Measurement of Higgs production cross sections in the four lepton channel at 13 TeV with the ATLAS detector

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ATLAS EXPERIMENT

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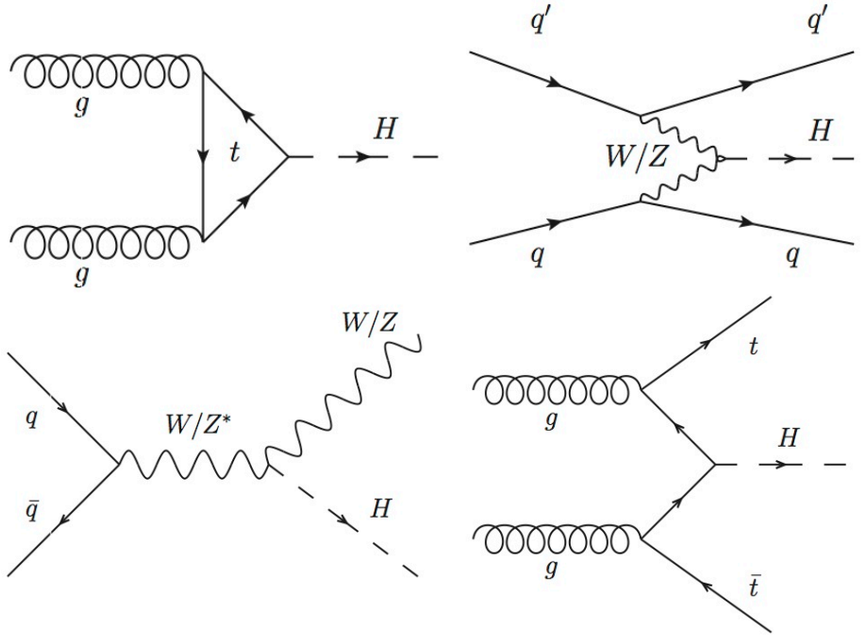
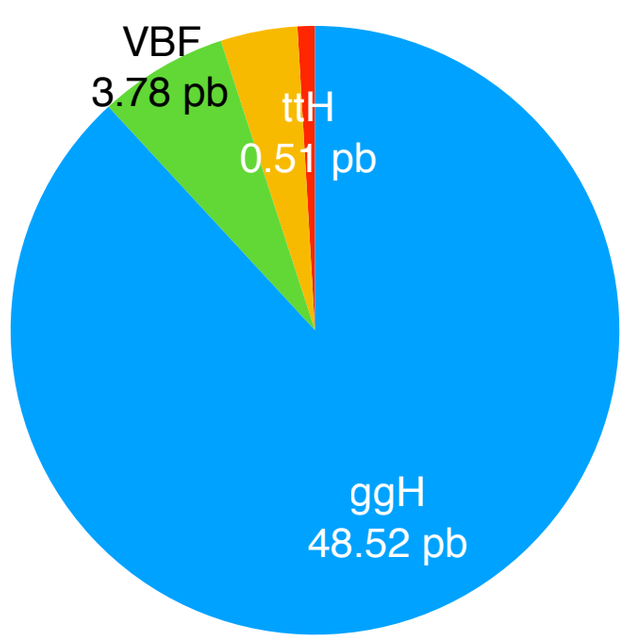
Introduction and Motivation

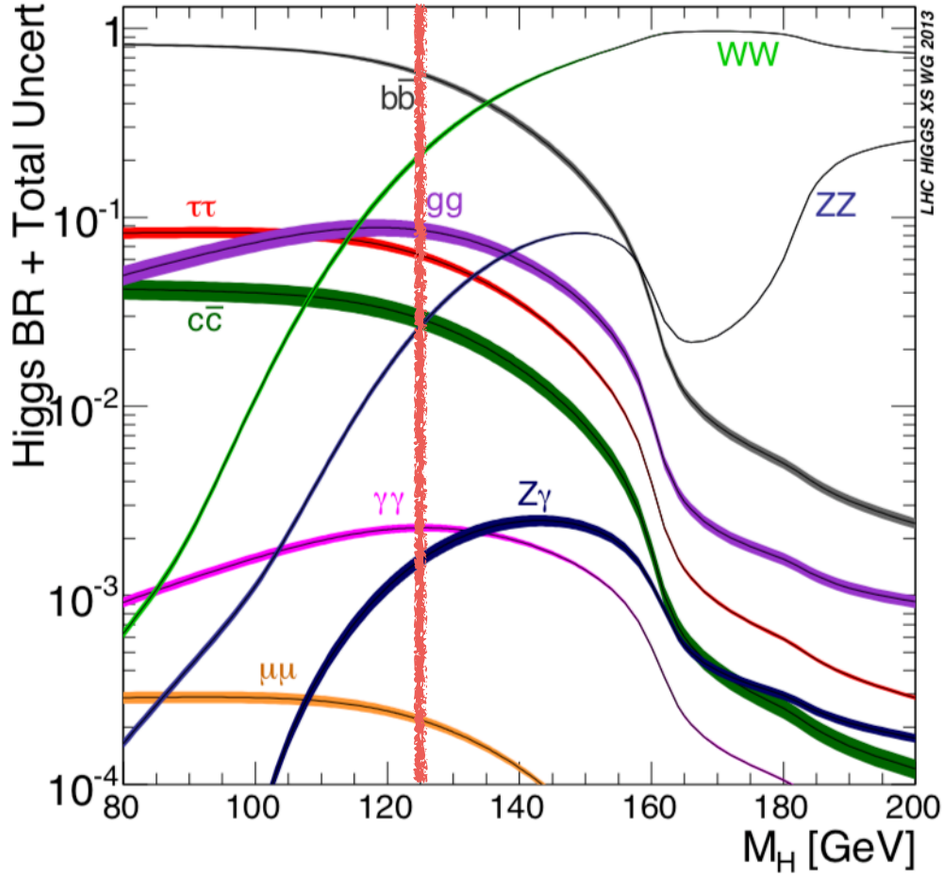
- Important to measure properties of Higgs to study any deviation from standard model theory
- H—>ZZ—>4l (e, μ), Br(H—>ZZ) * Br(ZZ—>4l), low rate, small background make this channel have a clean signature
- Cross section measurement can be used to constrain Higgs coupling g_{Hgg}, g_{HZZ}, and some EFT parameters

Production VH 2.25 pb **Decay** **m_H = 125.09 GeV**





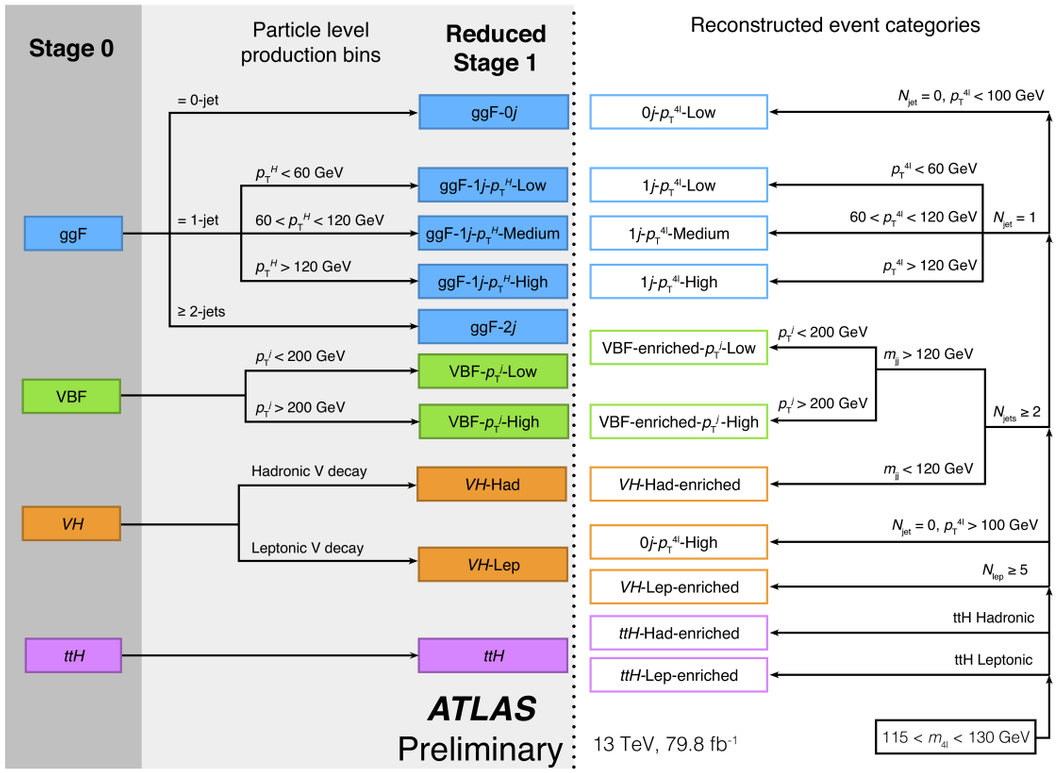
$$\frac{d\sigma_{pp\to H\to ZZ}}{dM_{4l}^2} \sim \frac{g_{Hgg}^2 g_{HZZ}^2}{(M_{4l}^2 - m_H^2)^2 + m_H^2\Gamma_H^2}$$

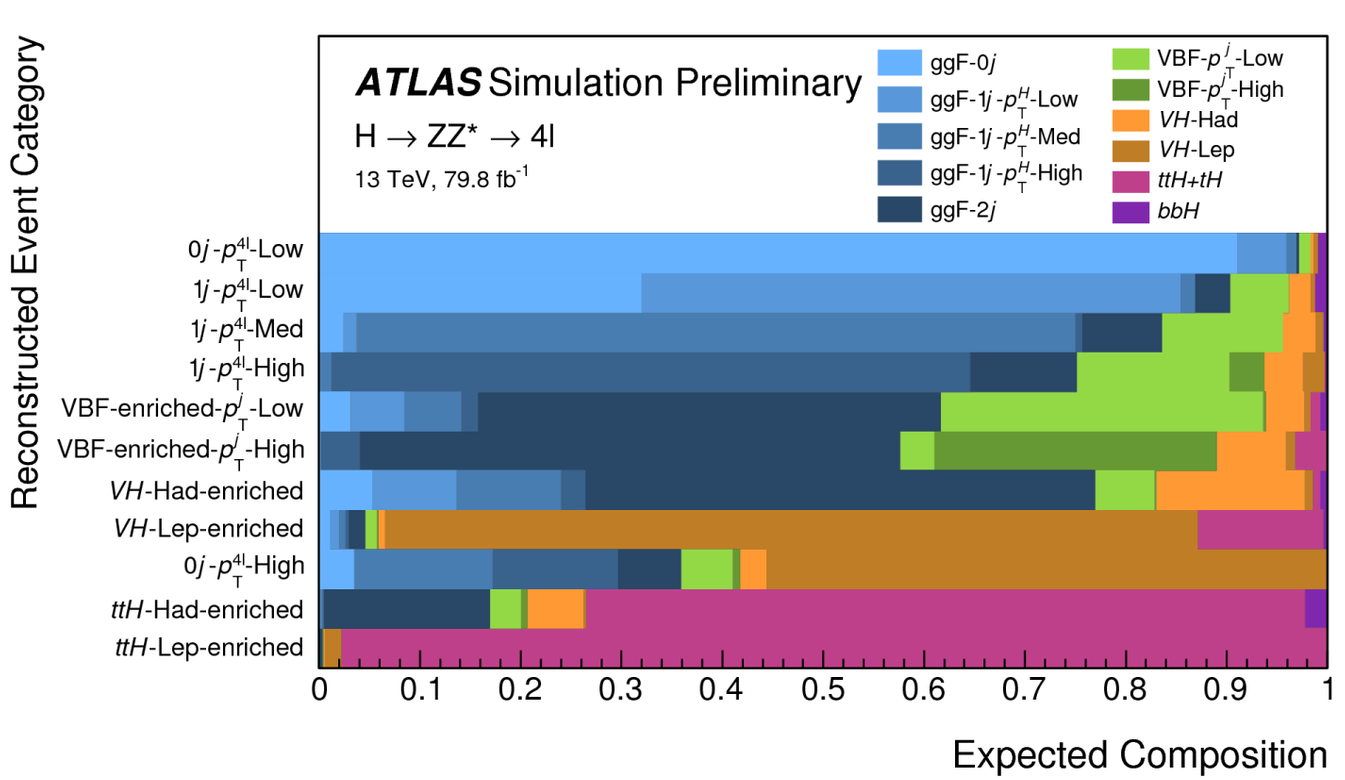


STXS Categorization

$$\mathcal{L}(\mathrm{d}ata \mid \vec{\sigma}, \vec{\theta}) = \prod_{j}^{N_{\text{categories}}} \prod_{i}^{N_{\text{bins}}} P(N_{i,j} \mid \vec{\sigma}_j \cdot S_{i,j}(\vec{\theta}) + B_{i,j}(\vec{\theta})) \times \mathcal{A}_{i,j}(\vec{\theta})$$

- Simplified template cross section(STXS) framework.
  - Simultaneously measure production cross sections.
- Fiducial truth categories - granularity vs sensitivity:
  - Stage 0: 4 production modes
  - Reduced Stage 1, njets, decay modes, kinematic cuts: 10 categories
- Reconstruction-level categories: mimic truth categories, with additional split and Boosted Decision Tree (BDT) to increase sensitivity



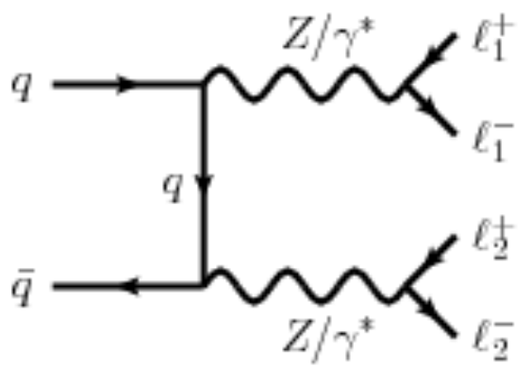


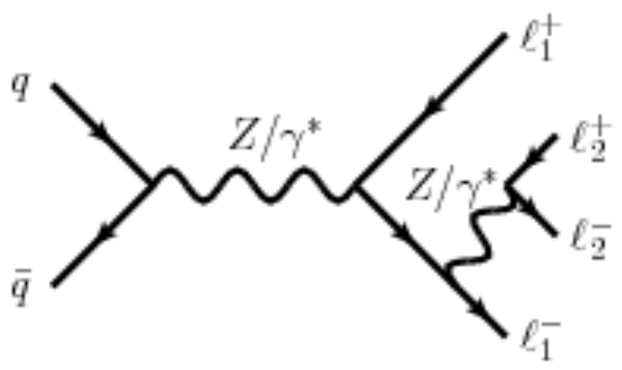
Event Selection

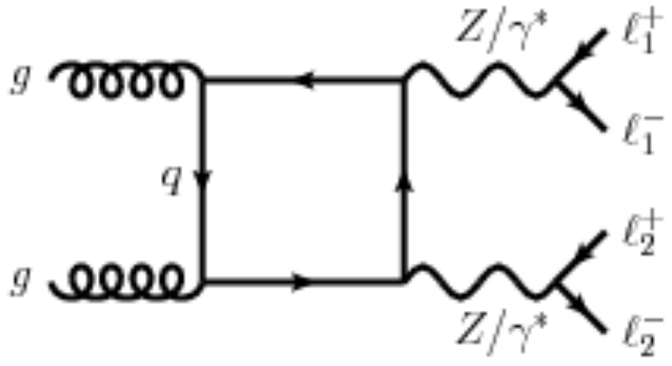
- Object definition and selection:
  - Electrons: E_T > 7 GeV, |η| < 2.47, d0/z0 cut, isolated
  - Muons: p_T > 5 GeV, |η| < 2.7, d0/z0 cut, isolated
  - Jets: anti-kT jets, p_T > 30 GeV, |η| < 4.5
- Two pairs of same-flavor opposite sign leptons
- $p_T^{lepton1,2,3}$ > 20, 15, 10 GeV
- dR_{ll} > 0.1 for same flavor leptons, 0.2 for different
- Z masses cut:
  - 50 < m_{12} < 106 GeV, 12 < m_{34} < 115 GeV
- Higgs mass window:
  - 115 < m_{4l} < 130 GeV

Dataset, Signal and Background

- Dataset: 13 TeV 2015-17 data, 79.8 fb^{-1}
- Signal:
  - Major: ggF, VBF, VH, ttH
  - Minor: bbH, ggZH, merged with other productions due to similar acceptance
- Irreducible background modelled by MC, validated in the sideband CR:
  - qq/gg—>ZZ, major background
  - VVV and ttV
- Reducible fake background from hadron/hadron decay products
  - Z+jets, ttbar
  - Estimated from data in control region (CR) and extrapolated to signal region (SR). Transfer factors and shape derived from MC.







ZZ backgrounds

(c)

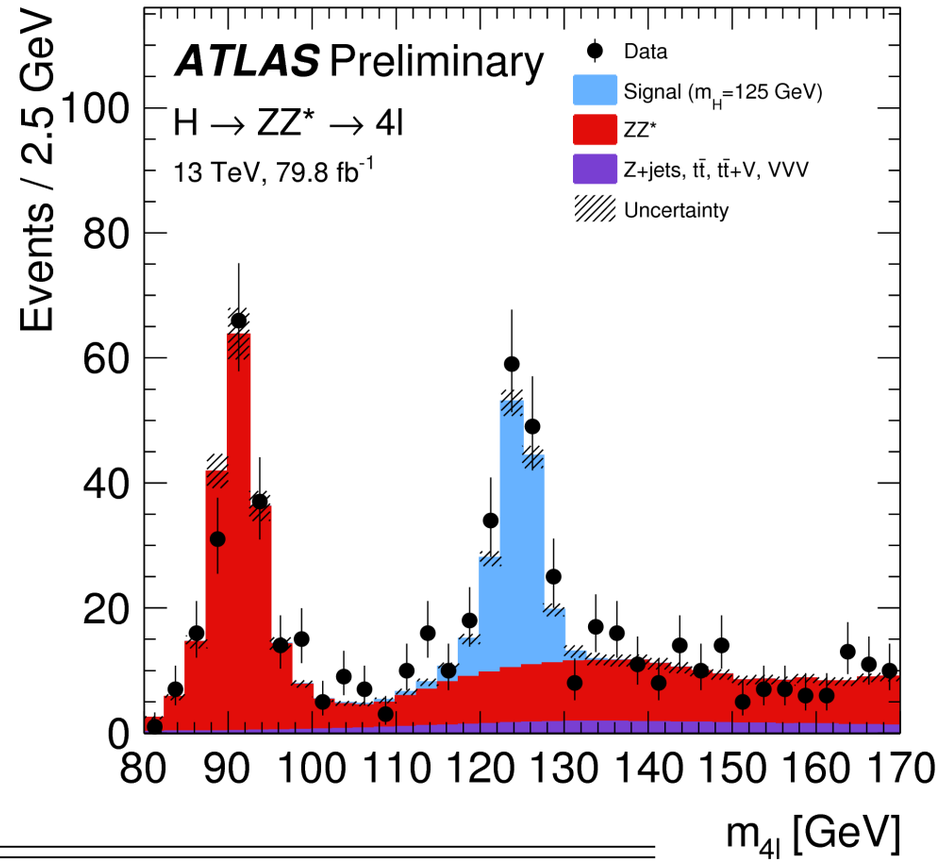
Systematics

- Experimental
  - Luminosity, Pileup Reweighting
  - Lepton related: Reconstruction, Identification, Isolation, Scale & Resolution
  - Jet related: Jet Energy Scale, Flavor tagging, Jet Energy Resolution
  - Data-driven background uncertainty
  - BDT modeling systematics.
  - Theory: pdf, QCD scale(k-factor), parton showering

Measurement	Experimental uncertainties [%]				Theory uncertainties [%]			
	Lum.	e, μ, pile-up	Jets, flavour tagging	Reducible backgr.	ZZ^* backgr.	PDF	QCD scale	Signal Parton Shower
ggF	2.9	3.9	1.3	0.7	2.3	0.4	2.1	0.7
VBF	1.7	1.5	10.5	0.5	2.3	2.3	9.5	5.1
VH	2.0	1.7	7.8	1.8	5.6	2.1	14.9	3.1
ttH	2.5	1.9	3.9	1.5	1.9	0.3	8.8	9.6

Results - yields

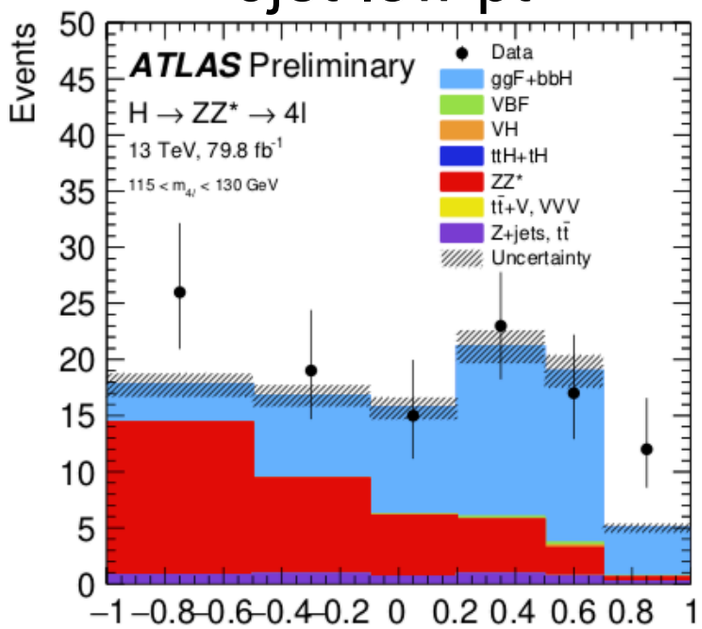
- New in 2017 data compared to 2015-16 data
  - 1 event in VH-leptonic, 2 event in VH-Hadronic category high BDT region
- 0 events observed in ttH category



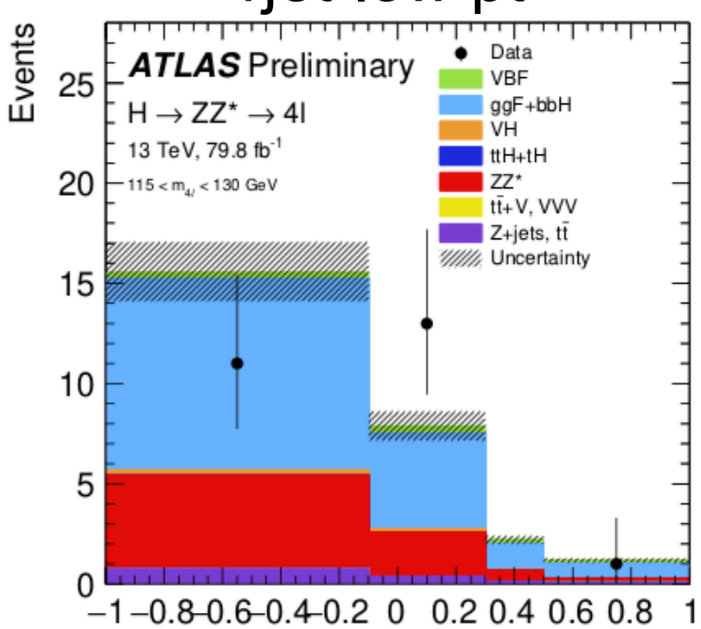
Reconstructed event category	Signal	ZZ^* background	Other backgrounds	Total expected	Observed
$0j$-$p_{\mathrm{T}}^{4\ell}$-Low	56 ± 5	35.2 ± 2.5	4.1 ± 0.4	95 ± 6	112
$1j$-$p_{\mathrm{T}}^{4\ell}$-Low	17.9 ± 2.2	7.6 ± 1.1	1.36 ± 0.14	26.9 ± 2.5	25
$1j$-$p_{\mathrm{T}}^{4\ell}$-Med	11.5 ± 1.5	2.25 ± 0.32	0.72 ± 0.08	14.5 ± 1.5	14
$1j$-$p_{\mathrm{T}}^{4\ell}$-High	3.3 ± 0.5	0.31 ± 0.05	0.198 ± 0.028	3.8 ± 0.5	4
VBF-enriched-p_{T}^{j}-Low	12.8 ± 1.6	2.8 ± 0.7	1.04 ± 0.10	16.6 ± 1.8	24
VBF-enriched-p_{T}^{j}-High	1.25 ± 0.20	0.28 ± 0.09	0.155 ± 0.025	1.68 ± 0.23	4
VH-Had-enriched	7.2 ± 1.1	1.6 ± 0.4	0.59 ± 0.07	9.4 ± 1.2	11
VH-Lep-enriched	0.70 ± 0.05	0.068 ± 0.013	0.035 ± 0.008	0.80 ± 0.05	1
$0j$-$p_{\mathrm{T}}^{4\ell}$-High	0.183 ± 0.025	0.0082 ± 0.0027	0.164 ± 0.023	0.355 ± 0.034	0
ttH-Had-enriched	0.60 ± 0.05	0.035 ± 0.016	0.194 ± 0.030	0.83 ± 0.06	0
ttH-Lep-enriched	0.238 ± 0.026	0.0005 ± 0.0005	0.0144 ± 0.0034	0.253 ± 0.026	0
Total	112 ± 5	50 ± 4	8.96 ± 0.12	171 ± 6	195

Results - BDT distributions

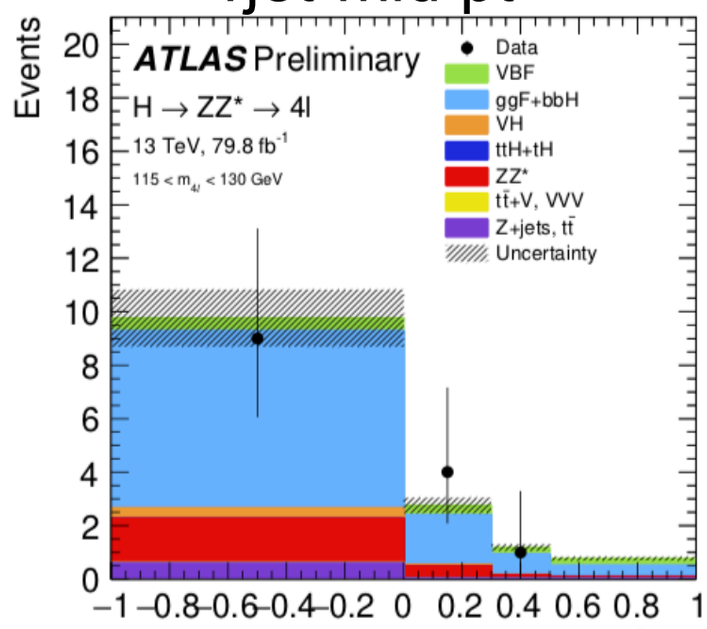
0jet-low pt

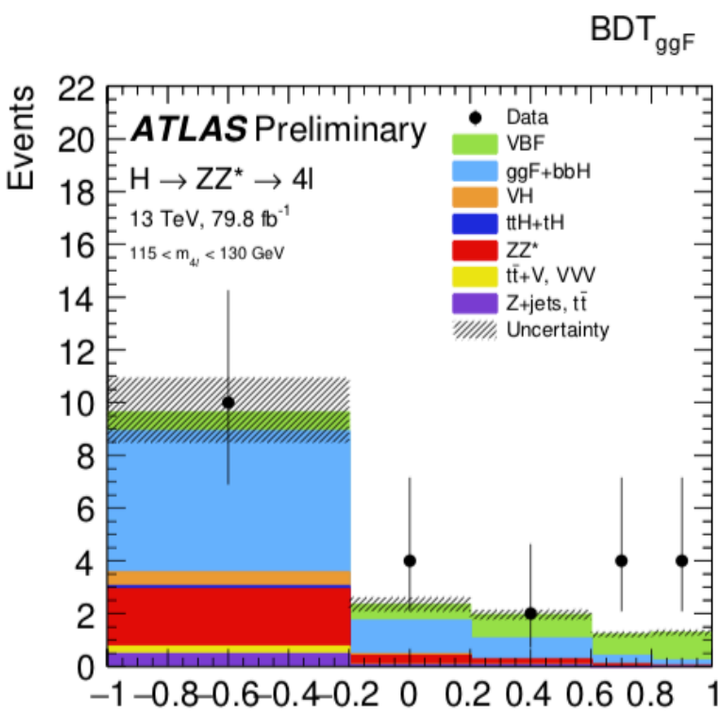


1jet-low pt

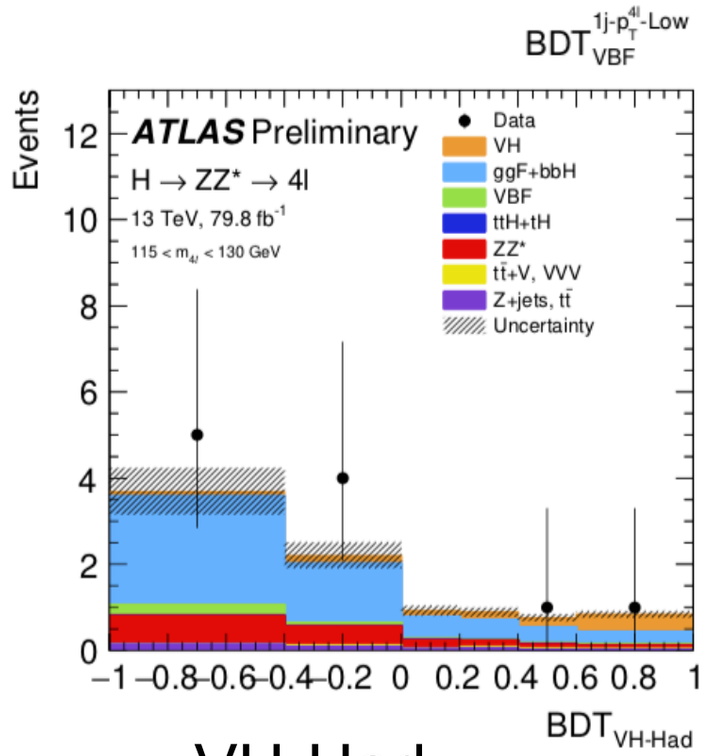


1jet-mid pt

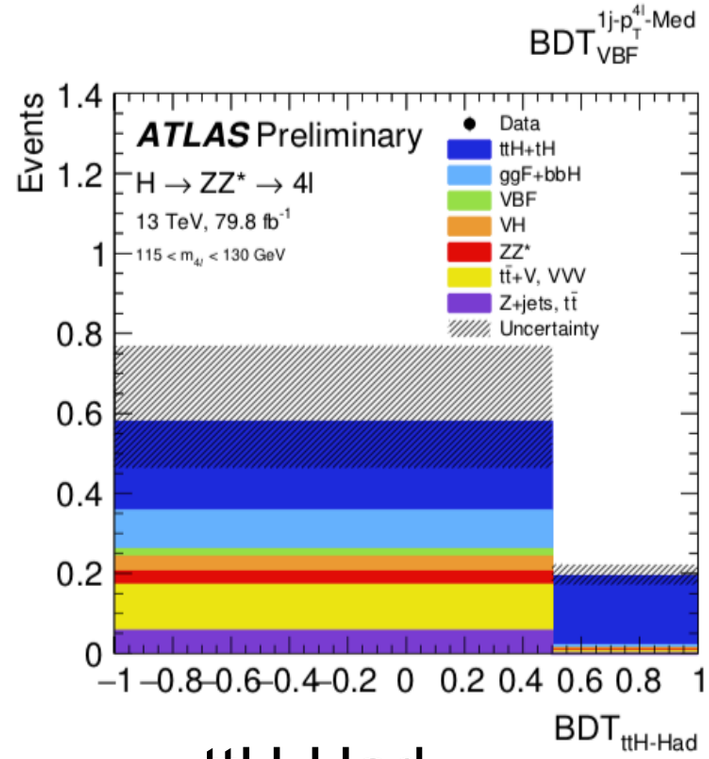




VBF-low jet pt



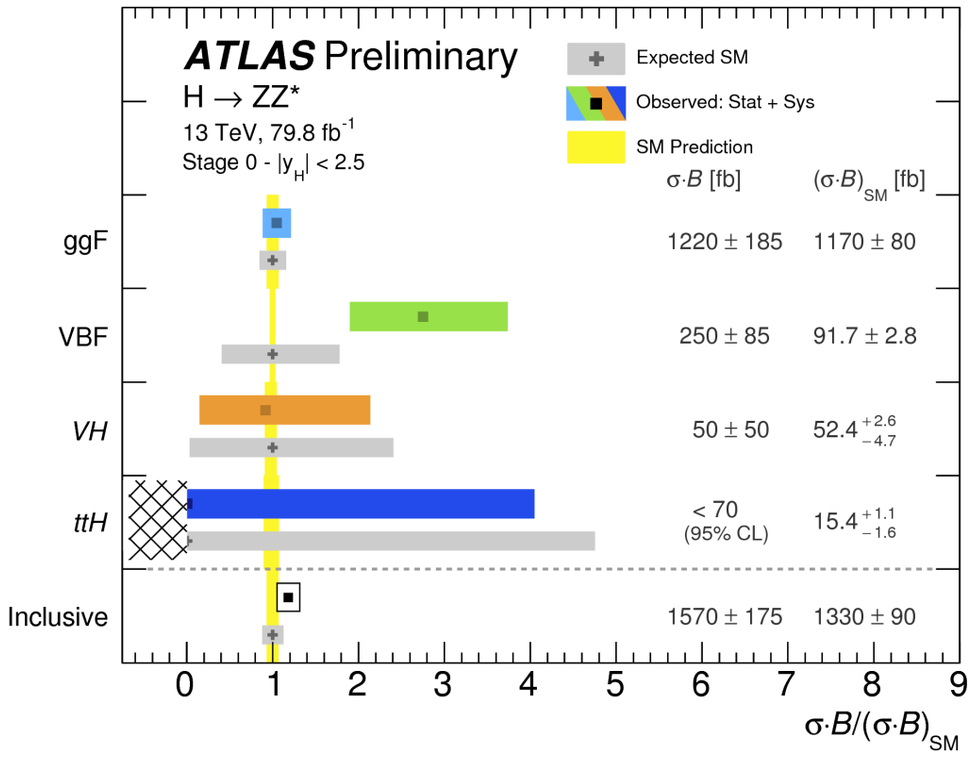
VH-Had

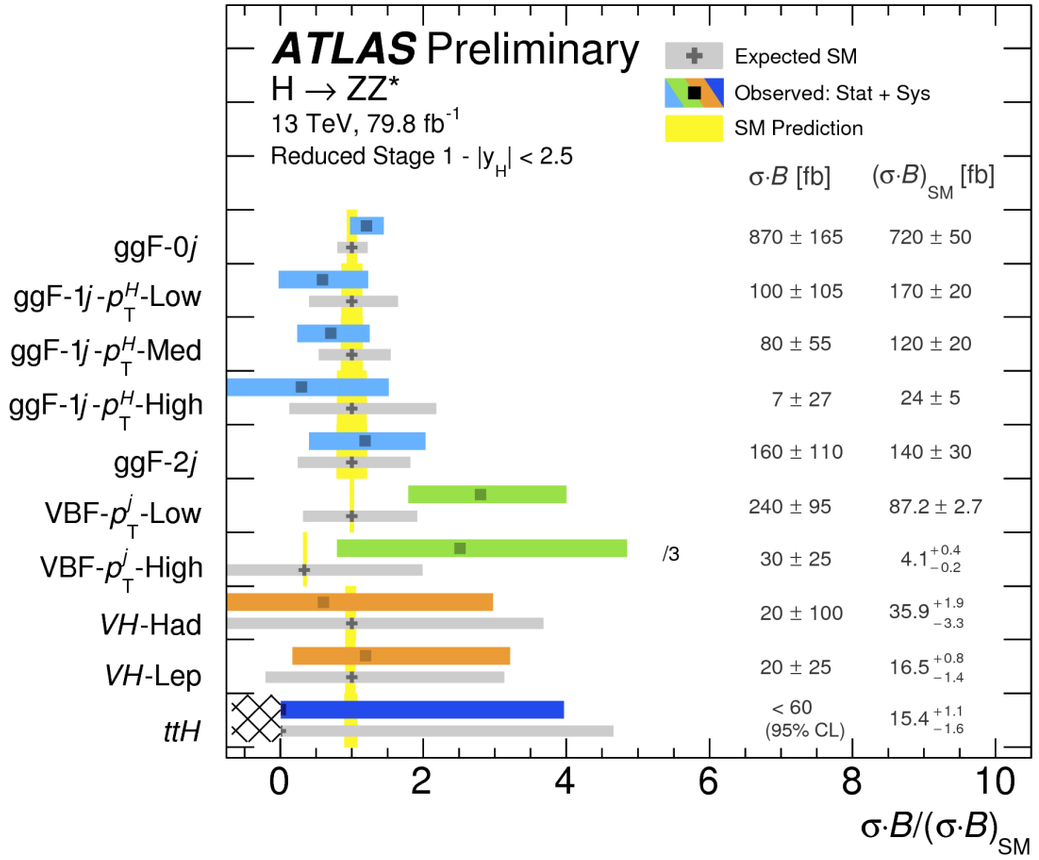


ttH-Had

Fit results

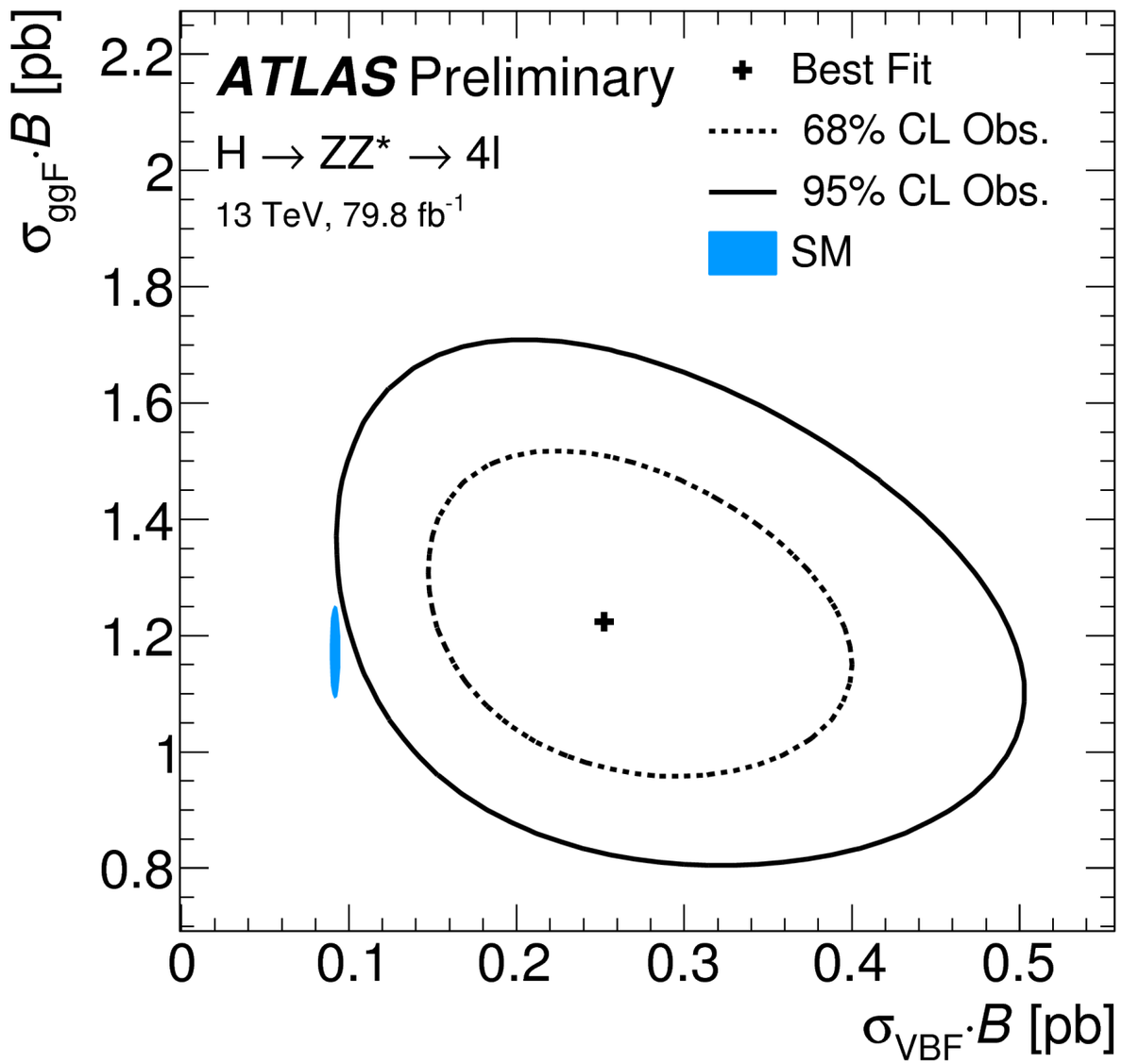
- Use poisson profile likelihood to extract inclusive σ·Br(HZZ)
  - Expected: 1.33 ± 0.09 pb
  - Observed: 1.57 ± 0.18 pb
    = 1.57 ± 0.15(stat.) ± 0.08(exp.) ± 0.04(th.) pb
- Still statistically dominated

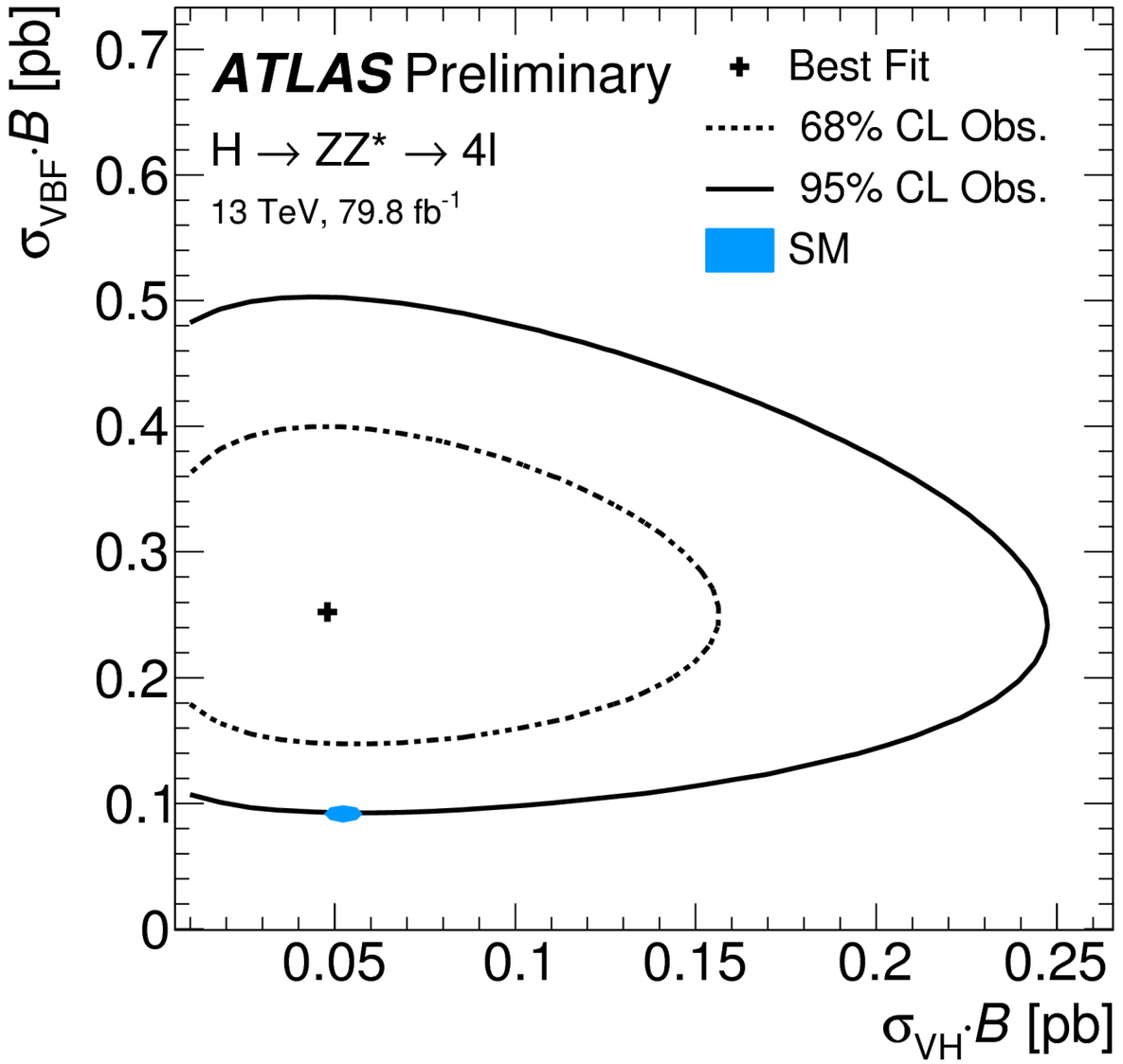




Fit results - 2D

- Also do ggF vs VBF and VBF vs VH cross section measurements.





Conclusions

- Very clean Higgs decay channel.
- Higgs boson production cross sections are measured with 79.8 fb^{-1} data. Measured cross sections agree well with prediction.
- Analysis is statistically limited.
  - With full Run 2 data, the analysis is going to be further improved.