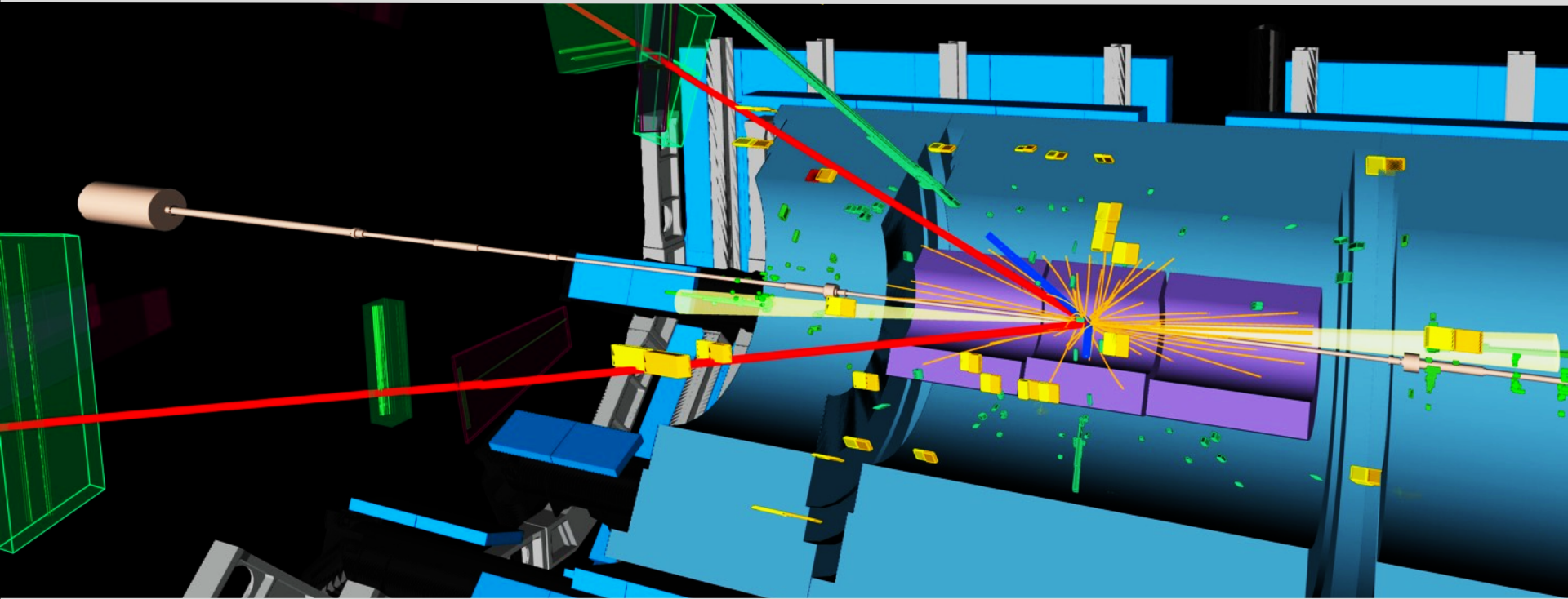


Measurement of Higgs boson properties — What will the (HL-)LHC achieve



Discuss Higgs boson properties here, but the HL-LHC is obviously much more than Higgs !

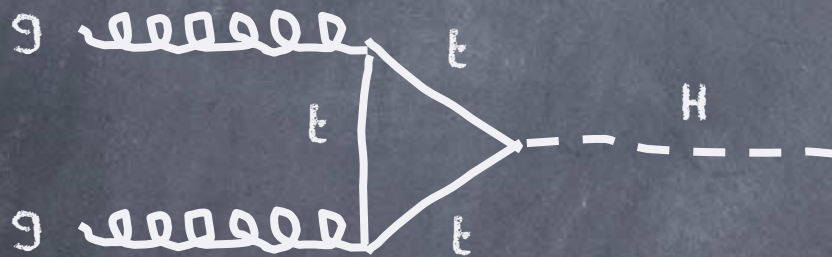
Andreas Hoecker (CERN)

Chicago University, January 14, 2019

Higgs boson production at the LHC

At the LHC, the Higgs boson is dominantly produced via gluon fusion for $\sigma_{H,\text{total}} = 56 \text{ pb}$ at $\sqrt{s} = 13 \text{ TeV}$ for $m_H = 125 \text{ GeV}$

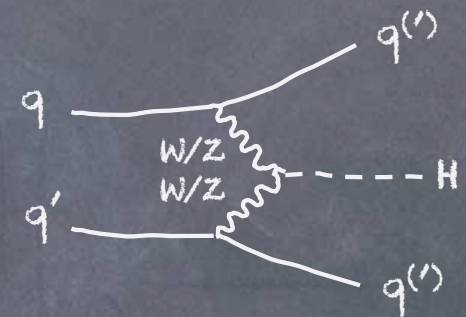
Cross section steeply falling with Higgs mass



$\sigma_{H,ggF} \sim 49 \text{ pb}$ at 13 TeV

Total production of almost 9 million SM Higgs bosons of 125 GeV by today in each of ATLAS and CMS

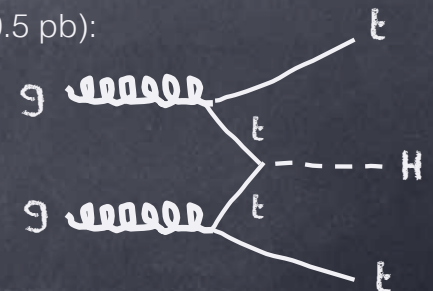
Weak boson fusion ($\sigma_{W/Z+H} \sim 3.8 \text{ pb}$):



Higgs-strahlung ($\sigma_{W/Z+H} \sim 1.4/0.9 \text{ pb}$):



“ttH” production ($\sigma_{ttH} \sim \sigma_{bbH} \sim 0.5 \text{ pb}$):



Higgs boson production at the LHC

Because of the coupling to the mass of the decay particles:

... the Higgs decays with preference to the heaviest particles allowed

... the Higgs does not couple directly to photons and gluons, but only via loops involving preferentially heavy particles (e.g., top, W)

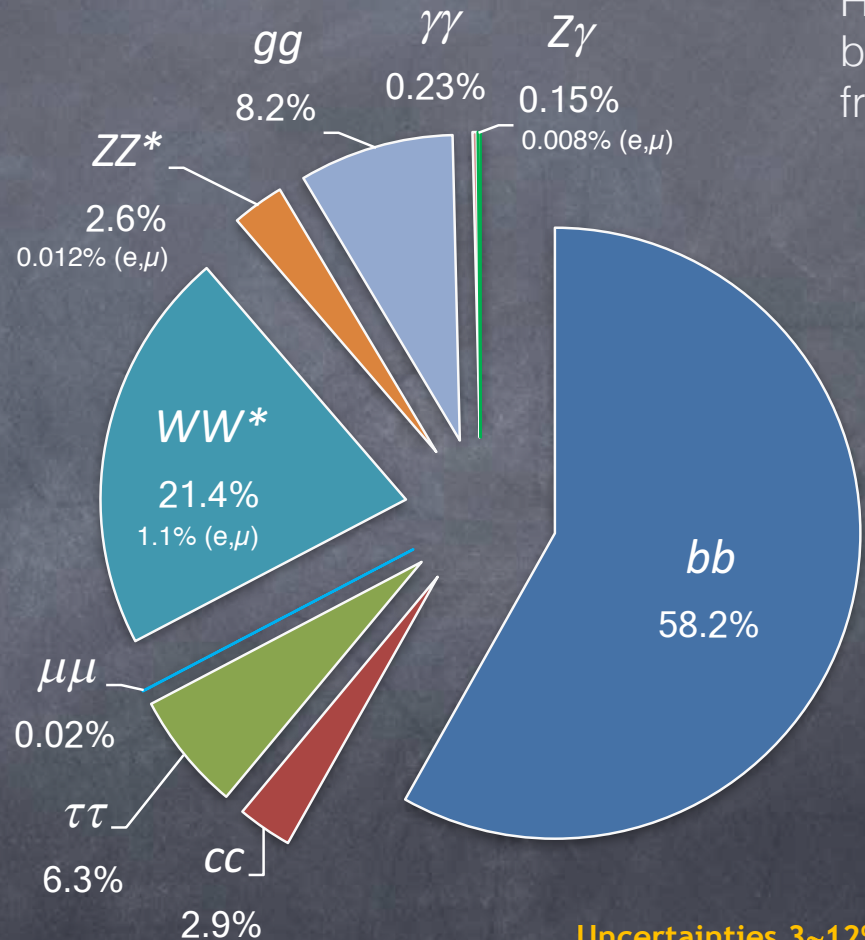
At the LHC we measure:

$$\text{Rate}(pp \rightarrow H \rightarrow f) \propto \sigma_H \cdot \frac{\Gamma_{H \rightarrow f}}{\Gamma_H}$$

Higgs boson width Γ_H not directly accessible (except using tricks)

Absolute coupling measurement requires extraction of $\sigma_H \cdot \Gamma_{H \rightarrow f}$

Therefore, only coupling ratios model-independent at LHC



H(125 GeV)
branching
fractions:

Uncertainties 3~12%

Higgs boson production at the LHC

Leptonic (e/μ) and photonic final states provided best discovery significance

$H \rightarrow \gamma\gamma / ZZ^*(\rightarrow 4\ell)$ have best mass resolution

$H \rightarrow WW^* \rightarrow 2\ell 2\nu$ good trigger, sustainable background level, and large branching fraction

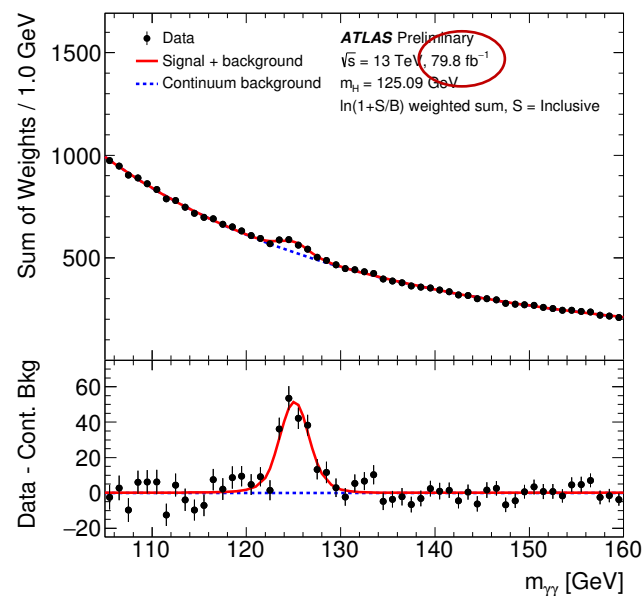
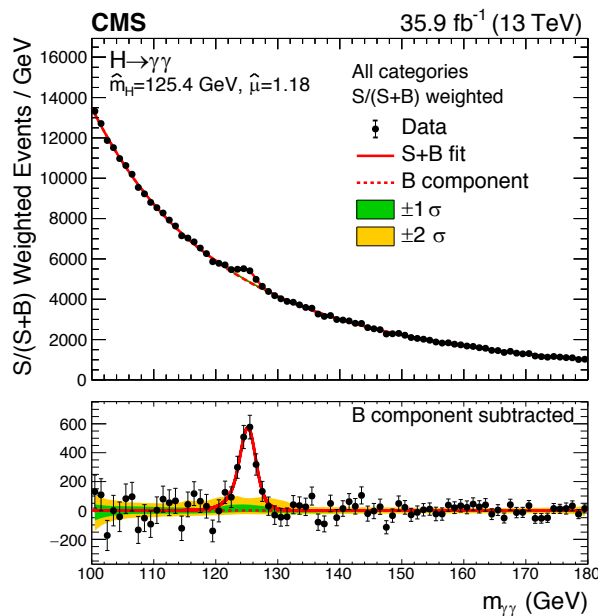
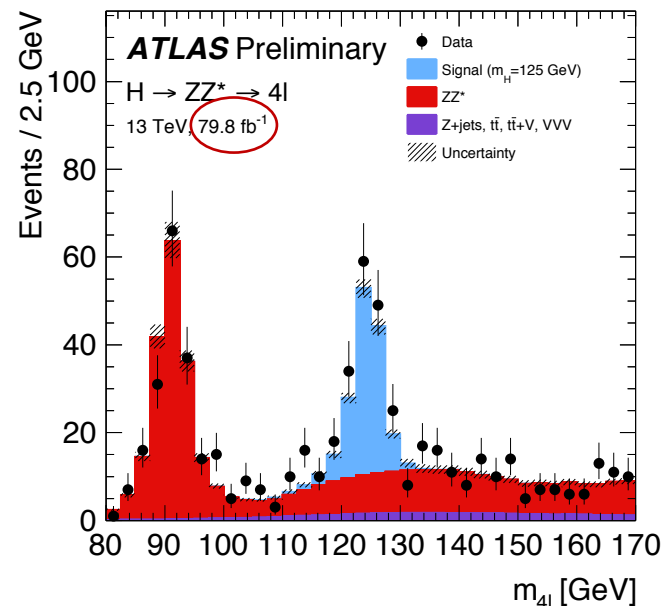
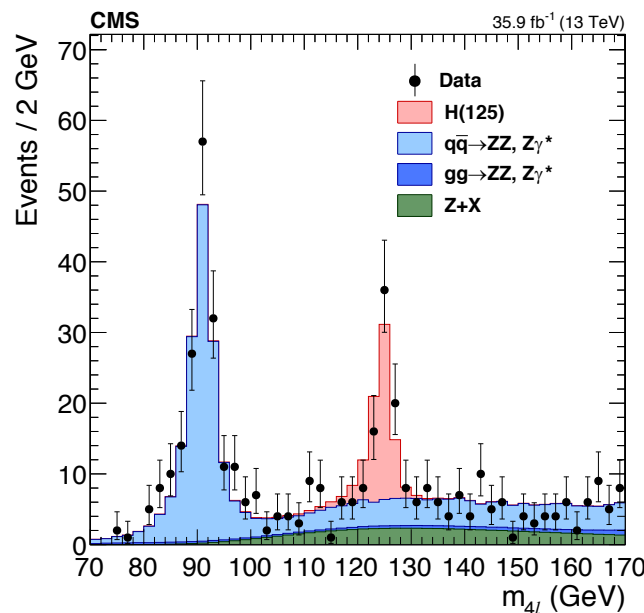
H(125 GeV)

Decay channel	Mass resolution
$H \rightarrow \gamma\gamma$	1–2%
$H \rightarrow ZZ^* \rightarrow 4\ell$	1–2%
$H \rightarrow WW^* \rightarrow 2\ell 2\nu$	20%
$H \rightarrow b\bar{b}$	10%
$H \rightarrow \tau\tau$	15%

A long time passed since the July 2012 discovery of a “Higgs-like” boson...

Higgs to diphoton and four-lepton discovery channels

Using up to 80 fb⁻¹
13 TeV data from
Run-2



Combined ATLAS & CMS Higgs analysis — Run-1 legacy

ATLAS & CMS Run-1 combination of Higgs coupling measurements

Signal strength parameter: $\mu = \sigma(\text{exp}) / \sigma(\text{SM})$

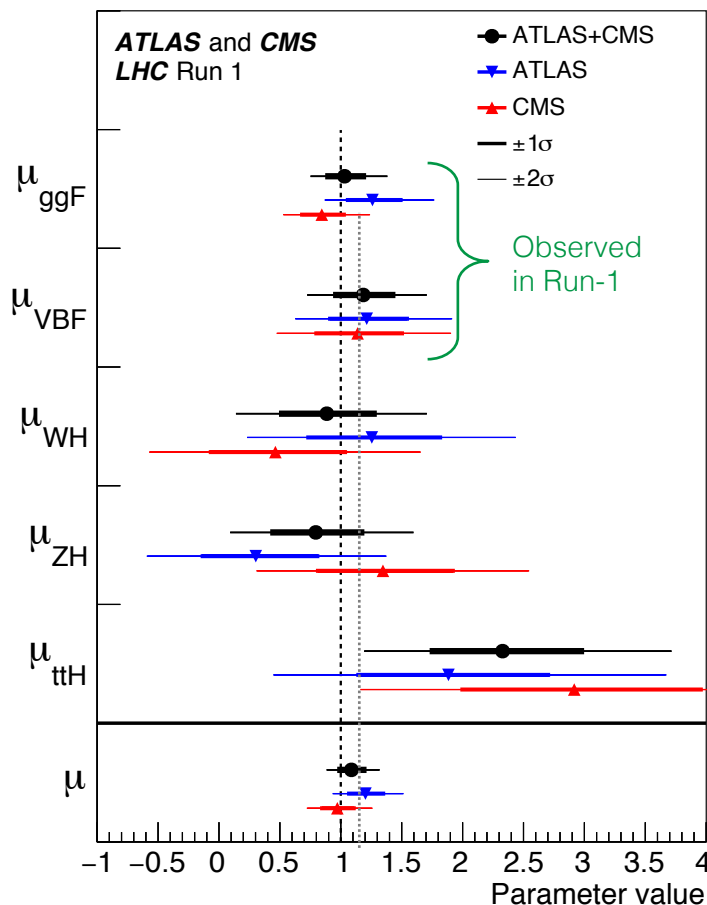
Agreement among experiments

Overall signal strength (Run-1): $\mu = 1.09 \pm 0.11$ (A & C)

Run-2: 1.17 ± 0.10 (CMS)

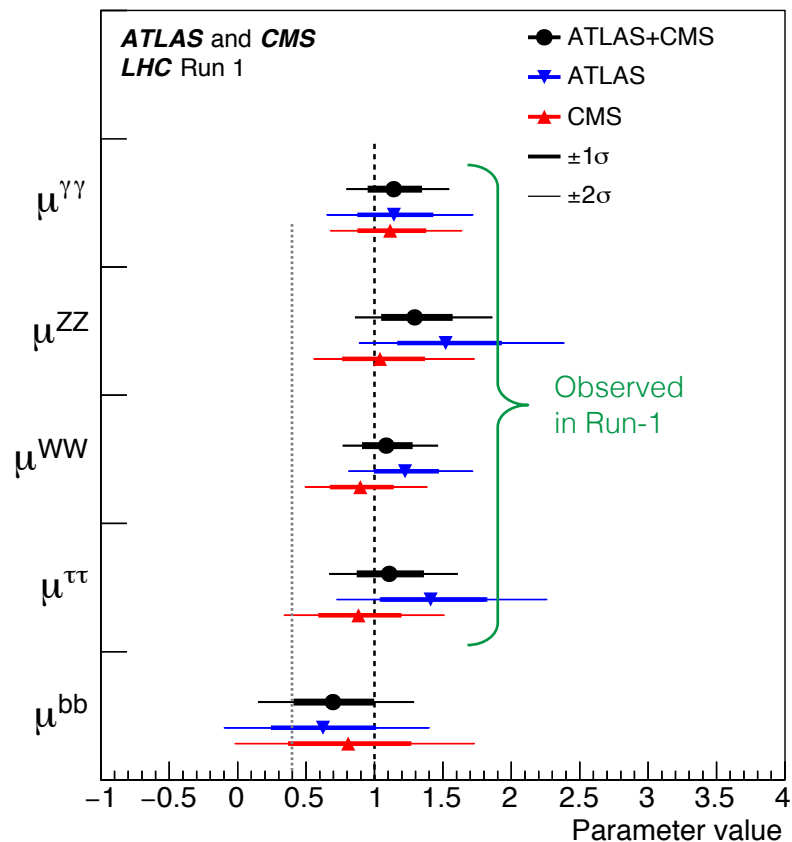
$1.13^{+0.09}_{-0.08}$ (ATLAS)

Higgs production processes



Higgs decay processes

arXiv1606.02266

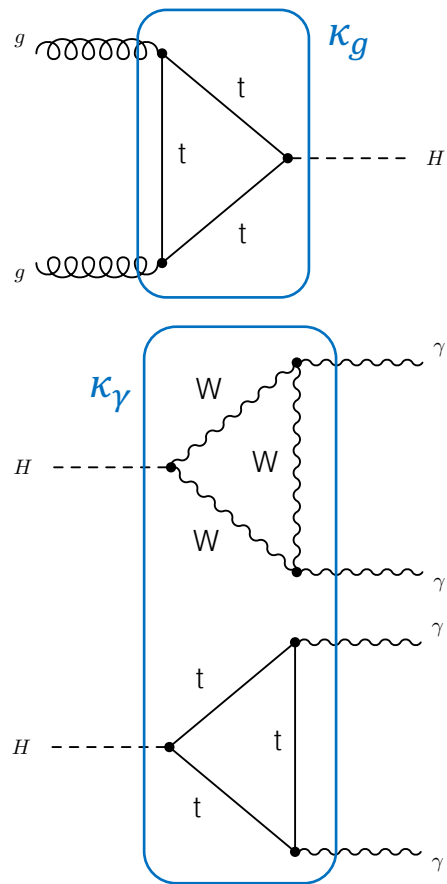
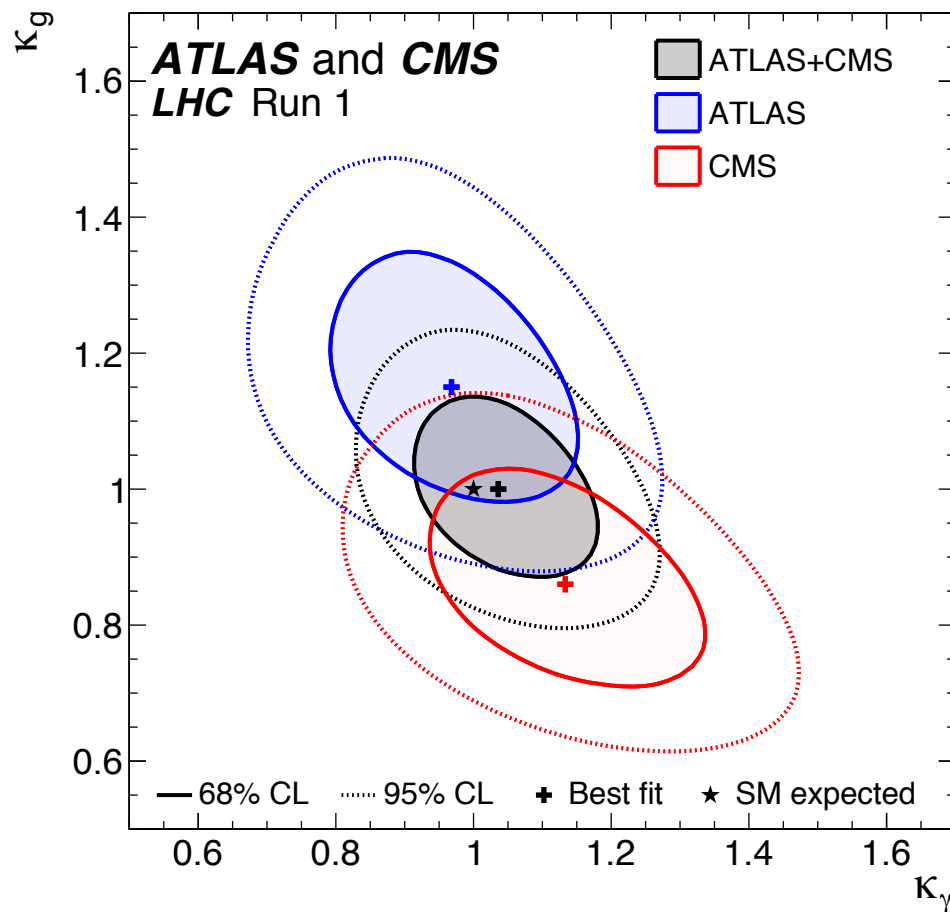


Combined ATLAS & CMS Higgs analysis — Run-1 legacy

ATLAS & CMS Run-1 combination of Higgs coupling measurements

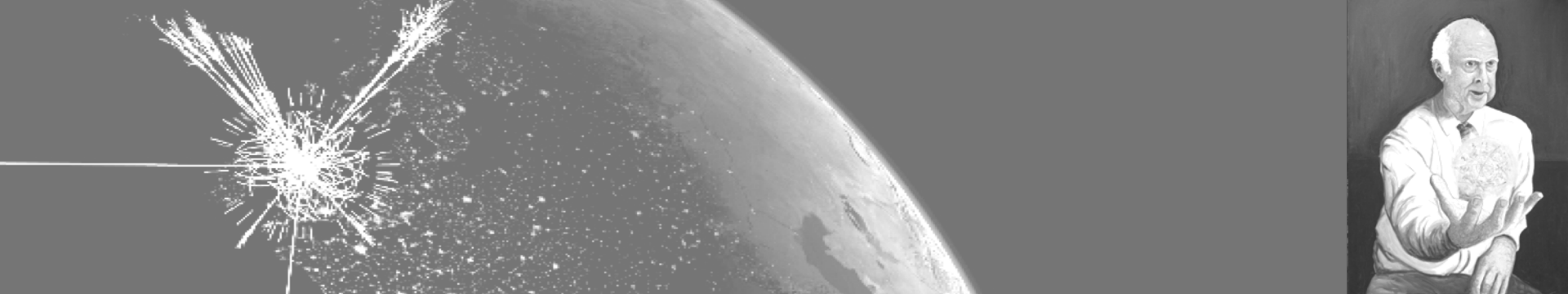
Coupling modifier: $\kappa = \kappa(\text{exp}) / \kappa(\text{SM})$

arXiv1606.02266

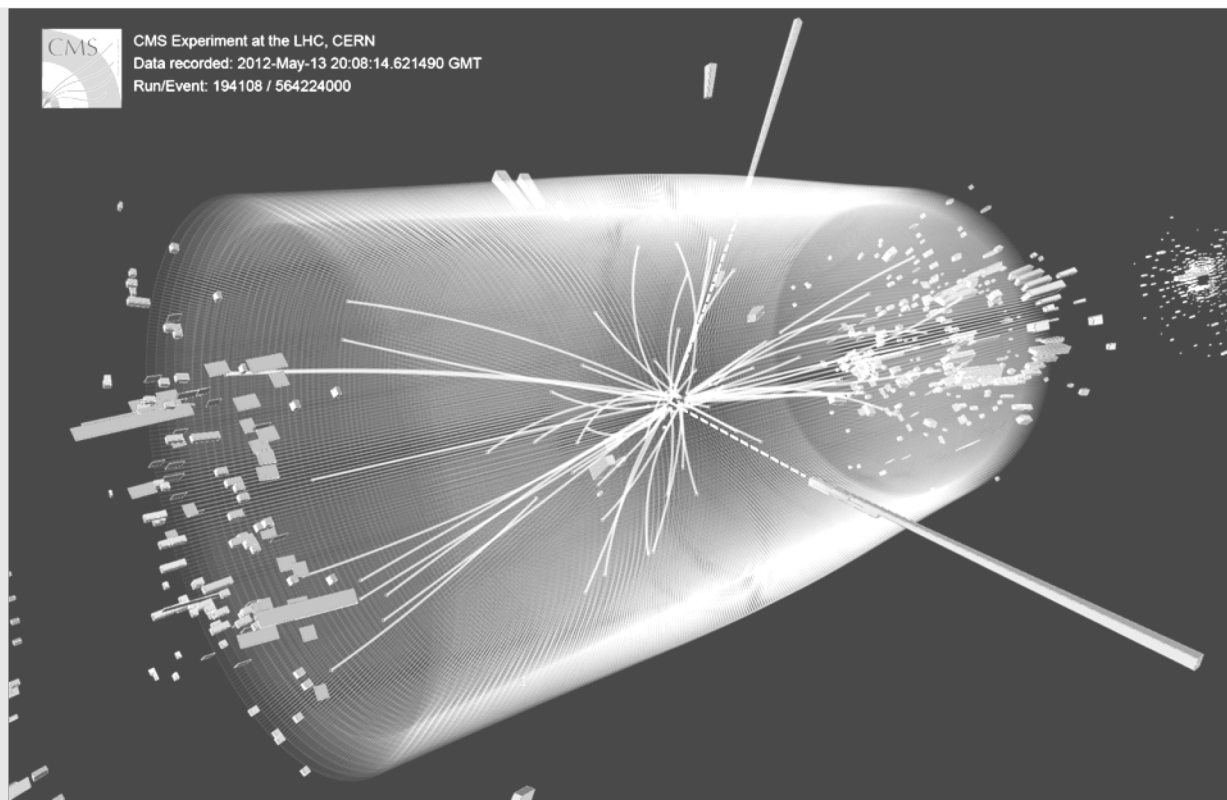


Couplings to massless particles mediated by loops involving heavy particles

Powerful test for new physics (eg, excludes SM-like heavy 4th fermion generation)

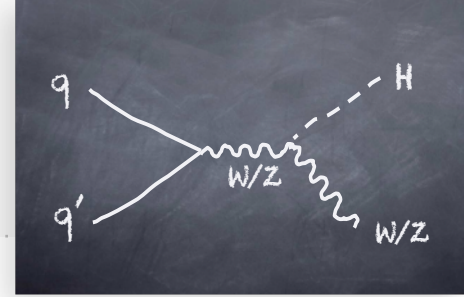


Higgs boson Highlights in 2018: fermionic channels

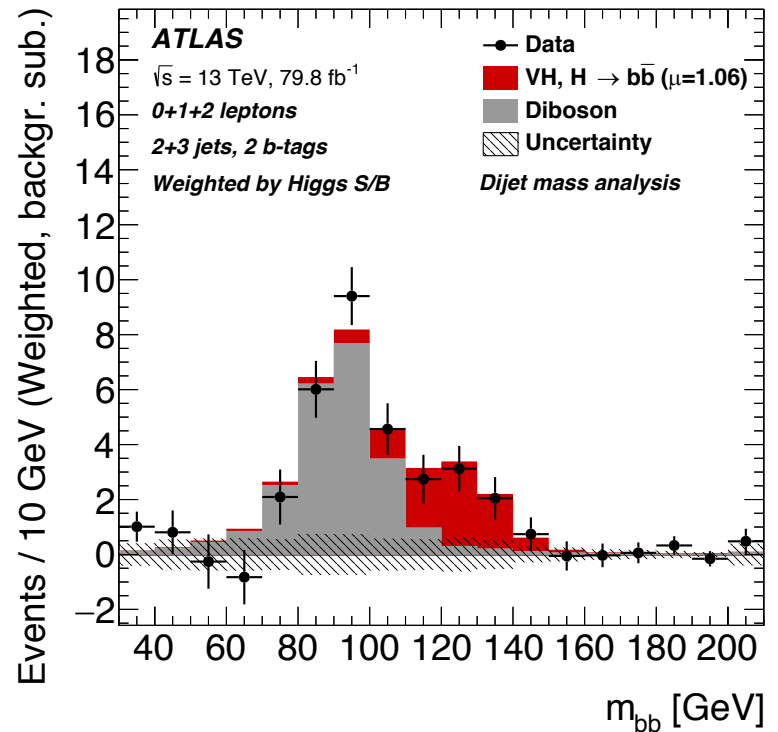
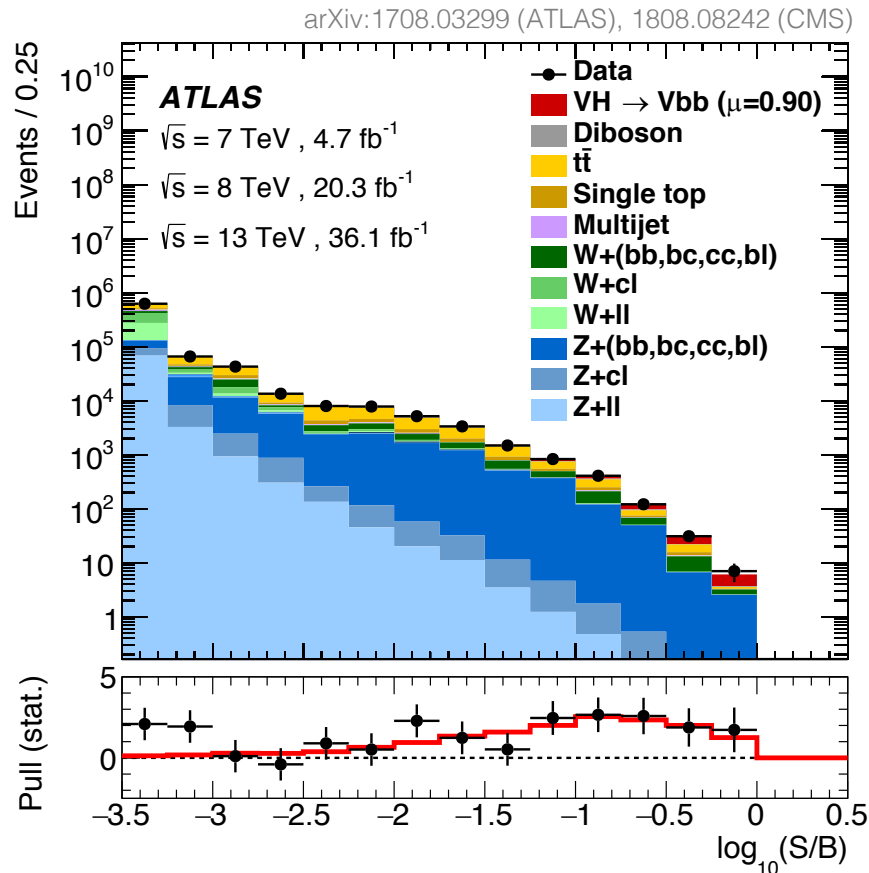


Observation of $H \rightarrow b\bar{b}$ (ATLAS & CMS)

$H \rightarrow b\bar{b}$ (BR: 58%), best channel: $W/Z+H \rightarrow 0$ (+MET), 1, 2 leptons + H



Extremely challenging analysis requiring multivariate techniques to suppress background, and data driven constraint of background uncertainties. Powerful validation channel: $W/Z+Z(\rightarrow b\bar{b})$

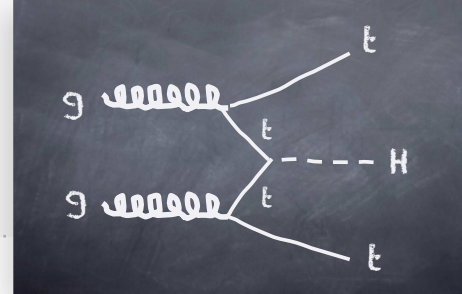


$$\mu(VH(bb)) = 1.01 \pm 0.20 \text{ (ATLAS)}$$

$$1.04 \pm 0.20 \text{ (CMS)}$$

Observation of $t\bar{t}H$ production (CMS & ATLAS)

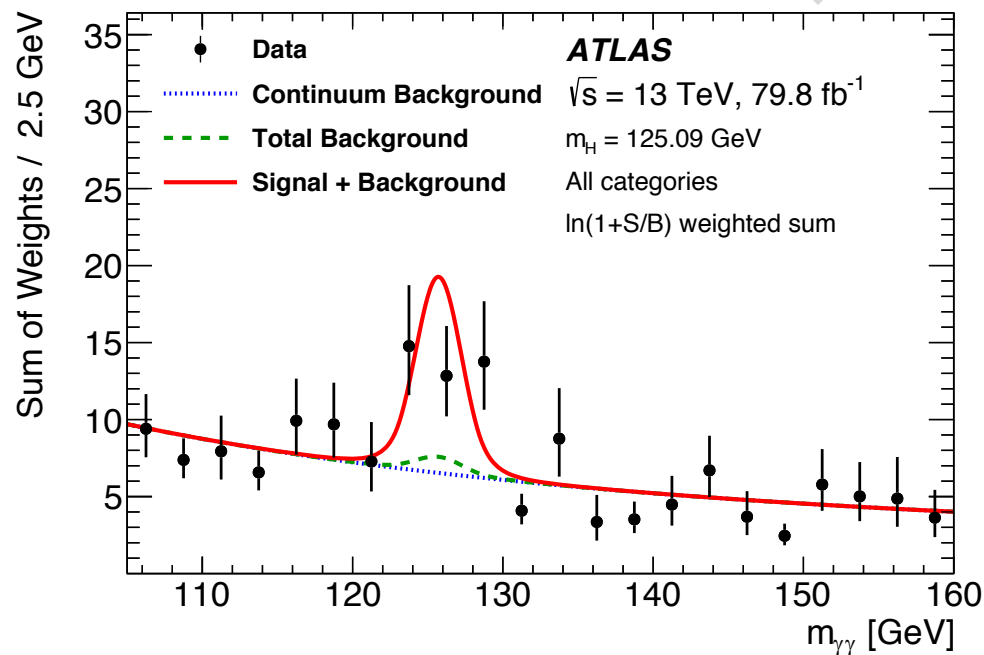
Direct probe of Higgs–top coupling



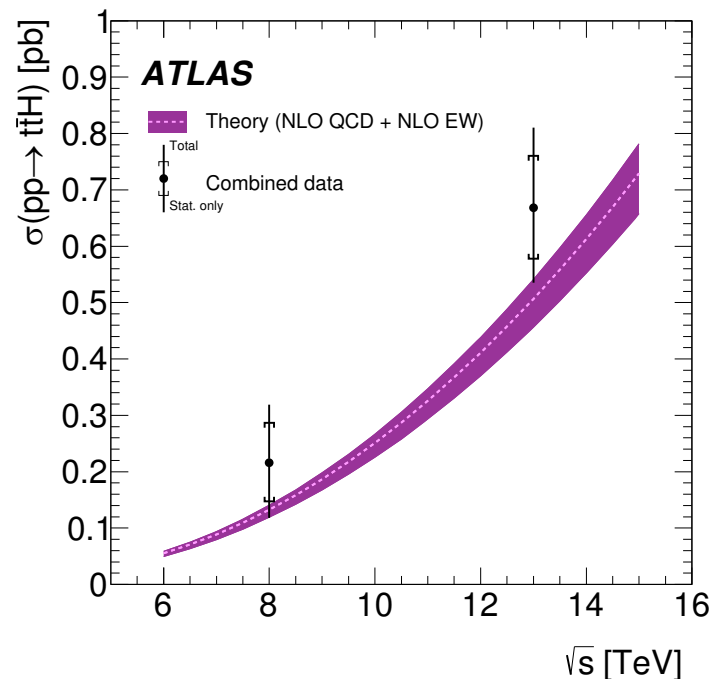
1806.00425 (ATLAS)
1804.02610 (CMS)

Combine large variety of final state depending on top and Higgs decays

Distinguish: $t\bar{t}+H(\rightarrow b\bar{b})$, $t\bar{t}+H(\rightarrow W W^*, \tau\tau)$, $t\bar{t}+H(\rightarrow \gamma\gamma)$, $t\bar{t}+H(\rightarrow Z Z^*)$



Heavy use of data-driven constraints
and multivariate classification



Measurements agree with prediction
Strong rise with collision energy

The Higgs boson as a “portal” to beyond the SM physics

Higgs is narrow: 4.1 MeV

For comparison:

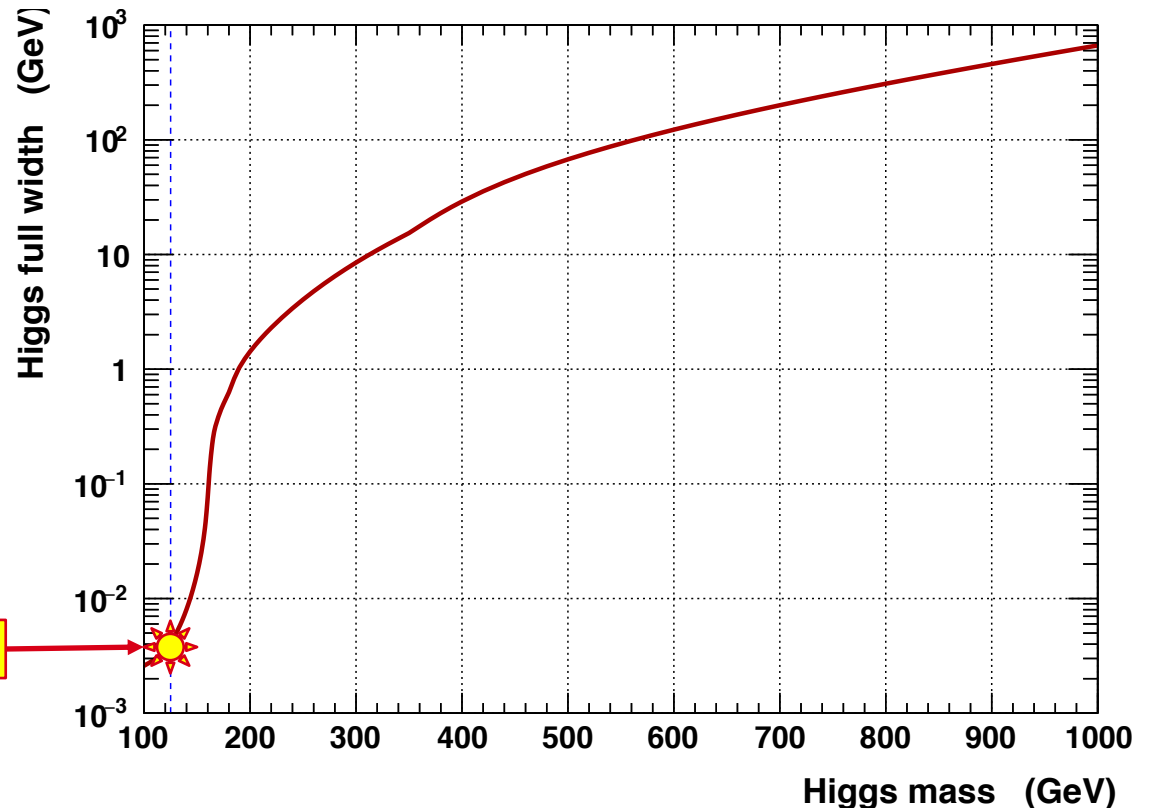
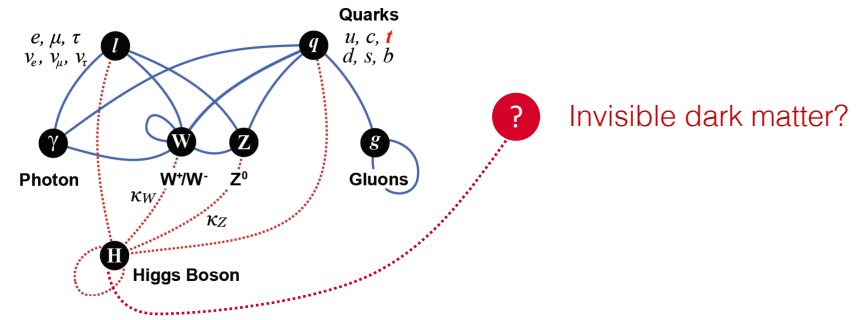
$$\Gamma_W = 2.1 \text{ GeV}$$

$$\Gamma_Z = 2.5 \text{ GeV}$$

$$\Gamma_{\text{top}} = 1.3 \text{ GeV}$$

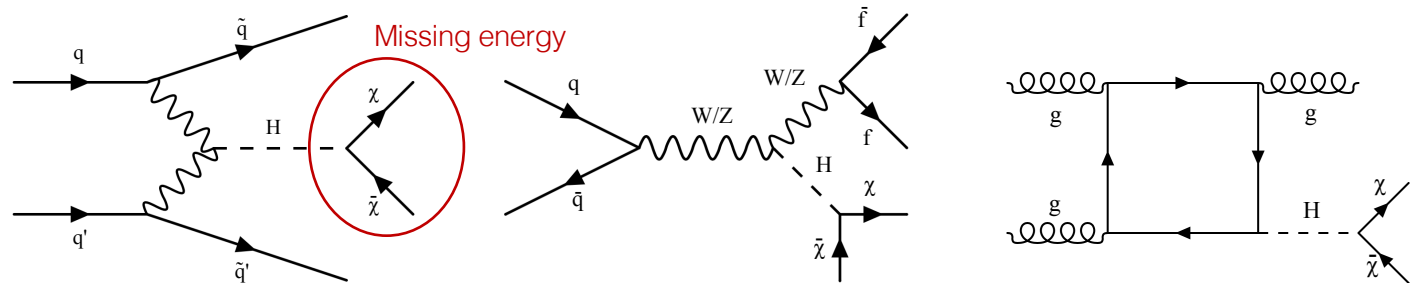
Even small couplings
to new light states can
measurably distort
branching fractions

→ Search for invisible
Higgs boson decays

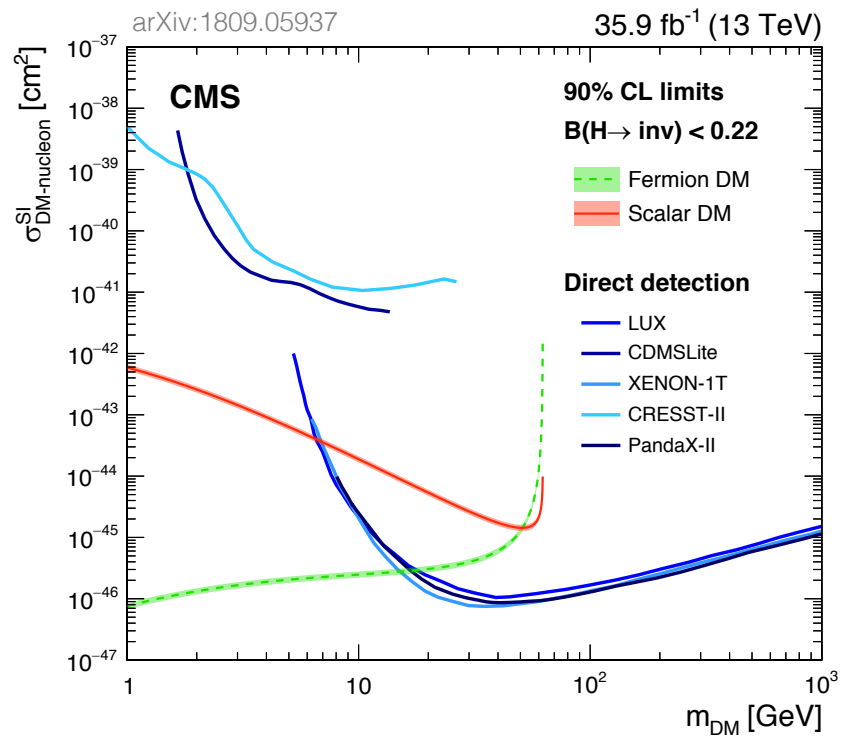
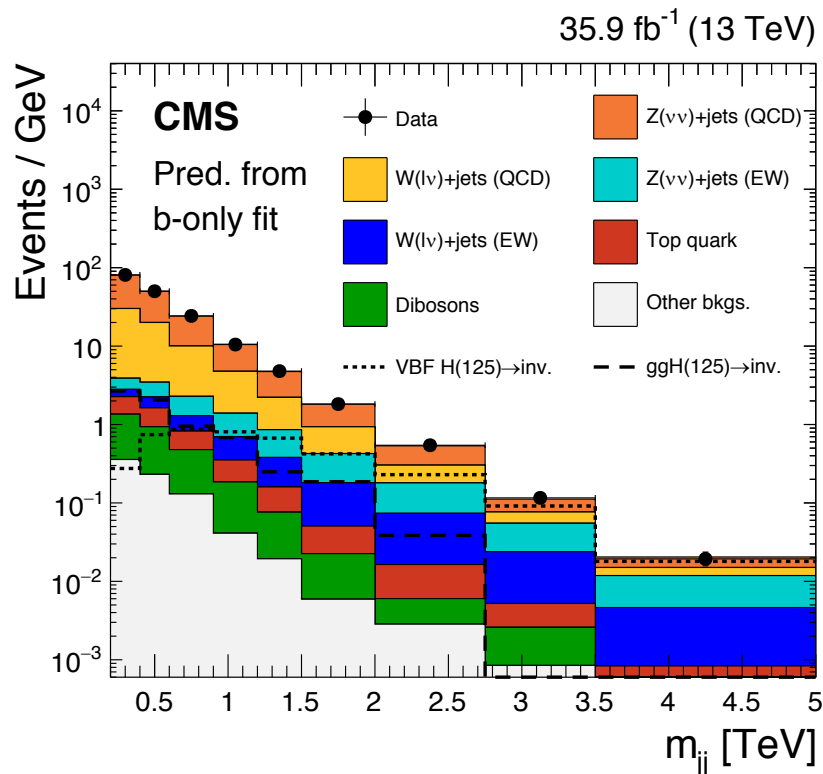


Search for dark matter through invisibly decaying Higgs

Invisible Higgs decays can be probed by associated production (VBF, VH, ...)



Sensitivity to WIMP mass $< m_H / 2$, complementary to direct dark matter searches



Inventory of Higgs boson property measurements

Mass: Run-1 (ATLAS & CMS): 125.09 ± 0.24 GeV | confirmed by ATLAS and CMS with Run-2 data

Spin / CP: Spin 1, 2 excluded with high significance | CP-even, but CP-odd admixtures possible

Width: < 1.1 GeV from direct measurement | < 9.2 MeV from off-shell coupling | < 7 MeV from fit
 SM: 4.1 MeV (both results are model-dependent)

BR(H $\rightarrow$ invisible): $< 26\%$ (assuming SM production)

SM production and decay channels:

Decay $\rightarrow$ Production $\downarrow$	$\gamma\gamma$	ZZ^*	WW^*	bb	cc	$\tau\tau$	$\mu\mu$	$Z\gamma$	Combined
ggF	Observed	Observed	Observed	UL	–	Evidence	UL	UL	Observed
VBF	UL	UL	UL	UL	–	Evidence	UL	–	Observed
VH	UL	UL	UL	Evidence	UL	UL	–	–	Observed
ttH	Evidence	UL	Evidence*	UL	–	Evidence*	–	–	Observed
Combined	Observed	Observed	Observed	Observed	UL	Observed	UL	UL	* both channels together

Upper Limit

Differential cross section measurements ($p_T(H)$, N_{jets} , ...): performed in most channels (+ STXS)

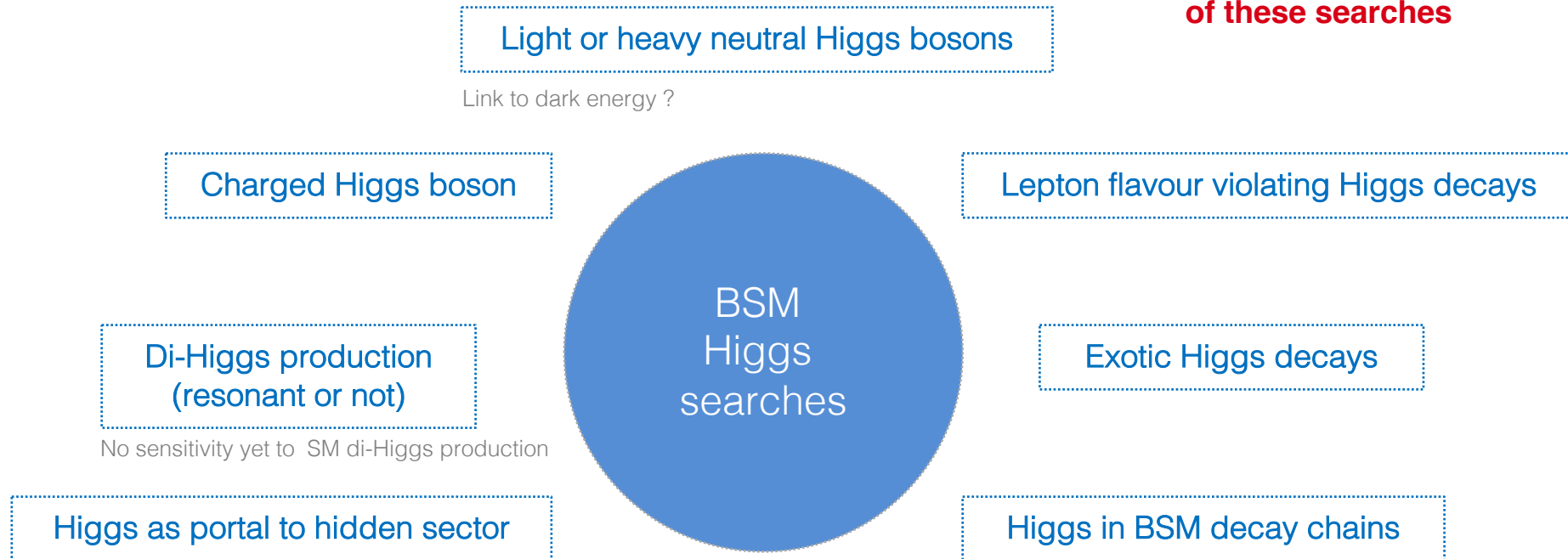
Di-Higgs production: $< 6.7 \times \sigma_{\text{SM}}$ (33 fb at $\sqrt{s} = 13$ TeV), strongest channels: $bb\gamma\gamma$, $bb\tau\tau$

Is the scalar sector just that of the SM ?

Higgs sector may be non-minimal and/or Higgs boson may couple to new physics

Diverse search programme at the LHC:

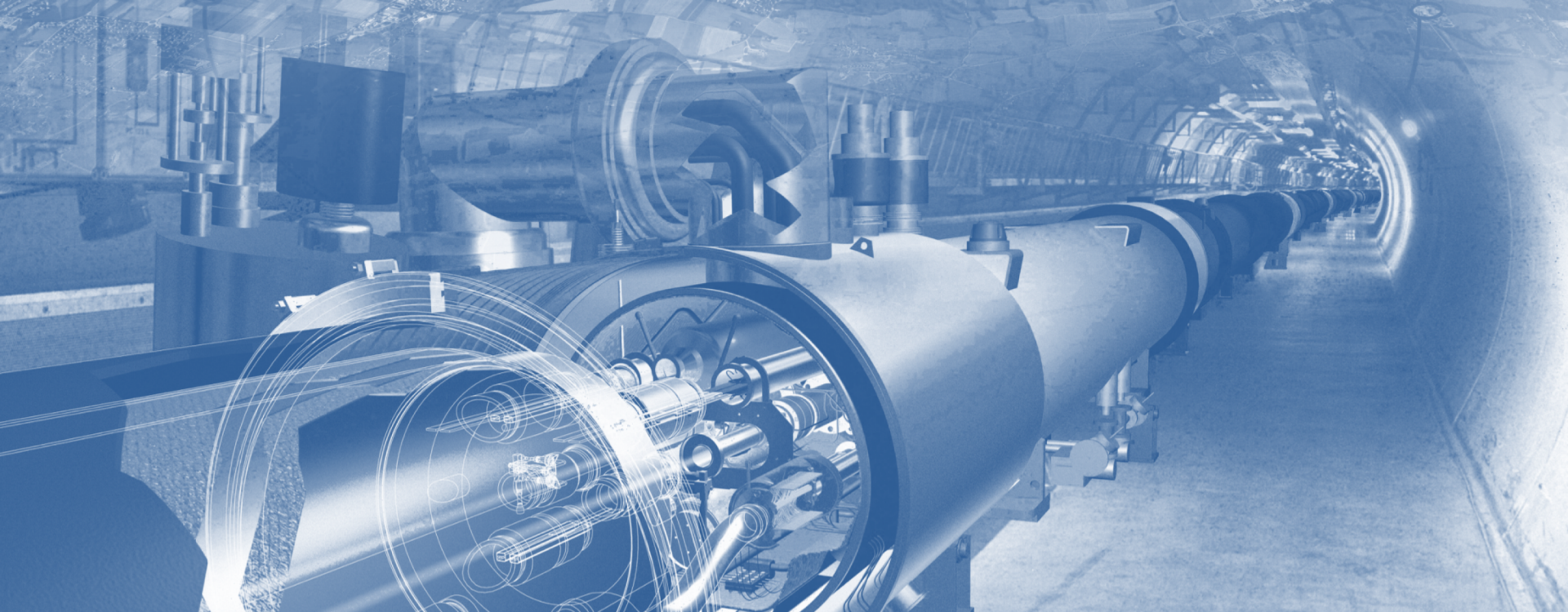
**So far no deviation
from SM found in any
of these searches**



$$V(\phi) = \mu_{<0}^2 |\phi|^2 + \lambda |\phi|^4 + Y^{ij} \psi_L^i \psi_R^j \phi$$

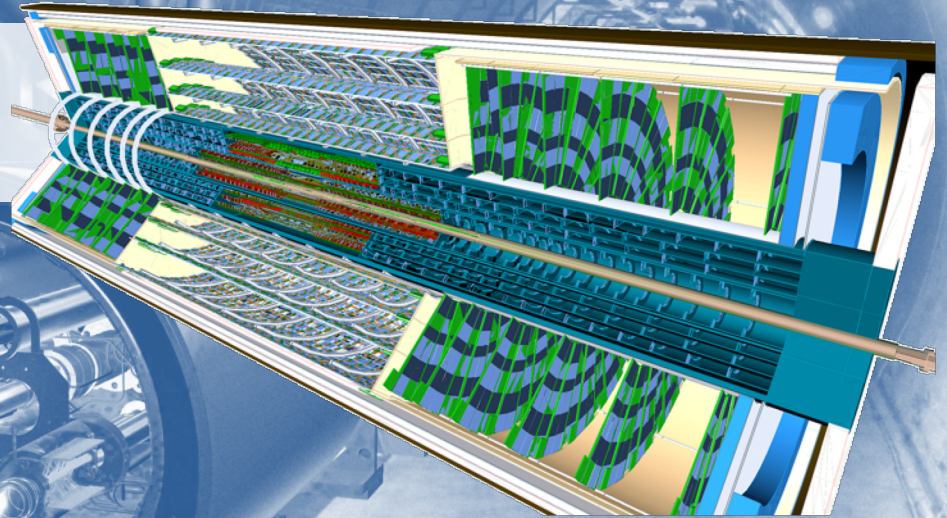
Higgs potential
Is it just the simplest model?

Carries the seed of new physics ?

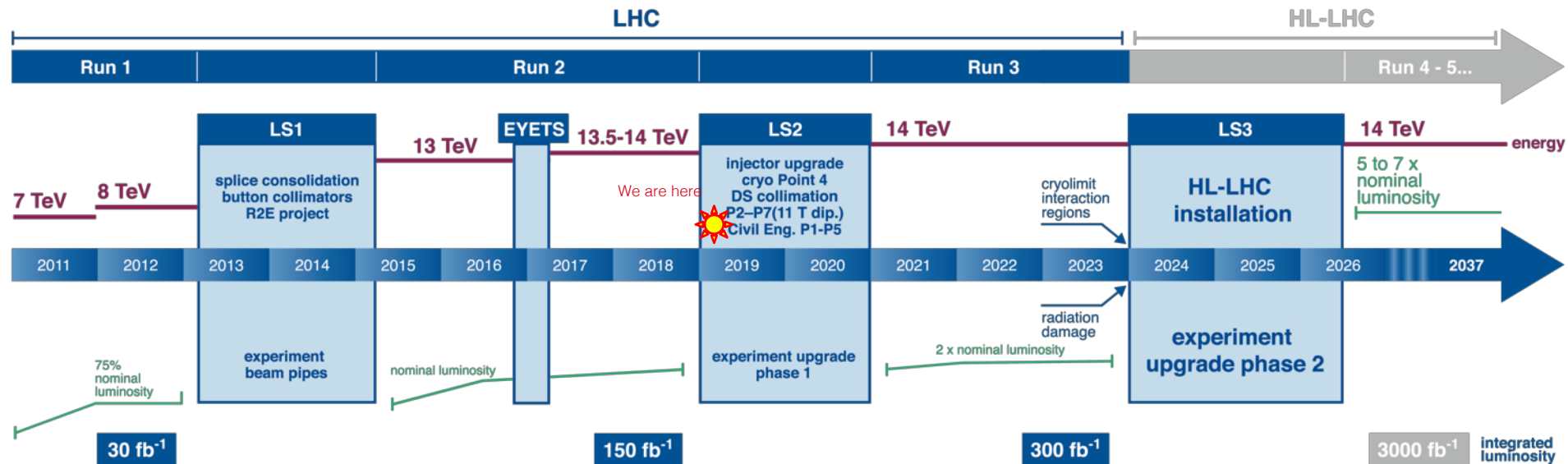


The next steps

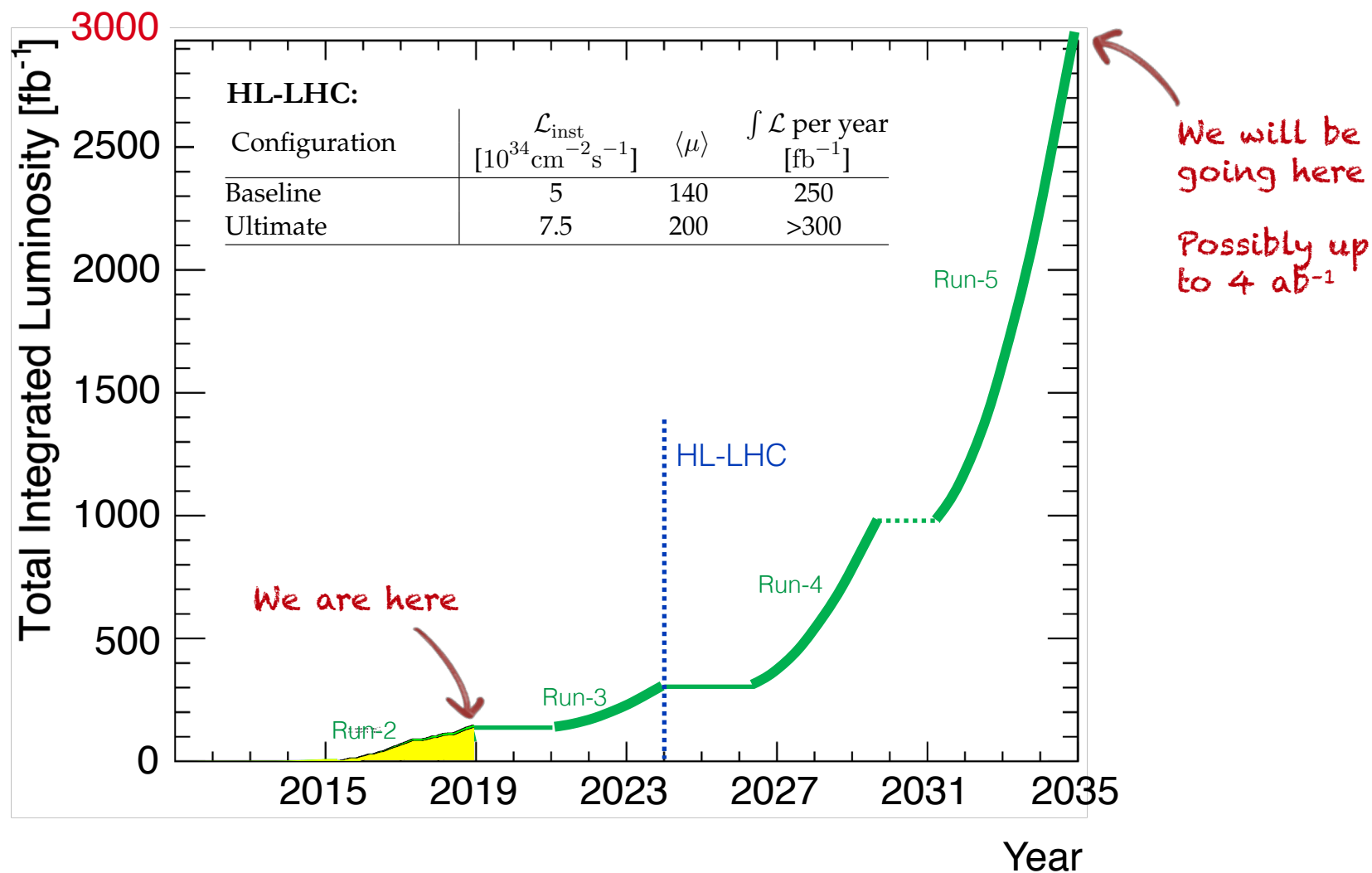
Phase-II: The High-Luminosity LHC



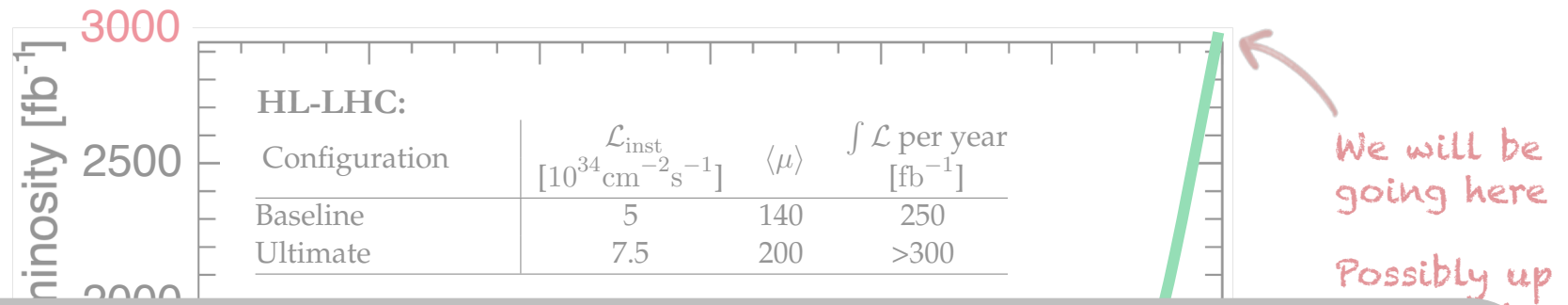
LHC / HL-LHC Plan



Expected integrated luminosity of LHC & HL-LHC

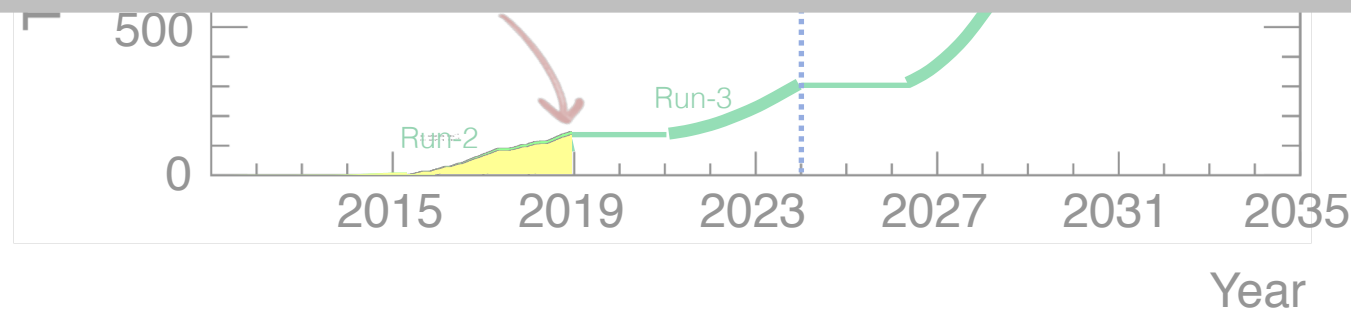


Expected integrated luminosity of LHC & HL-LHC

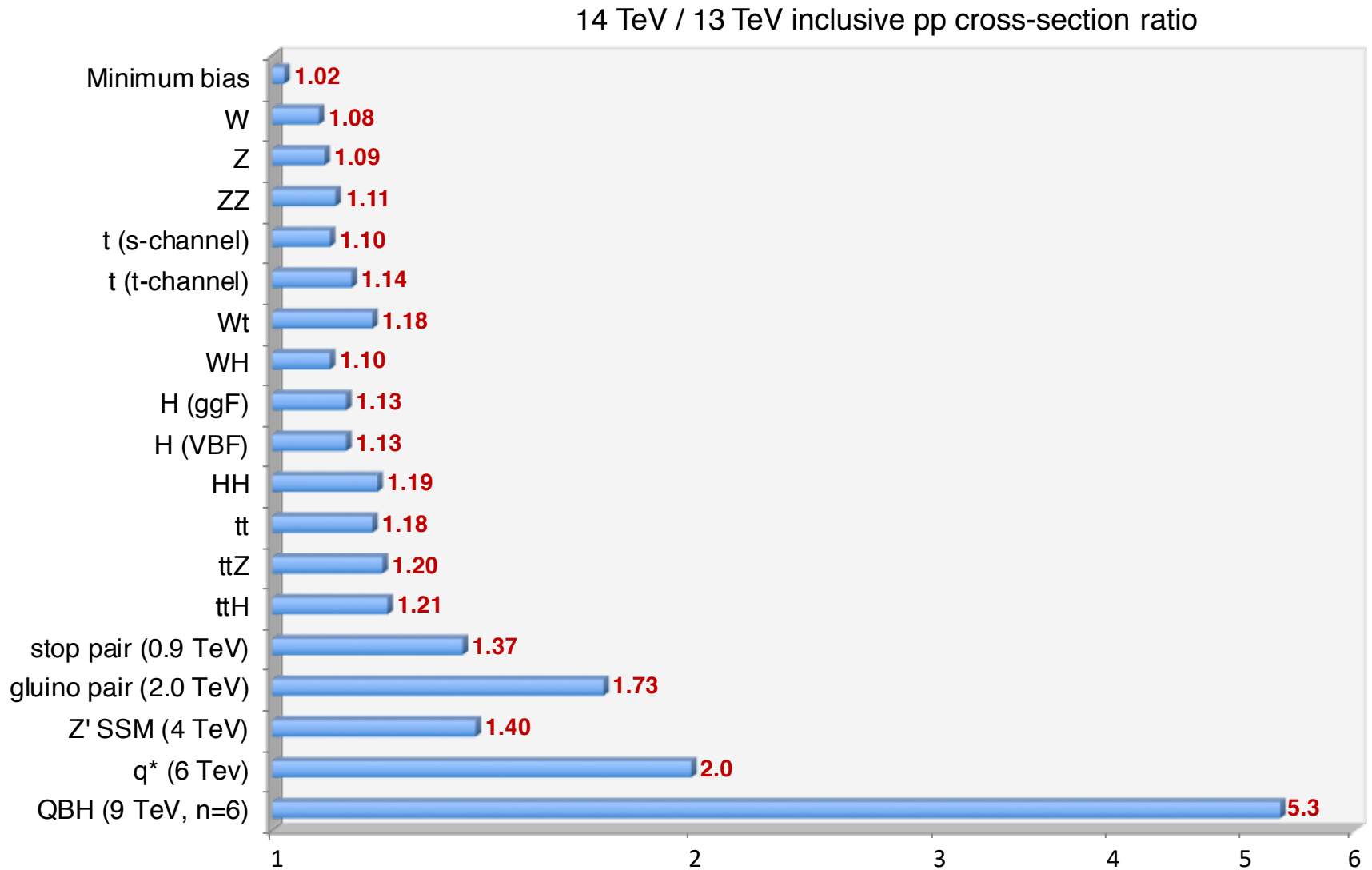


HL-LHC inclusive Higgs sample will be 23 times larger (30 times for 4 ab^{-1}) than that of the full Run-2 ($\sim 150 \text{ fb}^{-1}$ at 13 TeV)

With 3 ab^{-1} : 190 million H and 120 thousand HH (ggF) produced (SM)



14 TeV proton-proton centre-of-mass energy

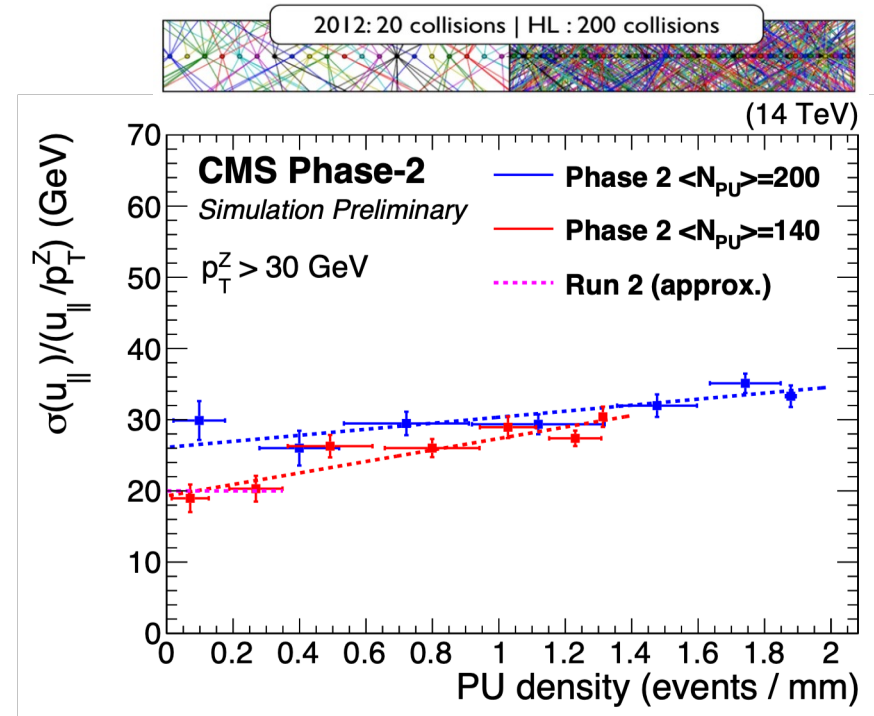
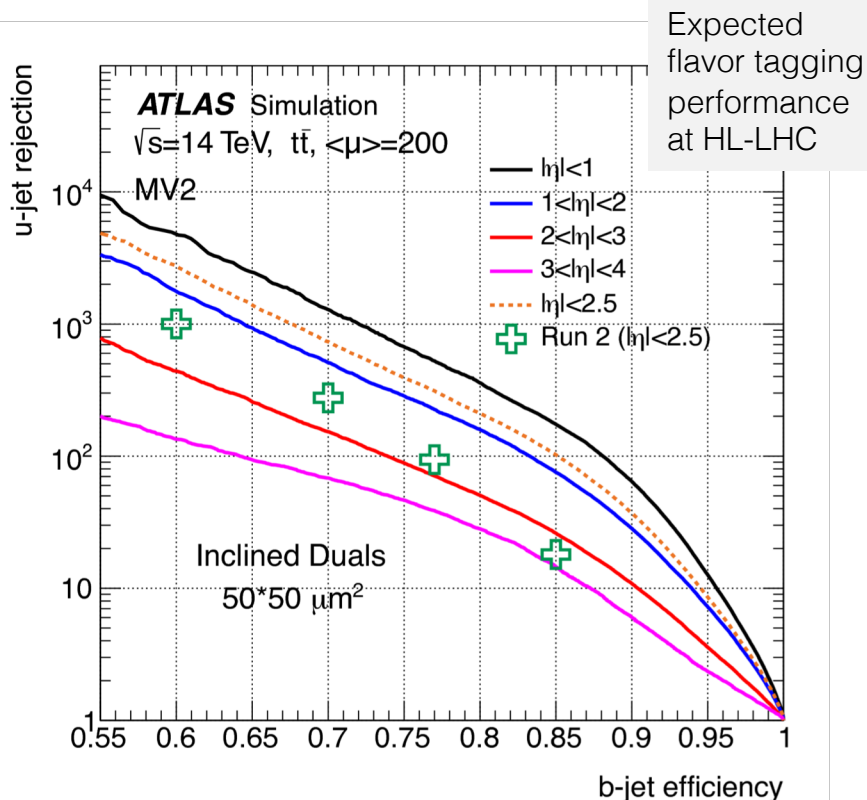


ATLAS & CMS Detector performance

The performance of trigger and physics object reconstruction degrades with pileup

Upgrades of HL-LHC (Phase-II) detectors designed to recover Phase-0 performance under high pileup

- Improved trigger (L1 tracking, μ , e/γ , (b-)jets, E_T^{miss}), latency and bandwidth (~ 10 kHz output rate)
- Improved pileup rejection (extended tracking acceptance, better z-vertex resolution, timing detectors)
- Improved radiation hardness



Parallel p-flow MET resolution vs. pileup density in $Z \rightarrow \mu\mu$ events using PUPPI pileup mitigation

Higgs physics programme at the HL-LHC in a nutshell

Higgs properties:

- mass (well known, expect to improve to ~ 33 MeV in $H \rightarrow 4\mu$), width (through interference measurements)
- spin (0^+ established), CP (odd admixture possible) — not discussed today

Rare Higgs decays:

- Observation of $H \rightarrow \mu\mu$, $H \rightarrow Z\gamma$, HH production (constraint on Higgs self coupling)
- Search for very rare (eg, $H \rightarrow M\gamma$, $M=J/\psi$, ϕ , ρ), difficult ($H \rightarrow cc$) or anomalous decays (invisible or new particles, or flavour violating)

Higgs couplings:

- Study of Higgs production and anomalous couplings by differential cross-section measurements
- Global and partially global coupling fits: experiments moving from “kappa” interpretation to EFT

New physics in Higgs production or other scalar states

- Search for anomalous FCNC through top decays, Higgs production via SUSY cascades, etc.
- Search for additional scalar particles

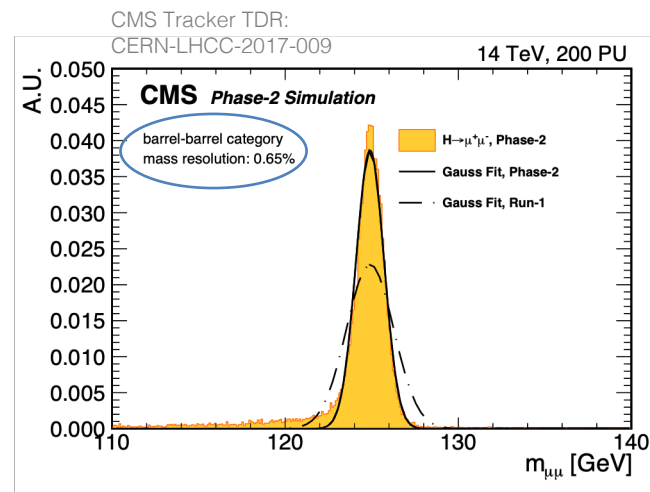
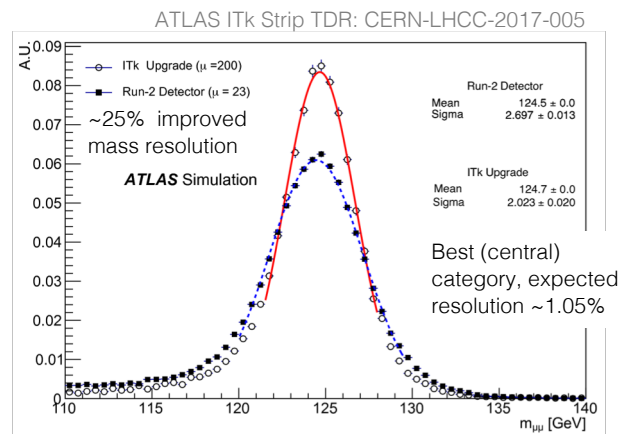
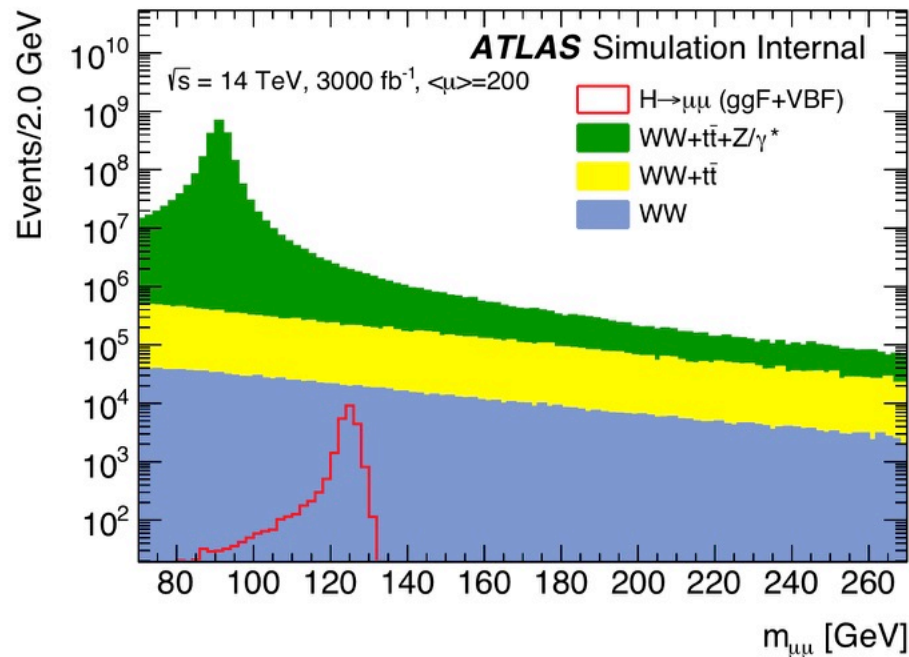
Coupling to 2nd generation: Higgs decay to $H \rightarrow \mu\mu$ (BR: 0.022% in SM)

Upgraded detectors feature improved di-muon mass resolution

If SM branching fraction, $H \rightarrow \mu\mu$ could be observed in Run-3 (ATLAS & CMS combined)

Cross-section times branching fraction measurement to ~14% (ATLAS), 10% (CMS) precision for 3 ab⁻¹

Challenging data-driven Drell-Yan background determination



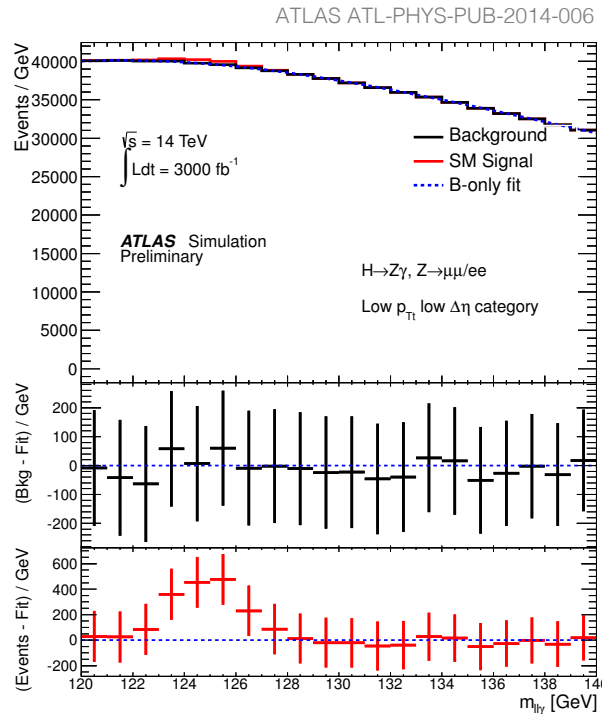
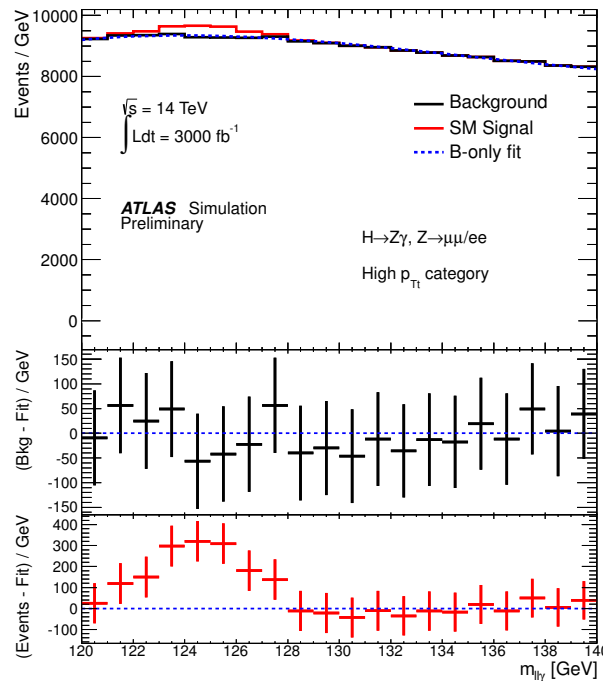
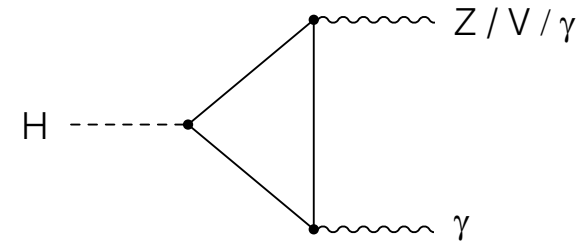
Rare loop decay to $H \rightarrow Z\gamma$ (BR: 0.15% in SM, 0.010% with $Z \rightarrow ee, \mu\mu$)

Large background from Z production with radiative photons

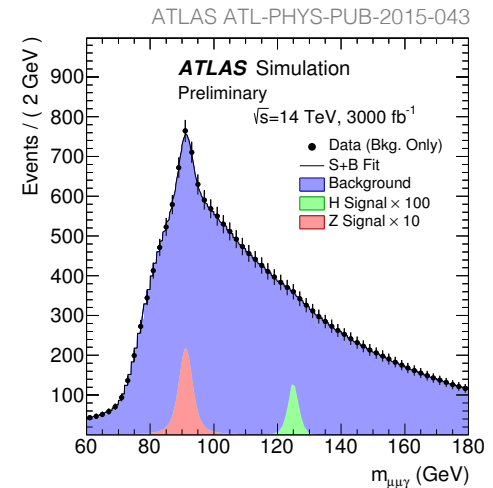
Observation with combined ATLAS & CMS dataset expected with 3 ab^{-1}

Combined statistical precision of about 17% on cross-section

Challenging data-driven background determination



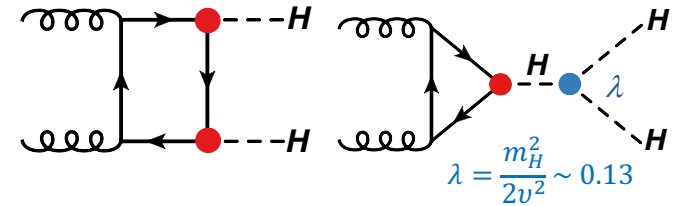
Also searches for, eg,
 $H \rightarrow J/\psi \gamma$ with expected sensitivity of 15 times SM prediction (BR: $2.9 \cdot 10^{-6}$)



Di-Higgs production

HH ggF cross section predicted to 37 fb at 14 TeV,
ie, >1000 times smaller than for single Higgs production

Sophisticated analyses needed, room for innovation;
Extrapolation uncertainty in continuum background prediction

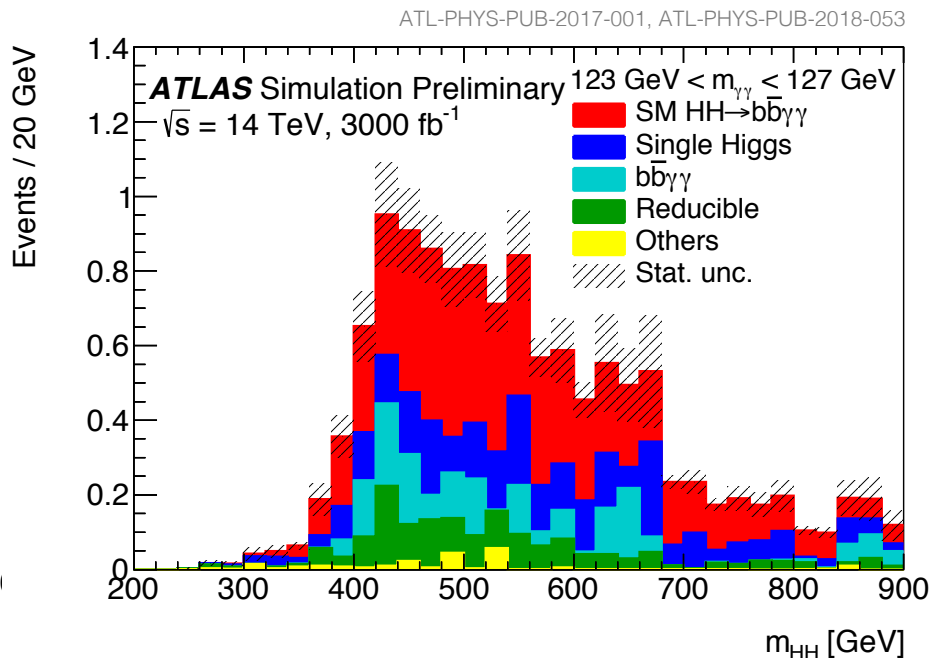
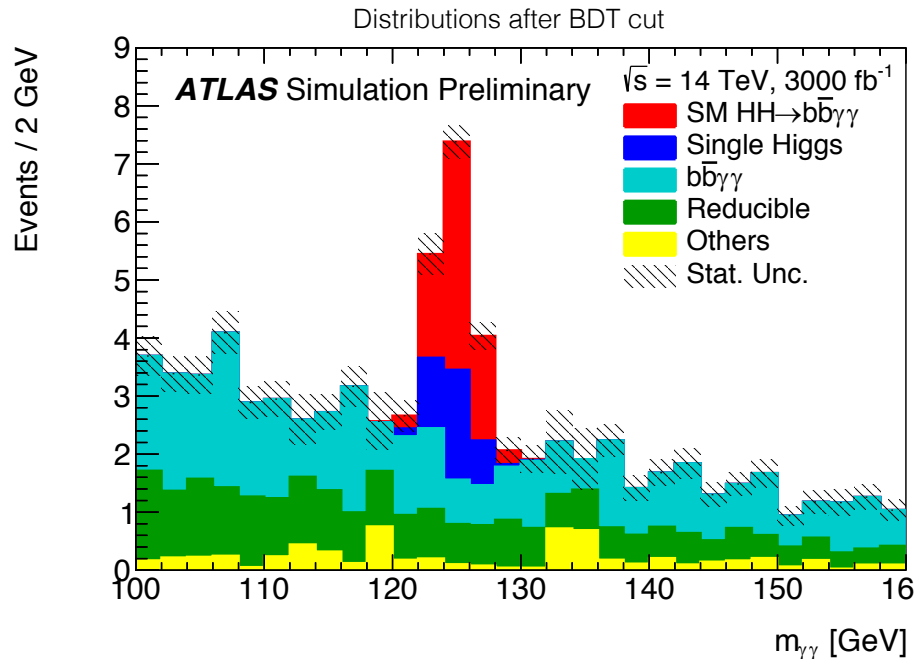


Best channels: $b\bar{b}\gamma\gamma$ (BR = 0.26%), $b\bar{b}\tau\tau$ (7.3%), $b\bar{b}b\bar{b}$ (34%), $b\bar{b}WW$, 25% → combination

Currently ATLAS (36 fb⁻¹ combination at 13 TeV): $\mu_{HH} < 6.7$ (10.4_{exp}), CMS: 22.2 (12.8_{exp})

Best expected sensitivity in ATLAS from $b\bar{b}t\bar{t}$ (14.6) !

Projection to HL-LHC: 3.0σ significance for ATLAS, CMS: 2.6σ



Di-Higgs production

HH ggF cross section predicted to 37 fb at 14 TeV,
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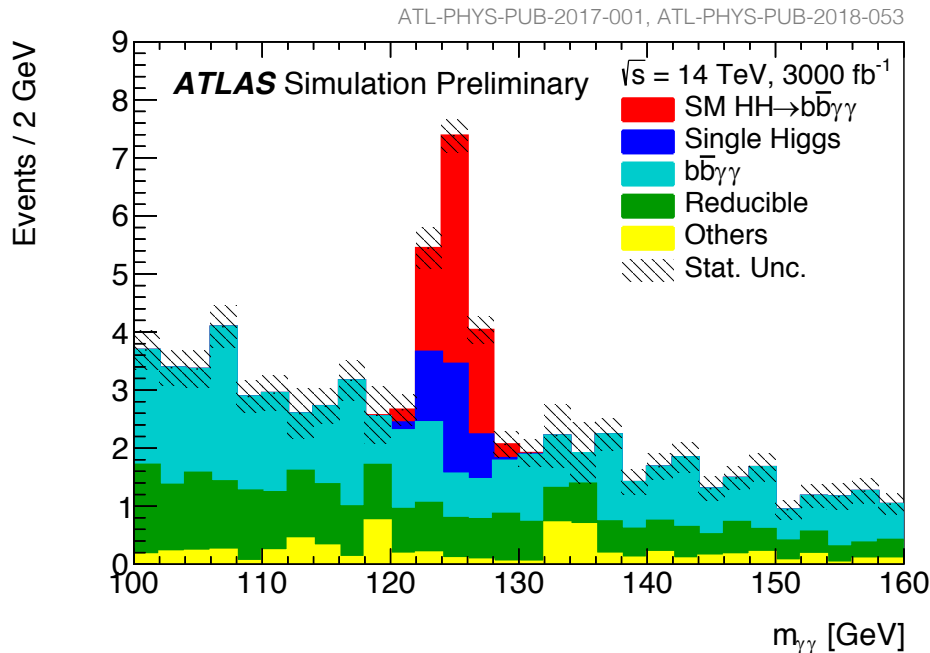
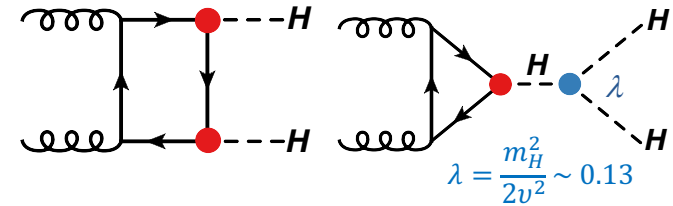
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Best expected sensitivity in ATLAS from $b\bar{b}t\bar{t}$ (14.6) !

Projection to HL-LHC: 3.0 σ significance for ATLAS, CMS: 2.6 σ



It remains to be seen which of the three
main channels will eventually be best

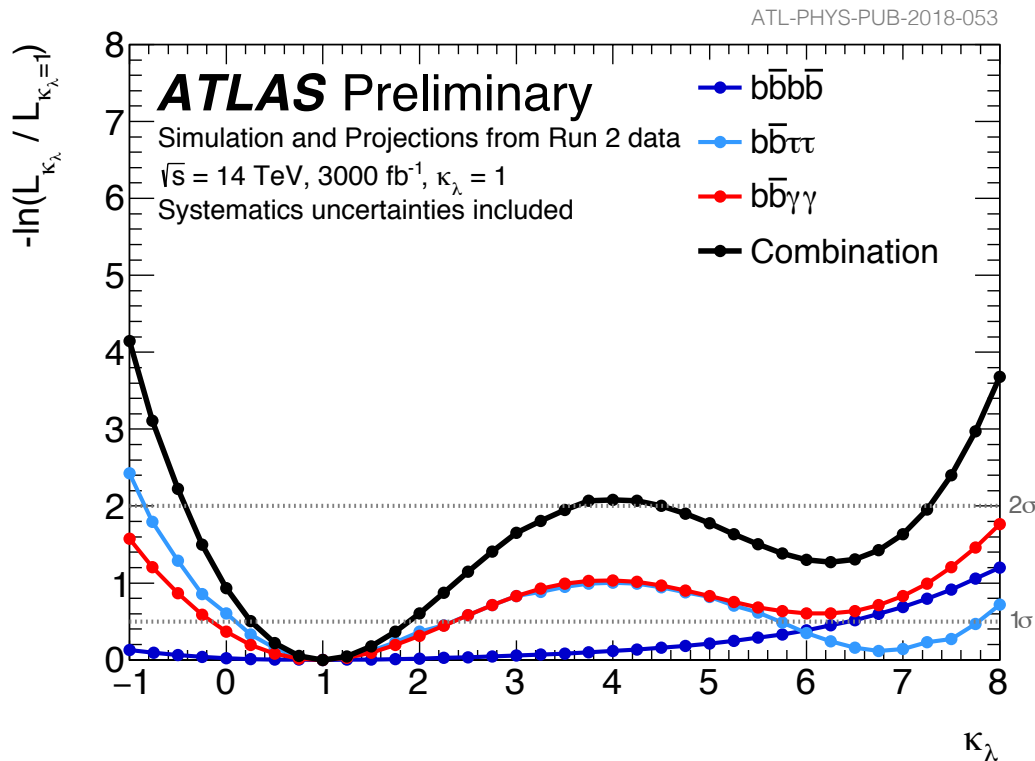
The $b\bar{b}b\bar{b}$ channel strongly depends on
the lowest jet p_T trigger threshold and on
top background modelling

Combining ATLAS & CMS in all channels,
hoping for analysis improvements, and
including new channels may give 4 σ HH
sensitivity with 3 ab⁻¹

Constraints on Higgs trilinear self coupling λ_{HHH}

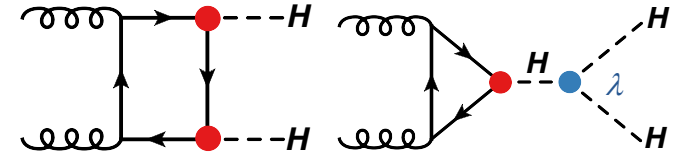
Constraint on λ_{HHH} by comparing data to NLO m_{HH} distributions for different λ_{HHH} values. Effects on total HH cross section and acceptance

Projection to HL-LHC (combined channels)



95% CL limit: $-0.4 < \lambda / \lambda_{SM} < 7.3$

$\lambda / \lambda_{SM} = 1^{+0.9}_{-0.8}$ [Note: $\sim 20\%$ measurement expected at HE-LHC with 15 ab^{-1}]



LO diagrams contributing with negative interference to SM HH production

Box diagram dominates inclusive production

Sensitivity to H self coupling rises at low m_{HH}

Fitting differential variables such as m_{HH} , $\rho_{T,H}$ allows to improve the constraint on λ
[See, eg, 1607.07441]

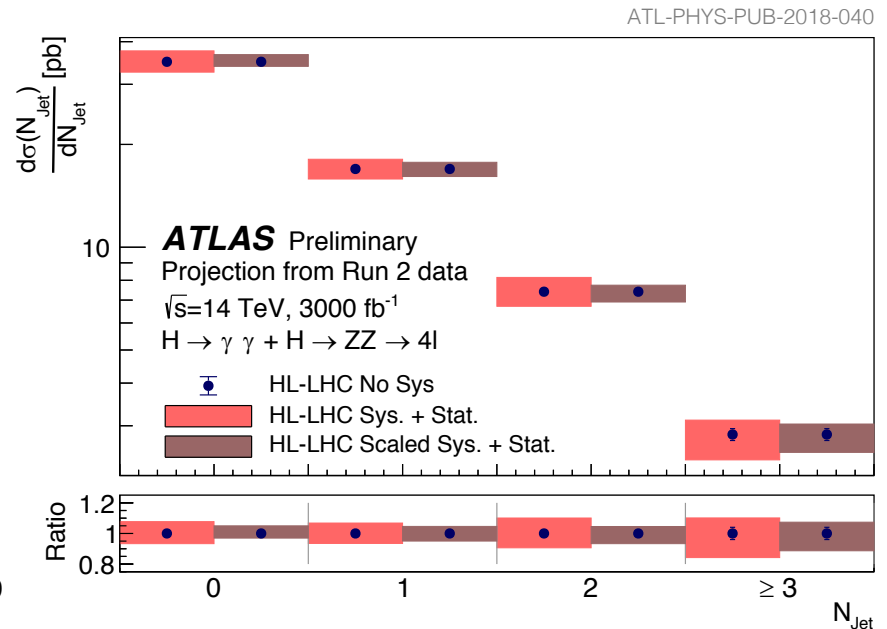
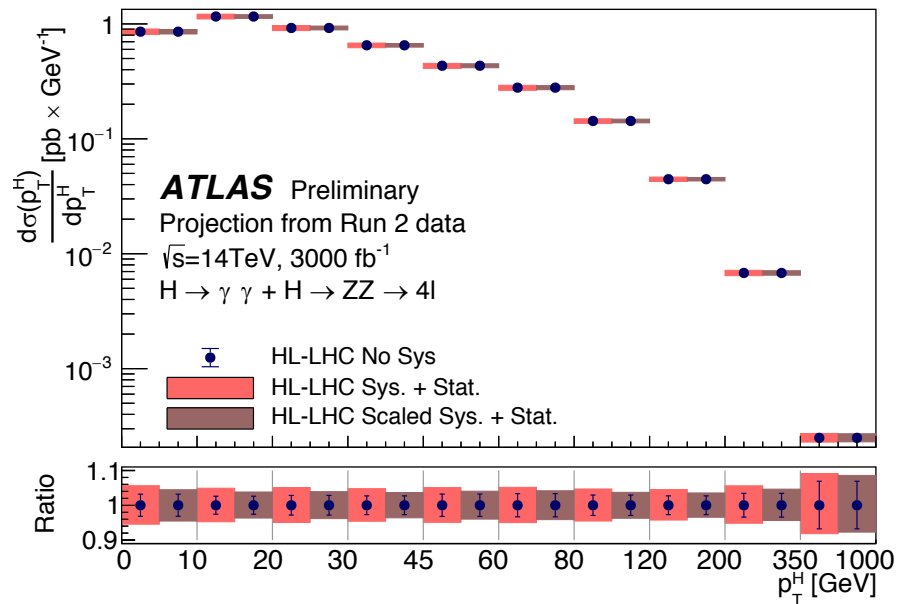
λ_{HHH} also affects single-H production at NLO through internal H loops $\rightarrow$ Complementary information from differential H cross-section measurements

Higgs production: differential cross-section measurements

The $H \rightarrow \gamma\gamma, 4\ell$ channels will dominate most precise differential cross-section measurements at the HL-LHC

Inclusive spectra with 5% statistical uncertainty up to 400 GeV

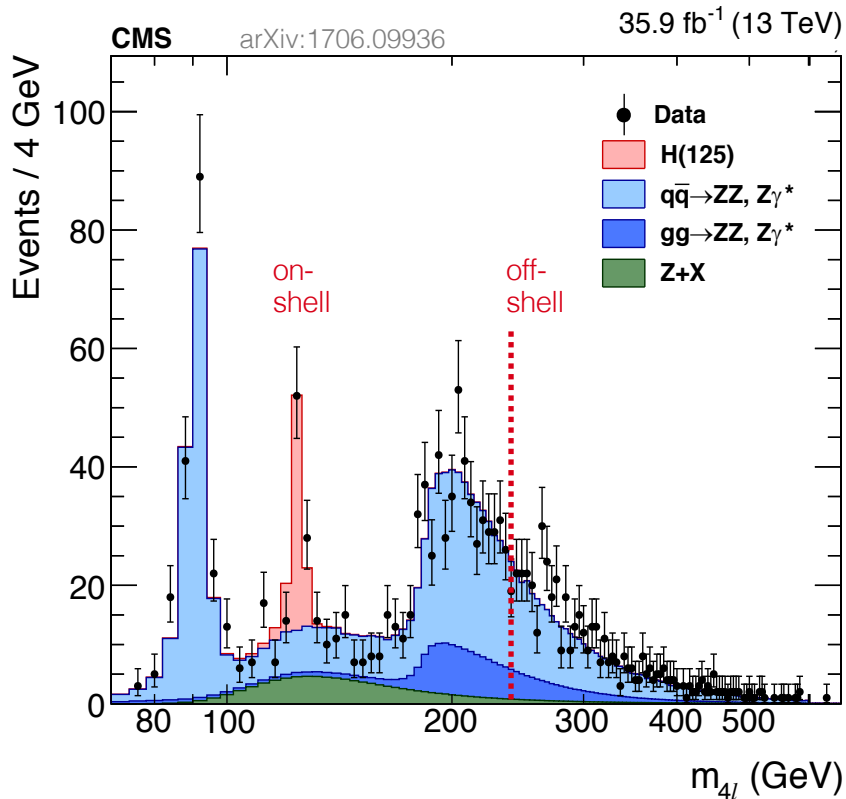
Sensitive to Higgs to b/c coupling and QCD at low p_T , and to top coupling and BSM at high p_T



Off-shell coupling measurement — constraining the Higgs boson width

Both CMS and ATLAS have constrained the Higgs off-shell coupling and through this obtained upper limits on the Higgs total width Γ_H .

The method uses the independence of off-shell cross section on Γ_H and relies on identical on-shell and off-shell Higgs couplings. One can then determine Γ_H from measurements of $\mu_{\text{off-shell}}$ and $\mu_{\text{on-shell}}$



$$\mu_{\text{off-shell}}(\hat{s}) \equiv \frac{\sigma_{\text{off-shell}}^{gg \rightarrow H^* \rightarrow VV}(\hat{s})}{\sigma_{\text{off-shell, SM}}^{gg \rightarrow H^* \rightarrow VV}(\hat{s})} = \kappa_{g, \text{off-shell}}^2(\hat{s}) \cdot \kappa_{V, \text{off-shell}}^2(\hat{s})$$

$$\mu_{\text{on-shell}} = \frac{\sigma_{\text{on-shell}}^{gg \rightarrow H \rightarrow ZZ}}{\sigma_{\text{on-shell, SM}}^{gg \rightarrow H \rightarrow ZZ}} = \frac{\kappa_{g, \text{on-shell}}^2 \cdot \kappa_{Z, \text{on-shell}}^2}{\Gamma_H / \Gamma_H^{\text{SM}}}$$

With $\mathcal{L}_2 = 3 \text{ ab}^{-1}$, we may find:

$$\mu_{\text{off-shell}}^{(L2)} = 1.00^{+0.43}_{-0.50} \text{ (stat+sys)}$$

$$\Rightarrow \Gamma_H^{(L2)} = 4.2^{+1.5}_{-2.1} \text{ MeV (stat+sys)}$$

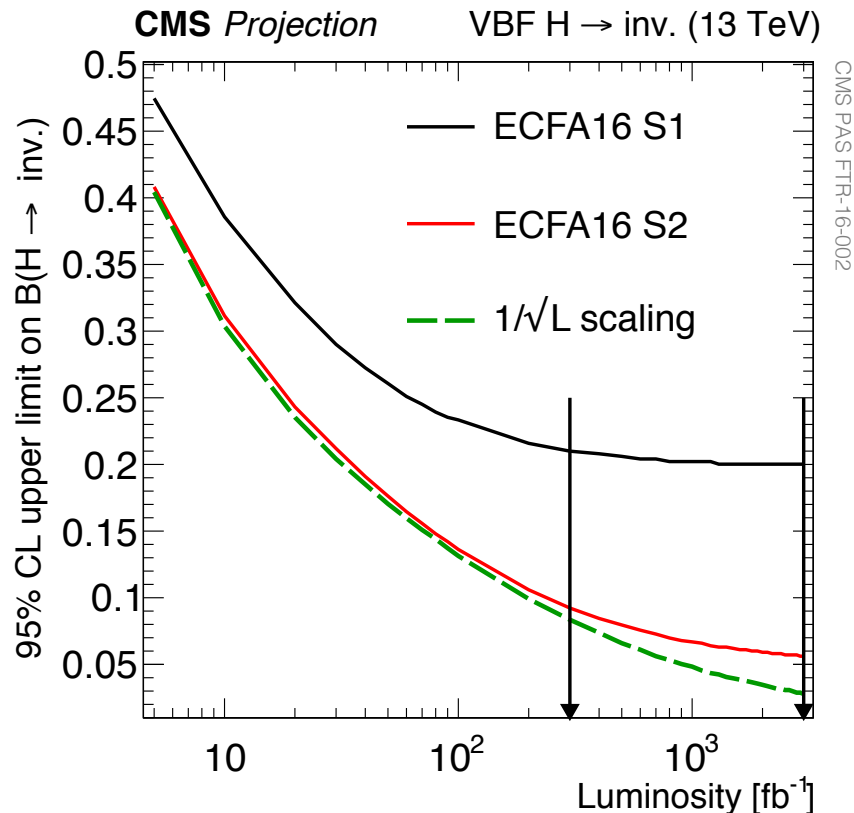
ATLAS: ATL-PHYS-PUB-2015-024

Large theory uncertainty ($\sim 30\%$) from $gg \rightarrow ZZ$

Higgs $\rightarrow$ invisible constraints

If dark matter (DM) is a thermal relic of the early universe and it is light enough so the Higgs can decay to it, it leads to invisible Higgs decays

Such decays can be detected through Higgs VBF, ZH or ISR-jet production, or in a model-dependent way through the coupling fit (eg, assuming SM couplings to SM particles)



Best limit of $\sim 3\%$ on $H \rightarrow \text{invisible}$ branching fraction at 3 ab^{-1} (reminder: current limit: 26%)

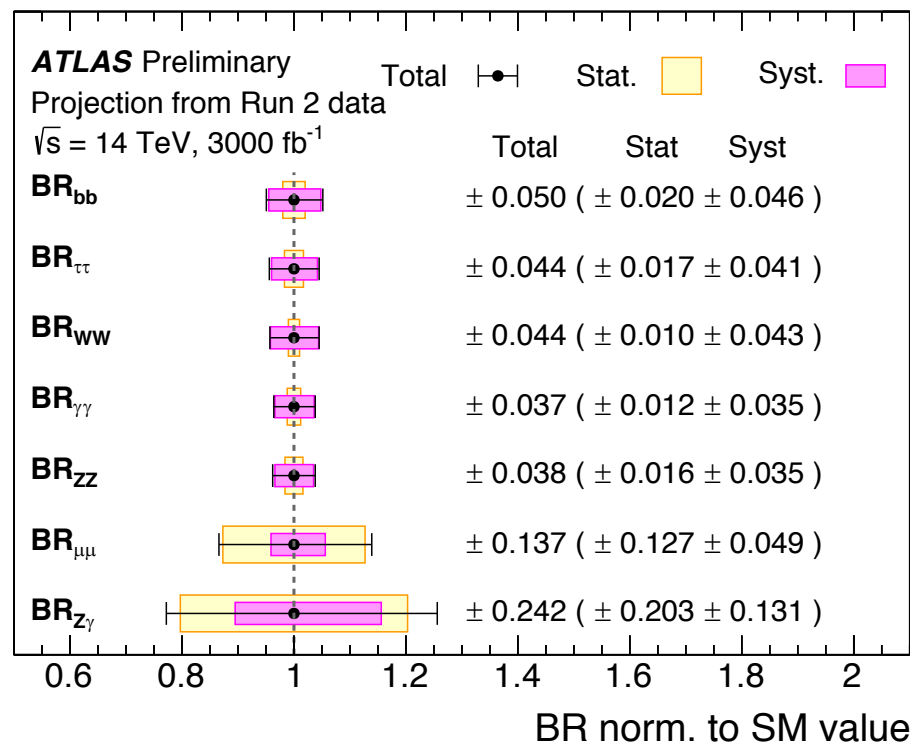
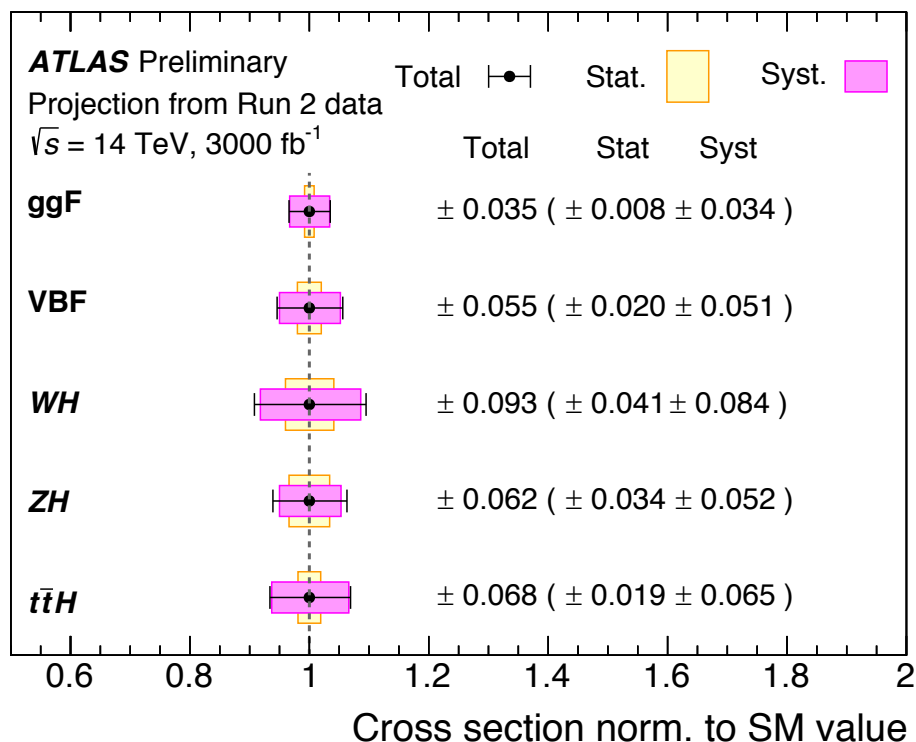
However, systematics limited so difficult extrapolation

Higgs couplings from global fit — ATLAS (Status 2018)

Consider two scenarios: S1 (Run-2 systematics), S2 (halved theory systematics, baseline shown here)

Luminosity uncertainty 1%, neglected spurious signal and MC statistics uncertainties

Most cross section measurements dominated by systematic uncertainties



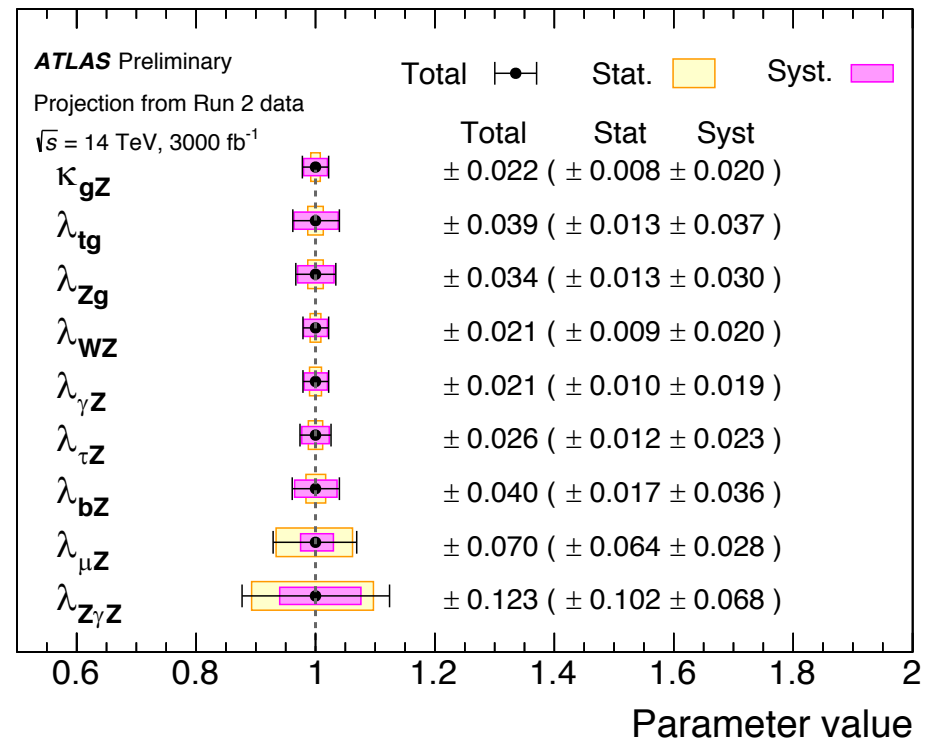
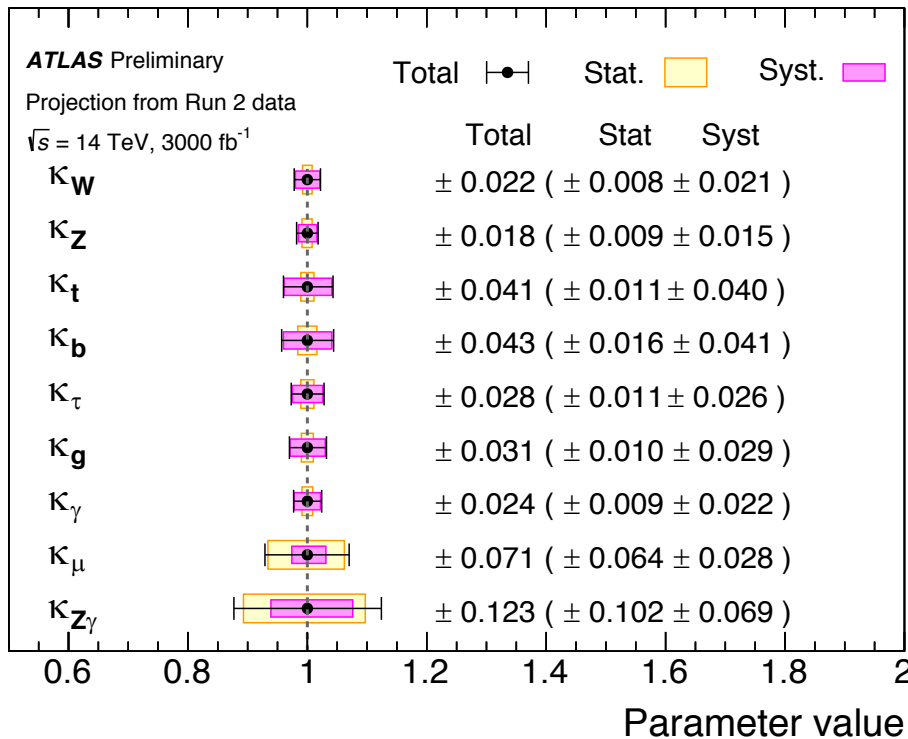
Global signal strength: $\mu = 1.000^{+0.038}_{-0.037} \left({}^{+0.025}_{-0.024} \right)$

S1 (S2)
 $= 1.000 \pm 0.006 \text{ (stat)} \pm 0.016 \text{ (0.013) (exp)} {}^{+0.030}_{-0.028} \left({}^{+0.017}_{-0.017} \right) \text{ (sig)} {}^{+0.016}_{-0.015} \left({}^{+0.010}_{-0.010} \right) \text{ (bkg)}$

Higgs couplings from global fit — ATLAS (Status 2018)

Consider two scenarios: S1 (Run-2 systematics), S2 (halved theory systematics, baseline shown here)

Luminosity uncertainty 1%, neglected spurious signal and MC statistics uncertainties

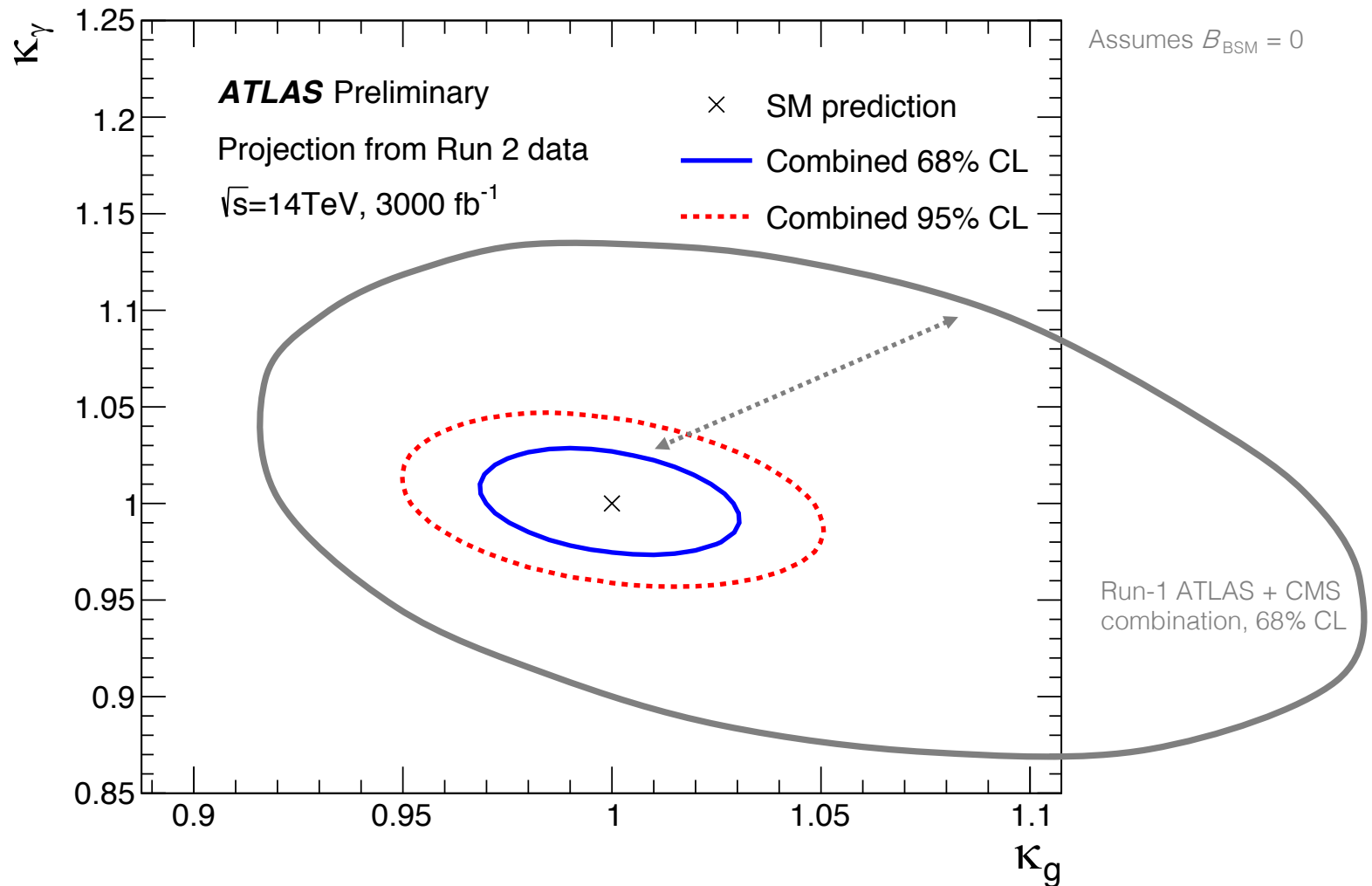


$$\sigma_i \times B(H \rightarrow f) = \frac{\sigma_i \times \Gamma_f}{\Gamma_H} = \frac{\kappa_i^2 \kappa_f^2}{\kappa_H^2} \sigma_i^{\text{SM}} \times B^{\text{SM}}(H \rightarrow f)$$

Higgs couplings from global fit — ATLAS (Status 2018)

Consider two scenarios: S1 (Run-2 systematics), S2 (halved theory systematics, baseline shown here)

Luminosity uncertainty 1%, neglected spurious signal and MC statistics uncertainties



Higgs couplings from global fit — ATLAS & CMS

Combination of ATLAS and CMS not yet released, expect following approximate precision on couplings

Assumes $B_{\text{BSM}} = 0$

Coupling	Total uncertainty (%)	Comments
κ_γ	~ 1.5	Similar stat, exp, theo uncertainties
κ_W	~ 1.5	Similar stat, exp, theo uncertainties
κ_Z	~ 1.3	Best precision, similar stat, exp, theo uncertainties
κ_g	~ 2	Dominated by systematic (theo) uncertainties
κ_t	$3 \sim 4$	Dominated by systematic uncertainties
κ_b	~ 3	Dominated by systematic (theo) uncertainties
κ_τ	$1.5 \sim 2$	Similar stat, exp, theo uncertainties
κ_μ	~ 4	Statistics dominated
$\kappa_{Z\gamma}$	~ 10	Statistics dominated

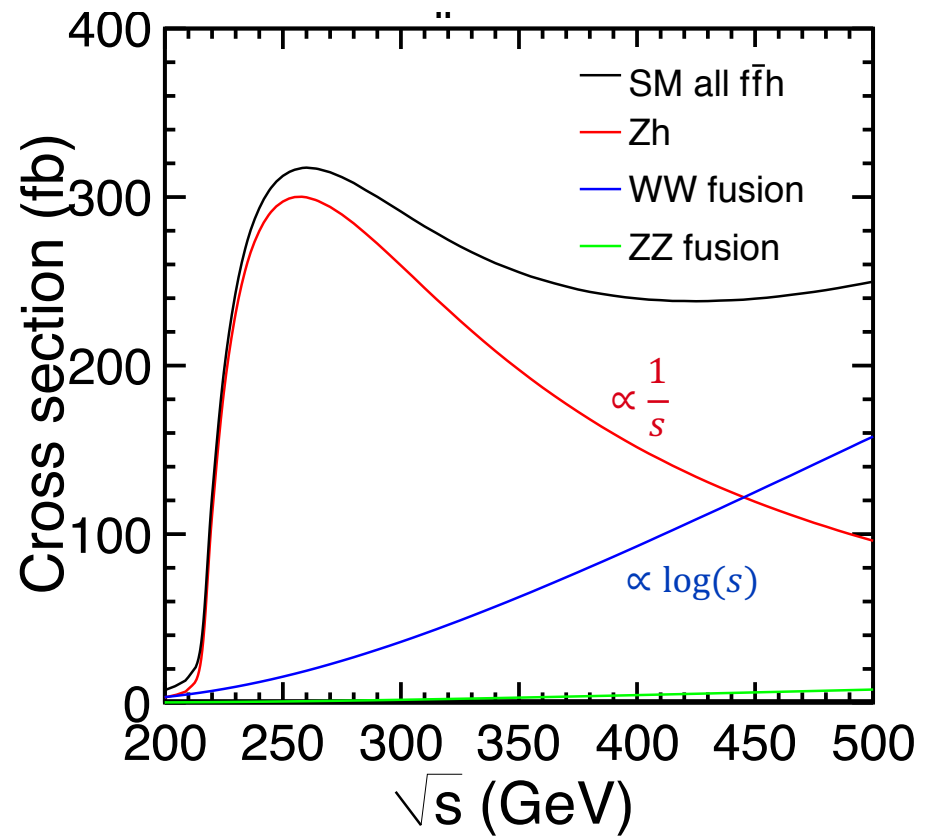
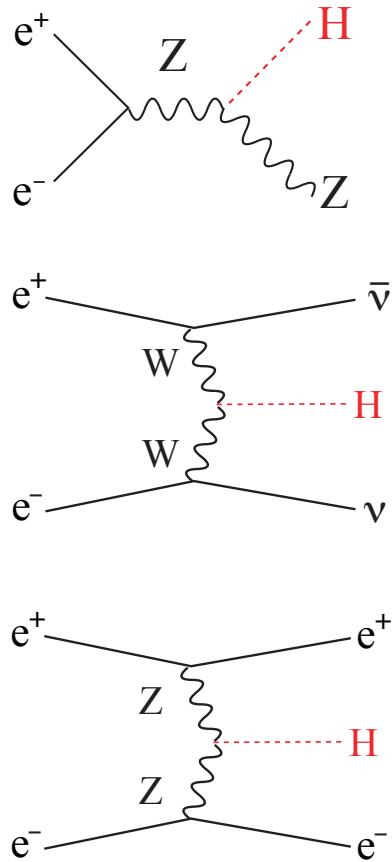
LHCb adds sensitivity to $H \rightarrow cc$ of $\sim 5 \cdot \text{BR}(\text{SM})$ with 300 fb^{-1} [LHCb-CONF-2016-006]

ATLAS study indicates $\mu < 6.3$ at 95% CL

Future e^+e^- collider

Several future e^+e^- collider options: linear (ILC, CLIC), circular (FCC-ee, CEPC)

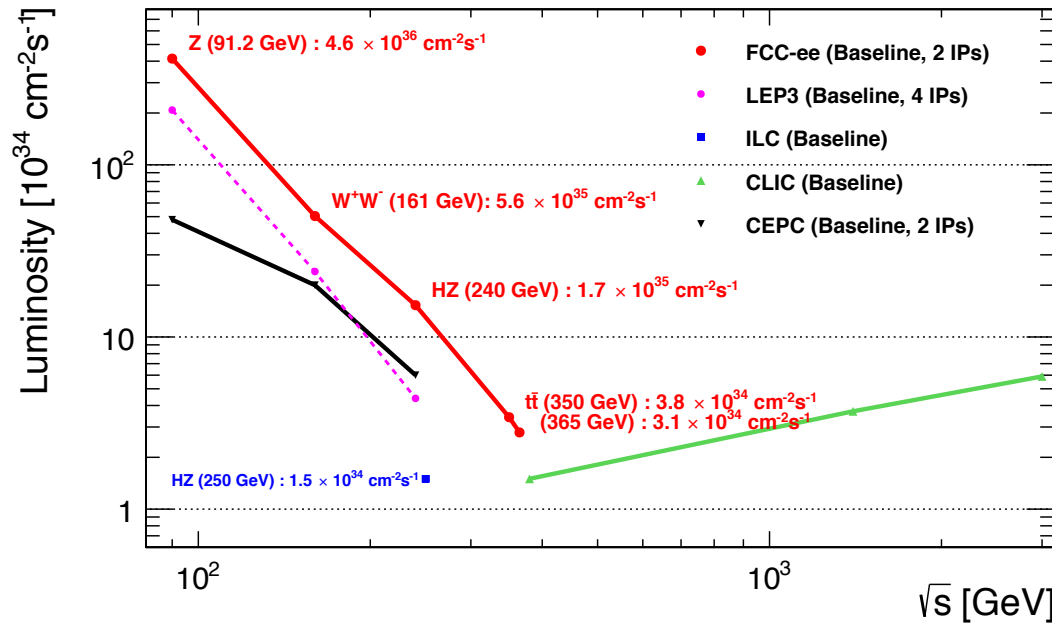
Dominant production mechanisms: $e^+e^- \rightarrow ZH$ (Higgsstrahlung), $\nu\nu H$ (W fusion), eeH (Z fusion)



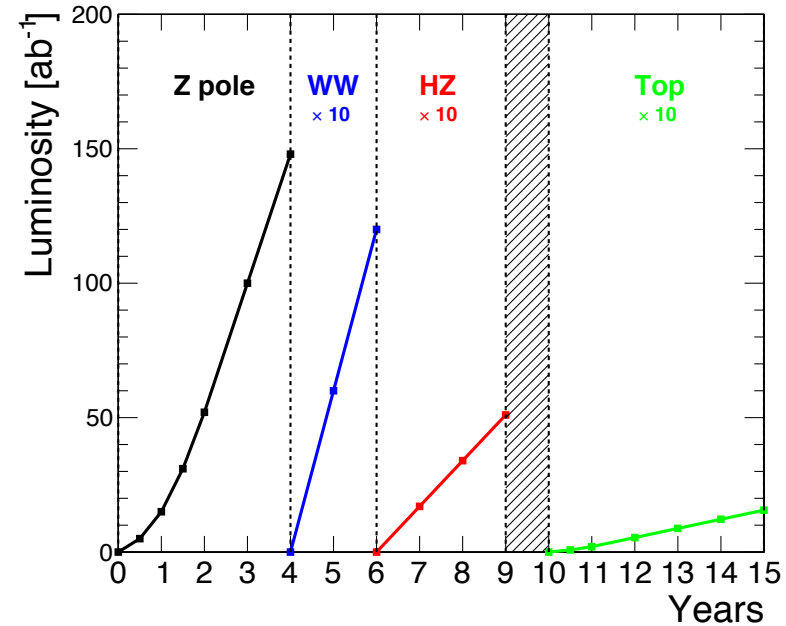
Future e⁺e⁻ collider

Several future e⁺e⁻ collider options: linear (ILC, CLIC), circular (FCC-ee, CEPC)

Baseline luminosity scenarios



Operational model for FCC-ee



Run plan for FCC-ee baseline configuration with two experiments

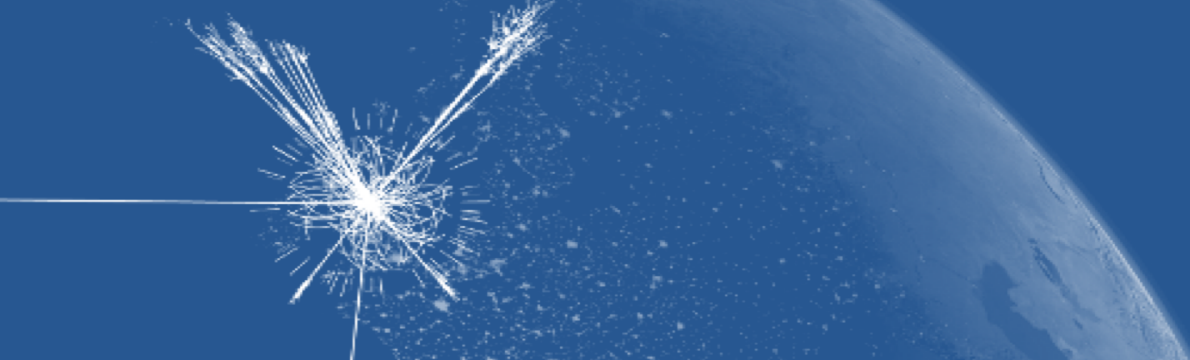
Phase	Run duration (years)	Centre-of-mass Energies (GeV)	Integrated Luminosity (ab^{-1})	Event Statistics
FCC-ee-Z	4	88-95	150	$> 10^5 \times \text{LEP}$ 3×10^{12} visible Z decays
FCC-ee-W	2	158-162	12	10^8 WW events
FCC-ee-H	3	240	5	10^6 ZH events
FCC-ee-tt	5	345-365	1.5	10^6 tt events

Comparison among colliders

Numbers taken from Nov 2018 FCC CDR (Physics case)

Uncertainties in %

Coupling	HL-LHC	ILC 240 GeV, 2 ab ⁻¹	FCC-ee 240 GeV, 5 ab ⁻¹	FCC-ee → 365 GeV, 6.5 ab ⁻¹	Comments
κ_γ	~ 1.5	6.4	4.7	3.8	All e ⁺ e ⁻ uncertainties are statistical only Experimental systematic uncertainties expected to be small, unlike at LHC BR_{inv} sensitivity ten times better at lepton colliders than LHC FCC-ee numbers taken from recent CDR CEPC numbers similar to FCC-ee[240]
κ_W	~ 1.5	1.7	1.3	0.5	
κ_Z	~ 1.3	0.35	0.25	0.22	
κ_g	~ 2	2.2	1.7	1.0	
κ_t	3 ~ 4	~5% @ ILC-500	–	–	
κ_b	~3	1.8	1.4	0.7	
κ_c	UL	2.3	1.8	1.2	
κ_τ	1.5 ~ 2	1.9	1.4	0.8	
κ_μ	~ 4	13	10	9	
$\kappa_{Z\gamma}$	~10	–	–	–	
Γ_H	~50% (model dep.)	3.8	1.8	1.6	
λ_{HHH}	~ 60%	~30% @ ILC-500	~40% through loops + EFT		FCC-hh: ~5%, CLIC: 10~15%

A visualization of a particle collision, showing a central point from which numerous lines radiate outwards, representing the paths of particles. The background is a dark blue gradient with a faint, curved horizon line on the right side.

Some conclusions

We live in **data-driven times**, experiment must guide us to the next stage. That means we need a **broad and diverse research programme. Higgs physics is key in that programme.**

The HL-LHC will make a strong impact on Higgs property measurements. It has sensitivity to discover rare Higgs decays to $\mu\mu$ and $Z\gamma$, to study couplings to bosons and third generation fermions to (few) percent precision, and to significantly constrain invisible decays.

Most coupling measurements will be limited by theoretical uncertainties highlighting the importance of improving these.

Di-Higgs production can likely be seen, but a significant measurement of Higgs self-coupling seems beyond reach. However, important constraints can be obtained.

Higgs measurements in conjunction with other SM sectors such as diboson and top will allow to obtain coherent information in the framework of EFT or model extensions of the SM.

Precision measurements in the SM sector will contribute to these constraints.

Hadron and lepton colliders have complementary strengths

Extra slides

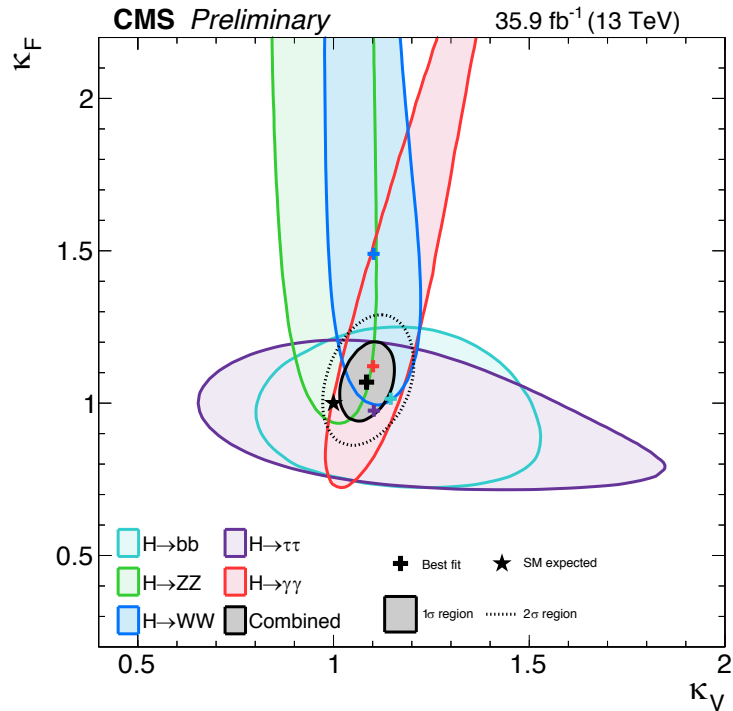
Current status of property measurements

Combined coupling fit (CMS)

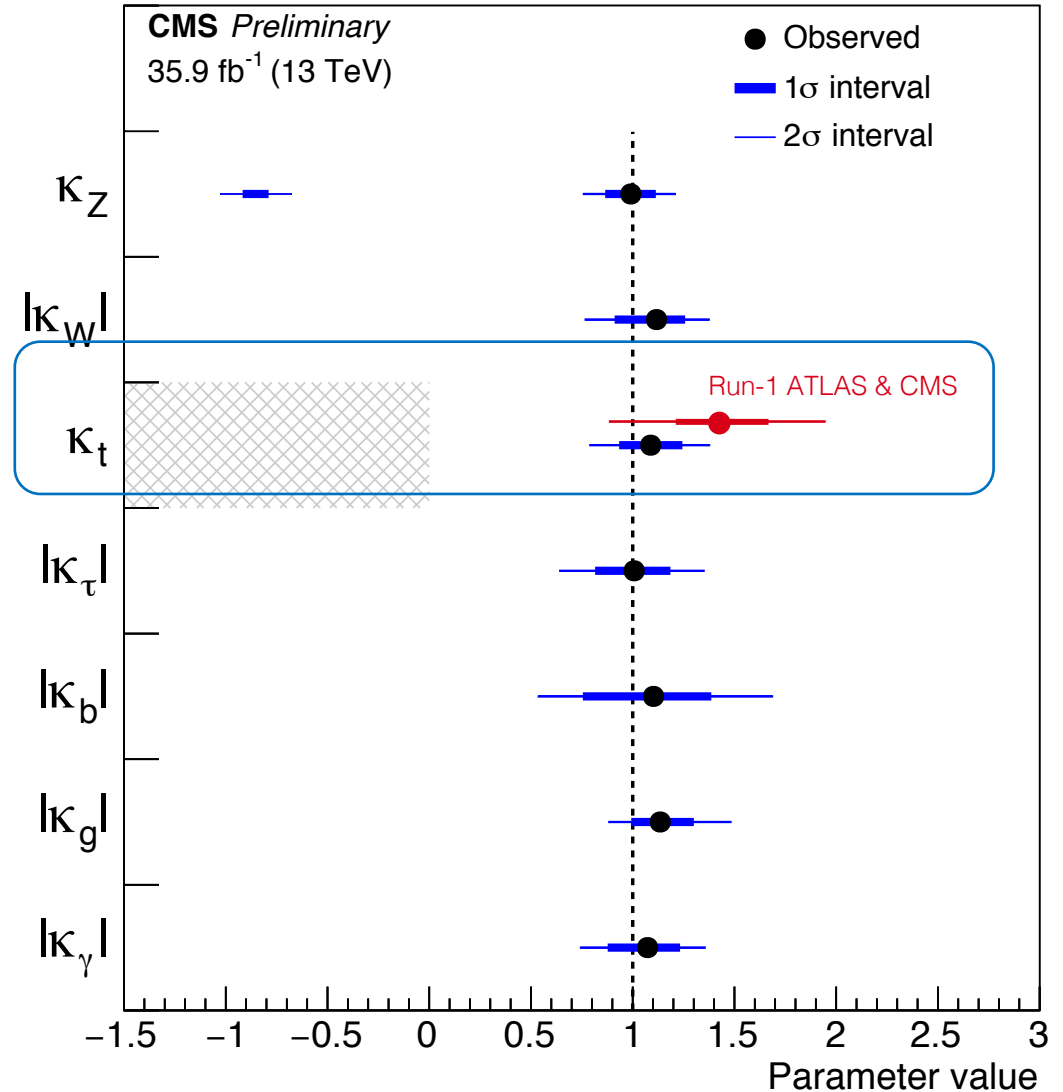
2016 data, $\sqrt{s} = 13$ TeV

CMS-PAS-HIG-17-031

Higgs to boson and fermion coupling modifiers:



Assumes: $BR_{inv} = 0$

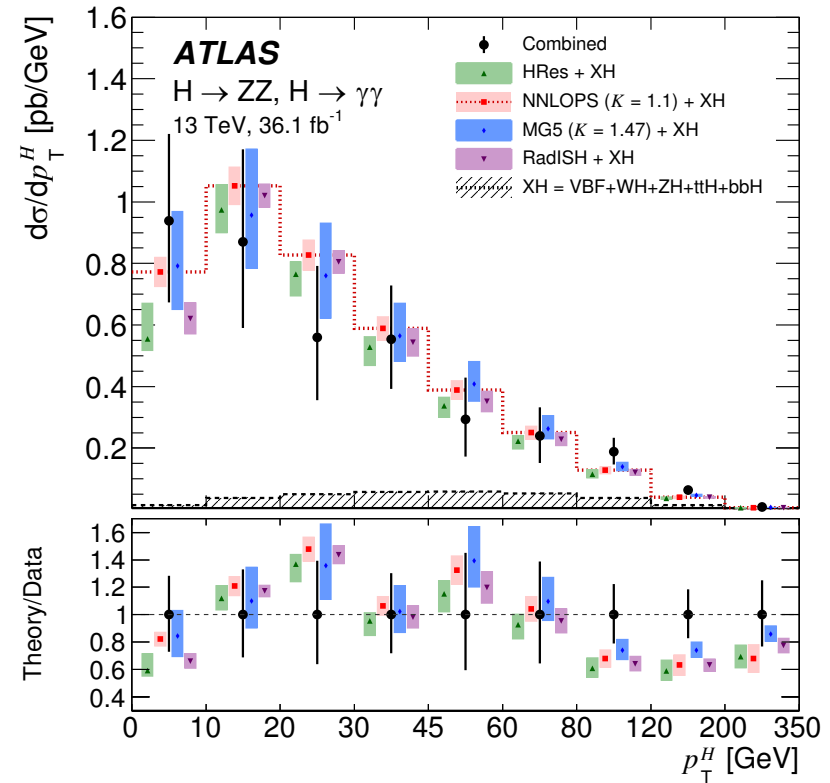
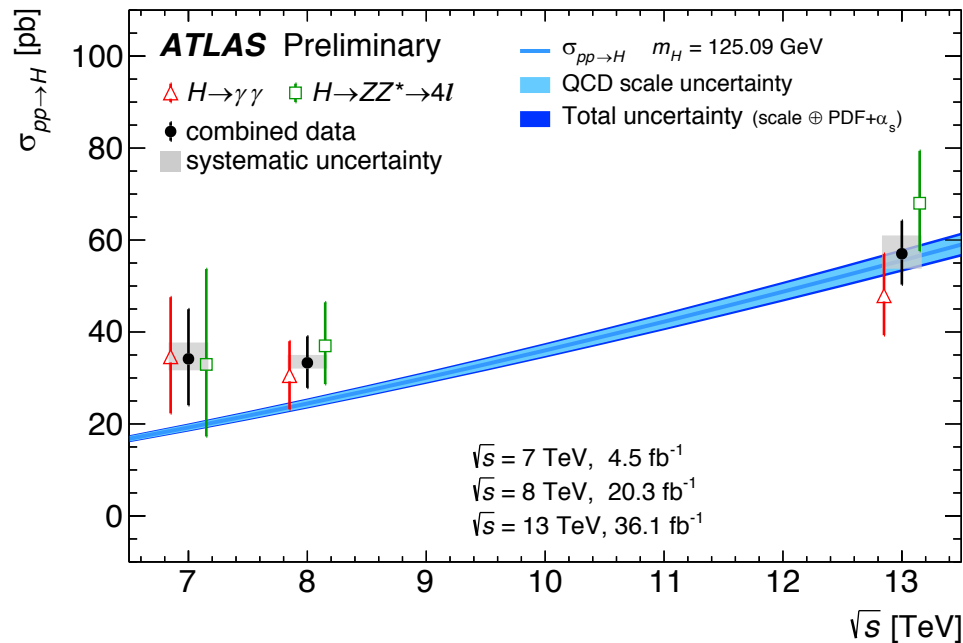


More than observation: detailed measurements

Cross section measurements

2015+2016 data, $\sqrt{s} = 13$ TeV

ATLAS-CONF-2018-002



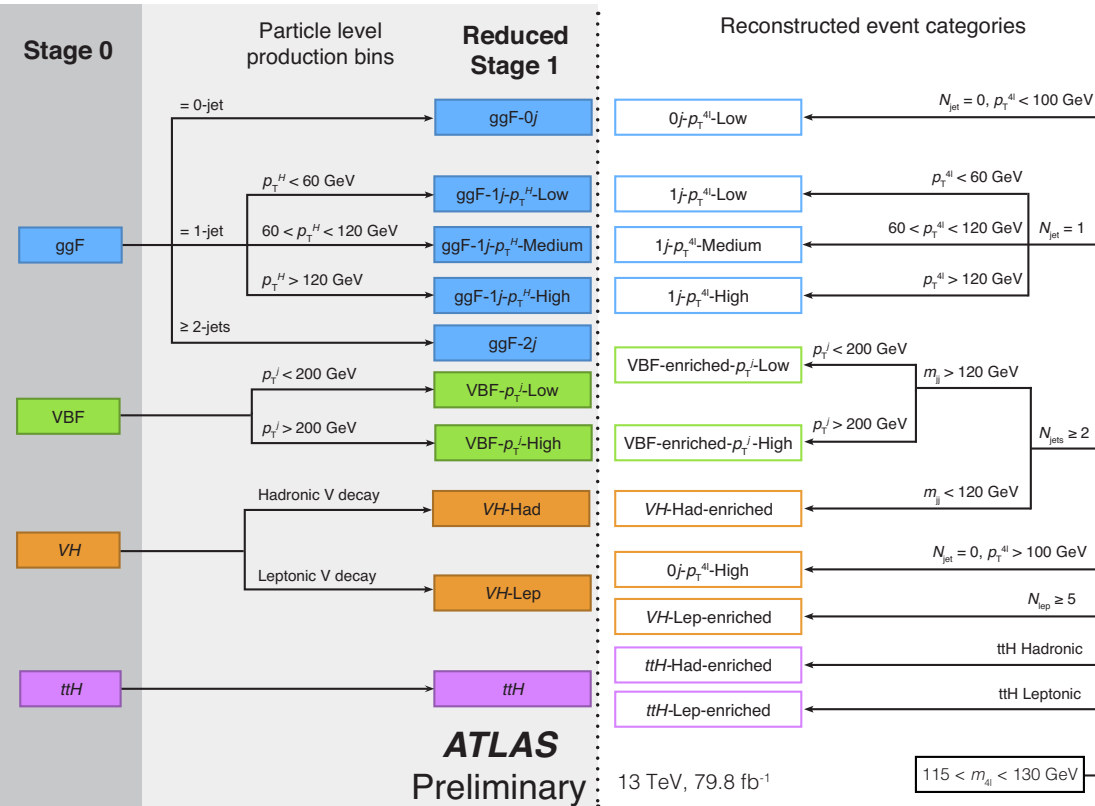
Combination of cleanest $\gamma\gamma$ and 4-lepton channels provides currently most sensitive differential cross section measurements, but still a long way to go to achieve good precision

More than observation: detailed measurements

Simplified template cross (STXS) section measurements

2015+2016 data, $\sqrt{s} = 13$ TeV

ATLAS arXiv:1712.02304, 1802.04146, ATLAS-CONF-2018-018



STXS define particle-level bins to maximize measurement precision and reduce theory dependence

