Starting the LHC Higgs Cross Section Working Group
- experimental perspective -

Reisaburo TANAKA (Université Paris-Saclay, IJCLab/IN2P3/CNRS)

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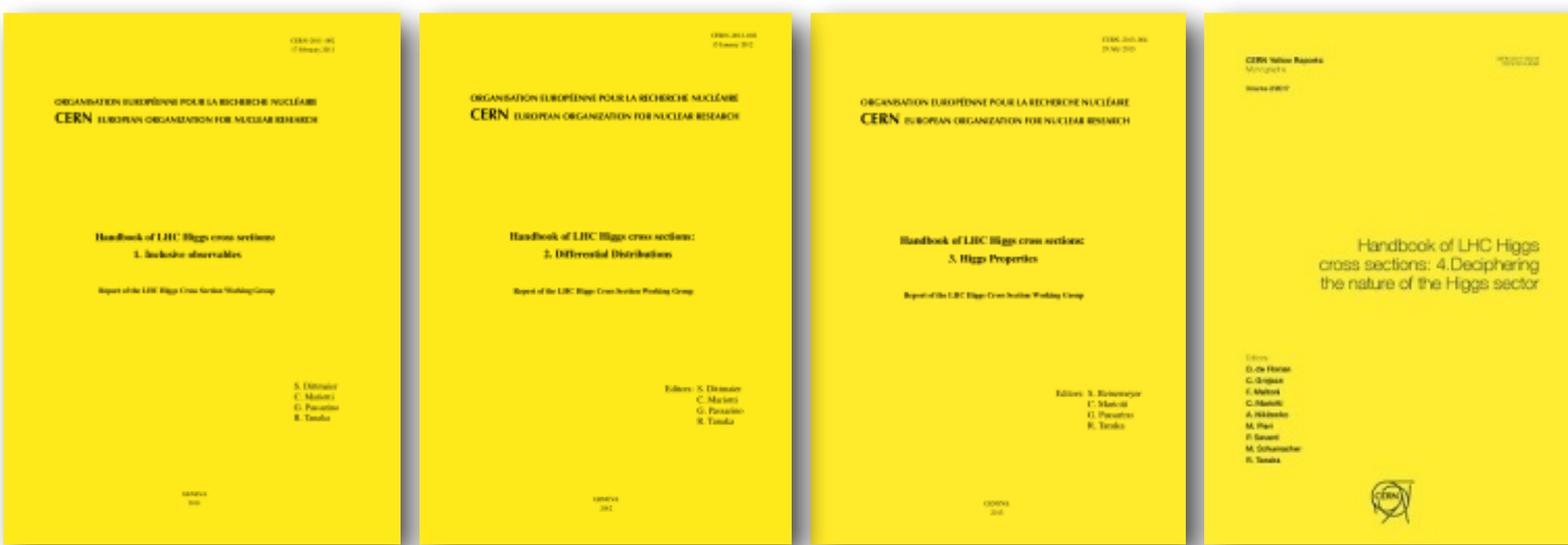
The 20th LHC Higgs Working Group Meeting
November 14th 2023, CERN

LHC Higgs Cross Section Working Group

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHWG

Run 1	Run 2	Run 3
2011–2012	2015–2018	2022–

2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	20
Aug. TH&ATLAS& CMS proposal for joint forum for Higgs XS Nov. 23-24 Torino WS @ LHC 1st pp collision	Jan. Creation LHCHXSWG Apr. Inauguration WS in Freiburg	YR1	YR2 July 4th Higgs boson Discovery	YR3				YR4			Nov. LHC Higgs XS WG ➪ LHC Higgs WG			



WG1: Higgs XS&BR
WG2: Higgs Properties
WG3: BSM Higgs

Annual meetings at Freiburg, Bari, BNL, LAL and CERN

Important interaction with:
- PDF4LHC, MCNet
- LHC Higgs Combination WG
- LHC EW/Top Physics WG
- LHC Effective Field Theory WG

LHC Higgs XS WG CERN Reports

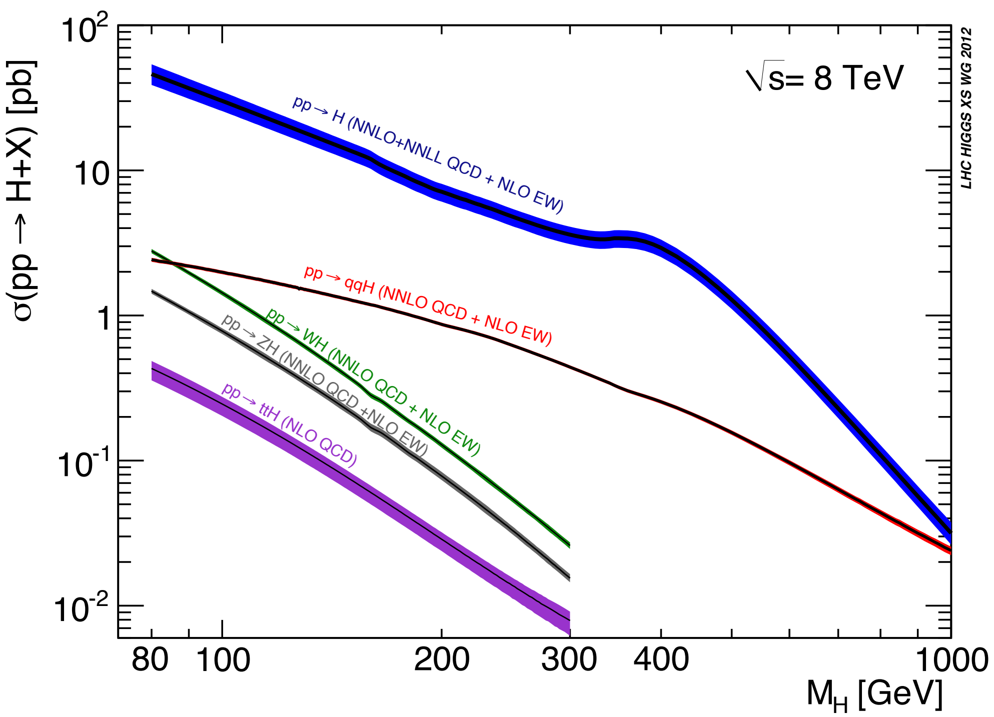
Handbook of LHC Higgs Cross Sections:
1. Inclusive Observables (CERN-2011-002, 151 pp.)
2. Differential Distributions (CERN-2012-002, 275 pp.) ← July 4th 2012 Higgs boson Discovery
3. Higgs Properties (CERN-2013-004, 392 pp.)
4. Deciphering the nature of the Higgs sector (CERN-2017-002-M, 869 pp.)

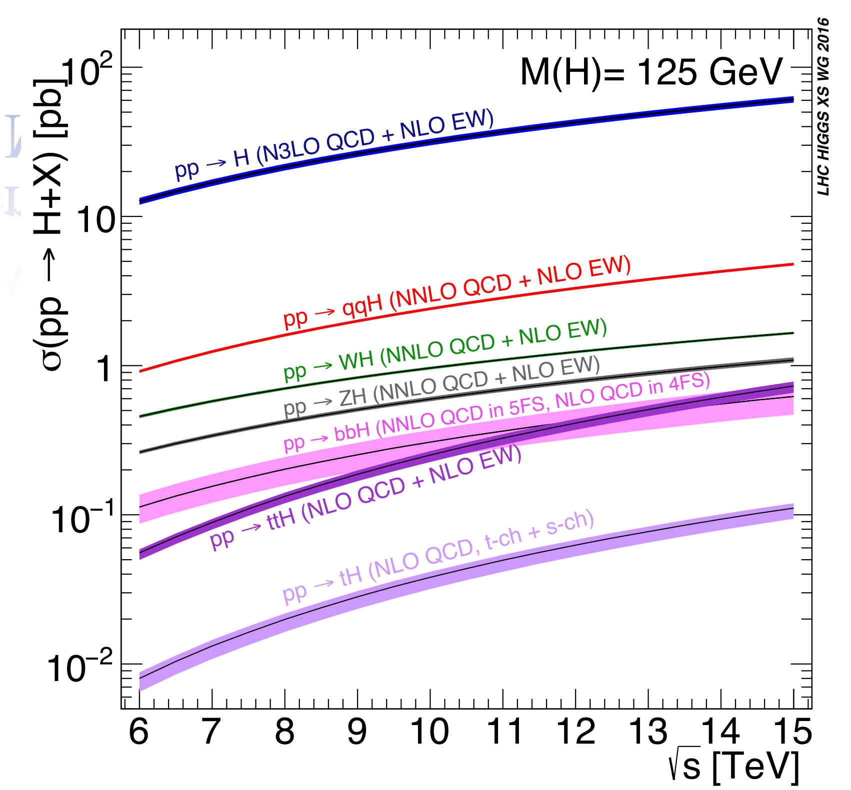
Everything was ready well before Higgs boson discovery in 2012 !

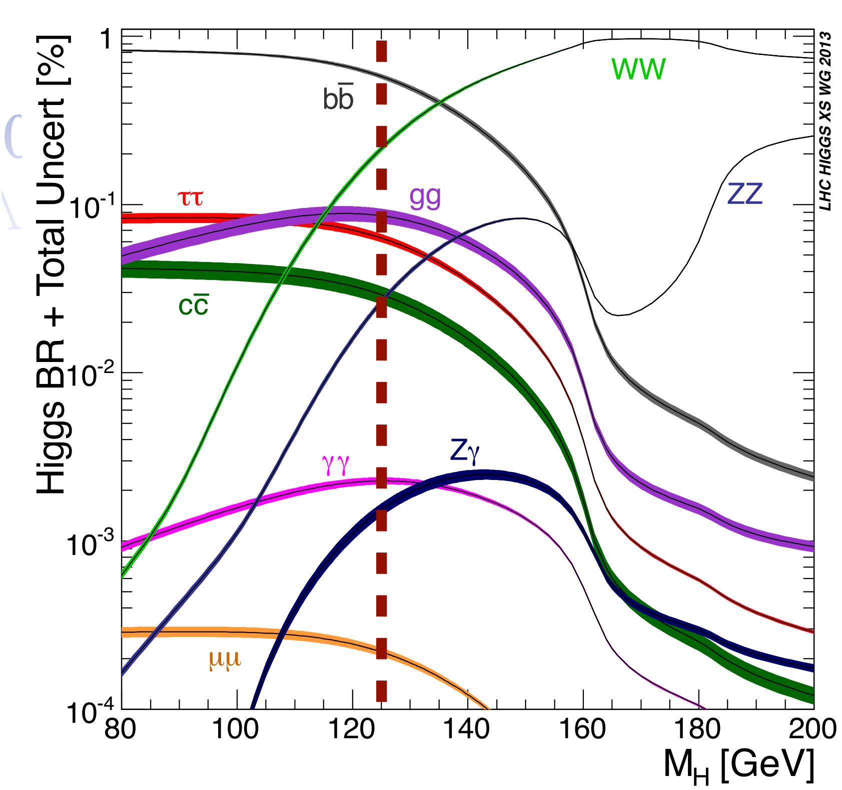
Higgs boson production XS & decay BR

- State-of-the-art Higgs XS and BR predictions with estimated theory uncertainties
  - Common SM input parameters coordinated for calculation for different processes
  - Mostly NNLO QCD + NLO EW production cross section
    - N3LO for ggF (ATLAS and CMS adopted promptly)
  - M_H=125GeV was lucky to have many different decay channels

- ATLAS and CMS had common XS&BR numbers since Day-0 well before Higgs boson discovery when we did not know where it is.
- ~240k Higgs boson @ Discovery (L=5-6 fb^{-1} at each $\sqrt{s}$=7/8 TeV), 9M in RUN-2 (L=160 fb^{-1} at $\sqrt{s}$=13 TeV), will produce 17M in RUN-3 (L=290 fb^{-1}) and 190M in HL-LHC (L=3 ab^{-1}).







https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHWG

LHC Higgs Combination Group (ATLAS+CMS)

- Feedback to the LHC Higgs Combination Working Group was vital before Higgs boson discovery.
  - The LHC Higgs Combination Working Group (LHC-HCG)

    "Procedure for the LHC Higgs boson search combination in Summer 2011"

    ATL-PHYS-PUB-2011-11 CMS NOTE-2011/005

- All essential ingredients were already there !
  - Limit setting procedure
  - Look-elsewhere effect
  - Statistical methods, nuisance parameters
  - Higgs boson mass scan points
  - Treatment of systematic uncertainties
  - Jet-bin uncertainties
  - PDF uncertainty correlations among diff. ch

Table 3: List of nuisance parameters for systematic uncertainties assumed to be 100% correlated between ATLAS and CMS.

PDF+α_s uncertainties

nuisance	groups of physics processes
pdf_gg	$gg \to H$, $t\bar{t}H$, VQQ, $t\bar{t}$, tW, tb (s-channel), $gg \to VV$
pdf_qqbar	VBF H, VH, V, VV, $\gamma\gamma$
pdf_qg	tbq (t-channel), γ+jets

QCD scale uncertainties

nuisance	groups of physics processes
QCDscale_ggH	total inclusive $gg \to H$
QCDscale_ggH1in	inclusive $gg/qg \to H + \geq 1$ jets
QCDscale_ggH2in	inclusive $gg/qg \to H + \geq 2$ jets
QCDscale_qqH	VBF H
QCDscale_VH	associate VH
QCDscale_ttH	$t\bar{t}H$
QCDscale_V	W and Z
QCDscale_VV	WW, WZ, and ZZ up to NLO
QCDscale_ggVV	$gg \to WW$ and $gg \to ZZ$
QCDscale_ZQQ	Z with heavy flavor $q\bar{q}$-pair
QCDscale_WQQ	W with heavy flavor $q\bar{q}$-pair
QCDscale_ttbar	$t\bar{t}$, single top productions are lumped here for simplicity

Acknowledgements

We would like to thank the ATLAS statistics forum and CMS statistics committee for their extremely valuable and continuous feedback and for the guiding suggestions and corrections. We would like to acknowledge the role of the LHC Higgs Cross Section group that helped settle a number of non-trivial questions on correlations of theoretical errors for exclusive final states of Higgs boson production in association with jets. The prompt response of the group on the request to produce SM Higgs boson production cross sections and branching ratios for the fine grid of Higgs boson mass points needed for the combination was simply spectacular. We would also like to thank the ATLAS and CMS Higgs working groups for their close involvement in the overall effort and for preparing analysis Workspaces for performing technical exercises as reported in this document.

gg→H gluon-gluon fusion Cross Section

New in CERN Report 4

- First complete N3LO calculation at hadron collider ! [Anastasiou:2016cez]

$\delta(\text{scale})$	$\delta(\text{trunc})$	$\delta(\text{PDF-TH})$	$\delta(\text{EW})$	$\delta(t,b,c)$	$\delta(1/m_t)$
$^{+0.10\text{ pb}}_{-1.15\text{ pb}}$	±0.18 pb	±0.56 pb	±0.49 pb	±0.40 pb	±0.49 pb
$^{+0.21\%}_{-2.37\%}$	$\pm0.37\%$	$\pm1.16\%$	$\pm1\%$	$\pm0.83\%$	$\pm1\%$

missing higher-orders — uncertainty from the soft expansion — missing N3LO PDFs — EW corrections — uncertainty from heavy-quark mass dependence — uncertainty in the $1/m_t$ included corrections

$\sqrt{s}$=13TeV, M_H=125GeV: cross section went up by +10%

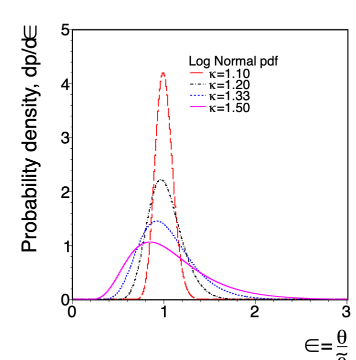
$$\sigma = 48.58\,\text{pb}\,^{+2.22\,\text{pb}\,(+4.56\%)}_{-3.27\,\text{pb}\,(-6.72\%)}\ (\text{theory}) \pm 1.56\,\text{pb}\,(3.20\%)\ (\text{PDF}+\alpha_s)$$

- NNLO+NNLL: σ = 44.14 pb +7.6 -8.1% (QCD scale) ± 3.1% (PDF+α_s)

- Debates on theoretical QCD scale uncertainty treatment:
  - **TH: use Flat uncertainty: [−6.7, +4.6]% @100% CL**
  - **EXP: use Gaussian uncertainty: max{neg,pos}/√3 = ±3.9% @67% CL**

Log-normal distribution (Θ=σ for κ=1)

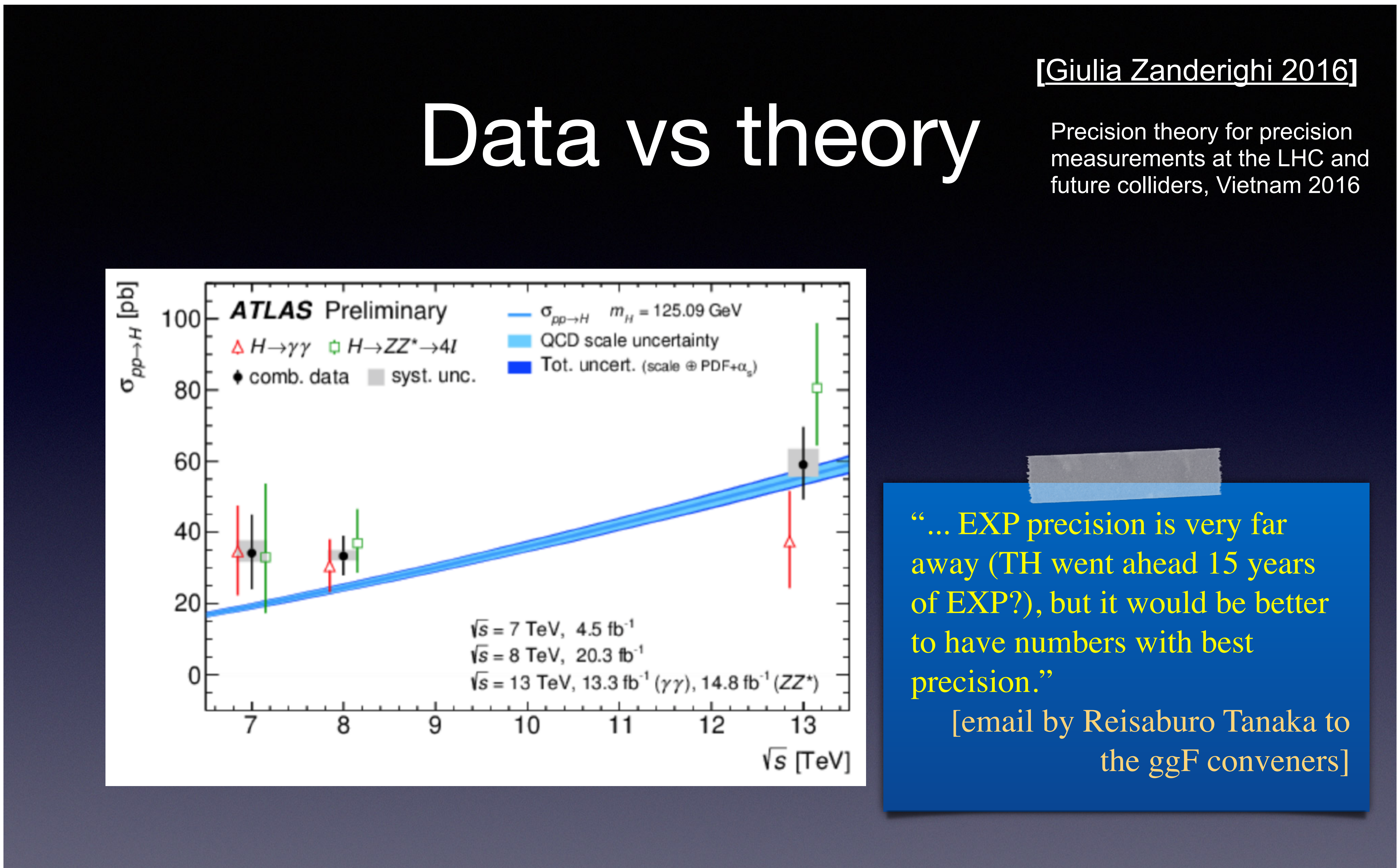
$$\rho(\theta) = \frac{1}{\sqrt{2\pi}\ln(\kappa)} \exp\left(-\frac{(\ln(\theta/\tilde{\theta}))^2}{2(\ln\kappa)^2}\right)\frac{1}{\theta}.$$



TH ⊕ PDF ⊕ α_s = 5.1%

Higgs Boson Production Cross Section at LHC

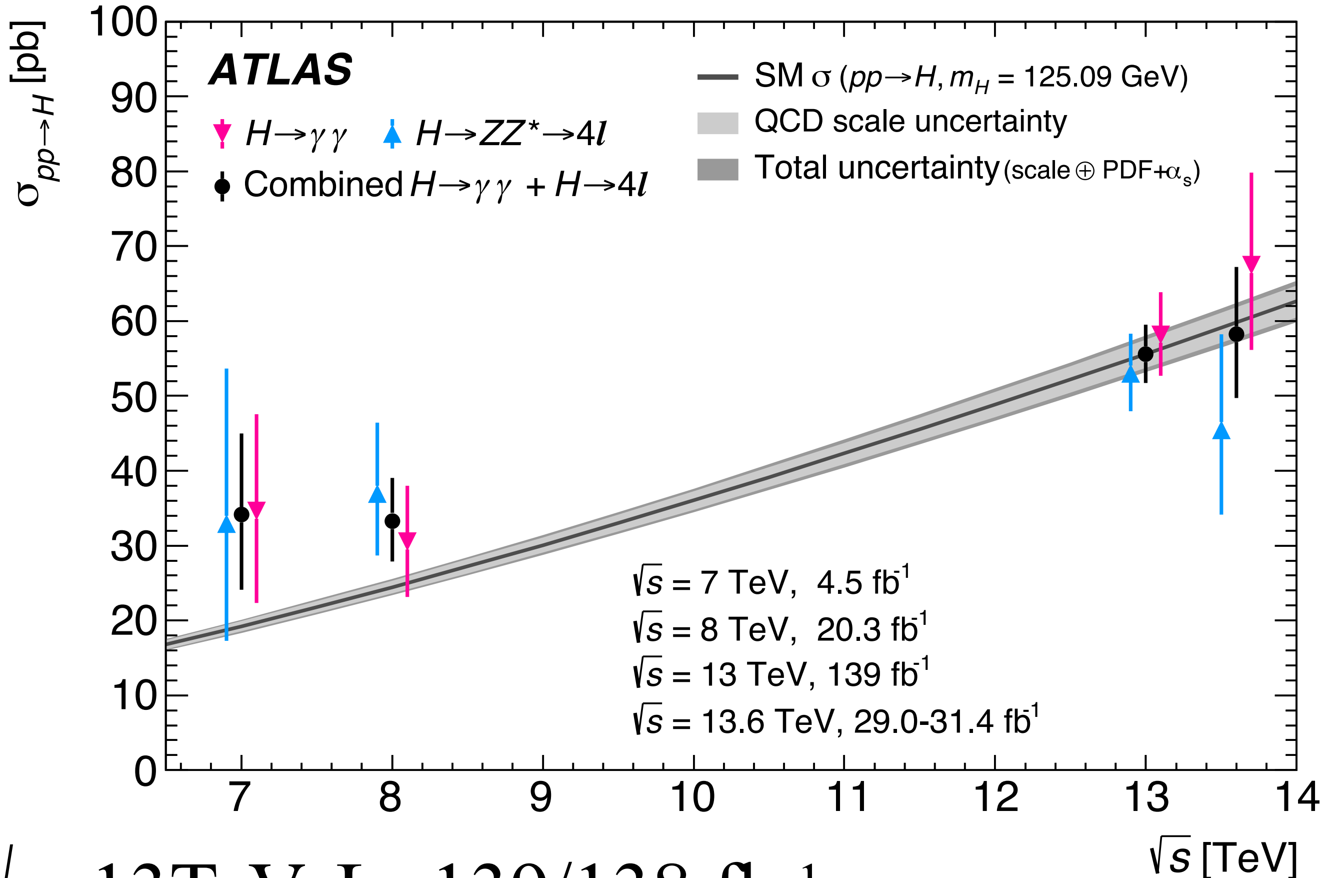
- I thought theory community went too far but EXP and TH uncertainties are competing !!
- Very important to have the competitive numbers.



Higgs Boson Production Cross Section at LHC

- I thought theory community went too far but EXP and TH uncertainties are competing after RUN-2 !!
- Very important to have the competitive numbers.
- Example: ATLAS $H\to\gamma\gamma+4\ell$, RUN-2 $\sqrt{s}$=13TeV, 139 fb^{-1}

$$\sigma_{\rm obs}/\sigma_{\rm TH} = 1.00 \pm 5.8\%\,({\rm stat.}) \pm 4.1\%\,({\rm syst.}) \pm 4.5\%\,({\rm theory})$$



[ATLAS: arXiv:2306.11379]

- Full RUN-2 $\sqrt{s}$=13TeV, L=139/138 fb^{-1}

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$$\text{ATLAS} \quad \mu = 1.05 \pm 0.06 = 1.05 \pm 0.03({\rm stat.}) \pm 0.03({\rm exp.syst.}) \pm 0.04({\rm sig.th.}) \pm 0.02({\rm bkg.th.})$$

$$\text{CMS} \quad \mu = 1.002 \pm 0.057 = 1.002 \pm 0.029({\rm stat.}) \pm 0.033({\rm exp.syst.}) \pm 0.036({\rm sig.th.})$$

Higgs boson decay width and branching ratio

Uncertainties in Branching Ratio (LHC-HCG)

1. Start with Higgs boson decay width
   $\Gamma_H = \Gamma^{HDECAY} - \Gamma^{HDECAY}_{WW} - \Gamma^{HDECAY}_{ZZ} + \Gamma^{Prophecy4f}_{4f}$
2. Categorize PU(α_s, m_b, m_c, m_t) and THU
   Separate treatment of PU($\Delta\alpha_s$, Δm_q) and THU
3. Convert to BR (correlations are taken into)

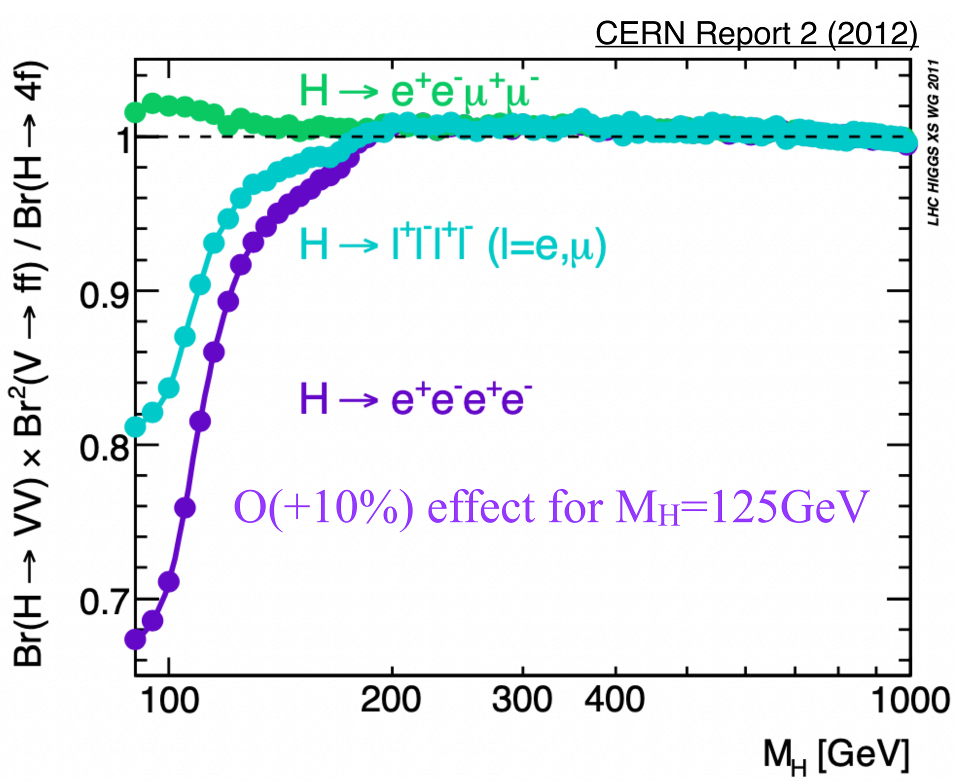
$$BR(\mathrm{H} \to VV) = \frac{\Gamma_{VV}}{\Gamma_{\mathrm{tot}}} = \frac{\Gamma_{VV}}{\Gamma_{\mathrm{f\bar{f}}} + \Gamma_{gg} + \Gamma_{VV}}$$

$$\Gamma_{\mathrm{f\bar{f}}} : \Gamma_{VV} \simeq 3:1 \text{ (dominated by } \Gamma_{\mathrm{b\bar{b}}})$$

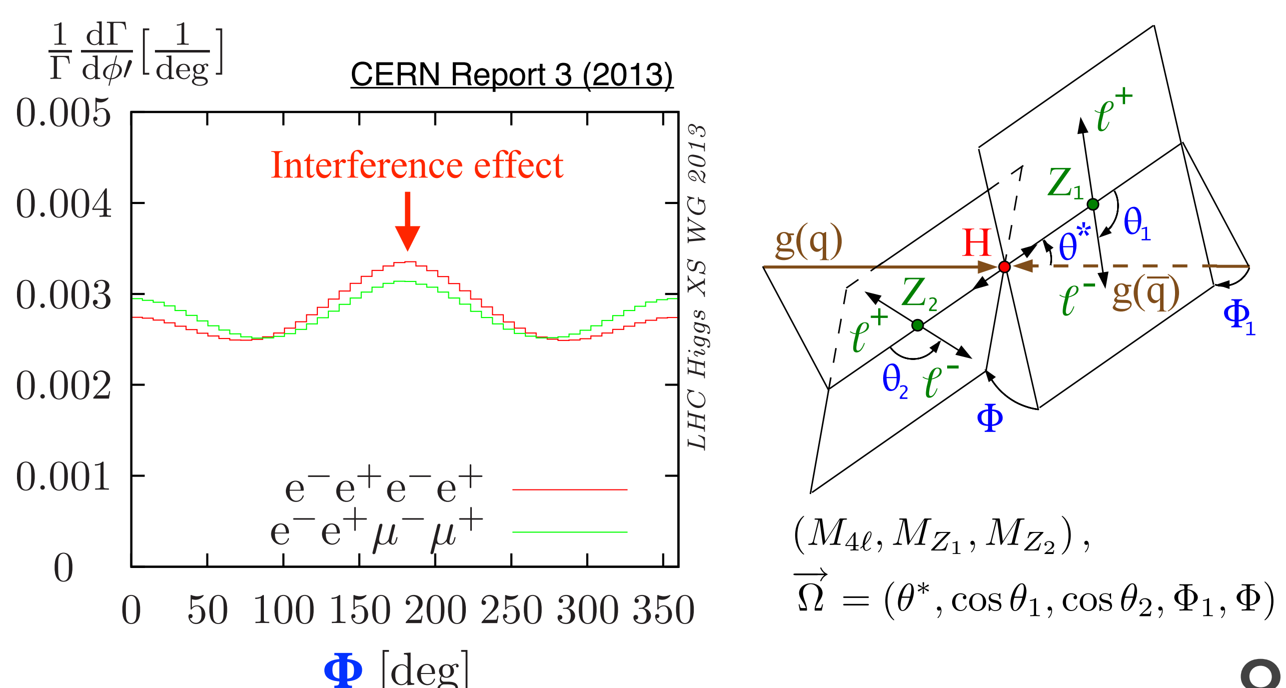
M_H=126GeV	Decay width uncertainty				
Decay	$\Delta\alpha_s$	Δm_b	Δm_c	Δm_t	THU
H→bb	∓2.3%	±3.3%	±0.0%	±0.0%	±2.0%
H→cc	∓7.1%	-0.1%	±6.2%	±0.1%	±2.0%
H→ττ	±0.0%	±0.0%	±0.0%	±0.1%	±2.0%
H→μμ	±0.0%	±0.0%	±0.1%	±0.1%	±2.0%
H→gg	±4.2%	-0.1%	±0.0%	∓0.2%	±3.0%
H→γγ	±0.0%	±0.0%	±0.0%	±0.1%	±1.0%
H→Zγ	±0.0%	±0.0%	±0.1%	±0.1%	±5.0%
H→WW	±0.0%	±0.0%	±0.0%	±0.0%	±0.5%
H→ZZ	±0.0%	±0.0%	±0.0%	±0.0%	±0.5%

Precise H→4f BR estimation and Monte Carlo at NLO EW

Interference effect in H→ZZ*→$e^+e^-e^+e^-$, $\mu^+\mu^-\mu^+\mu^-$



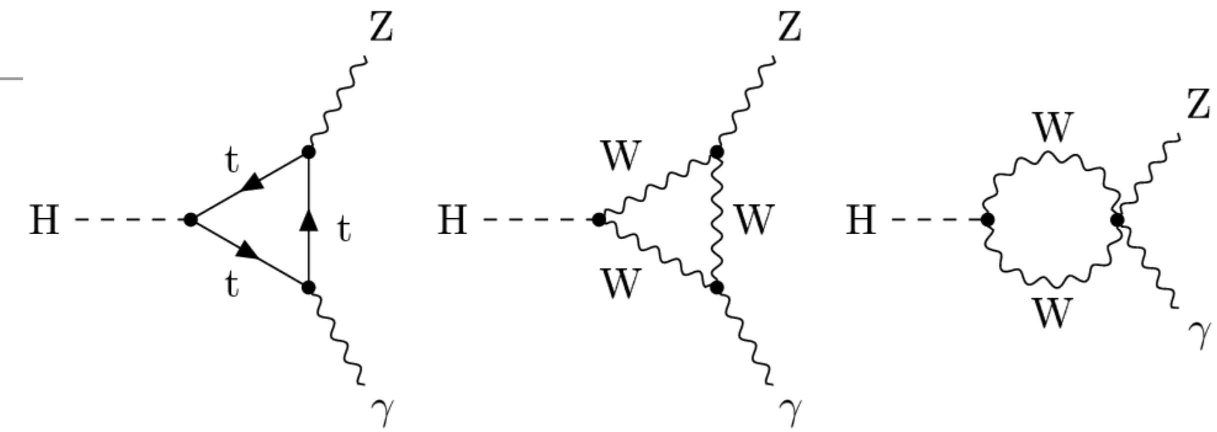
Precise H→4f Monte Carlo (Prophecy4f) at NLO EW



$(M_{4\ell}, M_{Z_1}, M_{Z_2})$,
$\vec{\Omega} = (\theta^*, \cos\theta_1, \cos\theta_2, \Phi_1, \Phi)$

Branching Ratio in H→Zγ

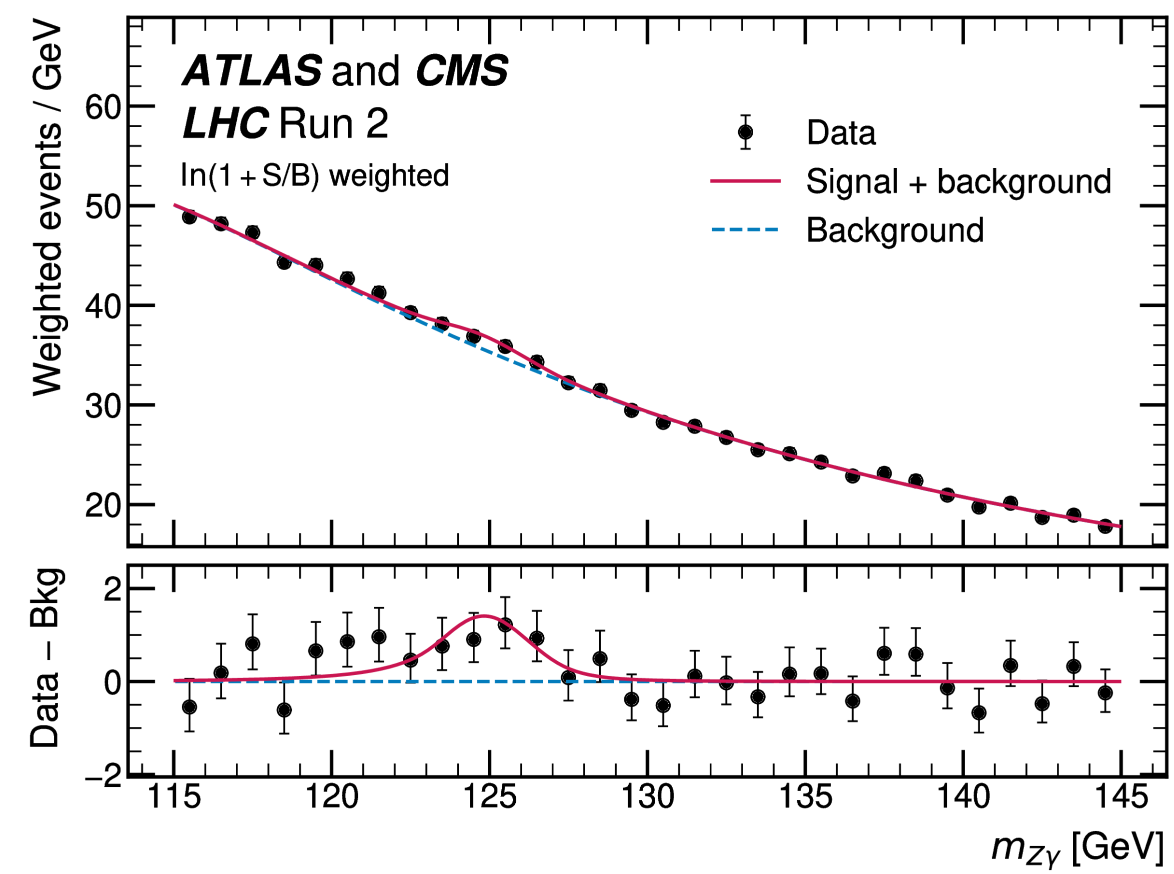
- Statistics limited by very important channel to search for BMS physics.



- The measured H→Zγ branching fraction is (3.4±1.1)x10-3.
- SM BR(H→Zγ)=(1.54±0.09)x10-3
  - 5.7% uncertainty in THU
- The largest systematic uncertainties are BR(H→Zγ) and background modeling.

- BR subgroup needs to wake up !

[ATLAS&CMS: arXiv:2309.03501]



Higgs Signal Strength and kappa-framework

LO κ-framework

$$\mu = \frac{\sigma \cdot \mathrm{BR}}{(\sigma \cdot \mathrm{BR})_{\mathrm{SM}}}$$

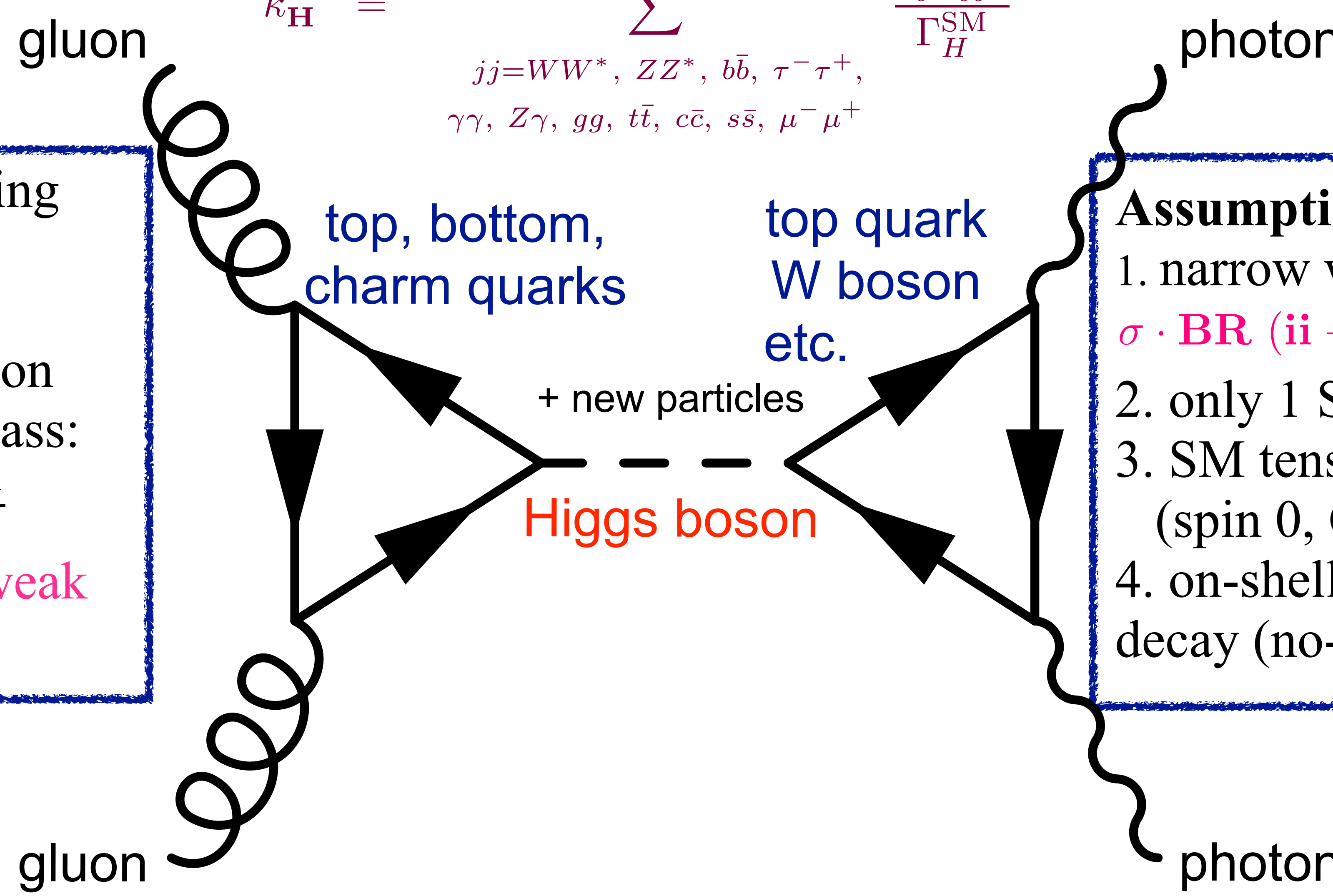
$$\mu = \frac{(\sigma \cdot \mathrm{BR})(gg \to \mathrm{H} \to \gamma\gamma)}{\{\sigma(gg \to \mathrm{H}) \cdot \mathrm{BR}(\mathrm{H} \to \gamma\gamma)\}_{\mathrm{SM}}} = \frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_{\mathrm{H}}^2}$$

$$\kappa_{\mathbf{H}}^{\mathbf{2}} = \sum_{\substack{jj=WW^*,\, ZZ^*,\, b\bar{b},\, \tau^-\tau^+,\\ \gamma\gamma,\, Z\gamma,\, gg,\, t\bar{t},\, c\bar{c},\, s\bar{s},\, \mu^-\mu^+}} \frac{\kappa_j^2 \Gamma_{jj}^{\mathrm{SM}}}{\Gamma_H^{\mathrm{SM}}}$$

- Measure with coupling scale factors κ_i.
- The coupling of SM particles to Higgs boson scales with particle mass:

$$g_F = \sqrt{2}\frac{m_f}{v},\; g_V = 2\frac{m_V^2}{v}$$

- Holds up to electroweak effects of O(5-10%).



Assumptions

1. narrow width approx.

$$\sigma \cdot \mathbf{BR}\ (\mathbf{ii} \to \mathbf{H} \to \mathbf{ff}) = \frac{\sigma_{\mathbf{ii}} \cdot \Gamma_{\mathbf{ff}}}{\Gamma_{\mathbf{H}}}$$

2. only 1 SM-like Higgs
3. SM tensor structure (spin 0, CP-even)
4. on-shell production and decay (no-sense for offshell).

Note on Coupling versus Mass relation

$$g_F = \sqrt{2}\frac{m_f}{v} \qquad g_V = 2\frac{m_V^2}{v}$$

- Prescription for mass vs coupling plot, Quark mass (M. Spira)
- Square-root of the coupling modifier for gauge bosons (hence 1/2 error bar)

$$\begin{cases} y_F = \kappa_F \frac{m_f}{v} \\ y_V = \sqrt{\kappa_V}\frac{m_V}{v} \end{cases}$$

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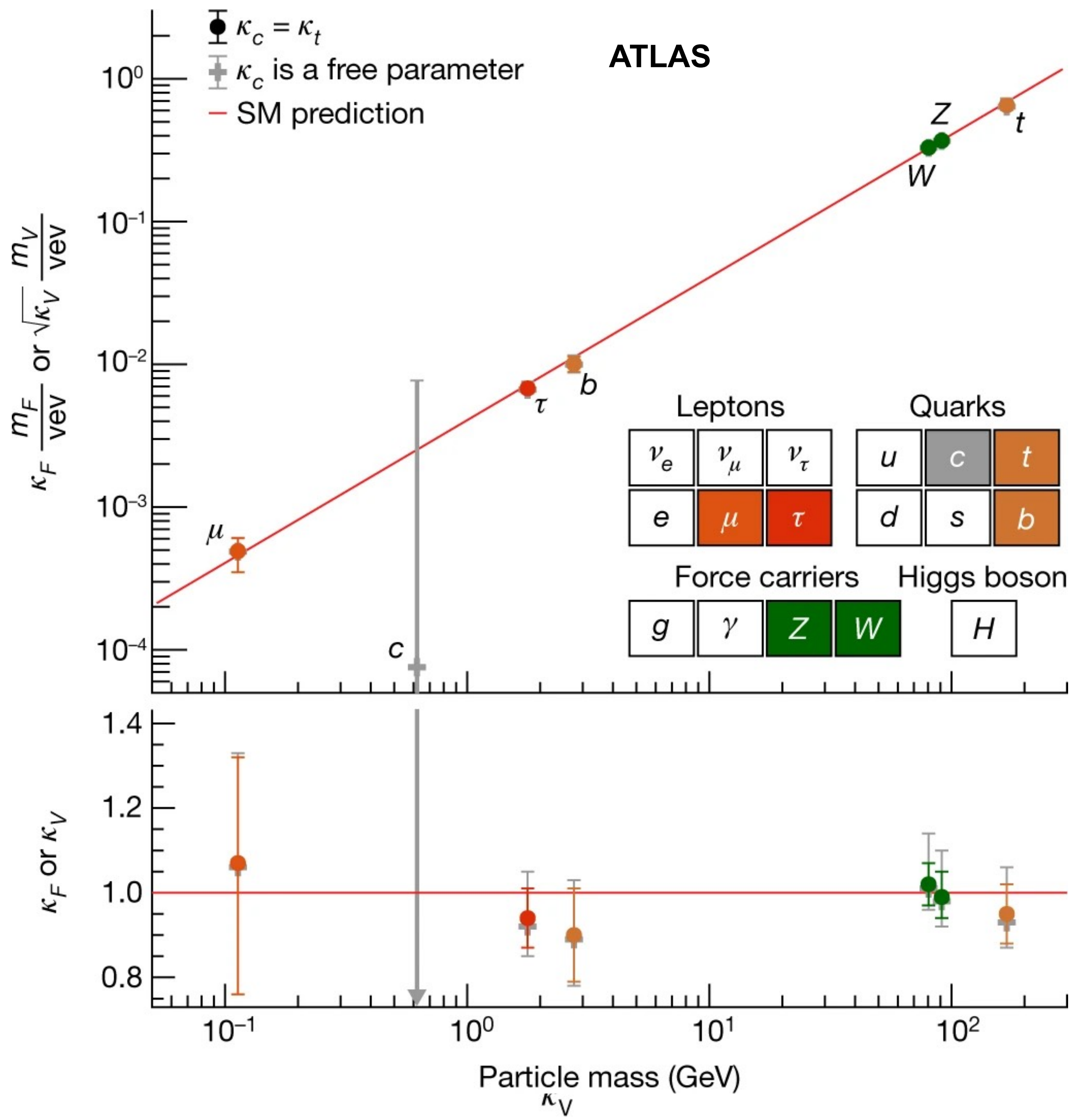
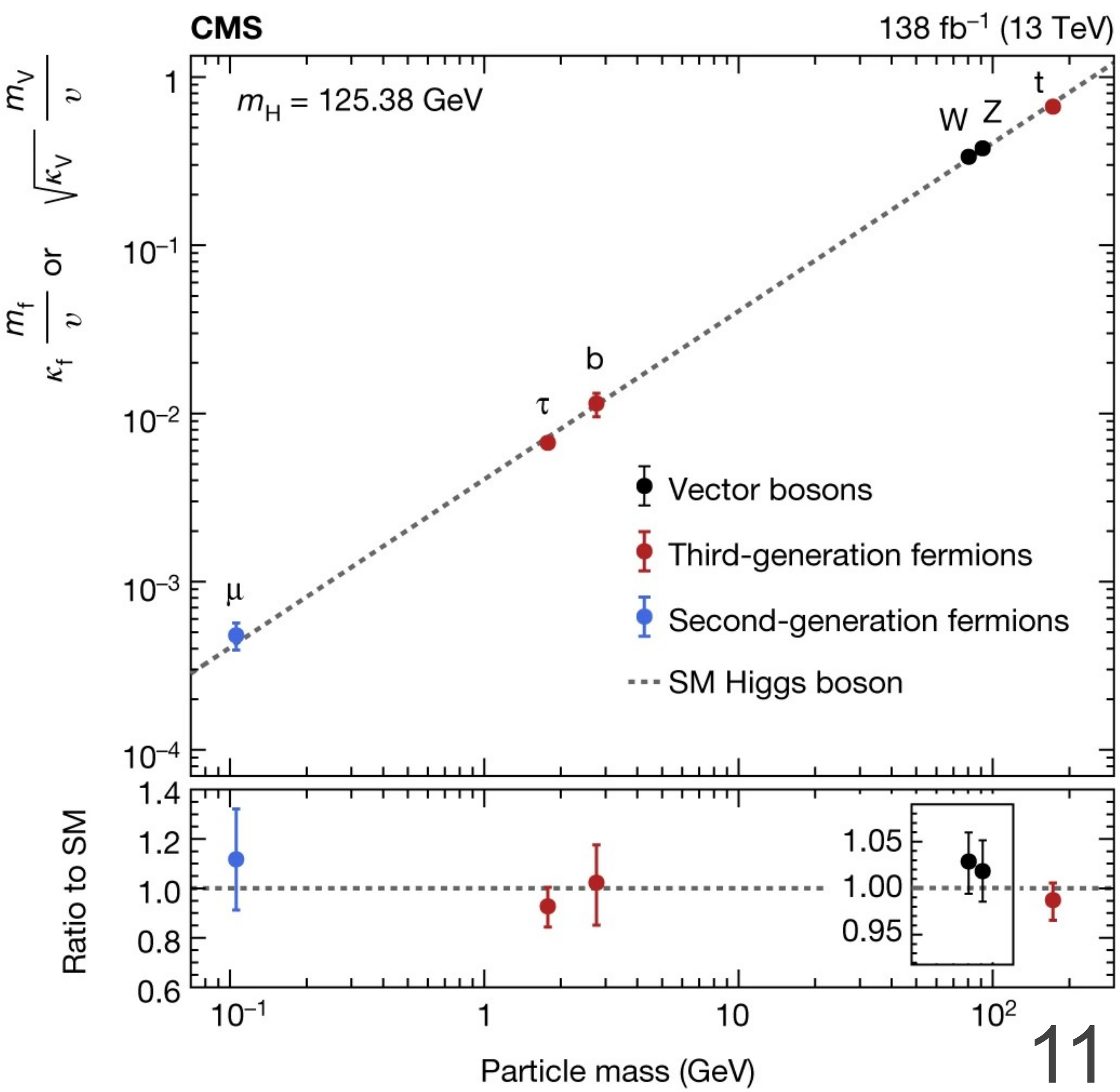


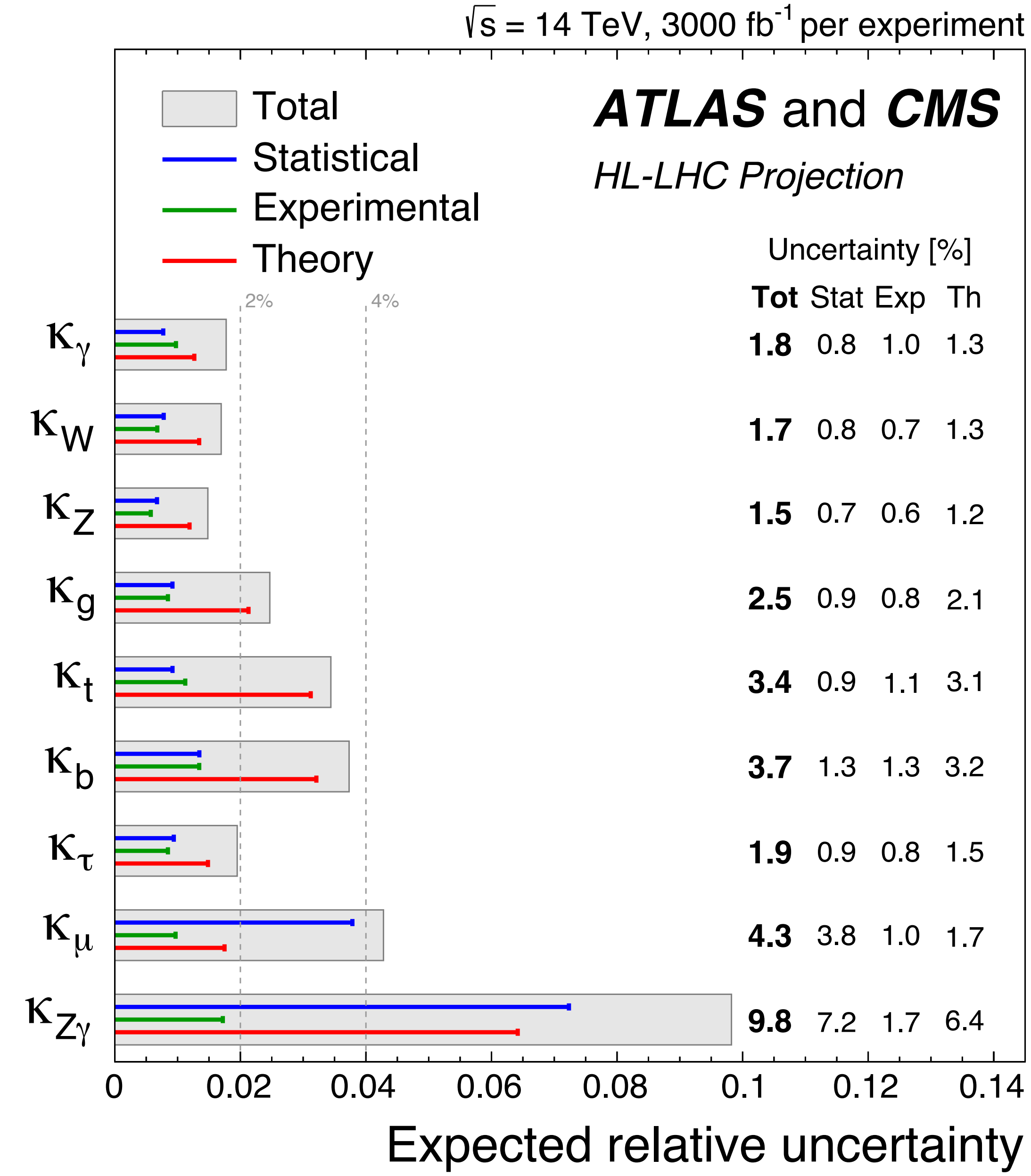
Nature 607 (2022) 60–68



Until when do we want to continue with κ-framework?

- LHC HXSWG interm recommendations (LHCHXSWG-2012-001)
- Worked well when looking for large deviation from SM in RUN-1(2), but…
- Limitations on LO coupling modifier
  - Missing higher-order calculations
    - QCD correction factorizes but not for EW
    - NLO EW O(5%) for ggF cross section
      - $d\sigma/\sigma = 2d\kappa/\kappa$ … O(2.5%) accuracy in κ
  - Zero-width approximation
    - O(10%) off-shell event in $gg \to (H) \to VV$
  - Signal interference effects
    - $gg \to (H) \to \gamma\gamma$, VV
  - Light fermions in loop (c,s,μ)
- Idem for EFT (though better motivated)

HL/HE-LHC Physics
CERN-2019-007

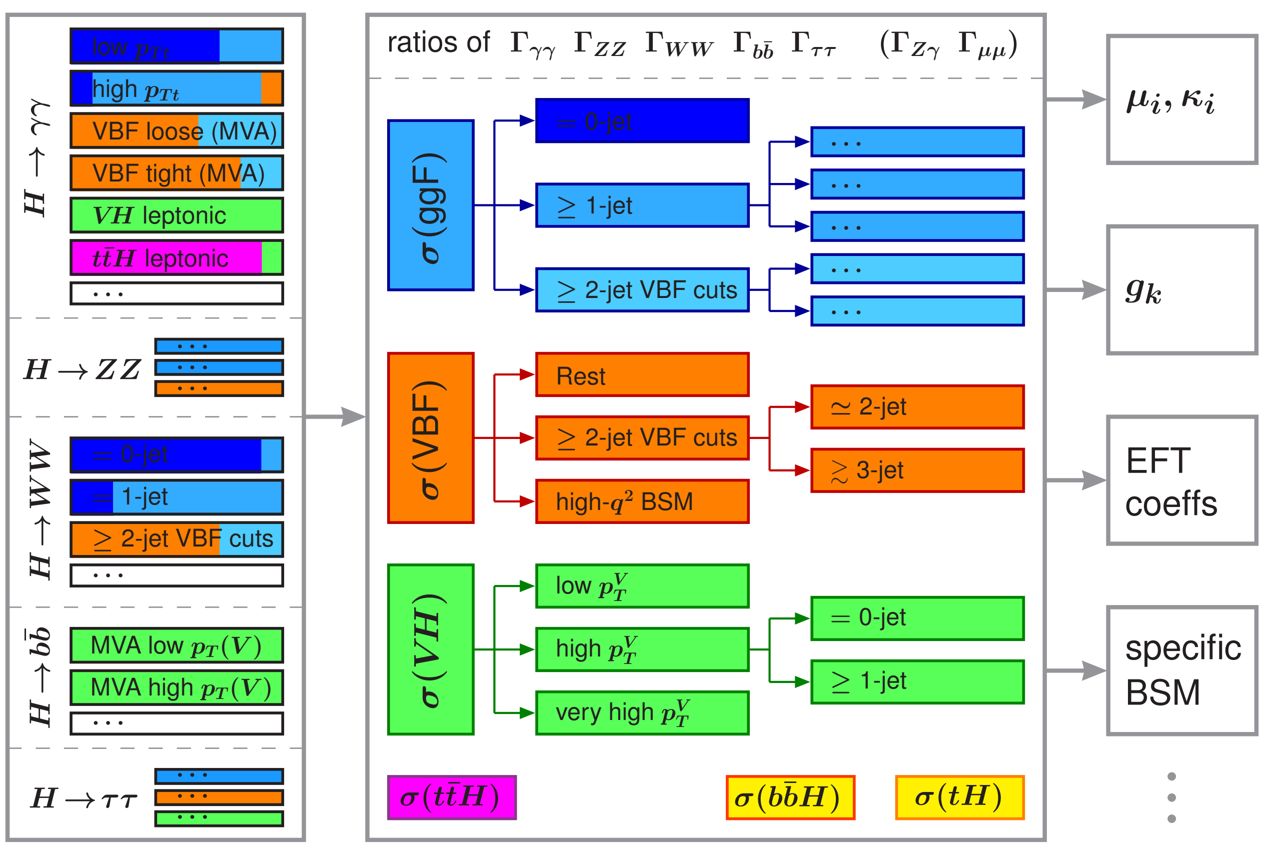


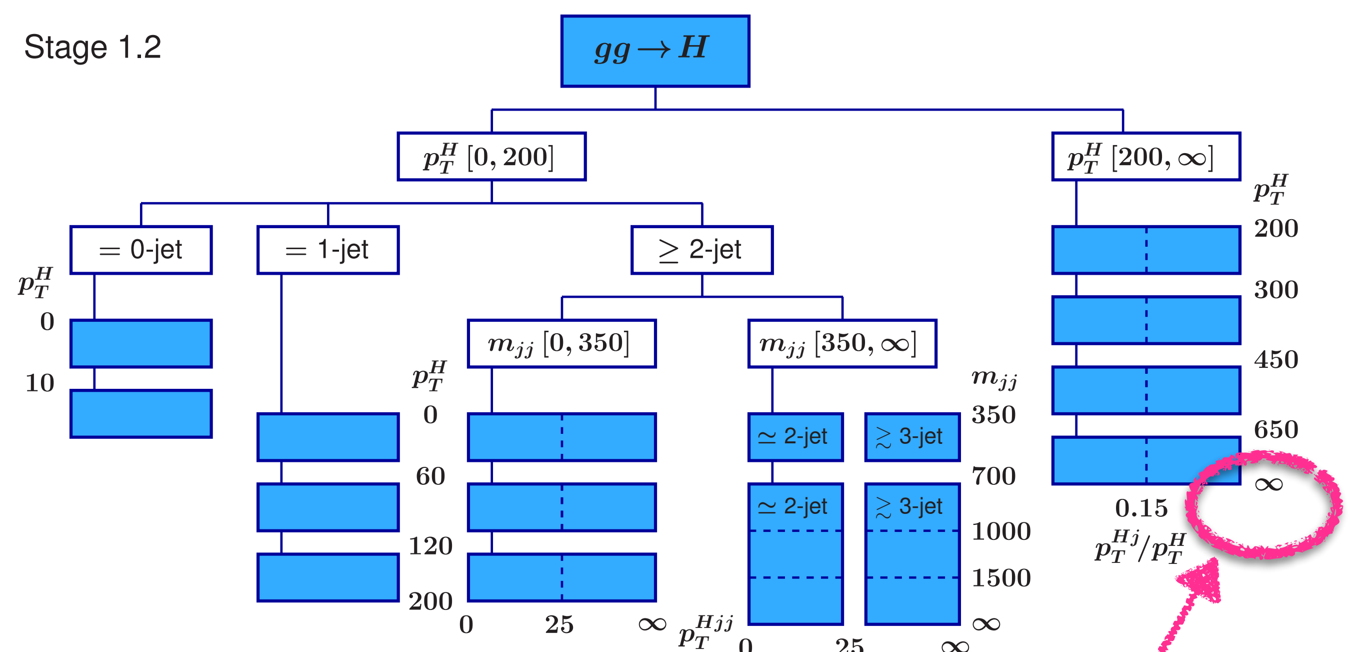
- Shouldn't we (TH+ATLAS+CMS) pursue joint efforts for complete 2-loop calculation to exploit the maximal physics output at LHC ?

Simplified Template Cross Section (STXS)

- Divide phase space into simplified "bins"
  - Maximize the measurement precision and the sensitivity to BSM contributions
  - Production cross sections times BR measured in mutually exclusive phase space regions
  - Based on production properties → allows combination of various decay modes
- Facilitates to compare/combine ATLAS+CMS results and to interpret theory models.
- Interpretation via Effective Field Theory (EFT)

- Fiducial Cross Section measurements in model-independent way.





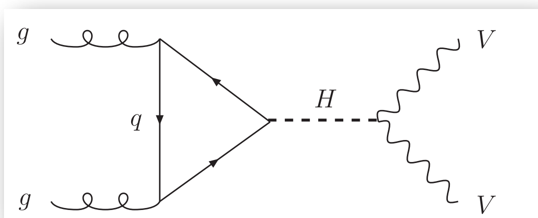
New physics might manifest itself in high pT bin.
Precise theory prediction needed.

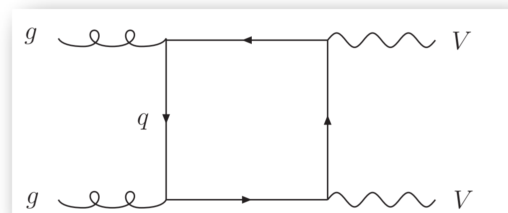
Off-shell Higgs Boson Production and Interference

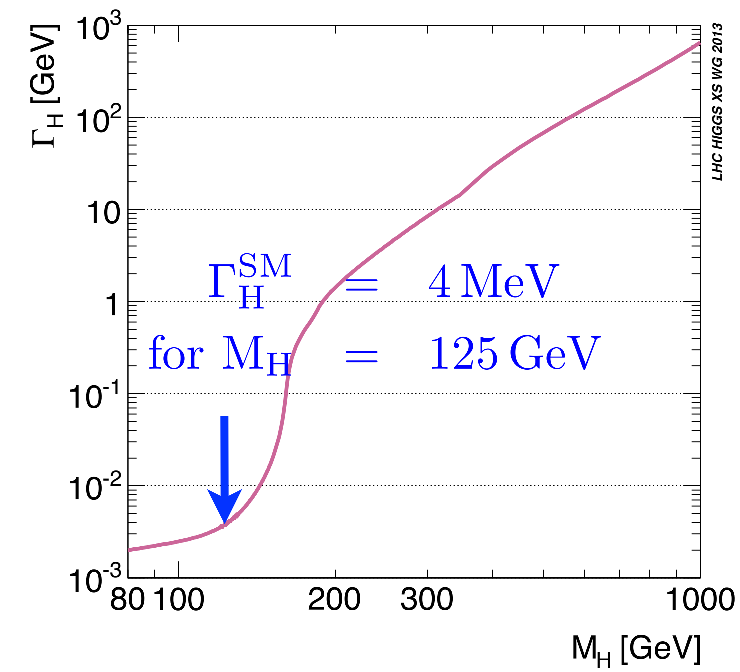
- Kauer-Passarino-Caola-Melnikov Effect
- Total gg→H→VV* receives an O(10%) off-shell correction
  - On-shell signal cross section is proportional to $1/\Gamma_H$
  - Off-shell signal cross section is independent of Γ_H
  - $\mu_{\text{off-shell}}/\mu_{\text{on-shell}}$ gives the information on Γ_H !
- Negative signal-background interference effect

$$\sigma^{\text{on-shell}}_{gg\to H\to VV} \sim \frac{g^2_{Hgg}\, g^2_{HVV}}{m_H \Gamma_H}$$

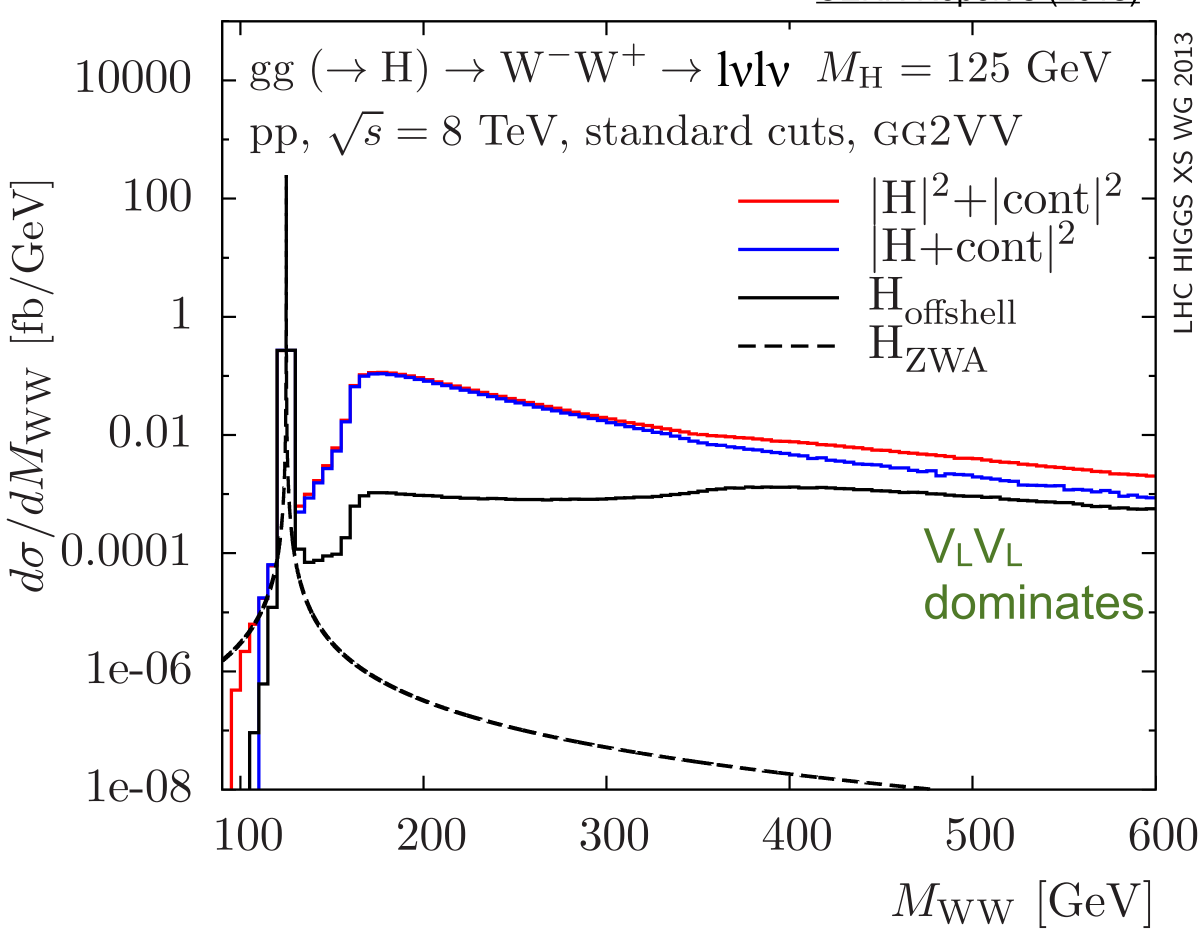
$$\sigma^{\text{off-shell}}_{gg\to H\to VV} \sim \frac{g^2_{Hgg}\, g^2_{HVV}}{m^2_{VV}}$$







CERN Report 3 (2013)



- 125GeV Higgs boson discovery by theorist ! Breit-Wigner has long-tail.
- Off-shell Sensitive to new physics
  ➪ EFT interpretation
- Large theoretical uncertainties in kinematical distributions due to QCD, PDF and EW corrections of O(20-30%) at high-mass.

Challenges beyond CERN Report 4 - selected topics

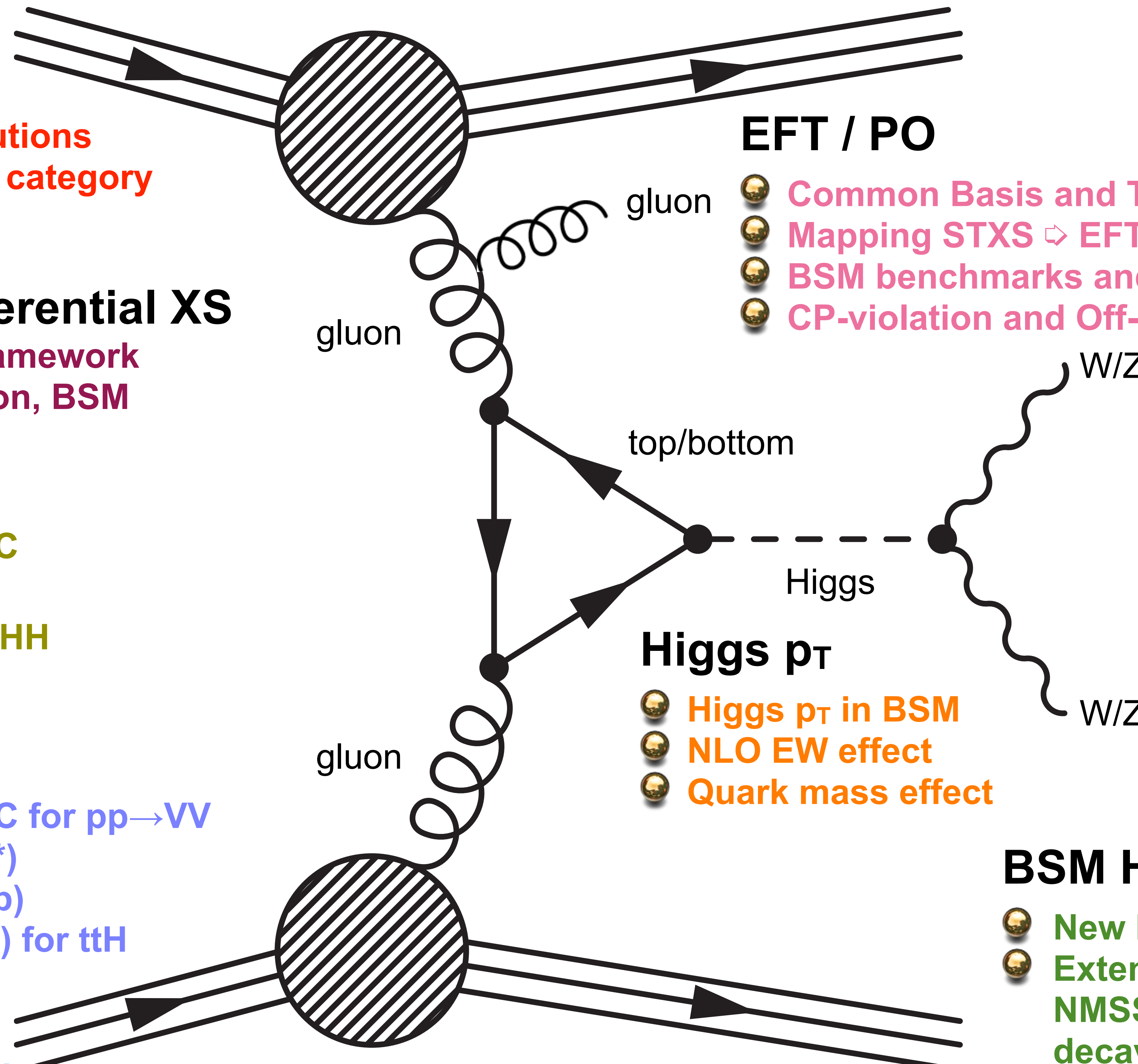
ggF
- N3LO differential distributions
- Reduction of ggF in VBF category
- Boosted Higgs XS

STXS & Fiducial/Differential XS
- Uncertainties in STXS framework
- STXS bins for CP-violation, BSM

(N)NLO MC
- NNLO QCD + NLO EW MC
- $\Delta\phi_{jj}$ in H+2-jets MC
- NLO MC for $gg\rightarrow VV$, ZH, HH
- PS Uncertainties

SM Backgrounds
- NNLO QCD + NLO EW MC for $pp\rightarrow VV$ (include off-shell, ex Z*Z*)
- V+HF modeling for VH(bb)
- ttbar+V/HF+jets (ttbb, ttV) for ttH

HH
- Combination of H and HH



EFT / PO
- Common Basis and Tools development
- Mapping STXS ➪ EFT
- BSM benchmarks and interpretation
- CP-violation and Off-shell Higgs interpret.

Higgs p_T
- Higgs p_T in BSM
- NLO EW effect
- Quark mass effect

BSM Higgs
- New benchmark scenario
- Extended Higgs, MSSM, NMSSM, Exotic Higgs decays, bbH/bH

PDF
- N3LO PDF set for N3LO, missing higher-order correction
- Reduction of PDF (small/large-x) and α_s uncertainties
- Inclusion of EW corrections

Tools for Higgs Analysis

ggF
- ihixs (N3LO QCD+NLO EW)
- HIGLU (NNLO QCD+NLO EW)
- FeHiPro (NNLO QCD+NLO EW)
- HNNLO, HRes (NNLO+NNLL QCD)
- RGHiggs (NNLO+NNNLL QCD)
- SusHi, aMCSusHi (N3LO/NLO QCD)
- ggHiggs (N3LO QCD)
- TROLL (N3LL' QCD)

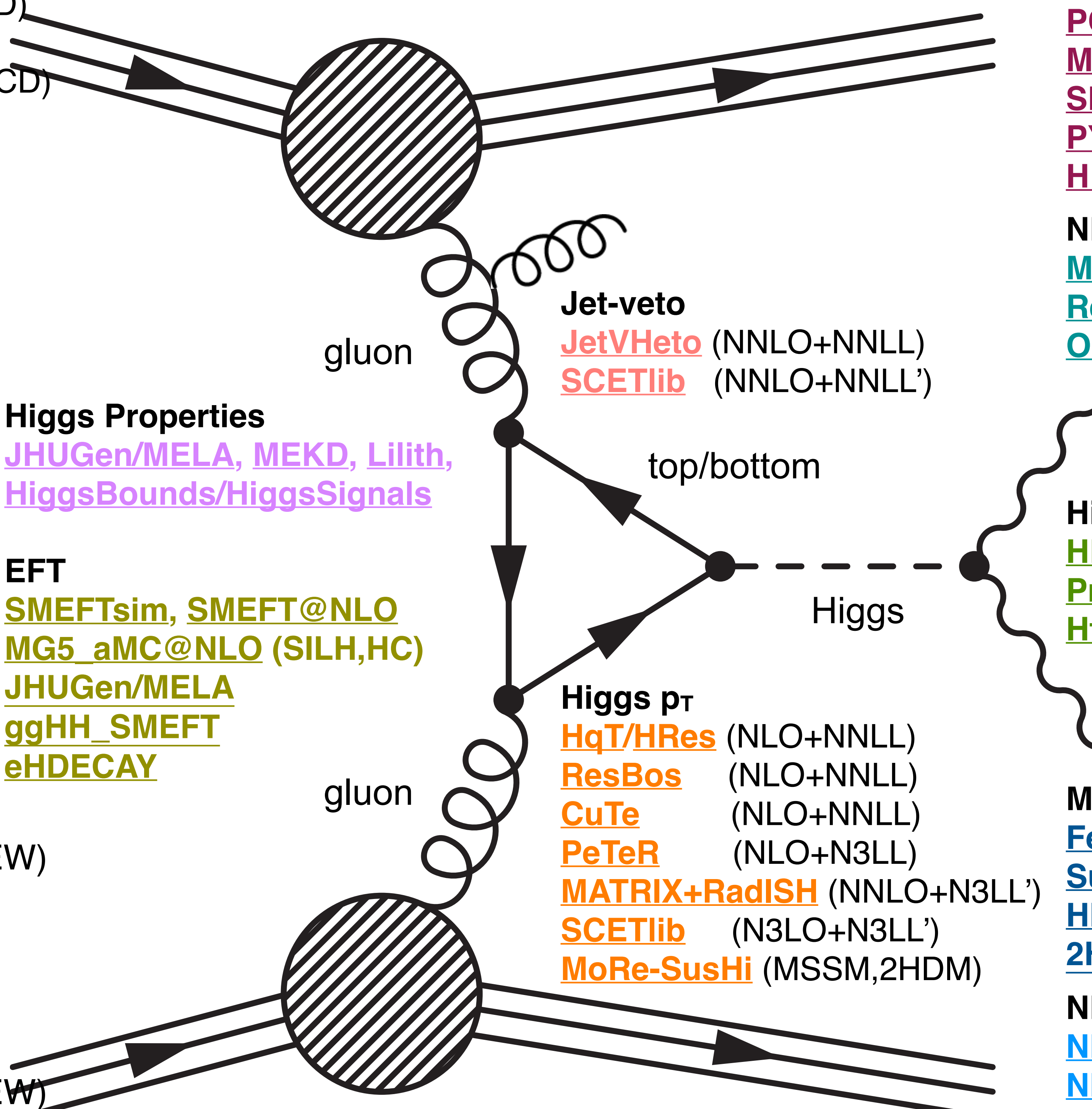
VBF
- VV2H (NLO QCD)
- VBFNLO (NLO QCD)
- HAWK (NLO QCD+EW)
- VBF@NNLO (NNLO QCD)
- HJets (NLO QCD)
- proVBFH (NNLO QCD)

WH/ZH
- V2HV (NLO QCD)
- HAWK (NLO QCD+EW)
- VH@NNLO (NNLO)

ttH
- HQQ (LO QCD)
- POWHEL (NLO QCD)
- MG5_aMC@NLO (NLO QCD+EW)

bbH
- bbh@NNLO (NNLO QCD)
- bbhFONLL (NLO+NNLL QCD)
- bbX (NLO+NNLL QCD)
- MG5_aMC@NLO (NLO QCD+EW)

HH
- HPAIR (NLO QCD)
- ggHH (NLO QCD)
- proVBFHH (NNLO QCD)



Higgs Properties
JHUGen/MELA, MEKD, Lilith, HiggsBounds/HiggsSignals

EFT
- SMEFTsim, SMEFT@NLO
- MG5_aMC@NLO (SILH,HC)
- JHUGen/MELA
- ggHH_SMEFT
- eHDECAY

Jet-veto
- JetVHeto (NNLO+NNLL)
- SCETlib (NNLO+NNLL')

Higgs p_T
- HqT/HRes (NLO+NNLL)
- ResBos (NLO+NNLL)
- CuTe (NLO+NNLL)
- PeTeR (NLO+N3LL)
- MATRIX+RadISH (NNLO+N3LL')
- SCETlib (N3LO+N3LL')
- MoRe-SusHi (MSSM,2HDM)

PDF: MMHT/MSHT, CTEQ, NNPDF, EKO, xFitter, PDF4LHC, ... METAPDF, LHAPDF, HOPPET, APFEL

SM: MCFM, MATRIX. MG5_aMC@NLO, VVamp, gg2VV, DiffTop, ...

NNLO+PS MC
- NNLOPS (MiNLO'+reweighting)
- MiNNLO
- GenEvA

NLO+PS MC (Multi-purpose)
- POWHEG-BOX
- MadGraph5_aMC@NLO
- SHERPA MEPS@NLO
- PYTHIA8 UNLOPS
- HERWIG7 Matchbox

NLO ME/Automated NLO
MCFM, MG5_aMC@NLO, Recola, GoSam, HELAC, OpenLoops, BlackHat, etc.

Higgs Decay
- HDECAY (NLO++)
- Prophecy4f (NLO QCD+EW)
- Hto4l (NLO QCD+EW)

MSSM/2HDM
- FeynHiggs, CPSuperH
- SusHi+2HDMC
- HIGLU+HDECAY
- 2HDECAY

NMSSM
NMSSMCALC (EW), NMSSMTools, FlexibleSUSY, SOFTSUSY, SPheno

+ many codes for BSM physics

Clickable Link (July 4th 2022) Suggestions to R. Tanaka

Theory Paper Citations

- It is up to ATLAS and CMS collaborations to decide which theory papers to quote in their Higgs papers.
- We made some efforts to cite all relevant theory papers in the Higgs discovery paper in 2012.
  - ATLAS 38, CMS 47 papers for Higgs XS&BR+PDF
  - Was a bit chaos when asked to theorists.
- Proper theory paper citations are the vital issue for theory community.

ATLAS : PLB 716 (2012) 1–29

3. Signal and background simulation samples

The SM Higgs boson production processes considered in this analysis are the dominant gluon fusion ($gg \to H$, denoted ggF), vector-boson fusion ($qq' \to qq'H$, denoted VBF) and Higgs-strahlung ($qq' \to WH, ZH$, denoted WH/ZH). The small contribution from the associated production with a $t\bar{t}$ pair ($q\bar{q}/gg \to t\bar{t}H$, denoted $t\bar{t}H$) is taken into account only in the $H \to \gamma\gamma$ analysis.

For the ggF process, the signal cross section is computed at up to next-to-next-to-leading order (NNLO) in QCD [22–28]. Next-to-leading order (NLO) electroweak (EW) corrections are applied [29, 30], as well as QCD soft-gluon re-summations at up to next-to-next-to-leading logarithm (NNLL) [31]. These calculations, which are described in Refs. [32–35], assume factorisation between QCD and EW corrections. The transverse momentum, p_{T}, spectrum of the Higgs boson in the ggF process follows the HqT calculation [36], which includes QCD corrections at NLO and QCD soft-gluon re-summations up to NNLL; the effects of finite quark masses are also taken into account [37].

For the VBF process, full QCD and EW corrections up to NLO [38–41] and approximate NNLO QCD corrections [42] are used to calculate the cross section. Cross sections of the associated WH/ZH processes (VH) are calculated including QCD corrections up to NNLO [43–45] and EW corrections up to NLO [46]. The cross sections for the $t\bar{t}H$ process are estimated up to NLO QCD [47–51].

The total cross sections for SM Higgs boson production at the LHC with $m_H = 125$ GeV are predicted to be 17.5 pb for $\sqrt{s} = 7$ TeV and 22.3 pb for $\sqrt{s} = 8$ TeV [52,53].

The branching ratios of the SM Higgs boson as a function of m_H, as well as their uncertainties, are calculated using the HDECAY [54] and PROPHECY4F [55,56] programs and are taken from Refs. [52,53]. The interference in the $H \to ZZ^{(*)} \to 4\ell$ final states with identical leptons is taken into account [55,56,53].

CMS: PLB 716 (2012) 30–61

4. Searches for the standard model Higgs boson

Initial phenomenological discussions of Higgs boson production and decay can be found in Refs. [49–56]. Four main mechanisms are predicted for Higgs boson production in pp collisions: the gluon–gluon fusion mechanism, which has the largest cross section, followed in turn by vector-boson fusion (VBF), associated WH and ZH production (VH), and production in association with top quarks ($t\bar{t}$H). The cross sections for the individual production mechanisms and the decay branching fractions, together with their uncertainties, have been computed following Refs. [57–101] and are compiled in Refs. [23,102].

LHC Higgs (XS) Working Group - Initial Phase

- It was always easy among initial overall contacts (Chiara, Giampiero and Stefan + Sven in 2nd phase) to steer the working group.
- Typical response from Giampiero:

PG **Passarino Giampiero** October 9, 2010 15:04

Re: YR task sharing

To: Reisaburo TANAKA, Cc: Dittmaier Stefan, Passarino Giampiero, Chiara Mariotti & 1 more Details

Some changes/additions, shoot it and shhot it now!

best

Giampiero,

%---

Dear all,

There is some partialprogress for our CERN Yellow Report.
To keep the documentation coherent throughout the report, we would like
to ask you, once again, to follow the instructions:

- *Sense of trust among overall contacts. Thank you for this from my side.*

Reflections and Prospects

- The LHC Higgs Cross Section Working Group brought together the TH and EXP communities working on the Higgs physics.
  - Provided the state-of-the-art Higgs XS&BR since the beginning.
    - Enabled early determination of the nature of "Higgs-like" particle.
  - Our mandate was originally Higgs XS&BR only but gradually we gained the confidence from ATLAS and CMS collaborations and expanded our activities to Higgs property measurements, BSM Higgs physics and now to HH.
  - Attempts were made for proper theory paper citation as it is vital (citation policy owes to ATLAS&CMS).
  - LHC Higgs XS WG became the role model for many LHC wide working groups.
- Collaboration between TH and EXP is even more necessary now to find any hints for BSM physics.
  - There are many areas where experimental and theoretical uncertainties are competing.
  - How to go beyond κ-framework? Collaborative work to go to complete 2-loop calc. ?
  - LHC Higgs WG should remain as the forum to assemble physicists at front line from both theory and experimental communities.

backup

Parton Distribution Functions (PDF)

PDF4LHC Prescription:

- Uncertainty provided by the envelope of PDF sets and central prediction as mid-point.
- Large improvements in PDF due to inclusion of LHC data and improve in the fitting formalisms.
- PDF4LHC15: ggF PDF⊕α_s uncertainty at $\sqrt{s}$=14TeV for M_H=125GeV:
  +8-7% → **±3.2% (PDF ±1.9%, α_s ±2.6%)**
- Alternative PDF sets: ABM12, CJ15, HERAPDF2.0, JR14 (richness of this field !)
- New PDF4LHC21: Good agreement between global PDF fits in both gg- and qq-parton luminosities and reduction in uncertainties !

- **PDF4LHC** (2011) NLO
  CT10, MSTW2008, NNPDF2.3
- **PDF4LHC15** (2015) NNLO
  CT14, MMHT2014, NNPDF3.0
- **PDF4LHC21** (2022) NNLO
  CT18, MSHT20, NNPDF3.1