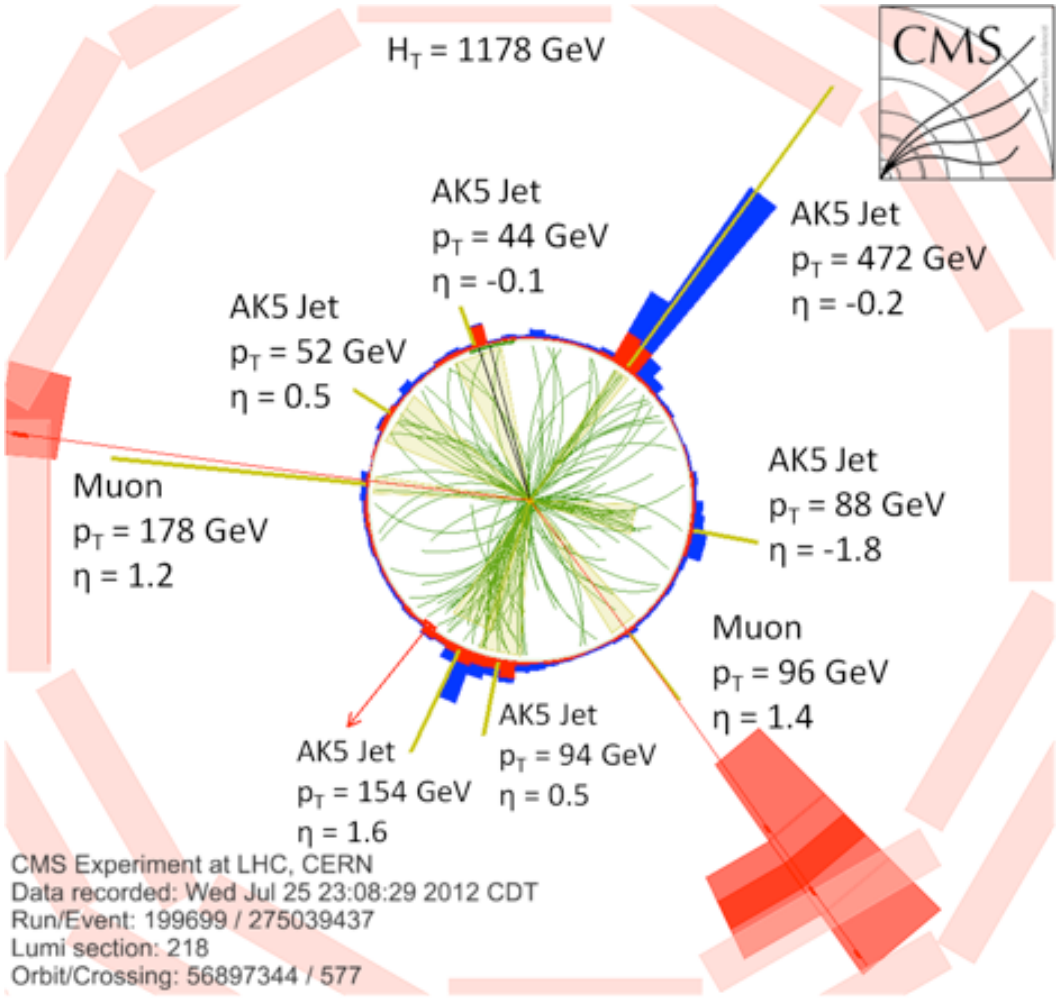
SUSY searches with light leptons, photons and taus



Cristina Botta (CERN)
on behalf of the ATLAS and CMS collaborations

EPS-HEP 2015 Conference. 22-29 July, Vienna, Austria

Outline

- How and why ATLAS and CMS have used reconstructed **electrons, muons, taus and photons** to search for SUSY with RunI LHC data
  - Results refer to **8 TeV** data, **~20 fb^{-1}**
  - Most of the time the results are presented in the context of the **simplified models:**
    - only the targeted production and decay schemes are examined, with all non-participating BSM particles assumed to be too heavy to be relevant

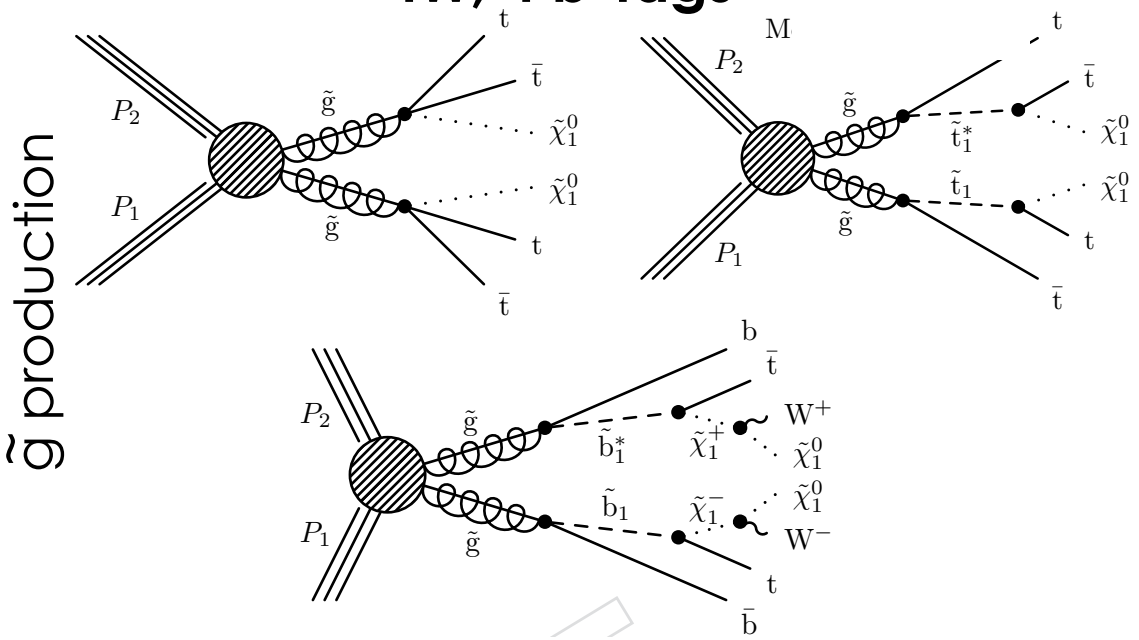
Why light leptons?

- Leptonic SUSY searches vs Hadronic SUSY searches
  - **less signal acceptance** due to lower branching fractions
  - **less SM background**
  - may lead to a more **precise reconstruction of the final state**
  - most sensitive in **compressed scenarios**
    - lower trigger thresholds
    - final state with low missing energy, too SM like for hadronic searches
  - most sensitive when searching for **EWKinos production** (many leptons due to the decay via sleptons/W/Z/H)
- Experimental Signatures (focusing on ≥ 2 leptons)
  - **2 same-sign leptons, e or μ (SS di-leptons) + jets + E_T^{miss}**
  - **2 opposite-sign same-flavour e or μ (OSSF di-leptons) + jets + E_T^{miss}**
  - **>= 3 leptons, e or μ (multi-leptons) + jets + E_T^{miss}**

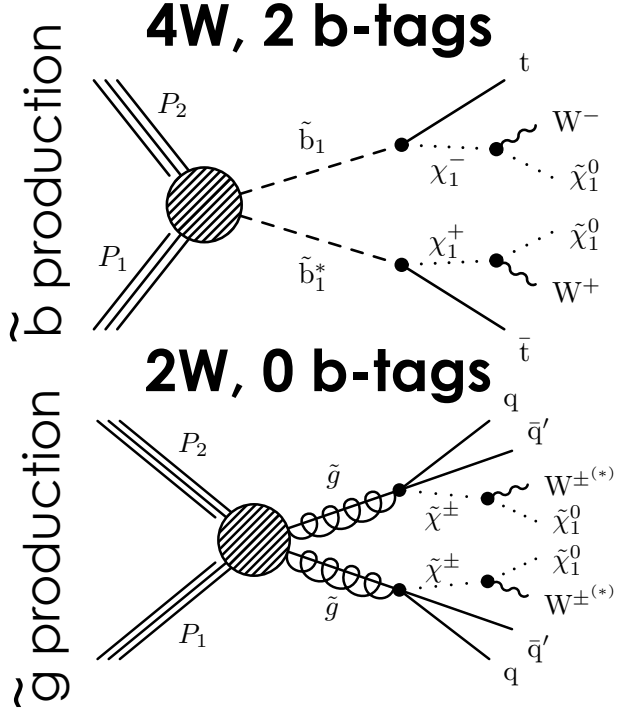
SS di-leptons: motivations

Strong Production (some SMS in R-parity-conserving scenario)

4W, 4 b-tags



4W, 2 b-tags



2W, 0 b-tags

Decreasing leptons p_T, jets p_T, E_T^{miss} with decreasing Δm(sparticle-$\tilde{X}_1^0$)

- Gluino is its own antiparticle, same probability to decay in a final state with either a +charged or -charged lepton
- Prompt and isolated ss di-lepton events are produced only through very rare SM processes: tt+W, tt+Z, tt+H, same-sign WW production

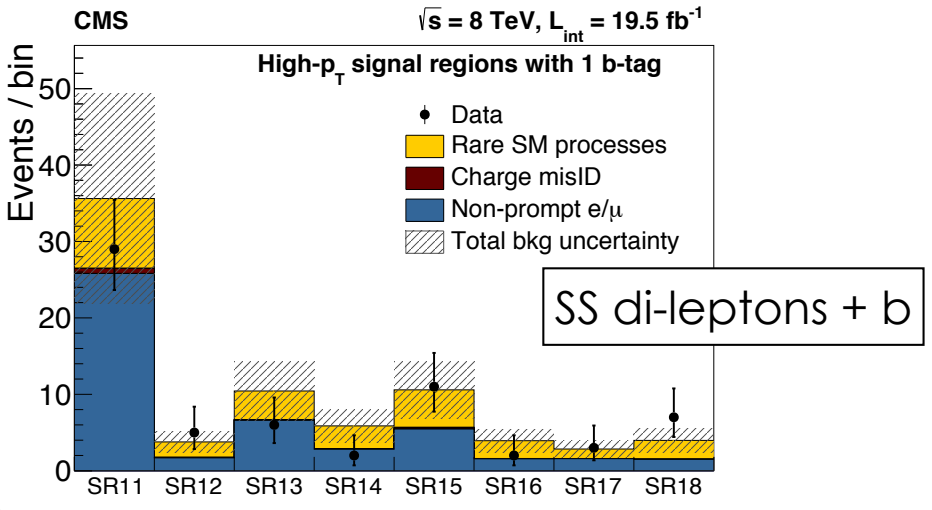
For EWK Production: see dedicated talk

SS di-leptons: analysis strategy

from CMS. arXiv:1311.6736

- Require the two ss leptons (e/μ) down to **p_T >10 GeV** ($|\eta| < 2.5/2.4$) in order to extend the sensitivity in the compressed scenarios with off-shell W
- Require the leptons to pass tight IP and Isolation criteria to reject tt and W events with 2nd same-sign lepton from B decay or hadron mis-identification
- Cut&count events in grid of signal region based on **N_{jets}, $N_{b\text{-}jets}$, H_T** (scalar sum of jets p_T), **E_T^{miss}**
  - jets $p_T > 40$ GeV, $|\eta| < 2.4$
- Backgrounds from events with **non-prompt leptons** (data-driven), from **rare SM processes** (simulation), events with **charge mis-identified leptons** (data driven)

$N_{\text{b-jets}}$	$E_{\text{T}}^{\text{miss}}$ (GeV)	N_{jets}	$H_{\text{T}} \in [200, 400]$ (GeV)	$H_{\text{T}} > 400$ (GeV)
$= 0$	50-120	2-3	SR01	SR02
		≥ 4	SR03	SR04
	> 120	2-3	SR05	SR06
		≥ 4	SR07	SR08
$= 1$	50-120	2-3	SR11	SR12
		≥ 4	SR13	SR14
	> 120	2-3	SR15	SR16
		≥ 4	SR17	SR18
≥ 2	50-120	2-3	SR21	SR22
		≥ 4	SR23	SR24
	> 120	2-3	SR25	SR26
		≥ 4	SR27	SR28



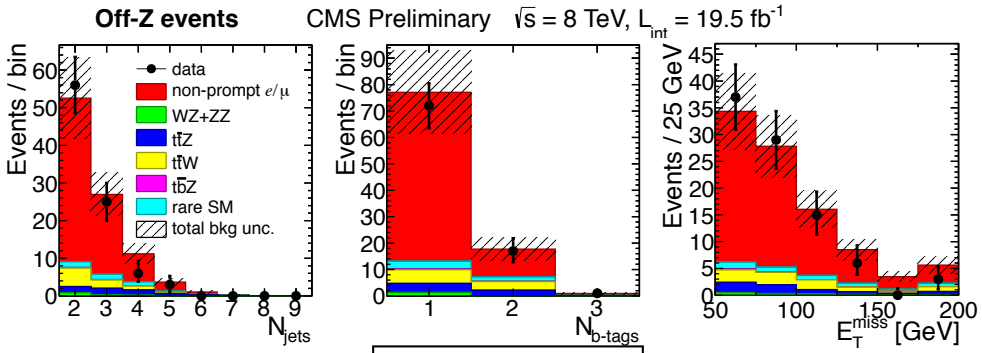
≥ 3 leptons + bjets

from CMS. PAS-SUS-13-008

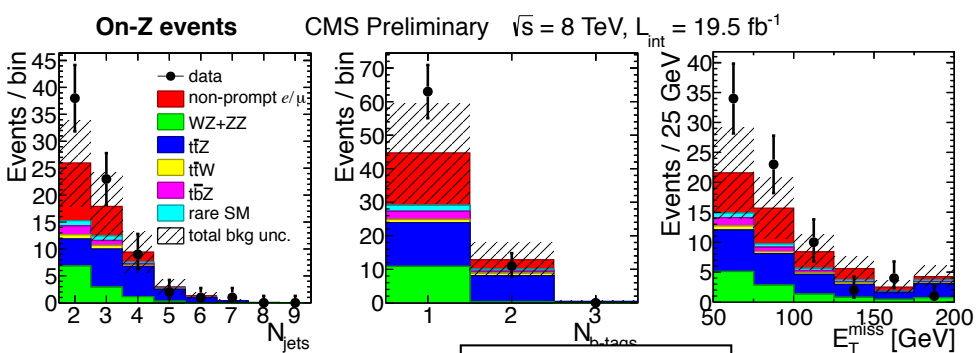
- All of the previous models with b-jets in the final state also allow more than 2 light leptons, with or without an on-Z l^+l^- combination
- Objects: isolated and prompt e/μ p_T >10 GeV $|\eta| < 2.4/2.5$, jets p_T > 30 GeV $|\eta| < 2.4$
  - if a pair of OSSF leptons has 50<m(l^+l^-)<100 GeV: **onZ event**. If not: **offZ event**
- Cut&count events in grid of signal region based on **N_{jets}, $N_{b\text{-}jets}$, H_T, E_T^{miss}**

Variable	Baseline	Search Regions		
Sign/Flavor	$3\,e/\mu$	On-Z	Off-Z	
$N_{b\text{-jets}}$	≥ 1	1	2	≥ 3
N_{jets}	≥ 2	2–3	≥ 4	
H_T (GeV)	≥ 60	60–200	≥ 200	
E_T^{miss} (GeV)	≥ 50	50–100	100–200	≥ 200

Extended acceptance in more compressed region due to lower thresholds (trigger and offline selection)



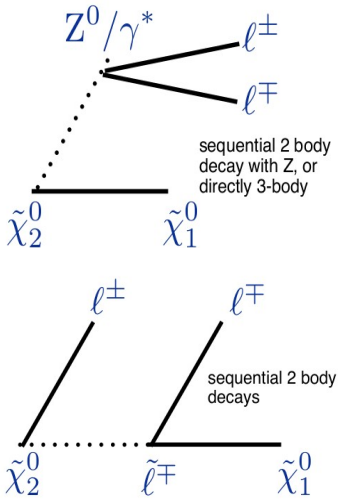
OnZ events



OffZ events

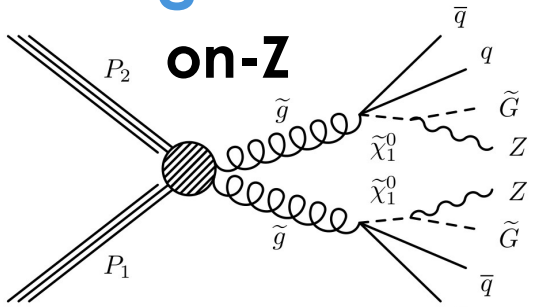
OS di-leptons: motivations

- SUSY decay chains can lead to opposite sign same flavor leptons in the final state
  - decays involving an on-shell Z boson will produce an **excess on the Z peak invariant mass: Z + E_T^{miss} + jets search**
  - off-shell Z boson or slepton decays will lead to a characteristic **"edge" shape in the m(l^+l^-) spectrum: "edge" search**



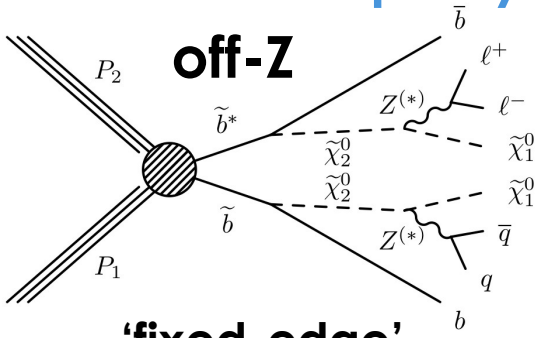
Strong Production (some SMS in R-parity-conserving scenario)

$\tilde{g}$ production

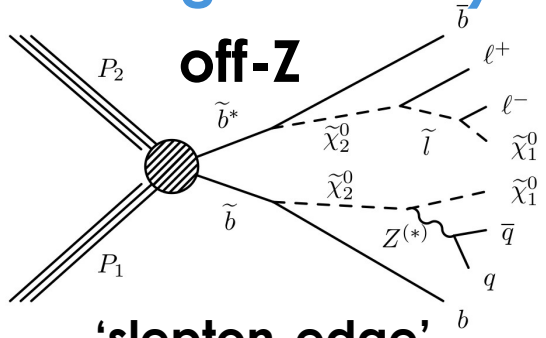


GMSB, LSP = gravitino

$\tilde{b}$ production



'fixed-edge'



'slepton-edge'

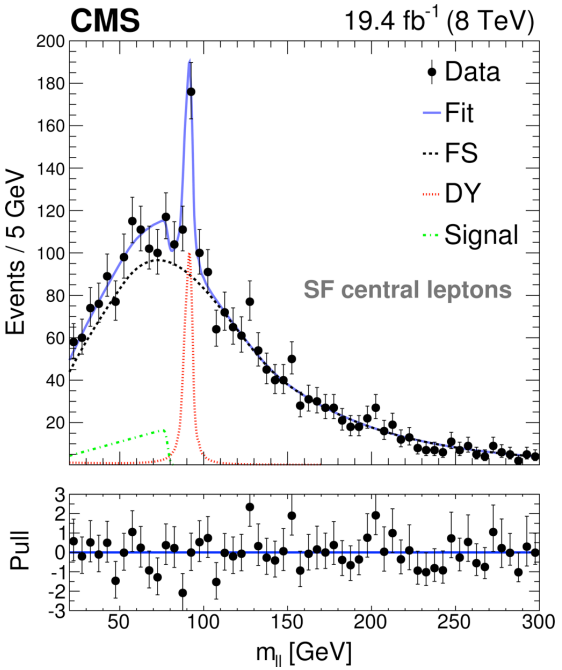
- OS di-lepton signature also used for exclusive stop searches in difficult regions (m_{stop}-mX_1^0)~m_{top} with Z/H in the cascade, and (m_{stop}-mX_1^0)<m_W with soft leptons, motivated by Naturalness arguments: **see dedicated talks on 3rd generation, and compressed spectra**

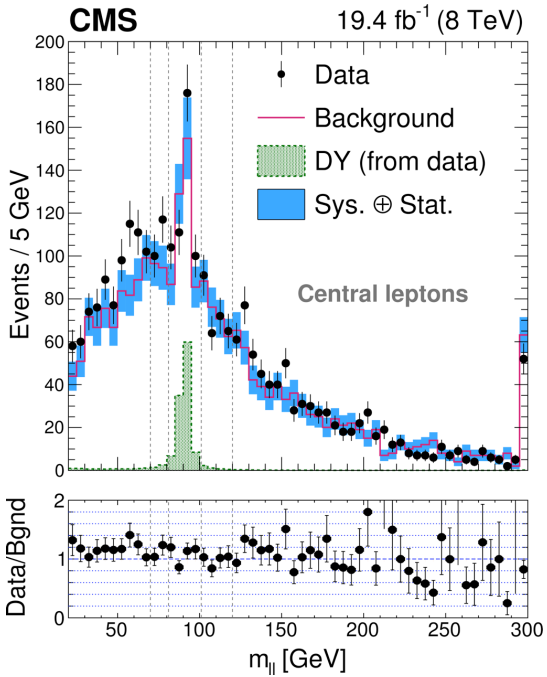
For EWK Production: see dedicated talk

OS di-leptons "edge" analysis strategy

from CMS. arXiv:1502.06031

- **Selection:** $e^{\pm}e^{\mp}$ or $\mu^{\pm}\mu^{\mp}$ with $m(l^+l^-) > 20$ GeV, isolated leptons $p_T > 20$ GeV ($N_{jets} \geq 2$ and $E_T^{miss} > 150$) or ($N_{jets} \geq 3$ and $E_T^{miss} > 100$), jets $p_T > 40$ GeV
- **Strategy:**
  - **A.** **Symultaneously fitting** the signal and bkg hypotheses (DY, same-flavour symmetric bkg like tt) to data in the $20 < m(l^+l^-) < 300$ GeV range
  - **B.** Direct comparison of **event counts** in regions: $20 < m(l^+l^-) < 70$ GeV, $81 < m(l^+l^-) < 101$ GeV, $20 < m(l^+l^-) < 70$ GeV. Background yields from control regions.





Excess **(2.6 σ)** in low-mass region, interpreted as a potential signal excess with an edge located at 78.7±1.4 GeV **(2.4 σ)** by the fit.

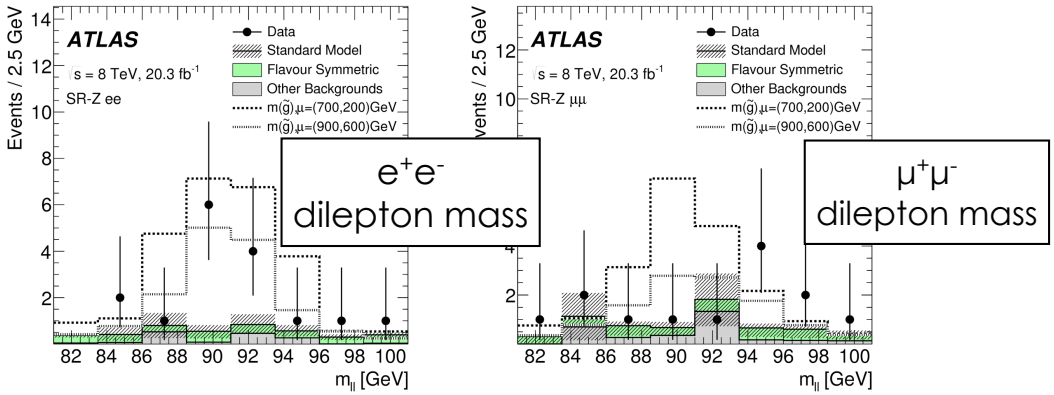
In the off-Z search of the other experiment there's no excess. Similar kinematic requirements.

Approach B used to set upper limits

OS di-leptons on-Z: analysis strategy

from ATLAS. arXiv:1503.03290

- **Selection:** $e^{\pm}e^{\mp}$ or $\mu^{\pm}\mu^{\mp}$ with $81 < m(l^+l^-) < 101$ GeV, isolated leptons $p_T > 25,14\text{-}10$ GeV
  $N_{jets} \geq 2$, (jets $p_T > 35$ GeV), H_T (scalar sum of jets and leptons p_T) > 600 GeV,
  $E_T^{miss} > 225$ GeV, $\Delta\varphi(j_{1,2}, E_T^{miss}) < 0.4$
- **Strategy:** Direct comparison of **event counts**. Background predictions from control regions (same-flavour symmetric bkgs, WW, ZZ)



Excess of events **(3σ)** mainly driven by the electron channel

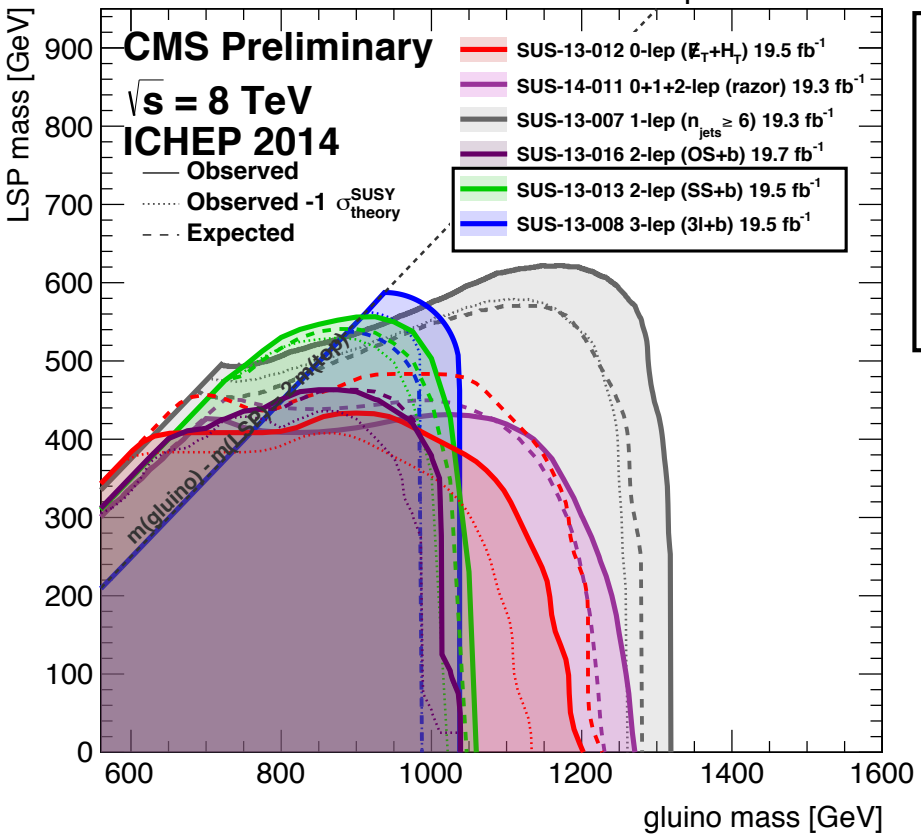
In the on-Z search of the other experiment there's no excess. But very different kinematic requirements.

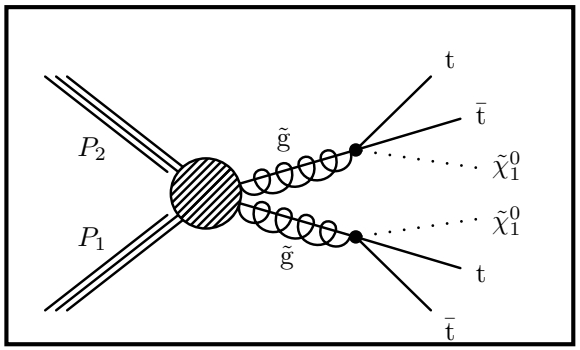
Leptonic searches interpretation

- Given the lack of significant excesses wrt the expected SM backgrounds, the results of the searches are used to derive limits on the parameters of various SMs
  - **few examples of these interpretations from CMS**

SS di-leptons and Trilepton

$\tilde{g}$-$\tilde{g}$ production, $\tilde{g} \rightarrow t\,\bar{t}\,\tilde{\chi}_1^0$



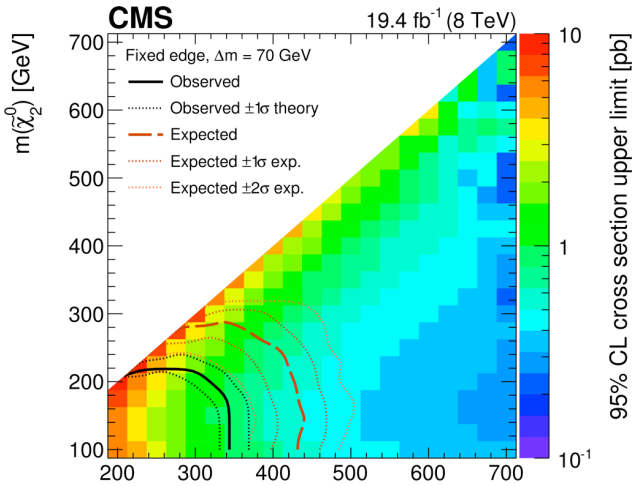


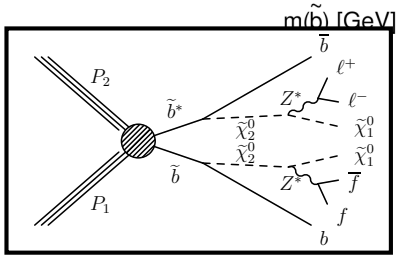
Leptonic searches interpretation (2)

- Given the lack of significant excess wrt the expected SM backgrounds, the results of the searches are used to derive limits on the parameters of various SMs
  - **few examples of these interpretations from CMS**

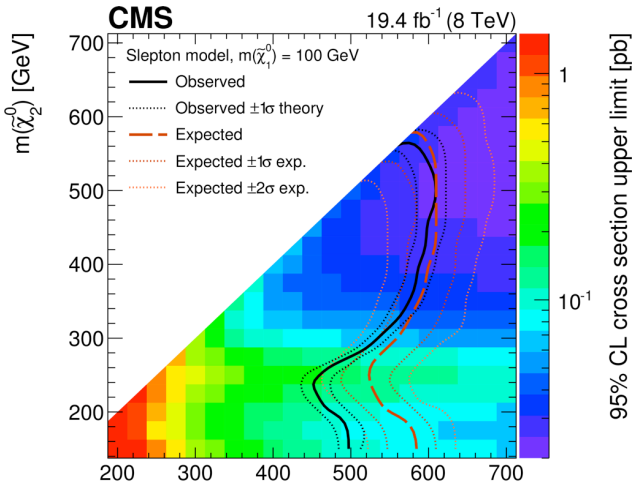
OS di-lepton

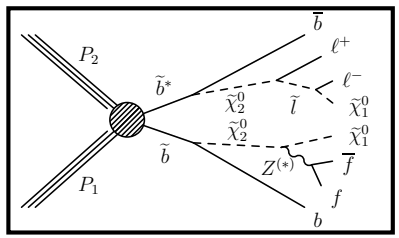
fixed edge



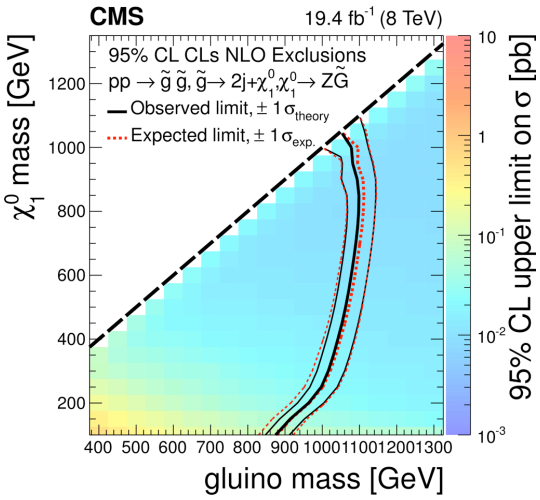


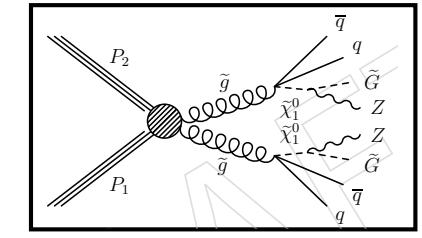
slepton edge





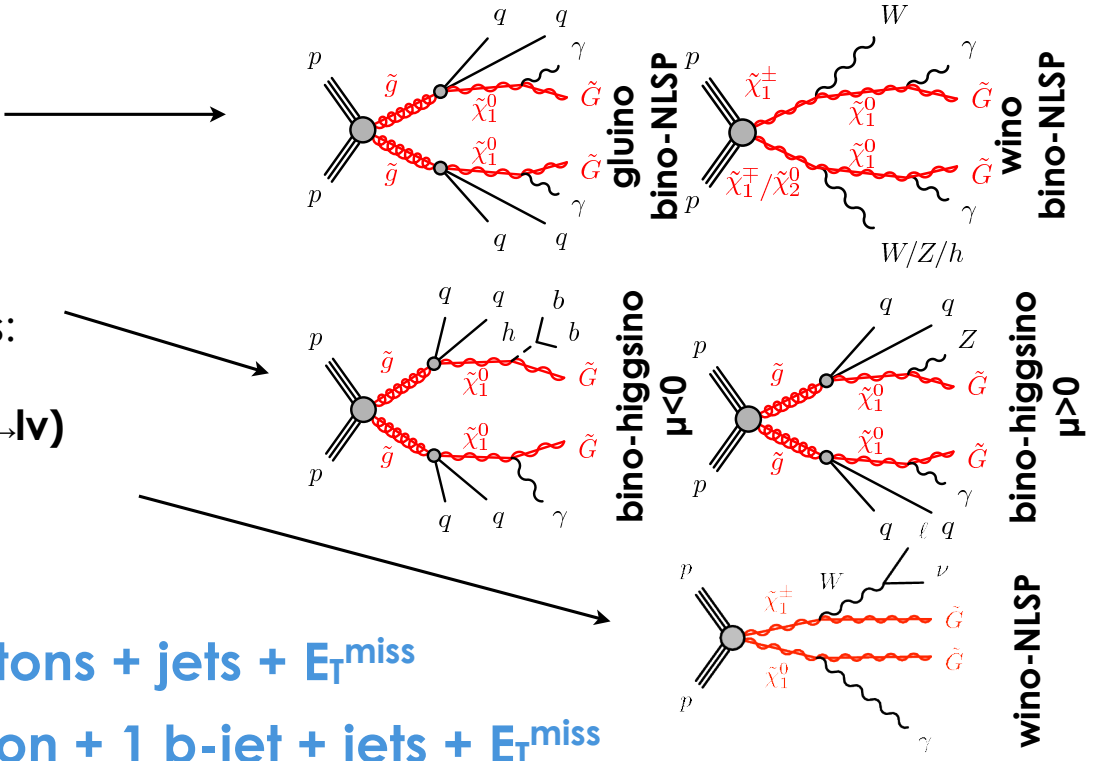
OS "onZ" GMSB





Why photons?

- Motivated in **generalized models of gauge mediated SB (GGM)**
  - the decay of SUSY spartners proceed through the NLSP→ G(LSP) + SM particle, with high probability being a ɣ
  - NLSP usually admixture of any of the SUSY partners of the EWK gauge and Higgs boson states. Three scenarios:
    - NLSP purely bino-like: **NLSP → G + ɣ**
    - NLSP admixture of bino and higgsino: significant contribution from **NLSP → G + h(→bb) or NLSP → G + Z(→jj)**
    - NLSP degenerate triplet of wino-cases: significant contribution from **NLSP (charged components)→ G + W(→lν)**



- Experimental Signatures:
  - **2 high energetic, isolated photons + jets + E_T^{miss}**
  - **1 high energetic isolated photon + 1 b-jet + jets + E_T^{miss}**
  - **1 high energetic isolated photon + 1 isolated lepton (e,μ) + jets + E_T^{miss}**
  - **1 high energetic isolated photon + multiple jets + E_T^{miss}**

SUSY searches with photons

from ATLAS. arXiv:1507.05493

NEW

- **Objects:** γ with p_T >75/125, e/μ p_T >20, jets p_T >20, leading jets p_T >75/140 GeV
- Cut&count events in grid of signal region based on:
  - N_{jets}, $N_{b\text{-}jets}$, $N_{leptons}$, $\Delta\phi(\gamma, E_T^{miss})$, $\Delta\phi(jet, E_T^{miss})$, $\Delta\phi(jet, \gamma)$, H_T (scalar sum of p_T of selected photons, leptons and jets), H_T^{jets}, $m_{eff} = H_T^2 + E_T^{miss}$, R_T^4 (scalar sum of p_T of 4 highest-p_T jets divided by H_T^{jets})

DiPhoton analysis
targeting the gluino-bino model

Signal Region	$SR^{\gamma\gamma}_{S-L}$	$SR^{\gamma\gamma}_{S-H}$
No. photons (E_T GeV)	> 1 (> 75)	> 1 (> 75)
E_T^{miss} (GeV)	> 150	> 250
$H_T(m_{eff})$ (GeV)	(> 1800)	(> 1500)
$\Delta\phi_{min}$(jet, E_T^{miss}) (No. leading jets)	> 0.5 (2)	> 0.5 (2)
$\Delta\phi_{min}(\gamma, E_T^{miss})$	–	> 0.5

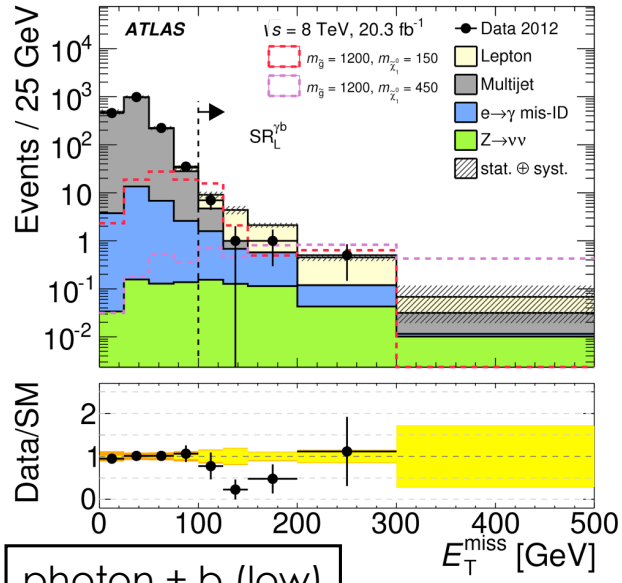
low and high NLSP masses

Photon + b targeting higgsino-bino model μ < 0, low and high NLSP masses

Signal Region	$SR^{\gamma b}_{L}$	$SR^{\gamma b}_{H}$	$SR^{\gamma j}_{L}$	$SR^{\gamma j}_{H}$
No. photons (E_T GeV)	> 0 (> 125)	> 0 (> 150)	1 (> 125)	1 (> 300)
E_T^{miss} (GeV)	> 100	> 200	> 200	> 300
H_T (GeV)	–	> 1000	–	> 800
No. jets (No. b-jets)	2 – 4 (> 1)	> 3 (> 0)	> 3[a]	> 1[a]
No. leptons	0	–	0	0
M_{bb} (GeV)	75 – 150	–	–	–
$M_T^{\gamma, E_T^{miss}}$ (GeV)	> 90	> 90	–	–
$\Delta\phi_{min}$(jet, E_T^{miss}) (No. leading jets)	> 0.3 (2)	> 0.3 (4)	> 0.4 (2)	> 0.4 (2)
R_T^4	–	–	< 0.85	
$\Delta\phi_{min}$(jet, γ)	–	–	–	< 2.0

Photon + j targeting higgsino-bino model μ > 0, low and high NLSP masses

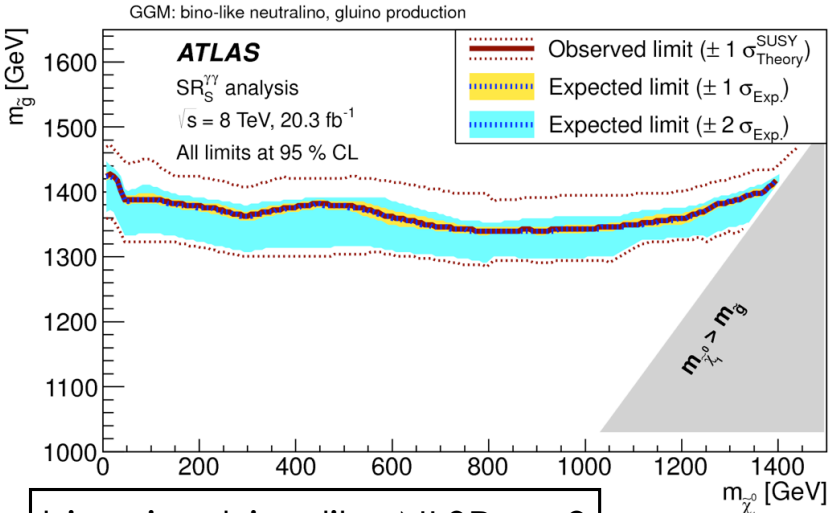
SUSY searches with photons (3)



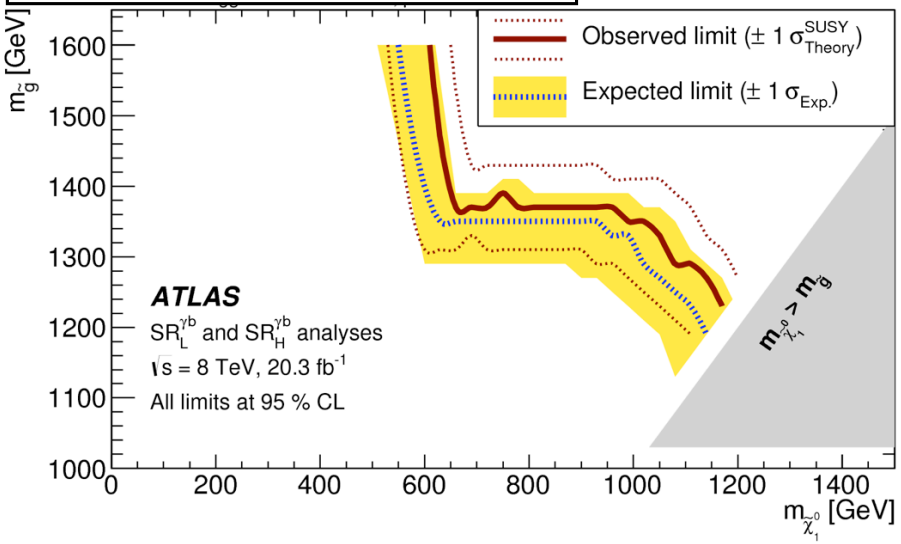
photon + b (low)

Given that no significative excess with respect to SM prediction is found in any of the 6 SR described, results are interpreted in terms of **limits on the parameters** of the considered models

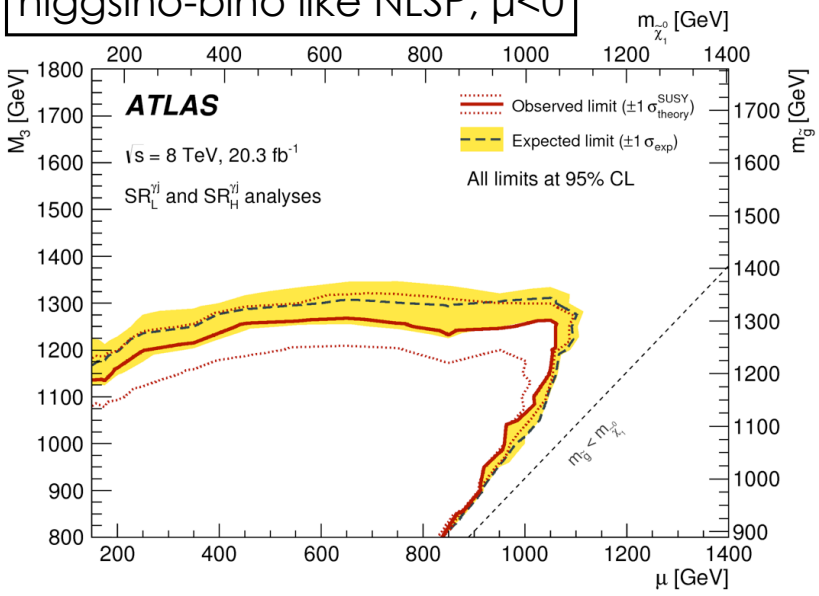
bino-like NLSP, gluino production



higgsino-bino like NLSP, μ>0



higgsino-bino like NLSP, μ<0



NEW

signal regions for wino-NLSP, and wino-bino models are also defined and used in the paper to extract relative limits

similar searches from CMS in arXiv:1507.02898

Taus

- Naturalness arguments suggest that the **lightest third-generation sparticles** should have masses of a few hundred GeV
- **Light sleptons** could play a role in the co-annihilation of neutralinos in the early universe
  - models with **light tau sleptons** are consistent with dark matter searches)
- Searches of strong SUSY production with **at least one hadronic tau + jets + E_T^{miss} performed by ATLAS** are particularly sensitive to **GMSB models** where the next-to-lightest SUSY particle is the stau and final states contain between two and four tau leptons

from ATLAS. arXiv:1407.0603

- Channels: **$1\tau_h$ + 0 light leptons, $\geq 2\tau_h$ + 0 light leptons, $\geq 1\tau_h$ + 1e, $\geq 1\tau_h$ + 1μ**
- In **a nGM model**, a limit on the gluino mass of 1090 GeV independent on the stau mass, provided it is the NLSP, is obtained

Conclusions

- During LHC RunI ATLAS and CMS have searched for SUSY exploiting final states with **light leptons, photons and taus**
  - why and how was discussed, focusing on searches for **strong SUSY production** (R-parity conserving)
  - results from all searches have been used to extract **limits on the parameters of several simplified models**

- **ATLAS and CMS are now commissioning electrons, muons, photons and taus identification with the first 13 TeV data, to be ready to use them to continue the hunt.**

Backup