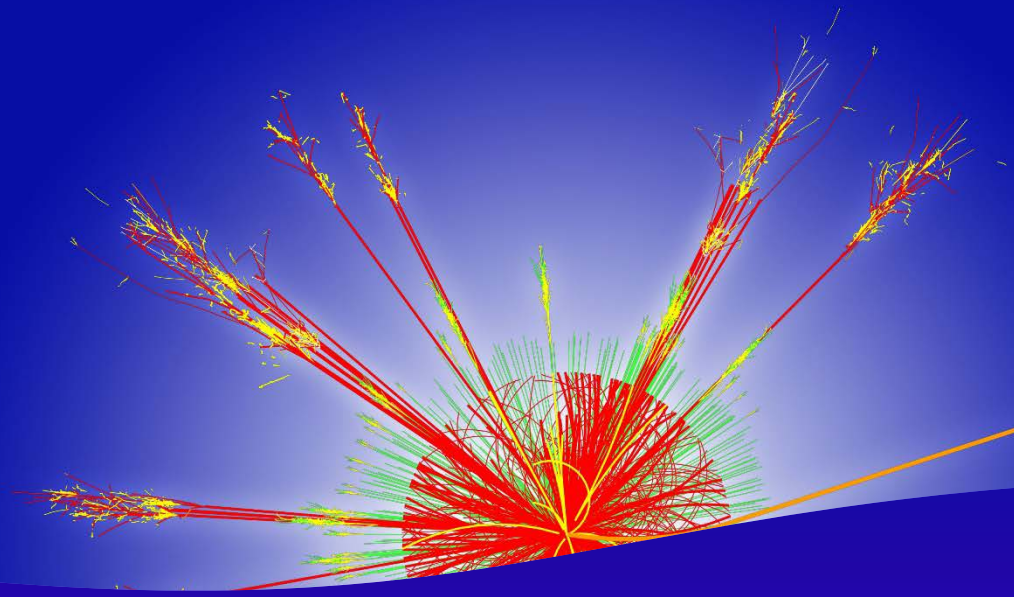
Highlights and perspectives

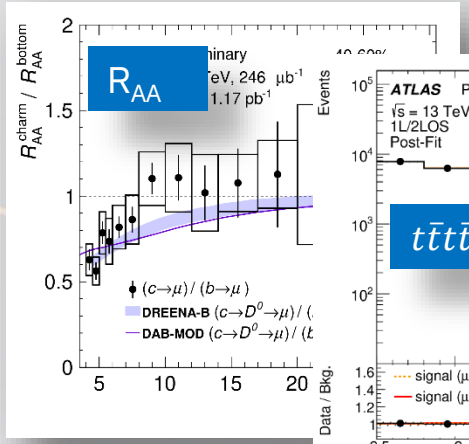


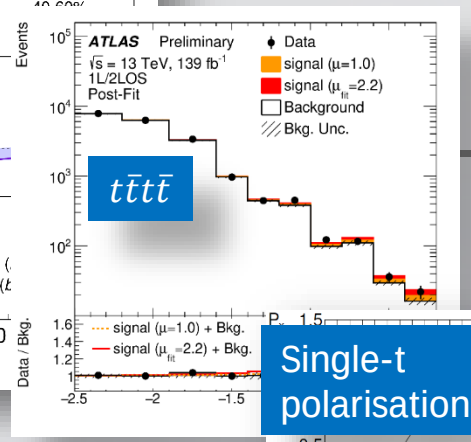
from ATLAS EXPERIMENT

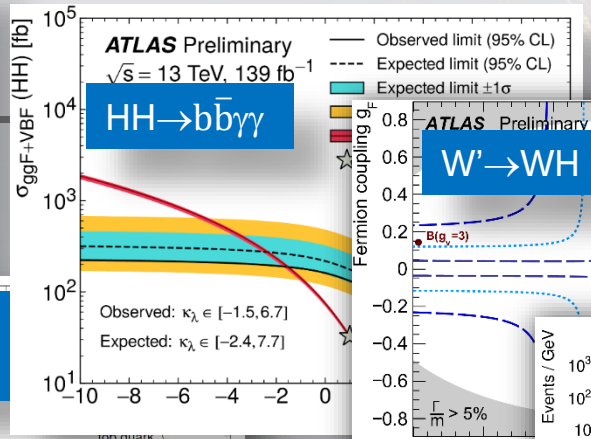
Manuella G. Vincter (Carleton University)
On behalf of the ATLAS Collaboration

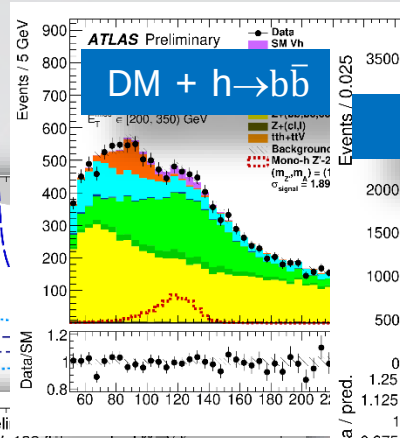
LHCP – June 7, 2021

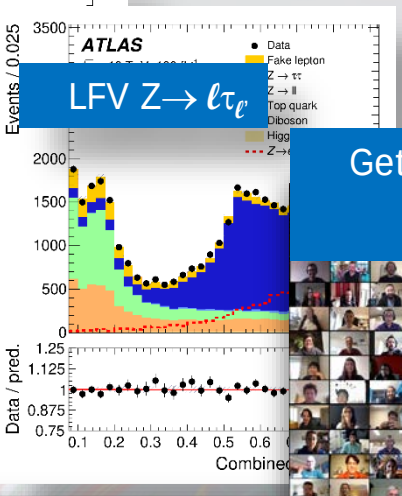
On the menu...

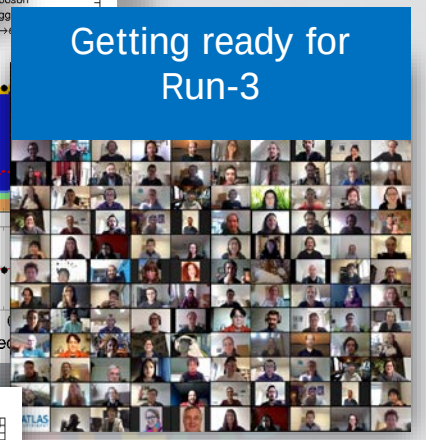


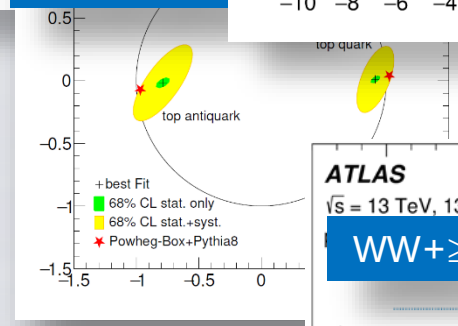


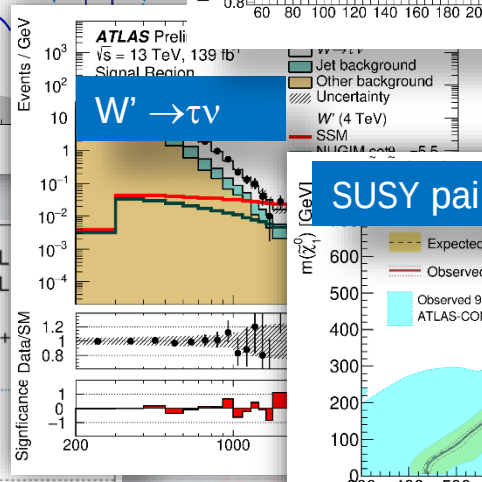


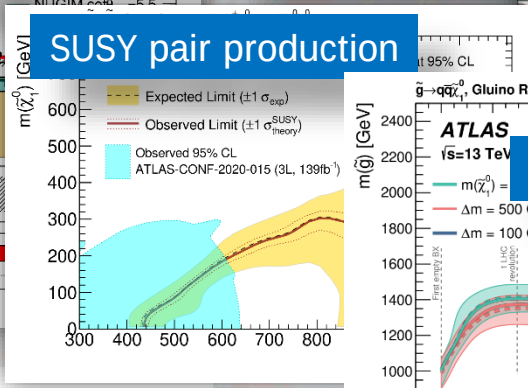


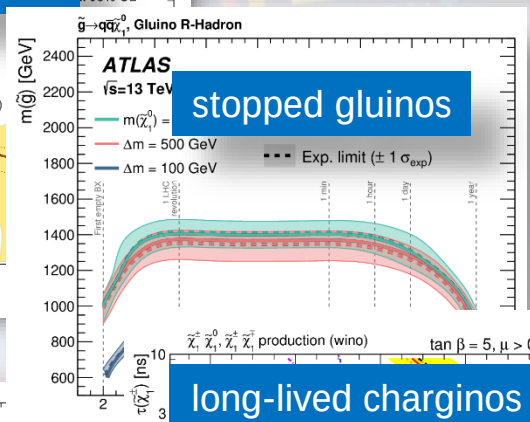


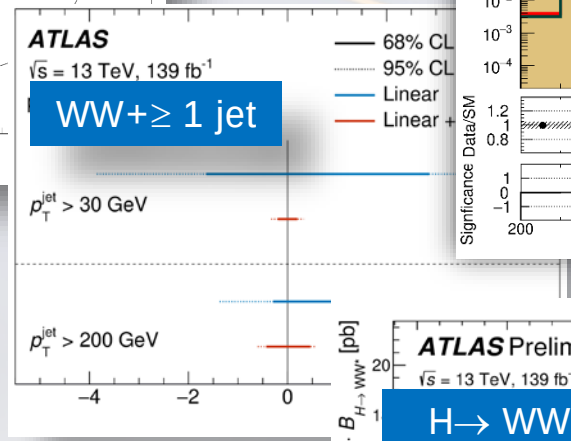


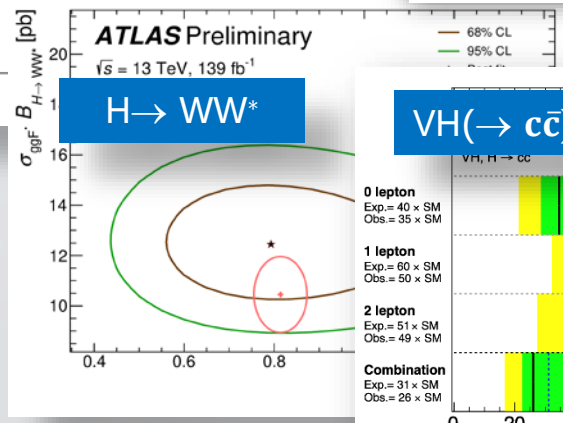


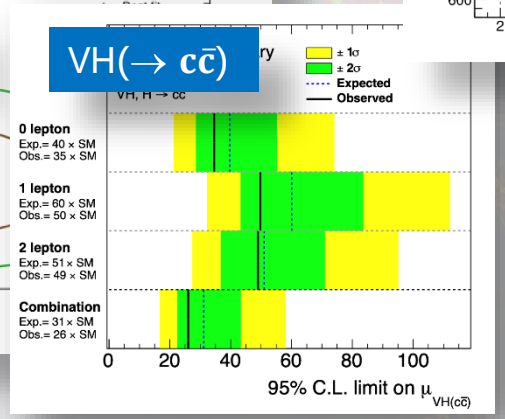


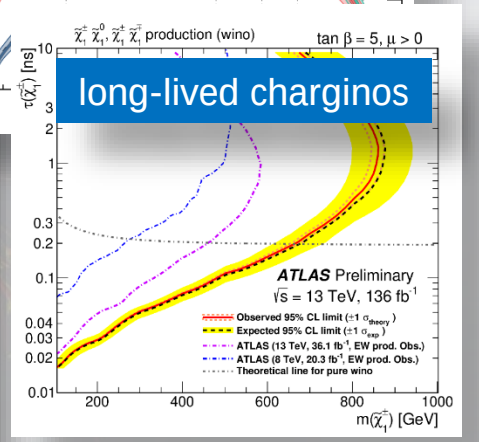












Heavy Ion

- b,c nuclear modification

Standard Model

- $t\bar{t}t\bar{t}$, single-t polarisation
- WW+≥ 1 jet

Higgs boson & searches

- H→ WW*, VH(→ cc)
- HH→ bb̄γγ, W'→WH→ℓνbb̄

Searches beyond SM

- W'→τν
- SUSY: electroweakinos in fully hadronic state, stopped gluinos, long-lived charginos
- Dark Matter in association to h→bb̄
- Lepton-flavour violation: Z→ℓτ$_{\ell'}$

Getting ready for Run 3

Some links only available after this talk...

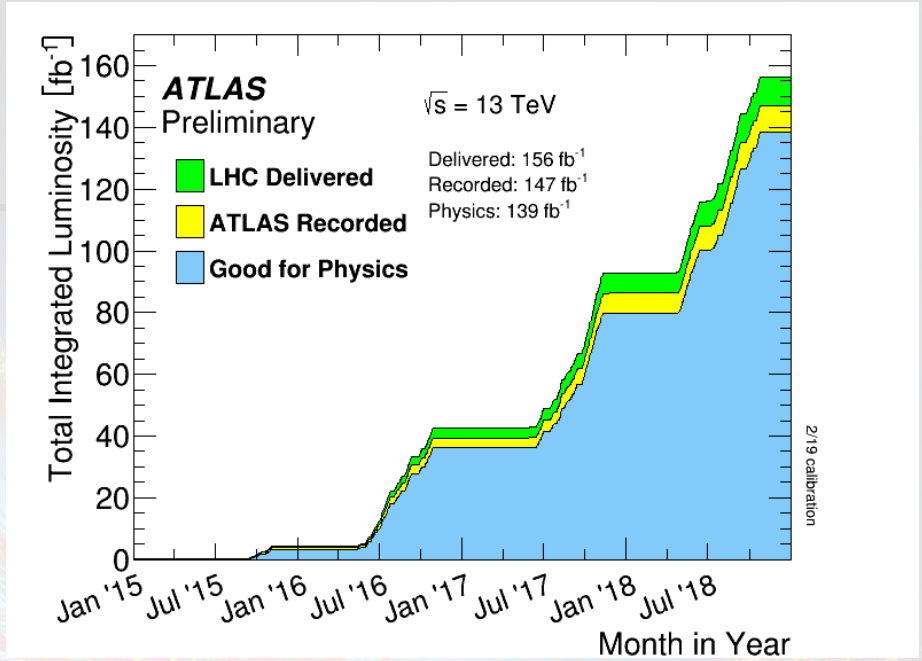
The Run-2 dataset

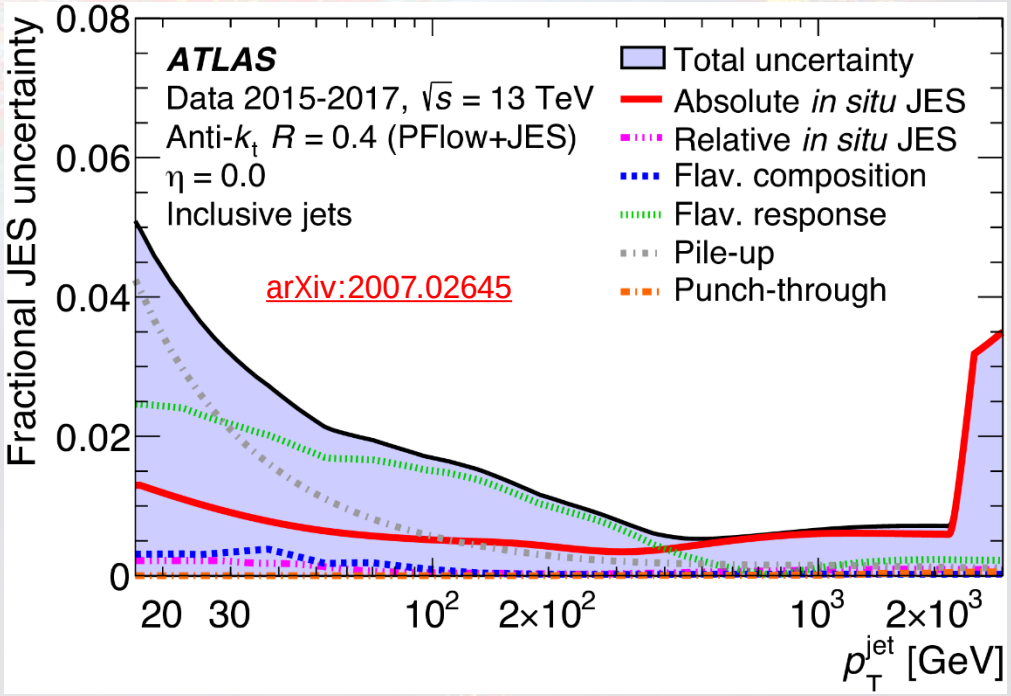
- Results presented today:
  - Full Run-2, 139 fb^{-1}pp collisions:
    - very well understood dataset!
- High data-taking efficiency

ATLAS pp Run-2: July 2015 – October 2018										
Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.5	99.9	99.7	99.6	99.7	99.8	99.6	100	100	99.8	98.8
Good for physics: 95.6% (139 fb^{-1})										

- Precision object performance. Uncertainties:
  - Identification of electrons < 1% [p_T ~ 30-250 GeV] and muons < 1‰ [p_T ~ 10-150 GeV]
  - Energy scale for central jets ~1% for p_T ~ 250-2000 GeV.
- Luminosity uncertainty of 1.7%

- **~135 full Run-2 results** (~90 submitted for publication)





Heavy-ion collisions

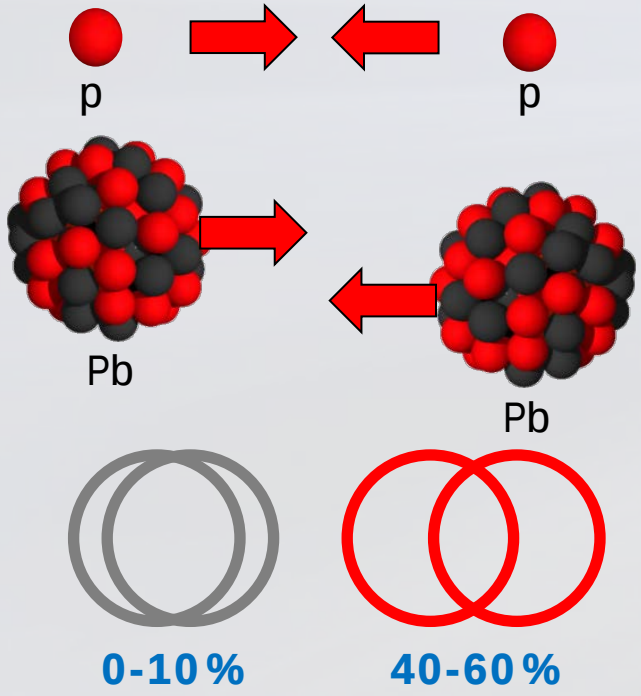
To probe the quark-gluon plasma...

5.02 TeV, PbPb: 246 μb^{-1}, pp: 1.17 pb^{-1}
$b \to \mu$, $c \to \mu$

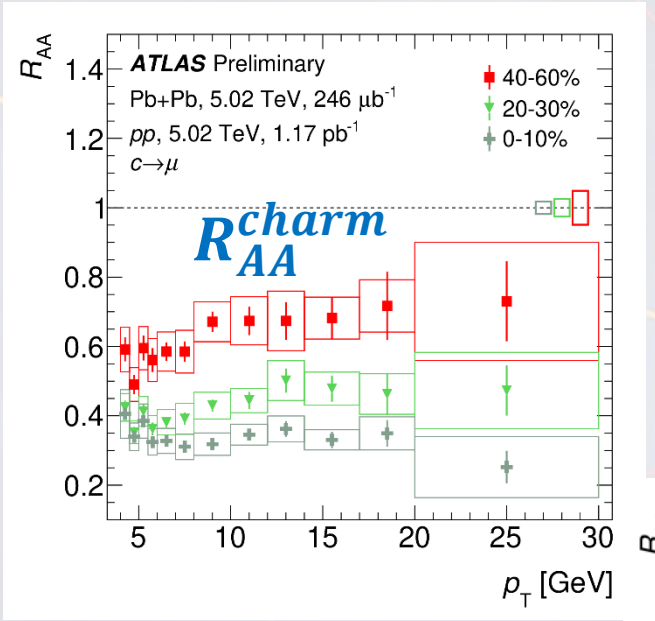
- Partons lose energy when traverse nuclear medium
- Suppression of small-angle gluon radiation for massive quarks at low p_T

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

Modification to particle yields compared to pp scattering

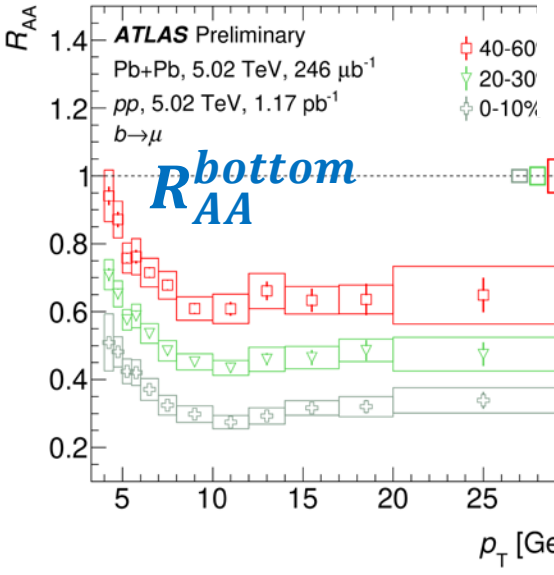


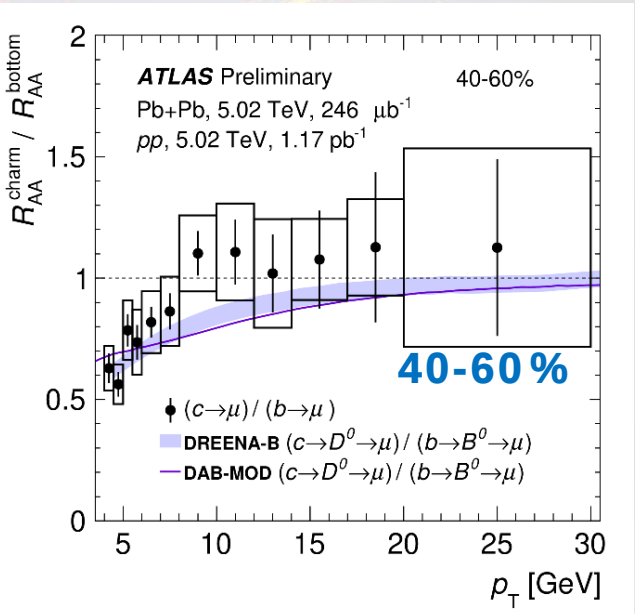
Centrality: overlap of colliding nuclei



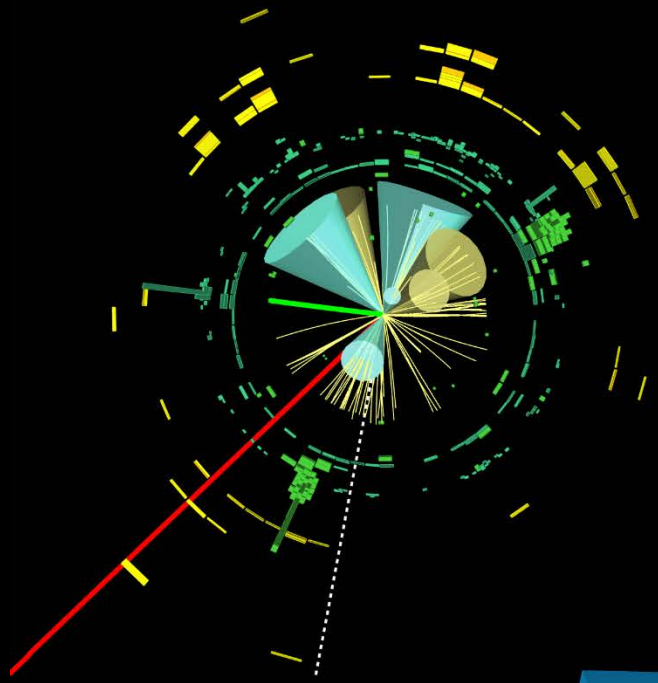
Suppression increases monotonically from peripheral to central collisions

Stronger $c \to \mu$ modification at low p_T





$$\frac{R_{AA}^{charm}}{R_{AA}^{bottom}}$$



Candidate four-top-quark event

Leptons & (b-tagged) jets

ATLAS EXPERIMENT

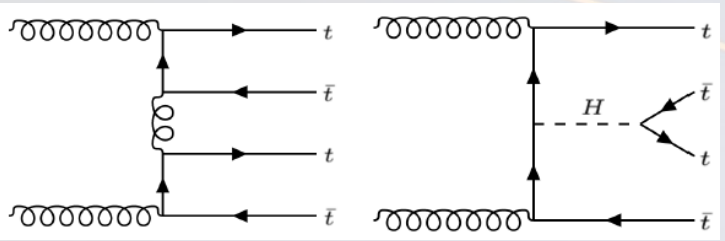
Run: 349114
Event: 1280053930
2018-04-29 10:53:24 CEST

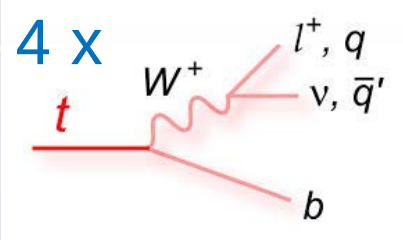
$t\bar{t}t\bar{t}$ production

To probe t-H Yukawa coupling, sensitivity to BSM processes…

13 TeV, 139 fb^{-1}
$t\bar{t}t\bar{t}$ 1 ℓ / 2 ℓ OS (ℓ = e,μ)
[57% of $t\bar{t}t\bar{t}$ events]

Challenge: $t\bar{t}$ bkg



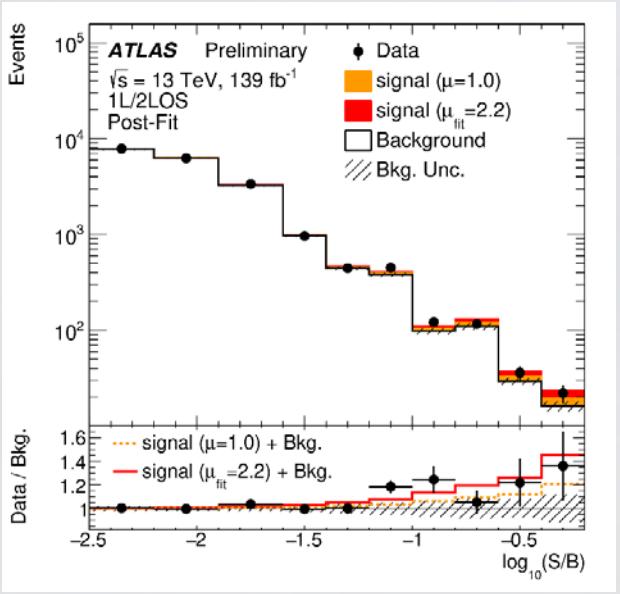


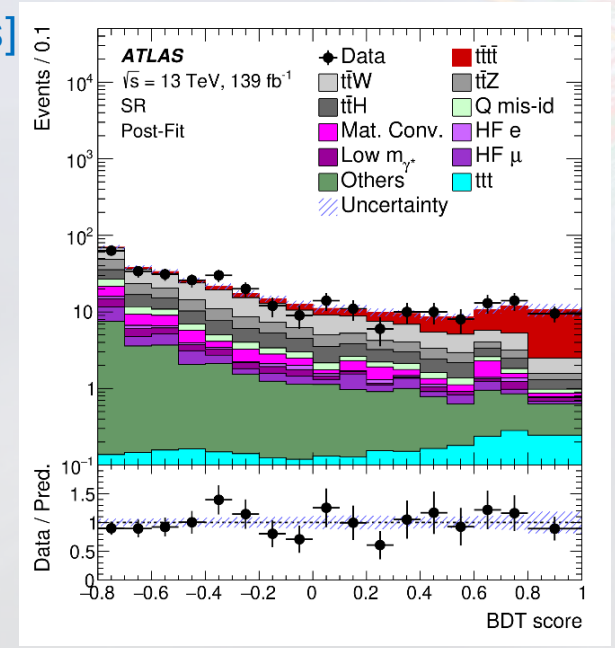
Enhancements from pair production gluino & scalar gluons, 2HDM

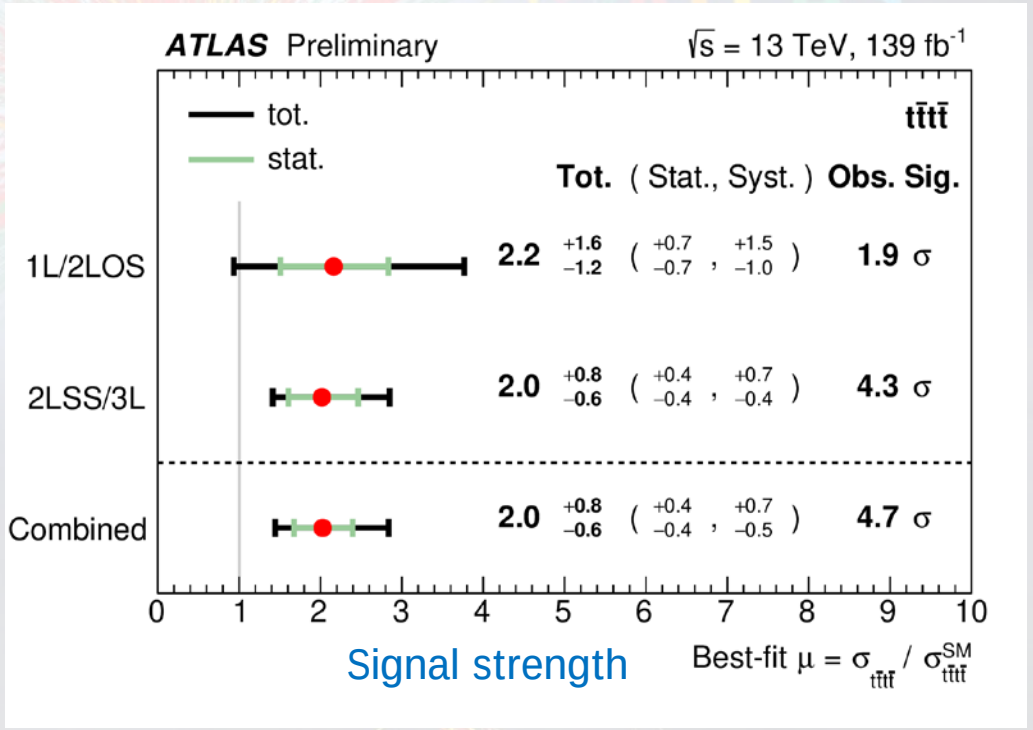
+ combined fit with Eur. Phys. J. C 80 (2020) 1085

13 TeV, 139 fb^{-1}
$t\bar{t}t\bar{t}$ 2 ℓ SS / 3 ℓ (ℓ = e,μ)
[13% of $t\bar{t}t\bar{t}$ events]

Binned profile likelihood [BDT in signal regions]







Prediction: $\sigma_{t\bar{t}t\bar{t}} = 12.0 \pm 2.4$ fb (NLO, incl EW corrs.)

Result: $\sigma_{t\bar{t}t\bar{t}} = 26 \pm 8\,(\text{stat.}) \pm {}^{15}_{13}\,(\text{syst.})$ **fb,** 1.9 obs. (1.0 exp.) σ

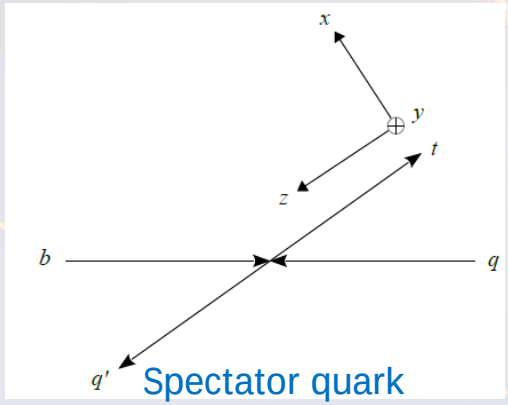
4.7 σ obs. (2.6 σ exp.) above bkg-only hypothesis

Single-top-quark polarisation in t channel

To probe tWb vertex...

13 TeV, 139 fb^{-1}
ℓ + (b) jets (ℓ = e,μ)

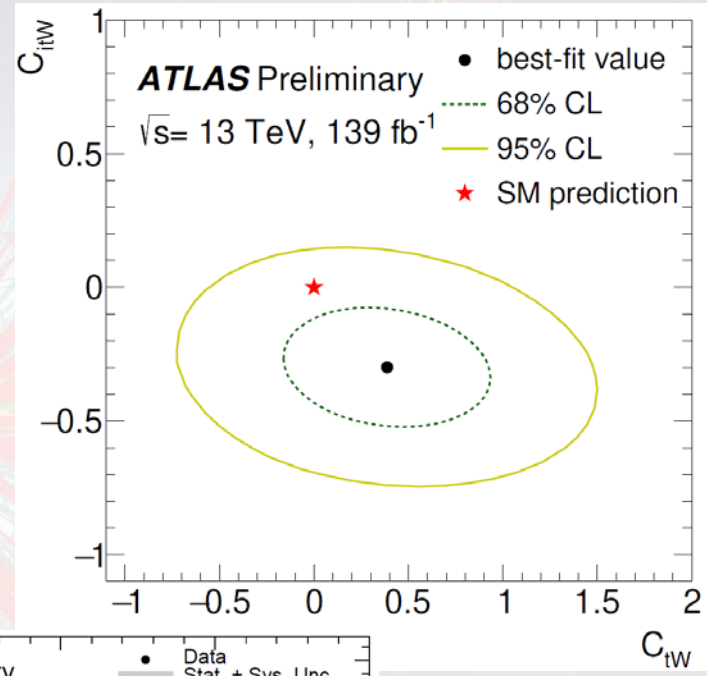
- Due to V-A of tWb: t ($\bar{t}$) polarisation mostly along (against) spectator quark direction for single-top t-channel process
- Spin info transmitted angular distributions of decay products.
- Polarisation: {P_x, P_y, P_z}

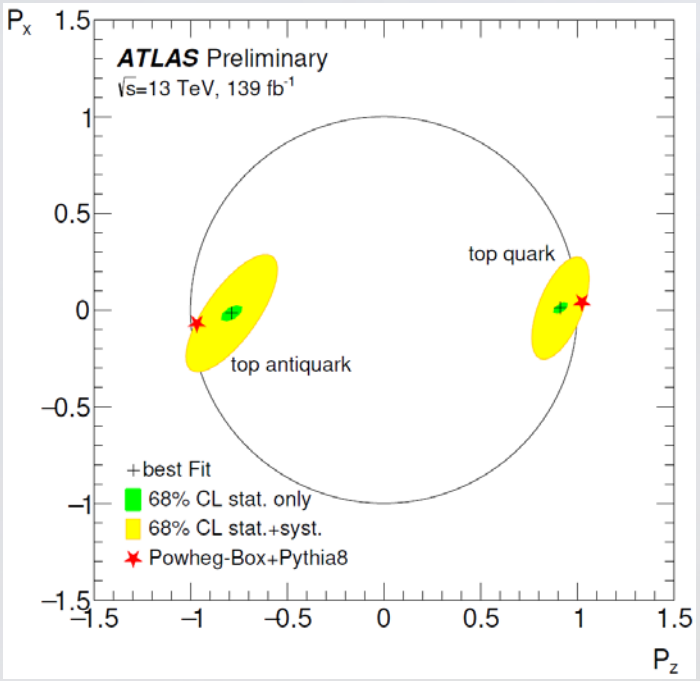


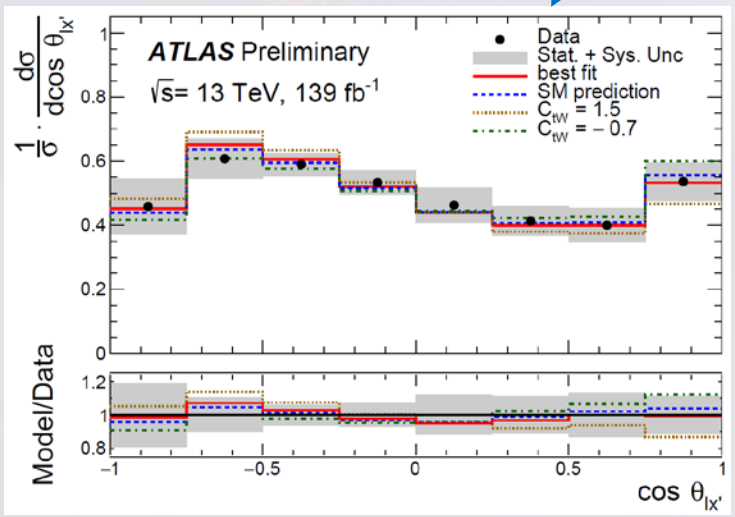
Sensitivity new physics in tWb vertex.
EFT, Wilson Coefficients
Real & imaginary:

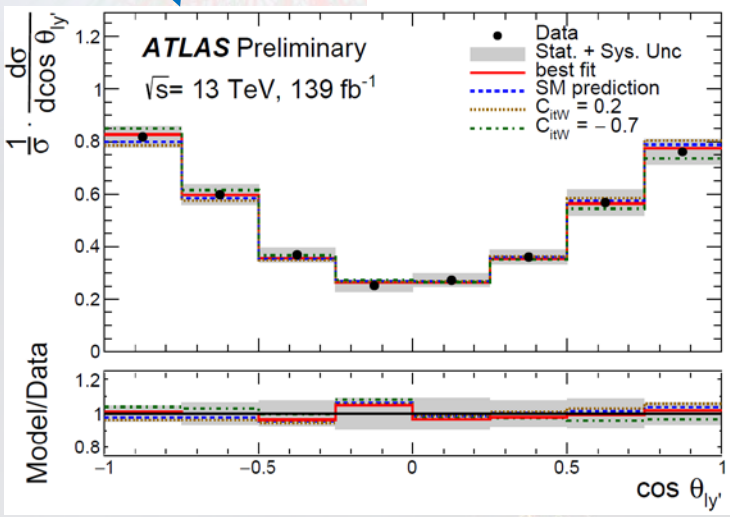
C_{tW} ⇓ P_x ⇓ cos $\theta_{\ell x}$

C_{itW} ⇓ P_y ⇓ cos $\theta_{\ell y}$









Consistent with SM prediction

arXiv:2103.10319

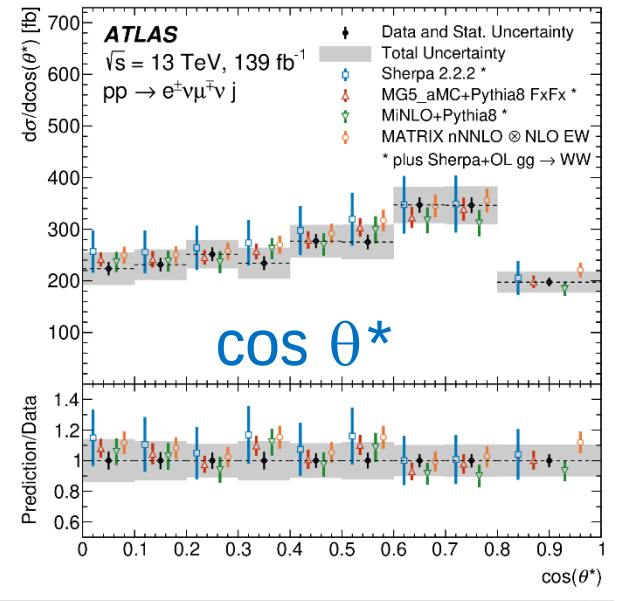
WW + ≥1 jet production

To probe EW&QCD at the highest energy scales…

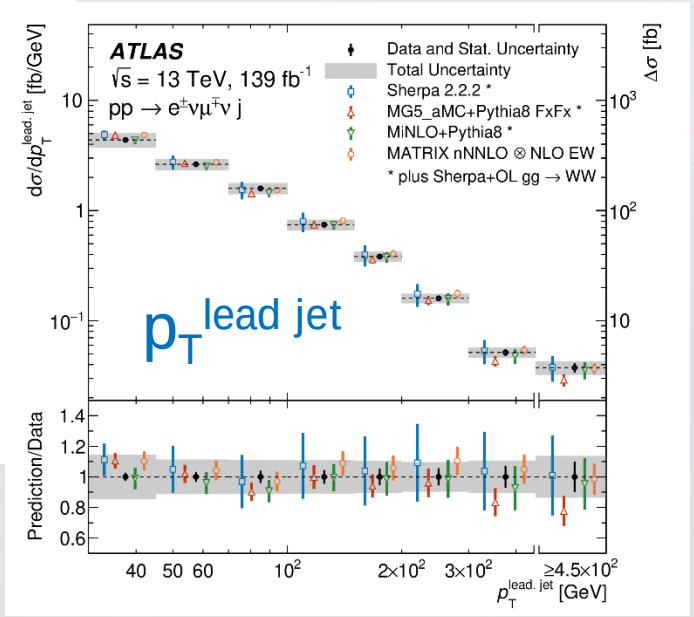
To probe EW self-interactions…

13 TeV, 139 fb^{-1}
$W^{\pm}W^{\mp}$ ($\rightarrow e^{\pm}\nu\mu^{\mp}\nu$) + ≥1 jet Challenge: top bkg!

Differential cross section vs. variables that characterise W kinematics and jet production

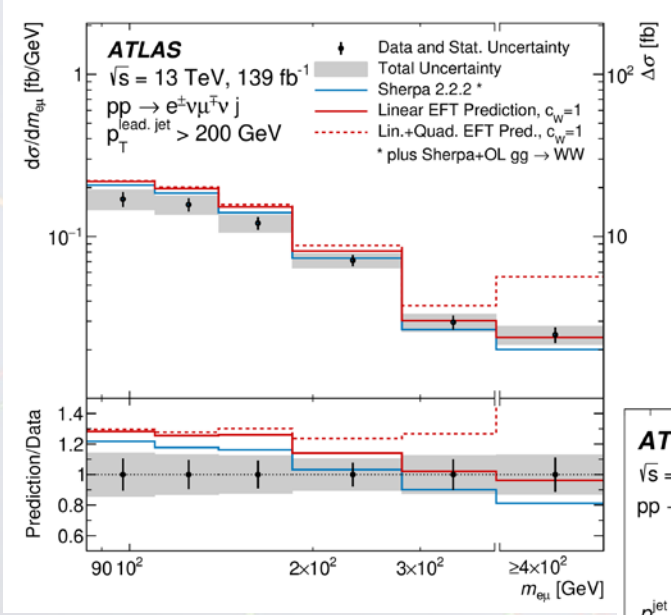


Sensitive to WW spin structure

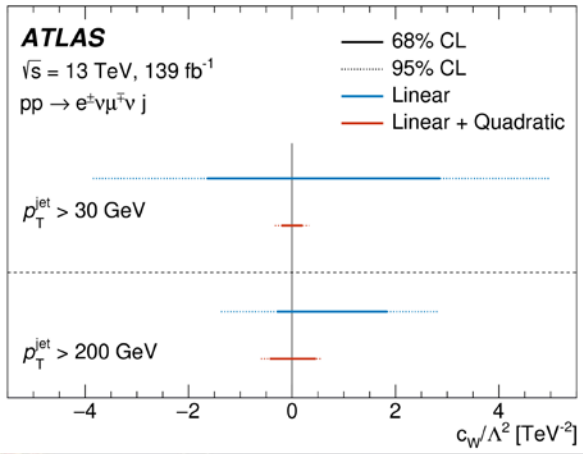


~10 % systematics

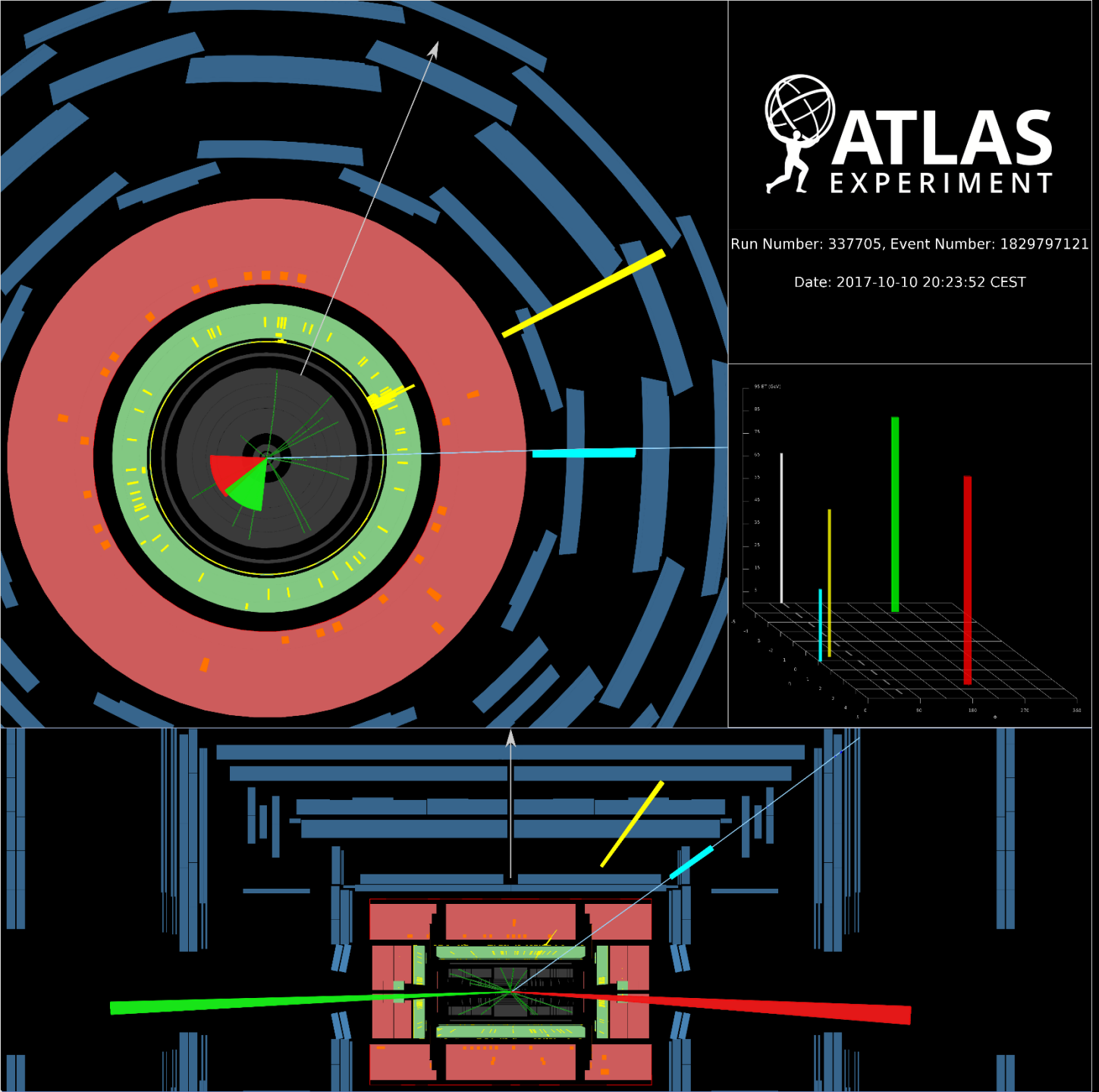
WW+≥ 1 (hard) jet improves the sensitivity to searches for anomalous triple gauge boson couplings (aTGCs)



$m_{e\mu}$ most sensitive



EFT: constraints on Wilson coefficient C_W

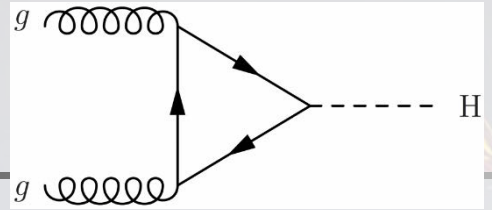


Candidate $H \rightarrow WW^* \rightarrow e\nu\mu\nu$ through VBF production mode

Small opening angle between e and μ expected due to spin-0 nature of Higgs boson and V-A structure of W-boson decays

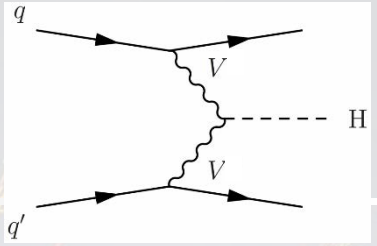
H→ WW* production

13 TeV, 139 fb^{-1}
H→W$^{\pm}$W$^{\mp}$* → e$^{\pm}$νμ$^{\mp}$ν



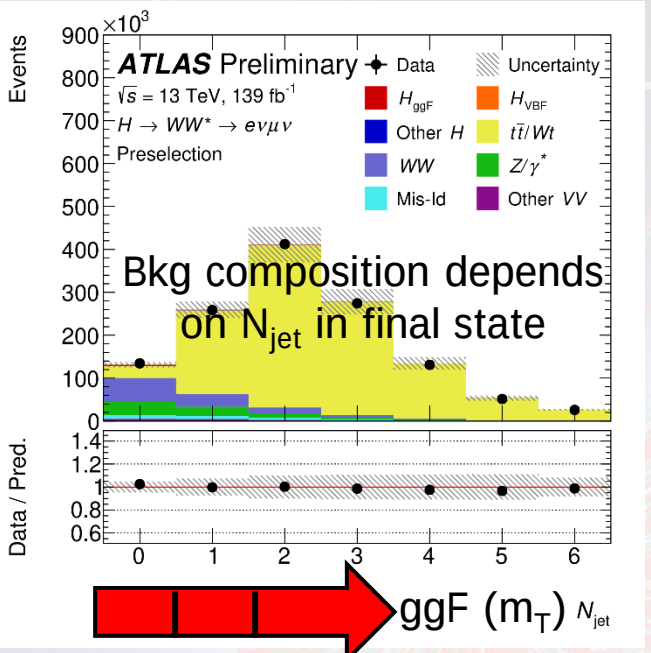
Gluon fusion ggF
σ·B(H→WW*) ~ 10 pb

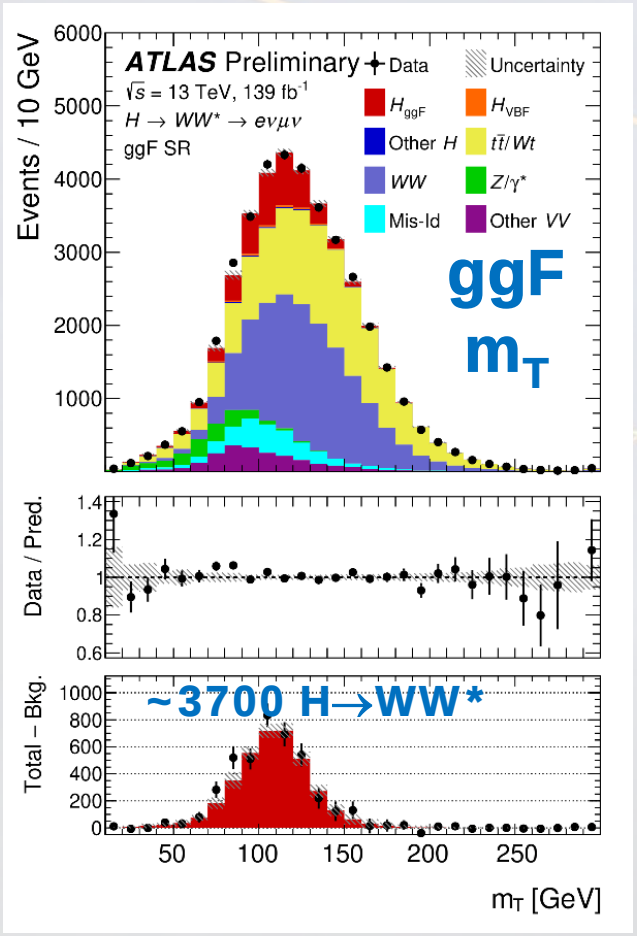
ATLAS-CONF-2021-014
Physics Briefing



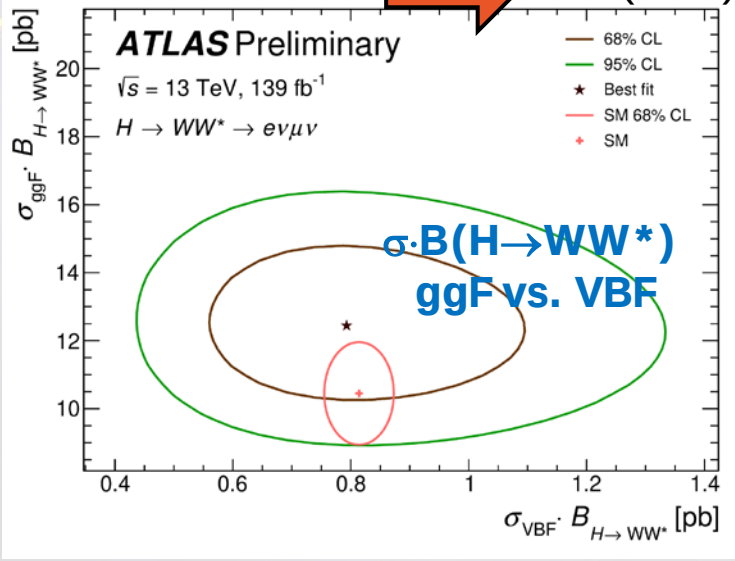
Vector-boson fusion VBF
σ·B(H→WW*) ~ 1 pb

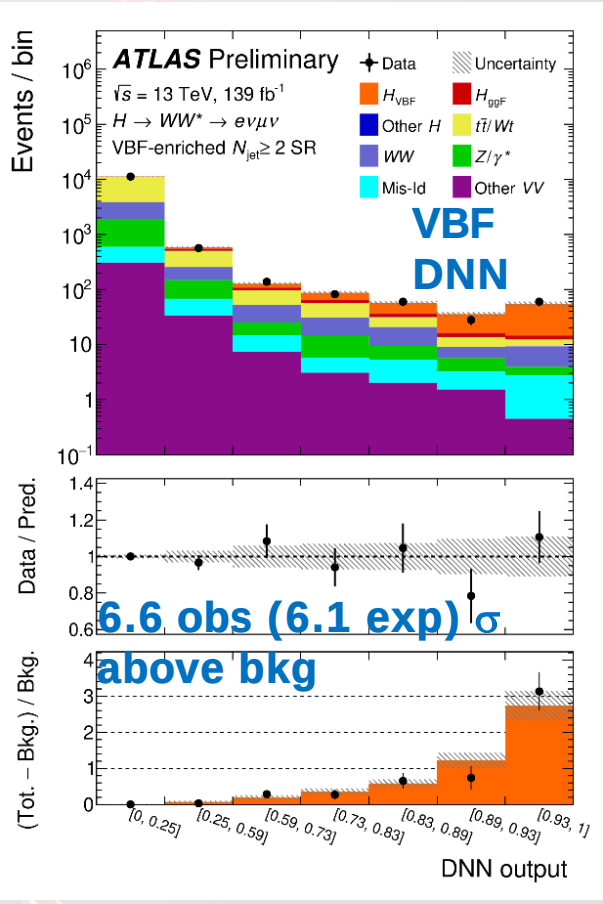
To probe Higgs-boson production and decay mechanisms...





VBF (DNN)





11 fiducial [Stage 1.2 STXS] cross sections
(6 ggH, 5 EW qqH)
[see backup]

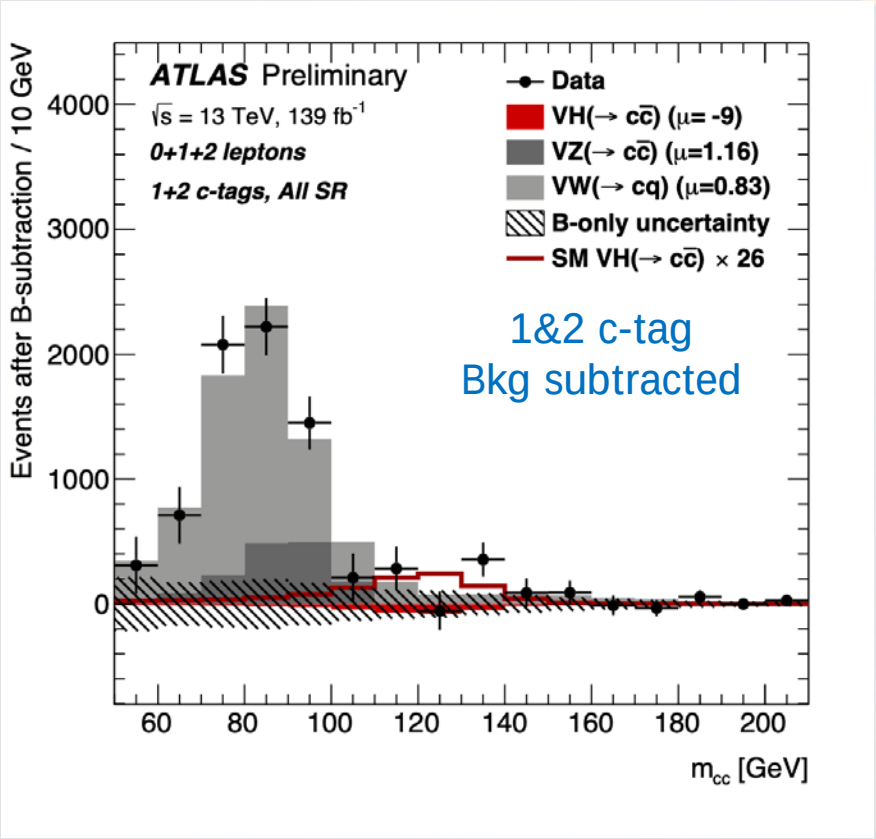
VH(→ $c\bar{c}$)

To probe the Higgs-boson coupling to second-generation quarks…

13 TeV, 139 fb^{-1}
0, 1, 2, ℓ (ℓ = e, μ) + jets, VH(→$b\bar{b}$) veto
ZH→$\nu\nu c\bar{c}$, WH→ $\ell\nu c\bar{c}$, ZH → $\ell\ell c\bar{c}$

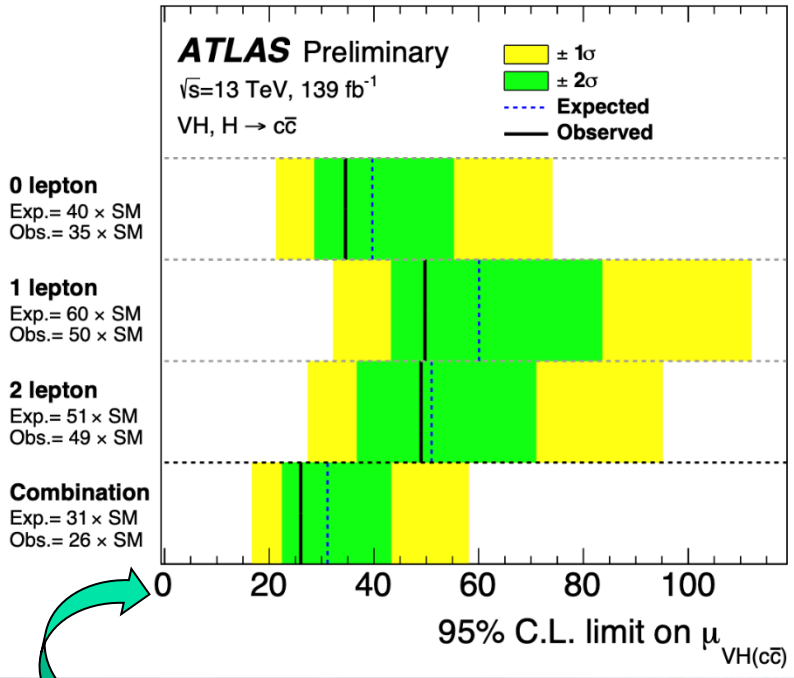
B(H→ $c\bar{c}$) ~ 3%

Binned max-likelihood fit: m_{cc}



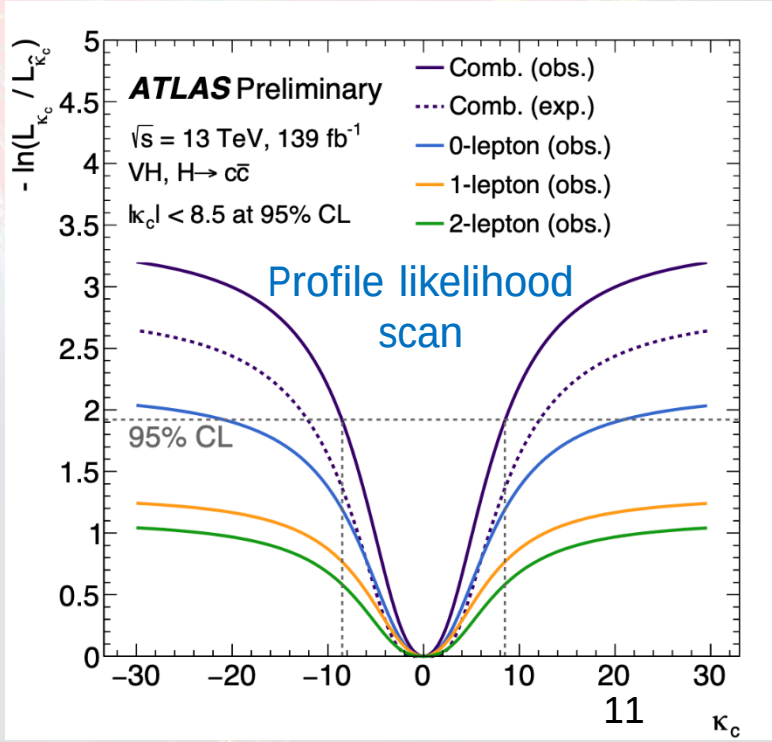
1&2 c-tag
Bkg subtracted

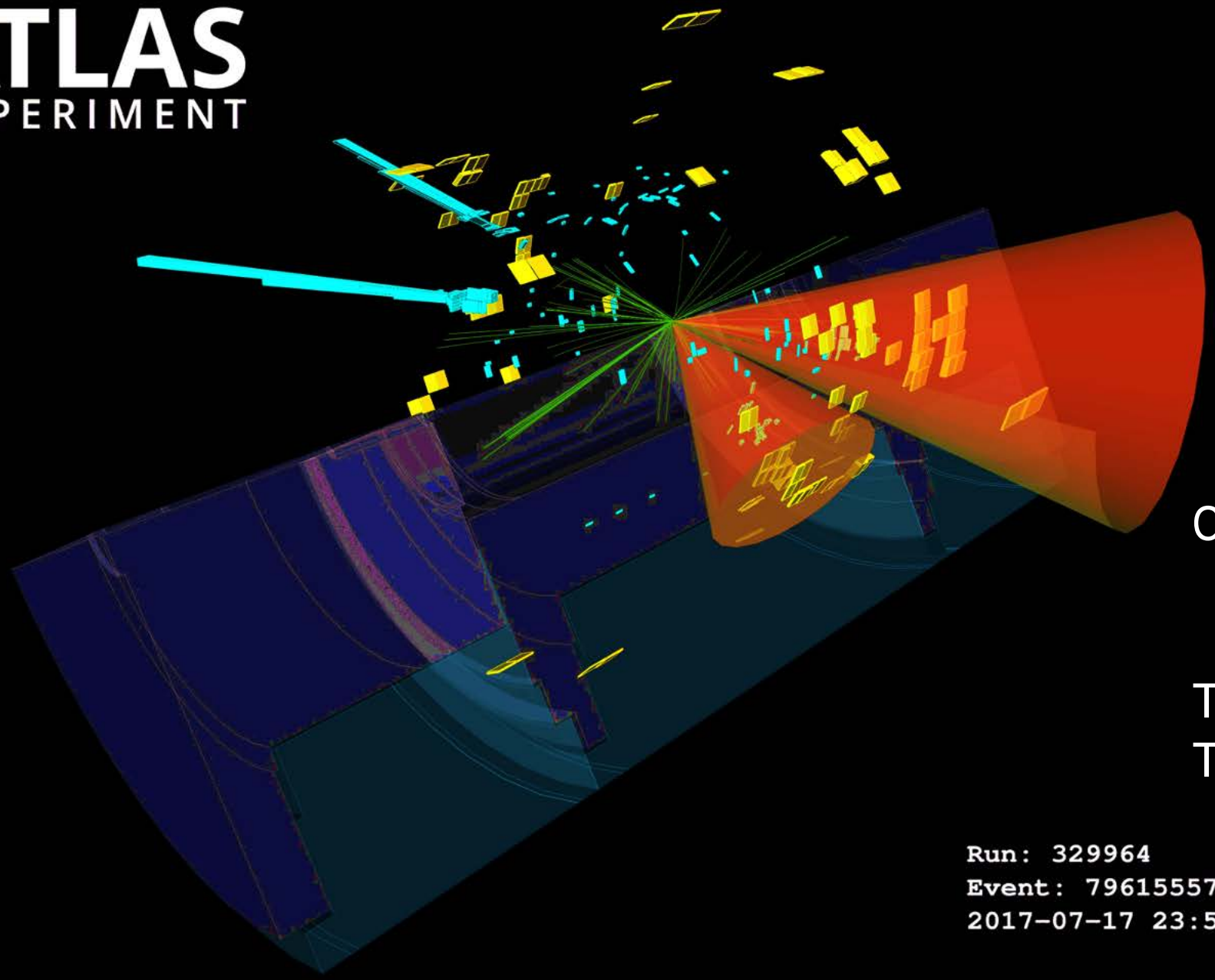
No VH(→ $c\bar{c}$) excess observed



μ signal strength {x $[\sigma \cdot Br]_{SM}$ }
→26 (31) obs (exp)

Kappa framework
Yukawa coupling modifier κ_c
$|\kappa_c|$<8.5 at 95% CL
Most stringent constraint to date





Candidate HH $\rightarrow \mathbf{b\bar{b}}\gamma\gamma$

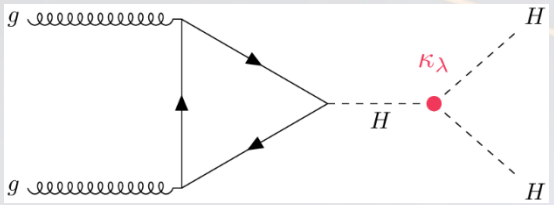
Two *isolated* γ
Two *b-tagged* jets

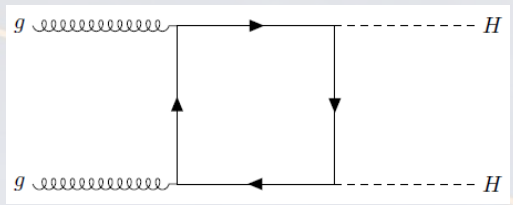
Search for HH→ bb̄γγ production

To probe Higgs potential via H self-coupling λ_{HHH}...

To explore BSM enhancements ...

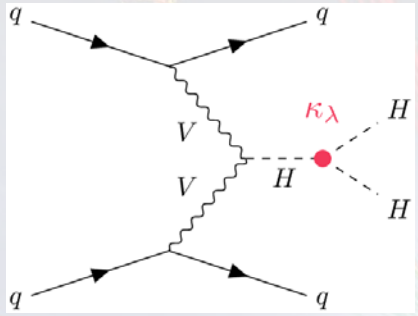
13 TeV, 139 fb^{-1}
HH→bb̄γγ



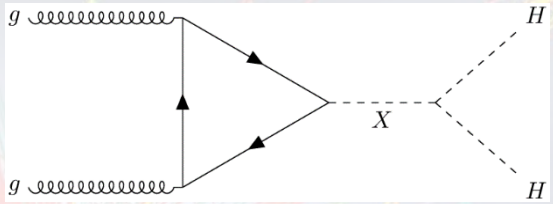


ggF: gg → HH
σ_{NNLO} ~ 31 fb

$$\kappa_\lambda = \lambda_{HHH}/\lambda^{SM}_{HHH}$$



VBF: qq → VV → HH
σ_{N3LO} ~ 2 fb



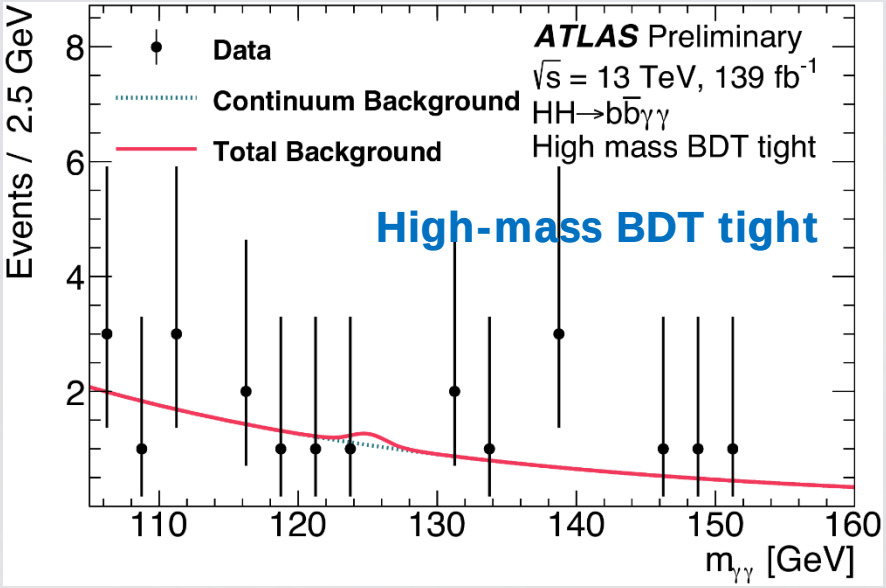
heavy scalar X → HH

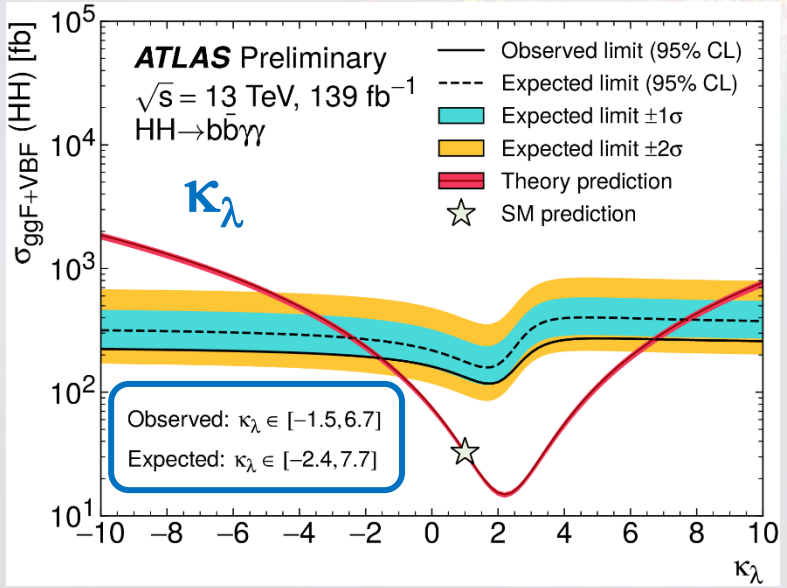
Non-resonant search: 4 categories [low/high $m^*_{bb\gamma\gamma}$ and BDT]
- Multivariate BDT, fit to $m_{\gamma\gamma}$

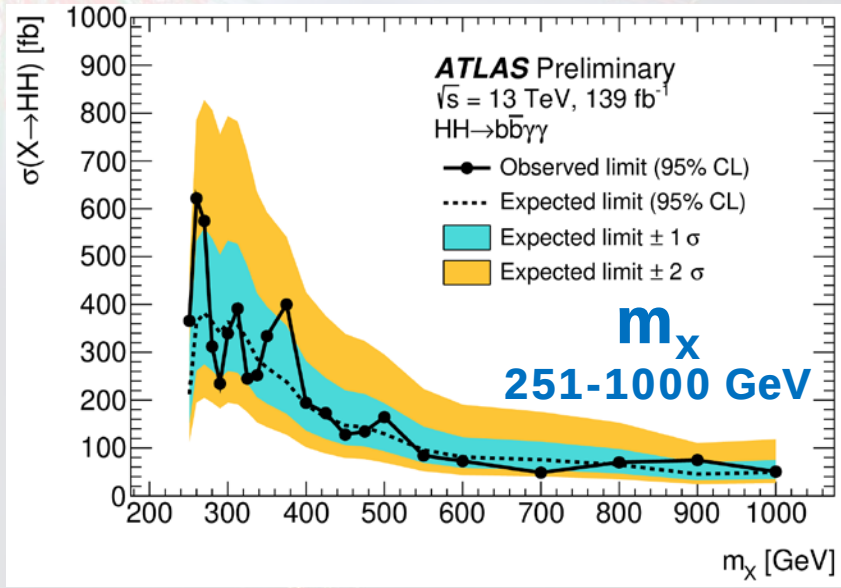
4.1 obs. (5.5 exp.) x σ_{SM}

Resonant search (narrow-width)
- Multivariate BDT, fit to $m_{\gamma\gamma}$

Upper limit 610-47 fb obs. (360-43 fb exp.)





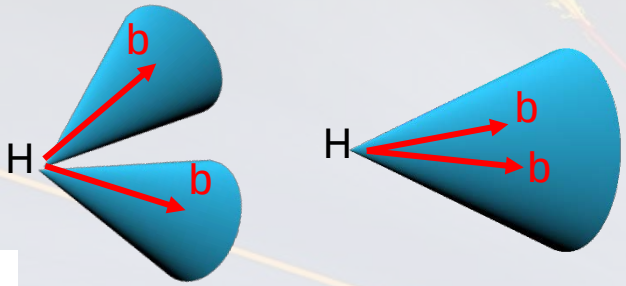


Search for W'→WH

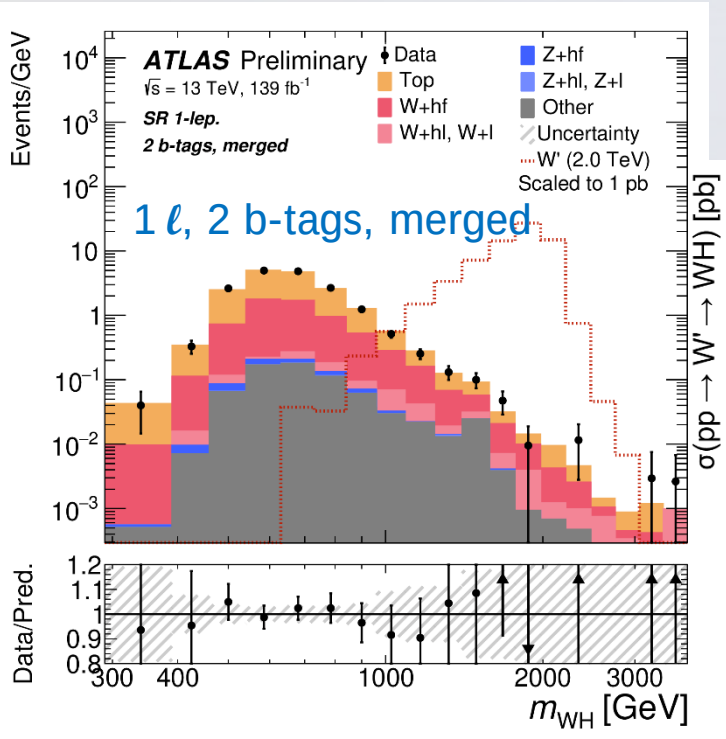
To probe EW symmetry breaking...
Search for new vector resonances

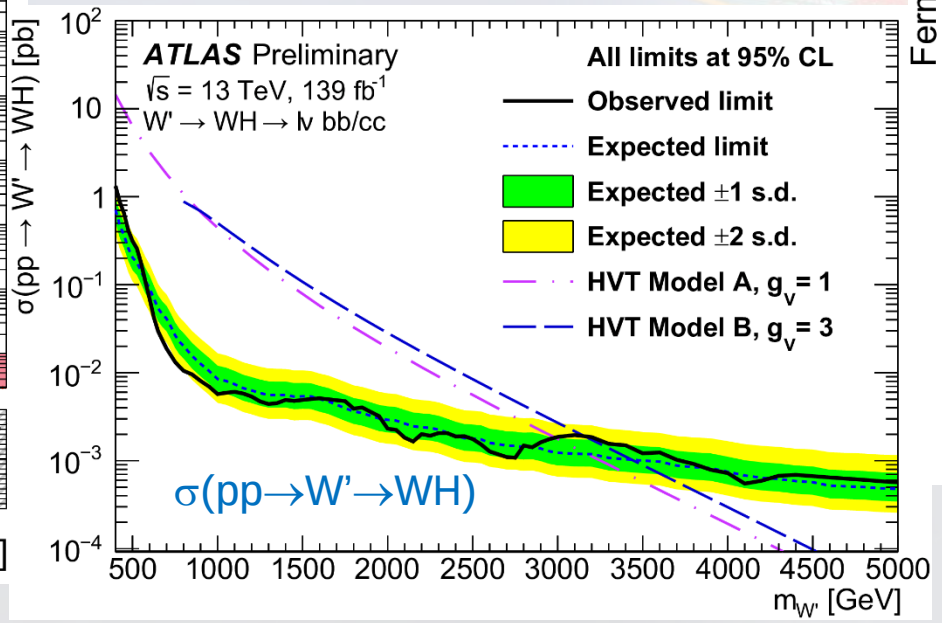
13 TeV, 139 fb^{-1}
1 ℓ + b jets (ℓ=e,μ,τ)
W'→WH→$\ell\nu b\bar{b}$

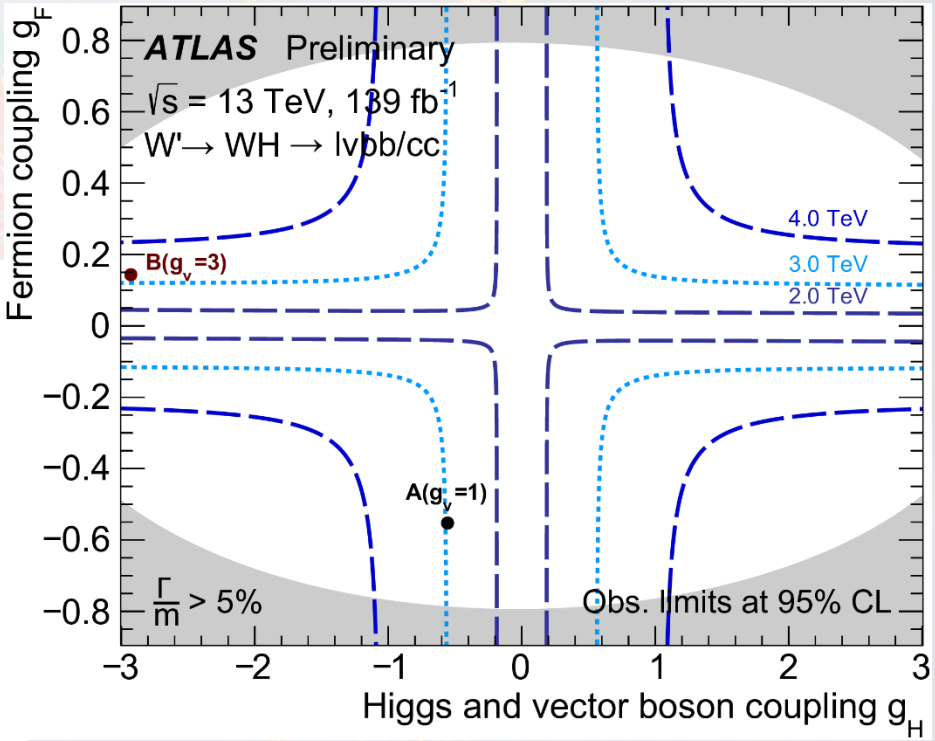
With resolved or merged b jets:



2 benchmarks of Heavy Vector Triplet model
A: comparable branching to fermions & gauge bosons
B: fermionic coupling suppressed







Look for excess in m_{WH}
Binned max-likelihood fit.

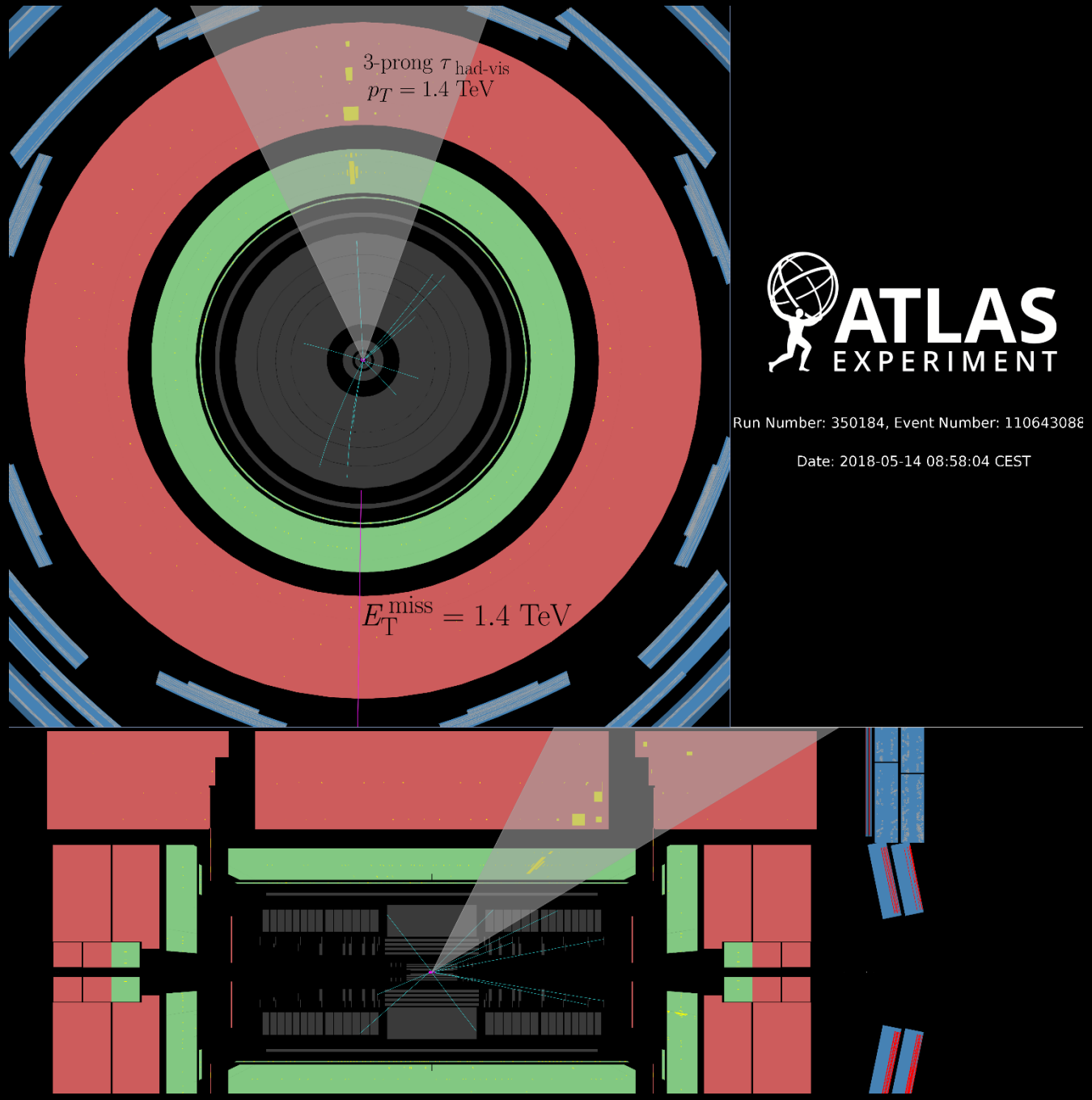
95% CL: 1.3 pb [400 GeV] to 0.56 fb [5 TeV]
$m_{W'}$ <~3 TeV excluded in both benchmarks

Observed limits HVT model: g_F vs. g_H plane for $m_{W'}$ = 2, 3, 4 TeV

W'→ $\tau_{\text{had-vis}}$ ν

Highest m_T event: 2.8 TeV

p_T & E_T^{miss} ~ 1.4TeV



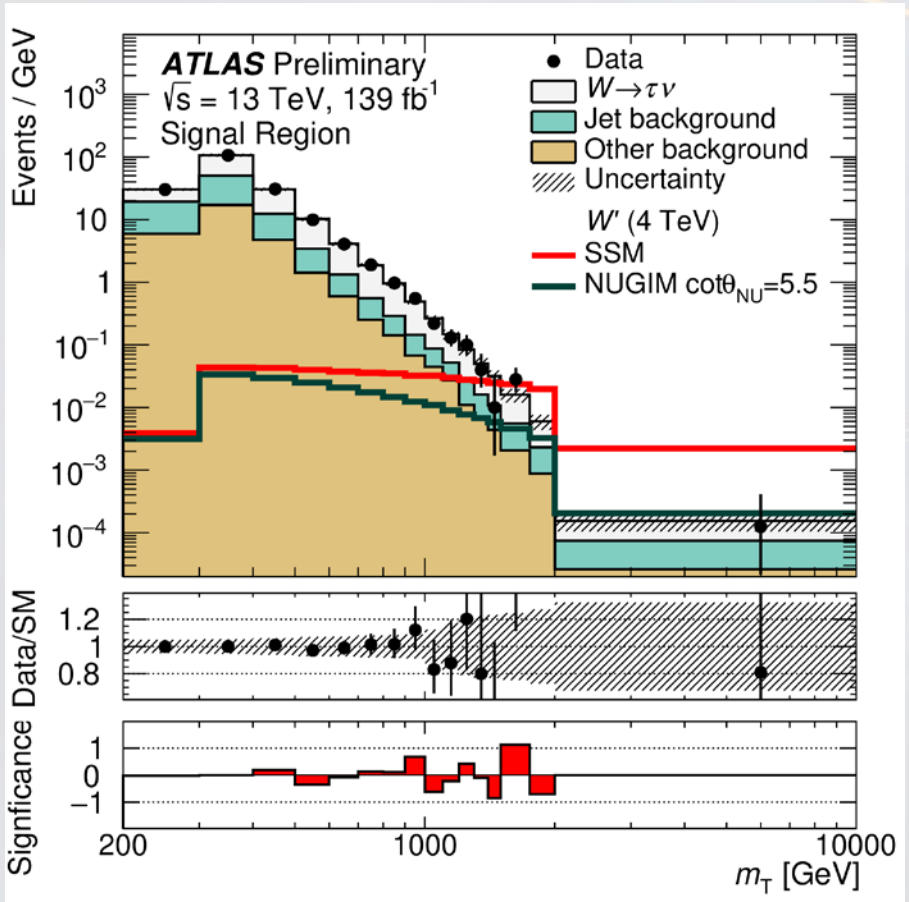
Search for W'→τν

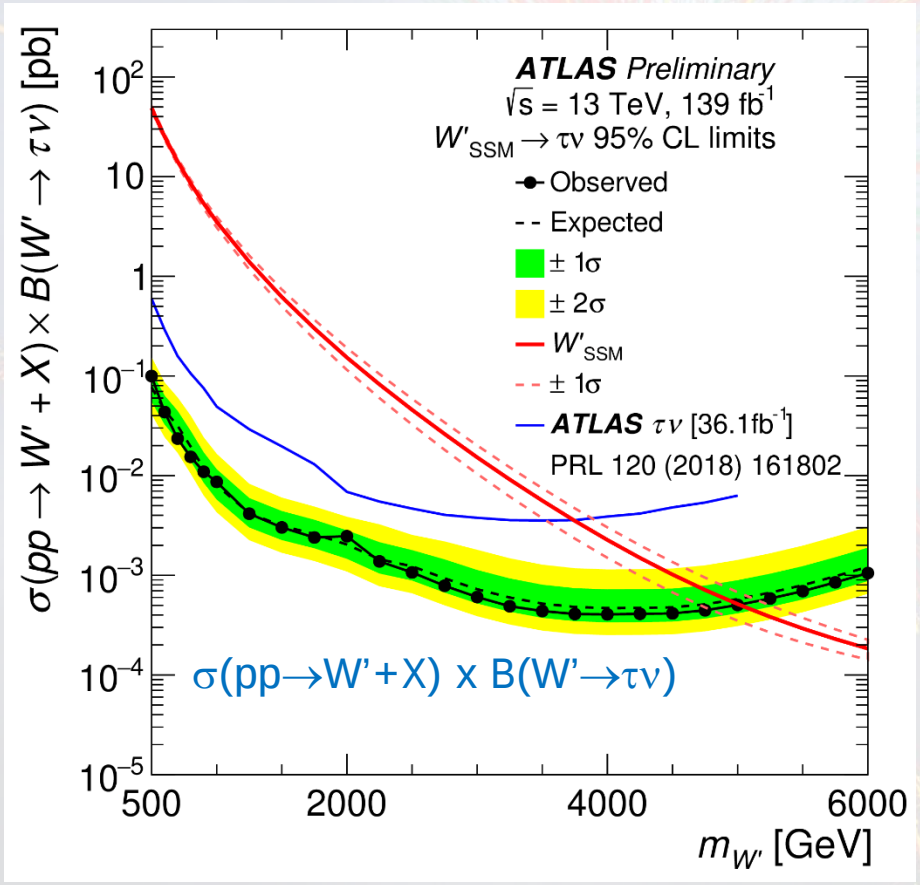
To search for additional charged heavy gauge bosons...

13 TeV, 139 fb^{-1}
W'→ $\tau_{had\text{-}vis}\nu$

Hadronic τ decays with Recurrent Neural Network (RNN)
Profile-likelihood fit to m_T

Sequential Standard Model (SSM)
[flavour-universal, W' couplings to fermions same as W]
Non-Universal Gauge Interaction Models (NUGIM)
[violate lepton universality, different couplings for 3 lepton generations, parameterised by θ_{NU}]





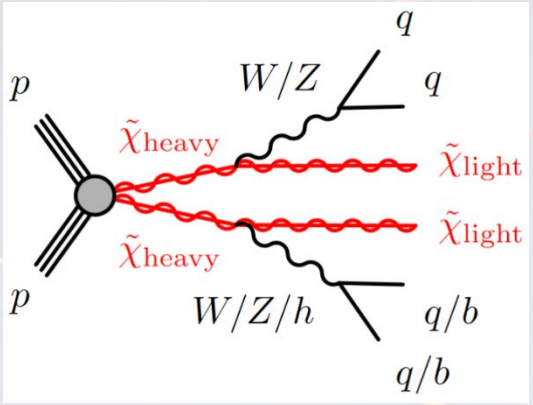
Excludes at 95% CL
$m_{W'}$ < 5 TeV (SSM)
$m_{W'}$ < 3.5-5 TeV (NUGIM)

Search for electroweakinos in fully hadronic final state

ATLAS-CONF-2021-022

To search for SUSY pair production...

13 TeV, 139 fb^{-1}
W/Z/h, qqqq/qqbb + E_T^{miss}



Electroweakinos: bino $\tilde{B}$, wino $\tilde{W}$, higgsino $\tilde{H}$

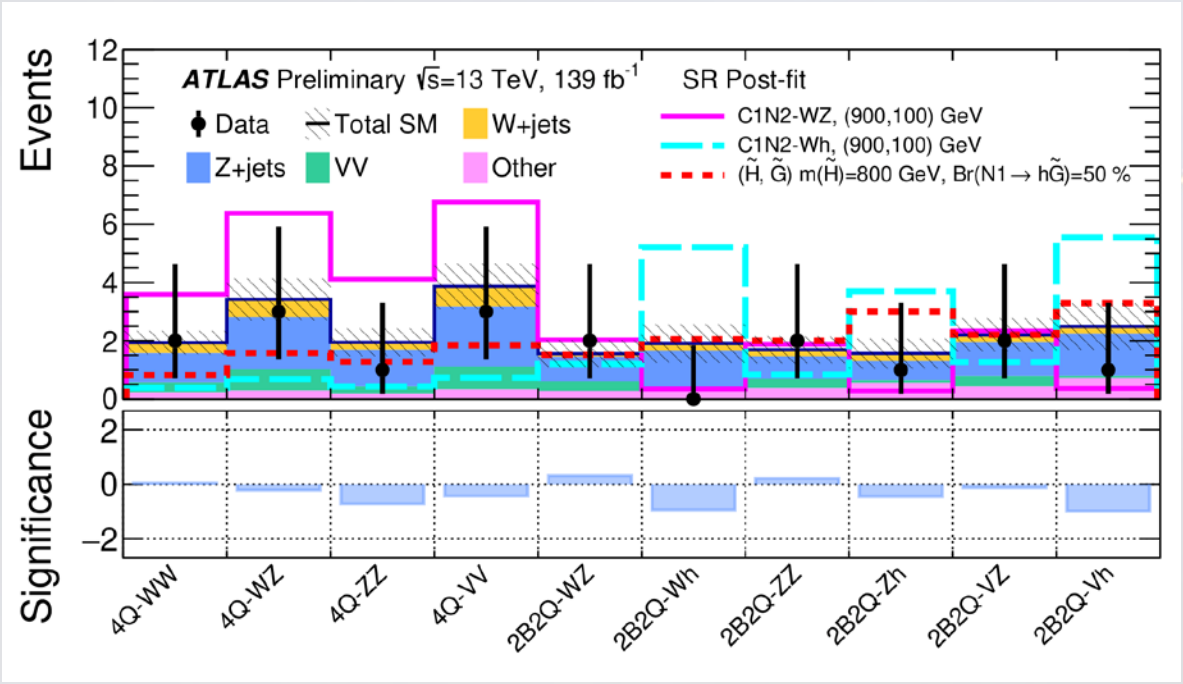
Large radius jet:
- capture collimated energetic jets

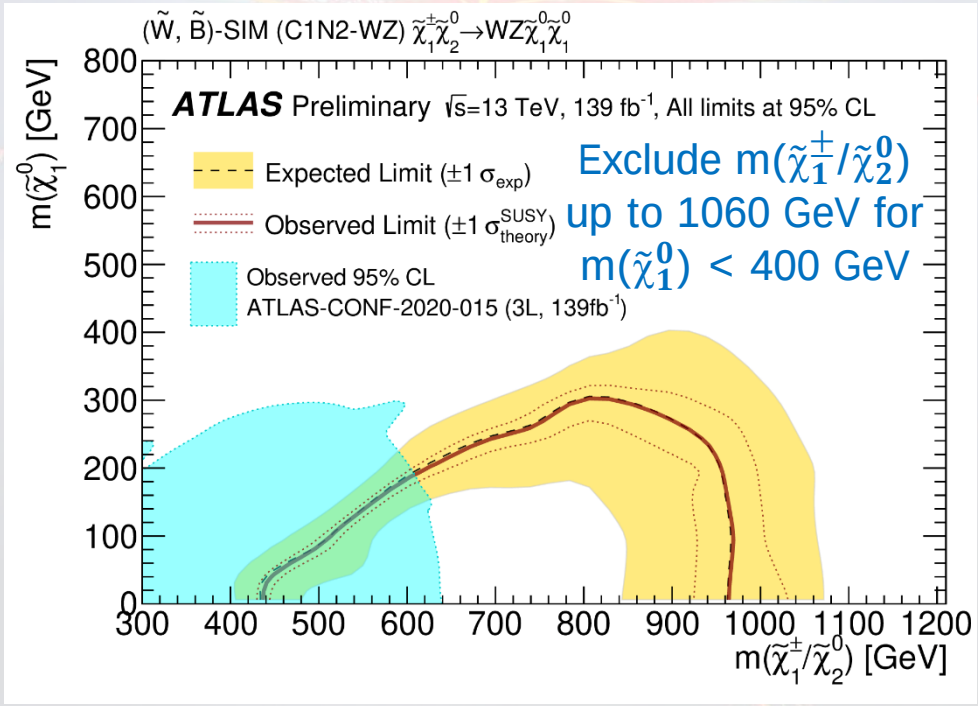
Jet substructure:
- identify hadronic decays of W/Z/h

Orthogonal signal regions: 4Q, 2B2Q

Interpretations:
- Minimal Supersymmetric Standard Model MSSM: bino, wino and higgsino are $\tilde{\chi}_{heavy}$ and $\tilde{\chi}_{light}$
- gravitino LSP, light higgsinos
- axino LSP

One e.g.: exclusion limits wino pair decaying to bino LSPs (C1N2-WZ)





Most stringent Limit on the model to date!

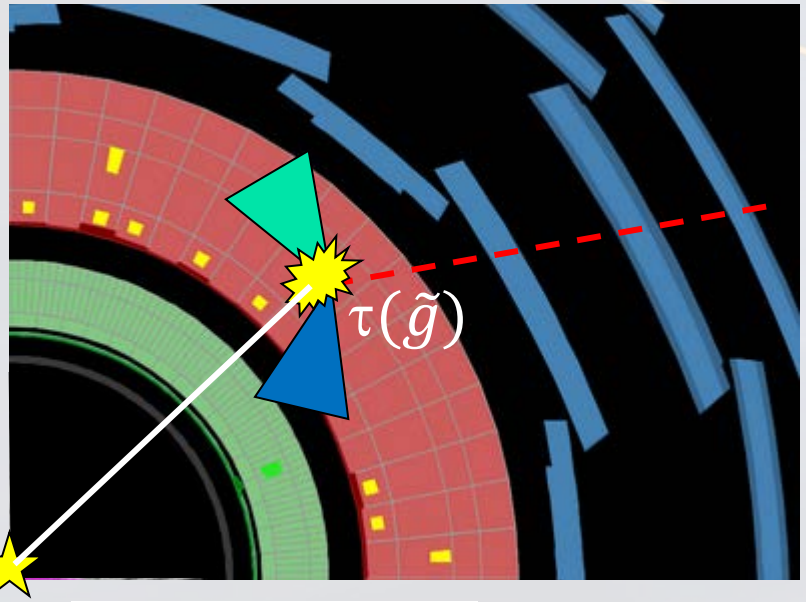
See also backup for another analysis.

arXiv:2104.03050
Physics Briefing

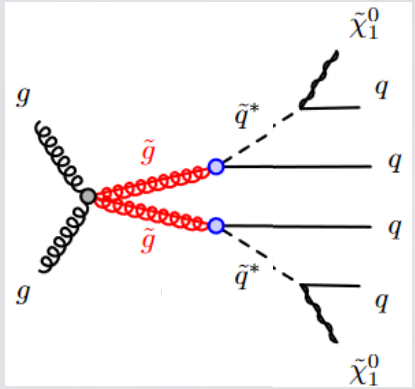
Search for stopped gluinos

To search for exotic metastable particles...
R-parity-conserving SUSY

13 TeV, 49 (2017) + 62 (2018) fb^{-1}
Stopped long-lived particles
Large out-of-time energy deposits



p-p

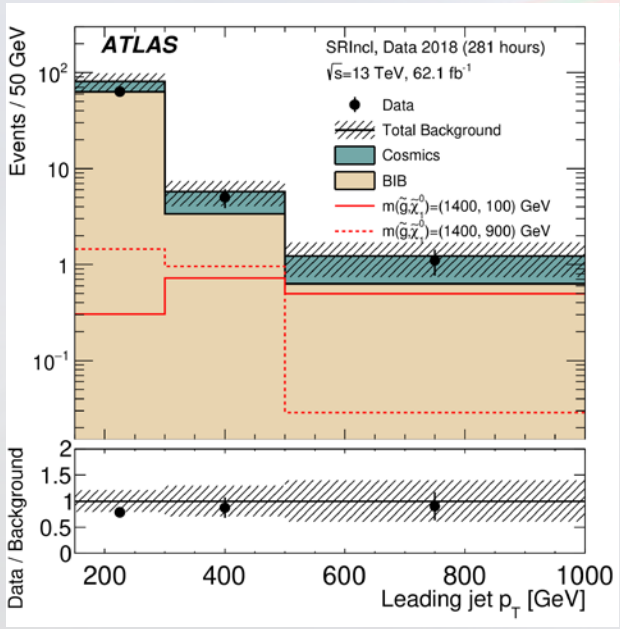


Interpreted in split-SUSY-inspired simplified model. Gluinos forming R-hadrons, $\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0$

Challenges! Non-standard:

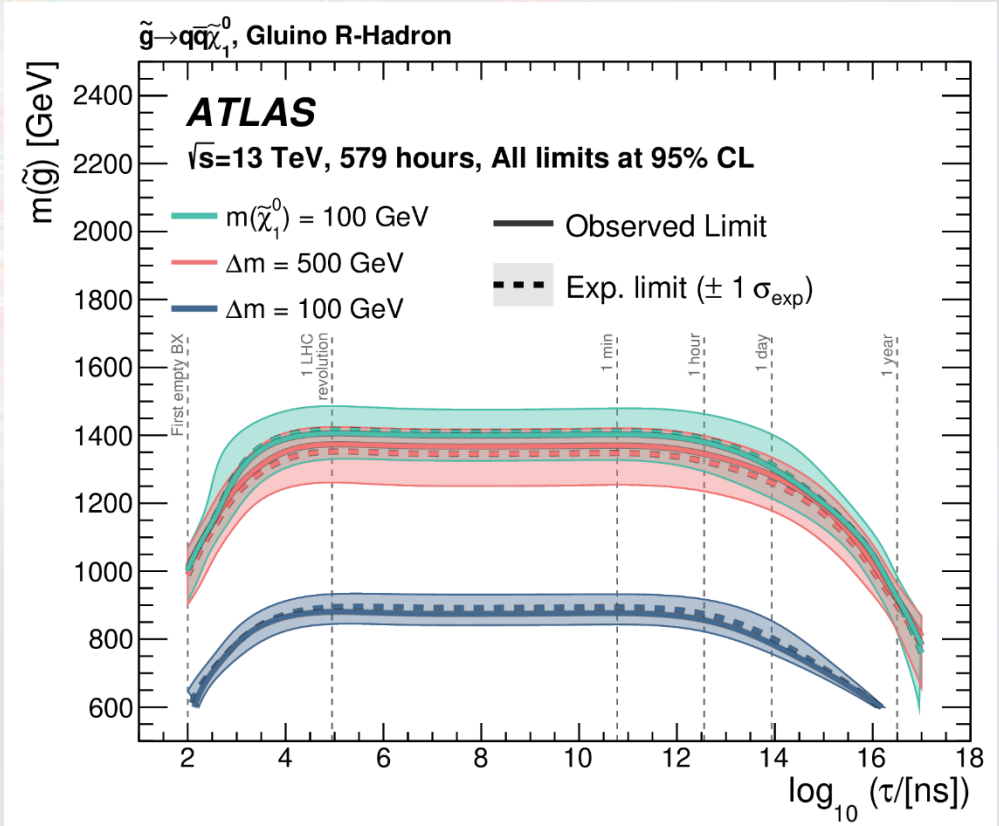
- Triggers: empty bunches
- Reconstruction (cosmics)
- Bkg (cosmics, beam-induced)
- Determine *expected* signal

Signal regions based on leading-jet $|\eta|$, p_T



Mass scenarios:

- Lightest neutralino $m(\tilde{\chi}_1^0)$ = 100 GeV
- Mass diff $\Delta m \equiv m(\tilde{g})$ - $m(\tilde{\chi}_1^0)$ = 100&500 GeV

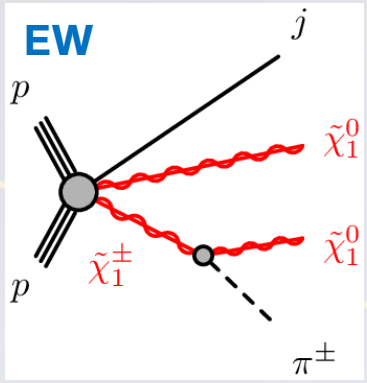


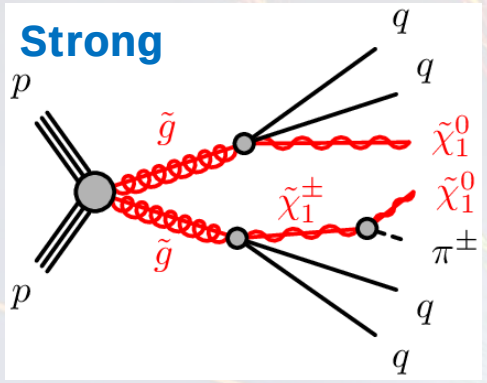
Exclusion limits:
0.6-1.4 TeV, depending on $\tau(\tilde{g})$ and mass scenario

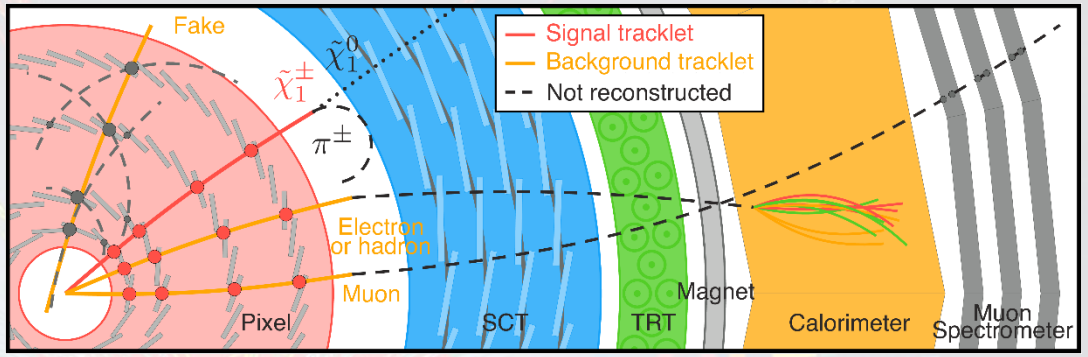
Search for long-lived charginos

To search for long-lived exotic particles...
SUSY scenarios with wino and higgsino LSP

13 TeV, 136 fb^{-1}
$\tilde{\chi}_1^{\pm} \rightarrow \tilde{\chi}_1^0 + \pi^{\pm}$







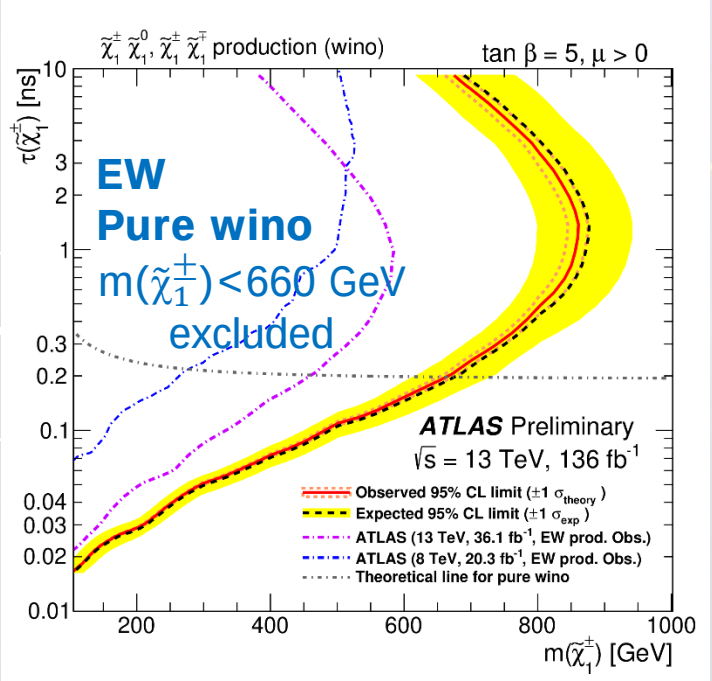
Signature:

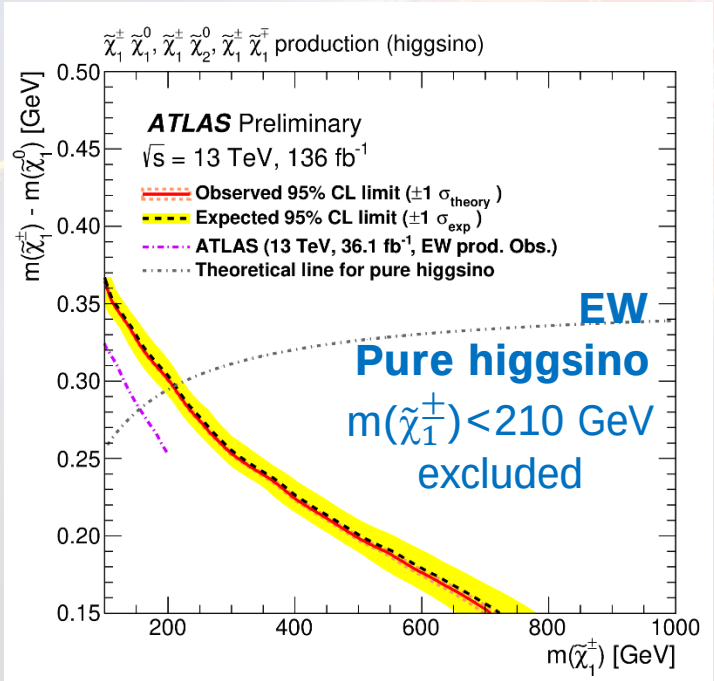
- Disappearing track early in inner tracker: pixel tracklet + no calo activity
- Significant E_T^{miss}
- high-p_T jet(s)

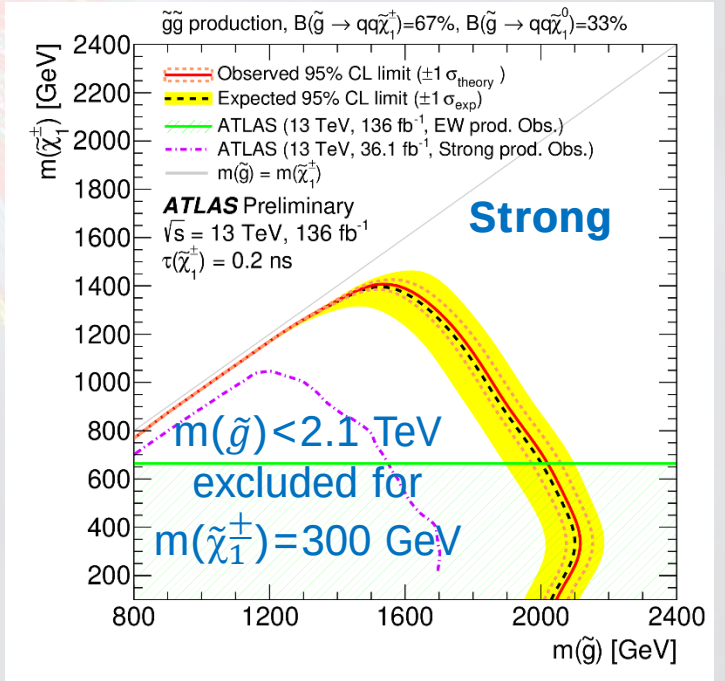
Chargino $\tilde{\chi}_1^{\pm}$ lives long enough to traverse multiple layers of Pixel detector before decaying

Two signal regions

EW	Strong
3 evts (3.0 exp.)	1 evt (0.84 exp.)



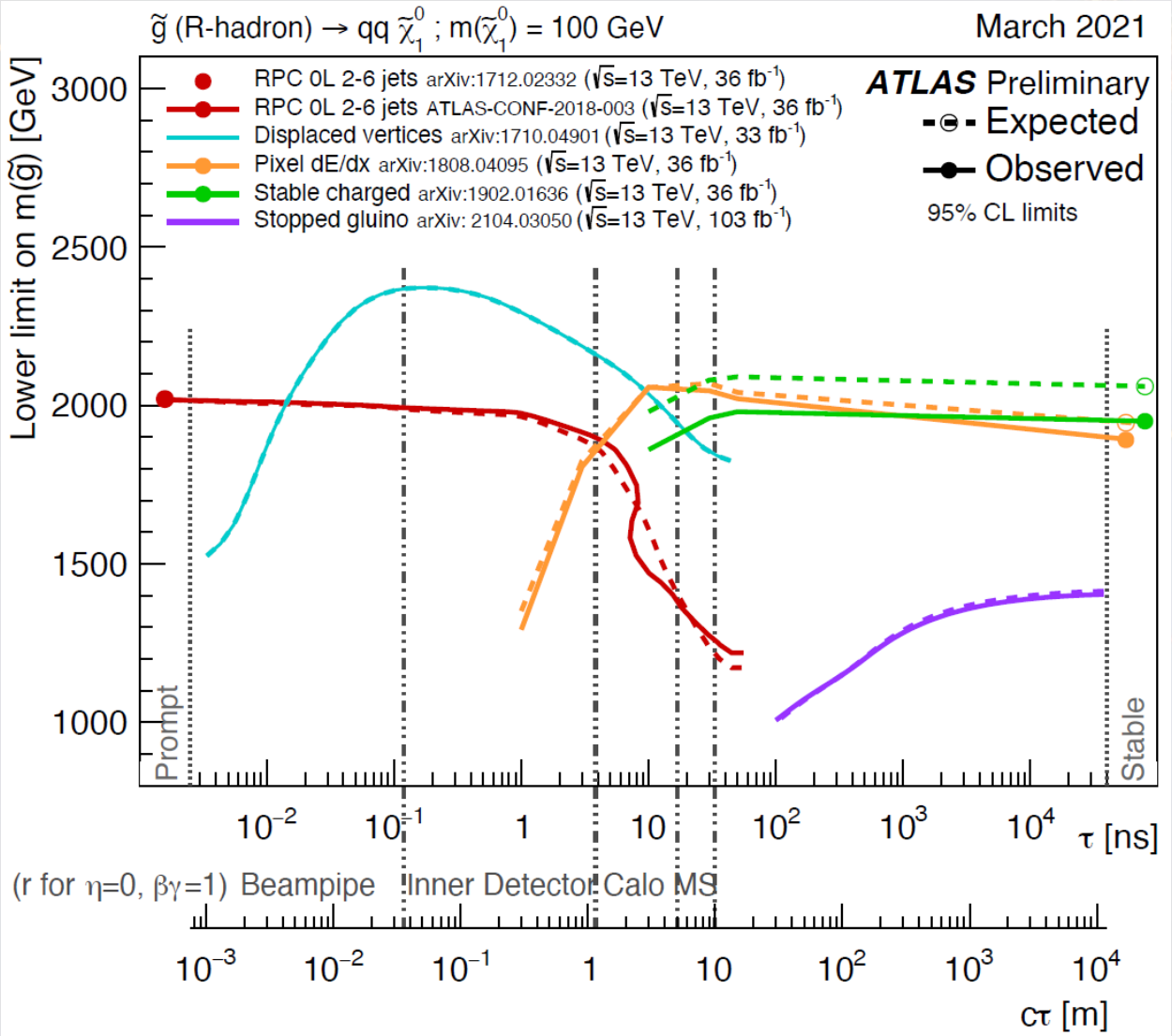




Full LLP programme covers extensive range…

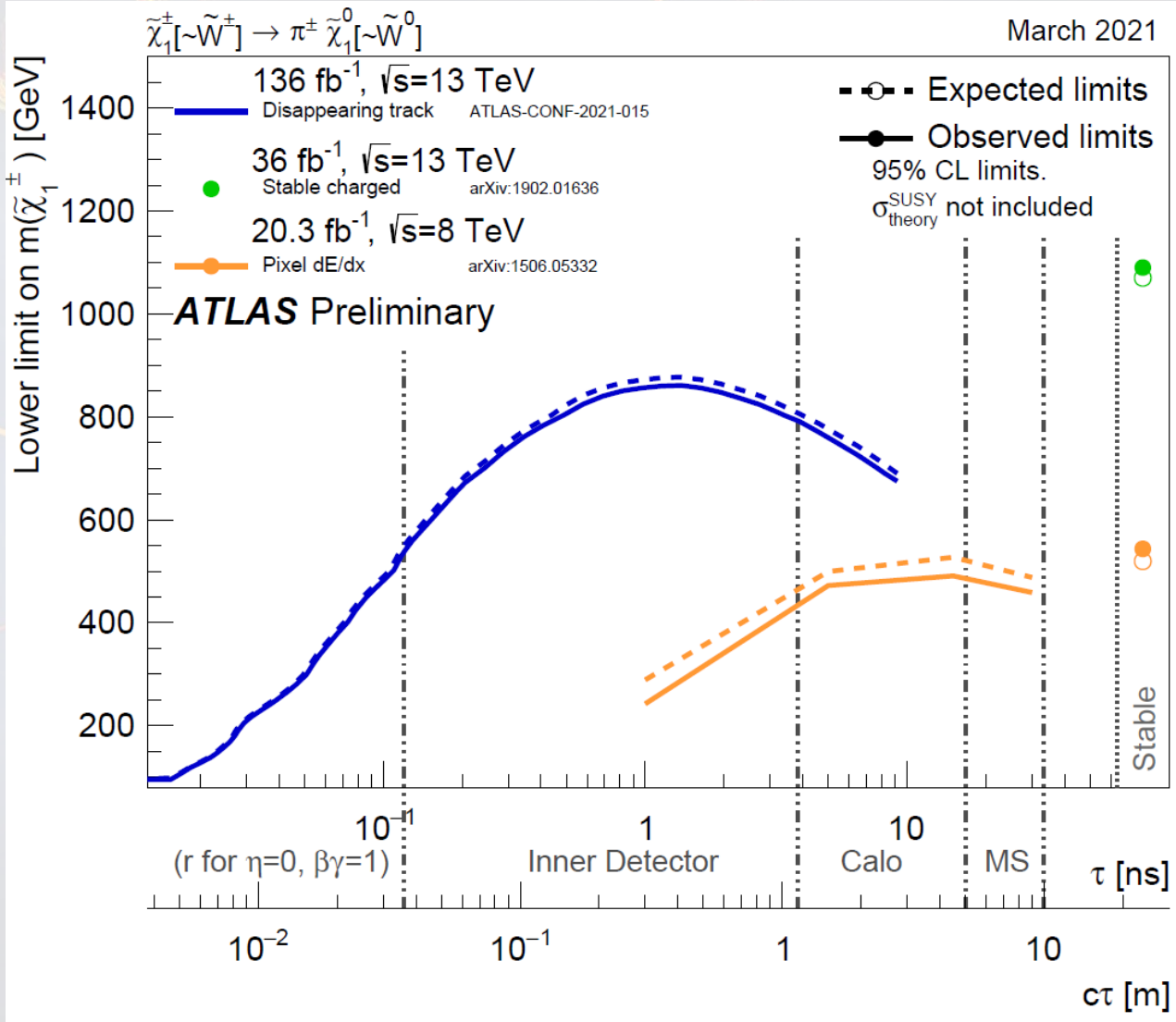
ATL-PHYS-PUB-2021-019

Constraints on gluino mass vs. lifetime



Gluino mass vs. lifetime for split-SUSY model with gluino R-hadron decaying into a gluon or light quarks and a neutralino with mass of 100 GeV.

Constraints on chargino mass vs. lifetime



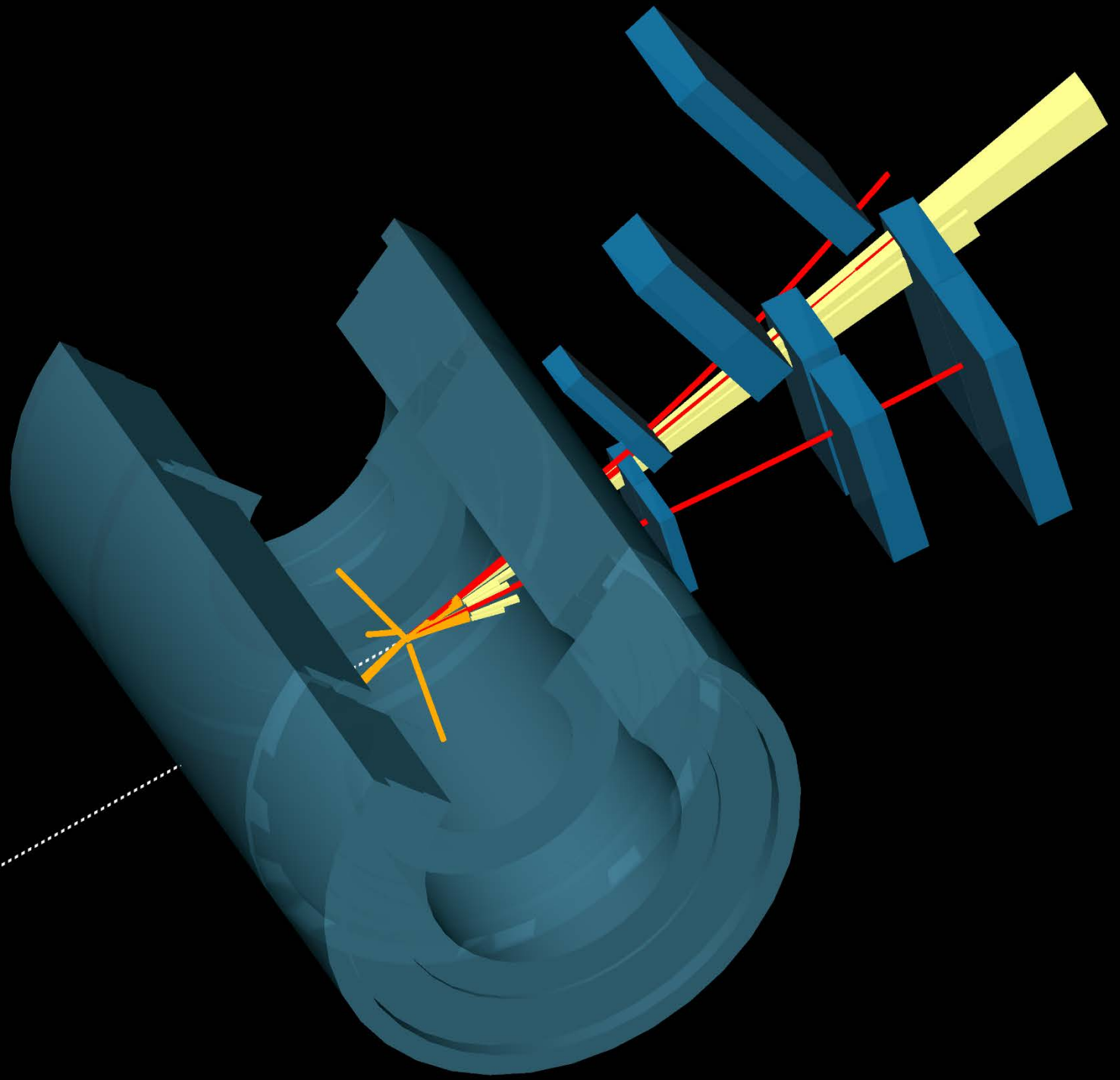
Chargino mass vs. lifetime for AMSB model with tan(β)=5, μ>0. Wino-like chargino is pair-produced and decays to wino-like neutralino and a very soft charged pion.

ATLAS EXPERIMENT

Run: 349309
Event: 769175011
2018-05-01 13:57:22 CEST

Candidate Dark Matter in association to $h \rightarrow \mathbf{b\bar{b}}$

Merged b jets arising from boosted h contained in large-radius jet



Dark Matter in association to h→bb̄

To probe the origins of Dark Matter (DM)...

13 TeV, 139 fb^{-1}
E_T^{miss} + b jets

Complementarity of direct and indirect experiments.

Higgs boson couples directly to DM or via another BSM particle
Two-Higgs-Doublet Model (2HDM), neutral scalars: CP-even h(=125 GeV) & odd A

Two simplified benchmark models:

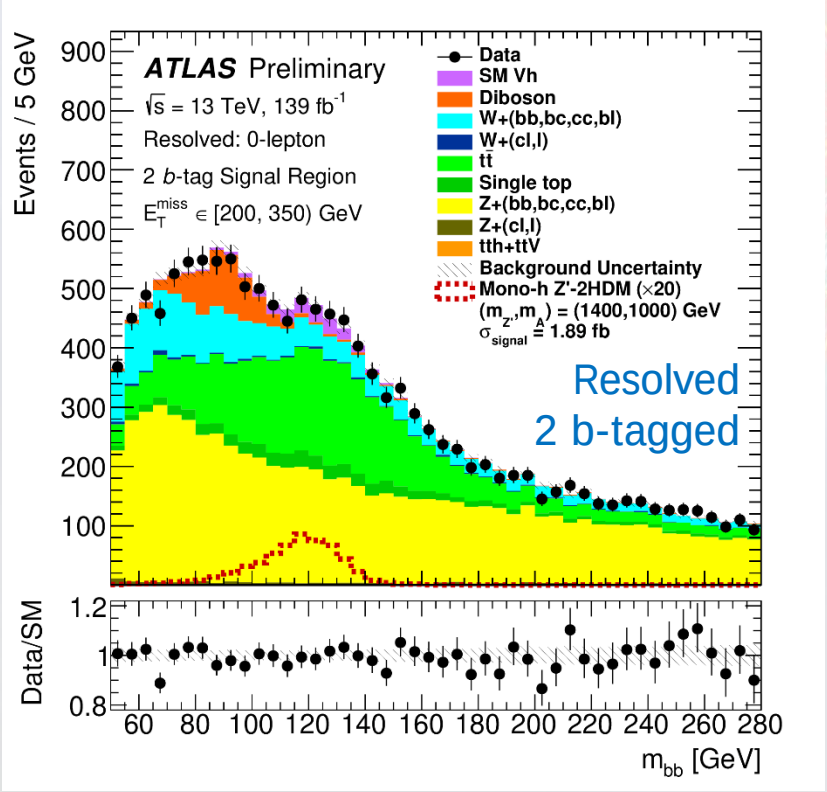
Z'-2HDM:

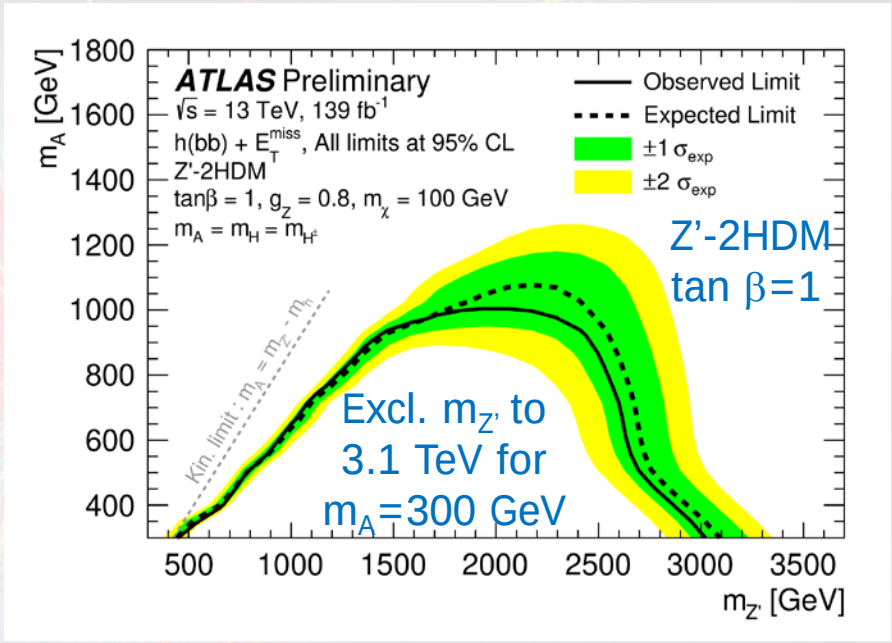
Z' → A h
- A → bb̄
- h → DM DM

2HDM+a:
(a=pseudoscalar singlet)

A (→ a h) [+bb̄]
- h → bb̄
- a → DM DM

Signature: imbalance in p_T (i.e. E_T^{miss})
+ merged/resolved b jets [+ associated jets]





Exclusion for 2HDM+a up to:
- m_a=520 GeV for m_A=1.25 TeV [ggF, tan β =1]
- m_a=240 GeV for m_A=900 GeV [bbA, tan β =10]

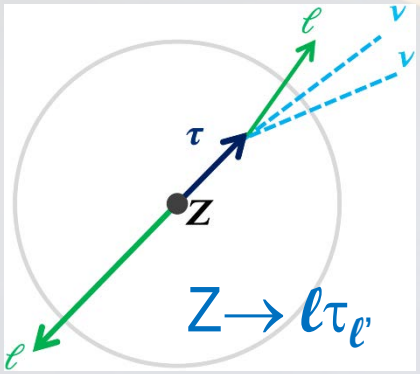
arXiv:2105.12491

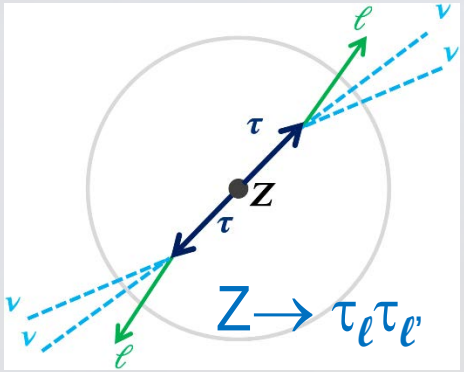
Lepton flavour violation (LFV)

To probe lepton-flavour universality...

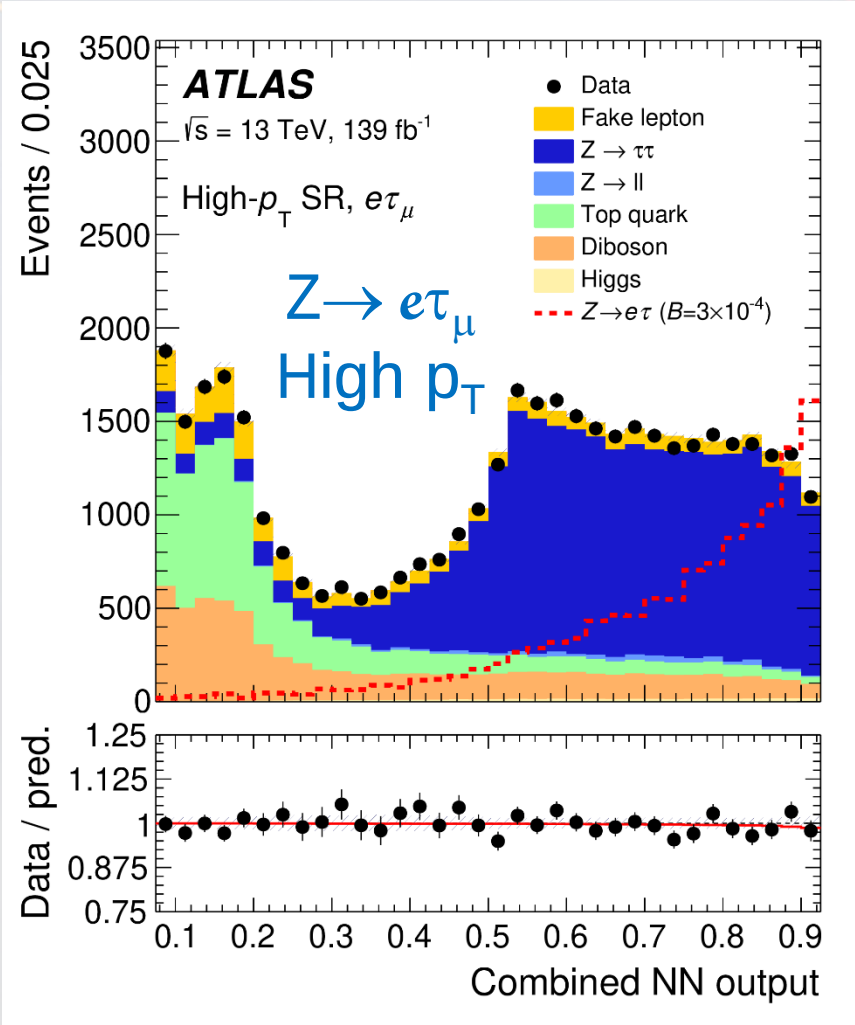
13 TeV, 139 fb^{-1}
$Z\rightarrow \ell\tau_{\ell'}$ where ℓ, ℓ'=e,μ

Lepton flavour conserved in SM, but not protected by any fundamental principle. Observed in neutrino oscillations.





Three Neutral Network binary classifiers into a combined output.
Maximum likelihood fit.
Signal regions: low/high p_T



Combined with:

13 TeV, 139 fb^{-1} and 8 TeV, 20 fb^{-1}
$Z\rightarrow \ell\tau_{had}$ where ℓ=e,μ

arXiv:2010.02566

Most stringent constraints on LFV Z boson decays involving τ to date!
$B(Z\rightarrow \ell\tau) <$ ~5-8 x10^{-6}
Mainly limited by statistics.

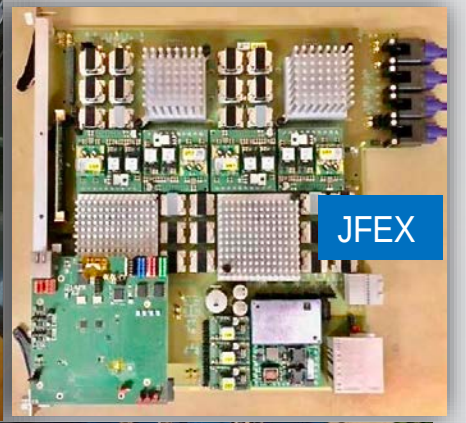
Final state, polarization assumption	Observed (expected) upper limit on $\mathcal{B}(Z \rightarrow \ell\tau)$ [×10^{-6}] $e\tau$	$\mu\tau$
Combined $\ell\tau$ Run 1 + Run 2, unpolarized τ	5.0 (6.0)	6.5 (5.3)
Combined $\ell\tau$ Run 2, left-handed τ	4.5 (5.7)	5.6 (5.3)
Combined $\ell\tau$ Run 2, right-handed τ	5.4 (6.2)	7.7 (5.3)

Different τ polarisation scenarios

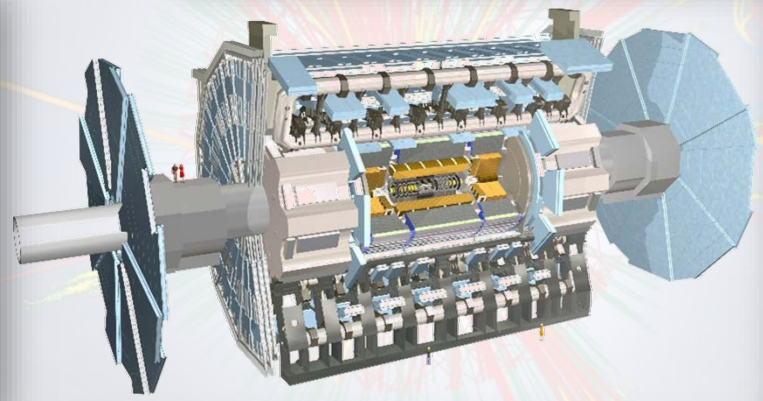
Getting ready for Run 3

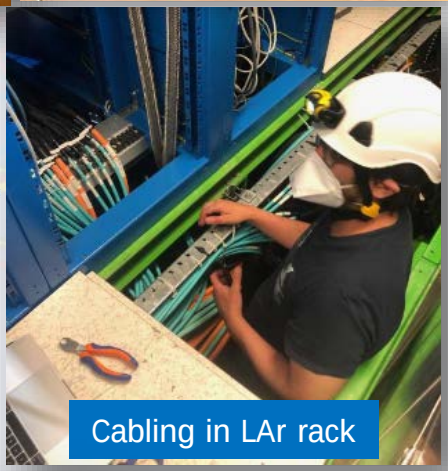

Muon New Small Wheels


Pixel optoboard replacement


JFEX

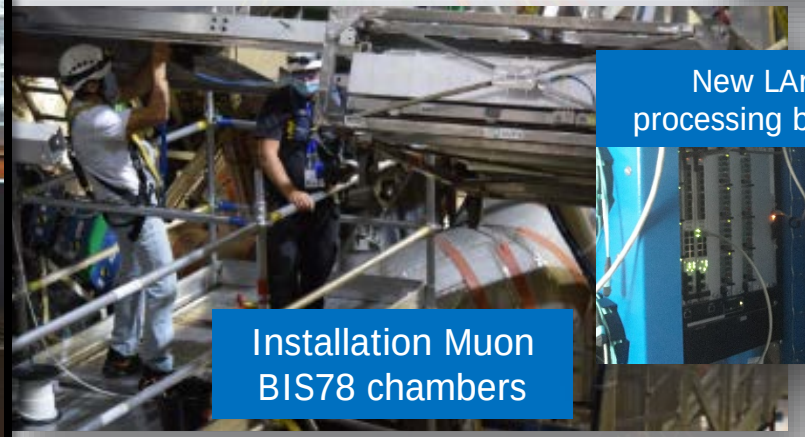
Tile Calorimeter maintenance




Cabling in LAr rack

Run-3 Trigger Workshop


Milestone Weeks in ATLAS Control Room


Installation Muon BIS78 chambers

New LAr processing blade

FELIX

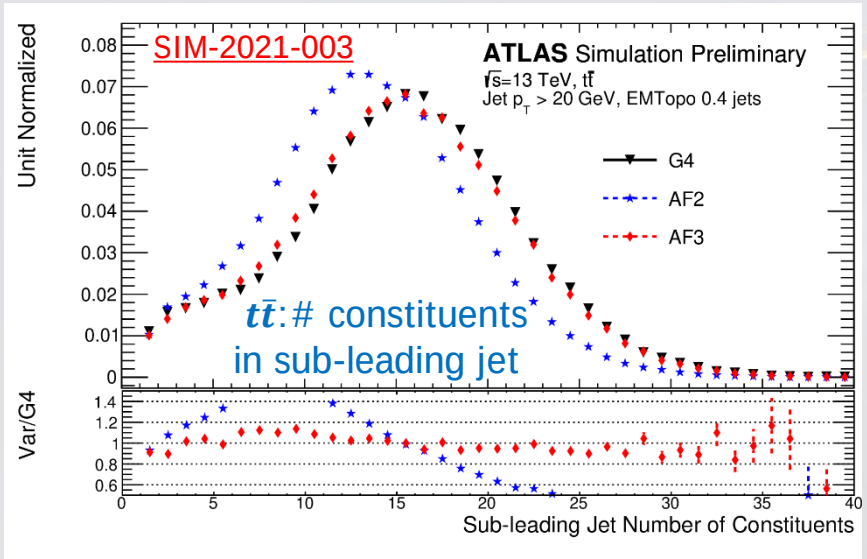
Getting ready for Run 3

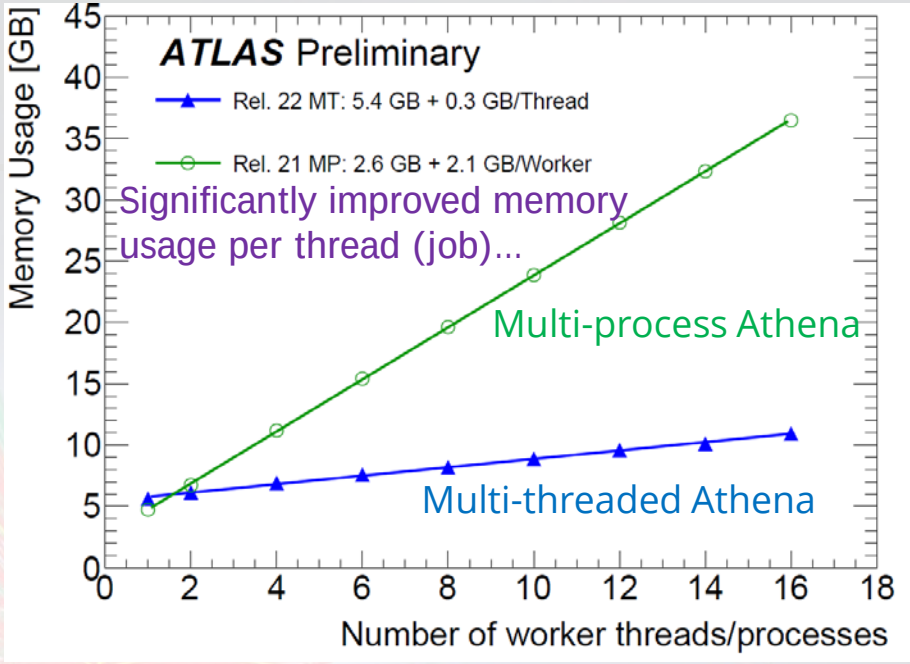
Take full advantage of the many detector improvements for Run 3

- Finer granularity of Liquid Argon calorimeter for Level-1 trigger
- New “feature extractors” at Level-1 trigger to enable new event topologies
- New Small Wheel muon chambers in forward region

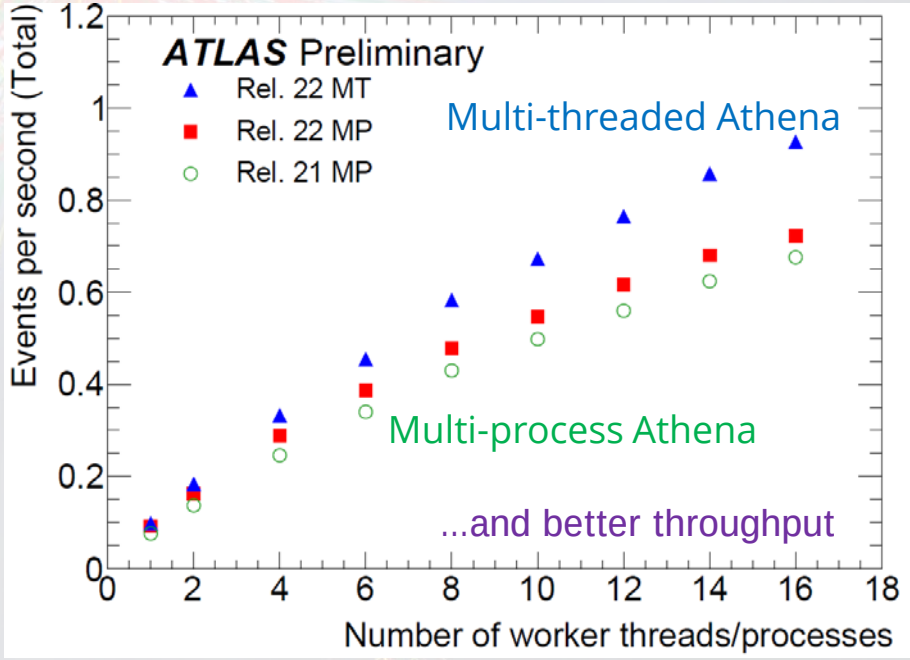
Huge effort preparing ATLAS for Run 3 data-taking and analyses

- (early) Run-3+Run-2 data combinations
- single lightweight data format
- Software migration to multi-thread-capable release
- Finalisation trigger strategies, algorithms
- New fast calorimeter simulation with significantly improved performance: AF3





ATL-PHYS-PUB to come...



Summary and outlook

- Broad set of full Run-2 pp collision + heavy-ion results, including
  - 4.7 σ evidence for $t\bar{t}t\bar{t}$, observation of 1000s of H$\rightarrow$ WW* (6.6 σ VBF), significant improvements in the limit on HH$\rightarrow$ b$\bar{\text{b}}\gamma\gamma$ trilinear coupling modifier κ_λ: [-1.5, 6.7], new tighter constraints in the search for long-lived particles, most stringent constraints to date on LFV Z decays involving τ

- Preparations for Run 3 in full swing!
  - Many ongoing maintenance, upgrade, and recommissioning activities
  - Significant software, trigger, simulation improvements

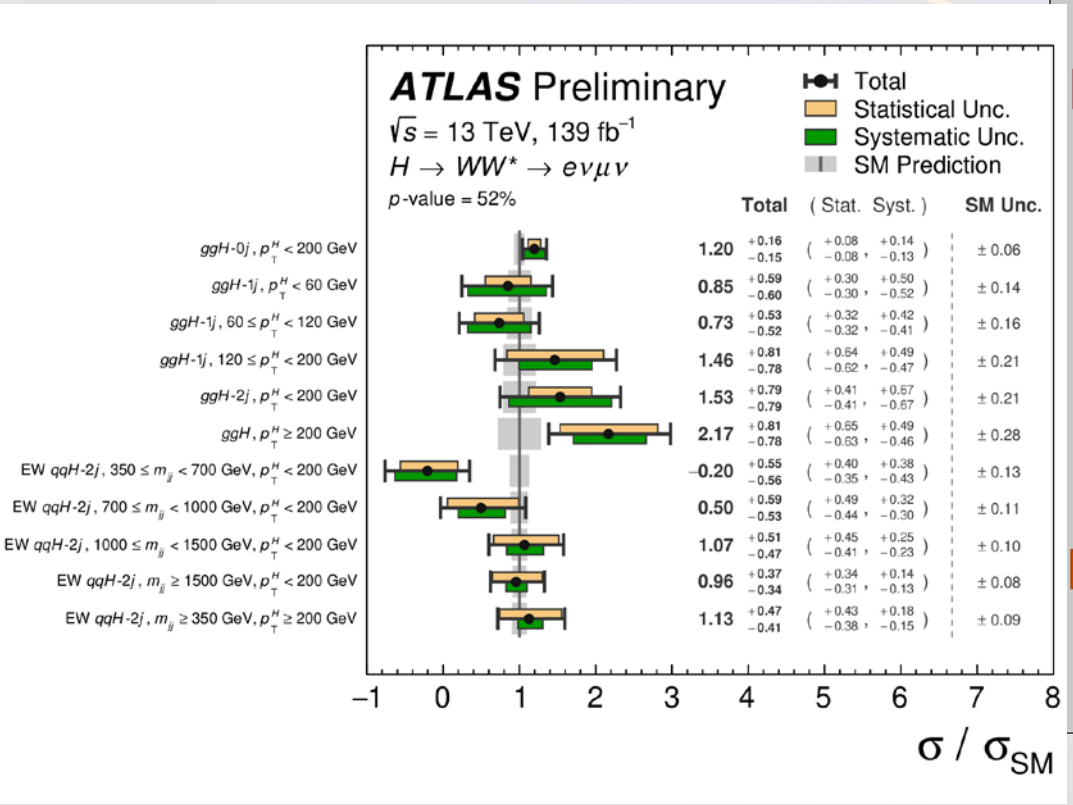
  ➡ This time next year, new pp collisions hopefully at 14 TeV!

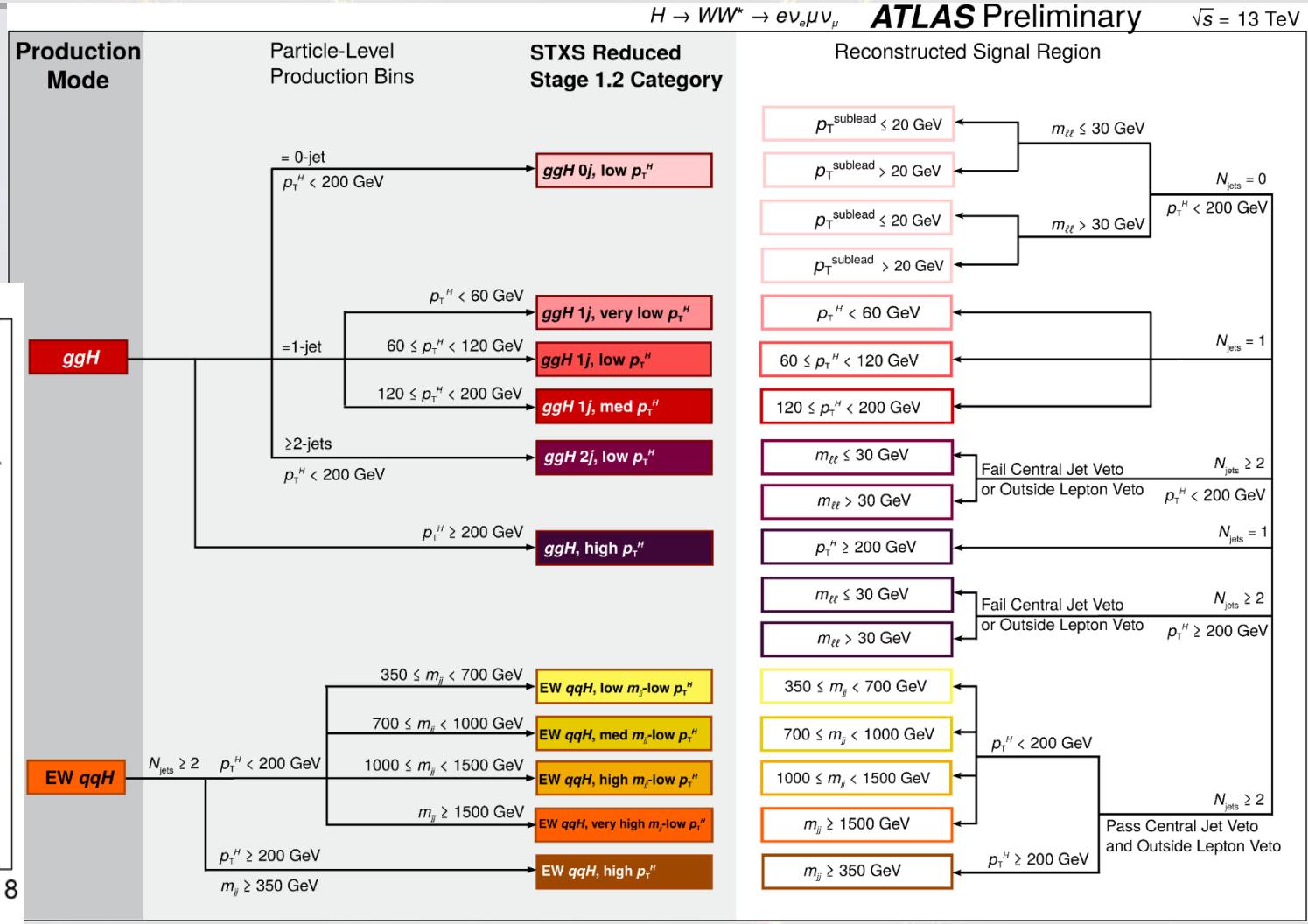
- ATLAS is deeply committed to its Phase-II upgrade programme, including
  - New all-silicon inner tracker, replacement of barrel Muon chambers, electronics upgrades for calorimeters and muon spectrometer, L0-based TDAQ system at 1 MHz, new High Granularity Timing Detector. See talk on Wednesday.

Backup material

H→WW*

11 fiducial [Stage 1.2 STXS] cross sections (6 ggH, 5 EW qqH)



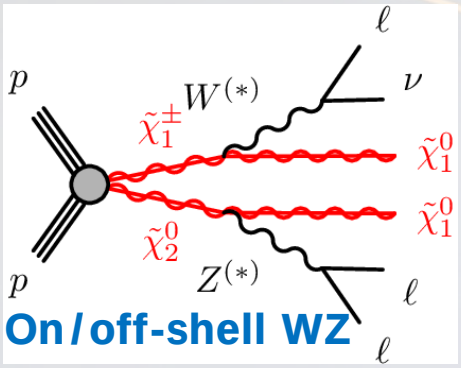


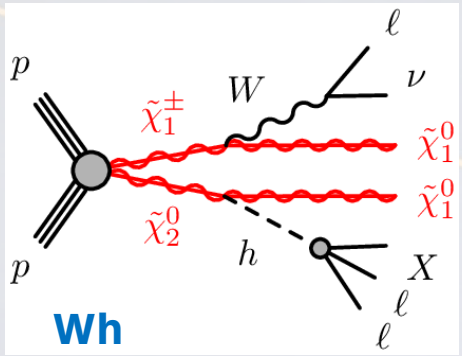
Search for Chargino-Neutralino $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ pair production

SUSY-2019-09
Physics Briefing to come

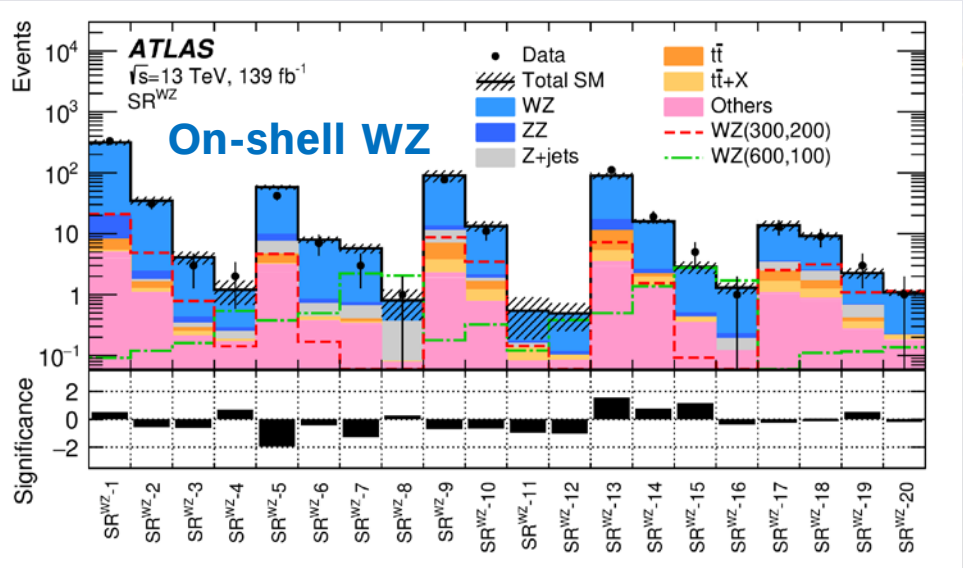
To search for SUSY...

13 TeV, 139 fb^{-1}
$W^{(*)}Z^{(*)}$, $Wh \rightarrow 3\ell + E_T^{miss}$



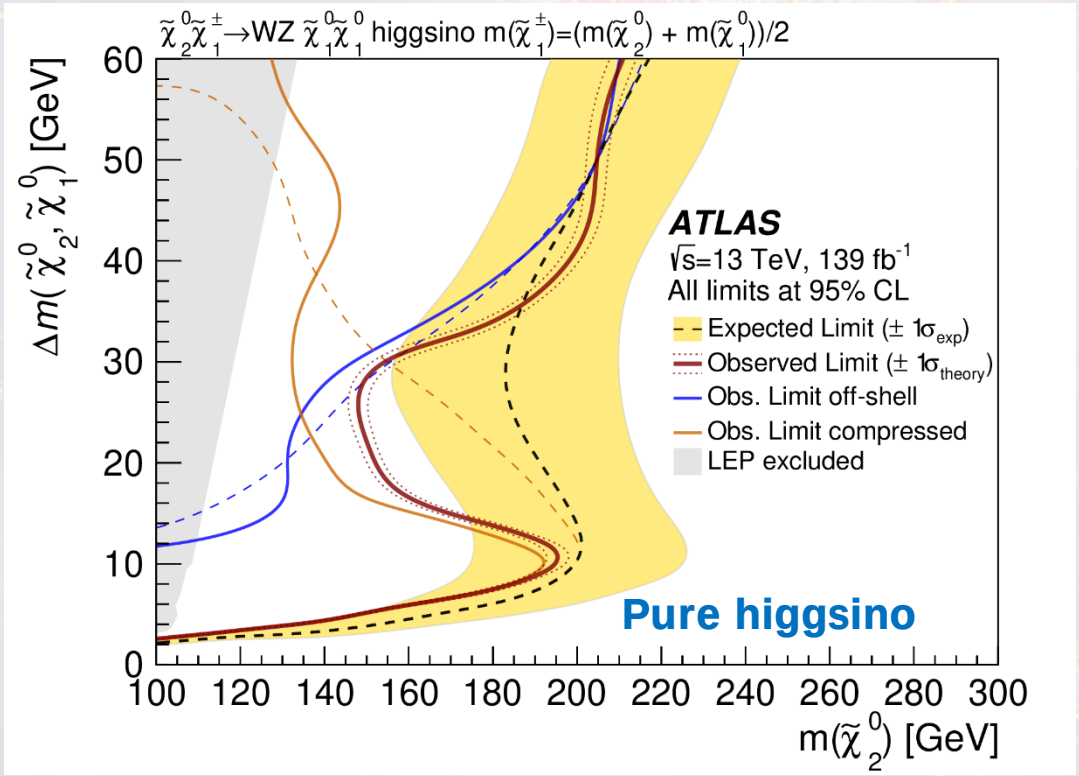


Dedicated selections targeting SUSY scenarios
- ~60 signal regions: charge&flavour of leptons...



Simplified SUSY models
- $\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$ purely wino, $\tilde{\chi}_1^0$ LSP purely bino
- $\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0, \tilde{\chi}_2^0$ purely Higgsino

Combined with 2ℓ search arXiv: 1911.12606
targeting compressed mass spectra



Δm=15-30 GeV: impact of combination of offshell WZ and compressed is largest!

Exclusions

Pure higgsino $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$:
$m(\tilde{\chi}_2^0)$ up to 210 GeV

Pure wino $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$:
$m(\tilde{\chi}_2^0)$ up to
- 640 GeV [on-shell WZ]
- 300 GeV [off-shell WZ]
- 190 GeV [Wh]