Study of Higgs boson properties in H → WW^* (→ $e\nu\mu\nu$) + 2 jets events

Proseminar “Physik am LHC“

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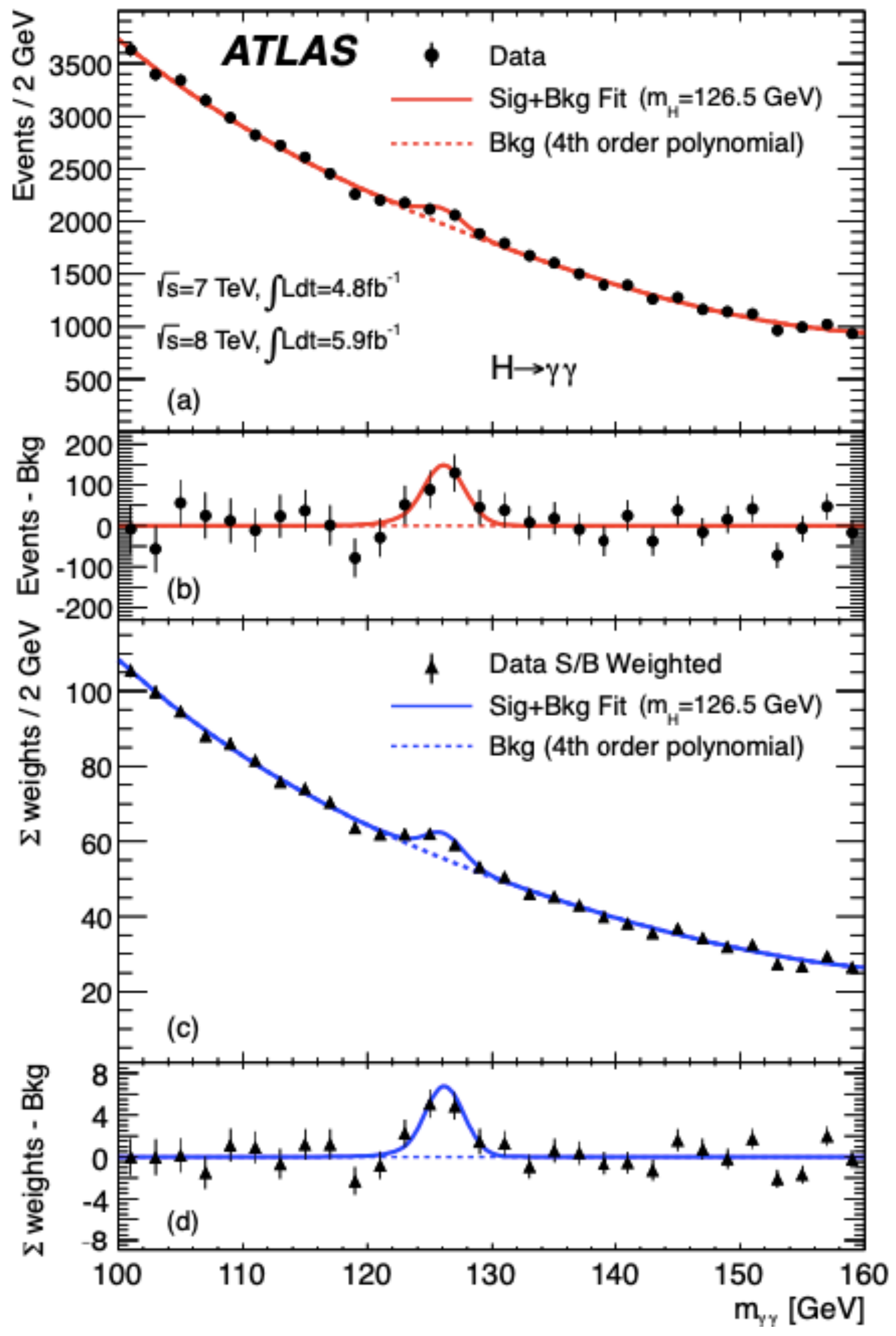
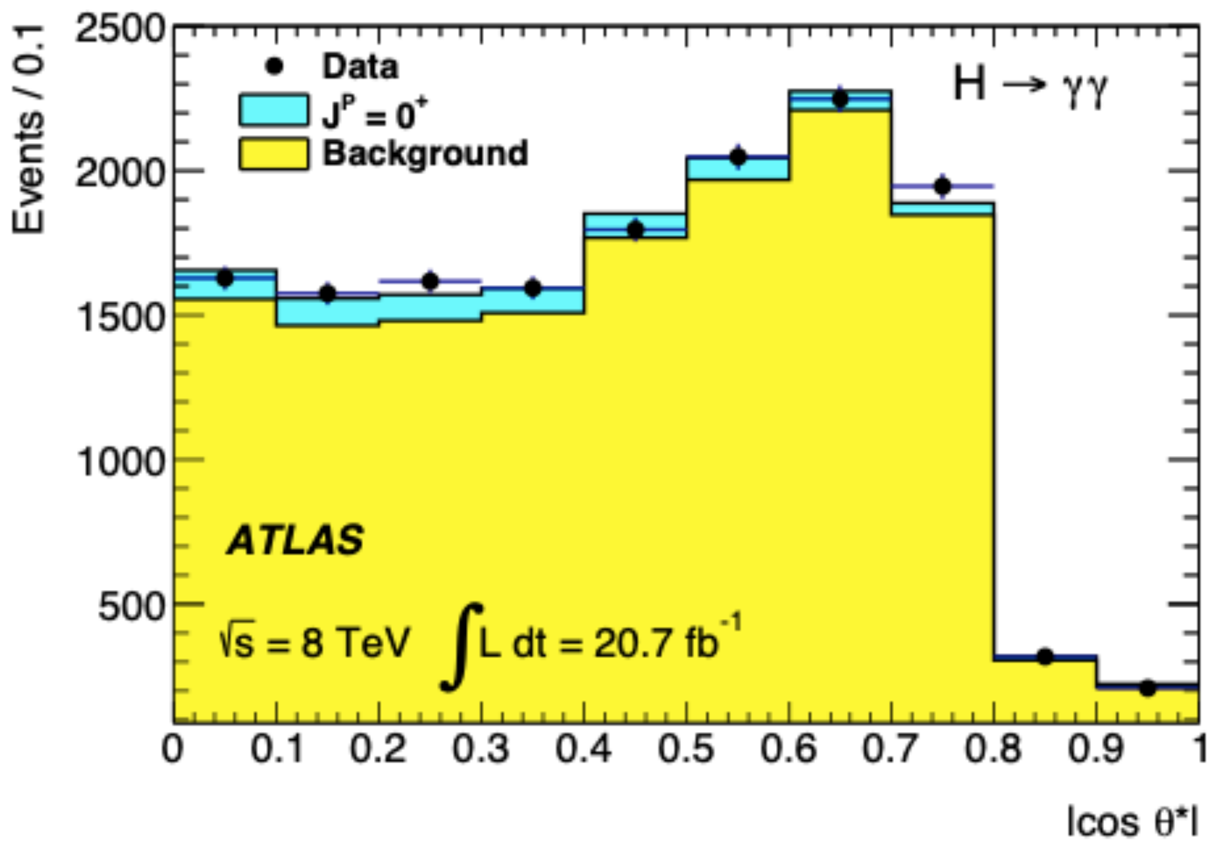
Overview

I. Higgs Boson and its Production
II. Motivation and Approach
III. Theoretical Framework
IV. Data Sets and Monte Carlo Predictions
V. Object Selection
VI. Event Selection
VII. Uncertainties
VIII. Results
IX. Background Reduction (for future studies)

Higgs Boson

- Discovered 2012 at LHC
- Proof for Higgs Mechanism
- $m_H = 125.09 \pm 0.21(\text{stat.}) \pm 0.11(\text{syst.})$ GeV
- A pure CP odd Higgs boson has been excluded at more than 99.9% confidence level (CL)
- Strong hints for $J^P = 0^+$
- **Some open questions**:
    - SM or BSM particle?
    - CP properties of Higgs boson couplings (HVV, ggH, Hff)

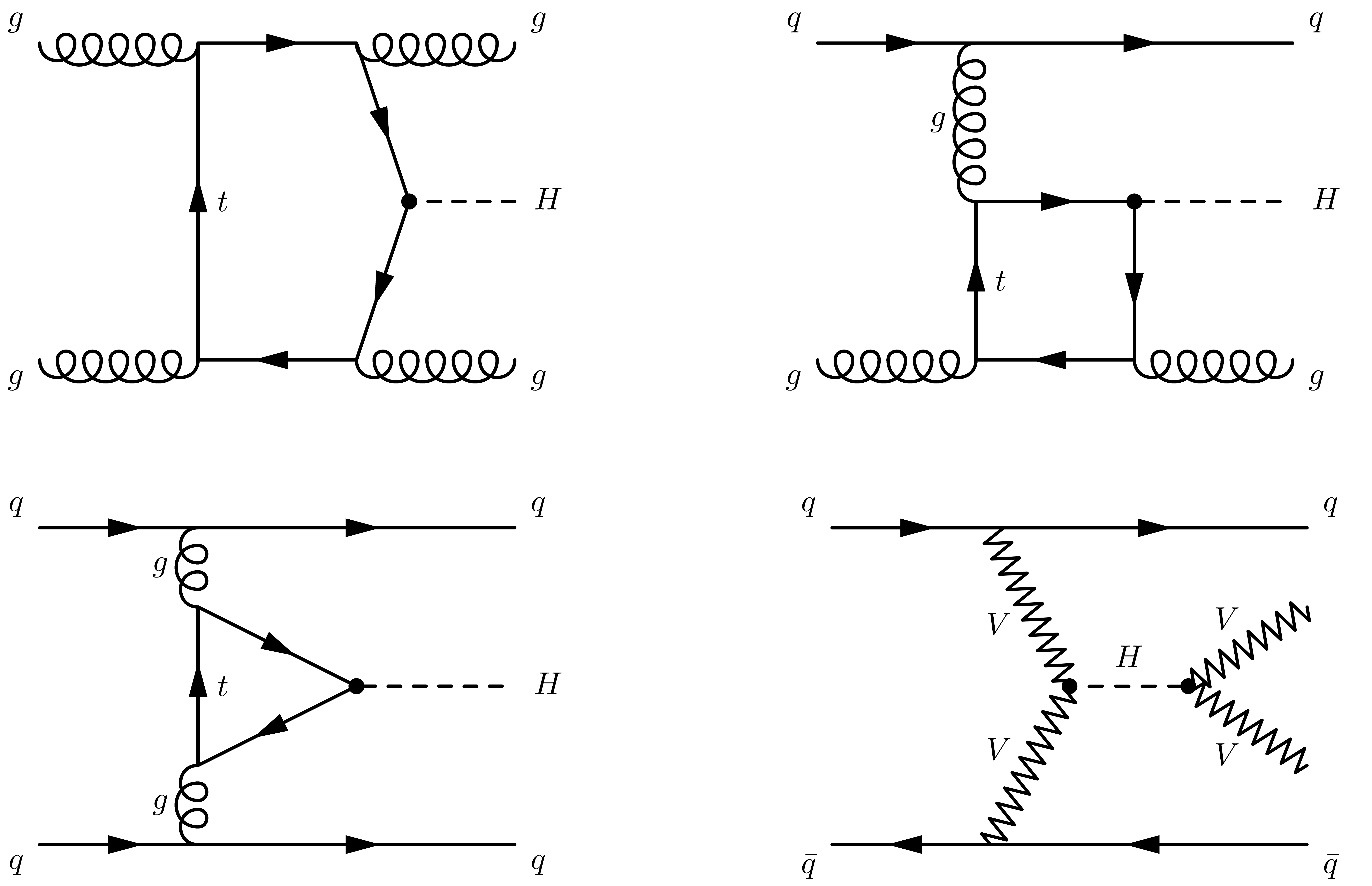




https://arxiv.org/pdf/1207.7235.pdf

https://arxiv.org/pdf/1207.7214.pdf https://arxiv.org/pdf/1307.1432.pdf

Study of Higgs Boson Production in association with two jets



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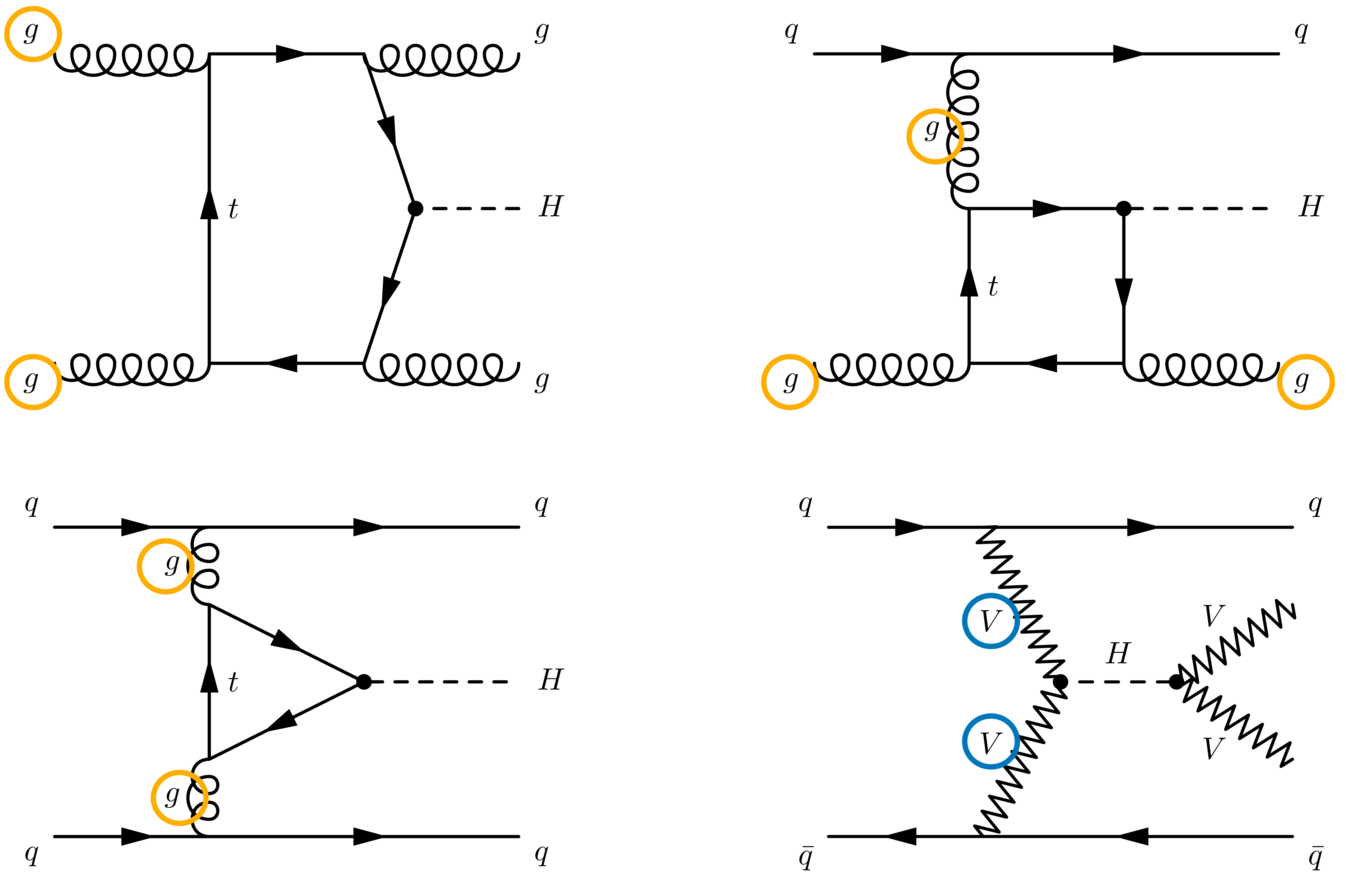
Study of Higgs Boson Production in association with two jets



ggF

VBF

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H $\rightarrow WW^{*}(\rightarrow e\nu\mu\nu)jj$
Motivation

- Studying properties of the Higgs boson looking at WW decay and its production in association with two jets
- **ggF**
  - **Constrain CP properties of effective Higgs-gluon vertex** (in $e\nu\mu\nu jj$ final state)
  - Effects from new particles in gluon-fusion loop
- **VBF**
  - Constrain Higgs boson coupling to longitudinally and transversely polarised W/Z boson in production and decay
  - Strength of Higgs coupling to longitudinally polarised W boson ensures unitarity of SM
  - CP even Higgs boson is assumed
- Are there deviations from the SM expectations?

H → $WW^*(\rightarrow e\nu\mu\nu)jj$

Experimental Approach

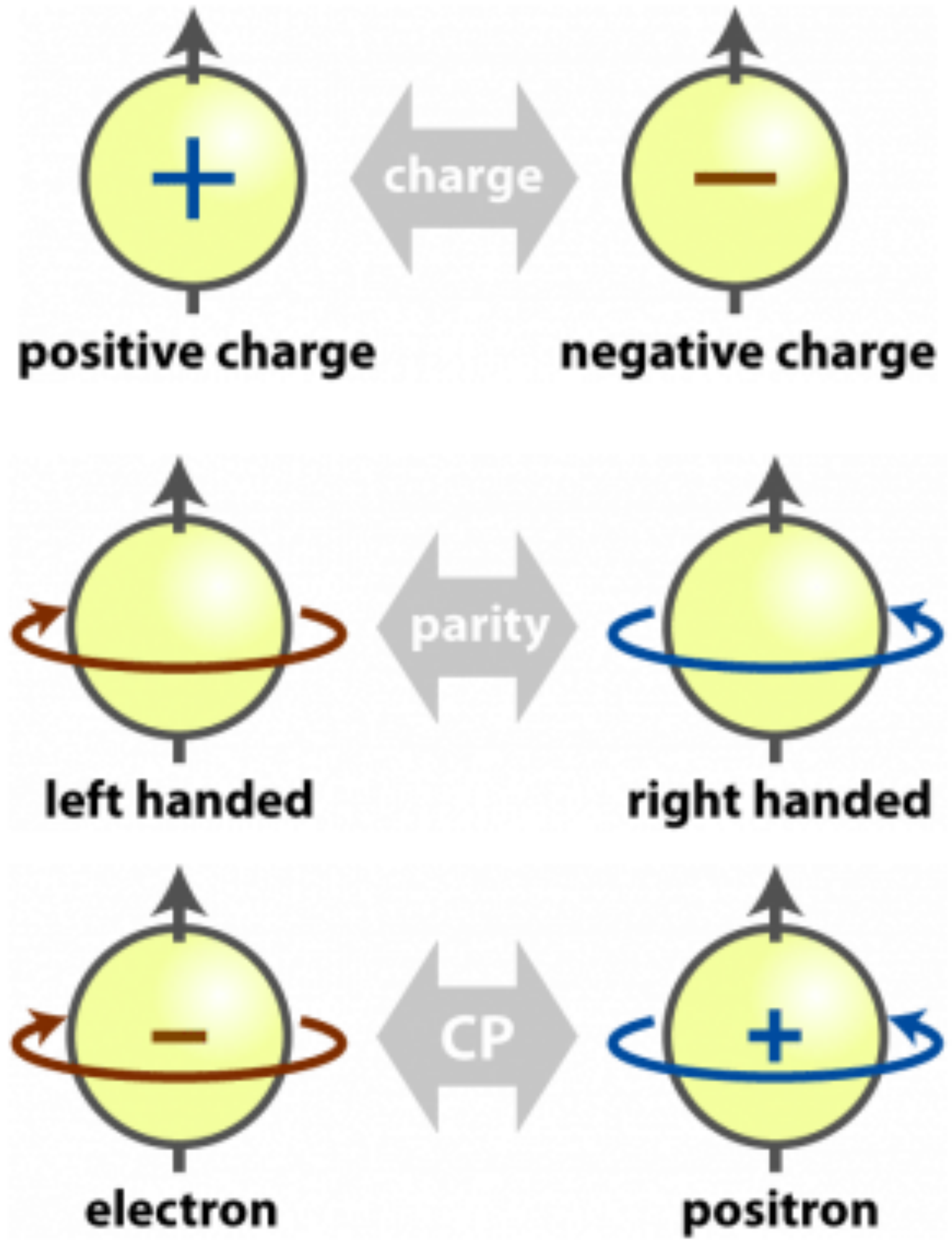
- Based on data collected from the ATLAS detector (36.1 fb^{-1}, $\sqrt{s}$= 13 TeV) 2015 and 2016

- Using $\Delta\Phi_{jj}$ between two leading jets

$\Delta\Phi_{jj} = \phi_{j1} - \phi_{j2}$ with $\eta_{j1} > \eta_{j2}$ and $\Delta\Phi_{jj} = \phi_{j2} - \phi_{j1}$ with $\eta_{j2} > \eta_{j1}$

$\eta = -\ln(\tan(\theta/2))$

CP Violation



- Symmetry is a physical or mathematical feature of the system that is preserved or remains unchanged under some transformation
- Charge Symmetry (C); Parity Symmetry (P)
- Violation of combined CP Symmetry = CP Violation
- $CP\,|P\rangle = \pm\,|\overline{P}\rangle$ → CP even/odd
- CP Violation in the SM: Weak interaction violates CP Symmetry
  - Meson-Antimeson oszillations, Quark mixing (V_{CKM}), Neutrino mixing (V_{PMNS})
  - Only slightly violated
- CPT Symmetry as basic principles of quantum field theory → Time reversal symmetry also violated
- Necessary to explain the observed baryon asymmetry of the universe, but SM CP Violation is not great enough

→ Search for new sources of CP Violation e.g. in Higgs Interaction

Theoretical Framework

ggF

scale factor for CP even interaction

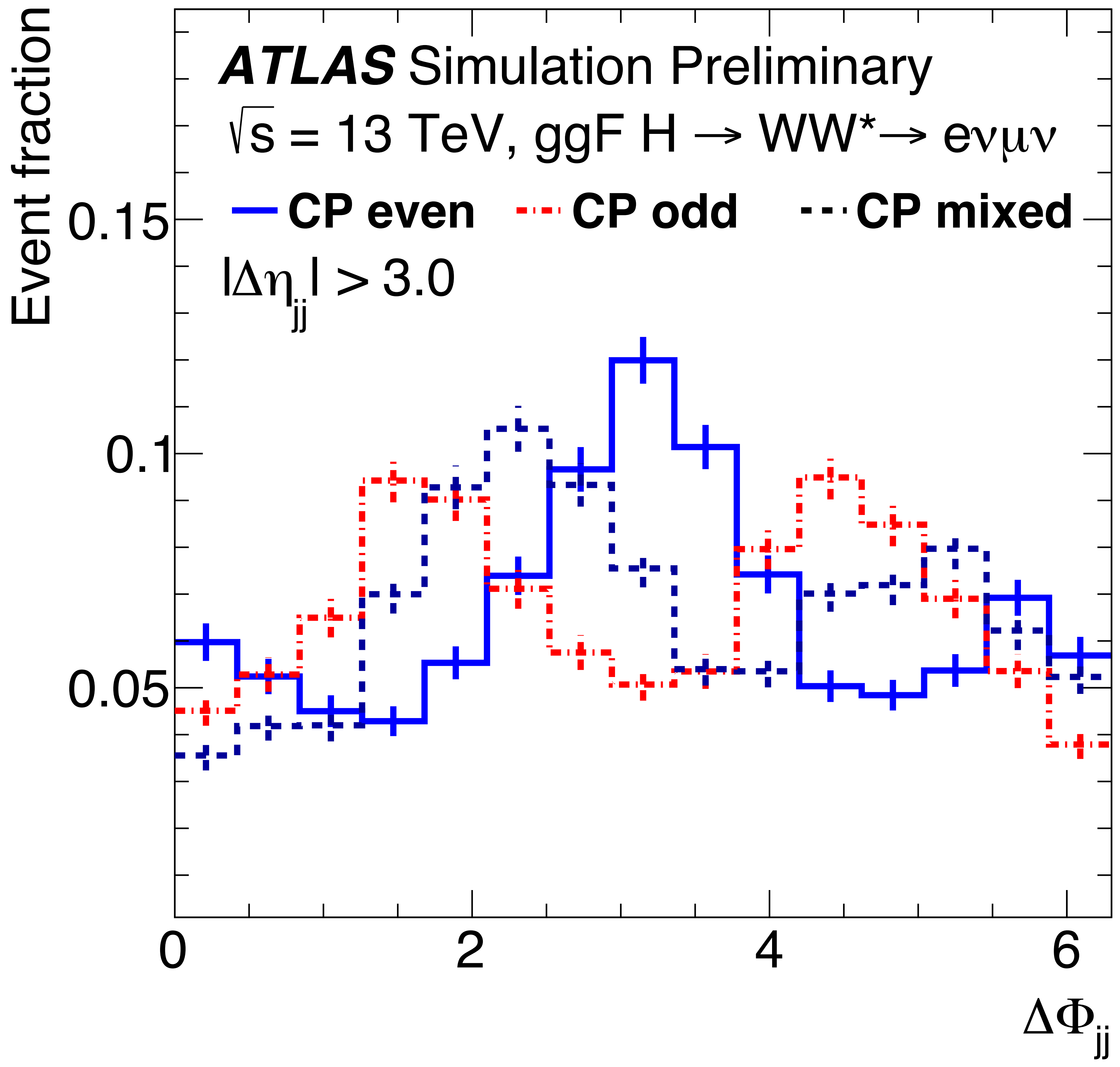
scale factor for CP even interaction

$$\mathcal{L}_0^{\text{loop}} = -\frac{1}{4}\left(\kappa_{Hgg} g_{Hgg} G^a_{\mu\nu} G^{a,\mu\nu} + \kappa_{Agg} g_{Hgg} G^a_{\mu\nu} \tilde{G}^{a,\mu\nu}\right) H$$

effective coupling (SM CP-even ggH interaction)

Gluon field strength tensor

- **CP-even** $\kappa_{Hgg} = 1,\ \kappa_{Agg} = 0$ **(SM)**
- **CP-odd** $\kappa_{Hgg} = 0,\ \kappa_{Agg} = 1$
- **CP-mixed** $\kappa_{Hgg} = \frac{1}{\sqrt{2}},\ \kappa_{Agg} = \frac{1}{\sqrt{2}}$



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Theoretical Framework

VBF

- Polarisation-dependent coupling-strength scale factors $a_L = \frac{g_{HV_LV_L}}{g_{HVV}}$ $a_T = \frac{g_{HV_TV_T}}{g_{HVV}}$
- Mixed-polarisation couplings do not contribute

Lorentz invariant pseudo observables

$$\mathcal{L} = \kappa_{VV}\left(\frac{2m_W^2}{v}HW_\mu^+W^{-\mu} + \frac{m_Z^2}{v}HZ_\mu Z^\mu\right) - \frac{\varepsilon_{VV}}{2v}\left(2HW_{\mu\nu}^+W^{-\mu\nu} + HZ_{\mu\nu}Z^{\mu\nu} + HA_{\mu\nu}A^{\mu\nu}\right)$$

$\kappa_{VV} \simeq a_L\,, \quad \varepsilon_{VV} \simeq 0.5\cdot(a_T - a_L)$ (Approximation based on Madgraph5_aMC@NLO simulations)

→ **SM** $a_L = a_T = 1$ and $\kappa_{VV} = 1$ $\varepsilon_{VV} = 0$

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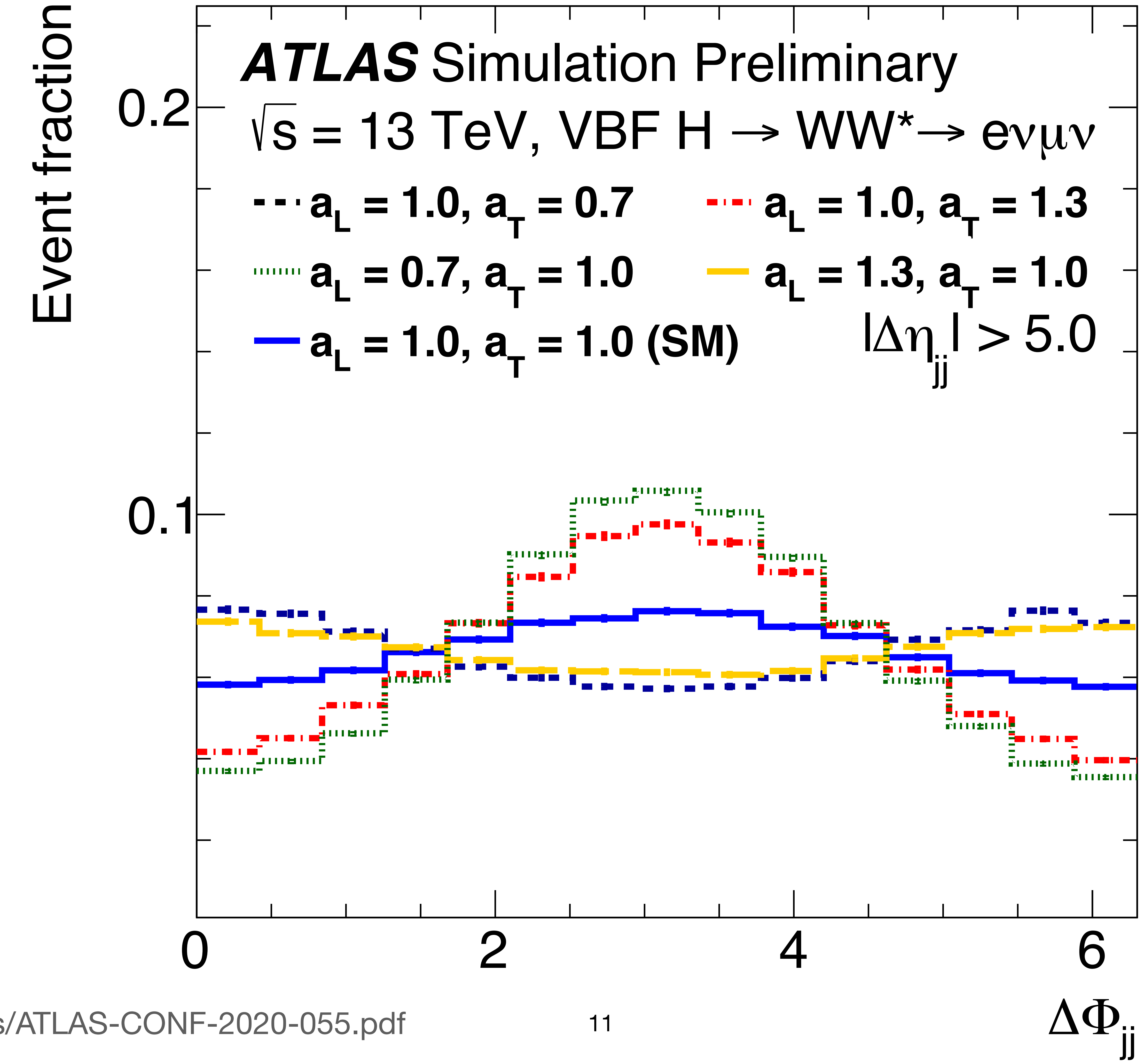
Theoretical Framework

VBF



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Data Sets and Monte Carlo Predictions
ggF/VBF

- ggF
  - Three different Monte-Carlo samples: CP-even, CP-odd, CP-mixed
  - $H \to WW^* \to e\nu\mu\nu$ is modelled according to SM
  - VBF is considered background
- VBF
  - For BSM helicity amplitudes are modified to account for deviations in Higgs coupling strengths
- Other Higgs boson decay or productions are either fixed to SM predictions or neglected (VH, $H \to \tau\tau$, $t\bar{t}H$, $b\bar{b}H$)
- Simulated events using $\sqrt{s}$= 13 TeV, passed trough full ATLAS detector simulation and overlaid with additional inelastic pp interactions (generated with PYTHIA 8) to match pile-up conditions

Process	Matrix element (alternative model)	UEPS	PDF set	Prediction order for total cross-section
ggF	MG5_aMC@NLO v2.4.2	Pythia 8.212	NNPDF3.0 NLO	NNNLO QCD
	(MG5_aMC@NLO v2.4.2 + Herwig 7.0.1)			
VBF ($a_{\mathrm{L}} = 1$, $a_{\mathrm{T}} = 1$)	MG5_aMC@NLO v2.4.2	Pythia 8.212	NNPDF3.0 NLO	NNLO QCD + NLO EW
VBF	Powheg-Box v2	Pythia 8.212	PDF4LHC15 NLO	NNLO QCD + NLO EW
	(MG5_aMC@NLO v2.3.3 + Pythia 8.212)			
	(Powheg-Box v2 + Herwig 7.0.1)			
VH	Powheg-Box v2	Pythia 8.186	PDF4LHC15 NLO	NNLO QCD + NLO EW
$t\bar{t}$	Powheg-Box v2	Pythia 8.210	NNPDF3.0 NLO	NNLO+NNLL QCD
	(Sherpa v2.2.1)			
	(Powheg-Box v2 + Herwig 7.0.1)			
Wt	Powheg-Box v2	Pythia 6.428	CT10	NLO QCD
	(MG5_aMC@NLO v2.2.2 + Herwig++)			
	(Powheg-Box v2 + Herwig++)			
$WZ/\gamma^\star$, $ZZ/\gamma^\star$	Sherpa v2.2.2		NNPDF3.0 NNLO	NLO QCD
	(MG5_aMC@NLO v2.3.3 + Pythia 8.212)			
$W\gamma, Z\gamma$	Sherpa v2.2.2		NNPDF3.0 NNLO	NLO QCD
	(MG5_aMC@NLO v2.3.3 + Pythia 8.212)			
$qq, qg \to WW$	Sherpa v2.2.2		NNPDF3.0 NNLO	NLO QCD
	(MG5_aMC@NLO 2.3.3 + Pythia 8.212)			
$gg \to WW$	Sherpa v2.1.1		CT10	NLO QCD
$Z/\gamma^\star$	Sherpa v2.2.1		NNPDF3.0 NNLO	NNLO QCD
	(MG5_aMC@NLO v2.2.2 + Pythia 8.186)			

relevant background

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Object Selection

Electron

$\eta = -\ln(\tan(\theta/2))$

- Reconstructed from tracks in the inner tracking detector matched to energy deposits in den EM calorimeter system
- Events triggered using single-lepton and dilepton triggers
  - p_T 24-26 GeV for single-electron trigger
  - $p_T > 17$ GeV for dilepton trigger required
- $|\eta| < 2.47$ excluding $1.37 < |\eta| < 1.52$
- Hadrons and soft leptons from heavy-flavour decays are misidentified as prompt leptons

→ Identification efficiency 88%-94%

- Removed if reconstructed μ shares ID track
- Removed if within $\Delta R = \min(0.4, 0.04+10\ \text{GeV}/p_T)$ of axis of surviving jet

http://cdsweb.cern.ch/record/2743624/files/ATLAS-CONF-2020-055.pdf

Object Selection

Muon

- Reconstructed from combined tracks using information from inner tracking detector and muon spectrometer
- Events triggered using single-lepton and dilepton triggers
  - p_T 20-26 GeV for single-muon trigger
  - $p_T > 14$ GeV for dilepton trigger
- $|\eta| < 2.5$
- Hadrons and soft leptons from heavy-flavour decays are misidentified as prompt leptons

→ Identification efficiency close to 95%

- Removed if within ΔR = min(0.4, 0.04+10GeV/pT) of axis of surviving jet

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Object Selection
Jets

- Reconstructed from noise-suppressed topological cluster of energy deposits in calorimeter system (using anti-k_t algorithm)
- Four-momentum is corrected with scale factors (p_T, η dependent)
- $|\eta| < 4.5$ and $p_T > 30$ GeV
- Two classifiers (based on calorimeter & tracking information and jet shapes & topological jet correlations in pile-up interactions) to reduce contamination from jets from pile-up vertices
- B jets identified with MV2c10 b-tagging algorithm (efficiency of 85%)
- Discarded if within a cone ΔR = 0.2 around e candidate
- Discarded if less than 3 associated tracks within cone ΔR = 0.2 around μ candidate

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Event Selection

Events consistent with H ($\rightarrow WW \rightarrow e\nu\mu\nu$) + 2 jets are selected

	ggF + 2 jets	VBF
Preselection	Two isolated, different-flavour leptons ($\ell = e, \mu$) with opposite charge $p_{\mathrm{T}}^{\mathrm{lead}} > 22\ GeV$, $p_{\mathrm{T}}^{\mathrm{sublead}} > 15\ GeV$ $m_{\ell\ell} > 10\ GeV$ $N_{\mathrm{jet}} \geq 2$	
Background rejection	$N_{b-\mathrm{jet},(p_{\mathrm{T}}>20\ \mathrm{GeV})} = 0$ $m_{\tau\tau} < 66$ GeV	
	$\Delta R_{jj} > 1.0$ $p_{\mathrm{T},\ell\ell} > 20\ GeV$ $m_{\ell\ell} < 90\ GeV$ $m_{\mathrm{T}} < 150\ GeV$	central jet veto outside lepton veto
BDT input variables	$m_{\ell\ell}$, m_{T}, $p_{\mathrm{T},\ell\ell}$, $\Delta\phi_{\ell\ell}$ $\min \Delta R(\ell_1, j_i)$, $\min \Delta R(\ell_2, j_i)$	m_{jj}, ΔY_{jj}, $m_{\ell\ell}$, m_{T}, $\Delta\phi_{\ell\ell}$ $\sum_{\ell} C_{\ell}$, $\sum_{\ell,j} m_{\ell,j}$, $p_{\mathrm{T}}^{\mathrm{tot}}$

central jet veto: rejects events with additional jets (pT>20 GeV) in rapidity gap between 2 leading jets

outside lepton veto: requires ll within rapidity gap between 2 leading jets

BDT: "Boosted decision trees"

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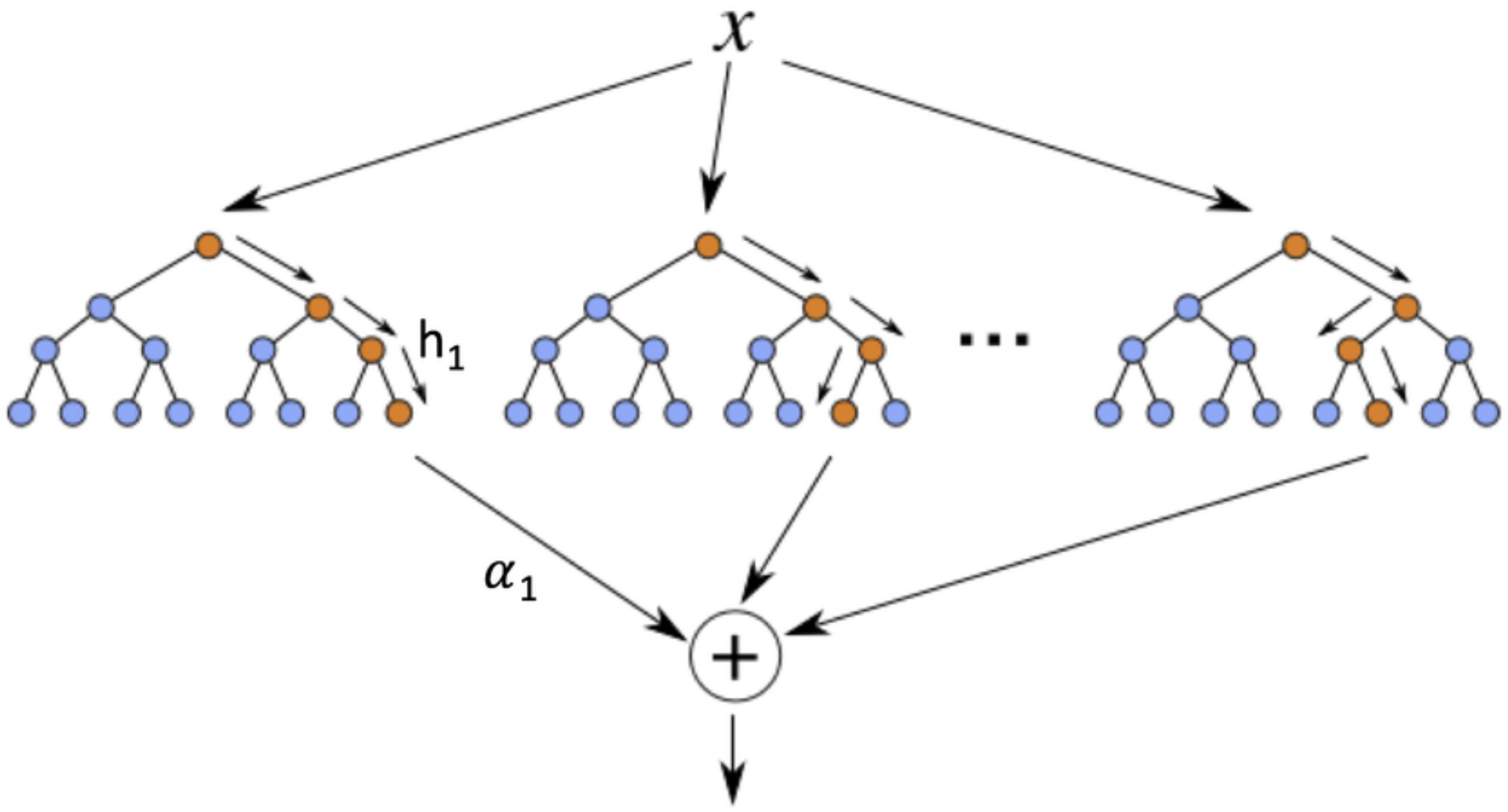
Boosted Decision Trees

Maschine Learning



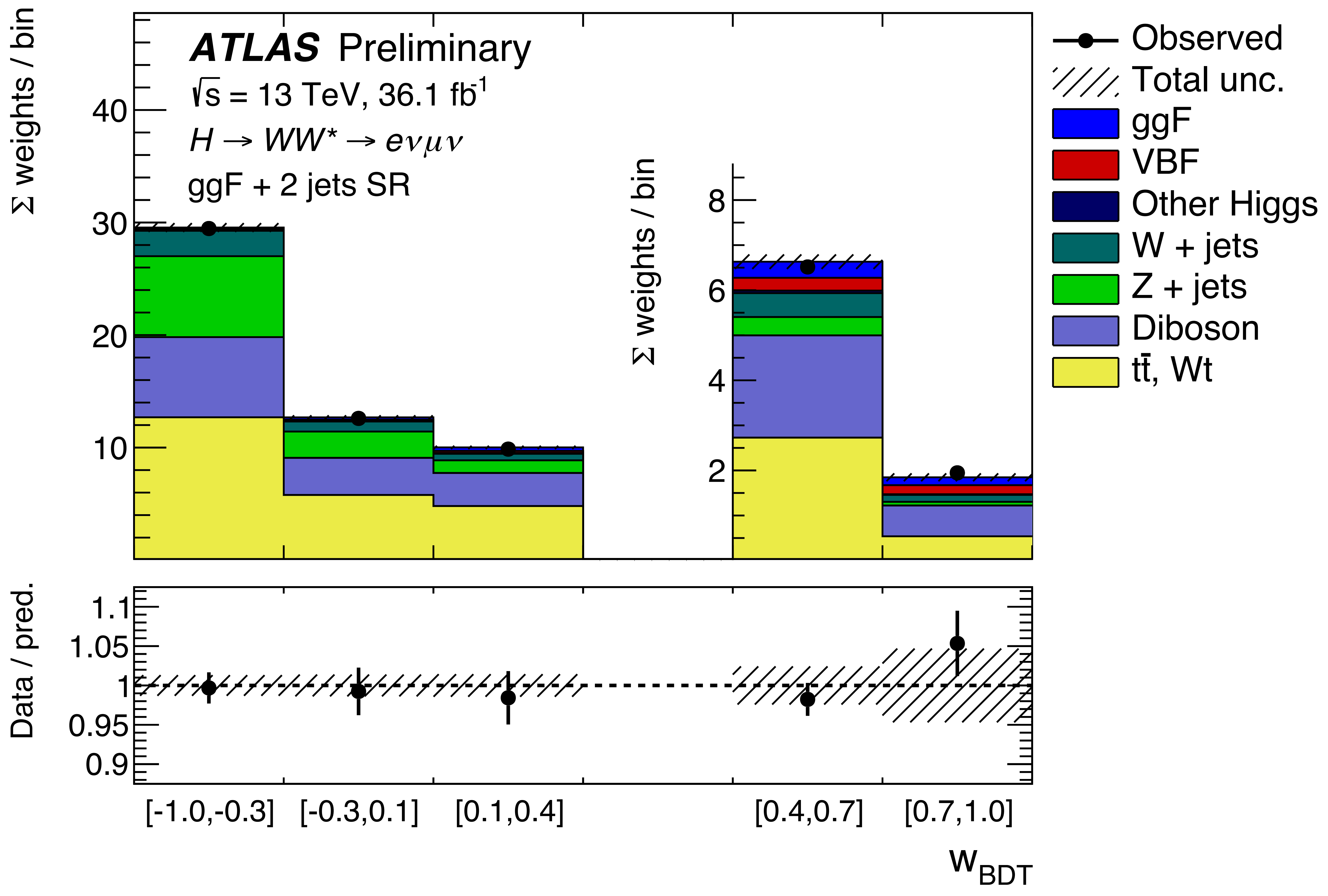
- Decision tree: Takes set of input features and splits input data recursively based on those features
- Boosting: Method of combining many weak learners trees into a strong classifier, the tree’s output is given a weight relative to its accuracy
- Benefits: Fast, Easy to tune, Not sensitive to scale, Good performance

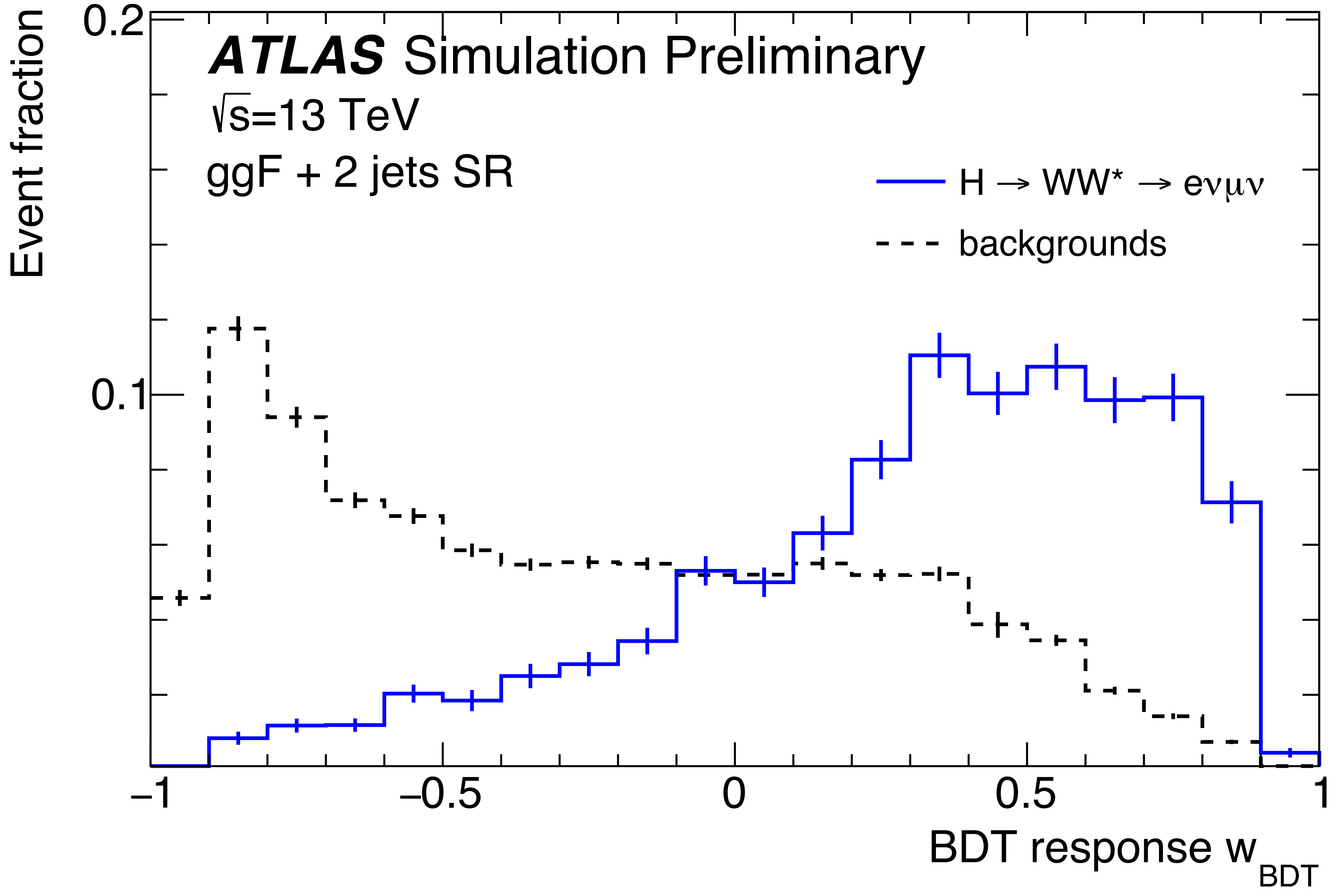
https://www.nikhef.nl/~h71/Lectures/2015/ppII-cpviolation-29012015

https://www.researchgate.net/figure/fig2_325632132

Event Selection

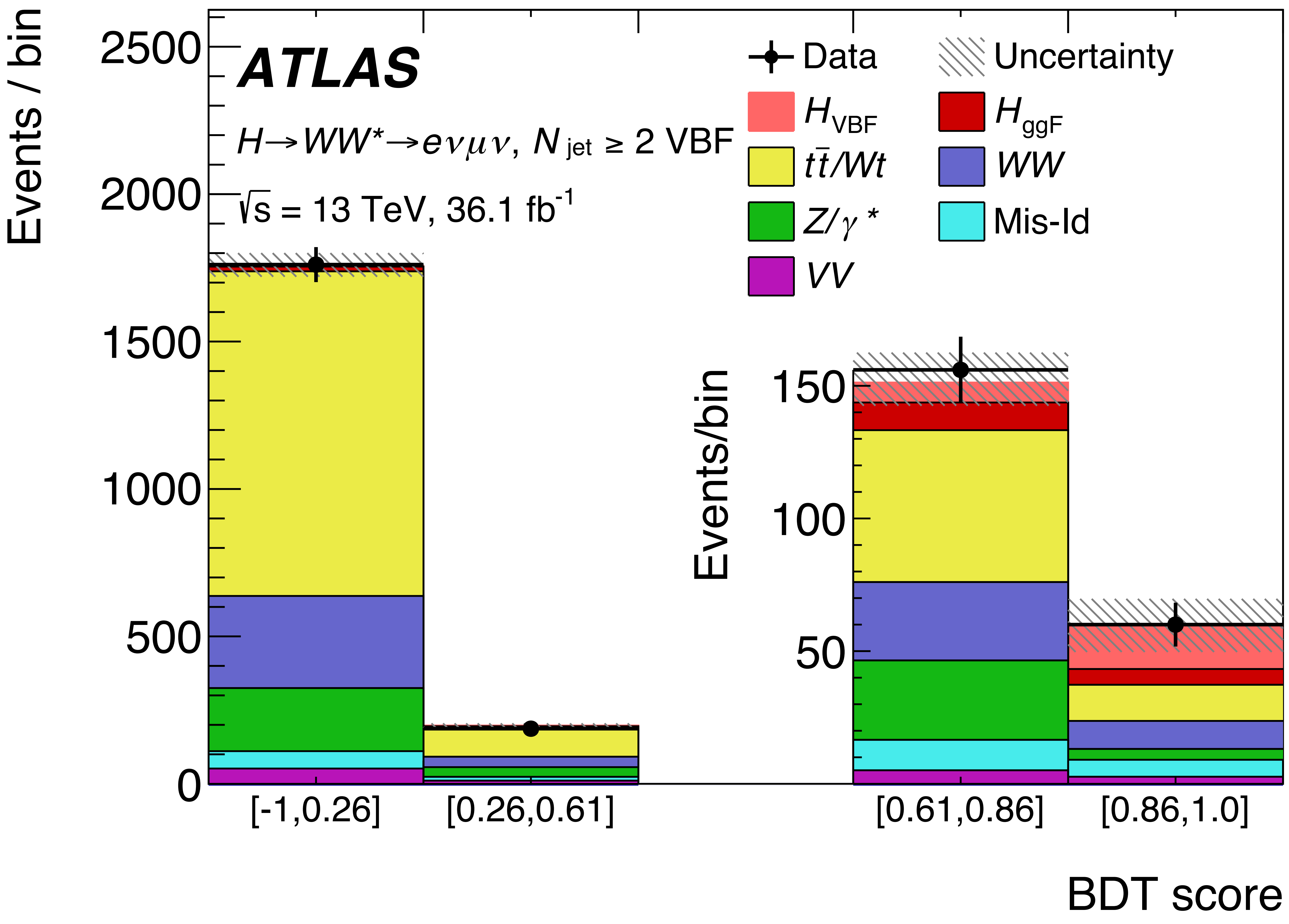
ggF





Event Selection

VBF



https://arxiv.org/pdf/1808.09054

Event Selection

Background

Control region	ggF + 2 jets	VBF
top CR	$N_{b-\text{jet},(p_\text{T}>30\ GeV)} = 1$	$N_{b-\text{jet},(p_\text{T}>20\ GeV)} = 1$
$Z \rightarrow \tau\tau$ CR	$\lvert m_{\tau\tau} - m_Z \rvert \leq 25\ GeV$	
	$p_{\text{T},\ell\ell}$ requirement is omitted	$m_{\ell\ell}$ ¡ 80 GeV
WW CR	$m_{\ell\ell} > 90\ GeV$ m_T requirement is omitted	—-

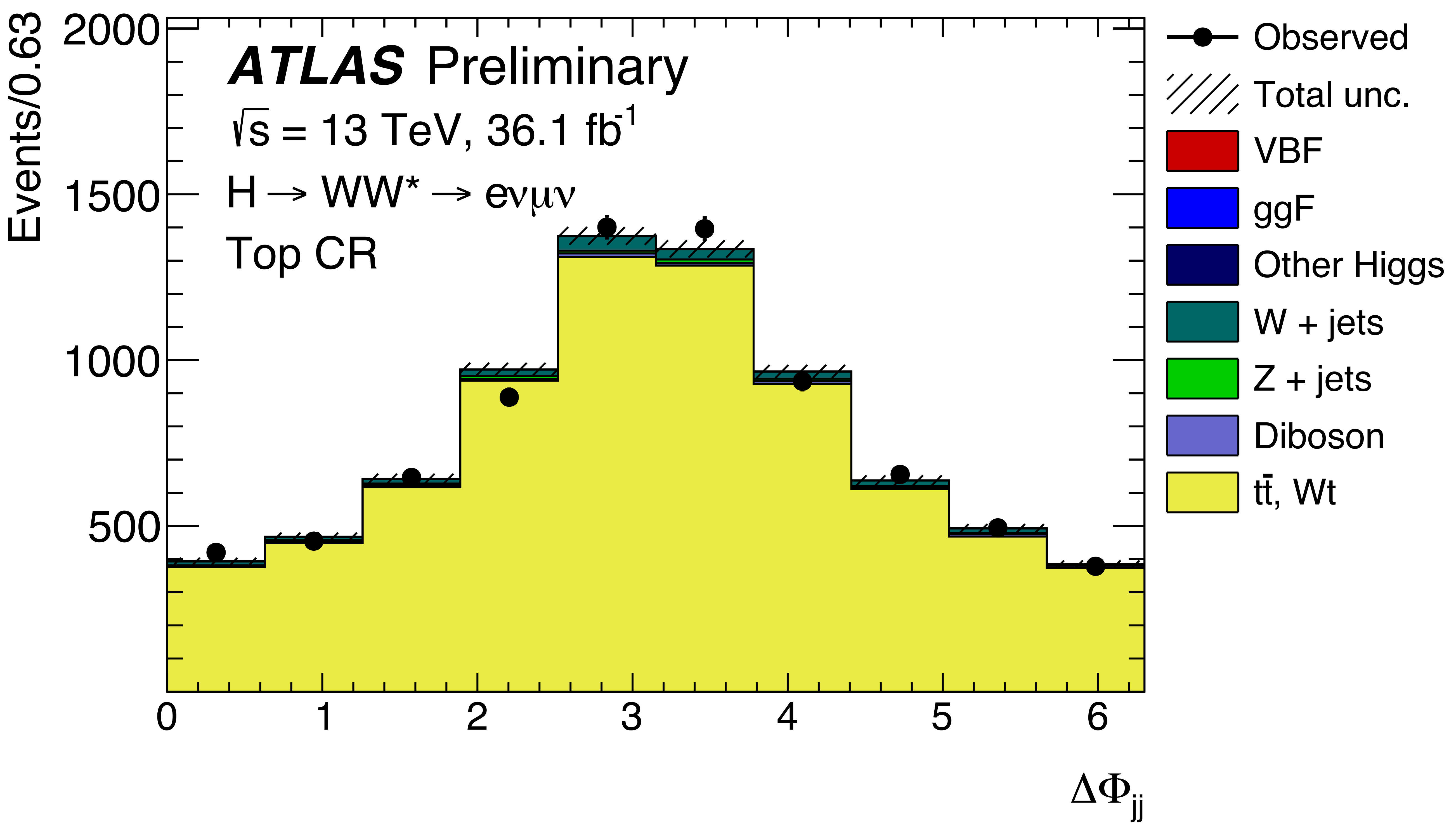
- **Control Regions**
  - Excluded to the signal region
  - Used for normalisation of most dominant background processes
  - Different CRs for different backgrounds
- Low contributing backgrounds estimated with MC simulation
- Misidentified leptons backgrounds estimated by scaling a control sample (events with one identified and one anti-identified lepton) via extrapolation factors (p_T and η dependent, ratio identified l/anti-identified l)

http://cdsweb.cern.ch/record/2743624/files/ATLAS-CONF-2020-055.pdf

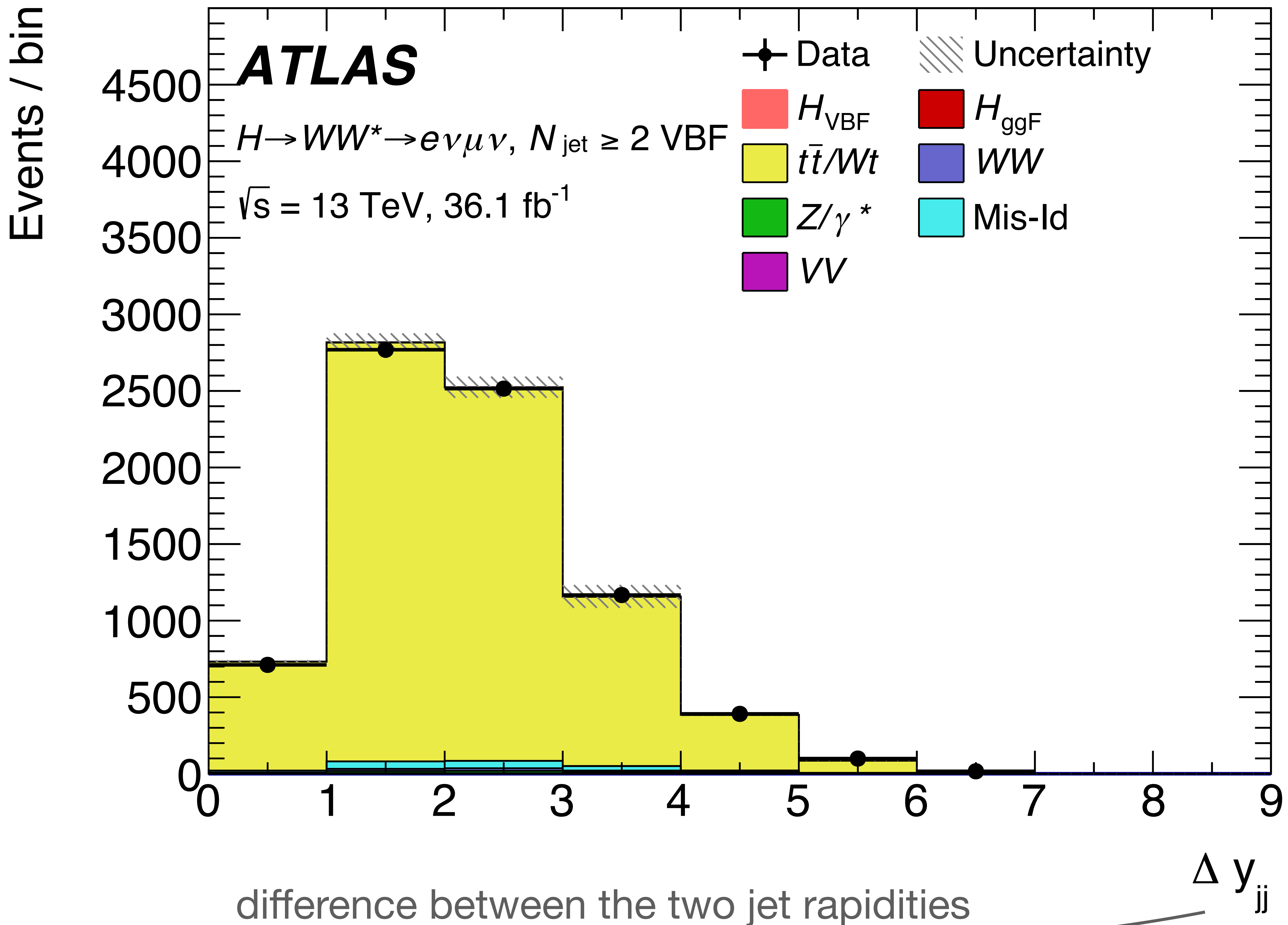
Event Selection

Background

ggF



VBF



difference between the two jet rapidities

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https://arxiv.org/pdf/1808.09054

Uncertainties

- Experimental
  - B-tagging efficiency, jet energy scale and resolution, pile-up activity modelling, estimation of misidentified lepton background
- Theoretical
  - Modelling uncertainties, assessed by comparing nominal and alternative event generators and UEPS models
  - Most significant: Modelling t, WW background, ggF process
  - ggF and VBF dominated by statistical uncertainties

Uncertainties

ggF

Source	$\Delta\left(\kappa_{Agg}/\kappa_{Hgg}\right)$
Total data statistical uncertainty	0.4
SR statistical uncertainty	0.33
CR statistical uncertainty	0.10
MC statistical uncertainty	0.14
Total systematic uncertainty	0.28
Theoretical uncertainty	0.23
Top quark bkg.	0.15
ggF signal	0.14
WZ, ZZ, $W\gamma$, $Z\gamma$ bkg.	0.06
WW bkg.	0.06
Z/γ^* bkg.	0.016
VBF bkg.	0.015
Experimental uncertainty	0.21
b-tagging	0.16
Modelling of pile-up	0.10
Jets	0.07
Misidentified leptons	0.04
Luminosity	0.034
Total	0.5

VBF

Source	$\Delta\kappa_{VV}$
Total data statistical uncertainty	0.11
SR data statistical uncertainty	0.10
CR data statistical uncertainty	0.019
MC statistical uncertainty	0.035
Total systematic uncertainty	0.12
Theoretical uncertainty	0.10
Top quark bkg.	0.072
WW bkg.	0.062
ggF bkg.	0.022
Z/γ^* bkg.	0.017
VBF signal	0.019
Experimental uncertainty	0.050
b-tagging	0.014
Jet	0.026
Misidentified leptons	0.041
Luminosity	0.011
Total	0.17

Results

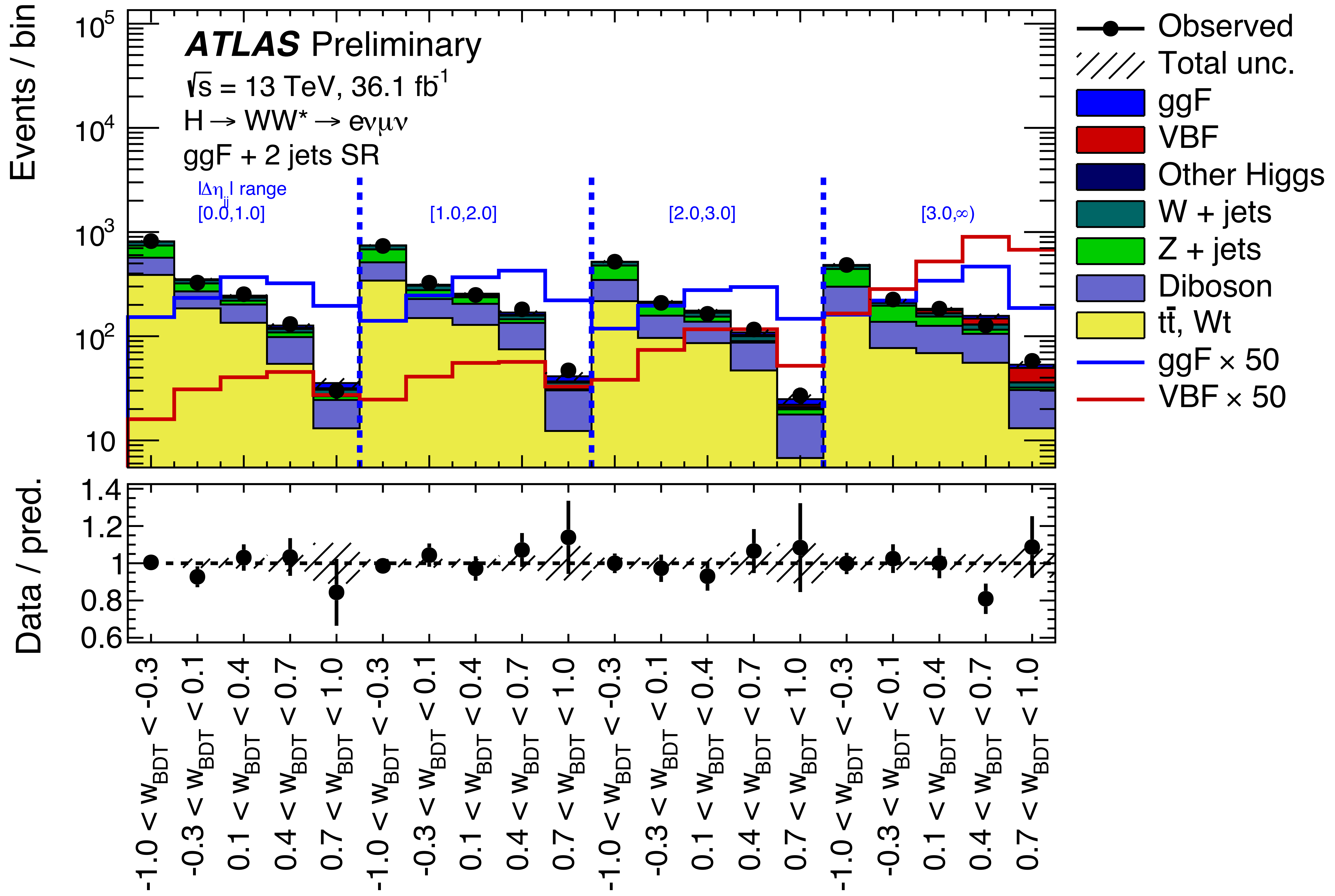
ggF

1. Signal strength parameter

$$\mu^{\text{ggF+2jets}} = \frac{\text{measured signal}}{\text{SM predicted signal}}$$

→ $\mu^{\text{ggF+2jets}} = 0.5 \pm 0.4(\text{stat.})^{+0.7}_{-0.6}(\text{syst.})$

→ **Consistent with SM prediction**



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Results

ggF

2. BSM effects in effective Higgs-gluon coupling ($\kappa_{Agg}/\kappa_{Hgg}$)

   a) Normalisation is unconstrained → only shape information of fit input distribution to distinguish between CP scenarios

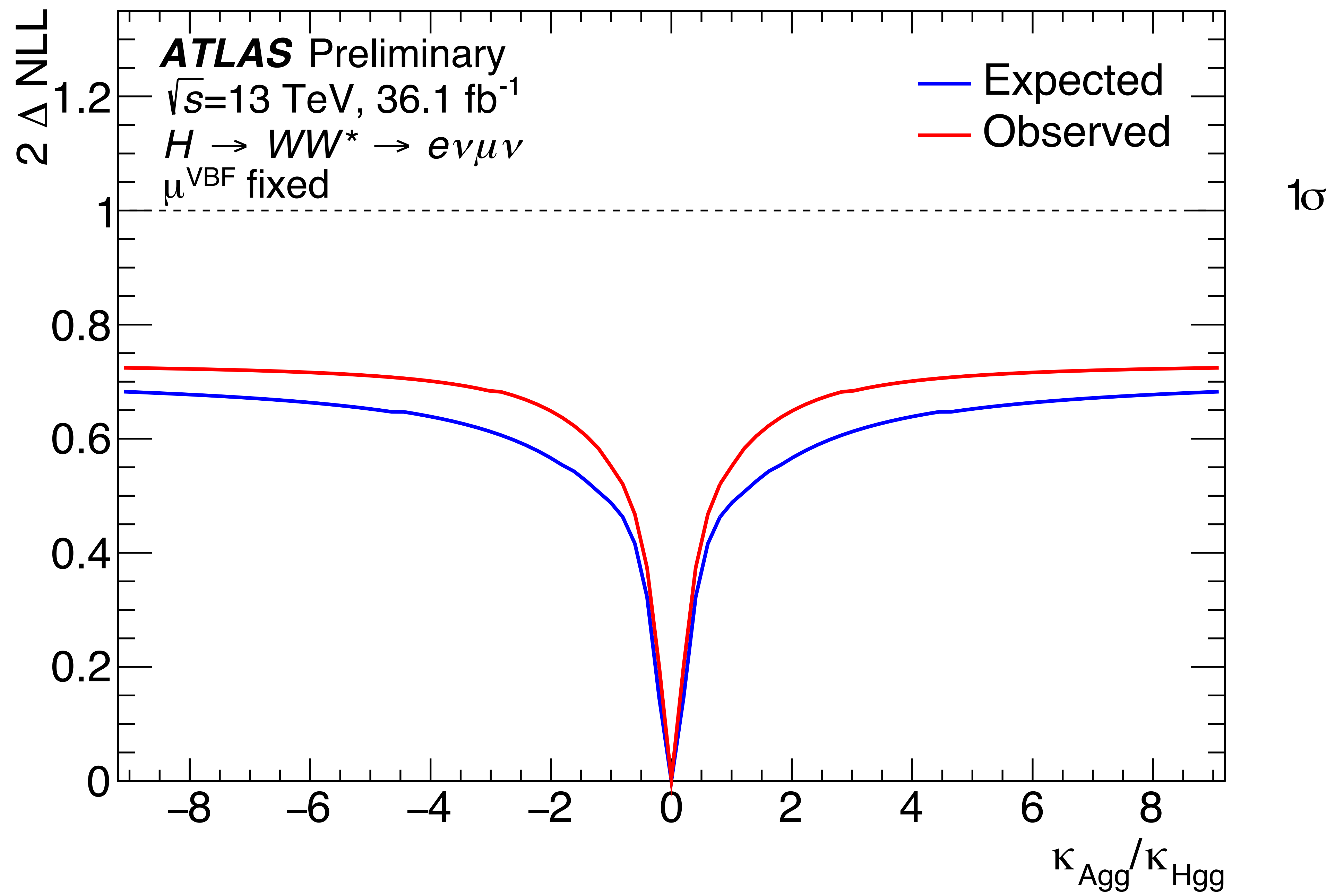
      → Not sensitiv enough to provide 68% CL

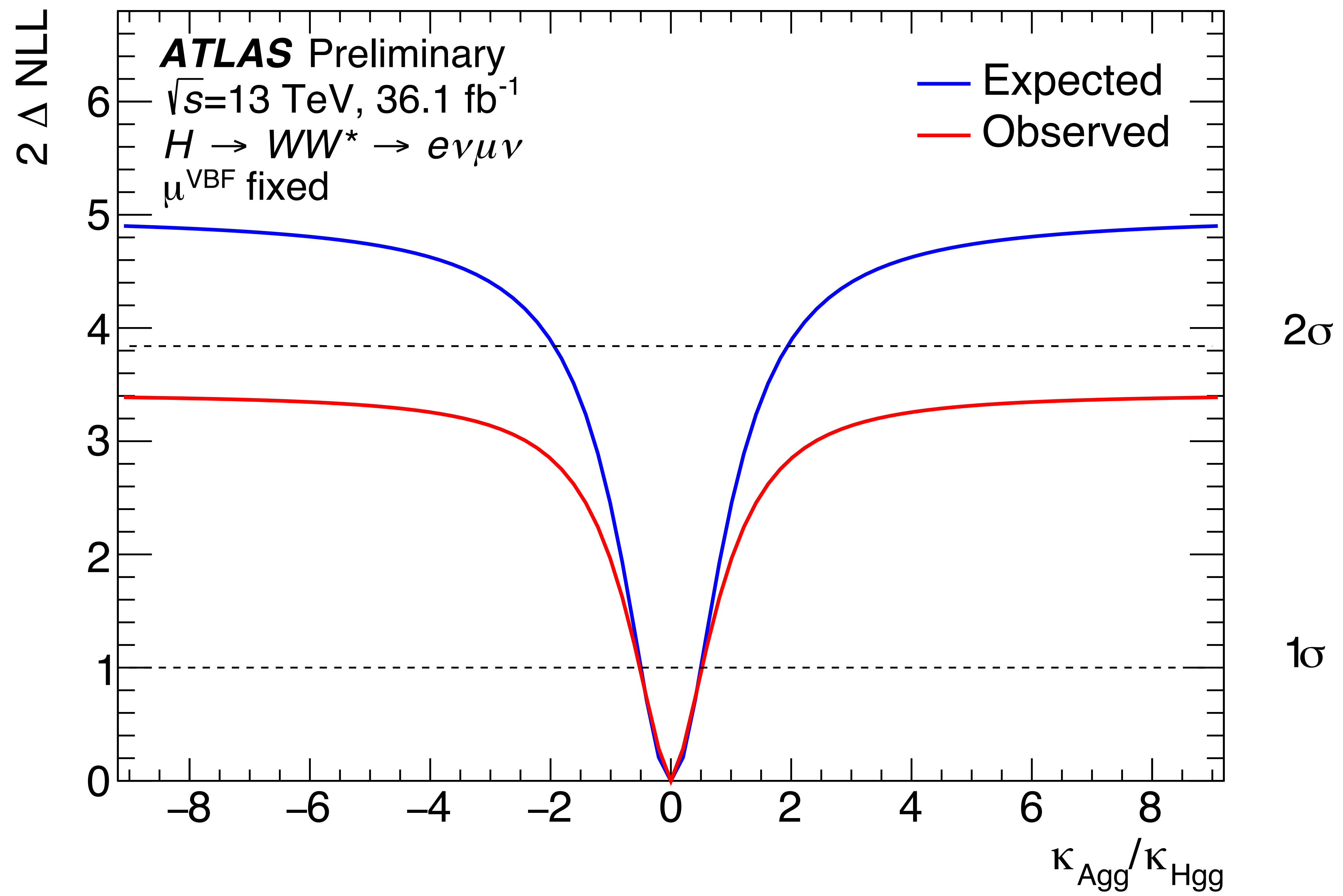
   b) Normalisation is constrained to model predictions → shape and rate information

      → $\kappa_{Agg}/\kappa_{Hgg} = 0.0 \pm 0.4(\text{stat.}) \pm 0.3(\text{syst.})$

      → No 95% CL

→ **Consistent with SM prediction**





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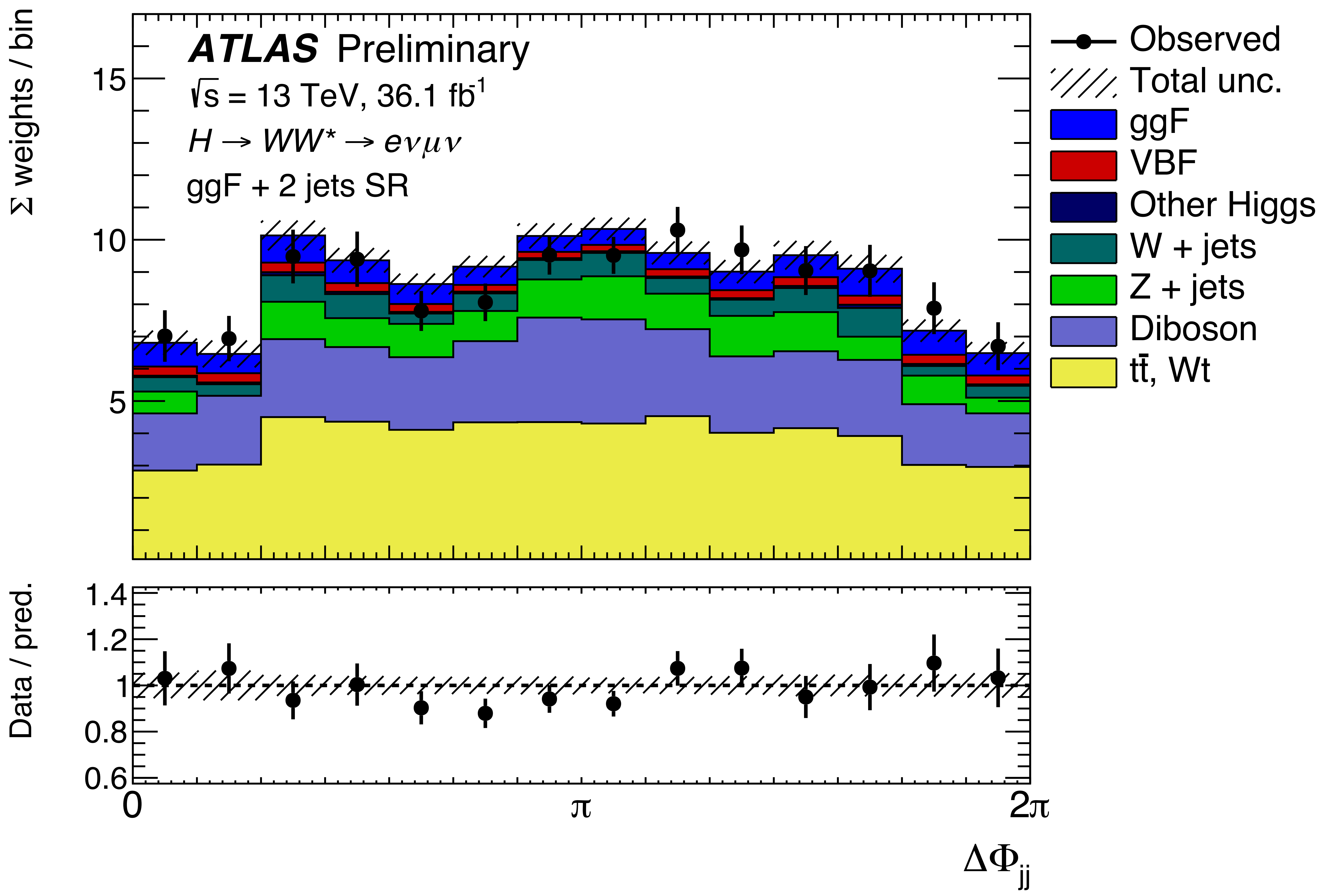
Results

ggF

- Weighted by ln(1+N_S/N_B), $N_{S/B}$: post-fit signal/ background event yield
- Signal and background yields fixed from shape and rate $\kappa_{Agg}/\kappa_{Hgg}$ fit



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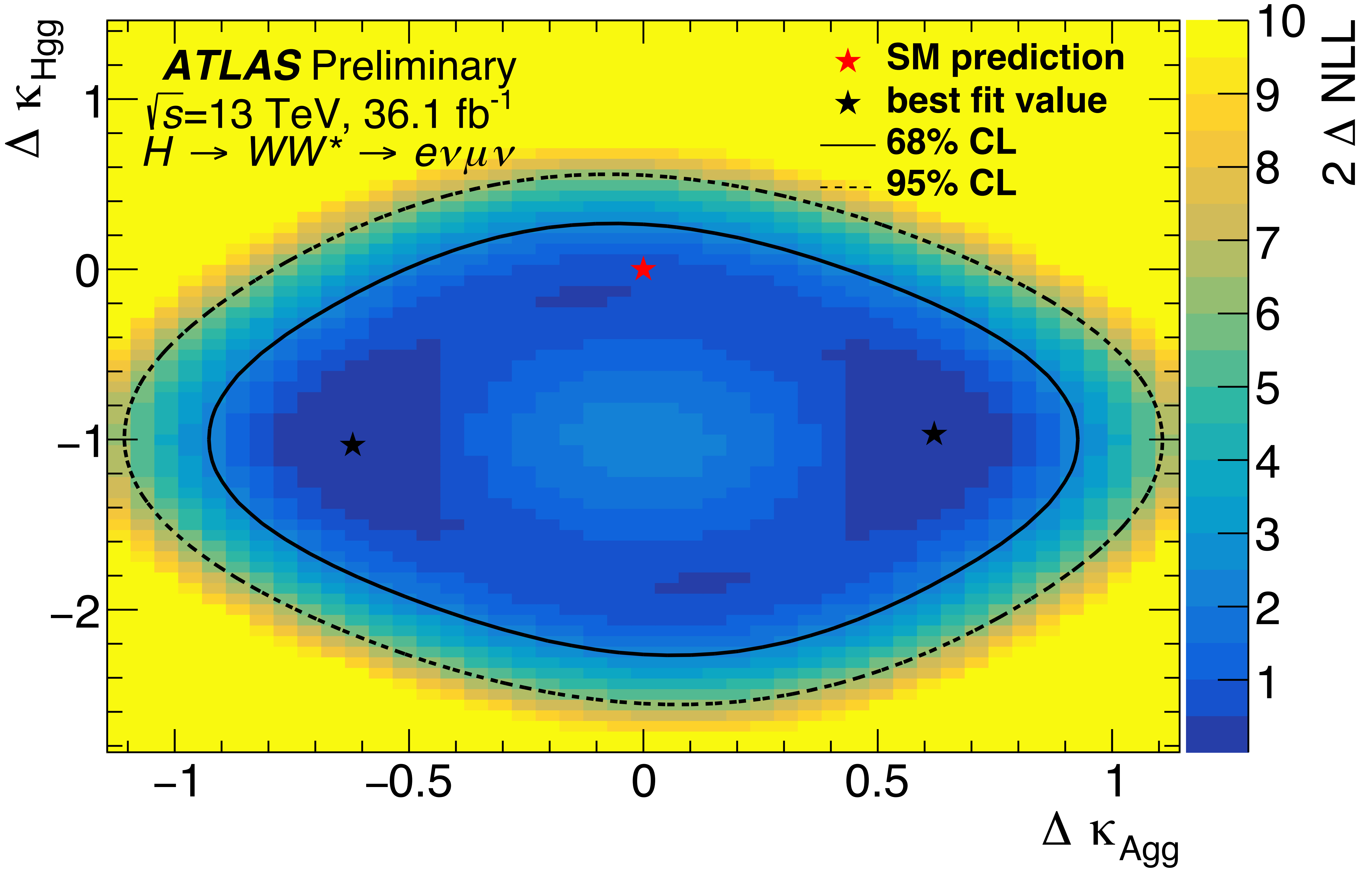
Results

ggF

3. Simultaneous fit of κ_{Hgg} and κ_{Agg} , exploiting shape and rate information

→ **Consistent with SM prediction**



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Results
VBF

- Fits with a_L, a_T and κ_{VV}, ε_{VV} parametrisation

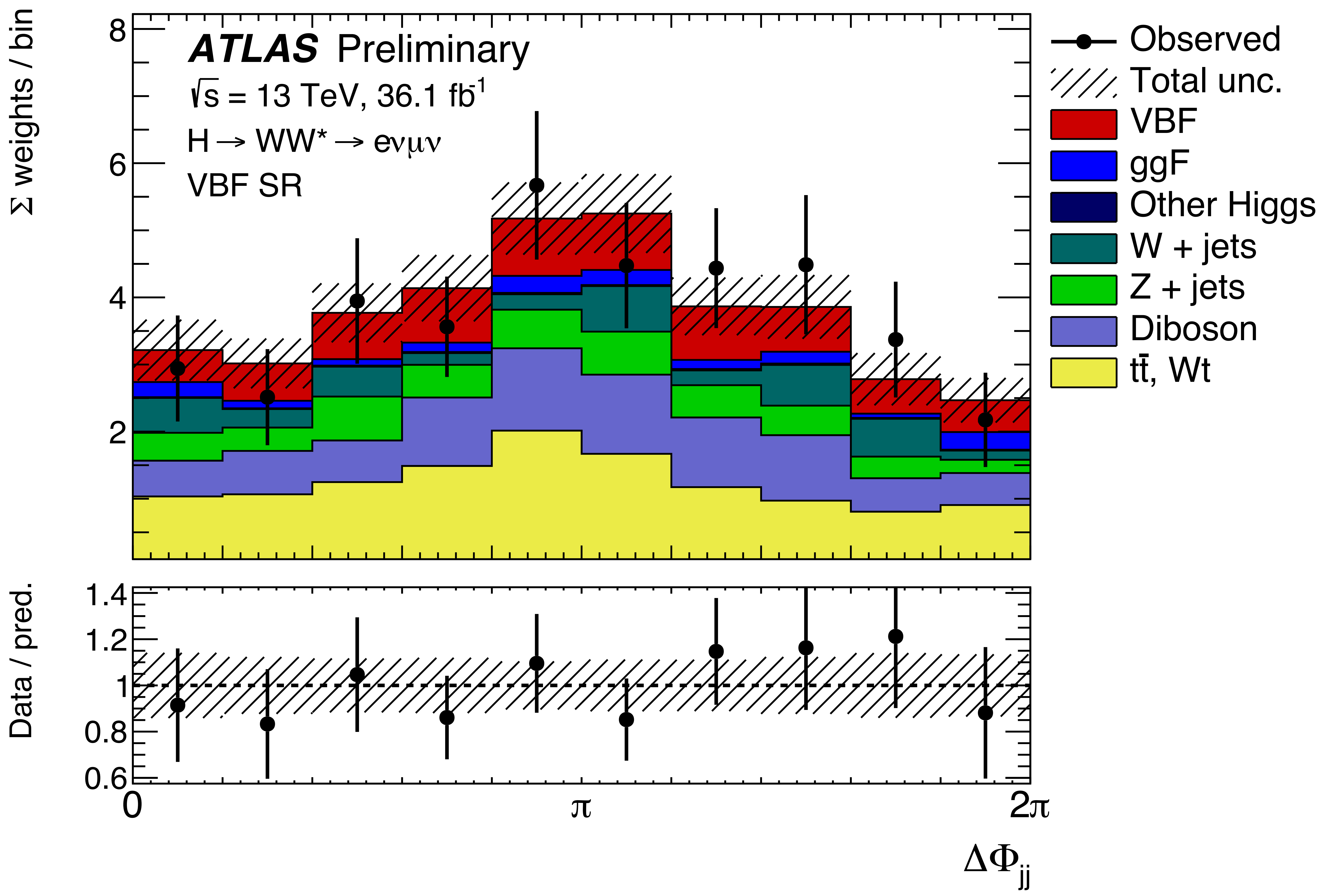
1. One dimensional fits
    a) Using shape dependence, other parameter fixed to SM value
    b) Using shape and rate information, other parameter fixed to SM value
2. Fits on one parameter, other being profiled

- a_L, κ_{VV} sensitive to total event yield
- a_T, ε_{VV} sensitive to $\Delta\Phi_{jj}$ shape
- Kinematic distribution of 2 jets related to structure of Higgs boson production vertex, carry information about polarisation of fusing gauge boson

Results

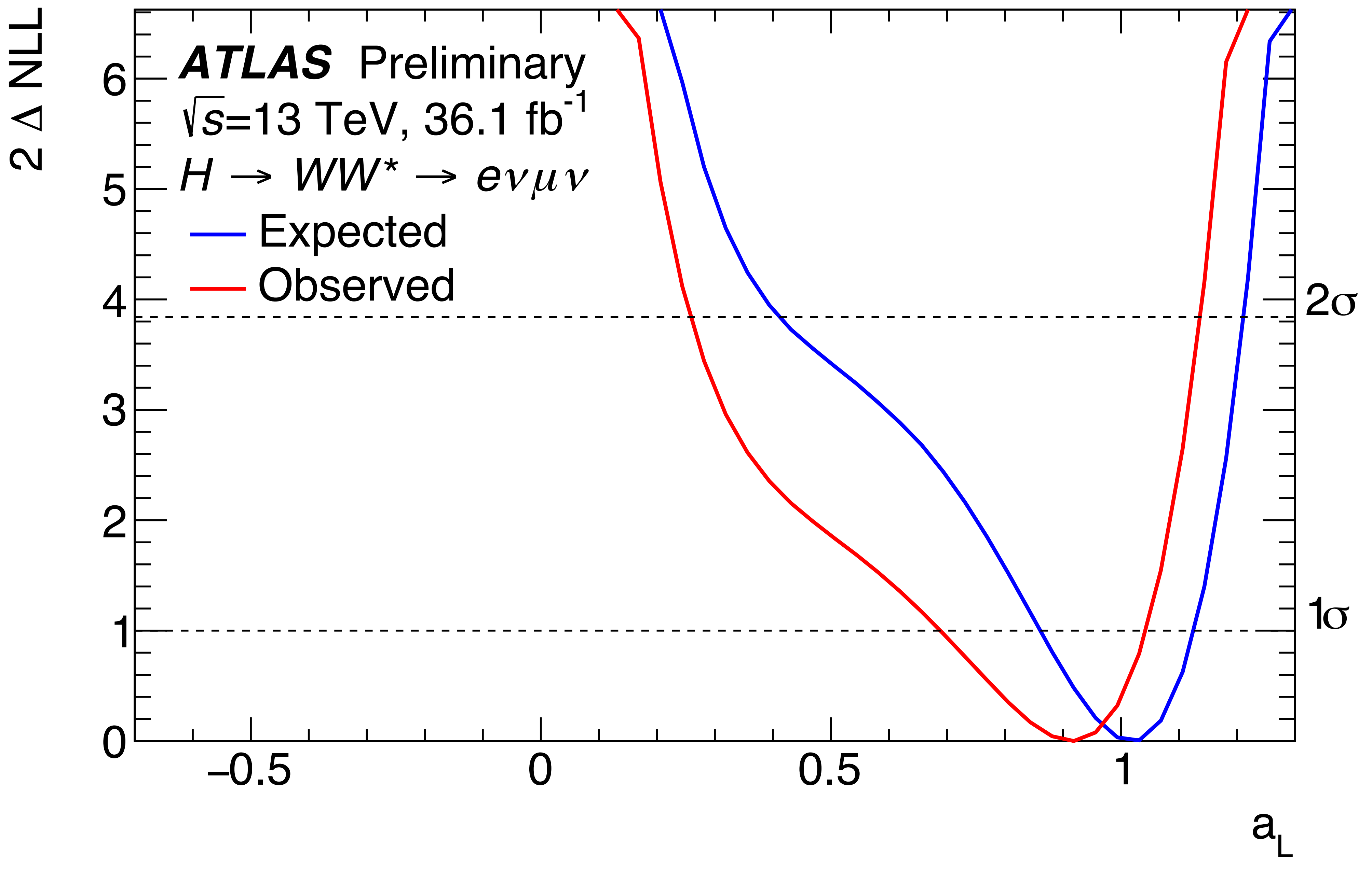
VBF

- Weighted by ln(1+N_S/N_B), $N_{S/B}$: post-fit signal/ background event yield
- Signal and background yields fixed from shape and rate ε_{VV} fit

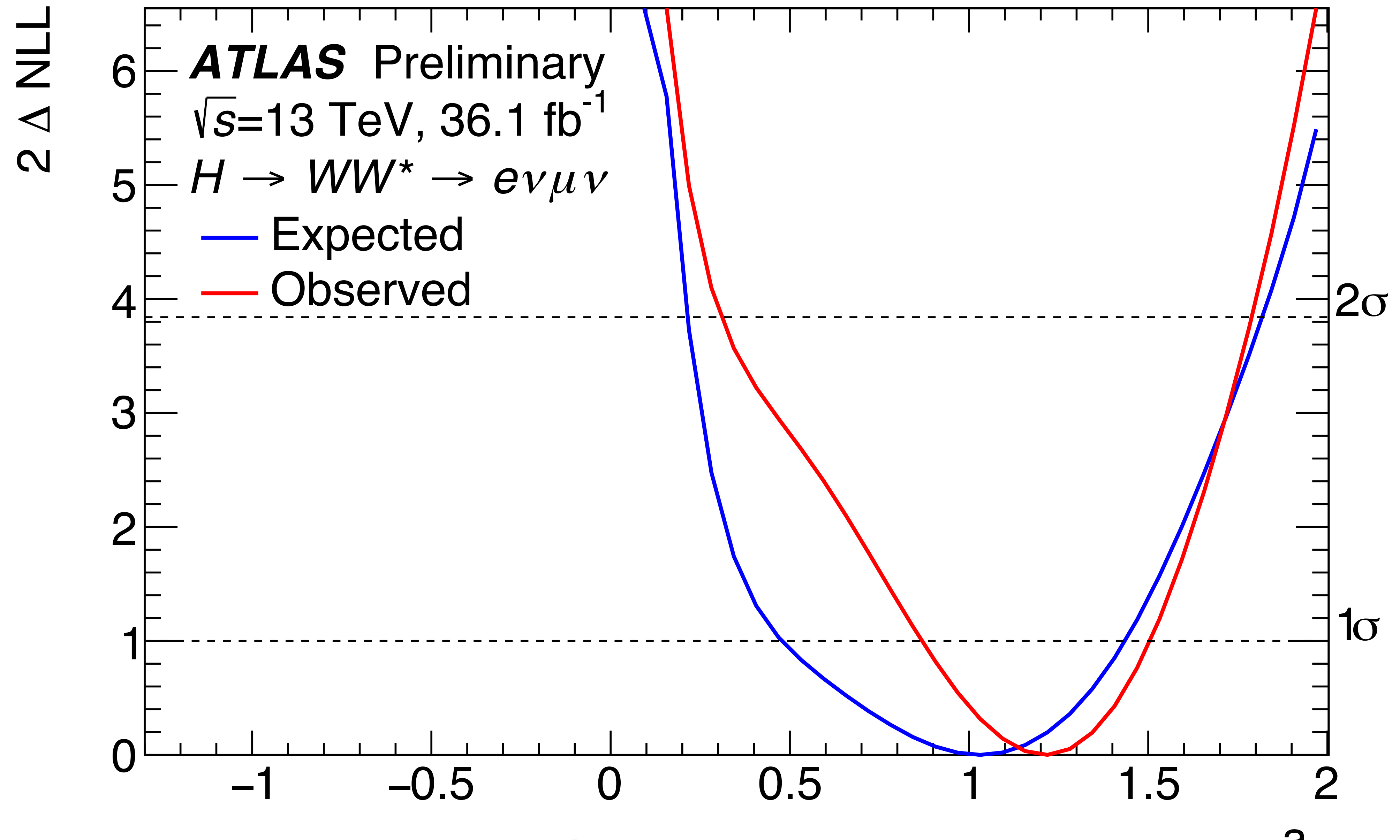


Results

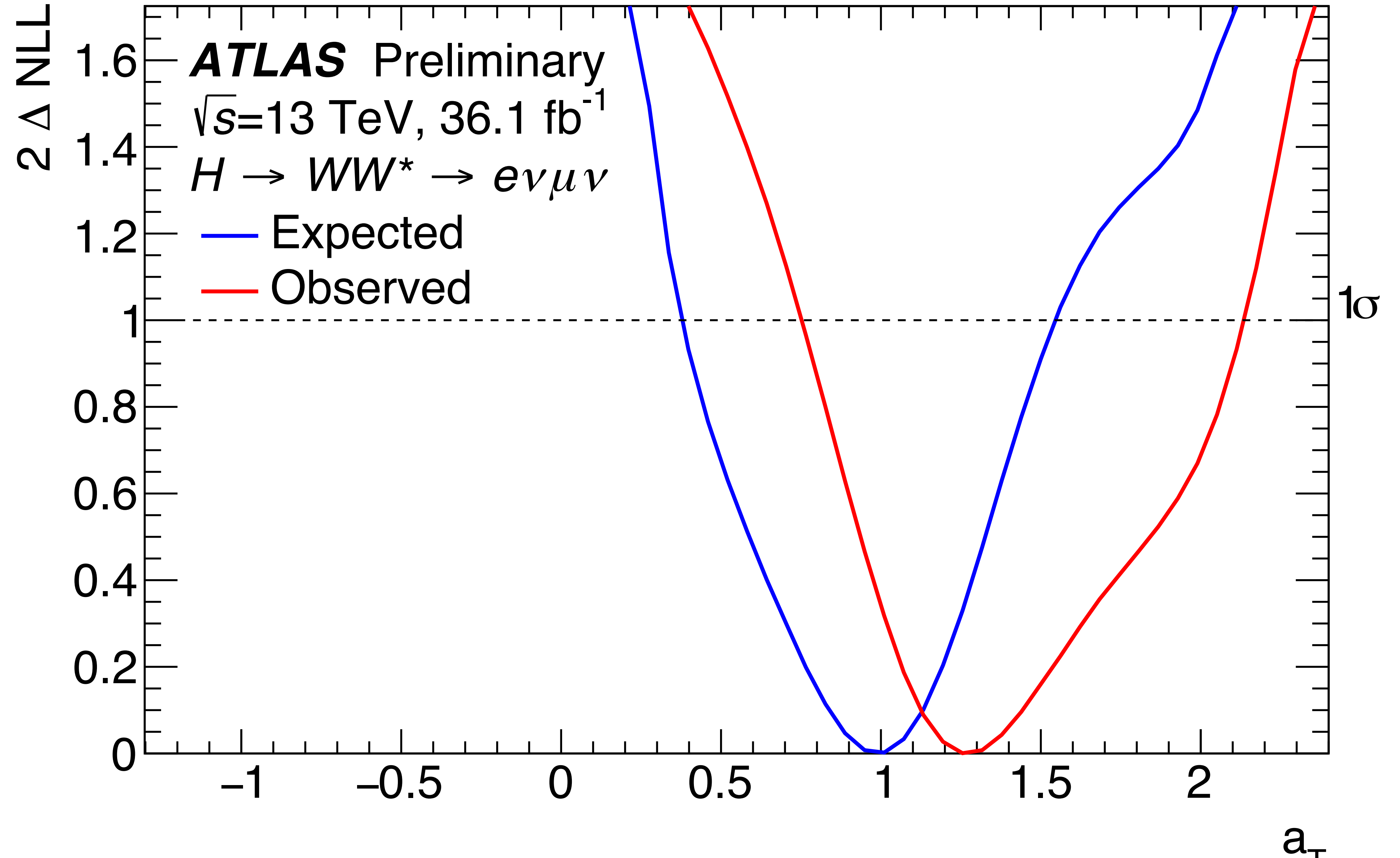
VBF



shape+rate, a_T=1



shape+rate, a_L=1



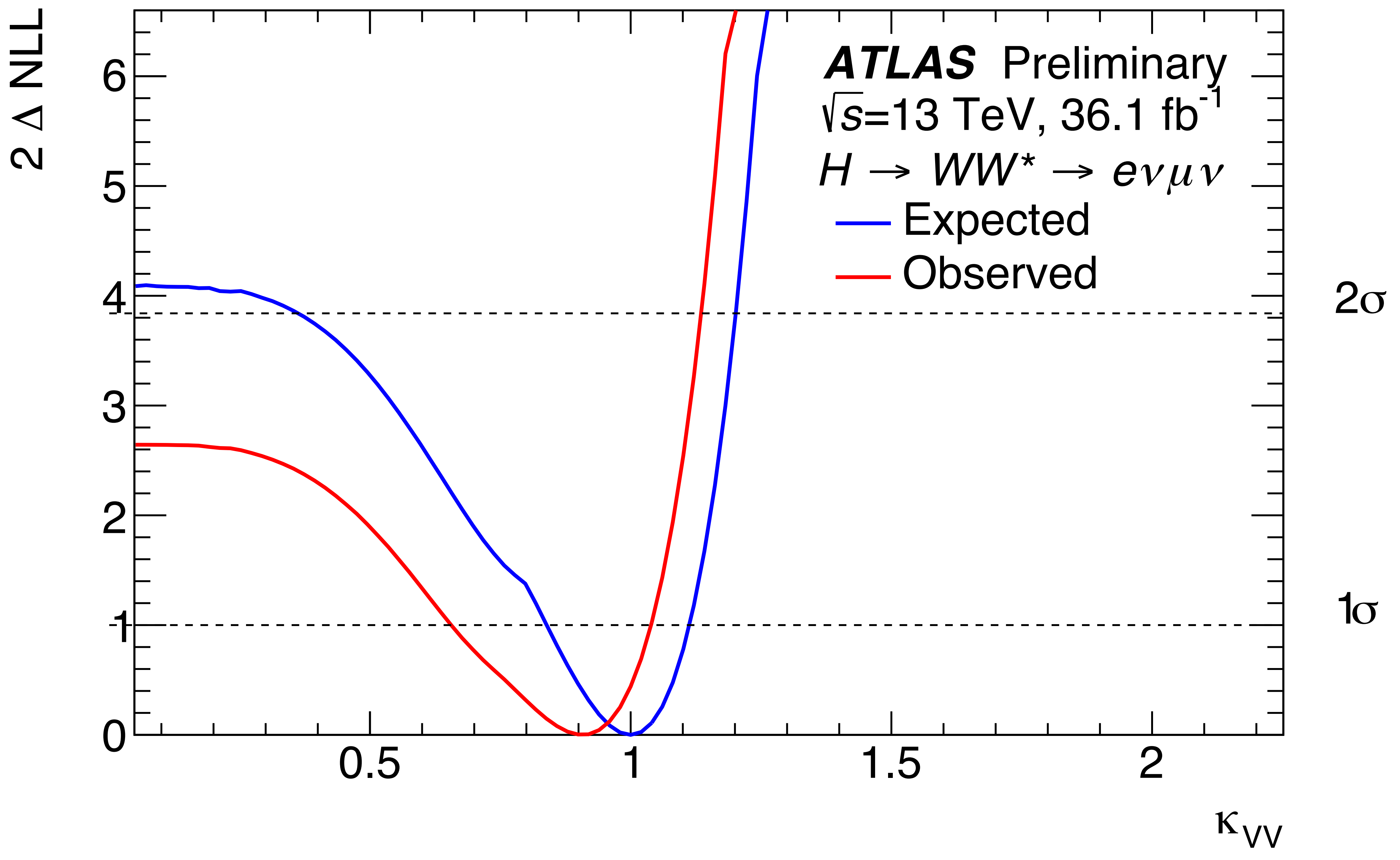
shape , a_L=1

http://cdsweb.cern.ch/record/2743624/files/ATLAS-CONF-2020-055.pdf

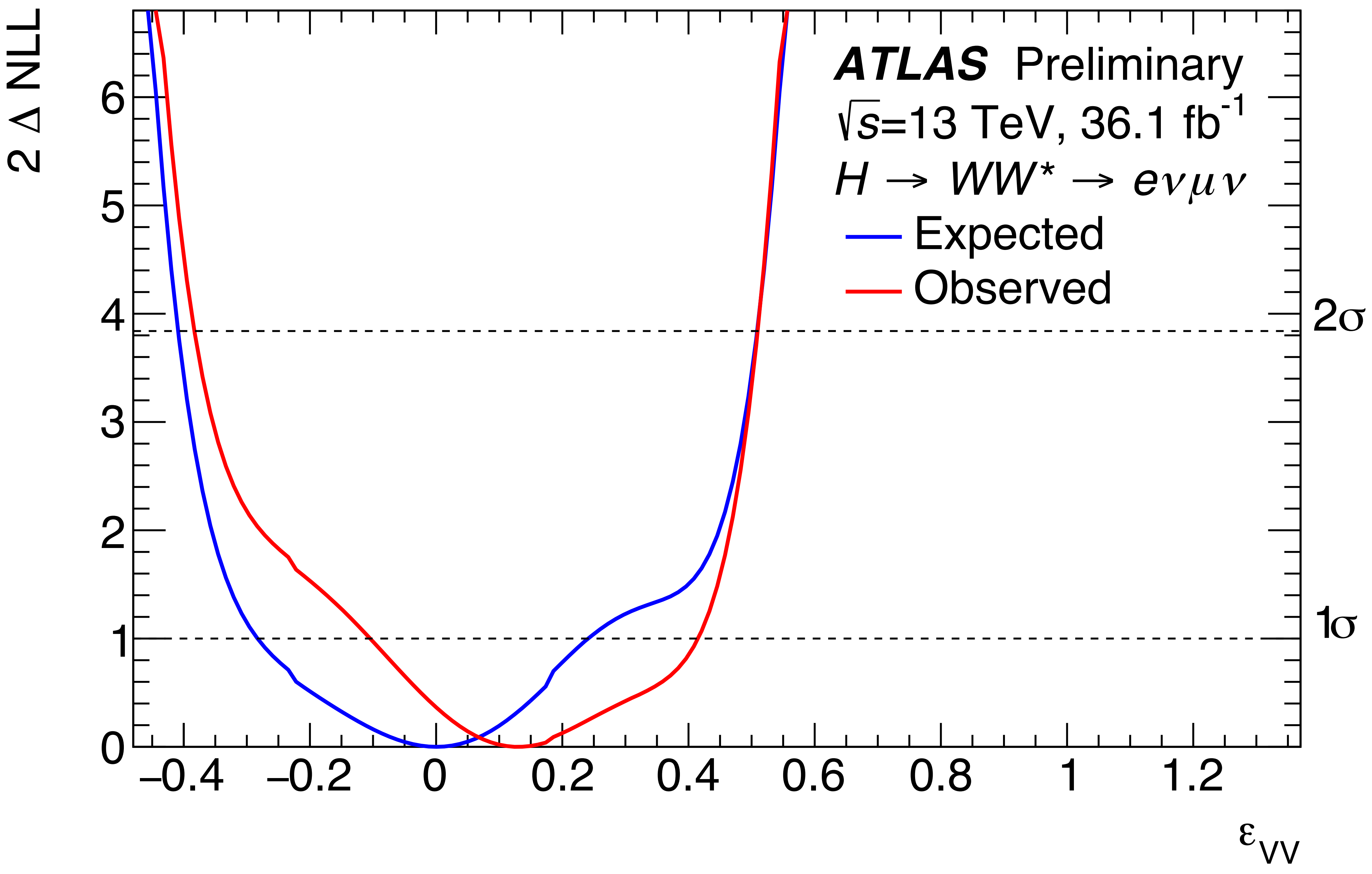
Results

VBF

$$\kappa_{VV} \simeq a_L\,, \quad \varepsilon_{VV} \simeq 0.5 \cdot (a_T - a_L)$$



shape+rate, profiled ε_{VV}



shape+rate, profiled κ_{VV}

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Results

VBF

$\kappa_{VV} \simeq a_{\mathrm{L}}, \quad \varepsilon_{VV} \simeq 0.5 \cdot (a_{\mathrm{T}} - a_{\mathrm{L}})$

Type	exp.	obs.
κ_{VV} shape-only fit ($\varepsilon_{VV} = 0$)	–	–
ε_{VV} shape-only fit ($\kappa_{VV} = 1$)	$0.00^{+0.23}_{-0.25}$ (stat.)$^{+0.17}_{-0.20}$(syst.)	$0.14^{+0.39}_{-0.22}$(stat.)$^{+0.18}_{-0.13}$(syst.)
κ_{VV} shape + rate fit ($\varepsilon_{VV} = 0$)	$1.00^{+0.08}_{-0.10}$(stat.)$^{+0.08}_{-0.12}$(syst.)	$0.91^{+0.09}_{-0.12}$(stat.)$^{+0.09}_{-0.17}$(syst.)
ε_{VV} shape + rate fit ($\kappa_{VV} = 1$)	$0.00^{+0.18}_{-0.24}$(stat.)$^{+0.10}_{-0.13}$(syst.)	$0.09^{+0.13}_{-0.16}$ (stat.)$^{+0.06}_{-0.07}$(syst.)
κ_{VV} shape + rate fit (ε_{VV} profiled)	$1.00^{+0.08}_{-0.10}$(stat.)$^{+0.08}_{-0.12}$(syst.)	$0.90^{+0.10}_{-0.18}$(stat.)$^{+0.09}_{-0.16}$(syst.)
ε_{VV} shape + rate fit (κ_{VV} profiled)	$0.00^{+0.22}_{-0.24}$ (stat.)$^{+0.11}_{-0.15}$(syst.)	$0.13^{+0.28}_{-0.20}$ (stat.)$^{+0.08}_{-0.10}$(syst.)

→ **Consistent with SM prediction**

Type	exp.	obs.
a_{L} shape-only fit ($a_{\mathrm{T}} = 1$)	–	–
a_{T} shape-only fit ($a_{\mathrm{L}} = 1$)	1.00 ± 0.5(stat.)$^{+0.35}_{-0.39}$(syst.)	$1.27^{+0.8}_{-0.4}$(stat.)$^{+0.35}_{-0.27}$(syst.)
a_{L} shape + rate fit ($a_{\mathrm{T}} = 1$)	$1.00^{+0.08}_{-0.10}$(stat.)$^{+0.08}_{-0.13}$(syst.)	$0.90^{+0.10}_{-0.13}$ (stat.)$^{+0.09}_{-0.19}$(syst.)
a_{T} shape + rate fit ($a_{\mathrm{L}} = 1$)	$1.00^{+0.36}_{-0.49}$(stat.)$^{+0.22}_{-0.32}$(syst.)	$1.18^{+0.26}_{-0.31}$(stat.)$^{+0.14}_{-0.16}$(syst.)
a_{L} shape + rate fit (a_{T} profiled)	$1.00^{+0.08}_{-0.10}$(stat.)$^{+0.08}_{-0.13}$(syst.)	$0.91^{+0.10}_{-0.18}$(stat.)$^{+0.09}_{-0.18}$(syst.)
a_{T} shape + rate fit (a_{L} profiled)	$1.00^{+0.38}_{-0.5}$(stat.)$^{+0.22}_{-0.43}$(syst.)	1.16 ± 0.4(stat.)$^{+0.4}_{-0.3}$(syst.)

http://cdsweb.cern.ch/record/2743624/files/ATLAS-CONF-2020-055.pdf

Summary

- ggF $\kappa_{Agg}/\kappa_{Hgg} = 0.0 \pm 0.4(\text{stat.}) \pm 0.3(\text{syst.})$ $\mu^{\text{ggF+2jets}} = 0.5 \pm 0.4(\text{stat.})^{+0.7}_{-0.6}(\text{syst.})$
- VBF $a_{\text{L}} = 0.91^{+0.10}_{-0.18}(\text{stat.})^{+0.09}_{-0.18}(\text{syst.})$ $a_{\text{T}} = 1.16 \pm 0.4(\text{stat.})^{+0.4}_{-0.3}(\text{syst.})$

  $\kappa_{VV} = 0.90^{+0.10}_{-0.18}(\text{stat.})^{+0.09}_{-0.16}(\text{syst.})$ $\epsilon_{VV} = 0.13^{+0.28}_{-0.20}(\text{stat.})^{+0.08}_{-0.10}(\text{syst.})$

- All results are consistent with the SM within their uncertainties
  → CP even Higgs boson
- Reduce uncertainties to get more precisely results
  - Data statistic → More data
  - Top modelling uncertainties → Reduce top quark background

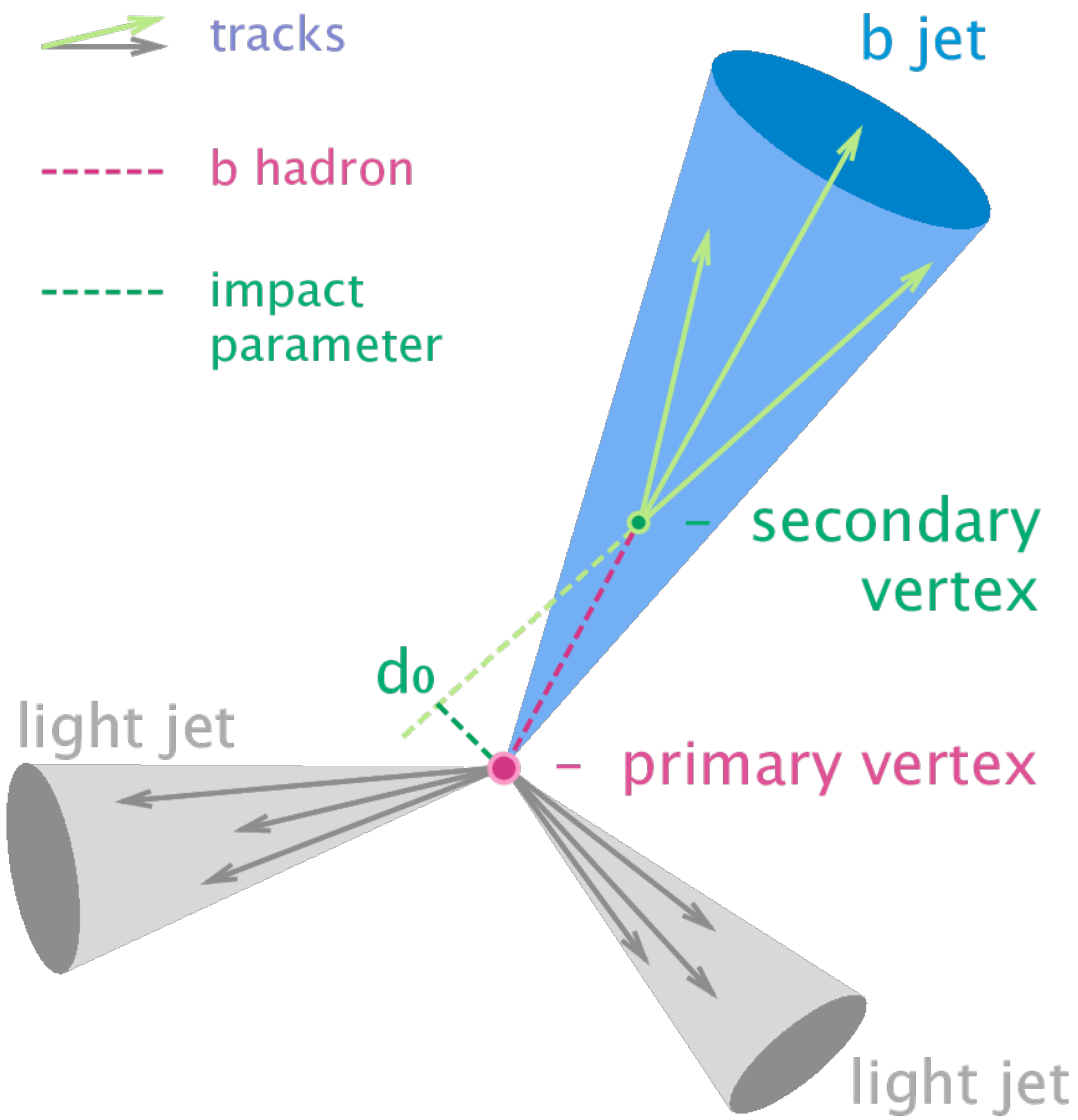
Reducing Top Background

How?

- Top quarks nearly always decay into bottom quarks
- B Tagging: Identify jets originating from b quarks

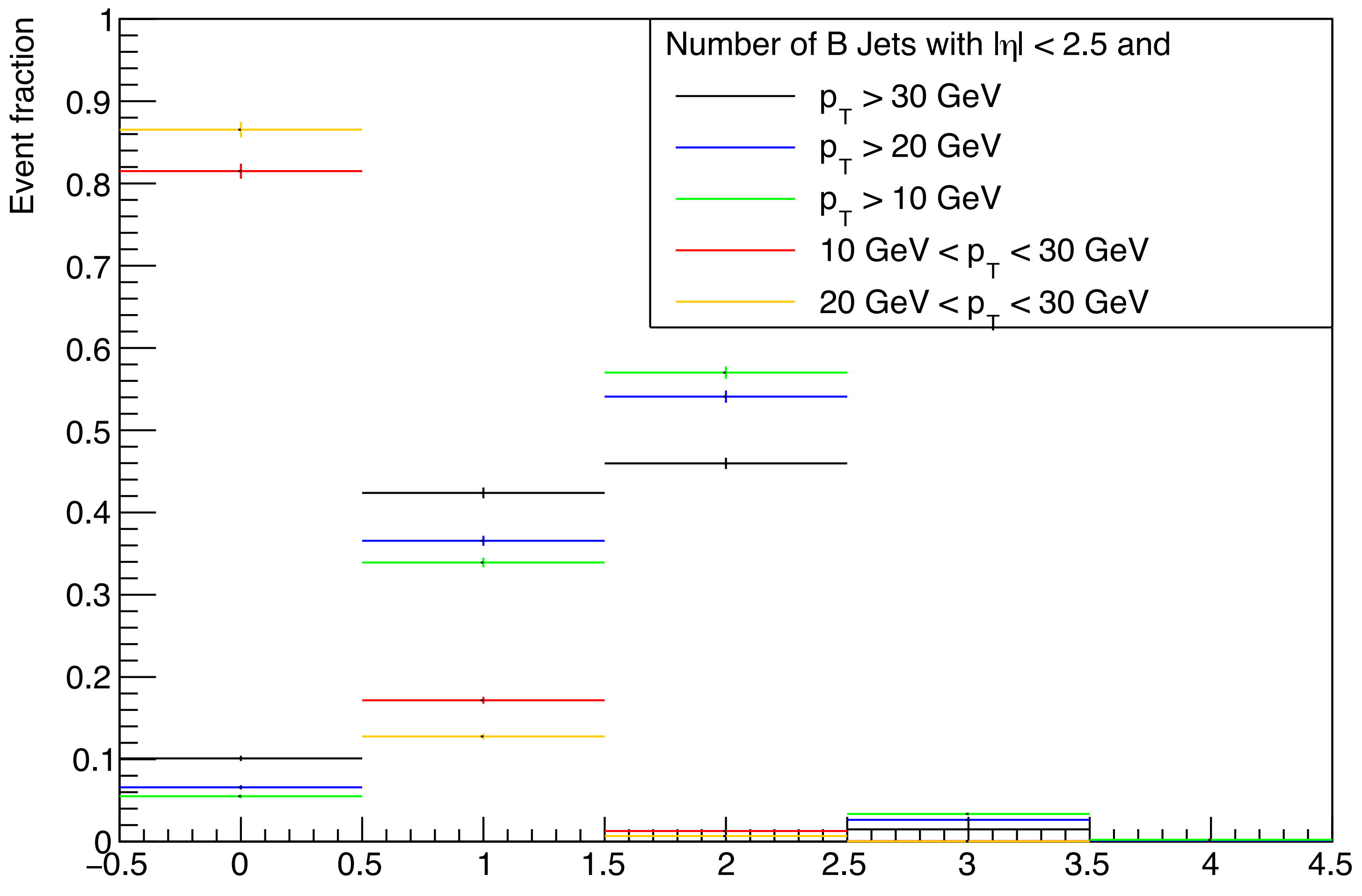
→ Veto against those b jets for this study

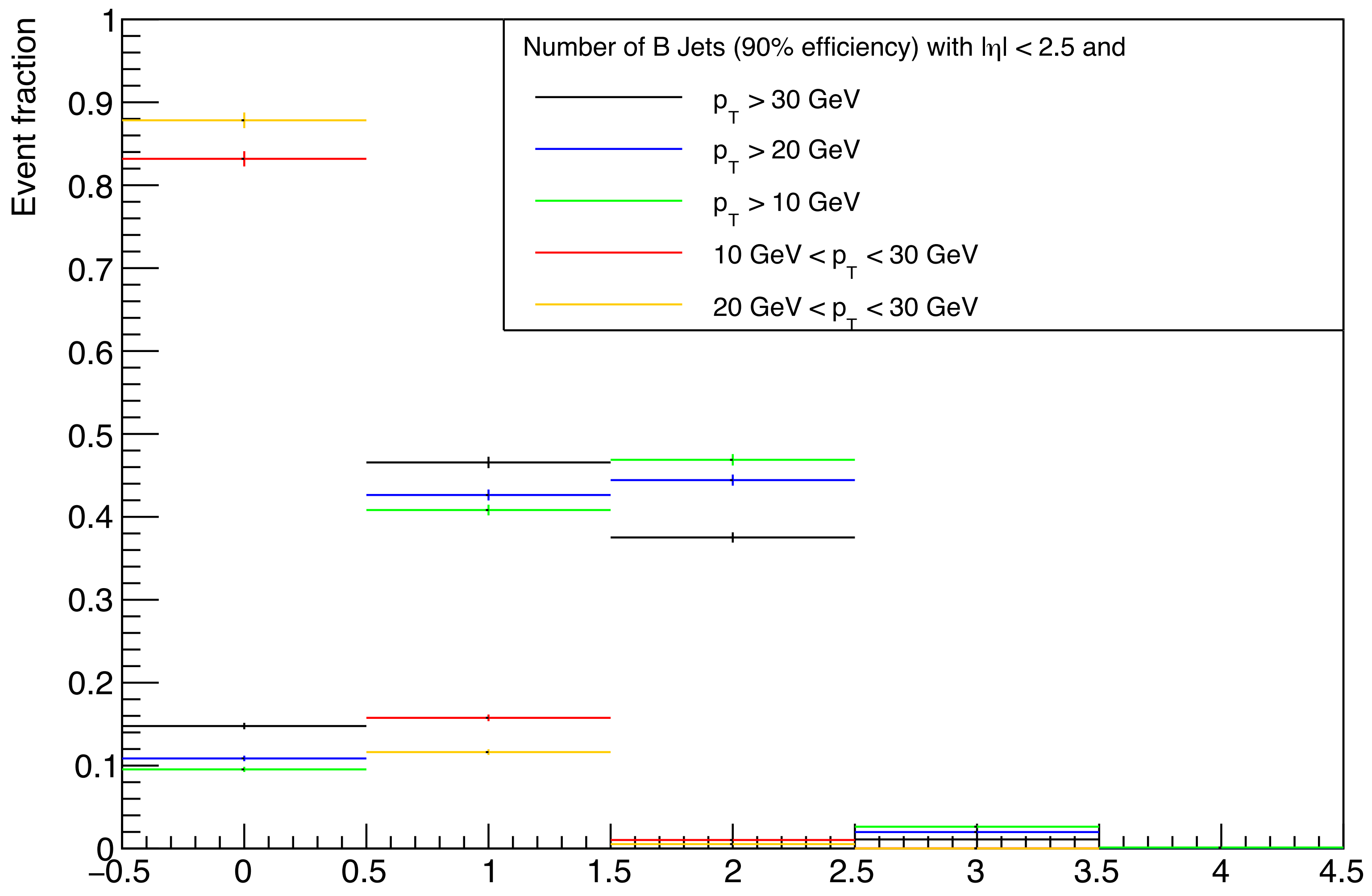
- So far b jets with $p_T > 20$ GeV were tagged
- Why do top quarks still come through?
  - Jets weren't found/identified
  - Jets with $|\eta| > 2.5$ (outside of tracking detector)
  - Jets with $p_T < 20$ GeV

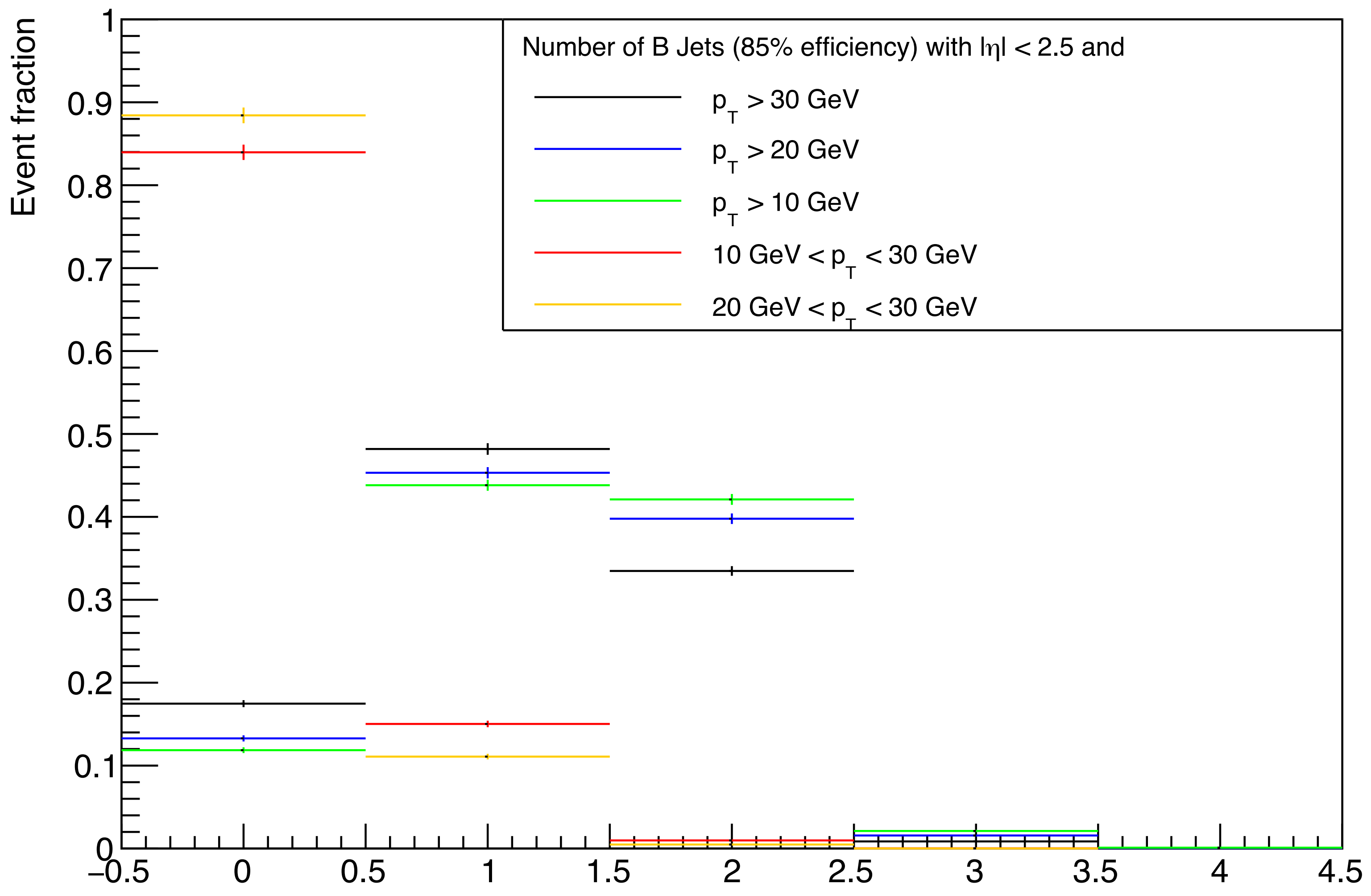


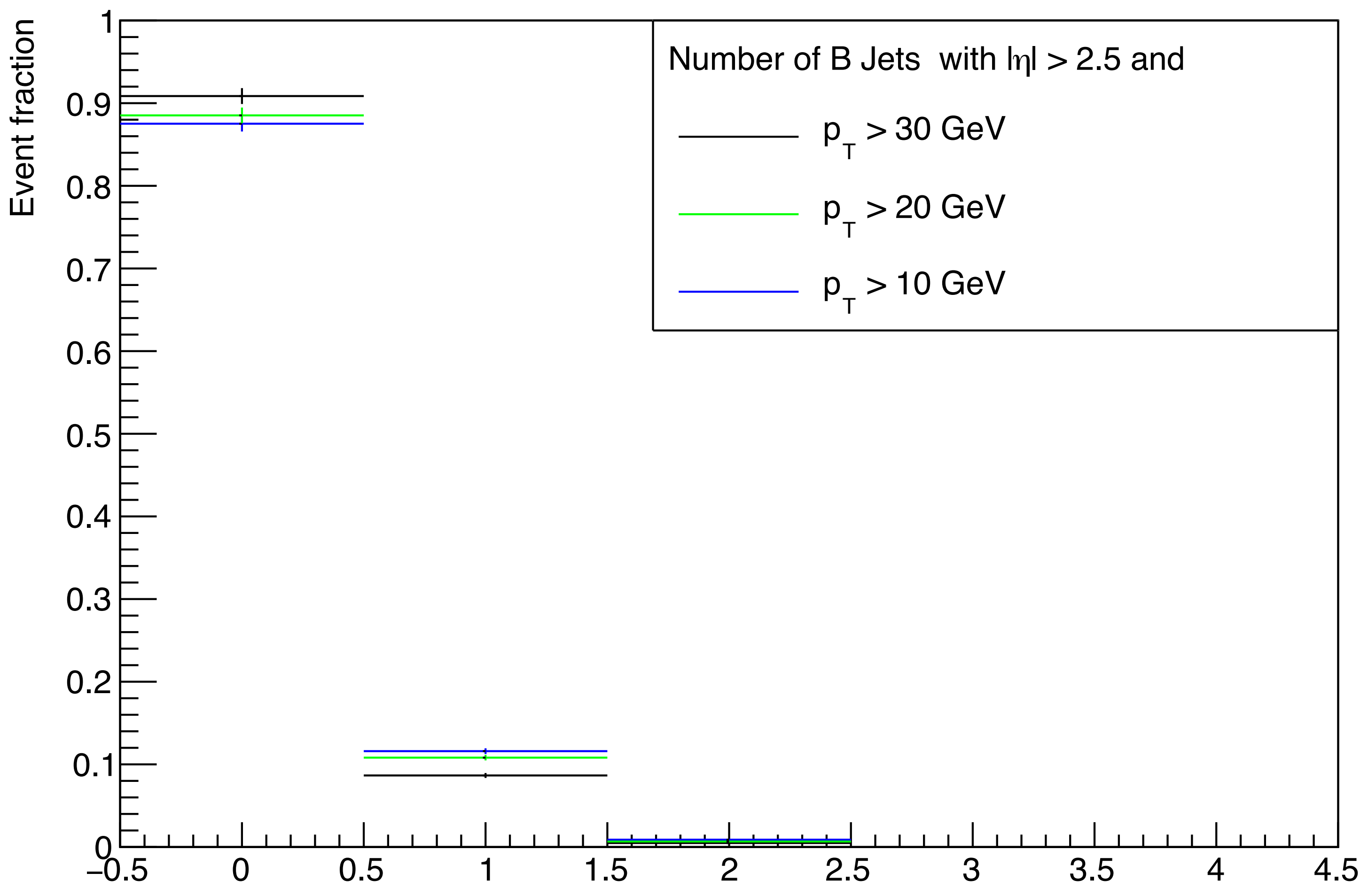
https://favpng.com/png_view/jet-particle-physics-jet-b-tagging-bottom-quark-png/dMKWPMmA

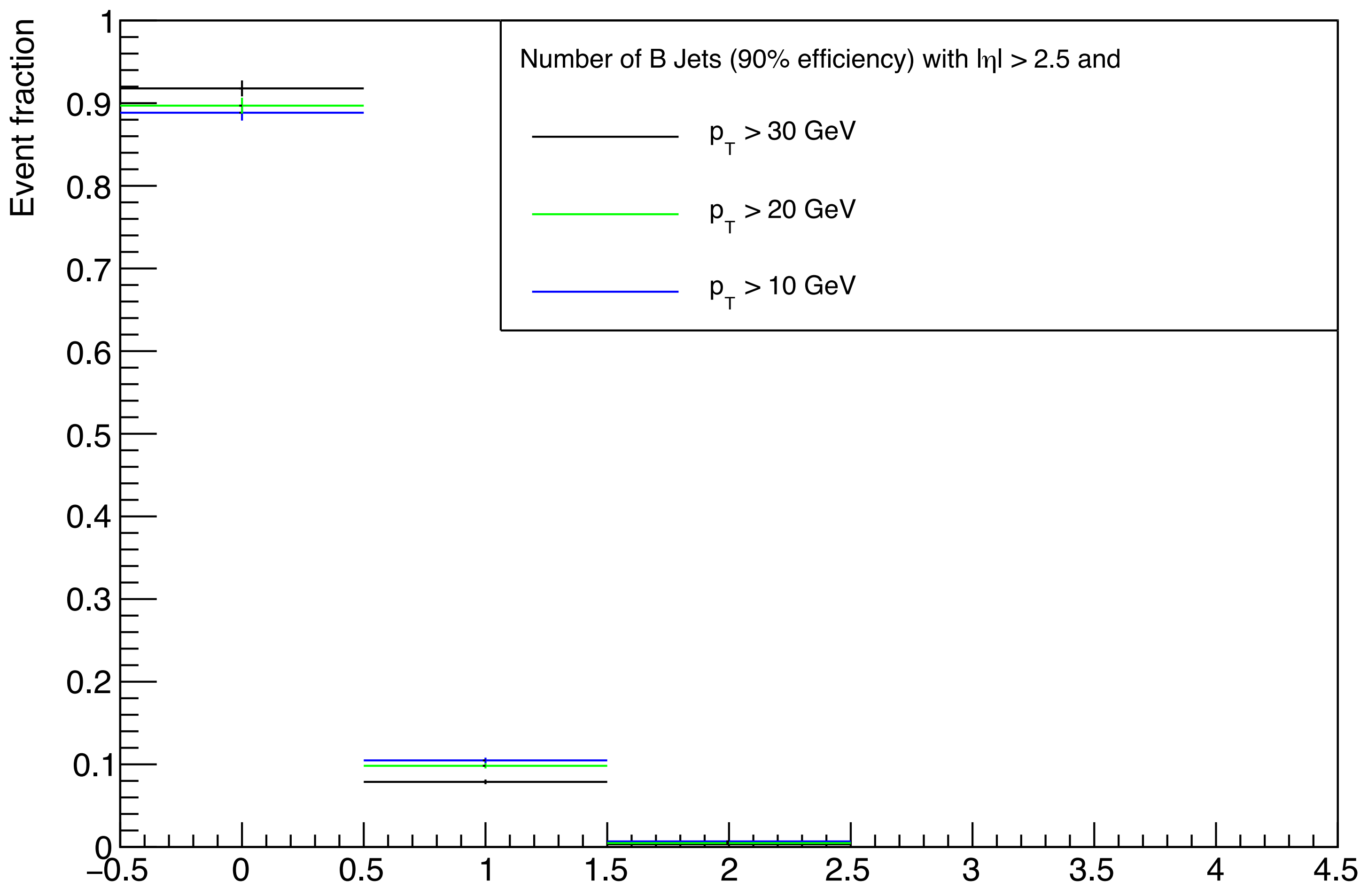
Reducing Top Background

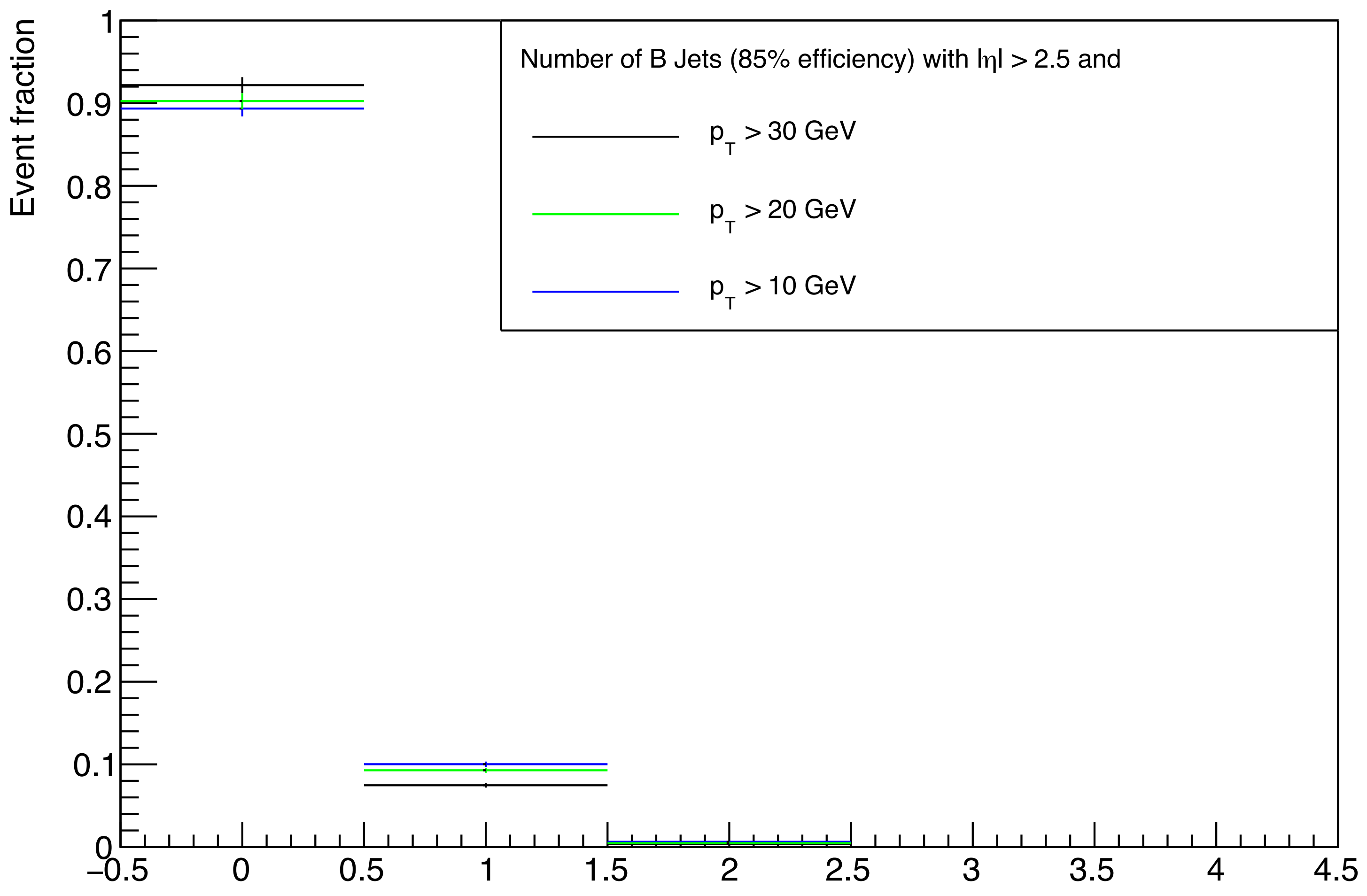












Reducing Top Background

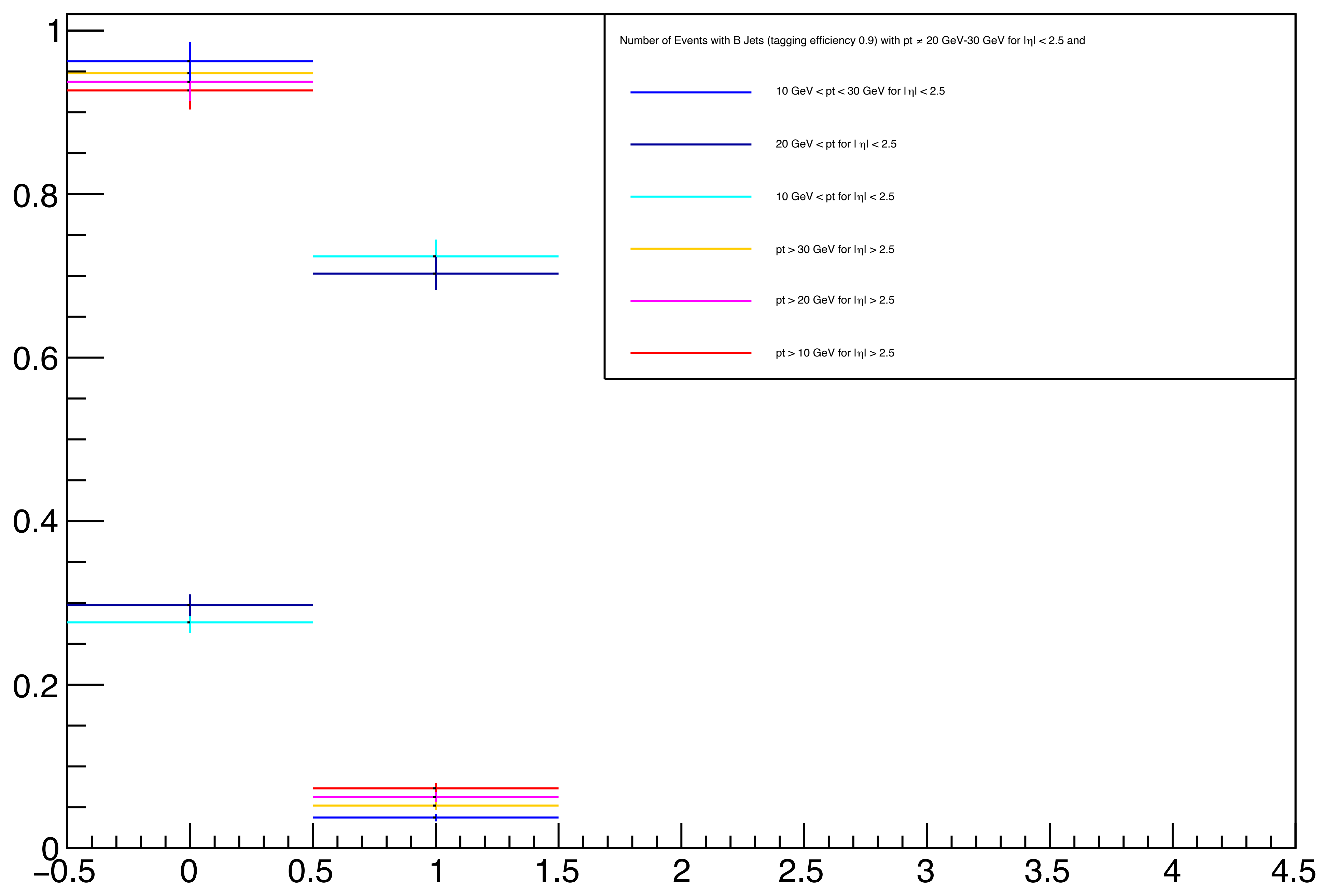
Number of B Jets

		B Tagging Efficiency														
		100 %					90 %					85 %				
		B Jets in Bin [%]					B Jets in Bin [%]					B Jets in Bin [%]				
		0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
B Jet Characteristics	$\lvert\eta\rvert < 2.5$															
	pt > 10 GeV	5.50	33.92	57.01	3.36	0.21	9.52	40.65	47.11	2.60	0.12	11.65	43.61	42.62	2.01	0.11
	pt > 20 GeV	6.59	36.56	54.09	2.64	0.12	10.87	42.49	44.54	2.03	0.07	12.97	45.27	40.12	1.57	0.07
	pt > 30 GeV	10.11	42.38	45.97	1.48	0.06	15.07	46.03	37.76	1.11	0.03	17.13	48.01	33.95	0.88	0.03
	10 GeV < pt < 30 GeV	81.50	17.17	1.28	0.05	0.00	83.02	15.84	1.10	0.04	0.00	84.27	14.83	0.87	0.03	0.00
	20 GeV < pt < 30 GeV	86.54	12.78	0.67	0.02	0.00	87.65	11.79	0.54	0.02	0.00	88.66	10.84	0.48	0.01	0.00
	$\lvert\eta\rvert > 2.5$															
	pt > 10 GeV	87.51	11.60	0.89	0.00	0.00	88.62	10.59	0.79	0.00	0.00	89.30	10.12	0.58	0.00	0.00
	pt > 20 GeV	88.52	10.81	0.66	0.00	0.00	89.55	9.86	0.59	0.00	0.00	90.17	9.39	0.43	0.00	0.00
	pt > 30 GeV	90.86	8.66	0.48	0.00	0.00	91.70	7.86	0.44	0.00	0.00	92.12	7.56	0.32	0.00	0.00

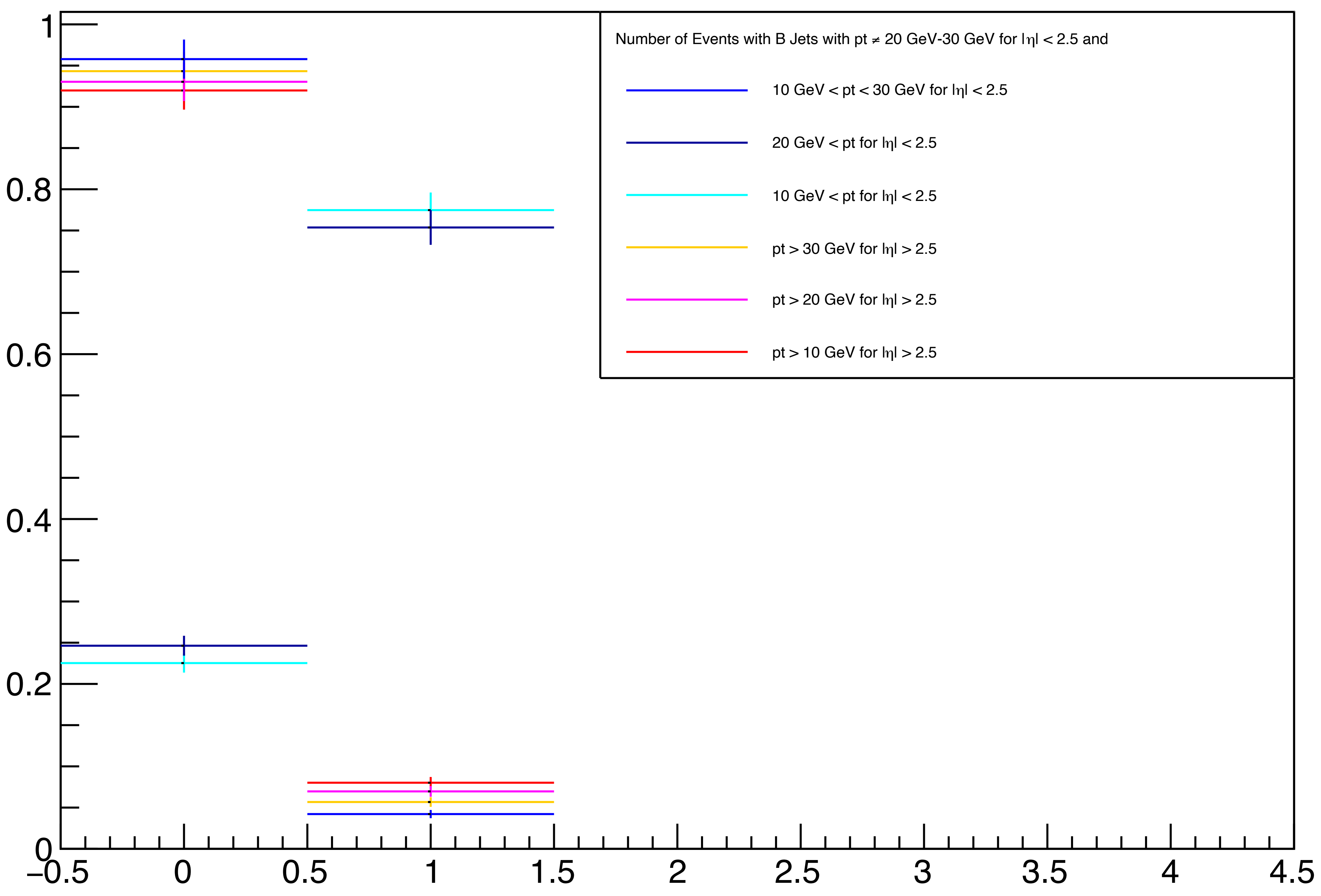
- Reducing the background can be improved by
  - Also tagging b jets with $p_T > 10$ GeV
  - Reach a 90% efficiency
  - access also $|\eta| > 2.5$

Thank you for your attention

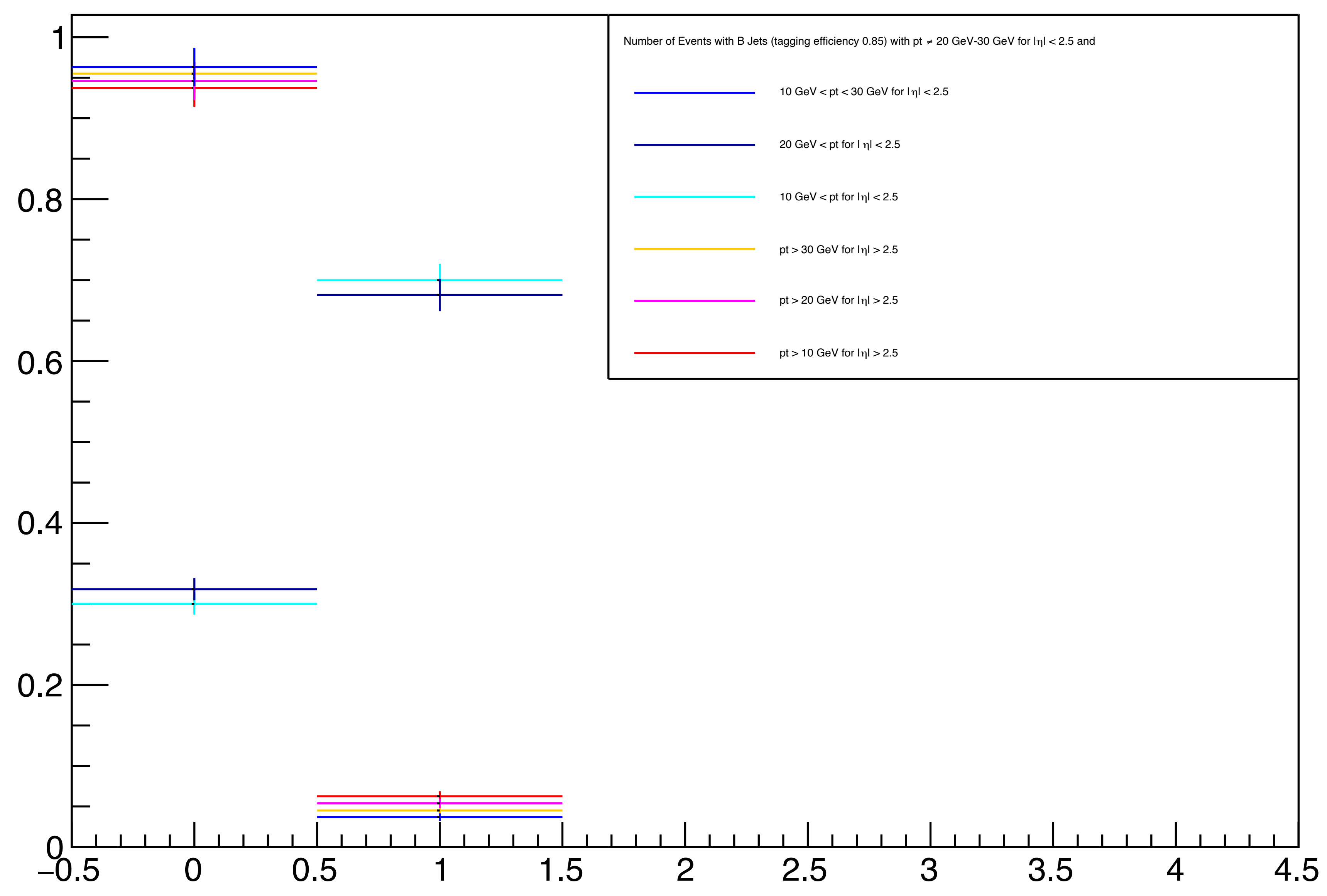
Special Thanks to Dominik Duda



Number of Events with B Jets (tagging efficiency 0.9) with pt ≠ 20 GeV-30 GeV for |η| < 2.5 and
10 GeV < pt < 30 GeV for |η| < 2.5
20 GeV < pt for | η| < 2.5
10 GeV < pt for |η| < 2.5
pt > 30 GeV for |η| > 2.5
pt > 20 GeV for |η| > 2.5
pt > 10 GeV for |η| > 2.5



Number of Events with B Jets with pt ≠ 20 GeV-30 GeV for |η| < 2.5 and
10 GeV < pt < 30 GeV for |η| < 2.5
20 GeV < pt for |η| < 2.5
10 GeV < pt for |η| < 2.5
pt > 30 GeV for |η| > 2.5
pt > 20 GeV for |η| > 2.5
pt > 10 GeV for |η| > 2.5



Number of Events with B Jets (tagging efficiency 0.85) with pt ≠ 20 GeV-30 GeV for |η| < 2.5 and
10 GeV < pt < 30 GeV for |η| < 2.5
20 GeV < pt for | η| < 2.5
10 GeV < pt for |η| < 2.5
pt > 30 GeV for |η| > 2.5
pt > 20 GeV for |η| > 2.5
pt > 10 GeV for |η| > 2.5