Latest Results from ATLAS Experiment

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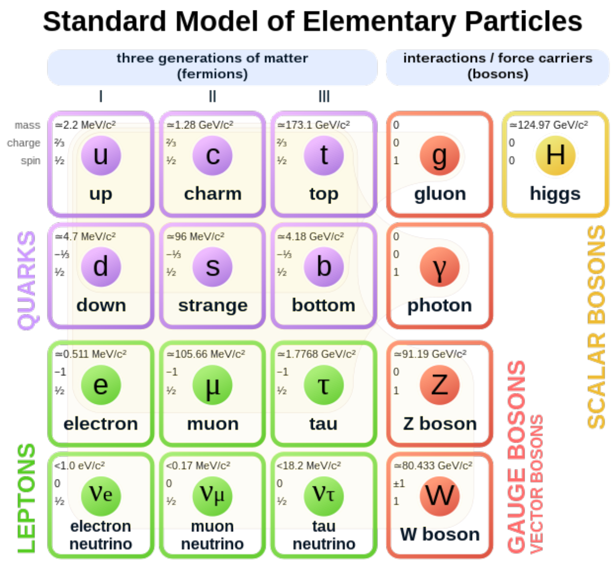
on the behalf of the ATLAS collaboration

Bormio 2023 Conference

The Standard Model of Particle Physics

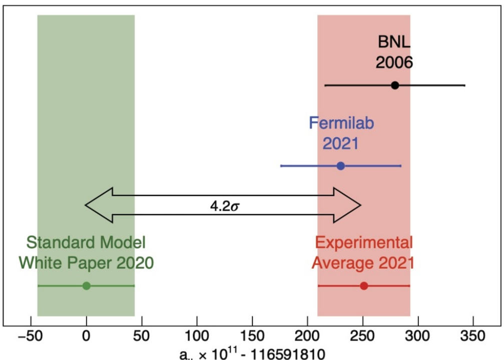


- Gauge symmetry group given by: $SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$
  - Except for gravity, gives good description of the other fundamental forces in nature
- We want to measure all particle properties and their interactions

Standard Model limitations

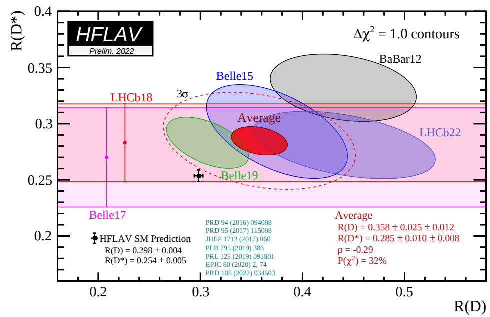
- Standard Model (SM) *fails* to explain/leave several opened questions:
  - Lepton Flavour Violation (LFV), like in neutrino oscillation
  - Muon anomalous magnetic moment
  - Anomalies in B-physics, $R_D^{(*)}$
  - Dark matter in the universe
  - Many Others ...
- All these opens to a new pletora of searches for physics Beyond Standard Model (BSM)

arxiv-2104.03281



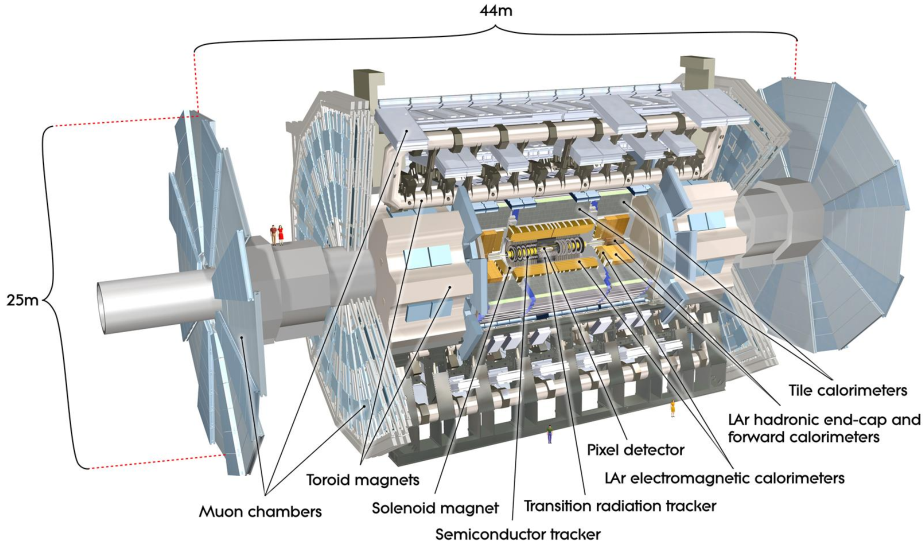
$$a_\mu^{SM} = 116591810(43) \times 10^{-11}$$
$$a_\mu^{exp} = 116592061(41) \times 10^{-11}$$

HFlav



3.2 σ discrepancy with respect to SM

The ATLAS experiment

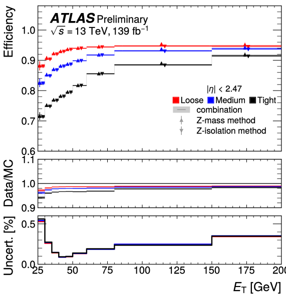


- Multi-purpose detector to measure *pp* and heavy ion collision products
- Tracking plus Calorimeter systems to measure particles
- 2 level trigger system to filter interesting events

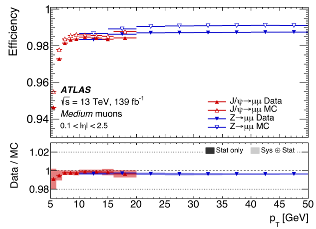
Object reconstruction performance

- Need high efficiency reconstruction and precise resolution for the different physics objects

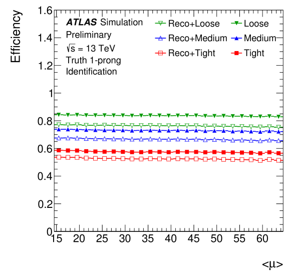
elec



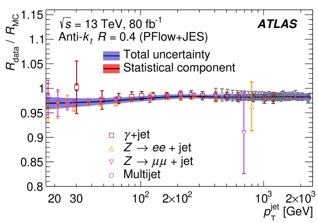
muon



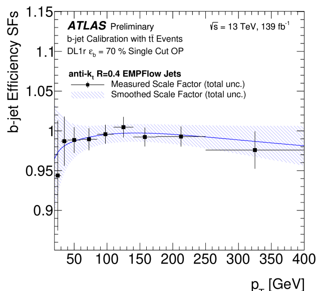
tau



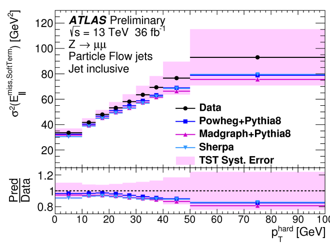
jet



b-jet



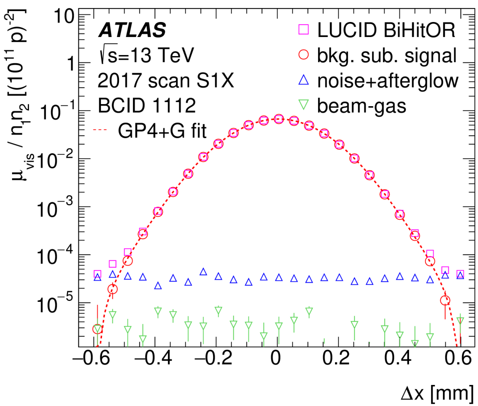
E_{miss}^T

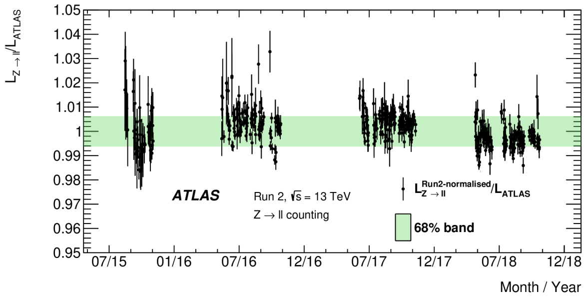


- % level uncertainties for light leptons, higher for other objects but still great performance

Luminosity measurement

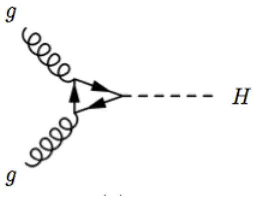
- Important since it can be leading uncertainty for example for cross-section measurements
- Lumi scale through Van der Meer scans, extrapolated using multiple detector information
- Run2 luminosity known with a precision of 0.83 %
  - most accurate lumi measurement at hadron collider so far



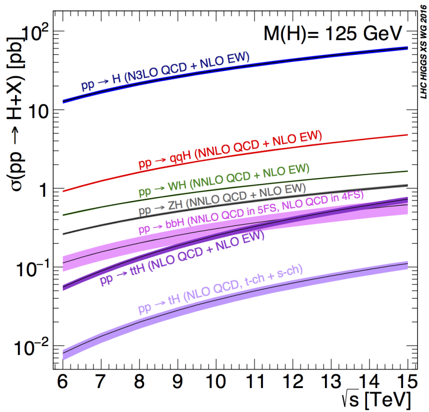


Higgs and Di-Higgs results

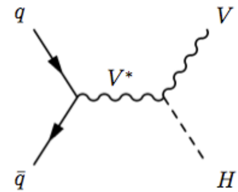
Higgs boson production modes



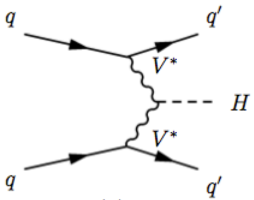
gluon fusion (ggH)



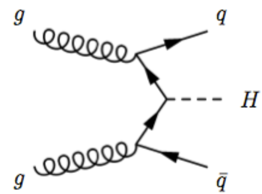
Production cross section



associated production with a gauge boson (VH)



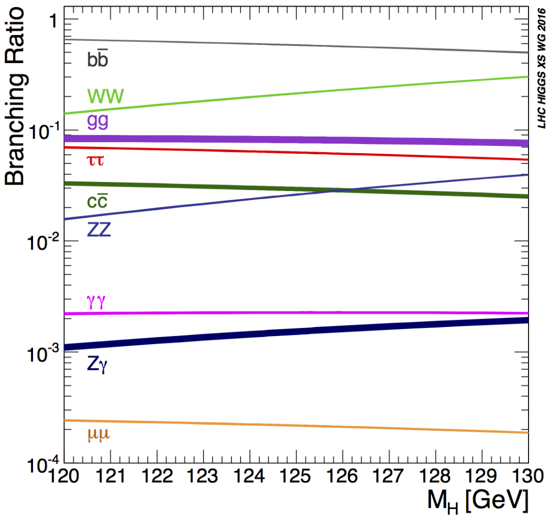
vector boson fusion (VBF)



associated production with a $t\bar{t}$ pair (ttH)

- Largest cross section for gluon fusion and vector boson fusion production modes

Higgs boson decay branching ratios



- Larger branching ratio (BR) for $H \to b\bar{b}$, $H \to WW^*$ and $H \to \tau\tau$, however poor mass resolution and large background contamination

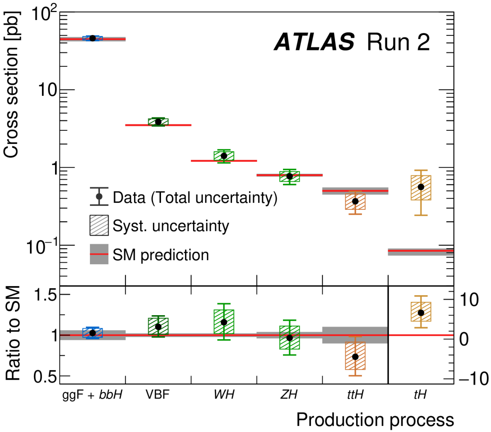
- $H \to \gamma\gamma$ and $H \to ZZ^* \to 4l$ have lower BR, but better mass resolution; can be used for precision measurements

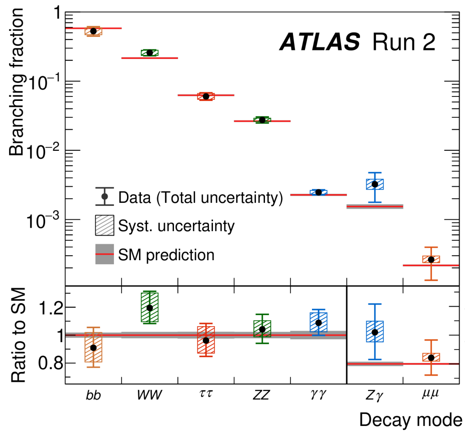
- $H \to Z\gamma$ and $H \to \mu\mu$ becoming now accessible thanks to the large Run 2 dataset and the good detector performance

Higgs Combination arxiv-2207.00092

- 2022 was the 10th anniversary of the Higgs boson discovery
- Combined measurement from the different Higgs boson decays
- Provide stringent test of the SM prediction and constrain to many BSM models
- Inclusive production rate with respect to SM prediction:

$$\mu = 1.05 \pm 0.06 = 1.05 \pm 0.03\ (\text{stat.}) \pm 0.03\ (\text{exp.}) \pm 0.04\ (\text{sig. th.}) \pm 0.02\ (\text{bkg. th.})$$

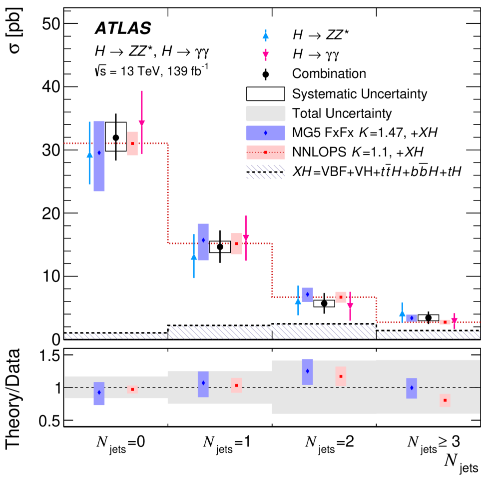


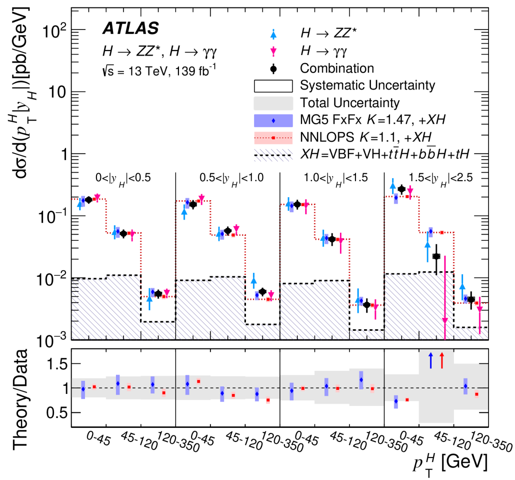


Differential cross-section results

arxiv-2207.08615

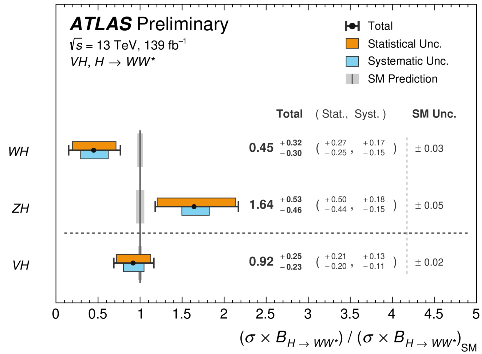
- Provide more in depth comparison of the SM prediction in various phase-space corner
- Combine results from H$\rightarrow ZZ^*$ and H$\rightarrow \gamma\gamma$ channels
- Measured total cross section $\sigma_{tot} = 55.5^{+4.0}_{-3.8}$ pb, in agreement with $\sigma_{SM} = 55.6 \pm 2.8$ pb
- All results compatible between the two channels and compatible with SM prediction
- Cross-section measured with respect to several variables, both in 1 and 2 dimensions

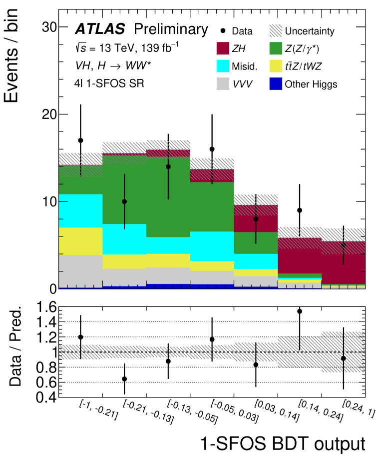


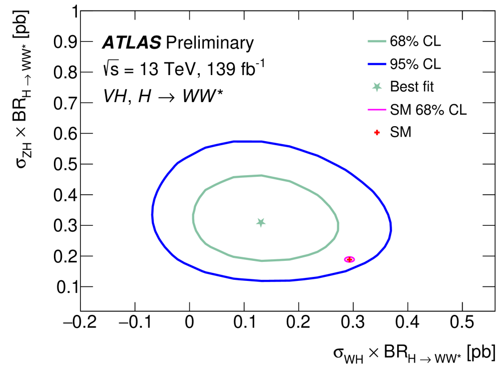


VH H→ WW^* coupling CONF-2022-067

- Considering H→ $WW^* \to l\nu l\nu$ and H→ $WW^* \to l\nu jj$ final states
- Challenging final state to observe; use multivariate analysis (MVA) to separate signal from background
- Obs. (Exp.) significance: $\sigma_{WH} = 1.5\ (3.3),\ \sigma_{ZH} = 4.6\ (3.1)$
- Measurement statistically dominated



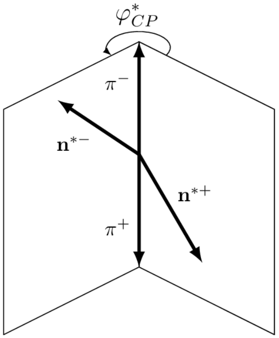


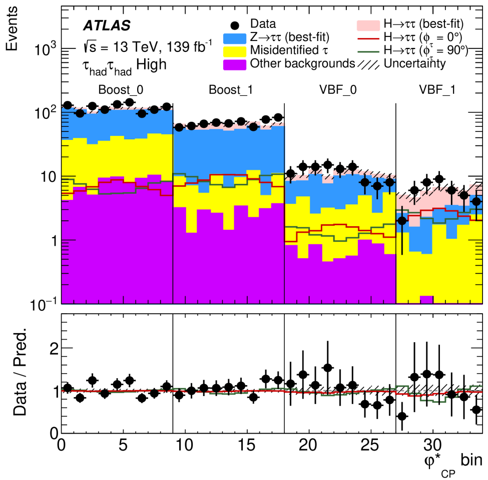


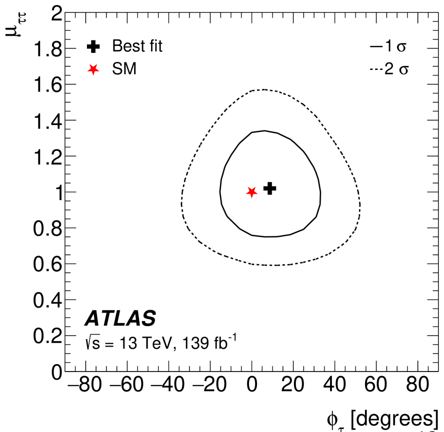
H→ $\tau\tau$ CP measurement

arxiv-2212.05833

- SM predicts Higgs to be pure CP even state
- Measure CP properties of the Higgs in H→ $\tau\tau$ decay vertex
- Using angle between τ decay planes as CP-sensitive variable
- Pure CP-odd hypothesis excluded at 3.4 σ





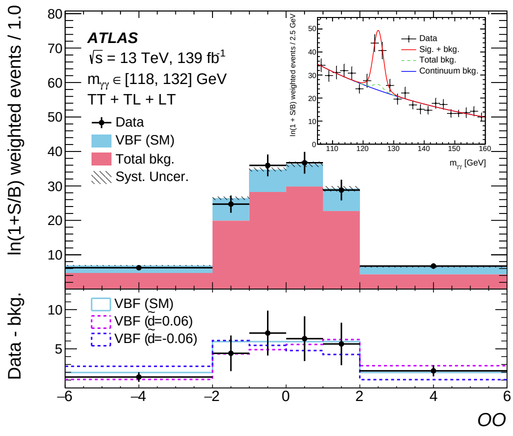


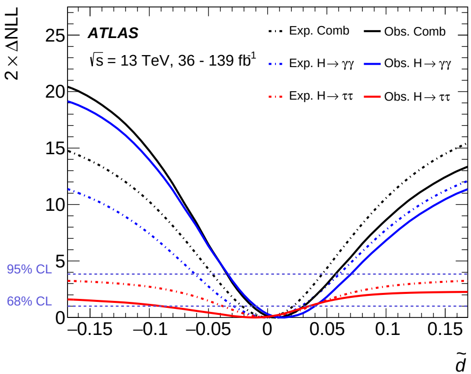
VBF H$\rightarrow \gamma\gamma$ CP measurement arxiv-2208.02338

- Measure CP properties of the Higgs in the HVV vertex
- Complementary with respect CP in decay
- Use *Optimal Observable* to measure CP-violating parameter $\tilde{d}$

$$OO = \frac{2\ Re(M^*_{SM} M_{CP-Odd})}{|M_{SM}|^2}$$

- No sign of CP violation, since <OO> compatible with 0



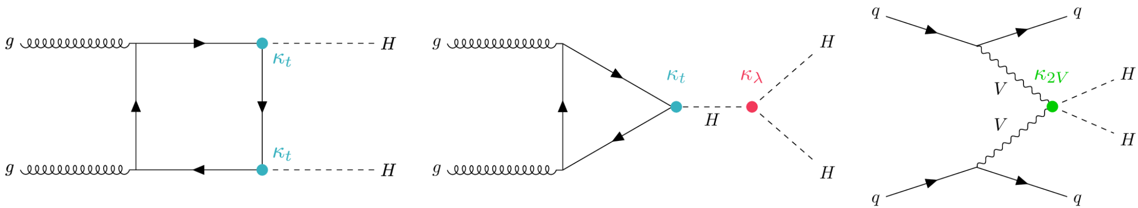


- $\tilde{d}\epsilon$ interval at 95% CL when combining with H$\rightarrow \tau\tau$

	68% CL	95% CL
Expected	[-0.022,0.021]	[-0.046,0.045]
Observed	[-0.012,0.030]	[-0.034,0.057]

Di-Higgs production

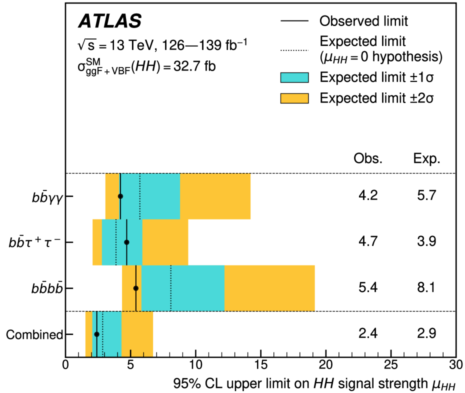
- Important for studying the EWK symmetry breaking and origin of the Universe
- Higgs potential influenced by Higgs boson trilinear self coupling term λ_{HHH}
- Direct way to measure the coupling modifier is through Higgs boson pair production
- Much smaller cross-section compared to single Higgs production ($\simeq 1/1000$)
- Production mainly through ggH and VBF
  - ggH provides most of the sensitivity to Higgs self-coupling modifier (k_λ)
  - VBF provides a unique way to probe VVHH vertex (k_{2V})

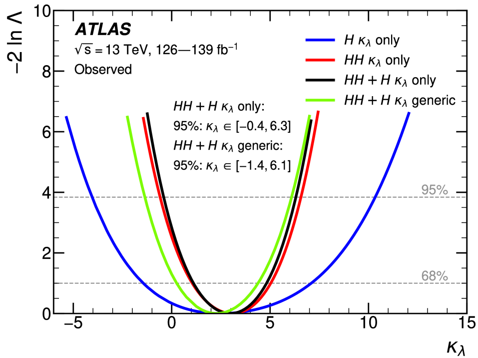


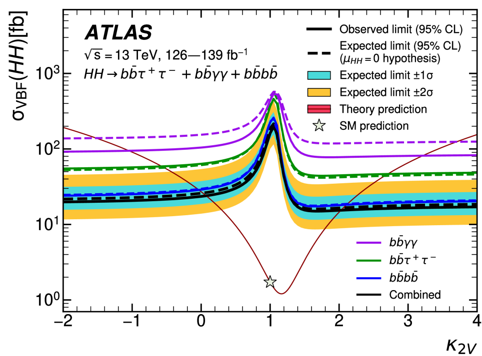
Higgs Decay	bb	WW	ττ	ZZ	γγ
bb	34%				
WW	25%	4.6%			
ττ	7.3%	2.7%	0.39%		
ZZ	3.1%	1.1%	0.33%	0.07%	
γγ	0.26%	0.10%	0.03%	0.01%	<0.001%

Di-Higgs Combination arxiv-2211.01216

- Combination of HH→bbbb, HH→bb$\gamma\gamma$ and HH→bb$\tau\tau$ final states
- 95% confidence limit (CL) on the di-Higgs cross section normalised to SM prediction: $\mu_{HH} < 2.4\,(2.9)$ obs. (exp)
- Combination with single-Higgs measurements, with no constraint on other k, lead to k_λ constraint at 95% CL: $-1.4\,(-2.2) < k_\lambda < 6.1\,(7.7)$ obs. (exp)
- Constraint on k_{2V} at 95% CL: $0.1\,(0.0) < k_{2V} < 2.0\,(2.1)$ obs. (exp)



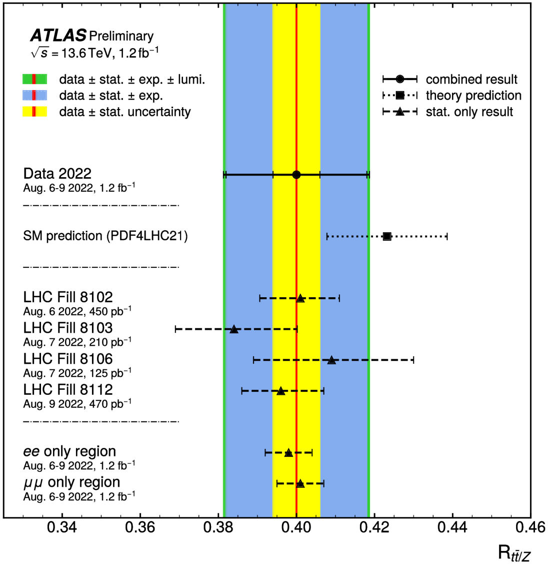




LHC as Top factory

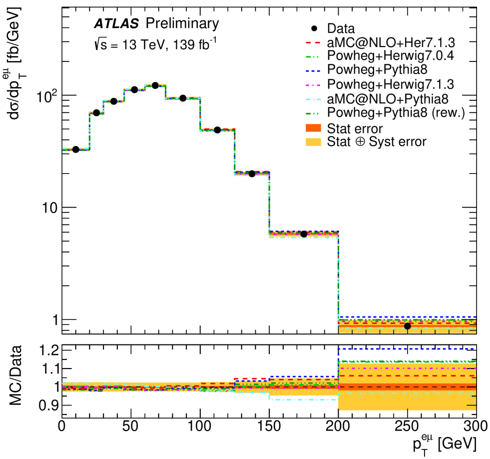
$t\bar{t}$ cross-section at $\sqrt{s}$=13.6 TeV CONF-2022-070

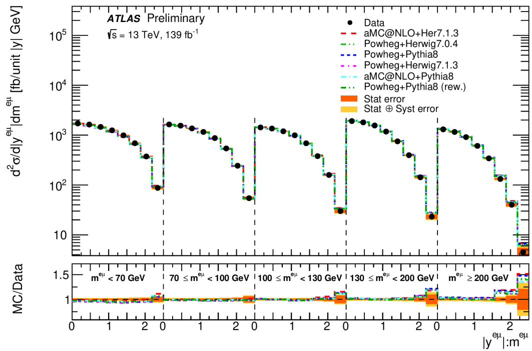
- First Run3 ATLAS measurement, performed using 1.2 fb^{-1} dataset collected in August 2022
- Use di-leptonic $t\bar{t} \rightarrow bbWW \rightarrow bbe\nu\mu\nu$ final state, no stat limitation
- Total measured cross section: $\sigma_{tot} = 830 \pm 12(\text{stat}) \pm 27(\text{syst}) \pm 86(\text{lumi})$ pb, in agreement with SM prediction
- Additionally, measure the ratio of $t\bar{t}$ Vs Z cross section in Z fiducial phase space ($m_{ll} > 40$ GeV) using Z$\rightarrow ee/\mu\mu$ final states: $R_{t\bar{t}/Z} = 0.400 \pm 0.006(\text{stat}) \pm 0.017(\text{syst}) \pm 0.005(\text{lumi})$, consistent with SM prediction using PDF4LHC21 PDF set



$t\bar{t}$ differential cross-section in dilepton final state at $\sqrt{s} = 13$ TeV CONF-2022-061

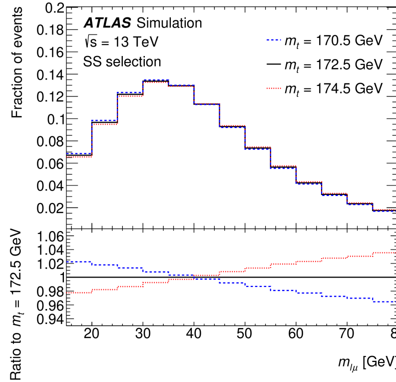
- Use di-leptonic $t\bar{t} \to bbWW \to bbe\nu\mu\nu$ final state
- Total cross section $\sigma_{tot} = 836 \pm 1$ (stat) $\pm\, 12$ (syst) $\pm\, 16$ (lumi) $\pm\, 2$ (beam) pb, in agreement with SM prediction
- Single and double differential cross-section measured with respect to several variables; results in agreement with SM prediction, useful to tune generators

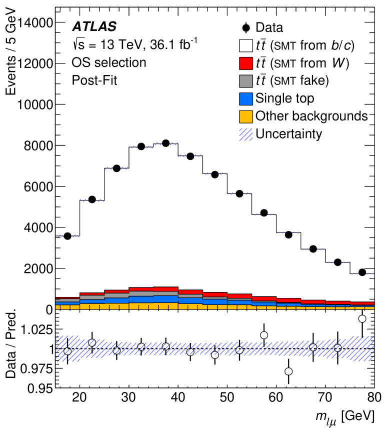


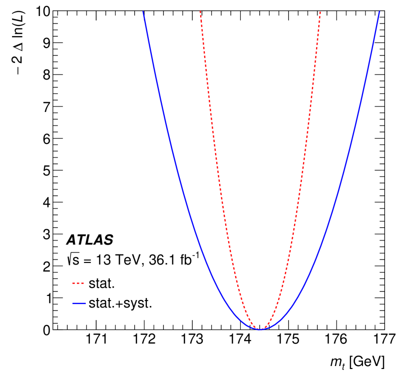


Top mass measurement arxiv-2209.00583

- New approach using semi-leptonic $t\bar{t}$ final state, $t\bar{t} \rightarrow bbWW \rightarrow bbl\nu jj$
- Use mass of two leptons, one from W$\rightarrow$ $l\nu$ and one muon from B-hadron decay
- Measured value: $m_t = 174.41 \pm 0.39$ (stat) $\pm$ 0.66 (syst) $\pm$ 0.25 (recoil) GeV, where *recoil* indicate parton shower variation



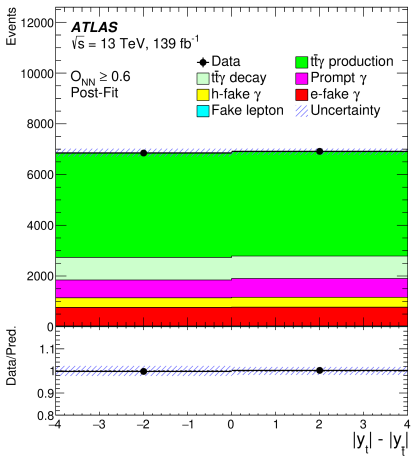


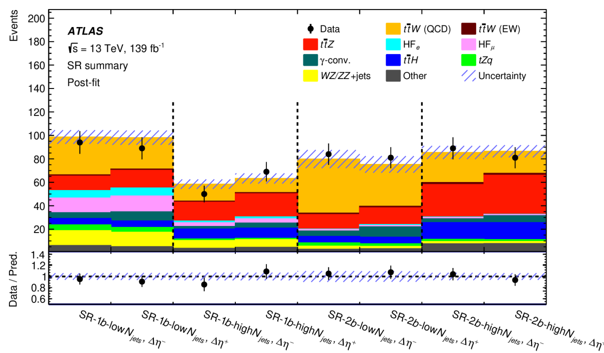


Charge asymmetry in $t\bar{t}\gamma$ arxiv-2212.10552 and $t\bar{t}W$ arxiv-2301.04245

- Important test of the SM prediction at Next-to-leading-order in QCD
- Use $t\bar{t} \to bbWW \to bbl\nu jj$ ($t\bar{t}\gamma$) or tri-lepton final state ($t\bar{t}W$)
- $t\bar{t}\gamma$: MVA to separate signal, $t\bar{t}+\gamma$ in production, from background, $t\bar{t}+\gamma$ in decay
- $t\bar{t}W$: MVA to distinguish lepton from top and from W
- Charge asymmetry measured from distribution of absolute rapidities of top and anti-top:

A_C	$t\bar{t}\gamma$	$t\bar{t}W$
measured	-0.003 $\pm$ 0.024 (stat) $\pm$ 0.017 (syst)	-0.123 $\pm$ 0.136 (stat.) $\pm$ 0.051 (syst.)
SM prediction	0.0064	-0.084 $^{0.005}_{-0.003}$ (scale) $\pm$ 0.006 (MC stat.)

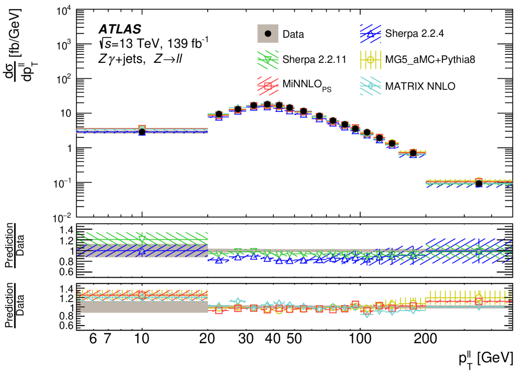


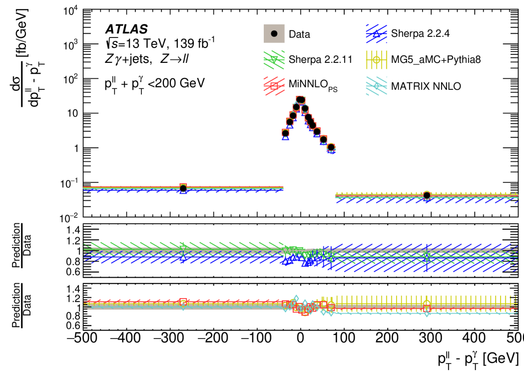


Other SM results

$Z\gamma$+jets cross-section arxiv-2212.07184

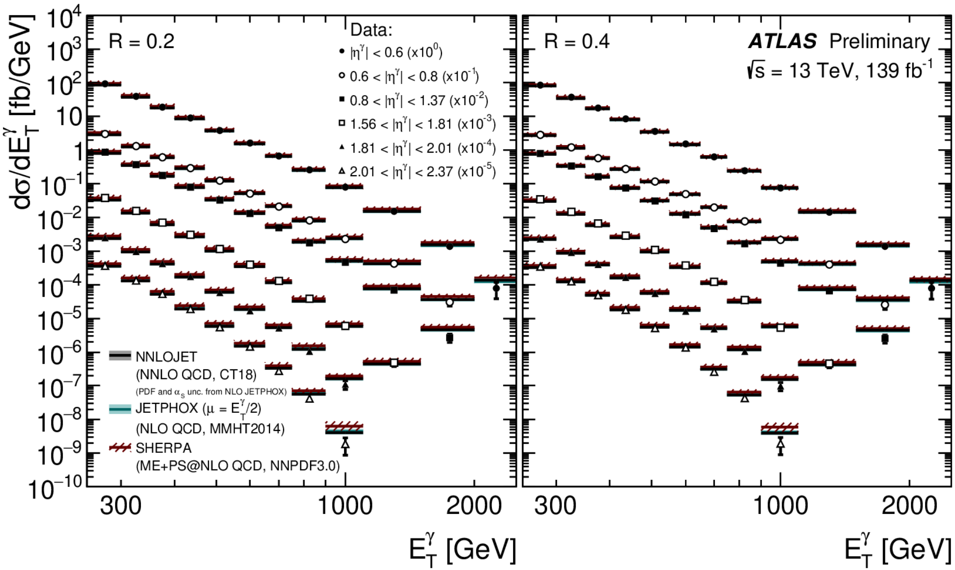
- Consider final state with Z$\to$ $ee/\mu\mu$ plus γ usually from initial state-radiation
- Results using different MC generators; helps to improve MC parton shower description/tuning, PDF functions
- Single an double differential cross-section measured for variables sensitive to hard-scattering production and soft/collinear radiation
- Important also to test and improve theory resummation models





Isolated γ cross-section CONF-2022-065

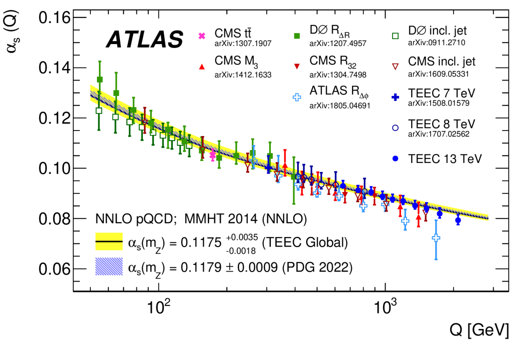
- Provide in-depth test of theoretical predictions for parton distribution functions
- γ are required to be isolated using fixed-cone method with two different cone radii
- Cross sections measured as functions of the γ transverse energy in different γ pseudorapidity regions
- Results in good agreement with the prediction in all the different phase spaces

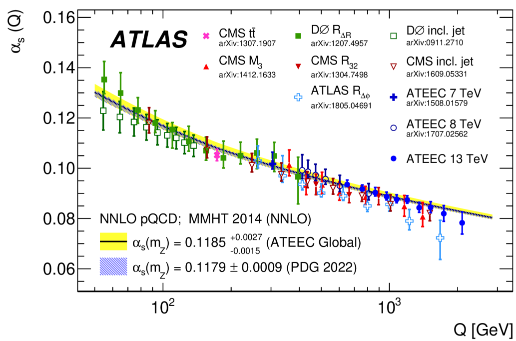


α_S measurement in multijet events

arxiv-2301.09351

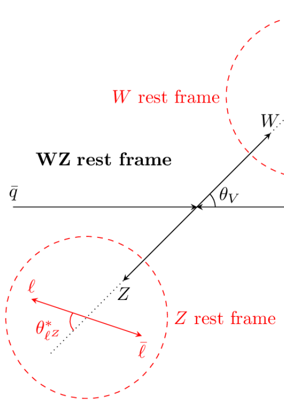
- Test perturbative QCD and possibly new physics
- Large theoretical improvement from NNLO correction to 3 jet production in pp collisions
  - results in reduction of theoretical uncertainty by factor 3
- Use transverse energy–energy correlations (*TEEC*) and their associated azimuthal asymmetries (*ATEEC*) to perform the measurement
- Results show good agreement with the renormalisation group equation up to highest energy scales and with previous measurement

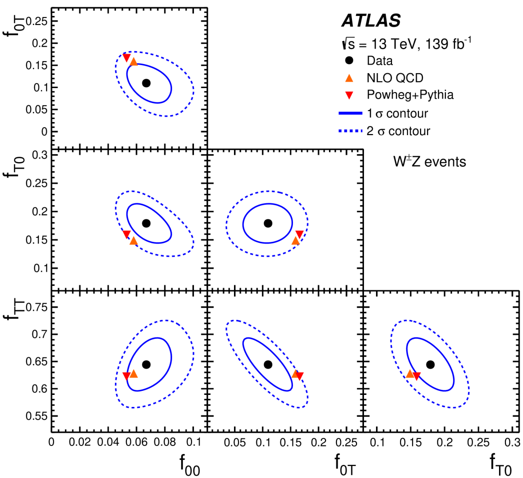




WZ polarisation arxiv-2211.09435

- Test of the SM gauge symmetry structure and triple gauge coupling
- Measure joint/individual helicity fractions, as well as inclusive/differential cross-sections
- Use WZ rest frame to extract fraction of events where both bosons are longitudinally/transversally polarised or mixed states
- Reach observation (7.1 σ) of events where both bosons are longitudinally polarised
  - $\simeq$ 7% of total considered events



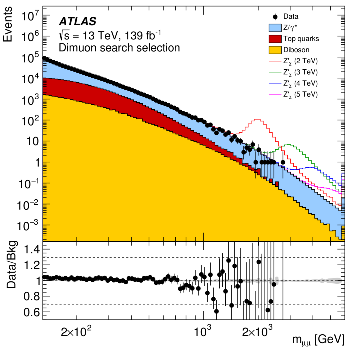


BSM searches

Search for BSM signatures

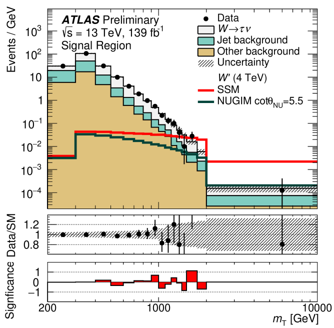
- At LHC, several data analyses are trying to search for BSM signatures
- Possible to test several signal hypotheses and tune models
- Requires also to develop new object reconstruction and machine learning algorithms

Bump Hunting



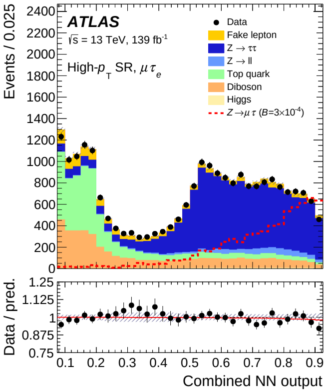
Phys. Lett. B 796 (2019) 68

Excess at high p_T regime



ATLAS-CONF-2021-025

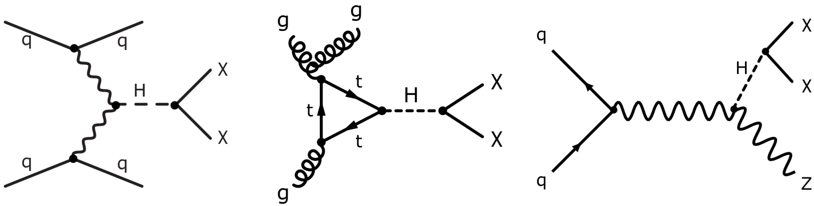
MVA

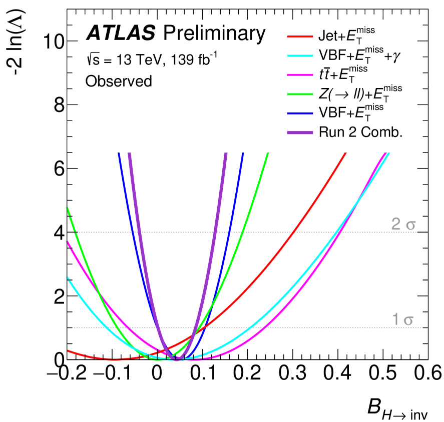


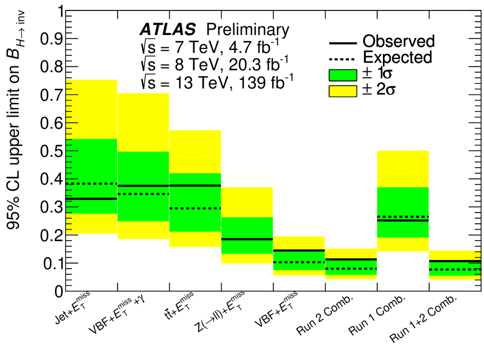
Phys. Rev. Lett. 127 (2021) 271801

H→ invisible combination HIGG-2021-05

- Search for Higgs decaying into dark matter particles, especially in VBF Higgs production
- Main background from strong and electroweak Z+jets production
- BR(H→ invisible) > 15 % excluded at 95% CL



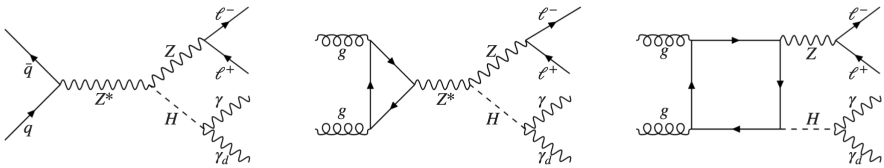


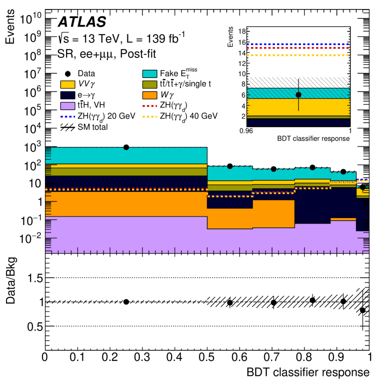


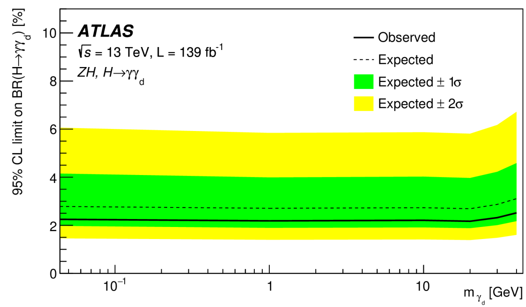
Search for Dark γ (γ_d) from Higgs decay

arxiv-2212.09649

- Dark sector can interact weakly with SM
- γ_d produced from H$\rightarrow \gamma\gamma_d$ decay and not detected, resulting in E^{T}_{miss}
- Consider the ZH production; use MVA to enhance the sensitivity
- Obs. (Exp.) upper limits at 95% CL on BR(H$\rightarrow \gamma\gamma_d$) of 2.28 % (2.82 $^{+1.33}_{-0.84}$%) for massless γ_d, 2.19% (2.71%) $< BR(H \rightarrow \gamma\gamma_d) <$ 2.52% (3.11%) for $M_{\gamma_d} <$ 40 GeV

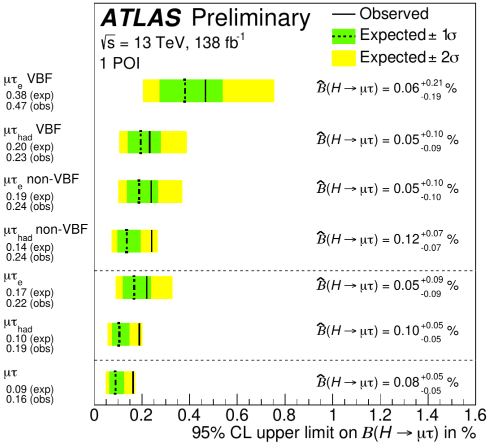


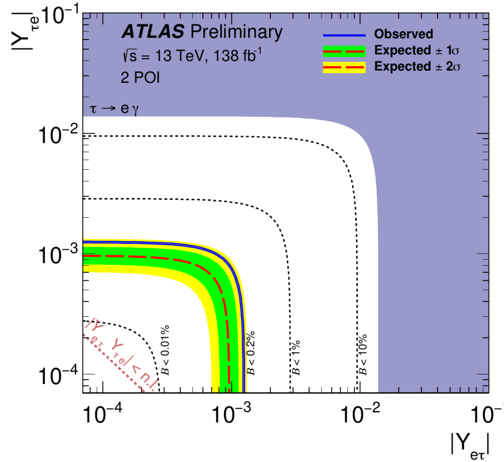




LFV search in H→ lτ ATLAS-CONF-2022-060

- Search in both leptonic and hadronic τ decay final state
- Use MVA discriminant to enhance signal over background and extract results





Obs. (Exp) $\mathcal{B}(H \to e\tau) < 0.19(0.11)\%$

Obs. (Exp) $\mathcal{B}(H \to e\tau) < 0.18(0.09)\%$

Obs. $\sqrt{|Y_{\tau e}^2 + |Y_{e\tau}|^2} < 0.0012$

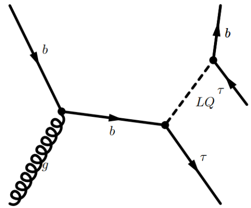
Obs. $\sqrt{|Y_{\tau\mu}^2 + |Y_{\mu\tau}|^2} < 0.0012$

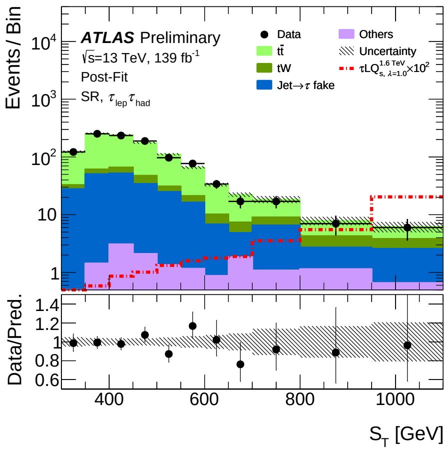
- Results can be interpreted as limits for non-diagonal Yukawa coupling matrix elements

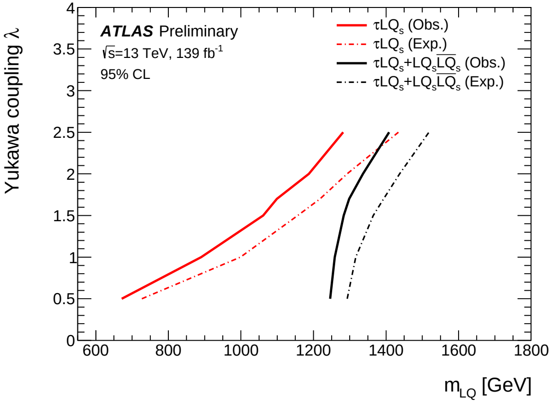
Leptoquark (LQ) search in $b\tau$ final state

ATLAS-CONF-2022-037

- LQs can explain anomalies in B-physics, decay to lepton-quark pairs
- Main focus on singly produced scalar LQ:
  - considering $\tilde{S}_1$ model with LQ having $4/3e$ and $3B + L = -2$
  - LQ production mostly through quark-gluon fusion and scattering
- Include also pair production of scalar LQs since similar final state
- Assuming LQ exclusive decay in $b\tau$



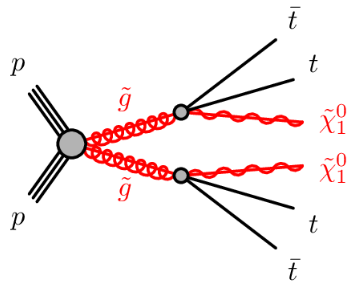


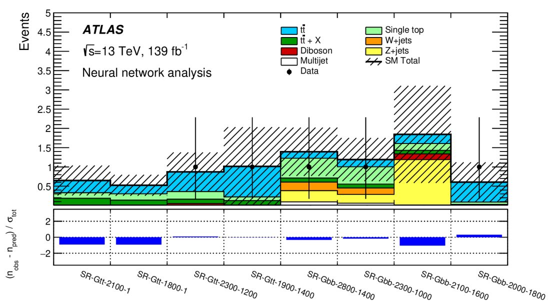


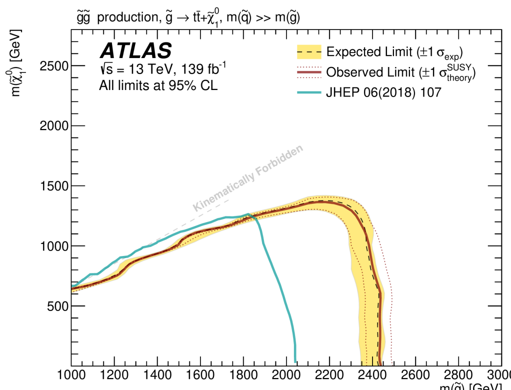
- First ATLAS result for the search of singly-produced LQ in $b\tau$ final state
- For singly+pair LQ production, masses below 1.25 TeV excluded for λ values > 0.5

SUSY search in final states with E_{miss}^{T} plus $\geq$ 3 b+jets arxiv-2211.08028

- Supersymmetry predicts a partner for each SM particle with spin differing by half unit
- Searching for pair production of gluinos, each decaying into a pair of heavy-flavor quarks and a neutralino ($\tilde{\chi}_1^0$)
- Use MVA to enhance sensitivity over SM background, but no significant excess found
- For simplified models with gluinos decaying via off-shell top (bottom) squarks, gluino masses less than 2.44 TeV (2.35 TeV) are excluded at 95% CL for massless $\tilde{\chi}_1^0$







Conclusion

Conclusion

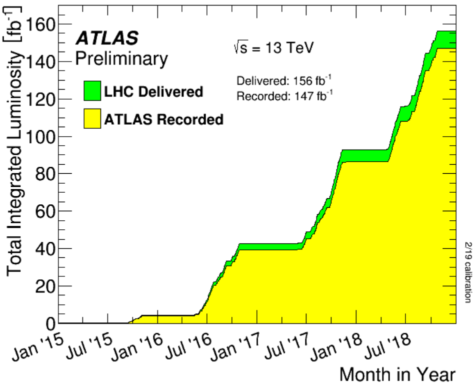
- Lots of exciting results from ATLAS experiment have been published recently
- Several physics topics covered: (Beyond) Standard Model measurements, including several results from Higgs and Top physics
- Great precision achieved thanks to the large available dataset and the good detector performance
- Run 3 just started, but already capable to make Standard Model measurements at increased center of mass energy
- More and more results still to come ....

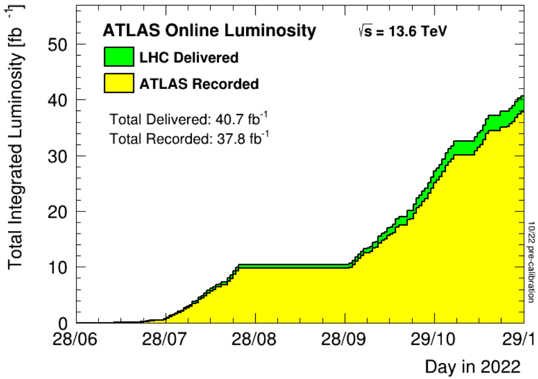
Thanks For Your Attention

Backup

Available datasets for measurements

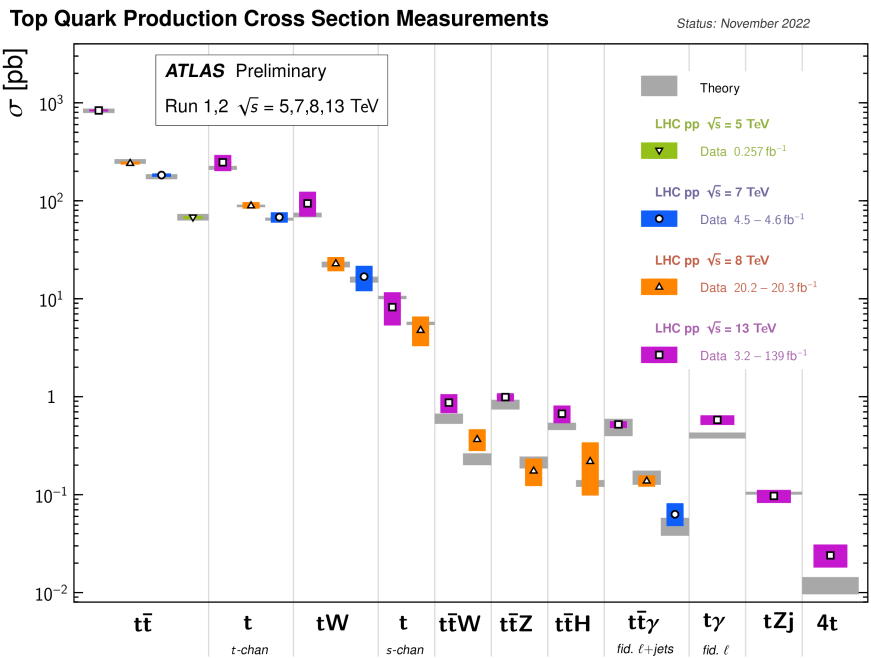
- Most of the current measurements use:
  - Run2 dataset, $\simeq 139\ \text{fb}^{-1}$ recorded in 2015-2018 at $\sqrt{s} = 13$ TeV R2lumi
  - Run3 dataset, started in 2022 (press) ; $\simeq 38\ \text{fb}^{-1}$ recorded at $\sqrt{s} = 13.6$ TeV R3lumi
- Large dataset allow to challenge LEP measurements precision





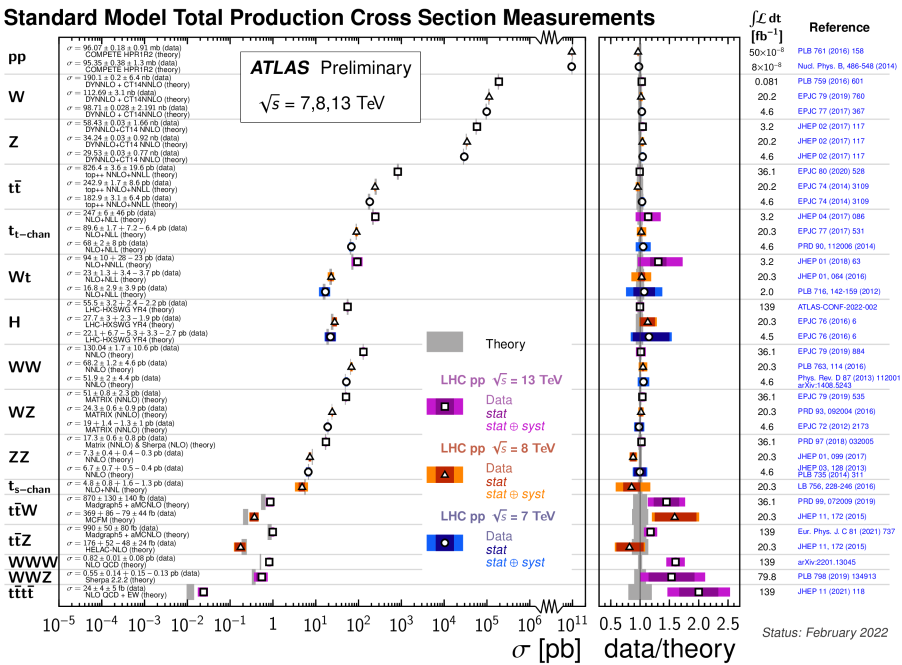
Top cross-section summary webpage

- Lots of measurements spanning over cross-section range of several order of magnitude



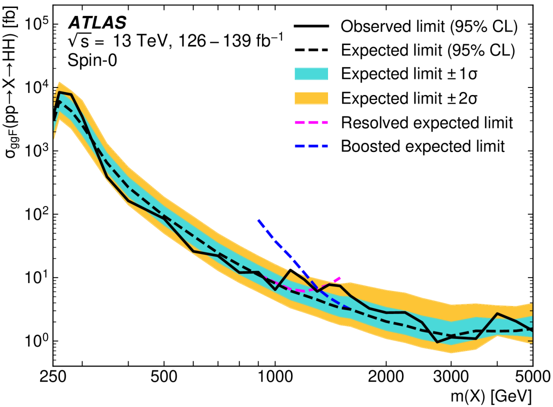
SM cross-section summary webpage

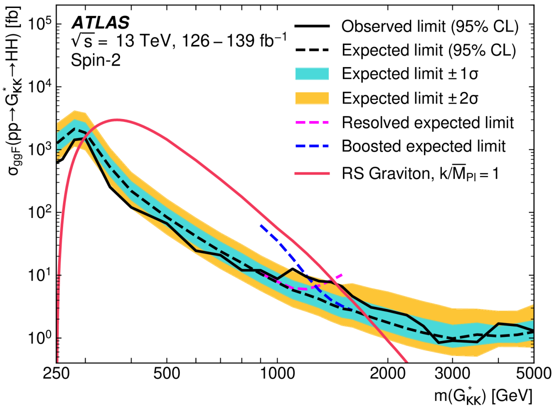
- Lots of measurements spanning over cross-section range of several order of magnitude
- No strong tensions between measurements and theory; large success of SM predictions



Search for $X \to HH \to 4b$ Phys.Rev.D105(2022)092002

- Considering spin-0 and spin-2 benchmark signal models
  - corresponds to resonant HH production via gluon-fusion
- Analysis performed in *Resolved* and *Boosted* regime:
  - *Resolved* for $M_X \epsilon [250, 1500]$ GeV, using anti-Kt 0.4 jets
  - *Boosted* for $M_X \epsilon [0.9, 5]$ TeV, using largeR jets





- Bulk Randall-Sundrum model excluded for graviton masses 298 GeV $<$ M $<$ 1460 GeV

Leptoquark (LQ) measurements

- LQs can explain deviations from lepton flavour universality from the SM in B-physics
  - Predicted in many BSM scenarios and decay to lepton-quark pairs
  - Carry color change, electric charge and non-zero baryon (B) and lepton (L) number
- Several searches for 1st,2nd and 3rd and cross-generations final states PUB-2022-012