

# BSM physics searches at ATLAS and CMS

Lesya Shchutska

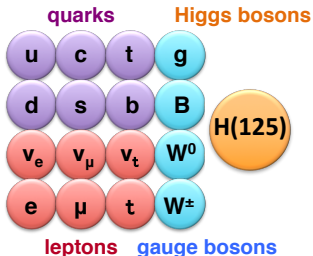
*ETH Zürich*

On behalf of ATLAS and CMS Collaborations

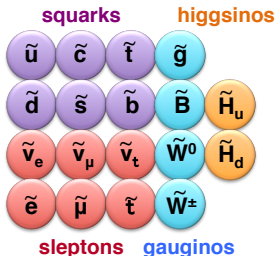
ICPPA'2017, October 5, 2017

# Flavors of new physics searches at the LHC

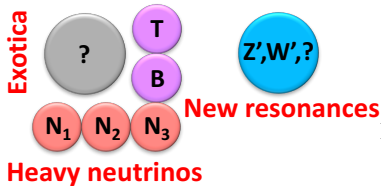
## Standard model



## Supersymmetry



## 4<sup>th</sup> generation



Searches for new particle production:

- resonant (heavy resonance-like)
- non-resonant (SUSY-like)
- long-lived signatures (charged or neutral)

Exploration of Higgs boson:

- invisible decays
- lepton-flavor violating decays

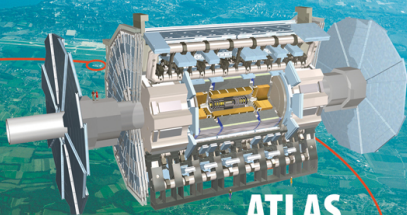
Established operation over the years:

$5 \text{ fb}^{-1}$  @ 7 TeV (2011)

$25 \text{ fb}^{-1}$  @ 8 TeV (2012)

$36 \text{ fb}^{-1}$  @ 13 TeV (2015-16)

$26+ \text{ fb}^{-1}$  @ 13 TeV (2017)



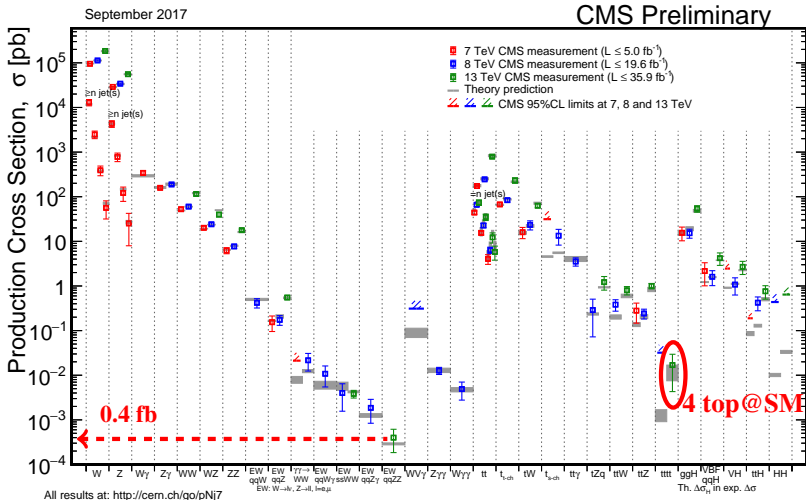
**ATLAS**



**CMS**

2 general purpose detectors  
Higgs boson discovery (2012)  
Wide physics programme

# SM processes at the LHC

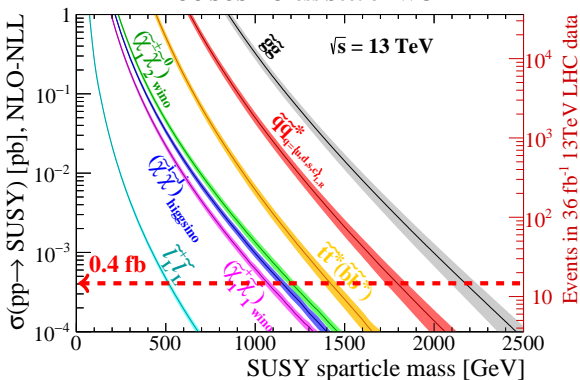


Measuring extremely rare SM processes: important background to searches



# SUSY production cross sections

LPCC SUSY Cross Section WG



Have a possibility to discover very massive new particles:

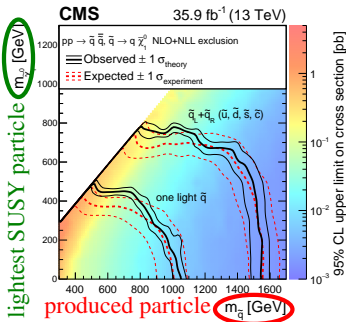
**Gluinos and 1<sup>st</sup>/2<sup>nd</sup> generation squarks:**  
“high” cross sections for masses up to 2 TeV

**3<sup>rd</sup> generation squarks:**  
“moderate” cross sections for masses up to 1 TeV

**Charginos, neutralinos, sleptons:**  
produced through weak interaction;  
“smaller” cross sections, but still detectable for light masses

## Intermezzo: how to read the limit plots

Many assumptions enter mass exclusion lines discussed later:



- always present - **simplified model spectrum (SMS)**: usually 2-particle spectrum with 100% BF to a considered final state
  - long chain decays ignored: can be important, lead to soft particles and low  $E_T^{\text{miss}}$   $\implies$  fall out of the acceptance of many searches
  - bringing the other SUSY particles down in mass can lead to much higher production cross sections
- assumptions on nature of produced particles, e.g.:
  - mass-degenerate squarks (8-fold cross section boost!)
  - type of produced EWK gauginos ( $\sigma_{\text{wino}} > \sigma_{\text{higgsino}}$ )
- assumptions enhancing BF to an analysis final state, e.g.:
  - decays via sleptons rather than W or Z: 100% BF to leptons
- always assume prompt decays of SUSY particles:
  - lifetime can be important in the diagonal (“compressed”) regions
  - in RPV models with small couplings
  - for wino (N)LSP (highly mass degenerate)

UL on production cross section:

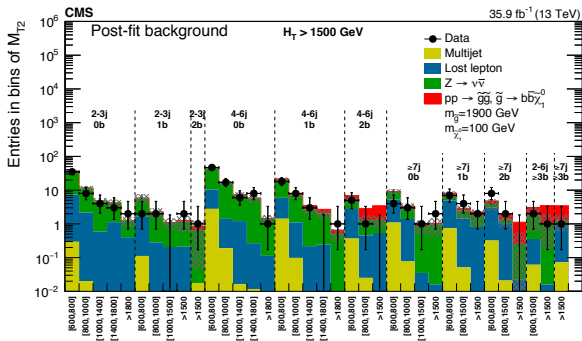
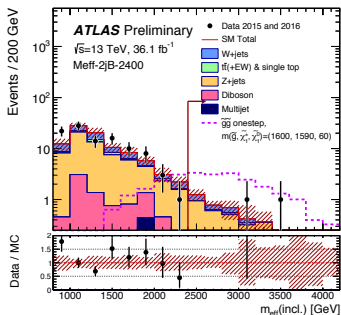
- ATLAS: numbers in the plot
- CMS: color map

Need to remember all this when seeing mass exclusion lines

# Inclusive searches

Plenty of inclusive searches looking for gluinos and 1<sup>st</sup>/2<sup>nd</sup> generation squarks:

- typically in R-parity conserving scenarios and hence with large  $E_T^{\text{miss}}$
- rely on many (b-)jets, possibly leptons
- explore various kinematic variables
- check various corners of space-space



# Glino landscape: various decay chains and limits

Consider several possible decay gluino decay scenarios:

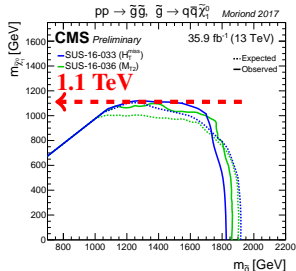
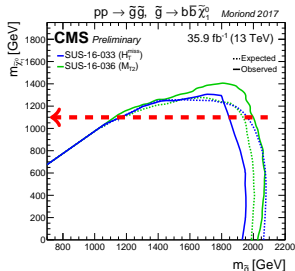
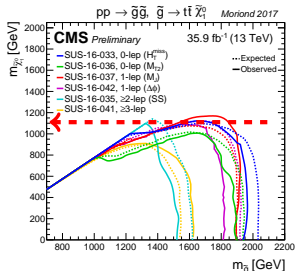
- via top, bottom or light quarks

Maximum excluded gluino mass is driven by gluino production cross section:

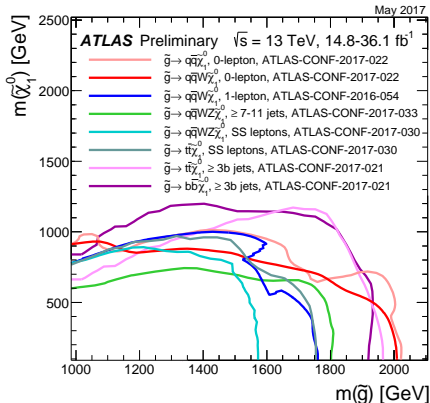
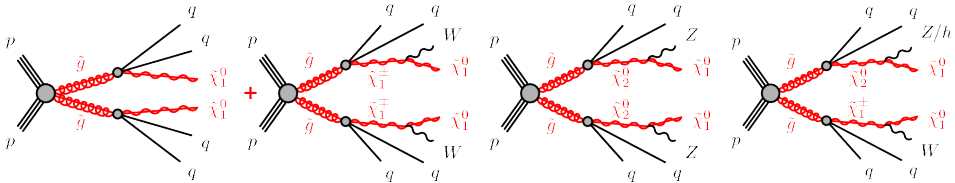
- about 1.8-2.0 TeV depending on decay mode

Compressed region behavior is much more sensitive to the final state:

- reach the same 1.1 TeV of LSP mass at different gluino masses: best in 4b final state, worst in 4t final state



# Gluinos: remembering about cascade decays



Adding more complex decay chains:

- e.g. intermediate charginos/neutralinos
- effectively decreases the boost of the LSP
- lower  $E_T^{\text{miss}} \Rightarrow$  higher background
- $\Rightarrow$  lower sensitivity
- mass exclusion drops to 1.8/0.6 TeV in gluino/LSP plane

Realistic scenarios might be a mixture of all presented  $\Rightarrow$  exclusions might be not as strong as in a single simplified model (though usually hold)

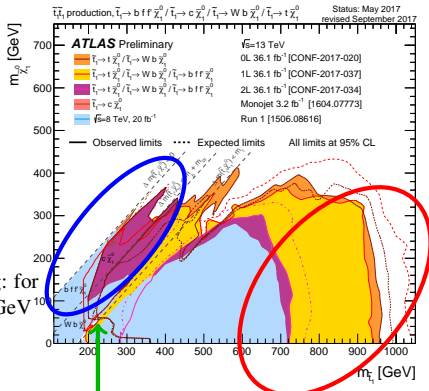
# Third generation squarks: rich topology

“low  $\Delta m$ ”

$$\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0 \text{ or } \tilde{t}_1 \rightarrow bff'\tilde{\chi}_1^0:$$

- $\tilde{t}_1$  could be long-lived
- ISR-tagging
- charm-tagging
- very soft leptons: down to 3.5 GeV
- secondary vertex tagging: for b-quarks with  $p_T < 20$  GeV

often systematics-limited!



SM-like  $\tilde{t}_1$  production:

- kinematics very similar to  $t\bar{t}$
- probed by  $t\bar{t}$  cross section and polarization measurements
- ISR-tagging for higher LSP mass

“high  $\Delta m$ ”

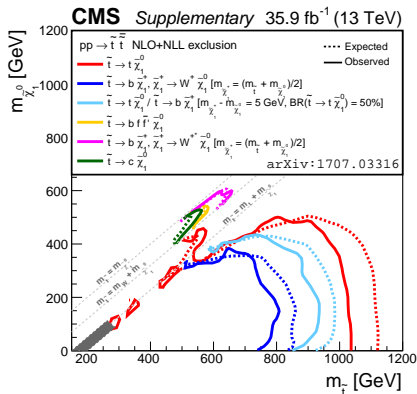
low-SM background:

- limited by cross section
- employ merged t and V reconstruction

The same “low  $\Delta m$ ” and “high  $\Delta m$ ” tools are used for other sparticle searches

## Third generation squarks searches

- target various  $\tilde{t}$  decay modes:  $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$ ,  $\tilde{t}_1 \rightarrow b\tilde{\chi}_1^\pm$ ,  $\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$ ,  $\tilde{t}_1 \rightarrow bff'\tilde{\chi}_1^0$
- look at all possible final states:  $0\ell$ ,  $1\ell$ ,  $2\ell$
- check cascade decays via Z or Higgs bosons: add multilepton searches



Interpretation of one  $0\ell$  search in several scenarios:

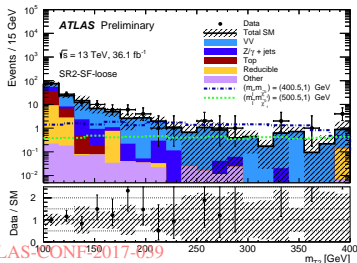
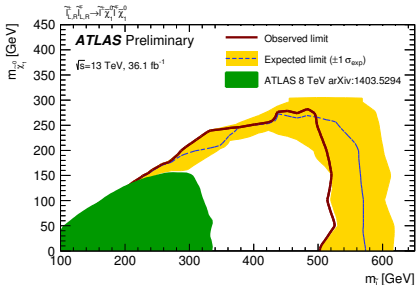
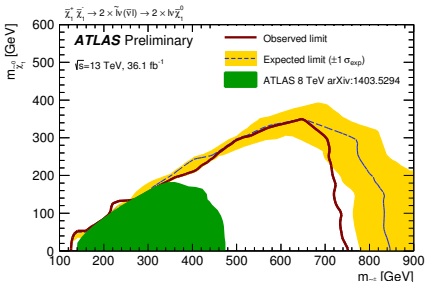
- $\sim 1$  TeV reach for direct decay  $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$
- for mixed case  $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0 / \tilde{t}_1 \rightarrow b\tilde{\chi}_1^\pm$ 
  - $\sim 0.9$  TeV for compressed  $\tilde{\chi}_1^\pm / \tilde{\chi}_1^0$
  - $\sim 0.8$  TeV for not compressed  $\tilde{\chi}_1^\pm / \tilde{\chi}_1^0$
- in compressed  $\tilde{t}_1 / \tilde{\chi}_1^0$  cases:
  - $\sim 550$  GeV for decays via off-shell W
  - $\sim 650$  GeV for decays via  $\tilde{\chi}_1^\pm$

“Universal” exclusion is at about  $\sim 500$  GeV for  $\tilde{t}_1$ .  
Similarly, 1 to 1.2 TeV reach for  $\tilde{b}_1$  squarks.



# Electroweak SUSY: charginos and sleptons

- mass exclusion significantly depends on the assumptions on the particle nature: left or right sleptons, number of families, direct or cascade decays of charginos

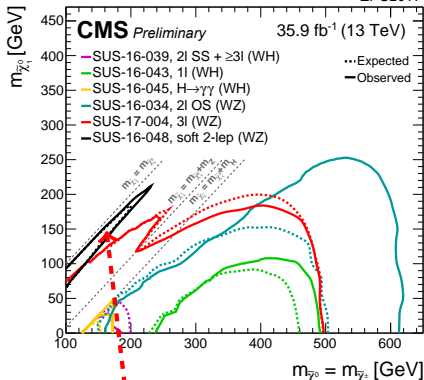


Small excess in the  $M_{T2}$  tail leads to observed limit below expected in both scenarios.

# Electroweak SUSY: $\tilde{\chi}_2^0 \tilde{\chi}_1^\pm$

## Individual searches

pp  $\rightarrow \tilde{\chi}_2^0 \tilde{\chi}_1^\pm$  EPS2017

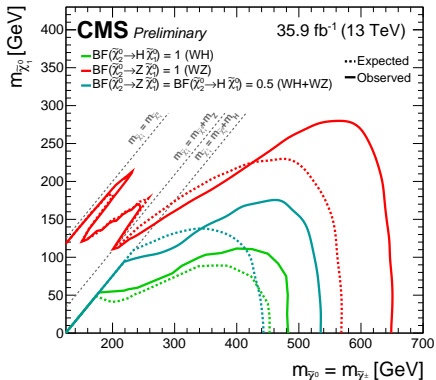


dedicated  $\cdot 2$  soft leptons + ISR search:  
first coverage since LEP!

2lOS search: observed is stronger by  $+1\sigma$ :  
downward data fluctuation

## Statistical combination

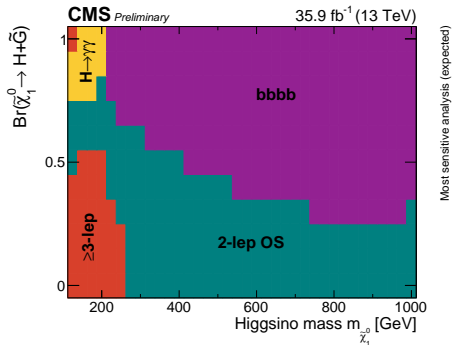
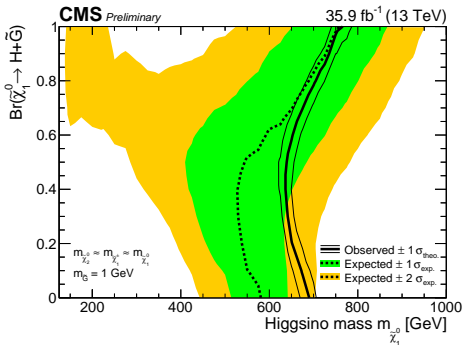
pp  $\rightarrow \tilde{\chi}_2^0 \tilde{\chi}_1^\pm$



Depending on  $\mathcal{B}(WZ/WH)$  and  $\Delta m$ , exclusion varies between 150 and 650 GeV

# Electroweak SUSY: higgsinos

- targeting  $HH + E_T^{\text{miss}}$  or  $ZZ + E_T^{\text{miss}}$  scenarios
- interpret in GMSB model with massless gravitino LSP
- an interplay of various final states due to complexity of the final states with intermediate Higgs bosons!



# SUSY summary

## ATLAS SUSY Searches\* - 95% CL Lower Limits

May 2017

ATLAS Preliminary

$\sqrt{s} = 7, 8, 13$  TeV

Model	$\epsilon, \mu, \tau, \gamma$	Jets	$E_{T}^{\text{miss}}$	$L/d(\text{fb}^{-1})$	Mass limit	$\sqrt{s} = 7, 8$ TeV	$\sqrt{s} = 13$ TeV	Reference		
Inclusive Searches	MSUGRA/CMSM	$0.3, \epsilon, \mu/1-2\tau$	2-10 jets $\beta$	Yes	20.3	4-3	1.85 TeV	$m(\tilde{g})=m(\tilde{q})$ $m(\tilde{g})=200 \text{ GeV}, m(\tilde{t}^{\pm}) \text{ free}, \mu=0, \tau=2\text{mm}$	1507.05525	
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}$	0	2-6 jets	Yes	36.1	3	1.57 TeV	$m(\tilde{g})=m(\tilde{t}^{\pm})=5 \text{ GeV}$	ATLAS-CONF-2017-022	
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}$ (compressed)	mono-jet	1-3 jets	Yes	3.2	3	608 GeV		1604.07773	
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}$	0	2-6 jets	Yes	36.1	3	2.02 TeV	$m(\tilde{g})=200 \text{ GeV}$	ATLAS-CONF-2017-022	
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}$	$0, \mu=1$	0-2 jets	Yes	36.1	3	2.01 TeV	$m(\tilde{g})=200 \text{ GeV}, m(\tilde{t}^{\pm})=0.5m(\tilde{g})+m(\tilde{q})$	ATLAS-CONF-2017-022	
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}$ (with $\tilde{\nu}_\tau$ )	$3\epsilon, \mu$	4 jets	Yes	36.1	3	1.825 TeV	$m(\tilde{g})=400 \text{ GeV}$	ATLAS-CONF-2017-030	
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}$ (with $\tilde{\nu}_\tau$ )	0	7-11 jets	Yes	36.1	3	1.8 TeV	$m(\tilde{g})=400 \text{ GeV}$	ATLAS-CONF-2017-033	
	GMSB ( $\tilde{g}$ NLSP)	$1.2 + \epsilon, 0-1\tau$	0-2 jets	Yes	3.2	3	2.0 TeV	$m(\tilde{g}) < 400 \text{ GeV}$	1607.05919	
	GGM (bino NLSP)	$2\gamma$	-	Yes	3.2	3	1.65 TeV	$\tau(\text{NLSP}) < 0.1 \text{ mm}$	1606.01550	
	GGM (higgsino-bino NLSP)	$7\tau$	1 $\beta$	Yes	20.3	3	1.37 TeV	$m(\tilde{g})=350 \text{ GeV}, \tau(\text{NLSP}) < 0.1 \text{ mm}, \mu=0$	1507.05493	
GGM (higgsino-bino NLSP)	$\gamma$	2 jets	Yes	13.5	3	1.8 TeV	$m(\tilde{g})=580 \text{ GeV}, \tau(\text{NLSP}) < 0.1 \text{ mm}, \mu=0$	ATLAS-CONF-2016-066		
GGM (higgsino NLSP)	$2\epsilon, \mu$ (Z)	2 jets	Yes	20.3	3	900 GeV	$m(\text{NLSP})=430 \text{ GeV}$	1500.02390		
Gravitino LSP	0	mono-jet	Yes	20.3	3	865 GeV	$m(\tilde{g})=1.8 \times 10^4 \text{ eV}, m(\tilde{g})=m(\tilde{q})=1.5 \text{ TeV}$	1502.01518		
$\tilde{\nu}_\tau$ gen. $\beta$ med.	$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}$	0	3 $\beta$	Yes	36.1	3	1.32 TeV	$m(\tilde{g})=600 \text{ GeV}$	ATLAS-CONF-2017-021	
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}$	$0-1\epsilon, \mu$	3 $\beta$	Yes	36.1	3	1.37 TeV	$m(\tilde{g})=200 \text{ GeV}$	ATLAS-CONF-2017-021	
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}$	$0-1\epsilon, \mu$	3 $\beta$	Yes	20.3	3	1.37 TeV	$m(\tilde{g})=300 \text{ GeV}$	1607.06000	
$\tilde{\nu}_\tau$ gen. $\beta$ med. $\beta$ med. $\beta$ med.	$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}, \tilde{g}\tilde{b}$	0	2 $\beta$	Yes	36.1	3	950 GeV	$m(\tilde{g})=420 \text{ GeV}$	ATLAS-CONF-2017-038	
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}, \tilde{g}\tilde{b}$	$2\epsilon, \mu$ (SS)	1 $\beta$	Yes	36.1	3	275-700 GeV	$m(\tilde{g})=200 \text{ GeV}, m(\tilde{t}^{\pm})=m(\tilde{b}^{\pm})+100 \text{ GeV}$	ATLAS-CONF-2017-030	
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}, \tilde{g}\tilde{b}$	$0.2\epsilon, \mu$	1-2 $\beta$	Yes	4.713.3	3	117-179 GeV	$m(\tilde{g})=200 \text{ GeV}$	1509.2102, ATLAS-CONF-2016-077	
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}, \tilde{g}\tilde{b}$	$0.2\epsilon, \mu$	0-2 jets+2 $\beta$	Yes	20.3, 6.1	3	90-198 GeV	$m(\tilde{g})=200 \text{ GeV}$	1506.08616, ATLAS-CONF-2017-020	
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}, \tilde{g}\tilde{b}$	0	mono-jet	Yes	3.2	3	90-323 GeV	$m(\tilde{g})=m(\tilde{t}^{\pm})=5 \text{ GeV}$	1604.07773	
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}, \tilde{g}\tilde{b}$ (natural GMSB)	$2\epsilon, \mu$ (Z)	1 $\beta$	Yes	20.3	3	150-600 GeV	$m(\tilde{g})=150 \text{ GeV}$	1403.5222	
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}, \tilde{g}\tilde{b}$	$3\epsilon, \mu$ (Z)	1 $\beta$	Yes	36.1	3	290-790 GeV	$m(\tilde{g})=100 \text{ GeV}$	ATLAS-CONF-2017-019	
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}, \tilde{g}\tilde{b}$	$1.2\epsilon, \mu$	4 $\beta$	Yes	36.1	3	320-690 GeV	$m(\tilde{g})=100 \text{ GeV}$	ATLAS-CONF-2017-019	
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}, \tilde{g}\tilde{b}$	$2\epsilon, \mu$	0	Yes	36.1	3	90-440 GeV	$m(\tilde{g})=0$	ATLAS-CONF-2017-039	
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}, \tilde{g}\tilde{b}$	$2\epsilon, \mu$	0	Yes	36.1	3	710 GeV	$m(\tilde{g})=0, m(\tilde{t}^{\pm}), m(\tilde{b}^{\pm}), m(\tilde{\nu}_\tau) < 0, m(\tilde{\nu}_\tau) < 0.5m(\tilde{g})+m(\tilde{q})$	ATLAS-CONF-2017-039	
EW direct	$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}, \tilde{g}\tilde{b}$	$2\epsilon, \mu$	0	Yes	36.1	3	760 GeV	$m(\tilde{g})=0, m(\tilde{t}^{\pm}), m(\tilde{b}^{\pm}), m(\tilde{\nu}_\tau) < 0, m(\tilde{\nu}_\tau) < 0.5m(\tilde{g})+m(\tilde{q})$	ATLAS-CONF-2017-035	
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}, \tilde{g}\tilde{b}$	$3\epsilon, \mu$	0	Yes	36.1	3	1.16 TeV	$m(\tilde{g})=m(\tilde{t}^{\pm}), m(\tilde{g})=0, m(\tilde{t}^{\pm}), m(\tilde{b}^{\pm}), m(\tilde{\nu}_\tau) < 0, f$ decoupled	ATLAS-CONF-2017-039	
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}, \tilde{g}\tilde{b}$	$2.3\epsilon, \mu$	0-2 jets	Yes	36.1	3	580 GeV	$m(\tilde{g})=m(\tilde{t}^{\pm}), m(\tilde{g})=0, f$ decoupled	ATLAS-CONF-2017-039	
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}, \tilde{g}\tilde{b}$	$\epsilon, \mu, \gamma$	0-2 $\beta$	Yes	20.3	3	270 GeV	$m(\tilde{g})=m(\tilde{t}^{\pm}), m(\tilde{g})=0, f$ decoupled	1501.07110	
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}, \tilde{g}\tilde{b}$	$4\epsilon, \mu$	0	Yes	20.3	3	635 GeV	$m(\tilde{g})=m(\tilde{t}^{\pm}), m(\tilde{g})=0, m(\tilde{t}^{\pm}), m(\tilde{b}^{\pm}), m(\tilde{\nu}_\tau) < 0, \tau < 1 \text{ mm}$	1405.5098	
	GGM (wino NLSP) weak prod., $\tilde{t}^{\pm} \rightarrow \gamma G$	$1\epsilon, \mu + \gamma$	-	Yes	20.3	3	115-370 GeV	$\tau < 1 \text{ mm}$	1507.05493	
	GGM (bino NLSP) weak prod., $\tilde{t}^{\pm} \rightarrow \gamma G$	$2\gamma$	-	Yes	20.3	3	500 GeV	$\tau < 1 \text{ mm}$	1507.05493	
	Long-lived particles	Direct $\tilde{t}^{\pm}, \tilde{b}^{\pm}$ prod., long-lived $\tilde{t}^{\pm}$	Disapp. trk	1 jet	Yes	16.1	3	430 GeV	$m(\tilde{t}^{\pm})=m(\tilde{b}^{\pm})=180 \text{ MeV}, \tau(\tilde{t}^{\pm}) > 0.2 \text{ ns}$	ATLAS-CONF-2017-017
		Direct $\tilde{t}^{\pm}, \tilde{b}^{\pm}$ prod., long-lived $\tilde{t}^{\pm}$	dE/dx trk	-	Yes	38.4	3	495 GeV	$m(\tilde{t}^{\pm})=m(\tilde{b}^{\pm})=180 \text{ MeV}, \tau(\tilde{t}^{\pm}) > 15 \text{ ns}$	1506.05332
		Stable, stopped $\beta$ R-hadron	0-1 jets	Yes	27.9	3	850 GeV	$m(\tilde{t}^{\pm})=100 \text{ GeV}, 10 \mu\text{m} < \tau < 1000 \text{ s}$	1370.6504	
Stable $\beta$ R-hadron		-	-	-	-	-	-	-	1506.05129	
Metastable $\beta$ R-hadron		dE/dx trk	-	-	-	-	-	-	1604.04520	
GMSB, stable $\tilde{t}^{\pm}, \tilde{b}^{\pm} \rightarrow \tilde{t}^{\pm}, \tilde{b}^{\pm} + \tilde{g}(\tilde{q}, \mu)$		1-2 $\mu$	-	Yes	19.1	3	537 GeV	$10\text{-damp-}50$	1411.67795	
GMSB, $\tilde{t}^{\pm} \rightarrow \tilde{t}^{\pm} + G$ , long-lived $\tilde{t}^{\pm}$		$2\gamma$	-	Yes	20.3	3	440 GeV	$1 - \tau(\tilde{t}^{\pm}) < 3 \text{ ns}$ , SP88 model	1409.35442	
$\tilde{g}\tilde{g}, \tilde{t}^{\pm} \rightarrow \text{exotic } \tilde{g}\tilde{q}\tilde{q}$		displ. $\nu\tilde{\nu}\tilde{q}\tilde{q}$ jets	-	Yes	20.3	3	1.0 TeV	$7 - \tau(\tilde{t}^{\pm}) < 740 \text{ ms}, m(\tilde{q}) > 1.3 \text{ TeV}$	1504.05162	
GGM $\tilde{g}\tilde{g}, \tilde{t}^{\pm} \rightarrow G$		displ. $\nu\tilde{\nu}\tilde{q}\tilde{q}$ jets	-	Yes	20.3	3	1.0 TeV	$6 - \tau(\tilde{t}^{\pm}) < 480 \text{ ms}, m(\tilde{q}) > 1.1 \text{ TeV}$	1504.05162	
RPV		LFV $\tilde{g}\tilde{g} \rightarrow \tilde{g}, \tilde{g}\tilde{q}, \tilde{g}\tilde{q} \rightarrow \tilde{g}\tilde{q}\tilde{q}$	$\mu\tau, \mu\tau$	-	Yes	20.3	3	1.45 TeV	$\epsilon_{11}, \epsilon_{12}, \epsilon_{21}, \epsilon_{22} < 0.07$	1607.08079
	Bilinear RPV CMSM	$2\epsilon, \mu$ (SS)	$0.3\beta$	Yes	20.3	3	1.45 TeV	$m(\tilde{g})=0, \tau < 0.1 \text{ mm}$	1404.2500	
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}, \tilde{g}\tilde{q}$	$4\epsilon, \mu$	-	Yes	13.2	3	1.14 TeV	$m(\tilde{g})=400 \text{ GeV}, A_{1,2} > 0 (\beta = 1, 2)$	ATLAS-CONF-2016-075	
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}, \tilde{g}\tilde{q}$	$3\epsilon, \mu + \tau$	-	Yes	20.3	3	450 GeV	$m(\tilde{g})=0, 0.2m(\tilde{t}^{\pm}), A_{1,2} > 0$	1405.5086	
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}$	0	4-5 large-R jets	-	14.8	3	1.08 TeV	$\text{BR}(\tilde{g} \rightarrow \text{BR}) > 10\%$	ATLAS-CONF-2016-097	
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}$	$1\epsilon, \mu$	8-10 jets+0-4 $\beta$	-	36.1	3	1.35 TeV	$m(\tilde{g})=800 \text{ GeV}$	ATLAS-CONF-2016-097	
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}$	$1\epsilon, \mu$	8-10 jets+0-4 $\beta$	-	36.1	3	2.1 TeV	$m(\tilde{g})=1 \text{ TeV}, A_{1,2} > 0$	ATLAS-CONF-2017-013	
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}$	$1\epsilon, \mu$	8-10 jets+0-4 $\beta$	-	36.1	3	1.65 TeV	$m(\tilde{g})=1 \text{ TeV}, A_{1,2} > 0$	ATLAS-CONF-2017-013	
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}$	$2\epsilon, \mu$	2 jets + 2 $\beta$	-	15.4	3	410 GeV	$\text{BR}(\tilde{g} \rightarrow \text{BR}) > 20\%$	ATLAS-CONF-2016-022, ATLAS-CONF-2016-084	
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}$	$2\epsilon, \mu$	2 $\beta$	-	36.1	3	850-510 GeV	$m(\tilde{g})=200 \text{ GeV}$	ATLAS-CONF-2017-036	
Other	Scalar charm, $\tilde{t}^{\pm} \rightarrow c\tilde{t}^{\pm}$	0	2 $c$	Yes	20.3	3	510 GeV	$m(\tilde{t}^{\pm})=200 \text{ GeV}$	1501.01325	

\*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.

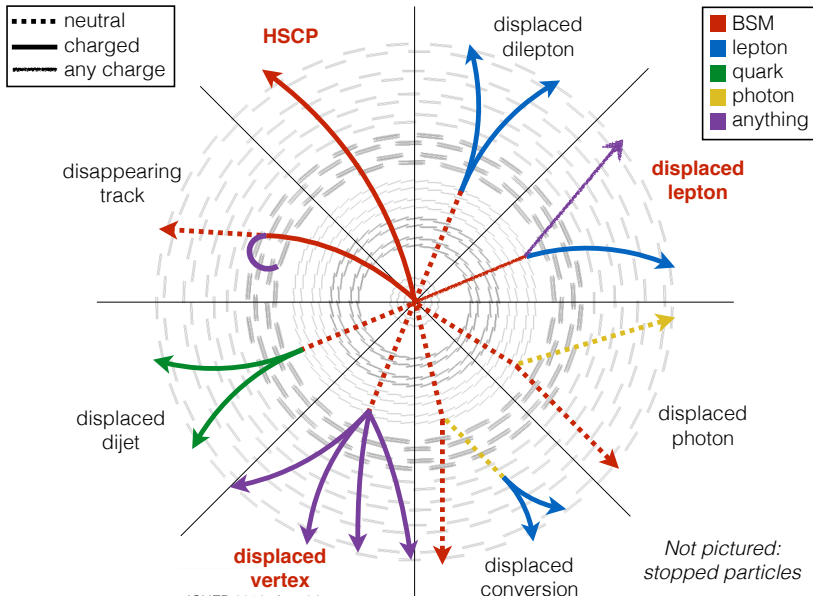
$10^{-1}$

1

Mass scale [TeV]

# Long-lived particle signatures in a detector

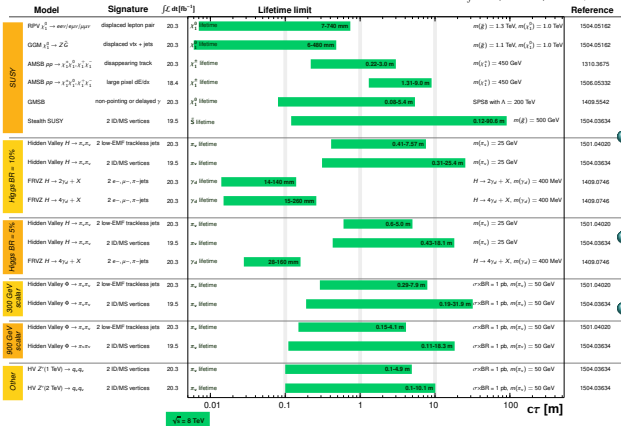
J. Antonelli



# Long-lived particle searches: possible new physics scenarios

ATLAS Long-lived Particle Searches\* - 95% CL Exclusion  
Status: July 2015

ATLAS Preliminary  
 $\int \mathcal{L} dt = (18.4 - 20.3) \text{ fb}^{-1}$   
 $\sqrt{s} = 8 \text{ TeV}$

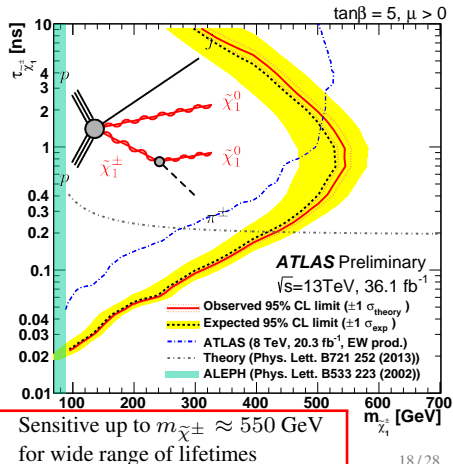
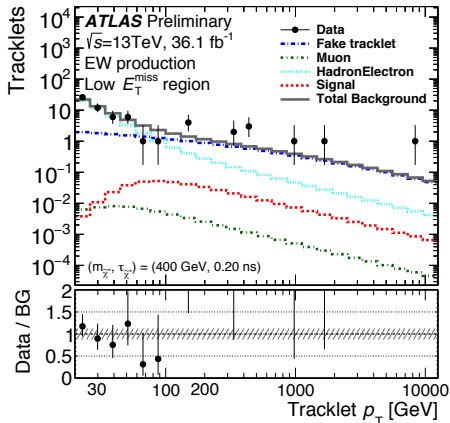


- small mass-splittings: close in mass NLSP SUSY particle
- small couplings: RPV SUSY, heavy neutrinos
- hidden valley sector

\*Only a selection of the available Lifetime limits on new states is shown.

## Long-lived particle searches: disappearing tracks

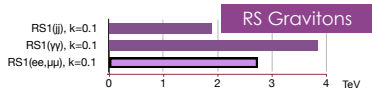
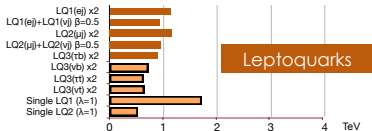
- look for long-lived charged (disappearing tracks) or neutral (decaying to visible daughters) particles
- helps to constrain very compressed case of SUSY particles:  $m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0} \lesssim 200$  MeV:
  - $\tilde{\chi}_1^\pm \rightarrow \pi^\pm \tilde{\chi}_1^0$  leads to a disappearing track signature
  - analysis sensitive to the presence of compressed  $\tilde{\chi}_1^\pm / \tilde{\chi}_1^0$  at the end of the decay chains



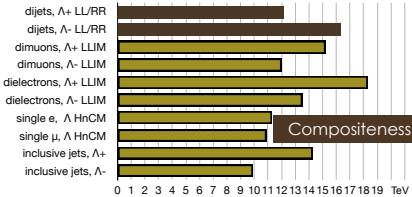
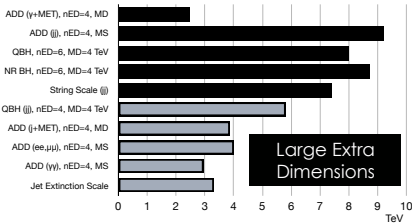
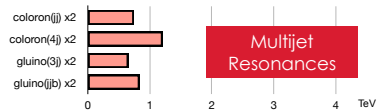
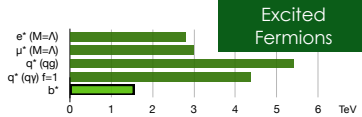
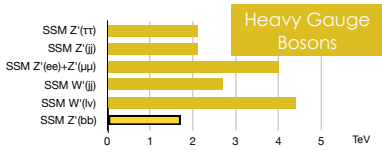


# Exotica searches

13 TeV 8 TeV

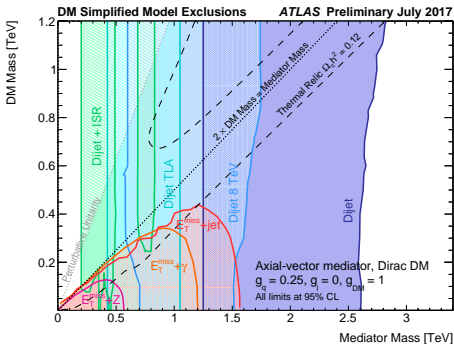
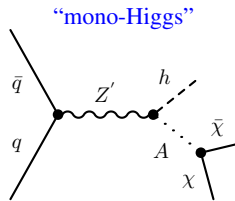
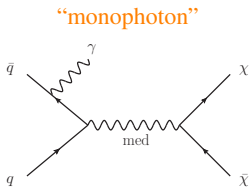
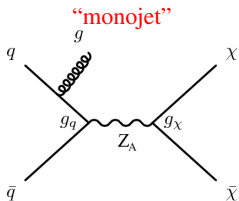


## CMS Preliminary



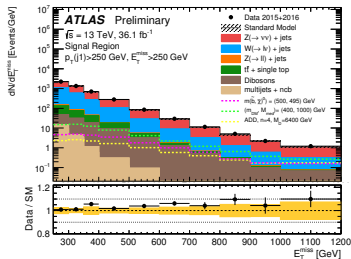
# Dark matter searches

“Visualize” dark matter production with an ISR or associated particle production:



- **DiJet**  
 $\sqrt{s} = 13 \text{ TeV}, 37.0 \text{ fb}^{-1}$   
 arXiv:1703.09127 [hep-ex]
- **DiJet 8 TeV**  
 $\sqrt{s} = 8 \text{ TeV}, 20.3 \text{ fb}^{-1}$   
 Phys. Rev. D. 91 (5):2007 (2015)
- **DiJet TLA**  
 $\sqrt{s} = 13 \text{ TeV}, 3.4 \text{ fb}^{-1}$   
 ATLAS-CONF-2016-090
- **DiJet + ISR**  
 $\sqrt{s} = 13 \text{ TeV}, 15.5 \text{ fb}^{-1}$   
 ATLAS-CONF-2016-070
- **$E_T^{\text{miss}} + \gamma$**   
 $\sqrt{s} = 13 \text{ TeV}, 36.1 \text{ fb}^{-1}$   
 Eur. Phys. J. C 77 (2017) 393
- **$E_T^{\text{miss}} + \text{j}et$**   
 $\sqrt{s} = 13 \text{ TeV}, 36.1 \text{ fb}^{-1}$   
 ATLAS-CONF-2017-060
- **$E_T^{\text{miss}} + Z$**   
 $\sqrt{s} = 13 \text{ TeV}, 36.1 \text{ fb}^{-1}$   
 ATLAS-CONF-2017-040

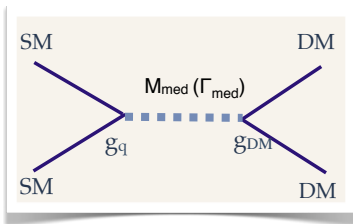
$E_T^{\text{miss}}$  is a typical search variable:



# Dark matter interpretations at the LHC

O. Buchmueller (summary of the LHC DM WG):

See e.g.  
[arXiv:1407.8257](https://arxiv.org/abs/1407.8257)  
[arXiv:1507.00966](https://arxiv.org/abs/1507.00966)  
[arXiv:1603.04156](https://arxiv.org/abs/1603.04156)

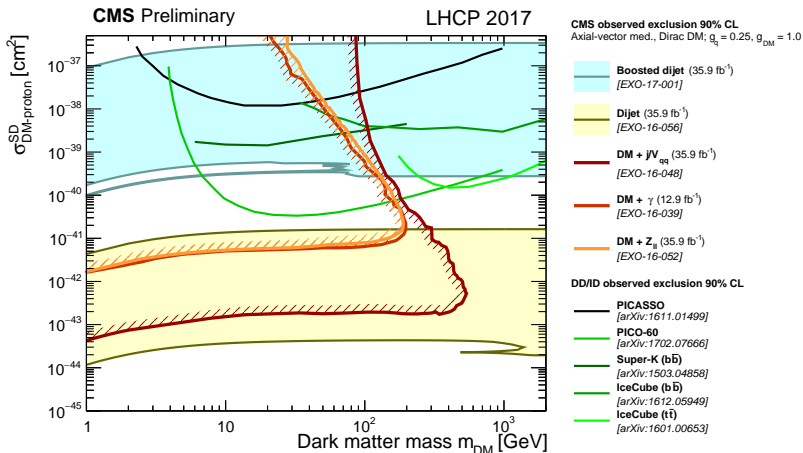


s-channel

Define simplified model with (minimum) 4 parameters		DM		Consider comprehensive set of diagrams for mediator	
Mediator mass ( $M_{\text{med}}$ )	DM mass ( $M_{\text{DM}}$ )	Dirac fermion	Scalar - real	Vector	Axial-vector
$g_q$	$g_{\text{DM}}$	Majorana fermion	Scalar - complex	Scalar	Pseudoscalar

# Comparison with the direct detection

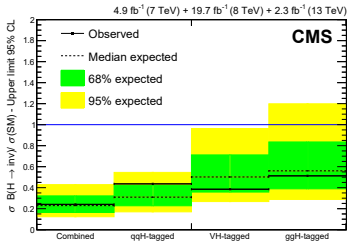
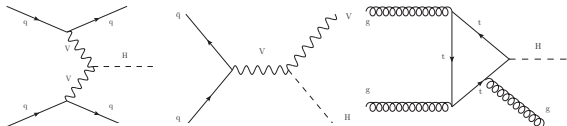
- the comparison is always coupling- and model-dependent
- shown: **axial-mediator** and Dirac DM,  $g_q = 0.25$ ,  $g_{DM} = 1.0$



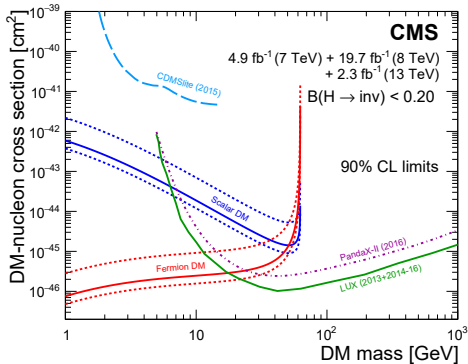
Direct detection and LHC are equal in overall sensitivity but probe different regions of parameter space.

# Higgs boson portal to new physics

- DM search in the invisible H decays  $H \rightarrow \chi\chi$
- combine all H production modes



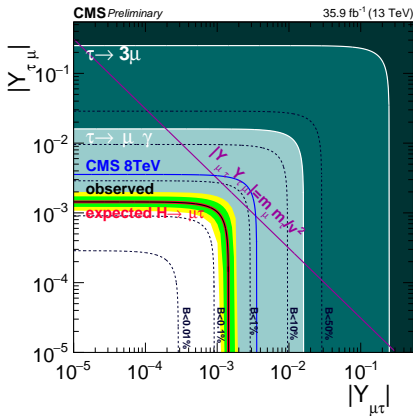
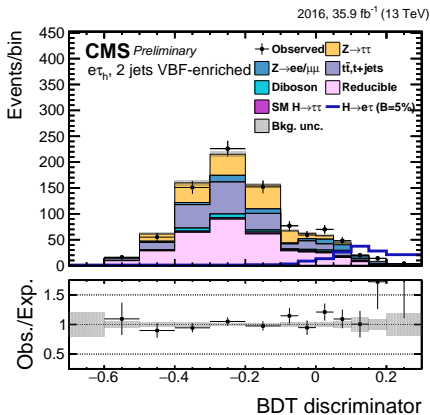
- $\mathcal{B}(H \rightarrow \text{inv}) < 0.24 @ 95\% \text{ CL}$
- $\text{SM}(H \rightarrow ZZ \rightarrow 4\nu) = 1.06 \times 10^{-3}$



- complementary constraints on low-mass DM

# LFV Higgs boson decays

- look for the off-diagonal Yukawa  $\mu\tau$  and  $e\tau$  couplings
- analysis is complementary to  $\tau \rightarrow 3\mu$  and other LFV processes searches
- upper limits are set at  $\mathcal{B}(H \rightarrow \mu\tau) < 0.25\%$  and  $\mathcal{B}(H \rightarrow e\tau) < 0.61\%$

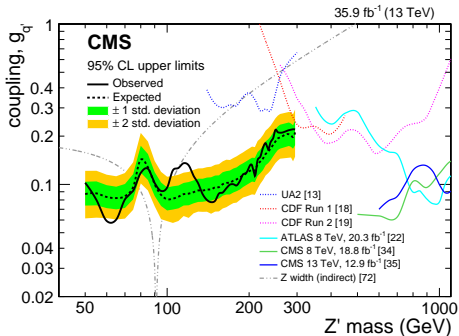
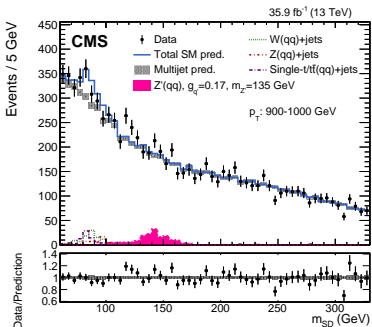


## Resonances: dijets

Check all possible scenarios:

- dijets,  $\gamma$ +jet, dileptons, lepton+ $E_T^{\text{miss}}$ , dibosons (VV,  $V\gamma$ ,  $\gamma\gamma$ , also with H), ditops, t+b

use ISR to unveil low-mass dijet resonances:

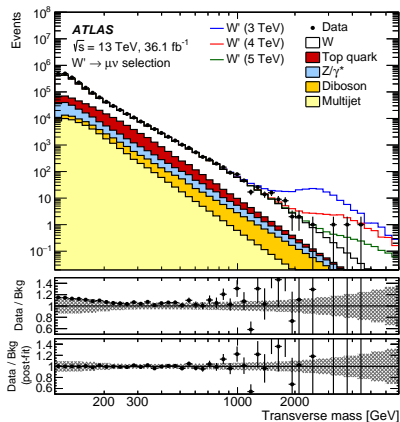
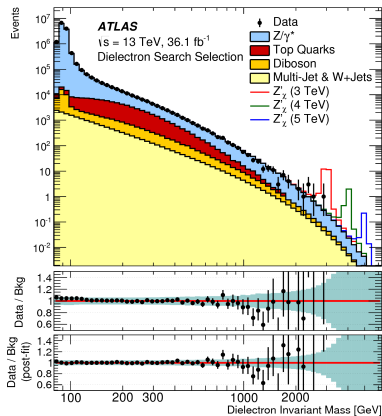


Local (global) significance  $2.9\sigma$  ( $2.2\sigma$ ) at 115 GeV



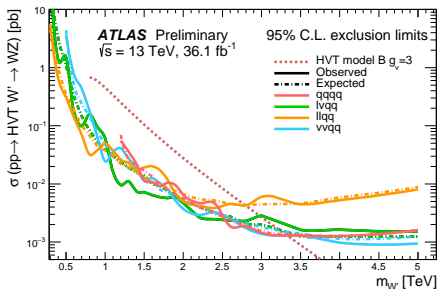
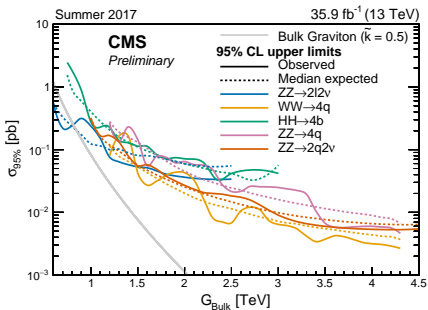
# Resonances: dileptons and lepton+ $E_T^{\text{miss}}$

- traditional searches looking for  $Z'$  and  $W'$
- results exist in electron, muon or tau channels
- depending on the model  $Z'$  and  $W'$  are excluded below 3.7-4.5 TeV



## Resonances: dibosons

- complete list of considered signatures
- look for heavy resonances decaying to Z, W, H,  $\gamma$  for both charged and neutral cases
- explore both gluon fusion and VBF production modes
- interpreted in various models



## Conclusions

No summary: that many limit plots would not fit in one slide!

- With current stage of our experimental knowledge we can say:
  - *no stone is left unturned!*
- LHC gives the access to lower and lower rates allowing to resort to new challenging signatures:
  - can sacrifice production cross section to turn to low background case
  - exploring initial-state radiation tagging, VBF signatures, low reconstruction efficiency objects
- detector upgrades underway ensure that these and new ideas can be successfully employed in the HL-LHC era
- both energy and intensity frontiers will be tackled in the years to come at the HL-LHC!