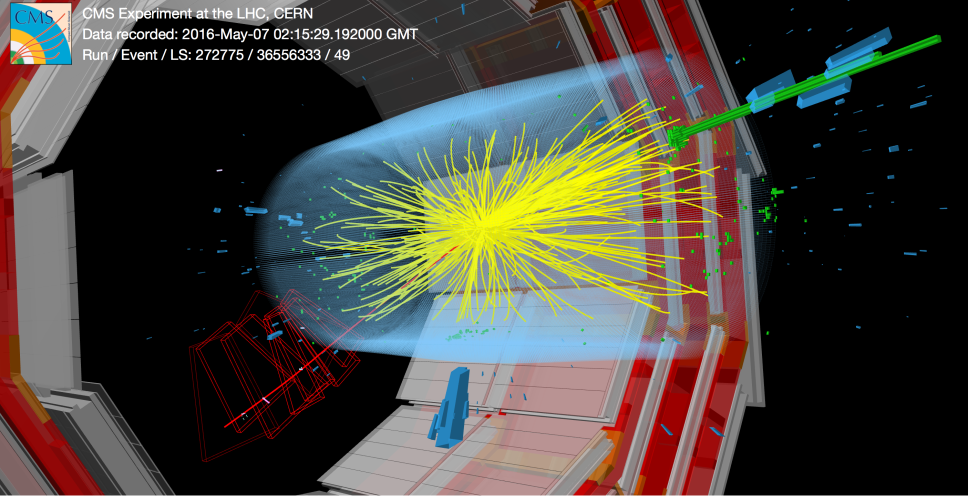


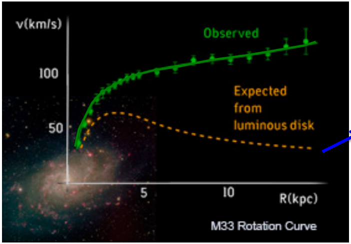
SUSY/BSM after the LHC restart: what's next?

Lesya Shchutska
University of Florida and FNAL LPC

November 28, 2016

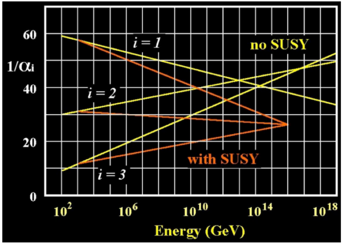
New (unexplained) physics in front of us!

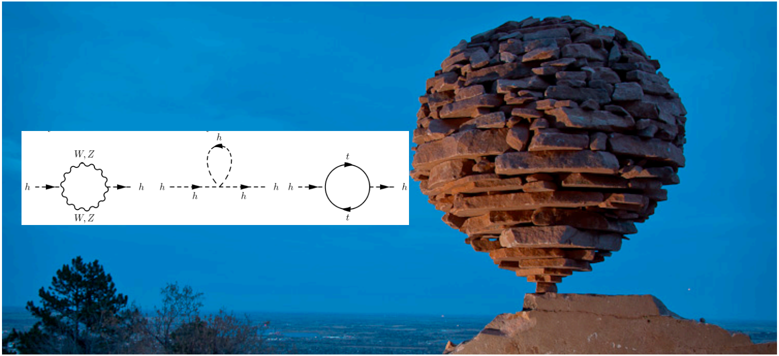
dark matter nature?



$$v^2 \propto \frac{M}{r}$$

ultimate force?





H mass stabilization?

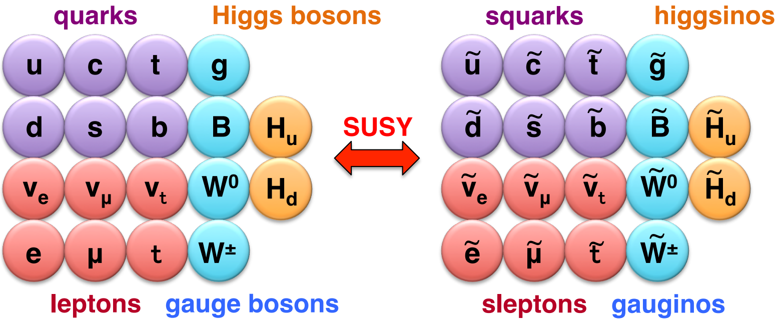
Supersymmetry of a theorist

Is a new symmetry between forces and matter (which has not been seen (*yet?*))

- for each $\frac{1}{2}$-integer spin particle (fermion) introduces an integer spin partner (boson) and vice versa
    - creates complete spectrum of partners to standard model particles
    - quantum numbers are the same apart from the spins which are different by $\frac{1}{2}$ unit
    - they are heavier (or else we'd have seen them already).

And incidentally solves outlined long-standing questions:

- provides a DM candidate; unifies couplings at $\sim 10^{16}$ GeV; stabilizes Higgs boson mass ...



Supersymmetry of an experimentalist

A convenient framework to look for deviations from the SM in many dimensions:

With missing transverse energy (R-parity conserving SUSY)

$E_{\mathrm{T}}^{\mathrm{miss}}$ and many more search variables and bins

All-hadronic

(b-)jets, $(M)H_{\mathrm{T}}$, M_{T2}

Single-lepton

(b-)jets, H_{T}, M_{T2}, M_{T}

2 opposite-sign leptons

(b-)jets, H_{T}, M_{T2}, $M_{\ell\ell}$

Photon+X

(b-)jets, H_{T}, leptons

≥ 3 leptons

(b-)jets, H_{T}, $M_{\ell\ell}$, M_{T}

2 same-sign leptons

(b-)jets, H_{T}, M_{T}, p_{T}^{ℓ}

Or without $E_{\mathrm{T}}^{\mathrm{miss}}$ (R-parity violating SUSY)

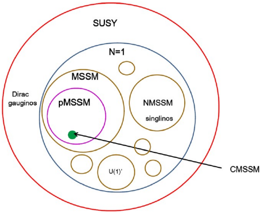
and $\sim$ the same list of the final states

Often end up with several analyses per one final state!

- profit from a complementary approach and independent background prediction methods

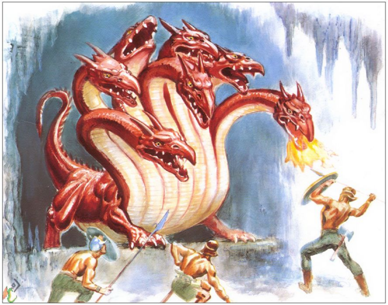
Motivation of such an approach: SUSY of a theorist is far from “minimality”

- SUSY is a broken symmetry: masses of superpartners are not fixed by theory
- a parameter space which is impossible to fully exclude but to only constrain



Within the MSSM only:

- MSSM: 109 parameters
- pMSSM: 19 parameters
- CMSSM: 5 parameters



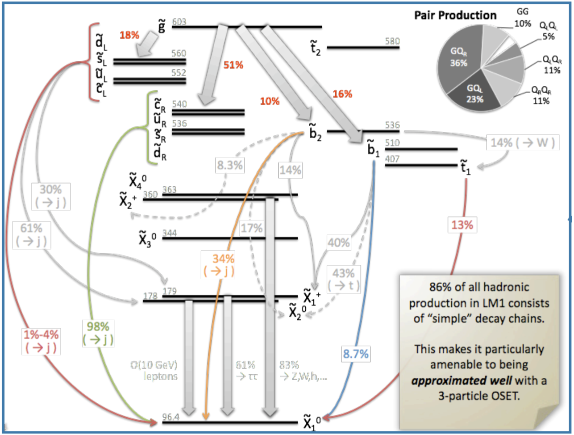
Impossible to exclude. Can only constrain with:

- direct and indirect dark matter detection experiments
- study of the rates of the rare processes (e.g. heavy-flavor physics)
- precision SM production cross section measurements (e.g. $t\bar{t}$ production)

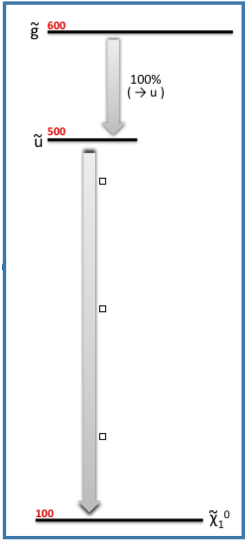
- **direct SUSY particle production in the pp collisions at the LHC and their detection in ATLAS or CMS experiments**

SUSY framework in searches

CMSSM



We go for a simpler goal:



Work with the **simplified model spectrum (SMS)**:

2-3 particles, 1-2 decay modes at a time:

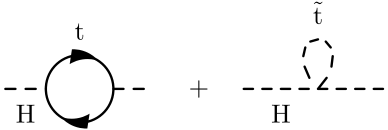
- helps to design concrete searches
- allows for a consistent interpretation through a span of searches

Concentrate on favorable SUSY parameters

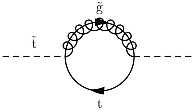
$\tilde{t}$ cancels out the largest divergency in the Higgs boson mass - from **t quark**:

1. 1-loop order: top contribution corrected by $\tilde{t} \to m_{\tilde{t}} \approx \mathcal{O}(100 \text{ GeV})$

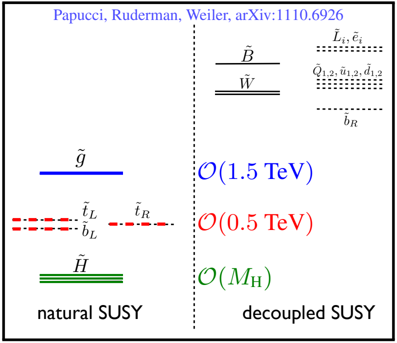
$\Delta m_H^2 \propto$



2. 2-loop order: gluino enters $\tilde{t}$ mass $\to m_{\tilde{g}} \approx \mathcal{O}(1 \text{ TeV})$



3. not too heavy $\widetilde{b}_L$: in the doublet with $\tilde{t}_L$

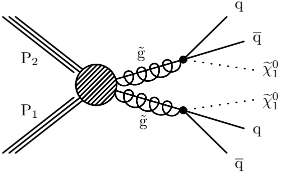


Plethora of the direct LHC searches are targeting:

- **gluinos**
- **3rd generation squarks**
- and **gauginos**!

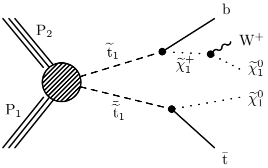
Experimental signatures

gluinos



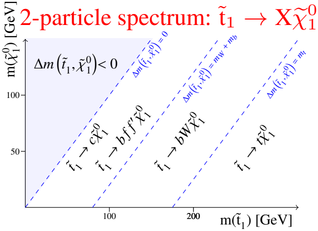
- the largest cross-sections
- generic signature based searches typically with large H_T
- can have other sparticles in the decay chain

stops

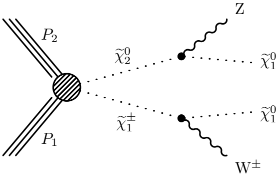


- more advanced techniques
- signals can be similar to SM $t\bar{t}$
- final state depends on $\Delta M(\tilde{t}_1, \tilde{\chi}_1^0)$

2-particle spectrum: $\tilde{t}_1 \to X\tilde{\chi}_1^0$



gauginos

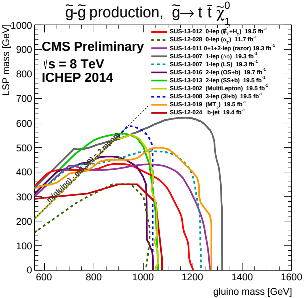


- accessible with large luminosities
- typically no jet activity
- best searched in leptonic final states

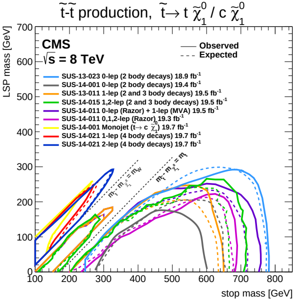
SUSY after the LHC Run I

- no smoking gun for a SUSY-like process in Run I data
- produced constraints on the sparticle masses in the SMS framework:
  - under 100% BF assumption!
  - mass reach can decrease significantly with adding realistic decay rates

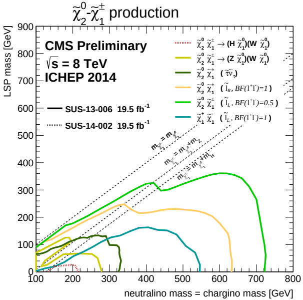
gluinos



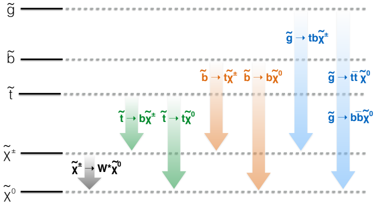
stops



gauginos

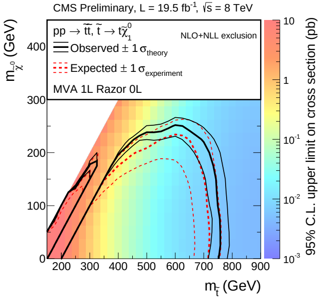


Impact of the branching fraction: stops

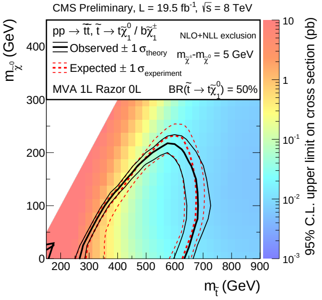


- competing decay channels: $\tilde{t} \to t\tilde{\chi}_1^0$ and $\tilde{t} \to b\tilde{\chi}_1^{\pm}$
- check "natural" spectrum with compressed higgsinos: $\Delta M(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0) \ll M_W$
- need to use both all-hadronic and 1ℓ searches for the best sensitivity
- sensitivity drops if go more compressed and if $\mathcal{BR}(\tilde{t} \to b\tilde{\chi}_1^{\pm})$ grows

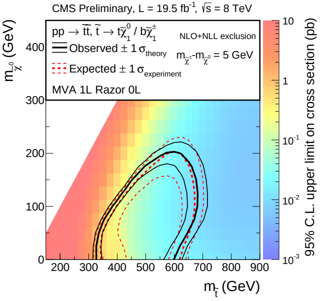
$100\%\ t\bar{t} + E_T^{miss}$



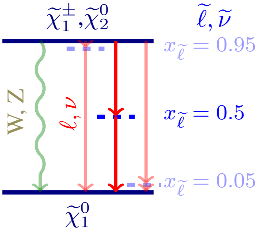
$t\bar{t}$ or $b\bar{b}W^*W^* + E_T^{miss}$



excluded in any BF



Consequences of model assumptions: EWKinos

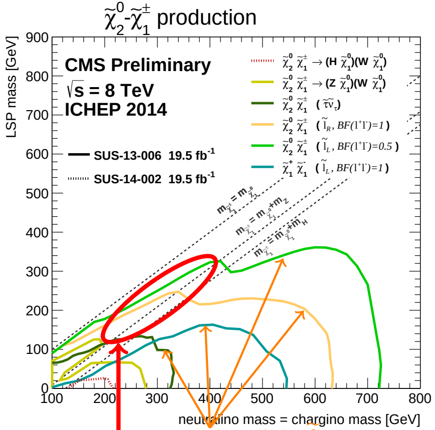


flavor-democratic

τ-enriched?

τ-dominated?

Gauginos excluded up to 740 GeV?



requires light $\tilde{\ell}$

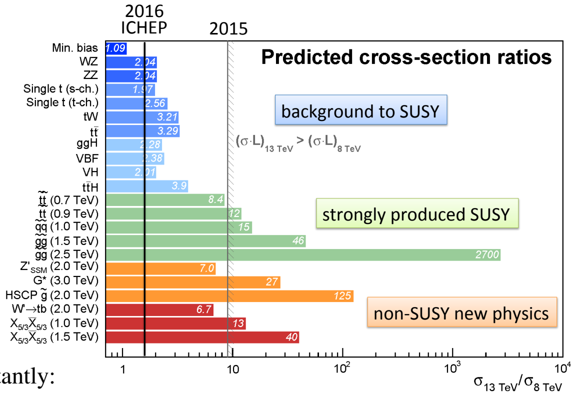
Unprobed in absence of $\tilde{\ell}$!

- assumptions on the intermediate particles move mass limits from 200 to 700 GeV!
- most "natural" scenarios with light gauginos only are practically unconstrained.

The story just begins

Why look for SUSY in Run II:

- LHC8 → LHC13 brought the last in the vicinity sizeable jump in $\sqrt{s}$
  - could try to find new particles just above the mass reach of LHC8
- LHC13 → HL-LHC is yet to bring another 2 orders of magnitude in cross section for the same masses (LHC13-end-of-2016 is already beyond the scope of the plot!)



More importantly:

- LHC8 experience and lessons triggered smarter strategies at LHC13
- hopefully less saturation there in the future!

SUSY searches with 2015 data (2.3/fb)

The results produced in Run 2 with 2015 data:

With missing transverse energy (R-parity conserving SUSY)

targeting strong production scenarios

All-hadronic

SUS-15-002: "MH_T"
SUS-15-003: "M_{T2}"
SUS-15-004: "razor"
SUS-15-005: "α_T"
SUS-16-001: $\widetilde{b}$ search
SUS-16-007: $\tilde{t}$ search

Single-lepton

SUS-15-004: "razor"
SUS-15-006: "$\Delta\phi$"
SUS-15-007: "M_J"
SUS-16-002: $\tilde{t}$ search

2 opposite-sign leptons

SUS-15-011: "edge"

Photon+X

SUS-15-012

$\geq$ 3 leptons

SUS-16-003

2 same-sign leptons

SUS-15-008

All available at the CMS SUSY summary page:

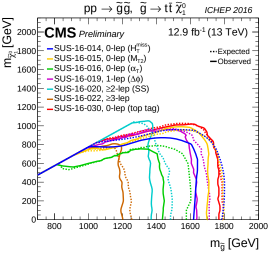
http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/SUS/index.html

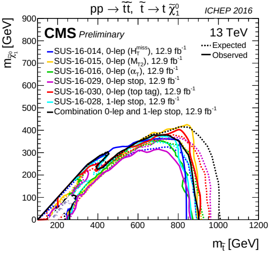
... and no SUSY

Some excitements along the way

Even with Run II and new energy frontier SUSY has been discovered yet ...

- gluino and stop quark masses are almost pushed out of naturalness: 1.8 and 1.0 TeV





- we just started getting any sensitivity to gauginos

Along the way there are some excitements in strong SUSY:

- Z/edge CMS and ATLAS battle

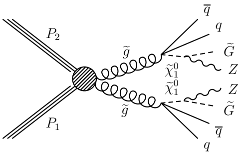
And searches which just start probing new territory:

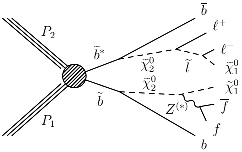
- first Run II results on the EWK SUSY searches
- first searches for compressed EWK SUSY

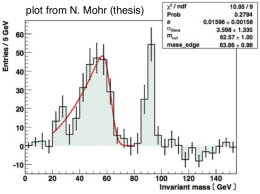
Bump-like search in SUSY: edge in 2ℓOS

Can have an on-shell or off-shell Z boson in the decay chain:

- **on-shell Z**: an excess on the Z peak invariant mass (traditional search in E_T^{miss} tails)
- **off-shell Z** or **slepton** decays: characteristic "edge" shape in same flavor leptons

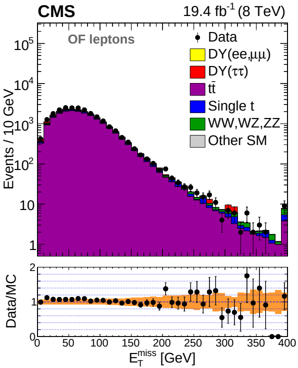




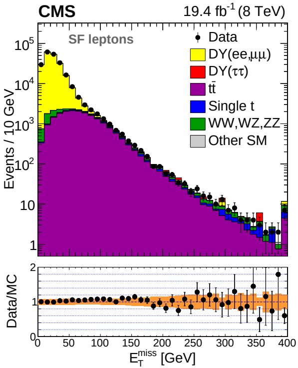


All possible mass endpoints calculated in CMS IN 2006/012, L.Pape, e.g. for a 3-body: $M_{ll}^{max} = M_X - M_0$

$e\mu$: measure SM background



ee and $\mu\mu$: look for deviations



Advantage for experimentalists: no signal in opposite flavor ($e\mu$)

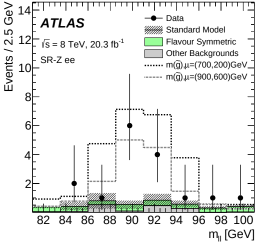
- estimate all the flavor-symmetric background in SF from OF data ($t\bar{t}$,WW,tW etc)

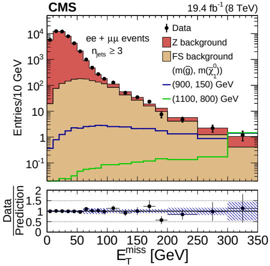
Tensions in Run I

ATLAS

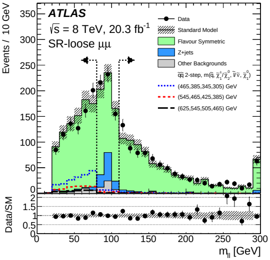
CMS

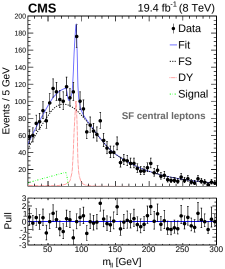
On – shell Z





Off – shell Z





Tensions in Run I

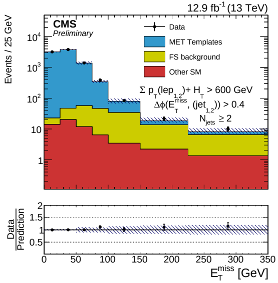
	ATLAS Eur. Phys. J. C75 (2015) 318	CMS JHEP 04 (2015) 124
On − shell Z	• 3.0σ excess • high $E_{\mathrm{T}}^{\mathrm{miss}}$ • high H_{T}	• No excess
Off − shell Z	• No excess	• 2.6σ excess • around $M_{\ell\ell} \approx 79$ GeV • central b-tagged events

Testing the same two regions with Run II data@CMS

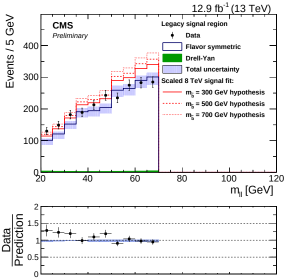
Kept a very similar strategy:

- OSSF leptons, $p_{\mathrm{T}} > 25/20$ GeV, $E_{\mathrm{T}}^{\mathrm{miss}} > 150$ GeV, at least 2 jets $p_{\mathrm{T}} > 35$ GeV
- event categorization: N_{jets}, $N_{\text{b-jets}}$, H_{T}, $E_{\mathrm{T}}^{\mathrm{miss}}$ for on-Z ($81 < M_{\ell\ell} < 101$ GeV)
- main backgrounds estimated from data: Z+jets and flavor-symmetric processes ($t\bar{t}$, WW)

$\mathbf{ATLAS-like\ \ region(on-Z)}$



$\mathbf{CMS-edge\ \ region(off-Z)}$



Data are consistent with the expectations in both regions

Not the end of the story

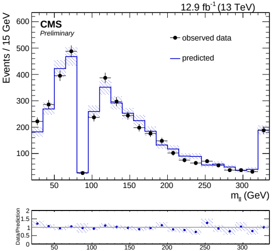
To target larger luminosity developed a new strategy:

- constructed a likelihood discriminant of kinematic variables (NLL):
  - $E_T^{\text{miss}}, p_T^{\ell\ell}, |\Delta\phi_{\ell\ell}|, \sum m_{\ell b}$
- two categories are formed based on NLL value: $t\bar{t}$-like and non-$t\bar{t}$-like
- search is done in $M_{\ell\ell}$ and NLL categories

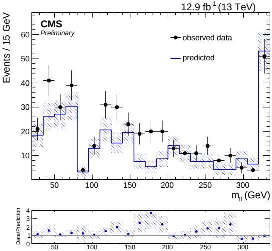
		ttbar-like	non-ttbar-like
mll < 81 GeV	pred. FS	1374.4 ± 48.1	105.8 ± 10.9
	pred. DY	13.5 ± 4.6	7.3 ± 2.5
	pred. total	1387.9 ± 48.3	113.1 ± 11.2
	obs	1417	135
mll > 101 GeV	pred. FS	2435.8 ± 72.2	208.3 ± 15.7
	pred. DY	7.6 ± 2.6	4.1 ± 1.4
	pred. total	2443.4 ± 72.3	212.4 ± 15.7
	obs	2347	285

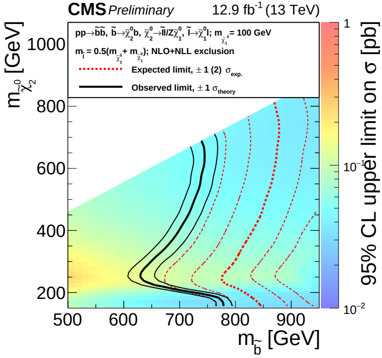
3.1σ excess in high-mass non-$t\bar{t}$-like region

$t\bar{t}$-like events



non-$t\bar{t}$-like events



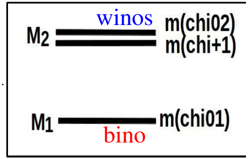


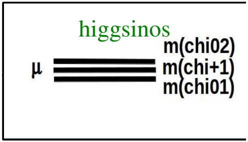
ATLAS colleagues are on the way to implement NLL...

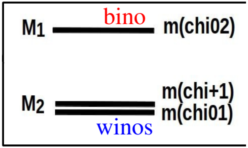
CMS-PAS-SUS-16-021

The place with the most to gain yet: EWK sector

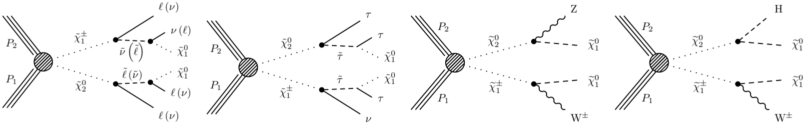
- light ($\mathcal{O}(100)$ GeV) gauginos are a key component of natural SUSY
- mass hierarchy is governed by 4 parameters: higgsino mass μ, bino mass M_1, wino mass M_2, $\tan\beta$
- **mass degeneracy** is not an accidental feature (as could happen with $\tilde{t}$, $\tilde{\chi}_1^0$), but a consequence of the mixing:
    - **winos** are typically quasi-mass degenerate: $\Delta M \sim \mathcal{O}(100\ \text{MeV})$
    - **higgsinos** are a bit less compressed: $\Delta M \sim \mathcal{O}(1\ \text{GeV})$
- higgsino and wino LSP good dark matter candidates
    - and the hardest for detection experimentally: LSP and NLSP are very compressed
    - detectable signature: very soft leptons



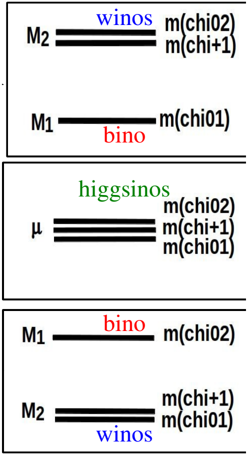




We almost did not look there with Run I data!



EWKino searches



Classic searches (SUS-16-024)

Mass-degenerate $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ decay via W, Z, H bosons or leptons to $\tilde{\chi}_1^0$

- search for events with multiple leptons, $E_{\mathrm{T}}^{\mathrm{miss}}$, no hadronic activity

Compressed searches (SUS-16-025)

Close in mass higgsinos decay via deeply off-shell W and Z bosons to a higgsino LSP

- multiple soft leptons, low $E_{\mathrm{T}}^{\mathrm{miss}}$ $\Longrightarrow$ not visible!
- need to boost the system in the transverse plane $\Longrightarrow$ use events with ISR jets

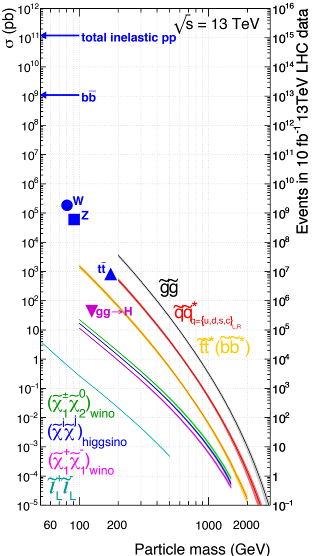
Long-lived searches (EXO-12-034)

Wino $\tilde{\chi}_1^{\pm}$ flies in the detector before a decay to $\tilde{\chi}_1^0$: $\tilde{\chi}_1^{\pm} \to \pi^{\pm}\tilde{\chi}_1^0$

- search for disappearing tracks in the detector
- complementary approach from EXO analyses

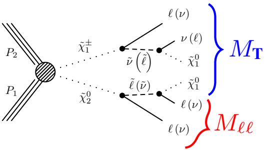
Cross section hierarchy

- EWK SM cross sections are orders of magnitude larger than similar SUSY processes: need to be creative in event selection

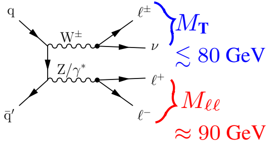


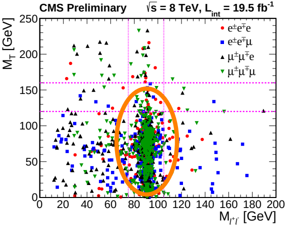
- pick a most Z-like pair of leptons and compute $M_{\ell\ell}$
- use the third lepton to get M_T

SUSY in 3ℓ



SM in 3ℓ

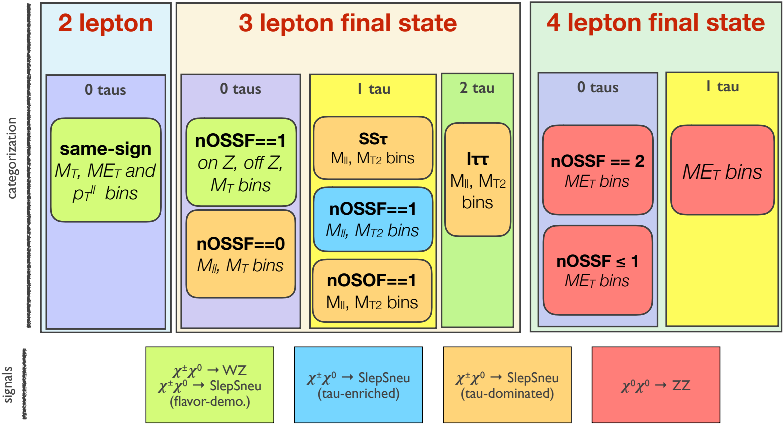




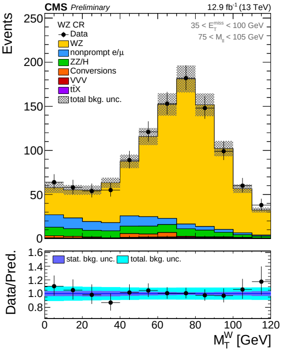
- contain all the SM WZ background in few bins of phase-space
- search for new physics in the tails

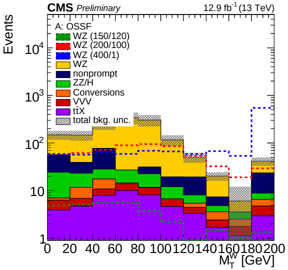
Considered final states

- categorize events by lepton multiplicity (2, 3, 4), flavor (e, μ, τ_{h}), charge (same-sign or not), and kinematic properties ($M_{\ell\ell}$, M_{T}, M_{T2})
- apply a b-veto to suppress $\mathrm{t\bar{t}}$, $E_{\mathrm{T}}^{\mathrm{miss}} > 50$ GeV for $\geq 3\ell$ and > 60 GeV for 2ℓSS
- main backgrounds: WZ$\rightarrow 3\ell$, non-prompt leptons ($\mathrm{t\bar{t}}$, DY), conversions, rare SM



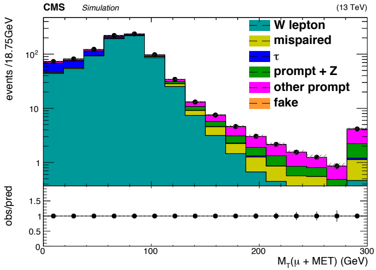
nOSSF = number of OSSF pairs (ee, μμ, ττ)
nOSOF = number of OS different flavour pairs (ee, μμ, eμ)





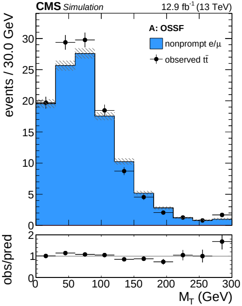
Classic EWKino: WZ background

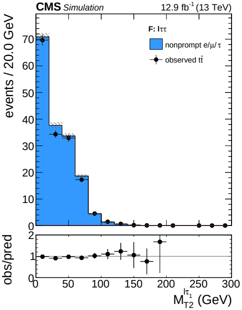
- the most important in the 3ℓ final state: use M_T variable to suppress it
- $M_T > 120$ GeV regions = the largest sensitivity:
  - need to describe WZ M_T tail accurately
- three main sources of the WZ leaking to the tails:
  - natural W width (W, prompt + Z)
  - detector mismeasurements leading to imperfect E_T^{miss}
  - picking a wrong lepton to compute M_T (other prompt and mispaired)



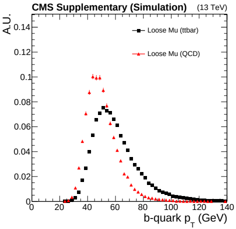
- lepton mispairing is insensitive to imperfections in the MC simulation
- the other two sources are checked in $W\gamma$ control region in data
- final result: from MC normalized in data control region and uncertainties from $W\gamma$ control region

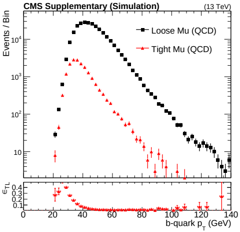
Classic EWKino: non-prompt lepton background





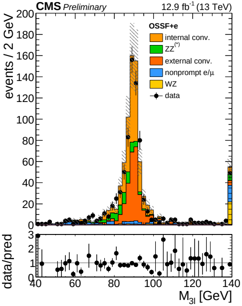
- the most important in 3ℓ w/o OSSF pair, and in regions with τ_{h}:
  - processes with 2 prompt leptons (from W, Z, H decays) and 1 non-prompt lepton (from b, c decays) or a misidentified jet
- estimate with events with at least one lepton failing isolation criteria: multiply yields with a transfer factor (fake rate)
- measure FR in QCD-enriched region for e, μ, and in Z+jets events for τ_{h}
- main challenge:
  - kinematics of jets in **measurement region** is different from the **application region**
  - FR strongly depends on jet p_{T}: the softer a jet is the larger is the probability of a lepton to become isolated

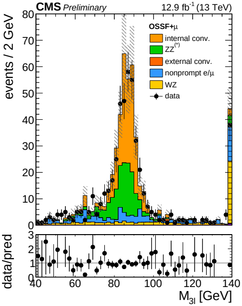




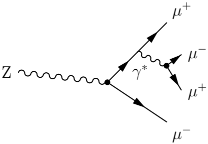
- solution: parameterize FR as a function of p_{T} of the jet containing a lepton

Classic EWKino: conversions and rare SM





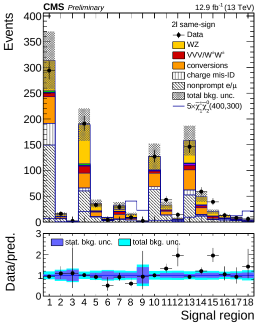
- overall minor background in 3ℓ:
  - external conversions: mostly $\gamma \to$ ee
  - internal conversions: $\gamma^* \to$ ee or $\gamma^* \to \mu\mu$



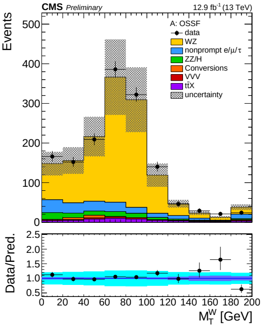
- enters selection when one lepton is too soft and lost
- suppressed by a dedicated veto: $|M_{3\ell} - M_{\mathrm{Z}}| > 15$ GeV
- estimated from MC normalized in control region in data:
  - $|M_{3\ell} - M_{\mathrm{Z}}| < 15$ GeV, $E_{\mathrm{T}}^{\mathrm{miss}} < 50$ GeV
- rare SM processes are estimated with MC simulation

Classic EWKino: yields

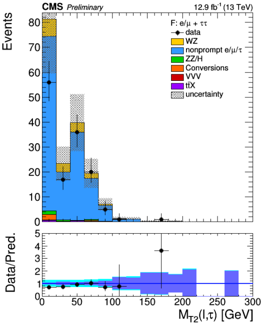
same-sign dileptons



trileptons (e/μ)



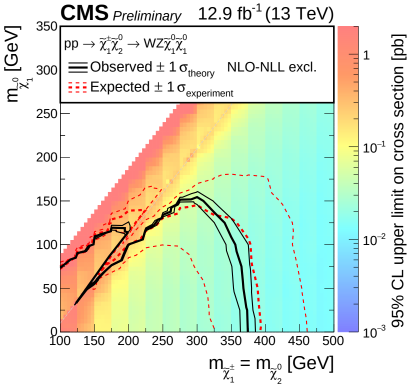
trileptons ($\ell\tau\tau$)

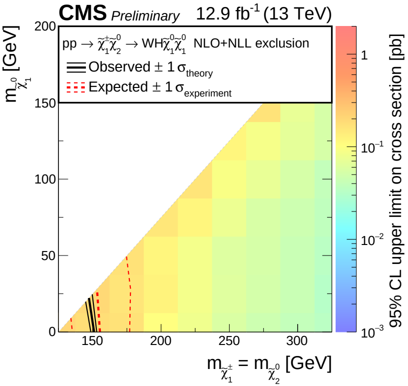


- data are consistent with the expectation
- slight excess in 2ℓSS channel for events with an ISR jet and $E_{\mathrm{T}}^{\mathrm{miss}} > 150$ GeV
- but no smoking gun

Classic EWKino: results

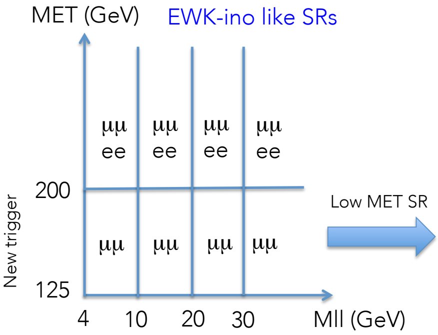
- observations are well consistent with the expectations
- results interpreted in various ewkino spectra
- most interesting ones: $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \rightarrow WZ\tilde{\chi}_1^0\tilde{\chi}_1^0$ and $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \rightarrow WH\tilde{\chi}_1^0\tilde{\chi}_1^0$
- improved sensitivity compared to Run I searches

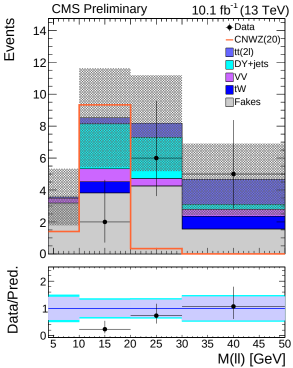




Compressed search

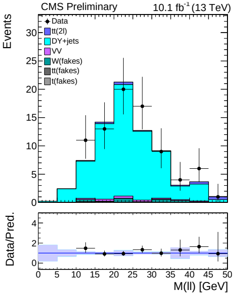
- classic search loses sensitivity when $\Delta M(\widetilde{\chi}_1^{\pm}, \widetilde{\chi}_1^0) < 30$ GeV
- design a dedicated soft-opposite-sign dilepton search:
  - **new trigger**: $\mu\mu$ $p_T > 3$ GeV, $M_{\mu\mu} < 60$ GeV, $E_T^{\rm miss} > 50$ GeV
  - **backgrounds**: $t\bar{t}$, W+jets (non-prompt), VV and DY $\rightarrow \tau\tau \rightarrow \ell\ell\nu\nu\nu\nu$



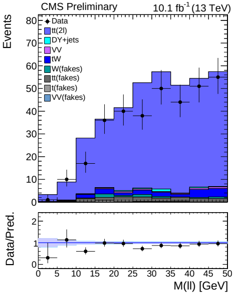


Compressed search: selection and backgrounds

DY control region



$t\bar{t}$ control region



Selection:

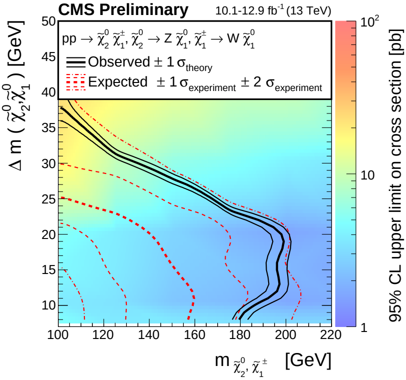
- $E_{\mathrm{T}}^{\mathrm{miss}} > 125$ GeV, $H_{\mathrm{T}} > 100$ GeV and $0.6 < E_{\mathrm{T}}^{\mathrm{miss}}/H_{\mathrm{T}} < 1.4$
  - target ISR topology und suppress QCD
- exactly two μ/e with $5 < p_{\mathrm{T}} < 30$ GeV
  - target phase-space of the search
- $4 < M_{\ell\ell} < 50$ GeV vetoing $9 < M_{\ell\ell} < 10.5$ GeV
  - suppress light resonances
- b-veto and $M_{\mathrm{T}} < 70$ GeV
  - suppress $t\bar{t}$ (in signal $E_{\mathrm{T}}^{\mathrm{miss}}$ is aligned with leptons)
- veto $M_{\tau\tau} \in [0, 160]$ GeV (reconstruct τ p_{T} from hadronic recoil)
  - suppress DY $\rightarrow \tau\tau \rightarrow \ell\ell\nu\nu\nu\nu$

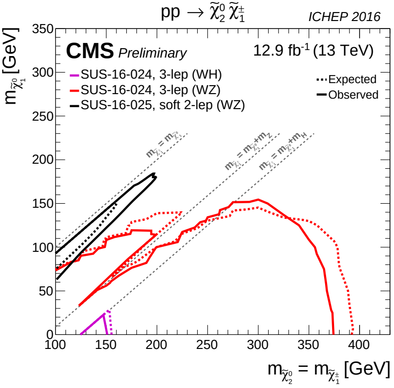
Backgrounds:

- estimate $t\bar{t}$ and DY from MC after validation in control regions in data
- non-prompt leptons with the same "tight-to-loose" method

Compressed search: results

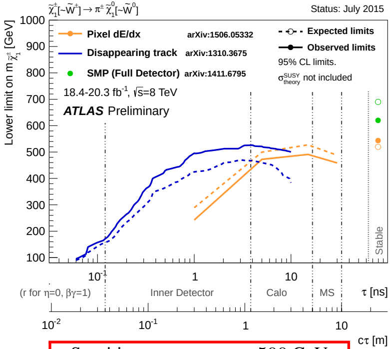
- for interpretation use wino cross sections:
  - realistic higgsino cross sections are several factors lower: need more data
- for $\Delta M = 7.5$ GeV probe charginos up to 180 GeV!
- first coverage at the LHC of a region 5 GeV< ΔM <30 GeV
  - previous constraints come from LEP era

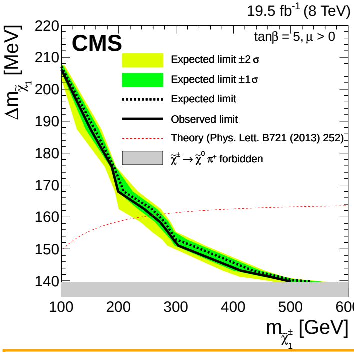




Long-lived particle searches: Run I results

- targeted at new long-lived charged (disappearing tracks) or neutral (decaying to visible daughters) particles
- helps to constrain very compressed case of gauginos: $m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0} \lesssim 200$ MeV:
  - $\tilde{\chi}_1^\pm \to \pi^\pm \tilde{\chi}_1^0$ leads to a disappearing track signature





Sensitive up to $m_{\tilde{\chi}^\pm} \approx 500$ GeV for wide range of lifetimes

Similar result from CMS shown in the $(m_{\tilde{\chi}_1^\pm}, \Delta M)$ plane: degenerate chargino excluded below 260 GeV

arXiv:1502.02522 arXiv:1411.6006 arXiv:1310.3675

Putting it all together: Run I searches in Full models

- interpreted in the general [19-parameter] pMSSM
  - R-parity conserving
  - neutralino LSP: sampled bino, wino and higgsino type
- random sampling of the parameters (with $m < 4$ TeV)
  - **500 million** models sampled
- apply prior experimental constraints:
  - EW precision measurements
  - mass bounds from LEP, Tevatron
  - $\Omega_{\rm LSP} < \Omega_{\rm Planck}$
- consider carefully the remainder
  - 310,327 : models before Run-1
  - 30 billion : signal events generated
  - 44,559 : models required detector simulation
  - 600 million : signal events through GEANT
- next: present exclusion (fraction of models survived) in 2D or 1D projections
- *similar reinterpretation in pMSSM is done by CMS as well*

Overall summary of 22 ATLAS Run I papers

Inclusive

0ℓ	+ 2-6 jets	+ E_T^{miss}
0ℓ	+ 7-10 jets	+ E_T^{miss}
1ℓ	+ jets	+ E_T^{miss}
$\tau(\tau/\ell)$	+ jets	+ E_T^{miss}
2ℓSS/3ℓ	+ jets	+ E_T^{miss}
0/1ℓ	+ 3b-jets	+ E_T^{miss}
monojet		

3rd generation

- $0\ell\ \tilde{t}$
- $1\ell\ \tilde{t}$
- 2ℓs $\tilde{t}$
- monojet $\tilde{t}$
- $\tilde{t}$ with a Z boson
- 2b-jets + E_T^{miss}
- tb + E_T^{miss}, $\tilde{t}$

Electroweak

- ℓh
- 2ℓ
- 2τ
- 3ℓ
- 4ℓ
- disappearing track

Other

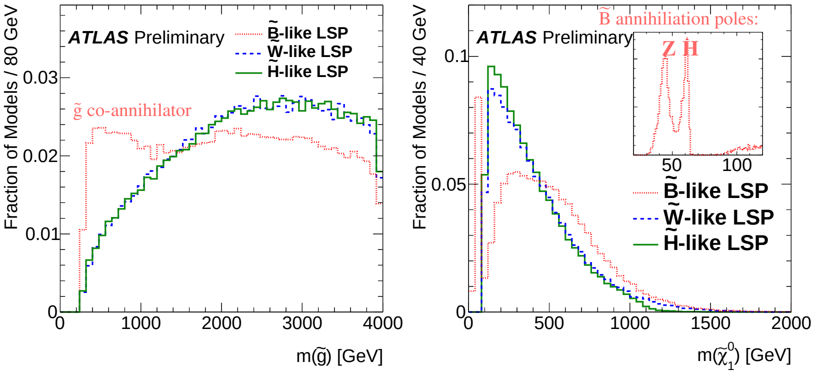
- long-lived particles
- H/A$\rightarrow \tau^+\tau^-$

Similar effort for Run I searches at CMS

arXiv:1508.06608 arXiv:1502.02522 arXiv:1606.03577

Sampling the models

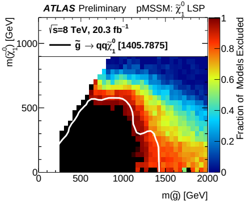
- special care for gaugino type: bino, wino and higgsino type
- bino-like LSP tend to produce too much dark matter
- therefore such models often rejected by DM contraints
- that's why gaugino-type categorization is done



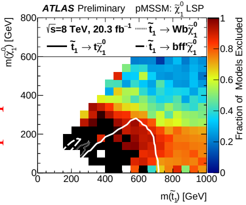
- note, light g̃ are not excluded in bino scenarios: g̃ very compressed with LSP and hard for detection

Landscape in pMSSM

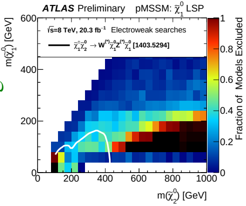
Gluinos



Top squarks

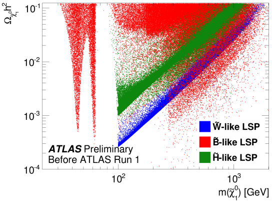


Gauginos

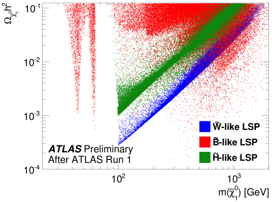


- in general exclusion follows simplified models
- horizontal band in large masses of $\tilde{g}$, $\tilde{t}$, $\tilde{\chi}_2^0$ and low mass $\tilde{\chi}_1^0$ is from exclusion of long-lived charginos:
    - a typical signature for wino LSP with $\Delta M_{\pm 0} < 200$ MeV

Before:



After:

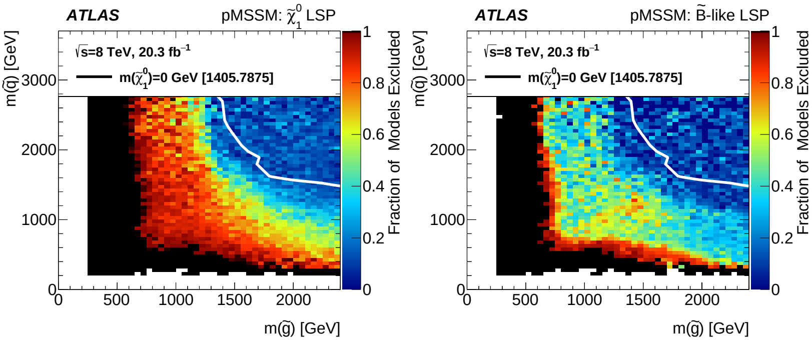


- for bino and wino sensitivity extends to $m_{\tilde{\chi}_1^0} < 800$ GeV
- winos with $m_{\tilde{\chi}_1^0} < 220$ GeV are depleted by disappearing track analysis
- much smaller sensitivity in higgsino case:
    - mass splitting too large for sizeable $\tilde{\chi}_1^\pm$ lifetime

More detailed look: squarks and gluinos

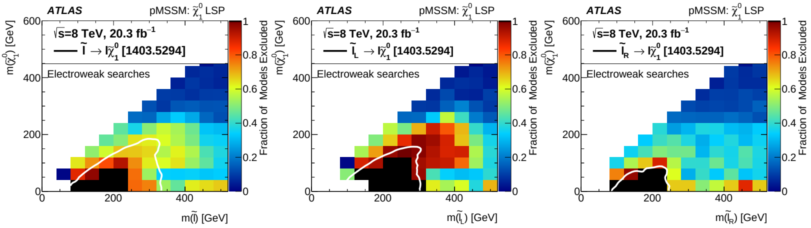
Exclusion in general follow SMS limits, but:

- with higher $\tilde{g}$ mass exclusion of squarks weakens
  - due to suppression of $\tilde{q}\bar{\tilde{q}}$ production via t-channel $\tilde{g}$ exchange
  - and suppression of $\tilde{q}\tilde{g}$ production cross section
- SMS assume 8-fold degeneracy in squarks: often too optimistic
- for bino-like LSP: $\tilde{q}$ or $\tilde{g}$ are mass-degenerate with LSP
  - do not leave detectable signature in the detector



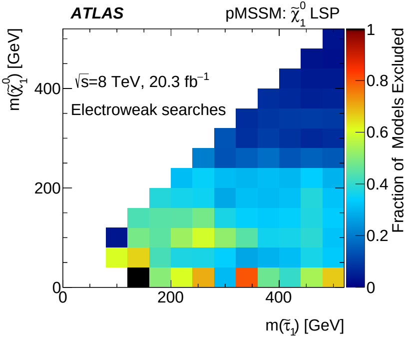
More detailed look: Sleptons

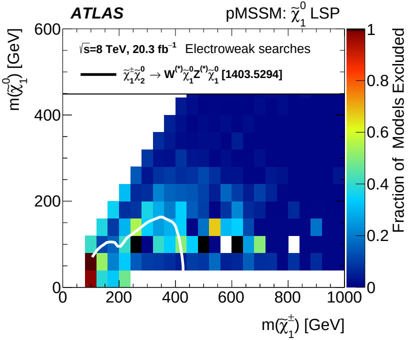
- good correspondence with SMS results for light LSP (< 75 GeV)
  - bino-like LSP
- not much sensitivity in compressed regime
  - need to resort to soft leptons + ISR jet in the future
- SMS are too optimistic assuming left and right sleptons degeneracy
  - SMS are more close to full model result, if split two cases
  - right sleptons have lower production cross section and are less bound by the searches



More detailed look: EWKinos

- $\widetilde{\tau}$ are almost no constrained at all by Run I searches
  - τ_h are hard to trigger on: thresholds are at $\sim$ 40GeV
  - suffer from high backgrounds
  - leptonic modes suffer from reduced total cross section
- chargino-neutralino pairs:
  - diagonal is excluded by disappeared track search in compressed scanerio
  - other points are probed by leptonic EWKino searches
  - and no mass point is fully excluded





Upgrade timeline

At 13–14 TeV:

- possible discovery with 300 fb^{-1}
- extension of discovery reach at HL-LHC
  - $\mathcal{L}$ matters for EWK processes
  - gain from improved detector
- and further study in case of discovery

8TeV

13-14TeV
$\mathcal{L} \sim 100\ \text{fb}^{-1}$
$\langle PU \rangle \approx 25$

LS1

Phase 0:
detector consolidation

14TeV
$\mathcal{L} \sim 300\ \text{fb}^{-1}$
$\langle PU \rangle \approx 50$

LS2

Phase 1:
- Pixel
- HCAL
- L1 trigger

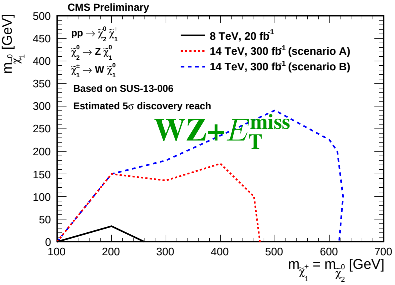
High-luminosity LHC
$\mathcal{L} \sim 3000\ \text{fb}^{-1}$
$\langle PU \rangle \approx 140$

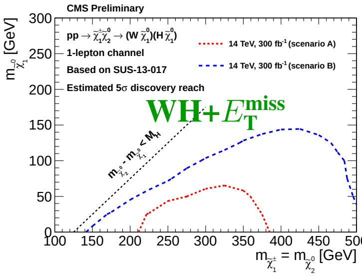
LS3

Phase 2 Upgrade:
- tracker replacement
- tracker up to $|\eta| < 4$
- forward calorimetry
- muon up to $|\eta| < 2.4$
- further trigger upgrade

Electroweak SUSY: $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ @ 300 fb^{-1}

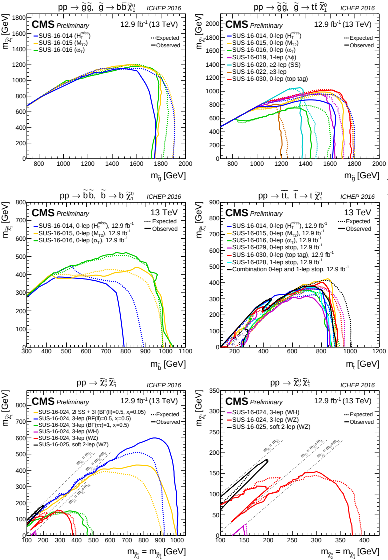
- projections are done with 8 TeV 3ℓ (SUS-13-006) and $\ell + b\bar{b}$ (SUS-13-007) analyses
- in the optimistic scenario the systematic uncertainty is decreased by $\times 2$
- realistic models include $\tilde{\chi}_2^0 \rightarrow$ Z/H$\tilde{\chi}_1^0$: the total sensitivity is in between the two





- drastic enhancement in **discovery** potential with 300 fb^{-1} @ 14 TeV: up to $m_\chi \sim 400 - 600$ GeV

Summary



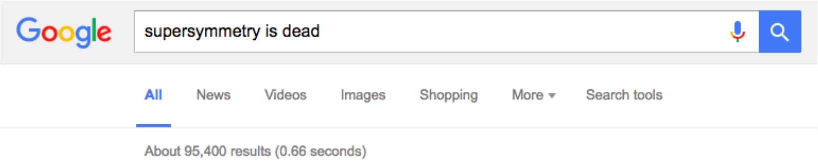
- with 13/fb of 13 TeV data profited cross section jump in many directions of SUSY searches

No luck so far ... But

- learned our lessons in the Run I aftermath
- along with the search for a spectacular new physics events developed new more sophisticated searches
  - compressed corners: with leptons or with soft b-jets
  - difficult objects: hadronic τ
  - signatures in vector-boson-fusion (VBF) topology (not covered here)
- HL-LHC is a sea of opportunity for such new ideas

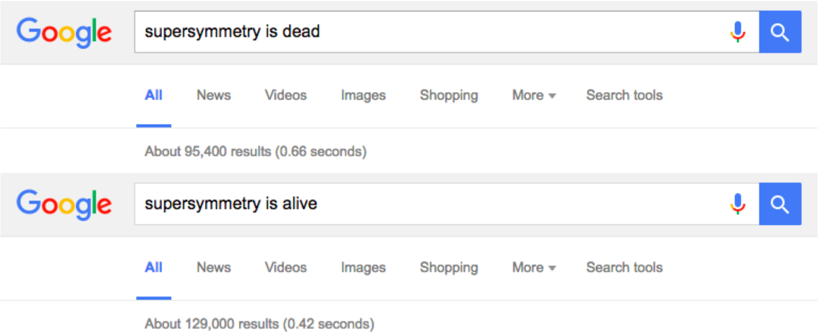
http://cms-results.web.cern.ch/cms-results/public-results/publications/SUS

We can ask:



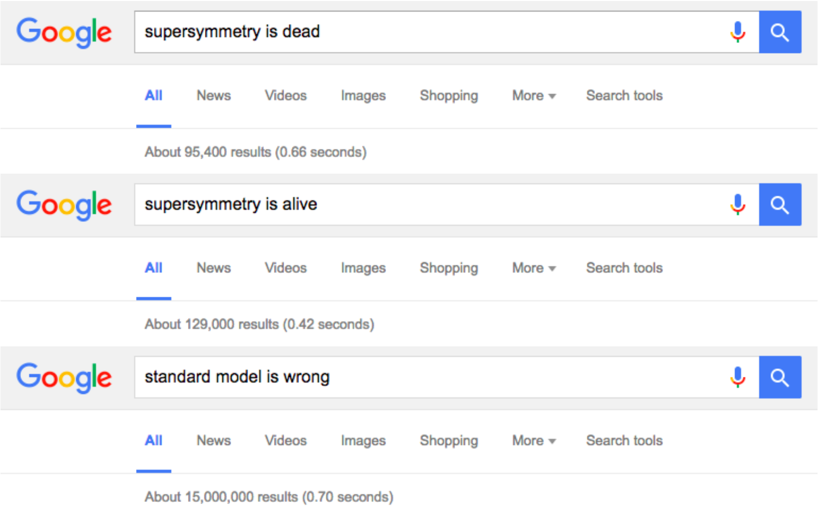
- one can choose not to believe in SUSY

We can ask:



- or one can choose to believe in SUSY

We can ask:



- but all agree on one thing!