On fiducial/differential XS measurements

based on discussions with many CMS/ATLAS/TH colleagues within LHC HXS WG, LHC-HCG, and beyond...

P. Milenovic (CERN)

Les Houches, June 7-8th, 2017

[*]Some recent discussions:

https://indico.cern.ch/event/632454/

http://indico.cern.ch/event/510558/

Perface

Fiducial: Optimized for maximal theory independence

- Minimize acceptance corrections
- Simple (rectangular) signal cuts
- “Exact” fiducial volume
- Fiducial in Higgs decay
- Targeted object definitions

Agnostic to production modes

(Single-)differential distributions
(overlapping events)

Only $H \to \gamma\gamma, ZZ, (WW)$
(by default no combination of channels)

Simplified: Maximize sensitivity while reducing theory dependence

- Allow larger acceptance corrections
- Allow event categories, MVAs, ...
- Abstracted/simplified fiducial volumes
- Inclusive in Higgs decay
- Common idealized object definitions

Xsec split by production mode

Xsec split into mutually exclusive regions of phase space

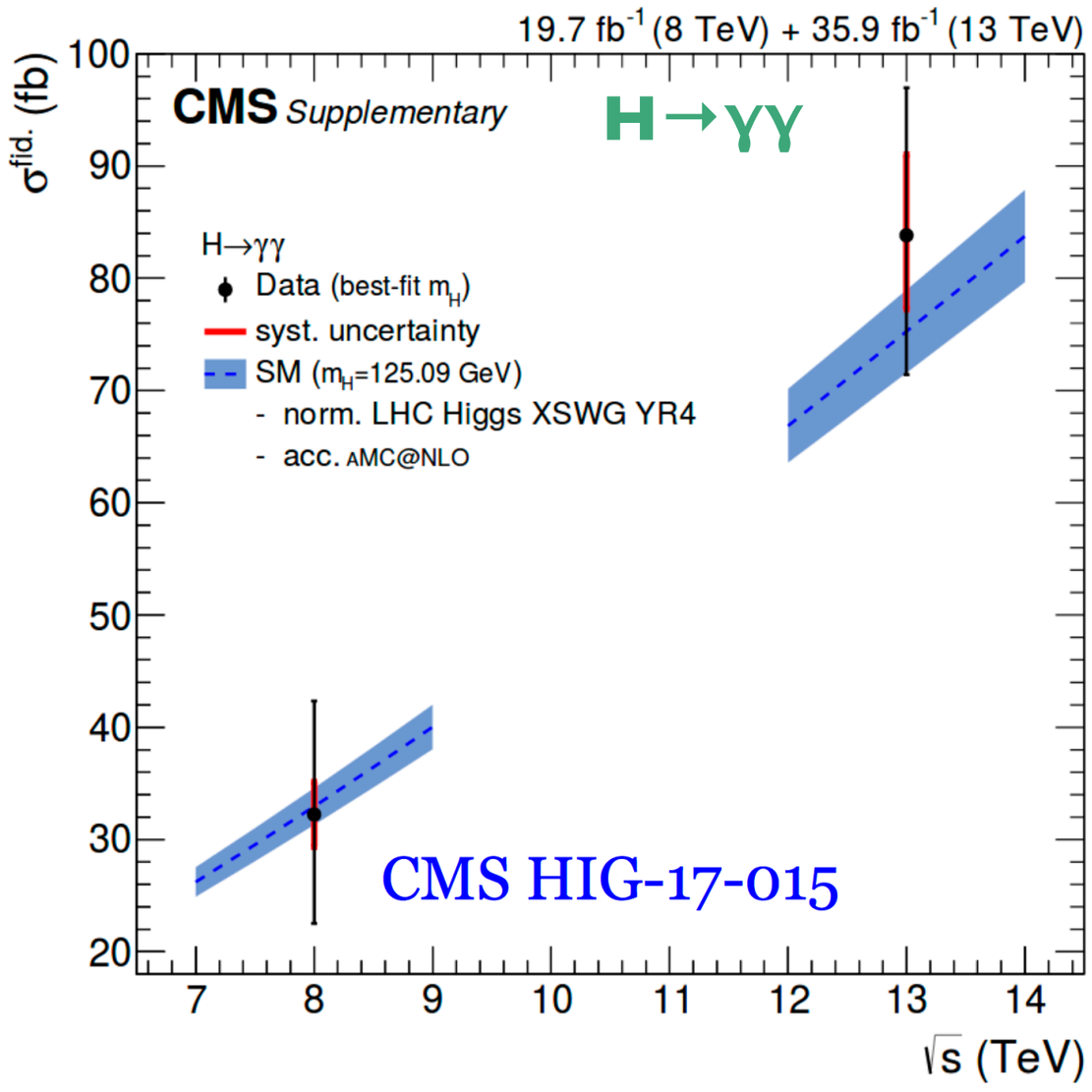
Explicitly designed for combination of all decay channels

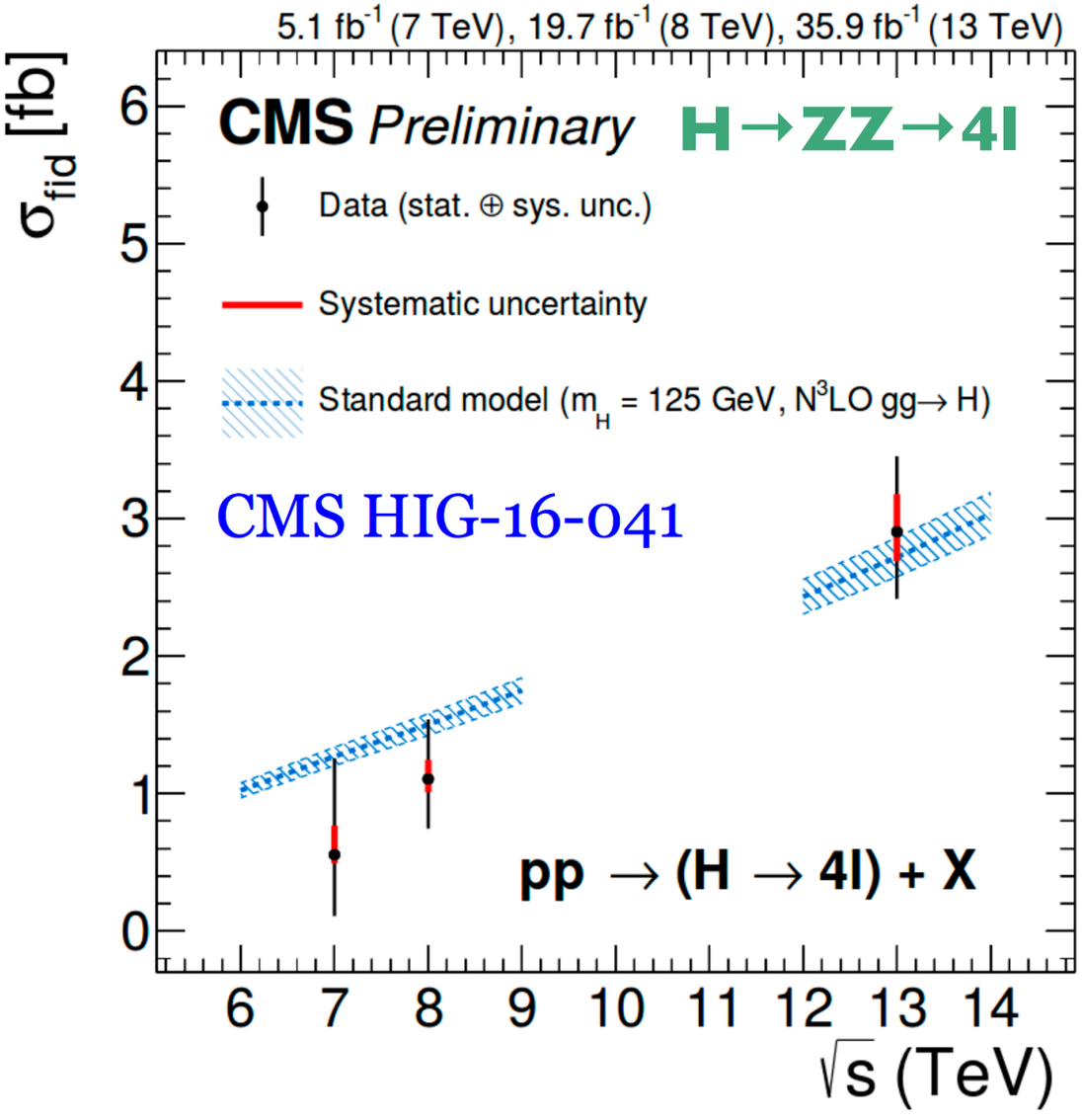
- Despite different focus, should discuss/identify common areas of interest
  - Residual theory/model uncertainties in measurements
  - Presentation of measurement results

Slide from Frank Tackmann

Measurements of fiducial XS @ 7/8/13 TeV

- **Inclusive fiducial XS** @ 7/8/13 TeV presented by experiments (**CMS**):
  - Not sensitive to production mechanism, but expected to be dominated by gluon fusion



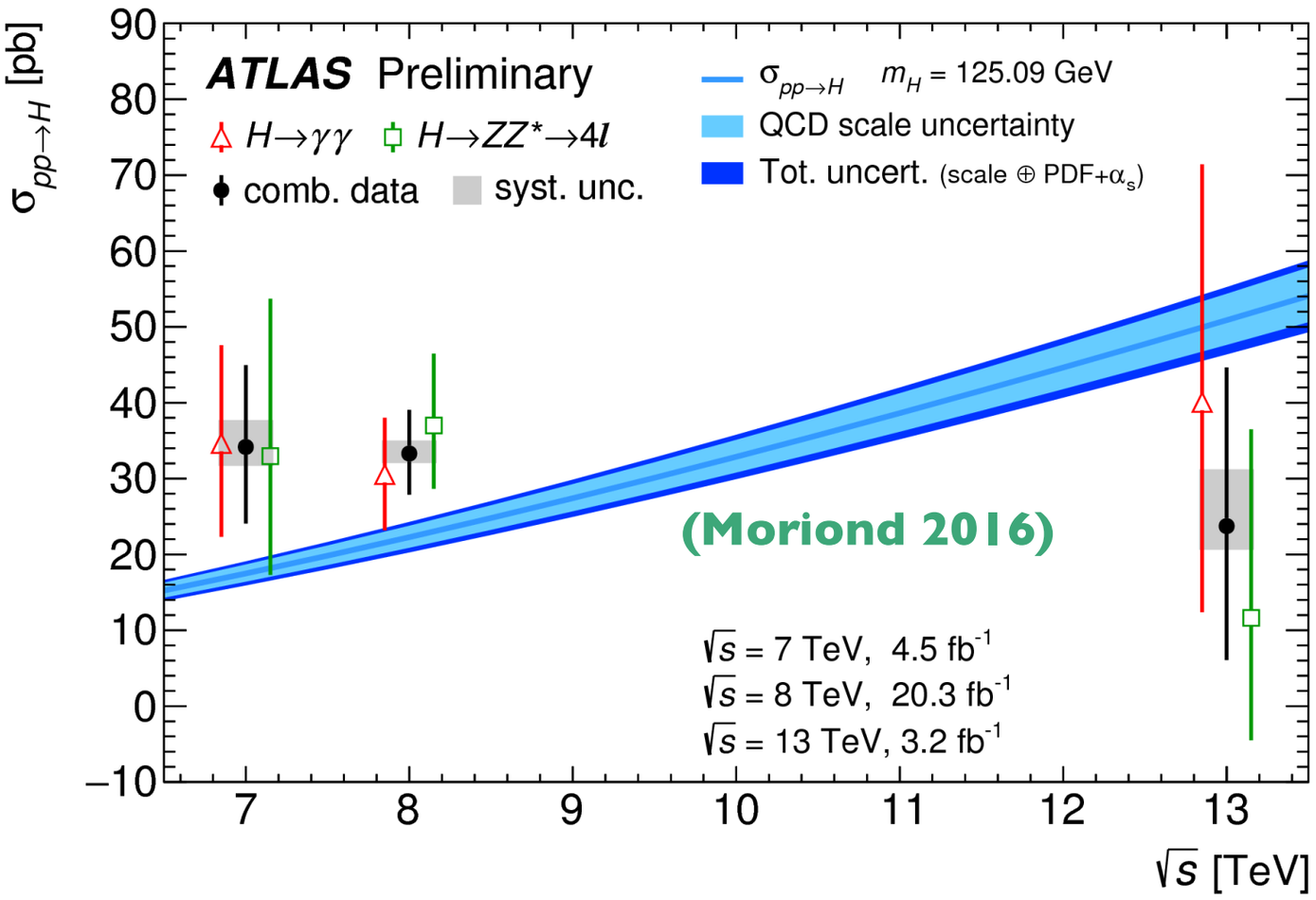


Compatible with theoretical estimates within existing uncertainties

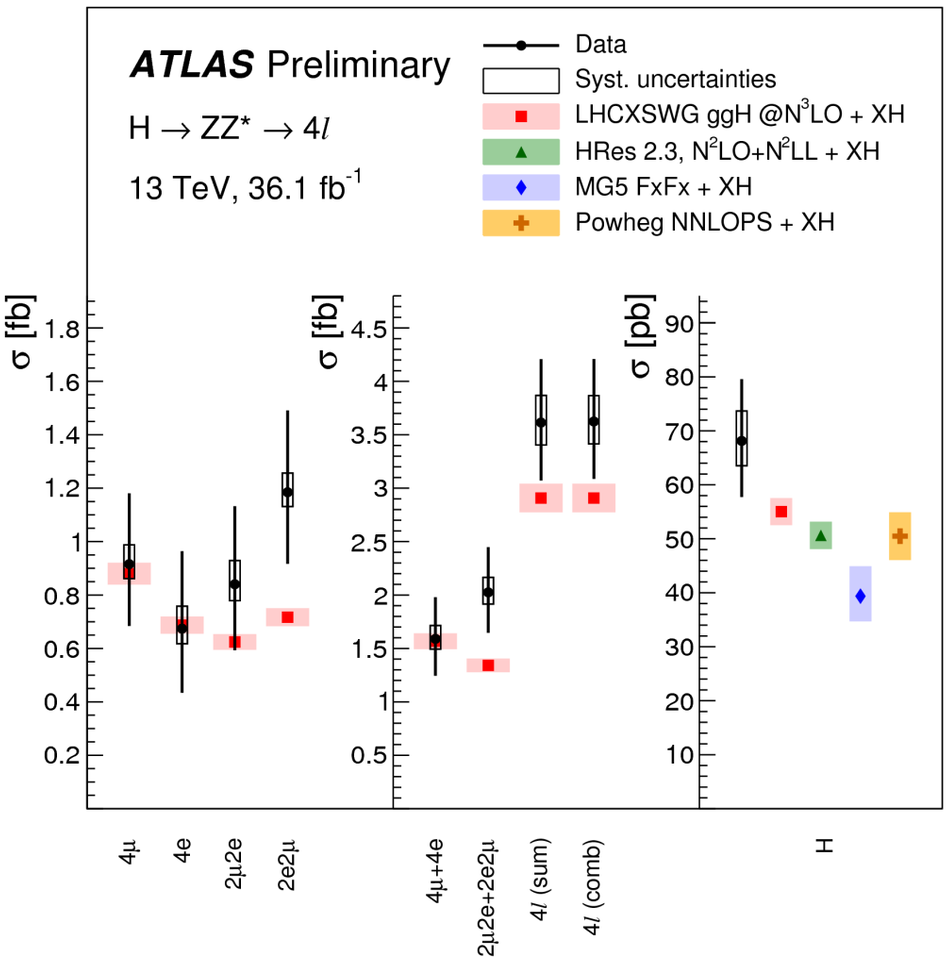
Measurements of fiducial XS @ 7/8/13 TeV

- **Inclusive fiducial XS** @ 7/8/13 TeV presented by experiments (**ATLAS**):
  - Not sensitive to production mechanism, but expected to be dominated by gluon fusion

H→γγ + H→ZZ→4l



H→ZZ→4l

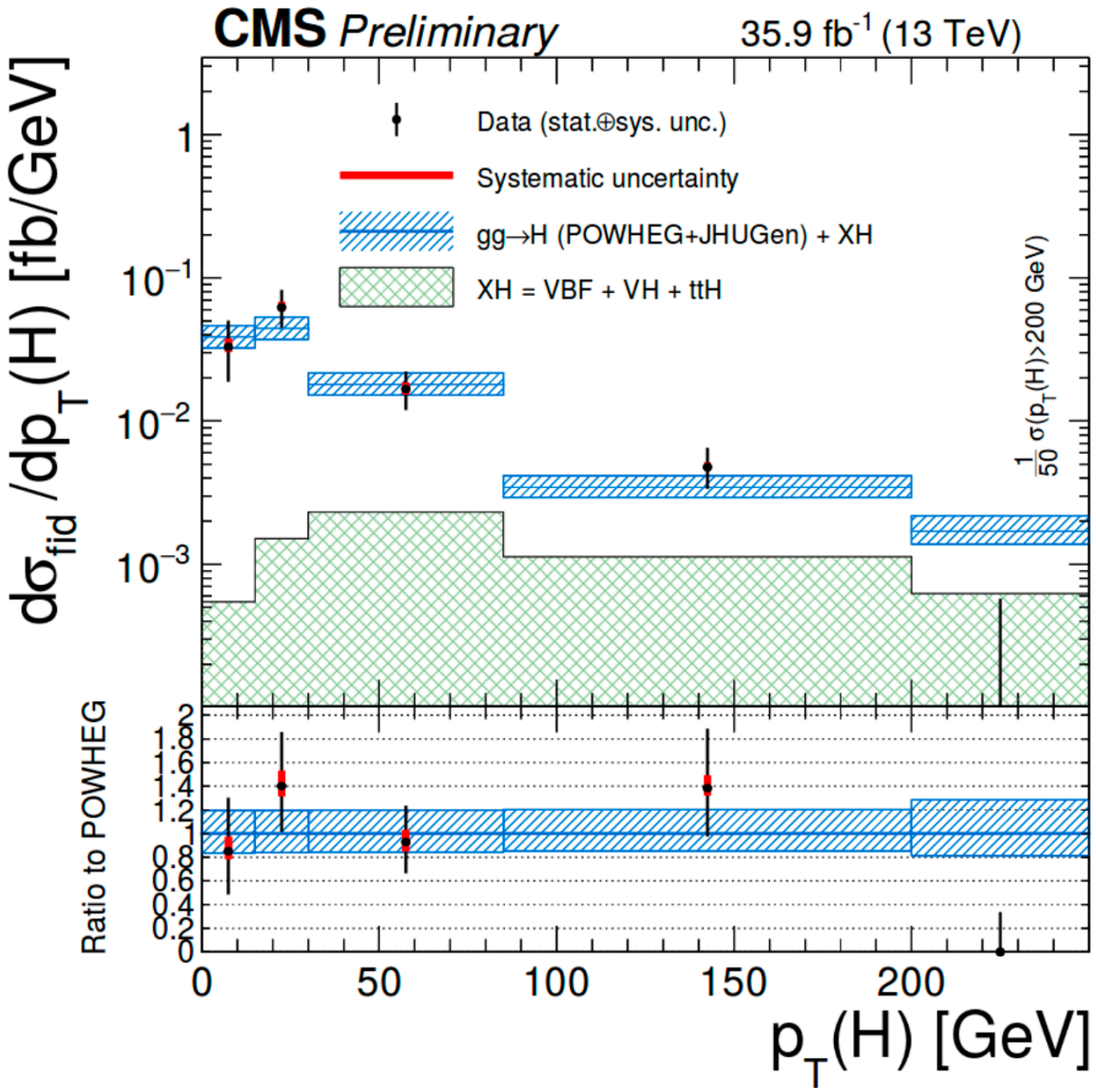


Compatible with theoretical estimates within existing uncertainties

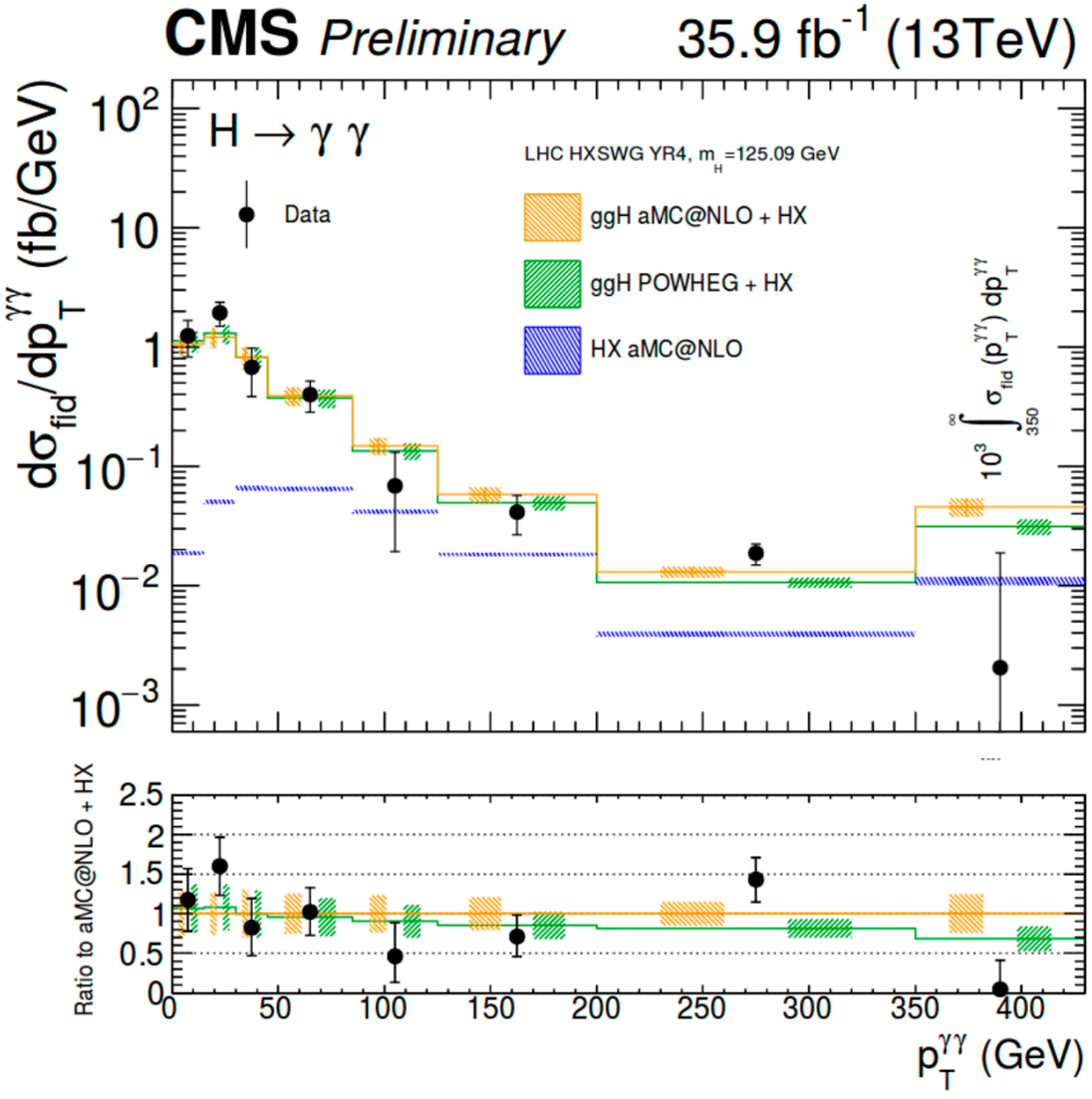
Differential fiducial cross sections @ 13 TeV

- **Differential $p_T(H)$** fiducial XS @ 13 TeV (**CMS**):
  - Sensitive to modelling of hard quark and gluon radiation, relative contributions of different production modes, BSM effects in the loops, etc.

H→ZZ→4l



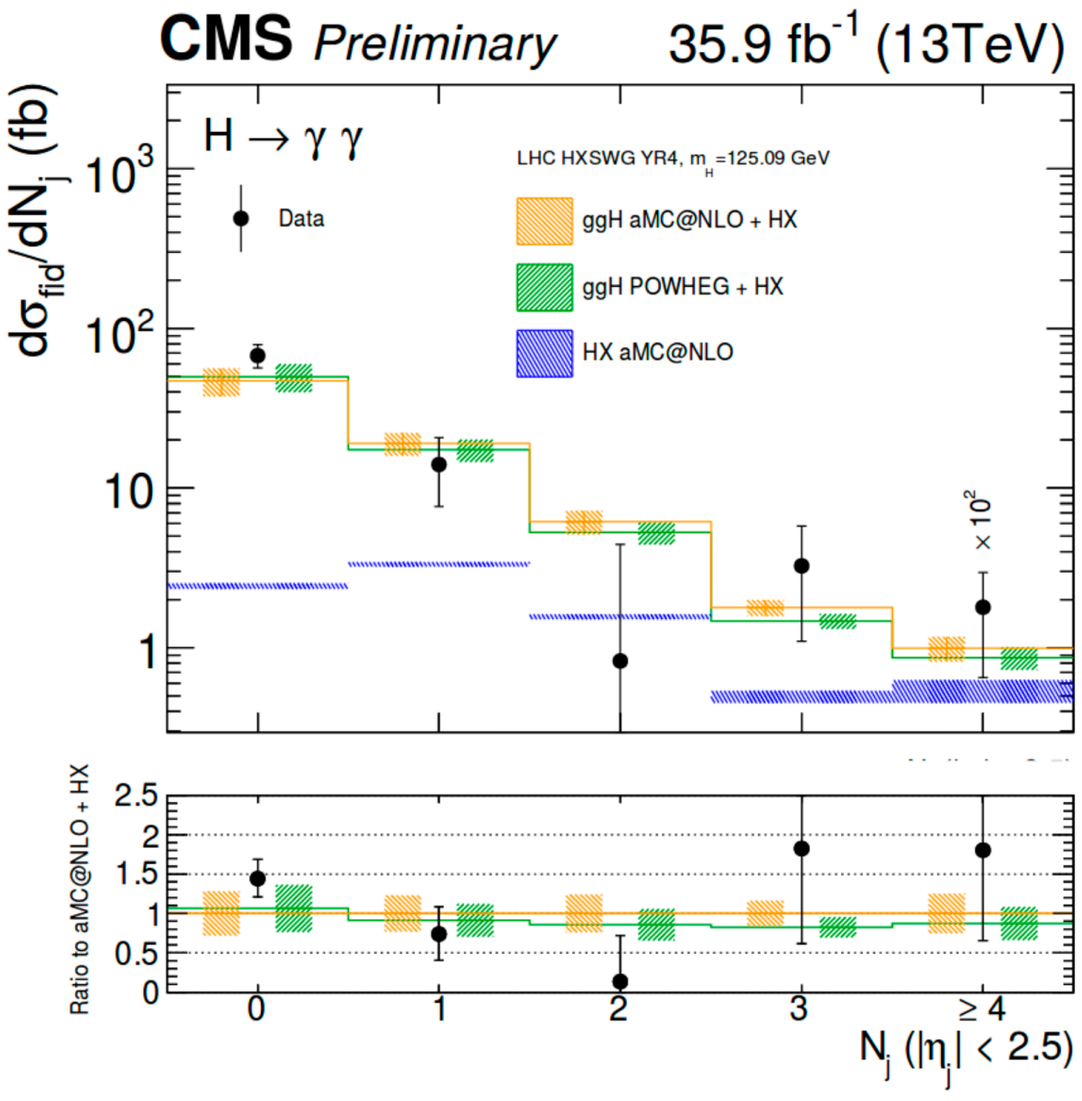
H→γγ



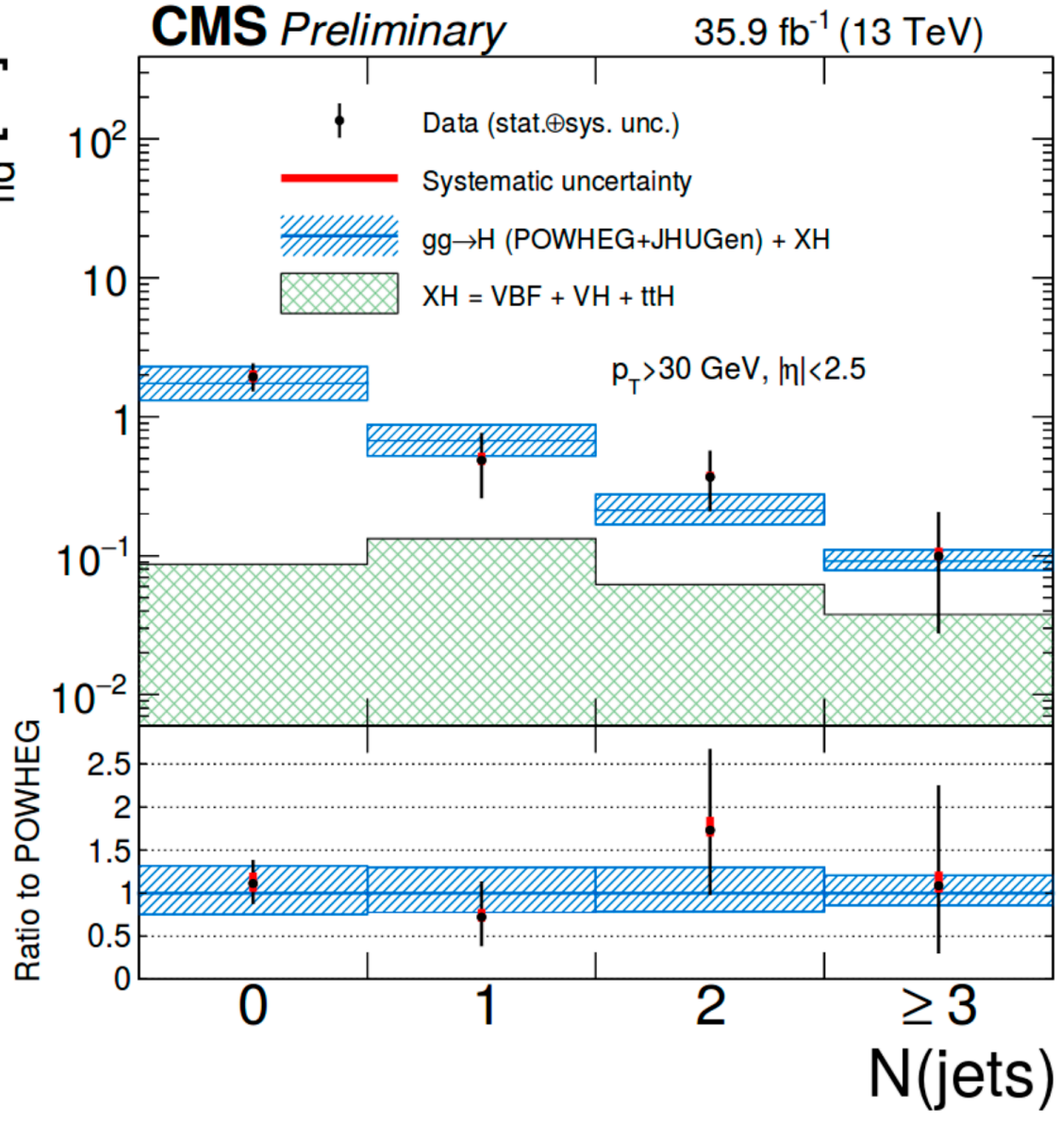
Differential fiducial cross sections @ 13 TeV

- **Differential N(jets)** fiducial XS @ 13 TeV (**CMS**):
  - Sensitive to modelling of hard quark and gluon radiation, relative contributions of different production modes, BSM effects in the loops, etc.

H→γγ



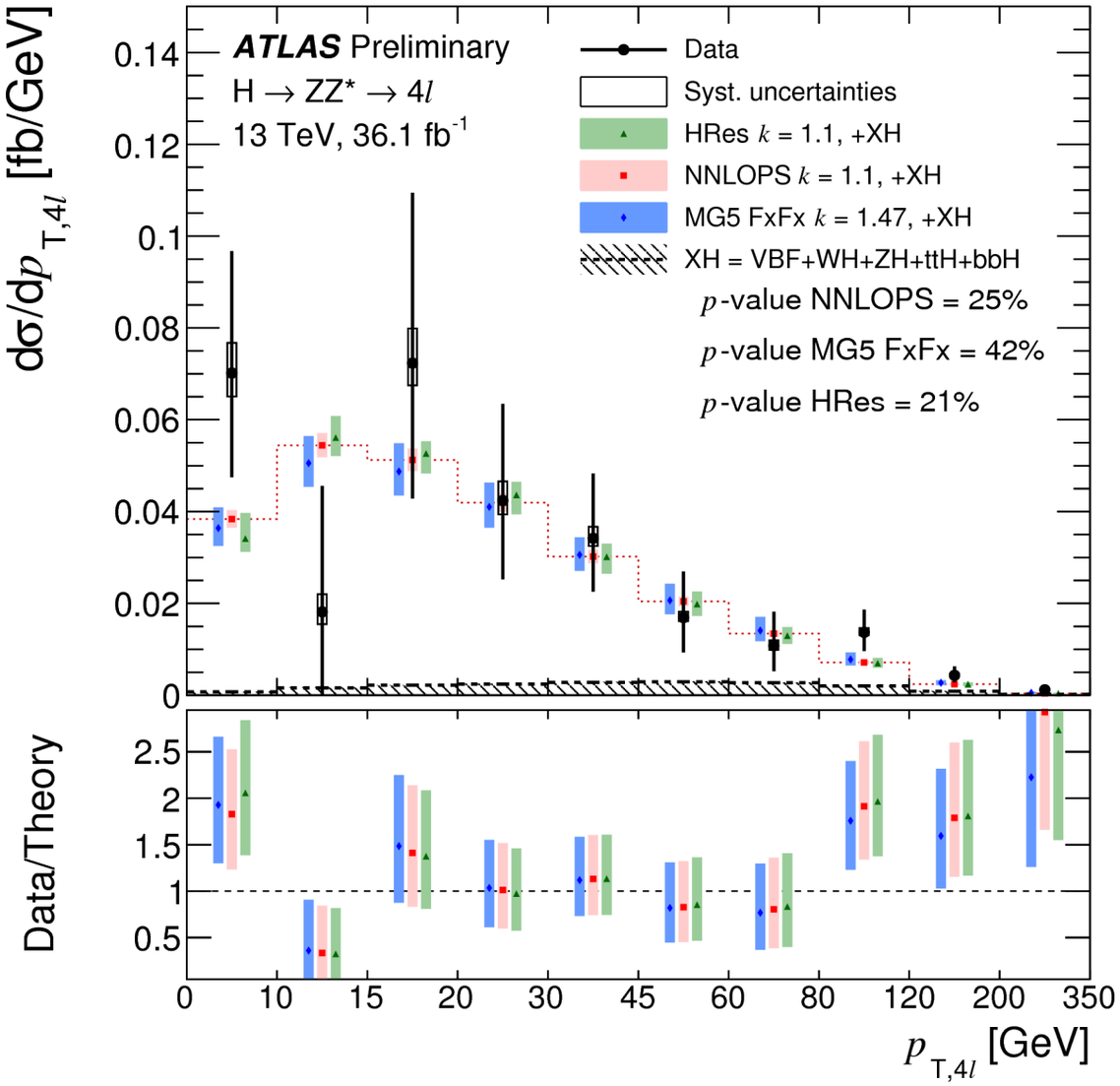
H→ZZ→4l



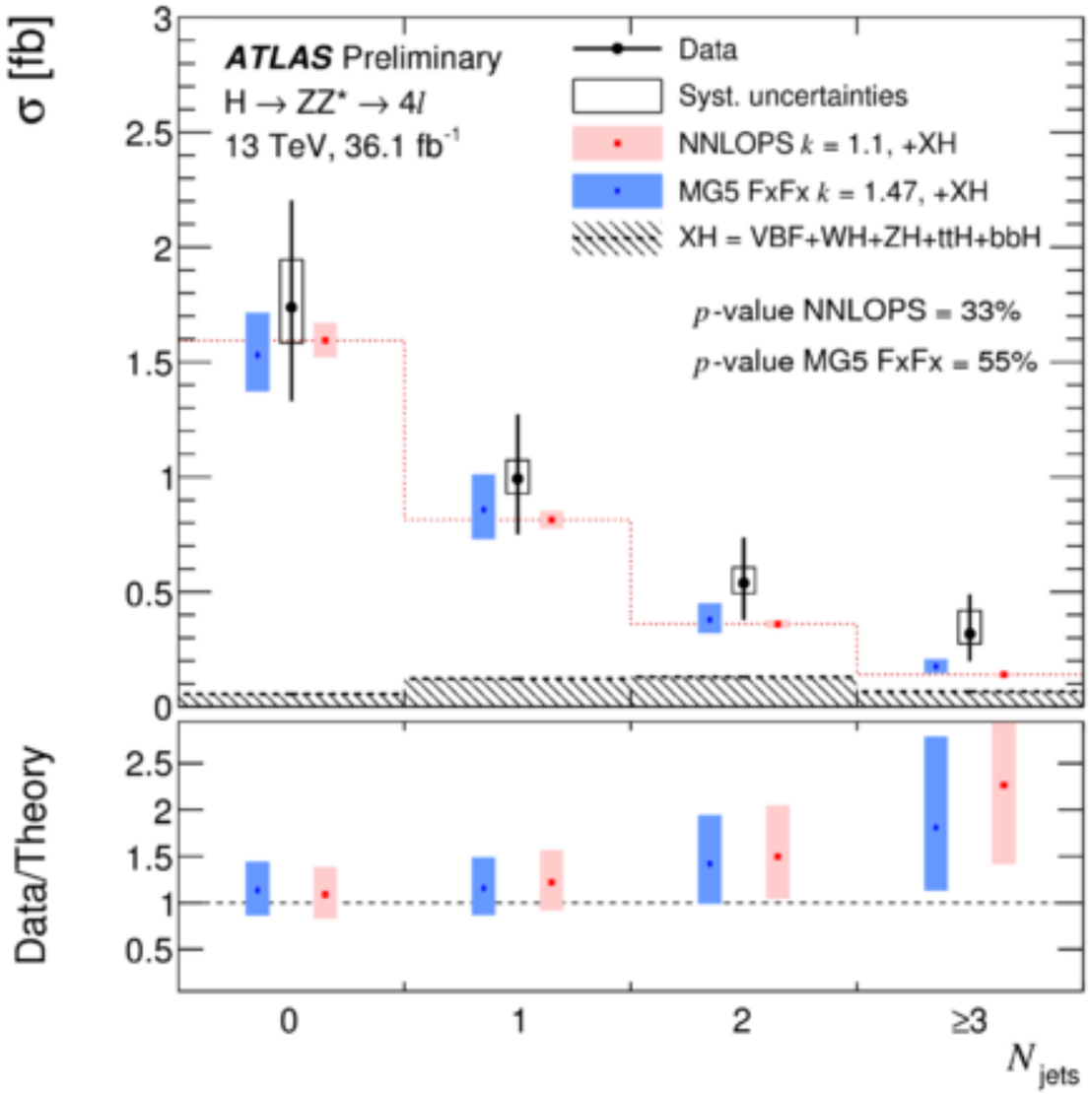
Differential fiducial cross sections @ 13 TeV

- **Differential H→ZZ→4l** fiducial XS @ 13 TeV (**ATLAS**):
  - Sensitive to modelling of hard quark and gluon radiation, relative contributions of different production modes, BSM effects in the loops, etc.

p_T(H→4l)



N(jets)



Choice of differential observables and binning

Observables considered:

Core Results / Nice to have

- **1D distributions**:

  p_T(H), N(jets), |Y(H)|, p_T(jet 1),
  p_T(jet 2), |p_T(H) - p_T(jet 1)|, |Y(H) - Y(jet 1)|, |Y(jet 1) - Y(jet 2)|, M_{jj}.

- **2D distributions**: **p_T(H) x N(jets),** **p_T(H) x |Y(H)|**.

  Still need to agree on the exact set of **1D/2D** variables.

Other ideas/proposals?

Binning:

- Need to have aligned coarse bin boundaries
- Criteria for bin boundaries related to the uncertainty on the expected yields
  - ATLAS: having > 2 sigma expected significance in each bin,
  - CMS: somewhat stronger requirement on the exp. signal yield uncertainty,

  Exceptions: overflow or boundary bins., match STXS boundaries if possible (for convenience)

Experiments have agreed (or are about to agree) on the bin boundaries.

Choice of binning boundaries

Possible binning scenarios (ATLAS/CMS)

XYZ **aligned boundaries**

possible finer boundaries

- Binning for $p_T(H)$:

H→γγ: 0 10 15 20 30 45 60 80 100 120 155 200 260 350

H→4l: 0 10 15 20 30 45 60 80 100 120 155 200 260 350

- Binning for |y(H)|:

H→γγ: 0 0.15 0.3 0.45 0.6 0.75 0.9 1.2 1.6 2 2.5

H→4l: 0 0.15 0.3 0.45 0.6 0.75 0.9 1.2 1.6 2 2.5

- Binning for p_T(lead jet):

Jet Definition anti-kt dR=0.4, 30 GeV, need to decide on centrality

H→γγ: 30 40 55 75 95 120 200 350

H→4l: 30 40 55 75 95 120 200 350

- Discussion on other observables and binning is ongoing...

Definition of fiducial region

Fiducial regions:

- **Too many differences** in ATLAS and CMS analyses/regions (p_T and η cuts, isolation, etc.):

  There is no need to aim the same fiducial phase space definitions.

- Combined measurement with different fiducial definitions:
  - **by extrapolation to the full phase space with restriction |y(H)| < 2.5**
    Easiest, additional model dependence, makes sense for H→γγ + H→4l combination.
    Fiducial with |y(H)| < 2.5 is interesting as it's experimentally accessible part of phase space.

Might also consider combination:

- **in "common" part or the "minimal enclosing" part of the phase space**
  Not easy to find for different channels, less add. model dependence,
  makes sense for individual H→γγ and H→4l - **proposal that this is not an initial priority.**

Any comment?

Definition of signal and out-of-fiducial component

Signal definitions:

- Perform measurement for the processes via the Higgs resonance.
  Subtract non-resonant contributions in **pp→(H→)γγ, pp→(H→)ZZ→4l, pp→(H→)WW→2l2ν**
- Measurement for the fiducial **pp→4l** and **pp→2l2ν** production ("un-subtracted") also important in the long term, but initially not a priority.

Out-of-fiducial component:

- Subtracted from signal. Experiments capable to treat it in two ways:
  (**fix** its absolute value to SM expectation, or fix its ratio to signal to the SM expectation and **float** it in fit)

Need to agree on a common approach for combination (pros and cons for both options).
Should be possible to find common ground. Impacts directly model dependance.

Other aspects of the measurements/analyses

Treatment of m(H):

- Question weather to fix m(H) as ext. parameter, or to float it as a nuisance.

Proposal is to fix m(H) - need to agree on the value (e.g. Run1 ATLAS+CMS combination).
Still an option to float m(H) in combination (but an additional work needed).

Model dependance:

- Not well defined. Currently common to consider variation of relative fraction of SM production modes.

Proposal is to vary relative fraction of production modes within experimental constraints.
Could agree to also consider alternative true spectra.

Unfolding:

- Desirable to be able to use likelihood fits with embedded response matrix.

On presentation of results

Results and their presentation:

- Possibilities:
  - **differential XSs in absolute values** (non-normalised), or
  - **differential XSs normalised** (to the integrated XS)
    (cancelation of BRs, easy to compare $H\to 4l$ and $H\to\gamma\gamma$).
- Comparisons to theory predictions: **follow YR4 prescriptions**
  (e.g. use **N^3LO QCD** for the ggH normalisation, and **NNLO+NNLL** QCD for shape).
- Exploring ideas to provide results before unfolding (perhaps in form of simplified likelihoods), and to provide parametrised detector effects

Any comment?

Combined measurements to perform:

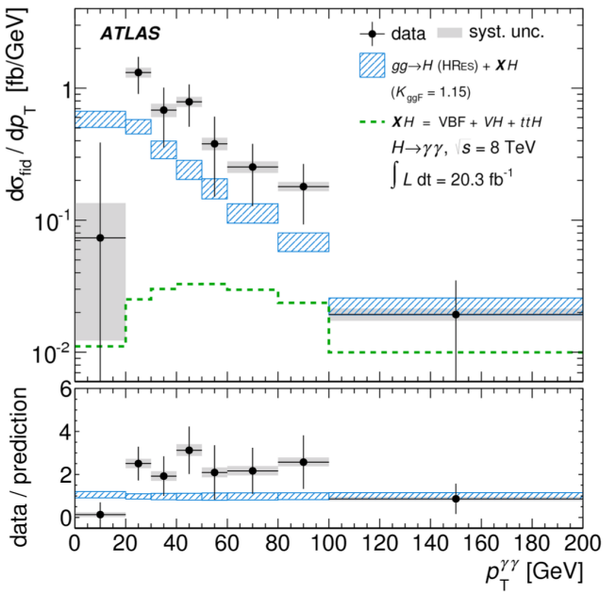
- Individual channels: **$H\to 4l$, $H\to\gamma\gamma$** (also **$H\to WW$** for **$p_T(H)$ and N(jets) if available?**)
- Combined all together: **$H\to 4l$ + $H\to\gamma\gamma$** (+ **$H\to WW$** for **$p_T(H)$ and N(jets) if available?**)

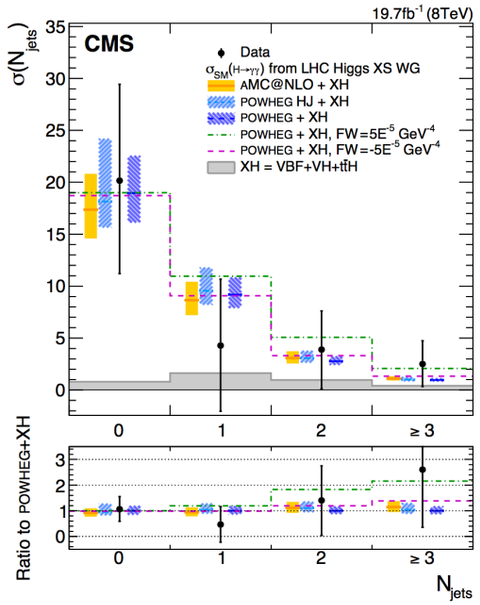
ADDITIONAL MATERIAL

Reminder: Fiducial cross sections @ Run I

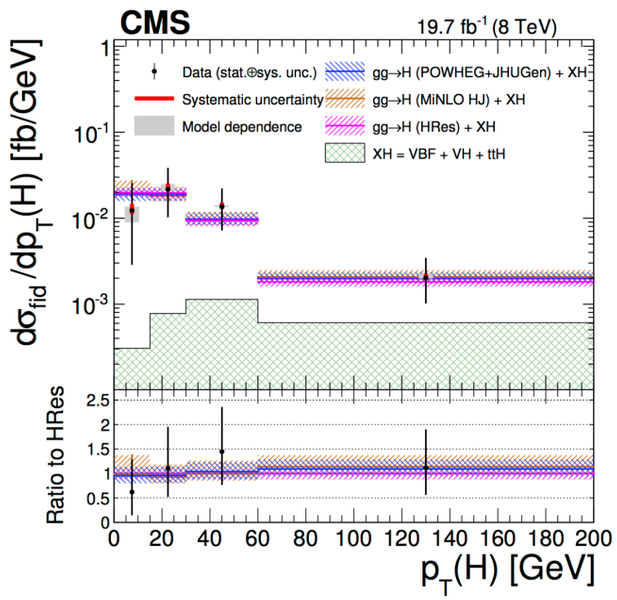
- **Inclusive and differential** fiducial XS @ 8 TeV in three channels:
  - Sensitive to modelling of hard quark and gluon radiation, relative contributions of different production modes, BSM effects in the loops, etc.

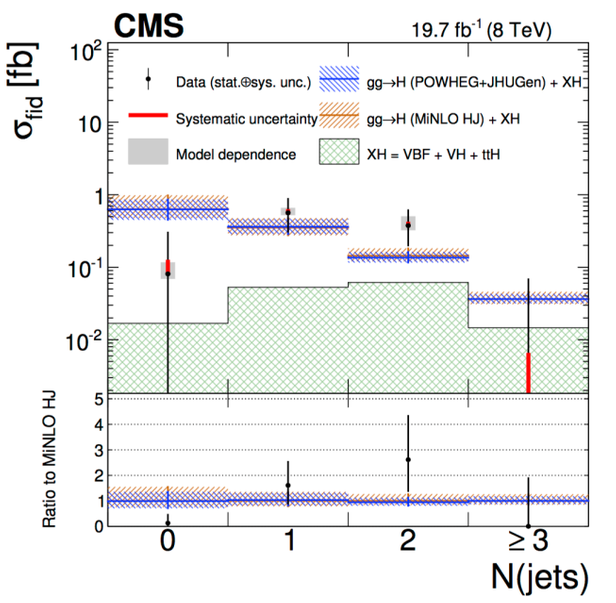
H→γγ



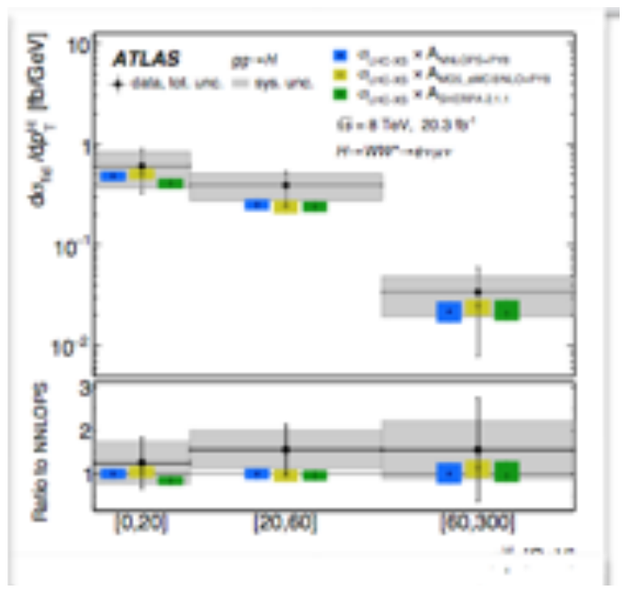


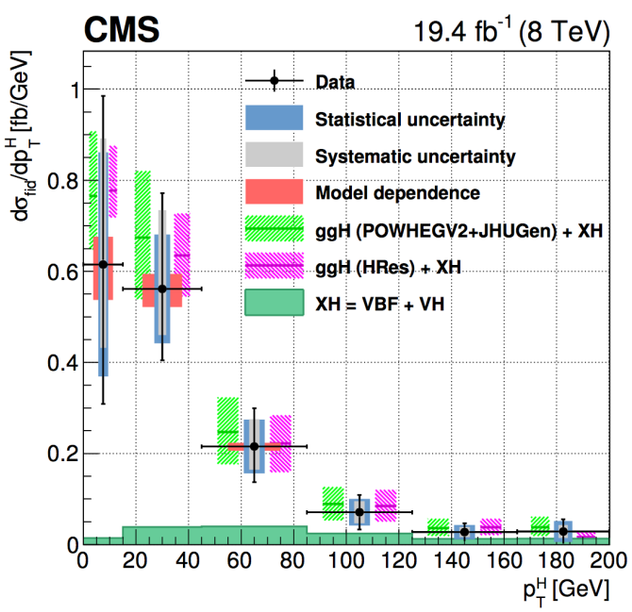
H→ZZ→4l





H→WW→2l2ν

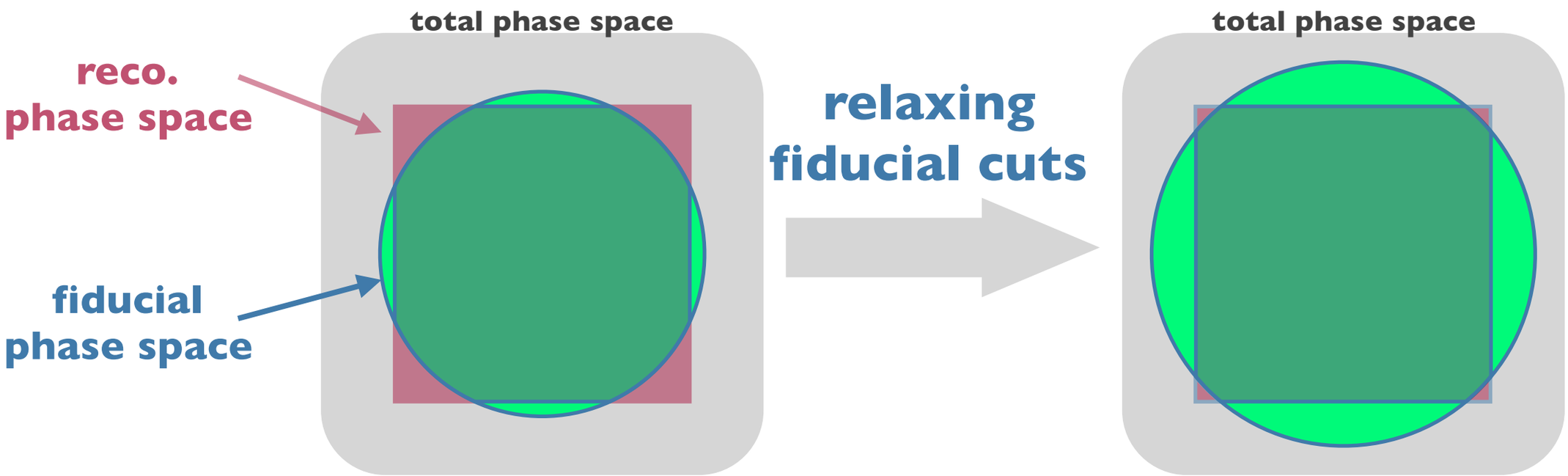




Fiducial requirements & observables with poor resolution

To be studied in each analysis:

- How to define the fiducial phase space when observables used to define the signal region have **poor experimental resolution** (missing E_T, jet p_T, etc.)?
  - Effects of migration of signal events can be large
  - Subtraction of non-fiducial signal events is model dependent
- Study if relaxing fiducial requirements can reduce model dependence.



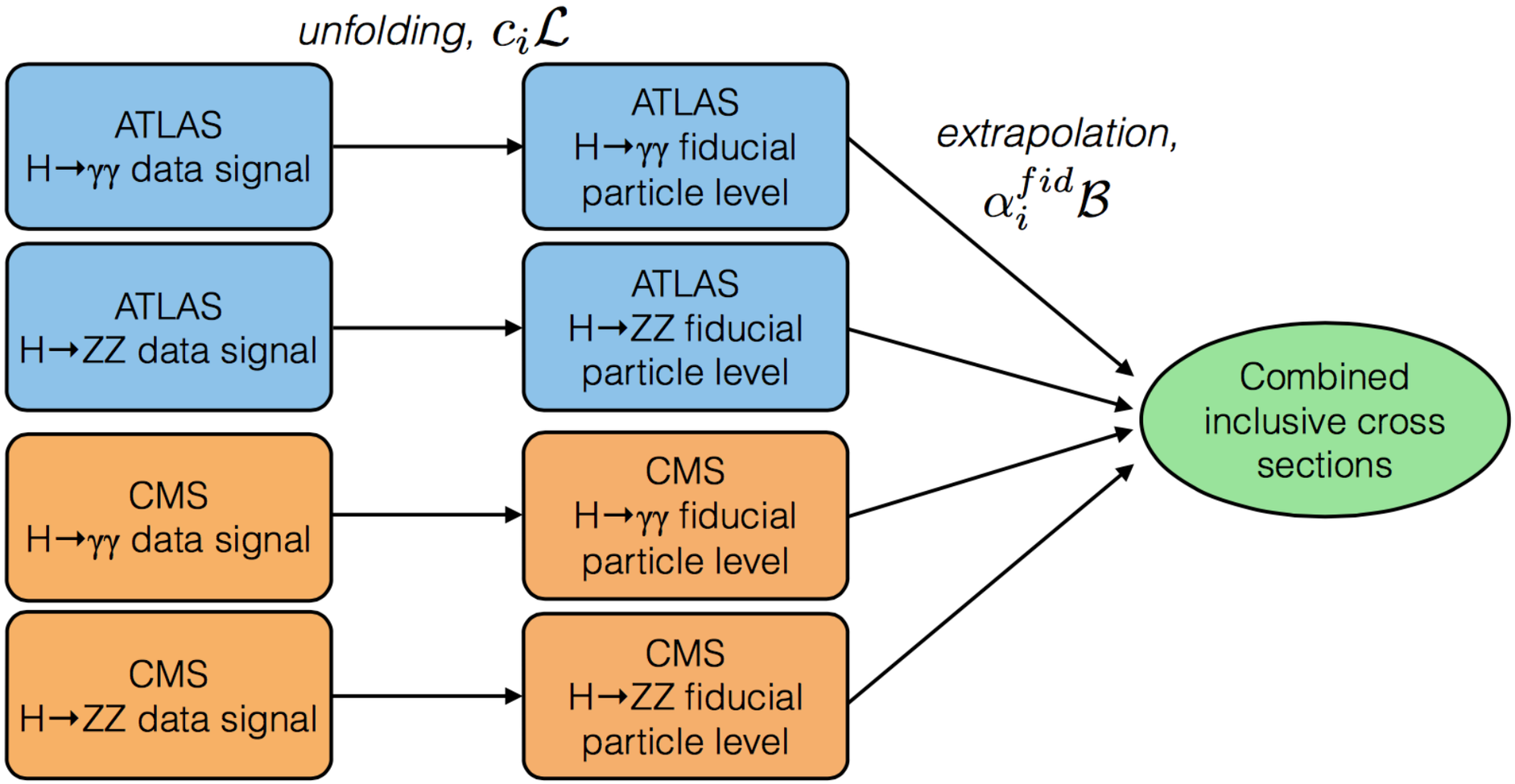
fiducial & reconstructed
fiducial & non-reconstructed
non-fiducial & reconstructed
non-fiducial & non-reconstructed

Combination of measurements

Combination between experiments:

- Potential to **combine inclusive and differential cross sections** (need harmonisation in fiducial objects, bin edges, unfolding, etc.)
- Choose **common fiducial** or **inclusive phase space?**
- **Define the common binning strategy**
- Benefit form the HCG experience, start **harmonization now!**

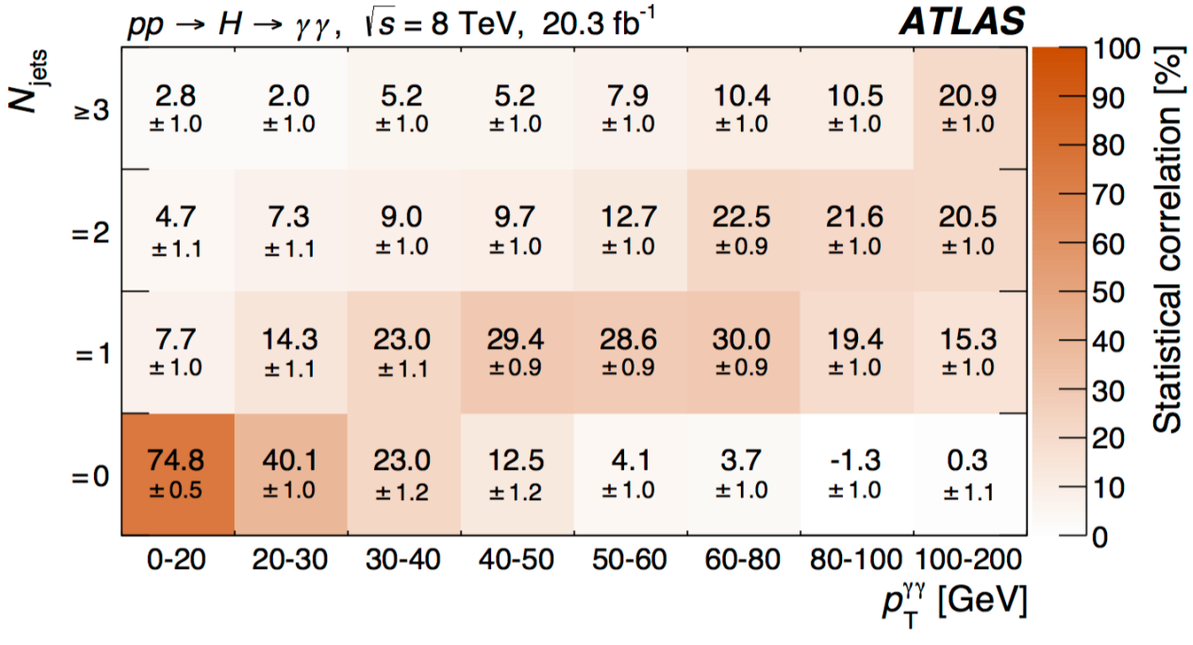
} starting discussion…

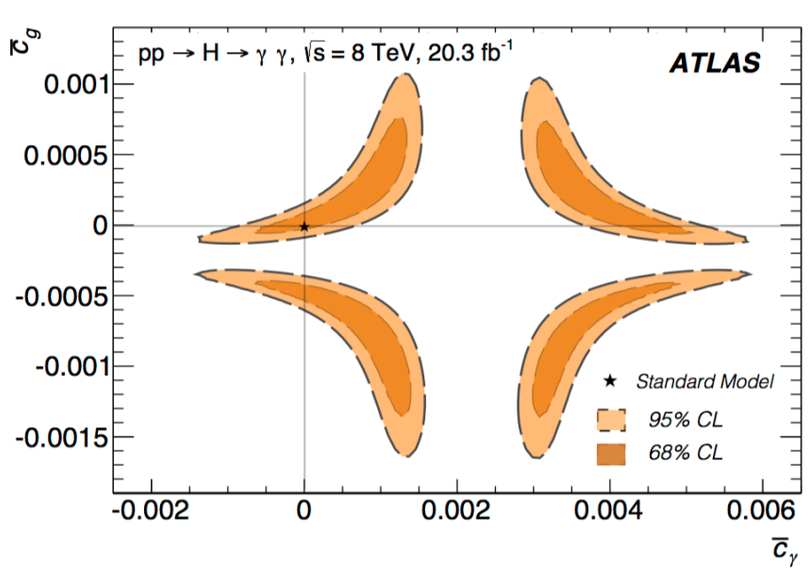


Towards global analysis... and beyond SM...

- A combined global analysis of several fiducial observables offers a unique probe to constrain NP effects
  - Complementary and more model independent to the simplified template cross section (limited to a subset of channels)
  - Requires theory predictions which match the experimental sensitivity and determination of **statistical correlations between observables**.

Example of global analsys





- Exploiting distributions with individ. modest sensitivity can lead to stronger limits
- Consider also double-differential distributions

Unfolding

GOAL: undo the effects of smearing due to detector resolution & efficiency

- Complex problem (and not very well defined), important for theory comparisons

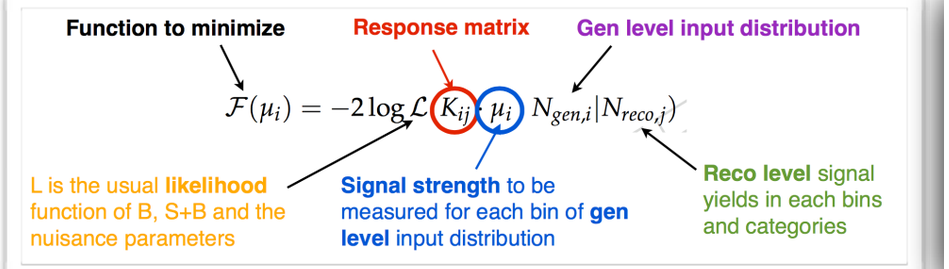
APPROACHES IN RUN 1:

- **ATLAS (HZZ, Hγγ)**: Used **bin-by-bin correction factors** (iterative d'Agostini unfolding method used for cross-check)

bin-by-bin corrections

$$\sigma_i = \frac{N_i^{\text{signal}}}{\mathcal{L}_{\text{int}} \cdot C_i}$$

unfolding fit



unfolding by matrix inversion

$$x_M^i = \hat{R}^{ij} x_T^j + b^i$$

- **CMS (HZZ, Hγγ):** Folded detector response matrix **(K)** in the likelihood and **perform background subtraction and signal unfolding simultaneously.**
- **CMS (HWW):** Two step procedure - first extract signal, then **unfold by inversion of detector response matrix (R)** and also **perform regularisation**

- Important to carefully consider and study effects of regularization, bin-by-bin migrations, etc.

Combination: Agreement between the channels

- Very good agreement between H → ZZ → 4l and H → γγ results in all variables
  - p-values higher than 56%