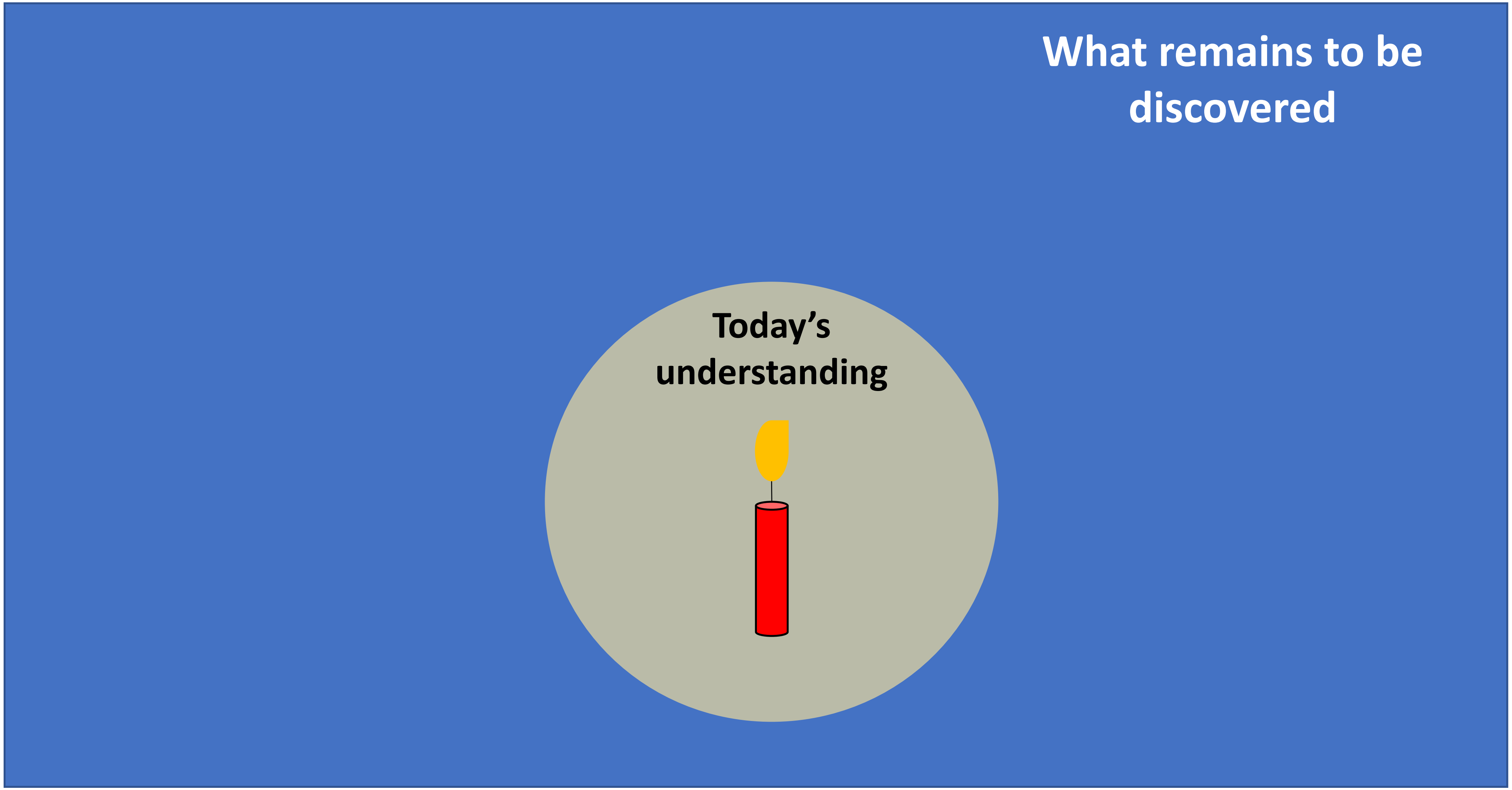
Searches at colliders (excluding DM & LLPs)

C. Collard (IPHC Strasbourg)

Séminaire thématique GT01 "Physique des particules"
de l'exercice des prospectives nationales 2020-2030,
12-13 mars 2020
(en vidéo-conférence)

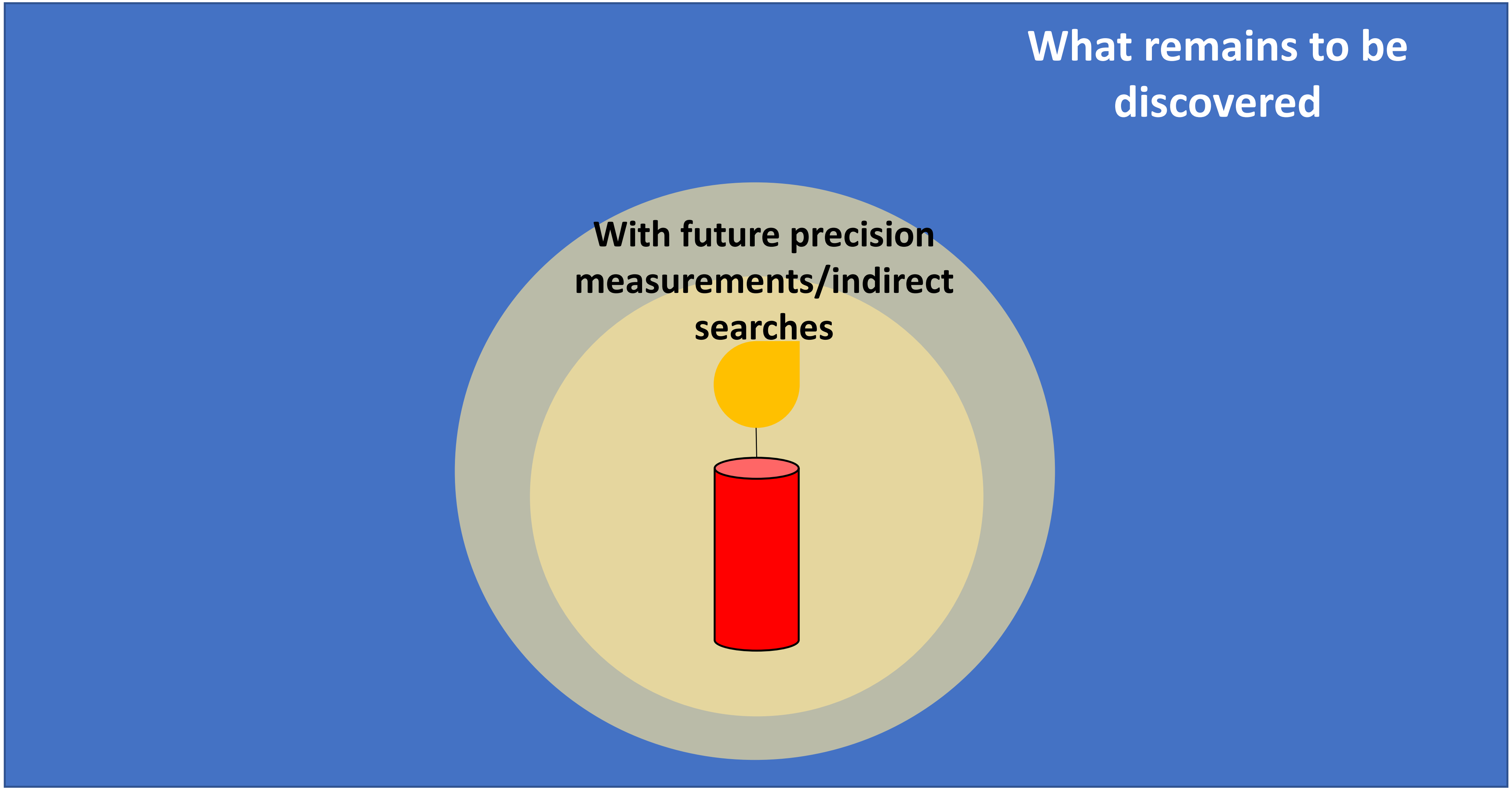
Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

dépasser les frontières



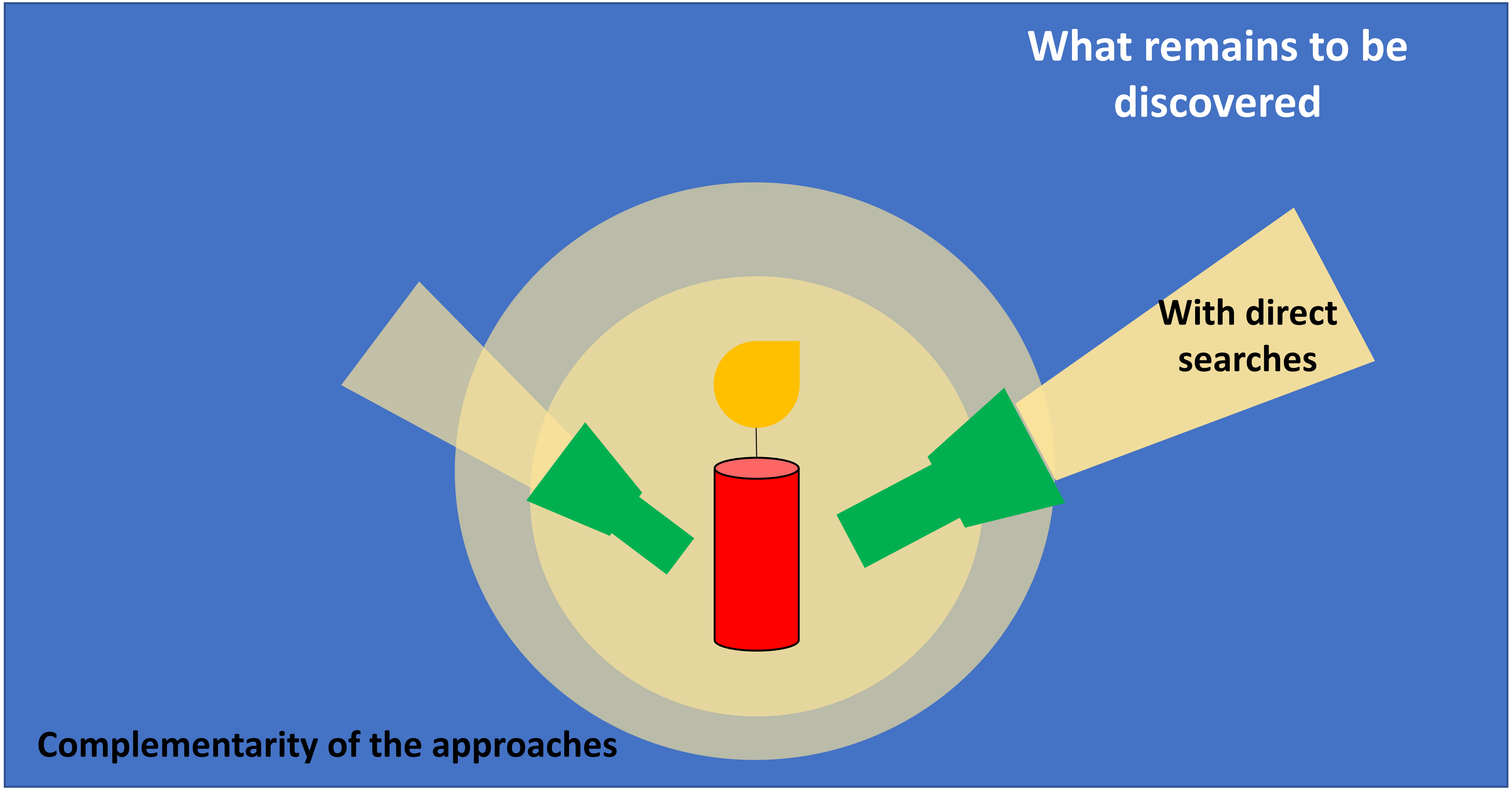
What remains to be discovered

Today's understanding



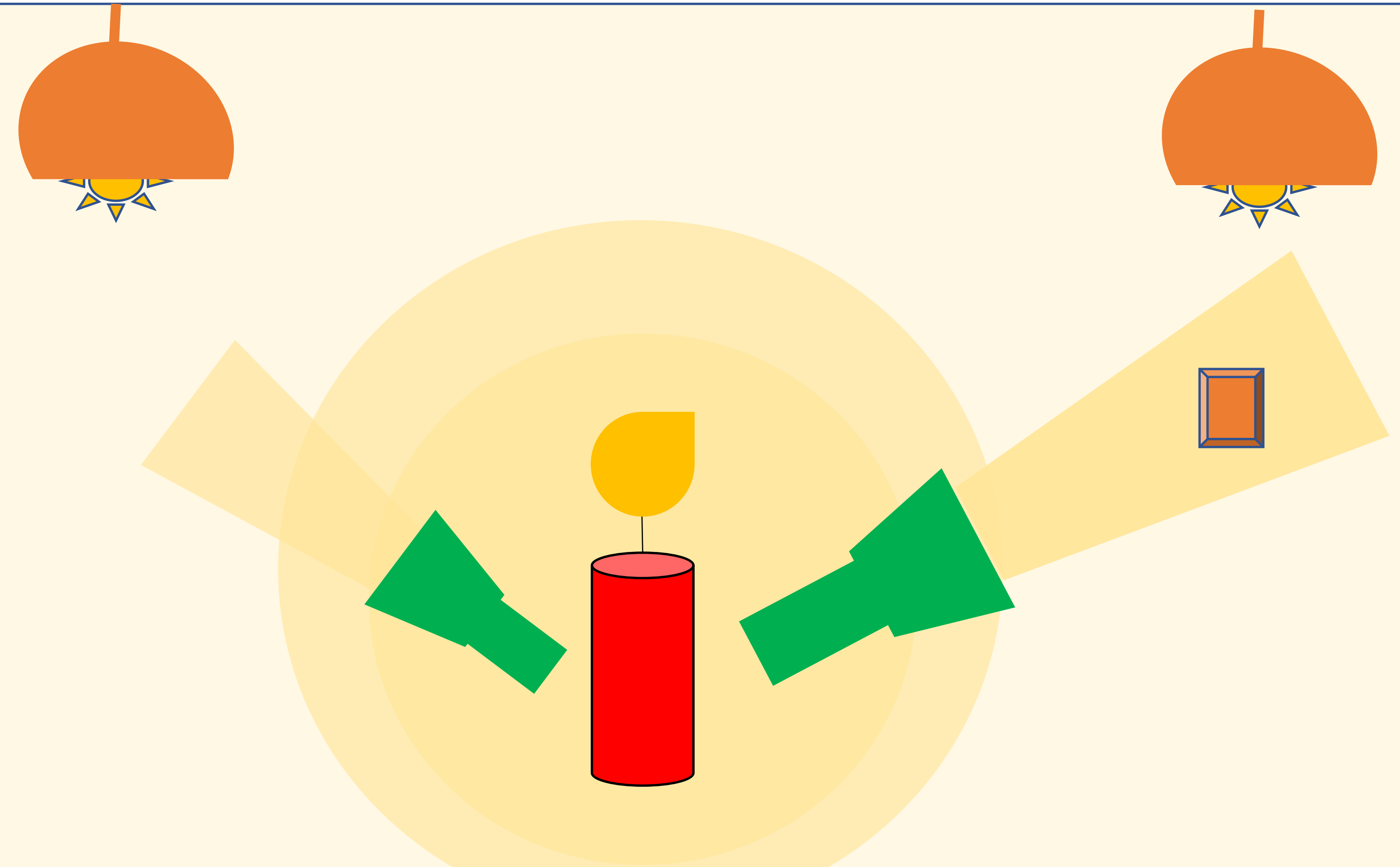
What remains to be discovered

With future precision measurements/indirect searches


What remains to be discovered
With direct searches
Complementarity of the approaches

There is no evidence where to search

There is no guarantee to find it with the next collider(s)…



The goal : get the full picture of Physics Beyond the Standard Model!

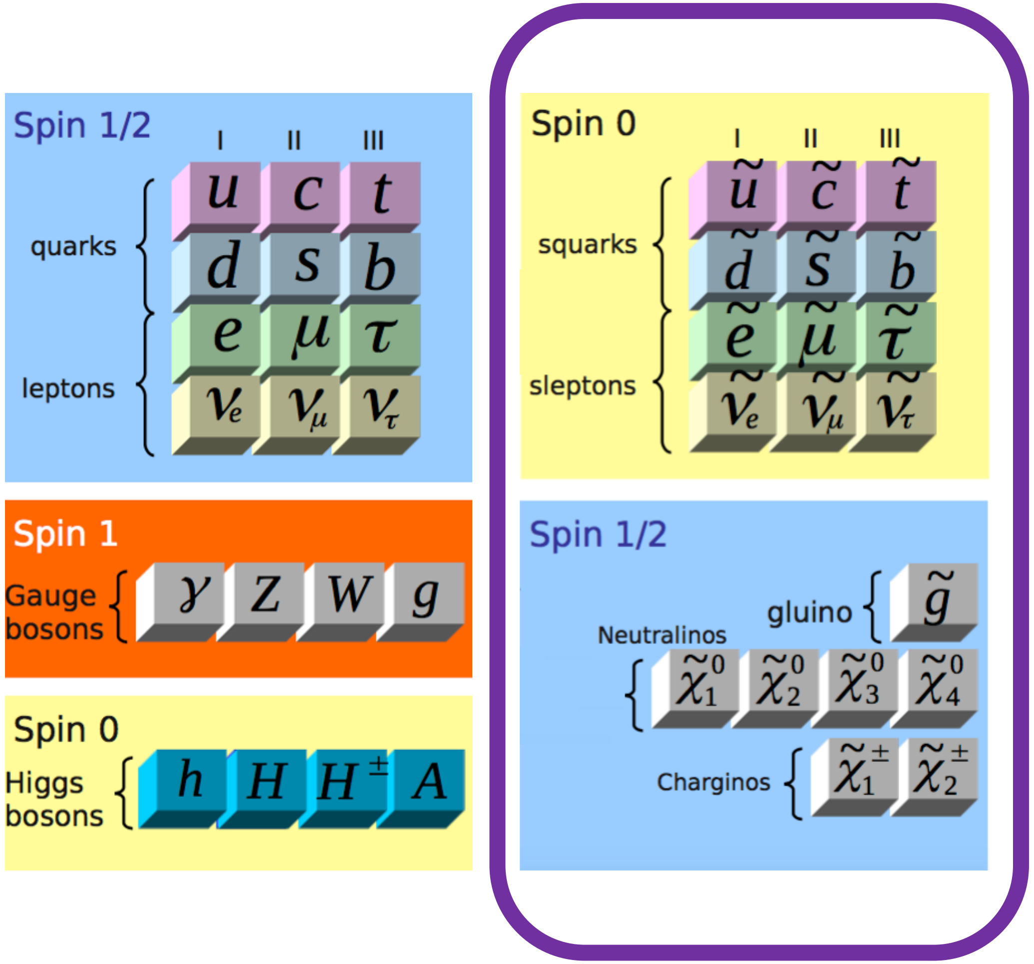
”Searches at colliders”

- **Searches:**
  - **Supersymmetric particles**
  - **New resonances**
  - [Dark Matter and Long Lived Particles → covered in the next talk]
  - [Contact interactions, … : not covered]
  - Focus on sensitivity and not on the characterization

- **@colliders:**
  - Focus on **LHC** (present) and **HL-LHC** (imminent future),
    with some mentions of other colliders HE-LHC, ILC, FCC, …

target of the prospective : 2020-2030

Search for supersymmetric particles

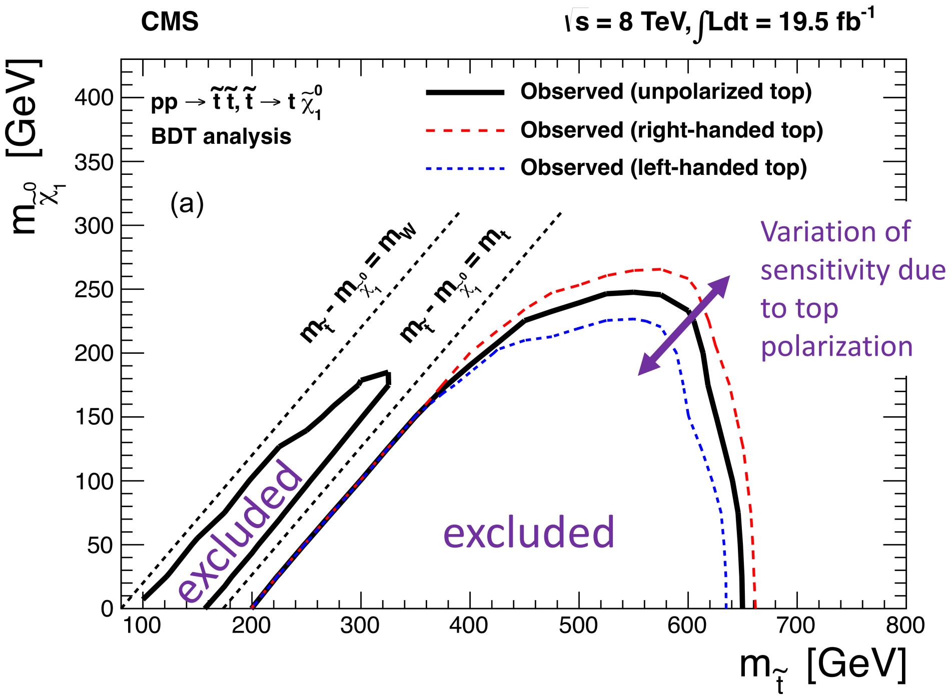


General considerations

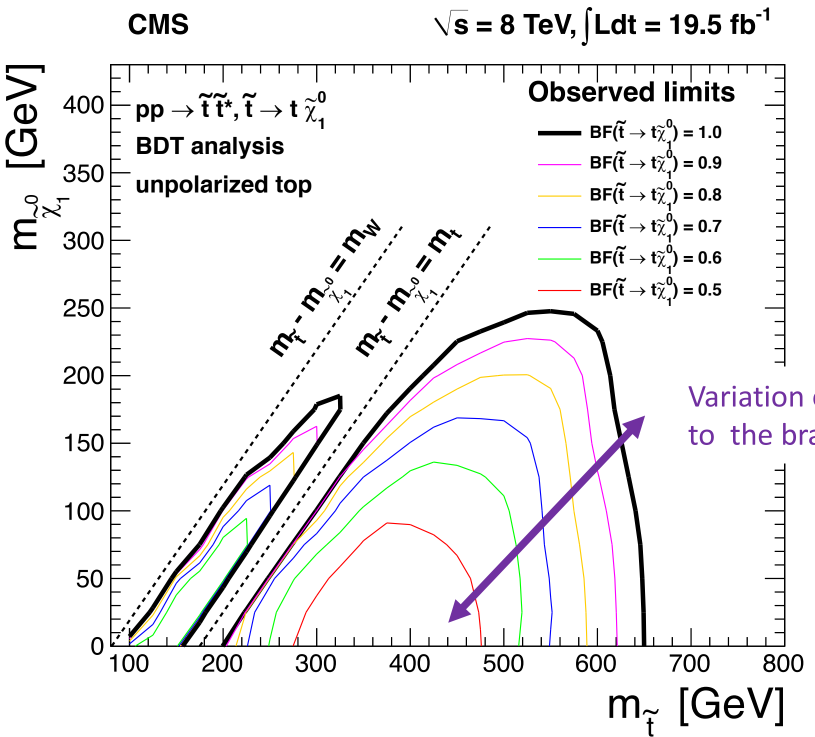
1) Limitations of the results:

- **Assumptions behind the results** (SMS, BR, …)

[Eur. Phys. J. C 73 (2013) 2677]



Variation of sensitivity due to top polarization



Variation of sensitivity due to the branching fraction

→ Scan of the sensitivity as a function of 2 parameters (masses of susy particles), assuming a BR of 100%

General considerations

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  - Generator, fast simulation like Delphes, full simulation of the detector

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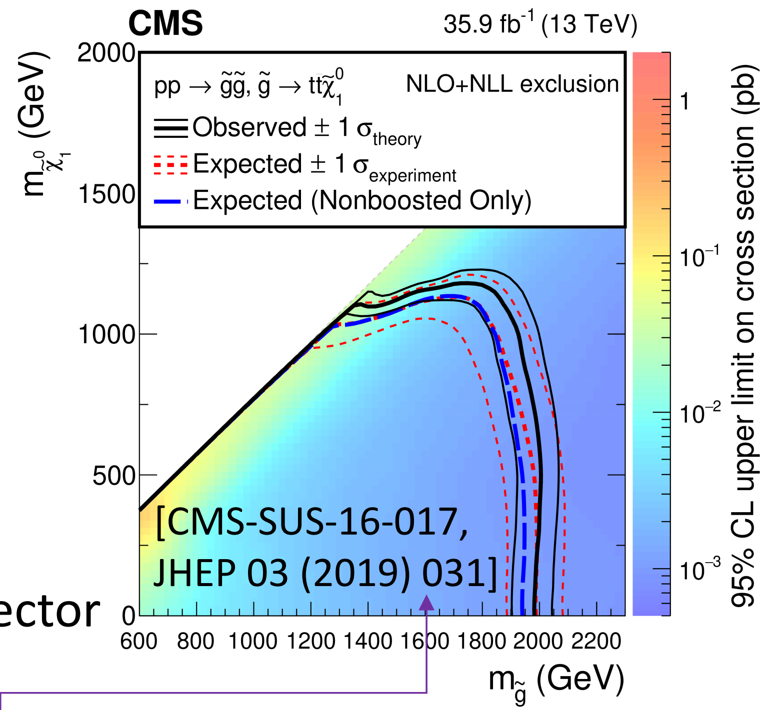
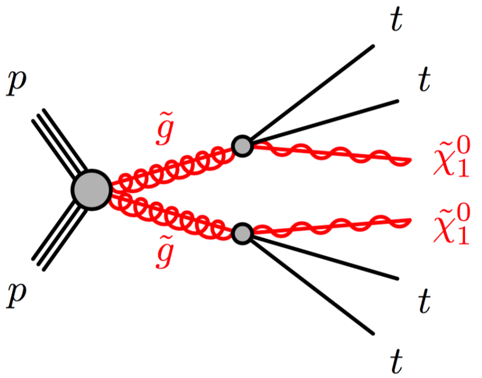
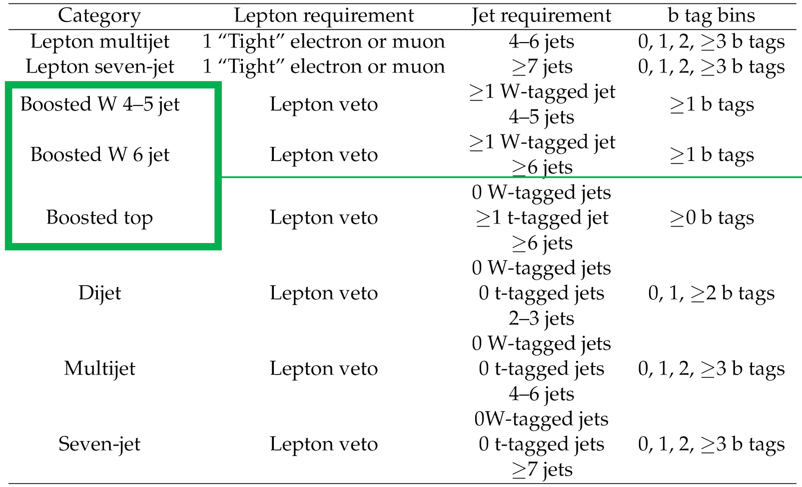
Example: Gluino searches with boosted W bosons or top quarks using the razor kinematic variables to the HL-LHC conditions.

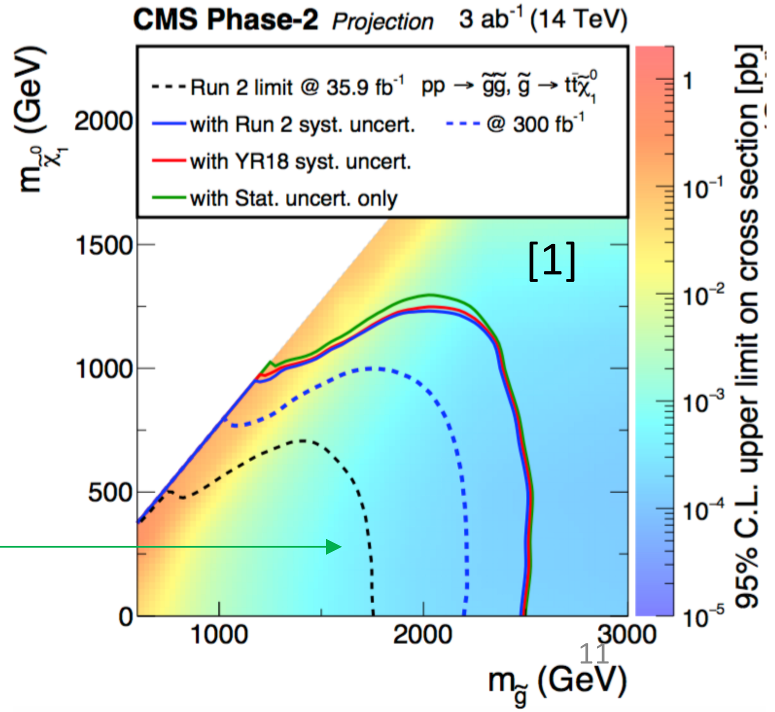


[CMS-SUS-16-017, JHEP 03 (2019) 031]





Category	Lepton requirement	Jet requirement	b tag bins
Lepton multijet	1 "Tight" electron or muon	4–6 jets	0, 1, 2, ≥3 b tags
Lepton seven-jet	1 "Tight" electron or muon	≥7 jets	0, 1, 2, ≥3 b tags
Boosted W 4–5 jet	Lepton veto	≥1 W-tagged jet 4–5 jets	≥1 b tags
Boosted W 6 jet	Lepton veto	≥1 W-tagged jet ≥6 jets	≥1 b tags
Boosted top	Lepton veto	0 W-tagged jets ≥1 t-tagged jet ≥6 jets	≥0 b tags
Dijet	Lepton veto	0 W-tagged jets 0 t-tagged jets 2–3 jets	0, 1, ≥2 b tags
Multijet	Lepton veto	0 W-tagged jets 0 t-tagged jets 4–6 jets	0, 1, 2, ≥3 b tags
Seven-jet	Lepton veto	0W-tagged jets 0 t-tagged jets ≥7 jets	0, 1, 2, ≥3 b tags



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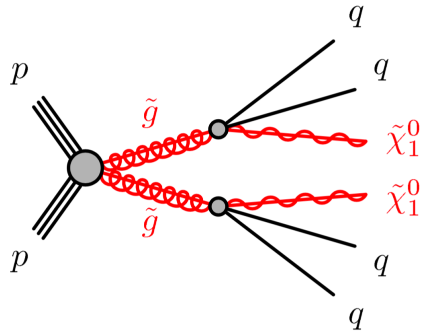
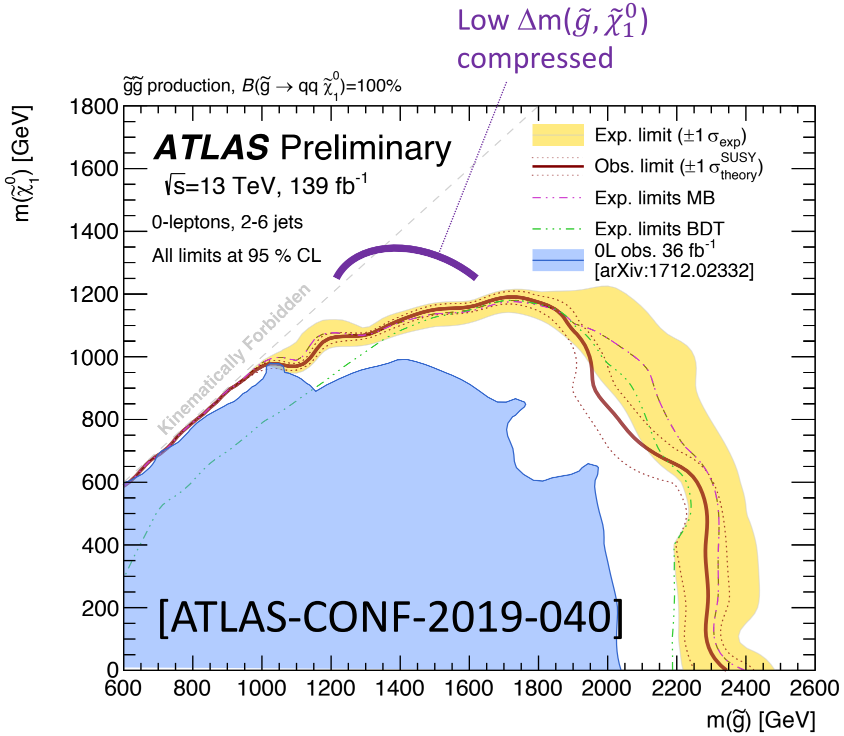
2) Some triviality:

- **Highest Energy → probe the high mass regime**
- **Highest Luminosity → probe the low coupling/cross-section regime**

Search for gluinos

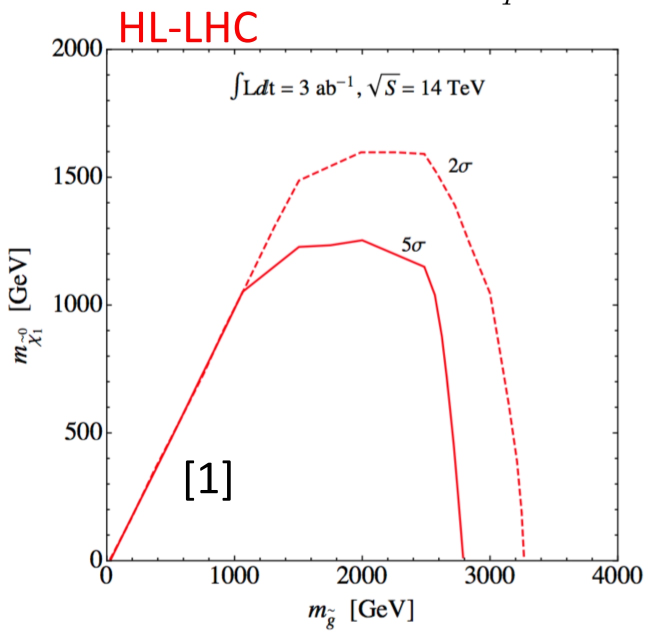


- Hadronic activity + MET in the final state
- @Hadron colliders: Loss of sensitivity at low $\Delta m(\tilde{g}, \tilde{\chi}_1^0)$ in what we call the "compressed" regime even with dedicated selection with a ISR jet



[ATLAS-CONF-2019-040]

HL-LHC



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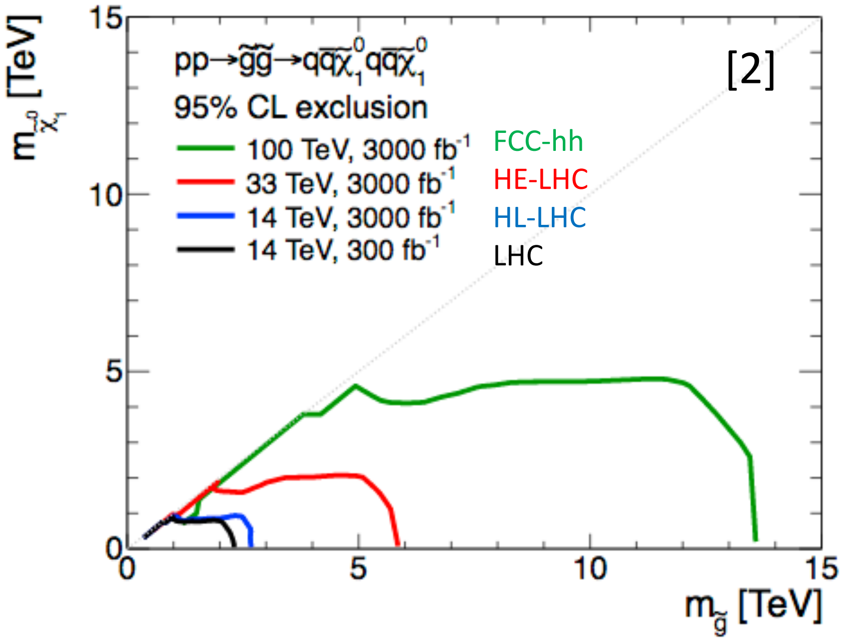
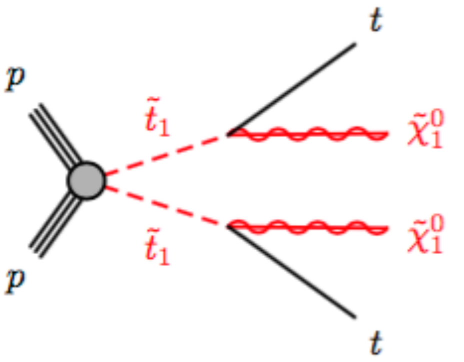


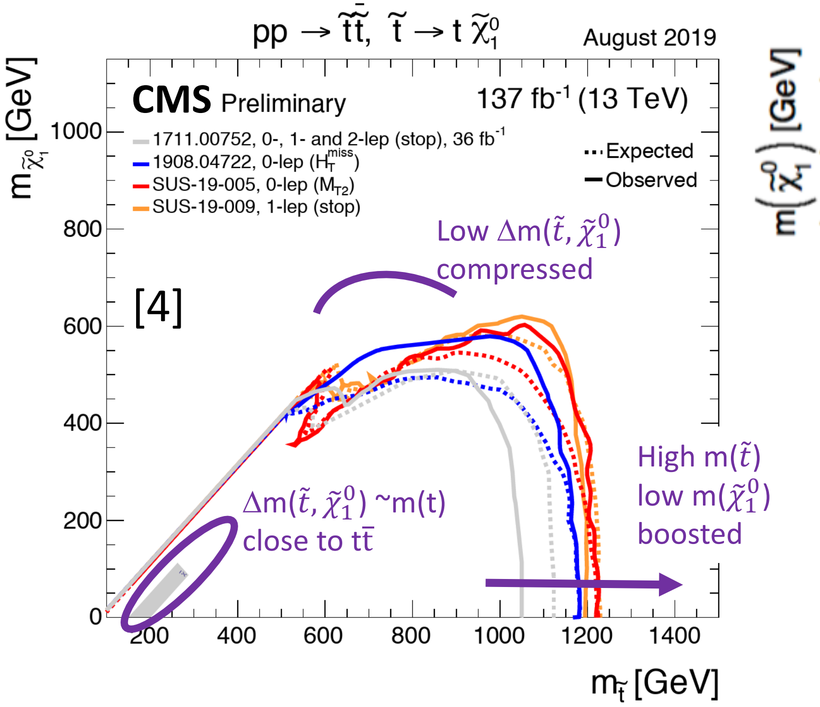
$\tilde{g}$ for $m(\tilde{\chi}_1^0) \approx 0$	LHC (139 fb^{-1})	HL-LHC (3 ab^{-1}) [1]	HE-LHC (27 TeV, 15 ab^{-1}) [1]	HE-LHC (33 TeV, 3 ab^{-1}) [plot [2]]	FCC-hh (3 ab^{-1}) [2]	FCC-hh (30 ab^{-1}) [3]
Exclusion @95%	2.35 TeV	3.2 TeV	5.7 TeV	˜5.8 TeV	13.5 TeV	17. TeV
5σ discovery		2.9 TeV	5.2 TeV		11 TeV	

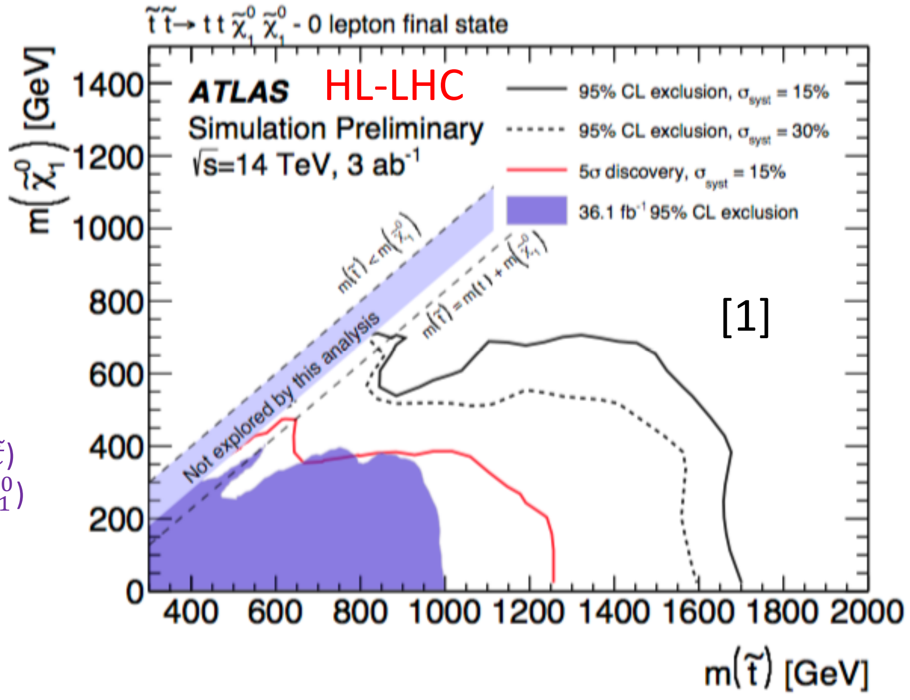
- Lepton colliders are ineffective in the search for gluinos, which are neutral with respect to the EW interaction [3]

Search for stops

- **French interest (related to the presence of tops in the final state)**
- #leptons and #jets depending on the top decays







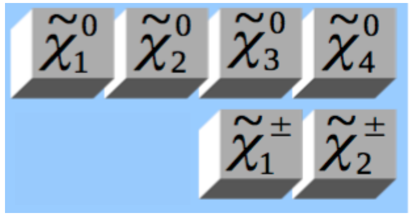
- High-energy lepton colliders, e.g. CLIC3000, might become competitive with HL-LHC at low $\Delta m(\tilde{t}, \tilde{\chi}_1^0)$, as their stop mass reach is close to $\sqrt{s}/2$ even for low Δm [3]
- Lower centre-of-mass energy lepton facilities do not have sufficient kinematic reach [3]

$\tilde{t}$ for $m(\tilde{\chi}_1^0)$ ≈0	LHC (139 fb^{-1})	HL-LHC (3 ab^{-1})	HE-LHC (27 TeV, 15 ab^{-1})	LE-FCC (37.5 TeV, 15 ab^{-1})	FCC-hh (30 ab^{-1})	CLIC 1500 (1.5 TeV, 2.5 ab^{-1})	CLIC 3000 (3 TeV, 5 ab^{-1})
Exclusion @95%	~1.2 TeV	1.7 TeV	3.65 TeV	4.6 TeV	10.8 TeV	0.75 TeV	1.5 TeV

[3]

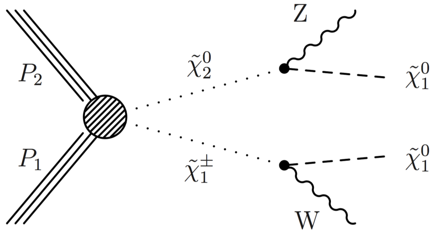
[the discovery potential in all channels is about 5% lower]

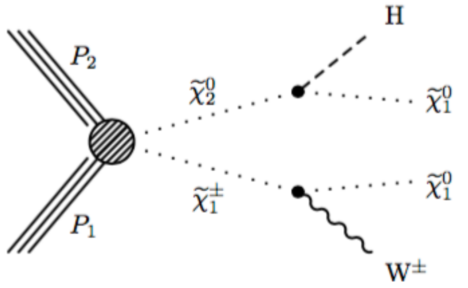
Search for electroweakinos (EWKino)

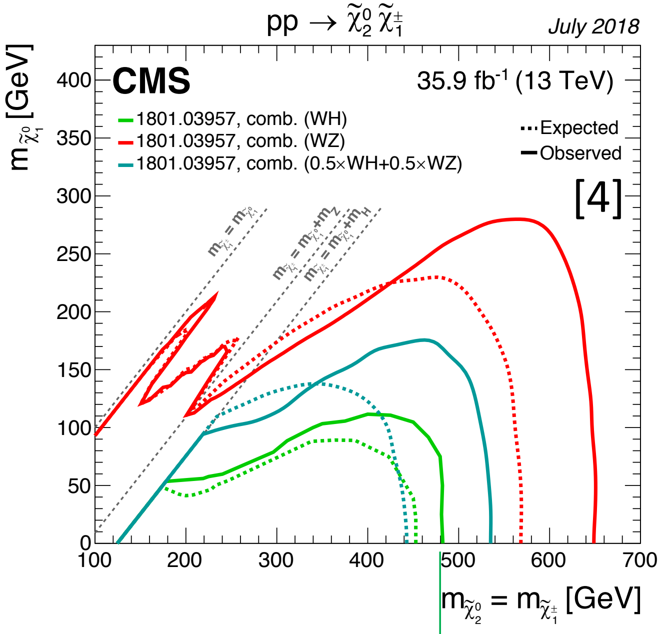


Electroweakinos (= neutralinos and charginos, which are coming from the mixing of the superpartners of the EW gauge and Higgs bosons) have cross sections typically much smaller than those of coloured superpartners at hadron colliders. But if the masses of the gluinos and squarks are beyond 3-4 TeV, the direct production of charginos and neutralinos through EW interactions may dominate the SUSY production at the LHC.

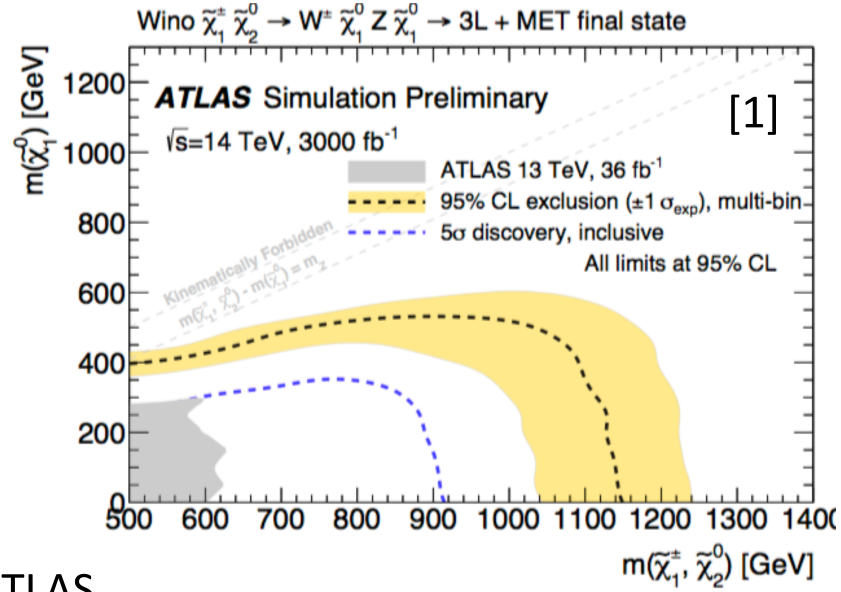
Assumptions: 1) $\tilde{\chi}_1^0$ is bino-like and 2) $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^\pm$ are wino-like and have the same mass.

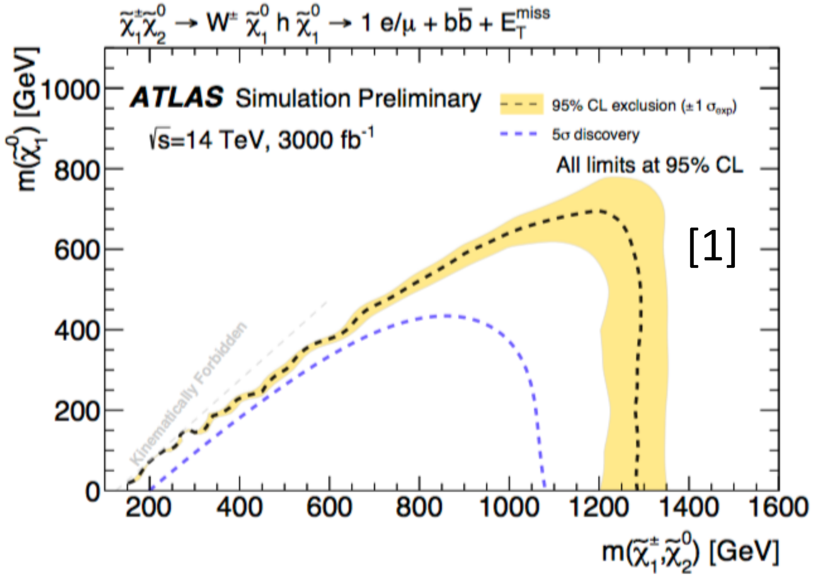






740 GeV excl by ATLAS with 139 fb^{-1} [5]





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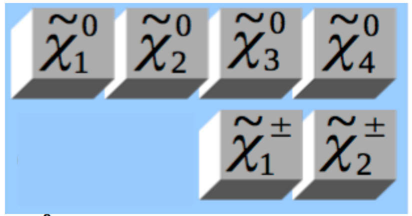

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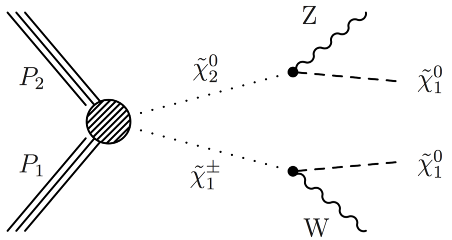
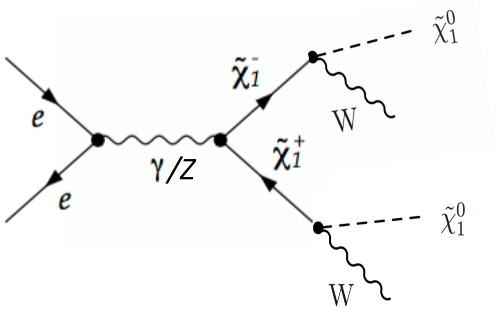
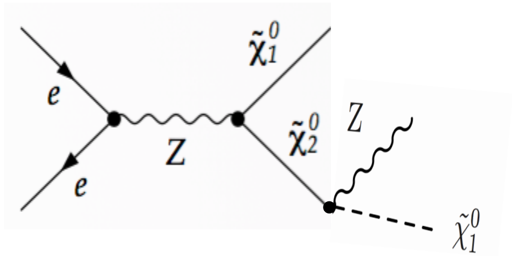
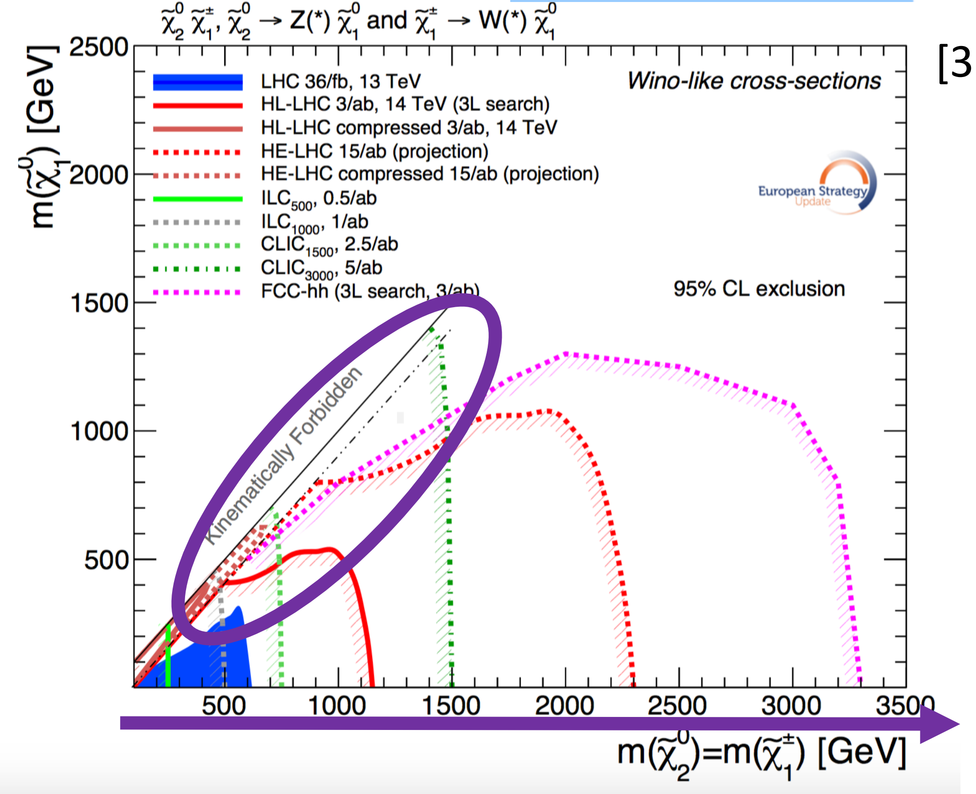






@HL-LHC compressed: reinterpretation of Higgsino $\tilde\chi_1^\pm\ \tilde\chi_2^0$ results
@HE-LHC: projection from HL-LHC



[3]

$\tilde\chi_2^0, \tilde\chi_1^\pm$ for m($\tilde\chi_1^0$) ≈0	LHC (139 fb^{-1})	HL-LHC (3 ab^{-1})	HE-LHC 27TeV (15 ab^{-1})	FCC-hh (30 ab^{-1})	ILC 500 (0.5 ab^{-1})	ILC 1000 (1 ab^{-1})	CLIC 1500 (2.5 ab^{-1})	CLIC 3000 (5 ab^{-1})
Exclusion@95%	0.74 TeV	1.15 TeV	2.3 TeV	3.3 TeV	0.25 TeV	0.5 TeV	0.75 TeV	1.5 TeV

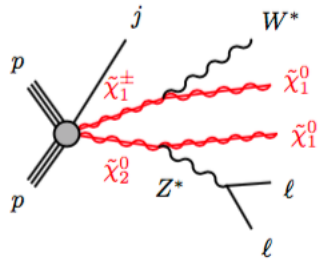
Search for electroweakinos (EWKino)

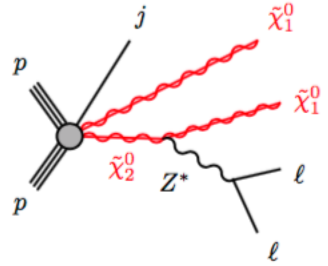
Assumptions: $\tilde{\chi}_1^0, \tilde{\chi}_2^0$ and $\tilde{\chi}_1^\pm$ are higgsino-like and the mass splitting Δm is ~ O(GeV)

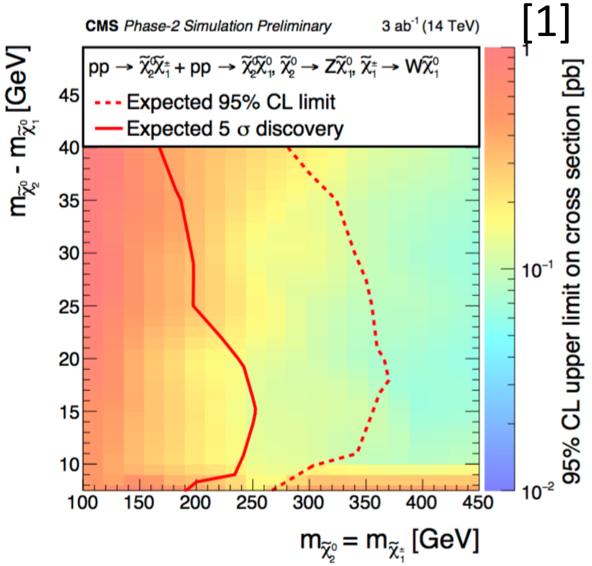
[if pure higgsino, Δm~160 MeV → disappearing track analyses]

EWkino production rates are smaller than in the previous case, making dedicated searches more challenging.

@HL-LHC: low pT lepton and ISR jet to provide large MET







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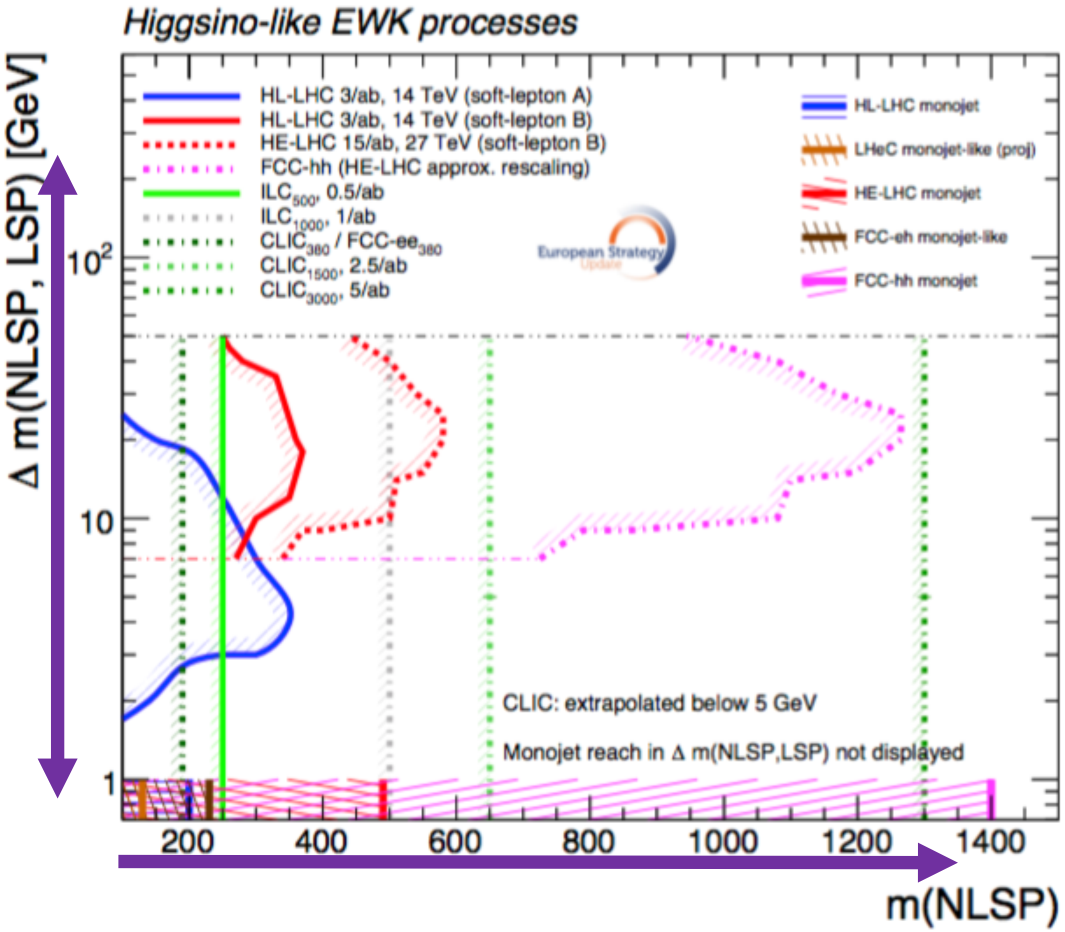


[3]

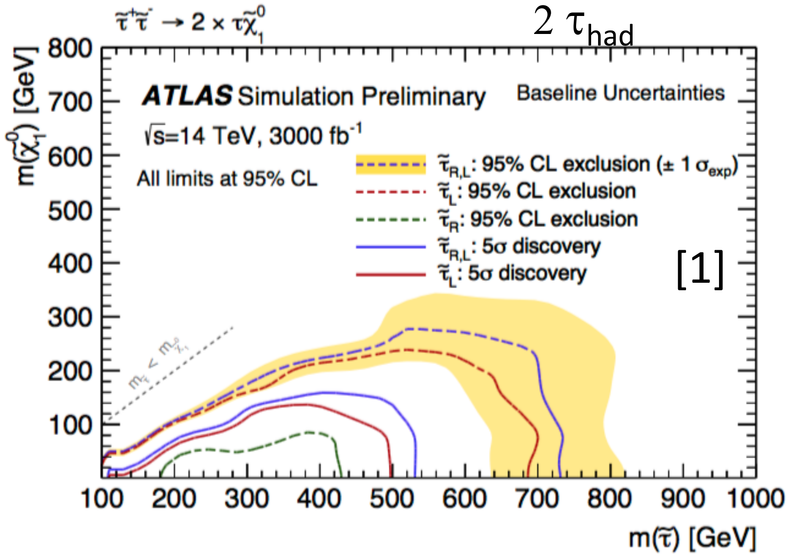
@ILC: sensitive up to $\sqrt{s}/2$ and down to 0(100 MeV)

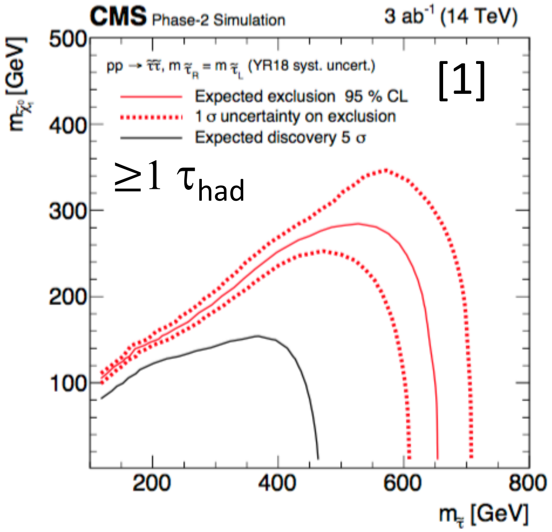
@CLIC: results @3TeV rescaled for lower $\sqrt{s}$, analysis performed for Δm=5 GeV and extrapolated below.

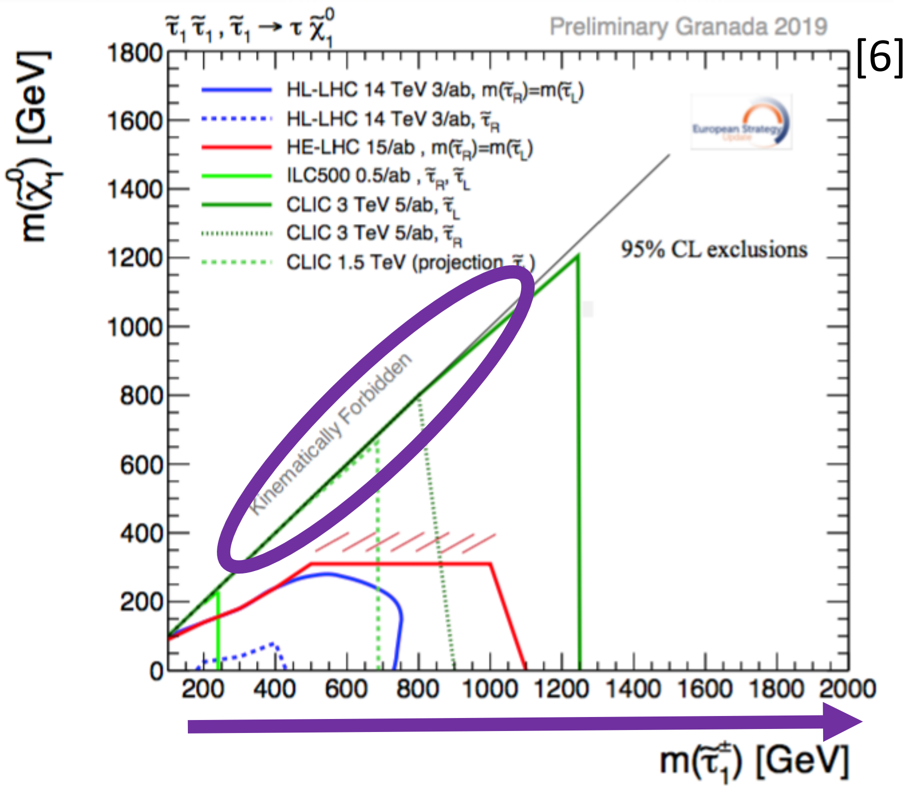
Search for staus

Particularly challenging at *pp* facilities due to the complexity of identifying τ_{had} and reject misidentified candidates!

The sensitivity depends if the $\tilde{\tau}$ is the susy partner of a τ_R or τ_L.







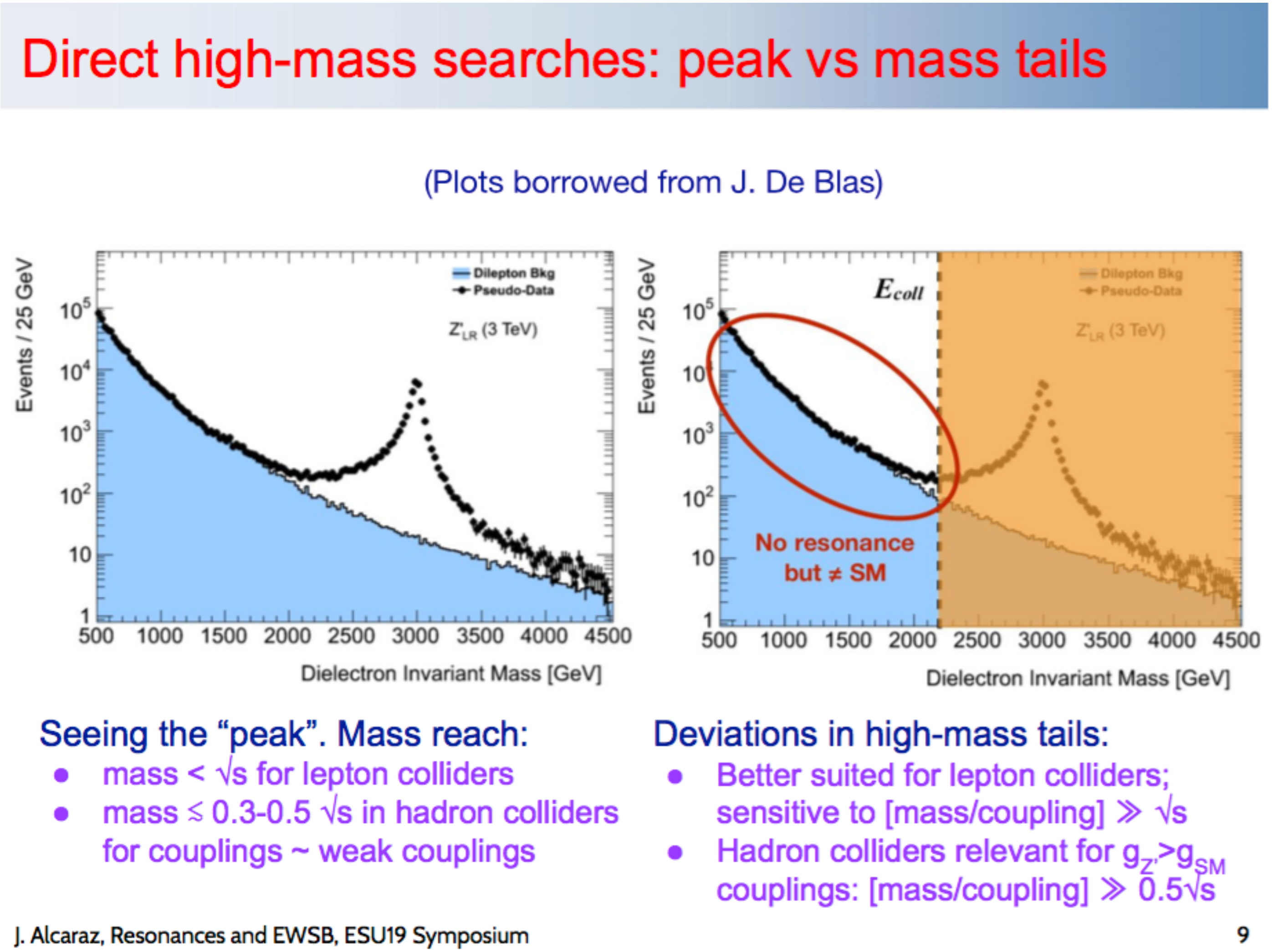
$\tilde{\tau}$ for $m(\tilde{\chi}_1^0) \approx 0$	LHC (139 fb^{-1})	HL-LHC (3 ab^{-1})	HE-LHC (27 TeV, 15 ab^{-1})	FCC-hh (30 ab^{-1})	ILC 500 (500 GeV, 0.5 ab^{-1})	CLIC 3000 (3 TeV, 5 ab^{-1})
Exclusion @95%	0.12-0.39 TeV [5]	0.73 TeV	1.1 TeV	(3-4 TeV)	0.23 TeV	1.25 TeV

[3]

Search for new resonances

A lot of possibilities:

- New gauge bosons
- Extra Dimensions
- Lepto-Quarks
- Heavy quarks (VLQ)
- Excited fermions
- ….



[7]

Direct high-mass searches: peak vs mass tails

(Plots borrowed from J. De Blas)

Seeing the "peak". Mass reach:

- mass < $\sqrt{s}$ for lepton colliders
- mass $\lesssim$ 0.3-0.5 $\sqrt{s}$ in hadron colliders for couplings ~ weak couplings

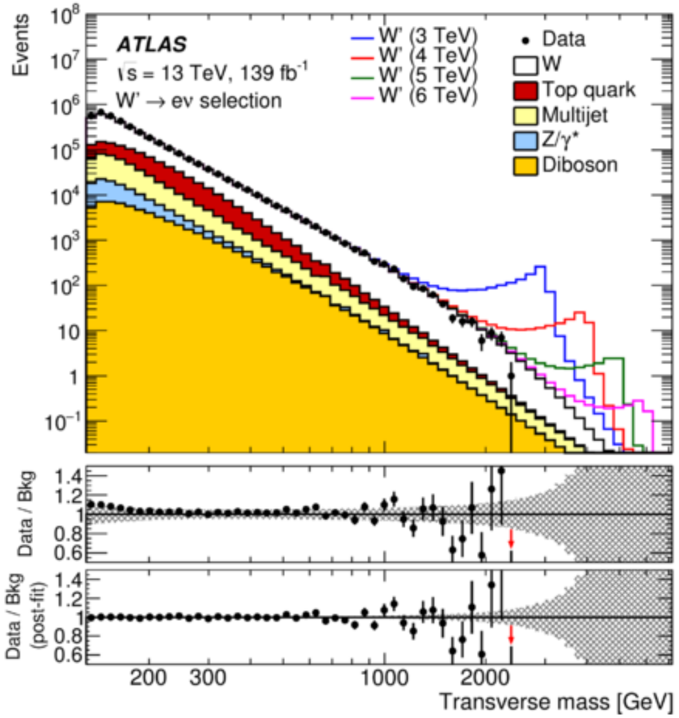
Deviations in high-mass tails:

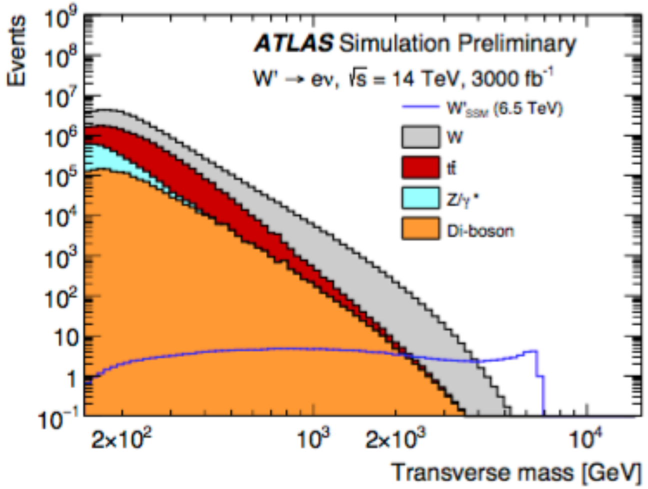
- Better suited for lepton colliders; sensitive to [mass/coupling] $\gg \sqrt{s}$
- Hadron colliders relevant for $g_{Z'}>g_{SM}$ couplings: [mass/coupling] $\gg 0.5\sqrt{s}$

J. Alcaraz, Resonances and EWSB, ESU19 Symposium 9

Search for W’ [1l +MET]

[PRD 100 (2019) 052013]





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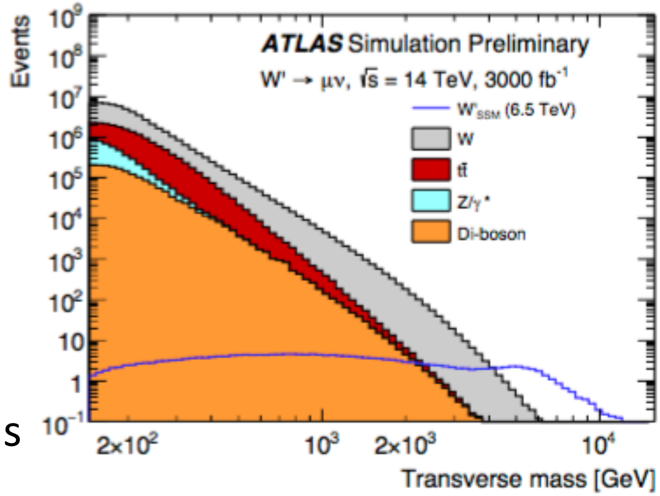

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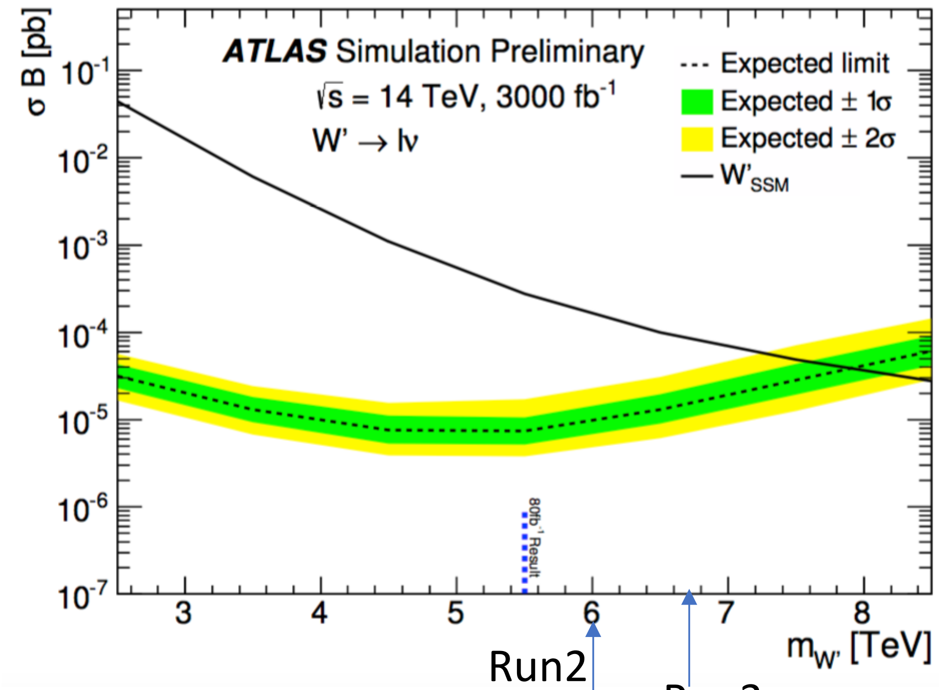


[1]

Run2 ~140 fb⁻¹

Run3 ~300 fb⁻¹

W' SSM → lν (l = e or μ)	LHC ATLAS (139 fb⁻¹)	HL-LHC (3 ab⁻¹)
Exclusion @95%	6.0 TeV	7.9 TeV

W' SSM → τν	LHC CMS (36 fb⁻¹)	HL-LHC (3 ab⁻¹)
Exclusion @95%	4.0 TeV	7.0 TeV

W’ -> l ν

@HL-LHC: Superior energy resolution of the calorimeter for high-p_T electrons as compared to that of the muon spectrometer for high-p_T muons

→ better sensitivity for electrons

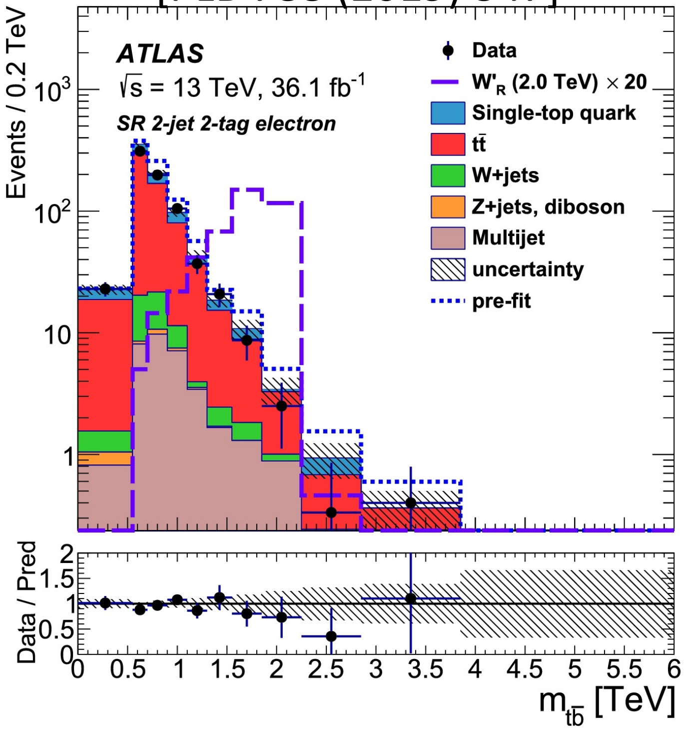
Search for W_R’ [1l+MET+bb]

French interest (related to the presence of a top in the final state) ?

To be sensitive to W_R’, the search is performed in the tb channel, with t -> Wb and W-> lν.

After having reconstructed the W and t systems, the mass of the reconstructed W’ system is used as discriminant variable.

[PLB 788 (2019) 347]



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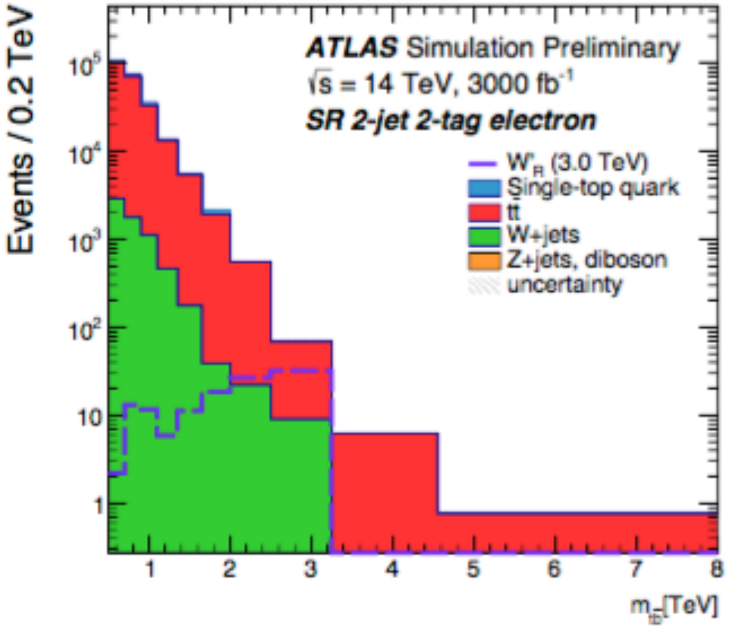

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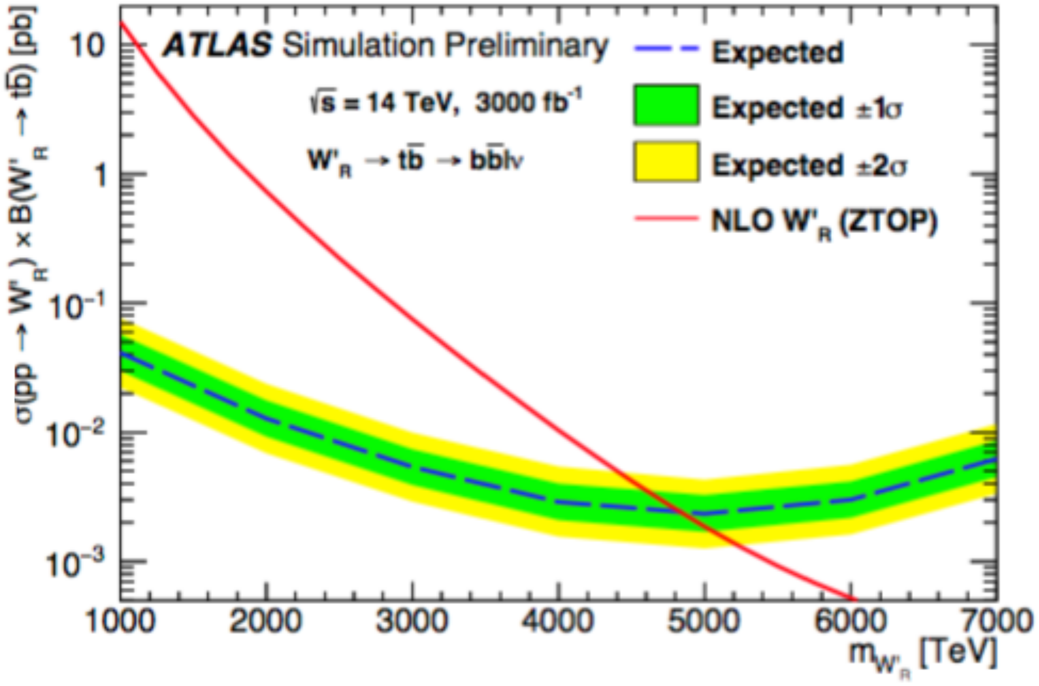
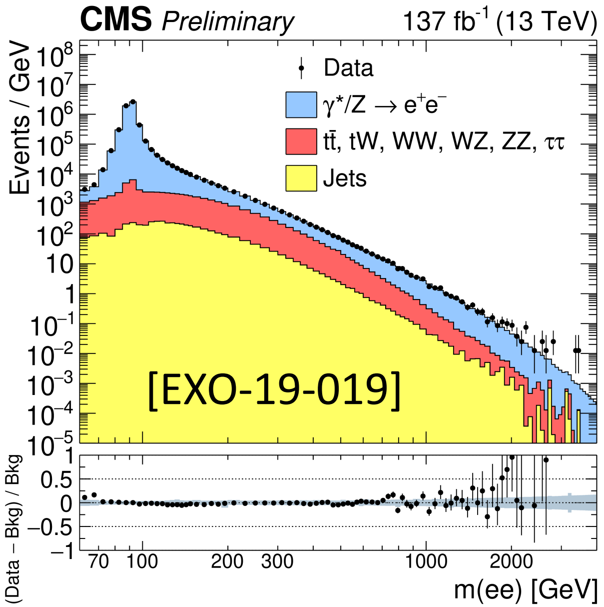


$W’_R$ → tb	LHC (36 fb^{-1})	HL-LHC (3 ab^{-1})
Exclusion @95%	3.15 TeV	4.9 TeV

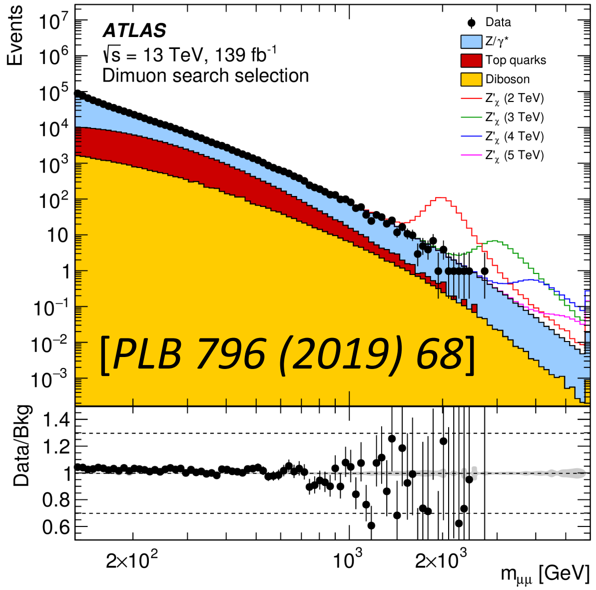
Search for Z' [2l]

Z'→ ll (electron or muon)

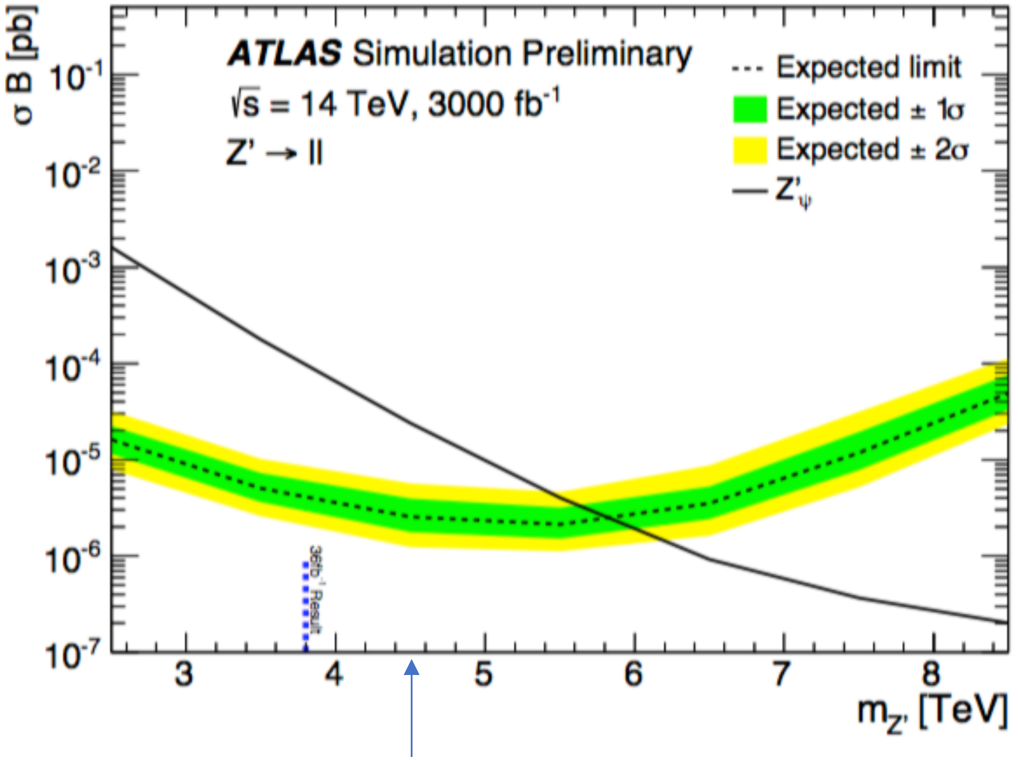
The sensitivity depends on the model



[EXO-19-019]



[PLB 796 (2019) 68]



Run2 : ~140 fb^{-1}

[1]

Z' SSM	LHC (~140 fb^{-1})	HL-LHC (3 ab^{-1})	HE-LHC (27 TeV, 15 ab^{-1})	ILC 500 (500 GeV, 4 ab^{-1})	CLIC 3000 (3 TeV, 3 ab^{-1})	FCC-hh (30 ab^{-1})
Exclusion @95%	5.1 TeV	6.5 TeV	12.8 TeV	9.8 TeV (indirect)		
5σ discovery		6.4 TeV	12.8 TeV	6.2 TeV	~20 TeV	42 TeV

[7]

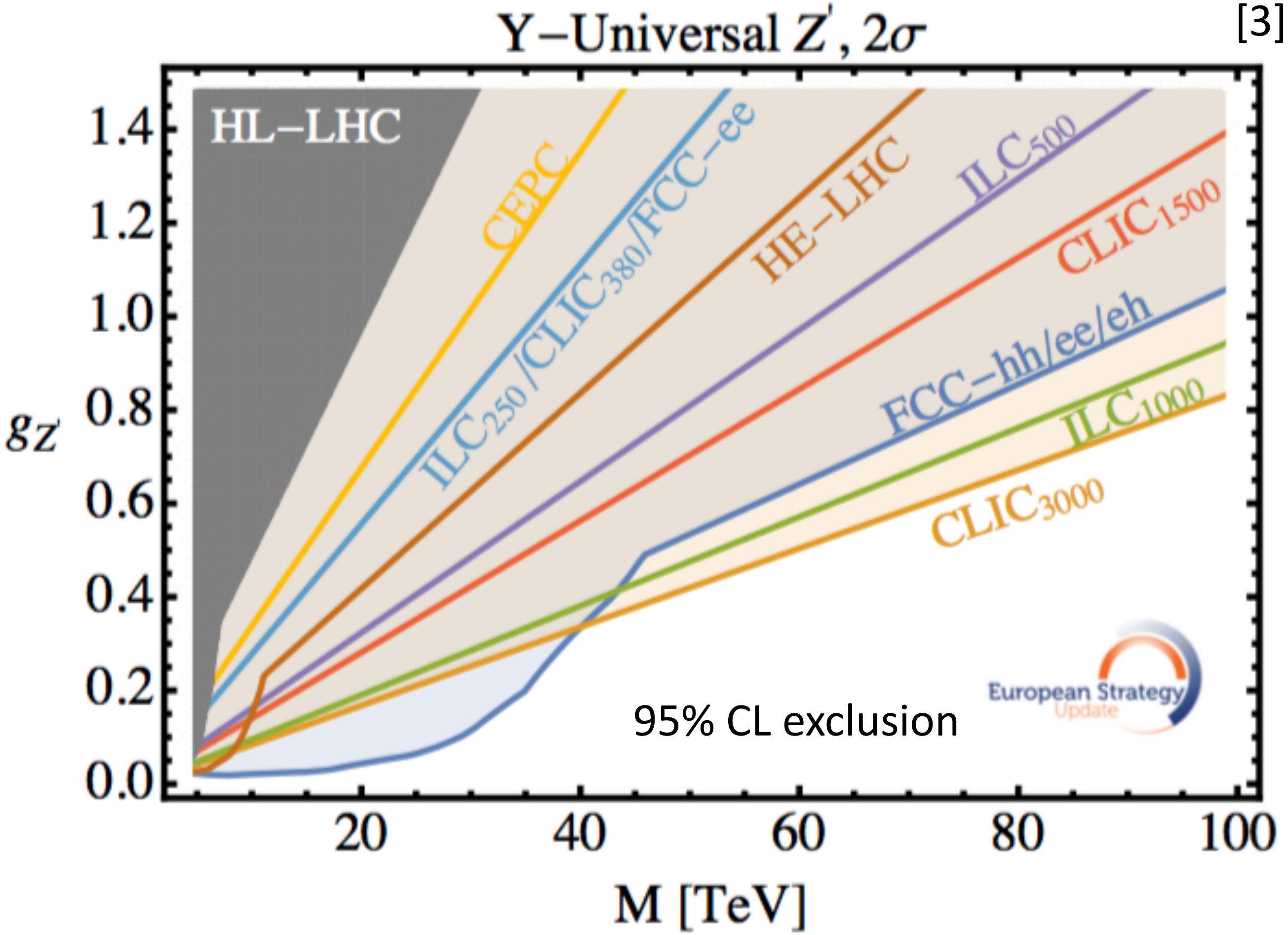
Search for Z'

Use of a specific model for sensitivity comparisons, with the coupling constant ($g_{Z'}$) taken as a free parameter.

Mixing the reaches of direct (round curves at small $g_{Z'}$) and indirect (diagonal straight lines at large $g_{Z'}$) searches.

The direct mass reach is inferior to the indirect one for high $g_{Z'}$.

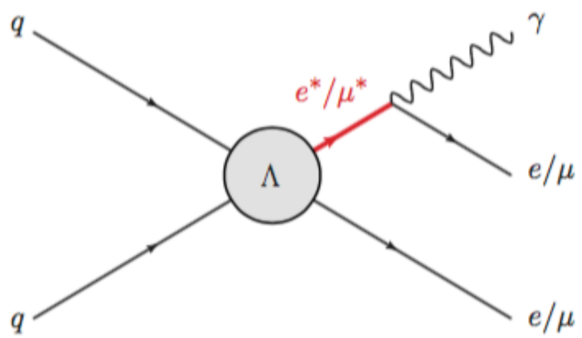
[3]



The gap in performances between CEPC or FCC-ee with respect to ILC250 or CLIC380 is most likely due to the lack of dedicated di-fermion production studies.

Search for excited leptons [2l + 1γ]

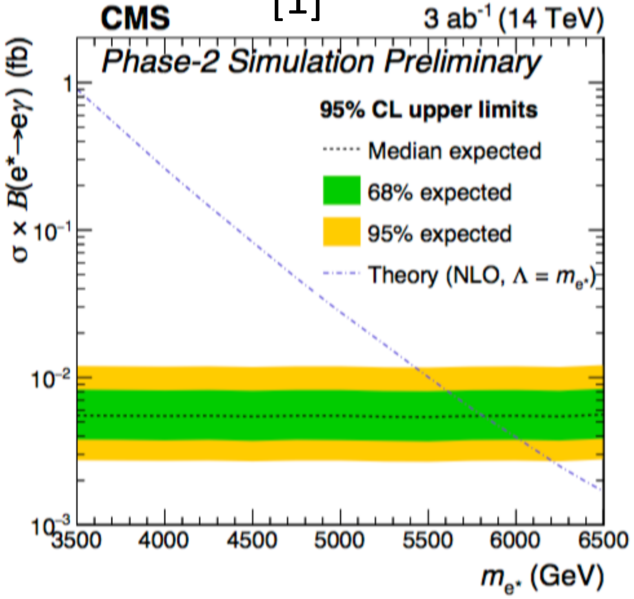
l* -> l + γ



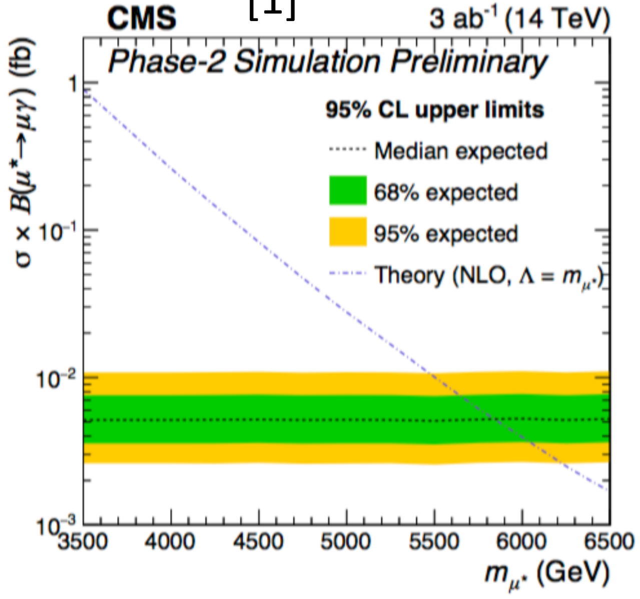
Search for final state with a pair of opposite-sign same-flavour leptons and a photon

Difficulty to identify which lepton is coming from l*

[1]



[1]



[8] [1]

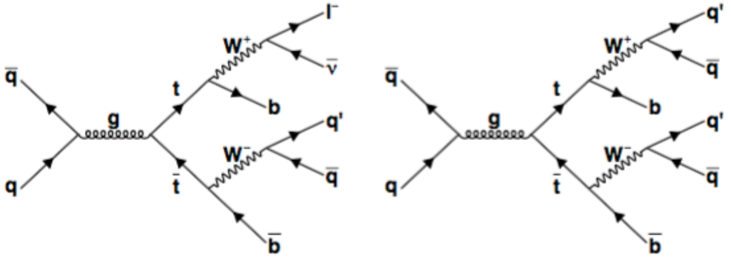
l* (Ml* =Λ)	LHC (36fb^{-1})	HL-LHC (3 ab^{-1})
Exclusion @95%	3.9 TeV	5.8 TeV
5σ discovery		5.1 TeV

While the electron channel has a lower signal yield than the muon channel, it also has lower background, and the net result is that the excluded cross sections differ only by about 10%, producing a similar exclusion limit on the excited lepton mass.

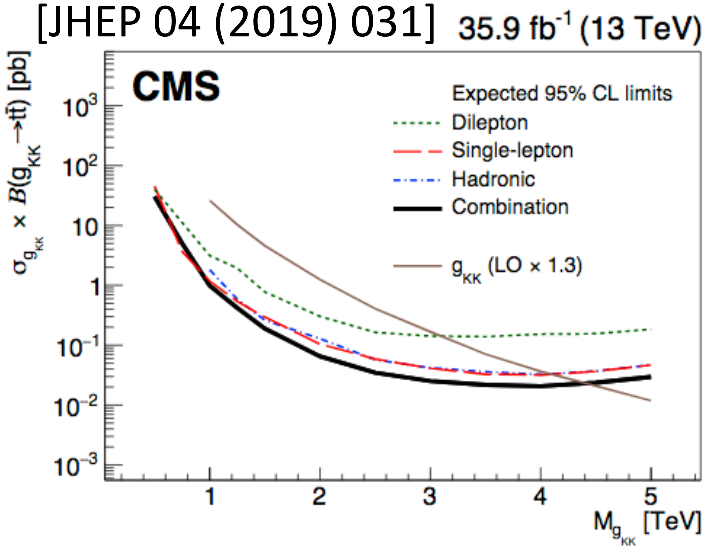
Search for Randall–Sundrum Gluon [2t]

French interest

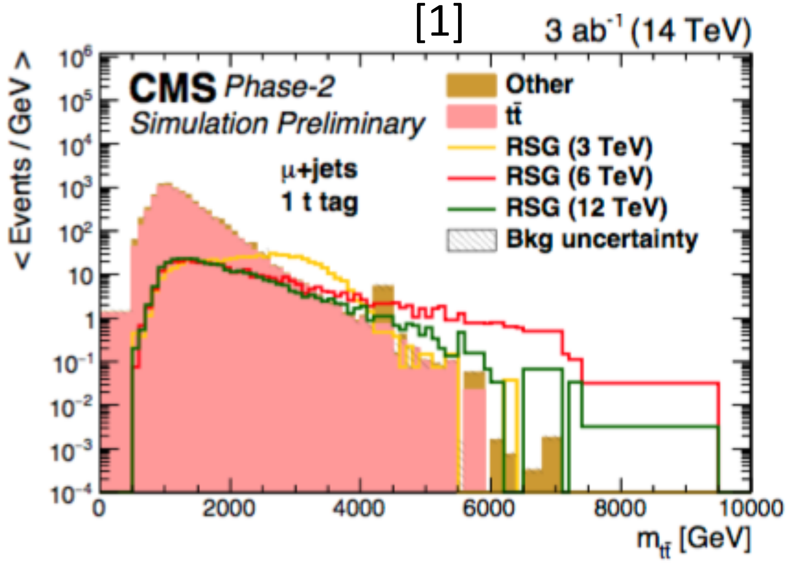
$g_{RS} \rightarrow t\bar{t}$: Two distinct final states with either a single lepton or no leptons are considered. Jet substructure techniques and top quark identification algorithms are used for the object reconstruction.



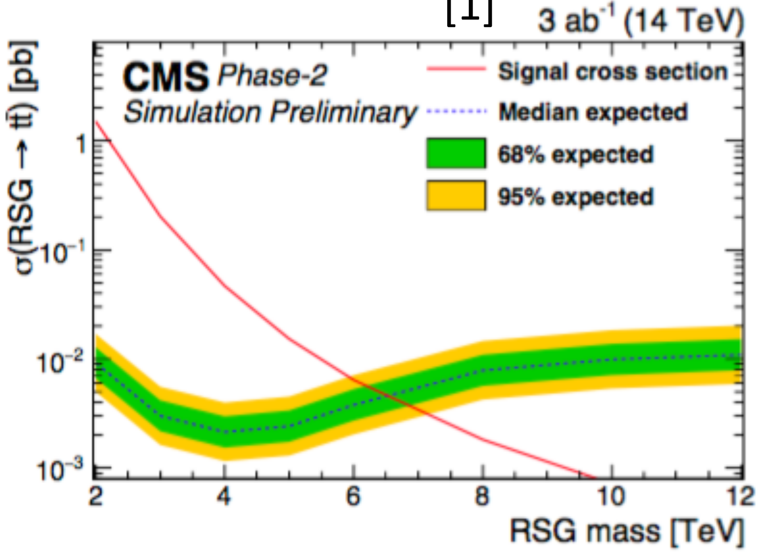
[JHEP 04 (2019) 031]



[1]



[1]

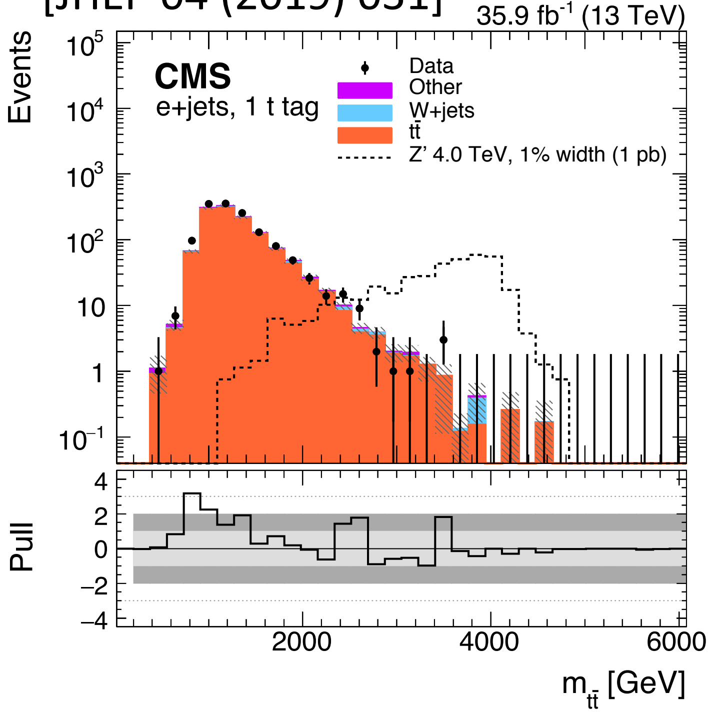


RS gluon $t\bar{t}$ $k/\overline{M}_{PL}$ =1	**LHC** **(36 fb^{-1})**	**HL-LHC** **(3 ab^{-1})**	**HE-LHC** **(27 TeV, 15 ab^{-1})**
Exclusion @95%	4.5 TeV	6.6 TeV	10.7 TeV
5σ discovery		5.7 TeV	9.4 TeV

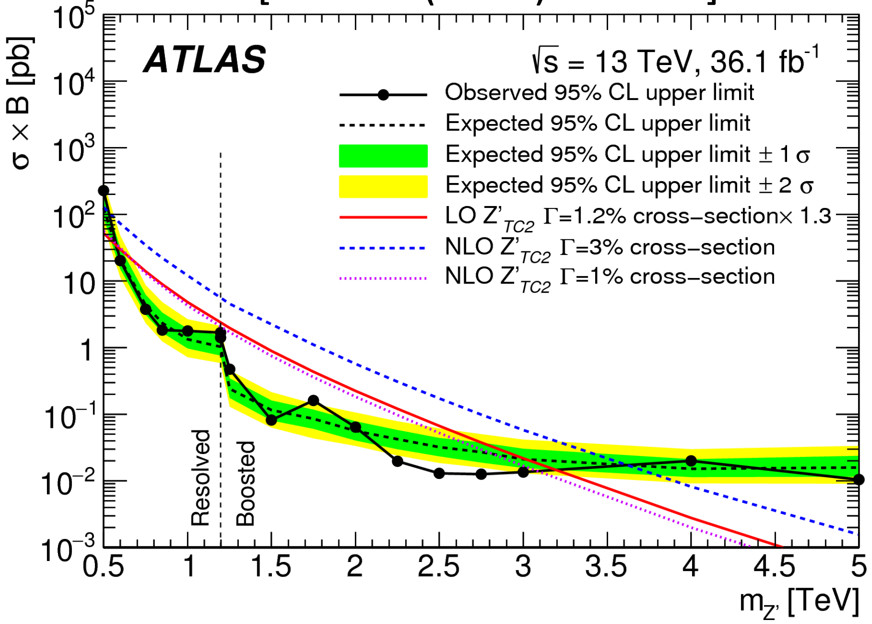
Search for Z' [2t]

Another interpretation for di-top resonances

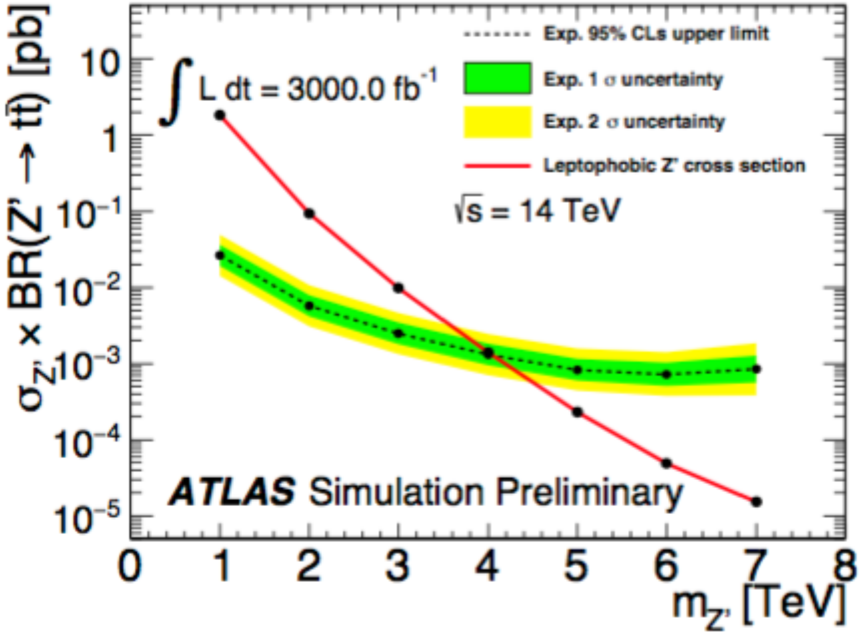
[JHEP 04 (2019) 031]



[PRD 99 (2019) 092004]



[1]



[PRD 99 (2019) 092004] [JHEP 04 (2019) 031]

Z' leptophobic tt	LHC ATLAS (36 fb^{-1}) [0l]	LHC CMS (36 fb^{-1}) [0l, 1l, 2l]	HL-LHC (3 ab^{-1}) [1l]	HE-LHC (27 TeV, 15 ab^{-1})	FCC-hh (30 ab^{-1})
Exclusion @95%	3.1 TeV for Γ =1%	3.8 TeV for Γ =1%	4 TeV for Γ =1.2%	10 TeV	28 TeV
		5.35 (6.65) TeV for Γ =10 (30)%			

[7]

Conclusions

- I try to give you some feeling about what we could expect from direct searches at colliders, focusing on susy and new resonances only.
- My conclusion is that future colliders will allow us to probe new physics in a very powerful way. Lepton and hadronic colliders would bring complementarity.
- Beyond that, I personally think that our future success will be based on
  - Hard work on detectors,
  - Creative interactions between theory and experiments,
  - Complementary searches performed in different experiments (not only in particle physics 🇫🇷),
  - Testing new ideas/approaches/analysis techniques/…

Additional information…

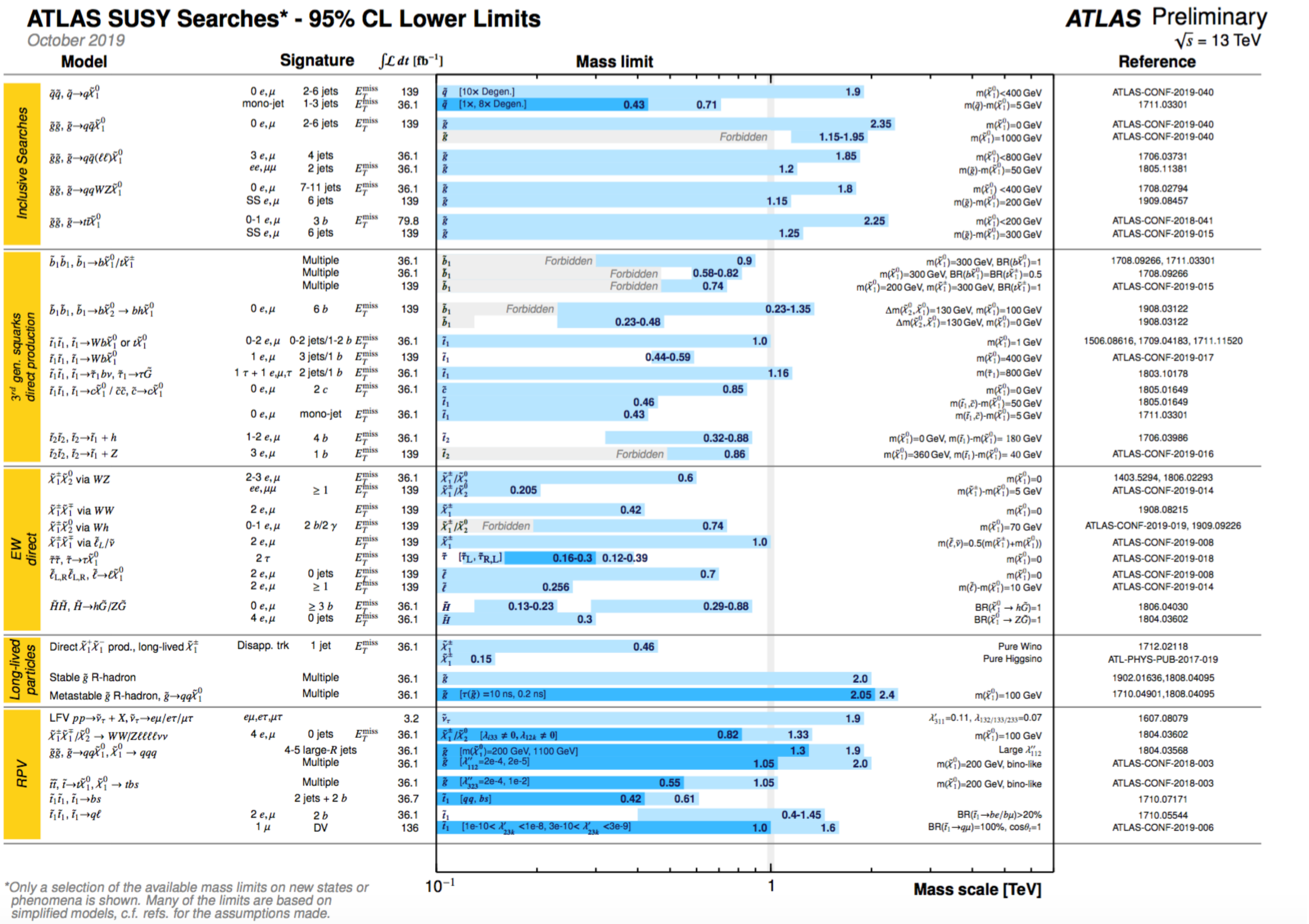
References

- [1] : HL/HE-LHC https://arxiv.org/pdf/1812.07831.pdf
- [2] : FCC https://arxiv.org/pdf/1606.00947.pdf
- [3] : Briefing book, https://arxiv.org/abs/1910.11775
- [4] : CMS susy summary plots https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS
- [5] : ATLAS susy results https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults
- [6] Talk of Monica D'Onofrio @ Granada symposium
- [7] Talk of Juan Alcaraz @ Granada symposium

References (2)

- [8] CMS exo summary plots https://twiki.cern.ch/twiki/bin/view/CMSPublic/SummaryPlotsEXO13TeV
- [9] ATLAS exo results https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults
- [10] CMS B2G results https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsB2G

More on Susy…



ATLAS SUSY Searches* - 95% CL Lower Limits

October 2019

ATLAS Preliminary

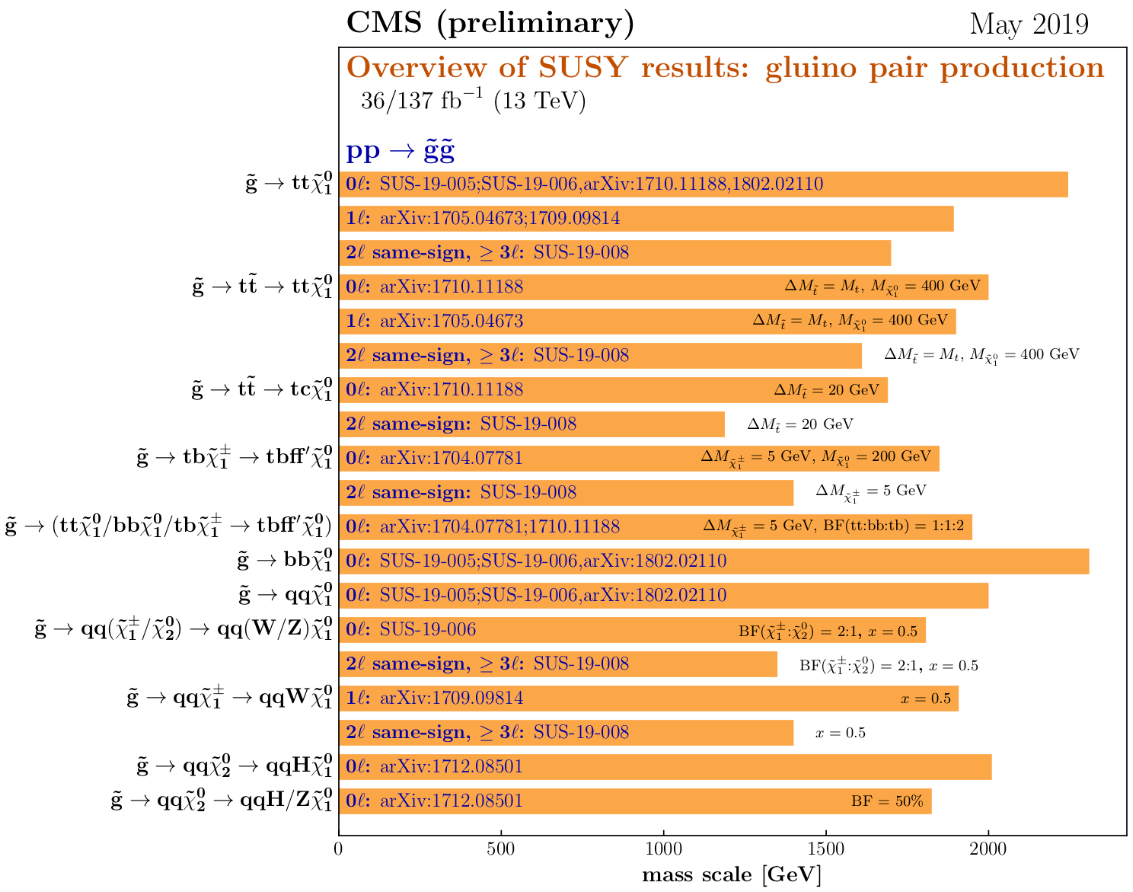
$\sqrt{s}$ = 13 TeV

[5]

	Model	Signature			$\int \mathcal{L}\,dt$ [fb^{-1}]	Mass limit			Reference
Inclusive Searches	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}_1^0$	0 e,μ	2-6 jets	$E_T^{\rm miss}$	139	$\tilde{q}$ [10× Degen.]	1.9	m($\tilde{\chi}_1^0$)<400 GeV	ATLAS-CONF-2019-040
		mono-jet	1-3 jets	$E_T^{\rm miss}$	36.1	$\tilde{q}$ [1×, 8× Degen.]	0.43 0.71	m($\tilde{q}$)-m($\tilde{\chi}_1^0$)=5 GeV	1711.03301
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0 e,μ	2-6 jets	$E_T^{\rm miss}$	139	$\tilde{g}$	2.35	m($\tilde{\chi}_1^0$)=0 GeV	ATLAS-CONF-2019-040
						$\tilde{g}$ Forbidden	1.15-1.95	m($\tilde{\chi}_1^0$)=1000 GeV	ATLAS-CONF-2019-040
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}(\ell\ell)\tilde{\chi}_1^0$	3 e,μ	4 jets		36.1	$\tilde{g}$	1.85	m($\tilde{\chi}_1^0$)<800 GeV	1706.03731
		$ee,\mu\mu$	2 jets	$E_T^{\rm miss}$	36.1	$\tilde{g}$	1.2	m($\tilde{g}$)-m($\tilde{\chi}_1^0$)=50 GeV	1805.11381
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qqWZ\tilde{\chi}_1^0$	0 e,μ	7-11 jets	$E_T^{\rm miss}$	36.1	$\tilde{g}$	1.8	m($\tilde{\chi}_1^0$) <400 GeV	1708.02794
		SS e,μ	6 jets		139	$\tilde{g}$	1.15	m($\tilde{g}$)-m($\tilde{\chi}_1^0$)=200 GeV	1909.08457
	$\tilde{g}\tilde{g}$, $\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0-1 e,μ	3 b	$E_T^{\rm miss}$	79.8	$\tilde{g}$	2.25	m($\tilde{\chi}_1^0$)<200 GeV	ATLAS-CONF-2018-041
		SS e,μ	6 jets		139	$\tilde{g}$	1.25	m($\tilde{g}$)-m($\tilde{\chi}_1^0$)=300 GeV	ATLAS-CONF-2019-015
3rd gen. squarks direct production	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to b\tilde{\chi}_1^0/t\tilde{\chi}_1^\pm$		Multiple		36.1	$\tilde{b}_1$ Forbidden	0.9	m($\tilde{\chi}_1^0$)=300 GeV, BR($b\tilde{\chi}_1^0$)=1	1708.09266, 1711.03301
			Multiple		36.1	$\tilde{b}_1$ Forbidden	0.58-0.82	m($\tilde{\chi}_1^0$)=300 GeV, BR($b\tilde{\chi}_1^0$)=BR($t\tilde{\chi}_1^\pm$)=0.5	1708.09266
			Multiple		139	$\tilde{b}_1$ Forbidden	0.74	m($\tilde{\chi}_1^0$)=200 GeV, m($\tilde{\chi}_1^\pm$)=300 GeV, BR($t\tilde{\chi}_1^\pm$)=1	ATLAS-CONF-2019-015
	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to b\tilde{\chi}_2^0\to bh\tilde{\chi}_1^0$	0 e,μ	6 b	$E_T^{\rm miss}$	139	$\tilde{b}_1$ Forbidden	0.23-1.35	Δm($\tilde{\chi}_2^0,\tilde{\chi}_1^0$)=130 GeV, m($\tilde{\chi}_1^0$)=100 GeV	1908.03122
						$\tilde{b}_1$	0.23-0.48	Δm($\tilde{\chi}_2^0,\tilde{\chi}_1^0$)=130 GeV, m($\tilde{\chi}_1^0$)=0 GeV	1908.03122
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to Wb\tilde{\chi}_1^0$ or $t\tilde{\chi}_1^0$	0-2 e,μ	0-2 jets/1-2 b	$E_T^{\rm miss}$	36.1	$\tilde{t}_1$	1.0	m($\tilde{\chi}_1^0$)=1 GeV	1506.08616, 1709.04183, 1711.11520
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to Wb\tilde{\chi}_1^0$	1 e,μ	3 jets/1 b	$E_T^{\rm miss}$	139	$\tilde{t}_1$	0.44-0.59	m($\tilde{\chi}_1^0$)=400 GeV	ATLAS-CONF-2019-017
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to\tilde{\tau}_1 b\nu$, $\tilde{\tau}_1\to\tau\tilde{G}$	1 τ + 1 e,μ,τ	2 jets/1 b	$E_T^{\rm miss}$	36.1	$\tilde{t}_1$	1.16	m($\tilde{\tau}_1$)=800 GeV	1803.10178
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to c\tilde{\chi}_1^0$ / $\tilde{c}\tilde{c}$, $\tilde{c}\to c\tilde{\chi}_1^0$	0 e,μ	2 c	$E_T^{\rm miss}$	36.1	$\tilde{c}$	0.85	m($\tilde{\chi}_1^0$)=0 GeV	1805.01649
						$\tilde{t}_1$	0.46	m($\tilde{t}_1,\tilde{c}$)-m($\tilde{\chi}_1^0$)=50 GeV	1805.01649
		0 e,μ	mono-jet	$E_T^{\rm miss}$	36.1	$\tilde{t}_1$	0.43	m($\tilde{t}_1,\tilde{c}$)-m($\tilde{\chi}_1^0$)=5 GeV	1711.03301
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1+h$	1-2 e,μ	4 b	$E_T^{\rm miss}$	36.1	$\tilde{t}_2$	0.32-0.88	m($\tilde{\chi}_1^0$)=0 GeV, m($\tilde{t}_1$)-m($\tilde{\chi}_1^0$)= 180 GeV	1706.03986
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1+Z$	3 e,μ	1 b	$E_T^{\rm miss}$	139	$\tilde{t}_2$ Forbidden	0.86	m($\tilde{\chi}_1^0$)=360 GeV, m($\tilde{t}_1$)-m($\tilde{\chi}_1^0$)= 40 GeV	ATLAS-CONF-2019-016
EW direct	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ via WZ	2-3 e,μ		$E_T^{\rm miss}$	36.1	$\tilde{\chi}_1^\pm/\tilde{\chi}_2^0$	0.6	m($\tilde{\chi}_1^0$)=0	1403.5294, 1806.02293
		$ee,\mu\mu$	≥ 1	$E_T^{\rm miss}$	139	$\tilde{\chi}_1^\pm/\tilde{\chi}_2^0$	0.205	m($\tilde{\chi}_1^\pm$)-m($\tilde{\chi}_1^0$)=5 GeV	ATLAS-CONF-2019-014
	$\tilde{\chi}_1^\pm\tilde{\chi}_1^\mp$ via WW	2 e,μ		$E_T^{\rm miss}$	139	$\tilde{\chi}_1^\pm$	0.42	m($\tilde{\chi}_1^0$)=0	1908.08215
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ via Wh	0-1 e,μ	2 b/2 γ	$E_T^{\rm miss}$	139	$\tilde{\chi}_1^\pm/\tilde{\chi}_2^0$ Forbidden	0.74	m($\tilde{\chi}_1^0$)=70 GeV	ATLAS-CONF-2019-019, 1909.09226
	$\tilde{\chi}_1^\pm\tilde{\chi}_1^\mp$ via $\tilde{\ell}_L/\tilde{\nu}$	2 e,μ		$E_T^{\rm miss}$	139	$\tilde{\chi}_1^\pm$	1.0	m($\tilde{\ell},\tilde{\nu}$)=0.5(m($\tilde{\chi}_1^\pm$)+m($\tilde{\chi}_1^0$))	ATLAS-CONF-2019-008
	$\tilde{\tau}\tilde{\tau}$, $\tilde{\tau}\to\tau\tilde{\chi}_1^0$	2 τ		$E_T^{\rm miss}$	139	$\tilde{\tau}$ [$\tilde{\tau}_L$, $\tilde{\tau}_{R,L}$]	0.16-0.3 0.12-0.39	m($\tilde{\chi}_1^0$)=0	ATLAS-CONF-2019-018
	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}$, $\tilde{\ell}\to\ell\tilde{\chi}_1^0$	2 e,μ	0 jets	$E_T^{\rm miss}$	139	$\tilde{\ell}$	0.7	m($\tilde{\chi}_1^0$)=0	ATLAS-CONF-2019-008
		2 e,μ	≥ 1	$E_T^{\rm miss}$	139	$\tilde{\ell}$	0.256	m($\tilde{\ell}$)-m($\tilde{\chi}_1^0$)=10 GeV	ATLAS-CONF-2019-014
	$\tilde{H}\tilde{H}$, $\tilde{H}\to h\tilde{G}/Z\tilde{G}$	0 e,μ	≥ 3 b	$E_T^{\rm miss}$	36.1	$\tilde{H}$	0.13-0.23 0.29-0.88	BR($\tilde{\chi}_1^0\to h\tilde{G}$)=1	1806.04030
		4 e,μ	0 jets	$E_T^{\rm miss}$	36.1	$\tilde{H}$	0.3	BR($\tilde{\chi}_1^0\to Z\tilde{G}$)=1	1804.03602
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	$E_T^{\rm miss}$	36.1	$\tilde{\chi}_1^\pm$	0.46	Pure Wino	1712.02118
						$\tilde{\chi}_1^\pm$	0.15	Pure Higgsino	ATL-PHYS-PUB-2017-019
	Stable $\tilde{g}$ R-hadron		Multiple		36.1	$\tilde{g}$	2.0		1902.01636,1808.04095
	Metastable $\tilde{g}$ R-hadron, $\tilde{g}\to qq\tilde{\chi}_1^0$		Multiple		36.1	$\tilde{g}$ [$\tau(\tilde{g})$ =10 ns, 0.2 ns]	2.05 2.4	m($\tilde{\chi}_1^0$)=100 GeV	1710.04901,1808.04095
RPV	LFV $pp\to\tilde{\nu}_\tau+X$, $\tilde{\nu}_\tau\to e\mu/e\tau/\mu\tau$	$e\mu,e\tau,\mu\tau$			3.2	$\tilde{\nu}_\tau$	1.9	λ'_{311}=0.11, $\lambda_{132/133/233}$=0.07	1607.08079
	$\tilde{\chi}_1^\pm\tilde{\chi}_1^\mp/\tilde{\chi}_2^0\to WW/Z\ell\ell\ell\ell\nu\nu$	4 e,μ	0 jets	$E_T^{\rm miss}$	36.1	$\tilde{\chi}_1^\pm/\tilde{\chi}_2^0$ [$\lambda_{i33}\neq 0, \lambda_{12k}\neq 0$]	0.82 1.33	m($\tilde{\chi}_1^0$)=100 GeV	1804.03602
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to qqq$		4-5 large-R jets		36.1	$\tilde{g}$ [m($\tilde{\chi}_1^0$)=200 GeV, 1100 GeV]	1.3 1.9	Large λ''_{112}	1804.03568
			Multiple		36.1	$\tilde{g}$ [λ''_{112}=2e-4, 2e-5]	1.05 2.0	m($\tilde{\chi}_1^0$)=200 GeV, bino-like	ATLAS-CONF-2018-003
	$\tilde{t}\tilde{t}$, $\tilde{t}\to t\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to tbs$		Multiple		36.1	$\tilde{g}$ [λ''_{323}=2e-4, 1e-2]	0.55 1.05	m($\tilde{\chi}_1^0$)=200 GeV, bino-like	ATLAS-CONF-2018-003
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to bs$		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	ATLAS-CONF-2019-006

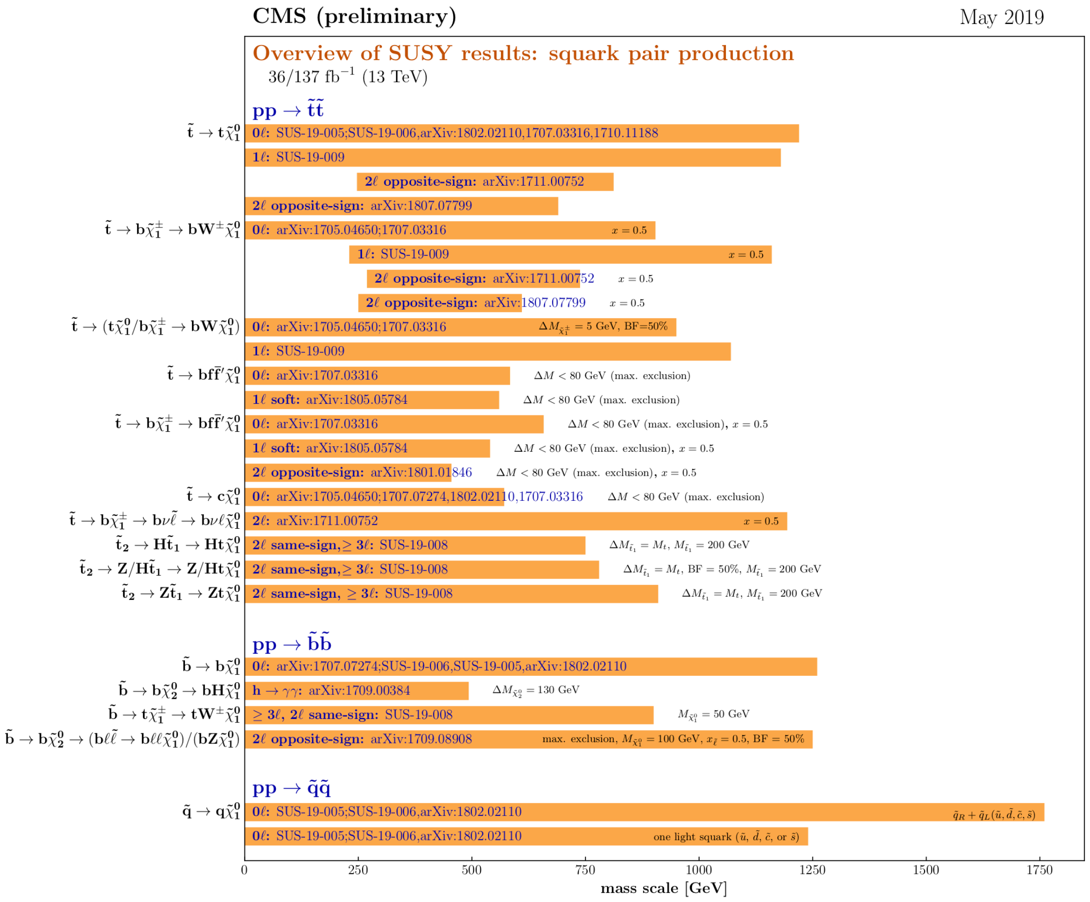
*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.

Susy results from CMS (1)



Selection of observed limits at 95% C.L. (theory uncertainties are not included). Probe **up to** the quoted mass limit for light LSPs unless stated otherwise. The quantities ΔM and x represent the absolute mass difference between the primary sparticle and the LSP, and the difference between the intermediate sparticle and the LSP relative to ΔM, respectively, unless indicated otherwise.

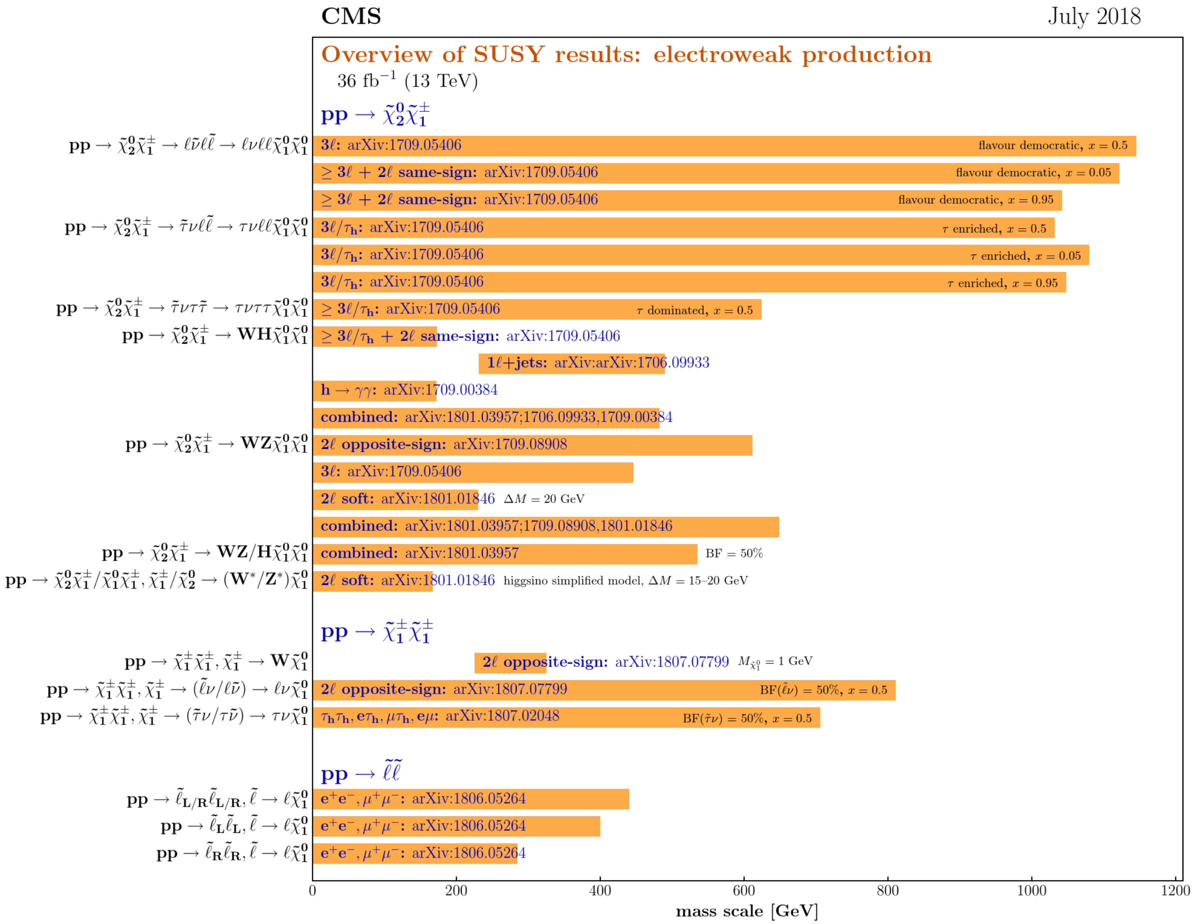
[4]



Selection of observed limits at 95% C.L. (theory uncertainties are not included). Probe **up to** the quoted mass limit for light LSPs unless stated otherwise. The quantities ΔM and x represent the absolute mass difference between the primary sparticle and the LSP, and the difference between the intermediate sparticle and the LSP relative to ΔM, respectively, unless indicated otherwise.

[4]

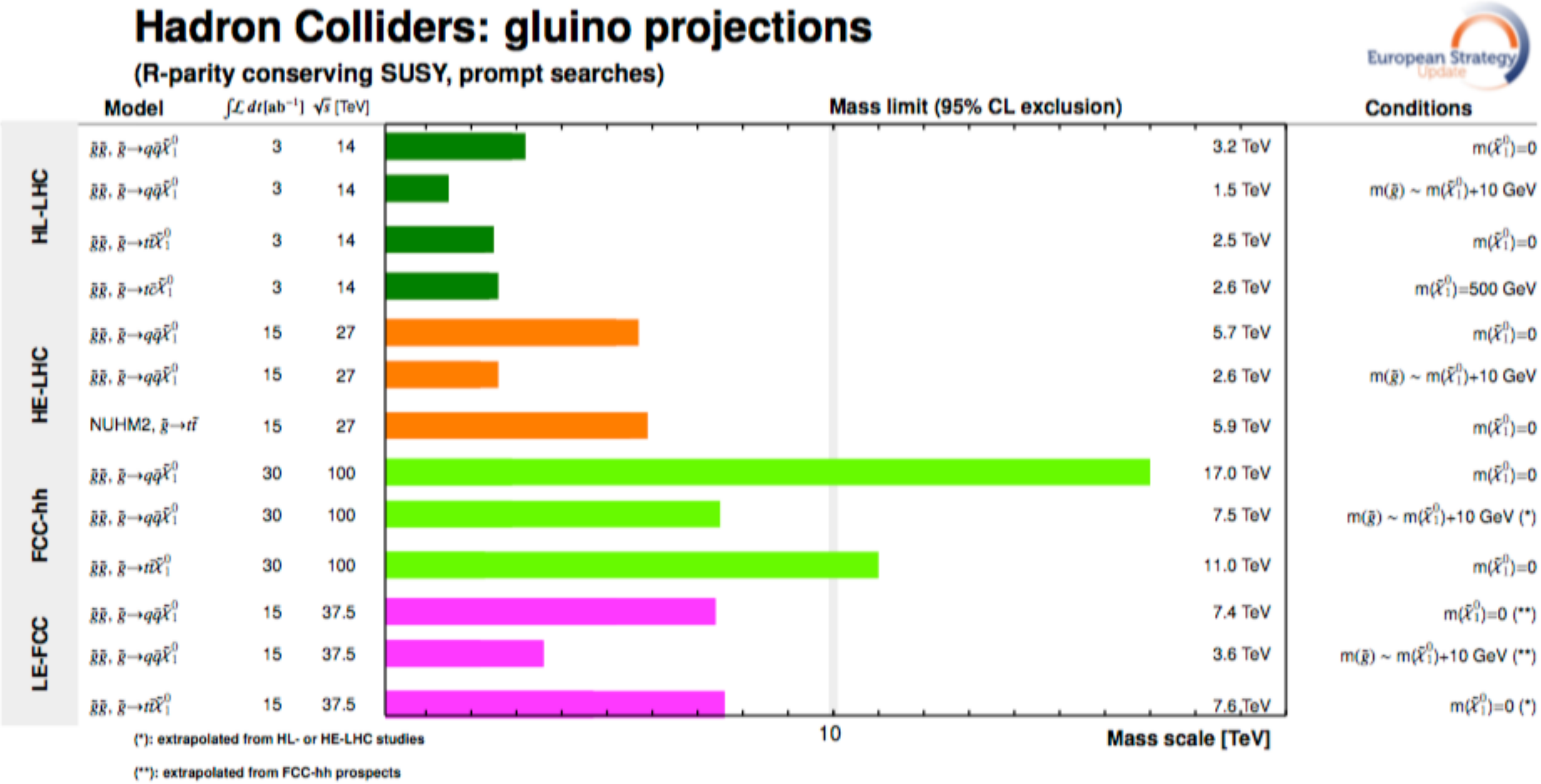
Susy results from CMS (2)



[4]

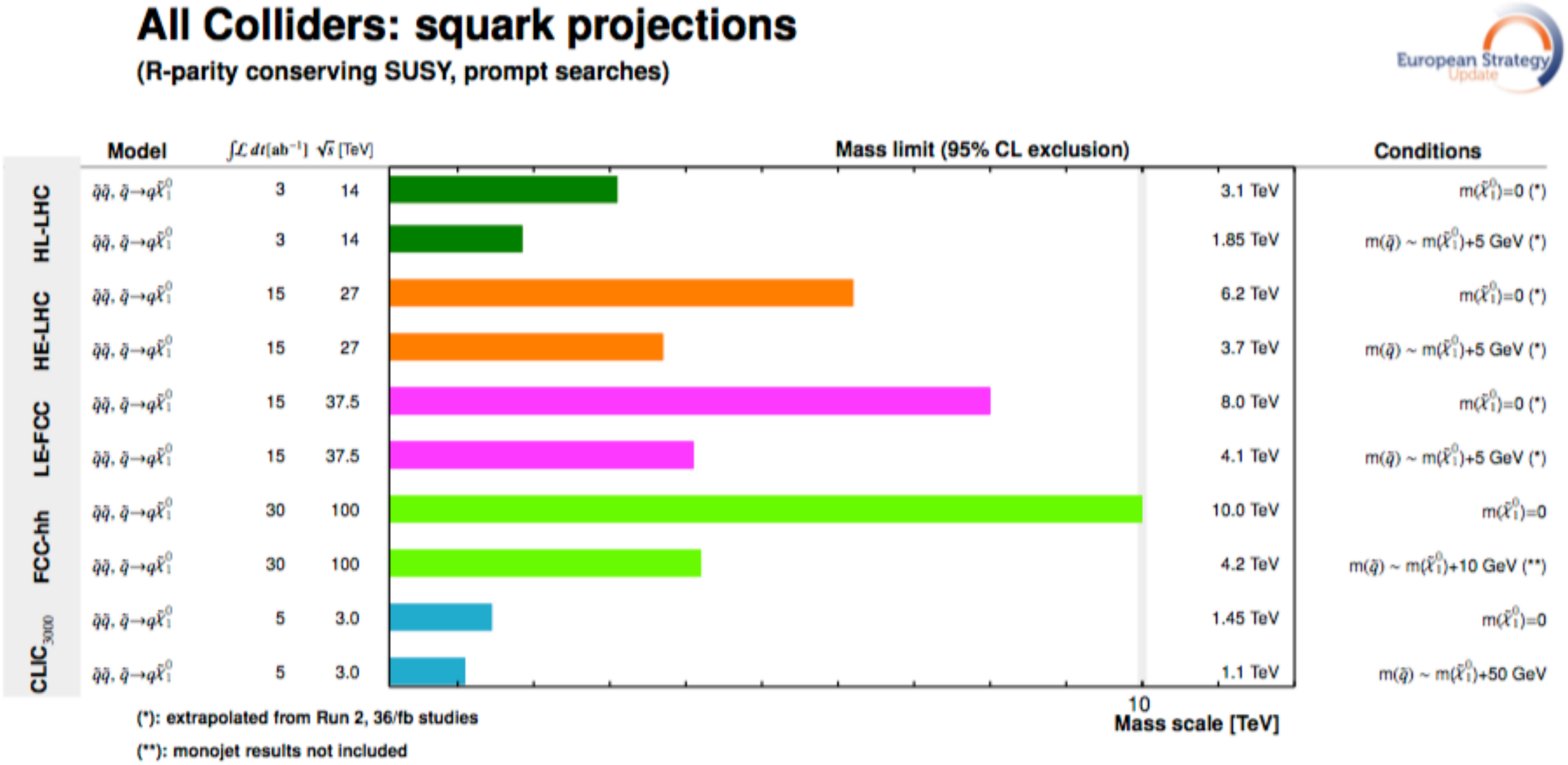
Selection of observed limits at 95% C.L. (theory uncertainties are not included). Probe **up to** the quoted mass limit for light LSPs unless stated otherwise. The quantities ΔM and x represent the absolute mass difference between the primary particle and the LSP, and the difference between the intermediate particle and the LSP relative to ΔM, respectively, unless indicated otherwise.

Summary plot for gluino searches



[3]

Summary plot for squarks of 1st and 2nd generations



All Colliders: squark projections

(R-parity conserving SUSY, prompt searches)

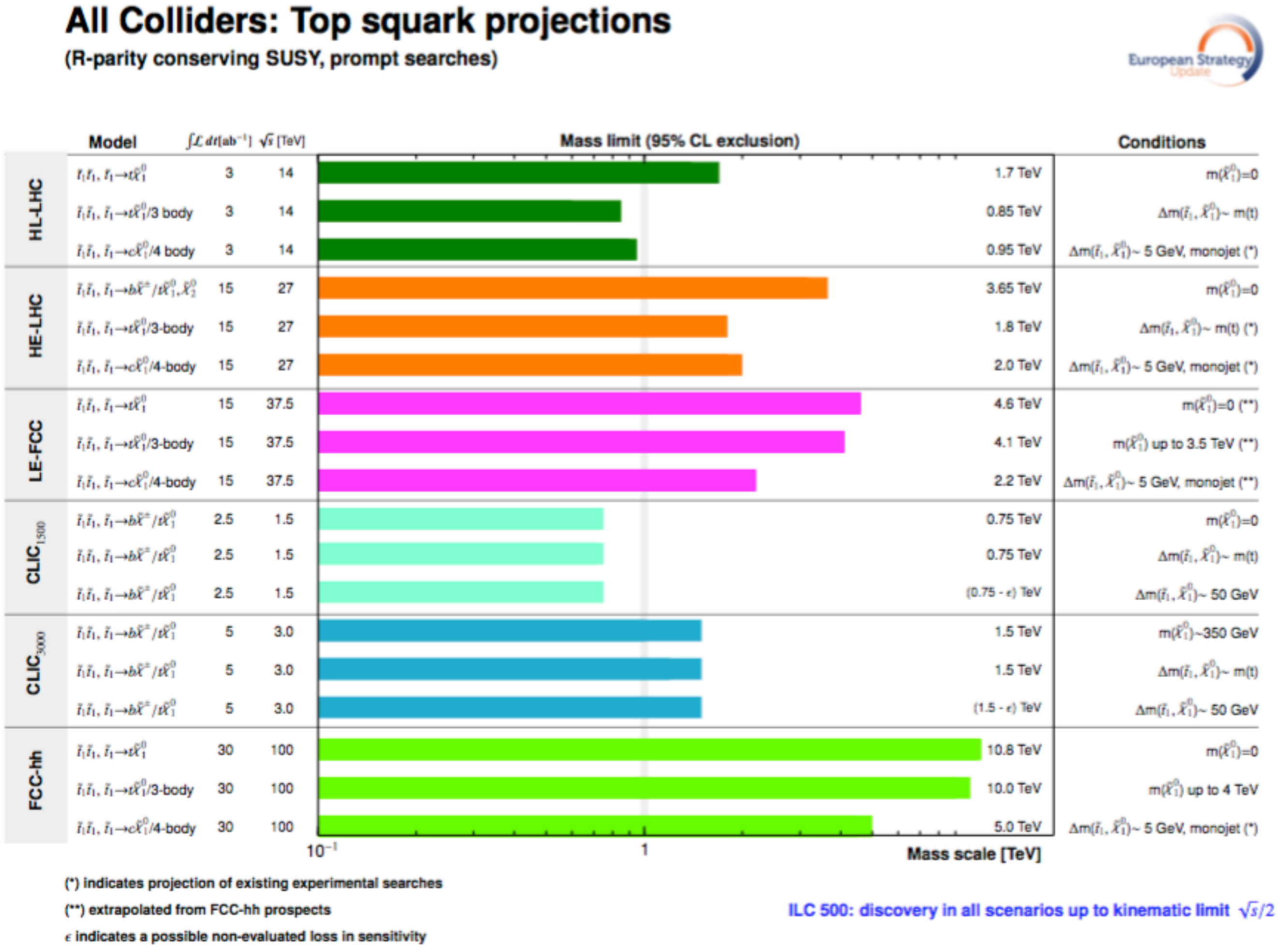
	Model	$\int\mathcal{L}\,dt[\mathrm{ab}^{-1}]$	$\sqrt{s}$ [TeV]	Mass limit (95% CL exclusion)	Conditions
HL-LHC	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$	3	14	3.1 TeV	$m(\tilde{\chi}_1^0)=0$ (*)
	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$	3	14	1.85 TeV	$m(\tilde{q}) \sim m(\tilde{\chi}_1^0)+5$ GeV (*)
HE-LHC	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$	15	27	6.2 TeV	$m(\tilde{\chi}_1^0)=0$ (*)
	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$	15	27	3.7 TeV	$m(\tilde{q}) \sim m(\tilde{\chi}_1^0)+5$ GeV (*)
LE-FCC	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$	15	37.5	8.0 TeV	$m(\tilde{\chi}_1^0)=0$ (*)
	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$	15	37.5	4.1 TeV	$m(\tilde{q}) \sim m(\tilde{\chi}_1^0)+5$ GeV (*)
FCC-hh	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$	30	100	10.0 TeV	$m(\tilde{\chi}_1^0)=0$
	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$	30	100	4.2 TeV	$m(\tilde{q}) \sim m(\tilde{\chi}_1^0)+10$ GeV (**)
CLIC_{3000}	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$	5	3.0	1.45 TeV	$m(\tilde{\chi}_1^0)=0$
	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$	5	3.0	1.1 TeV	$m(\tilde{q}) \sim m(\tilde{\chi}_1^0)+50$ GeV

(*): extrapolated from Run 2, 36/fb studies

(**): monojet results not included

[3]

Summary plot for stops



All Colliders: Top squark projections

(R-parity conserving SUSY, prompt searches)

	Model	$\int\mathcal{L}\,dt$[ab^{-1}]	$\sqrt{s}$ [TeV]	Mass limit (95% CL exclusion)	Conditions
HL-LHC	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to t\tilde{\chi}^0_1$	3	14	1.7 TeV	m($\tilde{\chi}^0_1$)=0
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to t\tilde{\chi}^0_1$/3 body	3	14	0.85 TeV	Δm($\tilde{t}_1$, $\tilde{\chi}^0_1$)~ m(t)
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to c\tilde{\chi}^0_1$/4 body	3	14	0.95 TeV	Δm($\tilde{t}_1$, $\tilde{\chi}^0_1$)~ 5 GeV, monojet (*)
HE-LHC	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\tilde{\chi}^\pm/t\tilde{\chi}^0_1,\tilde{\chi}^0_2$	15	27	3.65 TeV	m($\tilde{\chi}^0_1$)=0
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to t\tilde{\chi}^0_1$/3-body	15	27	1.8 TeV	Δm($\tilde{t}_1$, $\tilde{\chi}^0_1$)~ m(t) (*)
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to c\tilde{\chi}^0_1$/4-body	15	27	2.0 TeV	Δm($\tilde{t}_1$, $\tilde{\chi}^0_1$)~ 5 GeV, monojet (*)
LE-FCC	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to t\tilde{\chi}^0_1$	15	37.5	4.6 TeV	m($\tilde{\chi}^0_1$)=0 (**)
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to t\tilde{\chi}^0_1$/3-body	15	37.5	4.1 TeV	m($\tilde{\chi}^0_1$) up to 3.5 TeV (**)
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to c\tilde{\chi}^0_1$/4-body	15	37.5	2.2 TeV	Δm($\tilde{t}_1$, $\tilde{\chi}^0_1$)~ 5 GeV, monojet (**)
CLIC$_{1500}$	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\tilde{\chi}^\pm/t\tilde{\chi}^0_1$	2.5	1.5	0.75 TeV	m($\tilde{\chi}^0_1$)=0
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\tilde{\chi}^\pm/t\tilde{\chi}^0_1$	2.5	1.5	0.75 TeV	Δm($\tilde{t}_1$, $\tilde{\chi}^0_1$)~ m(t)
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\tilde{\chi}^\pm/t\tilde{\chi}^0_1$	2.5	1.5	(0.75 - ϵ) TeV	Δm($\tilde{t}_1$, $\tilde{\chi}^0_1$)~ 50 GeV
CLIC$_{3000}$	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\tilde{\chi}^\pm/t\tilde{\chi}^0_1$	5	3.0	1.5 TeV	m($\tilde{\chi}^0_1$)~350 GeV
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\tilde{\chi}^\pm/t\tilde{\chi}^0_1$	5	3.0	1.5 TeV	Δm($\tilde{t}_1$, $\tilde{\chi}^0_1$)~ m(t)
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\tilde{\chi}^\pm/t\tilde{\chi}^0_1$	5	3.0	(1.5 - ϵ) TeV	Δm($\tilde{t}_1$, $\tilde{\chi}^0_1$)~ 50 GeV
FCC-hh	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to t\tilde{\chi}^0_1$	30	100	10.8 TeV	m($\tilde{\chi}^0_1$)=0
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to t\tilde{\chi}^0_1$/3-body	30	100	10.0 TeV	m($\tilde{\chi}^0_1$) up to 4 TeV
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to c\tilde{\chi}^0_1$/4-body	30	100	5.0 TeV	Δm($\tilde{t}_1$, $\tilde{\chi}^0_1$)~ 5 GeV, monojet (*)

(*) indicates projection of existing experimental searches

(**) extrapolated from FCC-hh prospects

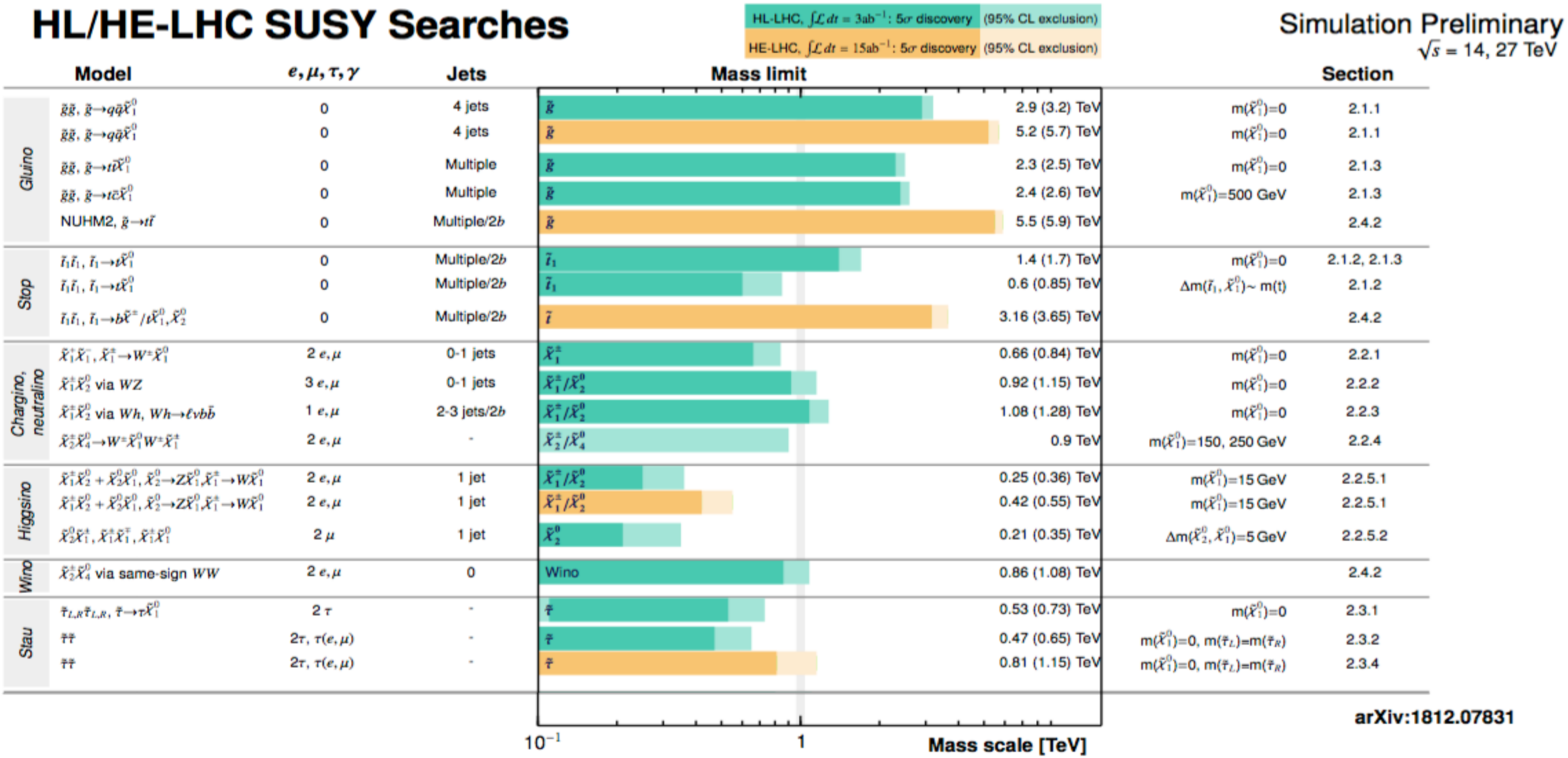
ϵ indicates a possible non-evaluated loss in sensitivity

ILC 500: discovery in all scenarios up to kinematic limit $\sqrt{s}/2$

Fig. 8.8: Top squark exclusion reach of different hadron and lepton colliders. All references are reported in the text. Results for CLIC have been communicated privately by the authors. Results for LE-FCC are extrapolated from HL- and HE-LHC studies.

[3]

Summary plot for HL/HE-LHC SUSY Searches



HL/HE-LHC SUSY Searches

HL-LHC, $\int\mathcal{L}dt = 3\mathrm{ab}^{-1}$: 5σ discovery (95% CL exclusion)

HE-LHC, $\int\mathcal{L}dt = 15\mathrm{ab}^{-1}$: 5σ discovery (95% CL exclusion)

Simulation Preliminary
$\sqrt{s}$ = 14, 27 TeV

	Model	e, μ, τ, γ	Jets	Mass limit			Section
Gluino	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow q\bar{q}\tilde{\chi}_1^0$	0	4 jets	$\tilde{g}$	2.9 (3.2) TeV	m($\tilde{\chi}_1^0$)=0	2.1.1
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow q\bar{q}\tilde{\chi}_1^0$	0	4 jets	$\tilde{g}$	5.2 (5.7) TeV	m($\tilde{\chi}_1^0$)=0	2.1.1
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow t\bar{t}\tilde{\chi}_1^0$	0	Multiple	$\tilde{g}$	2.3 (2.5) TeV	m($\tilde{\chi}_1^0$)=0	2.1.3
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow t\bar{c}\tilde{\chi}_1^0$	0	Multiple	$\tilde{g}$	2.4 (2.6) TeV	m($\tilde{\chi}_1^0$)=500 GeV	2.1.3
	NUHM2, $\tilde{g}\rightarrow t\tilde{t}$	0	Multiple/2b	$\tilde{g}$	5.5 (5.9) TeV		2.4.2
Stop	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\rightarrow t\tilde{\chi}_1^0$	0	Multiple/2b	$\tilde{t}_1$	1.4 (1.7) TeV	m($\tilde{\chi}_1^0$)=0	2.1.2, 2.1.3
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\rightarrow t\tilde{\chi}_1^0$	0	Multiple/2b	$\tilde{t}_1$	0.6 (0.85) TeV	Δm($\tilde{t}_1$, $\tilde{\chi}_1^0$)~ m(t)	2.1.2
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\rightarrow b\tilde{\chi}^\pm/t\tilde{\chi}_1^0,\tilde{\chi}_2^0$	0	Multiple/2b	$\tilde{t}$	3.16 (3.65) TeV		2.4.2
Chargino, neutralino	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^\pm\rightarrow W^\pm\tilde{\chi}_1^0$	2 e, μ	0-1 jets	$\tilde{\chi}_1^\pm$	0.66 (0.84) TeV	m($\tilde{\chi}_1^0$)=0	2.2.1
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ via WZ	3 e, μ	0-1 jets	$\tilde{\chi}_1^\pm/\tilde{\chi}_2^0$	0.92 (1.15) TeV	m($\tilde{\chi}_1^0$)=0	2.2.2
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ via Wh, $Wh\rightarrow\ell\nu b\bar{b}$	1 e, μ	2-3 jets/2b	$\tilde{\chi}_1^\pm/\tilde{\chi}_2^0$	1.08 (1.28) TeV	m($\tilde{\chi}_1^0$)=0	2.2.3
	$\tilde{\chi}_2^\pm\tilde{\chi}_4^0\rightarrow W^\pm\tilde{\chi}_1^0 W^\pm\tilde{\chi}_1^\pm$	2 e, μ	-	$\tilde{\chi}_2^\pm/\tilde{\chi}_4^0$	0.9 TeV	m($\tilde{\chi}_1^0$)=150, 250 GeV	2.2.4
Higgsino	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0+\tilde{\chi}_2^0\tilde{\chi}_1^0$, $\tilde{\chi}_2^0\rightarrow Z\tilde{\chi}_1^0$,$\tilde{\chi}_1^\pm\rightarrow W\tilde{\chi}_1^0$	2 e, μ	1 jet	$\tilde{\chi}_1^\pm/\tilde{\chi}_2^0$	0.25 (0.36) TeV	m($\tilde{\chi}_1^0$)=15 GeV	2.2.5.1
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0+\tilde{\chi}_2^0\tilde{\chi}_1^0$, $\tilde{\chi}_2^0\rightarrow Z\tilde{\chi}_1^0$,$\tilde{\chi}_1^\pm\rightarrow W\tilde{\chi}_1^0$	2 e, μ	1 jet	$\tilde{\chi}_1^\pm/\tilde{\chi}_2^0$	0.42 (0.55) TeV	m($\tilde{\chi}_1^0$)=15 GeV	2.2.5.1
	$\tilde{\chi}_2^0\tilde{\chi}_1^\pm$, $\tilde{\chi}_1^\pm\tilde{\chi}_1^\mp$, $\tilde{\chi}_1^\pm\tilde{\chi}_1^0$	2 μ	1 jet	$\tilde{\chi}_2^0$	0.21 (0.35) TeV	Δm($\tilde{\chi}_2^0$, $\tilde{\chi}_1^0$)=5 GeV	2.2.5.2
Wino	$\tilde{\chi}_2^\pm\tilde{\chi}_4^0$ via same-sign WW	2 e, μ	0	Wino	0.86 (1.08) TeV		2.4.2
Stau	$\tilde{\tau}_{L,R}\tilde{\tau}_{L,R}$, $\tilde{\tau}\rightarrow\tau\tilde{\chi}_1^0$	2 τ	-	$\tilde{\tau}$	0.53 (0.73) TeV	m($\tilde{\chi}_1^0$)=0	2.3.1
	$\tilde{\tau}\tilde{\tau}$	2τ, $\tau(e, \mu)$	-	$\tilde{\tau}$	0.47 (0.65) TeV	m($\tilde{\chi}_1^0$)=0, m($\tilde{\tau}_L$)=m($\tilde{\tau}_R$)	2.3.2
	$\tilde{\tau}\tilde{\tau}$	2τ, $\tau(e, \mu)$	-	$\tilde{\tau}$	0.81 (1.15) TeV	m($\tilde{\chi}_1^0$)=0, m($\tilde{\tau}_L$)=m($\tilde{\tau}_R$)	2.3.4

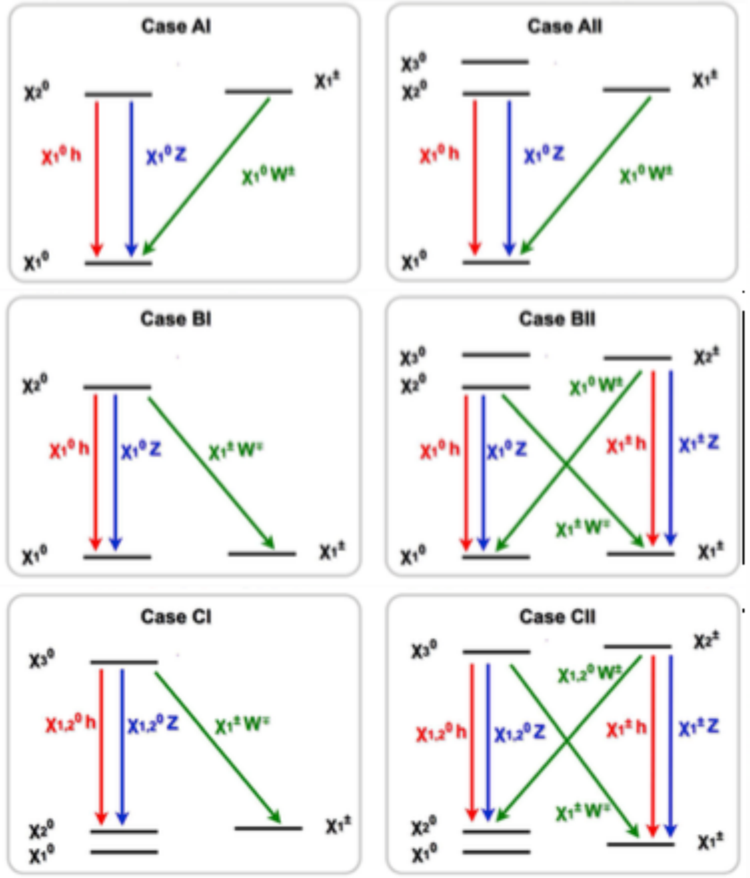
arXiv:1812.07831

[1]

Phenomenology

[6]

- Mass and hierarchy of the four neutralinos and the two charginos, as well as their production cross sections and decay modes, depend on the M_1, M_2, μ (bino, wino, higgsino) values and hierarchy
  - EWK phenomenology broadly driven by the LSP and Next-LSP nature
  - Examples of classifications (cf: arXiV: 1309.5966)



- **Scenario A:** $M_1 < M_2, |\mu|$

Bino LSP

- **Scenario B:** $M_2 < M_1, |\mu|$

Wino LSP

- **Scenario C:** $|\mu| < M_1, M_2$

Higgsino LSP

Used as benchmarks:

- Bino LSP, wino-bino cross sections
  (1) Mass($\chi^{\pm}_1$) = Mass (χ^0_2)
  (2) $\chi^+_1\chi^-_1$ and $\chi^{\pm}_1\chi^0_2$ processes

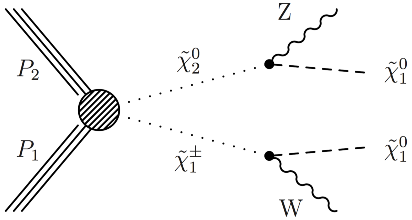
$$\sigma_W(\chi^{\pm}_1\chi^0_2) \sim 2\ \sigma_W(\chi^+_1\chi^-_1)$$

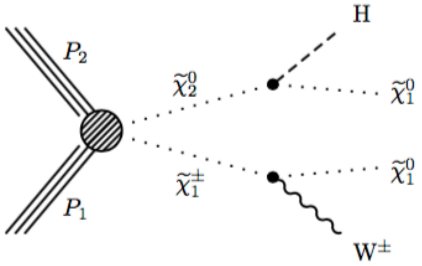
- Higgsino-LSP, higgsino-like cross sections
  (1) Small mass splitting $\chi^0_1, \chi^{\pm}_1, \chi^0_2$
  (2) Consider triplets for cross sections
  (3) Role of high-multiplicity neutralinos and charginos also relevant

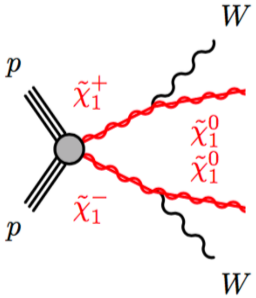
$$\sigma_H(\chi^{\pm}_1\chi^0_2 + \chi^+_1\chi^-_1 + \chi^{\pm}_1\chi^0_1) < 0.7\ \sigma_W(\chi^{\pm}_1\chi^0_2)$$

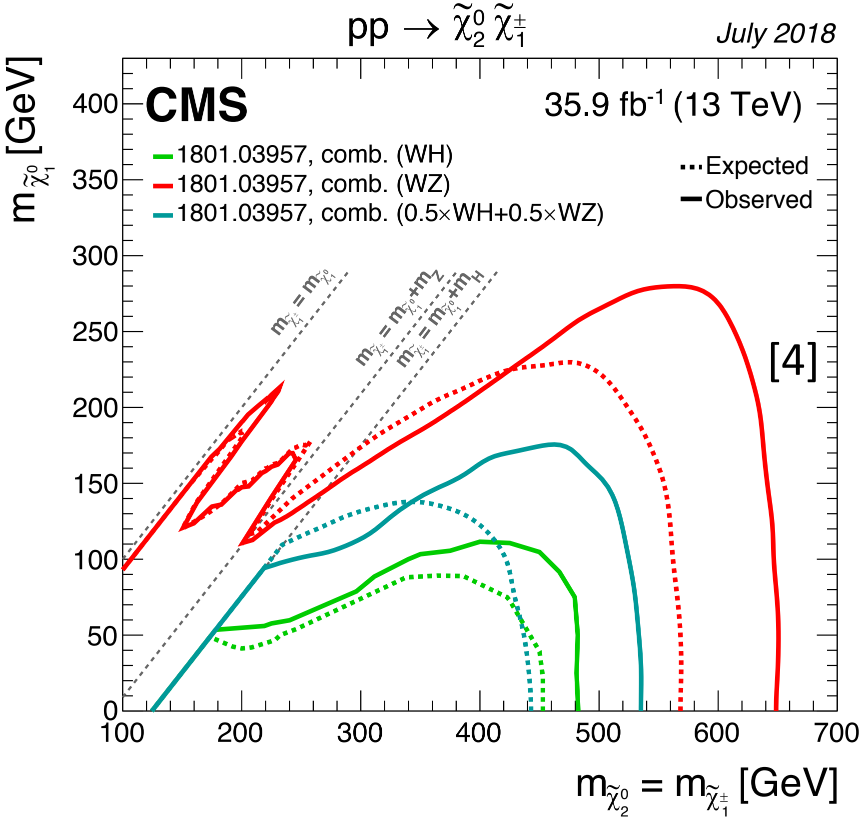
[depending on collider type and masses!]

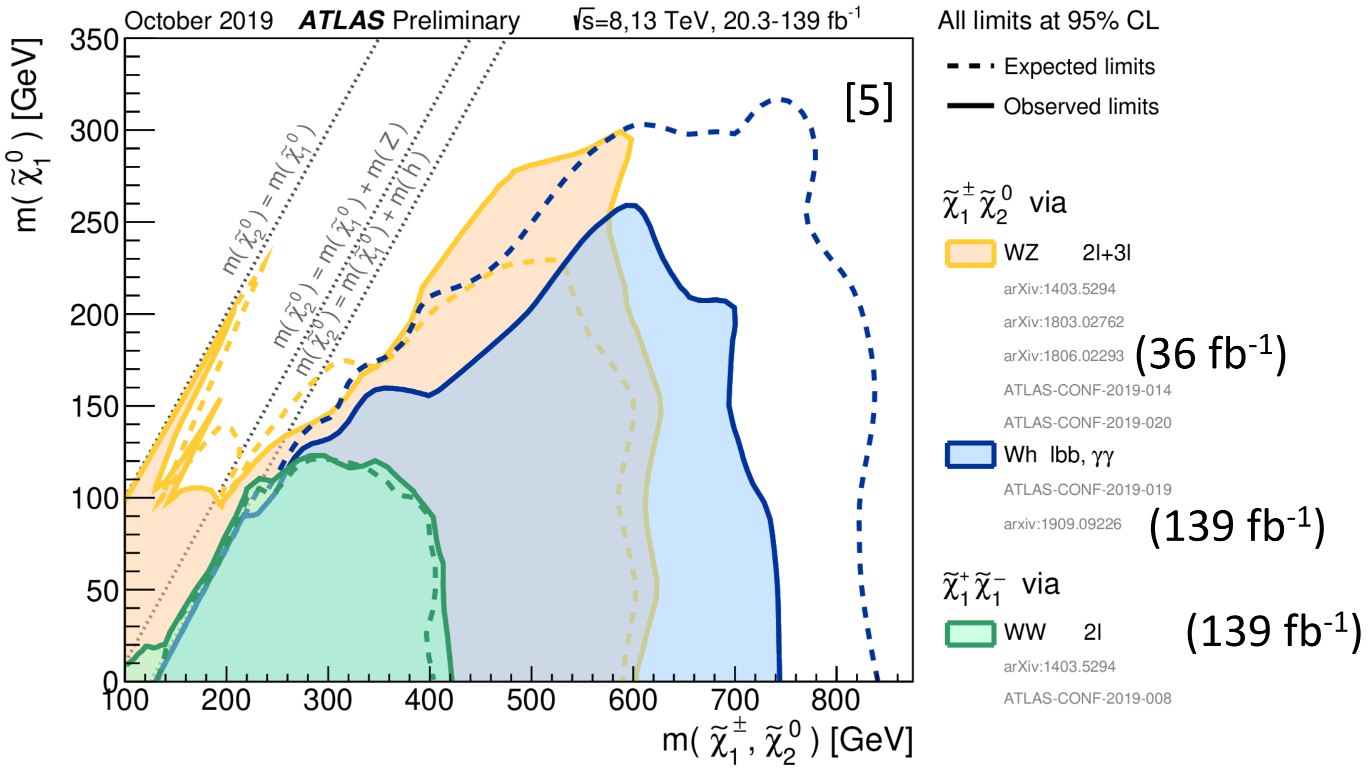
Actual limit from LHC for ewkino









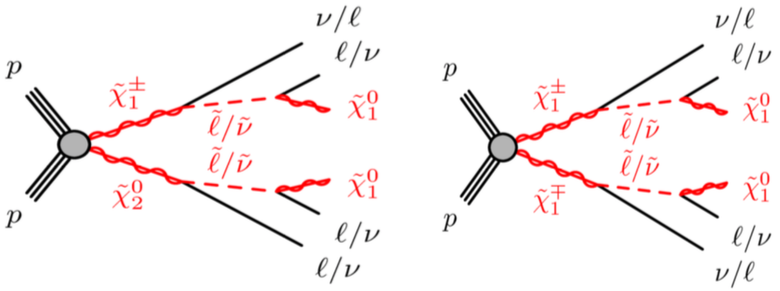


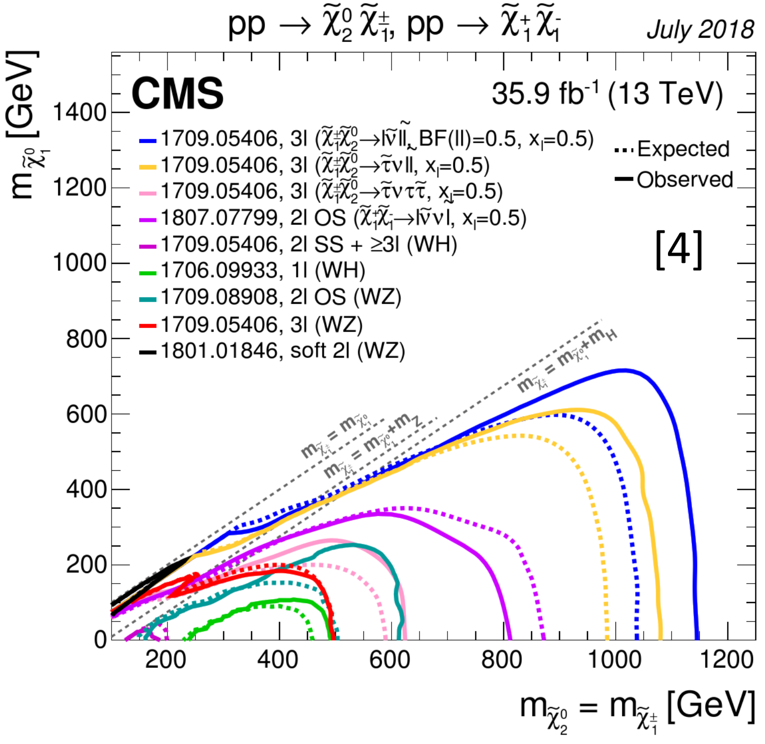
($36\ fb^{-1}$)

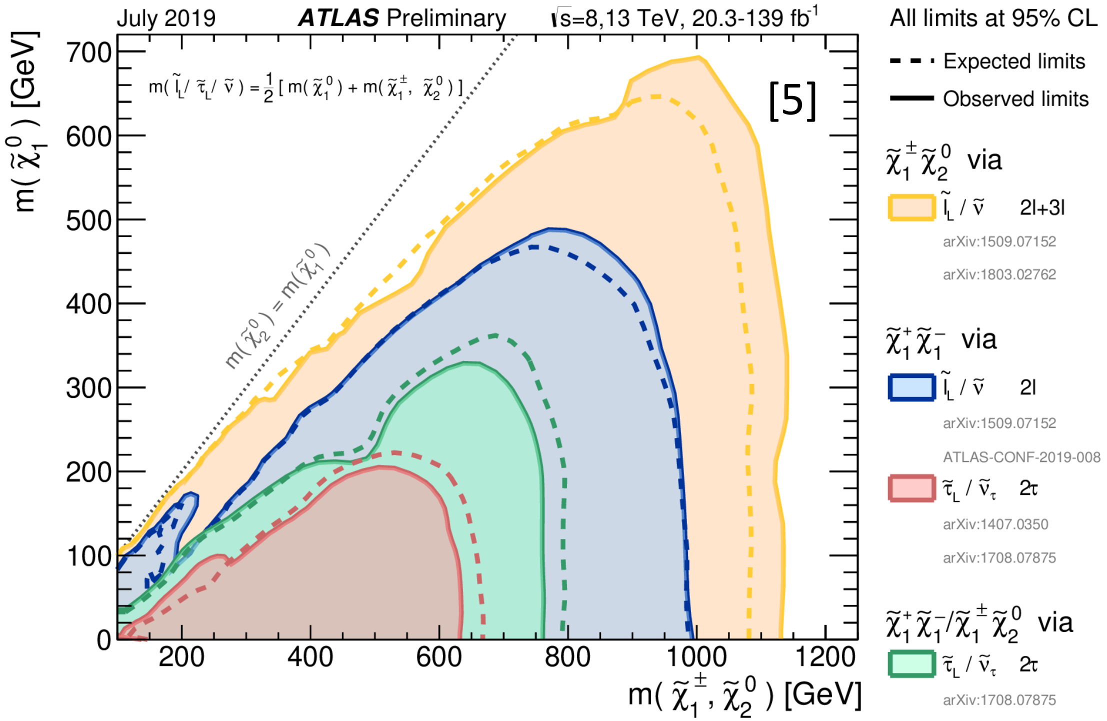
($139\ fb^{-1}$)

($139\ fb^{-1}$)

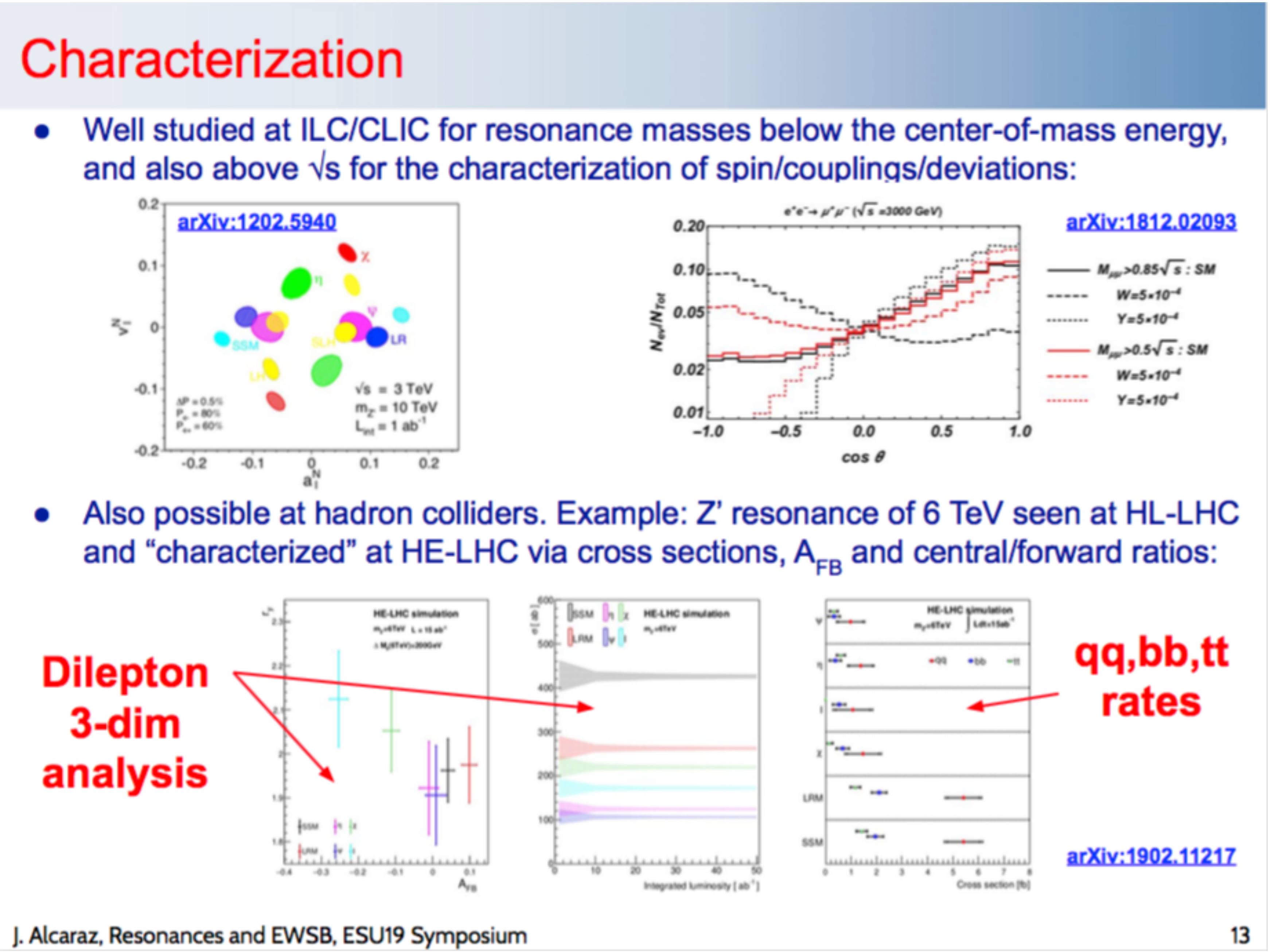
Actual limit from LHC for ewkino







More on Resonances…



Characterization

- Well studied at ILC/CLIC for resonance masses below the center-of-mass energy, and also above √s for the characterization of spin/couplings/deviations:

- Also possible at hadron colliders. Example: Z' resonance of 6 TeV seen at HL-LHC and "characterized" at HE-LHC via cross sections, A_{FB} and central/forward ratios:

Dilepton 3-dim analysis

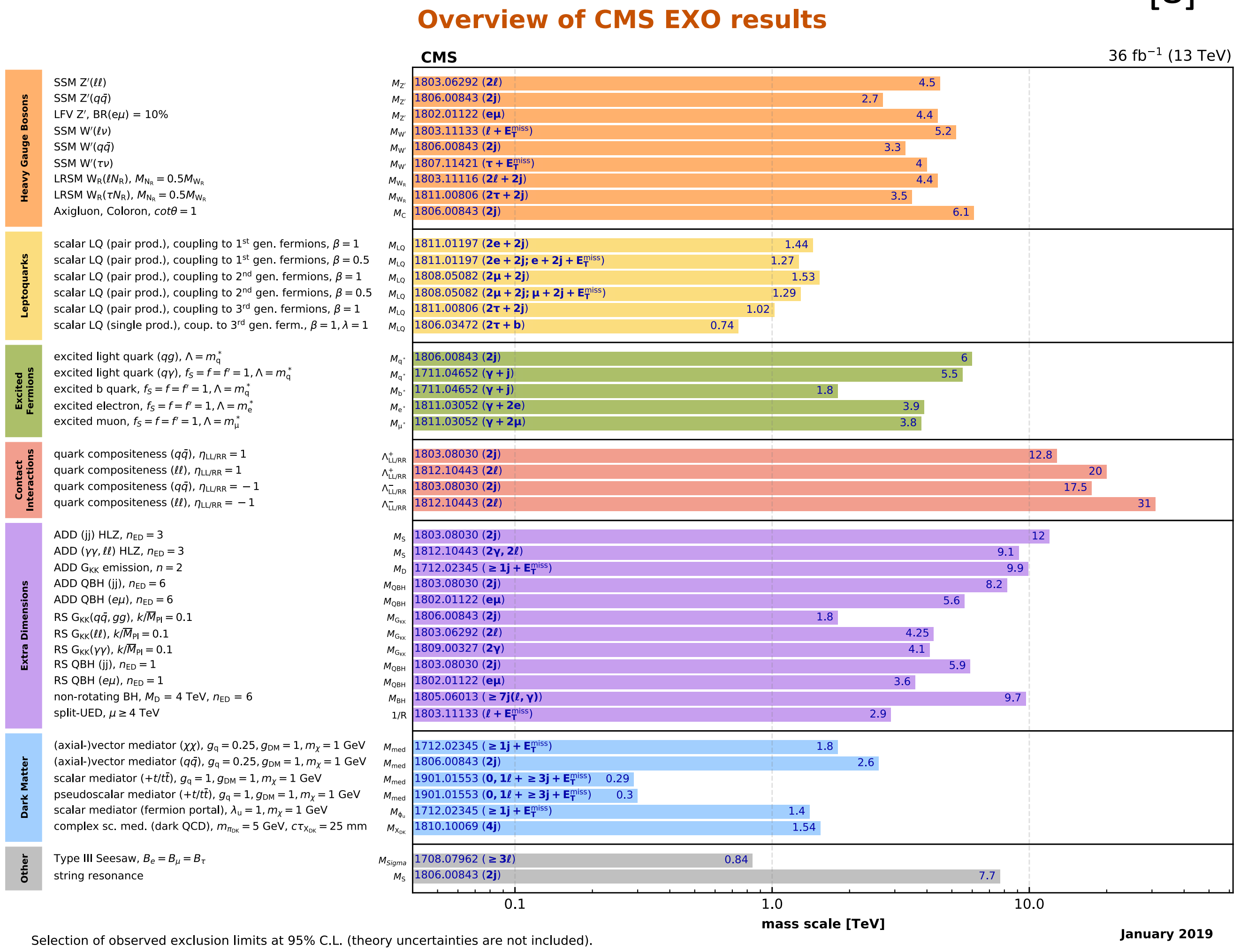
qq,bb,tt rates

J. Alcaraz, Resonances and EWSB, ESU19 Symposium

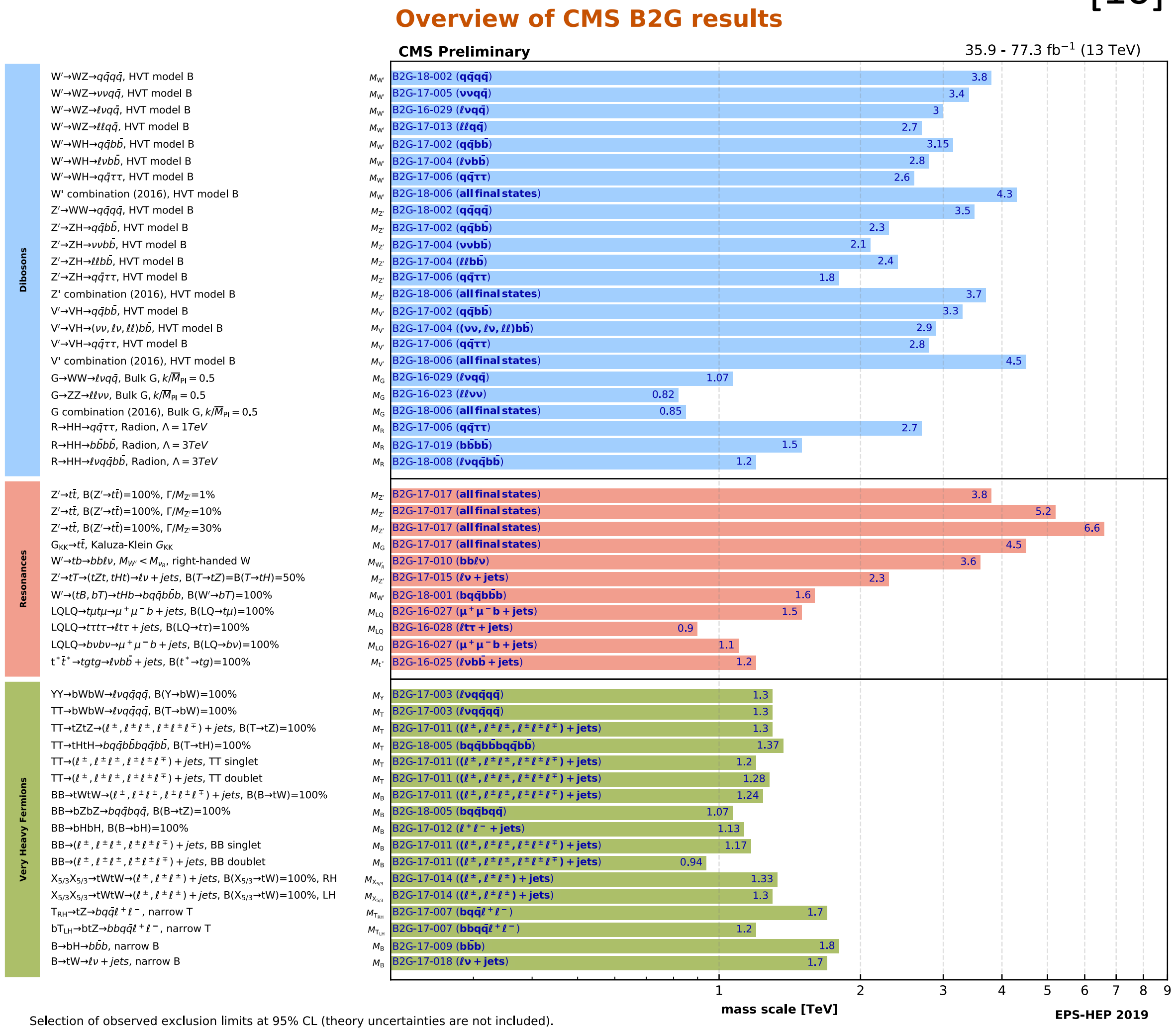
13

Exo Results from CMS

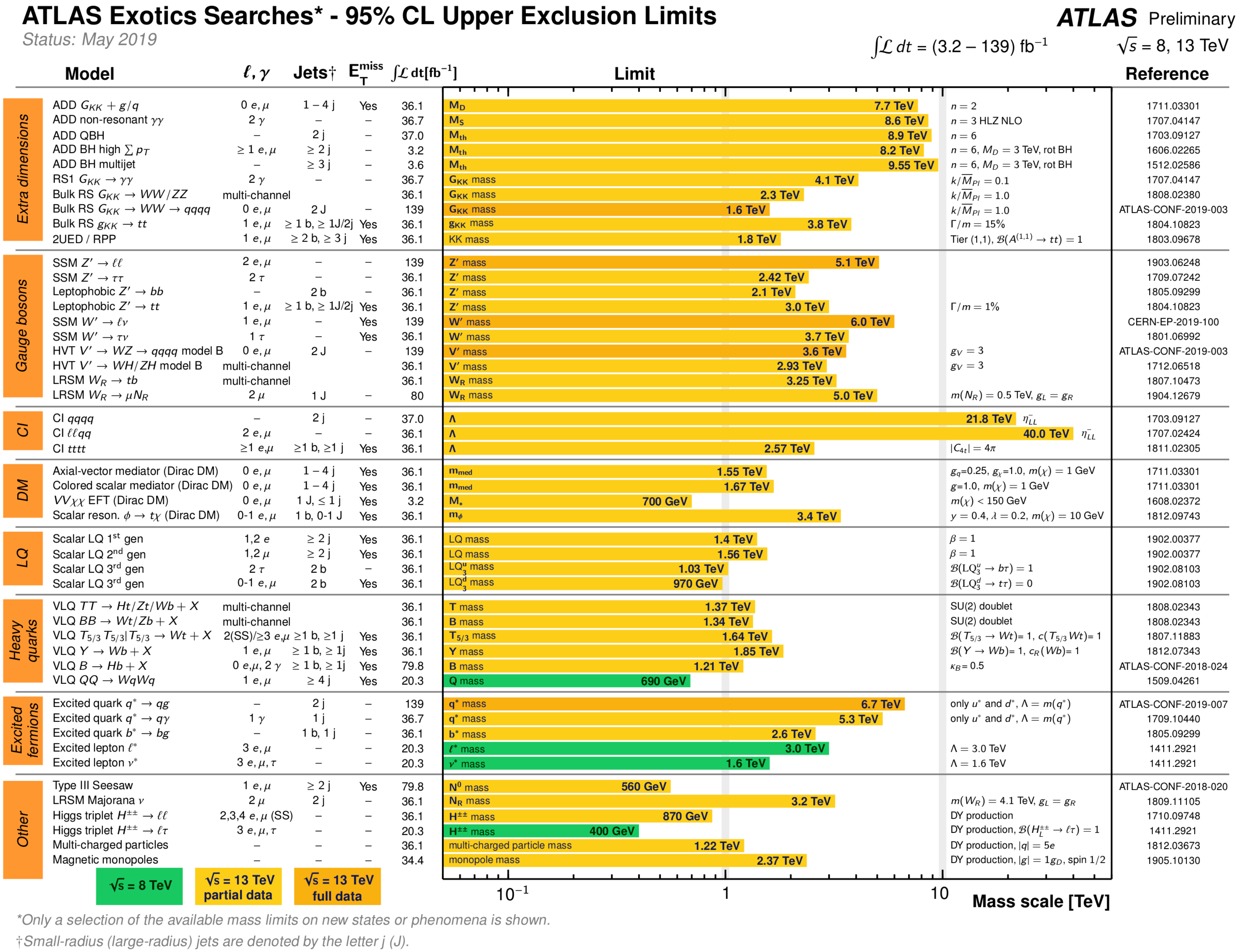
[8]



[10]



[9]



ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: May 2019

ATLAS Preliminary

$\int \mathcal{L}\, dt = (3.2 – 139)\ \mathrm{fb}^{-1}$

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

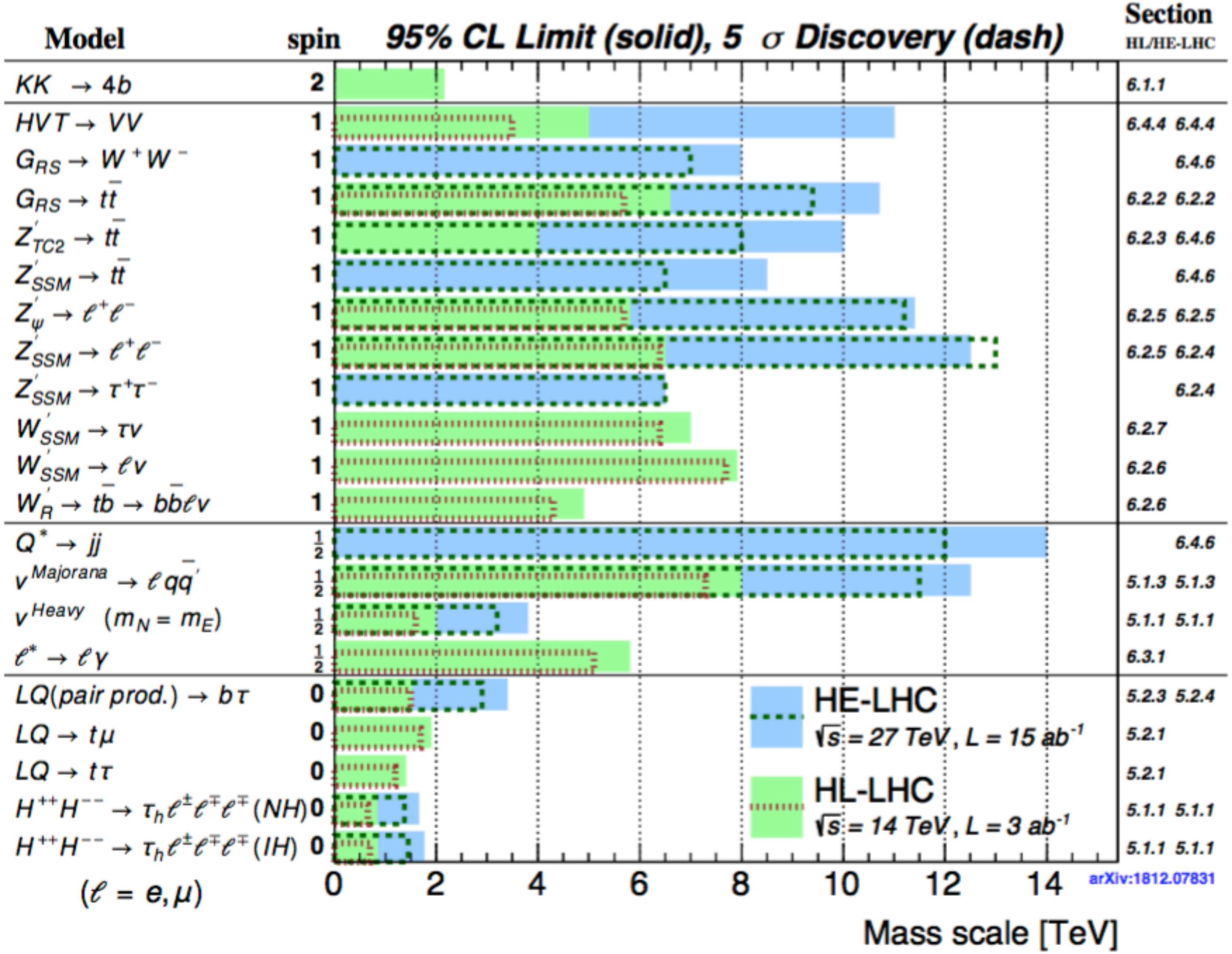
	Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L}\, dt[\mathrm{fb}^{-1}]$	Limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	0 e, μ	1 – 4 j	Yes	36.1	🟨 M_D 7.7 TeV	$n = 2$	1711.03301
	ADD non-resonant $\gamma\gamma$	2 γ	–	–	36.7	🟨 M_S 8.6 TeV	$n = 3$ HLZ NLO	1707.04147
	ADD QBH	–	2 j	–	37.0	🟨 M_{th} 8.9 TeV	$n = 6$	1703.09127
	ADD BH high $\sum p_T$	≥ 1 e, μ	≥ 2 j	–	3.2	🟨 M_{th} 8.2 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1606.02265
	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 γ	–	–	36.7	🟨 G_{KK} mass 4.1 TeV	$k/\overline{M}_{Pl} = 0.1$	1707.04147
	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 $G_{KK} \to WW \to qqqq$	0 e, μ	2 J	–	139	🟧 G_{KK} mass 1.6 TeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2019-003
	Bulk RS $g_{KK} \to tt$	1 e, μ	≥ 1 b, $\geq$ 1J/2j	Yes	36.1	🟨 g_{KK} mass 3.8 TeV	$\Gamma/m = 15\%$	1804.10823
	2UED / RPP	1 e, μ	≥ 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, μ	–	–	139	🟧 Z' mass 5.1 TeV		1903.06248
	SSM $Z' \to \tau\tau$	2 τ	–	–	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 $Z' \to tt$	1 e, μ	≥ 1 b, $\geq$ 1J/2j	Yes	36.1	🟨 Z' mass 3.0 TeV	$\Gamma/m = 1\%$	1804.10823
	SSM $W' \to \ell\nu$	1 e, μ	–	Yes	139	🟧 W' mass 6.0 TeV		CERN-EP-2019-100
	SSM $W' \to \tau\nu$	1 τ	–	Yes	36.1	🟨 W' mass 3.7 TeV		1801.06992
	HVT $V' \to WZ \to qqqq$ model B	0 e, μ	2 J	–	139	🟧 V' mass 3.6 TeV	$g_V = 3$	ATLAS-CONF-2019-003
	HVT $V' \to WH/ZH$ model B	multi-channel			36.1	🟨 V' mass 2.93 TeV	$g_V = 3$	1712.06518
	LRSM $W_R \to tb$	multi-channel			36.1	🟨 W_R mass 3.25 TeV		1807.10473
	LRSM $W_R \to \mu N_R$	2 μ	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, μ	–	–	36.1	🟨 Λ 40.0 TeV η_{LL}^-		1707.02424
	CI $tttt$	$\geq$1 e,μ	$\geq$1 b, $\geq$1 j	Yes	36.1	🟨 Λ 2.57 TeV	$\lvert C_{4t}\rvert = 4\pi$	1811.02305
DM	Axial-vector mediator (Dirac DM)	0 e, μ	1 – 4 j	Yes	36.1	🟨 m_{med} 1.55 TeV	g_q=0.25, g_χ=1.0, $m(\chi) = 1$ GeV	1711.03301
	Colored scalar mediator (Dirac DM)	0 e, μ	1 – 4 j	Yes	36.1	🟨 m_{med} 1.67 TeV	g=1.0, $m(\chi) = 1$ GeV	1711.03301
	$VV\chi\chi$ EFT (Dirac DM)	0 e, μ	1 J, ≤ 1 j	Yes	3.2	🟨 M_* 700 GeV	$m(\chi) < 150$ GeV	1608.02372
	Scalar reson. $\phi \to t\chi$ (Dirac DM)	0-1 e, μ	1 b, 0-1 J	Yes	36.1	🟨 m_ϕ 3.4 TeV	$y = 0.4$, $\lambda = 0.2$, $m(\chi) = 10$ GeV	1812.09743
LQ	Scalar LQ 1st gen	1,2 e	≥ 2 j	Yes	36.1	🟨 LQ mass 1.4 TeV	$\beta = 1$	1902.00377
	Scalar LQ 2nd gen	1,2 μ	≥ 2 j	Yes	36.1	🟨 LQ mass 1.56 TeV	$\beta = 1$	1902.00377
	Scalar LQ 3rd gen	2 τ	2 b	–	36.1	🟨 LQ_3^u mass 1.03 TeV	$\mathcal{B}(\mathrm{LQ}_3^u \to b\tau) = 1$	1902.08103
	Scalar LQ 3rd gen	0-1 e, μ	2 b	Yes	36.1	🟨 LQ_3^d mass 970 GeV	$\mathcal{B}(\mathrm{LQ}_3^d \to t\tau) = 0$	1902.08103
Heavy quarks	VLQ $TT \to Ht/Zt/Wb + X$	multi-channel			36.1	🟨 T mass 1.37 TeV	SU(2) doublet	1808.02343
	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)/$\geq$3 e,μ	$\geq$1 b, $\geq$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 $Y \to Wb + X$	1 e, μ	≥ 1 b, $\geq$ 1j	Yes	36.1	🟨 Y mass 1.85 TeV	$\mathcal{B}(Y \to Wb)$= 1, $c_R(Wb)$= 1	1812.07343
	VLQ $B \to Hb + X$	0 e,μ, 2 γ	≥ 1 b, $\geq$ 1j	Yes	79.8	🟨 B mass 1.21 TeV	κ_B= 0.5	ATLAS-CONF-2018-024
	VLQ $QQ \to WqWq$	1 e, μ	≥ 4 j	Yes	20.3	🟩 Q mass 690 GeV		1509.04261
Excited fermions	Excited quark $q^* \to qg$	–	2 j	–	139	🟧 q^* mass 6.7 TeV	only u^* and d^*, $\Lambda = m(q^*)$	ATLAS-CONF-2019-007
	Excited quark $q^* \to q\gamma$	1 γ	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	–	36.1	🟨 b^* mass 2.6 TeV		1805.09299
	Excited lepton ℓ^*	3 e, μ	–	–	20.3	🟩 ℓ^* mass 3.0 TeV	$\Lambda = 3.0$ TeV	1411.2921
	Excited lepton ν^*	3 e, μ, τ	–	–	20.3	🟩 ν^* mass 1.6 TeV	$\Lambda = 1.6$ TeV	1411.2921
Other	Type III Seesaw	1 e, μ	≥ 2 j	Yes	79.8	🟨 N^0 mass 560 GeV		ATLAS-CONF-2018-020
	LRSM Majorana ν	2 μ	2 j	–	36.1	🟨 N_R mass 3.2 TeV	$m(W_R) = 4.1$ TeV, $g_L = g_R$	1809.11105
	Higgs triplet $H^{\pm\pm} \to \ell\ell$	2,3,4 e, μ (SS)	–	–	36.1	🟨 $H^{\pm\pm}$ mass 870 GeV	DY production	1710.09748
	Higgs triplet $H^{\pm\pm} \to \ell\tau$	3 e, μ, τ	–	–	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	–	–	–	36.1	🟨 multi-charged particle mass 1.22 TeV	DY production, $\lvert q\rvert = 5e$	1812.03673
	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

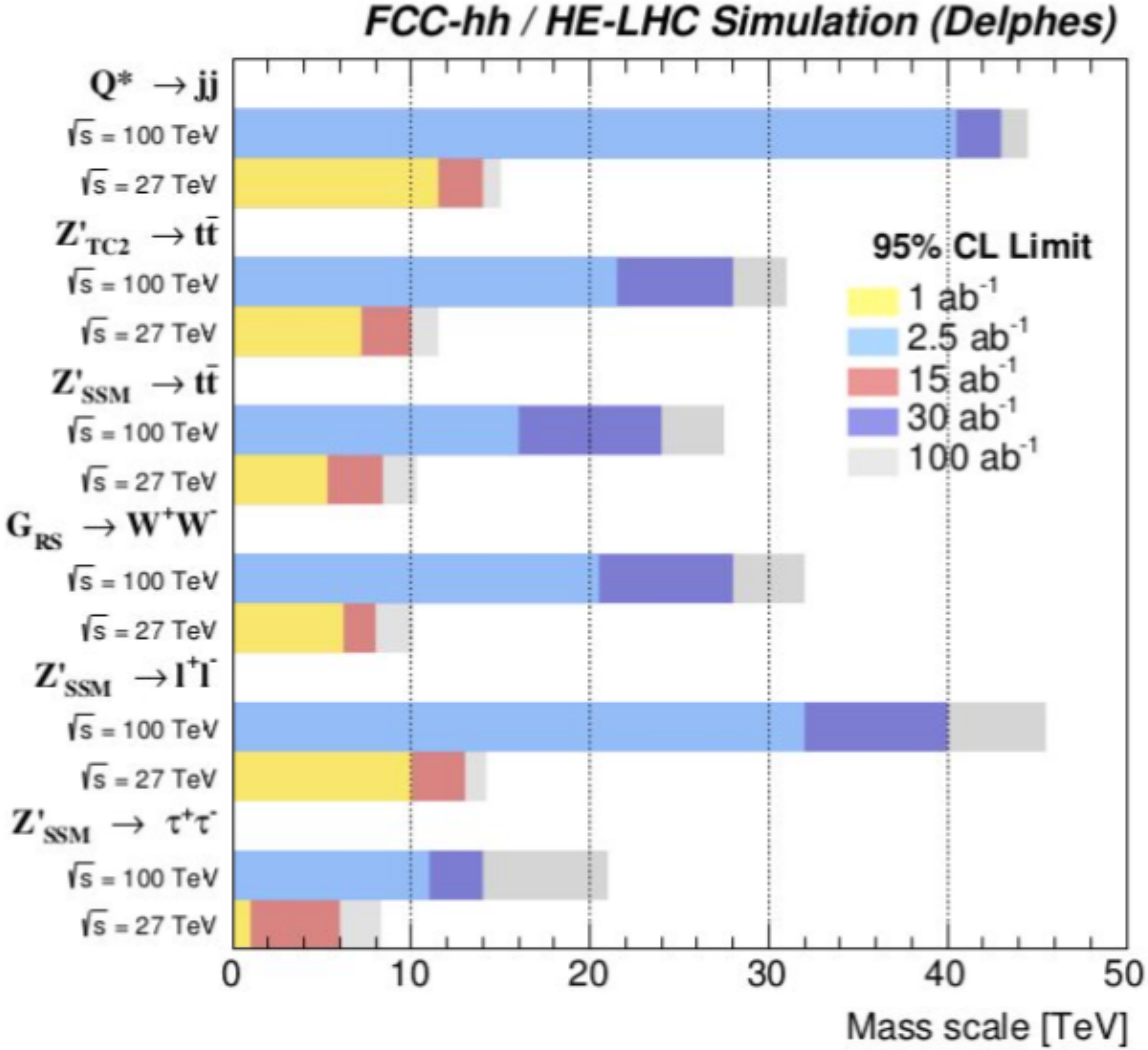
*Only a selection of the available mass limits on new states or phenomena is shown.

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

Summary plot for HL/HE-LHC resonances Searches



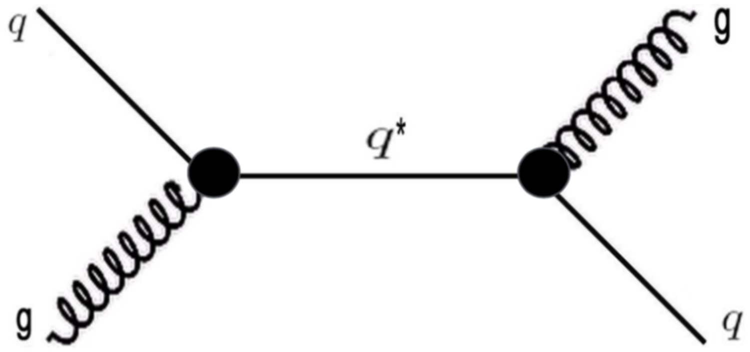
[1]

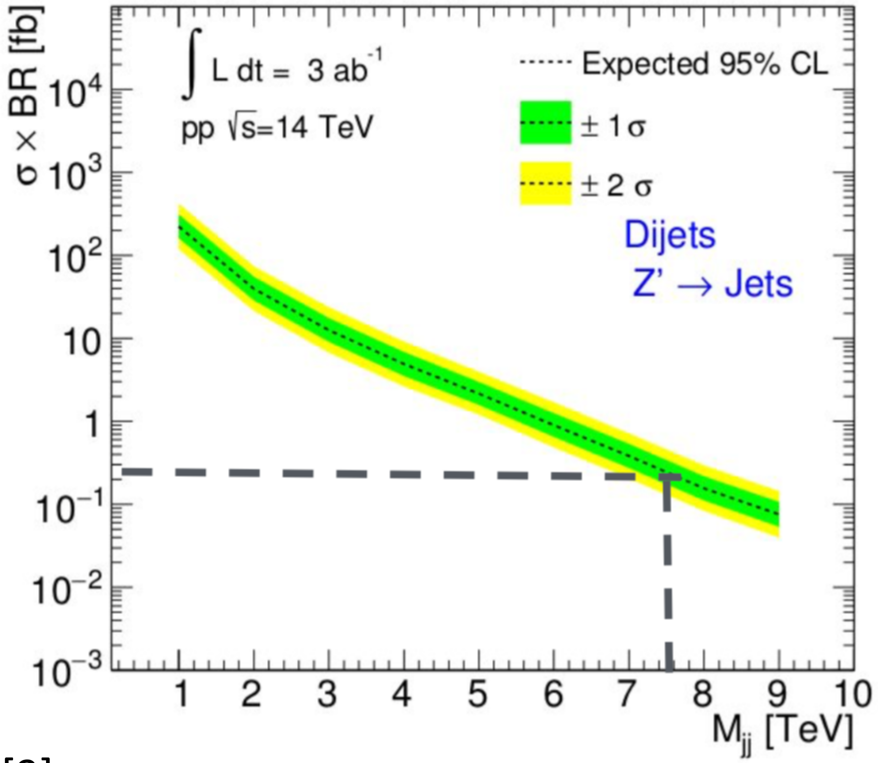

FCC-hh / HE-LHC Simulation (Delphes)
Q* → jj
√s = 100 TeV
√s = 27 TeV
Z'TC2 → tt̄
√s = 100 TeV
√s = 27 TeV
Z'SSM → tt̄
√s = 100 TeV
√s = 27 TeV
GRS → W+W-
√s = 100 TeV
√s = 27 TeV
Z'SSM → l+l-
√s = 100 TeV
√s = 27 TeV
Z'SSM → τ+τ-
√s = 100 TeV
√s = 27 TeV
95% CL Limit
1 ab-1
2.5 ab-1
15 ab-1
30 ab-1
100 ab-1
0
10
20
30
40
50
Mass scale [TeV]

[7]

Search for excited quarks [2jets]

Study of di-jet production





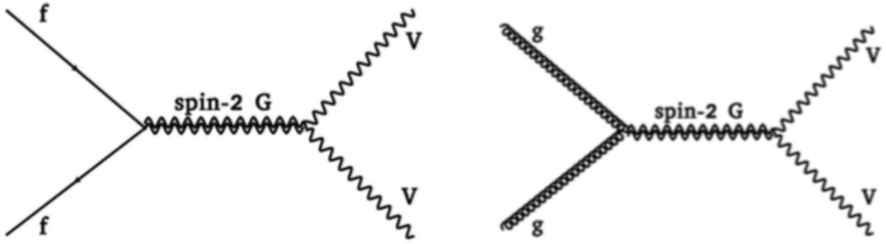
[7]

Limits @HL-LHC: by comparing estimated limits with precise cross section predictions for 14 TeV (~0.2 fb for 7.5 TeV mass)

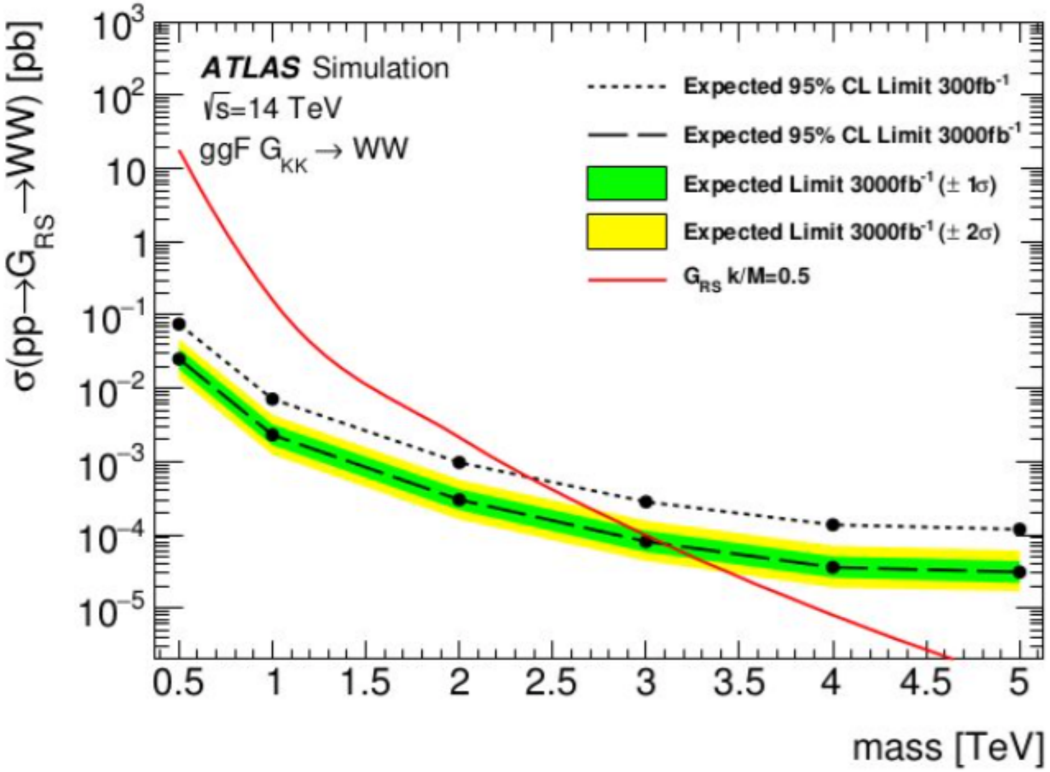
Q*	LHC CMS ($36\ fb^{-1}$) [8]	LHC ATLAS ($139\ fb^{-1}$) [9]	HL-LHC ($3\ ab^{-1}$)	HE-LHC (27 TeV, $15\ ab^{-1}$)	FCC-hh ($30\ ab^{-1}$)
Exclusion @95%	6 TeV	6.7 TeV	7.5 TeV	14 TeV	43 TeV

[7]

Search for Randall–Sundrum Graviton [2W]



1808.02380

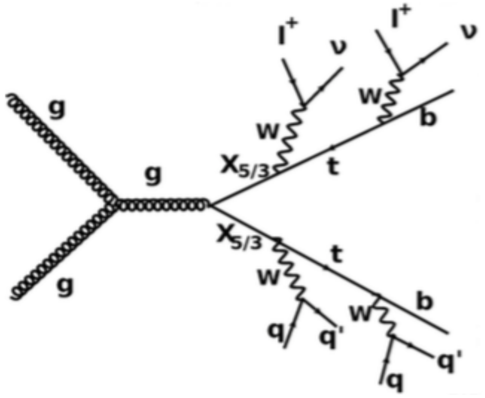


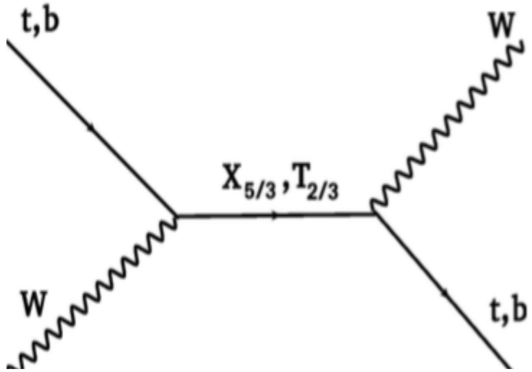
RS graviton WW	**LHC** **(36fb^{-1})**	**HL-LHC** **(3 ab^{-1})**	**HE-LHC** **(27 TeV, 15 ab^{-1})**	**FCC-hh** **(30 ab^{-1})**
Exclusion @95% k/$\overline{\mathbf{M}}_{PL}$ =1	1.7 TeV [0l, 1, 2l]	3.3 TeV [1l]		
k/$\overline{\mathbf{M}}_{PL}$ =0.1			8 TeV	28 TeV

[7]

Search for Vector-Like Quark (VLQ) $X_{5/3}$ [tW]

- @HL-LHC: search for same-sign di-lepton in the final state when pair production
- Analysis strategies currently in use at LHC, including identification of particles in boosted topologies
- @FCC-hh: the single production should be dominant at very high energy, although production rate is model dependent





[8,9]

$X_{5/3}$ tW **(pair production)**	**LHC** **(36 fb^{-1})**	**HL-LHC** **(3 ab^{-1})**	**HE-LHC** **(27 TeV, 15 ab^{-1})**	**FCC-hh** **(30 ab^{-1})**
Exclusion @95%	1.3 -1.6 TeV	1.8 TeV	-	-
5σ discovery		1.6 TeV	2 TeV	4.7 TeV

[7]