Highlights and Perspectives from ATLAS

Highlights (Recent and Selected)

HEP 2021 - 38th Conference on Recent Developments in High Energy Physics and cosmology

Thessaloniki - 16-19 June, 2021

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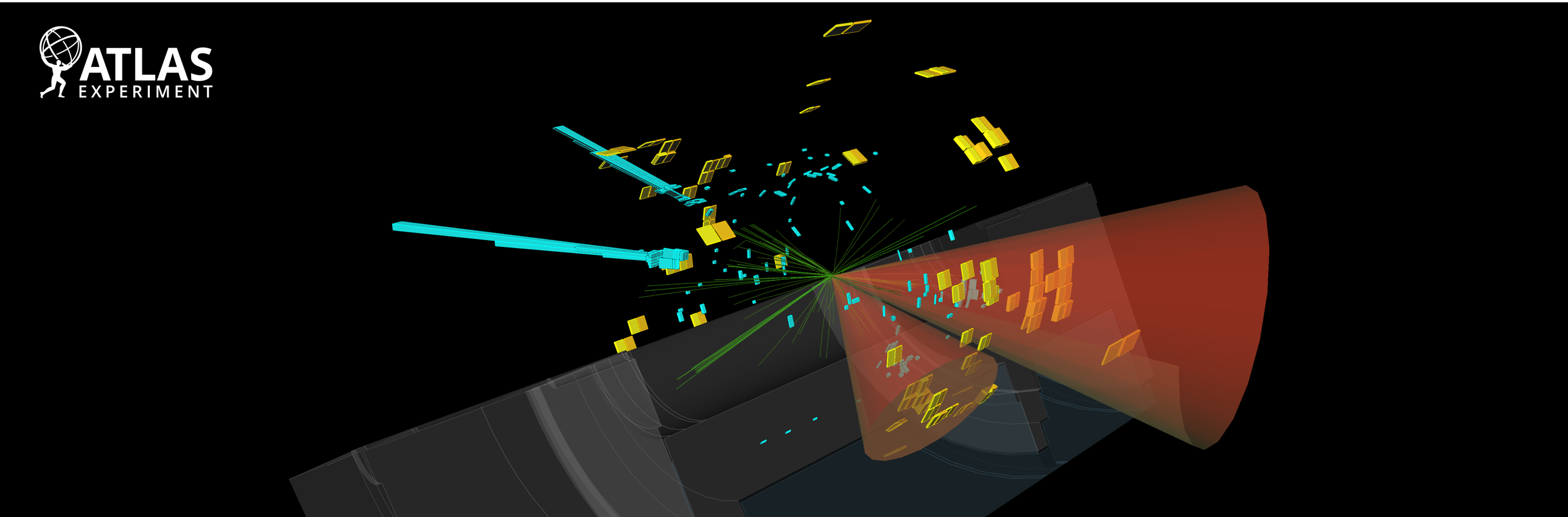


More Info on ATLAS Results

Disclaimer: Only very few highlights are covered in this talk, ATLAS has many more Run 2 results

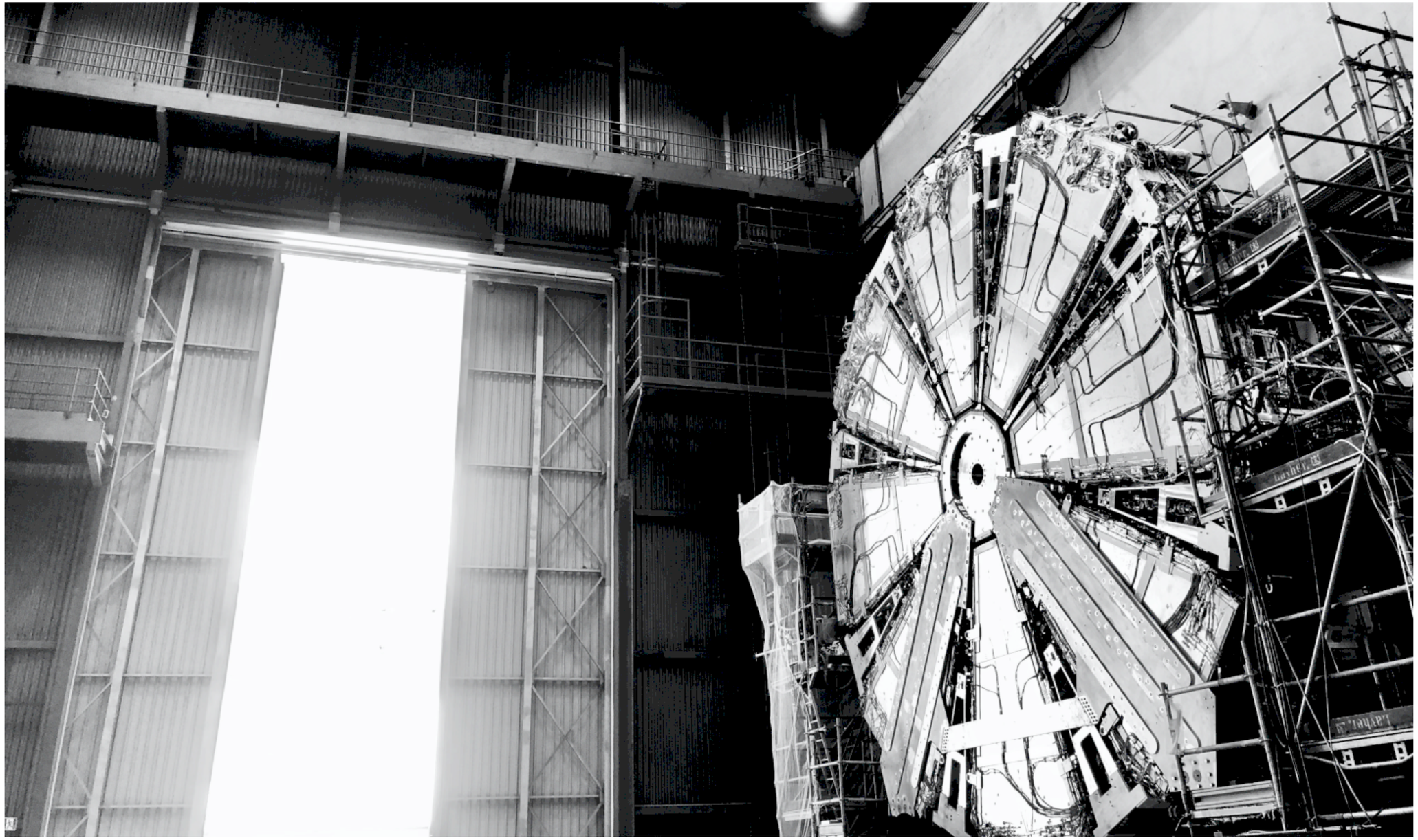
All ATLAS results are available at this link.

- Latest ATLAS results from Run 2 presented at LHCP 2021 last week! See summary here.
- Latest ATLAS results from Run 2 presented at 2021 Moriond Conference! See summary here!
- Latest ATLAS results from Run 2 presented at 2021 ICHEP Conference! See summary here!
- Latest news from LS2 can be found here.
- Review of challenges and opportunities: recent HL/HE-LHC CERN Yellow Report.
- European Strategy 2012-2013 Recommendations.
- European Strategy 2020 Recommendations.

- Check and bookmark our news page
- Subscribe to our ATLAS YouTube channel (and hit the like button)

YouTube

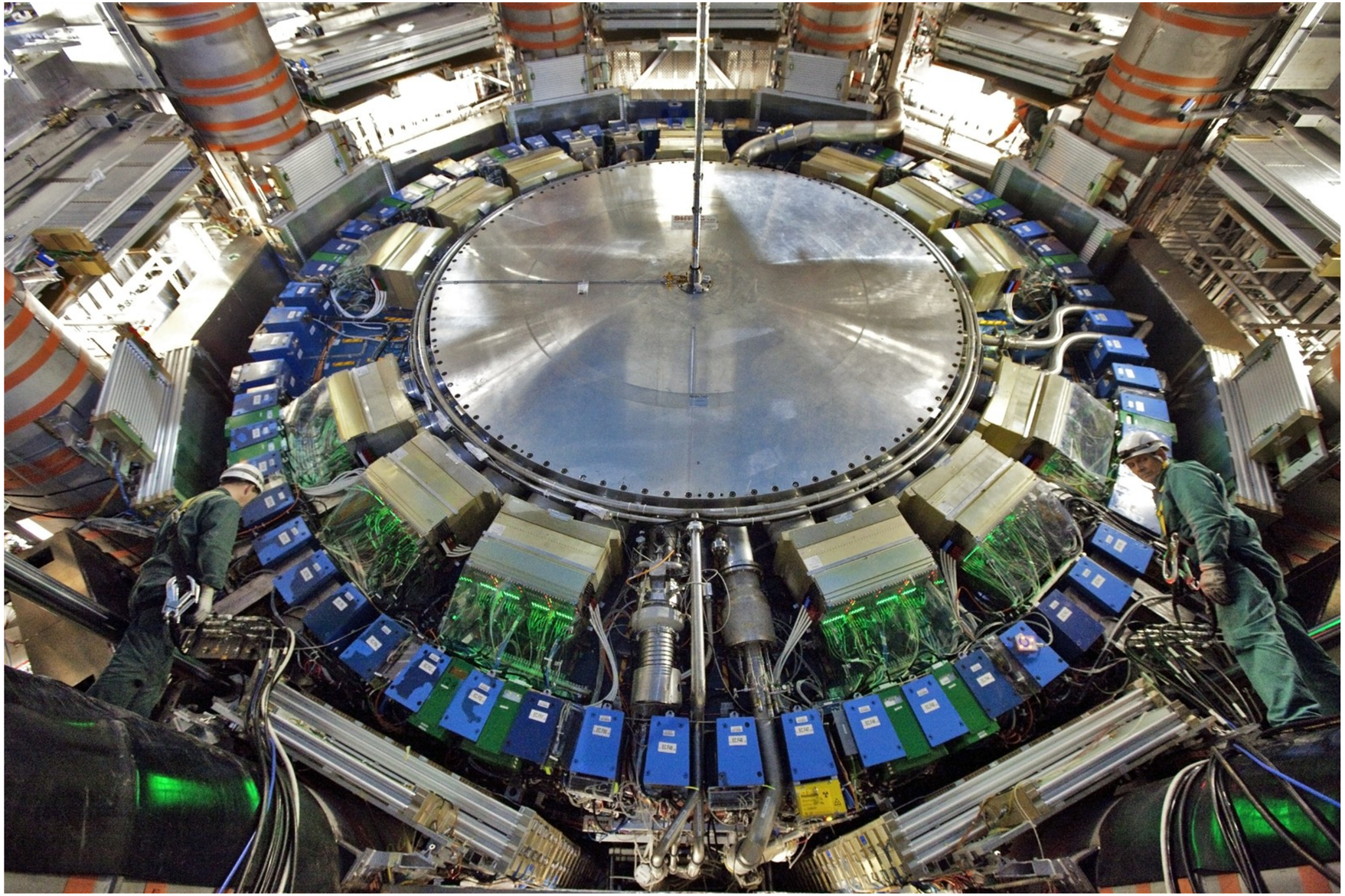
Gearing up towards the LHC Run 3 and Beyond…



Mechanical structure of Muon New Small Wheel A ready

Superb achievement of many groups, in particular from Greece!!

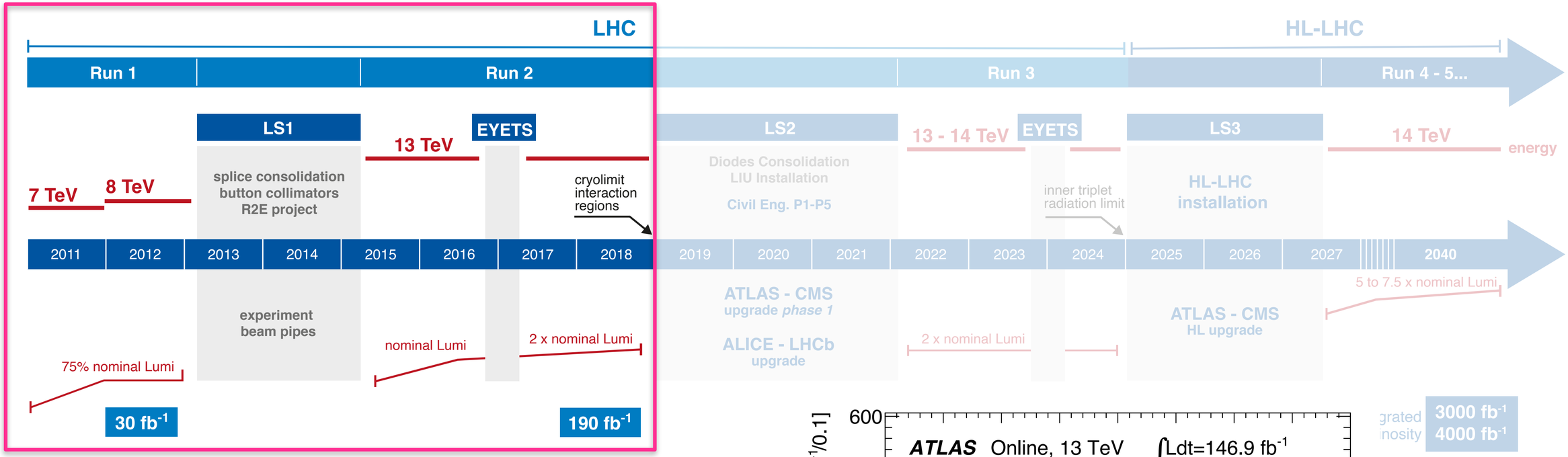
Where do we stand?

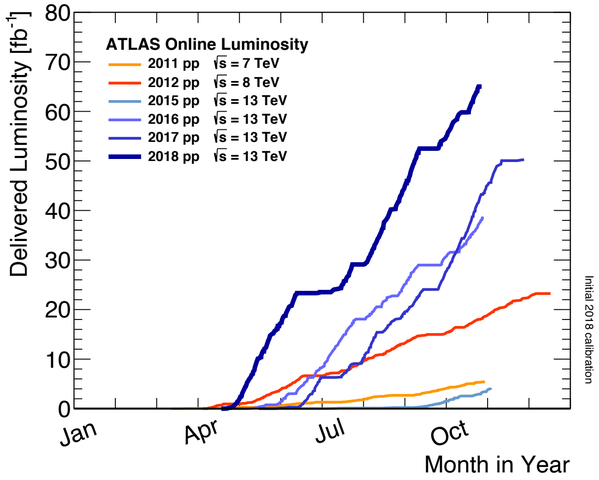


After **10 years of running** with superb operation efficiency typically over the entire running period of **90%…**

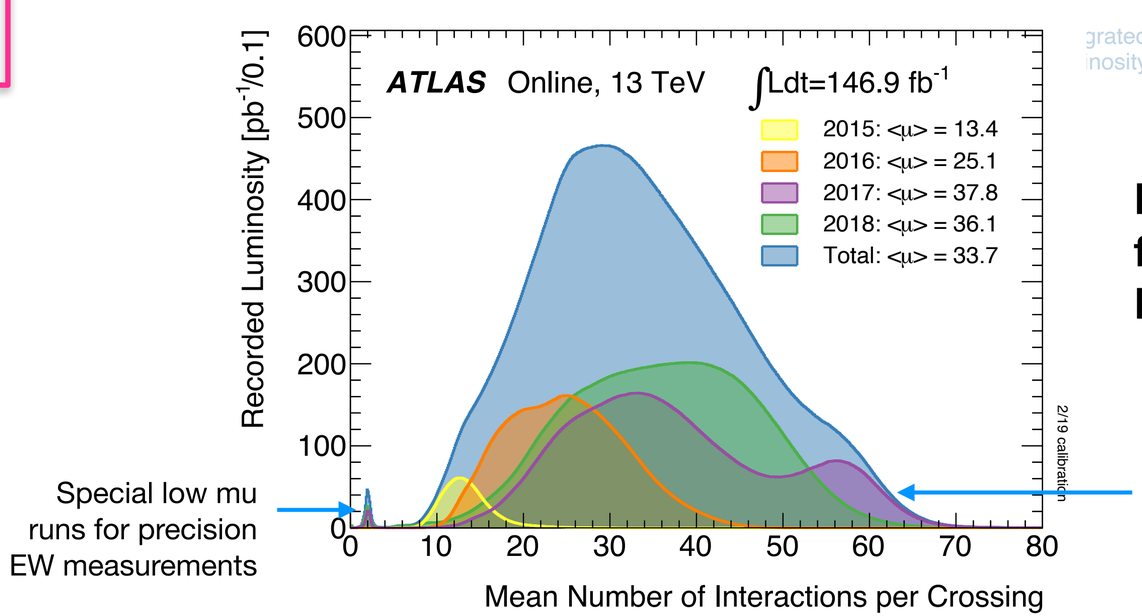
In 2019 opened the detector and started the **Long Shutdown (LS) 2** operations!

The LHC Timeline





Record 2018
More than 60 fb^{-1} collected by experiments

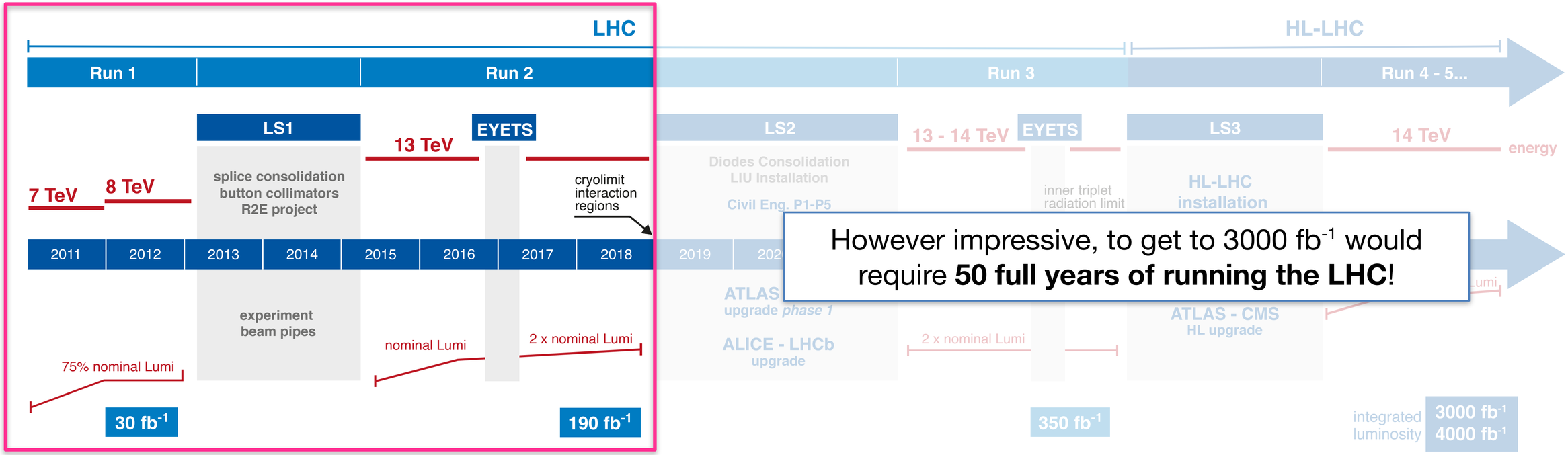


PU profile for the LHC Run 2

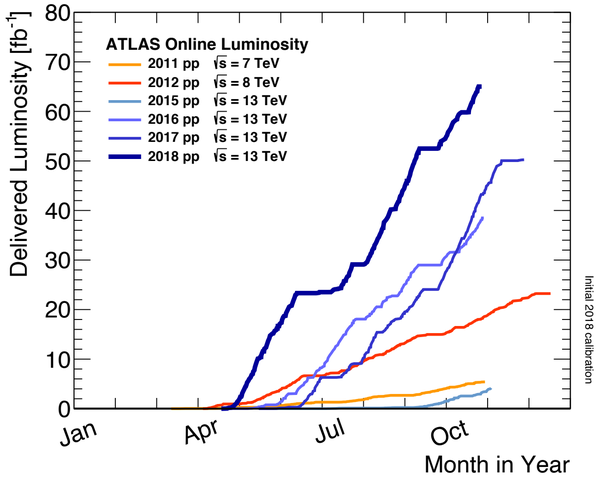
Special low mu runs for precision EW measurements

Larger PU following issue with 16L2 magnets

The LHC Timeline



However impressive, to get to 3000 fb^{-1} would require **50 full years of running the LHC**!

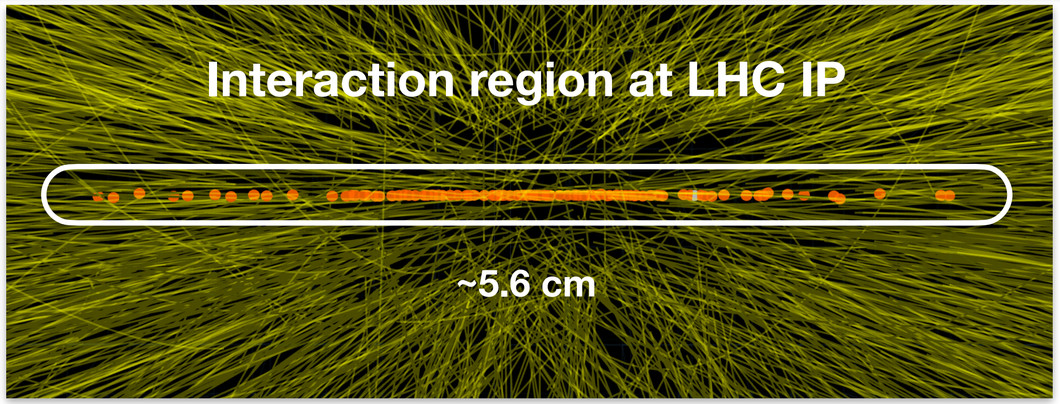


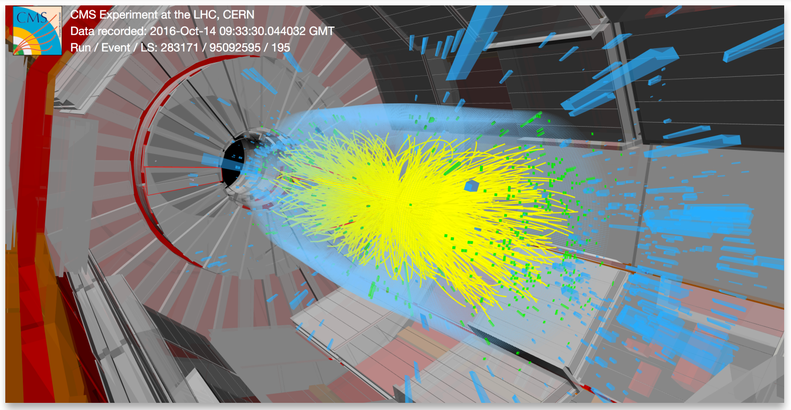
Record 2018
More than 60 fb^{-1} collected by experiments

- **Run 1 :** Centre-of-mass Energies of 7 and 8 TeV and luminosities of ~20 fb^{-1} and Pile-Up of ~30-40 (50 ns between bunch crossing).

- **Run 2 :** Centre-of-mass Energy of 13 TeV and luminosities of ~140 fb^{-1} with Pile Up of ~30-40 (25 ns between bunch crossings).

The LHC Timeline

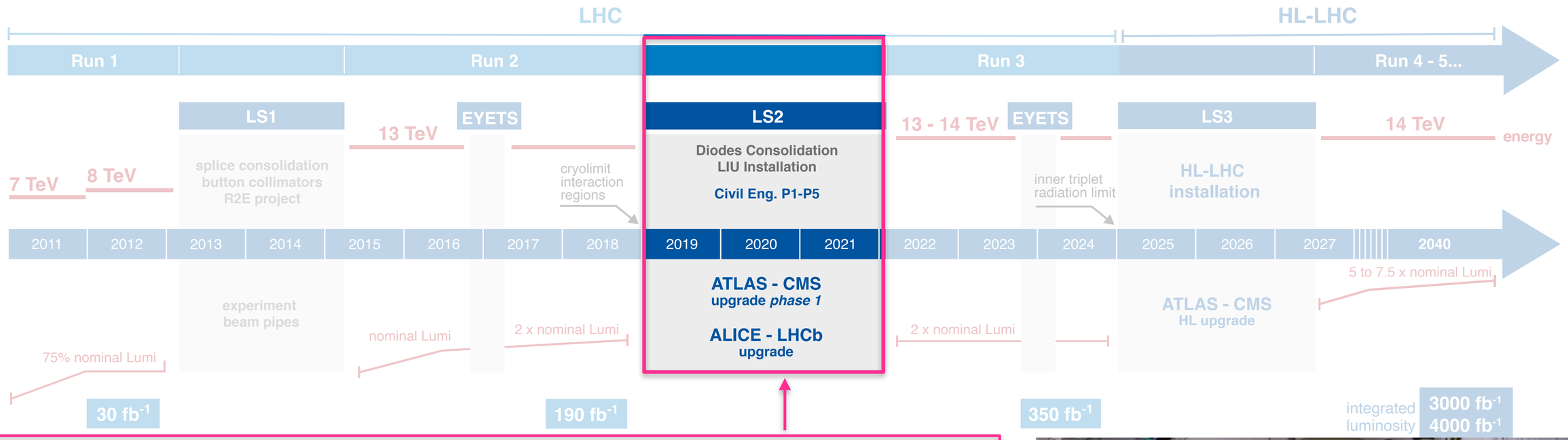




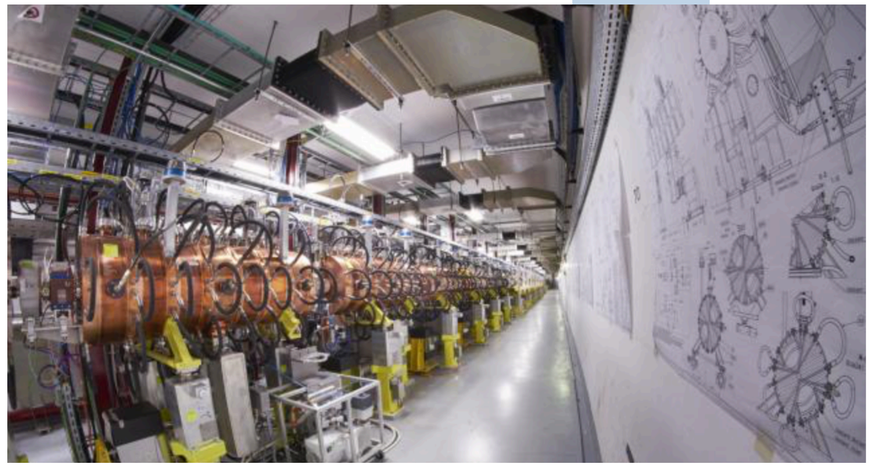
5-7 times the nominal luminosity!

Expected PU at HL-LHC **140-200**

The LHC Timeline

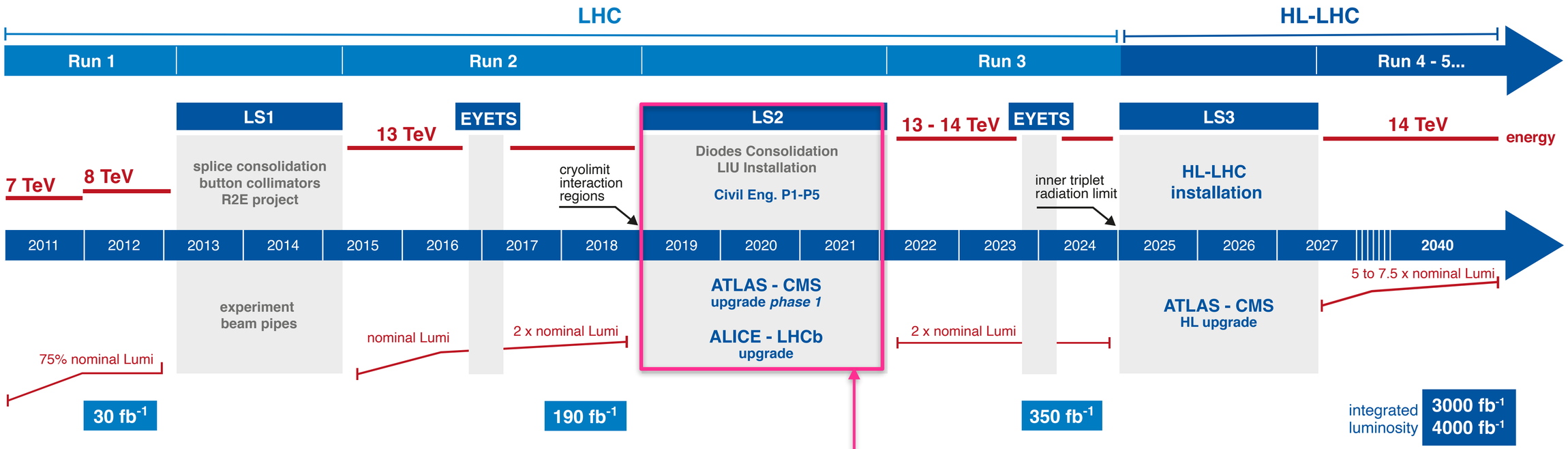


- LINAC 4: Extremely important milestone on the road towards higher luminosities (90 meters machine).
- « Crabbing protons » also one additional major step towards the High Luminosity, successfully tested at SPS.
- Ni3Sn ~100 magnet elements (dipoles and quadrupoles) with fields above 10T.
- TDIS (dump/absorber to protect downstream equipment)
- Collimation upgrades.
- Civil engineering at P1 - P5.



Will be accelerating negative Hydrogen ions. The electrons are stripped from the proton from the LINAC to the PS Booster (improves efficiency, intensity and quality).

The LHC Timeline



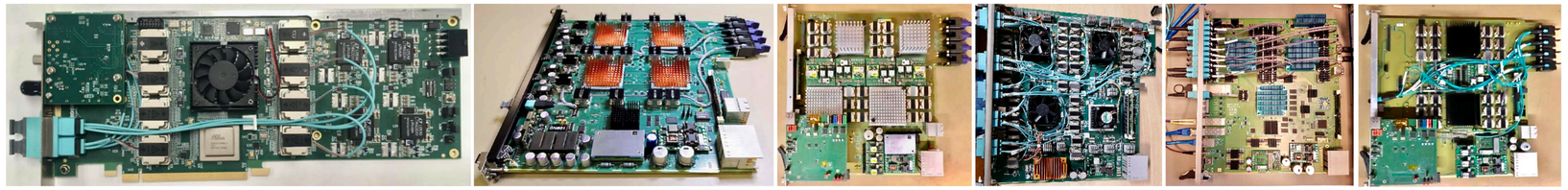
Phase 1 (Deployment ongoing during LS2)

- Muon chambers: **New Small Wheel** (innermost endocarp wheel replacement Micromegas and sTGC) and BIS78
- Trigger and Data Acquisition system (EM calorimeter increased granularity at L1, new trigger boards)
- Major software new release:

From I. Ochoa LHCC June 2021

Entire software release from Multi-Process to Multi-Thread

Large improvement in MEM consumption and speed!



FELIX eFEX jFEX gFEX MUCTPI L1Topo

The LHC Timeline

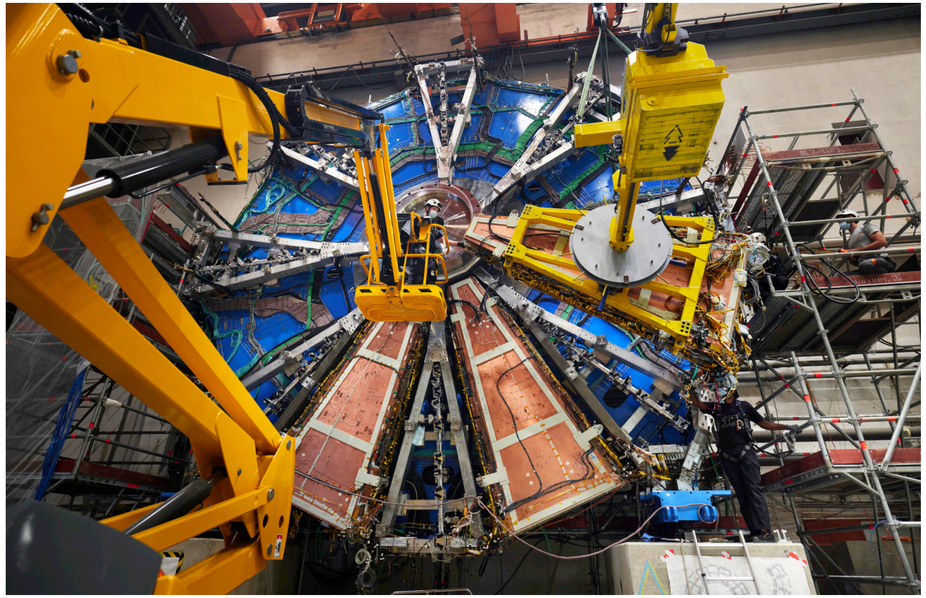
Phase 2 (Major **ATLAS** upgrades with deployment during LS3) **2025-2027**

- Full Silicon tracker
- Calorimeter electronics upgrade
- Timing detector with partial eta coverage (2.4 - 4) LGAD silicon: 30 ps resolution
- Muon coverage

Longer term LS4 **2031**

Possible upgrades under discussion

Where do we stand?



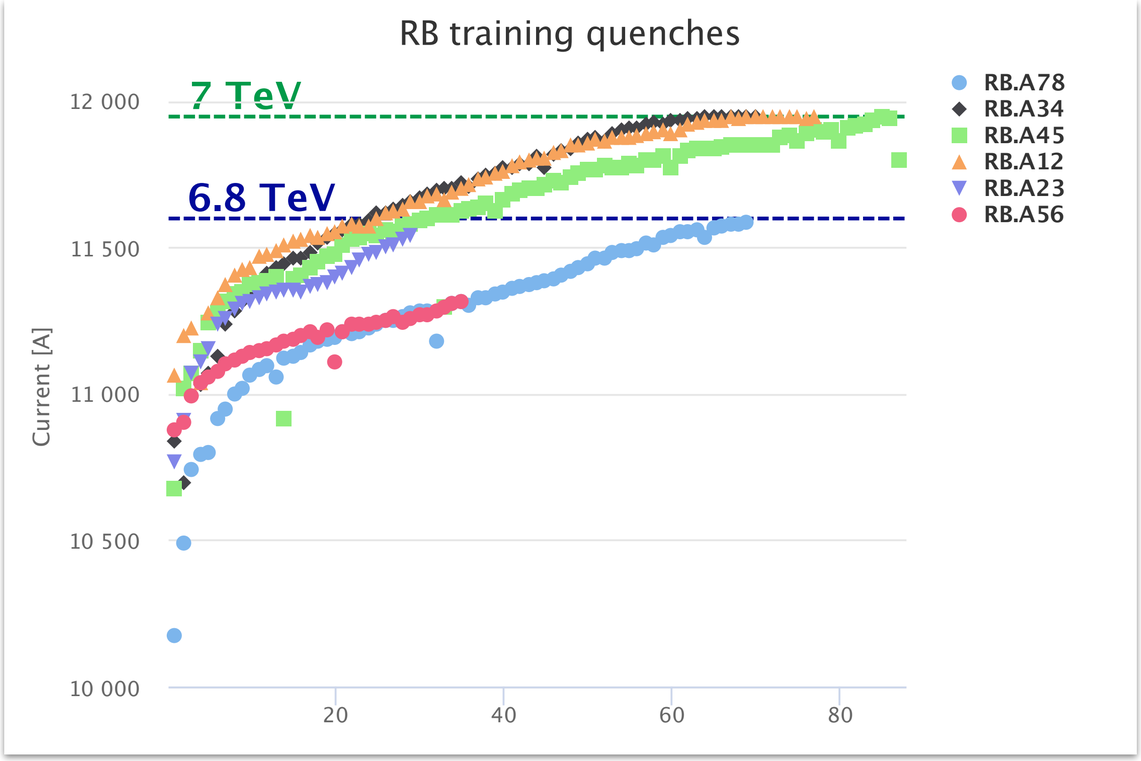
Intense preparation, assembly, installation, and commissioning of all upgrade systems and performing maintenance of all sub-detectors systems!

Machine status towards Run 3

Powering tests and magnet trainings ongoing

- Magnet replacement in sector 78 (required warming up)
- Diode replacement in sector 23 (also requires warming up)

Closing by end of February!



Highlights and Perspectives

Latest result using the entire 5.02 TeV Run 2 PbPb sample

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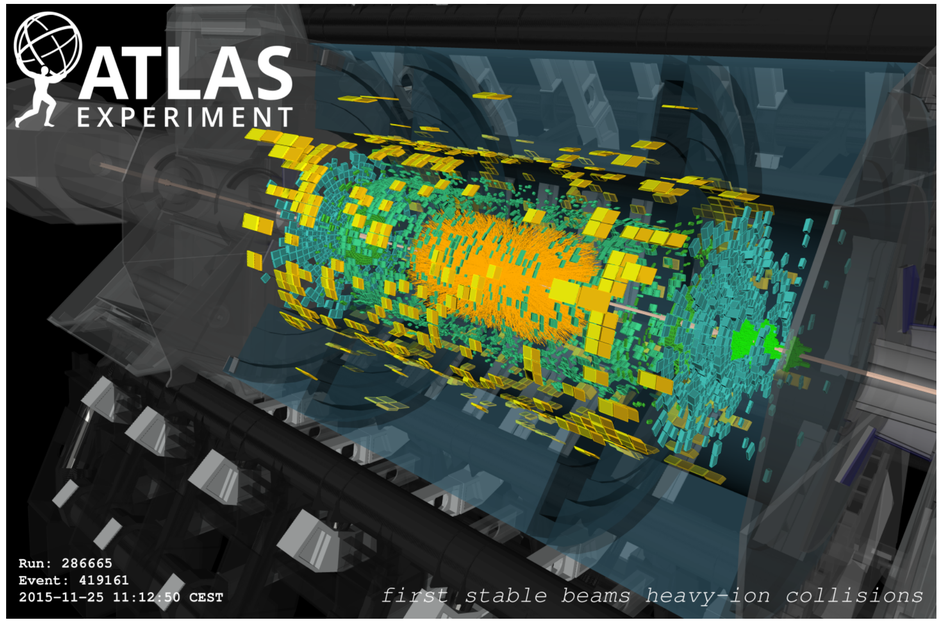
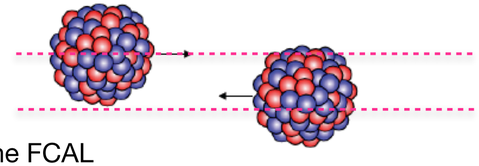


First HI PbPb collisions in 2015

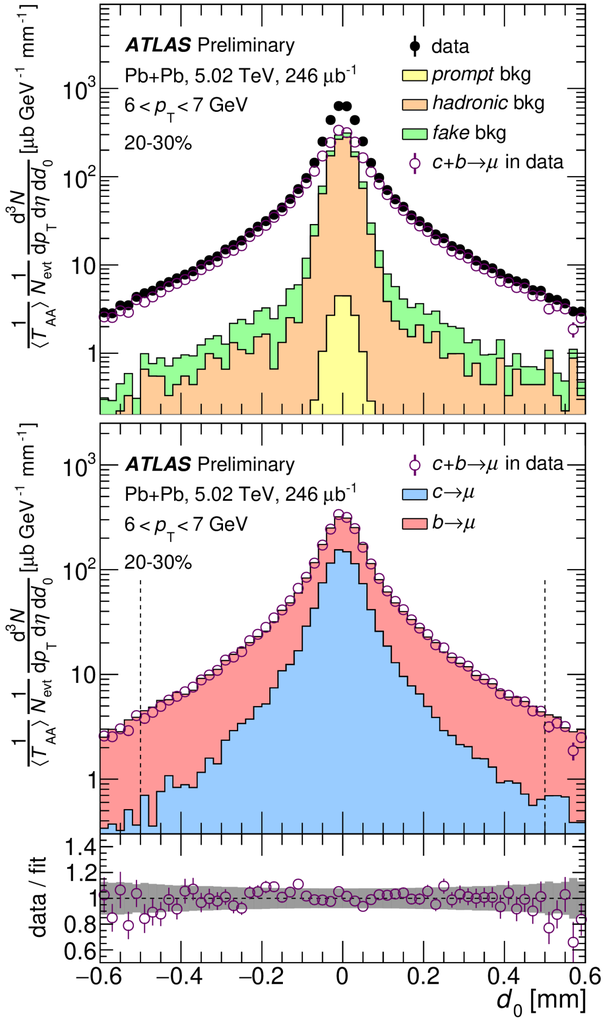
Measurement of the nuclear modification factors for inclusive heavy flavour muons (from B and D decays):

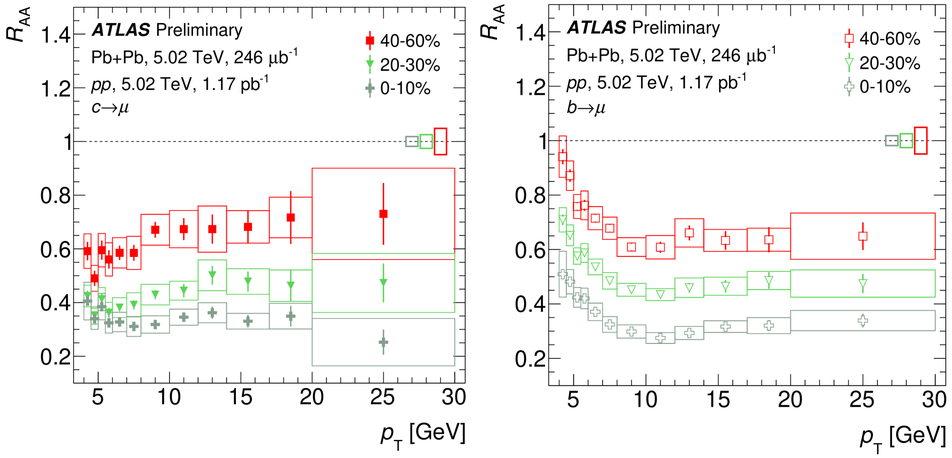
$$R_{\mathrm{AA}} = \frac{N_{\mathrm{AA}}/N_{\mathrm{evt}}}{\langle T_{\mathrm{AA}} \rangle \times \sigma^{pp}}$$

Measurements made as a function of centrality*



*Measured in the FCAL





Measurements indicate a **suppression increasing from peripheral to central collisions** (charm being more suppressed than b).

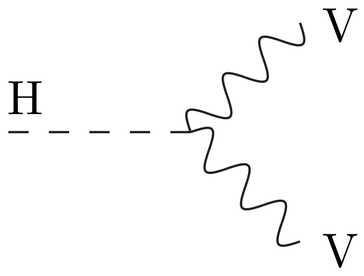
Important inputs for our understanding of heavy quark transport and QGP properties!

The Higgs Boson

All the couplings of the Higgs boson to Standard Model particles (except to itself) known well before the discovery…

However, still many more questions!

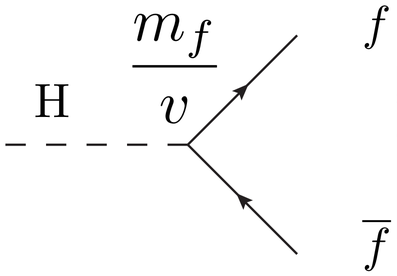
Making the weak interaction short range



$$\frac{2m_V^2}{v}$$

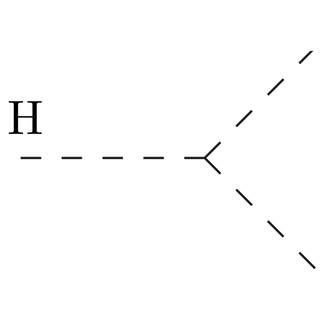
$$|D_\mu \phi|^2$$

Fundamental non gauge couplings
(never seen before)



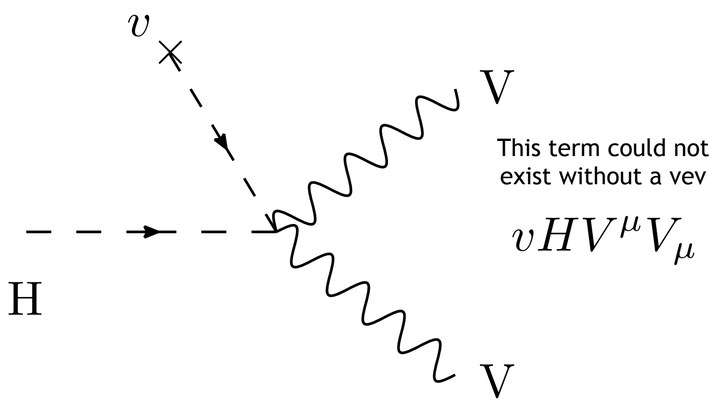
$$\bar{\psi}_i y_{ij} \psi_j \phi$$

Self interactions of a fundamental scalar
(never seen before)



$$\frac{3m_H^2}{v}$$

$$V(\phi)$$

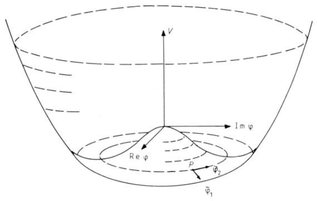


This term could not exist without a vev

$$vHV^\mu V_\mu$$

Proof of condensate !

- Unsolved question of flavour Hierarchy
- Couplings to top critical for the stability of the vacuum
- u and d Yukawa decide the stability of nuclei

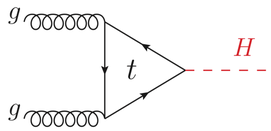
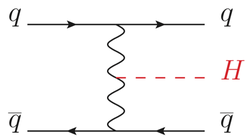
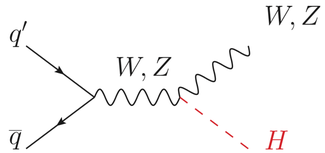
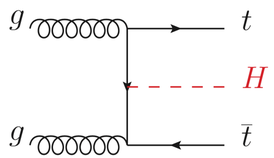


- No dynamical explanation in the SM for the shape of the potential
- The self coupling and shape of the potential critical to the EW transition

Measuring Higgs properties is a formidable potential window to physics beyond the Standard Model

Nano Overview of Main Higgs Analyses at (HL) LHC

Most channels already covered at the Run 2 with only 5% (~140 fb-1) of full HL-LHC dataset!

	Channel categories	Br	ggF  ~4 M vets produced	VBF  ~300 k vets produced	VH  ~200 k vets produced	ttH  ~40 k evts produced
	Cross Section 13 TeV (8 TeV)		48.6 (21.4) pb*	3.8 (1.6) pb	2.3 (1.1) pb	0.5 (0.1) pb
Observed modes	γγ	0.2 %	✓	✓	✓	✓
Observed modes	ZZ	3 %	✓	✓	✓	✓
Observed modes	WW	22 %	✓	✓	✓	✓
Observed modes	ττ	6.3 %	✓	✓	✓	✓
Observed modes	bb	55 %	✓	✓	✓	✓
Remaining to be observed	Zγ and γγ*	0.2 %	✓	✓	✓	✓
Remaining to be observed	μμ	0.02 %	✓	✓	✓	✓
Limits	Invisible	0.1 %	✓ (monojet)	✓	✓	✓

*N3LO

Higgs Couplings

The intricate WW channel

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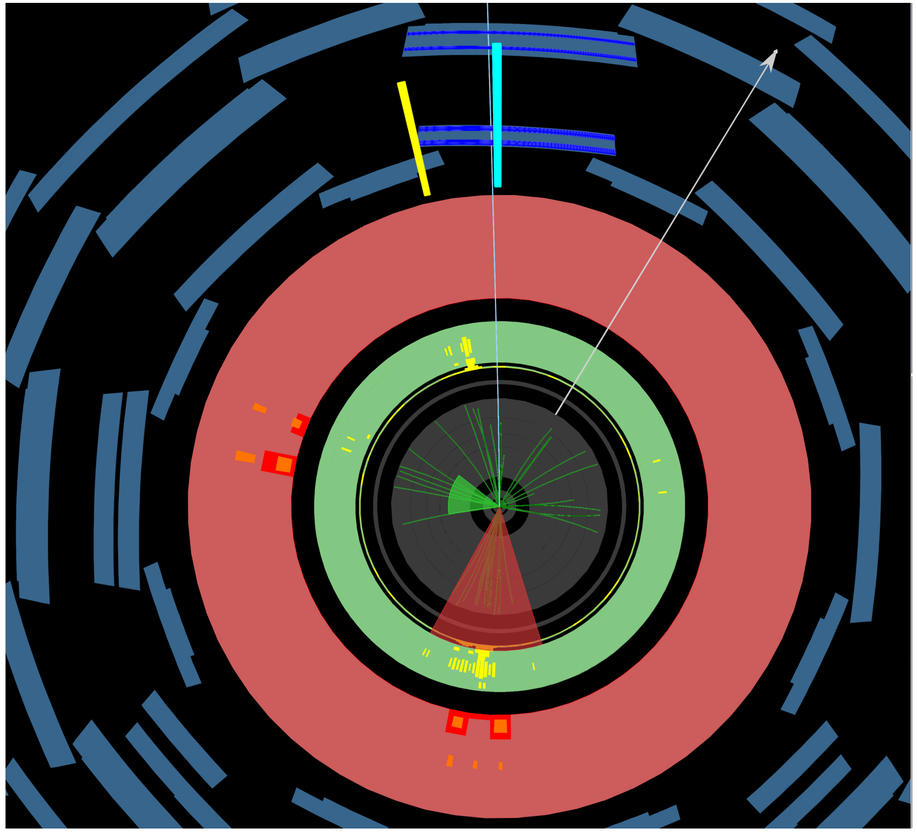


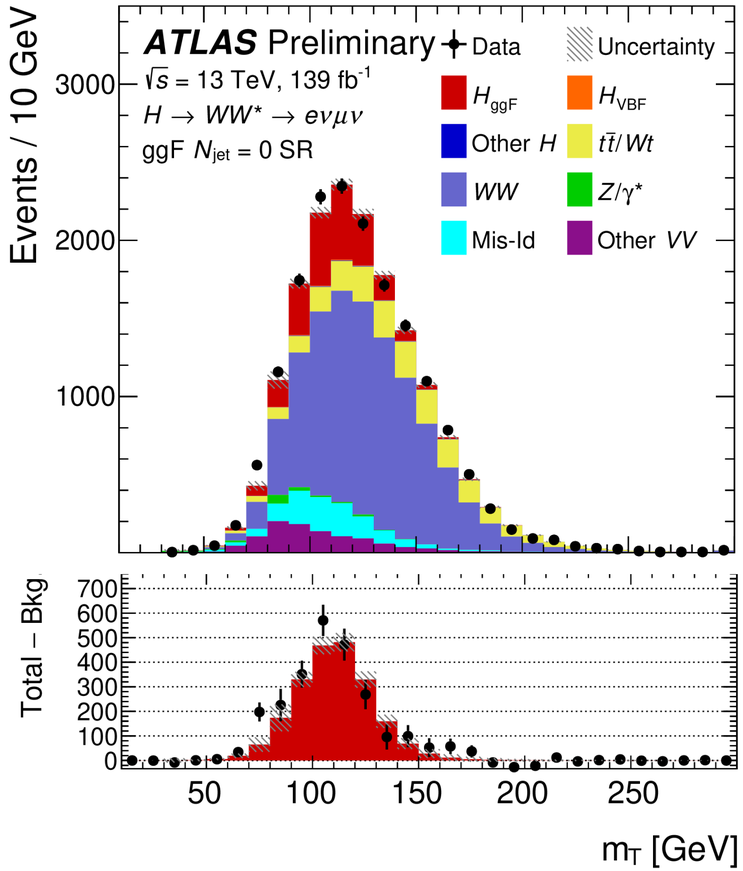
One of the most intricate channels!

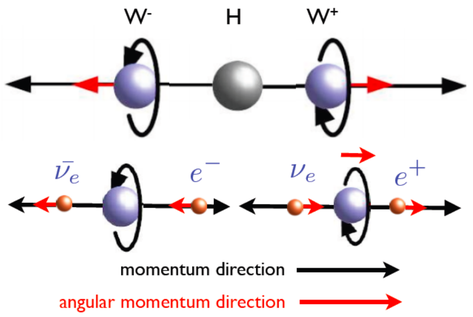
Channel where each of the W decays to leptons, the mass resolution is spoiled by the neutrinos!

Large event rate, but also large backgrounds from the WW and top production.

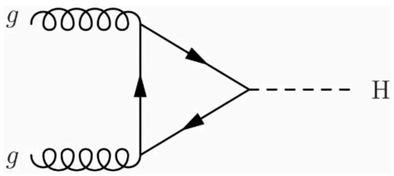
Requires good simulation of backgrounds and control regions in the data.

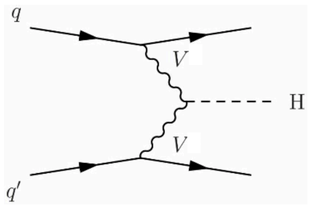
Analysis aiming at gluon fusion and VBF production modes!





Uses the V-A nature of the W coupling that transfers the W spin correlation to the electrons.





Measurements done in bins of number of jets and jet kinematics…

Higgs Couplings

The intricate WW channel

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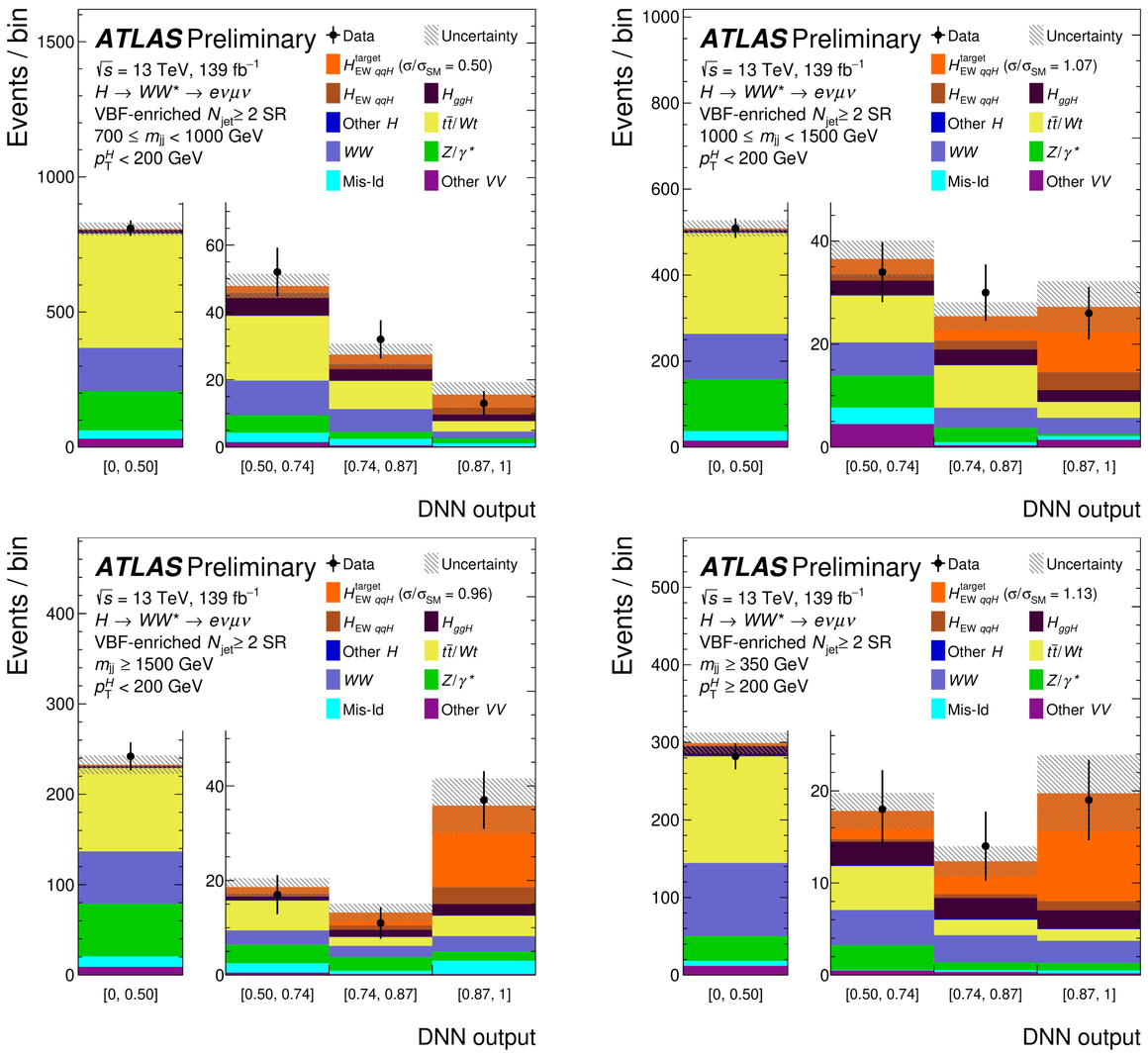
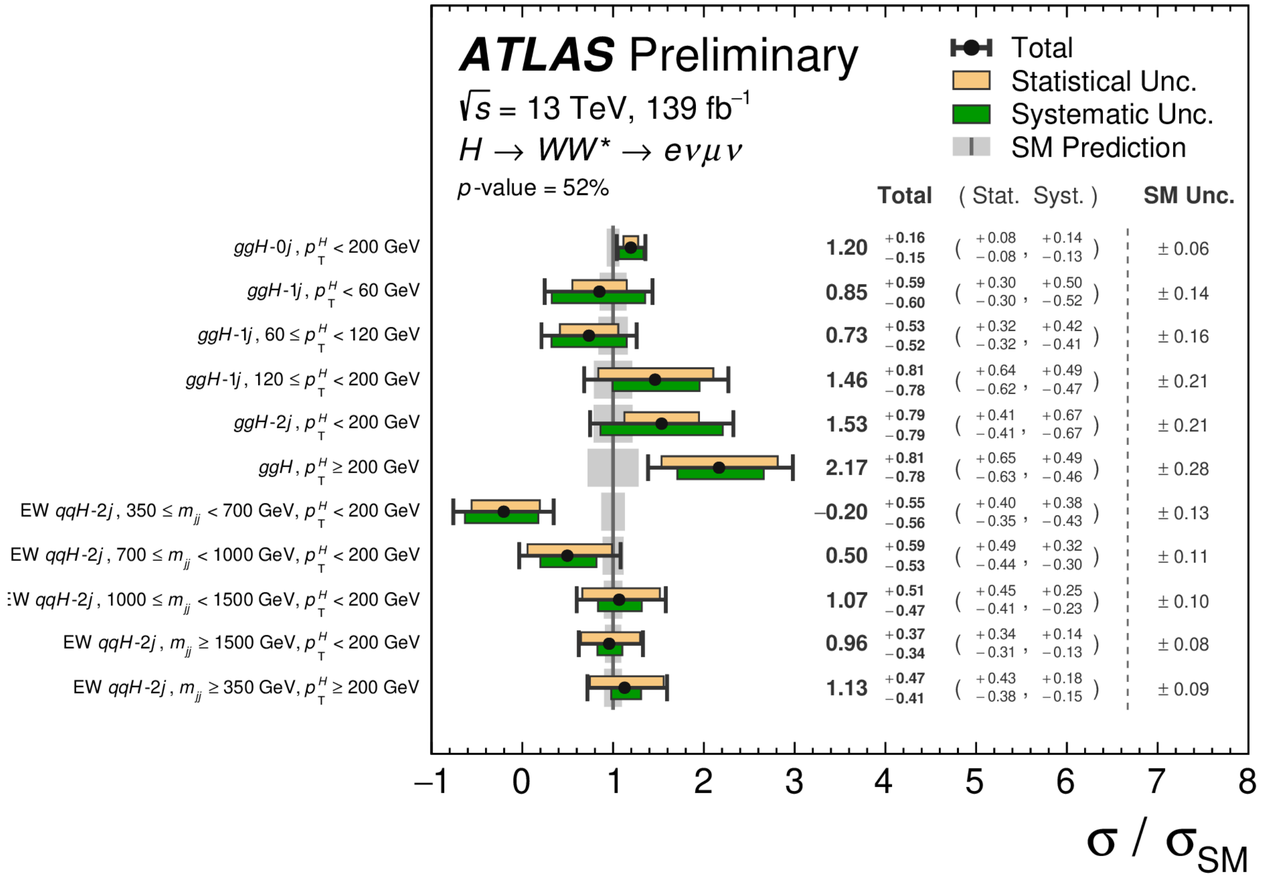
VBF channel done using **Deep Neural Network**



Measurement done in bins of **Simplified Template Cross Sections STXS** (hybrid fiducial cross sections)

Based on pTH, number of jets and di-jet mass



Higgs Couplings

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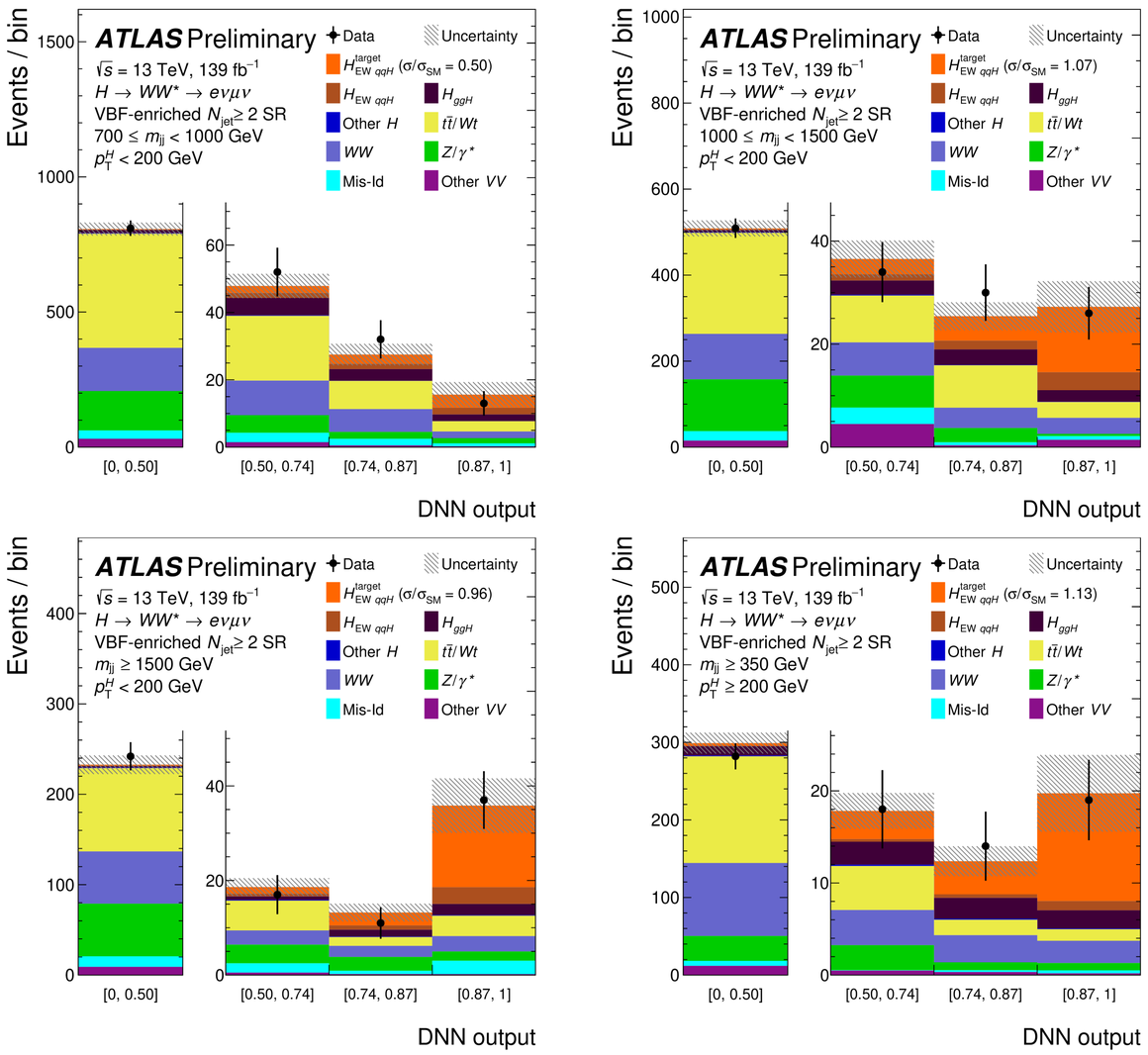

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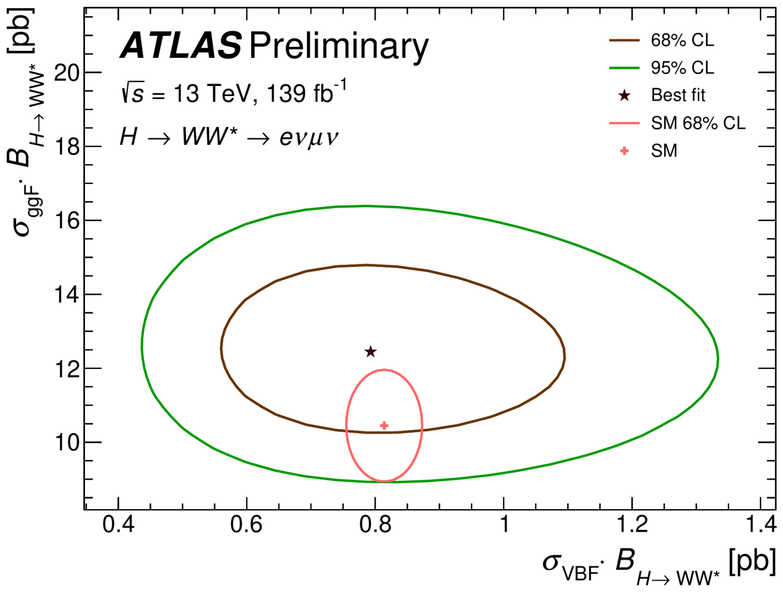


More inclusive result, show good consistency with SM predictions.

Taking a closer look at the ggF x H→WW measurement:

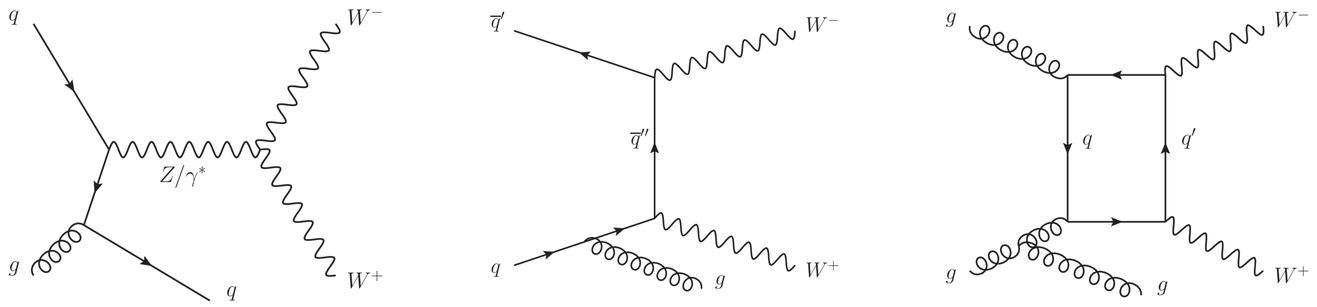
$$\sigma_{\mathrm{ggF}} \cdot \mathcal{B}_{H\to WW^*} = 12.4 \pm 1.5 \text{ pb}$$
$$= 12.4 \pm 0.6 \text{ (stat.)} \pm 0.9 \text{ (exp syst.)} \,^{+0.7}_{-0.6} \text{ (sig theo.)} \boxed{\pm 1.0 \text{ (bkg theo.)}} \text{ pb}$$

Error largely due to modelling of WW production

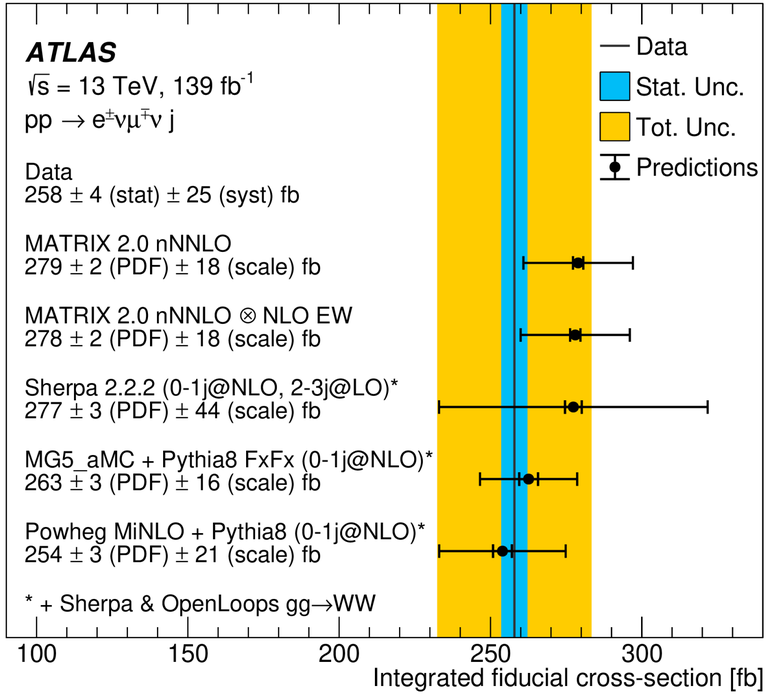
Standard Model EW

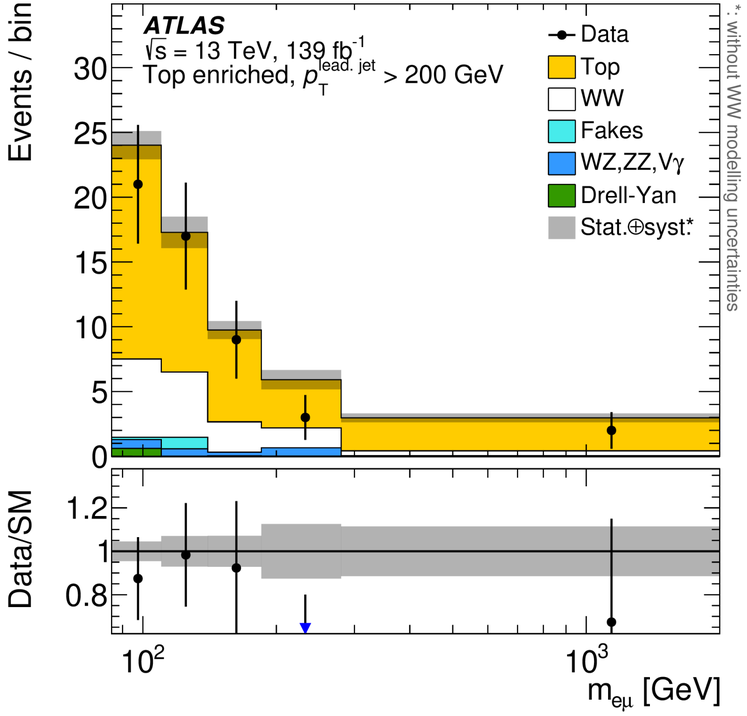
Diboson WW associated 1-jet production

2103.10319



Measurements of inclusive and differential $pp \to WW \to e\nu\mu\nu$ + 1 jet cross sections



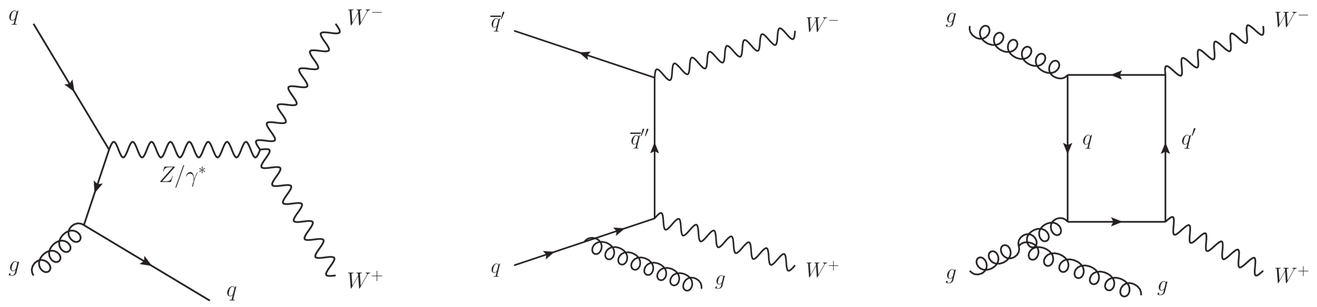


Provide excellent ancillary measurements for other channels such as HWW, but also excellent probe of anomalous **Triple gauge couplings aTGCs** (in particular at higher energies using the jet in the initial state).

Standard Model EW

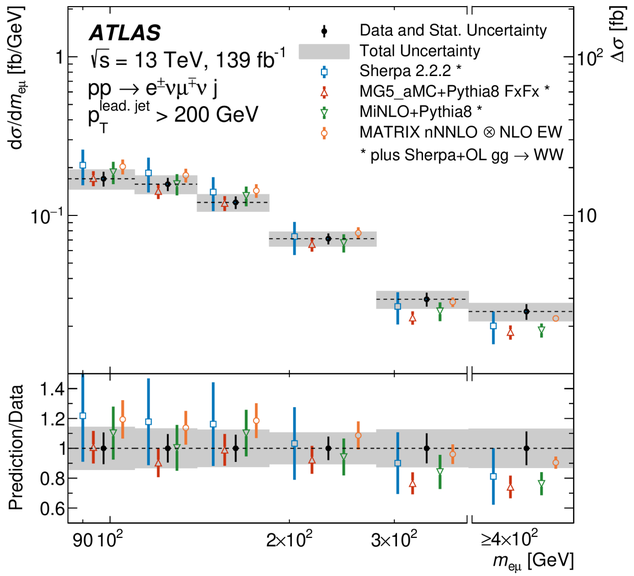
Diboson WW associated 1-jet production

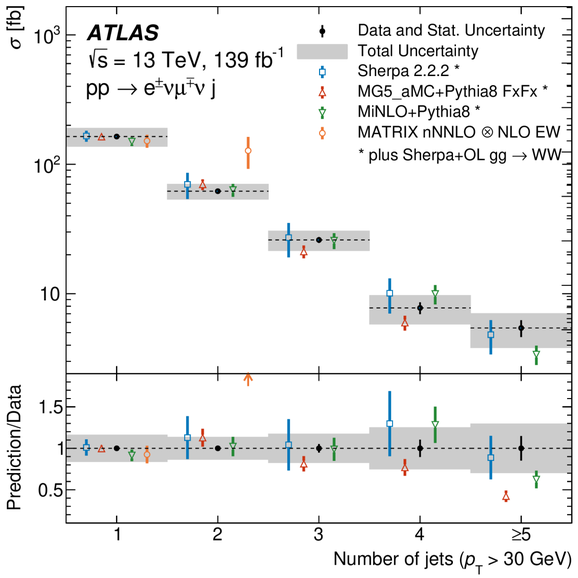
2103.10319

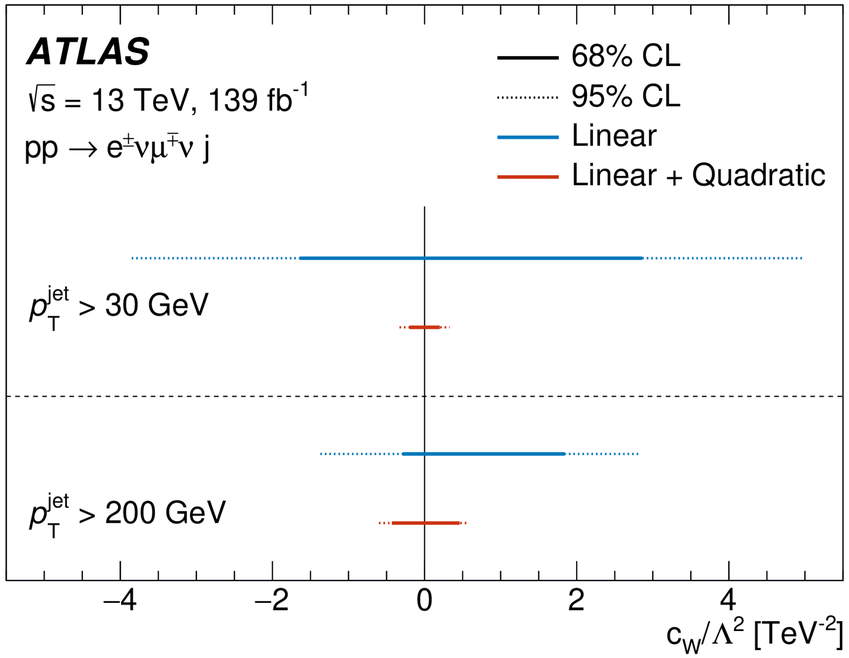


Measurements of inclusive and differential

$pp \to WW \to e\nu\mu\nu$ + 1 jet cross sections





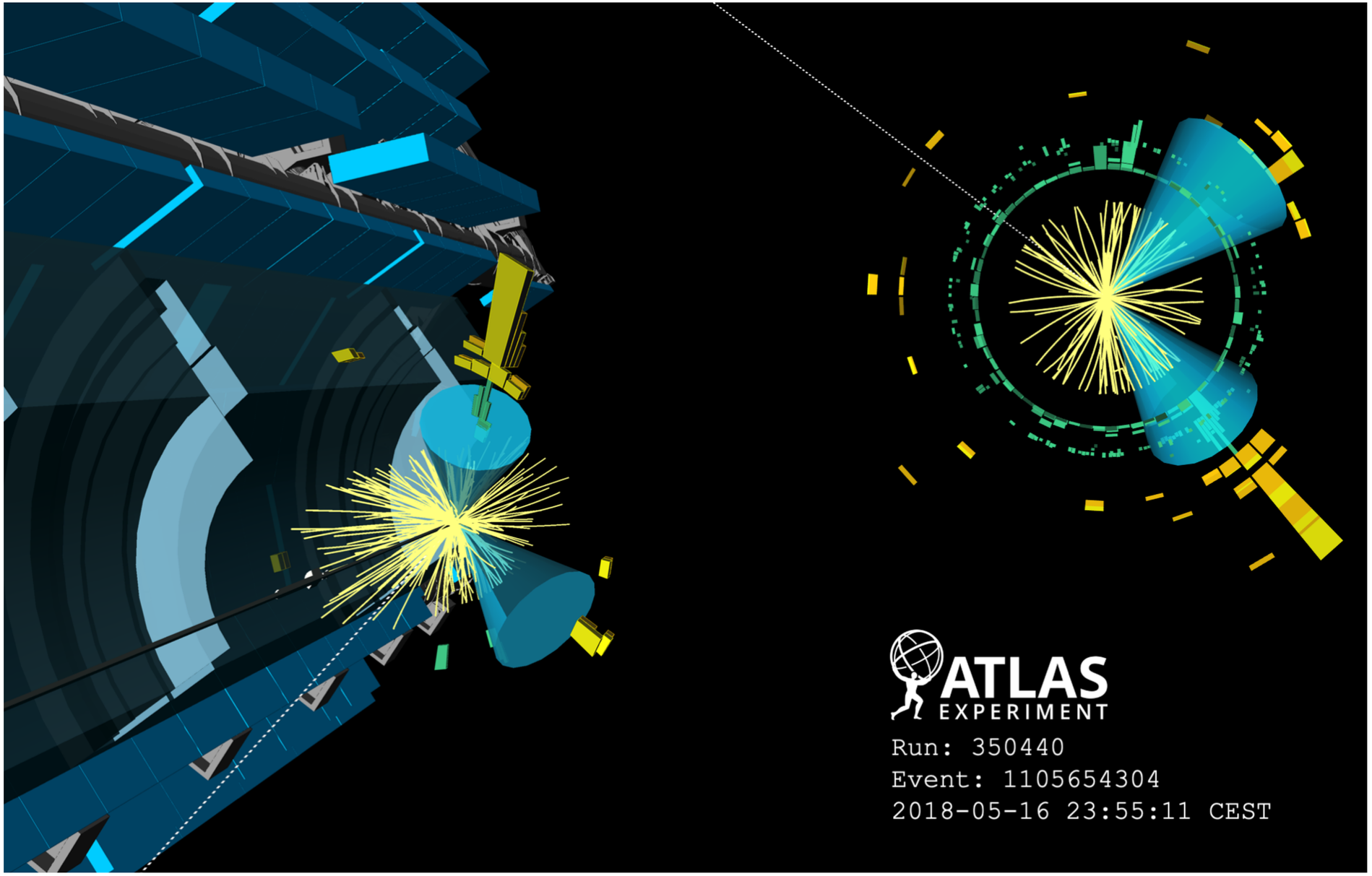


$M_{e\mu}$ mass sensitive variable to constrain the c_W Wilson coefficient corresponding to the Dim. six Q_W (WWW) operator

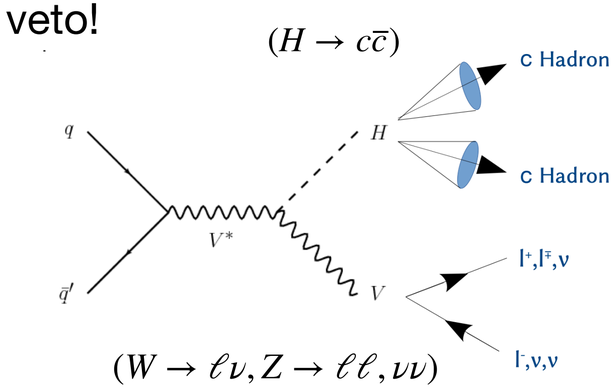
Higgs Couplings

The challenging Yukawa coupling to charm

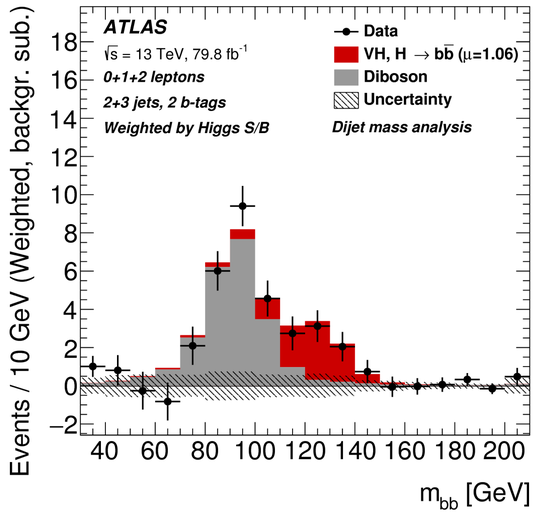
ATLAS-CONF-2021-021



Analysis similar to the VH(bb) but tagging charm quark jets instead and applying a b-tag veto!



Observation of VH(bb):



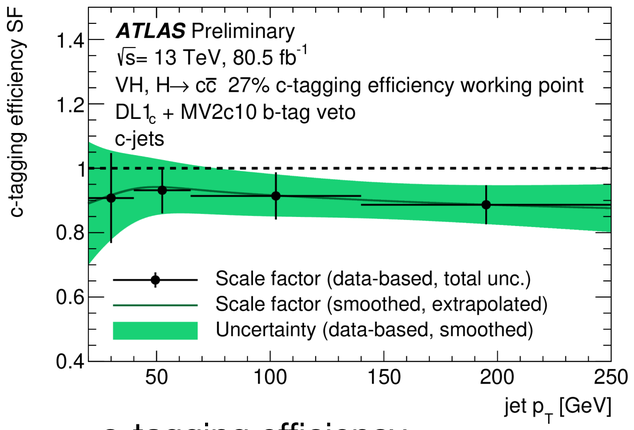
Higgs Couplings

The challenging Yukawa coupling to charm

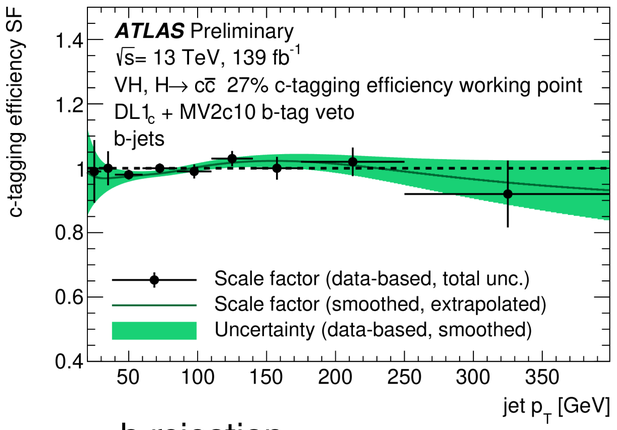
ATLAS-CONF-2021-021

H(cc) in the SM is only 3%

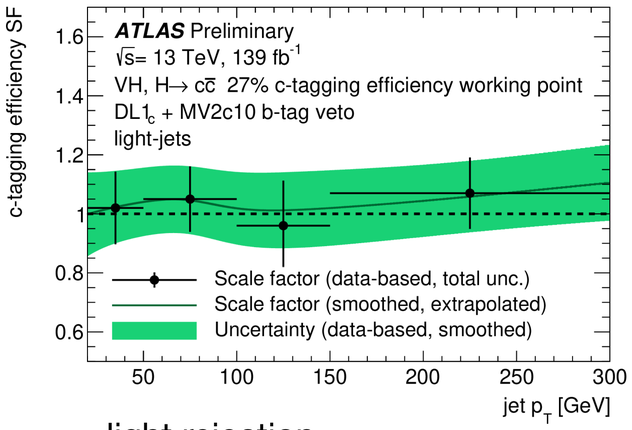
Charm tagging is key!



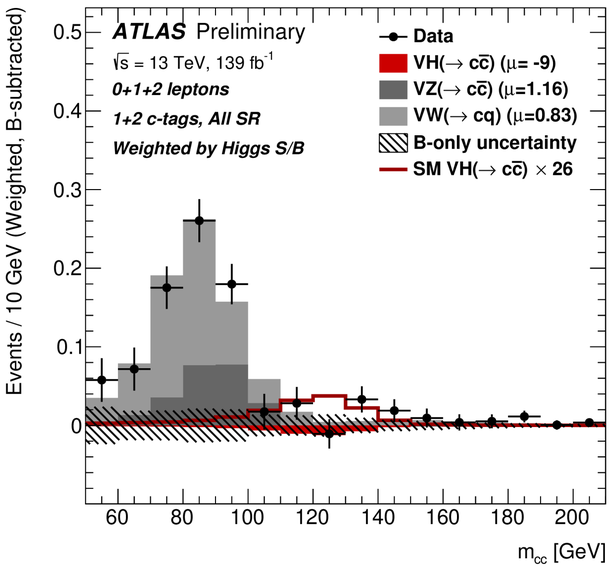
c-tagging efficiency
(with b-tag veto) ~25-30%

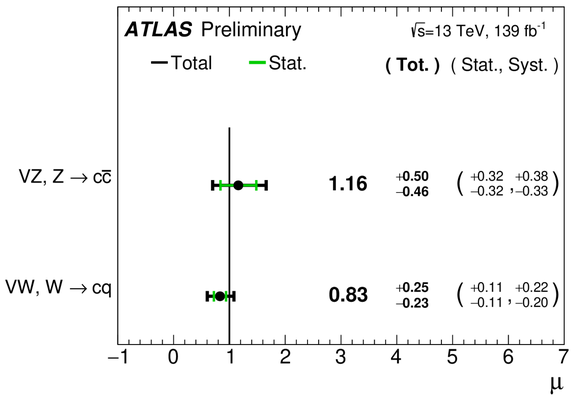


b rejection
(with b-tag veto) ~10

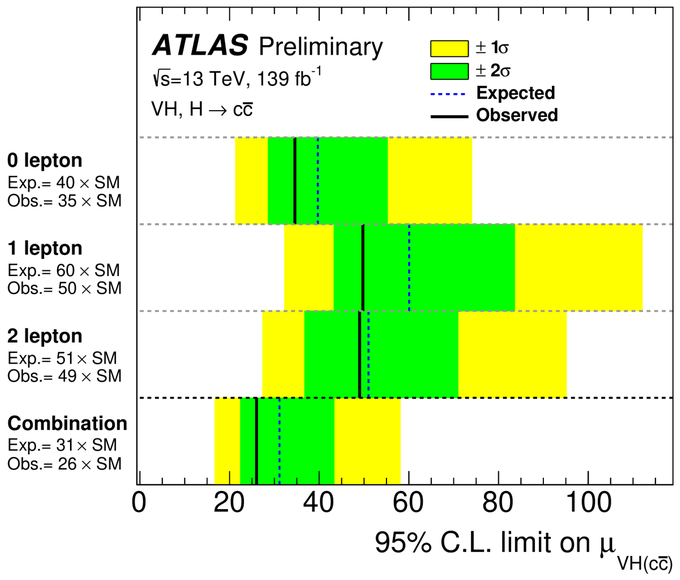


light rejection
(with b-tag veto) ~50

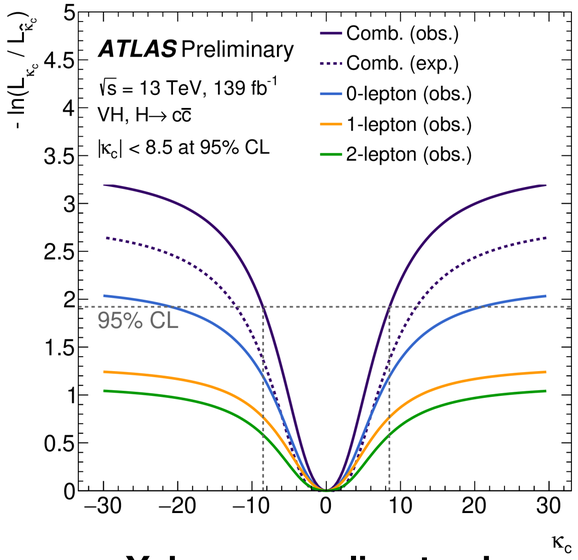




Important control of peaking Bkg. W(cq) and Z(cc)



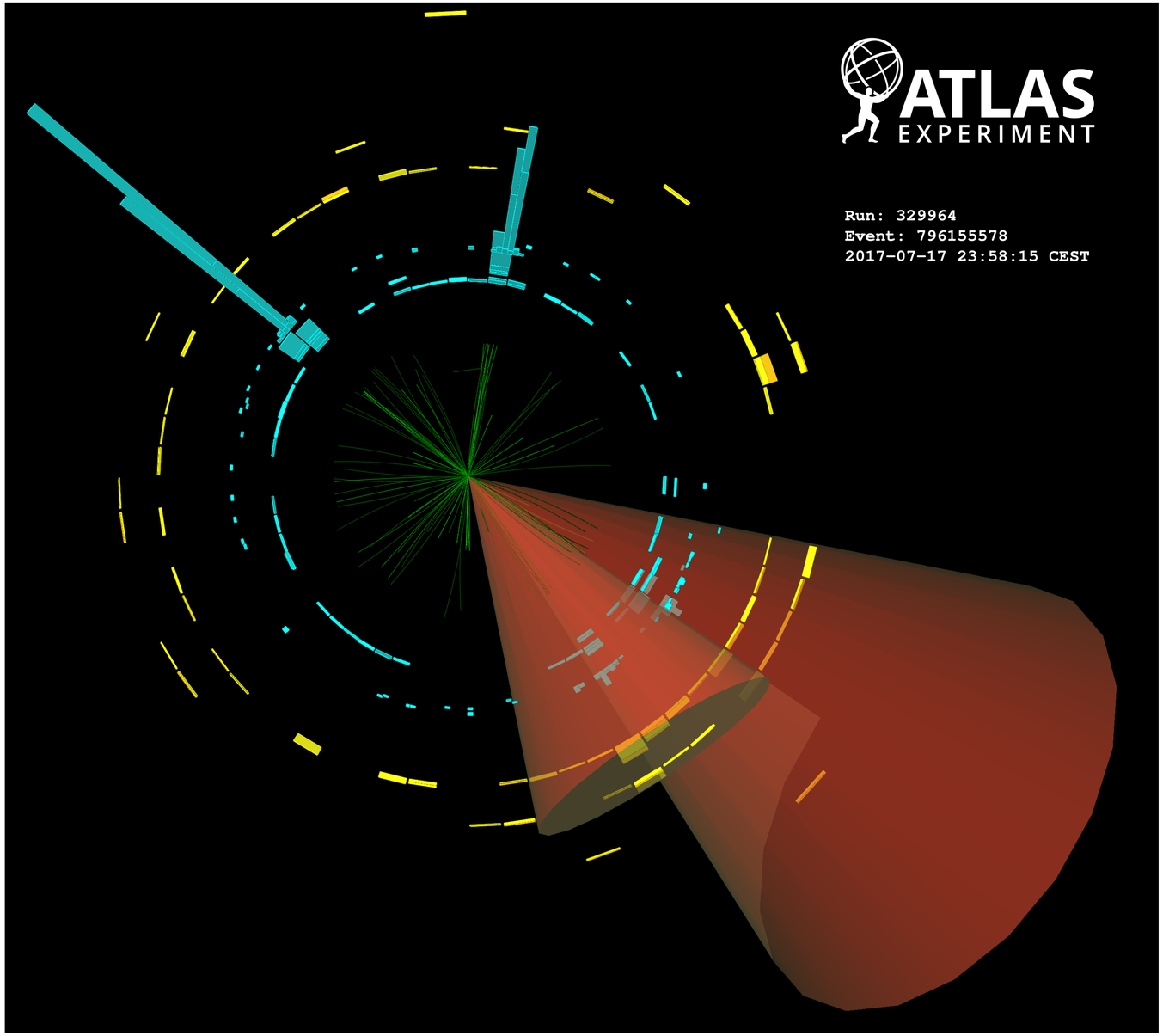
VH(cc) < 26 (31) obs. (exa.) x SM

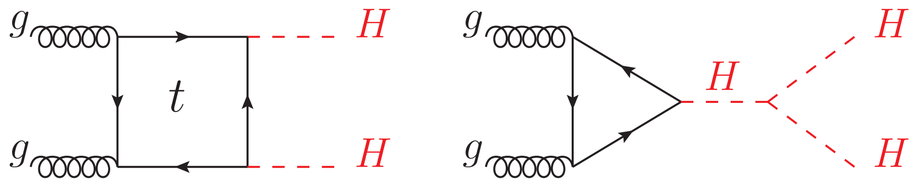


Yukawa coupling to charm < 8.5 x SM

Di-Higgs boson production

ATLAS-CONF-2021-016



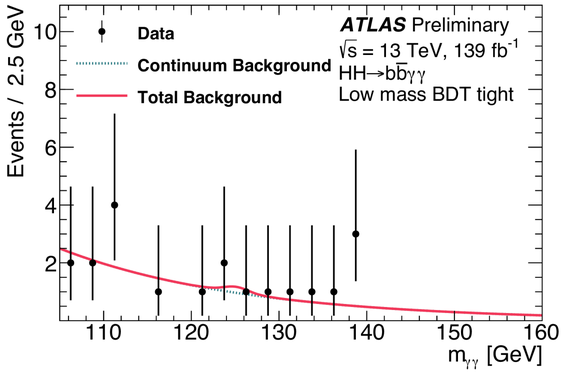


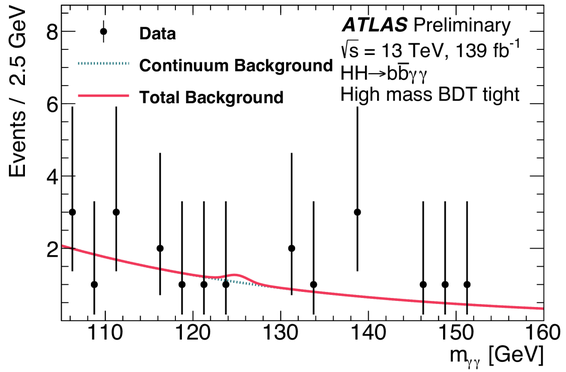
Incredibly small cross section ~1000 times smaller than Higgs production!

Huge challenge! but still more than 100k event will be produced at HL-LHC!

Multiple channels investigated: depending on the both Higgs decays considering (bb, yy, tautau, WW) - All complex topologies!!

Latest result using the full Run 2 data set in the $b\bar{b}\gamma\gamma$ channel

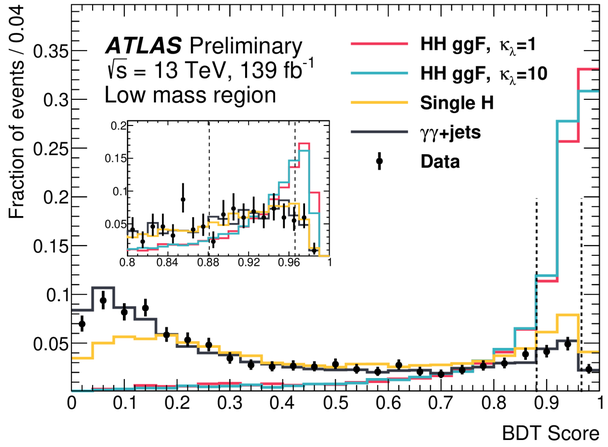


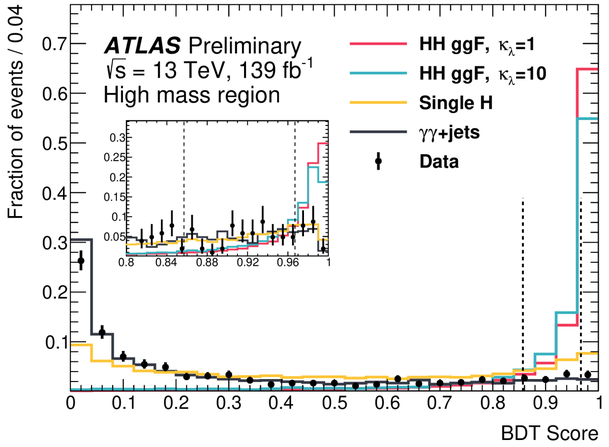


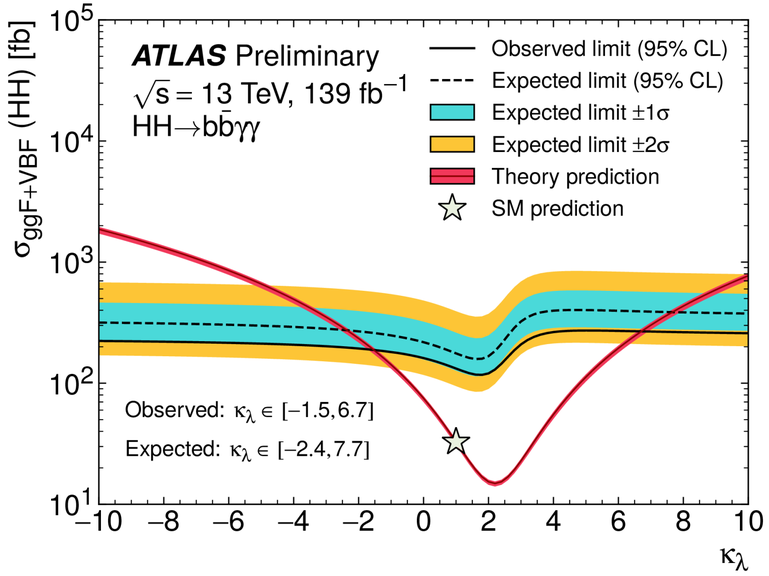
Di-Higgs boson production

ATLAS-CONF-2021-016

Various regions defined from a BDT based on photon and jet kinematics, and separated in two regions in HH mass (high and low important to discriminate HH components and constrain the trilinear coupling).







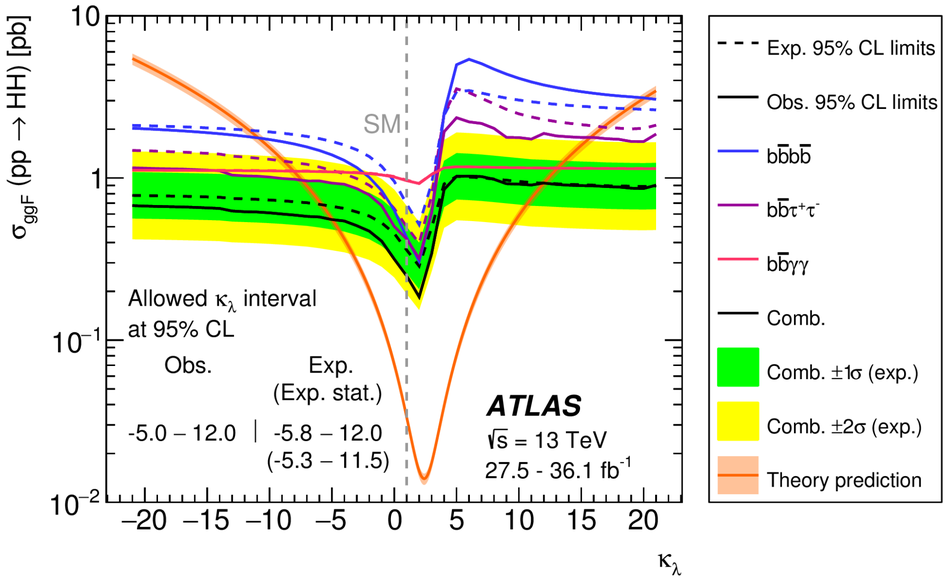
Limits on HH production at 4.1 obs. (5.5 exp.) x SM at 95% CL

Yields constraints on the trilinear coupling at [-1.5,6.7] at 95% CL

Very interesting improvements w.r.t. results obtained through the combination with 36 fb^{-1}!

Phys. Lett. B 800 (2020) 135103

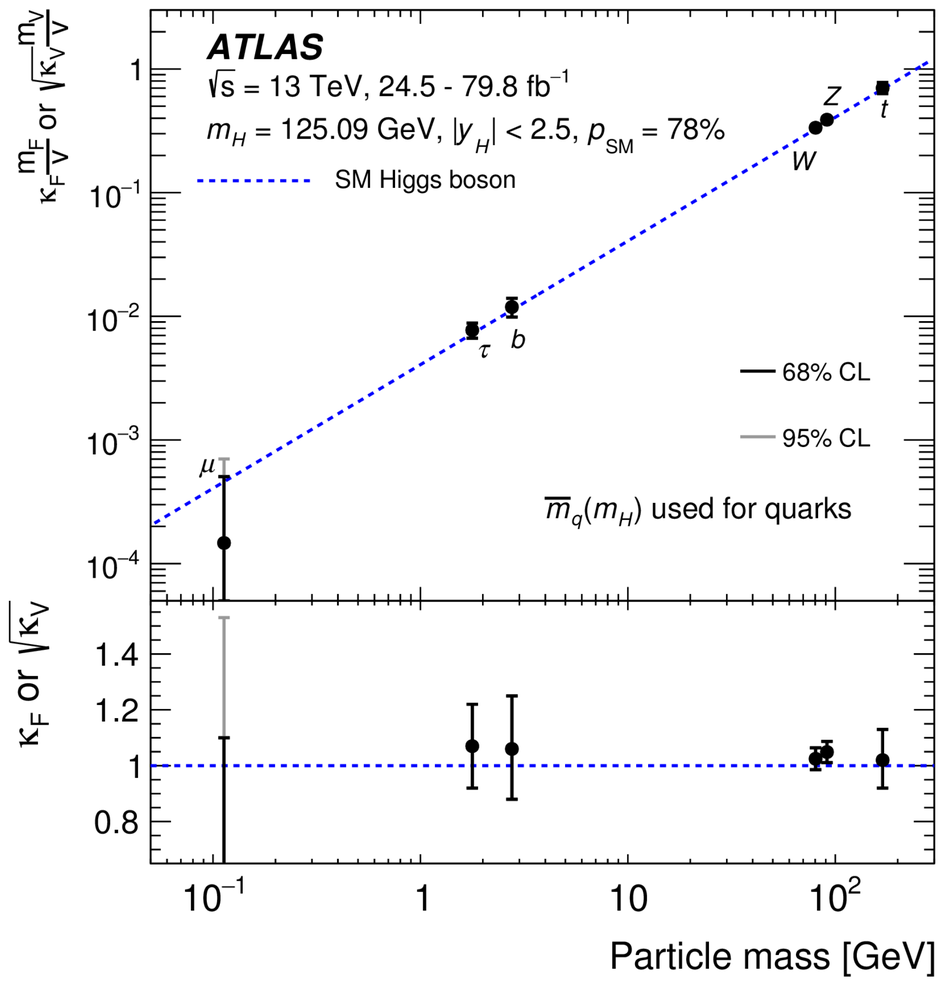
Channel	WW $\gamma\gamma$	bb $\gamma\gamma$	bb $\tau\tau$	bbWW	bbbb
$\sigma \times B$	0.1 %	0.26 %	7 %	25 %	34 %
Limits	<747 (386)	<22 (28)	<13 (15)	-	<13 (21)



SM Couplings Overview

From *Phys. Rev.* D86 (2012) 032003

Higgs boson coupling measurements



- To massive vector bosons (W and Z) scale as boson masses^2
- To massive fermions scale as fermion masses

Within the current precision all measurements are consistent with the Standard Model

- **However current precision is still low:**
  - vector bosons ~8% → *1-2% precision at HL-LHC*
  - Fermions ~10-20% → *2-3% precision at HL-LHC*
  - Self coupling ~ 6 x SM → *~50% precision at HL-LHC*

Higgs Physics Broad Landscape

Precision

- Mass and width
- Coupling properties
- Quantum numbers (Spin, CP)
- Differential cross sections
- STXS
- Off Shell couplings and width
- Interferometry

Rare Production

- tH (single top and Higgs)
- FCNC top decays
- Di-Higgs production (and trilinear couplings)

The Higgs particle

H^0 $\quad J = 0$

In the following H^0 refers to the signal that has been discovered in the Higgs searches. Whereas the observed signal is labeled as a spin 0 particle and is called a Higgs Boson, the detailed properties of H^0 and its role in the context of electroweak symmetry breaking need to be further clarified. These issues are addressed by the measurements listed below.

Concerning mass limits and cross section limits that have been obtained in the searches for neutral and charged Higgs bosons, see the sections "Searches for Neutral Higgs Bosons" and "Searches for Charged Higgs Bosons ($H^{\pm}$ and $H^{\pm\pm}$)", respectively.

H^0 MASS

VALUE (GeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
125.18±0.16 OUR AVERAGE				
125.26±0.20±0.08	[1] SIRUNYAN	17AV	CMS	pp, 13 TeV, $ZZ^* \to 4\ell$
125.09±0.21±0.11	[2,3] AAD	15B	LHC	pp, 7, 8 TeV

PDG Listing entry for the Higgs boson

Rare decays

- $Z\gamma$, $\gamma\gamma^*$, Muons $\mu^+\mu^-$
- LFV $\mu\tau$, $e\tau$
- $J/\Psi\gamma$, $Z\Upsilon$, WD, $\phi\gamma$, $\rho\gamma$

Non minimal Higgs sectors

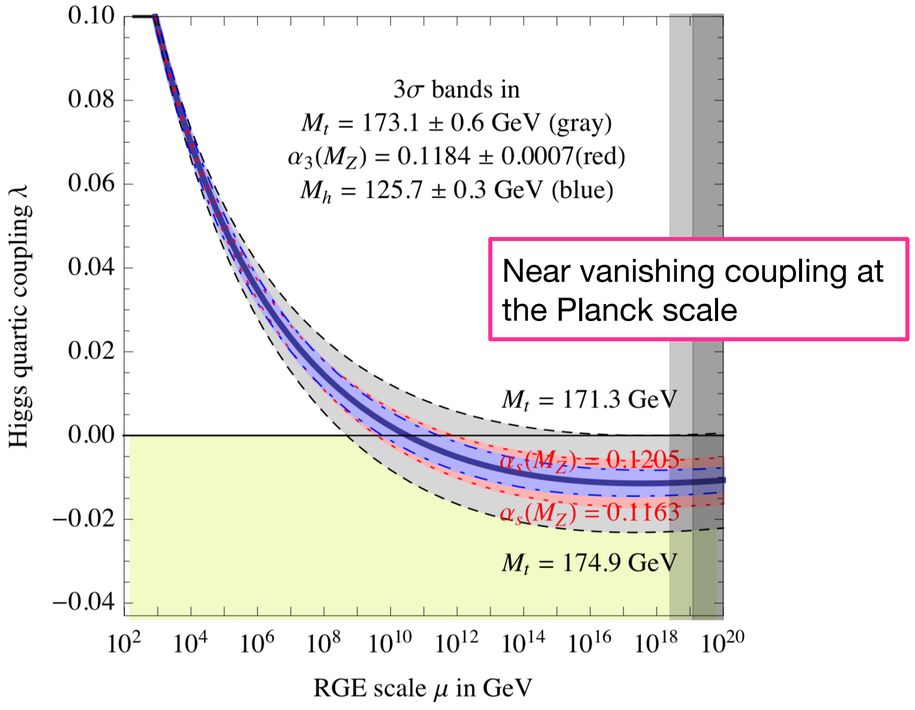
- 2 HDM searches
- MSSM, NMSSM searches
- Doubly charged Higgs bosons

Tool for discovery

- Portal to DM (invisible Higgs)
- Portal to hidden sectors
- Portal to BSM physics with H^0 in the final state (ZH^0, WH^0, H^0H^0)

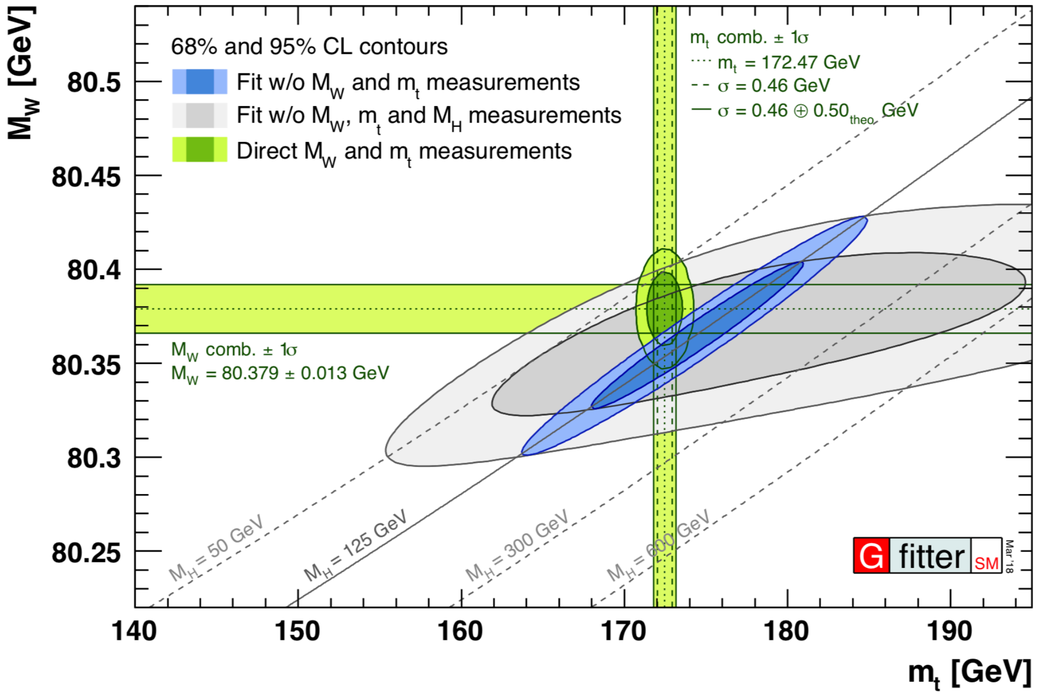
What have we Learned?

Running of the Higgs self coupling:



With the discovery of the Higgs, for the first time in our history, we have a self-consistent theory that can be extrapolated to exponentially higher energies.

Nima Arkani Hamed

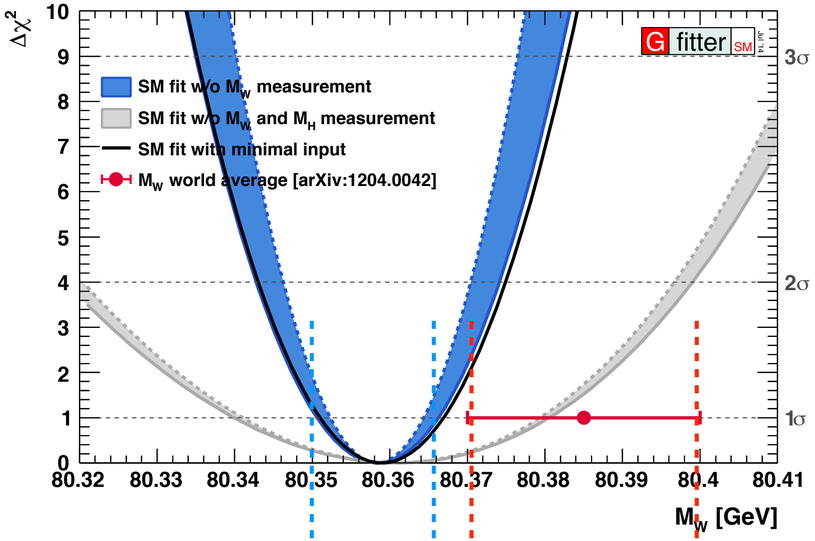


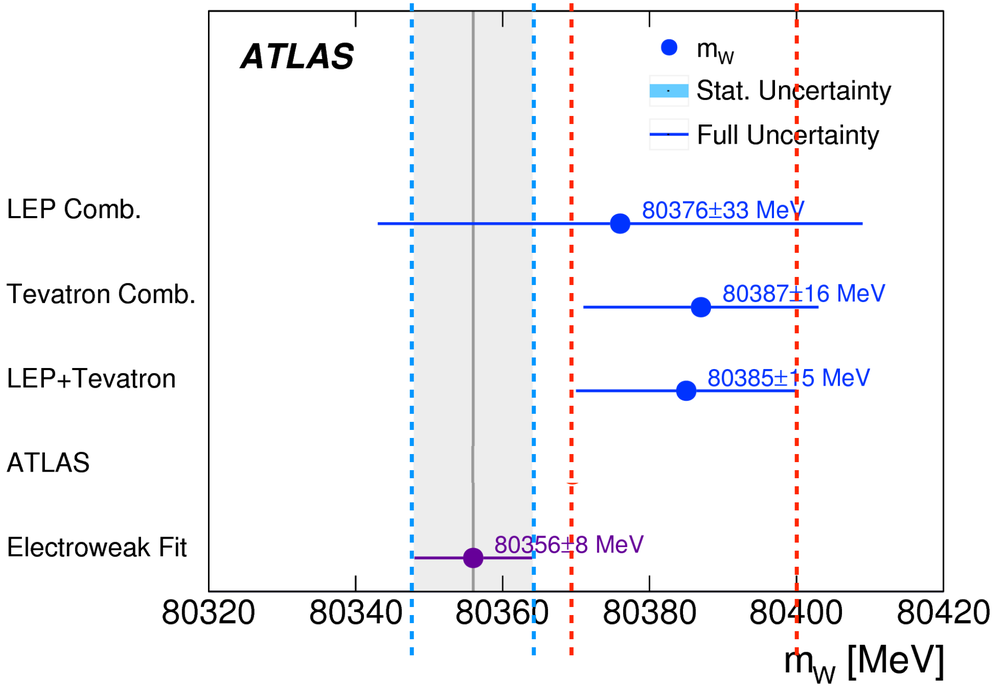
- Knowing the Higgs boson mass has a radical effect on global analysis of precision data and on the the fate of the Universe!
- Knowing the Higgs boson mass precisely has little impact on both aspects.

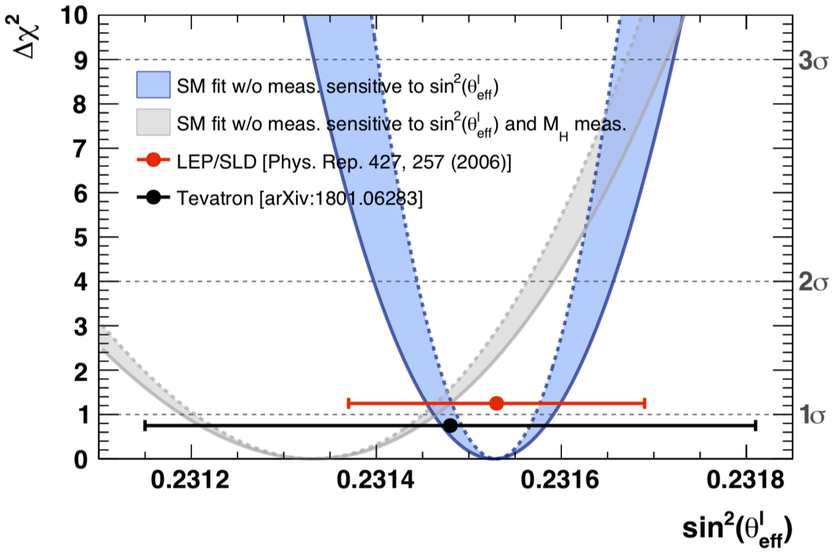
Precision EW Measurements

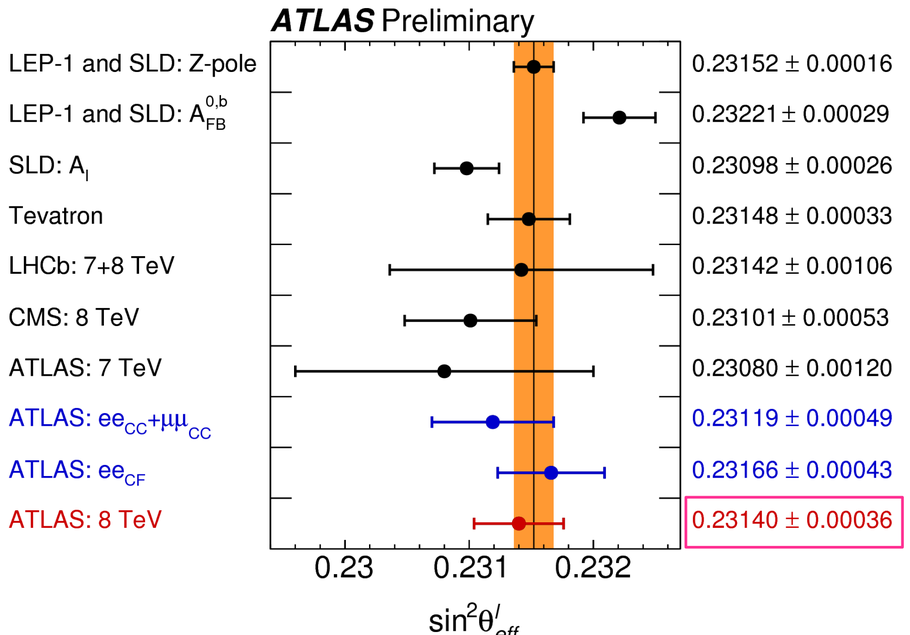
EP J C 78 (2018) 110

ATLAS-CONF-2018-037





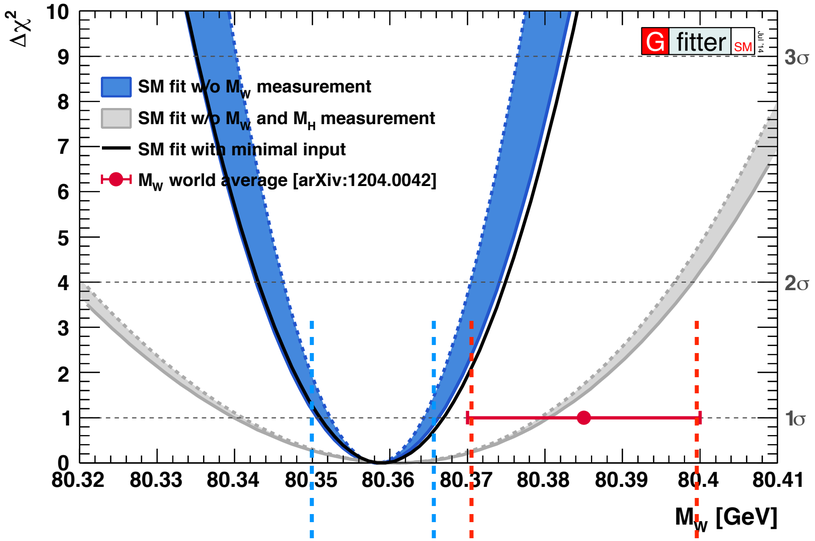


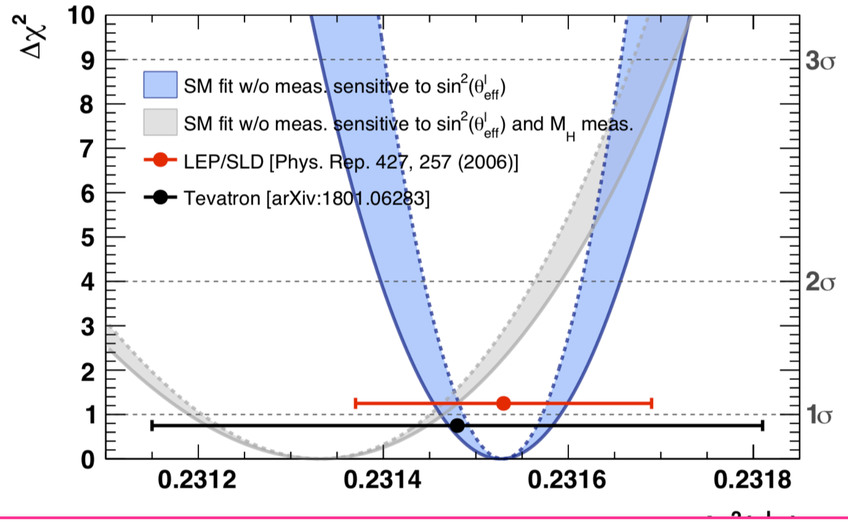


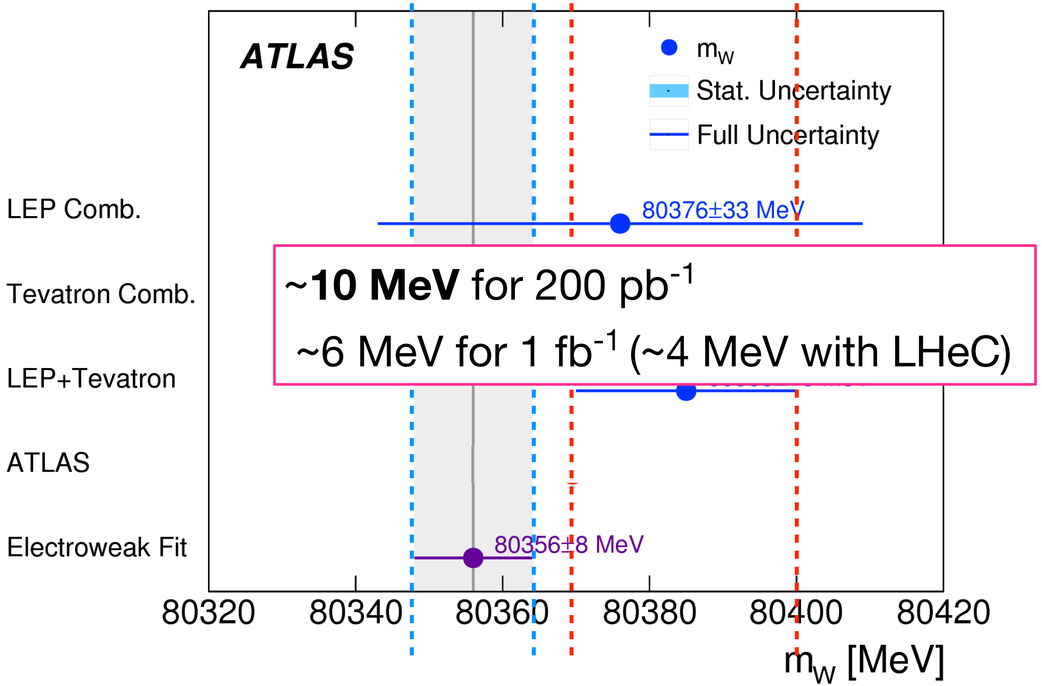
Precision EW Measurements

EP J C 78 (2018) 110

ATLAS-CONF-2018-037



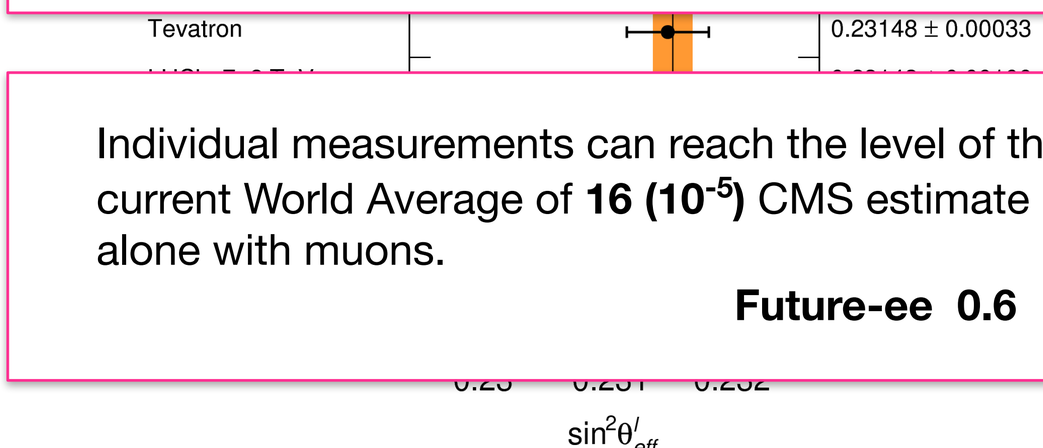




~**10 MeV** for 200 pb^{-1}

~6 MeV for 1 fb^{-1} (~4 MeV with LHeC)

$$\sin^2\theta^{\ell}_{\text{eff}} = 0.23140 \pm 0.00021\,(\text{stat}) \pm 0.00024(\text{PDFs}) \pm 0.00016\,(\text{syst})$$



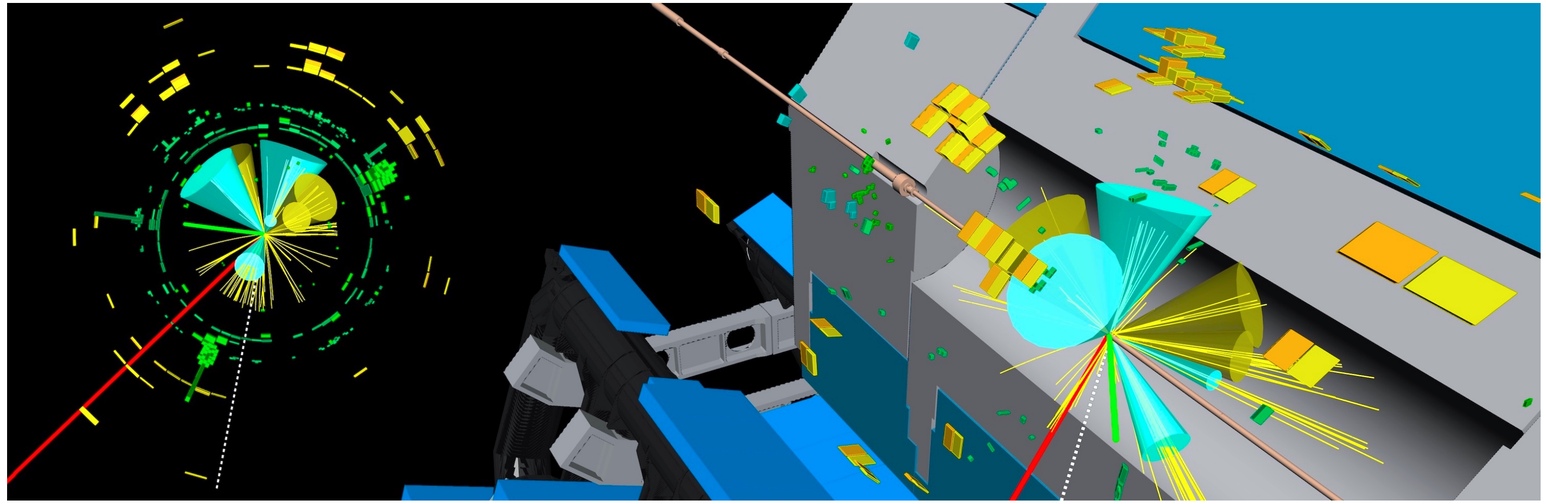
Individual measurements can reach the level of the current World Average of **16 (10^{-5})** CMS estimate alone with muons.

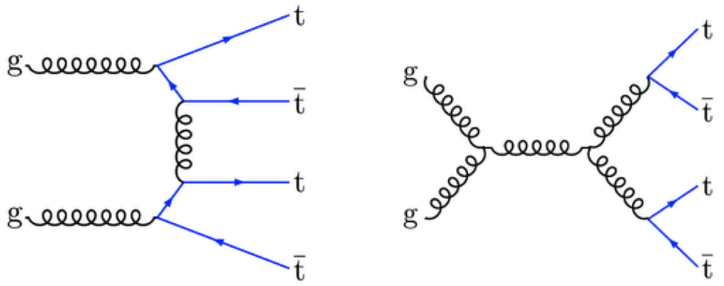
Future-ee 0.6

Top Physics

Four top quark production

ATLAS-CONF-2021-013





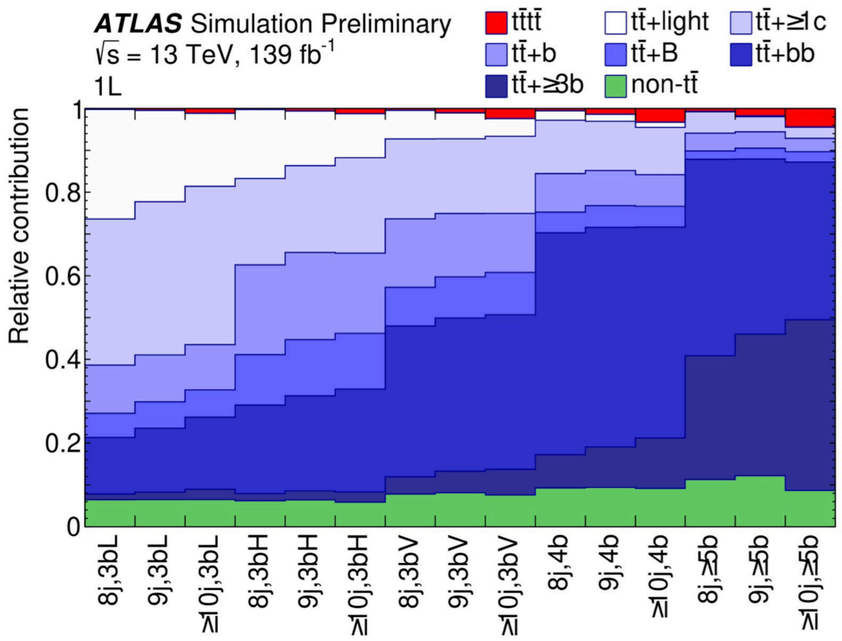
$$\sigma^{SM}_{t\bar{t}t\bar{t}} = 12.0 \pm 2.4 \text{ fb}$$

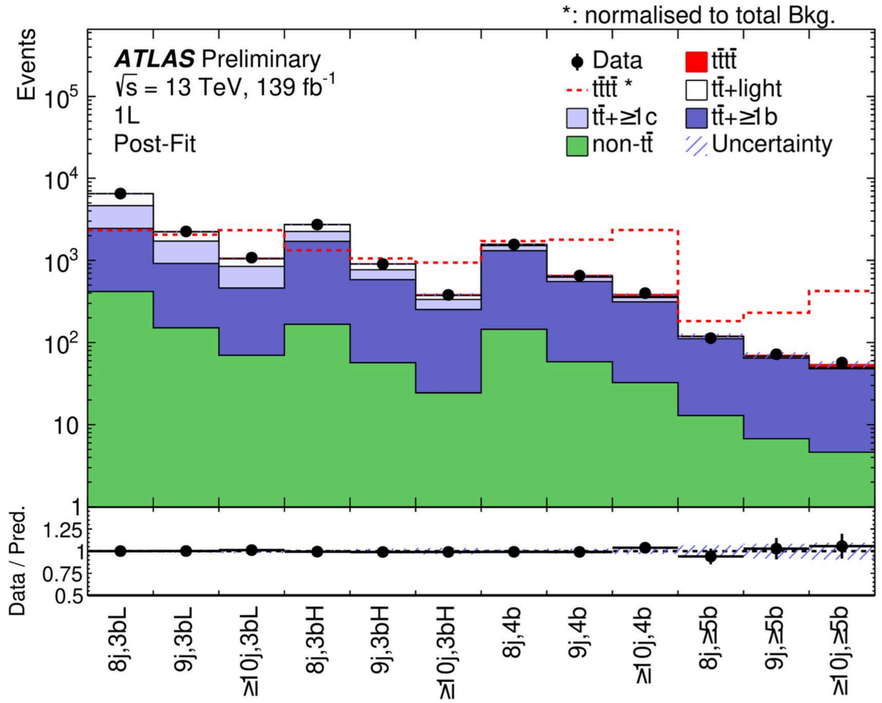
Final state with four W bosons and four b jets!

New intricate search channel: 1 lepton (and 2 leptons opposite sign) with up 10 jets and 5 b-jets!!

57% of the four top events!

Much more intricate than the 2 Same sign leptons (larger systematics - from tt-HF modelling)!

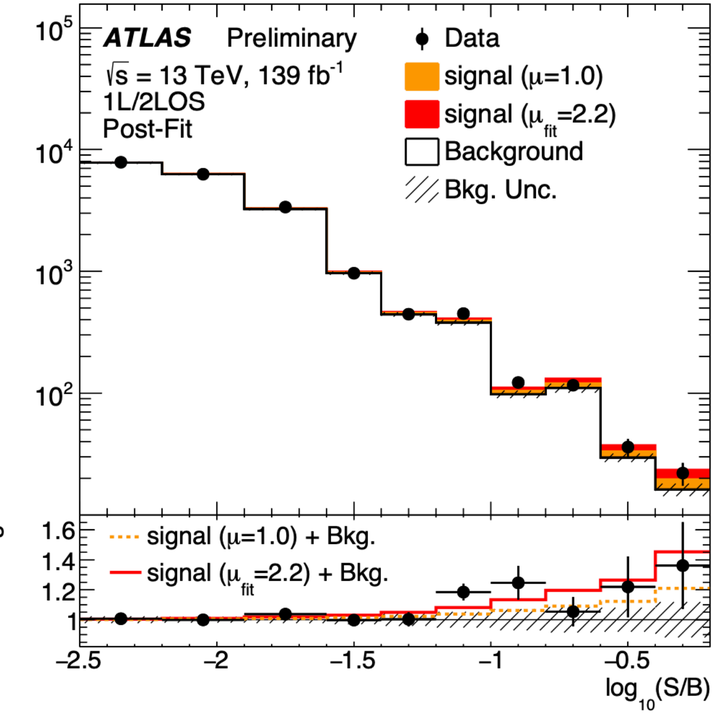


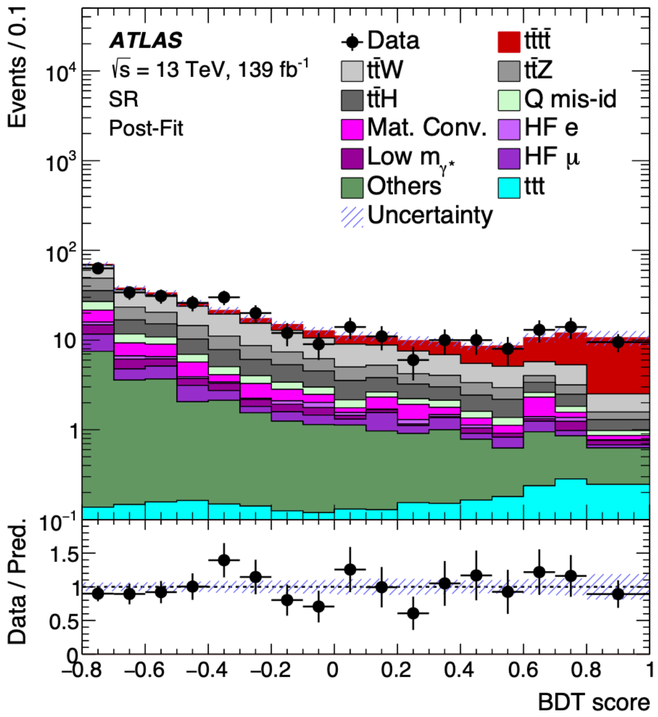


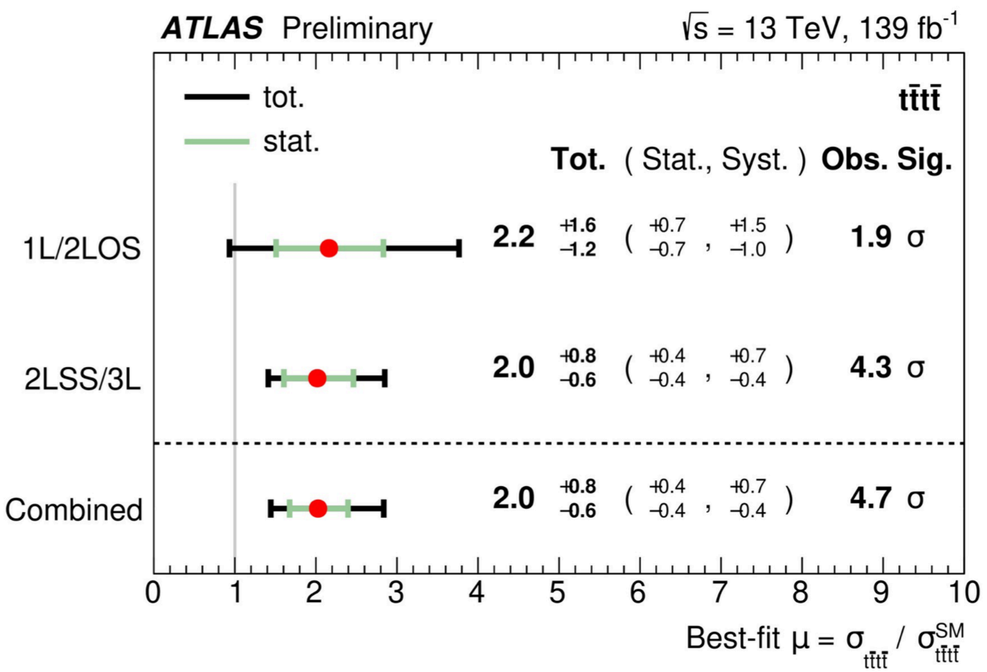
Top Physics

Four top quark production

ATLAS-CONF-2021-013







Cross section measurement (dominated by systematics)

$$\sigma_{t\bar{t}t\bar{t}} = 26 \pm 8\,(\text{stat.})\,^{+15}_{-13}\,(\text{syst.})$$

Combined cross section measurement:

$$\sigma_{t\bar{t}t\bar{t}} = 24 \pm 4\,(\text{stat.})\,^{+5}_{-4}\,(\text{syst.}) = 24\,^{+7}_{-6}\,\text{fb}$$

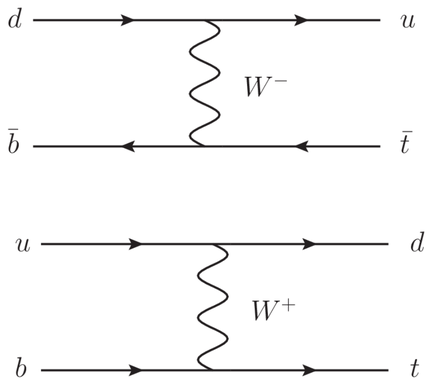
Combined significance of observation: **4.7σ obs.** (2.6 exp.)

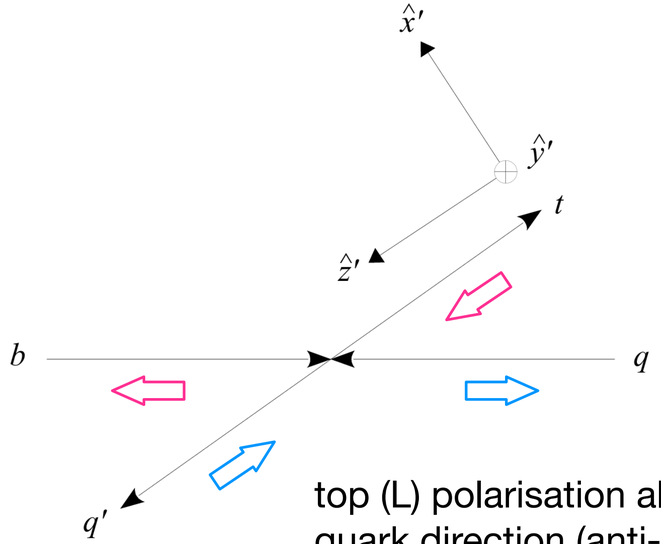
Top Physics

Top quark polarisation in single top production

ATLAS-CONF-2021-027

V-A coupling induces polarised production of single top quarks:

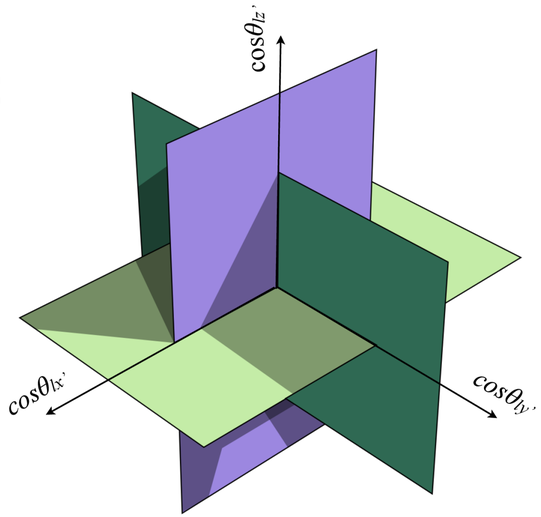


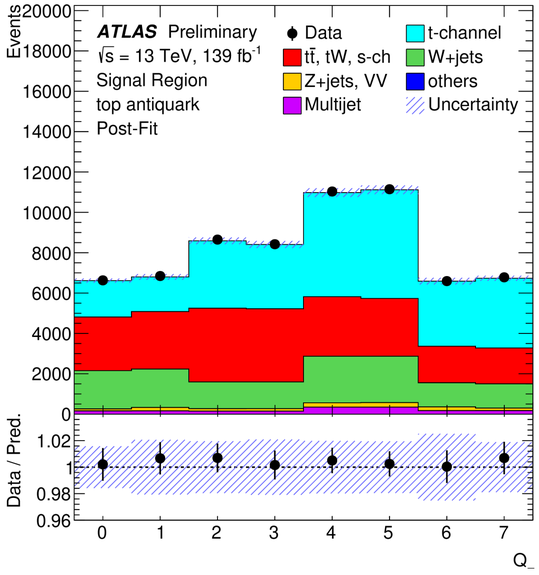


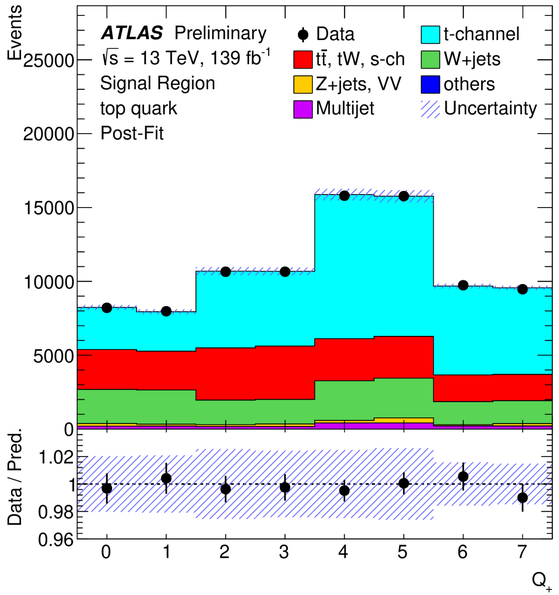
top (L) polarisation along spectator quark direction (anti-top (R) opposite)

Use semi-leptonic top decays!

Definition of a 3D discriminant based on the octant in which the lepton is produced!



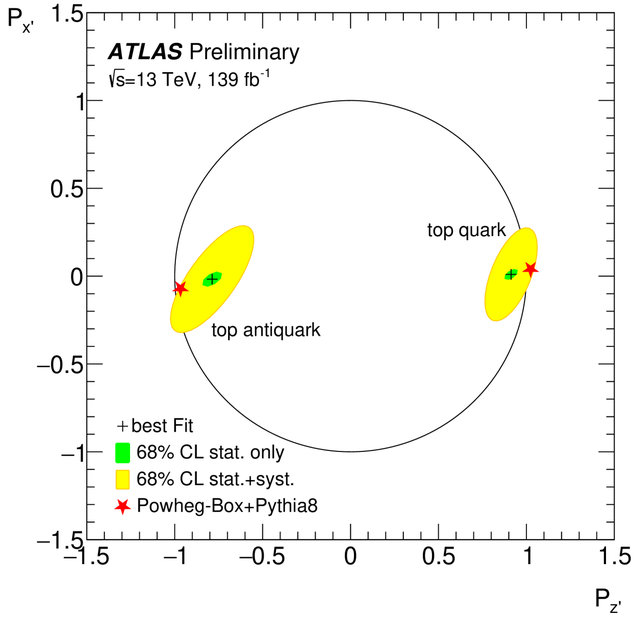




Fit to the polarisations Px, Py, Pz done using a parametrisation of this octant variable.

Py is sensitive to CP violating effects

Px is sensitive to NLO QCD effects



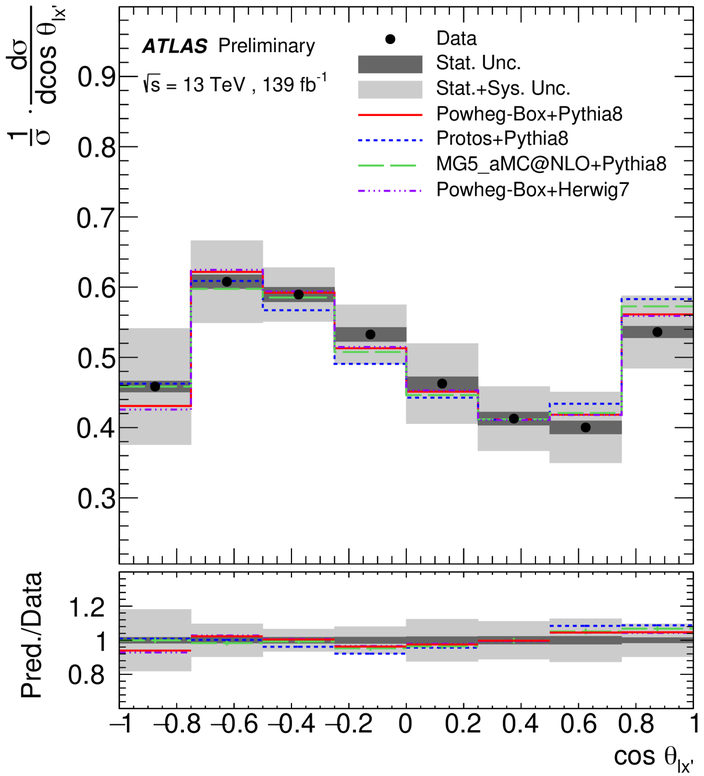
Top Physics

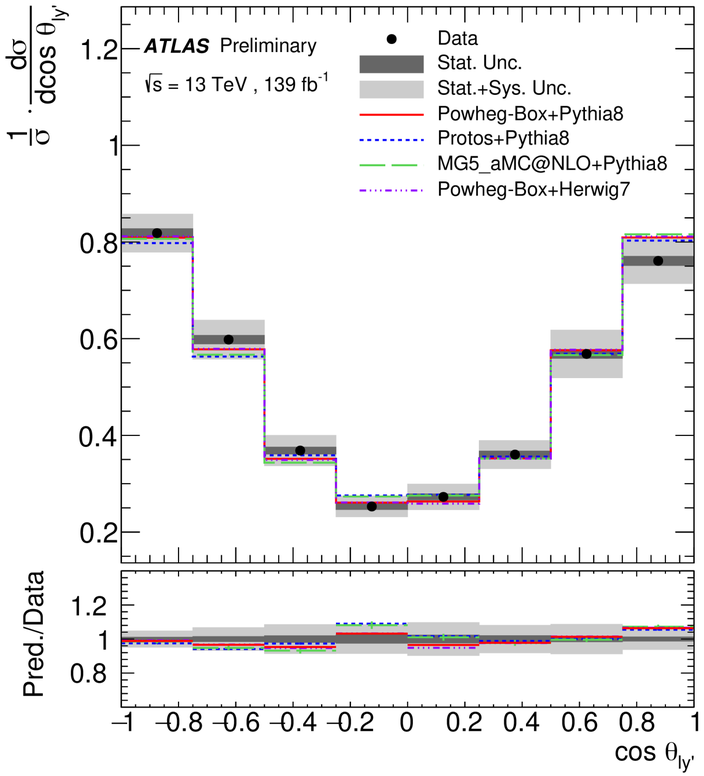
Top quark polarisation in single top production

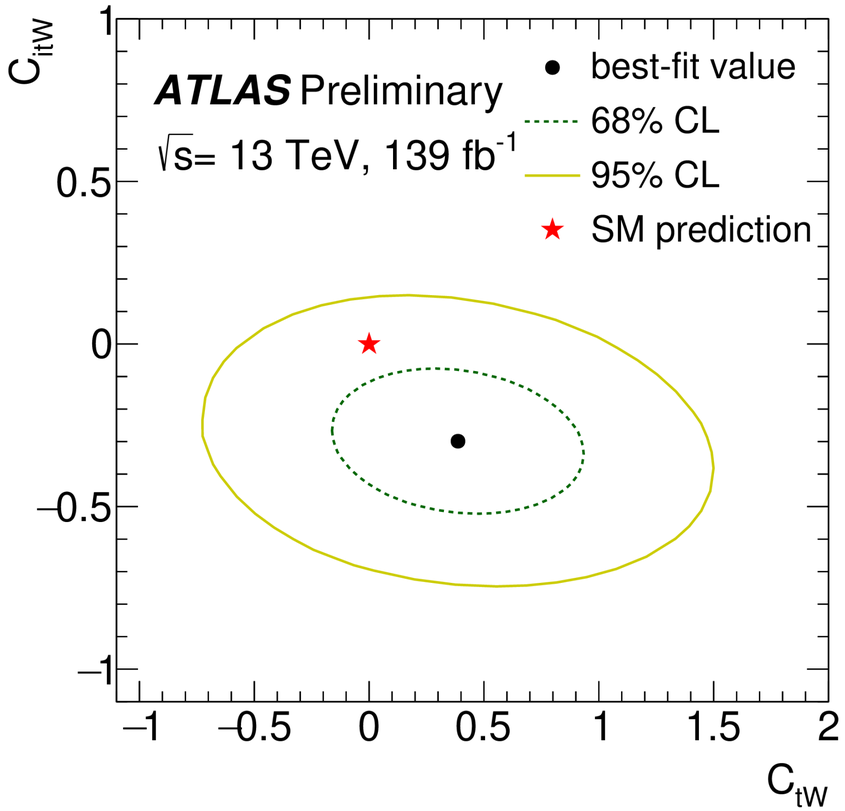
ATLAS-CONF-2021-027

Differential cross sections in $\cos\theta_{\ell x}$ and $\cos\theta_{\ell y}$ unfolded to particle level are also measured.

EFT Wilson coefficients for anomalous Dim. 6 tW coupling CP conserving and CP violating are fit simultaneously to the unfolded differential cross section measurements.



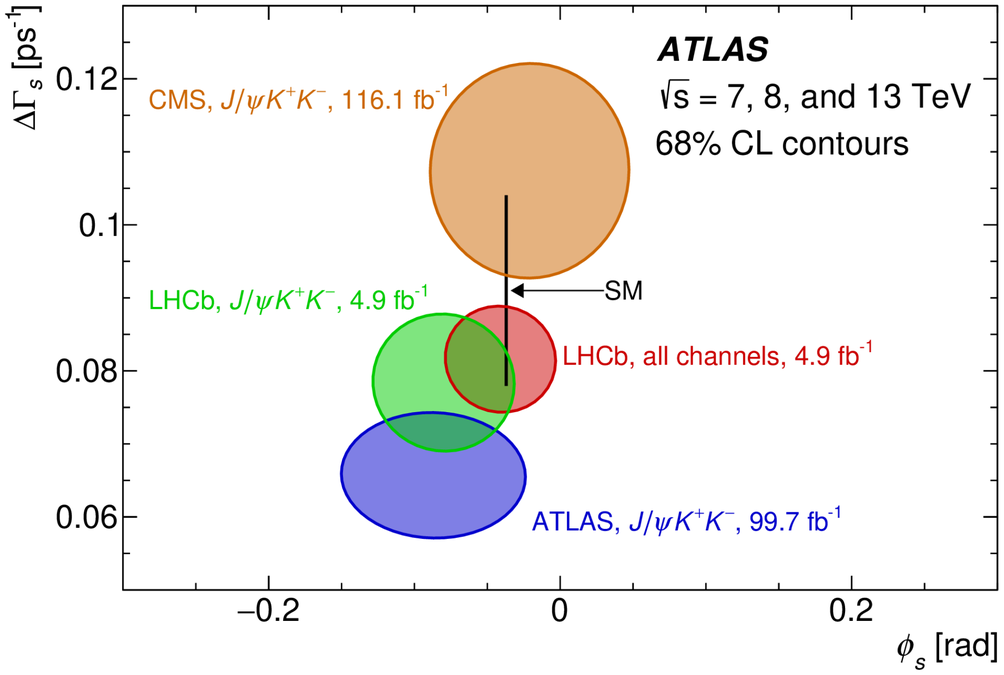




Flavor physics - Precision and Rare Decays

CP phase in Bs decays to $\mathbf{J/\Psi\phi}$

Eur. Phys. J. C 81 (2021) 342

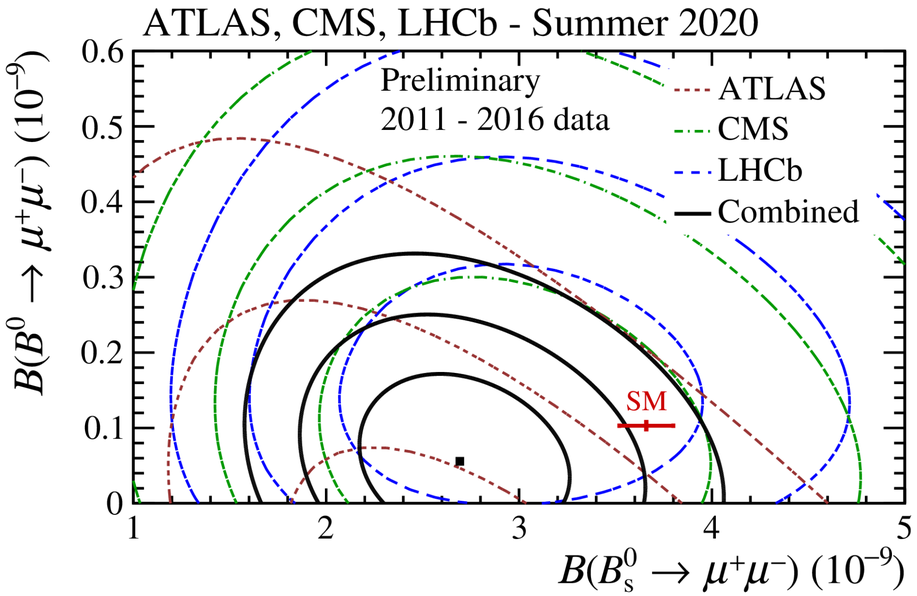


Excellent sensitivity from ATLAS with the help of the Insertable B-layer of pixels at 3 cm from the beam.

Combined results on $B_{s,d} \to \mu^+\mu^-$

Combination of ATLAS, CMS and LHCb

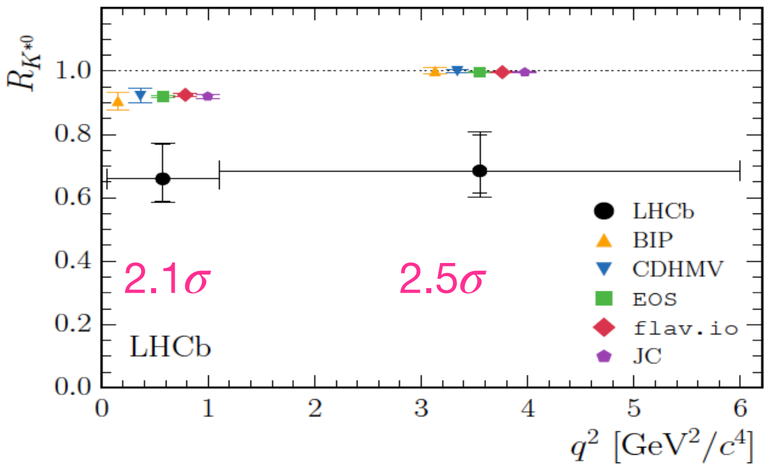
ATLAS-CONF-2020-049

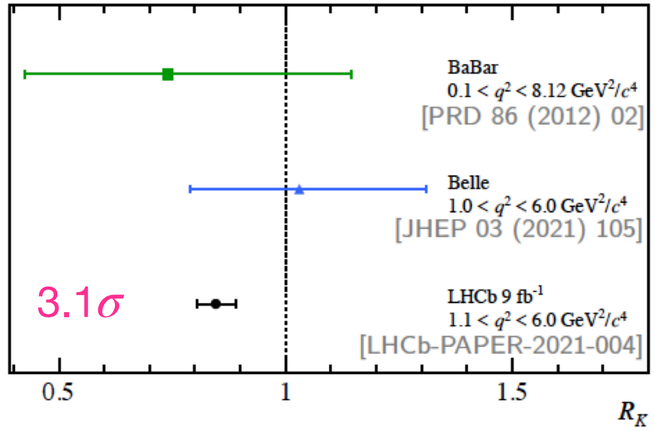


Small tension with SM value of **2.1σ**

LFU Anomalies in B decays

Part of the ''Footprints"* of rare B decays anomalies





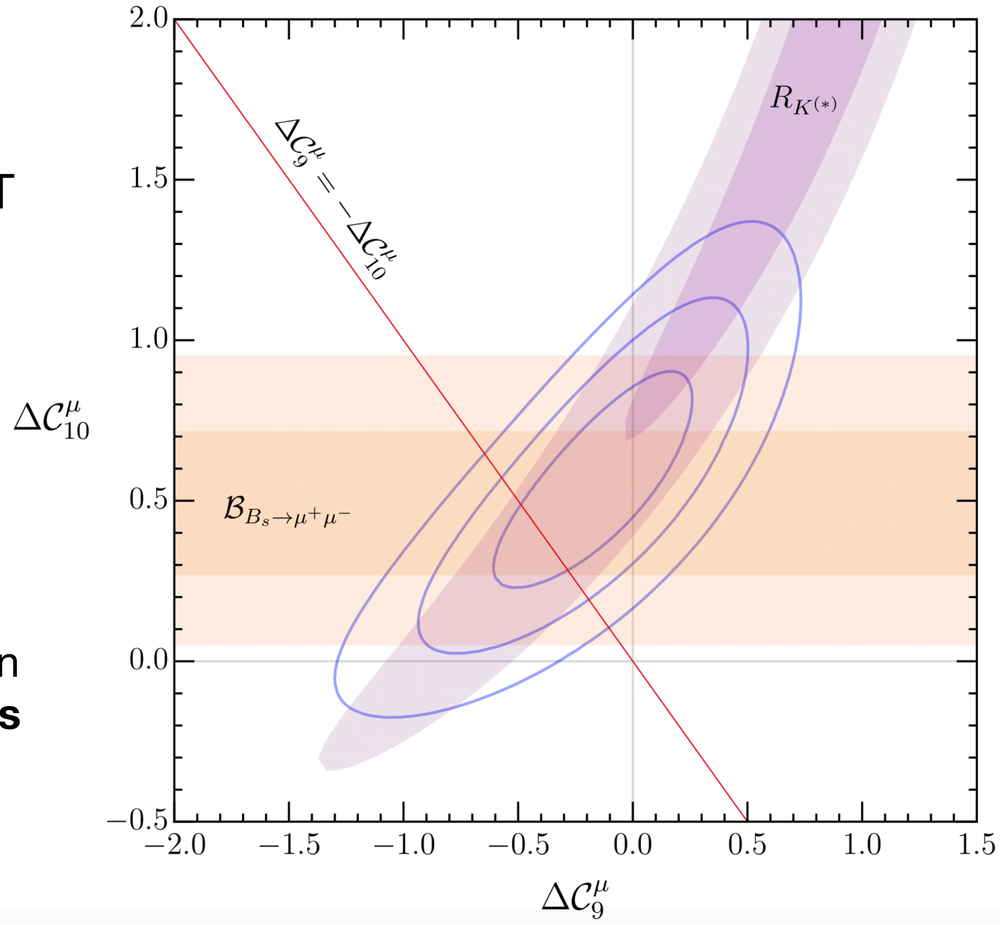
Combining through SM-EFT Dim.-6 FCNC operators:

$$\mathcal{O}_{10}^{\ell} = (\bar{s}_L \gamma_\mu b_L)(\bar{\ell}\gamma^\mu\gamma_5\ell)$$
$$\mathcal{O}_{9}^{\ell} = (\bar{s}_L \gamma_\mu b_L)(\bar{\ell}\gamma^\mu\ell)$$

These anomalies could be a sign of "**non trivial flavour dynamics at the TeV scale**"** further motivate direct searches of leptoquarks (both scalar and vector) and non universal heavy vector boson.

** Gino Isidori

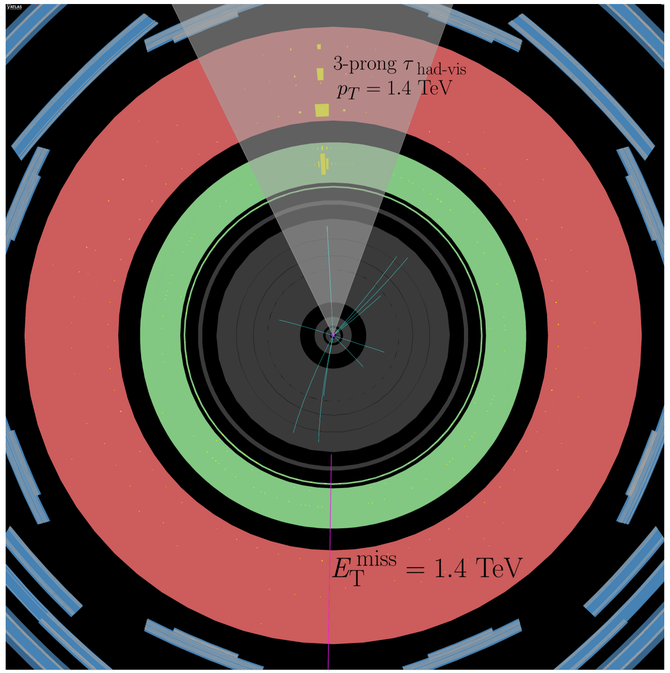
*C. Cornella et al. 2021



Combined with the RK* anomaly leads to a **4.6σ** tension

High mass resonances decaying to taus

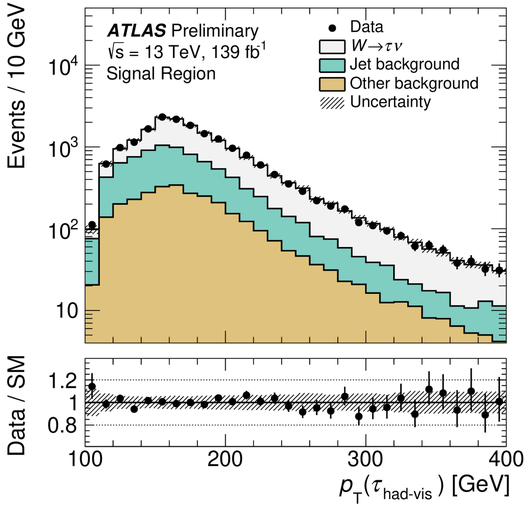
ATLAS-CONF-2021-025

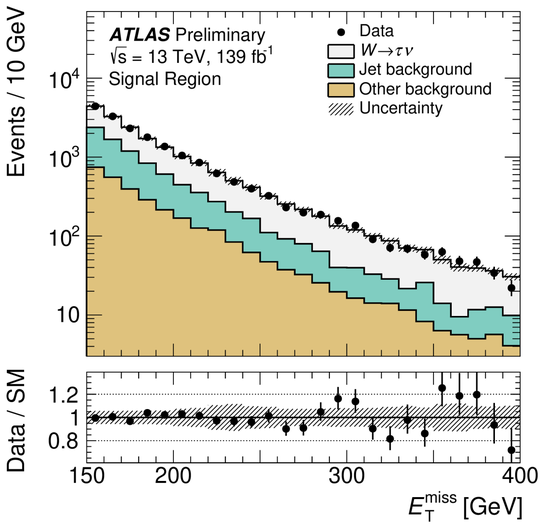


Search for $W' \to \tau\nu$

With high energetic taus reconstructed using a RNN technique.

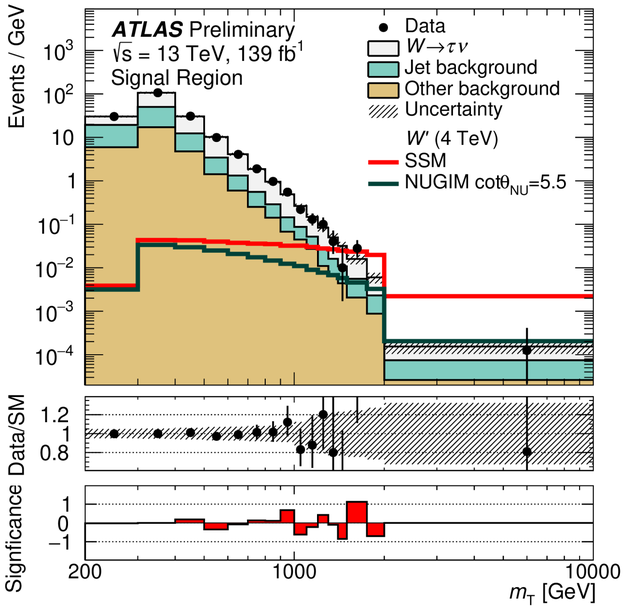
Excellent agreement between data and MC predictions!

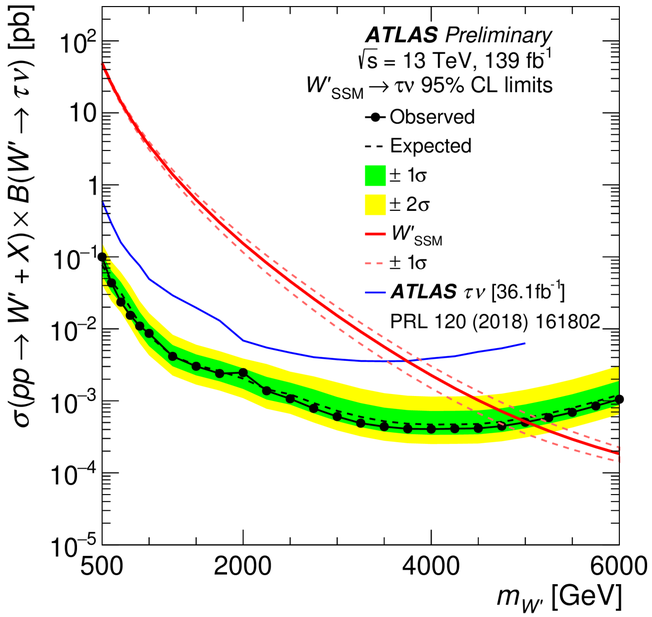




Results obtained to a fit of the transverse mass distribution.

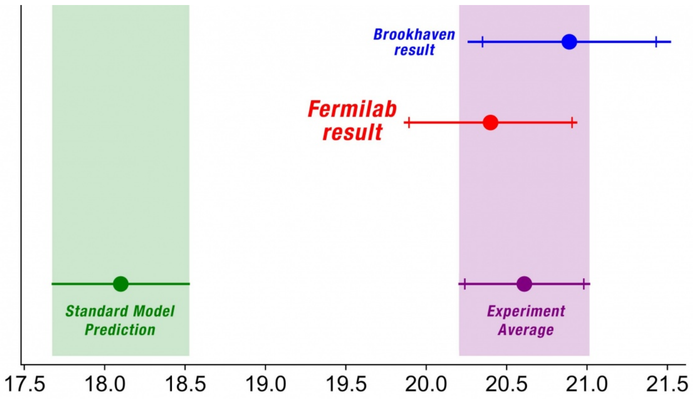
Highest transverse mass candidate (see above event display is at **mT ~2.8 TeV**)





Probing (g-2) and flavour Anomalies at High energy

Eur. Phys. J. C 80 (2020) 123

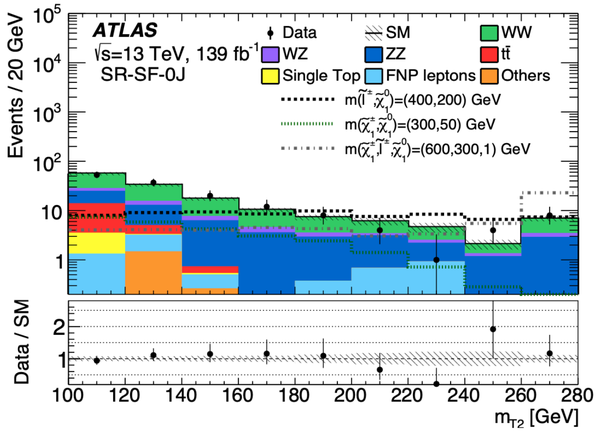


Recent muon (g-2) result from Fermilab reinforces the long standing tension with SM prediction

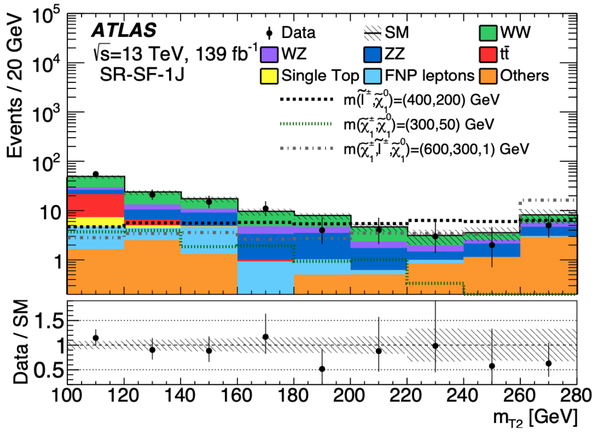
Muon (g-2) anomaly motivates searches for smuons

Using the s-transverse mass (estimated varying hypotheses of individual MET components)

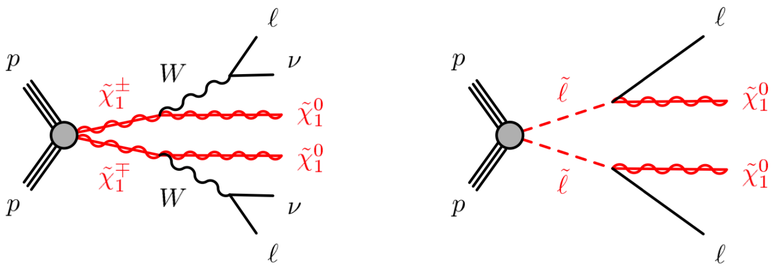
$$m_{\mathrm{T2}}(\mathbf{p}_{\mathrm{T},1}, \mathbf{p}_{\mathrm{T},2}, \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}) = \min_{\mathbf{q}_{\mathrm{T},1}+\mathbf{q}_{\mathrm{T},2}=\mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}} \left\{\max[\, m_{\mathrm{T}}(\mathbf{p}_{\mathrm{T},1}, \mathbf{q}_{\mathrm{T},1}), m_{\mathrm{T}}(\mathbf{p}_{\mathrm{T},2}, \mathbf{q}_{\mathrm{T},2})\,]\right\}$$



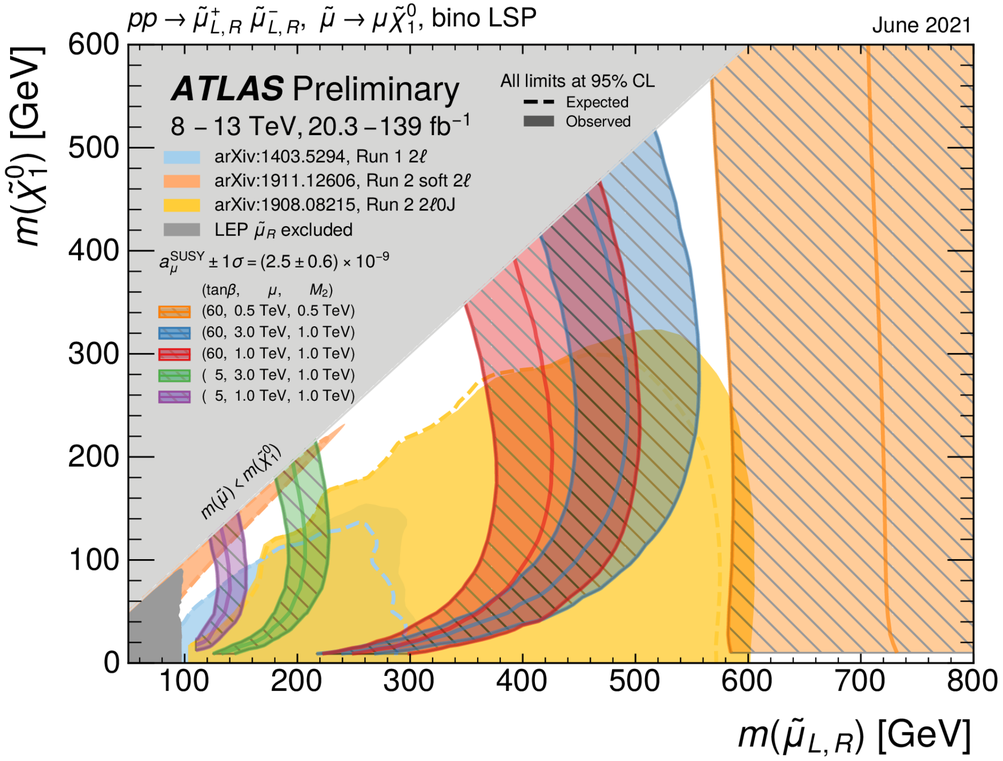
m_{T2} distribution in SR-SF-0J



m_{T2} distribution in SR-SF-1J



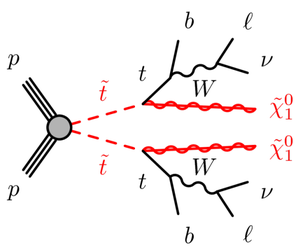
Search in scenarios with two leptons and MET



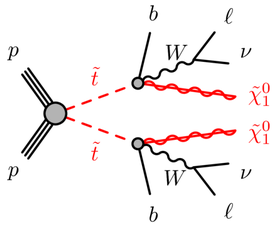
Searches for Natural and Strongly Produced SUSY

Stop

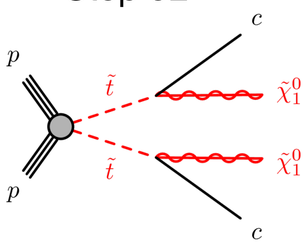
Stop 2L



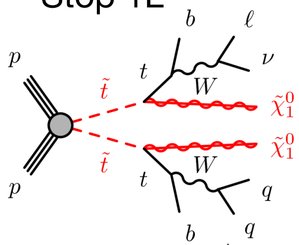
Stop 1,2-L



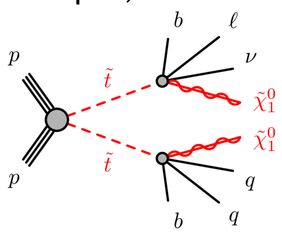
Stop 0L



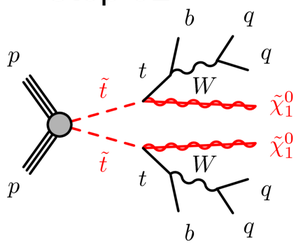
Stop 1L

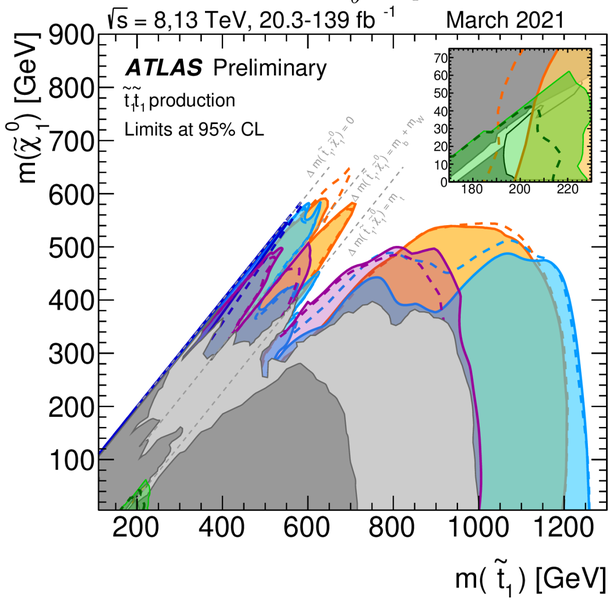


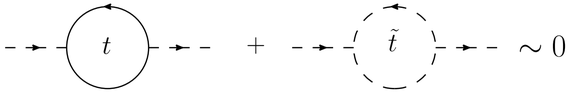
Stop 1,2-L



Stop 0L



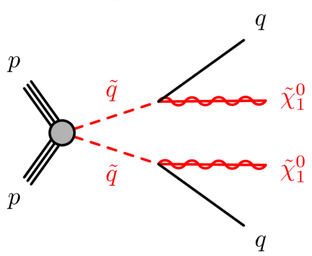




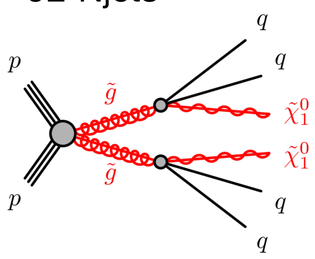
Not so natural SUSY: Stops > 1 TeV ~Tuning of factor **20**, but these exclusions are under specific conditions, and there are unexcluded corridors.

Squarks and gluinos

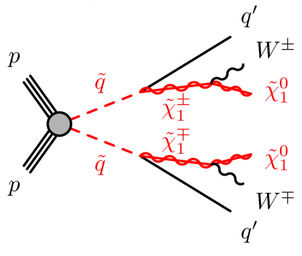
0L



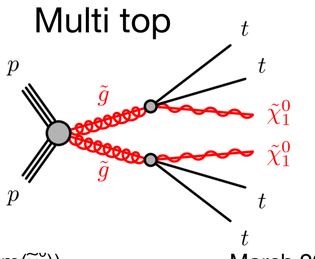
0L-Njets



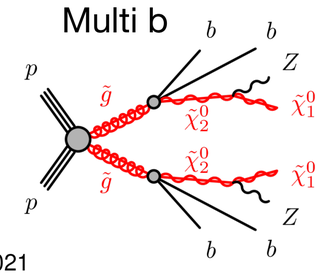
1L



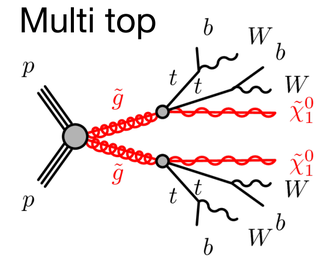
Multi top

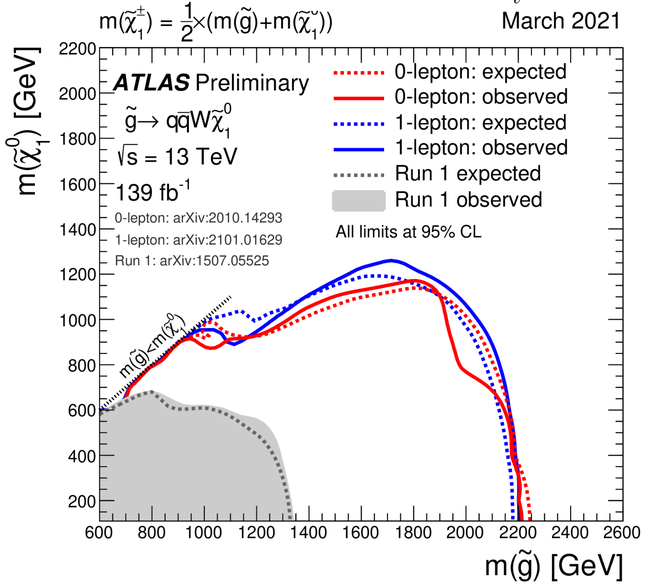


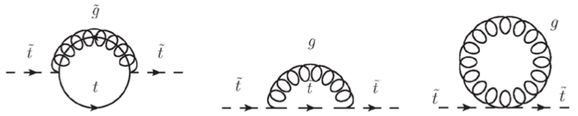
Multi b



Multi top





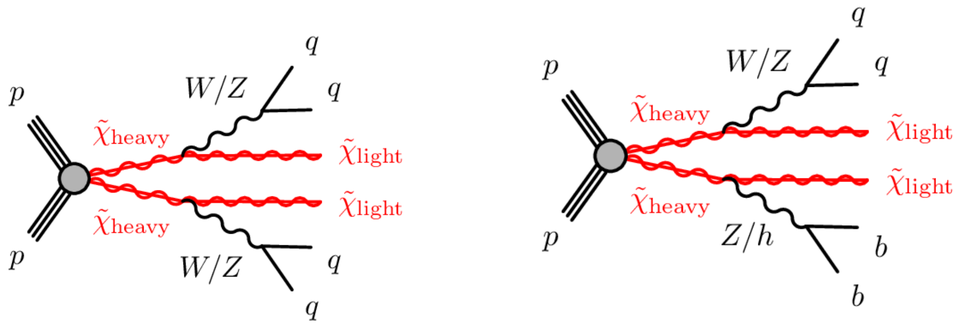


Stop also a scalar requires light gluinos to be light enough: for gluinos > 2 TeV ~tuning of Factor of **30**

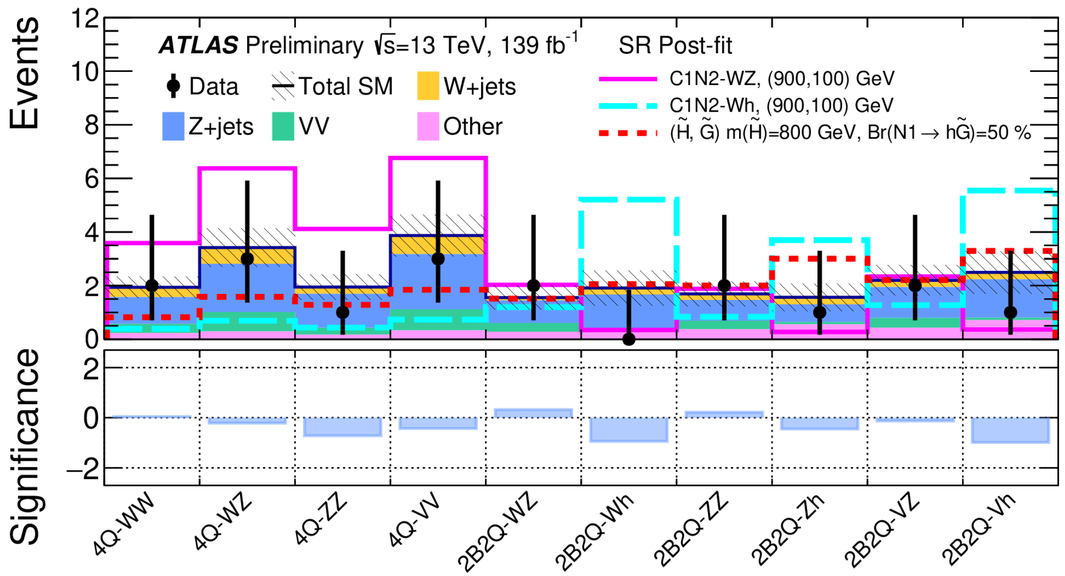
Search for Electroweakinos

ATLAS-CONF-2021-021

Search for electroweakinos at high mass in boosted fully hadronic final states (W/Z/H)



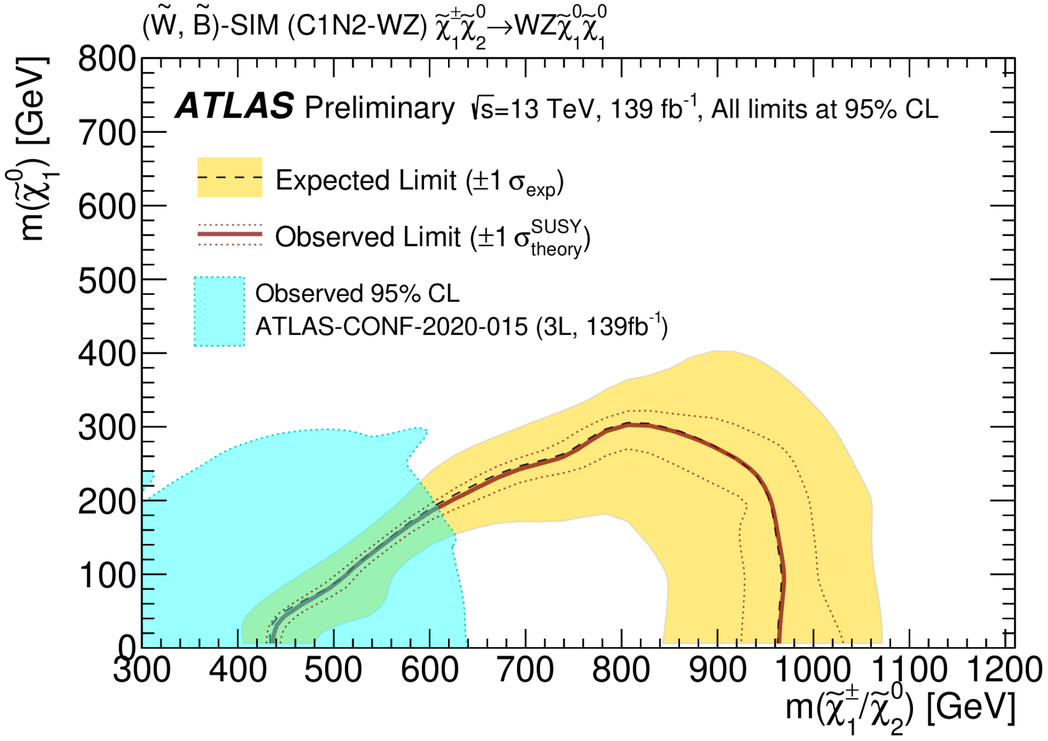
Topologies searched for qq,qq and qq,bb



Using boosted jets (above 200 GeV) with substructure (D2*)

Most stringent limit to date excluding EWKinos up to almost 1TeV

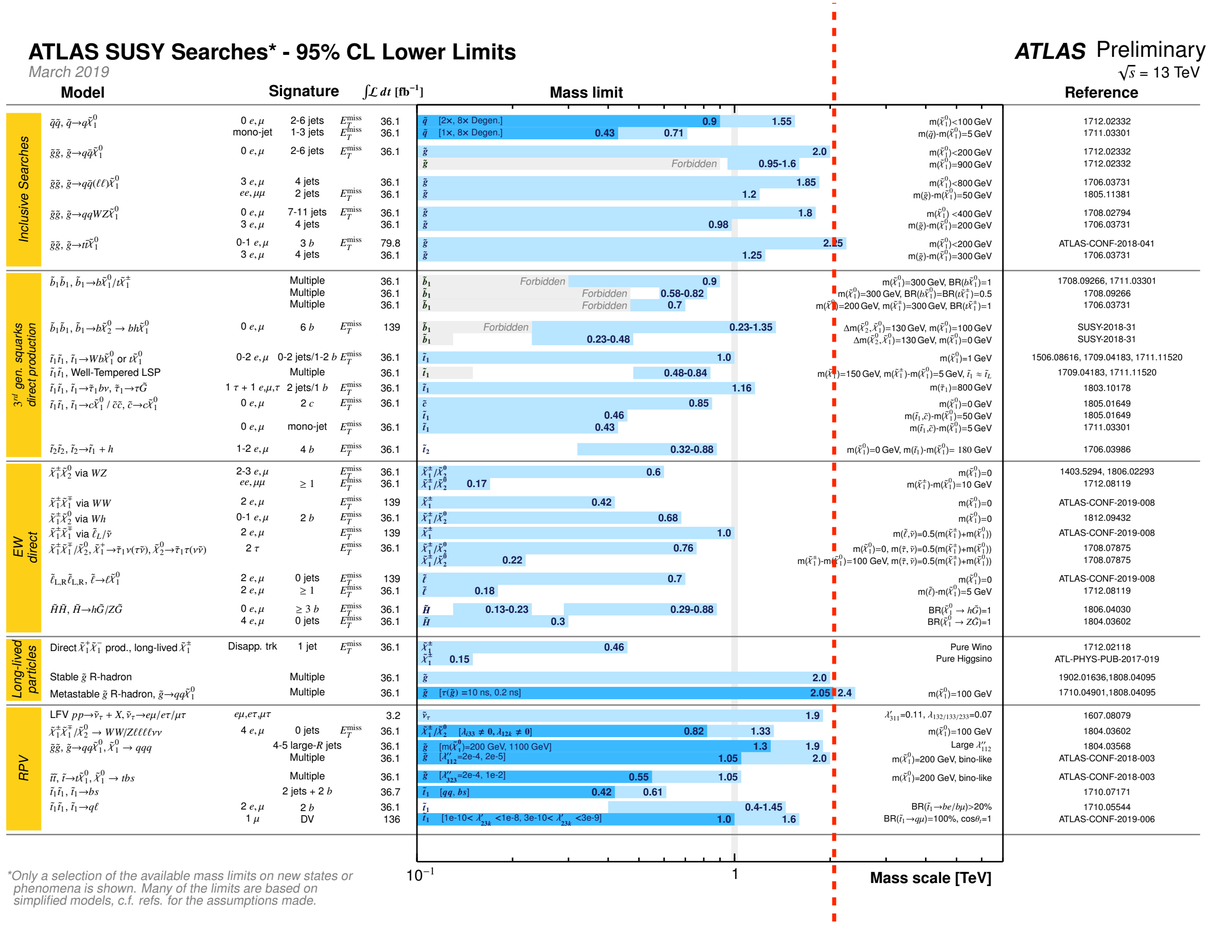
(of course larger corridor in mass difference to LSP which in this case should be significantly lighter)



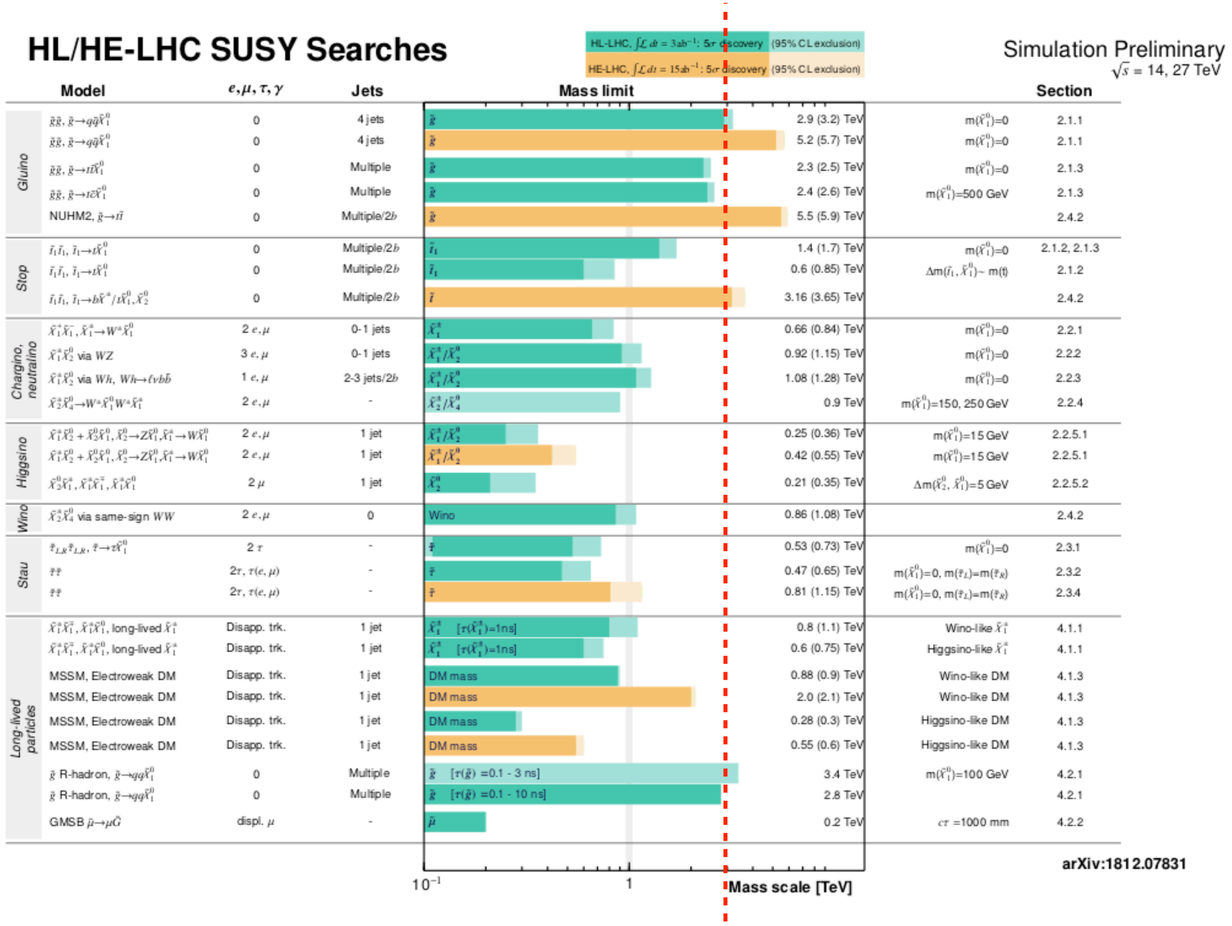
*Ratio of two-points to three points energy correlations between particles of a jet

Very Large Number of SUSY Searches

(in large variety of topologies and models)



2 TeV



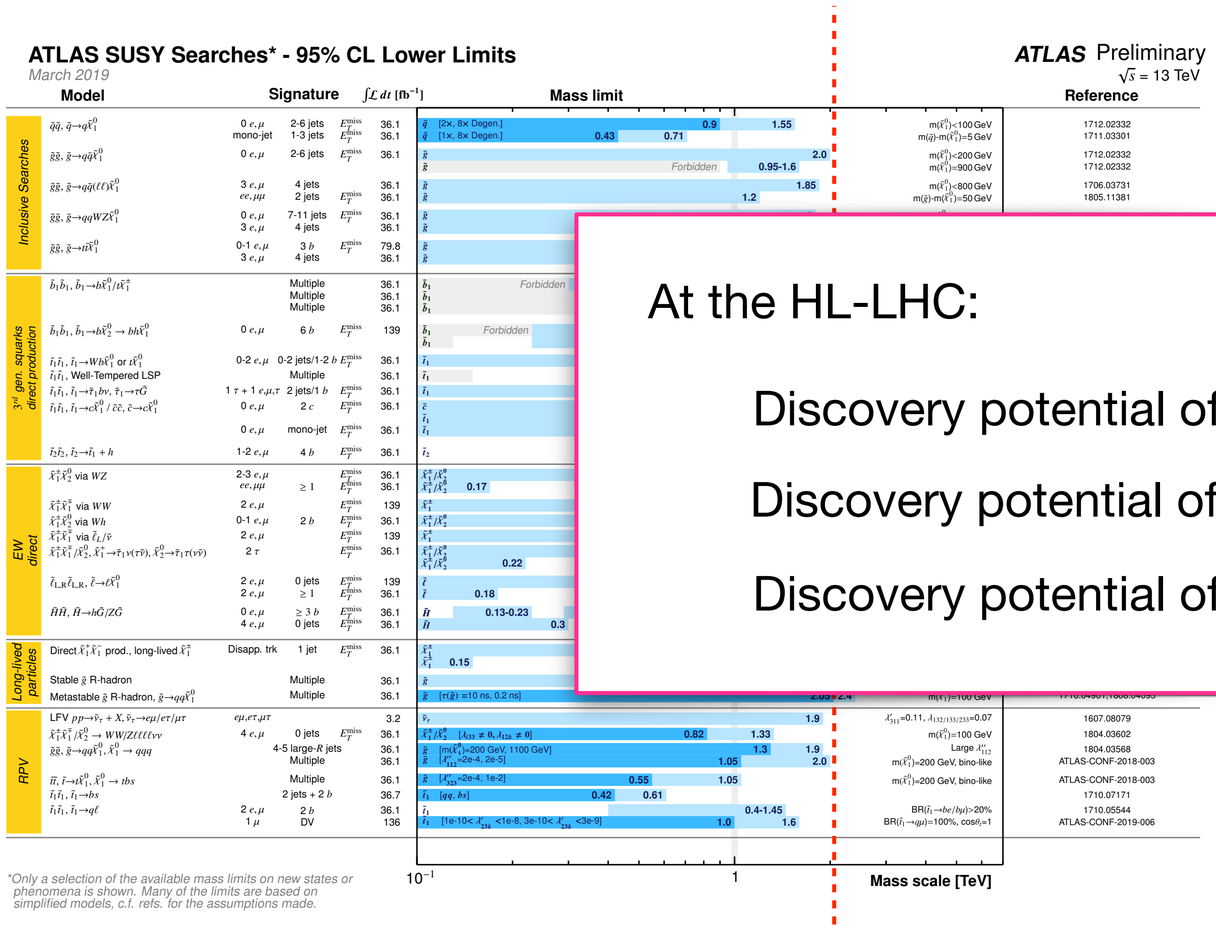
3 TeV

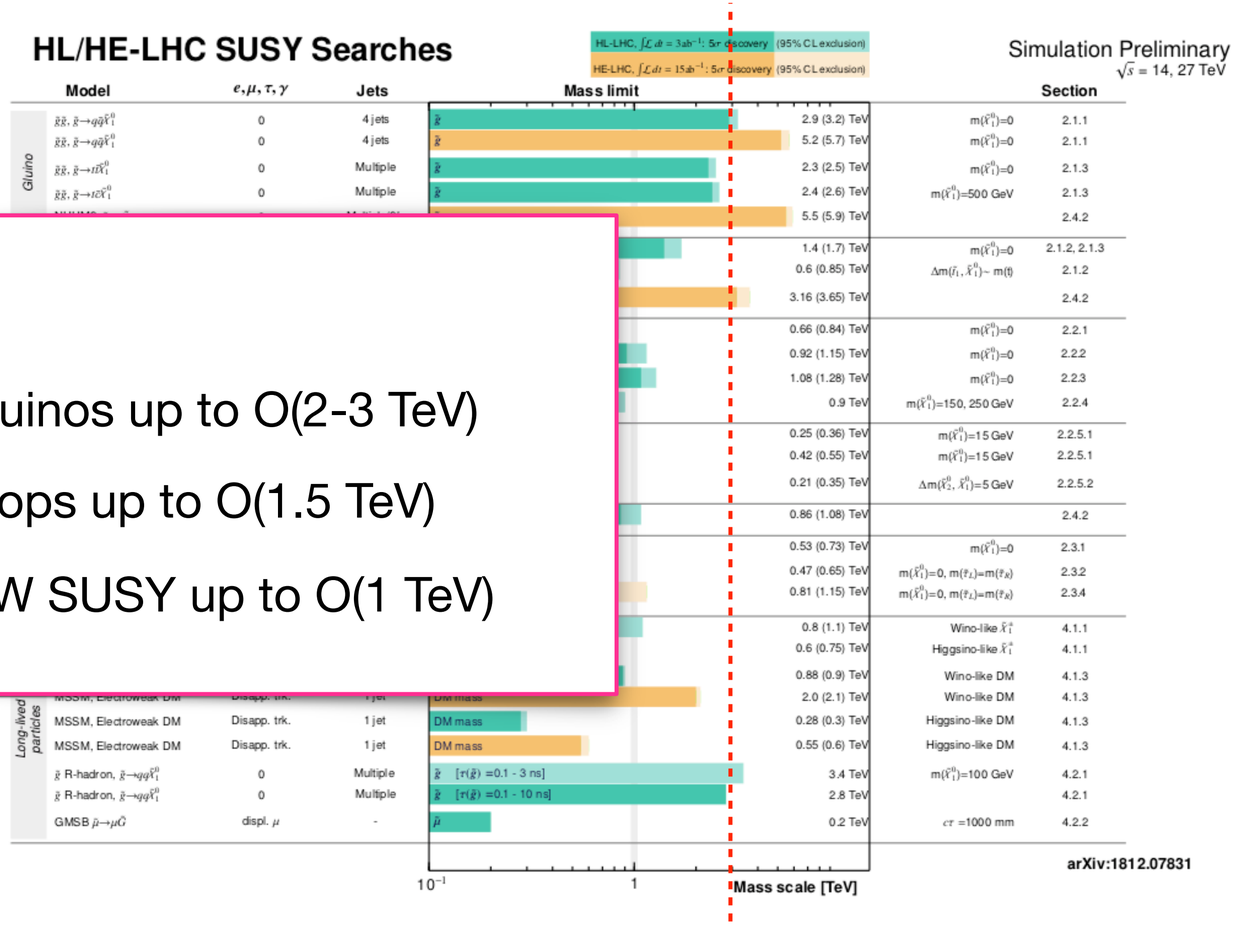
HL-LHC YR
1812.07831

Example from ATLAS (same for CMS)

Very Large Number of SUSY Searches

(in large variety of topologies and models)





At the HL-LHC:

Discovery potential of gluinos up to O(2-3 TeV)

Discovery potential of stops up to O(1.5 TeV)

Discovery potential of EW SUSY up to O(1 TeV)

2 TeV

3 TeV

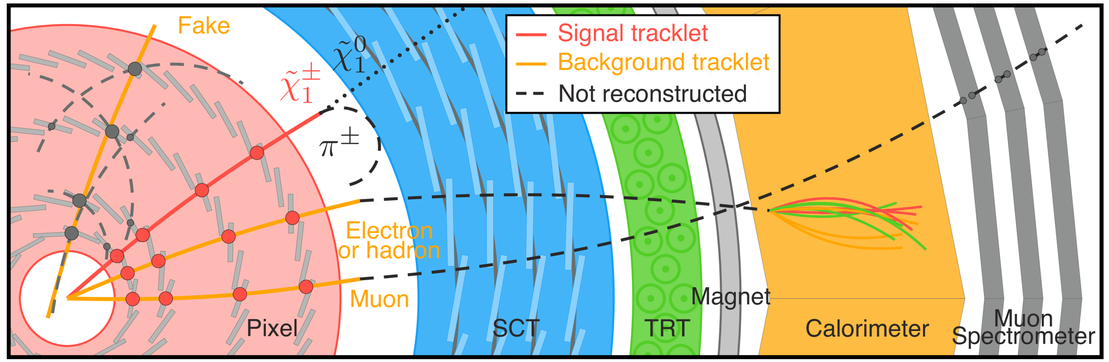
Example from ATLAS (same for CMS)

HL-LHC YR
1812.07831

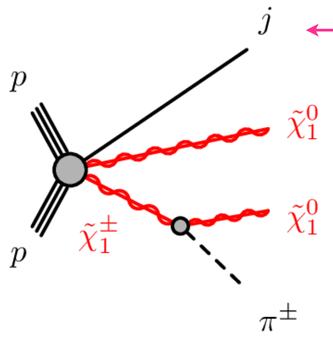
Long Lived

Charginos

ATLAS-CONF-2021-015

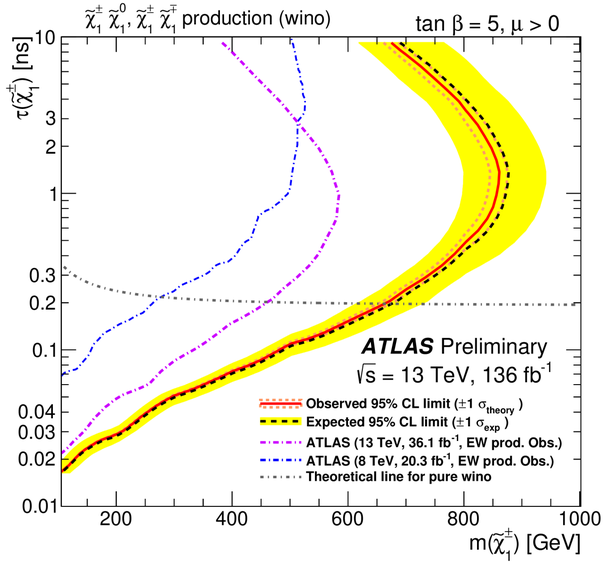


Tracklet topology: track disappearing in the ID



Jet needed to trigger event!

In the case of puro Wino chargino: lower limit on chargino mass of ~650 GeV!



Gluinos

CERN-EP-2021-41

Long lived gluinos would hadronise with quarks and gluons and for R-hadrons!

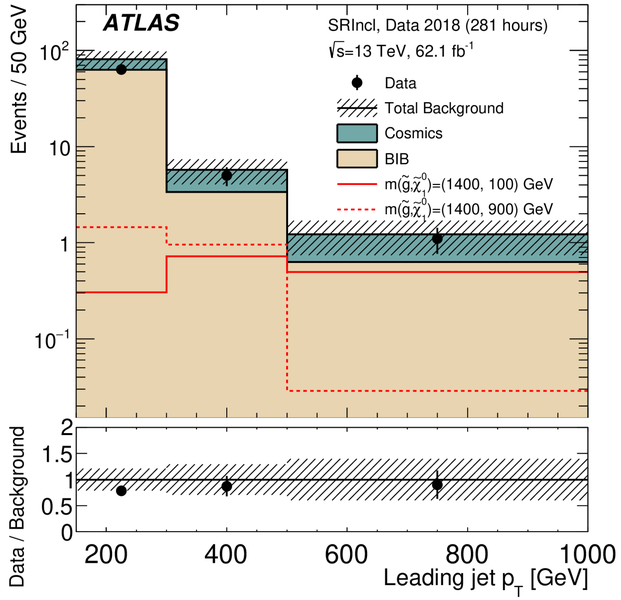
R-hadrons can come a stop in the detector volume and decay after a period of time.

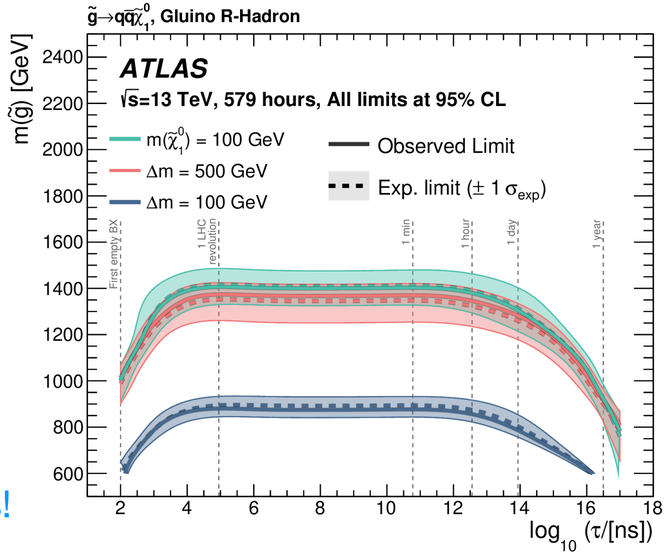
The search looks at "empty bunches" i.e. data taken at times when the no proton bunches collide.

Dominant backgrounds in absence of beams: cosmic muons and beam backgrounds (from collimators upstream).

Uses dedicated (jet) triggers in empty bunch crossings!

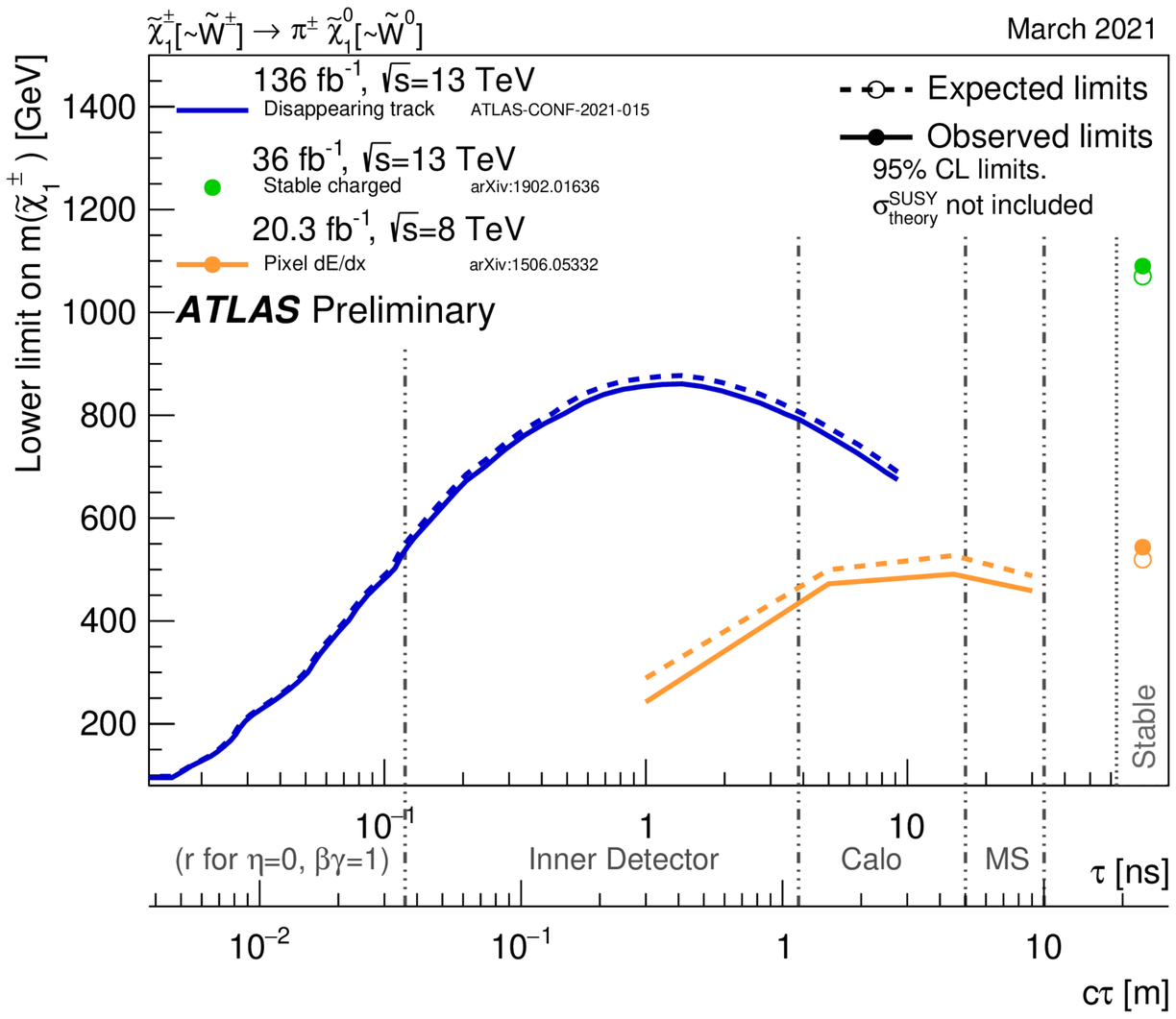
Limits between 400 GeV and 1.4 TeV over a very wide range of proper times!



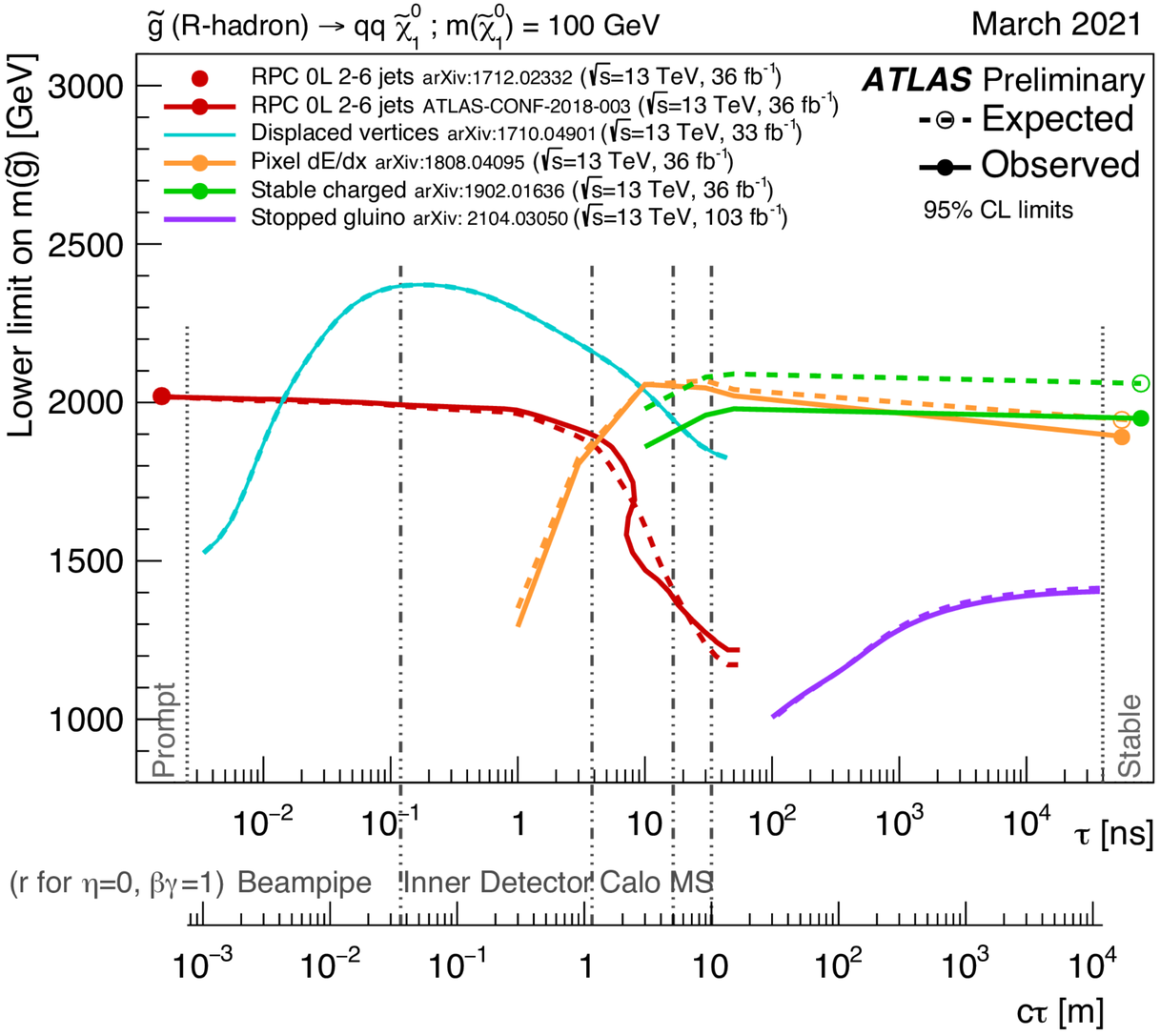


Long Lived

Charginos



Gluinos



Unconventional Signatures

Many extensions of the Standard Model predict new particles that are long lived heavy (neutral and charged) and can decay after several cm or even meters.

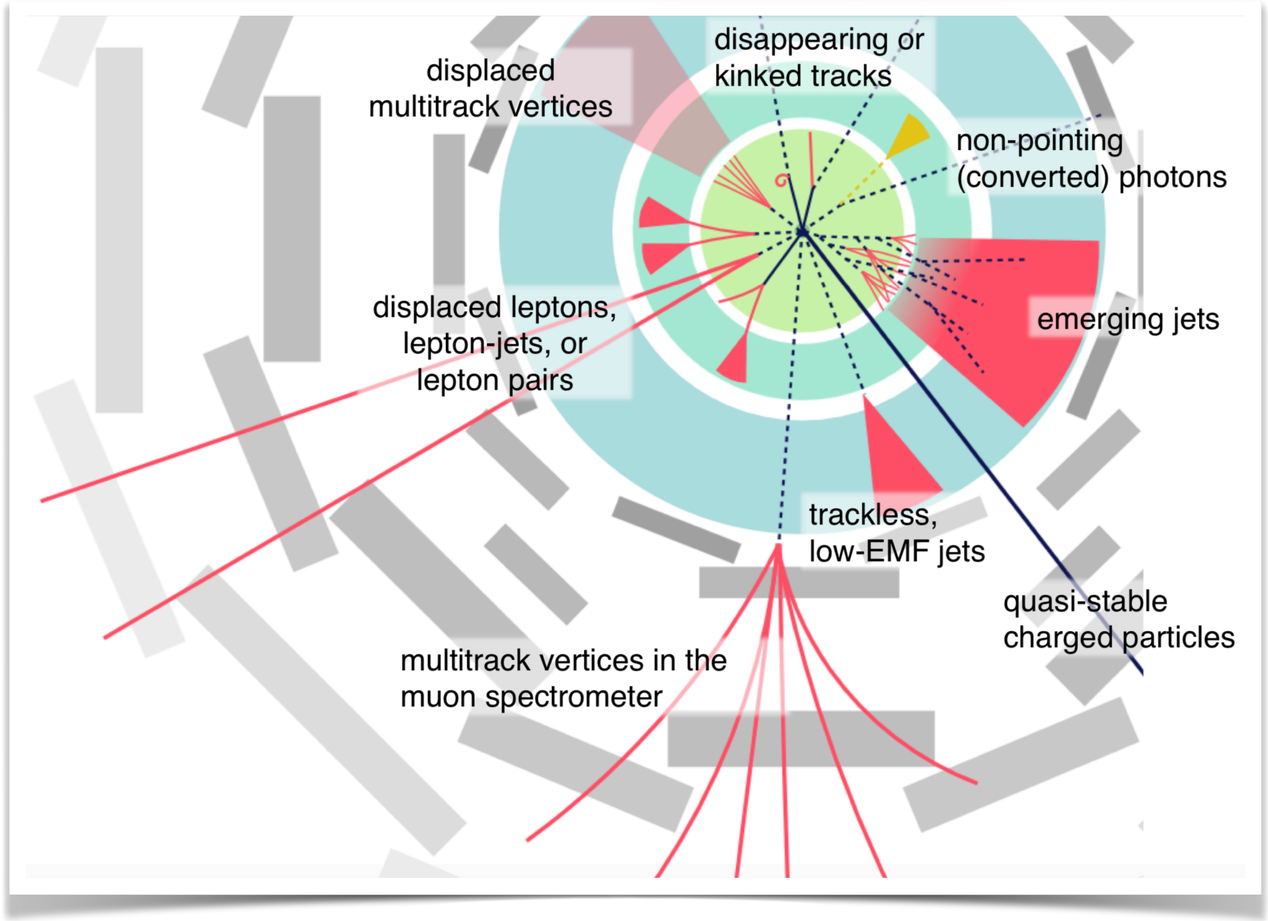
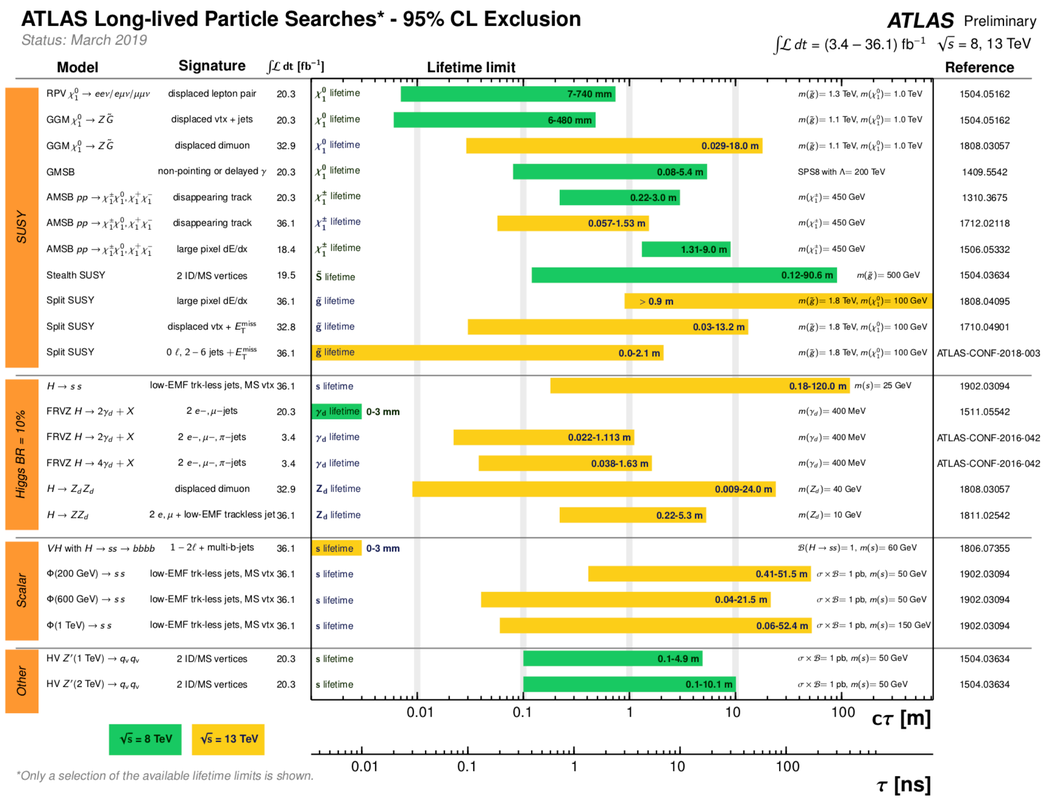


Image from H. Russel



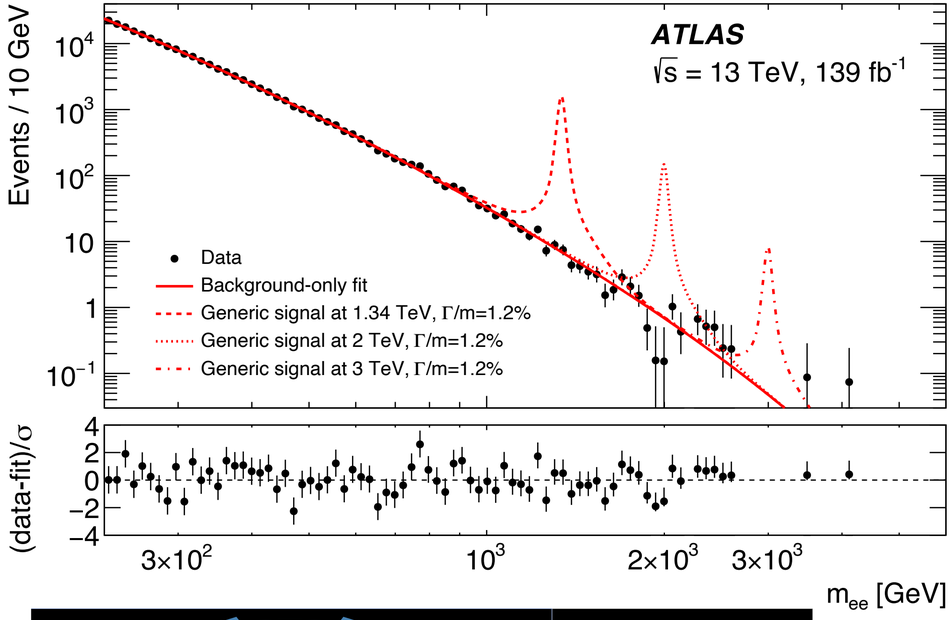
Sample for ATLAS (same for CMS)

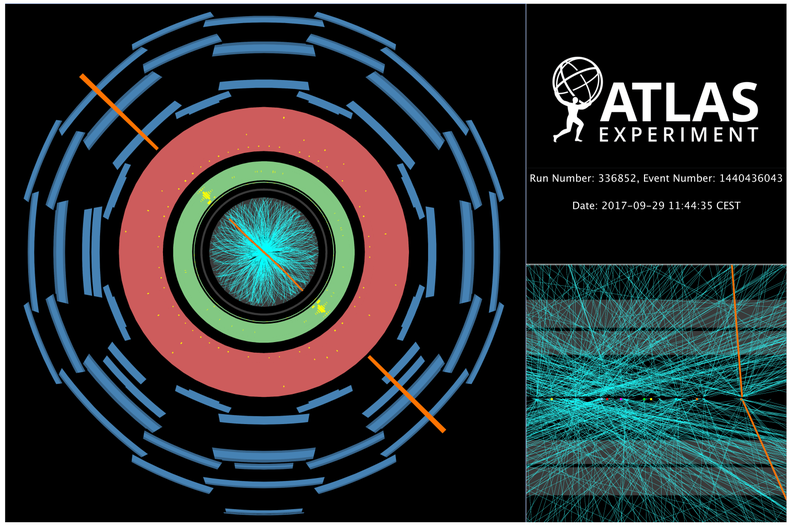
Difficult signatures requiring specific complex reconstruction and trigger!

Searches for High Mass Resonances

ATLAS Dilepton search

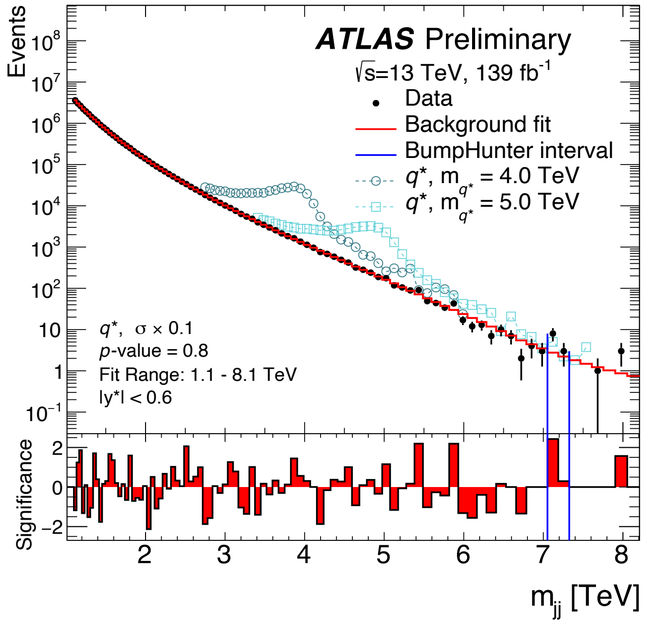
ATLAS 1903.06248





Exclusions up to ~5 TeV

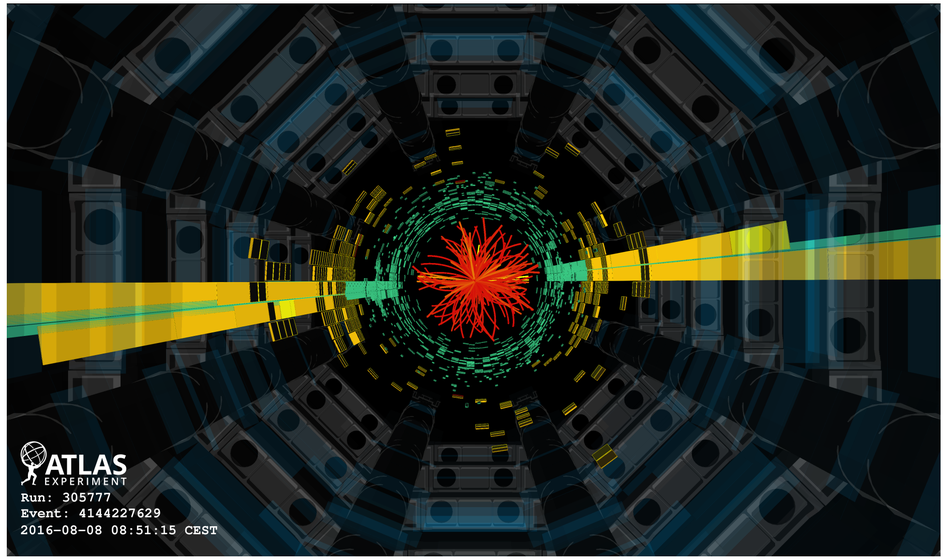
Highest mass di-electron event ~4 TeV



ATLAS Dijet search

ATLAS-CONF-2019-007

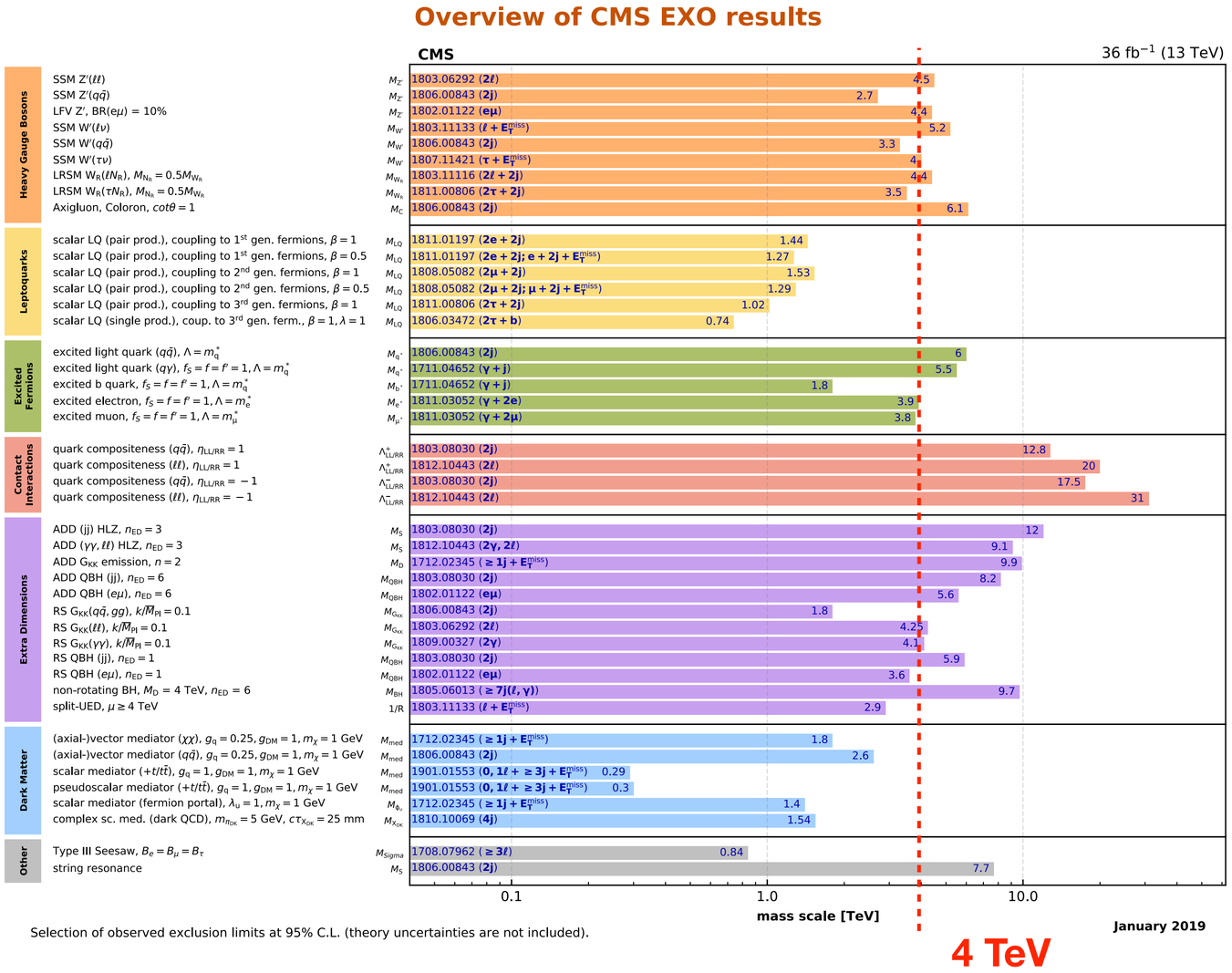
Limits on excited quarks at 6.7 TeV



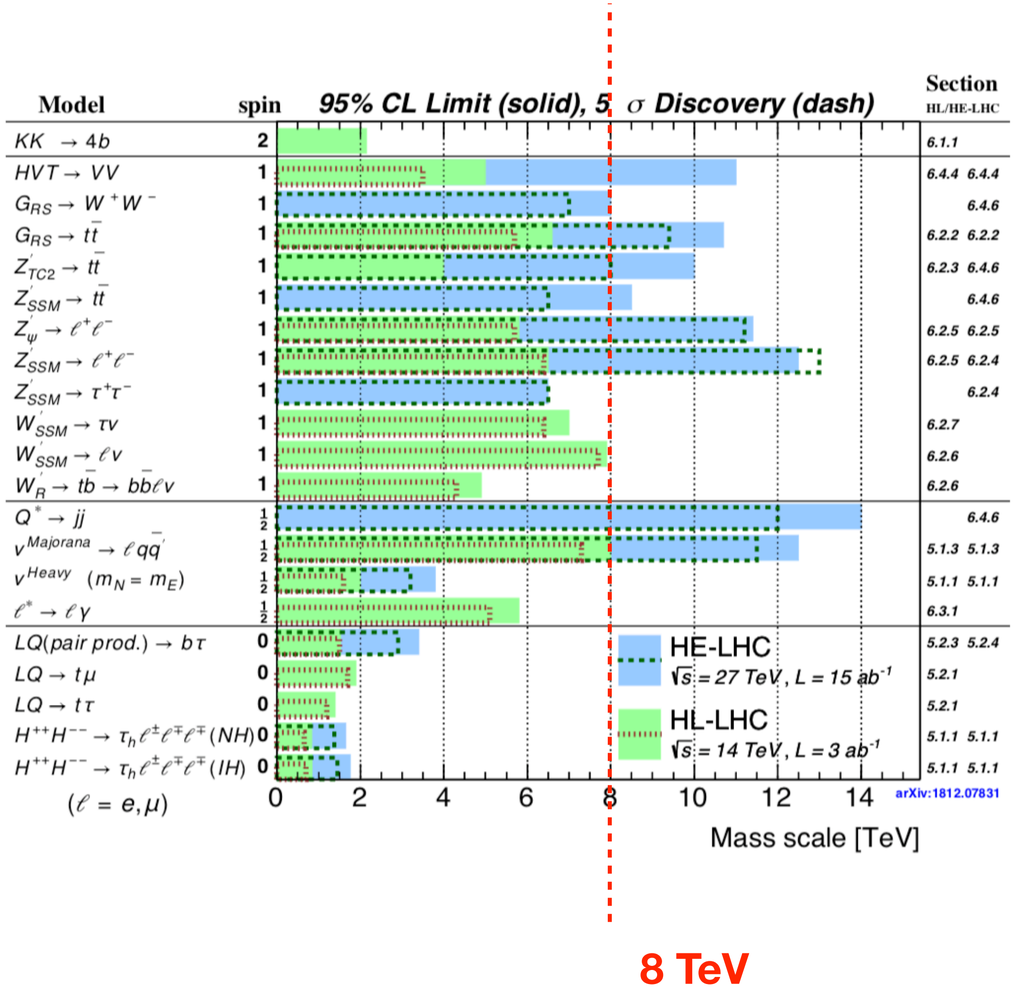
Highest mass (central) dijet event ~8 TeV

Very Large Number of Searches

(in large variety of topologies and models)



Selection of observed exclusion limits at 95% C.L. (theory uncertainties are not included).

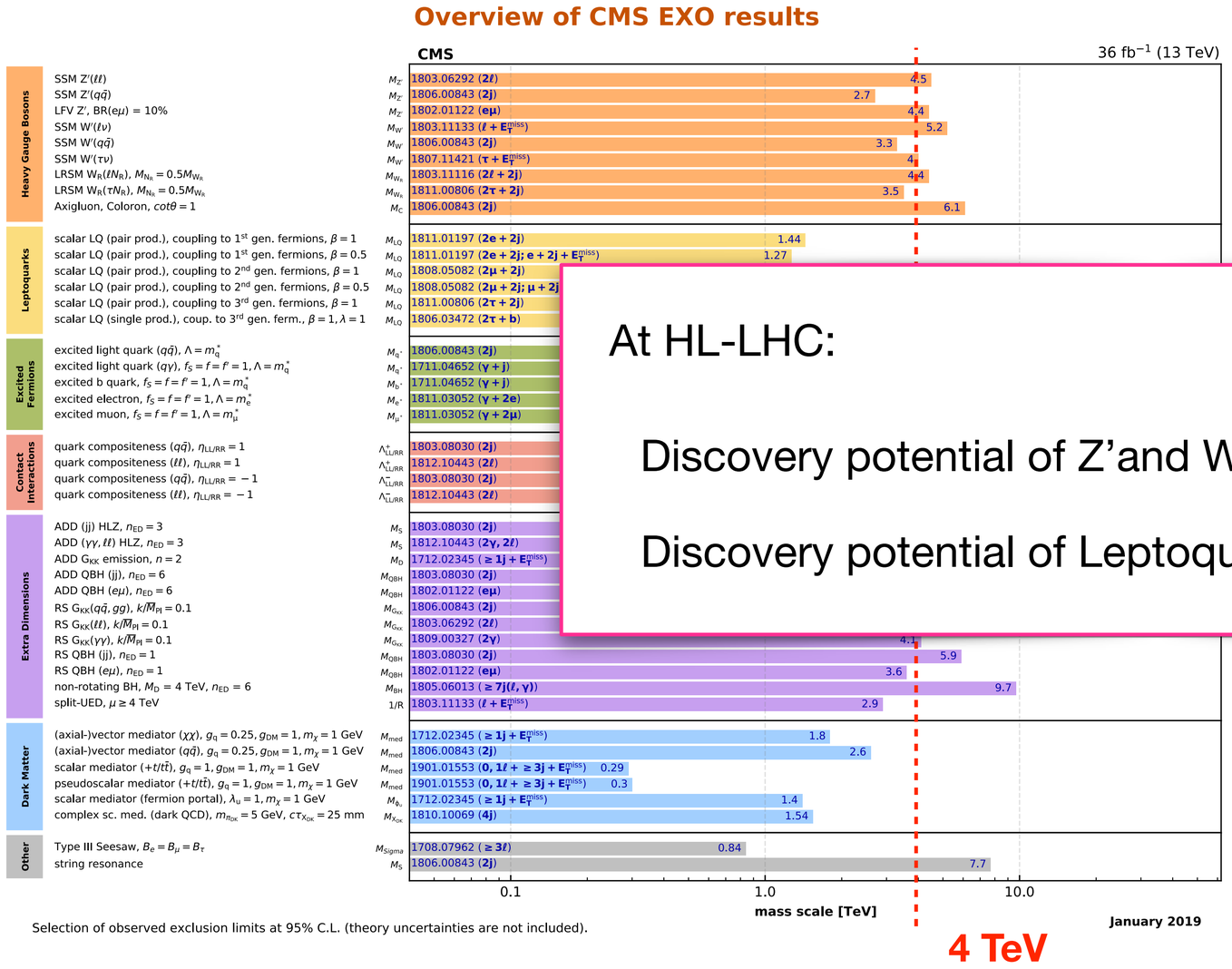


HL-LHC YR
1812.07831

Example from CMS (similar for ATLAS)

Very Large Number of Searches

(in large variety of topologies and models)



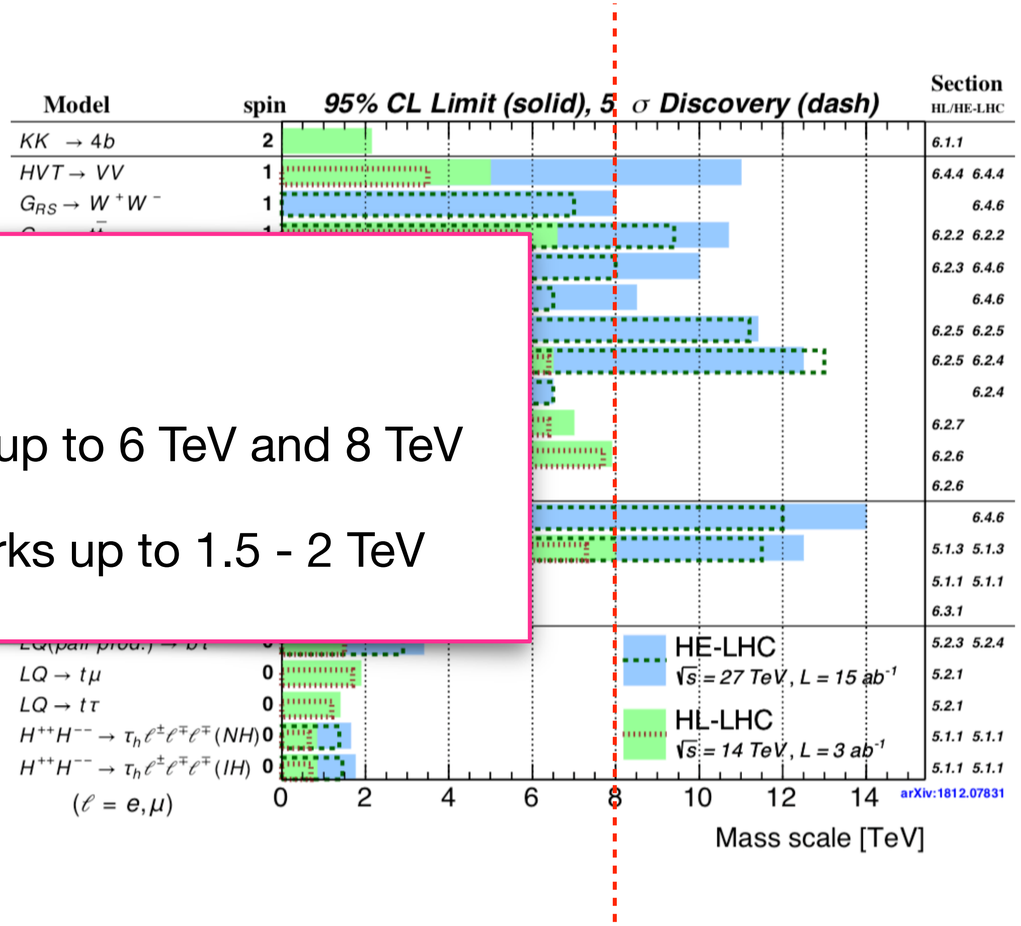
Selection of observed exclusion limits at 95% C.L. (theory uncertainties are not included).

4 TeV

At HL-LHC:

Discovery potential of Z'and W' up to 6 TeV and 8 TeV

Discovery potential of Leptoquarks up to 1.5 - 2 TeV



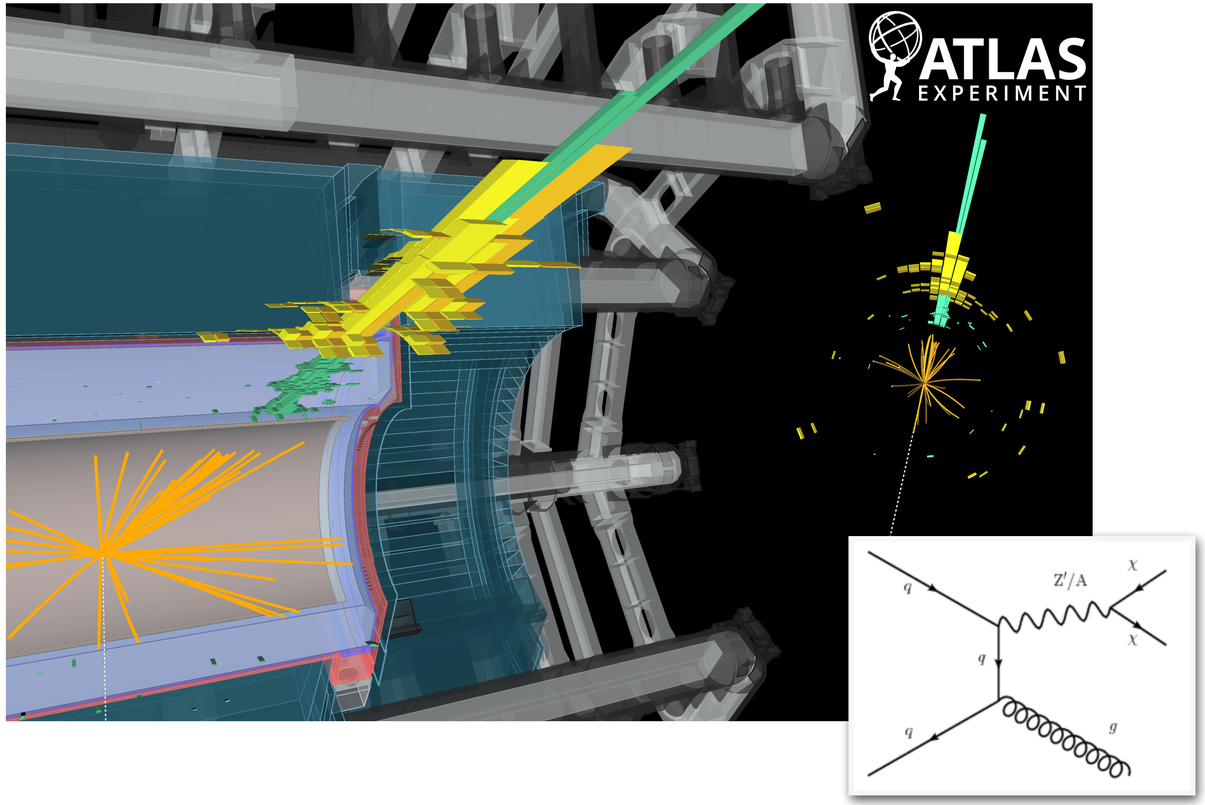
8 TeV

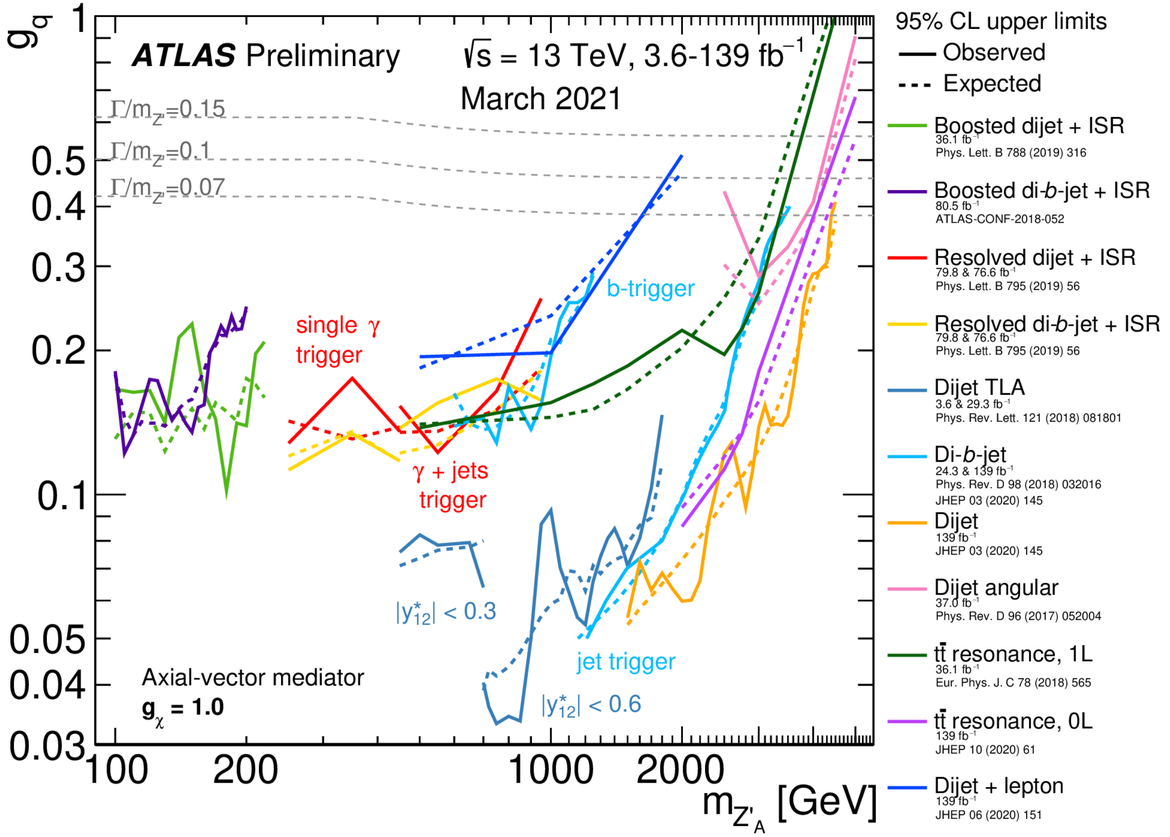
HL-LHC YR
1812.07831

Example from CMS (similar for ATLAS)

Generic Searches for Dark Matter

Primarily Searches for spectacular topologies: Mono-jet, mono-V, mono-photon mono-Higgs, mono-top, etc…





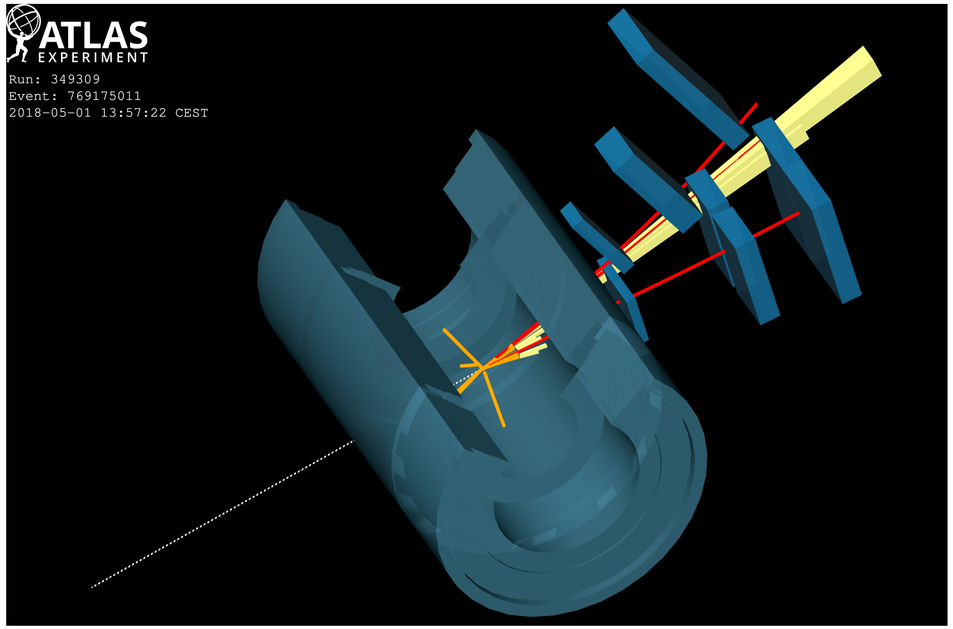
Interpretations in simplified models, introducing generic mediator searched for as well.

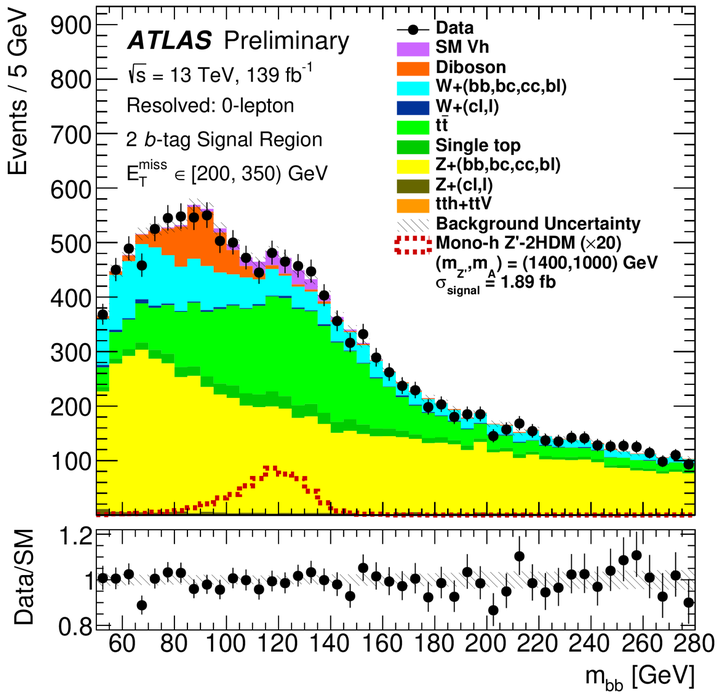
Numerous strategies to also cover lower masses e.g.:

- boosting (ISR)
- Trigger level analyses

Dark Matter - Mono Higgs search

ATLAS-CONF-2021-021



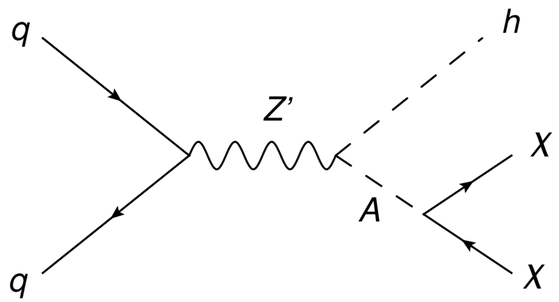


Exclusions set in the A and Z' masses plane (with DM mass of 100 GeV).

Exclusions of Z' masses of 3.1 TeV for a mass of th A of 300 GeV.

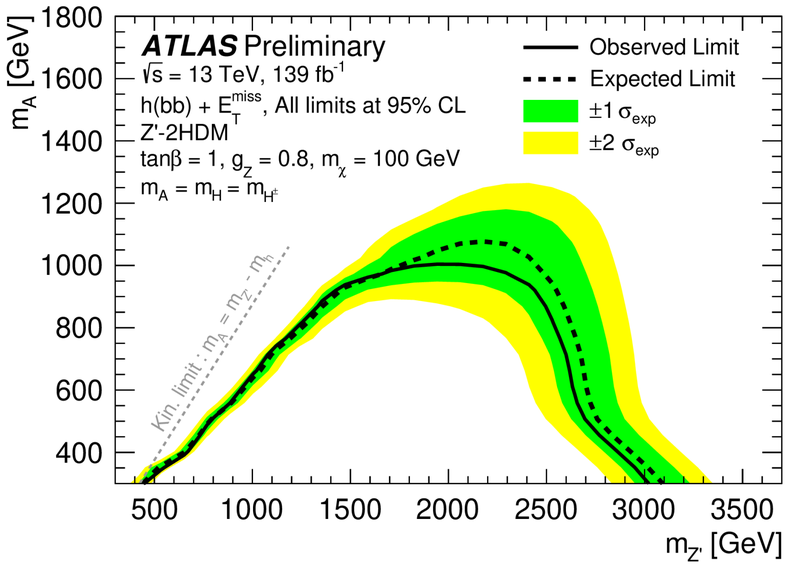
Higgs boson decaying to a pair of b-quarks

Using as benchmark Z' mediator simplified models and a CP-Odd A (2HDM) decaying to DM particles.



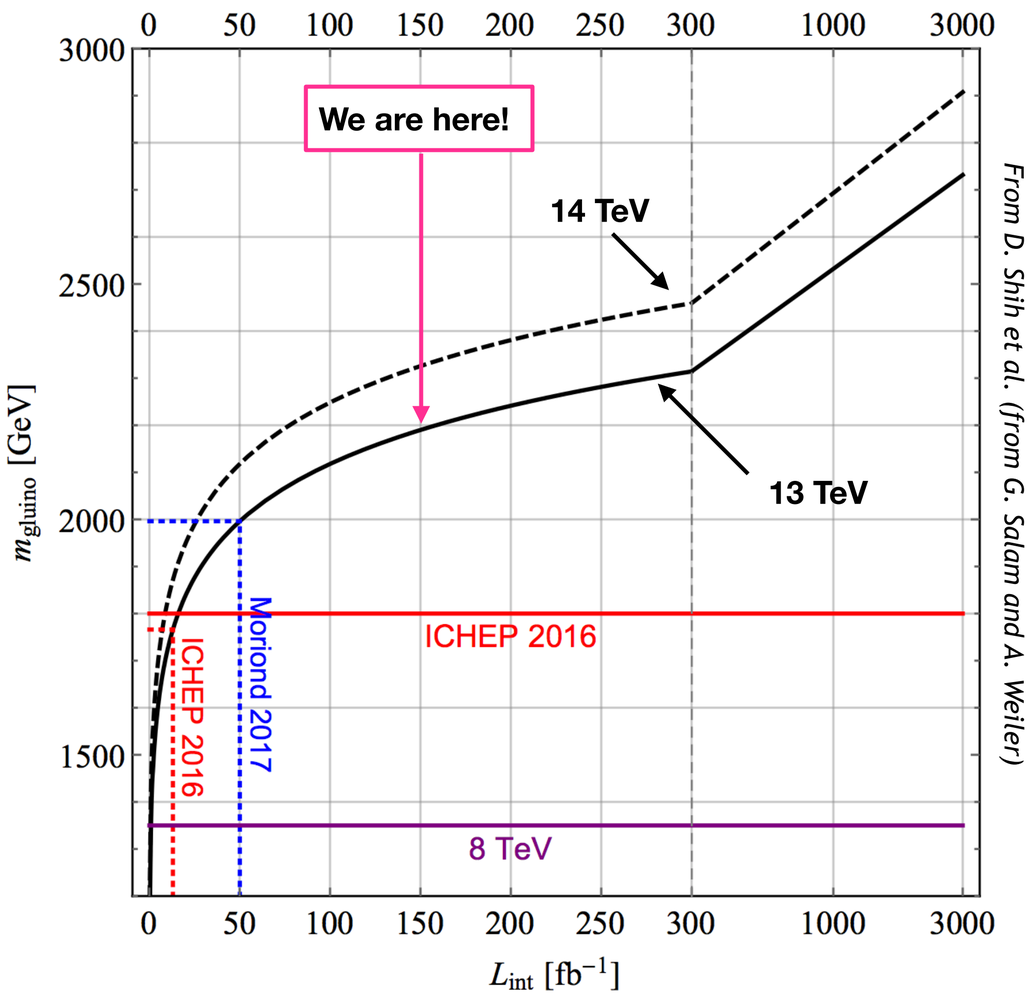
2HDM h is the observed Higgs boson decaying to b-quarks.

Analysis similar to the measurement of the H(bb) in the ZH production with Z decaying to neutrinos!



Towards HL-LHC and Precision Physics at LHC

Evolution of **exclusion** search sensitivity for generic strongly interacting particle (e.g. **gluino**)



http://collider-reach.web.cern.ch/collider-reach/

Towards HL-LHC still a **factor of 23** in luminosity:

- Still **room for discoveries!**
- Given that the **doubling time of the luminosity** is now counted in **several years**: discoveries will take time.
- Low hanging fruits typically have been (or are being) harvested! large effort in trying to expand search reach beyond the $\sqrt{L}$:
  - With new ideas and developments at all levels.
  - Improving precision!

Precision in general will be key!

Summary and Conclusions

- **Intense times for LHC** LS2 upgrades are being finalised and we are **gearing up for Run 3**!

- **After 10 years of running**: the LHC, ATLAS and all LHC experiments have been **extremely successful**!

  - **Landmark results**: the **Higgs boson** (Standard Model like) and so far **nothing else!**

  - Performance and precision reached in a number of major measurements (Higgs couplings, W mass, weak mixing angle, CPV in meson systems, top, EW, Heavy Ions, etc…) have **exceeded our projections**.

  - Pursuing a vast search program **leaving no stones unturned**!

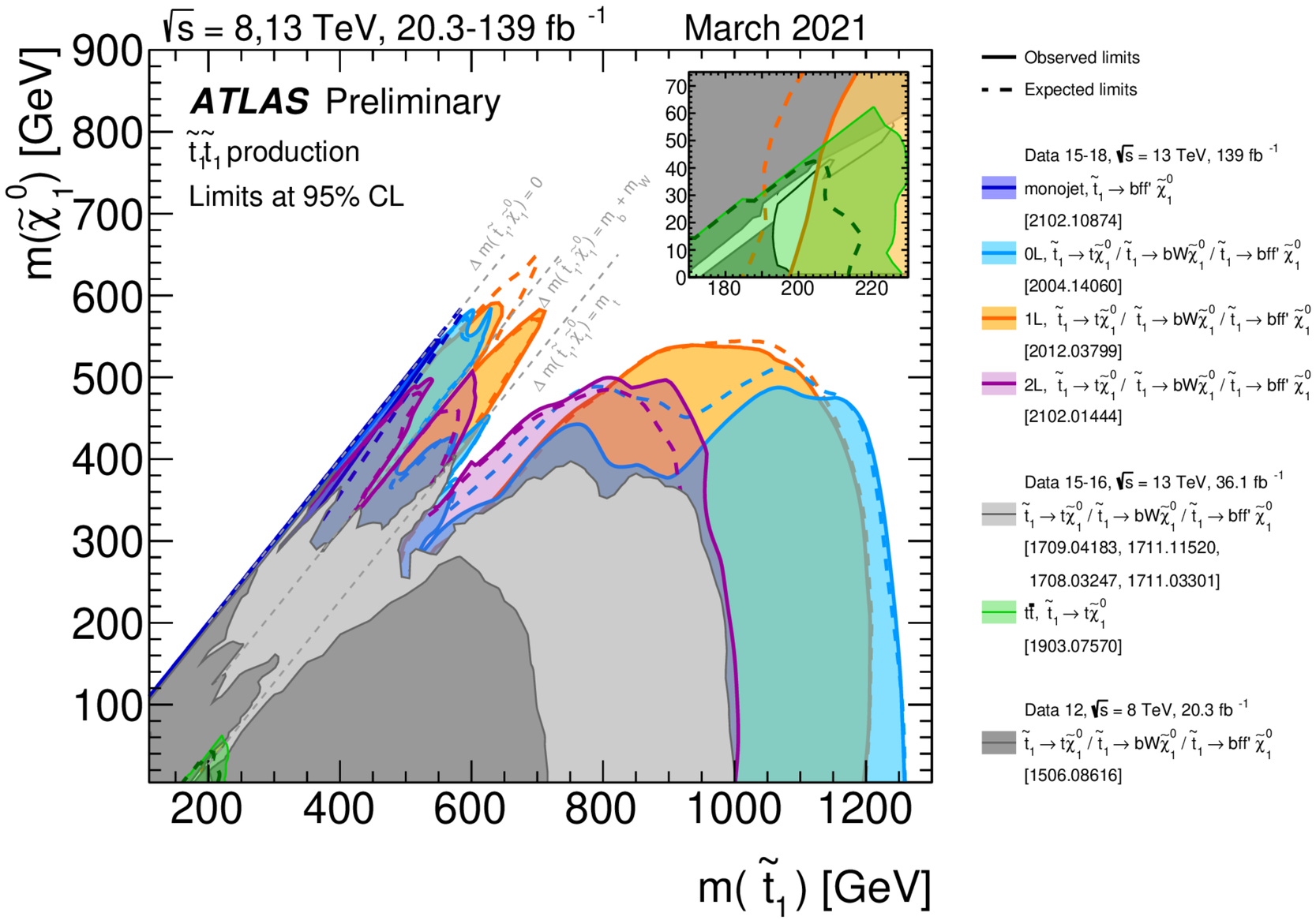
- **Precision will be key to improve our measurements and searches for new phenomena!**

- **The Run 3** will provide opportunities for new measurements (e.g. Yukawa coupling of the Higgs boson to second generation fermions (muons) and to consolidate important measurements and sharpen our tools towards the High Luminosity LHC.

- **The HL-LHC** will provide opportunities for percent level precision in Higgs couplings, first constraints on the Higgs boson self coupling, EW precision measurements, polarised vector boson scattering and unprecedented wide and strong probes of the SM through measurements and direct searches!

Backup

Stop Searches Summary



Performance Achievements and Goals

- Run 1 and Run 2: So far excellent trigger and object reconstruction performance in **increasing levels of PU**. Trigger Thresholds kept relatively stable throughout.

- The gain in acceptance and in performance with new detectors (to improve PU mitigation), new algorithms and new computing capabilities is expected to at least match current experimental performance.

    - Keeping Trigger thresholds at similar levels

    - Object reconstruction performance (efficiency vs rejection and energy scale and resolution) at stable levels.

    - Challenge to come: improve calibrations not only with more data to come but also improved strategies.

Objective Menus for HL-LHC

Signature	Run 1	Run 2	HL-LHC
Single e (isolated)	25	27	22 / 27
Single photon	120	140	120*
HT	700	700	375 / 350
MET	150	200	200

From A. Sfyrla LHCP 2018

- Increase readout rate 750-1000 kHz (currently 100 kHz).

- Increased latency and higher granularity.

- Enhanced data processing capabilities, storage rate up to 10 kHz (currently 1-2 kHz).