Les Houches 2015
Higgs Working Group Summary

Josh Bendavid
Massimiliano Grazzini, Kerstin Tackmann, Ciaran Williams

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Introduction: Main Topic Discussed

- Gluon Fusion Higgs Predictions and Uncertainties
  - Inclusive cross section
  - p_T Distribution
- What/How to Measure and Presentation of Results
  - Simplified Cross-Sections
  - Fiducial/Differential Cross Sections
- Off-Shell Higgs Production
  - Future measurements
  - Benchmark current calculations for high mass interference

Gluon Fusion Inclusive Cross Section

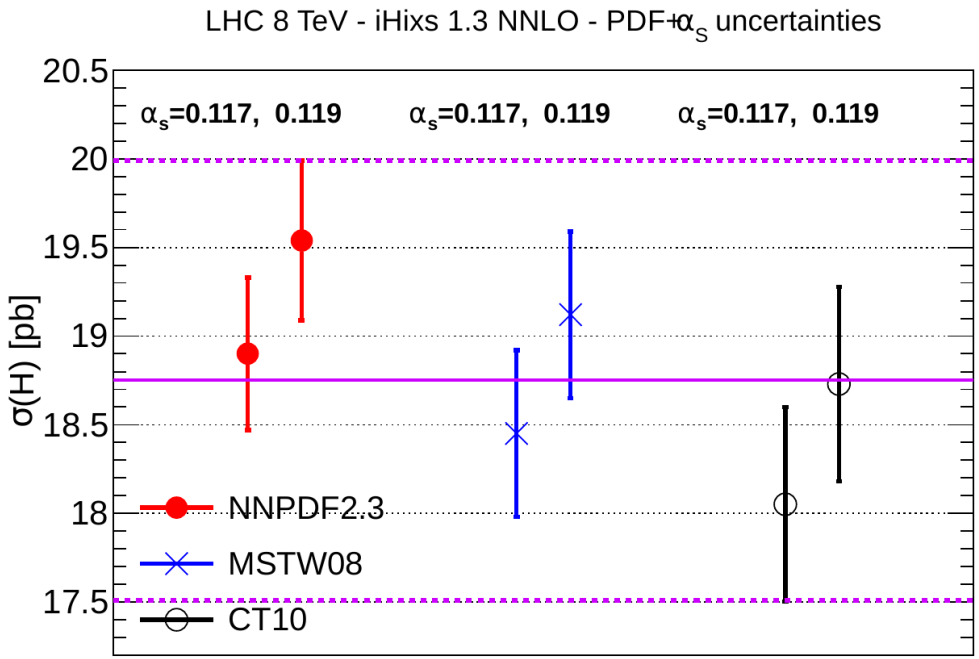
- Higgs XSWG meeting as part of Monday session:

  `https://indico.cern.ch/event/396887/`

- Inclusive cross section now know to N^3LO in infinite top mass limit $\rightarrow$ scale uncertainty reduced from 7-8% to 2-3%
- Remaining uncertainties need to be carefully assessed, even 1% effects are relevant
- Important Remaining Uncertainties
  - pdf $(+\alpha_s)$
  - finite quark mass effects
  - Electroweak corrections

Gluon Fusion Inclusive Cross Section: PDF Uncertainties

- Previously: Some tension between predictions from different pdf sets $\rightarrow$ conservative envelope$\rightarrow$ 6-7% uncertainty from pdf+α_s



Gluon Fusion Inclusive Cross Section: PDF Uncertainties

- Now: Improvements in methodology in pdf fits give much more consistent results. With appropriate combination (Meta-pdf, CMC, MC-H), pure pdf uncertainty will be $\sim 2\%$

A comparison of ggF at NNLO

	CT14	MMHT2014	NNPDF3.0
8 TeV	18.66 pb -2.2% +2.0%	18.65 pb -1.9% +1.4%	18.77 pb -1.8% +1.8%
13 TeV	42.68 pb -2.4% +2.0%	42.70 pb -1.8% +1.3%	42.97 pb -1.9% +1.9%

J.Huston, PDF4LHC, April 2015

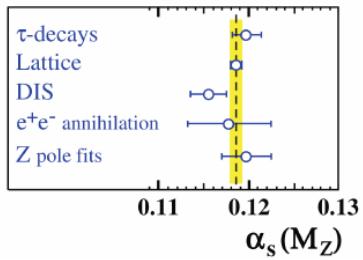
Gluon Fusion Inclusive Cross Section: α_s Uncertainties

THE VALUE OF α_s

PDG VALUE (AUGUST 2014): $\alpha_s(M_Z) = 0.1185 \pm 0.0006$

COMMENTS (S.F.)

- LATTICE UNCERTAINTY CURRENTLY ESTIMATED BY FLAG (arXiv:1310.8555) TO BE TWICE THE PDG VALUE (± 0.0012)
- IT IS AN AN AVERAGE OF AVERAGES
- SOME SUB-AVERAGES (E.G. DIS) INCLUDE MUTUALLY INCONSISTENT/INCOMPATIBLE DATA/EXTRACTIONS



- SOME SUB-AVERAGES (E.G. τ OR JETS) INCLUDE DETERMINATIONS WHICH DIFFER FROM EACH OTHER BY EVEN FOUR-FIVE σ
- AVERAGING THE TWO MOST RELIABLE VALUES (GLOBAL EW FIT & τ, BOTH N^{3}LO, NO DEP. ON HADRON STRUCTURE) GIVES

$$\alpha_s = 0.1196 \pm 0.0010$$

NEW PDF4LHC AGREEMENT

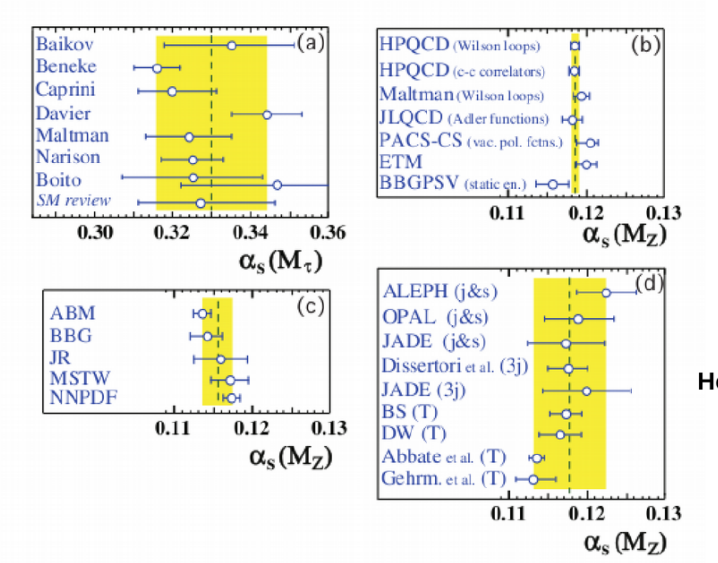
- PDG UNCERTAINTY CONSERVATIVELY MULTIPLIED BY 2
- CENTRAL VALUE & UNCERTAINTY ROUNDED: PDF SETS USUALLY GIVEN IN STEPS OF $\Delta\alpha_s(M_z) = 0.001$

$$\alpha_s(M_Z) = 0.118 \pm 0.001$$

S. Forte

Gluon Fusion Inclusive Cross Section: α_s Uncertainties

Value of α_s: perspectives



$\alpha_s(M_z)$=0.1172±0.0013 (NLO, jets)

CMS hep-ex/1412.1633

$\alpha_s(M_z)$=0.1151±0.003 (NLO, t-quark)

CMS hep-ex/1307.1907

$\alpha_s(M_z)$=0.1123±0.0015 (NNLO, e^+e^-, C-parameter)

Hoang, Kolodrubetz, Mateu, Stewart hep-ex/1501.04111

- The uncertainty in world average driven by the lattice determination is 0.0006
- Tension between lattice results and other determinations will be probably rising → more conservative estimate of the current uncertainty range is 0.115-0.118

S. Alekhin

Gluon Fusion Inclusive Cross Section: PDF Uncertainties

- Pure PDF uncertainties on gluon fusion cross section $\sim 2\%$
- Following PDF4LHC prescription for α_s uncertainty and combination with PDF uncertainty gives a total pdf+α_s uncertainty of $\sim 3\%$
- More conservative (± 0.003) estimate of α_s uncertainty would give total pdf+α_s uncertainty up to $\sim 6\%$

Gluon Fusion Inclusive Cross Section: Finite Quark Mass Effects

A. Lazopoulos

- EFT rescaled by LO finite quark mass effects has a 0.8% variation between $\bar{M}S$ and on-shell schemes
- NLO finite mass contributions probably have a larger dependence, to be checked
- Uncertainty from top mass variation in $\bar{M}S$ scheme 0.7% (bottom mass variations negligible)
- Nearly small enough to ignore

Gluon Fusion Inclusive Cross Section: Electroweak Corrections

S. Uccirati

- Two factorization options for QCD/ EW: $\boxed{\delta_{\rm EW} \sim 5\%}$
  - Partial factorization (PF): $G_{ij}^{\rm QCD} \to G_{ij}^{\rm QCD} + \delta_{\rm EW}\, G_{ij}^{\rm QCD,(0)}$
  - Complete factorization (CF): $G_{ij}^{\rm QCD} \to (1+\delta_{\rm EW}) G_{ij}^{\rm QCD}$
- Correct result: $G_{ij}^{\rm QCD} \to G_{ij}^{\rm QCD} + \delta_{\rm EW} G_{ij}^{\rm QCD,(0)} + a_s G_{ij}^{\rm QCD+EW,(1)} + a_s^2 G_{ij}^{\rm QCD+EW,(2)}$

- Even with conservative assumptions, deviation from complete factorization is small $\to <\sim 1\%$ uncertainty on total cross section

Gluon Fusion p_T Spectrum

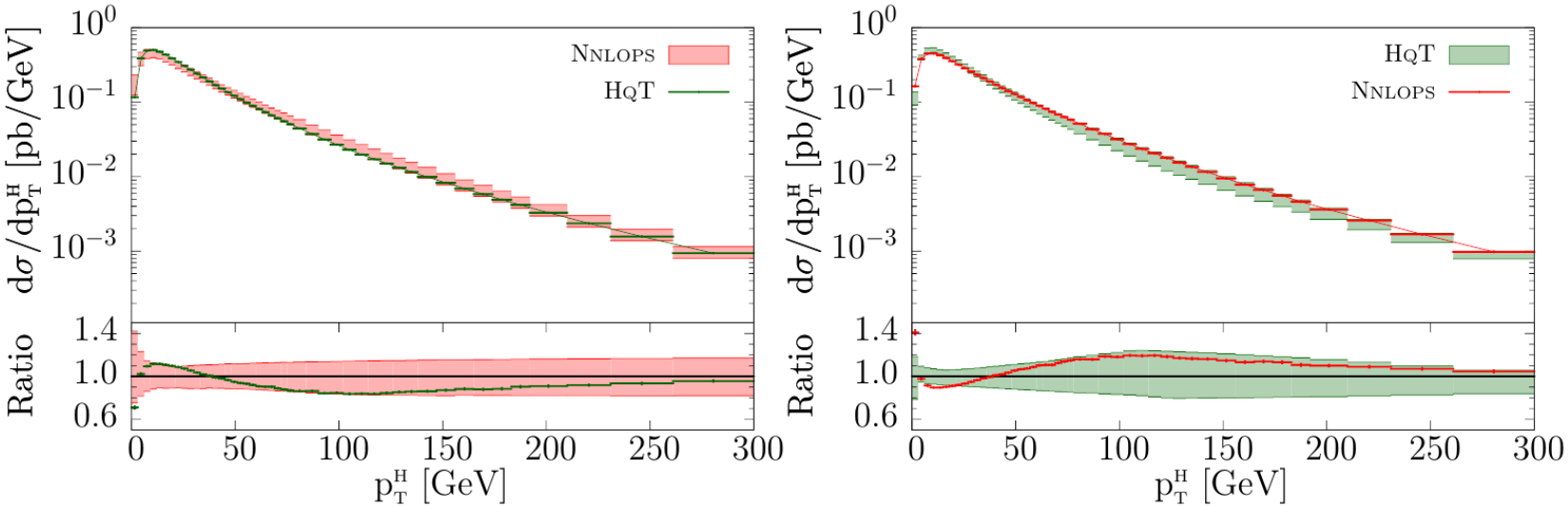
- Experiments used so far NLO+PS Monte Carlo (Powheg) as starting point for acceptance measurements
- Most advanced calculations of Higgs p_T spectrum are re-summed NNLO+NNLL (eg. HRes)
- In Run 1, some combination of reweighting and/or tuning of MC parameters (Powheg hfact) was used to more closely match higher order resummed calculation

Gluon Fusion p_T Spectrum: Discussion/Conclusions

- If applying reweighting, have to be very careful not to screw up other observables in the Monte Carlo
- "Tuning" of central scale choices or parameters to match central value from higher order/resummed calculation can be reasonable
- In all cases should propagate the full uncertainty of the Monte Carlo being used (and not try to constrain to the smaller uncertainty of the higher order calculation)

Gluon Fusion p_T Spectrum: Discussion/Conclusions

- Desirable closure tests: Monte Carlo should agree with higher order resummed calculation within its uncertainties (this test must be done with consistent inclusion/not of finite quark mass effects, etc) - closely related to the Higgs+jets study
- Greatly improved Monte Carlos are available (NLO+PS accuracy for Higgs+1 jet) $\rightarrow$ smaller MC uncertainties on Higgs p_T spectrum



Hamilton, Nason, Re, Zanderighi - arxiv 1309.0017

Gluon Fusion p_T Spectrum: Discussion/Conclusions

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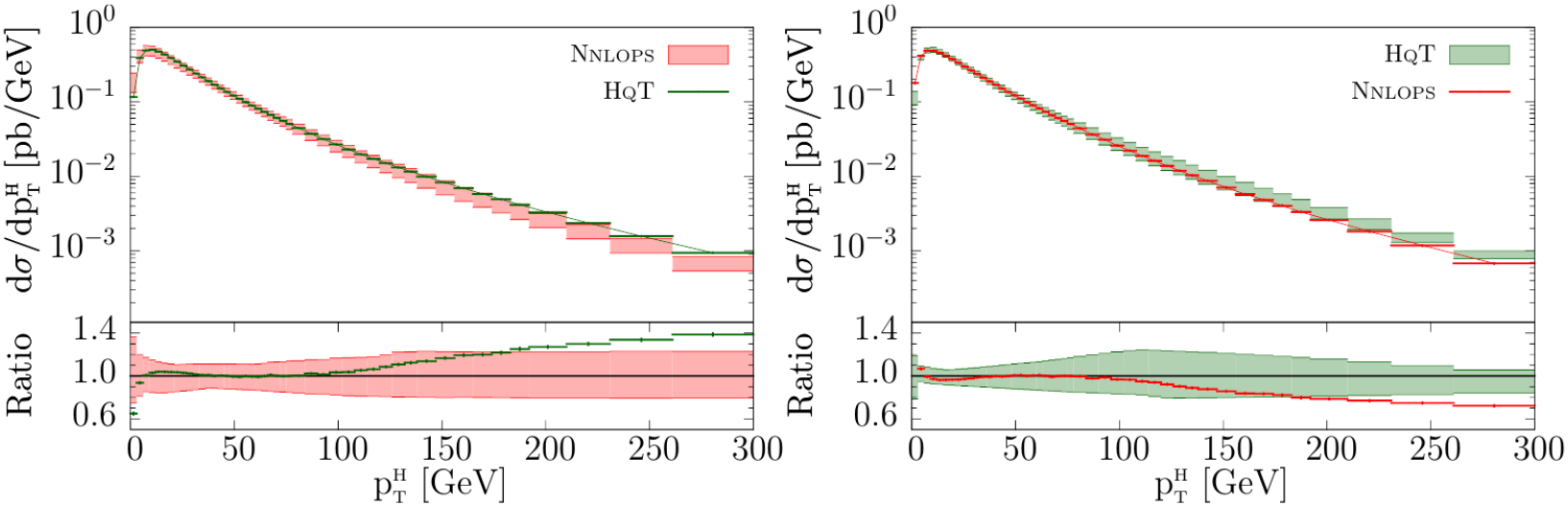

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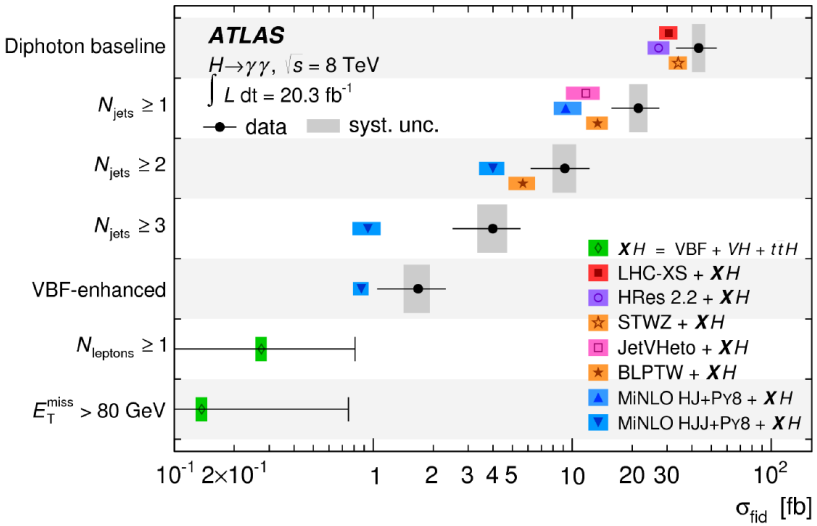
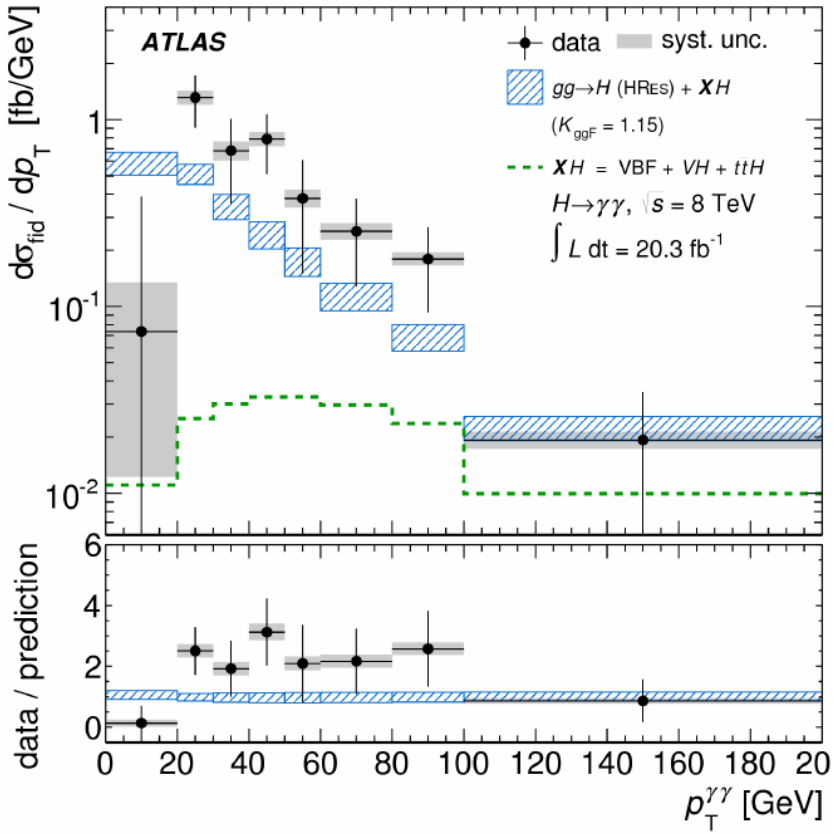
Off-shell Higgs Production

- ATLAS and CMS results inferring constraints on Higgs width from off-shell $gg \to H^* \to ZZ \to 4\ell$ production and interference with continuum
- Progress in NLO calculation of this process
- Merged LO+PS Monte Carlo possible for both 0 and 1 jet off-shell production+interference in both Madgraph_aMC@NLO (using generic loop-induced functionality) and VBFNLO
- Project underway to compare such merged results to the LO inclusive used so far, also at the level of matrix element likelihood discriminants of the kind already in use by the experiments (built from MCFM matrix elements)

Fiducial/Differential Cross Section Measurements

- First fiducial/differential cross sections from Atlas already available ($\gamma\gamma$,$ZZ \to 4\ell$, combination), CMS Run 1 results coming soon.
- Statistically limited for the moment





Fiducial/Differential Cross Section Measurements: What to Measure

- Number of suggestions for what to measure with more data:
  - Continue with both inclusive and exclusive jet bins
  - Finer binning in Higgs p_T and/or angular proxies for p_T (a la ϕ^*) to probe low p_T region
  - Measurements with several different jet p_T cuts
  - Some suggestions for additional jet variables
  - $H \to WW \to 2\ell 2\nu$ can be useful as well (with larger experimental uncertainties related to missing E_T reconstruction)
  - VH would be interesting as well, but requires **much** more data

Fiducial/Differential Cross Section Measurements: How to Quote/Present Results

- Covariance matrix highly desirable (effect of unfolding plus possible correlated experimental systematics)
- Covariance matrix between different bins and between differential distributions and fiducial cross sections also useful
- For $H \to ZZ \to 4\ell$ and $H \to WW \to 2\ell 2\nu$, could be useful/interesting to quote cross sections for Higgs+irreducible background together (with appropriate definition of fiducial phase space with $m_{4\ell}$ or $m_T, m_{\ell\ell}$, etc). For $H \to \gamma\gamma$, experimentally much more natural to continue subtracting the full background.
- Isolation as part of fiducial definition (to reduce dependence on production mode) is reasonable
- Measuring directly moments of distributions doesn't map well onto the experimental analysis (Theorists should just compute from the binned distributions if desired and properly account for the binning effect when comparing to theory.)

Fiducial/Differential Cross Section Measurements: How to Quote/Present Results

- General point: Theorists would like the full set of corrections/subtractions needed to easily compare to standalone/fixed order/analytic resummed/etc gluon fusion predictions.
  - Irreducible background prediction (where not already subtracted)
  - Non-ggH Higgs prediction
  - Non-perturbative corrections
  - Acceptance/Efficiency of isolation cut per production mechanism
  - Acceptance/Efficiency relative to full phase space per production mechanism (needed for each bin of differential measurements?)
- (Even if fiducial phase space definition provides all needed info to compute them later with standard MC tools)

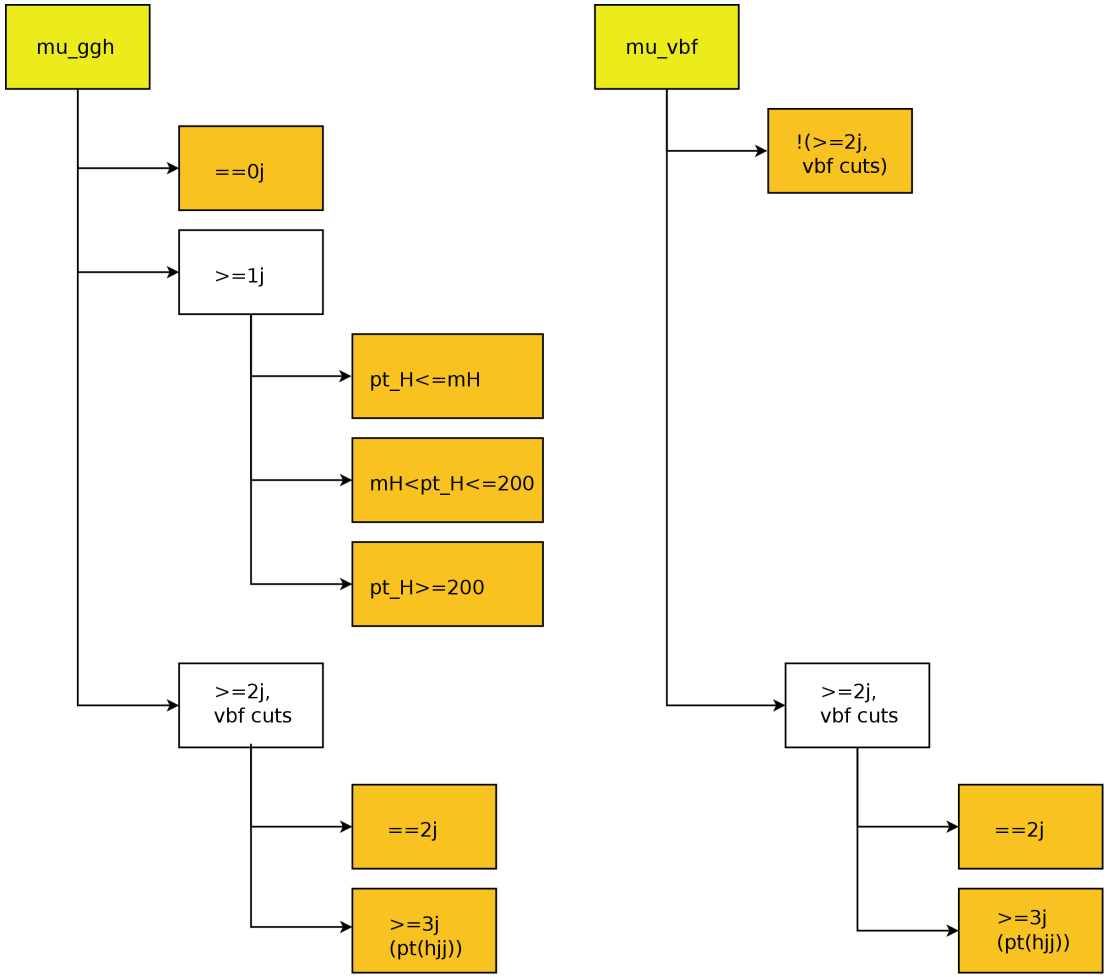
Evolution of the Higgs couplings fits

- Main Run 1 Higgs combinations consist of grand combined likelihood fit for "μ"'s and κ's (scale factors to SM for Higgs cross sections or LO couplings)
- Extensive use of non-trivial kinematic selections, including BDT's, even mixing kinematic and detector inputs
- Good: Maximum possible sensitivity (this is how we discovered the Higgs after all)
- Bad: Theory predictions and uncertainties maximally entangled in results. Non-trivial updates require new results from the experiments.
- Evolution of this procedure in Run 2 is an open point
- Discussion this week (Thanks to F .Tackmann, A. David, M. Duehrssen)

Evolution of the Higgs couplings fits: Simplified Cross Sections

- Basic idea: Experiments retain fully optimized selection/categorization at reconstruction/analysis level, but express results in terms of a set of simplified/pseudo-fiducial cross sections subdivided by production mode and phase space
- Reduce the theory uncertainties currently associated with correlating signal strengths across jet bins, different phase space, and/or extrapolating back to inclusive cross section
- Make results easier to interpret/reinterpret $\rightarrow$ increase useful lifetime of the results (less frequent results as $\int L$ doubling time increases)
- This effort would continue in parallel to "proper" fiducial and differential cross sections (with eventual convergence in high stats limit)

Simplified Cross Sections: Example



- Example/strawman proposal shown for gluon fusion and VBF
- Orange boxes represent fit parameters for the combination defined as cross sections for a given production mode with (not fully fiducial) phase space cuts
- Have already discussed also VH/ttH, proposals for evolution/further subdivision of phase space with integrated luminosity (more details on twiki)

`http://phystev.cnrs.fr/wiki/2015:groups:higgs:pseudoxsecs`

Simplified Cross Sections: Next Steps

- Concrete proposal for simplified cross sections for the proceedings
- SM-relevant scheme should be considered "fixed" for session 2 consideration, but further input useful for phase space regions relevant for BSM