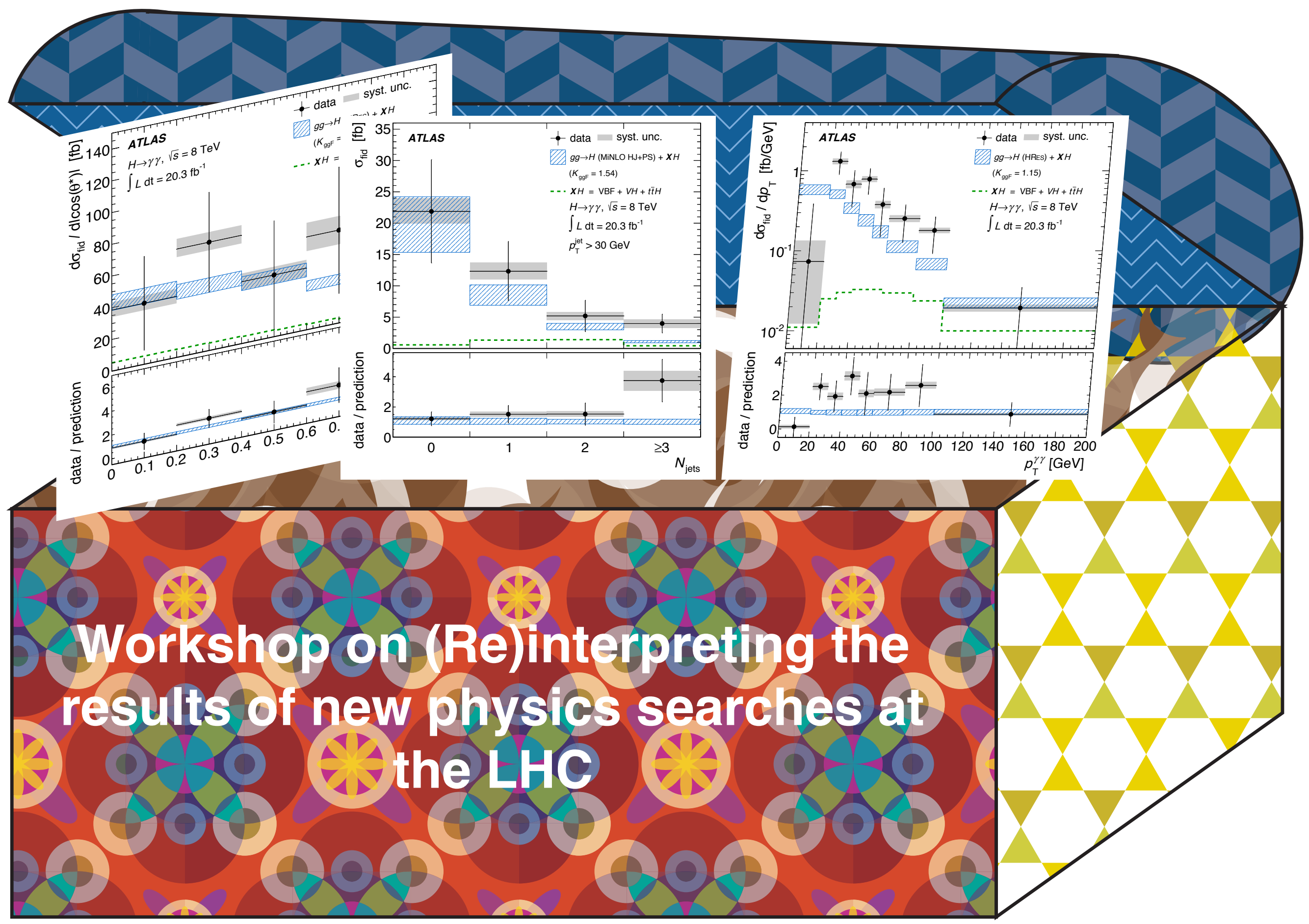
Higgs fiducial cross sections

*a nearly **model independent** path to constrain new physics in the Higgs sector*



ATLAS EXPERIMENT

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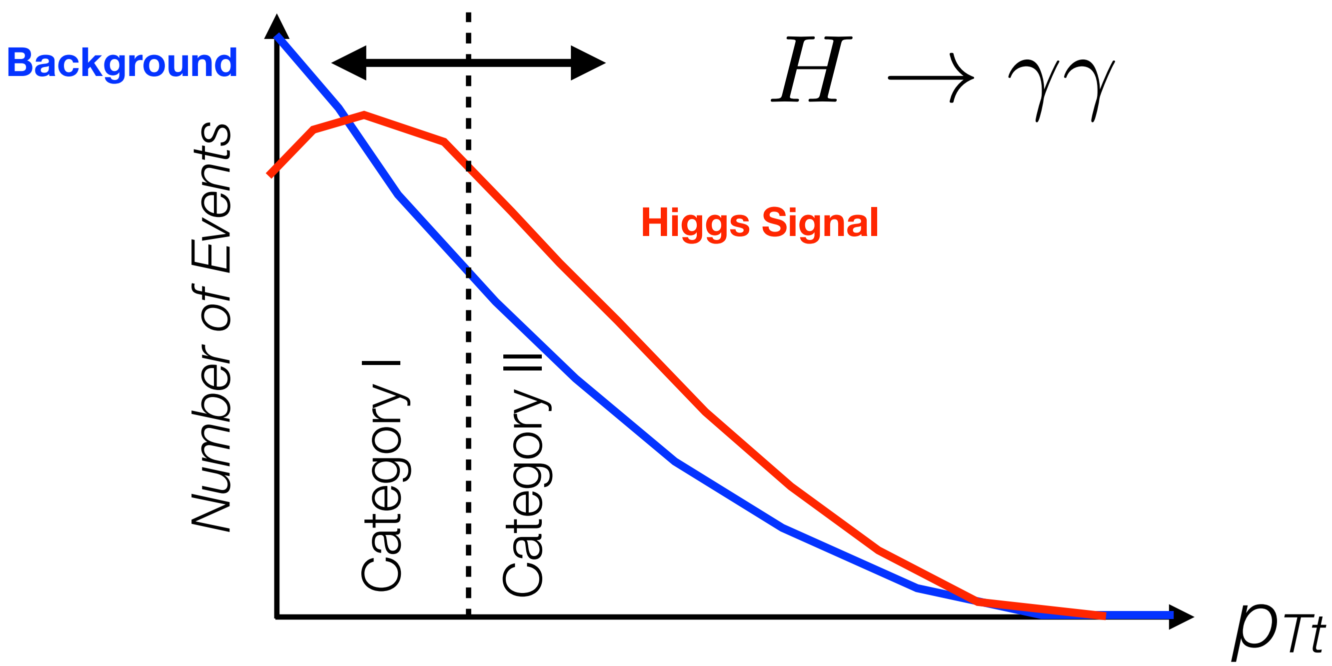
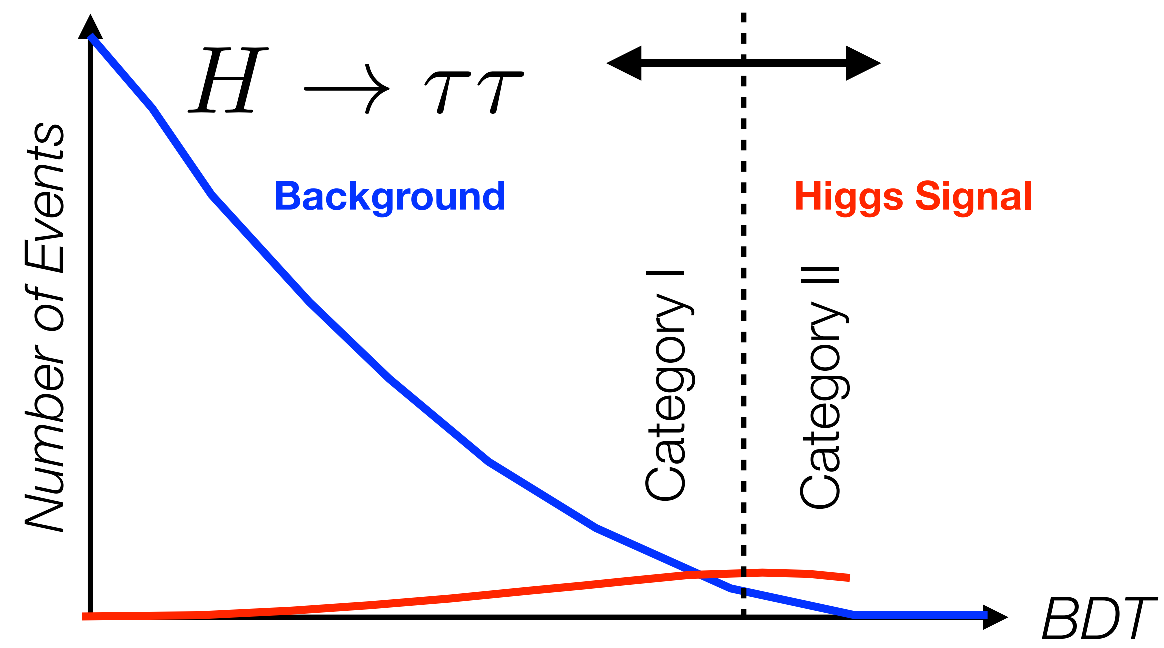
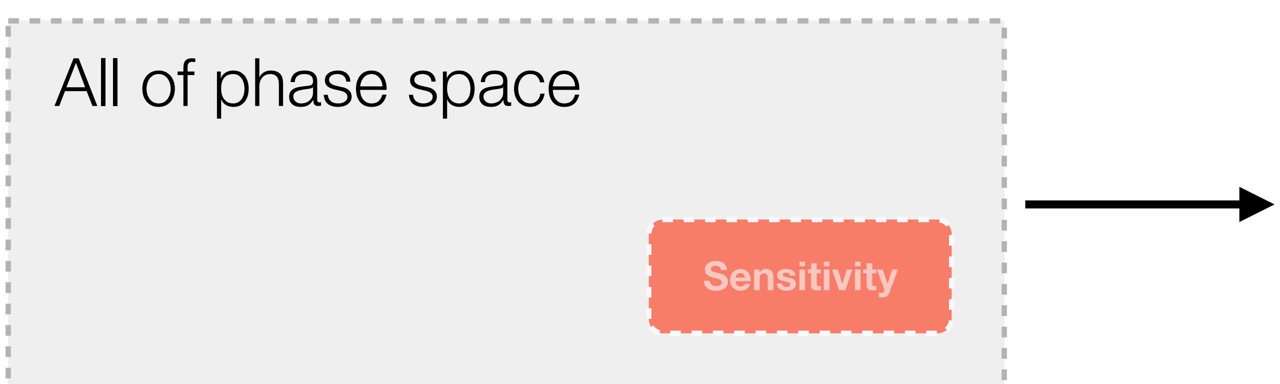
Fiducial cross sections *versus* coupling strength measurements

How did we find the Higgs? — *Illustrated for Higgs to di-photon or Higgs to di-tau*





- In a signal strength fit, category II gets more statistical weight than category I due to the higher expected S/B
- Events from a very specific region of phase space can get very high weight in a combined fit.

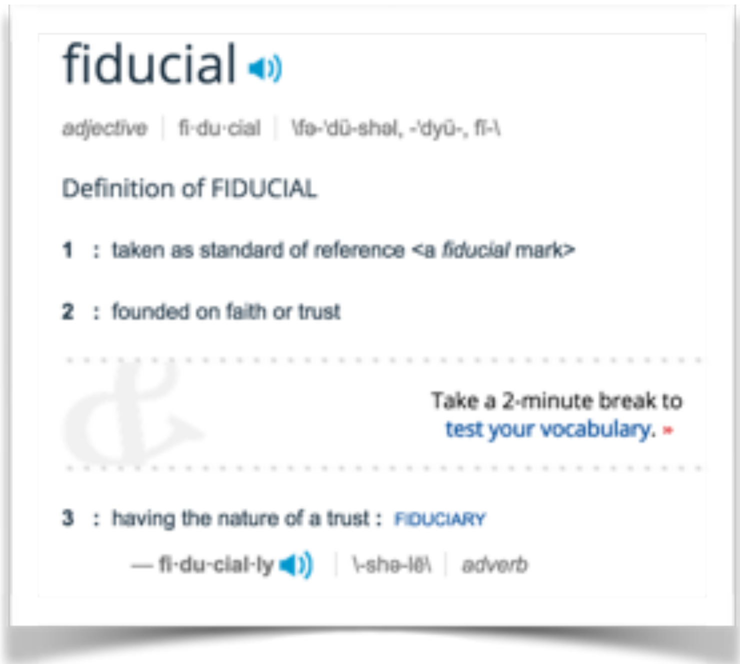


Problem:

i. if efficiencies are wrong, get a biased result

ii. Pretend to measure all of phase space, but effective sensitivity from a small, very specific region.

Fiducial cross sections avoid such extrapolations


fiducial

adjective | fi·du·cial | \fə-ˈdü-shəl, -ˈdyü-, fī-\

Definition of FIDUCIAL

1 : taken as standard of reference <a *fiducial* mark>

2 : founded on faith or trust

Take a 2-minute break to test your vocabulary. »

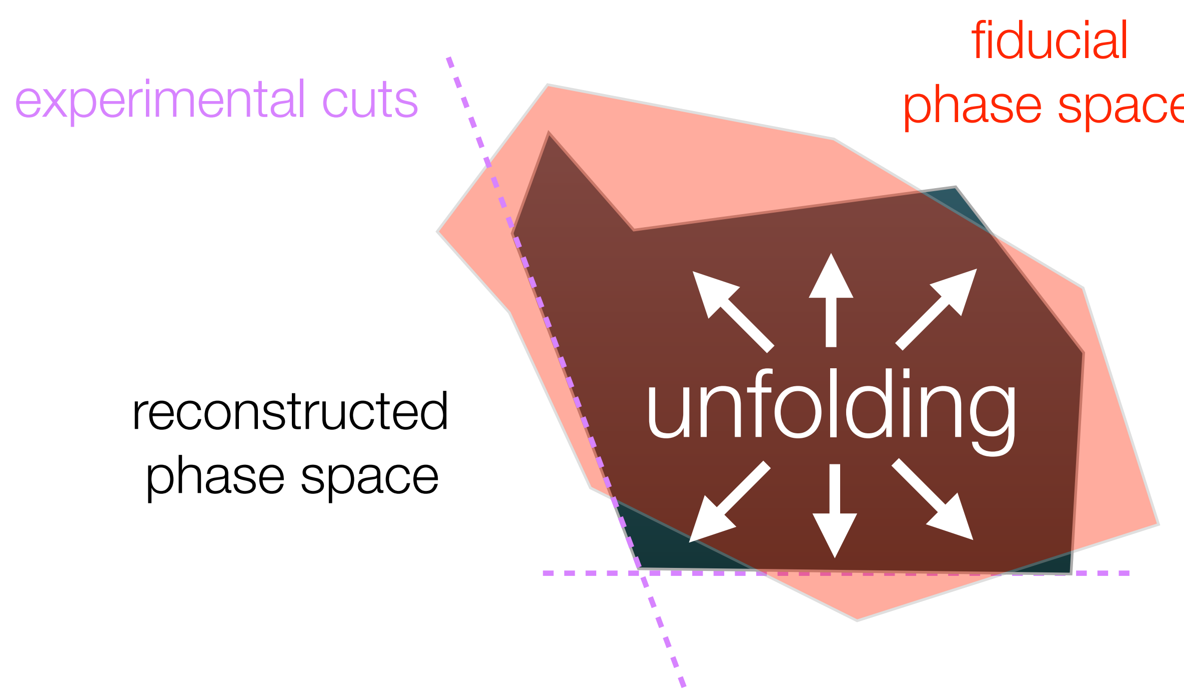
3 : having the nature of a trust : FIDUCIARY

— fi·du·cial·ly | \-shə-lē\ | *adverb*

In particle physics:

a fiducial cross-section is a cross-section measured only for the fiducial region, a clearly defined region in phase-space in which the detector operates with high efficiency, without extrapolating to regions where the experiment has no sensitivity.

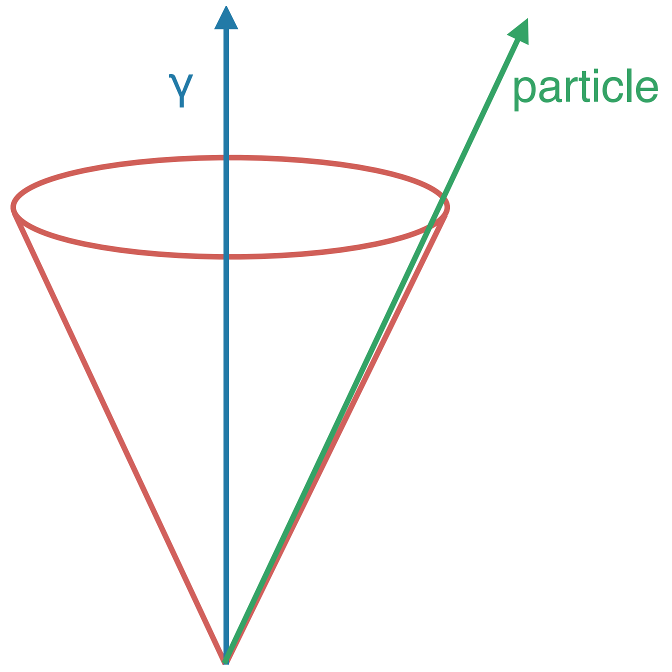
To obtain a cross section, one needs to account for migrations in & outside the fiducial region, i.e. unfold



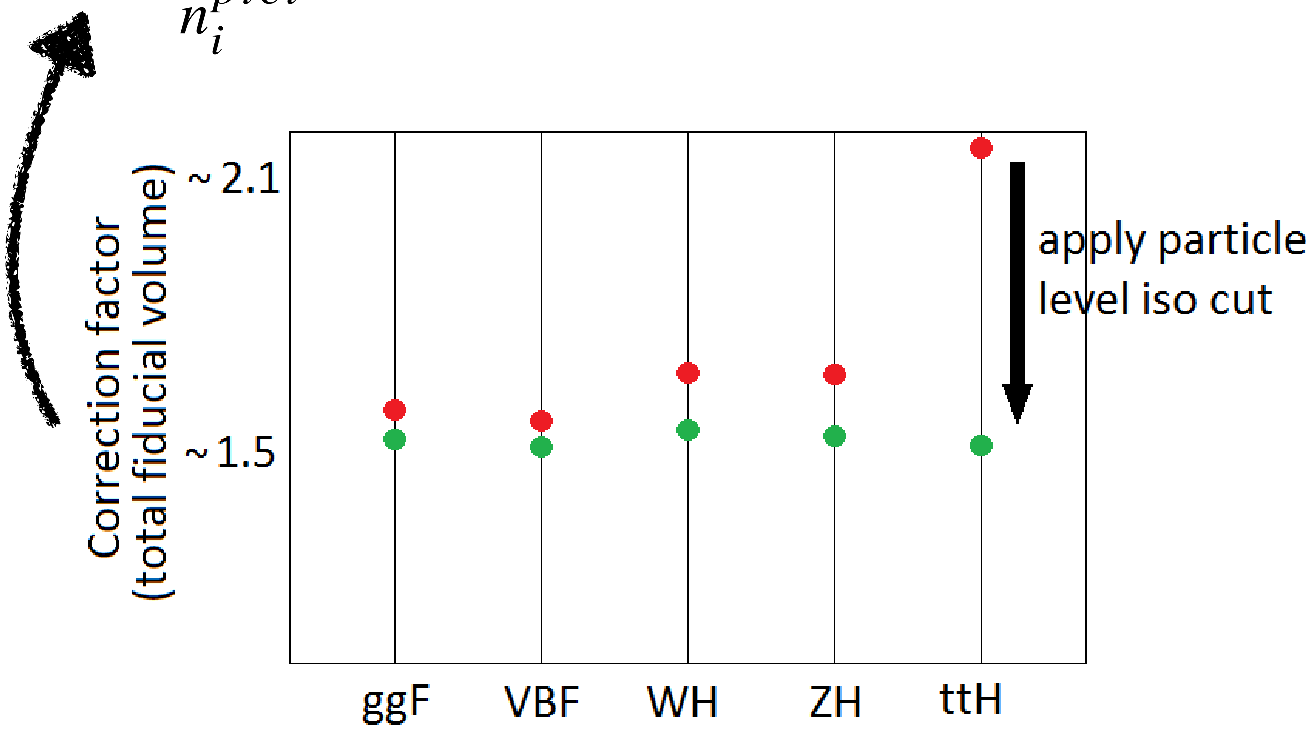
$$\sigma_i = \frac{n_i}{\mathcal{L}\, c_i}$$

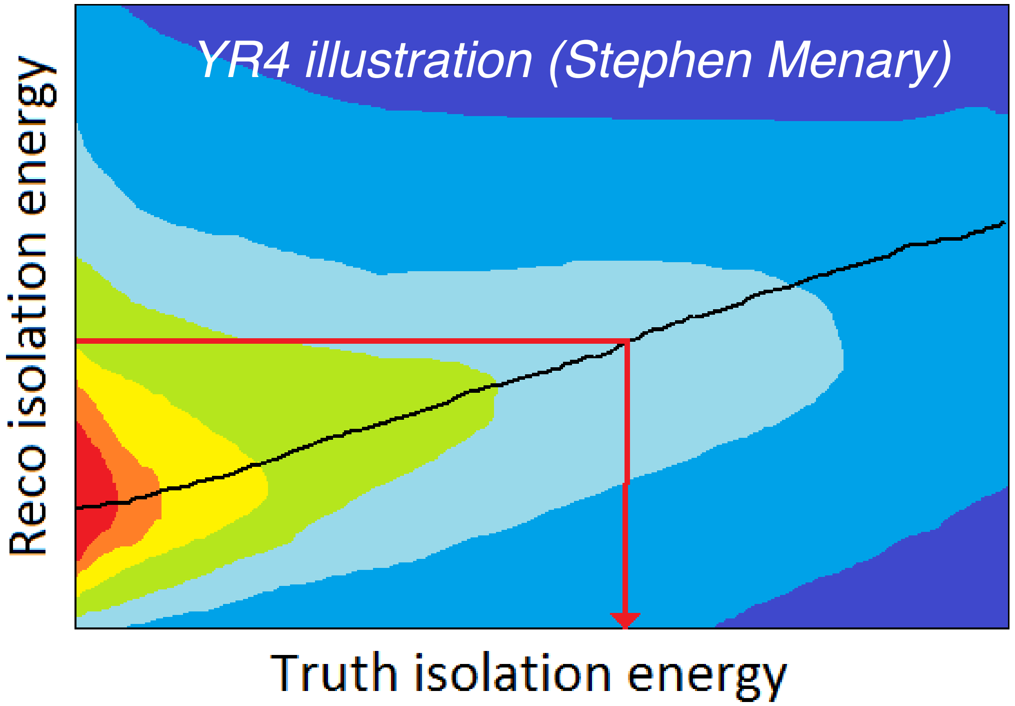
Object isolation

- Isolation important in reconstructing leptons and photons in measurements.
  - Typically require cone-type isolation and use tracks or clusters
- Need to be mapped to particle-level to avoid extrapolations
  - ie. if a reco event is rejected due to high activity, so should a truth event.



$$c_i = \frac{n_i^{det}}{n_i^{ptcl}}$$





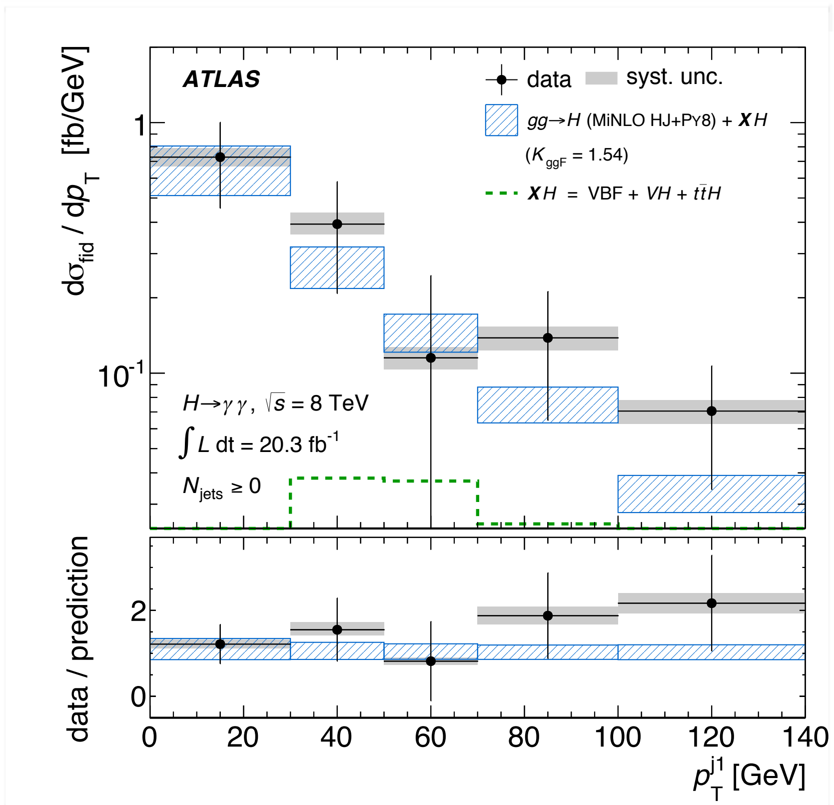
Run 1 results

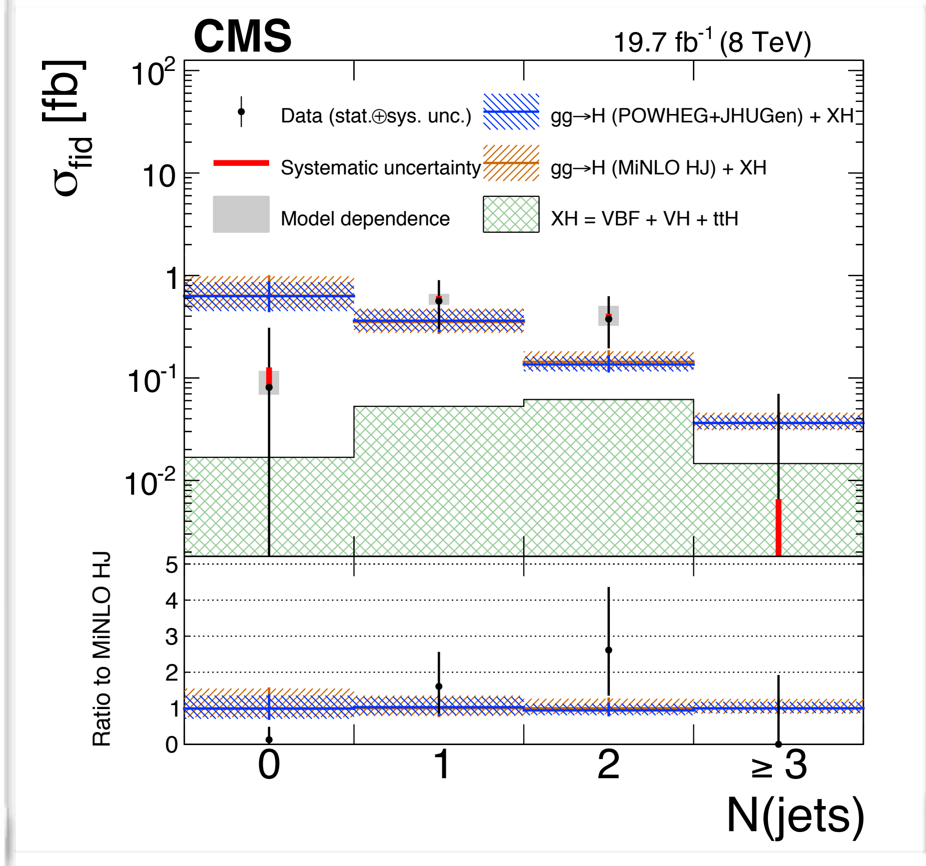
8 Papers

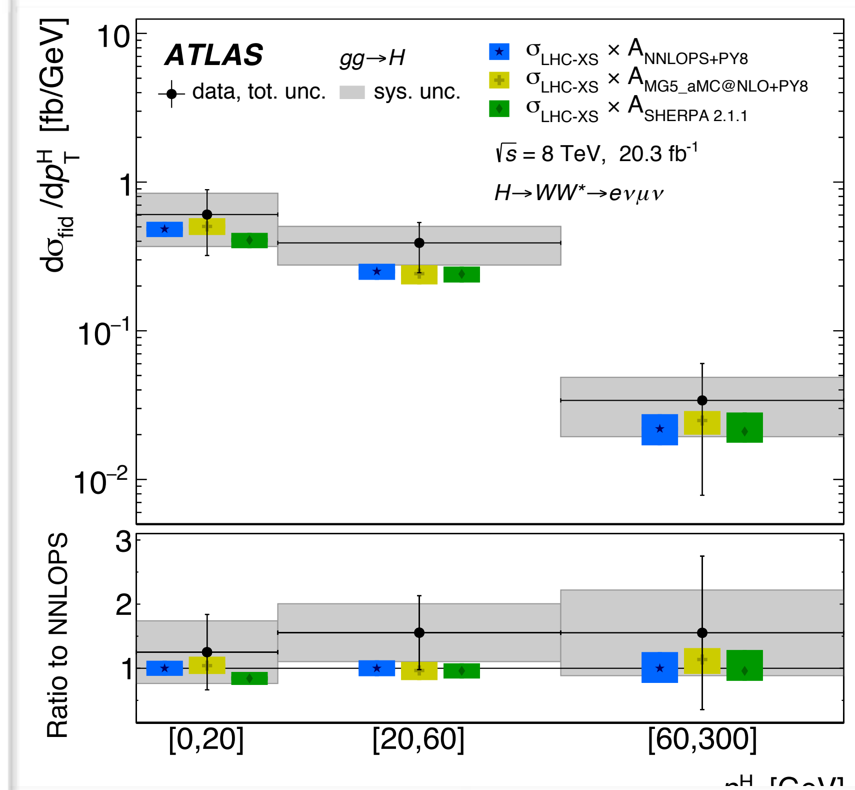
- Measurement of fiducial differential cross sections of gluon-fusion production of Higgs bosons decaying to $WW^* \to e\nu\mu\nu$ with the ATLAS detector at sqrt(s)=8 TeV, ATLAS Collaboration, arXiv:1604.02997
- Measurement of the transverse momentum spectrum of the Higgs boson produced in pp collisions at sqrt(s)=8 TeV using the $H \to WW$ decays, CMS Collaboration, CMS-PAS-HIG-15-010
- Measurement of differential and integrated fiducial cross sections for Higgs boson production in the four-lepton decay channel in pp collisions at sqrt(s)= 7 and 8 TeV, CMS Collaboration, arXiv:1512.08377
- Measurement of differential cross sections for Higgs boson production in the diphoton decay channel in pp collisions at sqrt(s)=8 TeV, CMS Collaboration, arXiv:1508.07819
- Constraints on non-Standard Model Higgs boson interactions in an effective field theory using differential cross sections measured in the $H \to \gamma\gamma$ decay channel at $\sqrt{s}$=8 TeV with the ATLAS detector, ATLAS Collaboration, arXiv:1508.02507
- Measurements of the Total and Differential Higgs Boson Production Cross Sections Combining the $H \to \gamma\gamma$ and $H \to ZZ^* \to 4\ell$ Decay Channels at $\sqrt{s}$=8 TeV with the ATLAS detector, ATLAS Collaboration, Phys. Rev. Lett. 115, 091801 (2015)
- Fiducial and differential cross sections of Higgs boson production measured in the four-lepton decay channel in pp collisions at $\sqrt{s}$=8 TeV with the ATLAS detector, ATLAS Collaboration, Physics Letters B 738 (2014) 234-253
- Measurements of fiducial and differential cross sections for Higgs boson production in the diphoton decay channel at $\sqrt{s}$=8 TeV with ATLAS, ATLAS Collaboration, JHEP09(2014)112

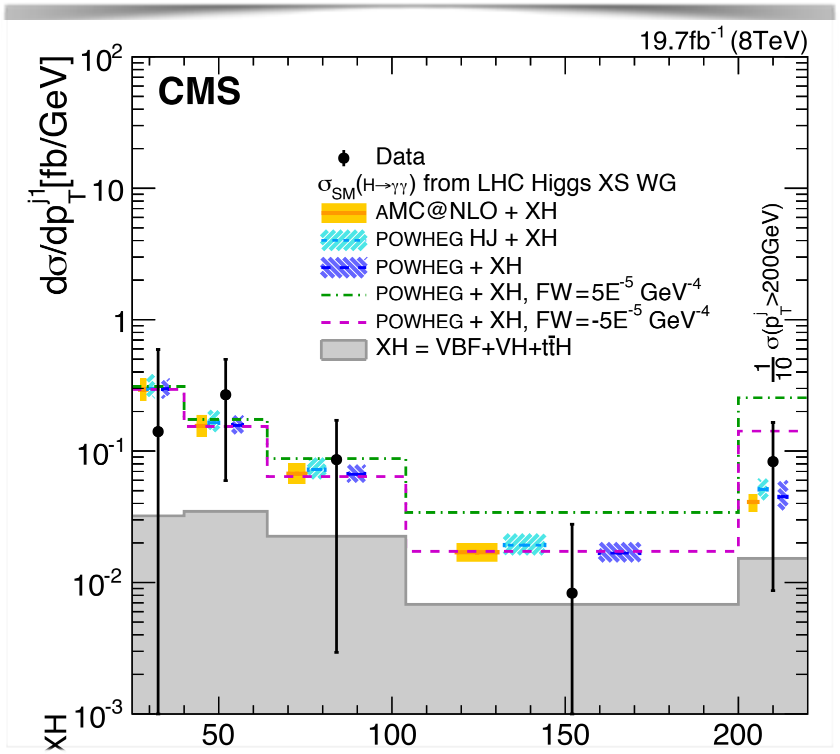
Run 1 Gallery

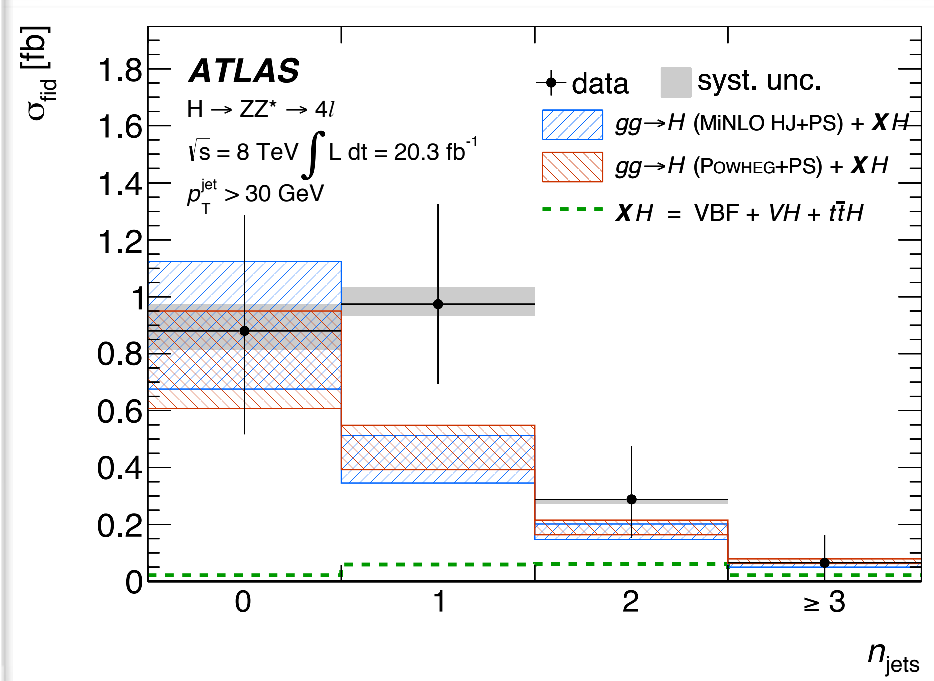
From left to right: H → γγ, H → ZZ* → 4l, H → WW → 2l2ν

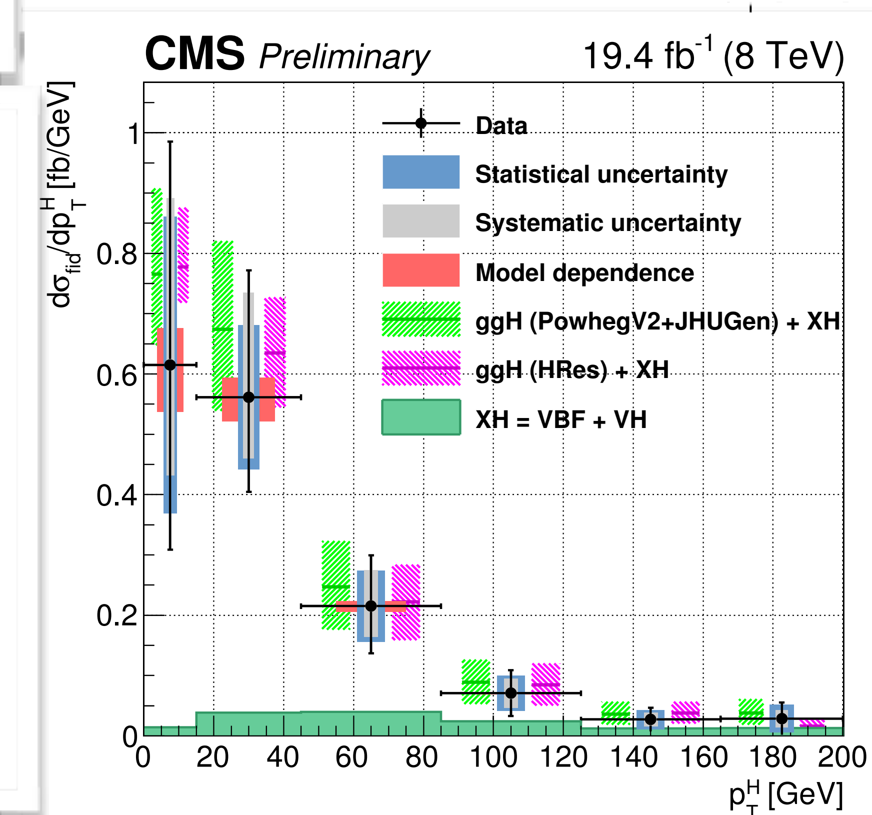








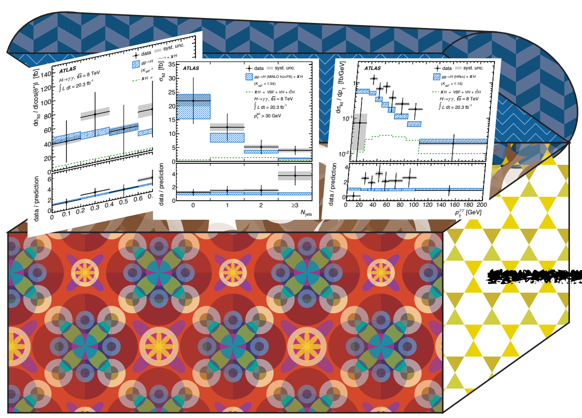




Interpretations

Disclaimer: Not an official ATLAS result, no one reviewed this and hacked together in one day

Fiducial measurements are a great starting point, to constrain new physics.



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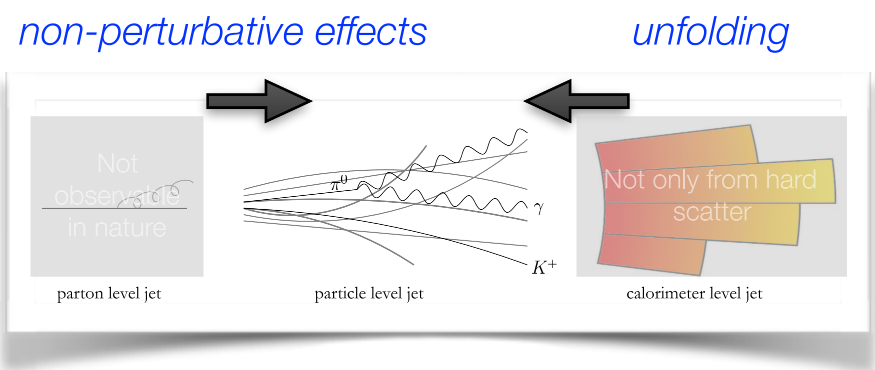
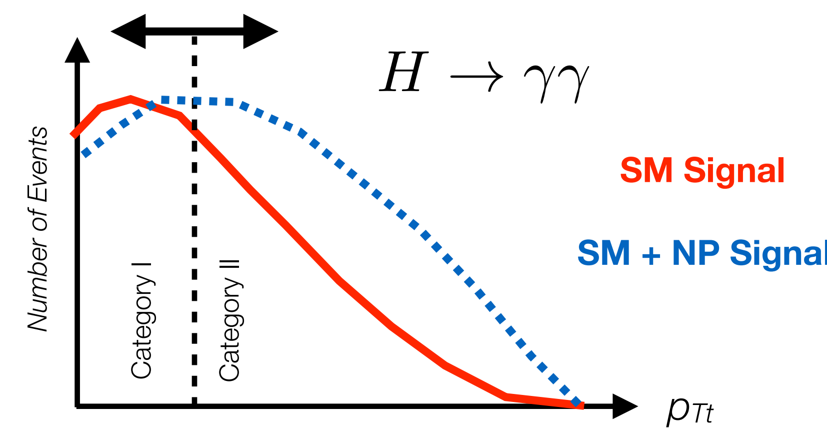


Benefits:

- There are no cut-flows and reco selections you need to replicate; all detector effects are accounted for
- Everything is unfolded to particle-level
- Measurement nearly independent of underlying theory, ie. fully consistent tests are possible



A lame example

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Time to play! — Let's do a kappa fit

- Use ATLAS H → γγ & H → ZZ* → 4l Higgs pT spectra
- Modify SM cross sections according to the formula on RHS
- Just build a simple χ^2 between data points and predictions
- Do a scan for k_V (scaling coupling of Higgs to vector bosons) and k_F (scaling coupling of Higgs to fermions)

$$\sigma^{SM}_{gg\to H\to\gamma\gamma} \times \frac{\kappa_F^2\,(1.59\,\kappa_V^2 + 0.07\,\kappa_F^2 - 0.66\,\kappa_V\kappa_F)}{0.25\,\kappa_V^2 + 0.75\,\kappa_F^2}$$

$$\sigma^{SM}_{\mathrm{VBF},H\to\gamma\gamma} \times \frac{\kappa_V^2\,(1.59\,\kappa_V^2 + 0.07\,\kappa_F^2 - 0.66\,\kappa_V\kappa_F)}{0.25\,\kappa_V^2 + 0.75\,\kappa_F^2}$$

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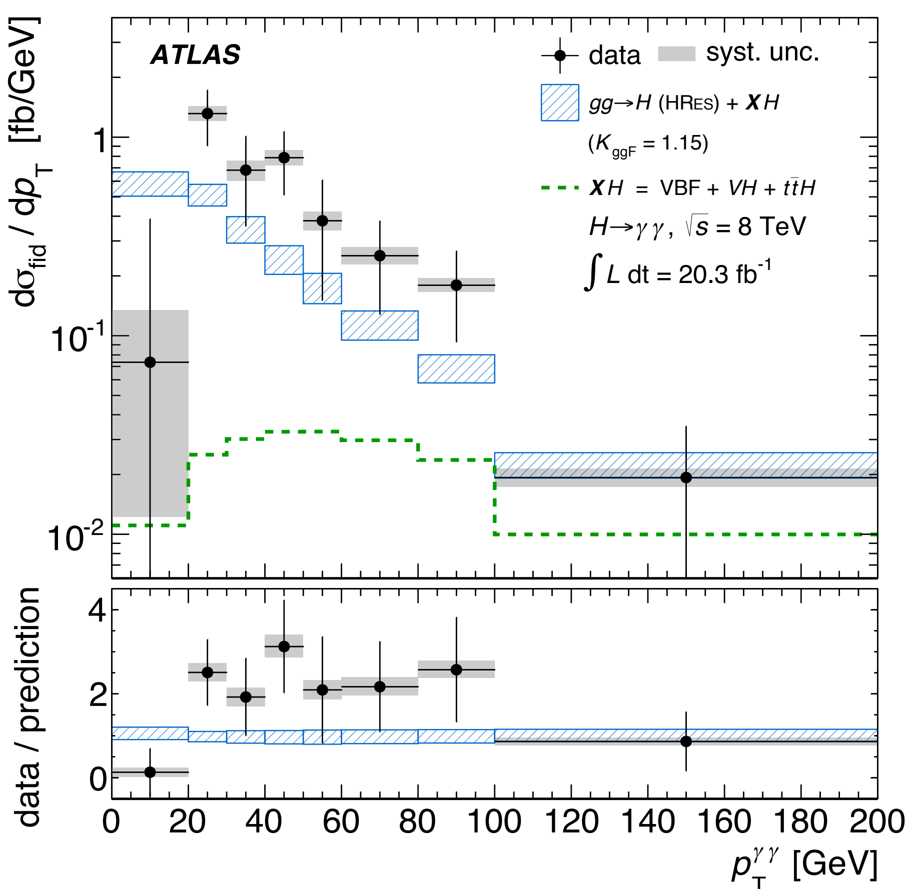
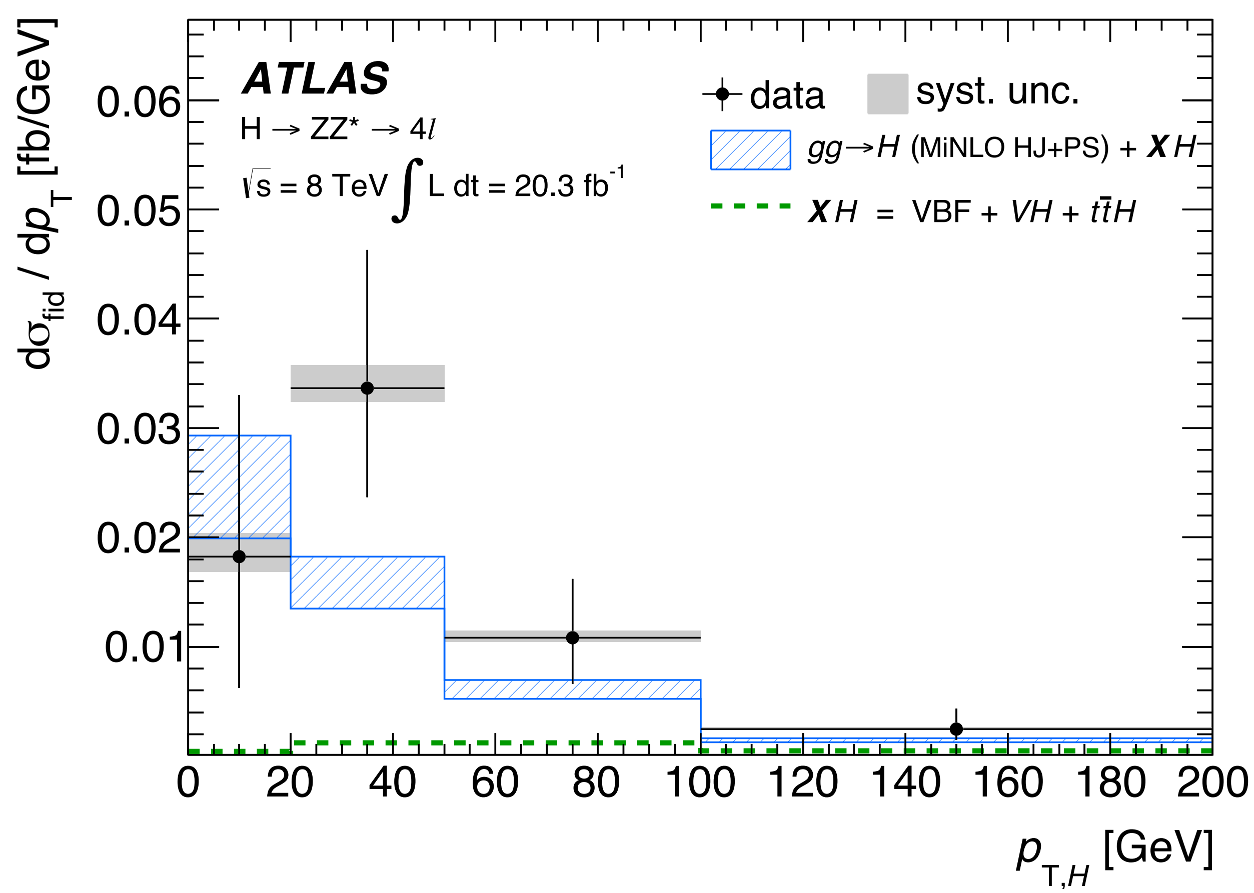
$$\sigma^{SM}_{\mathrm{VBF},H\to 4\ell} \times \frac{\kappa_V^4}{0.25\,\kappa_V^2 + 0.75\,\kappa_F^2}$$

See [ATLAS-CONF-2015-007] for more information





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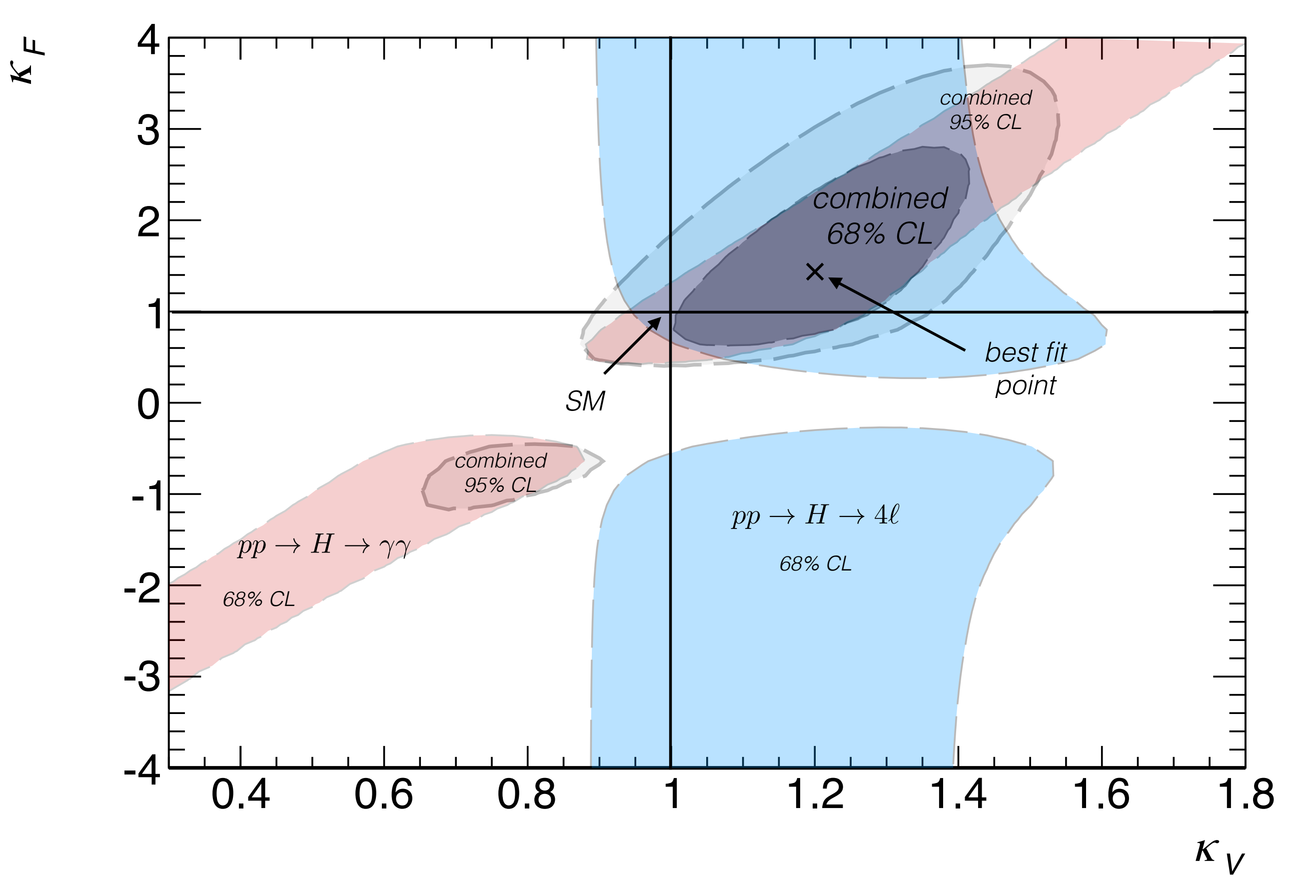
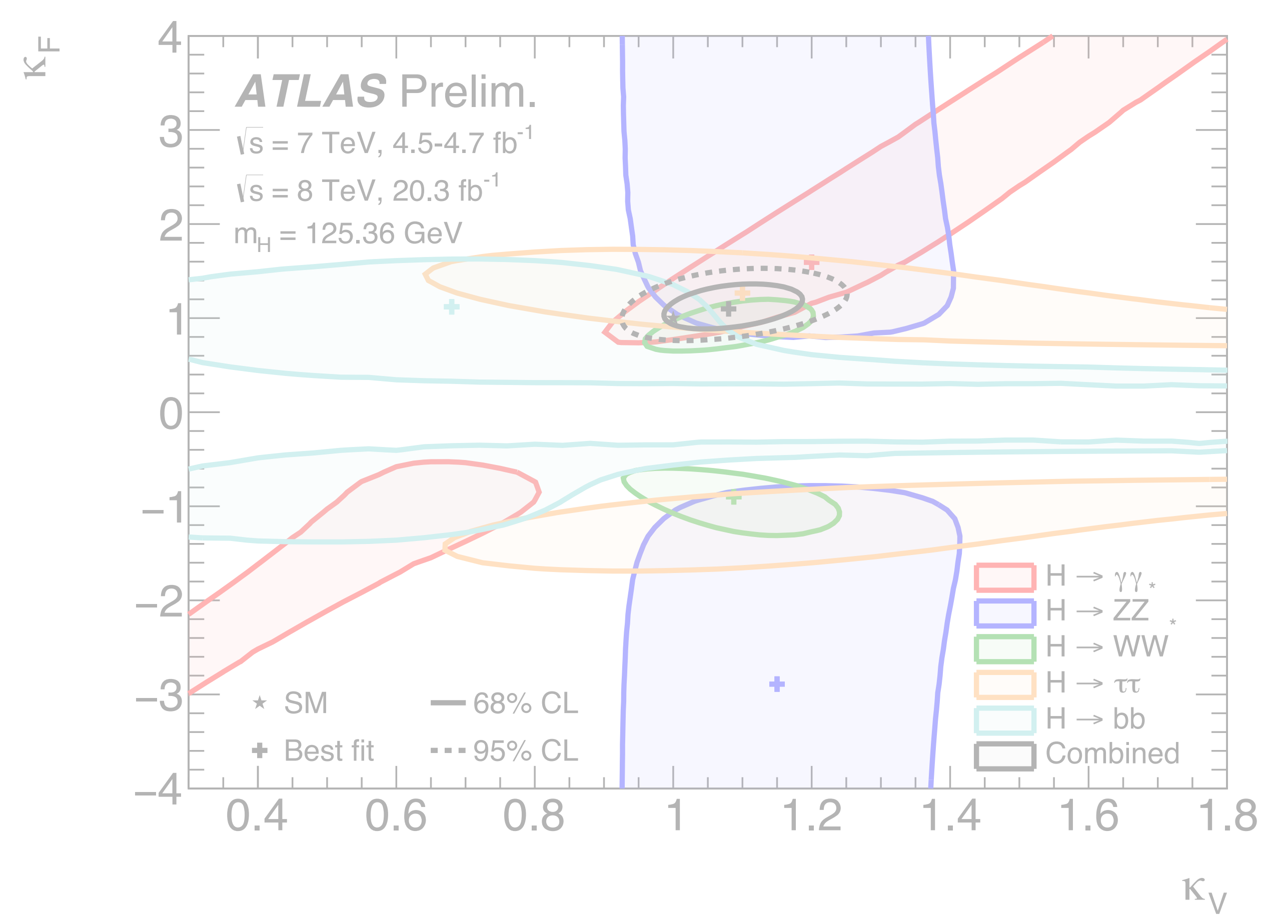


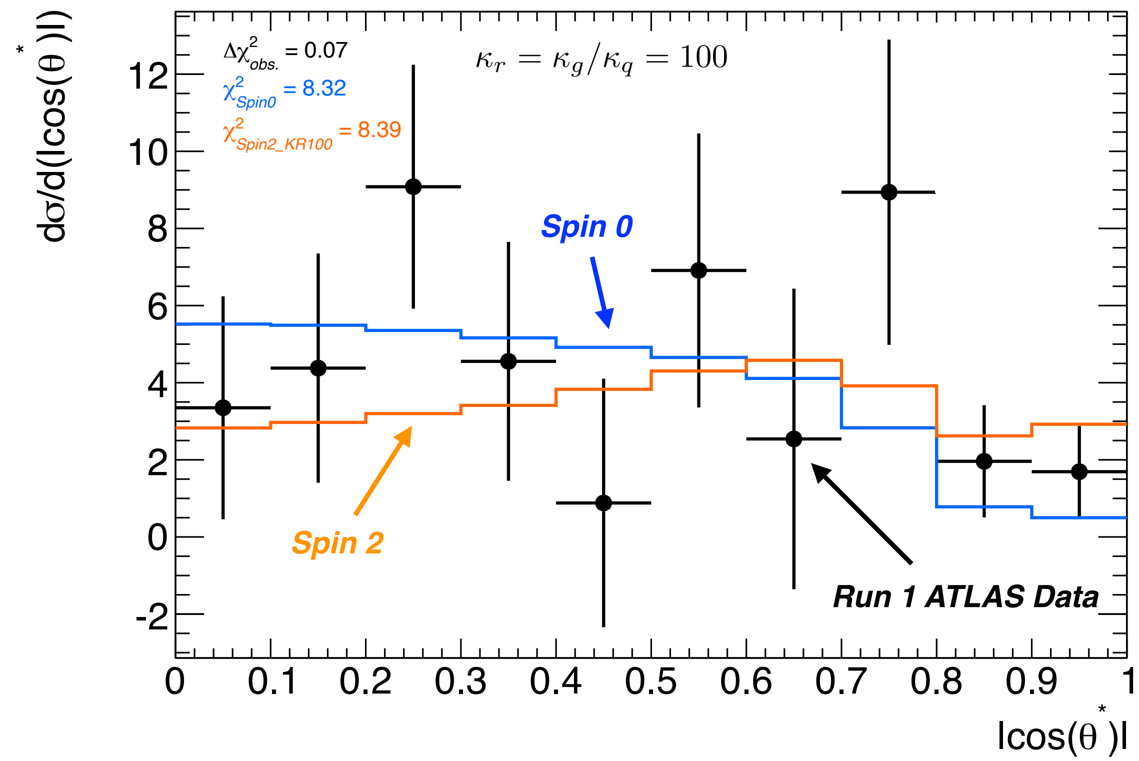


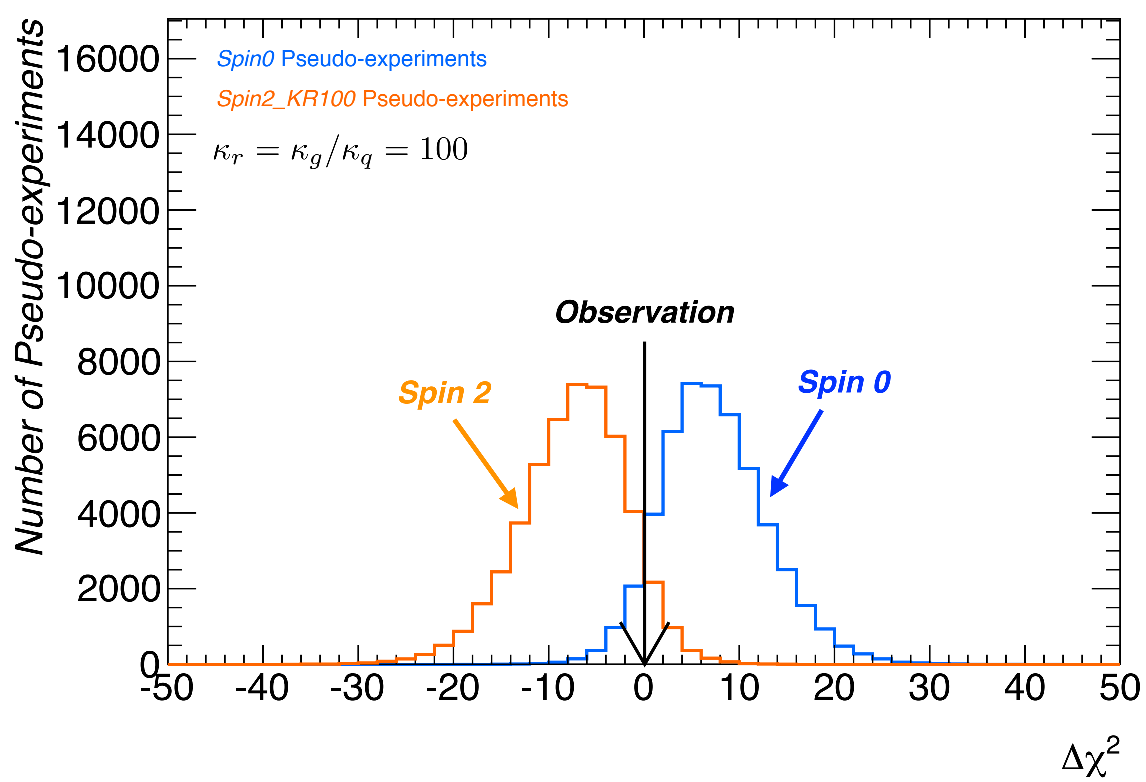
A slightly less lame example

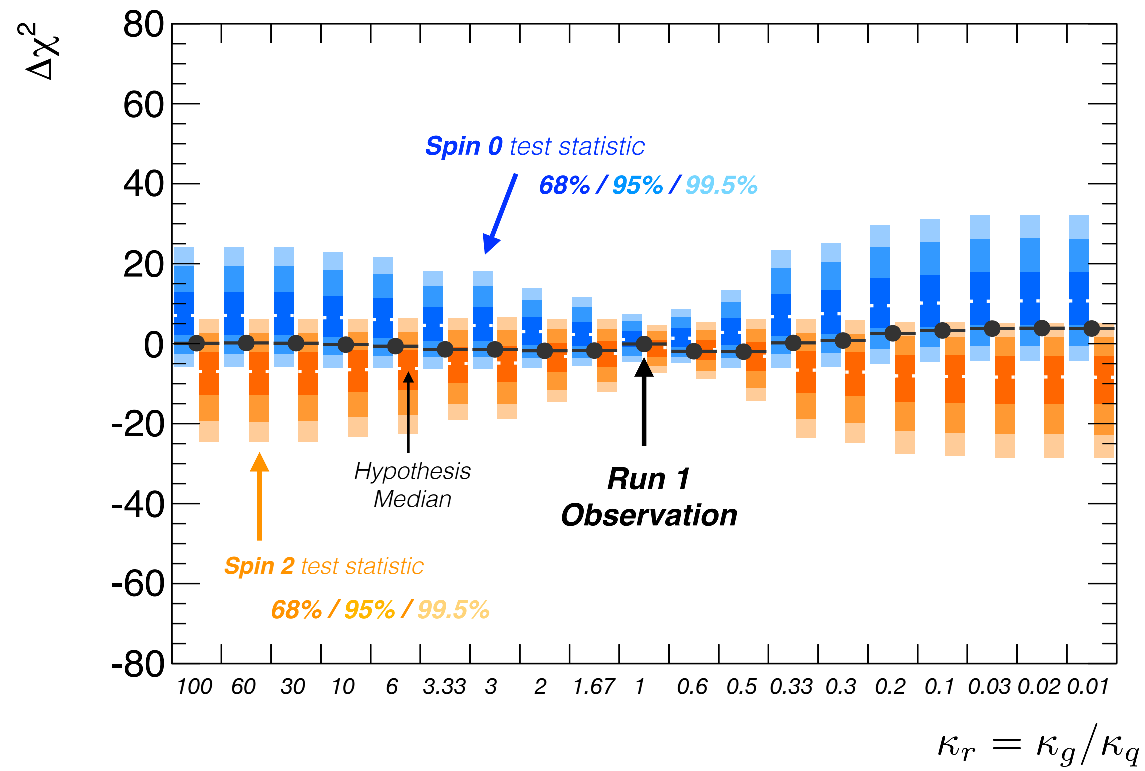
***Disclaimer**: Not an official ATLAS result, no one reviewed this and hacked together in one day*

Time to play! — Let's do a Spin hypothesis test

- Use ATLAS H → γγ measurement of |cos Θ$_{CS}$|
- aMC@NLO templates for Spin 2
- Just build a simple χ^2 between data points and predictions
- Do a scan for k_g/k_q (coupling strength of Spin 2 particle and gluons or quarks)



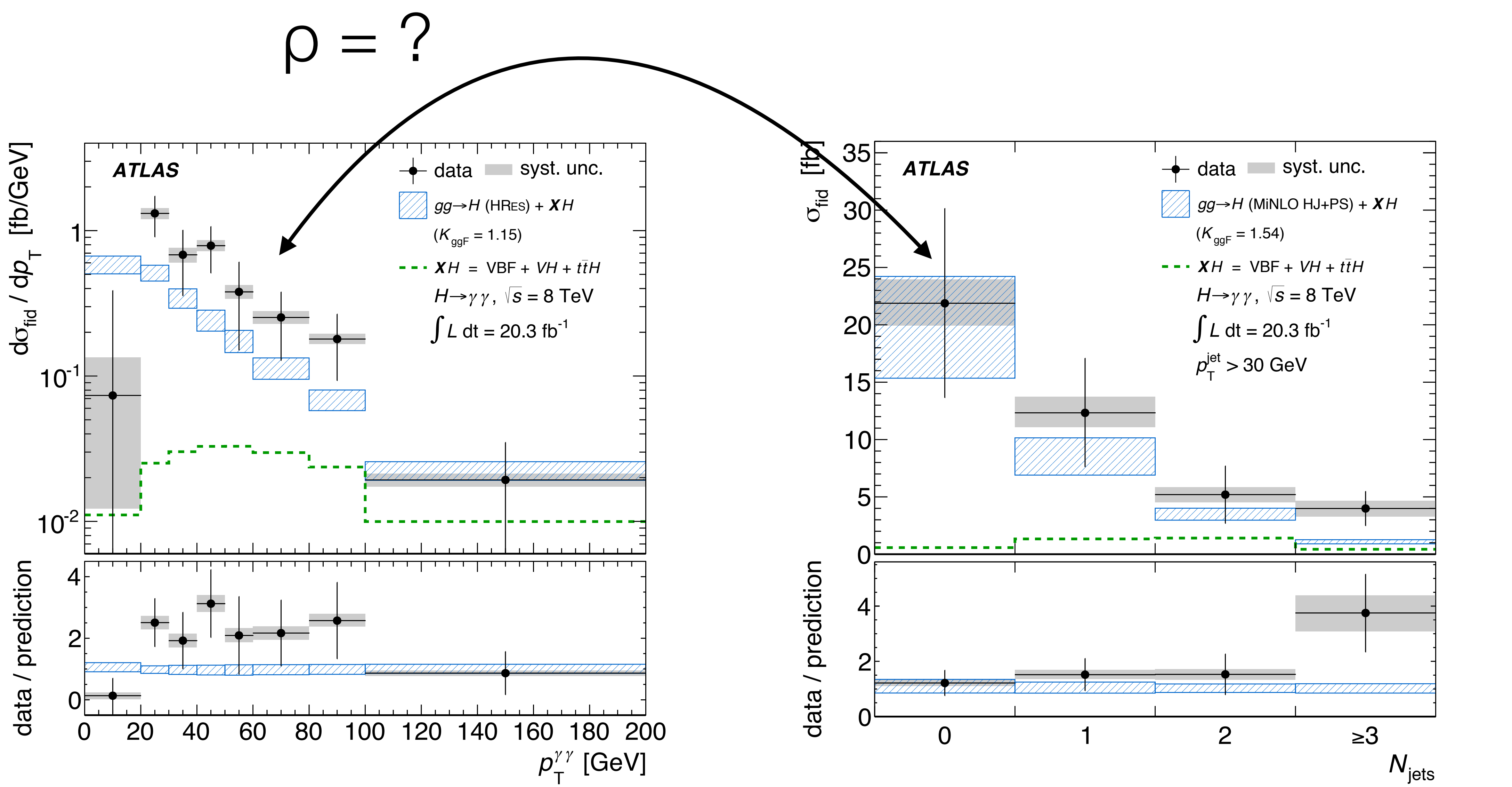




Constraining effective operators using differential measurements

That’s nice, and I can see that with that I can do combined fits with one distribution per channel and experiment. But what if you want to fit several distributions at once?

- All distributions use the same data; bins are statistically (not so trivial) and systematically (trivial) correlated



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For high-statistics channels there is an elegant way to derive such correlations from the data:

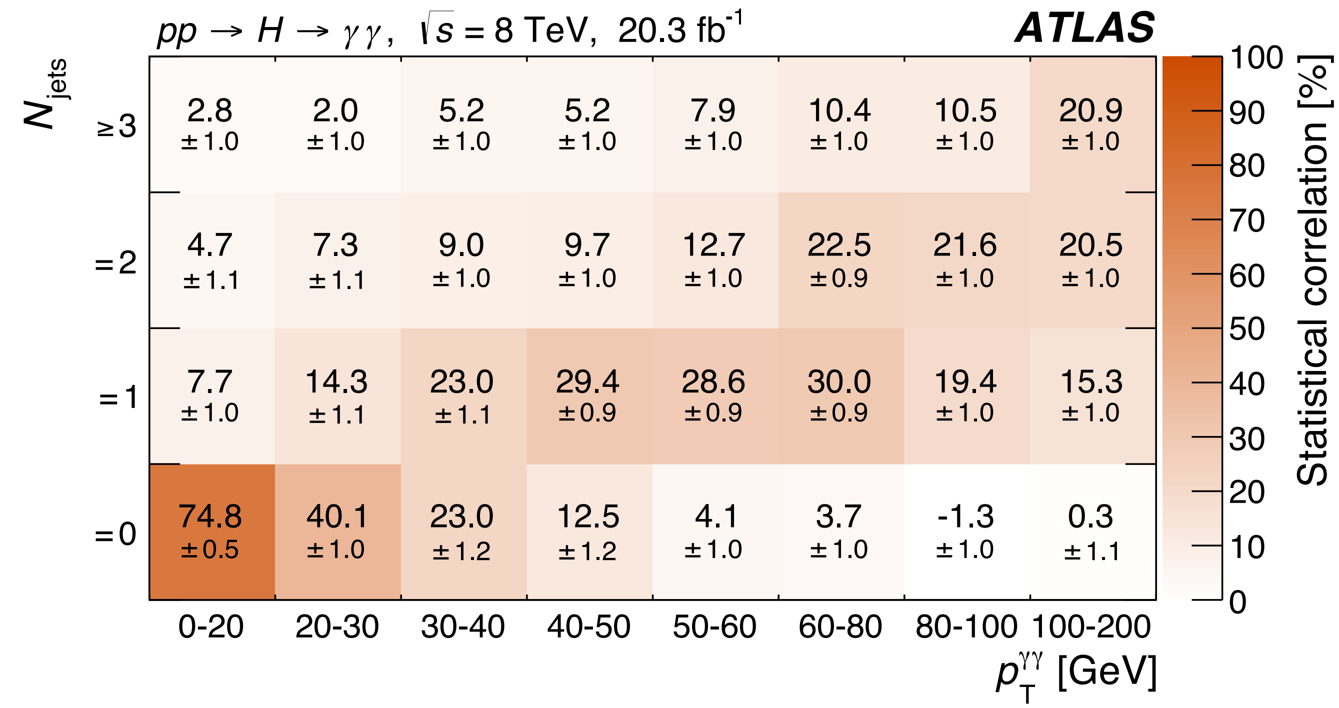
Bootstrapping — analyzing a weighted subset of the data to extract the correlation information

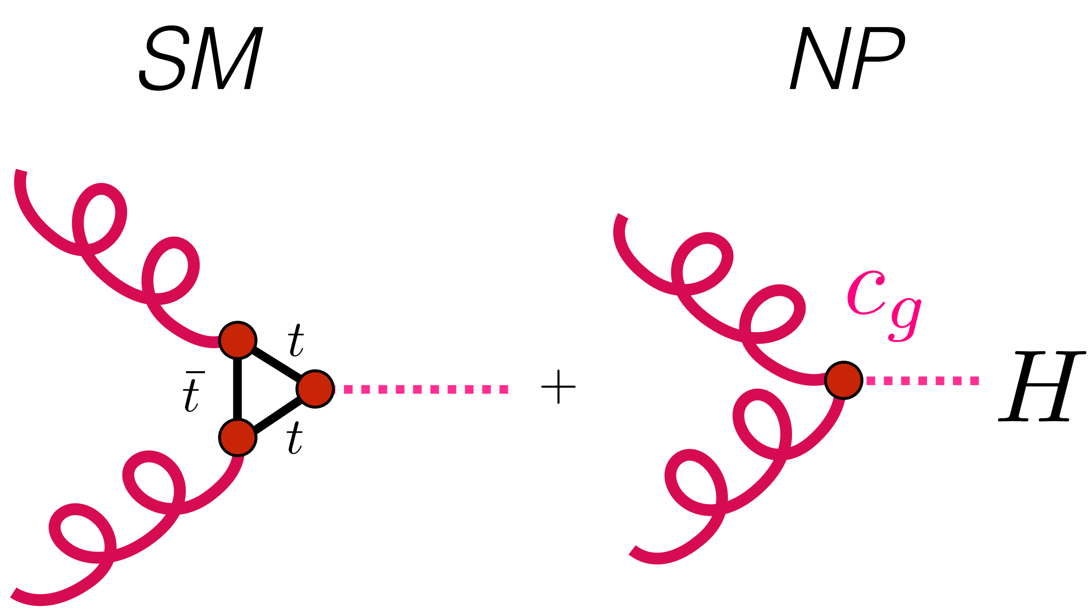
A non-lame example

Physics Letters B 753 (2016) 69-85, arXiv:1508.02507

Time to play! — Let's constrain new physics with an effective Lagrangian

- Uses 5 ATLAS H → γγ differential distributions
- Takes into account their statistical correlations
- Build a χ^2 between data points and predictions
- Do a scan for various Wilson coefficients of the SILH Lagrangian, e.g. c_g (eff. coupling to gluons), c_γ (eff. coupling to photons), etc. + **CP Conjugate counterparts**





$$\frac{d\sigma}{dX} = \sum_j \left(\frac{d\sigma_j}{dX}\right)^{\text{ref}} \cdot \left(\frac{d\sigma_j}{dX}\right)^{\text{MG5}}_{c_i} \Big/ \left(\frac{d\sigma_j}{dX}\right)^{\text{MG5}}_{c_i=0}$$

$$\mathcal{L} = \bar{c}_\gamma O_\gamma + \bar{c}_g O_g + \bar{c}_{HW} O_{HW} + \bar{c}_{HB} O_{HB} + \tilde{c}_\gamma \tilde{O}_\gamma + \tilde{c}_g \tilde{O}_g + \tilde{c}_{HW} \tilde{O}_{HW} + \tilde{c}_{HB} \tilde{O}_{HB},$$

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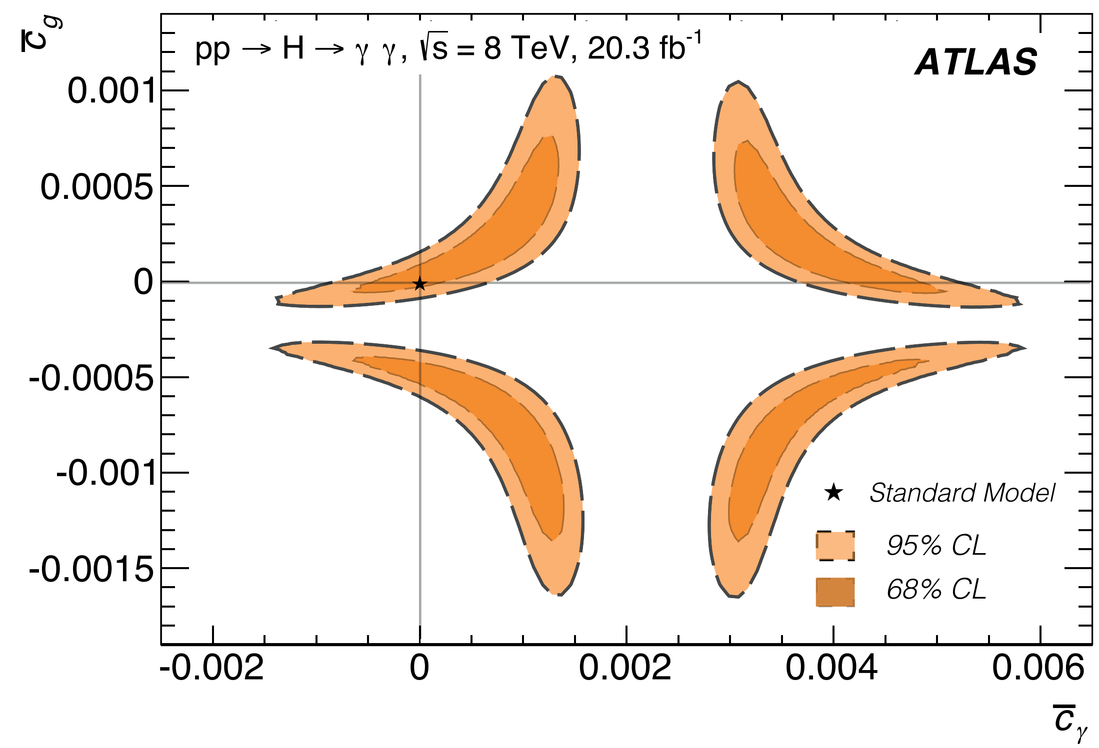
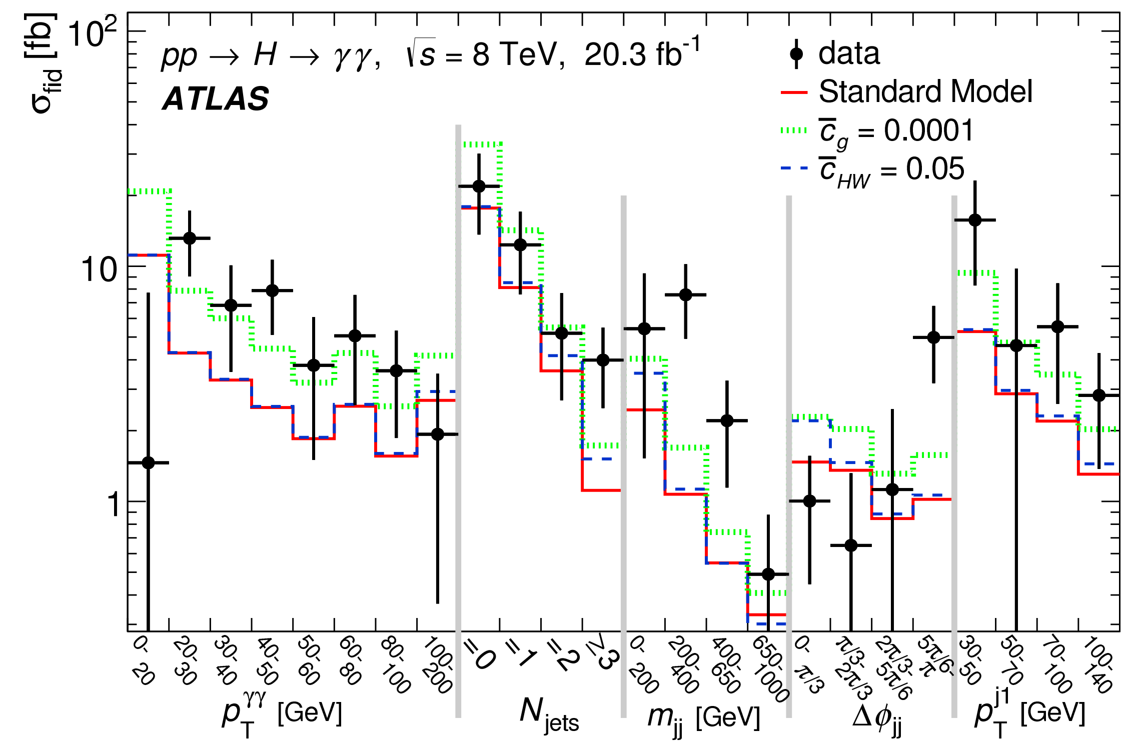
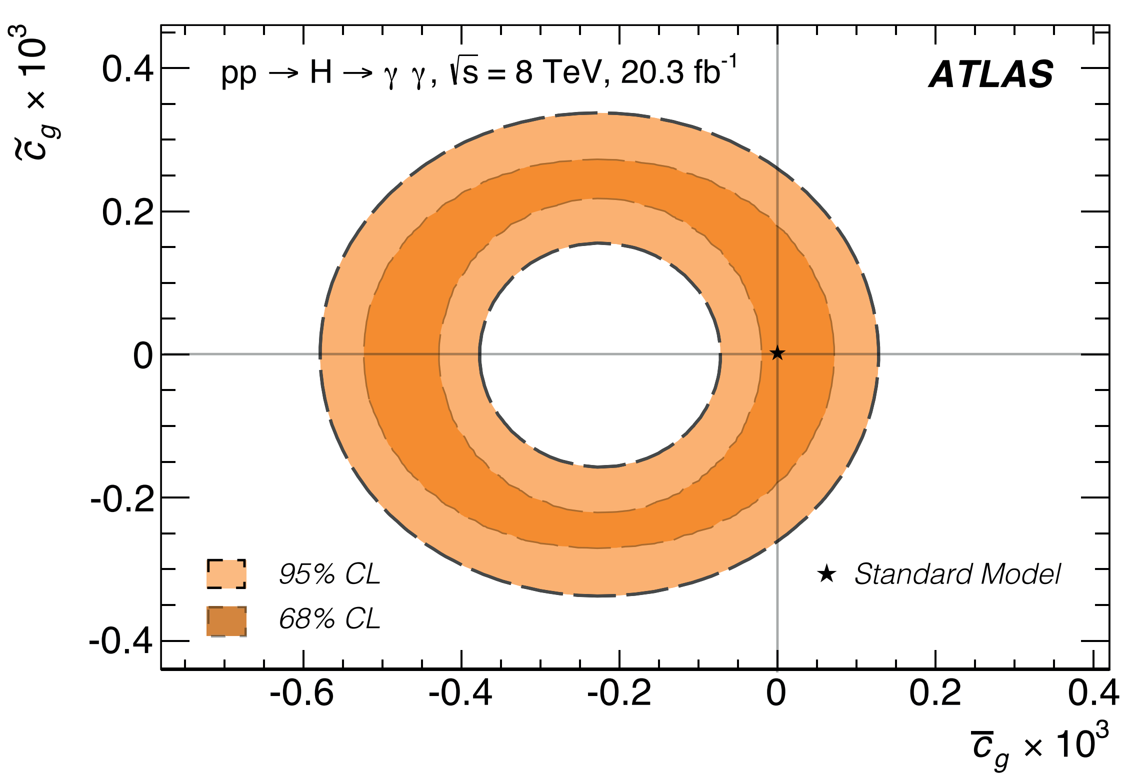
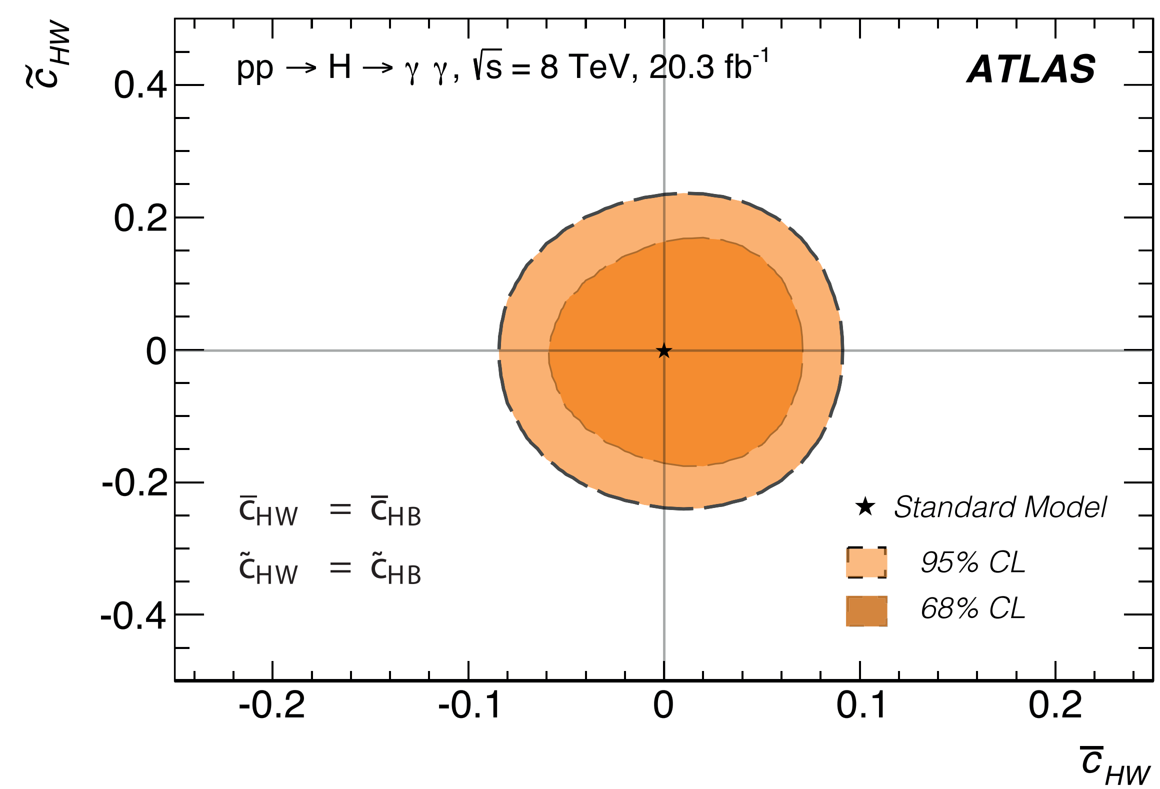








But fiducial cross sections are not for everyone (yet)

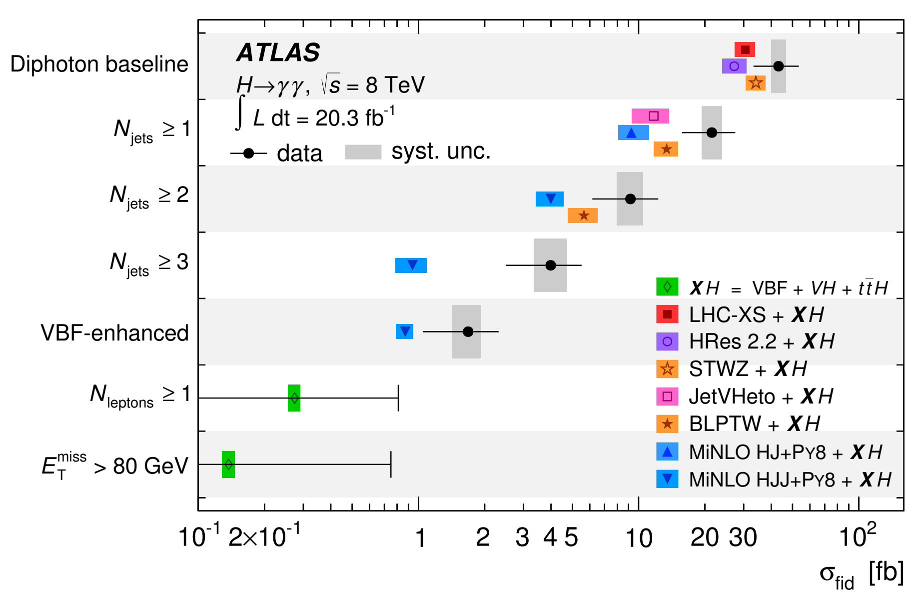
Similar methods might work for H → γγ, H → ZZ* → 4l, H → WW → 2l2v

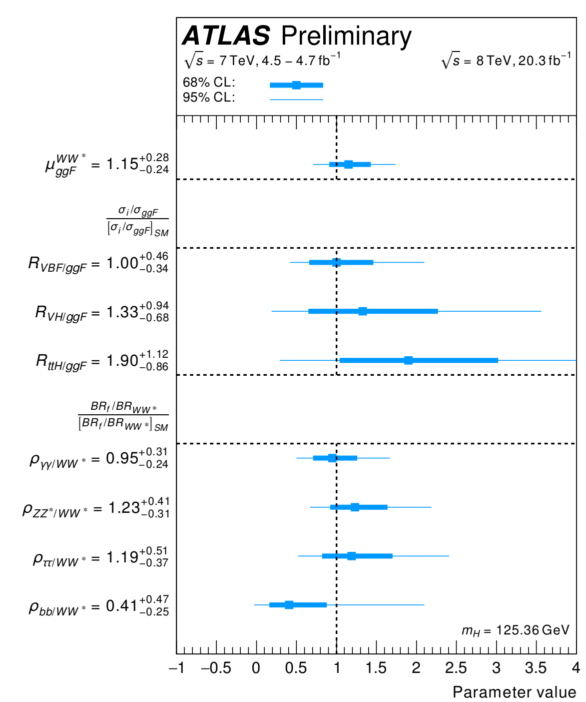
- Many kinematic distributions that characterize **Higgs production** and **decay**
- Many sensitive to **new physics**
- Combination of various distributions can be pretty powerful

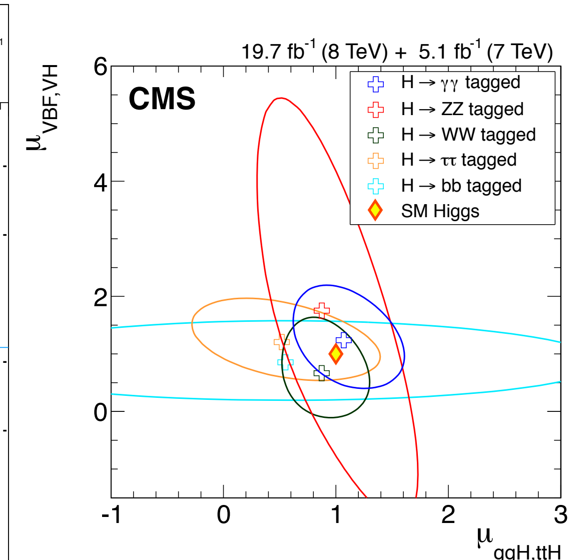
But: fiducial cross sections are not for everyone (yet)

- Channels with low sensitivity or channels that rely on MVAs won't be able to quote fiducial cross sections for a while
- Is there a path in the middle?

Illustration from Frank Tackmann, Kerstin Tackmann







Measurement ⟷ Interpretation

theory-independent ⟷ *theory-dependent*

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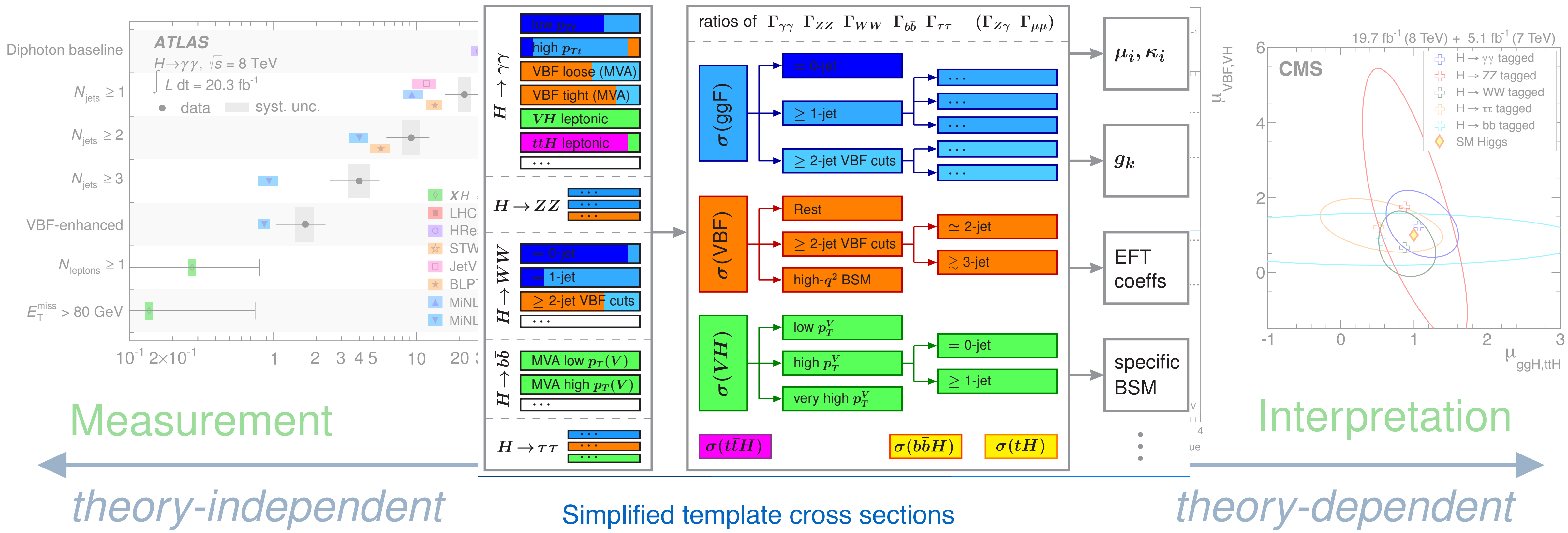
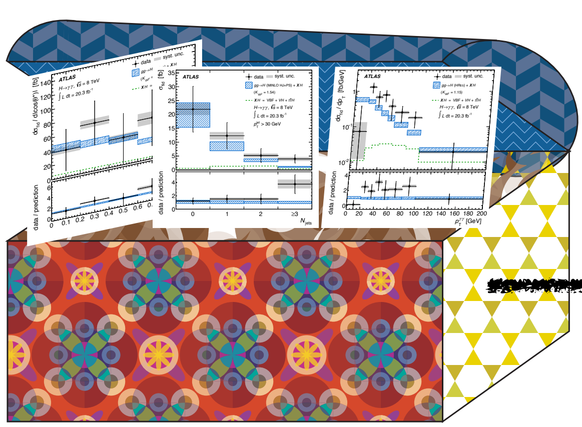


Summary (1/2)

Fiducial cross sections can be a powerful tool to constrain new physics

- Nearly independent of underlying theory
- Detector effects are reverted, distributions unfolded to particle level
- Quoted inside a well defined fiducial volume, many analyses provide Rivet routines that can be used



Confront with fiducial cross sections

MC Generator with some NP effect

Rivet routine that applies fiducial cuts

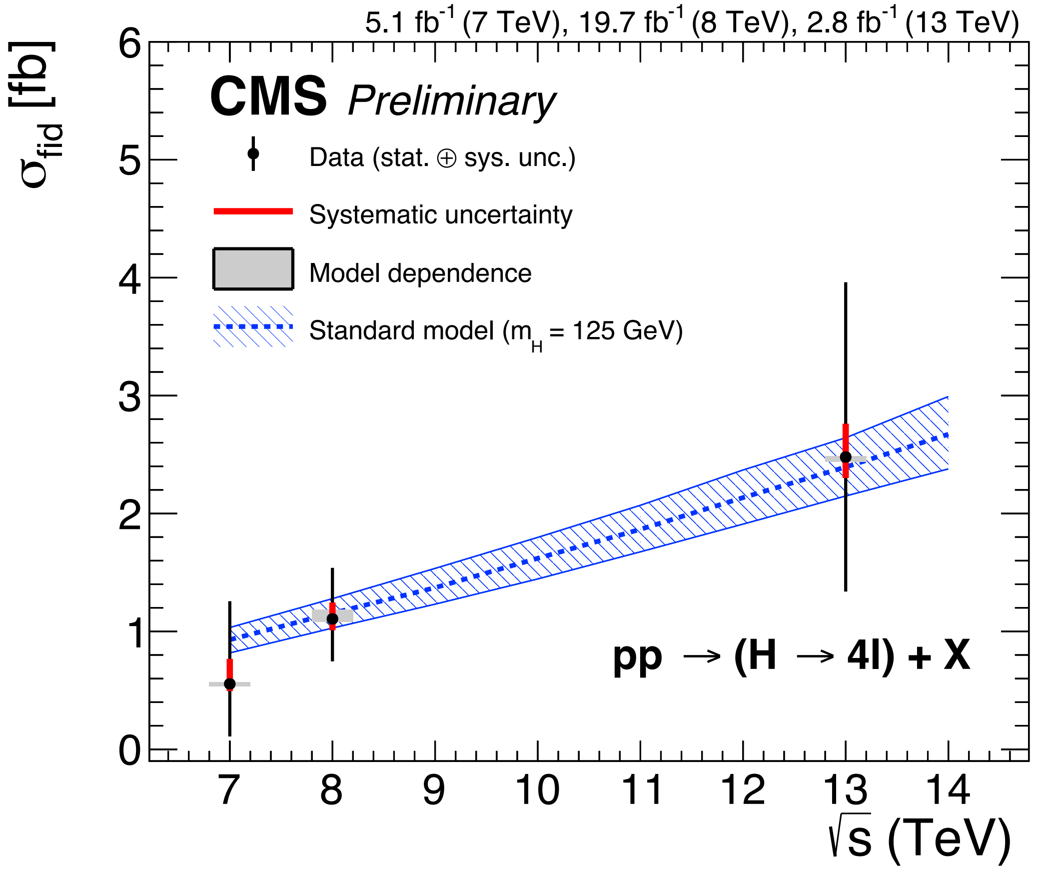
Summary (2/2)

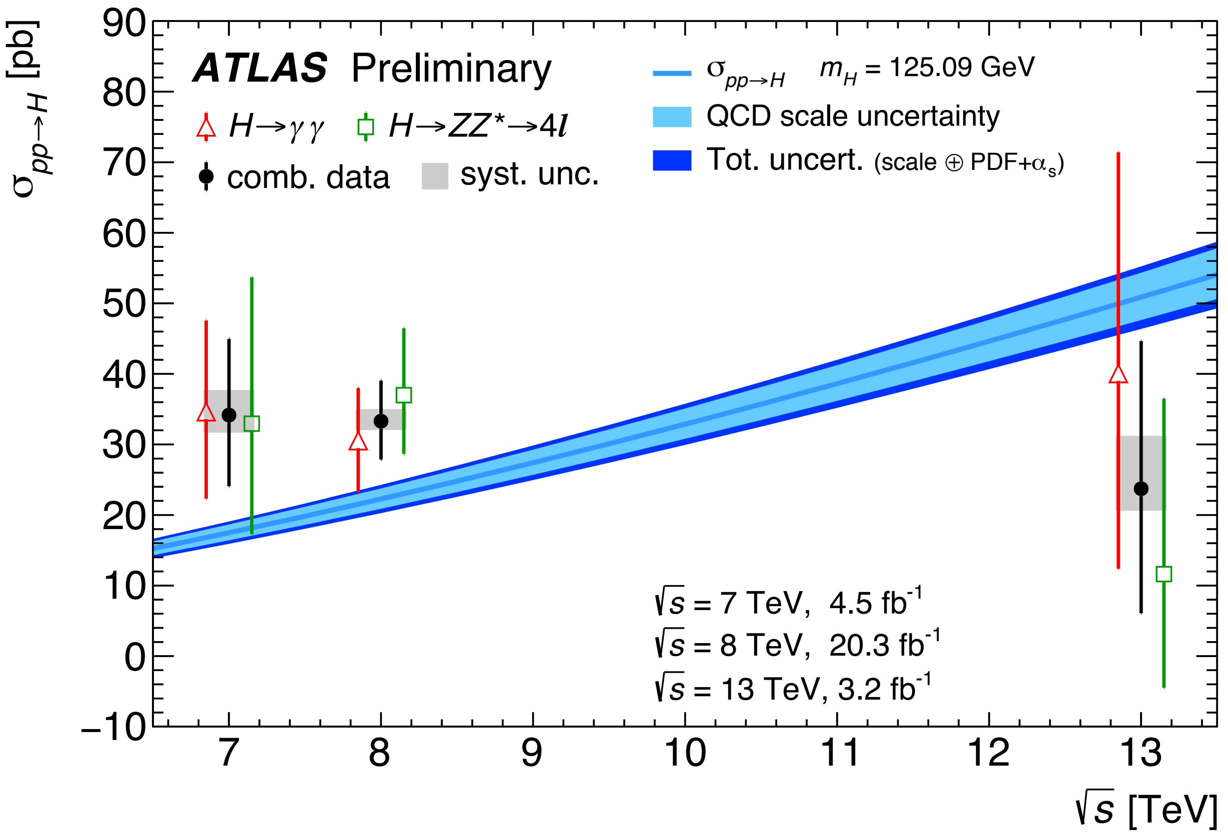
The YR4 has chapters about fiducial and simplified template cross sections

- If you are interested, check it out!

  https://cds.cern.ch/record/2157092 (fiducial cross sections)

  https://cds.cern.ch/record/2138079 (simplified template cross sections)





Thank you for your attention!