HXSWG FIDUCIAL CROSS SECTIONS
SUMMARY OF THE DISCUSSIONS

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Preface

MOTIVATION

- Fiducial cross section offer a **possibility to describe data in model independent** way
  - Fiducial volumes to be defined carefully
    (maximise the applicability of LHC data by factorising theory and experimental uncertainties)

GOALS

- Establish a **recommended sets of measurements**
  - Interesting by the theory community, deemed feasible by the experiments
  - For the short and medium term of the LHC running
  - Explore the **QCD effects** in the SM, and capture **BSM effects** in the Higgs physics

SO FAR...

- **Discussions** between relevant experts in HEP theory+experiment community
  - **kick-off meeting** brought together all interested parties
  - **follow-up meeting(s)** focused on particular issues, as necessary
- **Sharing synergies** with the other activities (LHC Higgs XS WG subgroups, Les Houches, etc.)

(Some of the) Discussion Topics

THEORETICAL ASPECTS:

- Improvements in the **theoretical modelling** of the Higgs production (WG1) and **important remaining uncertainties**
- Interconnection with **pseudo-observables** (WG2)
- **BSM aspects** (WG3)

This is why experimental scientists hate theoretical scientists.

Fiducial cross sections

- Fiducial cross sections, both total and differential, are standard measurements in HEP. They report the cross section in a "fiducial volume", specified by object definitions and kinematic selection cuts

- Fiducial cross sections can be interpreted in the context of whatever theoretical model, provided it is possible to compute its predictions for the fiducial cross section at hand (i.e. if implemented in a MC generator)

$$\sigma_i^{\text{fid}} = \sum_j A_{ij}^{\text{th}} \times \sigma_j^{\text{tot}}$$

↑ fiducial volume acceptance

- The advantage is that experimental uncertainties associated with the measurements and theoretical uncertainties associated with fiducial volume acceptances are nicely factorized.

- Updates of theoretical acceptances/uncertainties or a confrontation of new models against the experimental results do not require any re-analysis of experimental data.

Fiducial cross sections

- For Higgs physics, fiducial XS measurements can be categorized by targeting
  - decay mode: $H \to \gamma\gamma$, $H \to ZZ \to 4$leptons, $H \to WW \to l\nu l\nu$, ...
  - production mechanism: (VBF-like jj)+H, (V-like jj)+H, (ll)+H, (l+MET)+H, etc
  - signal 'purity': e.g. 0-jet, 1-jet, VBF-like jj, etc

Modelling of processes @ higher orders

- **Three major improvements** in the theoretical Higgs modelling in 2015:
  - **N^{3}LO** cross section, **fully inclusive**

    [Anastasiou, Duhr, Dulat, Herzog, Mistlberger (2015)]
  - **NNLO H+J** cross section, **fully exclusive**

    [Boughezal, Caola, Melnikov, Petriello, Schulze (2015)], [Boughezal, Focke, Giele, Liu, Petriello (2015)][Chen, Gerhmann, Glover, Jaquier (in progress)]
  - **NNLO VBF** cross section, **fully exclusive**

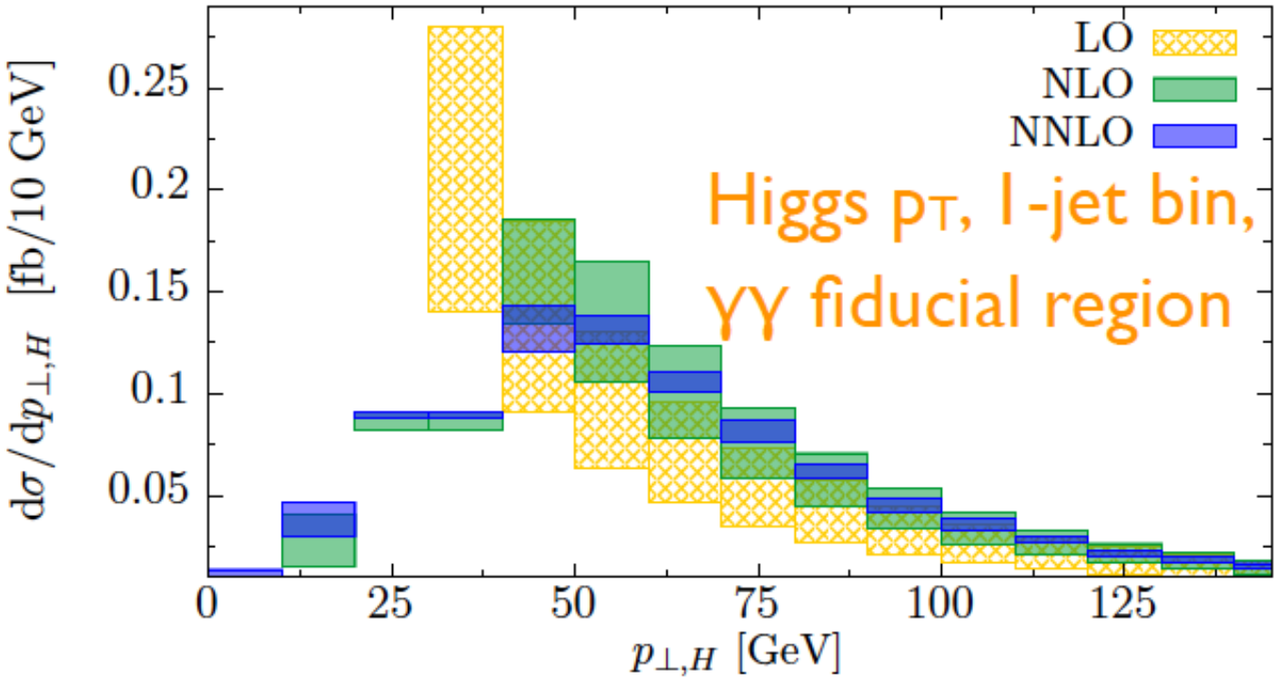
    [Cacciari, Dreyer, Karlberg, Salam, Zanderighi (2015)]
- **Improvements** in the theoretical modelling of VV' production:
  - **NNLO pp→VV'+X** cross section, **fully exclusive**

    [Catani, Cieri, de Florian, Ferrera, Grazzini; Grazzini, Kallweit, Rathlev (Vgamma)] [Gehrmann, Grazzini, Kallweit, Maieroefer, v. Manteuffel, Pozzorini, Rathlev, Tancredi (WW)] [Cascioli, Gehrmann, Grazzini, Kallweit, Maieroefer, v. Manteuffel, Pozzorini, Rathlev, Tancredi, Weihs (ZZ)] [Grazzini, Kallweit, Rathlev (ZZ*)]

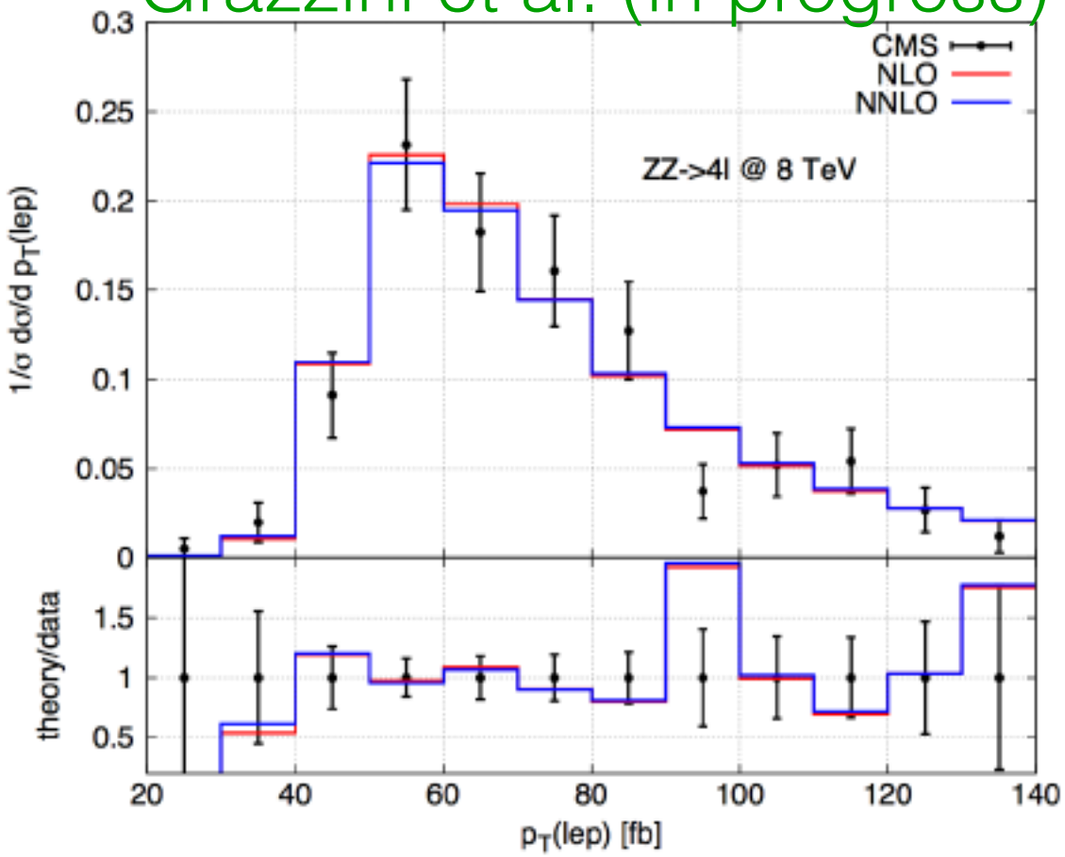
NNLO exclusive cross sections

- Fully differential QCD corrections available soon to NNLO both for ggF/VBF signal (yy, possible also for 4l and 2l2v) and background (yy, 4l, possible also for 2l2v)

Caola et al. (in progress)



Grazzini et al. (in progress)

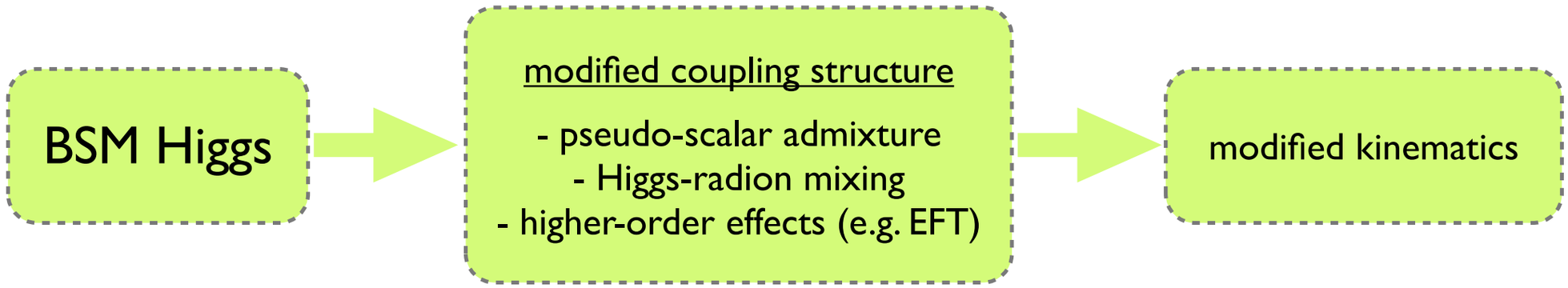


- Fully exclusive VBF cross section known to NNLO Cacciari et al.

- Computations very often CPU intensive
  - Agreement on realistic set of fiducial cuts within the HXSWG desirable for the authors (no public codes yet)

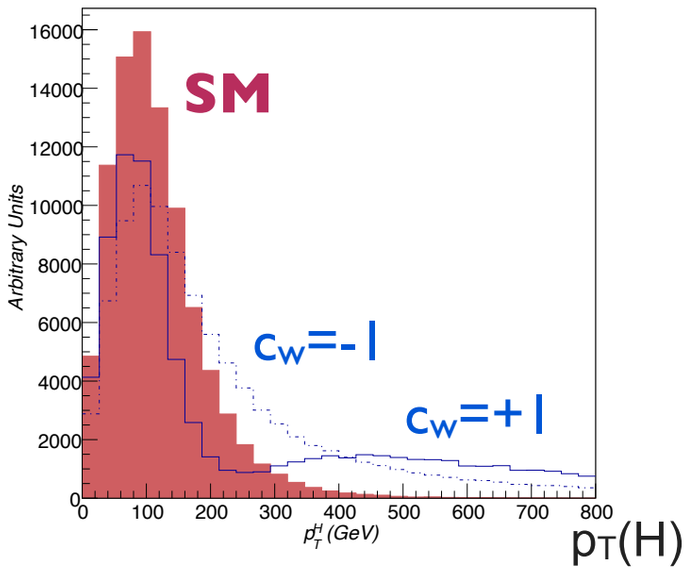
Sensitivity to BSM

- Fiducial cross sections (total or differential) offer a way to test BSM scenarios in which the kinematic distribution of the signal depends on the model parameters, leading to a change in the signal selection efficiencies w.r.t. the SM.



- Note that BSM typically affects production and decay processes
- Consider p_T, m_{jj}, η_{jj} , $\Delta\Phi$, inv. mass, etc. distributions
- Large effects may occur in extreme kinematic regions, where little or no SM signal is expected
- The same BSM may also affect the backgrounds
- Dedicated studies needed

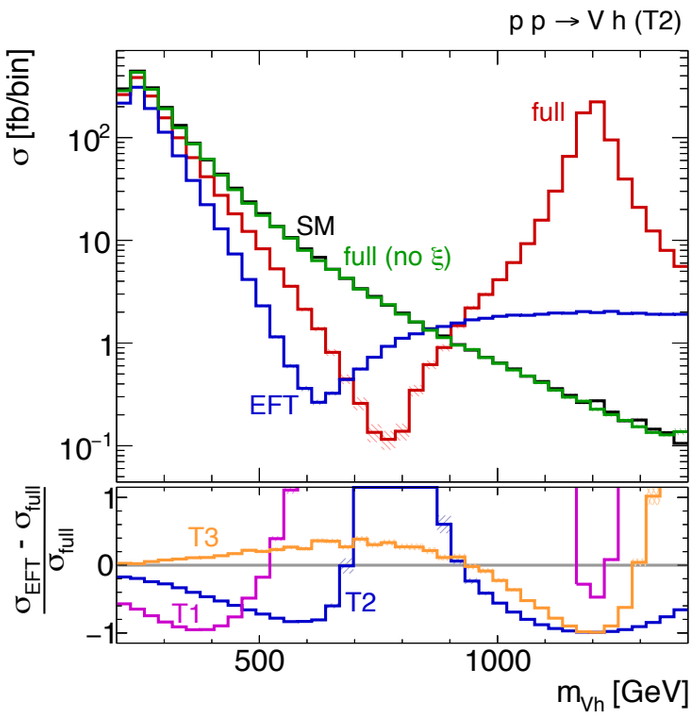
Example of EFT effects in VBF production [V. Sanz]

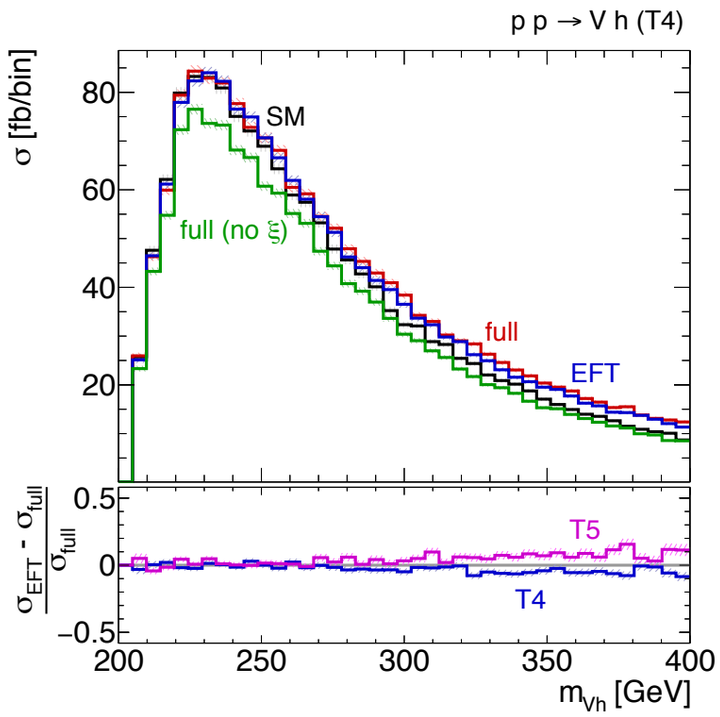


BSM review talk by Veronica Sanz at FXS kick-off meeting
https://indico.cern.ch/event/399923/session/3/contribution/14/attachments/800903/1097616/HXSWG_fiducial.pdf

Sensitivity to BSM (2)

- Kinematic distributions in VBF and VH production are particularly model-dependent
- Caveat: EFT is not always a good and reliable description of high-scale effects





[1510.03443]

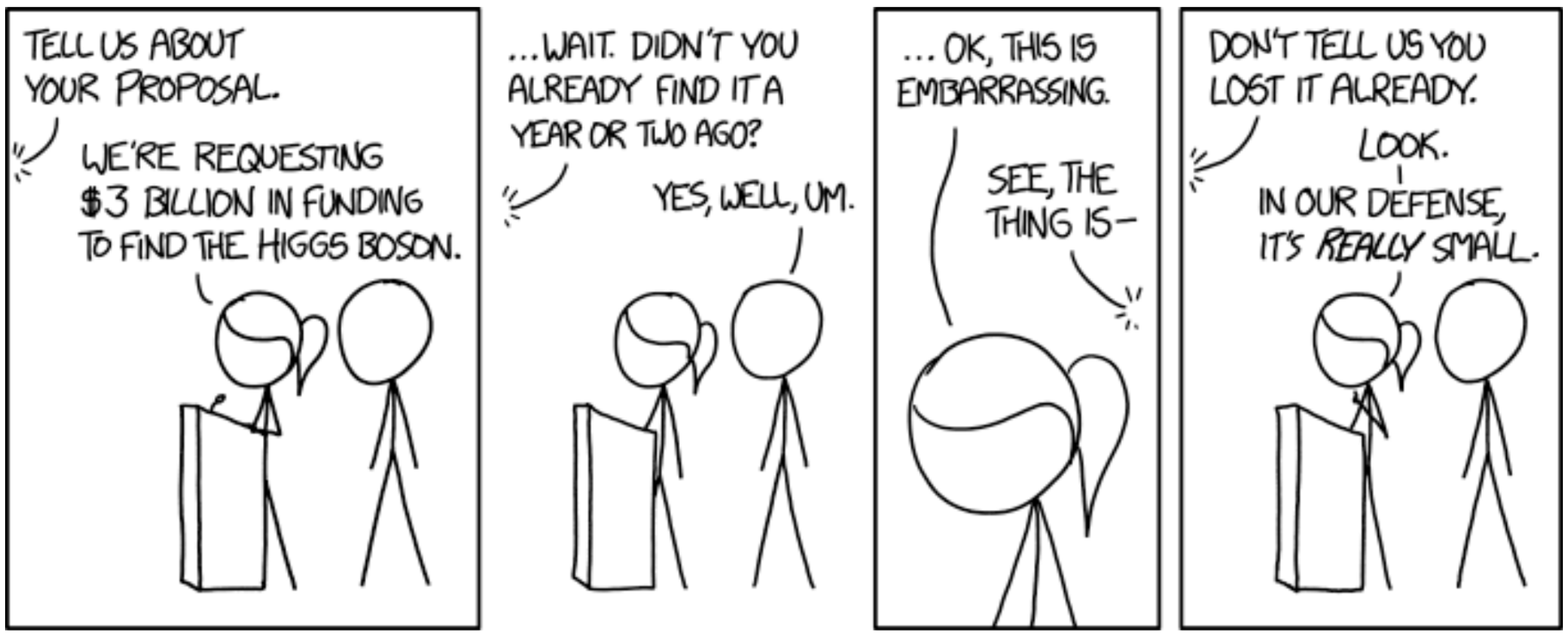
- Any measurement should be reported up to the point of zero SM expectation, with an overflow bin thereafter. Moreover, limits should be given in the overflow bin.
  (If any events are seen in the region with no SM expectation, it is useful to report their characteristics)

Talk by Tilman Plehn at 2nd FXS meeting
https://indico.cern.ch/event/460180/contribution/2/attachments/1195503/1737125/cern_nov.pdf

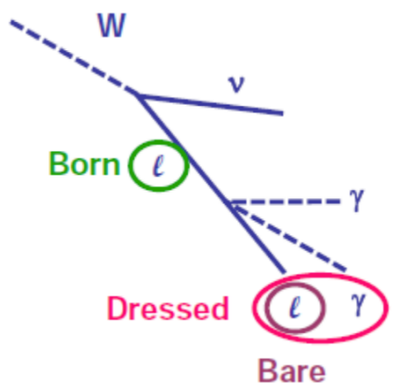
(Some of the) Discussion Topics

EXPERIMENTAL ASPECTS:

- definition of the **fiducial-level objects** and **fiducial phase space**
- treatment of the **model (in)dependance**
- **unfolding** strategies
- **presentation of the results**, and how to provide information to theorists



Fiducial definitions and objects



Fiducial-level objects (leptons, photons, jets):

- e.g. should **leptons be dressed** or **born-level**
- **include an isolation** requirement
- Jet definitions, **exclude neutrinos** from jet & iso. definition

} provisionally agreed

Fiducial phase-space:

- **different kinematical cuts** in ATLAS/CMS (maximises detector potential)
- Need to be careful with **out-of-fiducial** signal contributions

} provisionally agreed

Definition of the signal:

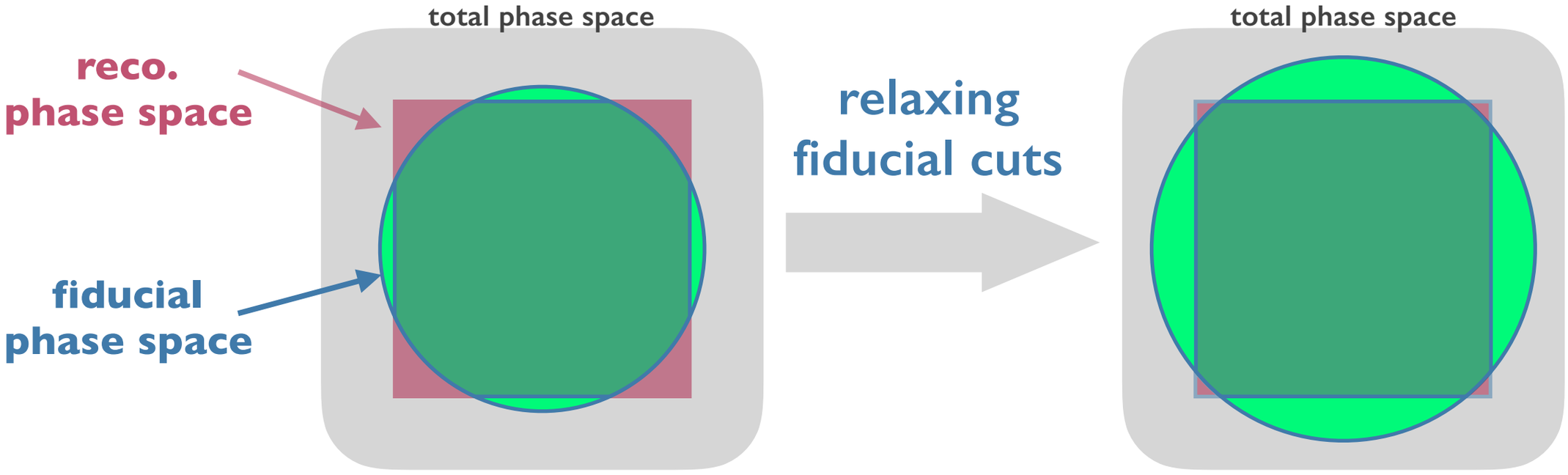
- **Resonant signal** (e.g. interested in σ x BR)
- **Irreducible processes**? e.g. pp→(H→)2l2ν, pp→(H→)4l
  - if subtracted - provide information on the MC estimate used

} provisionally agreed

On the fiducial phase space…

FOR DISCUSSION:

- **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
- Can we benefit from e.g. **relaxing the requirements** on those observables? We would like to have an input from theory colleagues.



fiducial & reconstructed

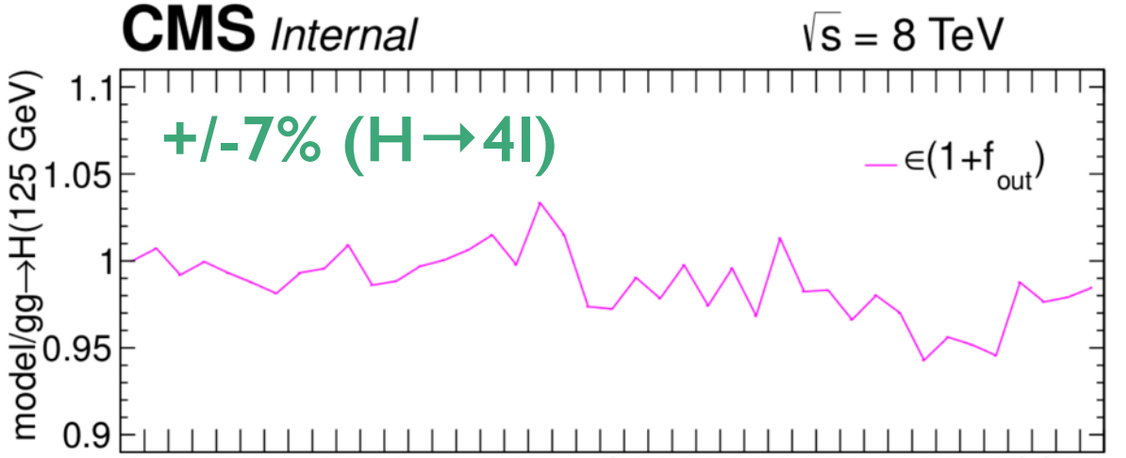
fiducial & non-reconstructed

non-fiducial & reconstructed

Model dependance

Aspects discussed:

- How to asses remaining model dependance?
- Preferred set of alternative signal models?
  - consider existing experimental constraints?
  - use the observed differential distributions?



Range of available alternative H models

Model dependance treatment:

- Build response matrix and repeat the unfolding procedure once per model
- Consider reweighing truth distributions to shapes observed in data
- **SM studies**: consider variations of SM production modes within **experimental constraints**
- **BSM studies**: consider **predefined set of exotic models** (expect input from WG3)
- Report the systematic effect for SM (and/or more BSM choices)

} provisionally agreed

Hypothesis on m(H)

Aspects discussed:

- Hot to treat the m(H) in the experimental measurement?
- What m(H) value to use for the theory predictions?
- What do we do if the knowledge of the Higgs mass evolves over time?

Hypothesis on m(H):

- **Use best-fit value measured by experiment(s) for the comparisons with theoretical estimates**
- **In the measurement procedure:**

  Option 1: treat m(H) as a free parameter and fit for it

  Option 2: Fix m(H) to best-fit value by experiment(s)

} provisionally agreed

Updating the Mass in measurements:

- **Provide the impact of ±Δm(H) on they yield**
- **This would allow to easily update new / existing measurements.**

} provisionally agreed

Unfolding techniques

Approaches to unfolding:

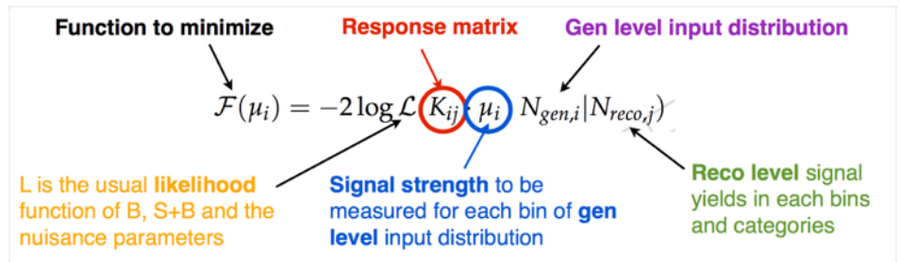
- Several approaches are being considered
- Important to consider/study the effects of regularization
- Perform signal extraction and detector response matrix inversion in two steps (SVD, Bayes, etc.)
- Perform **bin-by-bin correction factors** and **add systematics** to cover for possible biases
- Fold detector response matrix in likelihood and **perform fit and unfolding simultaneously**

} still to be discussed

bin-by-bin

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

folding fit



folding by matrix inversion

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

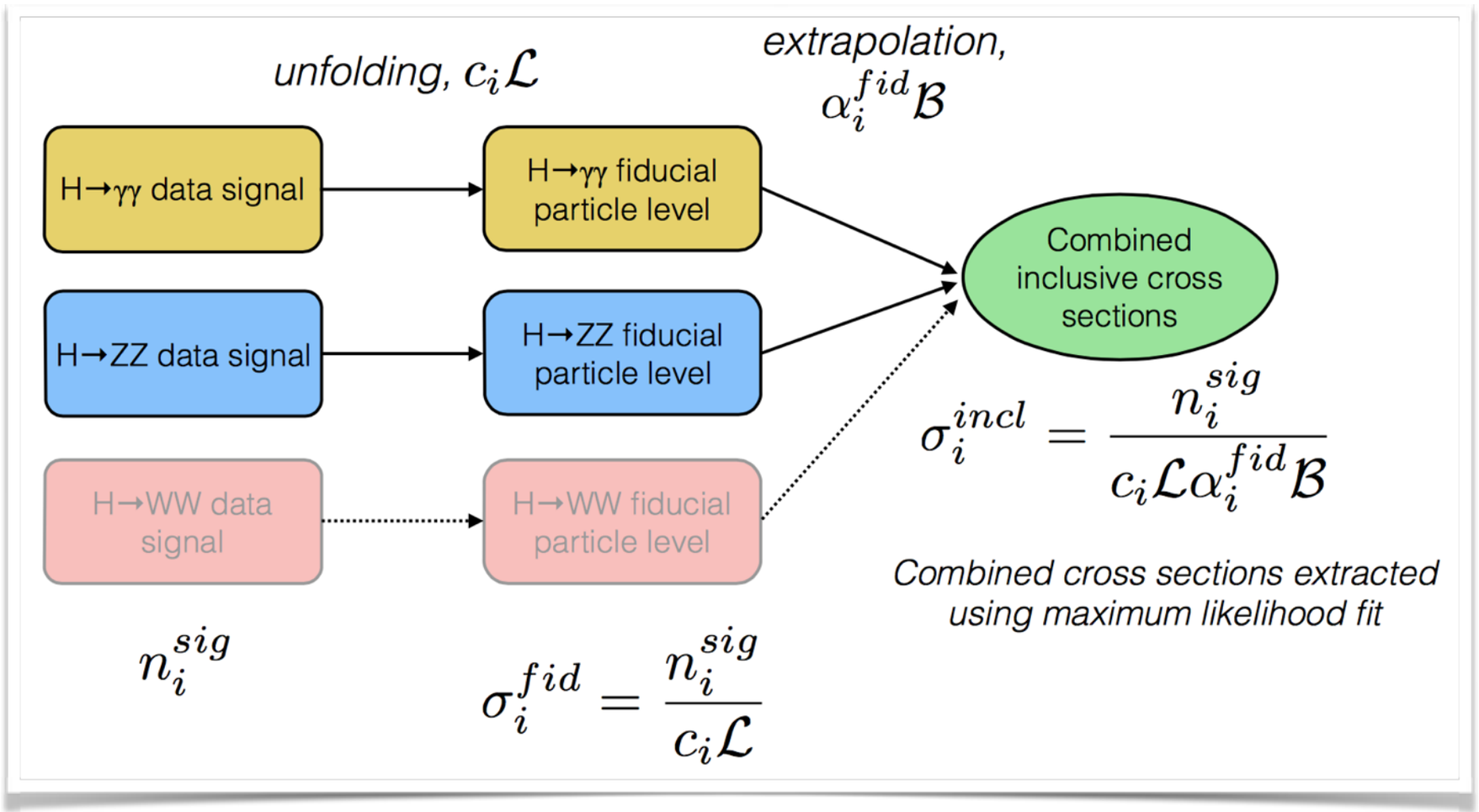
YR4 will not attempt to recommend unfolding procedures
(Rather just list important aspects to take care of)

Combination of results (I)

Combination between the decay channels:

- **Statistical precision** at the expense of model dependance (inherent assumption of the same source of decays)
- Choose **common fiducial** or **inclusive phase space**? (should be agnostic to Higgs decay products)
- Some parallels with the template cross sections

} still to be discussed



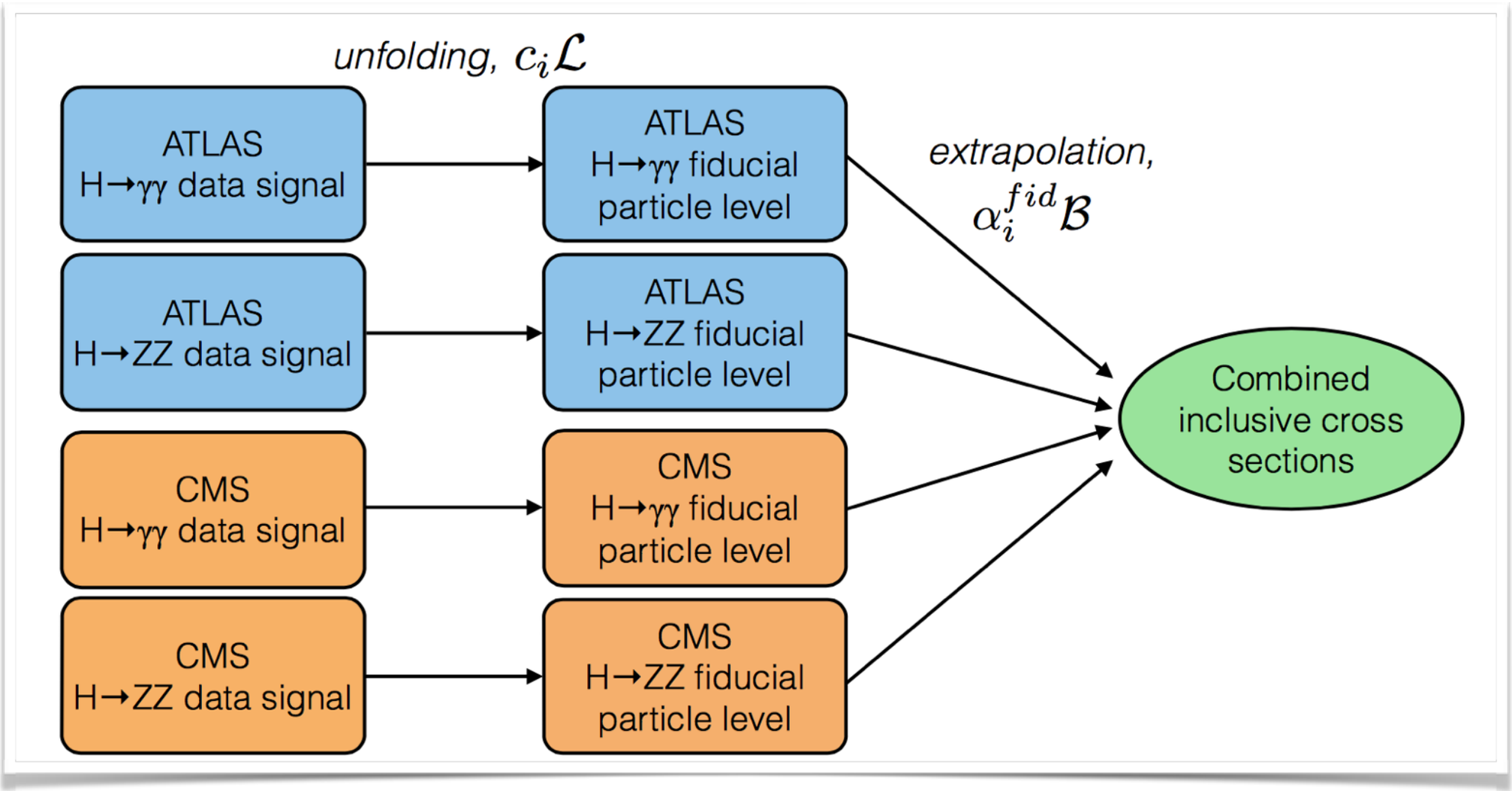
- Details (M. Q. Maitland): https://indico.cern.ch/event/399923/session/4/contribution/11/attachments/800898/1097608/FidXSecComb_LHCHXS_24thJun15.pdf

Combination of results (2)

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?**
- Benefit form the HCG experience, start harmonization in time

} still to be discussed



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Next steps

- Coordination of activities with **WG1 / WG2 / WG3** groups, and Les Houches activities
- Finalise the **list of contributions and studies** for YR4
  - List of co-authors/contributors is established
- Converging on the **write-up for YR4** with goal to have a first (non-complete) draft by the end of the year

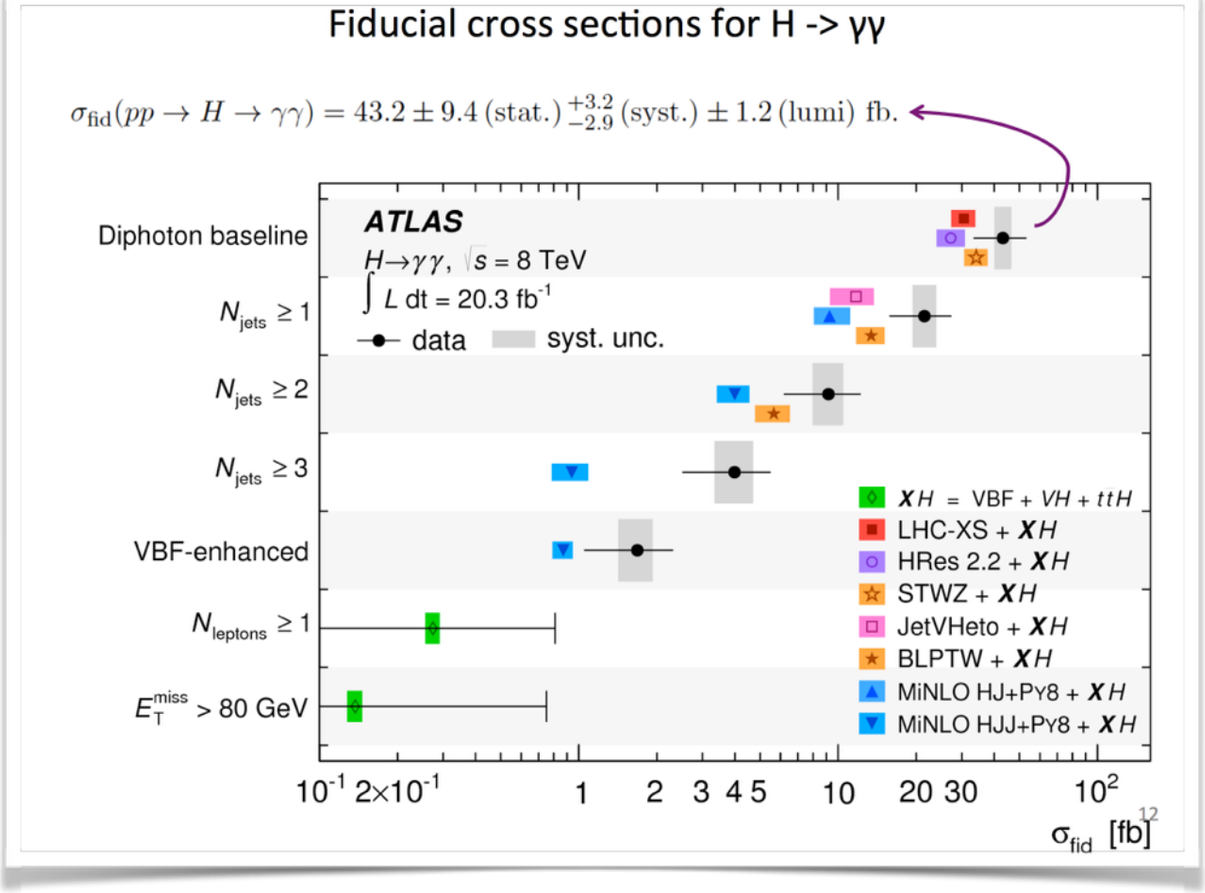
BACKUP SLIDES

Run I measurements

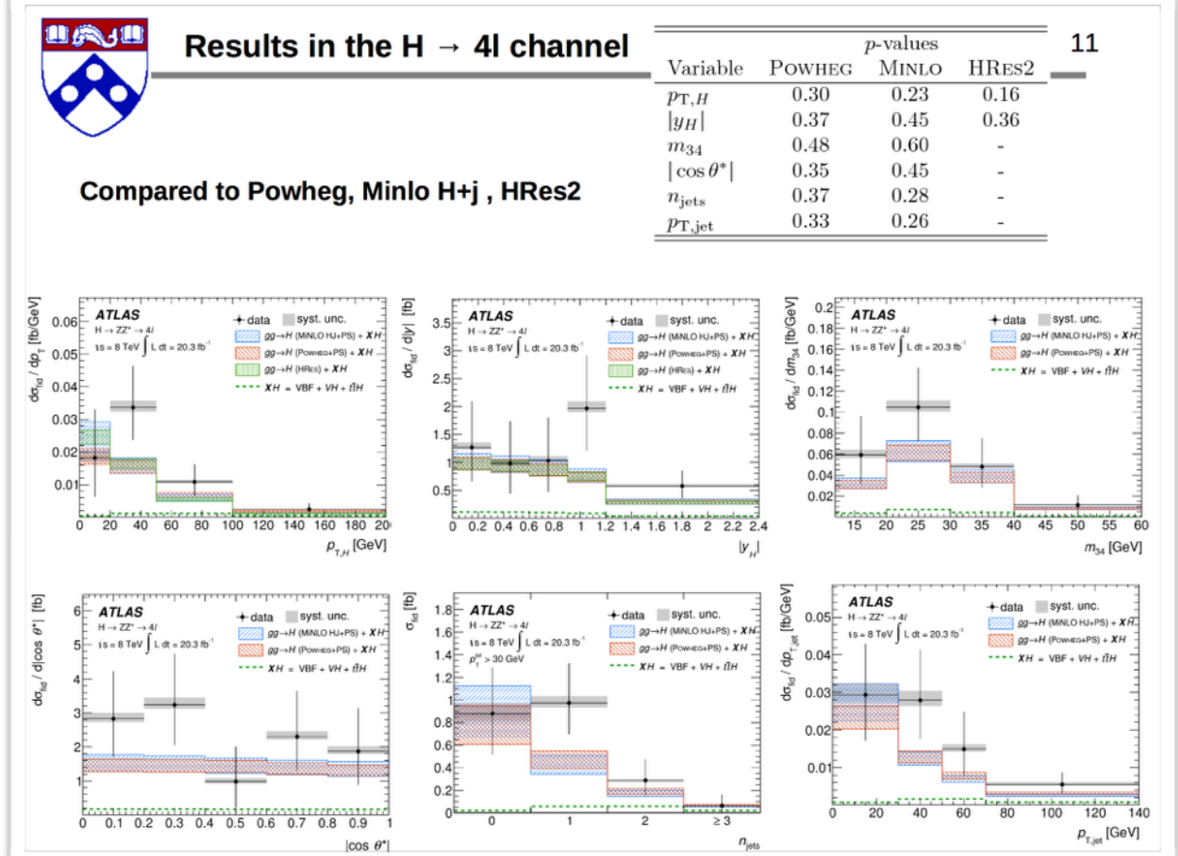
- Experiments presented approaches for Run I measurements
  - **ATLAS**: public results **H→2γ, H→4l, combination**
  - **CMS**: approaches to **H→2γ, H→4l**

(indico: https://indico.cern.ch/event/399923/?filterActive=0&showDate=all&showSession=all**)**

ATLAS H→2γ (A. Pilkington)



ATLAS H→4l (S. Heim)



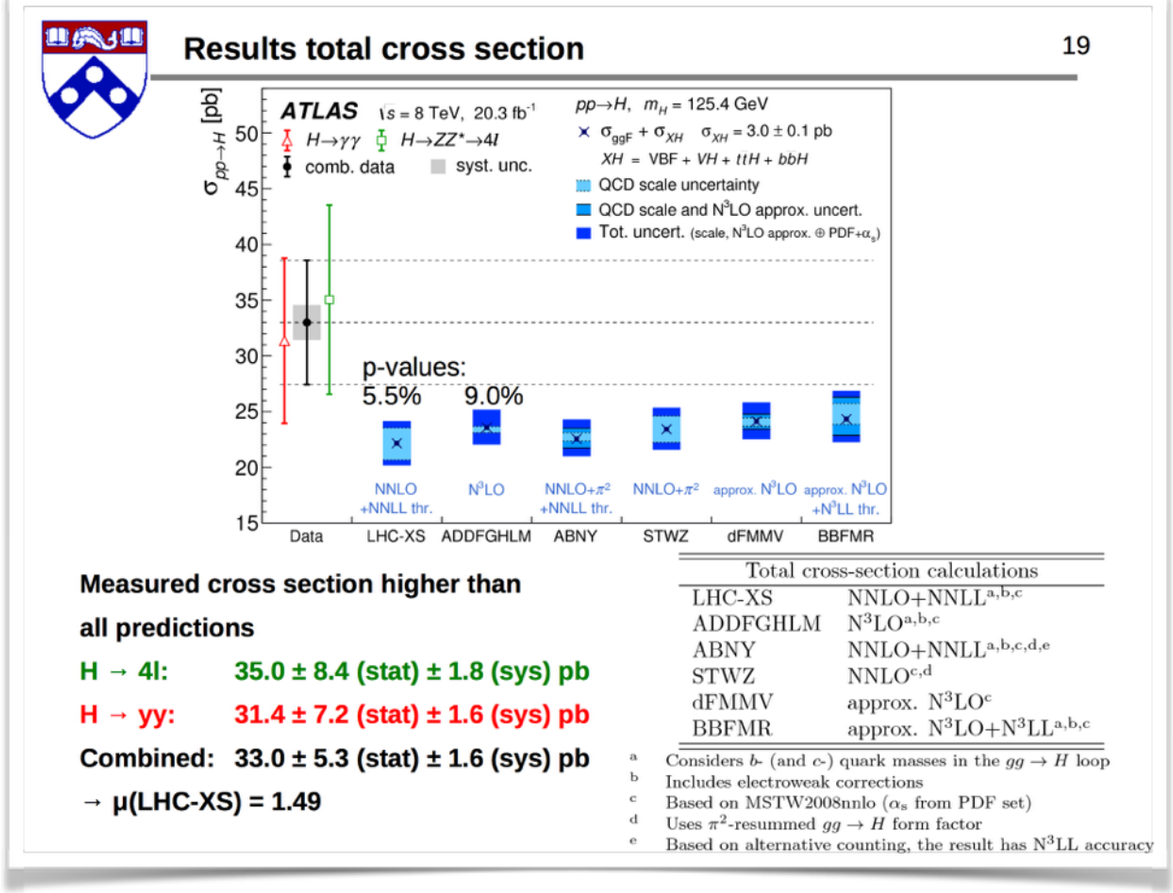
- Discussion on several experimental aspects and different approaches

Run I measurements

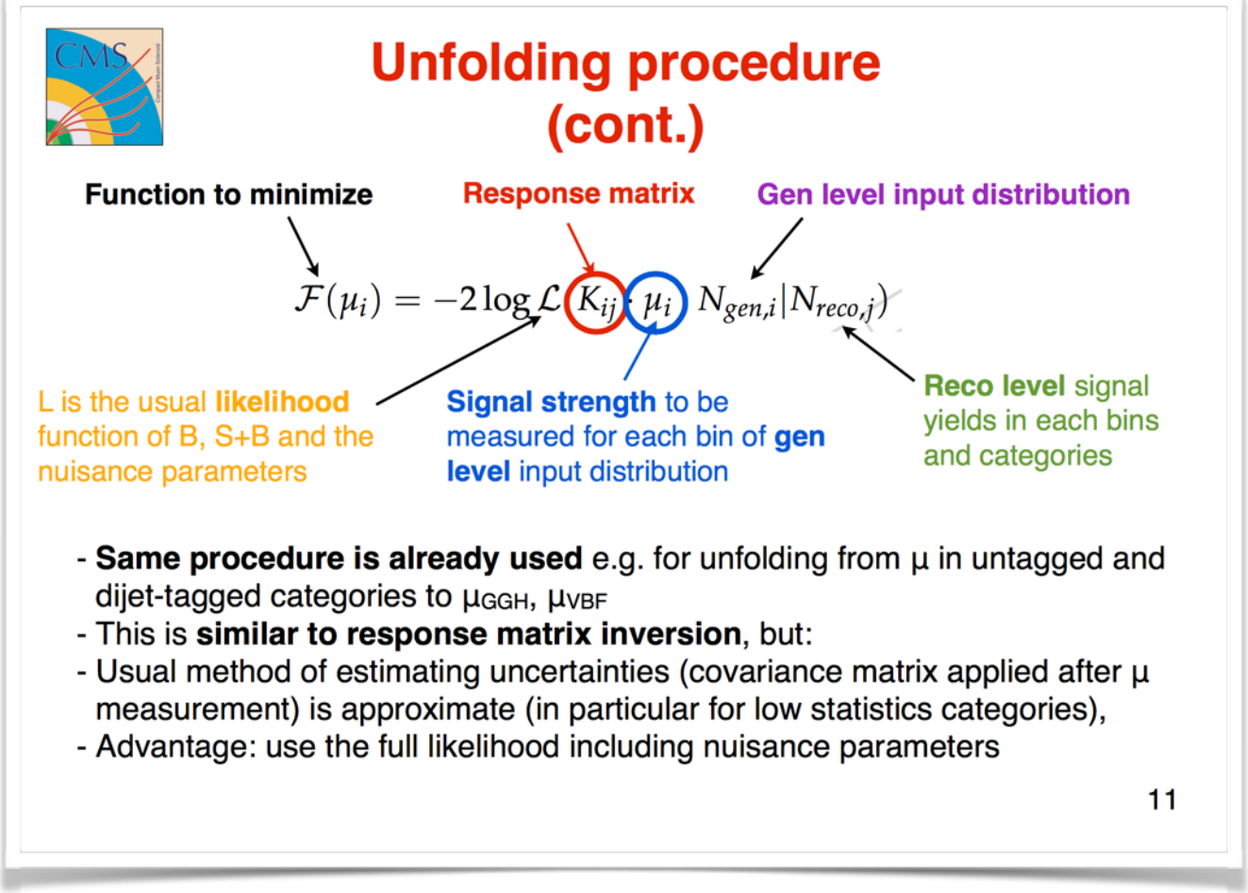
- Experiments presented approaches for Run I measurements
  - **ATLAS**: public results **H→2γ, H→4l, combination**
  - **CMS**: approaches to **H→2γ, H→4l**

(indico: https://indico.cern.ch/event/399923/?filterActive=0&showDate=all&showSession=all**)**

ATLAS combination (M. Q. Maitland)



CMS on H→2γ, H→4l (N.Chanon)



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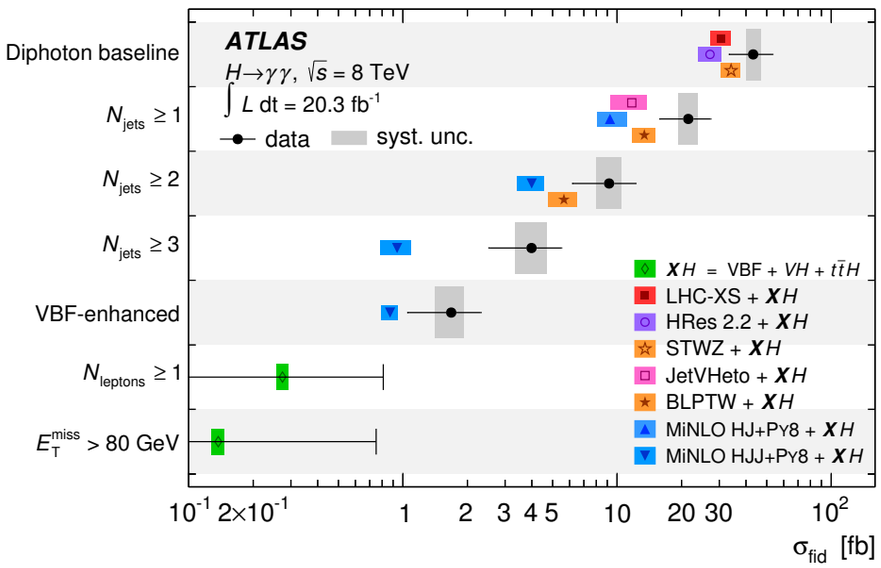
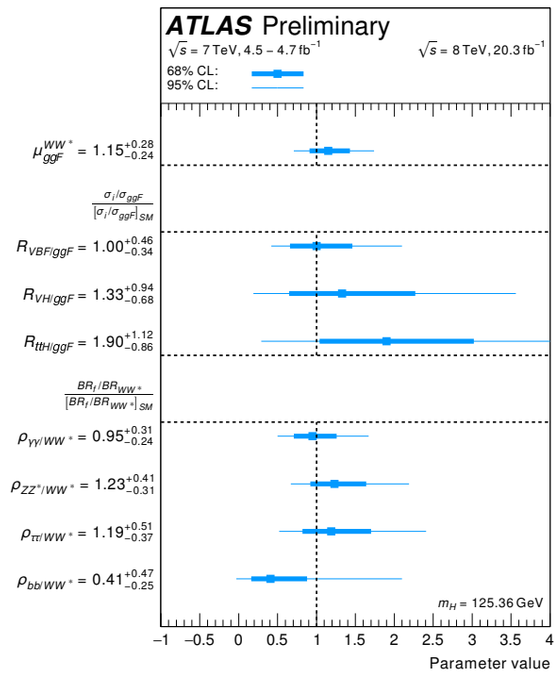
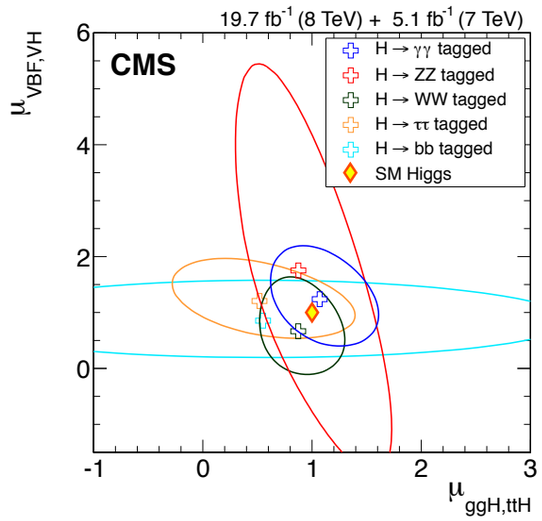
Simplified cross sections







Measurement

Interpretation

theory-independent

theory-dependent

Fiducial Cross sections

Coupling Fits

- Not everybody can measure fiducial cross sections; global analysis desirable.
- Idea: Place yourself somewhere in the middle of this picture.

e.g. $\mu_{gg\to H}$ ***old*** → $\mu_{gg\to H}^{0-jet}$ $\mu_{gg\to H}^{\geq 1-jet}$ $\mu_{gg\to H}^{\geq 2-jet+\mathrm{VBF}}$ ***new***

- Fiducial cross sections are defined for specific Higgs decay modes, whereas simplified cross sections focus on production modes; Fiducial cross sections can in principle also be used to derive simplified cross sections.
- For full story see Frank Tackmann (https://indico.cern.ch/event/350628/session/0/contribution/10/attachments/1126166/1607853/simplifiedXS_FT.pdf)