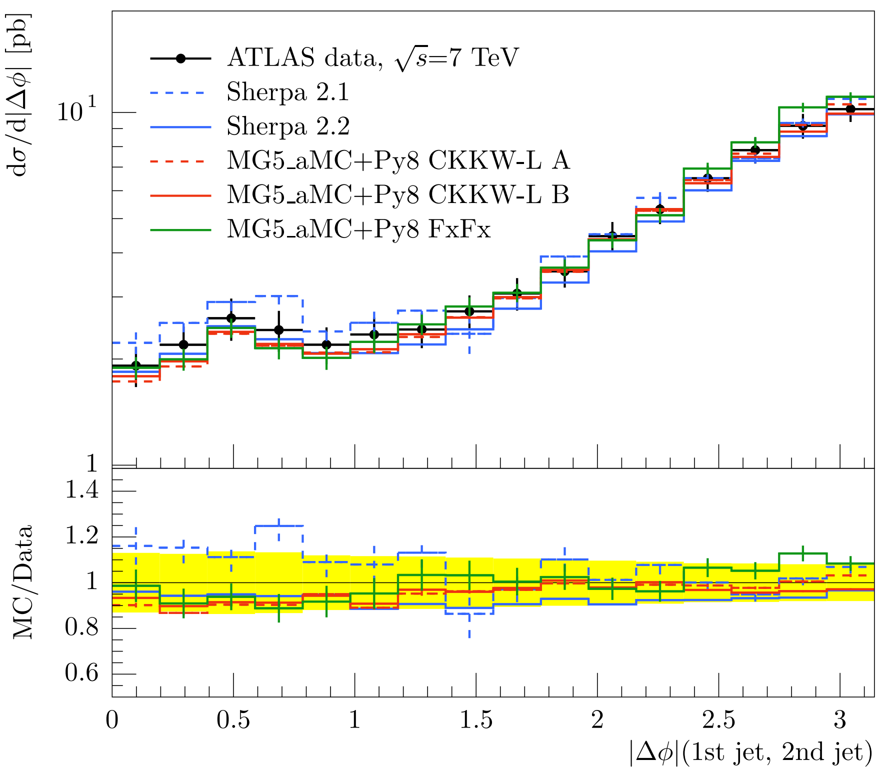




JHEP01(2015)069

- Some systematic difference between Sherpa and MG5_aMC+Py8 CKKW-L
  - The data sits between the two.
  - The modelling seems to be improved but much less data.

7 TeV – ratio wrt data



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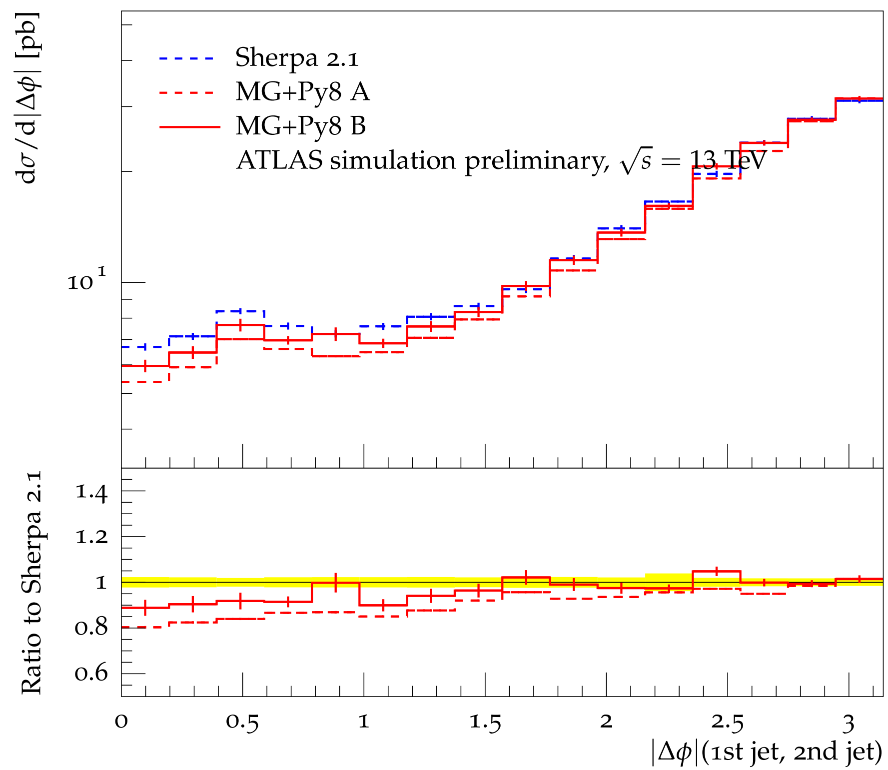
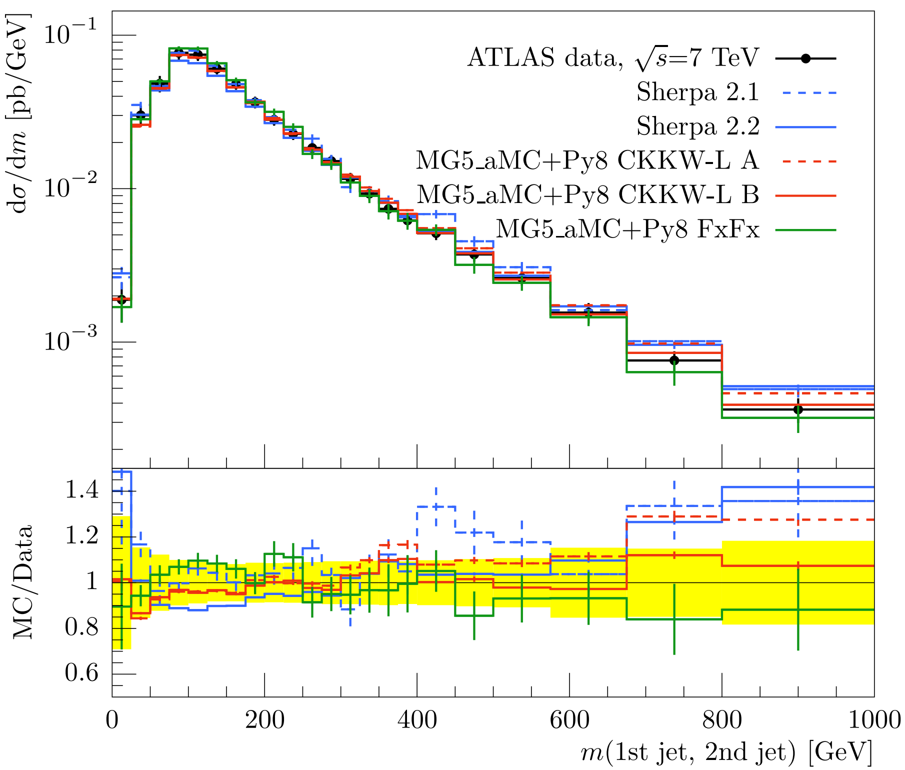


ATL-PHYS-PUB-2016-003

- Some systematic difference between Sherpa and MG5_aMC+Py8 CKKW-L
  - The data seems to prefer the MG5_aMC+Py8 CKKW-L shape.

7 TeV – ratio wrt data



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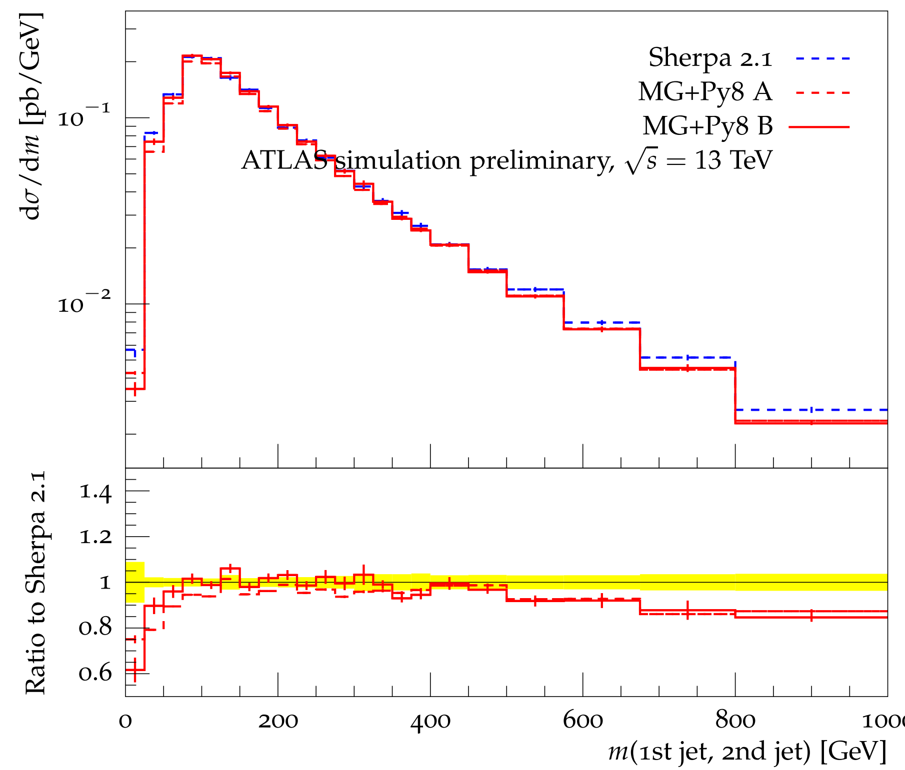
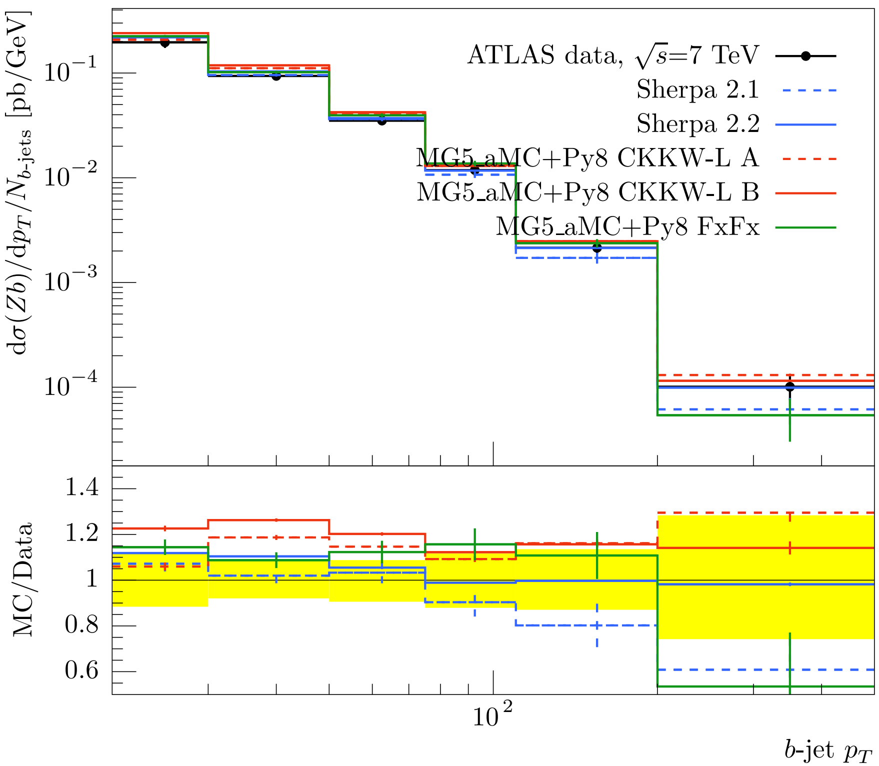


 ATL-PHYS-PUB-2016-003

7TeV vs 13TeV | Z+b(b)

- Main difference between Sherpa2.1 and MG5_aMC CKKW-L is in the rate
  - From early analyses we see that the data seems to prefer the higher rate.
  - Shape deviations are more important.

7 TeV – ratio wrt data



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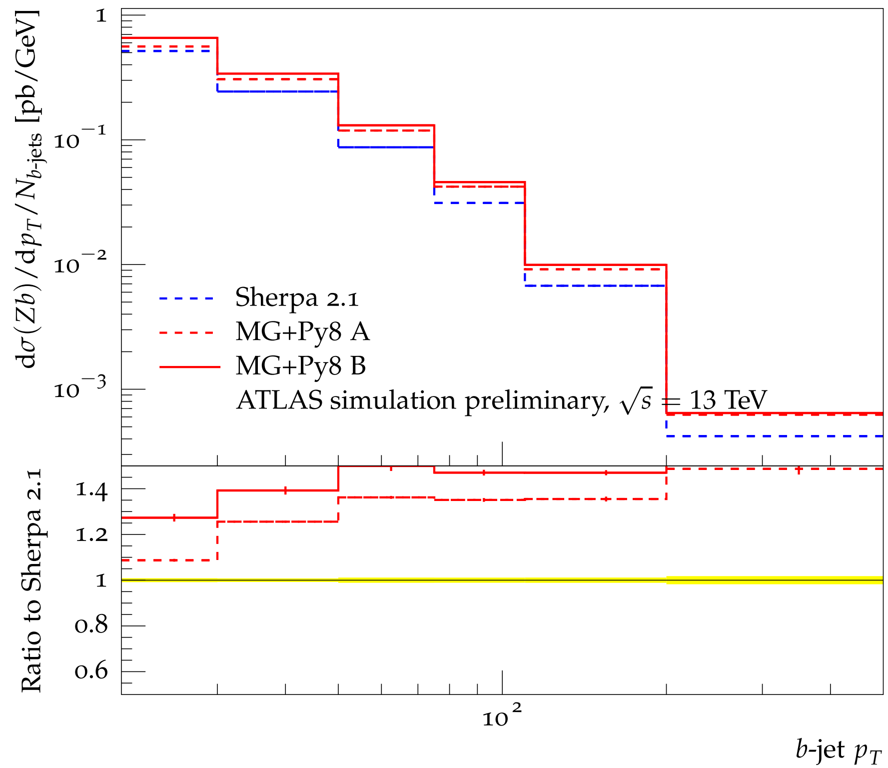
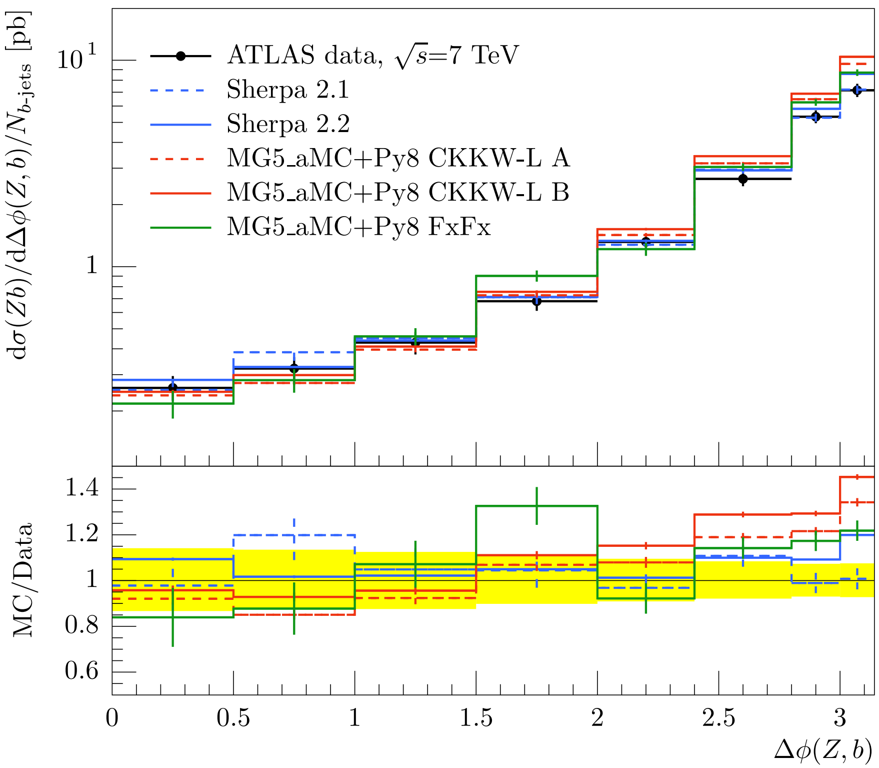


 ATL-PHYS-PUB-2016-003

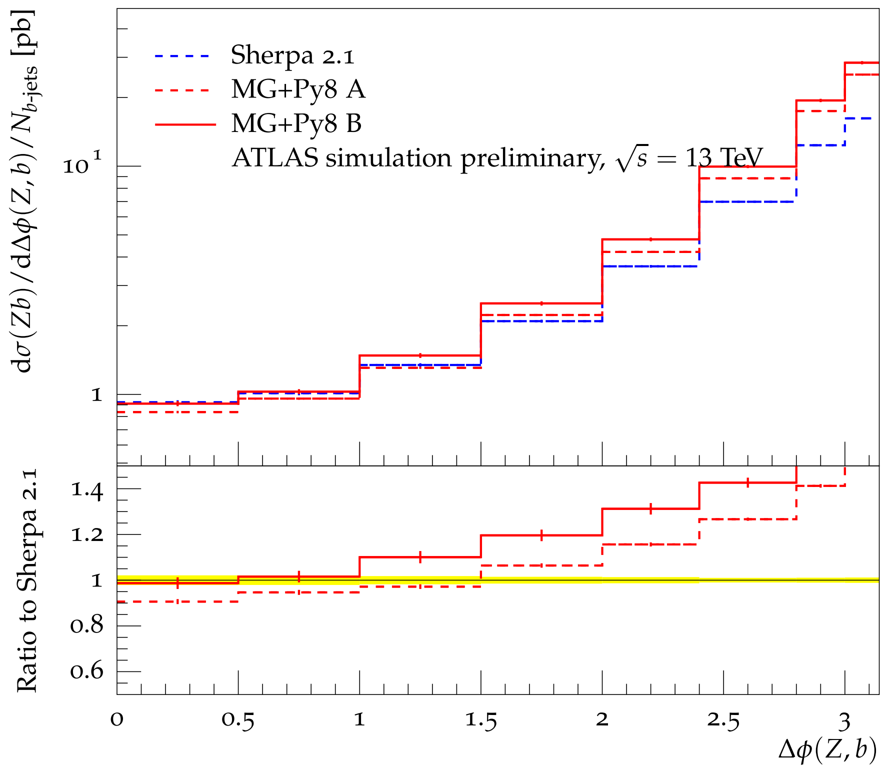
7TeV vs 13TeV | Z+b(b)

- Perhaps larger differences observed at 7 TeV than 13 TeV.
  - We have enough data to constrain the MC prediction here.
  - Improvement by going to NLO.

7 TeV – ratio wrt data



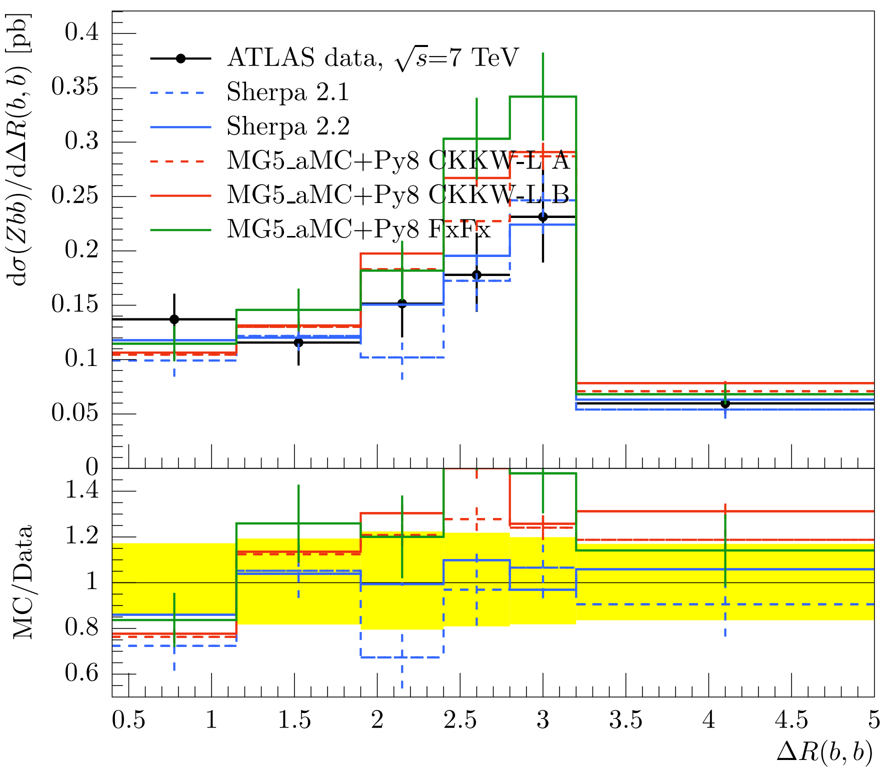
13 TeV – ratio wrt Sherpa2.1



ATL-PHYS-PUB-2016-003

- The familiar plot…
- Systematic shape differences observed
  - Sherpa seems to do a better job of modelling the shape of the low ΔR(b,b) region.

7 TeV – ratio wrt data



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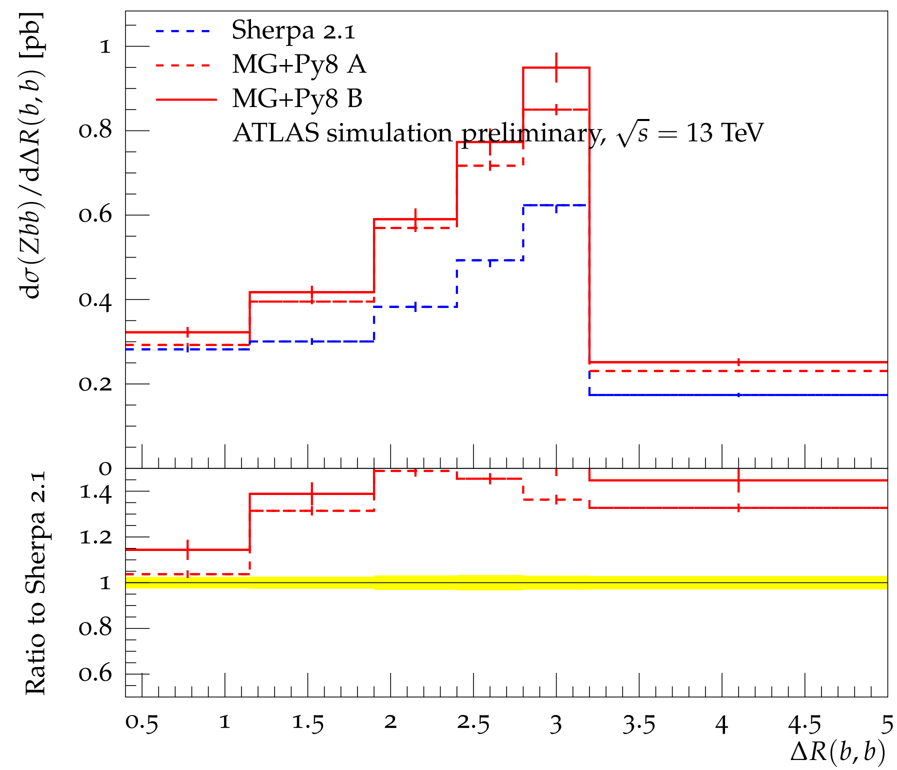
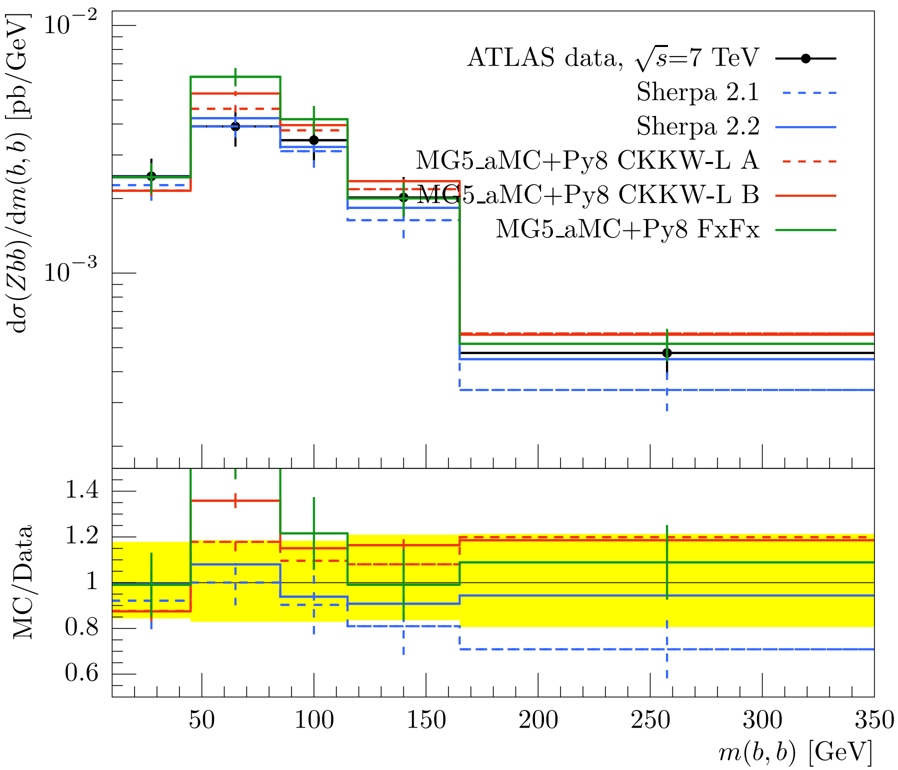


ATL-PHYS-PUB-2016-003

7TeV vs 13TeV | Z+b(b)

- Sherpa ~flat in m(b,b), some shape deviation from other

7 TeV – ratio wrt data



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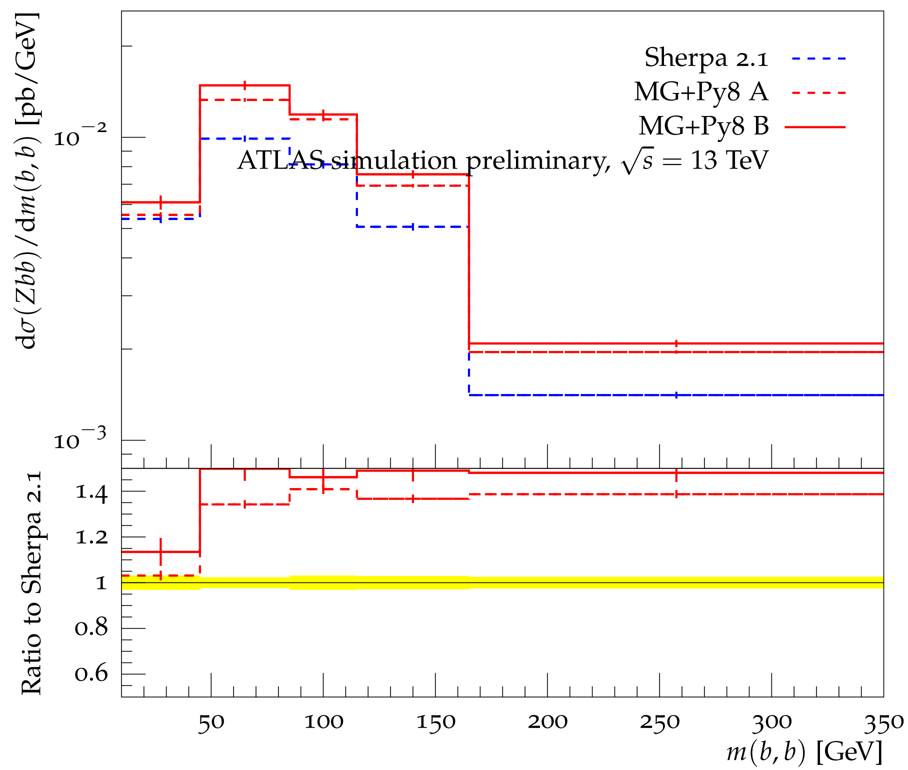
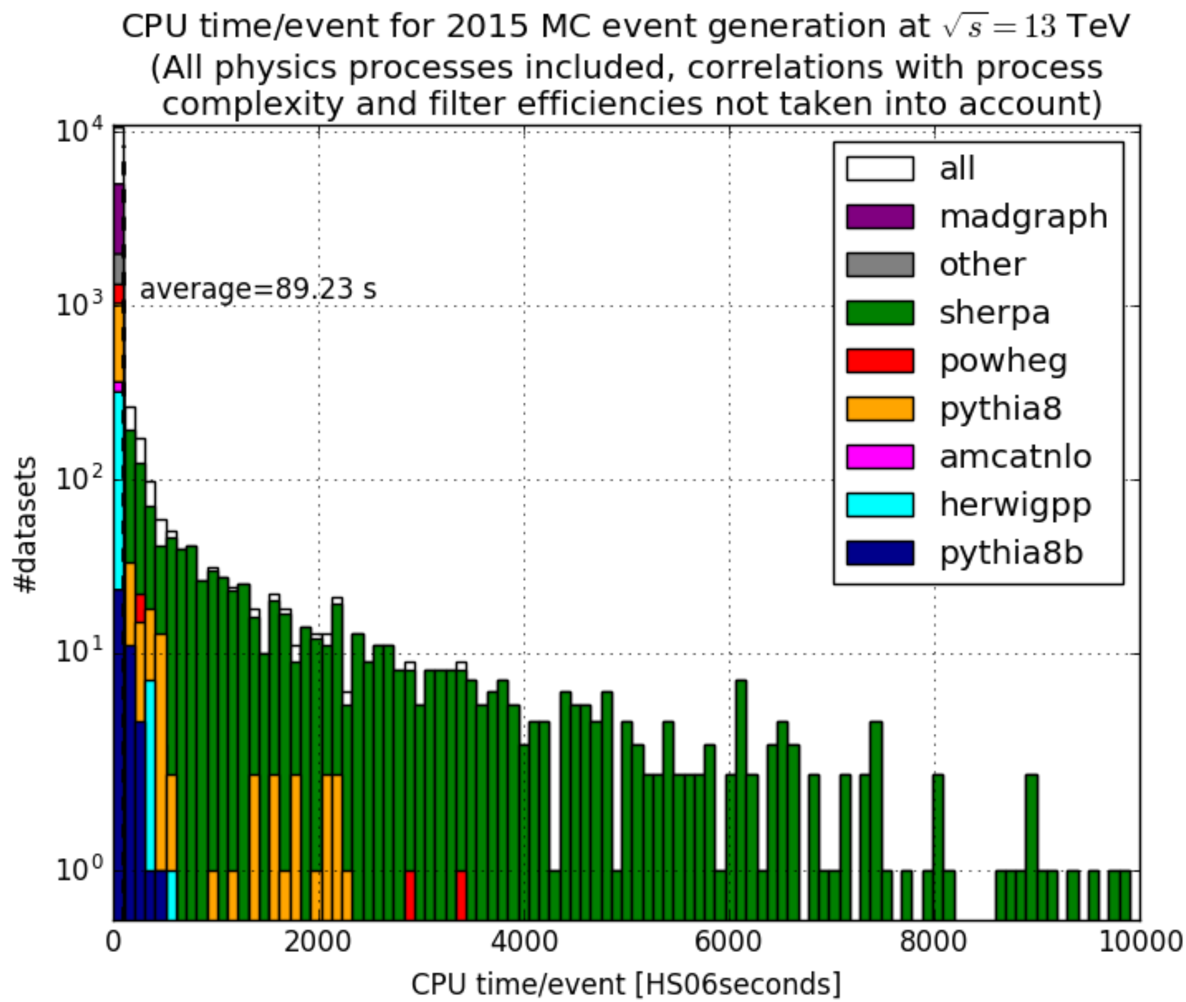


Practicalities…

Resource use by generator

- Average CPU time/event
- Sherpa has the highest CPU time/evt.



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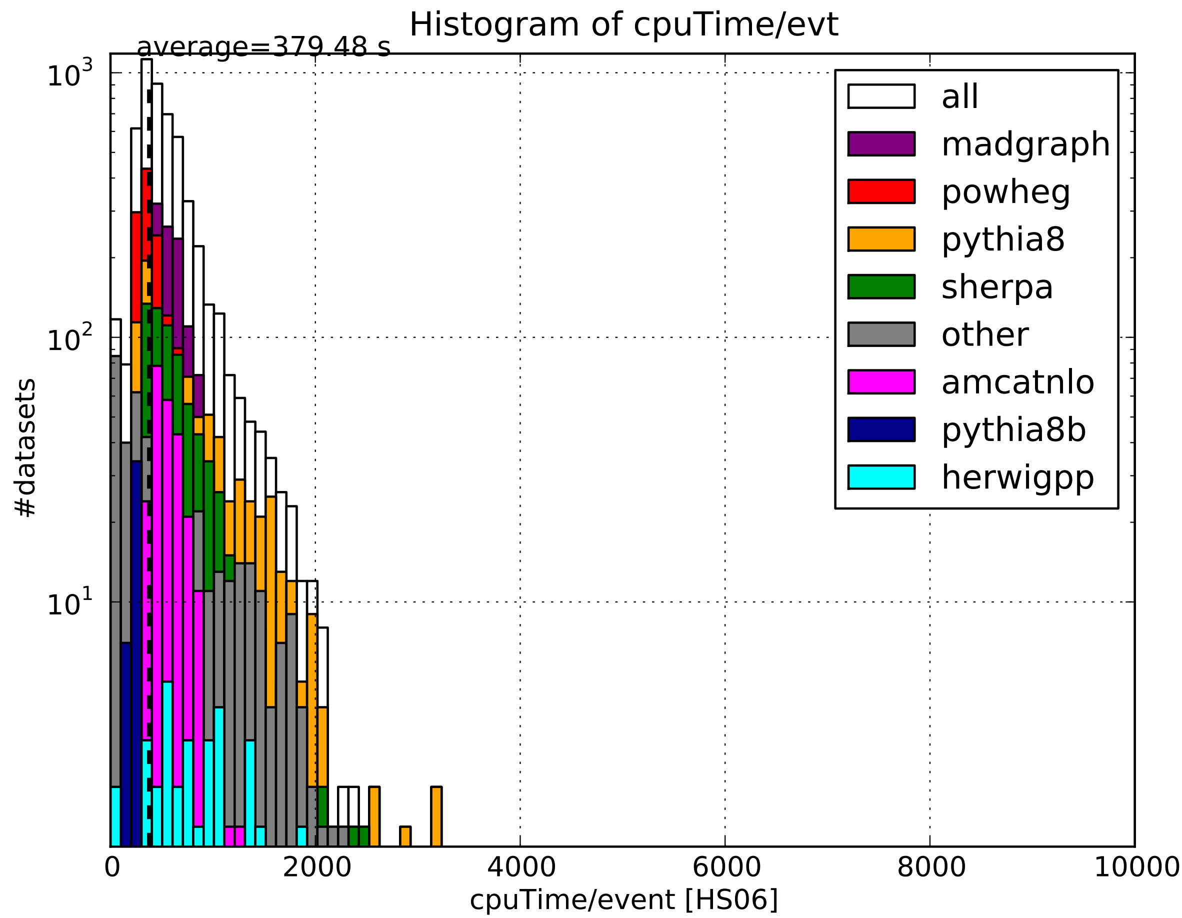

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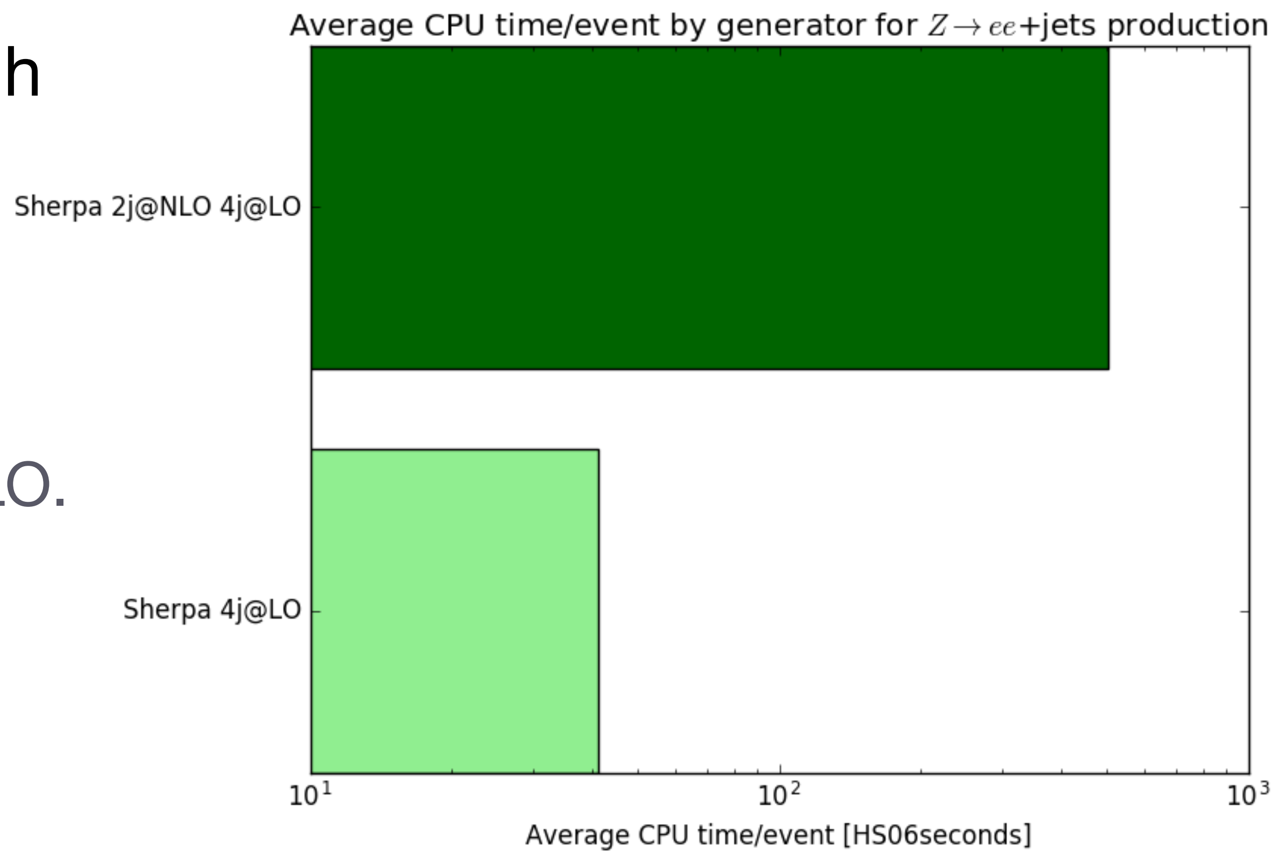
- Dominated by high pT(V) slices and filter efficiencies.
  - NLO significantly more CPU consuming than LO.
  - **B- and C-hadron filters have large effect.**



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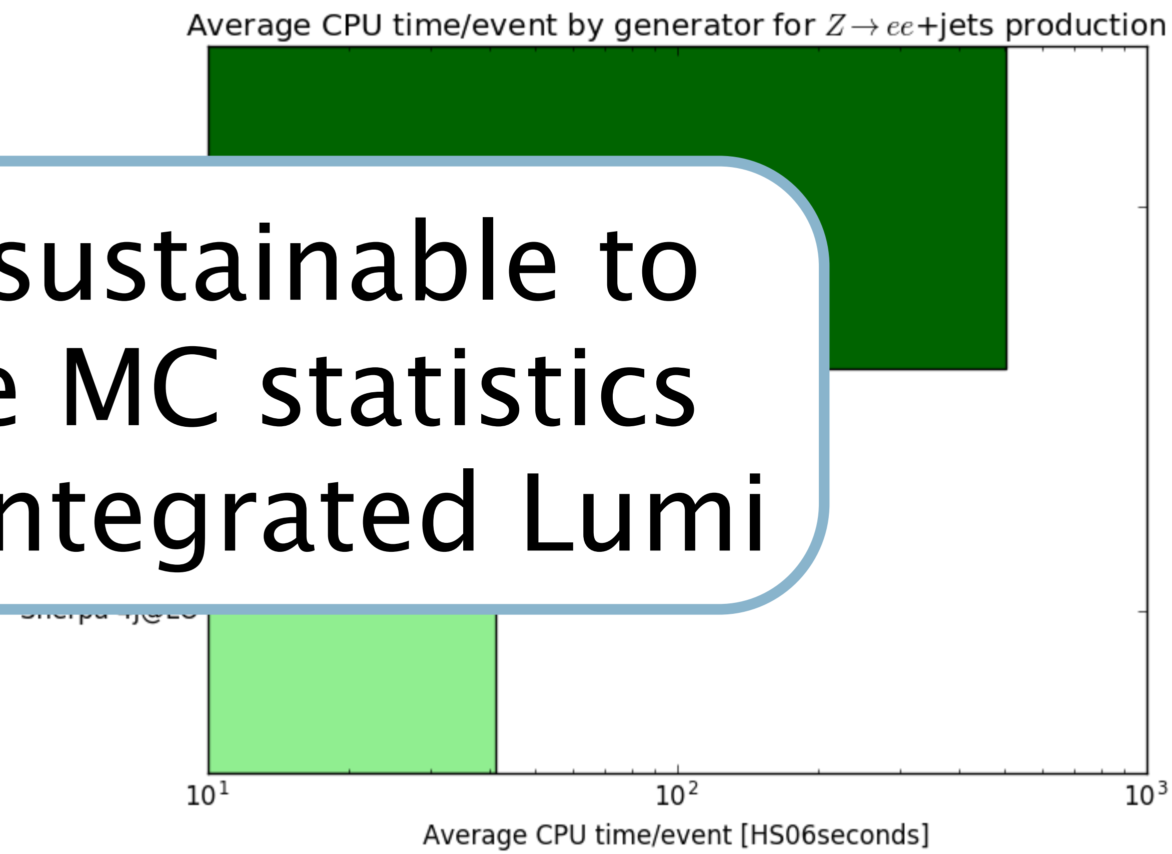

Not sustainable to scale MC statistics with integrated Lumi

HFOR...

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All 5-flavour scheme except Alpgen
→ HFOR needed.

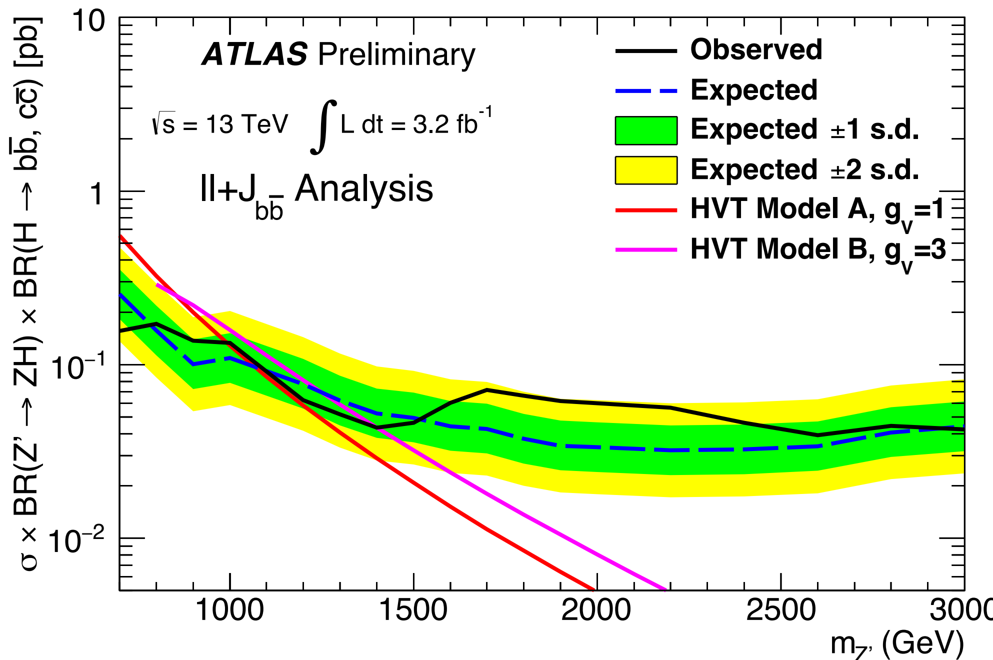
MC summary

- Modelling
  - Significant V+jets modelling improvements since Run 1.
  - Quite large HF variations but also large uncertainty on the data.
- HFOR
  - Conspicuous absence of 4-flavour samples due to difficulty in HFOR.
    - Can we do better here?
- Systematics
  - Is the variation between several 5-fl scheme MCs sufficient for systematic uncertainty evaluations?
  - Should we always add comparison to 4-fl scheme predictions?
  - Usually we take normalisation from a control region so only shape/ acceptance variations are significant.
  - Are there any other uncertainties that are not taken into account with this prescription?

Recent analysis

VH Resonances

- Search for VH production via a heavy resonance.
  - Interpreted HVT model.
- Selection very similar to SM VH(→bb) analysis



ATLAS-CONF-2015-074

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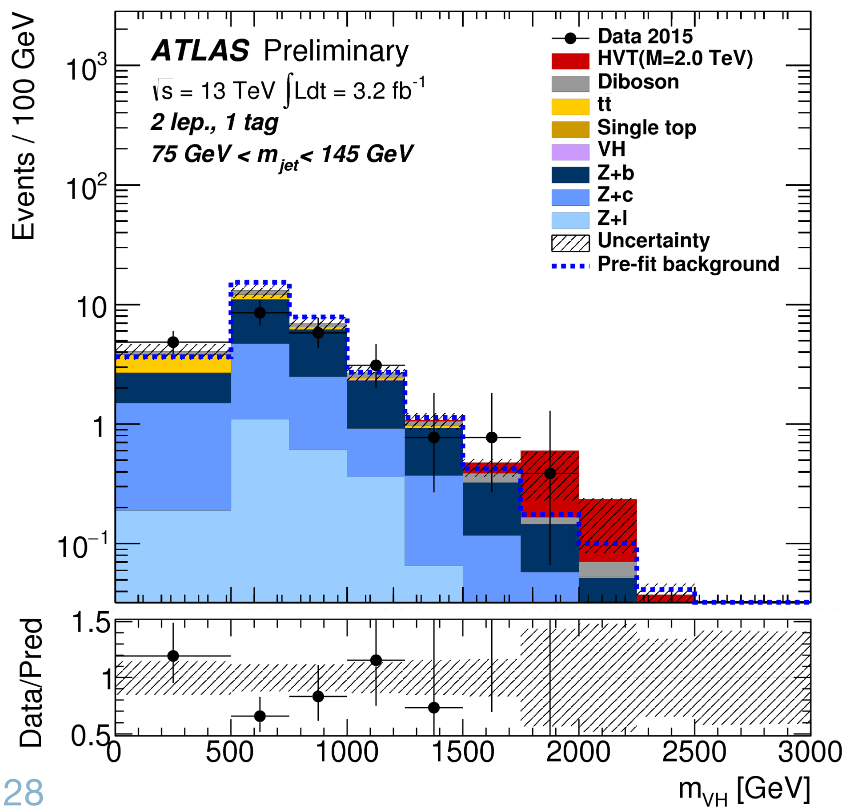

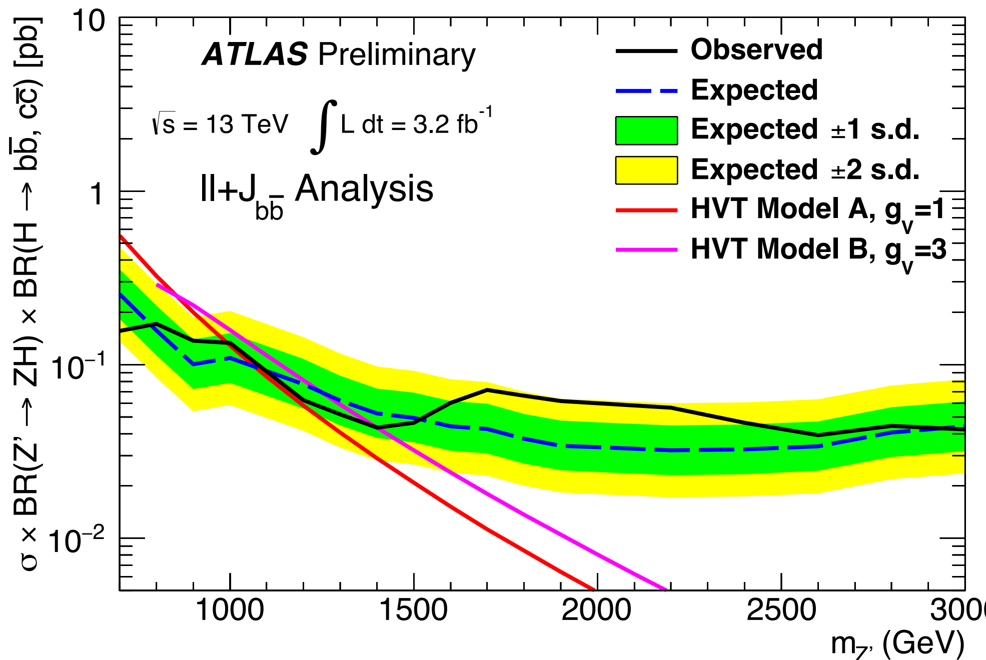

ATLAS-CONF-2015-074

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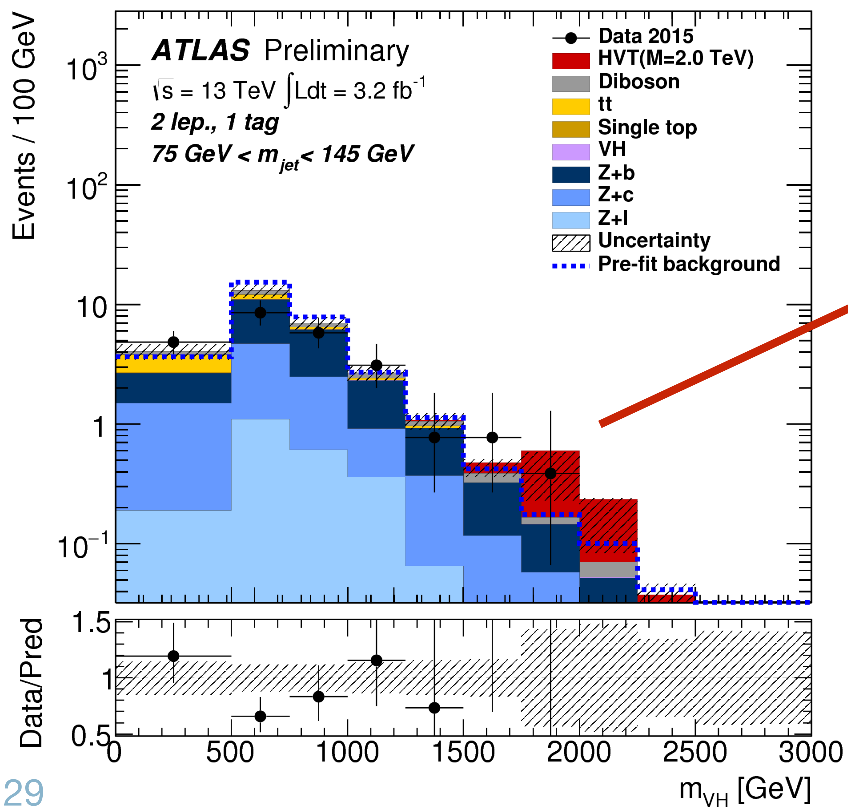

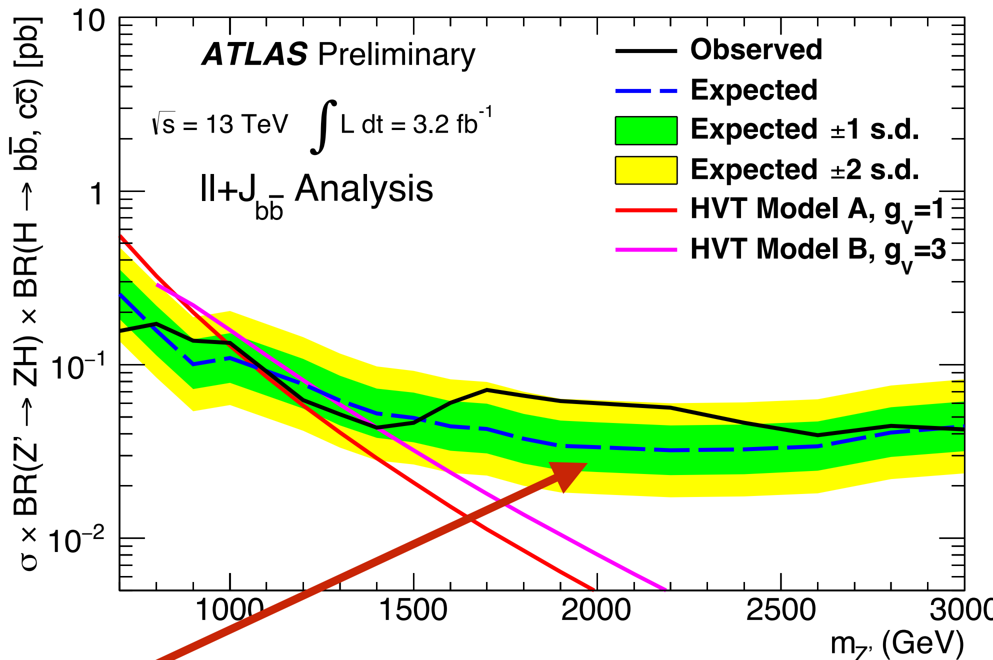

ATLAS-CONF-2015-074

- High mass optimisation means a focus on boosted regime.
- **ttbar and V+HF are dominant backgrounds**
- Fit $m_{(T)VH}$ distribution to look for resonances/set exclusion limits.

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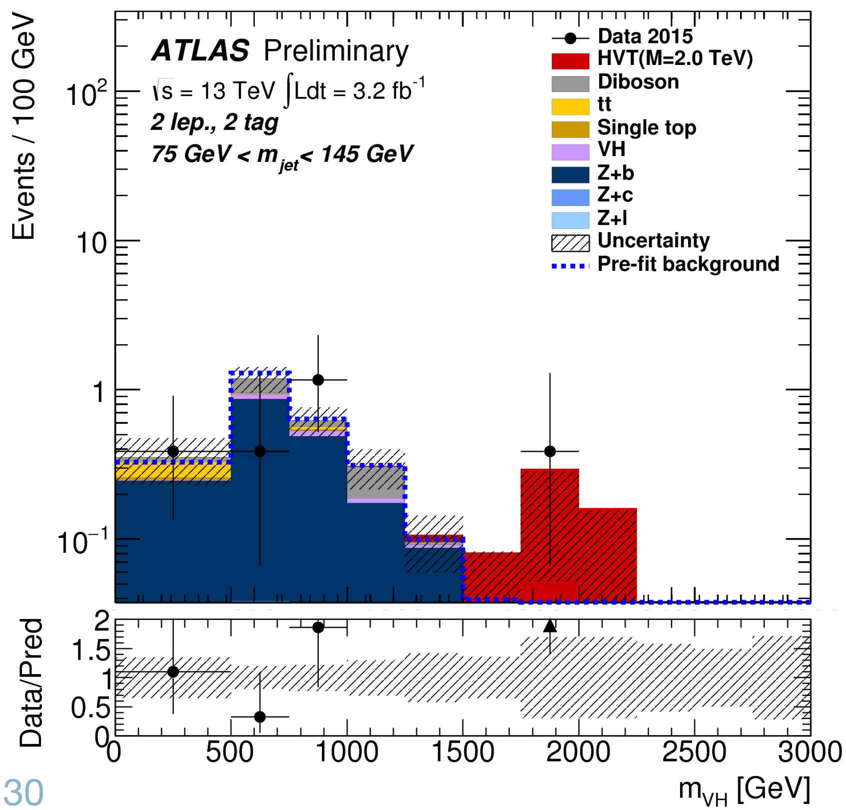
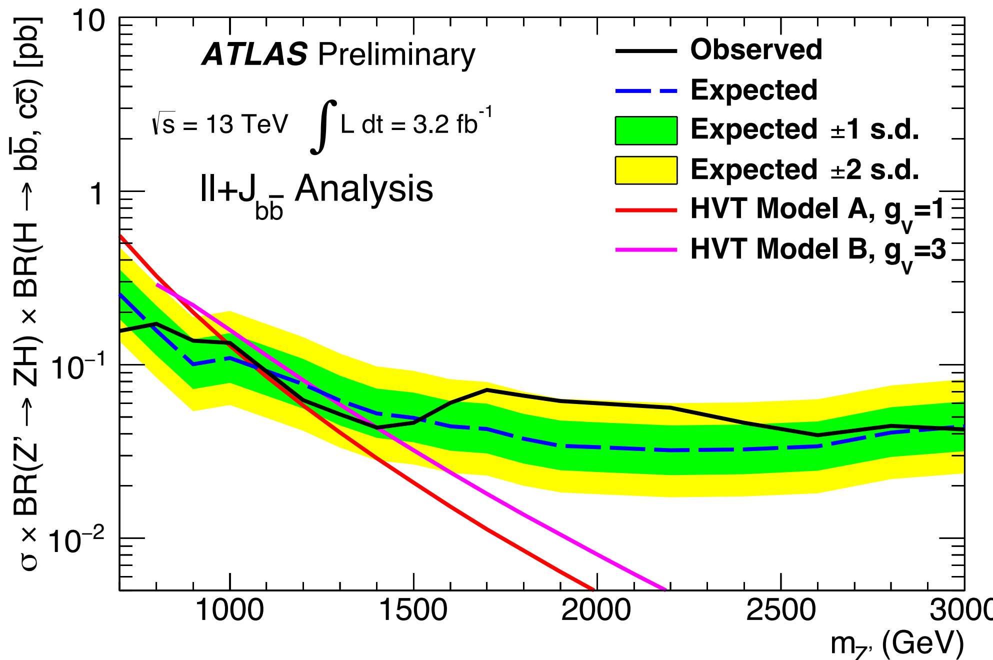
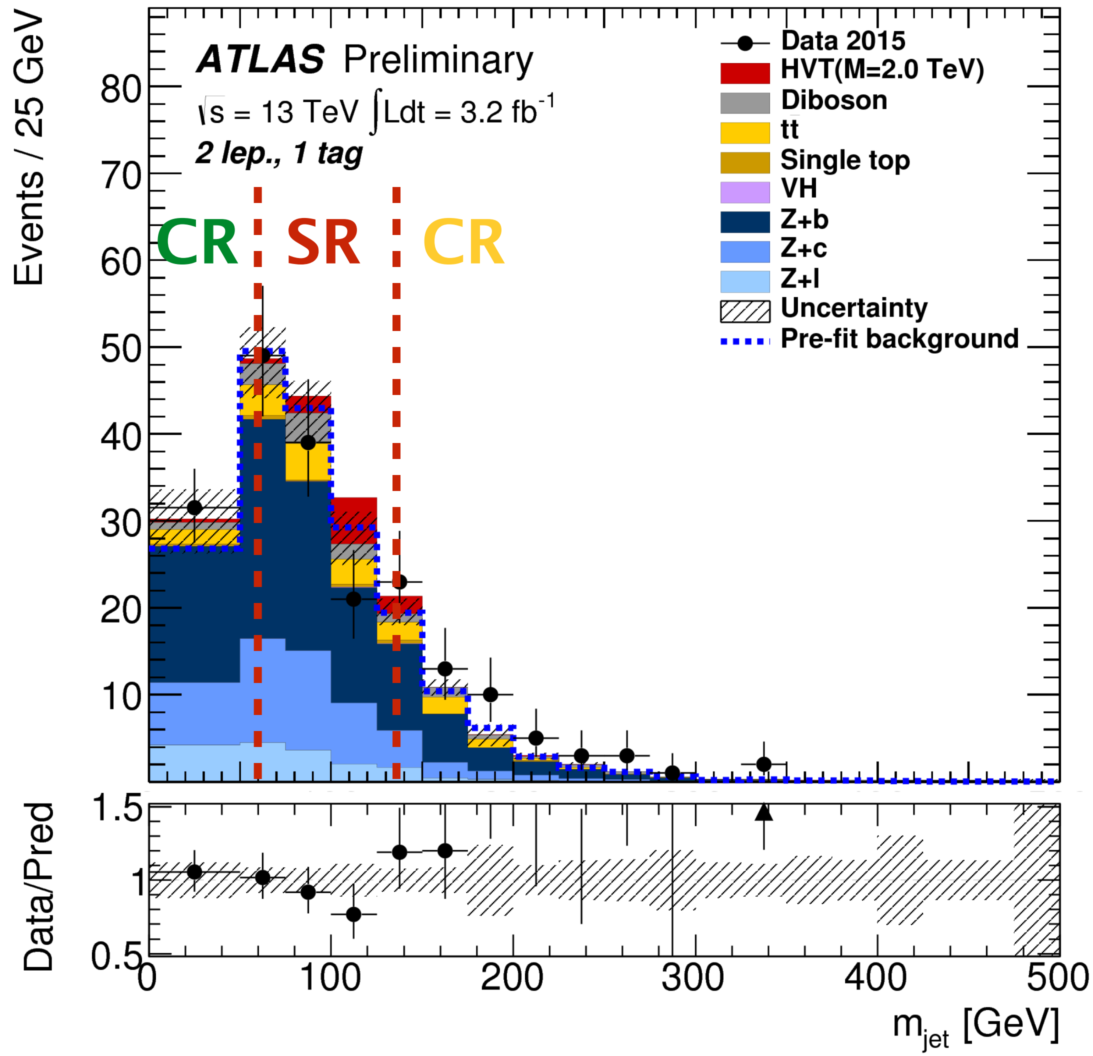




ATLAS-CONF-2015-074

- **Very low stats in 2-btag high stats region.**

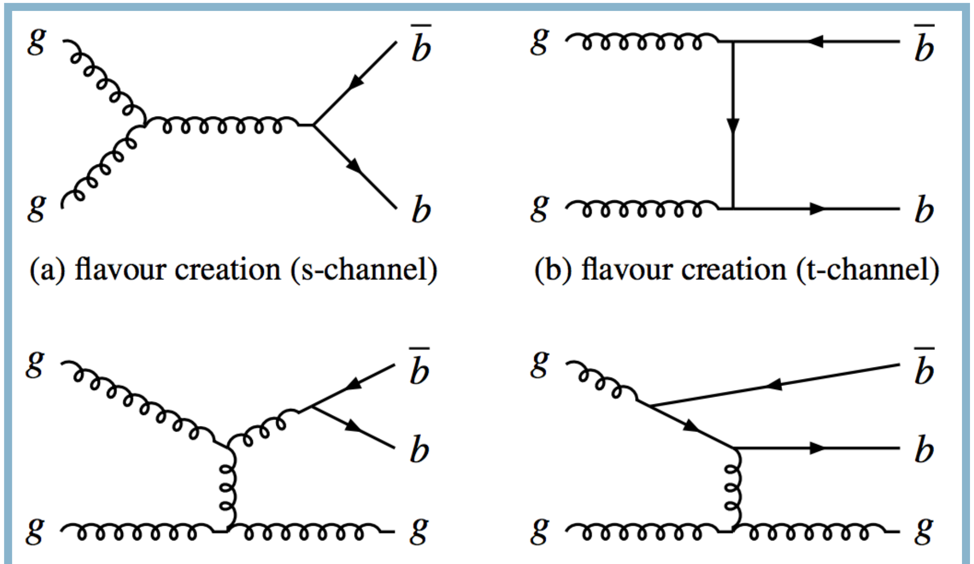
- Signal region defined by fat jet mass
  - Control regions defined outside m_{jet} window
  - Low m_{jet} region used for V+jets control region.
  - **Significant contribution from V+HF.**
  - Uncertainty on V+HF production is the dominant systematic uncertainties!
  - **Mismodelling observed in high mass m(bb)…**



Future measurements

Future measurements

- Measurements in the pipeline
  - 8 TeV Jpsi+mu
  - 13 TeV W/Z+HF
- What else should we be looking to measure?
  - Flavour-labelled kT-spittings?

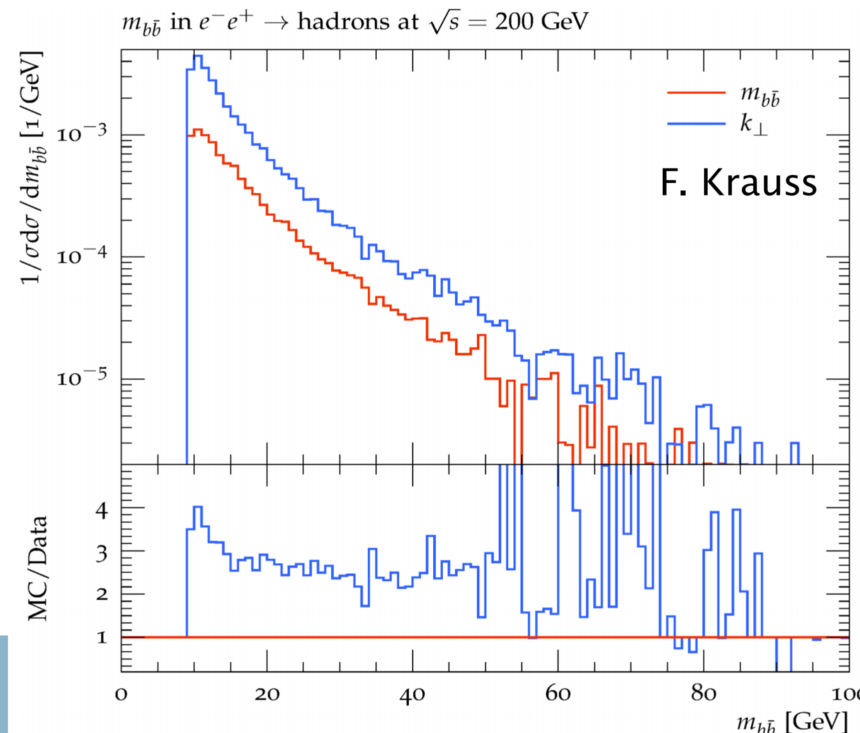


(a) flavour creation (s-channel)

(b) flavour creation (t-channel)

(c) gluon splitting

(d) flavour excitation



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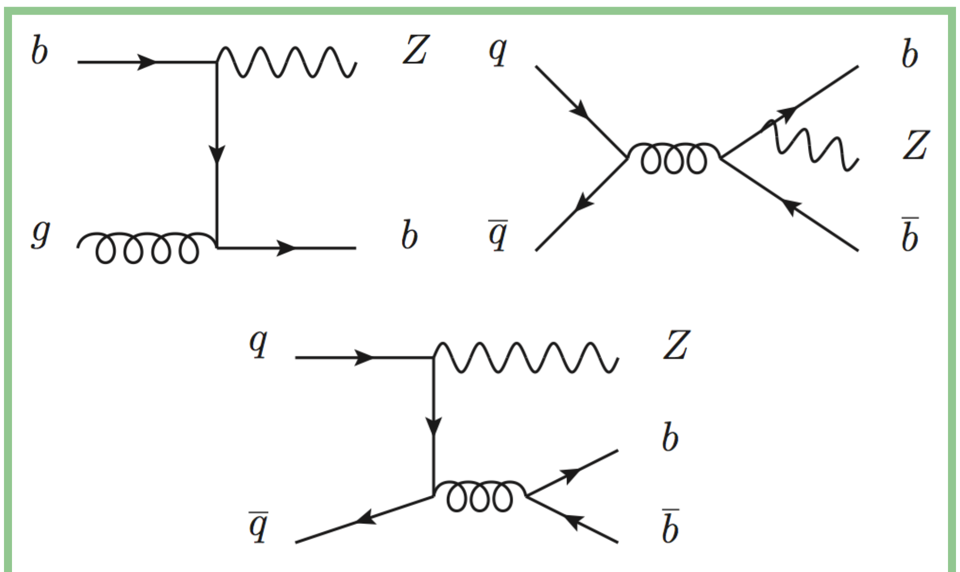

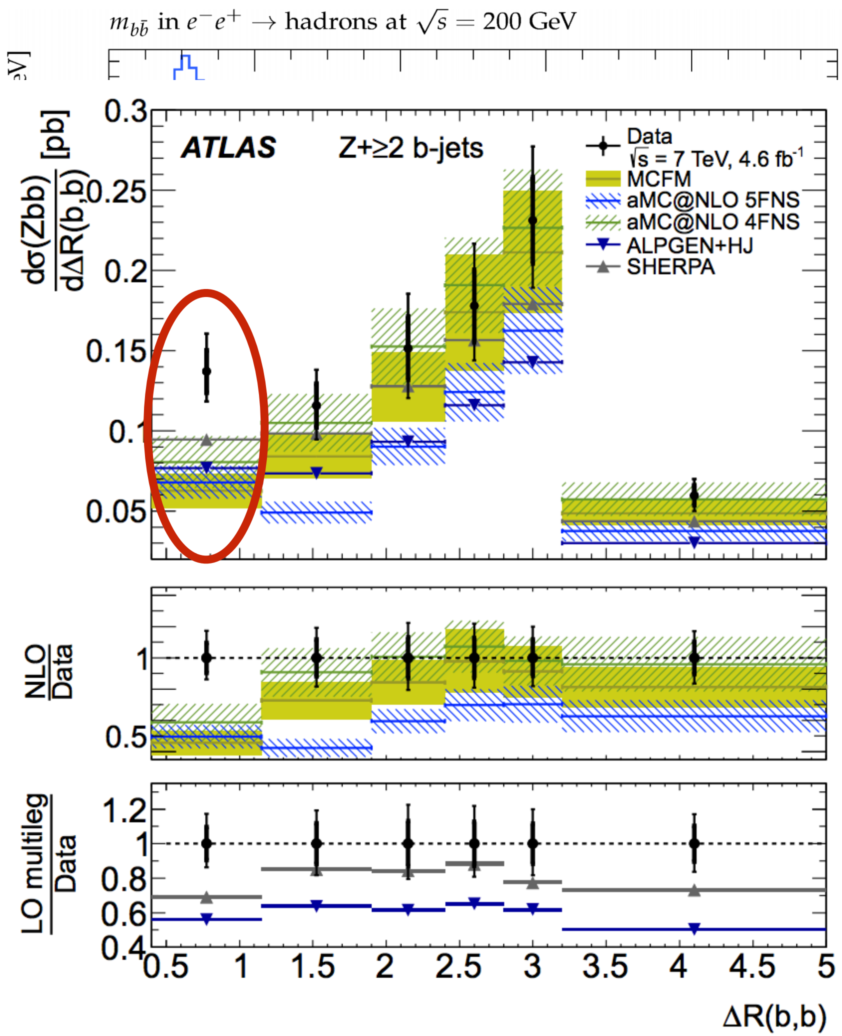

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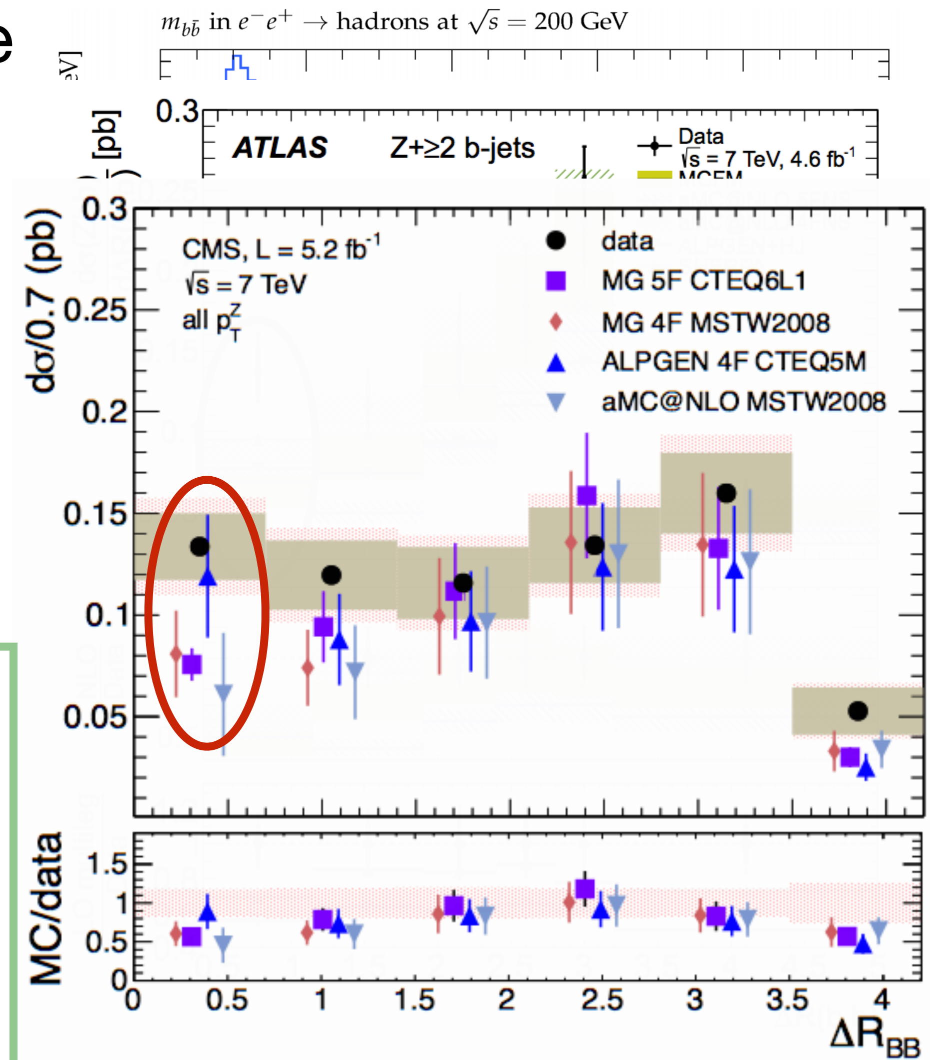
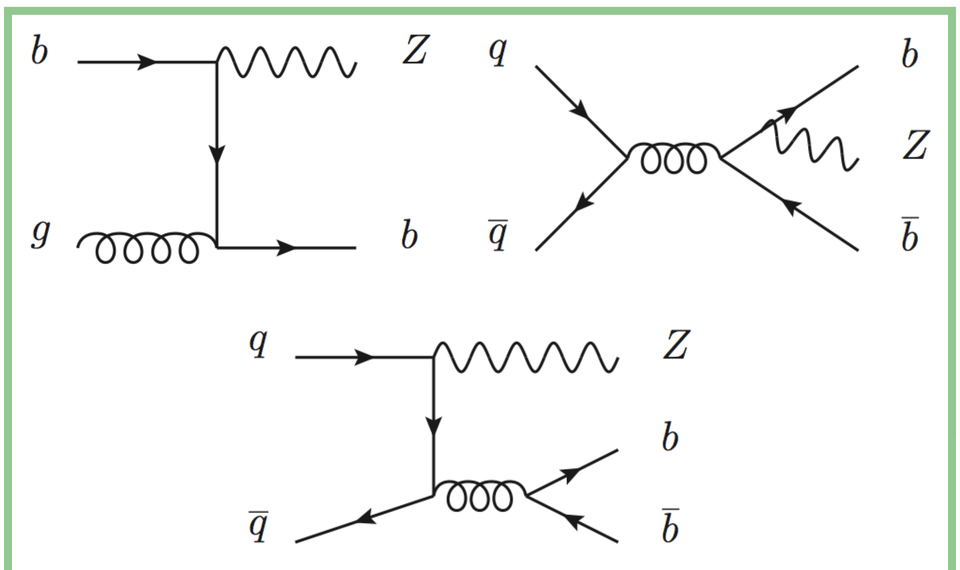


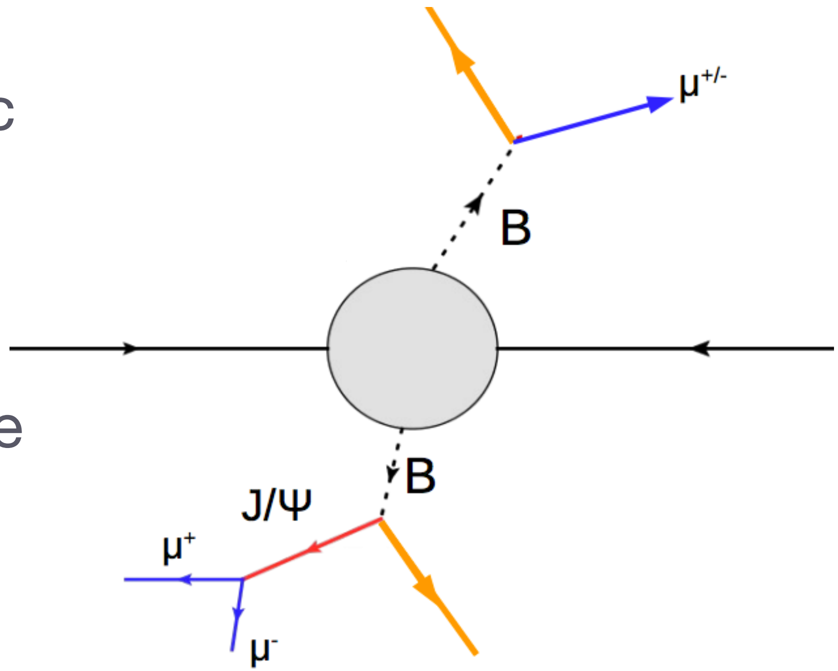


13 TeV W/Z+HF

- Repeat of 7 TeV measurements
  - Add W+HF to Z+HF measurement
  - More statistics
    - dR(b,b) with smaller statistical uncertainty
  - More differential measurements for W+HF
  - Add dedicated measurement in boosted regime
  - So far plan to have the following MC comparisons
    - Sherpa 2.2 5fl
    - MG5_aMC+Py8 CKKW-L 5fl
    - MG5_aMC+Py8 FxFx 5fl
    - Alpgen+Py6 4fl
  - What should we add?
    - MG5_aMC NLO Z+bb 4-fl
    - Sherpa 4-fl?

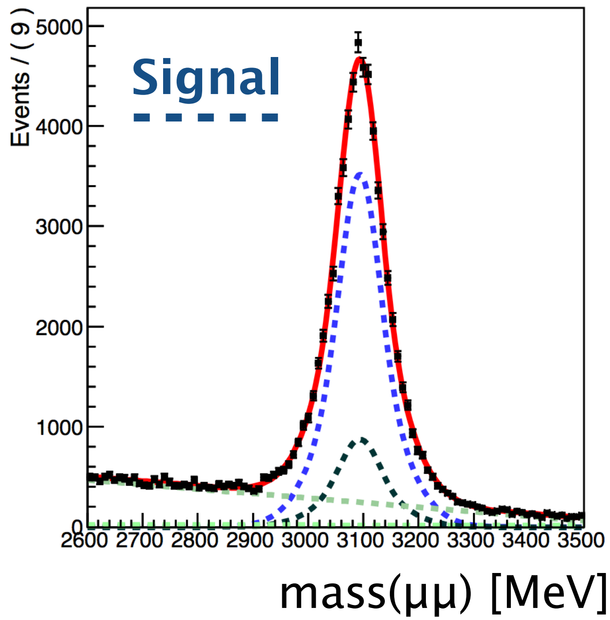
$J/\psi+\mu \Leftarrow B+B \Leftarrow g\rightarrow bb$

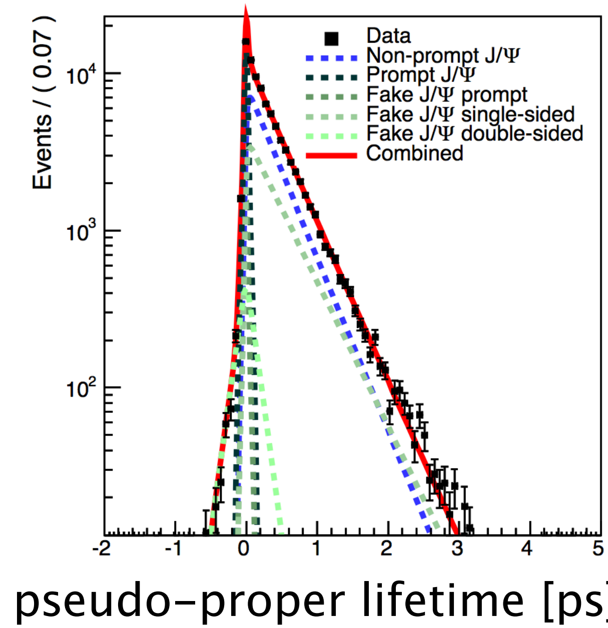
- A new measurement of **B hadron pair production** in progress at $\sqrt{s}$ = 8 TeV
  - Identifying the $B \rightarrow J/\psi(\rightarrow \mu+\mu-) + X$ and $B \rightarrow \mu + X$ decay
  - Fit to extract differential cross sections in a number of kinematic variables.
    - Non-prompt J/ψ
    - Non-prompt 3rd μ
  - New constraints particularly in the region of close-by B-hadron pair production
    - Sensitive to $g\rightarrow bb$ production.
    - No jet radius restriction.

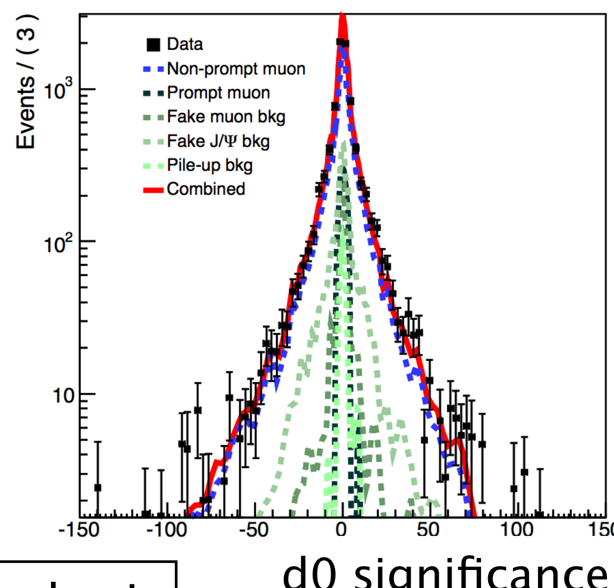


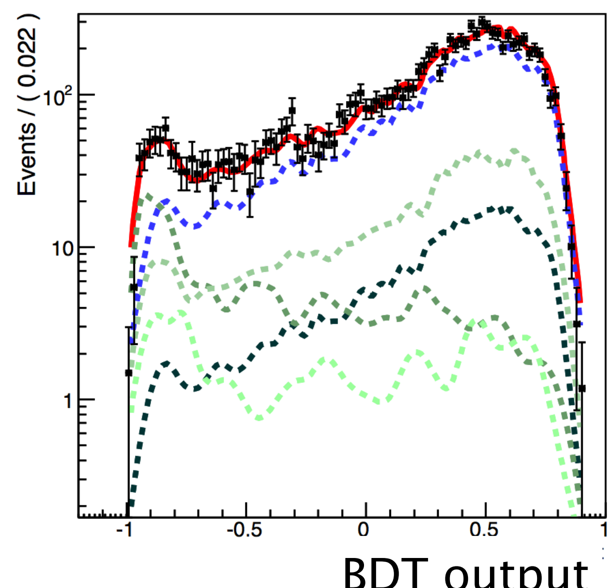
J/ψ+μ ⇐ B+B ⇐ g→bb

- Extract non-prompt J/ψ and 3rd μ
  - Repeat in each kinematic bin
- 2-D fit to J/ψ mass and lifetime.
  - Separate from prompt J/ψ and fakes
- 2-D fit to 3rd μ d0-significance and BDT output.
  - Separate from prompt, decay-in-flight and pileup μ.





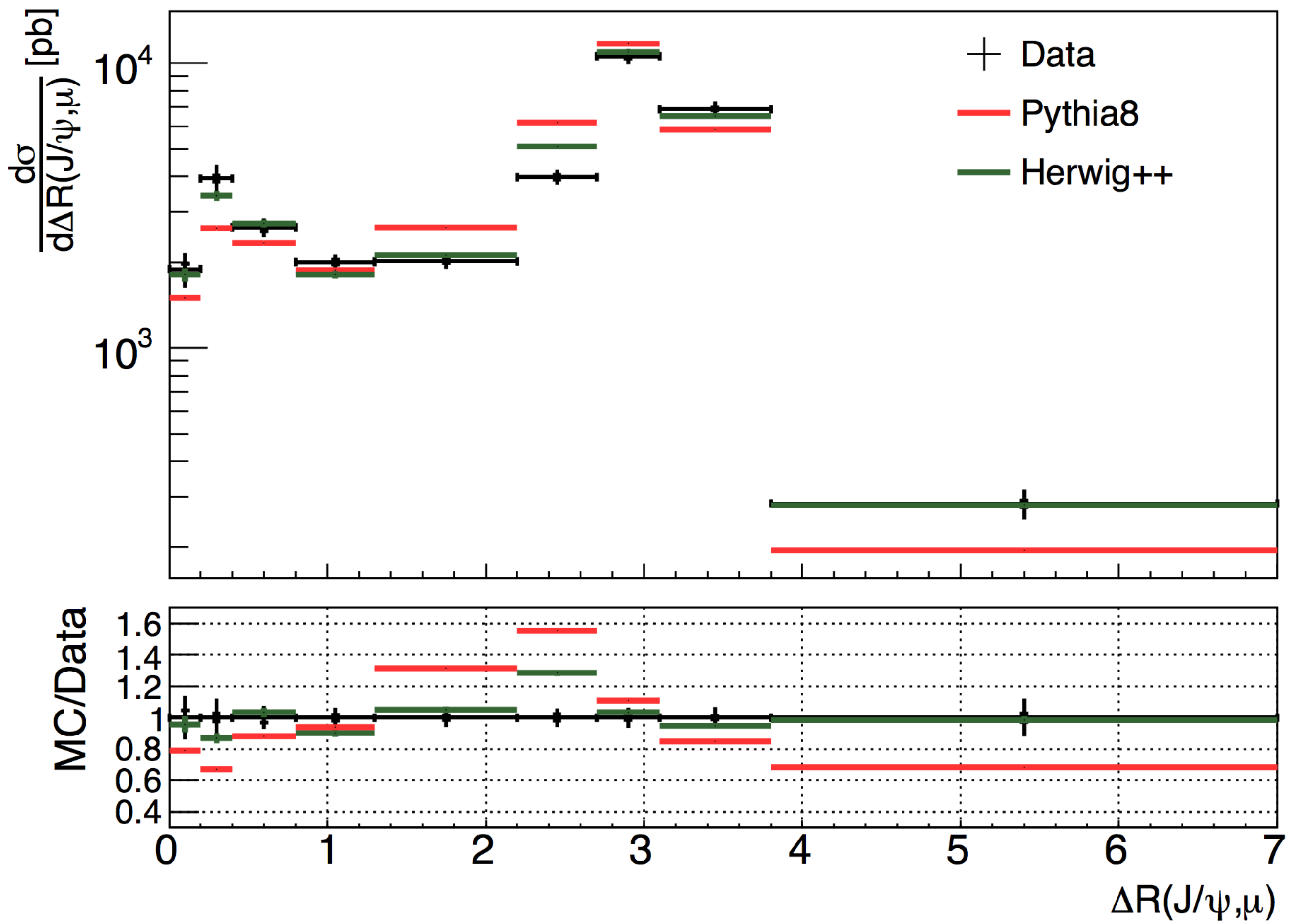




P. Davidson's thesis

J/ψ+μ ⟸ B+B ⟸ g→bb

- Signal cross section extracted as function of:
  - ΔR(J/ψ,μ)
  - Δφ(J/ψ,μ)
  - Δy(J/ψ,μ)
  - pT(J/ψ,μ)
  - m(J/ψ,μ)
  - yboost(J/ψ,μ)
  - m/pT
  - pt/m
- ~20% xs uncertaintiy in small ΔR region.



P. Davidson's thesis

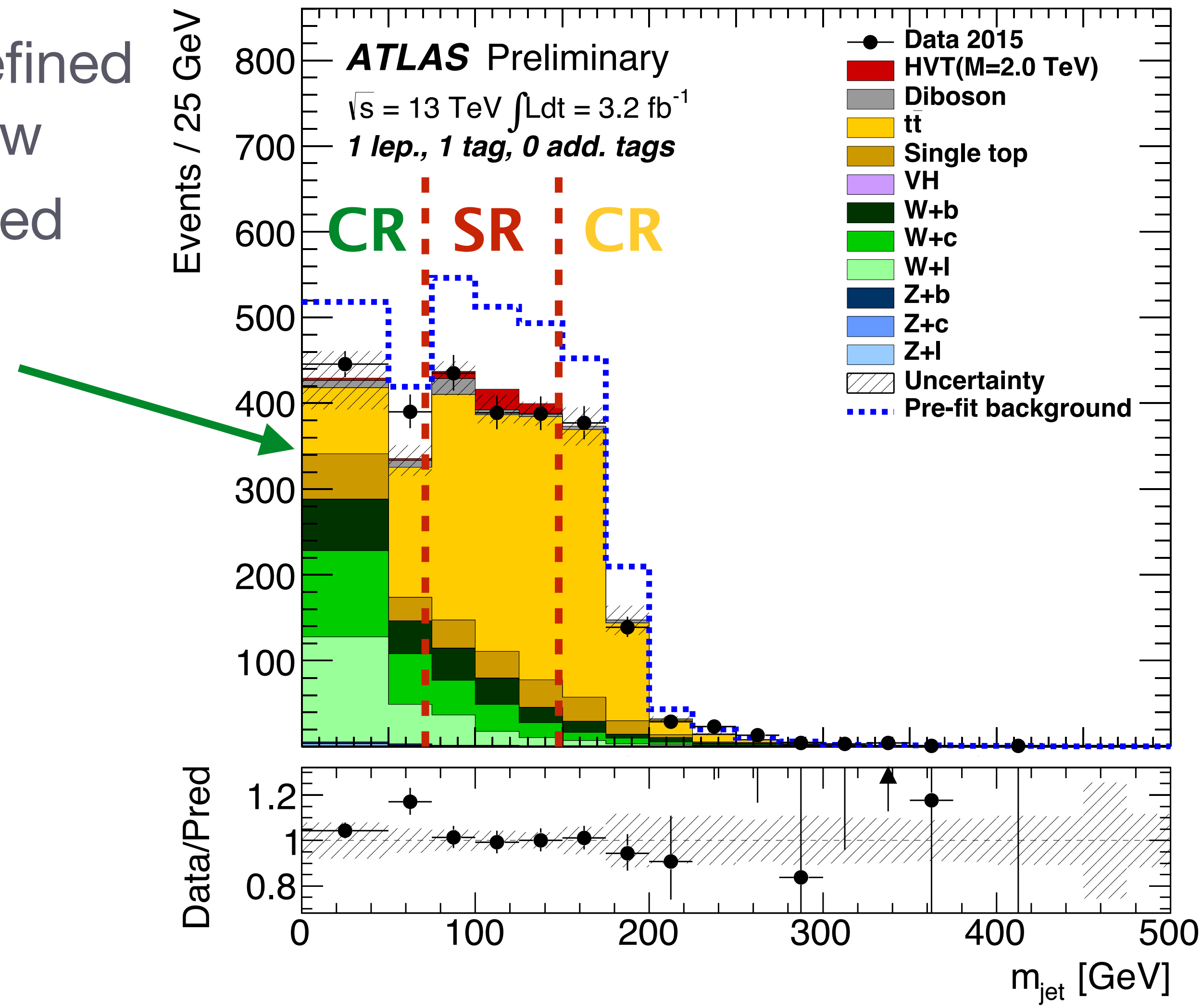
Summary

Summary

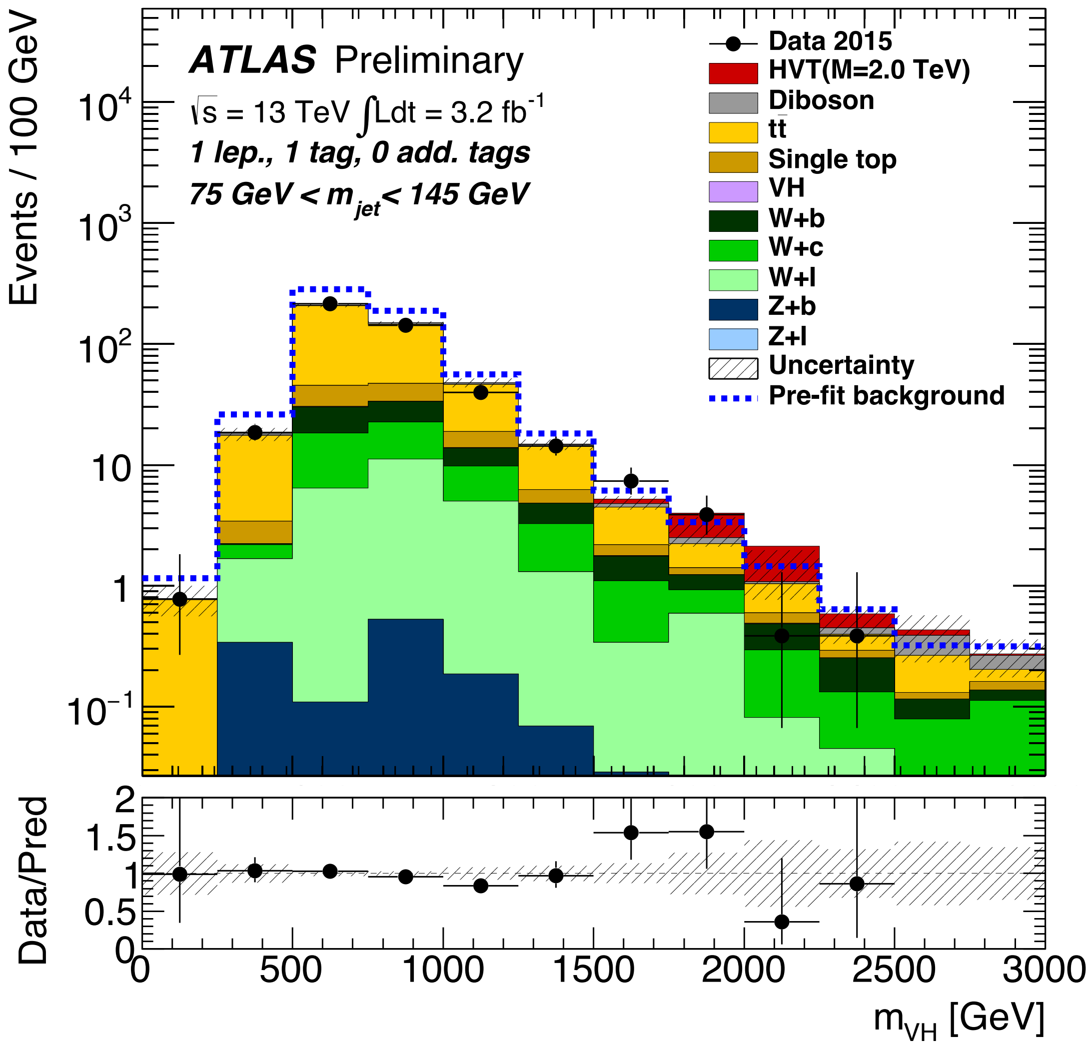
- Technical obstacles
  - HFOR
  - HF-enhanced generation to increase efficiency?
- New HF measurements in progress
  - Z+HF
  - W+HF
    - More stats, more kinematic variables…
- Close-by $g \rightarrow bb$ region of most interest:
  - BB hadron
  - $J/\psi+\mu$
  - 0.2 kT track jets?
- What else?!

Back-ups

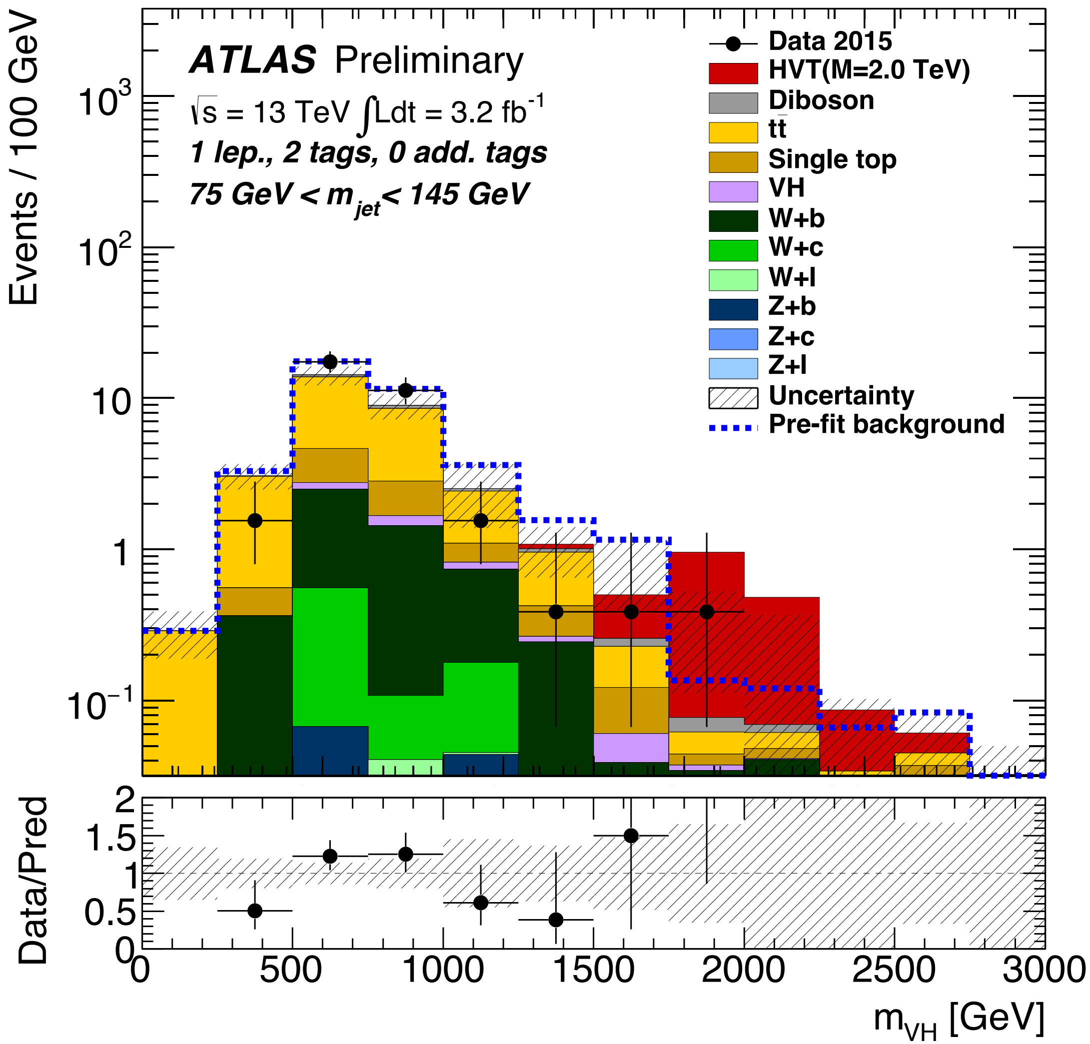
- Signal region defined by fat jet mass
  - Control regions defined outside m_{jet} window
  - Low m_{jet} region used for V+jets control region.



- Signal region defined by fat jet mass
  - Control regions defined outside m_{jet} window
  - Low m_{jet} region used for V+jets control region.
  - **Significant contribution from V+HF.**
  - Low statistics in tail after 1-btag requirement



- Signal region defined by fat jet mass
  - Control regions defined outside m_{jet} window
  - Low m_{jet} region used for V+jets control region.
  - Significant contribution from V+HF.
  - Very low statistics after 2-btag requirement
    - Will be worse with 10x luminosity!



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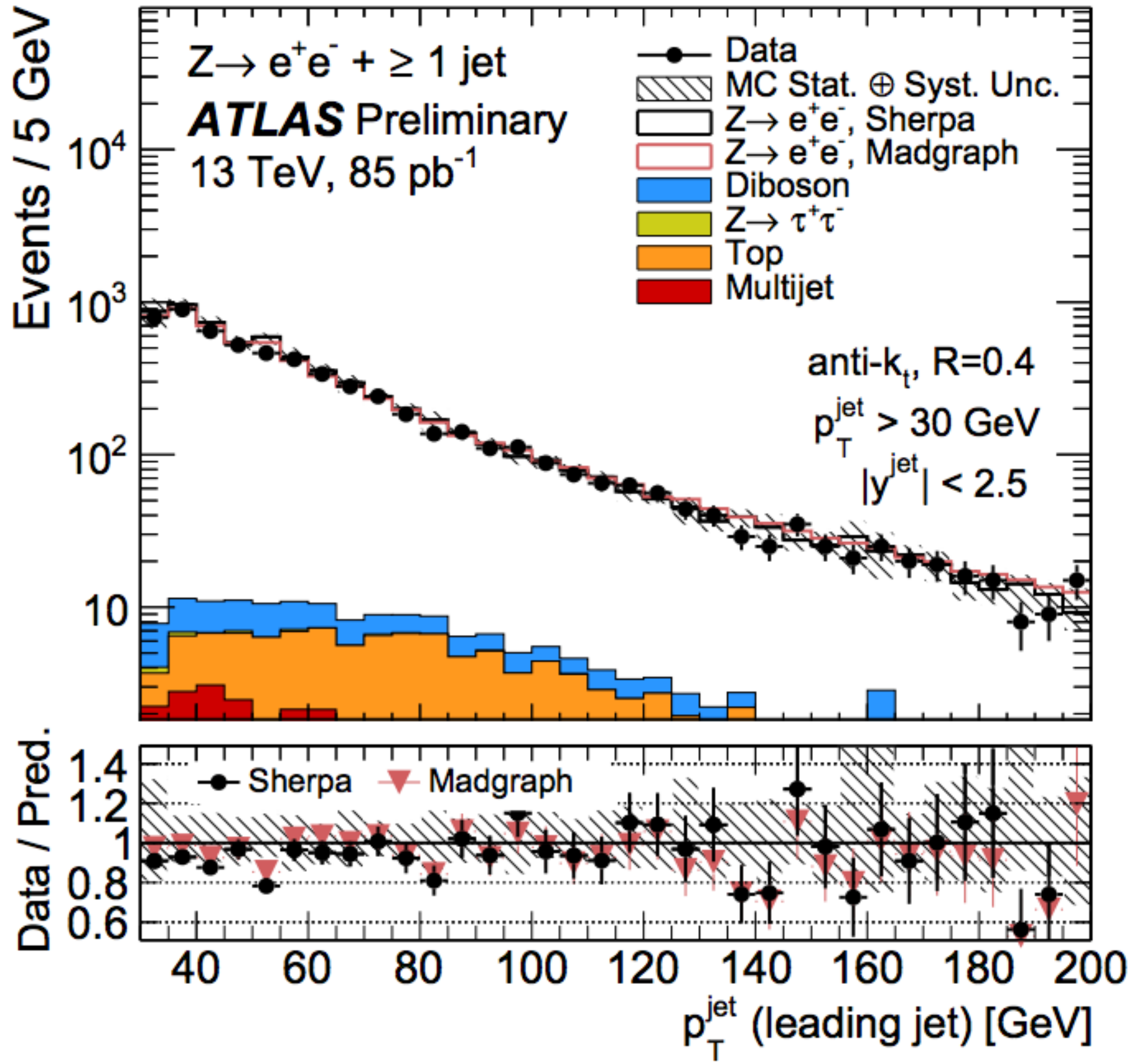
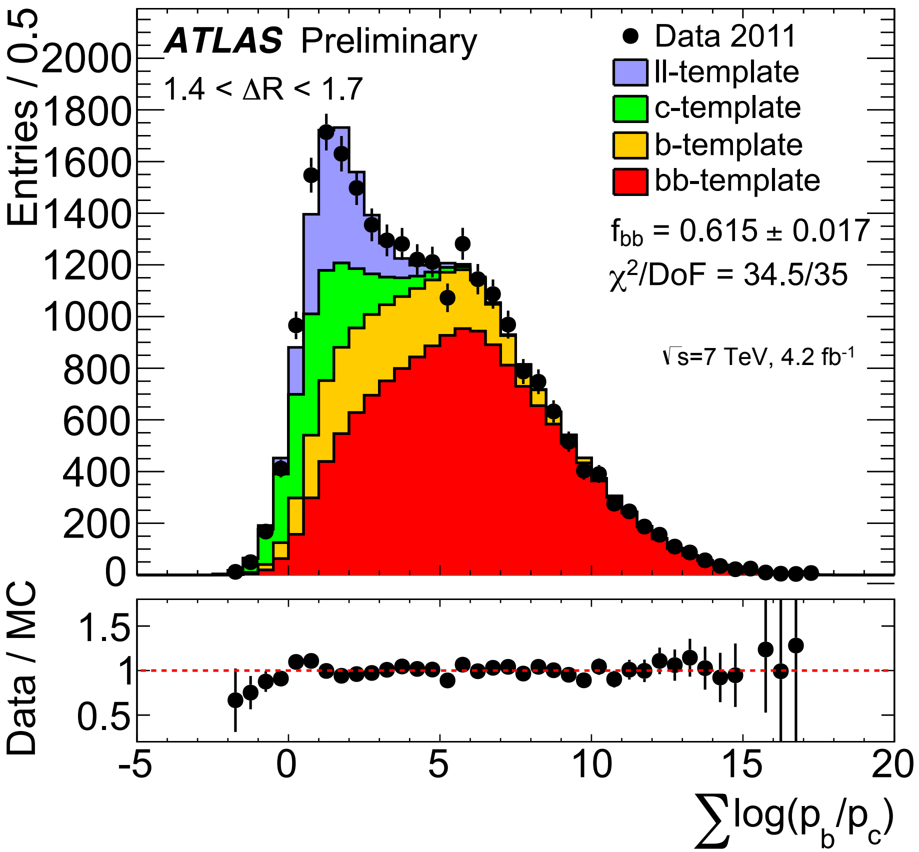


Sherpa slicing

	B-veto C-veto	C-Filter B-veto	B-Filter
PtV0-70			
PtV70-140			
PtV140-280			
PtV280-500			
PtV500-700			
PtV700-1000			
PtV1000-2000			
PtV2000+			

24 samples!

Di-b-jet template fit



Sherpa production time

- LO->NLO
  - Sample according to the optimised integrators, but for each PS point still have to calculate the ME, which is more expensive in the NLO case.
  - Also the unweighting efficiency is much worse for the subtracted real in the NLO.
- High pTV
  - The integrators do not adapt very well to the extreme phase space regions in the high pT slices so the unweighting efficiency goes down
  - Also, in these regions more multi-parton ME calculations are required instead of the cheap V+0p@NLO because they dominate the high pT region