Selected Highlights Results from ATLAS & Potentials at Future Colliders

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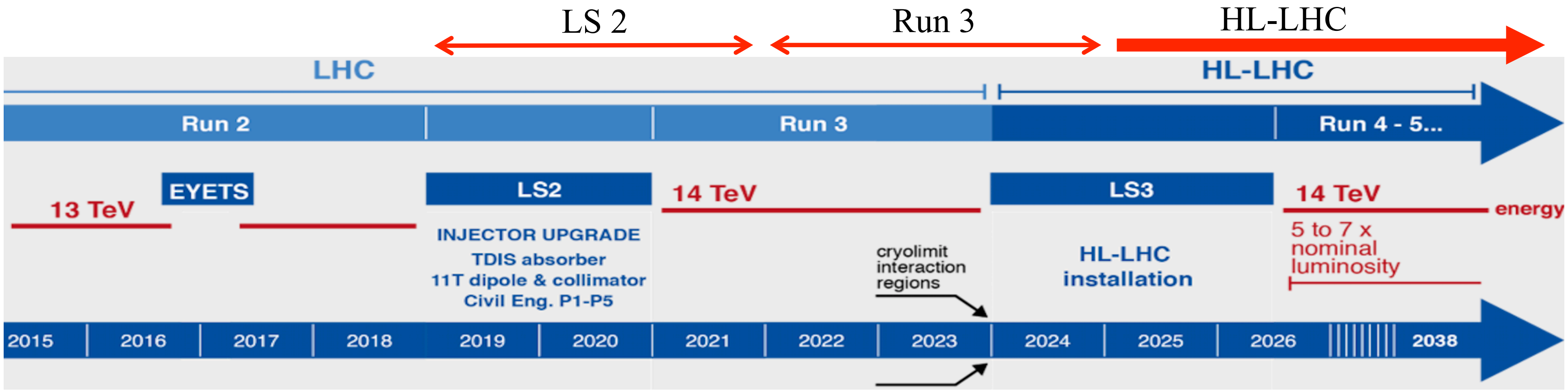
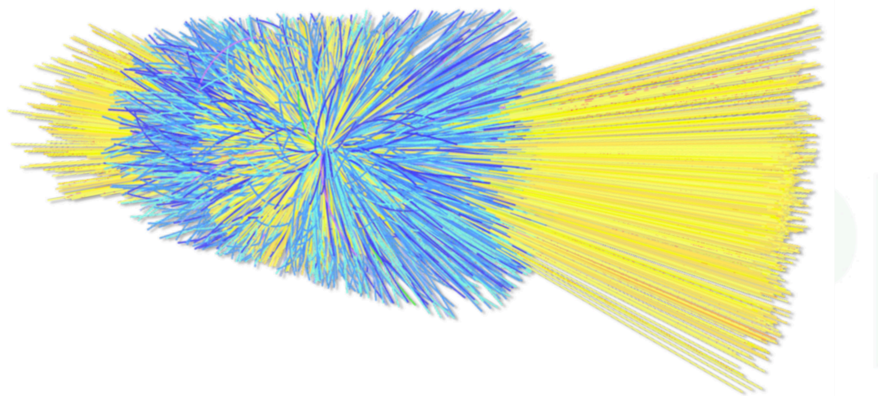
LHC, Run2, Run3 and HL-LHC



Run 2:

- •√s=13 TeV, $\int L \sim 140$ fb^{-1}
- $L_{max} \sim 2\times10^{34}$cm^{-2}s^{-1}
- Ave. pileup ~34

Simulated HL-LHC event, with 200 reconstructed vertices (μ=200)



Run 3:

- •Startup delay by ~1 yr
- •√s=13-14 TeV, depends on magnet training
- •$\int L \sim 150$ fb^{-1}
- $L_{max} \sim 2\text{-}2.5\times10^{34}$cm^{-2}s^{-1}
- Ave. pileup ~60

HL-LHC:

- •Startup also push back by ~1 yr
- •√s=14 TeV
- $\int L \sim 3000$ fb^{-1}
- $L_{max} \sim 5\text{-}7\times10^{34}$cm^{-2}s^{-1}
- Ave. pileup ~200

ATLAS Detector

•Large sophisticated general purpose particle detector

Upgrade for HL-LHC

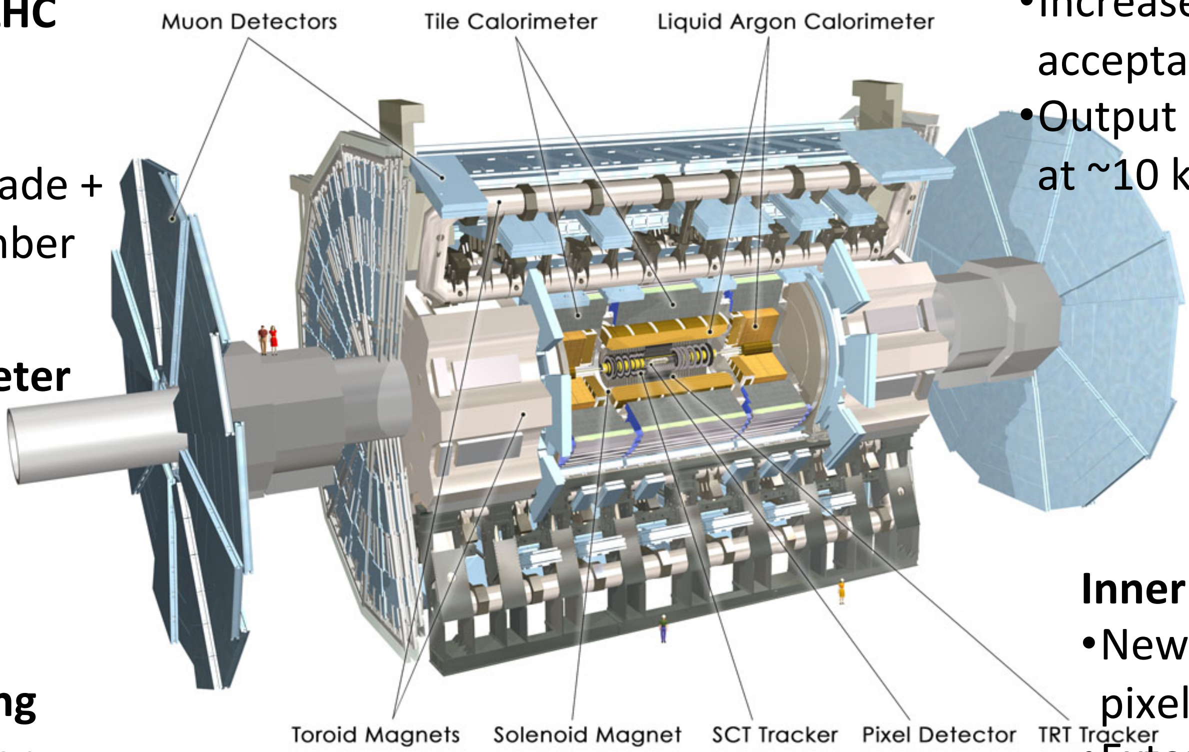
Muon

•Electronics upgrade + new muon chamber

LAr/Tile Calorimeter

•New readout electronics

New High Granularity Timing Detector in endcap



Trigger/DAQ

•Increase trigger acceptance rate at L1/HLT

•Output event rate to tape at ~10 kHz

Inner Tracker

•New silicon strip and pixel detectors

•Extend up to |η|<4, lower material budget than in Run2

•Extend η coverage

•Improve the trigger system

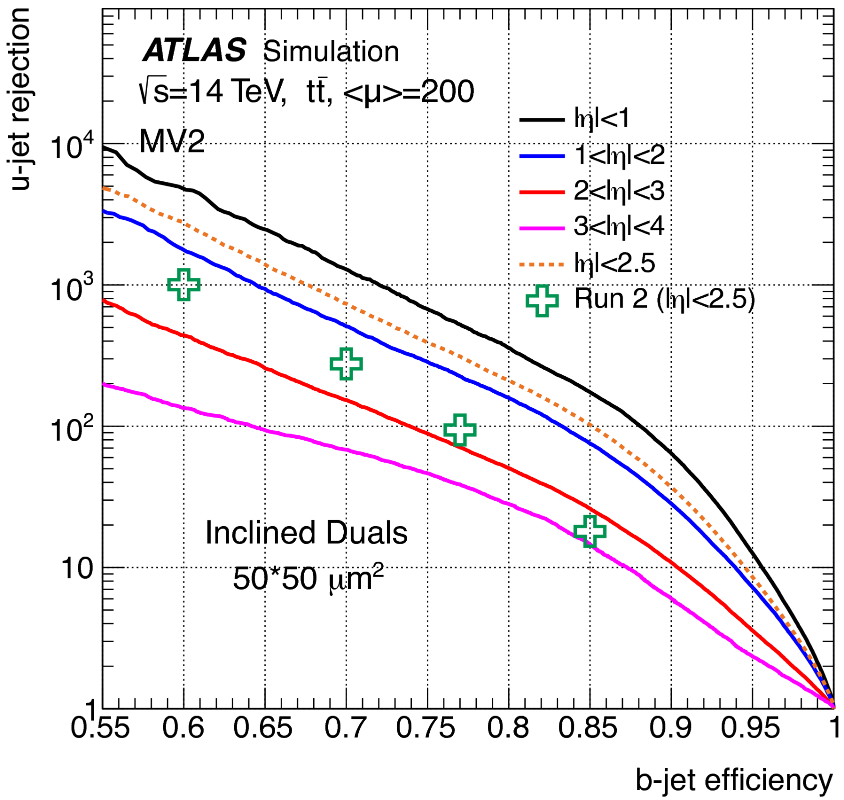
•Computation challenge on CPU and storage for HL-LHC

Detector Performance

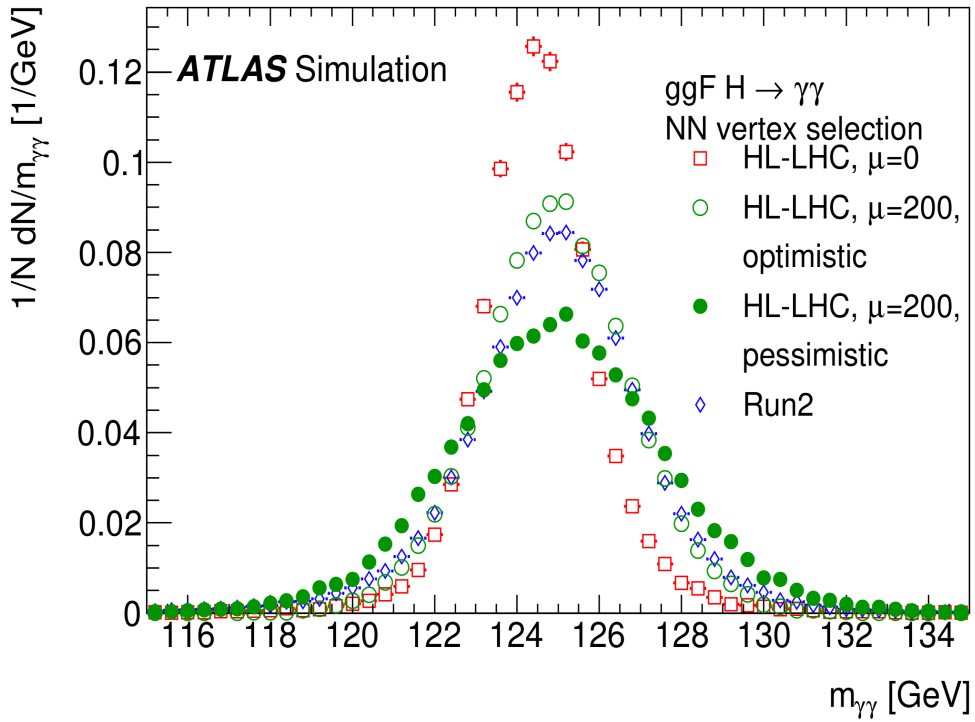
ATL-PHYS-PUB-2019-005

CERN-LHCC-2017-018

Tag b-jets



Di-Photon Mass



- Run2 performance (@<μ>~30) is shown as green crosses
- Performance at HL-LHC improved by more than factor of 2 in |η|<2.5, and enlarged geometrical coverage

- di-photon mass resolution at HL-LHC, with <μ>~200, is comparable to Run2 for the optimistic scenario

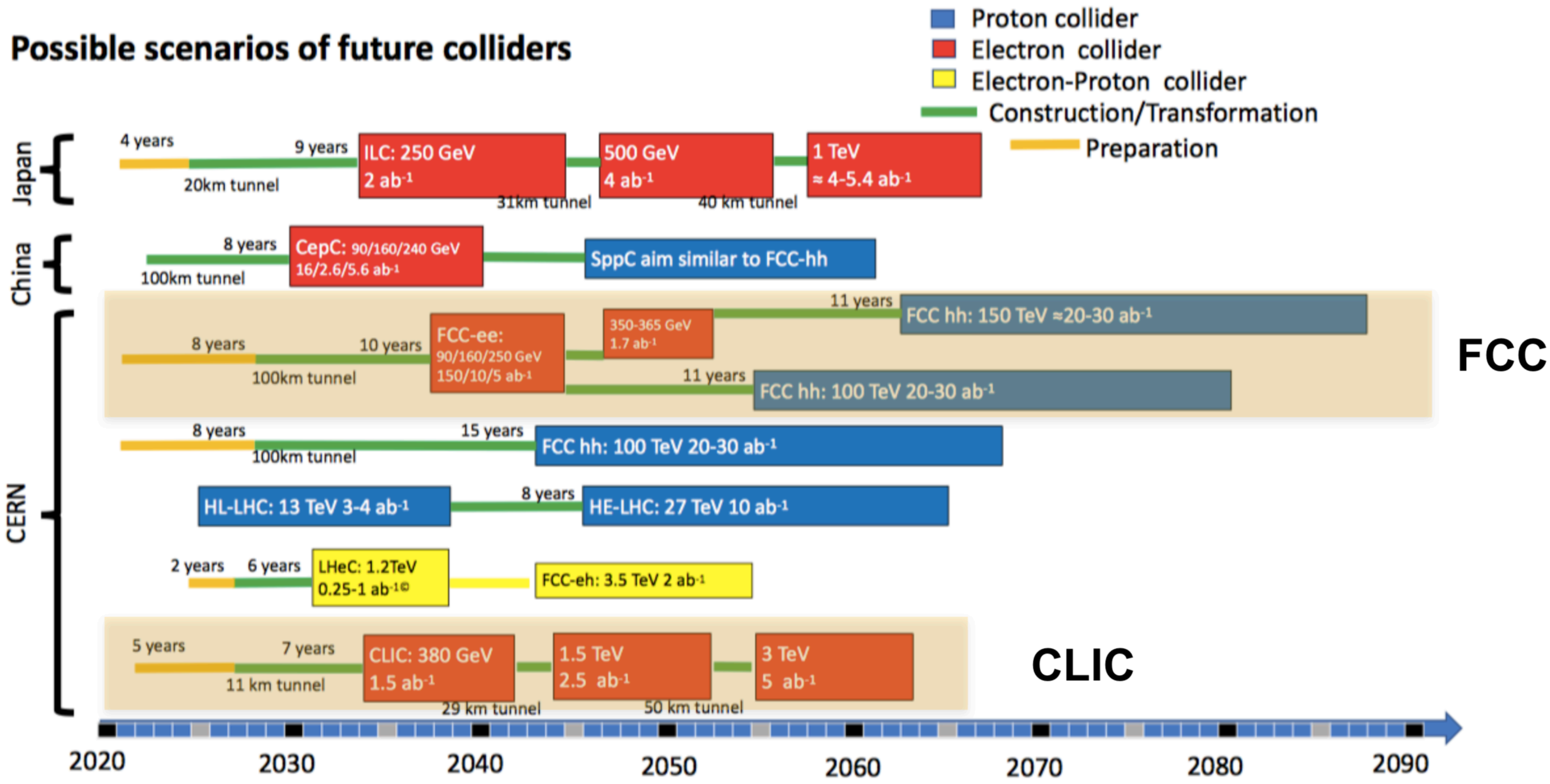
Possible Future Colliders

Type	Machine	√s / Total integrated luminosity			
e^+e^-	ILC	250 GeV / 2 ab^{-1}	500 GeV / 4 ab^{-1}	1 TeV / 4-5.4 ab^{-1}	
	CLIC	380 GeV / 1.5 ab^{-1}	1.5 TeV / 2.5 ab^{-1}	3 TeV / 5 ab^{-1}	
	CEPC	90 GeV / 16 ab^{-1}	160 GeV / 2.6 ab^{-1}	240 GeV / 5.6 ab^{-1}	
	FCC-ee	90 GeV / 150 ab^{-1}	160 GeV / 10 ab^{-1}	250 GeV / 5 ab^{-1}	350-365 GeV / 1.7 ab^{-1}
ep	LHeC	1.2 TeV / 0.025 – 0.1 ab^{-1}			
	FCC-eh	3.5 TeV / 2 ab^{-1}			
pp	HE-LHC	27 TeV / 10 ab^{-1}			
	FCC-hh	100 or 150 TeV / 20-30 ab^{-1}			
	SppC	100 TeV			

- The 2020 European Strategy for Particle Physics stated two high-priority future initiatives:
  - An e^+e^- Higgs factory to study the Higgs boson to high precision and to carry out other high precision test of the Standard Model
  - Perform vigorous R&D on innovative accelerator technologies to explore the energy frontier

CEPC, FCC-ee : below HH threshold

Possible Future Colliders Scenarios



Ursula Bassler @ Granada

- Timeline of each machine is different
- Span over several decades

Results and Projections

- Report recent results from ATLAS
    - Focus on Higgs measurements
- Projection studies for HL-LHC
- Potential reach at future colliders

Higgs Boson Measurements

- **Overview :**
  - All major production channels and coupling to the 3rd generation lepton/quarks have been observed
  - Now improving the coupling measurement precision and probing rare decays
  - Perform fiducial / differential cross section measurements in several kinematic variables
  - Search for signs of New Physics via these measurements

Updates on H→γγ , H→ZZ*→4l, H→WW

arXiv:2004.03447

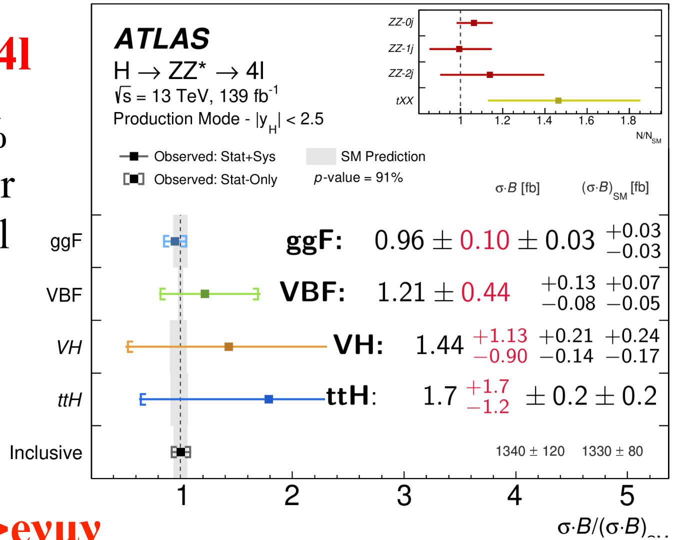
ATLAS-CONF-2020-026

ATLAS-CONF-2020-045

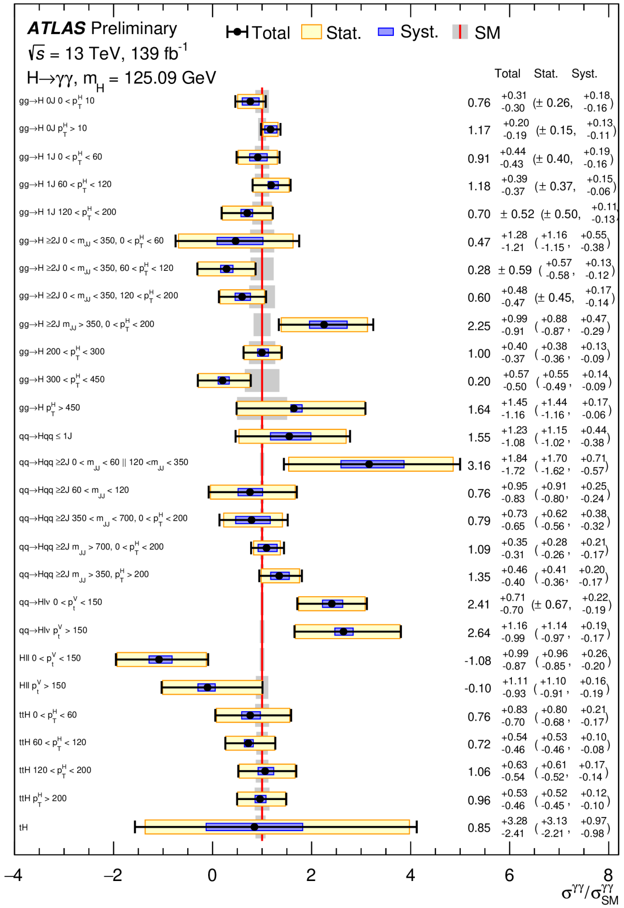
- Measure cross sections of individual production modes (for H→γγ , H→ZZ*)
- Study kinematic properties of Higgs production
  - Differential cross section, Production rates in excl. regions (simplified template cross section framework (STXS)) to reduce model dependency and maximize sensitivity to BSM

H→ZZ*→4l

- Up to ~10% precision for best channel



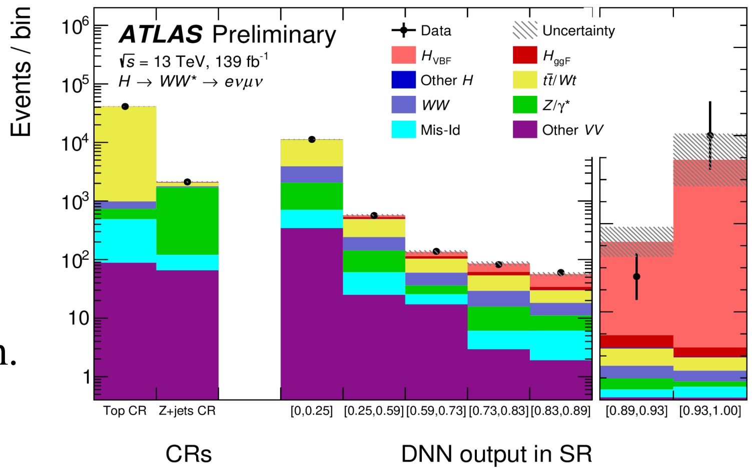
H→γγ



- Measured σγγ / σγγ(SM) in 27 STXS bins
- Compatibility with SM with p-value of 60%

H→WW→eνμν

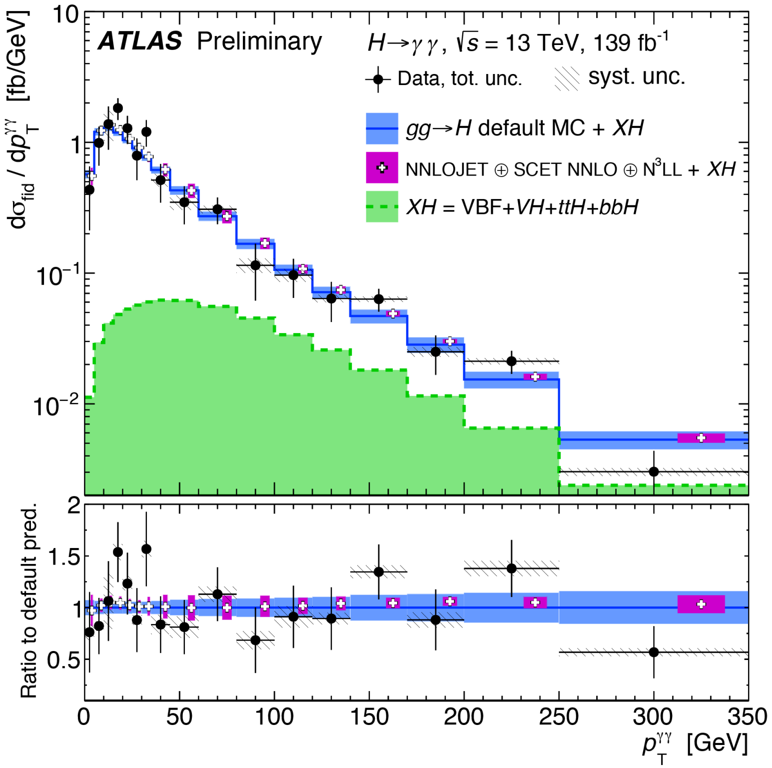
- Measured in VBF prod.
- DNN trained to isolate signal
- Obs(exp) sign. = 7.0 (6.2) σ

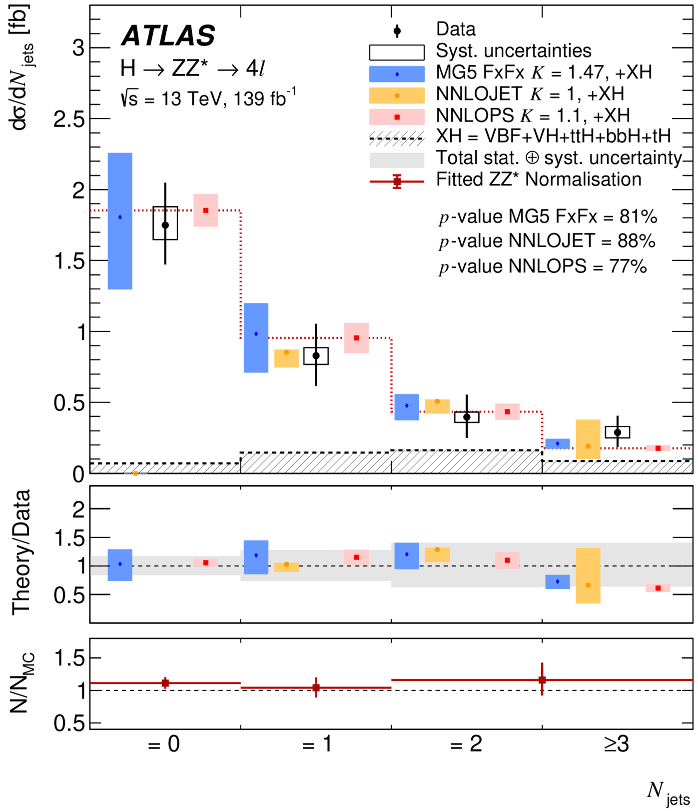


$$\mu_{VBF} = 1.04^{+0.13}_{-0.12}\ \text{stat.}\ ^{+0.09}_{-0.08}\ \text{exp.}\ ^{+0.17}_{-0.12}\ \text{sig. theo.}\ ^{+0.08}_{-0.07}\ \text{bkg. theo.}$$

Updates on H→γγ , H→ZZ*→4l

- Measured differential cross section for several kinematic variables





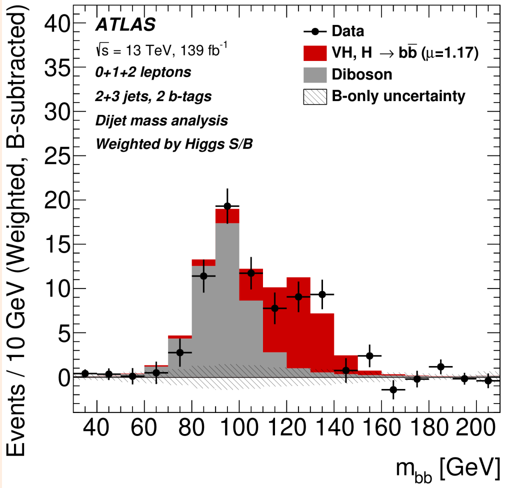
- pT(H) :
  - Low pT : sensitive to c/b-Yukawa
  - High pT : sensitive to new heavy particles in ggF loop
  - About ~50% precision at pT~300 GeV

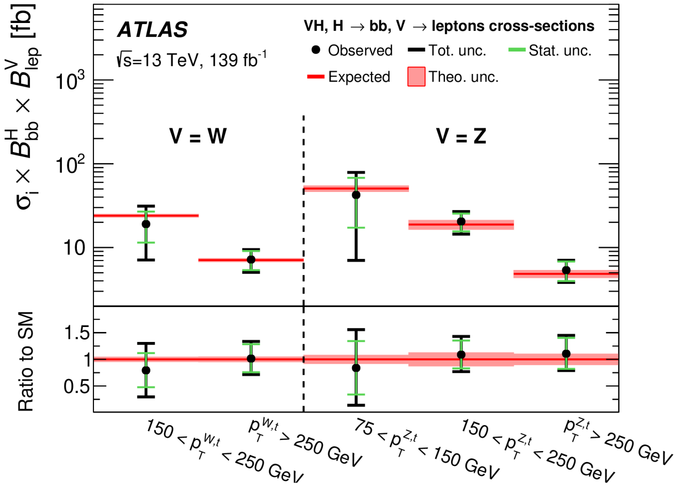
- Njets :
  - sensitive to production mode composition

Higgs Couplings to 3rd Generation Quarks

arXiv:2007.02873

- **H→bb** observed in 2018 via combination of several production modes (dominated by VH) and using Run1 and Run2(80 fb^{-1}) data
- Updated VH analysis with full Run2, also measured σ×BR in several pT(V) bins



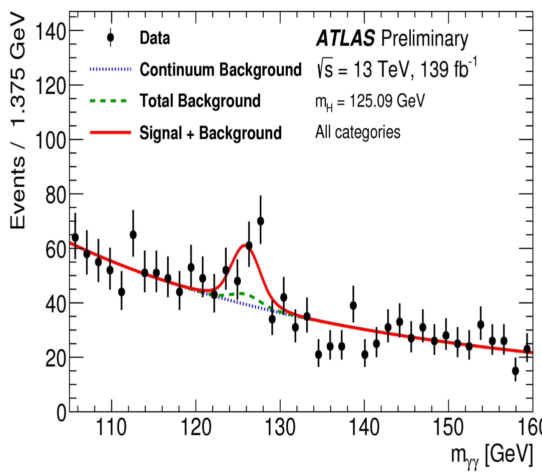


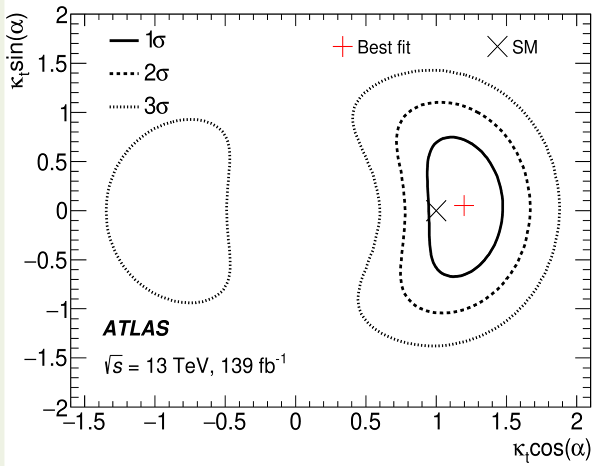
$$\mu = 1.02\,^{+0.18}_{-0.17} = \,^{+0.12}_{-0.11}(\text{stat})\,^{+0.14}_{-0.13}(\text{syst})$$

(Reach precision of ~20%)

WH	4.0σ (4.1σ exp)
ZH	**5.3σ** (5.1σ exp)

- **ttH** was also observed in 2018, when combining various H decay modes
- Updated ttH with full Run2 in γγ
  - Obs.(exp.) sign=4.9 (4.2) σ
  - $\sigma_{ttH} \times B_{\gamma\gamma} = 1.59^{+0.43}_{-0.39}$ fb
    (SM: $1.15^{+0.09}_{-0.12}$ fb)
- Also probe CP-structure of Higgs-top Yukawa coupling (κt)
  - SM: κt=1, CP-even (α=0)
  - CP-odd : α=90°





- Obs (exp) : |α|>43° (|α|>63°)
- Pure CP-odd coupling is excluded at 3.9σ

ATLAS-CONF-2019-004

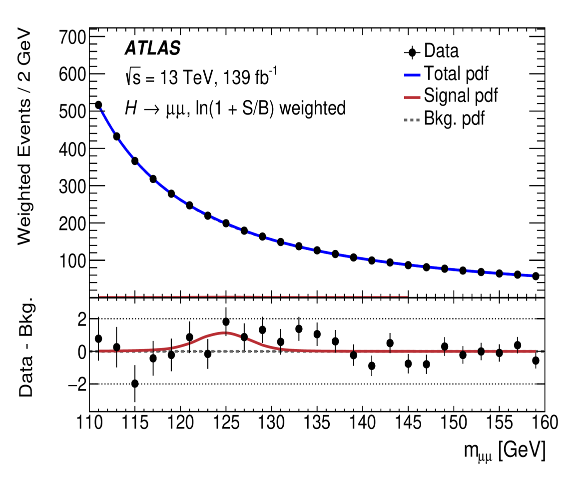
arXiv:2004.04545

Rare Decays (H→μμ , H→ee, H→eμ)

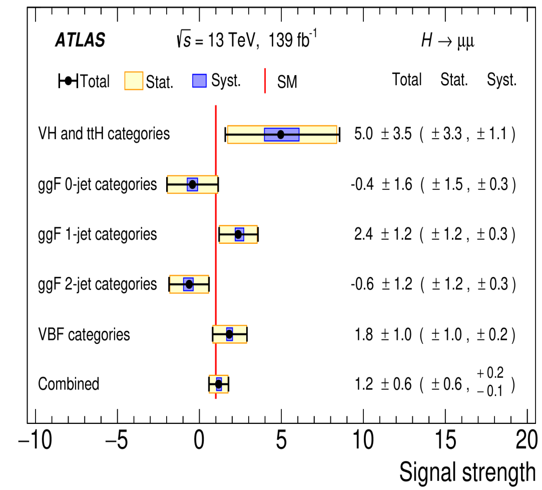
- To probe yet un-observed Higgs coupling to 1st and 2nd generation fermions
- Test BSM by searching for LFV Higgs decays

arXiv:2007.07830

- **H→μμ** : BR(SM)=2.2e-4
- Huge background from Drell-Yan μμ production
- Classified search into production modes (ttH, VH, VBF, ggF) and different sensitivity categories
- Obs signal strength = 1.2±0.6
- Obs (exp) significance = 2.0σ (1.7σ)
- Obs BR limit < 4.7e-4 @ 95% CL

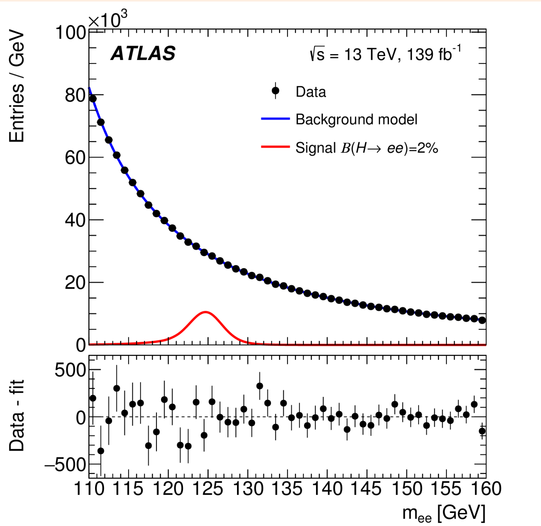


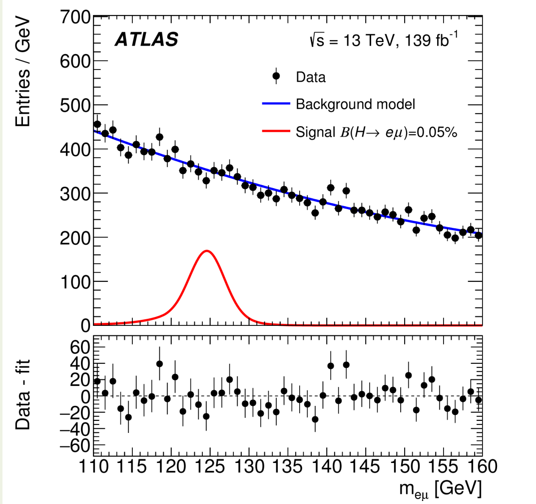
CMS: Obs (exp) sign.= 3.0σ (2.5σ)



- **H→ee, eμ**
- BR(H→ee)~5e-9, far below experiment sensitivity. Test of BSM models
- Categorize search into ggF and VBF production, and into different kinematic bins of sensitivities

	ee	eμ
Obs BR limit	3.6e-4	6.2e-5
Exp BR limit	3.5e-4	5.9e-5





PLB 801 (2020) 135148

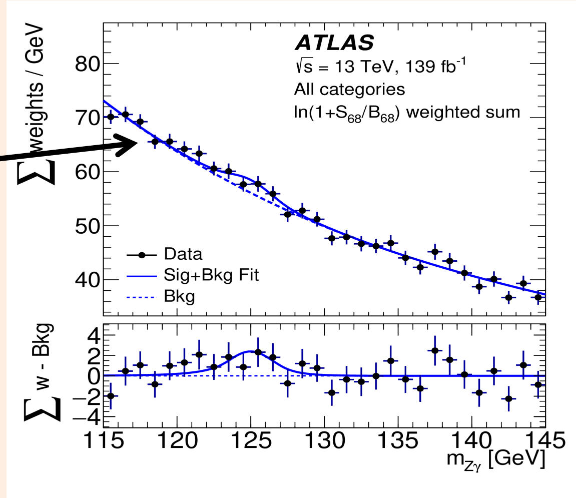
Rare and Invisible Decays

- **H→Zγ** : BR~1.54e-3 in SM
- Search in Z(→ee/μμ)+γ final state
- Classify selected events into different S/B ratios and mass resolution categories
- Obs (exp) significance=2.2 (1.2) σ
- Best fit signal strength:

$$2.0 \pm 0.9\ (\text{stat})\ ^{+0.4}_{-0.3}\ (\text{syst})$$

arXiv:2005.05382

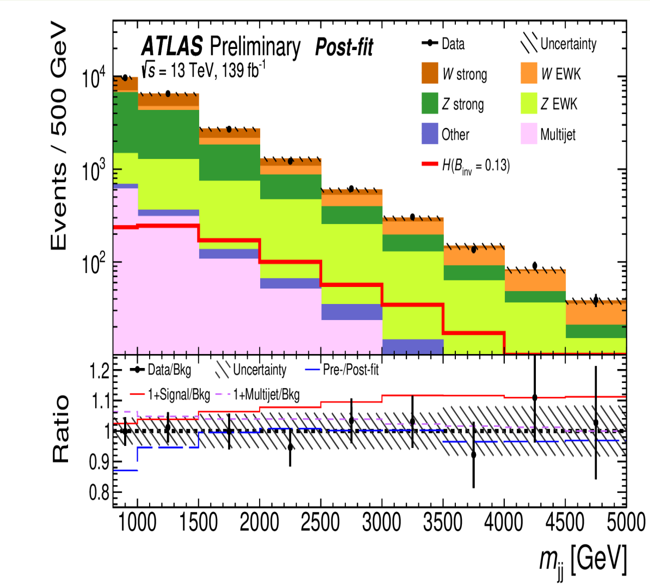
Combining all categories



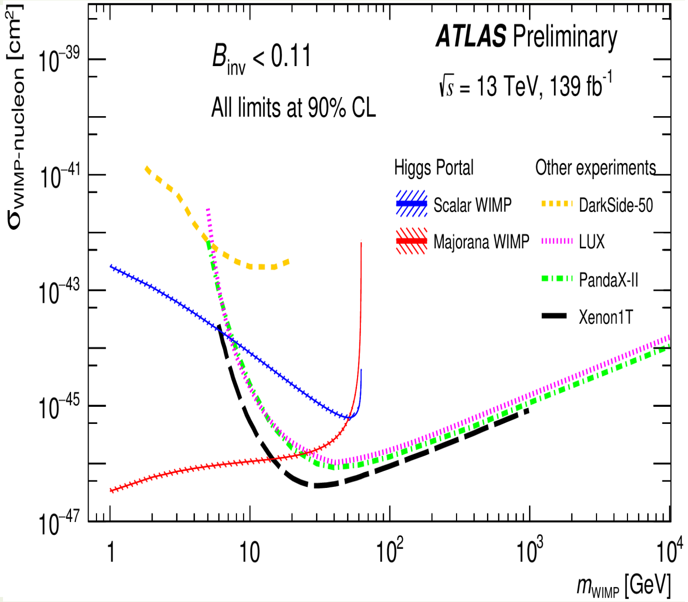
H→Invisible Decay

ATLAS-CONF-2020-008

- In SM BR(H→inv) ~0.1% (H→ZZ→4ν)
- Can be enhanced in some BSM where H couples to dark matter
- Searched previously in various H production modes
  - VBF most sensitive
- Updated VBF analysis
- Signature: Large MET, 2 widely separated jets, large mJJ

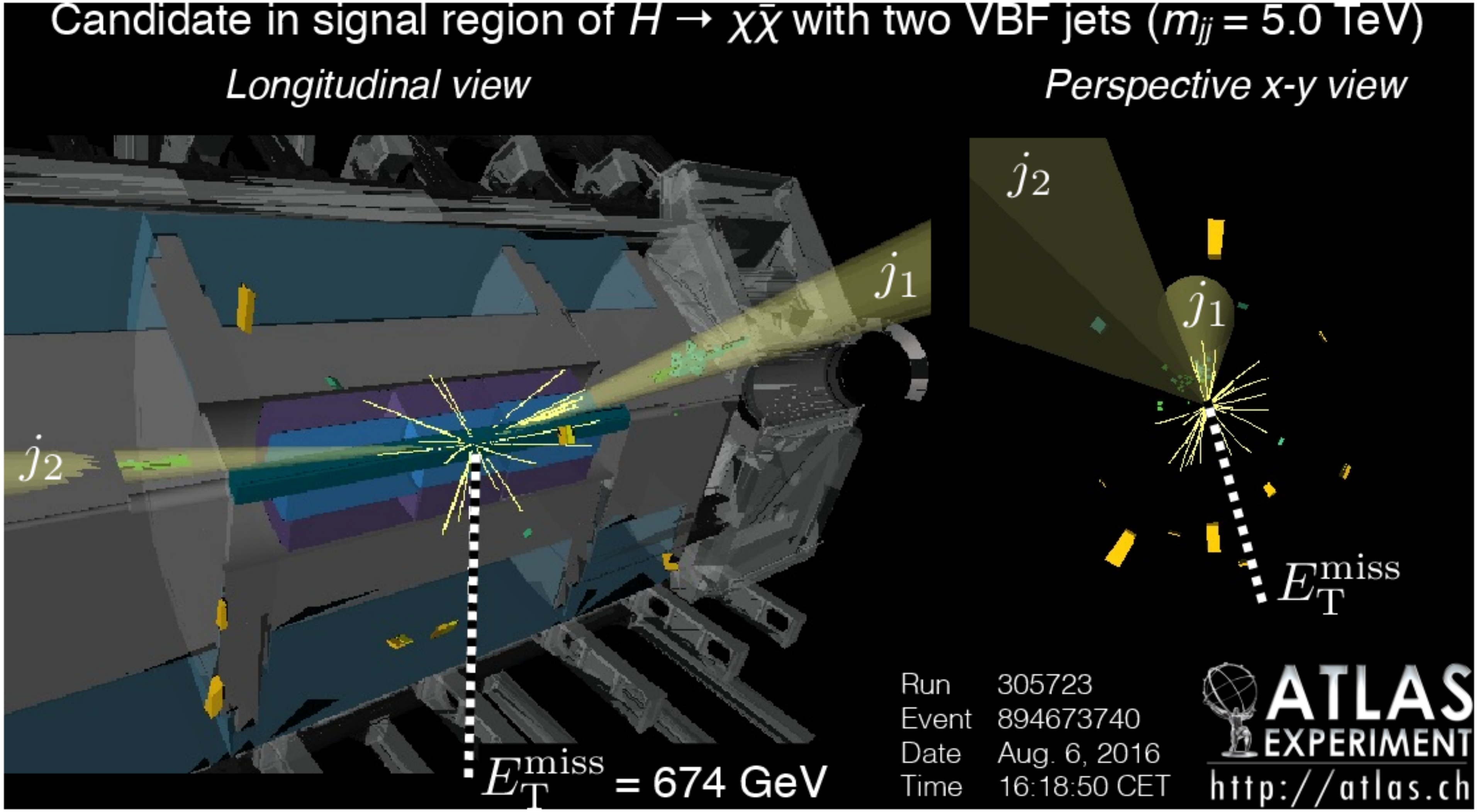


Limit on BR(H→inv): <0.13 (0.13 exp) @ 95%CL
CMS limit : 0.19 (0.15 exp)



BR limit interpreted as limit on WIMP-nucleon elastic scattering cross section in Higgs portal model

VBF Higgs→Invisible Decay Candidate Event



Higgs Combination

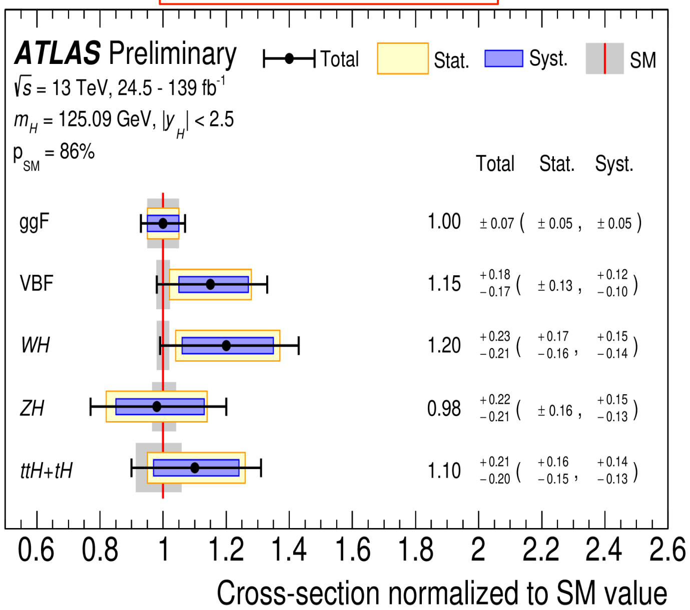
ATLAS-CONF-2020-027

- Combined all major production/decay mode measurements (13 TeV, L~36-140 fb^{-1})
- Global signal strength : $\mu = 1.06 \pm 0.07 = 1.06 \pm 0.04(\text{stat.}) \pm 0.03(\text{exp.})^{+0.05}_{-0.04}(\text{sig. th.}) \pm 0.02(\text{bkg. th.})$

$$\mu_{global} = \frac{\sigma(\exp)}{\sigma(SM)}$$

Signal theory uncertainty becoming the dominant uncertainty source

Production



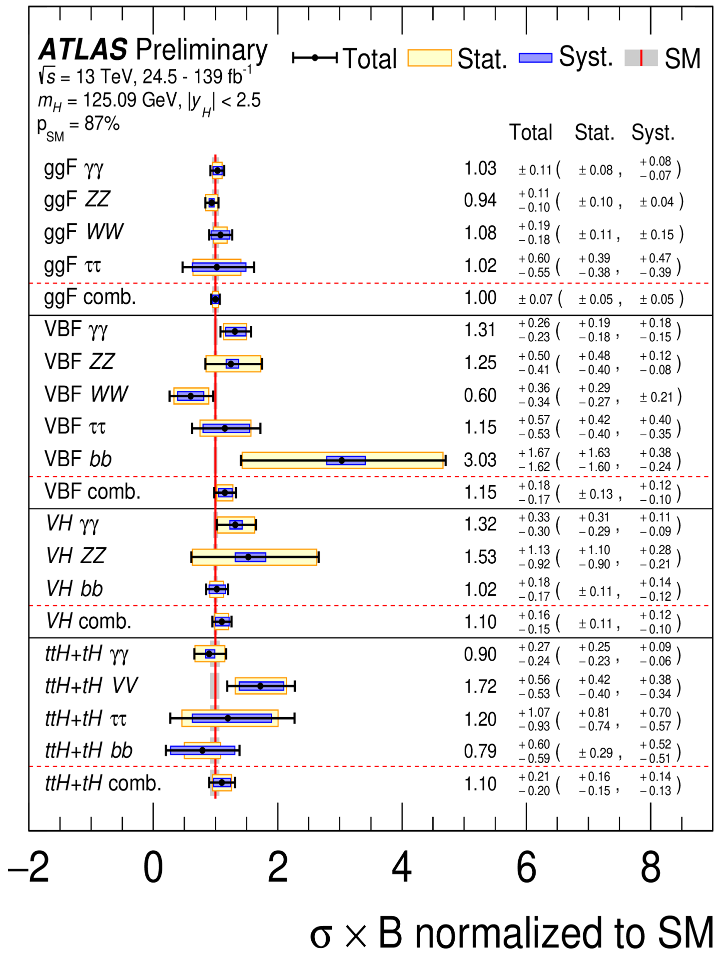
- Float each $(\sigma\times B)_{if}$
- Good agreement with SM

- Assume SM branching fractions
- Productions probed to ~7% precision in best channel

WH	**6.3σ** (5.2σ exp)
ZH	**5.0σ** (5.4σ exp)

Observation of WH, ZH productions!

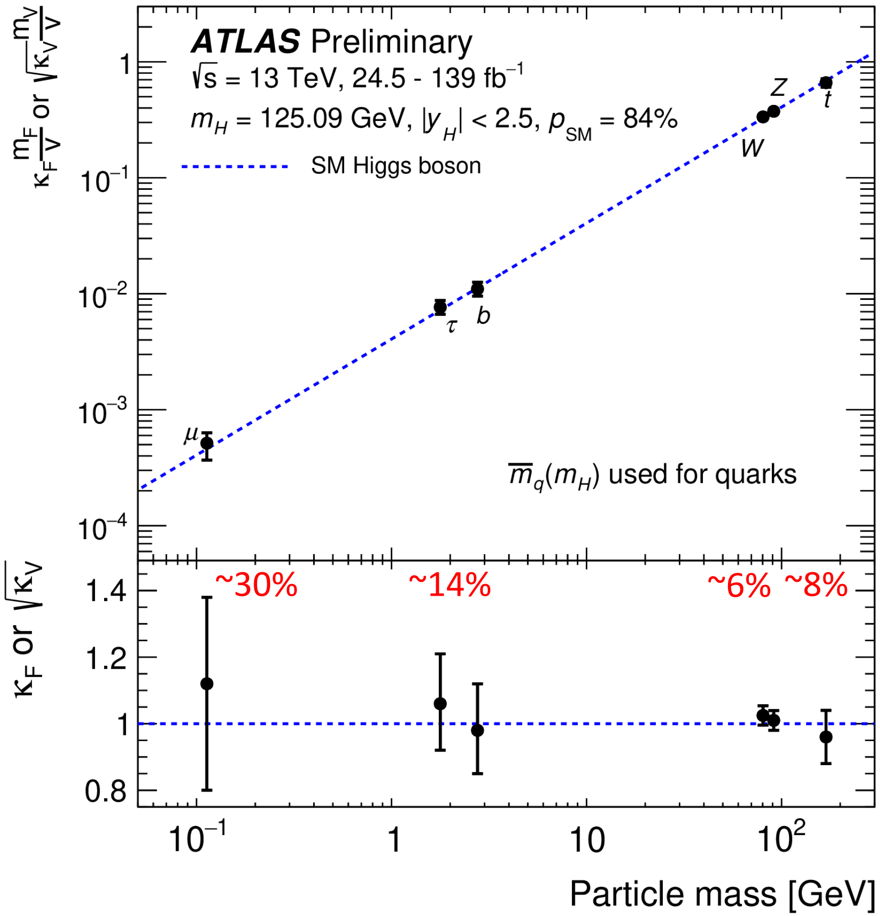
Production and Decay



Higgs Combination

ATLAS-CONF-2020-027

couplings



•Extract coupling strength modifiers (in κ framework) as function of particle mass

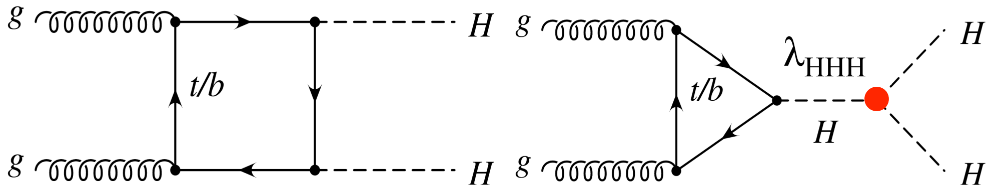
•Assume no BSM contribution to Higgs decay

•Good agreement of couplings through three orders of magnitude of particle mass

Di-Higgs Production

PLB 800 (2020) 135103

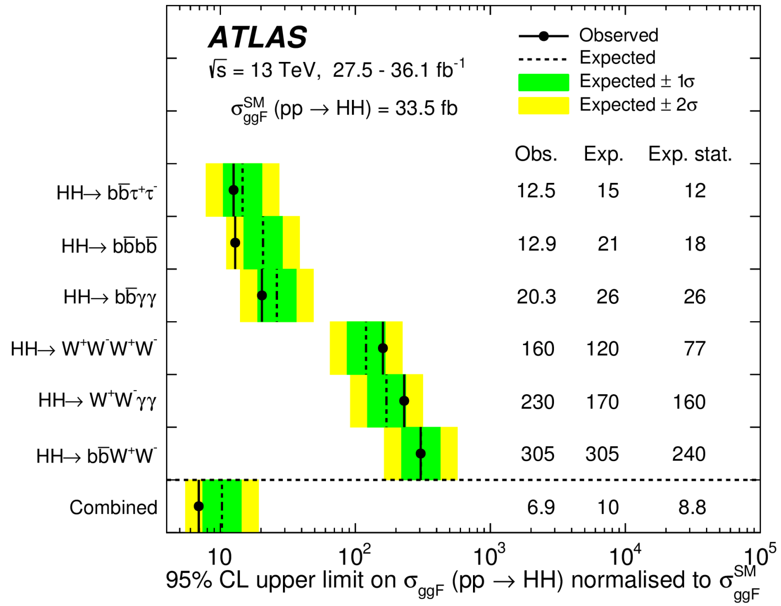
- Observation of di-Higgs production provides a direct measurement of the Higgs boson self-coupling λ_{HHH} and validate the BEH mechanism



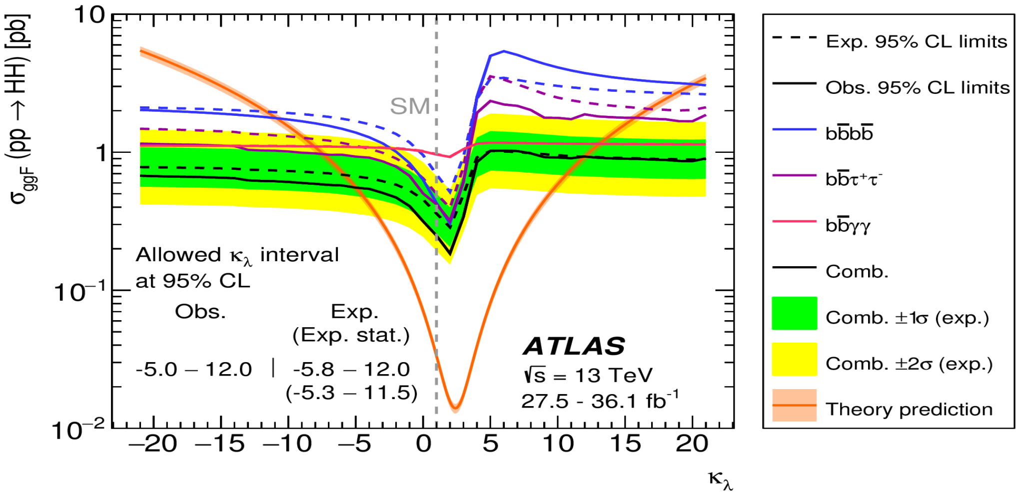
- ggF HH has highest production rate, but still ~1000X smaller than ggH (due to destructive interference)
- Performed search via ggF production in several di-Higgs decay channels

Most sensitive channels :

- HH→bbbb : highest BR, large BG from multi-jets
- HH→bbγγ : clean, but small BR
- HH→bbττ : moderate BG and BR
- HH→bbVV : V(W,Z) decays leptonically



- Set limits on σ(ggF) at 6.9 (10) × SM



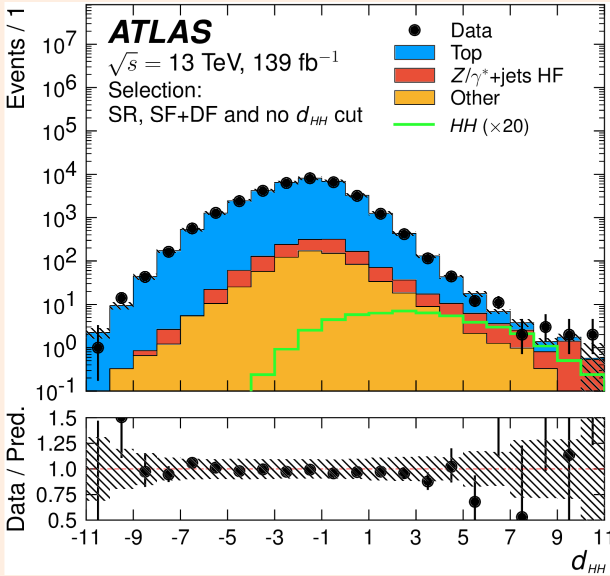
- Scanned $\kappa_\lambda = \dfrac{\lambda_{HHH}}{\lambda_{HHH}^{SM}}$ (Higgs self-coupling modifier)
- $\kappa_\lambda^{SM} = 1$
- Constraint κ_λ at 95% CL
  - $-5.0 < \kappa_\lambda < 12.0$ (exp. $-5.8 < \kappa_\lambda < 12.0$)

New HH with Full Run-2

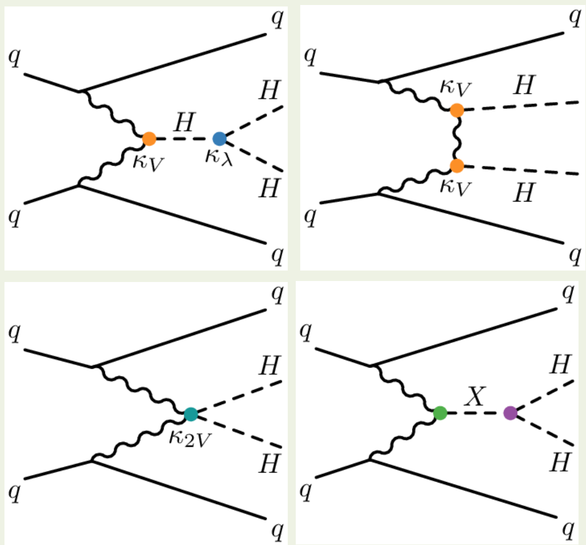
- **HH→bblνlν** : PLB 801 (2020) 135145
- Include HH→bb,WW/ZZ/ττ
- Search in ggF production

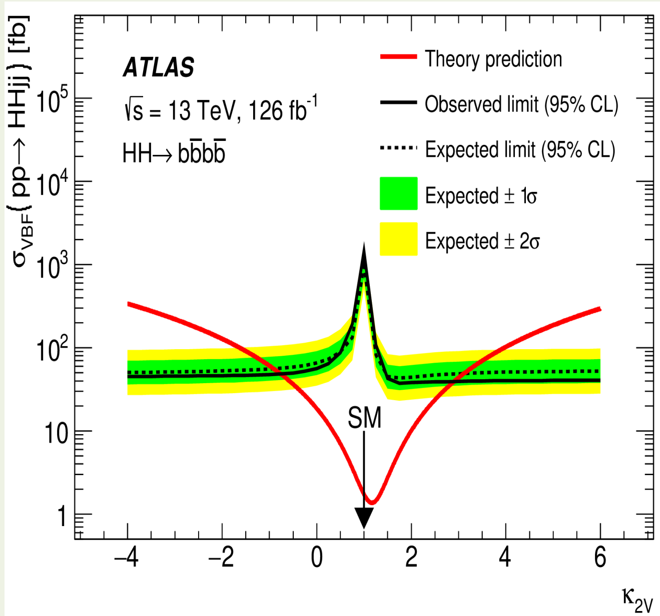
$$d_{HH} = \ln\left[p_{HH} / (p_{Top} + p_{Z-ll} + p_{Z-\tau\tau})\right]$$

- Final state : 2 b-jets, 2 opposite charged leptons (e or μ)
- Main background: Top, and Z(*ll*, ττ) +jets
- Trained Deep NN classifier on signal against 3 dominant background
- Obs. (exp.) limit on ggF : 40 (29) × SM



- **VBF, HH→4b** JHEP 07 (2020) 108
- VBF : less sensitive to κ_λ , but unique sensitive to κ_{2V}
- Distinct event topology: 4 central b-jets, 2 forward jets
- Main background from multi-jet, estimate from data with lower b-jet multiplicity
- Obs. (exp.) limit on VBF : 840 (550) × SM

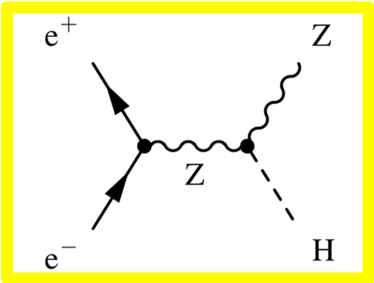




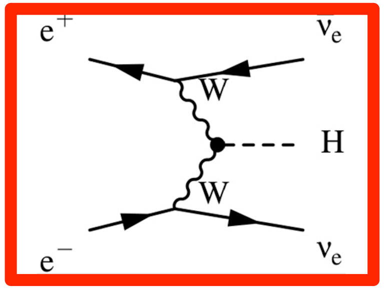
- Set limit on quartic coupling : -0.76 (-0.91) < κ_{2V} < 2.90 (3.11)

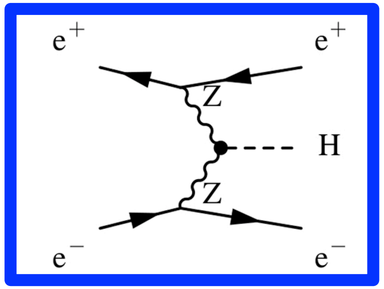
From LHC to HL-LHC and Future Colliders

Single Higgs and Di-Higgs Production (e+e-)

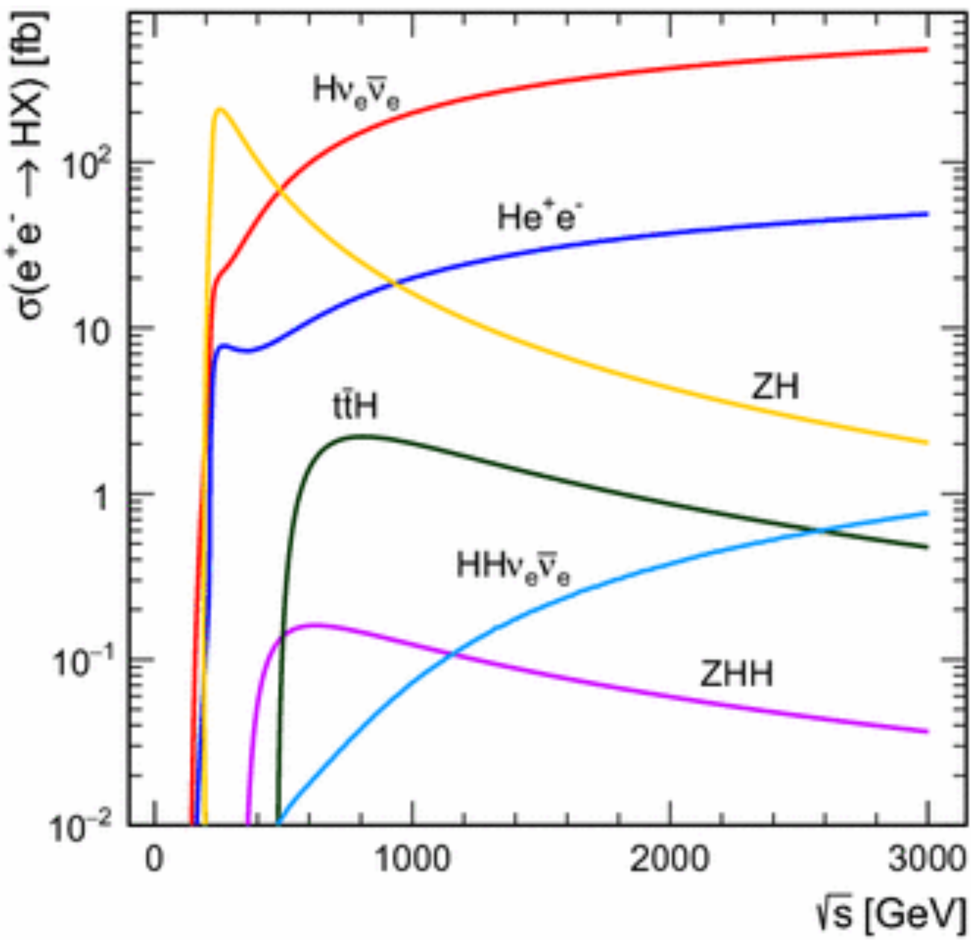


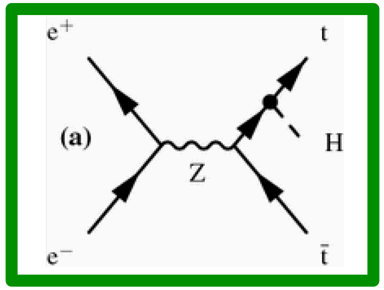
Associated Production



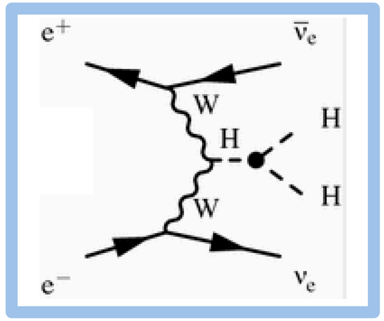


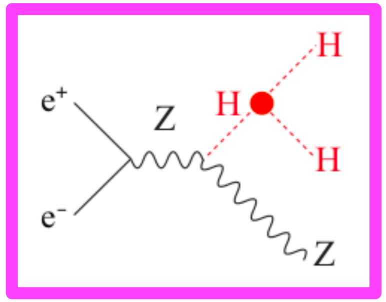
Vector Boson Fusion





ttH

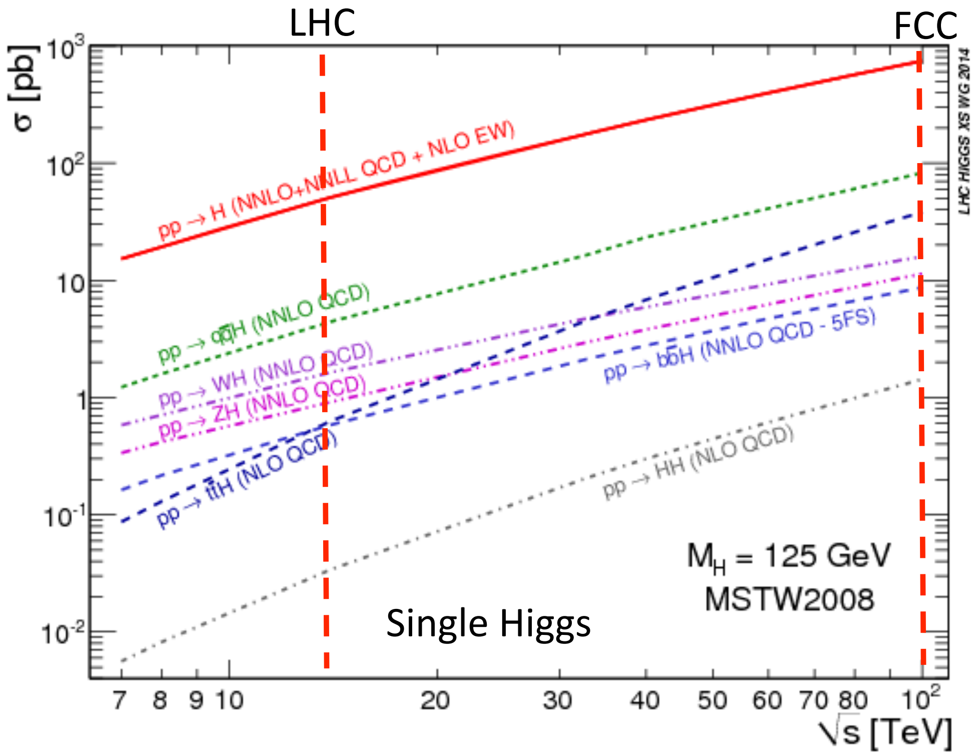


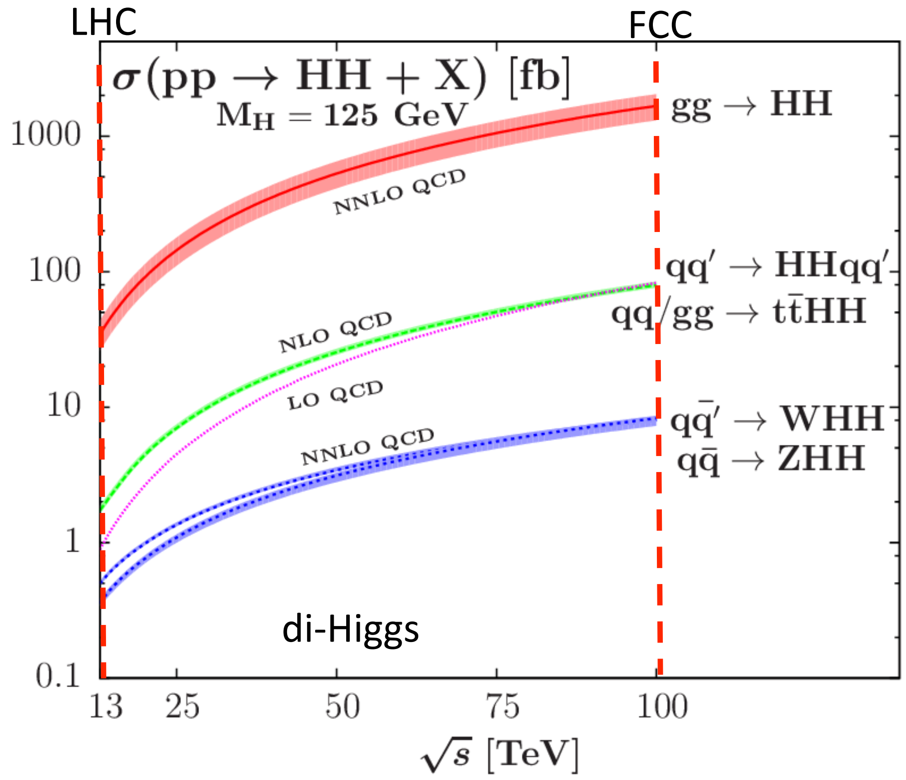


di-Higgs

- Single Higgs measurement starts at 250 GeV
- Di-Higgs probing begins around 500 GeV

Single Higgs and Di-Higgs Production (pp)





- LHC to HL-LHC :
  - ∫L : increase by 10X
  - H (ggF) : σ(14 TeV)/σ(13 TeV) ~ 1.15
  - HH (ggF) : σ(14 TeV)/σ(13 TeV) ~ 1.18

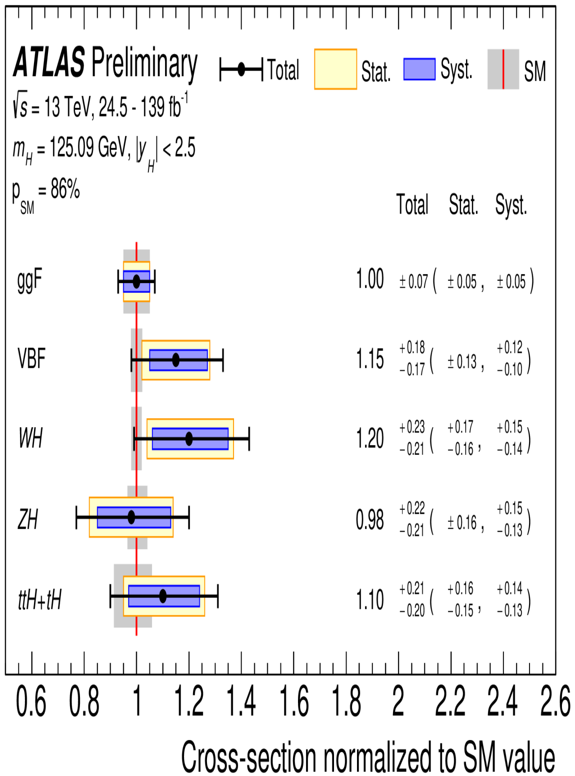
- HL-LHC to FCC-hh :
  - ∫L : increase by 10X
  - H (ggF) : σ(100 TeV)/σ(14 TeV) ~ 15
  - HH (ggF) : σ(100 TeV)/σ(14 TeV) ~ 30

Projections for Production Measurements

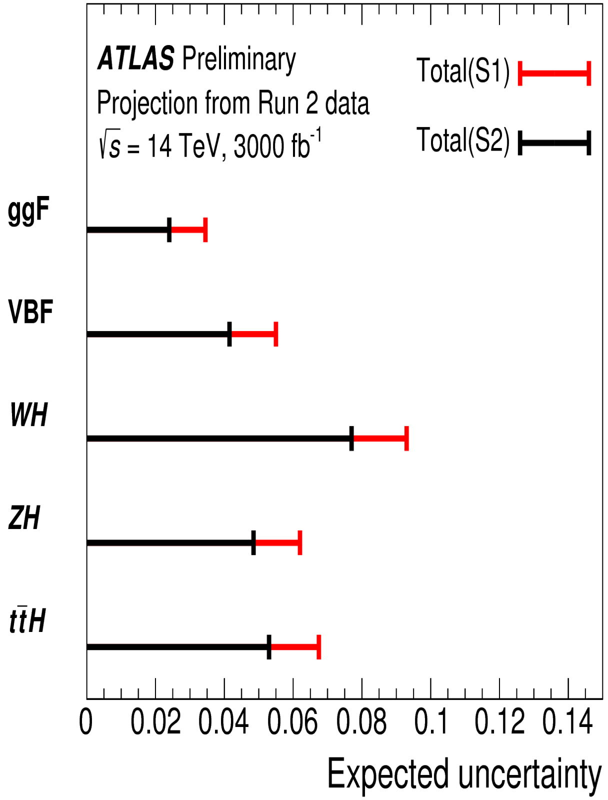
•Combined all major production/decay mode measurements

arXiv:1902.00134

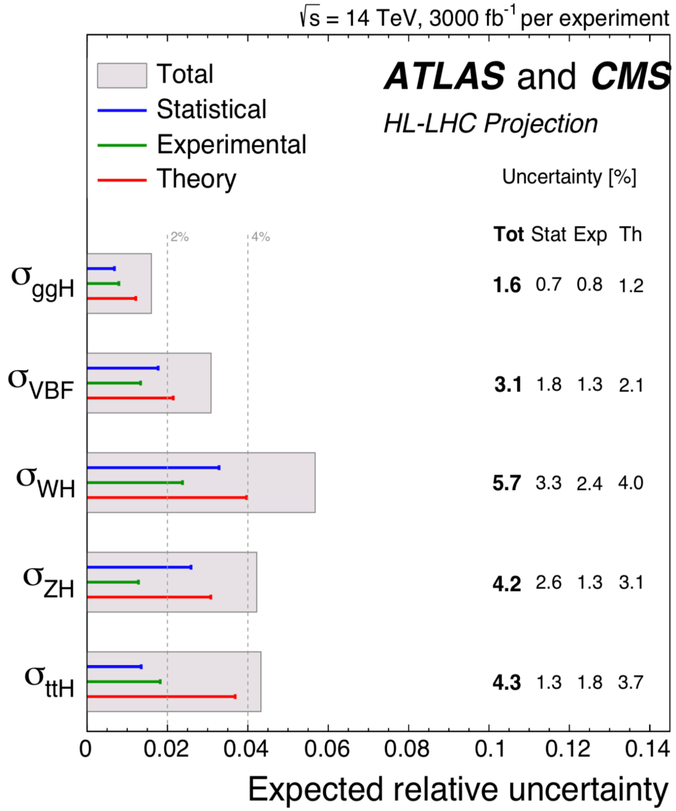
LHC, Run-2 (ATLAS)



HL-LHC (ATLAS)



HL-LHC (ATLAS+CMS)



- ggF measured at ~7%
- WH measured at ~20%

- ggF can be measured at ~2.4%
- WH can be measured at ~8%

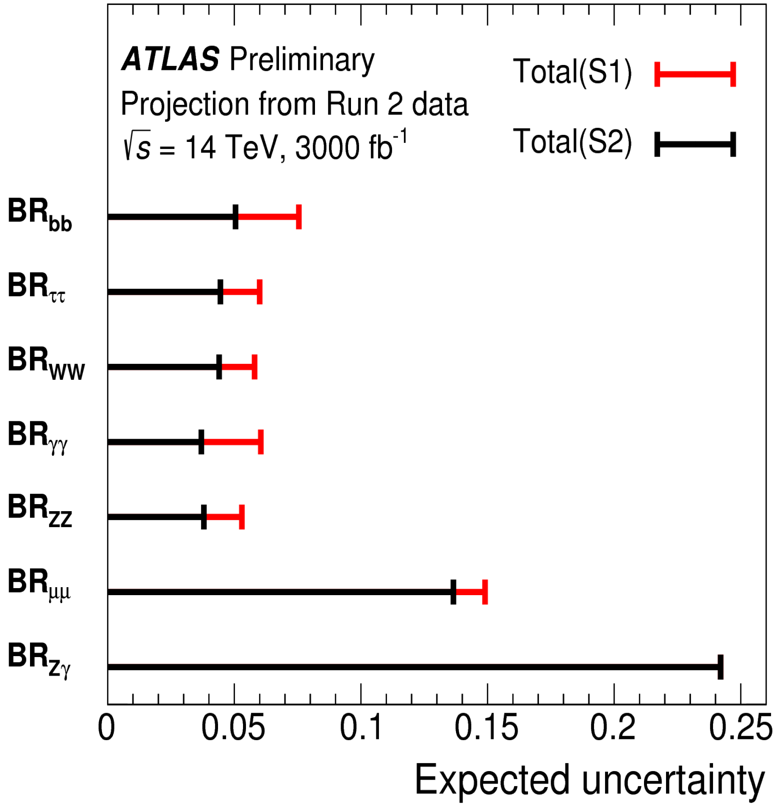
- ggF can be measured at ~2%
- WH can be measured at ~6%

•Scenario S1: Keep Run2 systematic uncertainties (pessimistic)
•Scenario S2: Reduction of syst. uncertainties defined in CERN Yellow Report

•In several cases the uncertainties will be dominated by theory

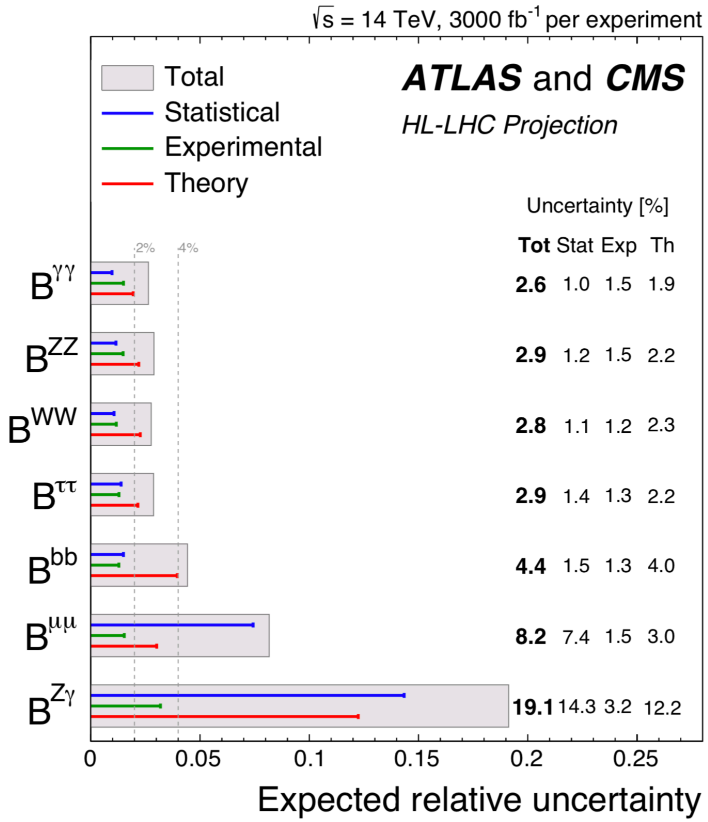
Projections for Decay Measurements

HL-LHC (ATLAS)



- Gauge boson decays can reach ~4-5%
- Fermion decays (bb,ττ) can reach ~5%
- μμ can be measured at ~14% precision

HL-LHC (ATLAS+CMS)



- Gauge boson decays can reach ~3%
- Fermion decays (bb,ττ) can reach ~3-4%
- μμ can be observed with ~8%

arXiv:1902.00134

- In several cases the uncertainties will be dominated by theory

Projections for Coupling Measurements

- Assume no BSM contribution

kappa-0	HL-LHC	LHeC	HE-LHC		ILC			CLIC			CEPC	FCC-ee		FCC-ee/eh/hh
			S2	S2′	250	500	1000	380	15000	3000		240	365	
κ_W [%]	1.7	0.75	1.4	0.98	1.8	0.29	0.24	0.86	0.16	0.11	1.3	1.3	0.43	0.14
κ_Z [%]	1.5	1.2	1.3	0.9	0.29	0.23	0.22	0.5	0.26	0.23	0.14	0.20	0.17	0.12
κ_g [%]	2.3	3.6	1.9	1.2	2.3	0.97	0.66	2.5	1.3	0.9	1.5	1.7	1.0	0.49
κ_γ [%]	1.9	7.6	1.6	1.2	6.7	3.4	1.9	98⋆	5.0	2.2	3.7	4.7	3.9	0.29
$\kappa_{Z\gamma}$ [%]	10.	–	5.7	3.8	99⋆	86⋆	85⋆	120⋆	15	6.9	8.2	81⋆	75⋆	0.69
κ_c [%]	–	4.1	–	–	2.5	1.3	0.9	4.3	1.8	1.4	2.2	1.8	1.3	0.95
κ_t [%]	3.3	–	2.8	1.7	–	6.9	1.6	–	–	2.7	–	–	–	1.0
κ_b [%]	3.6	2.1	3.2	2.3	1.8	0.58	0.48	1.9	0.46	0.37	1.2	1.3	0.67	0.43
κ_μ [%]	4.6	–	2.5	1.7	15	9.4	6.2	320⋆	13	5.8	8.9	10	8.9	0.41
κ_τ [%]	1.9	3.3	1.5	1.1	1.9	0.70	0.57	3.0	1.3	0.88	1.3	1.4	0.73	0.44

- HL-LHC can improve upon current ATLAS Run-2 measurements by factors ~2.5-7
    - Achieve about ~2-4% precision in most cases
- Proposed e+e- colliders can improve w.r.t. HL-LHC by factors up to ~15

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* : parameter left free in fit due to lack of input in reference documentation

Projections for Differential Distributions Measurements

- Important to measure the differential distributions of Higgs production
    - Provide a probe of the SM
    - Constraint effects from beyond the SM
- HL-LHC projections based on Run 2 analyses
- Most precisely measured by $H \rightarrow \gamma\gamma$, $H \rightarrow ZZ^{*} \rightarrow 4l$ channels

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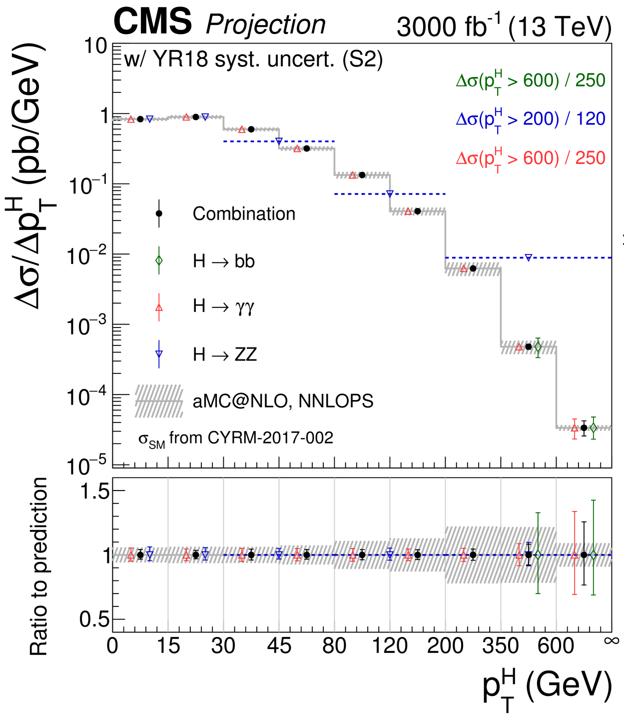
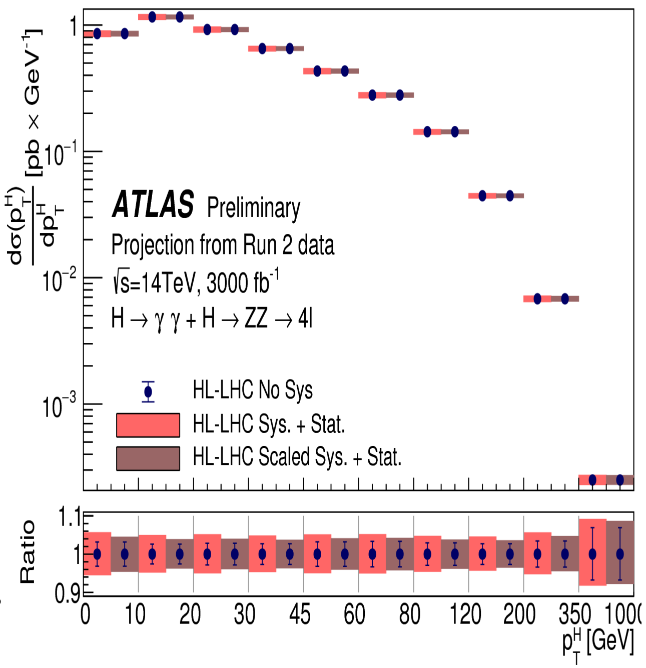
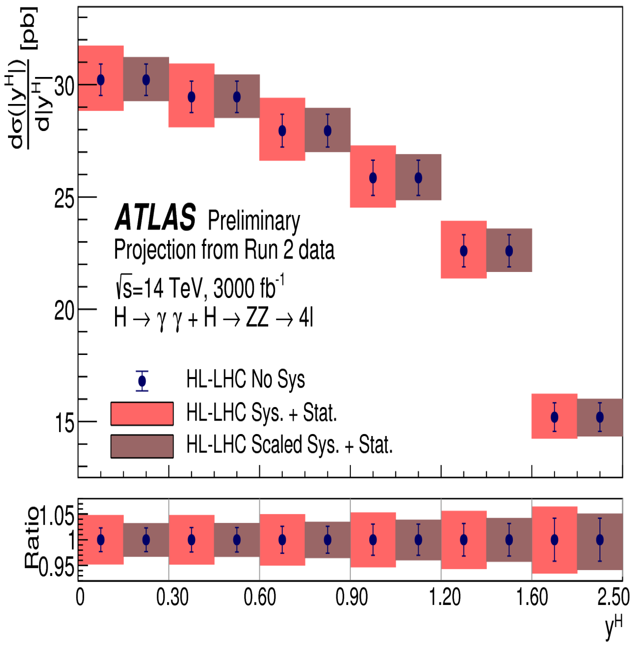






- Expect to probe with precision of ~10% at p_T^H ~350-600 GeV (HL-LHC)

Projection for Higgs Mass Measurement

- Current PDG average (ATLAS+CMS) m_H = 125.10 ± 0.14 GeV (from γγ, 4l(ZZ^*))
- Latest CMS: 125.38±0.14 GeV (Run1+2016)
- Latest ATLAS : $124.92 \pm 0.19^{+0.09}_{-0.06}$ GeV (4l, full Run2)
- γγ is now systematically limited
- 4l is statistically limited
  - Mass value will be driven by 4l (muon) channel

- Extrapolate ATLAS Run2 4μ results to 3000 fb^{-1} in four scenarios
  - Total uncertainty vary between 33 to 52 MeV

Expected Higgs mass precision with 3 ab^{-1} (ATLAS)

	Δ_{tot} (MeV)	Δ_{stat} (MeV)	Δ_{syst} (MeV)
Current Detector	52	39	35
μ momentum resolution improvement by 30% or similar	47	30	37
μ momentum resolution/scale improvement of 30% / 50%	38	30	24
μ momentum resolution/scale improvement 30% / 80%	33	30	14

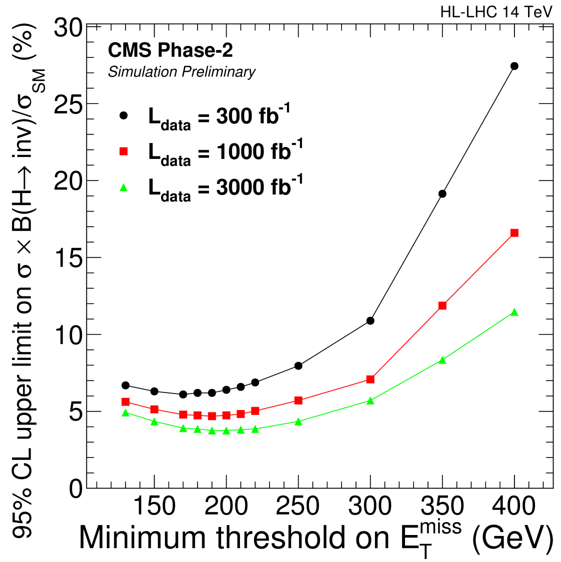
- Expect better resolution from CMS due to stronger magnetic field
  - ➔ expect uncertainty < 20 MeV when combining CMS and ATLAS

ATLAS-CONF-2020-005 | PLB 805 (2020) 135425 | arXiv:1902.00134 | ATL-PHYS-PUB-2018-054

Projections for Higgs to Invisible Decays

- For HL-LHC, projection is studied with VBF channel by CMS
- Pileup suppression will be very important
  - Degrade MET resolution, false identification of pileup jets as VBF jets in forward region
- Expected reach of upper limit BR(H→inv)~3.8% at 95% CL (assume SM VBF production)
- Can reach BR(H→inv)≤2.5% including VH channel and assuming ATLAS has same performance
  - 5X smaller than current best limit

arXiv:1902.00134



Collider	95% CL upper bound on				
		BR_{inv} [%]		BR_{unt} [%]	
	Direct	kappa-3	BR_{inv} only	kappa-3	BR_{unt} only
HL-LHC	2.6	1.9	1.9	4.0	3.6
HL-LHC + HE-LHC(S'_2)		1.5	1.5	2.4	1.9
FCC-hh	0.025	0.024	0.024	1.0	0.36
HL-LHC + LHeC	2.3	1.1	1.1	1.3	1.3
HL-LHC + CEPC	0.3	0.27	0.26	1.1	0.49
HL-LHC + $FCC\text{-}ee_{240}$	0.3	0.22	0.22	1.2	0.62
HL-LHC + $FCC\text{-}ee_{365}$		0.19	0.19	1.0	0.54
HL-LHC + ILC_{250}	0.3	0.26	0.25	1.8	0.85
HL-LHC + ILC_{500}		0.23	0.22	1.4	0.55
HL-LHC + ILC_{1000}		0.22	0.20	1.4	0.43
HL-LHC + $CLIC_{380}$	0.69	0.63	0.56	2.7	1.0
HL-LHC + $CLIC_{1500}$		0.62	0.40	2.4	0.51
HL-LHC + $CLIC_{3000}$		0.62	0.30	2.4	0.33

- Projections from direct searches and from combine fits
- HL-LHC improves by ~5X w.r.t. current LHC best limit
- e+e- improves by ~10X w.r.t. HL-LHC
- FCC-hh further improves by another ~10X
  - limit below SM BR of 0.1%

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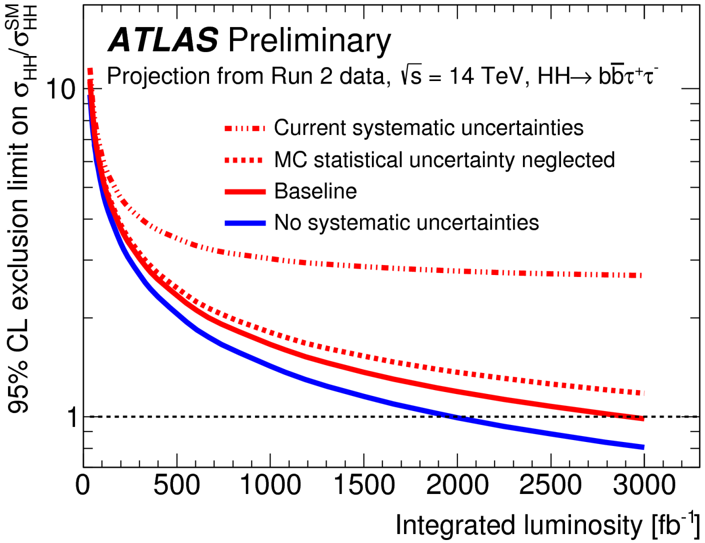
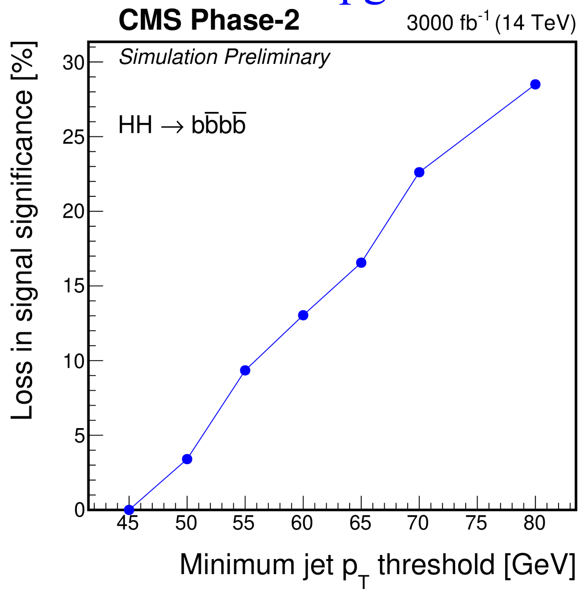
Di-Higgs : Projection for HL-LHC

- Extrapolation based on current analyses and on the estimate of upgraded detector performance





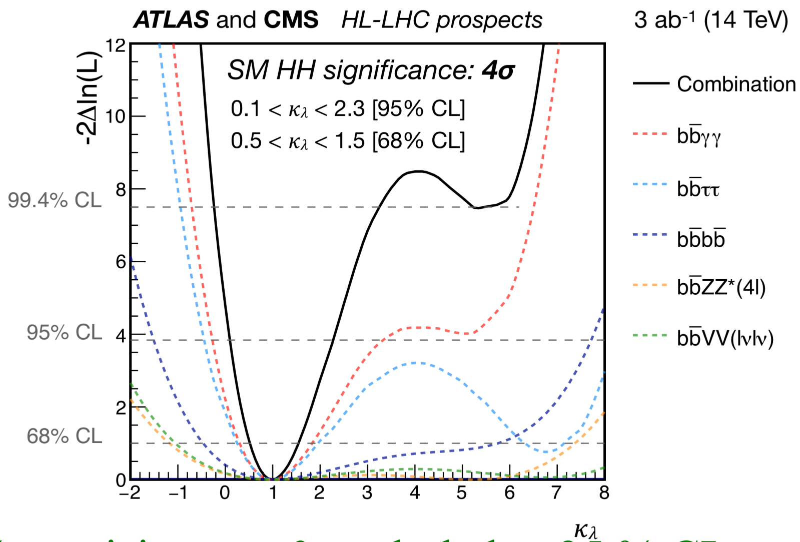
CMS-FTR-18-019

ATL-PHYS-PUB-2018-053

arXiv:1902.00134

- Vary the scenarios of systematic uncertainties
- High pileup at HL-LHC may require to raise trigger threshold (maybe a challenge for bbbb channel)

	Statistical-only		Statistical + Systematic	
	ATLAS	CMS	ATLAS	CMS
$HH \to b\bar{b}b\bar{b}$	1.4	1.2	0.61	0.95
$HH \to b\bar{b}\tau\tau$	2.5	1.6	2.1	1.4
$HH \to b\bar{b}\gamma\gamma$	2.1	1.8	2.0	1.8
$HH \to b\bar{b}VV(ll\nu\nu)$	-	0.59	-	0.56
$HH \to b\bar{b}ZZ(4l)$	-	0.37	-	0.37
combined	3.5	2.8	3.0	2.6
	Combined 4.5		Combined 4.0	



- κ_λ can reach ~50% precision, κ_λ=0 excluded at 95 % CL

Di-Higgs : Projection for Future Colliders

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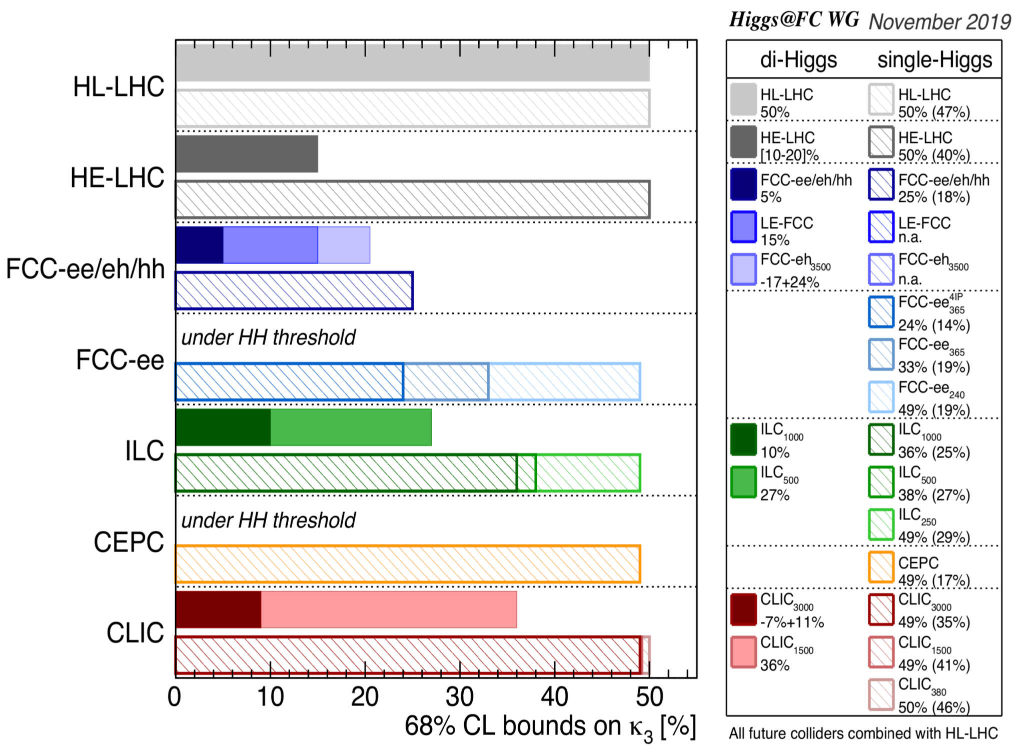
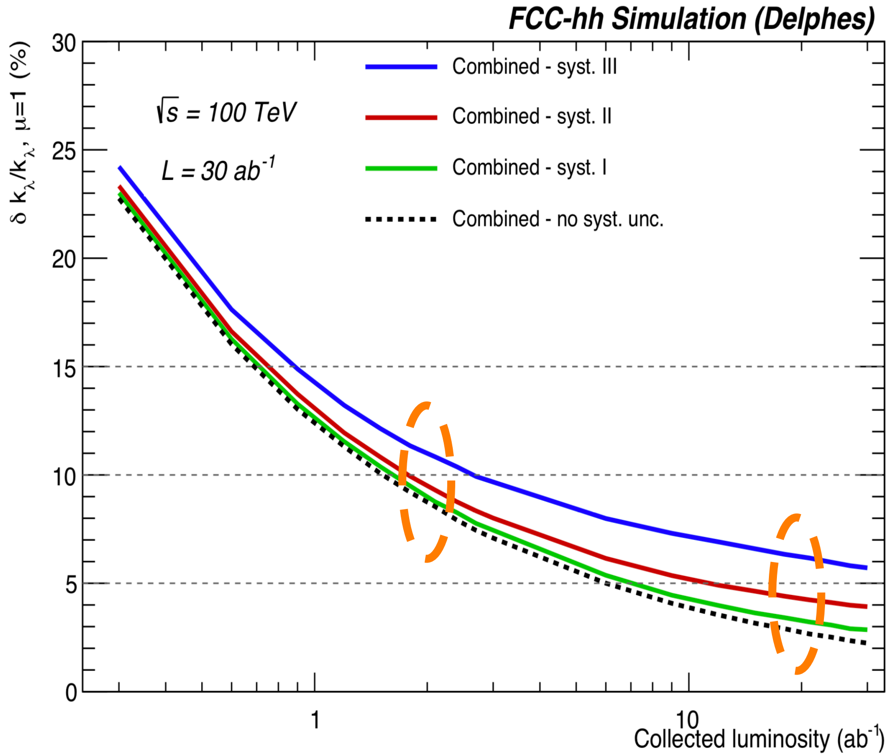
arXiv:2004.03505





- HL-LHC : 50% accuracy
- HE-LHC, future e+e- : 10-20% accuracy , reach discovery of SM-like λ_{HHH}
- FCC-hh :
  - 10% precision with 2 ab^{-1}
  - 5% precision with 20 ab^{-1} (10X more precise than HL-LHC) , allow to probe the size of the quantum corrections of the Higgs potential

Summary

- Many Higgs results have been updated using the full Run2 data, and have improved upon the previous measurements
  - More productions channels have been observed (e.g. individual WH, ZH) and are probing the rare decay modes
- Projections for the HL-LHC show the Higgs productions and decays can be measured to a precision of a few percent and we may reach the discovery level of di-Higgs production at the end of HL-LHC
- The future colliders could improve further the precision of these measurements by more than an order of magnitude w.r.t. HL-LHC

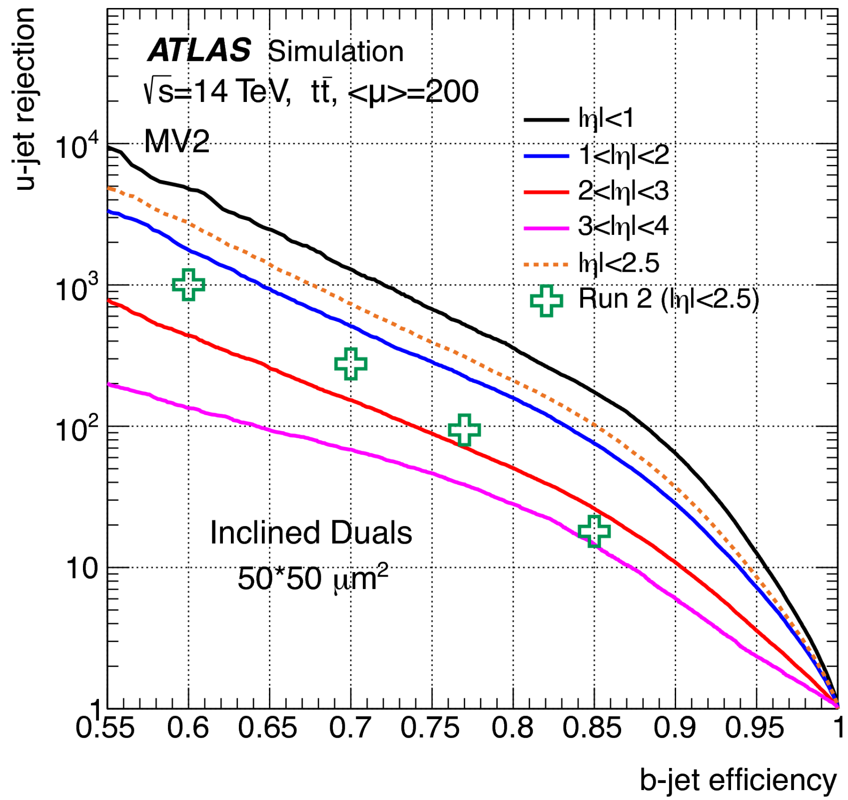
Backup

Detector Performance

ATL-PHYS-PUB-2019-005

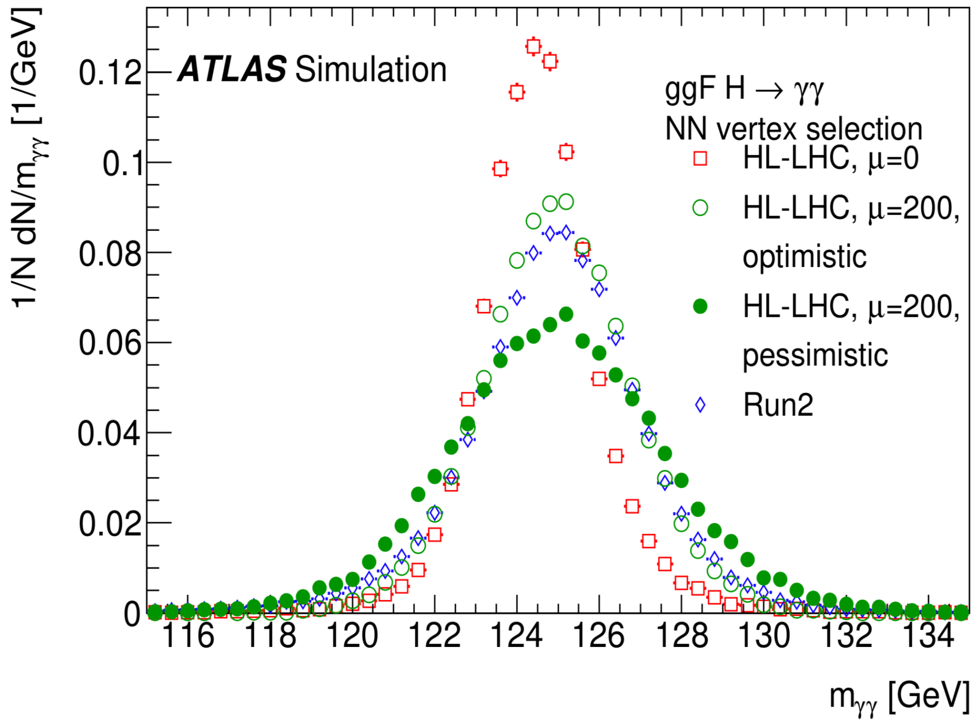
CERN-LHCC-2017-018

Tag b-jets



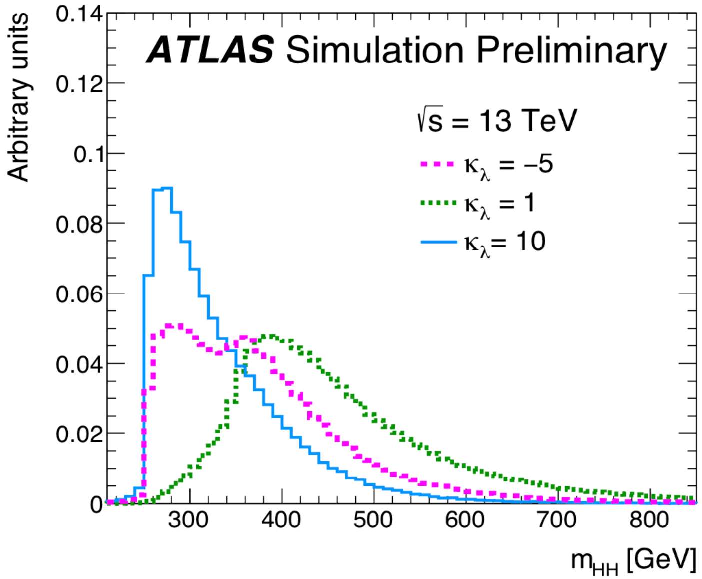
- Run2 performance (@<μ>~30) is shown as green crosses
- Performance at HL-LHC improved by more than factor of 2 in |η|<2.5, and enlarged geometrical coverage

Di-Photon Mass

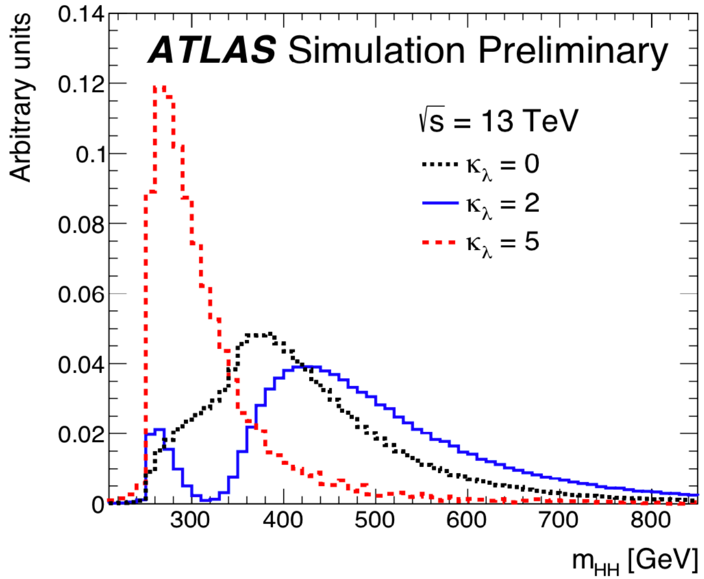


- di-photon mass resolution at HL-LHC, with <μ>~200, is comparable to Run2 for the optimistic scenario
  - pessimistic : same resolution constant term as Run2, pileup noise with Run2 reconstruction alg,
  - optimistic : reduce the resolution constant term to its design value, pileup noise reduce to level equivalent to <μ>=75

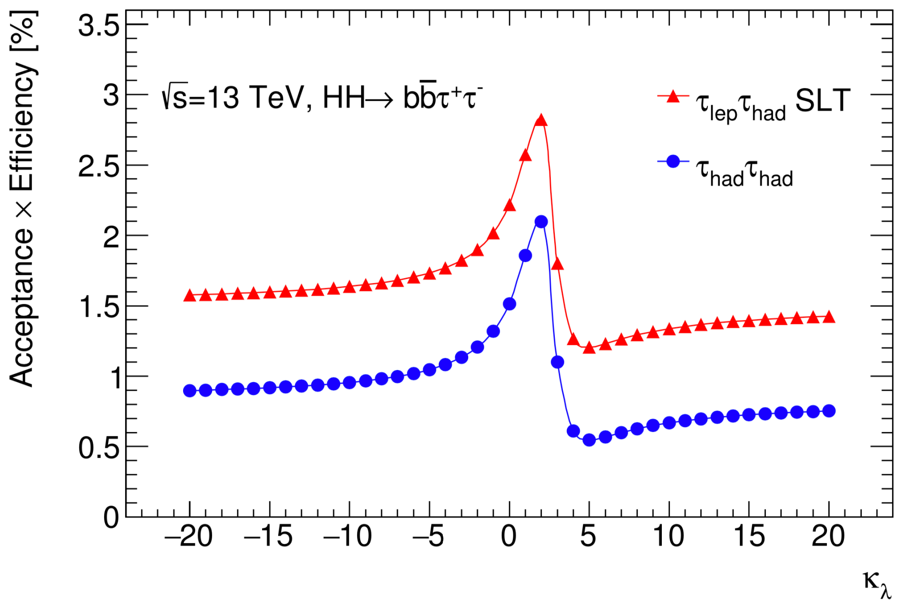
HH



ATLAS Simulation Preliminary
√s = 13 TeV
κλ = −5
κλ = 1
κλ= 10
Arbitrary units
m_HH [GeV]

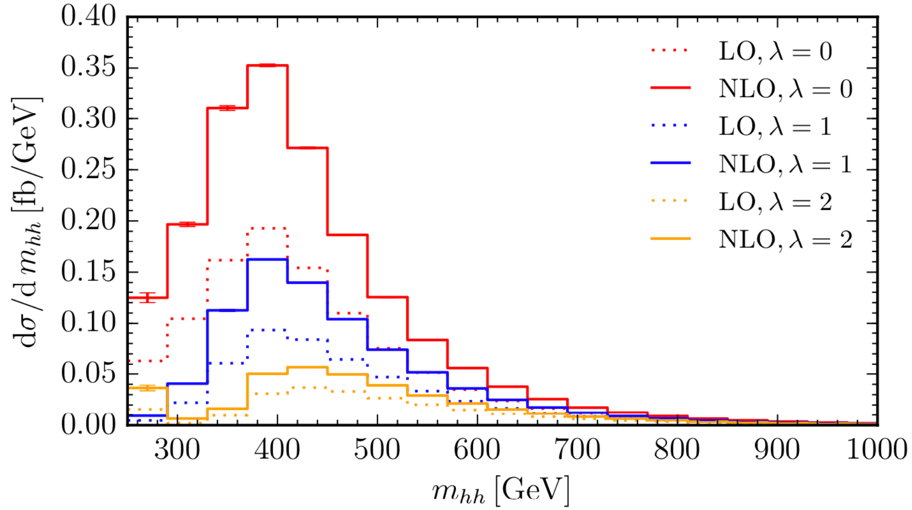


ATLAS Simulation Preliminary
√s = 13 TeV
κλ = 0
κλ = 2
κλ = 5
Arbitrary units
m_HH [GeV]



√s=13 TeV, HH→ bb̄τ⁺τ⁻
τlepτhad SLT
τhadτhad
Acceptance × Efficiency [%]
κλ

HH



(a)

Fig. 42: Higgs boson pair invariant mass distributions for various values of λ (relative to $\lambda_{\rm SM}$) at 14 TeV.

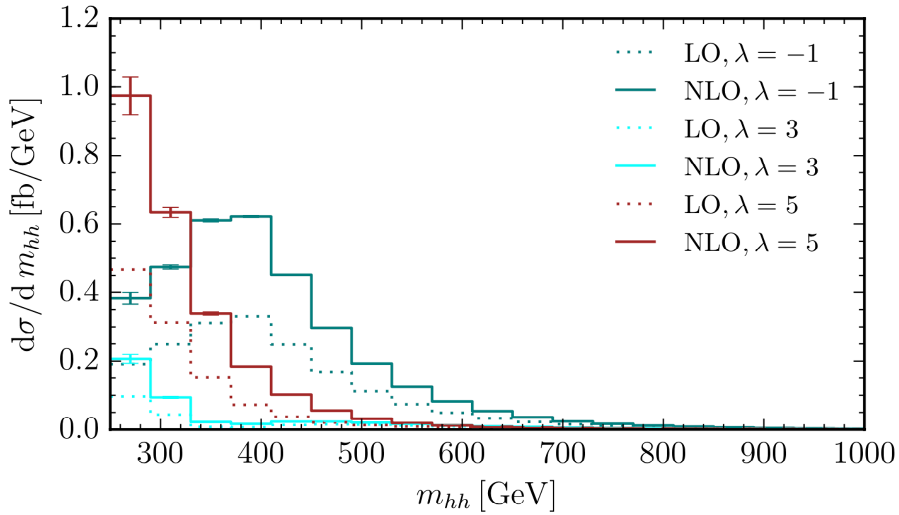
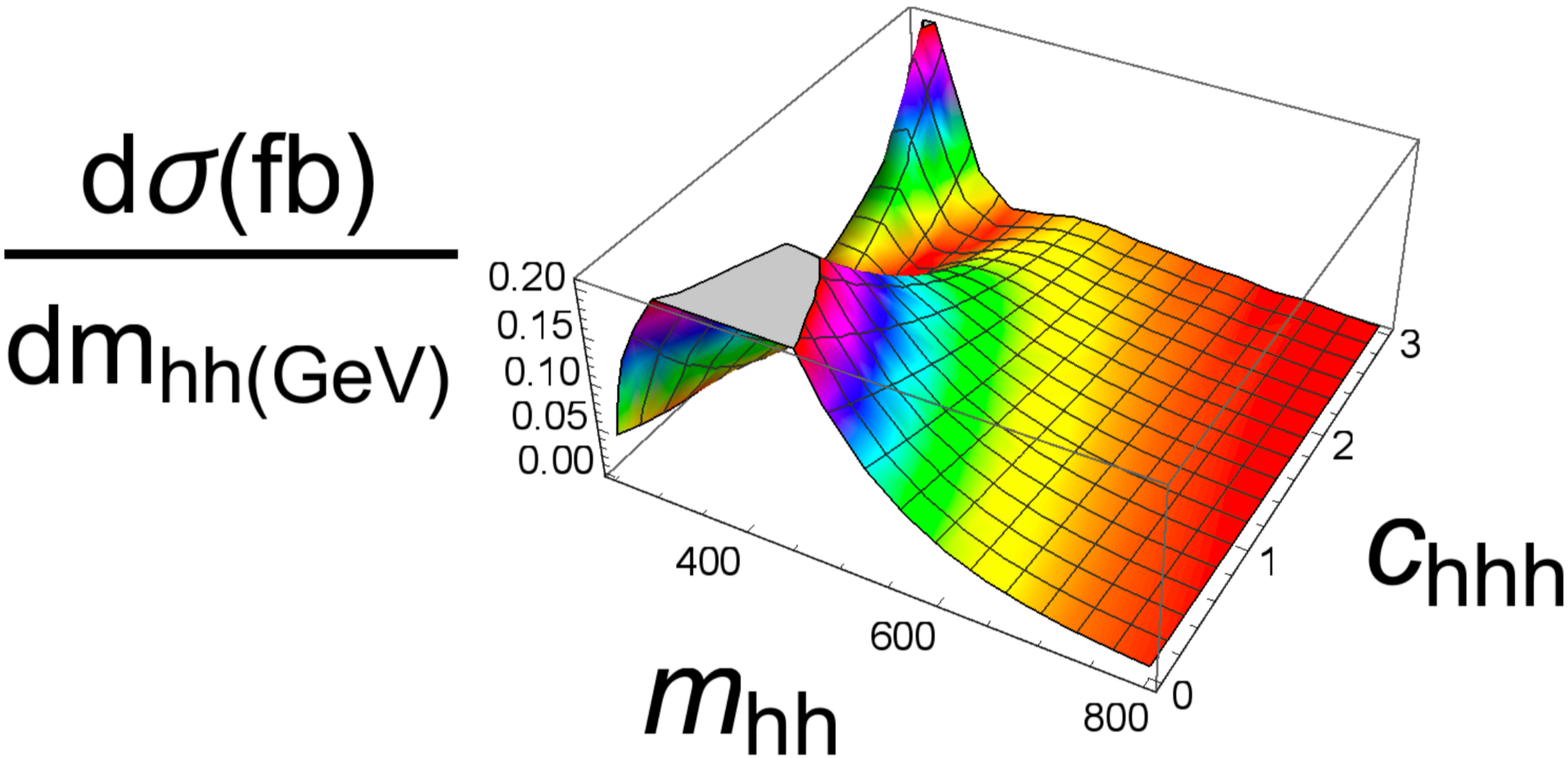
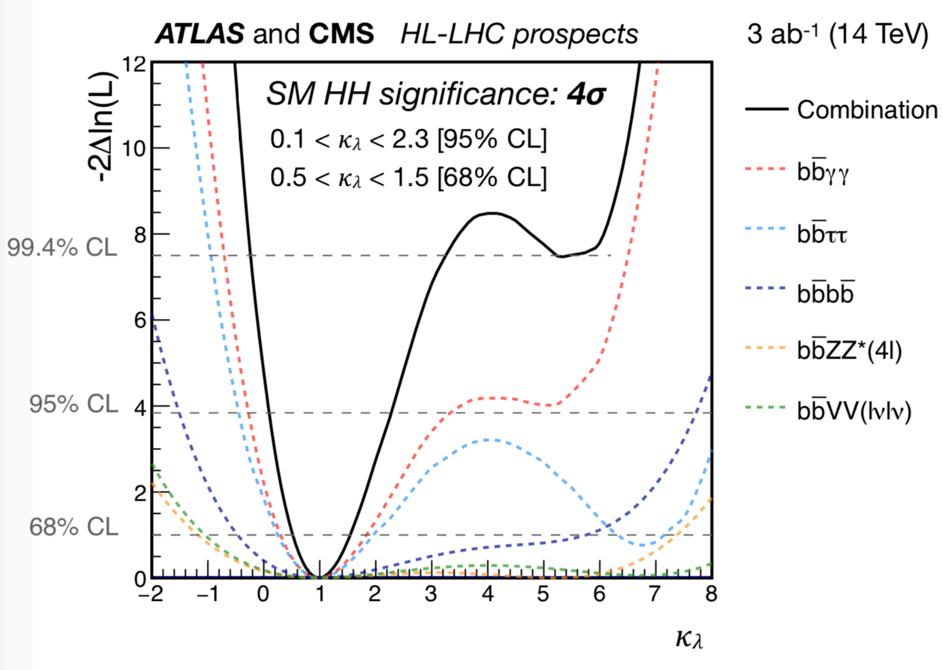


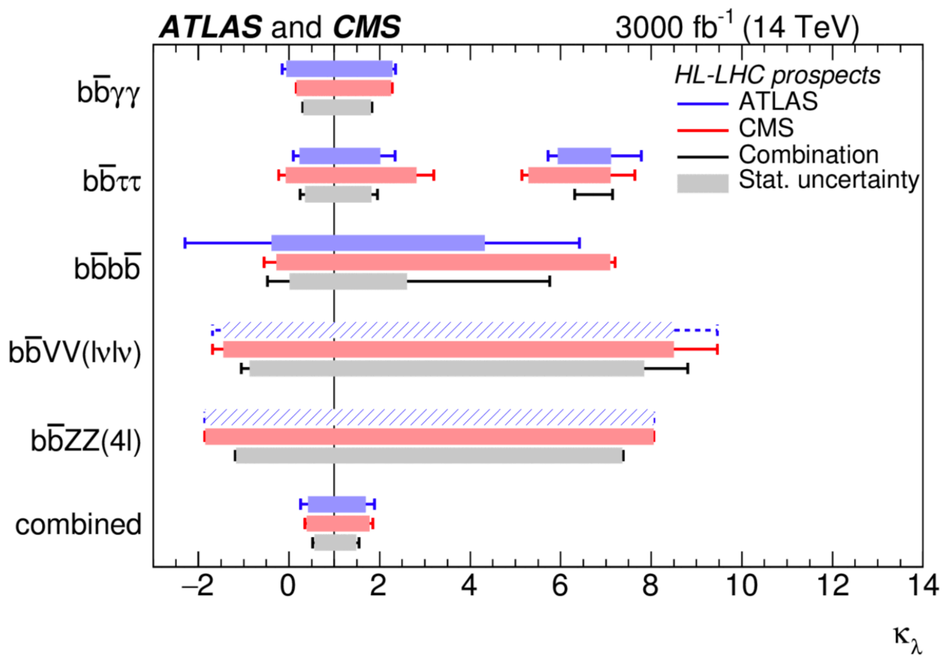
Fig. 43: Higgs boson pair invariant mass distributions for $\lambda = \lambda_{\rm BSM}/\lambda_{\rm SM} = -1, 3, 5$ at 14 TeV.

HH



HH


ATLAS and CMS HL-LHC prospects
3 ab-1 (14 TeV)
SM HH significance: 4σ
0.1 < κλ < 2.3 [95% CL]
0.5 < κλ < 1.5 [68% CL]
-2Δln(L)
99.4% CL
95% CL
68% CL
Combination
bb̄γγ
bb̄ττ
bb̄bb̄
bb̄ZZ*(4l)
bb̄VV(lνlν)
κλ


ATLAS and CMS
3000 fb-1 (14 TeV)
HL-LHC prospects
ATLAS
CMS
Combination
Stat. uncertainty
bb̄γγ
bb̄ττ
bb̄bb̄
bb̄VV(lνlν)
bb̄ZZ(4l)
combined
κλ

Physics Projection at HL-LHC

- Assume center of mass energy at 14 TeV and total integrated luminosity is 3000 fb^{-1}

- Methods for projection:
  - **Detailed simulations** are used to access performance of upgraded detector and HL-LHC condition
  - Existing results are **extrapolated** and take into account of increase in energy and performance of upgraded detector, or **parametric simulations** are used to allow full re-optimization of the analyses

- **Systematic uncertainties :**

- Baseline scenario (“YR18” or “S2”) :
  - Theory uncertainties ½ of Run-2
  - No simulation statistical uncertainty
  - luminosity uncertainty ~1%
  - Statistical uncertainty reduced by 1/√L
  - Uncertainties due to detector limitations remain unchanged or revised according to simulation studies of upgraded detector.

- Conservative scenario (“S1”) :
  - Use uncertainties of Run-2 measurements, assuming the higher pile-up effects will be compensated by detector upgrades.

ATL-PHYS-PUB-2018-054
CMS-PAS-FTR-18-011

Possible HL-LHC Triggers

ATL-PHYS-PUB-2019-005

Table 2: Representative trigger menu for ATLAS operations at the HL-LHC. The offline p_T thresholds indicate the momentum above which a typical analysis would use the data. Where multiple object triggers are described only one threshold is given if both objects are required to be at the same p_T; otherwise, each threshold is given with the two values separated by a comma. In the case of the $e - \mu$ trigger in Run 2, two sets of thresholds were used depending on running period, and both are listed. This table is a subset of Table 6.4 from the TDAQ TDR [10].

Trigger Selection	Run 1 Offline p_T Threshold [GeV]	Run 2 (2017) Offline p_T Threshold [GeV]	Planned HL-LHC Offline p_T Threshold [GeV]
isolated single e	25	27	22
isolated single μ	25	27	20
single γ	120	145	120
forward e			35
di-γ	25	25	25
di-e	15	18	10
di-μ	15	15	10
$e - \mu$	17,6	8,25 / 18,15	10
single τ	100	170	150
di-τ	40,30	40,30	40,30
single b-jet	200	235	180
single jet	370	460	400
large-R jet	470	500	300
four-jet (w/ b-tags)		45(1-tag)	65(2-tags)
four-jet	85	125	100
H_T	700	700	375
E_T^{miss}	150	200	210
VBF inclusive (di-jets)			2x75 w/ ($\Delta\eta > 2.5$ & $\Delta\phi < 2.5$)

Example of S1 and S2 Uncertainty Scenarios

CMS-PAS-FTR-18-011

Table 1: The sources of systematic uncertainty for which minimum values are applied in S2.

Source	Component	Run 2 uncertainty	Projection minimum uncertainty
Muon ID		1–2%	0.5%
Electron ID		1–2%	0.5%
Photon ID		0.5–2%	0.25–1%
Hadronic tau ID		6%	2.5%
Jet energy scale	Absolute	0.5%	0.1–0.2%
	Relative	0.1–3%	0.1–0.5%
	Pileup	0–2%	Same as Run 2
	Method and sample	0.5–5%	No limit
	Jet flavour	1.5%	0.75%
	Time stability	0.2%	No limit
Jet energy res.		Varies with p_T and η	Half of Run 2
MET scale		Varies with analysis selection	Half of Run 2
b-Tagging	b-/c-jets (syst.)	Varies with p_T and η	Same as Run 2
	light mis-tag (syst.)	Varies with p_T and η	Same as Run 2
	b-/c-jets (stat.)	Varies with p_T and η	No limit
	light mis-tag (stat.)	Varies with p_T and η	No limit
Integrated lumi.		2.5%	1%