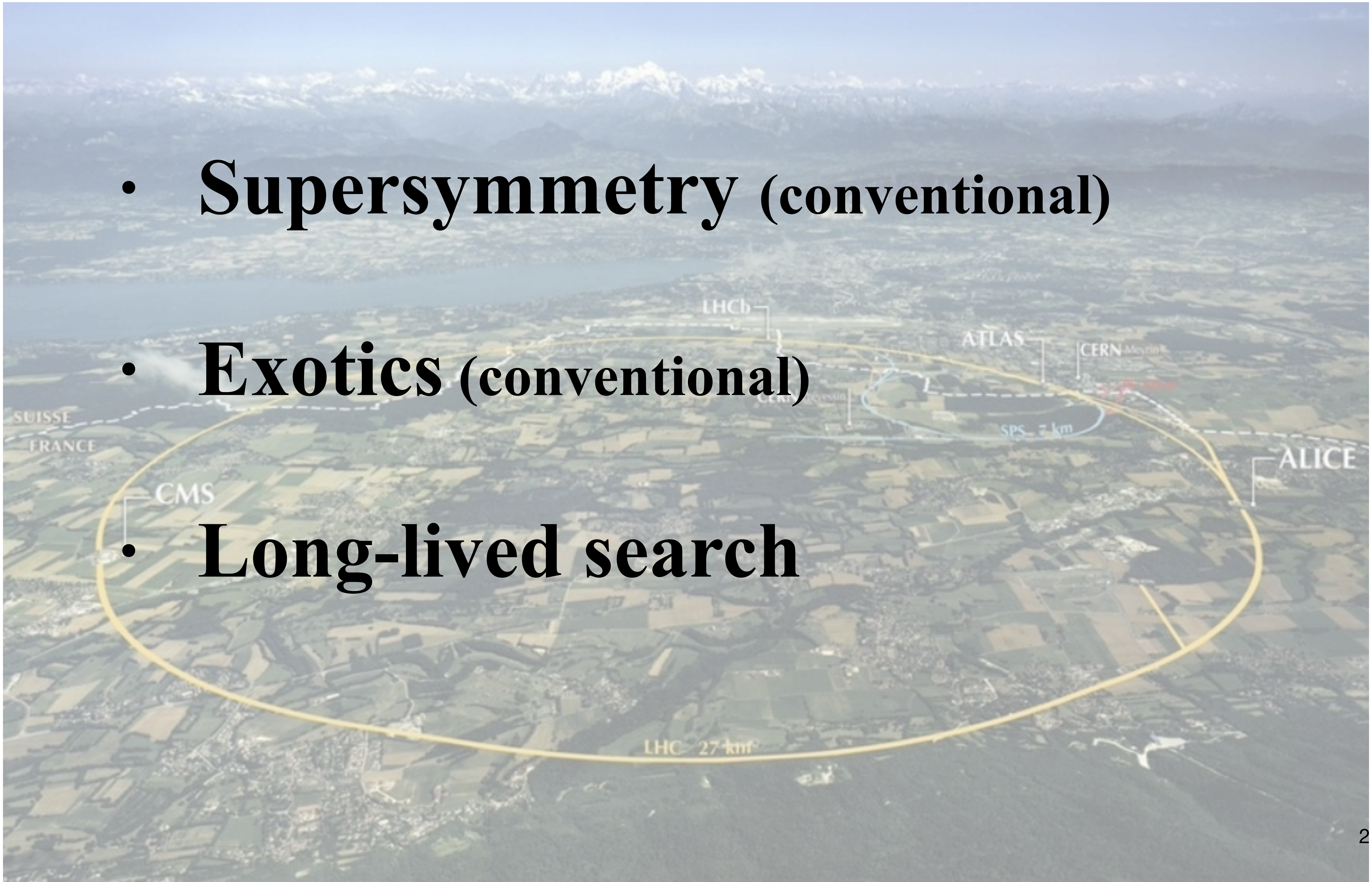
Results on SUSY and Exotics at LHC

(incl. non-conventional signatures)

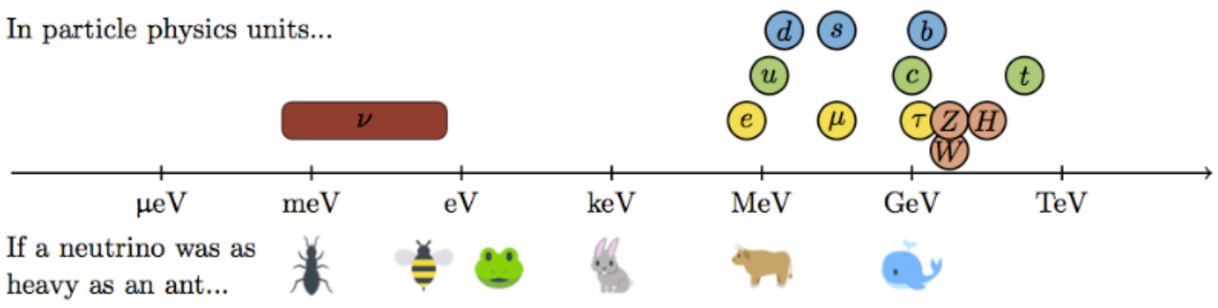
Da XU (IHEP, CAS)
on behalf of ATLAS, CMS and LHCb experiments
PIC 2022

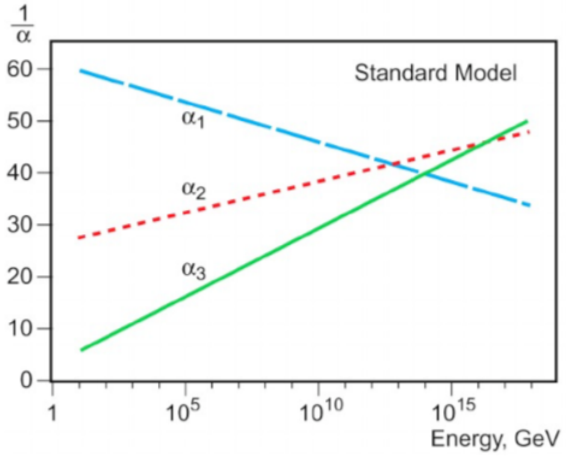
中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

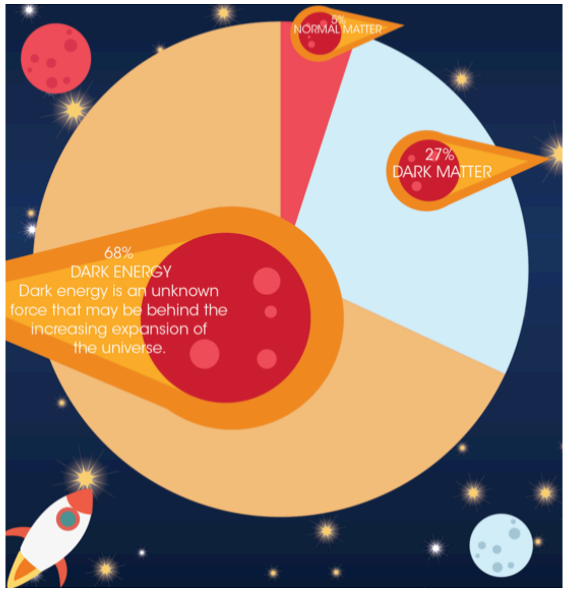
Outline

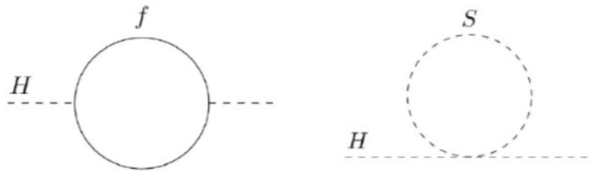


- **Supersymmetry (conventional)**
- **Exotics (conventional)**
- **Long-lived search**









Supersymmetry

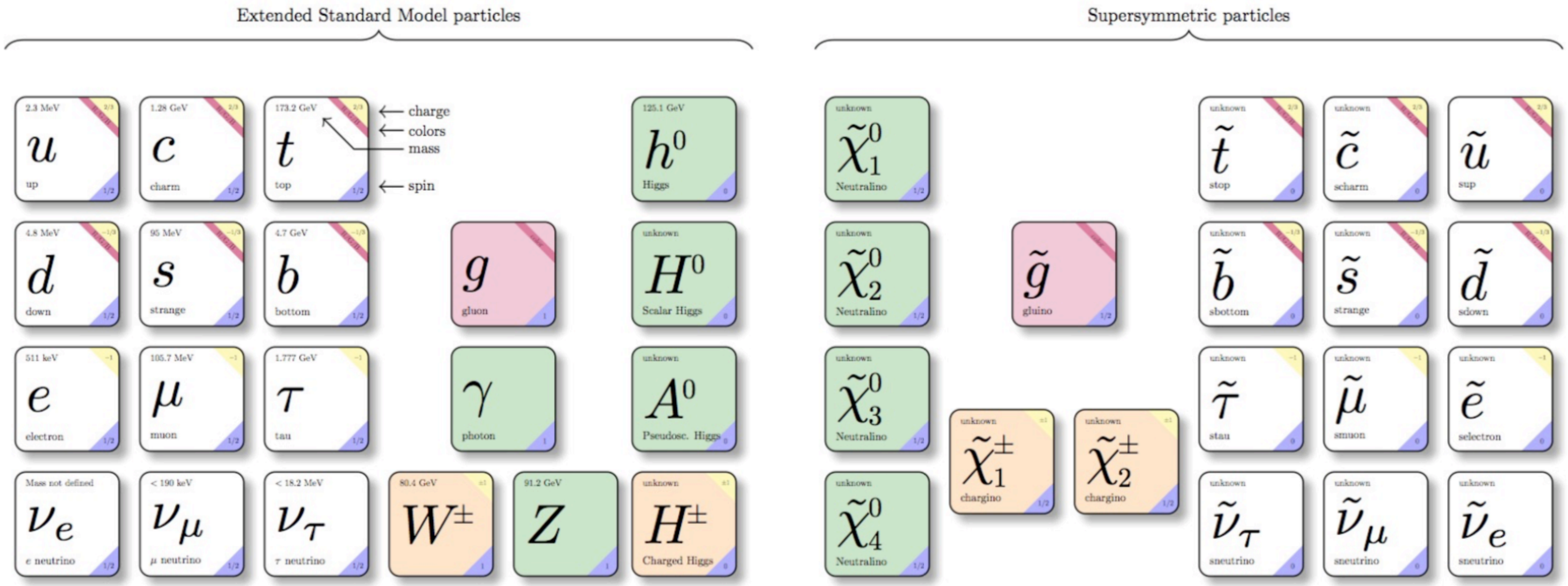
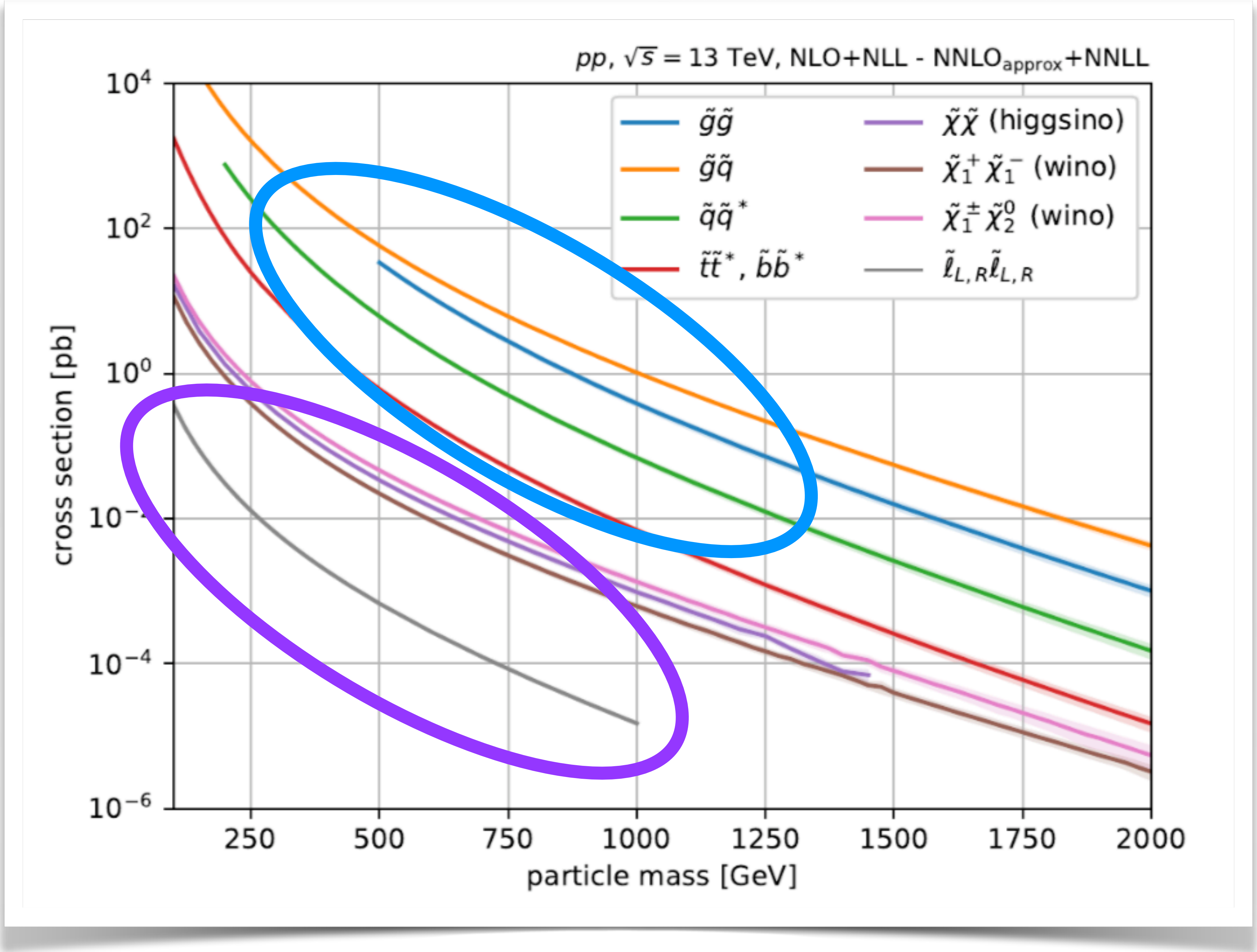


Image credit: M. Rimoldi

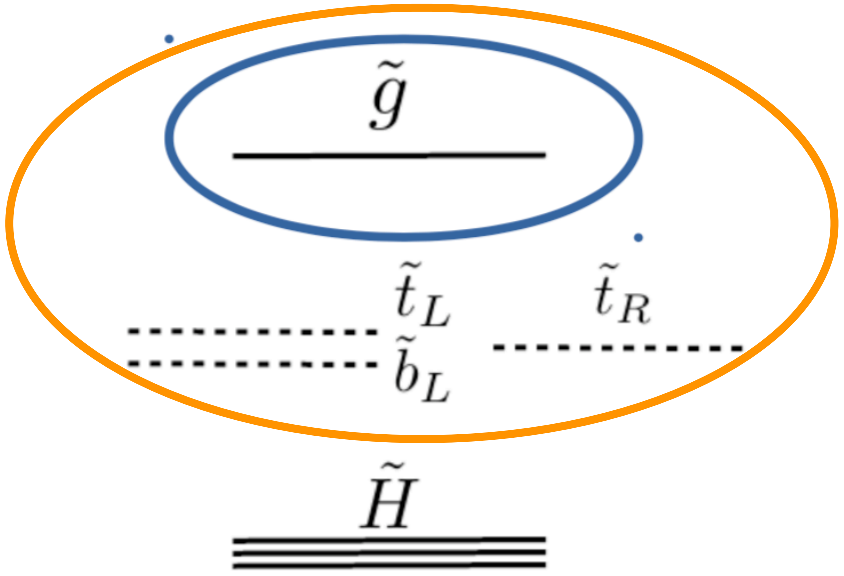
The SUSY production @ 13TeV

Strong SUSY: larger cross-section; energetic jet activity.

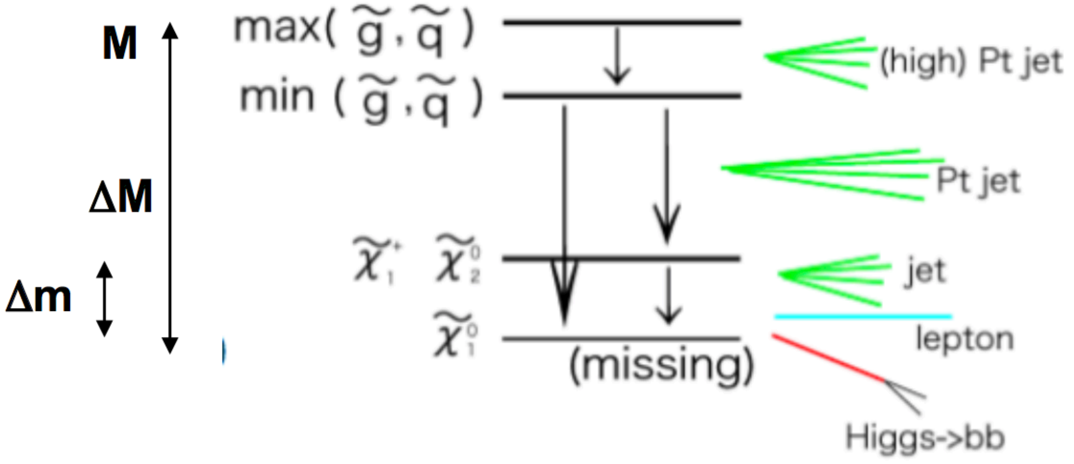


Electroweak SUSY: smaller cross-section; less jet; cleaner signature.

Gluino and squark (incl. 3rd gen)

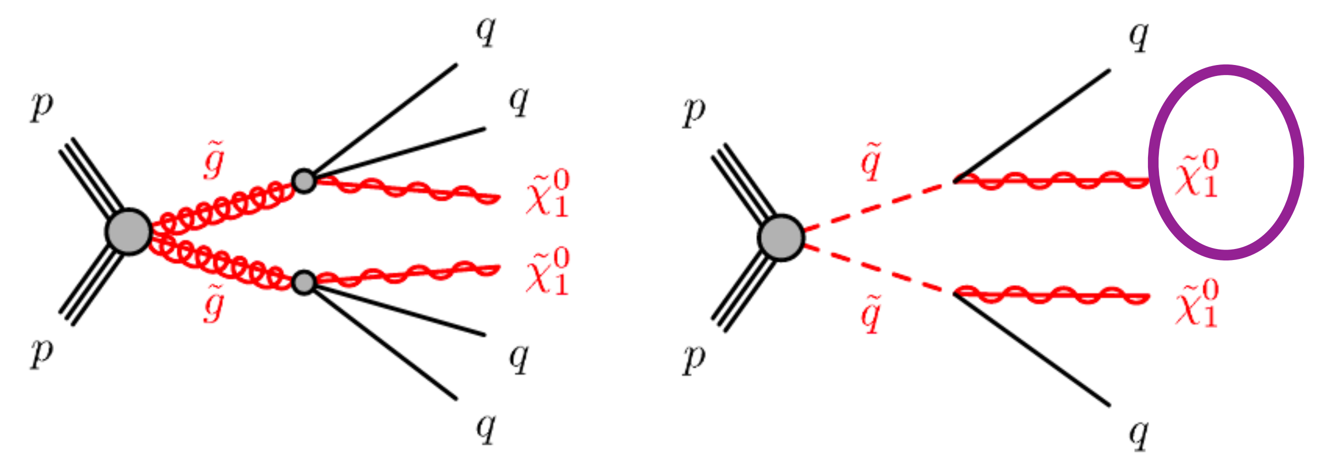


natural SUSY

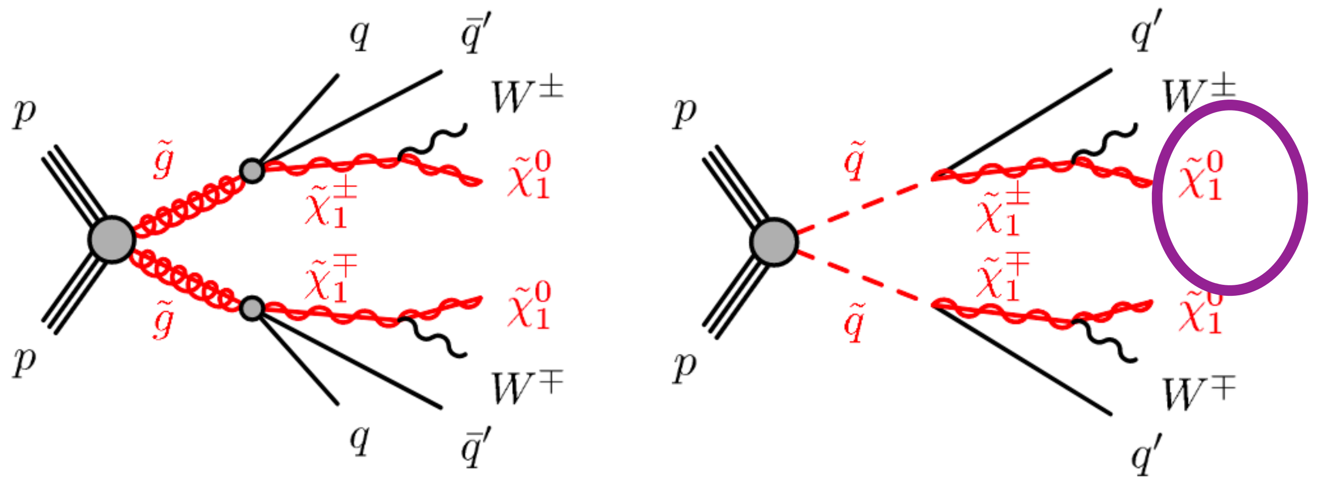


Gluino/squark search with jets

- *Target cascade decays of squarks or gluiness into **jets** + **LSP (Etmiss)**.*



Lightest SUSY Particle（LSP）— Etmiss



0-step decay

- **Gluino: >= 4 jets**
- **Squark: >= 2 jets**

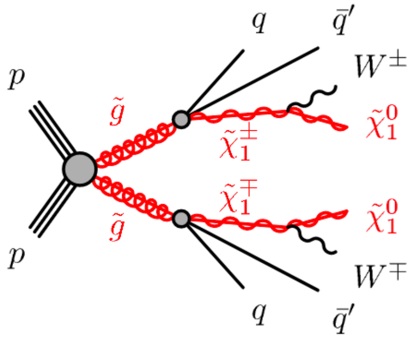
1-step decay via chargino

- **Gluino: >= 4-8 jets**
- **Squark: >= 2-6 jets**

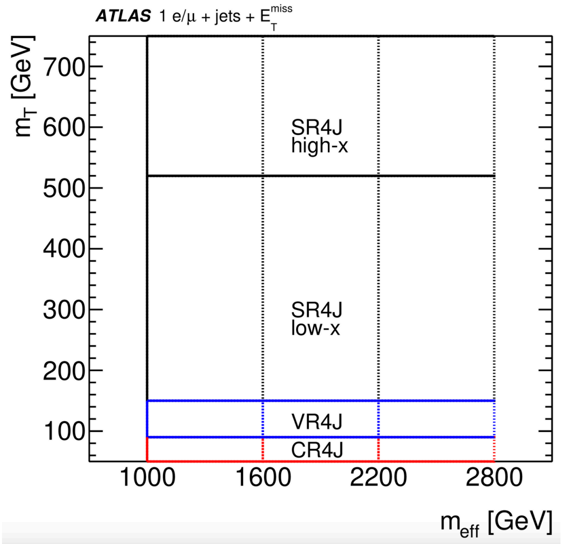
Eur. Phys. J. C 81 (2021) 600

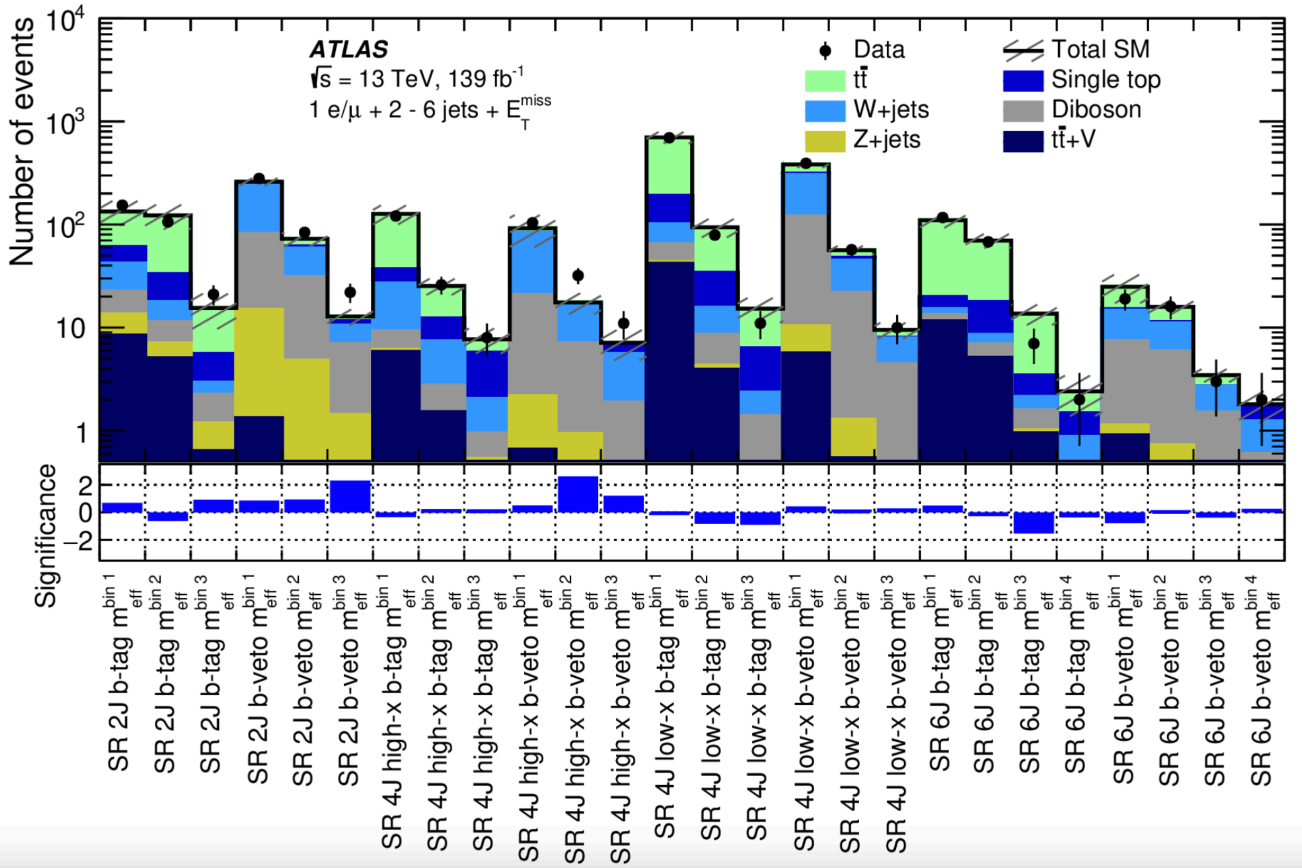
Gluino search with jets

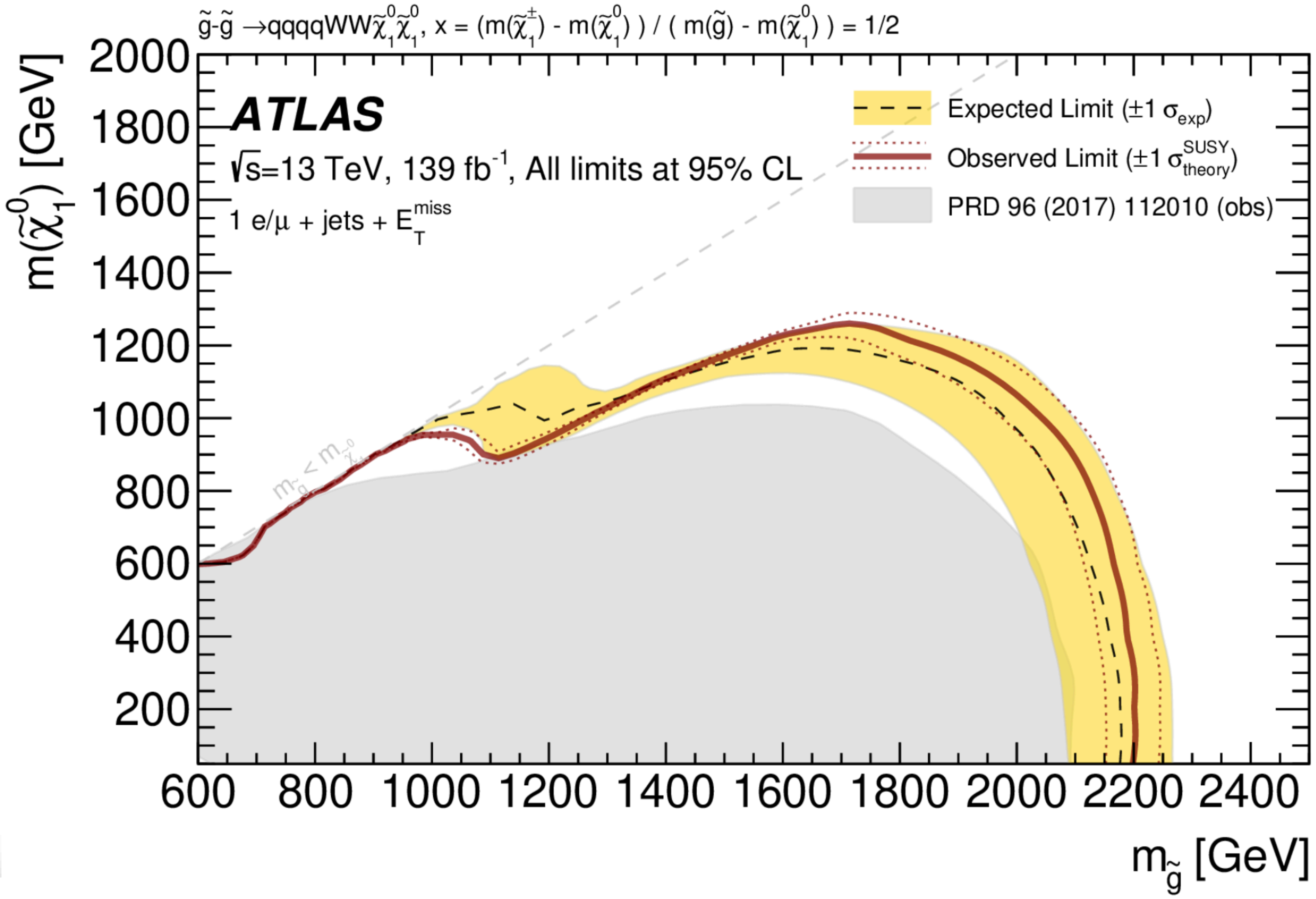
- *Target cascade decays of squarks or gluinos into* ***jets + LSP (Etmiss)****.*



- **Considering one W decay leptonically, one can require final state with one isolated lepton —> highly suppress multi-jet background**
- **Categorized in 2J, 4J and 6J + binned in meff and mT**
- **Dominant background W+jets and ttbar estimated in CR**



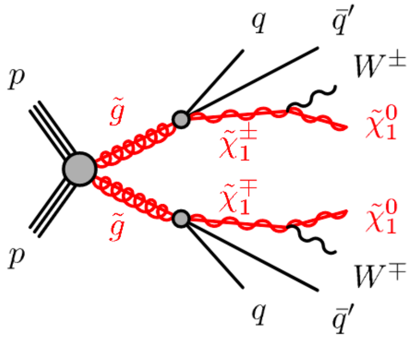




CMS-PAS-SUS-21-007

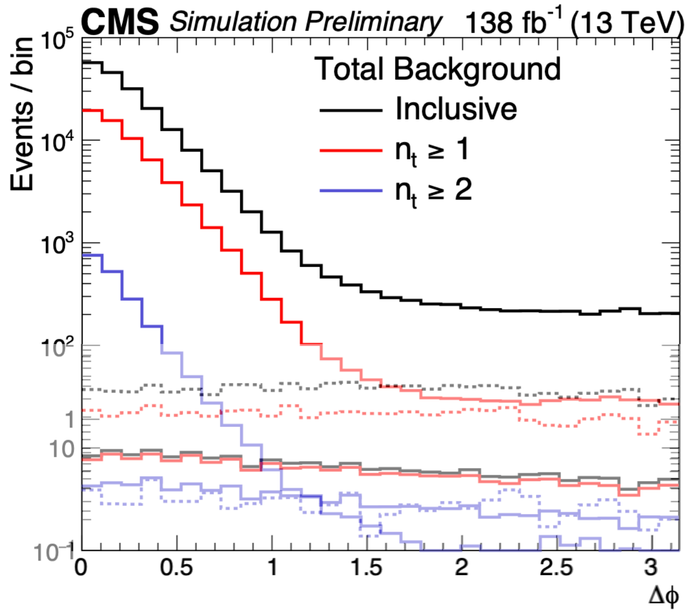
Gluino search with jets

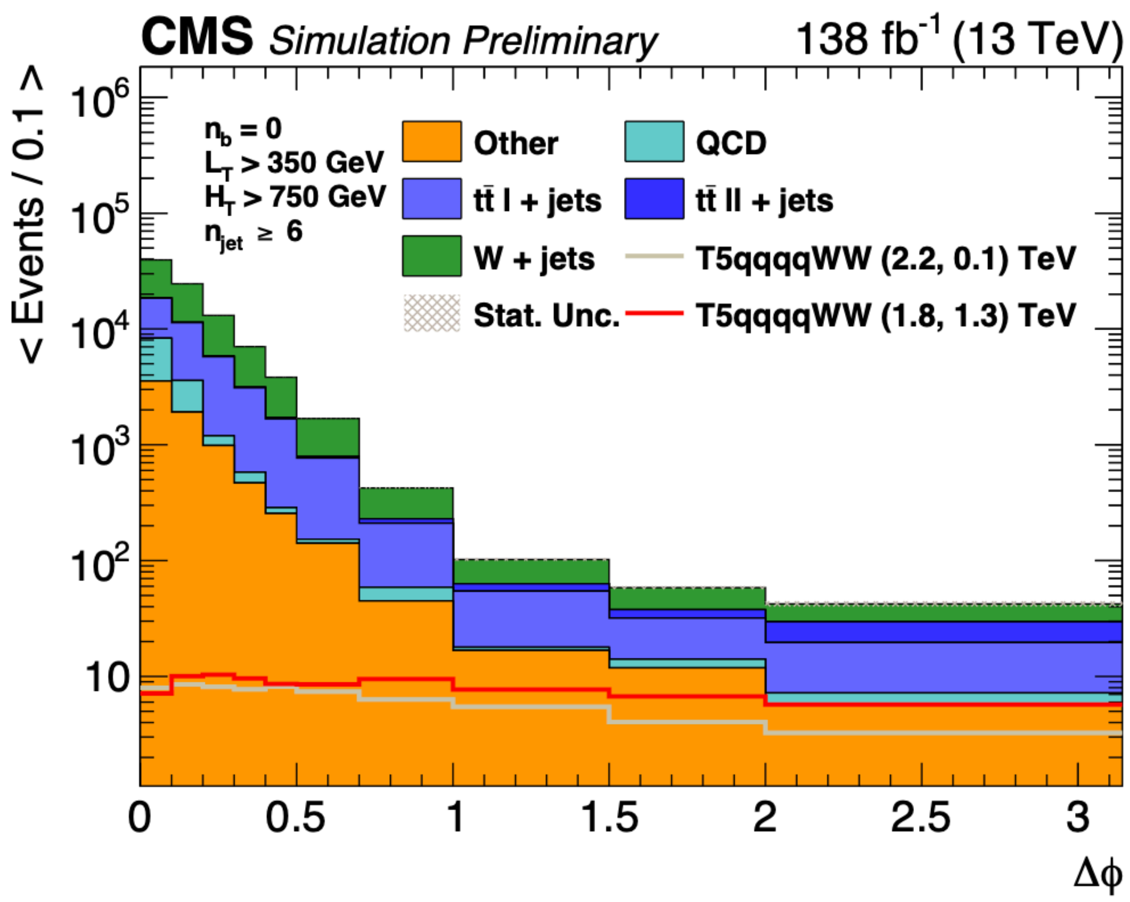
- *Target cascade decays of squarks or gluinos into **jets + LSP (Etmiss)**.*

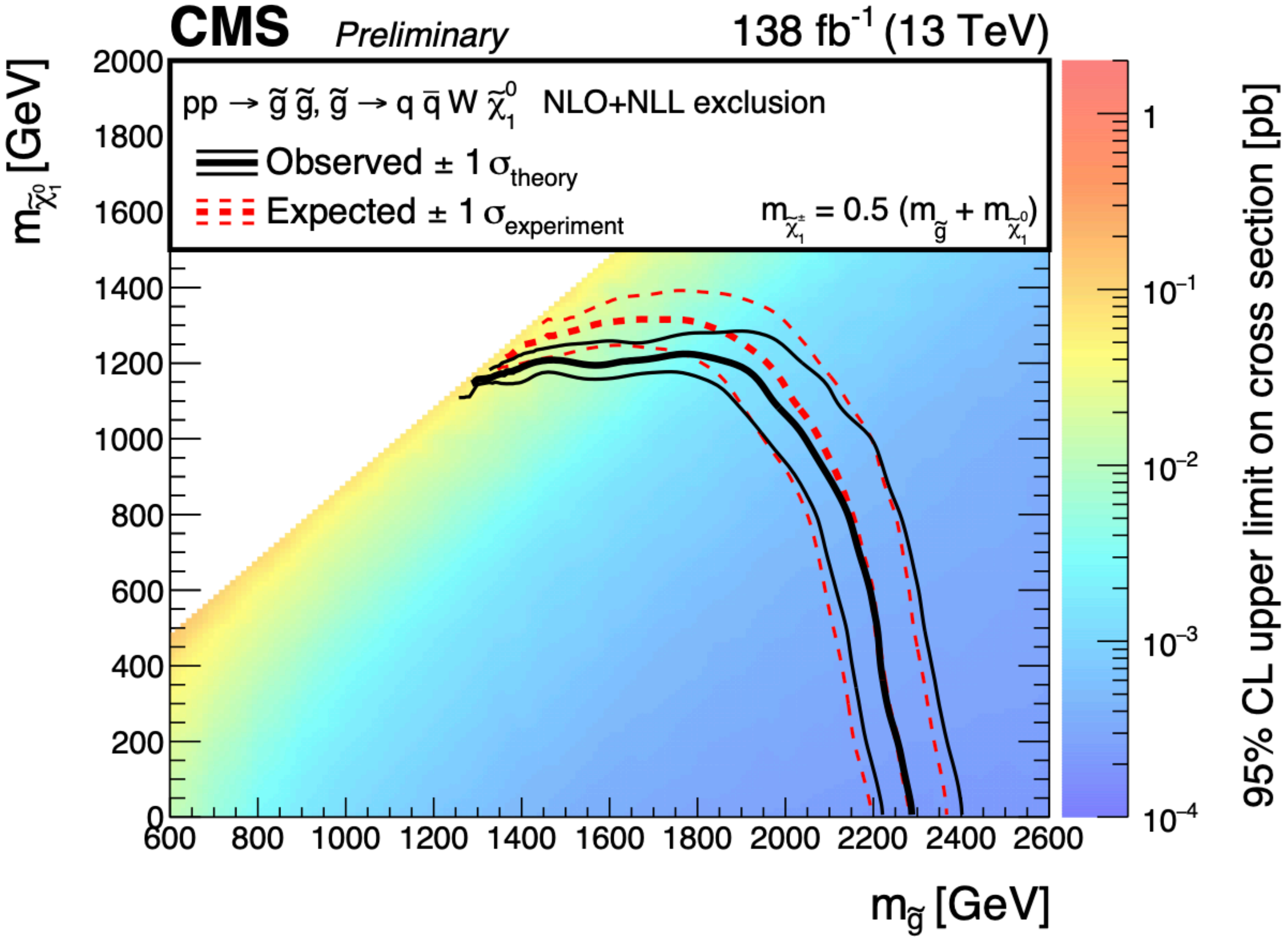


The same SUSY scenario targeted by CMS

- **Requirement on the azimuthal angle between the lepton and the reconstructed leptonic W boson candidate**
- **Top quark and W boson tagging based on machine-learning**







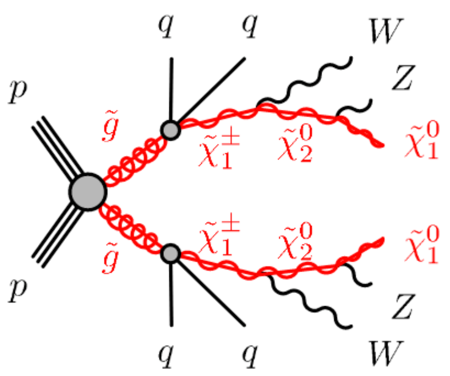
JHEP10(2020)062
JHEP10(2019)244

Gluino search with large jet multiplicities

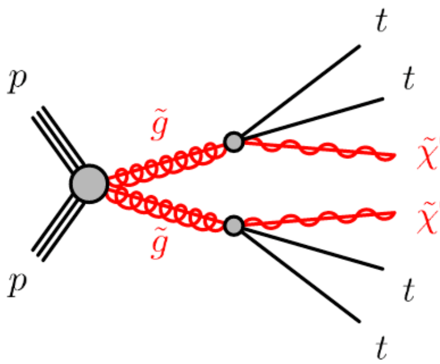
- *Target **LONG** cascade decays of gluinos into large jet activity.*

- **Large jet activity—> events with >=8,9,10,11,12 jets**
- **Include b-jet if top in the decay chain—> event categories in 0,1,2 b-jets**
- **Large Etmiss from stable LSPs(RPC case); no large Etmiss in RPV case.**

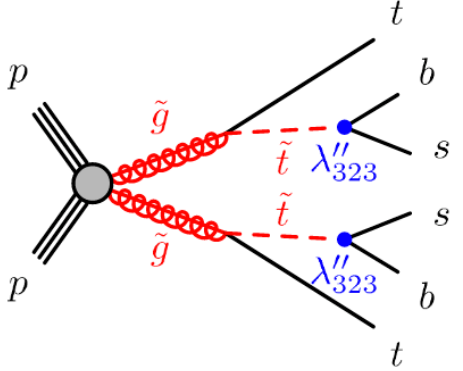
2-step decay

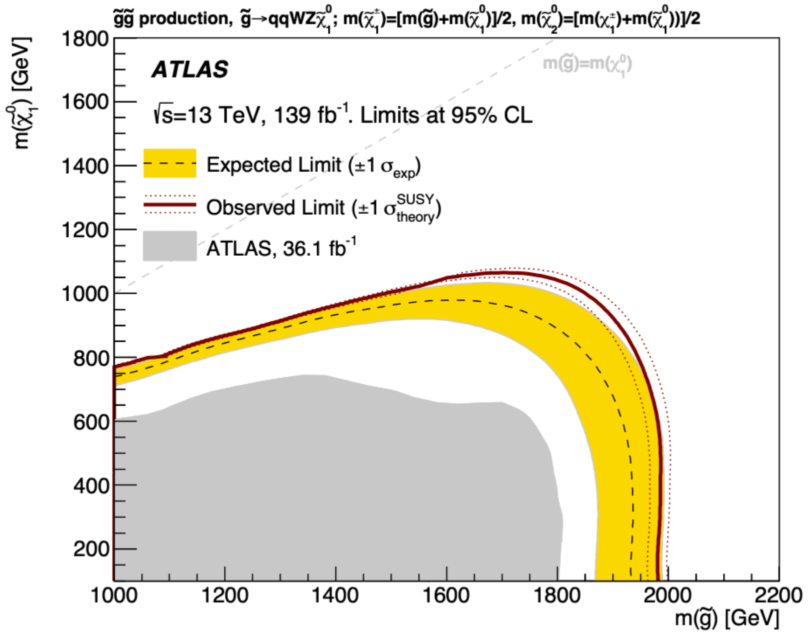


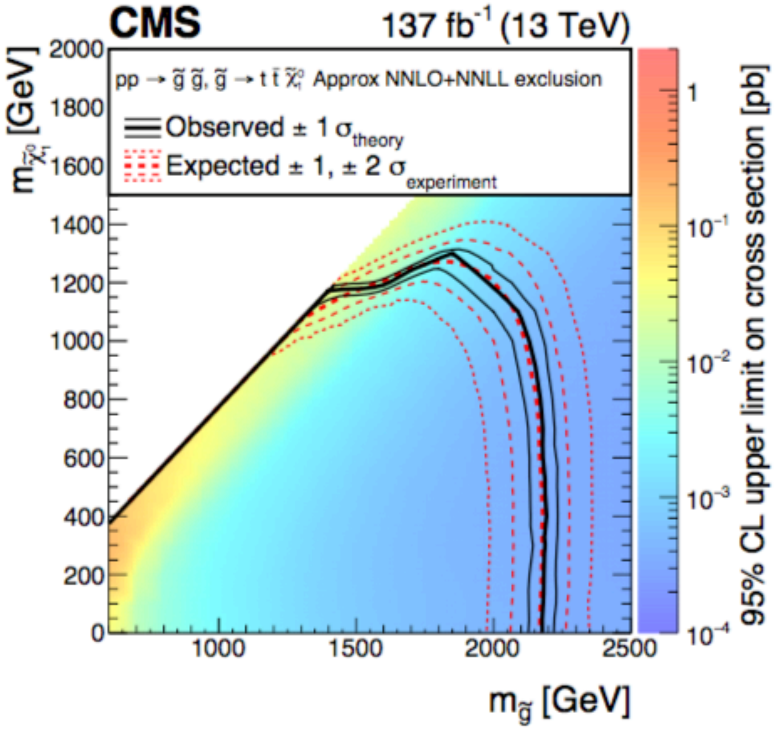
Gtt decay

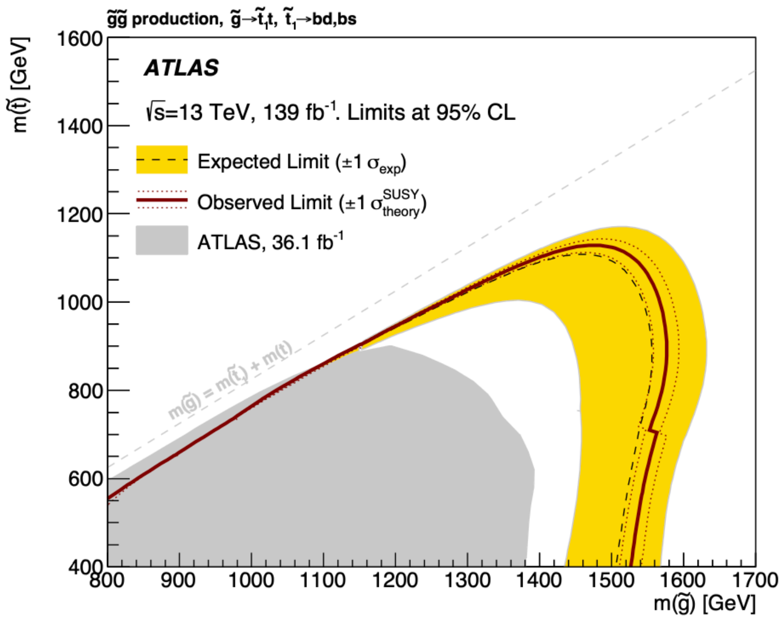


Decay via RPV coupling









JHEP 06 (2020) 46

Phys.Rev.D 101(2020)052010

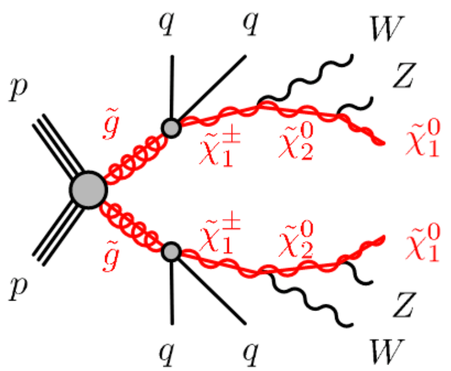
Eur. Phys. J. C 81 (2021) 1023

Gluino search with leptons

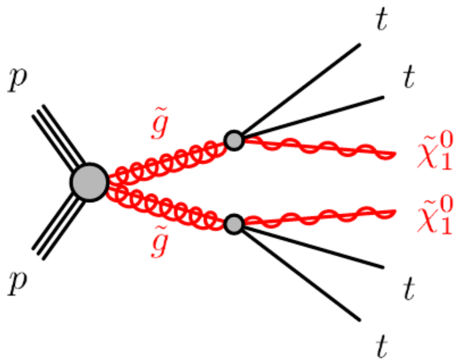
- *Target **LONG** cascade decays of **one lepton, same-sign(SS) two or three leptons**.*

- **Such long cascade decays can also be targeted by lepton final states**
- **i.e. when leptons come from different decay chain, requiring SS leptons can highly suppress SM.**
- **i.e. one lepton + large radius jets rich in top-quark —> Gtt model**

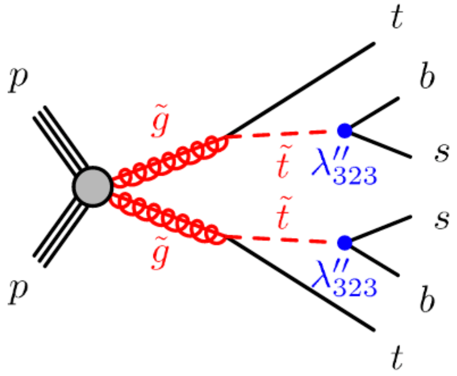
2-step decay

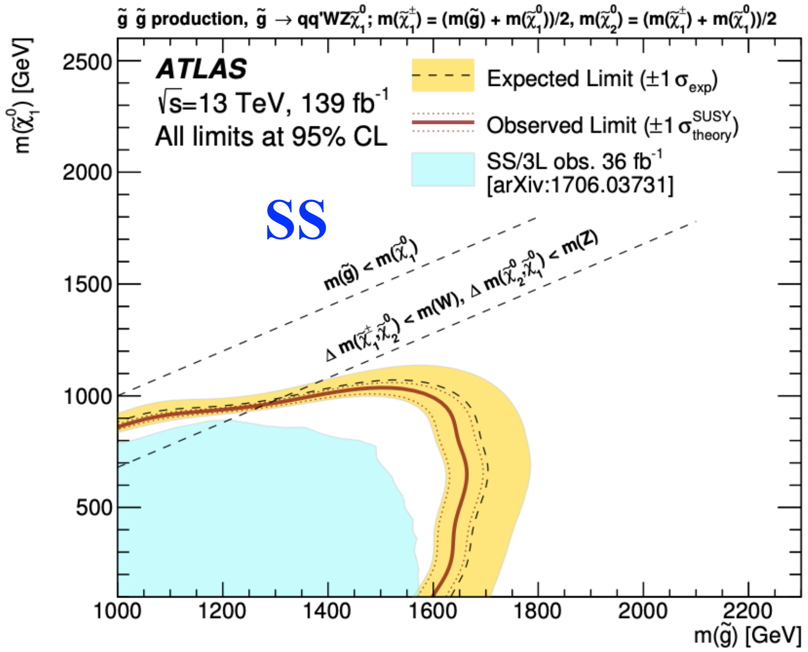


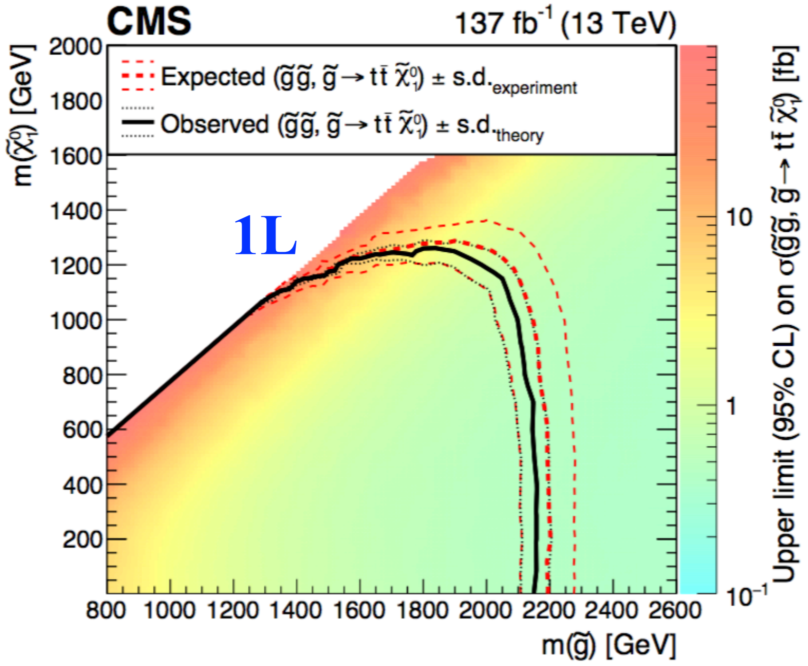
Gtt decay

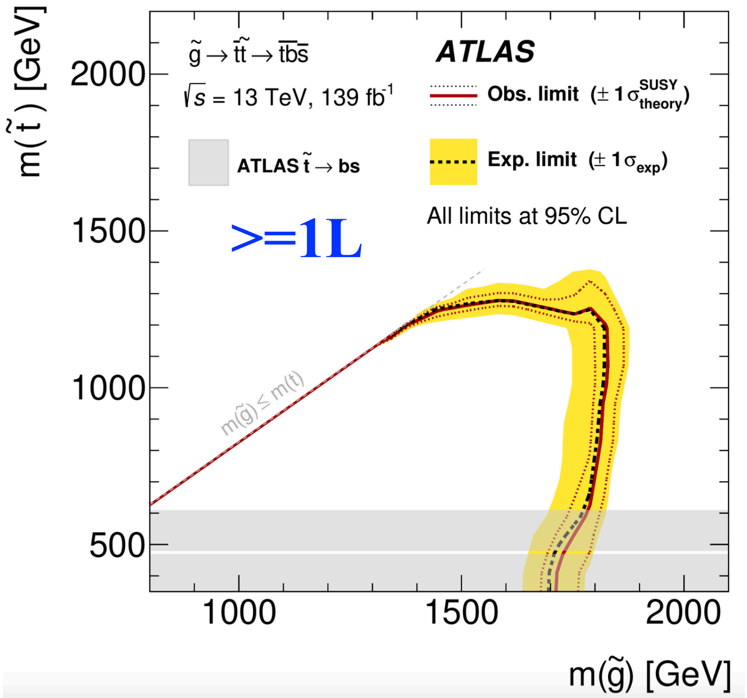


Decay via RPV coupling

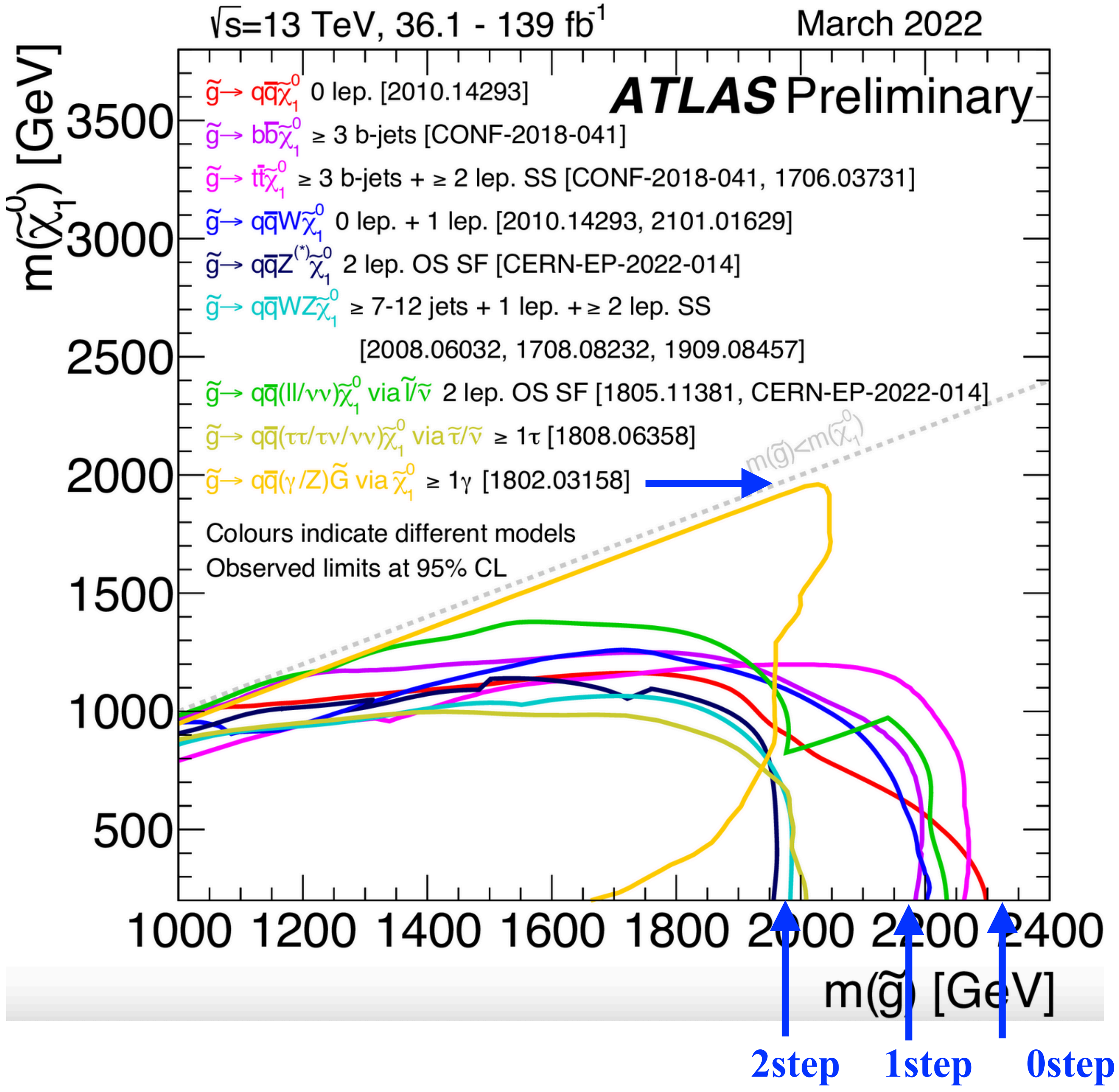


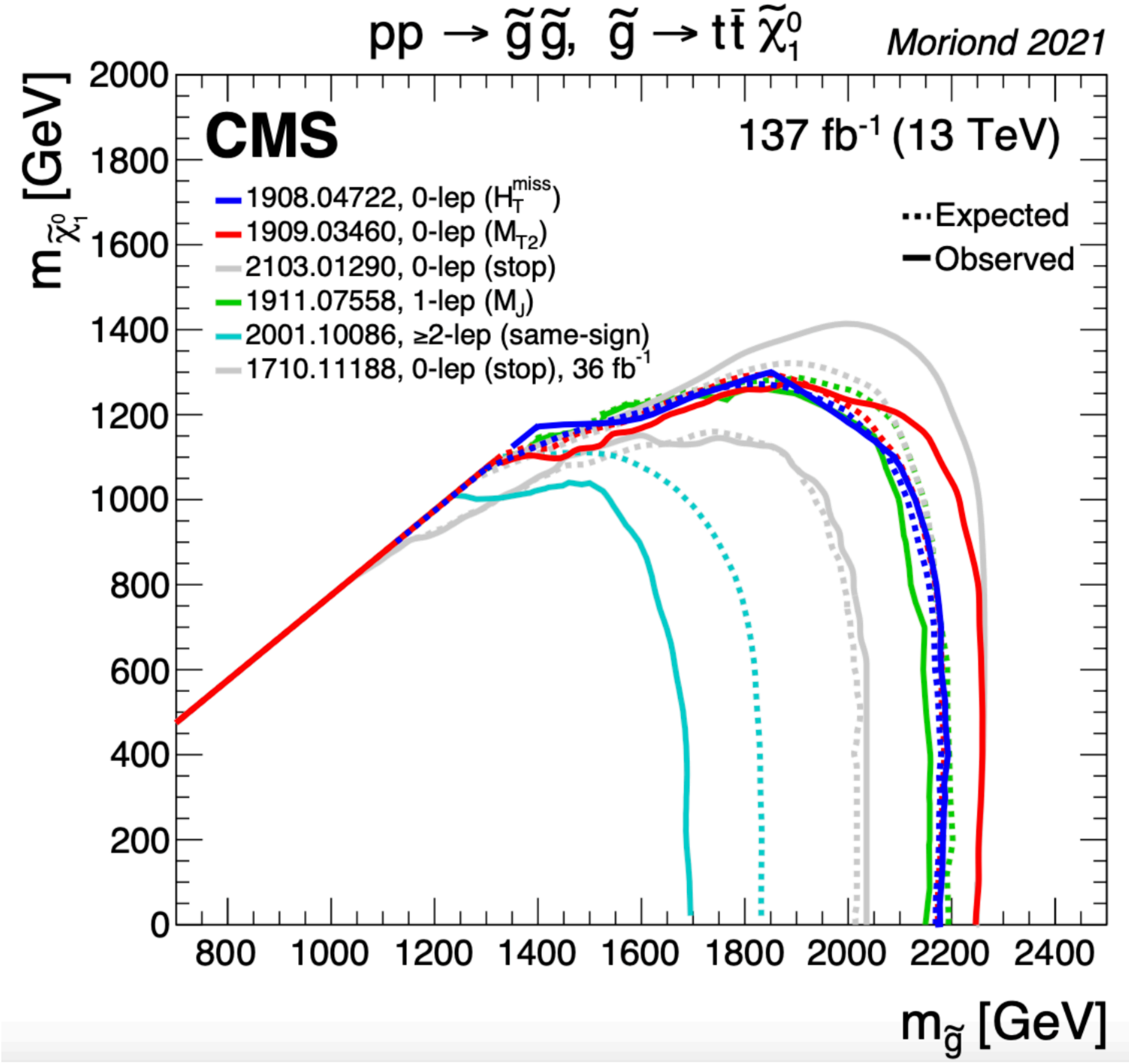




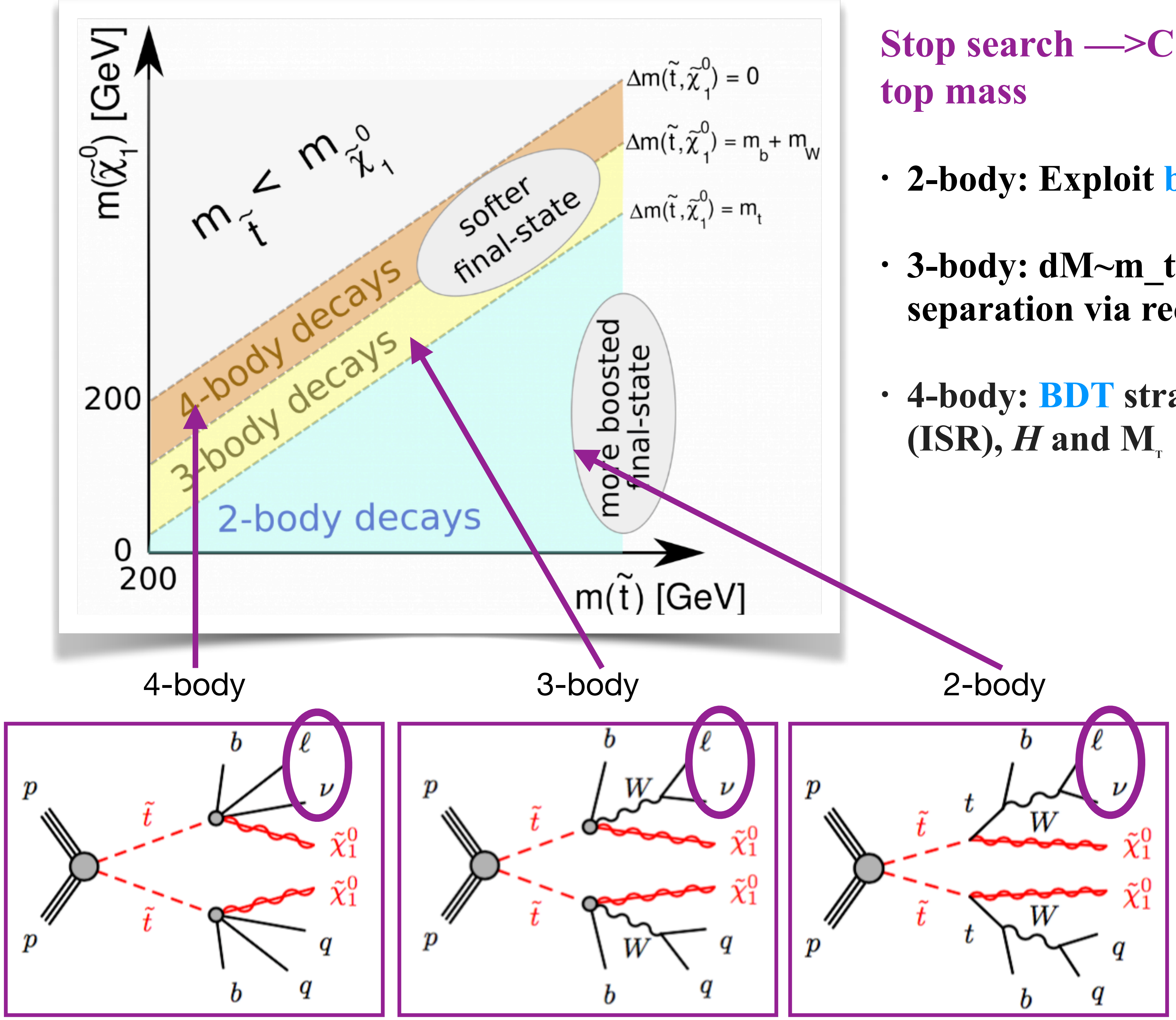


Gluino summary



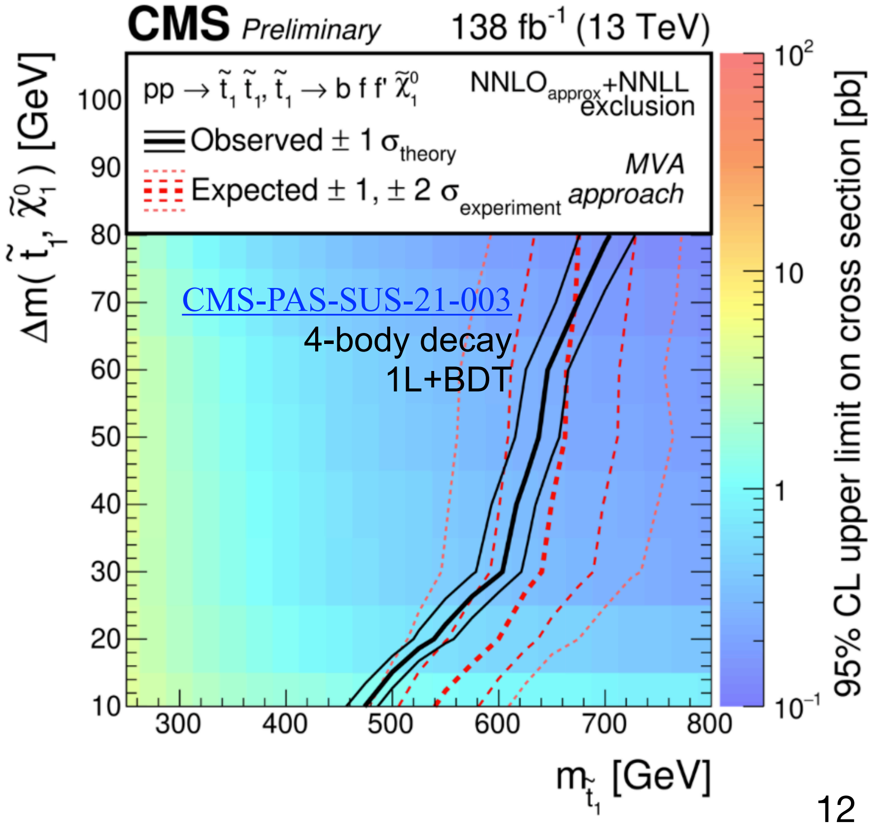


3rd generation: Stop search

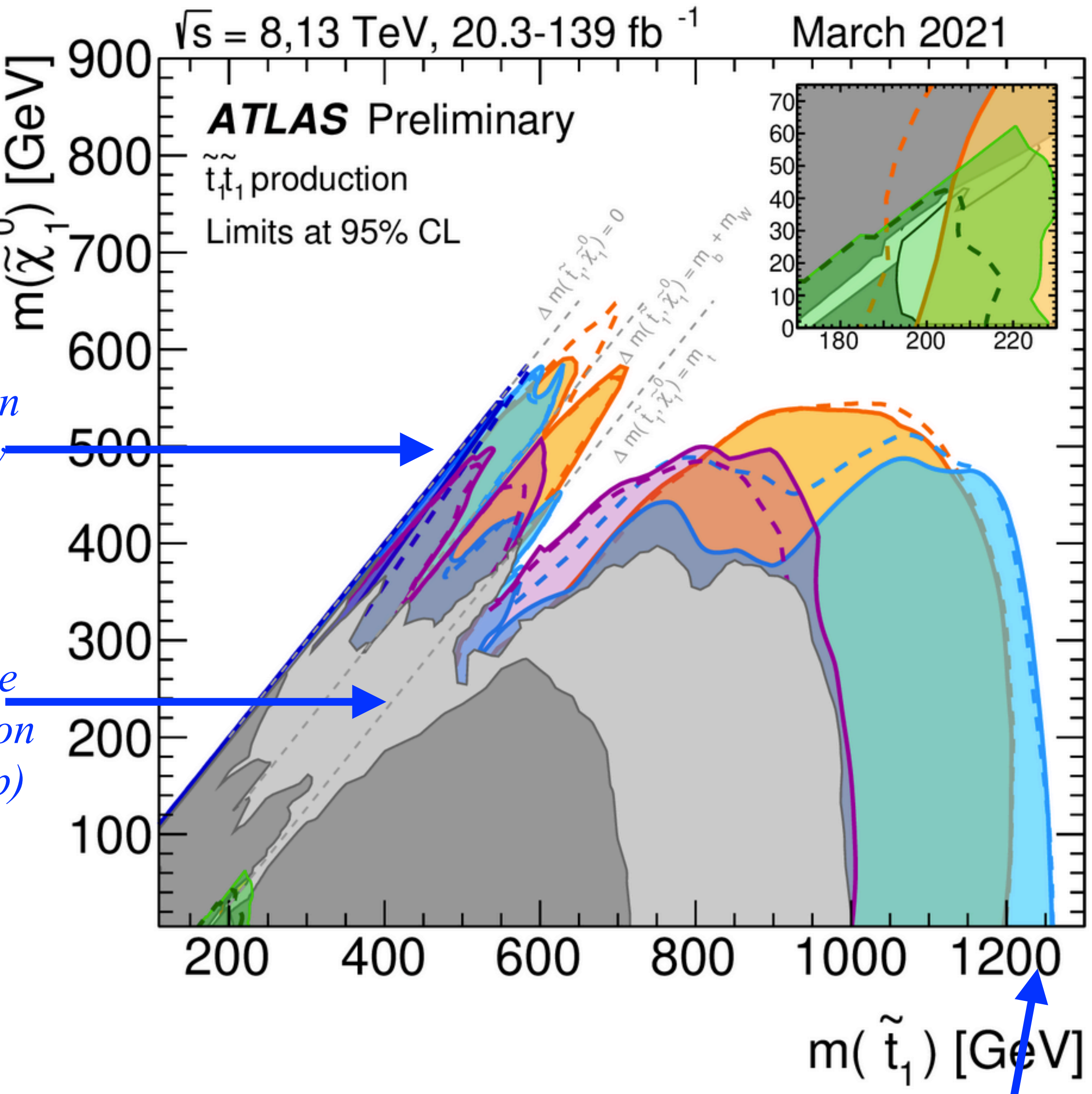


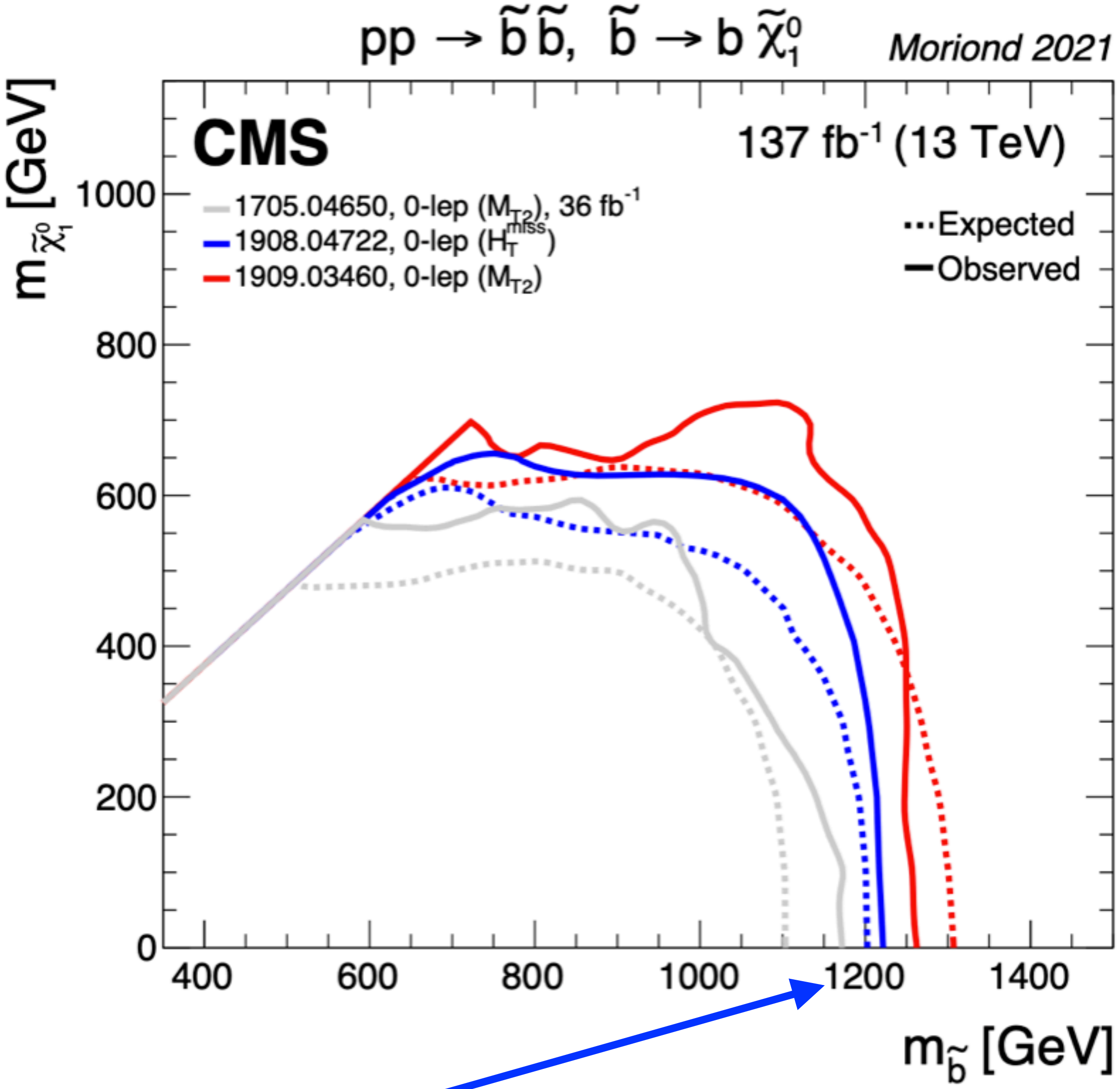
Stop search —>Complex decay topologies due to large top mass

- **2-body: Exploit boost top reconstruction using largeR jet**
- **3-body: dM~m_top, main background ttbar <— separation via requiring ISR jet**
- **4-body: BDT strategy, i.e. trained based on *p* (l), *p*$^{\text{miss}}$, *p* (ISR), *H* and M$_{\text{T}}$**



Stop, sbottom summary

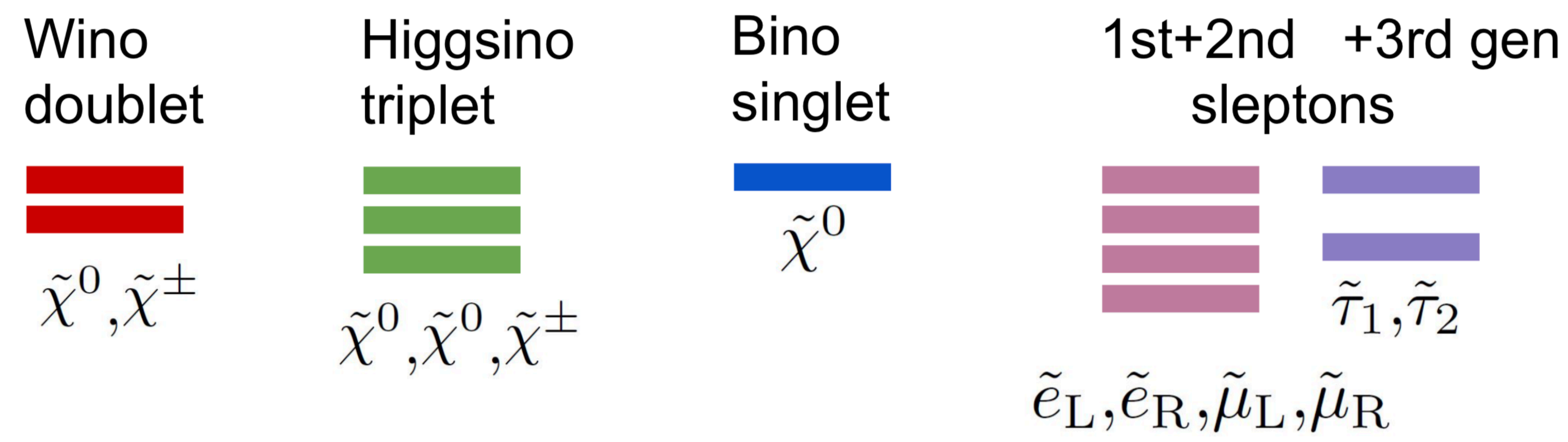




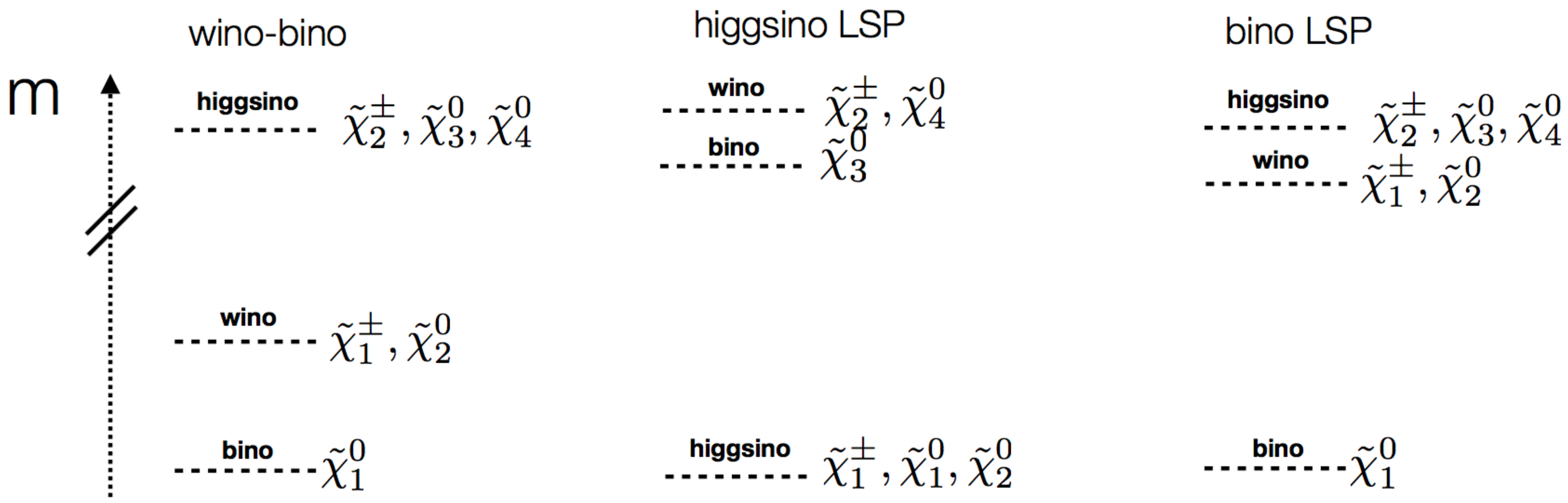
Improvement in 3- and 4-body regions

Good coverage of difficult region with dM~m(top)

Reaching significantly higher stop masses



Electroweakino



Phenomenology depends on wino-bino-higgsino mixing, mass hierarchy, and decay channels.

NEW!

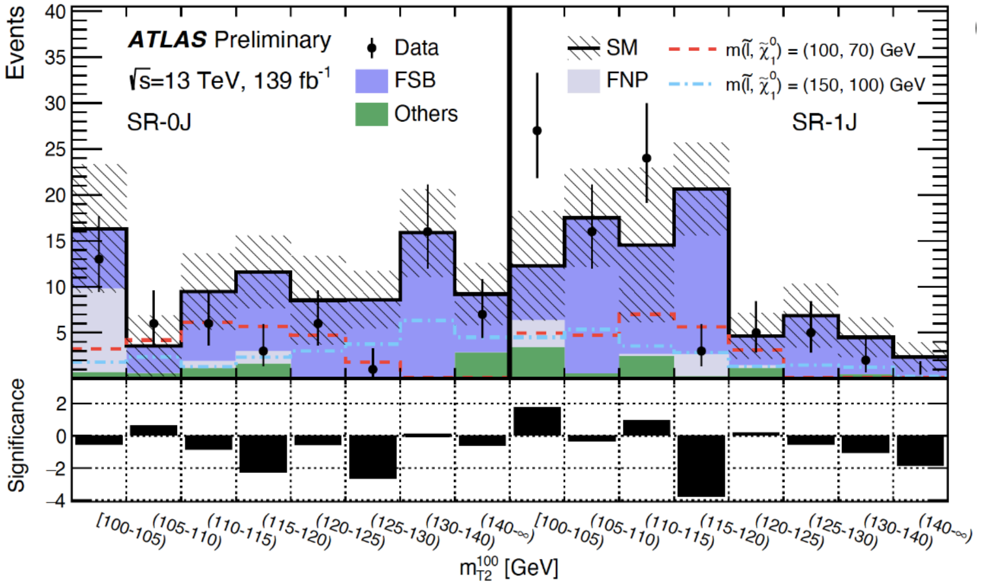
ATLAS-CONF-2022-006

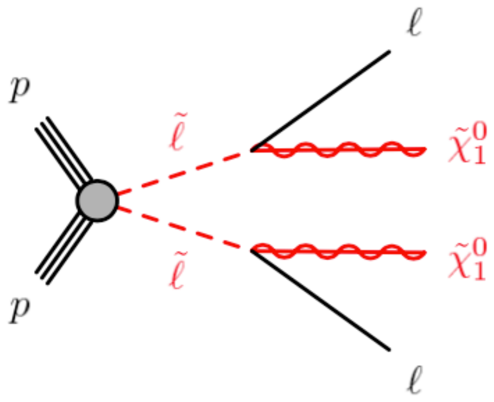
Wino-bino/Slepton search with 2L0J

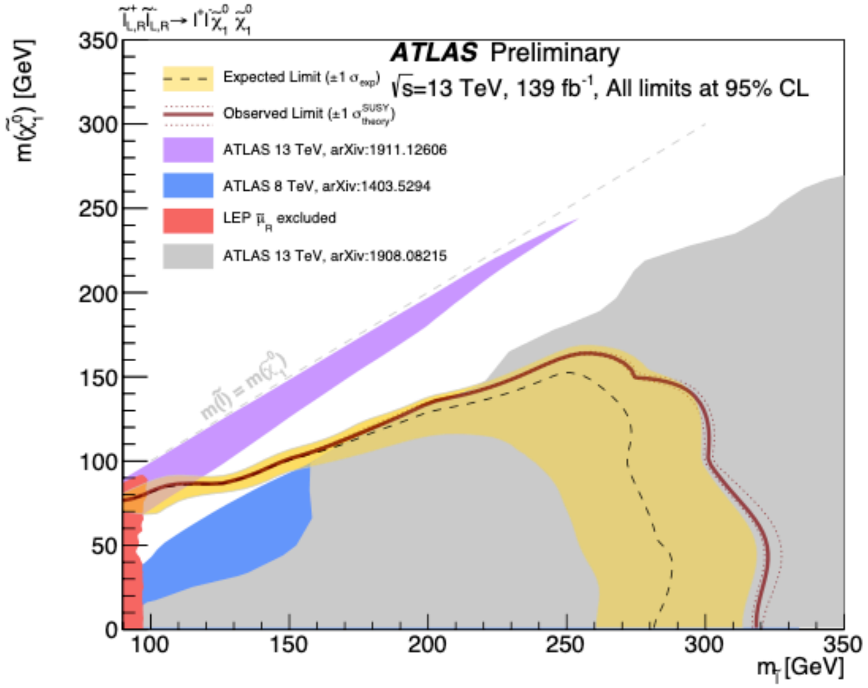
Targeting moderately compressed regions, mass splitting close to W boson mass.

Slepton production

- Light smuon and LSP could explain g-2 anomaly through loop corrections
- Same-flavour opposite sign final state, 0 or 1 jet SR

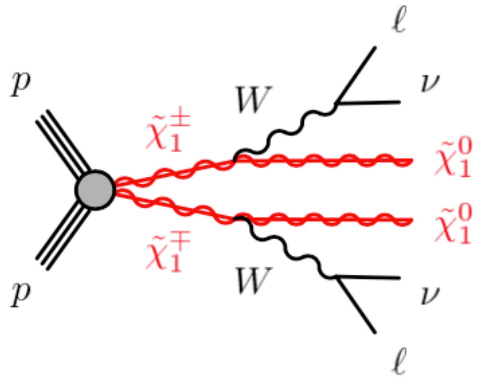


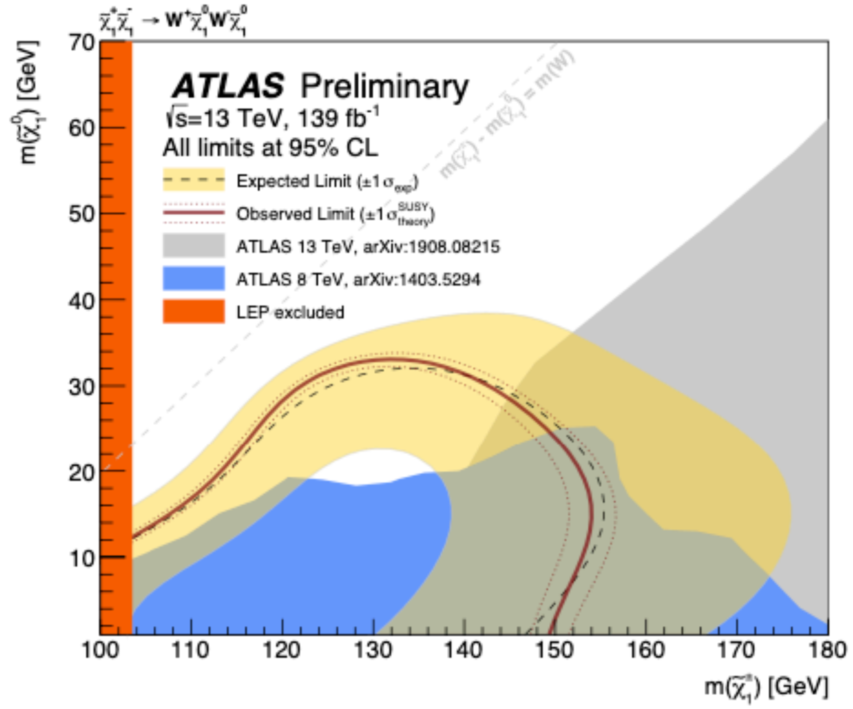




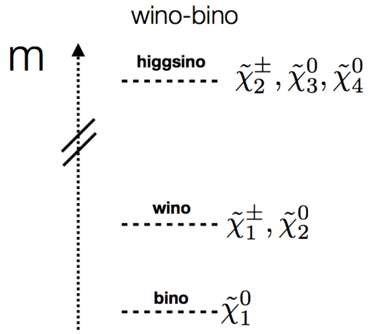
Chargino production

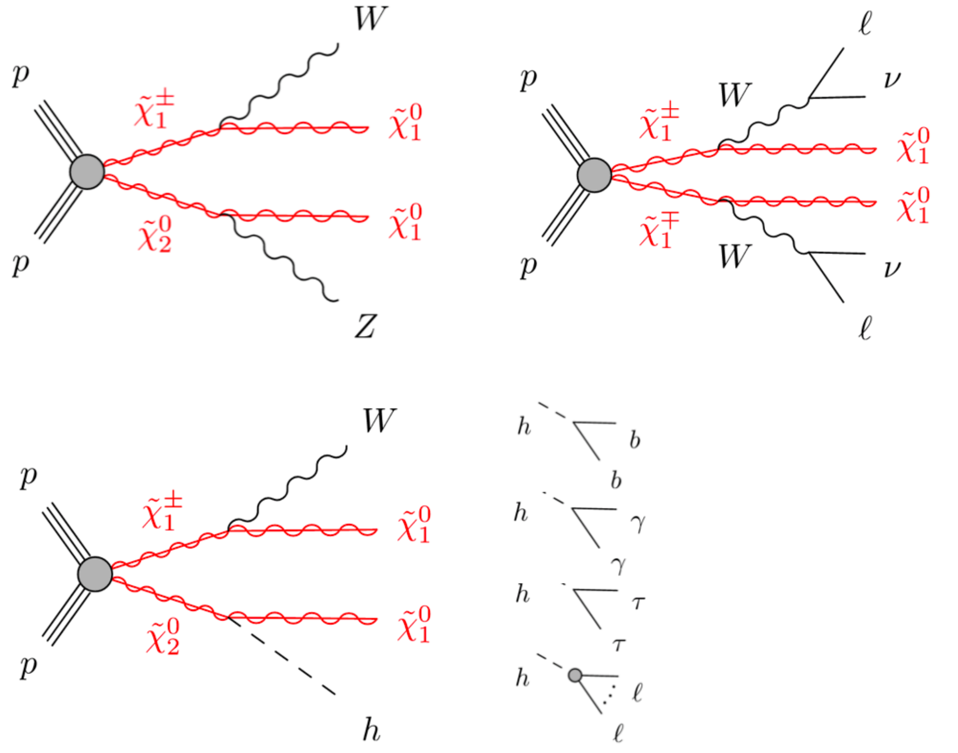
- Same flavour and different flavour opposite sign final state
- Boosted Decision Tree approach, SRs binned in BDT output

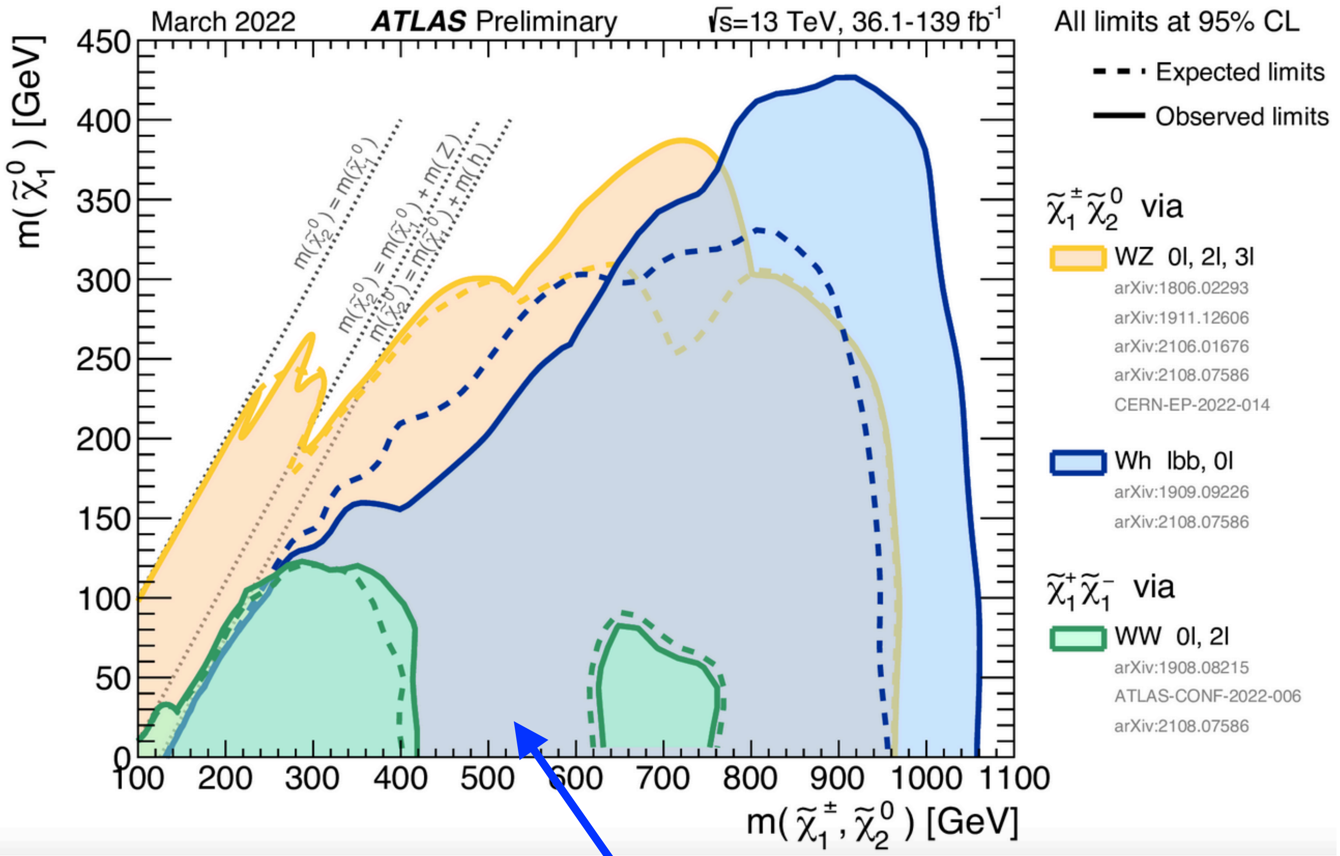


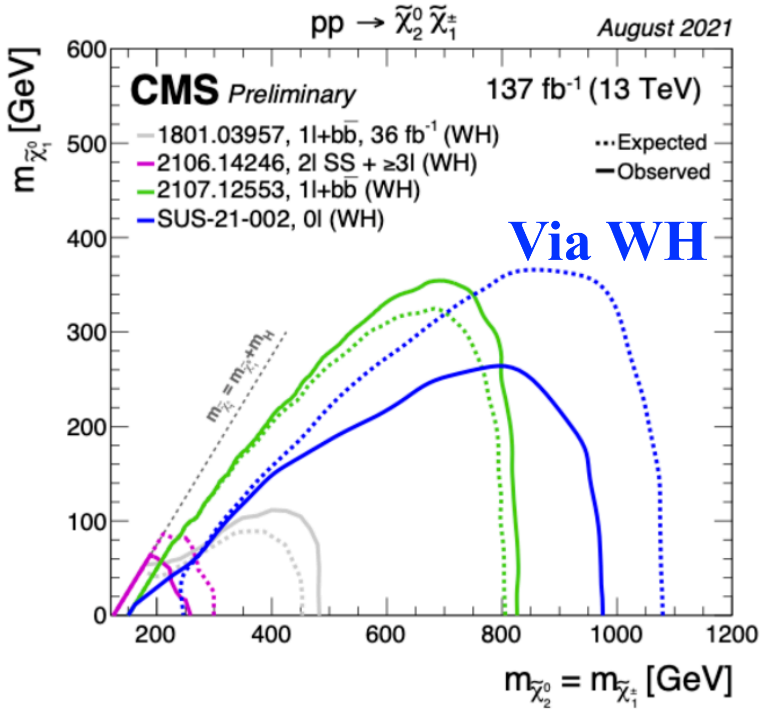


Wino-bino summary

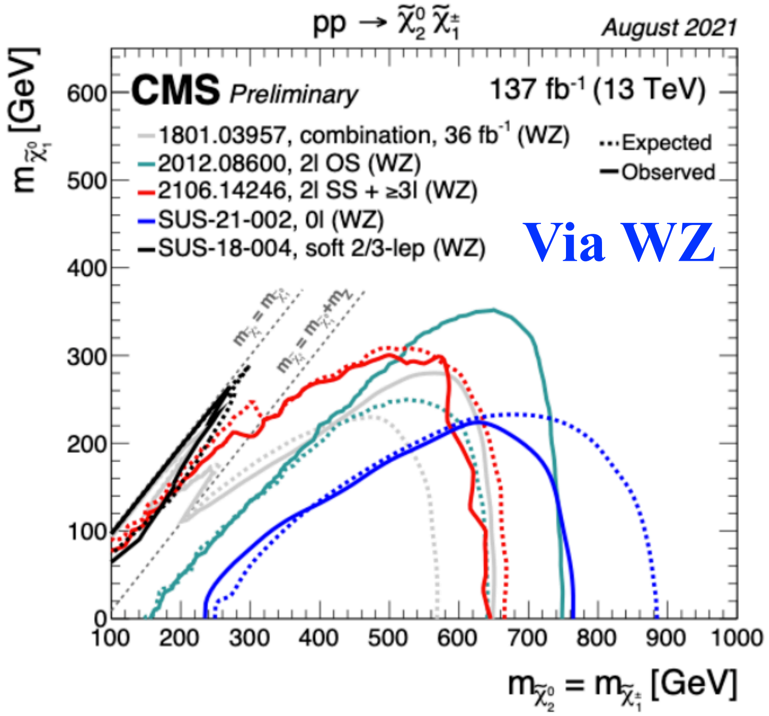




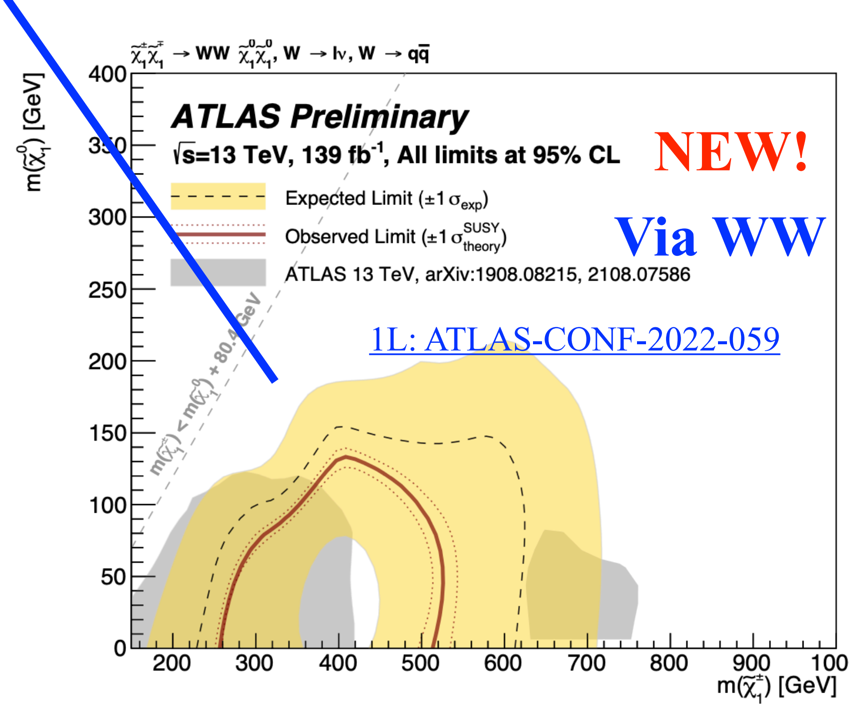




Via WH



Via WZ

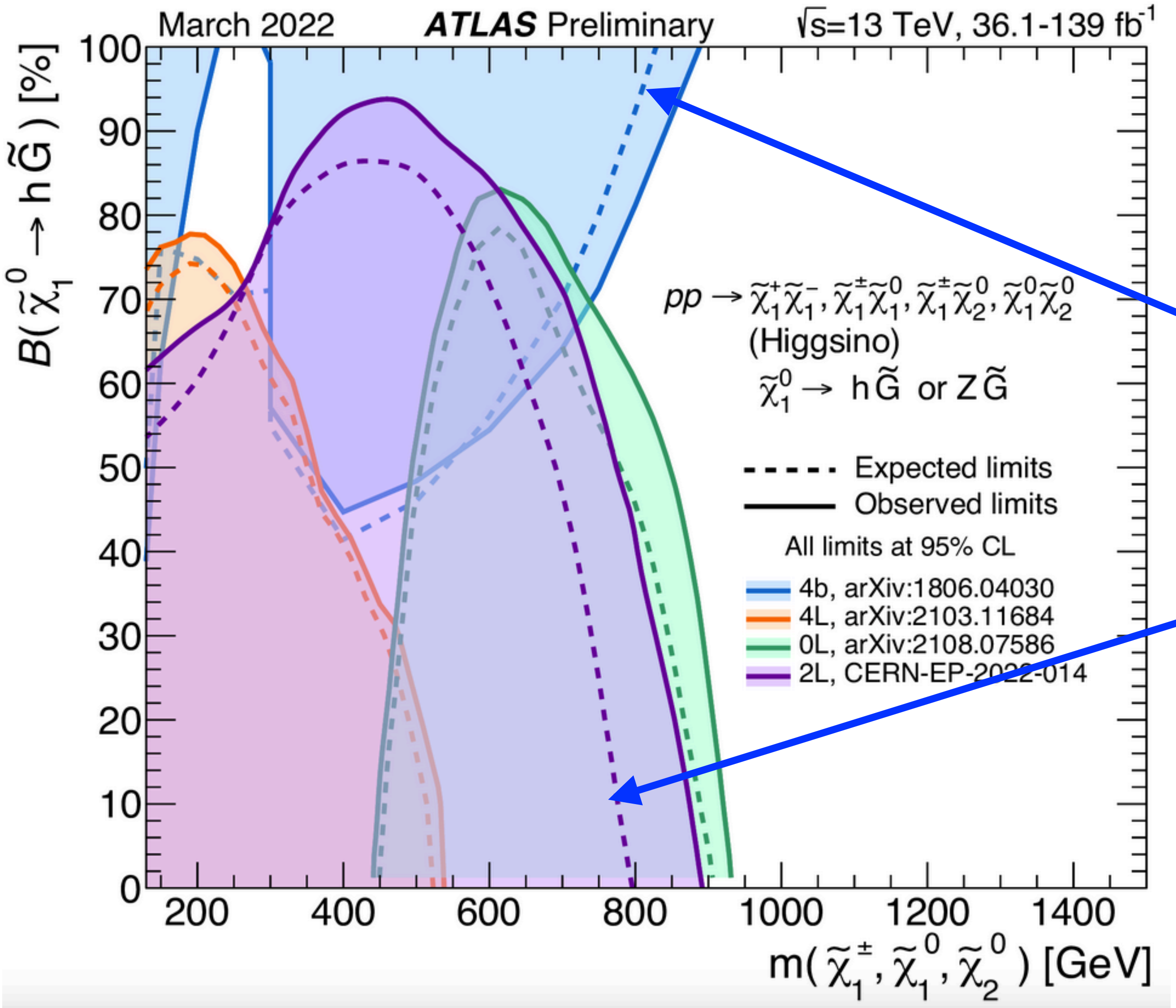


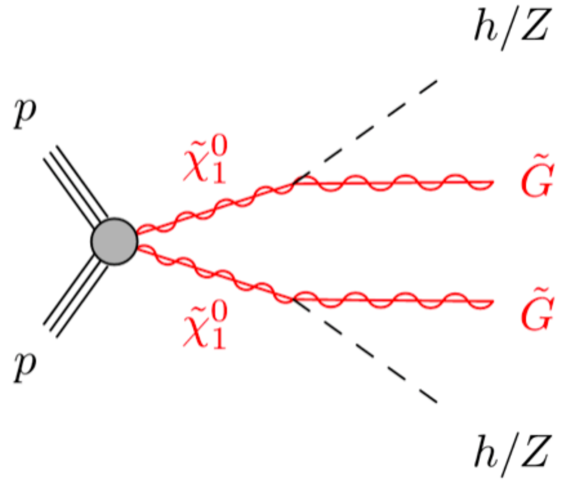
NEW!

Via WW

1L: ATLAS-CONF-2022-059

Higgsino summary

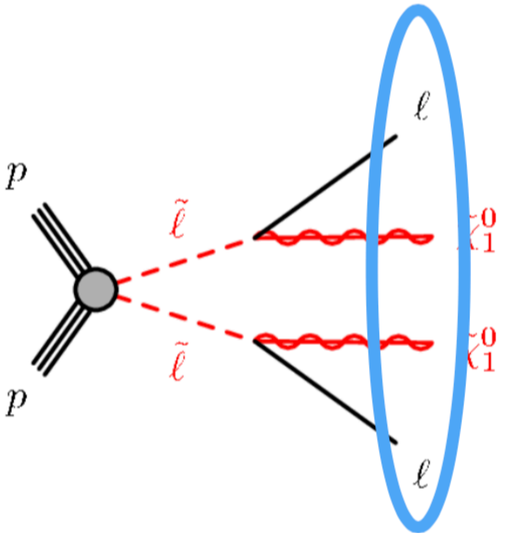


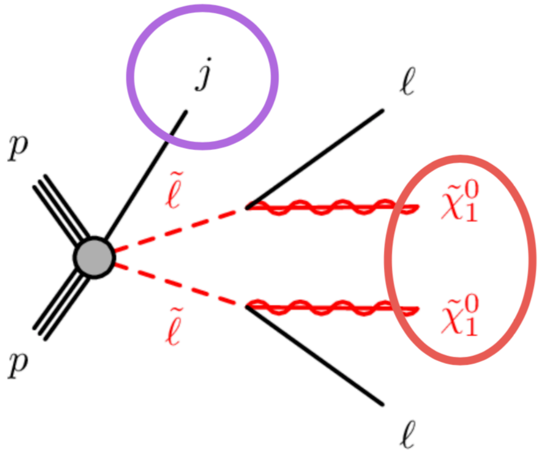


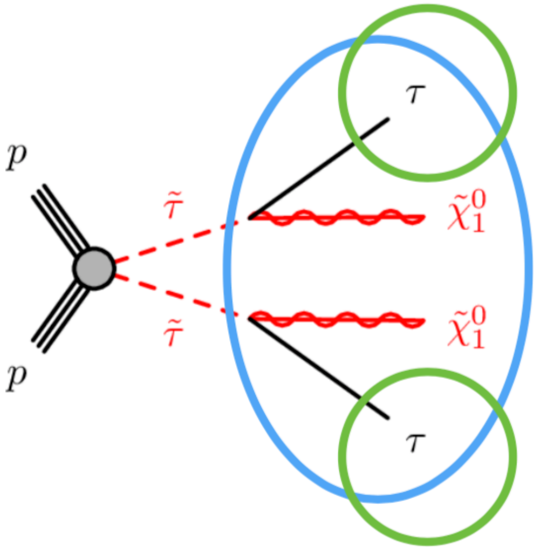
- For Higgs dominant decay mode, 4b channel wins
- For Z dominant decay mode
  - Low mass region: 4L channel
  - High mass region: 0L wins (w/ boost strategy)
  - Overall region: 2L2J **NEW!** channel wins!

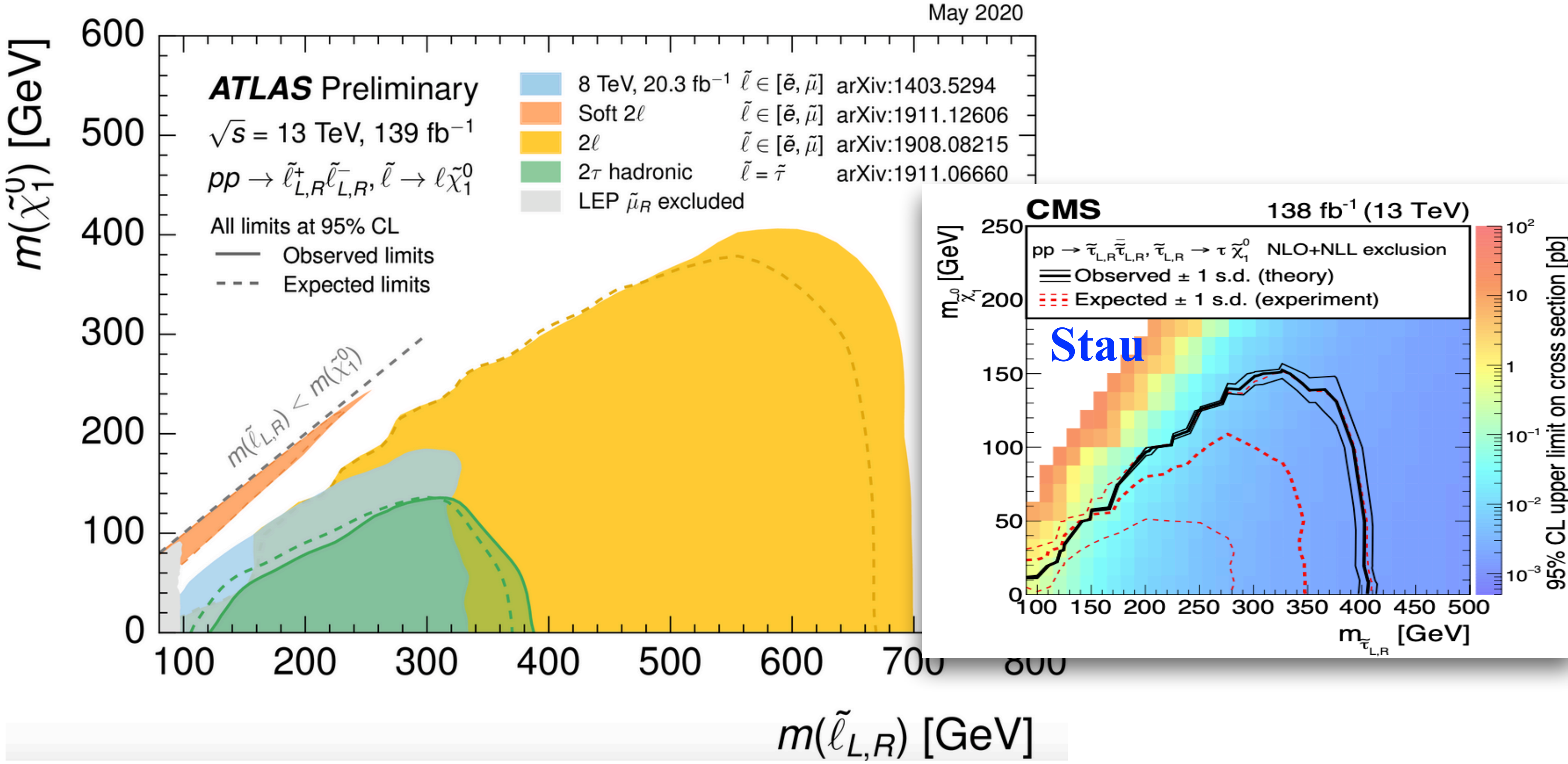
arXiv:2207.02254

Slepton summary







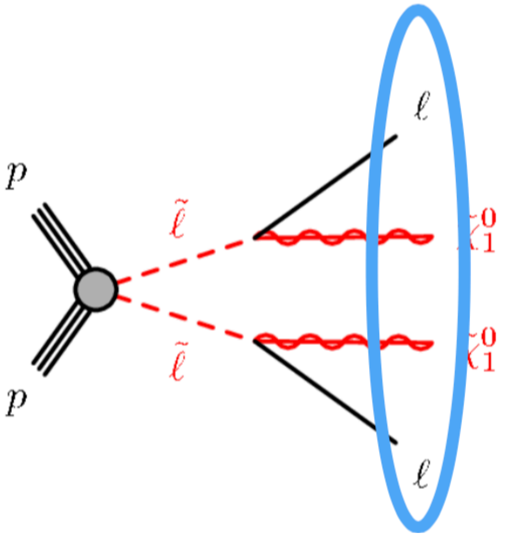


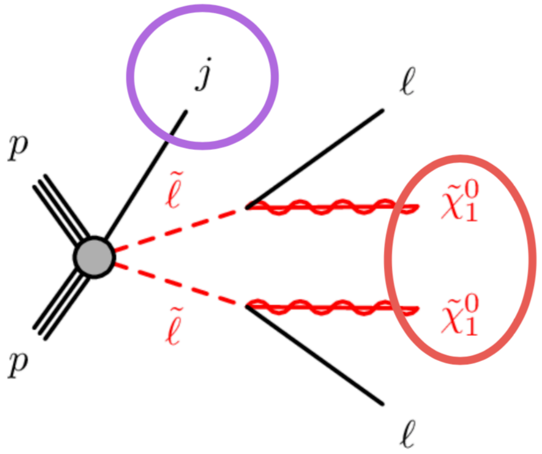
- Search 1: Final states with 2 hard e/μ (pT>25GeV) —> target high mass region!

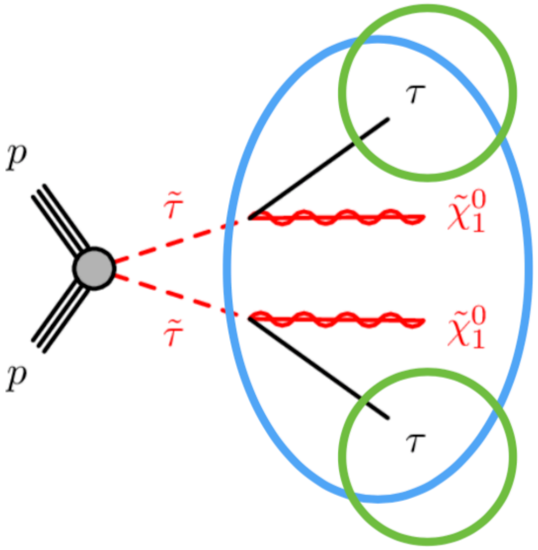
- Search 2: Compressed analysis — 2 soft e/μ (pT_e>4.5GeV and pT_μ>3GeV) + ISR-jet —> target small mass splitting region!

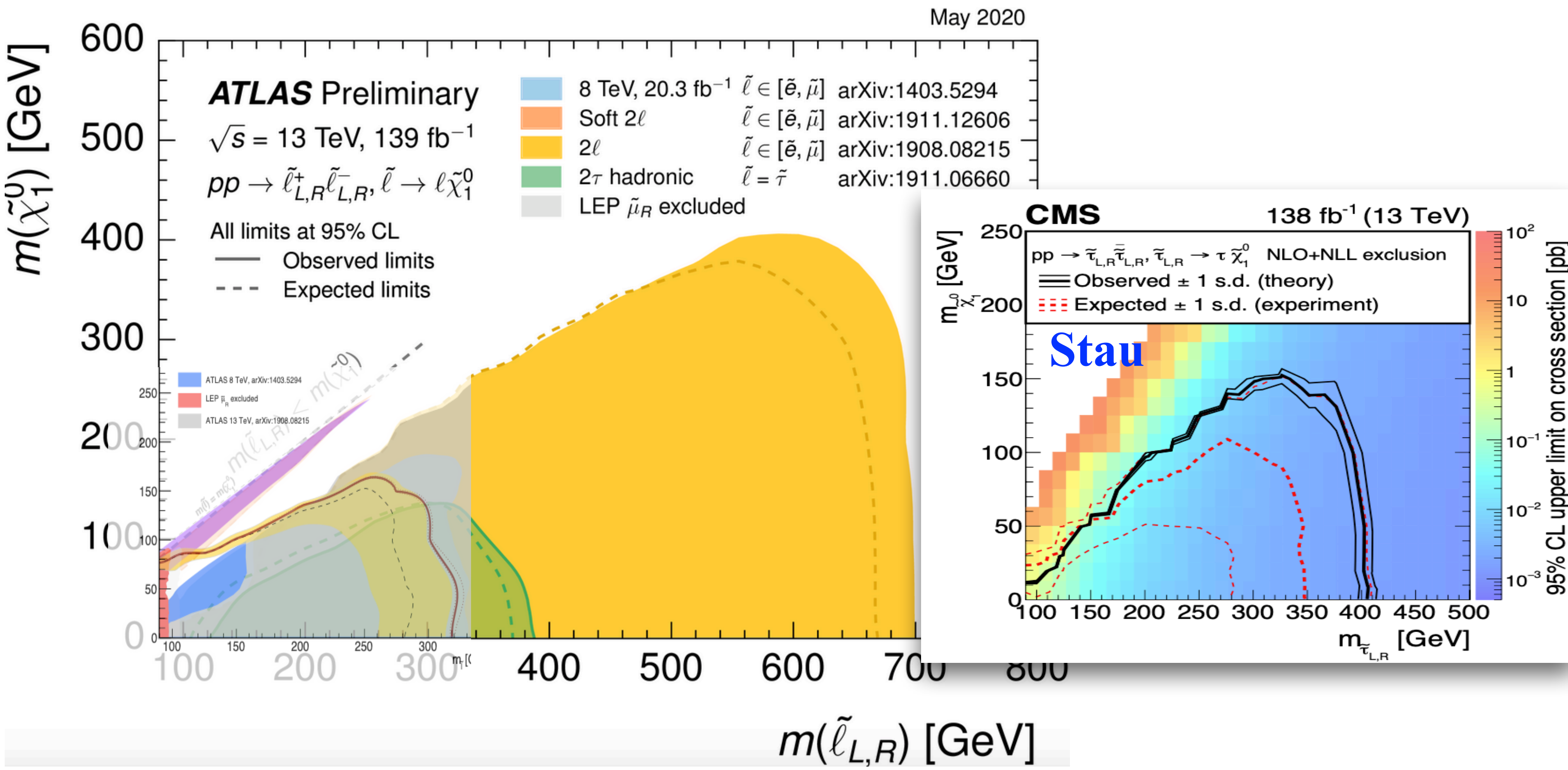
- Search 3: 2 hadronic tau analysis — combining di-tau trigger and Etmiss trigger arXiv:2207.02254

Slepton summary

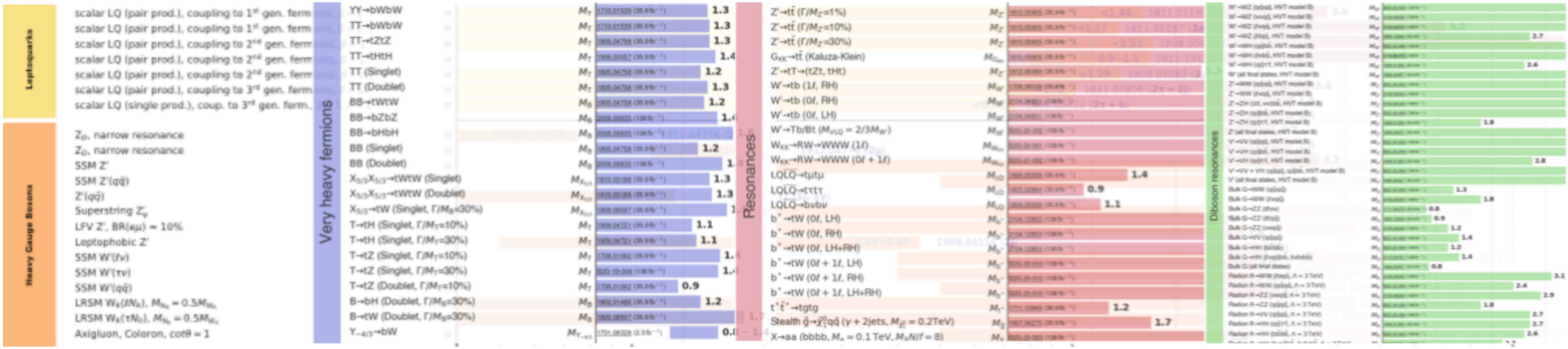






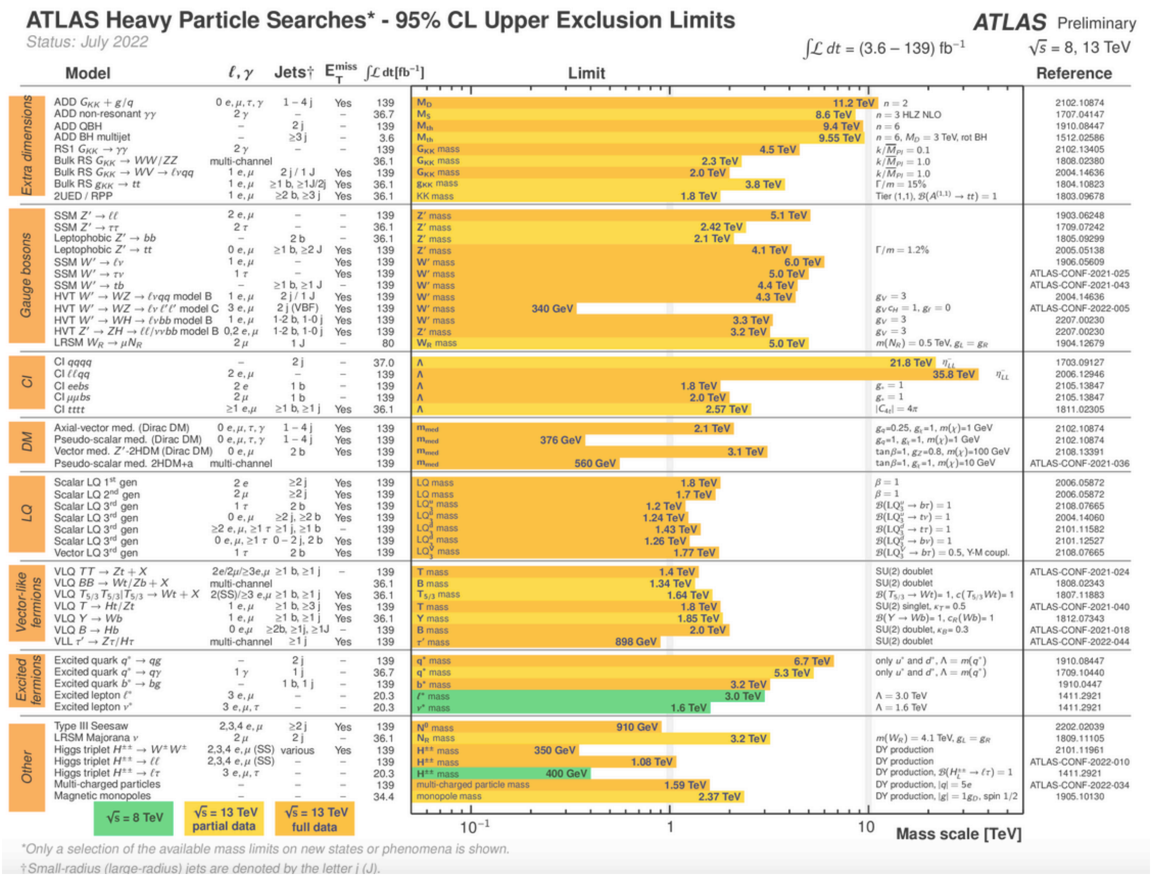


- **Advanced Search 1**: Final states with 2 hard e/μ (pT>25GeV) —> target *moderate* mass region! **NEW!**
- Search 2: Compressed analysis — 2 soft e/μ (pT_e>4.5GeV and pT_μ>3GeV) + ISR-jet —> target small mass splitting region!
- Search 3: 2 hadronic tau analysis — combining di-tau trigger and Etmiss trigger



Exotics (non SUSY)

- Leptoquarks (LQ)
- New gauge bosons
- New fermions
- Dark matter
- ...

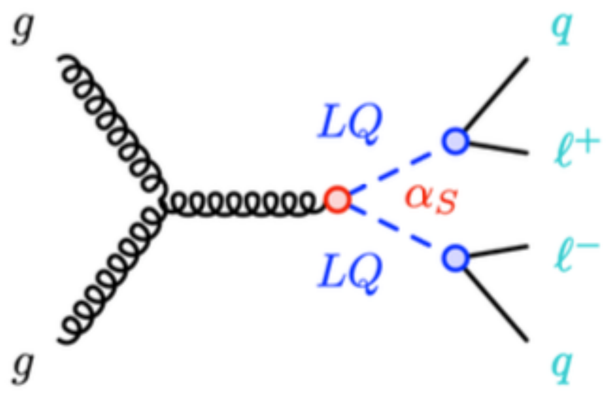


LQ search

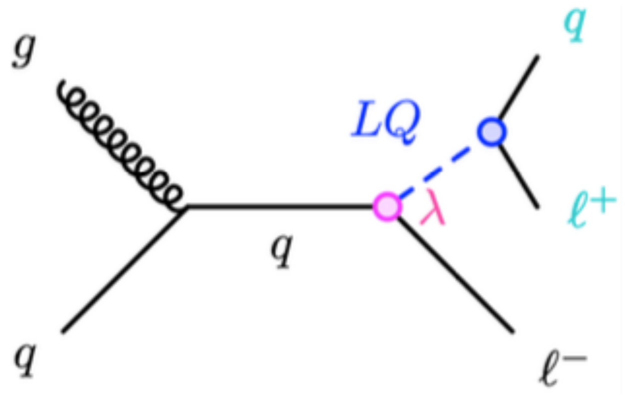
- What ?
- Hypothetical particles with non-zero baryon and lepton number
- Carry color charge and fractional electric charge
- Decay into quark-lepton pair
- Can be a scalar or a vector particle

- Why ?
- Appear in many BSM scenarios, relate quark and lepton sector
- Can explain observed deviations from lepton universality in B-meson decays, g-2 anomaly etc.

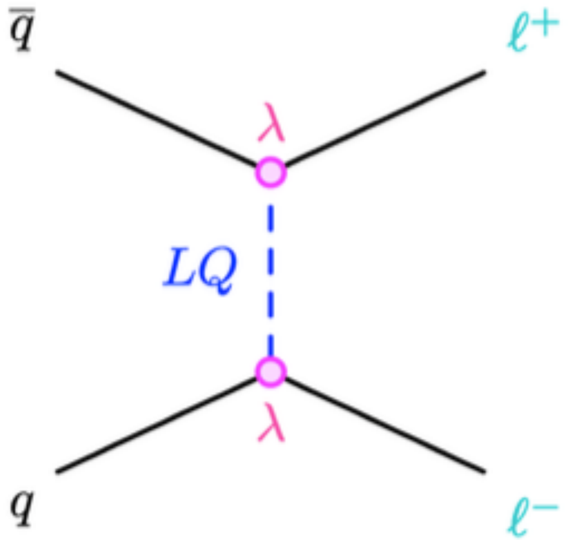
Pair produced LQ



Single LQ production

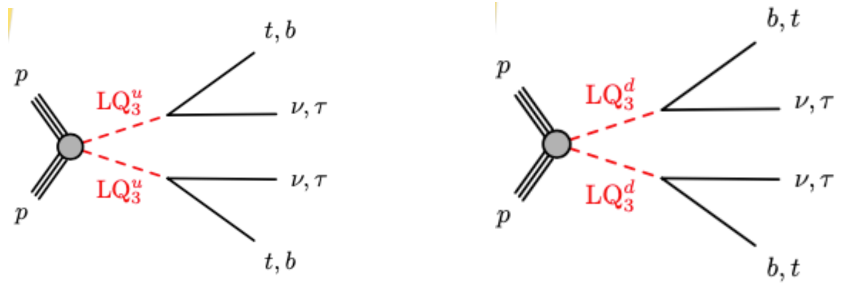


LQ mediator

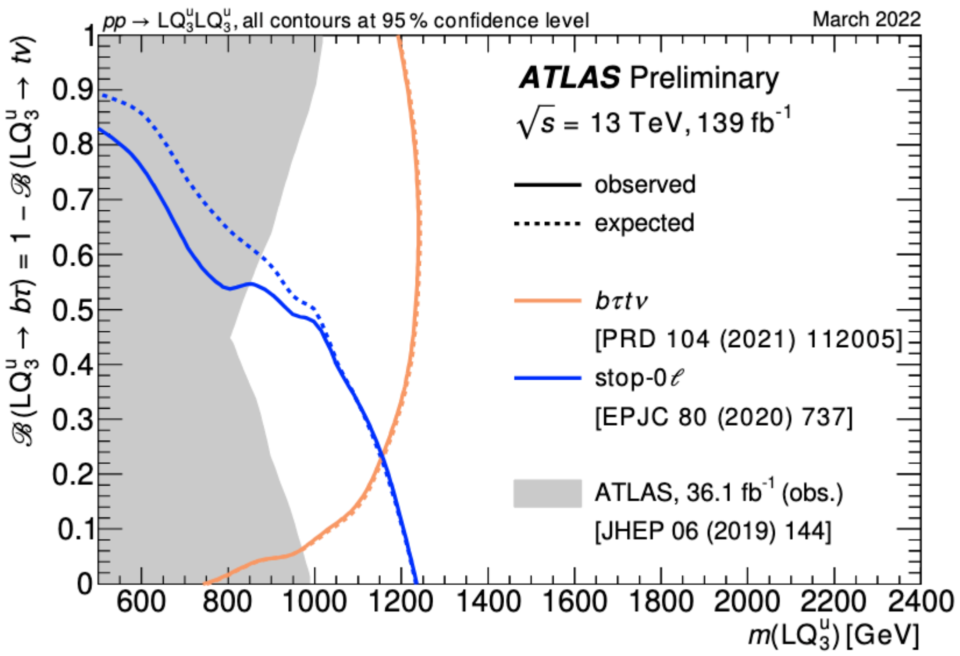


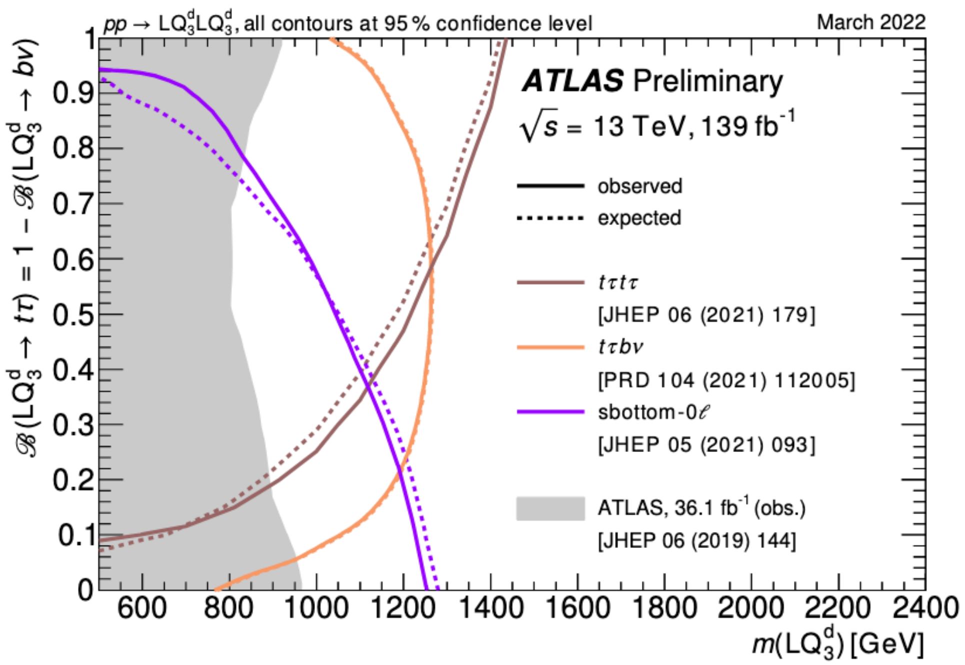
ATL-PHYS-PUB-2022-012

Pair produced LQ

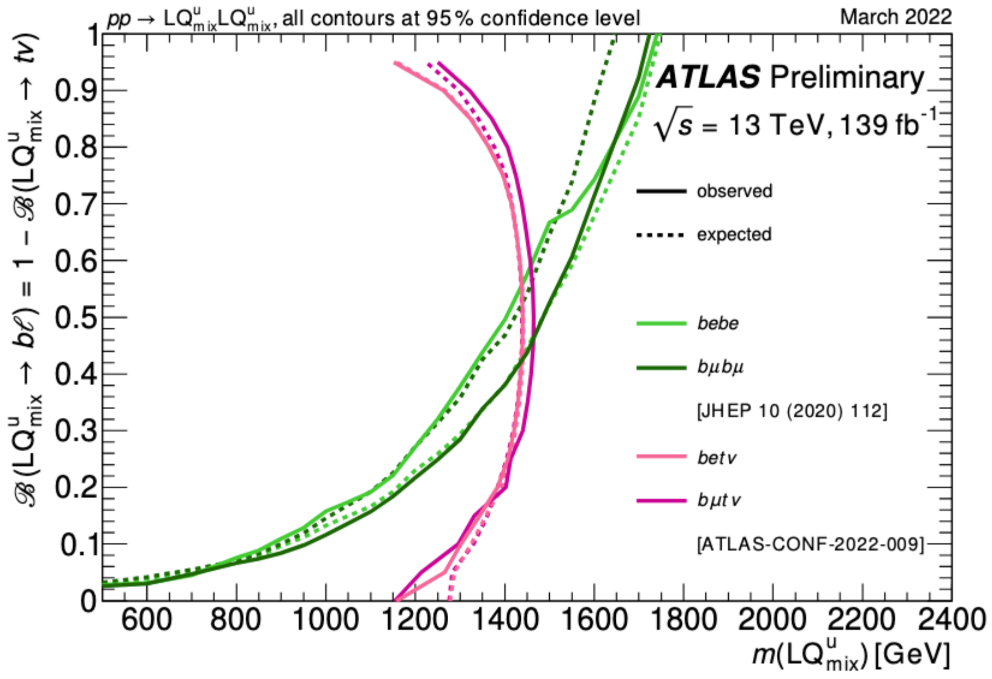


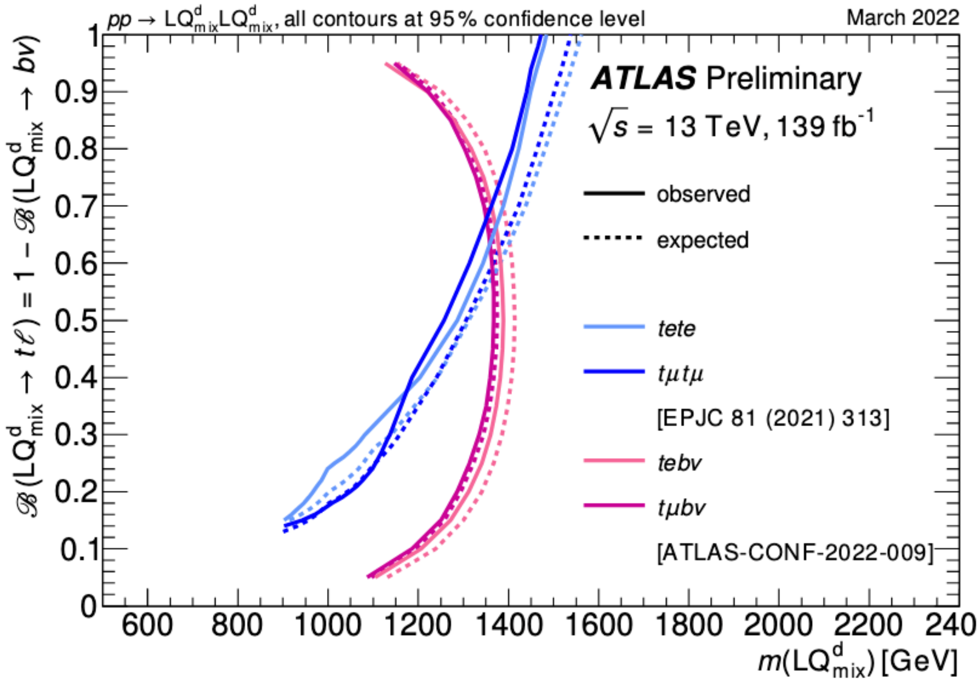
Third-Generation LQ





Mixed-Generation LQ





There is a broad/complementary program underway (well beyond the preferred decay modes by the B anomalies) and several of these results will be combined.

ATLAS-CONF-2022-052

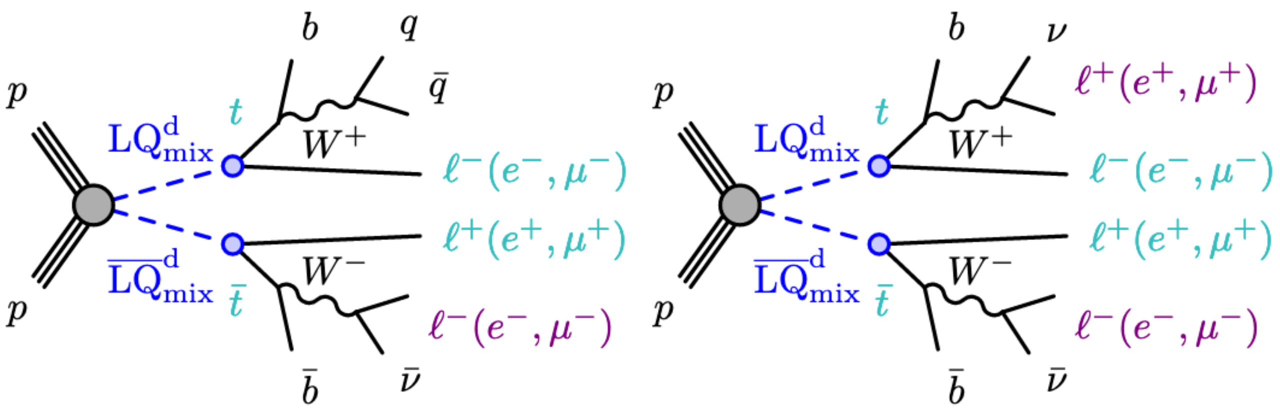
CMS-PAS-EXO-19-016

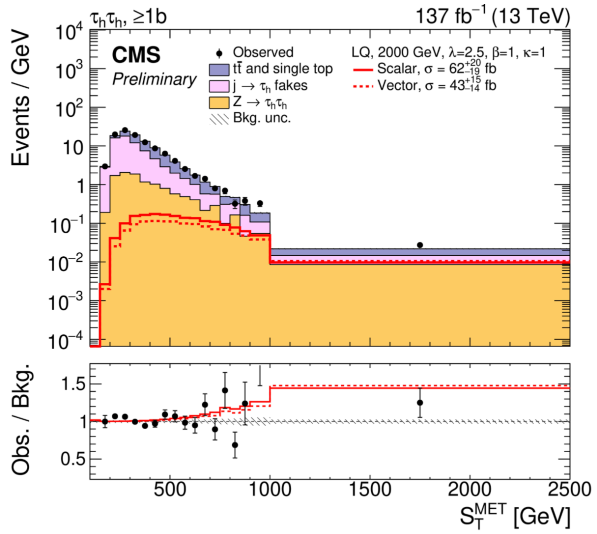
NEW!

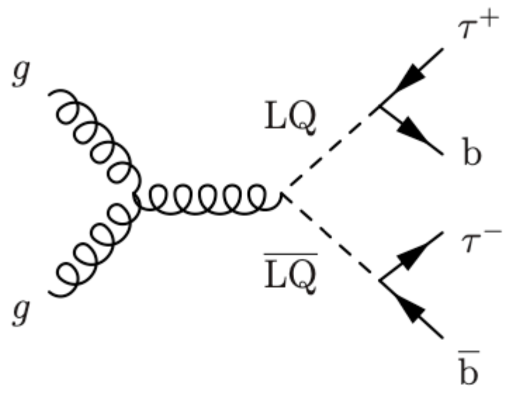
Pair produced LQ

LQ_mix pair decays via tl, into 3L/4L FS

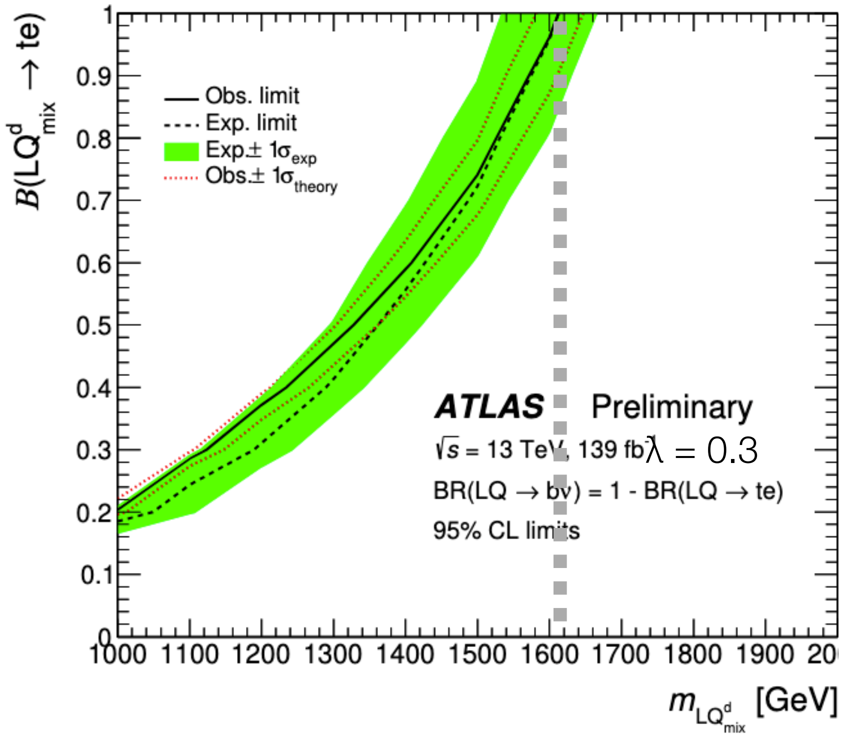
LQ3 pair decays via bτ

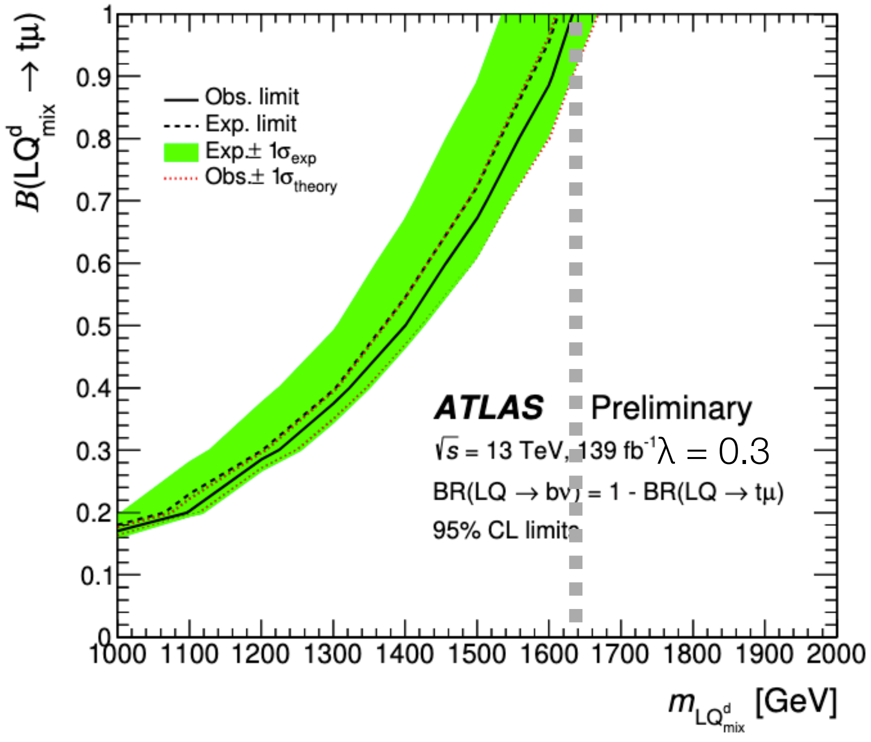


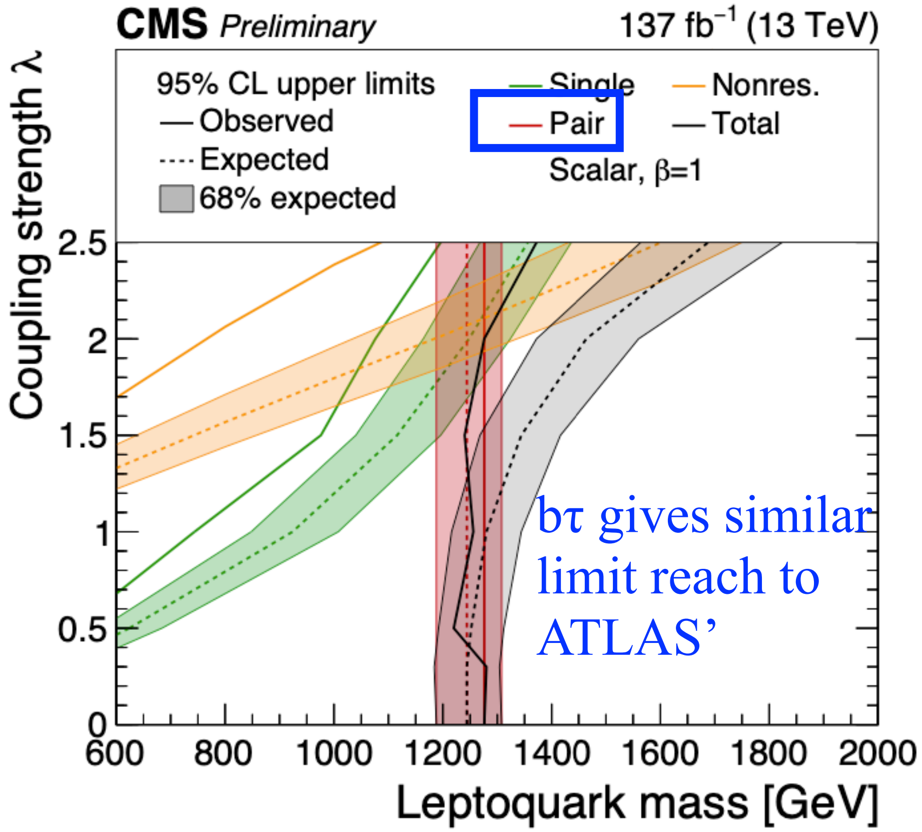




The tl result provides improved limits up to 1.6 TeV w.r.t. previous summary; Scalar LQ shown. The mass limits for vector LQ reach up to 2 TeV.







bτ gives similar limit reach to ATLAS’

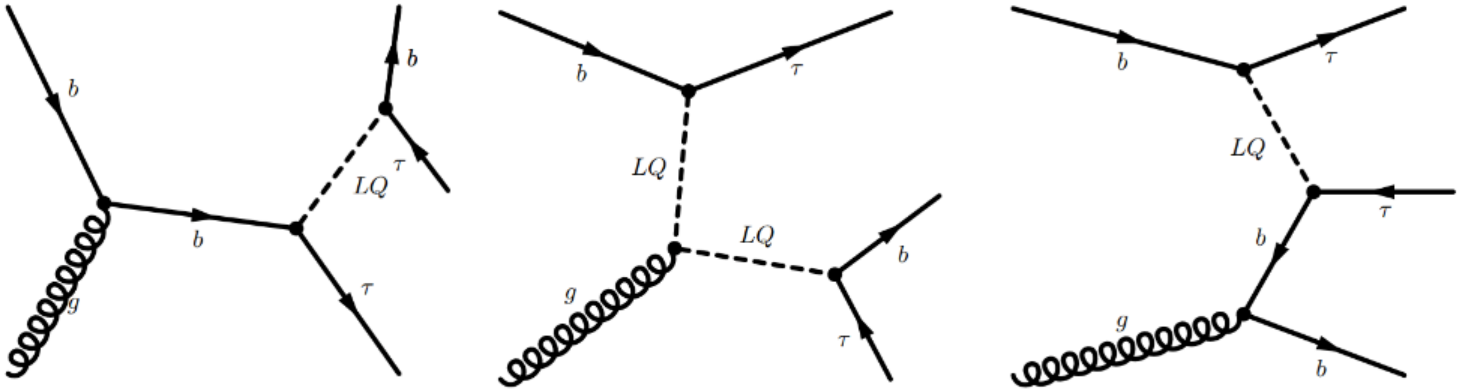
ATLAS-CONF-2022-037

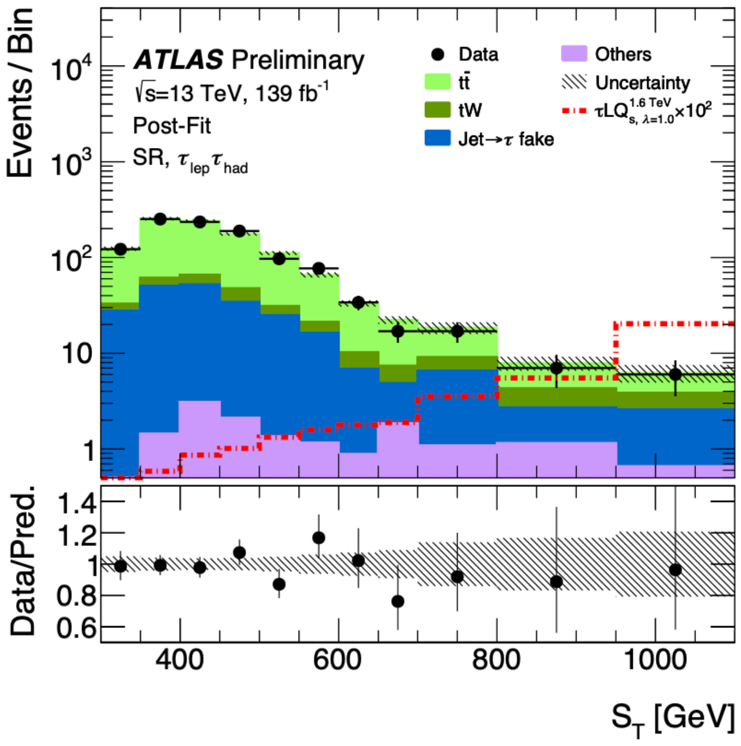
CMS-PAS-EXO-19-016

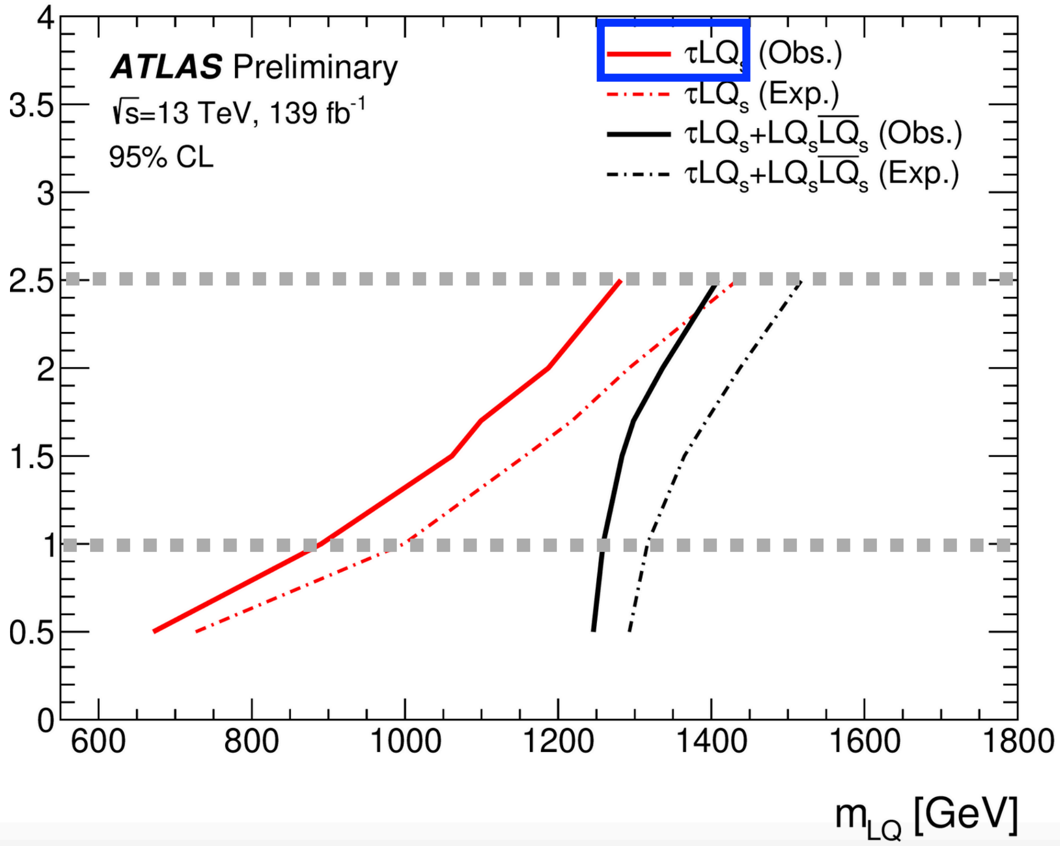
NEW!

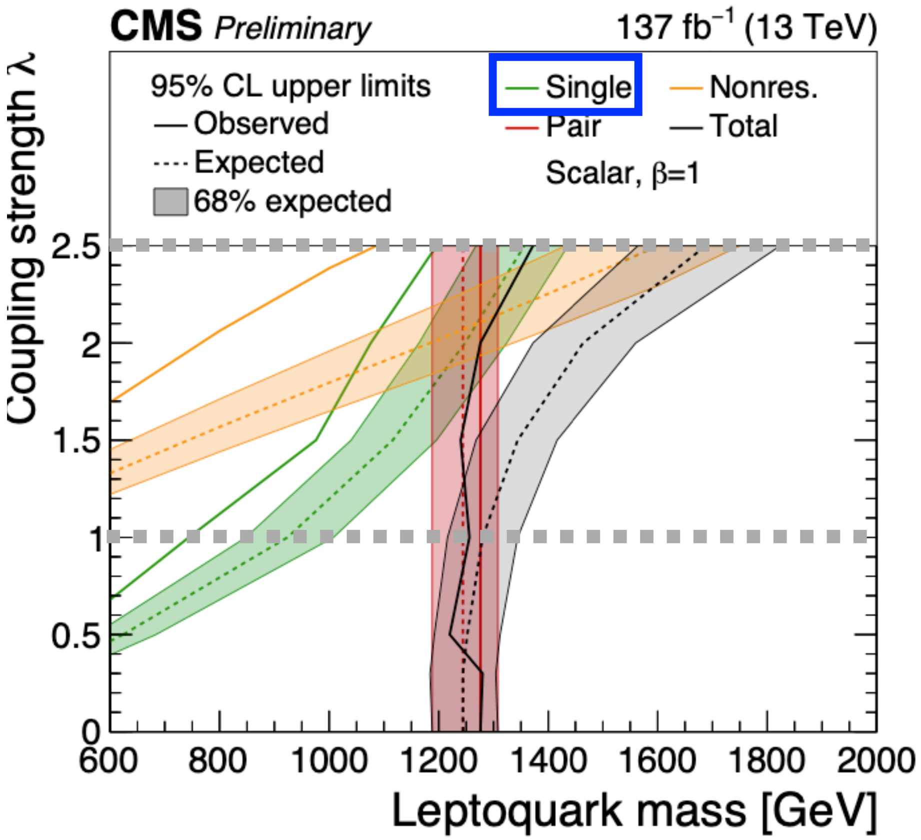
Single LQ

- **Single LQ decay via bτ, into 2τ+b FS**
- **Combined τlep-τhad and τhad-τhad channels are exploited**









Similar scenario targeted by two experiments: similar sensitivity reach from two independent analyses.

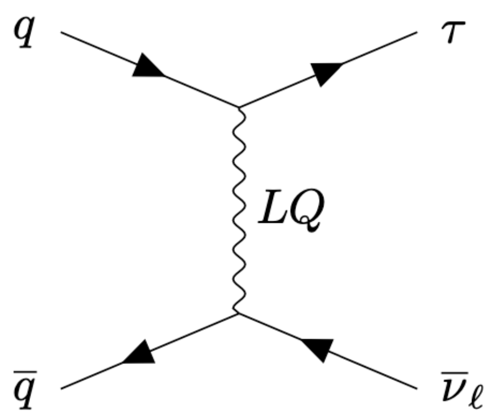
NEW!

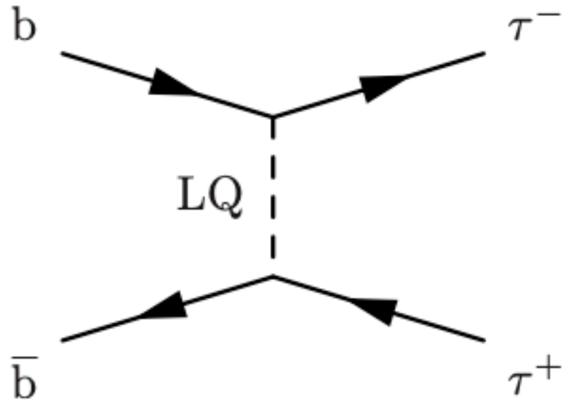
CMS-PAS-EXO-21-009

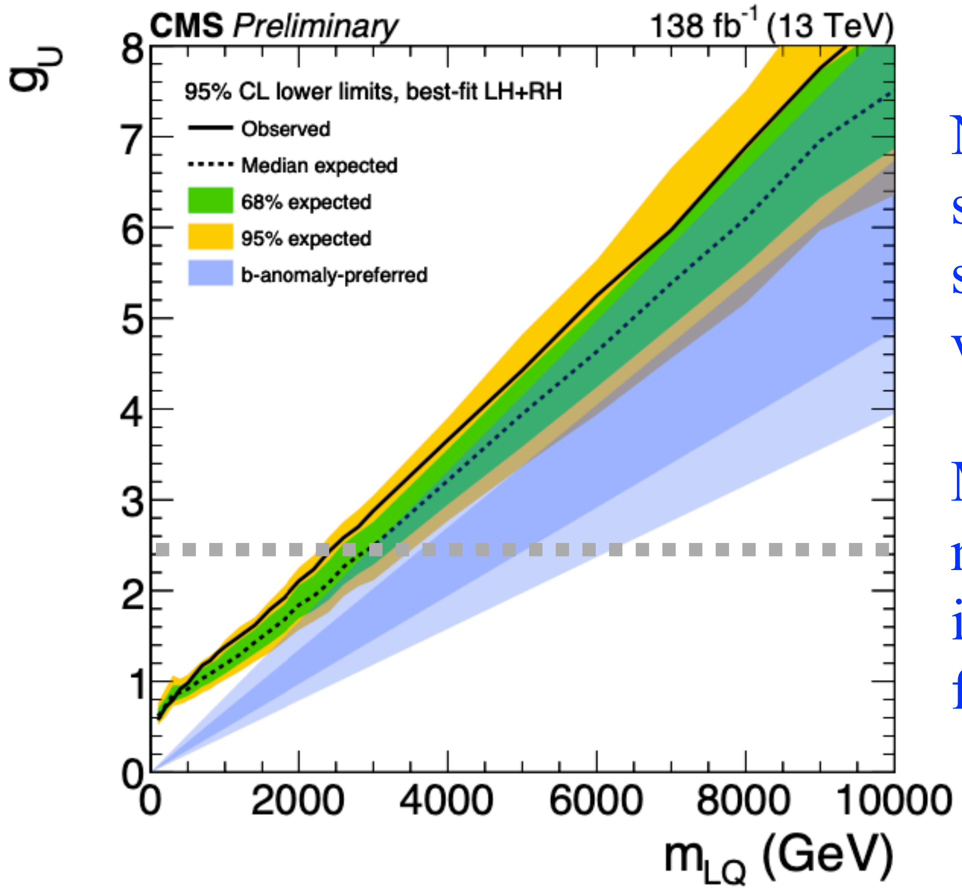
CMS-PAS-EXO-19-016

LQ as a mediator

Non-resonant production of $\tau\,\tau$ *or* τ+MET via *t*-channel LQ exchange

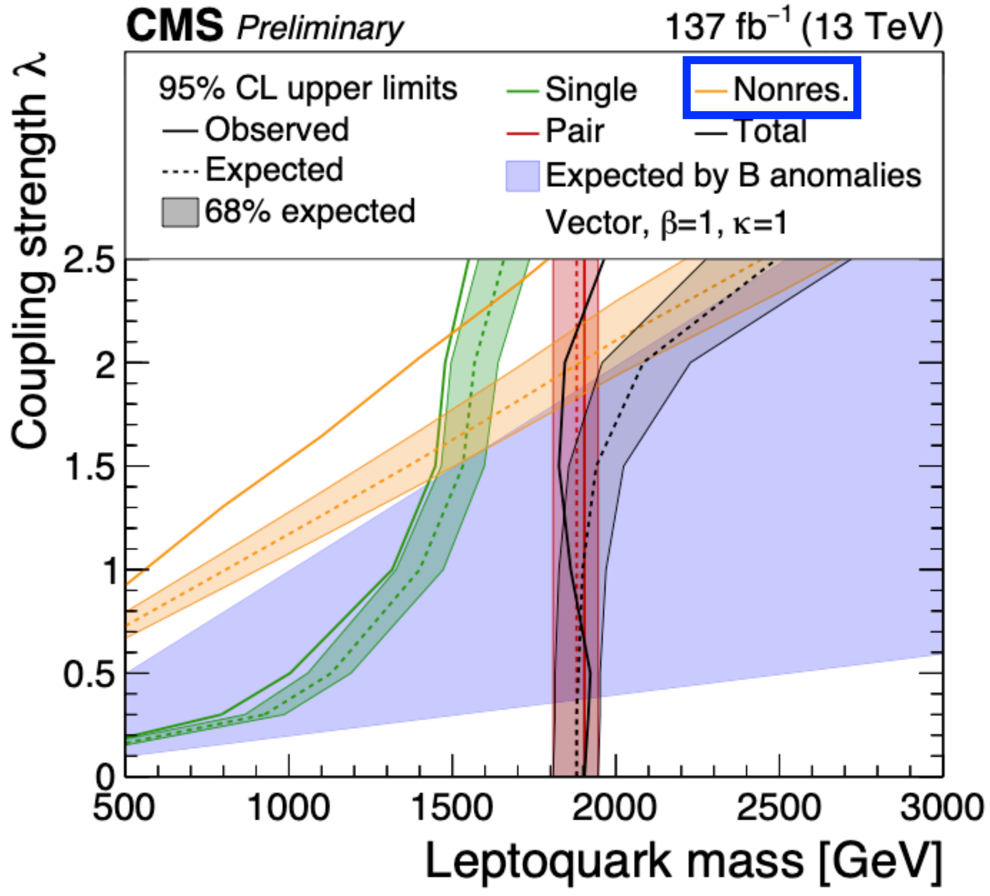






Nonresonant production start to contribute more significantly at higher values of λ

Mild excess found in the non-resonant search, which is sensitive to the region favored by the B anomalies



New gauge bosons

- Spin-1 W’, Z’
  - In many models, e.g. composite Higgs
  - Possible solution to hierarchy problem

- Axion-like particles (spin-0 pseudoscalars)
  - Specific case of axion is a solution to Strong CP problem
  - DM candidate

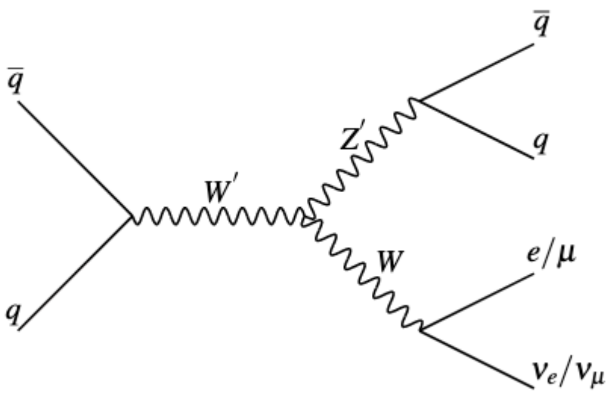
NEW!

CMS-PAS-EXO-21-009

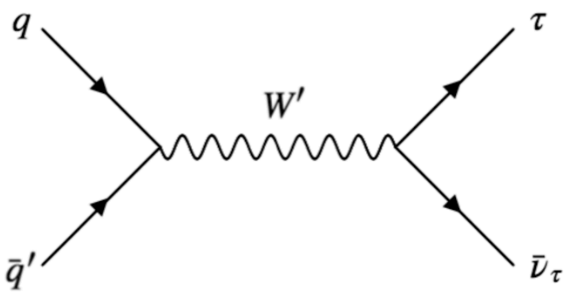
ATLAS-CONF-2022-048

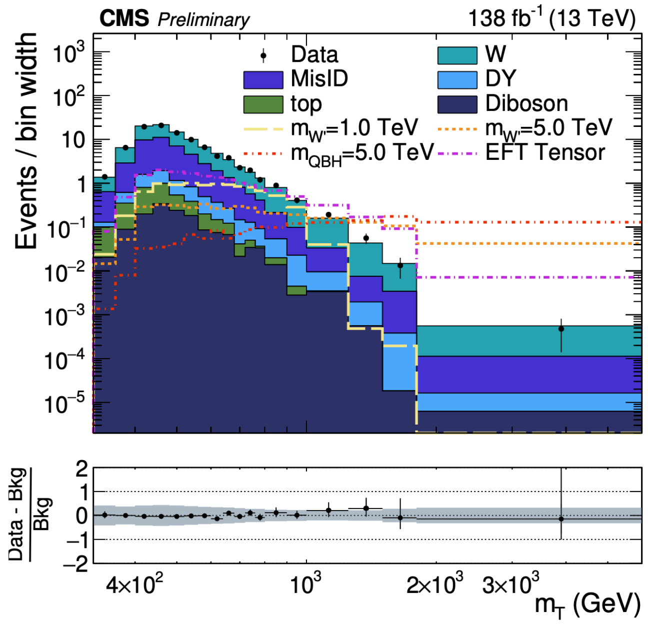
W', Z' search

- W'→Z'W; $Z' \to qq$ giving rise to two high-energetic jets, while a W decays leptonically
- Key var: **inv.mass** reconstructed from lepton and jets

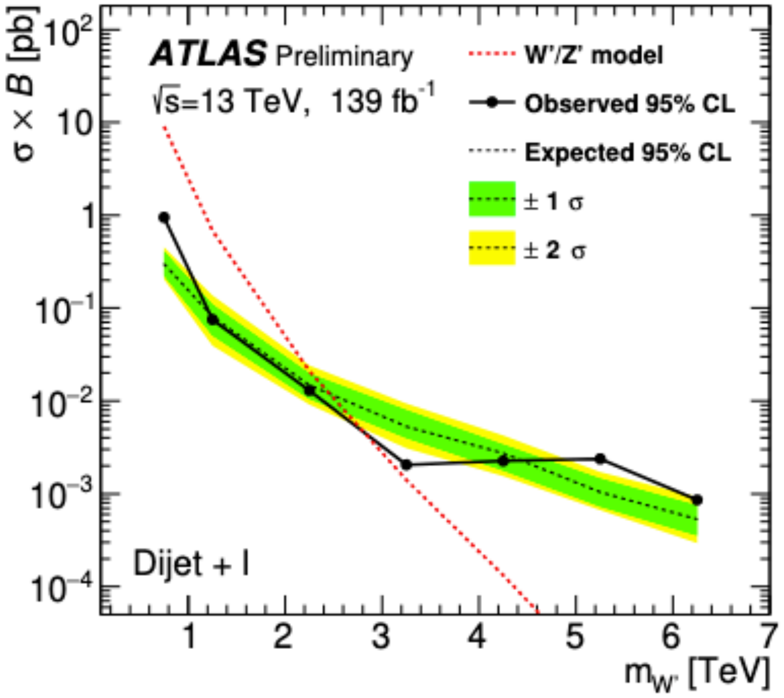


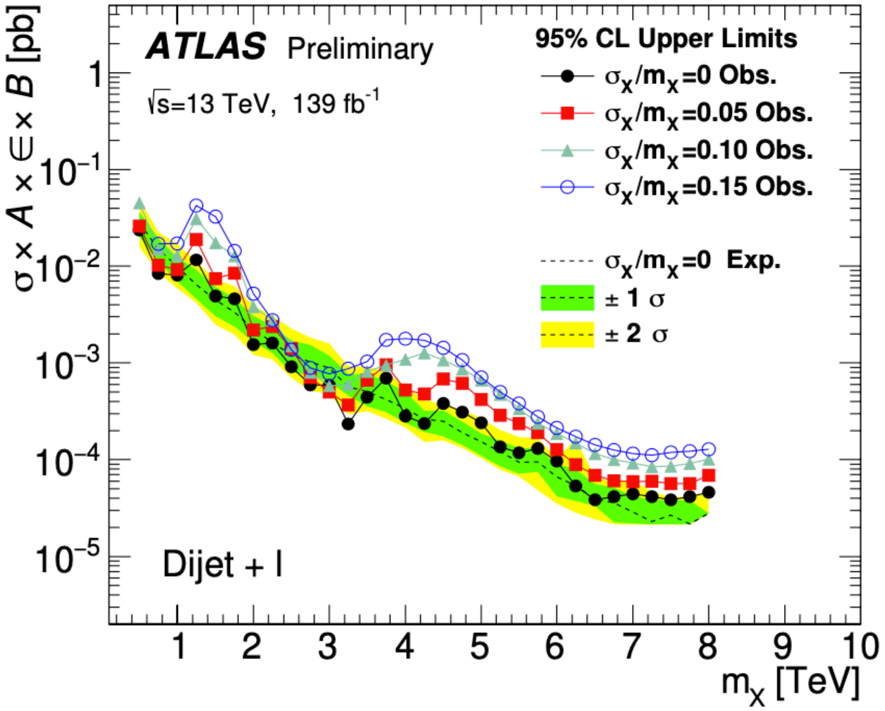
- W′ fermion couplings are similar to SM W boson except the additional W′→ tb due to higher boson mass

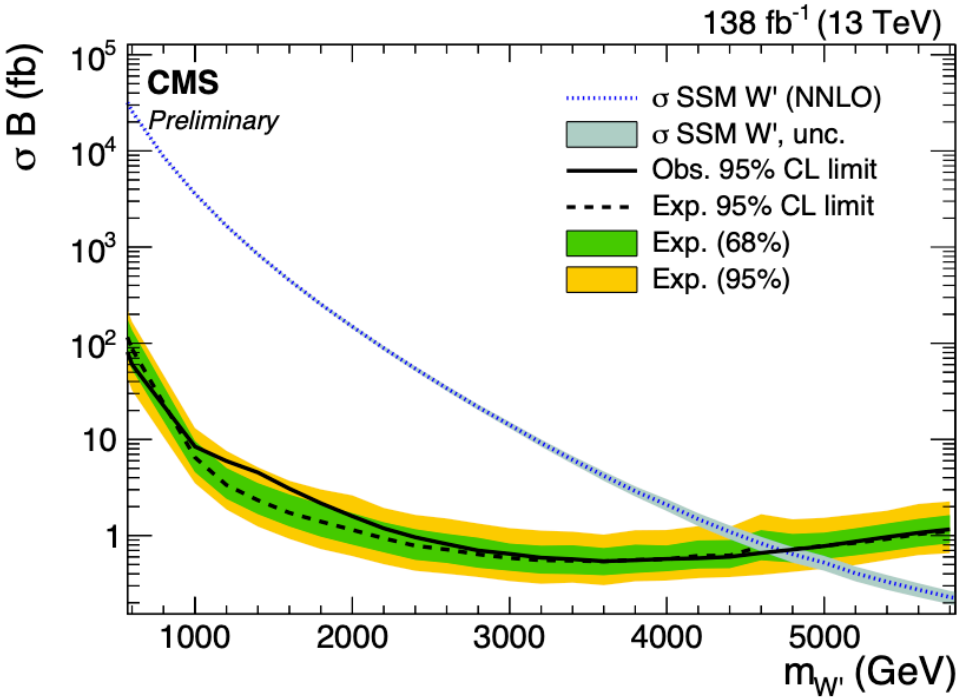




Model-independent limits for X-jjl: weaker limits for broader resonances







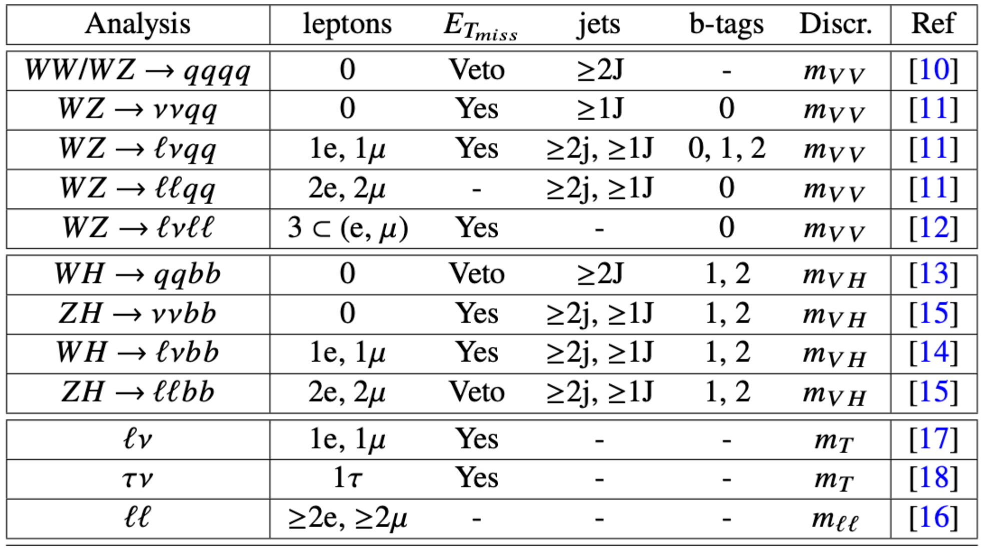
NEW!

ATLAS-CONF-2022-028

CMS-PAS-B2G-20-009

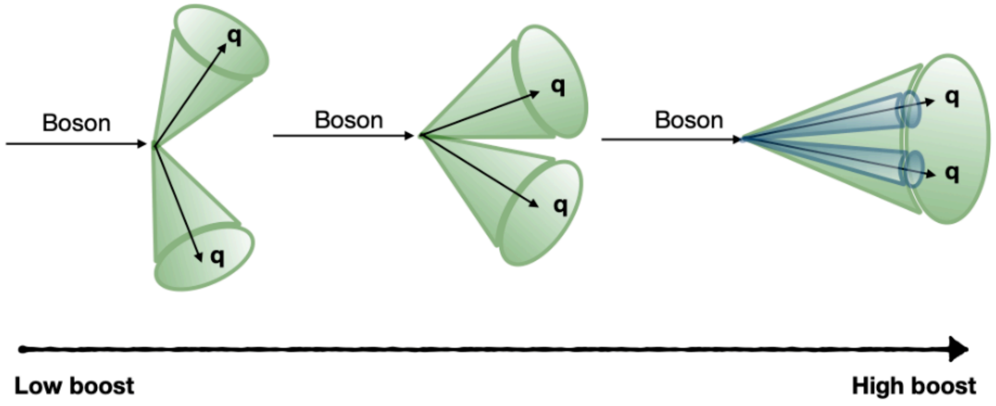
Searches for heavy resonances V’

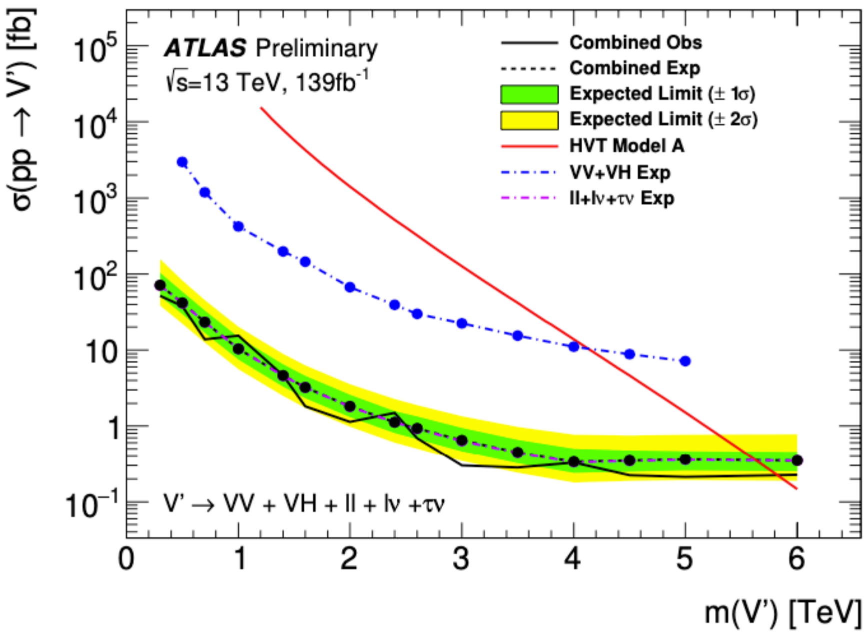
A combination of various V’->VV/VH and leptonic channels, exploring Heavy Vector Triplet (HVT) model

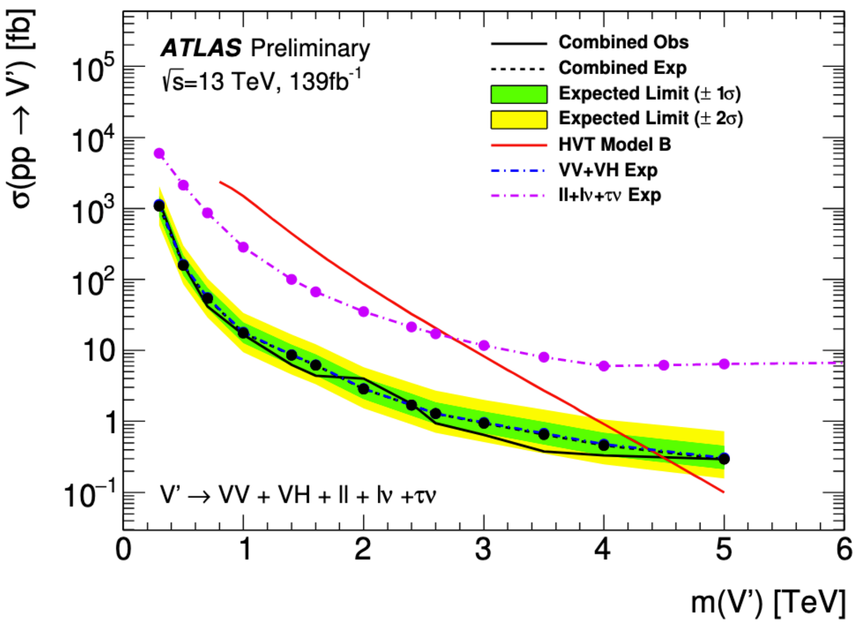


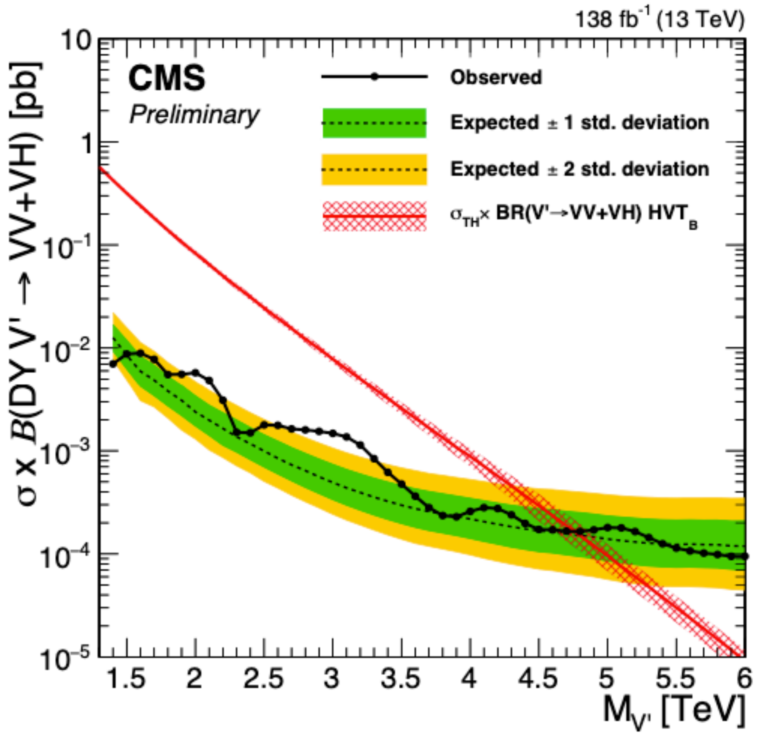
Analysis	leptons	$E_{T_{miss}}$	jets	b-tags	Discr.	Ref
$WW/WZ \to qqqq$	0	Veto	≥2J	-	m_{VV}	[10]
$WZ \to \nu\nu qq$	0	Yes	≥1J	0	m_{VV}	[11]
$WZ \to \ell\nu qq$	1e, 1μ	Yes	≥2j, ≥1J	0, 1, 2	m_{VV}	[11]
$WZ \to \ell\ell qq$	2e, 2μ	-	≥2j, ≥1J	0	m_{VV}	[11]
$WZ \to \ell\nu\ell\ell$	3 ⊂ (e, μ)	Yes	-	0	m_{VV}	[12]
$WH \to qqbb$	0	Veto	≥2J	1, 2	m_{VH}	[13]
$ZH \to \nu\nu bb$	0	Yes	≥2j, ≥1J	1, 2	m_{VH}	[15]
$WH \to \ell\nu bb$	1e, 1μ	Yes	≥2j, ≥1J	1, 2	m_{VH}	[14]
$ZH \to \ell\ell bb$	2e, 2μ	Veto	≥2j, ≥1J	1, 2	m_{VH}	[15]
$\ell\nu$	1e, 1μ	Yes	-	-	m_T	[17]
$\tau\nu$	1τ	Yes	-	-	m_T	[18]
$\ell\ell$	≥2e, ≥2μ	-	-	-	$m_{\ell\ell}$	[16]

Large-*R* radius jets widely used in high boost region









Similar sensitivity reach between ATLAS and CMS results

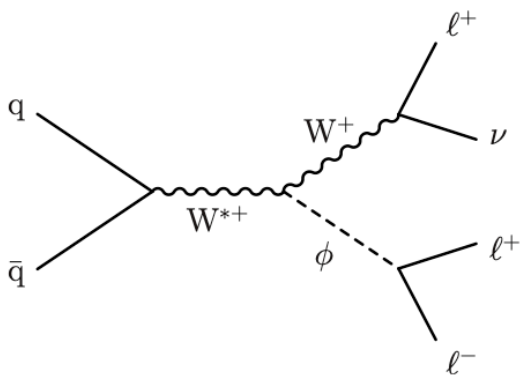
The CMS excesses are excluded by ATLAS

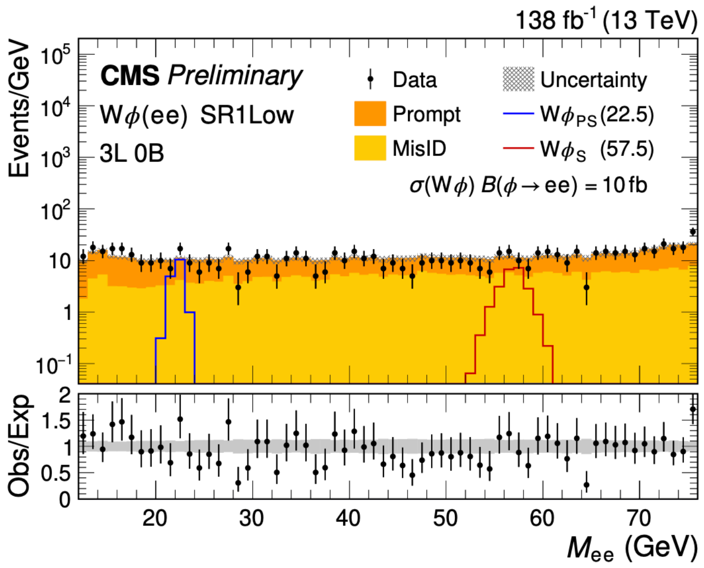
NEW!

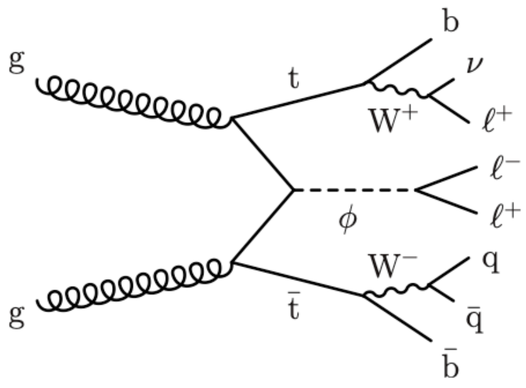
CMS-PAS-EXO-21-018

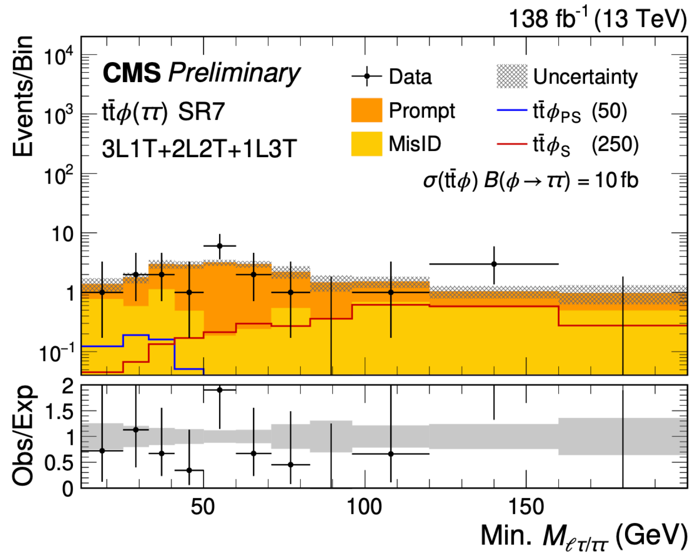
(Pseudo)scalar bosons search

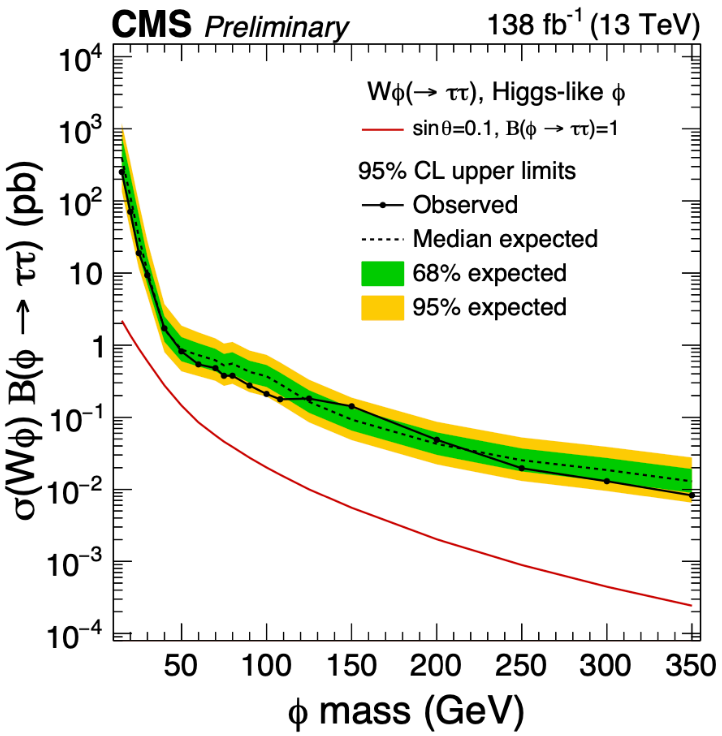
Target signal models of new spin-0 particles with scalar, pseudoscalar, or Higgs-like couplings; Produced with dilepton resonances or top associate production; Consider 7 orthogonal channels according to NlepNtau

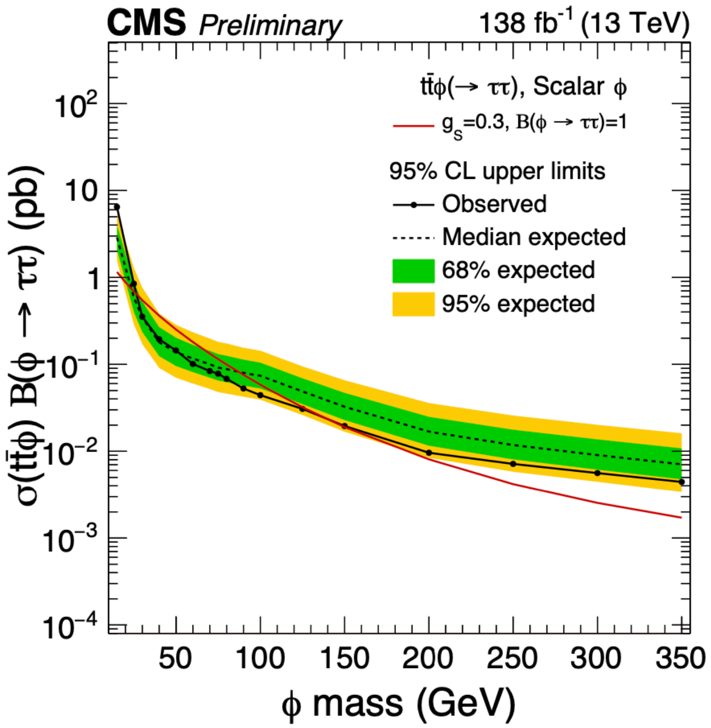


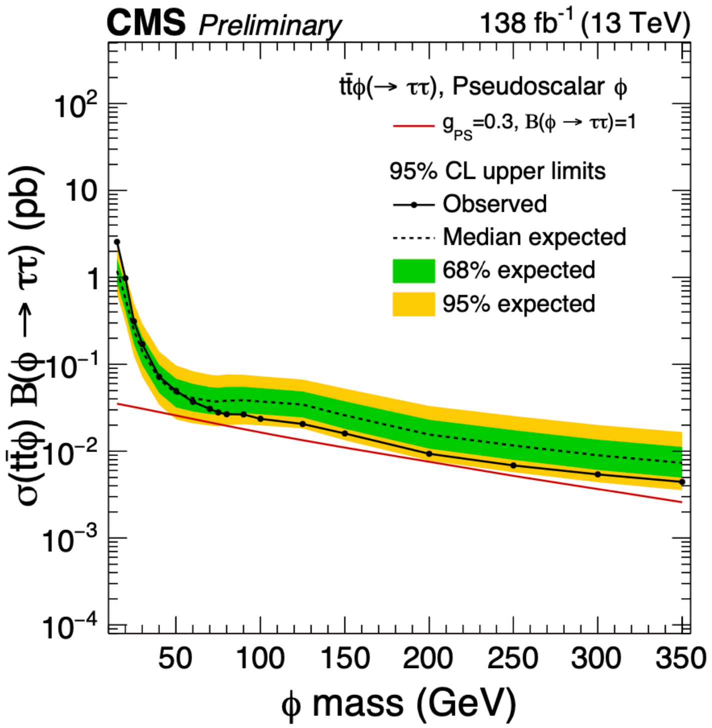












New fermions

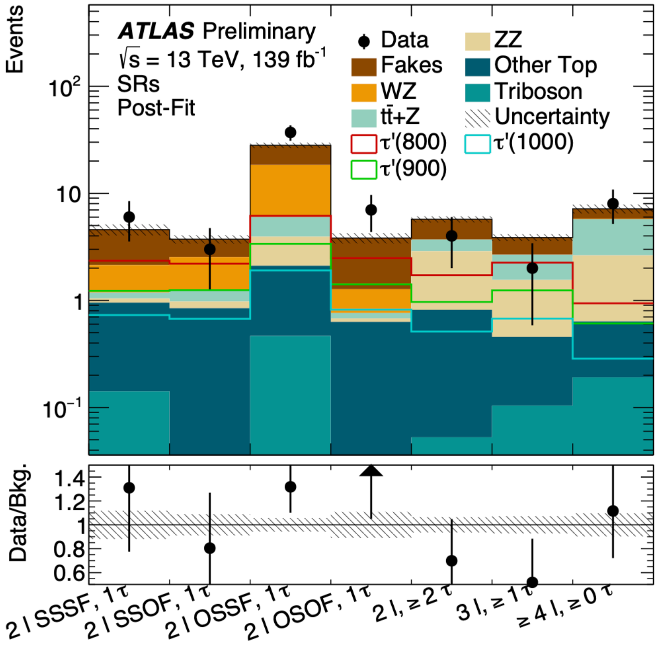
- Vector-like quarks (VLQ)
  - Present in various scenarios (extra dimensions, Little Higgs,...) trying to solve the hierarchy problem;
  - colored spin-1/2 fermions;
  - in simplified models VLQ mix with their SM partners to regulate the Higgs boson mass

- Excited states of quarks/leptons (q*, l*)

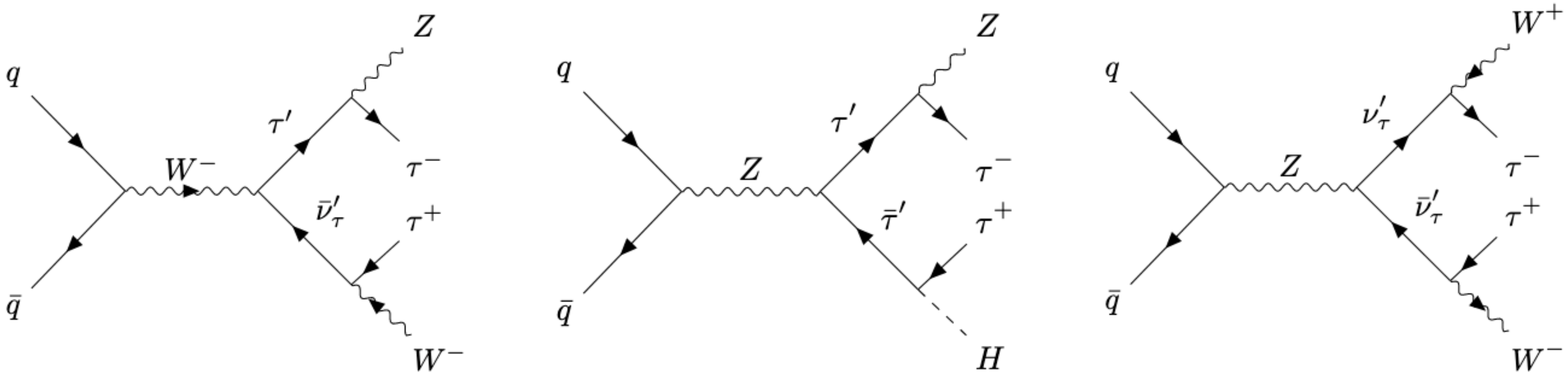
NEW!

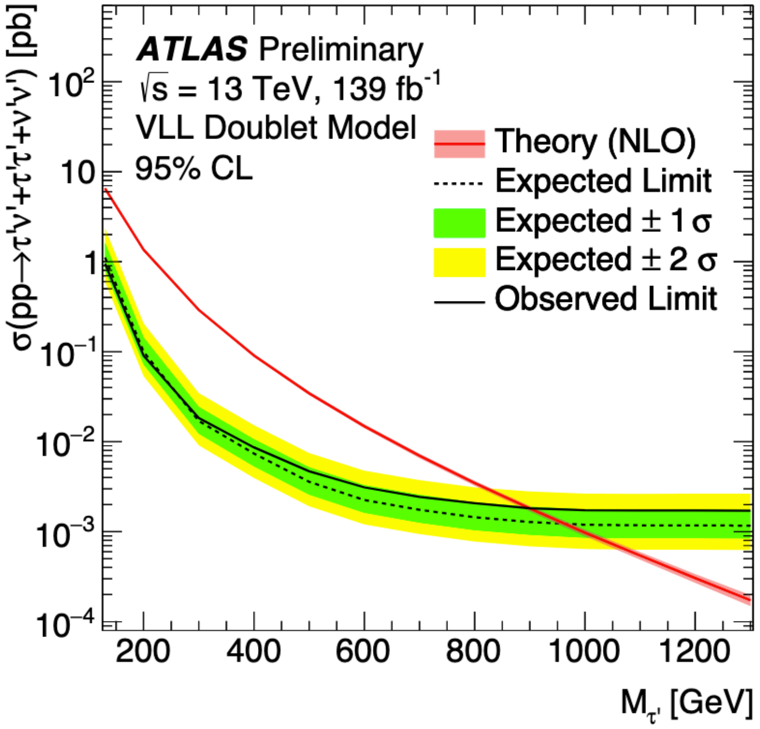
ATLAS-CONF-2022-044
arXiv:2202.08676

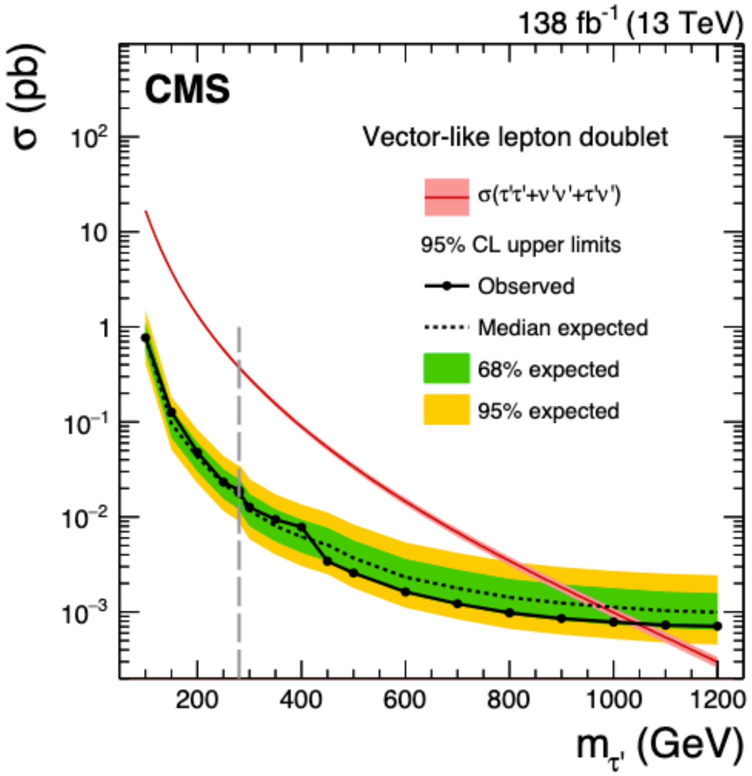
Vector-like Taus

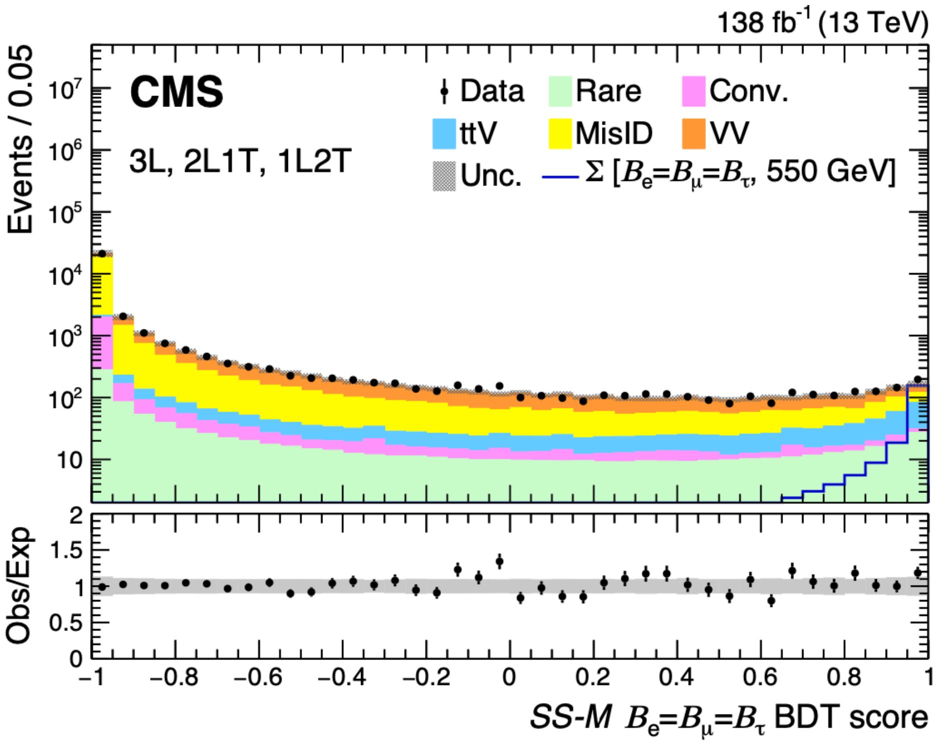


Search in multi-lepton(tau) channels with machine learning.









Similar sensitivity reach between ATLAS and CMS results

NEW!

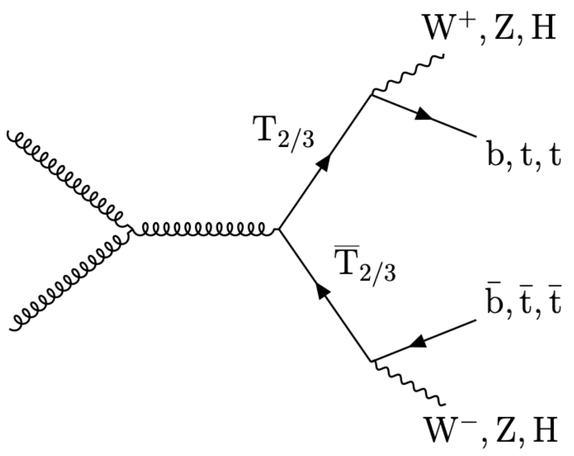
ATLAS-CONF-2022-036
CMS-PAS-B2G-20-011
CMS-PAS-B2G-21-007

Vector-like T quark

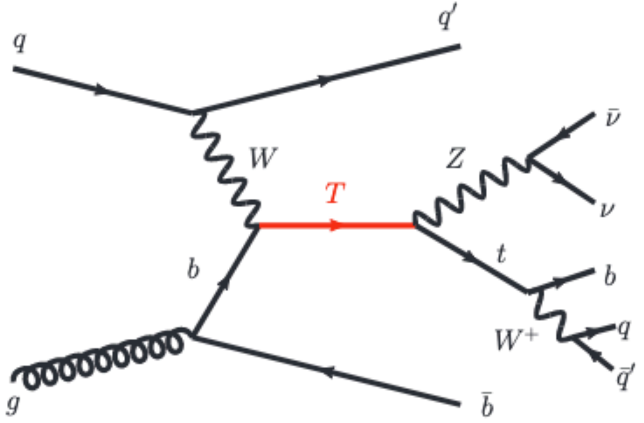
Vector-like T quark, decaying via Zt/Wb/Ht

T’ → tH (H→ γ γ)

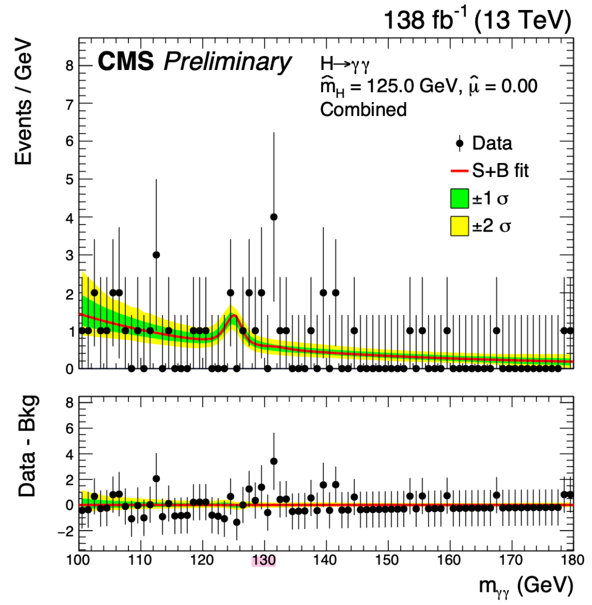
Pair production

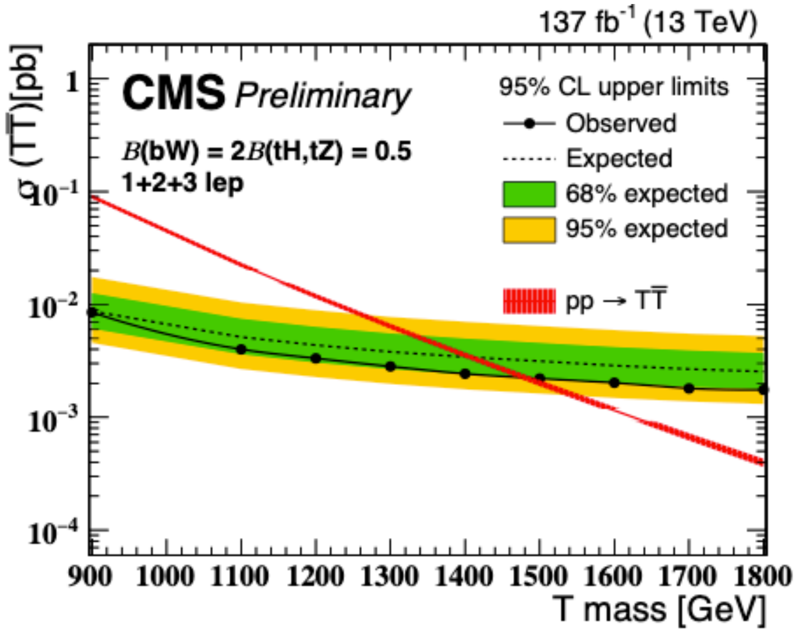


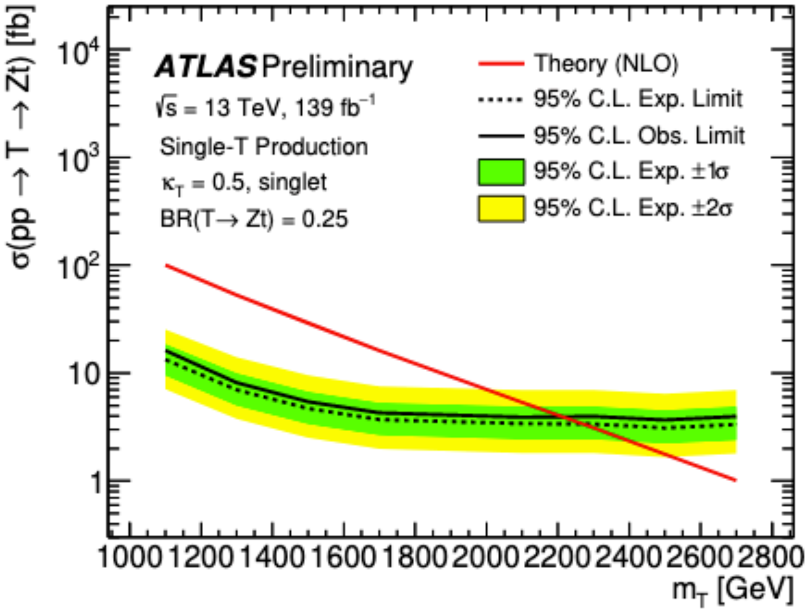
Single production

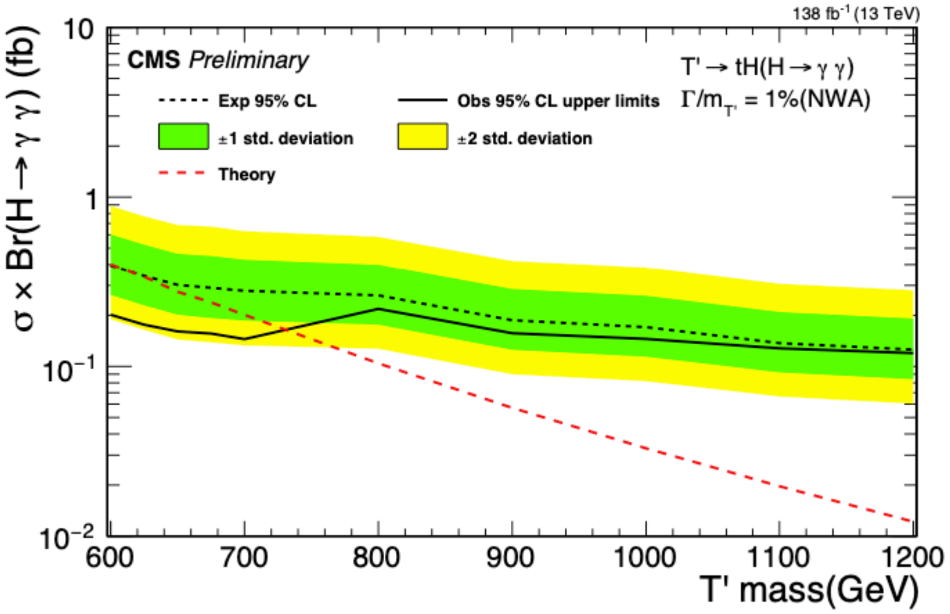


Mono top result currently placing the most restrictive limits for single production of a vector-like T singlet









Pair and single production searches are complementary: pair production just depends on the VLQ mass, but cross section steeply falling; single production allows to probe up to higher VLQ mass, but depends on the coupling strength kappa.

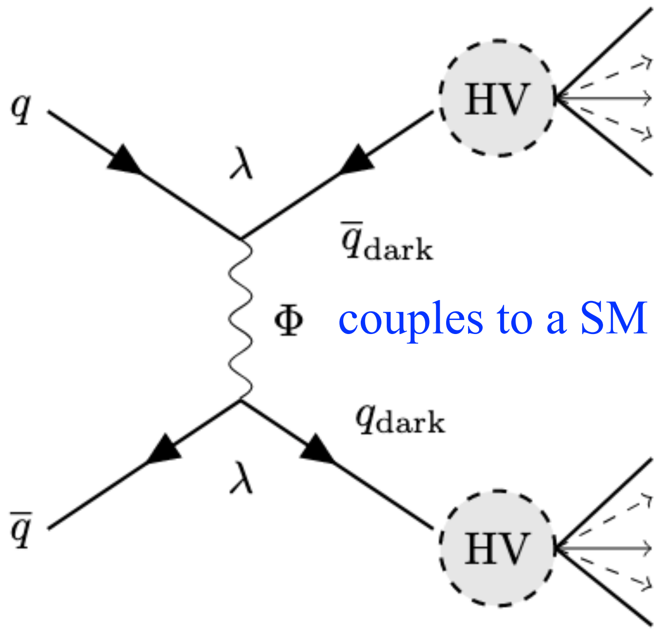
ATLAS-CONF-2022-038

Dark matter

- What ?
  - Various invisible scenarios…

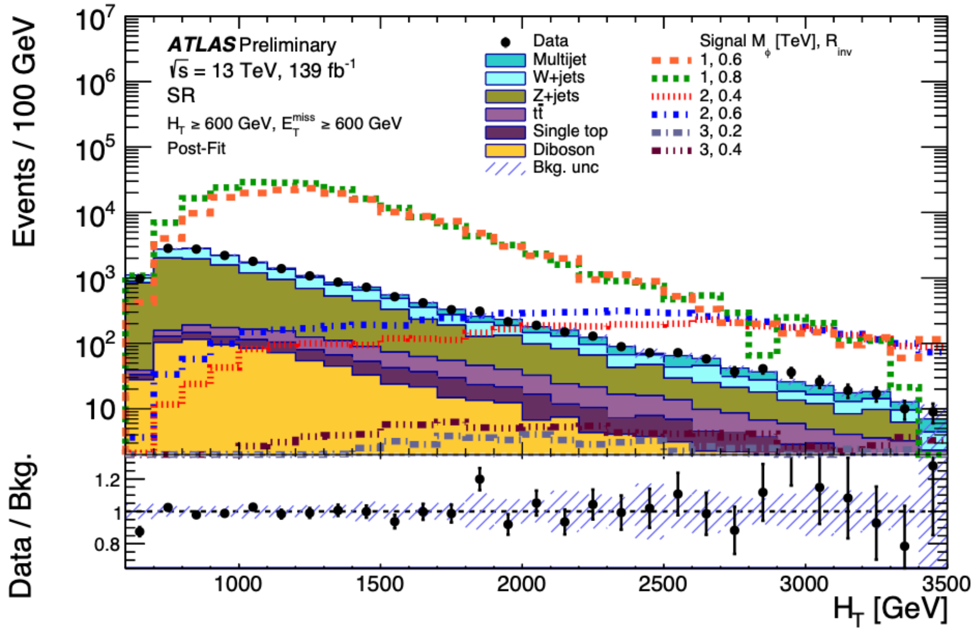
Semi-visible jets in strongly-interacting dark sectors

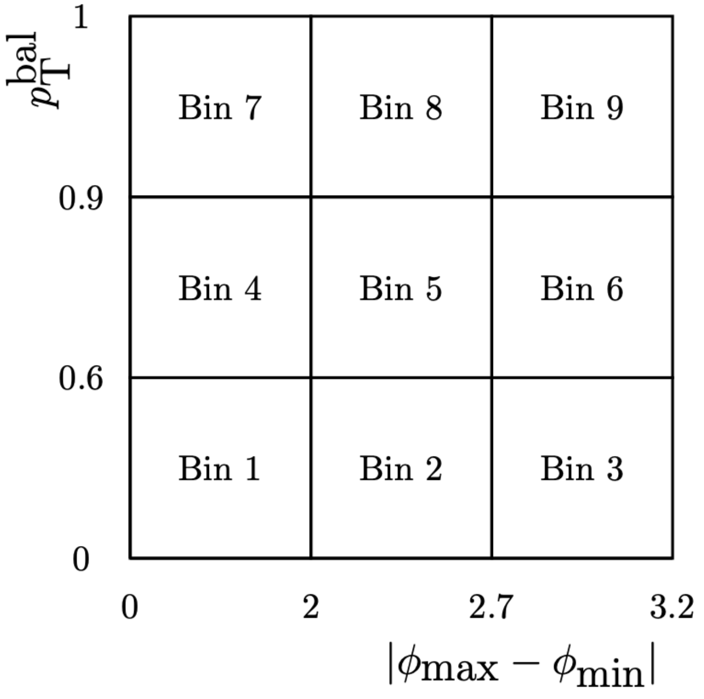
—> one of the jets is aligned with the missing energy

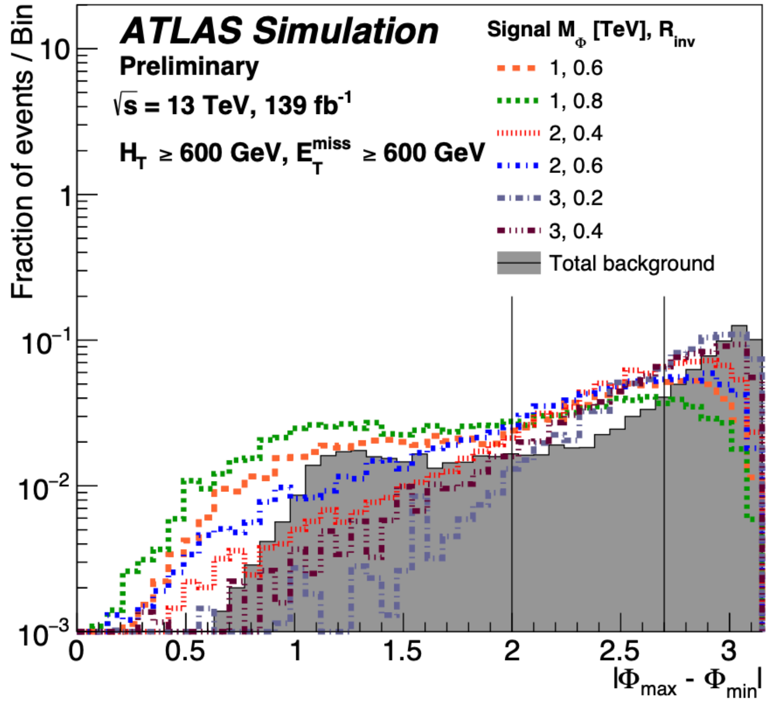


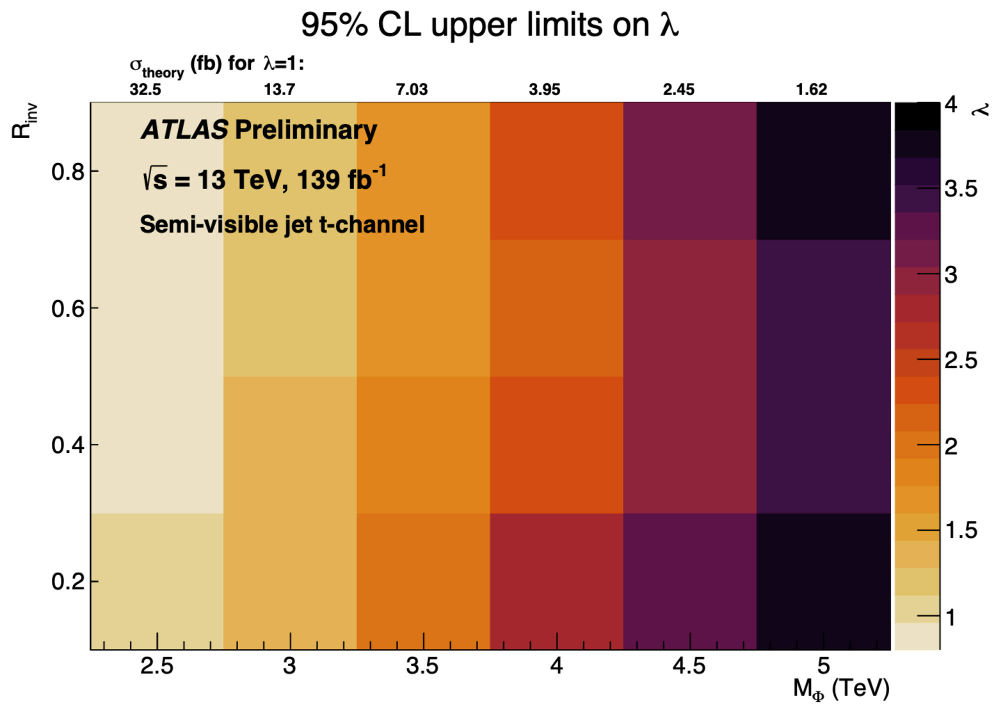
couples to a SM quark and a dark quark

a final state consisting of SM hadrons and dark hadrons, governed by the *R*inv fraction

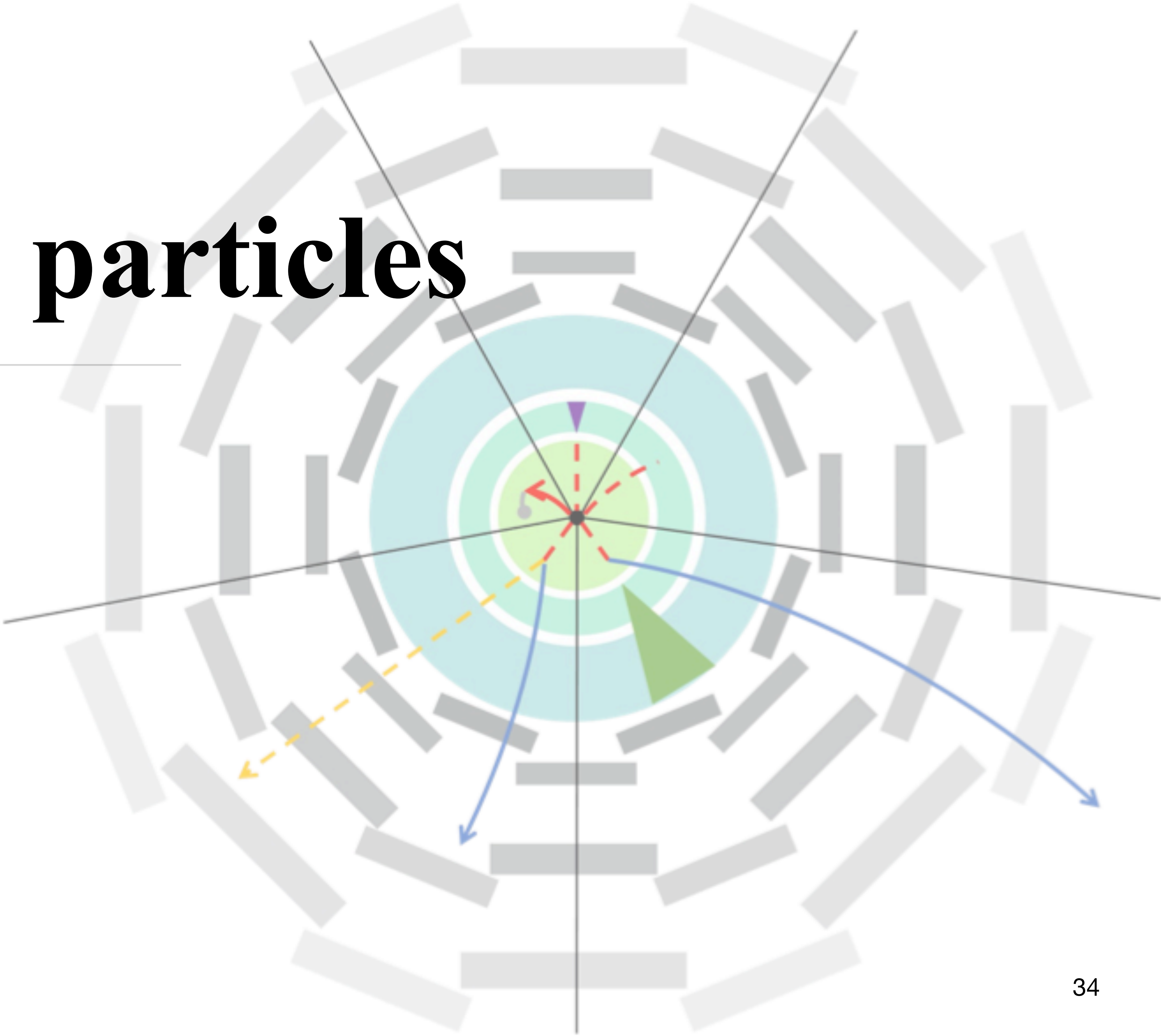






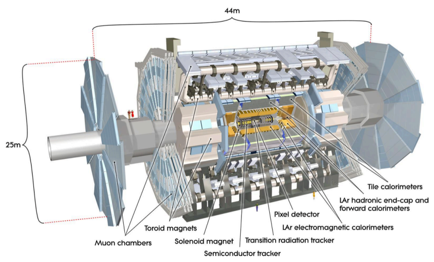


Long-lived particles

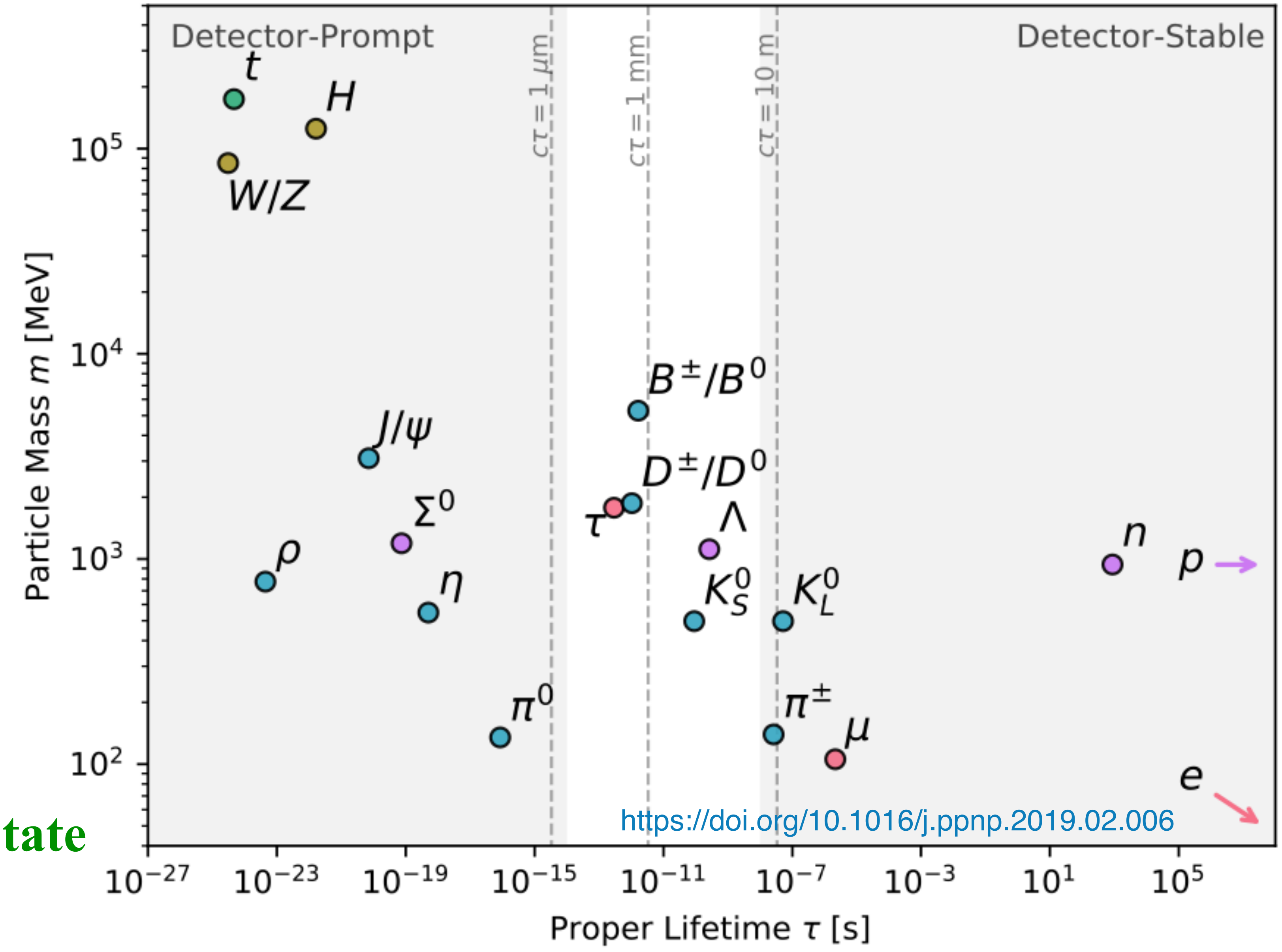


Why search for long lived particles?

Many SM particles are long-lived!



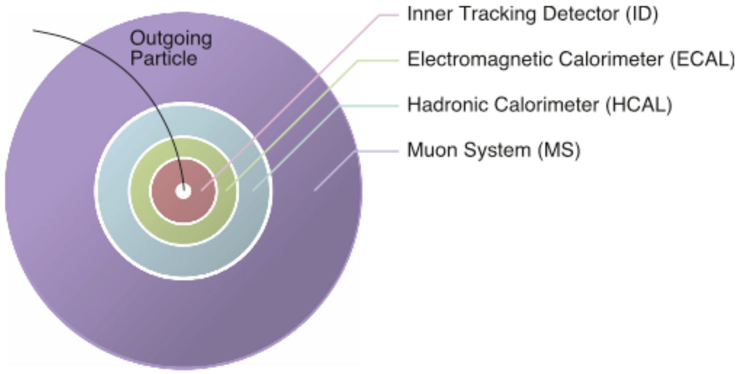
Decay suppression also plays in a variety of BSM scenarios.



https://doi.org/10.1016/j.ppnp.2019.02.006

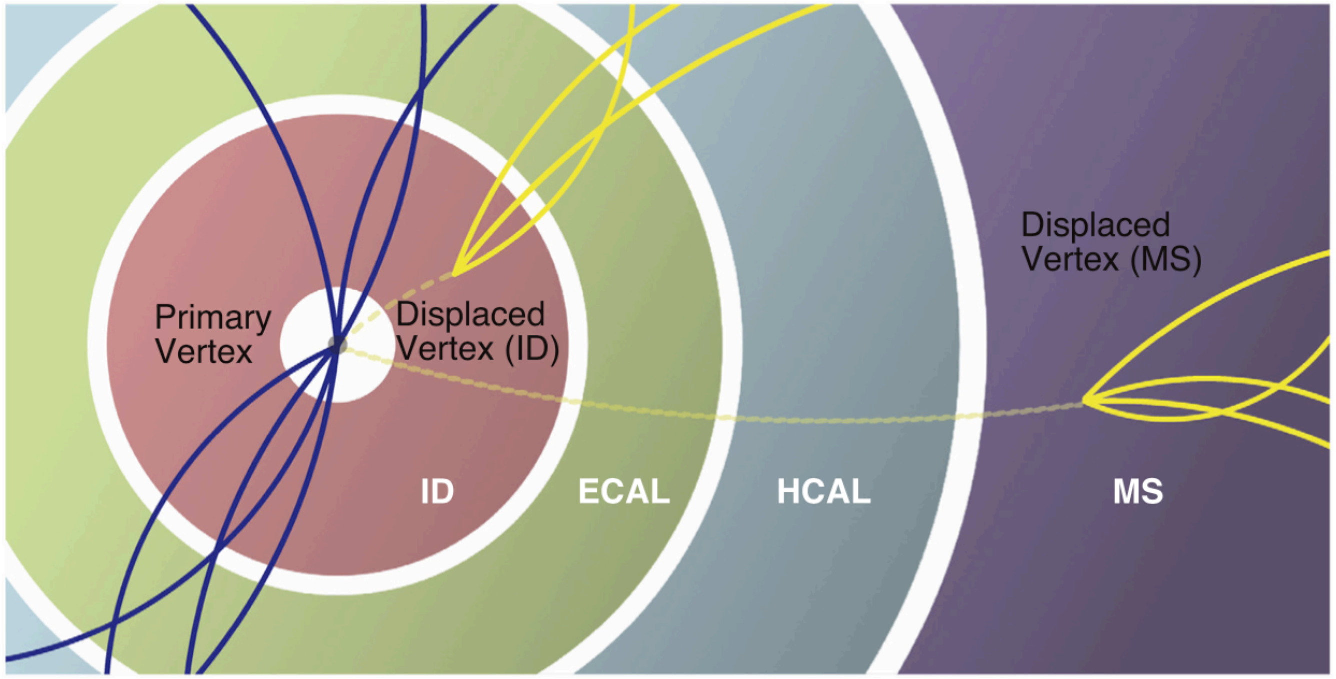
LLP model essentials

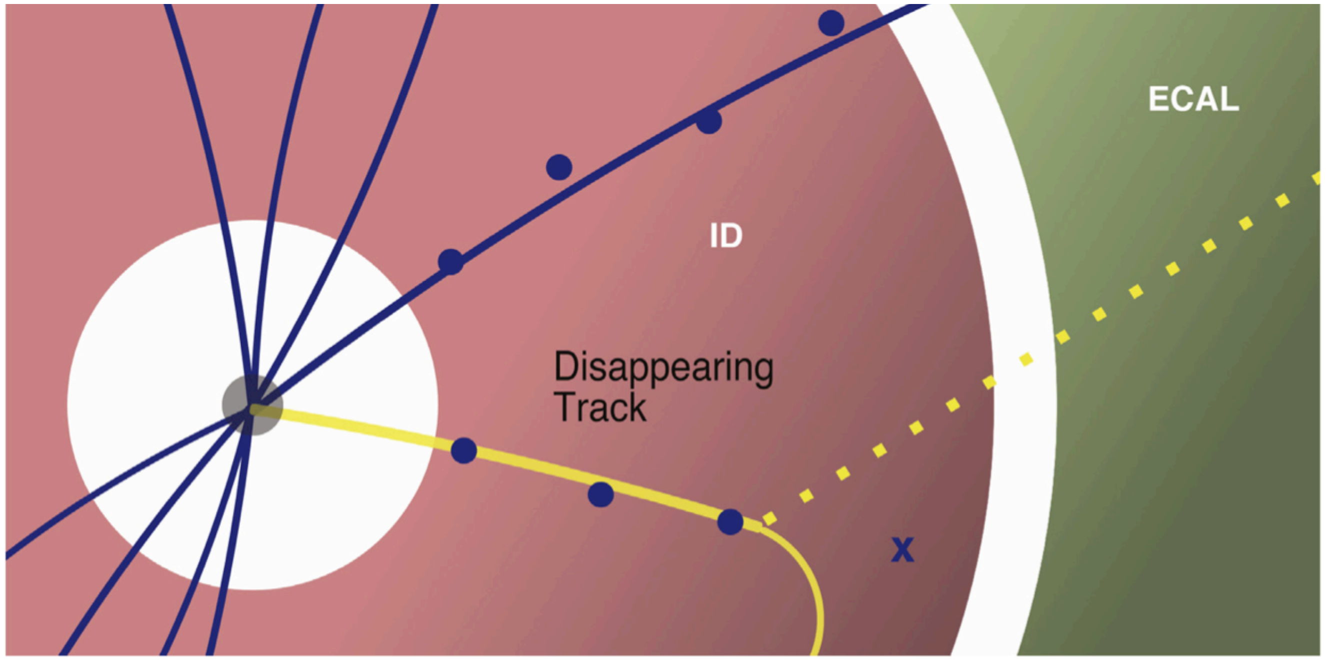
- (nearly) mass-degenerate
- small couplings
- highly virtual intermediate state

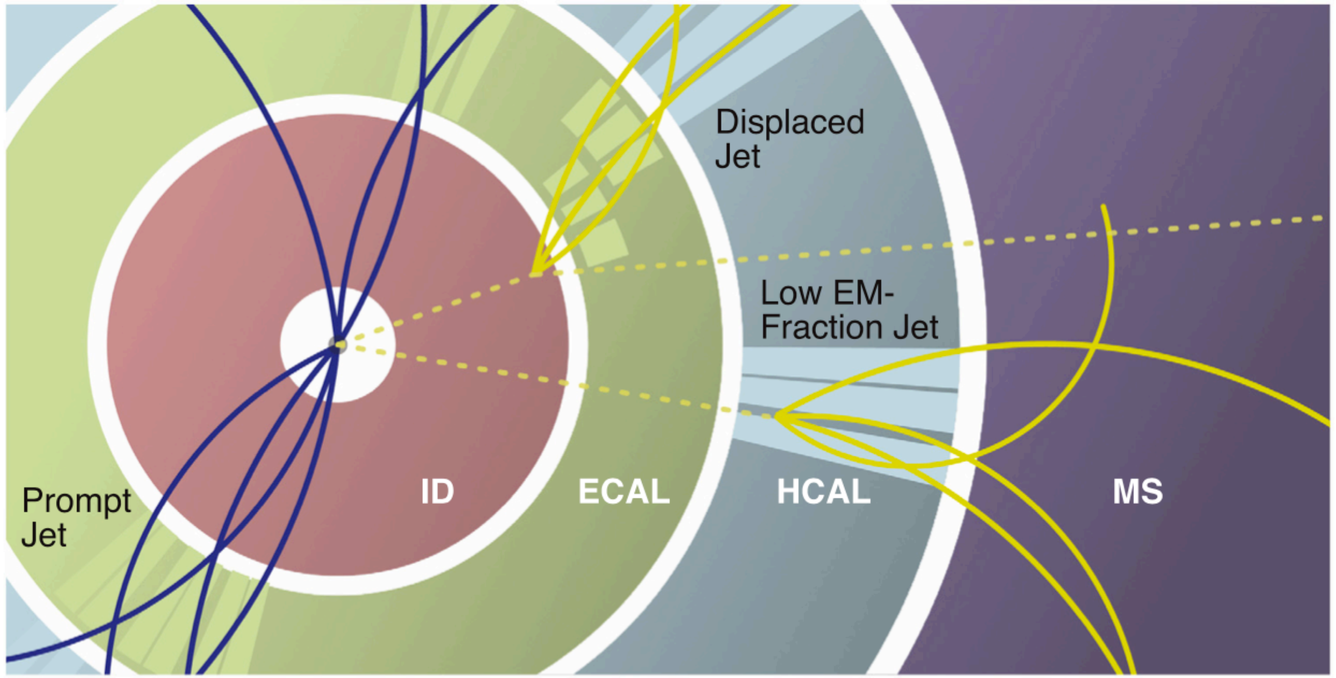


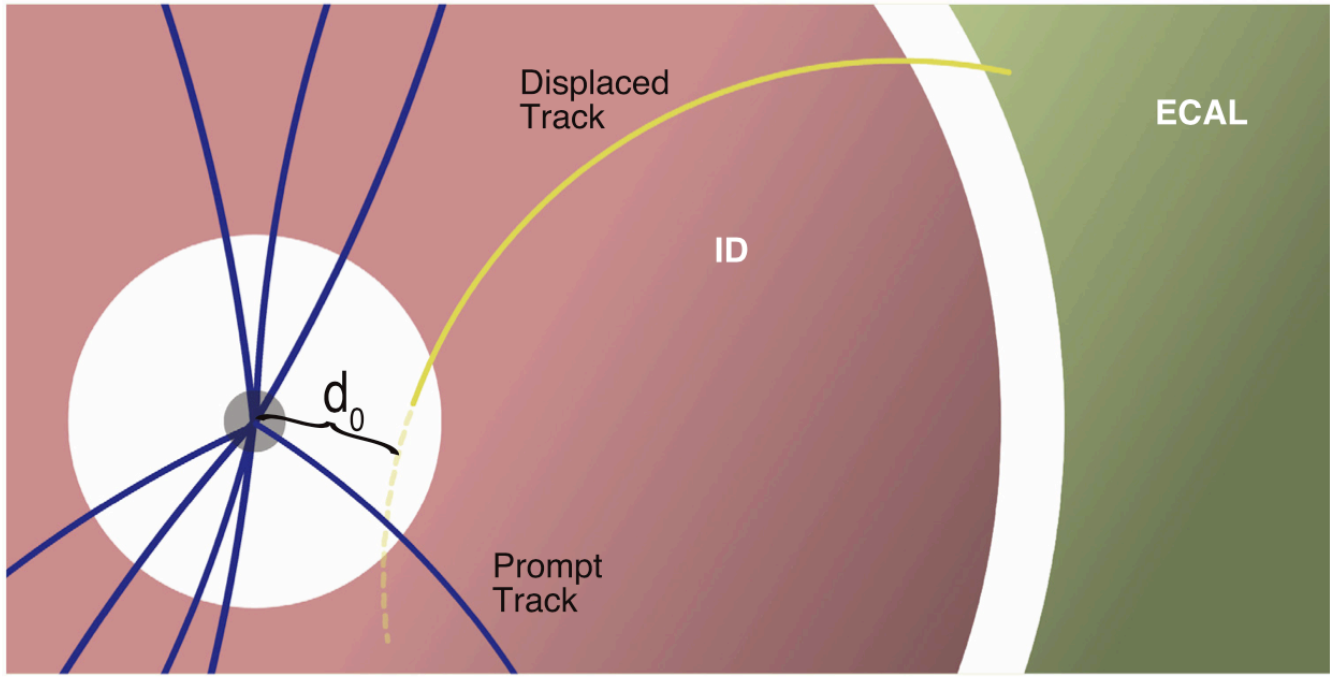
Detector signature

- Anomalous Ionization
- Delayed Detector Signals
- Disappearing Tracks
- Displaced Tracks
- Displaced Vertices
- …









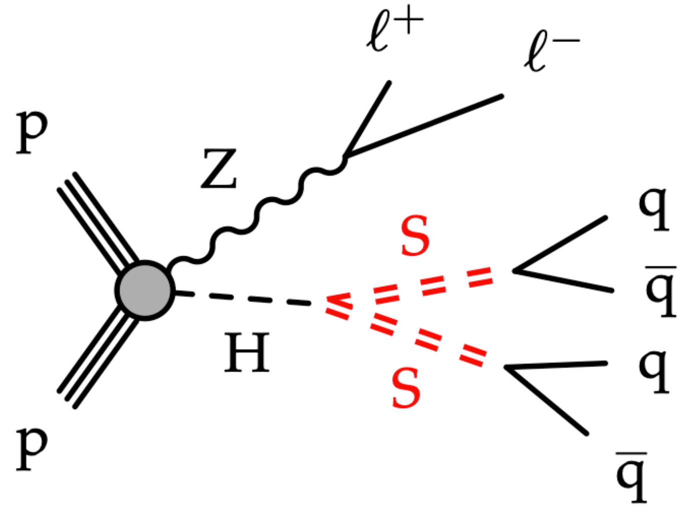
NEW!

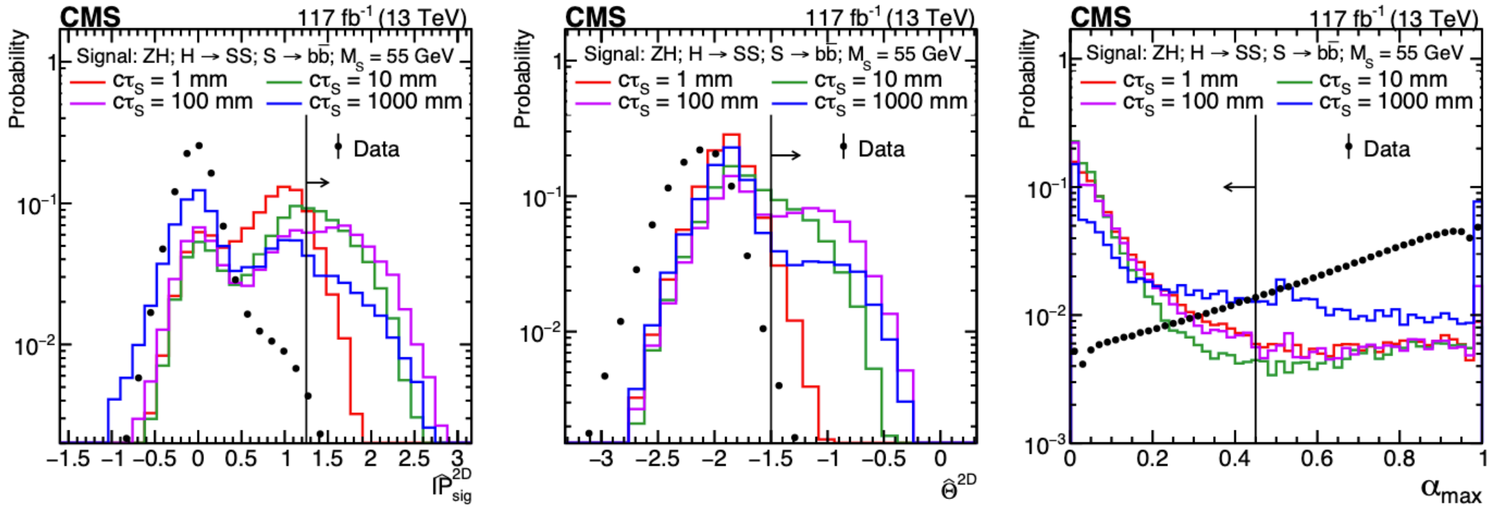
JHEP 03 (2022) 160

Displaced jets

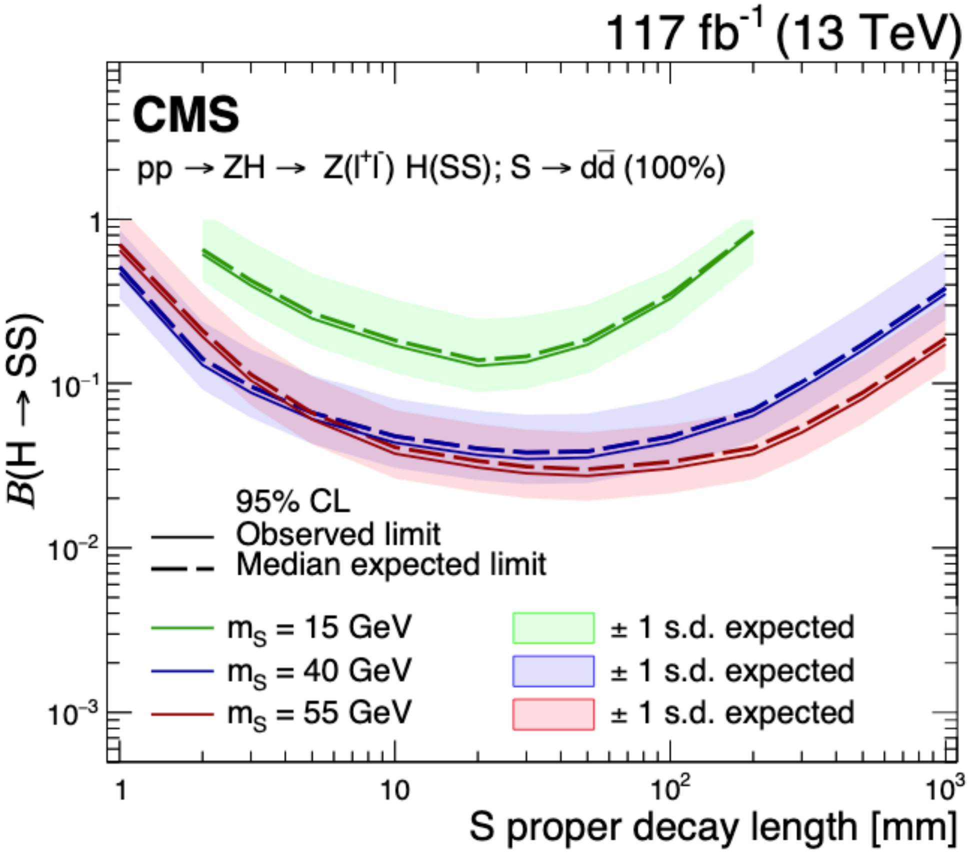
Search for LLPs produced in association with a Z boson

- The LLPs are assumed to decay to a pair of SM quarks that are identified as displaced jets.
- Triggers and selections based on Z boson decays to electron or muon pairs improve the sensitivity to light LLPs (down to 15 GeV)
- Displaced jet is defined as a jet that passes specified selections made on the three tagging variables:jet impact parameter significance, jet transverse angle, the ratio of the summed-p_T *track*





Three tagging variables: discriminating signal from background



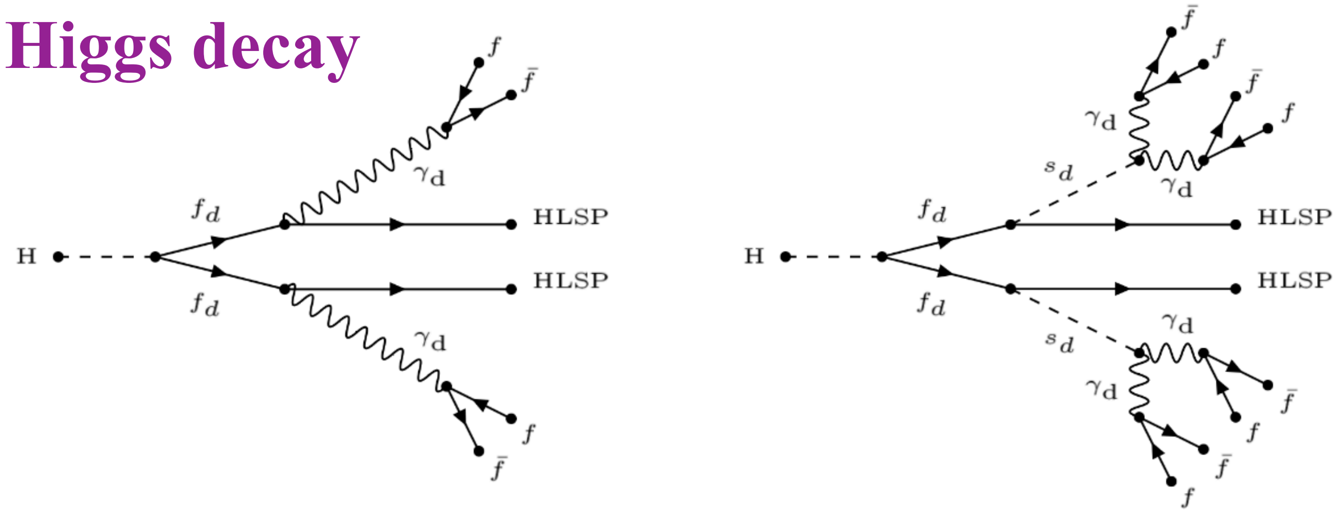
NEW!

arXiv:2206.12181

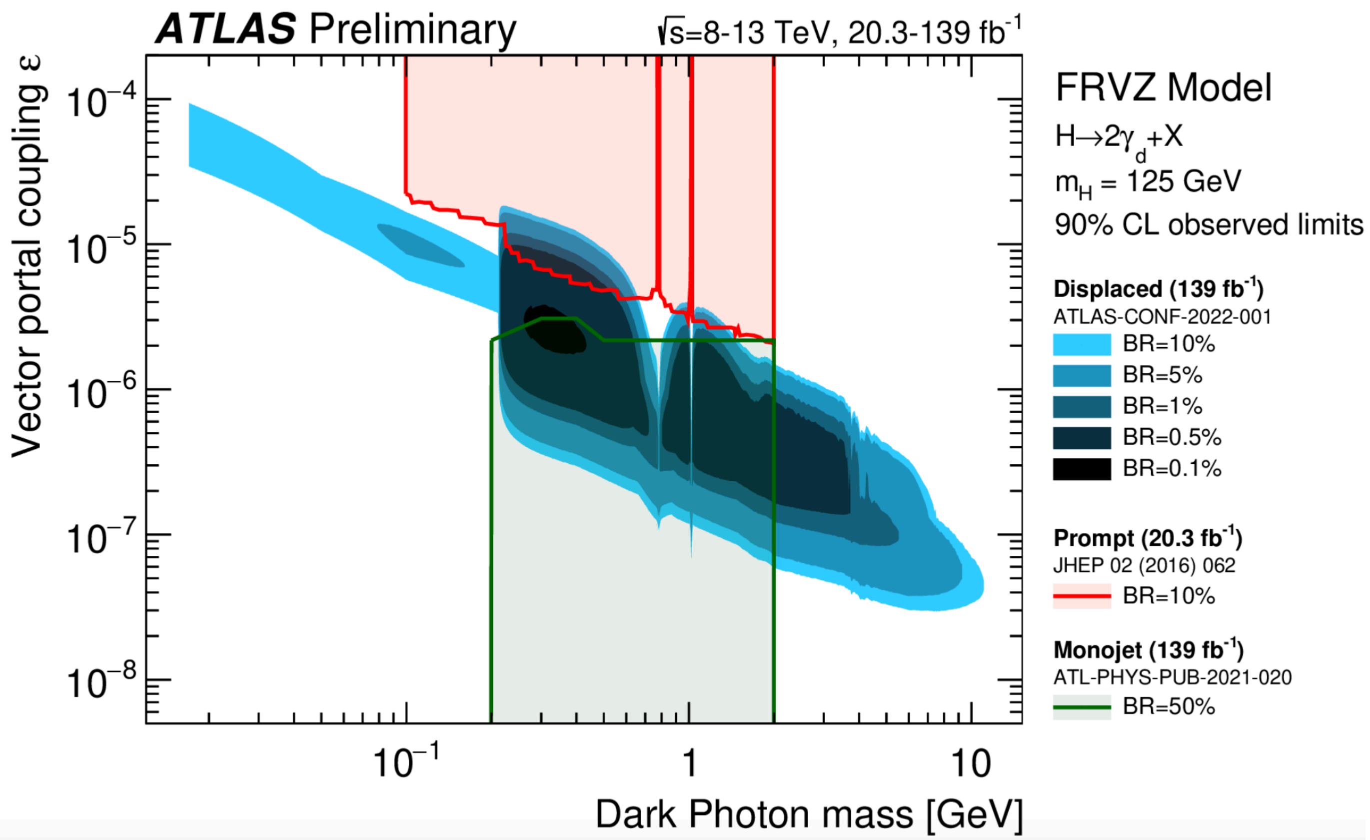
Displaced lepton and jets

Search for long-lived dark photons from Higgs decay

- Search for LLP decays into collimated pairs of leptons and light hadrons
- A γ_d decay into a displaced muon pair is expected to leave two or more collimated stand-alone MS tracks, expected to have very little nearby track activity in the ID
- A γ_d decaying into a displaced electron or quark pair leads to energy deposits in the calorimeters reconstructed as a single jet with low EM fraction (the ratio of the energy deposited in the EM calorimeter to the total jet energy)
- Significantly higher sensitivity than previous searches for light LL neutral particles to collimated pairs of fermions.

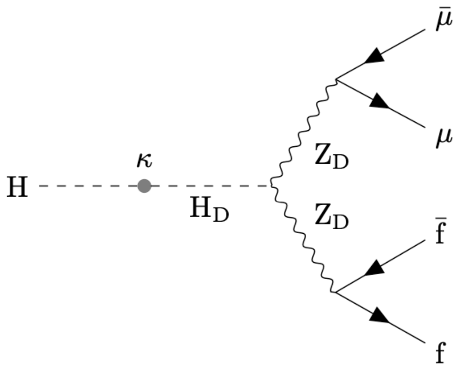


(a) FRVZ $2\gamma_d$ (b) FRVZ $4\gamma_d$



NEW!

arXiv:2205.08582

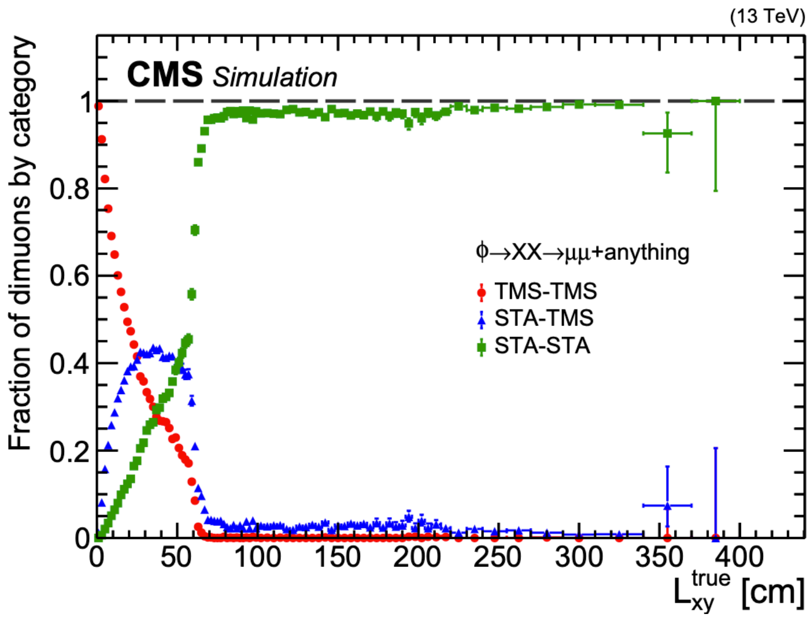


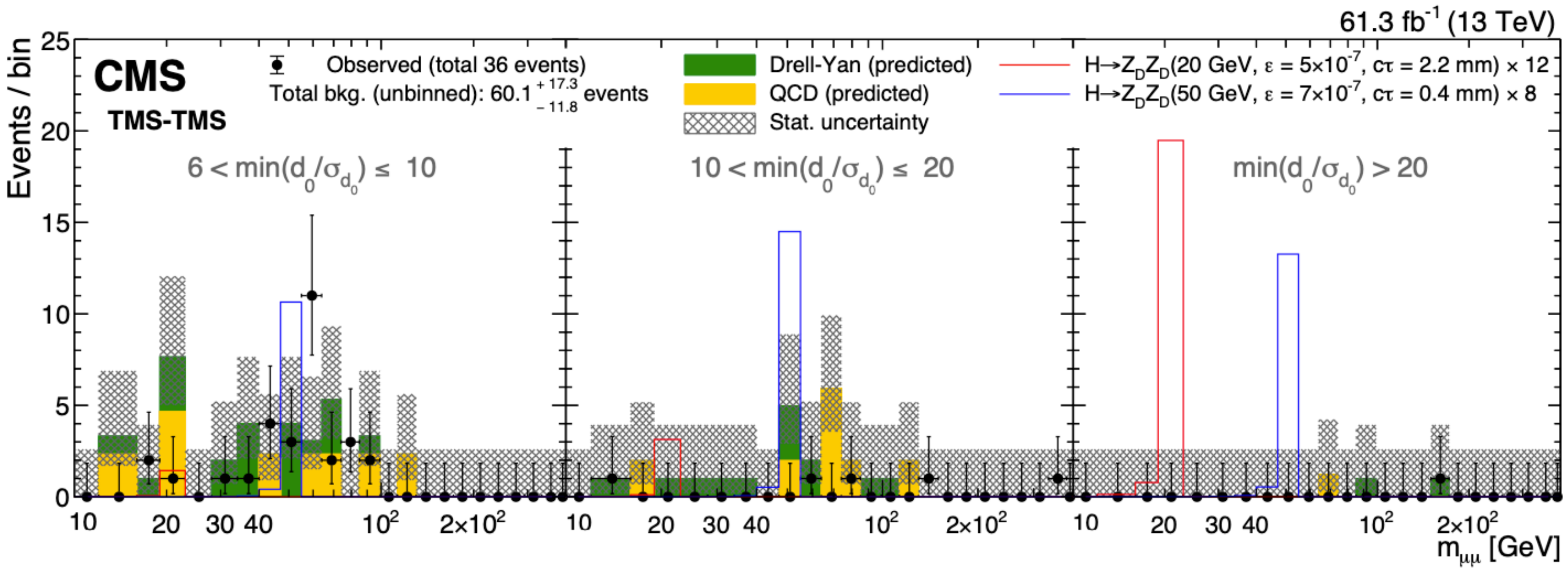
Displaced di-muon vertex

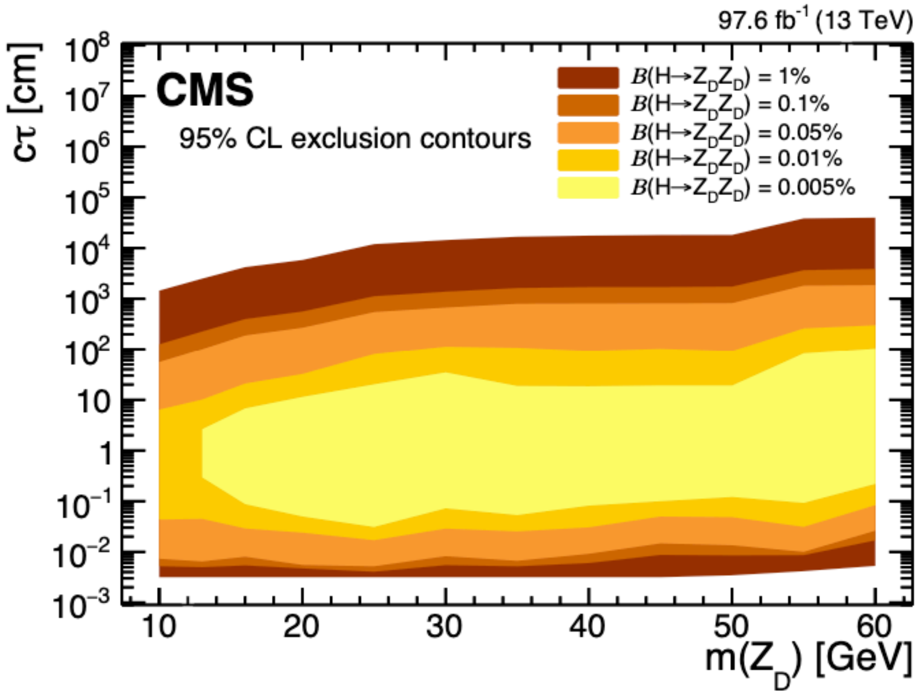
Search for LL exotic particles decaying to a pair of muons

- **Interpretation on the hidden Abelian Higgs model: Higgs decays to a pair of long-lived dark photons**
- **Signature is a pair of OS charged μs originating from a common secondary vertex spatially separated from the pp interaction point**
- **Uses μ from tracker+MS, MS-only, or mix**

Transverse decay length: distance between the PV and the common vertex in transverse plane



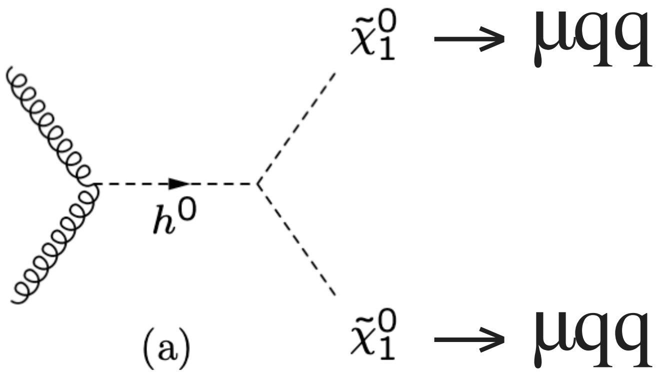




NEW!

arXiv:2110.07293

Displaced vertex

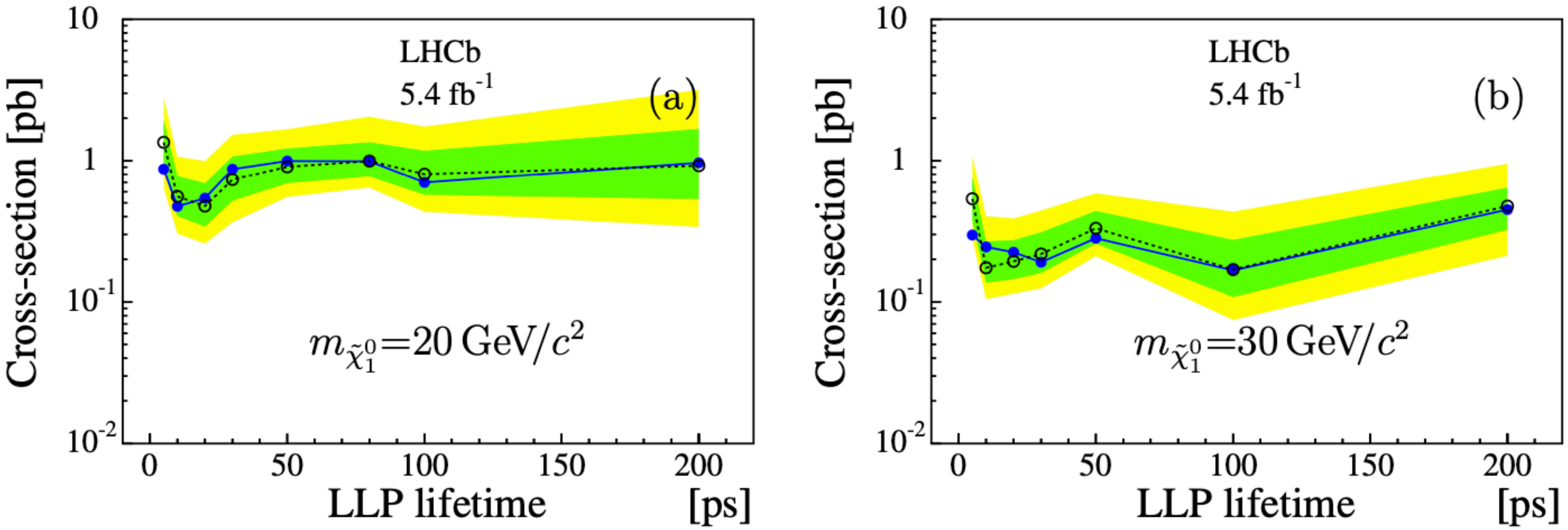


Search for massive LLP decaying semileptonically into a μ and two quarks.

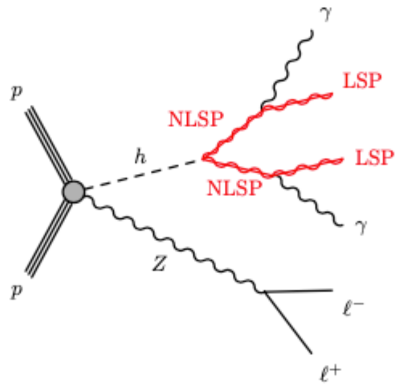
- Di-LLP production via a scalar particle h^0
- LLP(neutralino) → μqq
- A displaced vertex made of charged tracks accompanied by an isolated high pT μ

Benefits from LHCb:

- Excellent vertex reconstruction provided the LHCb vertex locator VELO
- Low trigger p_T threshold allows exploring relatively small LLP masses
- LHCb is probing a rapidity region only partially accessible by other LHC experiments



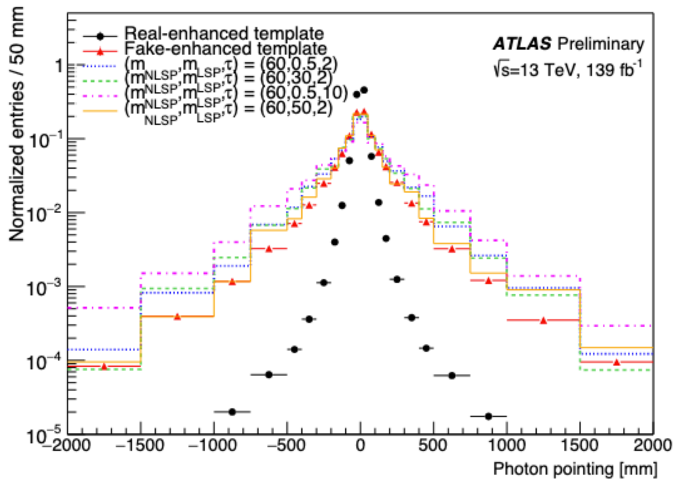
Non-pointing photons



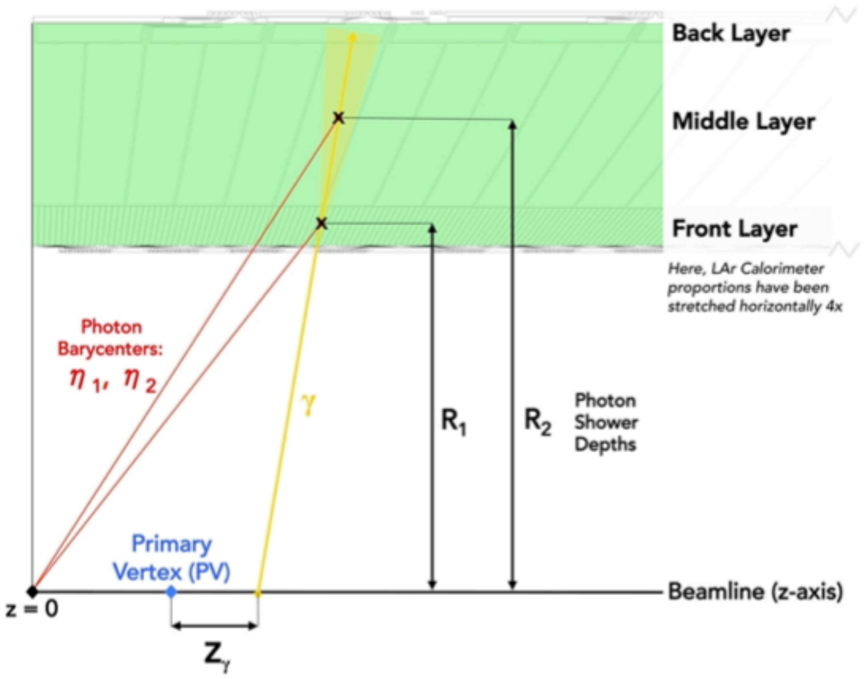
ATLAS-CONF-2022-017

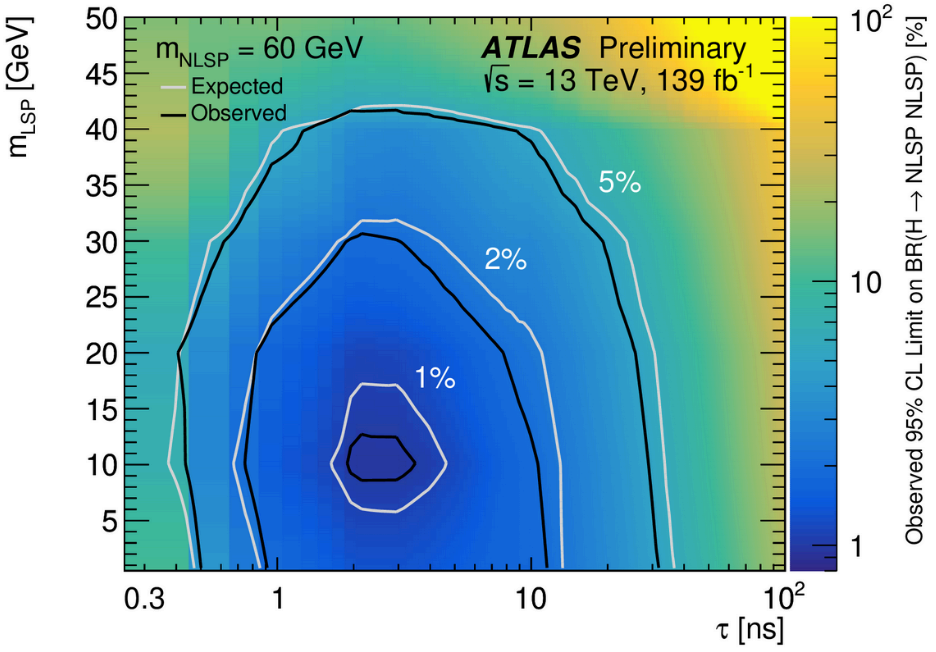
Search for delayed and non-pointing photons originating from displaced decay of a neutral LLP , which can escape the direct detection.

- **Delayed and non-pointing photon due to the opening angle between the γ and LSP.**
- **Take advantage of potential Higgs to BSM branching ratio (~13%).**



- **Schematic showing the calculation of the photon "pointing" value using LAr calorimeter layers' barycenter information → Key discriminants are pointing and timing measurements from the LAr calorimeter.**





Summary

- **A broad overview on the SUSY, Exotic, LLP searches in LHC is presented with full Run2 data analyzed.**

- **No discovery yet, the limits are probed in new/challenge scenarios, with various novel techniques developed.**

- **More challenge signatures to come, including combinations, pMSSM interpretations. Hopefully more new ideas will be inspired!** 💡🔑

- **For more, please visit: ATLAS Publication Web and CMS Publication Web**

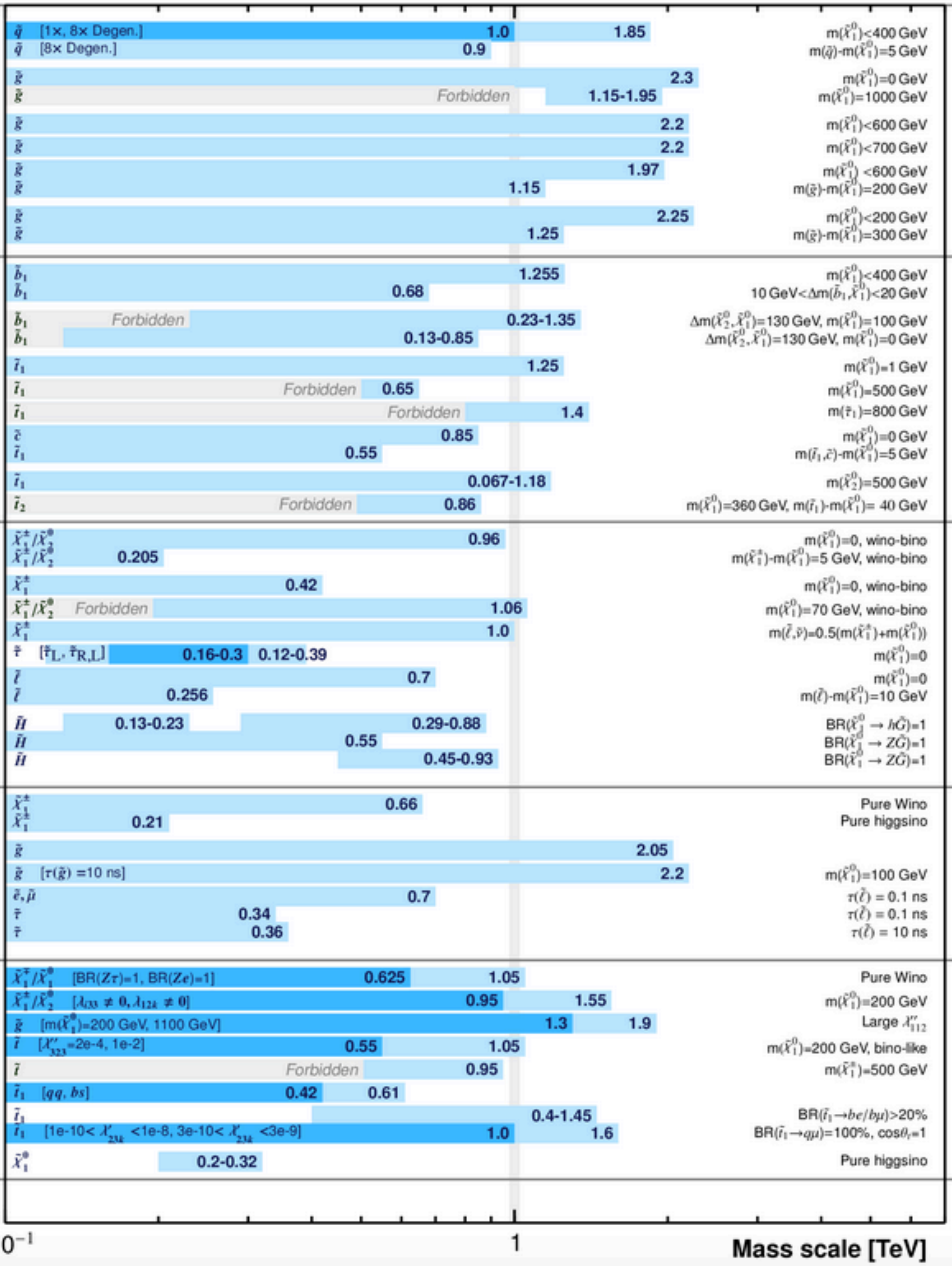
Extra slides

ATLAS SUSY Searches* - 95% CL Lower Limits

March 2022

ATLAS Preliminary

$\sqrt{s}$ = 13 TeV



	Model	Signature			$\int\mathcal{L}\,dt$ [fb^{-1}]	Mass limit		Reference
Inclusive Searches	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}^0_1$	0 e,μ	2-6 jets	E_T^{miss}	139	$\tilde{q}$ [1×, 8× Degen.] 1.0 1.85	m($\tilde{\chi}^0_1$)<400 GeV	2010.14293
		mono-jet	1-3 jets	E_T^{miss}	139	$\tilde{q}$ [8× Degen.] 0.9	m($\tilde{q}$)-m($\tilde{\chi}^0_1$)=5 GeV	2102.10874
	$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}\tilde{\chi}^0_1$	0 e,μ	2-6 jets	E_T^{miss}	139	$\tilde{g}$ 2.3	m($\tilde{\chi}^0_1$)=0 GeV	2010.14293
						$\tilde{g}$ Forbidden 1.15-1.95	m($\tilde{\chi}^0_1$)=1000 GeV	2010.14293
	$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}W\tilde{\chi}^0_1$	1 e,μ	2-6 jets		139	$\tilde{g}$ 2.2	m($\tilde{\chi}^0_1$)<600 GeV	2101.01629
	$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}(\ell\ell)\tilde{\chi}^0_1$	$ee,\mu\mu$	2 jets	E_T^{miss}	139	$\tilde{g}$ 2.2	m($\tilde{\chi}^0_1$)<700 GeV	CERN-EP-2022-014
	$\tilde{g}\tilde{g}, \tilde{g}\to qqWZ\tilde{\chi}^0_1$	0 e,μ	7-11 jets	E_T^{miss}	139	$\tilde{g}$ 1.97	m($\tilde{\chi}^0_1$) <600 GeV	2008.06032
		SS e,μ	6 jets		139	$\tilde{g}$ 1.15	m($\tilde{g}$)-m($\tilde{\chi}^0_1$)=200 GeV	1909.08457
	$\tilde{g}\tilde{g}, \tilde{g}\to t\bar{t}\tilde{\chi}^0_1$	0-1 e,μ	3 b	E_T^{miss}	79.8	$\tilde{g}$ 2.25	m($\tilde{\chi}^0_1$)<200 GeV	ATLAS-CONF-2018-041
		SS e,μ	6 jets		139	$\tilde{g}$ 1.25	m($\tilde{g}$)-m($\tilde{\chi}^0_1$)=300 GeV	1909.08457
3rd gen. squarks direct production	$\tilde{b}_1\tilde{b}_1$	0 e,μ	2 b	E_T^{miss}	139	$\tilde{b}_1$ 1.255	m($\tilde{\chi}^0_1$)<400 GeV	2101.12527
						$\tilde{b}_1$ 0.68	10 GeV<Δm($\tilde{b}_1$,$\tilde{\chi}^0_1$)<20 GeV	2101.12527
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to b\tilde{\chi}^0_2\to bh\tilde{\chi}^0_1$	0 e,μ	6 b	E_T^{miss}	139	$\tilde{b}_1$ Forbidden 0.23-1.35	Δm($\tilde{\chi}^0_2$,$\tilde{\chi}^0_1$)=130 GeV, m($\tilde{\chi}^0_1$)=100 GeV	1908.03122
		2 τ	2 b	E_T^{miss}	139	$\tilde{b}_1$ 0.13-0.85	Δm($\tilde{\chi}^0_2$,$\tilde{\chi}^0_1$)=130 GeV, m($\tilde{\chi}^0_1$)=0 GeV	2103.08189
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to t\tilde{\chi}^0_1$	0-1 e,μ	$\geq$ 1 jet	E_T^{miss}	139	$\tilde{t}_1$ 1.25	m($\tilde{\chi}^0_1$)=1 GeV	2004.14060,2012.03799
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to Wb\tilde{\chi}^0_1$	1 e,μ	3 jets/1 b	E_T^{miss}	139	$\tilde{t}_1$ Forbidden 0.65	m($\tilde{\chi}^0_1$)=500 GeV	2012.03799
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to\tilde{\tau}_1 b\nu, \tilde{\tau}_1\to\tau\tilde{G}$	1-2 τ	2 jets/1 b	E_T^{miss}	139	$\tilde{t}_1$ Forbidden 1.4	m($\tilde{\tau}_1$)=800 GeV	2108.07665
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to c\tilde{\chi}^0_1$ / $\tilde{c}\tilde{c}, \tilde{c}\to c\tilde{\chi}^0_1$	0 e,μ	2 c	E_T^{miss}	36.1	$\tilde{c}$ 0.85	m($\tilde{\chi}^0_1$)=0 GeV	1805.01649
		0 e,μ	mono-jet	E_T^{miss}	139	$\tilde{t}_1$ 0.55	m($\tilde{t}_1$,$\tilde{c}$)-m($\tilde{\chi}^0_1$)=5 GeV	2102.10874
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to t\tilde{\chi}^0_2, \tilde{\chi}^0_2\to Z/h\tilde{\chi}^0_1$	1-2 e,μ	1-4 b	E_T^{miss}	139	$\tilde{t}_1$ 0.067-1.18	m($\tilde{\chi}^0_2$)=500 GeV	2006.05880
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\to\tilde{t}_1+Z$	3 e,μ	1 b	E_T^{miss}	139	$\tilde{t}_2$ Forbidden 0.86	m($\tilde{\chi}^0_1$)=360 GeV, m($\tilde{t}_1$)-m($\tilde{\chi}^0_1$)= 40 GeV	2006.05880
EW direct	$\tilde{\chi}^\pm_1\tilde{\chi}^0_2$ via WZ	Multiple ℓ/jets		E_T^{miss}	139	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$ 0.96	m($\tilde{\chi}^0_1$)=0, wino-bino	2106.01676, 2108.07586
		$ee,\mu\mu$	$\geq$ 1 jet	E_T^{miss}	139	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$ 0.205	m($\tilde{\chi}^\pm_1$)-m($\tilde{\chi}^0_1$)=5 GeV, wino-bino	1911.12606
	$\tilde{\chi}^\pm_1\tilde{\chi}^\mp_1$ via WW	2 e,μ		E_T^{miss}	139	$\tilde{\chi}^\pm_1$ 0.42	m($\tilde{\chi}^0_1$)=0, wino-bino	1908.08215
	$\tilde{\chi}^\pm_1\tilde{\chi}^0_2$ via Wh	Multiple ℓ/jets		E_T^{miss}	139	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$ Forbidden 1.06	m($\tilde{\chi}^0_1$)=70 GeV, wino-bino	2004.10894, 2108.07586
	$\tilde{\chi}^\pm_1\tilde{\chi}^\mp_1$ via $\tilde{\ell}_L/\tilde{\nu}$	2 e,μ		E_T^{miss}	139	$\tilde{\chi}^\pm_1$ 1.0	m($\tilde{\ell}$,$\tilde{\nu}$)=0.5(m($\tilde{\chi}^\pm_1$)+m($\tilde{\chi}^0_1$))	1908.08215
	$\tilde{\tau}\tilde{\tau}, \tilde{\tau}\to\tau\tilde{\chi}^0_1$	2 τ		E_T^{miss}	139	$\tilde{\tau}$ [$\tilde{\tau}_L$, $\tilde{\tau}_{R,L}$] 0.16-0.3 0.12-0.39	m($\tilde{\chi}^0_1$)=0	1911.06660
	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell}\to\ell\tilde{\chi}^0_1$	2 e,μ	0 jets	E_T^{miss}	139	$\tilde{\ell}$ 0.7	m($\tilde{\chi}^0_1$)=0	1908.08215
		$ee,\mu\mu$	$\geq$ 1 jet	E_T^{miss}	139	$\tilde{\ell}$ 0.256	m($\tilde{\ell}$)-m($\tilde{\chi}^0_1$)=10 GeV	1911.12606
	$\tilde{H}\tilde{H}, \tilde{H}\to h\tilde{G}/Z\tilde{G}$	0 e,μ	$\geq$ 3 b	E_T^{miss}	36.1	$\tilde{H}$ 0.13-0.23 0.29-0.88	BR($\tilde{\chi}^0_1\to h\tilde{G}$)=1	1806.04030
		4 e,μ	0 jets	E_T^{miss}	139	$\tilde{H}$ 0.55	BR($\tilde{\chi}^0_1\to Z\tilde{G}$)=1	2103.11684
		0 e,μ	$\geq$ 2 large jets	E_T^{miss}	139	$\tilde{H}$ 0.45-0.93	BR($\tilde{\chi}^0_1\to Z\tilde{G}$)=1	2108.07586
Long-lived particles	Direct $\tilde{\chi}^+_1\tilde{\chi}^-_1$ prod., long-lived $\tilde{\chi}^\pm_1$	Disapp. trk	1 jet	E_T^{miss}	139	$\tilde{\chi}^\pm_1$ 0.66	Pure Wino	2201.02472
						$\tilde{\chi}^\pm_1$ 0.21	Pure higgsino	2201.02472
	Stable $\tilde{g}$ R-hadron	pixel dE/dx		E_T^{miss}	139	$\tilde{g}$ 2.05		CERN-EP-2022-029
	Metastable $\tilde{g}$ R-hadron, $\tilde{g}\to qq\tilde{\chi}^0_1$	pixel dE/dx		E_T^{miss}	139	$\tilde{g}$ [$\tau(\tilde{g})$ =10 ns] 2.2	m($\tilde{\chi}^0_1$)=100 GeV	CERN-EP-2022-029
	$\tilde{\ell}\tilde{\ell}, \tilde{\ell}\to\ell\tilde{G}$	Displ. lep		E_T^{miss}	139	$\tilde{e},\tilde{\mu}$ 0.7	$\tau(\tilde{\ell})$ = 0.1 ns	2011.07812
						$\tilde{\tau}$ 0.34	$\tau(\tilde{\ell})$ = 0.1 ns	2011.07812
		pixel dE/dx		E_T^{miss}	139	$\tilde{\tau}$ 0.36	$\tau(\tilde{\ell})$ = 10 ns	CERN-EP-2022-029
RPV	$\tilde{\chi}^\pm_1\tilde{\chi}^\mp_1/\tilde{\chi}^0_1, \tilde{\chi}^\pm_1\to Z\ell\to\ell\ell\ell$	3 e,μ			139	$\tilde{\chi}^\mp_1/\tilde{\chi}^0_1$ [BR($Z\tau$)=1, BR(Ze)=1] 0.625 1.05	Pure Wino	2011.10543
	$\tilde{\chi}^\pm_1\tilde{\chi}^\mp_1/\tilde{\chi}^0_2\to WW/Z\ell\ell\ell\ell\nu\nu$	4 e,μ	0 jets	E_T^{miss}	139	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$ [$\lambda_{i33}\neq 0, \lambda_{12k}\neq 0$] 0.95 1.55	m($\tilde{\chi}^0_1$)=200 GeV	2103.11684
	$\tilde{g}\tilde{g}, \tilde{g}\to qq\tilde{\chi}^0_1, \tilde{\chi}^0_1\to qqq$		4-5 large jets		36.1	$\tilde{g}$ [m($\tilde{\chi}^0_1$)=200 GeV, 1100 GeV] 1.3 1.9	Large λ''_{112}	1804.03568
	$\tilde{t}\tilde{t}, \tilde{t}\to t\tilde{\chi}^0_1, \tilde{\chi}^0_1\to tbs$		Multiple		36.1	$\tilde{t}$ [λ''_{323}=2e-4, 1e-2] 0.55 1.05	m($\tilde{\chi}^0_1$)=200 GeV, bino-like	ATLAS-CONF-2018-003
	$\tilde{t}\tilde{t}, \tilde{t}\to b\tilde{\chi}^\pm_1, \tilde{\chi}^\pm_1\to bbs$		$\geq 4b$		139	$\tilde{t}$ Forbidden 0.95	m($\tilde{\chi}^\pm_1$)=500 GeV	2010.01015
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to bs$		2 jets + 2 b		36.7	$\tilde{t}_1$ [qq, bs] 0.42 0.61		1710.07171
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to q\ell$	2 e,μ	2 b		36.1	$\tilde{t}_1$ 0.4-1.45	BR($\tilde{t}_1\to be/b\mu$)>20%	1710.05544
		1 μ	DV		136	$\tilde{t}_1$ [1e-10< λ'_{23k} <1e-8, 3e-10< λ'_{23k} <3e-9] 1.0 1.6	BR($\tilde{t}_1\to q\mu$)=100%, cosθ_t=1	2003.11956
	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2/\tilde{\chi}^0_1, \tilde{\chi}^0_{1,2}\to tbs, \tilde{\chi}^+_1\to bbs$	1-2 e,μ	$\geq$6 jets		139	$\tilde{\chi}^0_1$ 0.2-0.32	Pure higgsino	2106.09609

*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.

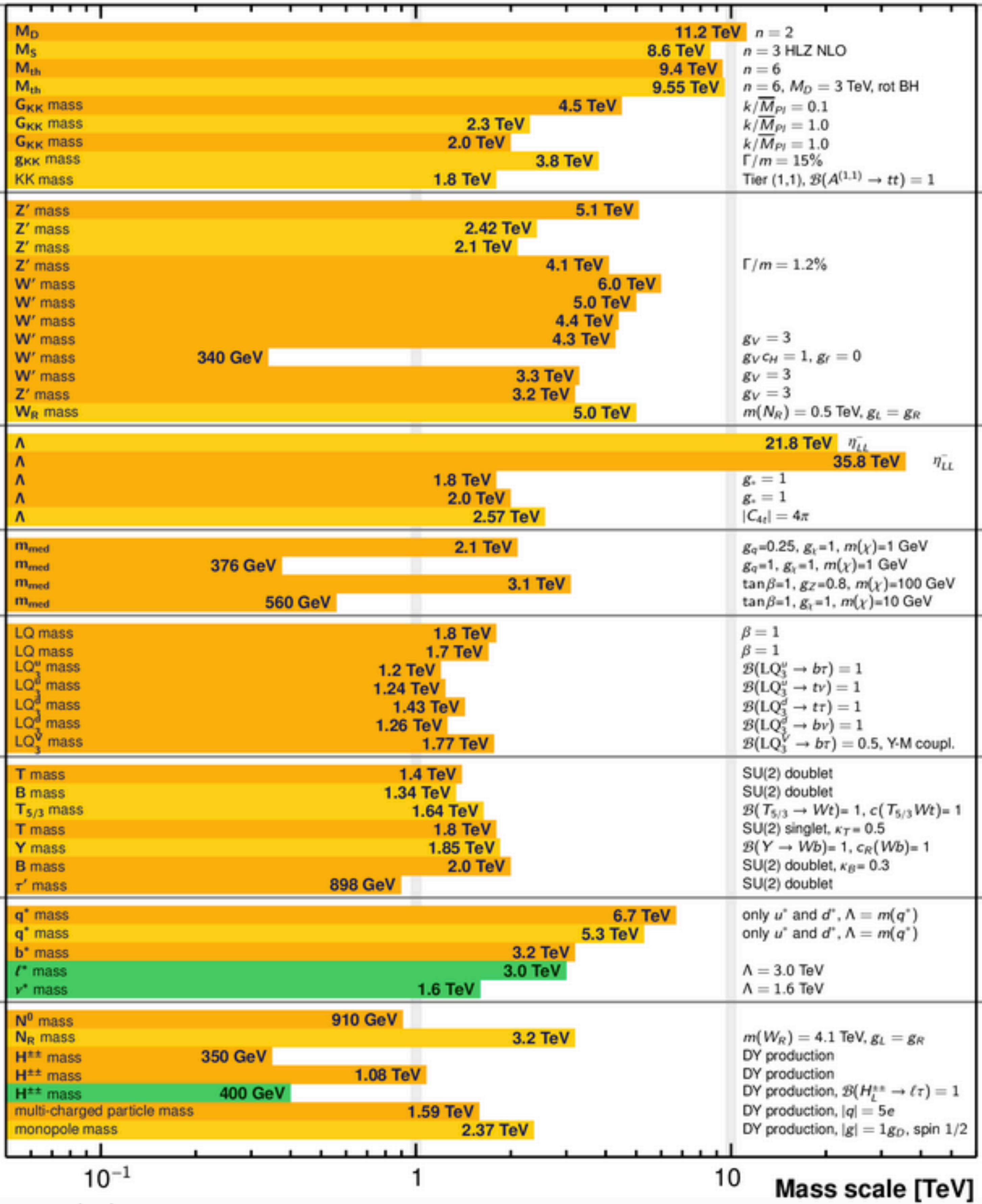
ATLAS Heavy Particle Searches* - 95% CL Upper Exclusion Limits

Status: July 2022

ATLAS Preliminary

$\int \mathcal{L}\, dt = (3.6 - 139)\ \mathrm{fb}^{-1}$

$\sqrt{s} = 8, 13$ TeV



	Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L}\, dt[\mathrm{fb}^{-1}]$	Limit			Reference
Extra dimensions	ADD $G_{KK} + g/q$	$0\ e, \mu, \tau, \gamma$	$1-4$ j	Yes	139	M_D	11.2 TeV	$n = 2$	2102.10874
	ADD non-resonant $\gamma\gamma$	$2\ \gamma$	–	–	36.7	M_S	8.6 TeV	$n = 3$ HLZ NLO	1707.04147
	ADD QBH	–	2 j	–	139	M_{th}	9.4 TeV	$n = 6$	1910.08447
	ADD BH multijet	–	≥3 j	–	3.6	M_{th}	9.55 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1512.02586
	RS1 $G_{KK} \to \gamma\gamma$	$2\ \gamma$	–	–	139	G_{KK} mass	4.5 TeV	$k/\overline{M}_{Pl} = 0.1$	2102.13405
	Bulk RS $G_{KK} \to WW/ZZ$	multi-channel			36.1	G_{KK} mass	2.3 TeV	$k/\overline{M}_{Pl} = 1.0$	1808.02380
	Bulk RS $G_{KK} \to WV \to \ell\nu qq$	$1\ e, \mu$	2 j / 1 J	Yes	139	G_{KK} mass	2.0 TeV	$k/\overline{M}_{Pl} = 1.0$	2004.14636
	Bulk RS $g_{KK} \to tt$	$1\ e, \mu$	≥1 b, ≥1J/2j	Yes	36.1	g_{KK} mass	3.8 TeV	$\Gamma/m = 15\%$	1804.10823
	2UED / RPP	$1\ e, \mu$	≥2 b, ≥3 j	Yes	36.1	KK mass	1.8 TeV	Tier (1,1), $\mathcal{B}(A^{(1,1)} \to tt) = 1$	1803.09678
Gauge bosons	SSM $Z' \to \ell\ell$	$2\ e, \mu$	–	–	139	Z' mass	5.1 TeV		1903.06248
	SSM $Z' \to \tau\tau$	$2\ \tau$	–	–	36.1	Z' mass	2.42 TeV		1709.07242
	Leptophobic $Z' \to bb$	–	2 b	–	36.1	Z' mass	2.1 TeV		1805.09299
	Leptophobic $Z' \to tt$	$0\ e, \mu$	≥1 b, ≥2 J	Yes	139	Z' mass	4.1 TeV	$\Gamma/m = 1.2\%$	2005.05138
	SSM $W' \to \ell\nu$	$1\ e, \mu$	–	Yes	139	W' mass	6.0 TeV		1906.05609
	SSM $W' \to \tau\nu$	$1\ \tau$	–	Yes	139	W' mass	5.0 TeV		ATLAS-CONF-2021-025
	SSM $W' \to tb$	–	≥1 b, ≥1 J	–	139	W' mass	4.4 TeV		ATLAS-CONF-2021-043
	HVT $W' \to WZ \to \ell\nu qq$ model B	$1\ e, \mu$	2 j / 1 J	Yes	139	W' mass	4.3 TeV	$g_V = 3$	2004.14636
	HVT $W' \to WZ \to \ell\nu\, \ell'\ell'$ model C	$3\ e, \mu$	2 j (VBF)	Yes	139	W' mass	340 GeV	$g_V c_H = 1$, $g_f = 0$	ATLAS-CONF-2022-005
	HVT $W' \to WH \to \ell\nu bb$ model B	$1\ e, \mu$	1-2 b, 1-0 j	Yes	139	W' mass	3.3 TeV	$g_V = 3$	2207.00230
	HVT $Z' \to ZH \to \ell\ell/\nu\nu bb$ model B	$0,2\ e, \mu$	1-2 b, 1-0 j	Yes	139	Z' mass	3.2 TeV	$g_V = 3$	2207.00230
	LRSM $W_R \to \mu N_R$	$2\ \mu$	1 J	–	80	W_R mass	5.0 TeV	$m(N_R) = 0.5$ TeV, $g_L = g_R$	1904.12679
CI	CI $qqqq$	–	2 j	–	37.0	Λ	21.8 TeV	η_{LL}^-	1703.09127
	CI $\ell\ell qq$	$2\ e, \mu$	–	–	139	Λ	35.8 TeV	η_{LL}^-	2006.12946
	CI $eebs$	$2\ e$	1 b	–	139	Λ	1.8 TeV	$g_* = 1$	2105.13847
	CI $\mu\mu bs$	$2\ \mu$	1 b	–	139	Λ	2.0 TeV	$g_* = 1$	2105.13847
	CI $tttt$	≥1 e,μ	≥1 b, ≥1 j	Yes	36.1	Λ	2.57 TeV	$\lvert C_{4t}\rvert = 4\pi$	1811.02305
DM	Axial-vector med. (Dirac DM)	$0\ e, \mu, \tau, \gamma$	$1-4$ j	Yes	139	m_{med}	2.1 TeV	g_q=0.25, g_χ=1, $m(\chi)$=1 GeV	2102.10874
	Pseudo-scalar med. (Dirac DM)	$0\ e, \mu, \tau, \gamma$	$1-4$ j	Yes	139	m_{med}	376 GeV	g_q=1, g_χ=1, $m(\chi)$=1 GeV	2102.10874
	Vector med. Z'-2HDM (Dirac DM)	$0\ e, \mu$	2 b	Yes	139	m_{med}	3.1 TeV	tanβ=1, g_Z=0.8, $m(\chi)$=100 GeV	2108.13391
	Pseudo-scalar med. 2HDM+a	multi-channel			139	m_{med}	560 GeV	tanβ=1, g_χ=1, $m(\chi)$=10 GeV	ATLAS-CONF-2021-036
LQ	Scalar LQ 1st gen	$2\ e$	≥2 j	Yes	139	LQ mass	1.8 TeV	$\beta = 1$	2006.05872
	Scalar LQ 2nd gen	$2\ \mu$	≥2 j	Yes	139	LQ mass	1.7 TeV	$\beta = 1$	2006.05872
	Scalar LQ 3rd gen	$1\ \tau$	2 b	Yes	139	LQ_3^u mass	1.2 TeV	$\mathcal{B}(LQ_3^u \to b\tau) = 1$	2108.07665
	Scalar LQ 3rd gen	$0\ e, \mu$	≥2 j, ≥2 b	Yes	139	LQ_3^u mass	1.24 TeV	$\mathcal{B}(LQ_3^u \to t\nu) = 1$	2004.14060
	Scalar LQ 3rd gen	≥2 e, μ, ≥1 τ	≥1 j, ≥1 b	–	139	LQ_3^d mass	1.43 TeV	$\mathcal{B}(LQ_3^d \to t\tau) = 1$	2101.11582
	Scalar LQ 3rd gen	$0\ e, \mu$, ≥1 τ	$0-2$ j, 2 b	Yes	139	LQ_3^d mass	1.26 TeV	$\mathcal{B}(LQ_3^d \to b\nu) = 1$	2101.12527
	Vector LQ 3rd gen	$1\ \tau$	2 b	Yes	139	LQ_3^V mass	1.77 TeV	$\mathcal{B}(LQ_3^V \to b\tau) = 0.5$, Y-M coupl.	2108.07665
Vector-like fermions	VLQ $TT \to Zt + X$	$2e/2\mu/{\geq}3e,\mu$	≥1 b, ≥1 j	–	139	T mass	1.4 TeV	SU(2) doublet	ATLAS-CONF-2021-024
	VLQ $BB \to Wt/Zb + X$	multi-channel			36.1	B mass	1.34 TeV	SU(2) doublet	1808.02343
	VLQ $T_{5/3}T_{5/3}\lvert T_{5/3} \to Wt + X$	2(SS)/≥3 e,μ	≥1 b, ≥1 j	Yes	36.1	$T_{5/3}$ mass	1.64 TeV	$\mathcal{B}(T_{5/3} \to Wt)$= 1, $c(T_{5/3}Wt)$= 1	1807.11883
	VLQ $T \to Ht/Zt$	$1\ e, \mu$	≥1 b, ≥3 j	Yes	139	T mass	1.8 TeV	SU(2) singlet, κ_T= 0.5	ATLAS-CONF-2021-040
	VLQ $Y \to Wb$	$1\ e, \mu$	≥1 b, ≥1 j	Yes	36.1	Y mass	1.85 TeV	$\mathcal{B}(Y \to Wb)$= 1, $c_R(Wb)$= 1	1812.07343
	VLQ $B \to Hb$	$0\ e,\mu$	≥2b, ≥1j, ≥1J	–	139	B mass	2.0 TeV	SU(2) doublet, κ_B= 0.3	ATLAS-CONF-2021-018
	VLL $\tau' \to Z\tau/H\tau$	multi-channel	≥1 j	Yes	139	τ' mass	898 GeV	SU(2) doublet	ATLAS-CONF-2022-044
Excited fermions	Excited quark $q^* \to qg$	–	2 j	–	139	q^* mass	6.7 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1910.08447
	Excited quark $q^* \to q\gamma$	$1\ \gamma$	1 j	–	36.7	q^* mass	5.3 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1709.10440
	Excited quark $b^* \to bg$	–	1 b, 1 j	–	139	b^* mass	3.2 TeV		1910.0447
	Excited lepton ℓ^*	$3\ e, \mu$	–	–	20.3	ℓ^* mass	3.0 TeV	$\Lambda = 3.0$ TeV	1411.2921
	Excited lepton ν^*	$3\ e, \mu, \tau$	–	–	20.3	ν^* mass	1.6 TeV	$\Lambda = 1.6$ TeV	1411.2921
Other	Type III Seesaw	$2,3,4\ e, \mu$	≥2 j	Yes	139	N^0 mass	910 GeV		2202.02039
	LRSM Majorana ν	$2\ \mu$	2 j	–	36.1	N_R mass	3.2 TeV	$m(W_R) = 4.1$ TeV, $g_L = g_R$	1809.11105
	Higgs triplet $H^{\pm\pm} \to W^{\pm}W^{\pm}$	$2,3,4\ e, \mu$ (SS)	various	Yes	139	$H^{\pm\pm}$ mass	350 GeV	DY production	2101.11961
	Higgs triplet $H^{\pm\pm} \to \ell\ell$	$2,3,4\ e, \mu$ (SS)	–	–	139	$H^{\pm\pm}$ mass	1.08 TeV	DY production	ATLAS-CONF-2022-010
	Higgs triplet $H^{\pm\pm} \to \ell\tau$	$3\ e, \mu, \tau$	–	–	20.3	$H^{\pm\pm}$ mass	400 GeV	DY production, $\mathcal{B}(H_L^{\pm\pm} \to \ell\tau) = 1$	1411.2921
	Multi-charged particles	–	–	–	139	multi-charged particle mass	1.59 TeV	DY production, $\lvert q\rvert = 5e$	ATLAS-CONF-2022-034
	Magnetic monopoles	–	–	–	34.4	monopole mass	2.37 TeV	DY production, $\lvert g\rvert = 1g_D$, spin 1/2	1905.10130

🟩 $\sqrt{s} = 8$ TeV

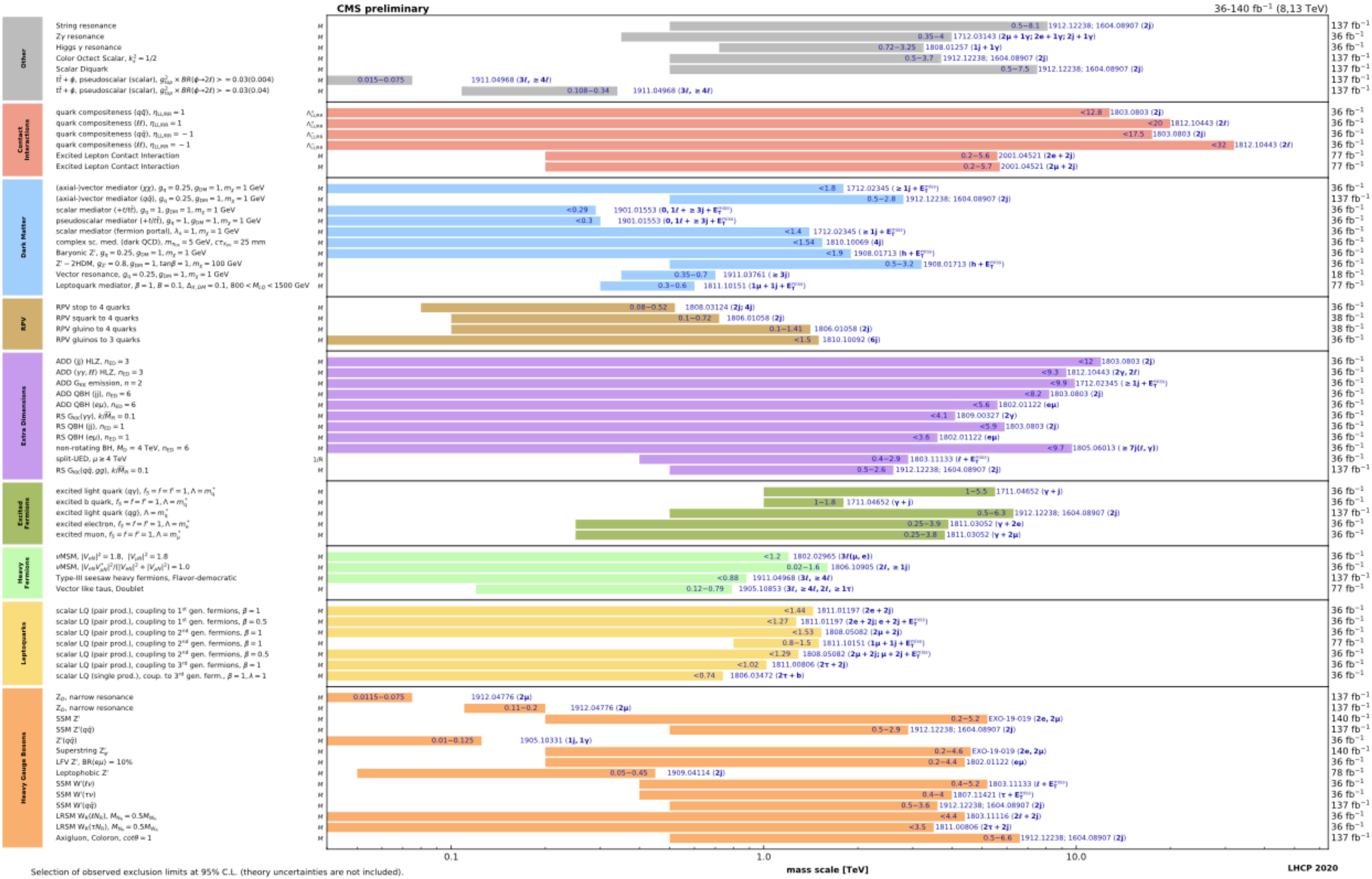
🟨 $\sqrt{s} = 13$ TeV partial data

🟧 $\sqrt{s} = 13$ TeV full data

*Only a selection of the available mass limits on new states or phenomena is shown.

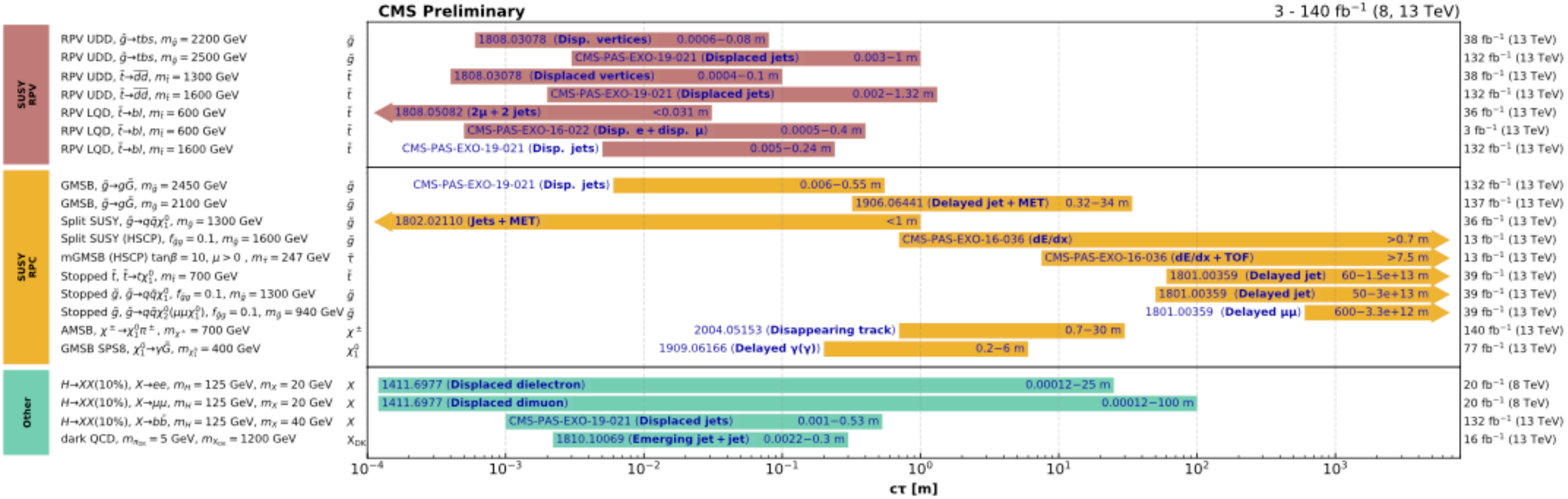
†Small-radius (large-radius) jets are denoted by the letter j (J).

Overview of CMS EXO results



Selection of observed exclusion limits at 95% C.L. (theory uncertainties are not included).

Overview of CMS long-lived particle searches



LHCP 2020

Selection of observed exclusion limits at 95% C.L. (theory uncertainties are not included). The y-axis tick labels indicate the studied long-lived particle.