FIDUCIAL CROSS SECTIONS TASK FORCE

ACTIVITIES AND YR4 PLANS

Conveners:

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CERN, January 14th, 2015

Fiducial cross sections

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

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

$$\sigma^{\text{fid}} = \epsilon\,\mathcal{A}^{\text{fid}} \times \sigma^{\text{tot}}$$

↑
fiducial volume acceptance
(fraction of signal events in the fiducial phase space)

- The big 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.

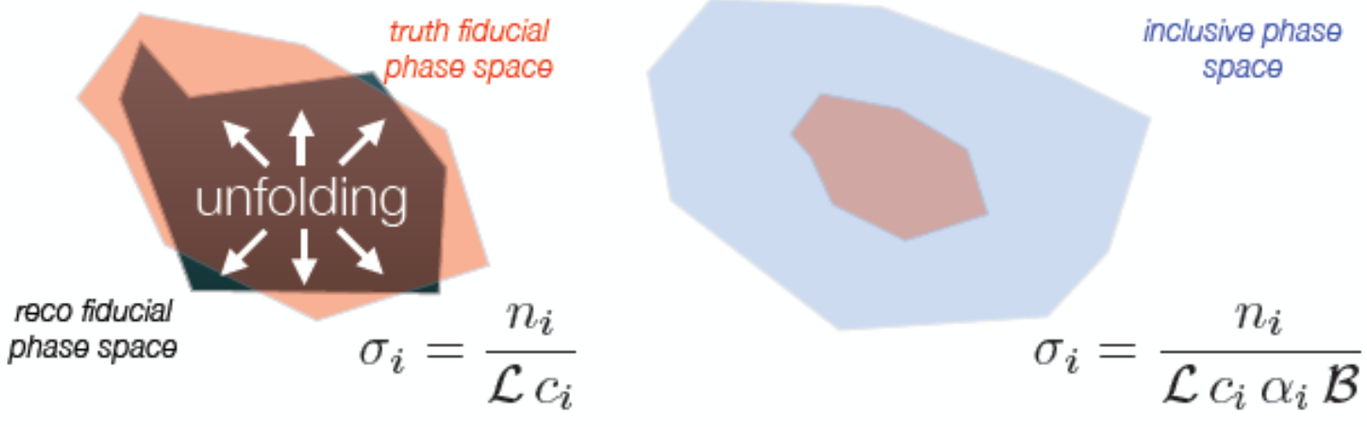
Fiducial cross sections

In Higgs physics, fiducial XS measurements may be categorized by targeting

- decay mode: H→γγ, H→ZZ→4leptons, H→WW→lνlν, ...
- production mechanism: (VBF-like jj)+H, (V-like jj)+H, (ll)+H, (l+MET)+H, ...
- signal 'purity': e.g. 0-jet, 1-jet, VBF-like jj, etc.

see also arxiv.:1307.5865

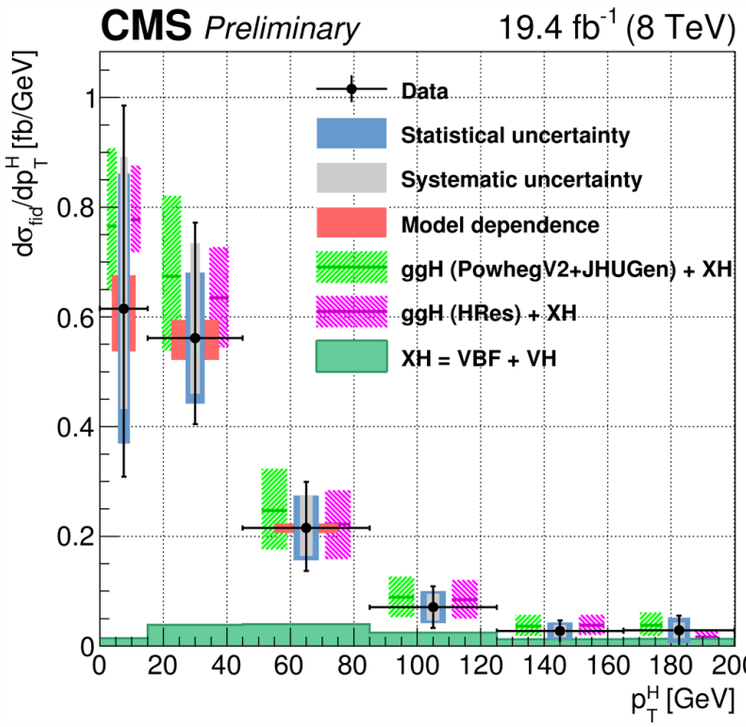
Maximize applicability and long-term use of LHC data to constrain the Higgs sector and BSM models by factorizing theory uncertainties from experimental ones (fiducial volumes need to be defined carefully to be 'model independent')

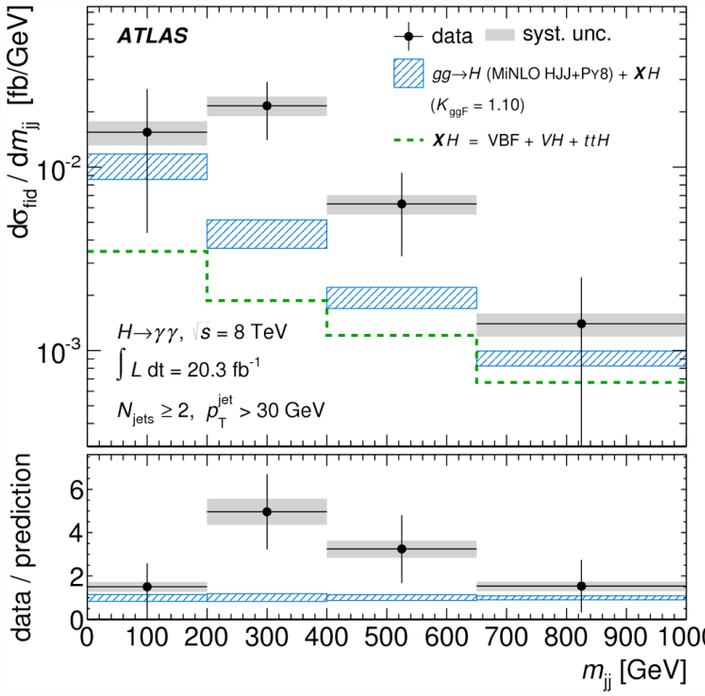


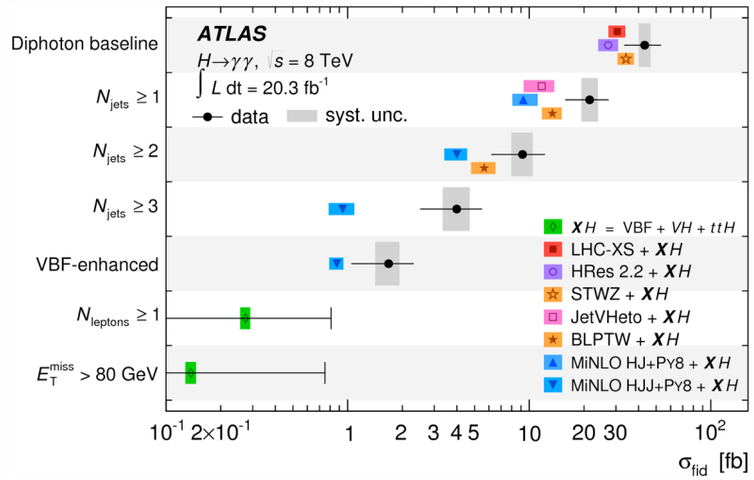
Run-1 results

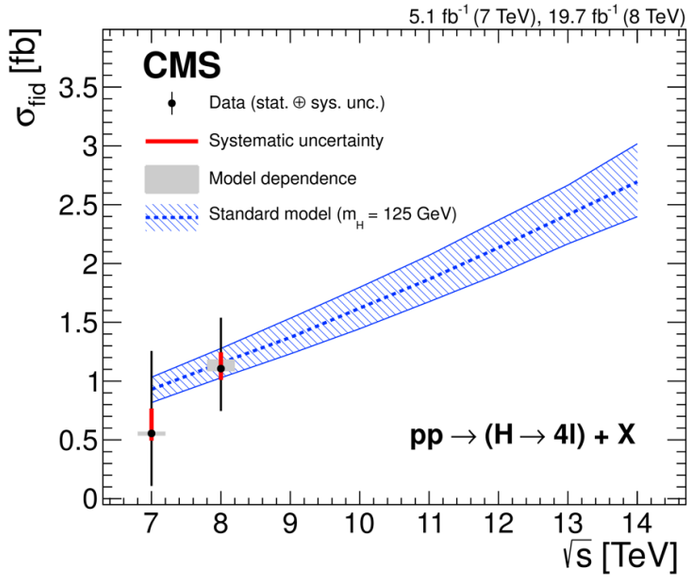
Both ATLAS and CMS have already published fiducial cross sections and distributions for H→γγ and H→ZZ*→4l, and CMS also for H→WW*→lνlν

ATLAS: 1407.4222 (γγ), 1408.3226, (4lep), 1504.05833 (γγ+4lep)
CMS: 1508.07819 (γγ), 1512.08377 (4lep), HIG-15-019 (2l2ν)









Considered a variety kinematic distributions that are sensitive to the Higgs production mode: p_T and η, N_{jets}, p_T(jet), Δηjj, ΔΦ, mjj, ... and compared them to SM predictions

RIVET routines for comparison (already available from ATLAS, in prep. by CMS)

Aspects discussed/addressed within HXSWG

THEORETICAL ASPECTS:

- Improvements in the **theoretical modelling** of the Higgs production (WG1) and **important remaining uncertainties**
- Interconnection with **POs / template XS** (WG2)
- **BSM effects:** EFT and full models (WG2/3)

This is why experimental scientists hate theoretical scientists.

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

Modelling of processes @ higher orders

Major improvements in the theoretical Higgs modelling in 2015:
N^{3}LO, NNLO H+J, NNLO VBF+VH, ... total and diff. XS reported in WG1

Aim of the fiducial XS group:

- Detailed benchmarking of the state-of-the-art predictions for the signal and (whenever necessary) irreducible backgrounds (notably WW*, ZZ*) for fiducial cross sections and relevant differential distributions
  fiducial volumes agreed upon with experimental collaborations
- Validation of MC tools (NLO/NNLO+PS) in fiducial volumes (radiation modelling, non-perturbative effects) - modelling of fiducial acceptances used in extrapolation to the inclusive phase space

So far only part of this work has been achieved given the lack of time since 13 TeV fiducial volumes have been defined (computations CPU intensive).

Modelling of processes @ higher orders

Content of the YR4 section:

- NNLO predictions for fiducial cross sections and kinematic distributions for $H\to\gamma\gamma$, $H\to ZZ^*\to 4$leptons, $H\to WW^*\to l\nu l\nu$ in association with ≥ 0 and ≥ 1 jets in gluon fusion (VBF+VH discussed by Luca Perrozzi this morning, WG1)

- NNLO predictions for the irreducible background $qq\to ZZ^*$ (WW^* not yet publicly available). Sizeable higher-order corrections also expected in $gg\to ZZ^*$ and $gg\to WW^*$; will be considered in future studies.

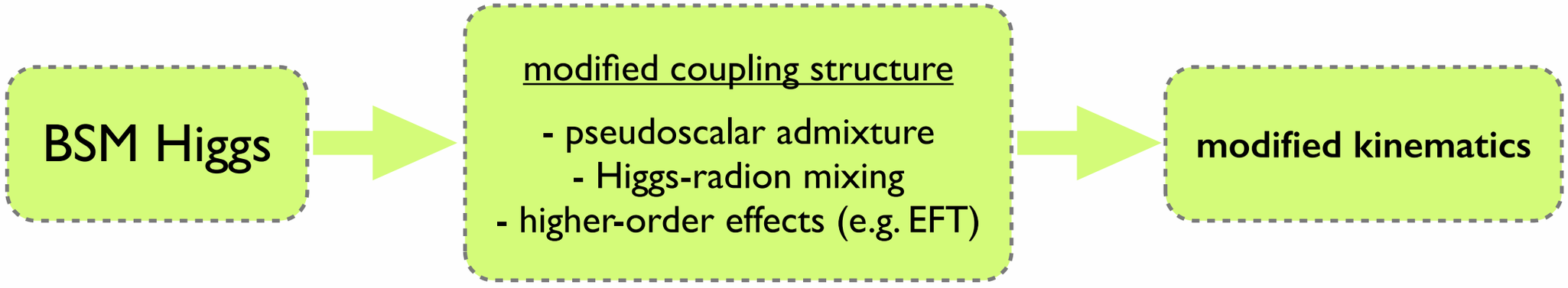
- Currently awaiting results. Final draft expected by the end of January.

Future activity (beyond YR4):

- More comparison & validation of MC tools (NLO/NNLO+PS) used in experimental analyses; coordination of activities with WG1

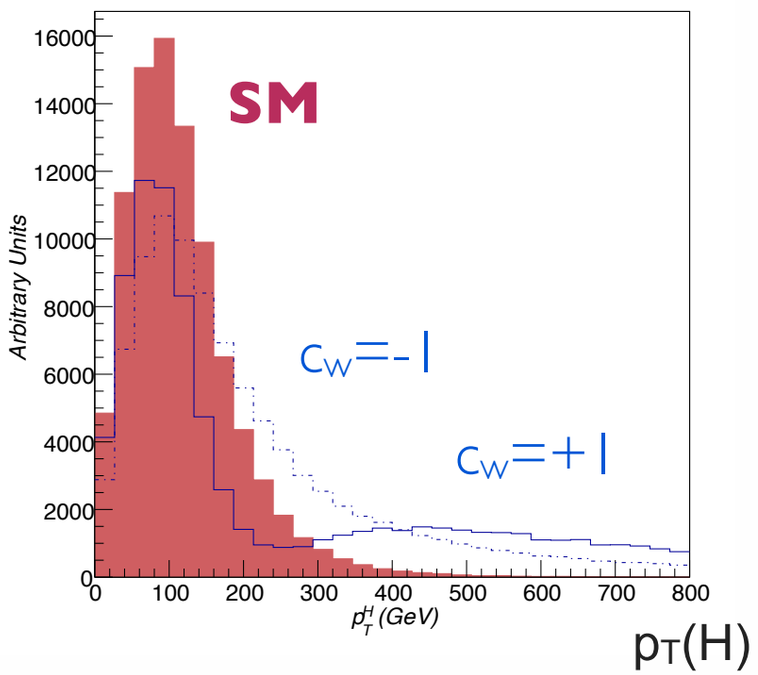
Sensitivity to BSM (I)

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.



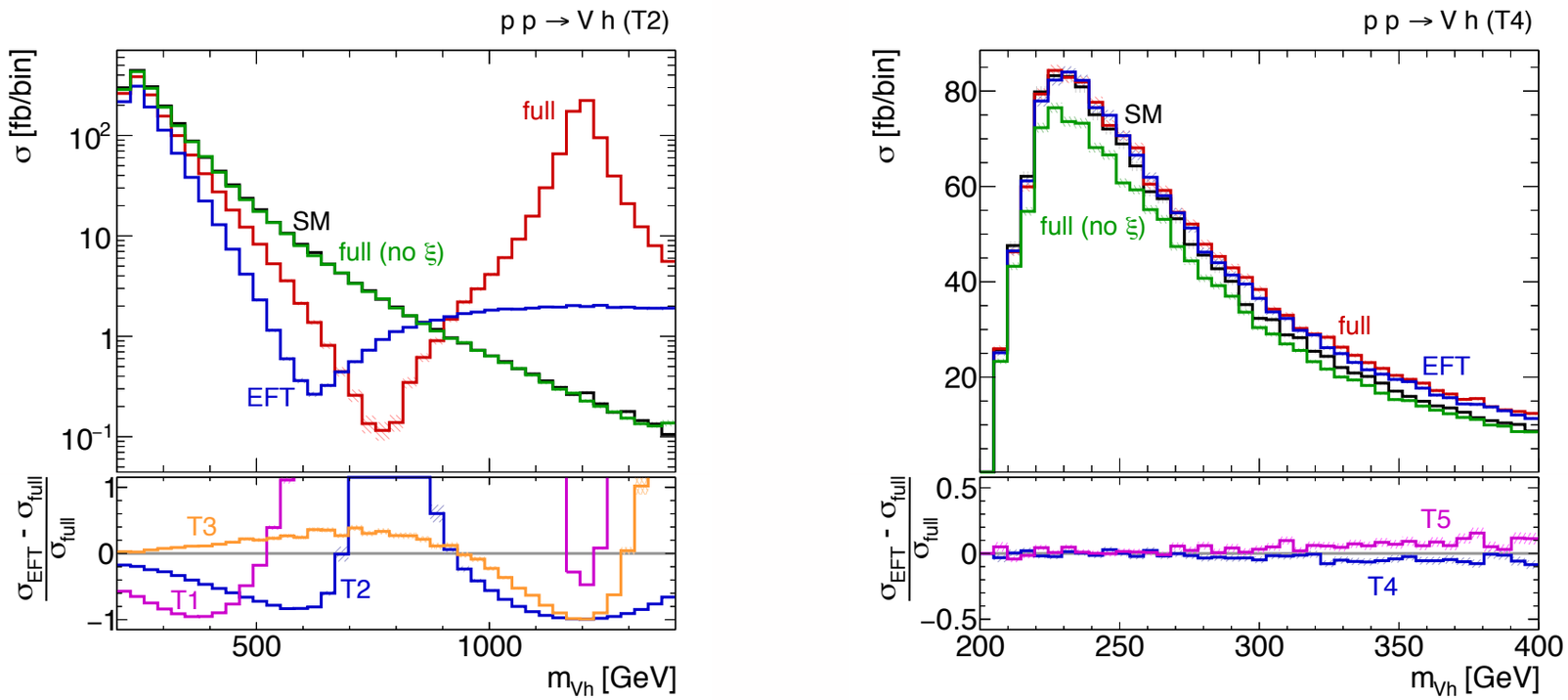
- Consider p_T, m_{jj}, η_{jj} , $\Delta\Phi$, inv. mass, etc. distributions
- Large effects may occur in extreme kinematic regions, where little or no SM signal is expected
- BSM typically affects production and decay processes
- The same BSM may also affect the backgrounds

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



Sensitivity to BSM (2)

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



J. Brehmer
A. Freitas
D. Lopez-Val
T. Plehn
1510.03443

Higgs-strahlung distibutions in vector triplet models

- Discussion what to do in region with no SM expectation → overflow bins, set limits
  (If any events are seen in the region with no SM expectation, it is of course useful to report their characteristics)

will be summarized in YR4; unfortunately no results so far with fiducial cuts

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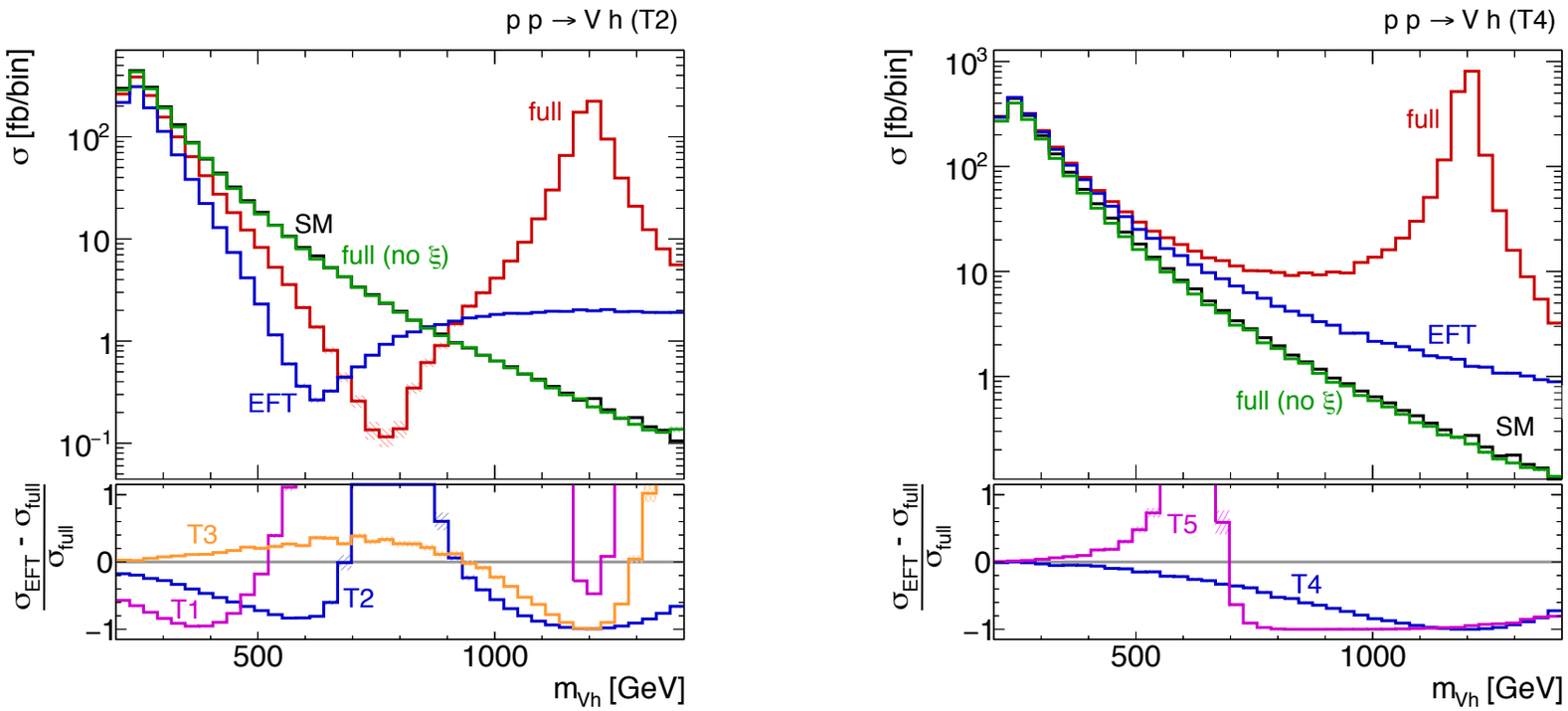

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- treatment of the **model (in)dependance**
- **unfolding** strategies
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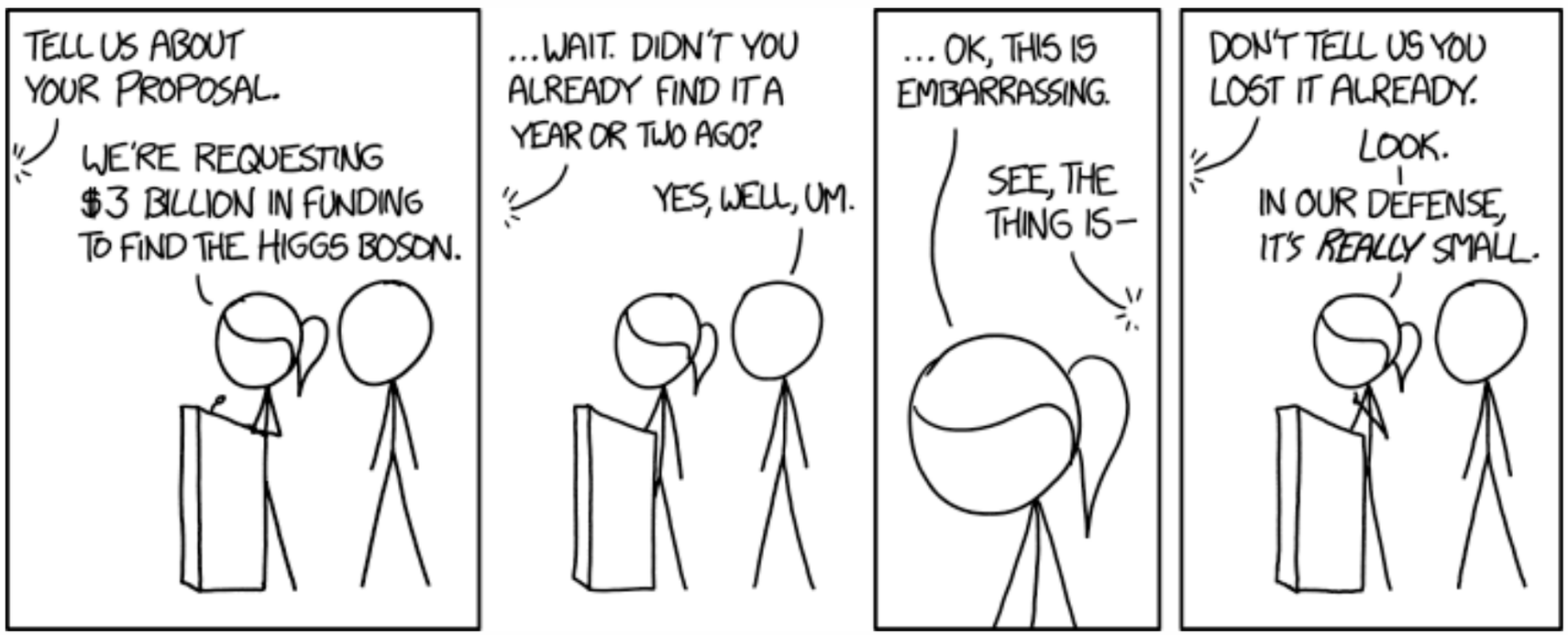
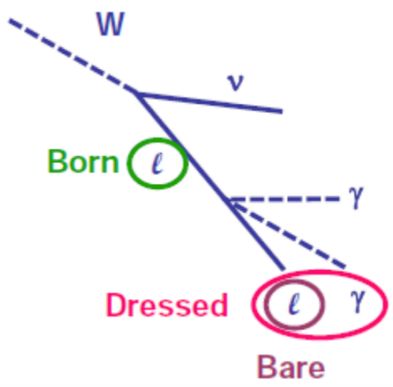


Fiducial definitions and objects



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

- use **dressed leptons** (**born-level is also ok for low stat.)**
- **include an isolation** requirement (**exclude neutrinos**)
- Jet definitions, **exclude neutrinos** from jets

} agreed

Fiducial phase-space:

- Keep the **different kinematical cuts** in ATLAS/CMS (maximises detector potential)
- Careful treatment for **out-of-fiducial** signal contributions
  - Special study how to define the fiducial phase space using observables with poor resolution (MET, jet p_T, ...)

} agreed

Definition of the signal:

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

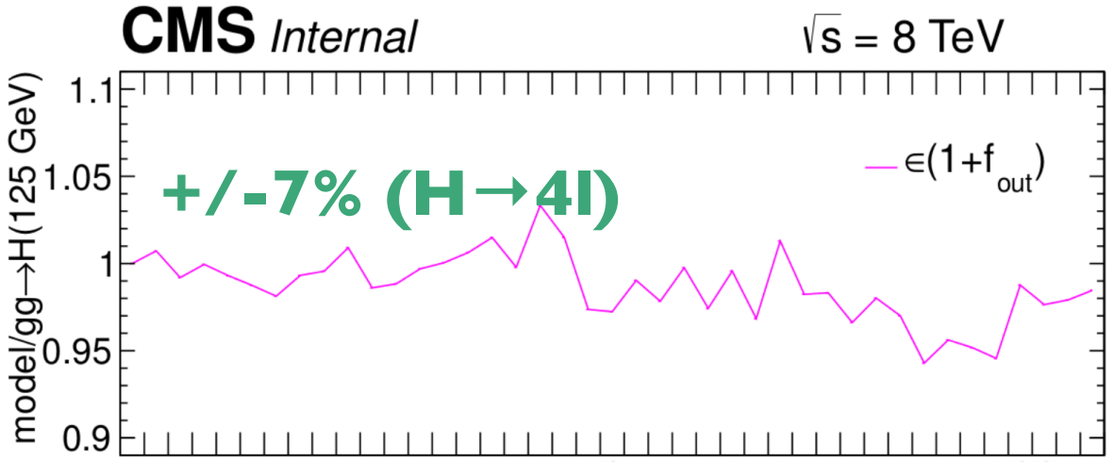
} agreed

YR4 will include these discussions/recommendations

Model dependance

Aspects discussed:

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



range of available alternative H models

Model dependance treatment:

- Build response matrix and repeat the complete unfolding procedure once per model
- Consider reweighing truth distributions to shapes observed in data
- **SM studies (recommended)**: allow variations of SM production modes within the **experimental constraints**
- **BSM studies (optional)**: consider also predefined set of exotic models (expect input from WG3)
- Report the systematic effect for SM and optionally for BSM choices also as a separate uncertainty

} agreed

YR4 will include these discussions/recommendations

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)** to compute XS 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 the **best-fit value by experiment(s)**

} agreed

Updating the m(H) in the measurements:

- Provide the **impact of ±Δm(H)** on the cross section
- This allows to easily update new / existing measurements.

} agreed

YR4 will include these discussions/recommendations

Unfolding techniques

Approaches to unfolding:

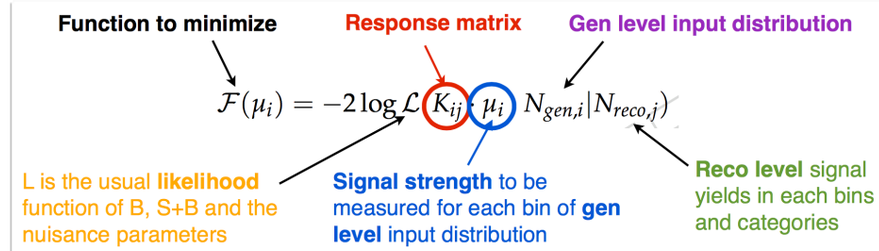
- Several approaches have been considered and discussed
  - Open to future discussions and studies from the experiments/analysts (still very active/hot field in the world of statistics)
- Important to carefully consider and study the effects of the regularization, bin-by-bin migrations, etc.

} very "live" discussion

bin-by-bin

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

folding fit



folding by matrix inversion

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

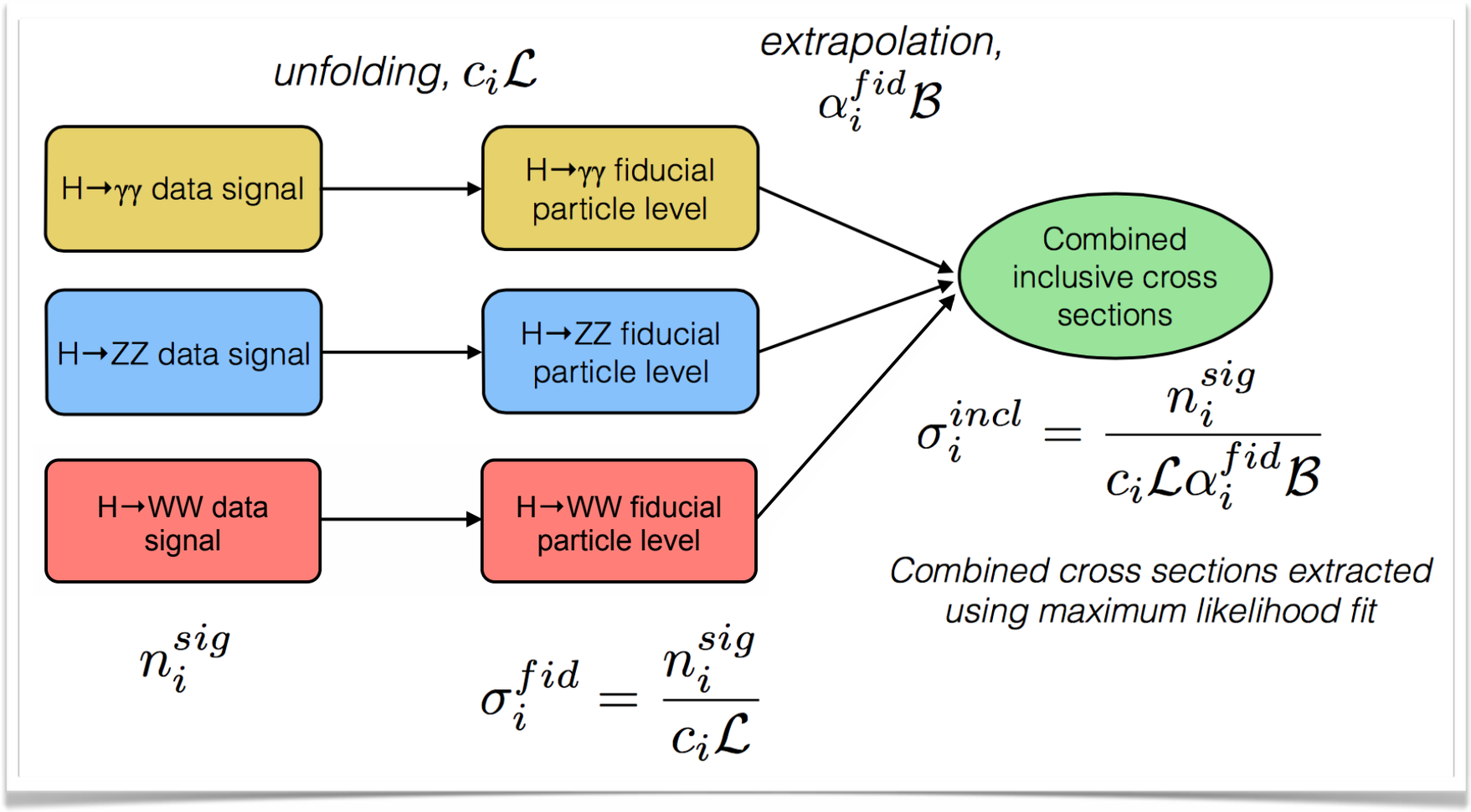
YR4 will not attempt to recommend the exact unfolding procedures
(Rather just list briefly the important aspects to take care of)

Combination of results (I)

Combination between the decay channels:

- Extrapolate to a the **inclusive phase space.**
- Statistical precision at the expense of the model dependance (inherent assumption of the same source of decays)
- Needs careful validation of MC tools and control of uncertainties

} agreed



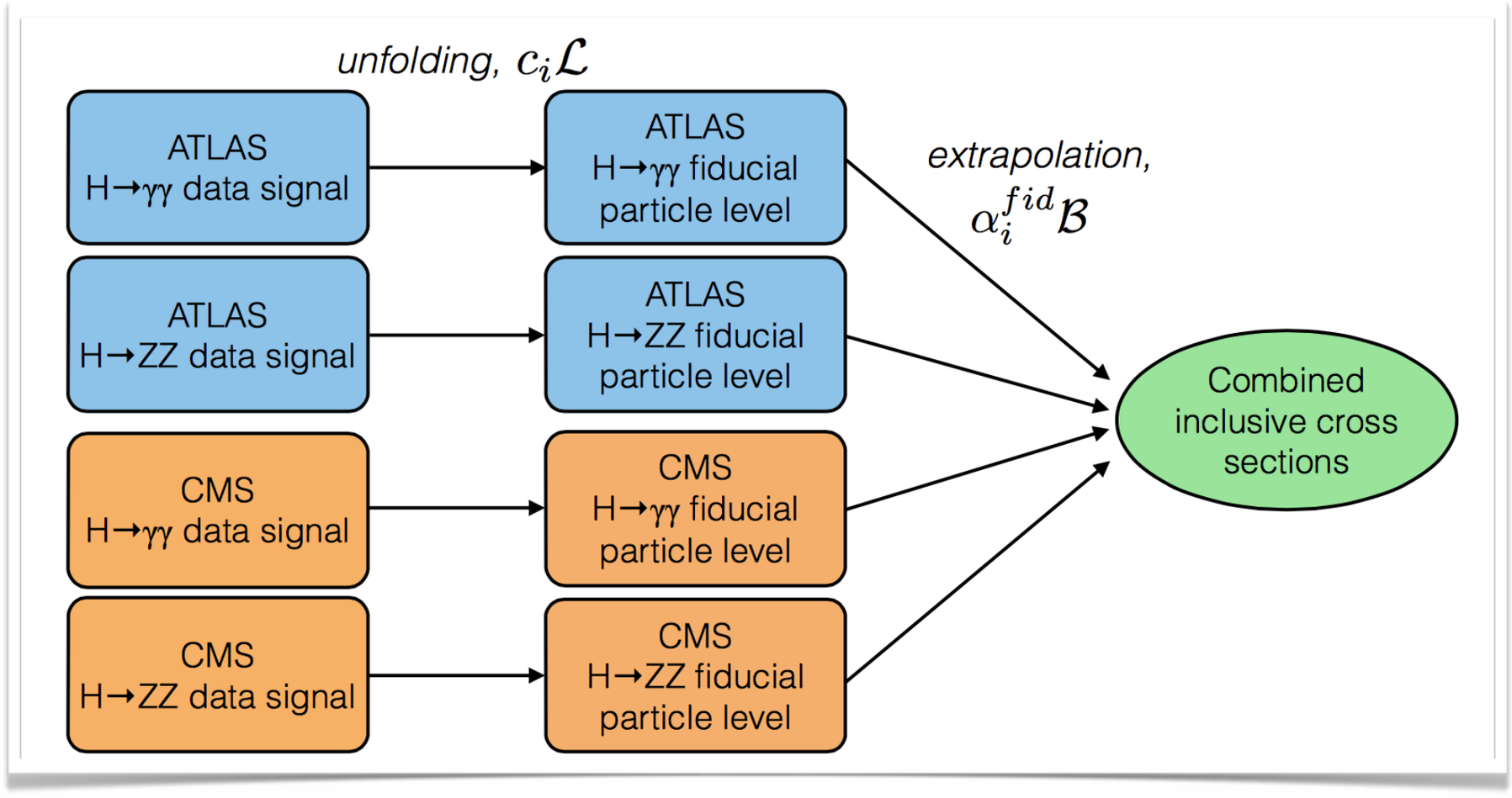
YR4 will include these discussions/recommendations

Combination of results (2)

Combination between experiments:

- Extrapolate to a the **inclusive phase space.**
- Need careful validation of MC tools and control of uncertainties
- Benefit form the HCG experience, start harmonization in time (need harmonization in fiducial objects, bin edges, unfolding)

} agreed



YR4 will include these discussions/recommendations

Towards YR4 and beyond...

GOAL

- Establish a **recommended sets of measurements** for short and medium term LHC running
- Explore effects of **higher-order corrections** in the SM, assess **BSM effects**
- Help provide **state-of-the-art tools** to the community

FOR YR4 (no draft yet)

- Discussion of experimental aspects made good progress and should be written up soon
- Benchmarking of the state-of-the-art SM predictions for fiducial XS in progress (target YR4)
- Study of BSM effects in progress (EFT and full models) but not sure to what extent we will have definite fiducial results for YR4

FUTURE

- So far only on-shell Higgs, no off-shell production
- So far considered $H\to\gamma\gamma$, $H\to ZZ^*\to 4l$, $H\to WW^*\to l\nu l\nu$, extend to fermionic modes $\tau\tau$, bb in the future (VBF+VH)
- Need more BSM studies, more coordination with other WGs

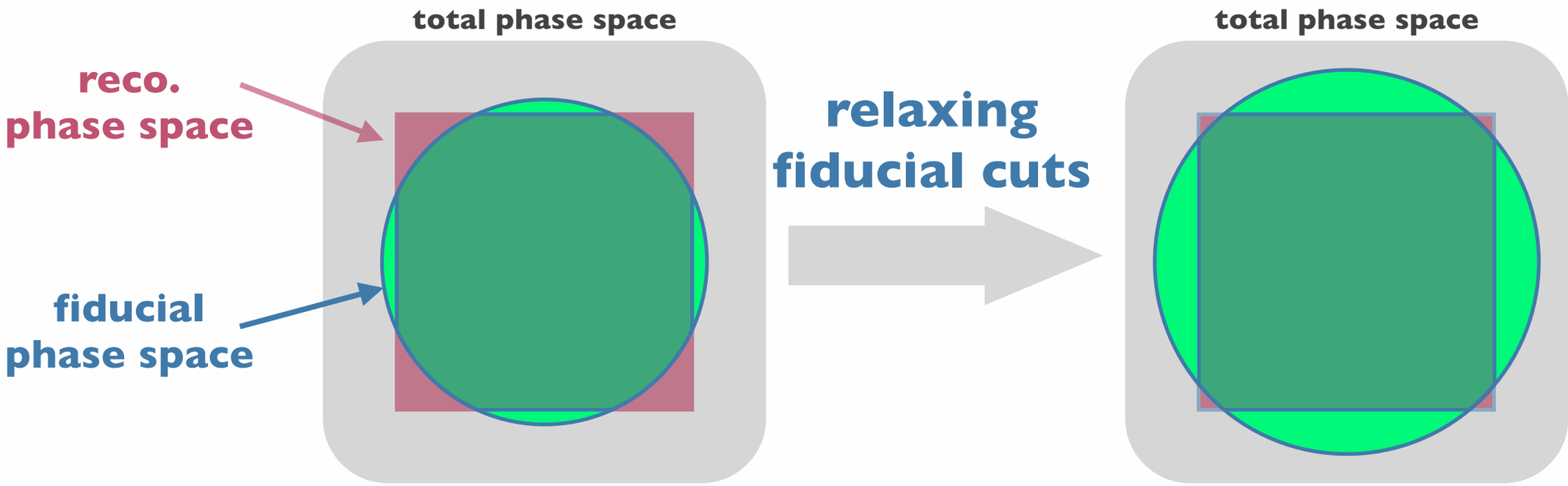
Our group started off in June 2015, it is just the beginning ...

BACKUP SLIDES

Fiducial requirements & observables with poor resolution

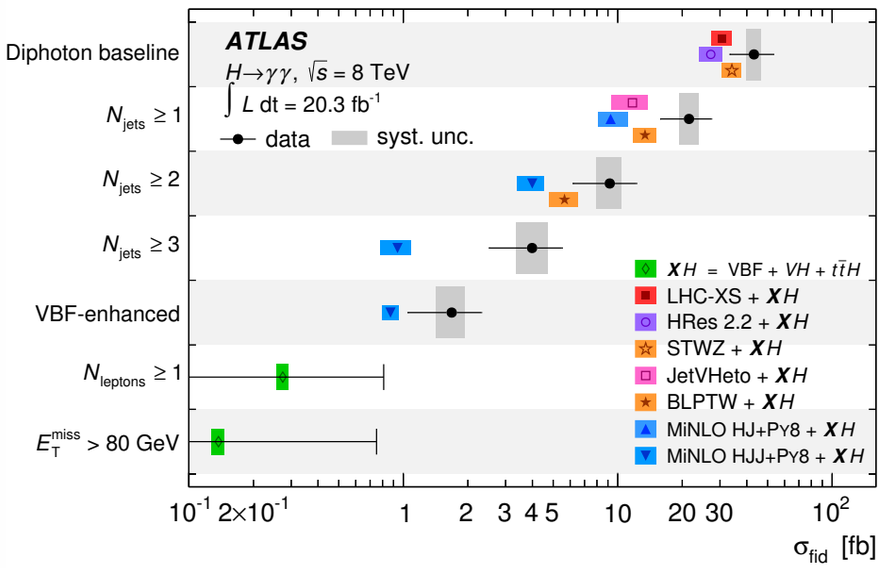
Aspects discussed:

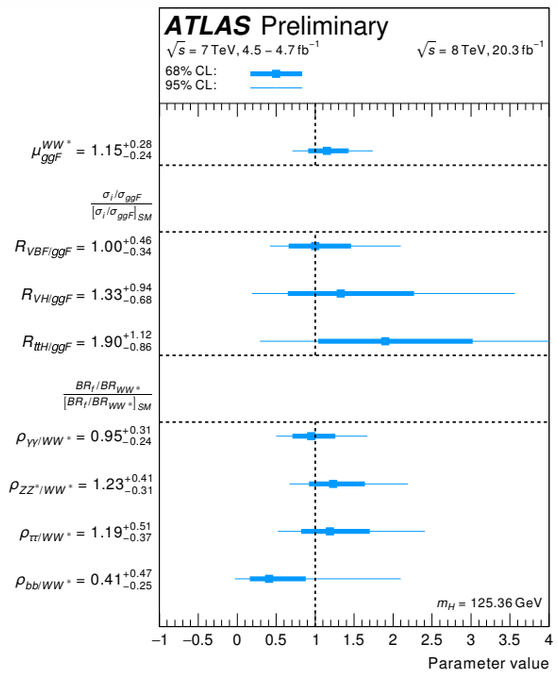
- How to define the fiducial phase space when observables used to define the signal region have **poor experimental resolution** (missing E_T, jet p_T, etc.)?
  - Effects of migration of signal events can be large
  - Subtraction of non-fiducial signal events is model dependent
- Recommendation: study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

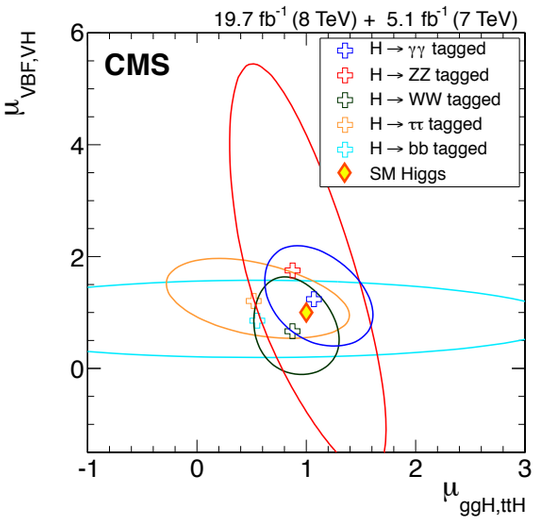


fiducial & reconstructed
fiducial & non-reconstructed
non-fiducial & reconstructed
non-fiducial & non-reconstructed

Simplified cross sections







Measurement — *theory-independent*

Interpretation — *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.
- See discussion later today