Highlight on recent ATLAS results
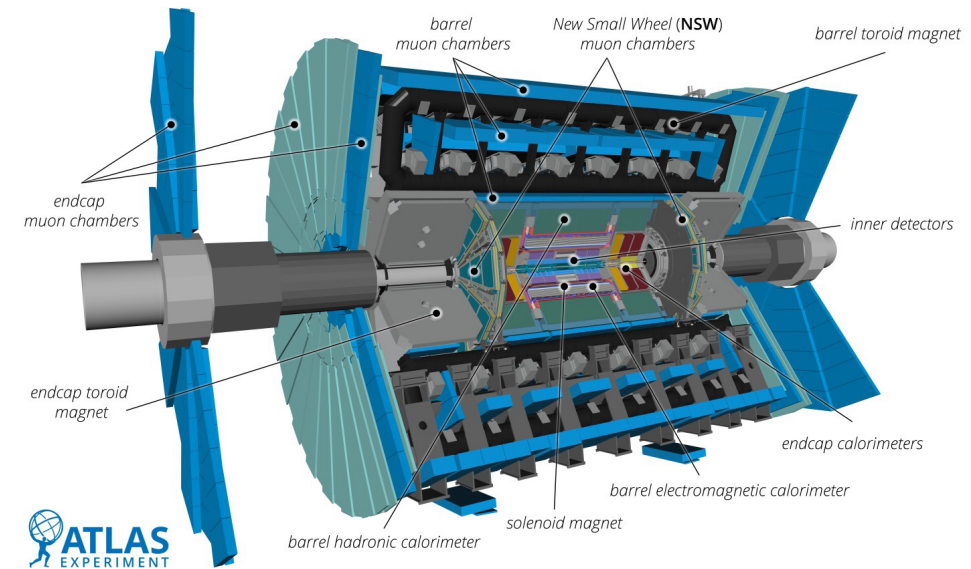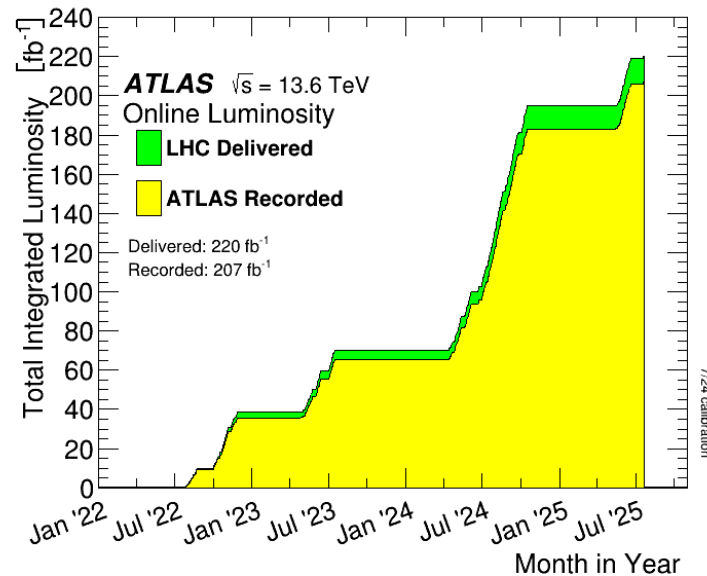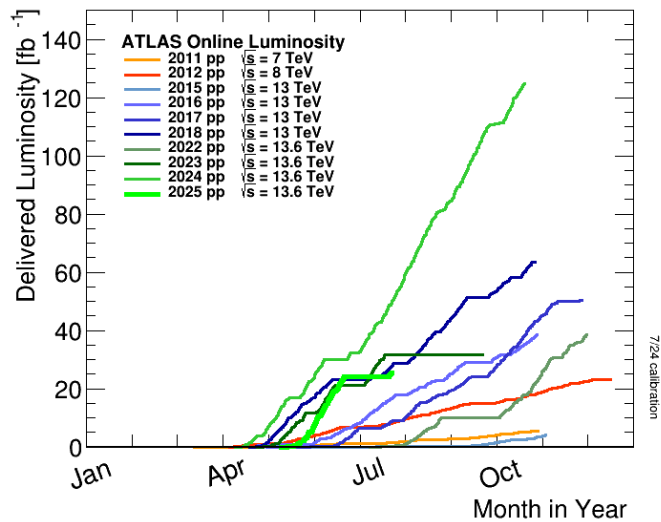
Jun Guo

**Shanghai Jiao Tong University**

On behalf of the ATLAS Collaboration

ATLAS data


- Smooth LHC and ATLAS running recorded ~207 fb^{-1} in Run3

- ATLAS has already published > 1400 papers

- Great amounts of work have been dedicated to reconstruction, calibration and performance study

- Physics analyses are carried out from different perspectives: new channels, new theoretical motivation, …

- Run3 data has already been analyzed !
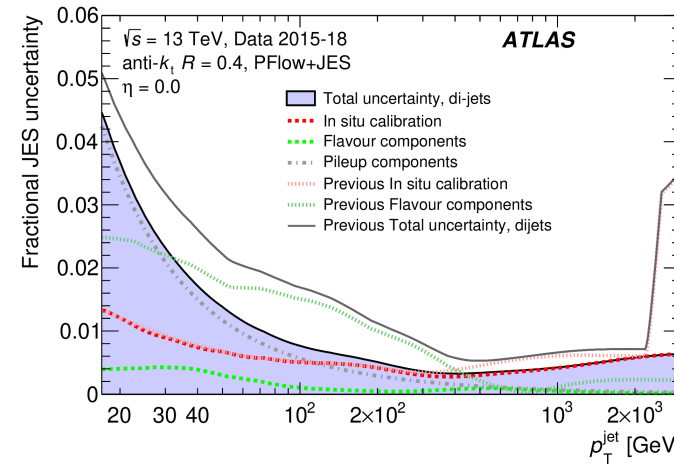
Excellent calibration & performance
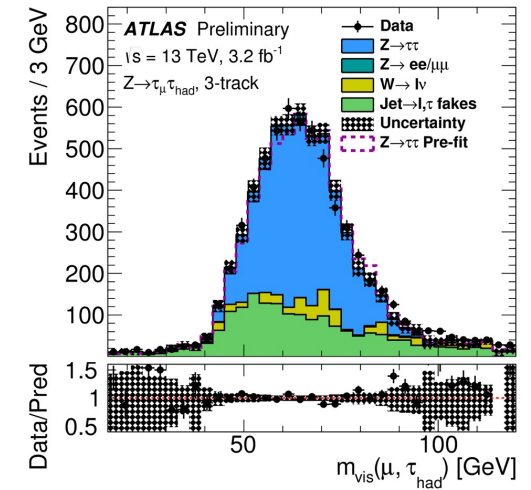

JINST 19 (2024)
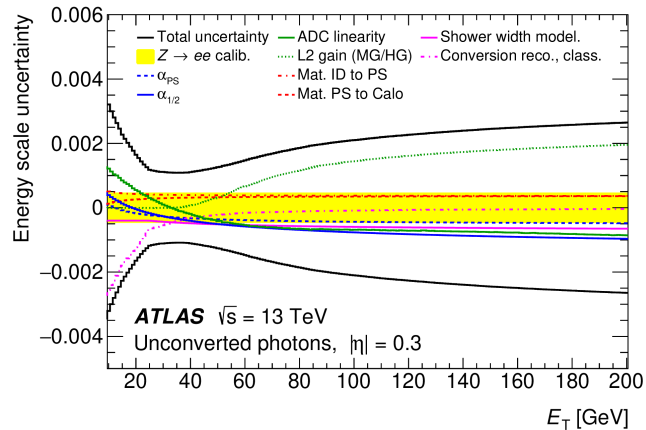
Eur. Phys J. C 83 (2023) 686
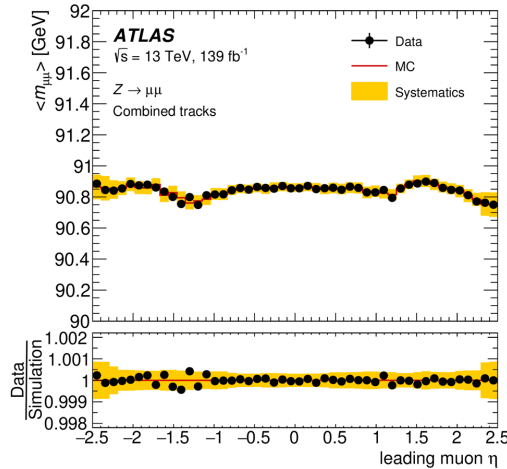

2407.15627 Subm. EPJC

ATLAS-CONF-2017-029

➤ The excellent performance requires **excellent calibrations**:

  ➤ γ: energy calibration **0.2%** at 60 GeV, e energy calibration **0.05%** at 45 GeV

  ➤ μ: energy scale calibration at **0.1-0.05%**

  ➤ Jet: energy calibration scale at **(better than) 1%** level for p_T above 60 GeV

  ➤ τ: energy scale calibrated at ~2%(3%)

Jet flavor tag:
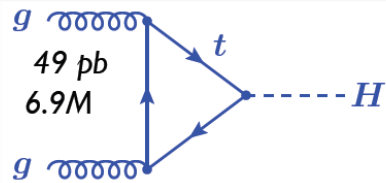
arXiv:2505.19689 Sub. to Nature Communications

- Traditional approach (**DL1r**): track-based low-level quantities followed by high-level multivariate classifier

- New approach (**GN2**): direct process trk and jet info, additionally reconstructing jet internal structure

3
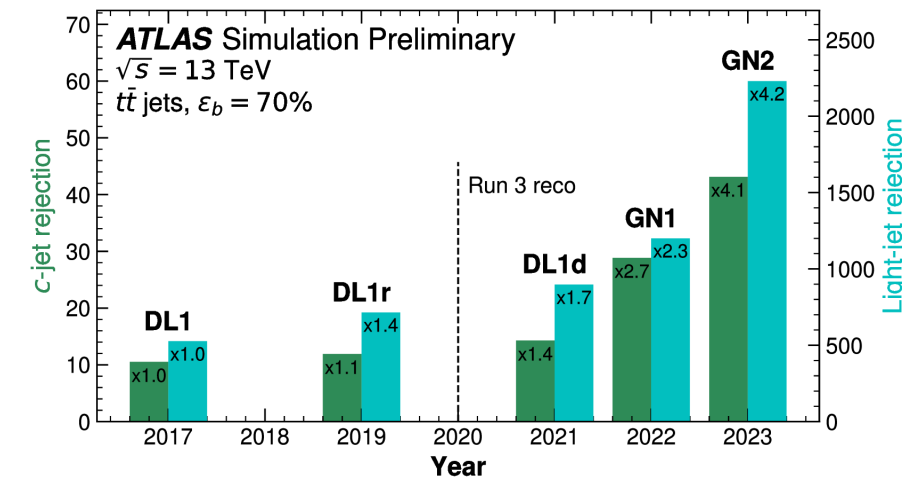
Higgs Physics

Decreasing cross-section

**gluon fusion
ggH: 86%**

49 pb
6.9M
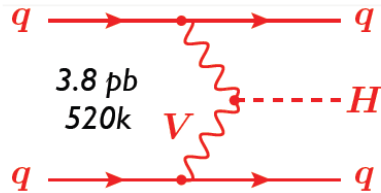
**vector boson
fusion (VBF): 6.5%**

3.8 pb
520k
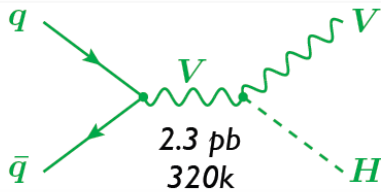
**W,Z associated
production
WH/ZH: 4%**

2.3 pb
320k
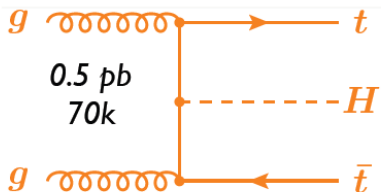
$t\bar{t}H$ **associated
production: 1%**

0.5 pb
70k

σ [pb]
#Higgs produced during
Run-2

H→ff

H→VV

H→γγ
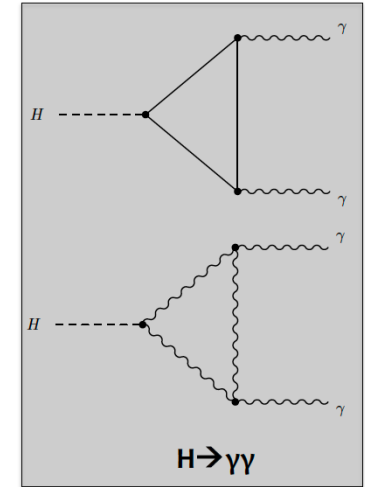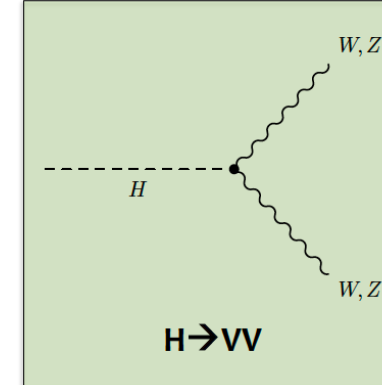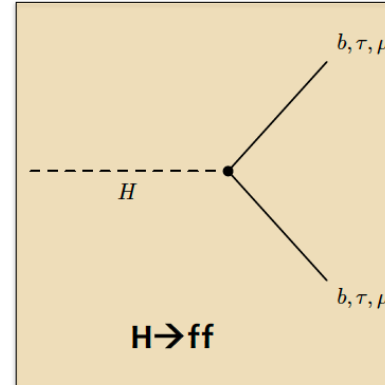
- **LHC is a Higgs factory**

- **~8 million Higgs bosons** produced by LHC during Run-2 **per experiment**

- Over a decade of measurements including all productions & decay => Higgs boson precision probe!

- The **LHC Run2 and Run3** data used to fully characterize the Higgs boson
  - Run2: 140 fb^{-1}; Run3: 60fb^{-1}(2022-2023), 100fb^{-1}(2024)

4

HH->bbγγ

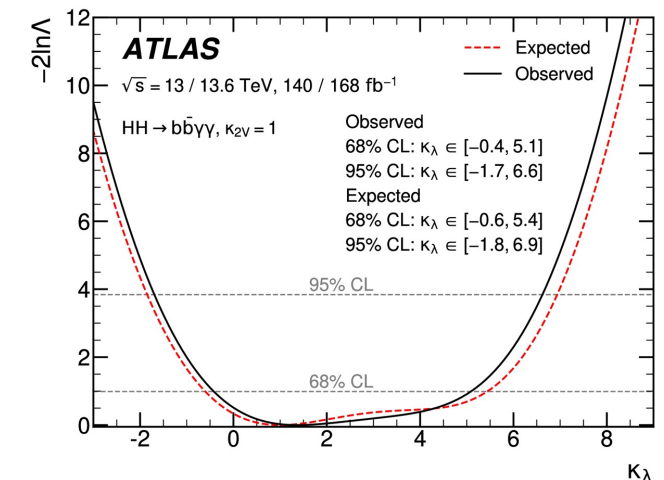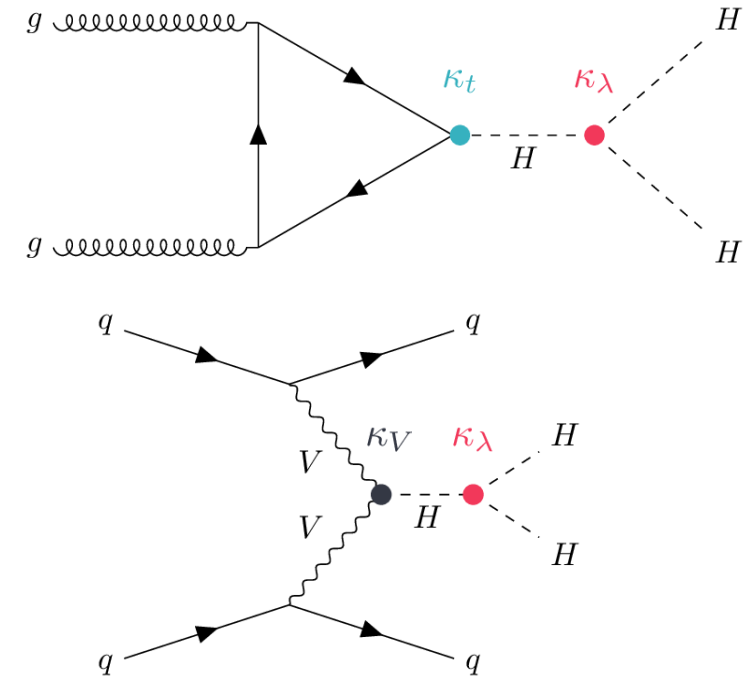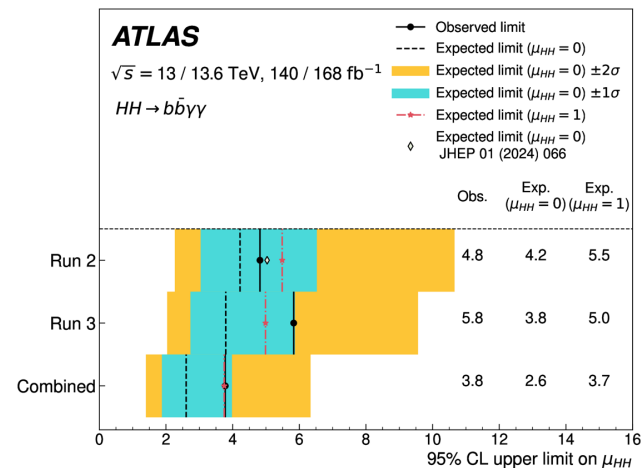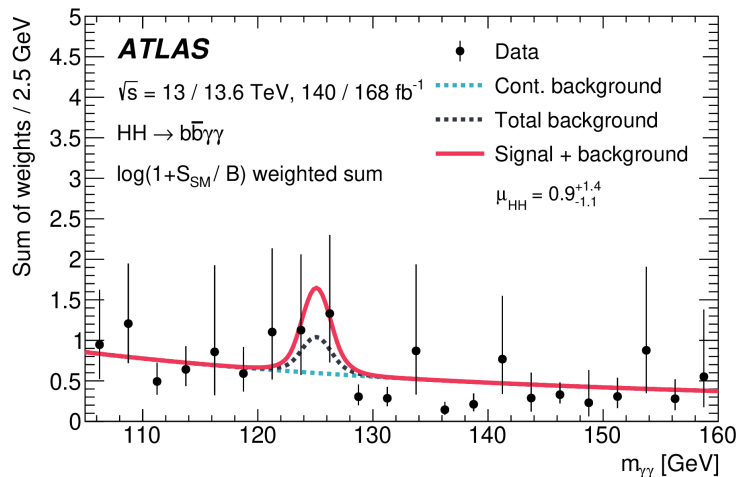- Probe Higgs potential: self-coupling, …

- Significance improvements compared to Run2 result:
  - 20% from new b-tagging based on transformer neural network (GN2)
  - 5% from kinematic fit
  - 50% from additional data
  - 10% from category optimization

- Observed $\mu_{HH} = 0.9^{+1.3}_{-1.0}$ (stat.) $^{+0.6}_{-0.5}$ (syst.) ;

- Significance: 0.8σ(obs)/1.0σ (exp)

- $-1.7 < \kappa_\lambda < 6.6$ ($-1.8 < \kappa_\lambda < 6.9$ expected) @95% C.L.

Run 2+Run 3(up to 2024): 140 fb^{-1} , 168 fb^{-1}

H->Zγ
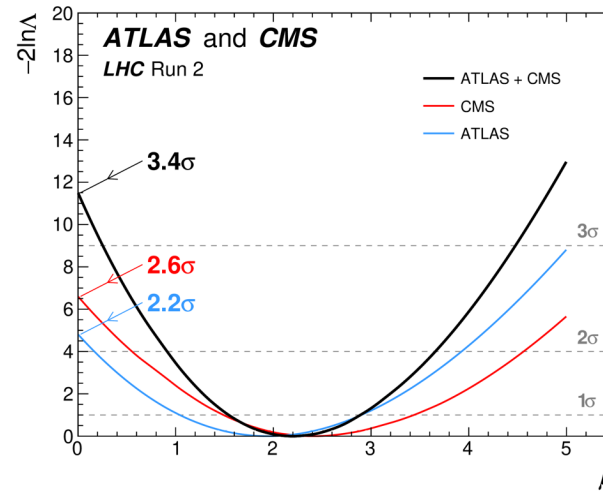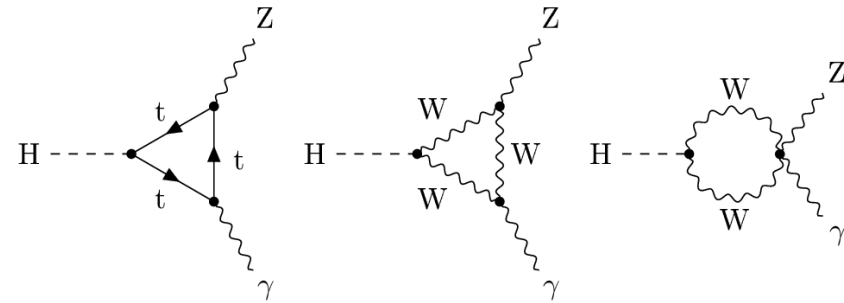
Run 2+Run 3(up to 2024): 140 fb^{-1} , 165 fb^{-1}

- BR(H->Zγ)/BR(H->γγ) is sensitive to new physics, via contributions in the loops

- Would complete the suite of H decay into gauge boson pairs (γγ, ZZ*, WW*)

- What is new in Run 3 in addition to higher E, xsect and more data:
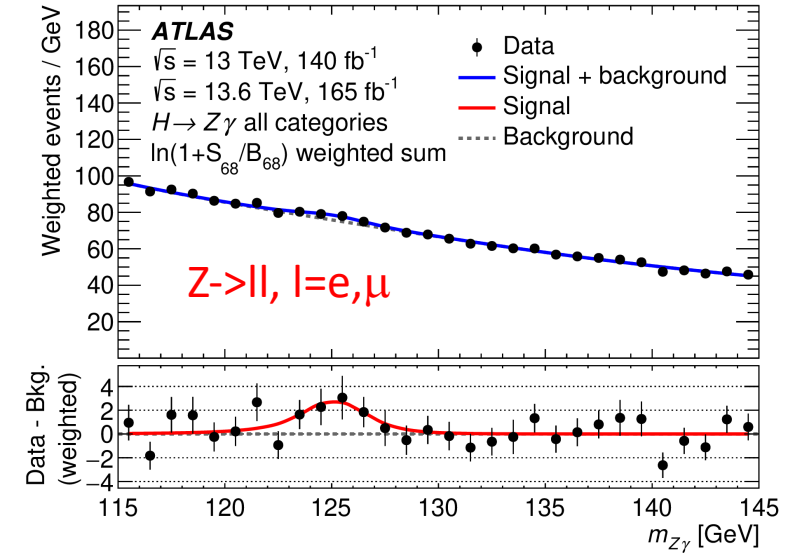 - Relaxed pT cut for muon and photon
  - 13 mutually exclusive categories (first time with multi-l's)
  - MVA (XGBoost), replacing previous cut-based selection

Run3: μ = 0.9$^{+0.7}_{-0.6}$, significance: 1.4σ(obs)/1.5σ(exp)

Run2+Run3: μ = 1.3$^{+0.6}_{-0.5}$, significance: 2.5σ(obs)/1.9σ(exp)

Sensitivity improved by 61% relative to Run2, 20% relative to ATLAS+CMS Run2 combination

6

H->μμ

- Opportunity to first observe H coupling to a second-generation fermion
  - Target ggF, VBF, VH, ttH production modes
- What is new in Run 3, apart from doubled statistics :
  - 5 billion NLO Drell-Yan MC sample
  - Improved mass resolution by H->μμ decay vertex fit
  - Inclusion of 2-lepton VH category, use of fully hadronic ttH decay, …
- 23 categories based on topological and kinematic info
- Run3: μ = 1.6±0.6, significance: 2.8σ(obs)/1.8σ(exp)
- Run2+Run3: μ = 1.4±0.4, significance: 3.4σ(obs)/2.5σ(exp)

Evidence of Yukawa coupling to 2nd-generation is seen !

Run 2+Run 3(up to 2024), 140 fb^{-1} , 165 fb^{-1}
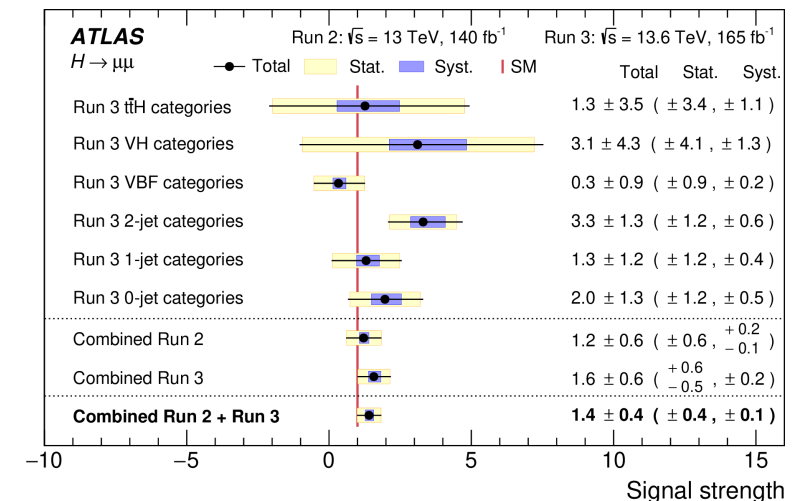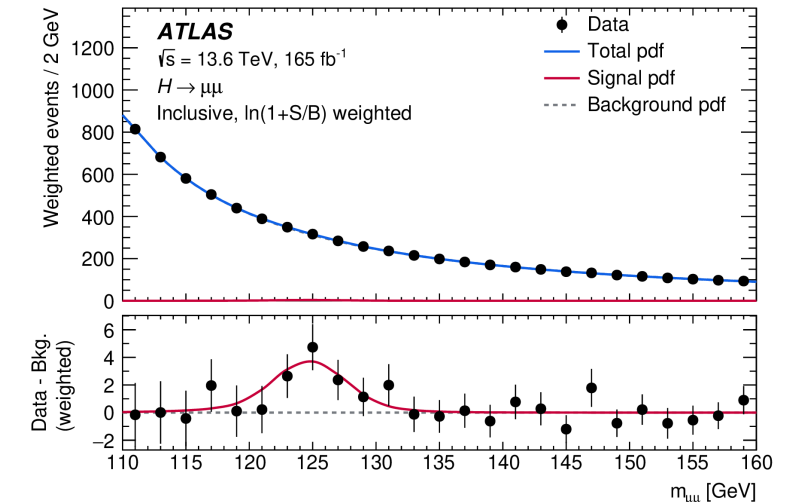
Standard Model
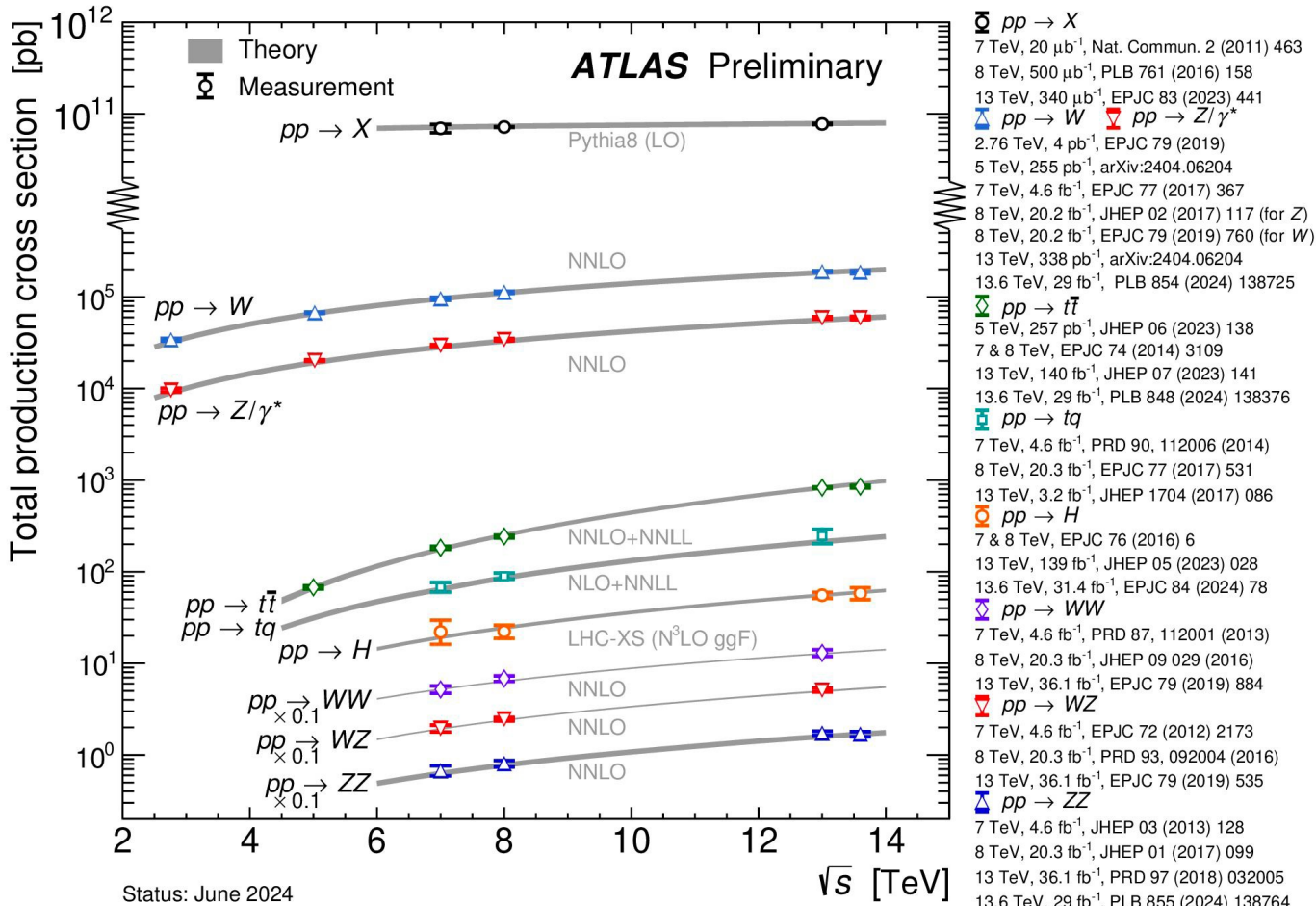
- Rich program at the LHC covers many aspects of the Standard Model
  - Non-perturbative & Perturbative QCD
  - Tests/extraction of strong coupling constant and proton structure
  - Precision measurements of SM parameters (m_W, m_Z, $\sin^2$theta$_W$, m_{top})
  - Measurements of rare processes and differential cross sections at high energies to probe vector boson and top couplings

- Precision measurements of the SM parameters offer indirect searches for new physics

W$^\pm$Z cross section

- Sensitive to gauge boson self-interaction, related to non-Abelian structure of EW interaction
  - Directly probe TGC, in particular WWZ gauge coupling
  - Explore additional sources of CP violation
  - Constrain anomalous interactions
- 15 observables are compared with state-of-the-art predictions
- Measured inclusive cross-section in the fiducial region:

$$\sigma^{\text{fid.}}_{W^\pm Z \to \ell' \nu \ell \ell} = 60.7 \pm 0.5 \,(\text{stat.}) \pm 1.4 \,(\text{exp. syst.}) \pm 1.8 \,(\text{mod. syst.}) \pm 0.6 \,(\text{lumi.}) \text{ fb}$$

- Consistent with NNLO QCD × EW MATRIX prediction: 61.3 ± 1.3 (scale) fb


9
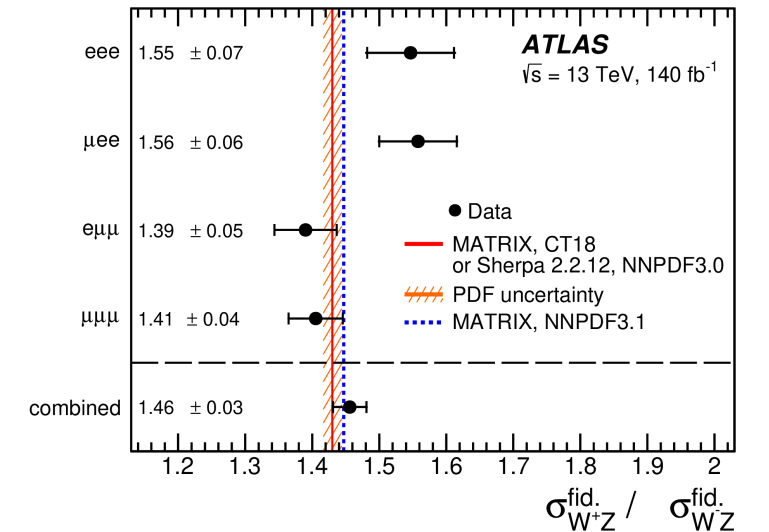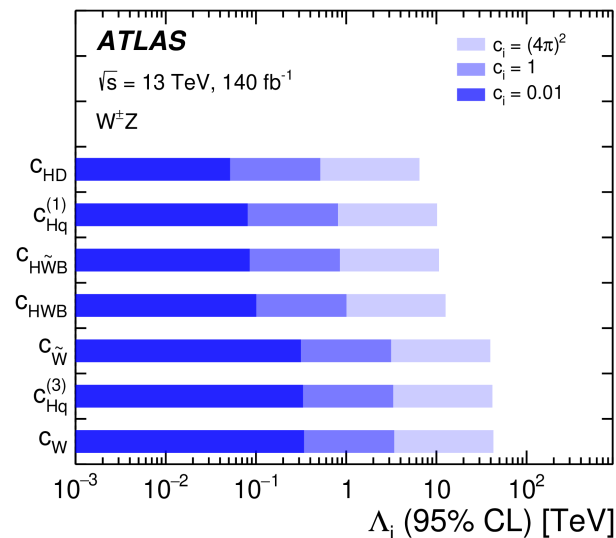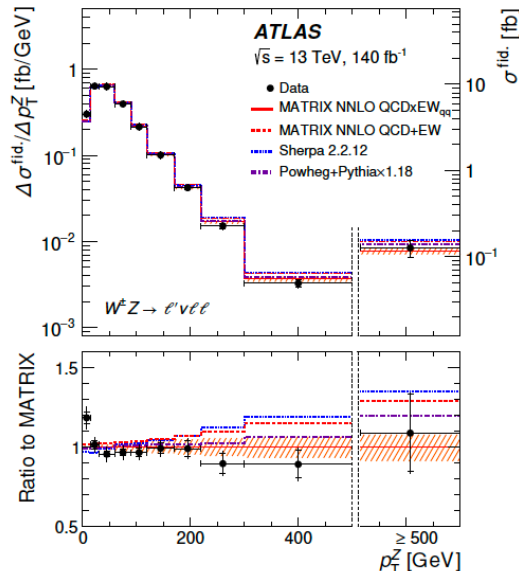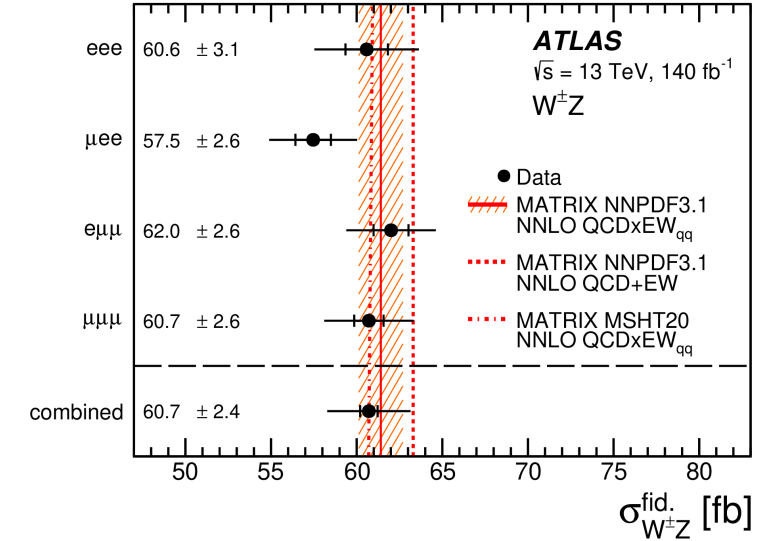
ttbar near threshold

- In low kinematic regime, ttbar are largely in colour-singlet and maximally entangled.

- Formation of colour-singlet, *S*-wave, quasi-bound-states with masses just below the production threshold
  - Local enhancement with width well below experimental resolution
  - Stringently probe QCD in non-relativistic regime (NRQCD)

- Rely one m_{tt} and two angular variables, sensitive to spin-correlations:
  - 9 SRs based on c_{hel} and c_{han}

- Combine pQCD tt MC and NRQCD, with the normalization of NRQCD as a free floating parameter in fits

- X-section(tt_{NRQCD})= 9.0 ± 1.3 pb, significance: **7.7σ(obs)/5.7σ(exp)** -> **NRQCD is observed !**
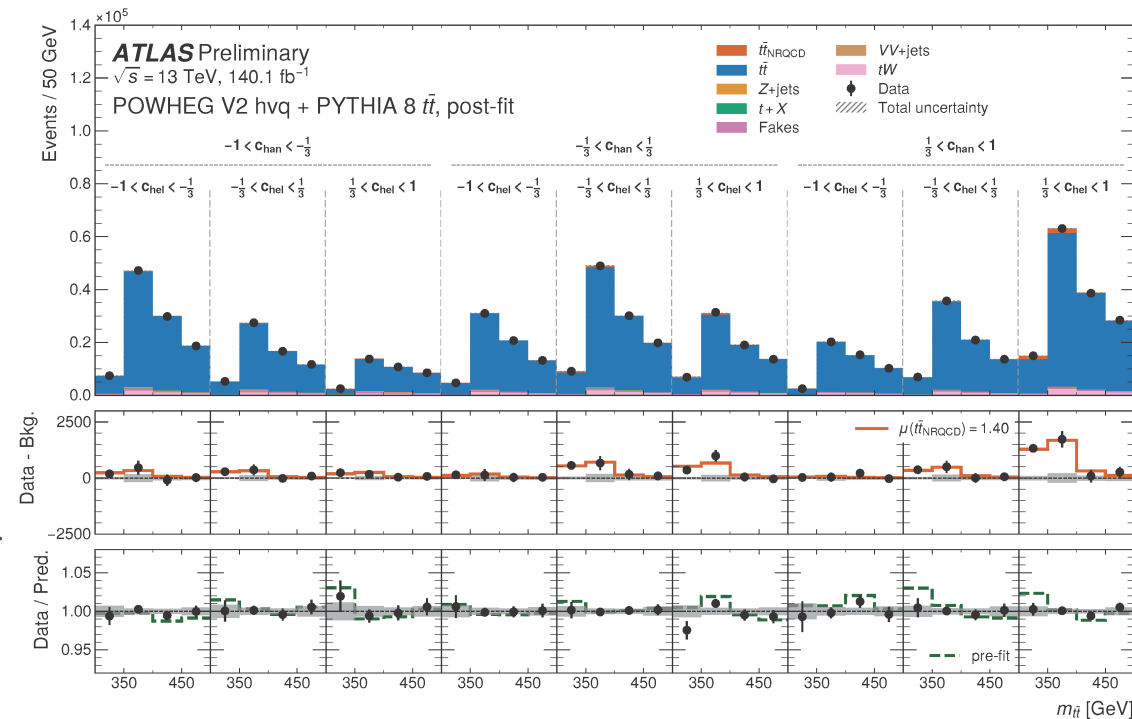
➢ **Next**: Further characterization of the excess and quantify off-shell top decays, resummation, …

BSM searches
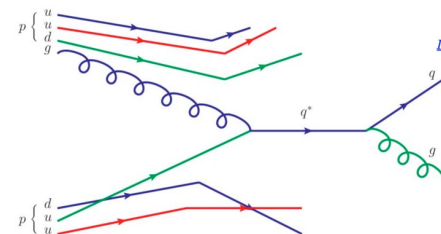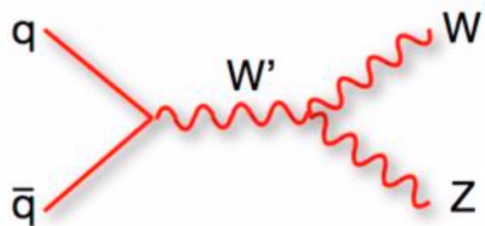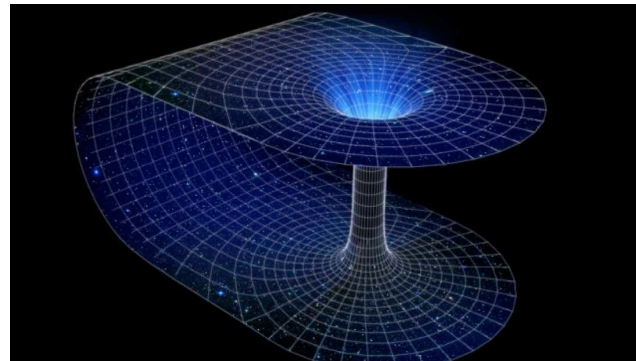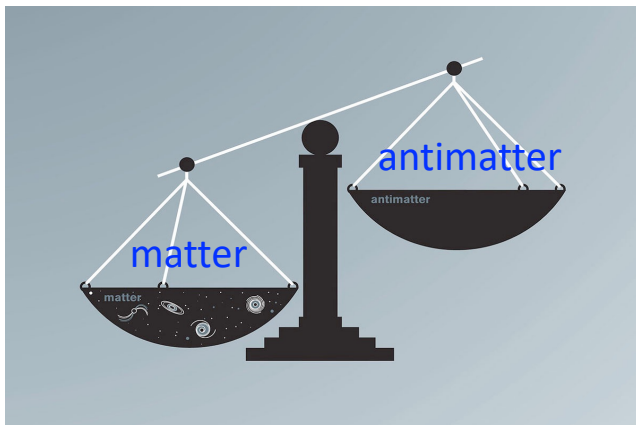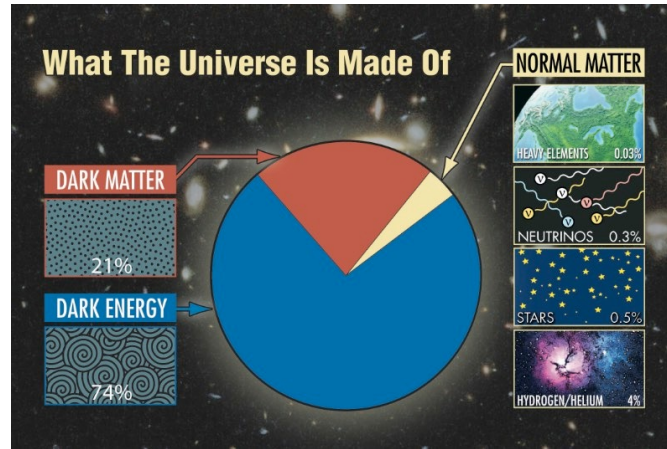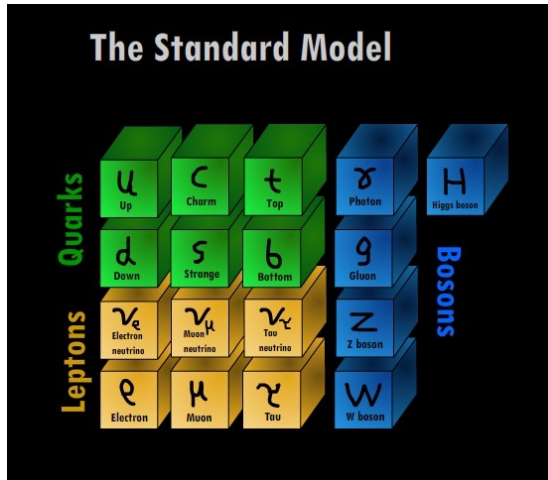
- Tremendous success has been achieved by the SM. There are, however, too many free parameters. And some fundamental questions remain unanswered.

  - Why 3 generations of quarks & leptons

  - Hierarchy problem

  - Dark matter/energy

  - …

- Many extensions to the SM aim to solve these problems, which generally predict new phenomena: new resonance, non-resonance, …

  - HVT, Compositeness, Extra dimensions, SUSY, …

  - Z', W', Leptoquarks, long-lived particle, …

Leptoquarks (LQ)
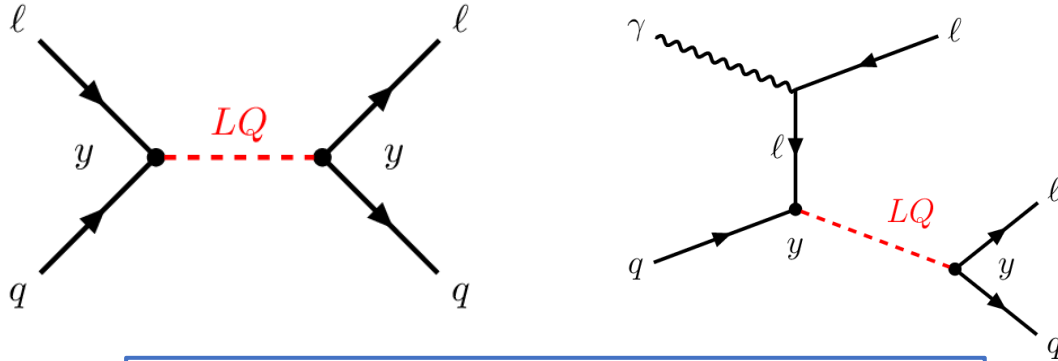
Run 2+Run 3(up to 2023): 140 fb⁻¹ , 55 fb⁻¹
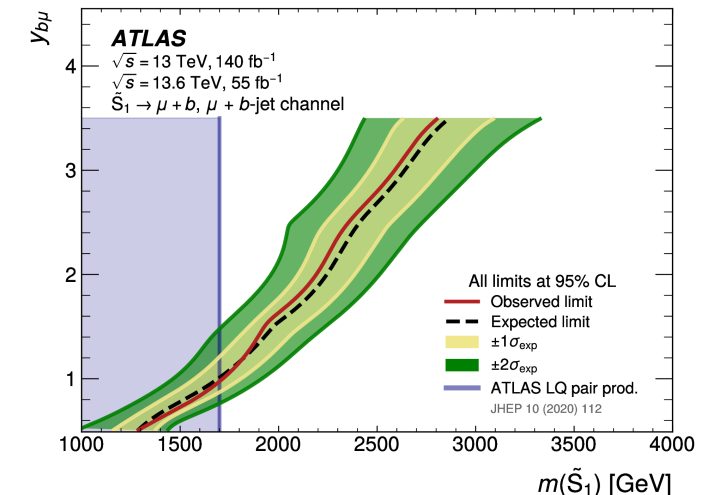
- **First LHC search for resonance LQ coupling to e's & μ's**
  - Exploit the lepton content of the proton
  - State-of-the-art NLO of lepton parton PDFs

- Four orthogonal channels—e + light-jet, μ + light-jet, e + b-jet, and μ + b-jet: each has **1L** and **2L** regions

- Constraints on scalar LQ improve at large coupling:
  - e+light-jet: 0.25
  - μ+light-jet: 0.7
  - Other channels: >1

SH->bbγγ
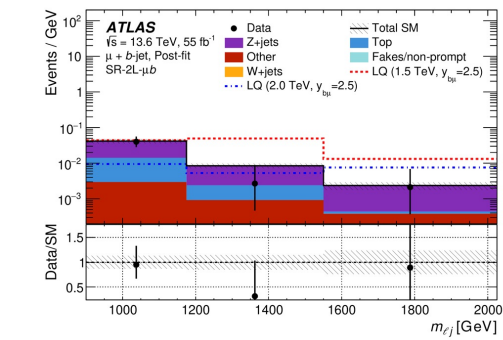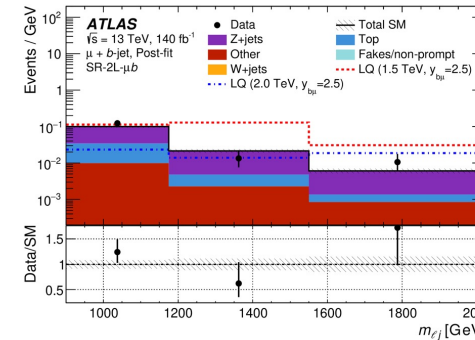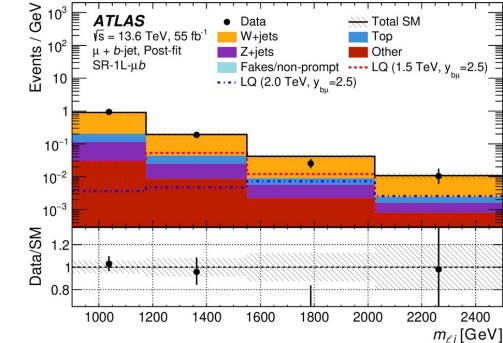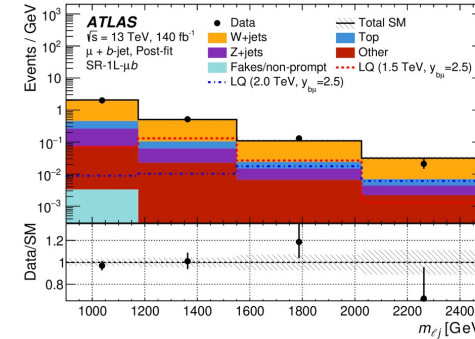
- Probe extended Higgs sector: small mixing between H and additional scalar bosons

- Main changes compared to Run 2 result: JHEP 11 (2024) 047

  - Improved reconstruction, identification and calibration

  - Retrain discriminating variables and improved SR definition
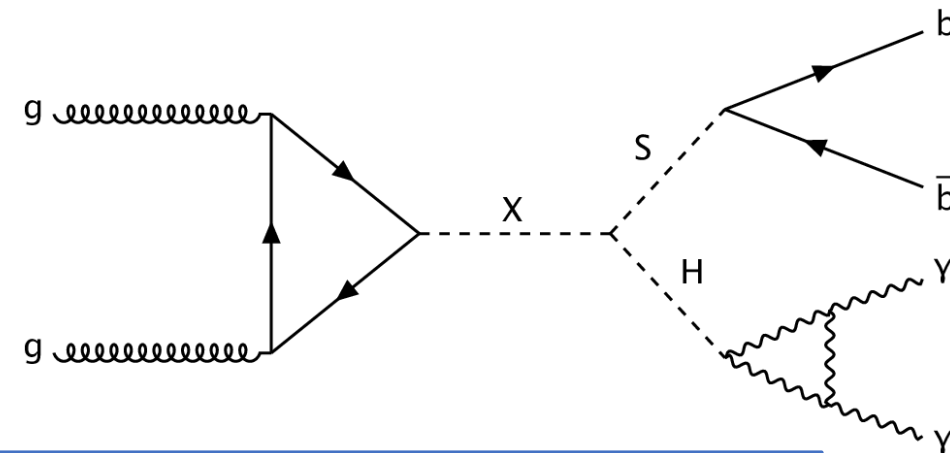
- Sensitivity improved by 15-73%: more effective in low-mass region

  - Run3 data contributes 9-30%

- Joint Ph.D between Marseille U.-CPPM and SJTU through CSC: **Xi Wang**

  - A main analyzer on Run2 SH paper

  - Co-supervisors: Emmanuel Monnier; Elisabeth Petit; Jun Guo

Run 2+Run 3(up to 2023), 140 fb⁻¹ , 58.6 fb⁻¹
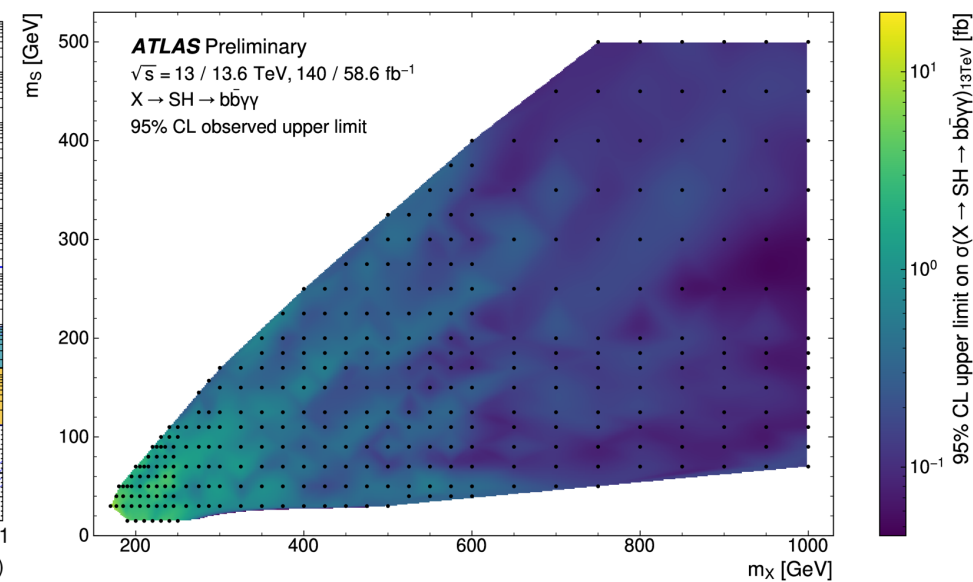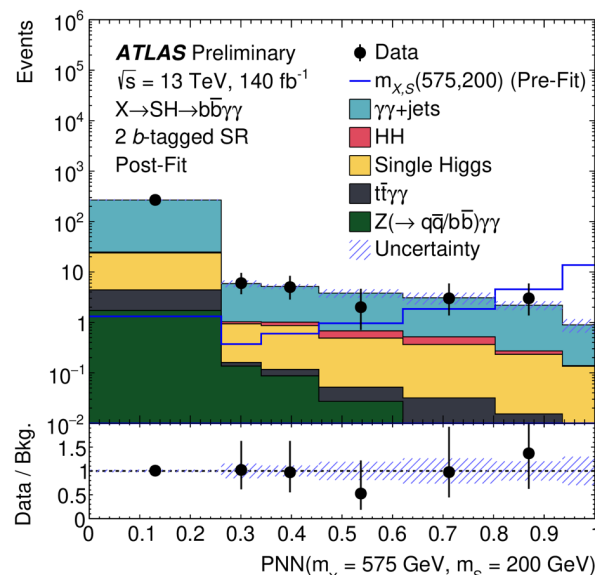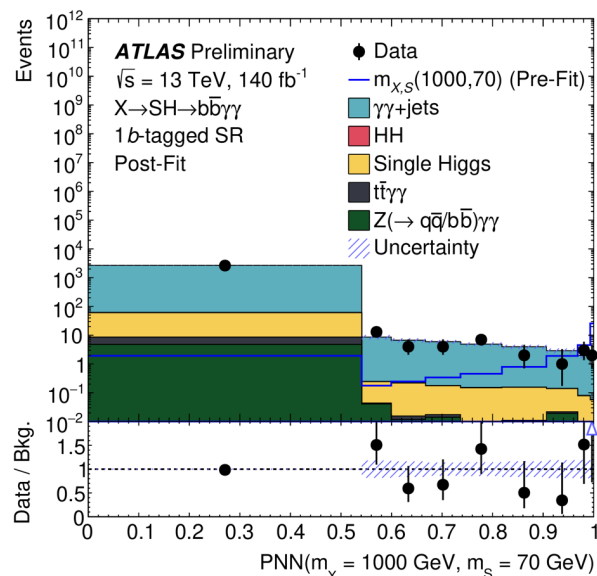
Summary & Next

- Relentless efforts have been made by ATLAS to explore the potential of LHC in advancing our knowledge about nature, productive with excellent results covering different aspects
  - High precision achieving in measuring Higgs, EW, Top, …
  - New scenarios and higher mass are probed in BSM search

- Phase II upgrade is undergoing to make the detector keep up with the upcoming HL-LHC running
  - 200 interactions/bunch crossing to reach 3 ab^{-1}

- More data (Run3, HL-LHC)and new analyzing techniques will shed more light on the way forward
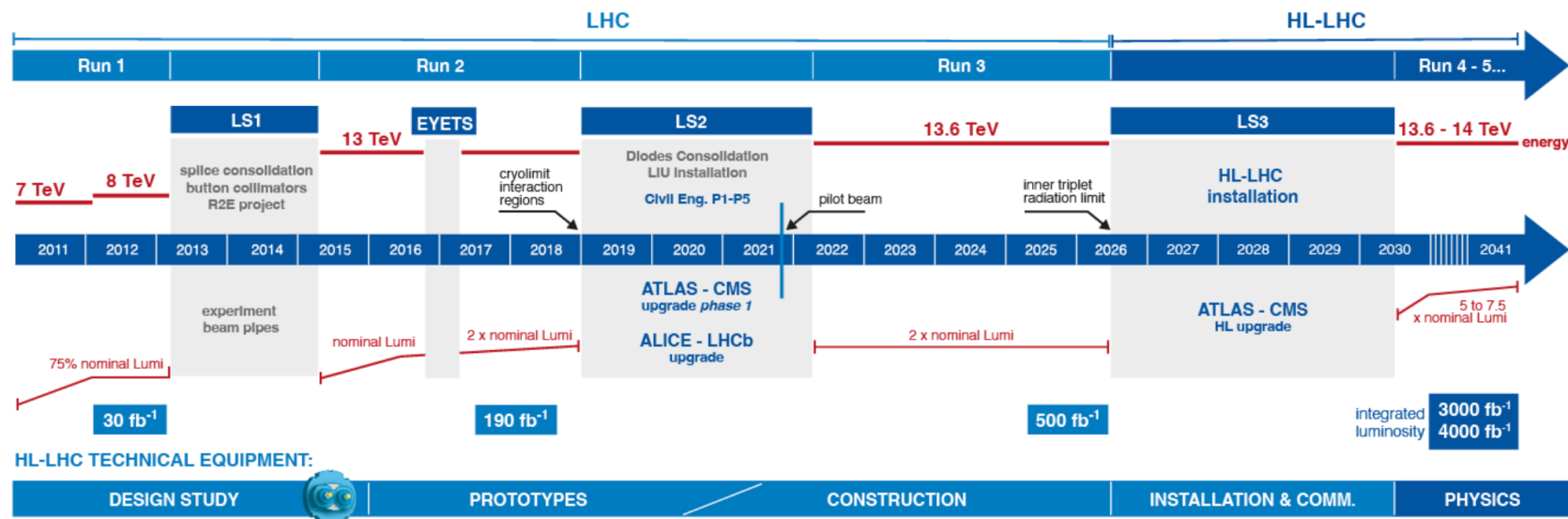
Backup

SUSY tau+X

Run 2+Run 3(up to 2023), 140 fb^{-1} , 51.8 fb^{-1}
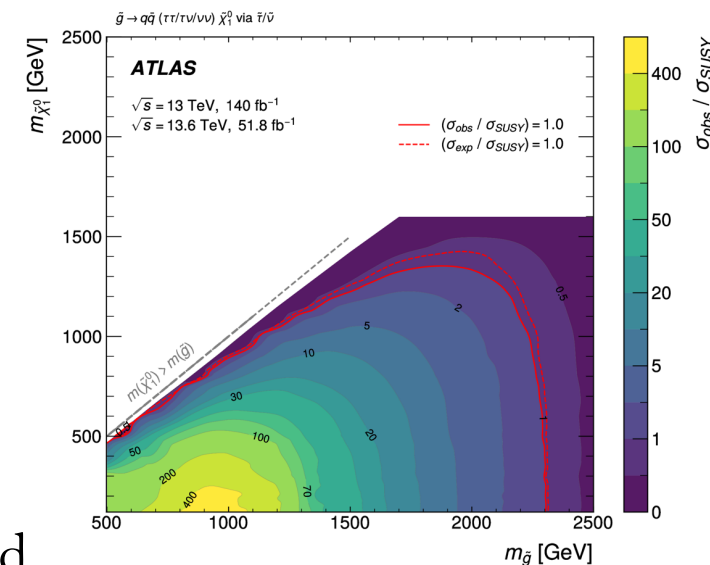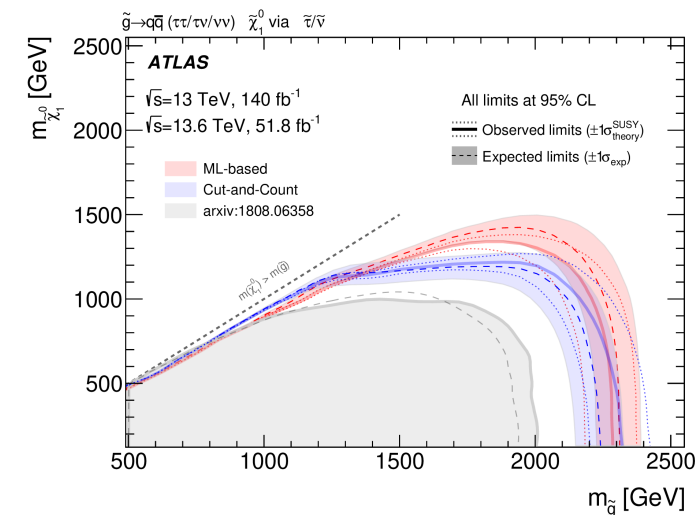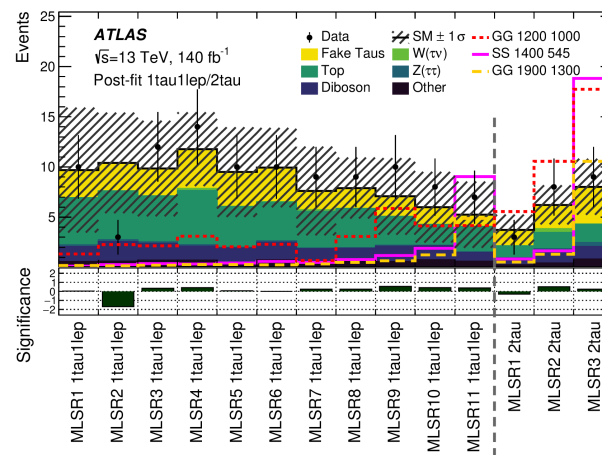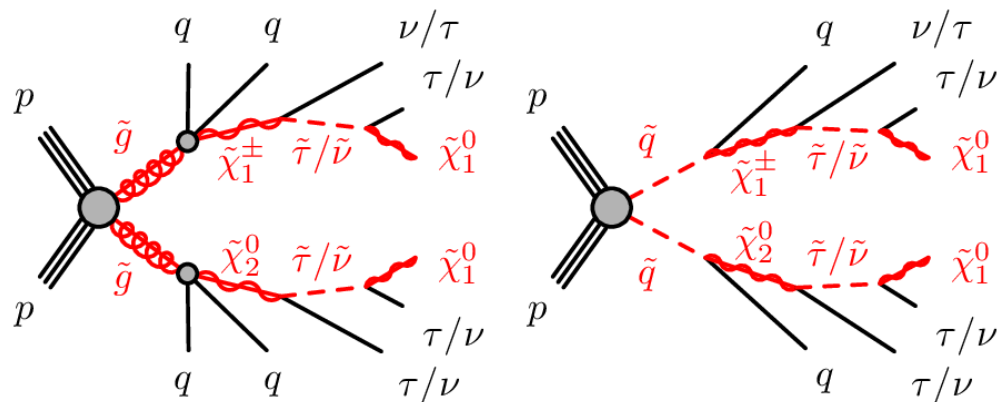
- A natural solution to the hierarchy problem

- Target pair-production of gluino and squark, in 3 channels depending on number of hadronic τ's: 1TAU0LEP; 1TAU1LEP; 2TAU

- Two strategies: cut-and-count; machine learning

- Improvements: enhanced calibration and identification algorithms, data sample, ML

- Gluino masses below 2.25 TeV and squark masses up to 1.7 TeV are excluded.

Phase II upgrade

1% luminosity accuracy
New and upgraded forward
and luminosity detectors

ATL-UPGRADE-PUB-2025-001/

Improve trigger performance/rate:
more physics despite more PU → L0 trigger at 1 MHz, EF 10kHz

Trigger & DAQ upgrades

Improve muon trigger coverage,
electronics and performance

New muon
chambers &
electronics

30ps time resolution per track
Improve PU rejection in forward region

New High
Granularity
Timing Detector
(HGTD)

Full granularity data accessible at L1
trigger, increased rate capability

Calorimeter
electronics
upgrade

ATLAS
EXPERIMENT

New all silicon Inner Tracker (ITk)
Improve tracking performance: increased coverage,
reduced occupancy, better track p_T resolution