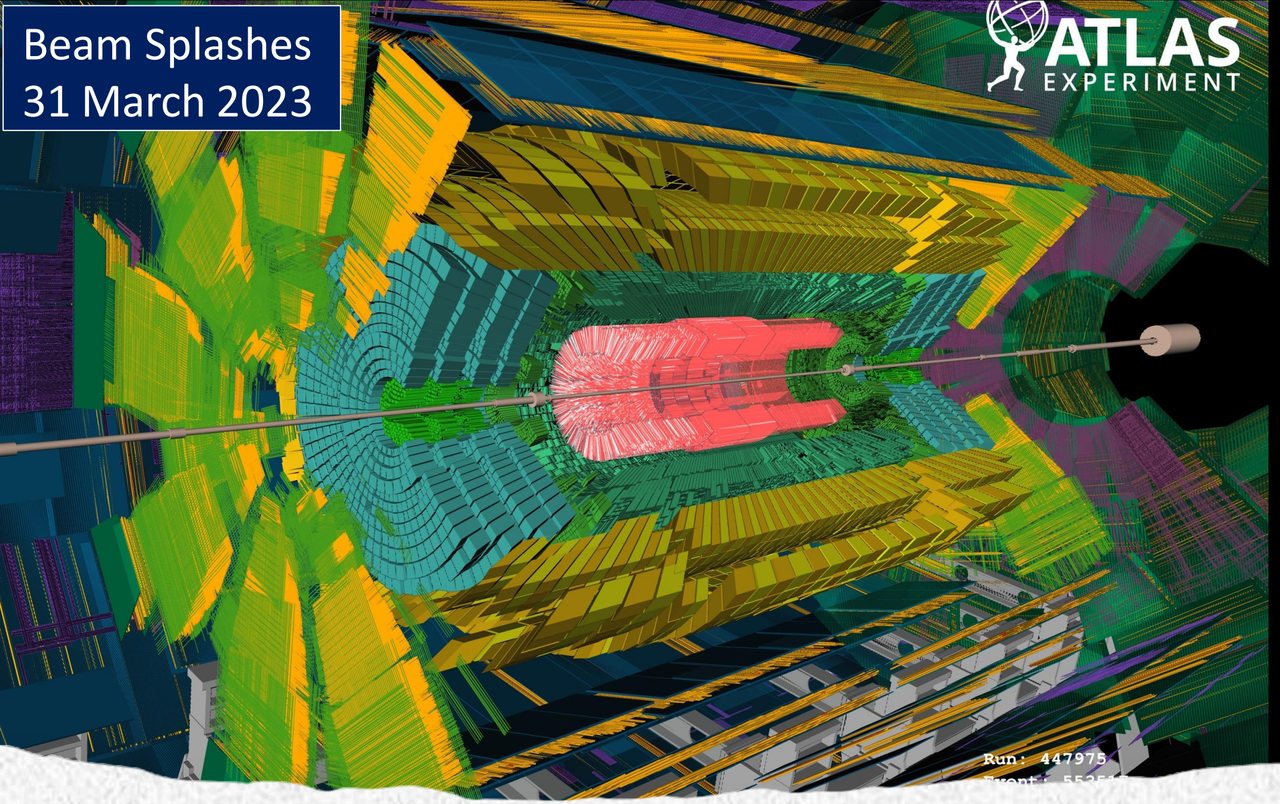
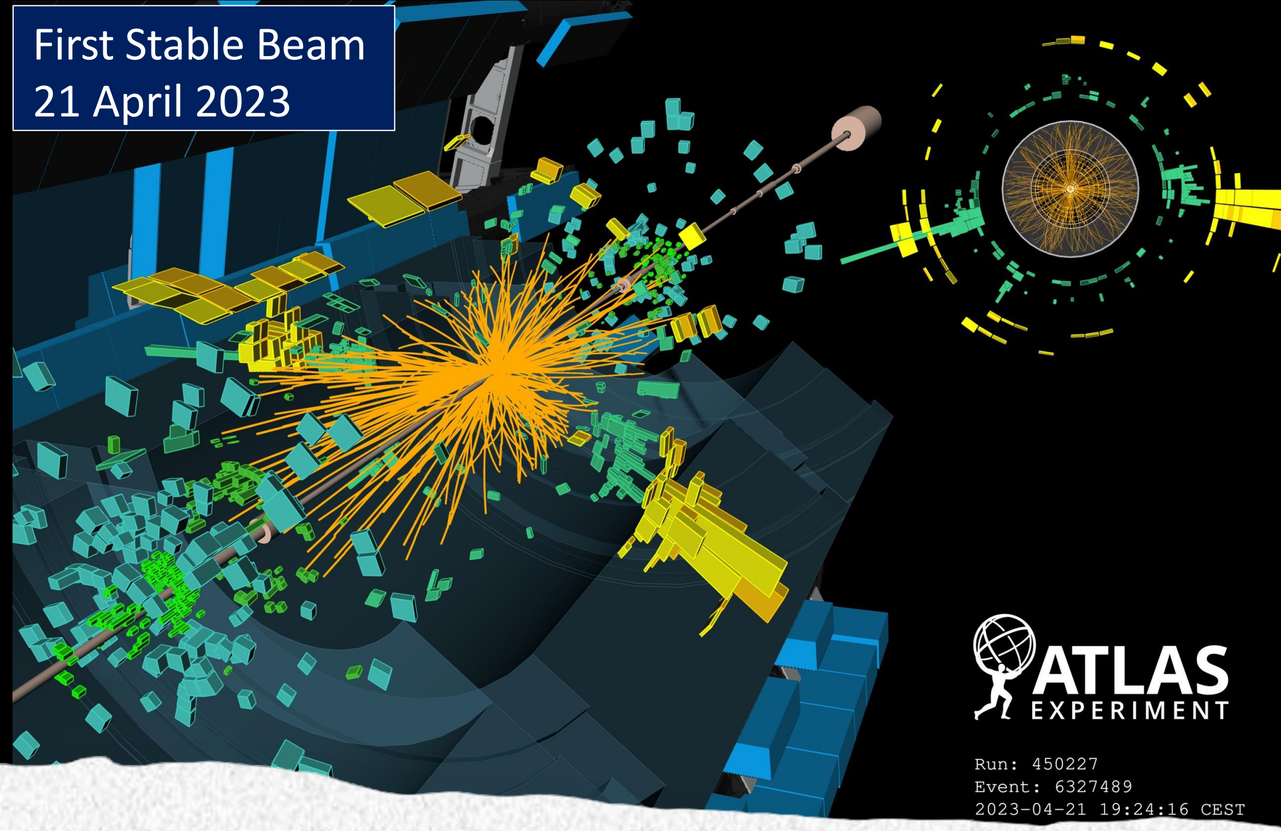
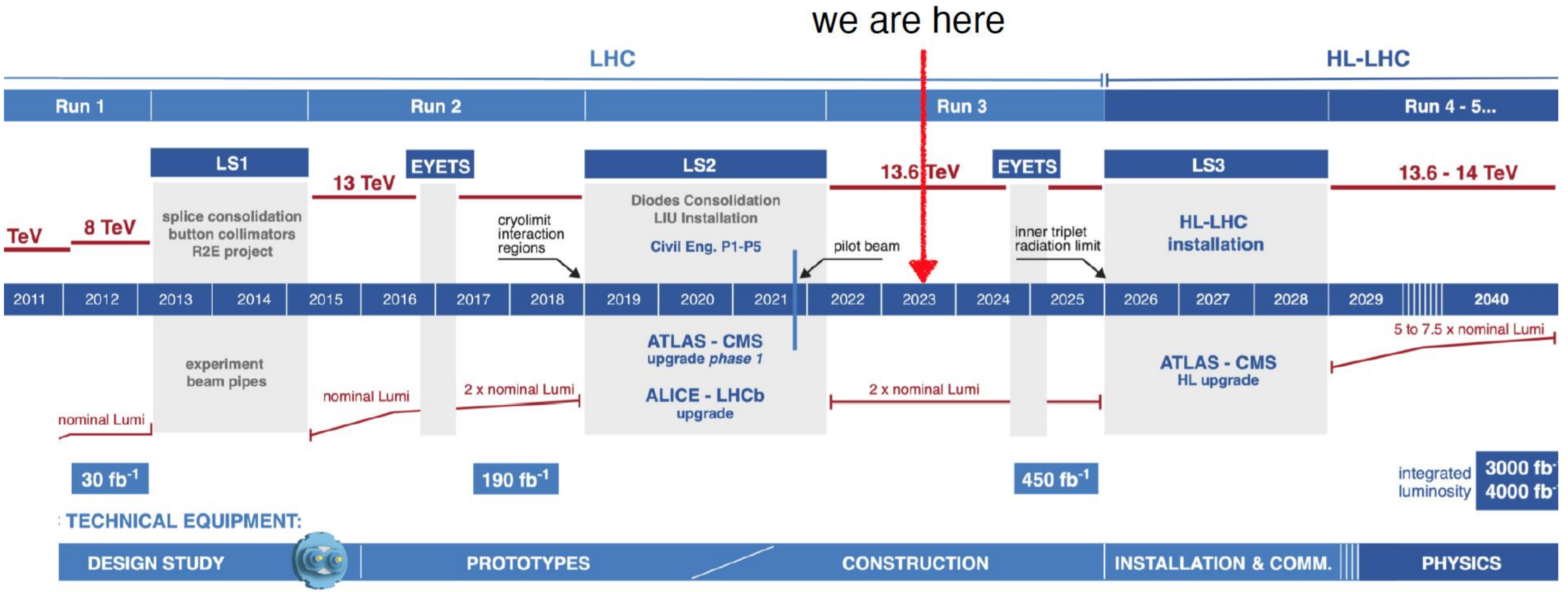




New ATLAS Results

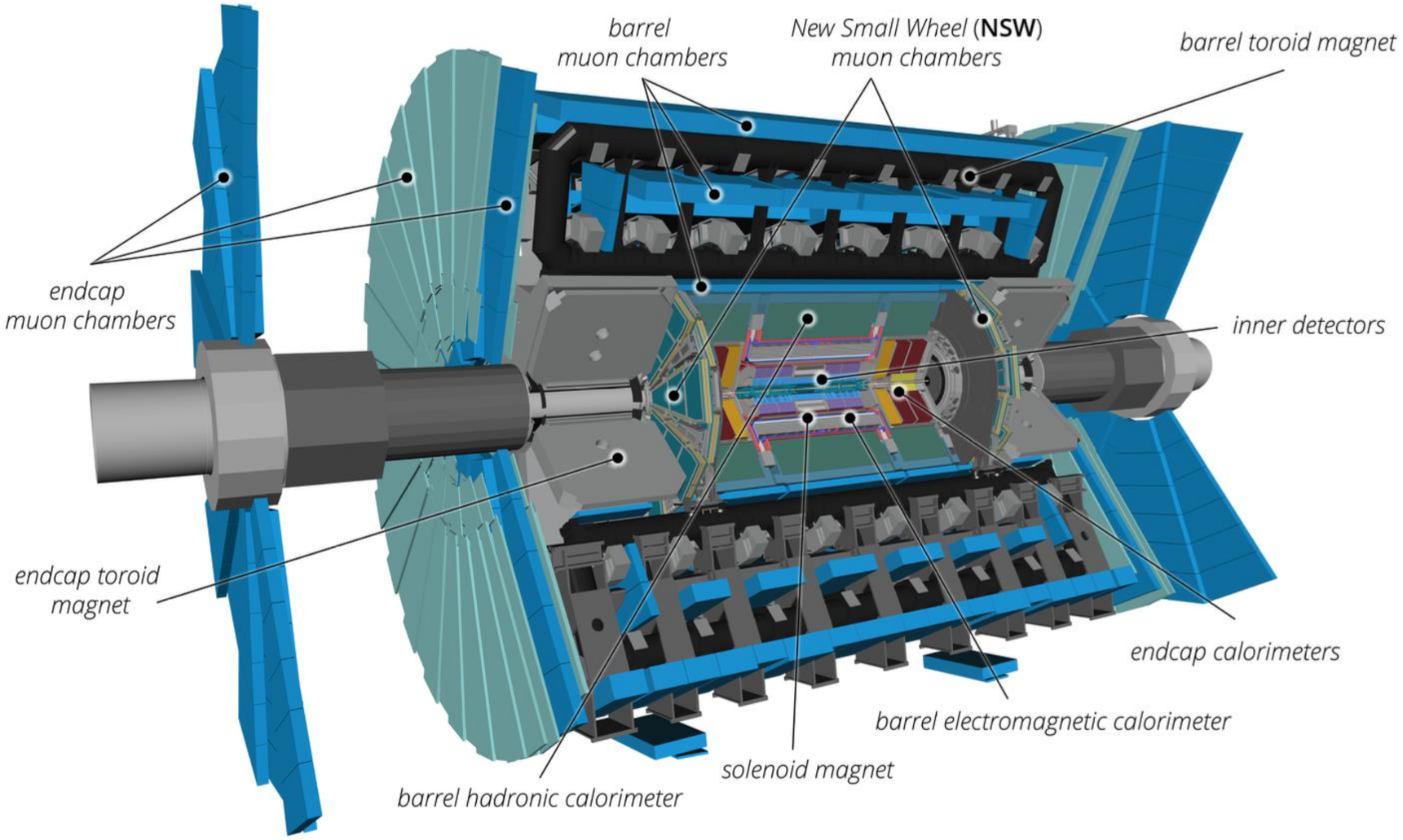
Marina Cobal, on behalf of the ATLAS Collaboration
University of Udine & INFN Trieste

LHC / HL-LHC Plan



arXiv:2305.16623

New ATLAS detector



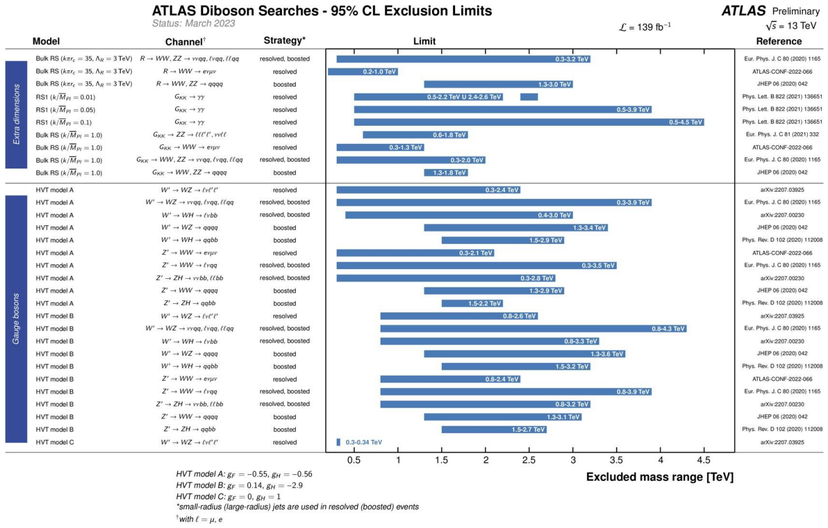
Height: 25 m
Lenght: 46 m
Weight 7000 t

Scientists: 6027
Institutes: 264
Countries: 47 t

- Extensive upgrades performed to prepare for Run 3
- Enphasis on making detectors & trigger as robust as possible
- First step to prepare ATLAS for HL-LHC

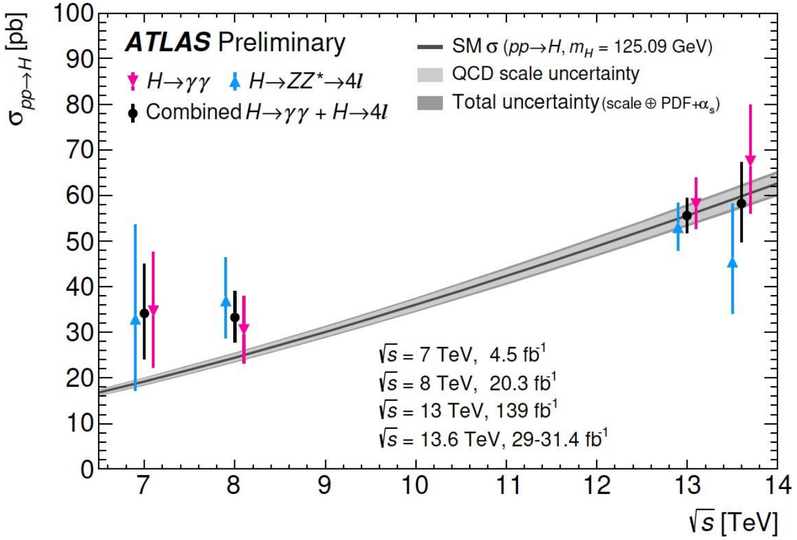
Run 2 Analyses

139 fb^{-1} collected
261 papers

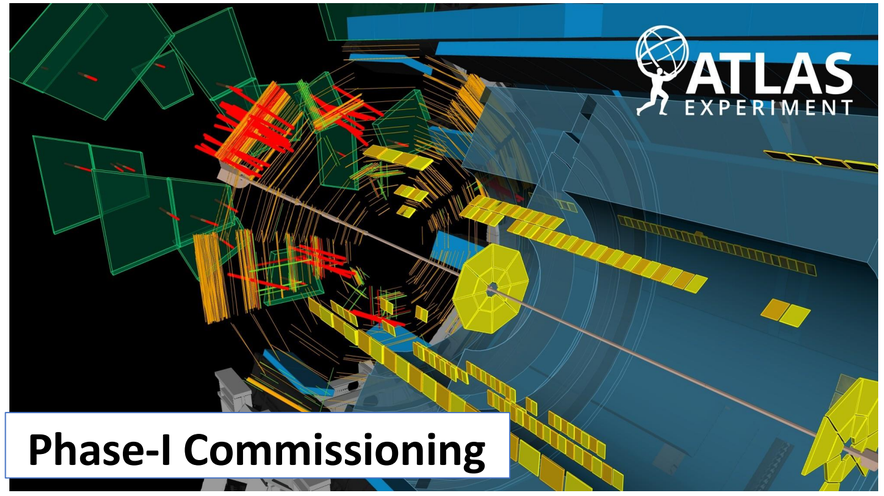


Run 3 Analyses

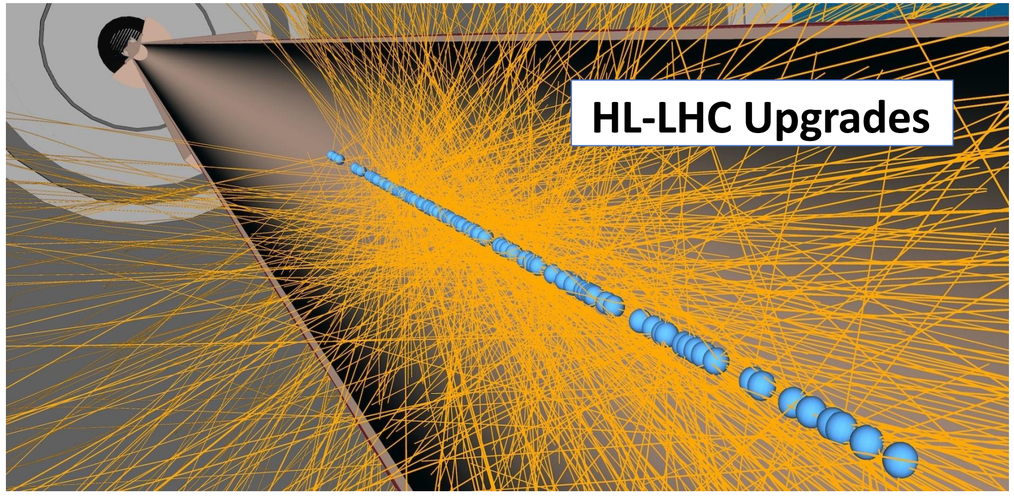
66 fb^{-1} collected



Many ongoing activities



Phase-I Commissioning



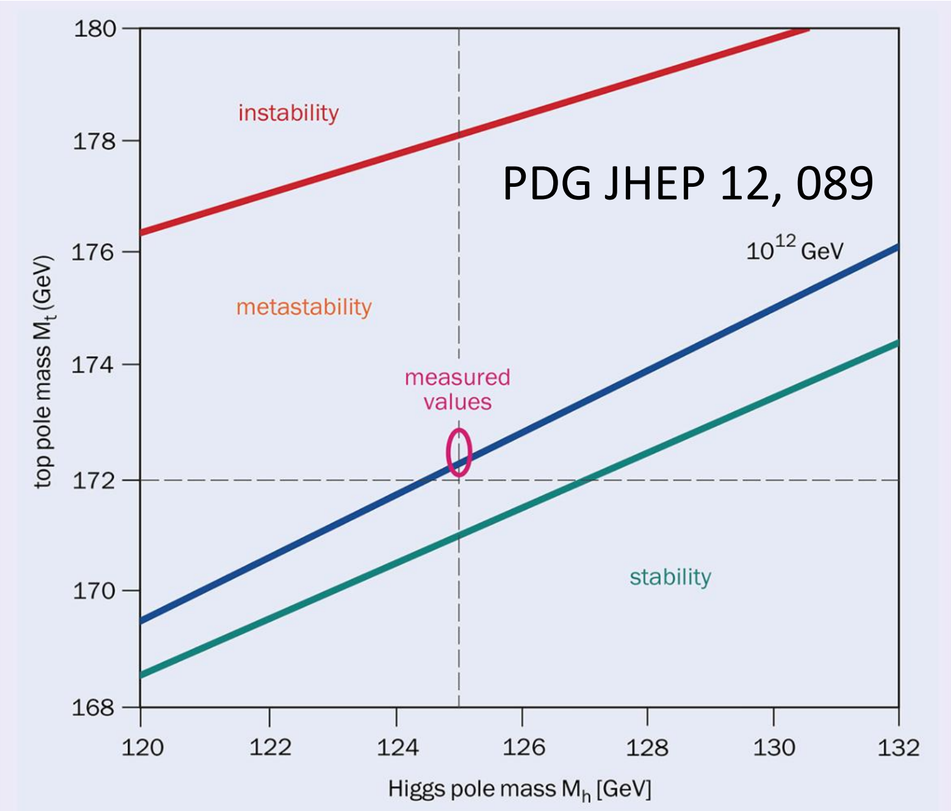
HL-LHC Upgrades


ATLAS
EXPERIMENT
We continue to improve our tools, developing techniques that let us extract more physics from our data, including getting a better handle on the amount of data we have taken.
The LHC, a **high-energy discovery machine,** is also becoming a **precision EW machine**.
Run: 286665
Event: 419161

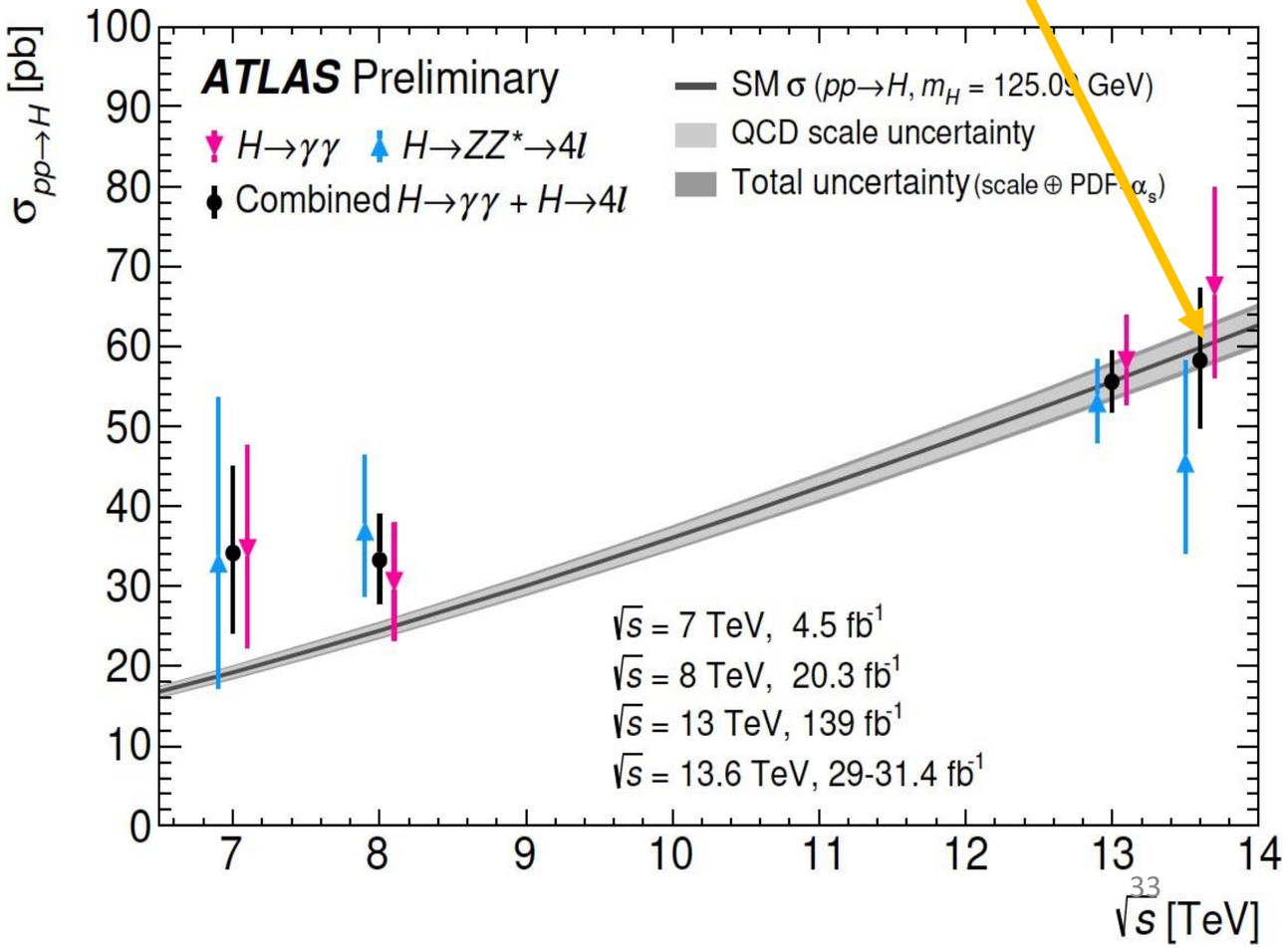
Re-observation of the Higgs boson

- In the Standard Model: 15* unpredictable parameters out of 19* related to Higgs sector
- Crucial to understand Higgs boson's properties in various measurements
- Connect to unresolved questions in the Universe

(*)not including neutrino mass



$\sigma = 58.2 \pm 8.7$ pb



Higgs boson measurements

Typically divided in:

- **Coupling measurements** (event count in various phase space regions)
- **Property measurements** (quantum numbers and other properties using dedicated analyses)

→ both sectors influence each other: mH determine the SM expectation for couplings

$m_W = gv/2$ $\quad$ $m_W/m_Z = \cos\theta_W$ $\quad$ m_H

$$\mathcal{L}_{EW} = \frac{1}{2}\partial_\mu H \partial^\mu H + \frac{g^2}{4}(v+H)^2(W^+_\mu W^{-\mu} + \frac{1}{2\cos^2\Theta_W} Z_\mu Z^\mu) + \frac{1}{2}(-2\mu^2)H^2 - \lambda v H^3 - \frac{1}{4}\lambda H^4 + \dots$$

HVV and **HHVV** vertices $\quad$ **HHH** and **HHHH** self-interaction vertices

$\sim g^2 v$ ($\sim m^2/v$) $\quad$ $\sim g^2$ ($\sim m^2/v^2$)

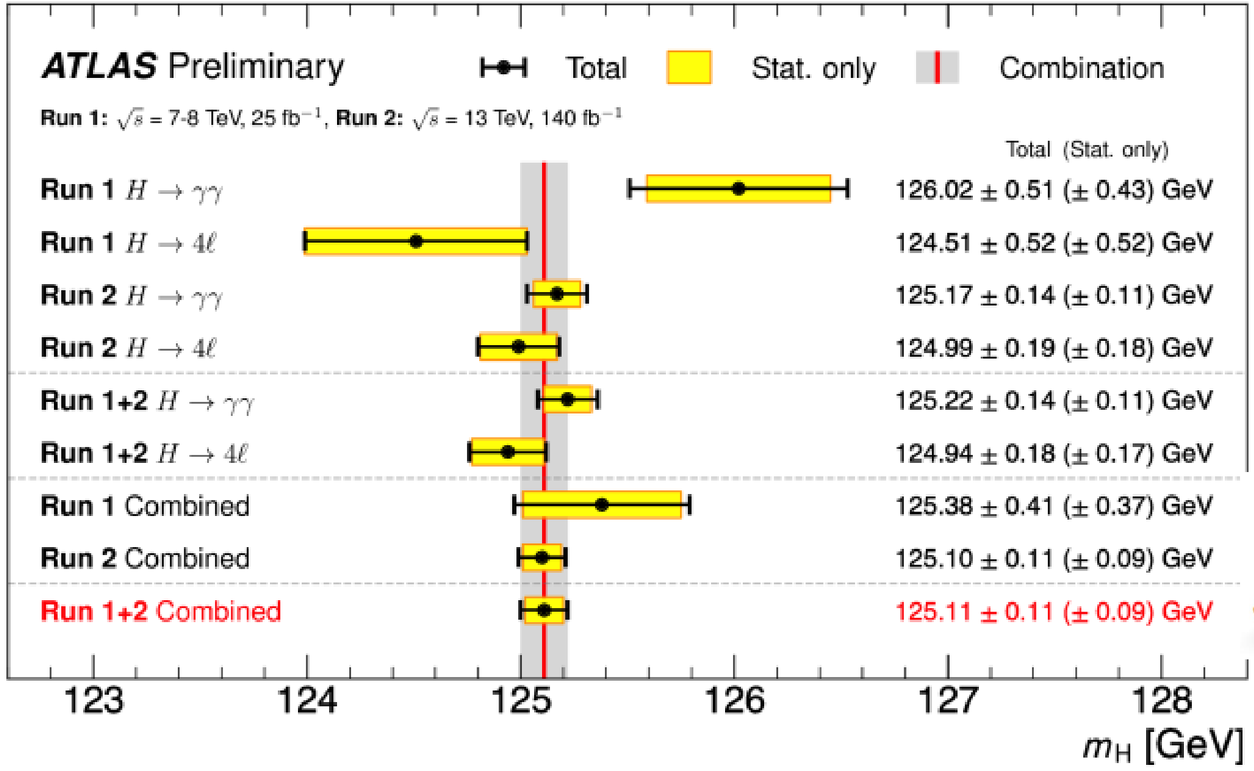
$$\mathcal{L}_{\text{Yuk,u.-gauge}} = -\frac{\lambda_f v}{\sqrt{2}}\bar{\Psi}_{f_L}\Psi_{f_R} - \frac{\lambda_f}{\sqrt{2}}\bar{\Psi}_{f_L}\Psi_{f_R}H + \dots$$

$m_f \sim \lambda_f v$ $\quad$ Hff vertices $\quad$ $\sim m_f / v$

Higgs mass

NEW

- Mass not from SM -> determined experimentally
- Interaction/coupling strengths of H with SM particles depends on M_H
- Value of M_H related to properties of H potential (→ to stability of EW vacuum)



Run 1+2 combined

- Huge efforts on γ calibration in Run2
  - Reduced γ energy scale/resolution uncertainties
  - 320 MeV (previous Run 2 results) -> 80 MeV
- Measured M_H with H→γγ (Run 1+2)
  - 125.22±0.11(stat)±0.09(syst) GeV
    (0.11% precision!)
- Combine H → γγ and H → ZZ → 4l (Run1+Run2)
  - 125.11±0.09(stat)±0.06(syst) GeV
    (0.09% precision!)

Run2 achievements and Run 3 status

Run 2
13 TeV

Partial data
~80fb^{-1}

ttH observation

VH, H->bb observation

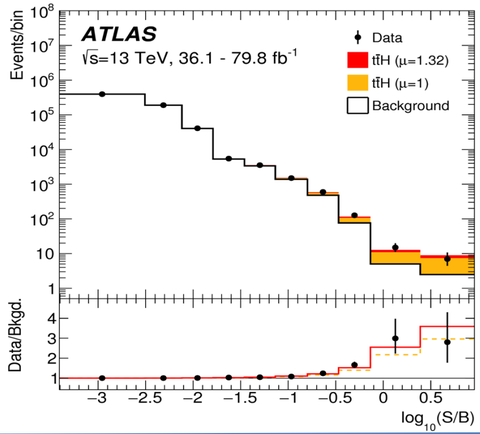
Full data
~140fb^{-1}

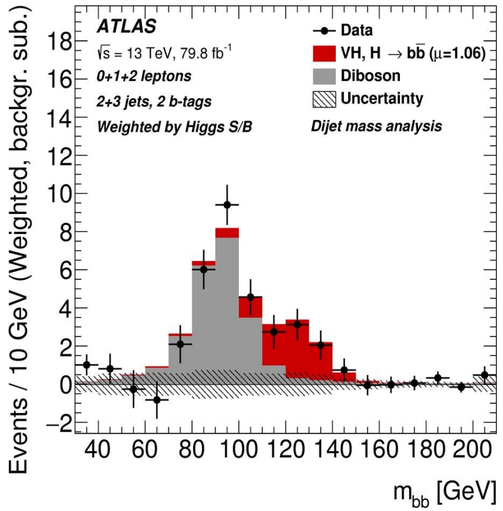
H->μμ evidence

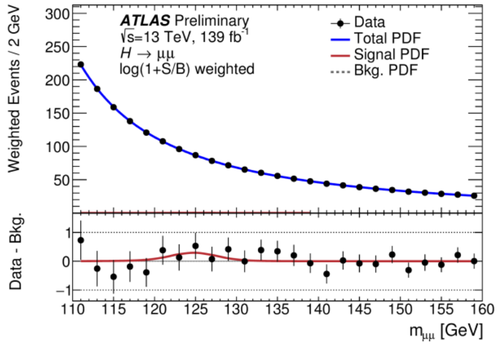
H->llγ evidence

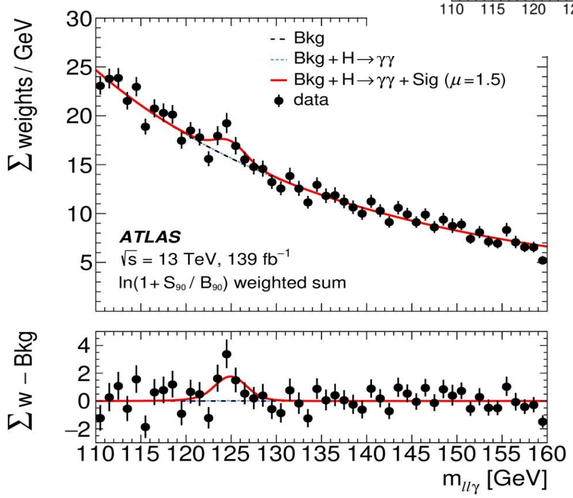
Run 3
13.6 TeV

~60fb^{-1}





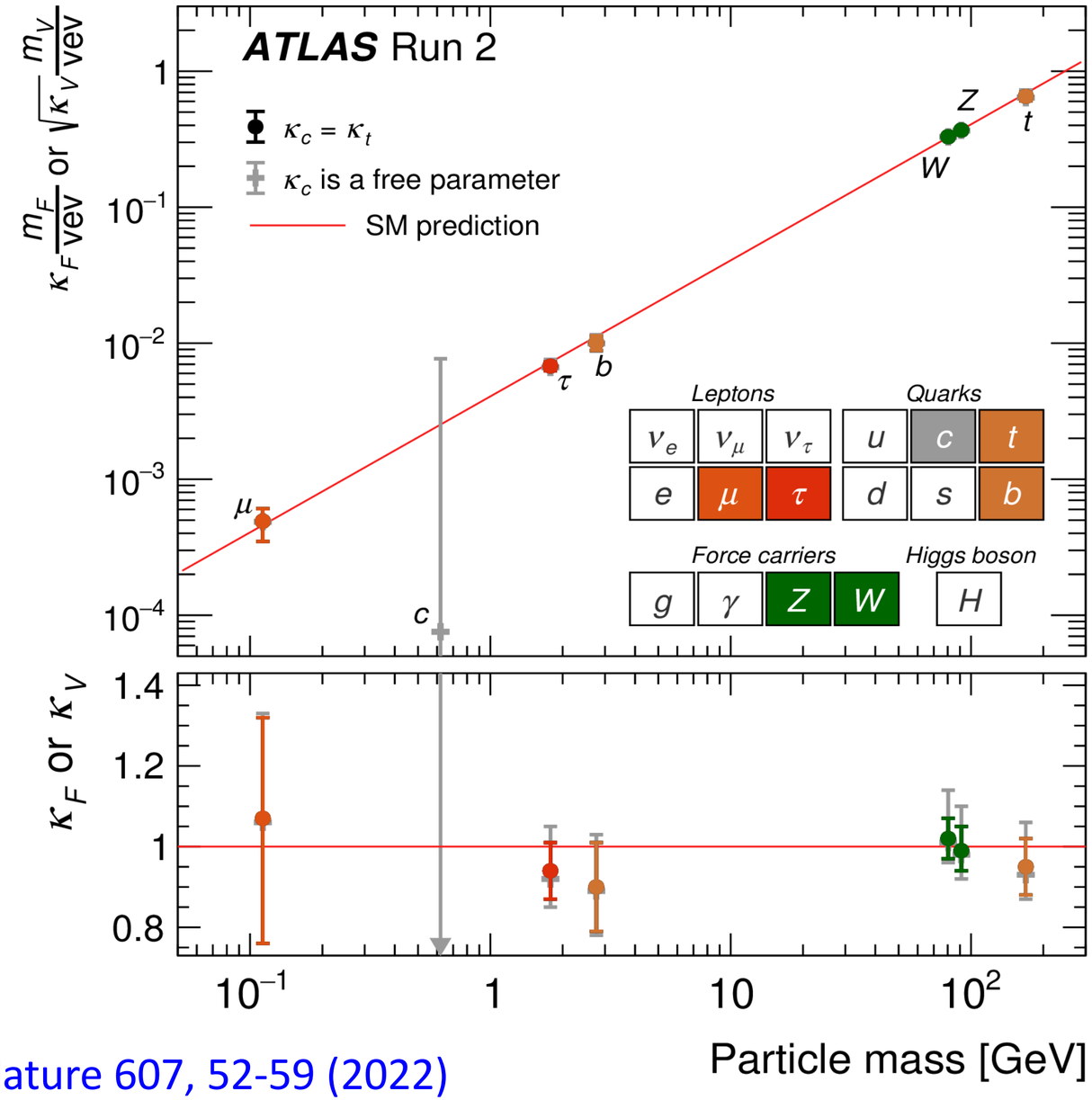




- Observed major production/decay processes in Run1 and Run2
- Large LHC data opens the door to access **rare Higgs processes** and **difficult corners of phase spaces**

ATLAS public page

Higgs couplings



Nature 607, 52-59 (2022)

Higgs couplings agree with SM over 3 order of magnitude in mass!!

(Visible) Branching Ratios:

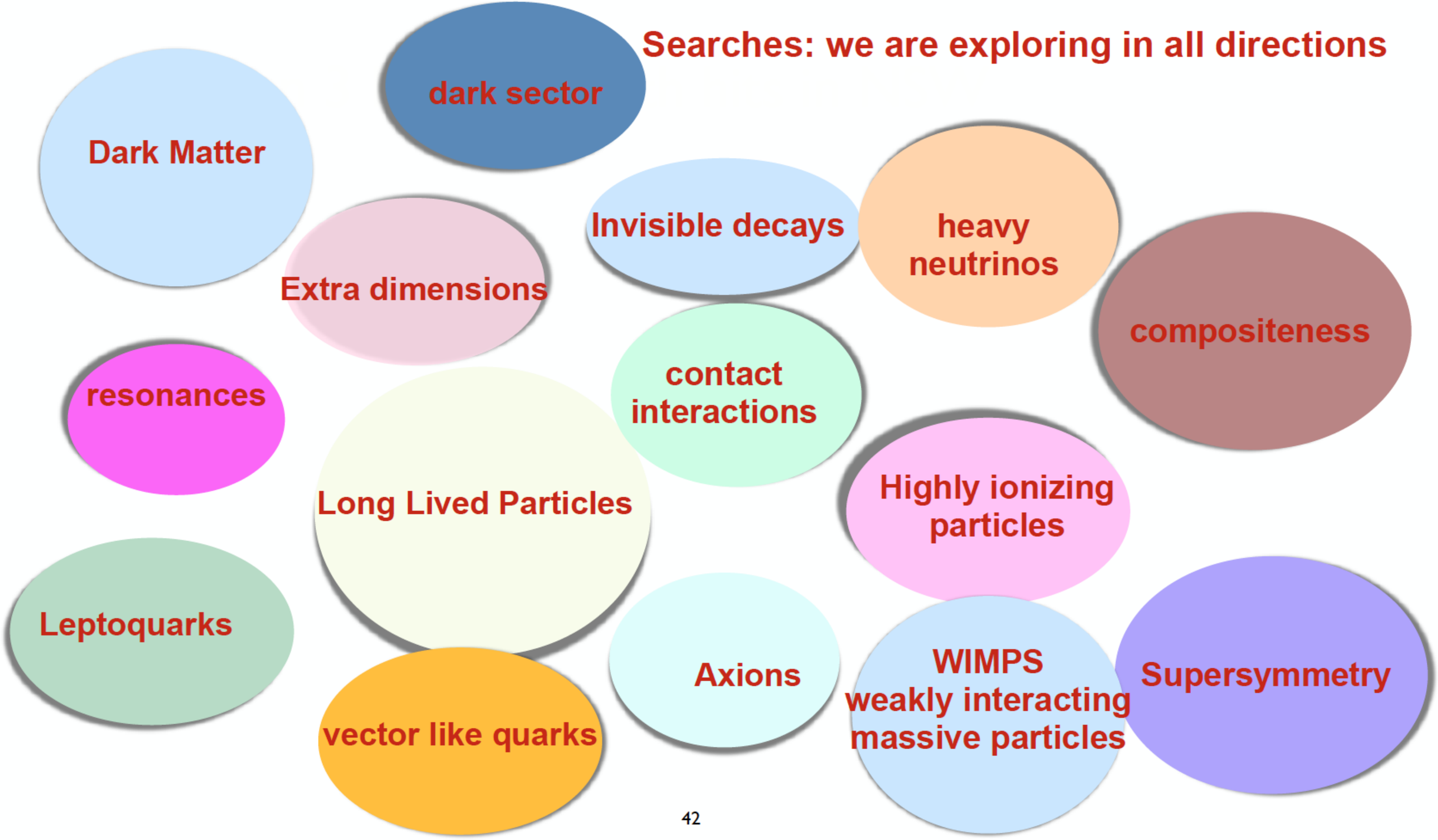
H -> γγ: **0.23%**

H -> μμ: **0.022%**

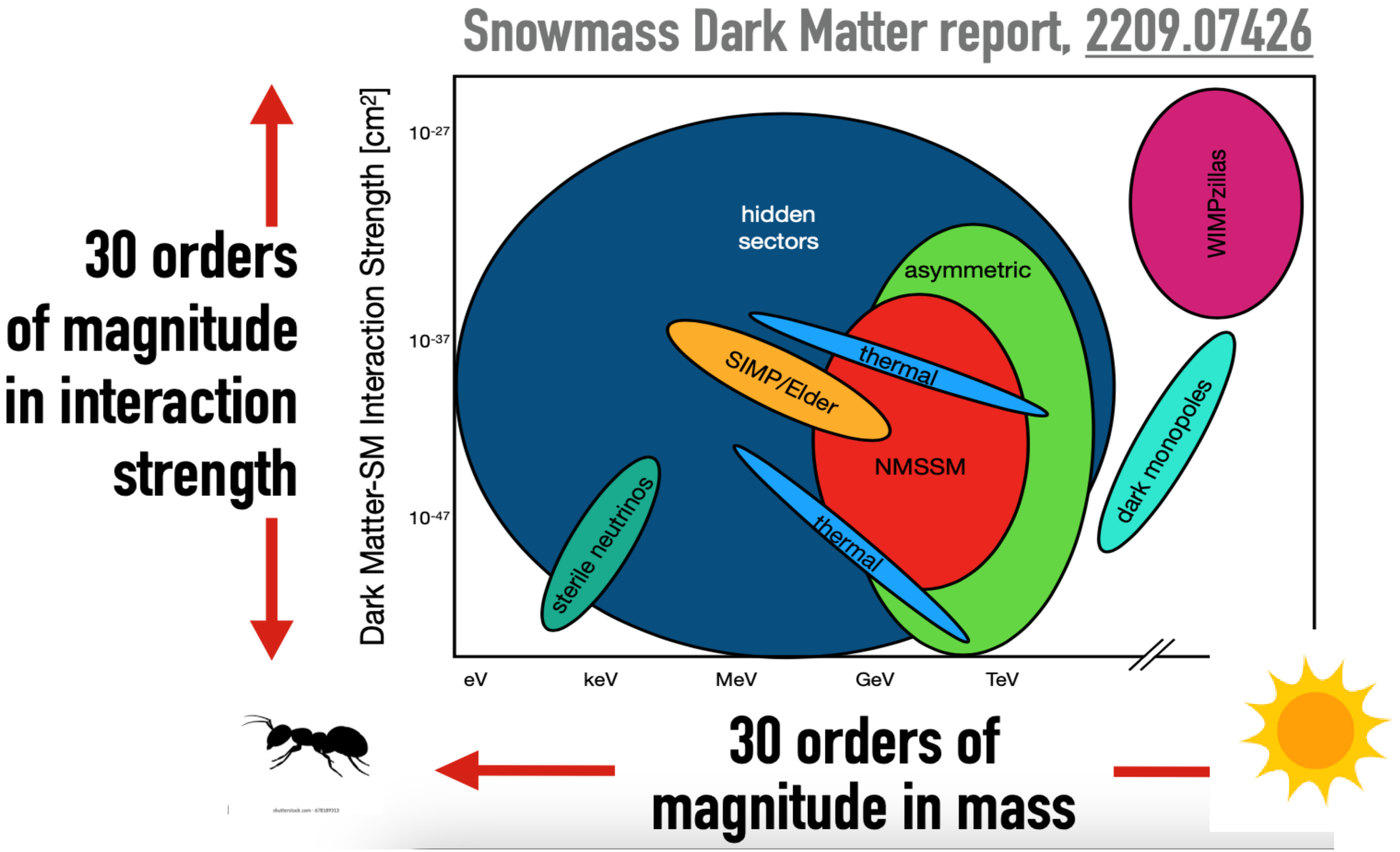
H -> 4l: **0.012%** (4e + 4μ + 2e2μ)

H -> Zγ: **0.010%** (for Z -> ee, μμ)

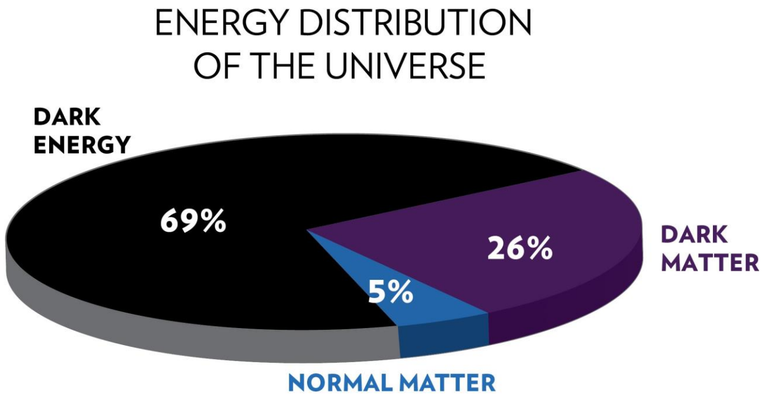
Searches: we are exploring in all directions



Delve deep, Search wild..



Dark Matter



Presence of Dark Matter (DM) well established.
Its nature is an open question

- Weakly Interacting Massive Particle (WIMP): an attractive option…

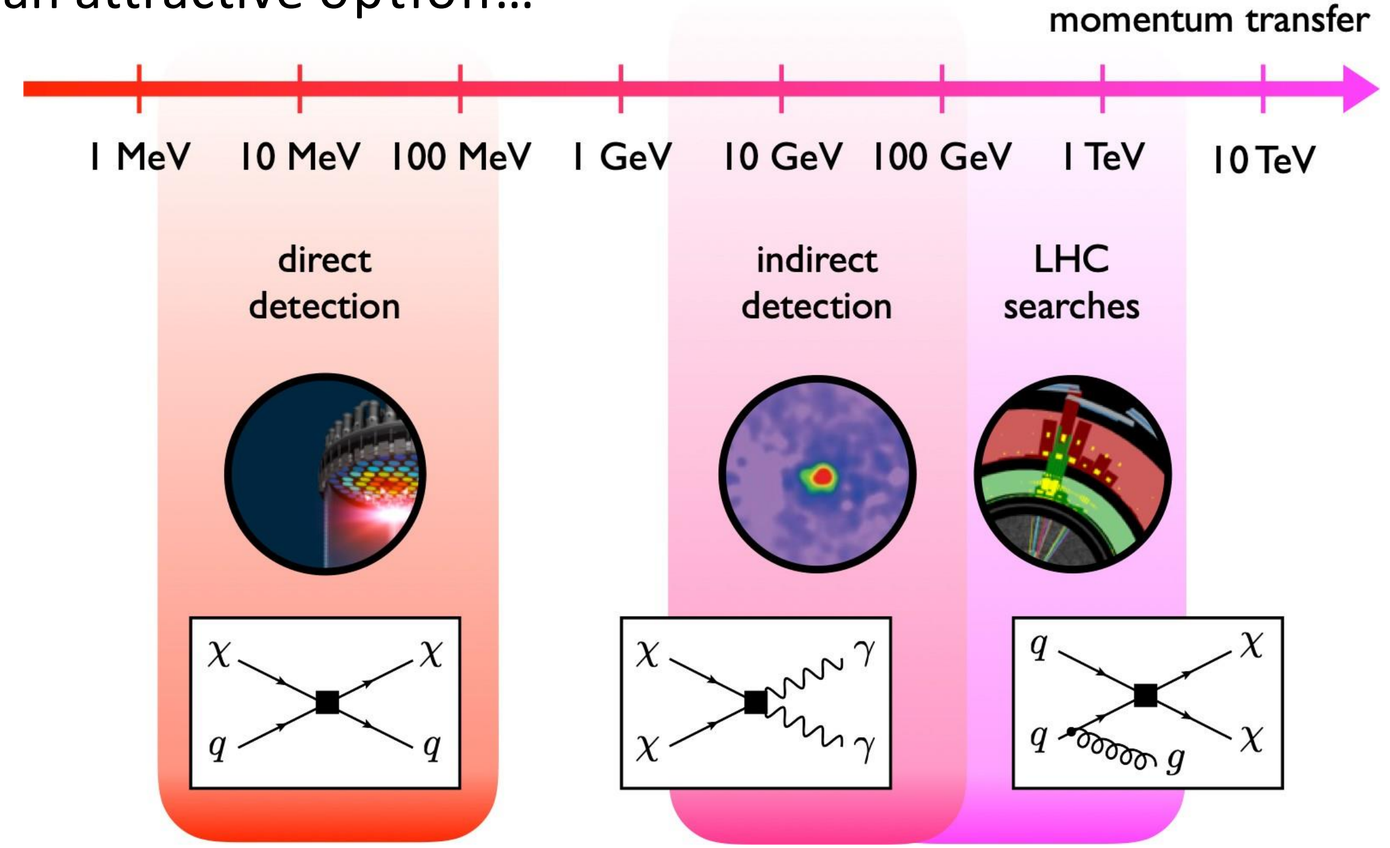
  Heavy, stable, & couples to SM

  Naturally accounts for observed relic density (WIMP Miracle)

- But many other hypotheses and models, e.g:

  Axion-like-particle (ALP)

  Dark sectors consisting of many DM particles

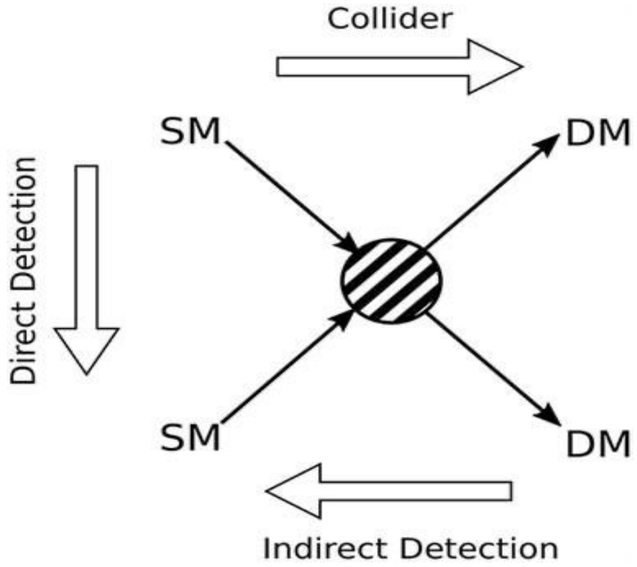


1810.09420

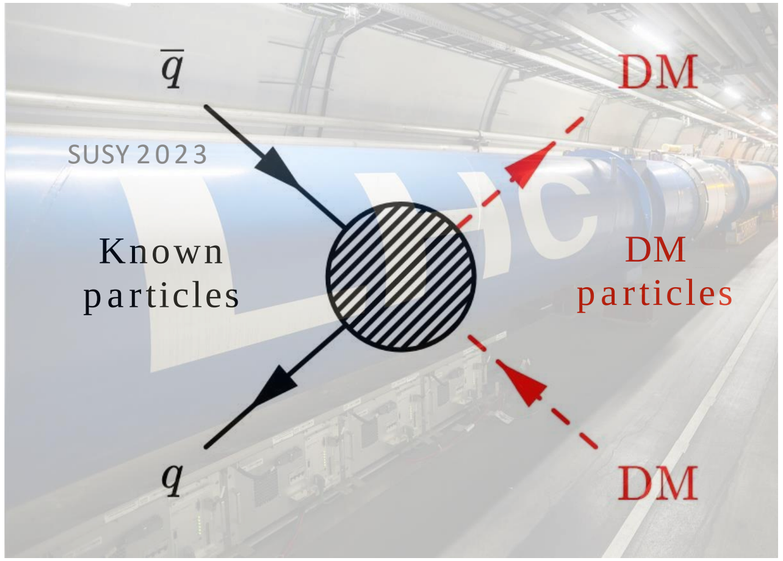
Dark Matter

- DM candidates can be produced at the LHC but cannot be observed directly ⇛

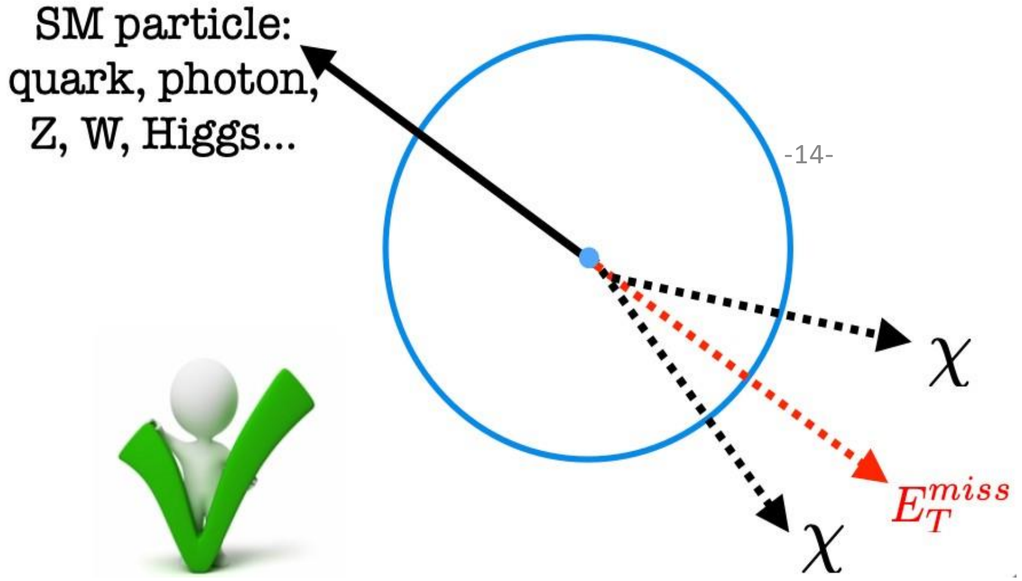
- A **SM particle** is needed to recoil against **DM candidates**
  - Inferred through **momentum imbalance (MET)** in plane transverse to beam
  - Visible particles from initial state radiation (ISR) or associated production can tag DM pair production



PRODUCTION

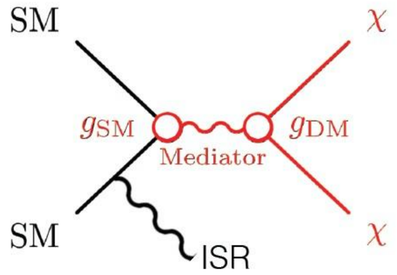


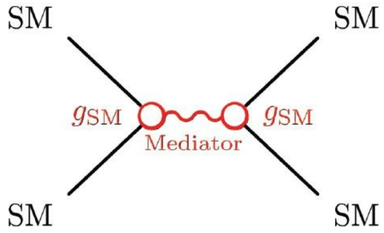
DETECTION



Overview of collider searches

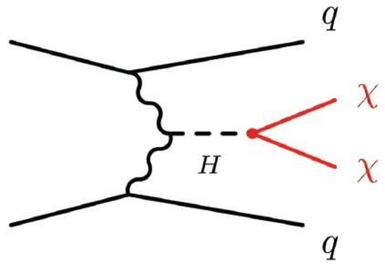
"Direct" searches: X + ETmiss using ISR or associated production
⇛ Look for deviation from SM backgrounds

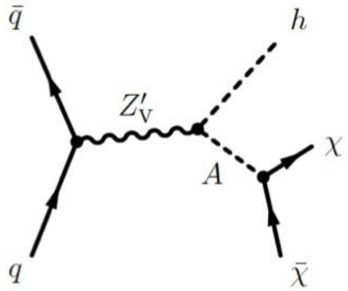




Mediator searches: bump hunt for mediator decays to fermions
⇛ Look for mass peak above background continuum

Searches with a Higgs boson mediator
⇛ Look for enhancement of Higgs boson decays to invisible





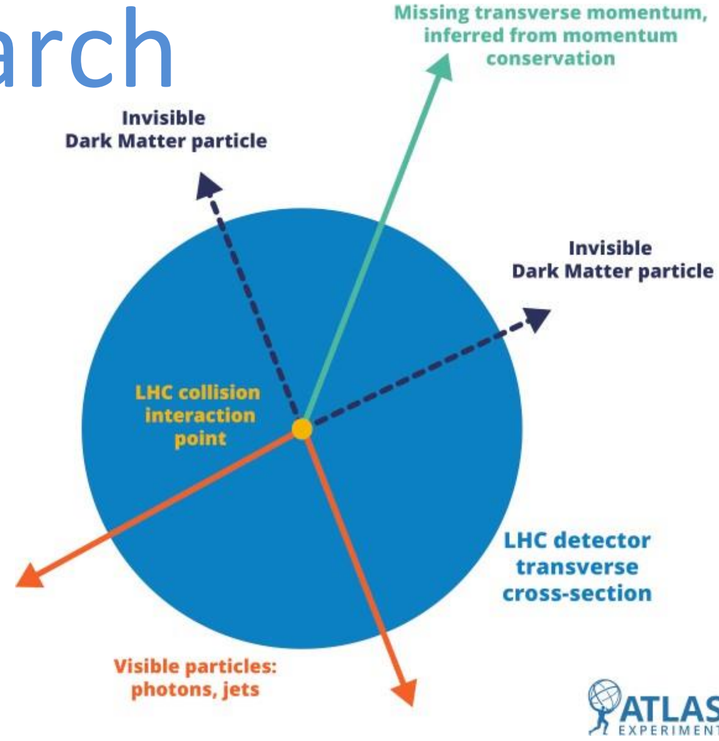
Searches in the extended Higgs sector: Two Higgs doublet model extended with a pseudoscalar A mediating the SM-DM interaction

Searches in Dark sectors: particles from a shadowy sector that interact with particles from SM through subtle mixing

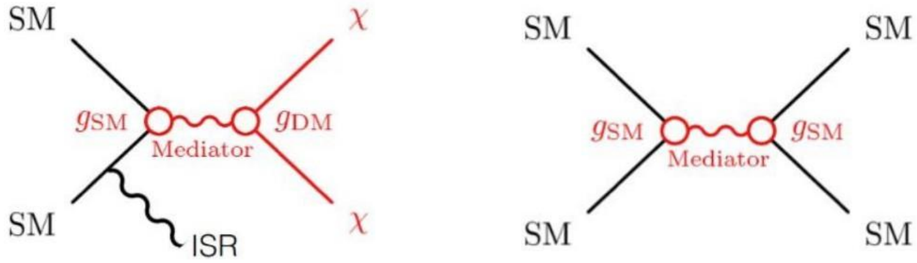
The typical ATLAS WIMP search

- Any WIMP DM produced at collider experiments will interact weakly and pass invisibly through the detector

- Theoretical models to optimize searches and characterize a possible discovery, e.g:

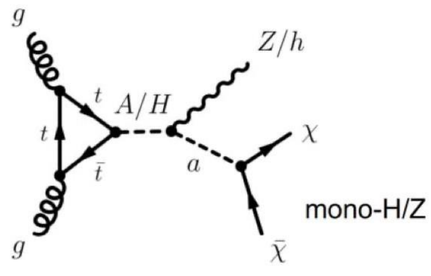


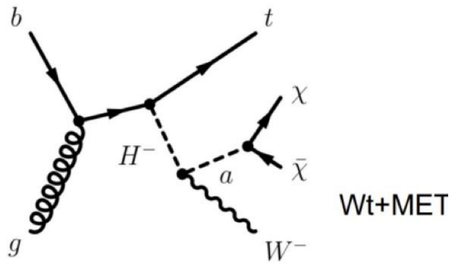
Simplified s-channel model



Small set of free parameters: M_χ, M_{med}, g_χ, g_q, g_l Complementarity between Mono-X (X+MET) and resonance searches

2HDM+a model

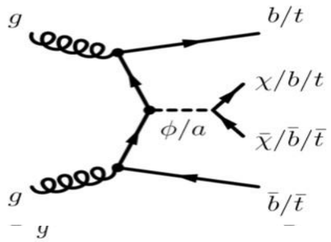


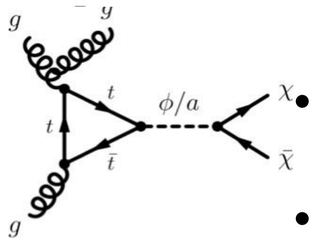


Two Higgs doublet extensions with an extra pseudoscalar. Gauge-invariant. Richer kinematics + phenomenology

Spin-0 Mediators

PHYS-PUB-2023-018



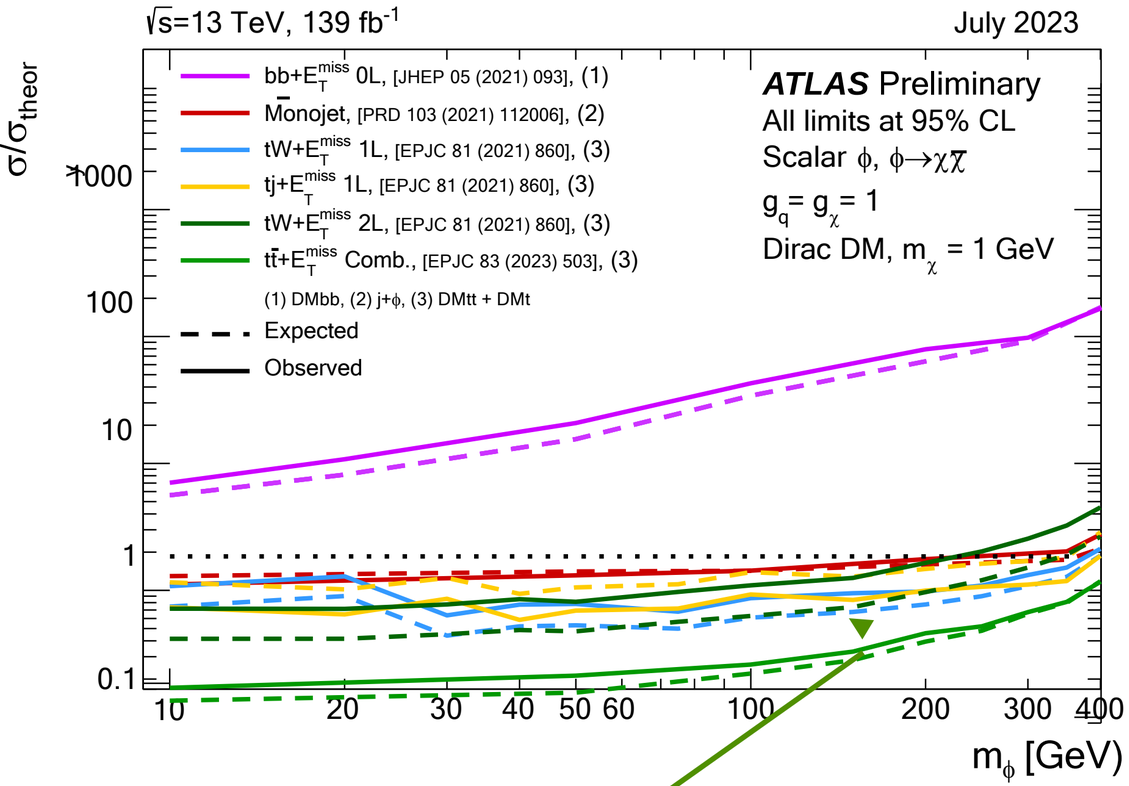


- Scalar (ϕ) or pseudoscalar (a) mediator
- Yukawa-type couplings →
  - heavy quark (b/t)-associated searches
  - Dominate: **tt+MET** comb, **tW+MET**, **bb+MET**, **mono-jet**

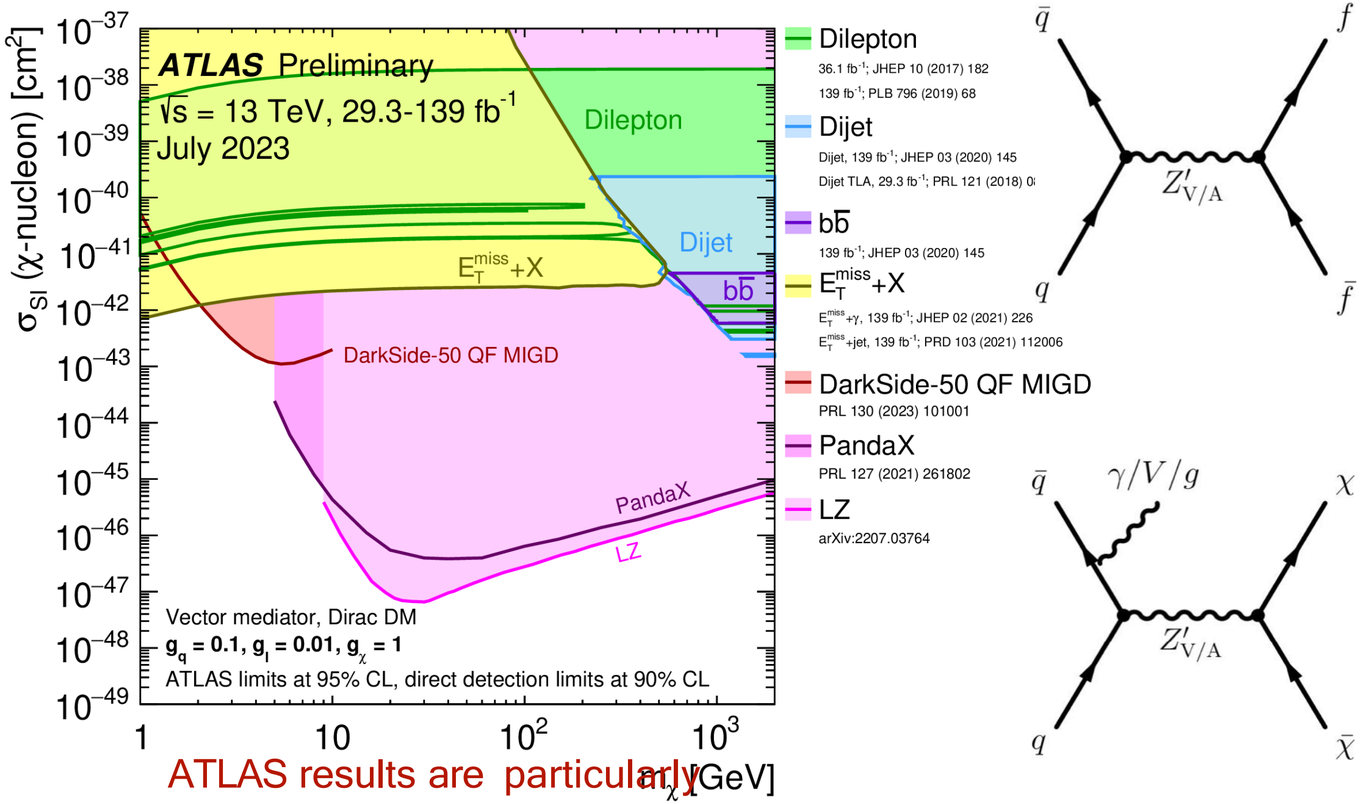
Spin-1 Mediators

PHYS-PUB-2023-018

- Vector or Axial-vector mediator
  - **mono-jet/photon, di(b)-jet, TLA di-jet, dilepton**
- Translated into spin-independent DM-nucleon elastic scattering cross-section limits → compared to direct searches



Strongest limits from new tt+MET combination EPJC83(2023)503

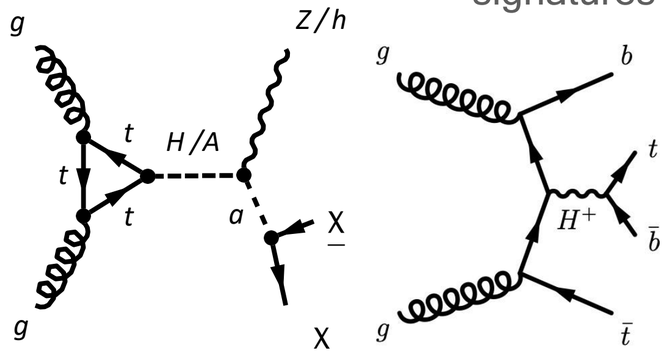


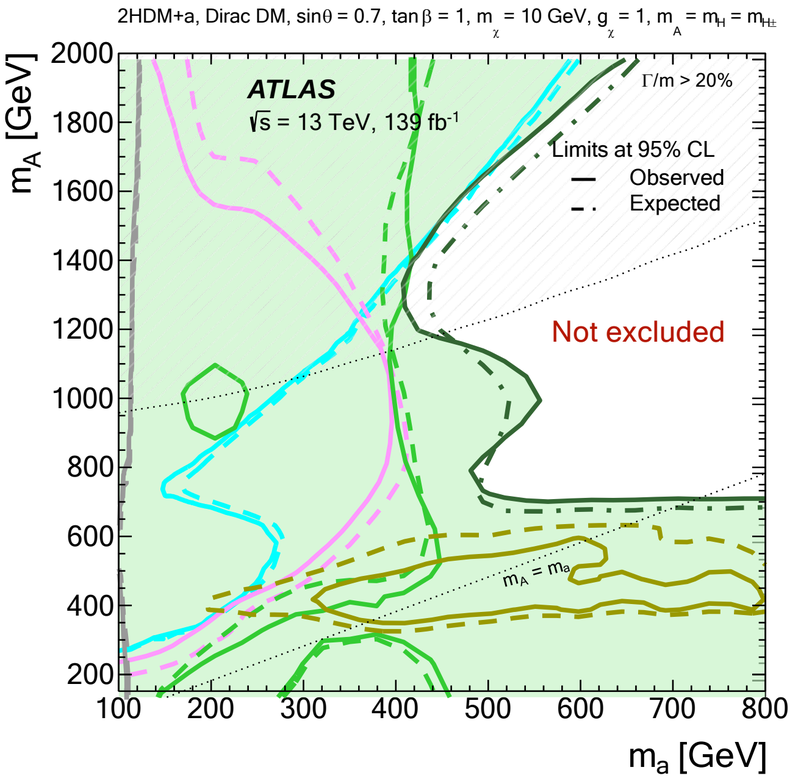
ATLAS results are particularly competitive for low DM masses

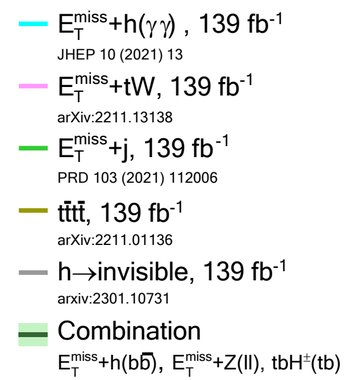
Combination and summary: 2HDM+a model

- Add complex doublet + pseudoscalar mediator + fermionic DM candidate
  - 3 of most sensitive searches combined statistically:
    mono-H(→bb), Mono-Z(→ll), tbH(→tb)
  - Complementarity with lower-mass searches for pseudoscalars (2202.12631)

Example signatures

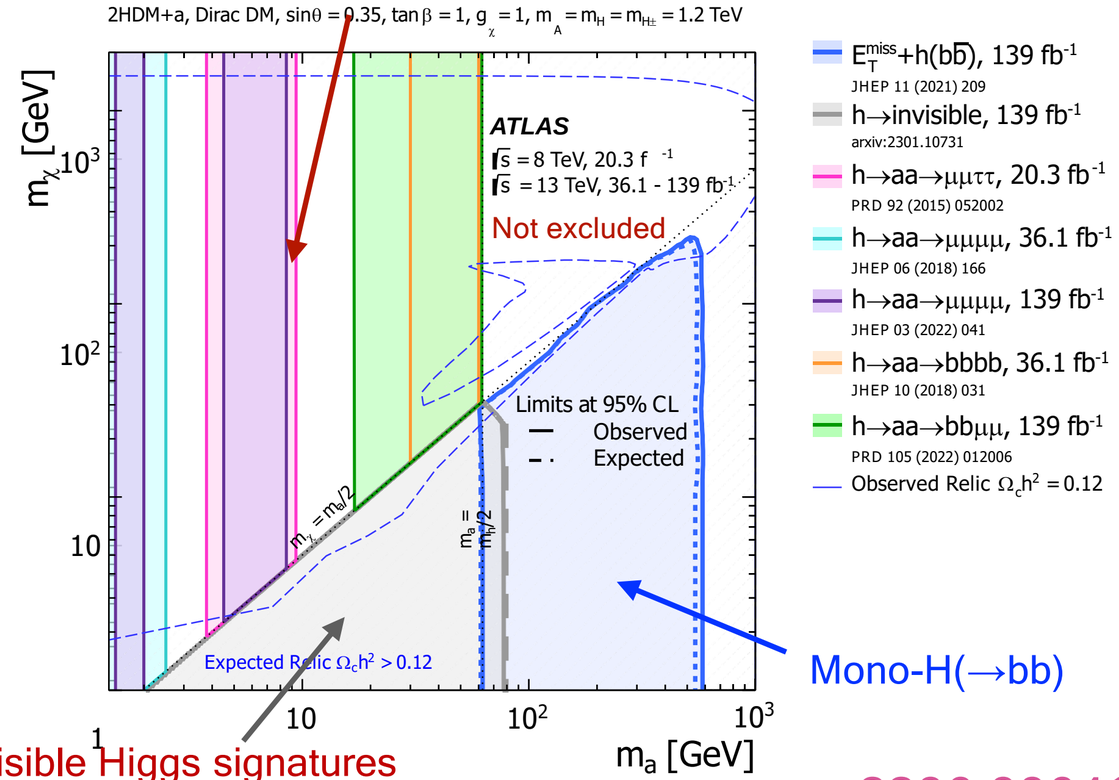






Wide range of masses are excluded

h→aa→SM resonance searches



Mono-H(→bb)

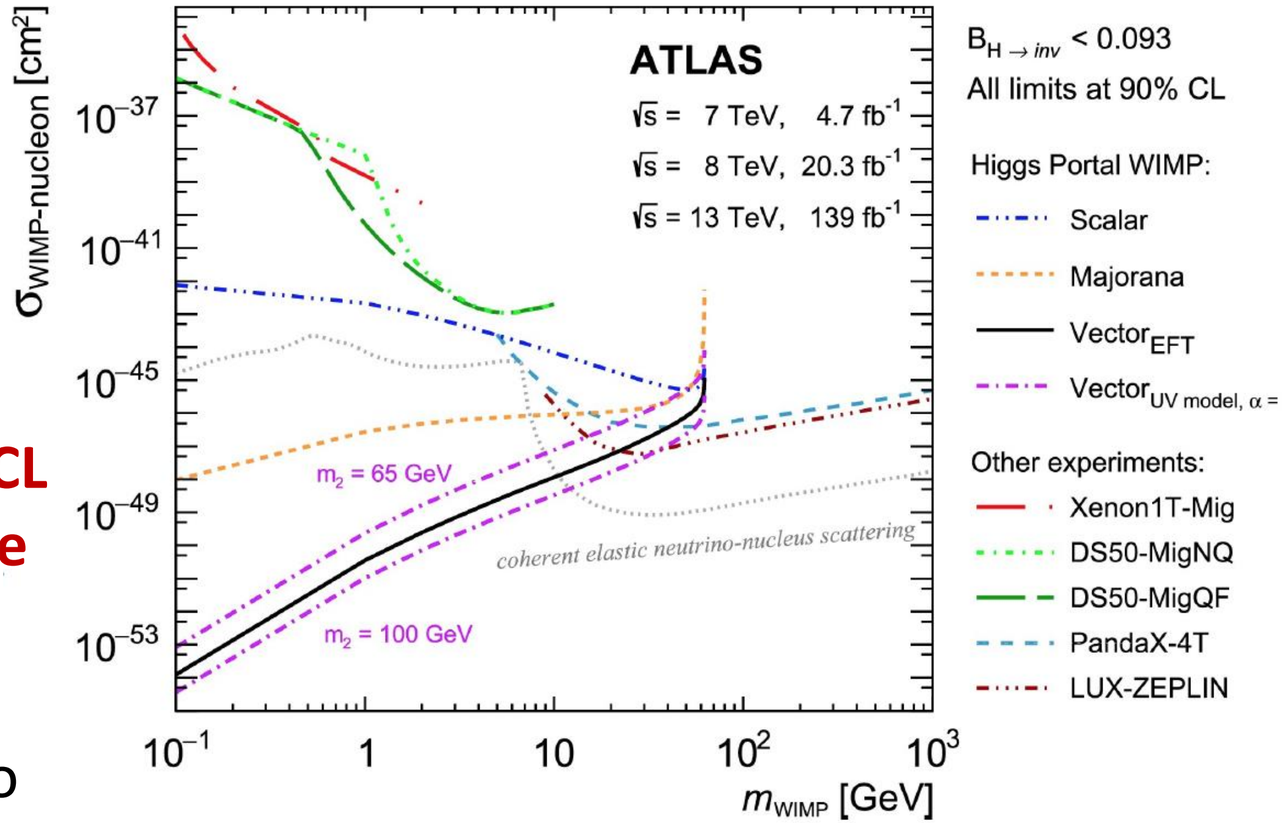
Invisible Higgs signatures kick in for lower DM masses

2306.00641

Combination and summary: Higgs portal

90% CL on the spin-independent WIMP-nucleon scattering cross-section

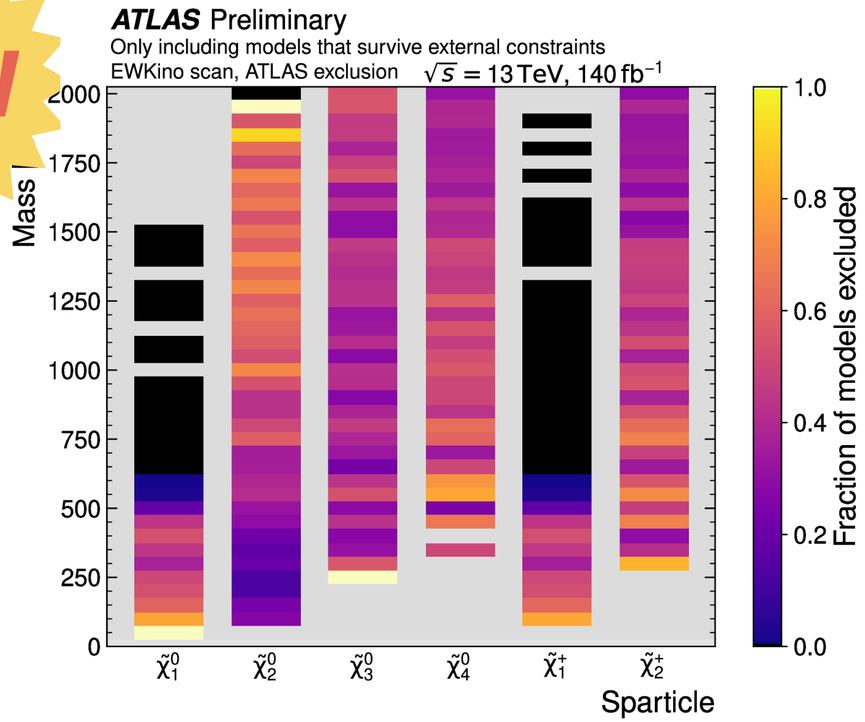
- SM particles get mass through the Higgs → DM could also be produced in Higgs decays
- SM Higgs invisible decays are <0.1%
- **The analysis: $B(H\rightarrow inv)_{obs} < 10.7\%$ @95%CL**
  $B(H\rightarrow inv)_{exp} < (7.7\%)$ @95%CL best to date
- Results also interpreted in the context of models with SM Higgs boson is portal to dark matter
- Exclusion regions extend to very low DM mass

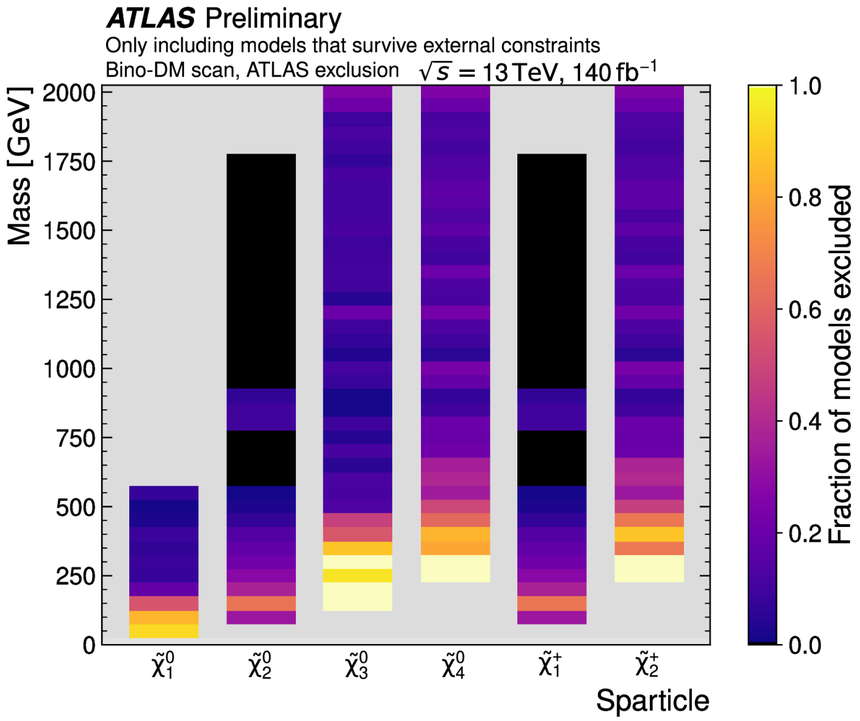


The regions above the limit contours are excluded

Phys. Lett. B 842 (2023) 137963

NEW

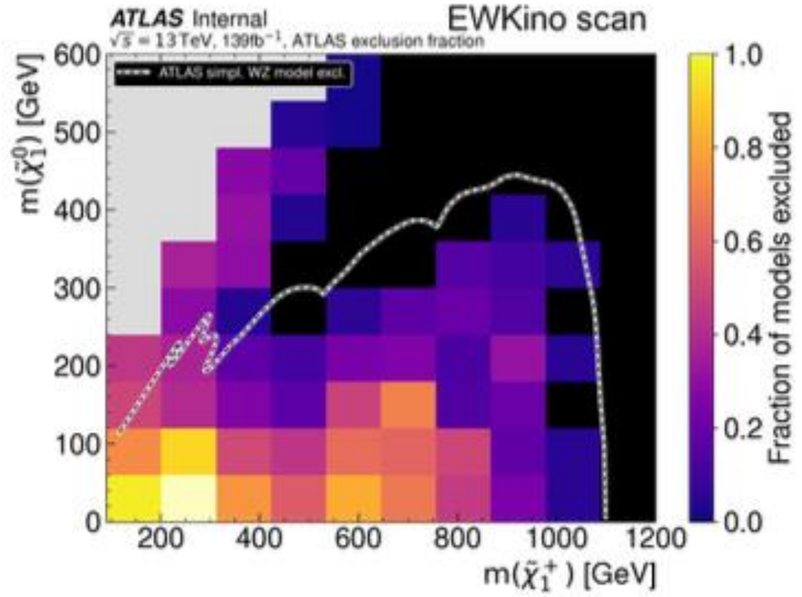




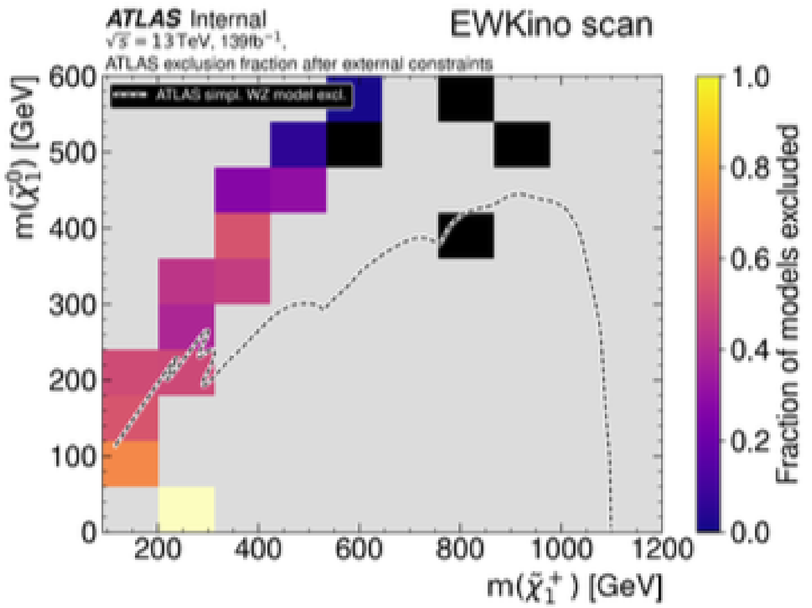
Review of SUSY Dark Matter

- Scan exploring Phenomenological Minimal Supersymmetry (**pMSSM**: UV complete Model, normally simplified models are used)
- Tens of thousands of different models, with different masses predictions tested
- Impose LHC + external constraints
  LEP, flavor, precision EWK, DM direct

Review of SUSY Dark Matter

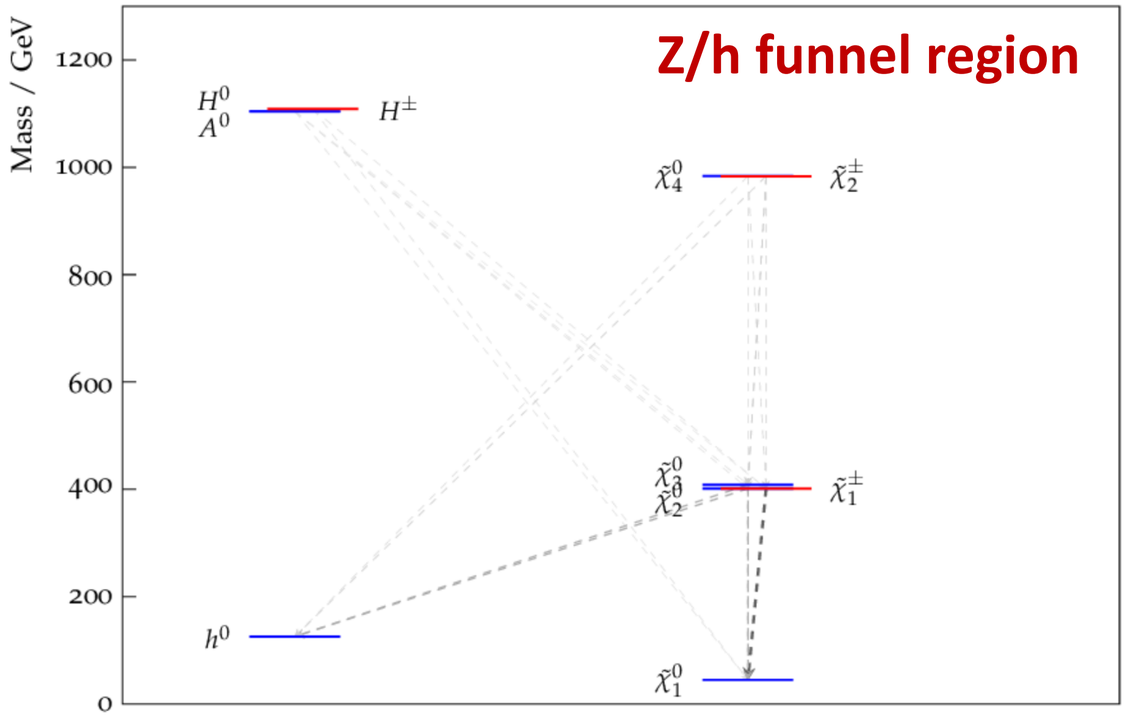


(a) All models



(e) Models passing all external constraints

- Almost full exclusion of low-mass χ_{01} in regions where it would not oversaturate DM relic abundance
- Surviving SUSY model: **not excluded** but with mass-spectrum within published simplified model contours.



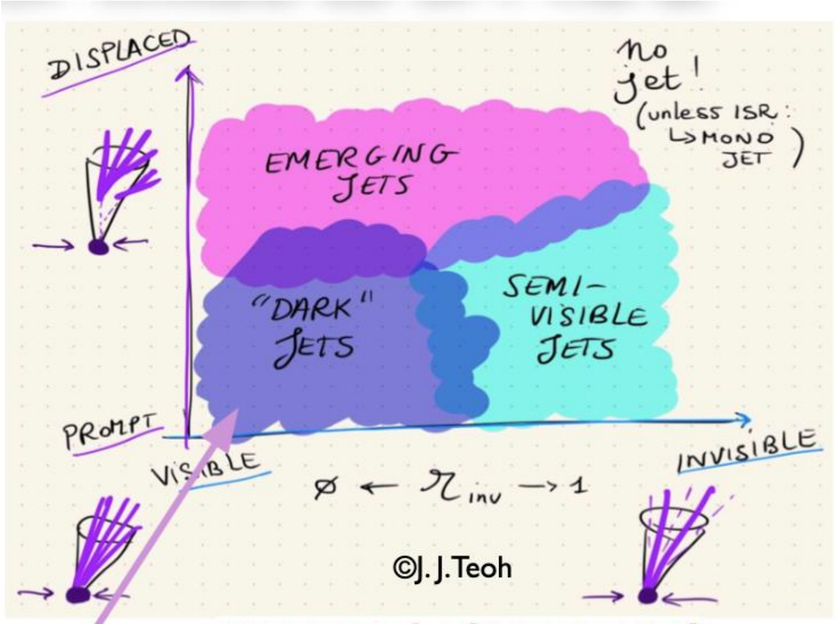
Dark sector searches

- DM in a hidden sector, with particles which don't undergo SM gauge interactions
  - May communicate with SM via mediators, which could be DM candidates OR provide portals to them
  - Coupling to SM encoded in a mixing term in the Lagrangian
- Can also have strongly interacting dark sectors with new SU(N)
  - Dark quarks form bound dark hadron states
  - Unstable dark hadrons can decay to SM quarks, others traverse the detector → dark or semi-visible jets

1901.09966

Portal	Coupling
Dark Photon, A_μ	$-\frac{\epsilon}{2\cos\theta_W}F'_{\mu\nu}B^{\mu\nu}$
Dark Higgs, S	$(\mu S+\lambda S^2)H^\dagger H$
Axion, a	$\frac{a}{f_a}F_{\mu\nu}\tilde{F}^{\mu\nu}$, $\frac{a}{f_a}G_{i,\mu\nu}\tilde{G}_i^{\mu\nu}$, $\frac{\partial_\mu a}{f_a}\overline{\psi}\gamma^\mu\gamma^5\psi$
Sterile Neutrino, N	$y_N LHN$

Very wide range of signatures to search for!



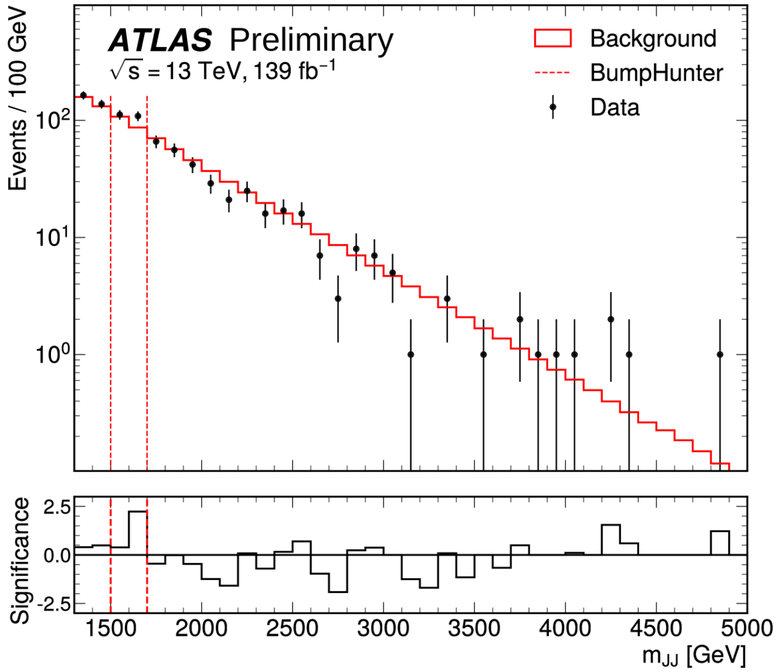
uncovered phase space!

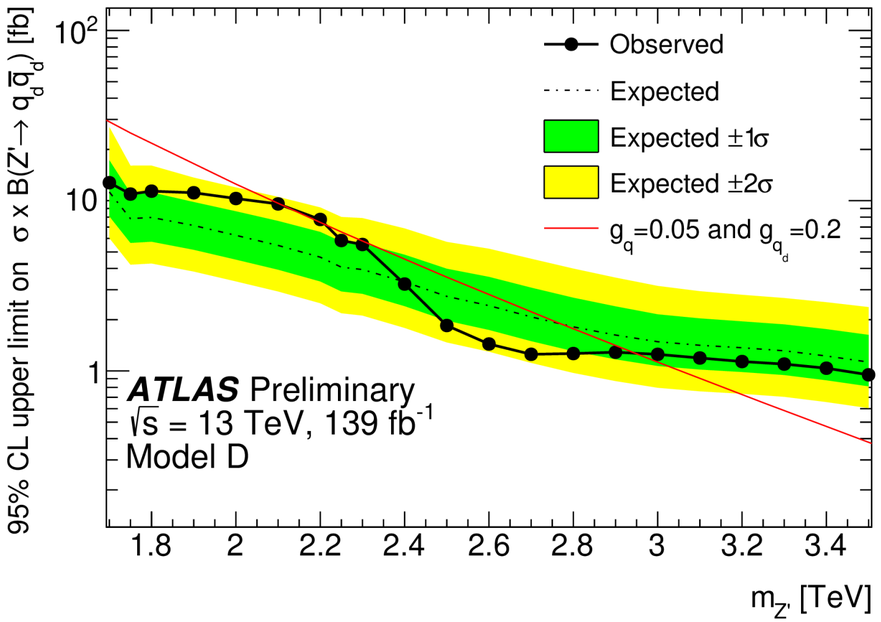
NEW

Dark Jet Resonance

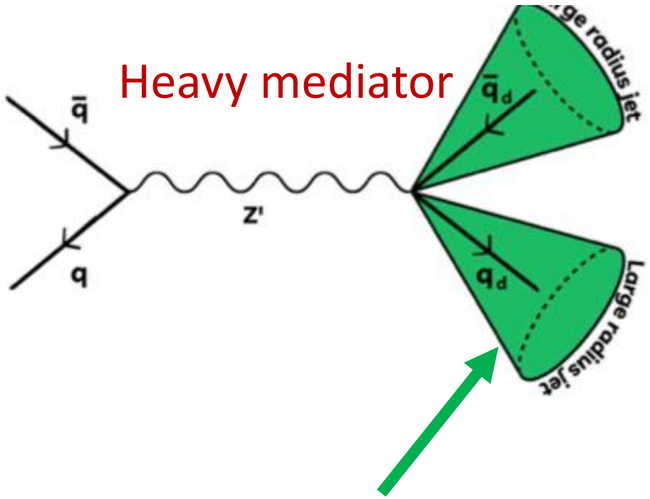
Model: QCD-like dark sector linked to SM through Z’

- Stable dark hadrons with unusual dijet signatures (higher charged-particle multiplicity)
- Search for dark jets bump in mass spectrum of two large-R jets





No excess found



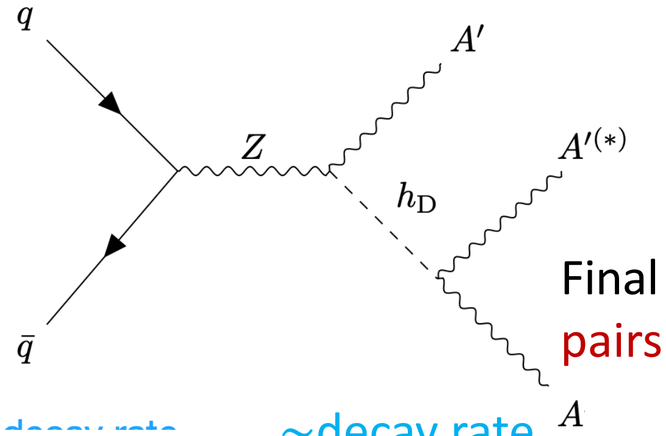
Jets wider and with higher multiplicy

CONF-2023-047

NEW

Dark photons in rare Z decays

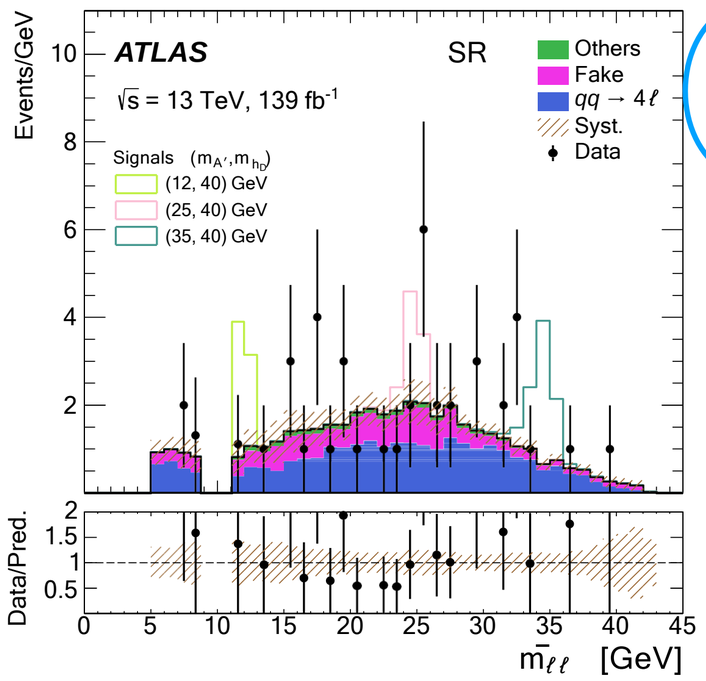
- Dark Abelian Higgs model adds dark Higgs h_D for massive dark photon A’
  - $Z \rightarrow h_D A'$ for light A’ masses
  - A’ decays into lepton pairs (or hadrons)



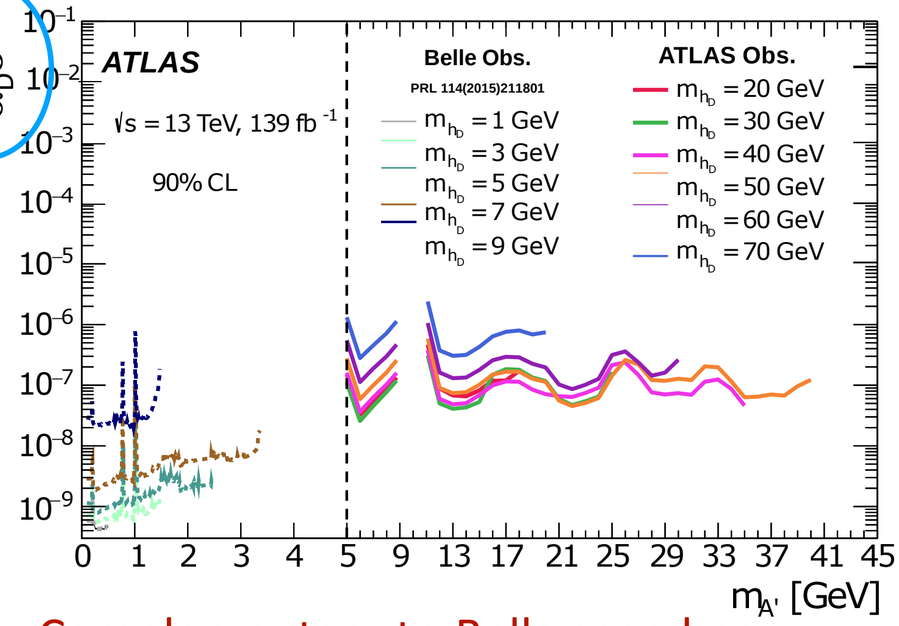
Final state: at least two lepton pairs with similar masses

Parameters:
m_{hD}, $m_{A'}$,
coupling of A with SM (ε),
coupling of A’ with DM (α_D)
coupling of h_D with H

~decay rate



$\alpha_D \varepsilon^2$

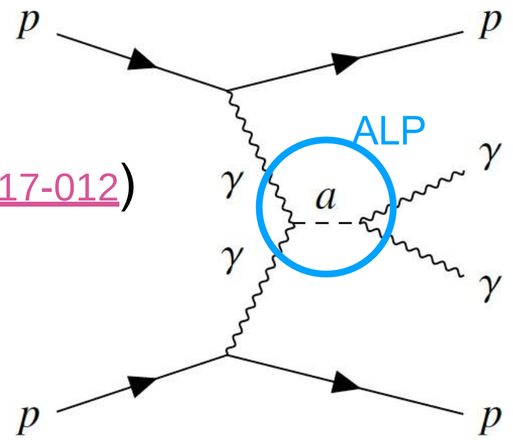


Complementary to Belle searches

2306.07413 submitted to PRL

ALP search with AFP

JHEP07(2023)234

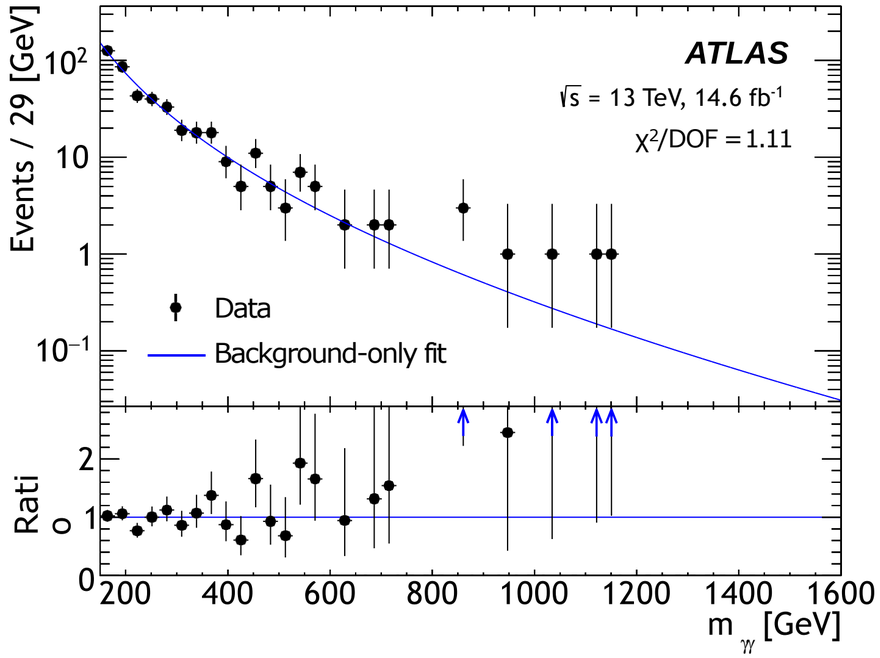


ALPs with forward proton scattering in association with photon pairs

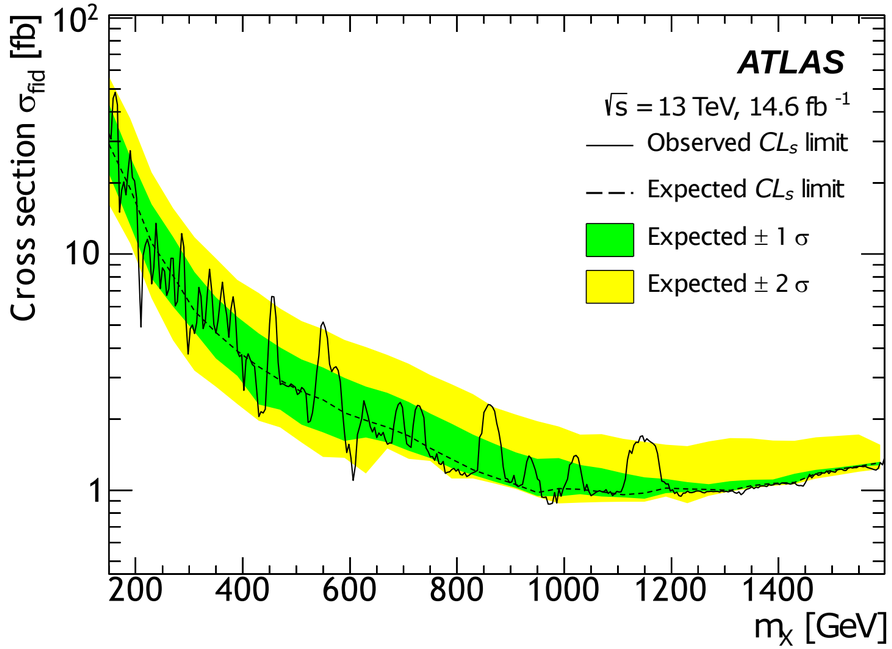
First BSM search using ATLAS Forward Proton (AFP) (ATLAS-TDR-024, ATL-PHYS-PUB-2017-012)

4 tracking units located at z= ± 205 m and ± 217 m

- Diphoton resonance search in events with at least one proton tagged in AFP
- Data-driven estimate of combinatorial background from photon pairs w/ protons from another collision



Unbinned maximum likelihood fit to the $m_{\gamma\gamma}$ distribution

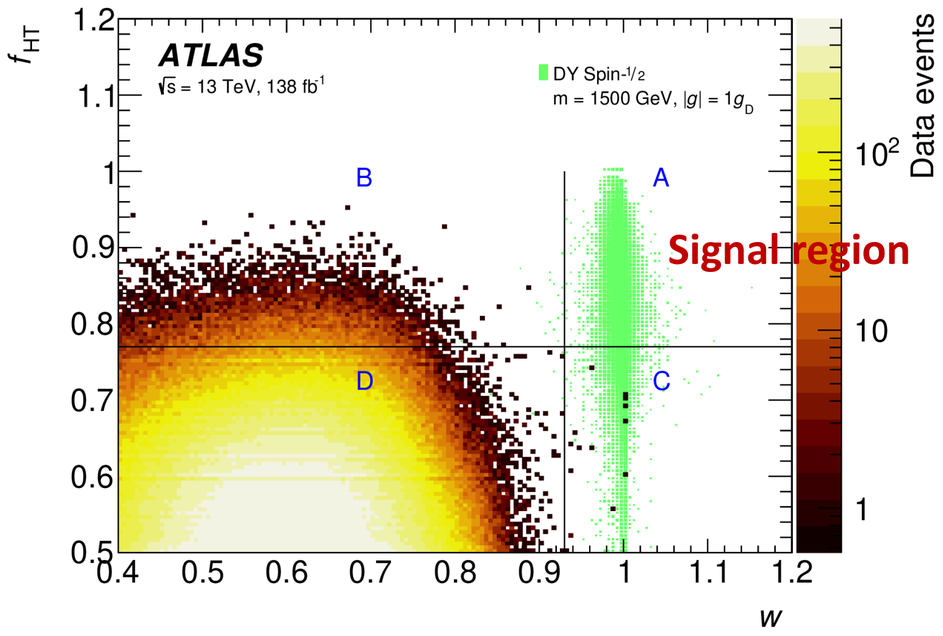


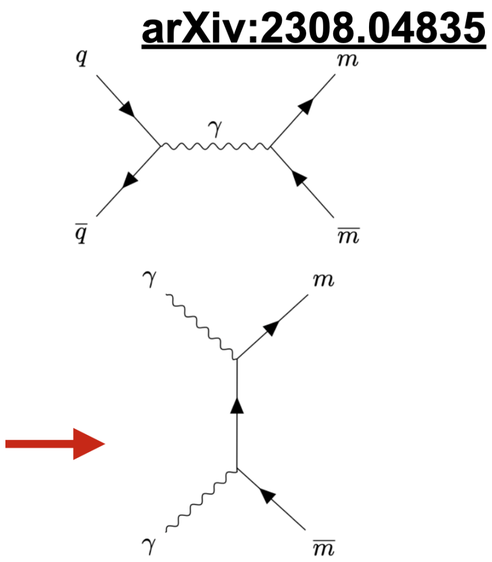
No excess → Cross section exclusion limits

NEW

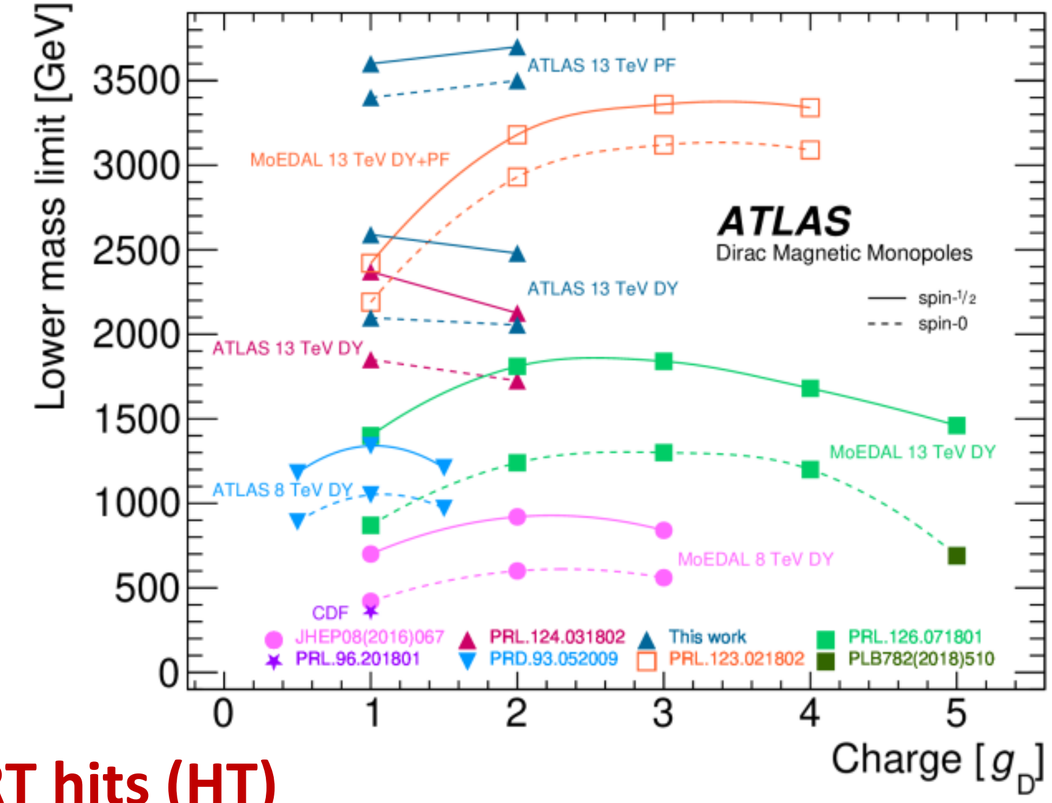
Highly ionizing particles

- Search for pair of magnetic monopoles and stable particles with high electric charges
- Factor 3 better than previous x-section limits by ATLAS, with 36 fb^{-1}
- First ATLAS limits on photon-fusion pair production mechanism.





arXiv:2308.04835



- HIPs produce TRT tracks with δ-rays → **many high TRT hits (HT)**
- Too massive to produce shower in EM calo → **low lateral dispersion** (w)

Conclusions

- ATLAS: taking data, preparing for an ambitious HL-LHC upgrade, and analysing its fantastic Run-1, 2 and 3 data samples, with an extremely broad and diverse physics programme

- Search program is benefiting from ever more sophisticated analyses

- ~40 new results released this summer: most with well-understood Run-2 dataset, first cross-section measurements at 13.6 TeV, incl. Higgs boson re-observation

- Succesfull **DM search programme**
  - Probing a wide range of final states and models
    - Range of WIMP hypotheses - still many options
    - Many results on other options: dark sectors, ALPs

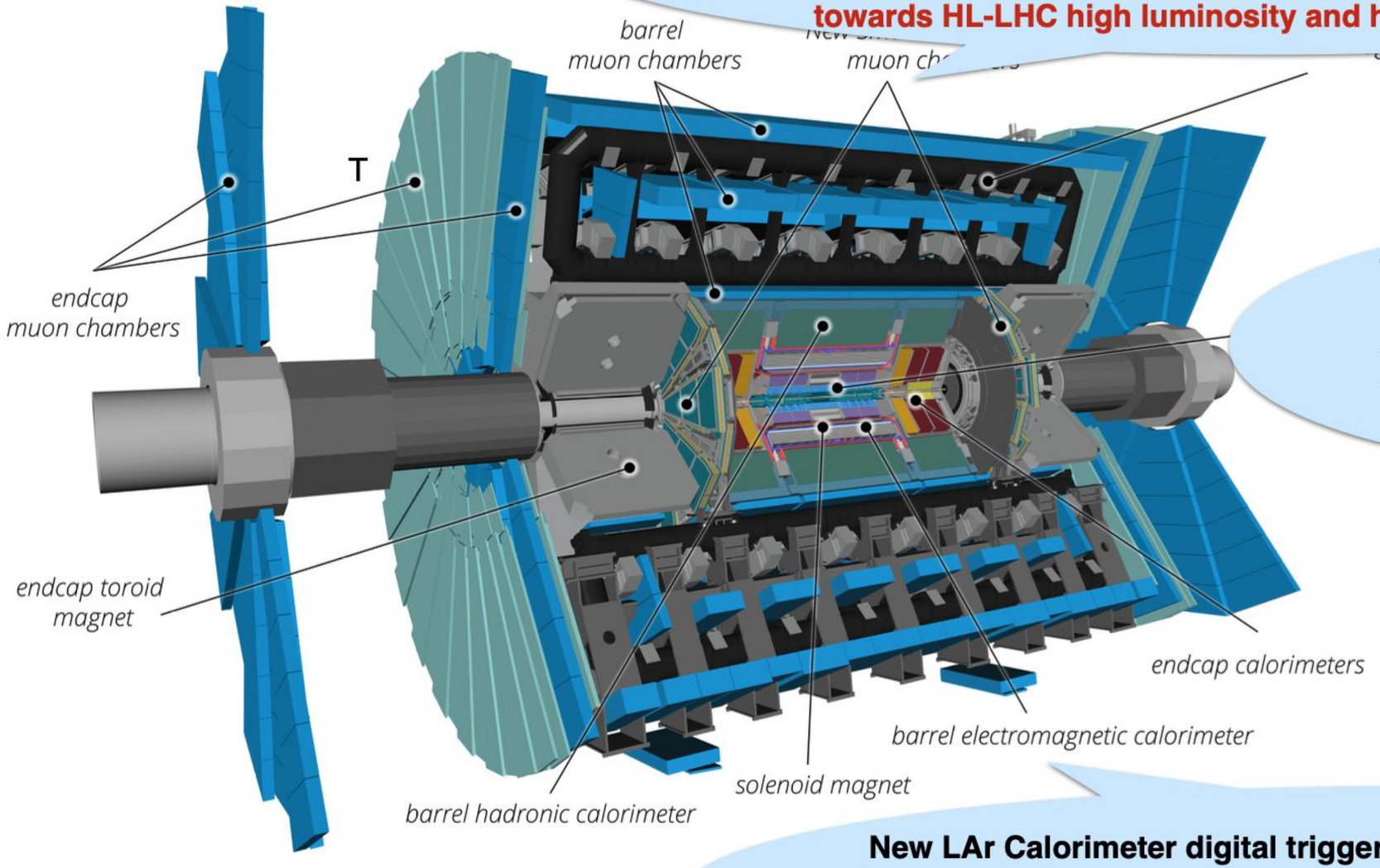
- LHC Run-2 results still coming and Run-3 dataset growing fast!
  - Many new ideas, improved techniques and new theoretical models

Thank you!

New ATLAS detector

arXiv:2305.16623

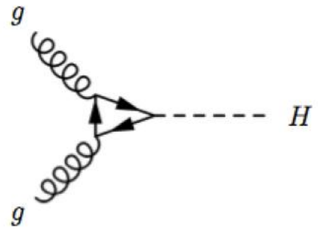
Muon New Small Wheels to replace innermost forward Muon station to
1) improve Level 1 trigger
2) maintain good tracking in end-cap region
towards HL-LHC high luminosity and high background rates



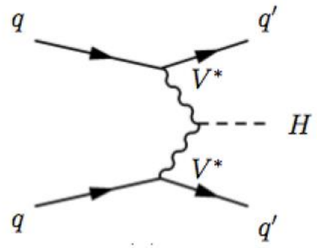
Trigger And data acquisition systems have upgraded hardware ad software allowing the trigger to spot a wide range of collision events (with same acceptance)

New LAr Calorimeter digital trigger electronic boards: improved trigger granularity!
towards HL-LHC high luminosity and high background rates

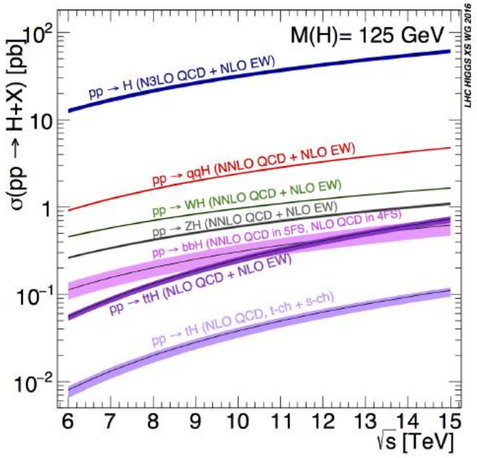
Higgs production



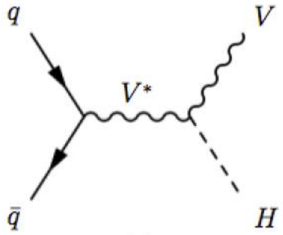
gluon fusion (ggF)



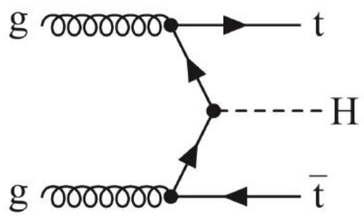
vector boson fusion (VBF)



Higgs boson production cross section



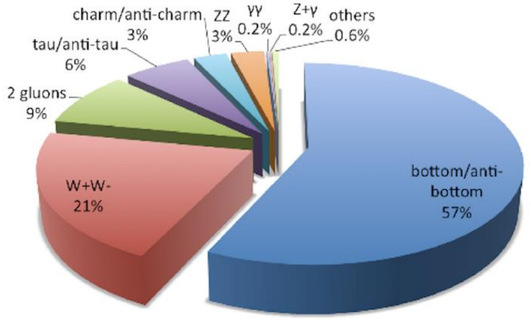
associated production with a gauge boson (VH)



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

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

Higgs decay



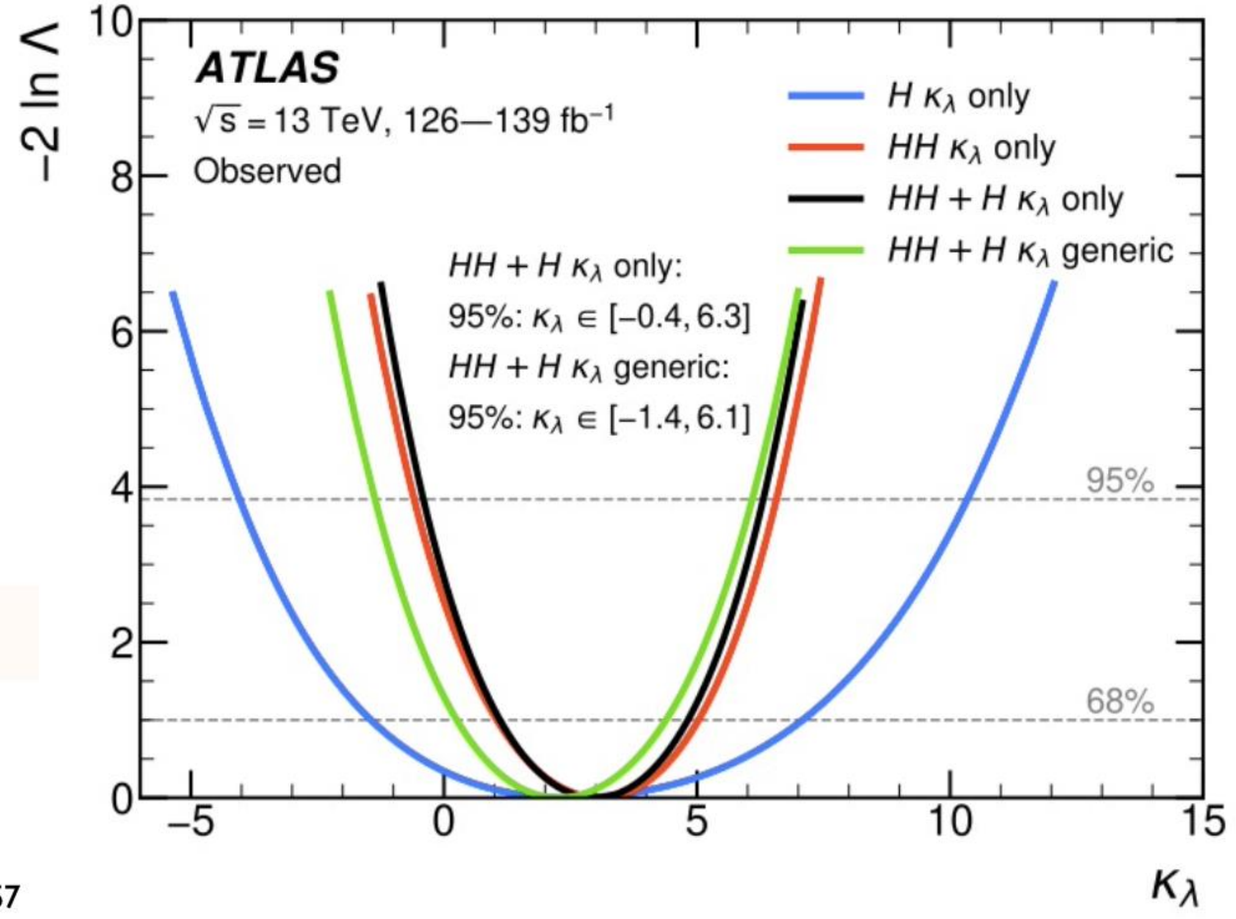
Higgs decay branching ratios

- Larger branching ratio (BR) for $H \to b\bar{b}$, $H \to WW^*$ and $H \to \tau\tau$, however poor mass resolution and large background contamination
- $H \to \gamma\gamma$ and $H \to ZZ^*(\to 4l)$ have lower BR, but high mass resolution; can be used for precision measurements

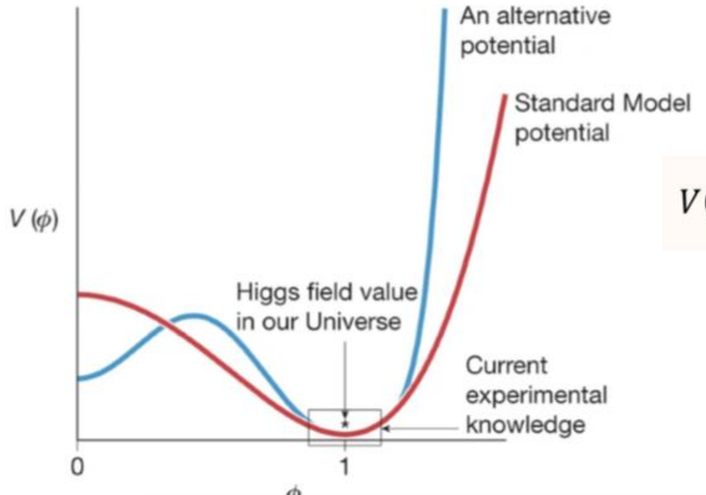
Combination of di-Higgs searches

- To directly explore the electroweak symmetry breaking and the Higgs self coupling
- HH → 4b, bbγγ, bbττ have been combined with single Higgs
- μHH: 2.4×SM (2.9×SM exp.) at 95% CL
- -0.4<κλ <6.3 @95%CL (HH+H combination)

Phys. Lett. B 843 (2023) 137745



[G. Salam, Nature 607, 41–47 (2022)]

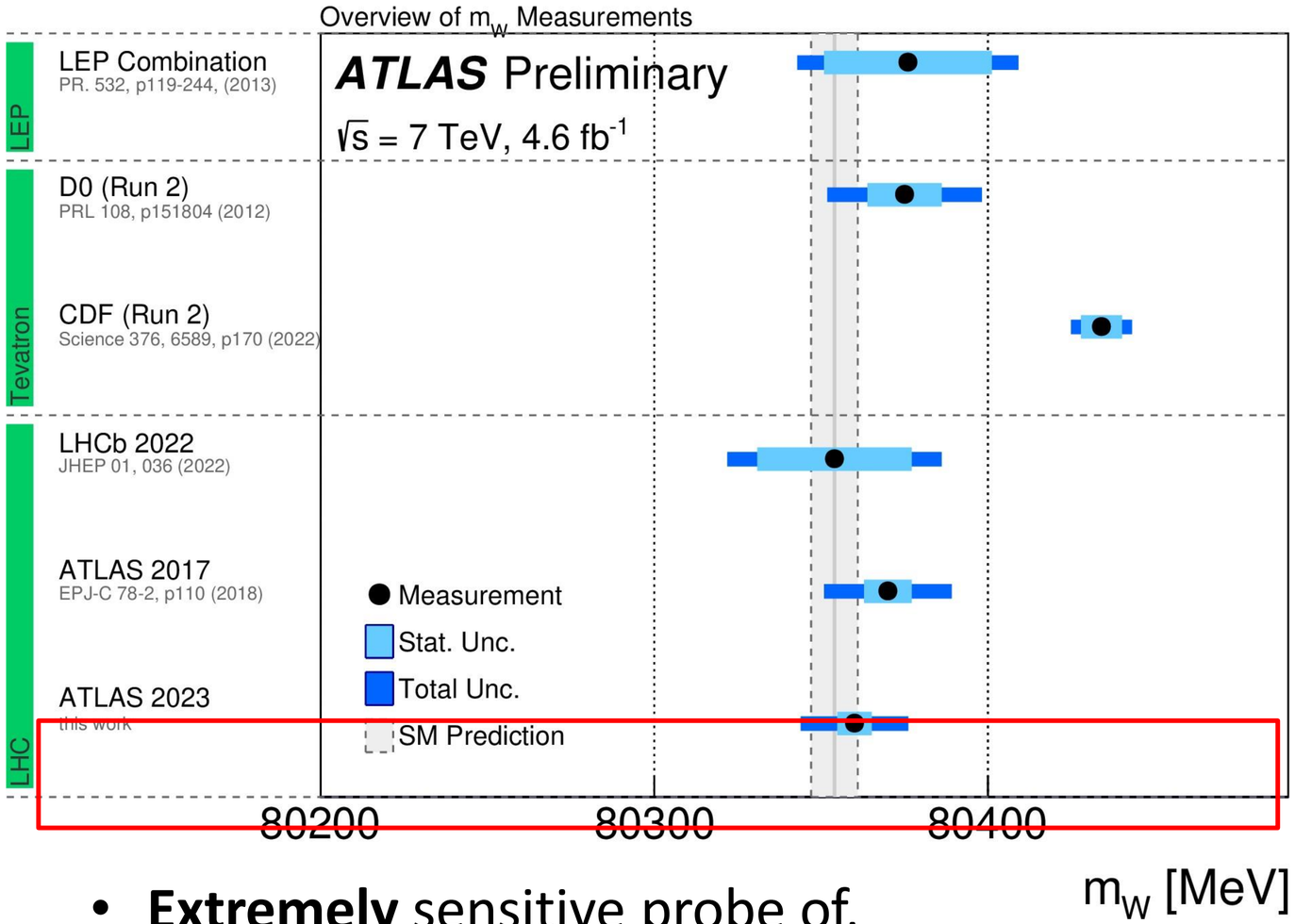


$$V(\phi) = -\frac{\mu^4}{4\lambda} - \mu^2 H^2 + \lambda v H^3 + \cdots$$

probing Higgs self-interaction and the shape of Higgs potential

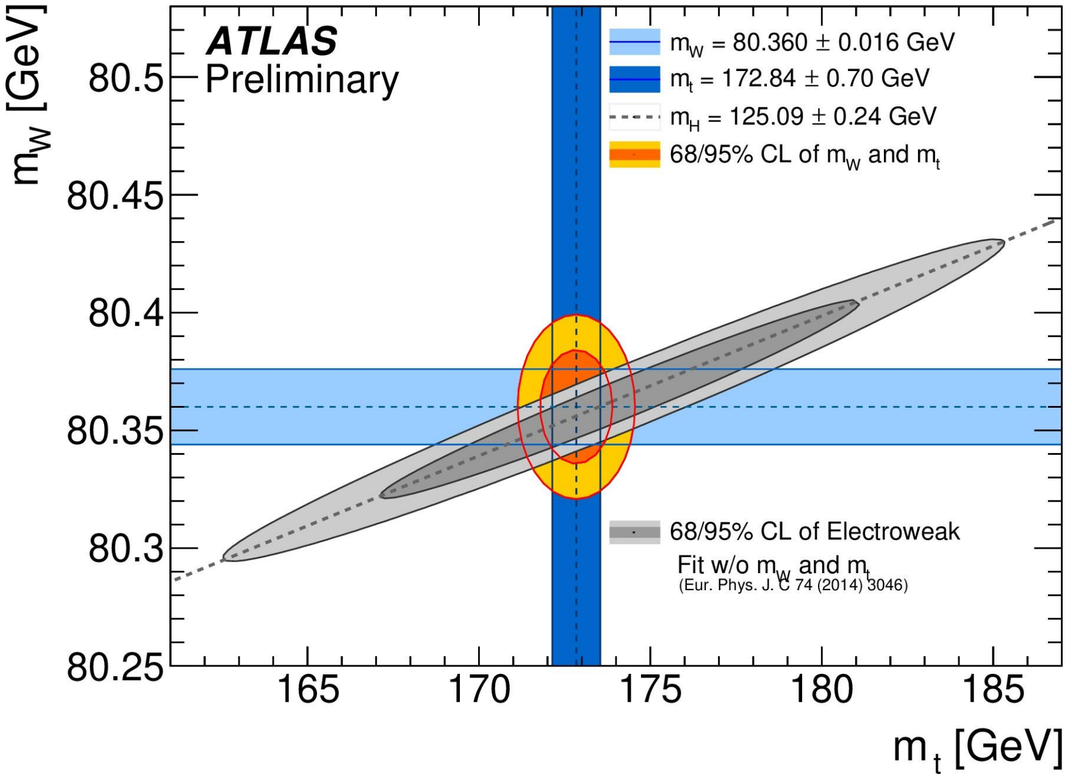
W boson mass with 7 TeV data

mW = 80360 ± 5 (stat.) ± 15 (syst.) = 80360 ± 16 MeV



- **Extremely** sensitive probe of, and constraint on, new physics

- Re-analysis: new log-likelihood fit constrains systematic uncertainties with data, more modern PDFs!



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