Searches for boosted $H \rightarrow bb$ with 80 fb^{-1}

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ATLAS EXPERIMENT

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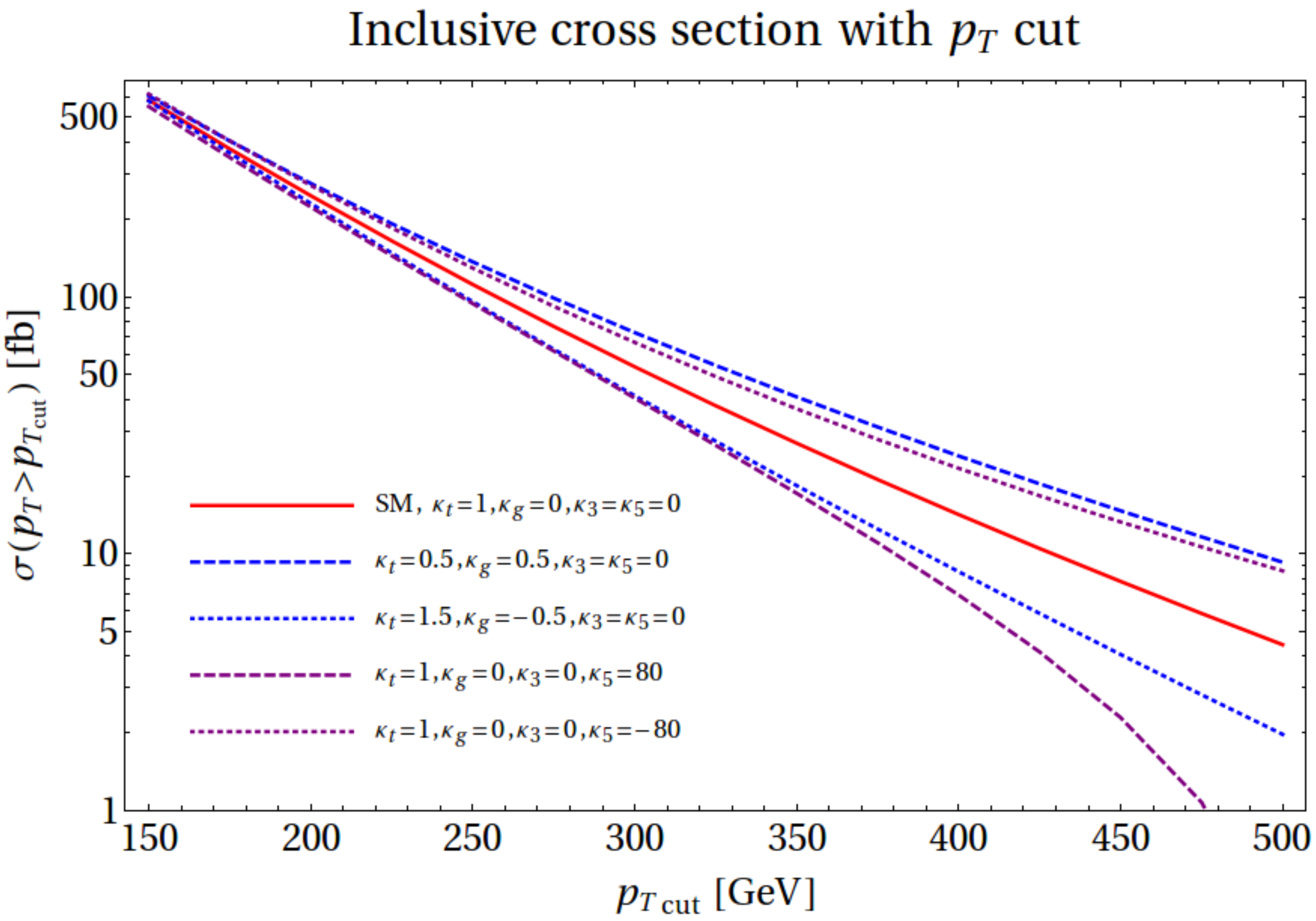
SLAC NATIONAL ACCELERATOR LABORATORY

Higgs at High p_T

Higgs production above top threshold:

- Dominated by gluon fusion (VBF becomes larger above ~800 GeV)
- Gluon fusion cross section sensitive to anomalous couplings effects in the top loop at high p_T!
- Distinctive boosted signature: opportunity for inclusive $H \rightarrow bb$ measurement

[arXiv:1501.04103]



Other Boosted bb Signatures

Great ATLAS exotics program looking for low mass boosted resonances + ISR!

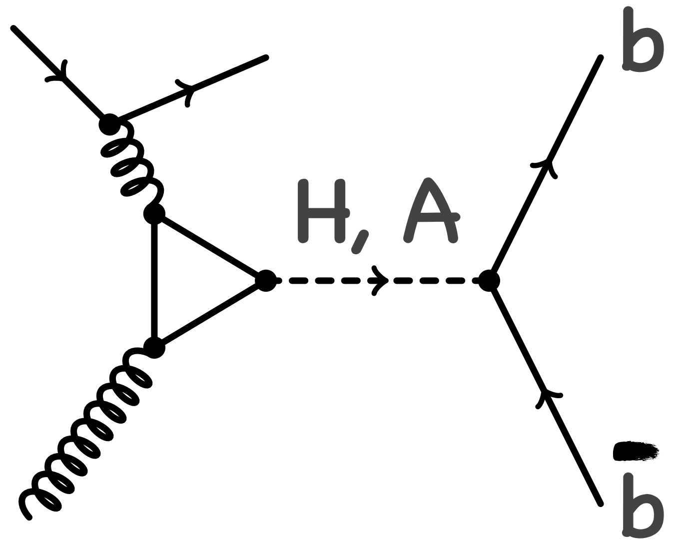
- Usually looking for leptophobic DM mediator models with democratic Z′→qq decays
- How can we improve?

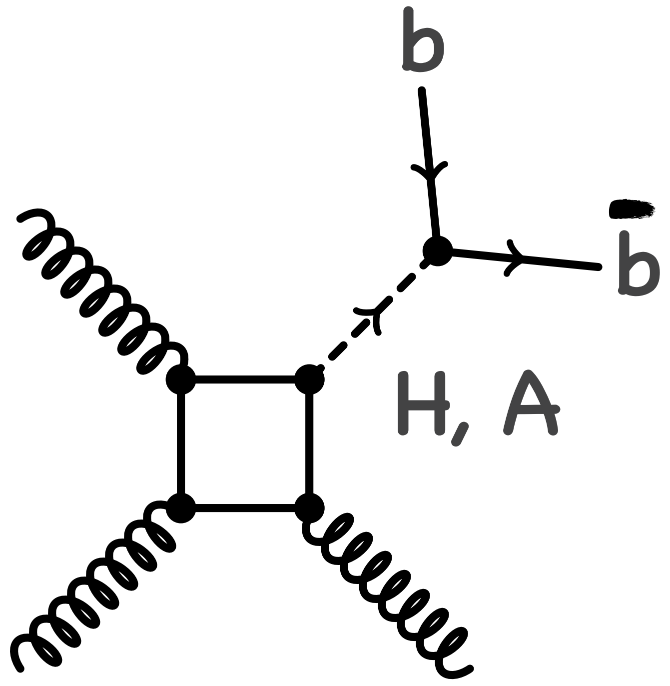
Look for resonances decaying to heavy flavor!

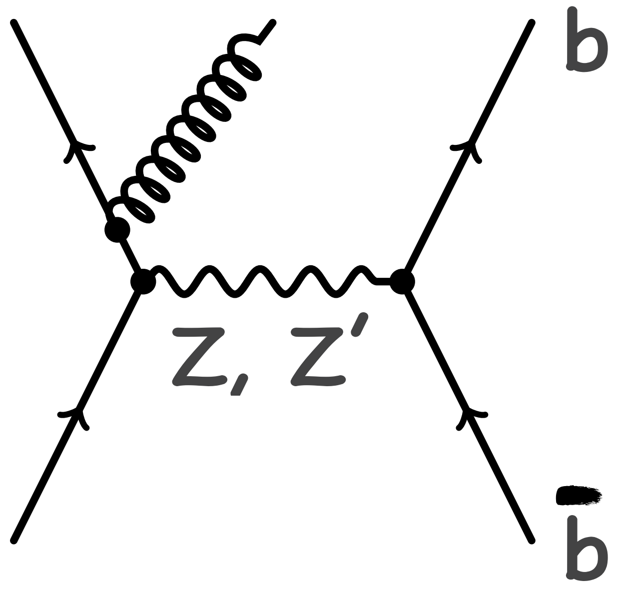
- Great way to reduce background
- Maybe DM mediator has Higgs like (coupling ~ mass), so heavy flavor decays favored

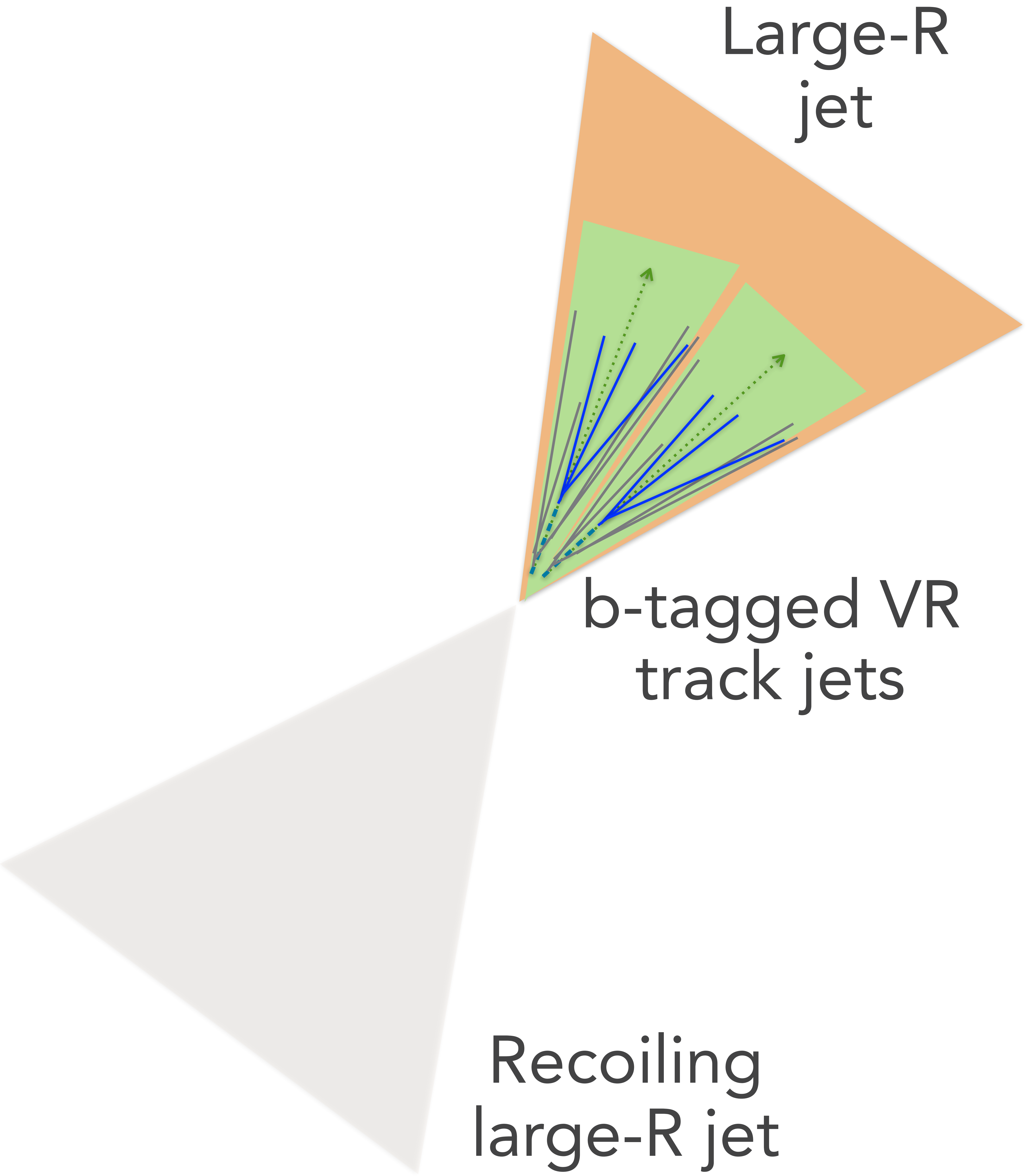
SM Z→bb is also there!

- Great way to reduce background









Event Selection

Trigger on large-R jets
At least 1 large-R jet with offline $p_T > 480$ GeV (~100% efficient for 2015+16+17 triggers)

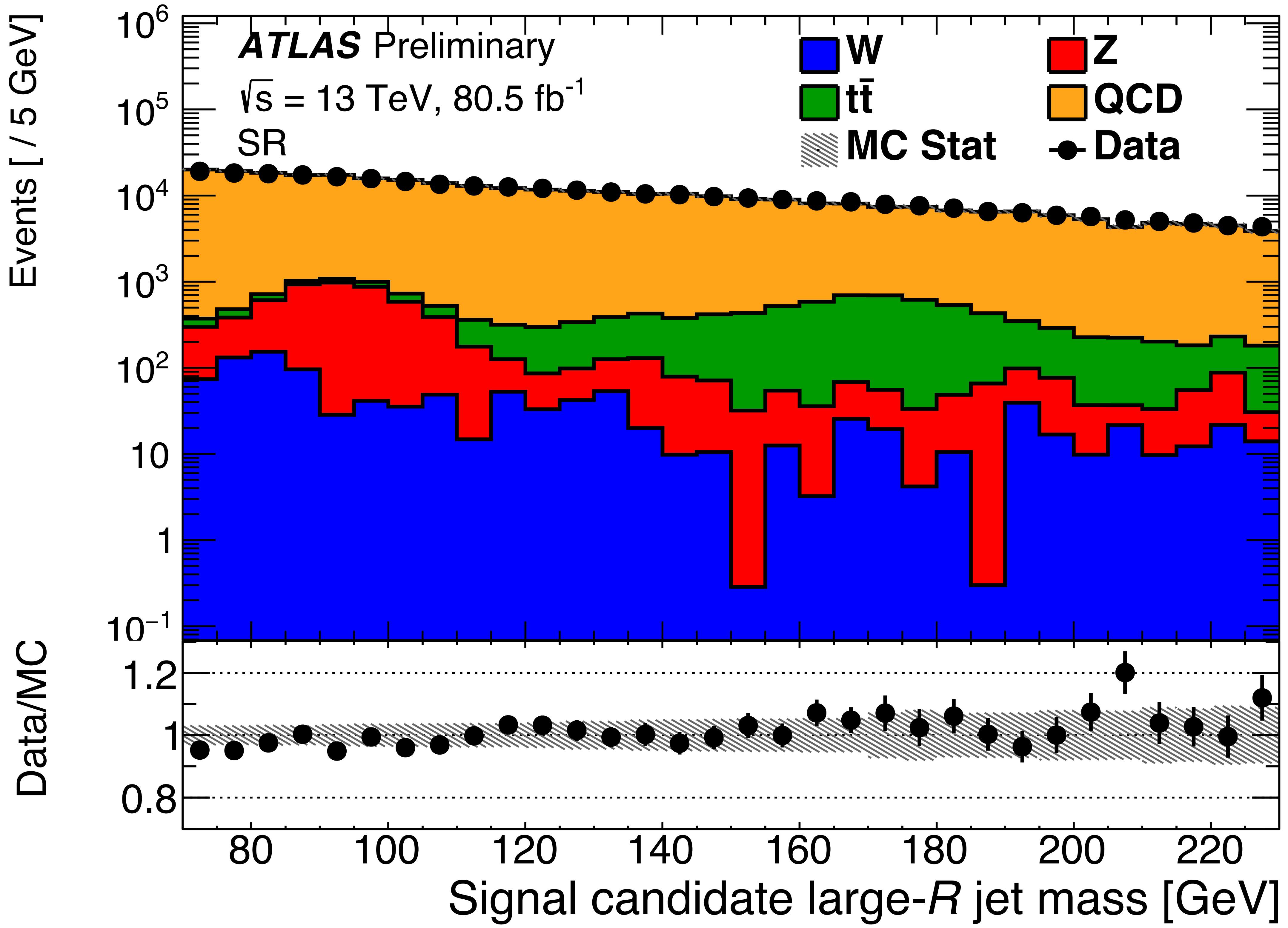
Recoiling jet and muon veto
At least two large-R jets with $p_T > 250$ GeV, and veto on isolated muons

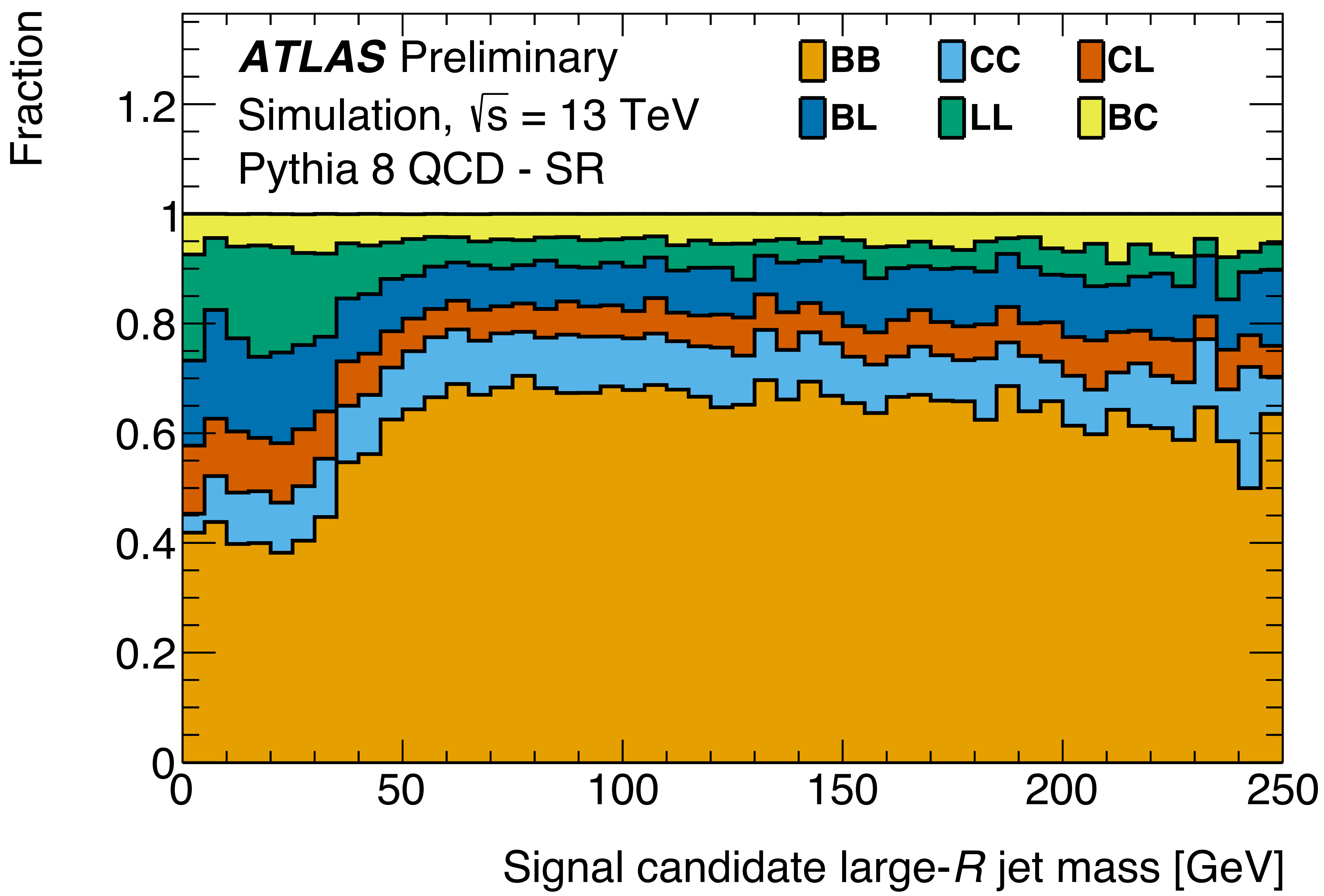
Signal Jet
At least one large-R jet with $p_T > 480$ GeV, two VR track jets, and $2m/p_T < 1$

Signal Region
Two track jets are b-tagged (77%WP MV2c10)

QCD Control Region
Two track jets fail b-tagged (85%WP MV2c10)

Signal Region





Very rich signal region

- Many “peaky" SM contributions: W/Z and top → can be estimated with MC-based templates
- After b-tagging, QCD in signal region is over 60% of gluon splitting to bb → needs data-driven description

Multijet Background

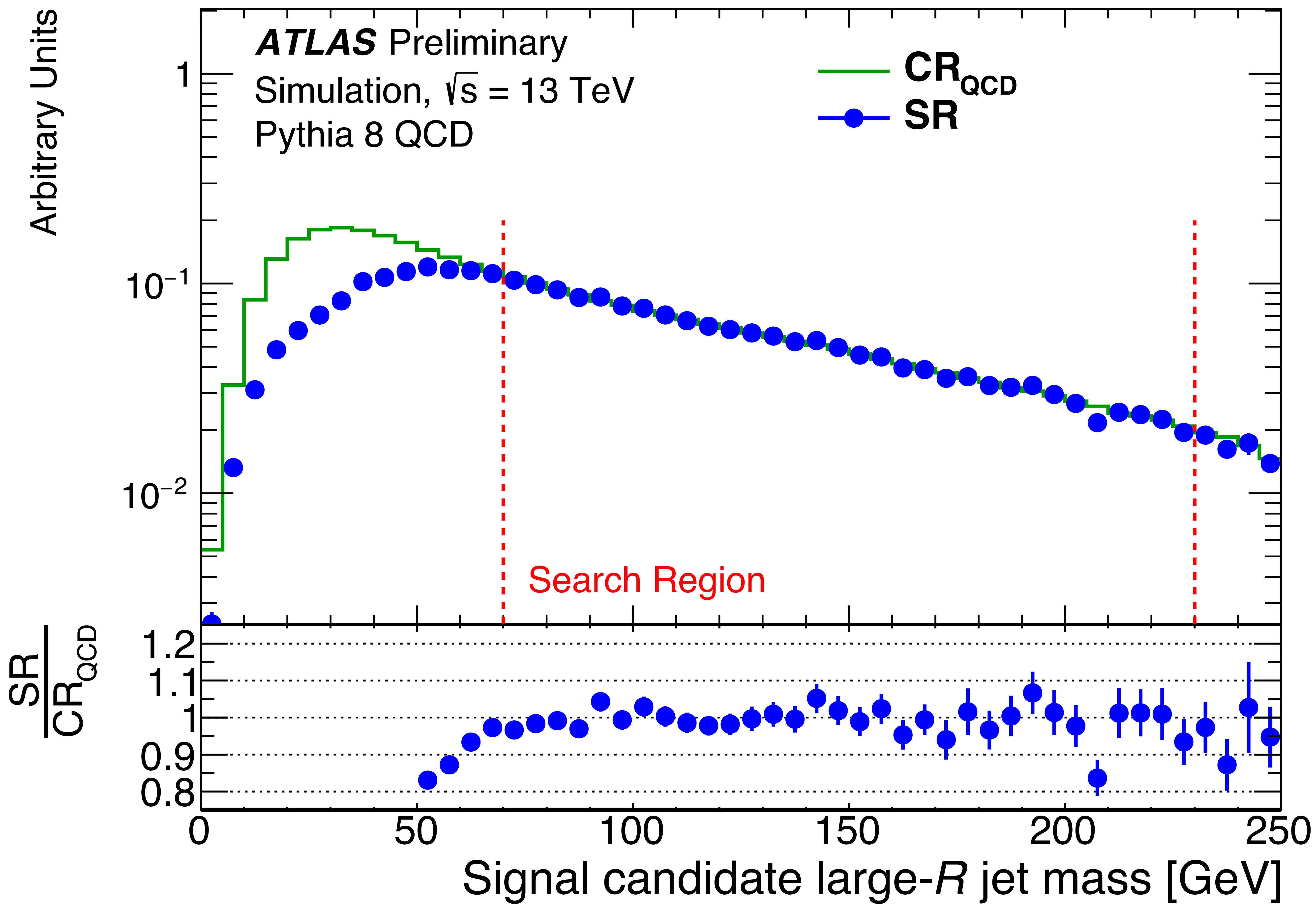
Multijet background modeled with parametric fit of exponential polynomial with 5 free parameters:

$$f_{QCD}\left(x \mid \theta\right) = \theta_0 \exp\left(\sum_{i=1}^{5} \theta_i x^i\right)$$

- x = (m_J - 150 GeV)/80 GeV
- Fit starts at 70 GeV to avoid turn-on due to VR track jets b-tagging

Multijet modeling hypothesis tested in QCD control region

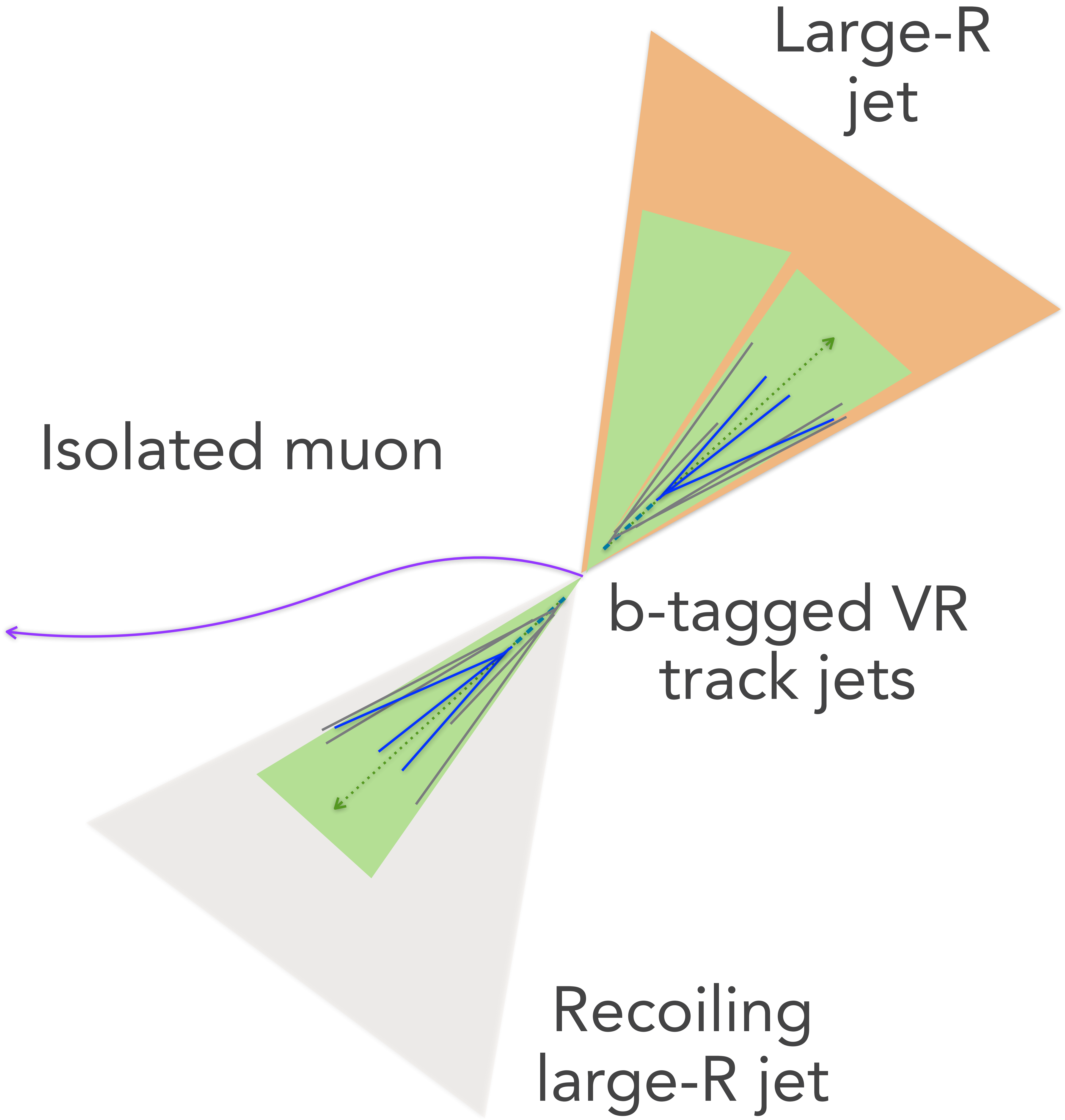
- After 70 GeV, CRqcd expected to reproduce well SR shape
- To match SR stats, CRqcd is divided into slices
- Signal injection and spurious signal tests show that model is unbiased



ttbar Modeling

Don’t trust ttbar MC normalization!

- Define CRttbar with only one VR b-tag in the signal jet, an isolated muon requirement (p_T > 40 GeV & $\Delta\phi(\mu, \text{sigJet}) > 2\pi/3$), and an extra VR b-tag in the recoiling jet
- Template fit (with full systematics) in CRttbar to extract k-factor with statistical and systematic uncertainties



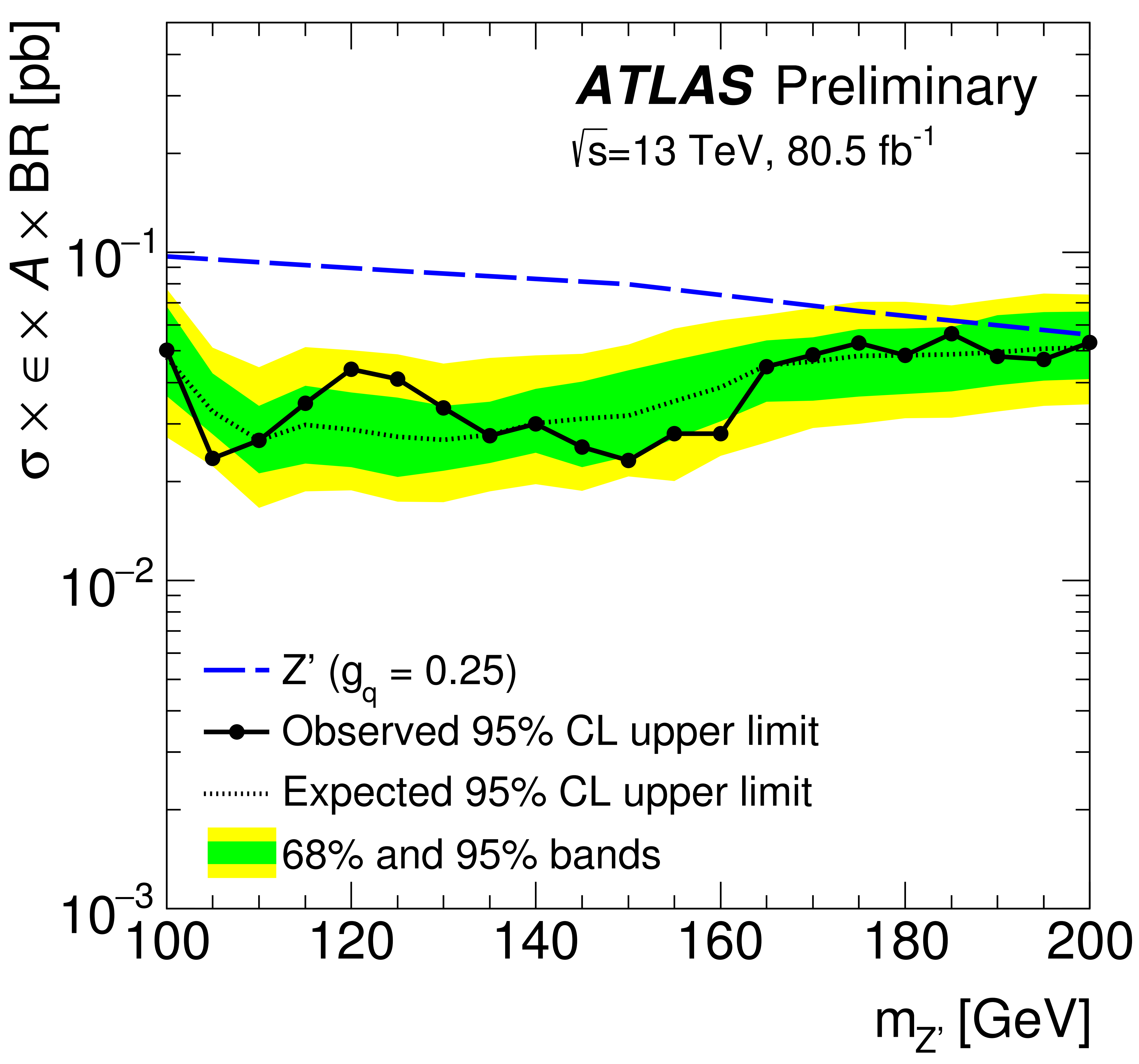
Systematic Uncertainties

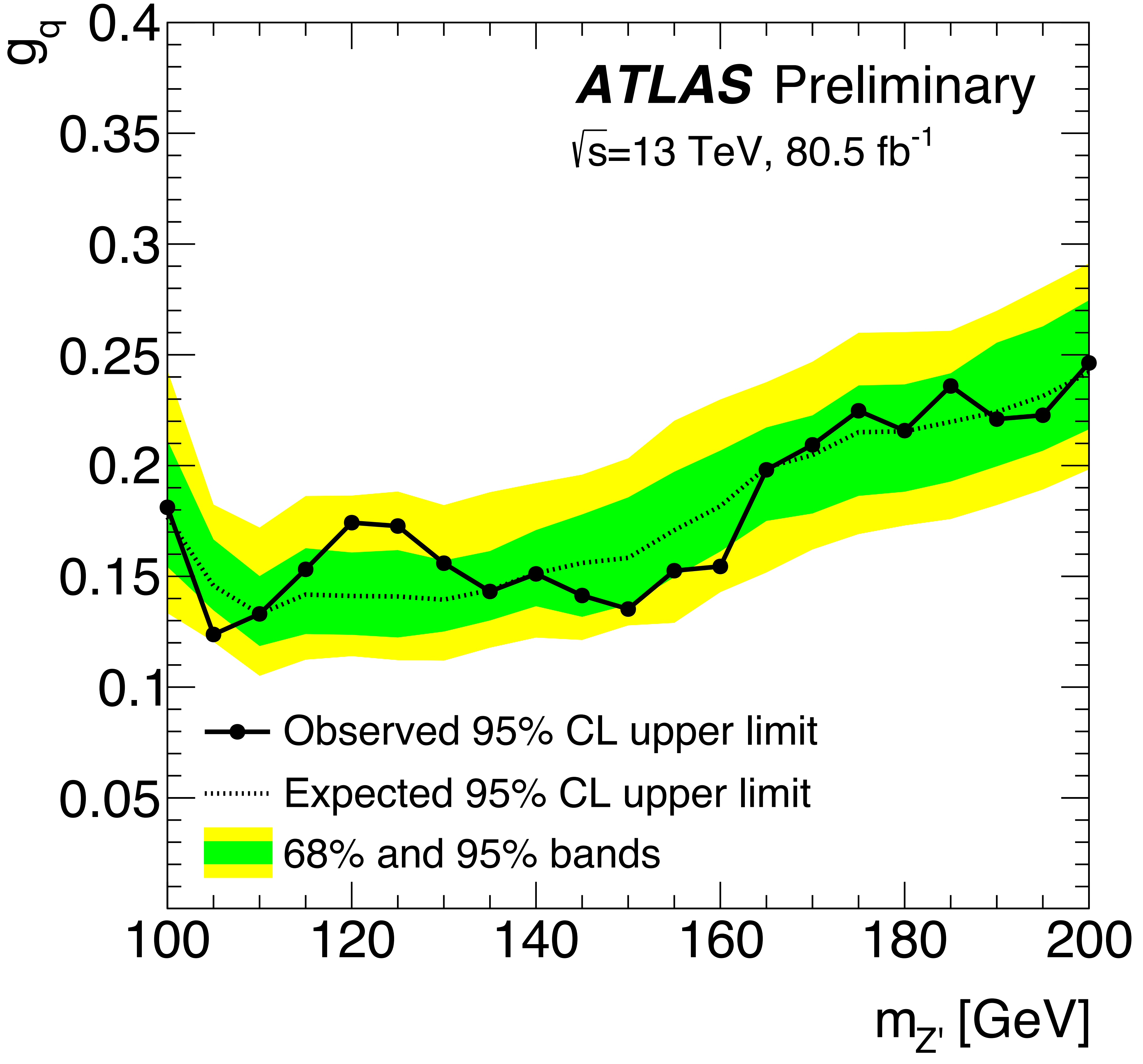
Largest systematic uncertainties!

		Impact on Signals ($\sqrt{\Delta\sigma^2}/\mu$)			
Source	Type	V+jets	Higgs	Z’ (100 GeV)	Z’ (175 GeV)
Jet energy and mass scale	Norm. & Shape	15%	14%	23%	18%
Jet mass resolution	Norm. & Shape	20%	17%	30%	20%
V + jets modeling	Shape	9%	4%	4%	$<1\%$
$t\bar{t}$ modeling	Shape	$<1\%$	1%	$<1\%$	11%
b-tagging (b)	Normalisation	11%	12%	11%	15%
b-tagging (c)	Normalisation	3%	1%	3%	5%
b-tagging (l)	Normalisation	4%	1%	4%	7%
$t\bar{t}$ scale factor	Normalisation	2%	3%	2%	58%
Luminosity	Normalisation	2%	2%	2%	3%
Alternative QCD function	Norm. & Shape	4%	4%	3%	17%
W/Z and QCD (Theory)	Normalisation	14%	–	–	–
Higgs (Theory)	Normalisation	–	30%	–	–

Rank by impact on expected significance

Exotics Search





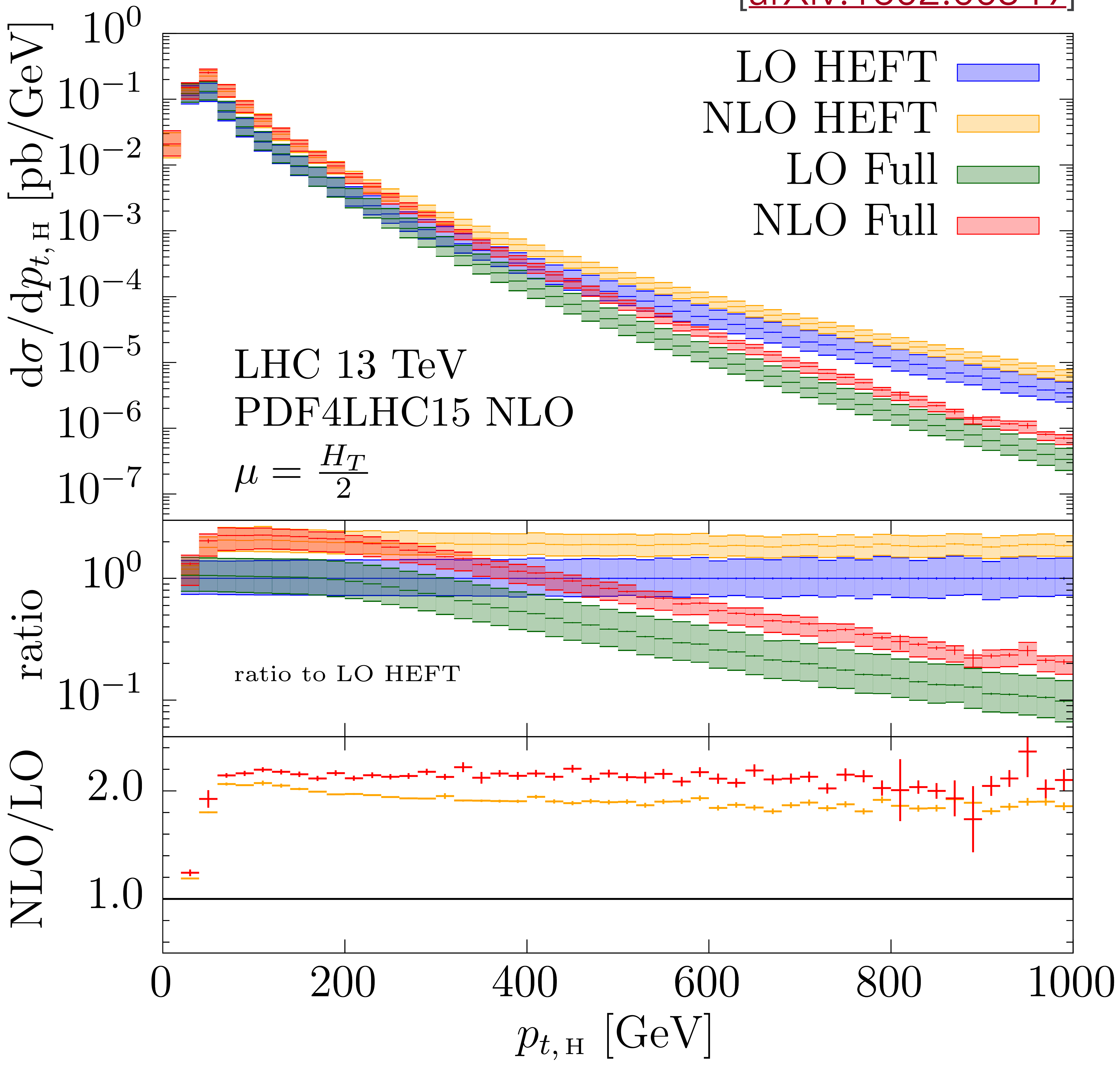
Limits on production cross section of Z′ decaying to bb, and on the Z′ couplings to quarks

What about the Higgs?

[arXiv:1802.00349]

Gluon fusion is > 50% of our expected Higgs signal

		% of signal in SR
$H \to b\bar{b}$	ggF	0.53
	VBF	0.25
	WH	0.12
	ZH	0.10



Very difficult to properly calculate gluon fusion Higgs cross section at very high p_T

- Can't trust HEFT, need resolved top loop/top mass effects
- Need high order QCD corrections on H+j process

LHCHXSWG Recommendations

From LHCHXSWG:

- NNLO calculations with top mass effect now available!
- HJ-MiNLO procedure (*Powheg HJ [inclusive NLO] + multi-scale improved NLO "matching"*) matches FO calculation within uncertainties

From ATLAS:

- Available ggF H->bb samples already produced with HJ-MiNLO procedure!
- No reweighting needed to match recommendations

Uncertainties on production taken from generator (about 25%)

[P.F.Monni, HC2018]

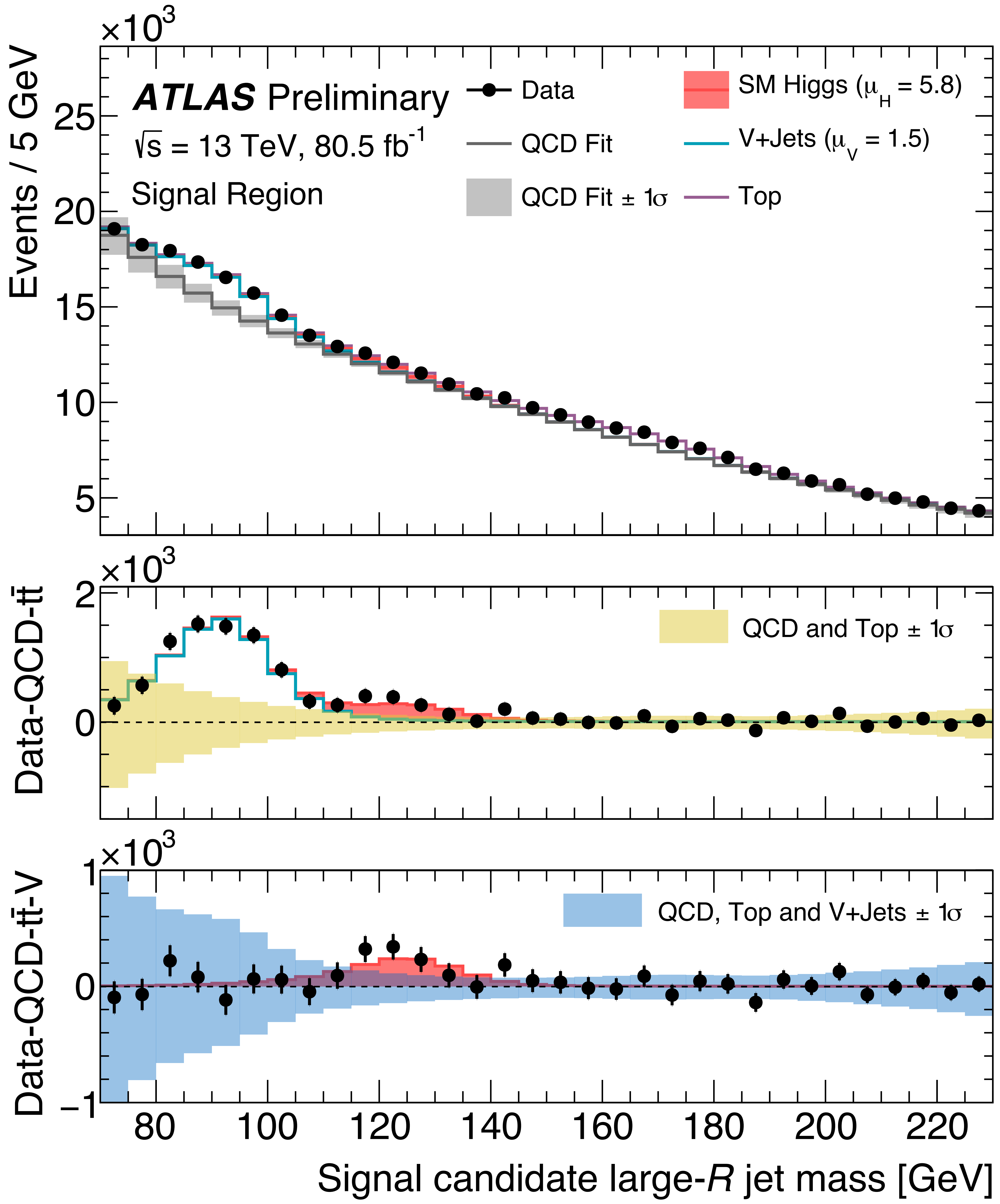
p_T^{cut}	$\mathrm{NNLO}^{\mathrm{approximate}}_{\mathrm{quad.unc.}}$ [fb]	HJ-MINLO [fb]	MG5_MC@NLO [fb]
400 GeV	$32.0^{+9.1\%}_{-11.6\%}$	$29^{+24\%}_{-21\%}$	$31.5^{+31\%}_{-25\%}$
430 GeV	$22.1^{+9\%}_{-11.4\%}$	-	$21.8^{+31\%}_{-25\%}$
450 GeV	$17.4^{+8.9\%}_{-11.5\%}$	$16.1^{+22\%}_{-21\%}$	$17.1^{+31\%}_{-25\%}$

Higgs Results (1)

Boosted V+Jets peak with 5σ observed (4.8σ expected)!

- V+jets peak = 80% Z, 20% W
- Validates analysis results
- Sensitivity is dominated by systematic uncertainties
  - Helps constraining uncertainties for Higgs (and exotics) search

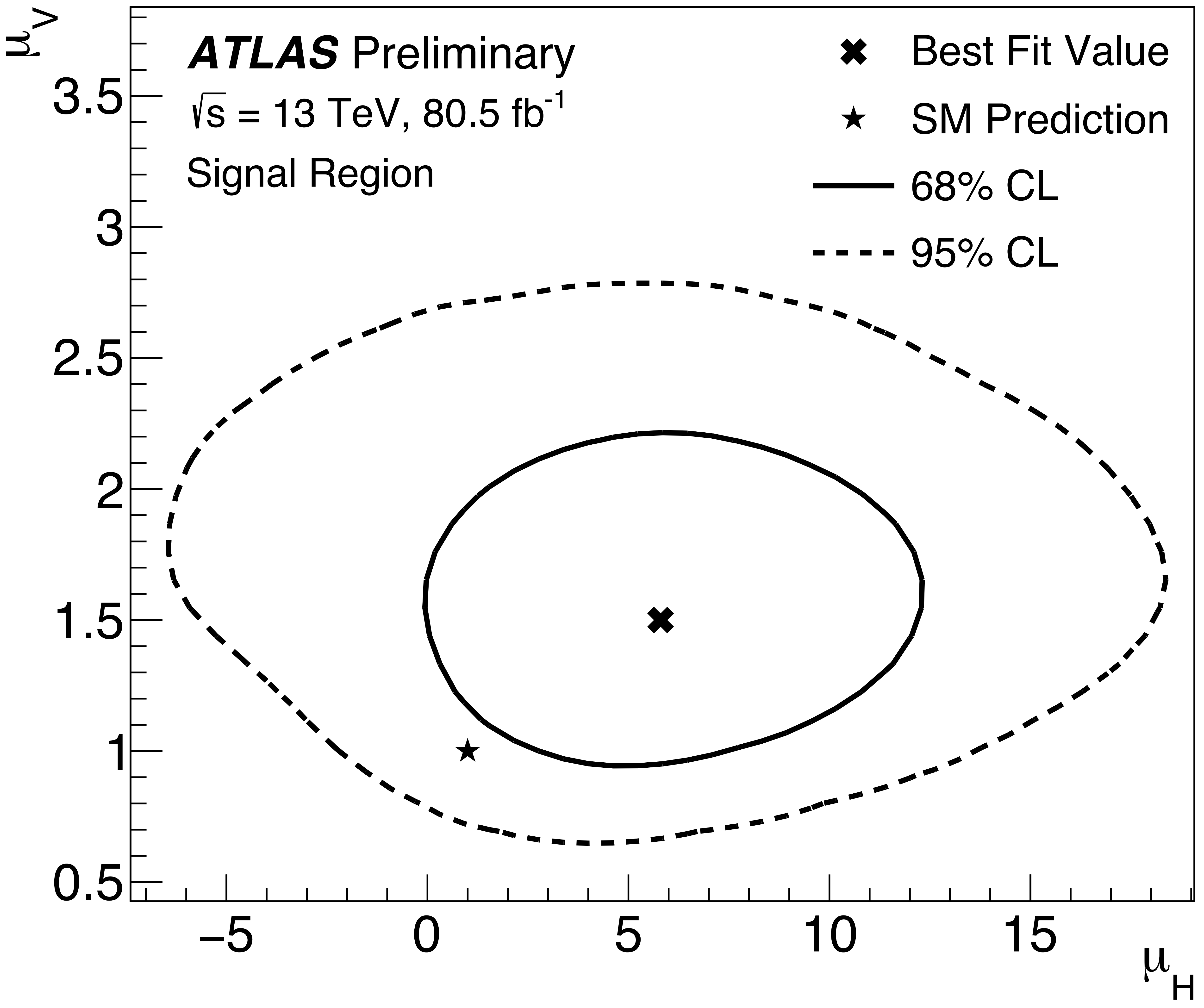
Sensitivity to SM Higgs: 1.6σ observed (0.28σ expected)!



Higgs Results (2)

$$\mu_V = 1.5 \pm 0.22\,(\mathrm{stat})\,^{+0.29}_{-0.25}\,(\mathrm{syst}) \;\pm 0.18\,(\mathrm{th})$$

$$\mu_H = 5.8 \pm 3.1\,(\mathrm{stat}) \;\pm 1.9\,(\mathrm{syst}) \;\pm 0.17\,(\mathrm{th})$$



Combined fit compatible with SM ($\mu_V = \mu_H = 1$) within 2σ!

Boosted H Results from CMS

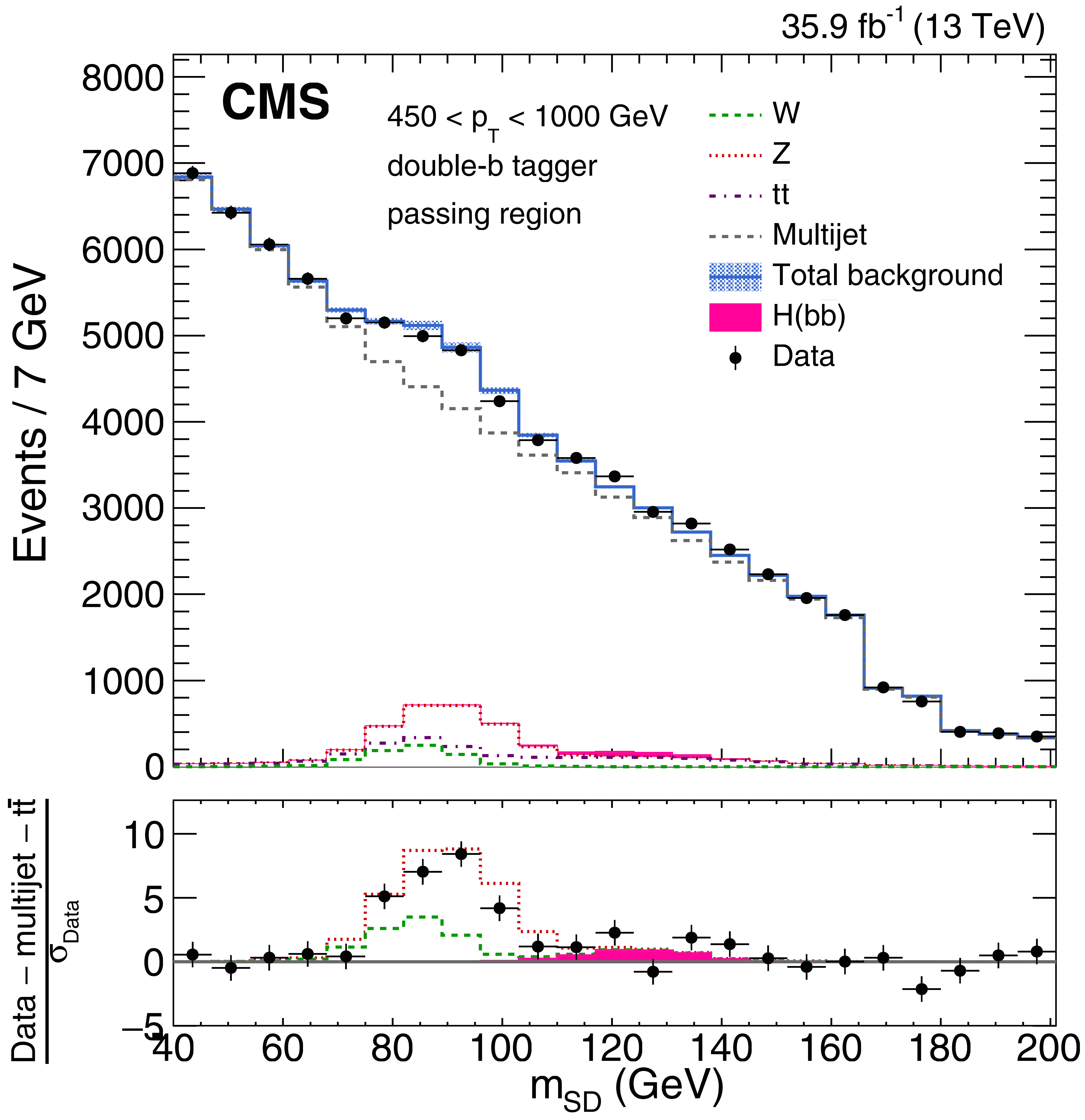
[PhysRevLett.120.071802]

CMS ggF reweighting procedure:

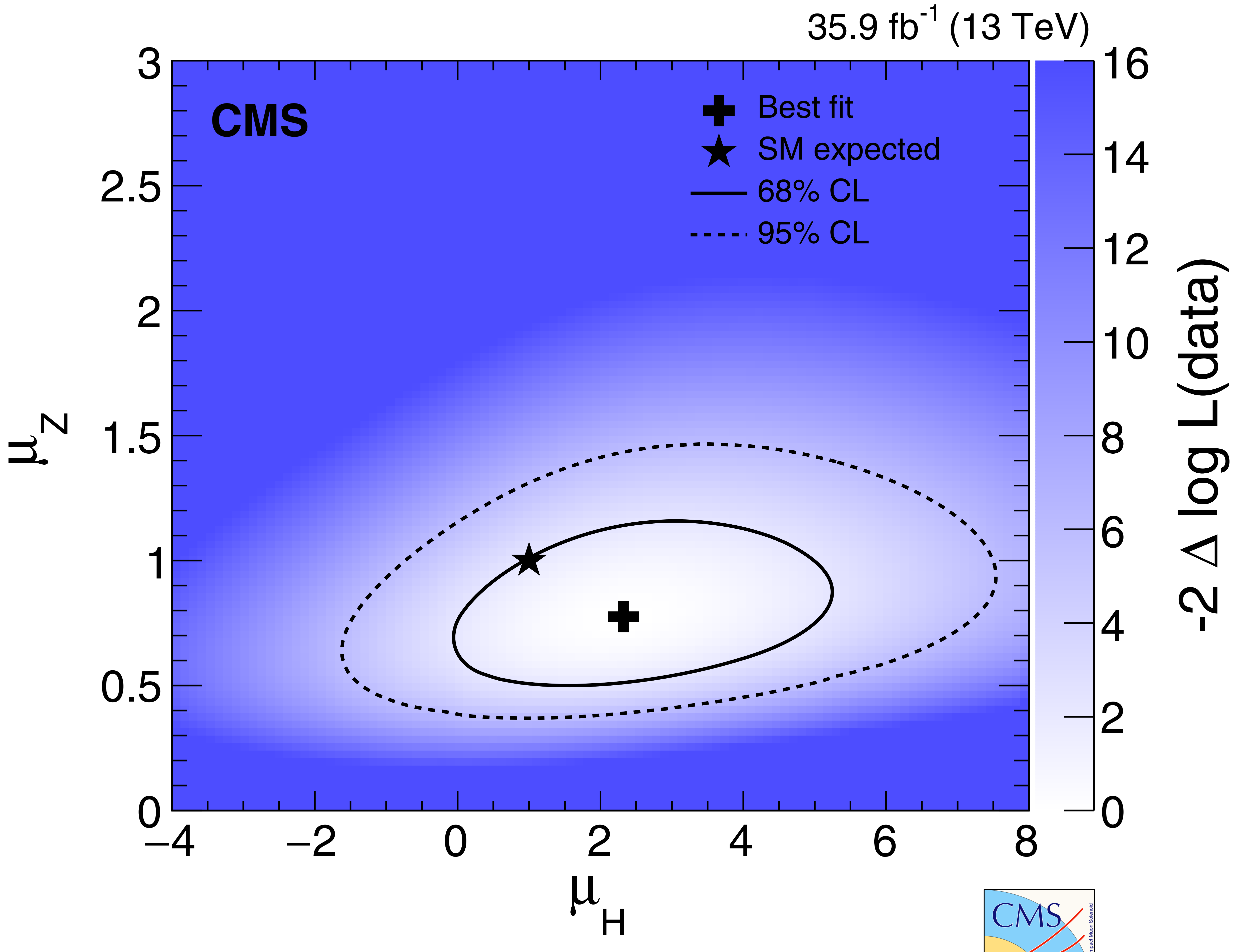
- (1) Start with Powheg HJ normalized (inclusively) to N^3LO
- (2) Powheg p_T spectrum reweighted to 0–2 jet CKKW-L merged LO GGF process (w/ finite top quark mass)
- (3) Cross section corrected by the approximate NLO to LO ratio, obtained by expanding in powers of $1/m_t^2$ up to $1/m_t^4$
- (4) Cross section corrected by the effective NNLO to NLO ratio in the infinite top quark mass approximation.
- 30% uncertainty on final cross section

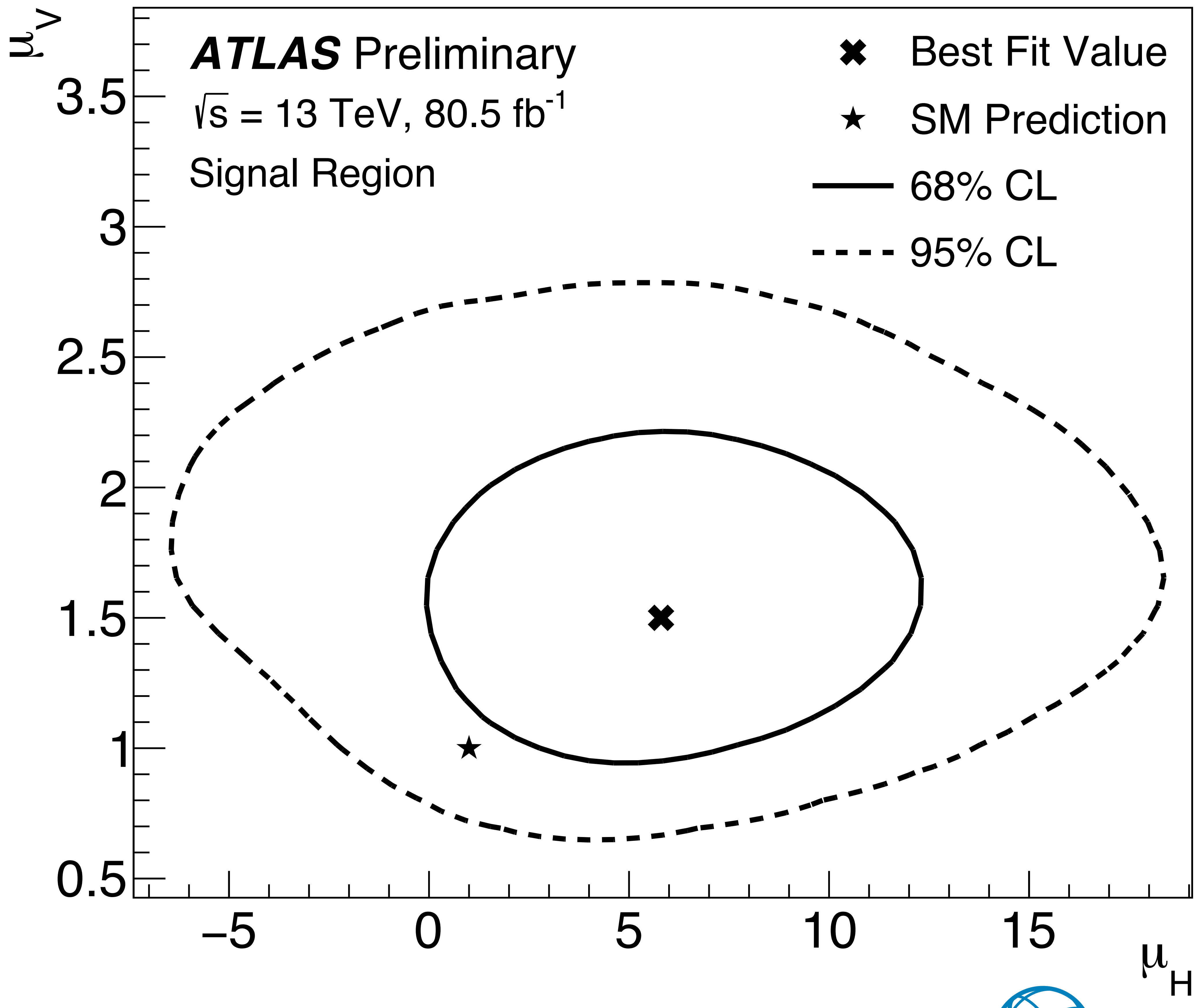
"The overall p_T-dependent correction to the initial N3LO Powheg GGF spectrum is found to be 1.27 ± 0.38, resulting in a GGF cross section times BR of **31.7 ± 9.5 fb for reconstructed Higgs boson p_T > 450 GeV and $|\eta|$ < 2.5**" *(~56 fb w/o BR)*

Higgs (exp): 1.5 (0.7) **σ**, Z (exp): 5.1 (5.8) **σ** *[36 fb^{-1}]*



CMS vs ATLAS





Two results consistent with SM within ~2σ

Conclusions

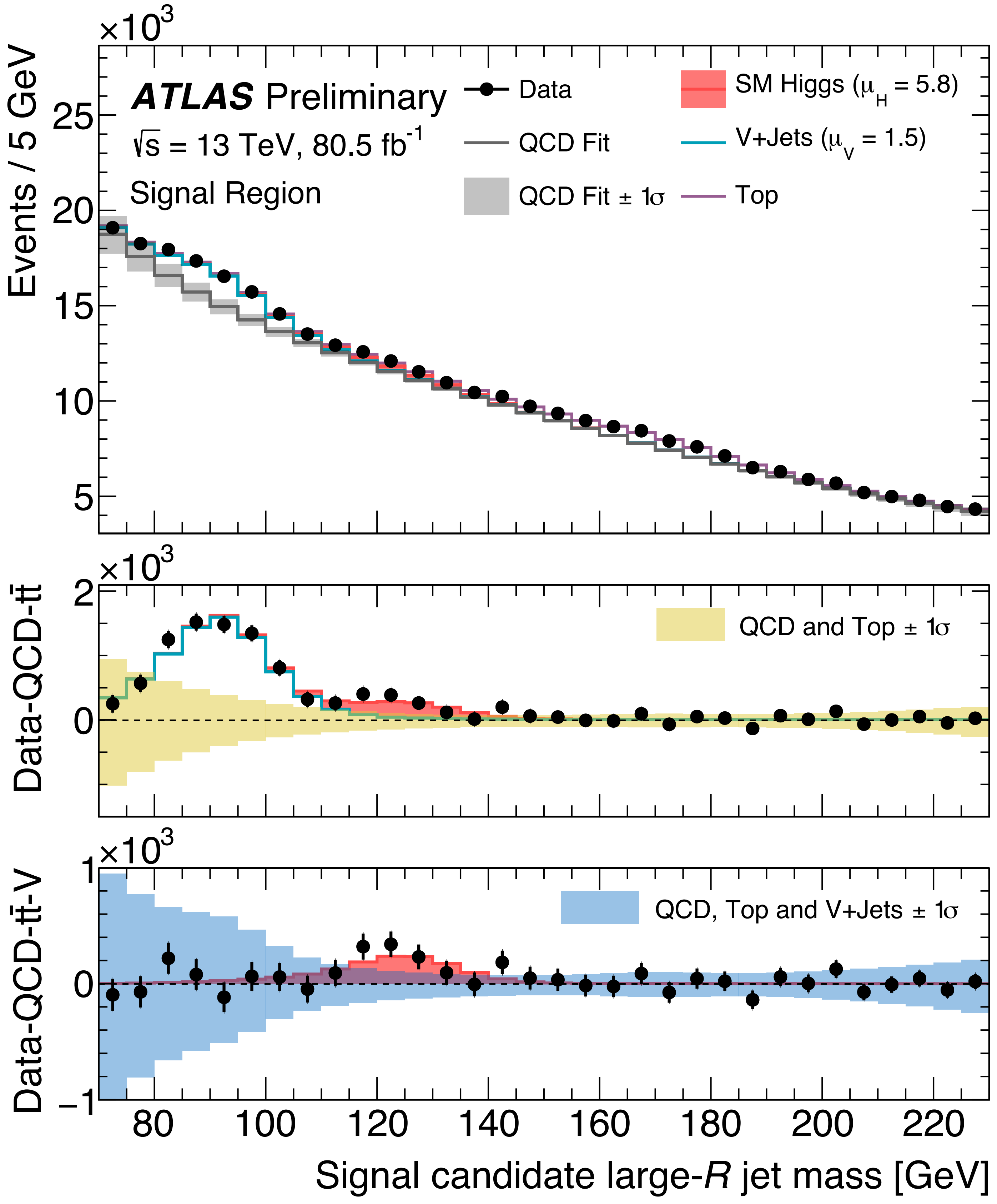
Exciting prospect for measuring H->bb process inclusively!

- Boosted topology is challenging but helps reducing background

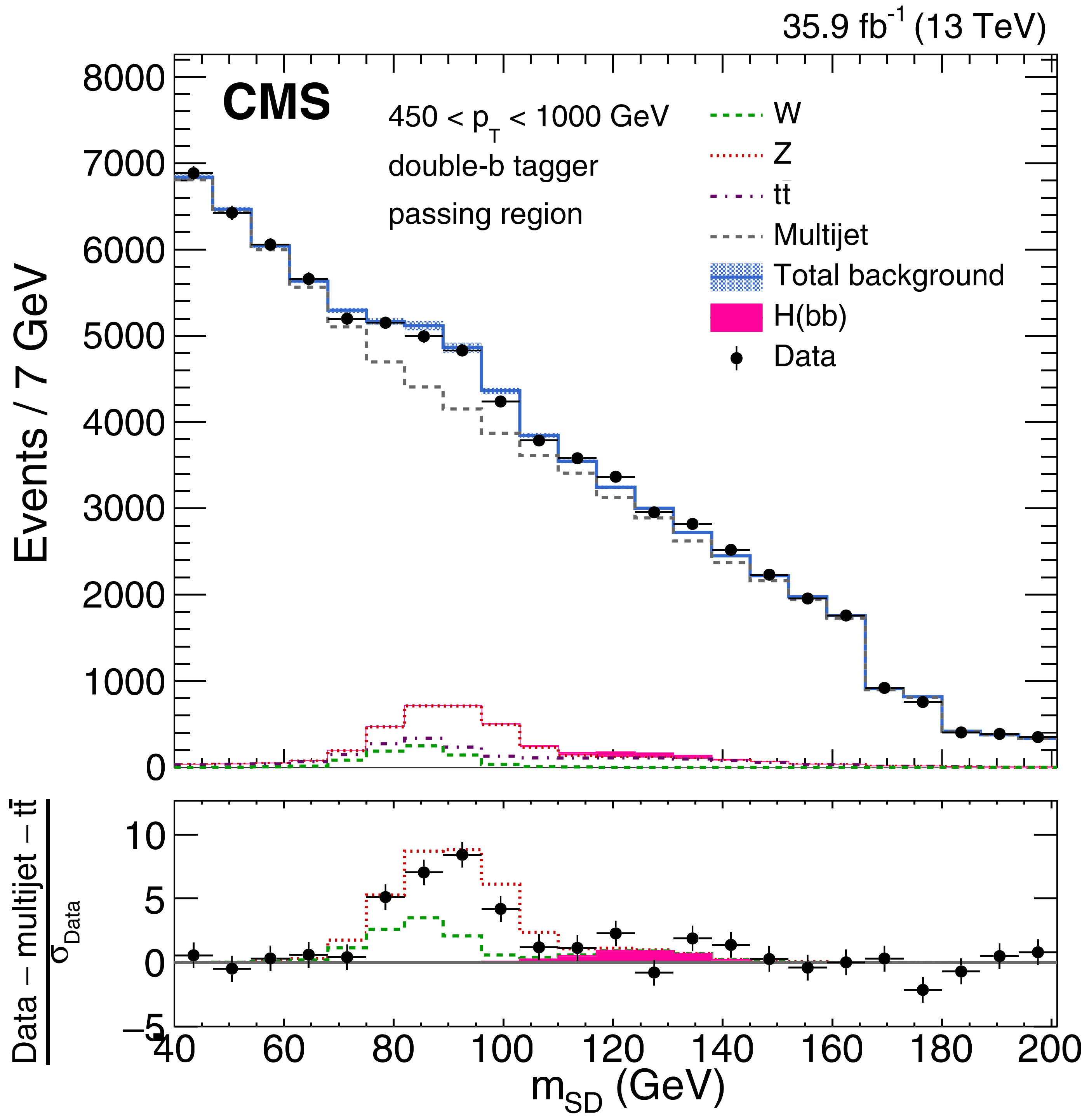
Higgs at high p_T puts the top loop under a microscope

- Sensitive to anomalous couplings, and new particles in the gluon fusion process

First set of recommendations from LHCHXSWG on high pT ggF modeling used in recent ATLAS result [Conf Note]!



[ATLAS-CONF-2018-052]



[PhysRevLett.120.071802]

Backup

Systematics

Systematic source	W/Z	H
Integrated luminosity	2.5%	2.5%
Trigger efficiency	4%	4%
Pileup	<1%	<1%
$N_2^{1,\mathrm{DDT}}$ selection efficiency	4.3%	4.3%
Double-b tag	4% (Z)	4%
Jet energy scale/ resolution	10/15%	10/15%
Jet mass scale (p_T)	0.4%/100 GeV (p_T)	0.4%/100 GeV (p_T)
Simulation sample size	2–25%	4–20% (GGF)
H p_T correction	…	30% (GGF)
NLO QCD corrections	10%	…
NLO EW corrections	15–35%	…
NLO EW W/Z decorrelation	5–15%	…

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