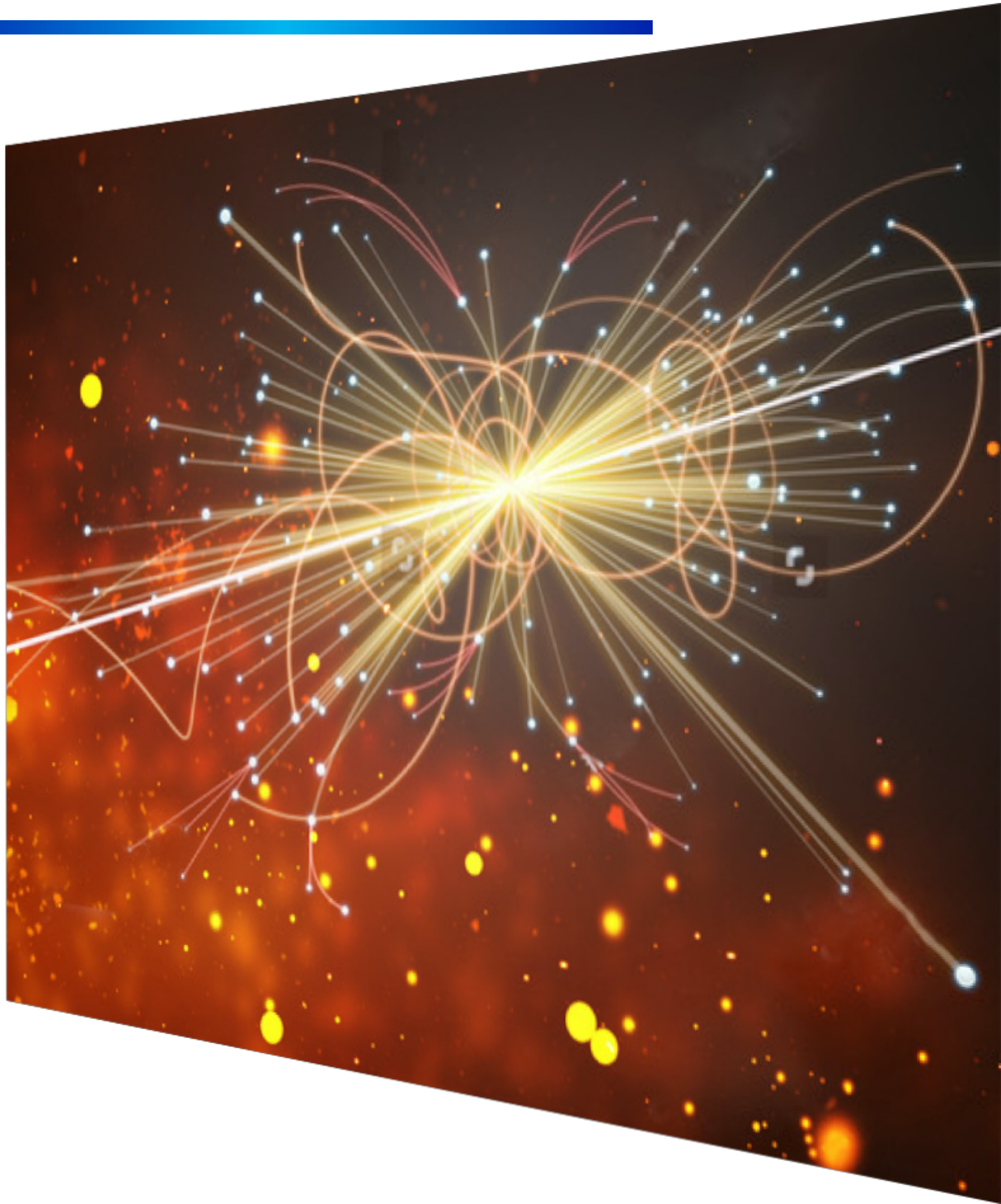
HL-LHC:
Prospects and Future



Matthias Kasemann
DESY
Germany

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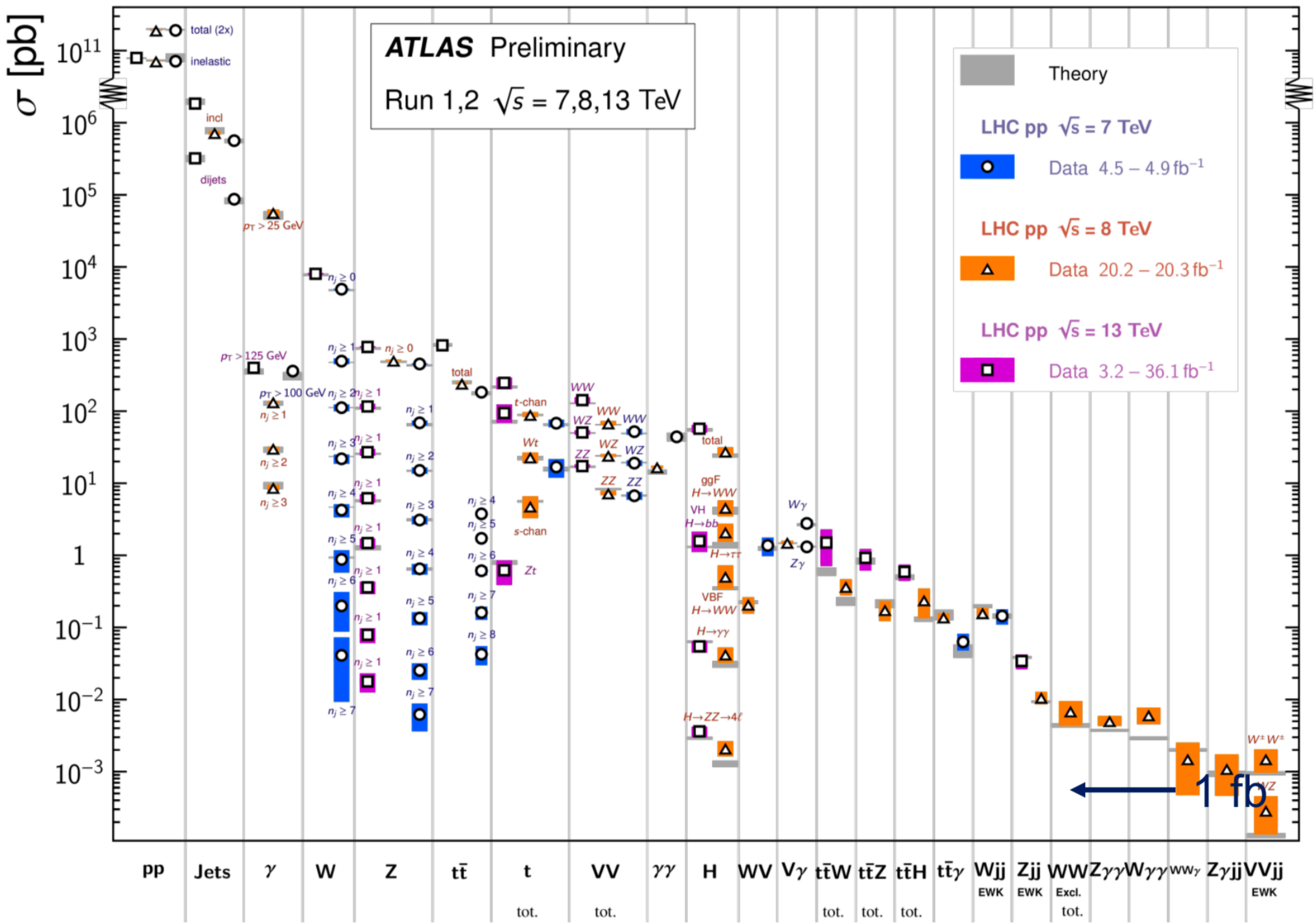
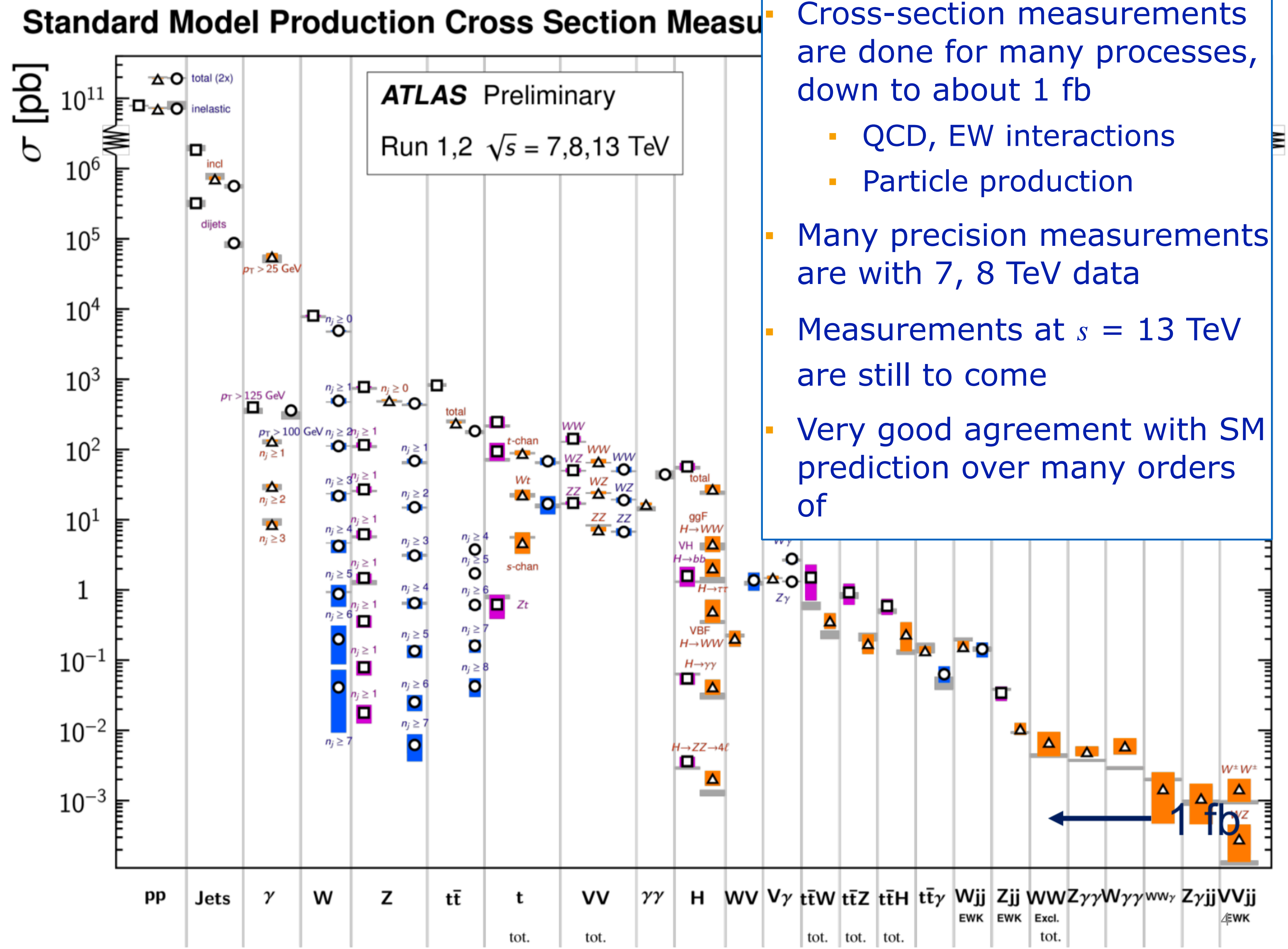
Outline - Abstract

- The Large Hadron Collider (LHC) has been successfully delivering proton-proton collision data at the unprecedented center of mass energy of 13 TeV.
- An upgrade is planned to increase the instantaneous luminosity delivered by LHC, aiming to deliver a total of about 3000/fb of data per experiment.
- To cope with the expected data-taking conditions ATLAS and CMS are planning major upgrades of the detector.
- Increased physics reach is expected for a wide range of measurements and searches at the HL-LHC for ATLAS and CMS:
  - Higgs coupling
  - di-Higgs boson production sensitivity
  - Vector Boson Scattering prospects
  - Discovery potential for electroweak SUSY and other exotic benchmark scenarios.

Standard Model Production Cross Section Measurements

Status: March 2018





- Cross-section measurements are done for many processes, down to about 1 fb
  - QCD, EW interactions
  - Particle production
- Many precision measurements are with 7, 8 TeV data
- Measurements at s = 13 TeV are still to come
- Very good agreement with SM prediction over many orders of

Physics at the High Luminosity LHC

- Precision measurements to be performed:
  - Tests of SM properties of Higgs in terms of couplings to vector bosons & fermions
  - Measure rare decays of Higgs (eg., H->μμ, H->Zγ)
  - Measure self-coupling of Higgs
  - Explore SM dynamics, from flavour physics in B decays at GeV scale to TeV scale scattering of W boson pairs

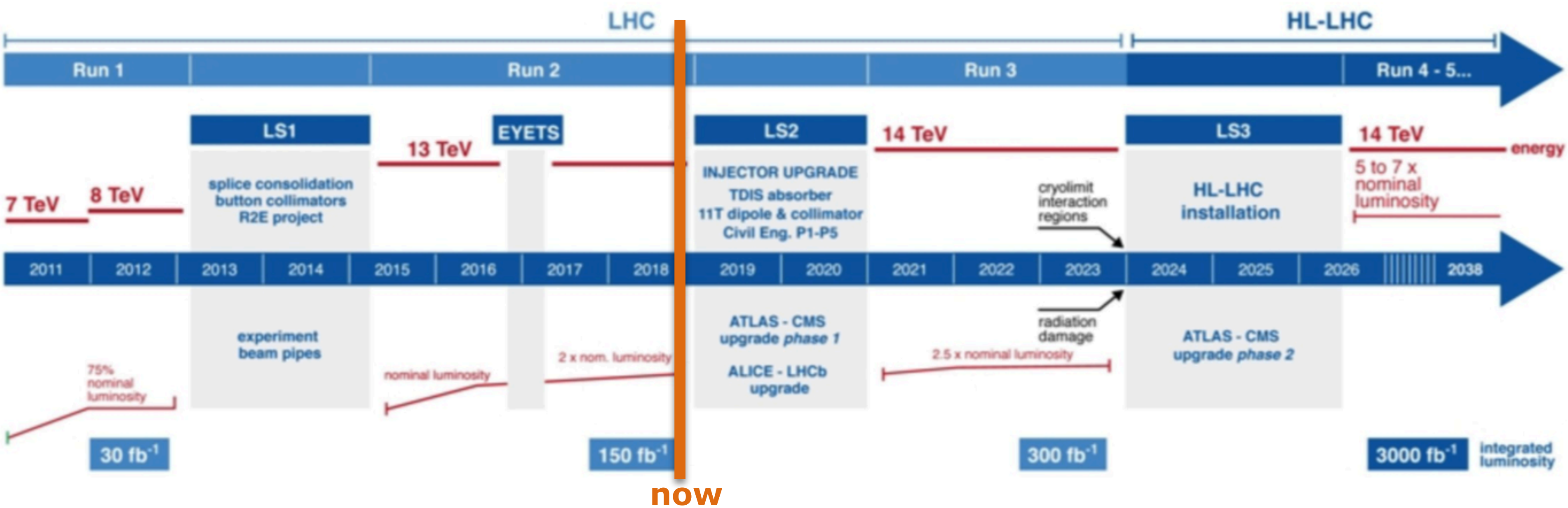
- In case of a discovery in Run2/Run3:
  - Find the detailed characteristics → 300 fb^{-1} is not enough!

- The High Lumi LHC (HL-LHC) is a discovery machine.

LHC upgrade to High Luminosity

- The accelerator will be upgraded to provide ~3-4 times higher luminosity by 2026
  - Luminosity:
    Phase I: < 2.2 x 10^{34} $cm^{-2}s^{-1}$
    Phase II: (5)7.5 x 10^{34} $cm^{-2}s^{-1}$
  - Planned to deliver 3-4000 fb^{-1} until 2037

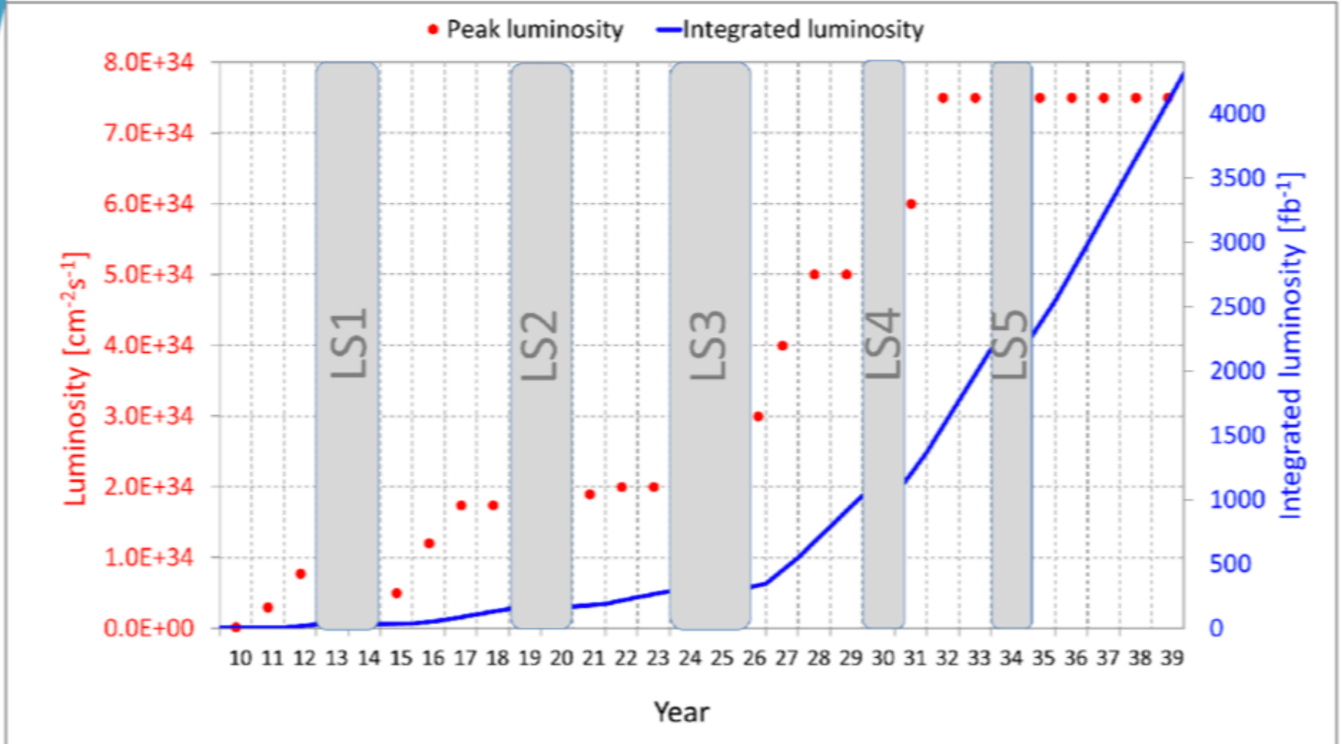
	LHC	HL-LHC
Pileup	~60	~140-200
Dataset	300/fb	3000-4000/fb
Instantaneous Lumi	~2x10^{34}	5-7.5x10^{34}



Overview: Current View of HL-LHC

- Overview of “ultimate luminosity” scenario – 7.5x10^{34}, high availability:

Luminosity profile: ULTIMATE

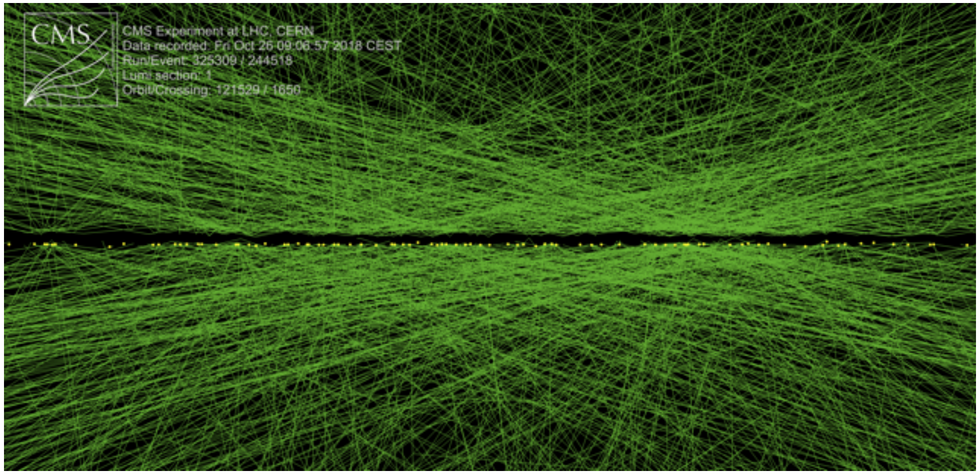


After LS4, proton physics days increase from standard 160 days to 200 and after LS5 to 220

L Rossi @ CM6 - HL status - Paris 14 Noc 2016 4

HL-LHC data taking

- 14 TeV center of mass energy
  - 6000 primary tracks per event
- Simultaneous events (Pileup) increases from ~60 to 140-200
  - Pileup of 135 reached in test run in October 2018

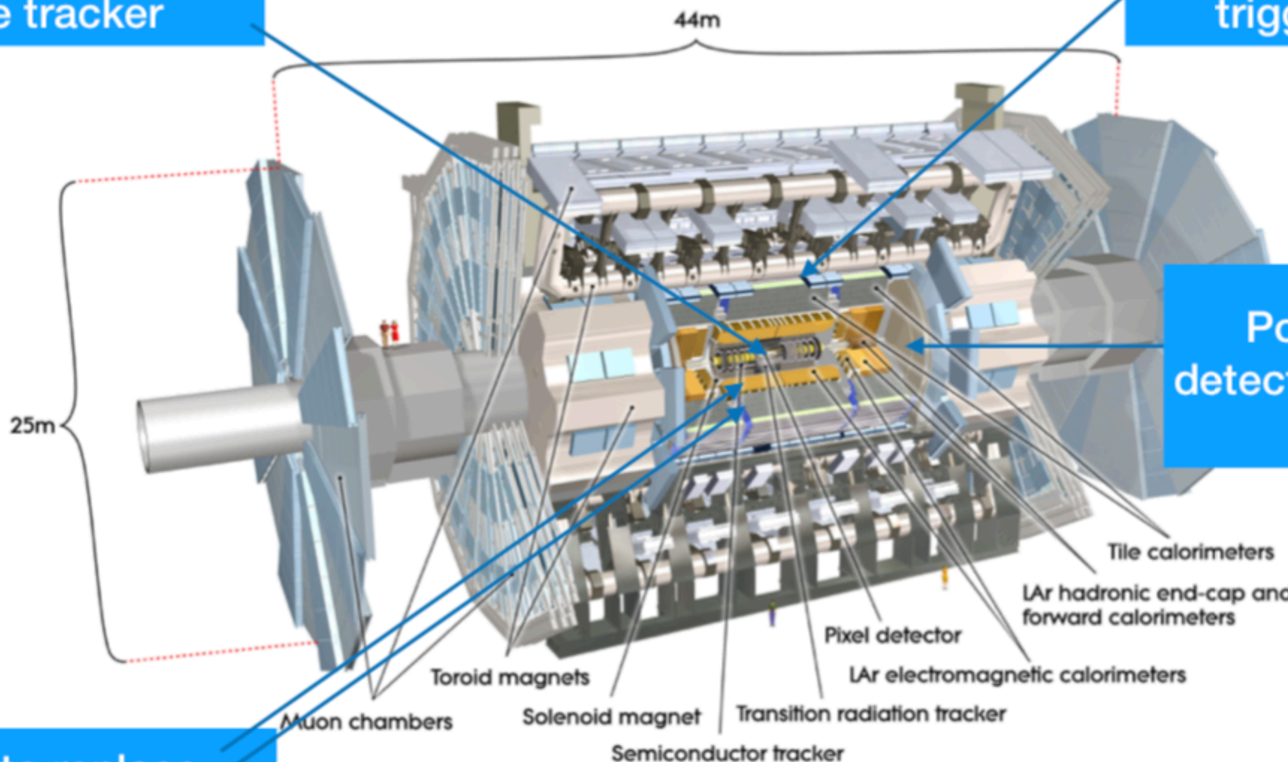


- Experiments have to upgrade their detectors
  - To achieve similar performance for the new data taking conditions
  - To cope with increased trigger and data rates
  - To improve reconstruction, identification, and rejection of background
- Strategies:
  - Increased use of silicon sensors (radiation tolerant)
  - More granularity in silicon to deal with high pileup
  - Precision timing, resolution of 50 ps to separate collisions (space and time)
  - Faster processing of data in real time for trigger.

ATLAS Detector Upgrades

Complete replacement of the tracker

New inner muon trigger system



Possible timing detector: High Granularity Timing Detector (HGTD)

Calorimeter to replace electronics, readouts and power supplies
Allow for higher resolution objects at the lowest trigger level

New trigger system

CMS Detector Summary

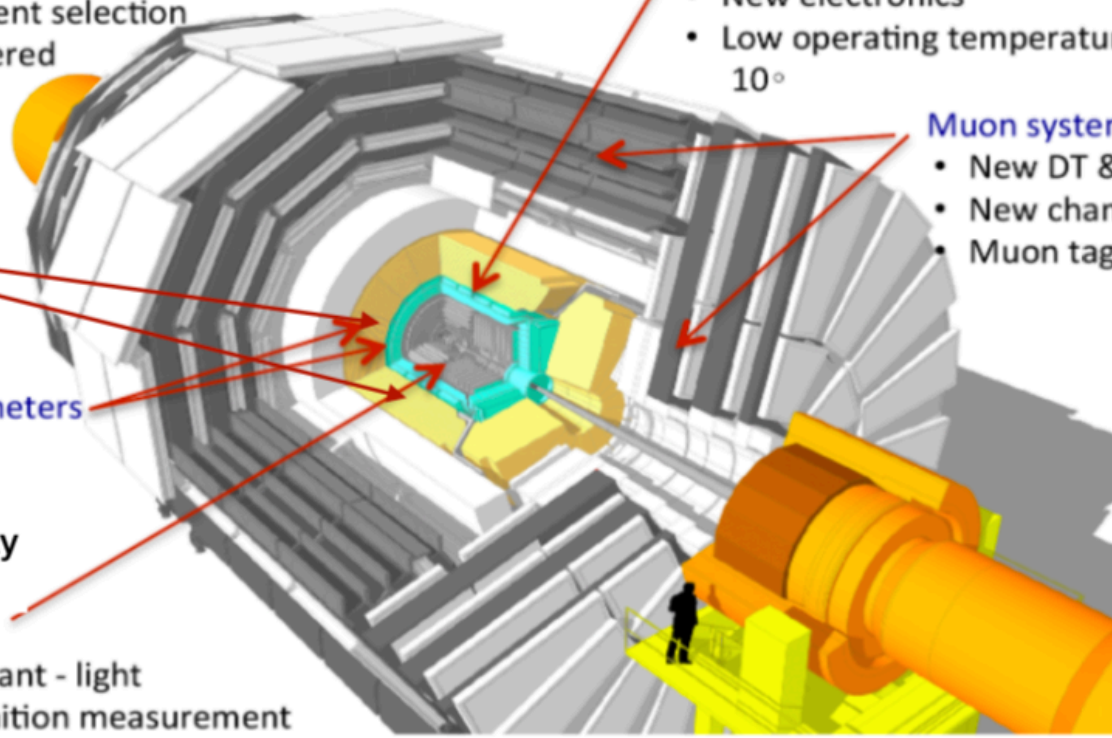
Trigger/HLT/DAQ
- Track information in hardware event selection
- 750 kHz hardware event selection
- 7.5 kHz events registered

Barrel EM calorimeter
- New electronics
- Low operating temperature ≈ 10°

Muon systems
- New DT & CSC electronics
- New chambers $1.6 < \eta < 2.4$
- Muon tagging $2.4 < \eta < 3$

Timing detector

- Mip Timing Detector (MTD)



New Endcap Calorimeters
- Rad. Tolerant
- 5D measurement

- higher granularity (HGCal)

New Tracker
- Rad. Tolerant - light
- High Definition measurement
- 40 MHz selective readout for hardware trigger
- Extended Pixel coverage to $\eta \simeq 3.8$

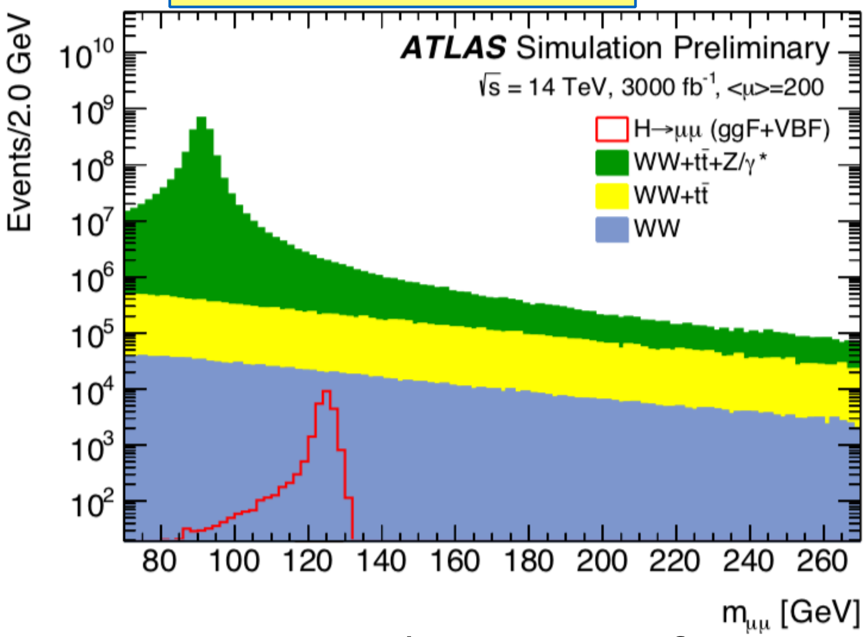
Beam radiation and luminosity

Common systems and infrastructure

HL-LHC as a Higgs factory

- Higgs particles produced in 3000 fb^{-1} : ~160M
- More than 1M events in each production mechanism spread over observable decay modes
  - ~ 400k H→γγ
    ~ 38k H→μμ
    ~ 20k H→ZZ*→4l
    ~ 17k H→Zγ
    ~ 800 VBF H→ττ
- This allows percent level uncertainty for couplings (currently ~20%)
- Rare Higgs decays in reach:
  - H→J/Ψγ, H→Zγ
    SM: B(H→J/Ψγ)=(2.9±0.2)x10^{-6}

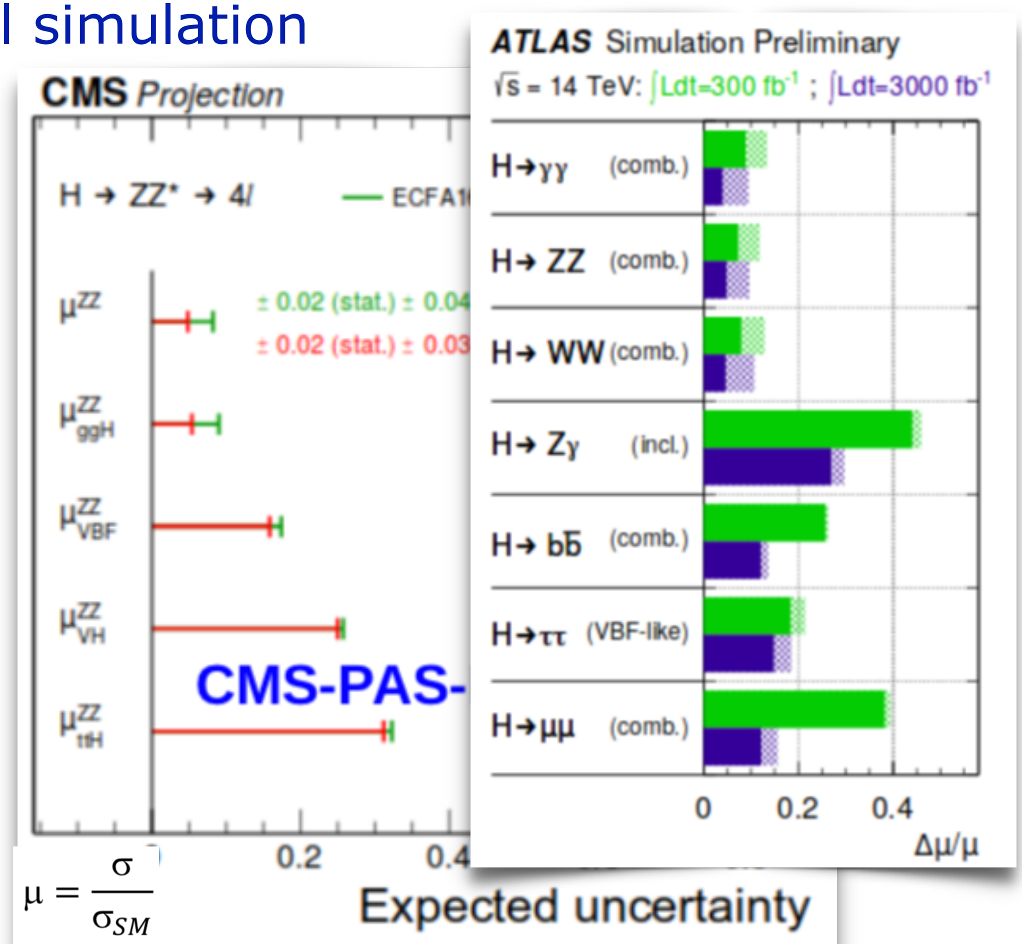
ATL-PHYS-PUB-2018-006



Expect >7σ observation of $H \to \mu\mu$

Higgs Couplings at HL-LHC

- Existing studies: comprehensive, largely based on extrapola-tions of Run-1 results
  - Few analysis done with full simulation of upgrade detector
  - Cross sections (translated to signal strengths) and couplings measured to few % level
- Projections will be updated to take into account analysis updates in forthcoming studies.



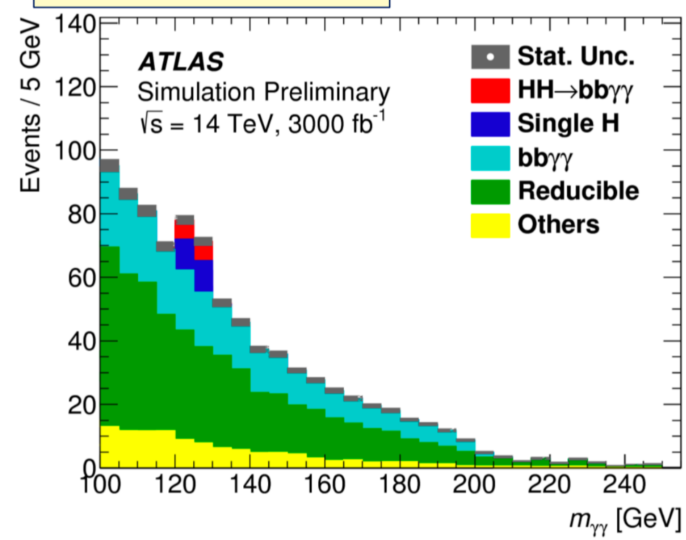
Higgs self-coupling

- Higgs self-coupling is a key prediction of the Standard Model.
  - Trilinear and quartic vertices are possible for the self-coupling.

Measurement of Higgs self-coupling

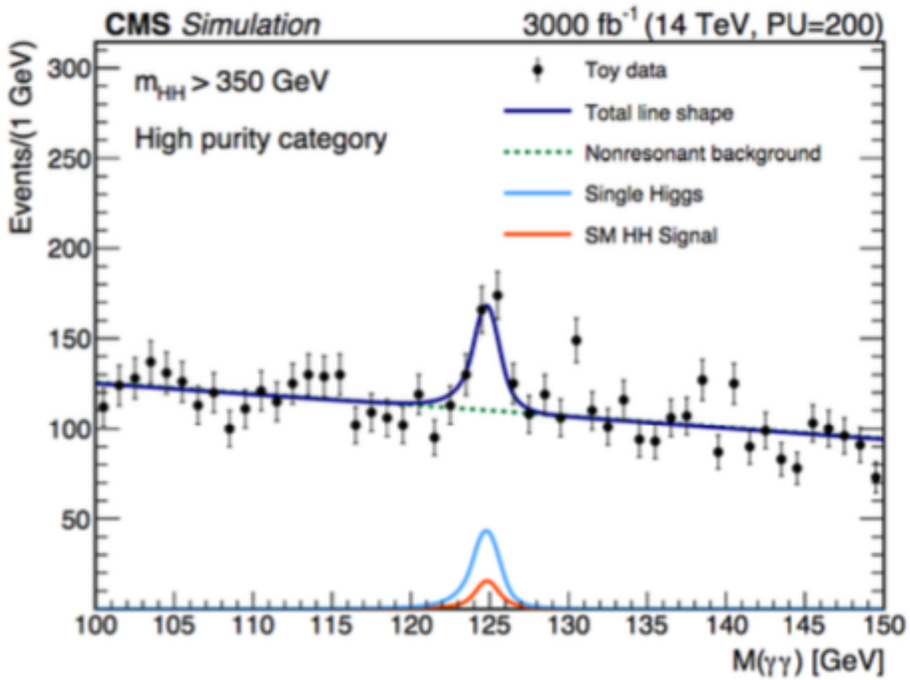
Destructive interfere

ATLAS-PUB-2017-001



- The measurement of the self-coupling is crucial:
  - to probe EW symmetry breaking
  - to measure the shape of the Higgs potential
-

Di-Higgs measurements at HL-LHC



- Observation of the SM di-Higgs production will be challenging.
- Several decay channels were investigated by ATLAS and CMS each with modest sensitivity.

Channel	ATLAS	CMS
bbγγ	1.5σ $0.2<\lambda_{HHH}/\lambda_{SM}<6.9$	1.43σ
bbττ	0.6σ $-4.0<\lambda_{HHH}/\lambda_{SM}<12.0$	0.39σ
bbbb	$-4.1<\lambda_{HHH}/\lambda_{SM}<8.7$	0.39σ
bbVV	N/A	0.45σ
ttHH, 4b	0.35σ	N/A
Total	1.8σ	1.7σ

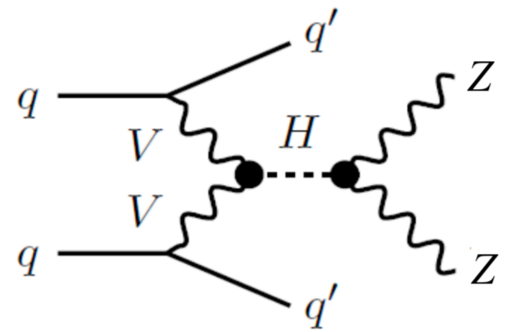
- Limits can exclude anomalous couplings down to around a factor of 5 from the SM.
- Further studies with improved results are being performed.

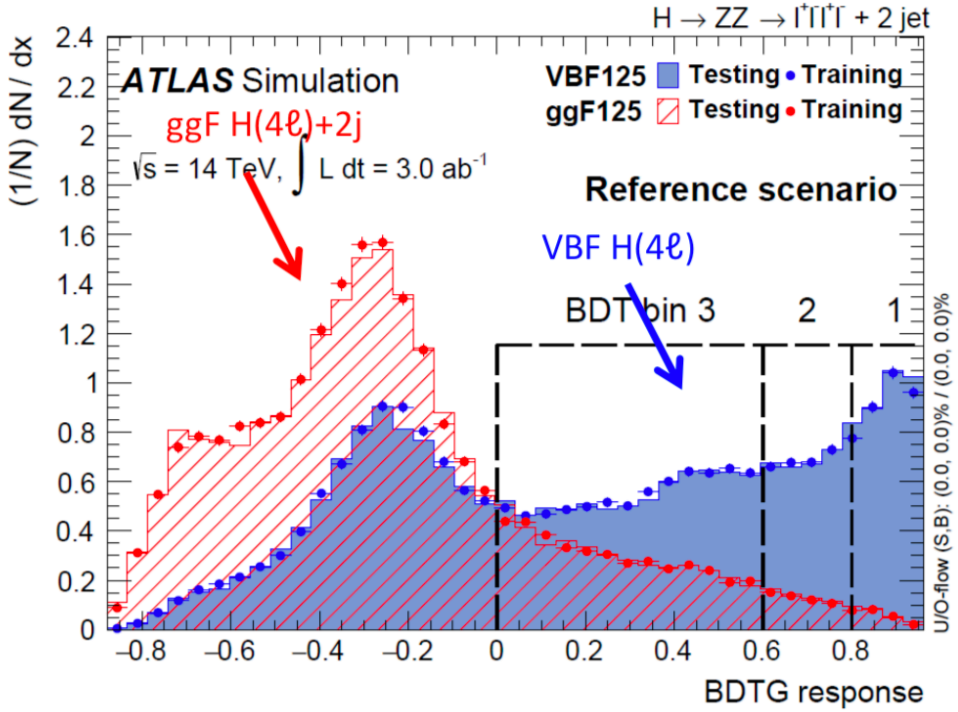
HL-LHC: Higgs in di-boson channels

Independent Pub Note: ATL-PHYS-PUB-2016-008 → *April 2016*
Phase-II Upg. Scoping Document: LHCC-G-166 → *June 2017*

VBF H → ZZ* → 4l

- Study conducted for μ=200 (cuts based + BDT classifier)
- A significance of 10.2 ± 0.2 is expected





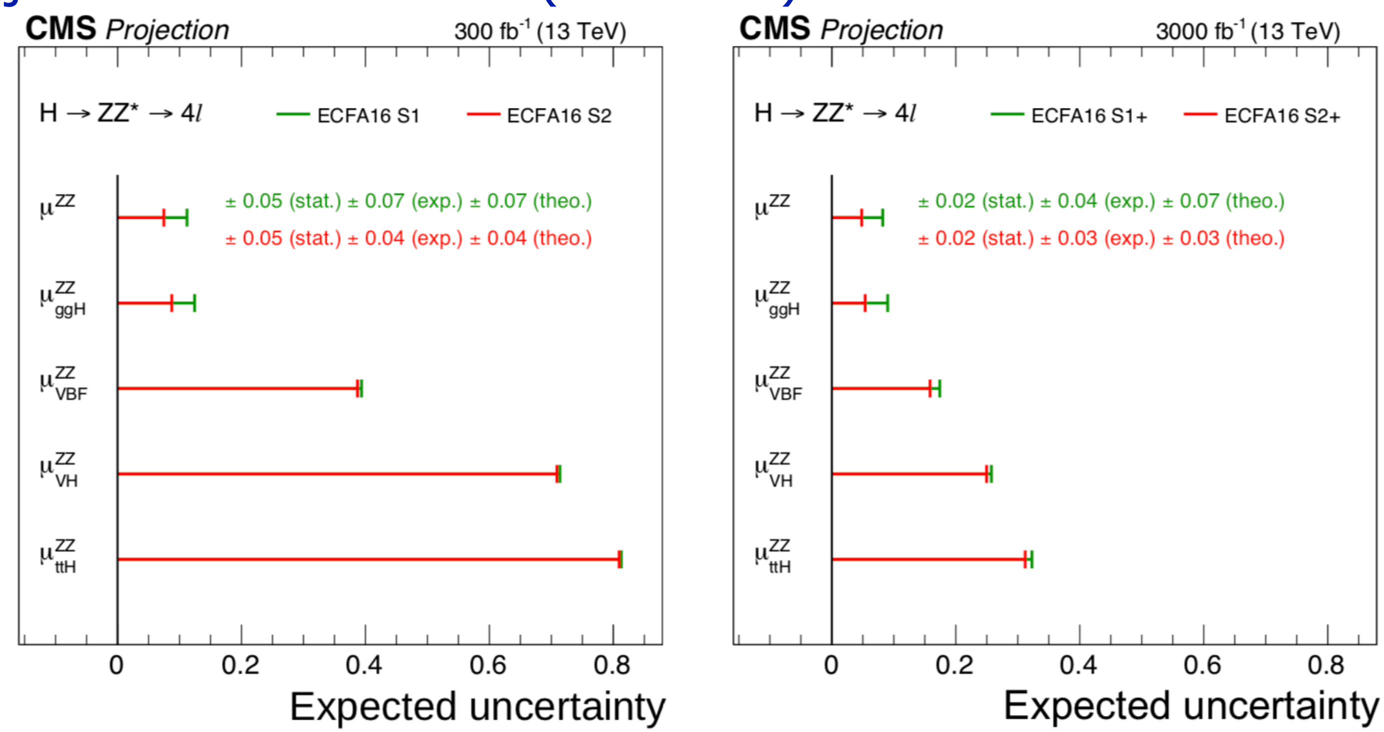
HL-LHC: Higgs in di-boson channels

ECFA 2016 Summary: CMS PAS FTR-16-002 → *May 2017*

VBF H → ZZ* → 4l

- Very clean, low backgrounds, expect huge benefit from high luminosity
  - Projection of 2016 data (12.9 fb^{-1}) to 3000 fb^{-1}

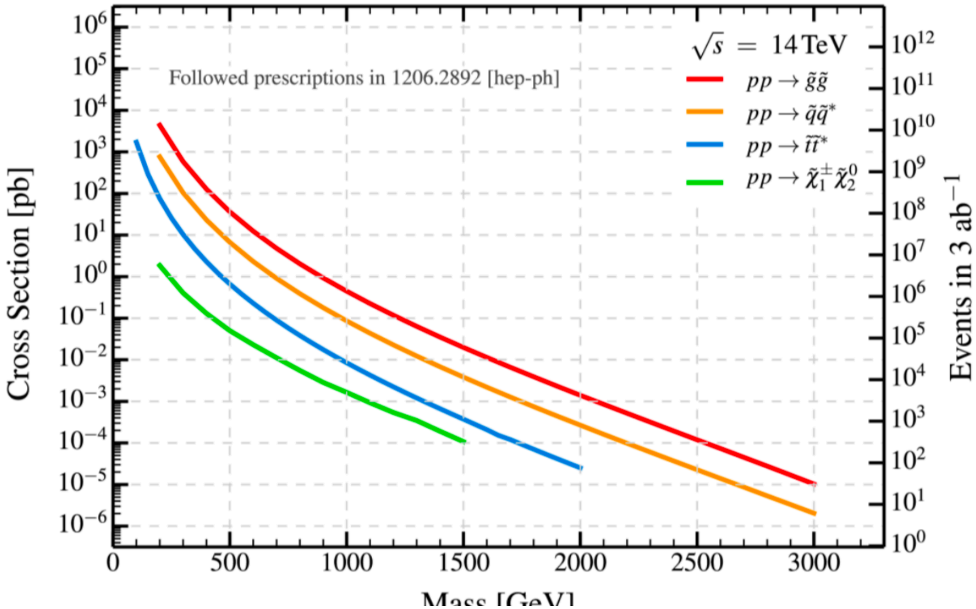
$$\mu = \frac{\sigma}{\sigma_{SM}}$$

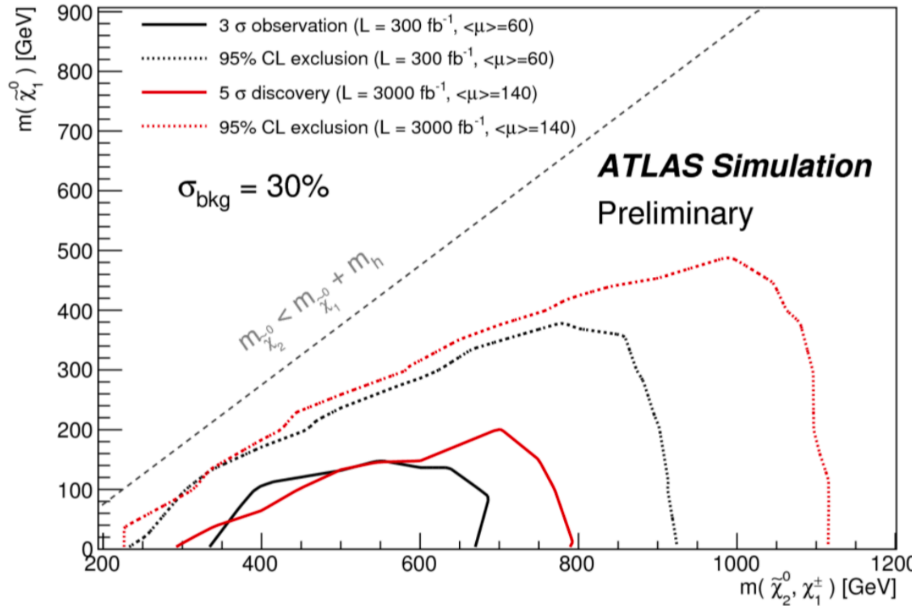


- Significant improve in measuring precision will be possible.

HL-LHC: SUSY - prospects

ATL-PHYS-PUB-2015-032



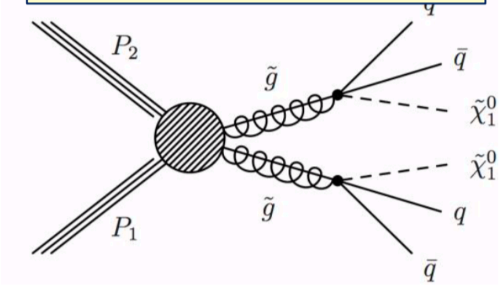


- Currently, exclusion of squarks and gluino masses go up to ~2 TeV
- Limits on gauginos and slepton masses are lower (500 – 1,000 GeV)
  - More data will extend the reach for these particles significantly
  - $m\chi$ < 900 1,100 GeV with 300 (3,000) fb^{-1}

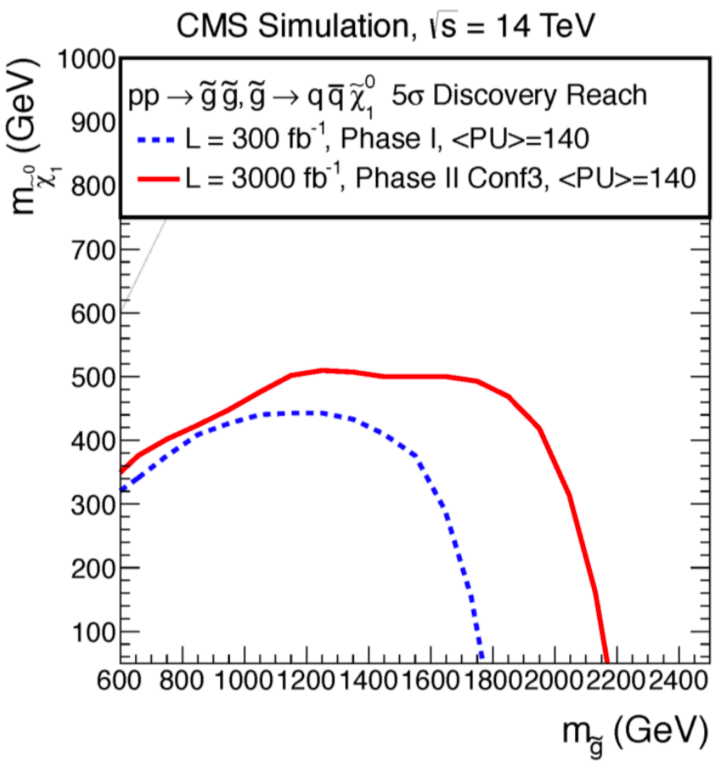
HL-LHC: SUSY - gluino prospects

CMS-PAS-FTR-13-014

- Large production cross section
- Gluino masses up to 2.2 (1.8) TeV and LSP mass up to 500 (400) GeV can be discovered with 3,000 (300) fb^{-1}

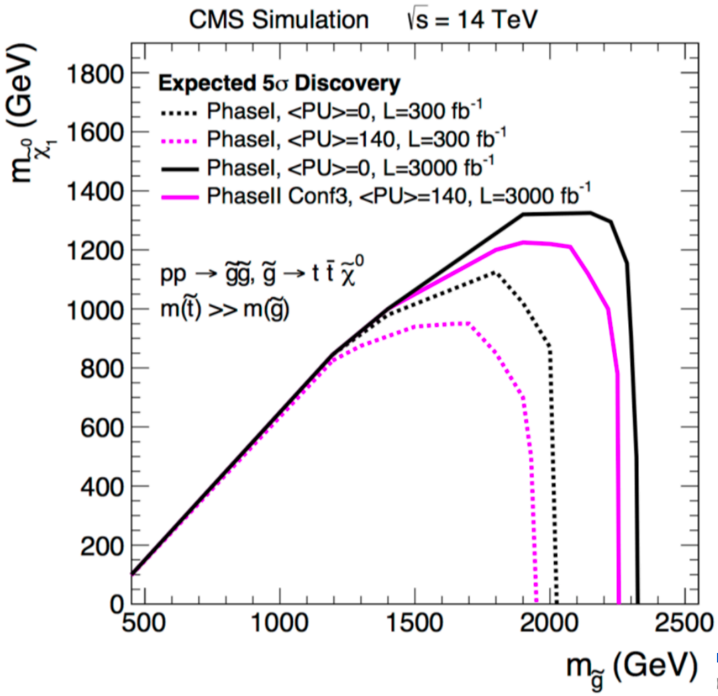


$\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0$: Multijet, E_T^{miss}



In case gluino decays preferentially to top

- $\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$: Multijet, E_T^{miss}, 1-lepton



Conclusion and outlook

- Very rich prospects of physics at the HL-LHC provides the motivation for a significant upgrade programme of the LHC machine and the experiments.
  - To test the Standard Model with precision measurements
  - To open the door to measure rare processes like di-higgs production.
  - To extend the reach of searches for BSM physics
- The experiments are upgrading the detectors using new technology.
  - Delivering better performance despite the harsh environment
  - Detailed studies are being made to estimate the performance.
- Few results of detector performance and physics reach has been presented highlighting the justification of massive investment and efforts for Phase-2 upgrade.