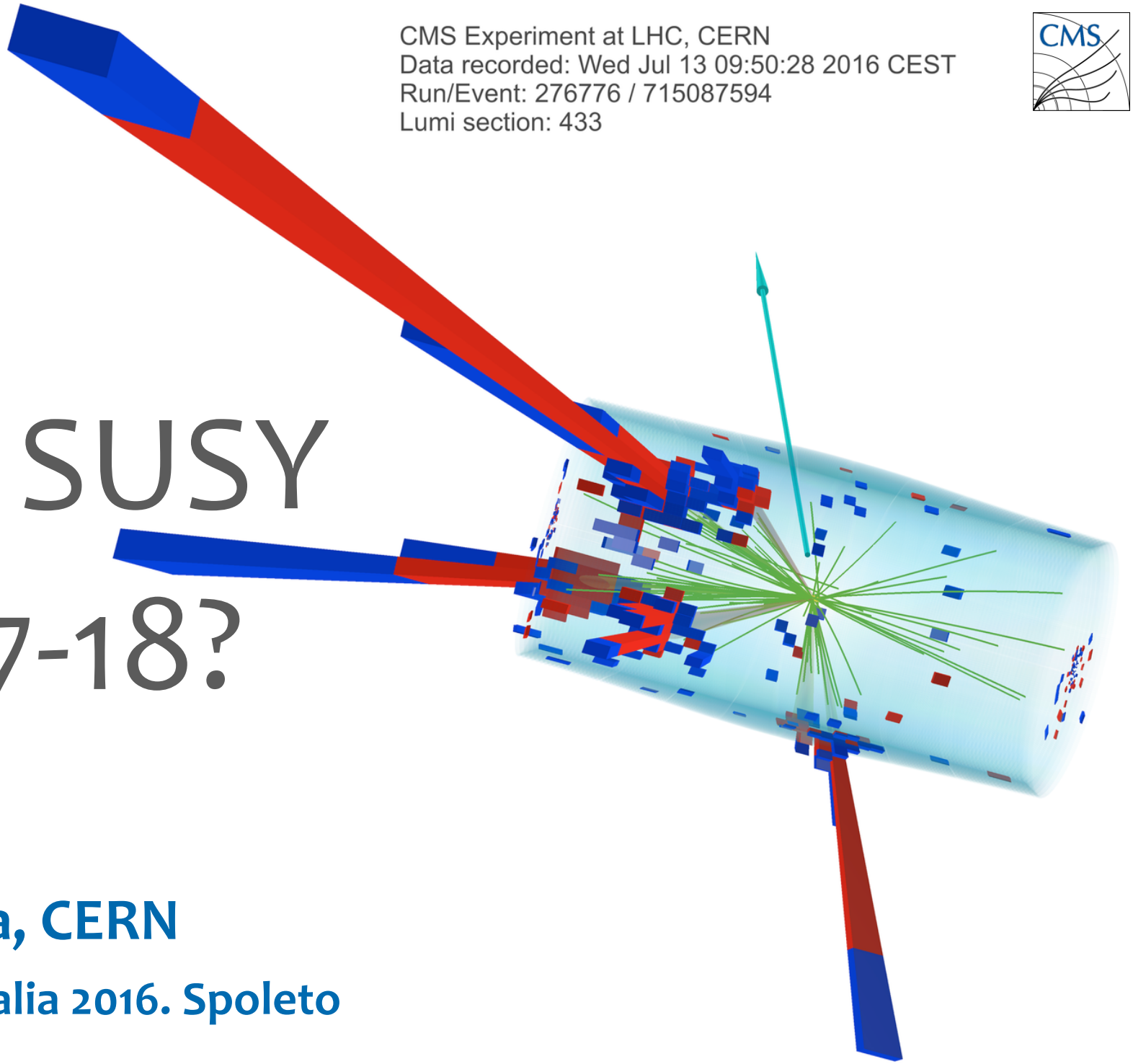
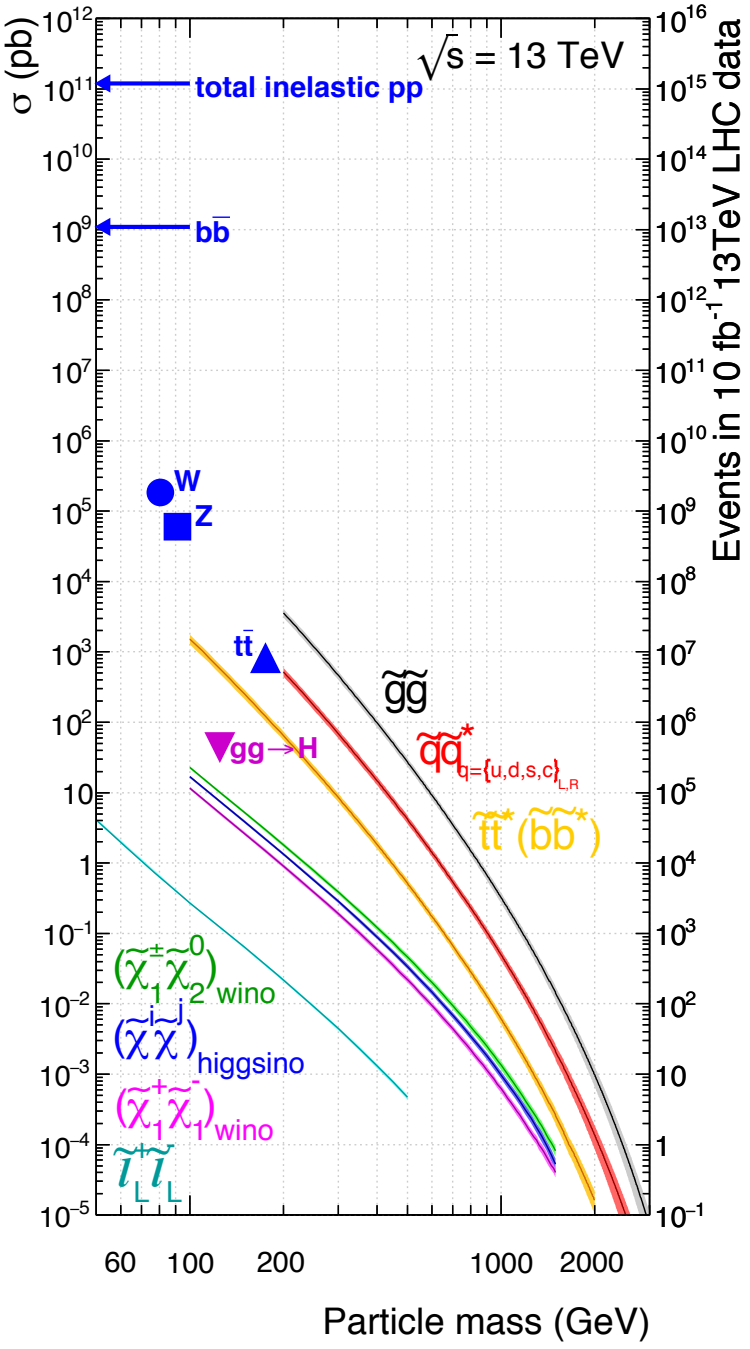


Quale SUSY in 2017-18?

Cristina Botta, CERN

Riunione CMS Italia 2016. Spoleto

The hunt for SUSY at LHC RunII



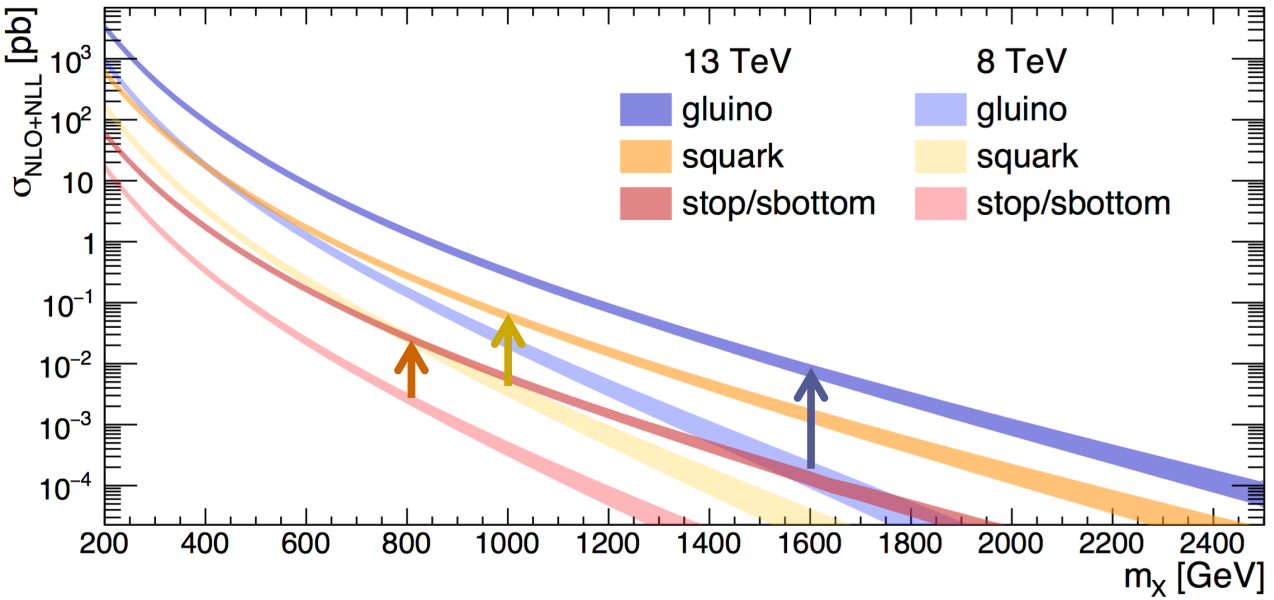
- **Standard (R_P conserved) SUSY:**
  - sparticles produced in pairs
  - LSP undetected E_T^{miss}
  - **Strong production**
    - intense hadronic activity and E_T^{miss}
    - inclusive searches for **gluinos**, **light-squarks**
    - dedicated searches for third generation squarks: **stop, sbottom**
  - **EWK production**
    - intense leptonic activity and E_T^{miss}
    - **charginos & neutralinos, sleptons**
  - **Natural SUSY, compressed spectra**
    - soft object, low E_T^{miss}
      - ISR, VBF, long lifetime searches
    - light **stop**, **higgsinos**
- **Exotic SUSY: RPV**
  - No E_T^{miss}, resonant structures

lower cross section, more difficult signatures

On the verge of new territories

ICHEP 2014
19.5 fb^{-1} @ 8TeV

December 2015
2.3 fb^{-1} @ 13TeV



- ***Lumi /10, but big jump in cross section***
- Inclusive 0-ℓ, 1-ℓ, 2-ℓ searches
  - x ~20 for 1.3 TeV **gluino** (RunI limit for LSP→0 GeV, BR 100%), new exclusion reach: **1.6 TeV**
  - x ~13 for 950 GeV **light squarks** (RunI limit for LSP→0 GeV, BR 100%), new exclusion reach: **1.2 TeV**
- Dedicated 0-ℓ, 1-ℓ searches for third generation quarks
  - x ~10 for 800 GeV **stop** (RunI limit for LSP→0 GeV, BR 100%), reach same sensitivity **~ 800 GeV**
- ***If natural SUSY is there it's not in the easy regions of the phase space***

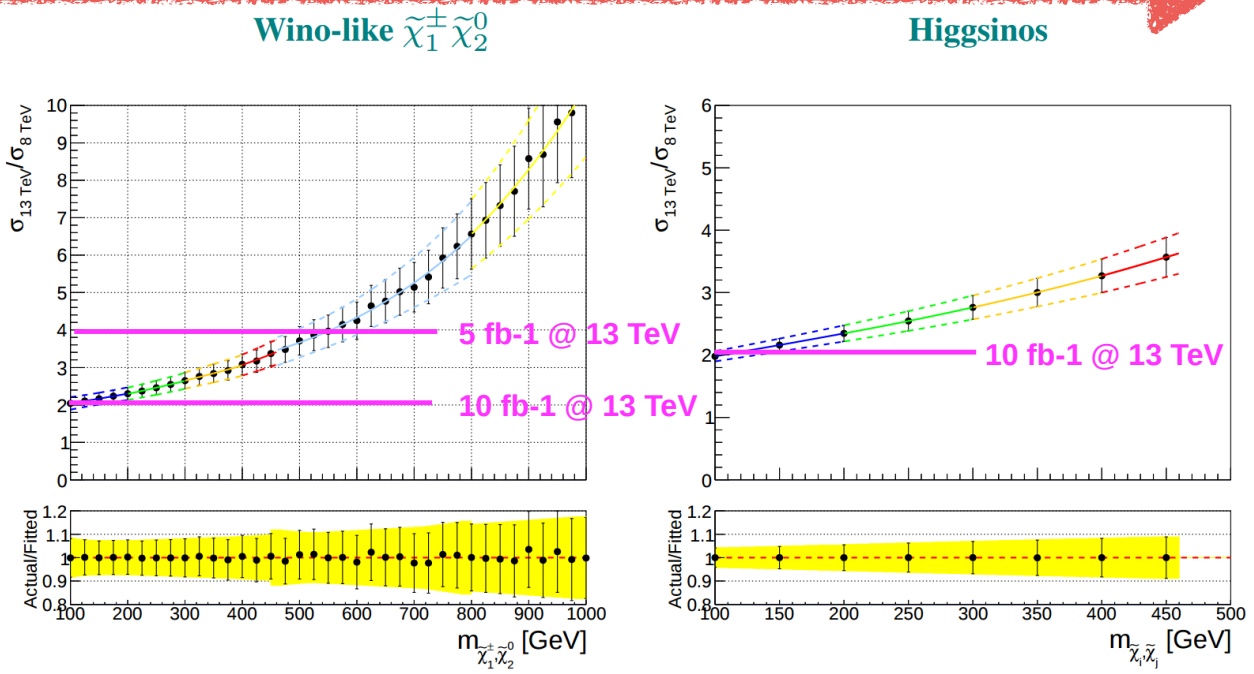
The ICHEP16 marathon

December 2015

2.3 fb^{-1}

ICHEP 2016

12.9 fb^{-1}



- ***Lumi x6!***
- ***"EWKino and Compressed SUSY Event at the LPC"*** **(April 2016)**
  - Enough data at ICHEP to start matching the immense EWK program of RunI
  - New searches to access the corners where Natural SUSY can still hide:
    - **quasi-degenerate Higgsinos, compressed stop (m_{stop}-m_{LSP}<m_W)**
- ***Plus extending the strong-production searches to new territories***
  - reload of well established inclusive searches (hadronic, leptonic, photonic)

12.9 fb^{-1} @ 13 TeV

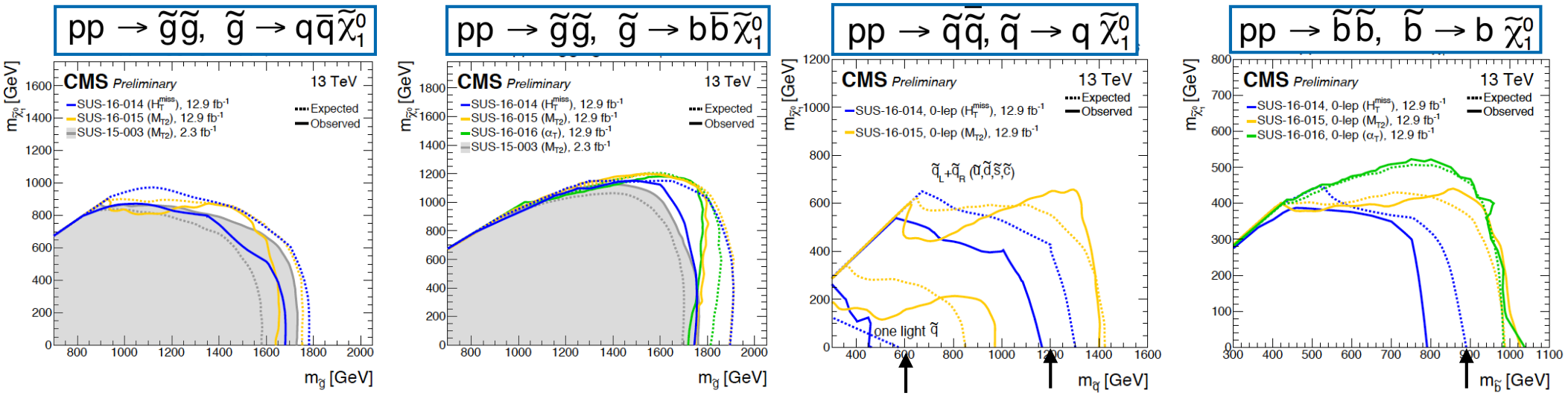
SUS-16-014	0-ℓ with H_T^{miss}
SUS-16-015	0-ℓ with M_{T2}
SUS-16-016	0-ℓ with α_T
SUS-16-017	0-ℓ+1-ℓ with Razor (COMING SOON)
SUS-16-018	1-ℓ with M_J (COMING SOON)
SUS-16-019	1-ℓ with Δφ
SUS-16-020	2SS-ℓ
SUS-16-021	2OS-ℓ
SUS-16-022	3-ℓ
SUS-16-027	2-ℓ stop
SUS-16-028	1-ℓ stop
SUS-16-029	0-ℓ stop
SUS-16-030	0-ℓ with top tagger
SUS-16-012	h->γγ with Razor
SUS-16-023	photons (GMSB)
SUS-16-024	EWK multileptons
SUS-16-025	EWK and stop soft 2OS-ℓ
SUS-16-026	EWK WH(1lbb)
SUS-16-031	stop soft 1-ℓ
SUS-16-032	sbottoms/light stops (COMING SOON)

What is still uncovered?

Squarks and gluinos

- **Three hadronic searches:** veto leptons and look for jets and E_T^{miss}
  - all binned in N_{Jets}, N_{btags}, H_T, and E_T^{miss}-like
    - **H_T^{miss}, α_T, M_{T2}**
    - **O(100) search regions**
  - Trigger leads to typically > 200 GeV in E_T^{miss}

SUS-16-014/15/16



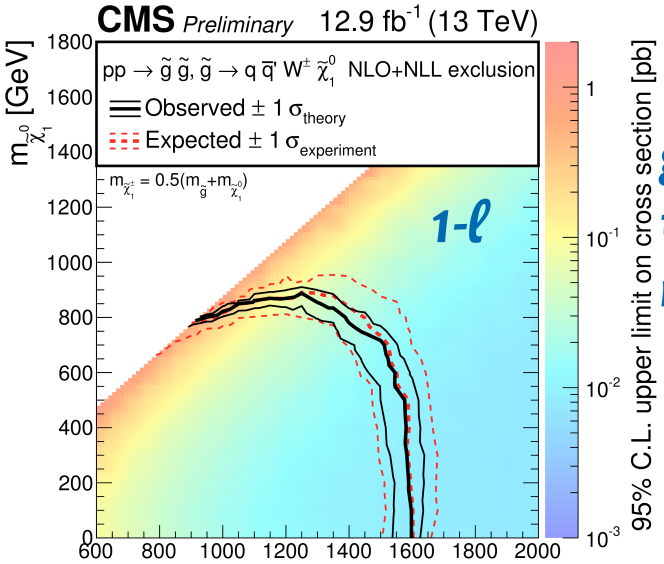
simplified models: 100% BR in decay chain, particles not involved are decoupled

Limits +200 GeV for modest LSP masses wrt pre-ICHEP

Gluinos with W bosons involved

$pp \rightarrow \tilde{g}\,\tilde{g},\ \tilde{g} \rightarrow q\,\bar{q}'\,W^{\pm}\,\tilde{\chi}_1^0$

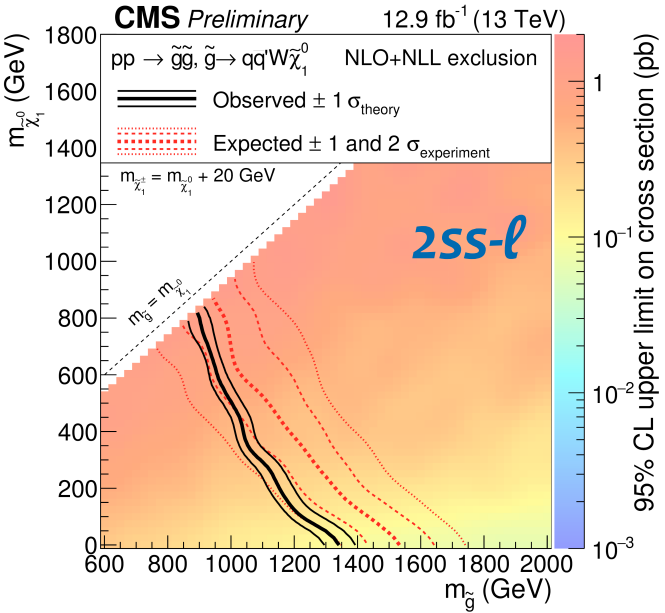
- **Single lepton search:**
  - one light lepton
  - $N_{jet}>4$, L_T ($E_T^{miss}+p_T(\ell)$) > 250 GeV
  - Search variables
    - $\Delta\varphi(E_T^{miss}+\ell,\ell)$ binned in L_T, H_T, N_{btag}, N_{jet}: **50 SR**
  - Trigger: H_T + lepton (500, 25 GeV)



gluinos excluded up to 1.6 TeV for LSP masses < 500 GeV

SUS-16-019

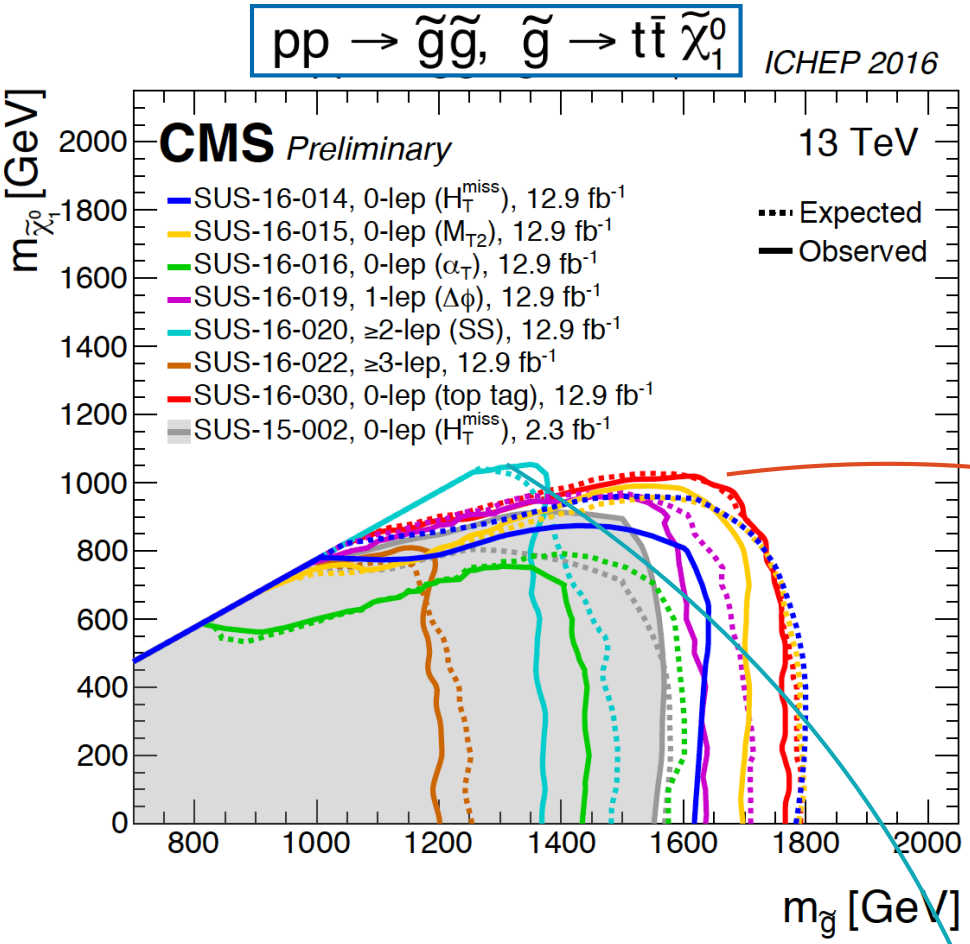
- **SS dilepton search:**
  - 2-SS light leptons, $N_{jet}>1$, $E_T^{miss}>50$
  - Search regions binned in H_T, E_T^{miss}, N_{btag}, min $M_T(\ell,E_T^{miss})$, $p_{T\ell i}$: **68 SR**
  - Trigger: Di-lepton (17/23,8/12 GeV), Di-lepton + H_T (8,8,300 GeV)



$\Delta m(\chi^{\pm},\chi_0)$=20GeV Sensitivity to more compressed regions

SUS-16-020/22

A combined effort



- **Several channels** interpreted with the T1tttt simplified model (4W)
- Inspired by natural argument (gluino and stop should not be too heavy)

gluinos excluded up to ~1.8 TeV for LSP masses< 800 GeV

2ss-ℓ *accessing more compressed regions (diagonal is at* $\Delta m = 2*(m_b + m_W)$*)*

What next - inclusive searches ?

ICHEP 2016
12.9 fb^{-1}

Moriond 2017
36.5 fb^{-1}

lumi x3

End of 2018
(?) ~ 100 fb^{-1}

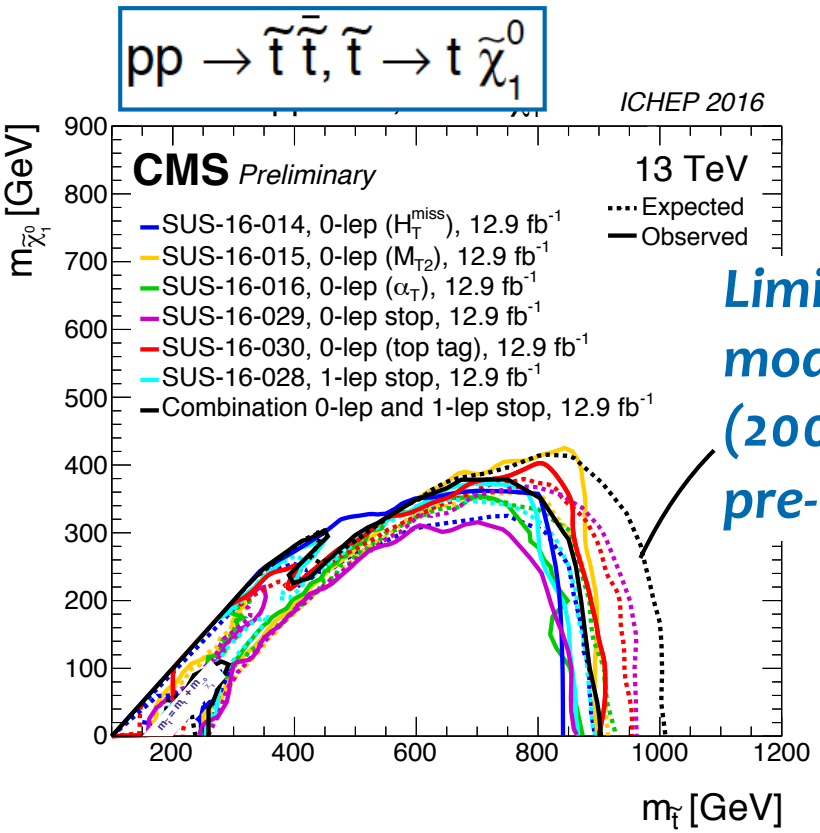
lumi x3

- ***Lumi x3, expected ~100 GeV extensions in gluino/squark masses***
  - *analyses being reloaded for Moriond2017 (papers)*
- ***For next steps (100 fb^{-1} and further)***
  - *it's maybe more appealing to start thinking in terms of* ***"coupling"*** *and not in terms of* ***"masses"***
  - *the assumptions of 100% BR is a loose one!*

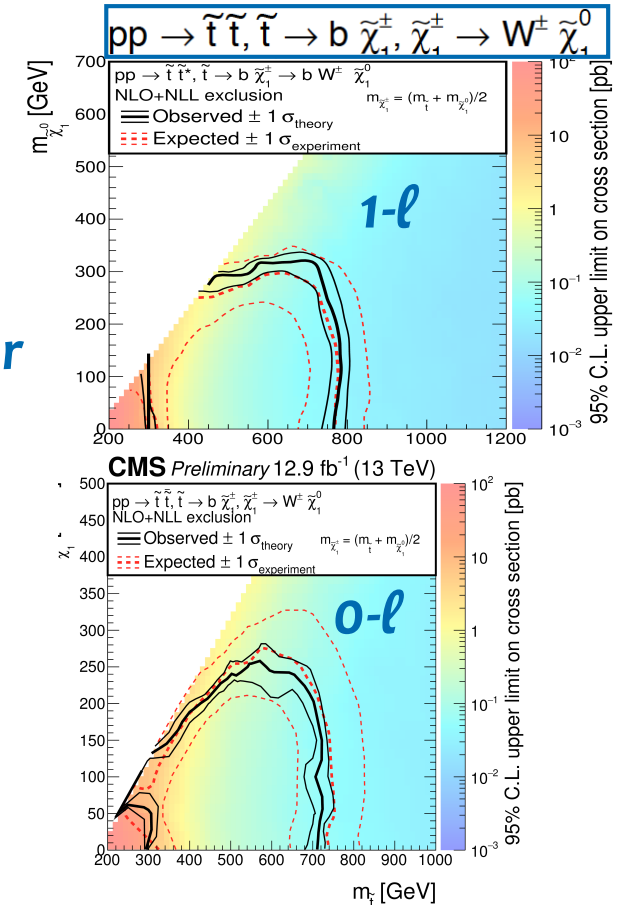
Stop searches

SUS-16-029
SUS-16-030
SUS-16-028

- **Most powerful searches: 0-ℓ and 1-ℓ**
- Target different stop decay modes (Δm(stop-LSP) > M_W)
  - **0-ℓ (SUS-16-029):** veto leptons, E_T^{miss}>250 (trigger), N_{bjet}^{L}>1 and N_{jet}>4
    - bins (**60 SR**) : Low/high M_T(b12,E_T^{miss}), N_{jet}, N_{bjet}(1,2), E_T^{miss}
      - high M_T(b12,E_T^{miss}): 4 categories with top/W tags



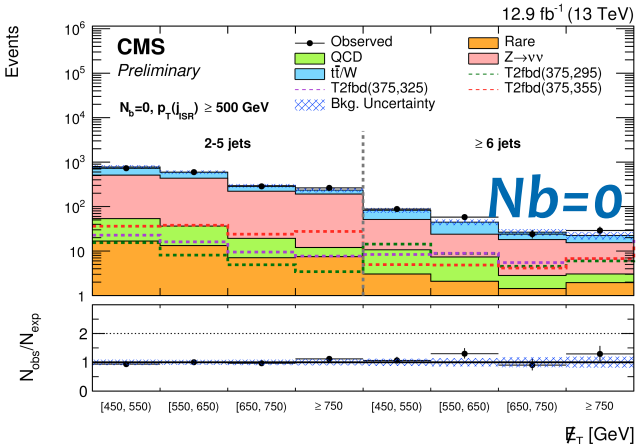
Limits close to 1TeV for modest LSP masses (200 GeV more then pre-ICHEP)

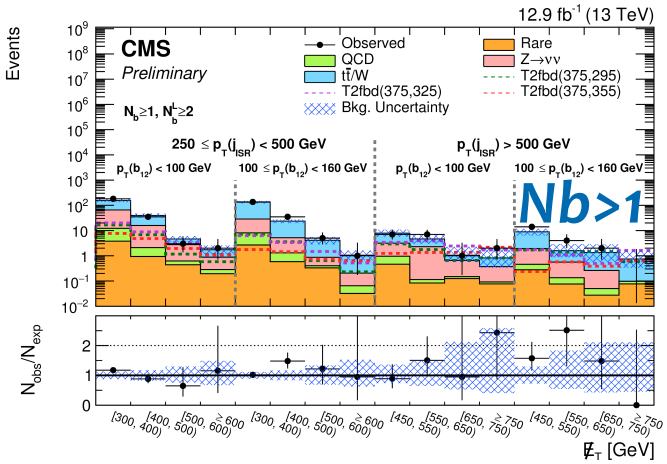


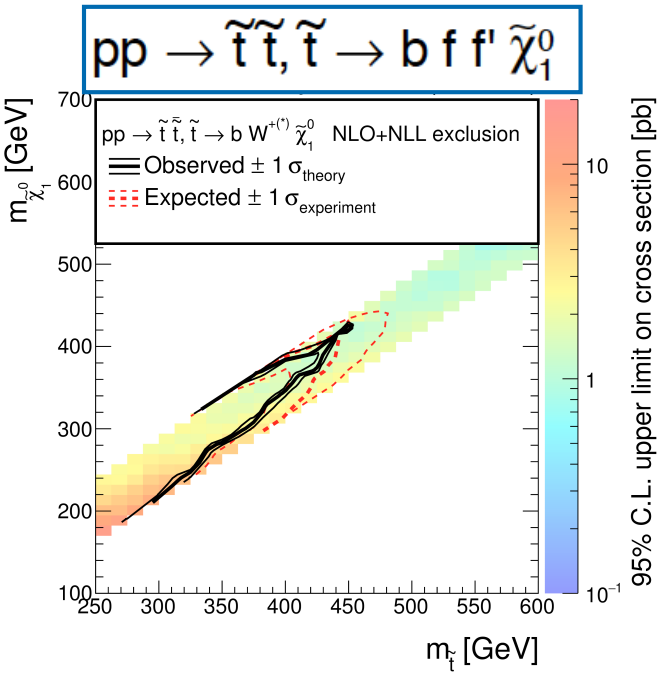
Compressed stop

- **Extension to low Δm(stop-LSP) < M_W of 0-lℓ analysis method A**
  - interesting for **Naturalness** and **DM co-annihilation** (PhysRevD.70.015007)
  - **4body- decay ($bff\tilde{X}_0^1$)** predicted to be dominant wrt 2body-decay ($c\tilde{X}_0^1$) for Δm>~20 GeV (arxiv 1408.4662)
  - stop pair **recoils against ISR (N_{ISRJet} >0),** and LSP carries most of the momentum: **soft b!**
  - N_{bjet}=0, N_{bjet}>0 & N_{bjet}^L=1, N_{bjet}>0 & N_{bjet}^L=2 (p_Tb>20GeV), and bin in N_{jets}, ISR_{jet} p_T, E_T^{miss}
    - if b_{jets} are present, further categorisation in p_T(b), pT(b_{12}) : **40 SR**

SUS-16-029







No significant excess over bkg predictions

Also searches with 1-soft-lepton (SUS-16-031) and 2OS-soft leptons (SUS-16-025)

What next - compressed stop ?

ICHEP 2016
12.9 fb^{-1}

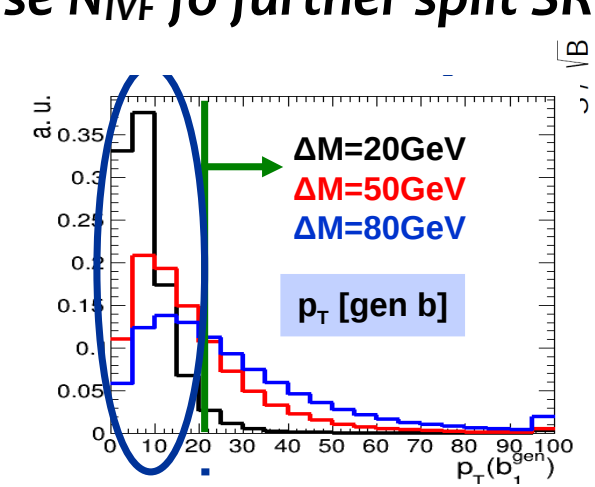
Moriond 2017
36.5 fb^{-1}

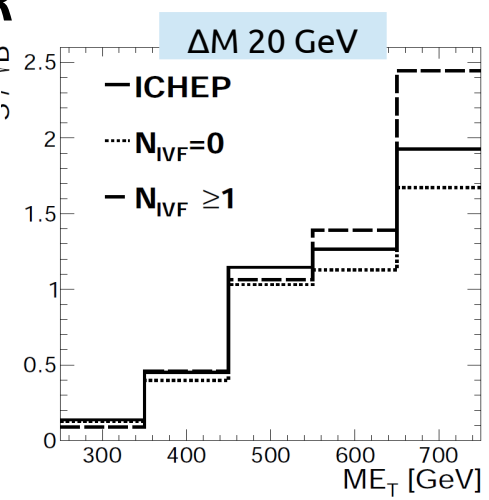
lumi x3

End of 2018
(?) ~ 100 fb^{-1}

lumi x3

- ***With more data and time new developments for going compressed are being developed***
  - ***Soft b-tagging using IVF secondary-vertices for $p_T(b) < 20$ GeV***
    - *50% efficiency vs 3% mis-tag rate*
    - *IVF efficiency measured in data*
  - ***Use N_{IVF} fo further split SR***



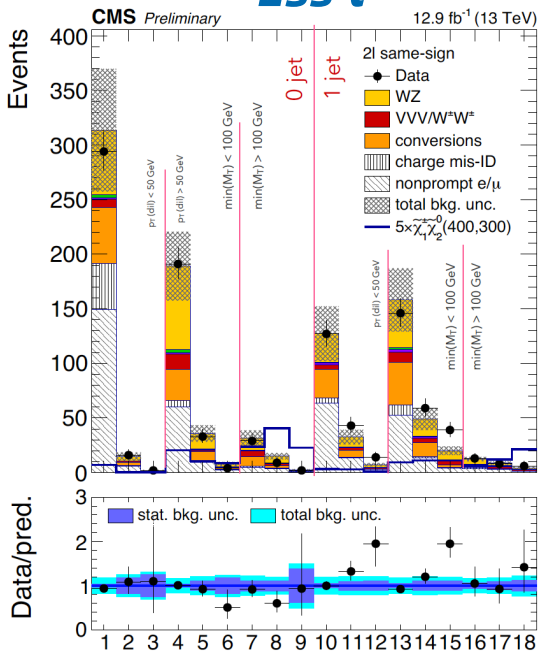


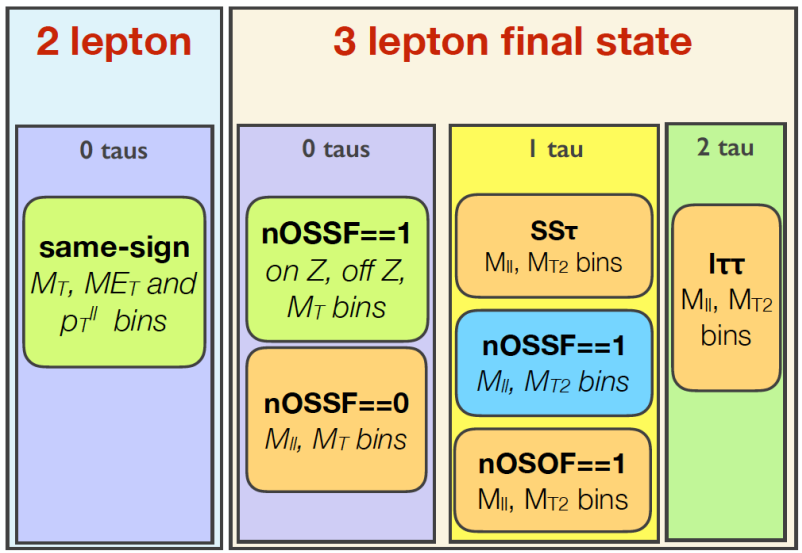
- ***Other studies on going for Δm < 20 GeV, where soft c-tagging can be interesting***

Electroweakinos: multilepton

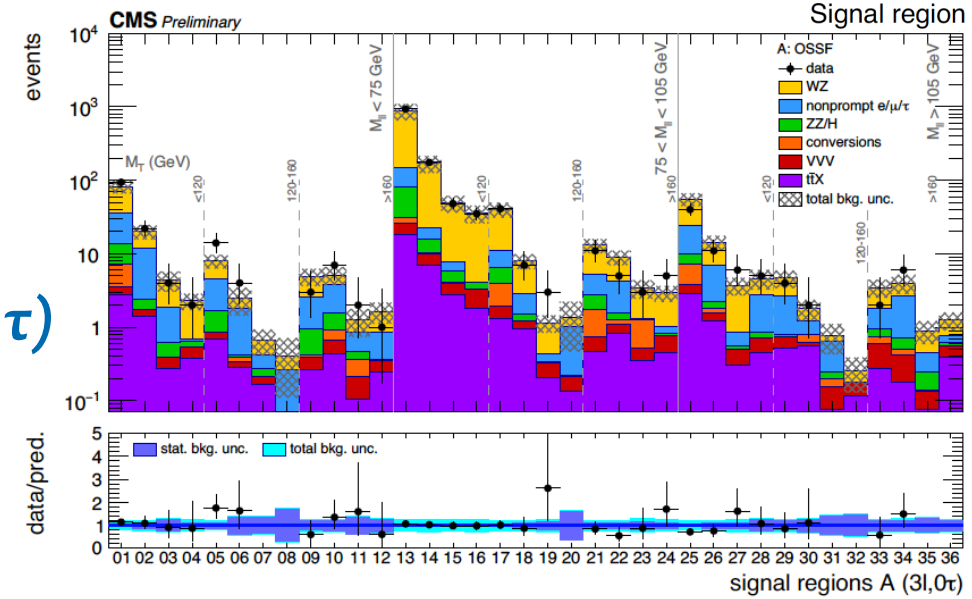
- **Typical signature: few jets, many W,Z,h,l̃, i.e. high lepton multiplicity or boson tagging**
  - **Multilepton search:** e, μ, τ_h with E_T^{miss}, M(ℓℓ), M_T, M_{T2}, $p_T(\ell\ell)$ as search variables
    - **advanced technique for lepton identification**
    - b_{jet} veto, E_T^{miss}> 50 GeV, leptonic trigger
    - **main bkg:** WZ, non-prompt leptons, conversions
    - **2lss** for more compressed region, analysis strategy completely revised: **18 SR**
    - **3l:** 2τ_h channel added: **88 SR**

2ss-ℓ





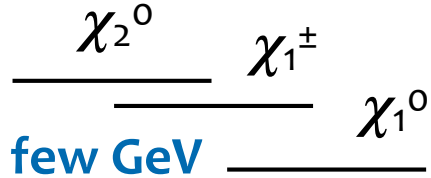
3-ℓ(0τ)



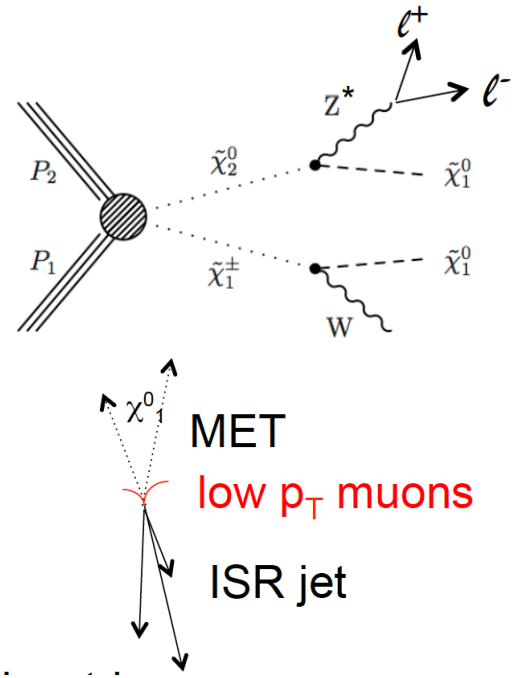
SUS-16-024

Electroweakinos compressed

- **Wino/Higgsinos mass degeneracy not accidental (unless they mix significantly)**
  - **Low higgsino masses** are an ingredient of natural SUSY not yet challenged at LHC
    - likely mass-compressed and light $X^0_2X^{\pm}_1X^0_1$ in natural SUSY (latest constraint from LEP)
  - interesting also for **DM co-annihilation** (PhysRevD.70.015007)
  - Difficult region because of **low E_T^{miss} and soft decay product**



- **New analysis: ISR + soft opposite-sign leptons + low E_T^{miss}**

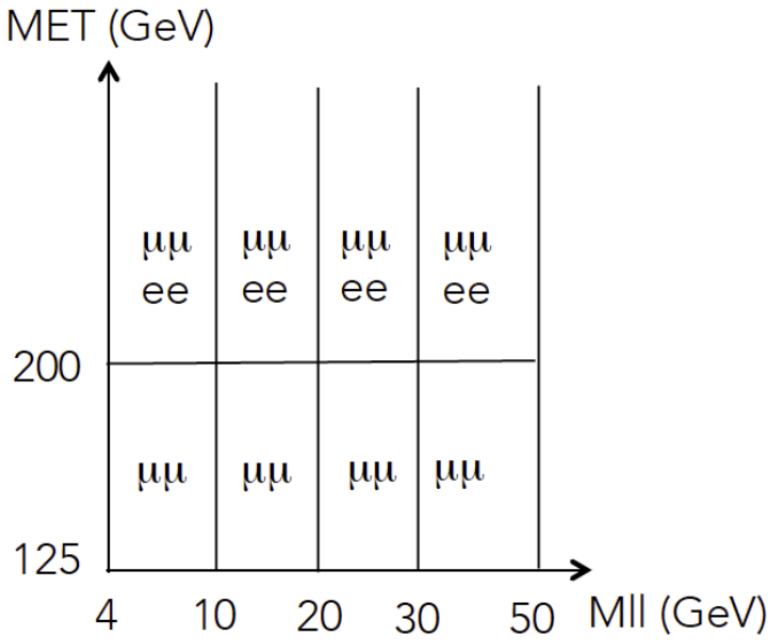


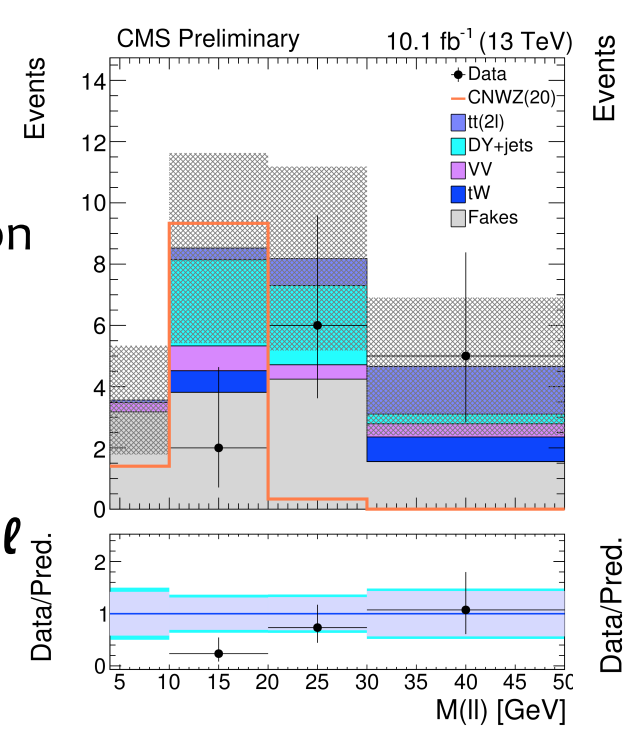
- ISR can lead to E_T^{miss} (mono-jet like)
- Soft lepton requirement reduce bkg up to 100.000
- **NEW TRIGGER:**
  - 2 opposite-sign muons, M(μμ)<60 GeV, E_T^{miss}
  - offline E_T^{miss} > 125 GeV, μ_{pT}>5 GeV
- **Analysis much improved wrt RunI thanks to lower E_T^{miss} and m(ℓℓ) binning**

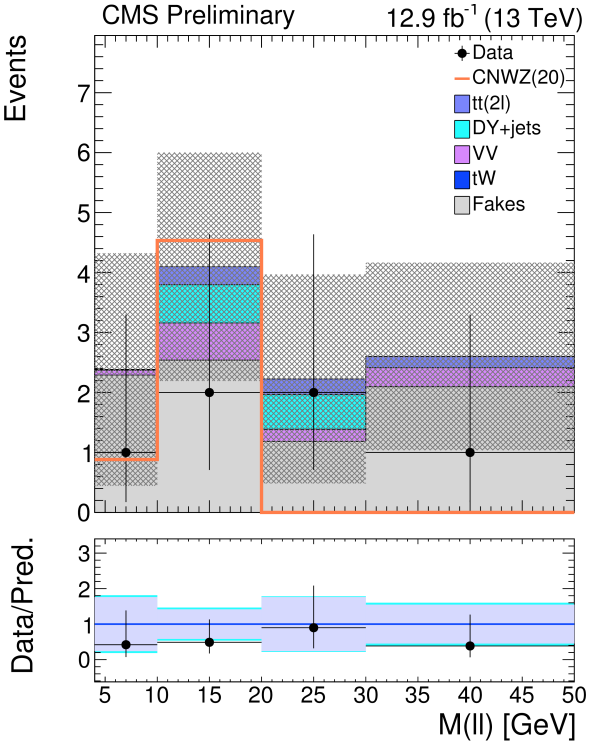
SUS-16-025

Electroweakinos: compressed spectra

- To reject main backgrounds:
  - b-veto, J/ψ and Υ vetoes
  - M(ττ) > 160 GeV and tight IP cut on leptons
    - **to reject DY->ττ**
  - $M_T(\ell_i, E_T^{miss}) < 70$ GeV
    - **in signal E_T^{miss} is aligned with ℓ**





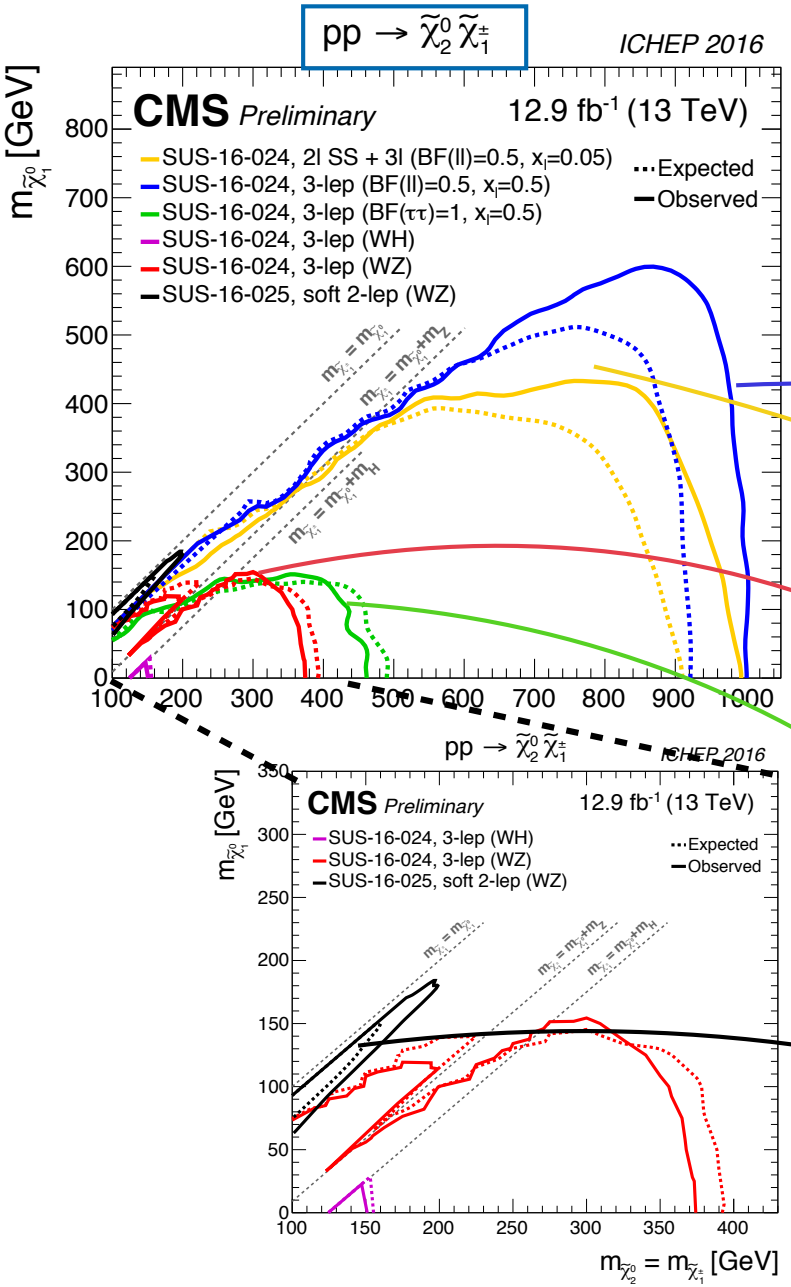


125 < E_T^{miss} < 200 GeV

(new trigger)

E_T^{miss} > 200 GeV

Electroweakinos: interpretation



First LHC results on EWKinos at 13 TeV extended and improved RunI searches, overcome previous sensitivity

Limits in $X_1^\pm=X_2^0$ vs X_1^0 plane (simplified model for $X_1^\pm,X_2^0$ production) with **Wino-like cross section** (Higgsino cross section not yet accessible)

***3l**, decay through sleptons (flavour democratic)*
$m_{slep}=0.5*(m_{X1\pm}-m_{X01})$

***3l**, heavy sleptons, decay through WZ*

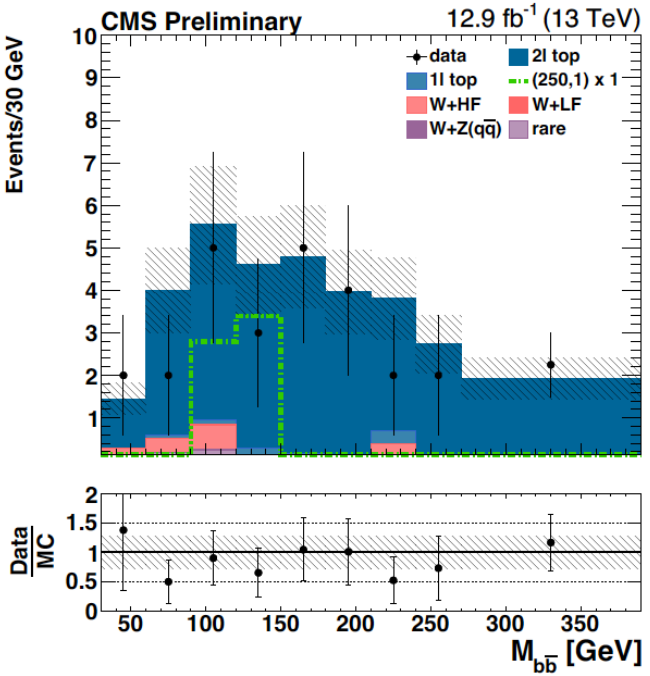
***3l**, decay through staus (tau dominated)*
$m_{stau}=0.5*(m_{X1\pm}-m_{X01})$

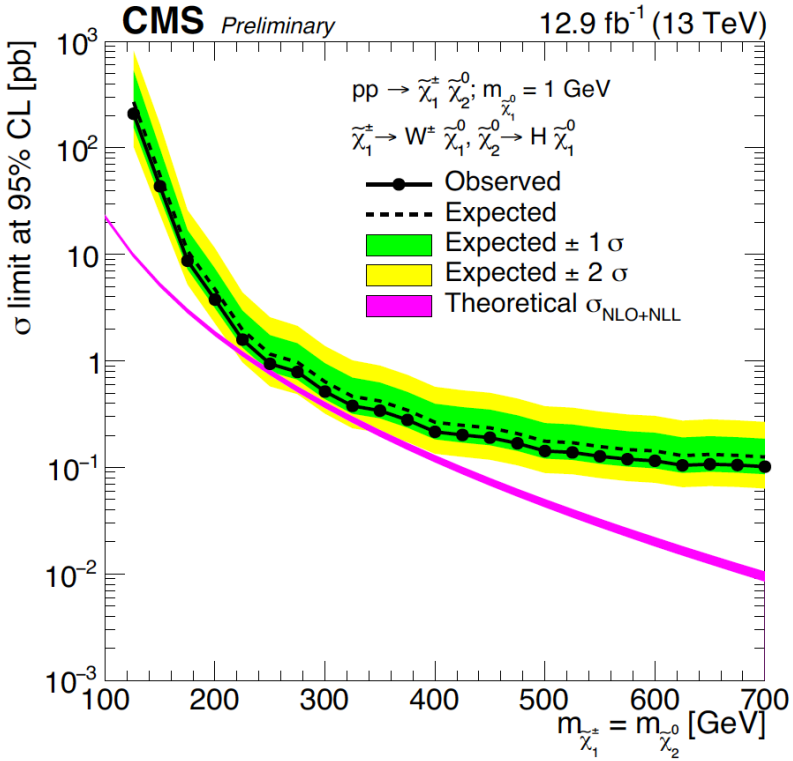
***3l**, **2lss** decay through sleptons (flavour democratic)*
$m_{slep}=0.05*(m_{X1\pm}-m_{X01})$

***2los soft**, heavy sleptons, decay through WZ (first coverage of dM 7.5-30 GeV, limit at 175 GeV for dM=7.5)*
Milestone for Higgsino searches at LHC

Electroweakinos: higgs tagging

- **Typical signature: few jets, many W,Z,h,l̃, i.e. high lepton multiplicity or boson tagging**
  - **Single Lepton + bb:** targeting WH(bb) decay of $X_1^{\pm}, X_2^0$
    - $60 < m(bb) < 150$, $M_T(l, E_T^{miss}) > 150$
    - M_{CT} variable built with the b-jets > 150 (endpoint at m(t) for tt)
    - $E_T^{miss} > 100$ GeV





Not yet reach RunI sensitivity

SUS-16-026

What next - Higgsinos ?

ICHEP 2016
12.9 fb^{-1}

Moriond 2017
36.5 fb^{-1}

lumi x3

End of 2018
(?) ~ 100 fb^{-1}

lumi x3

- *With more data* ***extend the current results (multilepton, 1lbb) for CN production*** *with* ***sleptons, WZ, WH + E_T^{miss}*** *final states*
- *Finally access the* ***Higgsino production***
  - ***ZZ, ZH, HH + E_T^{miss}*** *final states*
- *Analyses already performed in RunI (SUS-13-006, SUS-14-002) which are being prepared for 2017*
  - ***2OS-ℓ + E_T^{miss} + (b)jets for WZ,ZZ,ZH***
  - ***bbbb + E_T^{miss} for HH***
  - ***gg E_T^{miss} + jets or leptons (1,2) for WH,ZH,HH***
- ***Completely new program about to start***
  - *in RunI exclusions limits are only set in the GMSB, where the LSP is an almost massless gravitino*
    - *for BR in ZG/HG = 1, excluded χ_i <380/360 GeV*

What next - degenerate Higgsinos ?

ICHEP 2016
12.9 fb^{-1}

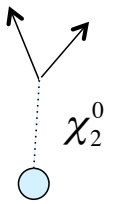
Moriond 2017
36.5 fb^{-1}

lumi x3

End of 2018
(?) ~ 100 fb^{-1}

lumi x3

- *With more data the **soft-opposite-sign dilepton analysis sensitive for the first time to light degenerate higgsinos***
  - ***Δm 5-20 GeV, with χ_1^0 LSP***
- *Plan to add additional channels*
  - ***soft triple-mu** with the dedicated TripleMu (5,3,3 GeV) triggers included in 2016 data-taking*
- *Extension to **displaced tracks/vertices?***
  - *when Δm(last decaying particle - LSP) ~ 1 GeV, displaced soft particles from sparticle decay*



O(>100μm)

What next - VBF ?

ICHEP 2016
12.9 fb^{-1}

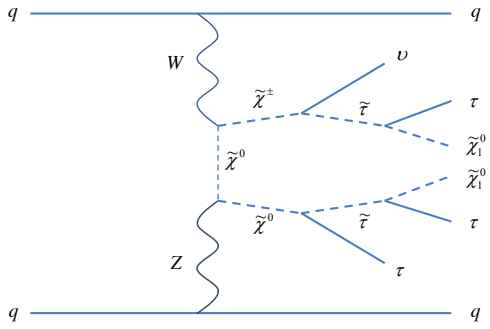
Moriond 2017
36.5 fb^{-1}

lumi x3

End of 2018
(?) ~ 100 fb^{-1}

lumi x3

- ***The VBF production of EWKinos can be an alternative handle to the ISR topology to access compressed spectra***
  - *VBF dijet topology with hard dijet p_T to reduce SM bkg*
  - *Analysis just being proposed:*
    - ***1 or 0 soft-ℓ, E_T^{miss} and jets (VBF+E_T^{miss}, VBF+μ triggers)***
    - *sensitivity with respect to ISR+soft-ℓ analyses (E_T^{miss}, E_T^{miss}+μ triggers)* ***not yet clear***



What next - RPV ?

ICHEP 2016
12.9 fb^{-1}

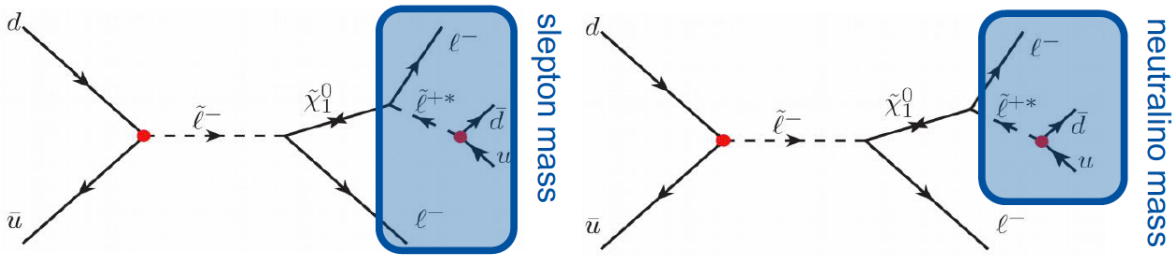
Moriond 2017
36.5 fb^{-1}

lumi x3

End of 2018
(?) ~ 100 fb^{-1}

lumi x3

- ***Searches for RPV SUSY are very different, no E_T^{miss} in the final state and resonant structures***
  - *just one public results with @ 13 TeV with 2015 data (SUS-16-013)*
    - *g→tbs, in the 0/1-ℓ channels with ≥ 8 jets and M_J binning*
  - *in preparation: search for **resonant slepton production***
    - *SS muons + jets with mass reconstructions*



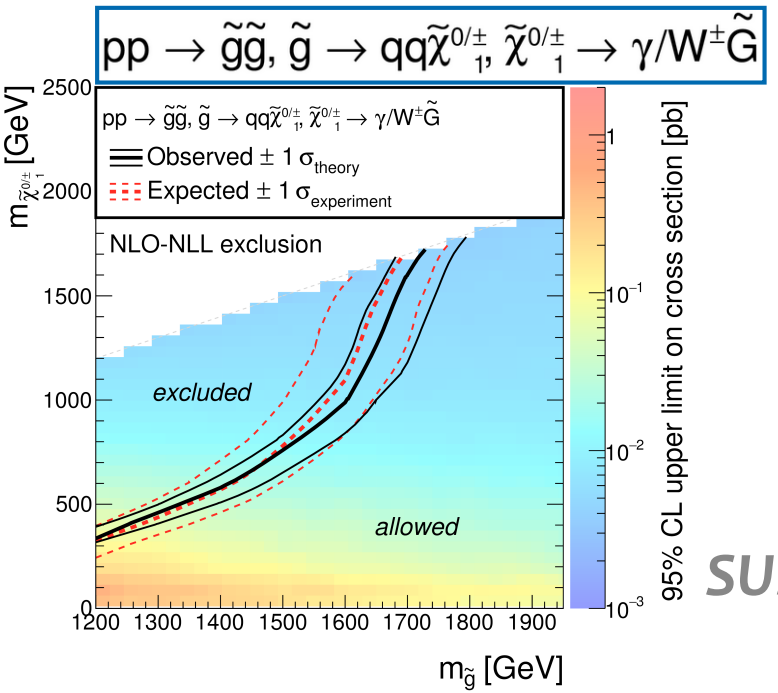
In conclusione

- *Le ricerche inclusive di gluini e squarks hanno escluso la possibilità di Strong SUSY "Naturale" nella maggior parte dello spazio delle fasi*
- *Nel settore EWK, il programma di* ***ricerche di Higgsini (WZ, ZZ, HZ, HH)*** *è appena agli albori*
- *La quantità di dati di RunII fornisce la* ***possibilità di esplorare con ricerche dedicate gli angoli più difficili*** *da sondare dove può ancora nascondersi una SUSY "leggera"*
  - ***stop leggeri e compressi con soft b(c)-tagging***
  - ***higgsini leggeri con leptoni leptoni soft (ISR o VBF)***
- *E, se interessa, il programma di ricerche di SUSY in RPV e' molto scoperto*

Backup

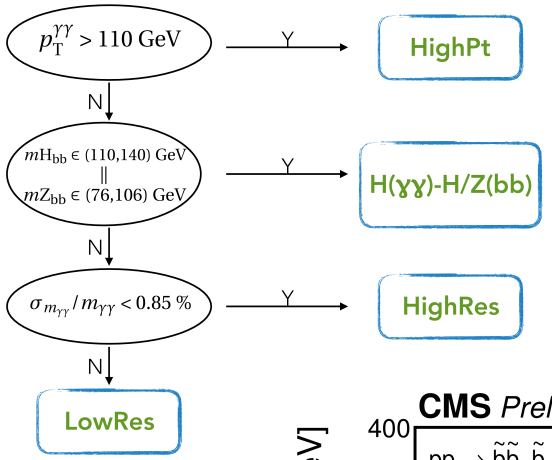
Photons + E_T^{miss}

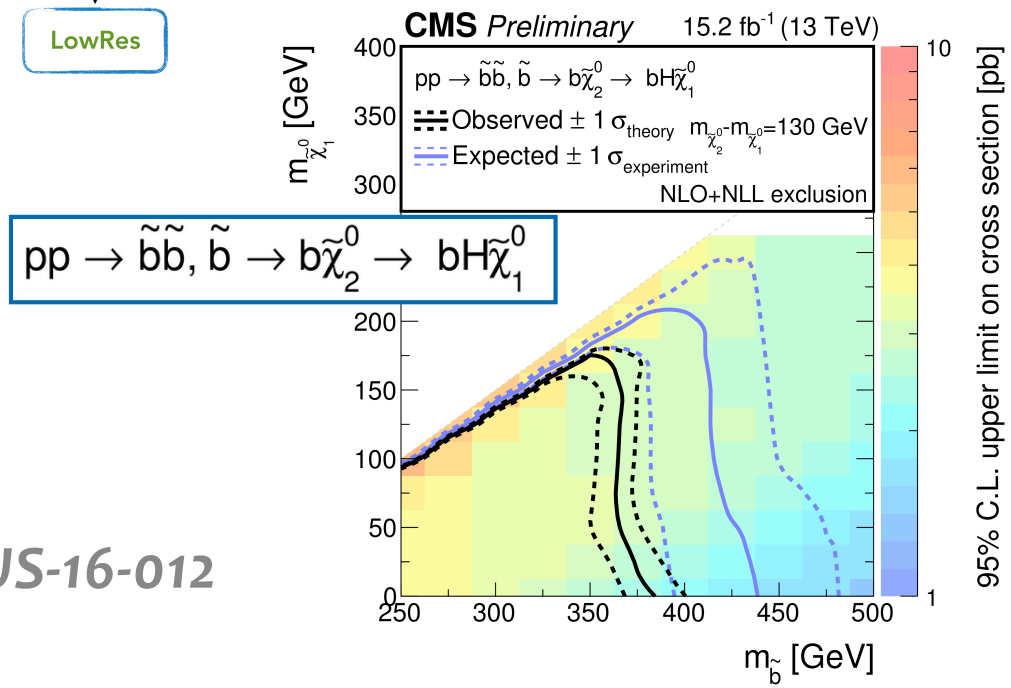
- **GMSB models give γ in the final state**
  - **from Bino X_1^0 decay**
  - **target both EWKinos and gluinos**
- No jets requirement, ≥ 1γ
- Search variables
  - $M_T(\gamma, E_T^{miss})$, E_T^{miss} significance, $S_T\gamma = E_T^{miss} + \sum p_T(\gamma)$
- Main backgrounds V+γ
- Trigger: Single γ (p_T > 180 GeV)



SUS-16-023

- **Probing strong produced SUSY with Razor and H->γγ**
- Razor, and several categories
- Signal extraction: sideband fit within categories



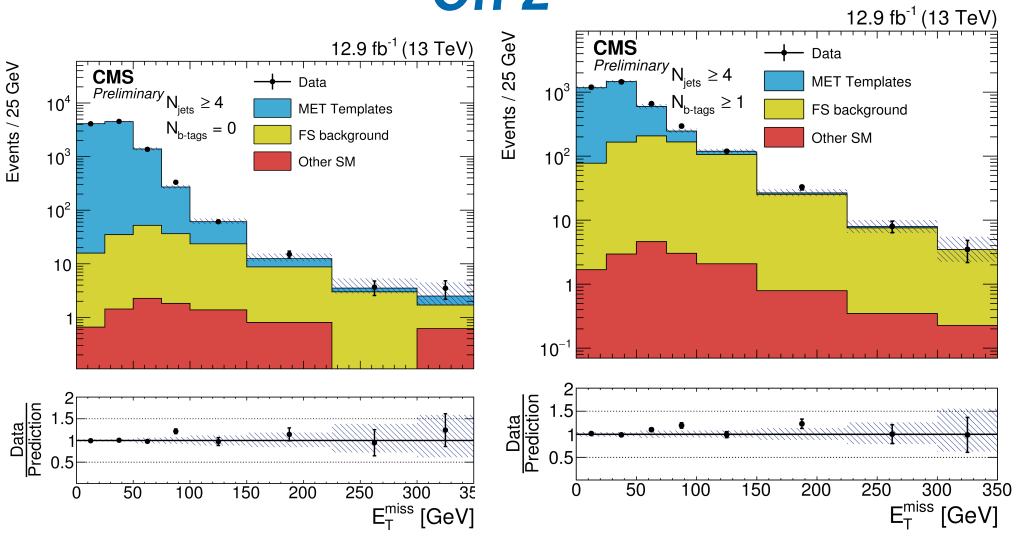


SUS-16-012

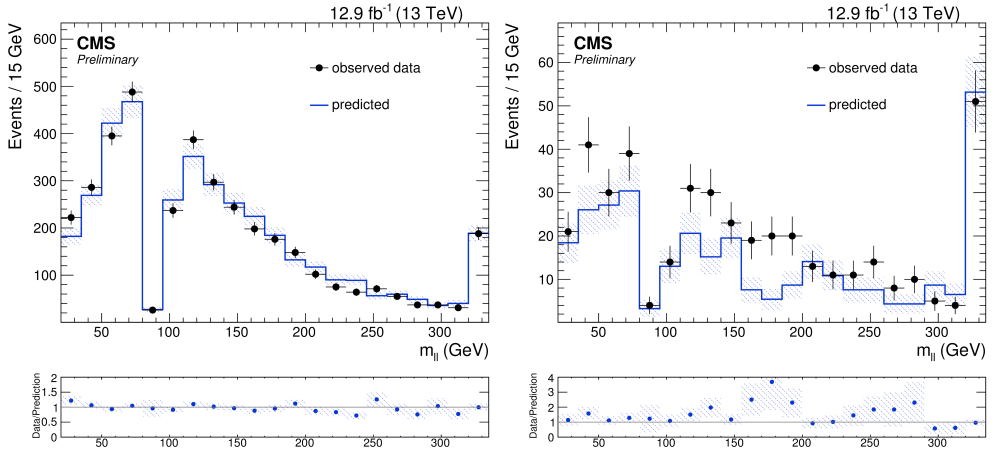
Z-Edge: 2 opposite-sign leptons

- **Extensive re-design w.r.t. 2015 result**
  - Introduced **likelihood discriminator (NLL)** for ttbar in off-Z analysis
    - $p_T(\ell\ell)$, $\sum m_{lb}$, E_T^{miss}, $\Delta\varphi(\ell\ell)$
- Baseline: 2 OSSF ℓ, $E_T^{miss}>150$, $N_{jet}>1$
  - **on-Z:** m($\ell\ell$) in 81-101 GeV, bin in Njet, Nbjet, E_T^{miss}: **16 SR** (also checked ATLAS excess SR)
  - **off-Z**: low and high m($\ell\ell$), bin in NLL (95%/5% ttbar eff)**: 4SR** (also checked CMS 8 TeV SR)
- Main backgrounds:
  - **Z+jets,** from γ+jets
  - **ttbar** (and other flavour-symmetric), from OF control sample
- Trigger: dilepton (offline 25/20 GeV)

On-Z



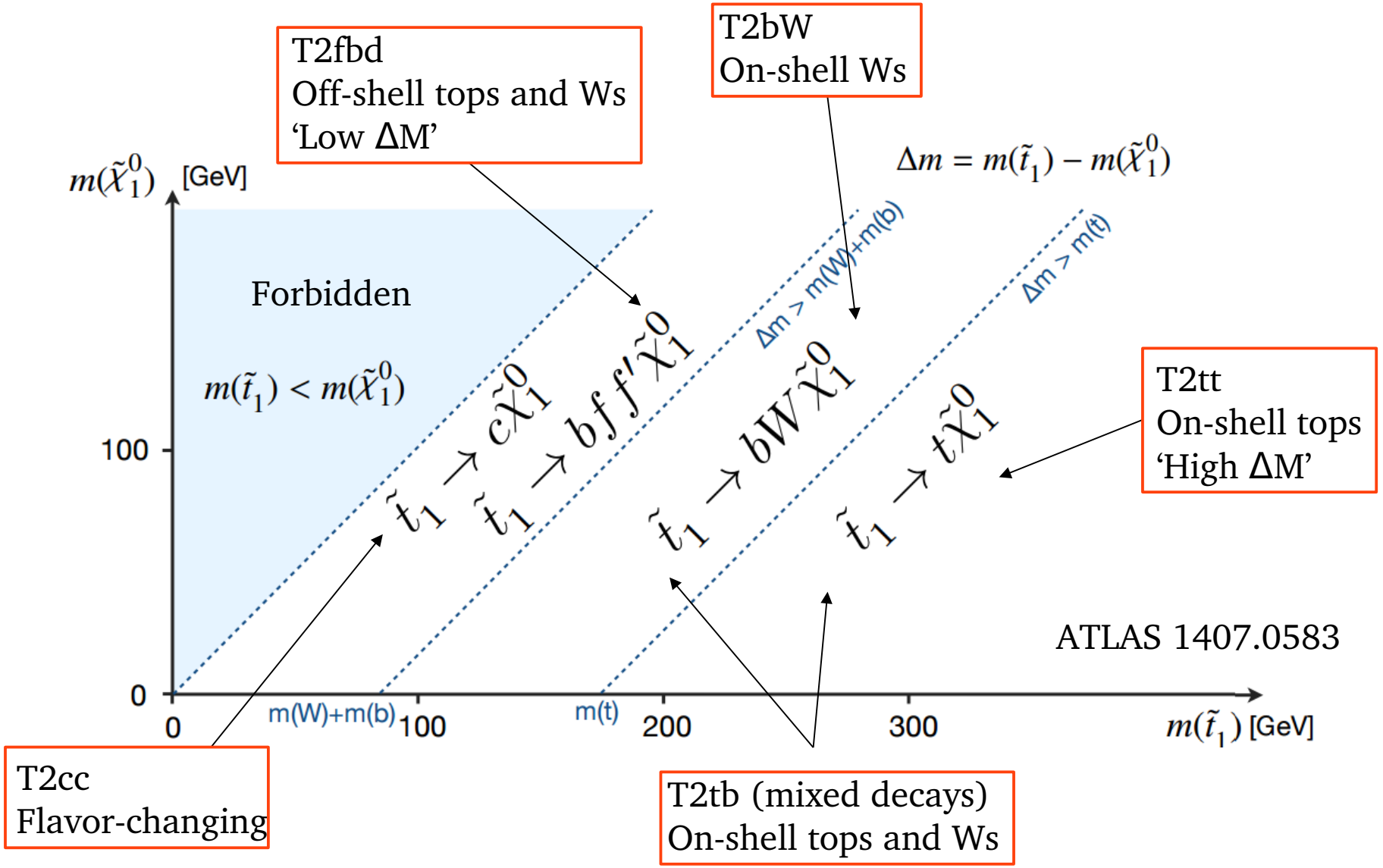
Off-Z

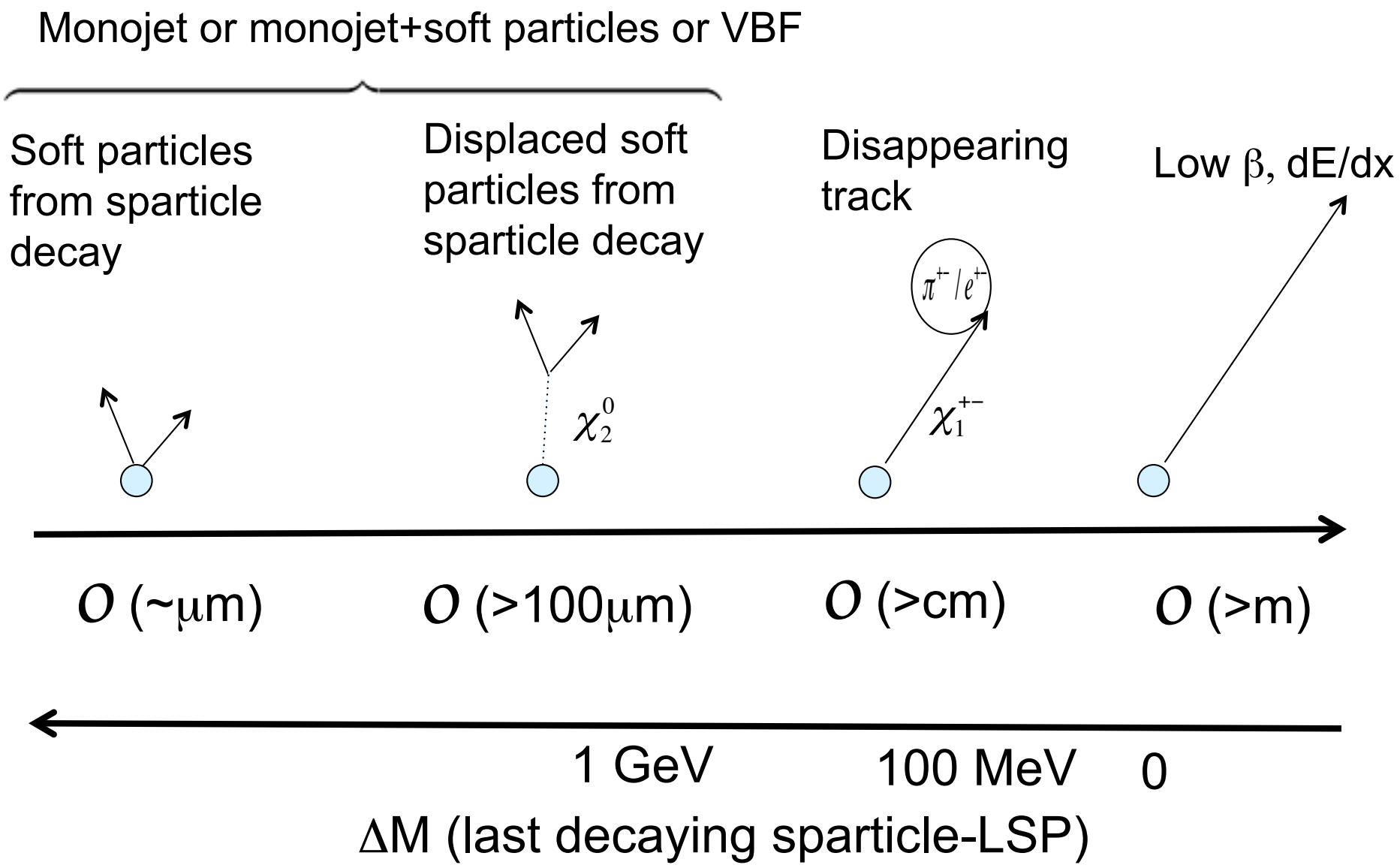


Significant excess only in High-Mass non ttbar like region (3.1σ local)

SUS-16-021

Probing the full stop mass plane




Monojet or monojet+soft particles or VBF
Soft particles from sparticle decay
Displaced soft particles from sparticle decay
Disappearing track
Low β, dE/dx
π^{+-}/e^{+-}
χ_2^0
χ_1^{+-}
O (~μm)
O (>100μm)
O (>cm)
O (>m)
1 GeV
100 MeV
0
ΔM (last decaying sparticle-LSP)