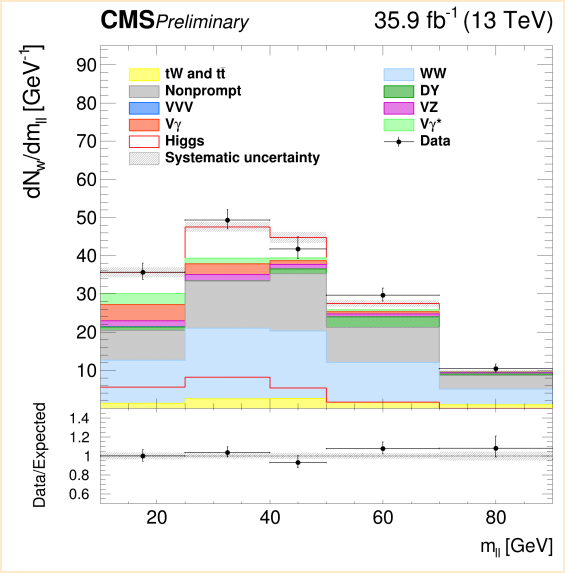
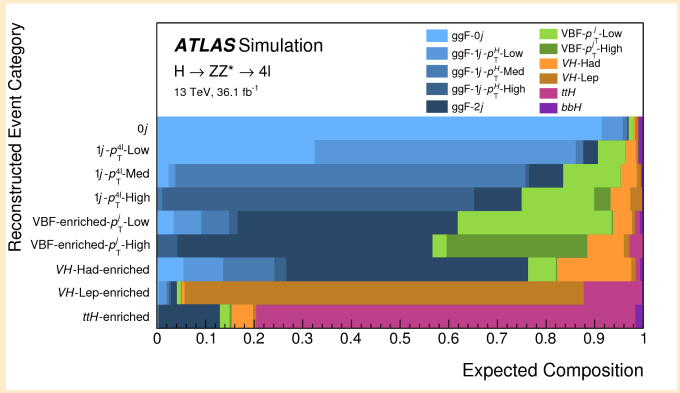
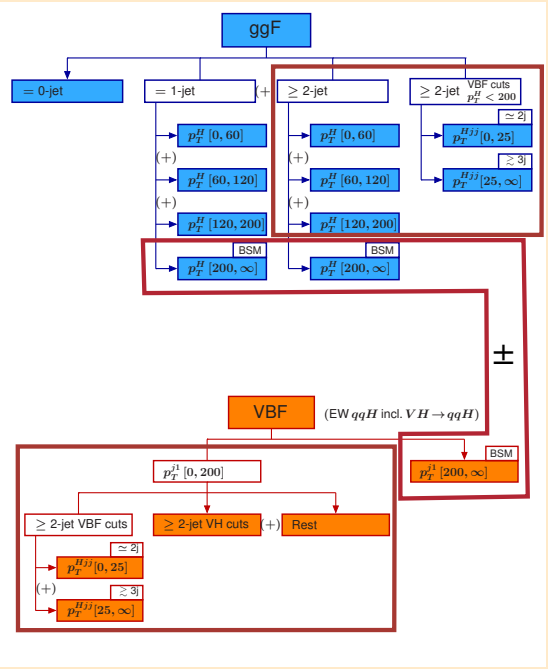
WG2 status and plans

Mingshui Chen, IHEP
Chris Hays, Oxford University
David Marzocca, INFN Trieste
Francesco Riva, University of Geneva

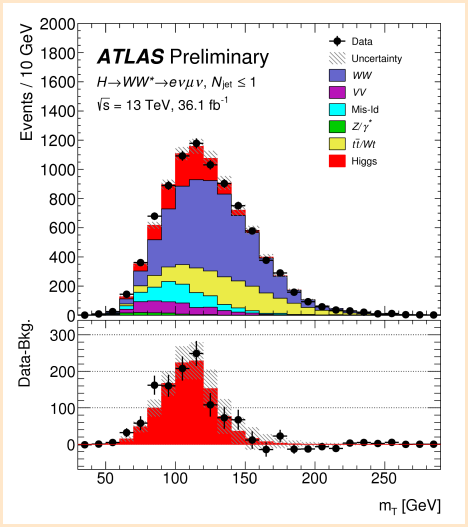




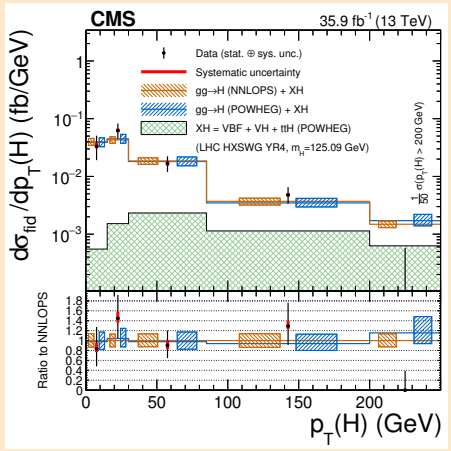


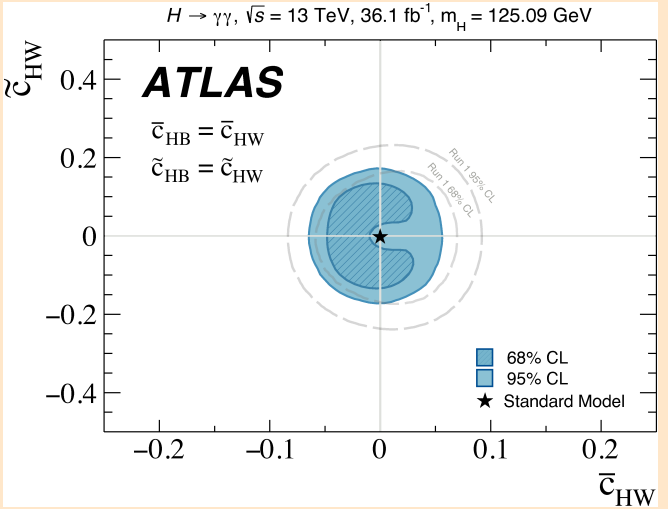
LHC Higgs XS WG general meeting
27 March, 2018

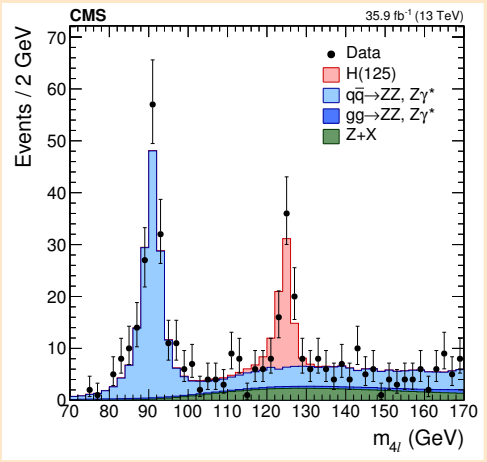
Data → Measurement → Interpretation

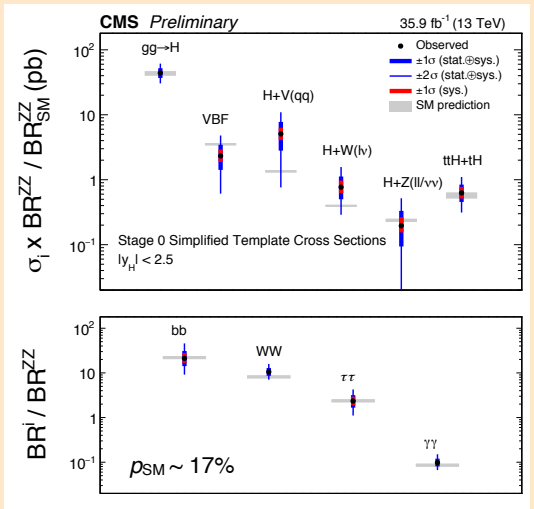


Differential cross sections

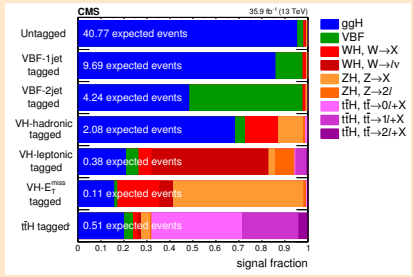




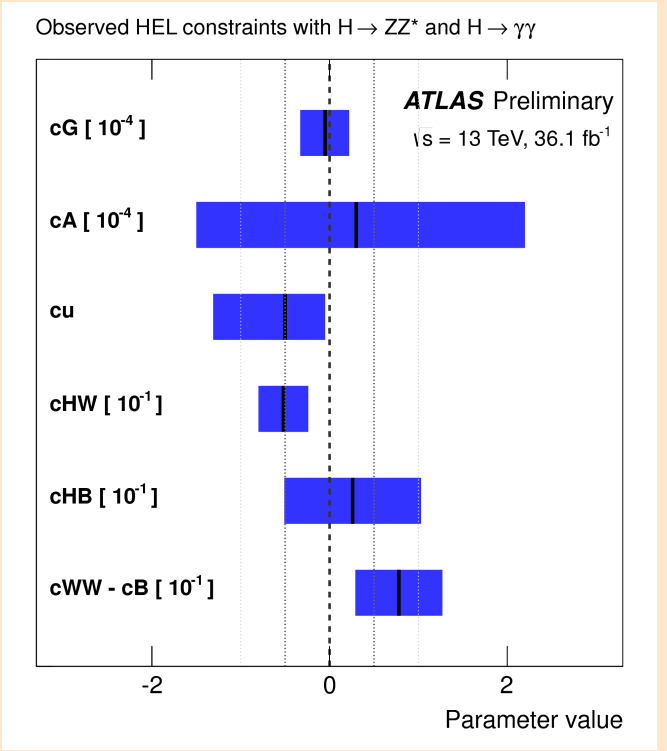


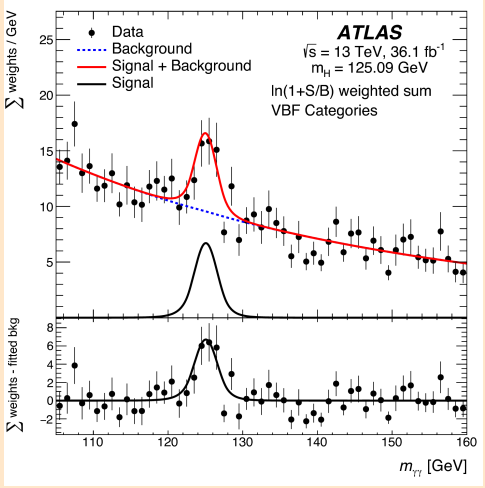


Simplified template cross sections

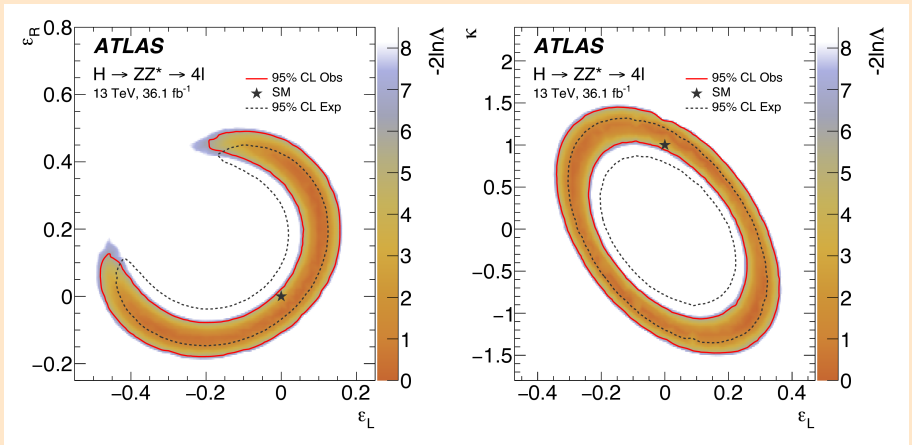


Effective field theory





Pseudo-observables



Organization

LHC Higgs Cross Section Working Group 2 - Higgs Properties

Organization:

- Mailing list: lhc-higgs-properties@cernNOSPAMPLEASE.ch
- Next meetings:
  - WG2 session in general meeting March 27, 9 am
- Recent meetings:
  - Benchmark scenarios February 23 (2018)
  - Winter meeting December 11 (2017)
  - WG2 session in general meeting July 14
  - Joint EW+WG2 meeting July 10
  - STXS meeting July 6
  - Kickoff meeting May 8

Topics:

- STXS & differential XS
  - Dedicated emails lhc-higgs-prop-fidSTXS@cernNOSPAMPLEASE.ch (for subgroup) and lhc-higgs-fidSTXS-convener@cernNOSPAMPLEASE.ch (for conveners Nicolas Berger, Predrag Milenovic, Frank Tackmann).
  - Plan to have note with updates to STXS uncertainties and framework
- PO
  - Overview of effective POs and tools for extraction from measurements
  - Reweighting code to apply to existing MC
  - HiggsPO model available in Madgraph with NLO QCD corrections for VH/VBF production
- EFT
  - Tools in development: Implementation of Warsaw basis in Madgraph with NLO QCD corrections
  - Validity issues under discussion: Defining the region of ci vs Lambda (square term gives an estimate of the uncertainty from higher powers of 1/Lambda)
  - Note on STXS->EFT mapping available
  - Tools required for fit to combined Higgs+EW+Top data
- BSM benchmarks

WG2 twiki summarizes topics and links to recent meetings

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHXSWG2

STXS/FidXS subgroup with conveners Nicolas Berger, Predrag Milenovic, & Frank Tackmann

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHXSWGFiducialAndSTXS

Documenting progress in LHCHXSWG internal notes

Collect into a WG2 summary of strategies and tools for the end of Run 2

WG2 session

Tuesday, 27 March

09:00 → 10:30 **WG2** — 40-S2-C01 - Salle Curie

- 09:00 **Introduction** 20m
  Speaker: Chris Hays (University of Oxford (GB))
- 09:30 **FidXS & STXS** 20m
  Speakers: Frank Tackmann, Nicolas Berger (Centre National de la Recherche Scientifique (FR)), Predrag Milenovic (CERN)
- 10:00 **Electroweak WG** 20m
  Speaker: Yusheng Wu (University of Science and Technology of China (CN))

10:30 → 10:50 **Coffee Break** 20m — Multiple locations

10:50 → 12:30 **WG2** — 40-S2-C01 - Salle Curie

- 10:50 **EFT in Top Physics** 20m
  Speaker: Gauthier Durieux (DESY)
- 11:20 **Benchmark models for EFT** 20m
  Speaker: Francesco Riva (CERN)
- 11:50 **Updated Global SM EFT Fit** 20m
  Speaker: Jonathan R. Ellis (University of London (GB))

Differential and simplified-template XS

(Nicolas Berger's talk)

Differential cross-sections: Standardized binning defined for combinations

Measurement distributions defined
More to add? E.g. $\Delta\phi(j_1,j_2)$, decay distributions

- **1D distributions**:
  $p_T(H)$, N(jets), $|Y(H)|$, p_T(jet 1),
  p_T(jet 2), $|p_T(H) - p_T(\text{jet 1})|$, $|Y(H) - Y(\text{jet 1})|$, $|Y(\text{jet 1}) - Y(\text{jet 2})|$, M_{jj}.
- **2D distributions**: $p_T(H)$ x N(jets), $p_T(H)$ x $|Y(H)|$.

Also: combined resonant (Higgs) + non-resonant (background) measurements in signal and control regions

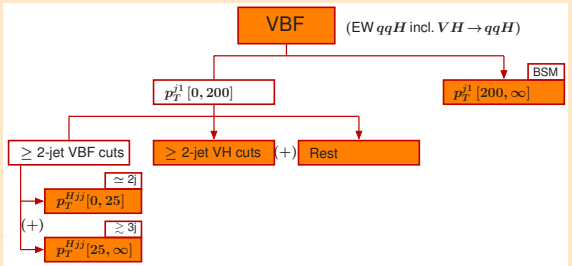
Standardize differential *production* cross sections & combine across channels? Include ratio of decay rates?

ST cross-sections: Refine categories and extend uncertainty estimates

Uncertainties: VBF and VH correlation strategy recently defined

Category updates:

ggF p_T^H binning (200-350, 350-500, >500; split 0-60 to 0-15, 15-60?) & merge ggF+bbH
ggF/VBF signed $\Delta\phi(j_1,j_2)$ bins?
Split ttH to p_T^H 0-200, >200
Should revisit VBF categories (m_{jj} bins?)

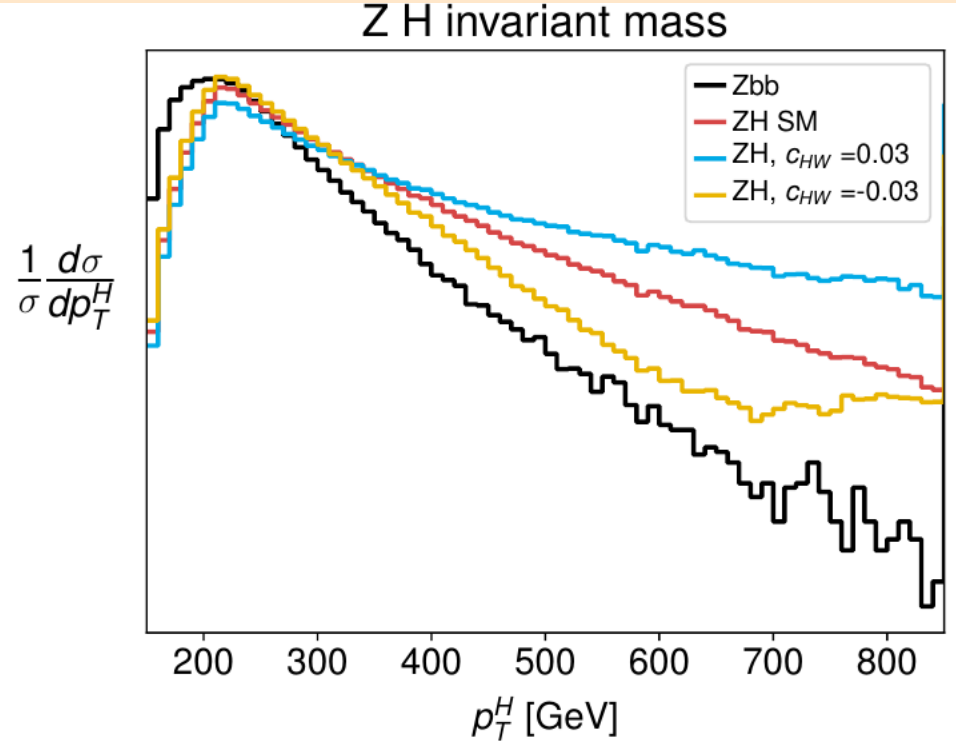


STXS vs optimized analysis

We want to know how the STXS compare to an optimized parameter probe
Dedicated study for VH performed by J De Blas, K Lohwasser, P Musella, K Mimasu
https://indico.cern.ch/event/699709/contributions/2907961/attachments/1606017/2548177/WG2_STXS_vs_EFT.pdf

$$\mathcal{O}_{HW} = \frac{ig}{2\Lambda^2}\left[D^\mu \varphi^\dagger \sigma_k D^\nu \varphi\right] W^k_{\mu\nu}$$

$$c_{HW} = \pm 0.03 \text{ and } \pm 0.01$$

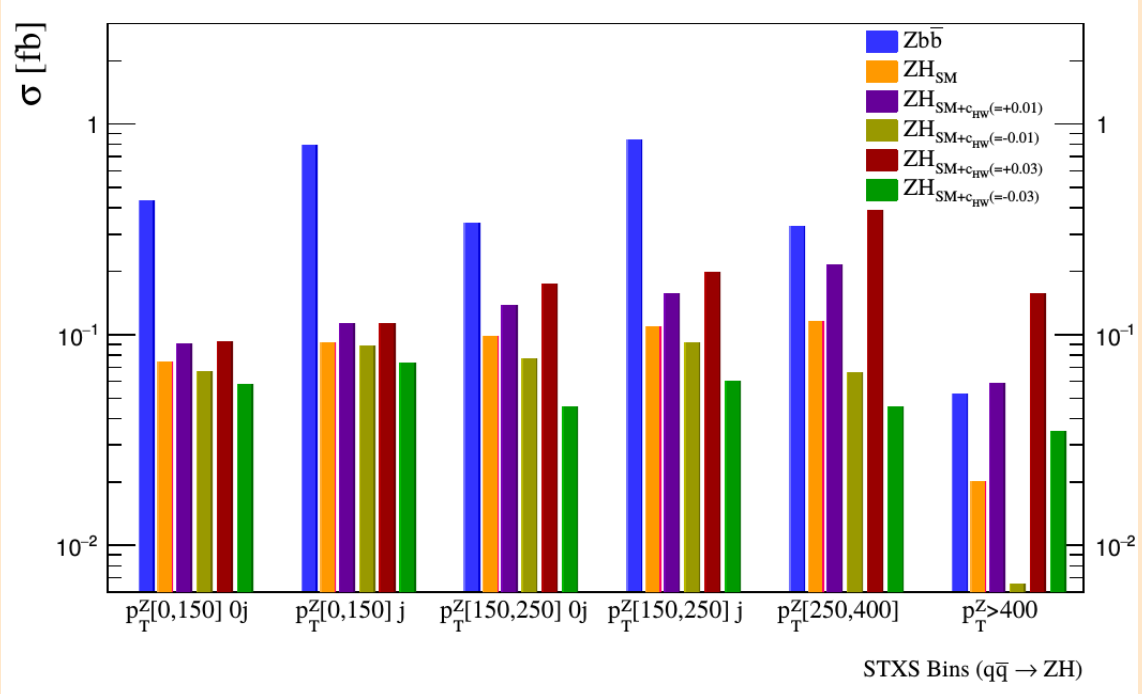


Fid. phase space
p_T(jet) > 20 GeV |η|<2.5
p_T(lep) > 25GeV |η|<2.5
n(lep) = 2
n(bjets) = 2 (ε(btag) = 0.7)
75 < M_{ll} < 105
60 < M_{bb} < 140

Distributions raise the question of applicability of STXS

STXS vs optimized analysis

SAMPLE	SEL. EFFICIENCY
Zbb	<0.01
SM VH	0.19
c_{HW} = 0.03	0.31
c_{HW} = -0.03	0.14
c_{HW} = 0.01	0.23
c_{HW} = -0.01	0.16



Ideally compare reconstruction efficiency in each STXS bin

BDT analysis gives ~5% sensitivity improvement to c_{HW} in VH production

Could check STXS applicability by fitting for c_{HW} in BDT and STXS analyses

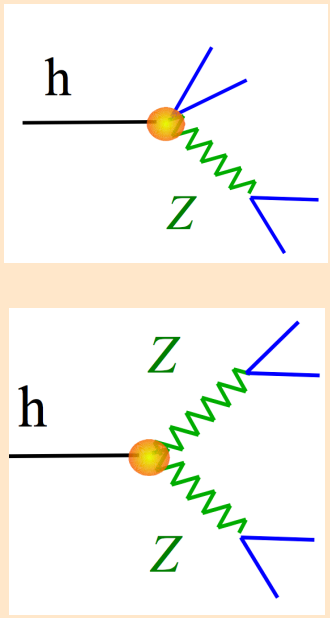
Worthwhile to perform exercise on VBF production

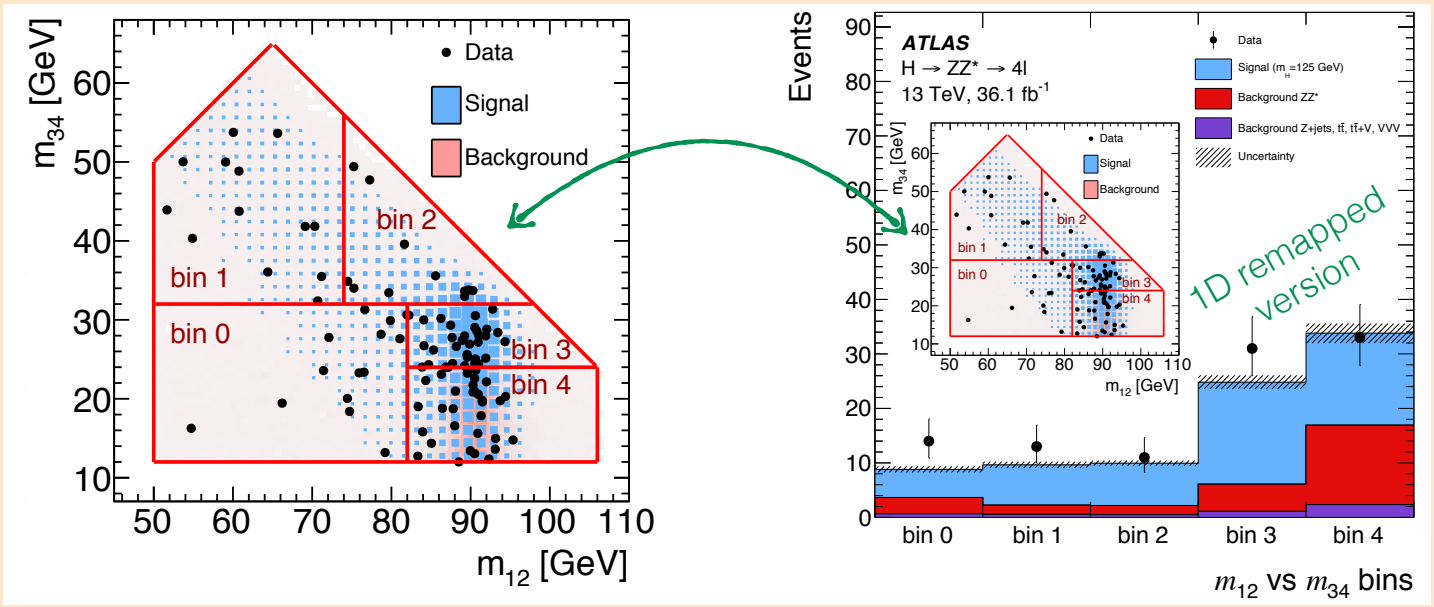
Pseudo-observables

ATLAS has probed YR4 pseudo-observables in H→4l decay
https://indico.cern.ch/event/682466/contributions/2796809/attachments/1573127/2482949/andrea_workshop.pdf

$$\kappa \equiv \{\kappa_{ZZ}, \varepsilon_{Ze_L}, \varepsilon_{Ze_R}, \varepsilon_{Z\mu_L}, \varepsilon_{Z\mu_R}, \varepsilon_{ZZ}, \varepsilon_{Z\gamma}, \varepsilon_{\gamma\gamma}, \varepsilon^{CP}_{ZZ}, \varepsilon^{CP}_{Z\gamma}, \varepsilon^{CP}_{\gamma\gamma}\}$$

Use unfolded measurement of bins in m_{12}-m_{34} plane to constrain contact interactions and rate assuming lepton universality



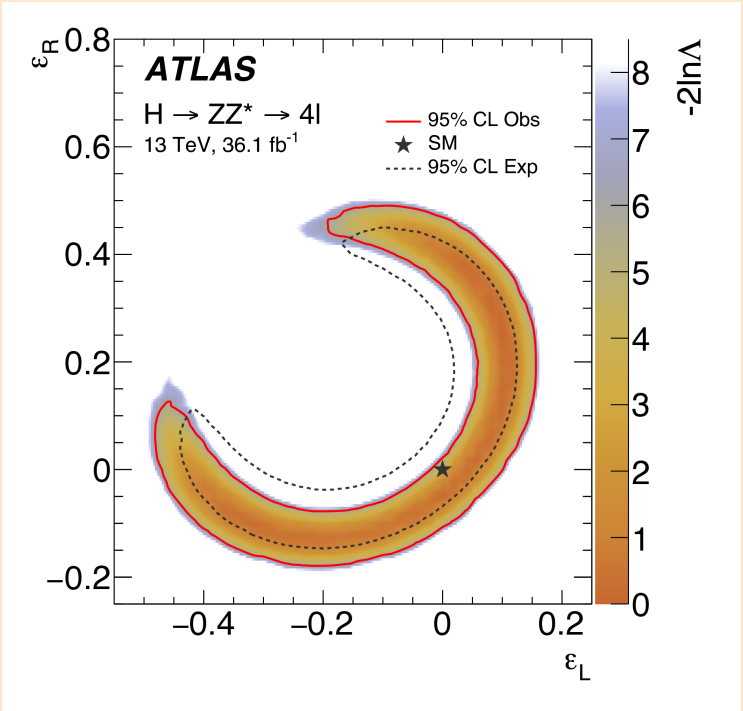


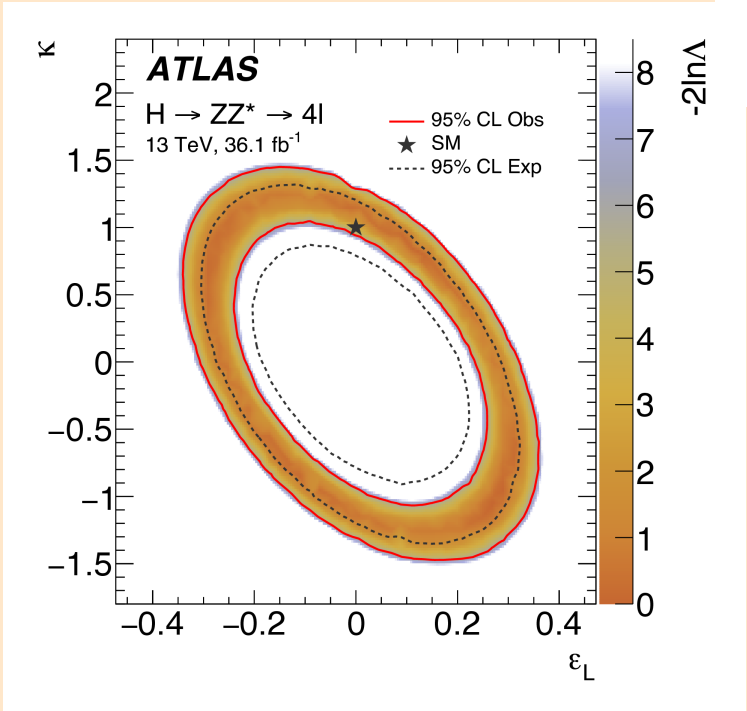
Pseudo-observables

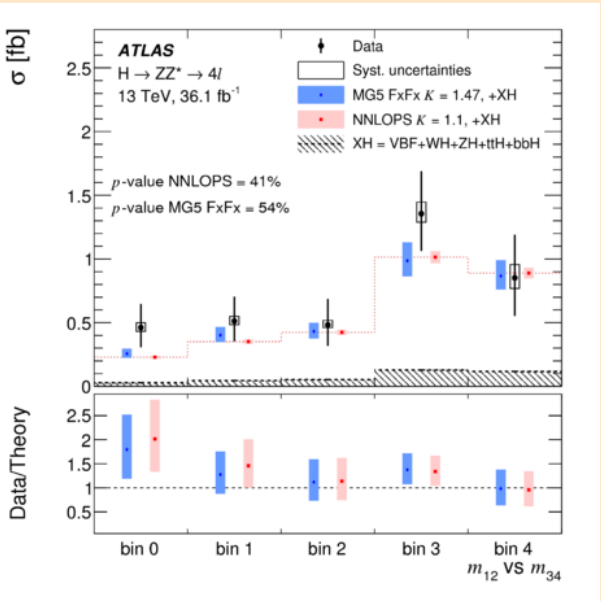
Proof-of-principle result, sensitivity not optimized

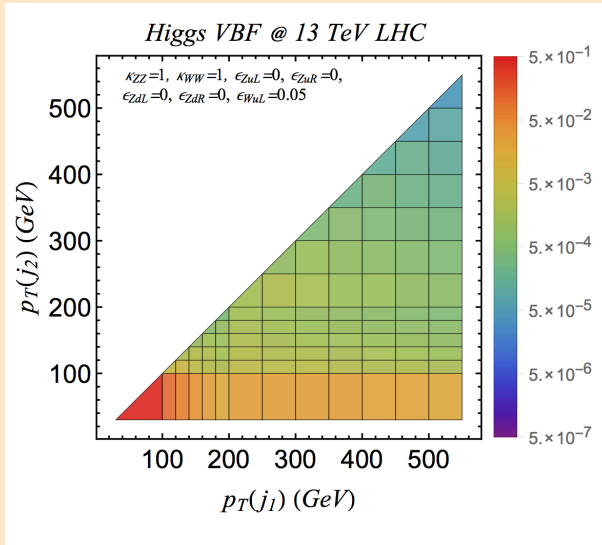
Future results could optimize sensitivity in decays
Add to STXS?

Also can add production modes and other channels









Pseudo-observables

HL-LHC prospects for POs studied by A Greljo, S Isakovic, N Selimov
https://indico.cern.ch/event/682466/contributions/2796809/attachments/1573127/2482949/andrea_workshop.pdf

Use ATLAS bins in m_{12}-m_{34} plane to project to HL-LHC

Signal (in the SM)

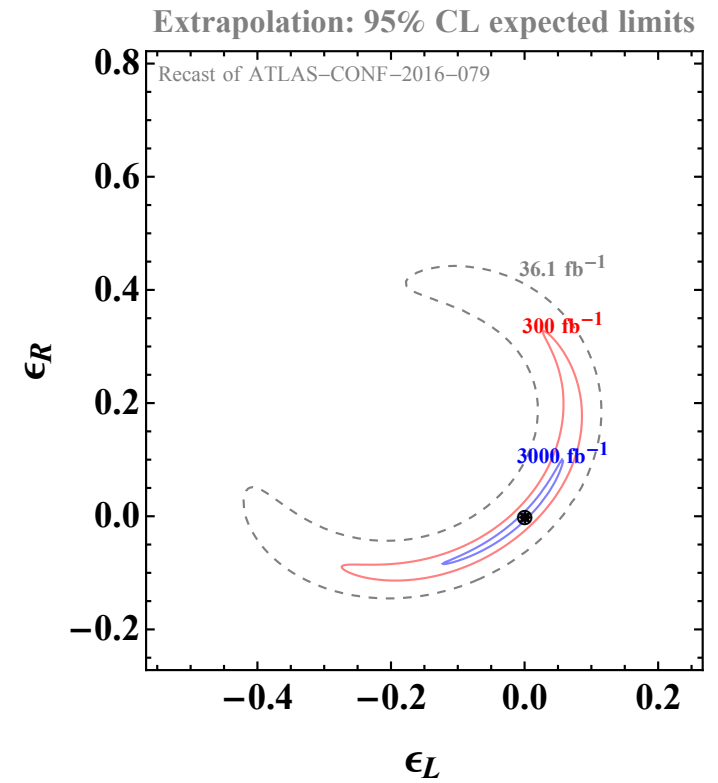
3000 fb^{-1}	4e	4μ	2e2μ	2μ2e
Bin 0	93	154	81	78
Bin 1	155	235	130	126
Bin 2	143	233	148	141
Bin 3	276	487	387	344
Bin 4	241	447	352	287

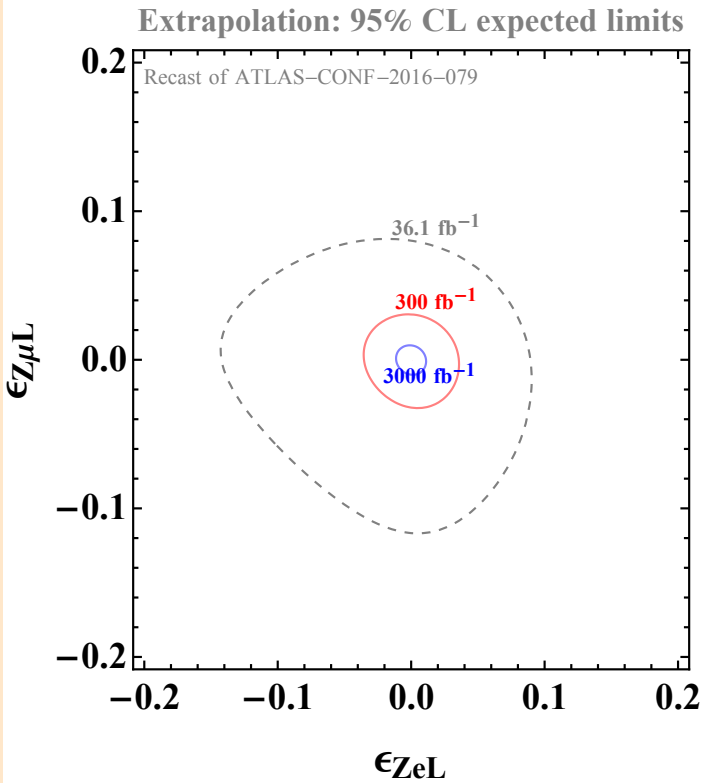
Background

3000 fb^{-1}	4e	4μ	2e2μ	2μ2e
Bin 0	26	48	36	29
Bin 1	14	24	6	6
Bin 2	17	24	16	16
Bin 3	71	123	99	89
Bin 4	185	435	330	239

$$\begin{pmatrix} \kappa_{ZZ} \\ \epsilon_{ZeL} \\ \epsilon_{ZeR} \\ \epsilon_{Z\mu L} \\ \epsilon_{Z\mu R} \end{pmatrix} = \begin{pmatrix} 1. \\ 0. \\ 0. \\ 0. \\ 0. \end{pmatrix} \pm \begin{pmatrix} 0.07 \\ 0.07 \\ 0.07 \\ 0.08 \\ 0.1 \end{pmatrix}$$

Remove assumption of lepton universality





Effective field theory

If new physics is confined to a high scale we can describe it with EFT

Few-particle scenario: *benchmarks described by limited number of EFT parameters*
February WG2 meeting on scenarios, document in preparation (Francesco Riva's talk)

Many-particle scenario: *model-independent global fit for EFT parameters*
Various strategies for global fits, e.g.:

- Electroweak data fit including EFT uncertainties (Berthier, Bjorn, Trott)
- Electroweak fit without flavor universality (A Falkowski, M Gonzalez-Alonso, K Mimouni)
- Electroweak + Higgs global fit & few-particle interpretation (John Ellis's talk)

A global fit to LHC data will need electroweak and top data

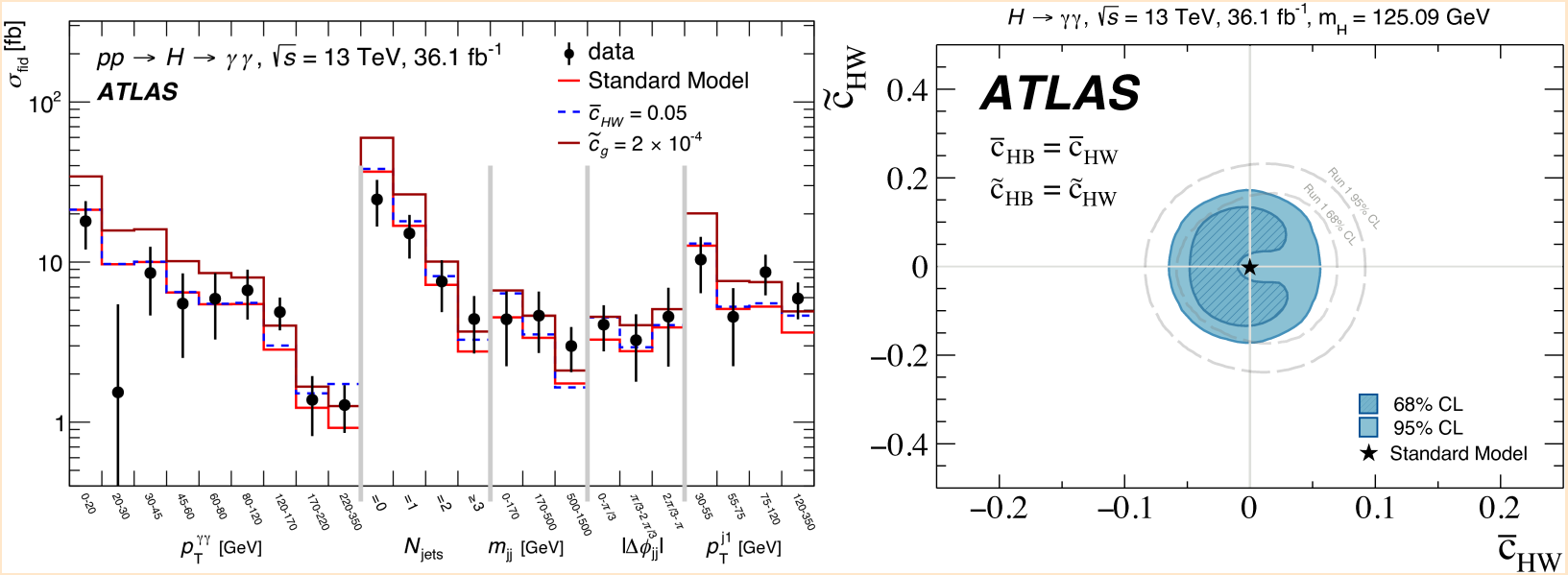
- Operators affecting Higgs data can be constrained by these measurements
- LHC WG activities in talks from Yusheng Wu (EW) & Markus Seidel (top)
- Comprehensive documentation on top EFT now available (Gauthier Durieux's talk)

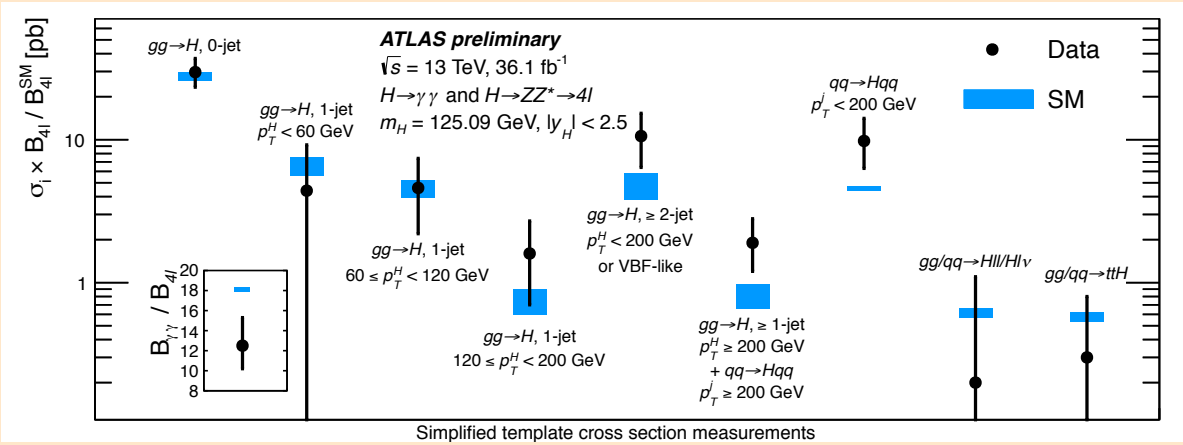
Existing EFT constraints from ATLAS use HEL implementation of SILH basis
https://indico.cern.ch/event/682466/contributions/2796813/attachments/1573262/2483194/WG2_dec.pdf

Effective field theory

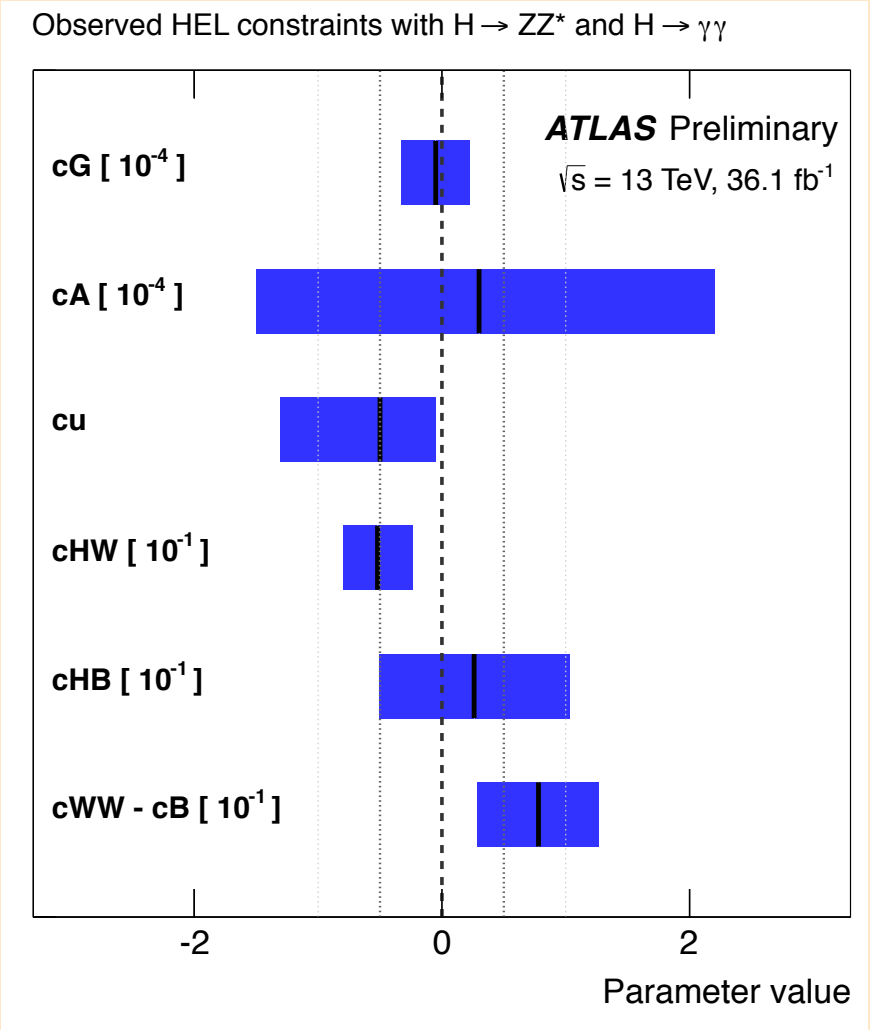
ATLAS use individual H→$\gamma\gamma$ differential XS or H→$\gamma\gamma$ + H→4l STXS combination

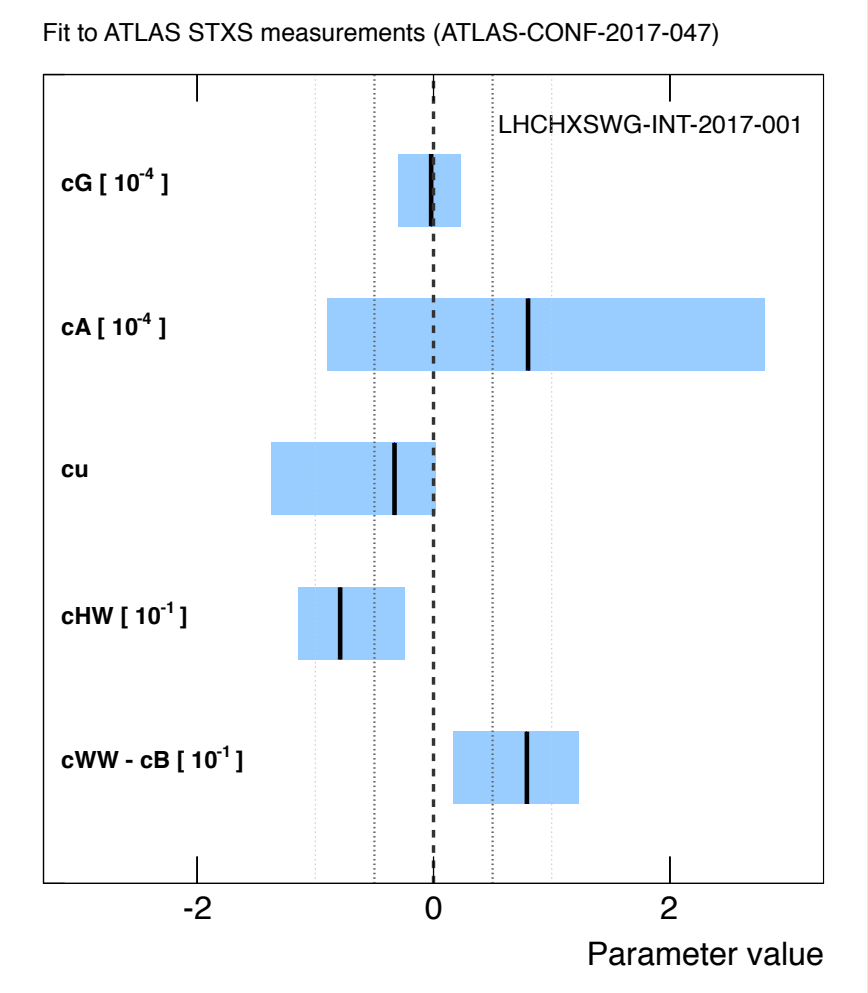
Individual channel results in 2-parameter fit, combination constrains 6 parameters





Effective field theory





ATLAS fit uses more categories than measured STXS

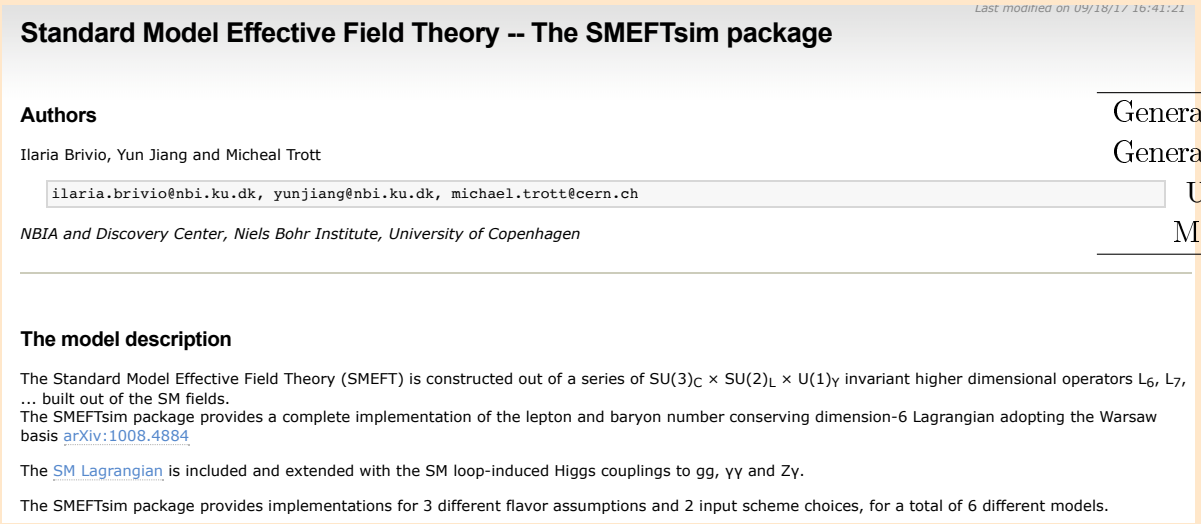
Fit to STXS measurement can only constrain five parameters

https://indico.cern.ch/event/682466/contributions/2796820/attachments/1573120/2482936/WG211Dec2017.pdf

Effective field theory

Recent and upcoming tools make a global experimental fit possible

SMEFTsim: complete flavor-general implementation of dimension-6 operators
Also includes a U(3)^5-symmetric version



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Standard Model Effective Field Theory -- The SMEFTsim package

Authors

Ilaria Brivio, Yun Jiang and Micheal Trott

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NBIA and Discovery Center, Niels Bohr Institute, University of Copenhagen

The model description

The Standard Model Effective Field Theory (SMEFT) is constructed out of a series of $SU(3)_C \times SU(2)_L \times U(1)_Y$ invariant higher dimensional operators L_6, L_7, ... built out of the SM fields.
The SMEFTsim package provides a complete implementation of the lepton and baryon number conserving dimension-6 Lagrangian adopting the Warsaw basis arXiv:1008.4884

The SM Lagrangian is included and extended with the SM loop-induced Higgs couplings to gg, γγ and Zγ.

The SMEFTsim package provides implementations for 3 different flavor assumptions and 2 input scheme choices, for a total of 6 different models.

Case	CP even	CP odd	WHZ Pole parameters
General SMEFT ($n_f = 1$)	53 [10]	23 [10]	~ 23
General SMEFT ($n_f = 3$)	1350 [10]	1149 [10]	~ 46
$U(3)^5$ SMEFT	~ 52	~ 17	~ 24
MFV SMEFT	~ 108	-	~ 30

An implementation to NLO in QCD is imminent
https://indico.cern.ch/event/682466/contributions/2796827/attachments/1573310/2483453/nloeftstatus.pdf
Will allow tests of EFT Hqq coupling in ggF loop

Effective field theory

Study of sensitivity to CP-odd observables using information geometry
https://indico.cern.ch/event/682466/contributions/2796822/attachments/1573344/2483360/cern_cp_17.pdf

Need to ensure CP-sensitive observables are included in differential and ST cross sections

- azimuthal angle difference [lab frame]

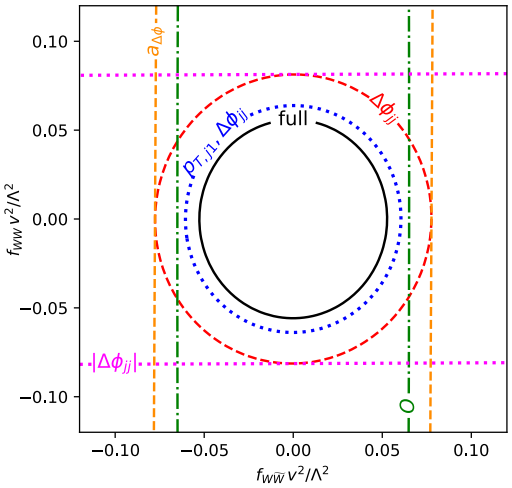
$$O = 2E_-(\vec{q}_- \times \vec{q}_+) \cdot \vec{k}_+ \quad \rightarrow \quad \sin\Delta\phi_{jj}$$

- *CP* asymmetry

$$a_{\Delta\phi_{jj}} \equiv \frac{\mathrm{d}\sigma(\Delta\phi_{jj}) - \mathrm{d}\sigma(-\Delta\phi_{jj})}{\mathrm{d}\sigma(\Delta\phi_{jj}) + \mathrm{d}\sigma(-\Delta\phi_{jj})}$$

- separating dimension-6 effects

Vector boson fusion



- *CP*-odd and $\hat{T}$-odd angle

$$O_1 = \epsilon_{\mu\nu\rho\sigma}\, k_1^\mu k_2^\nu q_{\ell+}^\rho q_{\ell-}^\sigma \ \mathrm{sign}((k_1 - k_2)\cdot(q_1 - q_2)) \quad \rightarrow \quad \sin\Delta\phi_{\ell\ell}$$

- *CP* asymmetry

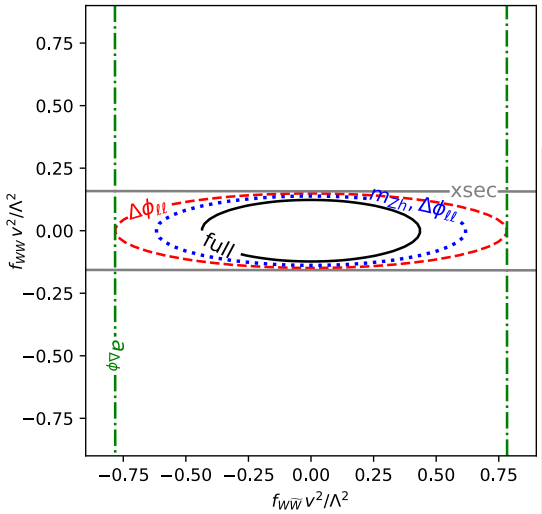
$$a_{\Delta\phi_{\ell\ell}} \equiv \frac{\mathrm{d}\sigma(\Delta\phi_{\ell\ell}) - \mathrm{d}\sigma(-\Delta\phi_{\ell\ell})}{\mathrm{d}\sigma(\Delta\phi_{\ell\ell}) + \mathrm{d}\sigma(-\Delta\phi_{\ell\ell})}$$

- *CP*-odd and $\hat{T}$-even, requiring second phase

$O_2 \rightarrow \Delta E_{\ell\ell}$ $\qquad$ $O_3 \rightarrow \Delta p_{T,\ell\ell}$

- separating dimension-6 effects

ZH production



Summary

WG2 working towards a comprehensive strategy for measurements and interpretations for Run 2

Recent interpretation tools can feed back to measurement strategies
Expect further iteration before end of Run 2

WG2 meetings every 3-6 months

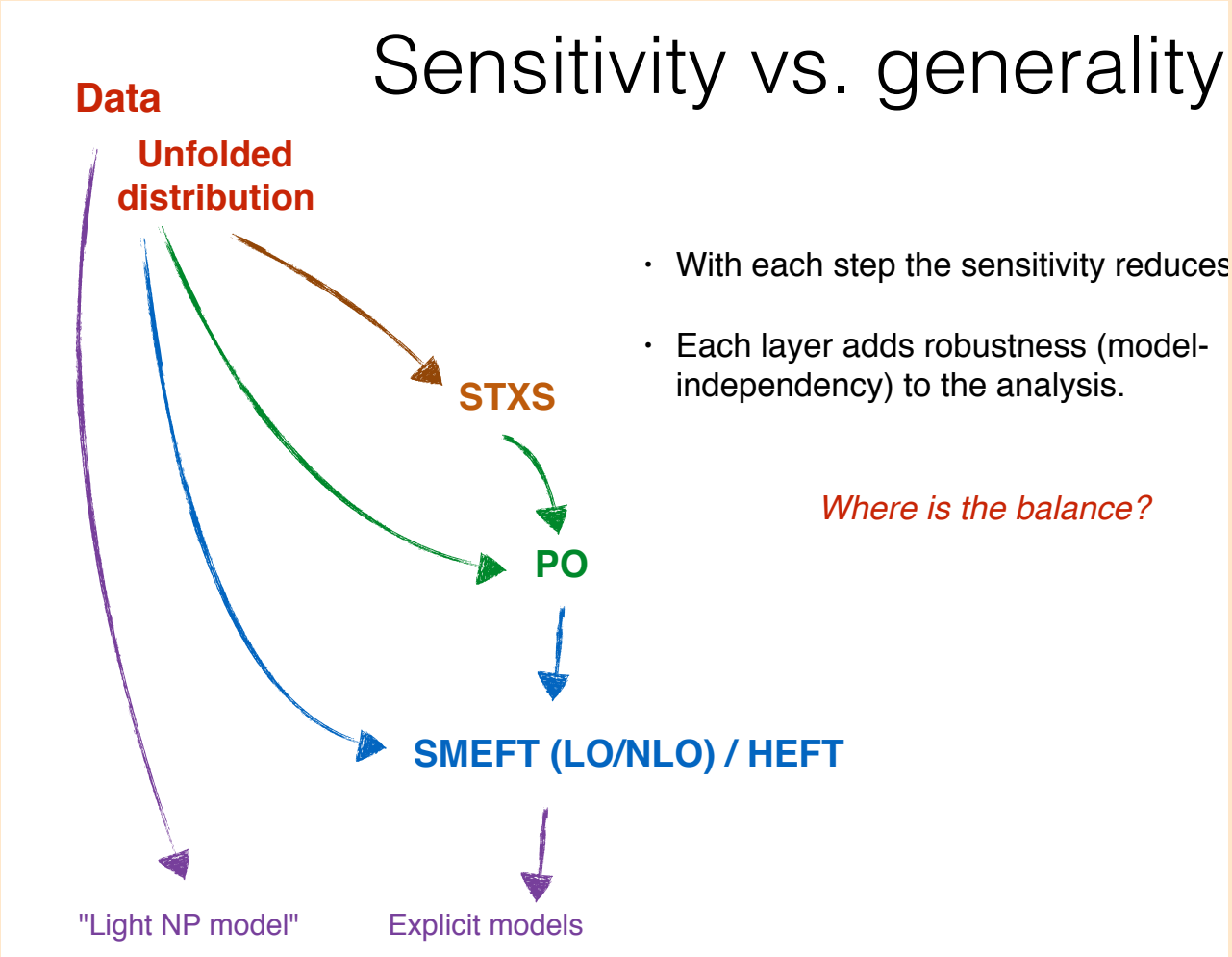
Documenting progress in LHCHXSWG internal notes
STXS/FidXS update (soon)
STXS mapping to HEL operators (posted)
Benchmark EFT scenarios (to appear)
EFT tools and fits (envisioned)

Collect into summary document for end of Run 2

Extras from December meeting

STXS-PO complementarity

David Marzocca



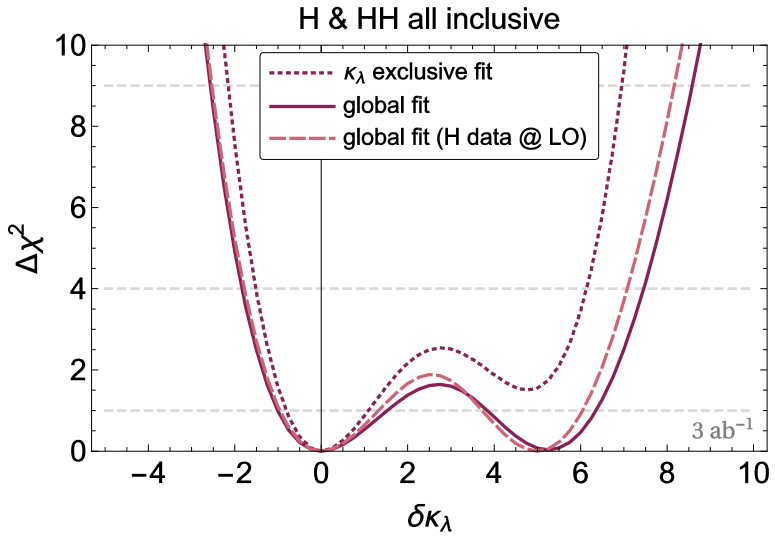
Procedurally STXS→PO is the same as STXS→EFT

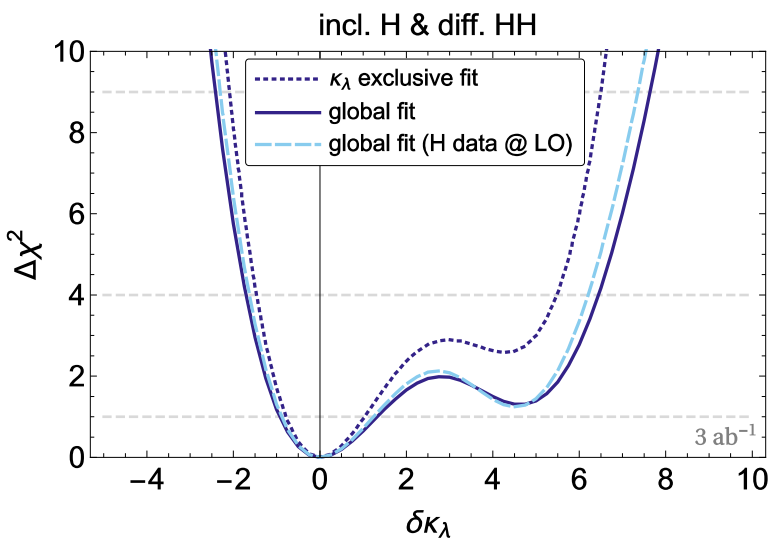
PO characterizes an amplitude; EFT characterizes all amplitudes

Higgs self-coupling

Stefano Di Vita

Compare & combine w/double-Higgs





Double-Higgs drives the bound on κ_λ while, single-Higgs observables are essential in order to constrain the **other** coefficients deforming σ(hh)

Differential (m_{hh}) double-Higgs removes degeneracy due to second minimum

HH will dominate sensitivity and differential M_{hh} measurement breaks degeneracy

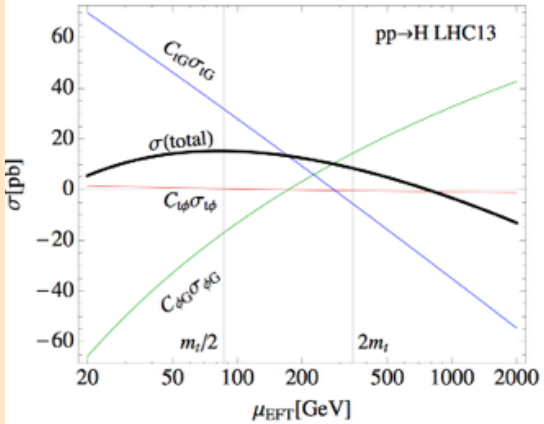
Time to add to STXS? To follow up

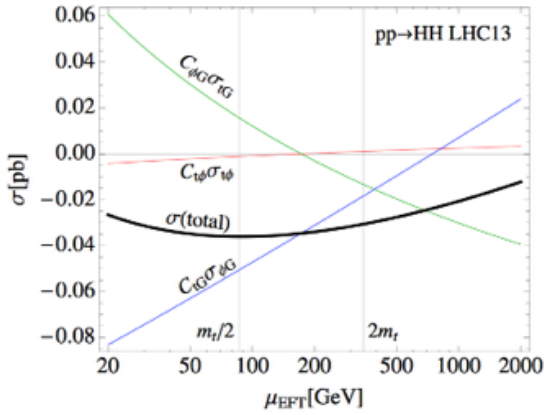
EFT in Madgraph to NLO in QCD

Ken Mimasu

New EFT scale uncertainty

- Scale variation uncertainty approximates missing higher orders in perturbative expansion
  - EFT description contains an additional source of scale dependence from the running/mixing of Wilson coefficients
- Proposal for a new scale uncertainty component
  - Take c_i defined at scales $2\mu_0$ & $\mu_0/2$ and run back to the central scale





Does not cancel in e.g. cross section ratios for which traditional scale uncertainty drops out

Does running of EFT coefficients already capture the uncertainty?

EFT in Madgraph to NLO in QCD

SMEFT@NLO in QCD

- Merger of HELatNLO and Top/Higgs-EFT
  - Use Warsaw basis but basis independent input choice will be provided by Rosetta (also preparing an MG5_aMC plugin)

Gauge/Higgs

Higgs vev & kinetic term	$\mathcal{O}_{\varphi}$	$(\varphi^\dagger\varphi)^3$	–	–
	$\mathcal{O}_{\varphi\Box}$	$(\varphi^\dagger\varphi)\Box(\varphi^\dagger\varphi)$	–	–
m_Z (cust. sym.)	$\mathcal{O}_{\varphi D}$	$(\varphi^\dagger D_\mu\varphi)^\dagger(\varphi^\dagger D_\mu\varphi)$	–	–
Gauge/Higgs & gauge kinetic terms/mixing	$\mathcal{O}_{\varphi G}$	$\varphi^\dagger\varphi\, G^{\mu\nu}_A G^A_{\mu\nu}$	$\mathcal{O}_{\varphi\tilde{G}}$	$\varphi^\dagger\varphi\, G^{\mu\nu}_A \tilde{G}^A_{\mu\nu}$
	$\mathcal{O}_{\varphi W}$	$\varphi^\dagger\varphi\, W^{\mu\nu}_i W^i_{\mu\nu}$	$\mathcal{O}_{\varphi\tilde{W}}$	$\varphi^\dagger\varphi\, W^{\mu\nu}_i \tilde{W}^i_{\mu\nu}$
	$\mathcal{O}_{\varphi B}$	$\varphi^\dagger\varphi\, B^{\mu\nu} B_{\mu\nu}$	$\mathcal{O}_{\varphi\tilde{B}}$	$\varphi^\dagger\varphi\, B^{\mu\nu} \tilde{B}_{\mu\nu}$
	$\mathcal{O}_{\varphi WB}$	$\varphi^\dagger\sigma^i\varphi\, W^{\mu\nu}_i B_{\mu\nu}$	$\mathcal{O}_{\varphi W\tilde{B}}$	$\varphi^\dagger\sigma^i\varphi\, W^{\mu\nu}_i \tilde{B}_{\mu\nu}$
Triple gauge,…	$\mathcal{O}_{3W}$	$\epsilon^{ijk} W_{i,\mu\nu} W^{\nu\rho}_j W^{\mu}_{k,\rho}$	$\mathcal{O}_{3\tilde{W}}$	$\epsilon^{ijk} \tilde{W}_{i,\mu\nu} W^{\nu\rho}_j W^{\mu}_{k,\rho}$

CP violation

Subset of operators, taking requests

Order ~1 month timescale

Higgs p_T in EFT