WP2: predictions and simulations of signal and background: theory part

Gudrun Heinrich

Max Planck Institute for Physics, Munich

1st Annual **HiggsTools** Meeting

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WP2 tasks

1. Improved predictions for Standard Model-like Higgs scenarios
2. Improved predictions for non-standard electroweak symmetry breaking scenarios
3. Backgrounds

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cutting edge calculations at the precision frontier

Tasks and Milestones

Task 2.1:

Improved predictions for Standard Model-like Higgs scenarios

M2.1.1 Specialised codes for the SM-like Higgs boson scenario

M2.1.2 Better control of theoretical uncertainties for the SM-like Higgs boson scenario

Task 2.2:

Improved predictions for non-standard electroweak symmetry breaking scenarios

M2.2.1 Precision calculations for vector boson scattering

M2.2.2 Precision calculations of non-standard Higgs boson scenarios

M2.2.3 Standardised description for non-standard Higgs boson interactions

M2.2.4 Interpretation of experimental data in the light of M2.2.3

Tasks and Milestones

Task 2.3: Backgrounds

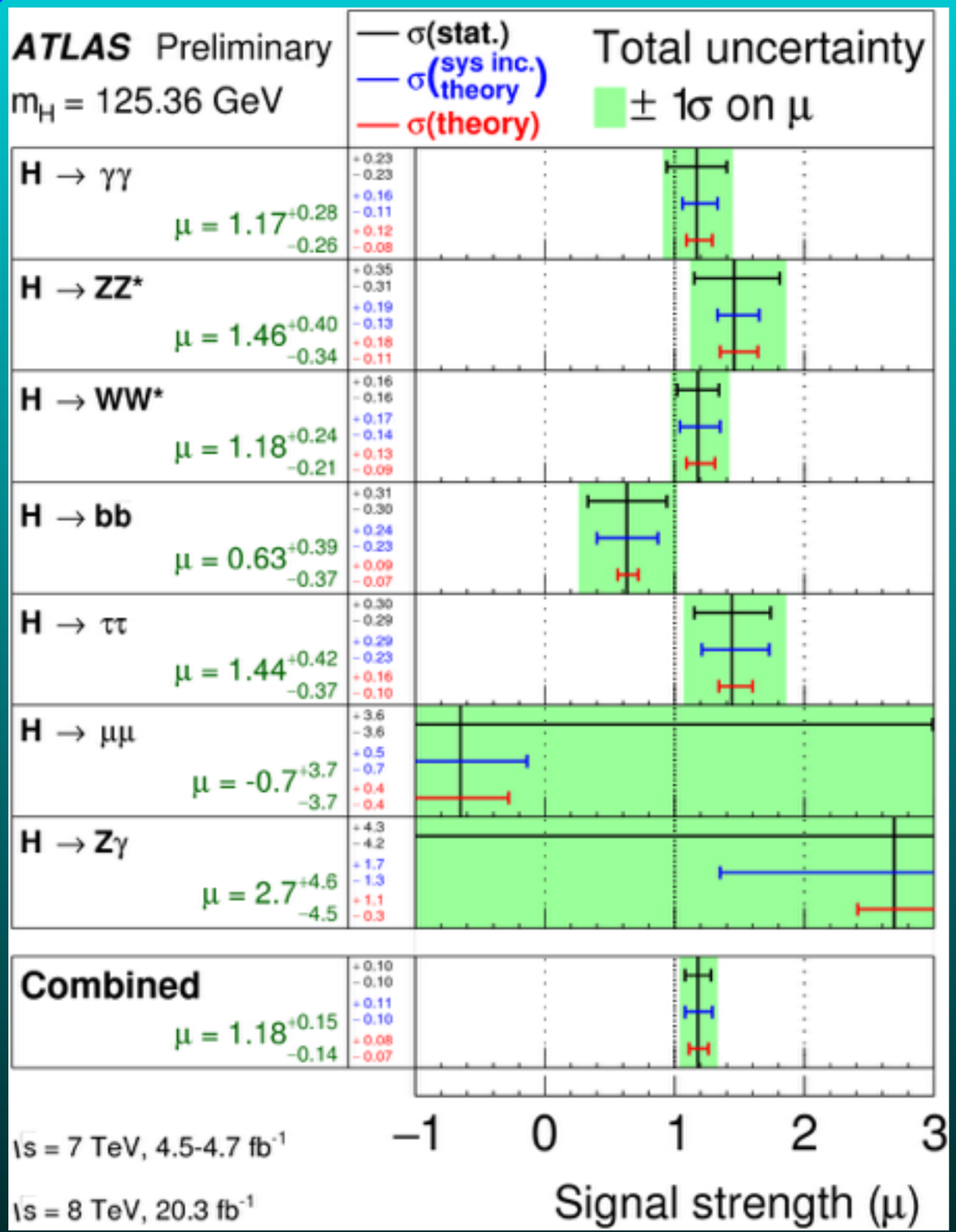
M2.3.1 Validation of key Higgs background processes and evaluation of uncertainties derived from extrapolating them to signal regions

M2.3.2 Better control of theoretical uncertainties

M2.3.3 Specialised codes for low multiplicity background processes

Higgs: status today

- σ x BR measured to 20-30%
- couplings (to vector bosons, fermions) measured to 15-20%



$$\mu = \sigma / \sigma_{SM}$$

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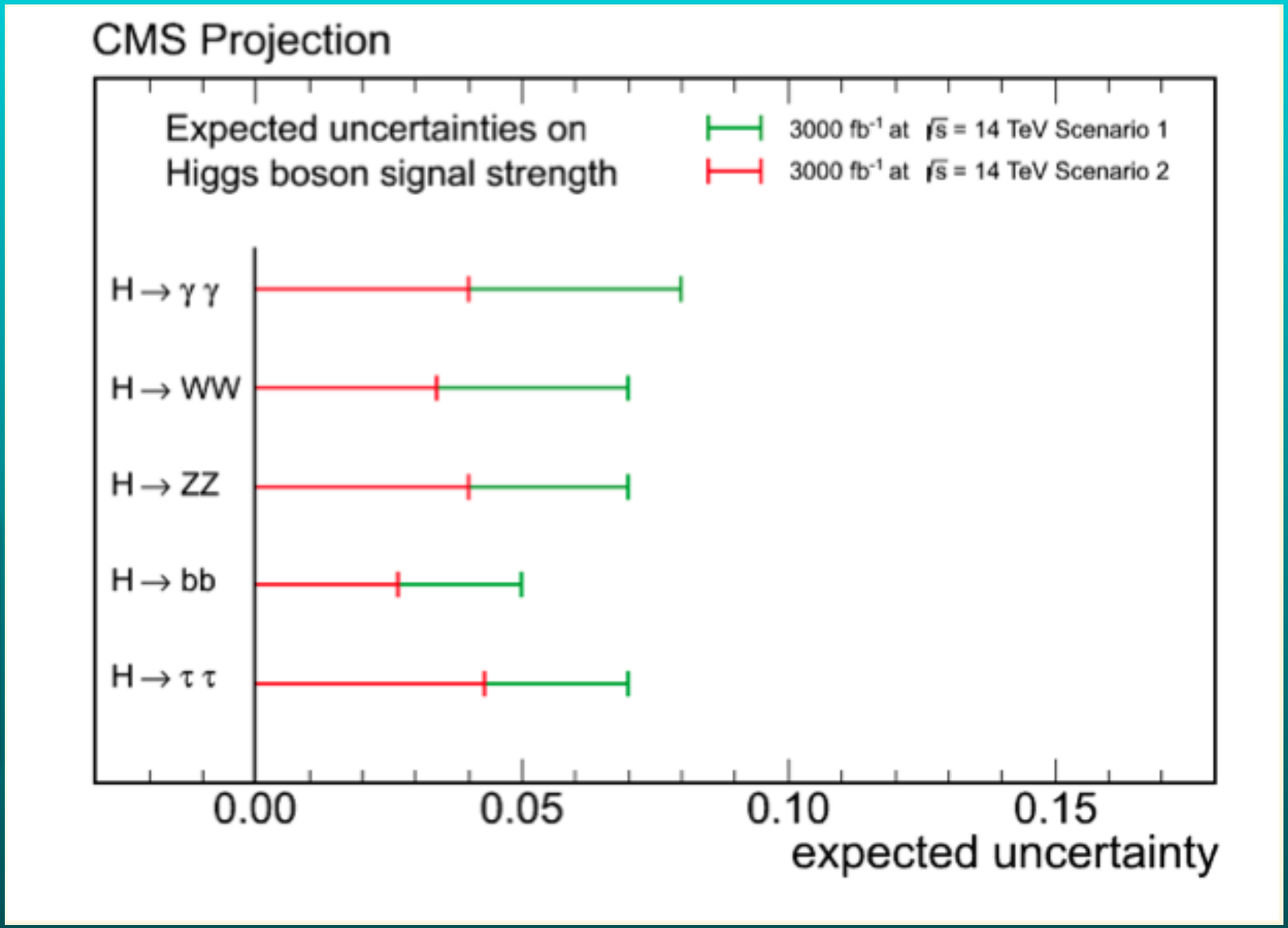
theorists wanted

scenario 1:

use current systematic uncertainties

scenario 2:

assume theory systematics improve by 50%,
scale exp. systematics by luminosity



Si Xie, Moriond 2015

tasks for LHC Run II (and beyond)

- Higgs properties: reduce uncertainties/establish:
  - Higgs couplings to b quarks
  - Higgs couplings to 2nd generation
  - Higgs to Z gamma
  - Higgs to invisible
  - anomalous couplings
  - Higgs self coupling and potential

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viable BSM models typically induce modifications in (some of) these of order ~1%-10%

→ **need precision calculations!**

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→ **need precision calculations!**

- find new particles/resonances

Status: precision frontier

impressive achievements !

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impressive achievements !

- Wγ and Zγ production at the LHC in NNLO QCD

  M. Grazzini, S. Kallweit, D. Rathlev arXiv:1504.01330

- Two-loop helicity amplitudes for $q\bar{q}'$, gg→V1V2→4 leptons

  T. Gehrmann, A. von Manteuffel, L. Tancredi arXiv:1503.04812

  arXiv:1503.08835

- Precise QCD predictions for the production of Higgs+jet final states

  X. Chen, T. Gehrmann, E.W.N. Glover, M. Jaquier arXiv:1408.5325

- W+W- production at hadron colliders in NNLO QCD

  T. Gehrmann, M. Grazzini, S. Kallweit, P. Maierhöfer, A. von Manteuffel, S. Pozzorini, D. Rathlev, L. Tancredi arXiv:1408.5243

UDUR/ZH nodes

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precision frontier

- Second order QCD corrections to gluonic jet production at hadron colliders arXiv:1407.5558

  J. Currie, A. Gehrmann-De Ridder, T. Gehrmann, N. Glover, J. Pires, S. Wells

- ZZ production at hadron colliders in NNLO QCD arXiv:1405.2219

  F. Cascioli, T. Gehrmann, M. Grazzini, S. Kallweit, P. Maierhöfer, A. von Manteuffel, S. Pozzorini, D. Rathlev, L. Tancredi, E. Weihs

- NNLO QCD corrections to top-antitop production in the qqbar channel

  G. Abelof, A. Gehrmann-De Ridder, P. Maierhöfer, S. Pozzorini

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- Updated Higgs cross section at approximate N3LO

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- Higgs boson gluon-fusion production at N3LO arXiv:1503.06056

  C.Anastasiou, C.Duhr, F.Dulat, F.Herzog, B.Mistlberger

UDUR/DFTTO/ZH nodes

precision frontier: beyond fixed order

- The method of regions and next-to-soft corrections in Drell-Yan production

  D. Bonocore, E. Laenen, L. Magnea, L. Vernazza, C. D. White

  arXiv:1410.6406

- Resummation prescriptions and ambiguities in SCET vs. direct QCD: Higgs production as a case study

  M. Bonvini, S. Forte, G. Ridolfi, L. Rottoli arXiv:1409.0864

UDUR/FOM/DFTTO nodes

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multi-particle final states

- Triple vector boson production through Higgs-Strahlung with NLO multijet merging

  S. Höche, F. Krauss, S. Pozzorini, M. Schönherr,
  J. M. Thompson, K. Zapp arXiv:1403.7516

- NLO electroweak automation and precise predictions for W+multijet production at the LHC

  S. Kallweit, J. Lindert, P. Maierhöfer, S. Pozzorini, M. Schönherr
  arXiv:1412.5157

- Next-to-leading order QCD predictions for top-quark pair production with up to two jets merged with a parton shower

  S. Höche, F. Krauss, P. Maierhöfer, S. Pozzorini,
  M. Schönherr, F. Siegert arXiv:1402.6293

UDUR/ZH nodes

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getting a handle on Higgs properties

- Unitarity-controlled resonances after Higgs discovery

C. Englert, P. Harris, M. Spannowsky, M. Takeuchi arXiv:1503.07459

investigate constraints on/effects of resonances in the Higgs sector which could show up in vector boson scattering at high energies

- On-shell interference effects in Higgs final states

C. Englert, Ian Low, M. Spannowsky arXiv:1502.04678

in the search for additional (heavy) Higgs states, interference effects (h-H, H-continuum) need to be taken into account

- Off-shell effects in Higgs processes at a linear collider and implications for the LHC

S. Liebler, G. Moortgat-Pick, G. Weiglein arXiv:1502.07970

off-shell effects in h -> VV very important at high energies at a LC, as well a precise knowledge of Higgs mass; study of h-H interference effects in 2HDM*

UDUR/DESY nodes

BSM Higgs boson scenarios

- Excessive Higgs pair production with little MET from squarks and gluinos in the NMSSM

  Ulrich Ellwanger, Ana M. Teixeira arXiv:1412.6394

- Possible explanation of excess events in the search for jets, missing transverse momentum and a Z boson in pp collisions

  Ulrich Ellwanger arXiv:1504.02244

CNRS node

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Looking ahead

selected topics of “work in progress”

BSM:

- Scan the parameter space of the Higgs sector of appealing BSM models which are consistent with present data
- Identify, for the various viable ranges of Higgs masses and decays the most promising signal rates
  (= production cross sections times branching fraction) for LHC Run II

CNRS (NMSSM) / DESY (complex MSSM) / DFTTO (EFT) nodes

SM:

- push the precision frontier in fixed order calculations (NNLO and beyond)
- better description of multi-jet/multi-particle final states
- inclusion of heavy quark effects
- complement fixed order approach by resummation, EFT, …

UDUR/ALU-FR/DESY/DFTTO/ETH/FOM/ IFJ-PAN/NCSR-D/UGR nodes

selected topics of work in progress

- study of $pp \to t\bar{t}\,b\bar{b}$ at NLO QCD including shower (main background to ttH)

  massive b-quarks, particular emphasis on study of impact of $g \to b\bar{b}$ splitting

- single top production at NNLO

  use 2-loop form factor approach, benefit from master integrals calculated by differential equations method

- QCD corrections to the two-Higgs doublet model (THDM)

  start with H+ H- production in VBF at NNLO QCD

FOM node

selected topics of work in progress

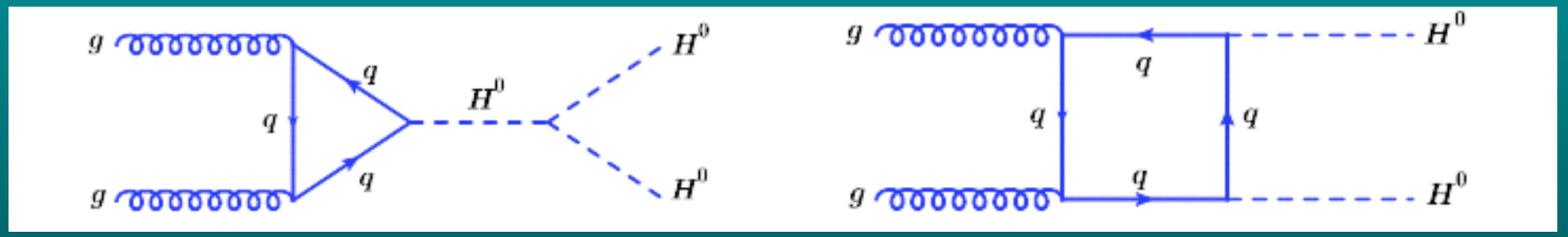
• double Higgs production with full top mass dependence at NLO

Higgs self couplings:

measurement of trilinear H coupling feasible at HL-LHC

dominant reaction $gg \to HH$

LO: loop induced ➡ NLO: 2 loops



$m_t \to \infty$ limit poor beyond threshold at $\sqrt{s} = 2\,m_H$

➡ need full m_t dependence ➡ need 2-loop box integrals with m_t, m_H

ALU-FR node

Outlook

"There is nothing new to be discovered in physics now.
All that remains is more and more precise measurement"

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Lord Kelvin 1900

Outlook

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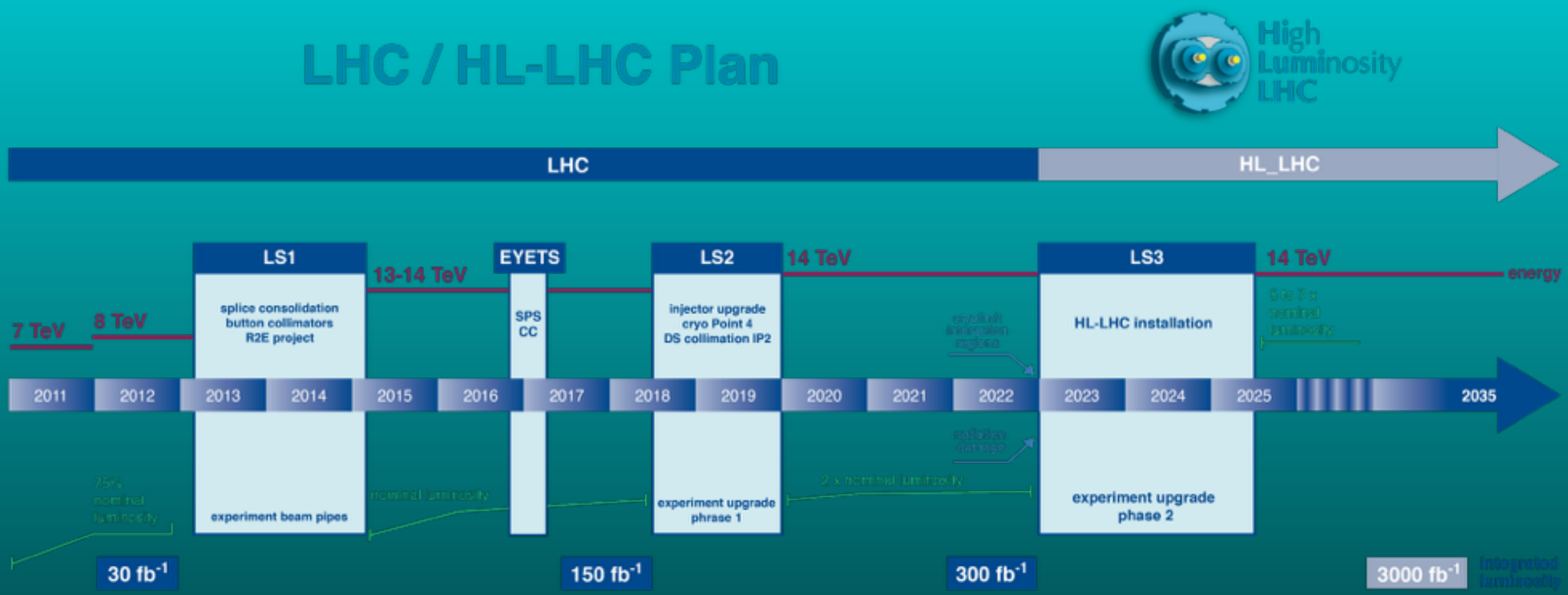
- with **H** being discovered, we probably see only the tip of the iceberg
- precision calculations/simulations are a way to uncover what is underneath with current/future data
- the HiggsTools network will contribute to a better understanding of electroweak symmetry breaking

extra slides

LHC Schedule



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