Gluon splitting with small opening angles at ATLAS

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on behalf of the ATLAS Collaboration

ATLAS EXPERIMENT

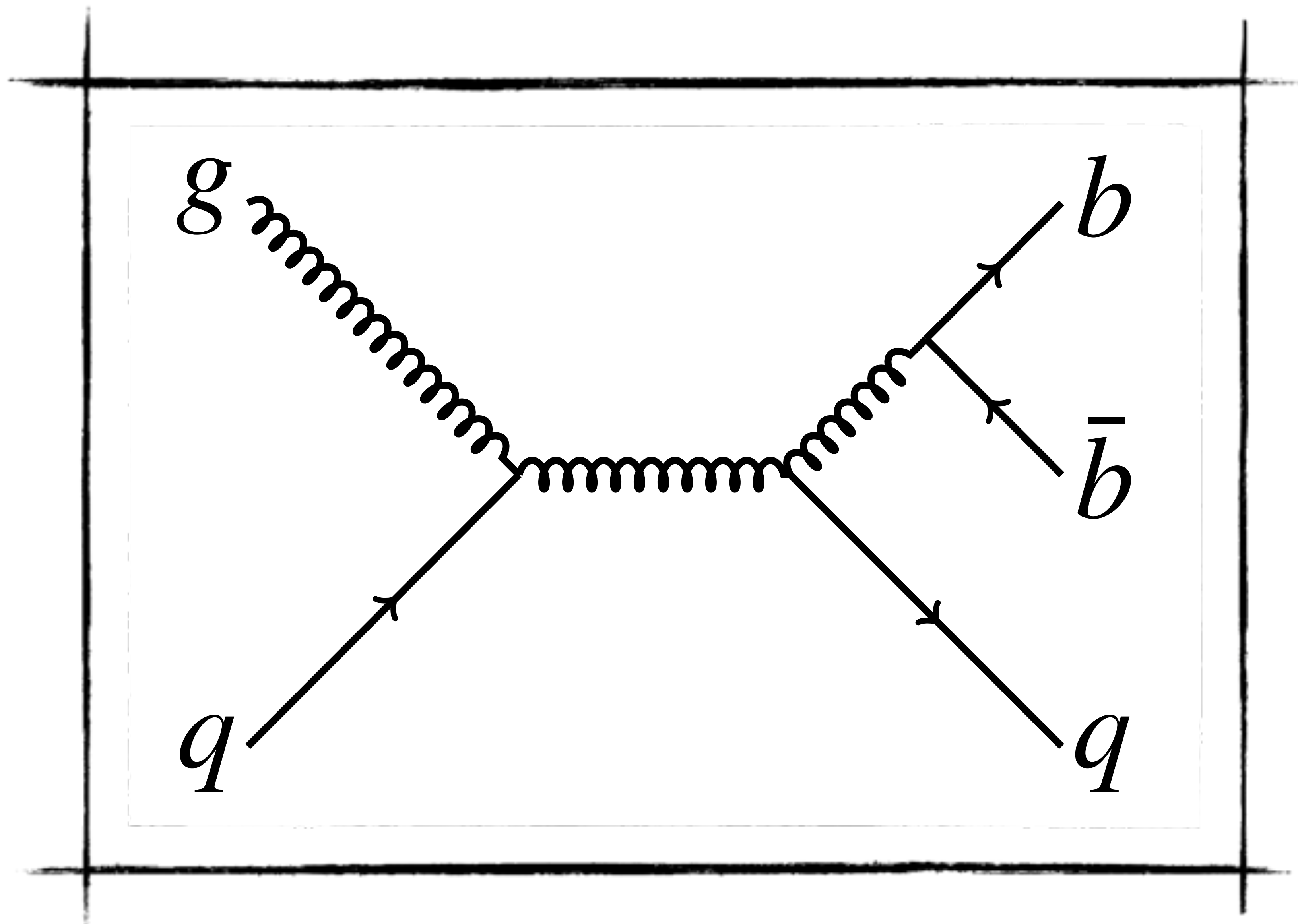
BERKELEY LAB

BERKELEY EXPERIMENTAL PARTICLE PHYSICS

CMS Flavor tagging workshop, May 2019

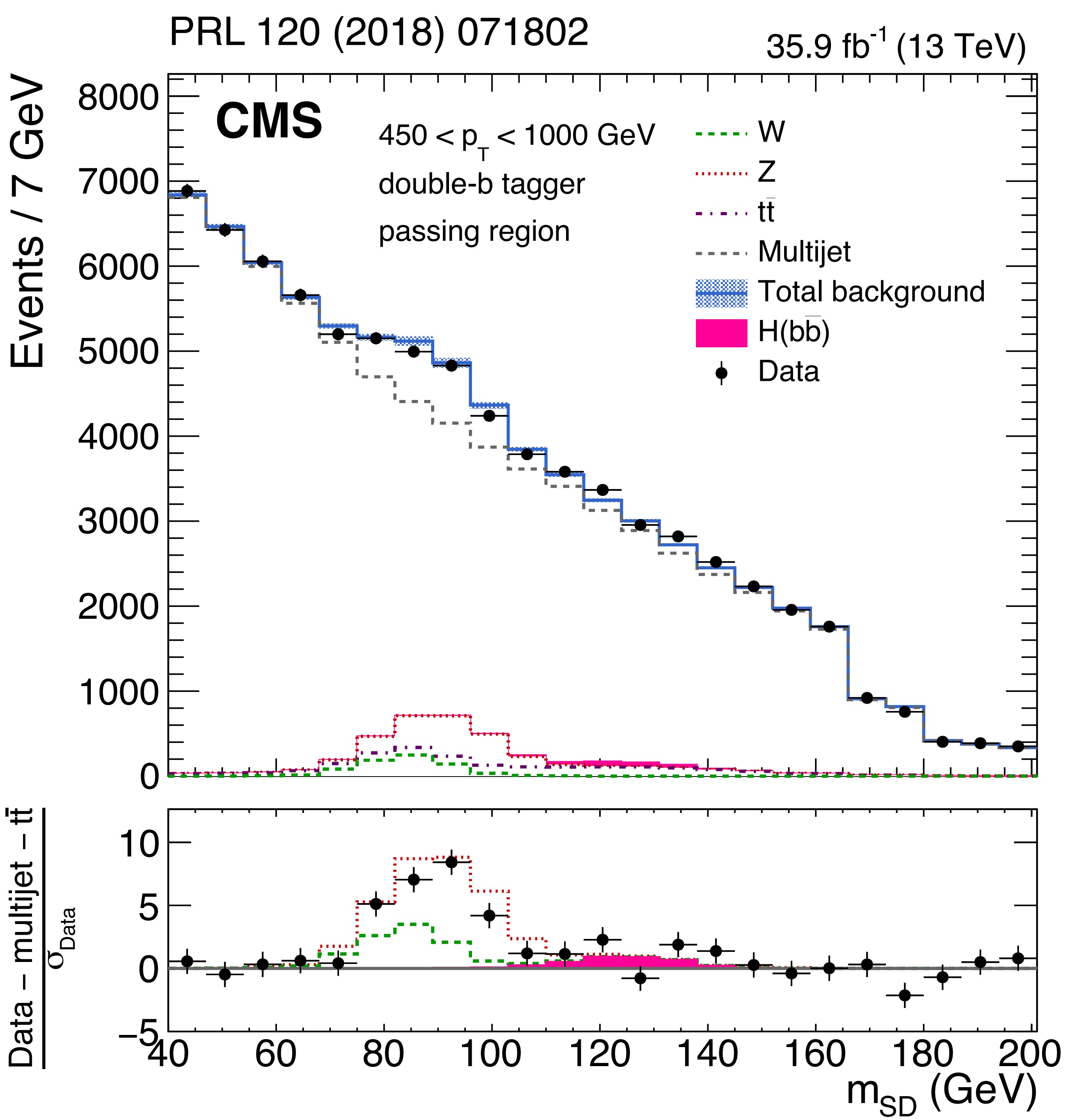
Outline

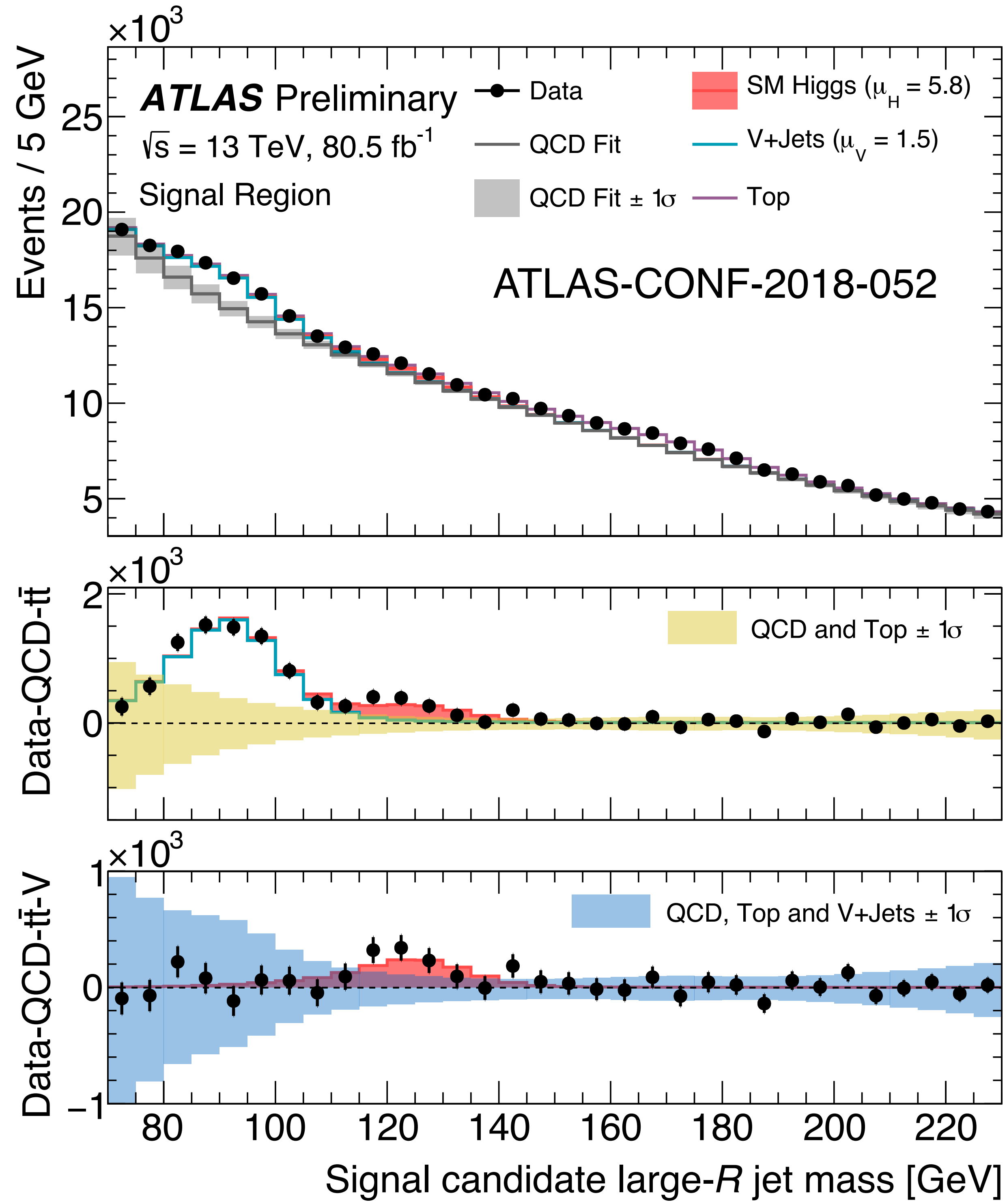
- Motivation
- Observables
- Background estimation
- Systematic uncertainties
- Results
- Conclusions & outlook



Motivation I *as an important background*

Search for boosted H → bb





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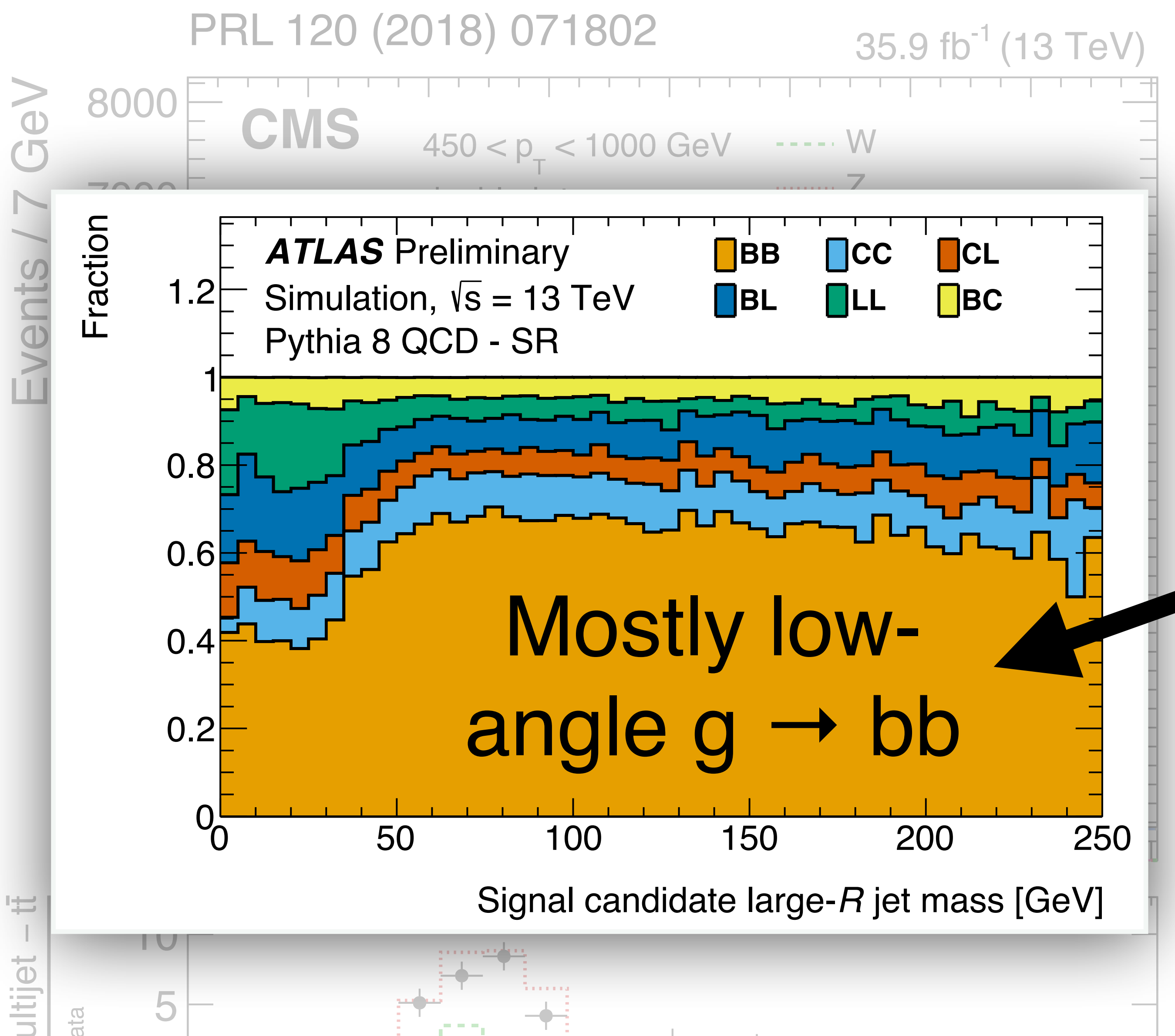
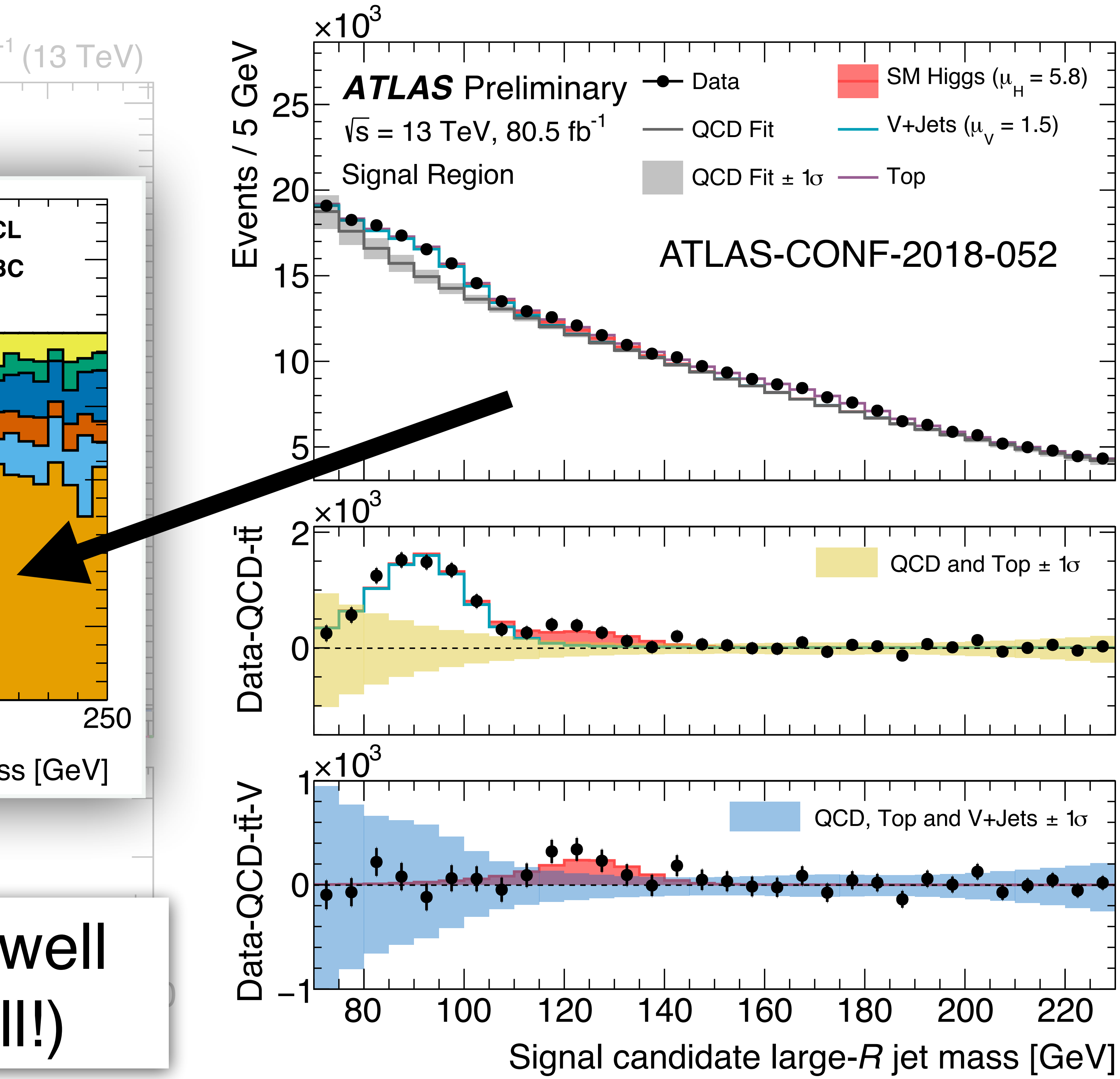
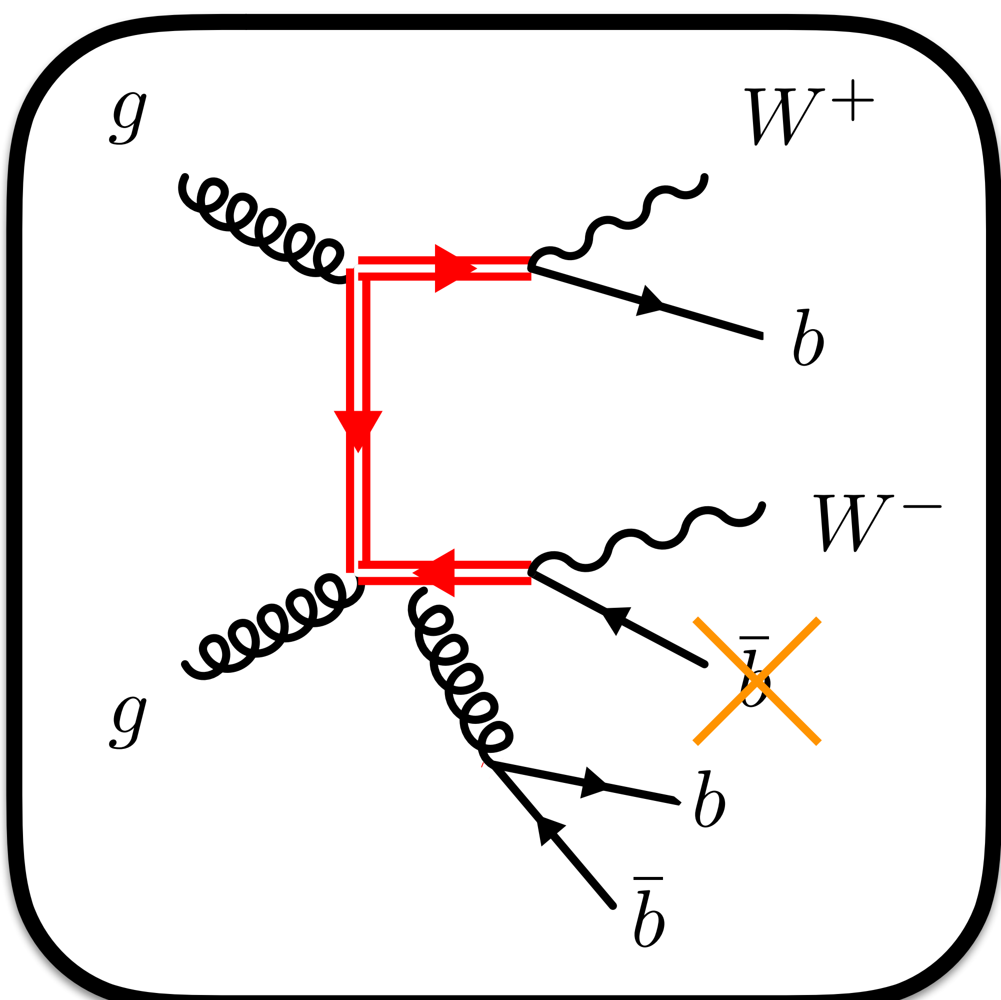




(currently not understood well enough to be used ~at all!)

Motivation I *as an important background*

Many top quark physics analyses and top-like searches where extra b's from gluon splitting are a nuisance.



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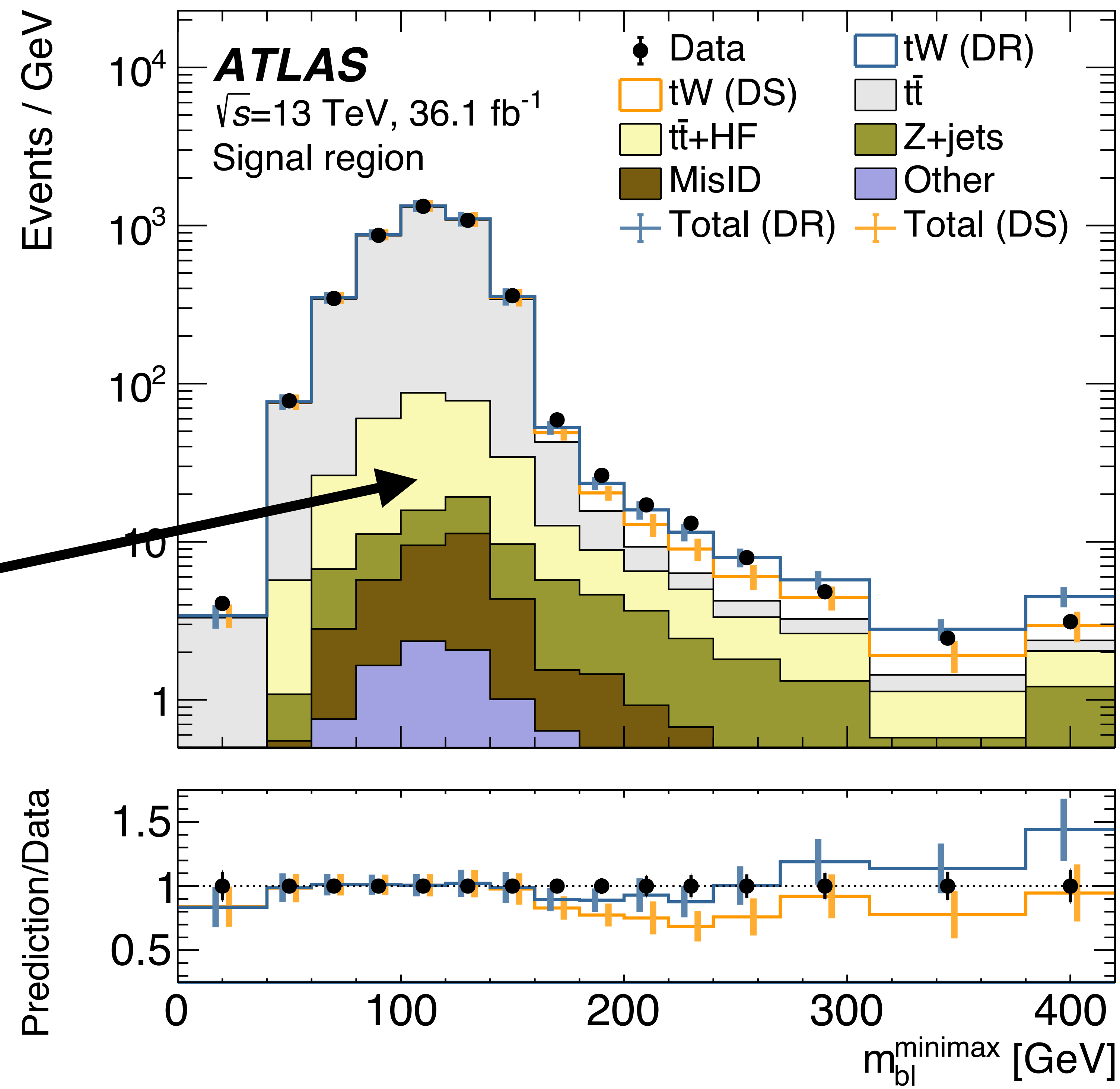
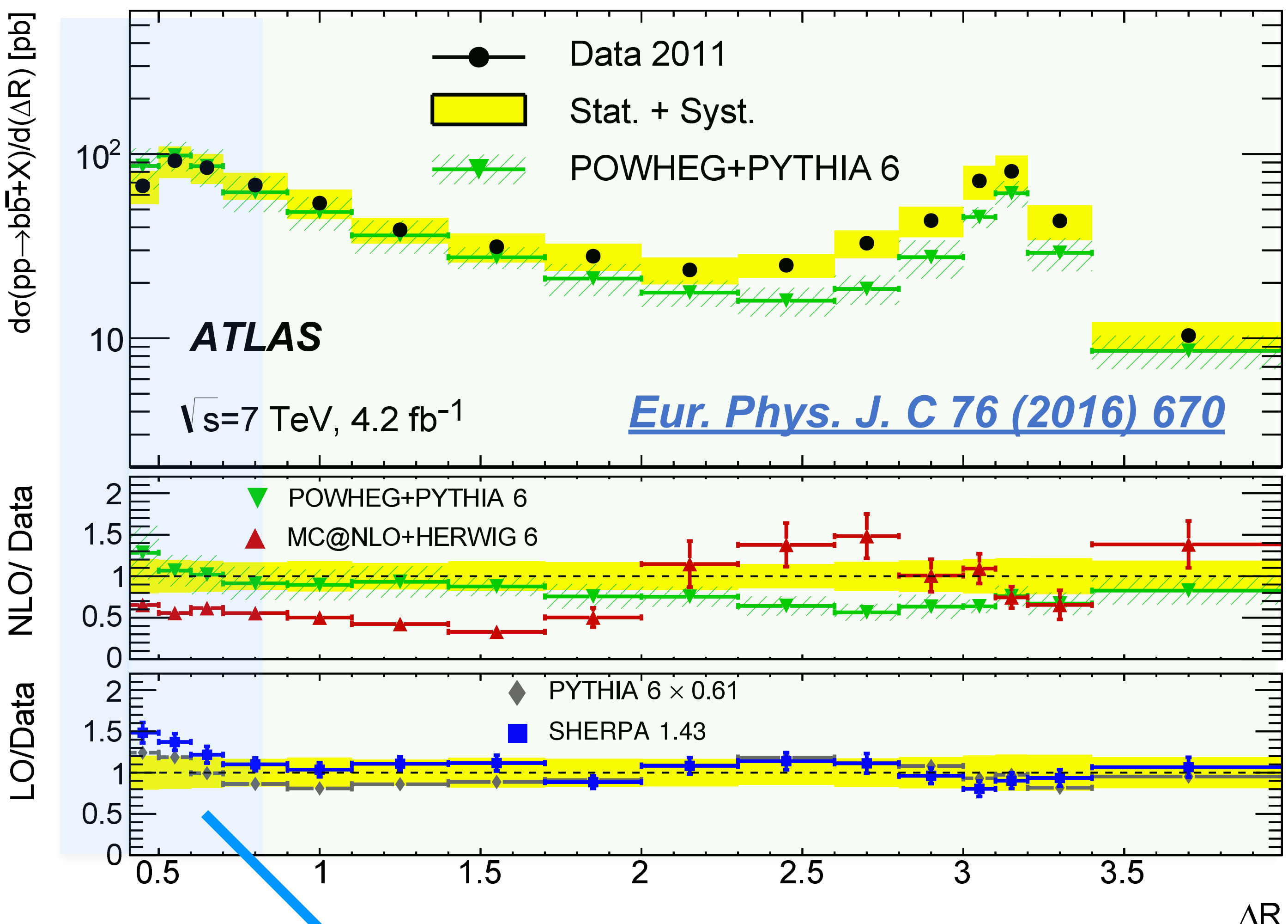
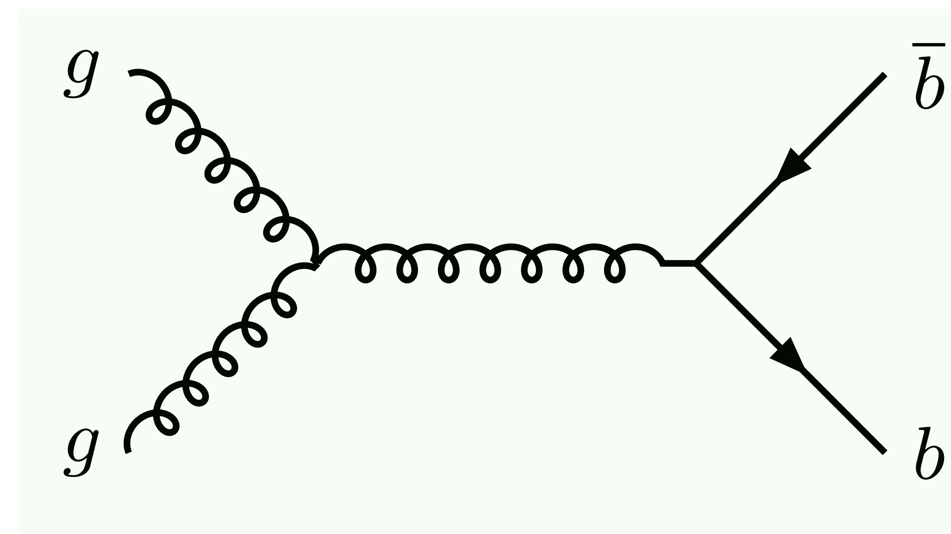


Motivation II *as an interesting QCD probe*

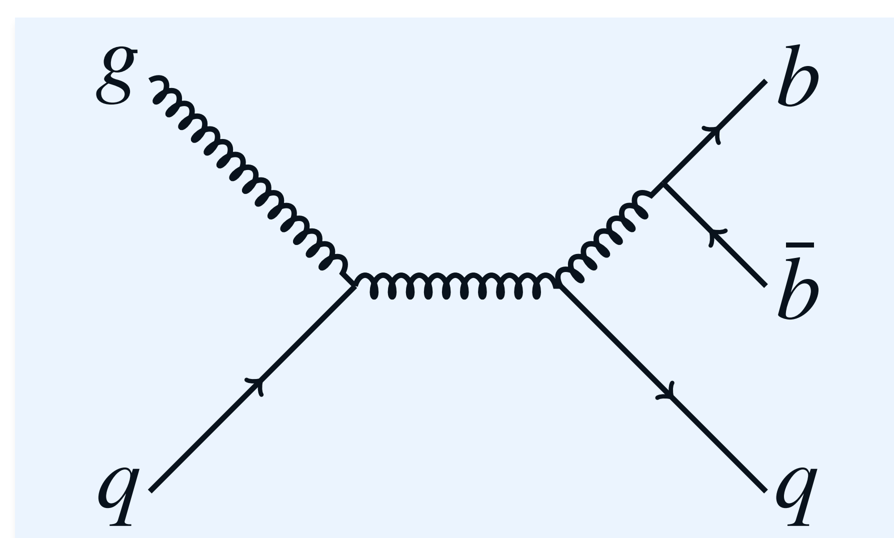


ATLAS and CMS have measured di-bjet cross-sections, but the small-angle region is largely ~unprobed (even by e.g. LEP)



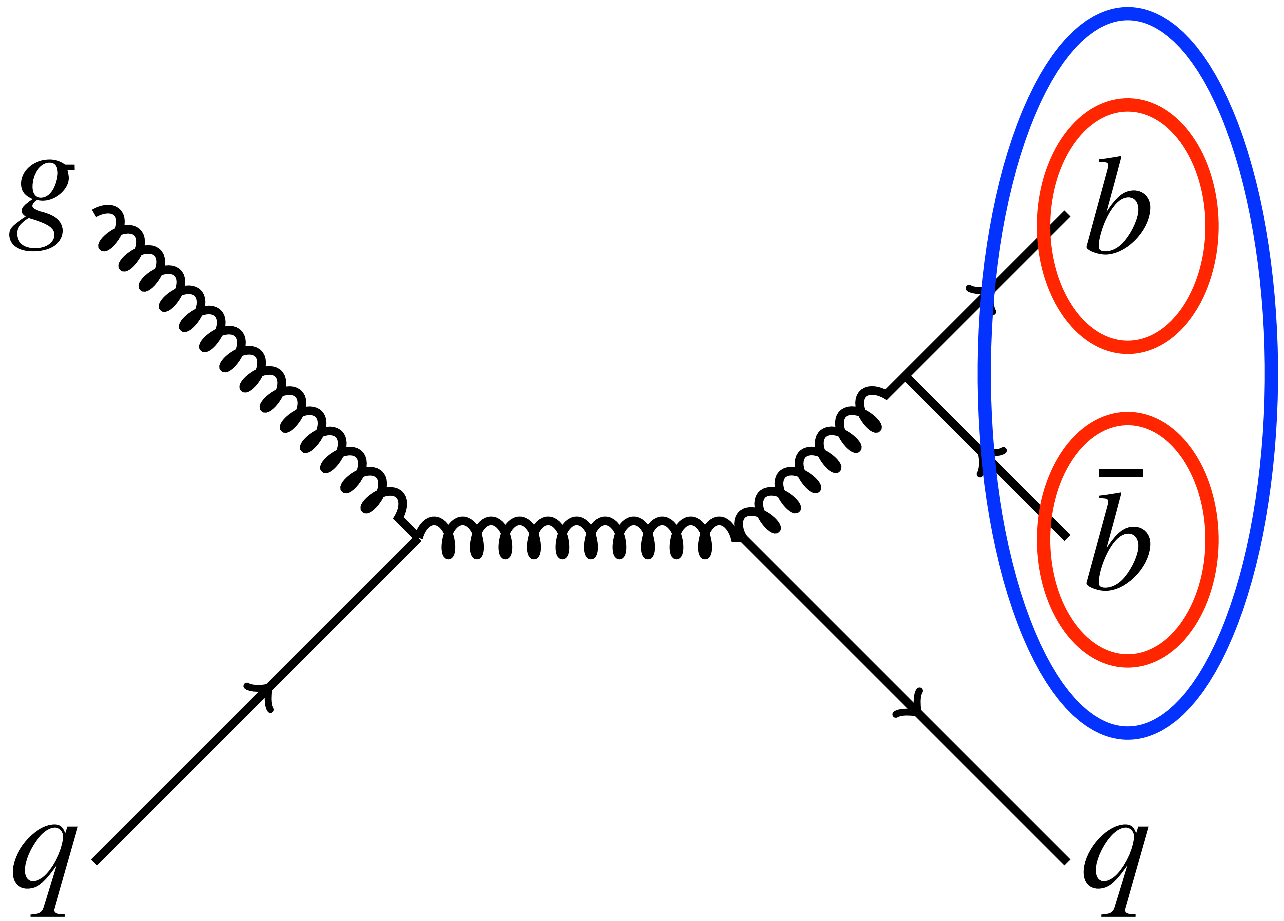
This measurement

… gives us a direct probe of massive QCD splitting function.



Measurement specs - phase space

Measure (unfold) kinematic properties of jets, acting as proxies for the quarks and gluons.



anti-k_t R = 1.0 trimmed jets as proxy for gluon

p_T > 450 GeV (trigger)

anti-k_t R = 0.2 track jets as proxies for the b-quarks

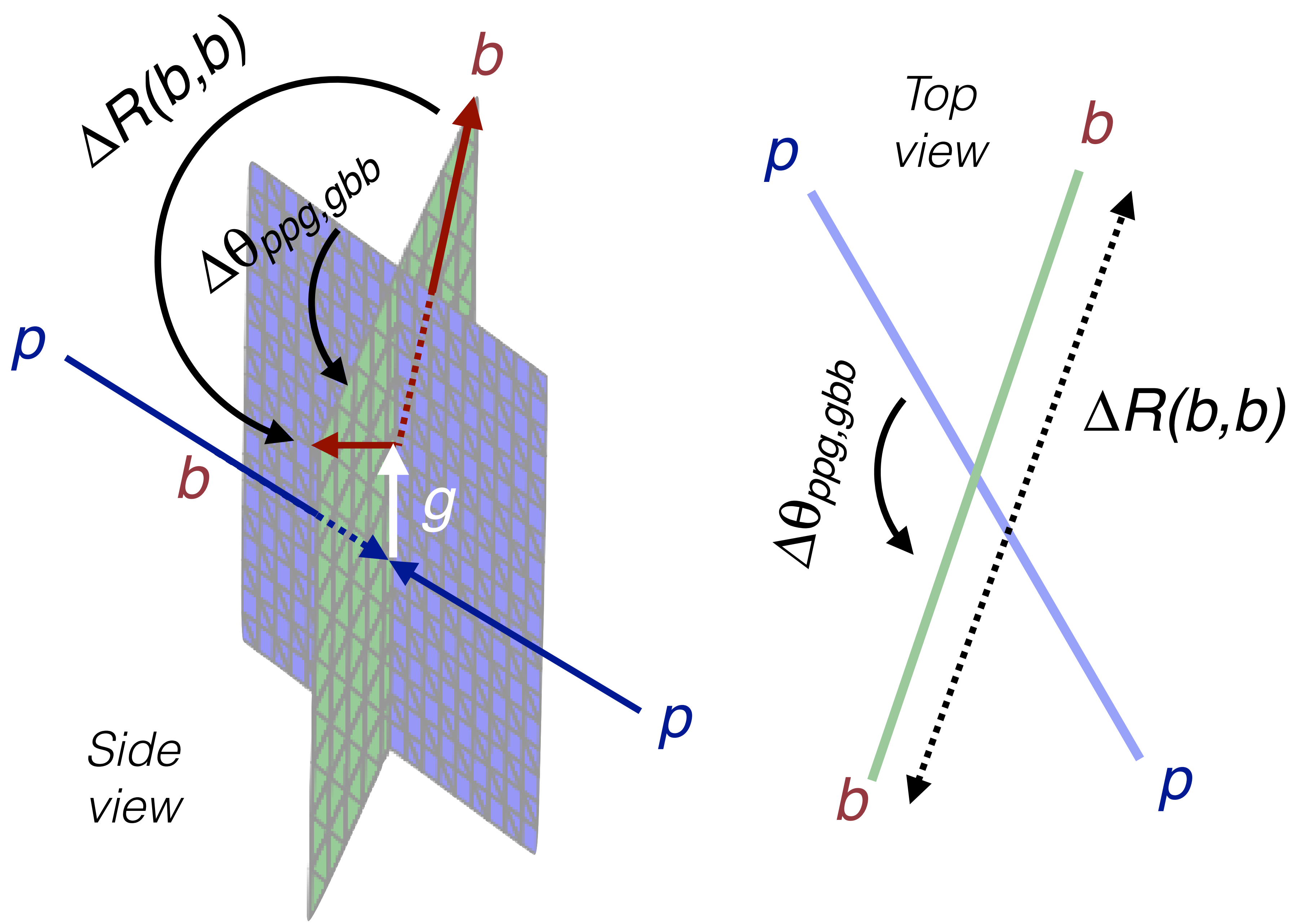
p_T > 10 GeV

MV2c10 ~ O(1000) rejection

b-tag (60% efficiency) one of the track jets (increase stats relative to double tag) & in situ extraction of flavor fractions

Measurement specs - observables

Usual suspects: $\Delta R(b,b)$, $\rho = m/p_T$, $z(p_T) = p_{T,1} / (p_{T,1}+p_{T,2})$



+ $\Delta\phi$(ppg,gbb) to probe the gluon polarization

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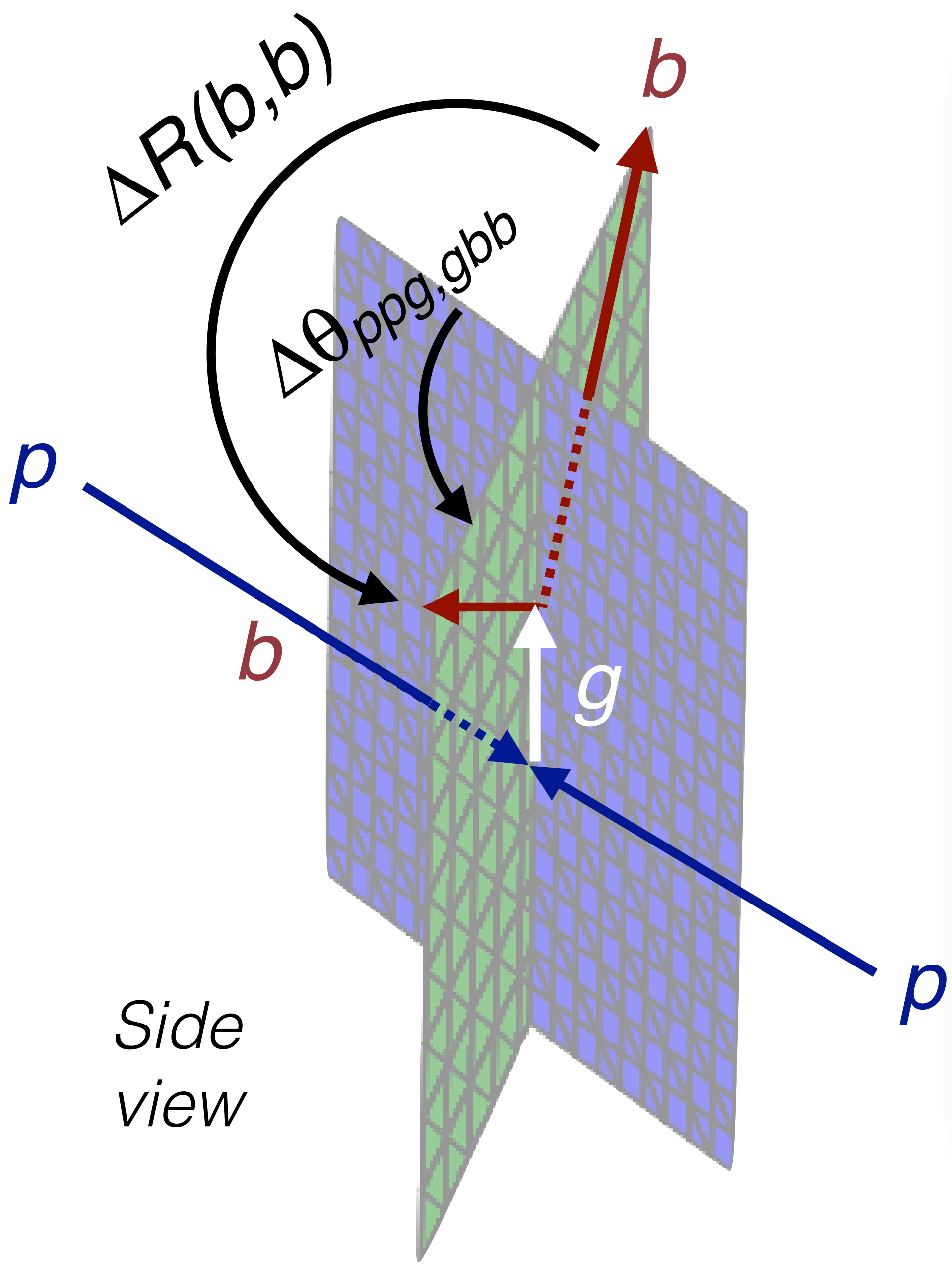

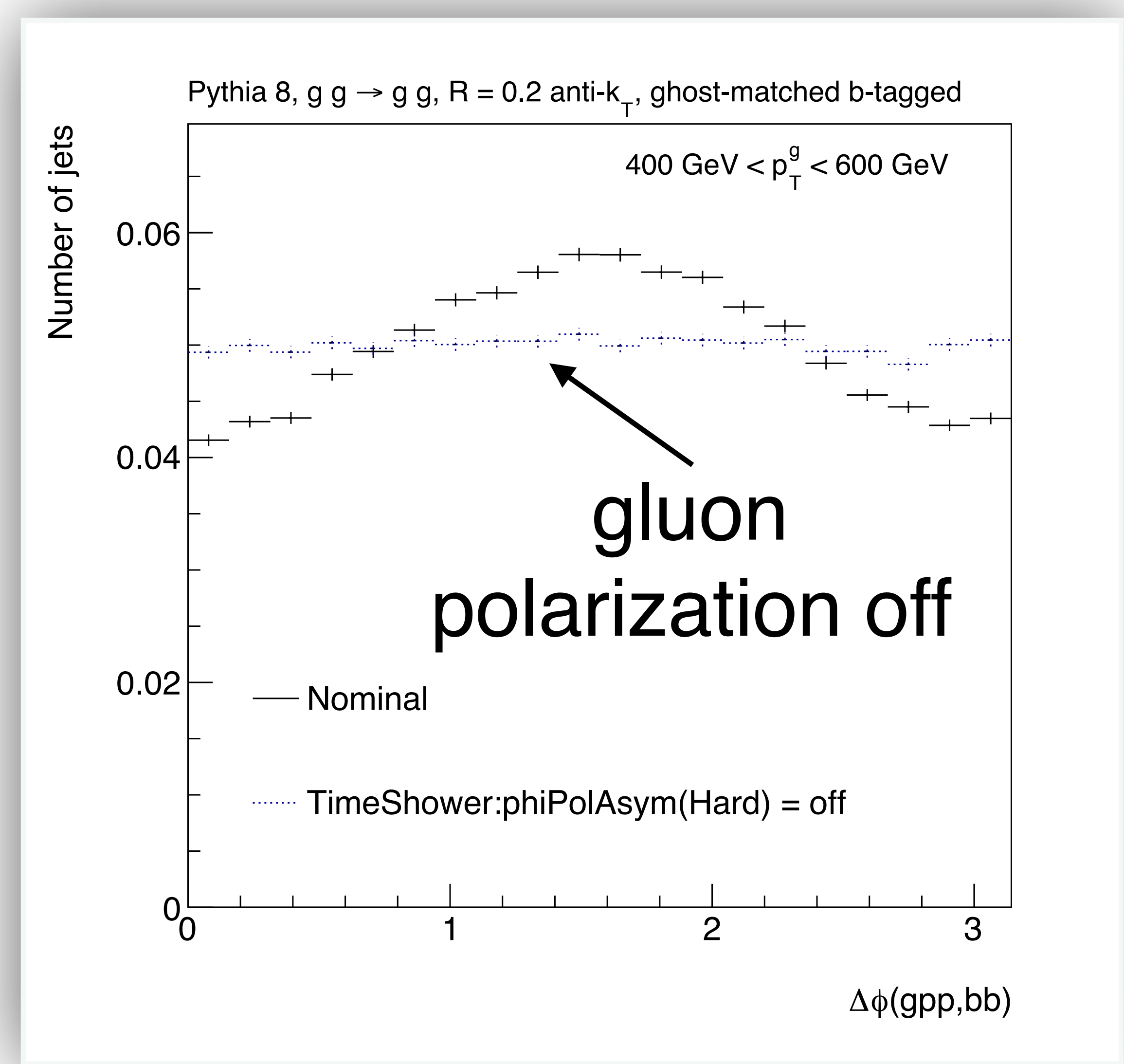

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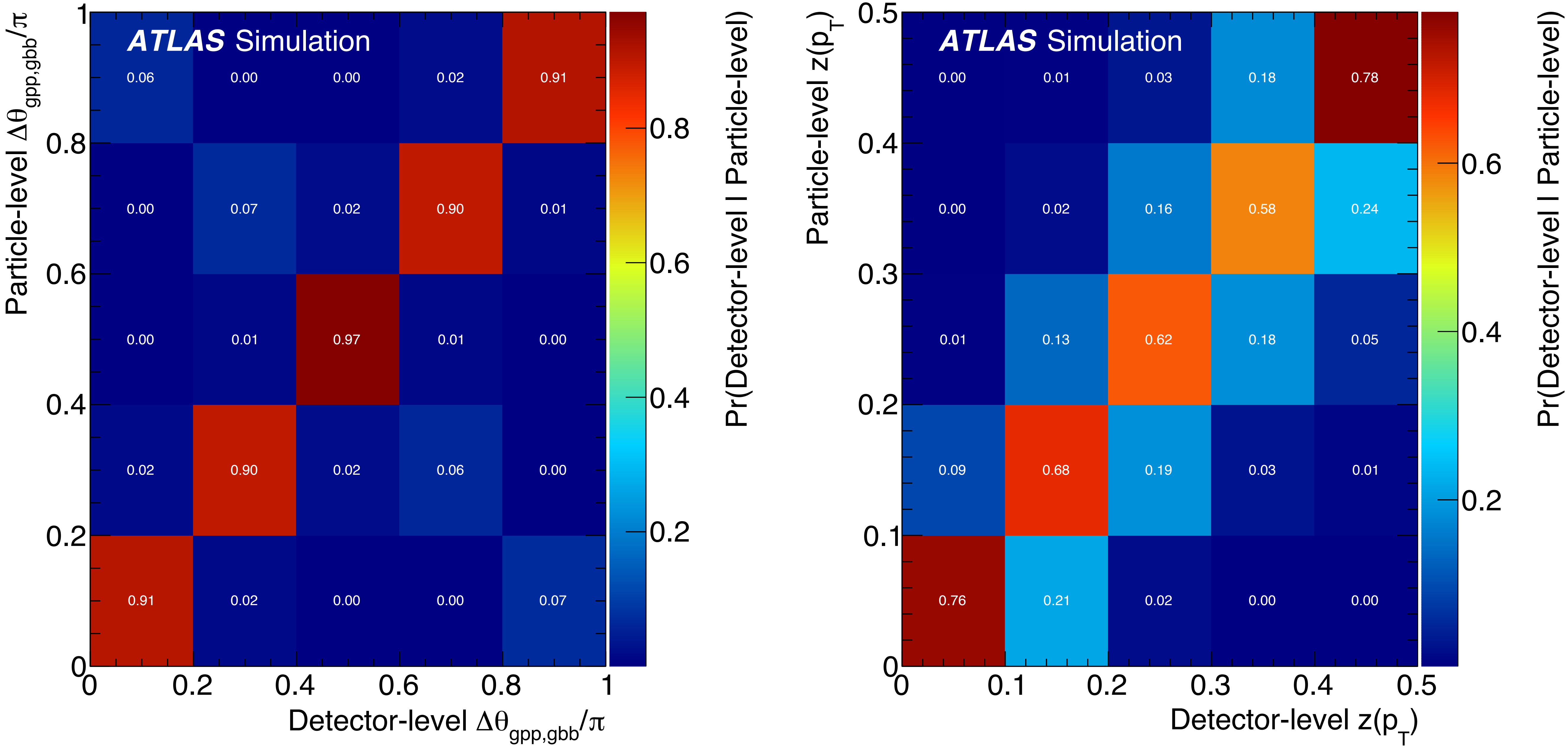
Measurement specs - observables



Tracking → excellent angular resolution

Tracking → less-good momentum resolution

Background estimation

The signed impact parameter significance is used for the leading and sub-leading jet.

use track with second highest value; better modeling, though consistent with leading and sub-sub leading.

$$\mathcal{L}(\text{data}|f) = \sum_{j\in\text{flavor}} f_j \prod_{i=1}^{\text{n}_\text{bins}} p_\text{lead jet}(s_{d_0,i}{}^\text{sub}|j) \times p_\text{sublead jet}(s_{d_0,i}^\text{sub}|j)$$

$$s_{d_0} = \text{sign} \times \frac{d_0}{\sigma d_0}$$

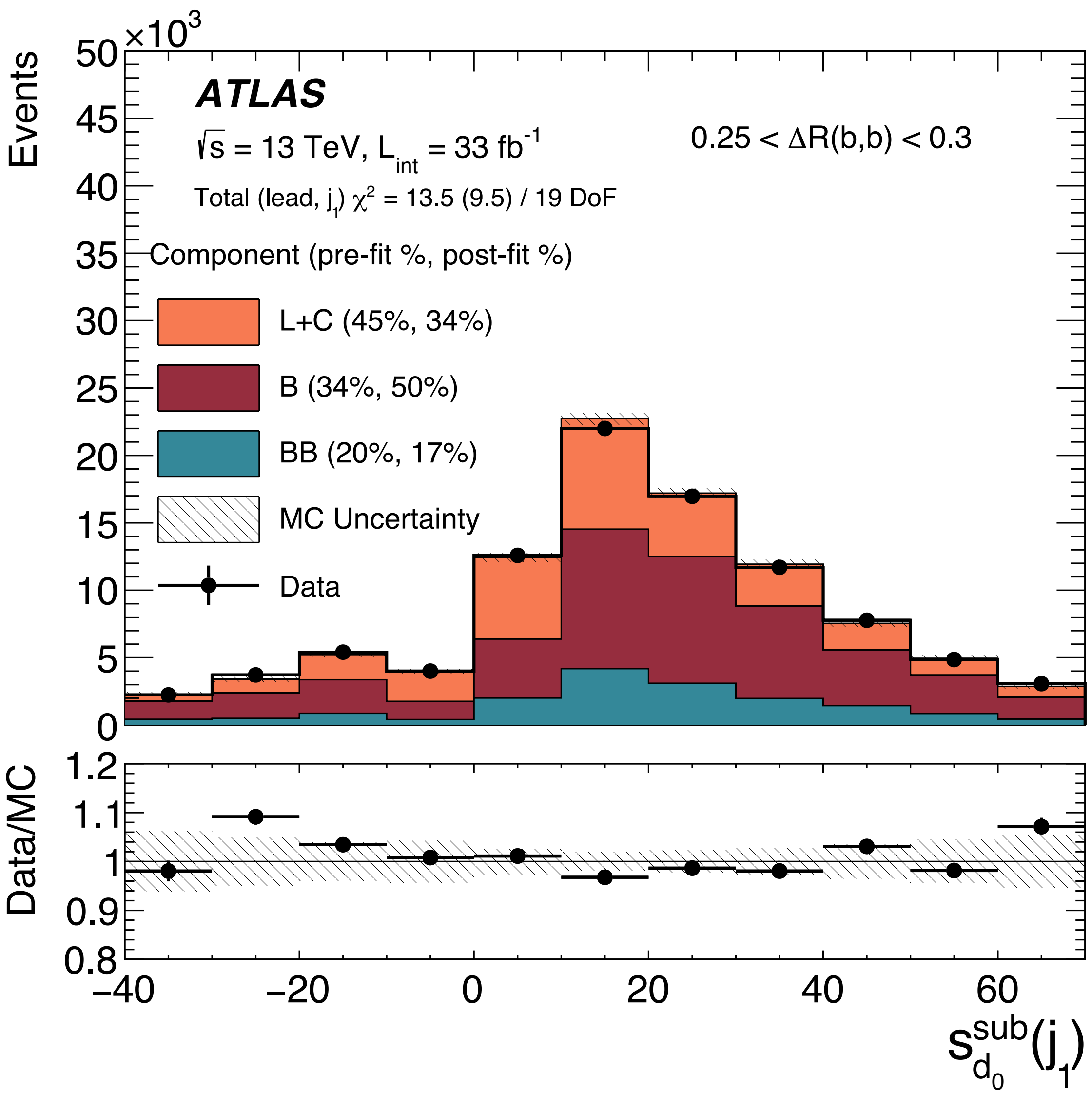
fitting for these!

There are 9 in total (BB, BC, BL, …) but we merge similar ones and fit for 3: BB, B, LC.

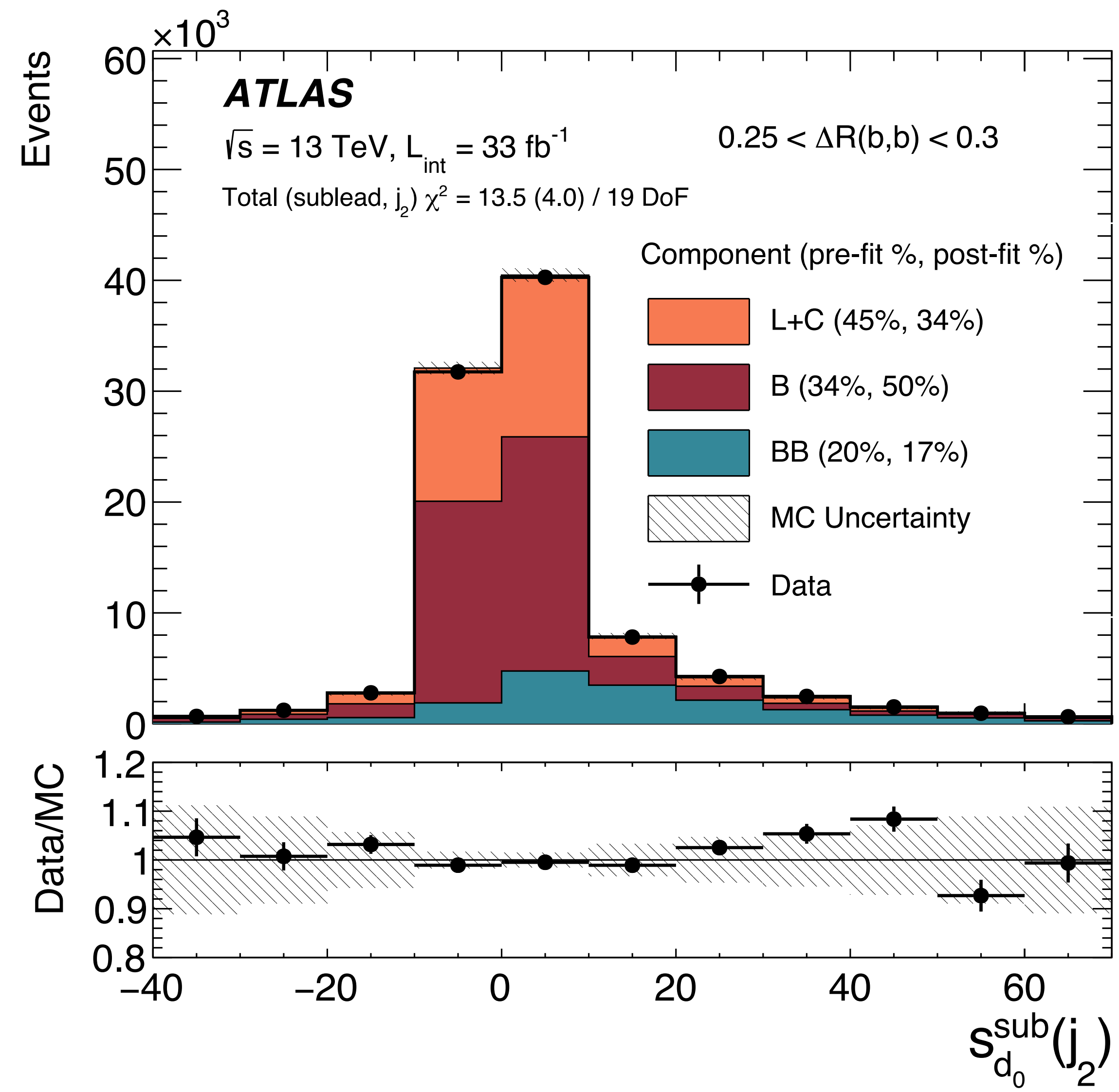
significances are nearly independent for the two jets given the flavor.

Background estimation

The signed impact parameter significance is used for the leading and sub-leading jet.



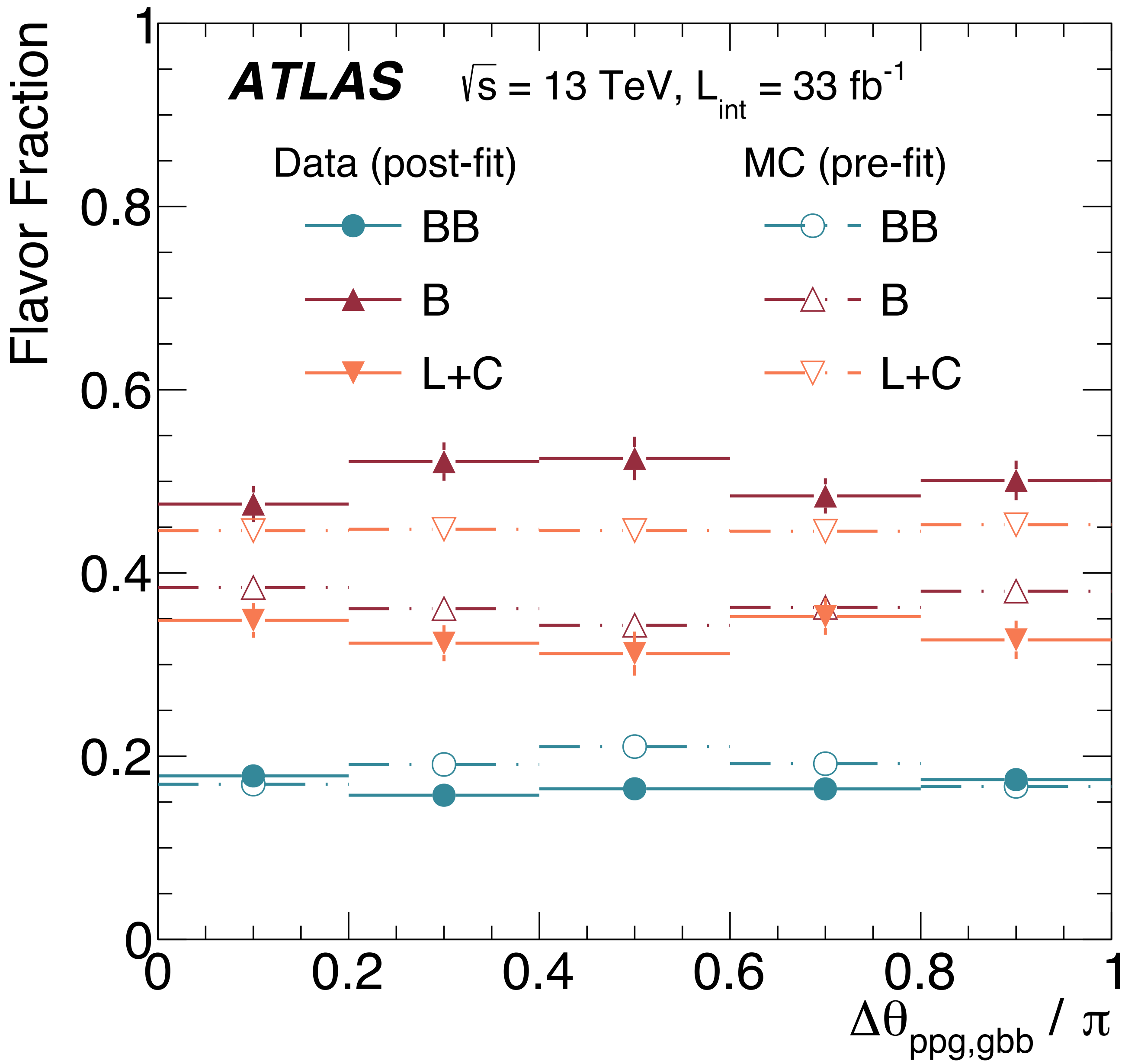
leading jet



subleading jet

Excellent description of the data post-fit.

Background estimation



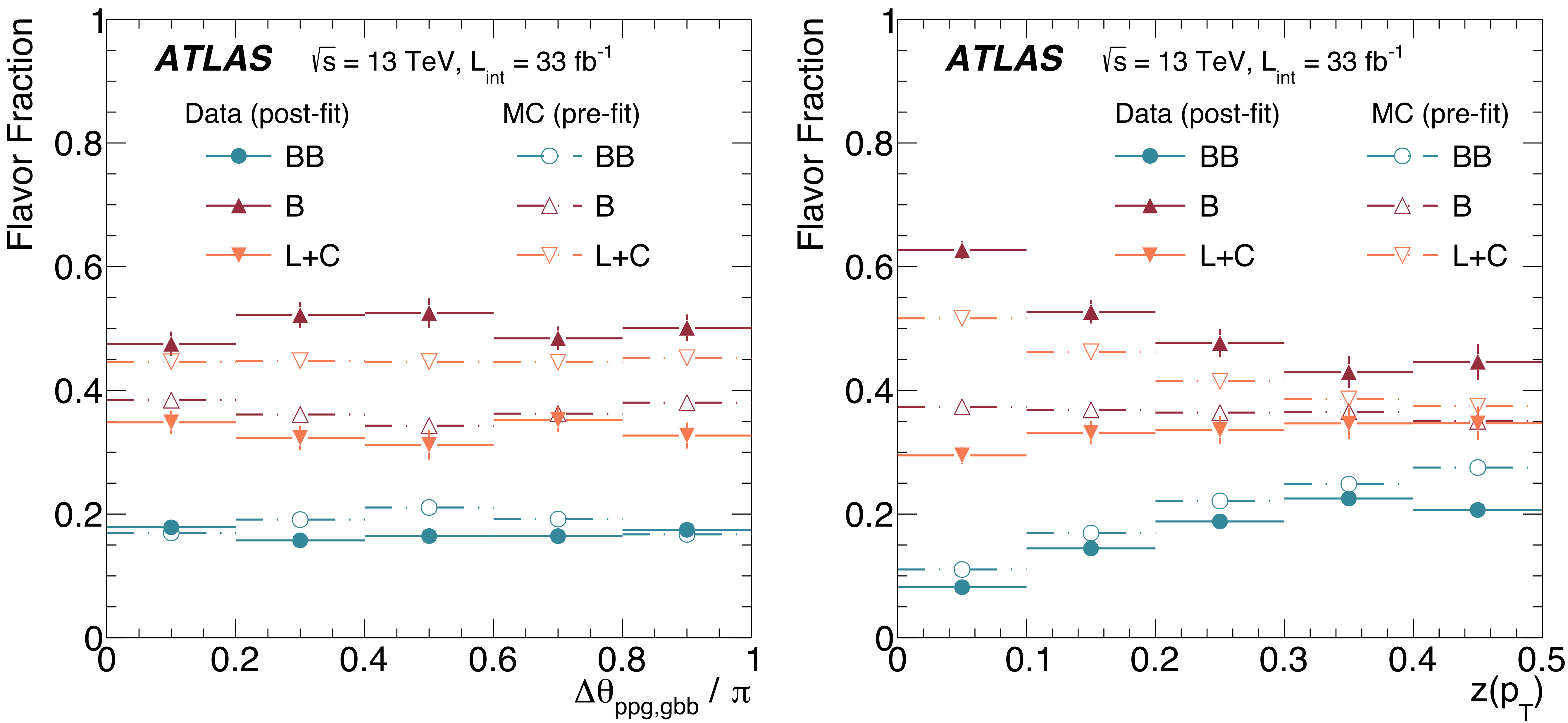
This procedure is repeated for each bin of each observable.

BB ~ 20%; slightly over-estimated in MC, but shape mostly okay.

B and **L+C** inverted between data and MC.

Uncertainties from template shapes, fit range, etc. (more on this shortly)

Background estimation



Similar trends for each observable.

Systematic uncertainties

	$\Delta R(b,b)$	$\Delta\theta_{\mathrm{ppg,gbb}}$	$z(p_{\mathrm{T}})$	$\log(m_{bb}/p_{\mathrm{T}})$
Calorimeter jet energy	2–3%	2–3%	2–6%	2–4%
Flavor tagging	<1%	<1%	<1%	<1%
Tracking	1–2%	1–2%	2–4%	1–2%
Background fit	1%	1%	1–2%	2%
Unfolding method	2–3%	2%	2–4%	2–5%
Theoretical modeling	3–10%	2–13%	3–10%	4–11%
Statistical	1%	1%	2%	1%
Total	3–10%	3–10%	3–14%	4–12%

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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Unfolding method	[illegible]	[illegible]	[illegible]	2–5%
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total	3–10%	3–10%	3–14%	4–12%

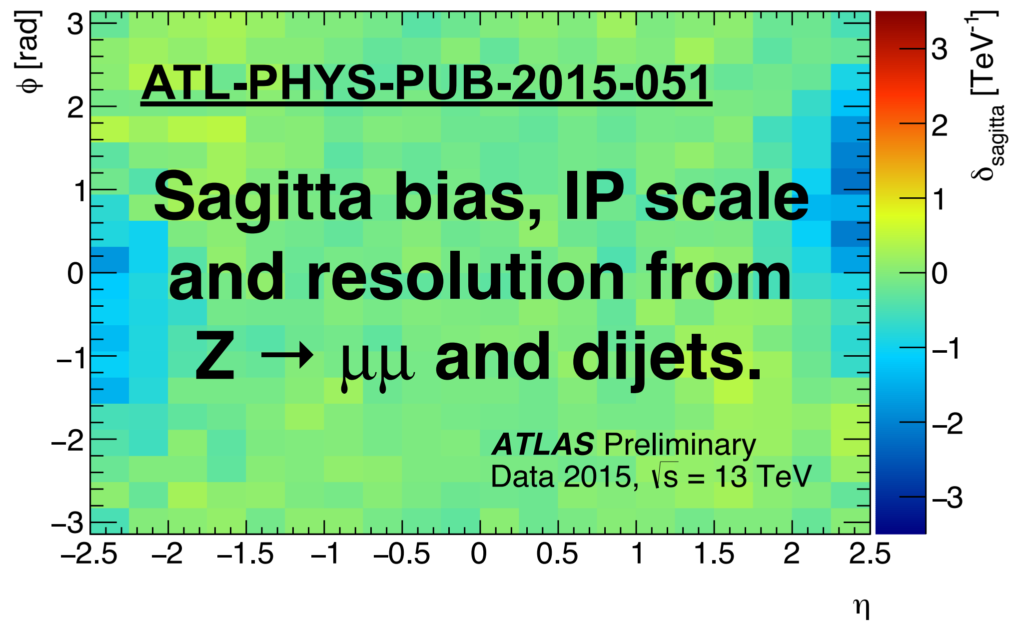
- Uncertainties up to 300 GeV using "usual" calibration schemes (e.g. ttbar events for b-jet efficiency)

- Extrapolation uncertainties using simulation variations.

- As the flavor fractions are constrained with the fit, there is little sensitivity to these flavor tagging uncertainties.

(N.B. our fit is only post-tagging, so there is still a small dependence on the flavor tagging uncertainty)

Systematic uncertainties



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Background fit	1%	1%	1–2%	2%
U[illegible]	[illegible]	2%	2–4%	[illegible]
Theoretical modeling	3–10%	2–13[illegible]	[illegible]	[illegible]

+ fake rate uncertainty (not shown)

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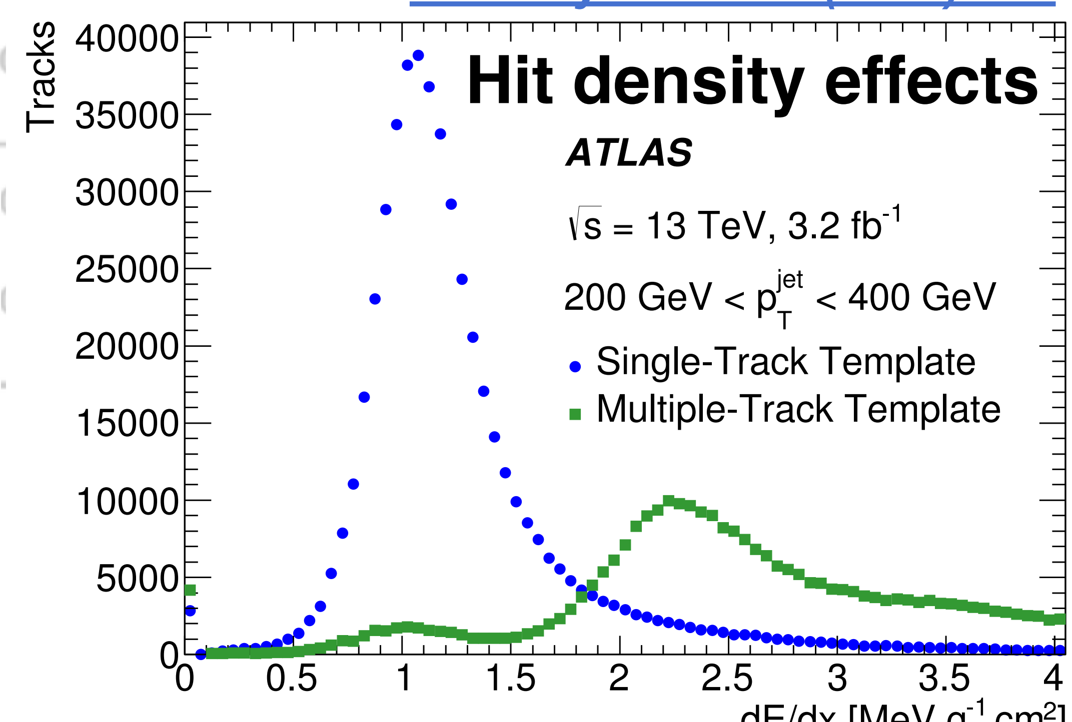

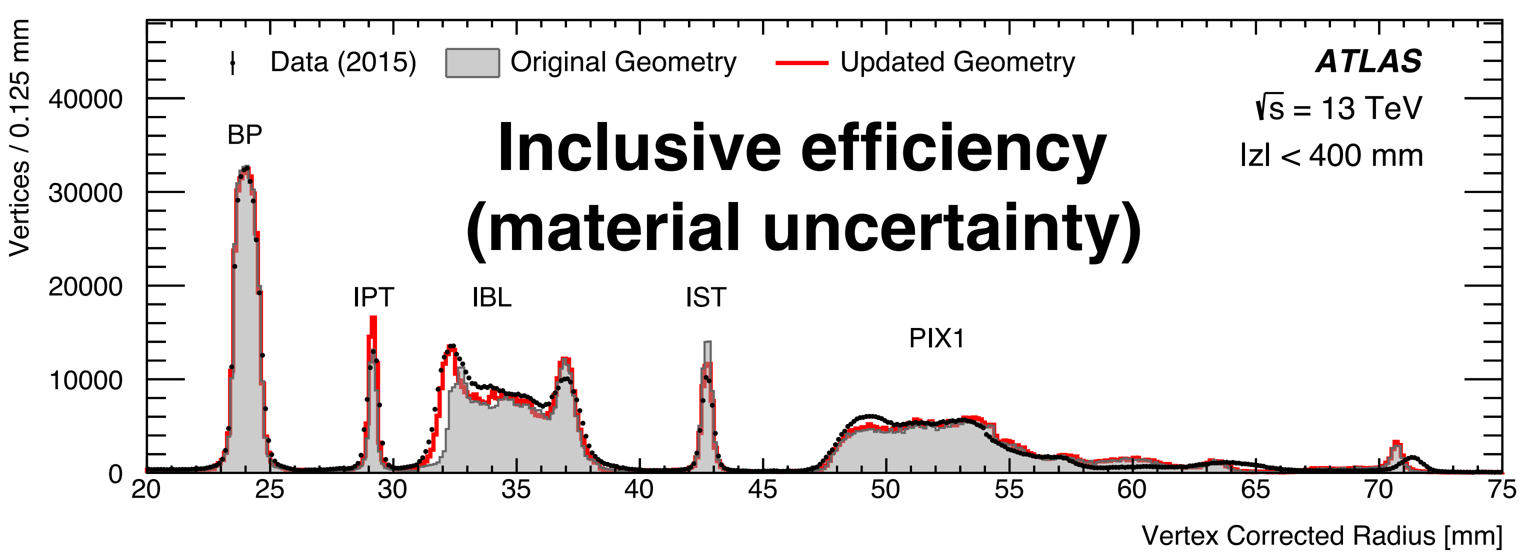

JINST 12 (2017) P12009

Systematic uncertainties

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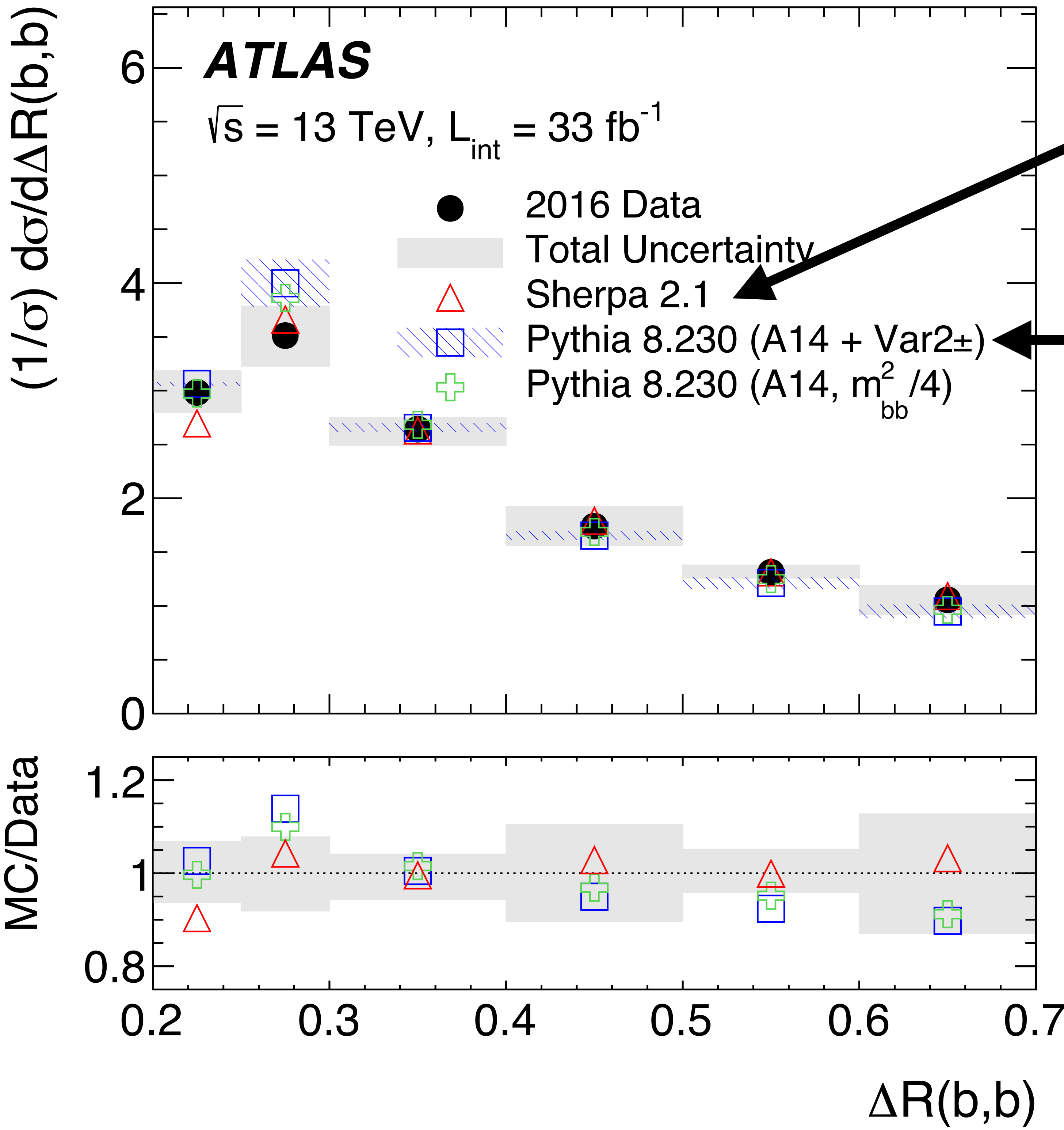
Sta[illegible]	[illegible]	1%	[illegible]	1%
Total	3–10%	3–10%	3–14%	4–12%

- Vary the fit range and vary the way the templates are merged from 9 (BB, BC, BL, …) to 3 (BB, B, CL).

- Additional cross-checks: leading and sub-sub leading s_{d_0}; fit in bins of jet p_{T}; re-weight jet kinematic properties.

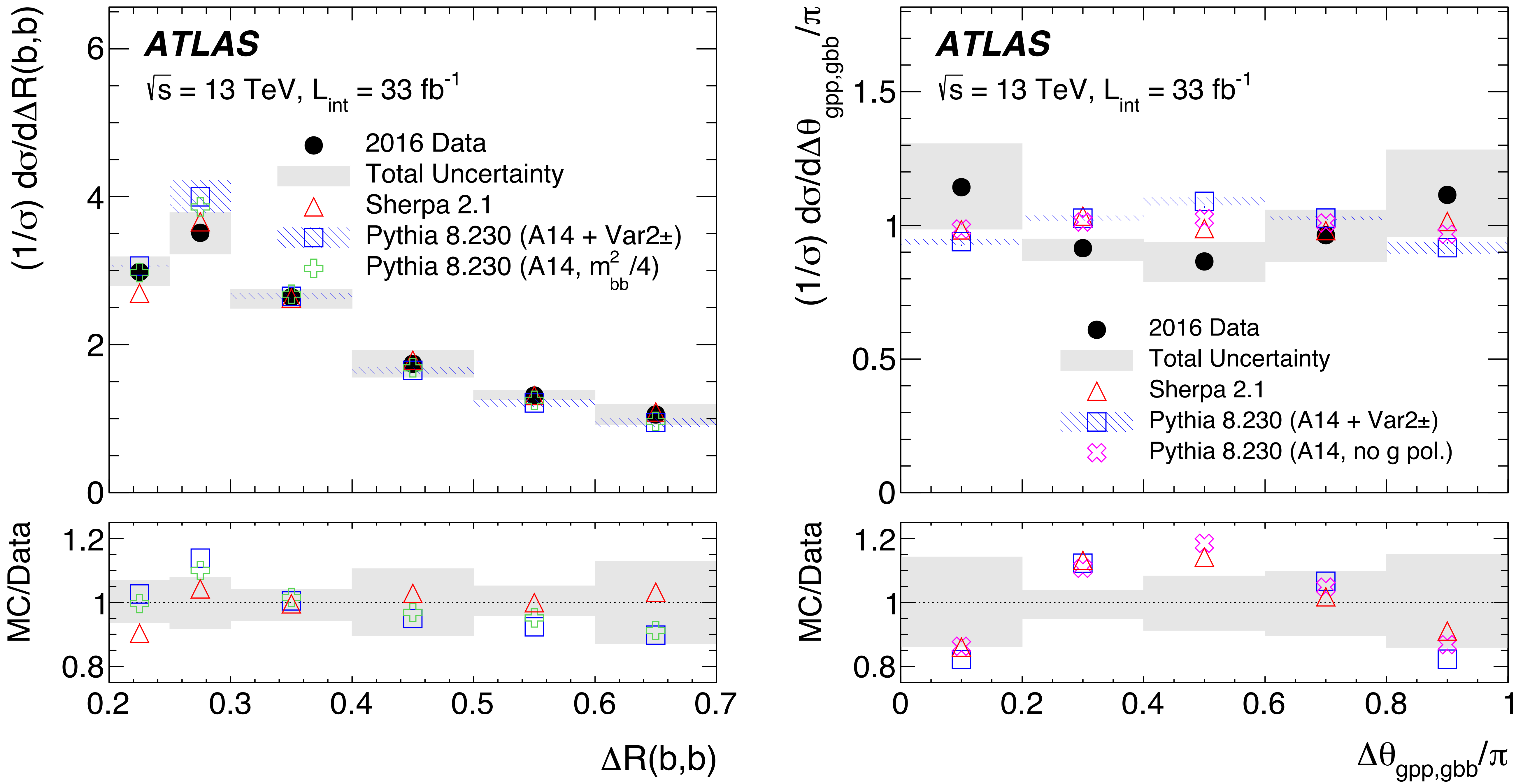
Results



Includes 2 → 3 LO MEs.

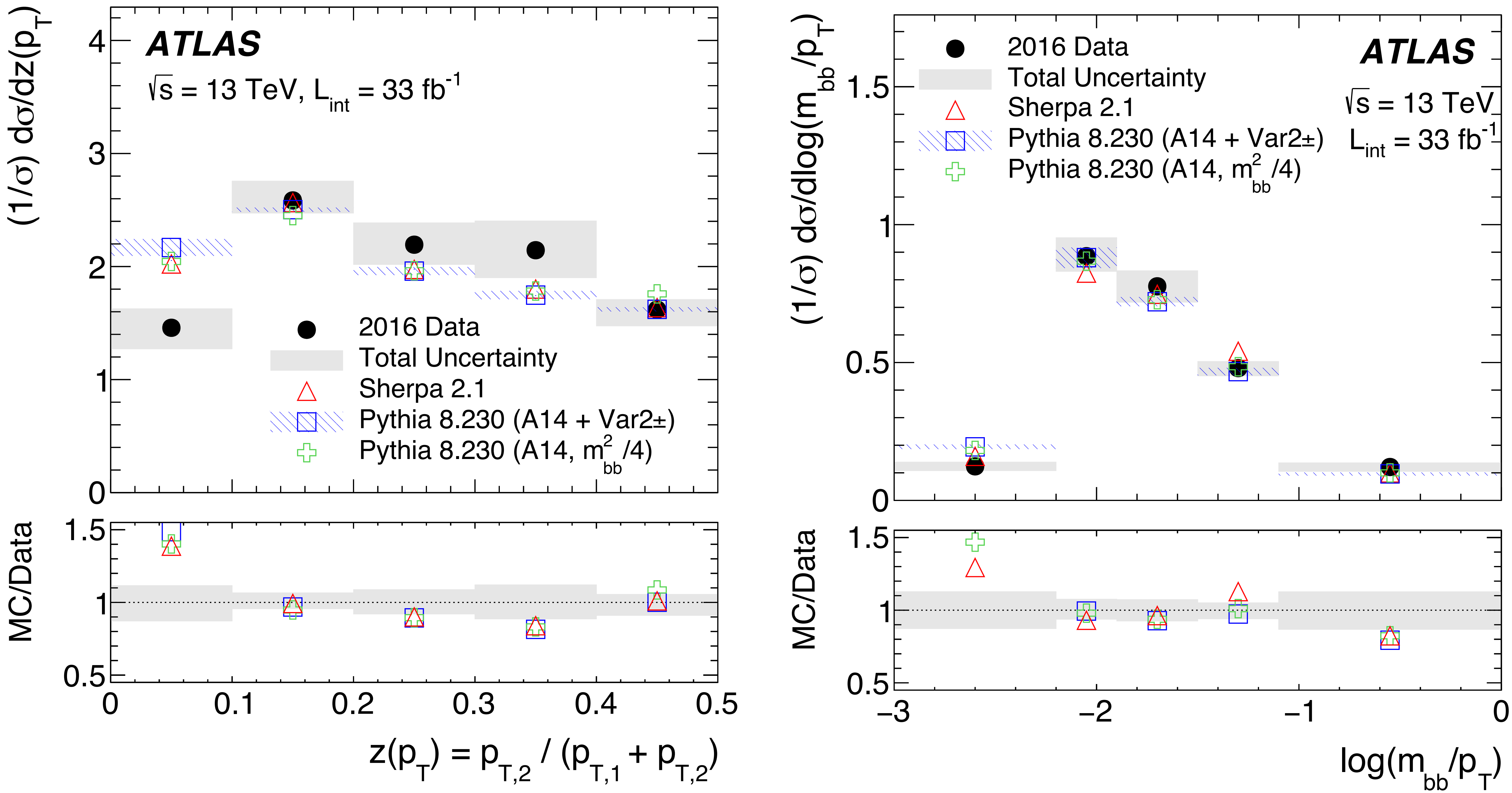
ATLAS default Pythia tune

Results - angular observables



Data seems to exhibit "less polarization" than Pythia, closer to Sherpa.

Results - momentum scale observables



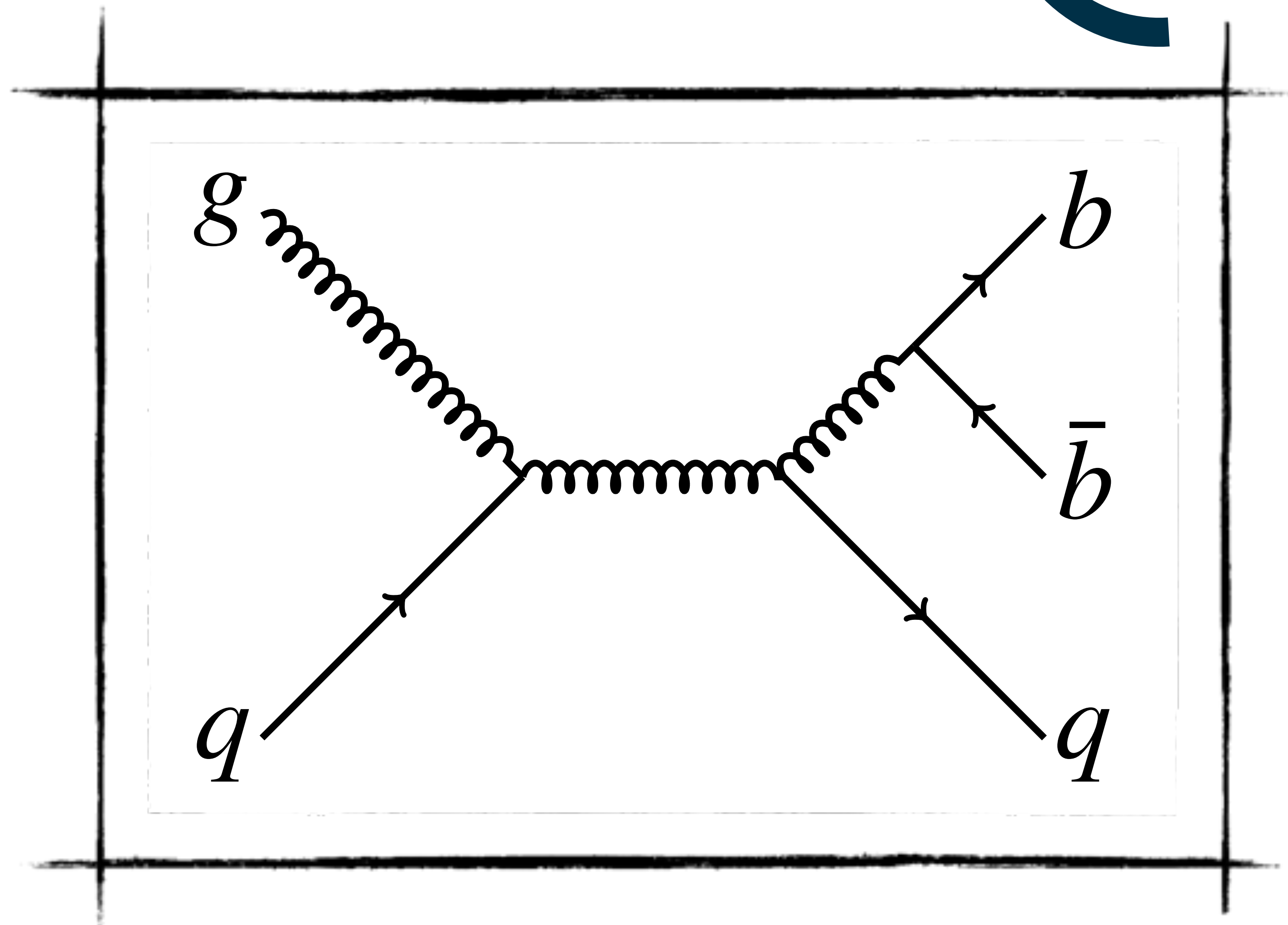
Significant disagreement for
unequal sharing and low mass.

Conclusions and outlook

We have performed a first differential measurement of g → bb at small opening angles.

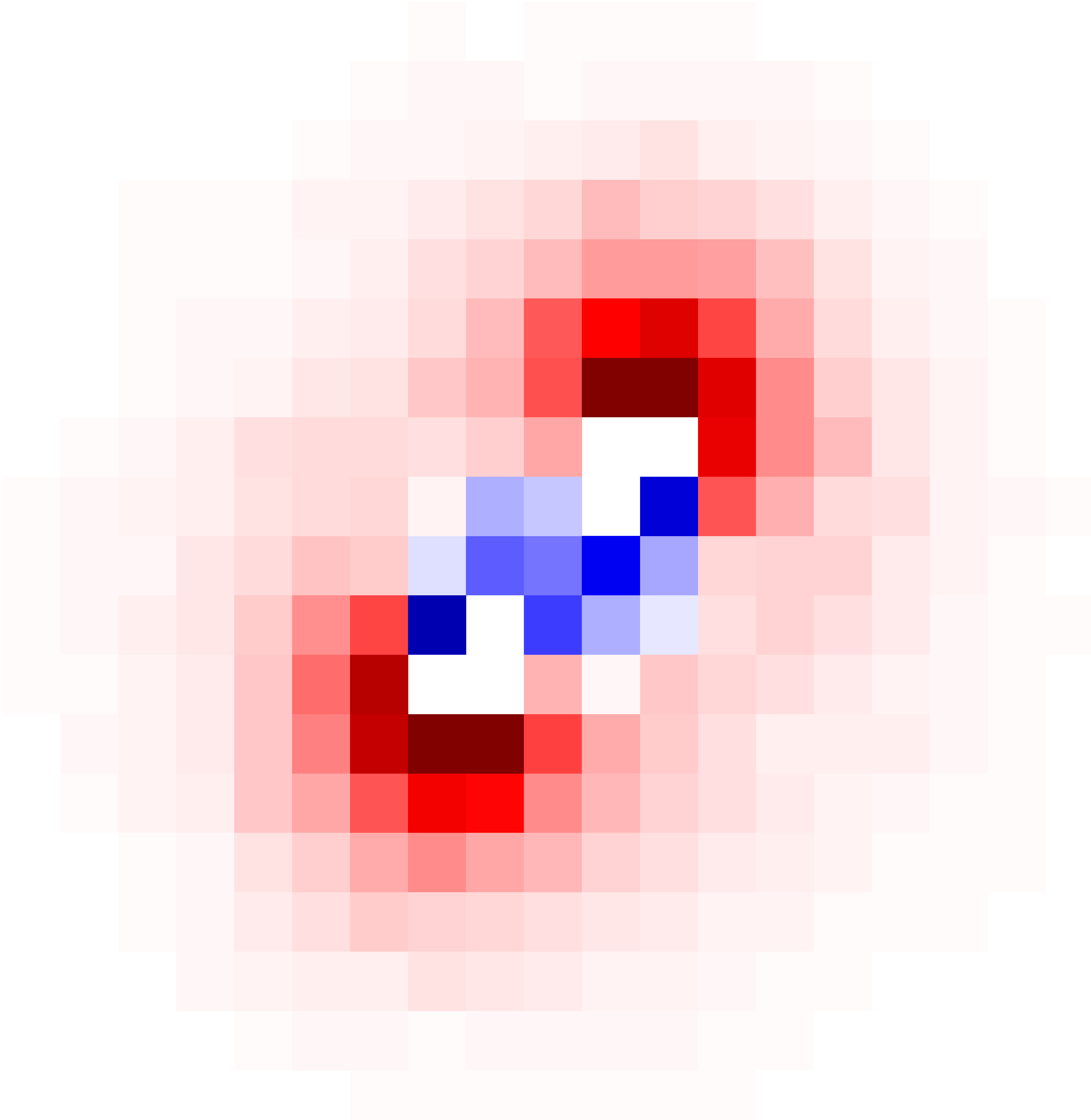
- Flavor fractions significantly disagree with MC

- Significant disagreement for gluon polarization, low m_{bb}, and unequal momentum sharing.



Data are public (+Rivet routine) … hopefully will improve modeling & our understanding of QCD in the future!

(already discussing with Vincia, Herwig, and Sherpa authors)



Fin.