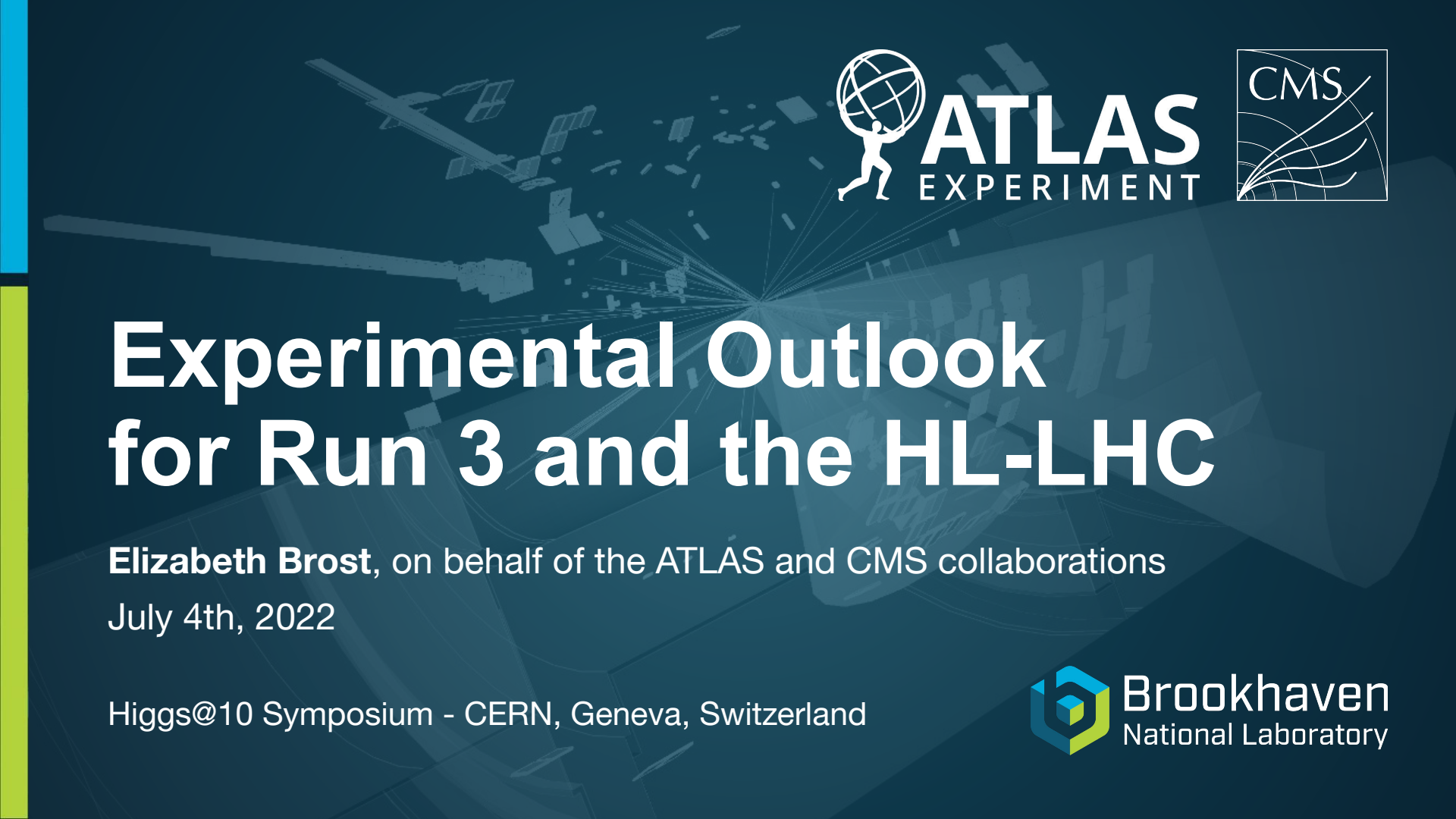


Experimental Outlook for Run 3 and the HL-LHC

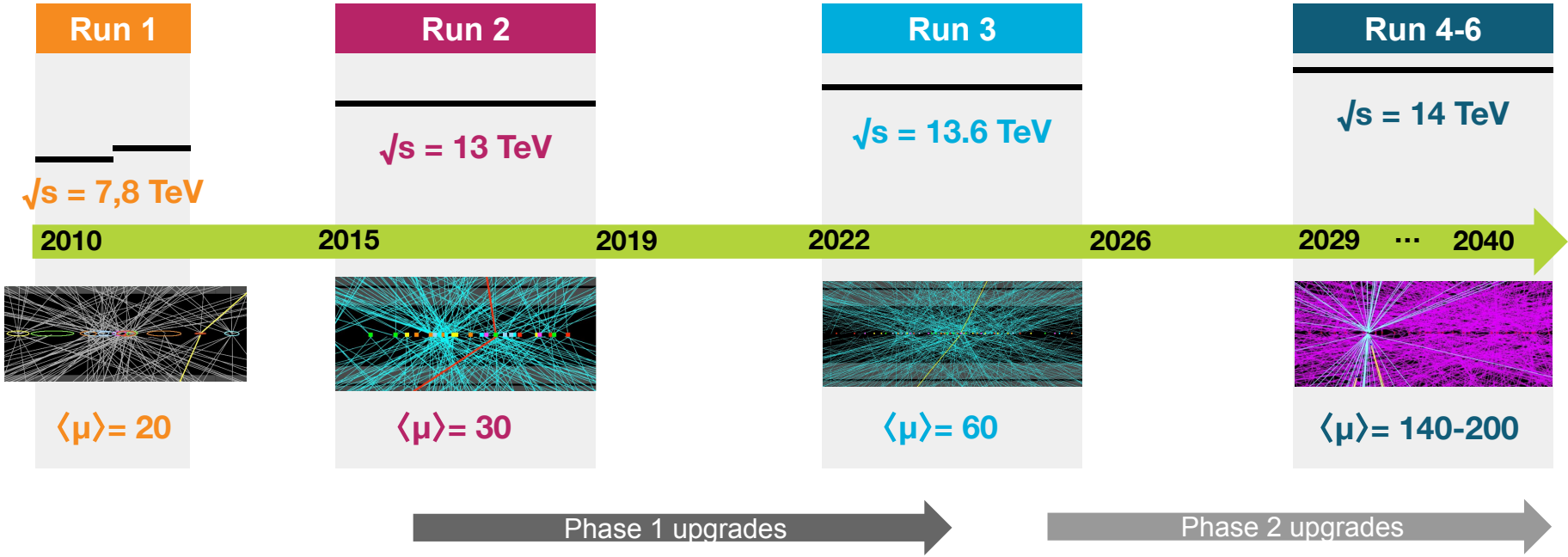
Elizabeth Brost, on behalf of the ATLAS and CMS collaborations

July 4th, 2022

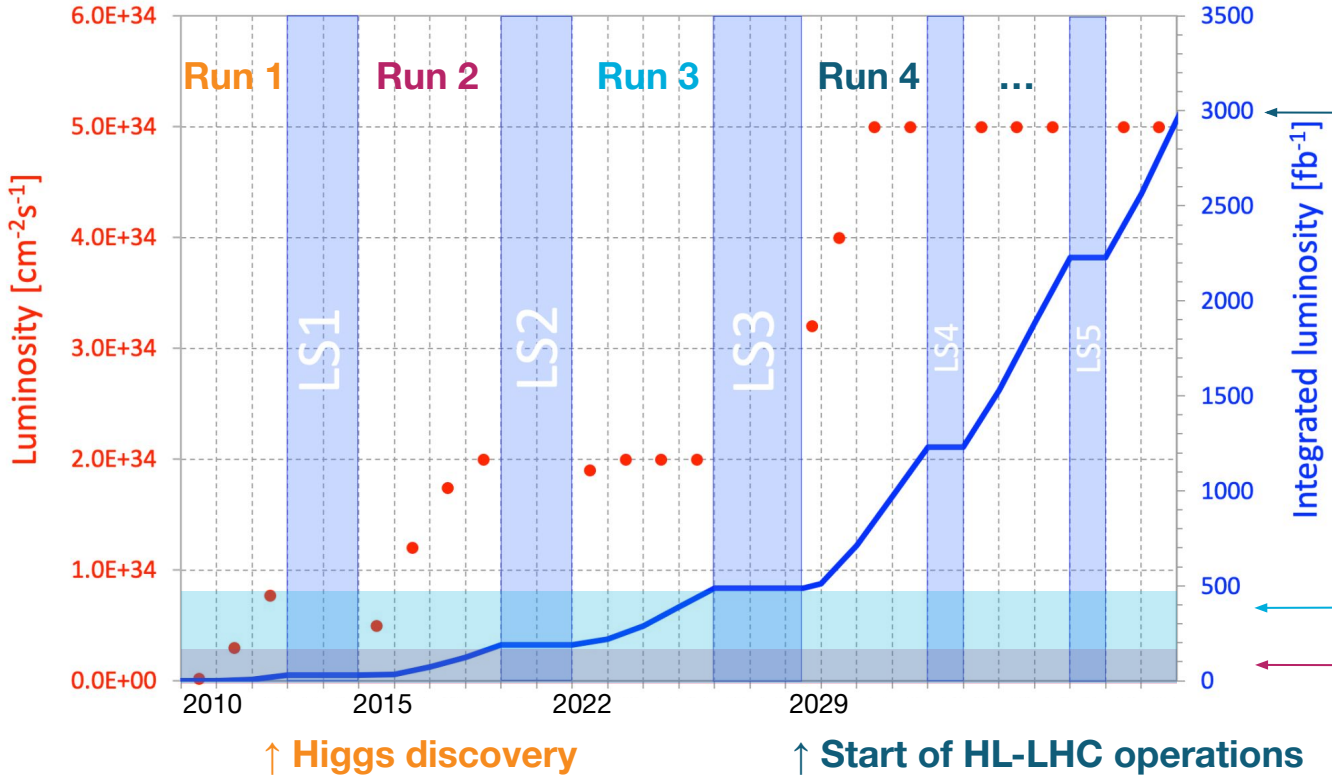
Higgs@10 Symposium - CERN, Geneva, Switzerland

Brookhaven National Laboratory

The LHC schedule, from the ATLAS and CMS perspective



LHC proton-proton dataset



Total HL-LHC dataset (3000 fb^{-1})

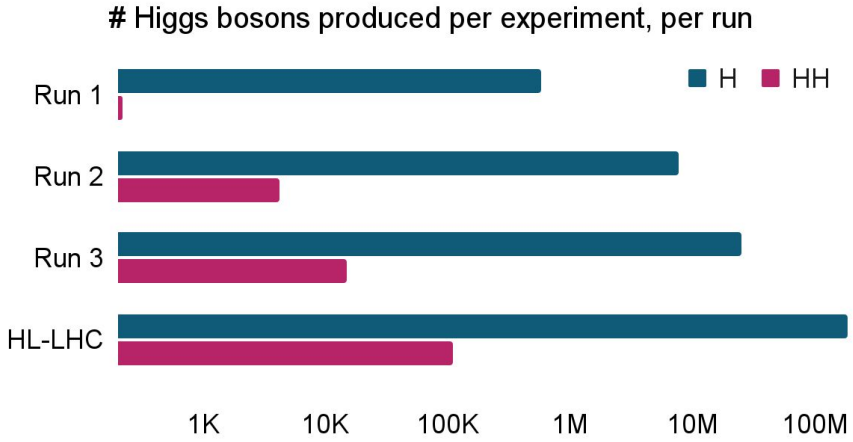
Run 3: ~10% of total dataset collected

Run 2: ~5% of total dataset collected

10 years later, what are we planning?

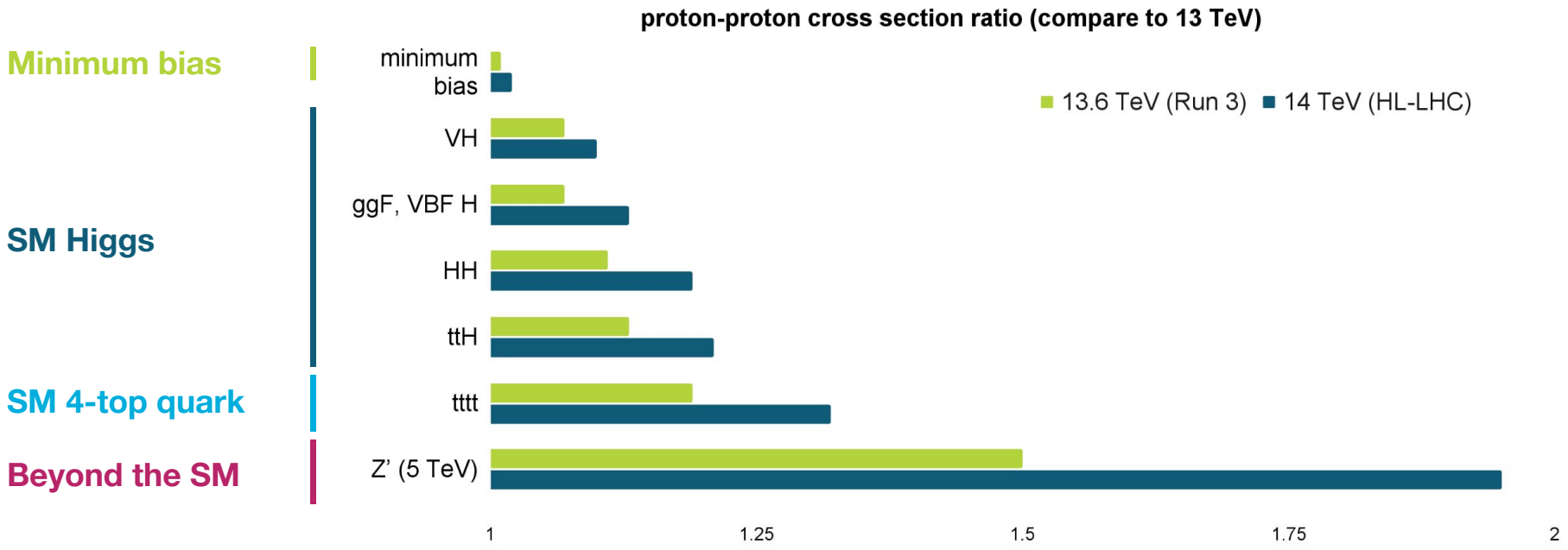
A detailed exploration of the mechanism of electroweak symmetry breaking through the properties of the Higgs boson, including:

- Couplings to other SM particles, mass, and width
- Rare decays
- HH cross section and trilinear self-coupling
- Connections to new physics through Higgs sector?

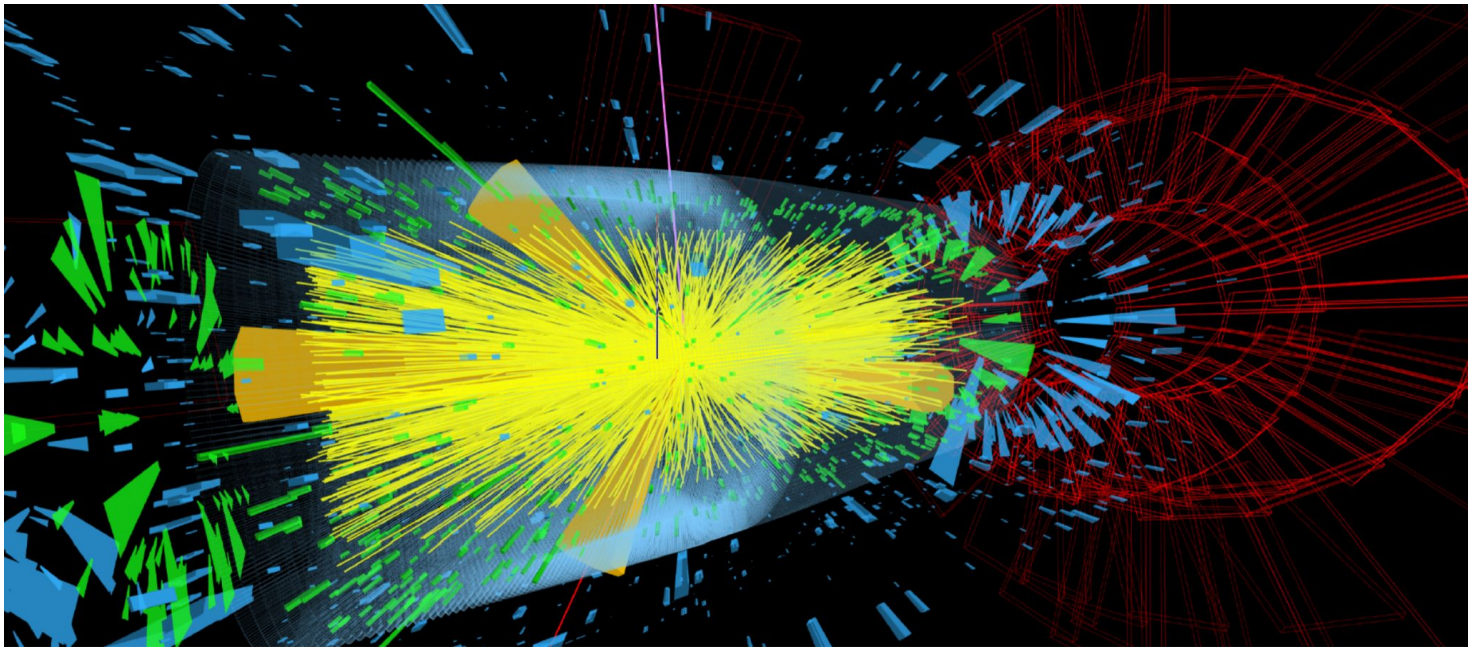


Cross sections from the LHC Higgs Working Group

Larger center-of-mass energy = larger Higgs cross sections



Challenge: Pileup



Simulated VBF H→ττ event in CMS
(with pileup 200)

High pileup environment at the HL-LHC brings new challenges: detector irradiation, higher detector occupancy, higher trigger rates

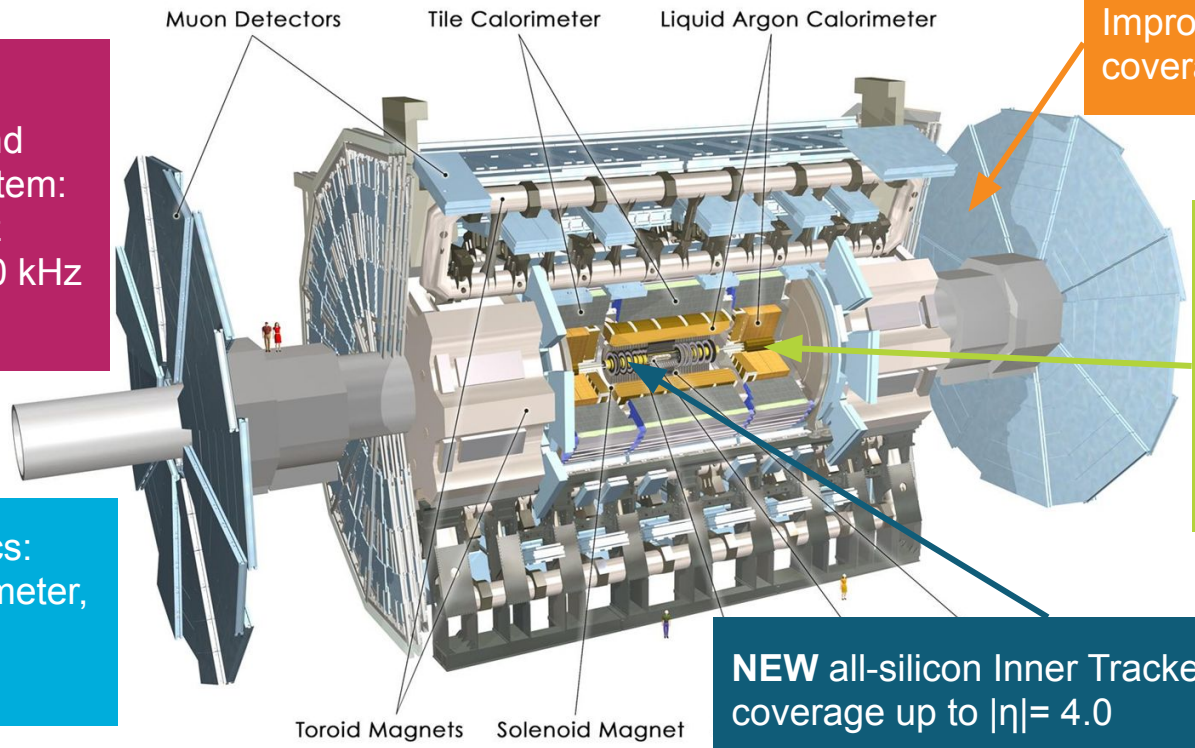
Experiment Upgrades for the HL-LHC

The harsh conditions at the HL-LHC will challenge the experiments in all areas, and will require improvements to:

- Detectors themselves
- Trigger menu and hardware
- Event reconstruction
- Software & computing
- Physics analysis techniques

ATLAS Detector Upgrade

Upgraded Trigger and Data Acquisition system:
- L0 rate: 1 MHz
- Event Filter: 10 kHz



Improved muon coverage and trigger

NEW endcap high - granularity timing detector

Upgraded electronics:
Liquid Argon Calorimeter,
Tile Calorimeter,
Muon system

NEW all-silicon Inner Tracker, coverage up to $|\eta|= 4.0$

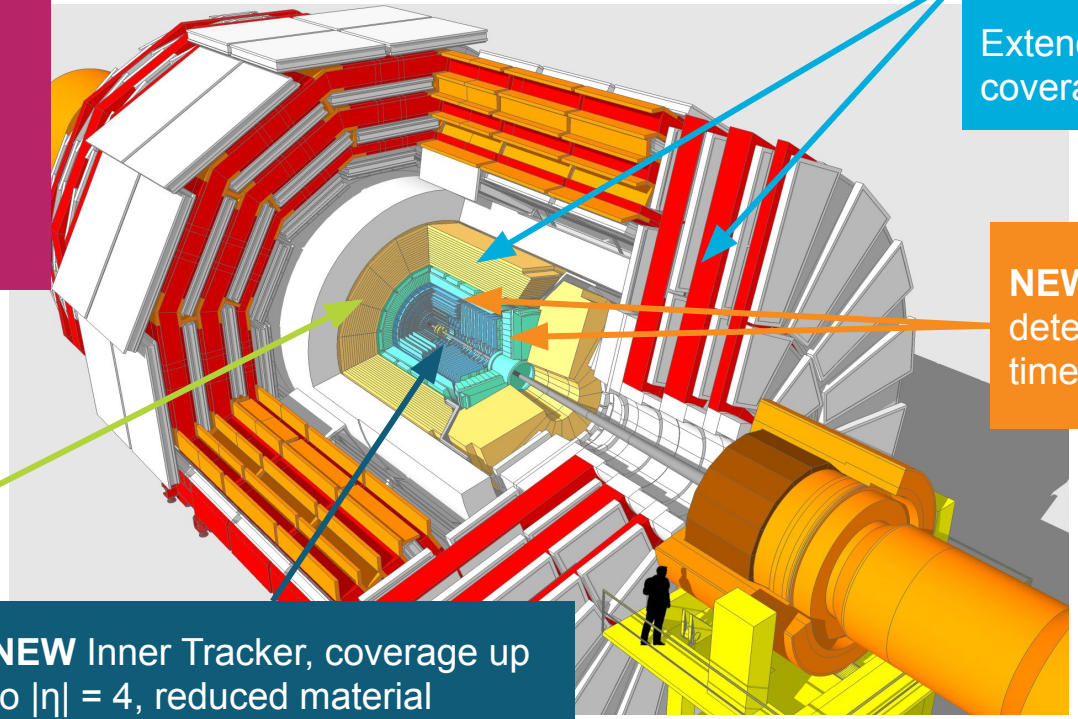
CMS Detector Upgrade

Upgraded Trigger and Data Acquisition system:

- Add tracks at L1 (1 MHz)
- High Level Trigger output 7.5 kHz

Electronics upgrade: barrel calorimeters and muon system

Extended muon coverage to |η| ~ 2.8



NEW MIP timing detector with 30 - 50 ps time resolution

NEW High-granularity calorimeter endcap

NEW Inner Tracker, coverage up to |η| = 4, reduced material

Recent efforts for HL-LHC projections

- **European Strategy Update (2018-2020)**
  - "The European Strategy for Particle Physics provides a clear prioritisation of European ambitions in advancing the science of particle physics. It takes into account the worldwide particle physics landscape and developments in related fields"
- **Snowmass Community Planning Exercise (2020-2022)**
  - "The Particle Physics Community Planning Exercise (a.k.a. "Snowmass") … provides an opportunity for the entire particle physics community to come together to identify and document a scientific vision for the future of particle physics in the U.S. and its international partners."

→ ATLAS and CMS produced many new HL-LHC projections for Snowmass this year, and I will focus on these results today

CERN-2019-007

Snowmass White Paper Contribution, 2022

How HL-LHC projections are made

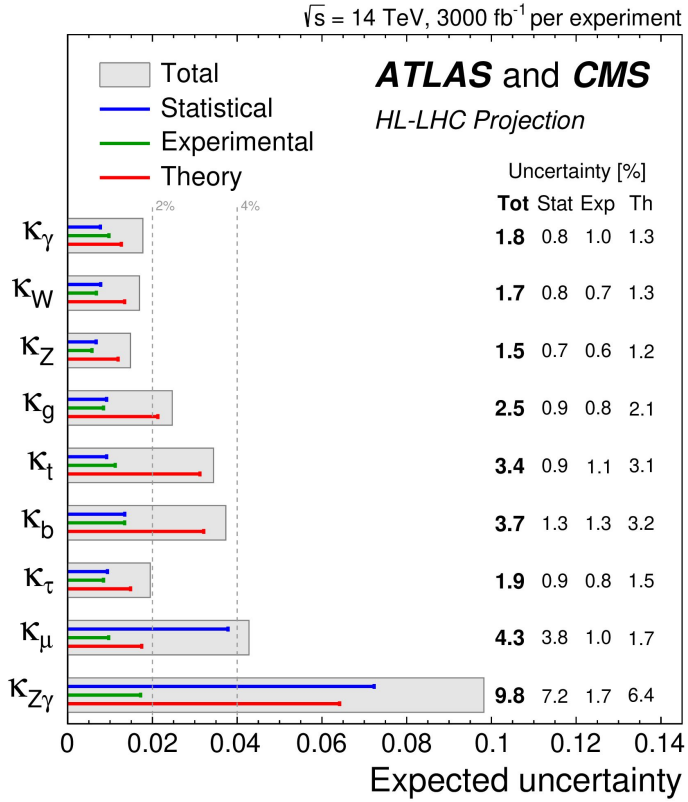
- **Start from:**
  - published LHC Run 2 results, or
  - simulations (usually using a simplified detector simulation such as DELPHES)
- **Adapt to HL-LHC conditions:**
  - center-of-mass energy: 13 TeV → 14 TeV
  - pileup: 30 → 200
  - larger dataset: 150 fb^{-1} → 3000 fb^{-1}
  - simulated detector and reconstruction performance
  - theory and experimental uncertainties: usually present a few scenarios
- **We already see the effect of advancements in analysis techniques since the last round of projections!**

Systematic Uncertainties

- **Baseline scenario:**
  - detector and trigger performance comparable to Run 2
  - most experimental uncertainties scaled down with $\sqrt{\mathcal{L}}$
  - theoretical uncertainties halved with respect to current values
  - 1% luminosity uncertainty
  - **used in these studies, unless otherwise specified**
- **Studied improvements to object reconstruction and the impact of detector upgrades, using simulation**

The Higgs boson at the HL-LHC

- **Higgs couplings move into precision regime**
  - those not dominated by statistical uncertainty will be known at few-% level
  - most dominated by theory uncertainties
- **More difficult to access at the HL-LHC:**
  - Higgs coupling to charm, invisible
  - Higgs self-coupling



Dominated by: theory uncertainties, stats

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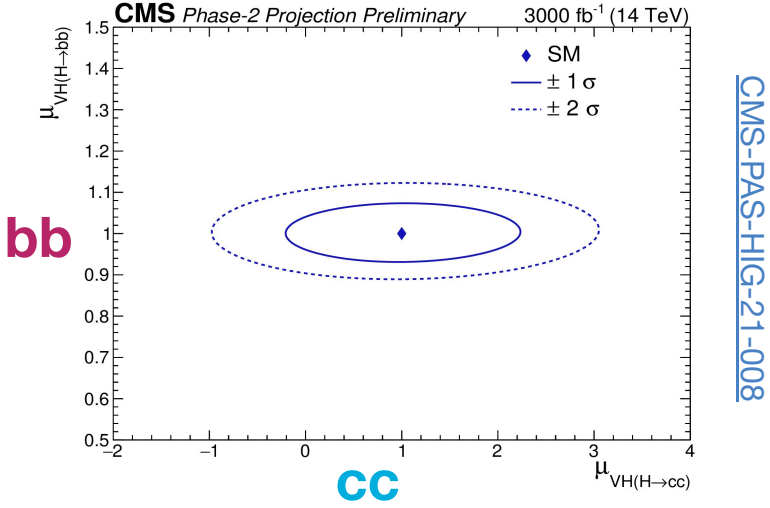
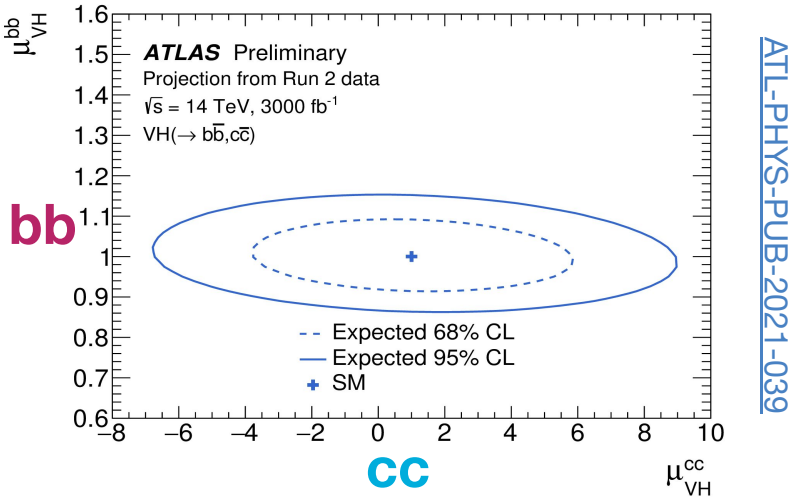
Higgs coupling to charm, bottom



CMS-PAS-HIG-21-008



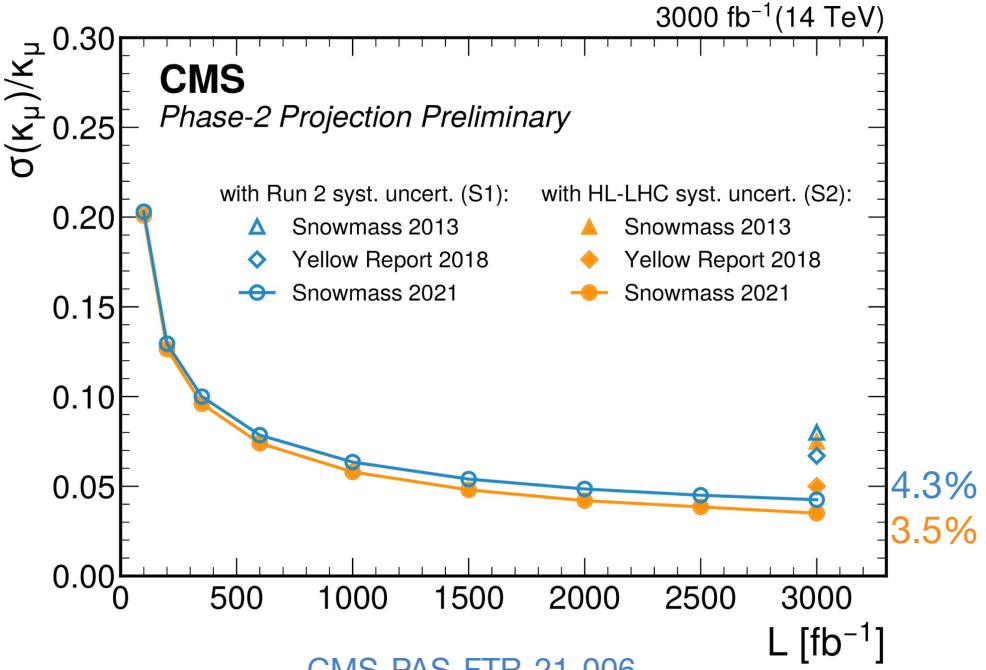
ATL-PHYS-PUB-2021-039

Use VH production mode to probe **H(bb)** and **H(cc)** couplings

Observation of Higgs coupling to charm will be difficult to achieve at the HL-LHC - new analysis techniques, such as the use of multivariate techniques and jet substructure variables, are making great progress in the right direction

Higgs coupling to muons

- H → μμ projection based on the CMS Run 2 3σ evidence analysis
- Estimate increases in signal and background yields due to new detectors
  - larger muon η acceptance
  - use DELPHES simulation
- Improvement over previous projection: ~ 30%



CMS-PAS-FTR-21-006

Searches for Higgs → invisible

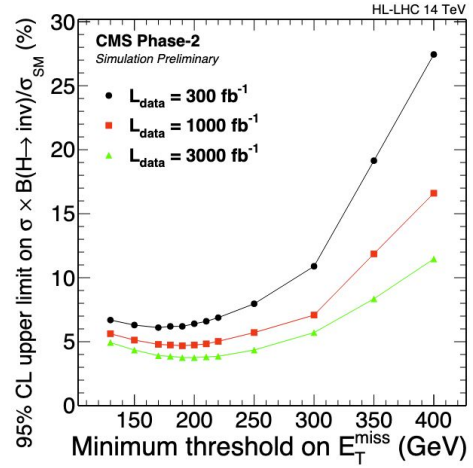
The SM Higgs branching ratio to invisible is below current O(10%) experimental limits: BR(H→ZZ→4*ν*) ~ 0.1%

Higgs → invisible searches rely on the MET trigger - significantly more difficult with more pileup

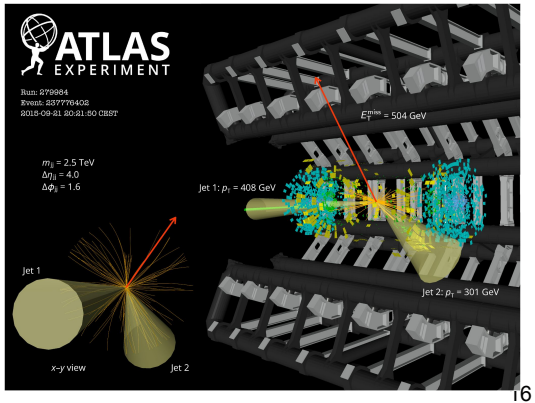
- CMS search for H → dark matter in VBF events: BR(H → invisible) < 3.8%, for MET > 190 GeV

→ ATLAS+CMS VBF+VH combination gives BR(H → invisible) < 2.5%

CERN-2019-007



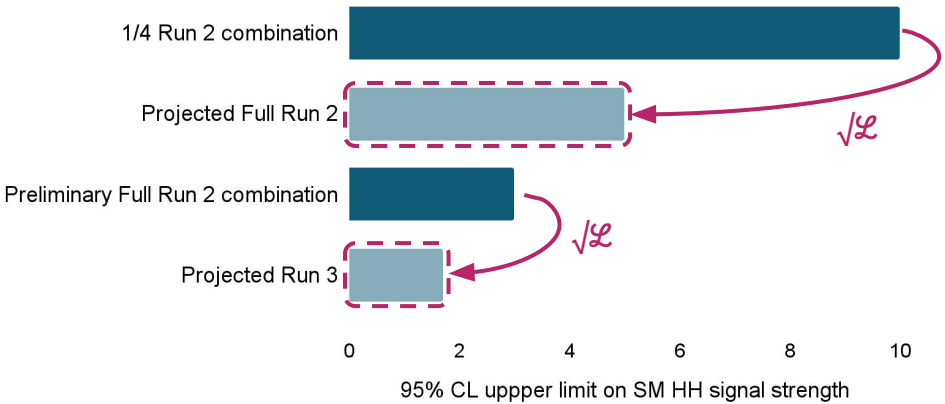
CMS-PAS-FTR-18-016



HIGG-2018-26

Higgs pair production is rare at the LHC…

…1000x more rare than single Higgs production. HH searches are stats-limited.

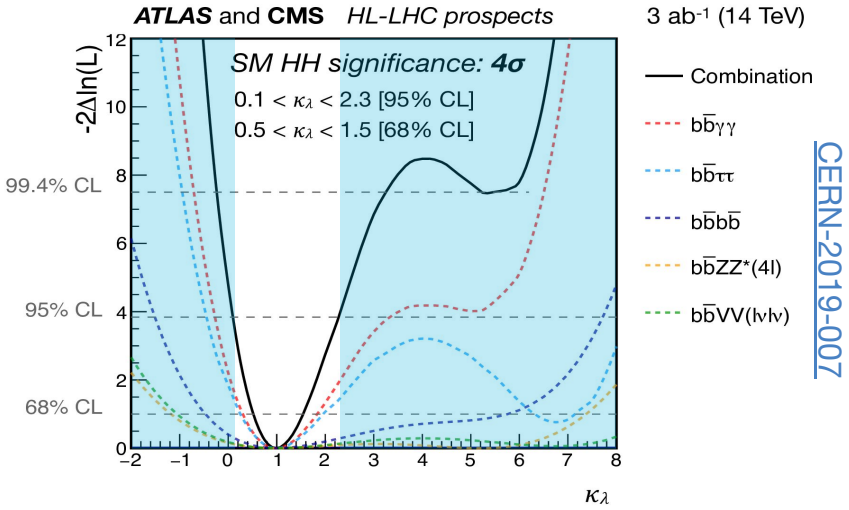


We've already seen a factor of ~1.7 improvement due to improved reconstruction and analysis techniques in full Run 2 dataset (compared to simple projection based on √ℒ)

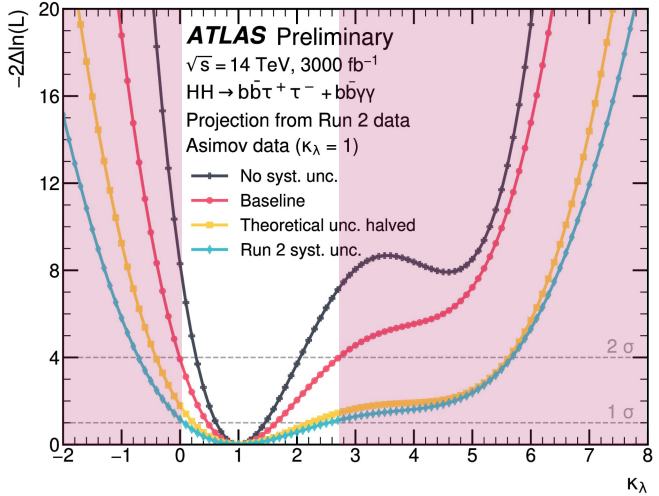
SM expectation within reach for Run 3 limits if we:

- Continue the same pace of analysis improvements, or
- Combine ATLAS+CMS results

HH projections for the HL-LHC



CERN-2019-007



ATL-PHYS-PUB-2022-005

European Strategy (2018)

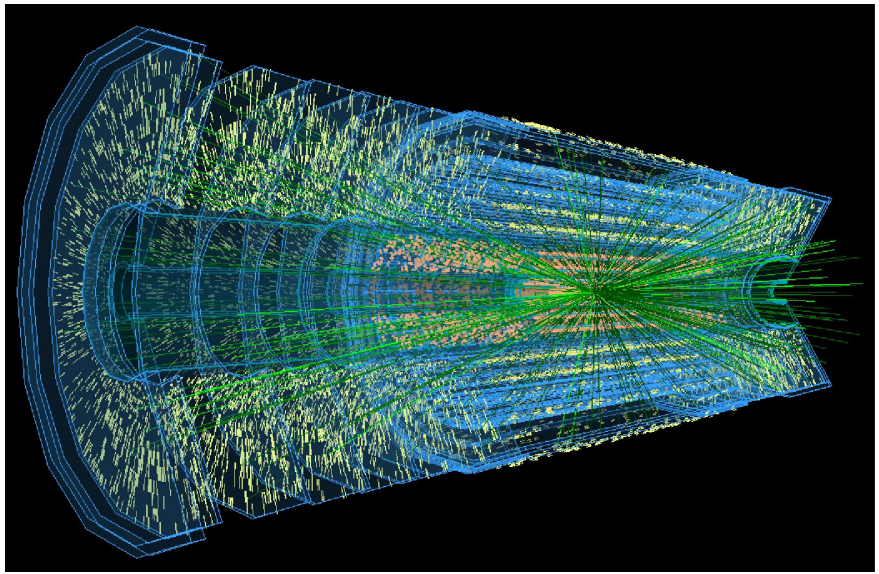
- Combination of 5 HH channels, many based on partial Run 2 analysis strategy
- 50% precision on self-coupling
- **4σ SM HH significance** (ATLAS+CMS)

Snowmass update (2022)

- ATLAS γγbb+bbττ combination: 3.2σ
- CMS updated γγbb results, added γγWW, γγττ, ttHH(bbbb)
- **5σ SM HH significance** from back-of-the-envelope combination

Conclusions and Outlook

- **ATLAS and CMS detector upgrades will maintain or improve upon current performance**
  - Phase 1 upgrades already being exercised as Run 3 begins
- **HL-LHC will bring new challenges**
- **Hard work and creativity in reconstruction and analysis techniques already evident since last round of projections**
  - Imagine what we can do in the next twenty years!



A simulated HL-LHC event in the ATLAS Inner Tracker, with 40 signal muons plus pileup of 140.

BACKUP