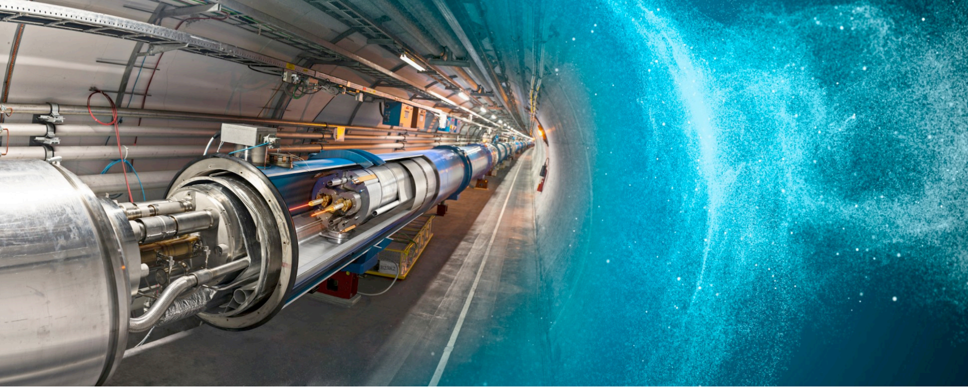


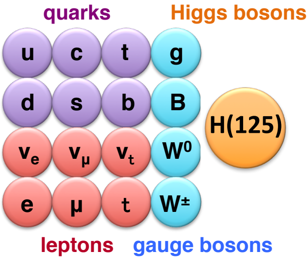
BSM physics searches at ATLAS and CMS

Lesya Shchutska
ETH Zürich
On behalf of ATLAS and CMS Collaborations

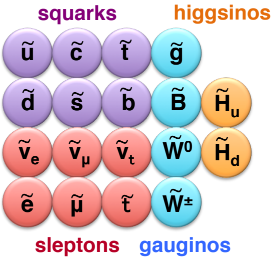
ICPPA'2017, October 5, 2017

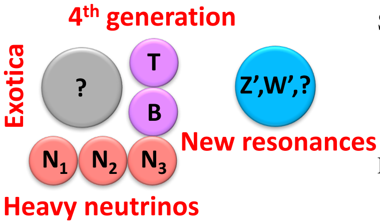
Flavors of new physics searches at the LHC

Standard model



Supersymmetry





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

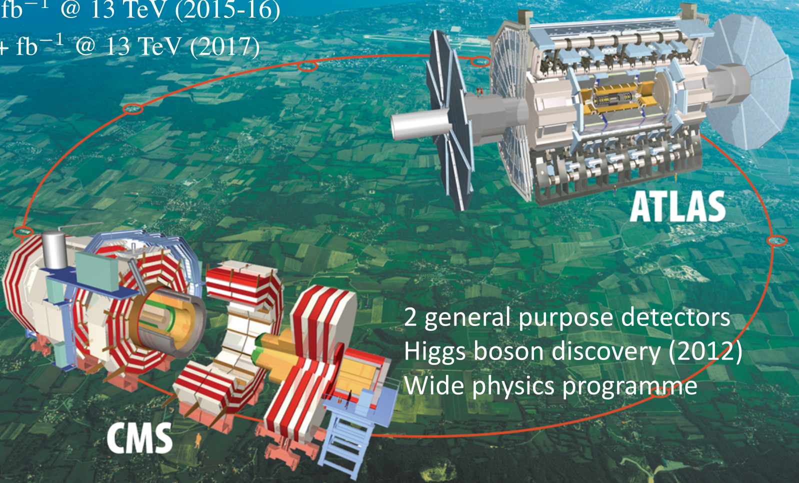
Established operation over the years:

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

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

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

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

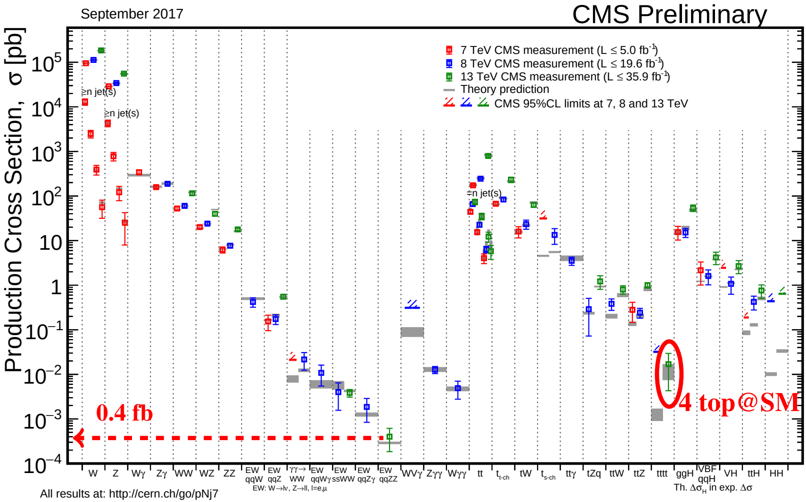


2 general purpose detectors

Higgs boson discovery (2012)

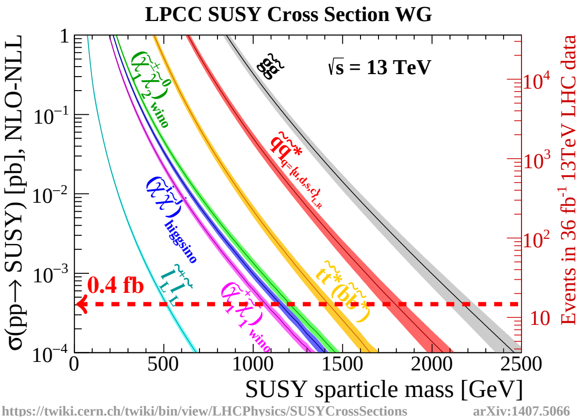
Wide physics programme

SM processes at the LHC



Measuring extremely rare SM processes: important background to searches

SUSY production cross sections



Have a possibility to discover very massive new particles:

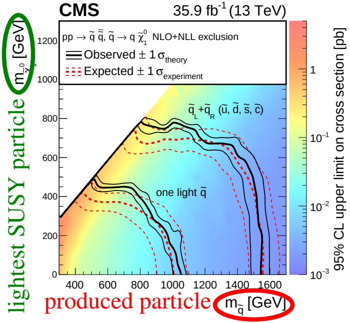
Gluinos and $1^{st}/2^{nd}$ generation squarks:
"high" cross sections for masses up to 2 TeV

3^{rd} 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:



UL on production cross section:

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

- 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^{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)

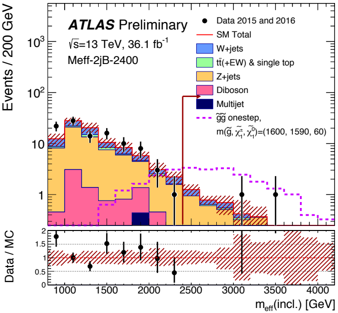
Need to remember all this when seeing mass exclusion lines

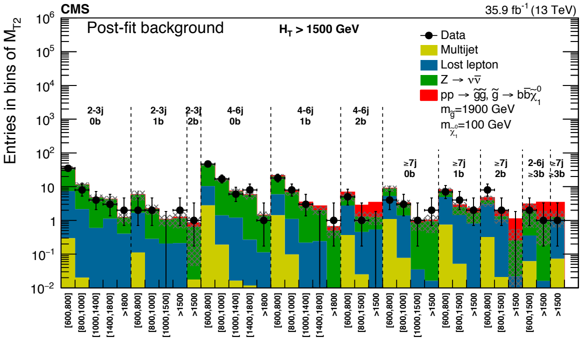
arXiv:1705.04650

Inclusive searches

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

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





Gluino landscape: various decay chains and limits

Consider several possible decay gluino decay scenarios:

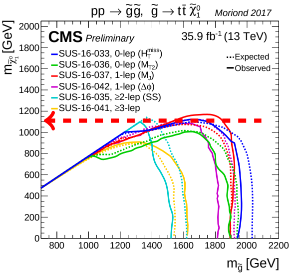
- via top, bottom or light quarks

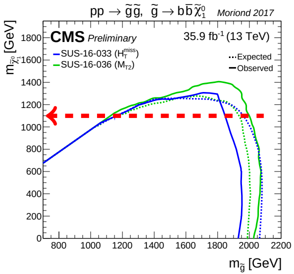
Maximum excluded gluino mass is driven by gluino production cross section:

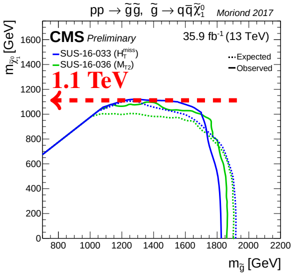
- about 1.8-2.0 TeV depending on decay mode

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

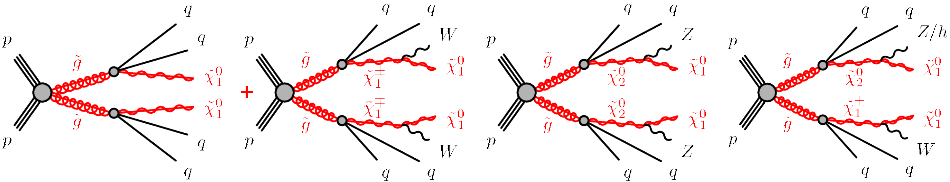
- reach the same 1.1 TeV of LSP mass at different gluino masses: best in 4b final state, worst in 4t final state

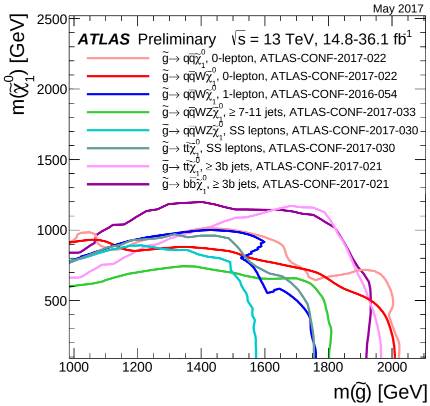






Gluinos: remembering about cascade decays





Adding more complex decay chains:

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

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

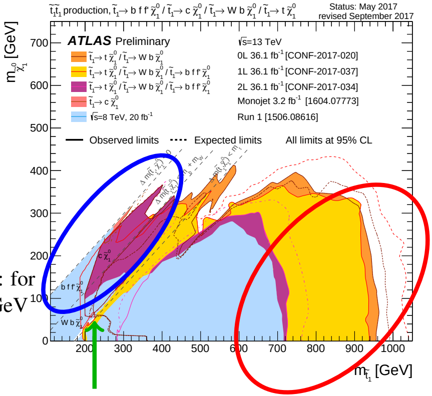
Third generation squarks: rich topology

"low Δm"

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

- $\tilde{t}_1$ 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 polarizaton measurements
- ISR-tagging for higher LSP mass

"high Δm"

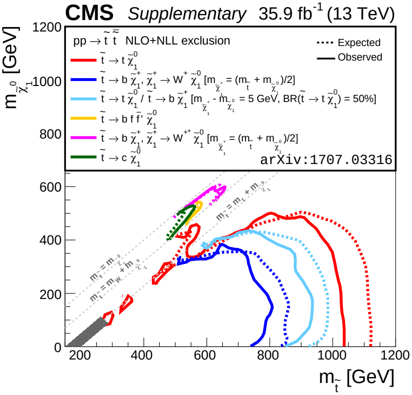
low-SM background:

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

The same "low Δm" and "high Δm" tools are used for other sparticle searches

Third generation squarks searches

- target various $\tilde{t}$ decay modes: $\tilde{t}_1 \to t\tilde{\chi}^0_1$, $\tilde{t}_1 \to b\tilde{\chi}^\pm_1$, $\tilde{t}_1 \to c\tilde{\chi}^0_1$, $\tilde{t}_1 \to bff'\tilde{\chi}^0_1$
- look at all possible final states: 0ℓ, 1ℓ, 2ℓ
- check cascade decays via Z or Higgs bosons: add multilepton searches



Interpretation of one 0ℓ search in several scenarios:

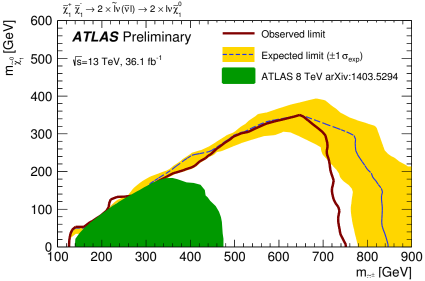
- $\sim$1 TeV reach for direct decay $\tilde{t}_1 \to t\tilde{\chi}^0_1$
- for mixed case $\tilde{t}_1 \to t\tilde{\chi}^0_1$ / $\tilde{t}_1 \to b\tilde{\chi}^\pm_1$
  - $\sim$0.9 TeV for compressed $\tilde{\chi}^\pm_1/\tilde{\chi}^0_1$
  - $\sim$0.8 TeV for not compressed $\tilde{\chi}^\pm_1/\tilde{\chi}^0_1$
- in compressed $\tilde{t}_1/\tilde{\chi}^0_1$ cases:
  - $\sim$550 GeV for decays via off-shell W
  - $\sim$650 GeV for decays via $\tilde{\chi}^\pm_1$

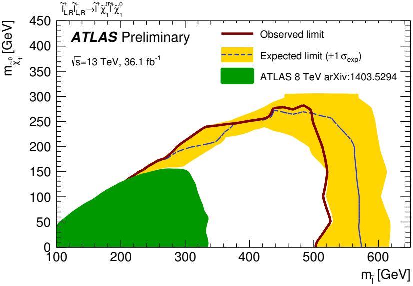
"Universal" exclusion is at about $\sim$500 GeV for $\tilde{t}_1$.
Similarly, 1 to 1.2 TeV reach for $\tilde{b}_1$ squarks.

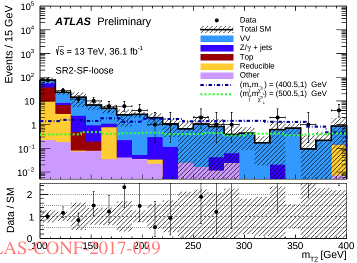
arXiv:1708.02794 arXiv:1707.03316

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





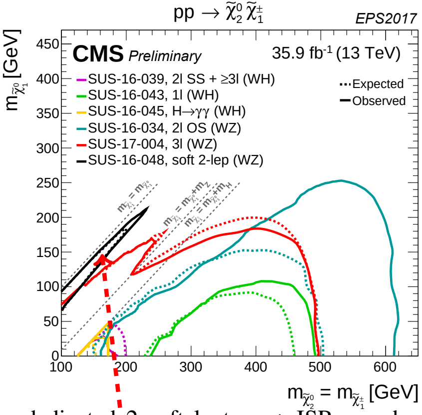


ATLAS-CONF-2017-039

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

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

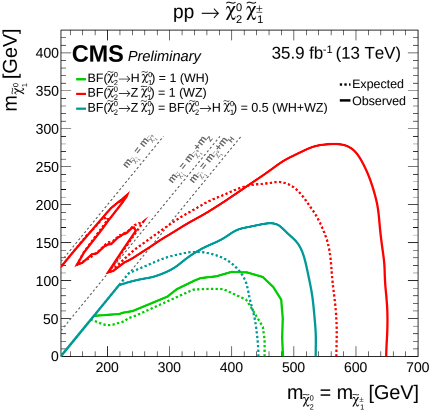
Individual searches



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

2ℓOS search: observed is stronger by +1σ: downward data fluctuation

Statistical combination

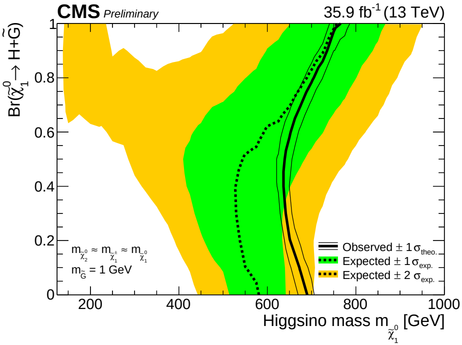


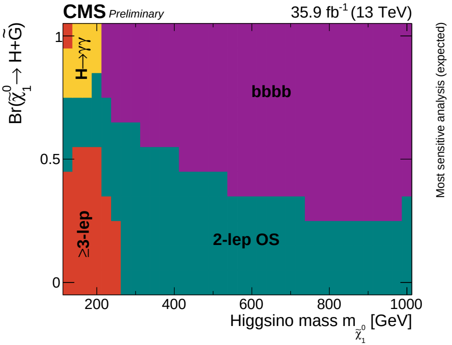
Depending on $\mathcal{B}$(WZ/WH) and Δm, exclusion varies between 150 and 650 GeV

CMS-PAS-SUS-17-004

Electroweak SUSY: higgsinos

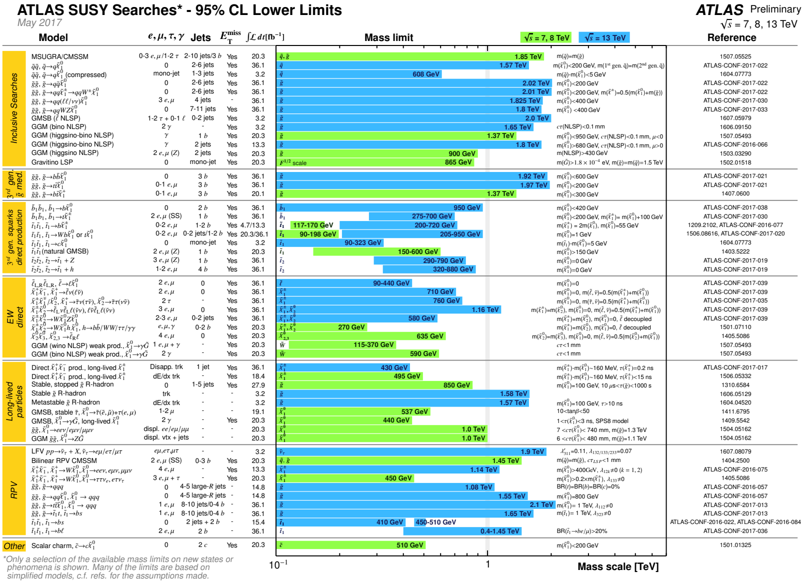
- targeting HH + E_T^{miss} or ZZ + E_T^{miss} scenarios
- interpret in GMSB model with massless gravitino LSP
- an interplay of various final states due to complexity of the final states with intermediate Higgs bosons!





CMS-PAS-SUS-17-004

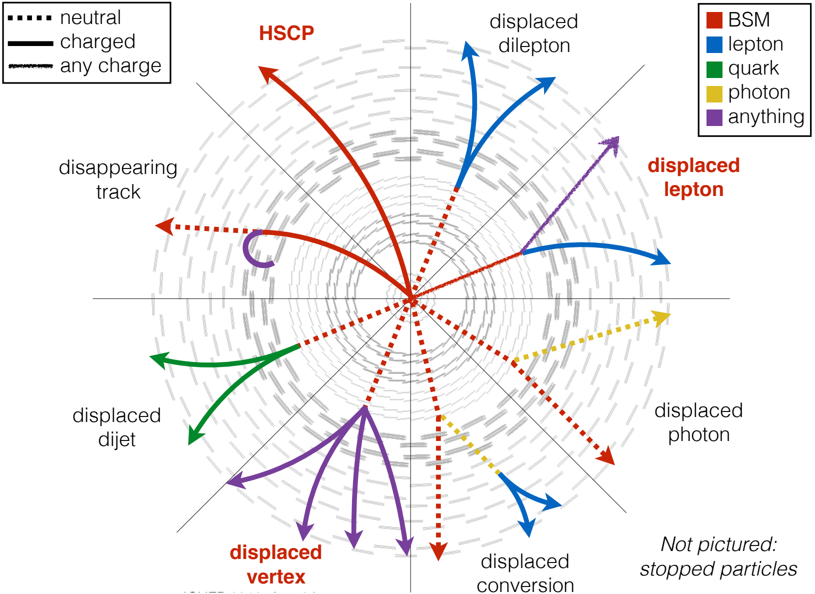
SUSY summary



CMS Summary plot

Long-lived particle signatures in a detector

J. Antonelli

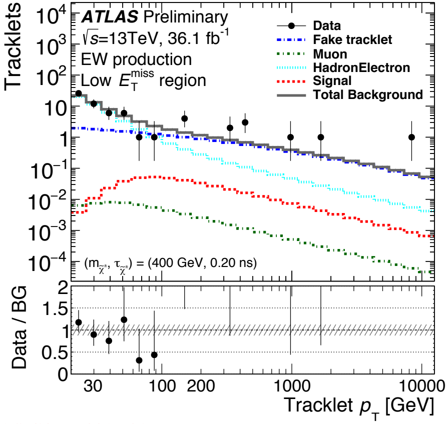


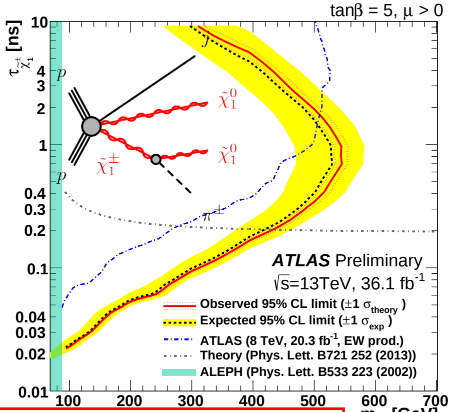
Long-lived particle searches: possible new physics scenarios

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

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:
  - $\tilde{\chi}_1^\pm \to \pi^\pm \tilde{\chi}_1^0$ 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

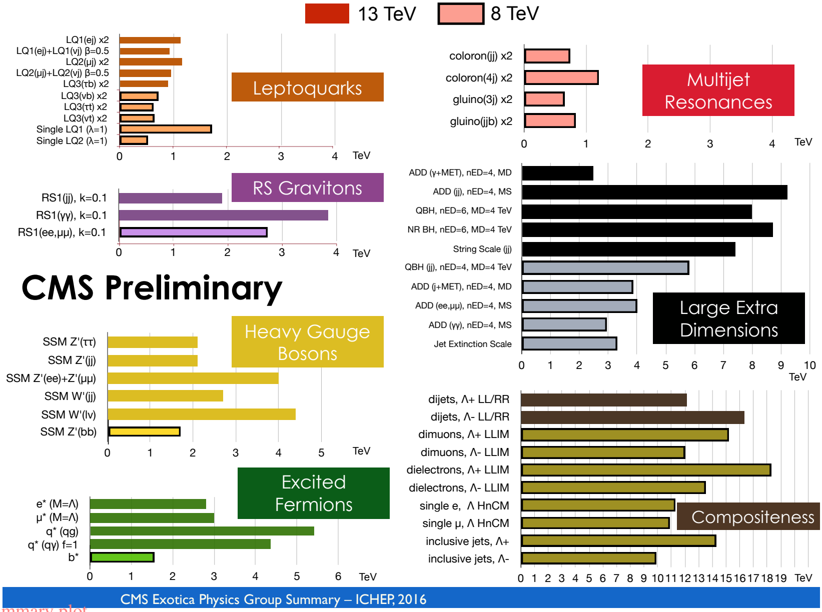




Sensitive up to $m_{\tilde{\chi}^\pm} \approx 550$ GeV for wide range of lifetimes

ATLAS-CONF-2017-017

Exotica searches

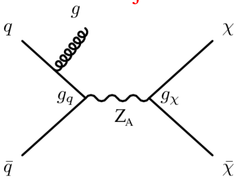


ATLAS Summary plot

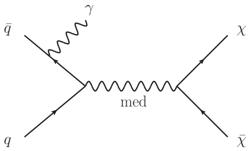
Dark matter searches

"Visualize" dark matter production with an **ISR** or **associated particle** production:

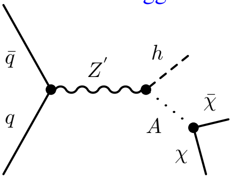
"monojet"

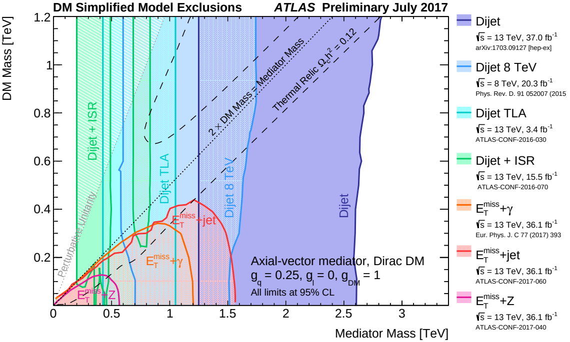


"monophoton"

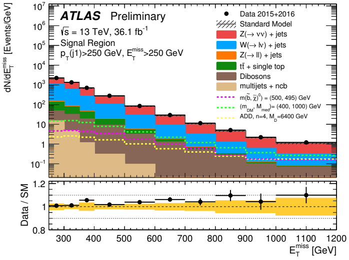


"mono-Higgs"





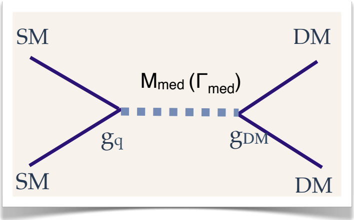
E_T^{miss} is a typical search variable:



Dark matter interpretations at the LHC

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

See e.g.
arXiv:1407.8257
arXiv:1507.00966
arXiv:1603.04156



s-channel

Define simplified model with (minimum) 4 parameters	
Mediator mass (M_{med})	DM mass (M_{DM})
g_q	g_{DM}

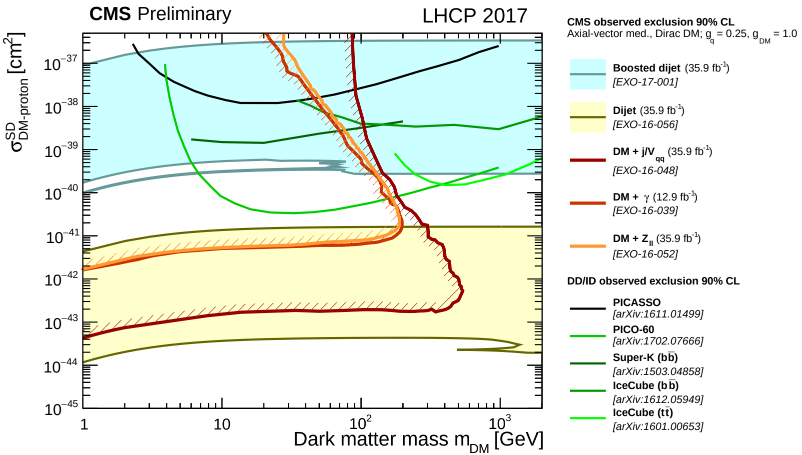
DM	
Dirac fermion	Scalar - real
Majorana fermion	Scalar - complex

Consider comprehensive set of diagrams for mediator	
Vector	Axial-vector
Scalar	Pseudoscalar

arXiv:1407.8257 arXiv:1507.00966 arXiv:1603.04156

Comparison with the direct detection

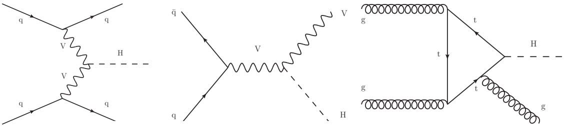
- the comparison is always coupling- and model-dependent
- shown: **axial-mediator** and Dirac DM, $g_q = 0.25$, $g_{DM} = 1.0$

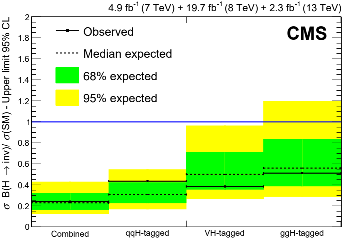


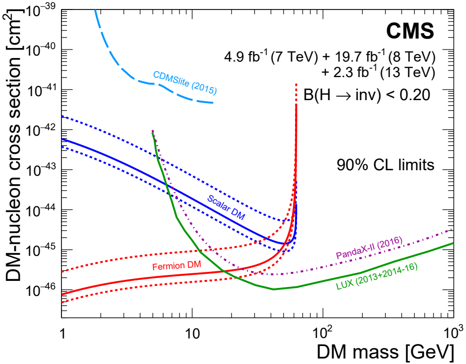
Direct detection and LHC are equal in overall sensitivity but probe different regions of parameter space.

Higgs boson portal to new physics

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







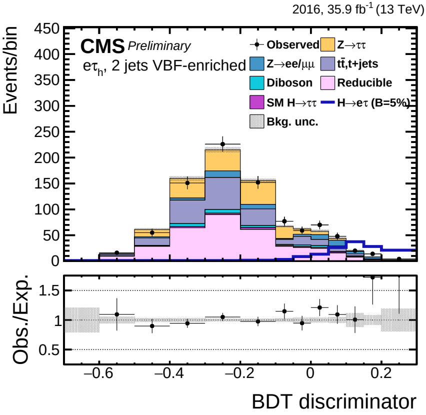
- $\mathcal{B}(H \rightarrow \text{inv}) < 0.24$ @ 95% CL
- SM ($H \rightarrow ZZ \rightarrow 4\nu$) = 1.06×10^{-3}

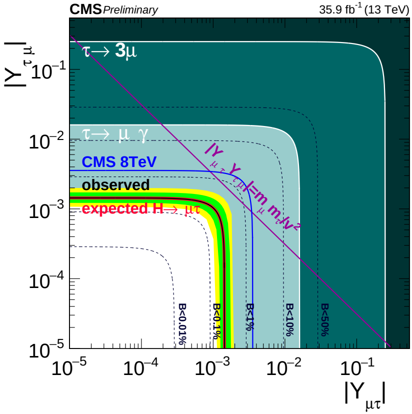
- complementary constraints on low-mass DM

arXiv:1610.09218 arXiv:1708.09624

LFV Higgs boson decays

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





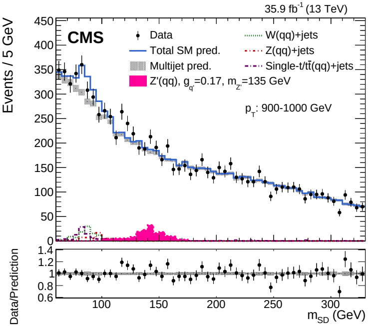
CMS-PAS-HIG-17-001

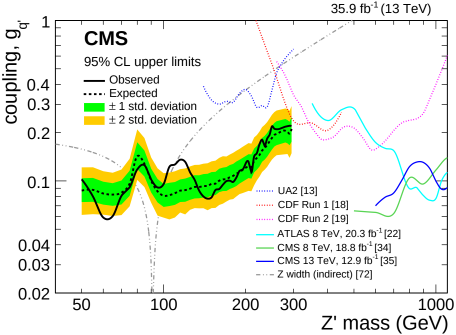
Resonances: dijets

Check all possible scenarios:

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

use ISR to unveil low-mass dijet resonances:



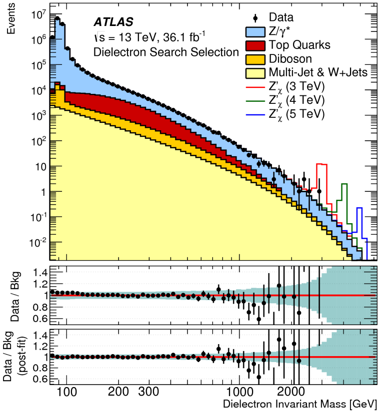


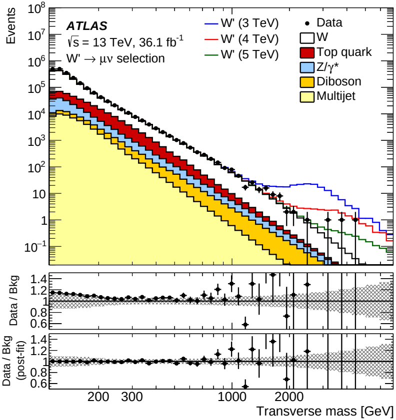
Local (global) significance 2.9σ (2.2σ) at 115 GeV

arXiv:1710.00159

Resonances: dileptons and lepton+E_T^{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

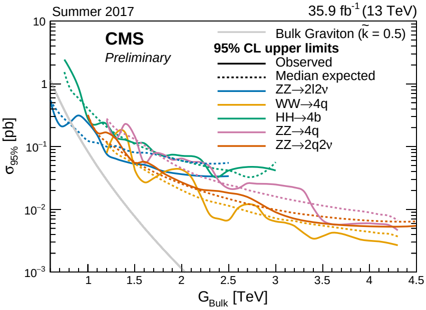


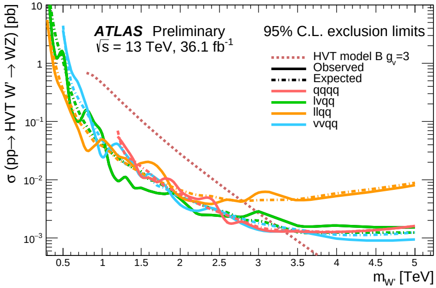


arXiv:1706.04786 arXiv:1707.02424

Resonances: dibosons

- complete list of considered signatures
- look for heavy resonances decaying to Z, W, H, γ 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!