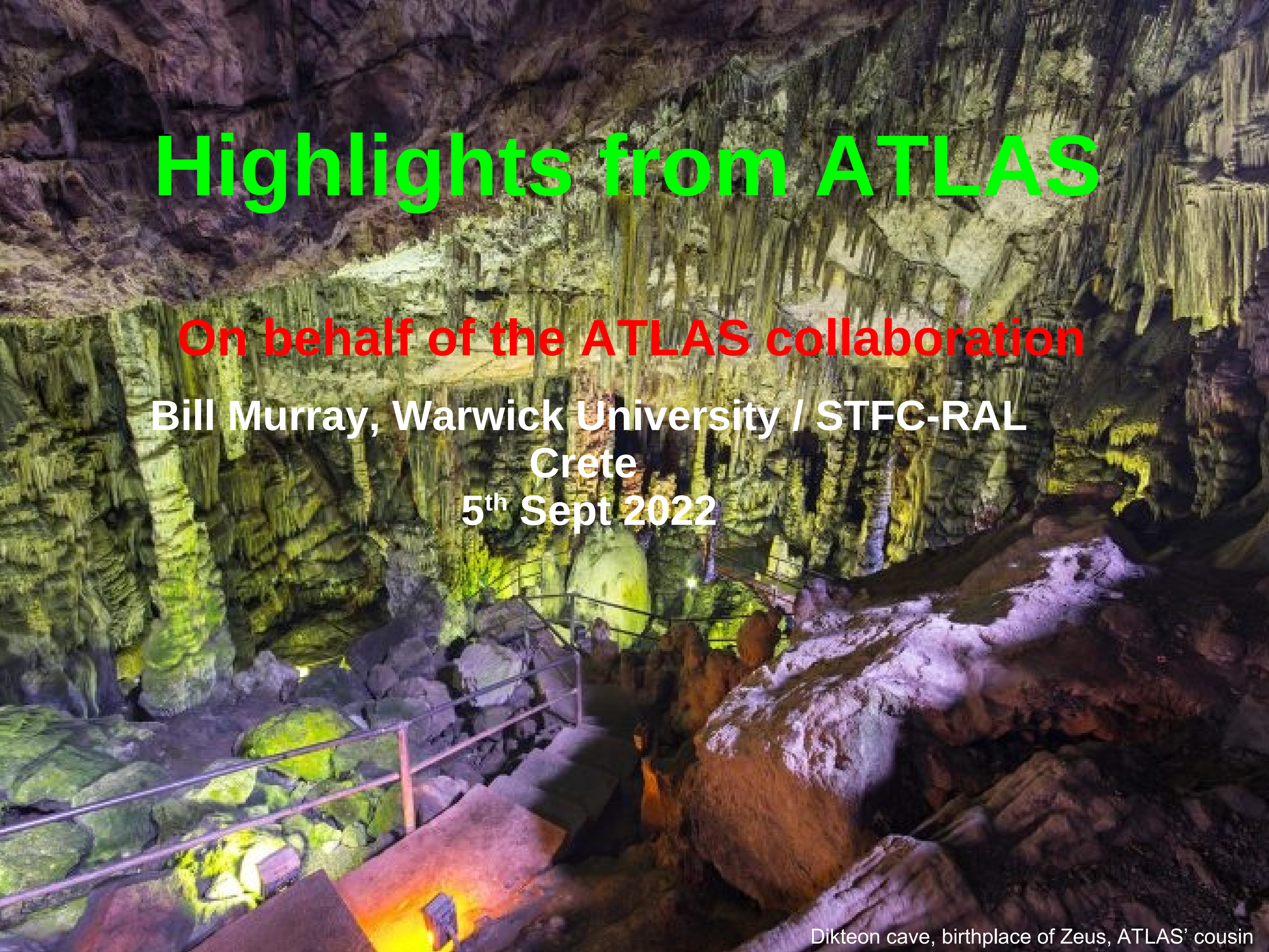
Highlights from ATLAS

On behalf of the ATLAS collaboration

Bill Murray, Warwick University / STFC-RAL

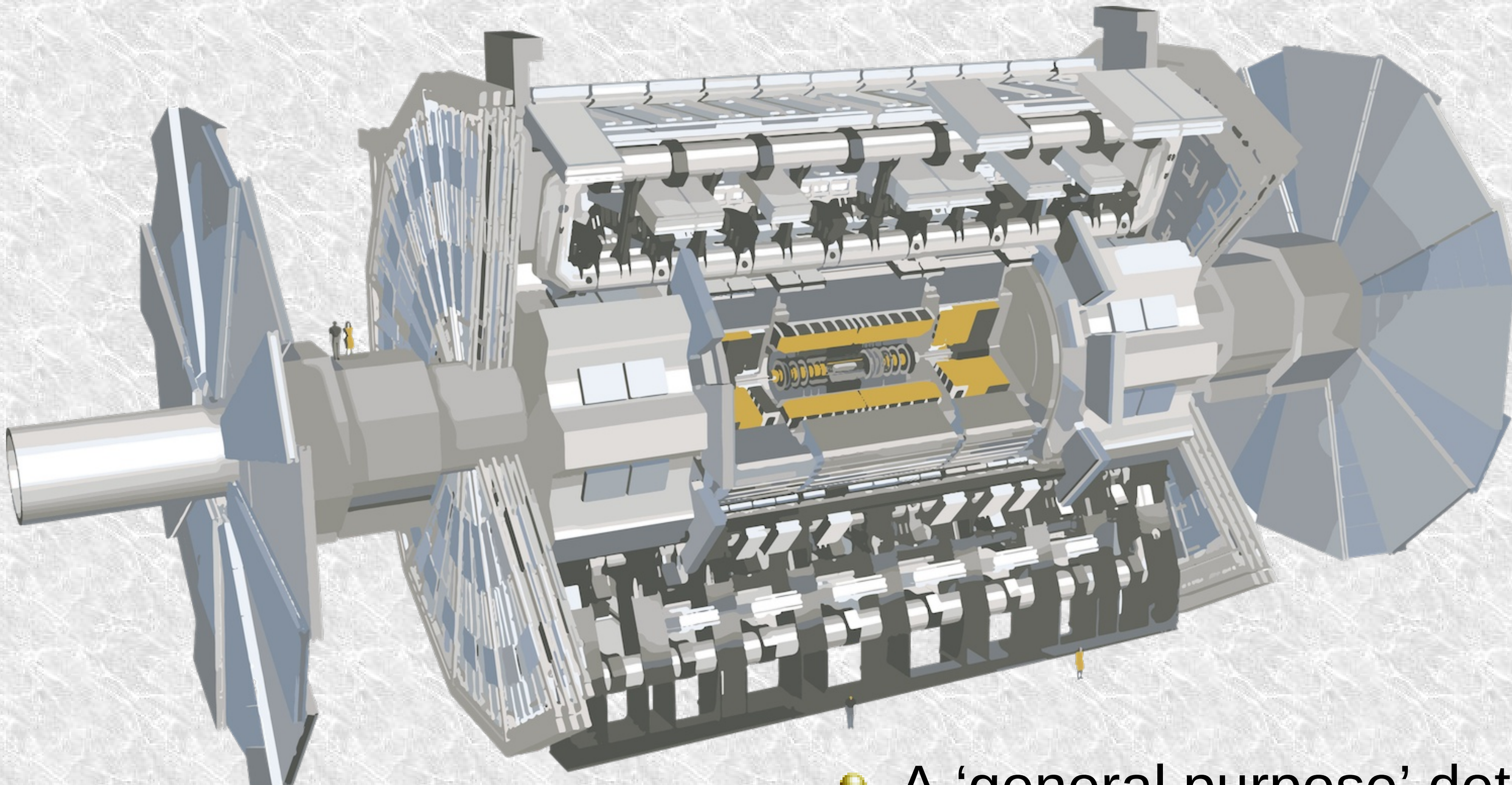
Crete

5th Sept 2022



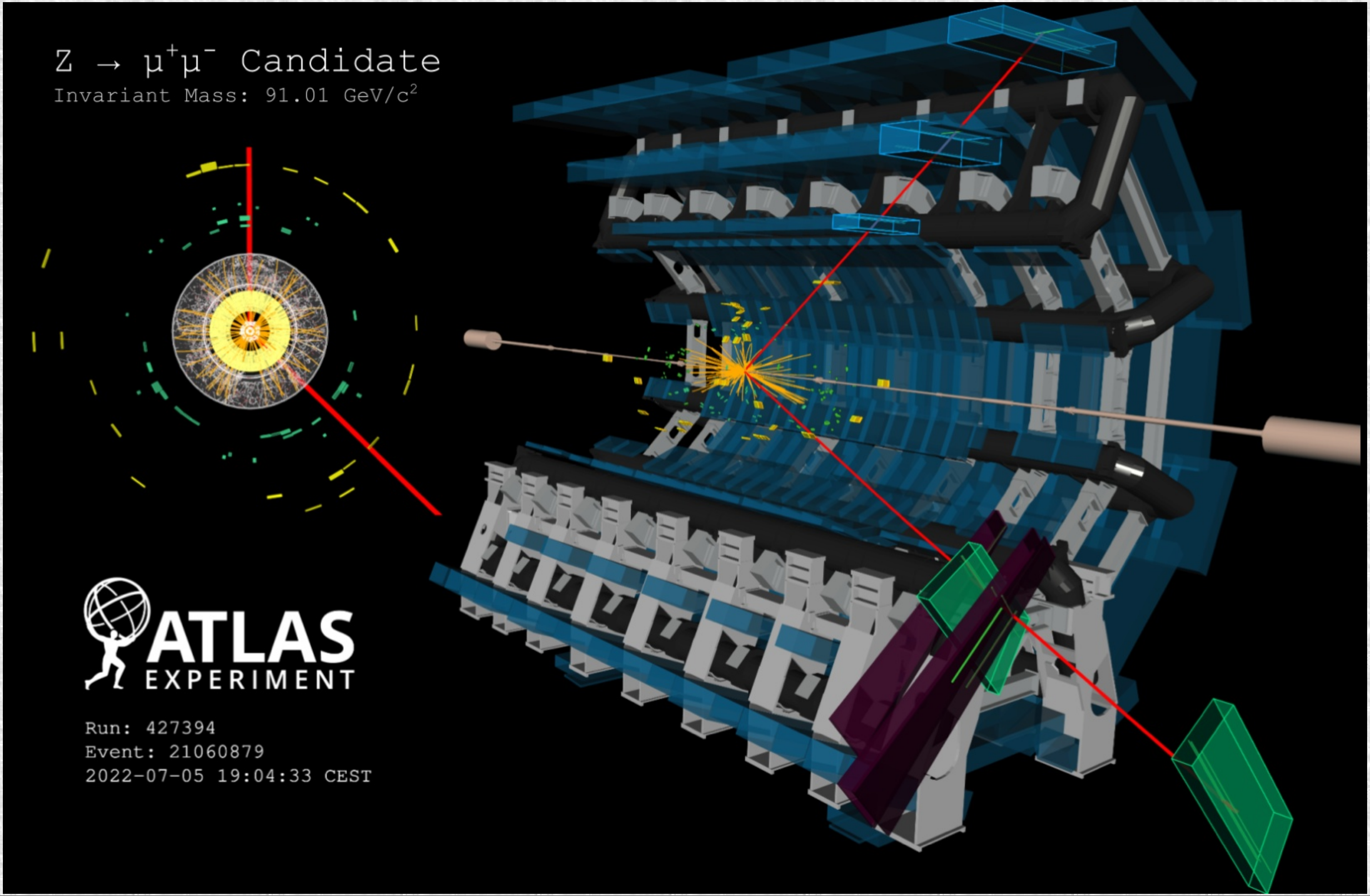
Dikteon cave, birthplace of Zeus, ATLAS' cousin

The ATLAS detector at LHC



- A ‘general purpose’ detector
- 1% measurement of muon momentum and electron energy
- Excellent calorimetry for jet energy and missing energy
- Triggering on muons, electrons, photons and jets

Run 3 is here



Z → μ+μ- Candidate
Invariant Mass: 91.01 GeV/c2
ATLAS
EXPERIMENT
Run: 427394
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ATLAS physics overview

- LHC is a general purpose collider
  - pp collisions allow many possibilities
  - ATLAS physics programme is very broad: 1085 papers

Title	Papers	Description
Standard Model	199	EW & QCD studies: W & Z bosons
Higgs	153	Studies of the H(125)
Top	126	Top quark studies
B physics	35	B hadron studies and light states
Heavy Ion	78	Collective effects, strong EM field
SUSY	161	Searches for Supersymmetry
Exotics	216	Other searches
HDBS	23	Searches: Exotic H decay, new H, HH, VV, VH (V=W,Z)

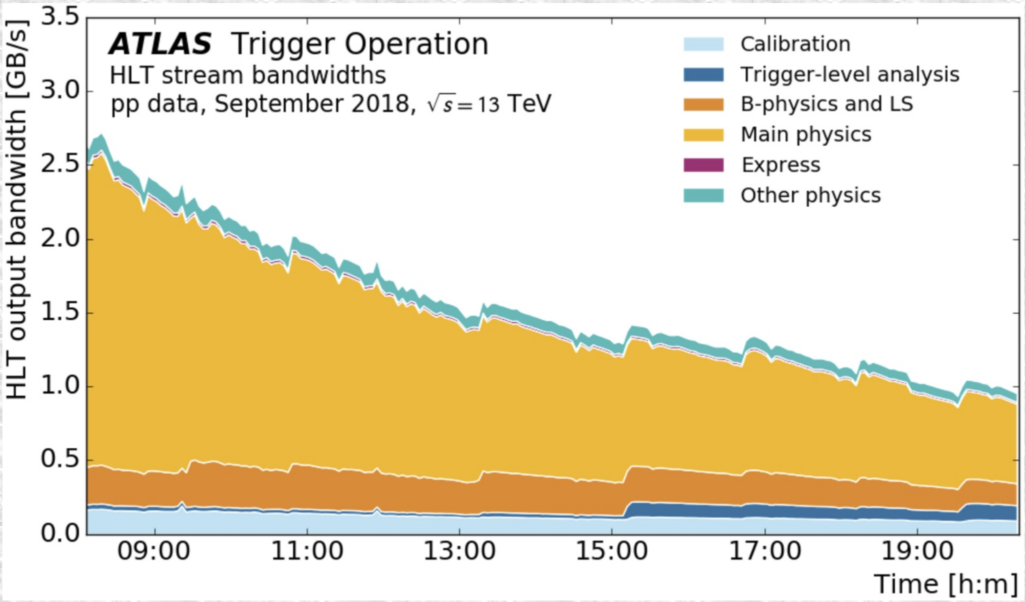
Alternative view: this meeting

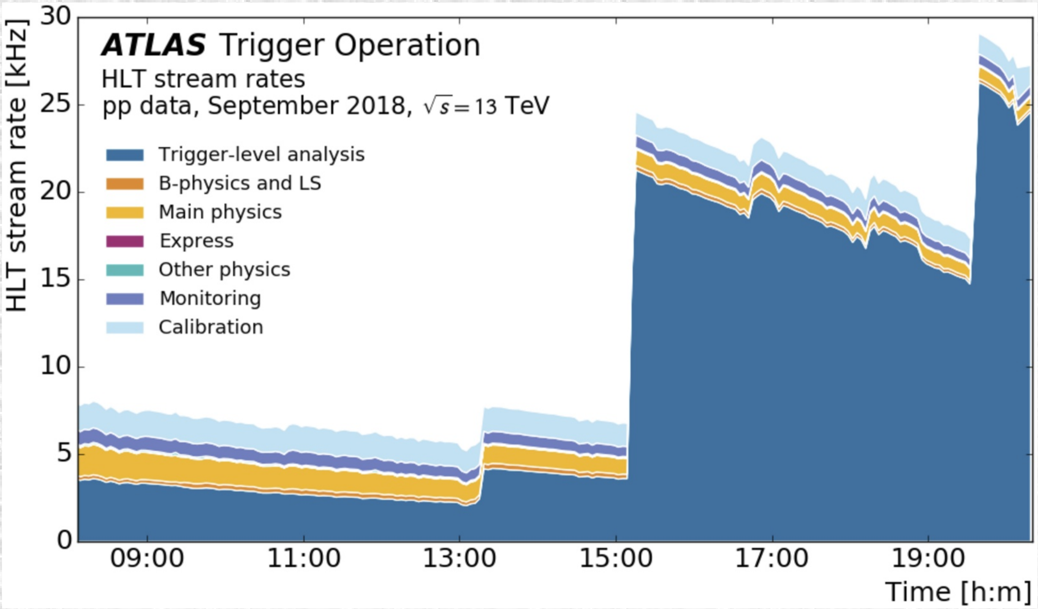
- Run 3 performance – Pawel Klimek
- 10 years of Higgs – Brian Moser
- Recent Searches – Eirik Gramstad
- Top quark physics – Peter Berta
- Rare top – Chenliang Wang
- ATLAS upgrades – Geoffrey Mullier
- Dark matter search – Alex Wang
- Prompt SUSY – ShuHui Huang
- W/Z/top tagging – Qibin Liu
- 3rd generation searches – Meng-lu Tsai
- Recent Higgs – Soshi Tsuno
- Higgs mass/width/CP – Brian Le
- Higgs couplings – Georges Aad
- Higgs pairs – Alessandr Betti
- Higgs fiducial/differential – Yasuyuki Horii
- Additional Higgs bosons – Noemi Cavalli
- Top precision measurements – Adam Rennie
- Run 3 data results – Stefano Rosati
- ATLAS new small wheels – Lorne Levinson
- JET/MET performance – Romain Bouquet
- Heavy Ion results – Martin Spousta
- Heavy Flavour results – Unberto de Sanctis
- Challenging/LLP searches – Maria Didenko
- Photons/Multijets – Josu Cantero Garcia
- ATLAS demographics – tbd
- SUSY with prompt – ShuHui Huang
- SUSY with LLPs – Kock Kiam Gan
- Exotic Hadronic – Ivan Yeletskikh
- Photon fusion and tau g-2 – Haifeng Li

Trigger

Trigger system

- Key to all physics at LHC
- Reducing 40 MHz collisions to order(few KHz)
  - Adapting to LHC luminosity
- One fill in 2018 shown
  - Main physics dominates bandwidth
    - e/μ p_T>27 GeV, 2x~200Hz
    - τ pair, p_T>35/25 GeV, 100Hz
    - Jet, p_T>460 GeV, 40Hz
    - MET > 110 GeV, 90Hz
  - Trigger-level analyses have highest rate
- 95.6% DQ eff. in Run 2



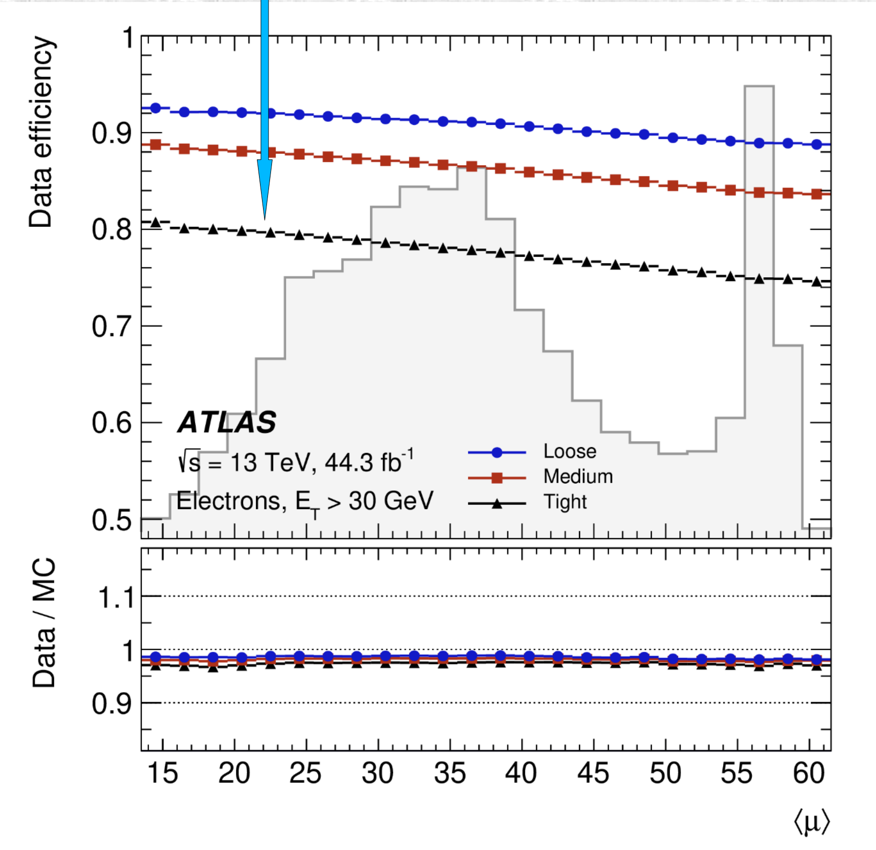


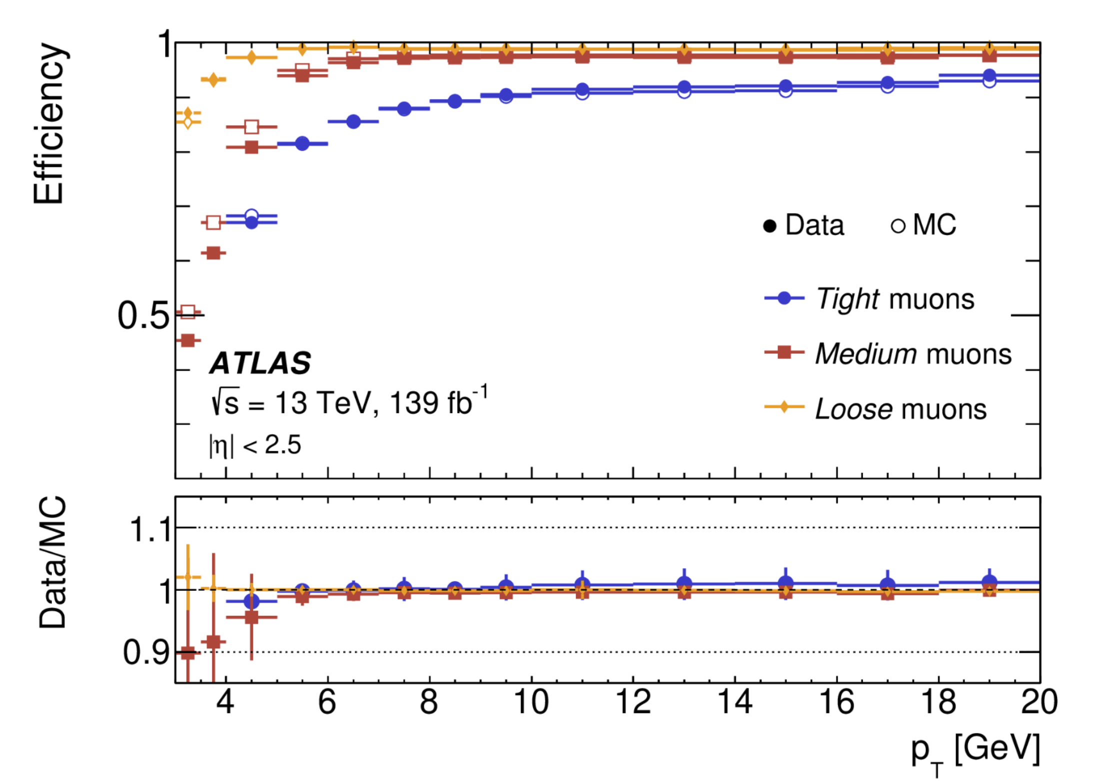
Performance

Performance and modelling

- Efficiency high, with limited pileup impact

Design μ



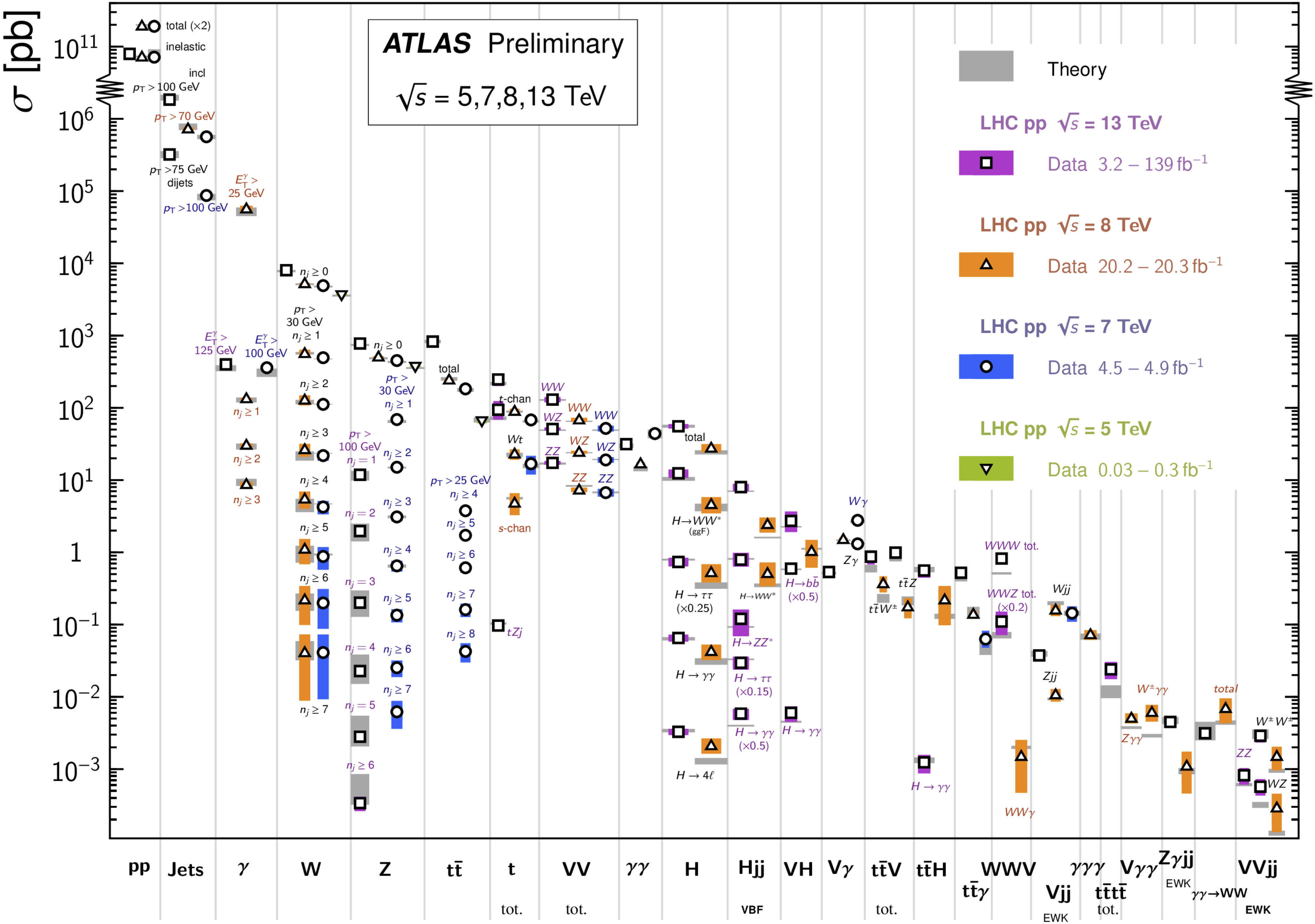


- Excellent MC Modelling
  - Correction factors measured in data are applied; generally close to 1

Standard Model

Standard Model Production Cross Section Measurements

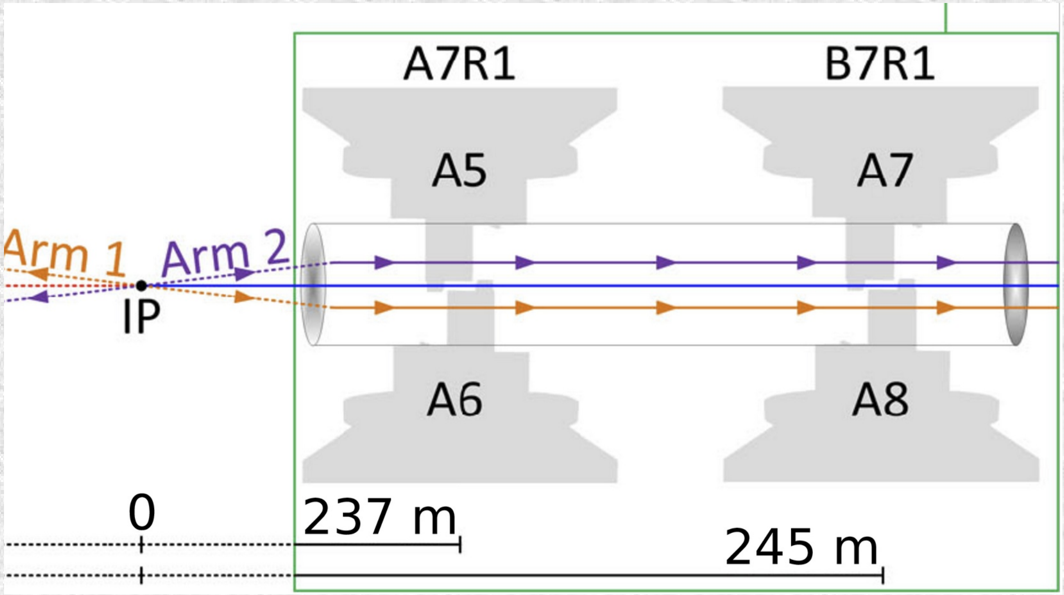
Status: February 2022

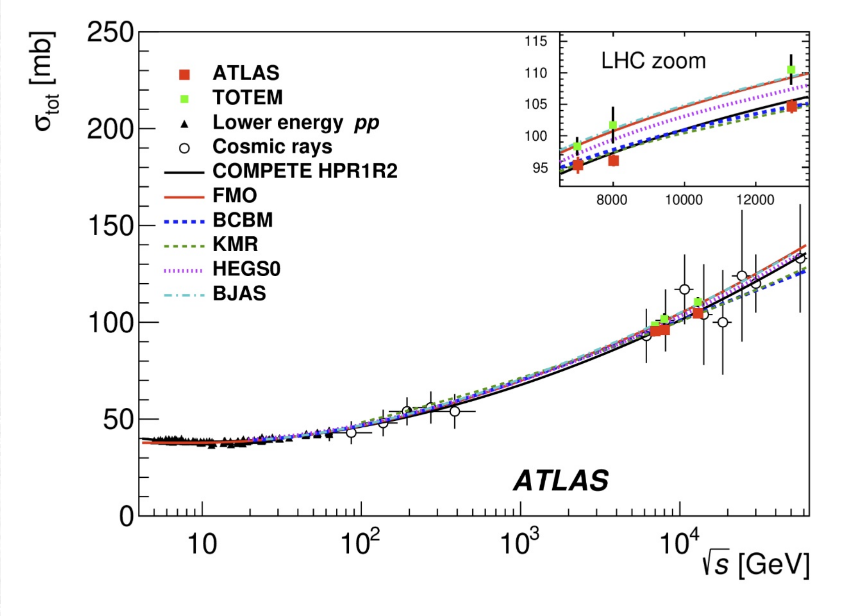


Total pp cross-section

STDM-2018-08

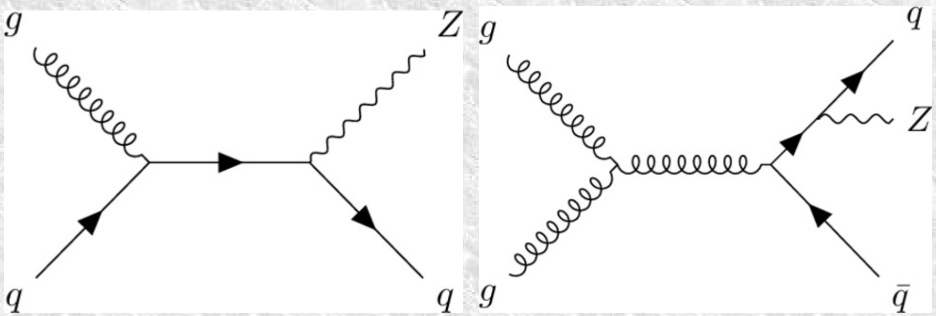
- ALFA subdetector
  - Scintillating fibres close to the beam
  - 240m forward and backward
- Run with $\beta^* = 2.5$km
- Measure mandelstam ‘t’ distribution
  - Extract cross-section using optical theorem
- Find: σ=104.7±1.1mb
  - Most precise, limited by lumi
- Also ρ=0.0975±0.0106
  - Ratio Re f(0)/ Im f(0)



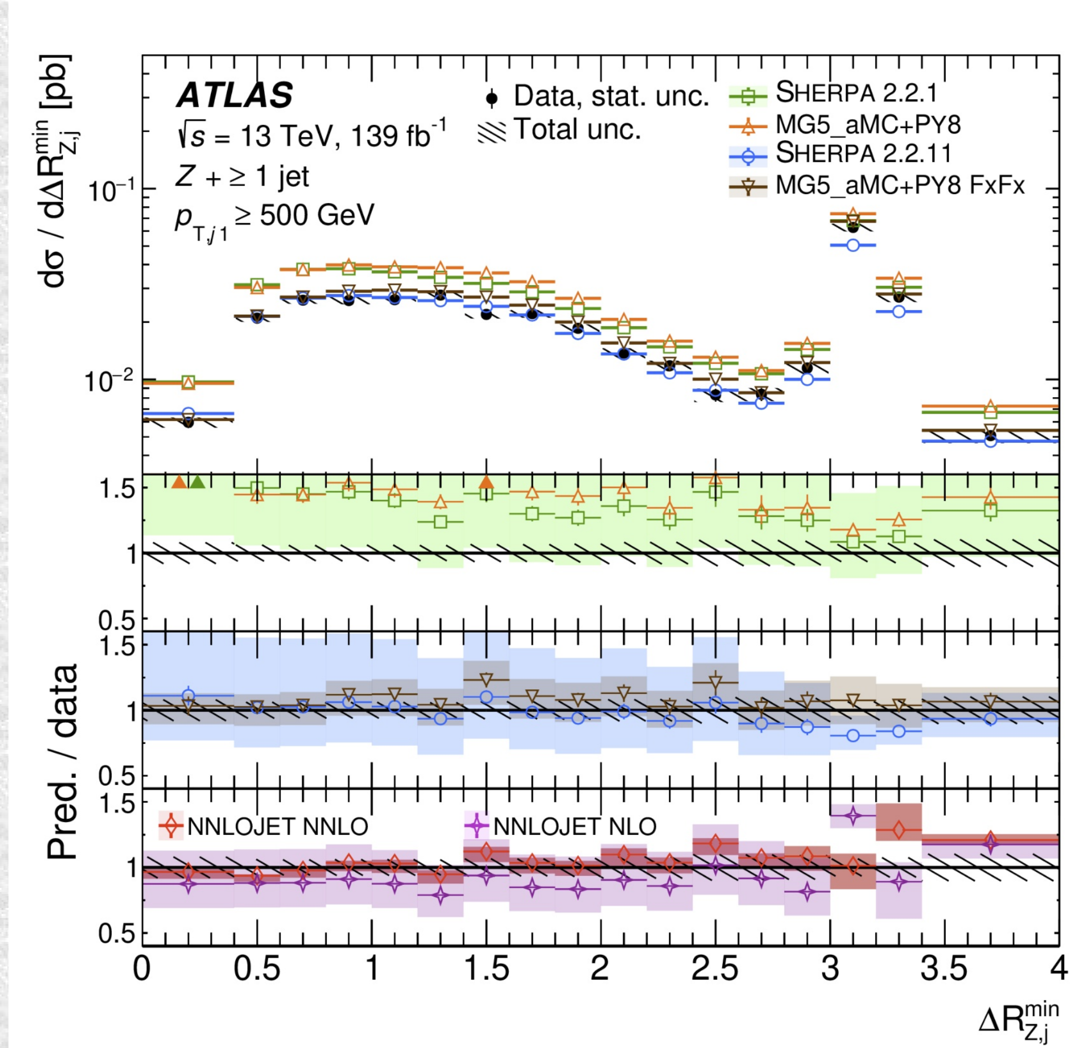


Z with jets

STDM-2018-49



- Z → ll with high p_T jet
- Aim to discriminate two diagrams above
- Right: ΔR, p_T>500GeV
- NLO multi-leg generators describe challenging situation well

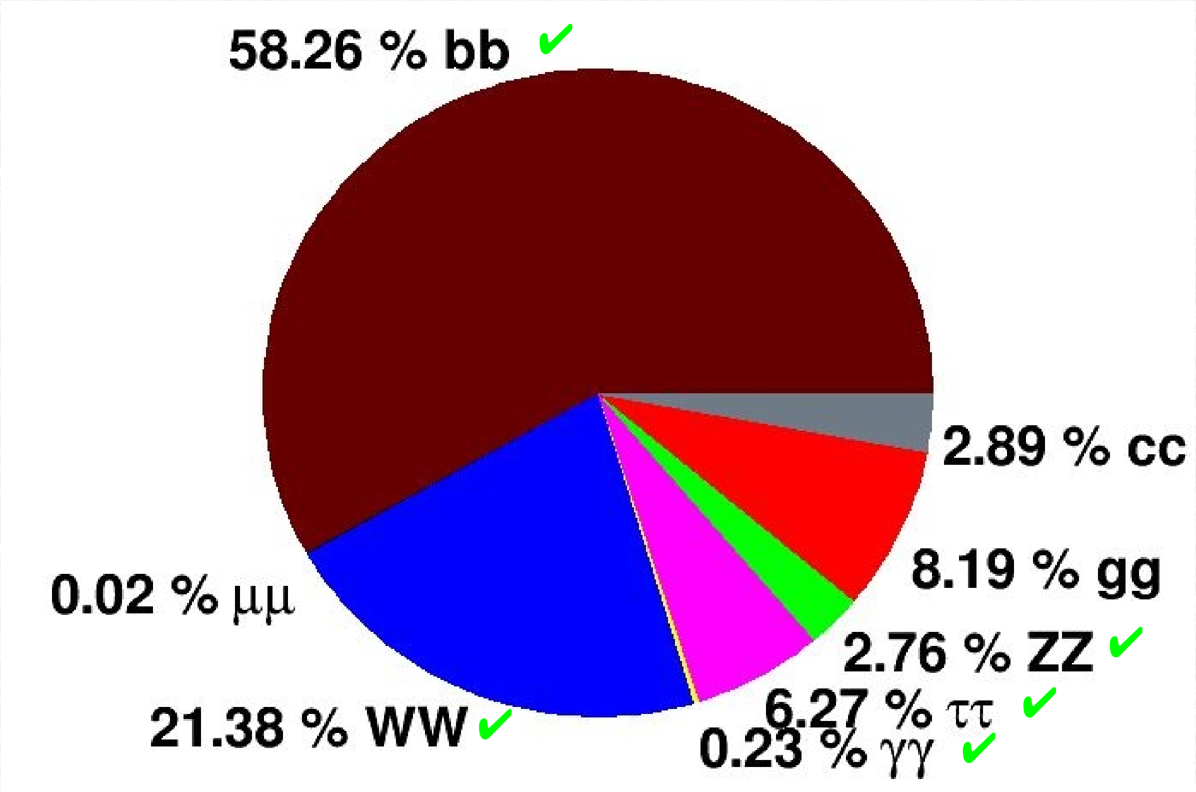


Higgs

Higgs boson: 10 years on

- The defining discovery of the LHC
- Decays to ZZ, γγ, WW, ττ, bb: all observed at 5σ
- Same for ggH, VBF, VH and ttH production

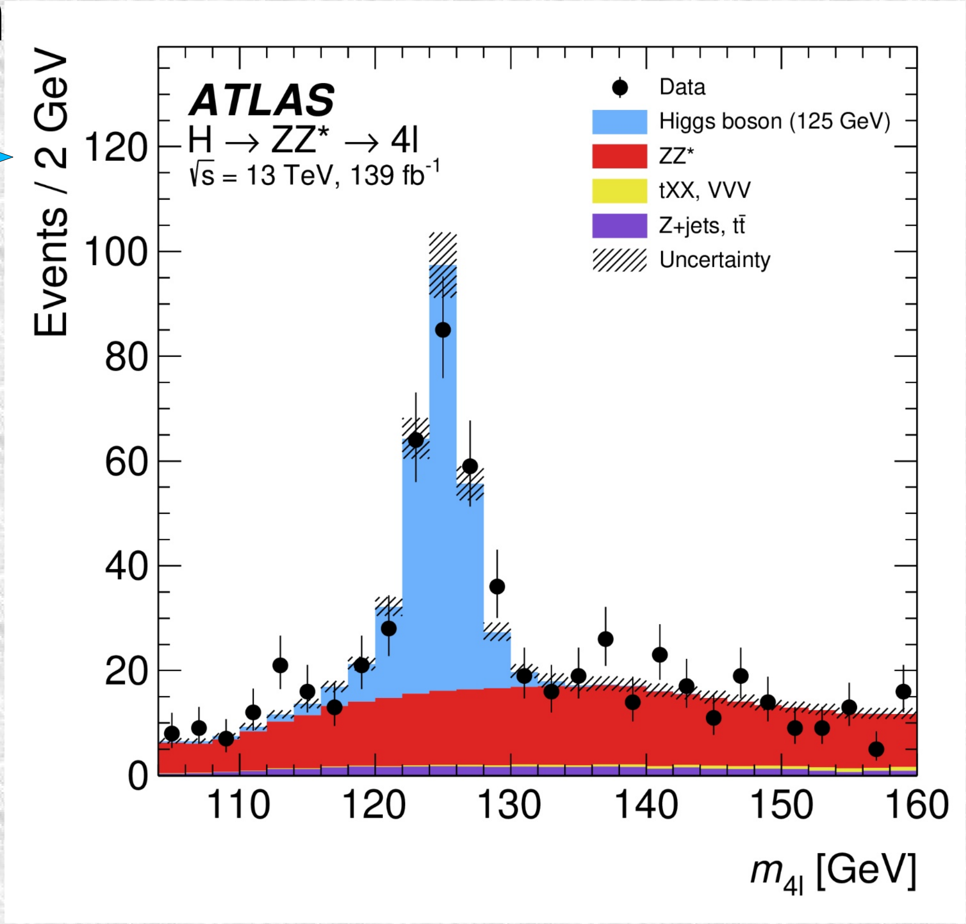
Phaistos Disk, 1908

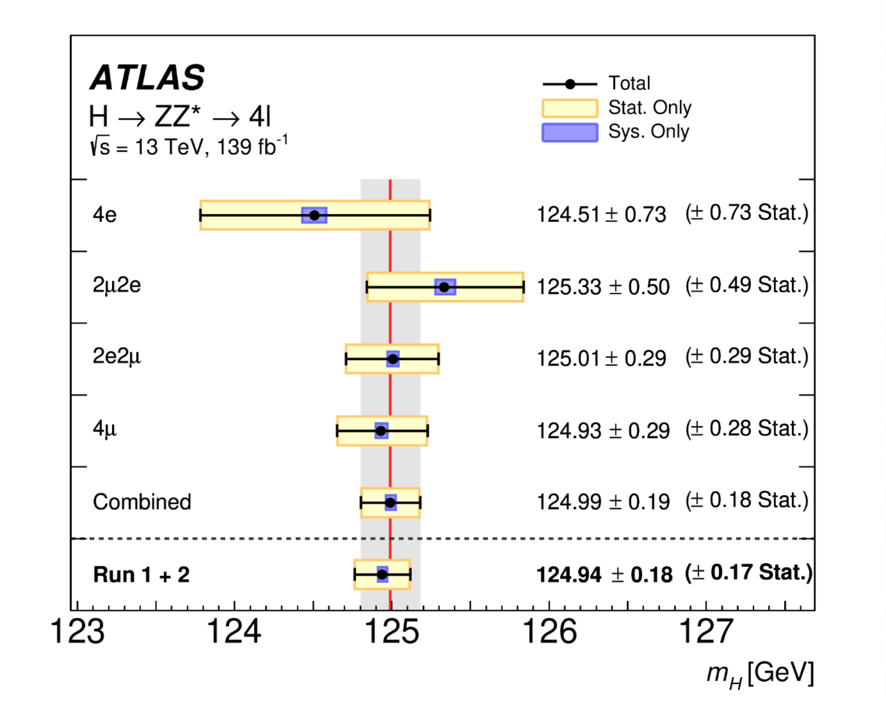


Higgs BRs, 2012: now less mysterious :)

H to ZZ & mass HIGG-2020-07

- Clean ZZ mode used for much
  - Fig is from mass paper
- M_H=124.94±0.19GeV
  - Stat dominated
  - 28 MeV unc. from μ p_T scale
    - (Run 2)

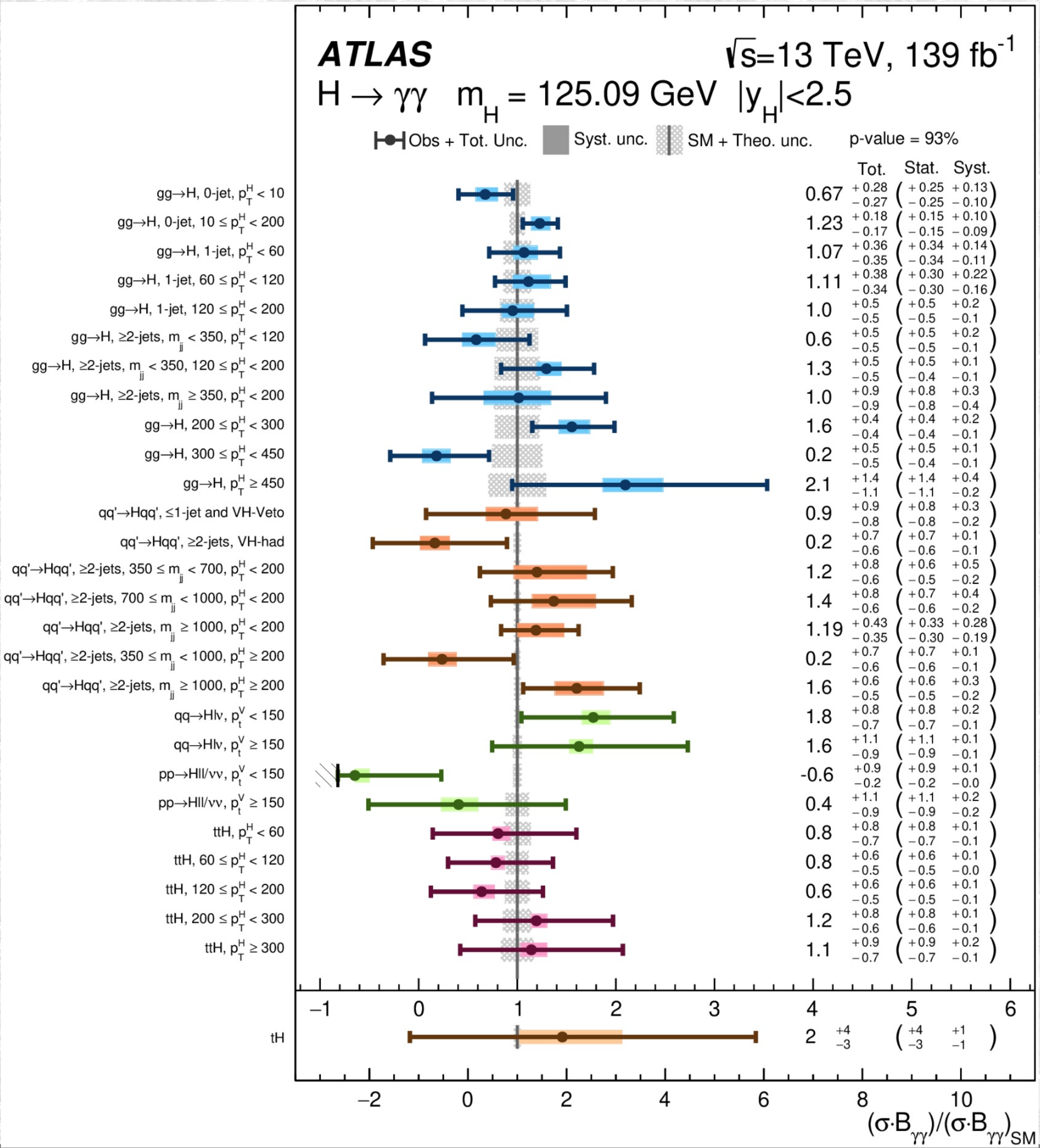


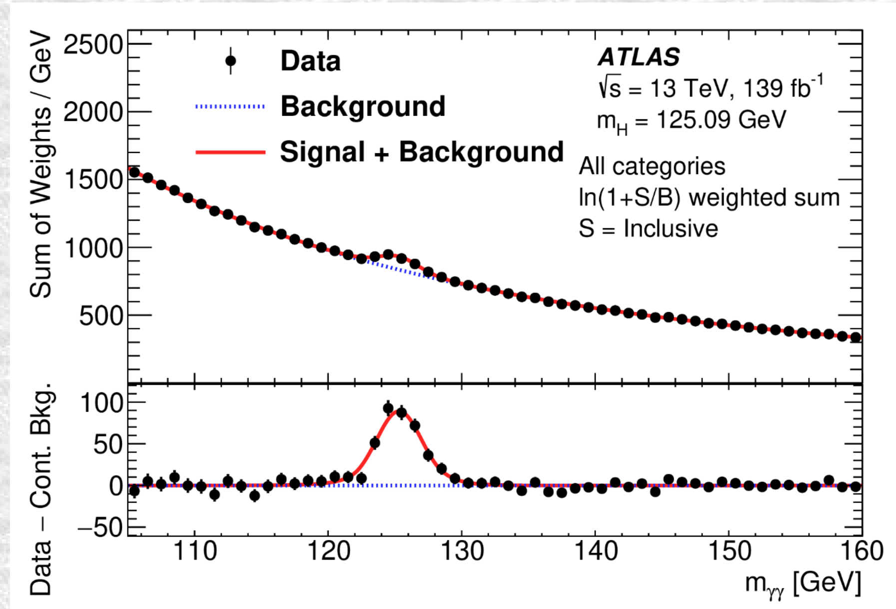


- 0.15% from single channel
  - More to come (γγ)

H to γγ

HIGG-2020-16

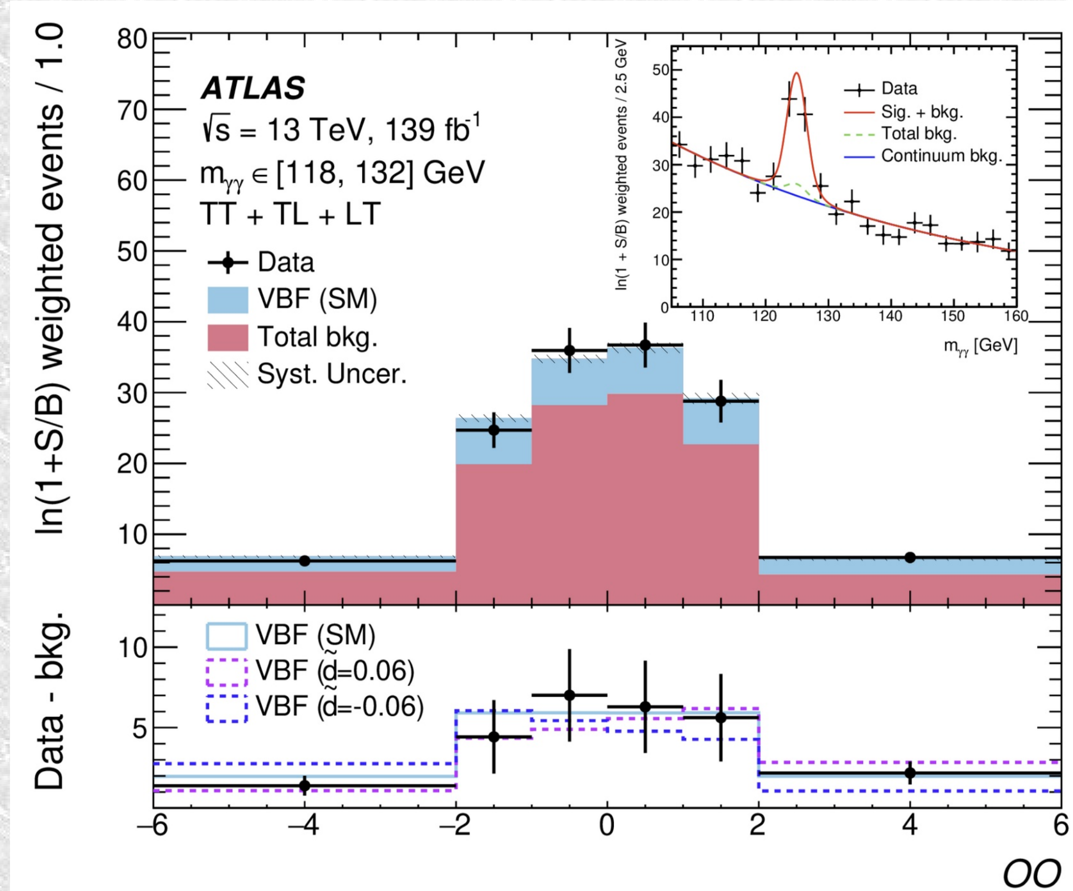


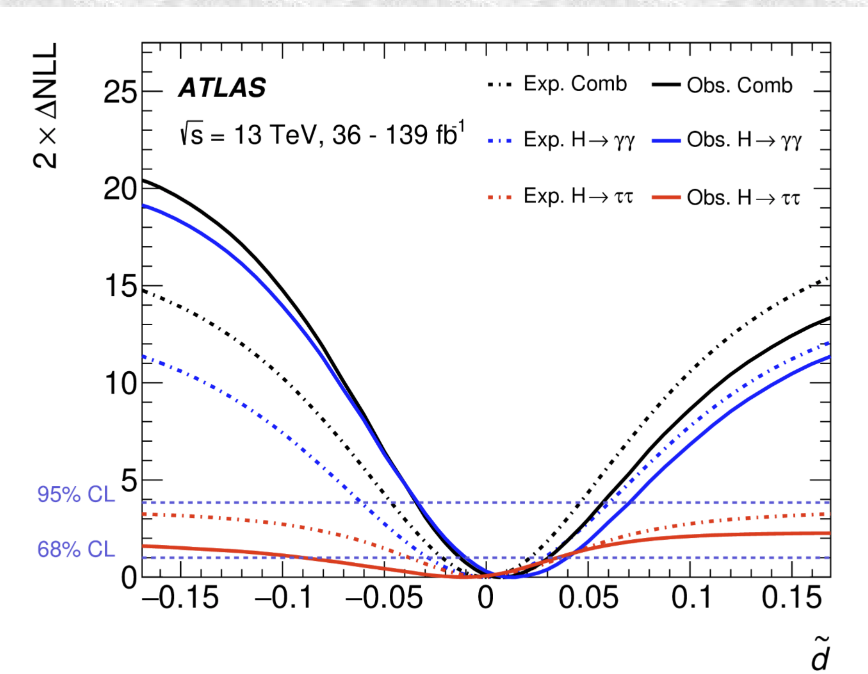


- Thousands of events
  - Allows probing many production modes
  - ggF, VBF, VH, ttH
- Overall $\mu=1.04^{+0.10}_{-0.09}$

H to γγ VBF HIGG-2020-08

- Use angle between recoil jets in VBF
- Construct optimal observable
- Test CP violating couplings
  - e.g. $\tilde{d}$, a CP violating EFT coefficient in HISZ





Results (combined with similar H→ττ):

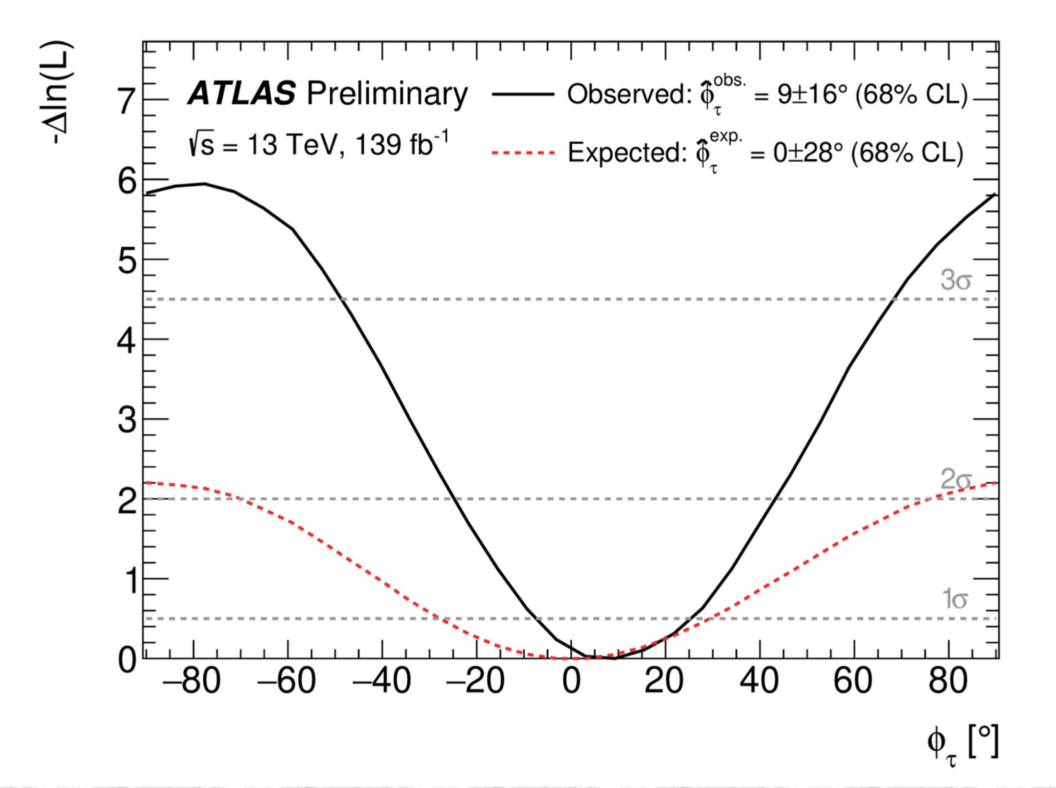
$-0.012 < \tilde{d} < 0.030$ (68%)

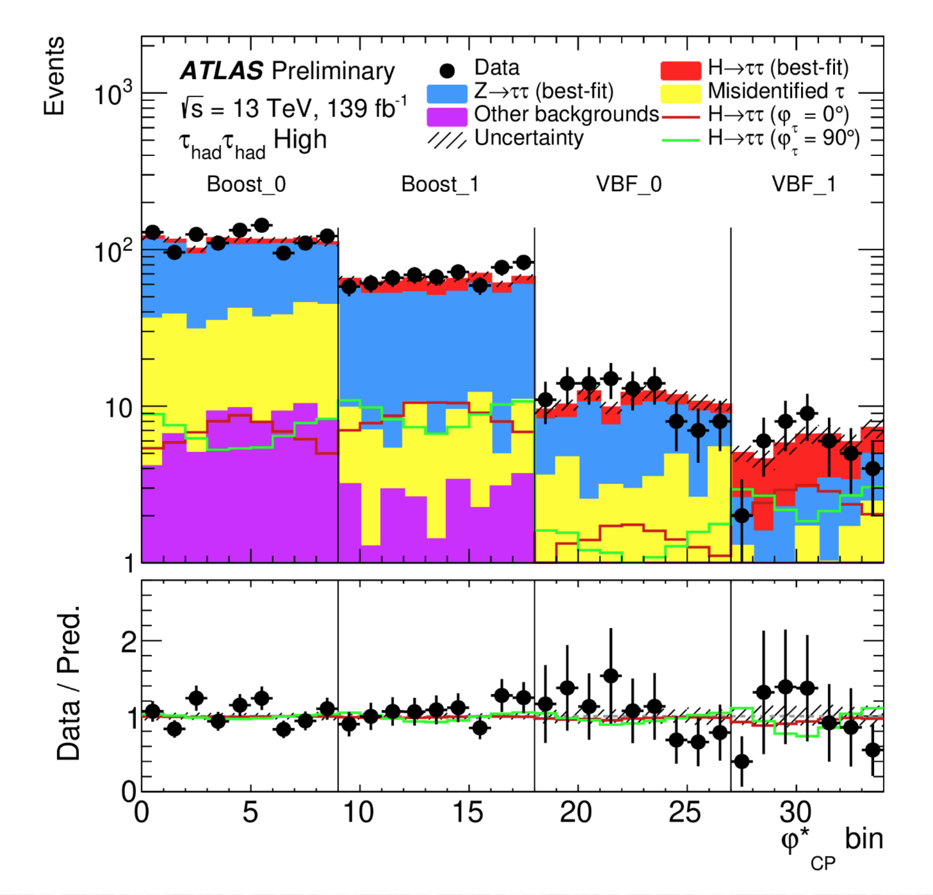
Most stringent limits on CP in H-VV coupling

H to ττ decay

ATLAS-CONF-2022-032

- Decay angles sensitive to CP coupling to fermions
  - Constrains mixing phase as 9±16°



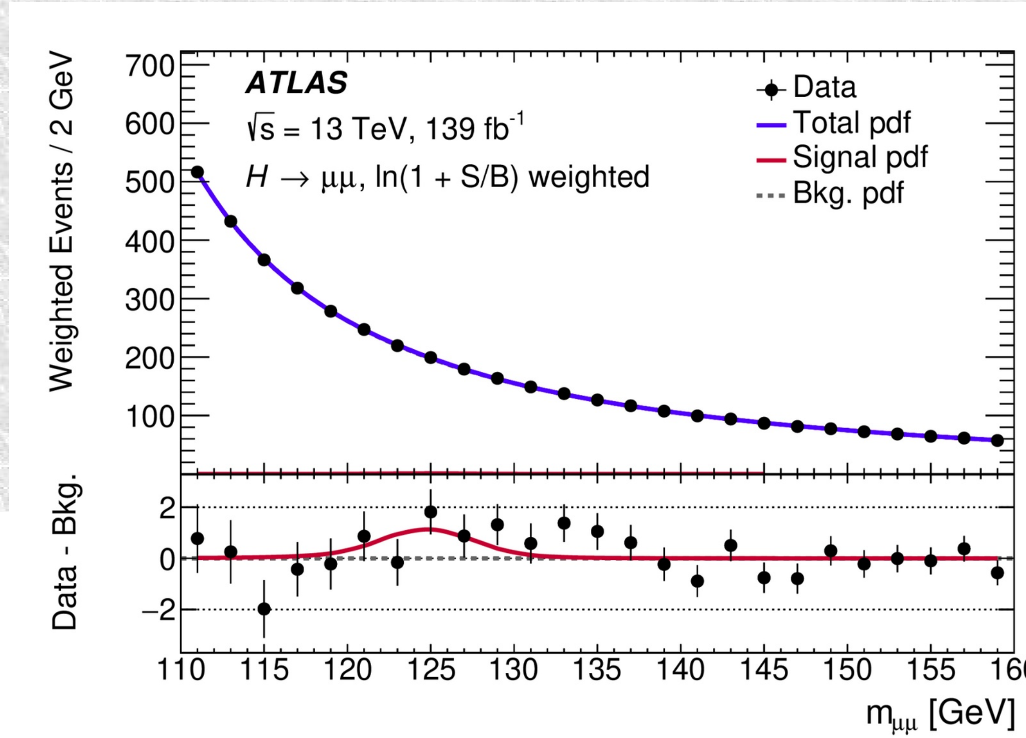


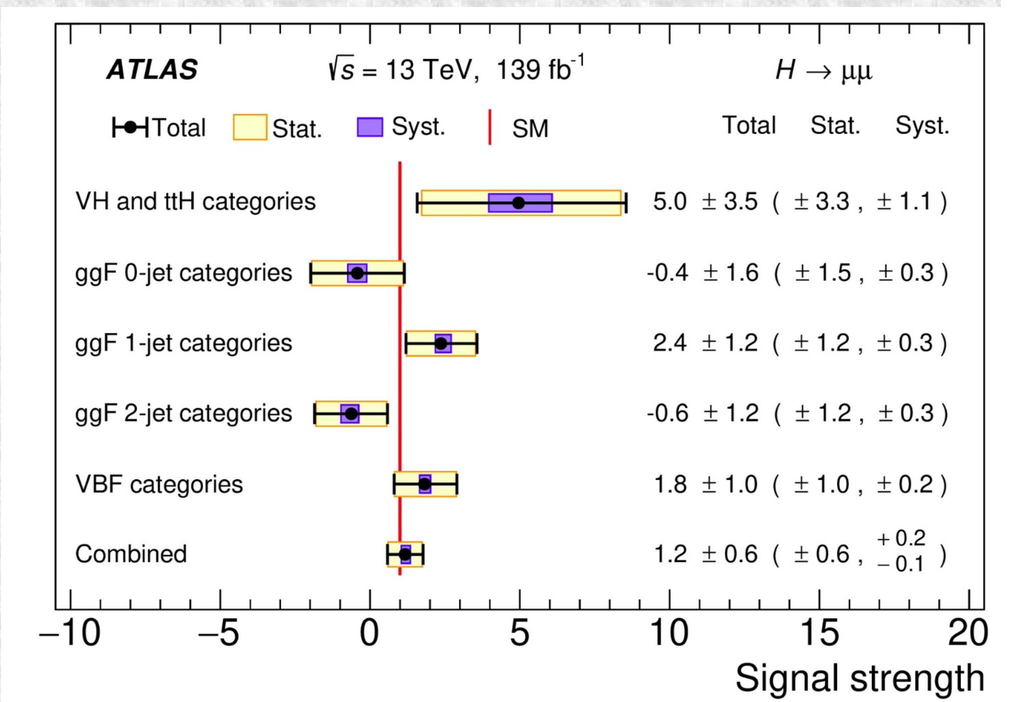
- Data gave unusually good error

H to μμ

Phys. Lett. B 812 (2021) 135980

- ‘Simple’ bump hunt
- 20 categories of p_T, eta, VBF. VH, ttH
- Approach like γγ, but:
  - 10 times lower rate
  - large Drell-Yan bckd.



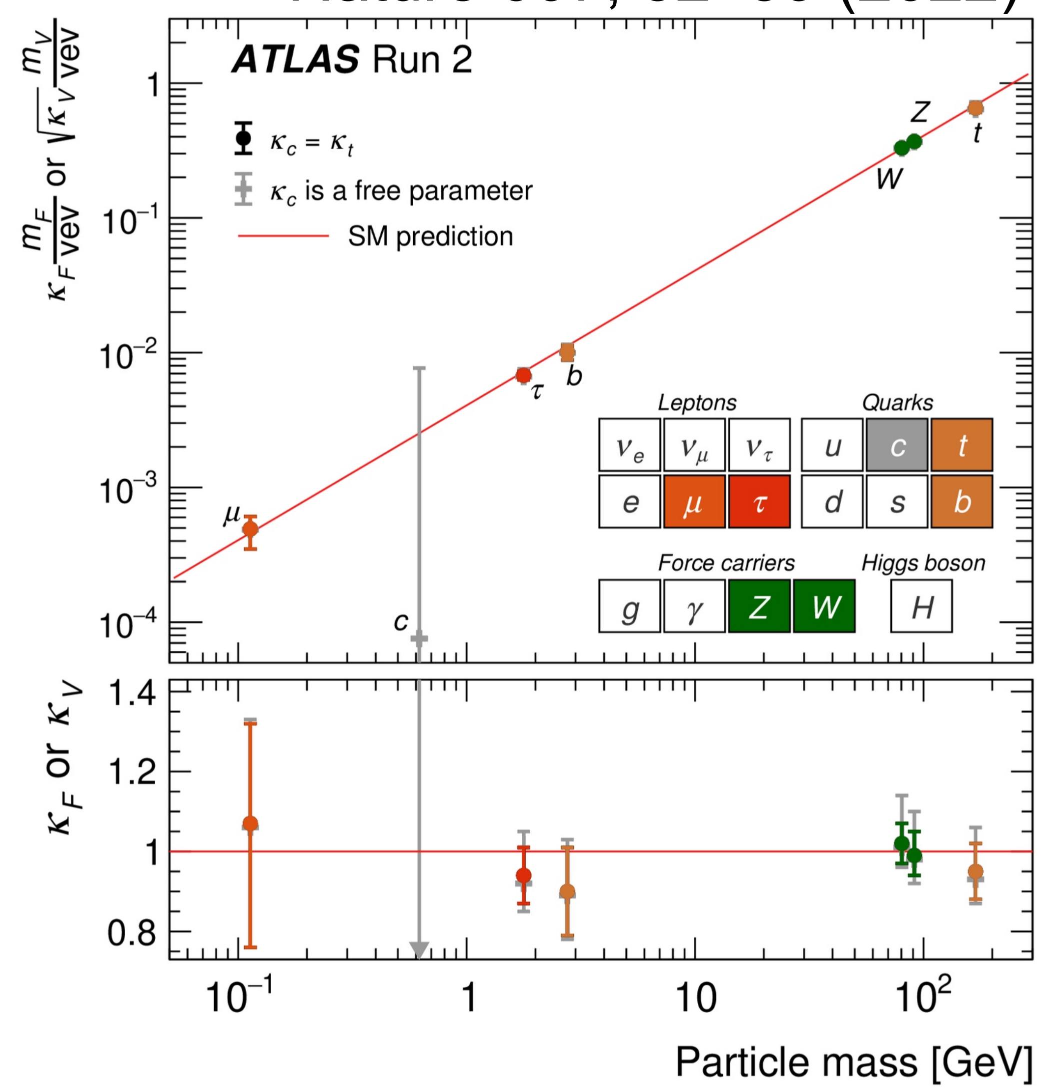


- Significance: 2σ obs (1.7σ exp. SM)
  - Statistics dominated
  - 2^{nd} generation in sight!

Interactions with all particles?

- Interaction should scale with mass
- Confirmed for vector bosons and all 3rd generation fermions
  - Save ν_τ!
- 2nd generation fermions now being constrained too

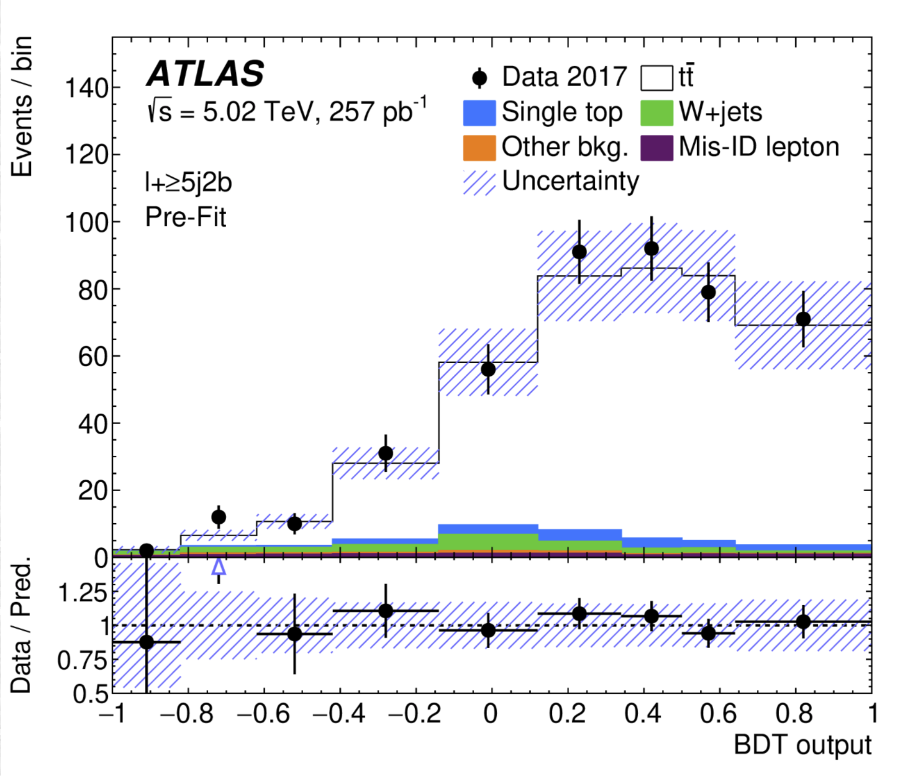
Nature 607, 52–59 (2022)

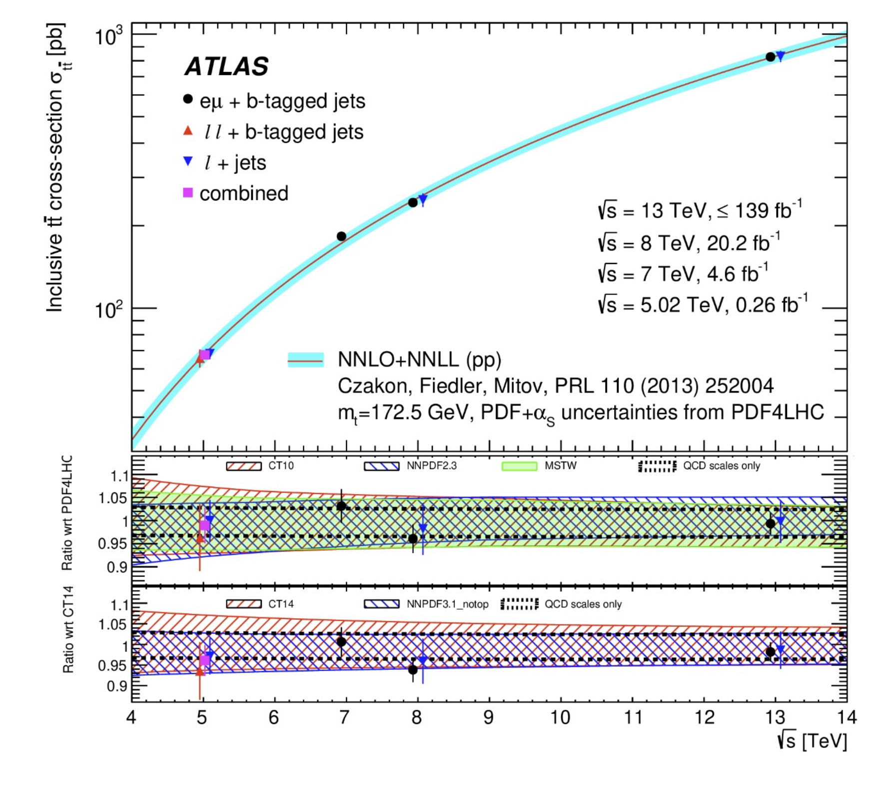


Top

Top cross-section @ 5 TeV TOPQ-2018-40

- 5.02 TeV data
  - Collected as PbPb reference
  - ll and l+jets channels
  - σ_{tt} = 67.5 ± 0.9(stat.) ± 2.3 (syst.) ± 1.1(lumi.) ± 0.2 (beam) pb

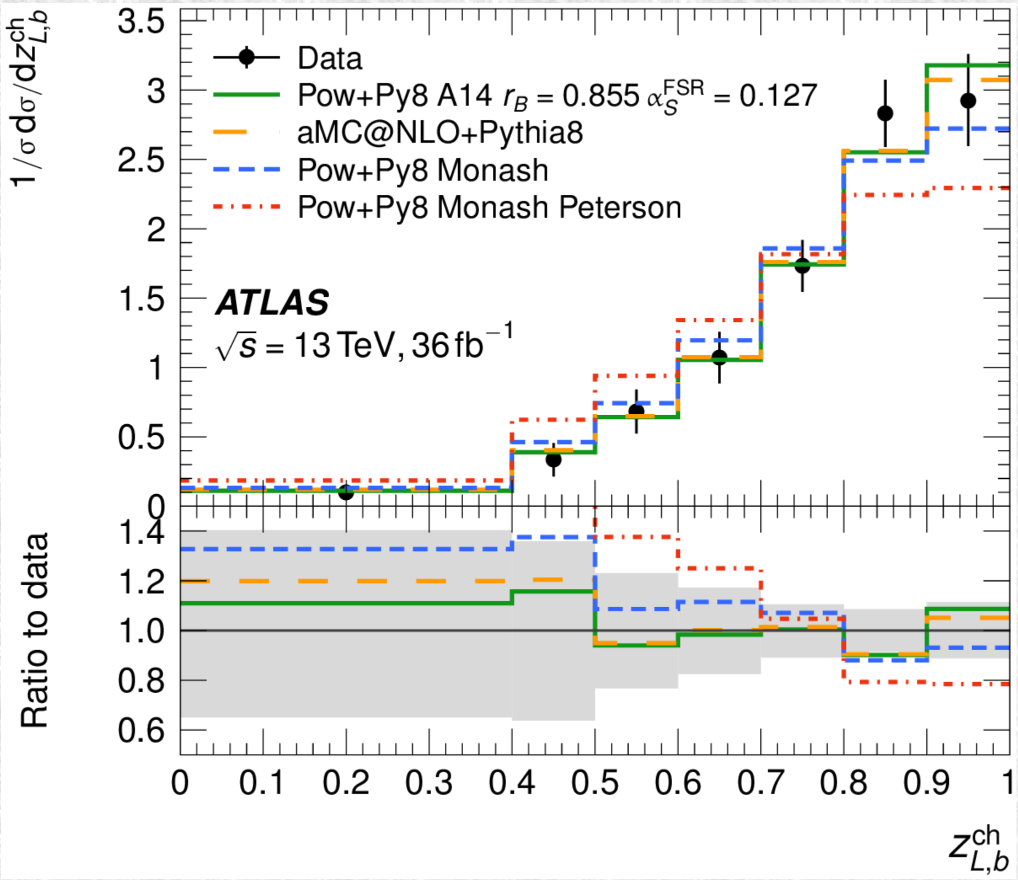




- Good agreement with expectations to 4% precision
  - Similar to 13 TeV
- Allows theory comparison across wide energy range

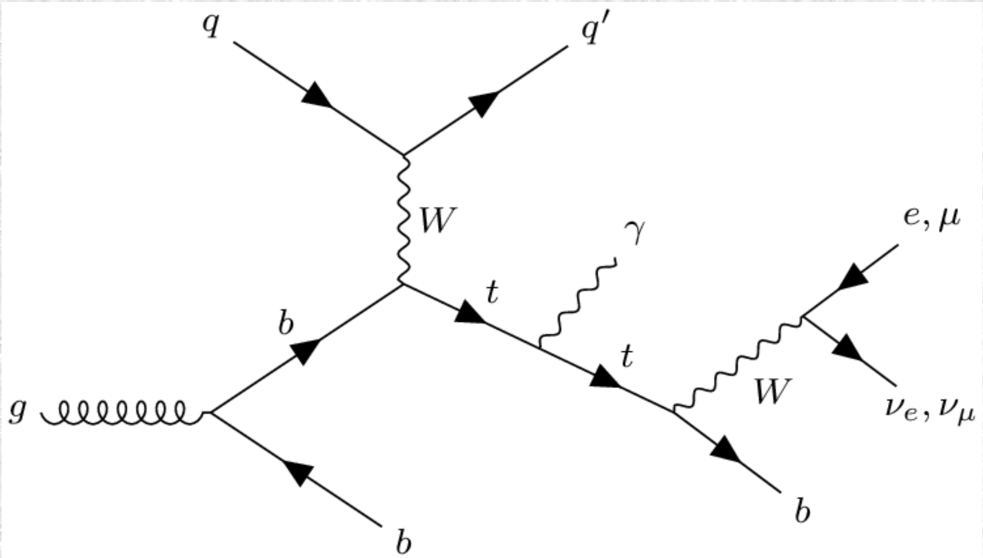
B fragmentation in $t\bar{t}$ TOPQ-2018-40

- Use top as source of high-p_T b quarks
  - Analyse using charged tracks
  - Plot $z_{L,b}$, p_T fraction coming from secondary vertex
- Unfold to particle level
- Comparison between simulations interesting
  - Generally in agreement
- Complementary to LEP Z→bb as here b are colour connected to the beam remnant



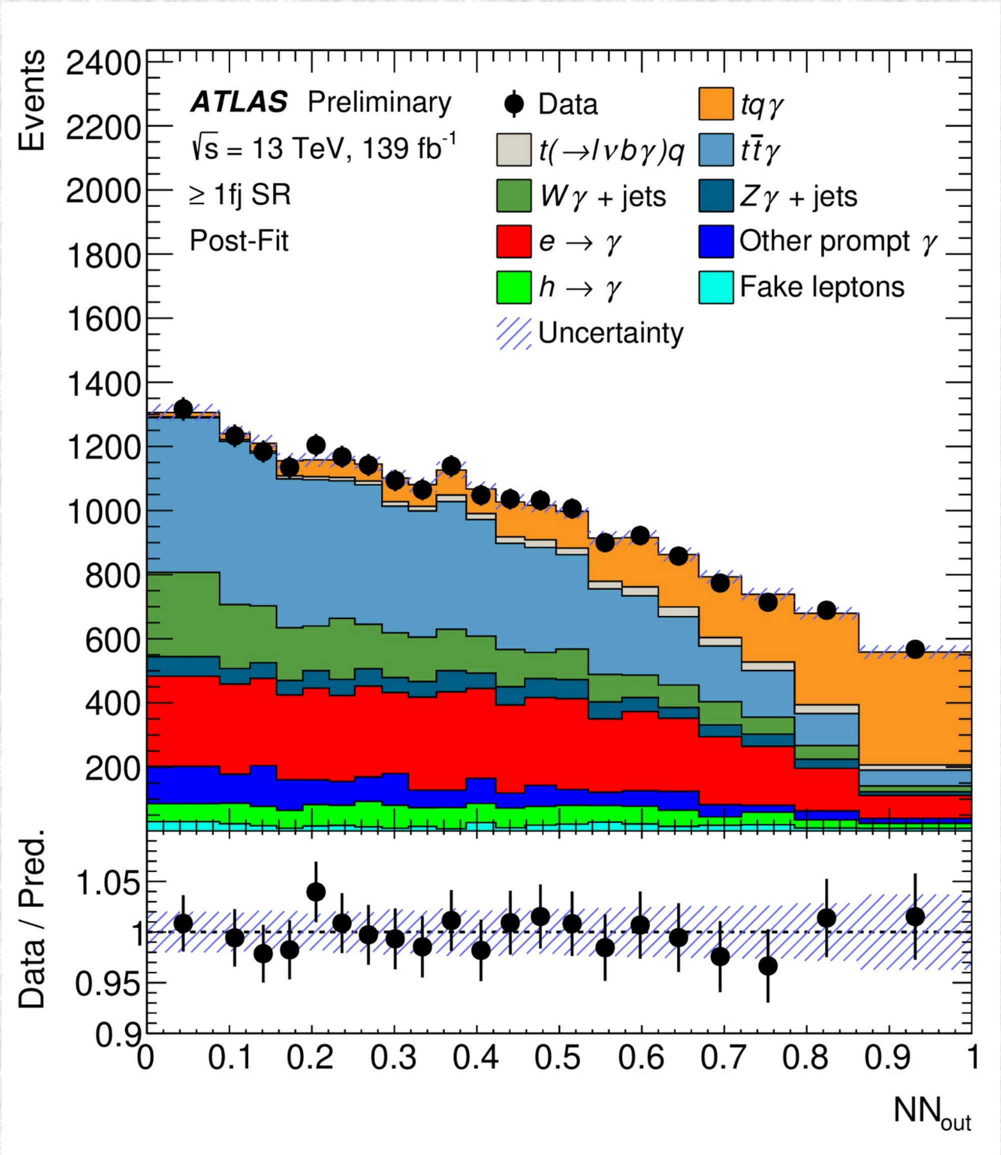
Single Top plus photon

ATLAS-CONF-2022-013



- Final t+EW boson channel
- p_T γ > 20 GeV
- Observed fiducial σ is:

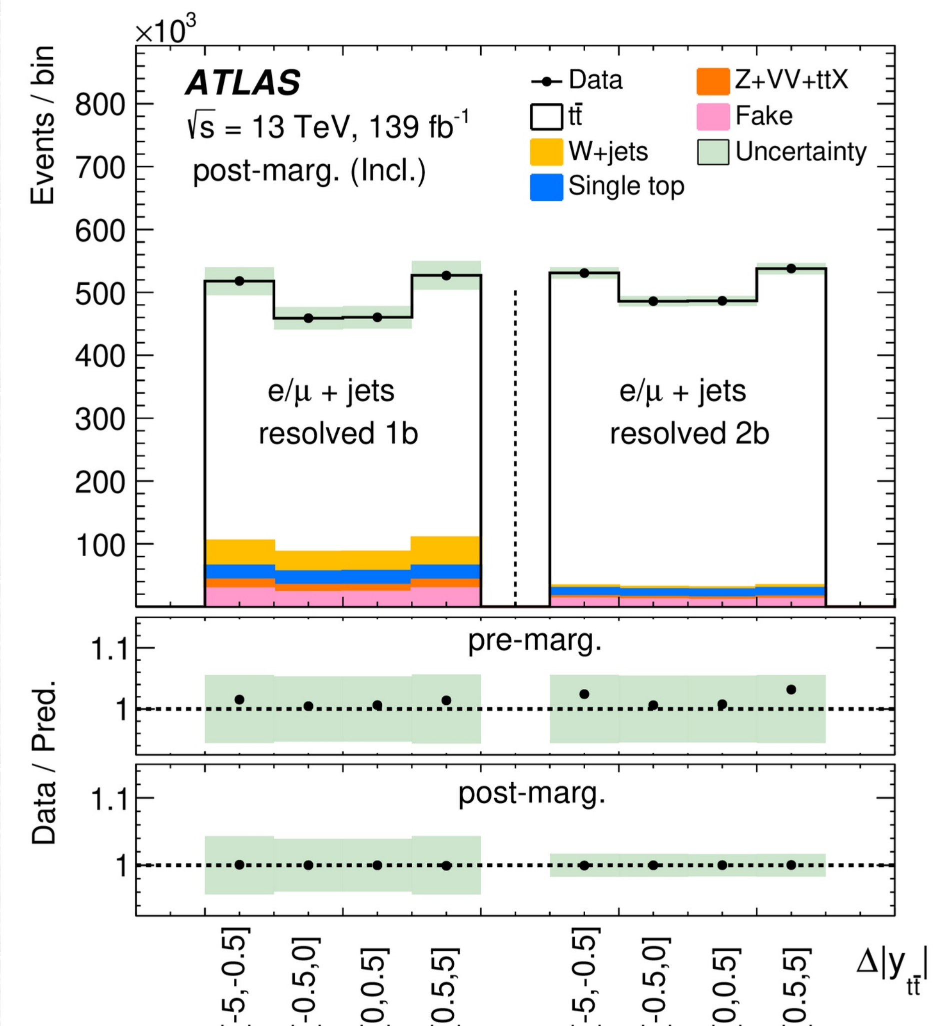
  580 ± 19 (stat.) ± 63 (syst.) fb.
  - Expected: 406^{+25}_{-32} fb.



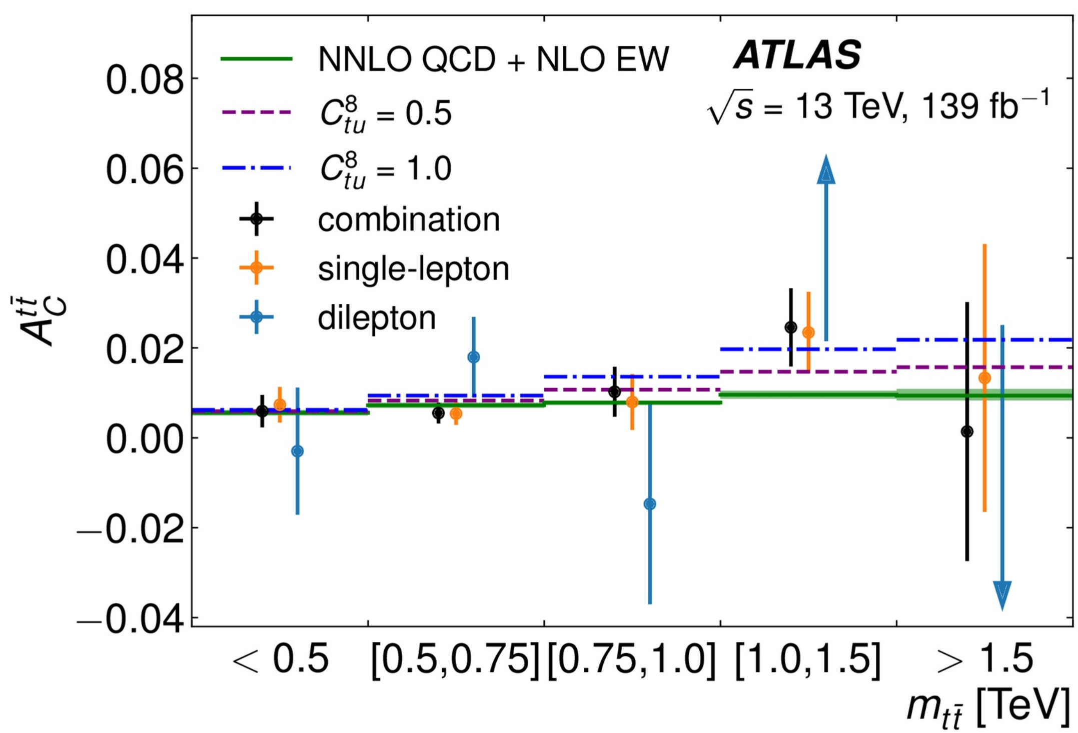
$t\bar{t}$ charge asymmetry

TOPQ-2020-06

$$A_C^{t\bar{t}} = \frac{N(\Delta|y_{t\bar{t}}| > 0) - N(\Delta|y_{t\bar{t}}| < 0)}{N(\Delta|y_{t\bar{t}}| > 0) + N(\Delta|y_{t\bar{t}}| < 0)},$$



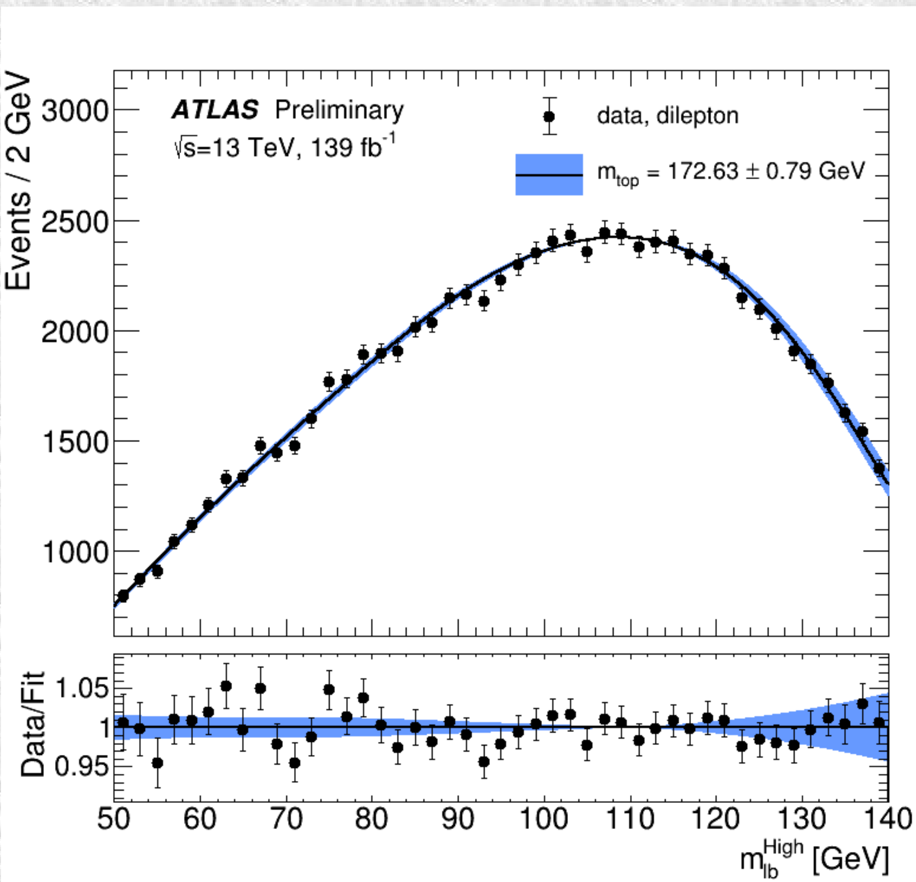
- Symmetric at LO, but at NLO $q\bar{q}$ and qg asymmetries appear
- Inc.: A_C=0.0068± 0.0015,
  - 4.7σ from zero

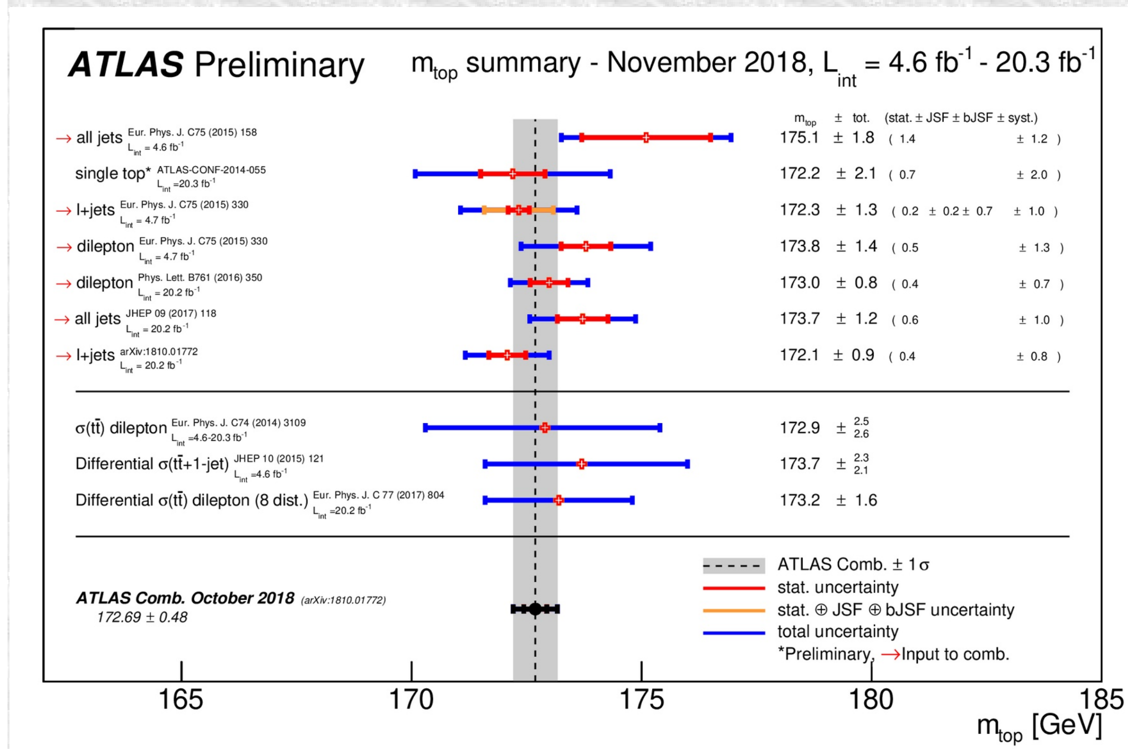


Run 2 Top mass in llbb ATLAS-CONF-2022-058

- m_{top}=172.63 ± 0.20 (stat) ± 0.67 (syst) ±0.37 (recoil) GeV
  - Recoil uncertainty (Brooks and Skands) new
- Matches 172.69 ± 0.48 GeV ATLAS Run 1 combination
  & 36fb-1 13 TeV 174.41± 0.39 (stat) ± 0.66 (syst) ±0.25 (recoil) GeV ll
- c/f 171.77 ± 0.38 GeV recent CMS (see J Fernandez talk)

New





Other new top

tbdtbd
TOPQ-2020-06

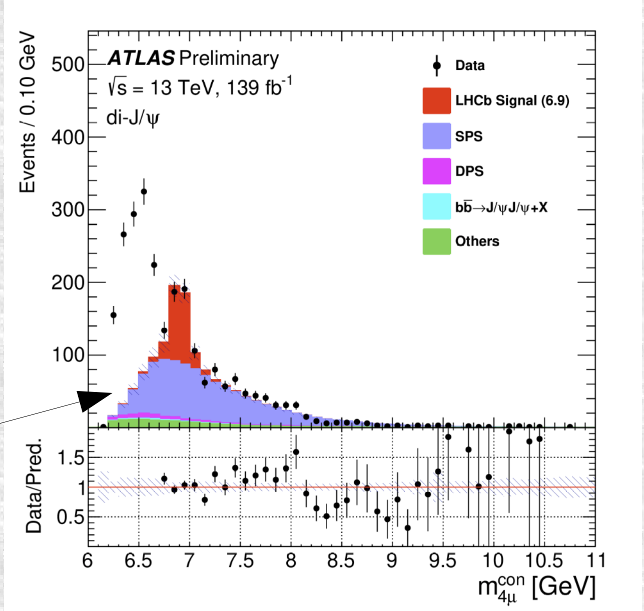
- S channel top at 13 TeV (CONF conversion):
  - ATLAS-CONF-2022-030
- $t\bar{t}\gamma$ charge asymmetry
  - ATLAS-CONF-2022-049
- 15th international workshop on top physics
  - Talks start this afternoon; links below will soon become active
  - $t\bar{t}W$ charge-asymmetry: ATLAS-CONF-2022-062
  - Differential $t\bar{t} \rightarrow e\mu$ cross-section: ATLAS-CONF-2022-061
  - And more likely

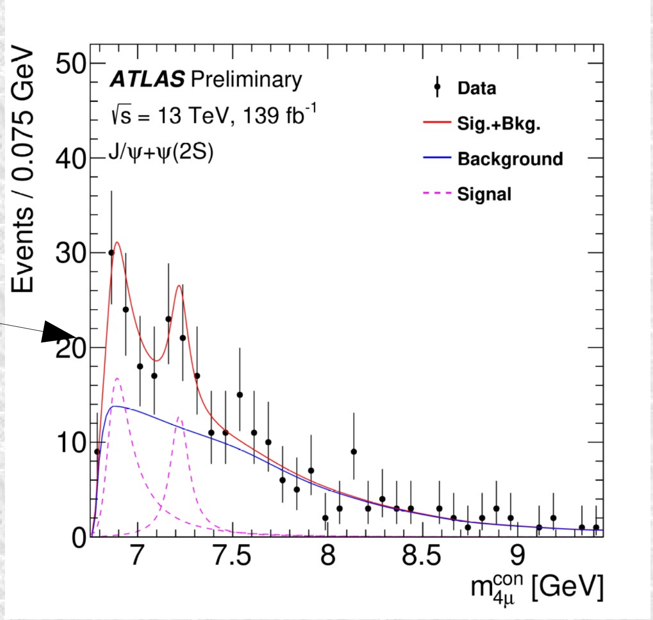
B physics

Di charmonium in 4μ states

ATLAS-CONF-2022-040

- Find prompt 4μ events, p_T>3,3,4,4GeV
  - J/ψ+J/ψ or J/ψ+ψ(2s)
  - ΔR<0.25 between charmonia
- J/ψ+J/ψ Analysis:
  - Single PS Background from MC
  - Excesses for mass below 7.5 GeV
    - 6.9 GeV peak seen also by LHCb
    - Broad lower mass structure best fitted with two more peaks, detail unclear
- J/ψ+ψ(2s) also show a 6.9 GeV peak
  - bump at 7.2 GeV
  - Also seen by LHCb & CMS in ψψ

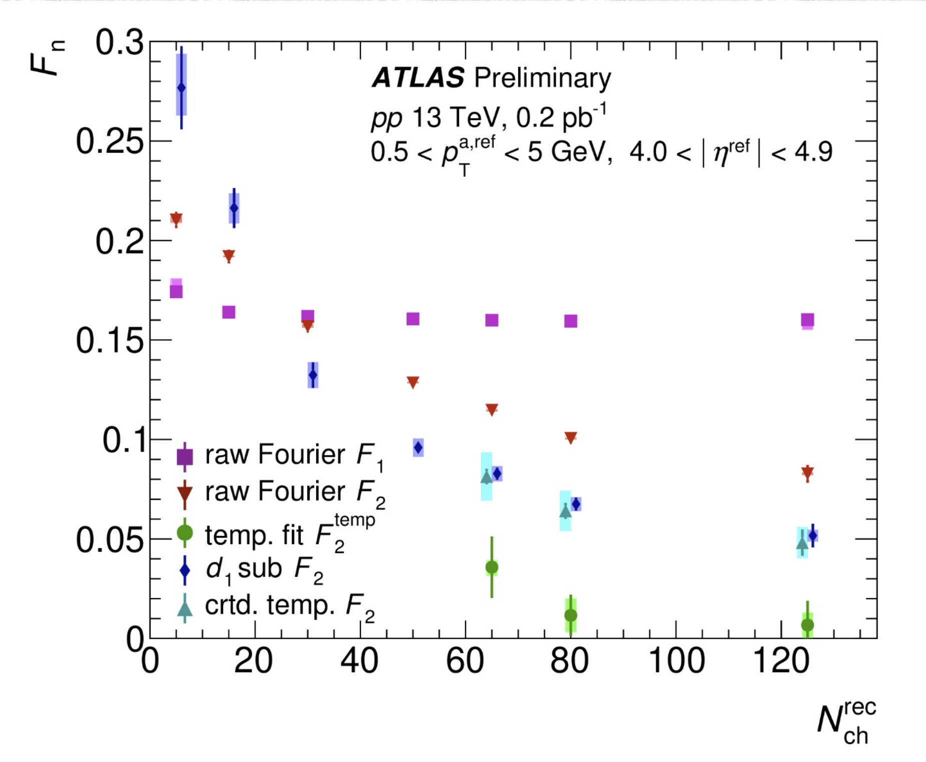


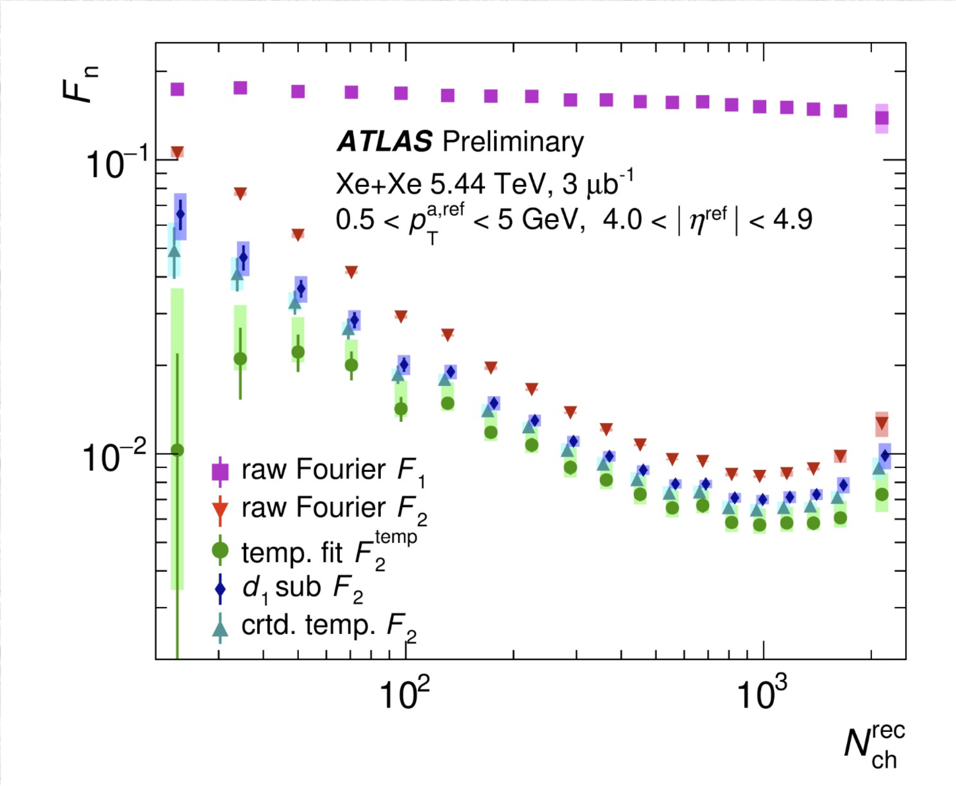


Heavy Ions

Flow decorrelations

ATLAS-CONF-2022-020/

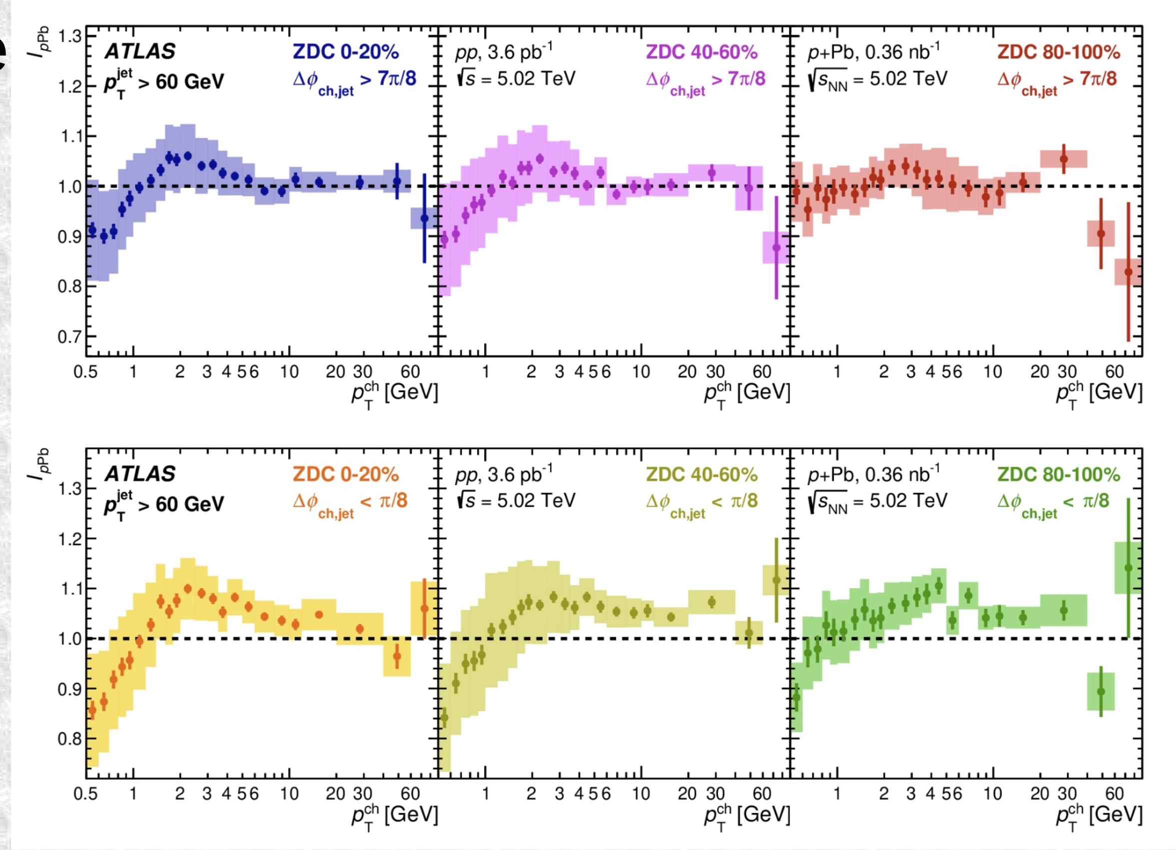




- Collective flow moments defined relative to the event plane in pp (left) and Xe+Xe (right)
  - F_1 independent of multiplicity
  - F_2, evaluated different ways, shows decreasing trend
- Xe+Xe and pp show similar behaviour

No jet quenching in p+Pb? HION-2021-17

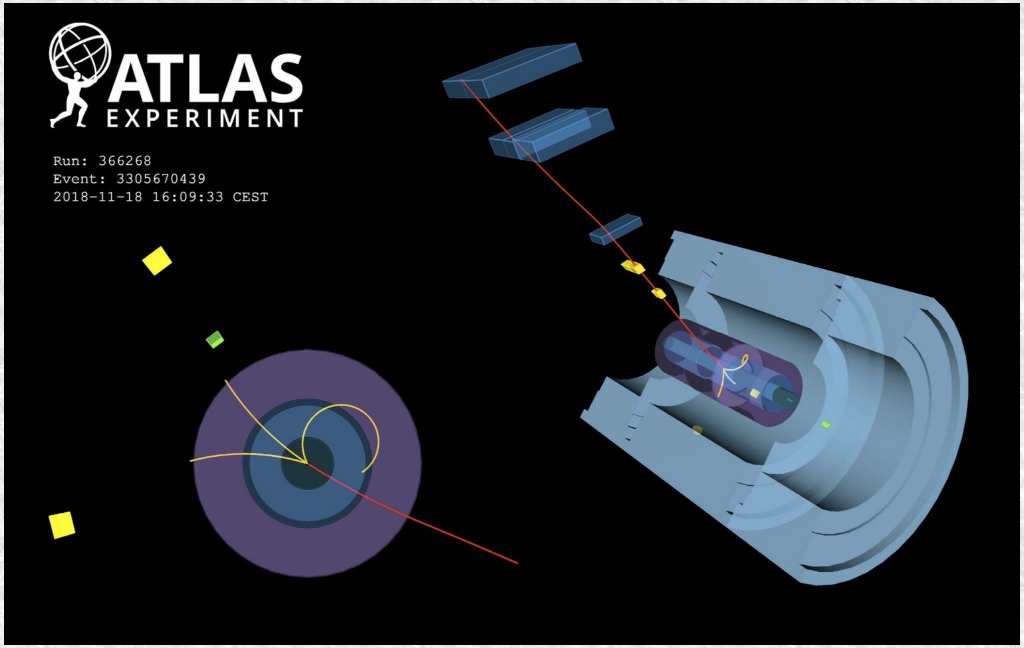
- The expansion of quark-gluon plasma droplets describes collective effects in Heavy ion, p+Pb and p+p.
- Here per-jet charged particle yields are compared:
  - Yield $N_{ch}(p+Pb) / N_{ch}(p+p)$
  - For $p_T > 4$ GeV there is no centrality dependence
  - In contrast to Pb+Pb
- This precludes almost any parton energy loss in p+Pb

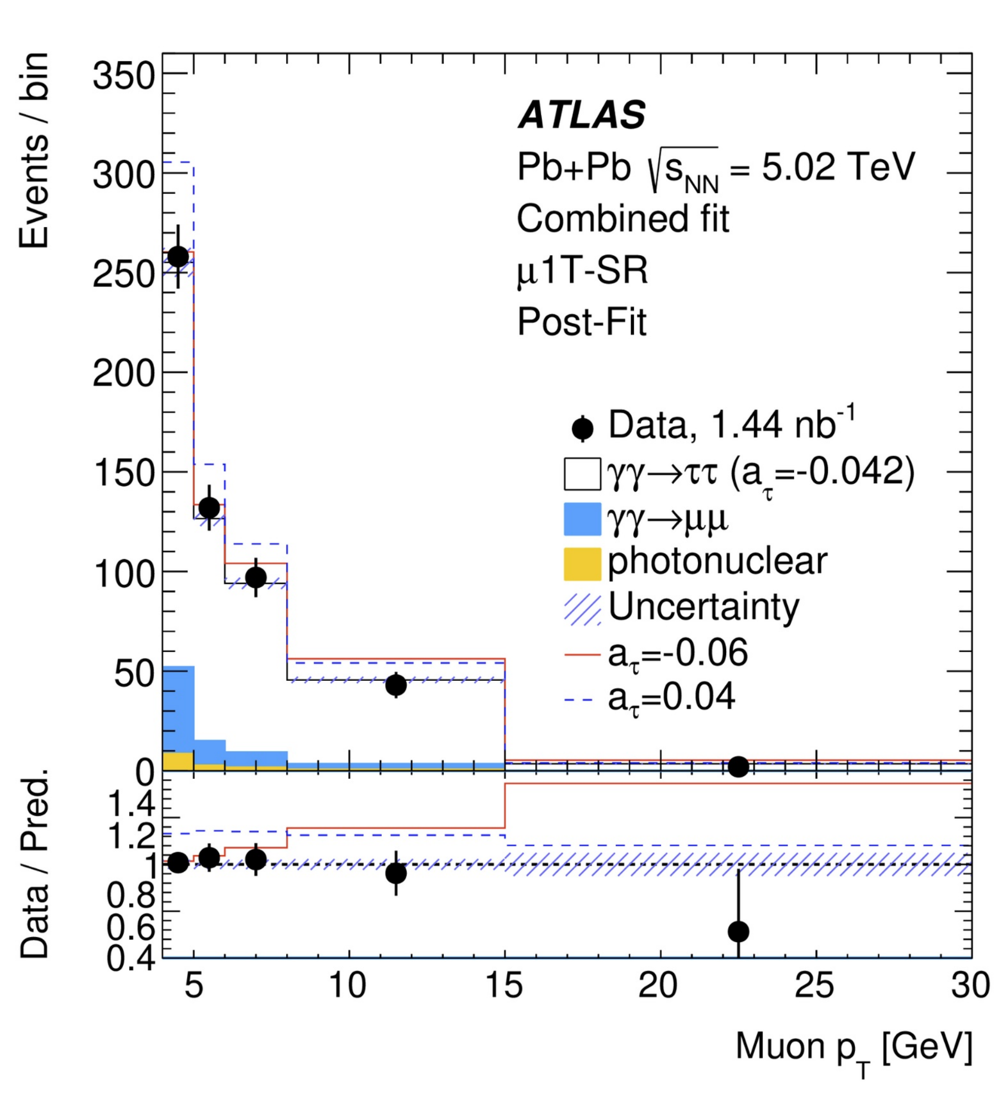


$\gamma\gamma \to \tau\tau$

STDM-2019-19

- PbPb ultraperipheral collisions provide intense EM fields
  - Allows clean $\gamma\gamma \to \tau\tau$
  - Set constraints on a_τ similar to LEP



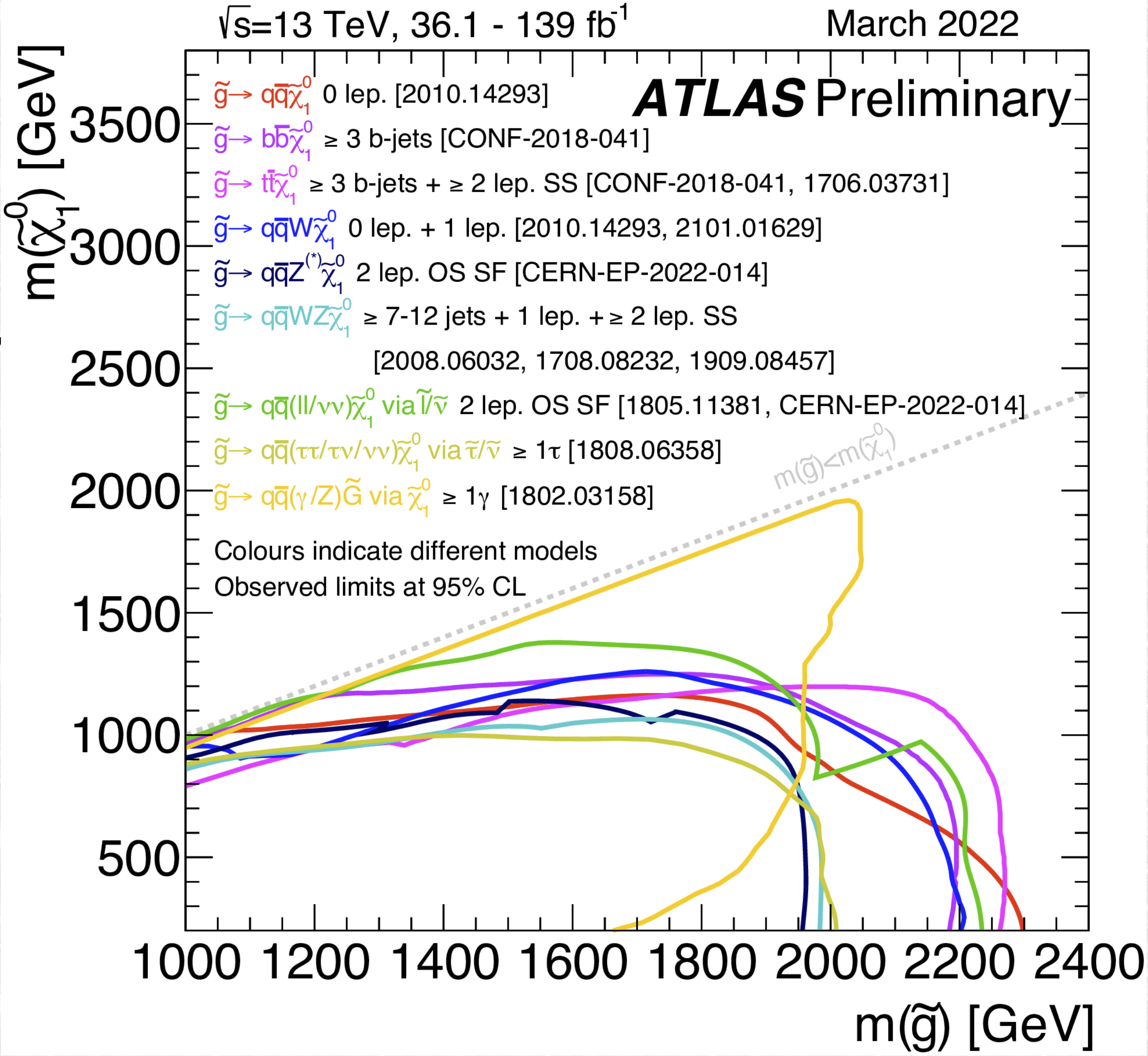


Supersymmetry

Gluino-neutralino limits

ATL-PHYS-PUB-2022-013

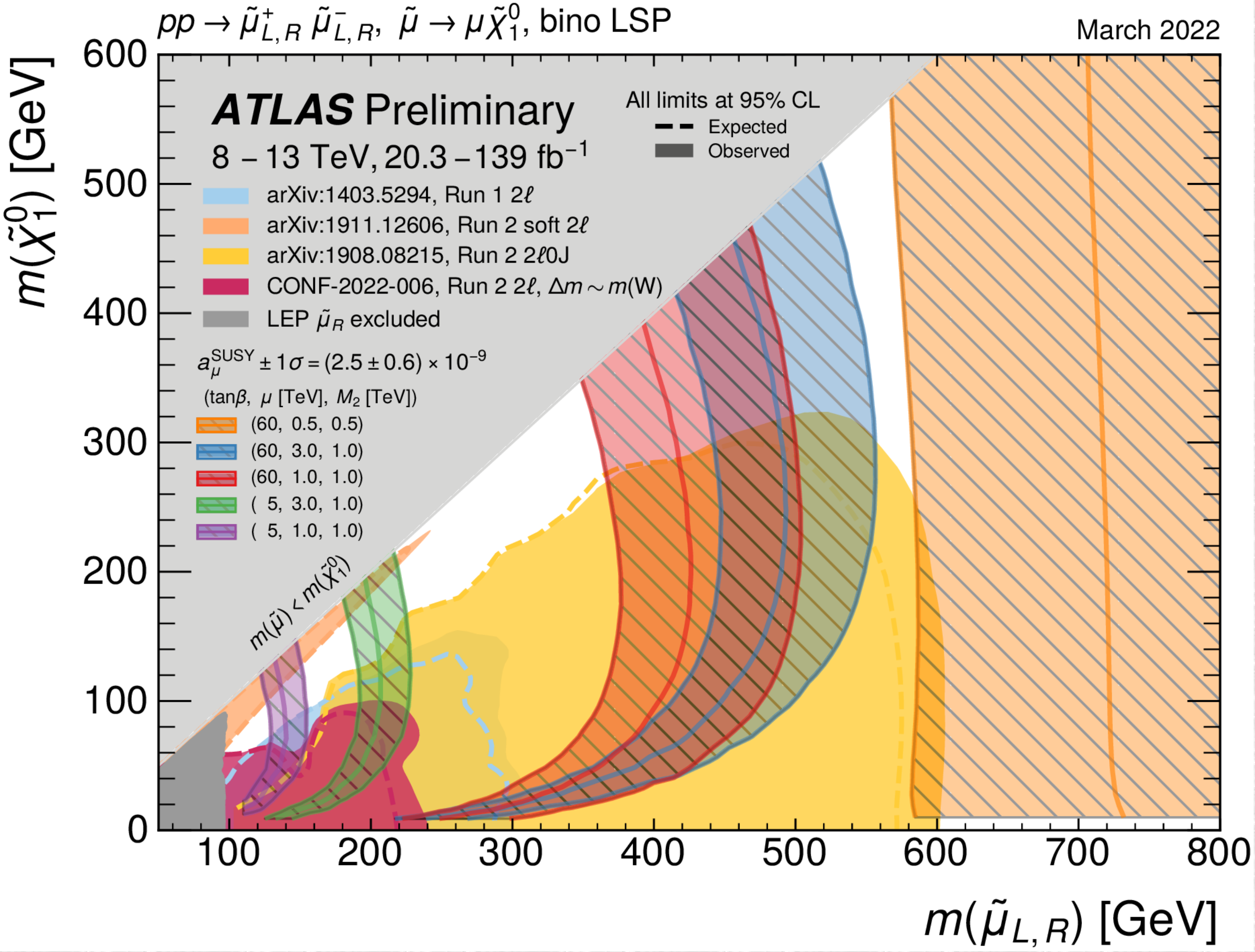
- Simplified models put bounds at 1 and 2 TeV on neutralino and gluino respectively



Electroweak SUSY

ATL-PHYS-PUB-2022-013

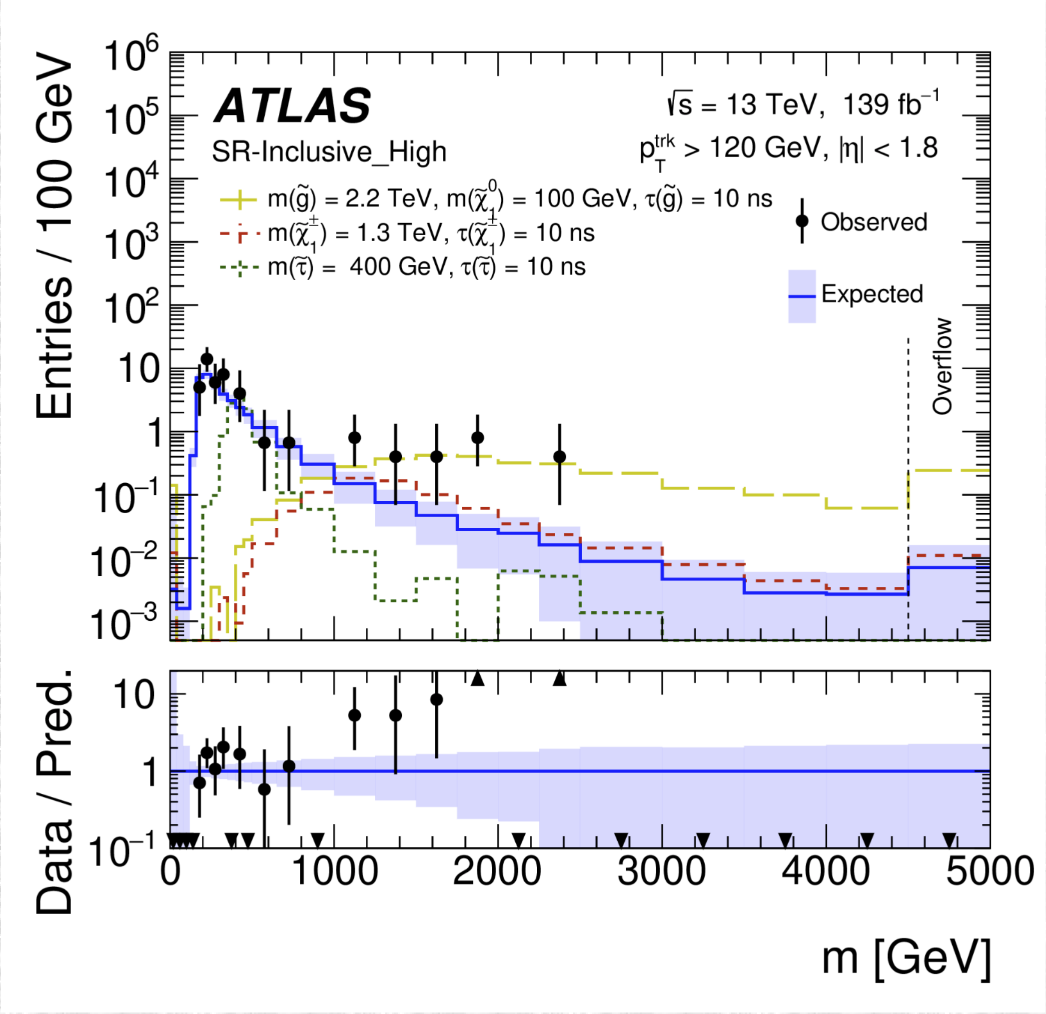
- Smuon limits overlayed
- Compare with regions favoured by muon g-2



Long lived SUSY

SUSY-2018-42

- Wide variety of displaced SUSY searches
- e.g. Massive long-lived particles are slow
  - Highly ionising
- Look for high MET events with high-p_T tracks
  - $dE/dx > 2.4\ MeVg^{-1}cm^2$
- Small excess seen
  - 3.6σ for 1.4 TeV signal
  - But not confirmed by timing in calo./muons

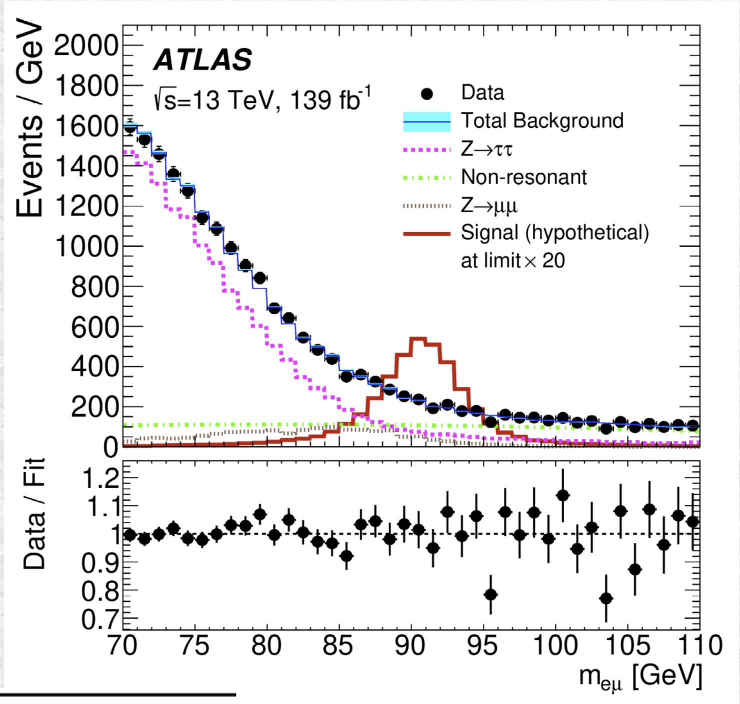


Exotics

Z → eμ / lτ search

EXOT-2018-35
EXOT-2020-28

- Charged lepton flavour violating Z to eμ search
- Use BDT to isolate signal
- Do a bump hunt.
- Upper limit B(Z → eμ)<2.62×10^{-7}
  - Tightest limit to date

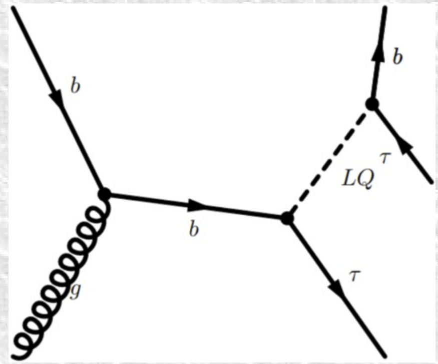


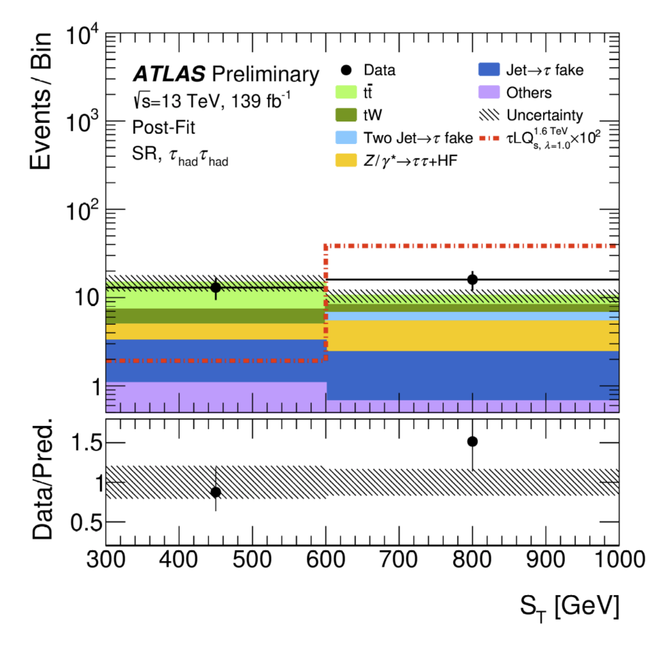
Final state, polarization assumption	Observed (expected) upper limit on $\mathcal{B}(Z \to \ell\tau)$ [$\times10^{-6}$] $e\tau$	$\mu\tau$
$\ell\tau_{had}$ Run 1 + Run 2, unpolarized τ	8.1 (8.1)	9.5 (6.1)
$\ell\tau_{had}$ Run 2, left-handed τ	8.2 (8.6)	9.5 (6.7)
$\ell\tau_{had}$ Run 2, right-handed τ	7.8 (7.6)	10 (5.8)
$\ell\tau_{\ell'}$ Run 2, unpolarized τ	7.0 (8.9)	7.2 (10)
$\ell\tau_{\ell'}$ Run 2, left-handed τ	5.9 (7.5)	5.7 (8.5)
$\ell\tau_{\ell'}$ Run 2, right-handed τ	8.4 (11)	9.8 (13)
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)

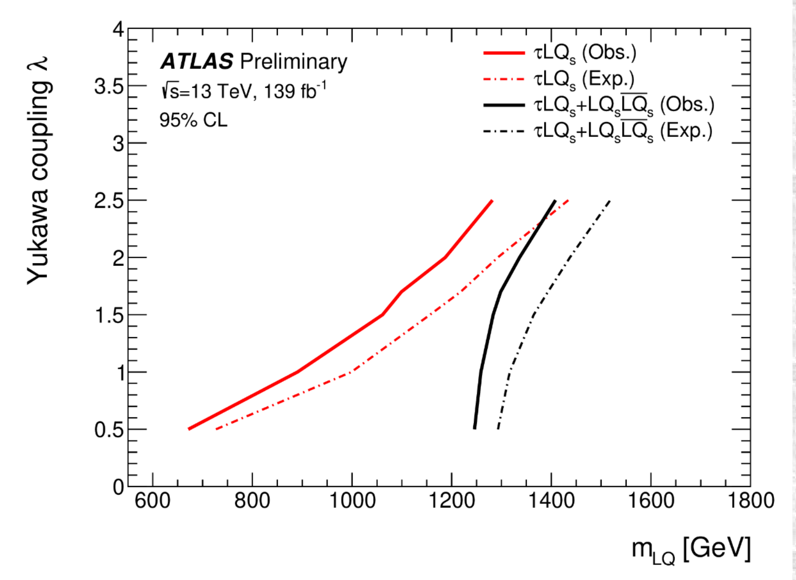
- Also Z → lτ limits
- All stat. dominated

Scalar leptoquark in bττ ATLAS-CONF-2022-037

- Model assumes q=4/3e
- Inspired by LFV hints from b decays
- Taus sought in lep-had and had-had configurations
  - Later dominates, show right.
- No evidence for signal
  - Single or pair produced
  - Combined: leptoquarks below 1.26 TeV excluded for a Yukawa coupling of 1
- Broad programme
  - see ATL-PHYS-PUB-2022-012



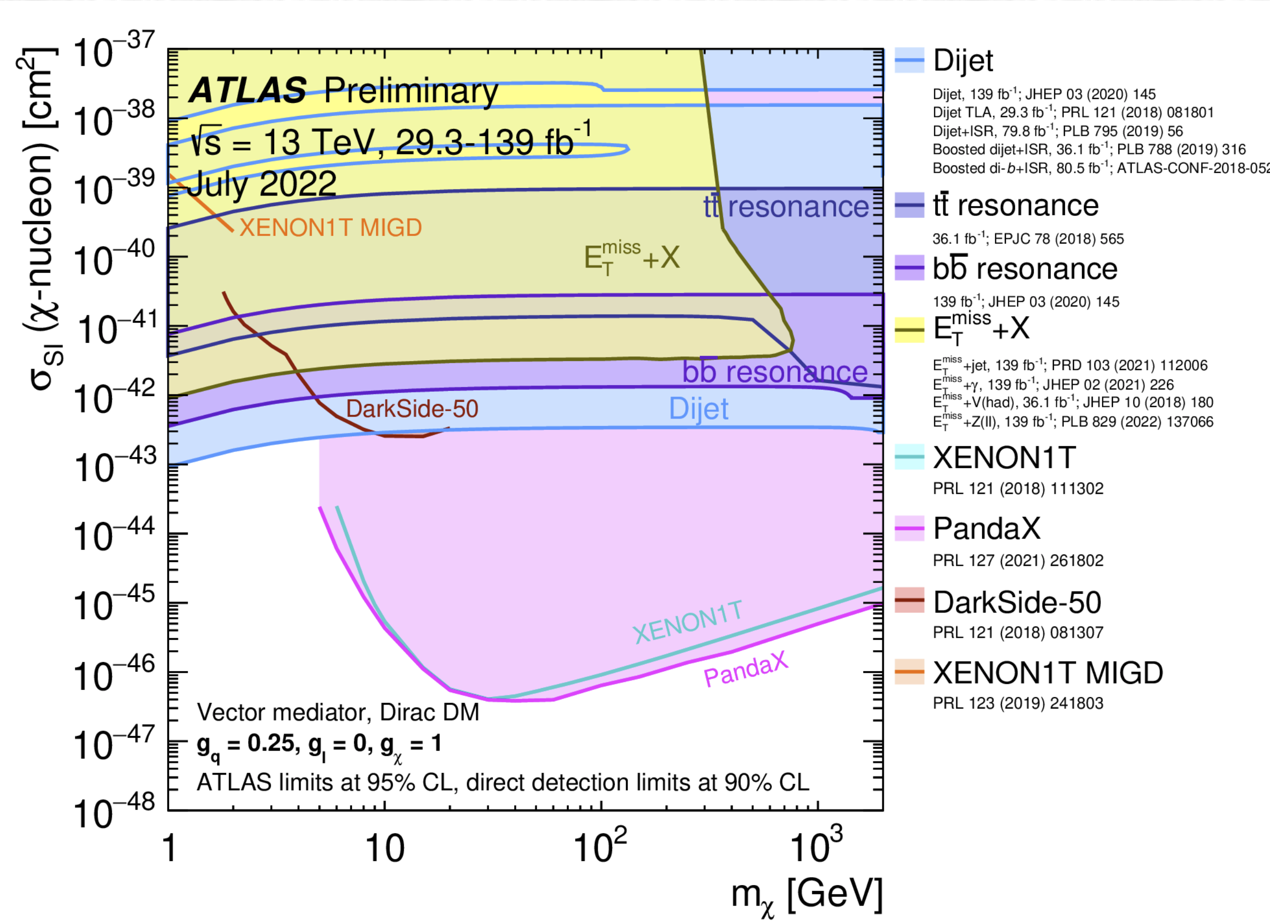




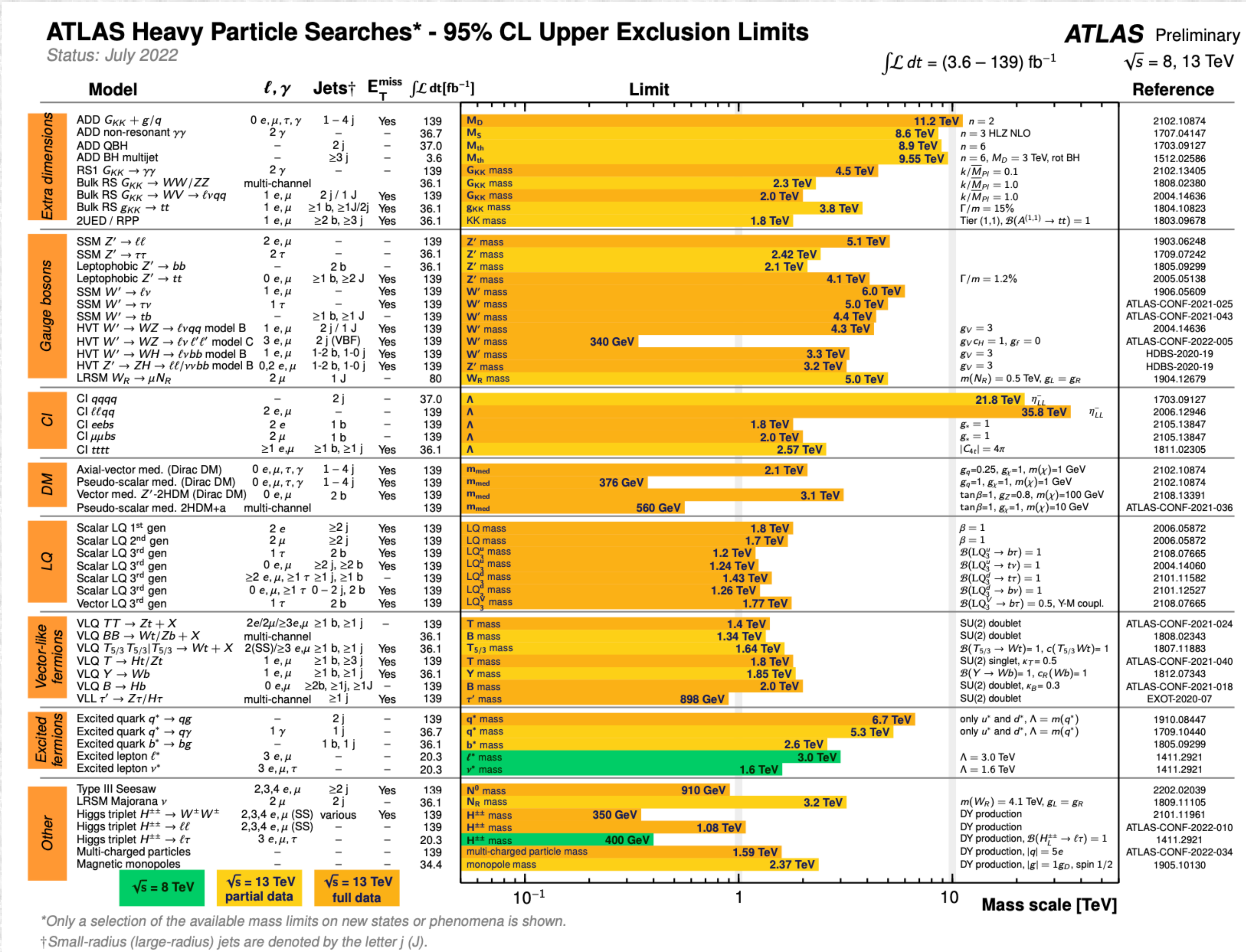
Dark matter

ATL-PHYS-PUB-2022-036/

- Missing energy and resonance searches can be used to limit specific DM models.
  - Here lepto-phobic vector mediator model used
- Will be much more instructive when we see signals!



Heavy resonance searches

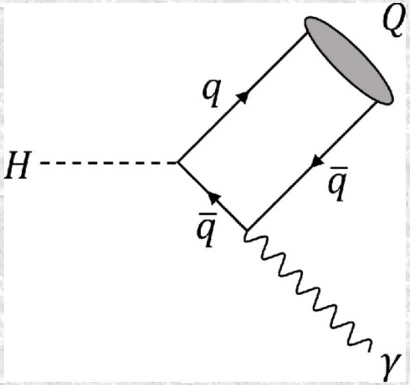


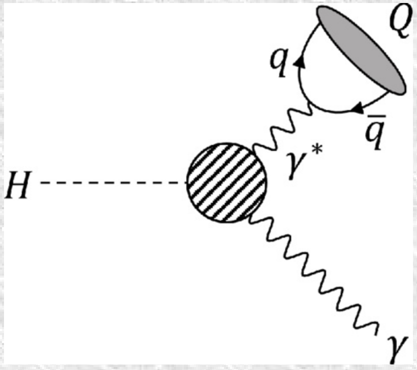
HDBS

Z or H to (J/ψ + γ) or (Υ + γ)

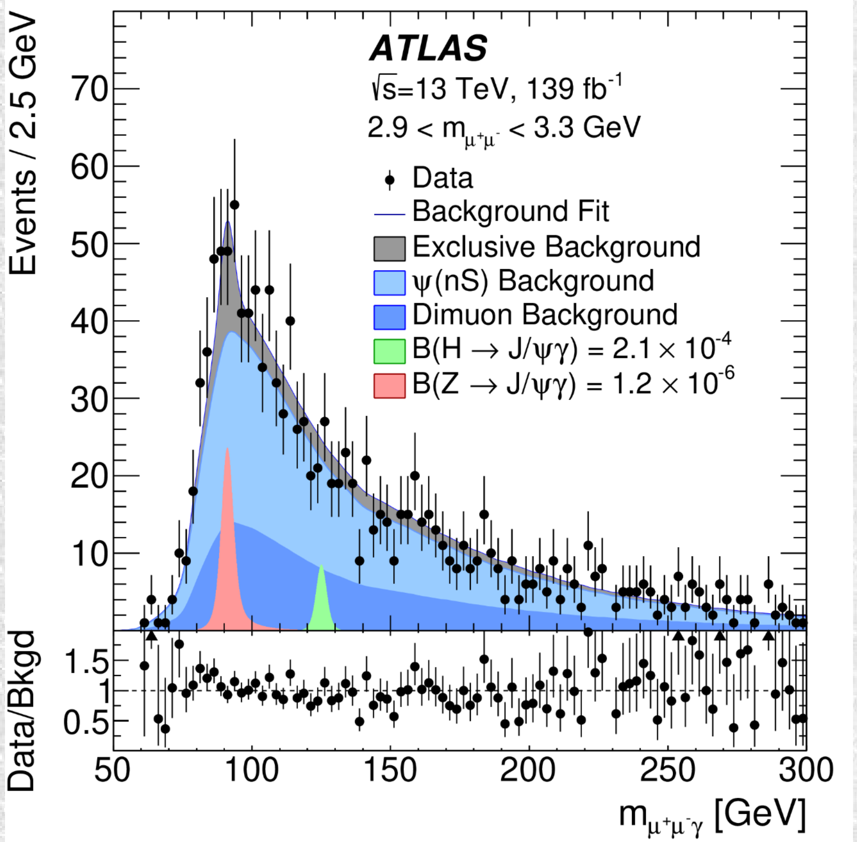
arxiv 2208.03122

- Decays to quarkonia sensitive to the Hcc / Hbb coupling
  - But also to Vector Meson Dominance production
- Data-driven background model describe data well
- Limits set here





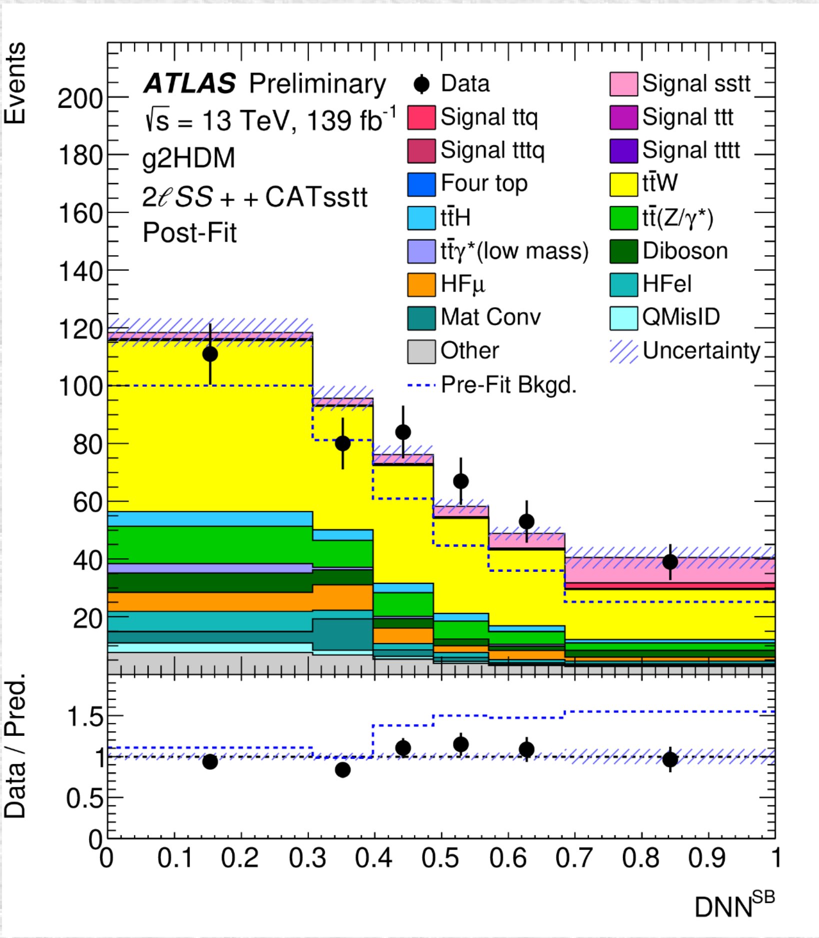
	95% CL_s upper limits					
	Branching fraction				$\sigma \times \mathcal{B}$	
Decay channel	Higgs boson [10^{-4}]		Z boson [10^{-6}]		Higgs boson [fb]	Z boson [fb]
	Expected	Observed	Expected	Observed	Observed	Observed
$J/\psi\,\gamma$	$1.9^{+0.8}_{-0.5}$	2.1	$0.6^{+0.3}_{-0.2}$	1.2	12	71
$\psi(2S)\,\gamma$	$8.5^{+3.8}_{-2.4}$	10.9	$2.9^{+1.3}_{-0.8}$	2.3	61	135
$\Upsilon(1S)\,\gamma$	$2.8^{+1.3}_{-0.8}$	2.6	$1.5^{+0.6}_{-0.4}$	1.0	14	59
$\Upsilon(2S)\,\gamma$	$3.5^{+1.6}_{-1.0}$	4.4	$2.0^{+0.8}_{-0.6}$	1.2	24	71
$\Upsilon(3S)\,\gamma$	$3.1^{+1.4}_{-0.9}$	3.5	$1.9^{+0.8}_{-0.5}$	2.3	19	135

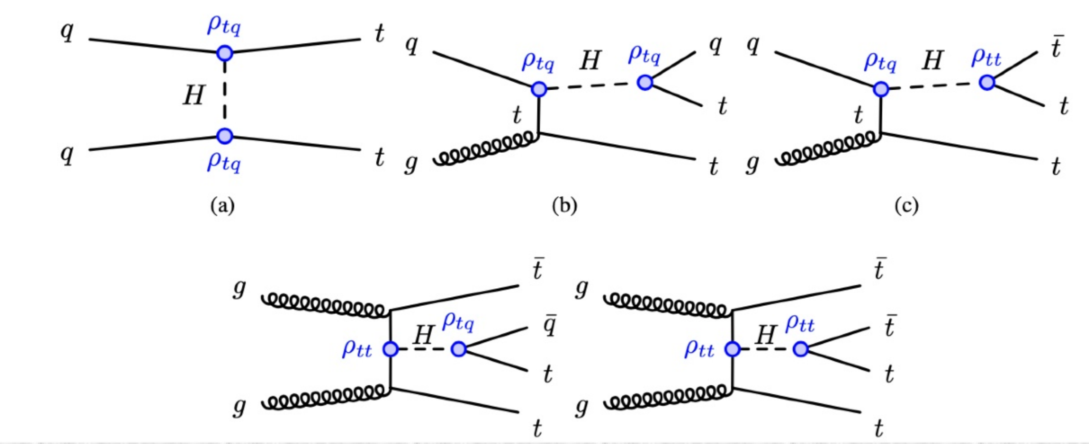


Generic 2HDM

ATLAS-CONF-2022-039

- Allows flavour violation
  - e.g. 3rd generation $uu \rightarrow tt$!!

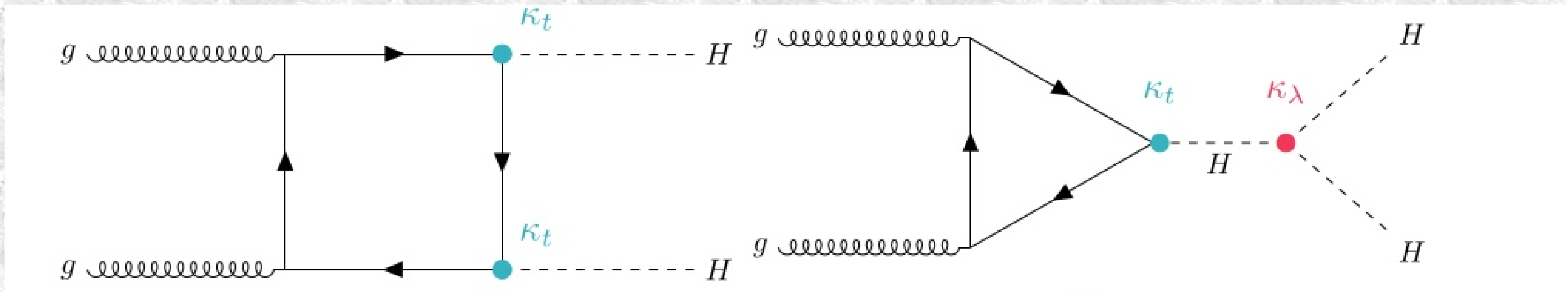




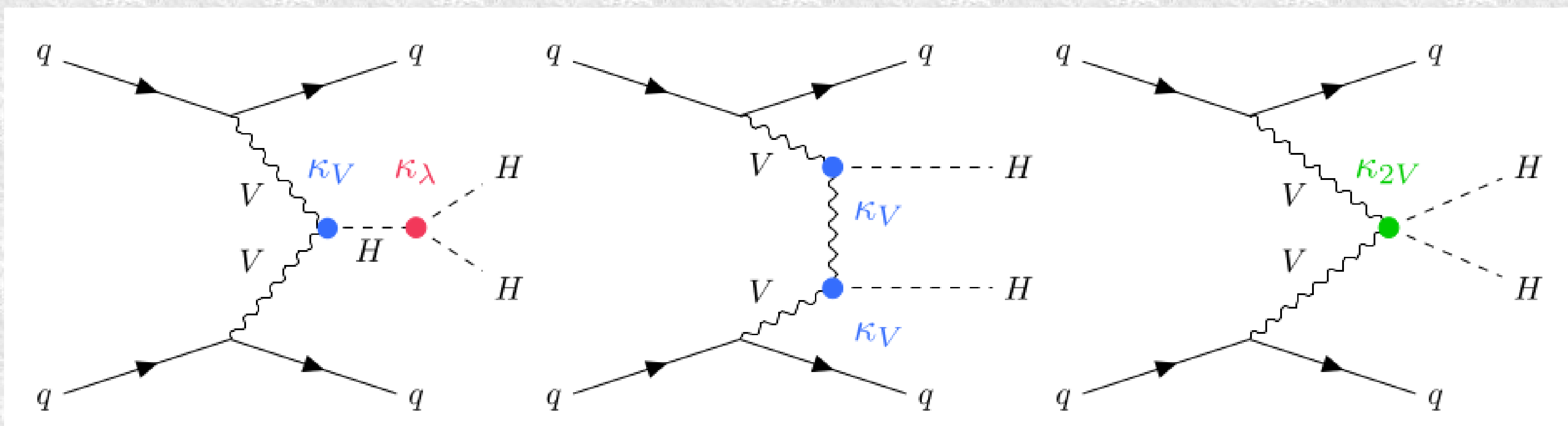
- Scan ρ_{tt}, ρ_{tc}, ρ_{tu} couplings
- and heavy Higgs masses 200 GeV < m_H < 1000 GeV
- largest deviation 2.8σ local
  - ρ_{tt}=0.32, ρ_{tc}=0.05, ρ_{tu}=0.85
  - m_H=1000

Di-Higgs production

- ggF



- VBF

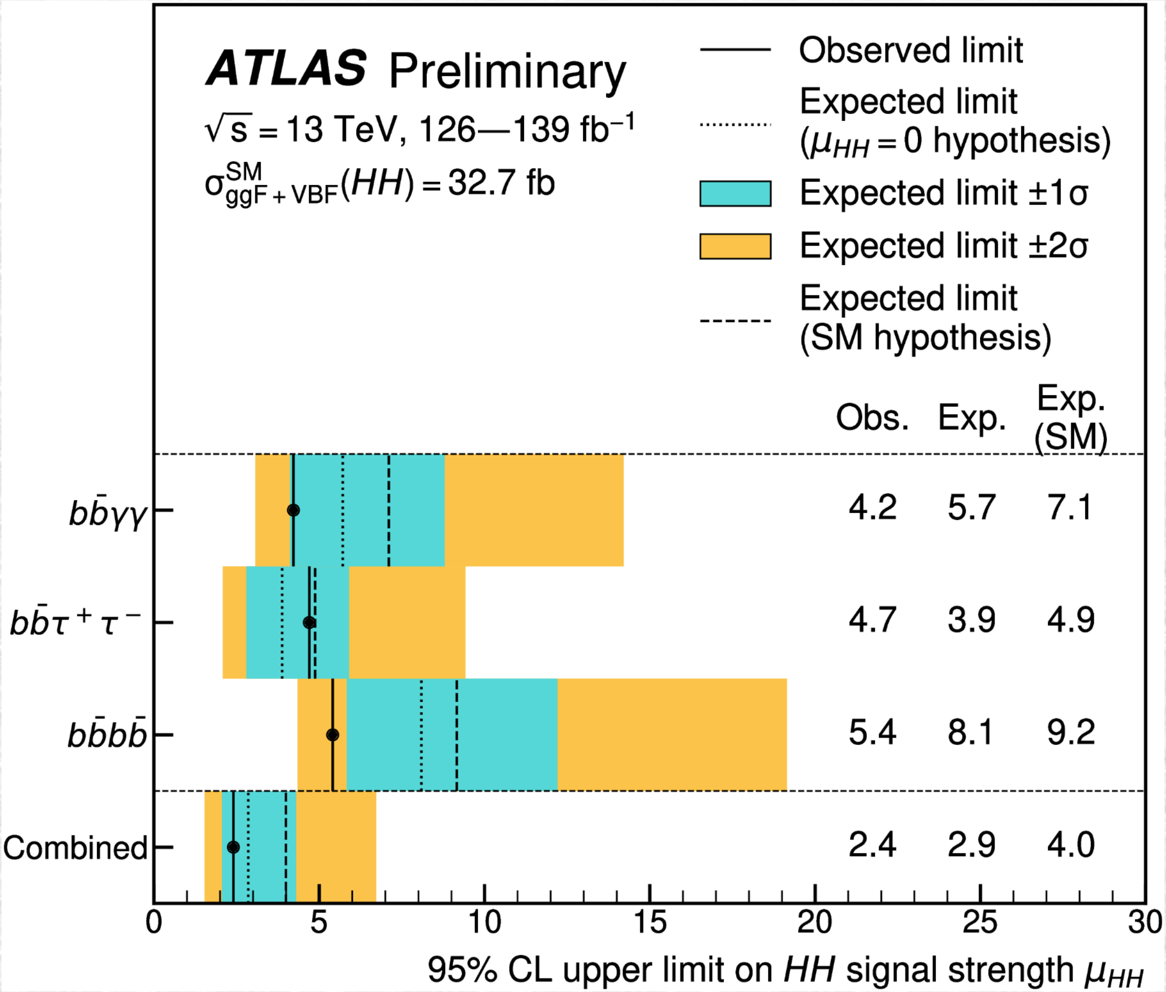


- Interference between paths destructive for both
- κ_λ scales coupling, SM=1. Affects both modes,
  - Interplay with κ_t in ggF, κ_V and κ_{2V} in VBF

  m(HH) spectrum depends on κ_λ, κ_{2V}

Combined HH

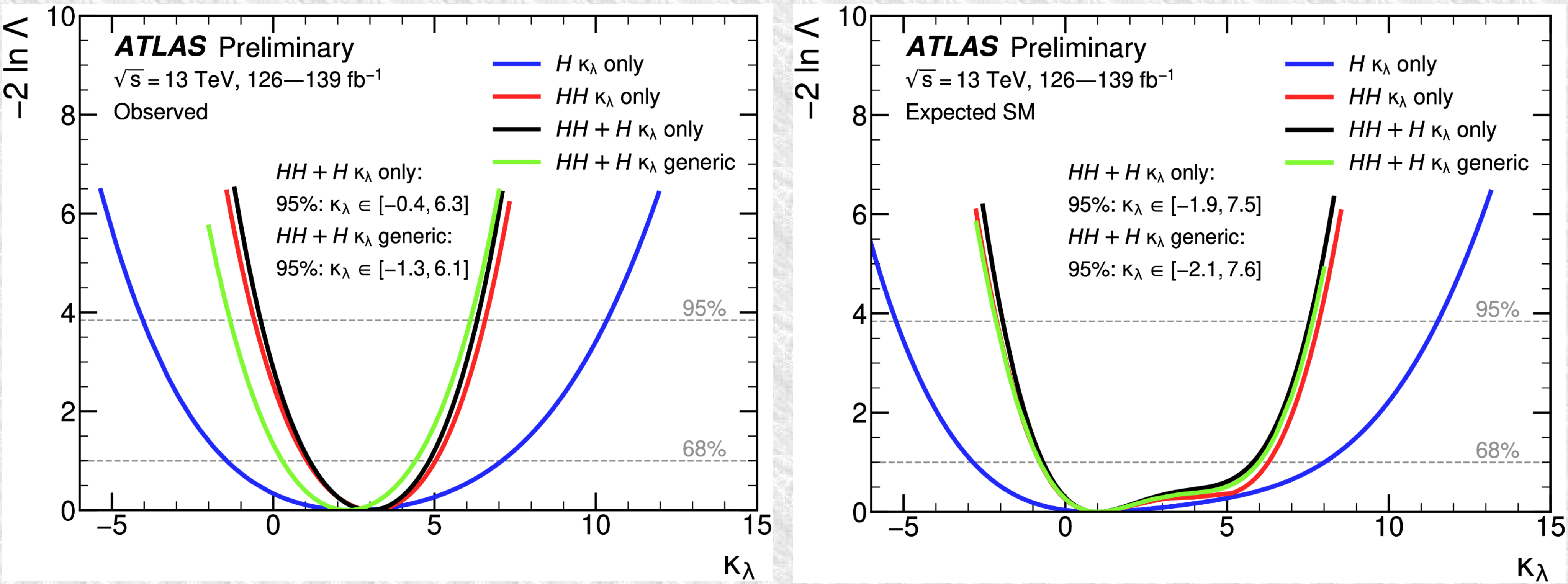
ATLAS-CONF-2022-050



- Limit on HH production at 2.4 x SM strength
  - c/f 2.9 expected (no HH) or 4.0 (SM)

κ_λ from H and HH

ATLAS-CONF-2022-050

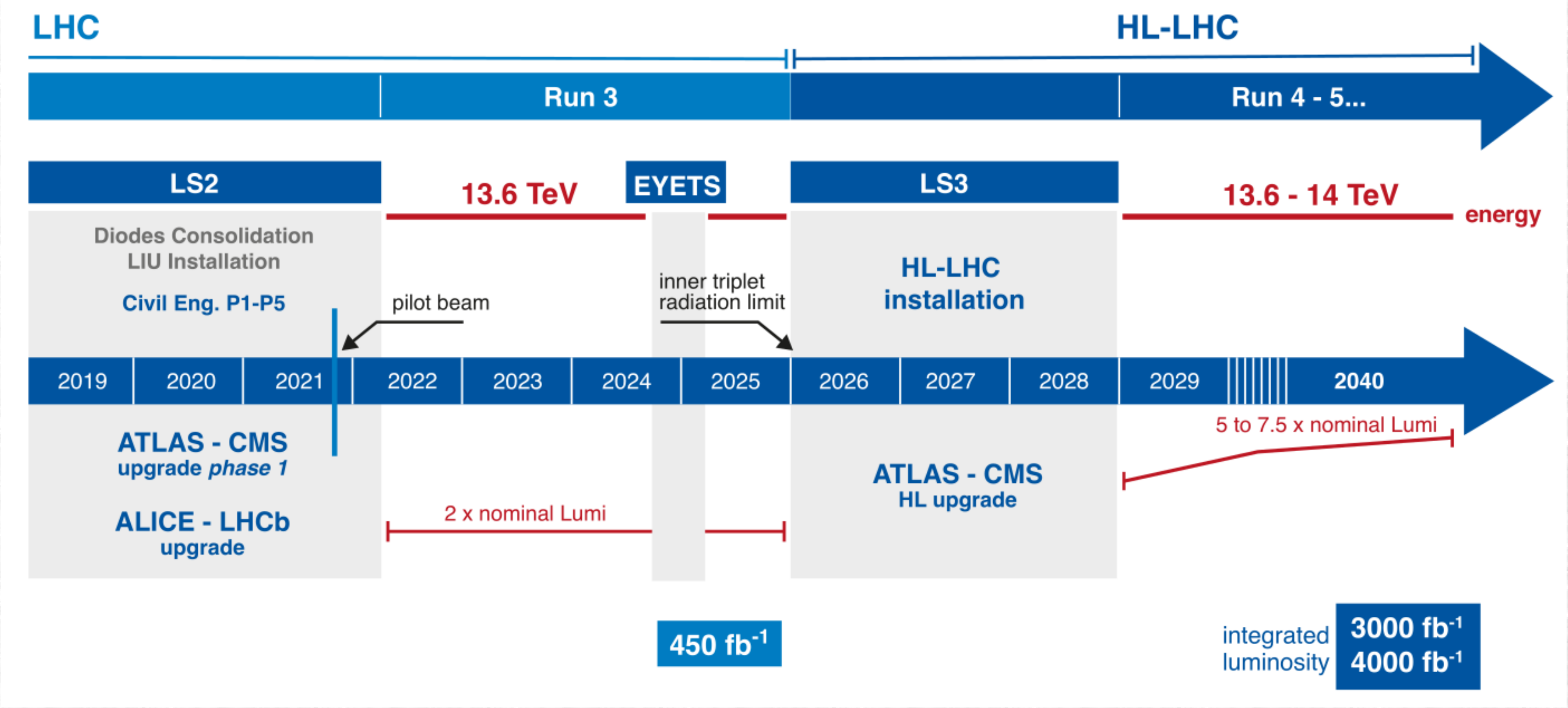


- κ_λ restricted to -1.3 – 6.1 (-2.1 – 7.6 expected)
  - Tightest constraint on κ_λ so far
- Range shrinks *slightly*, if κ_V, κ_t, κ_b, κ_τ all fixed
  - Because they are constrained by single H data

HL-LHC

The future

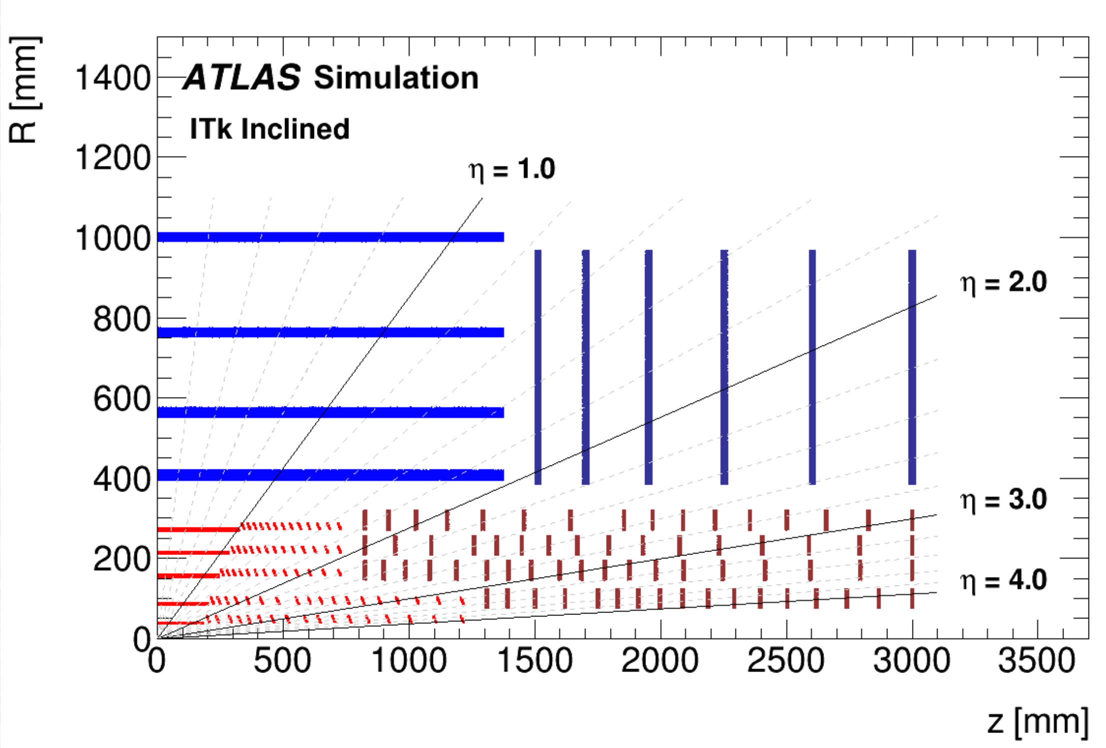
- ATLAS is using 139fb^{-1} @ 13TeV for most results
- Run 3 may bring 300fb^{-1} @ 13.6 TeV
- HL-LHC will bring an order of magnitude more



- As well as increasing experimental challenges

Upgrade Example: Inner tracker

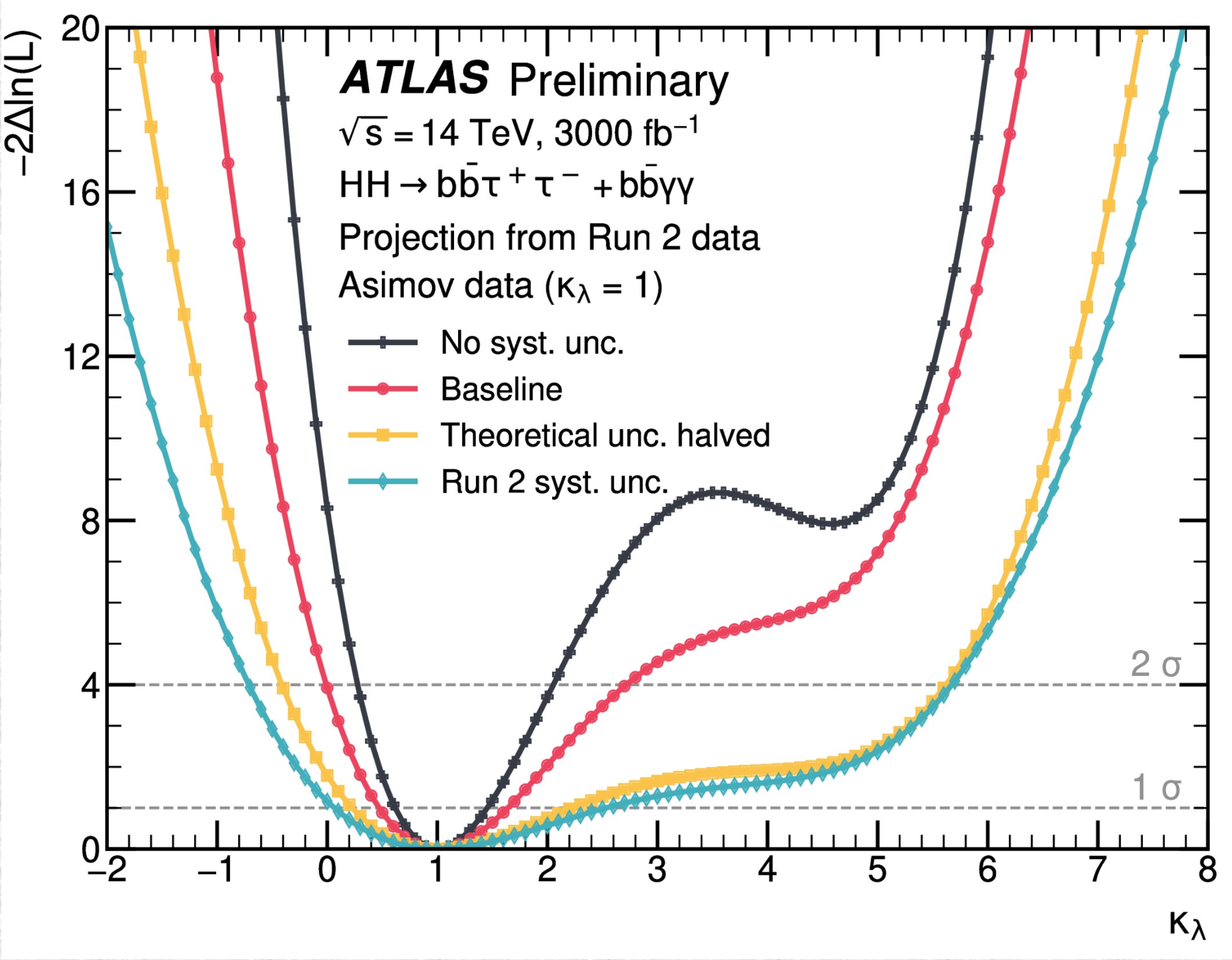
- Tracker rebuild to handle radiation & tracks density
- ITk features
  - All silicon (fast) layout
    - 5 pixel, 4 strip
  - Higher granularity
    - Reduced occupancy
  - Improved radiation handling
  - Extended coverage
    - $|\eta|$ limit 2.5 → 4



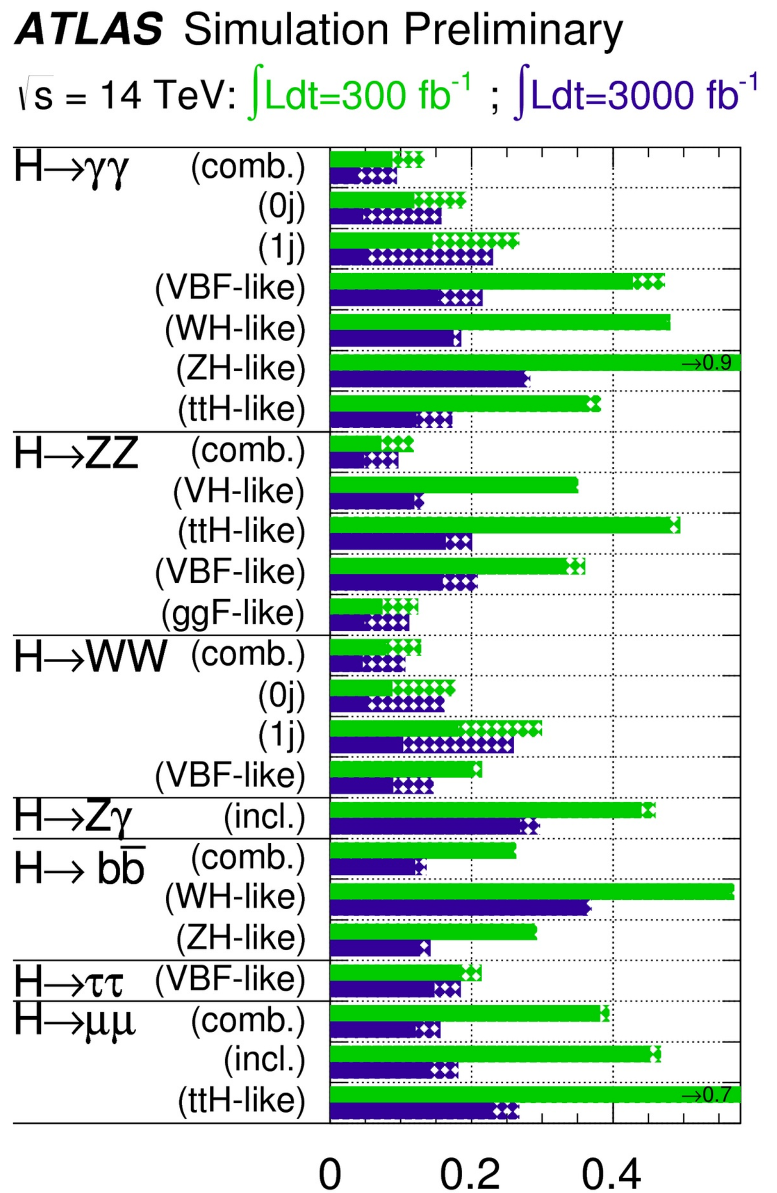
- Maintains or improves performance despite pileup
- The build schedule is tight but doable for 2029

Example HL-LHC sensitivity to κ_λ

- Baseline projection red
  - 1% lumi
  - Theory errors halved
  - Expt 1/√L
- $0<\kappa_\lambda<2.7$
  - Combining bbττ and bbγγ only
- Experiments can combine

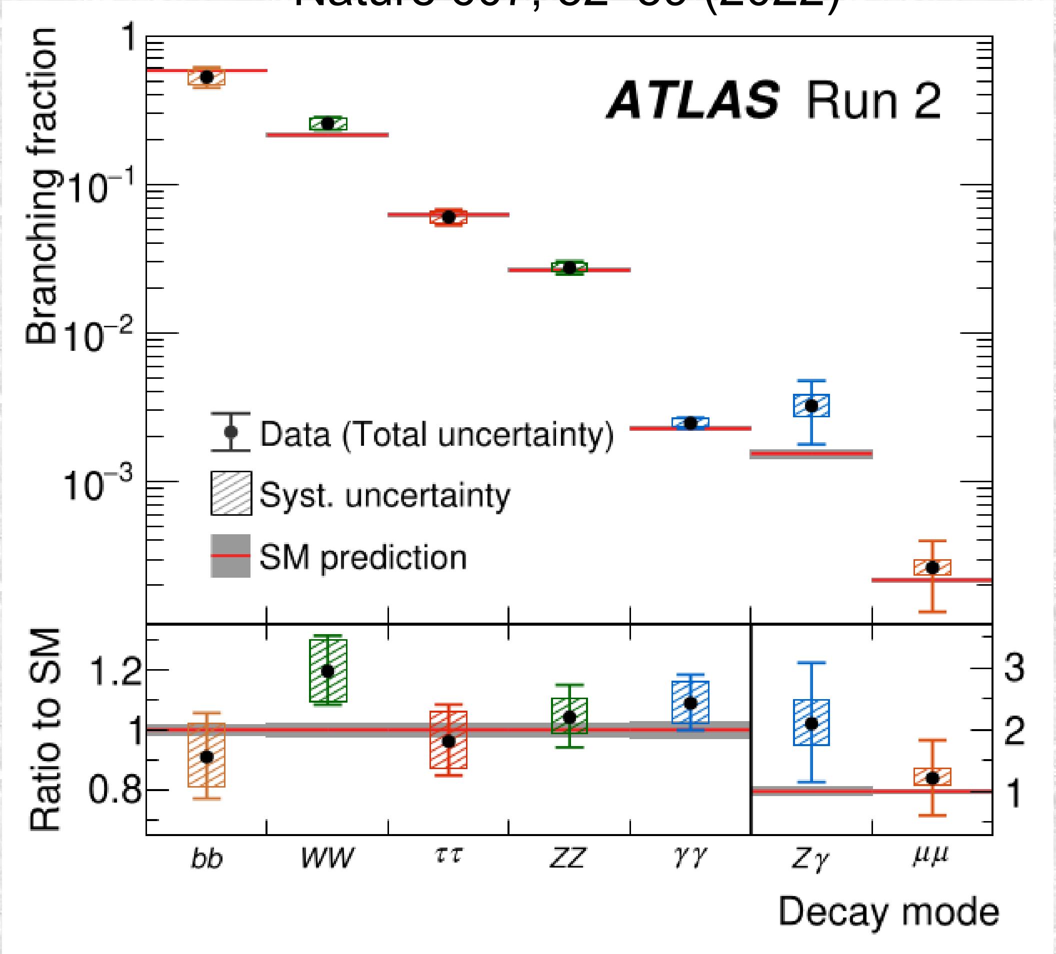


Expectations: exceeded



ATL-PHYS-PUB-2014-016

Nature 607, 52–59 (2022)



- Run 2 results are comparable to 2014 HL-LHC expectations

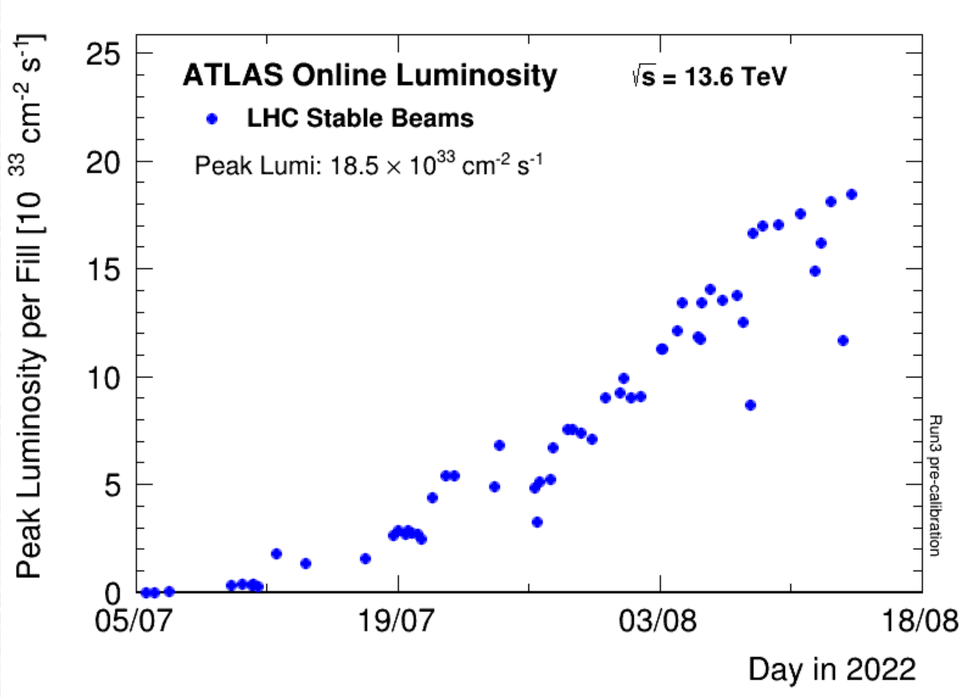
Outlook

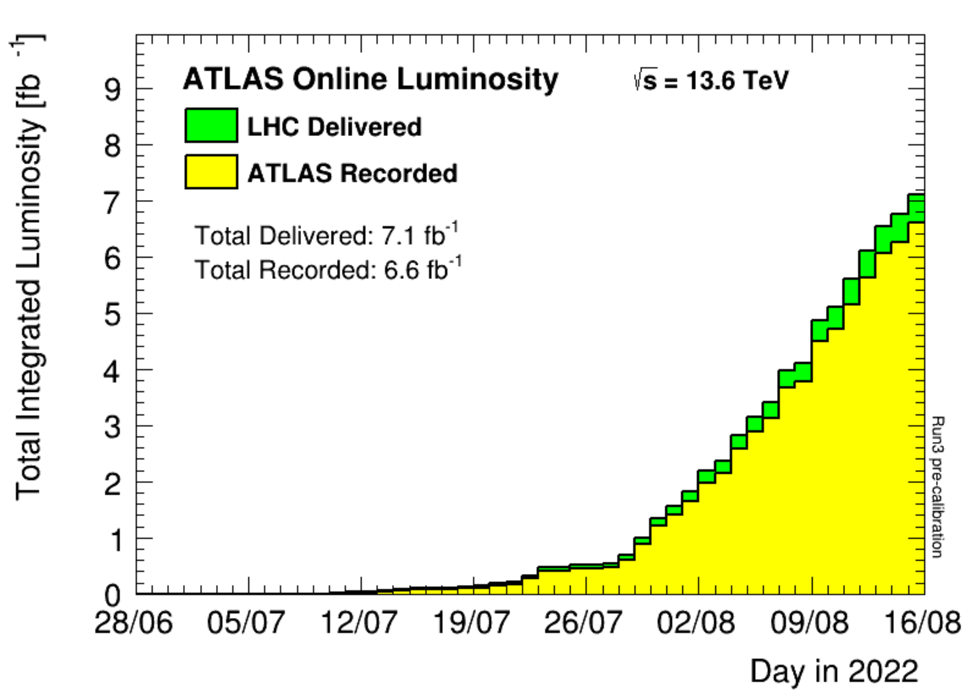
- Broad Physics programme
- Over 1000 papers published
  - With many more to come from Run 2
  - While Run 3 data is already on us
- No one knows what discoveries they will bring
  - But diHiggs sensitivity is approaching fast

- ATLAS is a friendly Titan…
  - Ready to gather more Golden Apples

Backup

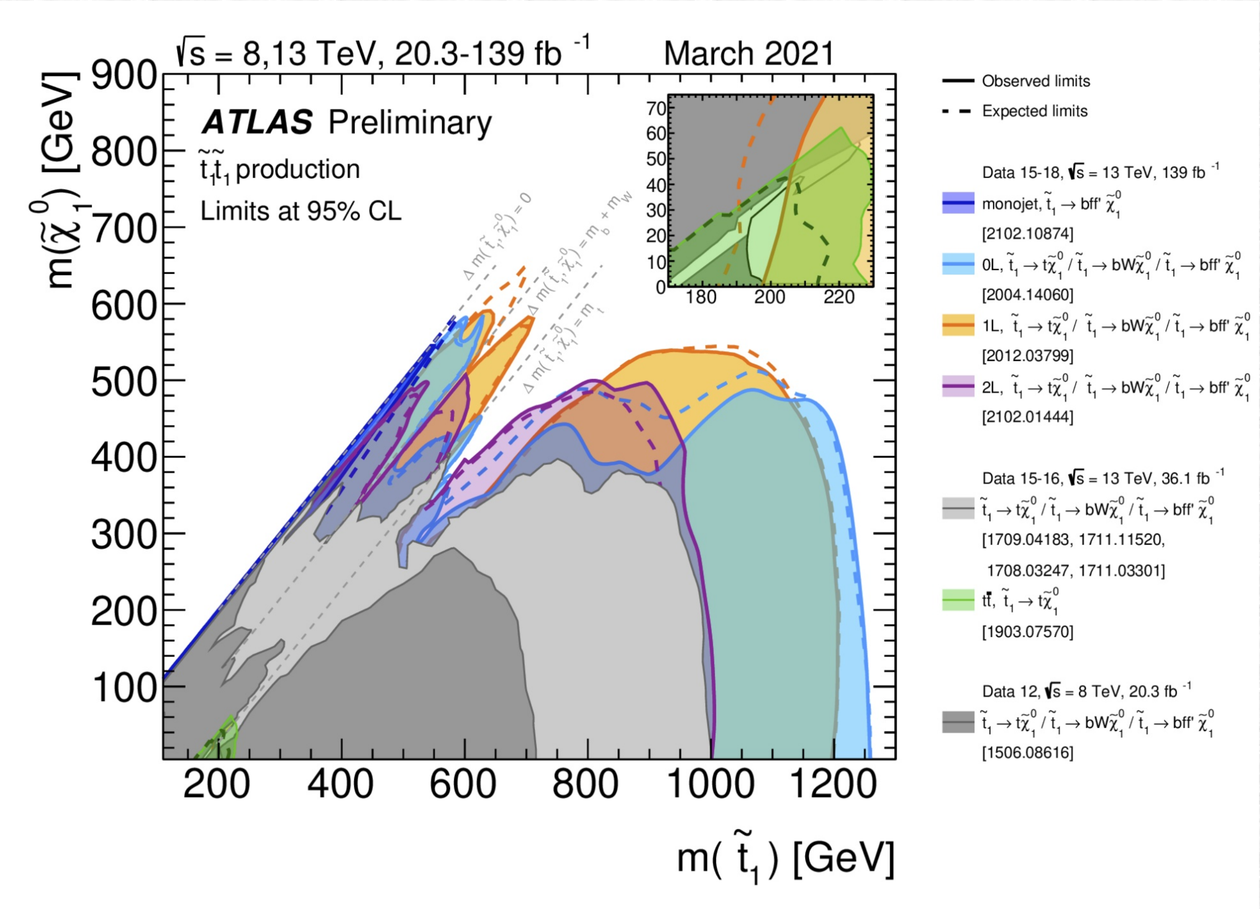
LHC status


ATLAS Online Luminosity
√s = 13.6 TeV
LHC Stable Beams
Peak Lumi: 18.5 × 10^33 cm^-2 s^-1
Peak Luminosity per Fill [10^33 cm^-2 s^-1]
Day in 2022
05/07
19/07
03/08
18/08
Run3 pre-calibration

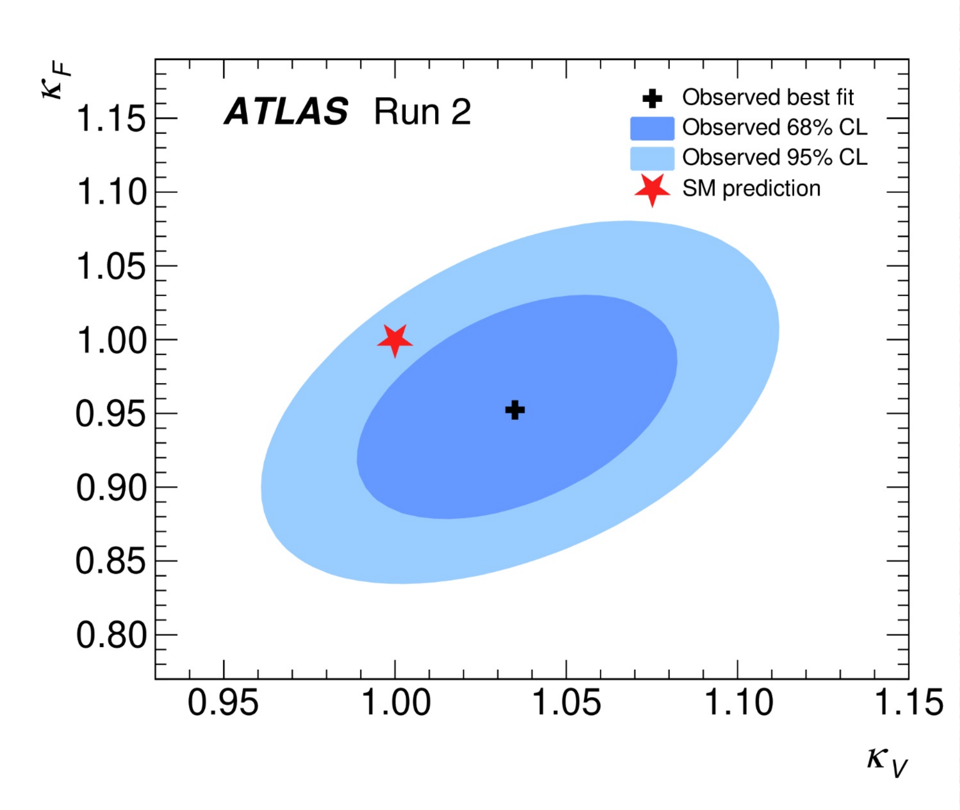

ATLAS Online Luminosity
√s = 13.6 TeV
LHC Delivered
ATLAS Recorded
Total Delivered: 7.1 fb^-1
Total Recorded: 6.6 fb^-1
Total Integrated Luminosity [fb^-1]
Day in 2022
28/06
05/07
12/07
19/07
26/07
02/08
09/08
16/08
Run3 pre-calibration

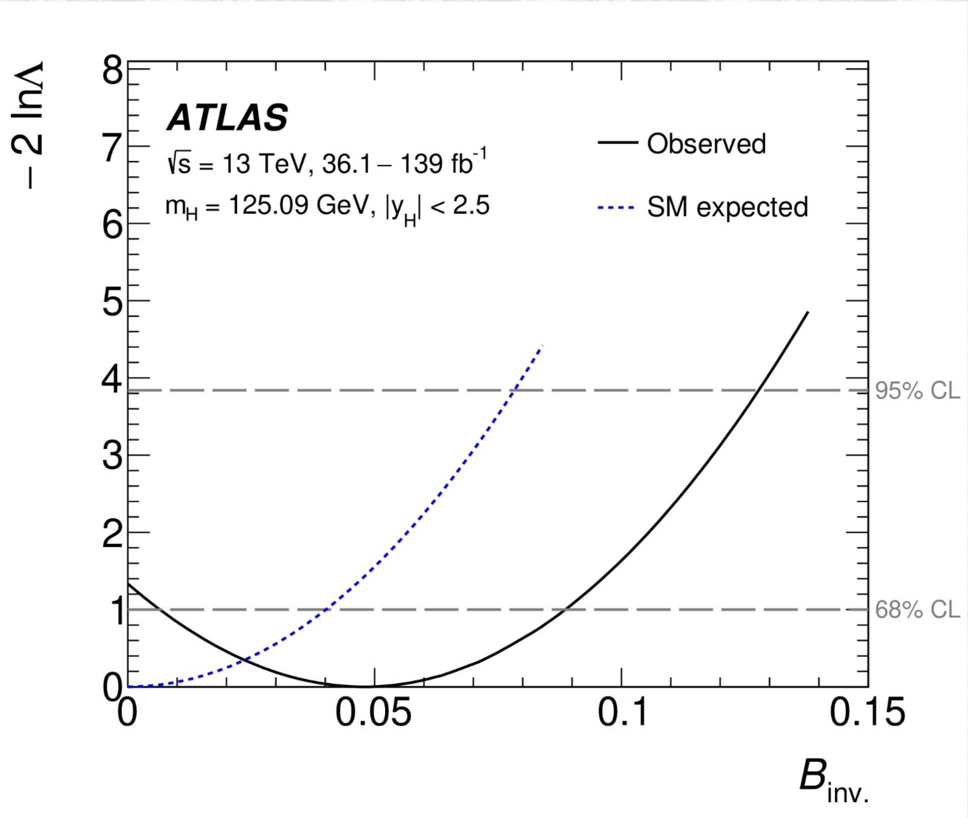
stop-neutralino limits

- Simplified models put bounds at 0.5 and 1.2 TeV on neutralino and stop



Combined: $\kappa_V - \kappa_f$ HIGG-2021-23



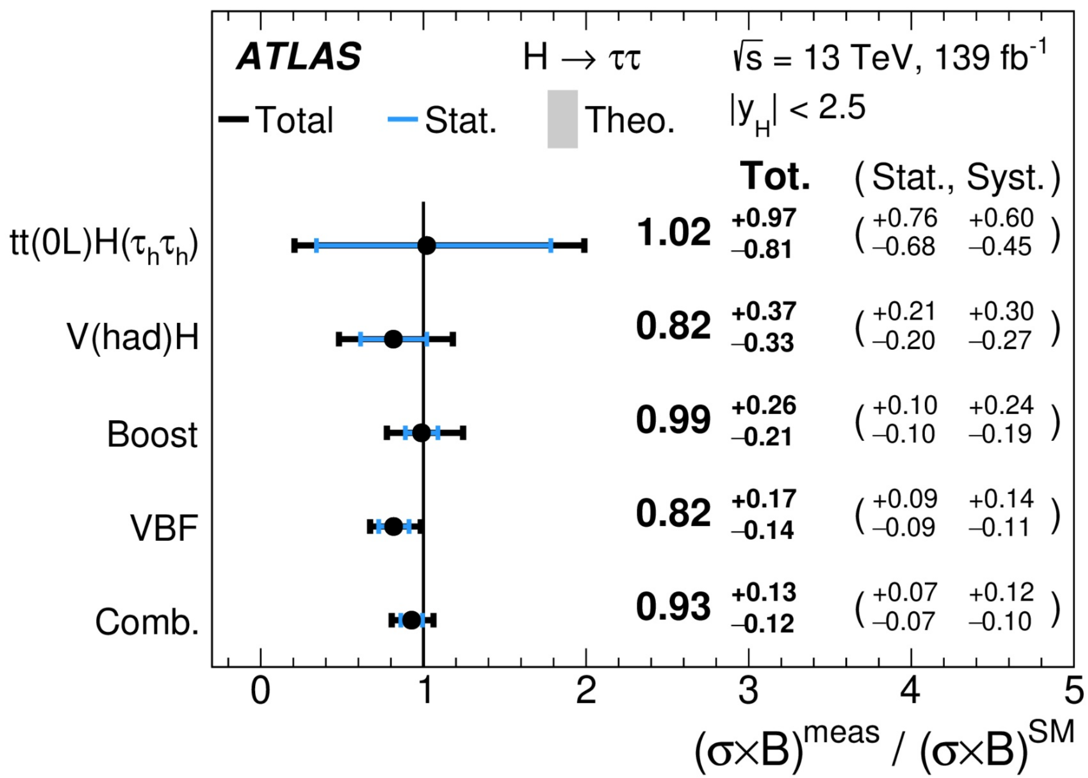


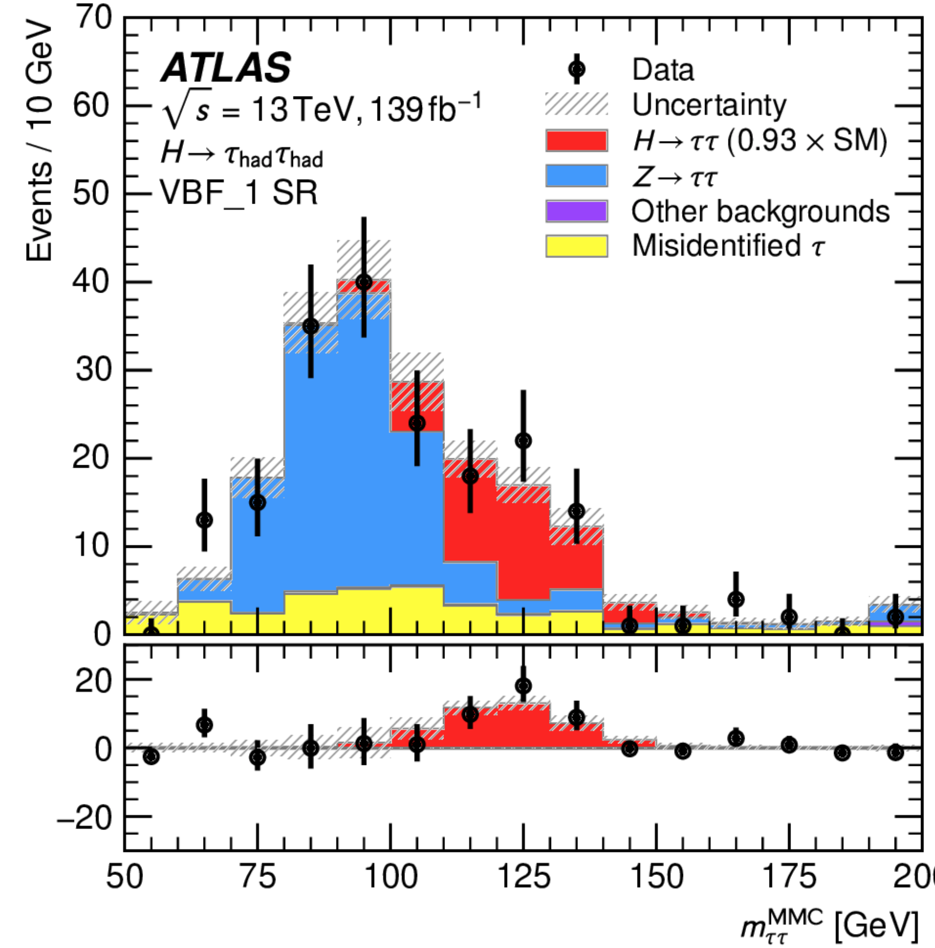
- Assuming vector and fermion couplings scale, errors 5% in fermion, 3% boson
- B_{inv} < 13% (8% expected) [κ_V constrained ≤ 1]
  - c/f 14% (10%) from VBF paper

H to ττ

HIGG-2019-09

- h-h, l-h and e-μ channels; 4200 signal events
- 4 main production modes
  - VBF best measured



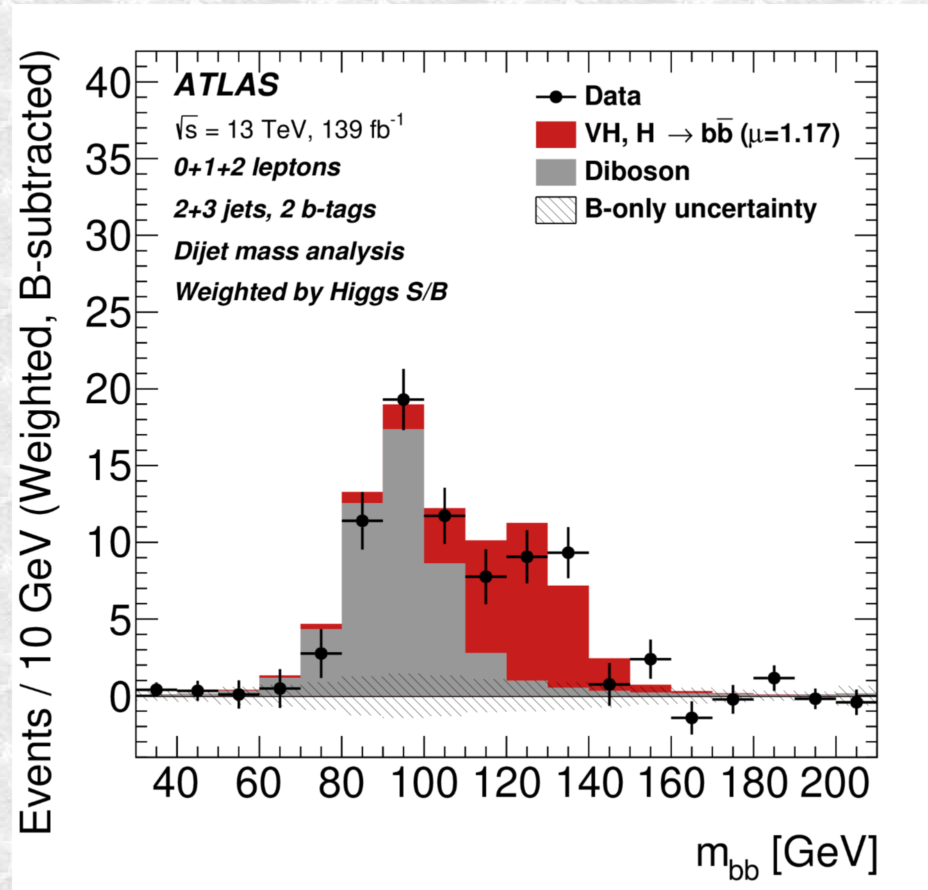


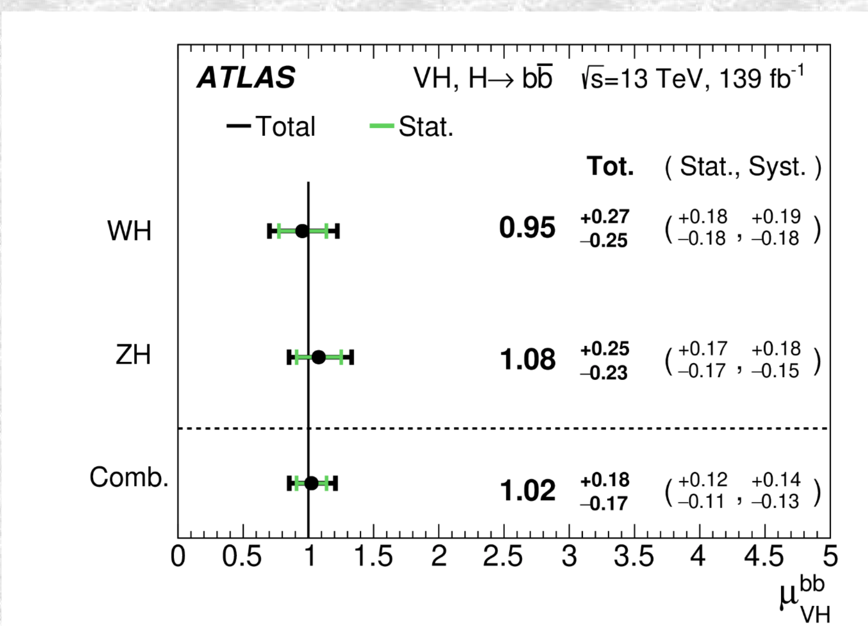
- All agree with SM

H to bb

Eur. Phys. J. C 81 (2021) 178

- Best sensitivity in VH mode
  - Tag W or Z as trigger
- Analysis uses BDT
  - But cut-n-count easier to visualise.
- 0/1/2 leptons → Z/W/Z



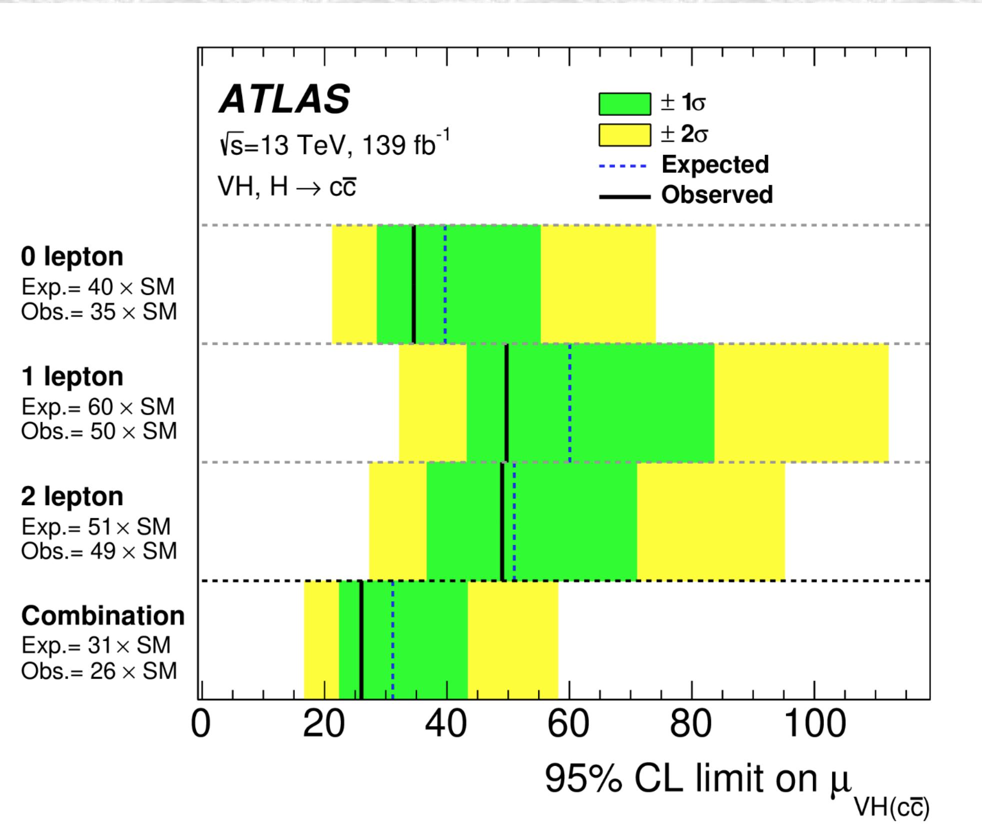


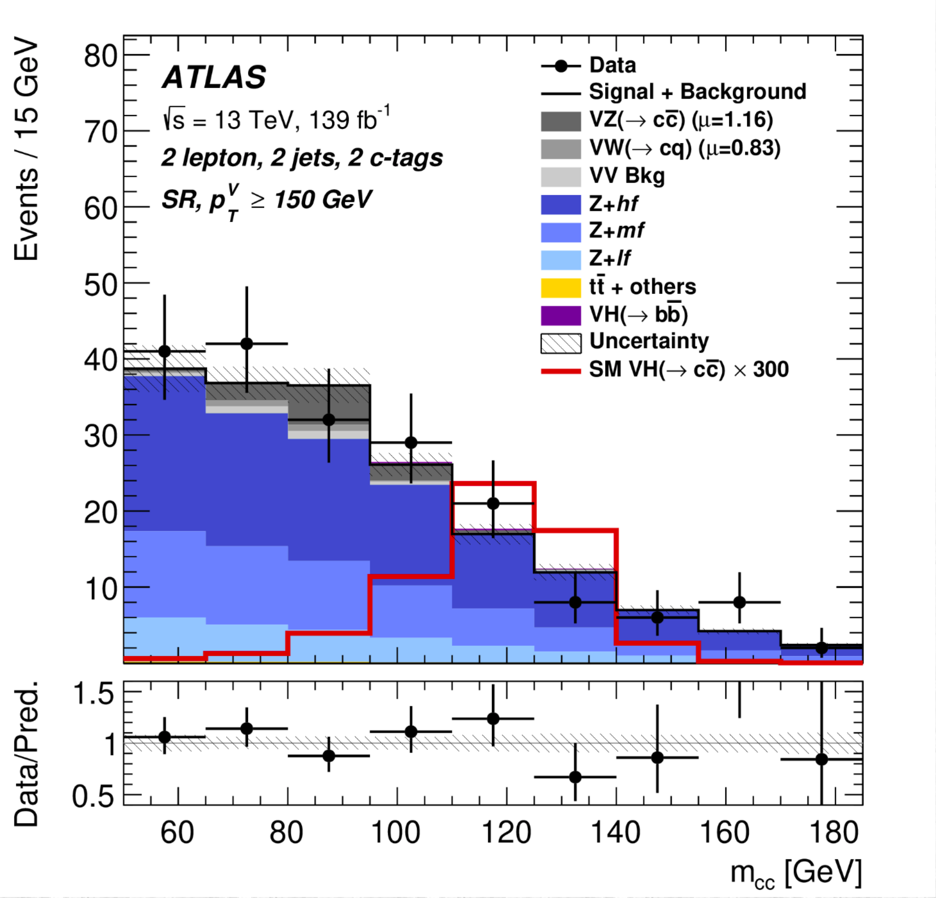
$$\mu^{bb}_{VH} = 1.02^{+0.18}_{-0.17} = 1.02^{+0.12}_{-0.11}(\text{stat.})^{+0.14}_{-0.13}(\text{syst.})$$

H to cc

arXiv:2201.11428

- Decay rate 3%, 1/20th bb
- Tagging charm quarks hard
  - Intermediate between light and b in mass and lifetime



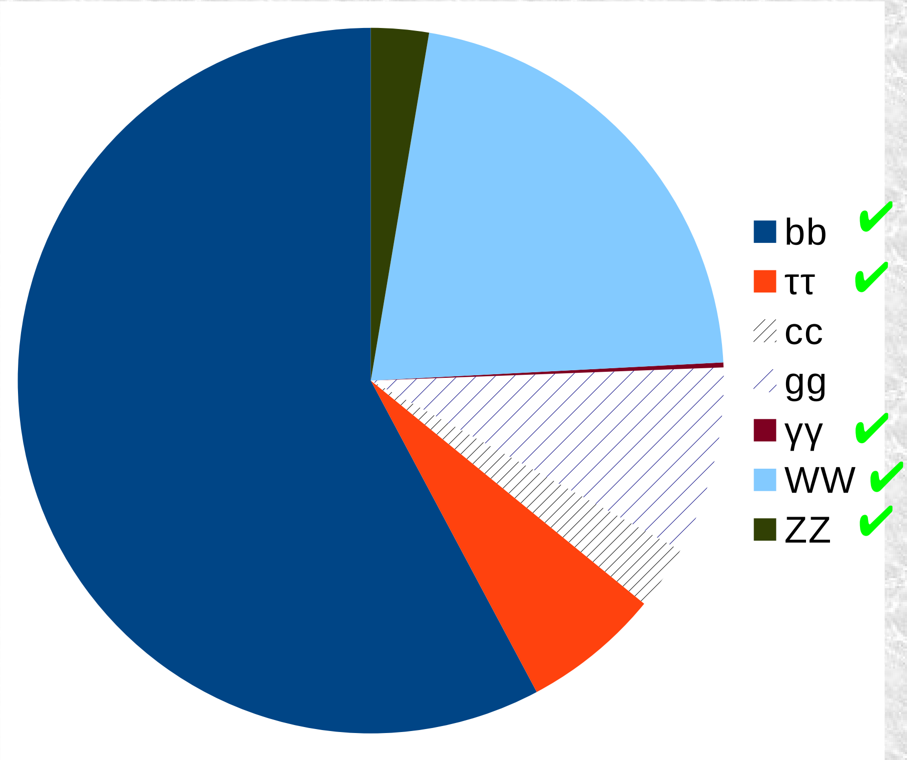


- Sensitive to O(30)x SM
  - Congrats. to CMS on their recent result!

Higgs boson: ATLAS overview

- The defining discovery of the LHC
- Decays to ZZ, γγ, WW, ττ, bb: all observed at 5σ
- Same for ggH, VBF, VH and ttH production

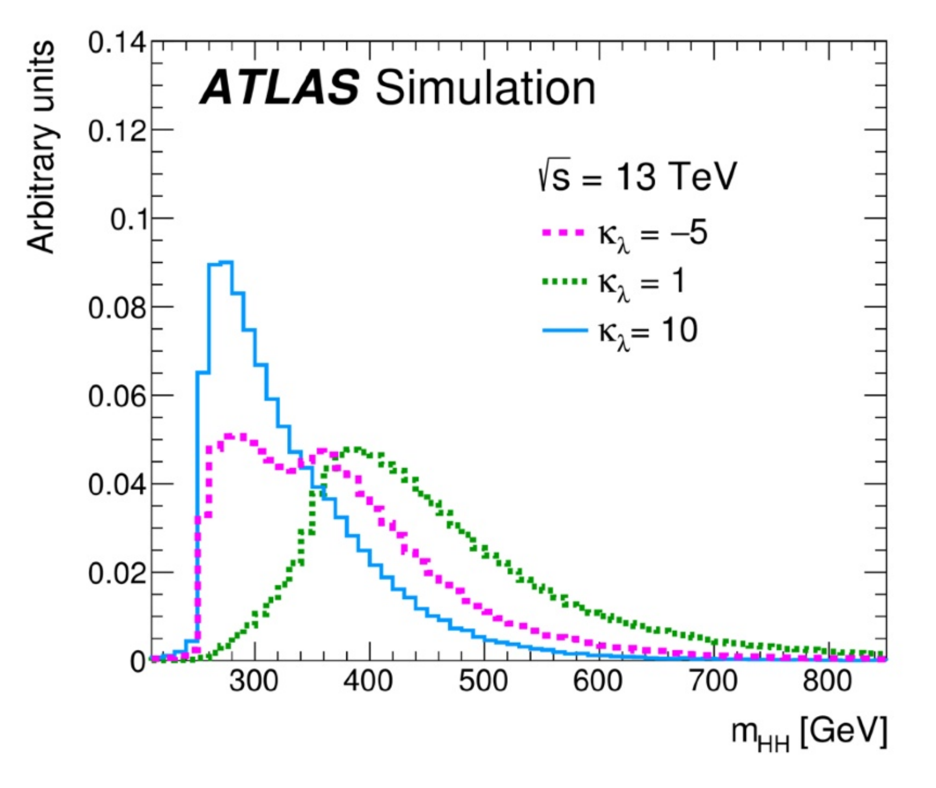
Phaistos Disk, 1908



Higgs BRs, 2012

Kinematic effects of κ_λ variation

- Cross-section of HH is 32.7fb
- Low value enforced by interference between modes
  - If you set κ_λ to zero, rate increases
- The spectrum also changes
  -
  - SM gives particularly high mass Higgs pairs.
  - Triggering easier than it might be

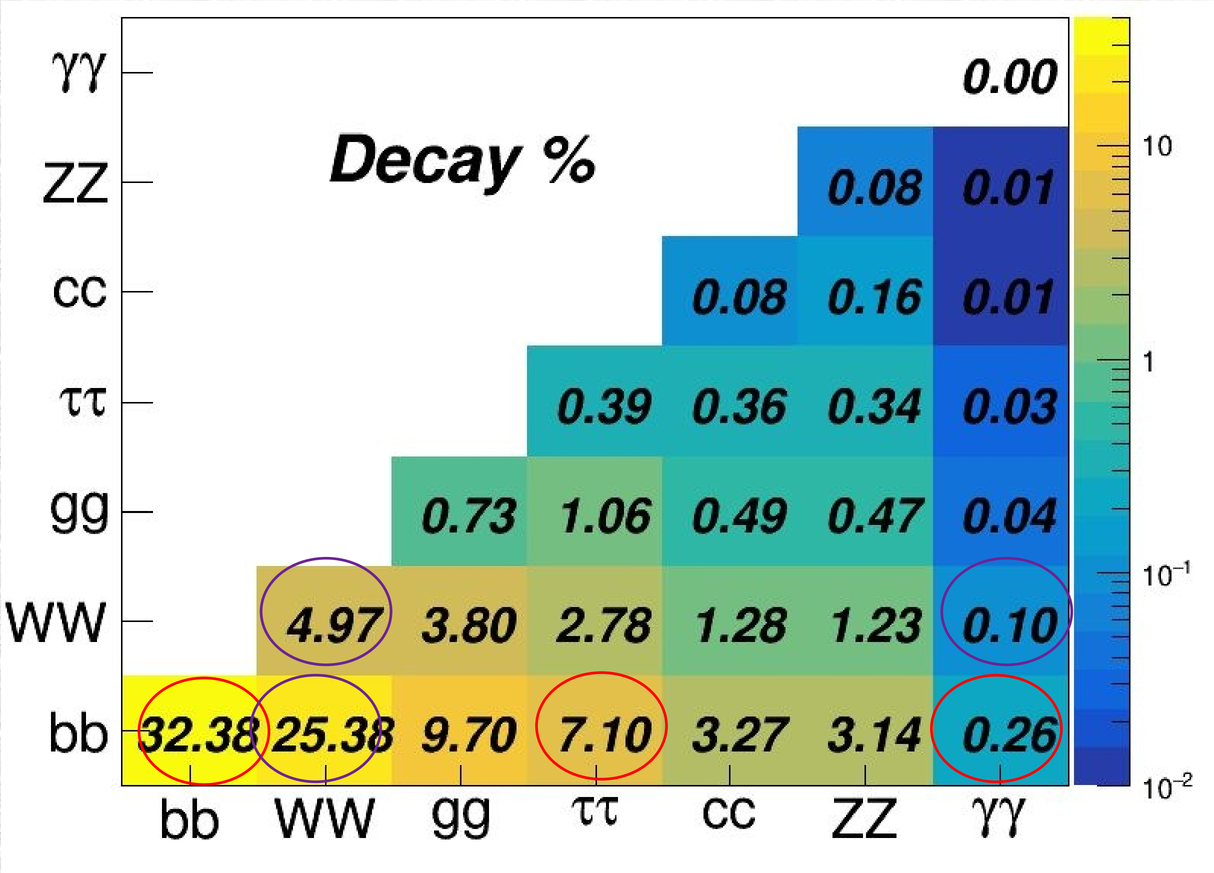


Science and Technology Facilities Council

WARWICK THE UNIVERSITY OF WARWICK

Di Higgs channels

- Right:Branching ratios of various decay modes
- Purple have results at 13 TeV
- Red circled channels have full run 2 data

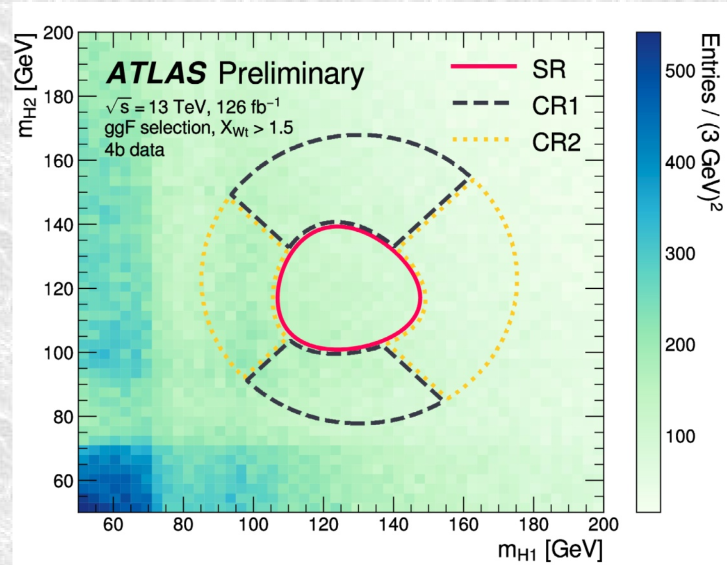


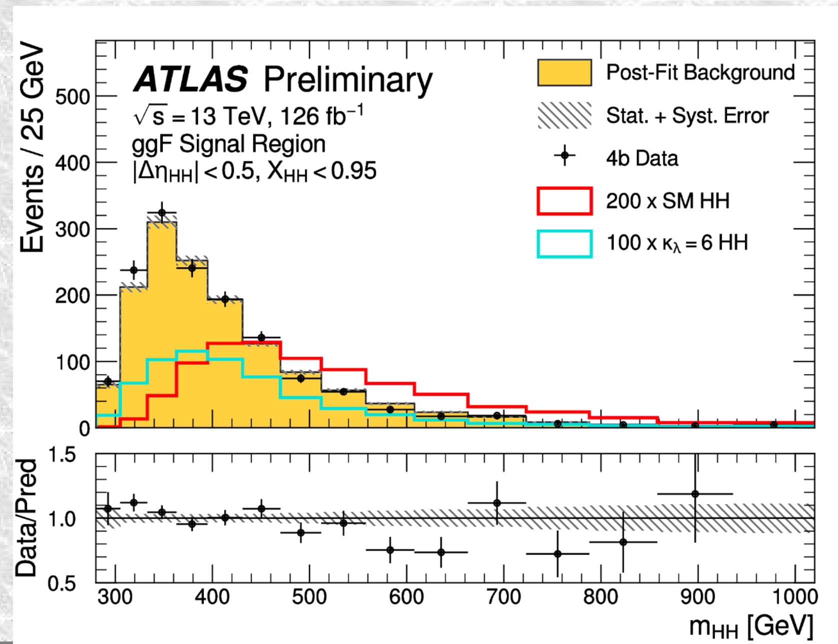
- Many weak channels are not exploited – some gain possible

HH → bbbb

ATLAS-CONF-2022-035

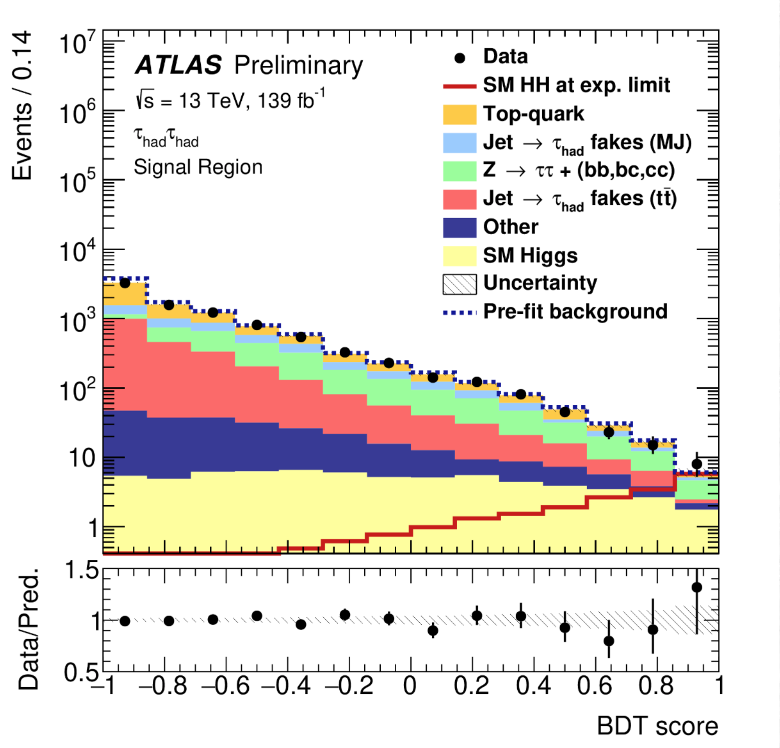
- Highest branching ratio
- ggF and VBF modes used
- Resolved channels
- Trigger tricky: combine:
  - 2b2j, pt>35 GeV all
  - 2b1j, non b jet pt>100-150
  - Tightened offline
- Backgrounds (multijet) from mass sidebands
- Best ggF signal region shown
- Obs (expected) limits:
  - 5.4(8.1) x SM rates





$HH \rightarrow bb\tau\tau$ ATLAS-CONF-2021-030

- Full data result just out
- lh and hh channels analyses
  - hh, shown right, most powerful
  - Z+HF most important background
    - Controlled with ll+HF CR
- Trigger: 1 or 2 tau, with thresholds/jets year dependent
- Most sensitive ATLAS channel

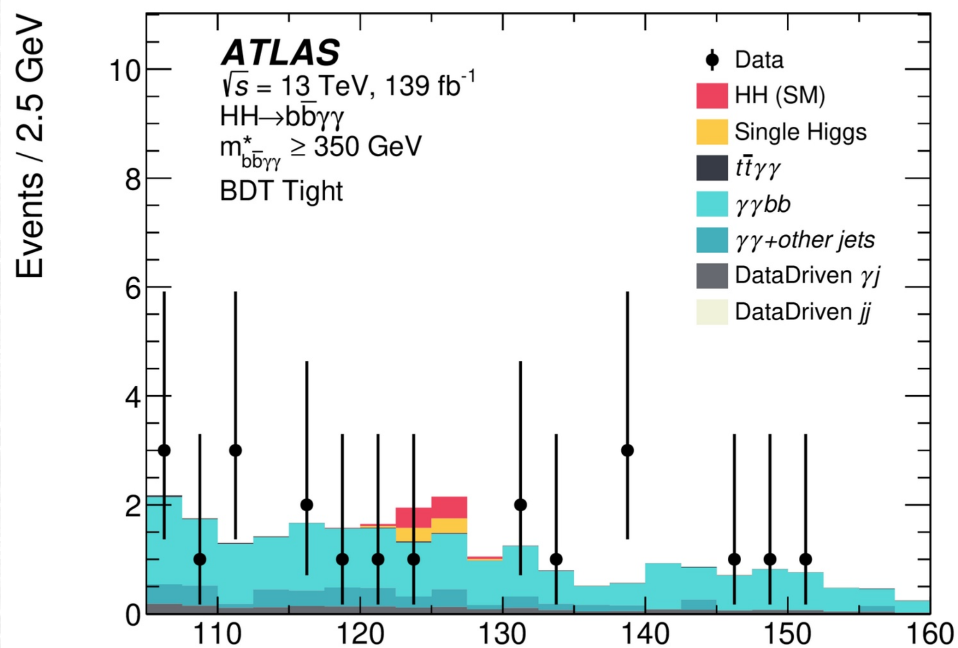


		Observed	$-2\,\sigma$	$-1\,\sigma$	Expected	$+1\,\sigma$	$+2\,\sigma$
$\tau_{\rm had}\tau_{\rm had}$	$\sigma_{\rm ggF+VBF}$ [fb]	145	70.5	94.6	131	183	245
	$\sigma_{\rm ggF+VBF}/\sigma^{\rm SM}_{\rm ggF+VBF}$	4.95	2.38	3.19	4.43	6.17	8.27
$\tau_{\rm lep}\tau_{\rm had}$	$\sigma_{\rm ggF+VBF}$ [fb]	265	124	167	231	322	432
	$\sigma_{\rm ggF+VBF}/\sigma^{\rm SM}_{\rm ggF+VBF}$	9.16	4.22	5.66	7.86	10.9	14.7
Combined	$\sigma_{\rm ggF+VBF}$ [fb]	135	61.3	82.3	114	159	213
	$\sigma_{\rm ggF+VBF}/\sigma^{\rm SM}_{\rm ggF+VBF}$	4.65	2.08	2.79	3.87	5.39	7.22

HH → bbγγ

arXiv:2112.11876

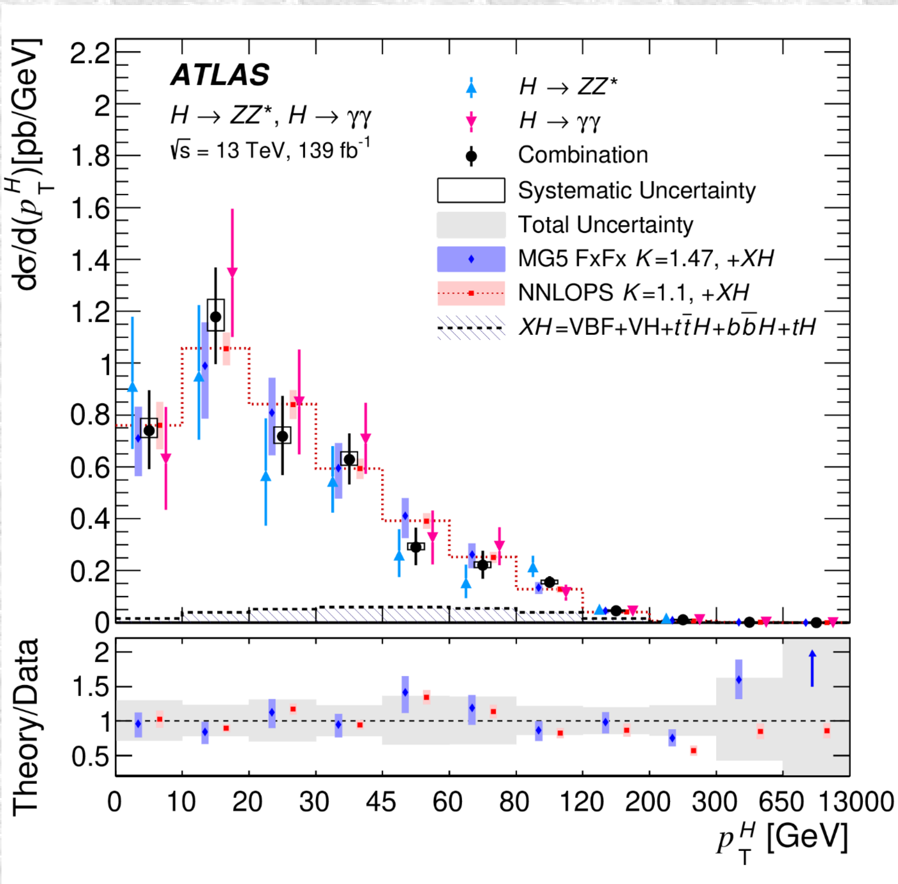
- H → γγ has good resolution & triggering; H → bb is high rate,
- Four slices: BDT score & HH mass
- Fit using exponential for bkd
- Single Higgs comparable to HH
- 1.4 Signal expected
- Expected UL 5.7xSMσ
- Observed UL 4.2xSMσ

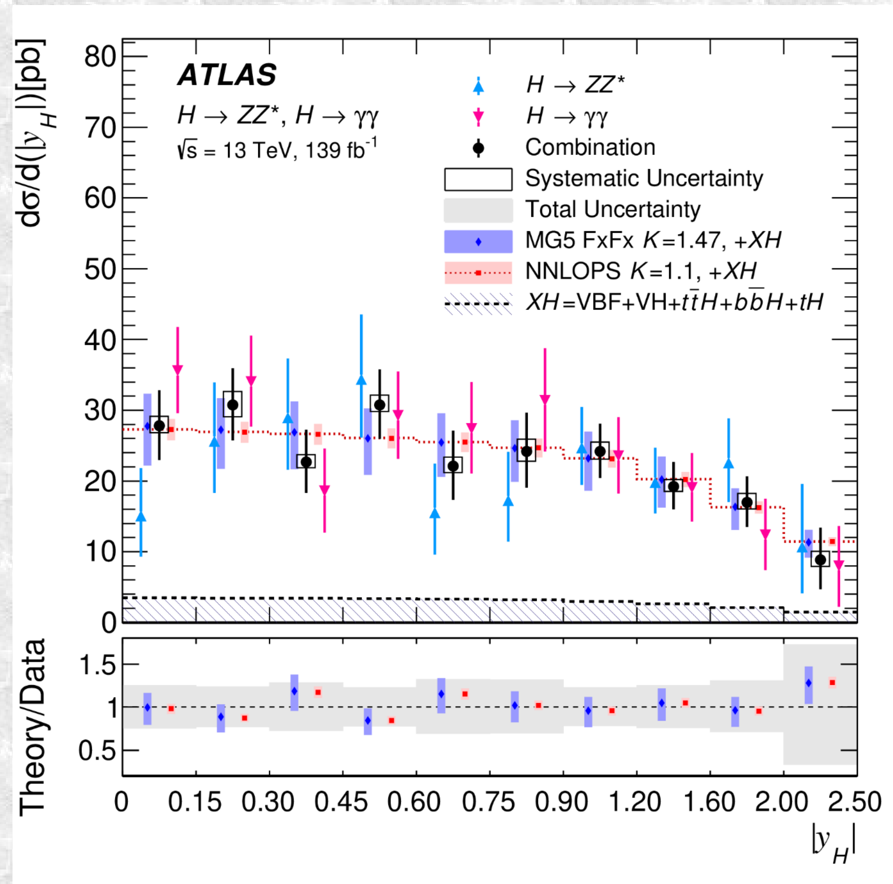


		Relative impact of the syst
Source	Type	Nonresonant analysis HH
Experimental		
Photon energy resolution	Norm. + Shape	0.4
Jet energy scale and resolution	Normalization	< 0.2
Flavor tagging	Normalization	< 0.2
Theoretical		
Factorization and renormalization scale	Normalization	0.3
Parton showering model	Norm. + Shape	0.6
Heavy-flavor content	Normalization	0.3
$\mathcal{B}(H \to \gamma\gamma, b\bar{b})$	Normalization	0.2
Spurious signal	Normalization	3.0

Differential distributions

HIGG-2022-04

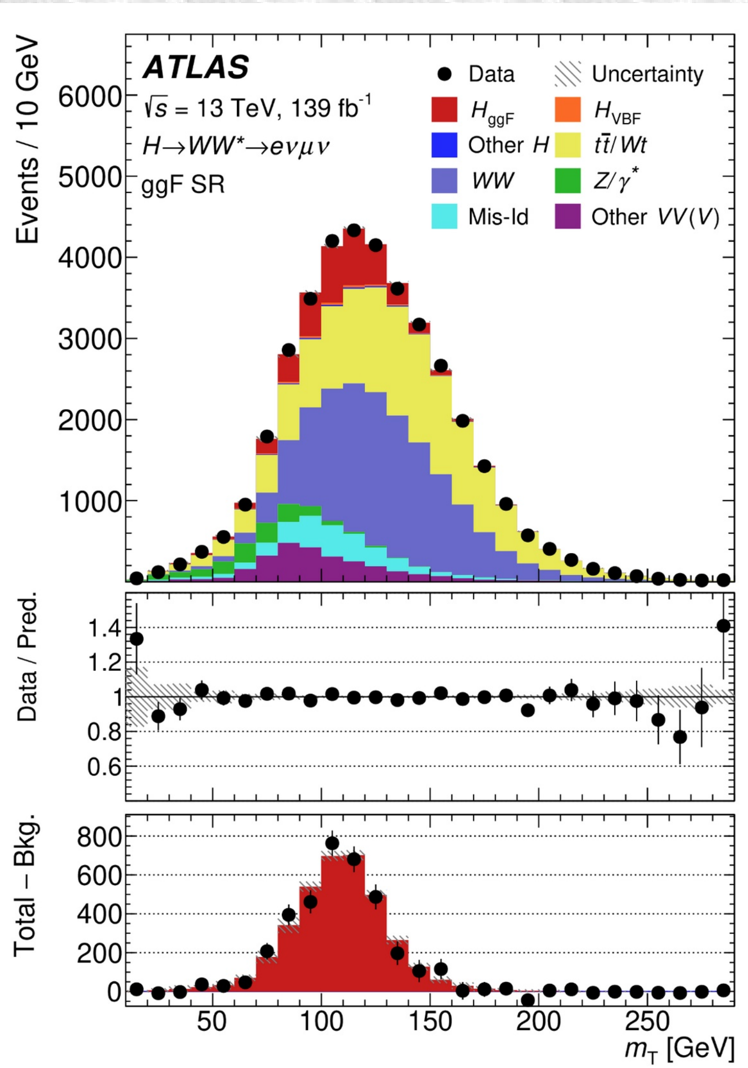




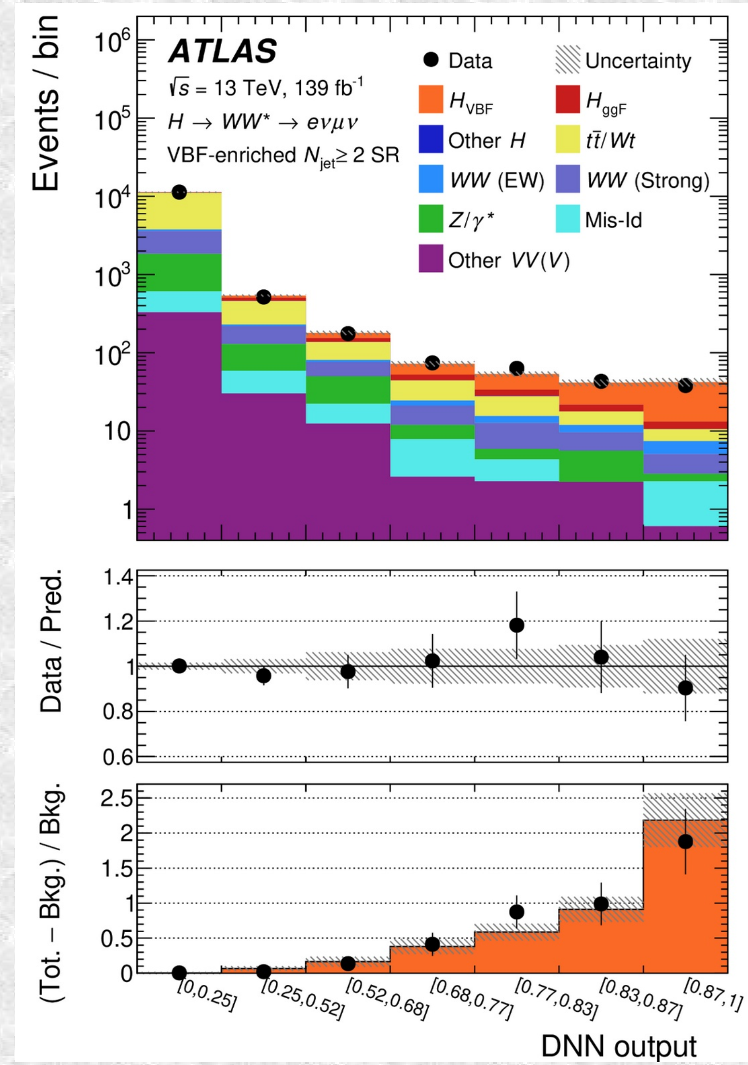
- Clean γγ and ZZ modes can access H p_T, η
- Shape sensitive to b, c components of ggF loop:
  $-8.6<\kappa_c<17.3$ (κ_c fixed to 1)

ggF & VBF H to WW

HIGG-2021-20



- ggF (left) and VBF (right)
- 4200 ggF signal events
- VBF purity excellent



- Measure: ggF: $\mu=1.15^{+0.14}_{-0.13}$ VBF: $\mu=0.93^{+0.23}_{-0.20}$