Beyond the SM searches: current status from the experiment side

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on behalf of the ATLAS and CMS Collaborations

CORFU2023 Workshop
on Future Accelerators
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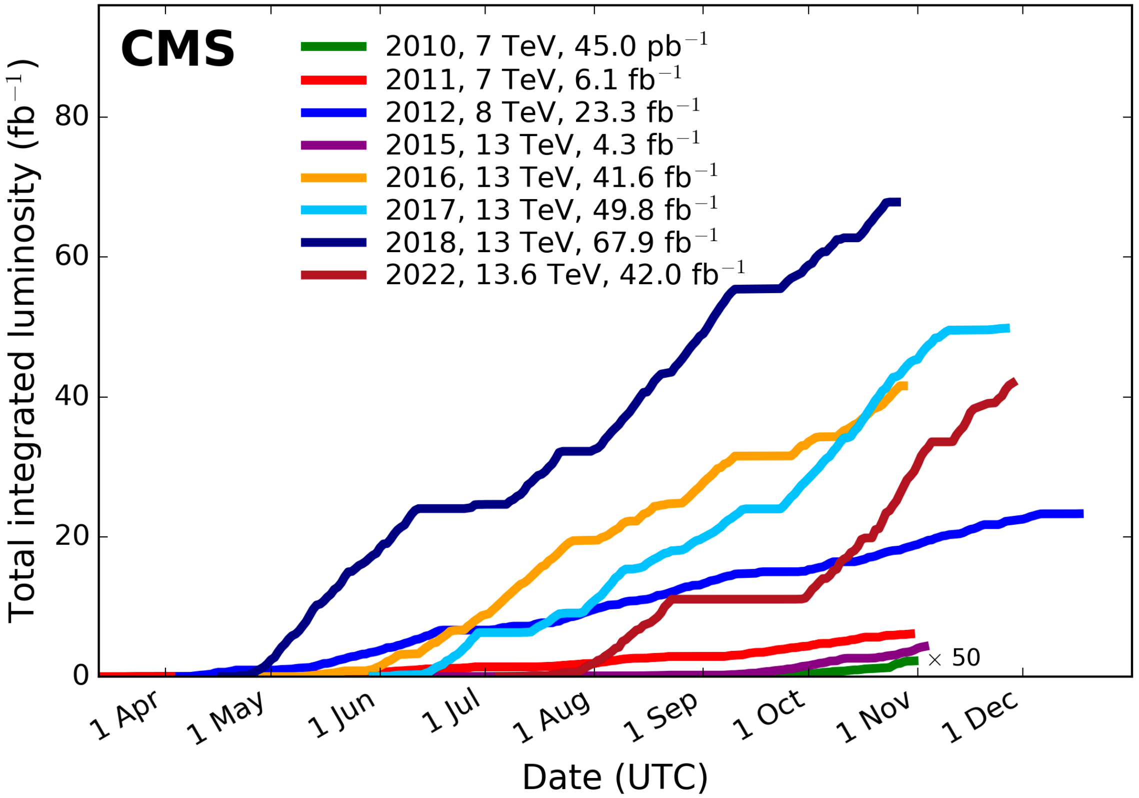
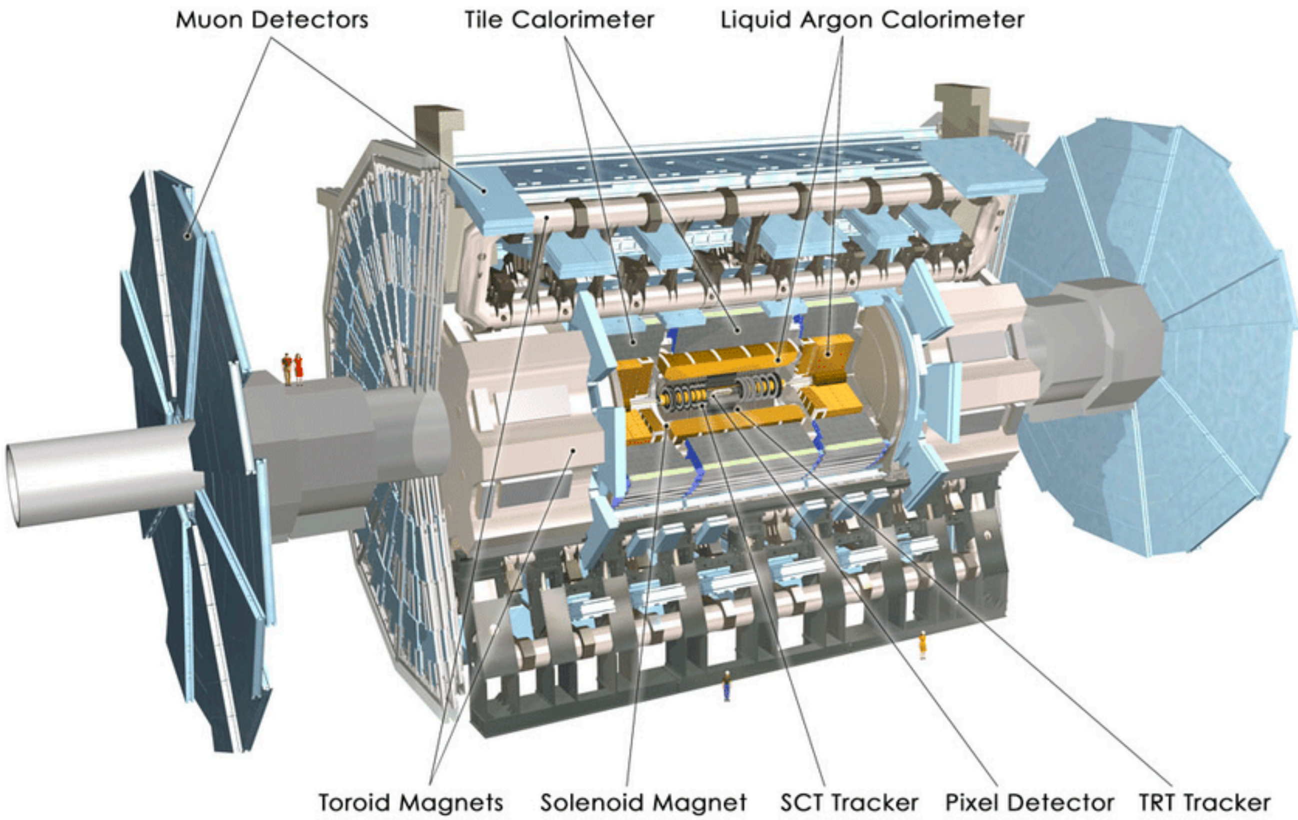
Introduction

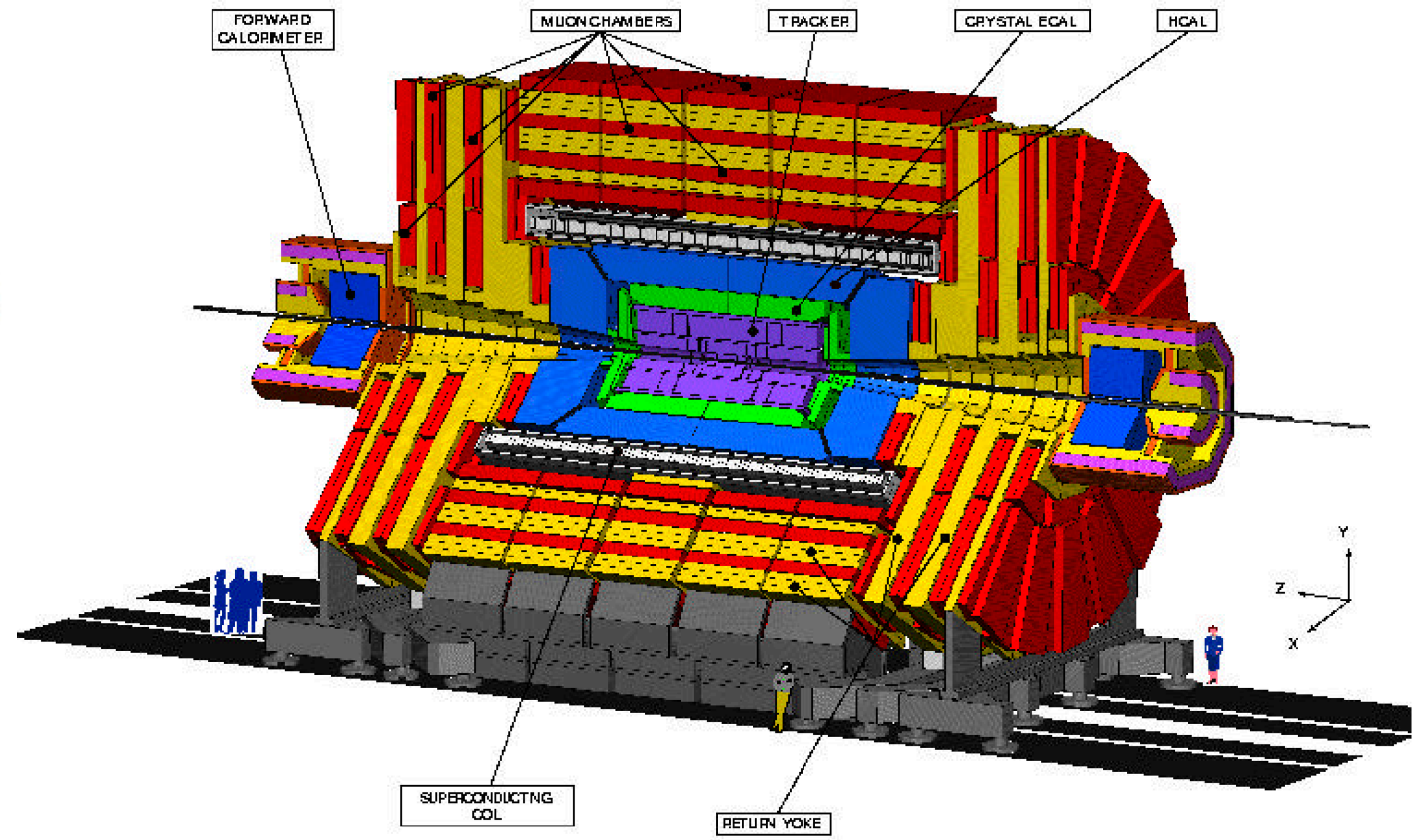
- The Large Hadron Collider is extremely powerful instrument to study fundamental processes
  at the energy frontier
  - Improve precision of the SM processes
  - Have an access to rare processes
  - Discover new processes for the first time

- Very successful Run 1 and 2 at the LHC
  - $\sqrt{s}$ = 8 TeV, Lumi = ~20/fb
  - $\sqrt{s}$ = 13 TeV, Lumi = ~140/fb



ATLAS and CMS Detectors

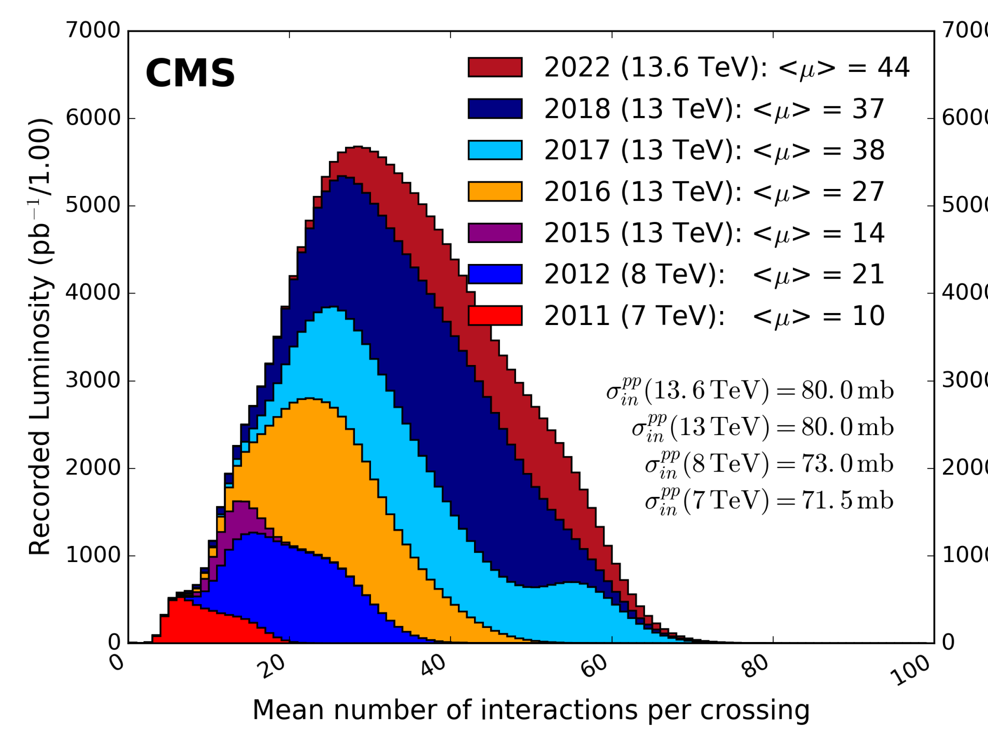




Multipurpose detectors with

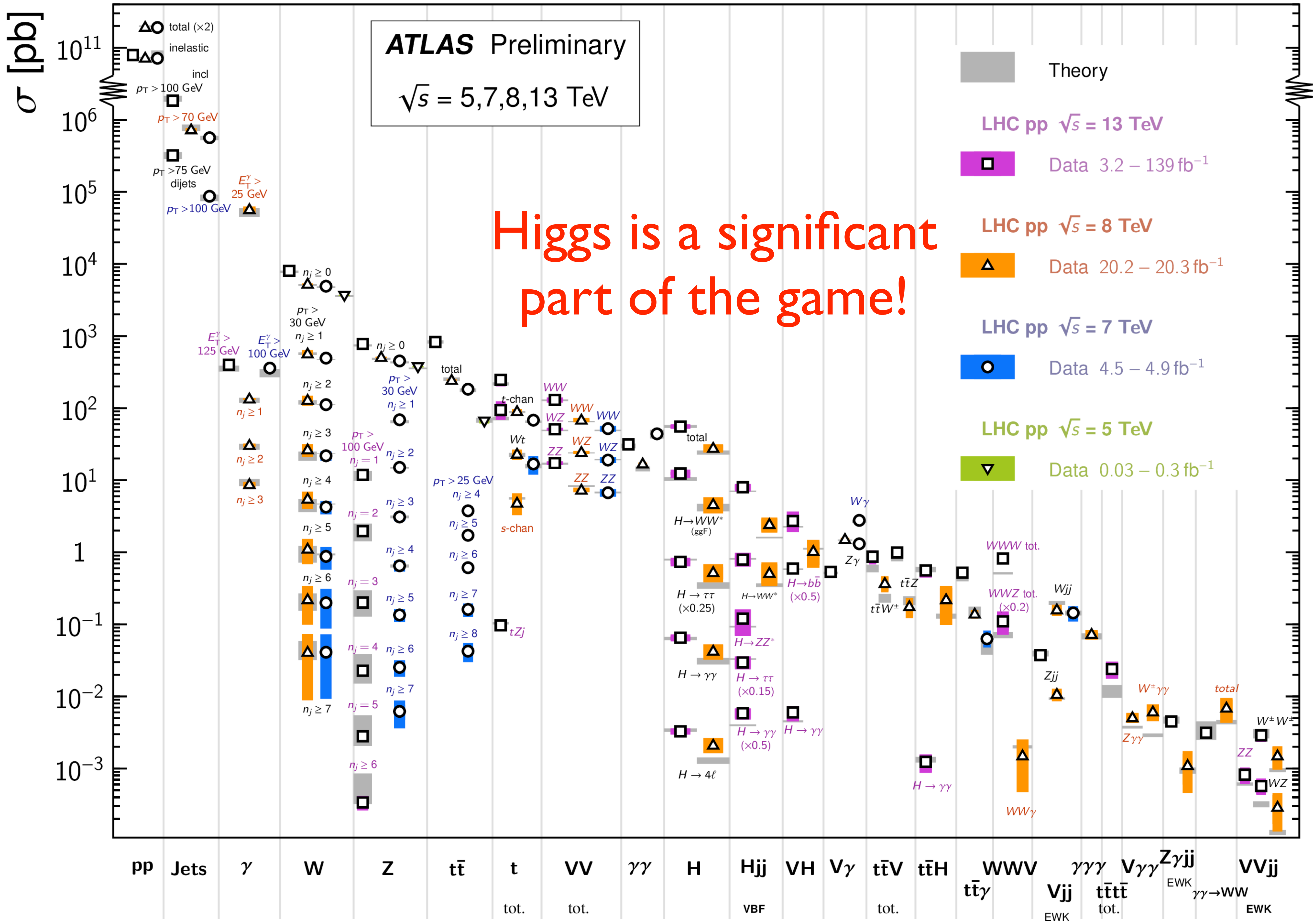
- Central tracking
- Calorimeter
- Muon detectors

Excellent performance even in high pileup environment with over 90% data-taking efficiency.



Standard Model Production Cross Section Measurements

Status: February 2022



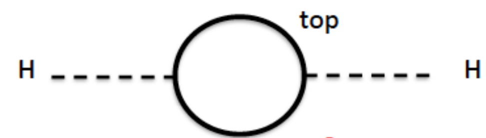
Higgs is a significant part of the game!

What the Higgs does not tell us?

at least, so far…

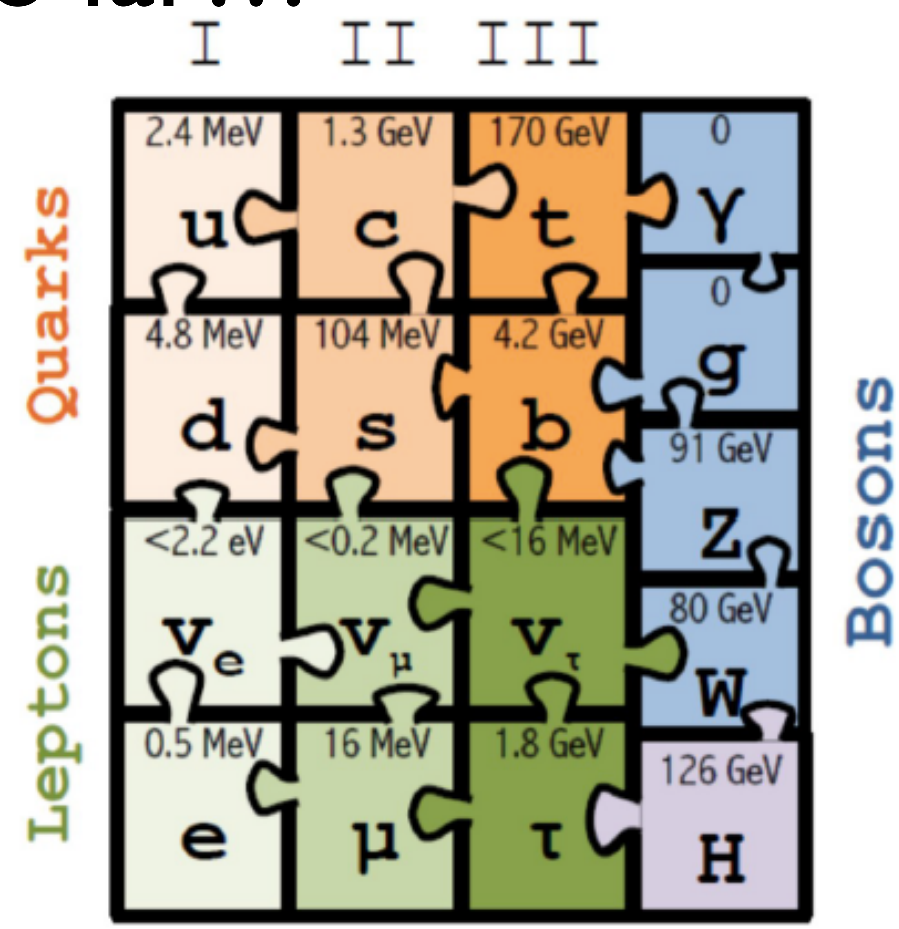
- Why Higgs mass is what it is?

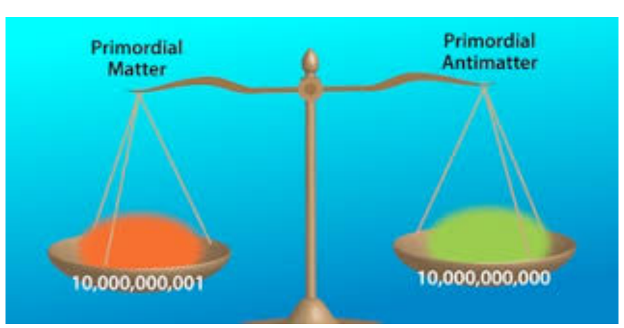
Higgs mass has calculable quantum corrections from highest mass scale in theory

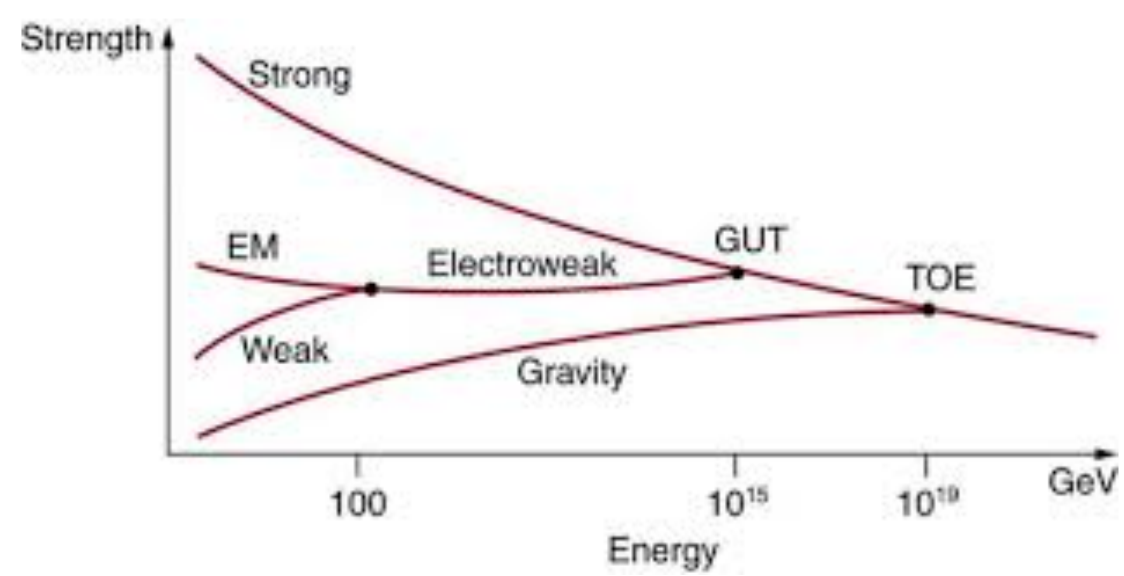


$$\delta M_H^2 = -\frac{3m_{top}^2}{8v^2\pi^2}\Lambda^2$$

- Are there other low/high mass Higgs particles?
- Why there are three generations of fermions?
- Can EM, weak, strong (& gravity) be unified?
- What happened to antimatter?

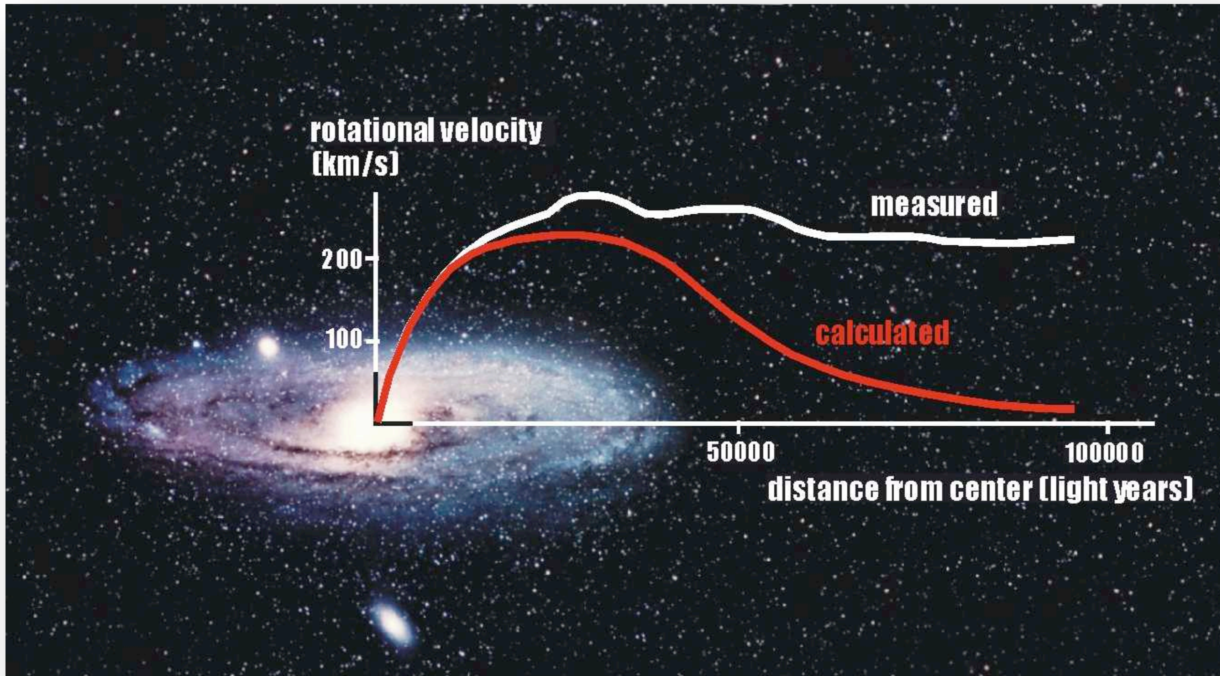


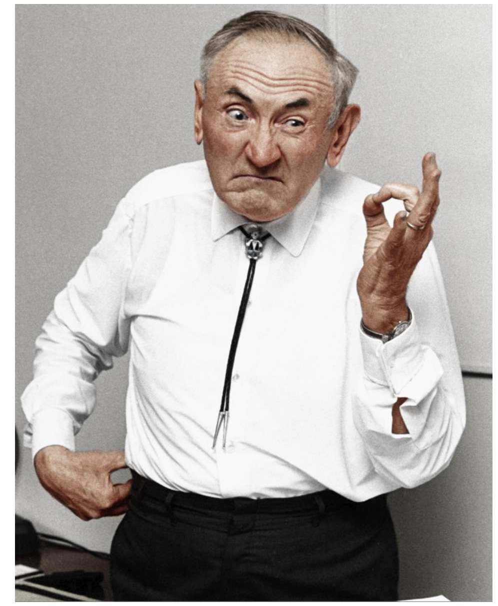


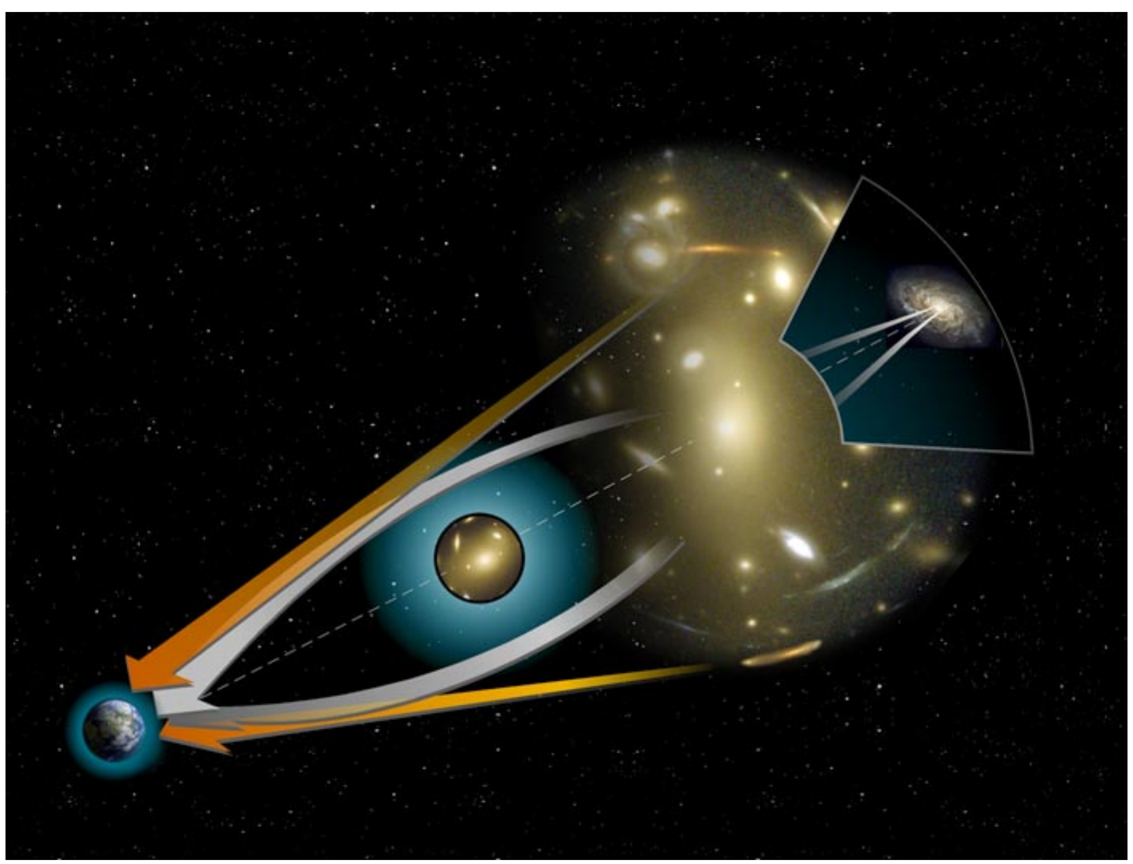


If the universe began from pure energy, we should have equal amounts of matter and antimatter.
But we see no naturally occurring anti-matter.

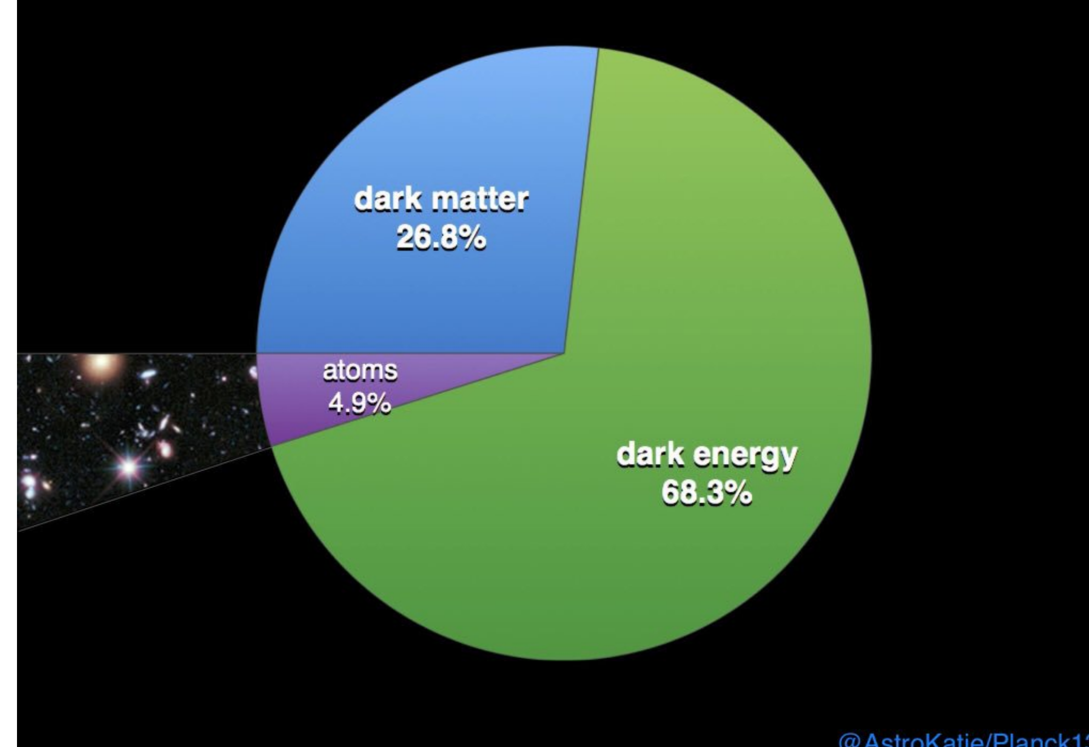
And, also Dark Matter…



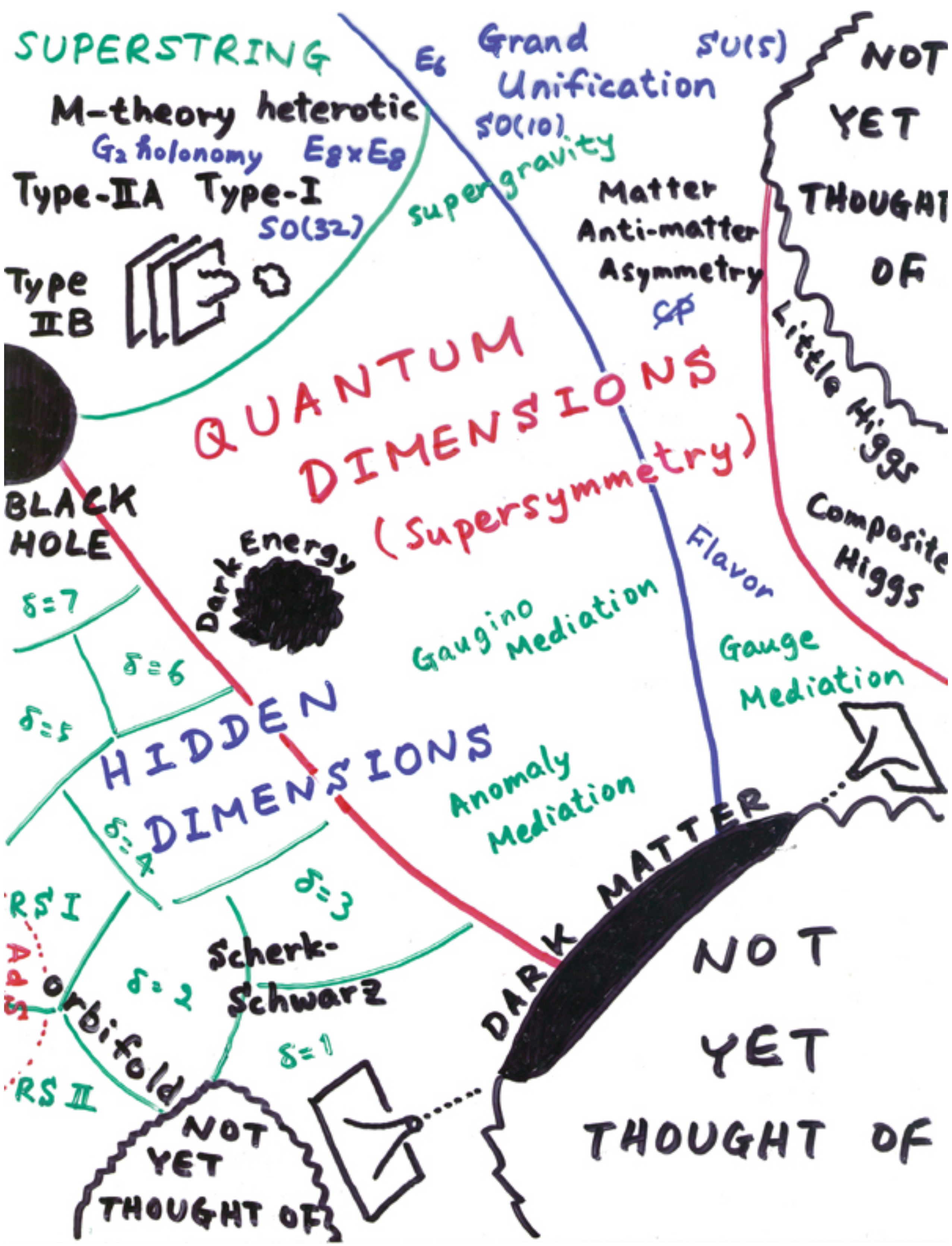




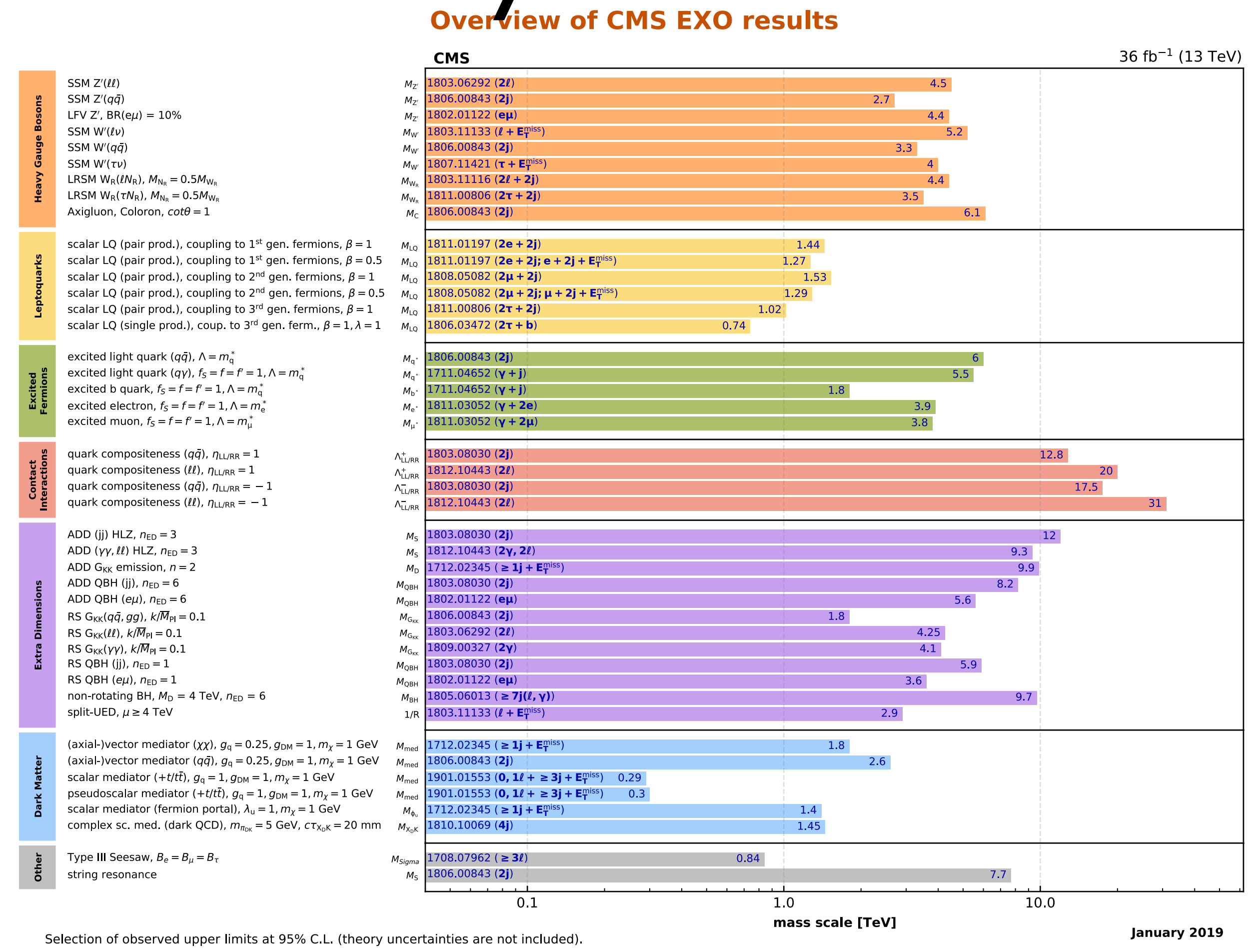
With the Higgs discovery we have 'just' understood ~5% of our universe

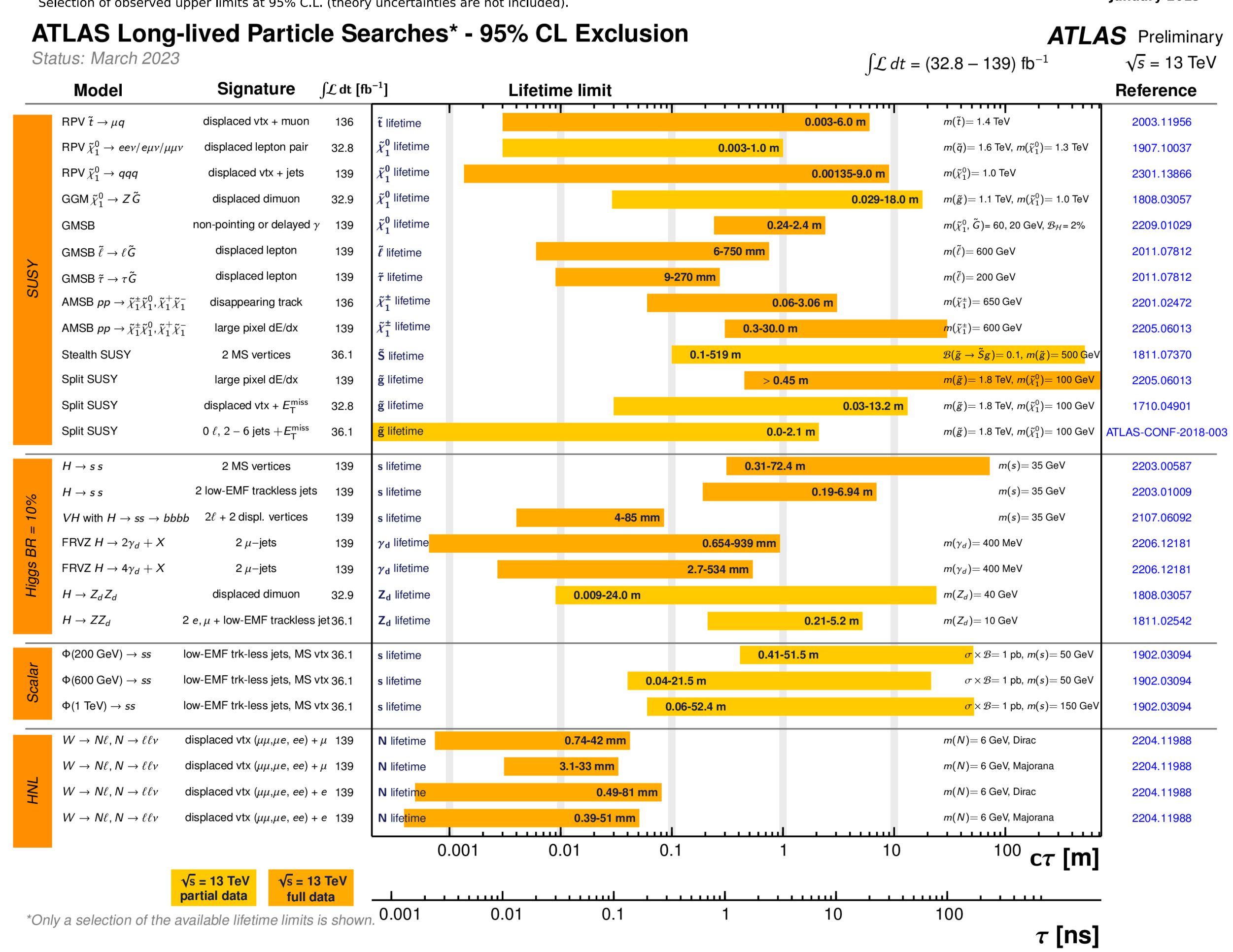


Many Theories



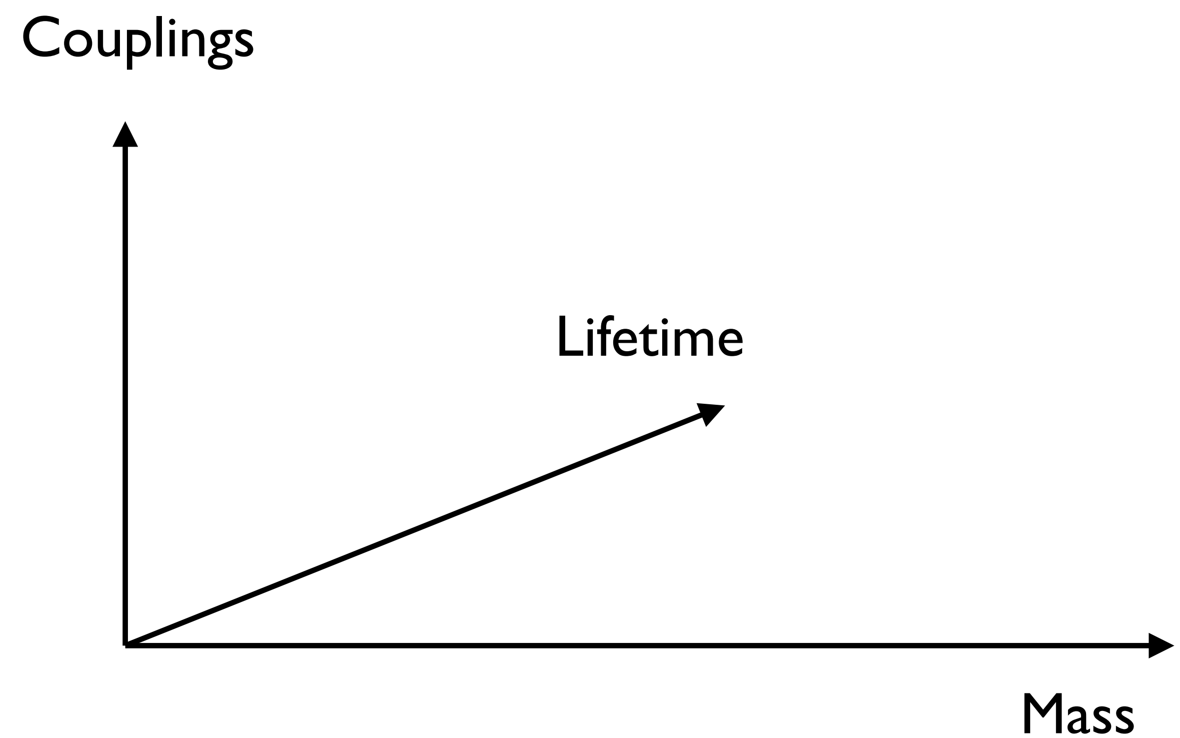
Many Searches



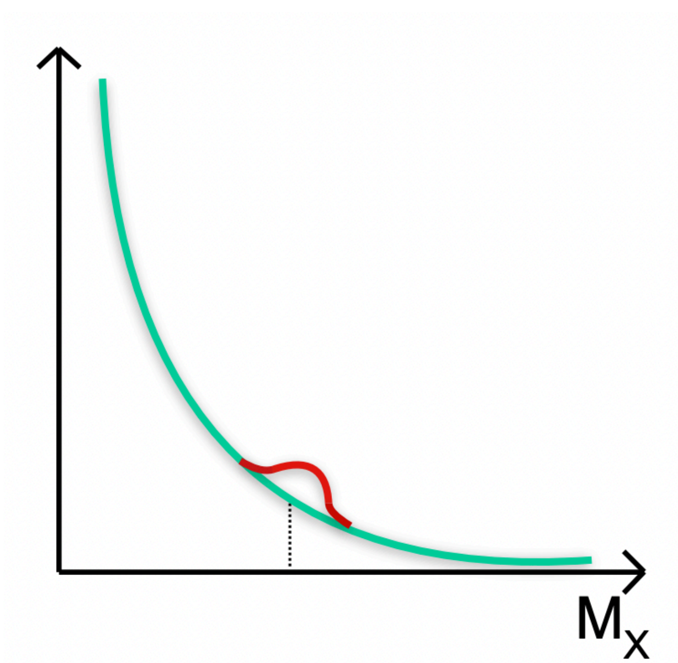


What we are going after?

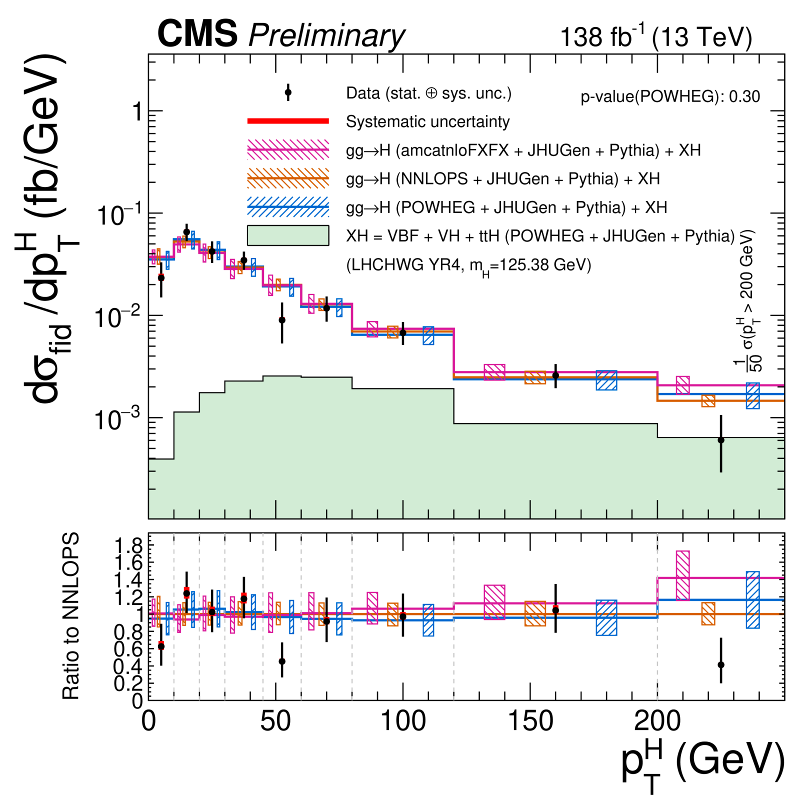
Looking for Unknown



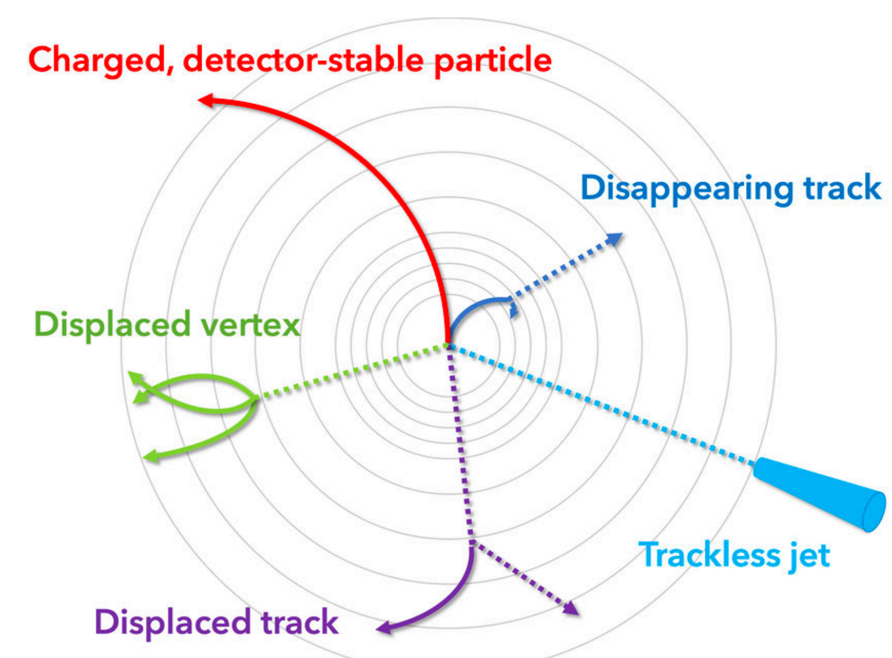
Limited by CME



Limited by data



Limited by detector acc.

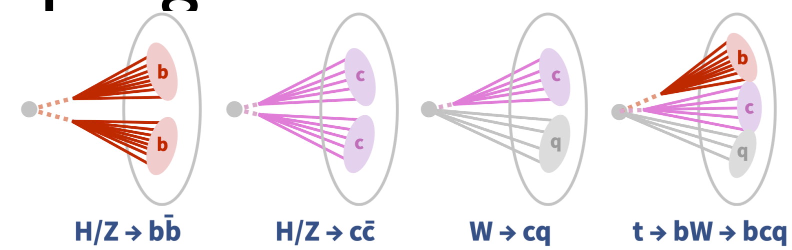


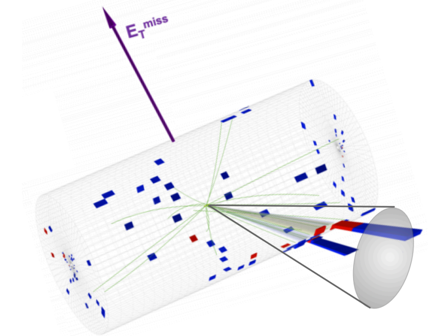
Focus

- I aim to present some of the latest results from ATLAS and CMS experiment focusing on
  - New methods and tools
  - Searches over broad mass and coupling range
  - Searches for long-lived particles
  - Searches to explain flavour anomalies
- All these are collected with a theme of "interesting and exciting hints"…
- Complete sets of BSM results can be found at
  - ATLAS
    https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HDBSPublicResults
    https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults
    https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults
  - CMS
    https://twiki.cern.ch/twiki/bin/view/CMS/B2G
    https://twiki.cern.ch/twiki/bin/view/CMS/SUS
    https://twiki.cern.ch/twiki/bin/view/CMS/EXOTICA

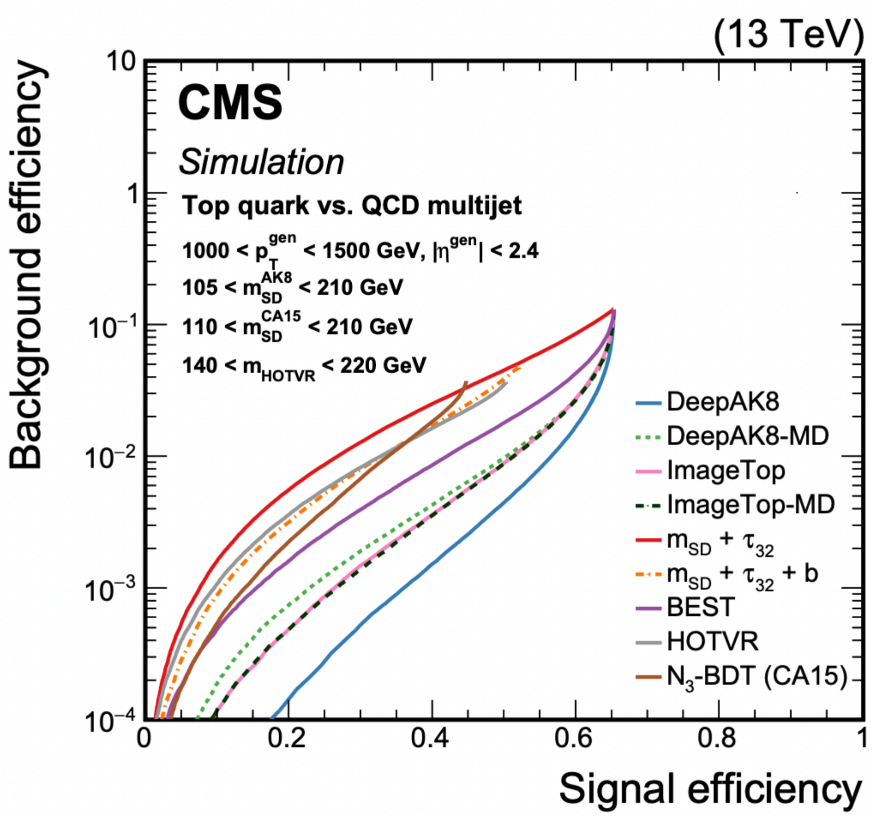
Boosted Jet Tagging and ML

- Jets are essential for the LHC physics program
  - Hadronic decays of highly boosted objects lead to distinct characteristics distinguishing



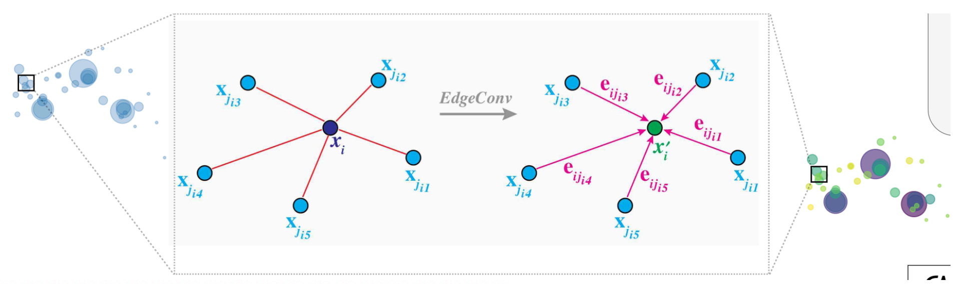


$\Delta R \sim \frac{2m}{p_T}$

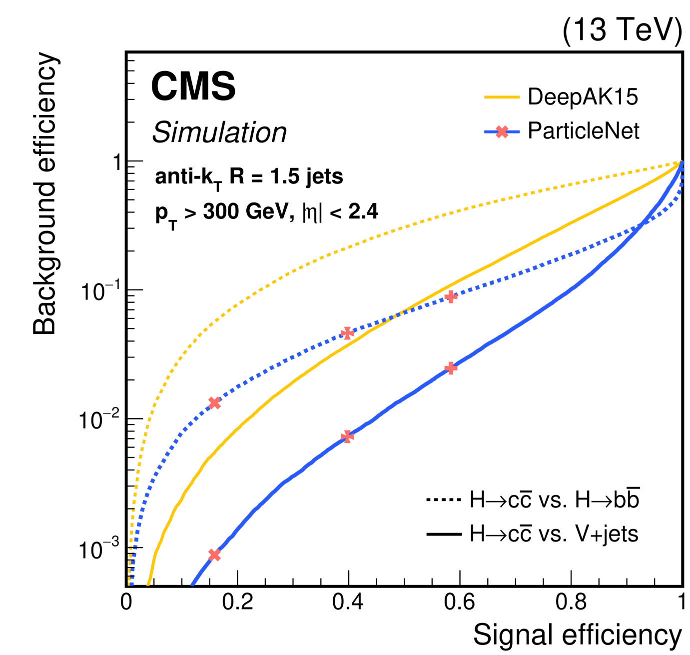


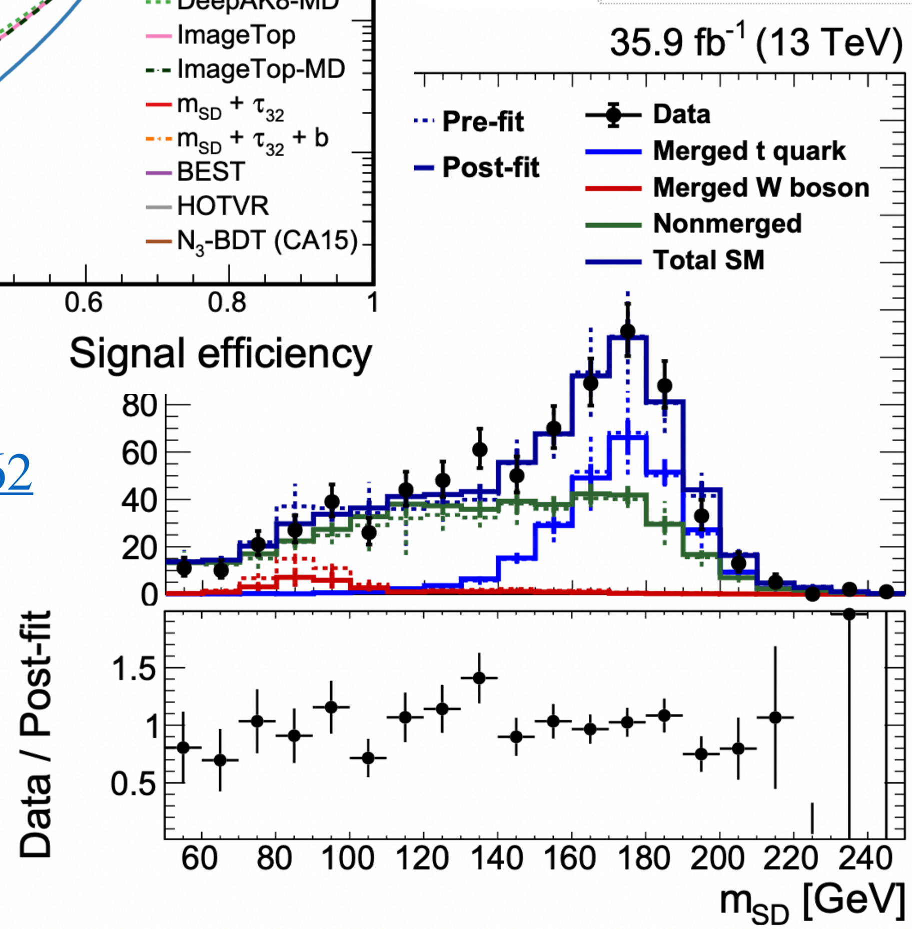
CMS arXiv:2004.08262

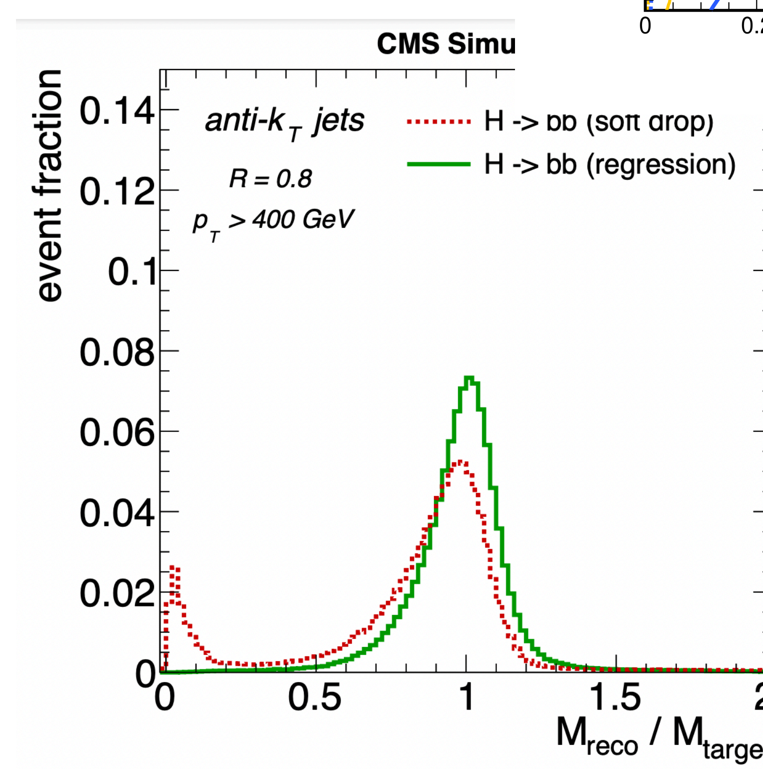
Jets: unordered set of particles
Using graph NN



CMS-DP-2021-017

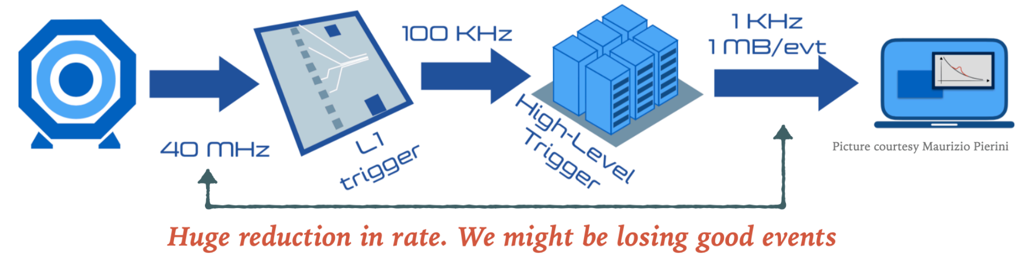






Significant improvement in the mass regression

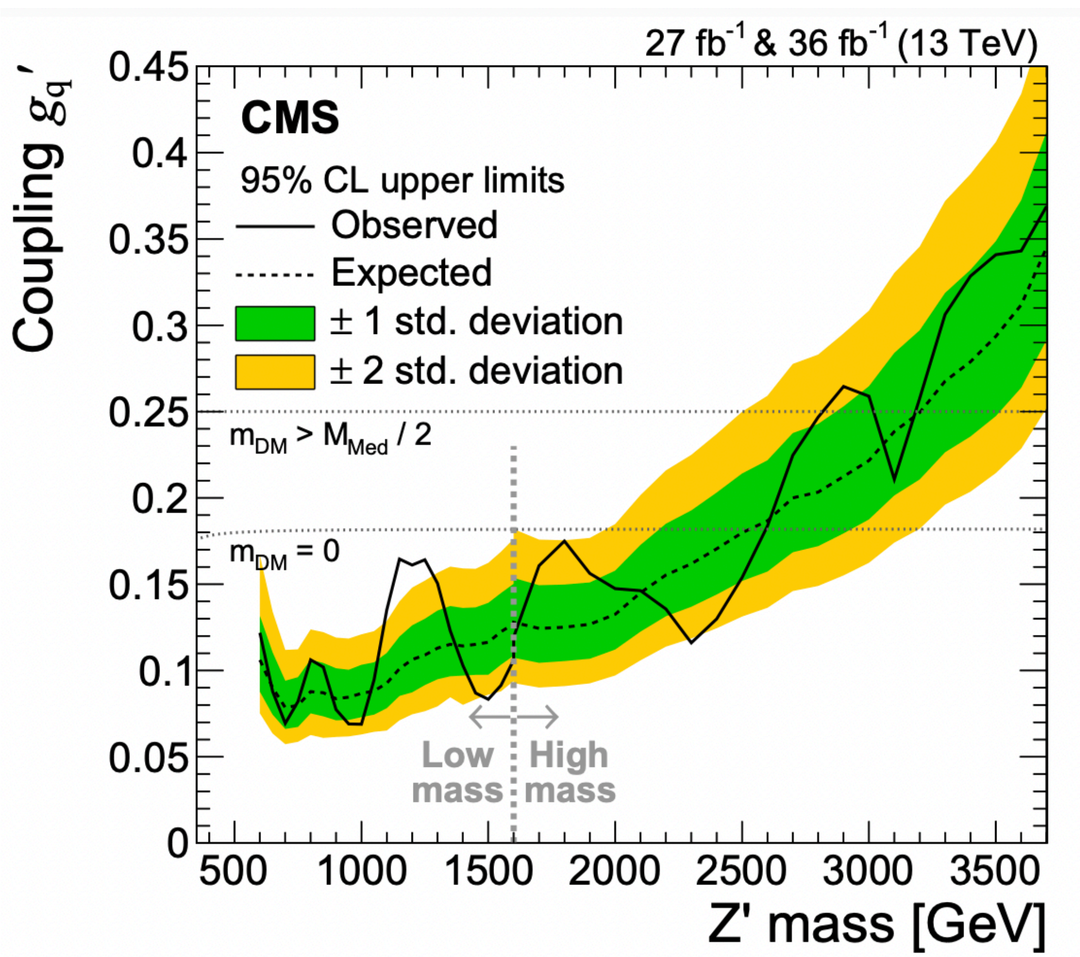
Data Scouting



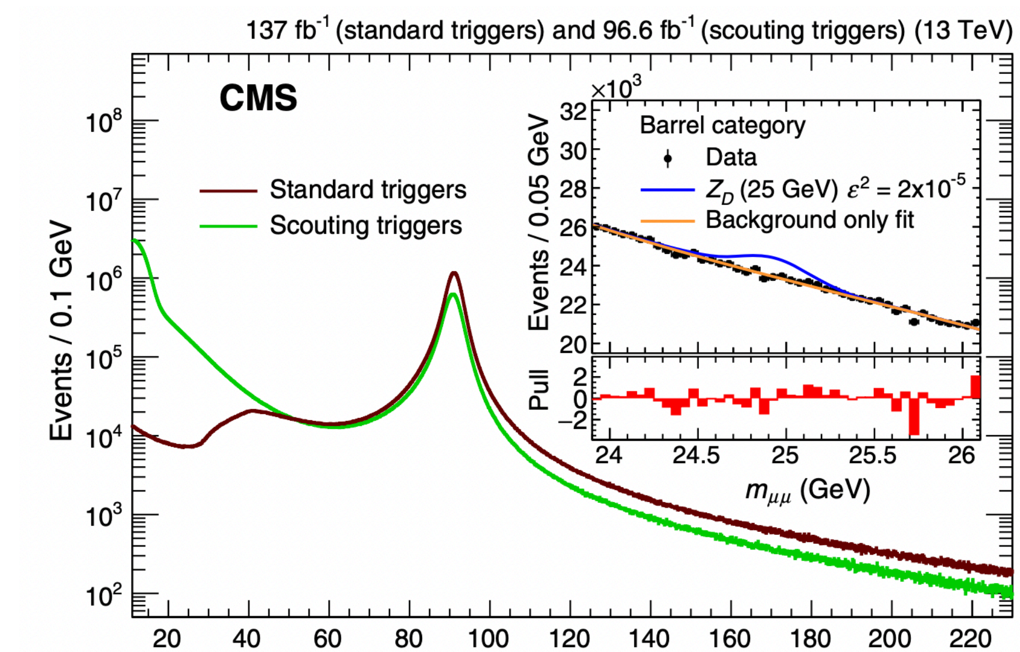
- Huge amount of data from the LHC. Trigger selection is gives priority to high pT objects
- Scouting: No offline reconstruction. Analyses based on the trigger objects
  - Used for both searches for hadronic and multi-muon final states

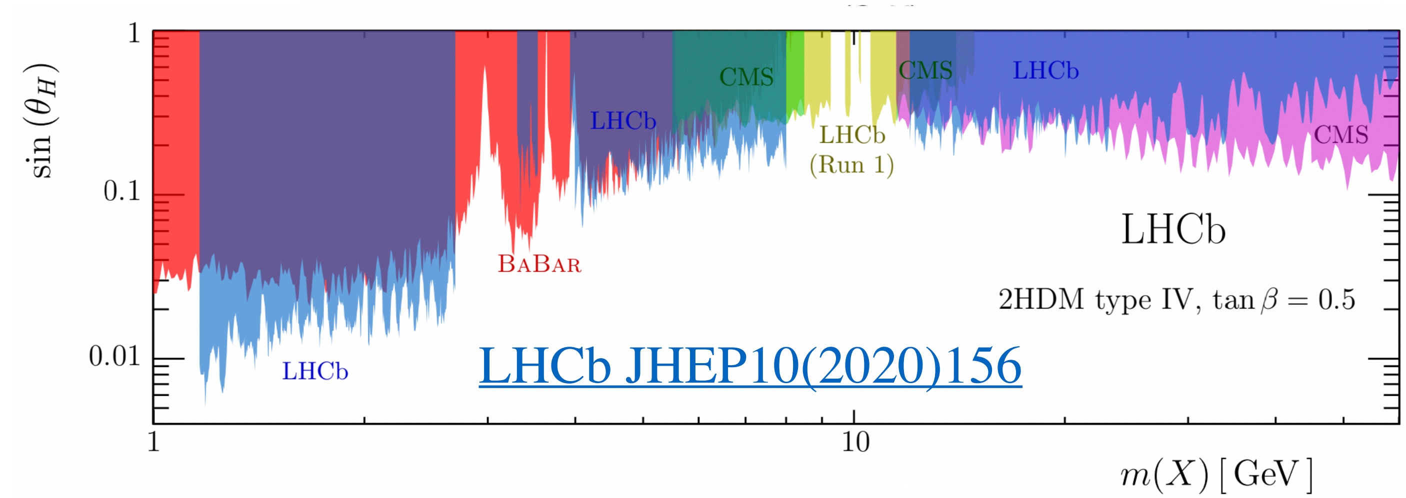
[CMS PRL 124.131802]

Interpreted for Dark Z boson or 2HDM with H-a mixing



[CMS arXiv:1806.00843]

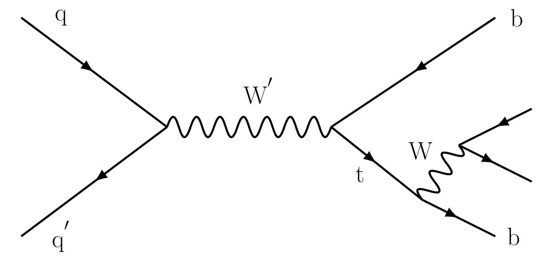




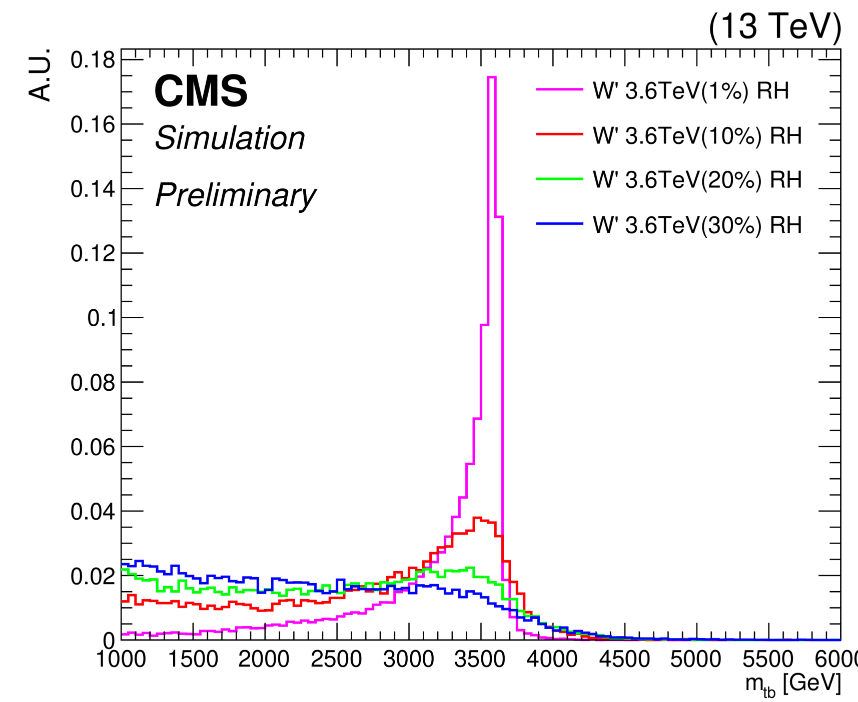
[LHCb JHEP10(2020)156]

[CMS-PAS-B2G-20-012](CMS-PAS-B2G-20-012)

High Mass Searches

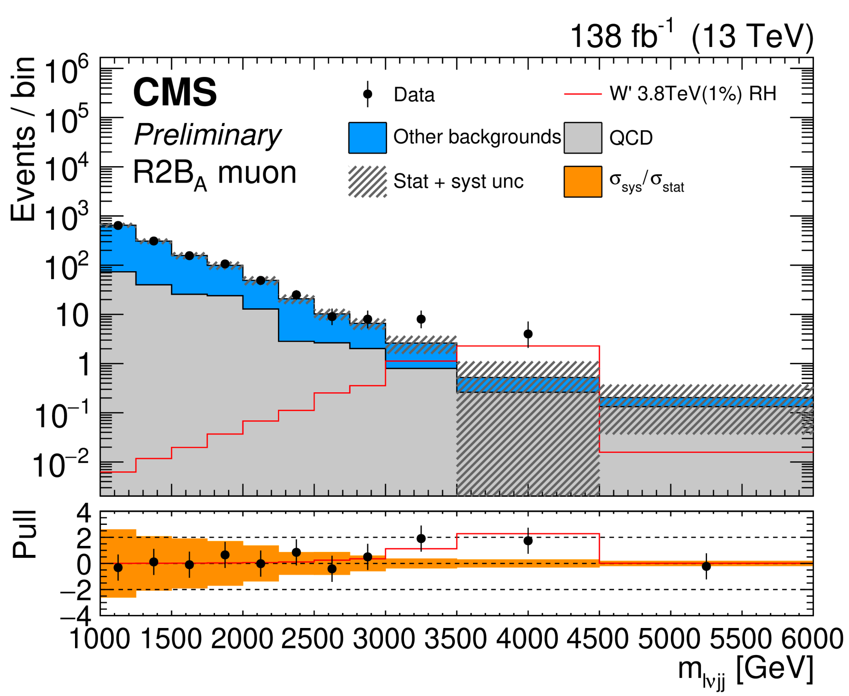


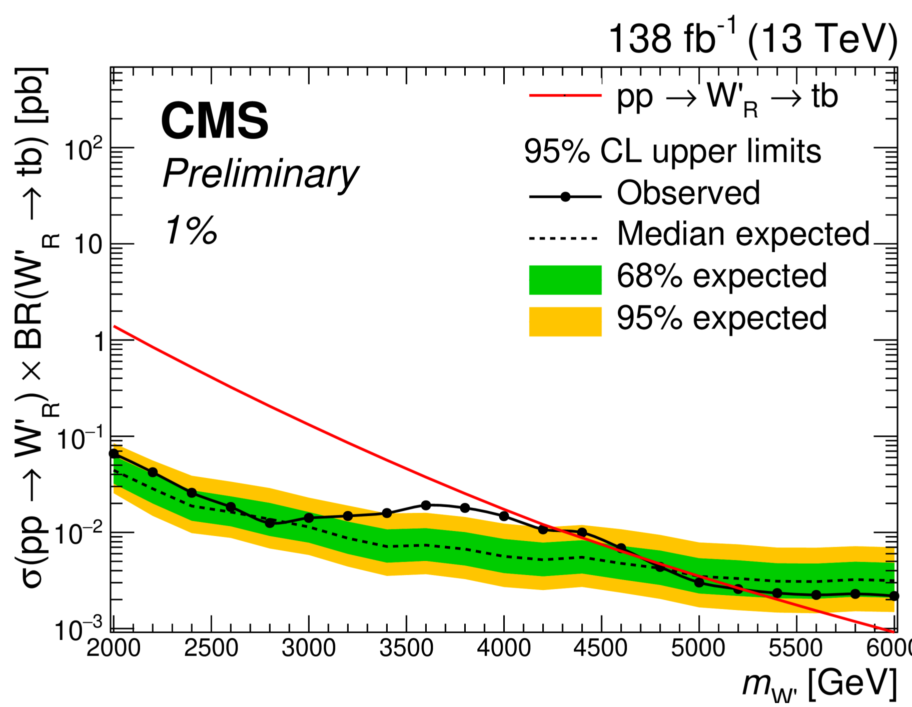
- Heavy SM-like W' resonance
  - Decaying preferentially to the third generation particles
  - Considering mass range 2 - 6 GeV, different width and chirality.
  - Constraining neutrino p_T by m_W; deciding a jet to be from top according to three body mass to be consistent to m_t, smallest ΔR between lepton and jet, picking lower pT jet.

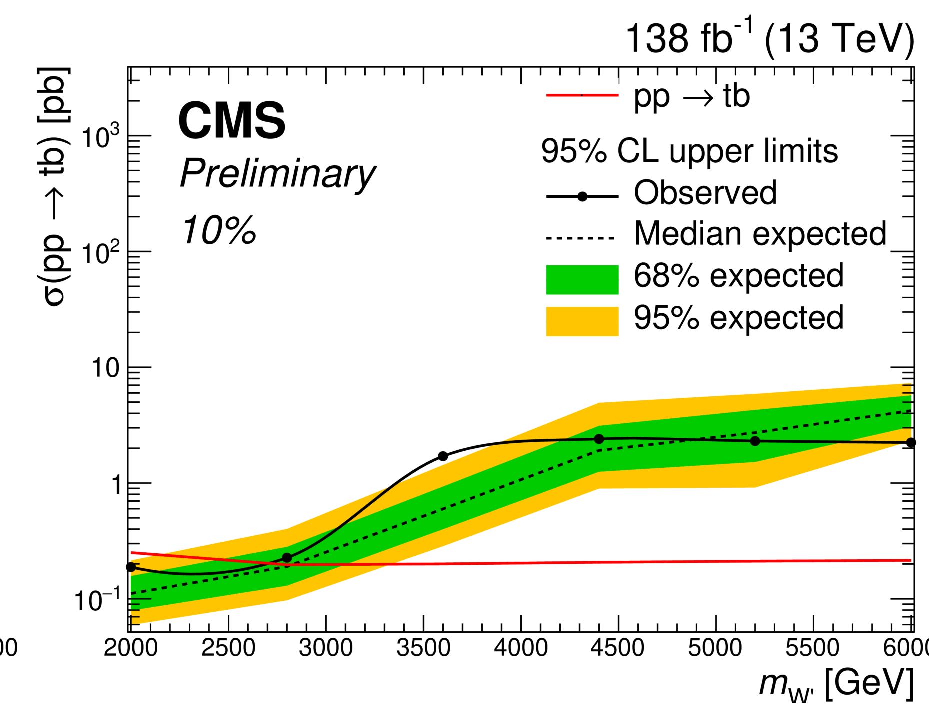


number of b jets	jet_{top} is a b-tagged jet	$jet_{W'}$ is a b-tagged jet	type of category (label)
0	no	no	Control region (R0)
	Signal-enriched regions		
1	yes	no	top jet region (RT)
1	no	yes	W' jet region (RW')
≥ 2	yes	yes	region with 2 b-jets (R2B)

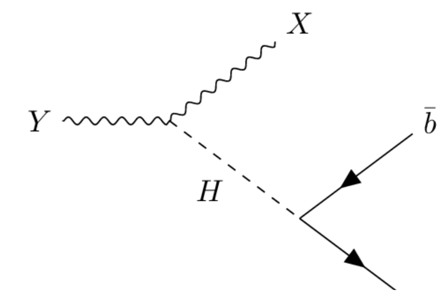
Largest excess around 3.8 TeV for 1% width and RH scenario with significance: 2.6 σ (2.0 σ)



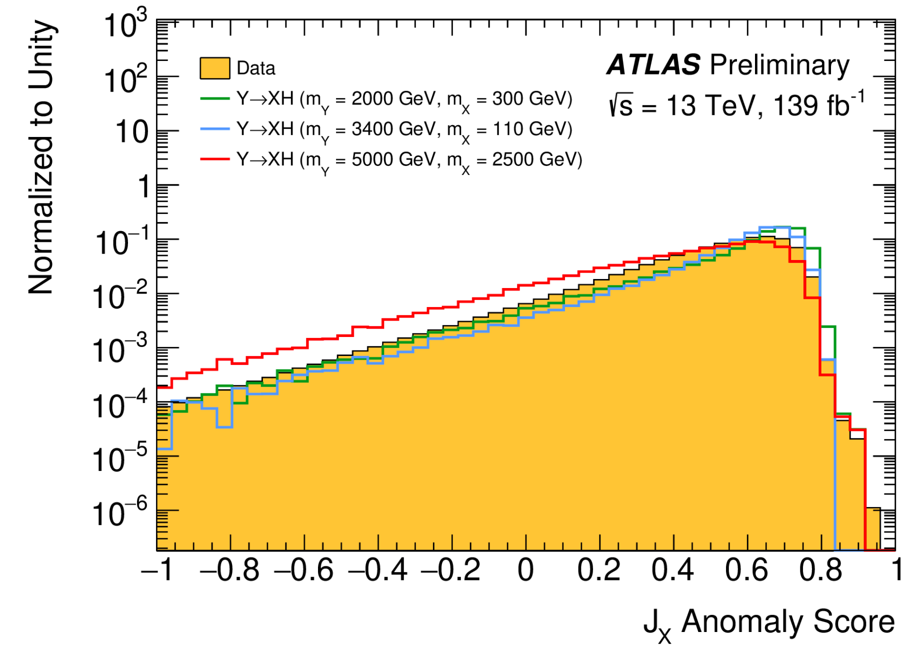


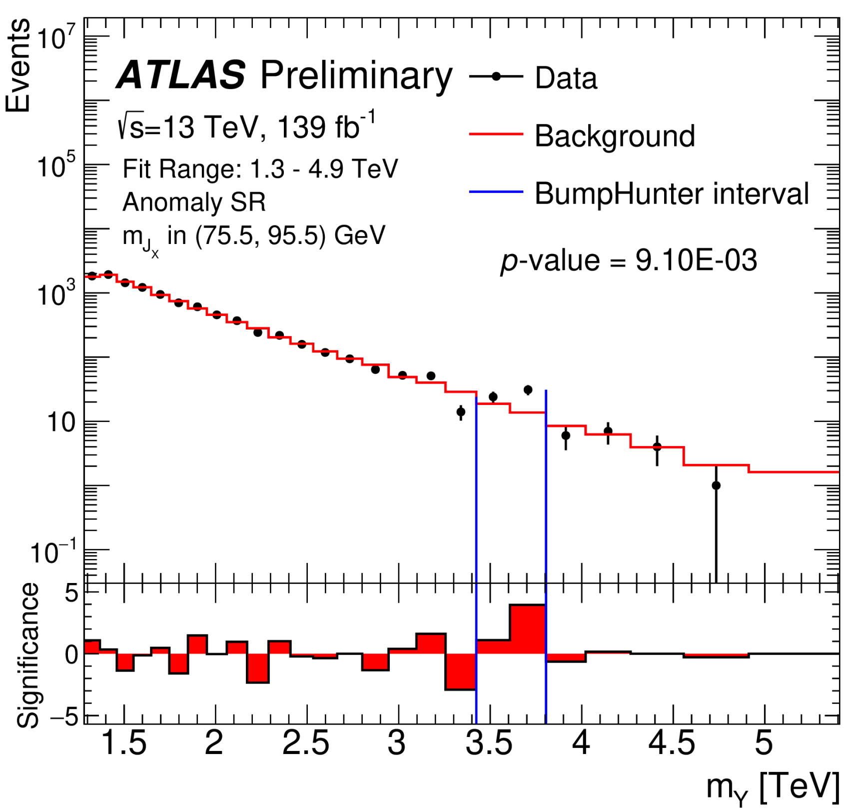


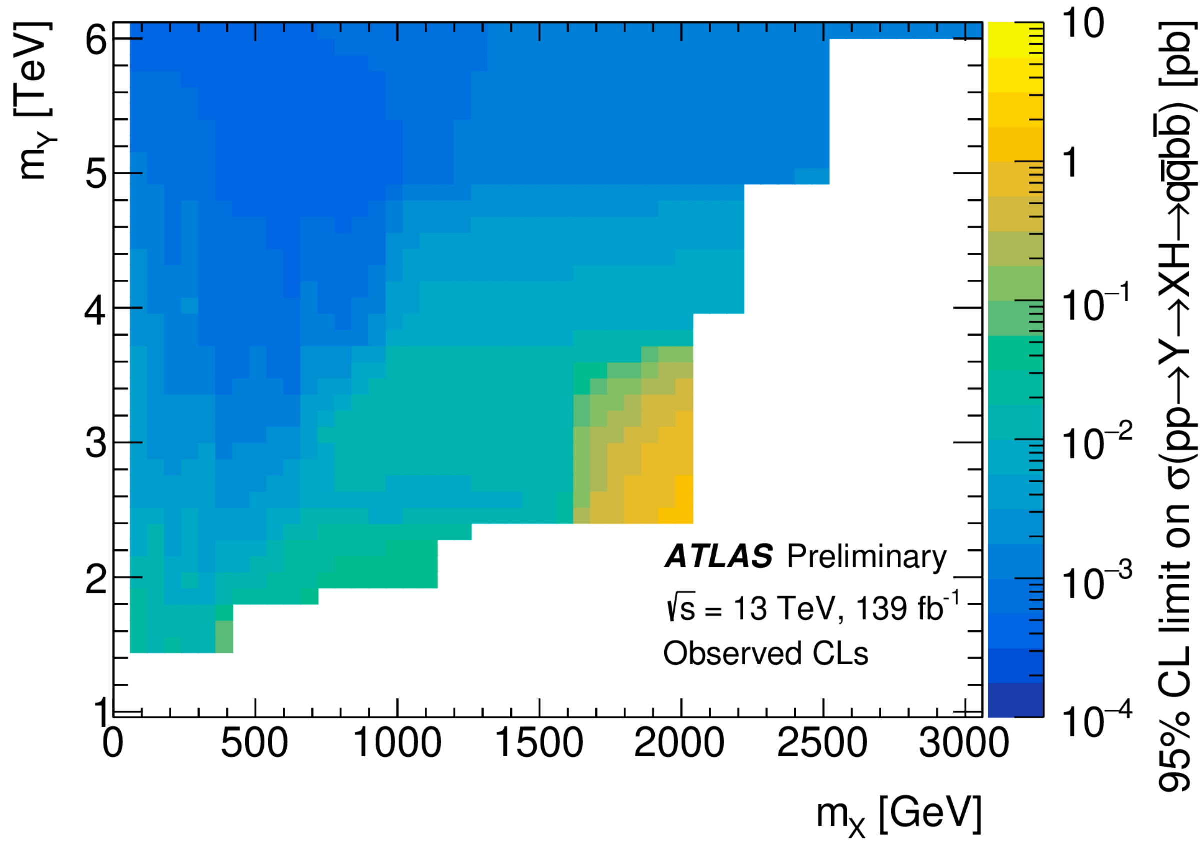
High Mass Searches



- Looking for very high mass resonance Y→XH→qqbb
  - 2HDM, Extra Dimensions, Heavy Vector Triplets
  - X and H could be boosted for specific Y(1.5 - 6 TeV) and X(65 - 3000 GeV) masses; Considering both resolved and boosted topologies
  - Novel jet-level implementation anomaly detection based on unsupervised ML training is used to select boosted X particles incompatible with the SM background.



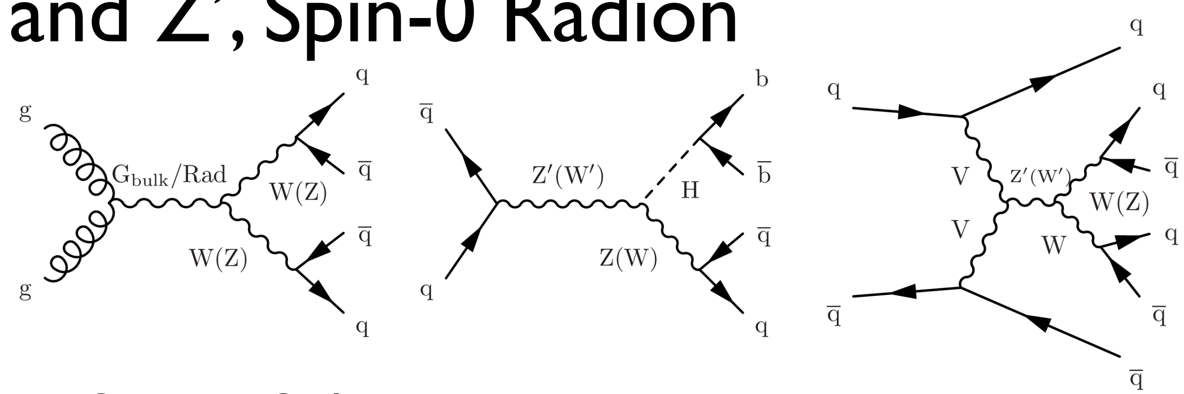




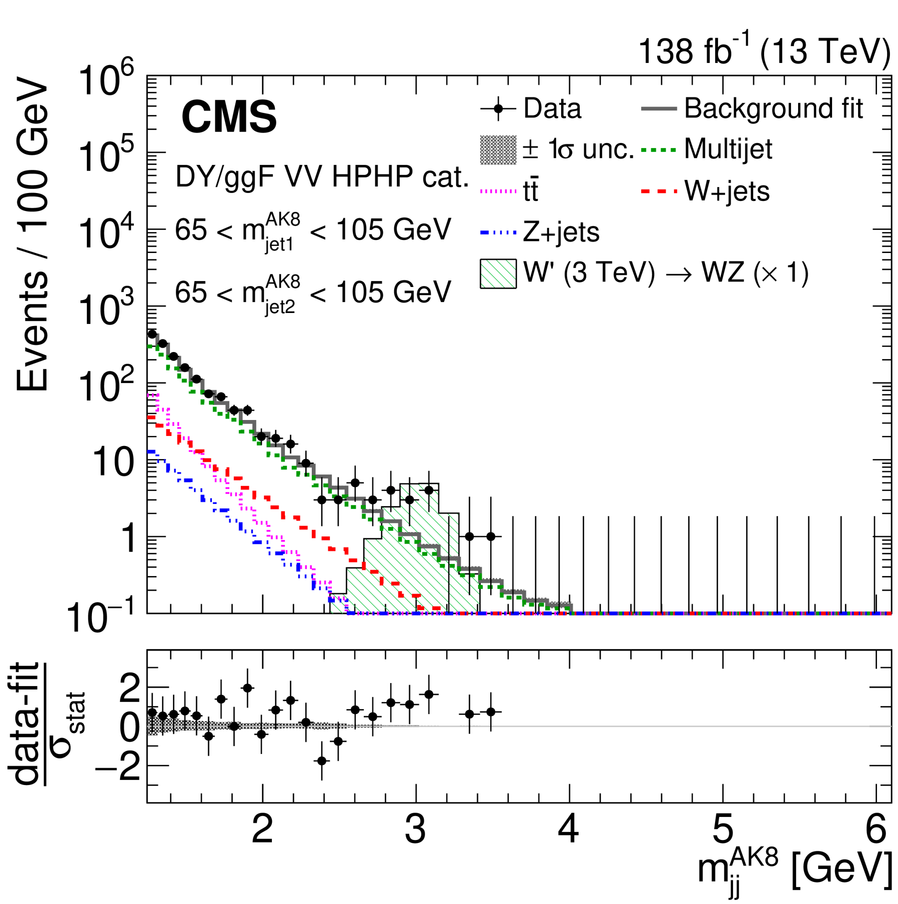
Largest deviation
@1.4σ (global)
m_X [75.5-95.5] GeV
m_Y [3424 - 3805] GeV

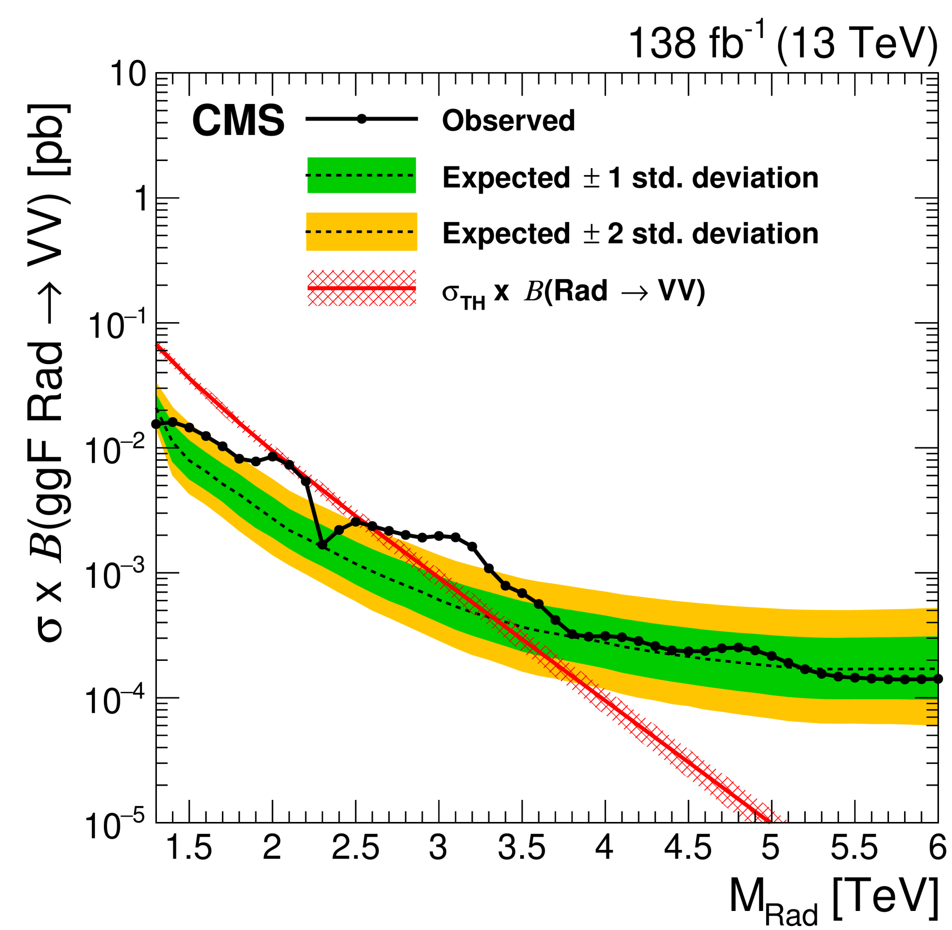
High Mass Searches

- Heavy Vector Triplet (HVT), Spin-1 W' and Z', Spin-0 Radion
- Boosted topologies are used
  - Two aK8 jets with or w/o two aK4 jets



- 3D observables: M_1(aK8):M_2(aK8):M_3(aK8$_1$,aK8$_2$)
- Events categorised based on ML analysing substructure of large-radius jets from W, Z, and H

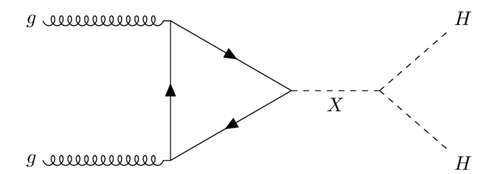




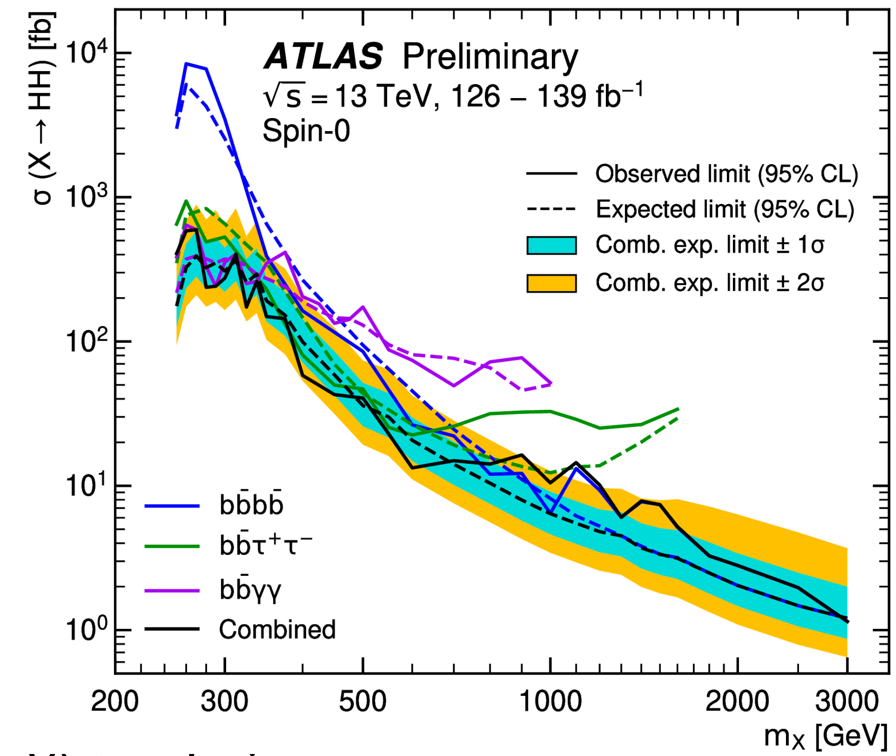
Excess around 2.1 and 2.9 TeV at 3.6 σ (2.3 σ)

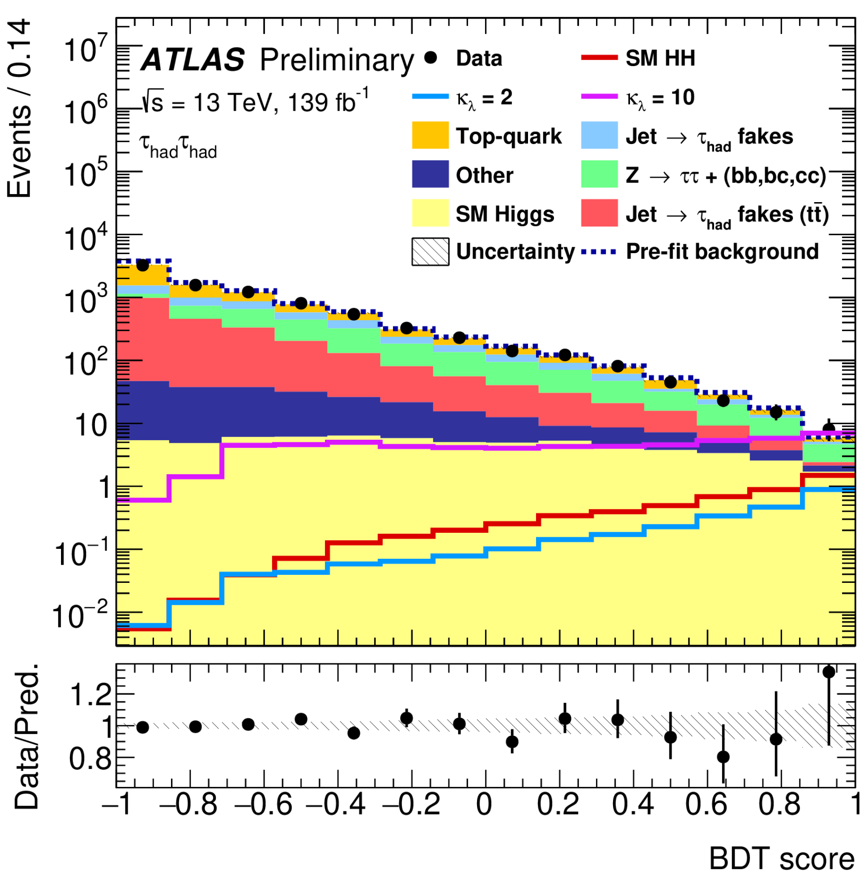
High Mass Searches

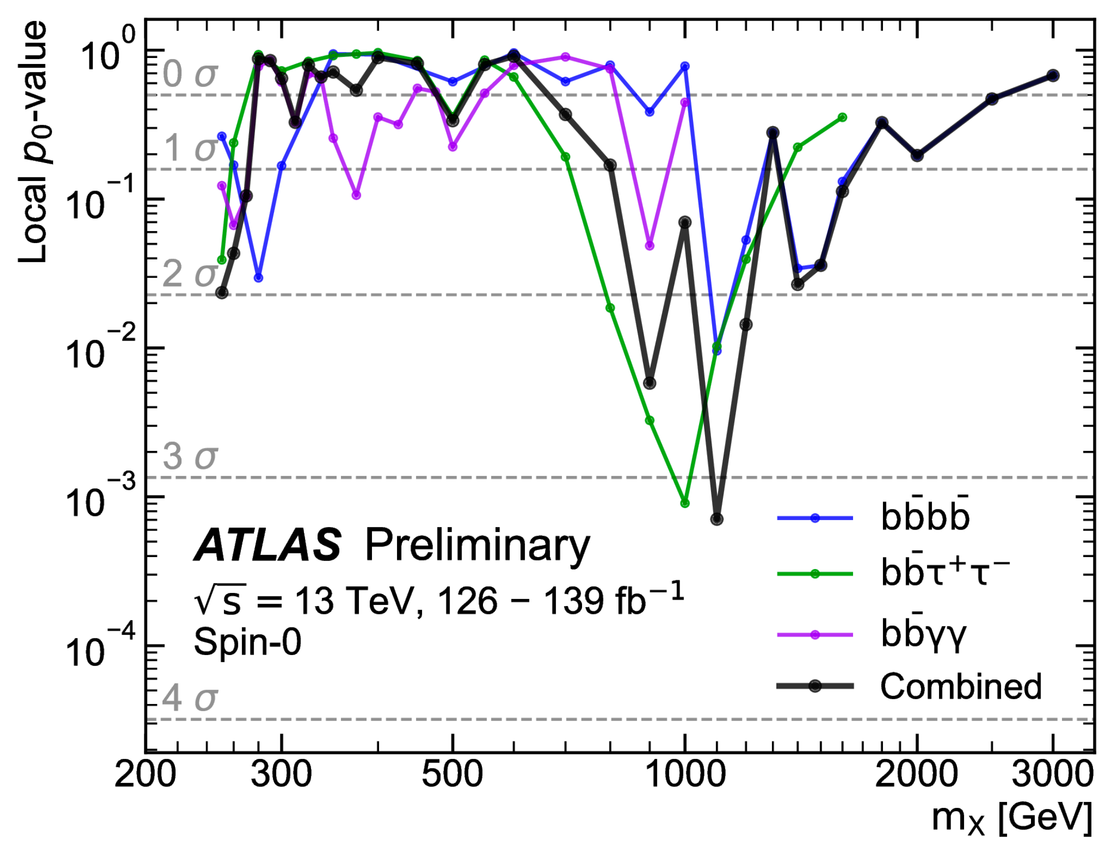
ATLAS-CONF-2021-052



- EW Singlet, 2HDM, MSSM predict di-H resonances
- Combining resonant Higgs pair-production searches.
  - bb$\gamma\gamma$ - final observable $m_{\gamma\gamma}$. Sensitive at low mass region. Search region: 251 - 1000 GeV.
  - bb$\tau\tau$ ($\ell\tau_h$ and $\tau_h\tau_h$ signatures) - final observable MVA. Sensitive at intermediate mass region. Search region: 251 - 1600 GeV.
  - bbbb - final observable m_{HH}. Sensitive at high mass region. Considering both resolved (search region 251-1500 GeV) and boosted (search region 900-3000 GeV) topologies.



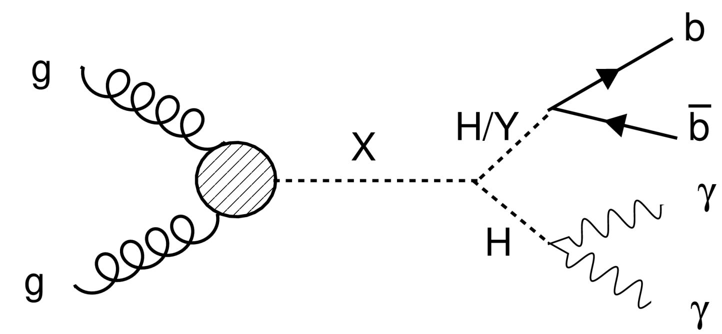




Excess around 1.1 TeV at 3.2 σ (2.1 σ)

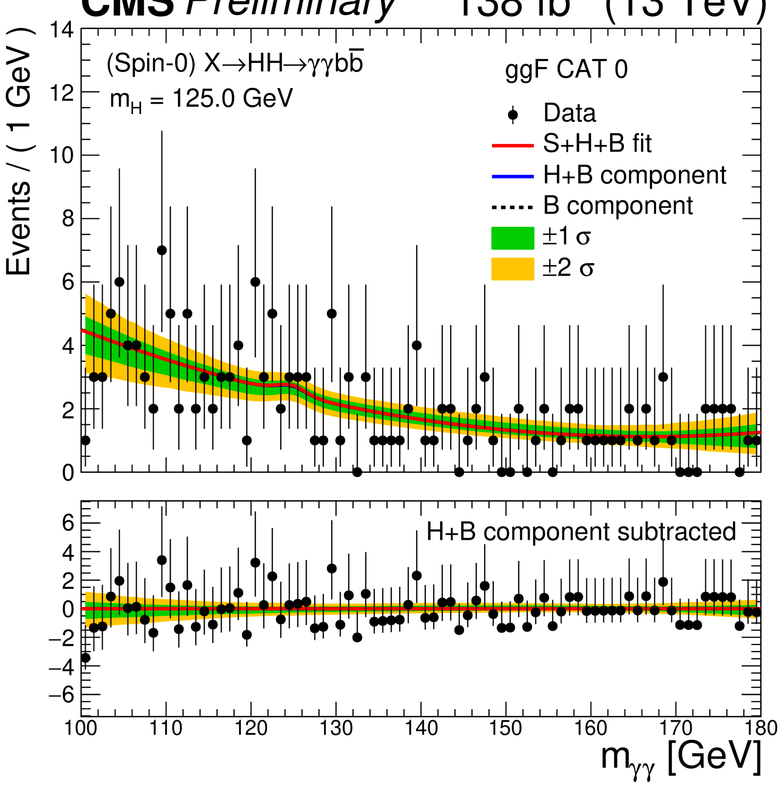
High Mass Searches

- Motivated from ED, NMSSM, Two-Real-Scalar-Singlet extension of SM (TRSM): X→HH (bulk-R) or HY(NMSSM)

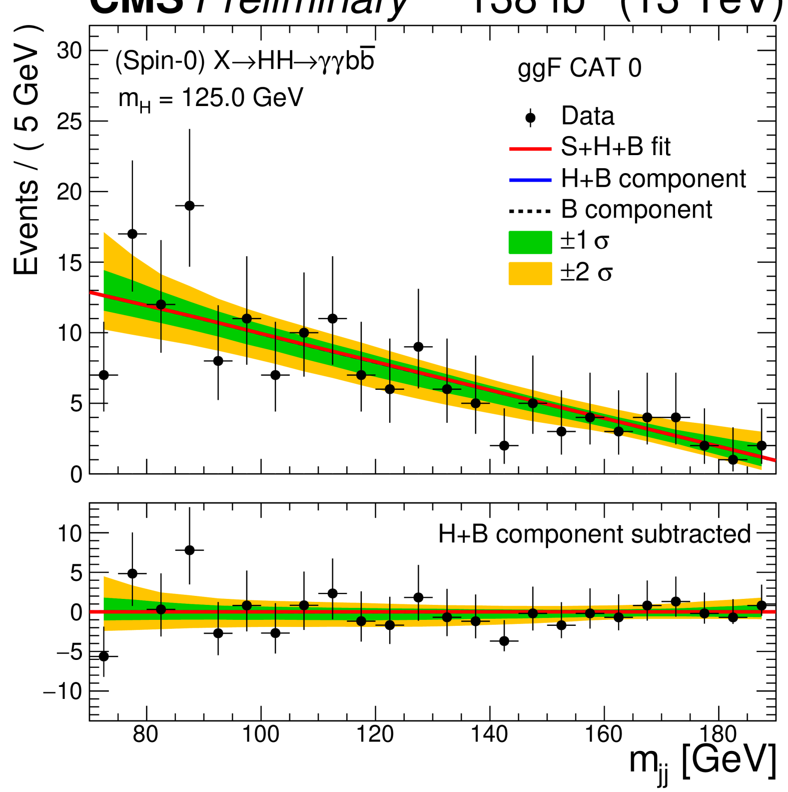


- Focusing on kinematic region where: $m_Y < m_X - m_H$; ~300 < m_X < 1 TeV, 90 < m_Y < 800 GeV
- Using ML techniques to discriminate against major ttH and other non-peaking backgrounds

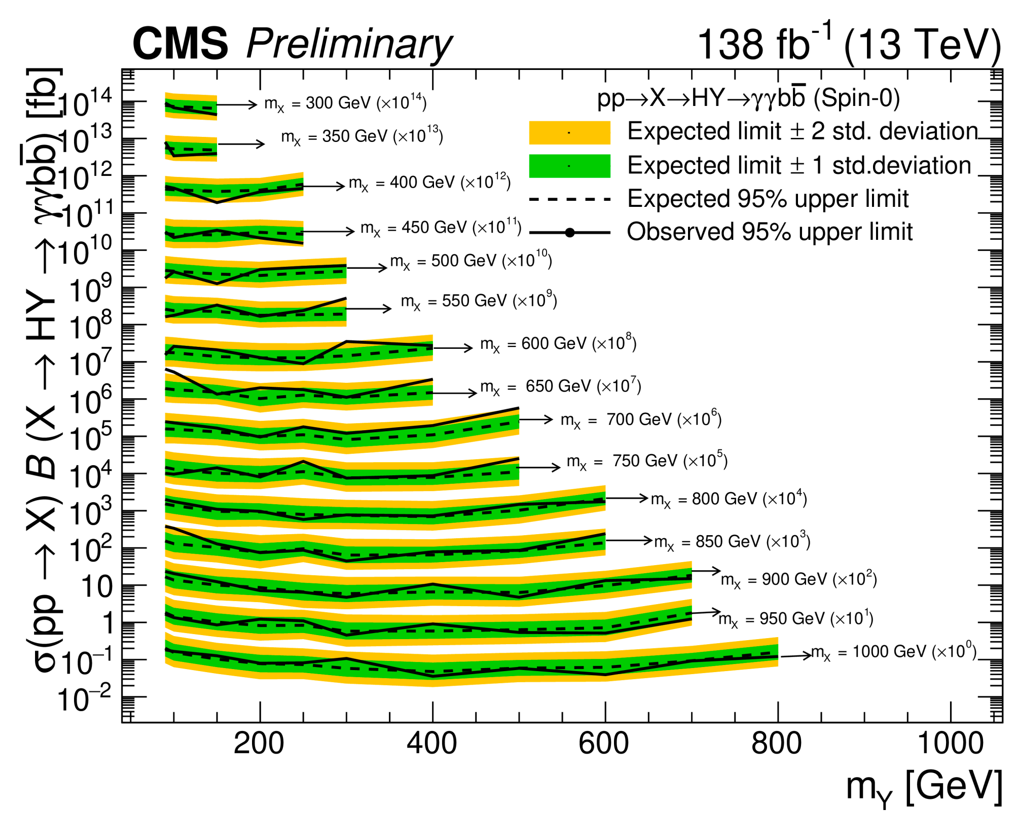
Di-photon mass



Di-jet mass

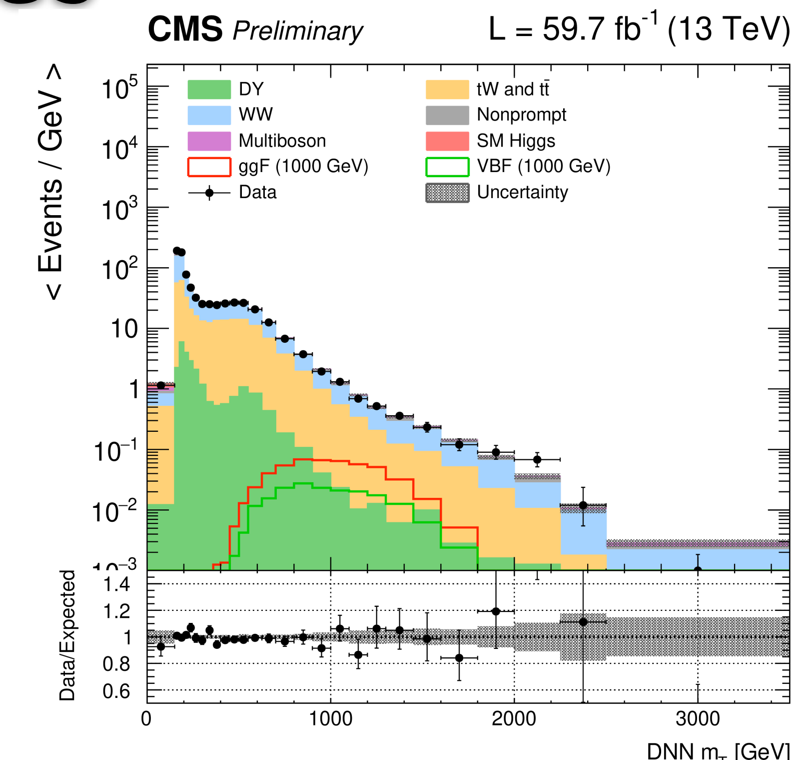


Deviation from the bkg at m_X = 650 GeV, m_Y = 90 GeV at 3.8σ local (2.8σ global)



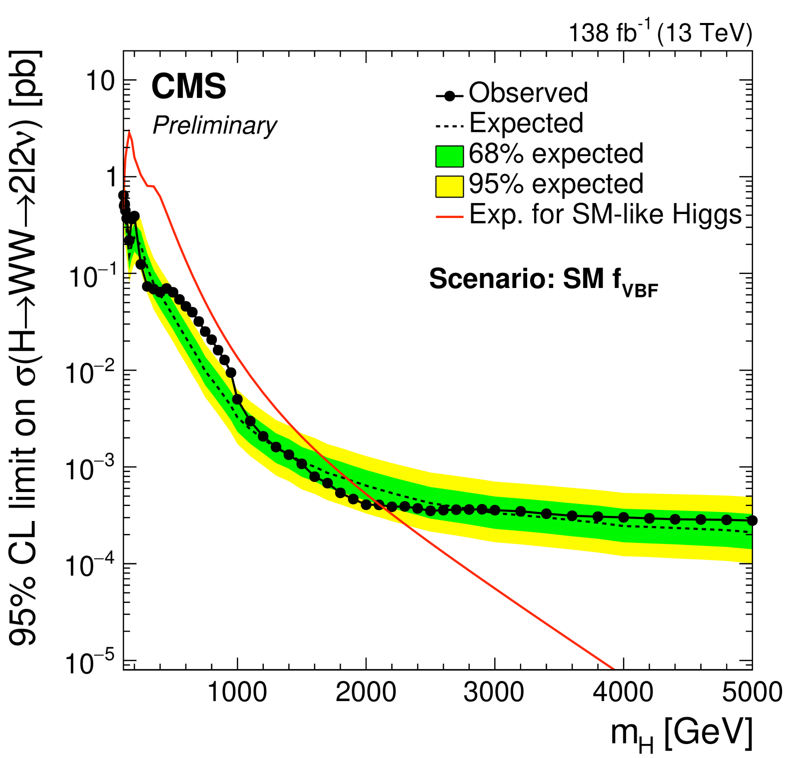
High Mass Searches

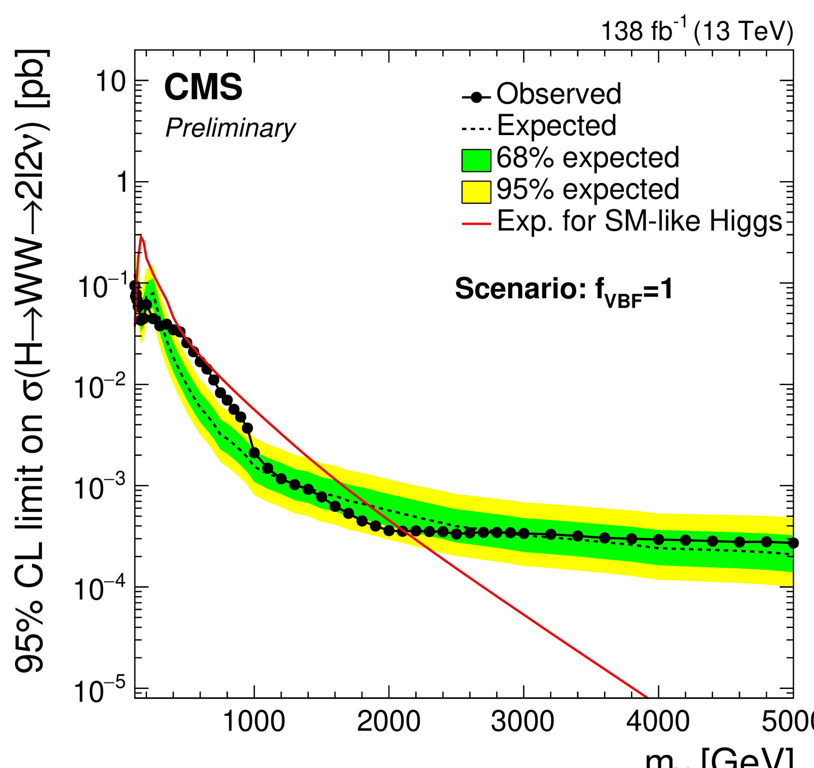
- High mass scalar H→WW decaying leptonically
  - Using DNN for classification between signals and bkgs
  - Using m_T from DNN as final observable
- Interpretations: SM-like couplings/decays, 2HDM/MSSM
  - Different width scenarios (0.1-10%); Interference with WW continuum and the SM H→WW is taken into account
  - f_{VBF} is used as free parameter

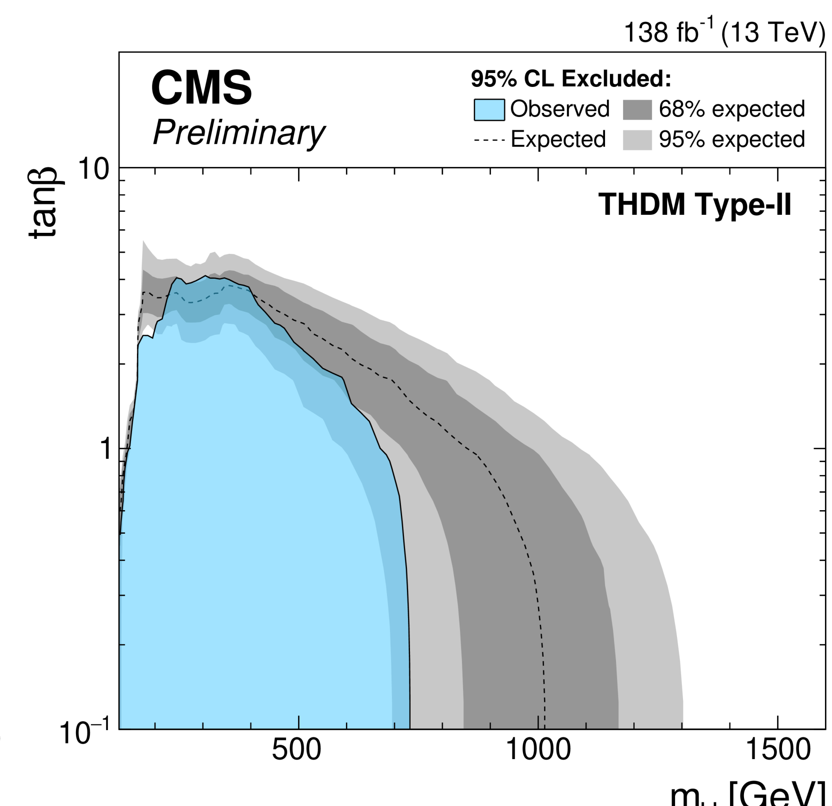


Mild excess in the mass range 400 - 1200 GeV for all f_{VBF} scenarios

Scenario	Mass [GeV]	ggF cross sec. [pb]	VBF cross sec. [pb]	Local signi. [σ]	Global signi. [σ]
SM f_{VBF}	800	0.16	0.057	3.2	1.7 ± 0.2
$f_{VBF} = 1$	650	0.0	0.16	3.8	2.6 ± 0.2
$f_{VBF} = 0$	950	0.19	0.0	2.6	0.4 ± 0.6
floating f_{VBF}	650	2.9×10^{-6}	0.16	3.8	2.4 ± 0.2

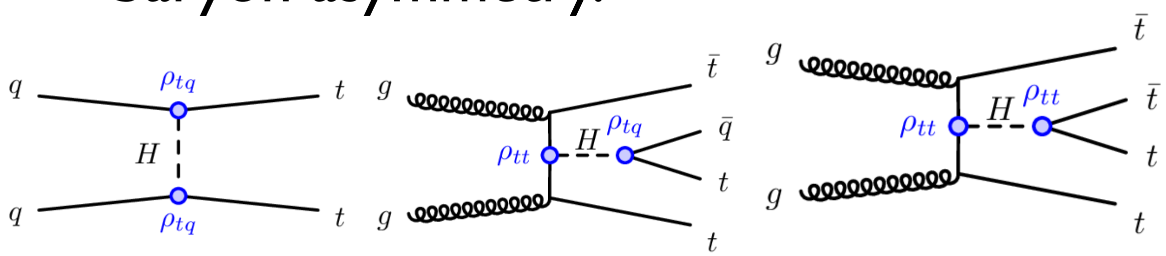


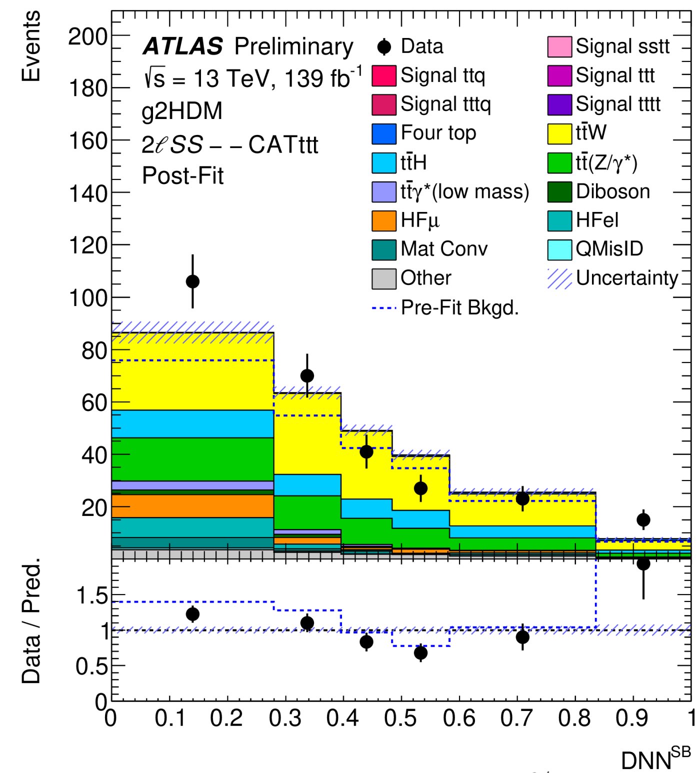


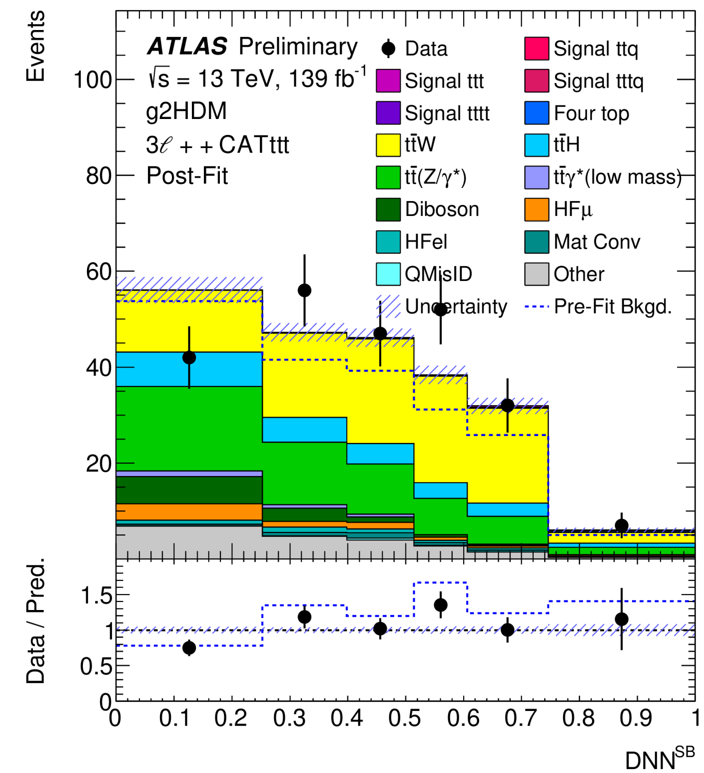


High Mass Searches

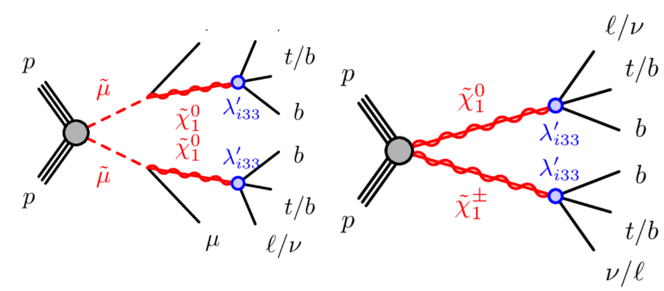
- Search in final states with multi-leptons and b-jets
  - 2HDM, heavy Higgs with FCNH couplings: ρ_{tt}, ρ_{tc}, ρ_{tu}, the former two can explain baryon asymmetry.





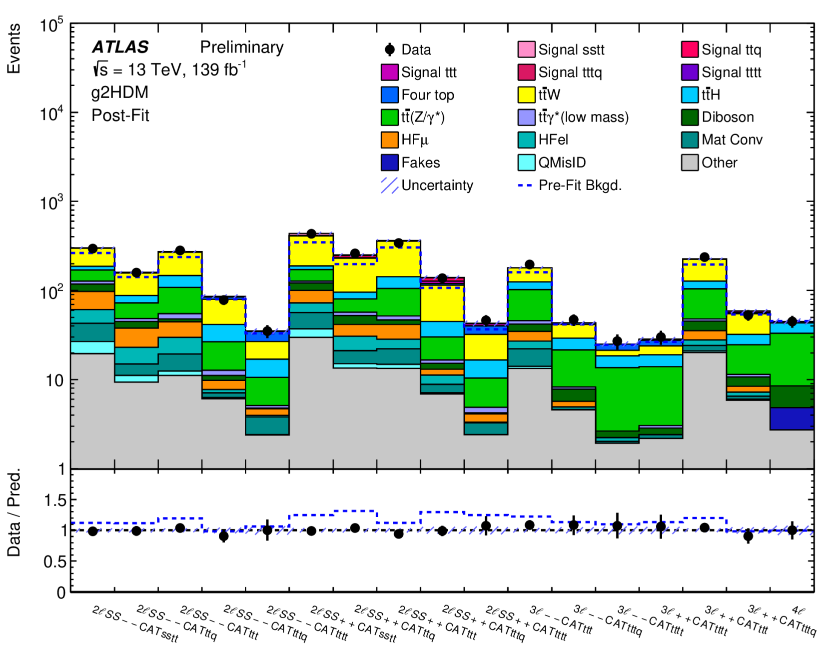


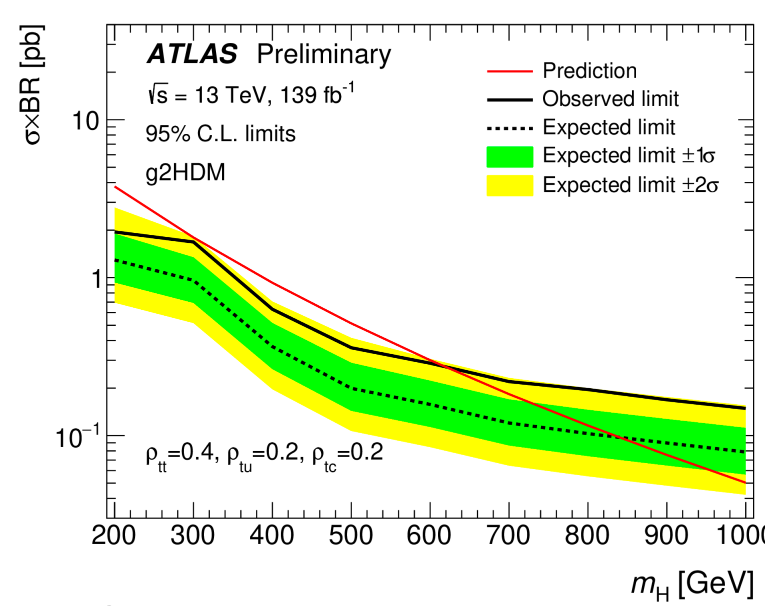
  - Interpreted in R-Parity violating SUSY. Motivated by flavour anomalies



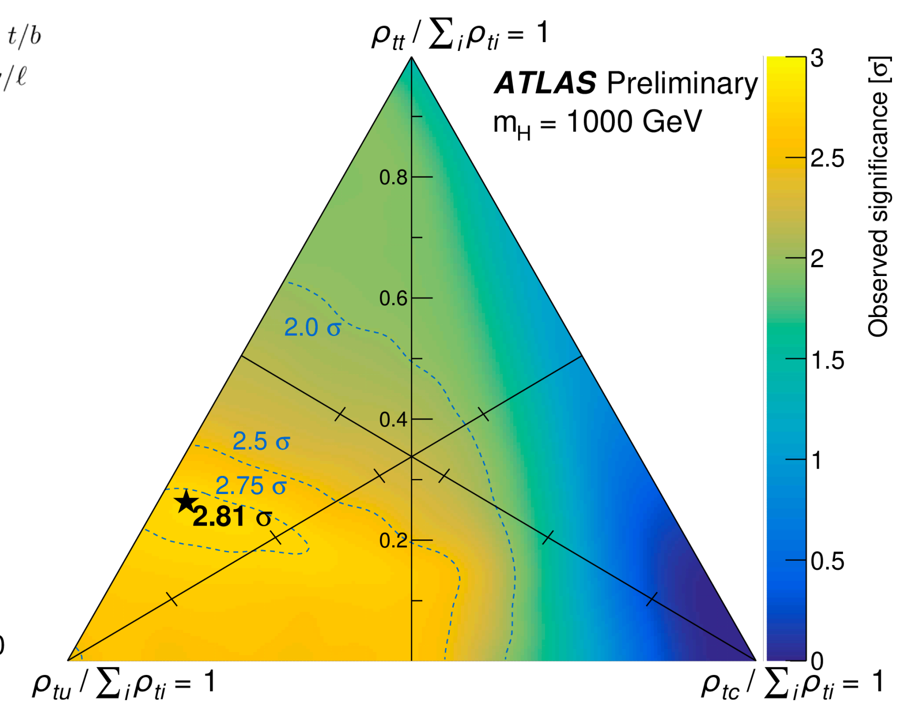
Improving indirect constraints set on ρ_{tt}, ρ_{tc}, ρ_{tu} from Higgs measurements, B physics

Events categorised based on N_ℓ, total charge, DNN[cat]





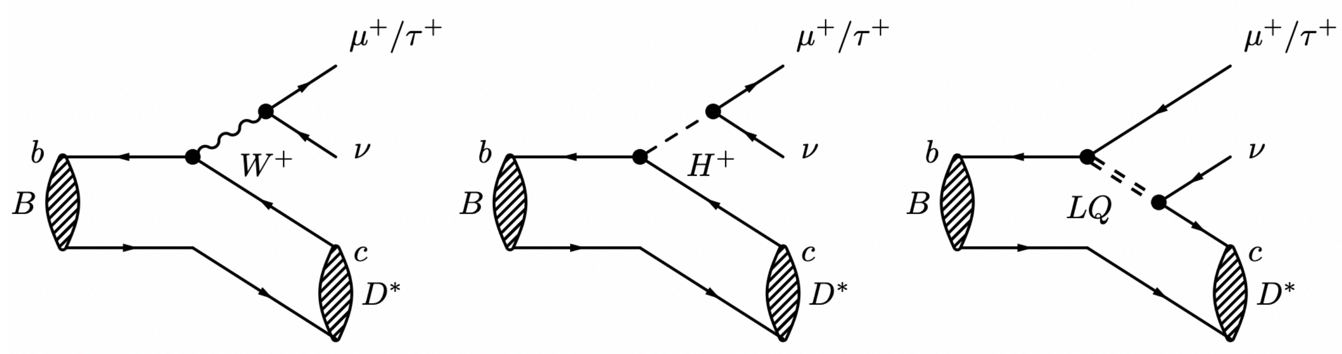
Chosen benchmark couplings could explain high ttW and tttt yields observed by ATLAS



$\rho_{tt} = 0.32$, $\rho_{tc} = 0.05$, $\rho_{tu} = 0.85$

Lepton Flavour Anomalies

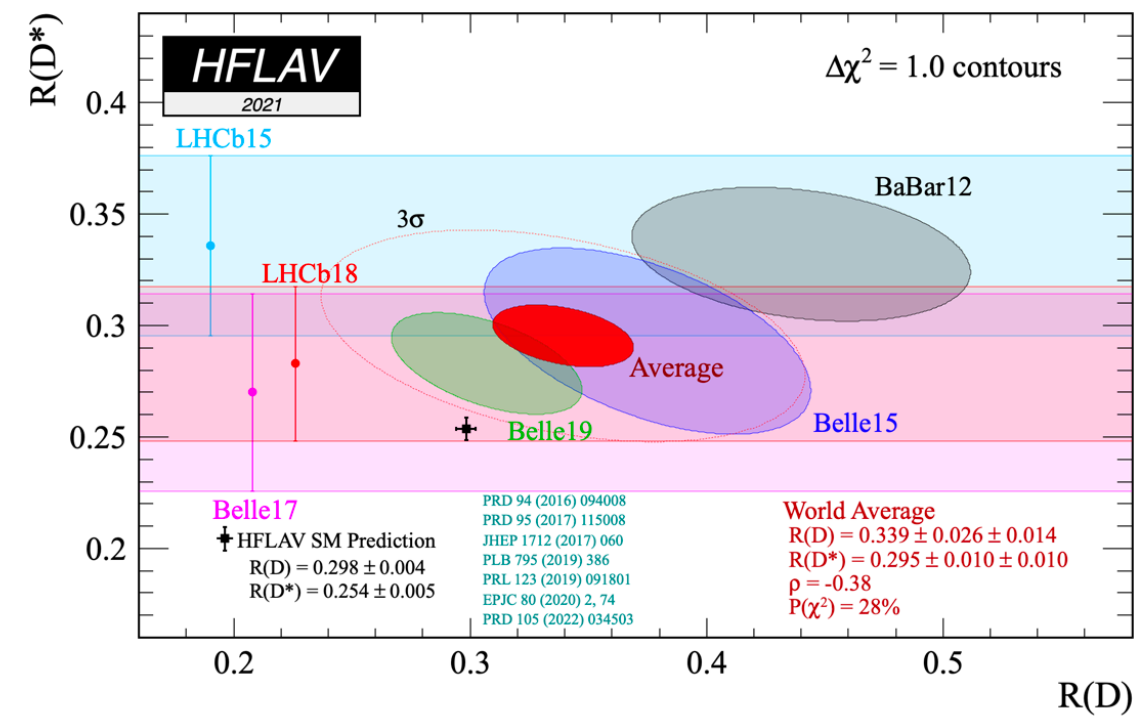
- Longstanding hint (~3 σ) of a deviation in lepton flavour universality test
  - LFU not sufficiently tested in heavy quark decays

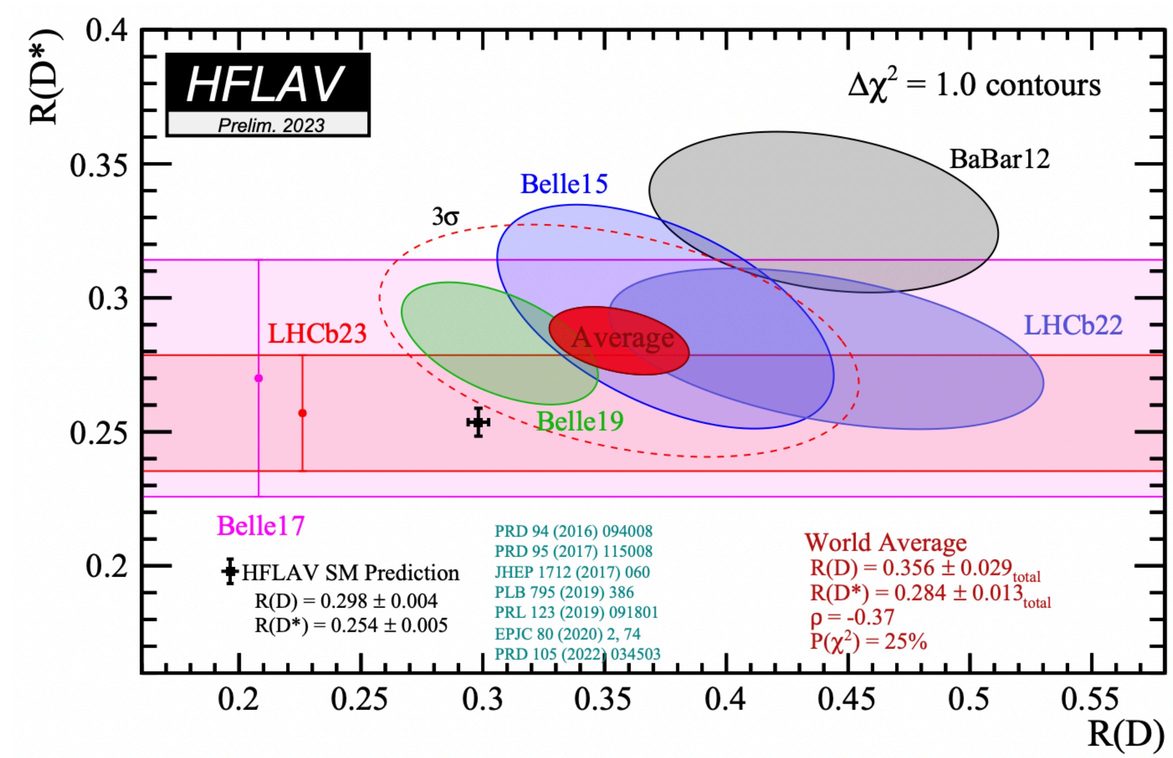


  - The ratio is sensitive to charged Higgs or LQ

$$R\left(D^{(*)}\right) \equiv \frac{\mathcal{B}(\bar{B}^0 \to D^{(*)}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B}^0 \to D^{(*)}\mu^-\bar{\nu}_\mu)}$$

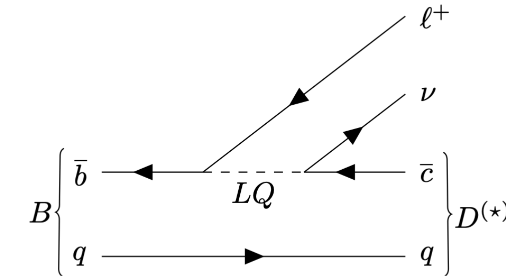
- Deviation wrt. the SM is at 3.2 σ;
- Perfect agreement between LHCb measurements



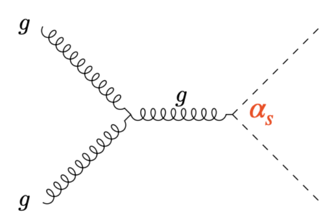


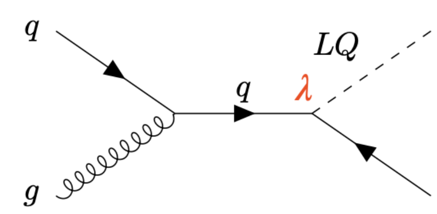
CMS-PAS-EXO-19-016

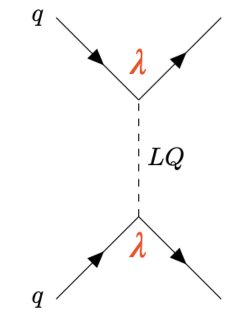
LQ Searches



- Leptoquarks are favourite model to explain anomalies
  - Can be scalar or vector
  - Can be produced in pair or singly
  - Typically, could couple across generations, with enhanced coupling to the third generation fermions motivates searches in fine states with τ, b-jets, top-quark decays..



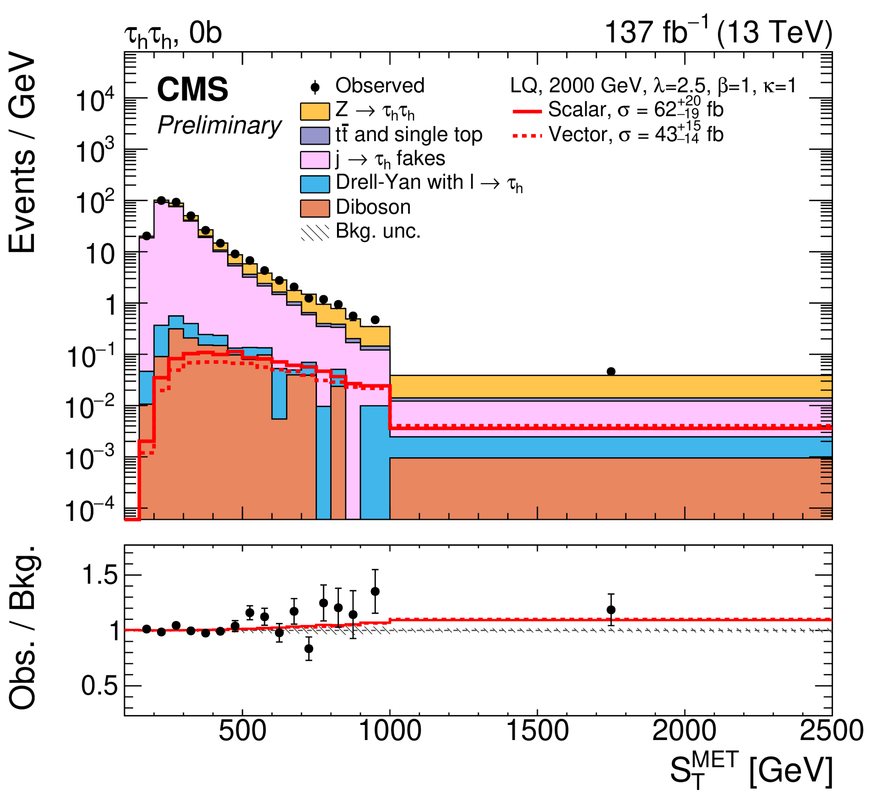


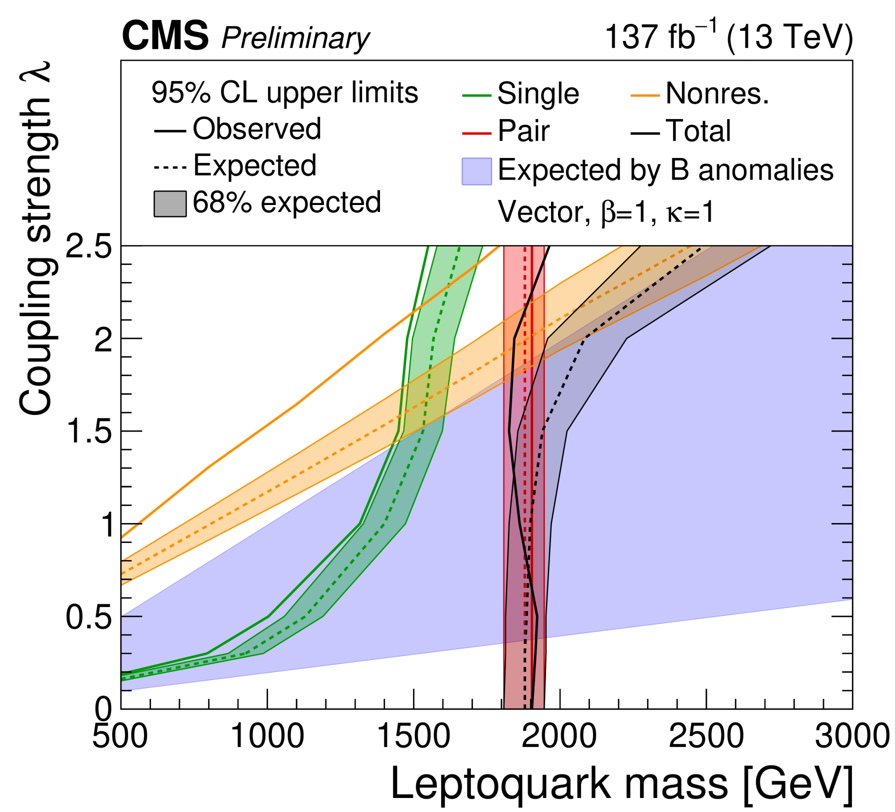


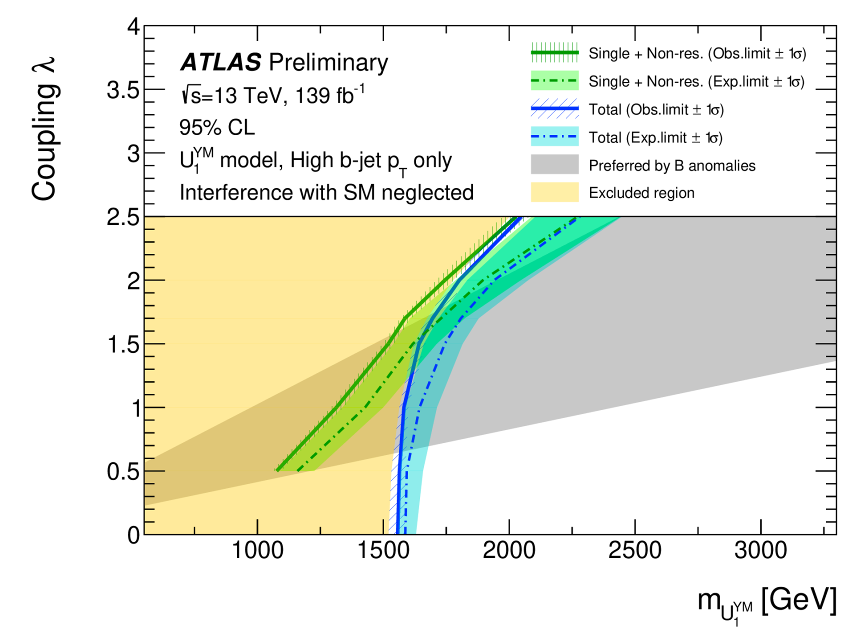
- Combined search for pair, single, non-resonant production

$$S_T^{MET} = p_T^{j\,1} + p_T^{e/\mu/\tau} + p_T^{\tau} + p_T^{miss}$$

3.4 σ excess found at high mass & high coupling



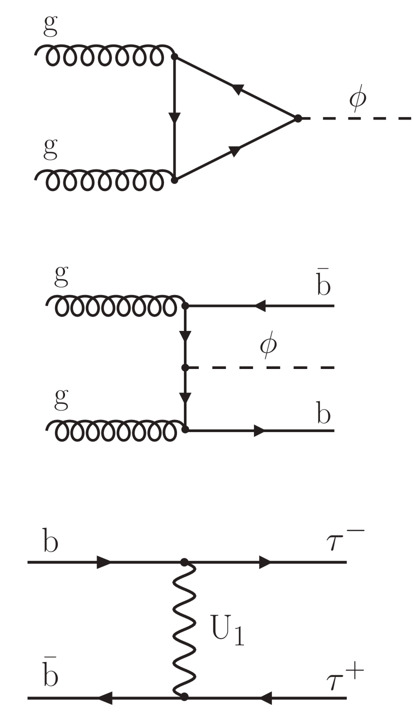


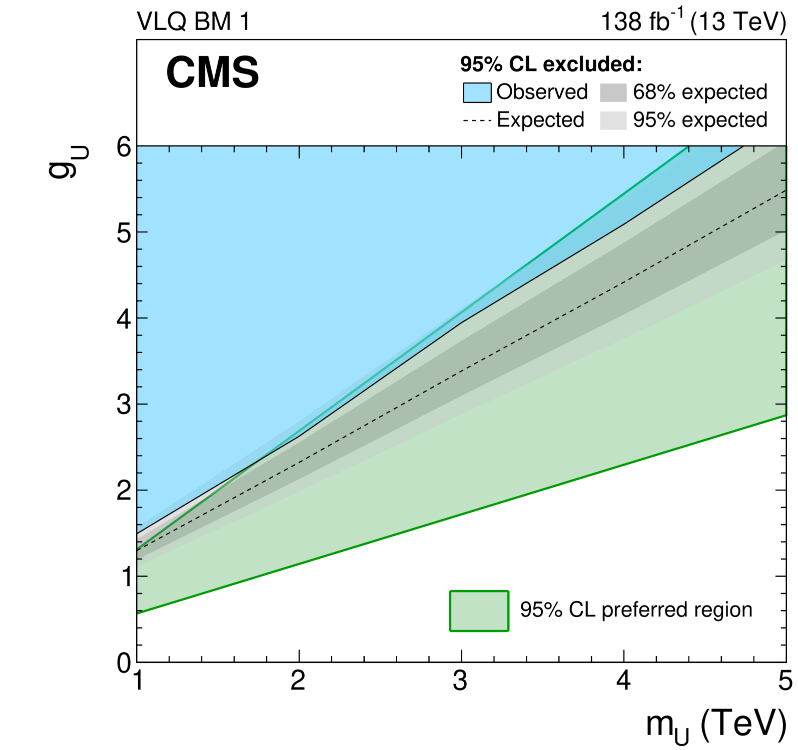


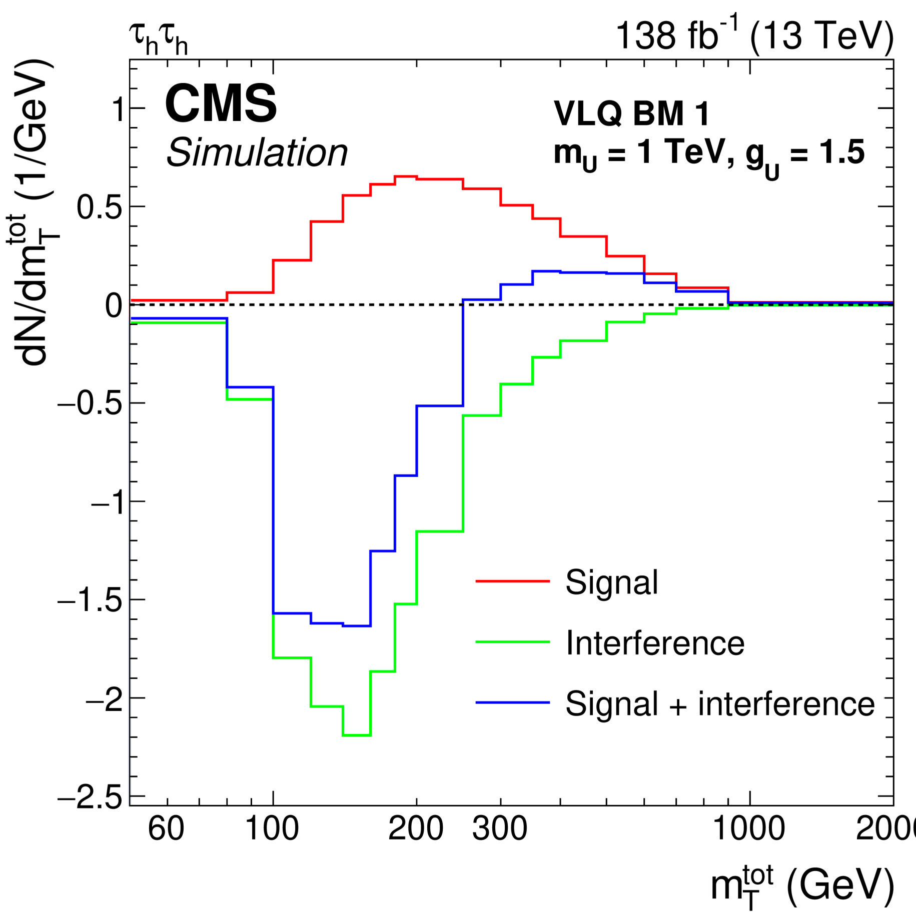
CMS arXiv:2208.02717

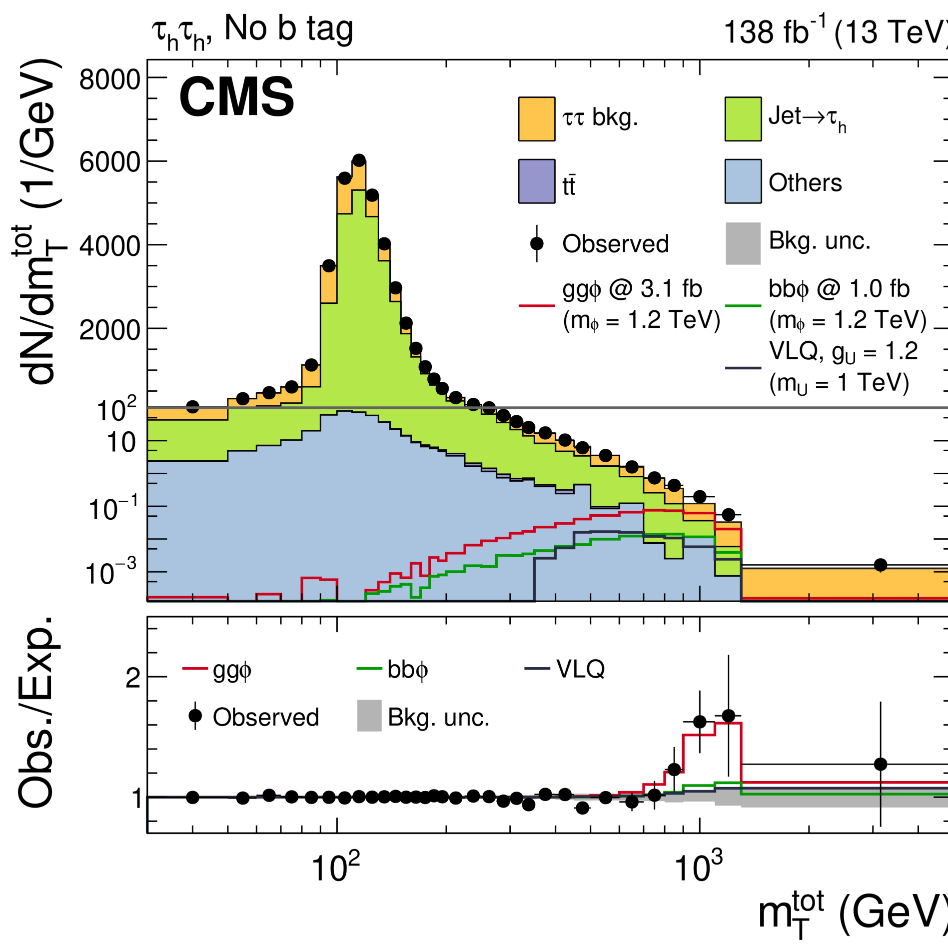
Di-τ search over wide mass range

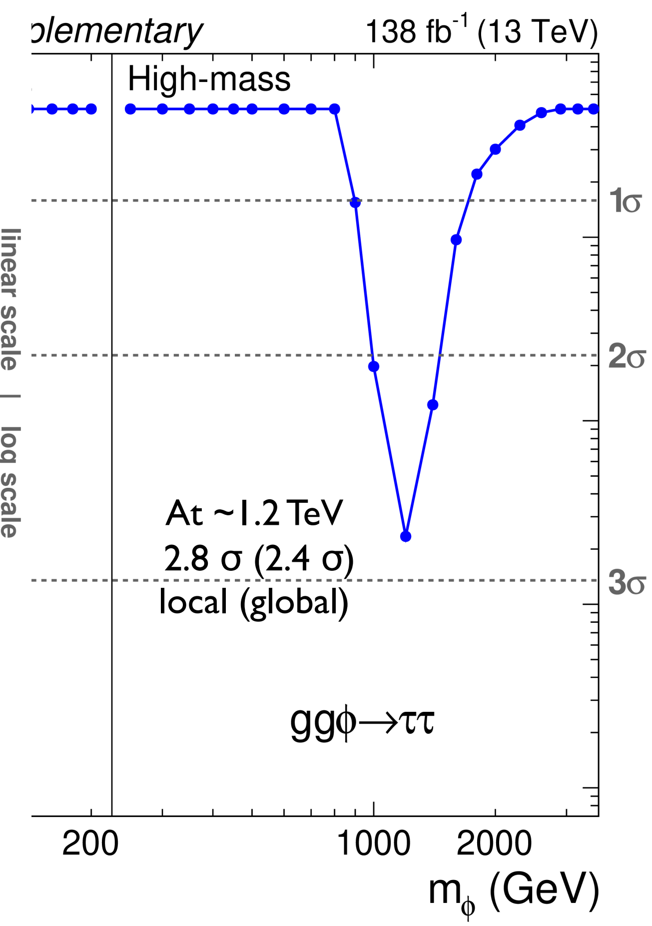
- Search in di-τ mass spectrum is motivated from additional Higgs in context of MSSM, non-resonant VLQ production
  - Interference with the SM ττ continuum taken into account







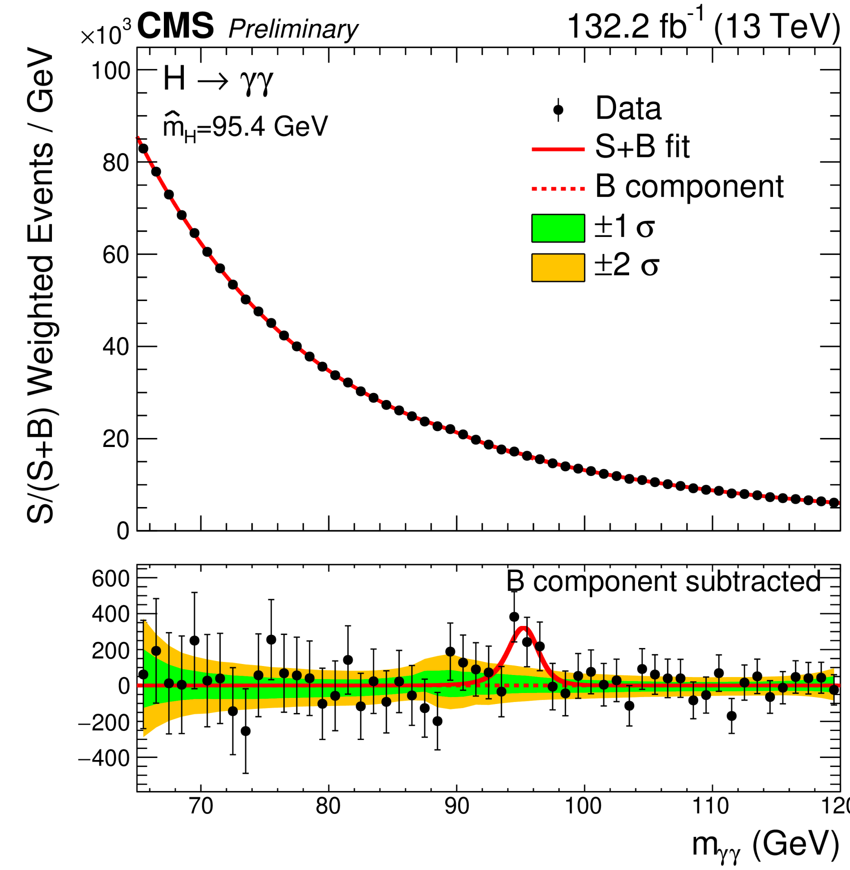


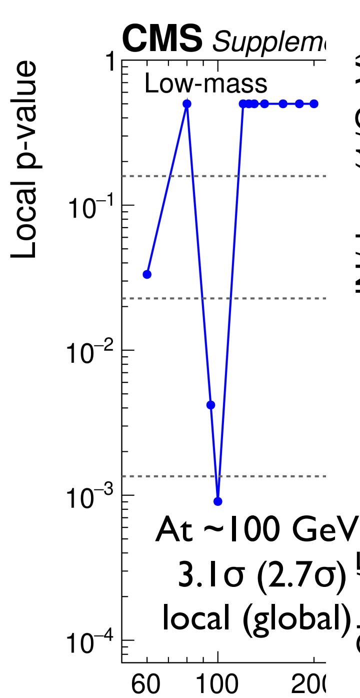


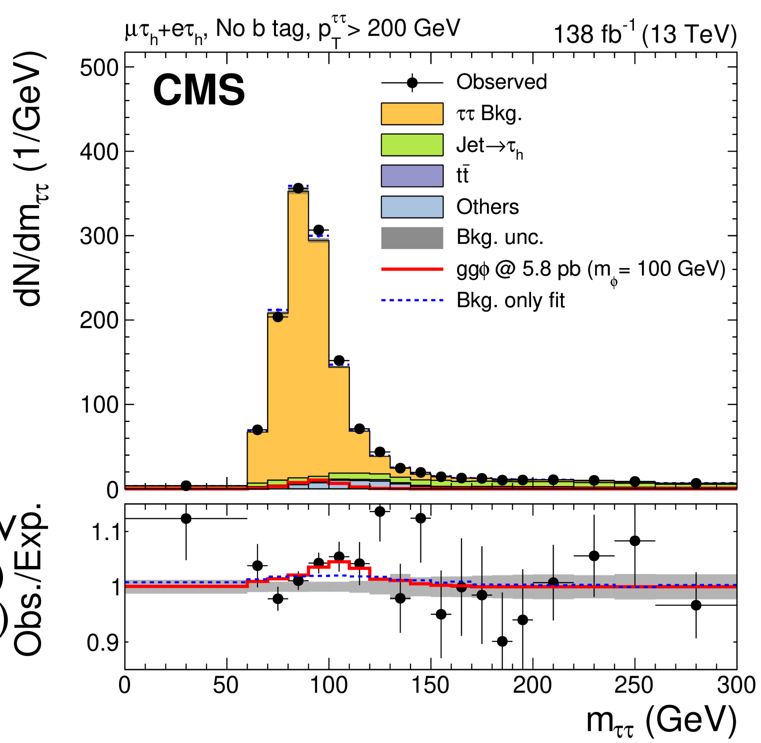
Hints to for additional Higgs?

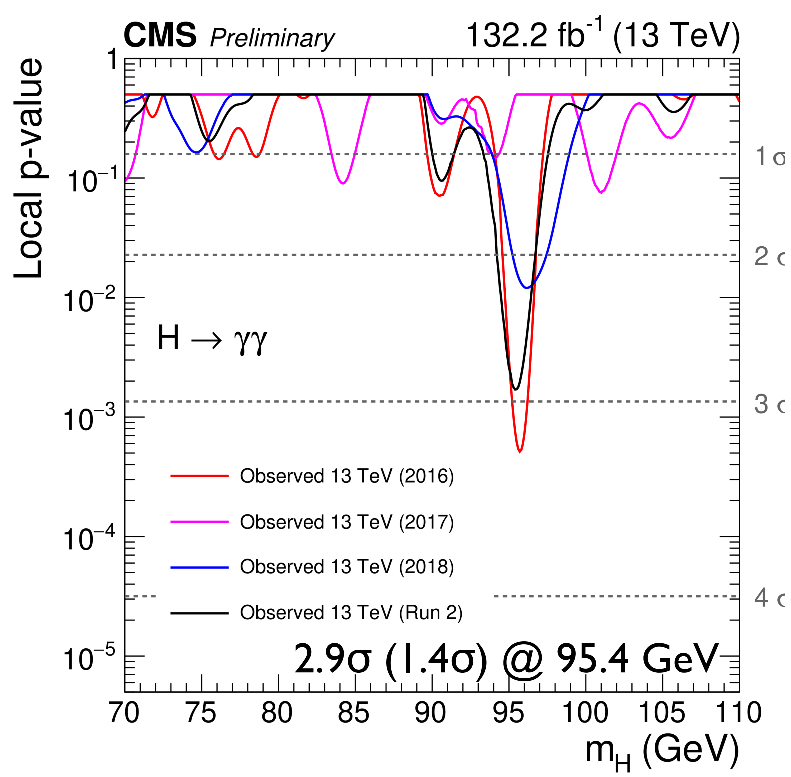
- Some interesting connections [CMS-PAS-HIG-21-011]
  - X→ HY → $\gamma\gamma$ bb : Excess at m_X=650 GeV, m_Y=90 GeV
  - H→ WW : Excess at m = 650 GeV [CMS-PAS-HIG-20-016]
  - H→$\gamma\gamma$: Excess at m = 95 GeV [CMS-PAS-HIG-20-002]
  - H→$\tau\tau$: Excess at m = 100 GeV [CMS arXiv:2208.02717]

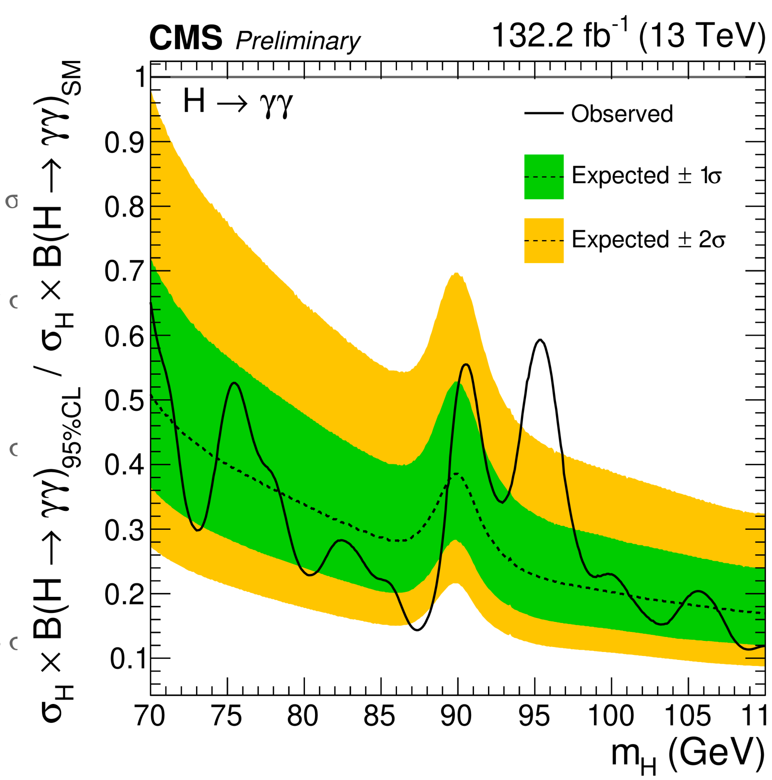
Each event reweighted by S/(S+B)





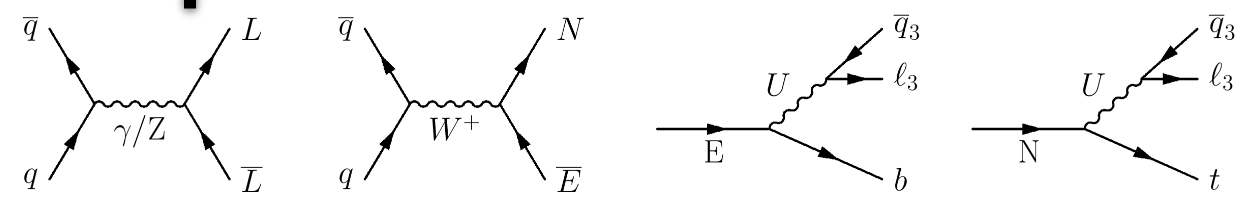






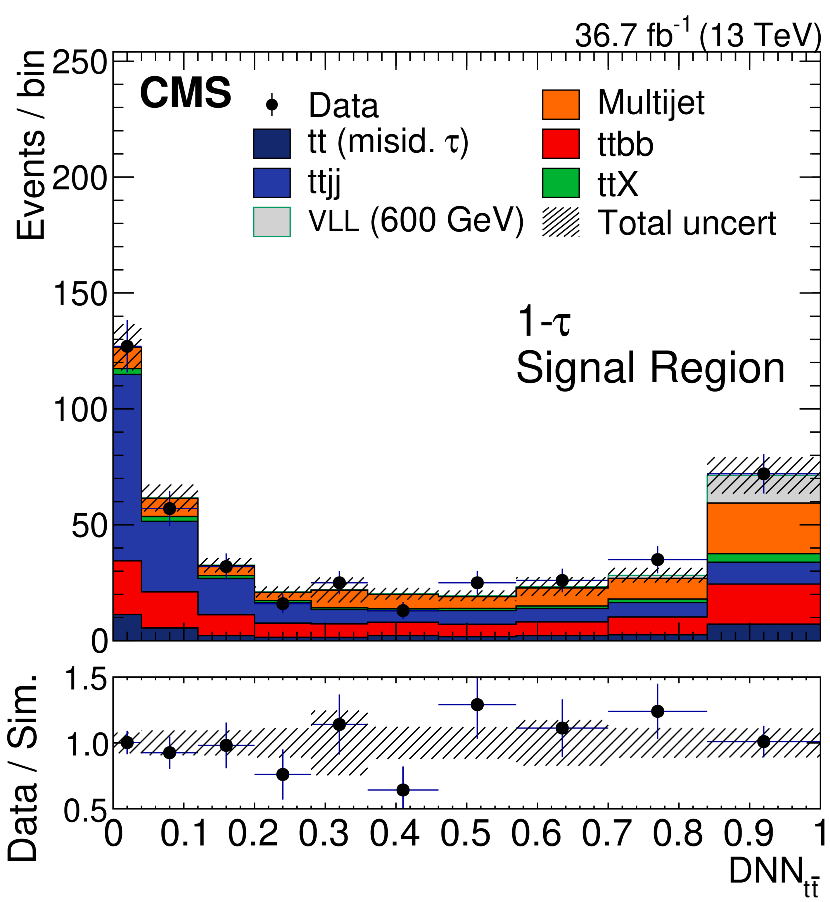
CMS arXiv:2208.09700

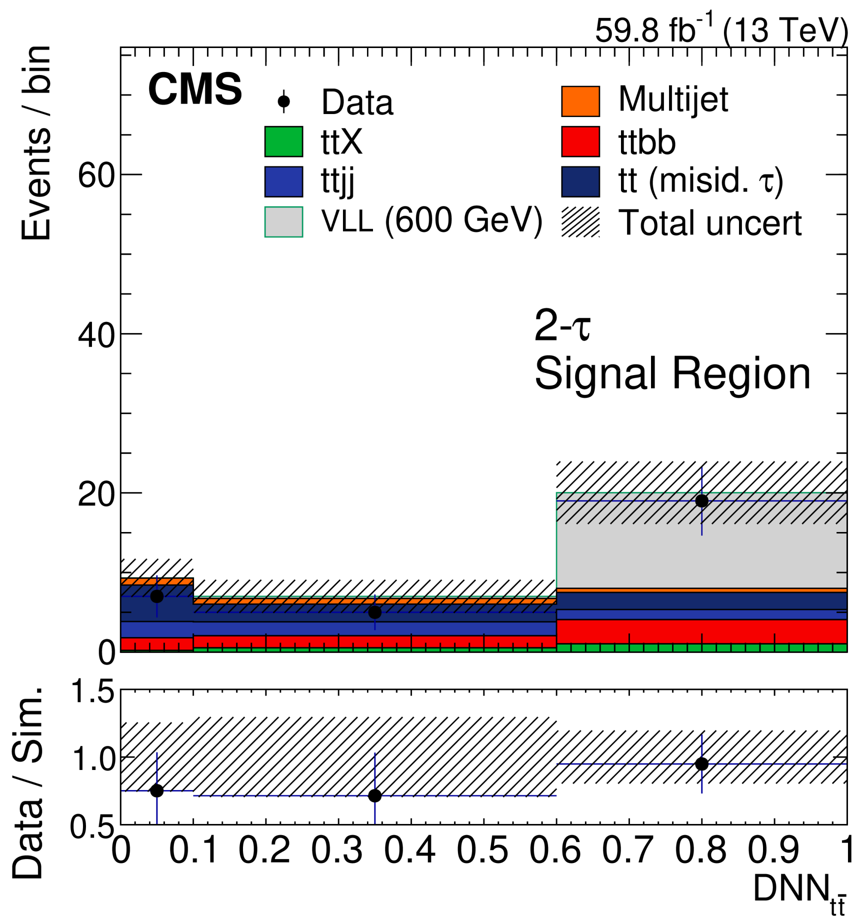
Vector-Like Leptons



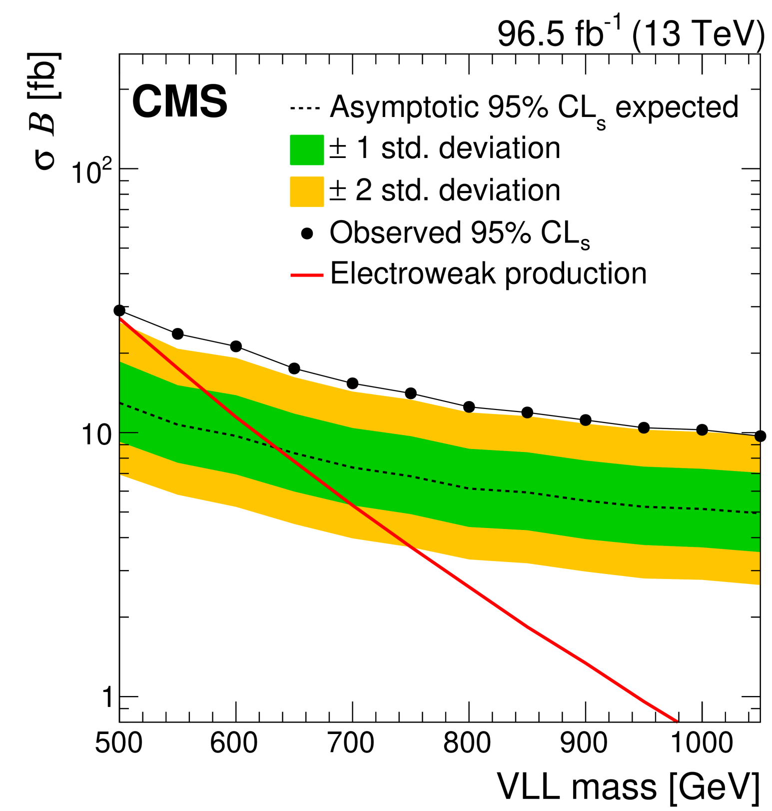
- Motivated from flavour anomalies
  - VLL decay via vector leptoquarks, which couple dominantly to the third generation
  - Categorise by number of b-jets and **τ**-leptons
  - Using DNN to discriminate against QCD and tt backgrounds

Tau multiplicity	VLL production + decay mode	Final state
	$\mathrm{EE} \to \mathrm{b}(\mathrm{t}\nu_\tau)\mathrm{b}(\mathrm{t}\nu_\tau)$	$4\mathrm{b} + 4\mathrm{j} + 2\nu_\tau$
$0\ \tau$	$\mathrm{EN} \to \mathrm{b}(\mathrm{t}\nu_\tau)\mathrm{t}(\mathrm{t}\nu_\tau)$	$4\mathrm{b} + 6\mathrm{j} + 2\nu_\tau$
	$\mathrm{NN} \to \mathrm{t}(\mathrm{t}\nu_\tau)\mathrm{t}(\mathrm{t}\nu_\tau)$	$4\mathrm{b} + 8\mathrm{j} + 2\nu_\tau$
	$\mathrm{EE} \to \mathrm{b}(\mathrm{b}\tau)\mathrm{b}(\mathrm{t}\nu_\tau)$	$4\mathrm{b} + 2\mathrm{j} + \tau + \nu_\tau$
$1\ \tau$	$\mathrm{EN} \to \mathrm{b}(\mathrm{t}\nu_\tau)\mathrm{t}(\mathrm{b}\tau)$	$4\mathrm{b} + 4\mathrm{j} + \tau + \nu_\tau$
	$\mathrm{EN} \to \mathrm{b}(\mathrm{b}\tau)\mathrm{t}(\mathrm{t}\nu_\tau)$	$4\mathrm{b} + 4\mathrm{j} + \tau + \nu_\tau$
	$\mathrm{NN} \to \mathrm{t}(\mathrm{b}\tau)\mathrm{t}(\mathrm{t}\nu_\tau)$	$4\mathrm{b} + 6\mathrm{j} + \tau + \nu_\tau$
	$\mathrm{EE} \to \mathrm{b}(\mathrm{b}\tau)\mathrm{b}(\mathrm{b}\tau)$	$4\mathrm{b} + 2\tau$
$2\ \tau$	$\mathrm{EN} \to \mathrm{b}(\mathrm{b}\tau)\mathrm{t}(\mathrm{b}\tau)$	$4\mathrm{b} + 2\mathrm{j} + 2\tau$
	$\mathrm{NN} \to \mathrm{t}(\mathrm{b}\tau)\mathrm{t}(\mathrm{b}\tau)$	$4\mathrm{b} + 4\mathrm{j} + 2\tau$





Excess of events at 600 GeV with 2.8 σ



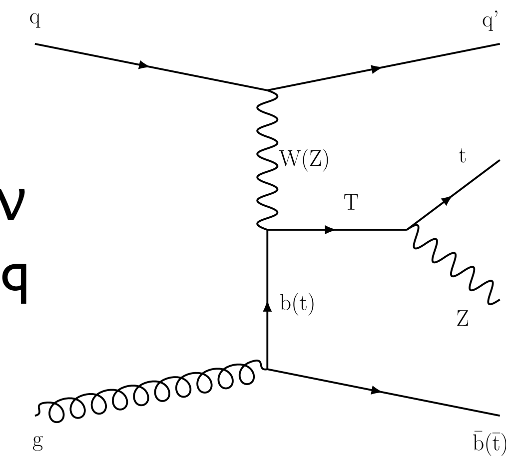
CMS arXiv:2201.02227

Vector-Like Quarks

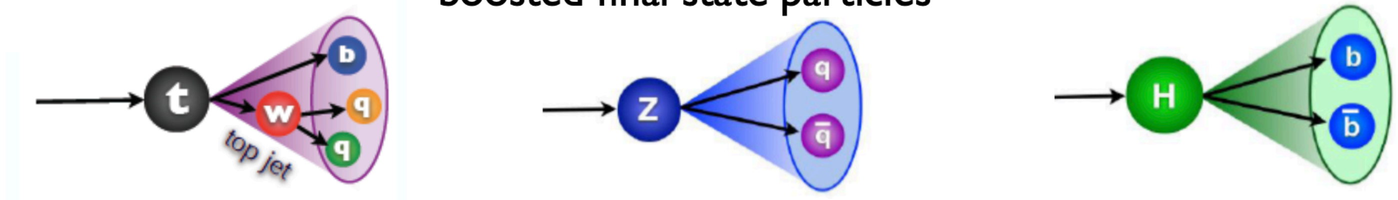
- VLQ could solve hierarchy problem
  - Searching in 0.6-1.8 TeV mass range; multiple width scenarios
  - Depending on T mass considering resolved and merged topologies

$Z \to \nu\nu$

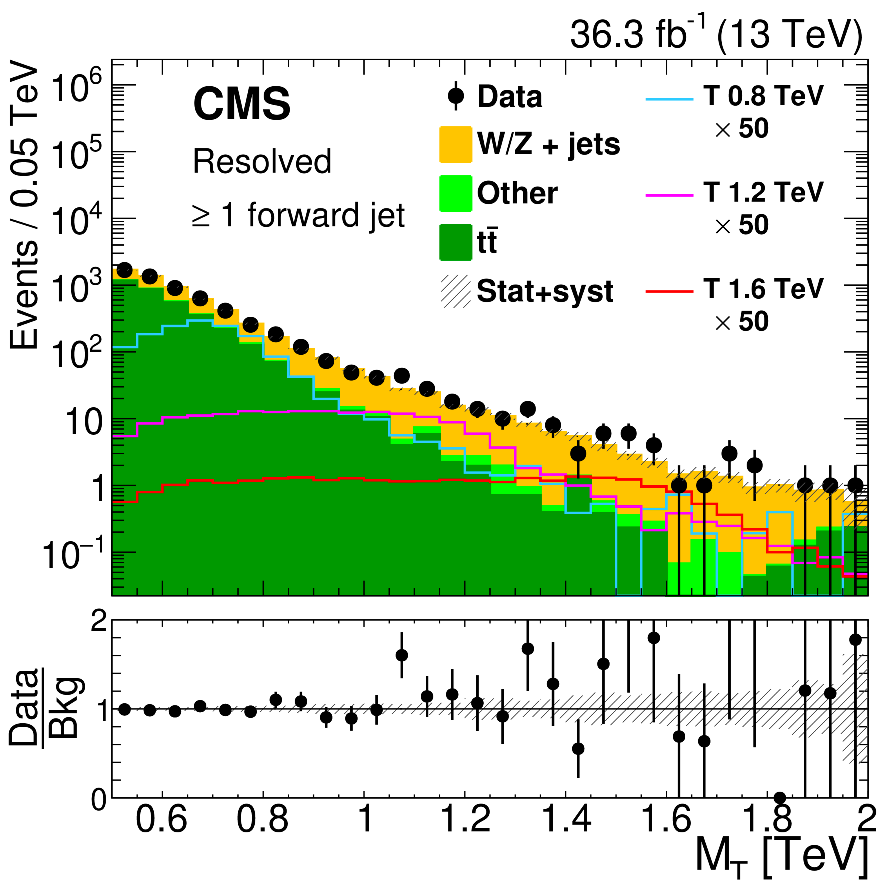
$t \to qqq$

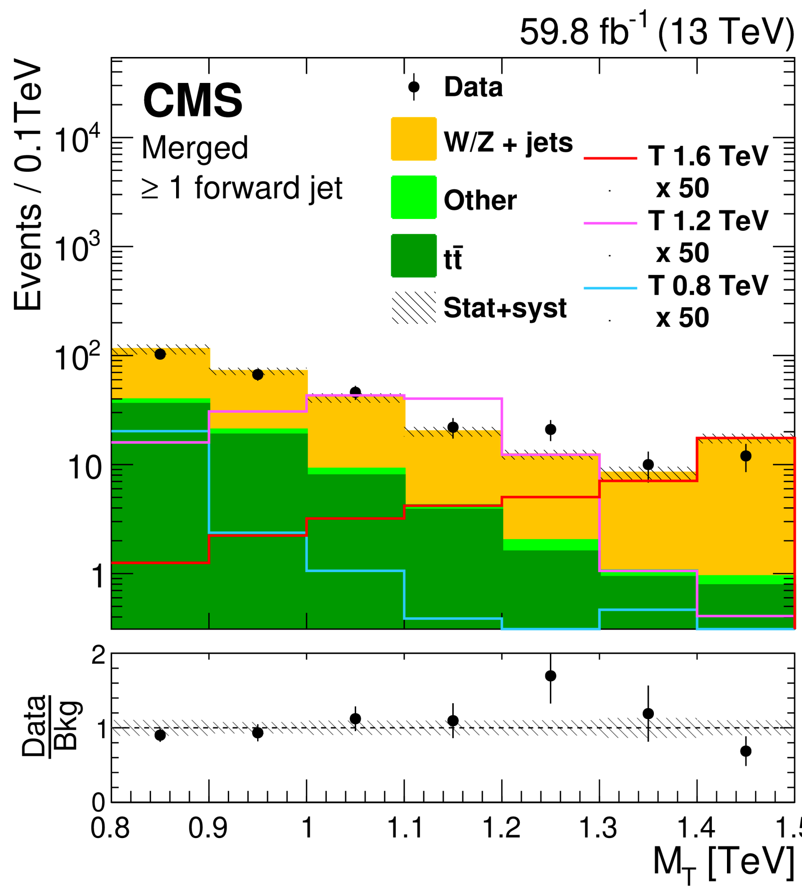


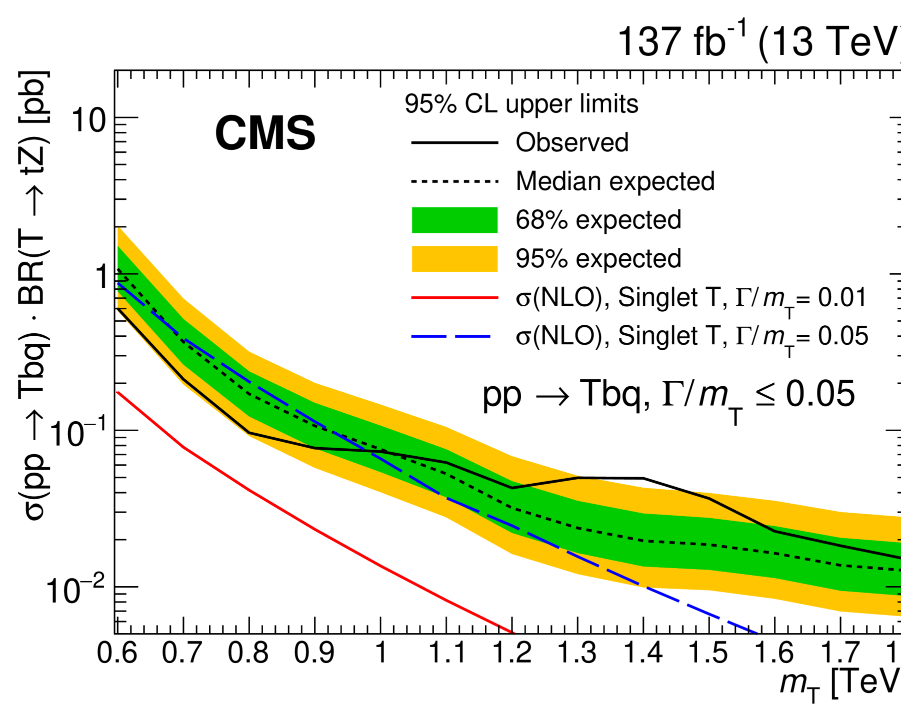
boosted final state particles



Largest excess around 1.4 TeV for narrow width with significance: 2.5 σ (2.2 σ)

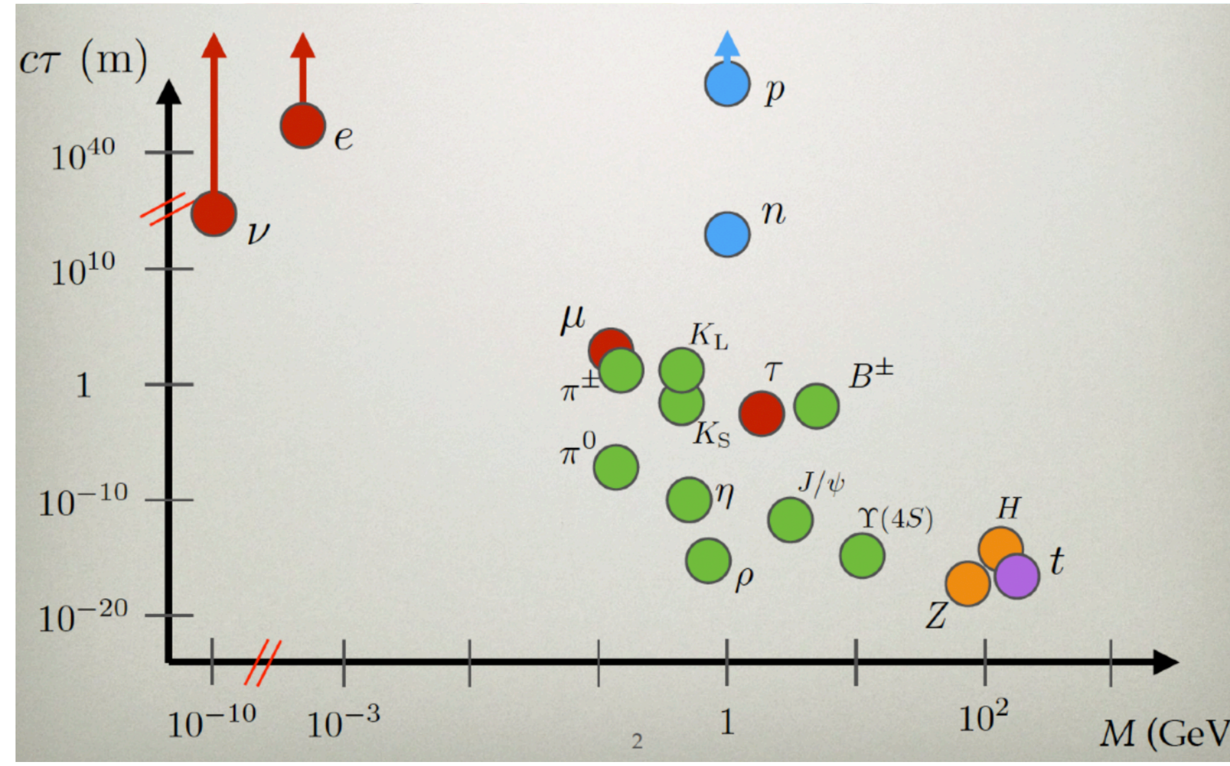




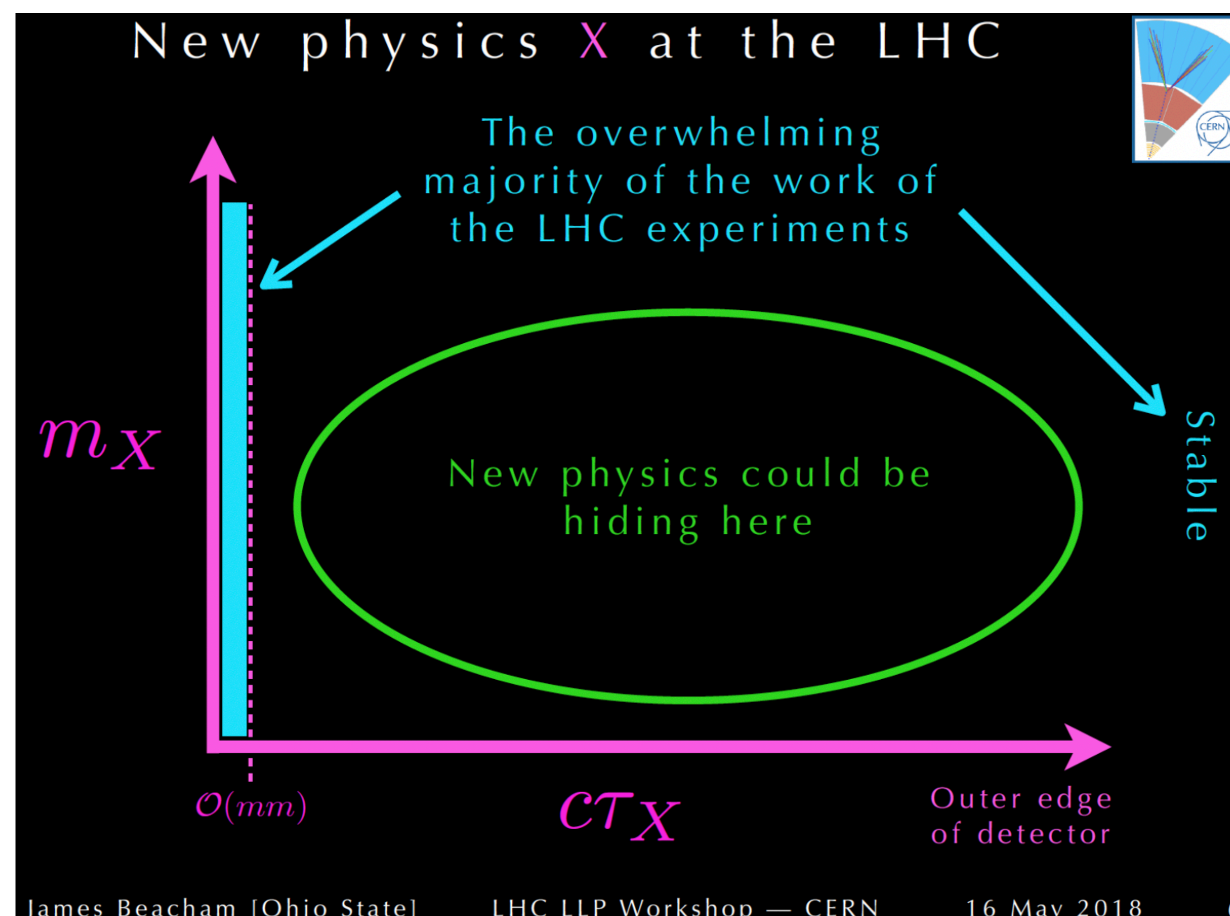


Why Long-Lived Particles Searches?

- We already have some long-lived particles around us.
  Could there be more of those — perfectly motivated
  - Small couplings
  - Suppressed decay phase space

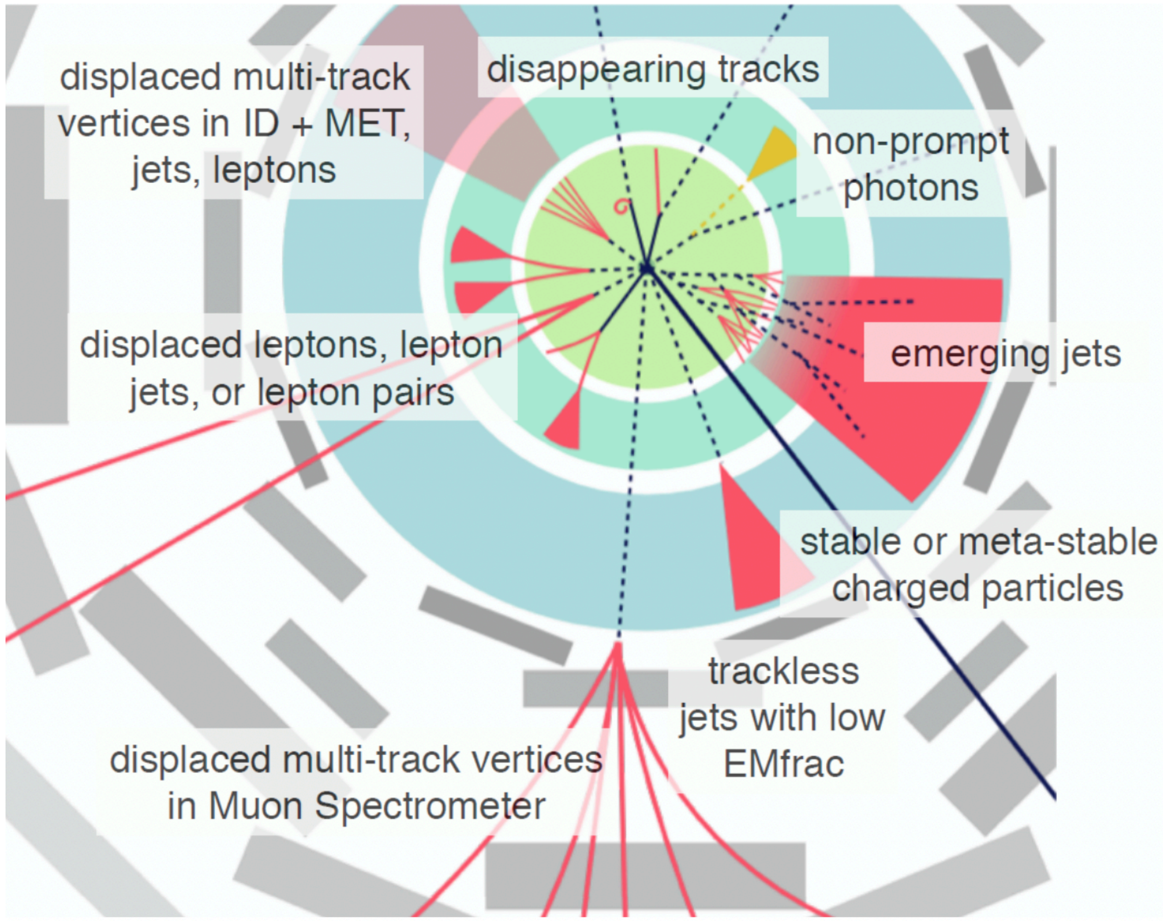


- So far no evidence for new physics. Experiment perfectly agrees with the Standard Model. We need to look in all possible directions.



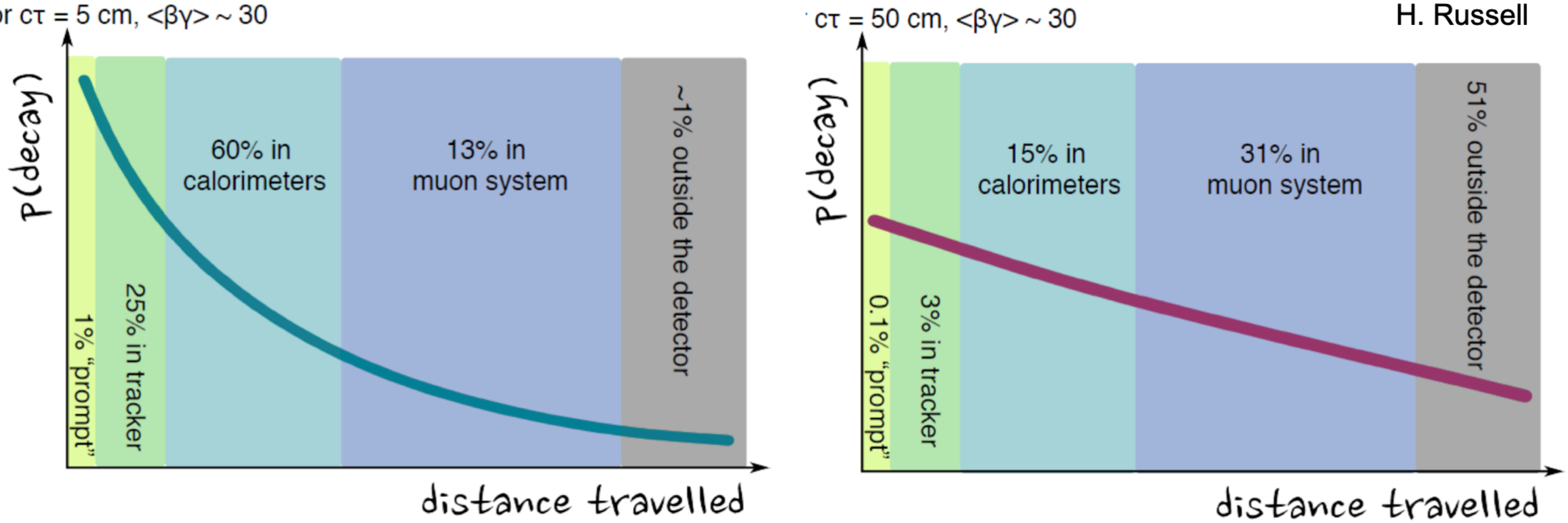
How to Find LLPs?

- Signatures define search strategy
  - Could be light or heavy
  - Could travel fast or slow
  - Could decay to quarks, gluons, or leptons, or even invisible particles (missing transverse momentum)
  - Main handles: timing, displacement, and ionisation



- Every sub-system important

distance travelled $= \beta\gamma \times c\tau$

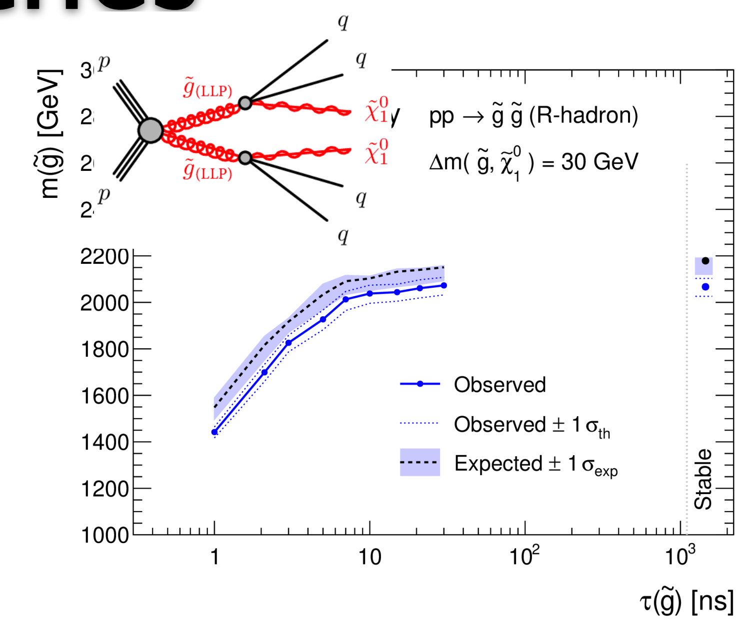


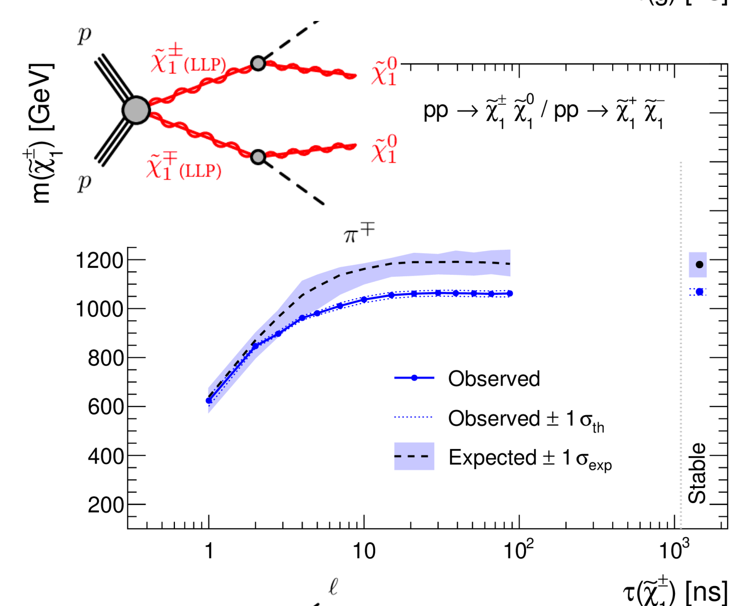
H. Russell

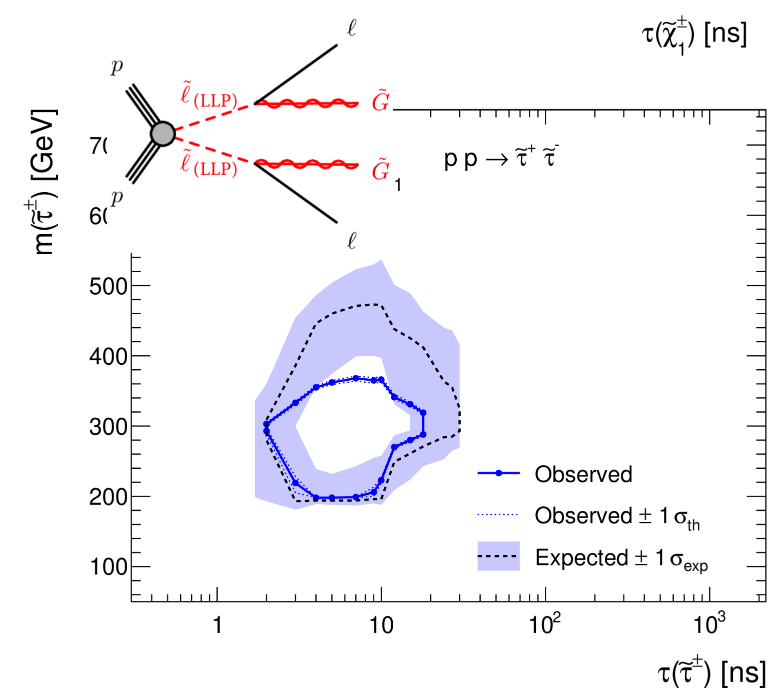
ATLAS arXiv:2205.06013

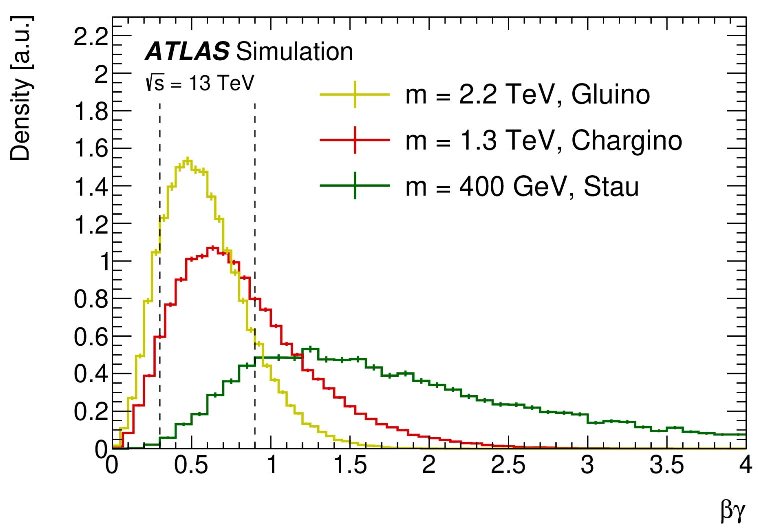
Long-Lived Particle Searches

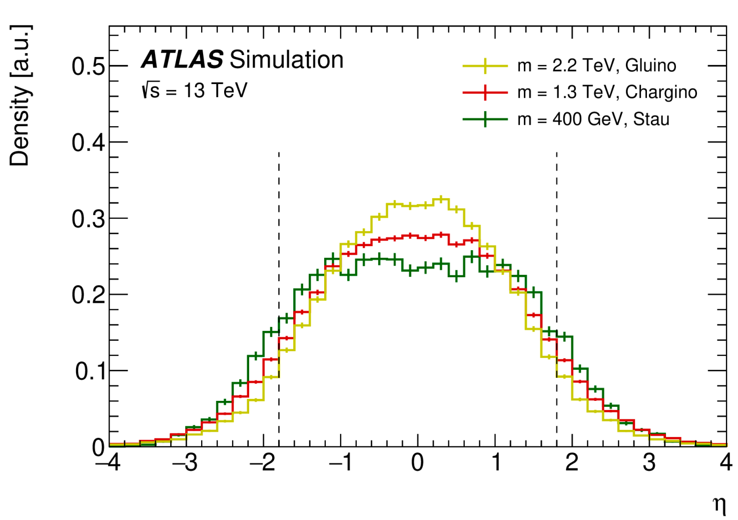
- LLPs arise in models of SUSY with compressed spectra or weakly coupled RPV, Hidden Valley, DM, QCD Axions,…
  - Search for massive, charged long-lived (>1ns) particles



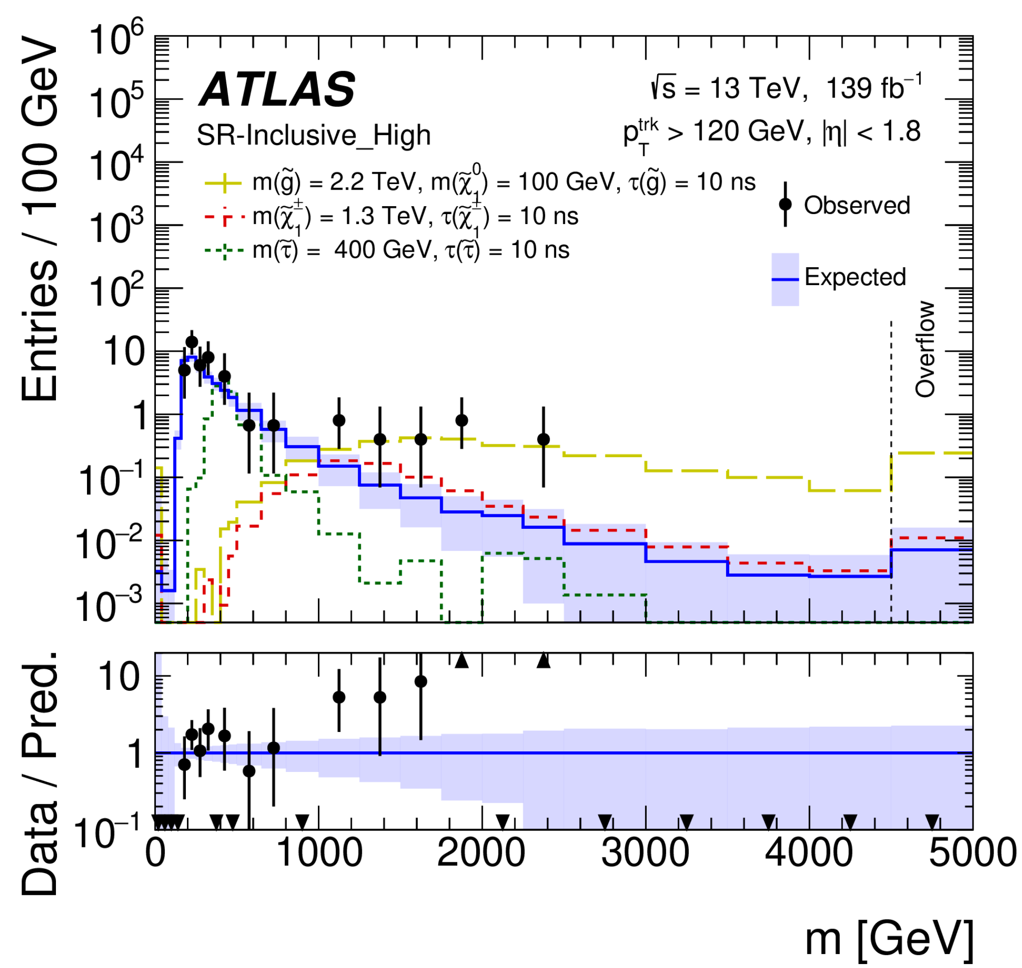




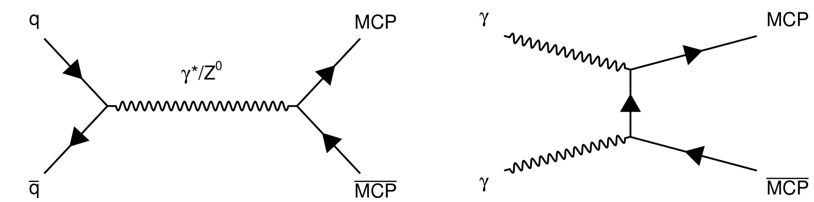




Excess 1.1-2.8 TeV corresponding to 1.4 TeV mass
0.7±0.4 evt expected | 7 evt observed
3.6 Z (3.3 Z) significance

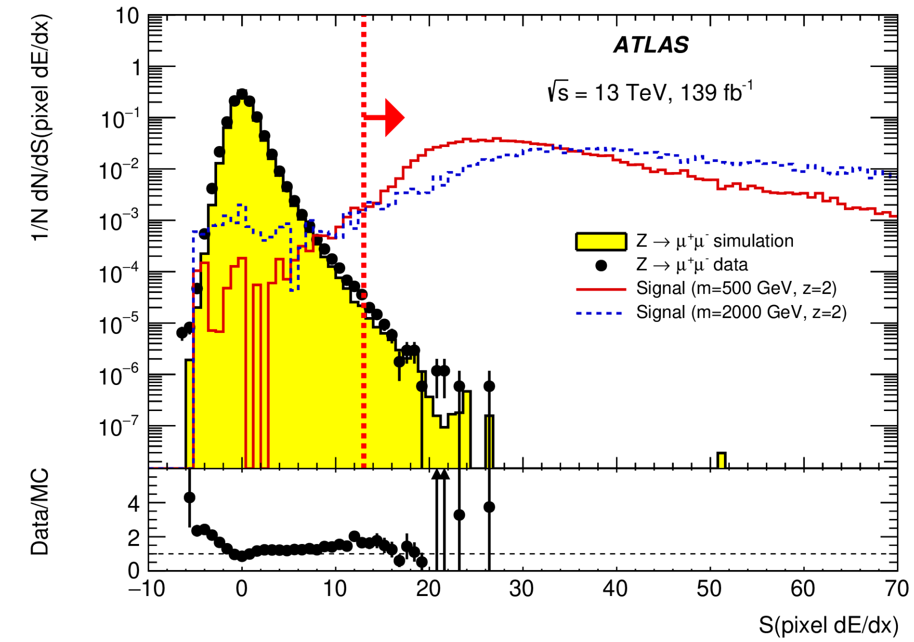


Long-Lived Multi-Charged Particles



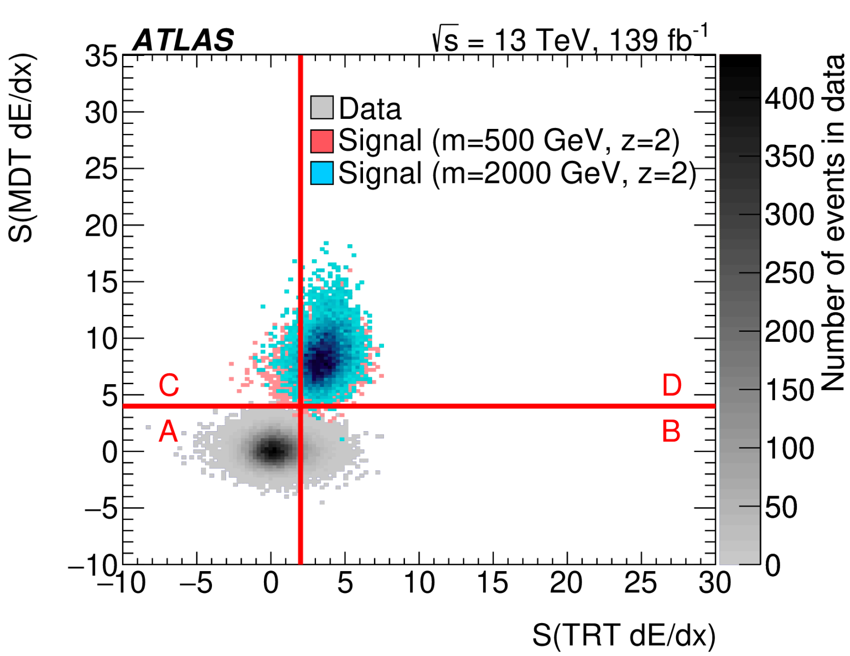
- Multi-charged particles (MCP): techno-baryons from TC, doubly charged Higgs from left-right symmetric model or from supersymmetric left-right model.
  - Q=ze, 1 < |z| < 8, 500 < mass < 2000 GeV, **μ**-like signatures
  - Higher mass and higher charge (high dE/dx in several subsystems) requires using additionally "late-**μ**" and MET trigger to catch signal ending between bunch crossings.

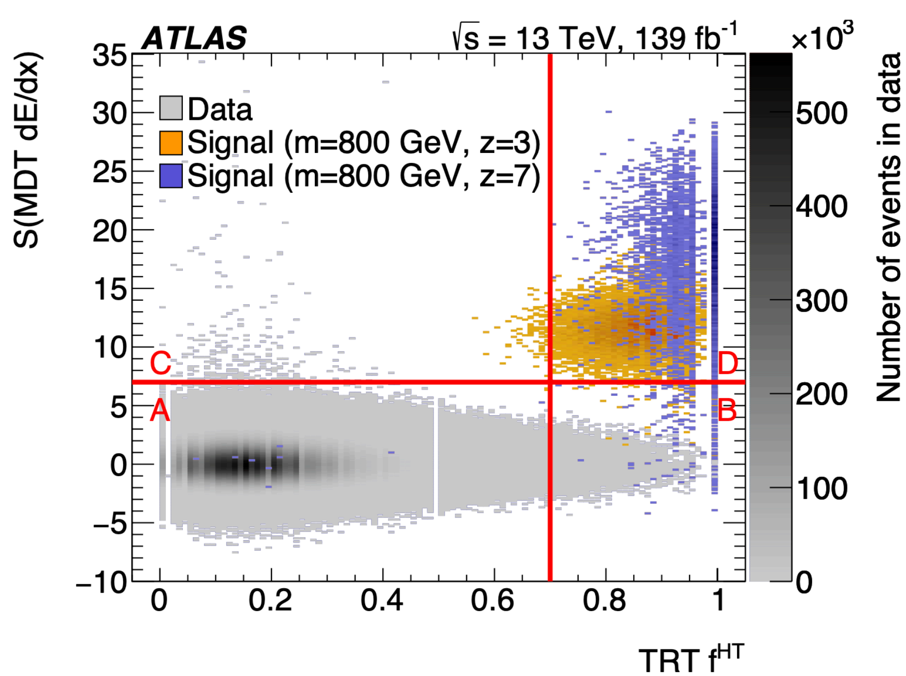
$$S(dE/dx) = \frac{dE/dx - \langle dE/dx \rangle_\mu}{\sigma(dE/dx)_\mu}$$

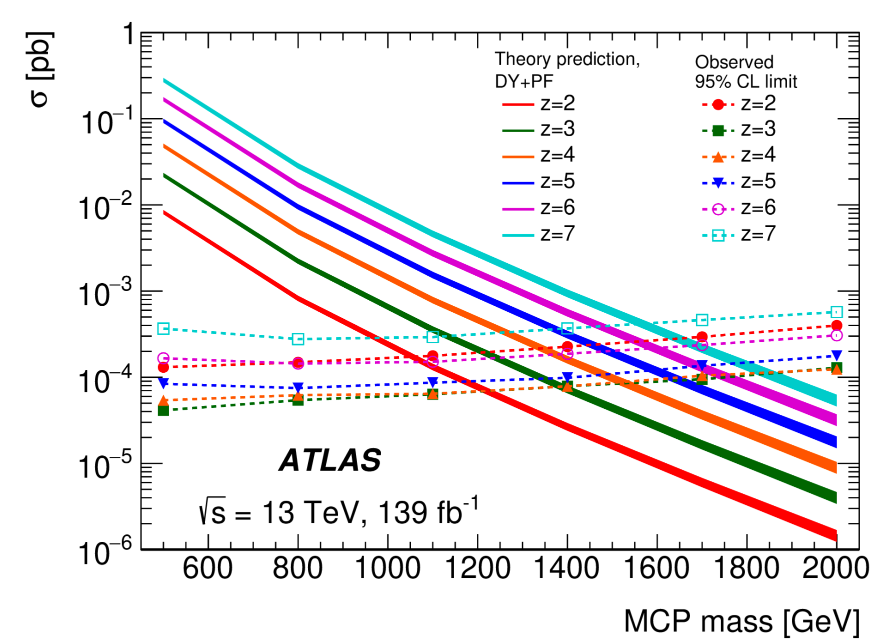


Some candidate events from dE/dx search were not selected by this search due to low ionisation loss in tracker and moun chambers.

z=2 1.6±0.4±0.5 evt exp. | 4 evt obs. | 1.5 Z sign.
z>2 0.034±0.002±0.004 evt exp. | 0 evt obs.



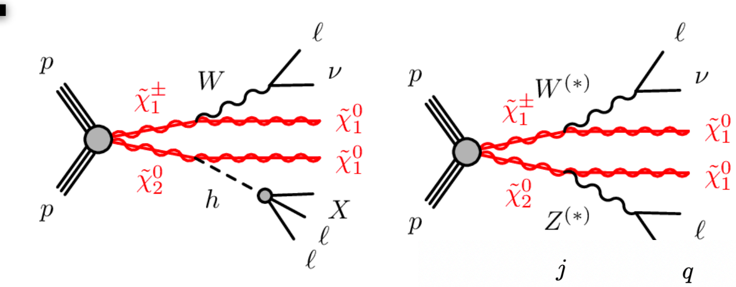




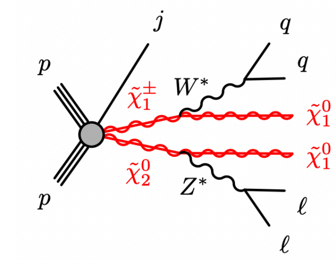
Search with 3L + MET

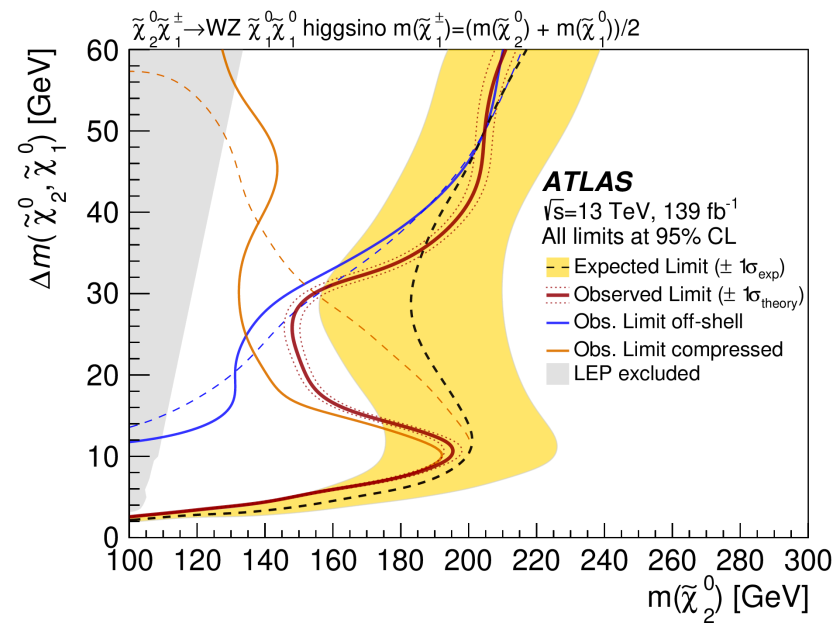
[ATLAS arXiv:2106.01676](https://arxiv.org/abs/2106.01676)

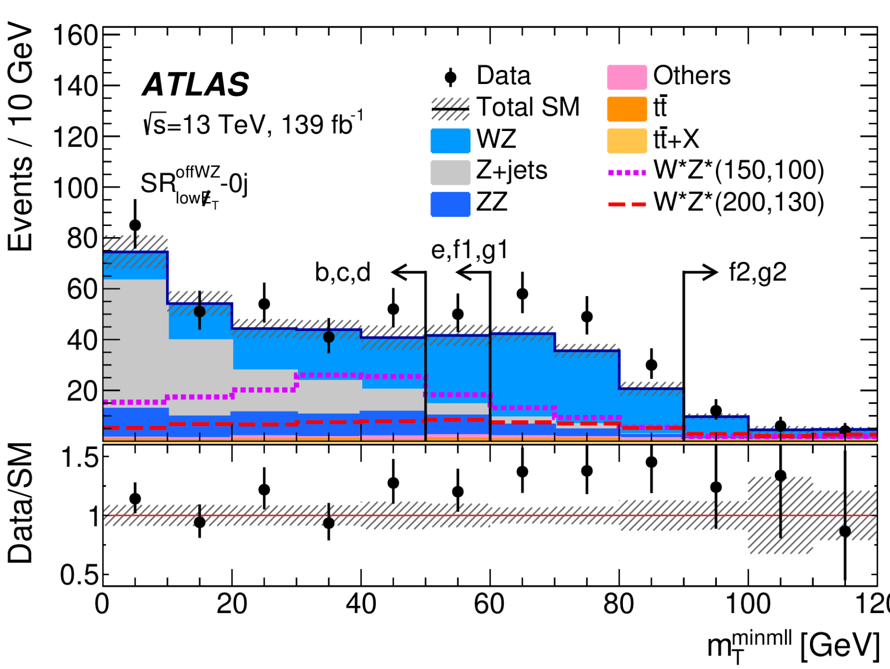
- SUSY chargino-neutralino pair-production
  - Simplified SUSY models with WZ and Wh mediated productions with final state of 3ℓ + missing transverse momentum
  - Considering different signal scenarios depending on mass spectra
  - Several aspects of the analysis are improved: selection, particle reconstruction, lepton id/isolation, as well as using MVA techniques
  - On-shell WZ, off-shell WZ, on-shell Wh are optimised separately taking into account lepton flavour, (in-)consistency with Z boson mass, etc..

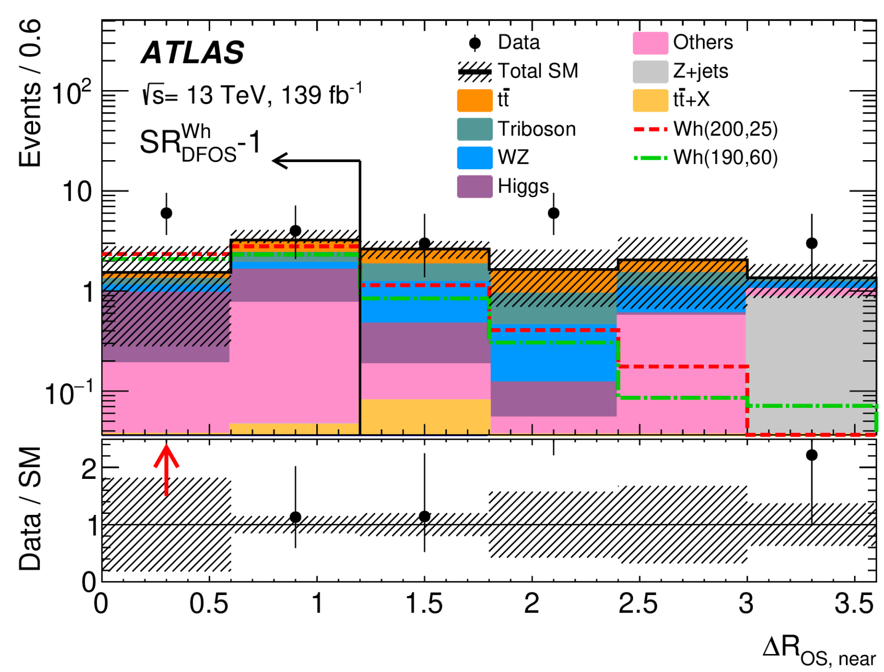


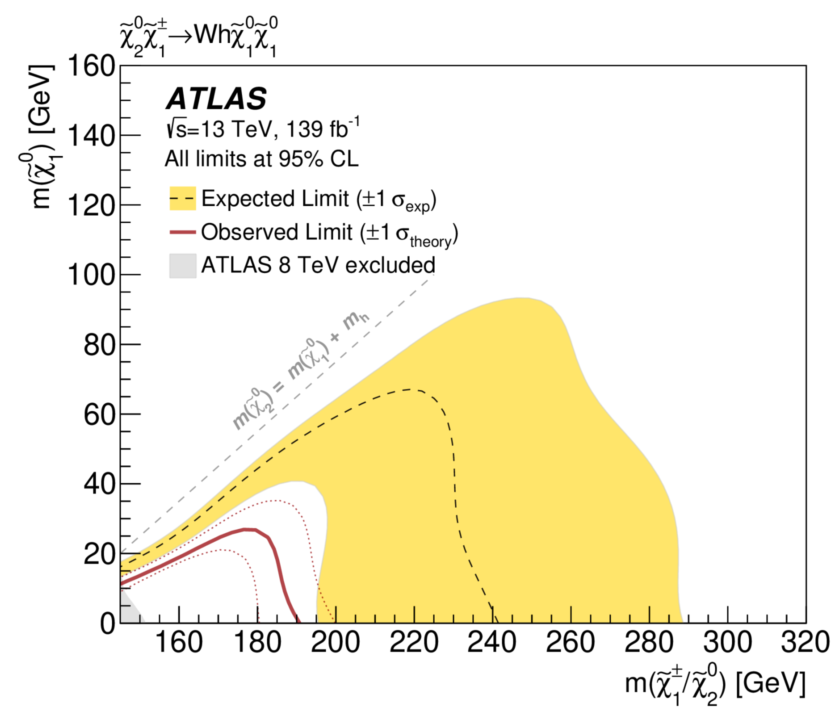
Results combined with 2L+MET search







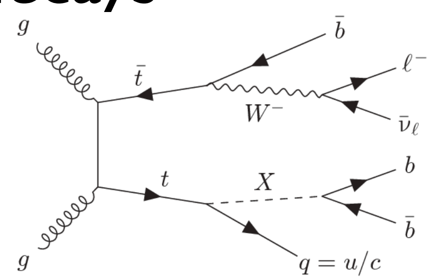


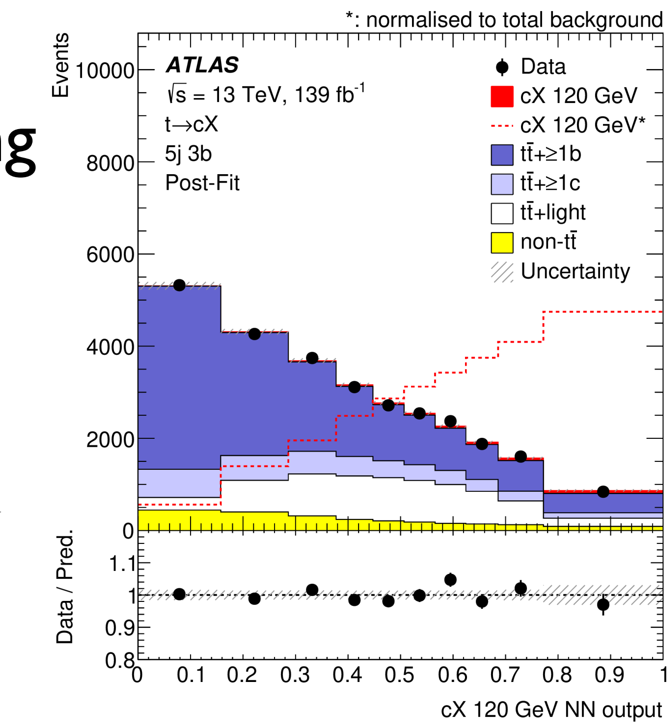


Searches in Top Decays

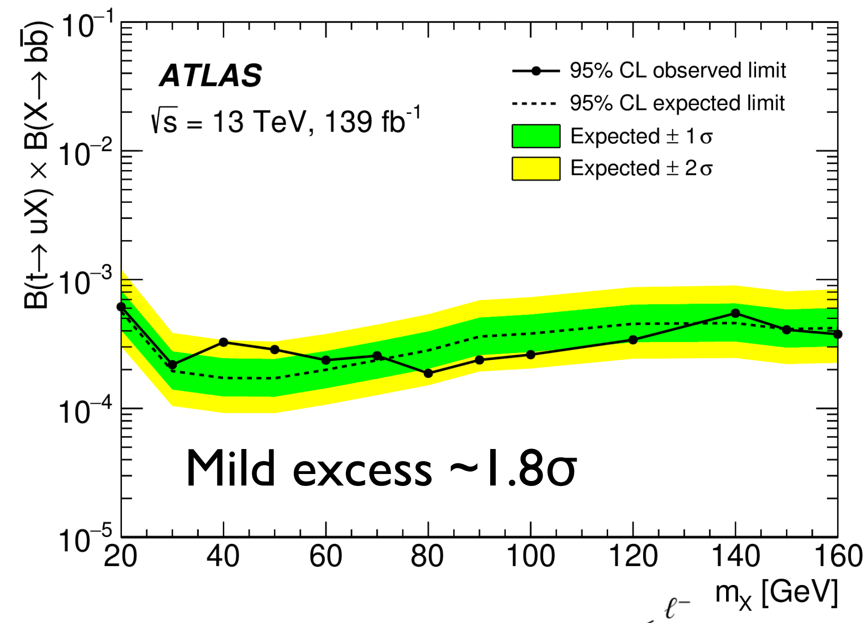
- LHC is a top quark factory. Searching for BSM signals in top quark decays is highly motivated

- FCNC in top quark decays
  - Categorised in N(j), N(b). q = u or c



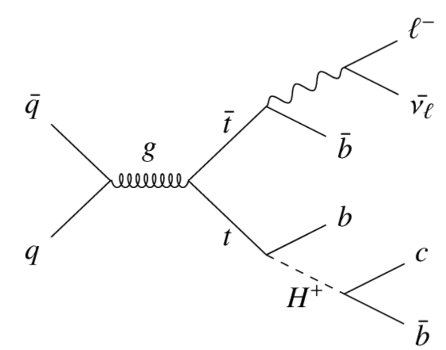


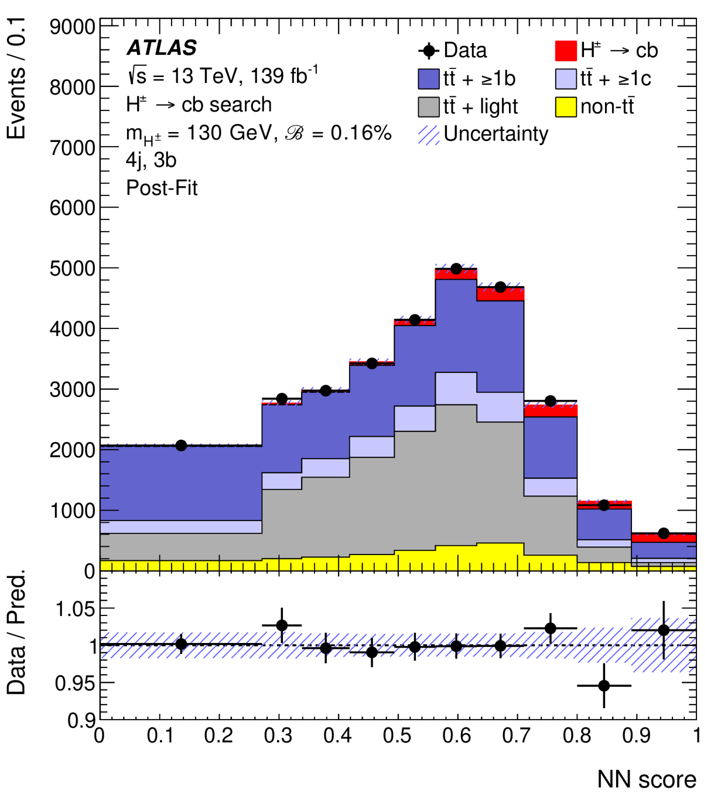
ATLAS arXiv:2301.03902

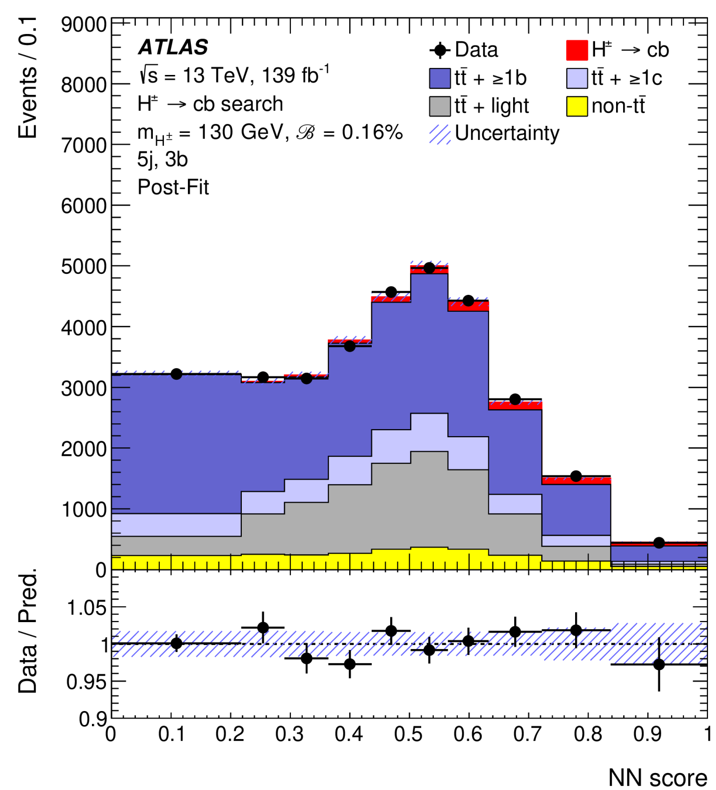


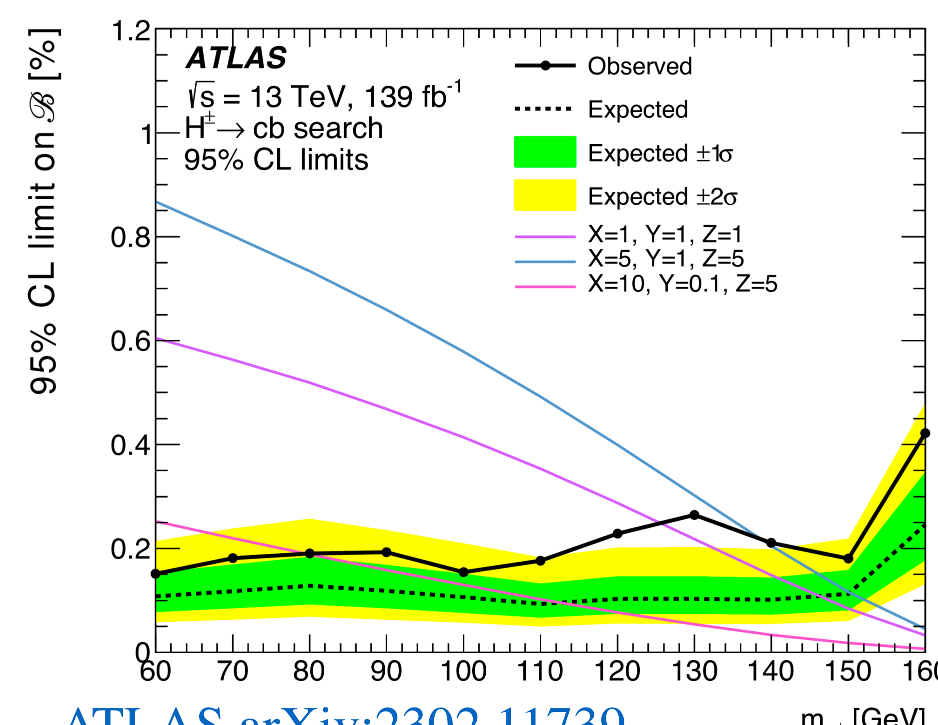
- Search for charged Higgs in top quark decays $H^\pm \to cb$
  - Significantly small background from $W \to cb$

Excess @130 GeV : 3 σ (2.5 σ)
$Br(H^\pm \to cb)$ = (0.16 ± 0.06) %









ATLAS arXiv:2302.11739

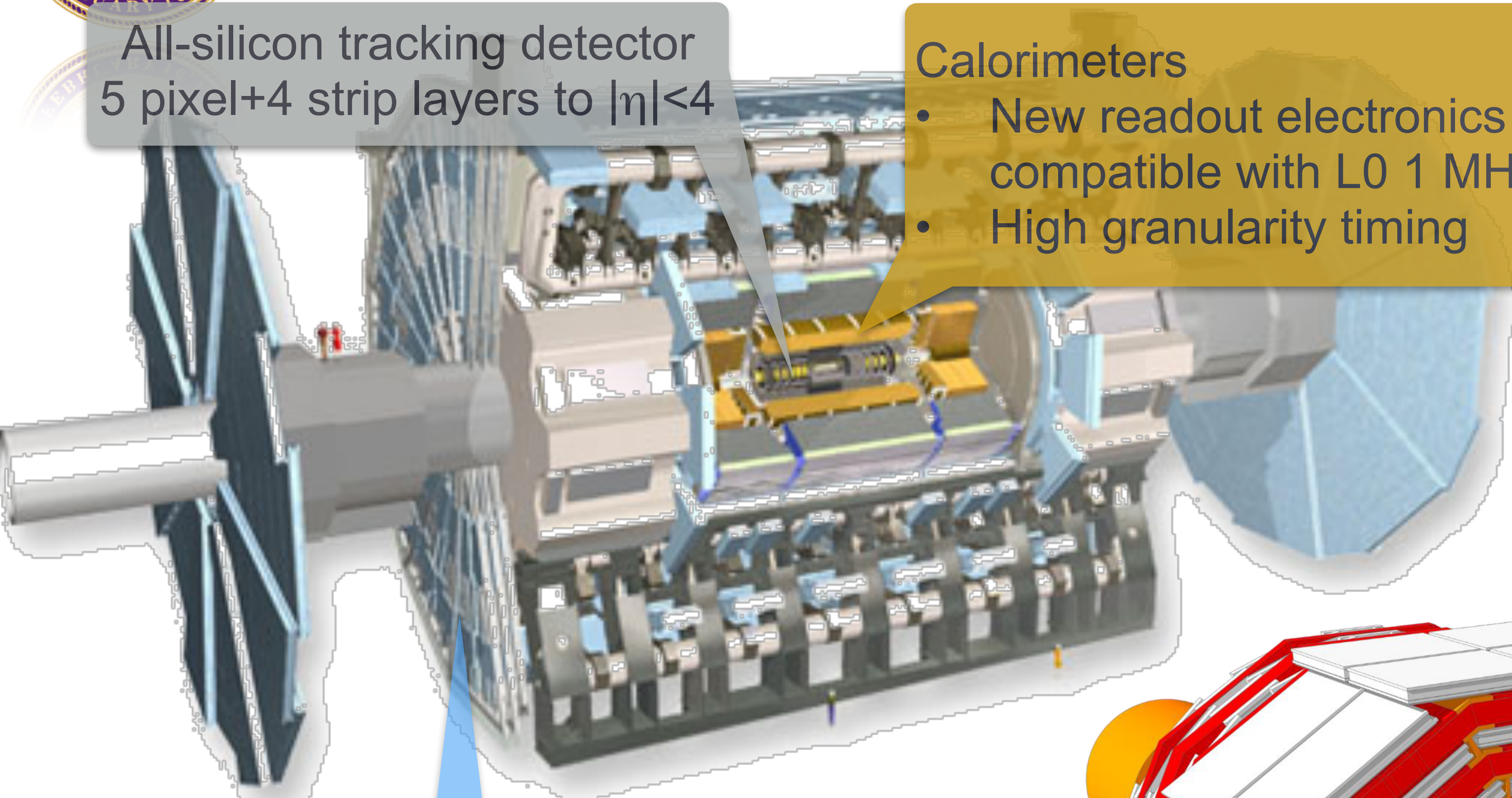
So far, collected only about 5% of data — x20 more data to come!

And before all those, Run 3 has 'just' started!

More data:

- Explore processes with smaller cross-sections
- Explore unusual signatures, smaller couplings
- Improve precision of the SM measurements and modelling

Major Detector Upgrades

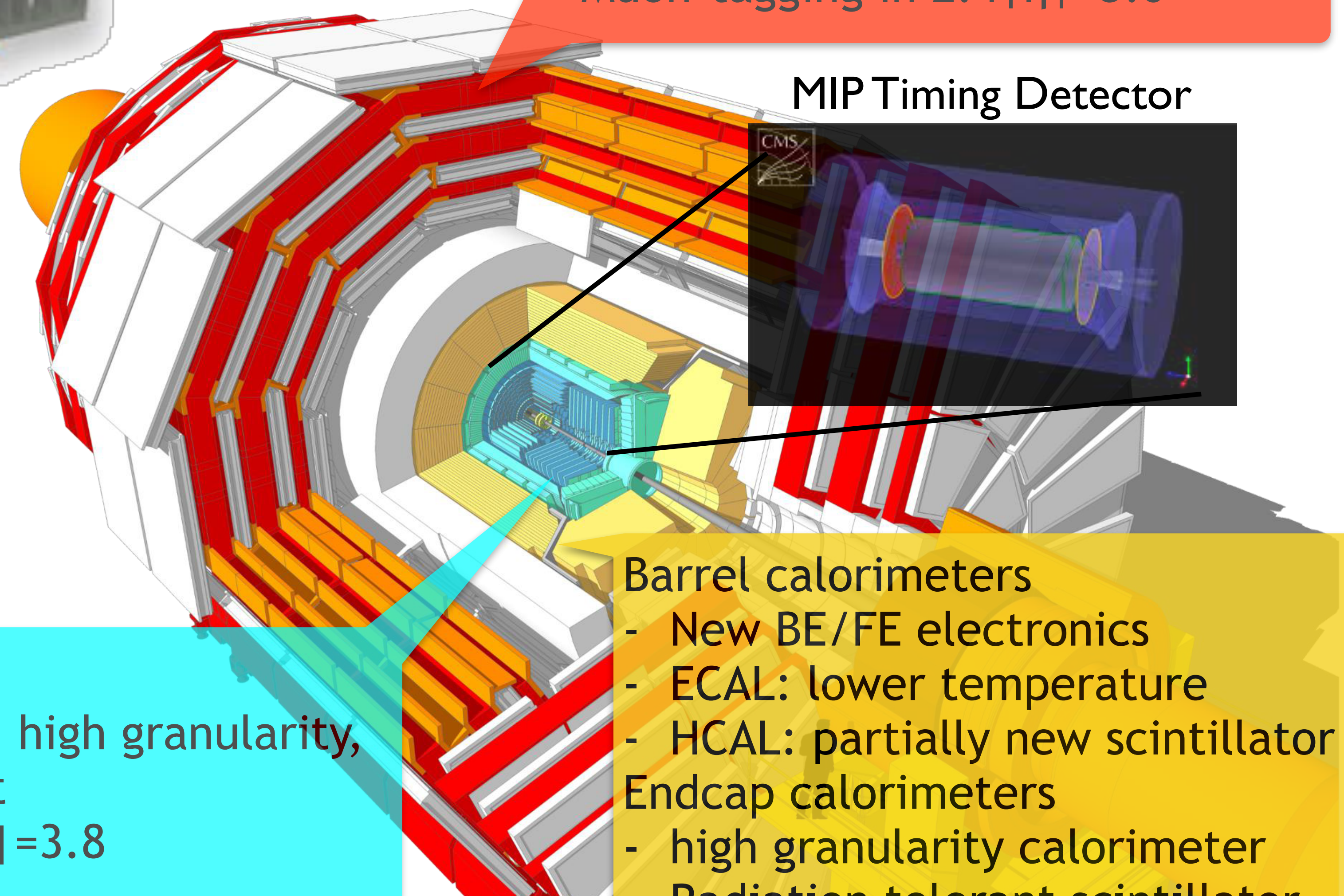


All-silicon tracking detector
5 pixel+4 strip layers to |η|<4

Calorimeters
- New readout electronics compatible with L0 1 MHz rate
- High granularity timing

ATLAS Trigger and DAQ
- L0 (Calo+μ): 1 MHz
- L1 (Calo+μ+Itk): 400 kHz
- HLT: 10 kHz

Muon systems
- New readout and trigger electronics
- Additional chambers for inner



Muon systems
- New DT/CSC BE/FE electronics
- GEM/RPC coverage in 1.5<|η|<2.4
- Muon-tagging in 2.4|η|<3.0

CMS Trigger & DAQ
- Track-trigger @L1
- L1 rate ~750kHz
- HLT output ~7.5kHz

TRACKER
- radiation tolerant, high granularity, low material budget
- coverage up to |η|=3.8
- track trigger at l1

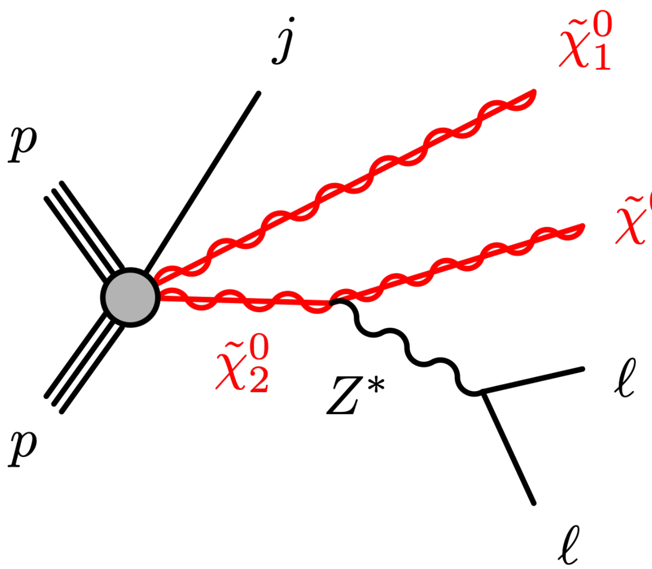
Barrel calorimeters
- New BE/FE electronics
- ECAL: lower temperature
- HCAL: partially new scintillator

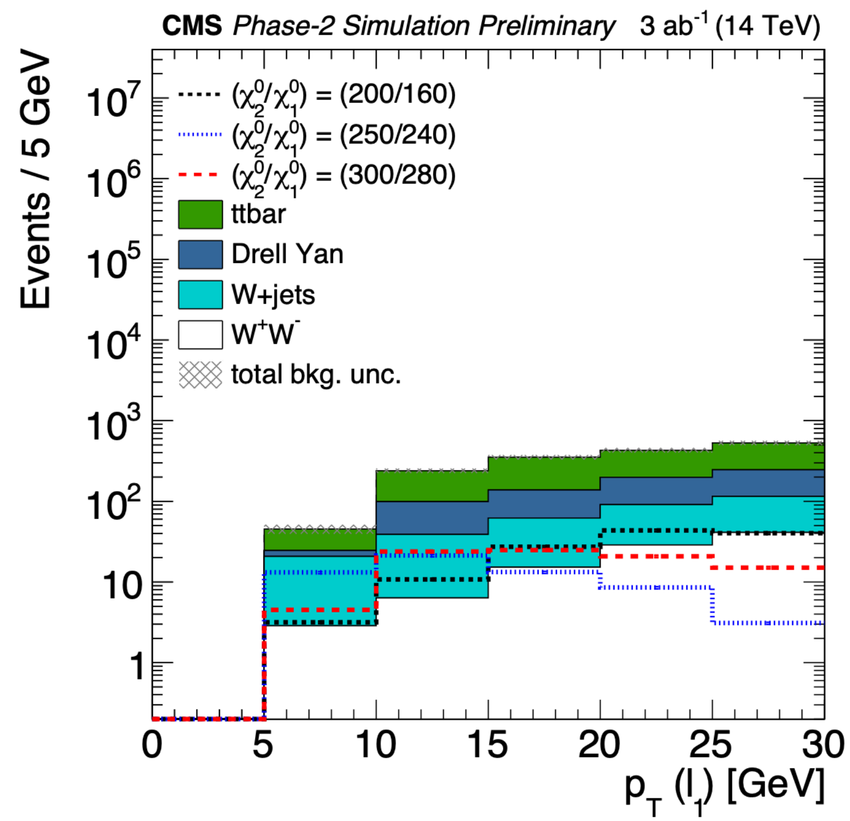
Endcap calorimeters
- high granularity calorimeter
- Radiation tolerant scintillator

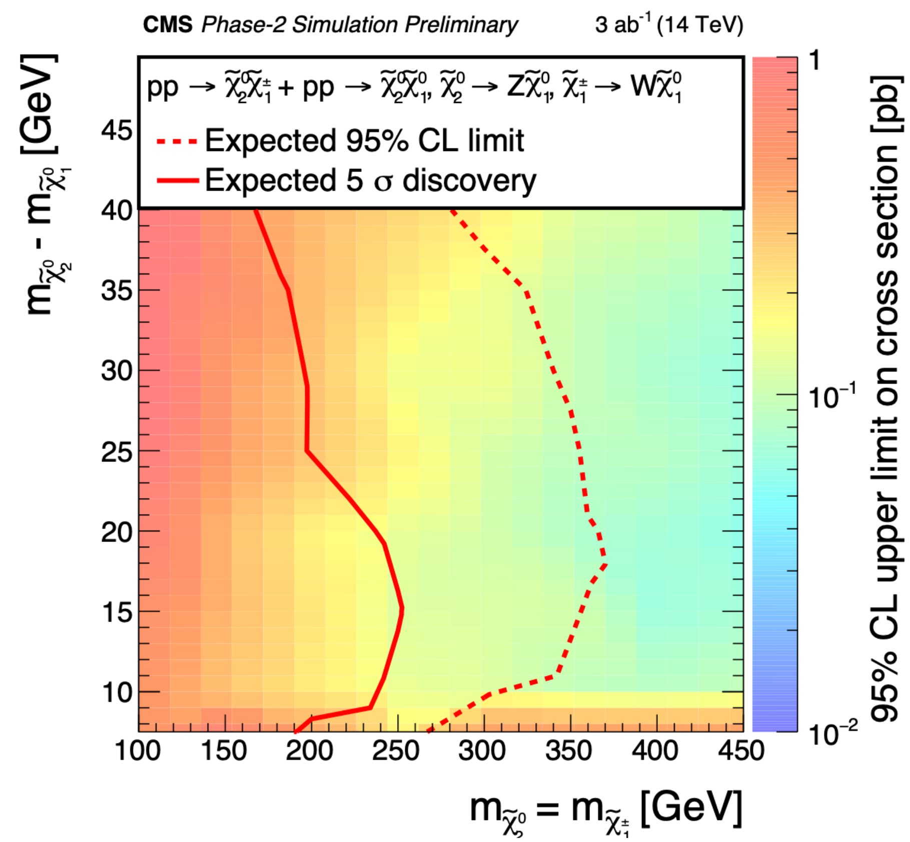
Supersymmetry

Electroweakino search with small $\Delta m = m_{\tilde{\chi}^0_2} - m_{\tilde{\chi}^0_1}$

CMS FTR 18-001

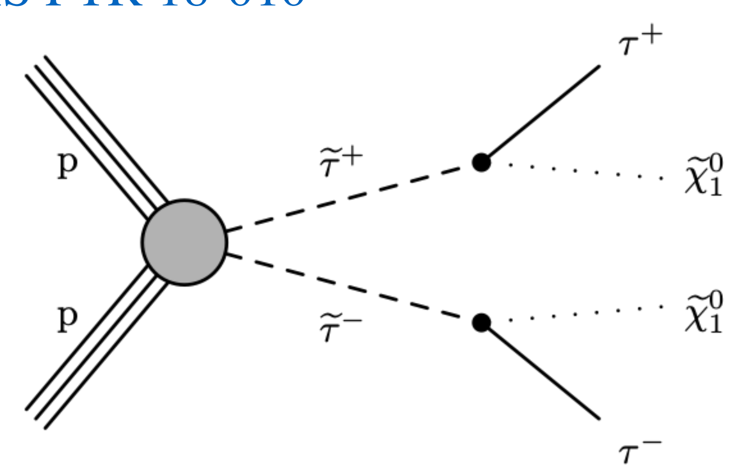


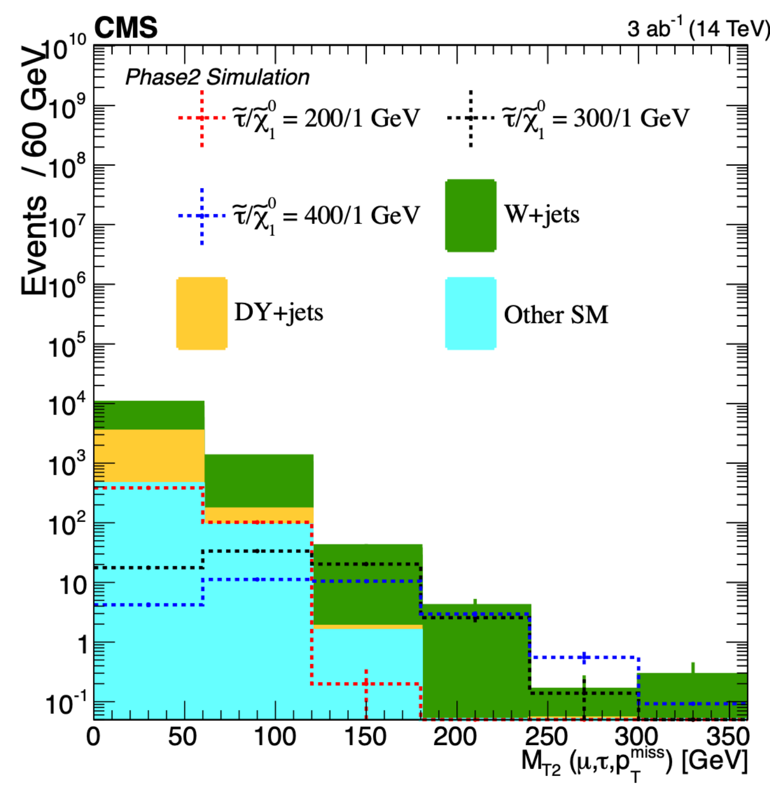


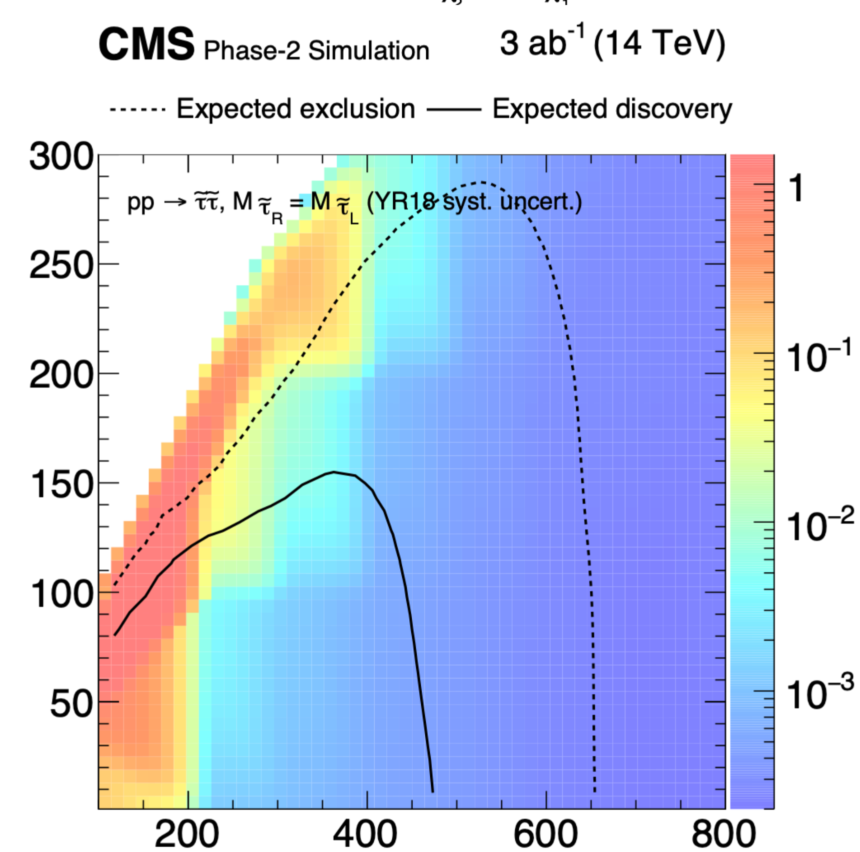


Stau search

CMS FTR 18-010



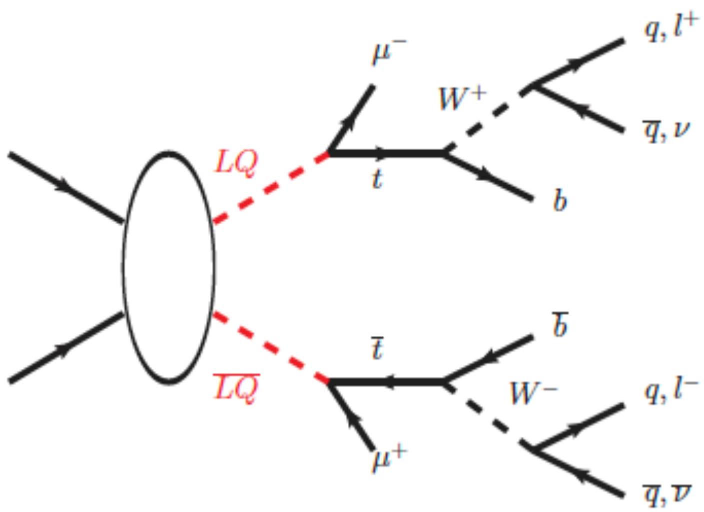


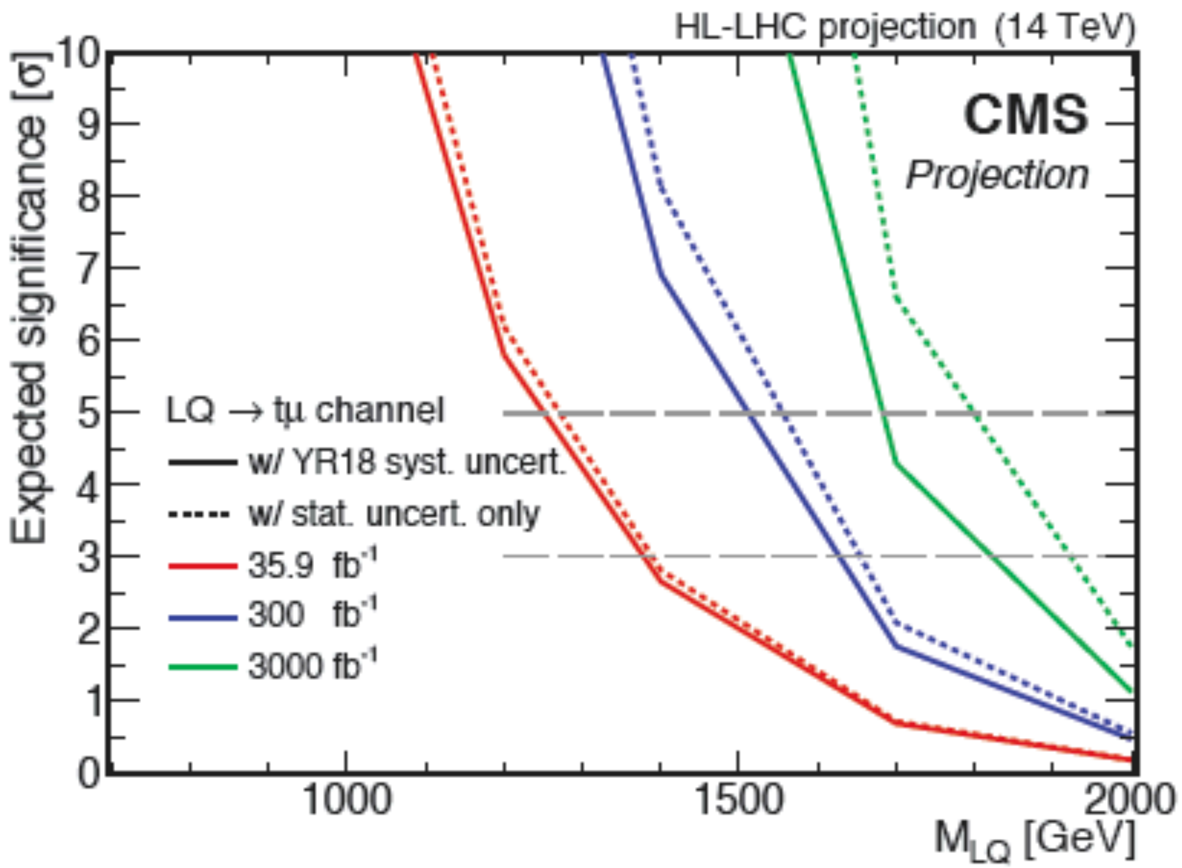


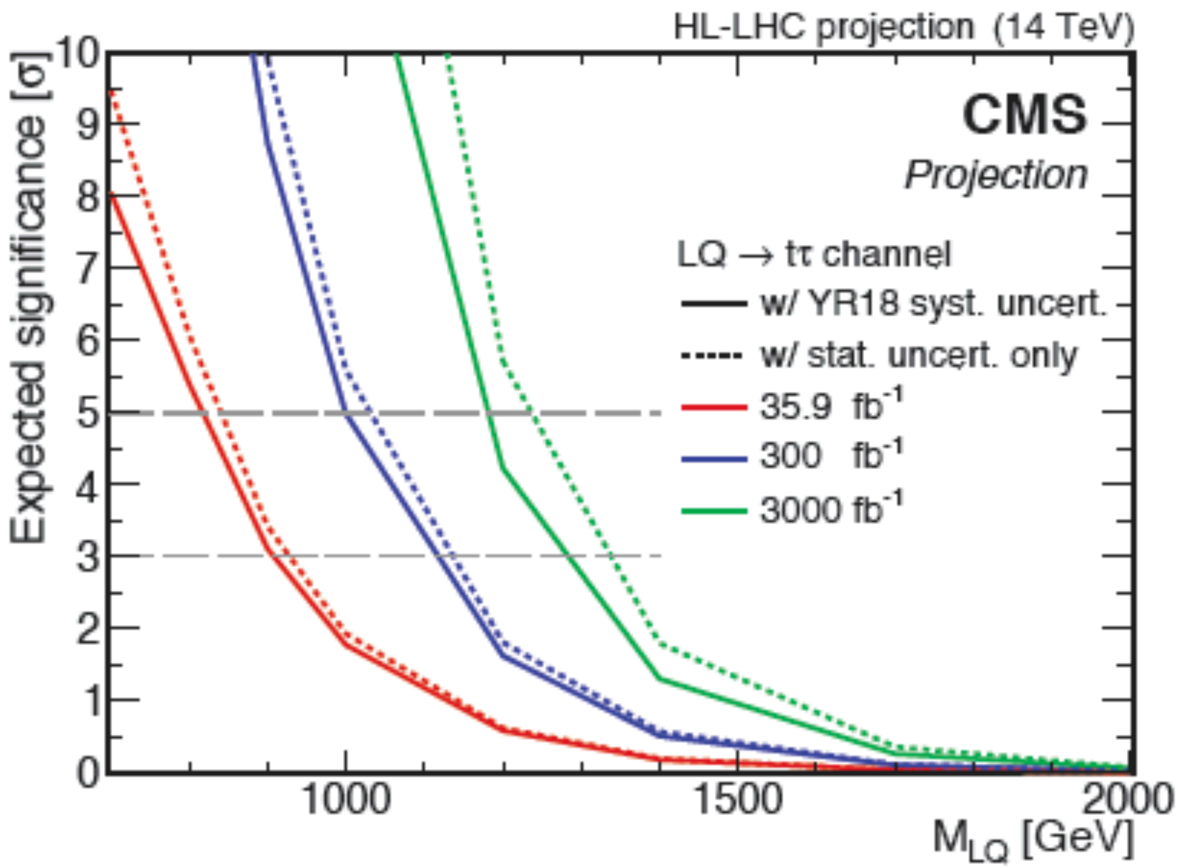
Leptoquarks

CMS FTR 18-008

- LQ could be searched in different final states
- Most of the current constraints assume Br(LQ→ℓq) = 100%. Large dataset will enable probing smaller Br.



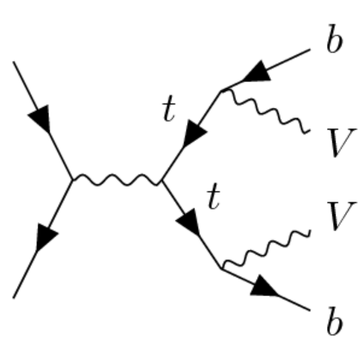


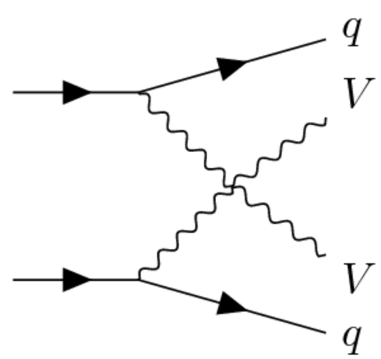


Heavy Resonances

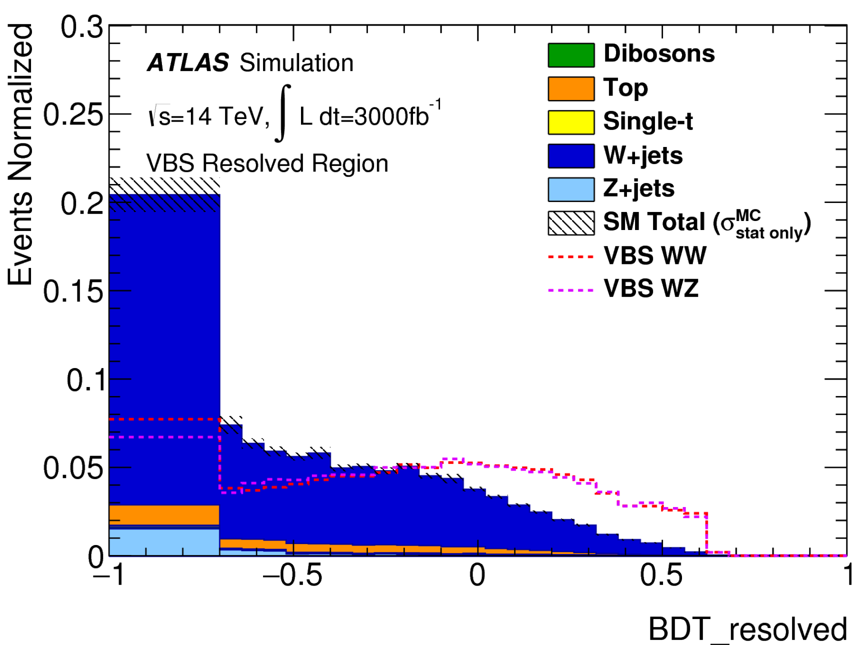
ATL-PHYS-PUB-2018-022

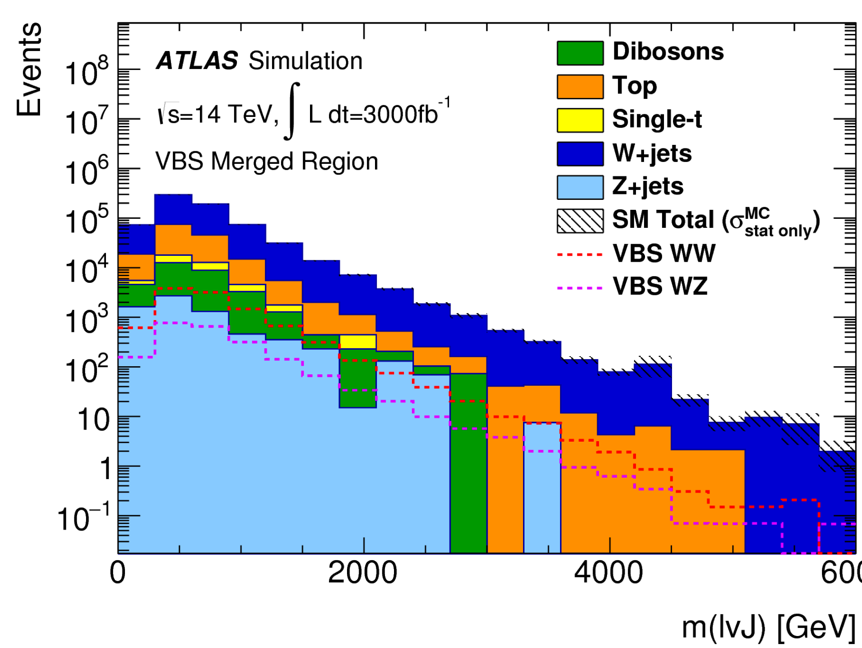
- Continue looking for a heavy resonance using powerful search techniques

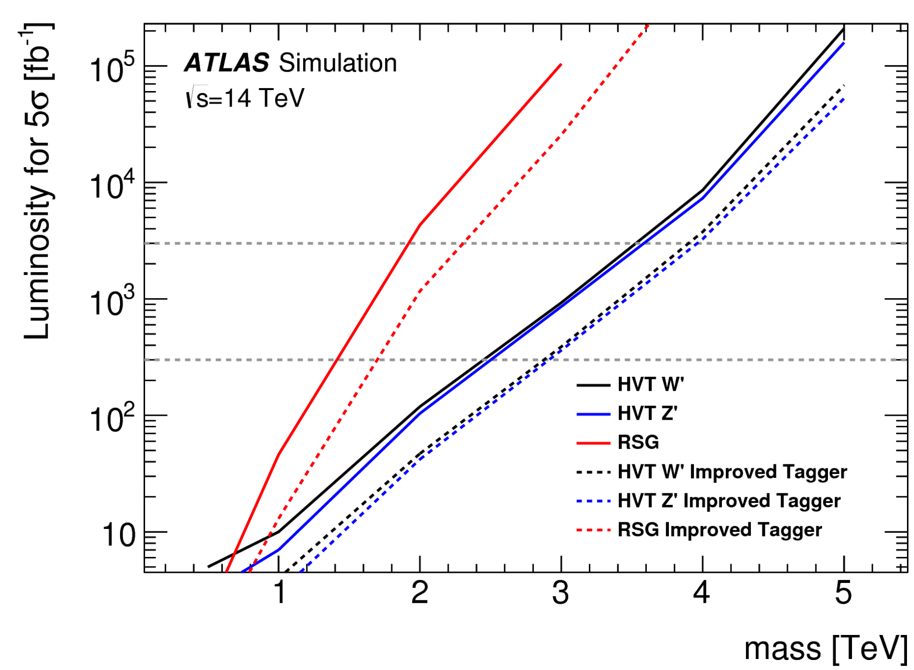




Selection	Resonance Resolved	Resonance Merged
$W \to \ell\nu$	1 isolated "tight" lepton 0 additional "loose" leptons	
	$E_T^{miss} > 60$ GeV $p_T(\ell\nu) > 75$ GeV	$E_T^{miss} > 100$ GeV $p_T(\ell\nu) > 200$ GeV
	$E_T^{miss}/p_T(e\nu) > 0.2$	
$V \to jj$	2 small-R jets $min\|m(jj) - m(W/Z)\|$ $p_T(j_1) > 60$ GeV, $p_T(j_2) > 40$ GeV $66 < m(jj) < 94$ GeV or $82 < m(jj) < 106$ GeV	large-R jet highest p_T $p_T(J) > 200$ GeV, $\|\eta(J)\| < 2$ $\|m(J) - m(W/Z)\| < 50$ GeV Scale by W/Z-tagger efficiency
Tagged jets (VBF Category)	Non-b-tagged $\eta(j_1^{tag}) \cdot \eta(j_2^{tag}) < 0$, highest $m(jj)$ $p_T(j_{1,2}^{tag}) > 30$ GeV, $m(jj) > 770$ GeV, $\Delta\eta(j,j) > 4.7$	
Topology	$p_T(\ell\nu)/m(\ell\nu jj) > 0.35$ (0.3 for VBF) $p_T(jj)/m(\ell\nu jj) > 0.35$ (0.3 for VBF) $\Delta\phi(j,\ell) > 1$, $\Delta\phi(j, E_T^{miss}) > 1$ $\Delta\phi(j,j) < 1$, $\Delta\phi(\ell, E_T^{miss}) < 1$	$p_T(\ell\nu)/m(\ell\nu J) > 0.4$ (0.3 for VBF) $p_T(J)/m(\ell\nu J) > 0.4$ (0.3 for VBF)
b-veto	No b-tagged jets in the event beside 1 (2) from $W(Z) \to jj$	



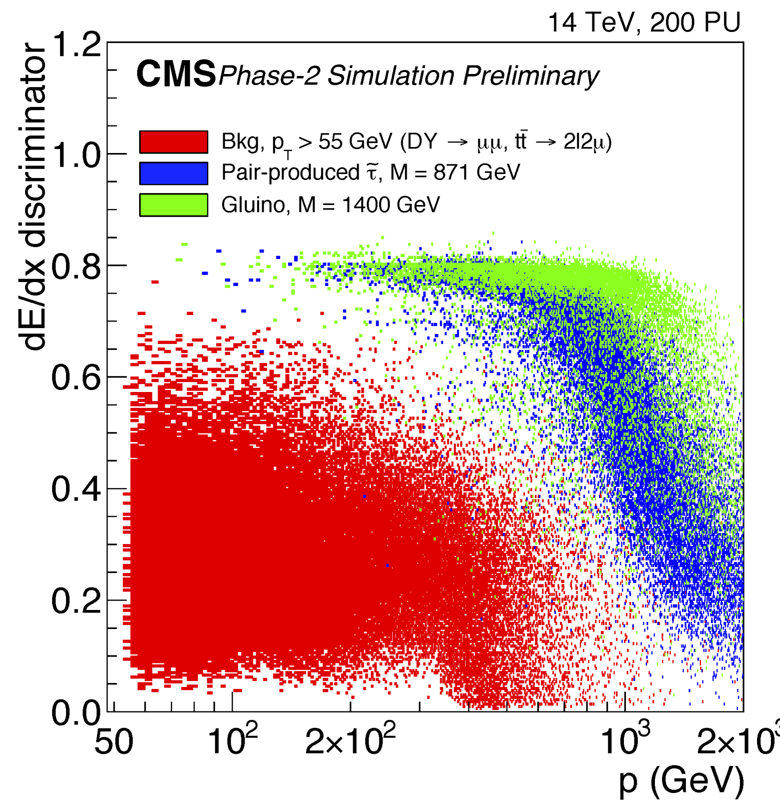


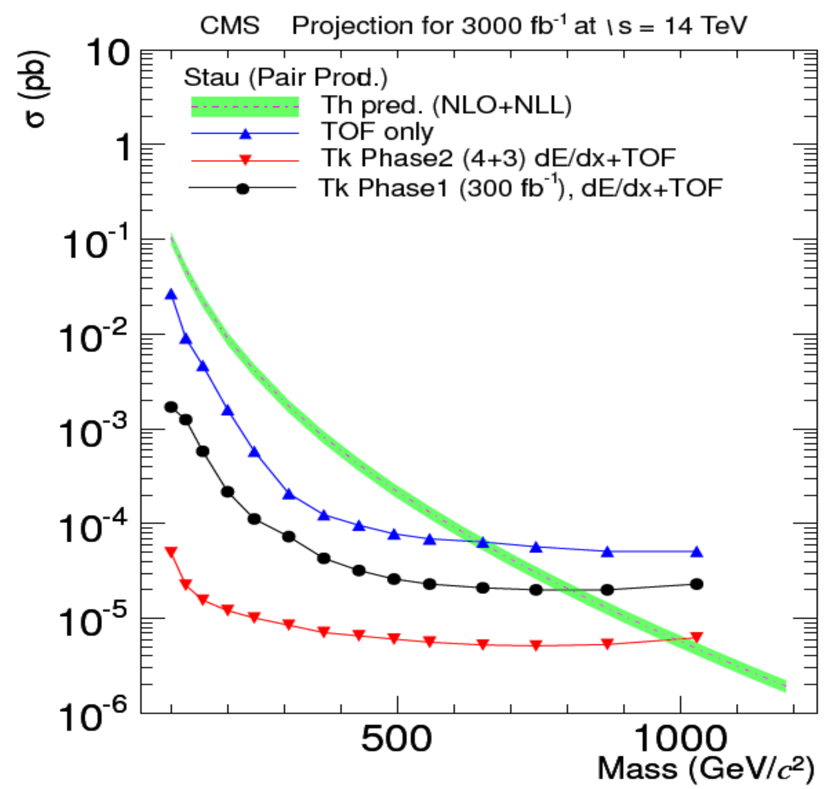


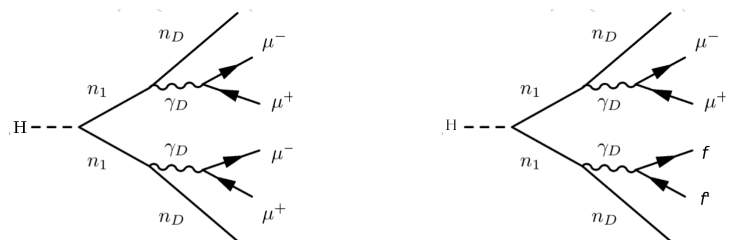
Non-prompt Searches

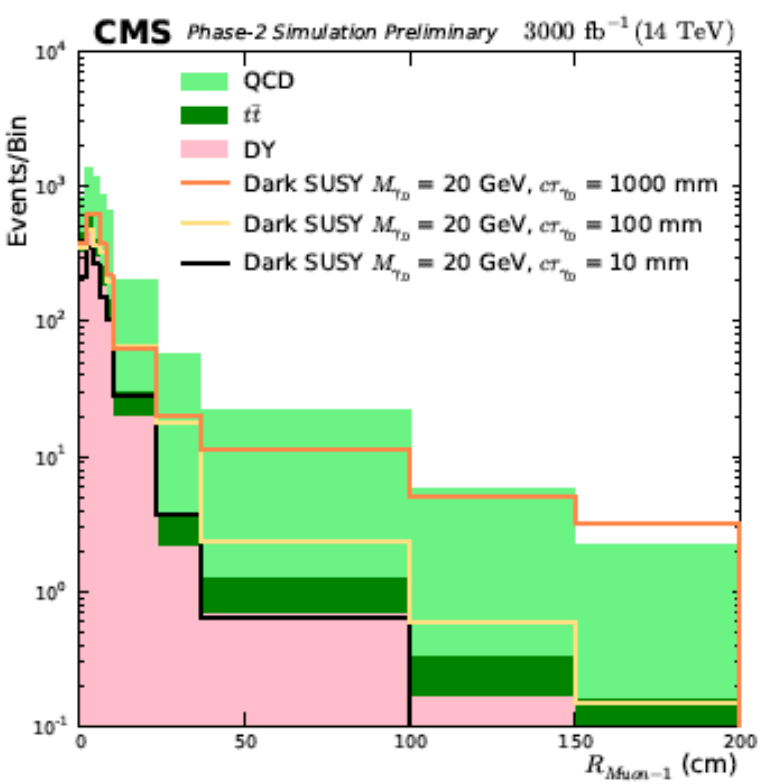
[CMS-PAS-EXO-14-007](CMS-PAS-EXO-14-007)

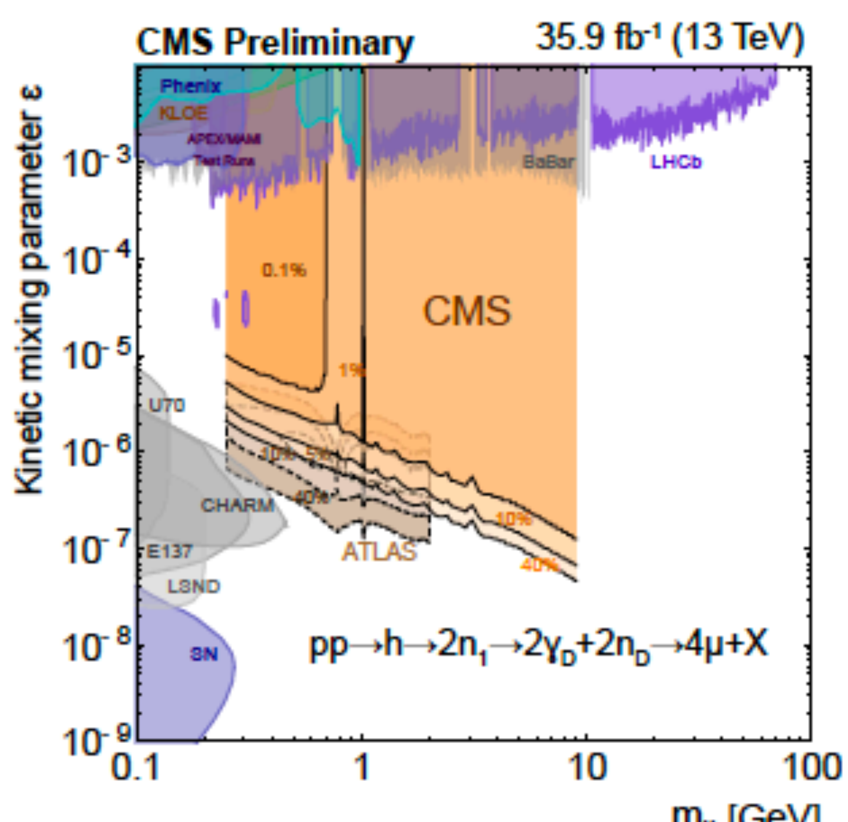
- Large dataset is essential for LLPs given their very small cross section
  - dE/dx is a powerful handle in these searches
- Search for dark photons



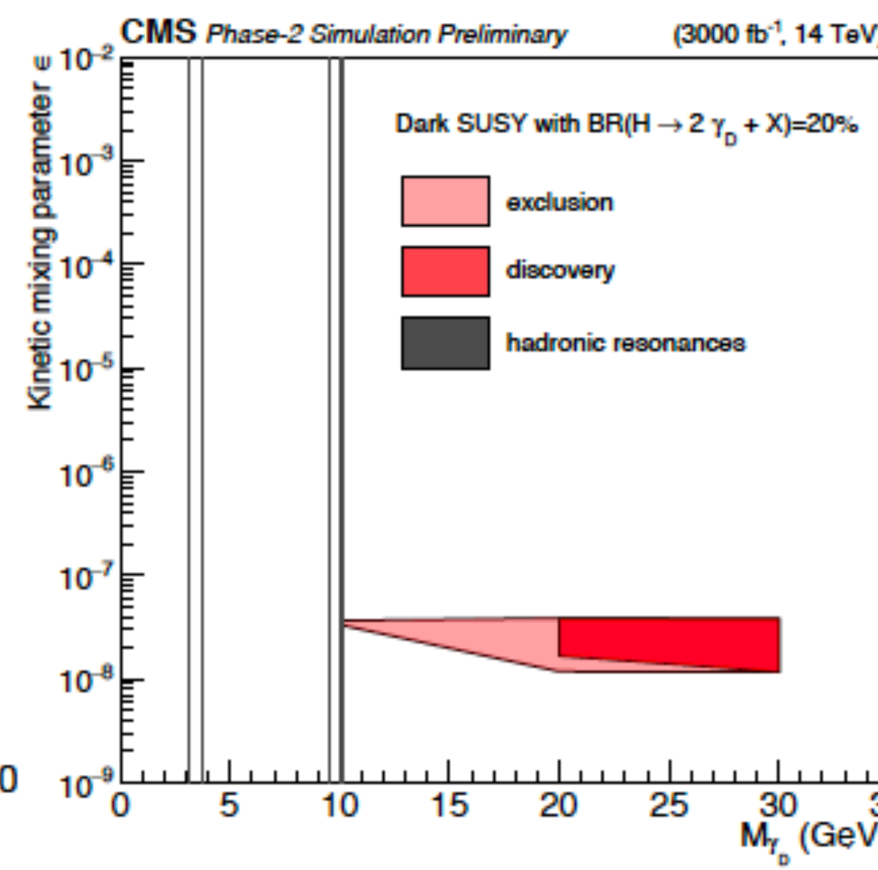








CMS-FTR-18-002

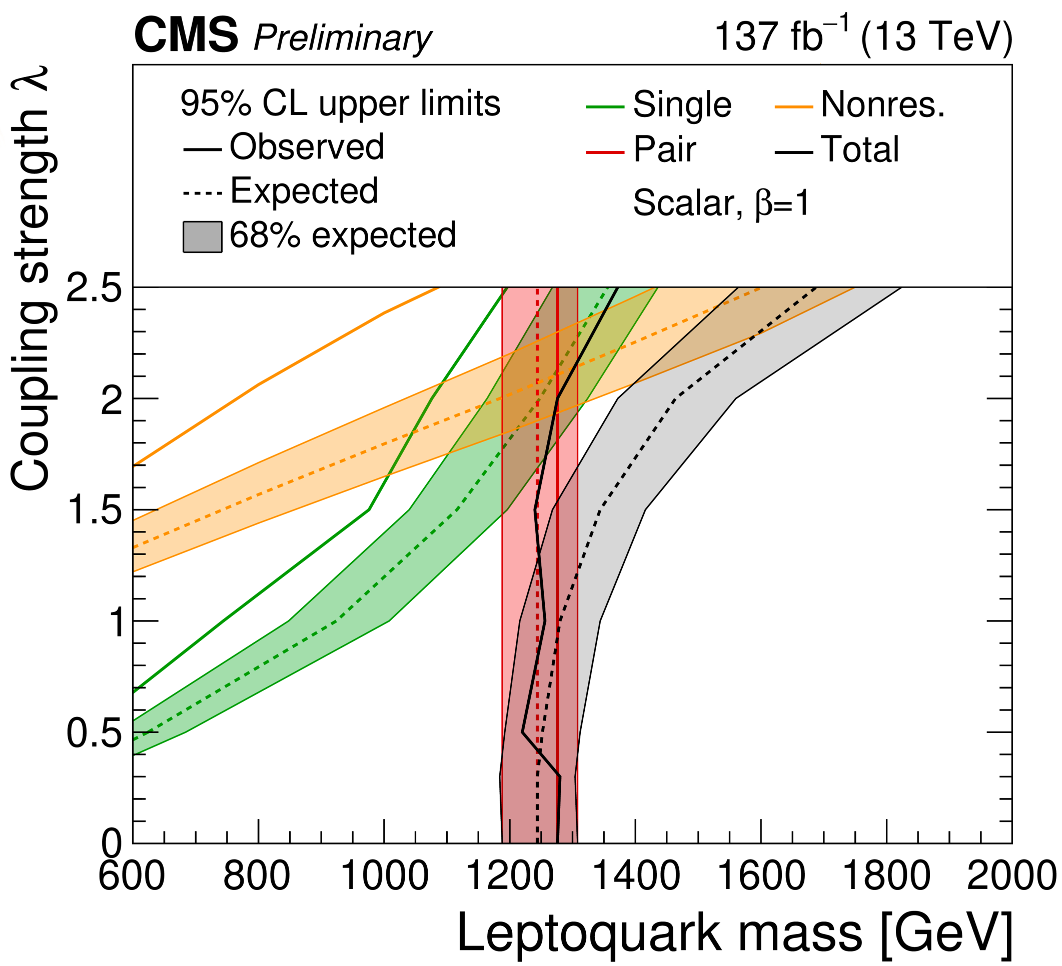


Summary

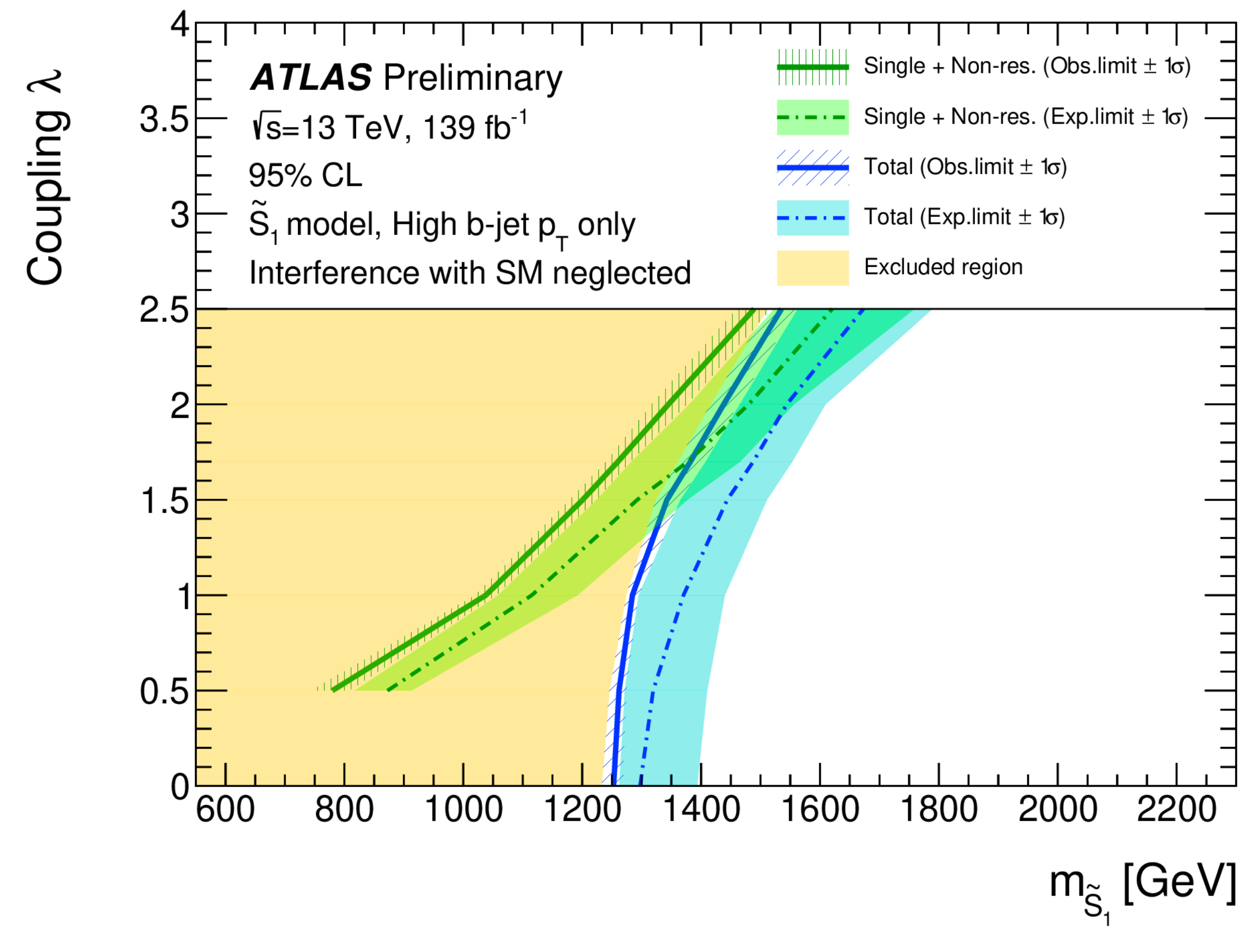
- The LHC has been a tremendous success and the ATLAS and CMS detectors have performed remarkably well
  - Discovery of the Higgs boson and detailed study of its properties
  - Measurement of the SM processes at the highest possible precision
  - Observation of rare processes
  - Yet, no discovery of the physics beyond the standard model
- But… The Run 2 data have shown a few excesses. Some of those even line up interestingly..
- And… The Run 3 is already ongoing. All those 'hints' will be checked with Run 3 (and combined) datasets
- High-Luminosity LHC is around the corner— will enable significantly extend probes for BSM using larger dataset and more sophisticated methods. Stay tuned!

BACKUP

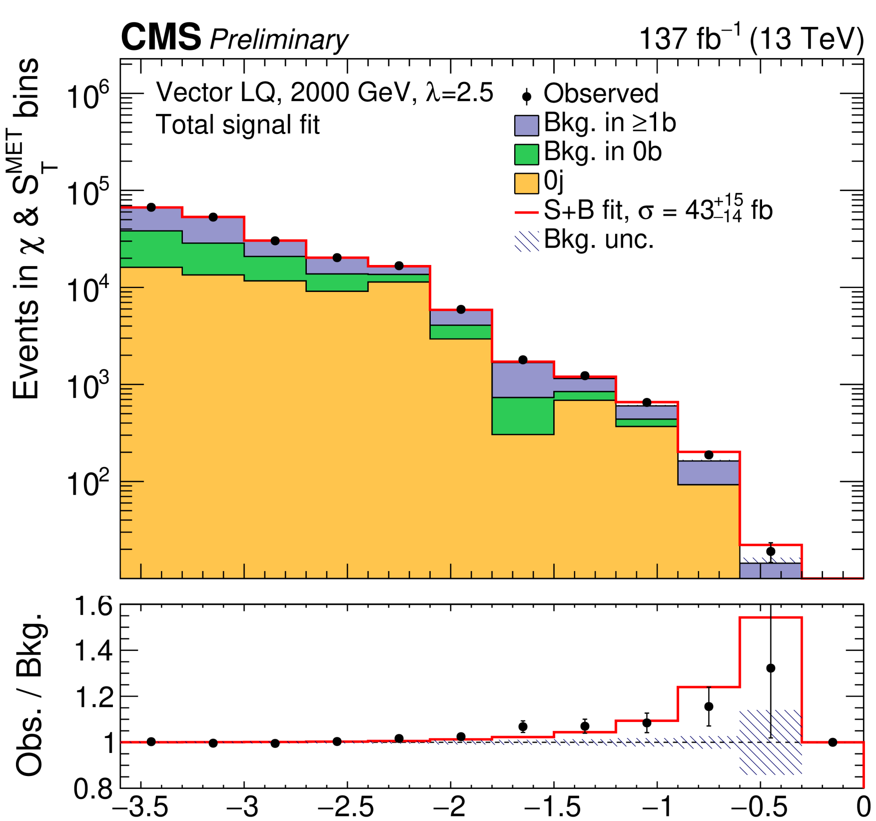
LQ Searches



CMS Preliminary
137 fb⁻¹ (13 TeV)
95% CL upper limits
Observed
Expected
68% expected
Single
Pair
Nonres.
Total
Scalar, β=1
Coupling strength λ
Leptoquark mass [GeV]



ATLAS Preliminary
√s=13 TeV, 139 fb⁻¹
95% CL
S̃1 model, High b-jet pT only
Interference with SM neglected
Single + Non-res. (Obs.limit ± 1σ)
Single + Non-res. (Exp.limit ± 1σ)
Total (Obs.limit ± 1σ)
Total (Exp.limit ± 1σ)
Excluded region
Coupling λ
m_S̃1 [GeV]



CMS Preliminary
137 fb⁻¹ (13 TeV)
Vector LQ, 2000 GeV, λ=2.5
Total signal fit
Observed
Bkg. in ≥1b
Bkg. in 0b
0j
S+B fit, σ = 43+15−14 fb
Bkg. unc.
Events in χ & S_T^MET bins
Obs. / Bkg.