Gluon splitting to bottom quarks at the LHC

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with a lot of useful discussions with Zihao Jiang and Peter Skands!

November 22, 2016

Parton radiation and fragmentation from LHC to FCC-ee

<u>Outline</u>

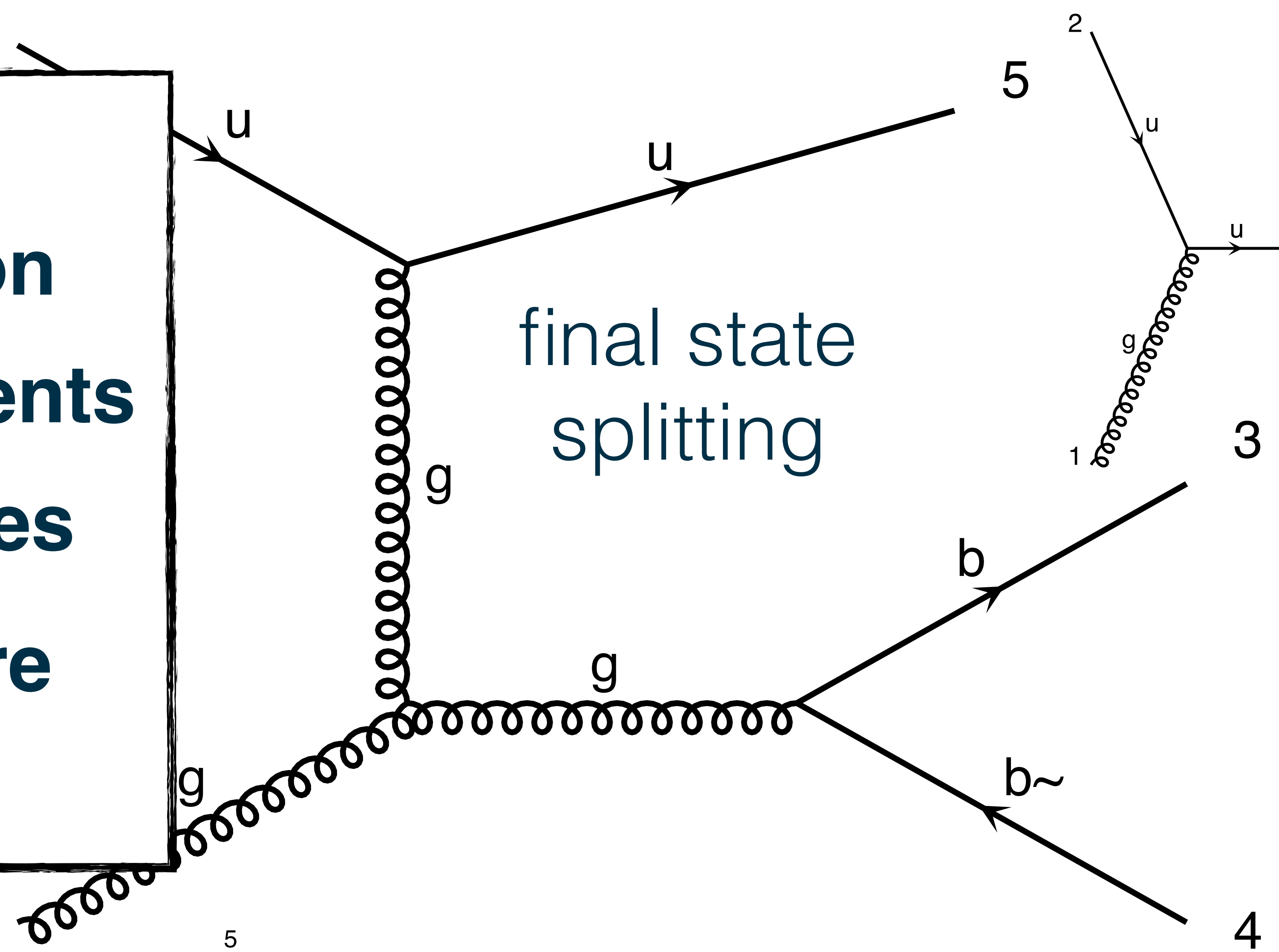
Motivation

Measurements

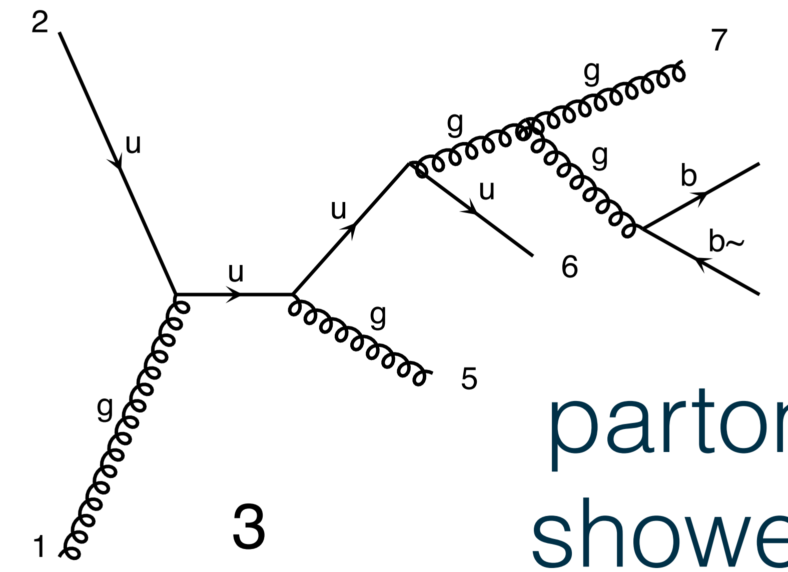
Techniques

The future

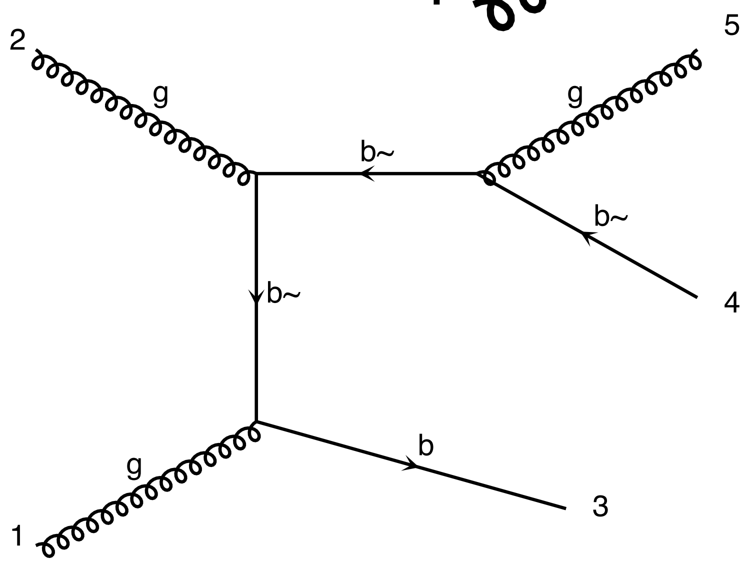
To e^+e^-!



final state splitting



parton shower splitting



initial state splitting

$$P_{q\leftarrow g}(x) = \frac{1}{2}\left[x^2 + (1-x)^2\right]$$

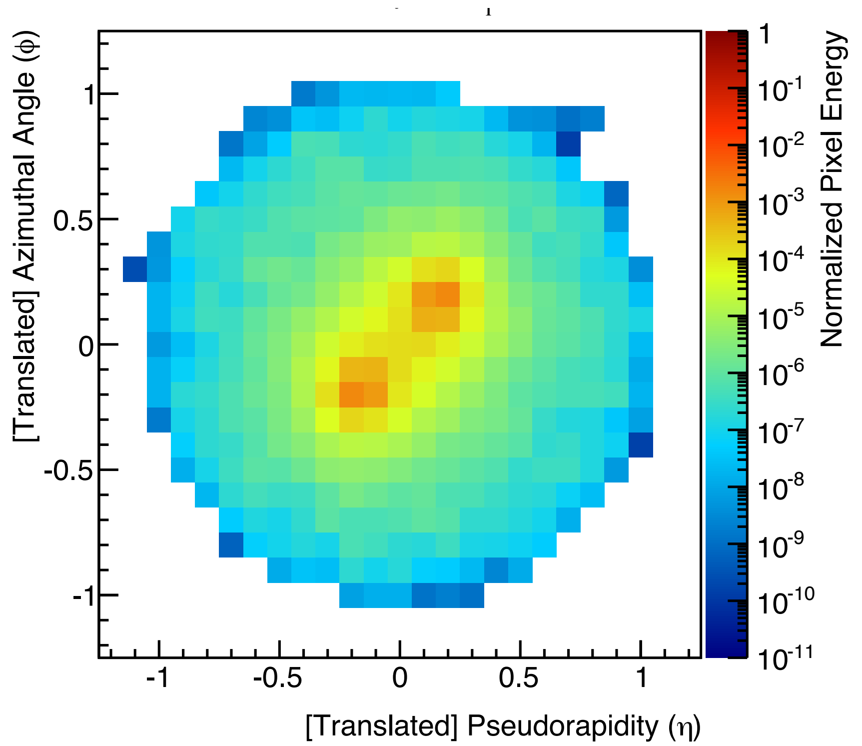
leading order splitting function

Diagram produced with MG5_aMC

Perturbative QCD

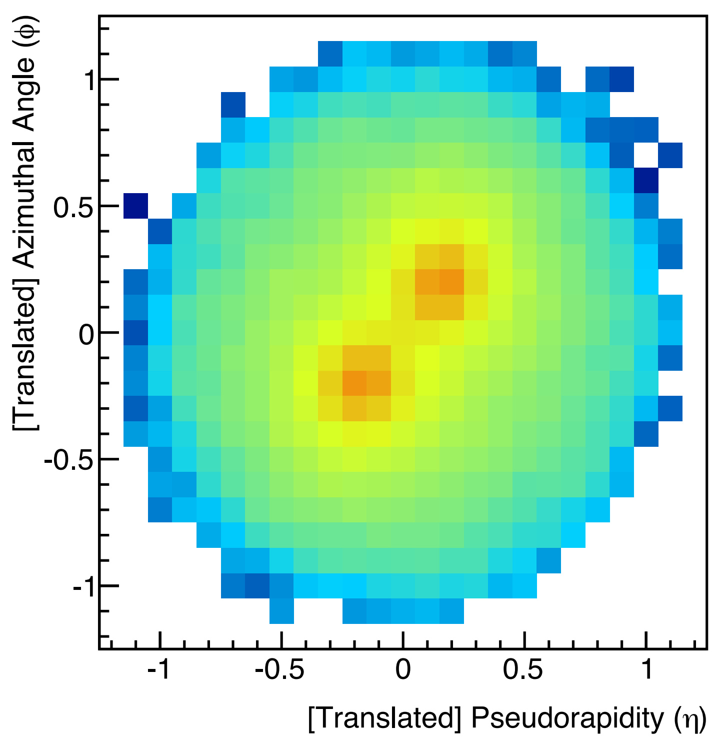
-essentially the only (nearly) direct measurement of a parton splitting function

-pure source of gluon jets (though complicated by B-hadrons)



Non-perturbative QCD

-pure source of color octets →

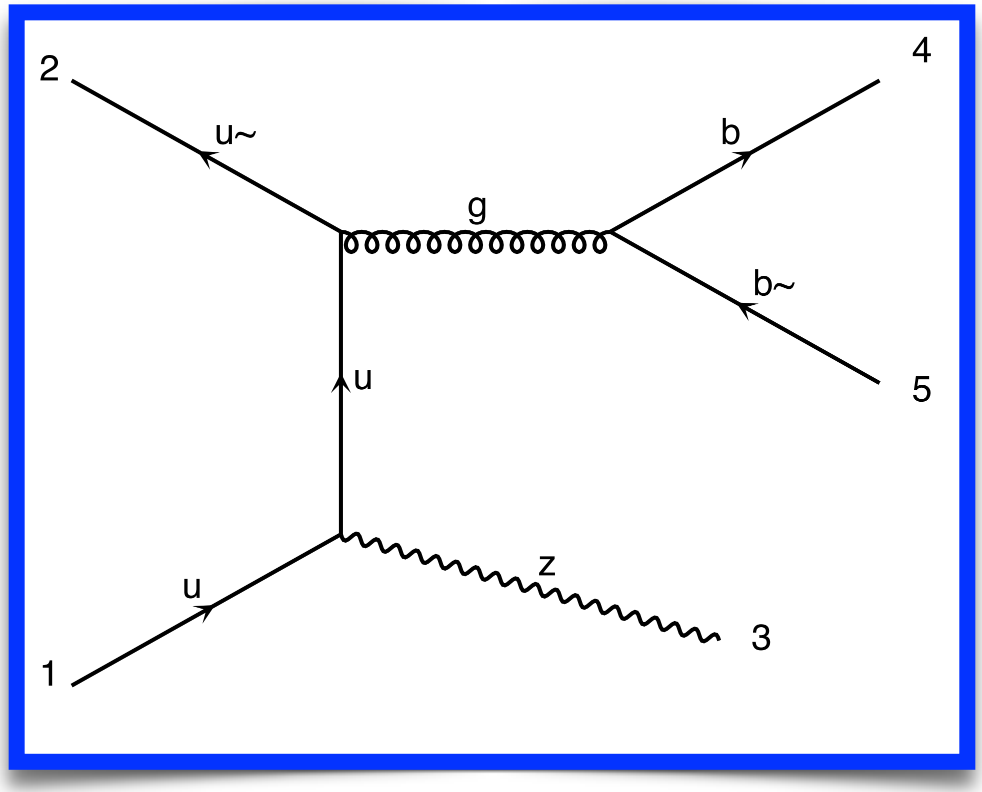


Higgs Boson (self-coupling)

-important background to many Higgs processed (VH, HH, BSM)

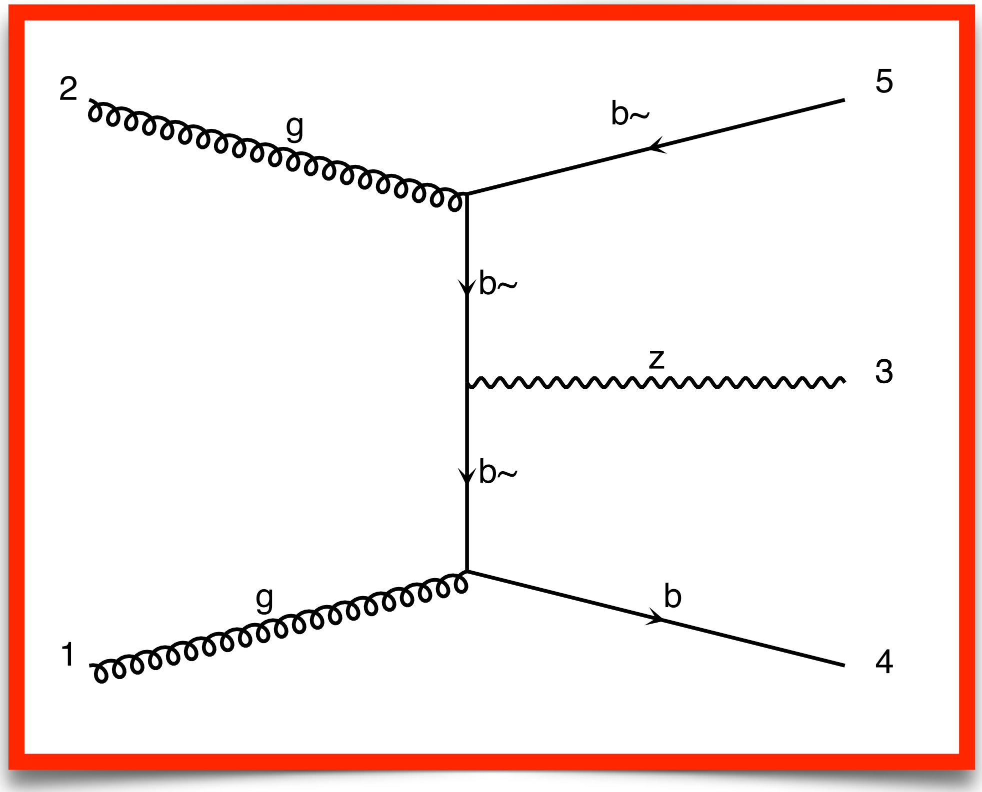
So far, several 7 TeV measurements (bb, Z+b(b), W+b(b)*)

I'll send a few minutes highlighting what has been done so far.

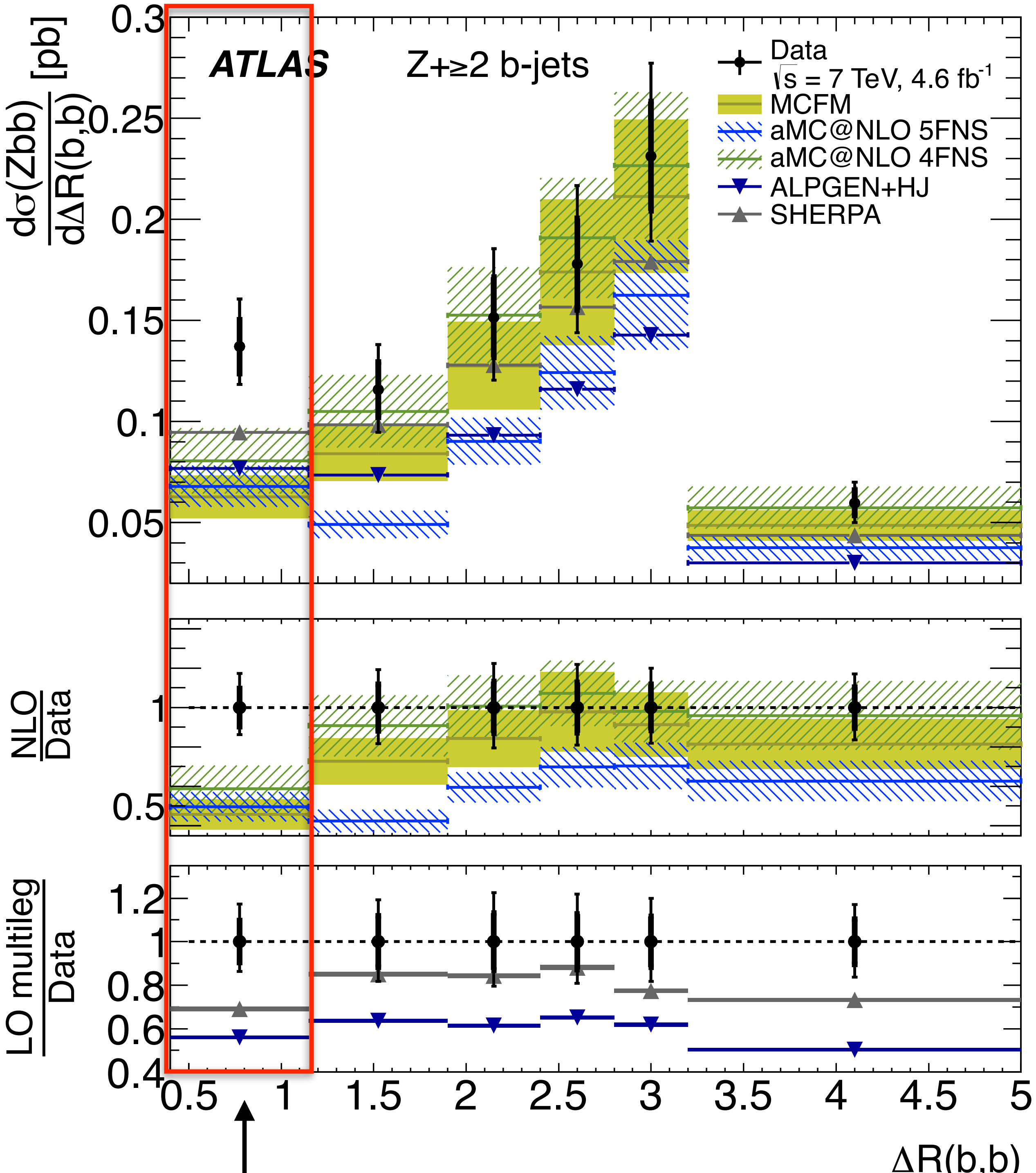


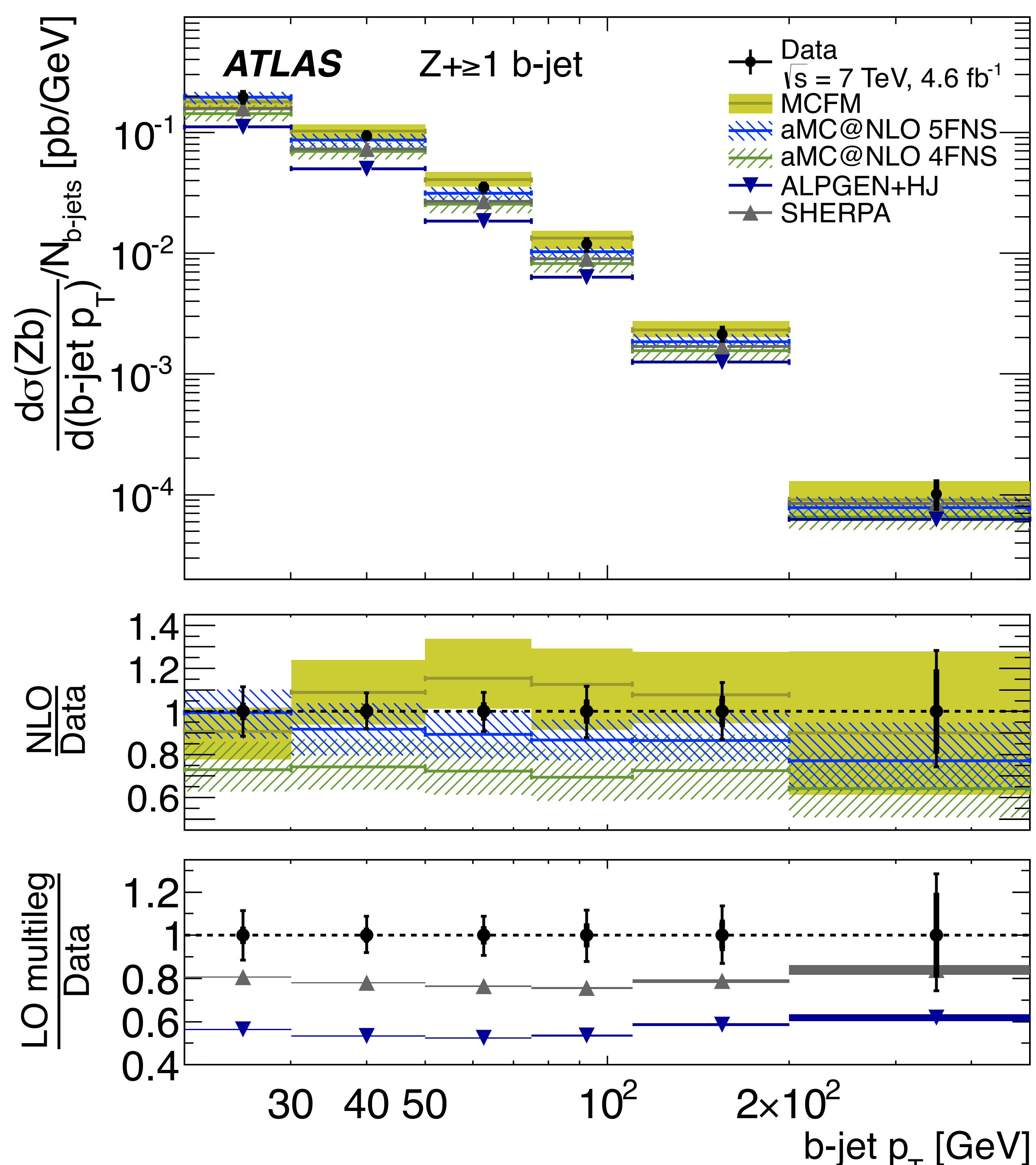
Not FS gluon splitting ➔

⬅ enhance by looking at low DR



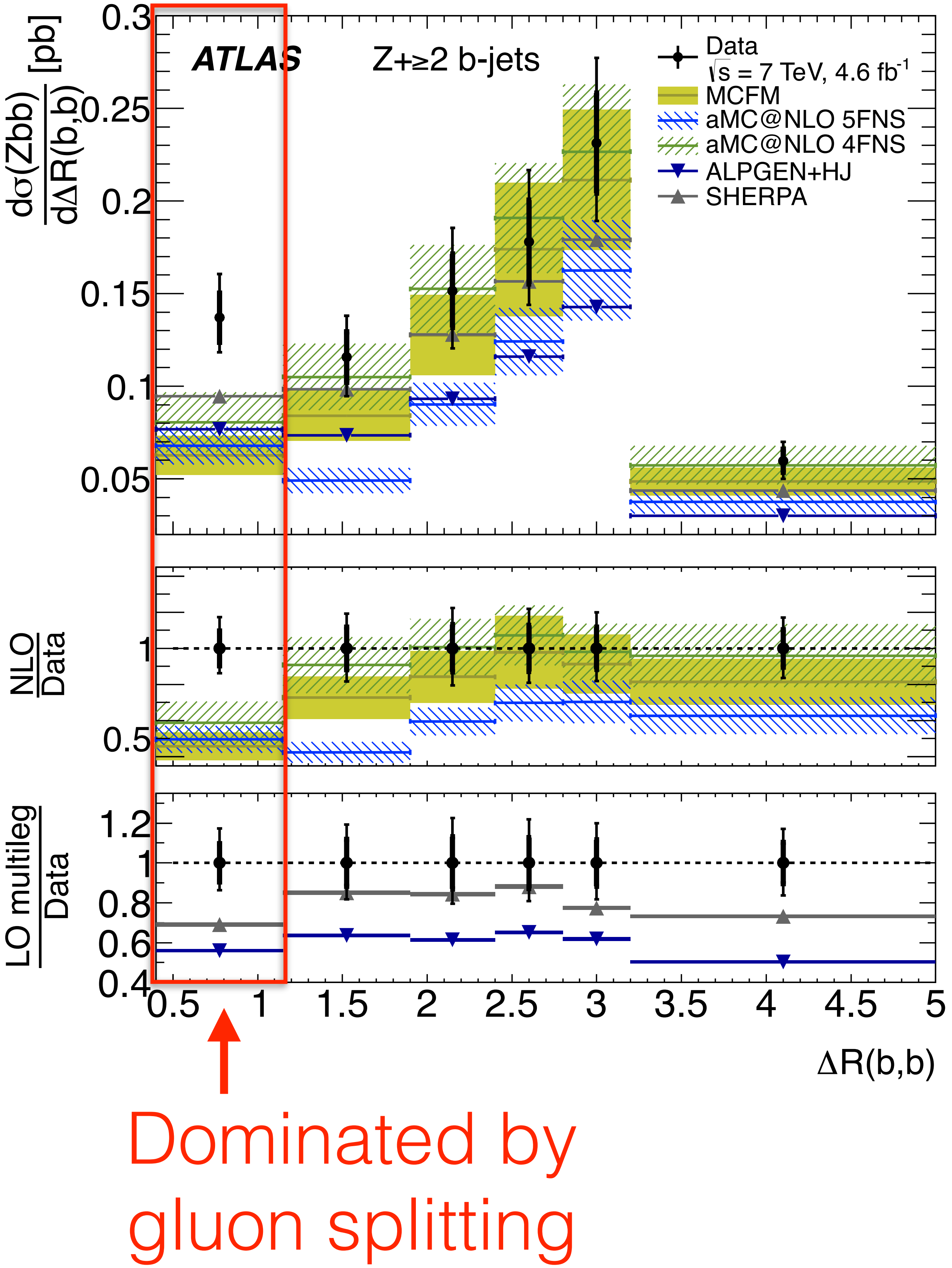
Why no gamma+bb? For gluon splitting, this is more interesting than Z+bb

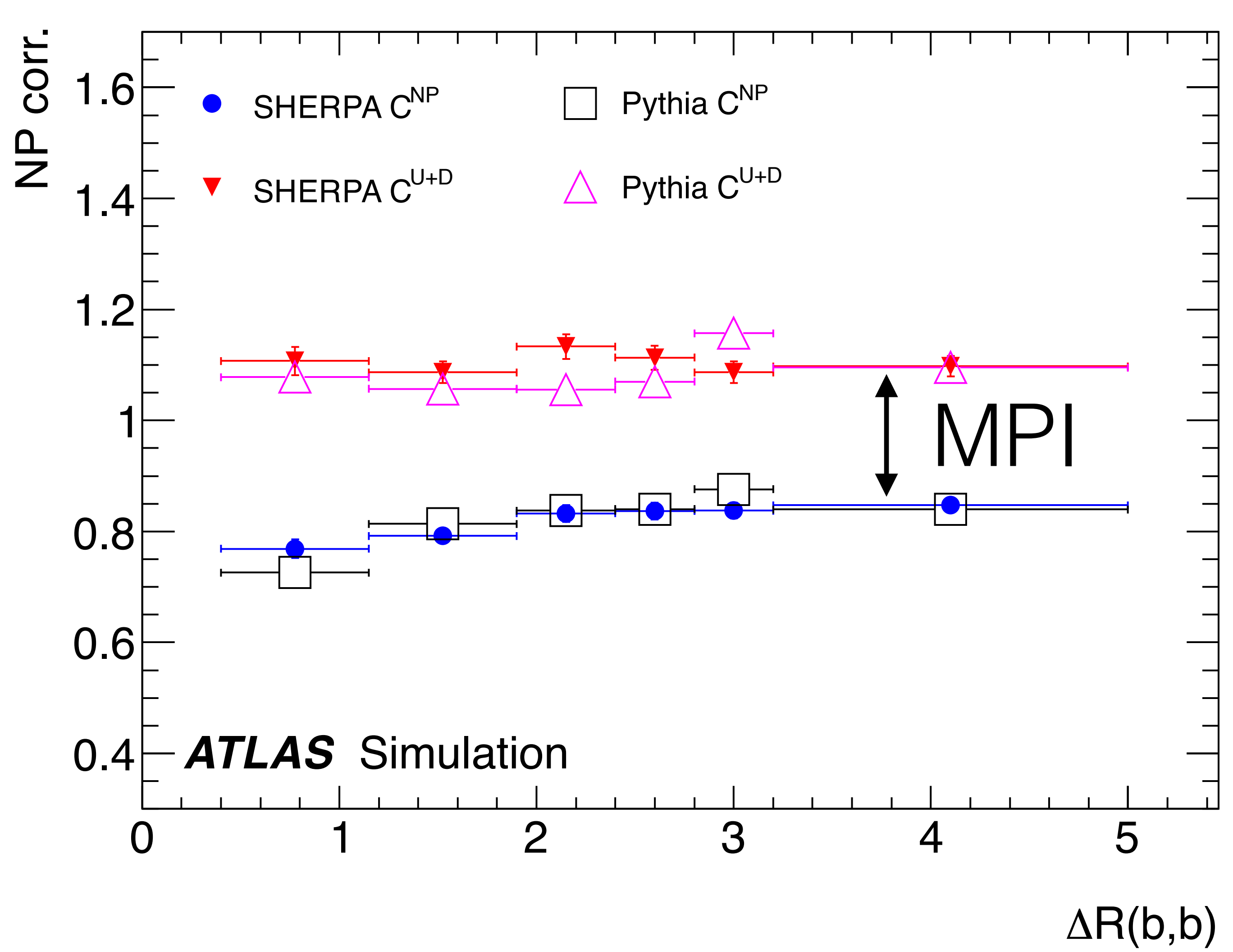




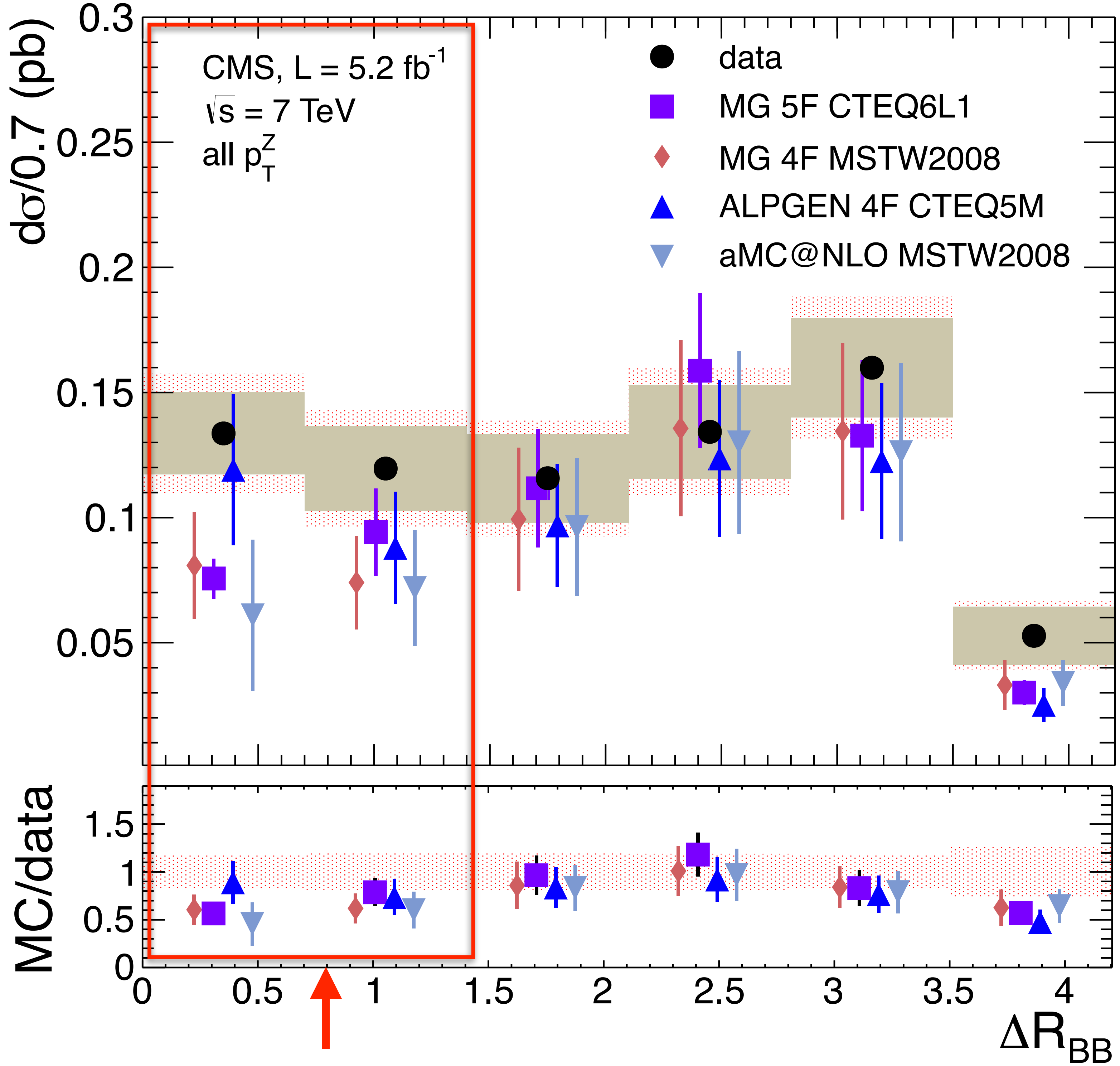
Approaching the PS phase space

Relatively low p_T regime

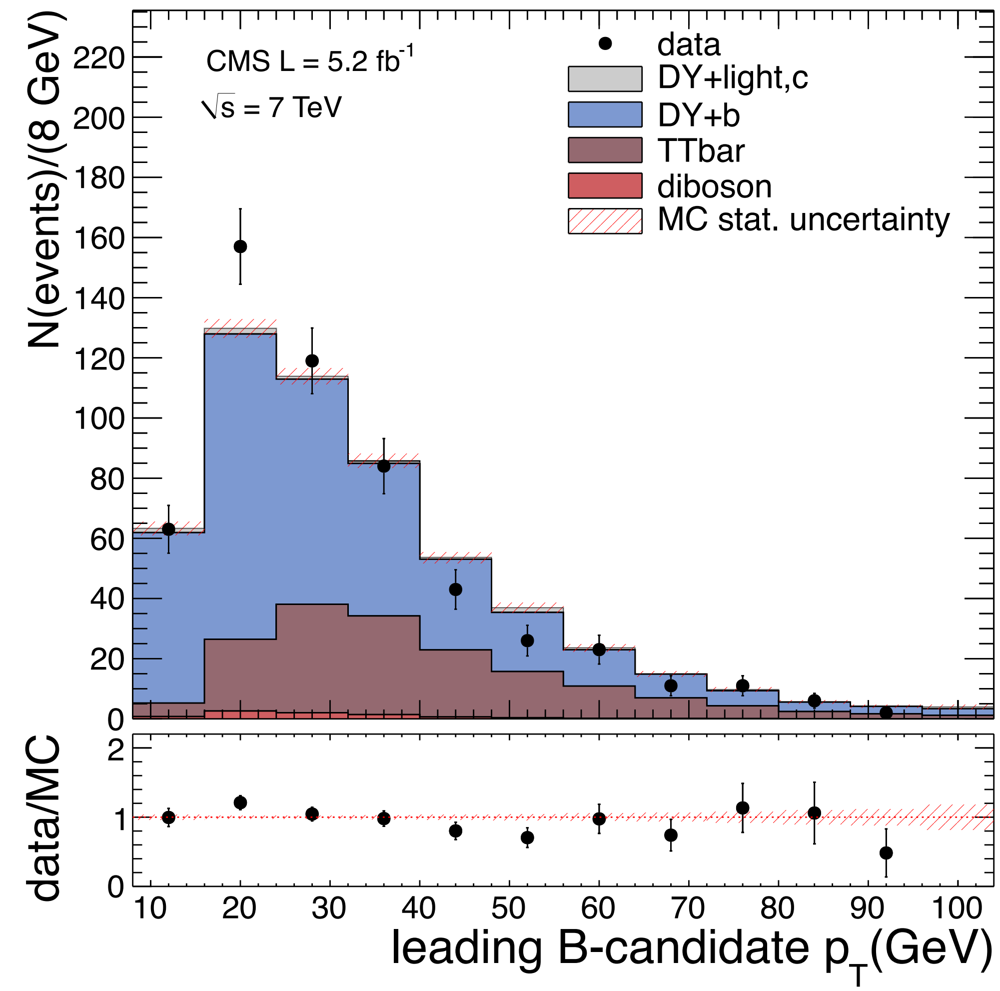




Interestingly, MPI is a relatively big effect here.

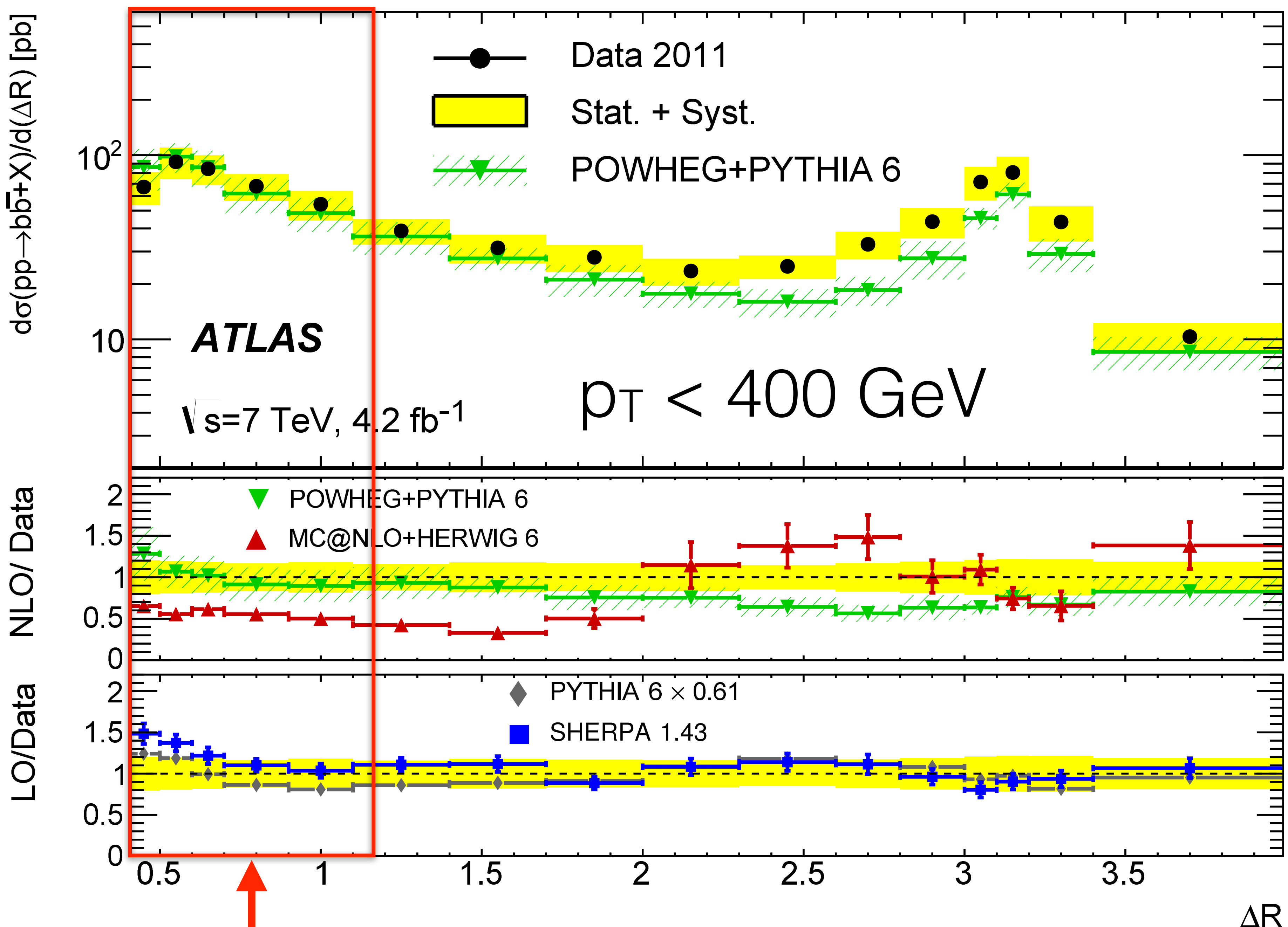


Dominated by gluon splitting



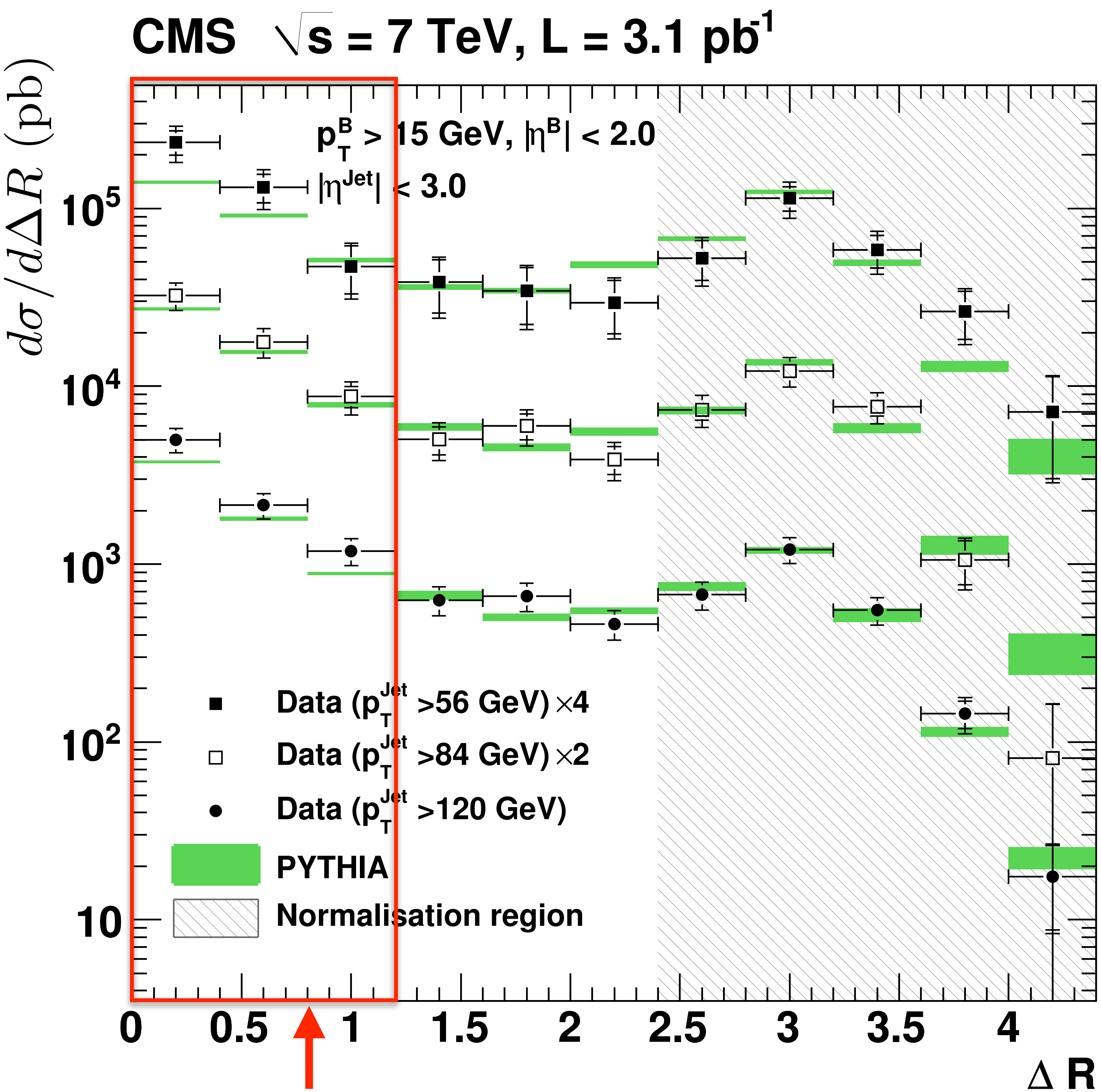
>> Inclusive cross-section with two b-jets

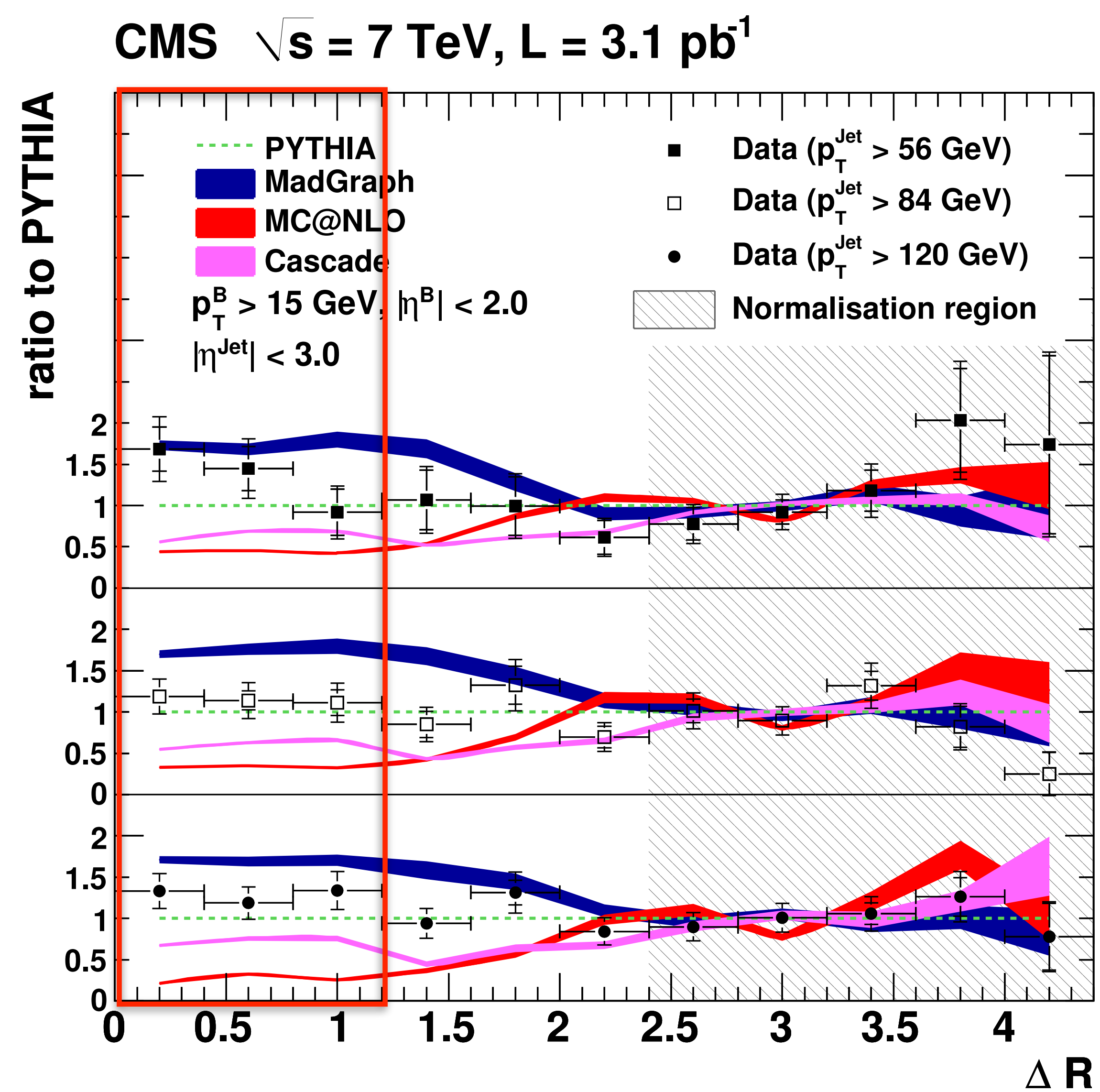
Higher p_T (though still relatively low) - trigger limited at low p_T



Starting to see the shape in the gluon-splitting dominated regime

(note that the theory comparisons here are rather dated)

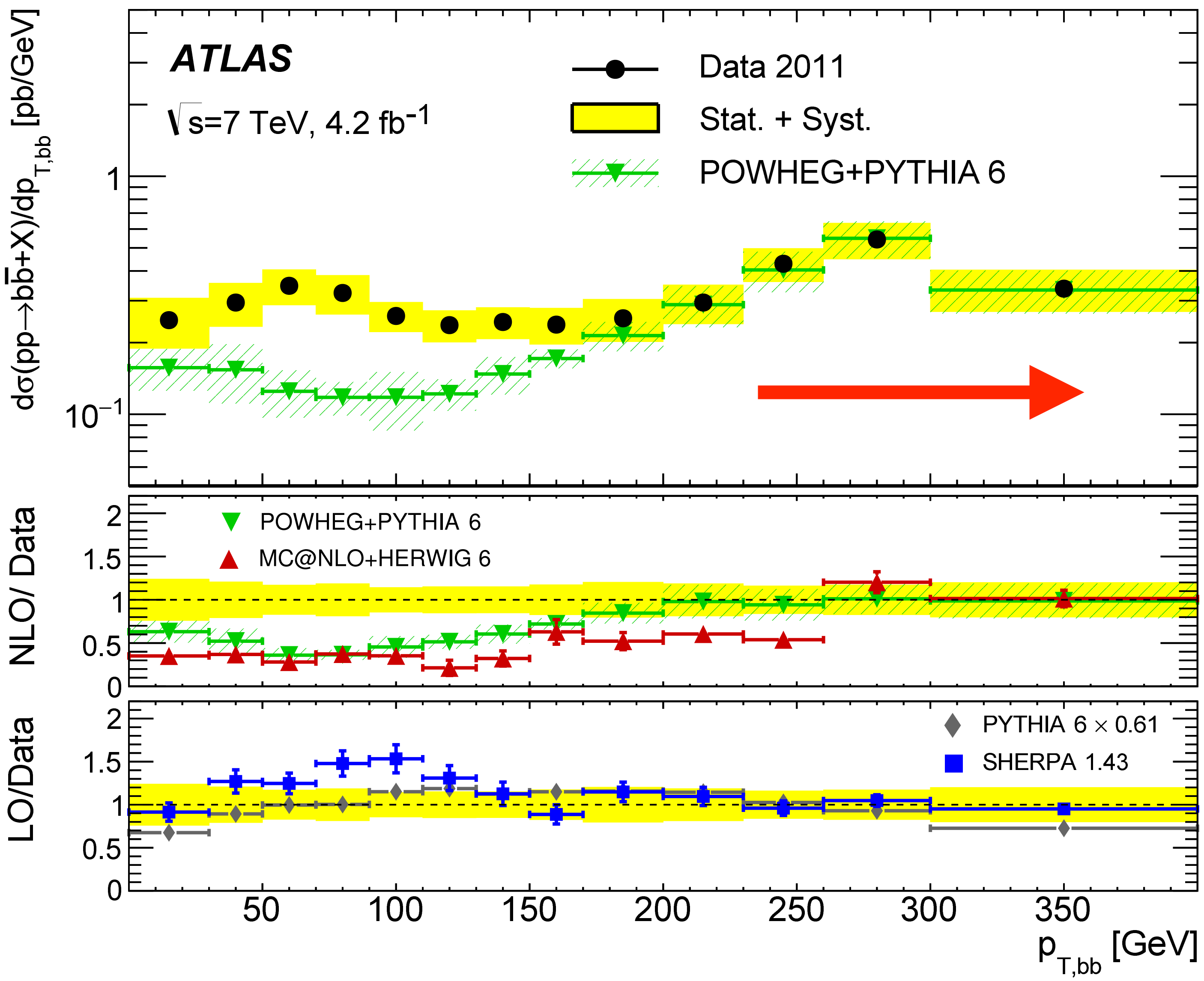


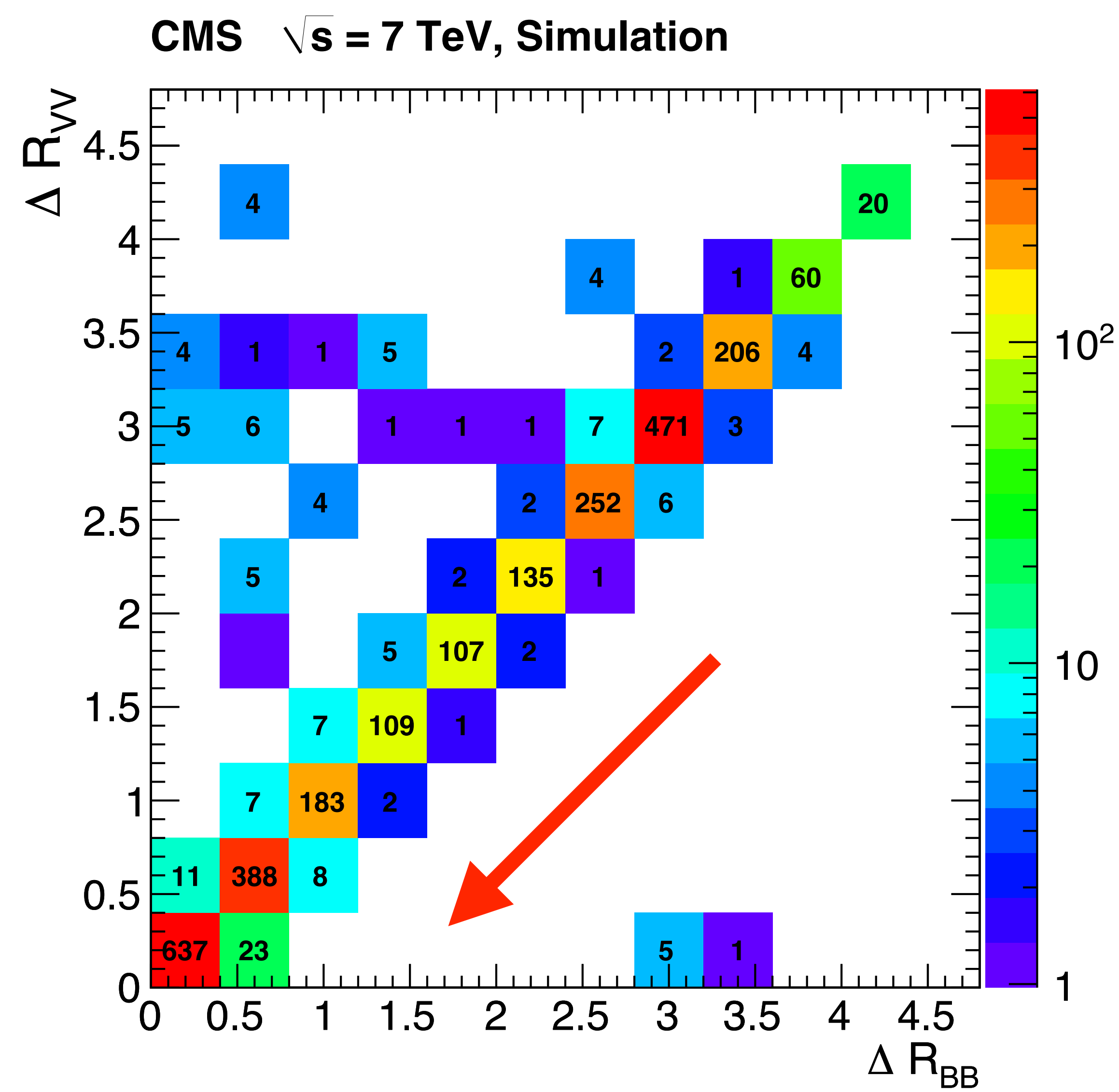


Starting to see the shape in the gluon-splitting dominated regime

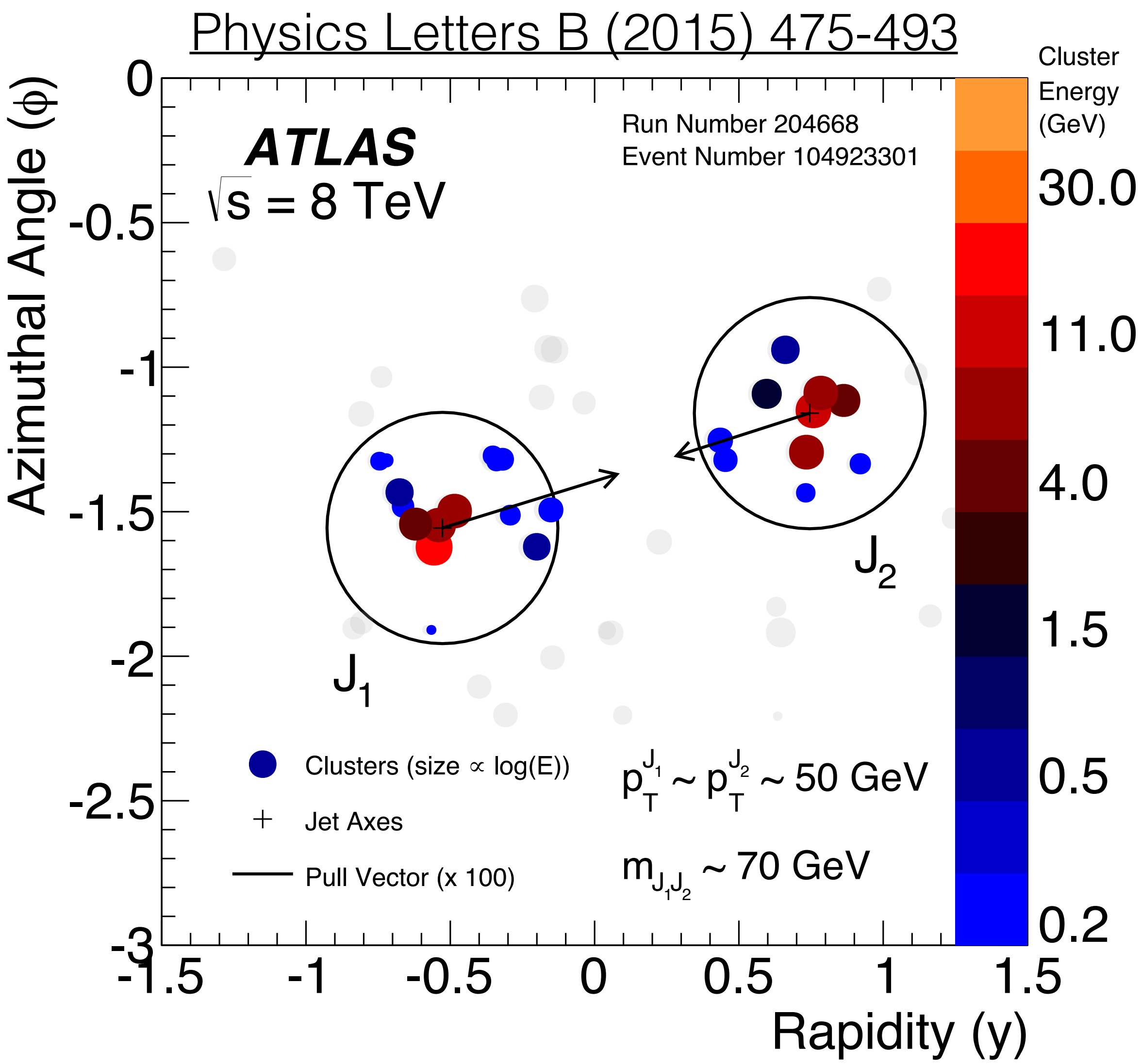
As with the ATLAS result, significant differences with the MC (though Pythia is not so bad), though the comparisons there are by now outdated.

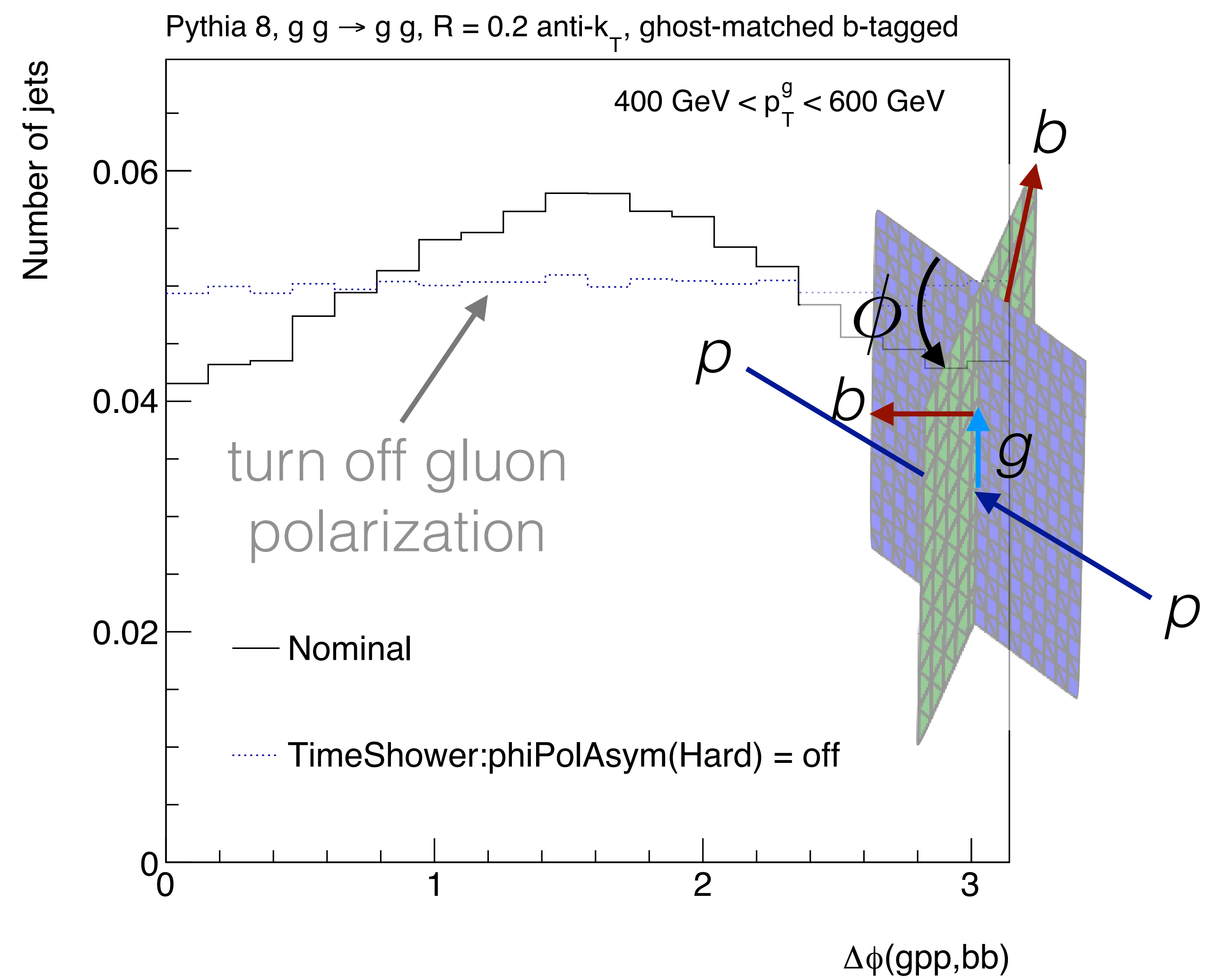
What does it look like with more data, higher p_T, and state-of-the-art simulation?





>> STAY TUNED <<

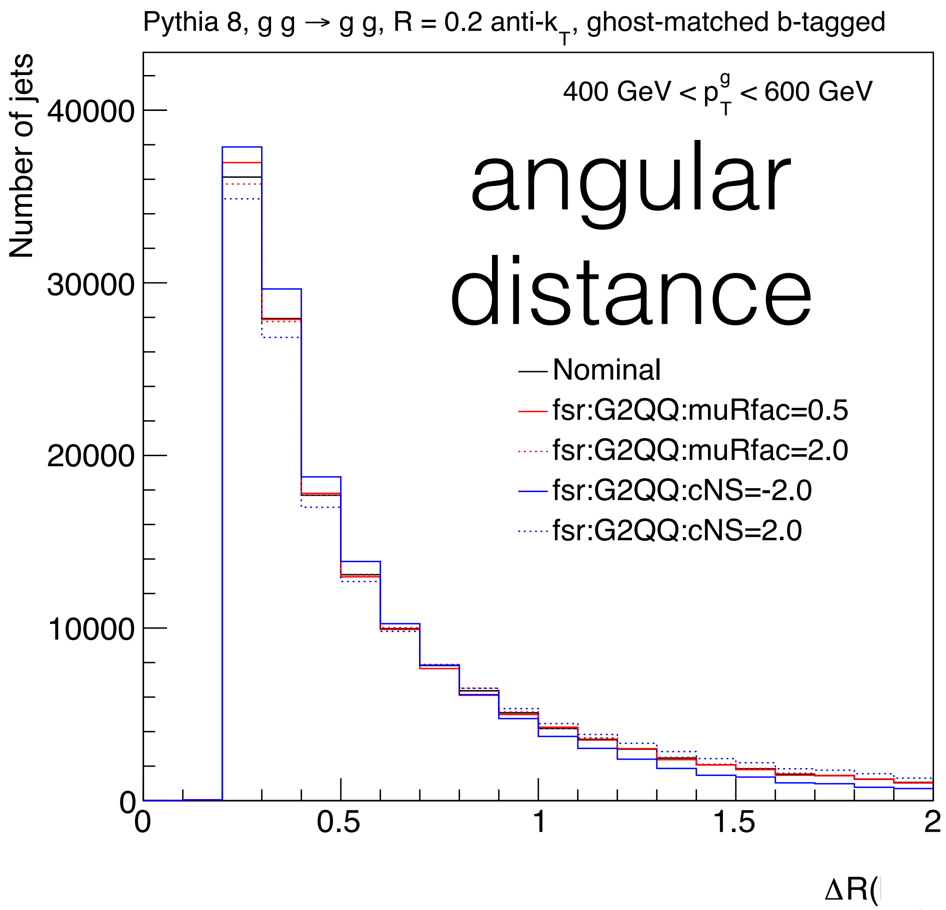


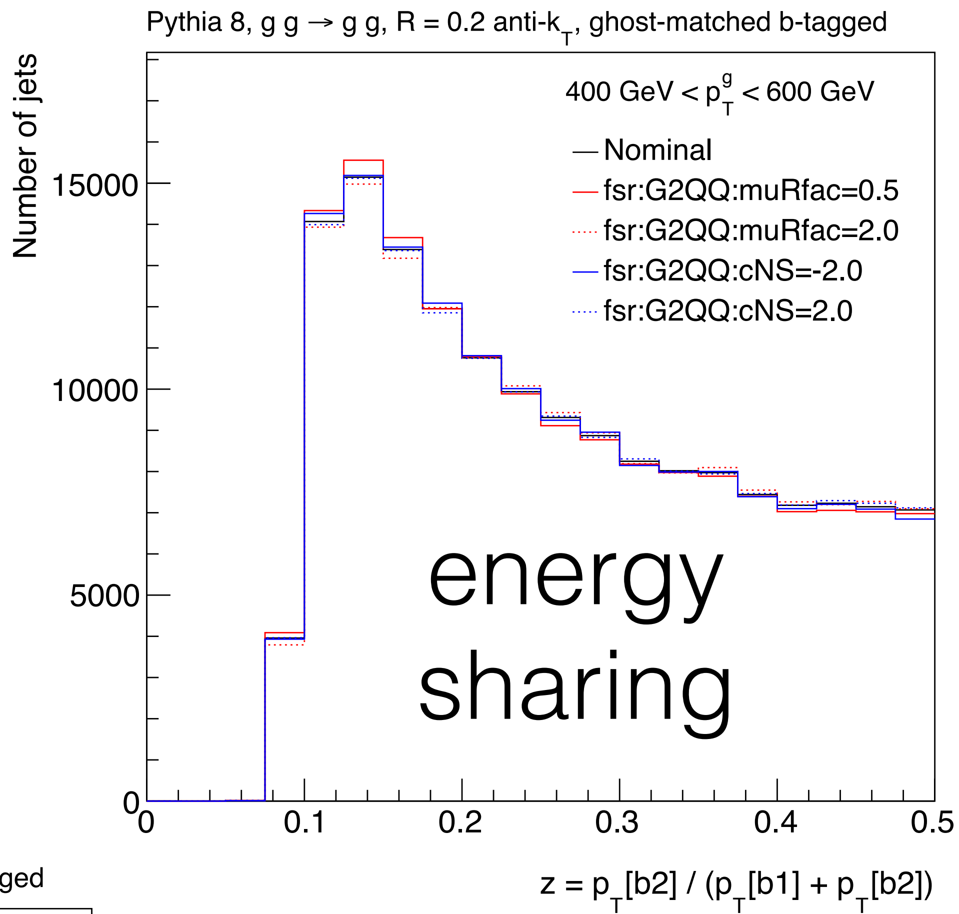


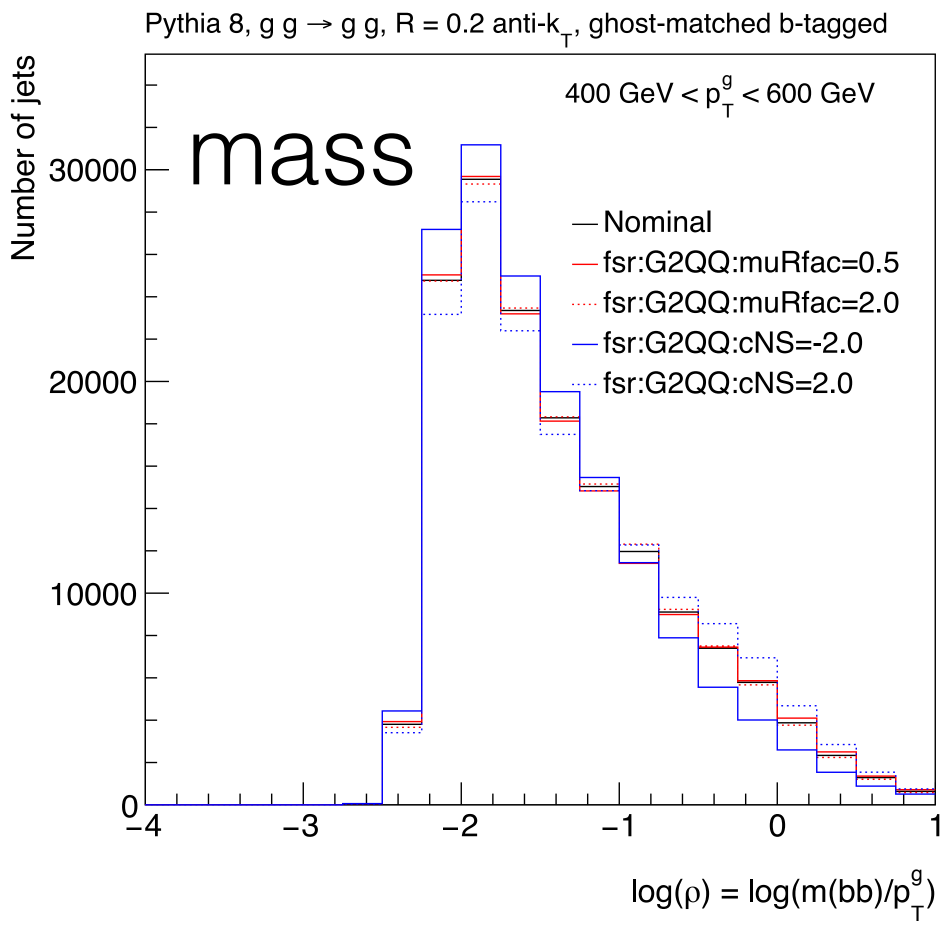
The singlet radiation pattern has been measured in W decays - should measure octet in g->bb!

We should measure all aspects of the g->bb production (angles + energies)

What else can and should we measure?



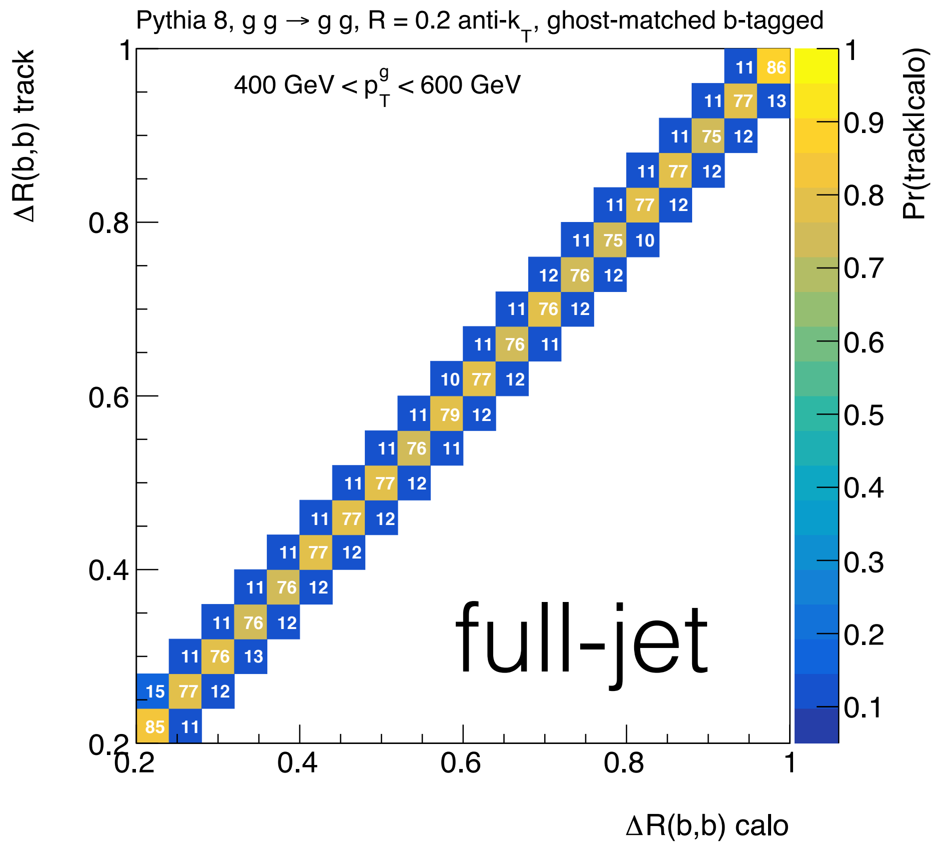




all the lines: tuning nobs in Pythia to see the sensitivity to the modeling of g->bb

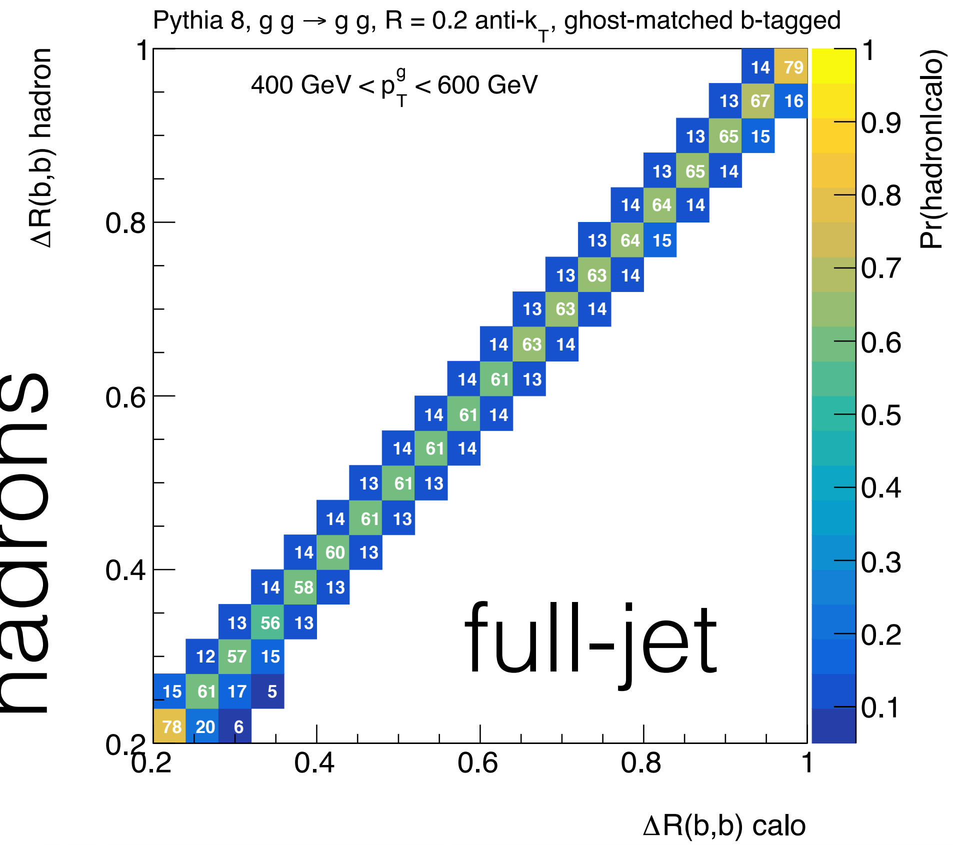
Caution: do we measure partons, hadrons, or (track) jets?

track-jet

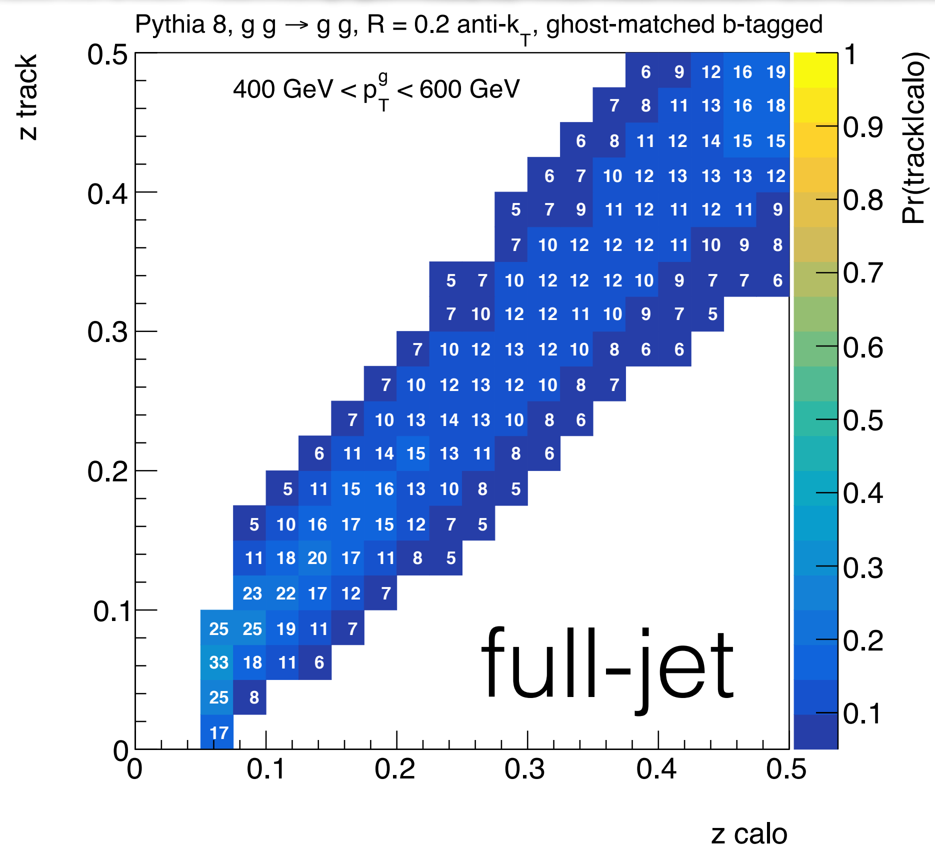


angular distance

hadrons

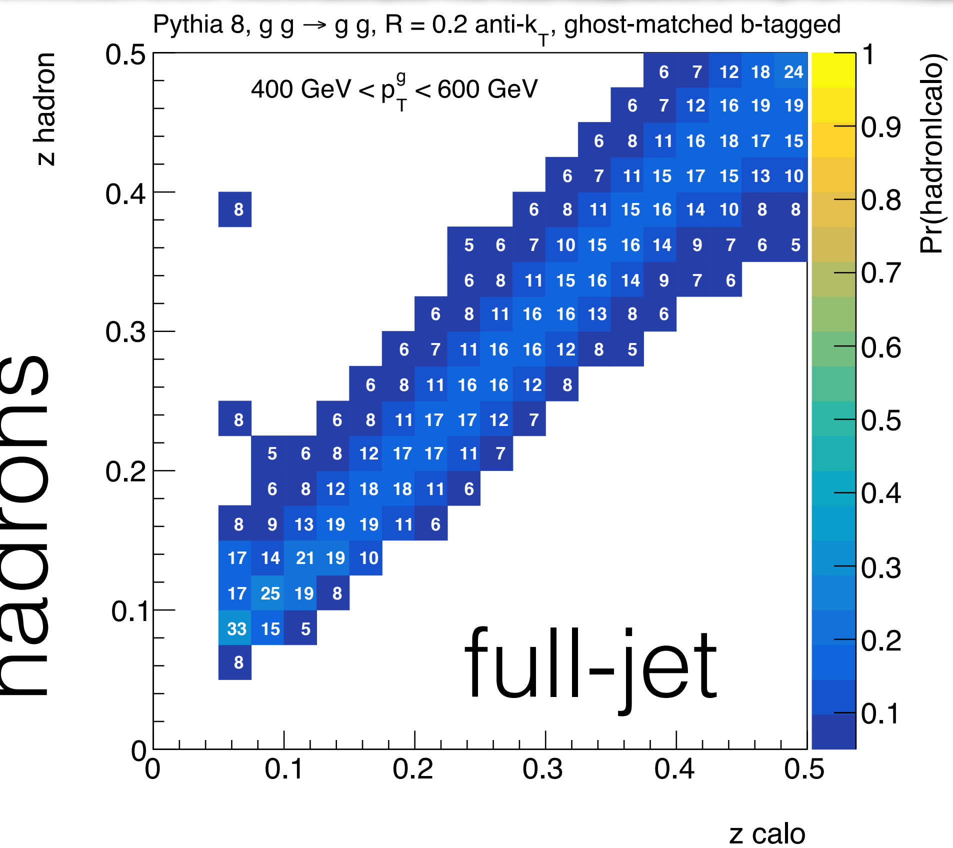


track-jet

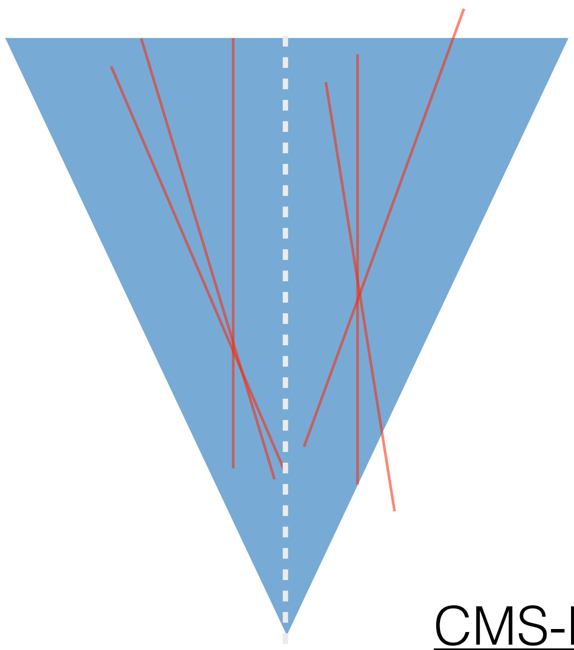


energy sharing

hadrons

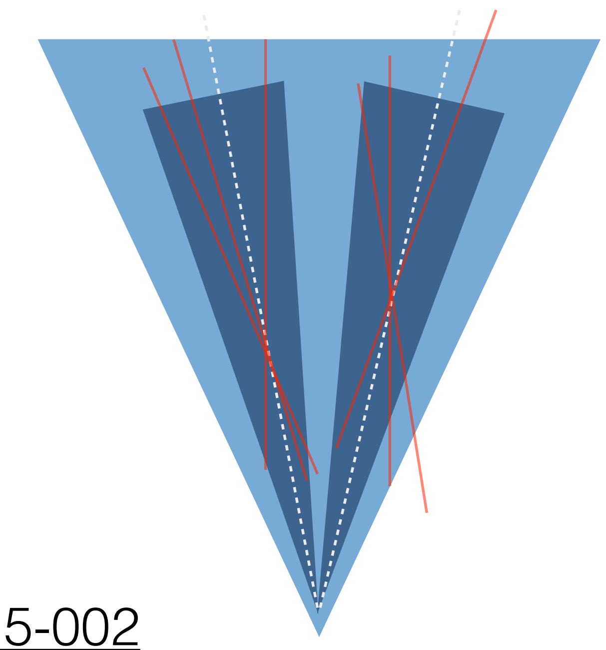


Since 7 TeV, there has been a lot of work to improve b-tagging inside jets and to measure the efficiency in data.

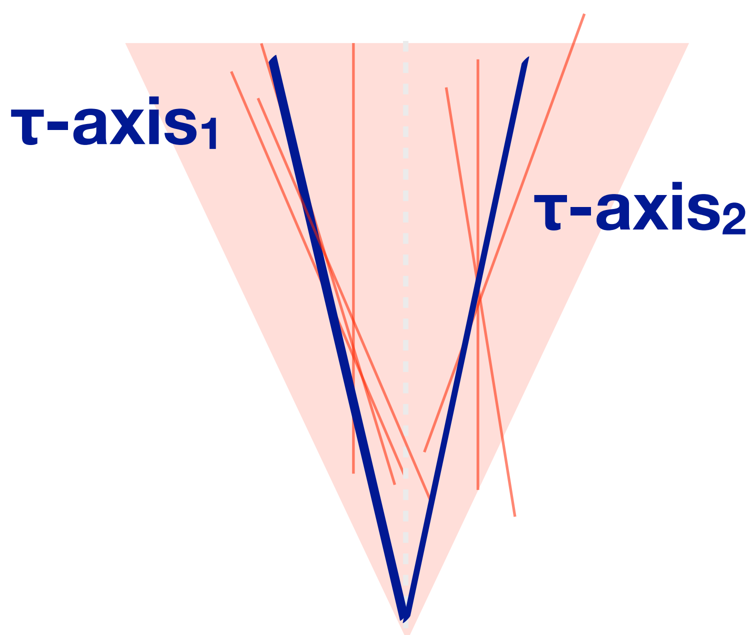


fatjet

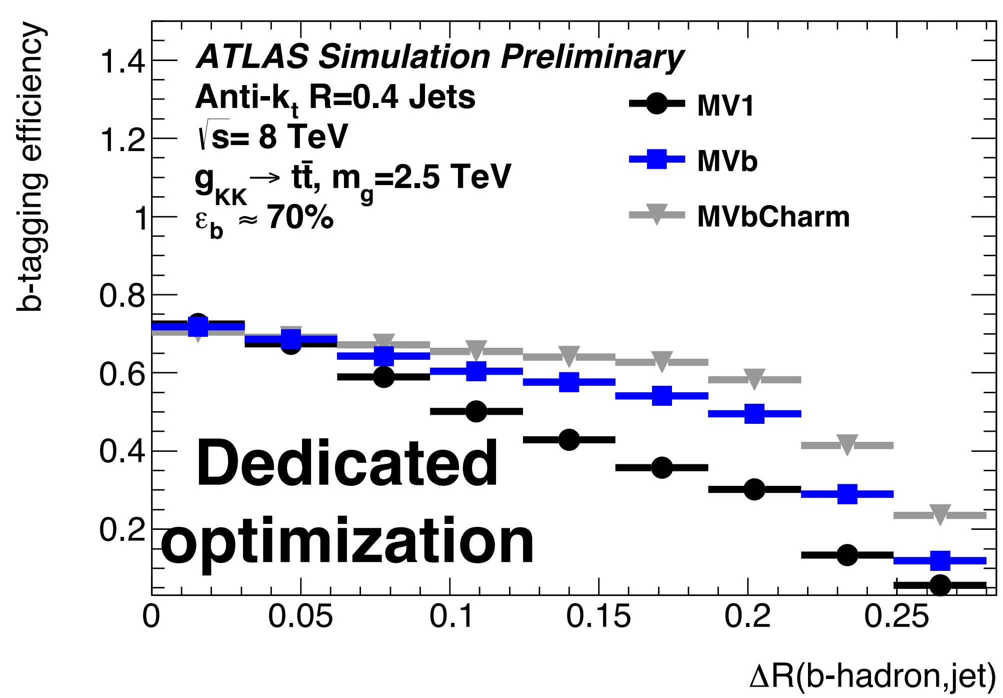
CMS-PAS-BTV-15-002



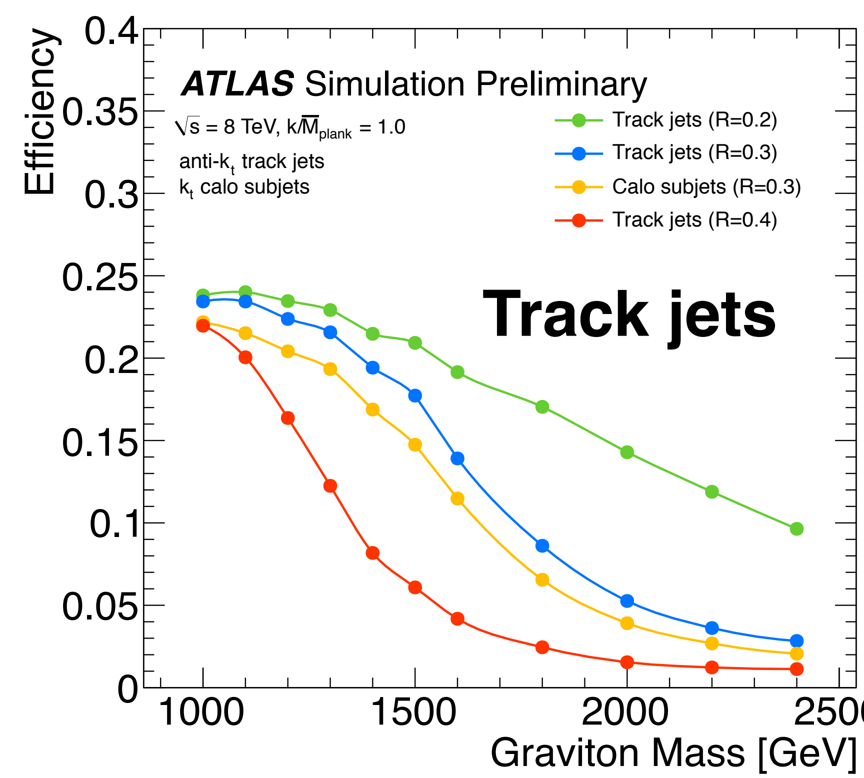
subjets



double-b

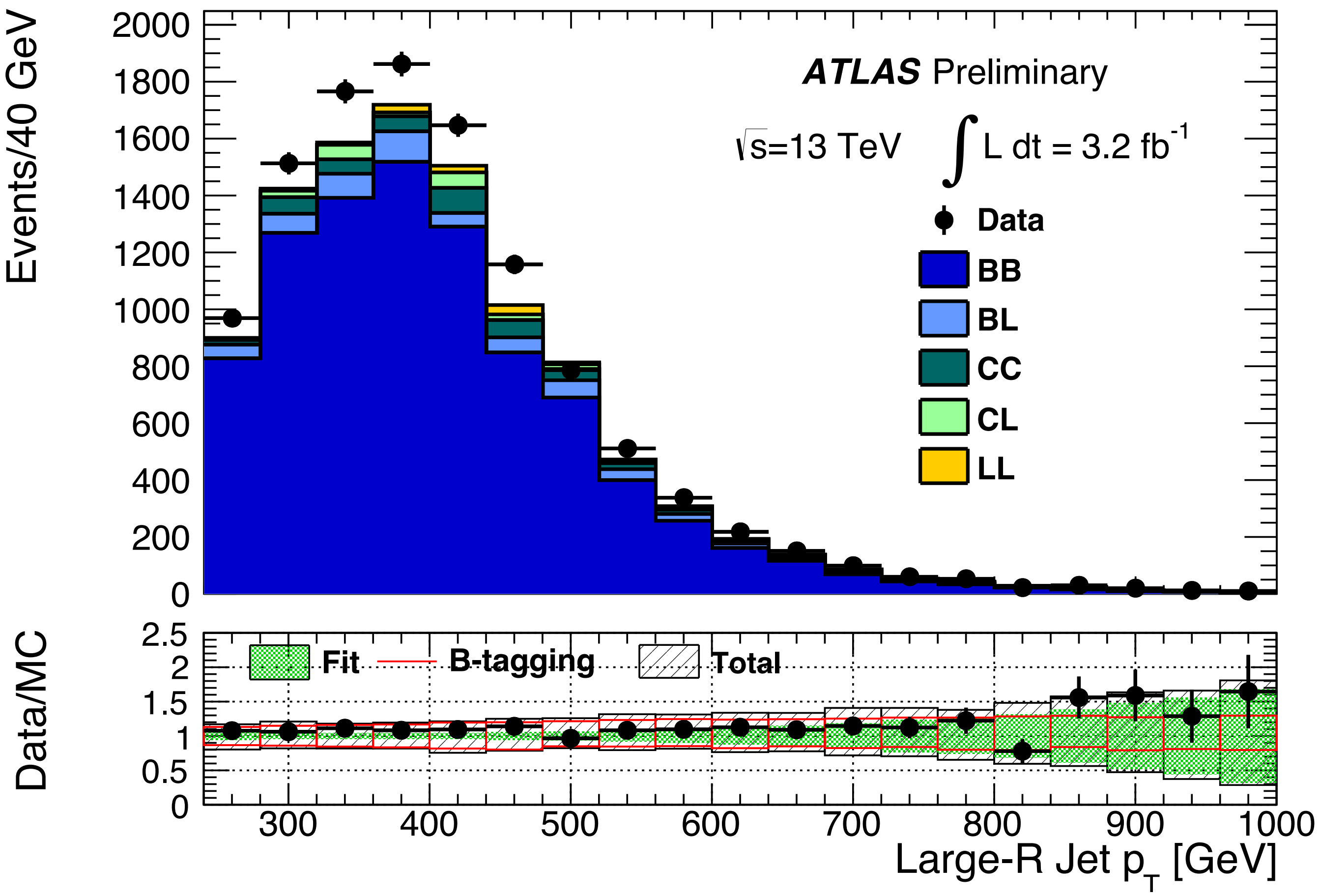


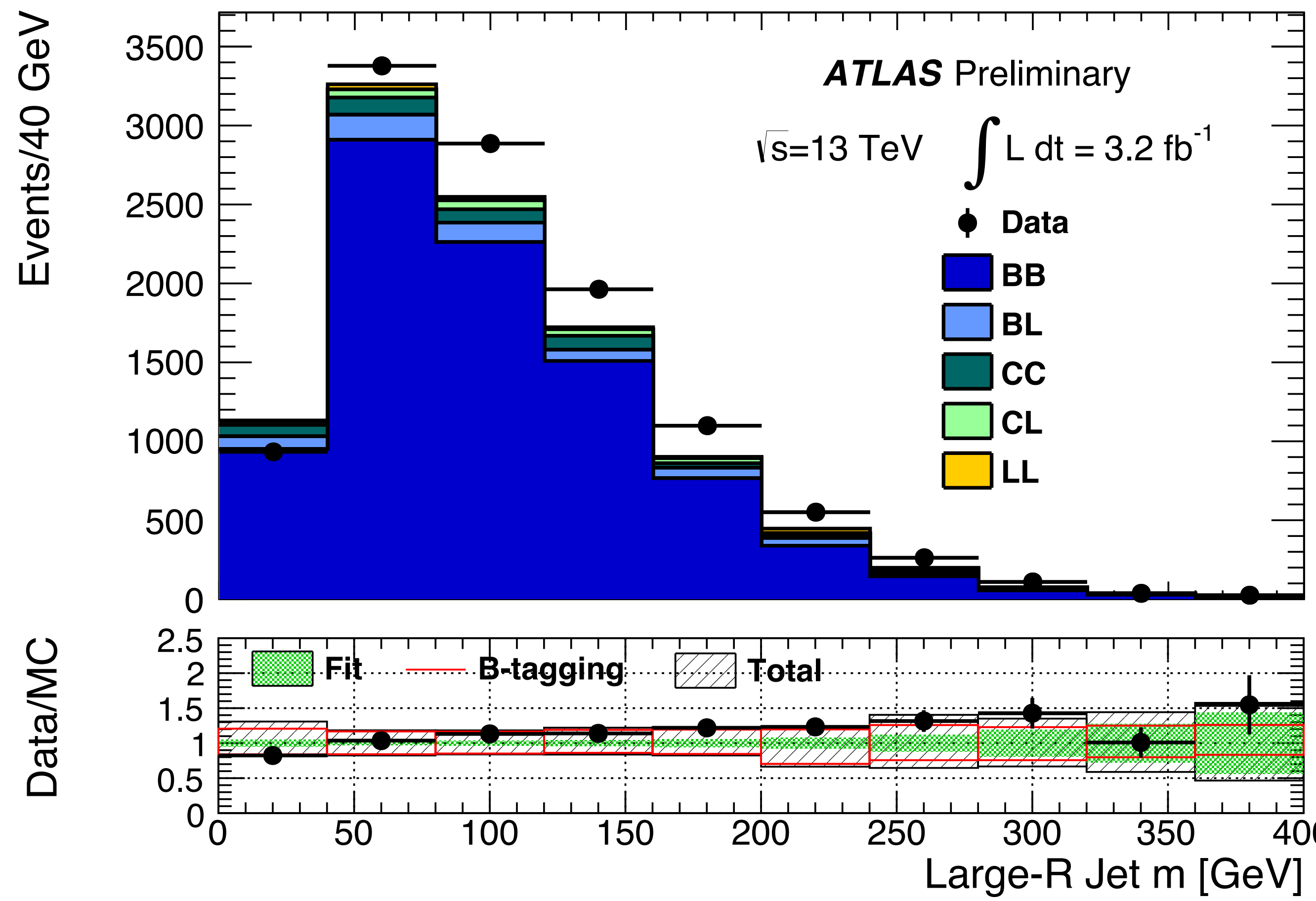
ATL-PHYS-PUB-2014-014



ATL-PHYS-PUB-2014-013

R = 0.2 anti-k_t track jets

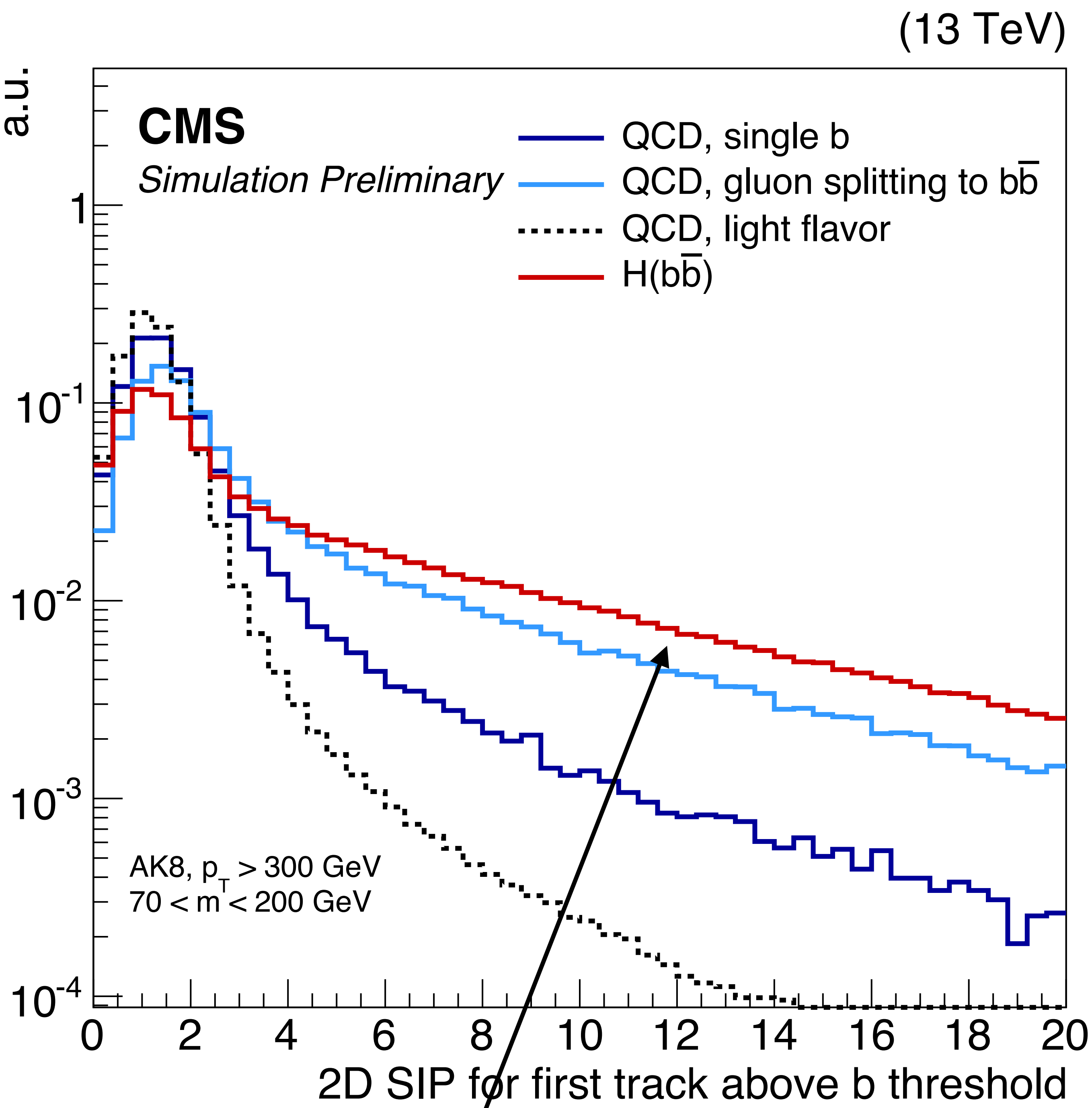


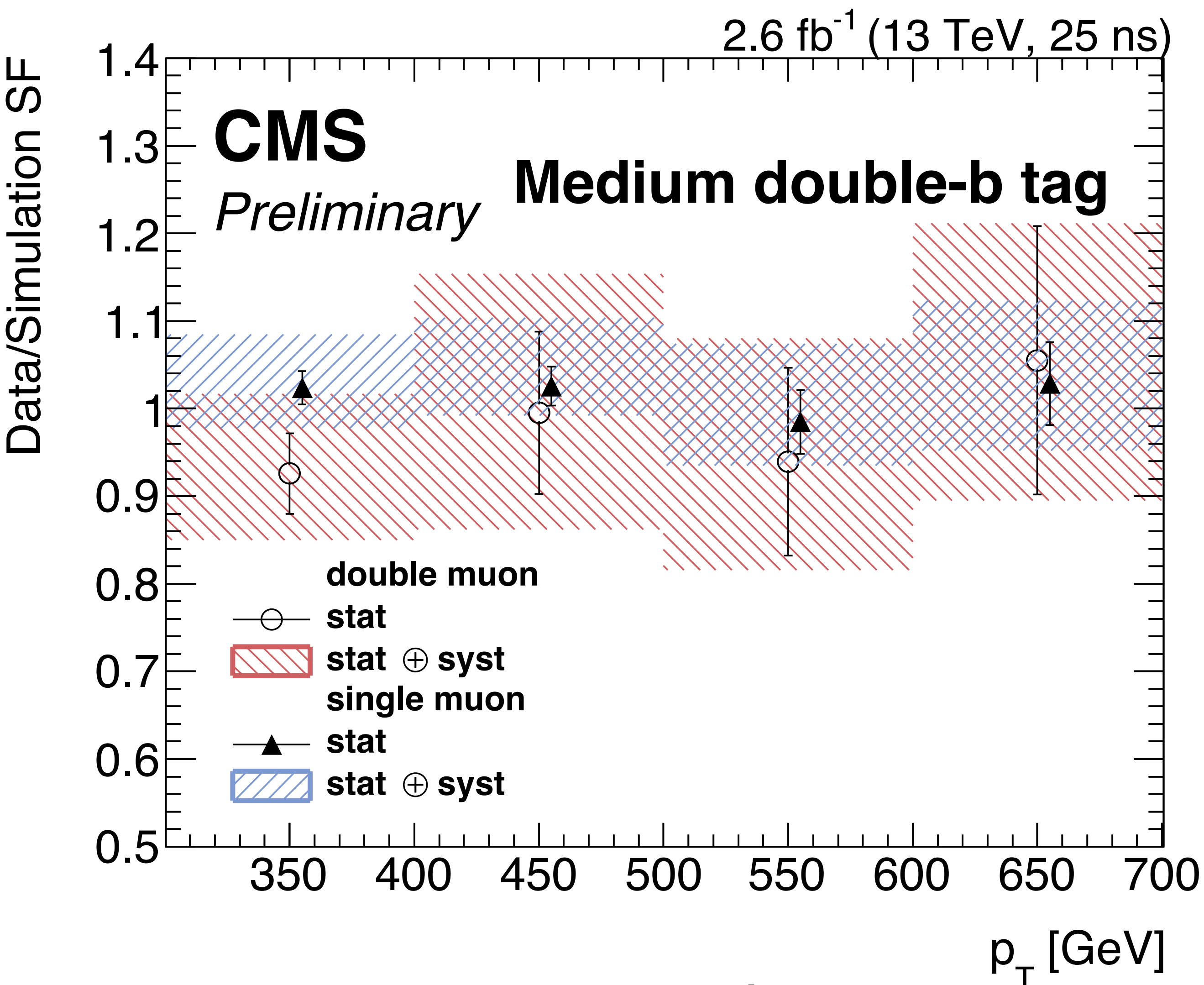


With the full Run 1 and Run 2 datasets, there are plenty of gluon jets for studying the modeling of double b-tagging

(in this case, use muons to increase purity)

>> 7 TeV double b-tagger >> 8 TeV analysis



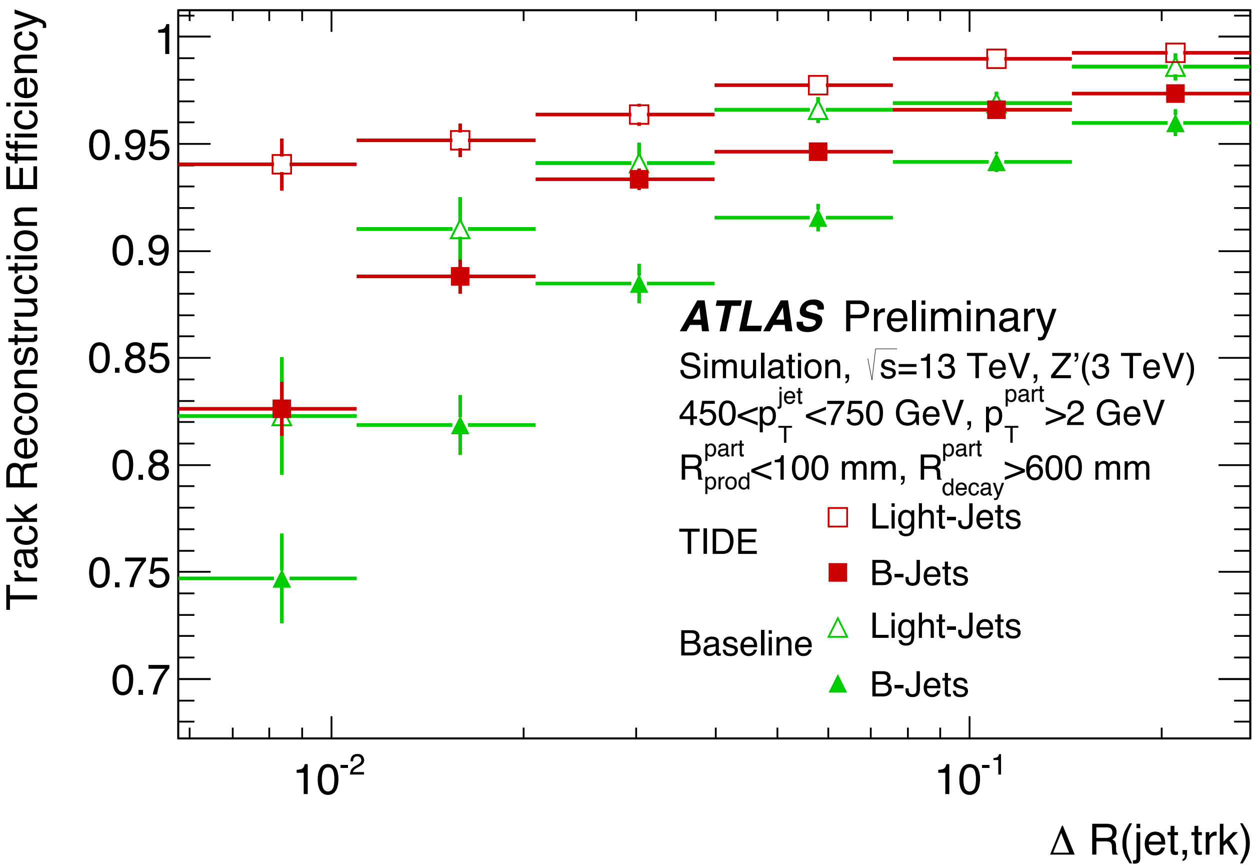


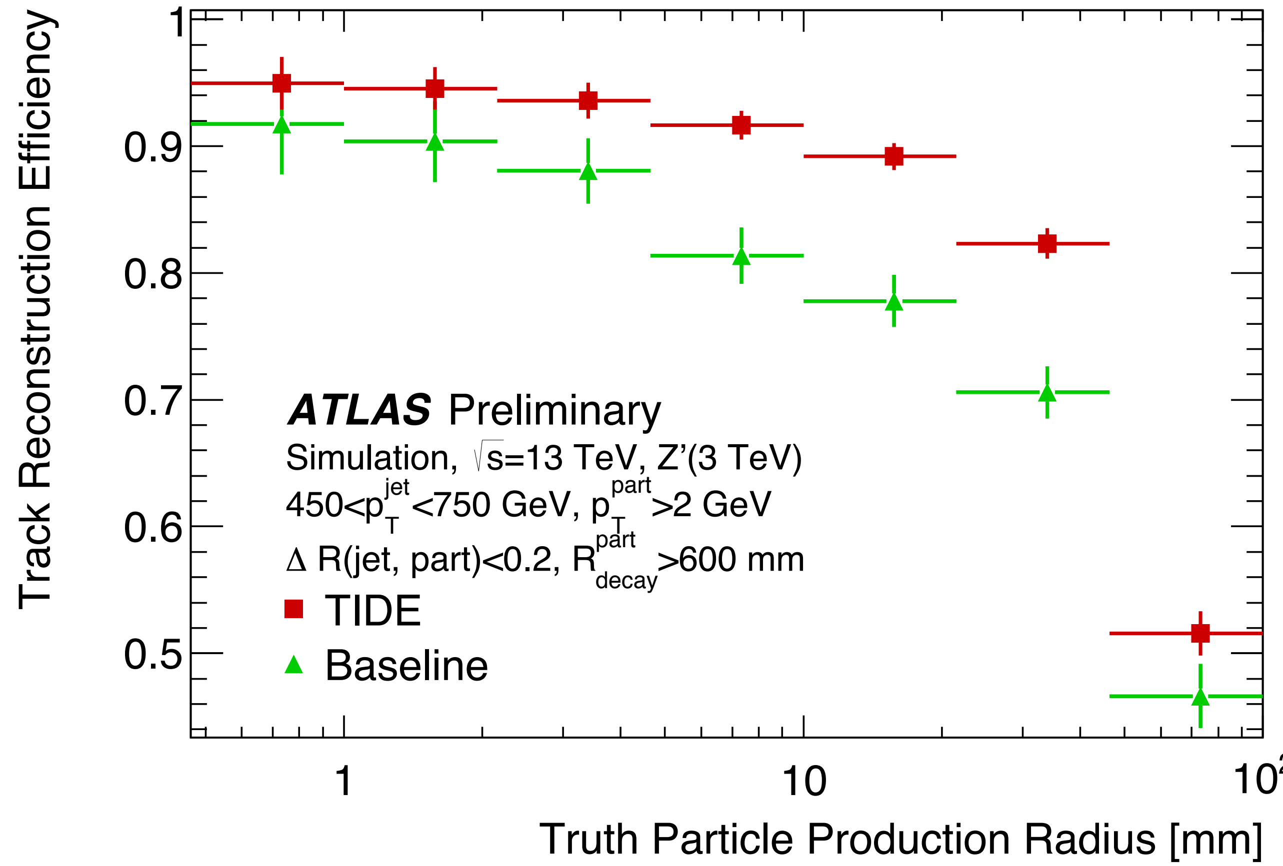
~10% uncertainty; stats limited

Higgs and g->bb are very similar!

>> 8 TeV analysis

Note: in order to maintain b-tagging performance, it is critical to have dedicate methods for tracking inside jets





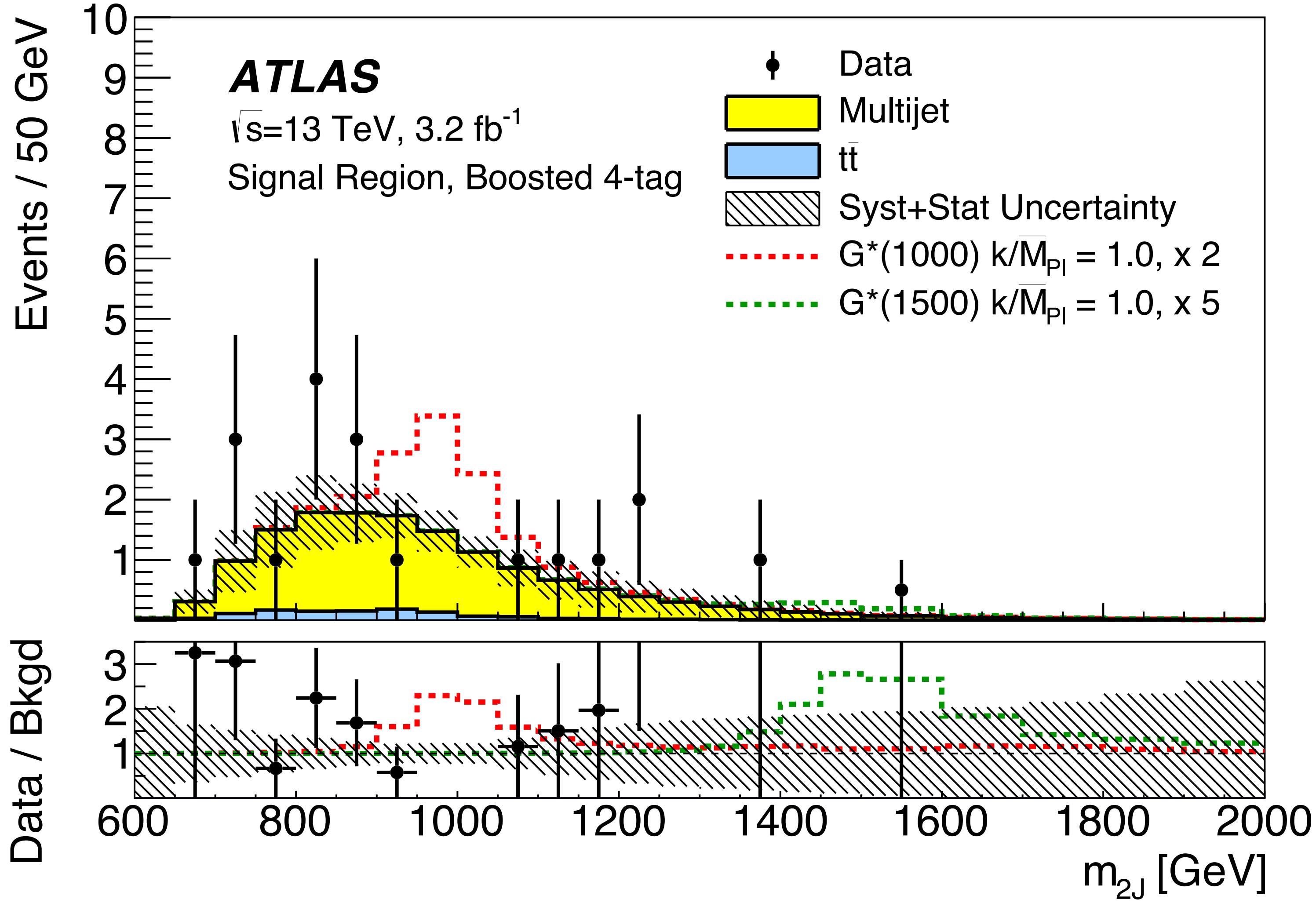
Algorithmic improvements are (much) cheaper than hardware ones - it is important to optimize performance when designing a new detector!

>> Similar studies in CMS

The Run 2 efforts are motivated by (boosted) Higgs tagging.

For many of these searches, g->bb is the main background.

Data-driven techniques are used because the MC is not reliable (still needed to check closure)



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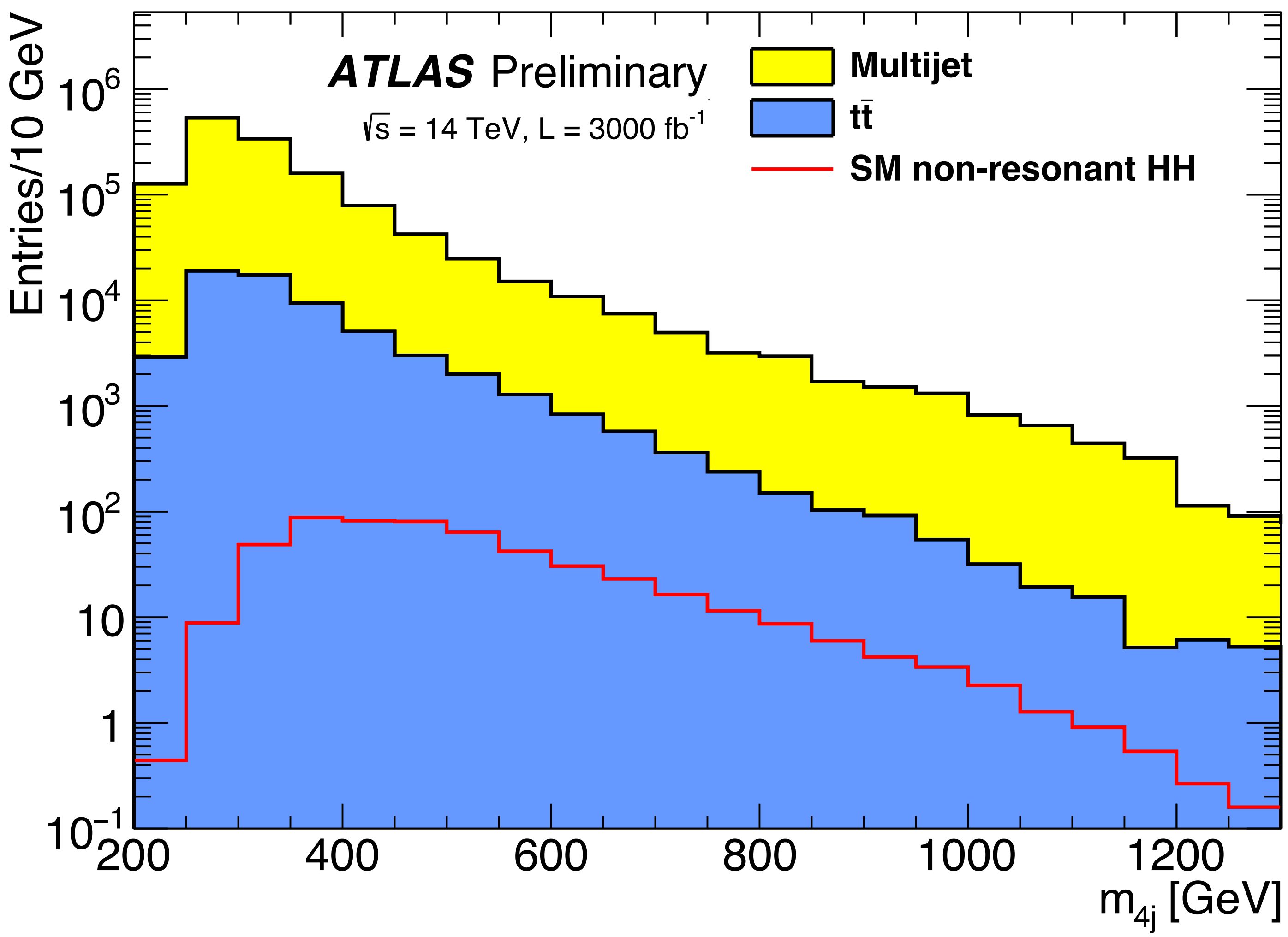
Is this something that could change in the next 10 years?

>> Similar CMS result



For example, one of the most challenging and important measurements is the Higgs self-coupling.

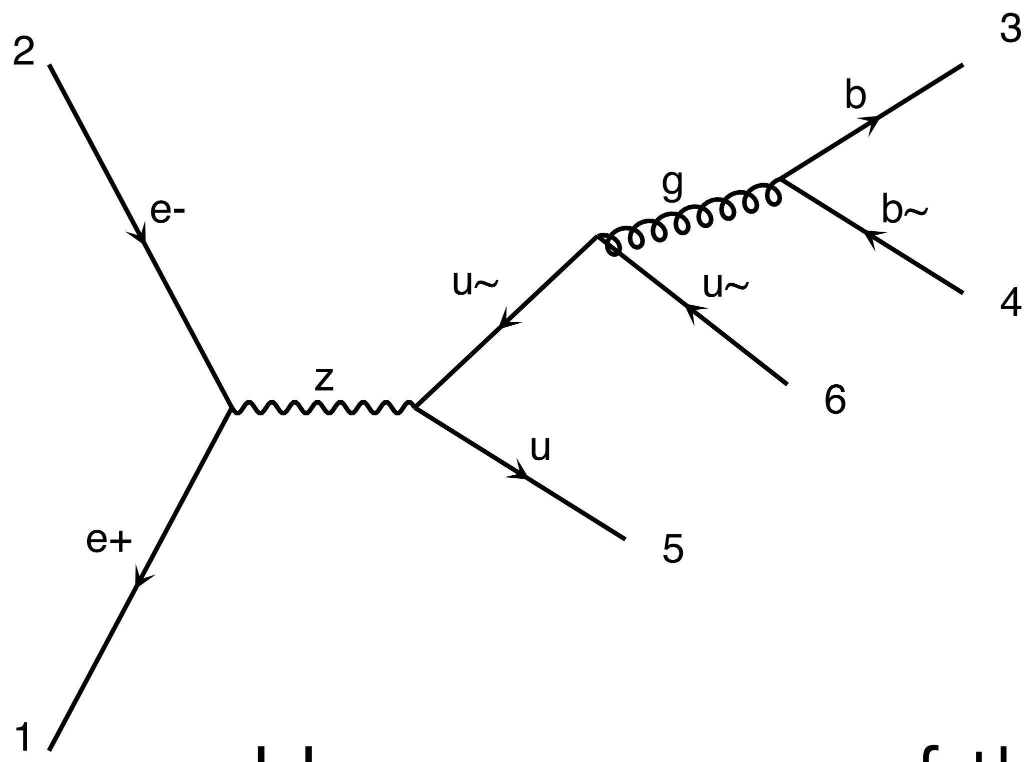
Source	$\Delta\mu$
Luminosity	0.05
Jet Energy	0.09
b-tagging	0.34
Theoretical	0.10
Multijet	1.85
$t\bar{t}$	2.83

The g->bb background is complicated, but maybe a better understanding could be a game-changer here!

>> CMS HH projections

At a lepton collider, we would have an experimentally and theoretically clean environment for studying g->bb

>> no pileup, UE, MPI, etc. <<



LEP measurements limited to inclusive rates of g->bb

can probe pQCD to high precision by measuring properties of the splitting

However, one of the most exciting prospects of FCC-ee is to perform a series of comparative measurements of g->bb, Z->bb, and H->bb

also, critical input for the Higgs at FCC-hh!

Conclusions

Double b-tagging is a very active area of R&D at the LHC

>> Significant gains from low-level tracking and b-tagging optimization

>> Data-driven calibrations and uncertainties using g->bb

>> QCD measurements using these techniques are, as expected, lagging the searches

FCC-ee offers an exciting opportunity for novel measurements

>> In addition to measuring g->bb to unprecedented precision, we can compare g->bb (**vector octet**), Z->bb (**vector singlet**), and H->bb (**scalar singlet**)!