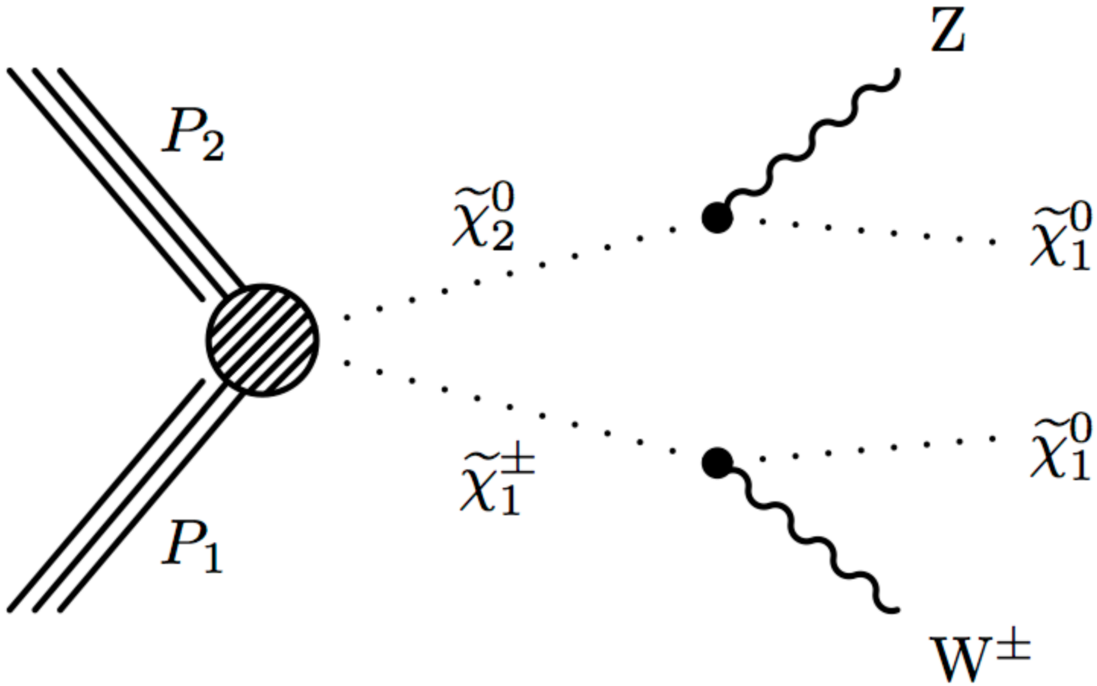
New searches for Supersymmetry in Electroweak production at CMS



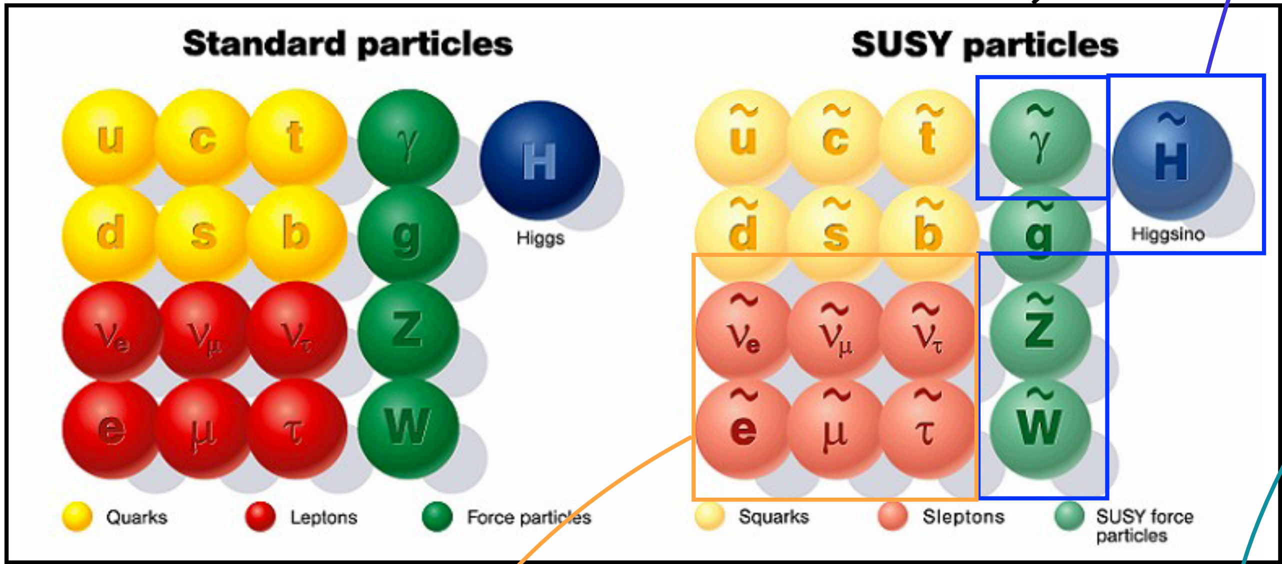
Cristina Botta, CERN

on behalf of the CMS Collaboration

CERN LHC Seminar, 04 April 2017

The Electroweak SUSY sector

*SM boson -> **fermionic partner***
*SM fermion -> **bosonic partner***
MSSM: 2 Higgs doublets required (2HDM)



*The **superpartners of the SM EWK bosons** (Winos, Bino, Higgsinos) **mix to form mass eigenstates (EWKinos):***

$\tilde{\chi}_1^0$ $\tilde{\chi}_2^0$ $\tilde{\chi}_3^0$ $\tilde{\chi}_4^0$

Neutralinos

$\tilde{\chi}_1^\pm$ $\tilde{\chi}_2^\pm$

Charginos

Sleptons and Sneutrinos *could be directly produced or appear in the decay of **EWKinos***

*If **R-parity:***
***Lightest SUSY Particle (LSP)** is stable and sparticles are pair produced*
Neutralino LSP can be dark matter candidate:
Standard searches based on large E_T^{miss} in final states

Example EWKino Spectrum

In principle, any bino/wino/higgsino mass hierarchy is allowed

$\tilde{\chi}_3^0\ \tilde{\chi}_4^0\ \tilde{\chi}_2^{\pm}$ — $\tilde{\mathrm{H}}$ (higgsino)

Δm ~ few – tens of GeV

$\tilde{\chi}_2^0\ \tilde{\chi}_1^{\pm}$ — $\tilde{\mathrm{W}}$ (wino)

Δm ~ few hundreds MeV
(assuming heavy sfermions and higgsinos)

$\tilde{\chi}_1^0$ — $\tilde{\mathrm{B}}$ (bino)

— $\tilde{\mathrm{G}}$ (gravitino)

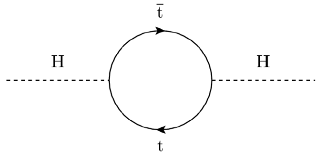
Appears in GMSB/GGM models, mass ~keV

Mass

The case for "compressed" EWK SUSY

- *If we want* ***"Naturalness"****, i.e.*

  'radiative corrections should not disturb the gauge hierarchy in the born term'



$$\Delta m_H^2 = \frac{-(|\lambda_f|^2)}{(8\pi)}[\Lambda_{UV}^2 + \ldots]$$

m($\tilde{g}$)< 2 TeV, m($\tilde{t}$)< 1 TeV, ***m($\tilde{H}$)< 200–300 GeV***

- *Given Higgsino are likely mass-compressed,* ***compressed spectra are an ingredient of natural SUSY*** *[1][2]*

- *Interesting also for* ***DM co-annihilation****[3]*
  - *co-annihilation regions are a mechanism to reduce DM and get right relic density (typically 10-30 GeV mass splitting between co-annihilation partners)*

- *Challenging detector signatures:* ***low E_T^{miss} and soft decay products***

~ 200–300 GeV

$\tilde{\chi}_1^0$ $\tilde{\chi}_2^0$ $\tilde{\chi}_1^{\pm}$ $\tilde{H}$ (higgsino)

Δm ~ few – tens of GeV

Mass

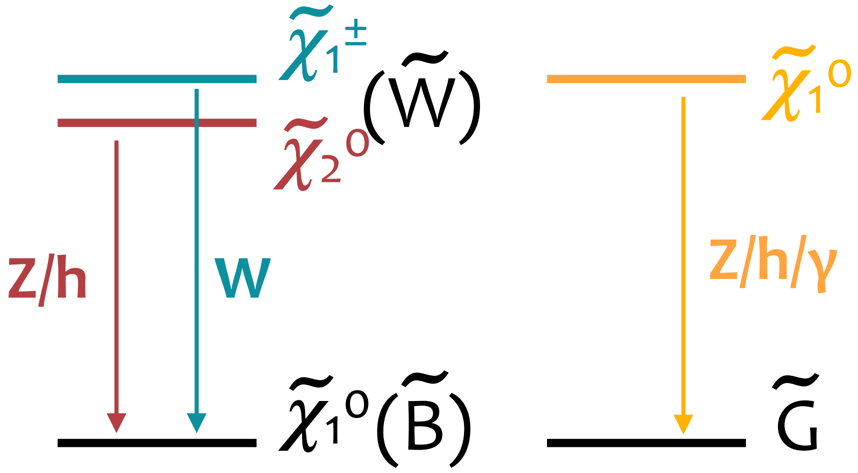
[1] https://arxiv.org/abs/1409.7058 ,

[2] https://arxiv.org/abs/1401.1235

[3]PhysRevD.70.015007

Decay chains

If sleptons are too heavy to participate



W/Z/h in the decay chain, Δm > m(Z,W,h), hadronic final states too much SM like:

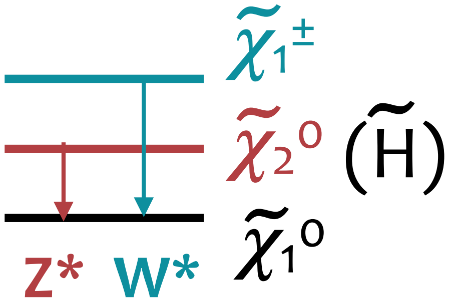
Need Leptonic decays (ℓ(e,μ) and τ_h) or Higgs boson tagging

Signatures covered in this presentation:

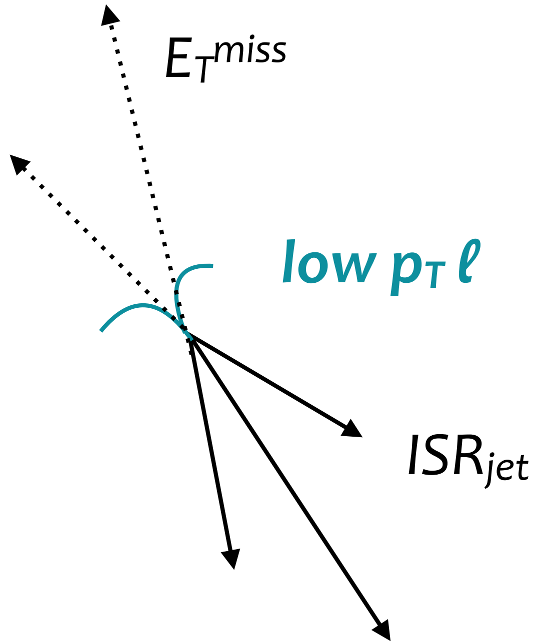
- ***3 or 4 ℓ (including τ_h) + E_T^{miss}*** [CMS-PAS-SUS-16-039]
- ***Z→ℓℓ + jets + E_T^{miss}*** [CMS-PAS-SUS-16-034]
- ***h→bb + 1ℓ + E_T^{miss}*** [CMS-PAS-SUS-16-043]
- ***h→bb + h→bb + E_T^{miss}*** [CMS-PAS-SUS-16-044]

Decay chains

If sleptons too heavy and LSP is part the Higgsino sector



- *Relatively low visible energy and E_T^{miss}*
- *Topologies missed by standard searches*
- ***Need ISR to boost the sparticle pair system***
  - ***induce E_T^{miss} in the event***
  - *other decay products remain soft:*
    - *need **Z*/W* leptonic decays** to reconstruct decay product and drastically reduce bkg*
  - *Mass differences are high enough to **ensure prompt decays** (unlike light Winos with mass differences of ~100 MeV that can lead to **'displaced, long-lived' topologies**)*

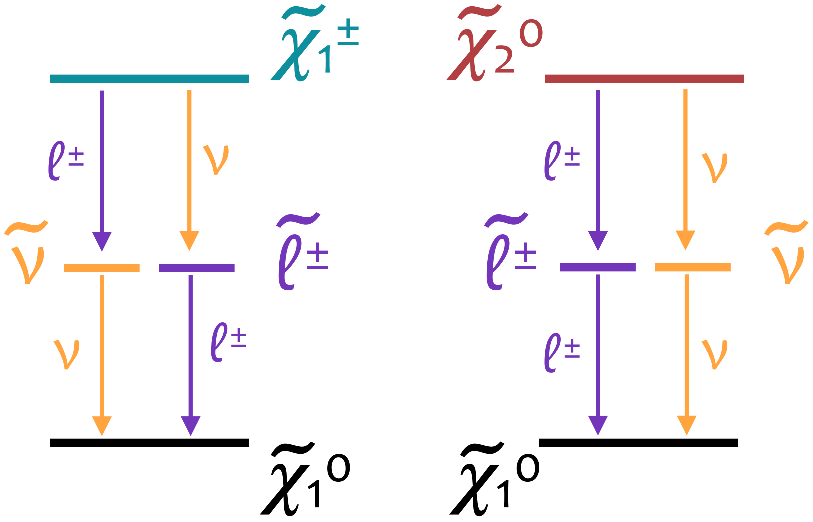


Signatures covered in this presentation:

- ***soft opposite-sign ℓ + E_T^{miss}*** [CMS-PAS-SUS-16-048]

Decay chains

If sleptons are "light"



$m_{\tilde{l}} = 0.5 m_{\tilde{\chi}_1^\pm} + 0.5 m_{\tilde{\chi}_1^0}$

$m_{\tilde{l}} = 0.05 m_{\tilde{\chi}_1^\pm} + 0.95 m_{\tilde{\chi}_1^0}$

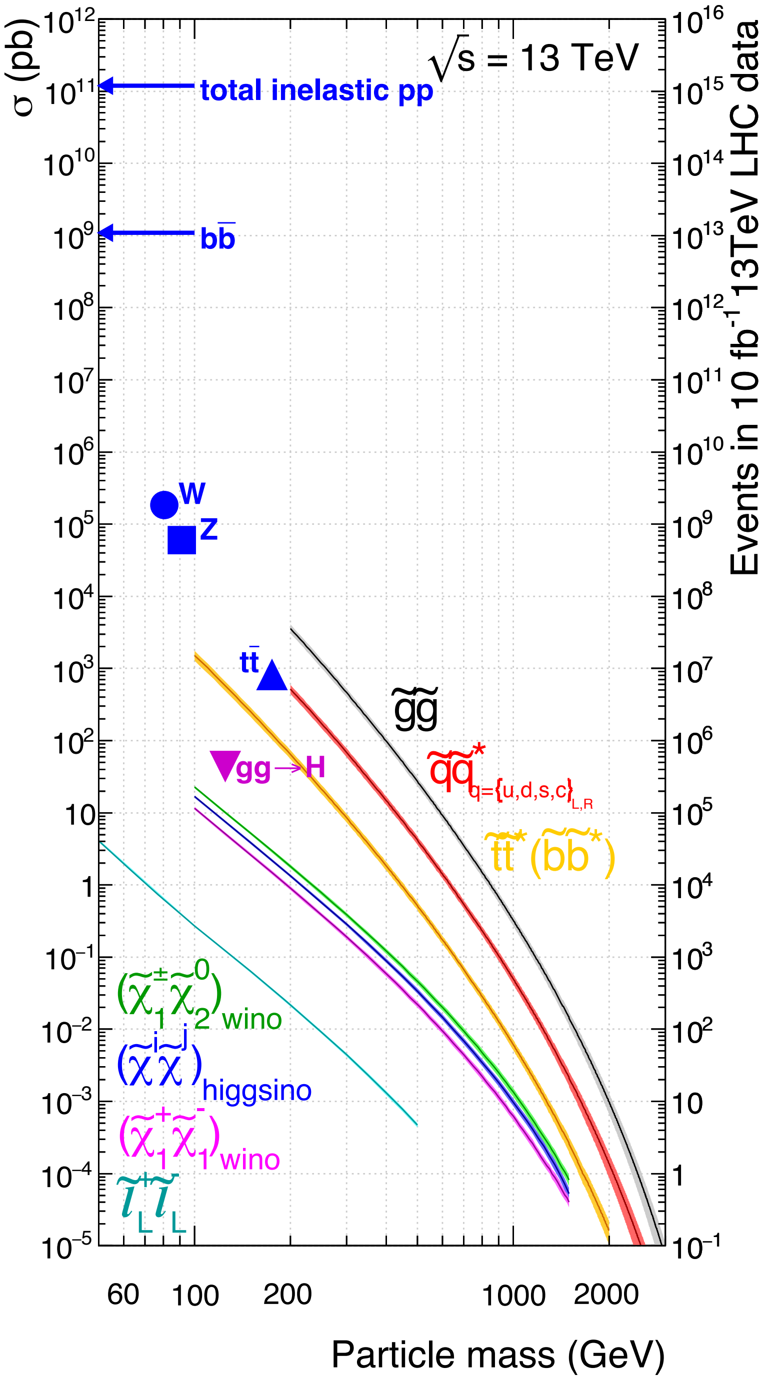
$m_{\tilde{l}} = 0.95 m_{\tilde{\chi}_1^\pm} + 0.05 m_{\tilde{\chi}_1^0}$

- ***Only leptonic final states*** *(no H/W/Z BR penalty)*
- ***Three different limiting flavour cases*** *are considered:*
  - *only* $\tilde{\ell}_L^\pm$ *and* $\tilde{\nu}$ *participate in the decay* ***(flavour democratic)***
  - *only* $\tilde{\ell}_R^\pm$ *participate in the decay*
    - *the BR into 3ℓ is 100%*
    - $\tilde{\ell}_R^\pm$ *couples via the higgsino component, decays into τ are preferred:*
      - ***τ enriched scenarios:*** $\tilde{\chi}_1^\pm$ *decays only to τ*
      - ***τ dominated scenarios:*** $\tilde{\chi}_1^\pm$, $\tilde{\chi}_2^0$ *decay only to τ*

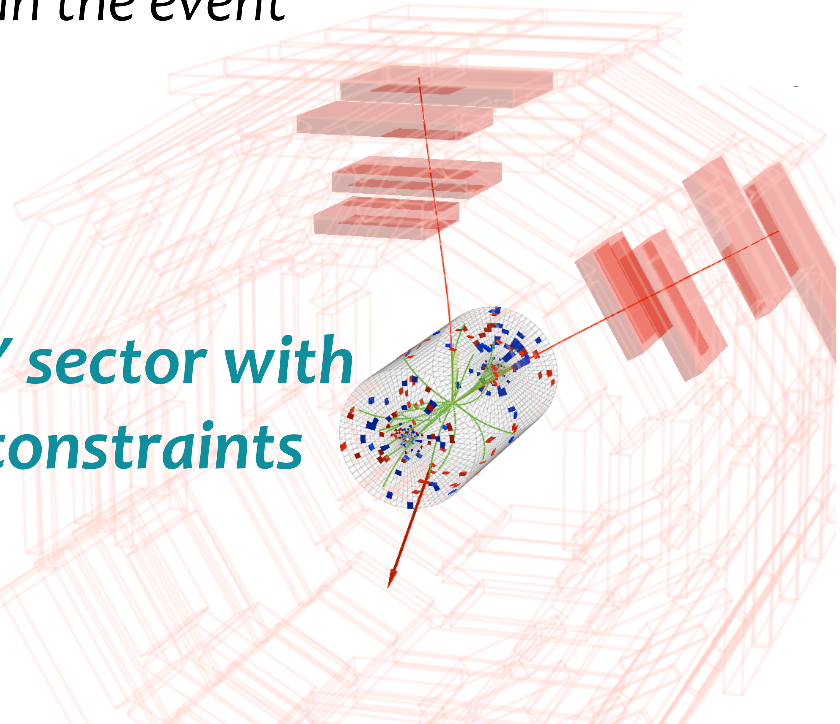
Signatures covered in this presentation:

- ***2 same-sign, 3ℓ (including*** τ_h***) +*** E_T^{miss} [CMS-PAS-SUS-16-039]

The lowest rate



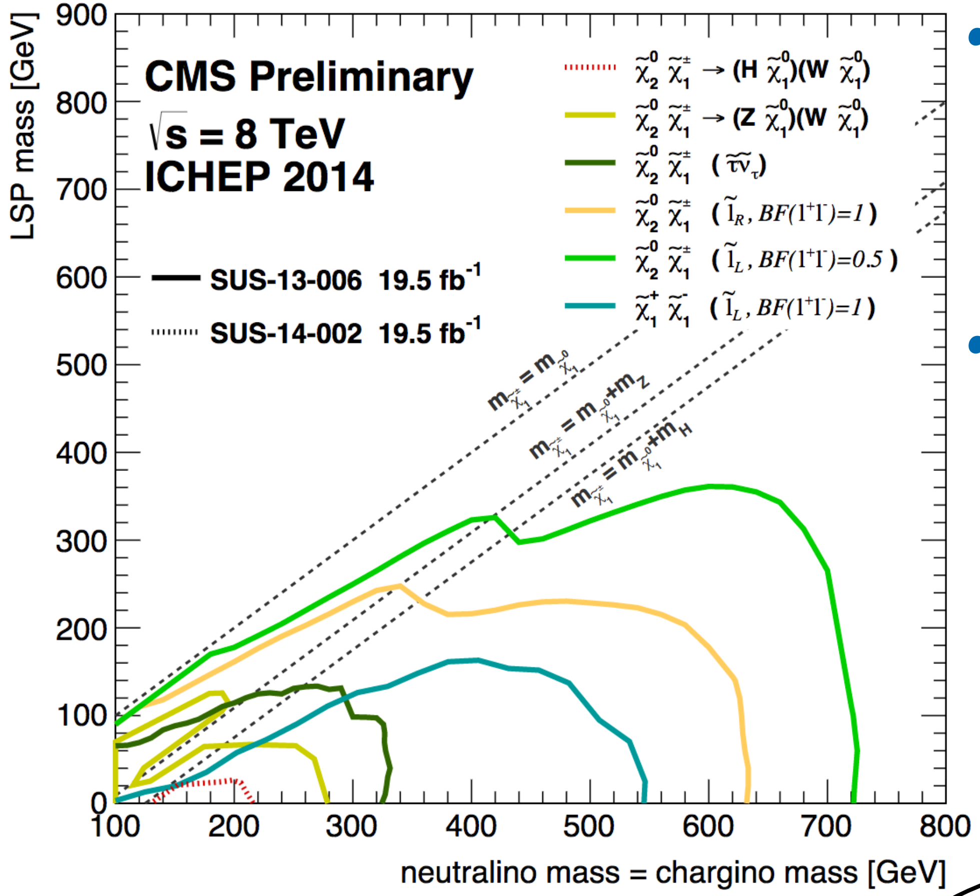
- ***Low production cross section***
  - *quark induced*
- ***Leptonic BR or Higgs tagging***
  - *W/Z/H in the decay chain, hadronic final states too much SM like*
- ***ISR-jet for compressed spectra***
  - *to boost the sparticle pair system and induce E_T^{miss} in the event*



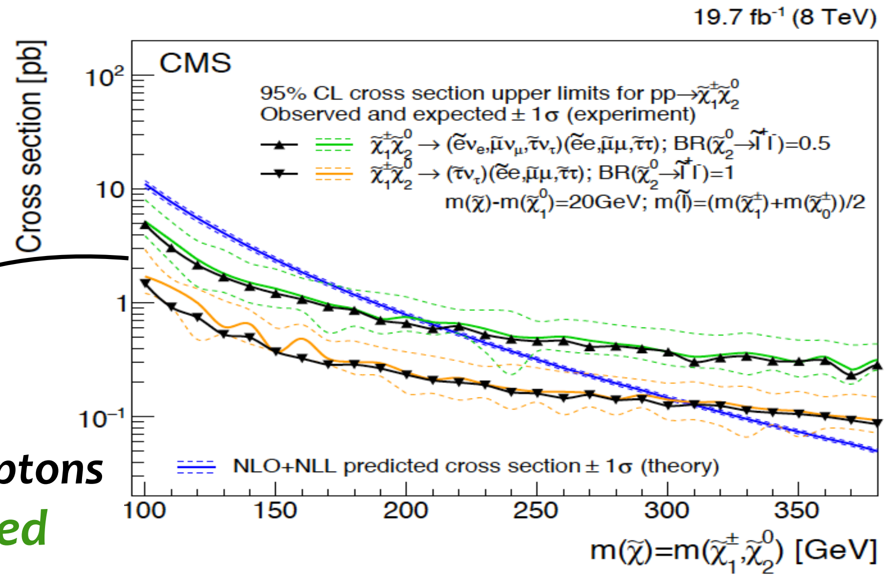
One of the SUSY sector with least stringent constraints after LHC RunI

LHC RunI results

$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ Winos- decaying into the $\tilde{\chi}_1^0$ LSP



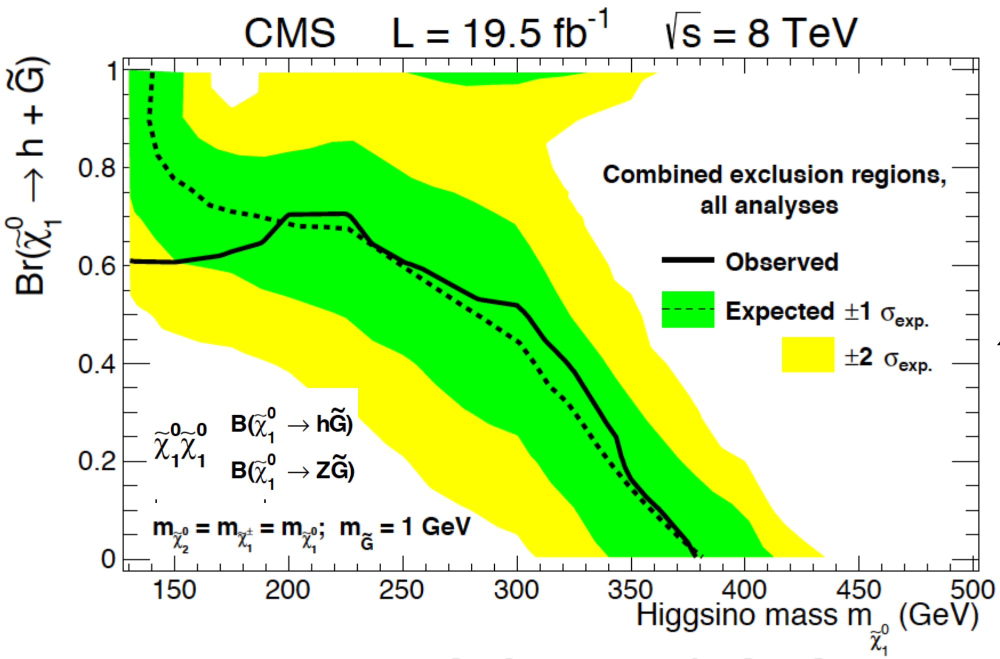
- ***assuming decays through sleptons***
  - *in flavour democratic scenario exclusions up to 700 GeV, for massless LSP*
  - *goes down to 300 for Δm = 20 GeV*
- ***assuming decays through W/Z/h***
  - *exclusions up to 200-300 GeV (with 100% BR in WH, or WZ) for massless LSP*
  - *no coverage of ΔM with LSP < 40-50 GeV*



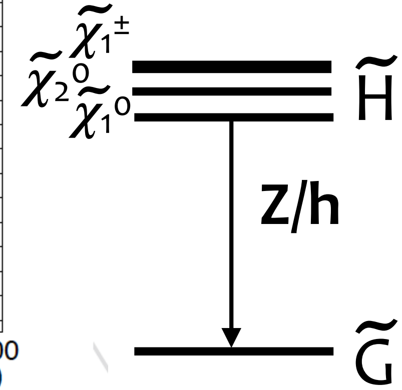
Δm=20 GeV, decay through sleptons

flavour democratic, τ enriched

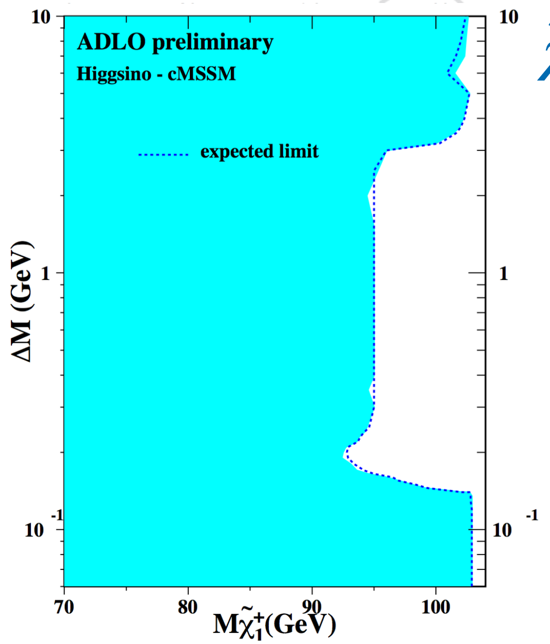
LHC RunI (or LEP) results



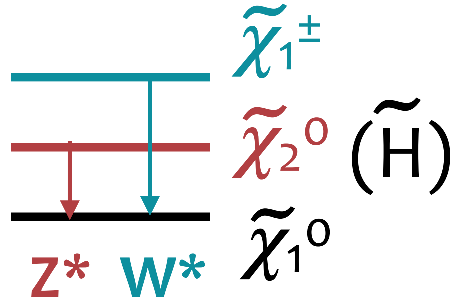
$\tilde{\chi}_1^0\tilde{\chi}_1^0$ Higgsinos- production cross section only in GMSB model, m(LSP=$\tilde{G}$)=1 GeV



- *ZZ/hZ/hh decays, limit as a function of BR into h*
- *up to 380 GeV for pure ZZ decay*

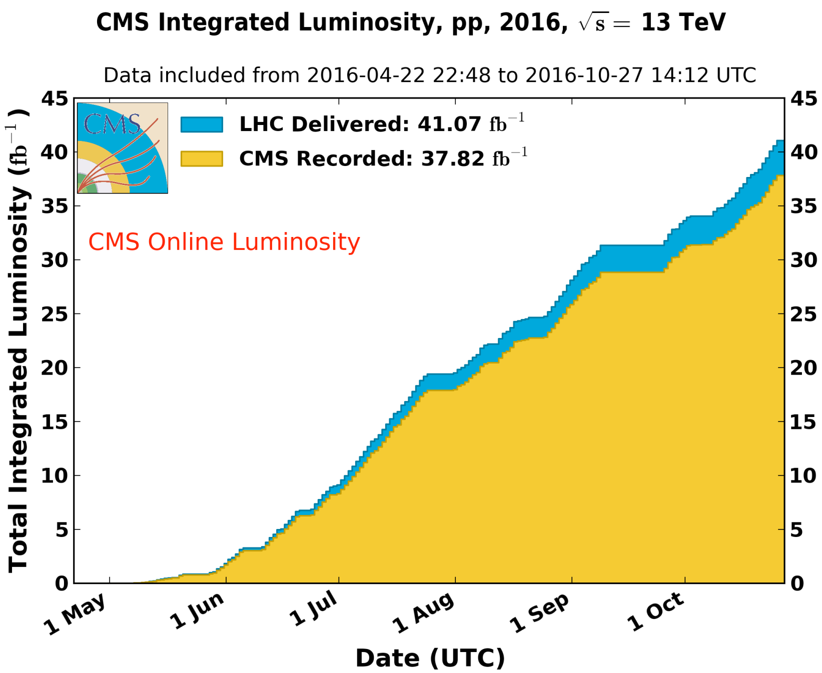


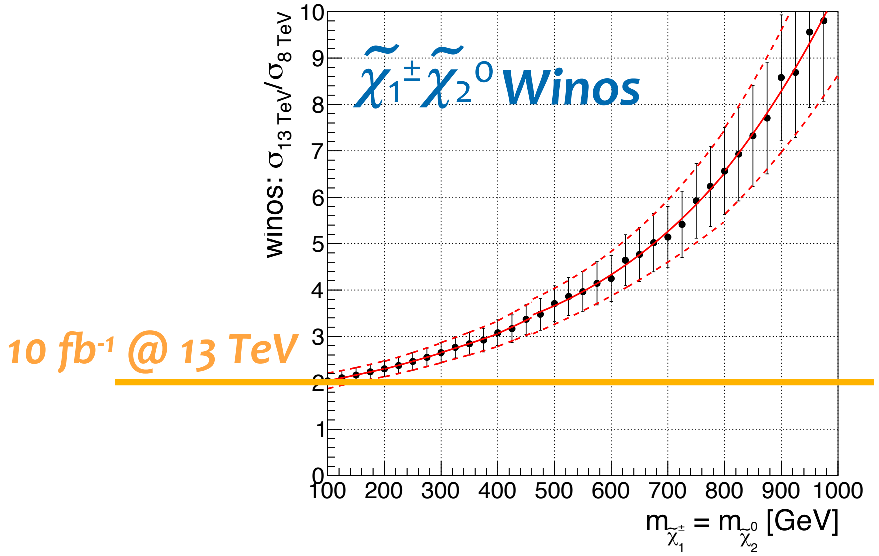
$\tilde{\chi}_1^\pm\ \tilde{\chi}_1^\mp$ Higgsinos LSP- production cross section

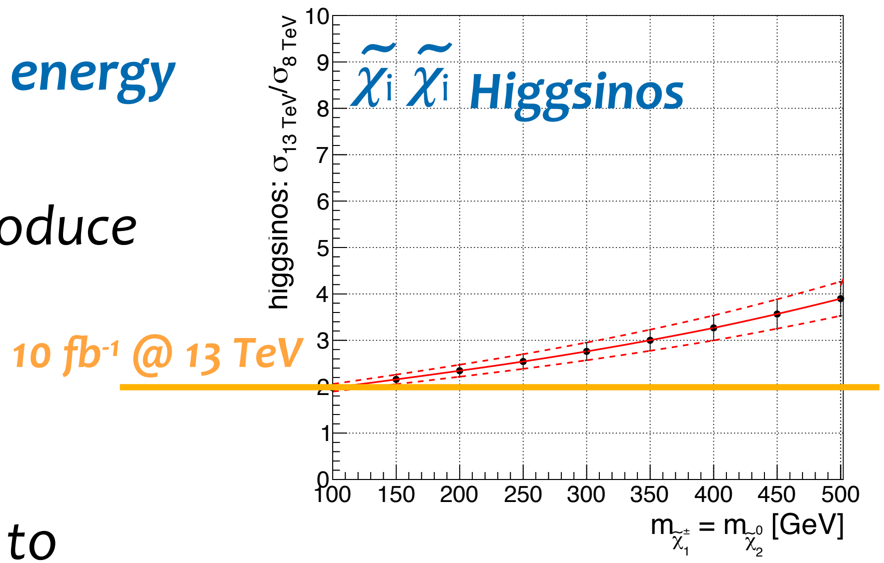


- *charginos excluded up to 100 GeV for all Δm range*
- *Photon ISR and soft decay products used down to Δm~200 MeV, for smaller Δm displaced tracks or HSCP*

From 8 to 13 TeV

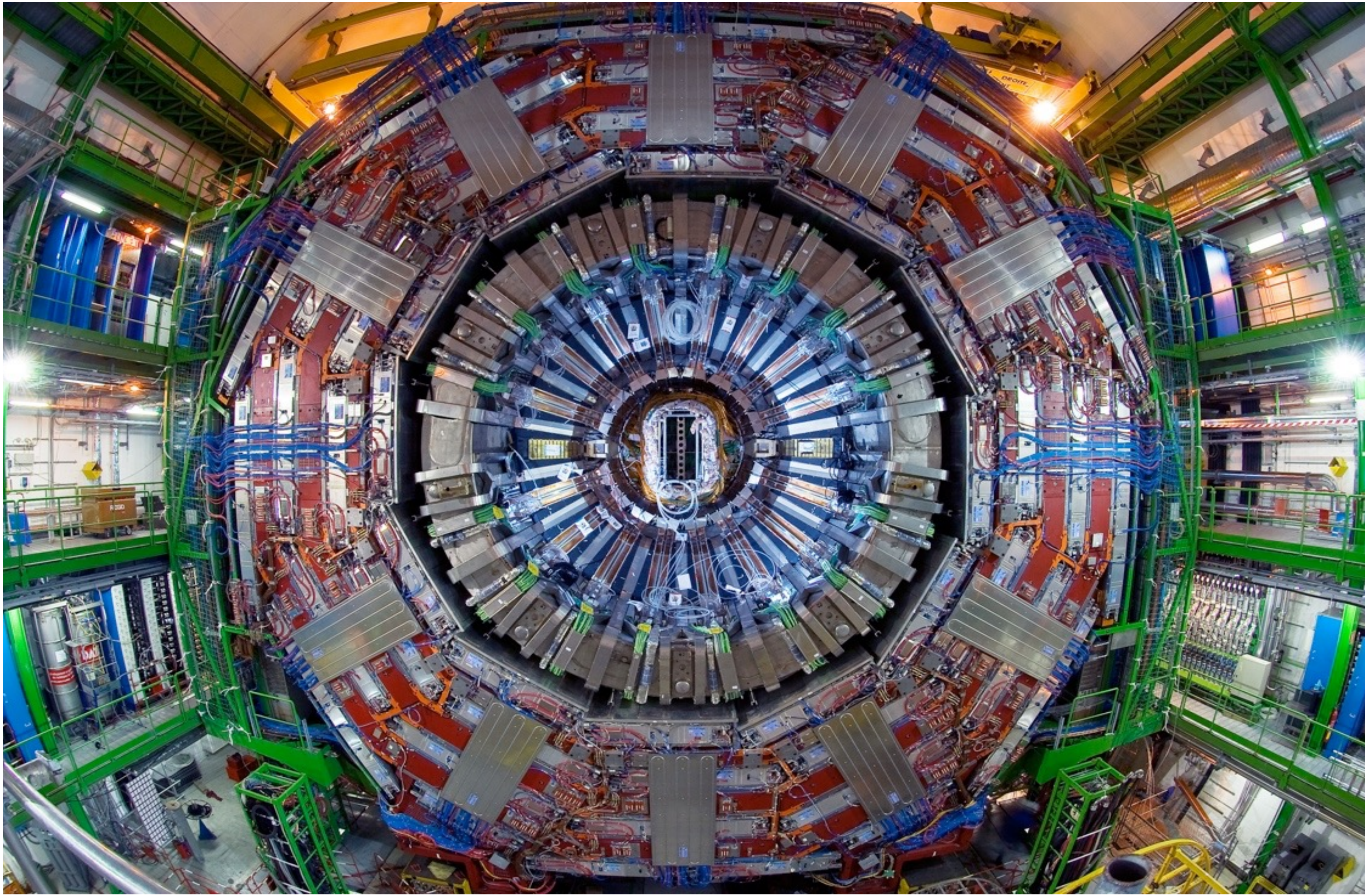




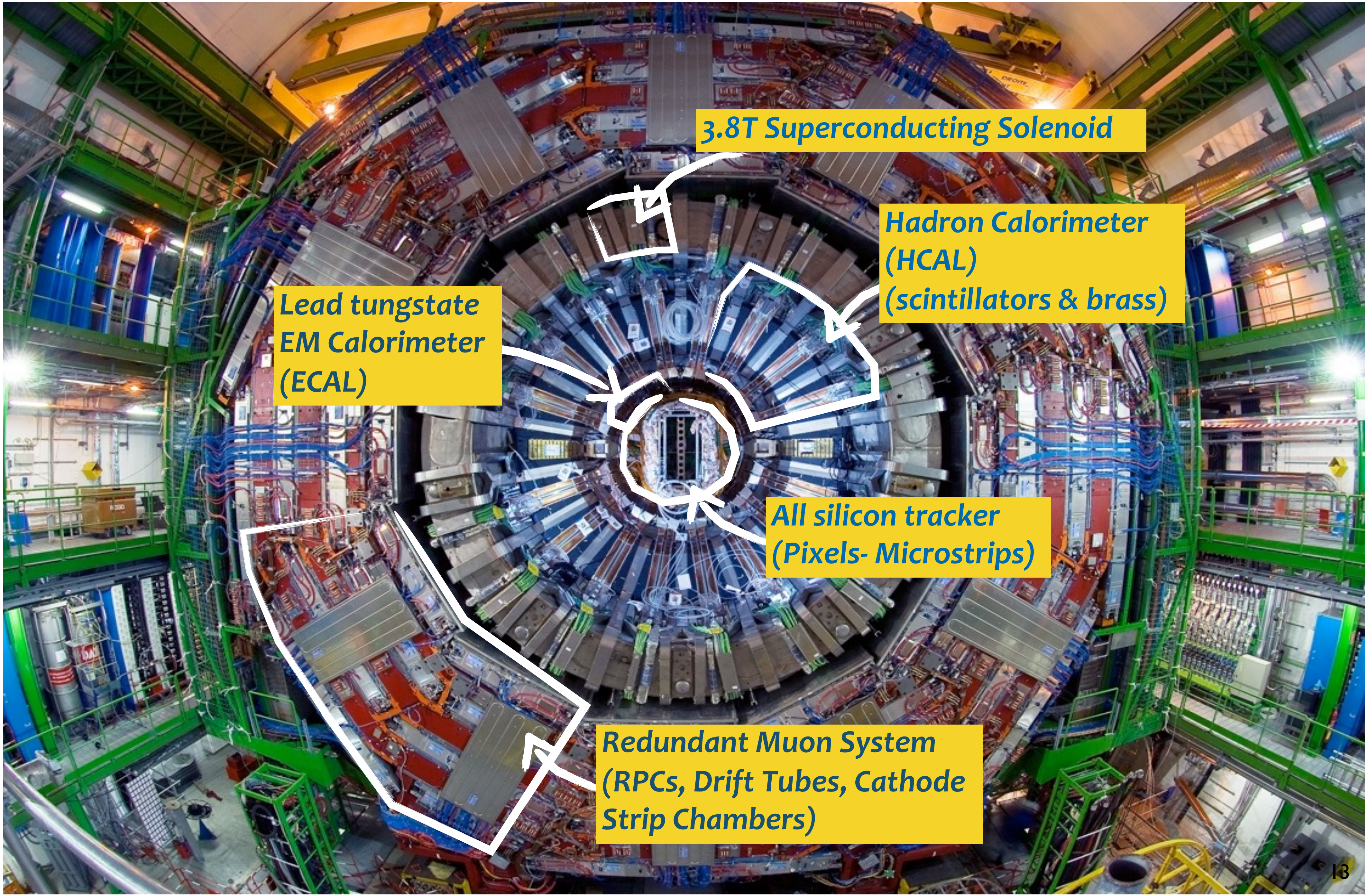


- ***LHC Run II, slower increase of cross section vs energy wrt Strong SUSY production***
  - *Summer 2016, ~10 fb^{-1} are sufficient to reproduce the RunI EWKino program*
- ***Full 2016 dataset: 36 fb^{-1}***
  - *Finally access to new territories, even to light-degenerate-Higgsinos thanks to more luminosity and new ideas!*

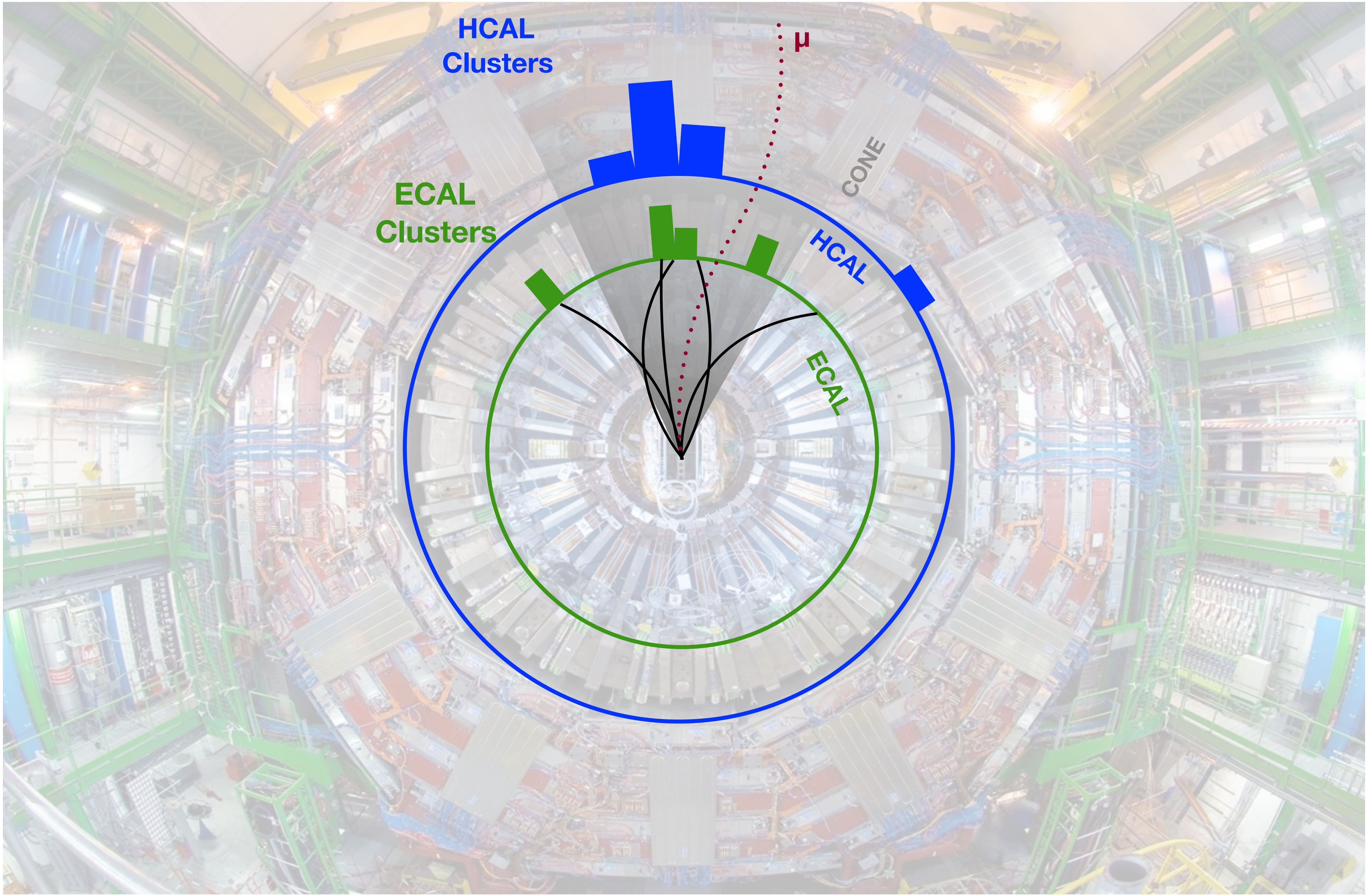
The detector



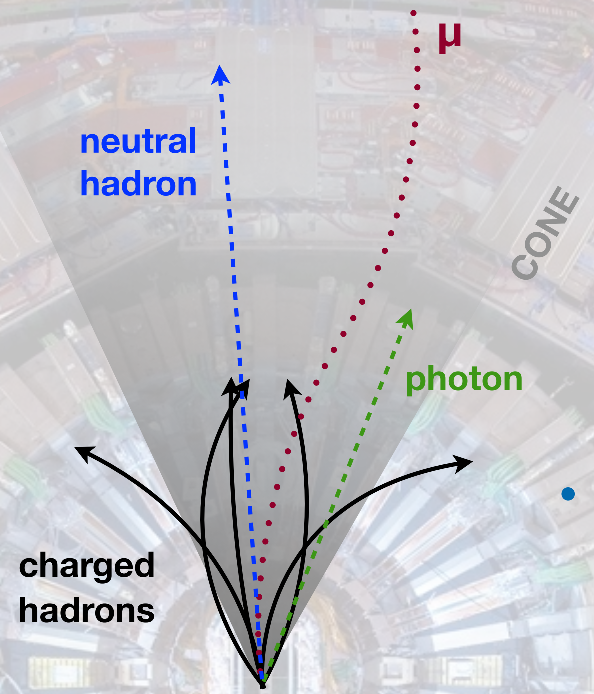
The detector



The reconstruction



The Particle Flow Identification



- Rely on high granularity to identify and reconstruct each ***individual particle, classified into mutually exclusive categories*** ***(charged hadrons, neutral hadrons, photons, muons, electrons)***

- Allows tagging of charged particles from pile-up: ***minimise impact of PU on jet reconstruction, and lepton or photon isolation.***

- ***Jets*** *are reconstructed by clustering PF candidates in the anti-*k_T *algorithm with R=0.4*
- E_T^{miss} *is calculated as the magnitude of the negative vector sum of the transverse momenta of all reconstructed PF candidates.*

Advanced lepton identification techniques

- *All "real" e/μ - prompt from W, Z, τ decays, non-prompt from b hadron decays or decay in flight of light hadrons - are retained by the PF identification*
- *Further* ***identification techniques are used to separate the prompt ("signal") leptons from non-prompt ("background") ones***
- *Rare signal and high lepton multiplicity:* ***highest signal lepton ID efficiency*** *is a must*

  - ***Multivariate approach used to combine several information:***

Standard

ISO

PF Isolation (p_T sum of charged hadrons from PV, neutral hadrons, photons p_T in a cone around the lepton)

- ***MiniIso: p_T dependent cone-size PF Isolation***

IP

- ***$d_{xy\,(PV)}$, $d_{z\,(PV)}$, Significance of $IP_{3D\,(PV)}$***

Innovative

Lep-Jet

Lepton's closest jet (leptons plus soft particles around it)

- ***$p_T(\ell)/p_T(\text{jet})$: « p_T ratio »***
- ***Lepton's p_T^{rel} wrt jet***
- ***jet b-tag discriminator (CSV)***

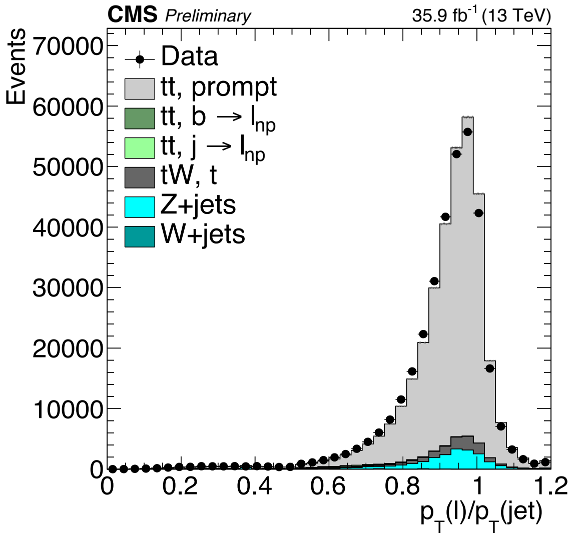
Advanced lepton identification techniques

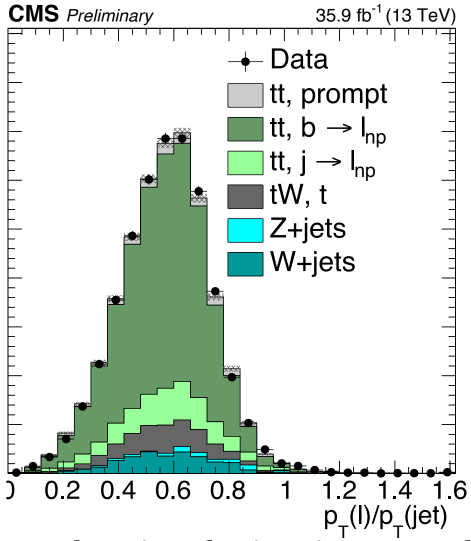
$p_T(\ell)/p_T(jet)$: « p_T ratio »

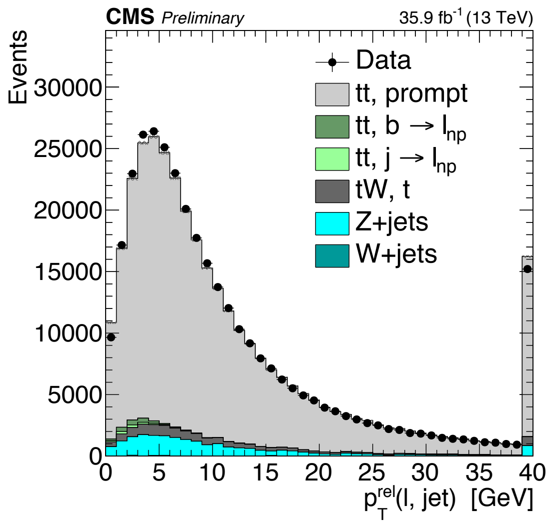
Prompt leptons in ttbar events — *Non prompt leptons in ttbar events*

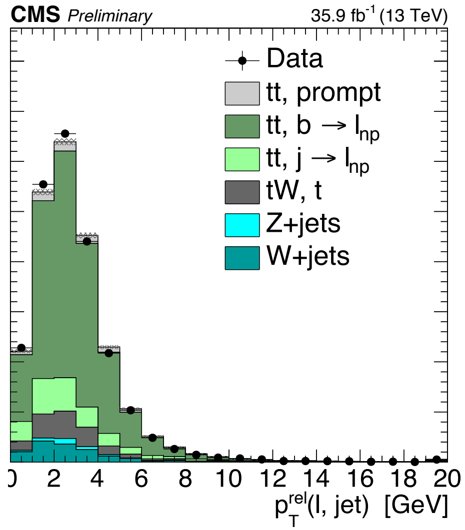
Lepton's p_T^{rel} wrt jet

Prompt leptons in ttbar events — *Non prompt leptons in ttbar events*



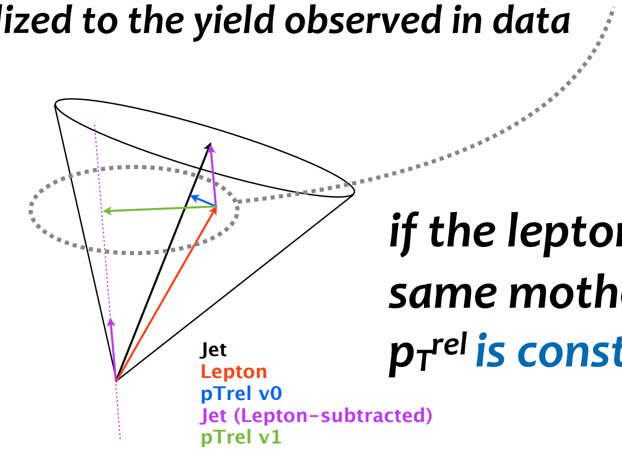






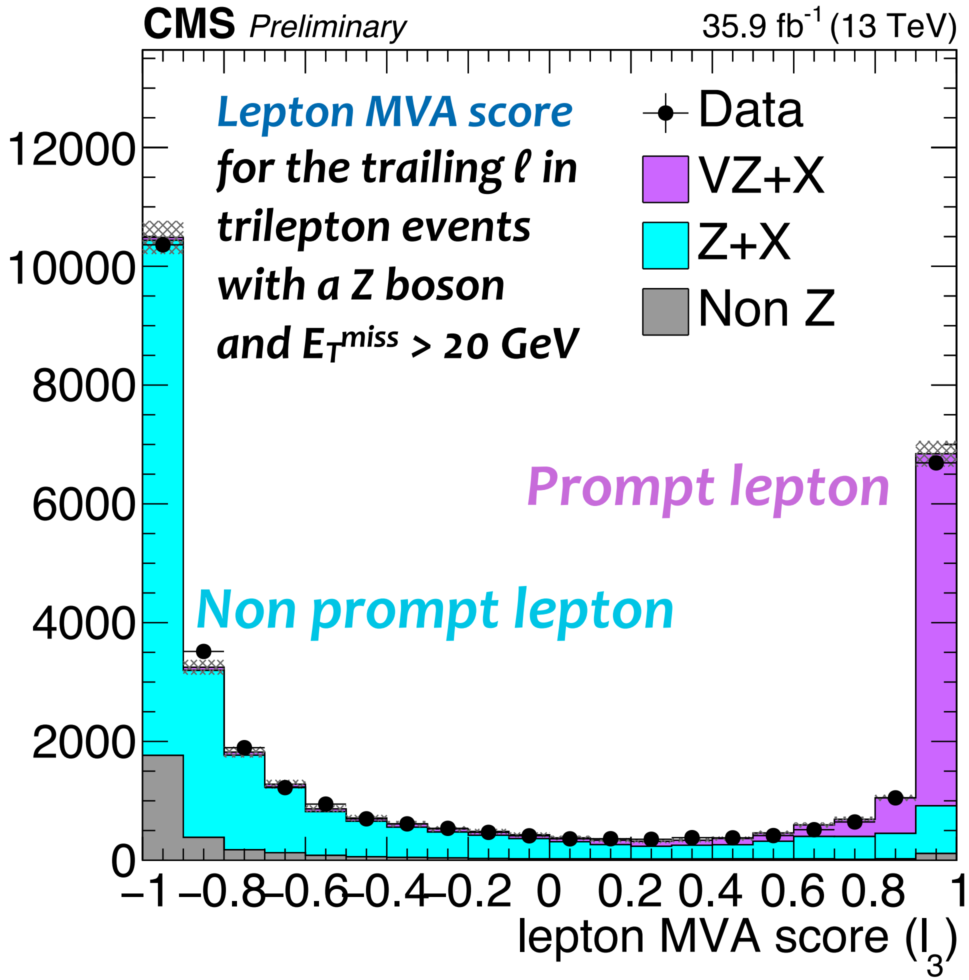
The simulation is normalized to the yield observed in data

Prompt leptons saturate the jet that contains it



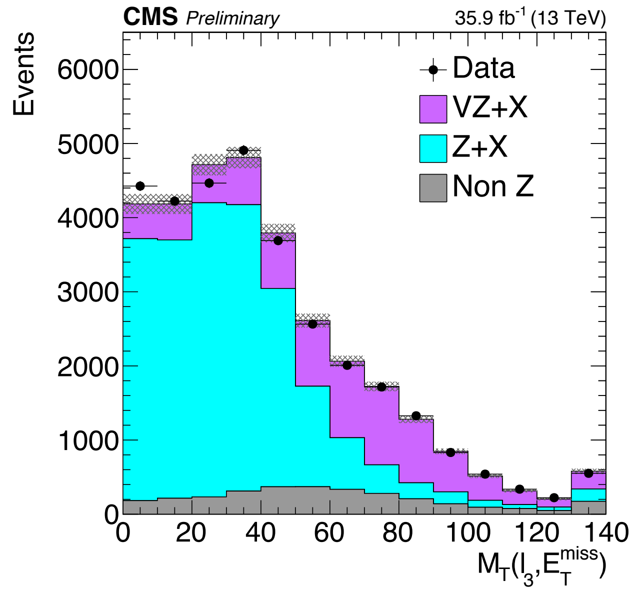
if the lepton comes from the same mother particle as the jet, p_T^{rel} is constrained by its mass

Advanced lepton identification techniques



Lepton ID performed with a cut value on the Lepton MVA score: *~ factor 2 in bkg rejection for the same signal efficiency wrt standard IDs.*

The Z+X and VZ+X predictions are normalized to data by means of a two-component fit of the transverse mass distribution $M_T(\ell_3, E_T^{miss})$

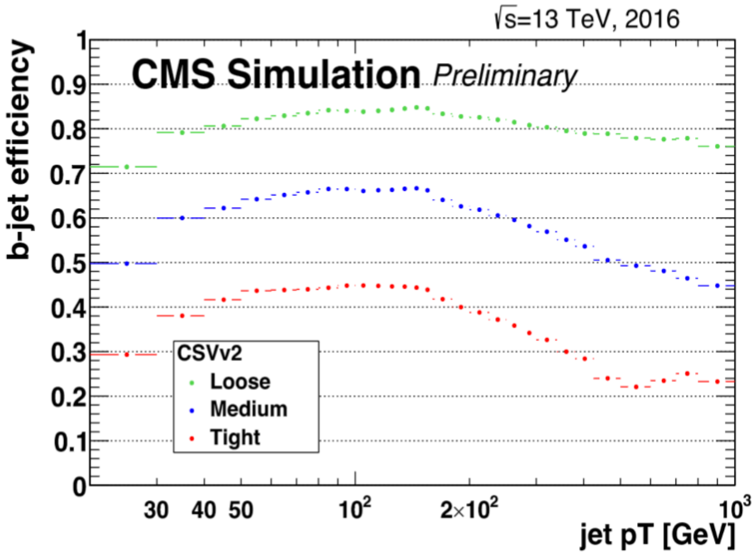


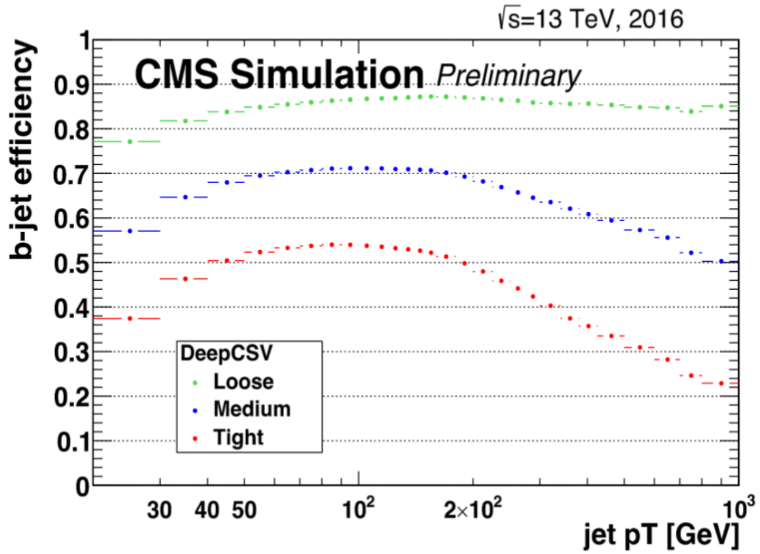
Used in:

- ***2 same-sign, 3ℓ or 4ℓ + E_T^{miss}*** [CMS-PAS-SUS-16-039]

Advanced b-tagging algorithms

- *Rare signal and high b-jets multiplicity (Higgs boson tagging) :* ***highest b-tagging efficiency*** *is a must*
- ***"CSVv2" standard CMS b-tagger****, based on secondary vertex and track based lifetime information combined with a neural network*
  - ***New approach based on Deep Neural Network: DeepCSV*** [CMS DP-2017/005]





Loose 10% mistag

Medium 1% mistag

Tight 0.1% mistag

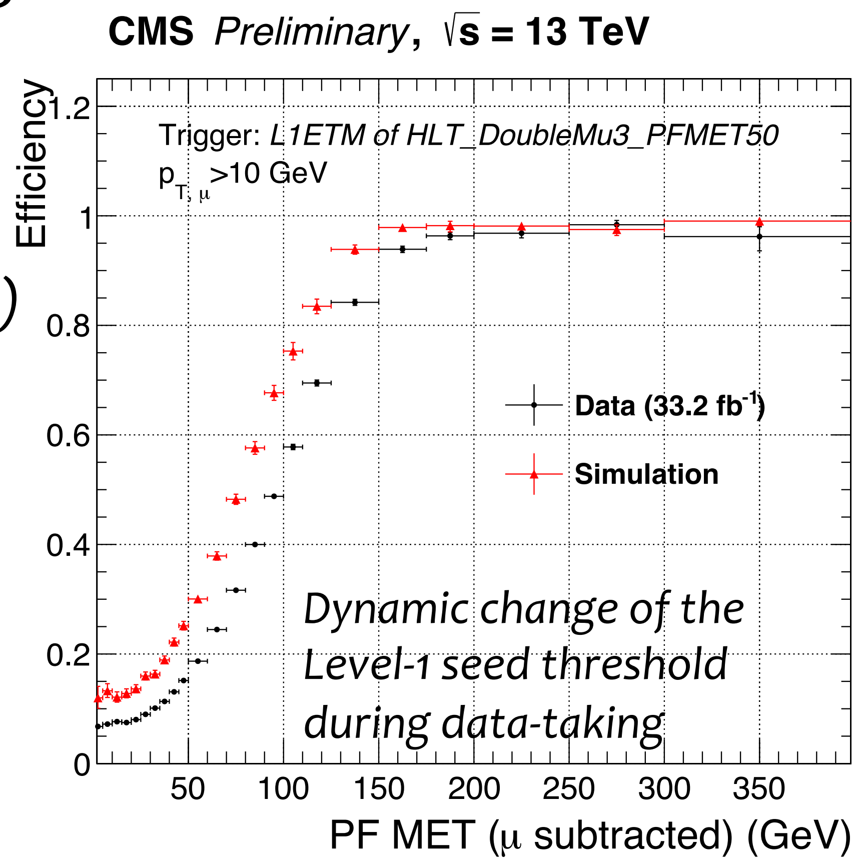
Used in:

- ***h→bb + h→bb*** [CMS-PAS-SUS-16-044]

+20% improvement in efficiency for 0.1% mistag rate !

Non standard trigger design

- *When high p_T leptons are present in the final state (>20 GeV) the analyses can rely on* ***leptonic triggers***
  - *no constraint on E_T^{miss}*
- *Hadronic analyses that target non-compressed regions rely on* ***E_T^{miss} triggers***
  - *impose offline E_T^{miss} > 200 GeV (90% trigger eff.)*
- ***Further development in 2016:***
  - ***Trigger for compressed-spectra that combined soft muons and E_T^{miss} at L1***
  - ***Imposes offline requirement of 2μ p_T > 5 GeV and E_T^{miss} > 125 GeV (80% trigger eff.)***



Used in:

- ***soft opposite-sign ℓ + E_T^{miss}*** [CMS-PAS-SUS-16-048]

CMS-PAS-SUS-16-039

The inclusive multilepton search

Search for direct production of EWKinos in signatures with
two light leptons of the same charge *and with* ***three or more leptons including up to two hadronically decaying τ leptons,***
little hadronic activity *and* ***significant E_T^{miss}***

General strategy

- *To face the small cross-section the analysis is subdivided into* ***several categories:***
  - **2 same-sign $\ell_{(e,\mu)}$ / $3\ell_{(e,\mu)}$ / 3ℓ with 1 or 2 τ_h / > 3ℓ with at max 2 τ_h**
- ***Signal regions: bins in kinematic variables (E_T^{miss} , $M_T(\ell, E_T^{miss})$*, $p_T(\ell\ell)$, $M_{T2}(\ell,\ell)$**)***
  - *discriminate from SM bkg and increase sensitivity to different sparticle mass hierarchies*
- *It uses* ***single/double lepton triggers*** *(offline p_T > 25/20 - 15/10 GeV)*
  - *doesn't cover the quasi-degenerate region of phase space, but it goes down to* **E_T^{miss} 50 GeV**
- Events with ***at least one b-tag jet are rejected***
- ***Main residual backgrounds:***

WZ production

External and internal conversions

Non-prompt leptons (W+Jets, ttbar, DY+Jets)

rare SM processes ZZ/H, VVV or ttV

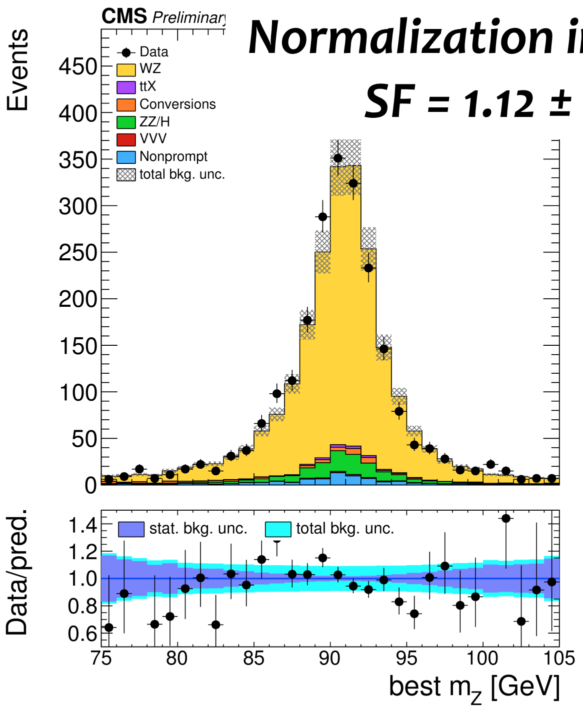
charge mis-identification

* $\left(M_T = \sqrt{2E_T^{\text{miss}} p_T^{\ell} \left(1 - \cos\left(\Delta\phi\right)\right)}\right)$

** $M_{T2}^2 = \min_{\vec{p}_{T1}^{\text{miss}} + \vec{p}_{T2}^{\text{miss}} = \vec{p}_T^{\text{miss}}} \left[\max\left\{M_T^2(\vec{p}_T^{\ell_1}, \vec{p}_{T1}^{\text{miss}}), M_T^2(\vec{p}_T^{\ell_2}, \vec{p}_{T2}^{\text{miss}})\right\}\right]$

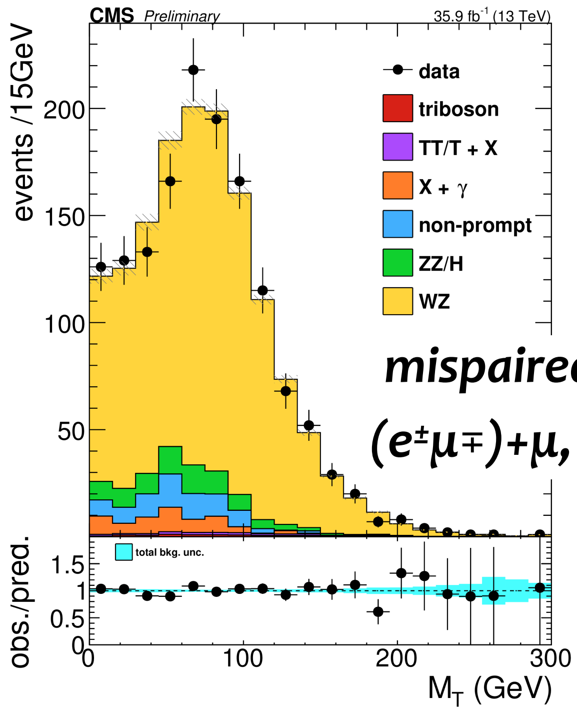
SM Backgrounds: WZ(γ*)

- Dominant bkg in $3\ell_{(e,\mu)}$ with an OSSF pair and 2 same-sign $\ell_{(e,\mu)}$ (lost lepton from γ*)
  - **Normalisation:** Simulation (Powheg) yields corrected from $3\ell_{(e,\mu)}$ control region with low E_T^{miss} and $M_T(\ell_{no\text{-}bestZ}, E_T^{miss})$
  - ***Shapes in tail of kinematic variables: M_T***
    - ***lepton mis-pairing*** *- validate data/simulation in dedicated control region*
    - ***E_T^{miss} resolution*** *- validate data/simulation in Wγ control region (reducing FSR contribution, very similar M_T distribution to WZ)*



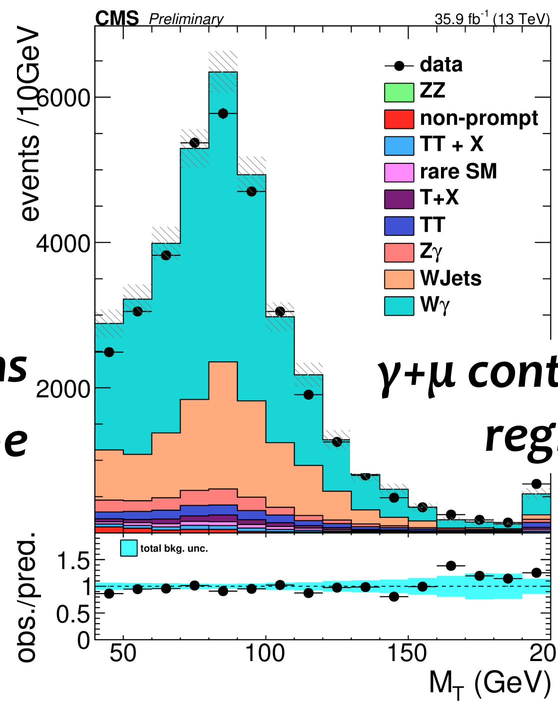
Normalization in CR

SF = 1.12 ± 0.10



mispaired leptons

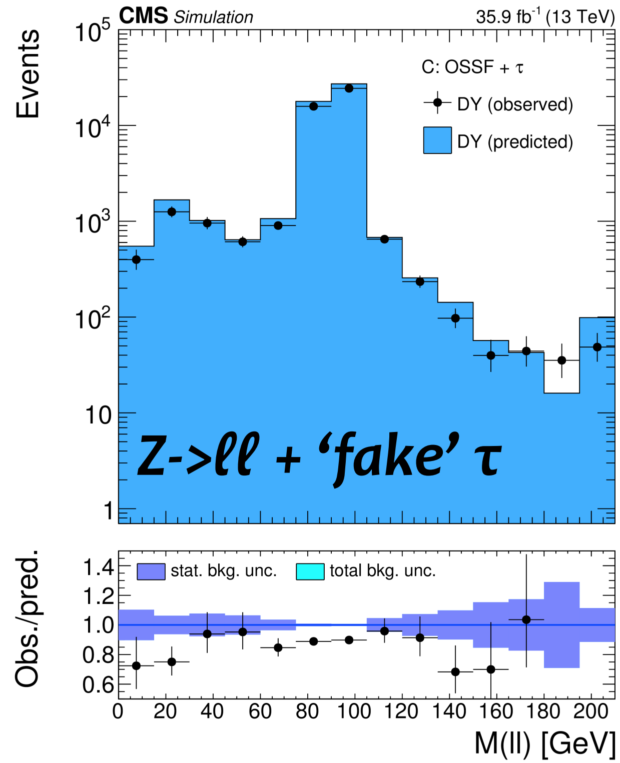
(e±μ∓)+μ, (e±μ∓)+e



γ+μ control region

Non-prompt and charge mis-ID leptons

- **Non-prompt:** *significant bkg in 2 same-sign ℓ(e,μ), 3ℓ$_{(e,\mu)}$ without an OSSF pair and in 3ℓ with τ_h*
  - **sources:** *real lepton in jets (μ,e), jets mis-identification (e, τ)*
  - **processes:** *W+jets, ttbar, DY+jets*
  - ***data driven estimation: "fake-rate" method***
    - *measure in data probability for non prompt lepton to pass lepton ID (fake-rate ratio)*
    - *extrapolate to event yields based on the number of lepton failing the tight selection*
    - *closure within 30%*

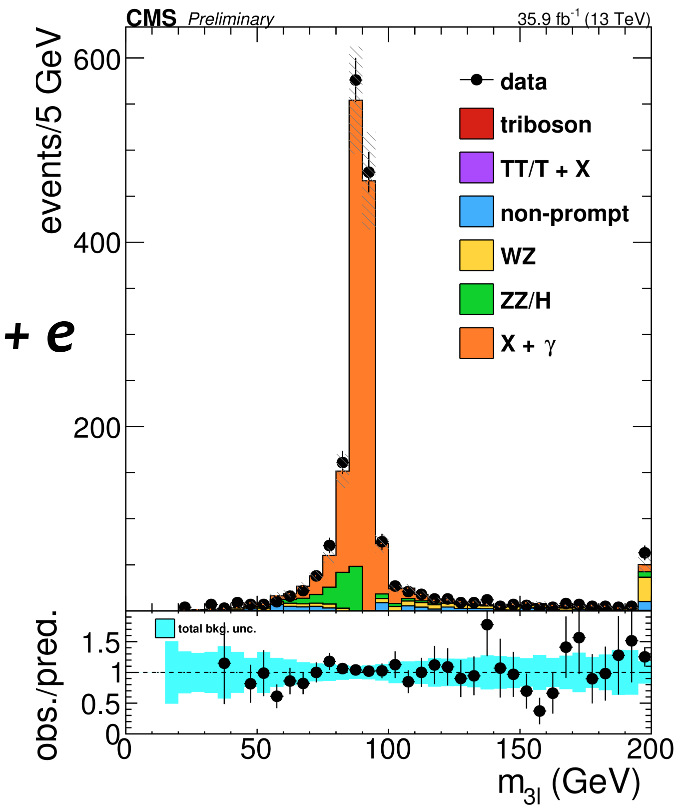


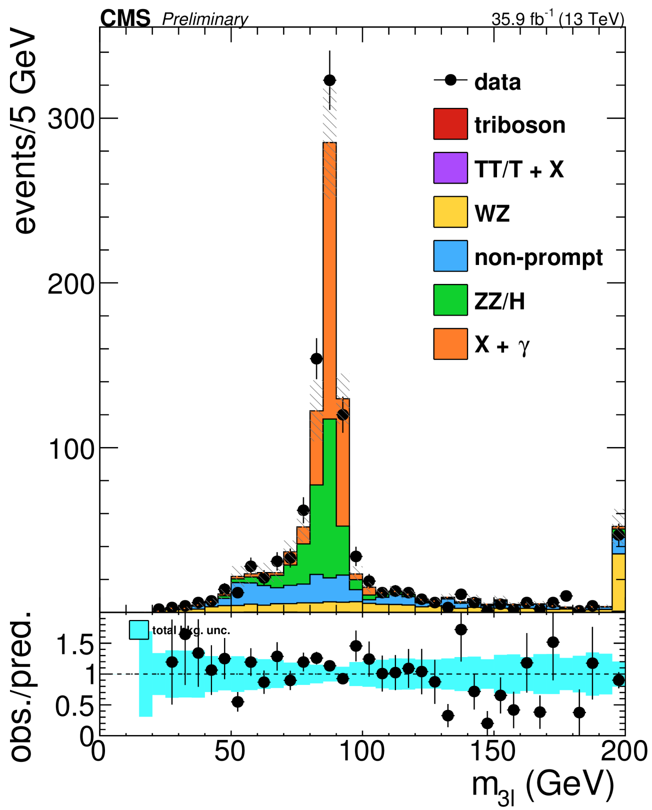
- **Charge-misID:** *significant in 2 same-sign ℓ$_{(e,\mu)}$*
  - **source:** *DY/tt events with one electron charge mis-measured*
  - ***data driven estimation:*** *reweighing OS lepton pairs events by charge mis-ID prob.*
    - *from simulated ttbar events and from Z->$e^{\pm}e^{\pm}$ control region in data (10^{-5}-10^{-3})*
    - *closure within 20%*

Internal and external conversions

- *Significant bkg in 3ℓ with OSSF pair, 2 same-sign ℓ$_{(e,\mu)}$*
  - ***Source:*** *DY/W+γ (FSR, ISR), with γ undergoing **external (ee) or internal (ee, μμ) asymmetric conversion***
  - ***Validation in control region** (scale factor derived)*
    - *target: Z-> ℓℓ + γ*->ℓℓ$_{\text{(with one lost lepton)}}$*
    - *|M(ℓℓ$_{bestZ}$) - MZ| > 15 GeV, low E_T^{miss}*

Z-> ℓℓ + e

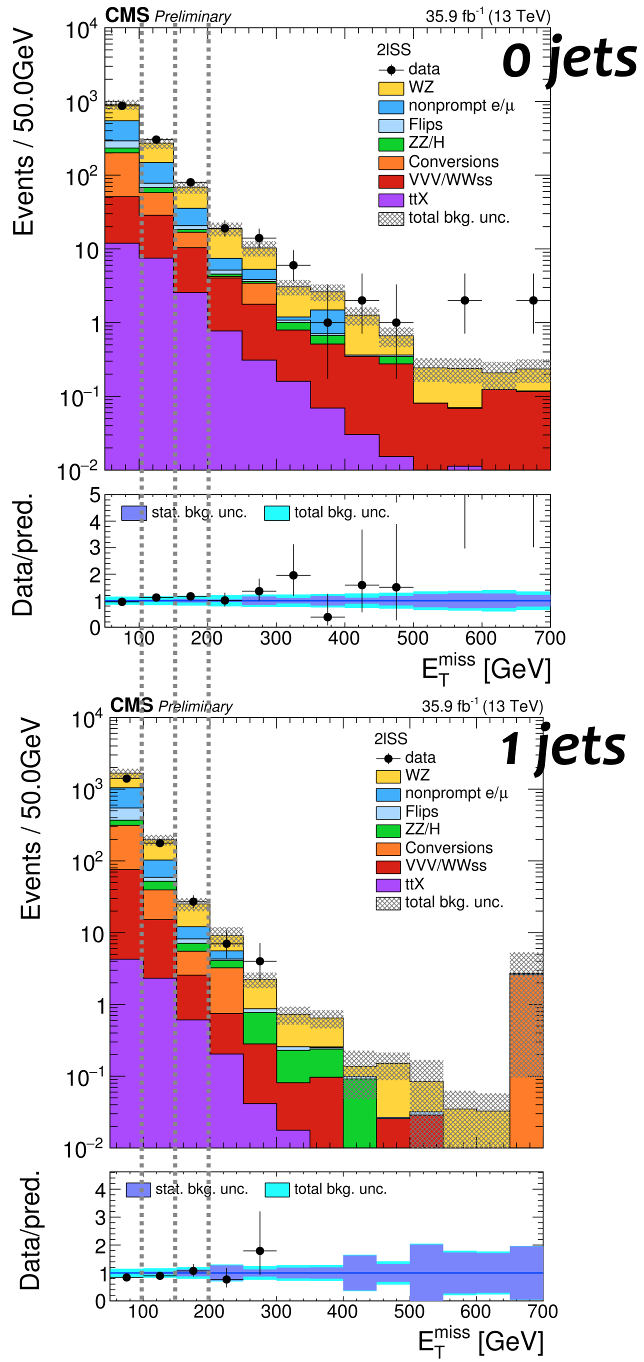




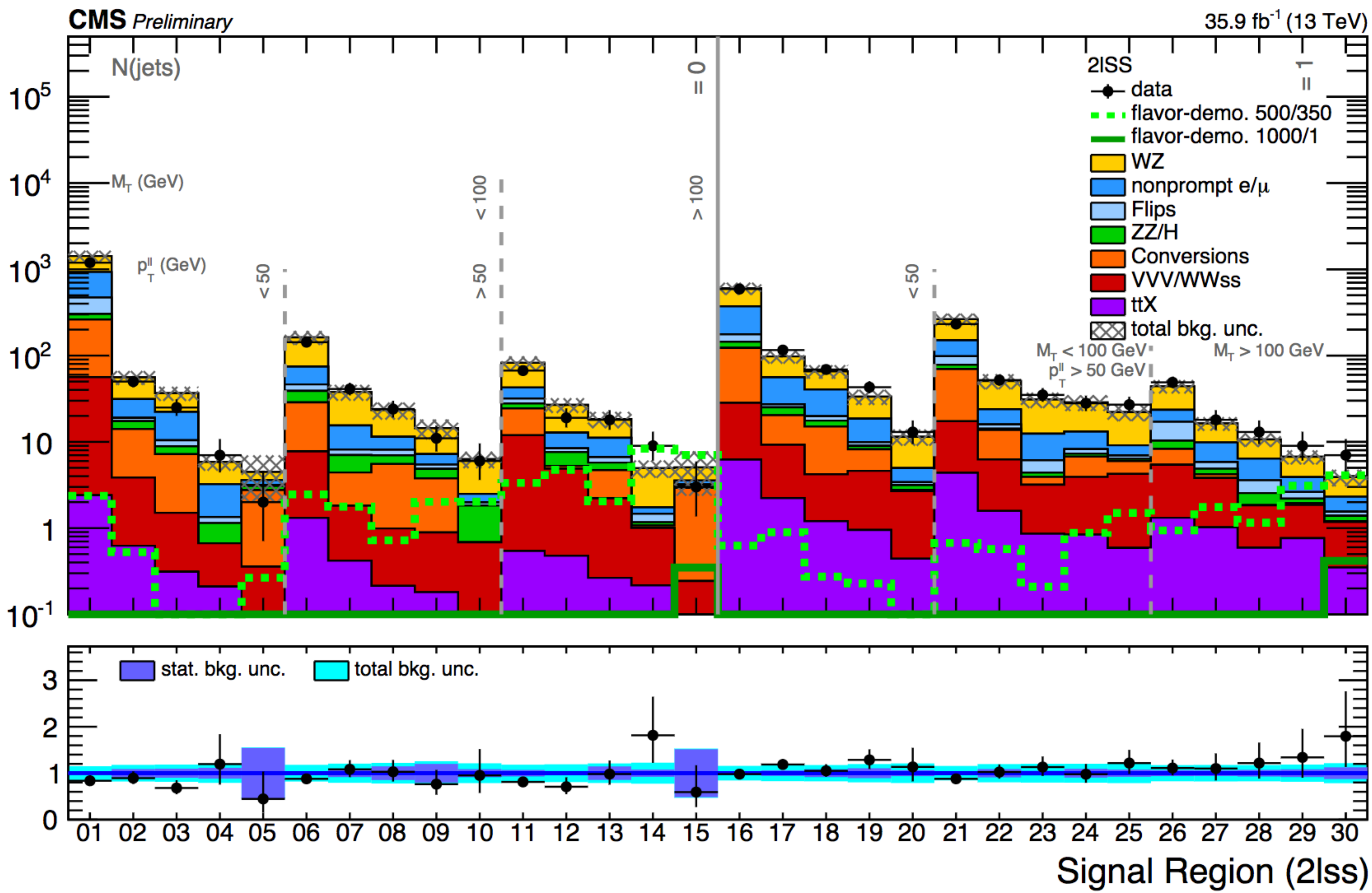
Z-> ℓℓ + μ

Two same-sign light leptons

- *Electrons(muons) with **p_T > 25 (20) - 15 (10) GeV***
- *Events rejected if they contain an OSSF pair with a third ('loose') lepton in the Z window or below 12 GeV (against WZ and low-mass resonances)*
- ***Bin in: 0 or 1 Jet (p_T > 40 GeV)***
  - ***ISR category** to enhance coverage in more compressed regions*
- ***Further binning in:***
  - ***E_T^{miss} :** main discriminating variable against SM bkg*
  - ***$M_T^{min}(\ell_i, E_T^{miss})$:** separate W+jets bkg*
  - ***$p_T(\ell\ell)$:** increase sensitivity to more compressed signal*
  - ***++ / - - :** further separate bkg with charge asymmetry*

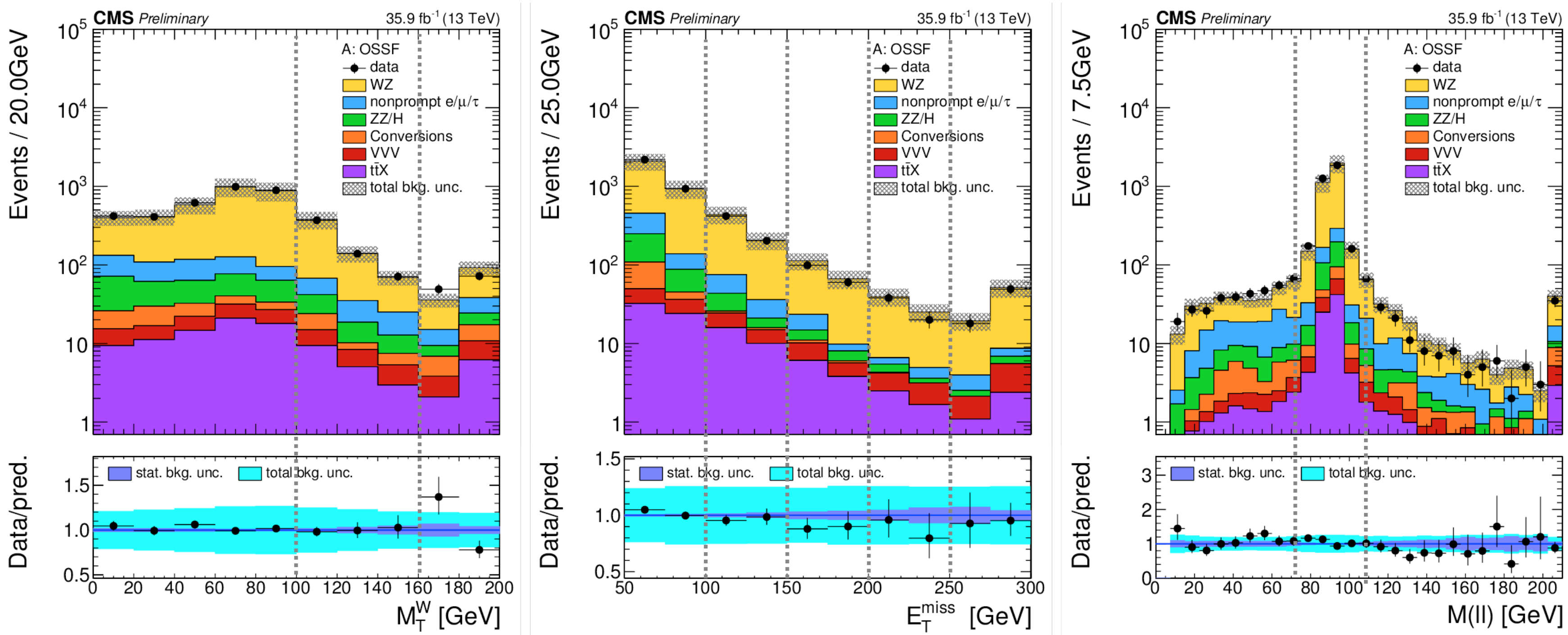


Two same-sign leptons: results



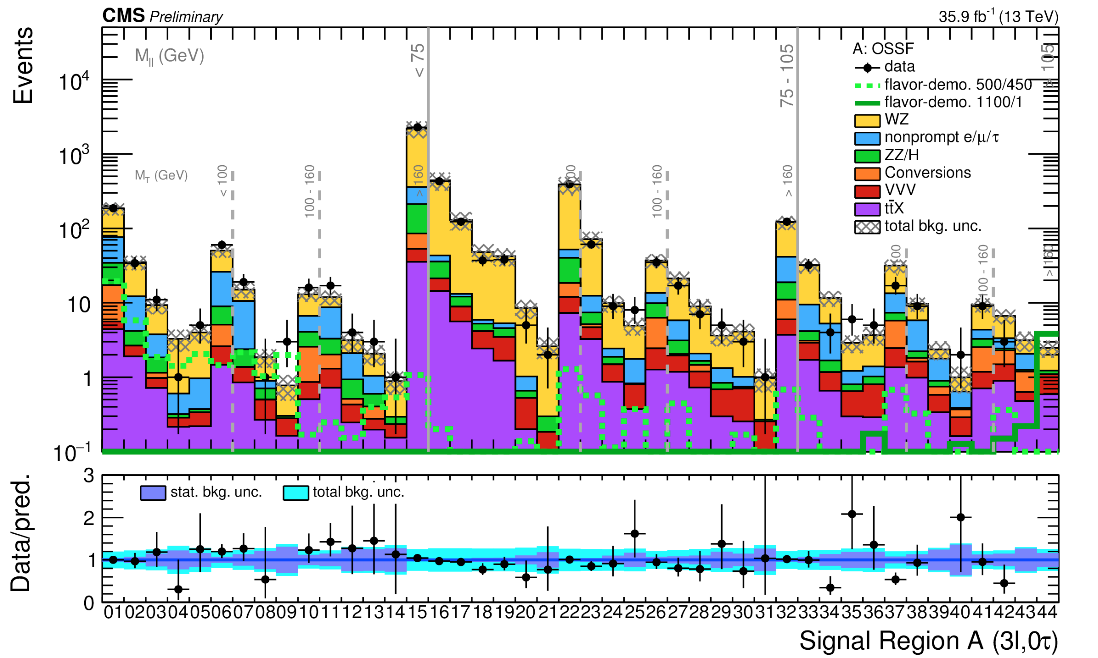
Three light leptons

- *Electrons(muons) with* ***p_T > 25 (20), 15 (10), 10 (10) GeV***
- *If an OSSF pair is present, $m_{3\ell}$ - m_Z > 15 GeV (to reject asymmetric γ-conversions)*
- ***Further binning in:***
  - ***E_T^{miss} :*** *main discriminating variable with respect to SM bkg*
  - ***m(ℓℓ - OSSF pair closest to Z):*** *separate SM bkg with or without a Z boson involved*
    - *if no OSSF pair, mainly* ***Z->ττ decay****, m(ℓℓ) computed with OS pair closest to m_Z (~50 GeV)*
  - ***$M_T(\ell_{no\text{-}bestZ}, E_T^{miss})$:*** *separate processes with leptonic W*

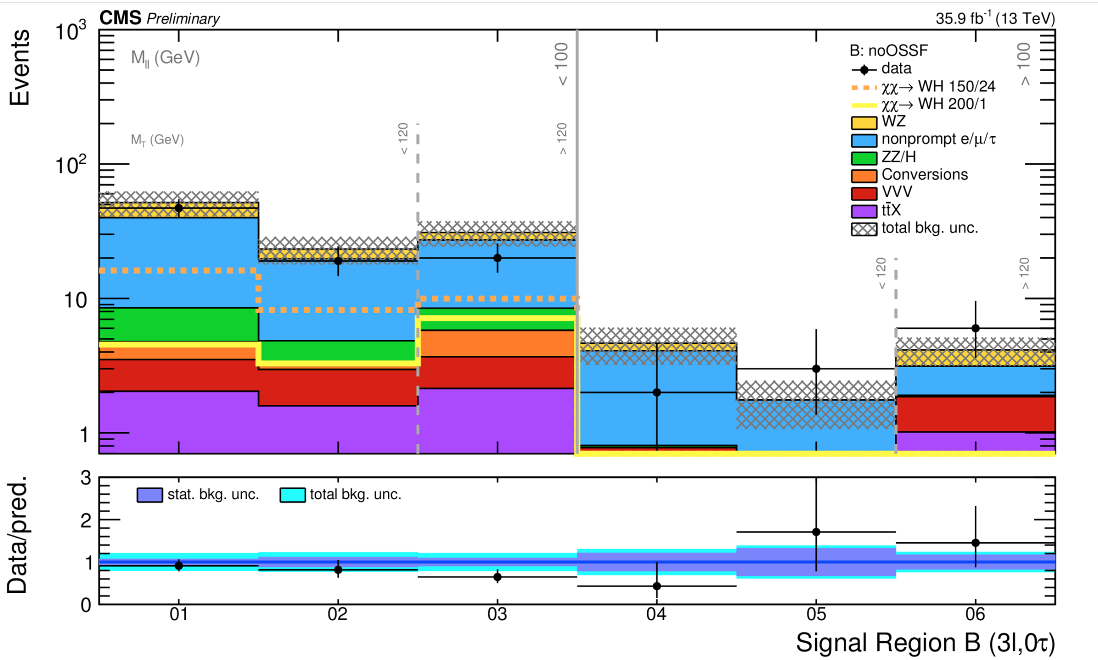


events with OSSF pair

Three light leptons: results



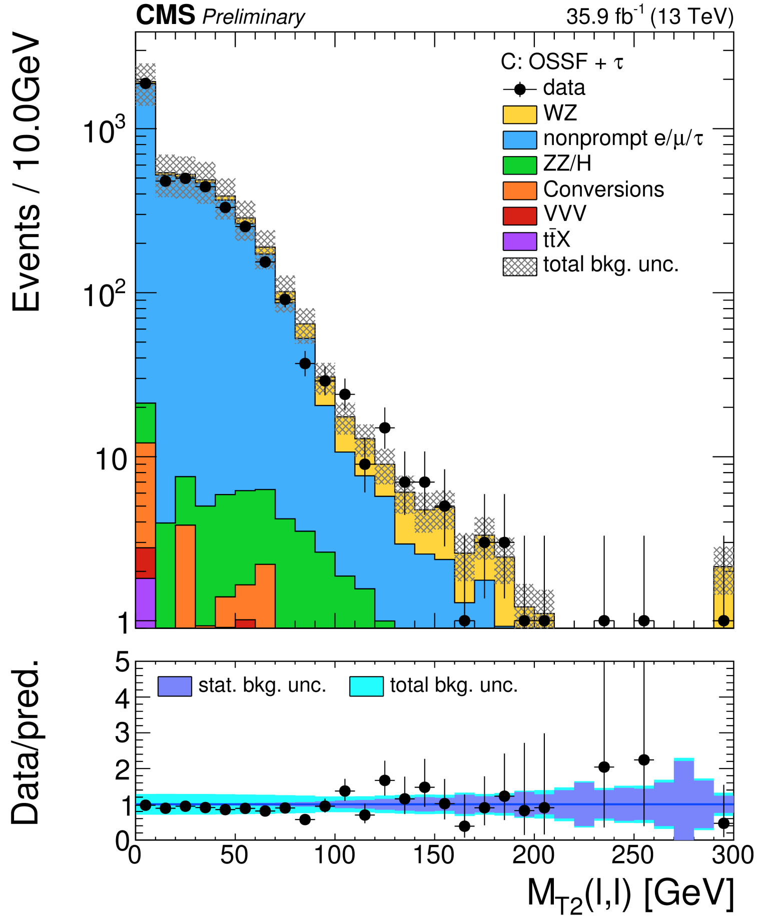
events with OSSF pair



events without OSSF pair

Three leptons with 1 or 2 τ_h

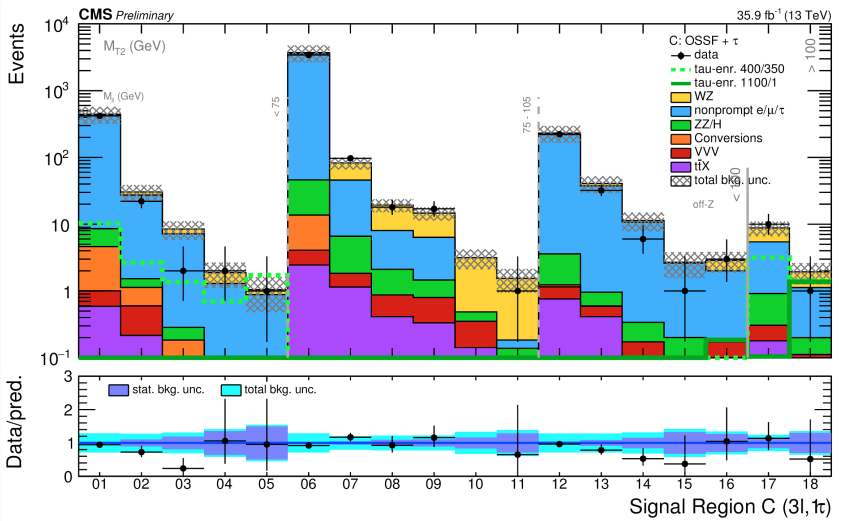
- *Single and double lepton trigger, i.e. leading light ℓ - e(μ)* ***p_T > 30(25) GeV***
- ***τ_h p_T > 20 GeV***
- ***Further binning in:***
  - ***E_T^{miss} :*** *main discriminating variable with respect to SM bkg*
  - ***M_{T2}(OS light leptons, or leading lepton and τ_h, or leading τ_h and a light lepton):*** *reduction of ttbar bkg*
  - ***m(ℓℓ):*** *separate SM bkg with or without a Z boson involved*
    - *light lepton OSSF pair or*
    - *OS pair closest to the m(Z->ττ)*
  - ***light leptons forming SS or OS pair:*** *different SM bkg*
  - ***N taus***



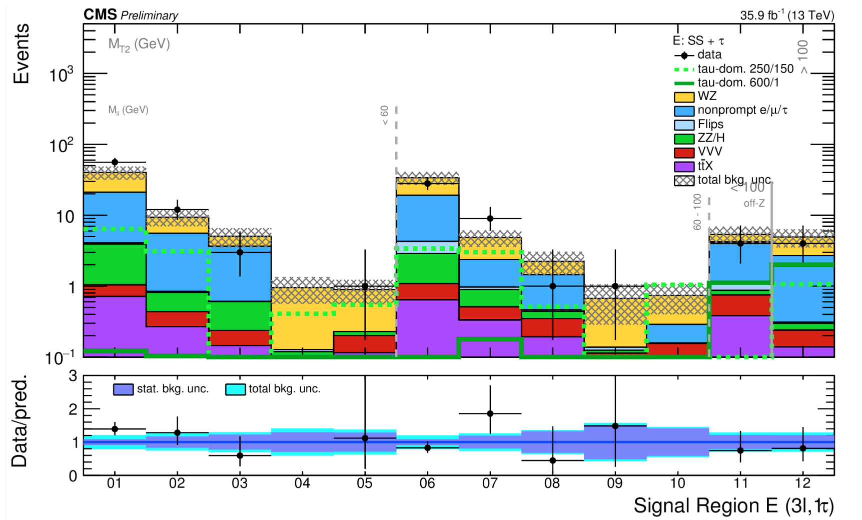
events with OSSF light lepton pair

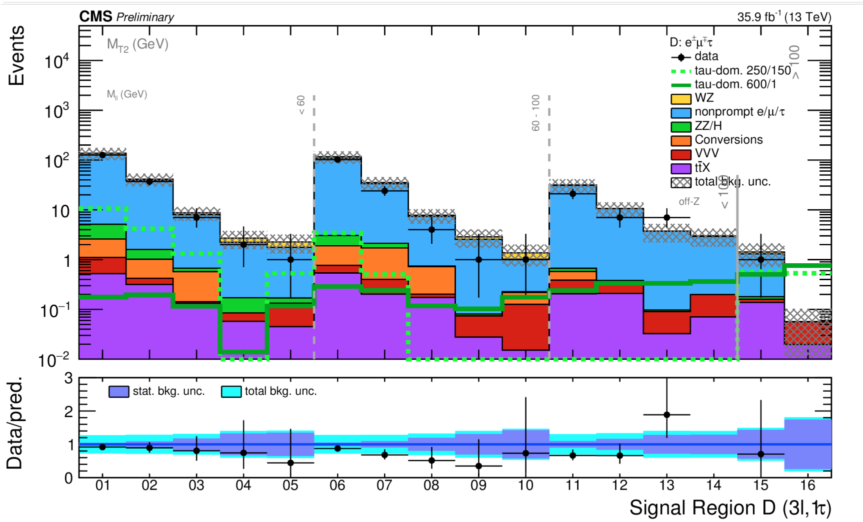
Three leptons with 1 or 2 τ_h: results

events with OSSF light lepton pair

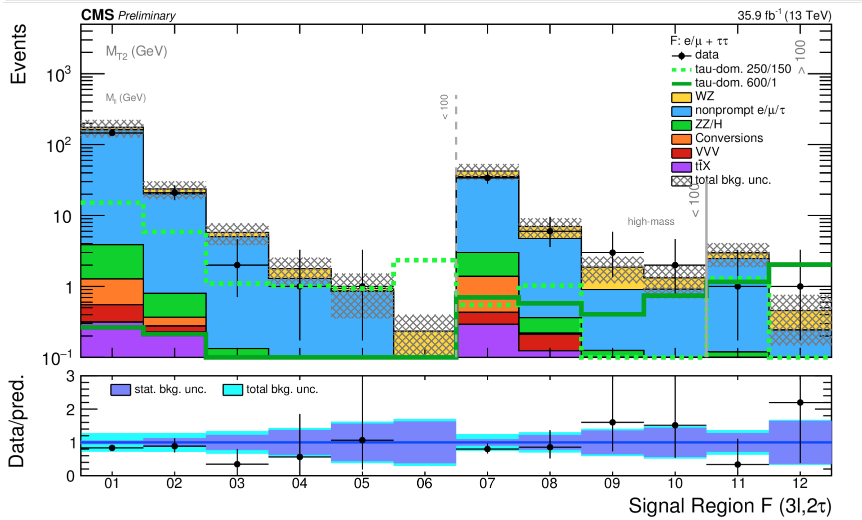


events with SS light lepton pair





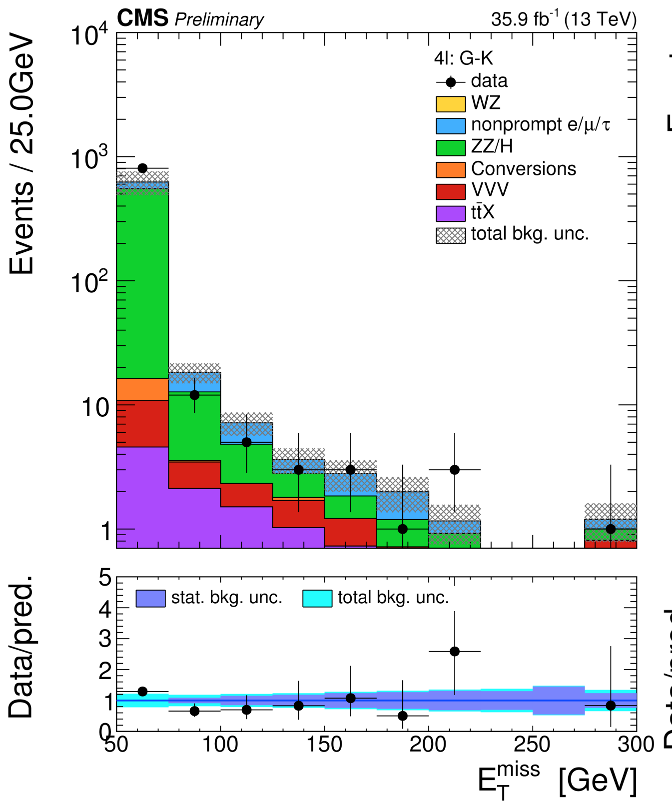
events with OSOF light lepton pair

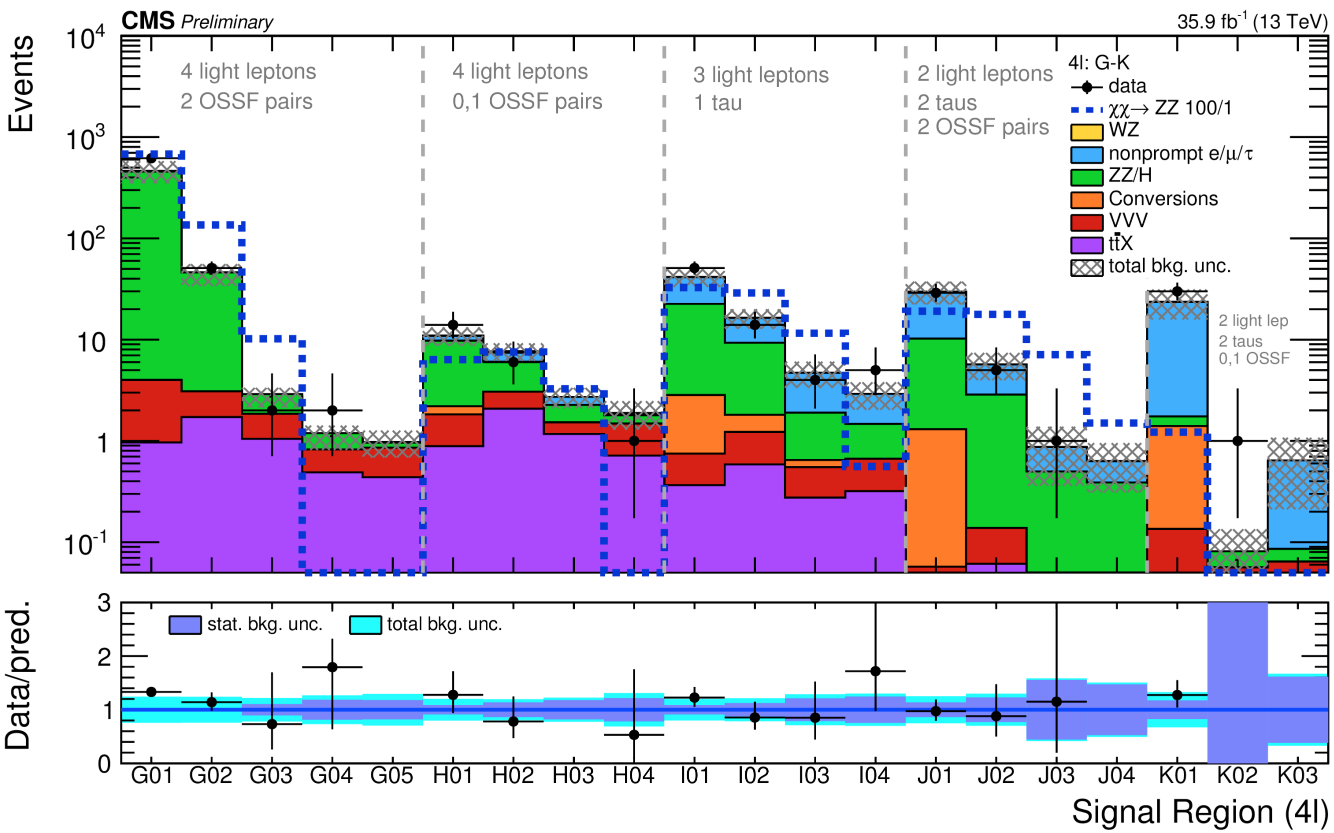


events with two τ_h

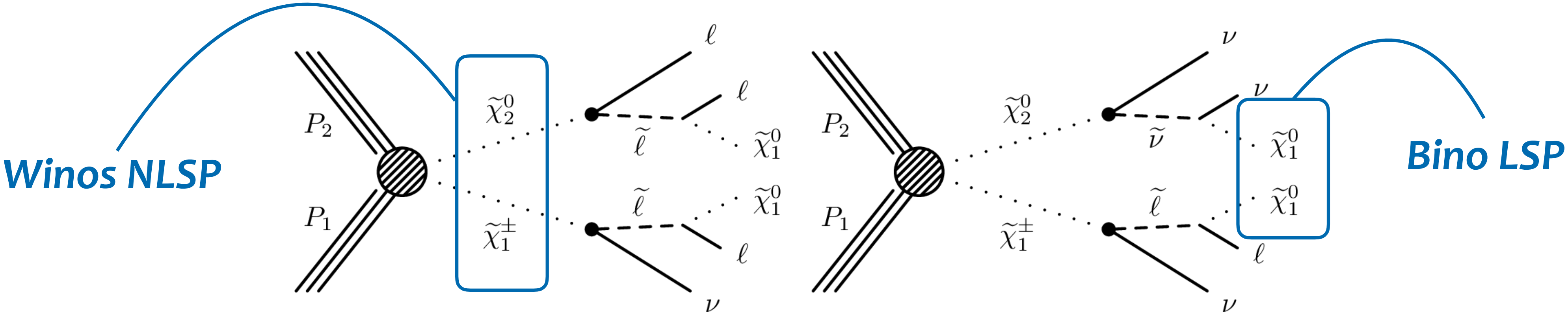
At least four leptons

- *Electrons(muons) with* ***p_T > 25 (20), 15 (10), 10 (10) GeV***
- *Low SM bkg, much lower signal rate: fewer SR binning*
- ***Further binning in:***
  - ***E_T^{miss} :*** *main discriminating variable with respect to SM bkg*
  - ***ntaus, nOSSF pairs:*** *to separate the presence of Z in the decay chain*

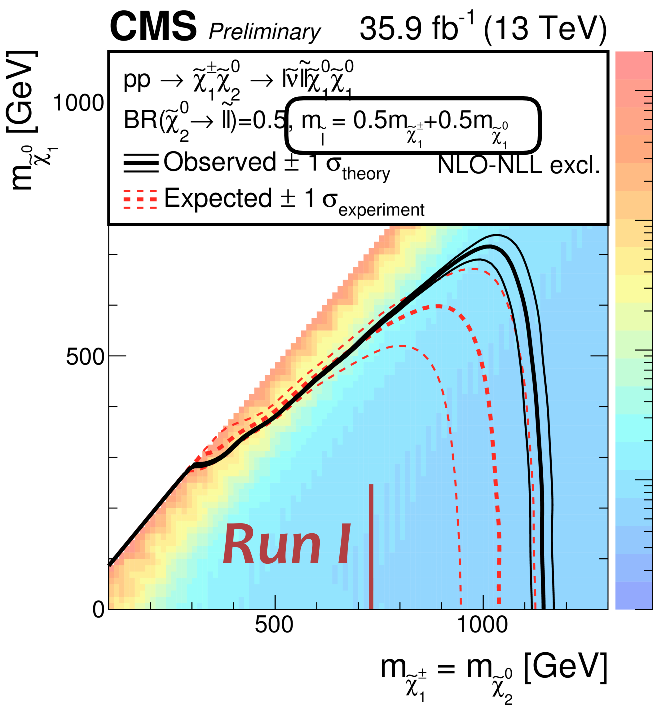




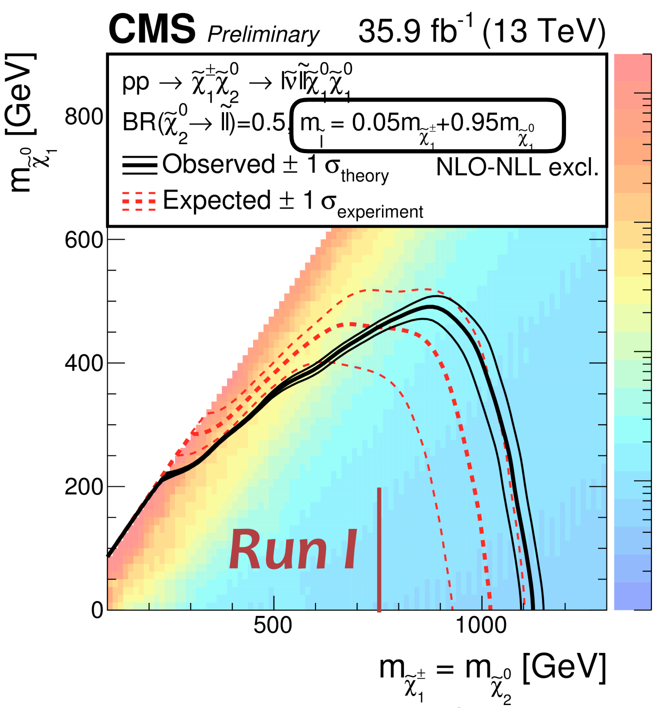
Winos, light sleptons



Flavour democratic scenario

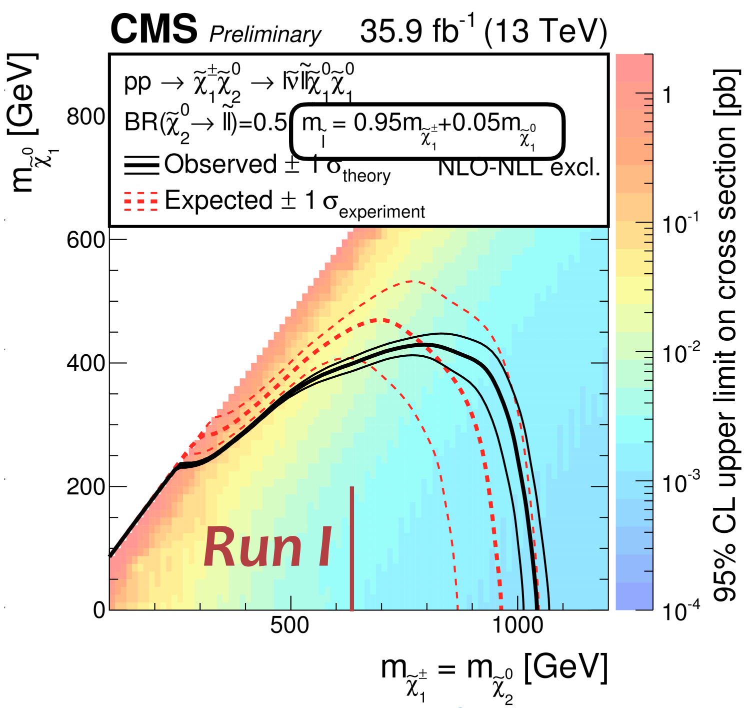


3ℓ(e,μ) with OSSF pair



2 same-sign ℓ(e,μ)

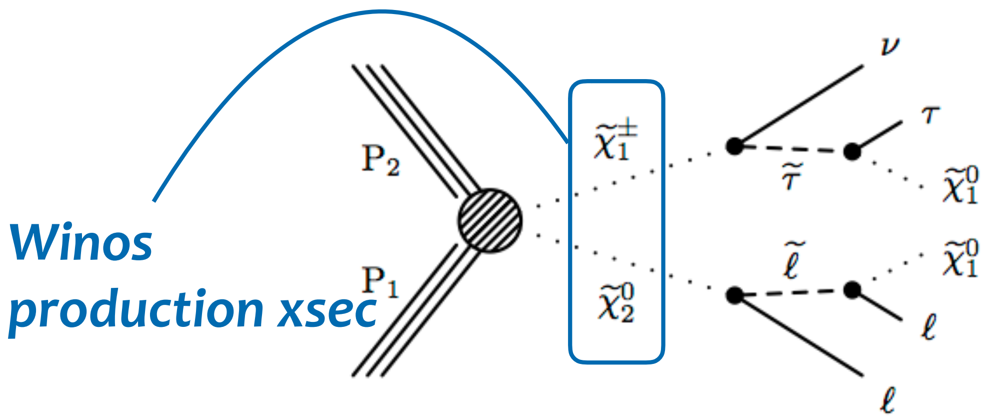
3ℓ(e,μ) with OSSF pair

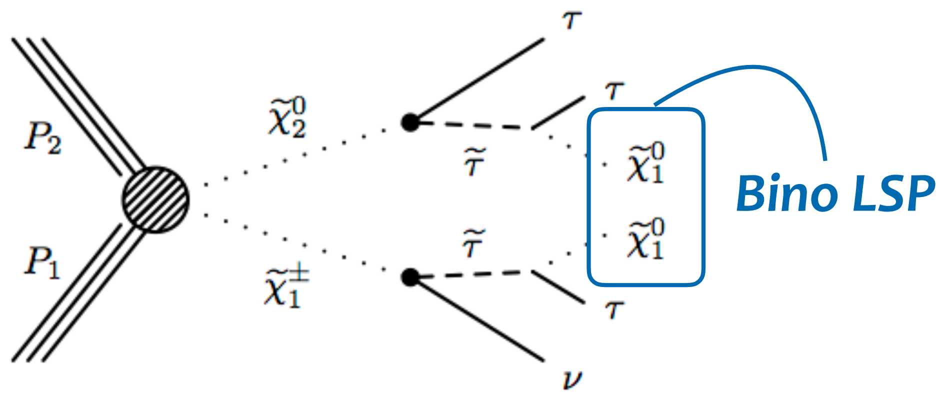


2 same-sign ℓ(e,μ)

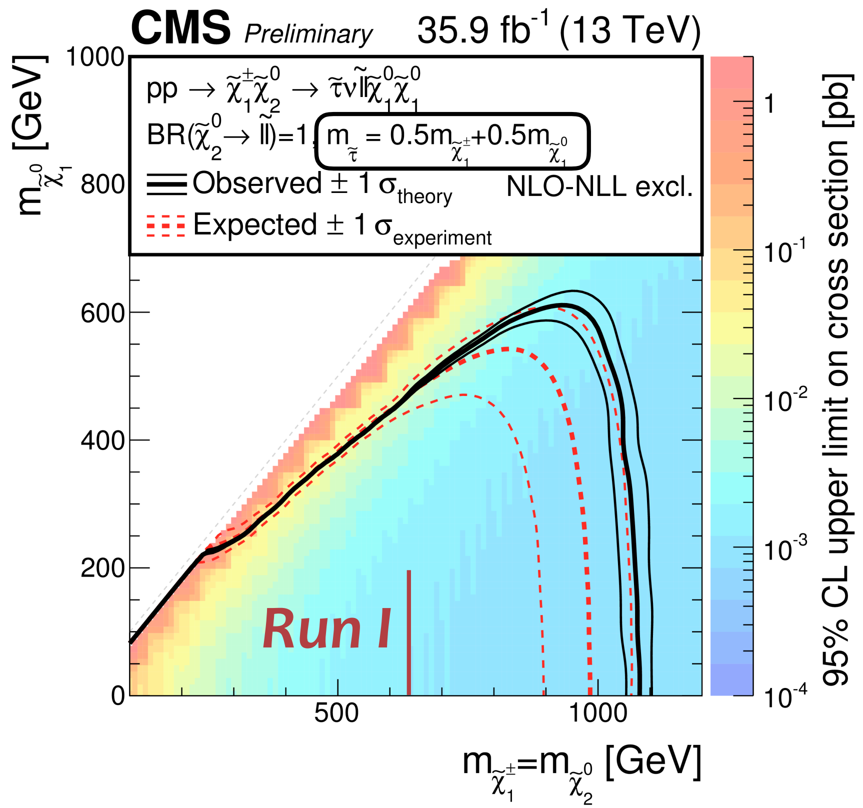
3ℓ(e,μ) with OSSF pair

Winos, light sleptons



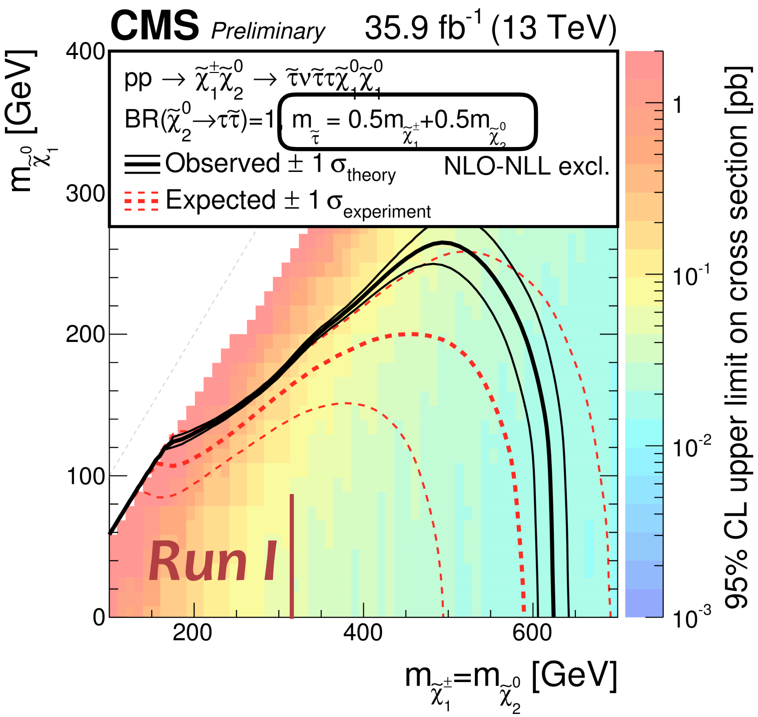


τ enriched scenario



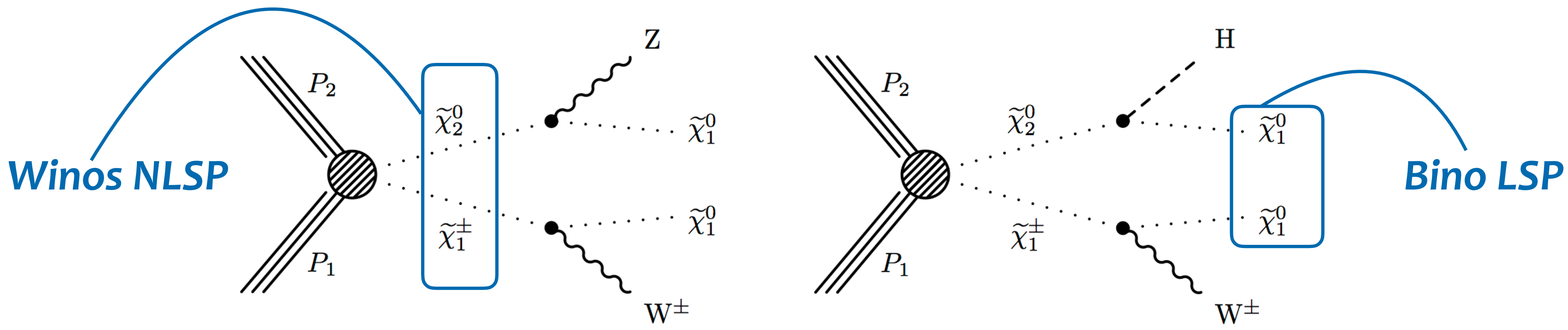
$3\ell_{(e,\mu)}$, 3ℓ with 1 τ_h with OSSF $\ell_{(e,\mu)}$ pair

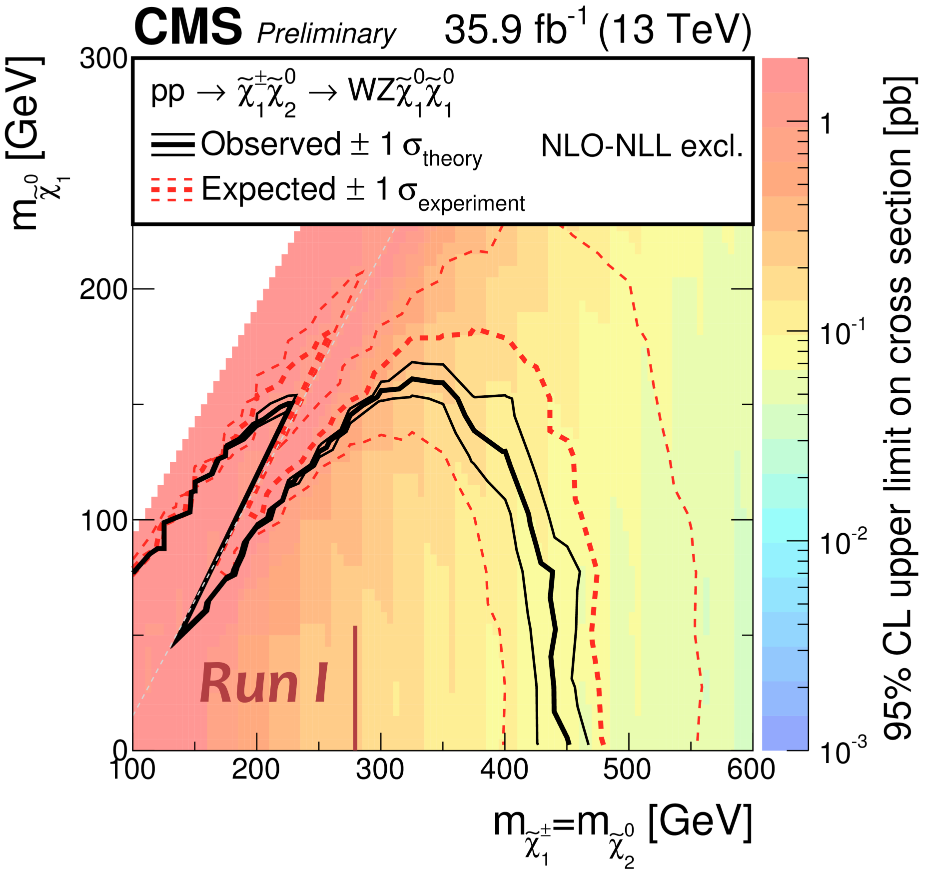
τ dominated scenario



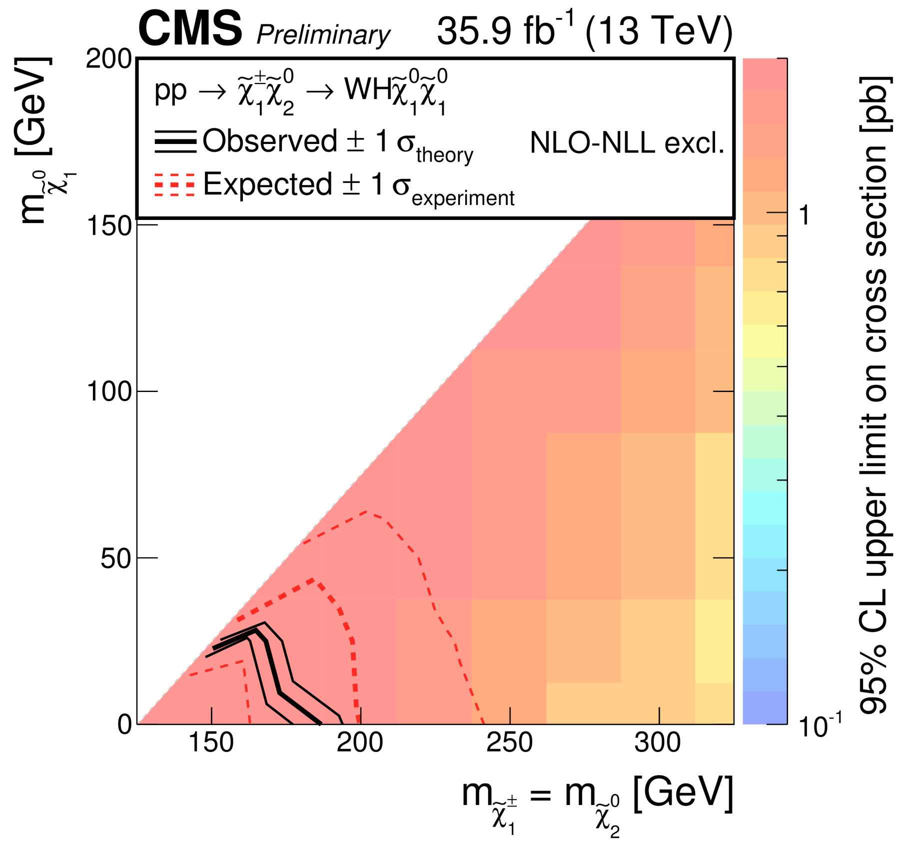
$3\ell_{(e,\mu)}$ without OSSF pair,
3ℓ with 1 τ_h, 3ℓ with 2 τ_h

Winos, heavy sleptons





$3\ell_{(e,\mu)}$ with OSSF pair



all final states

Other signatures to extend the search

Analysis details in public documents:

CMS-PAS-SUS-16-034

$Z \rightarrow \ell\ell + V \rightarrow jj + E_T^{miss}$

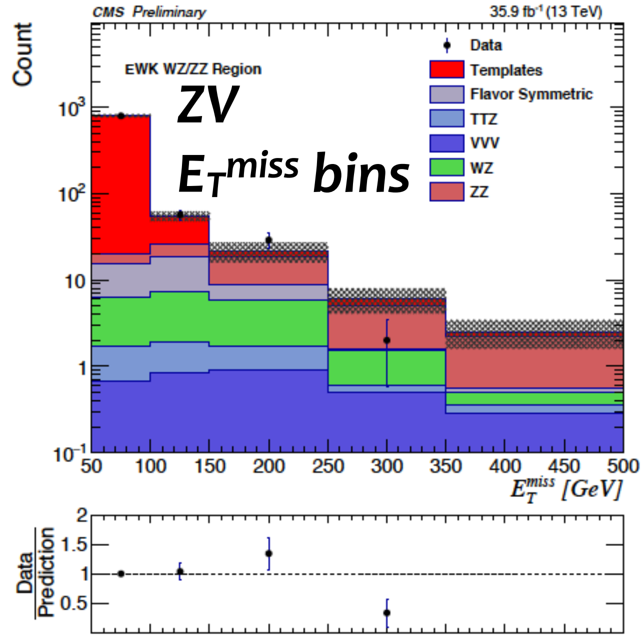
CMS-PAS-SUS-16-043

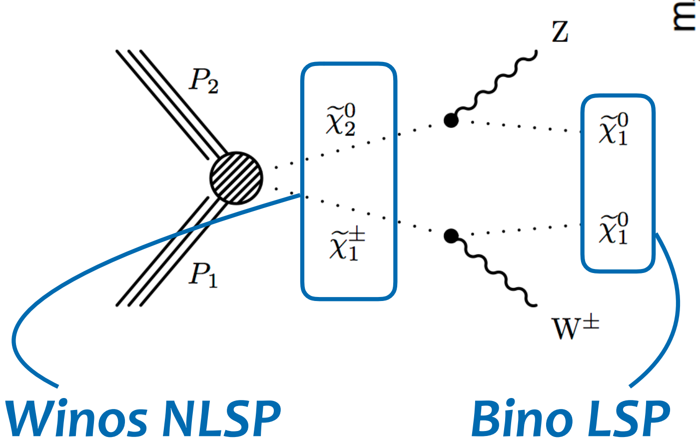
$W \rightarrow \ell\nu + h \rightarrow bb + E_T^{miss}$

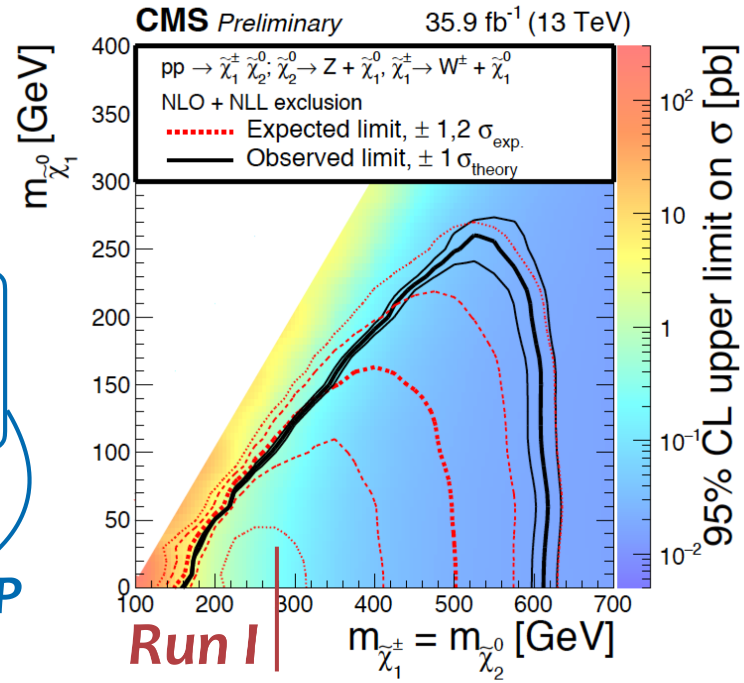
$Z \rightarrow \ell\ell$+jets+E_T^{miss}

CMS-PAS-SUS-16-034

- ***Use OSSF dilepton invariant mass pair to search for a resonant-like excess compatible with the Z boson mass***
- *Di-lepton trigger, E_T^{miss} > 100 GeV, at least 2 jets (35 GeV)*
- ***Z+V$_{hadronic}$ target:***
  - *b-jets veto and $M_{T2}(\ell\ell)$ > 80 GeV against ttbar*
  - *closest jets in φ must have m_{jj} < 110 GeV*
- ***Backgrounds:***
  - ***Z->ℓℓ+ jets:*** *instrumental E_T^{miss} driven mainly by jet resolution, estimated from a γ+jets data sample*
  - ***Flavour-symmetric:*** *mainly ttbar, WW, Z->ττ, predicted using OF channel as a sideband*
  - ***ZZ, WZ:*** *simulation validated in data CR*

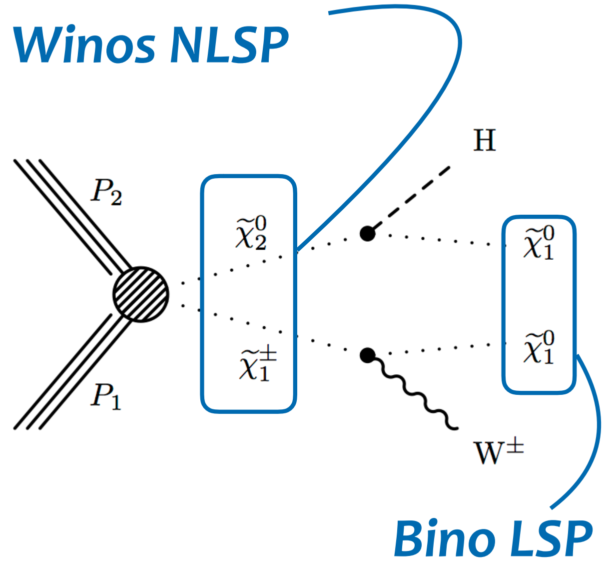


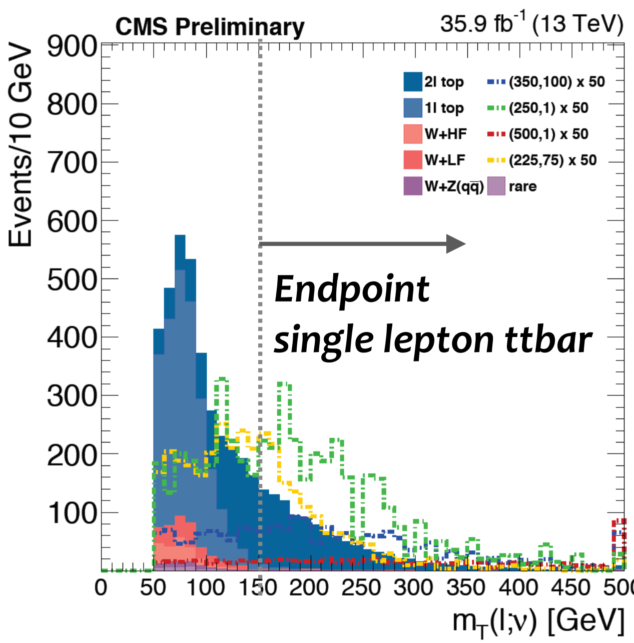


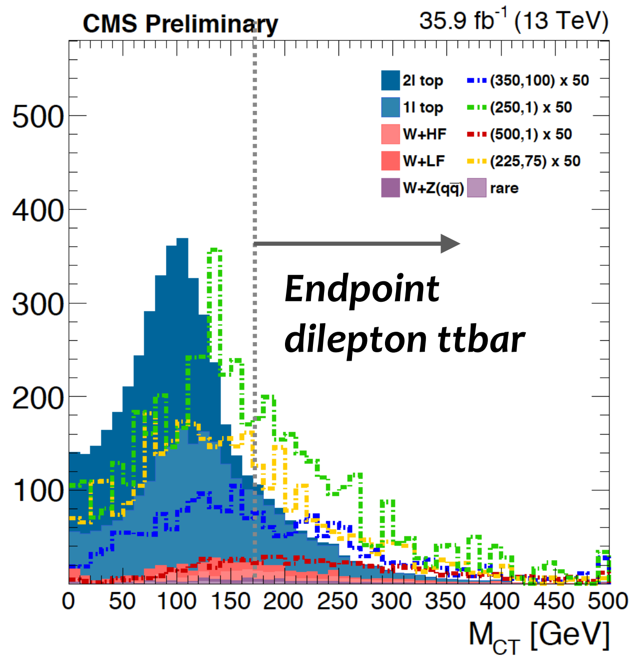


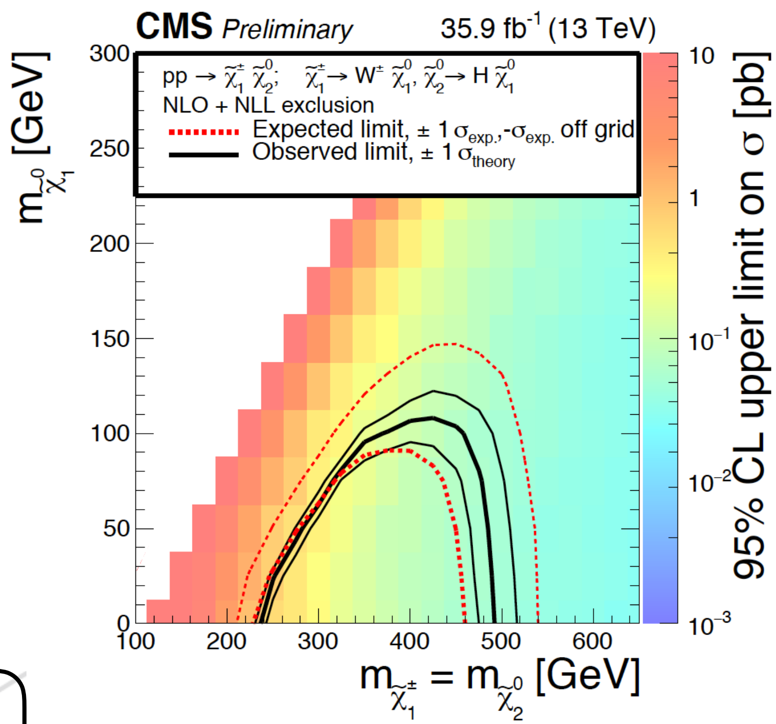
$W \rightarrow \ell\nu + h \rightarrow bb + E_T^{miss}$ CMS-PAS-SUS-16-043

- ***Select single lepton events (p_T > 25/30, trigger), 2 b-jets (p_T>30), E_T^{miss} > 125 GeV: targed WH final state***
  - *Veto additional leptons, isolated tracks, τ_h candidates to reduce main bkg: **dileptonic ttbar***
  - *Require 90<$m_{(bb)}$<150 GeV*
  - *M_T >150 GeV to reduce **single lepton ttbar***
  - *M_{CT}*> 170 GeV (endpoint at top mass for dilepton ttbar)*





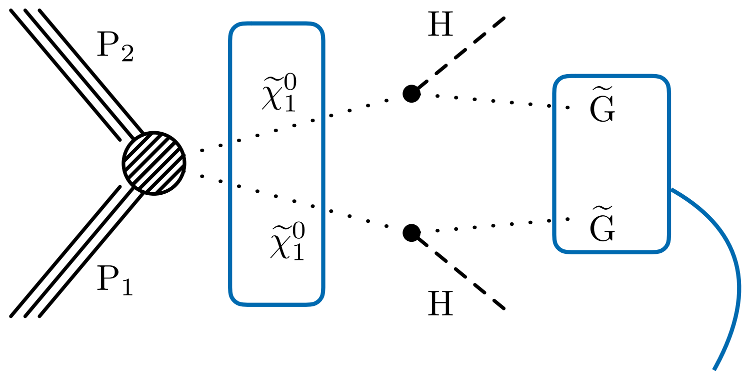




$$* \quad M_{CT}^2 = 2 p_T^{b1} p_T^{b2} (1 + \cos(\Delta\phi_{bb})),$$

Higgsino NLSP ($\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_2^{0}\tilde{\chi}_1^{0}$, $\tilde{\chi}_1^{0}\tilde{\chi}_1^{\pm}$,$\tilde{\chi}_2^{0}\tilde{\chi}_1^{\pm}$)

CMS-PAS-SUS-16-044



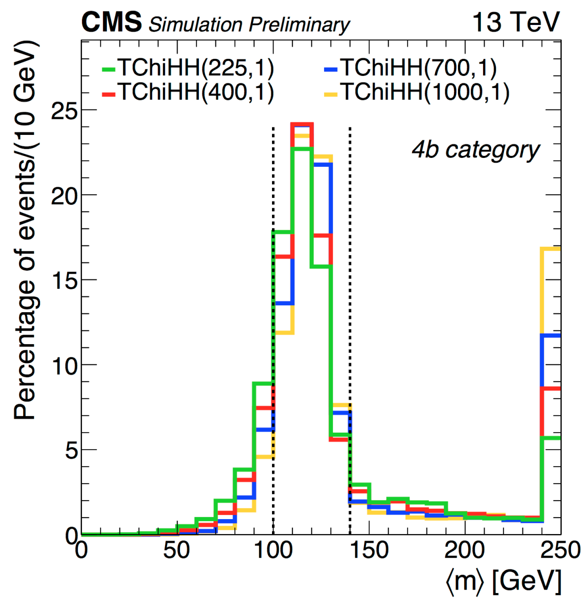
Gravitino LSP

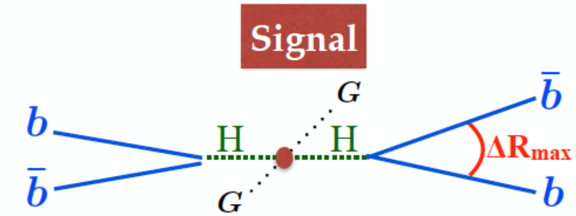
Targeted search with Higgs tagging

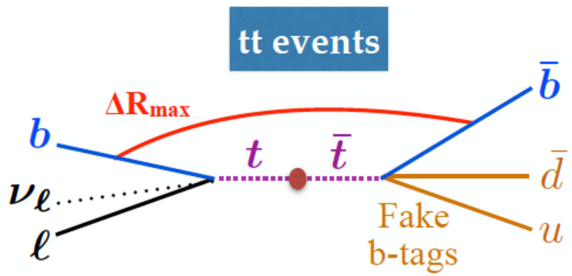
Each Higgs particle is reconstructed in its dominant decay mode ***h->bb and significant E_T^{miss}*** *is requested in the final state*

General strategy

- **Events with E_T^{miss} > 150 GeV (trigger), 4 or 5 jets (25 GeV)**
  - *Reject jets that are closely aligned with E_T^{miss}: **reduce QCD bkg***
  - *No leptons and no isolated tracks: **reduce main bkg, single lepton (τ_h) ttbar***
- ***Reconstruct two h->bb candidates:***
  - *Three possible h_1h_2 pairings from 4 highest b-tagging discriminator jets*
  - *Select pair that minimise $\Delta m_h = m_{h1}-m_{h2}$ (Δm< 40 GeV) and use <m> [100-140] GeV for signal extraction*
  - *ΔR_{max}= max(ΔR_{h1},ΔR_{h2}) < 2.2 against ttbar*
- ***Categories:***
  - *2b(tight), 3b(tight, tight, medium), 4b(tight, tight, medium, loose)*
  - *4 E_T^{miss} bins: 150-200-300-450-∞*
- ***Main Residual Backgrounds:***





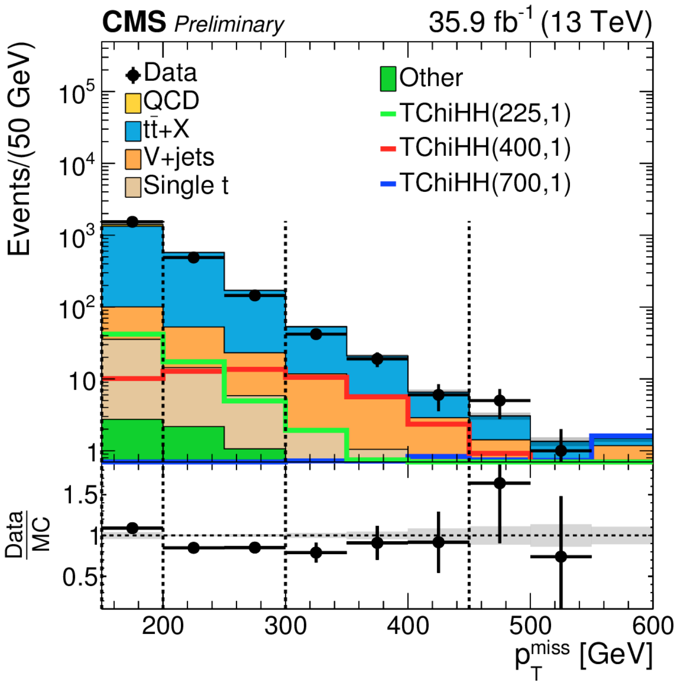


Single lepton (τ_h) ttbar (85%)

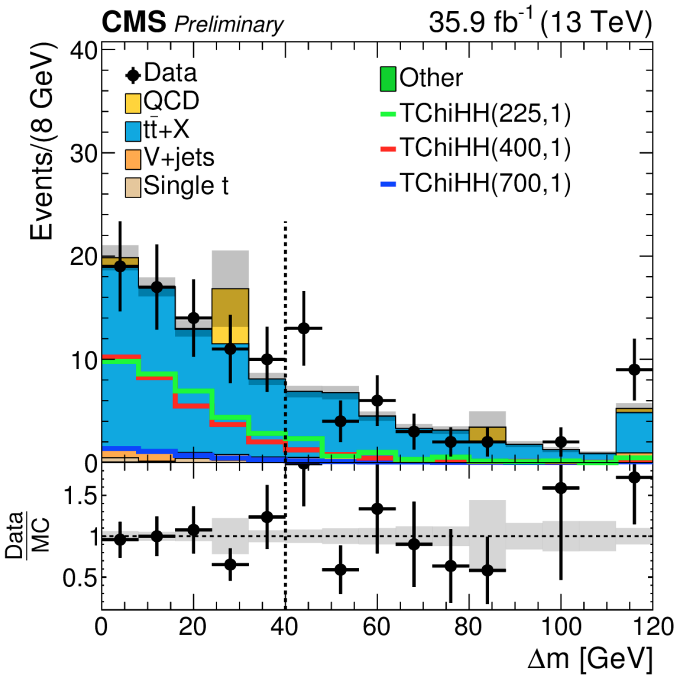
Z->νν + Jets (10%)

Main kinematic variables

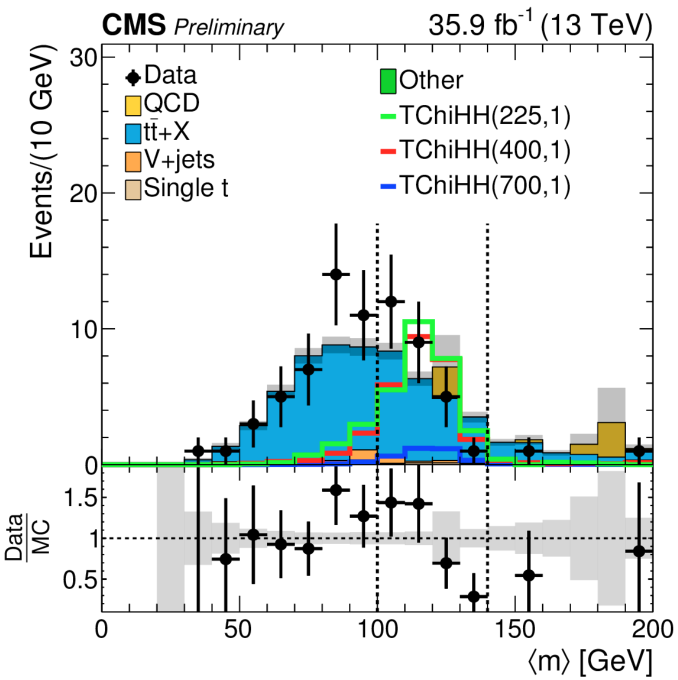
E_T^{miss}



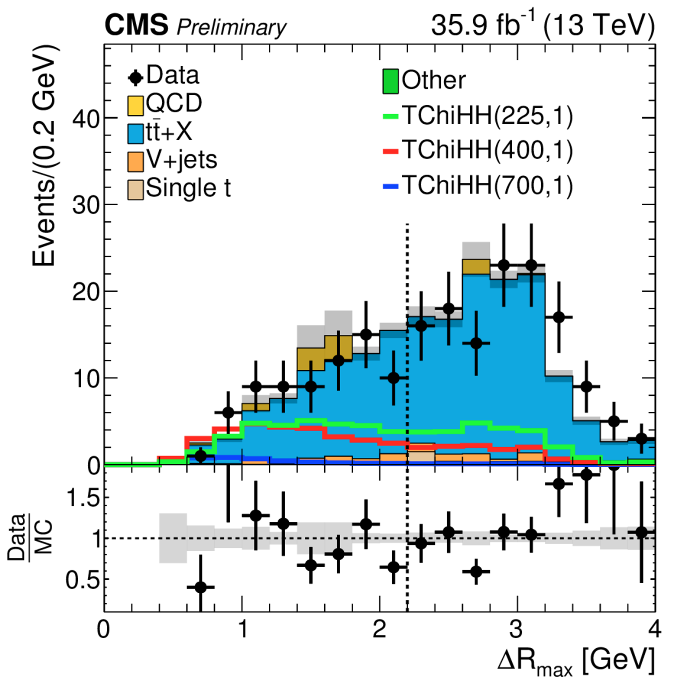
Δm



<m>



DR_{max}

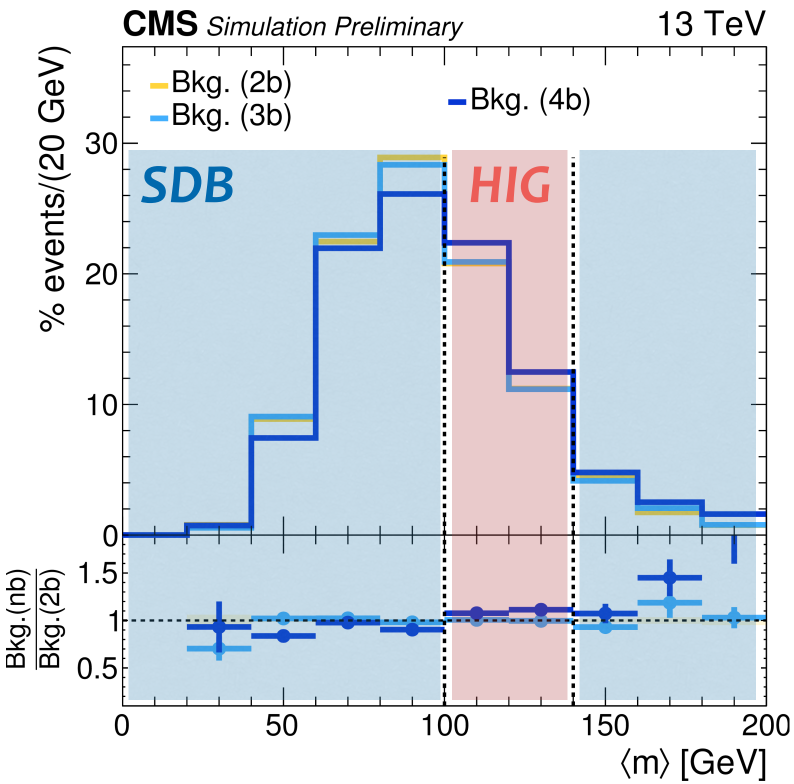


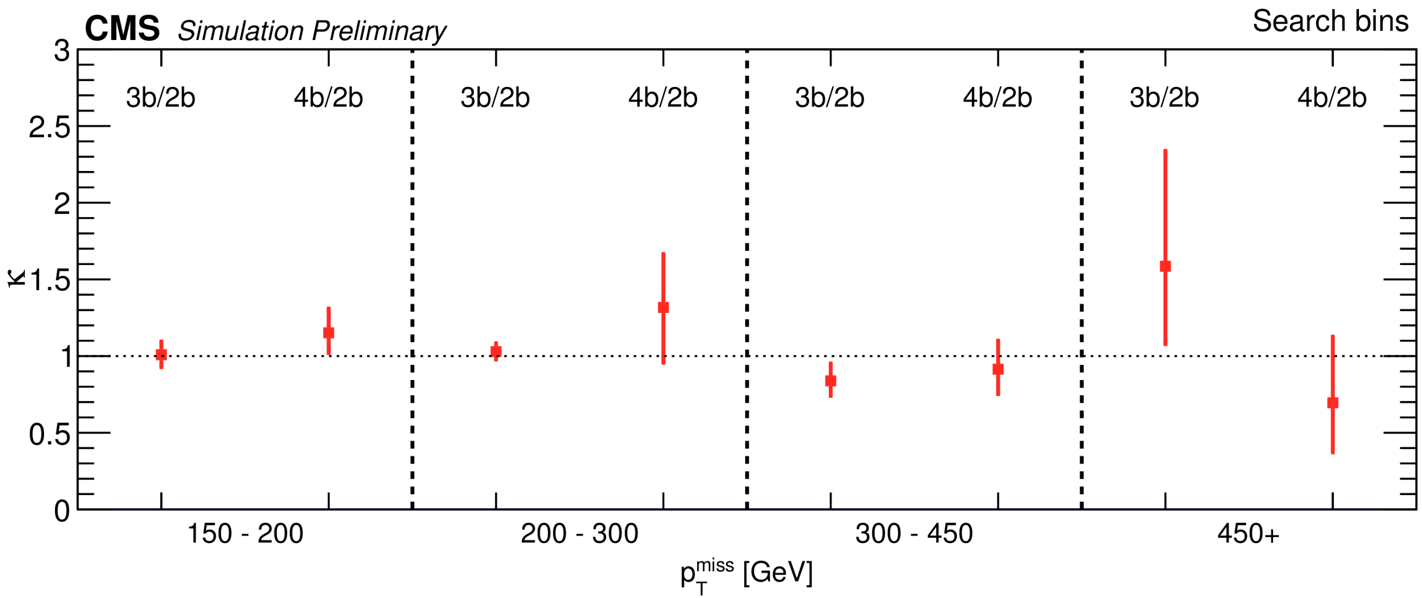
Data driven bkg estimation

- *All bkg processes have only 2 real b, additional tags (3b,4b categories) from mis-tagged light/gluon jets*
  - ***<m> is expected to be uncorrelated with N_{btags}***
- ***ABCD method:***
  - *use <m> shape in 2b to predict shape in 3b 4b*

$$N_{3b}^{HIG} = N_{3b}^{SBD} \times \frac{N_{2b}^{HIG}}{N_{2b}^{SBD}} \qquad N_{4b}^{HIG} = N_{4b}^{SBD} \times \frac{N_{2b}^{HIG}}{N_{2b}^{SBD}}$$

  - *closure in simulation (sum of all bkg):*



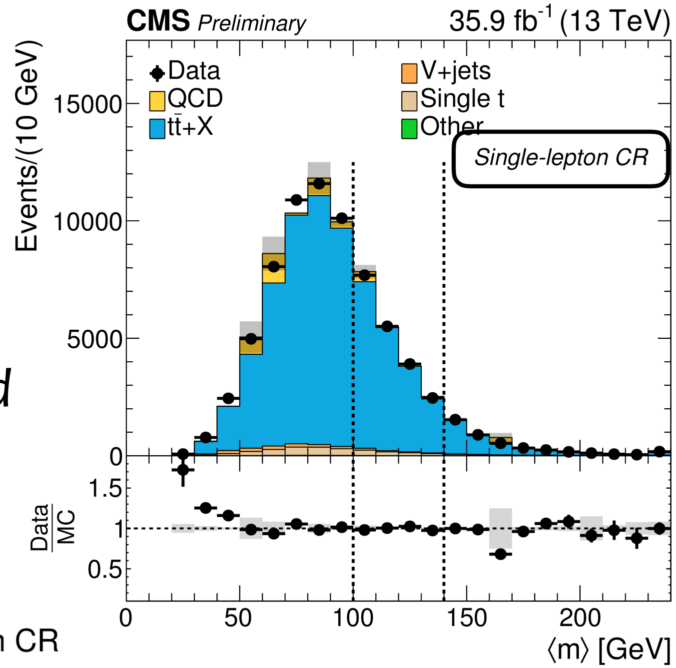


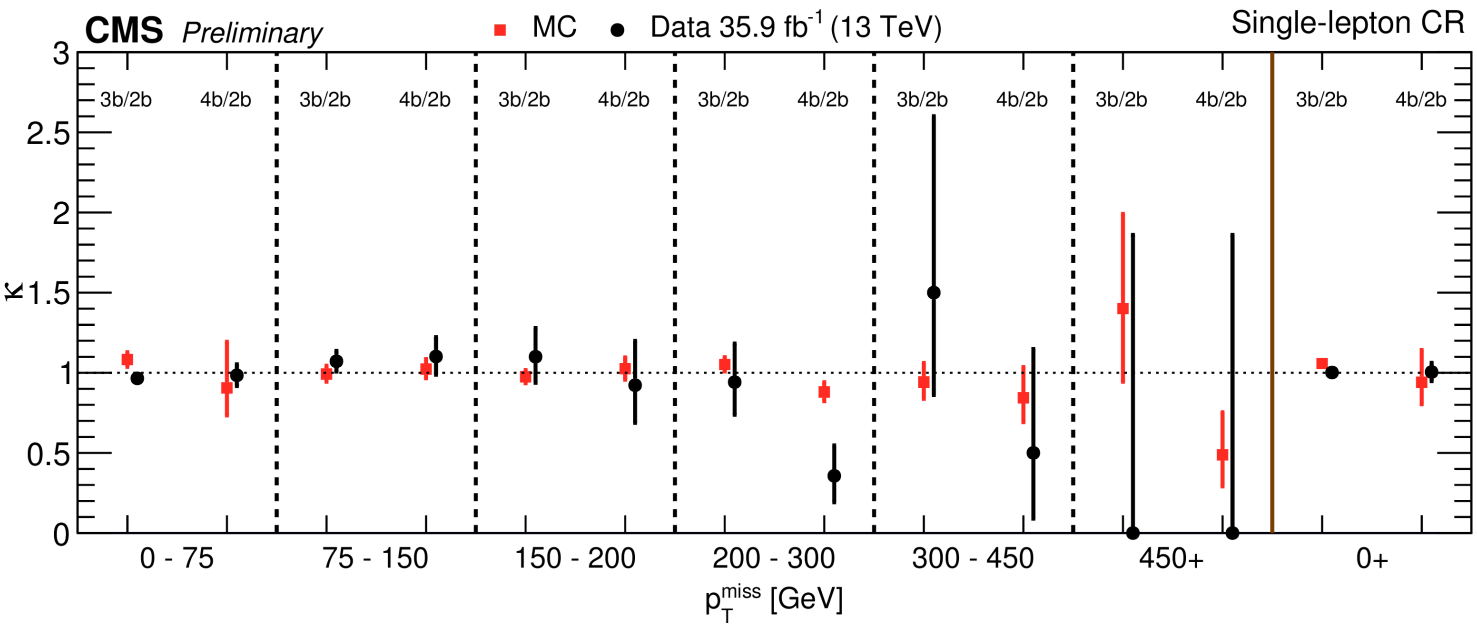
$$\kappa_{3b} = \left(\frac{\mu_{HIG}^{bkg}}{\mu_{SBD}^{bkg}}\right)_{3b} \Big/ \left(\frac{\mu_{HIG}^{bkg}}{\mu_{SBD}^{bkg}}\right)_{2b}$$

k factors in simulation are consistent with unity

Data driven bkg estimation

- **Closure is validated in data to assess systematics**
  - **ttbar bkg: single lepton control region**
    - remove track veto, require $m_T(\ell, E_T^{miss}) < 100$ GeV
    - lepton is spectator in <m>, N_b computation
      - the closure of the ABCD method can be performed in this region to check residual <m>-N_b correlation in signal region

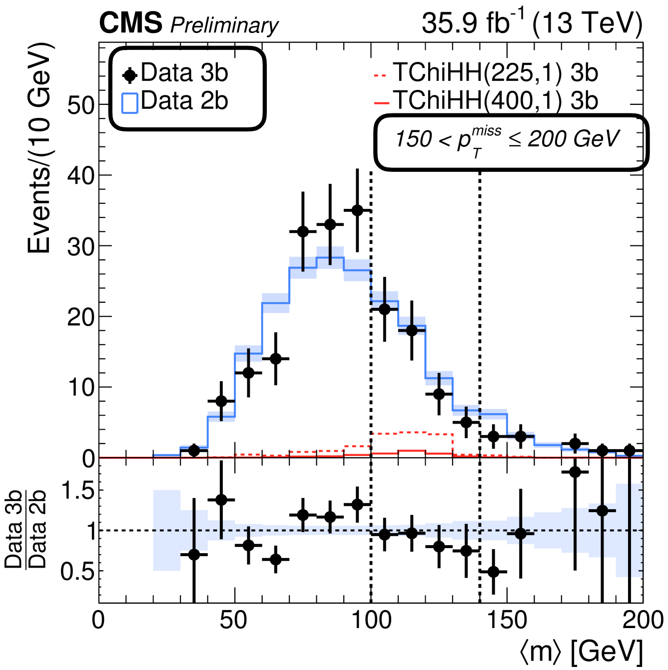


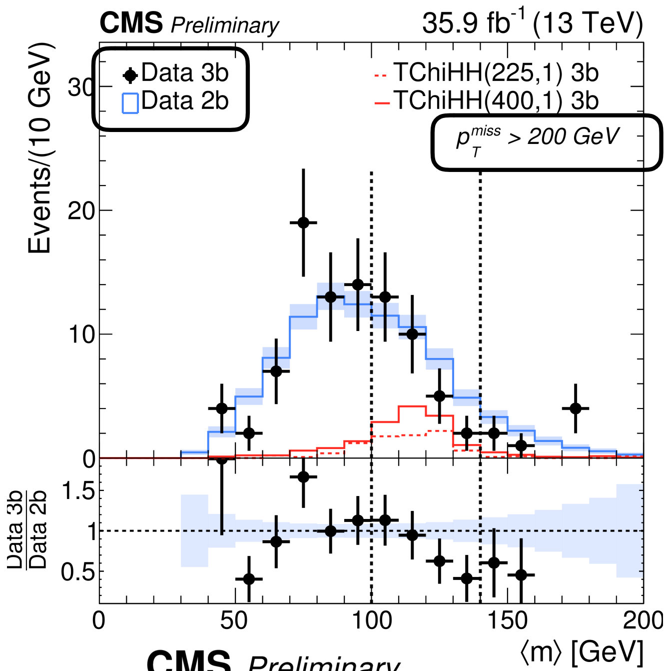


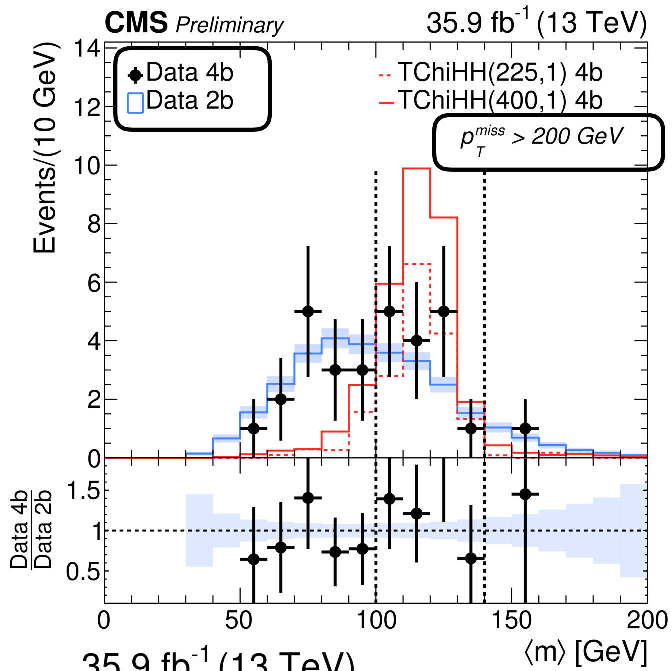
k factors in data consistent with unity

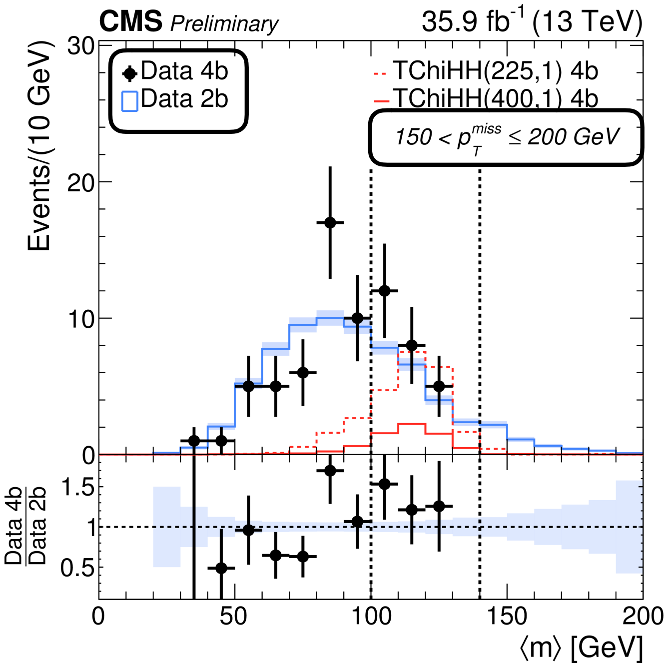
Systematic: larger of non closure and statistical uncert. (integrating in E_T^{miss})

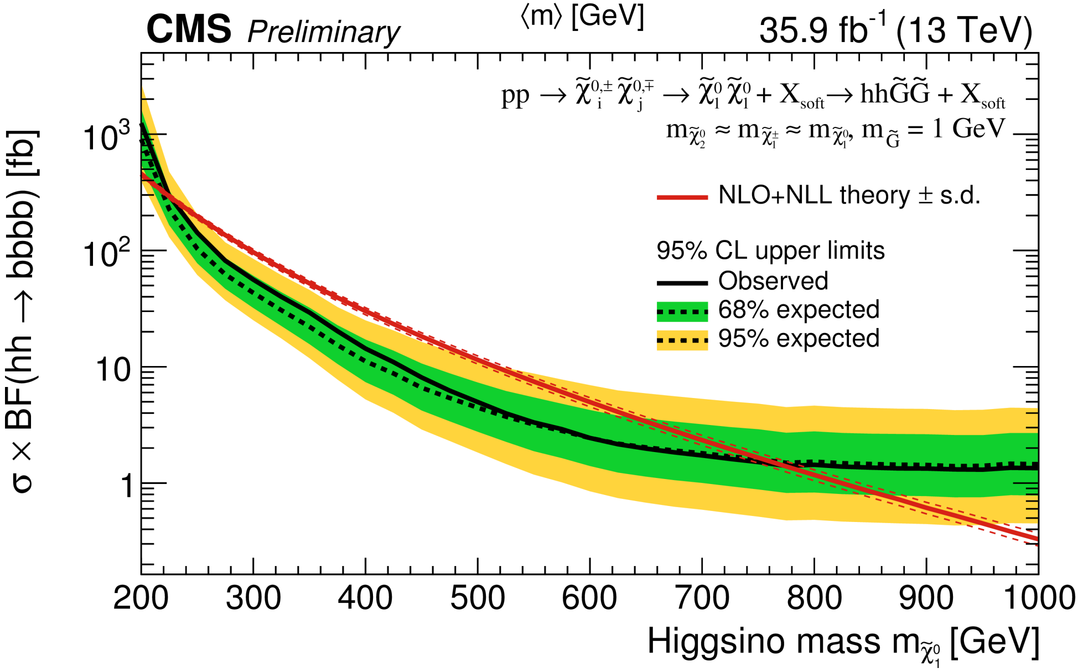
Results



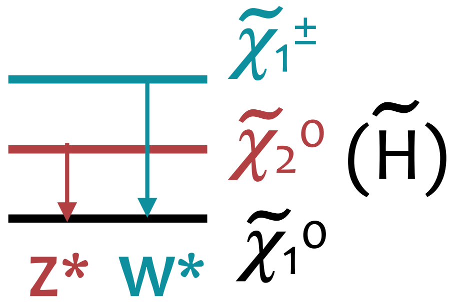








Exclusion: 230-770 GeV, was no-exclusion in Run I



CMS-PAS-SUS-16-048

Search with soft leptons targeting compressed spectra

Crucial to addressing the question of naturalness, the detection of particles in a ***nearly degenerate Higgsino sector*** *that contains the LSP poses a major experimental challenge*

General strategy

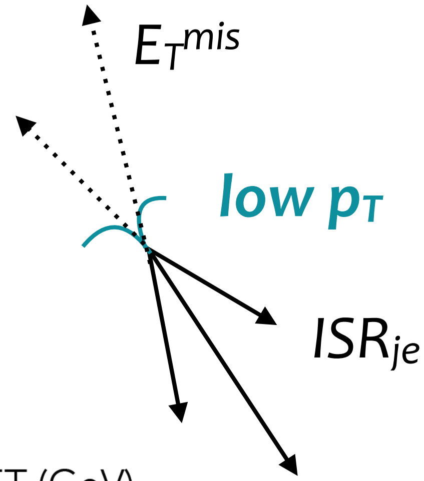
- **Focus on the presence of $Z^* \to \ell\ell$, i.e. production modes $\chi_2^0\chi_1^0$, $\chi_2^0\chi_1^\pm$**
  - *two opposite sign μ(e) **p_T 3.5(5)-30 GeV** with tight ID to reject non-prompt leptons*
    - *typical efficiency for μ(e) 80-90% (50-60%)*
  - ***ISR jet, E_T^{miss}> 125 GeV***
  - *binning in $m(\ell\ell)$ and E_T^{miss} (125-200-250-∞)*
  - ***$m(\tau\tau)$** > 160 GeV, to reduce boosted DY->ττ bkg (also reduced by tight lepton IP cuts)*
  - ***b-jet veto,** to reduce ttbar dileptonic bkg*
  - ***$M_T^{min}(\ell_i, E_T^{miss})$** < 70 GeV, in signal E_T^{miss} is aligned with the ℓ*
- **Main residual backgrounds**

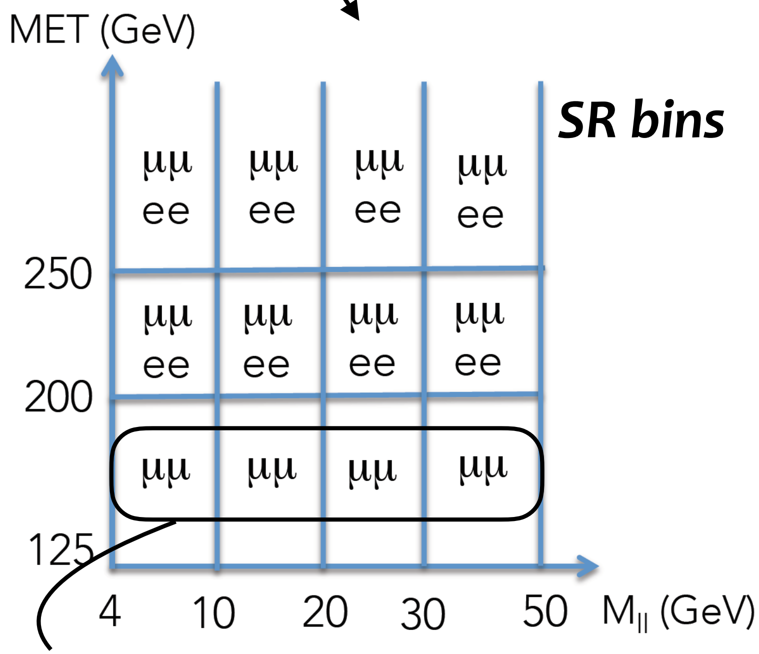
DY->ττ

non prompt leptons, mainly W+jets

ttbar dilepton

VV (mainly WW)

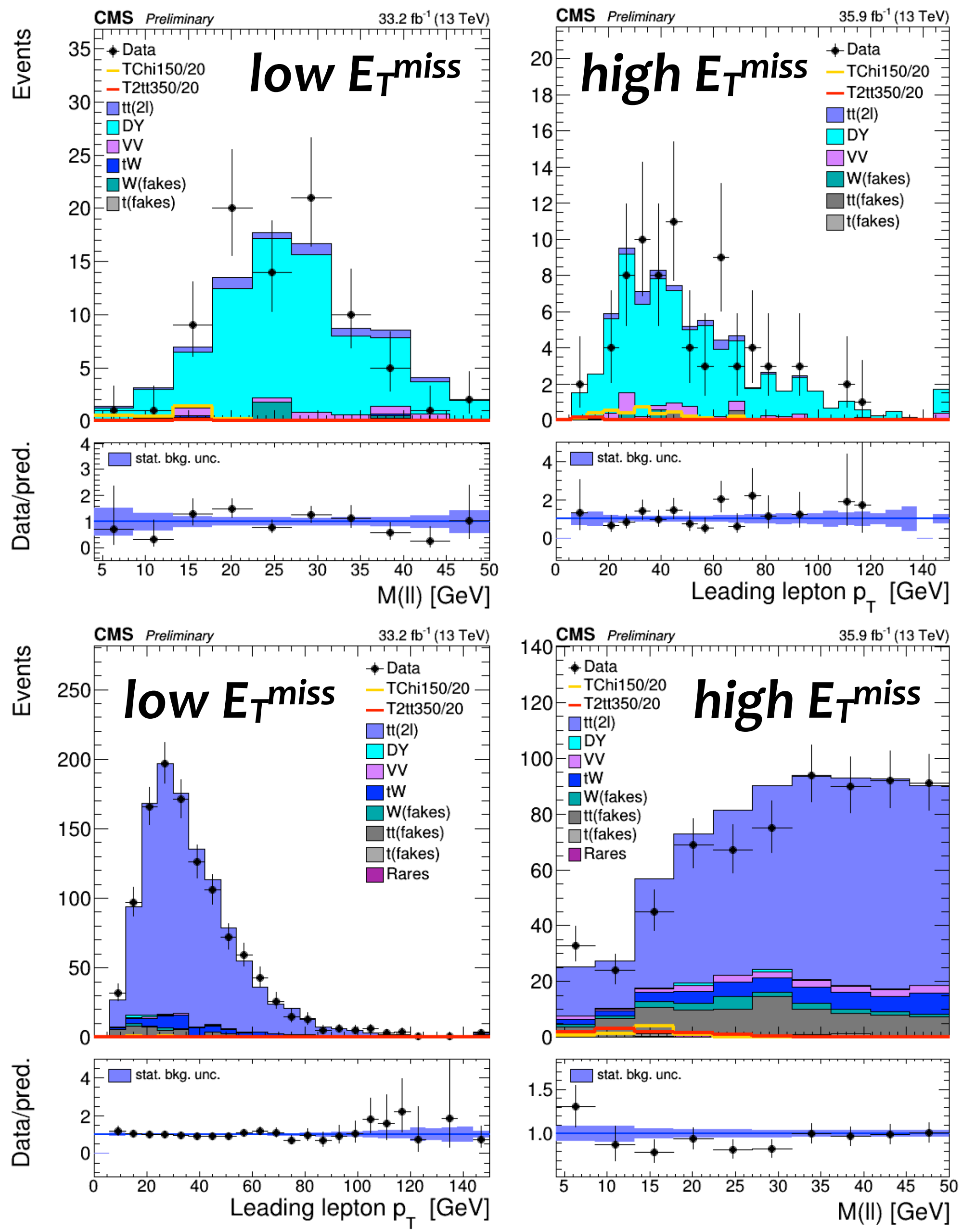




Extending reach down to 125 thanks to μμ+ E_T^{miss} special trigger

$Z\rightarrow\tau\tau$ and ttbar

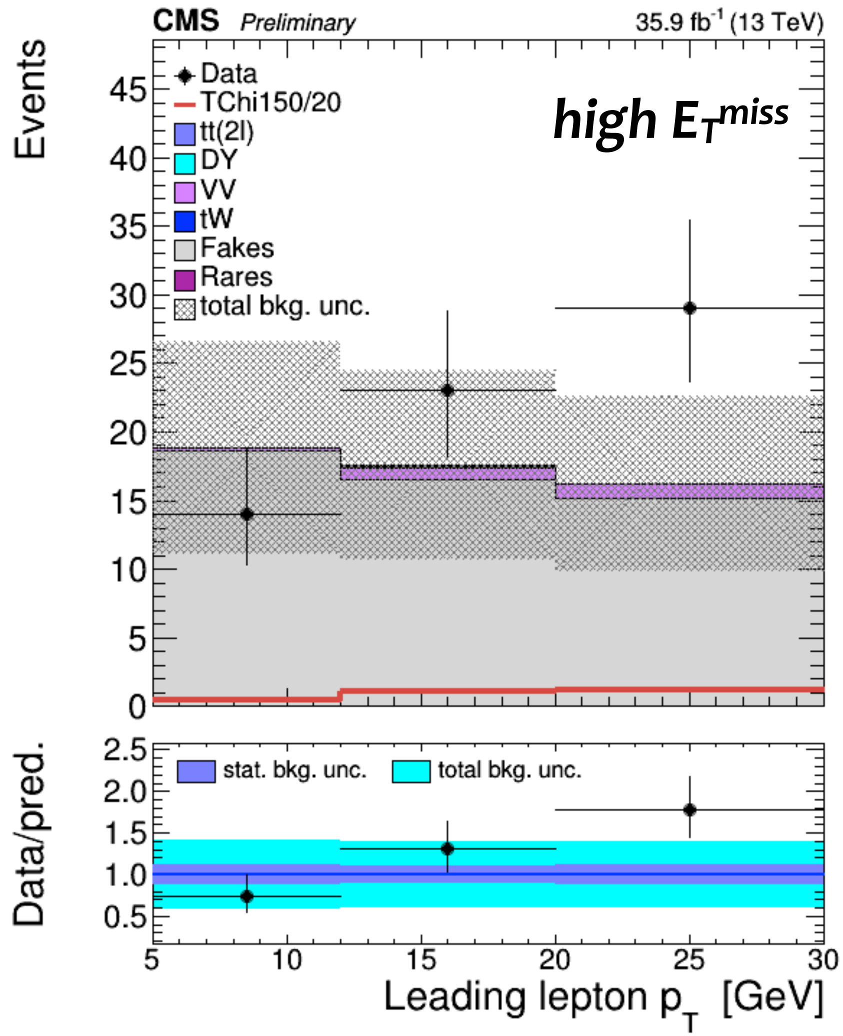
- *Define a bkg dominated control region similar in phase space to SRs*
  - CR ***fitted simultaneously to the SRs bins***, to constrain normalisation
- *Shapes validation in data*
  - ***DY Control region:* inverted m($\tau\tau$) cut, relax ℓ IP and upper ℓ p_T cuts**
  - ***ttbar control region:* ≥ 1 b-jet, relax upper ℓ p_T cuts**
- ***VV background*** *taken from simulation, normalisation validated in control region*



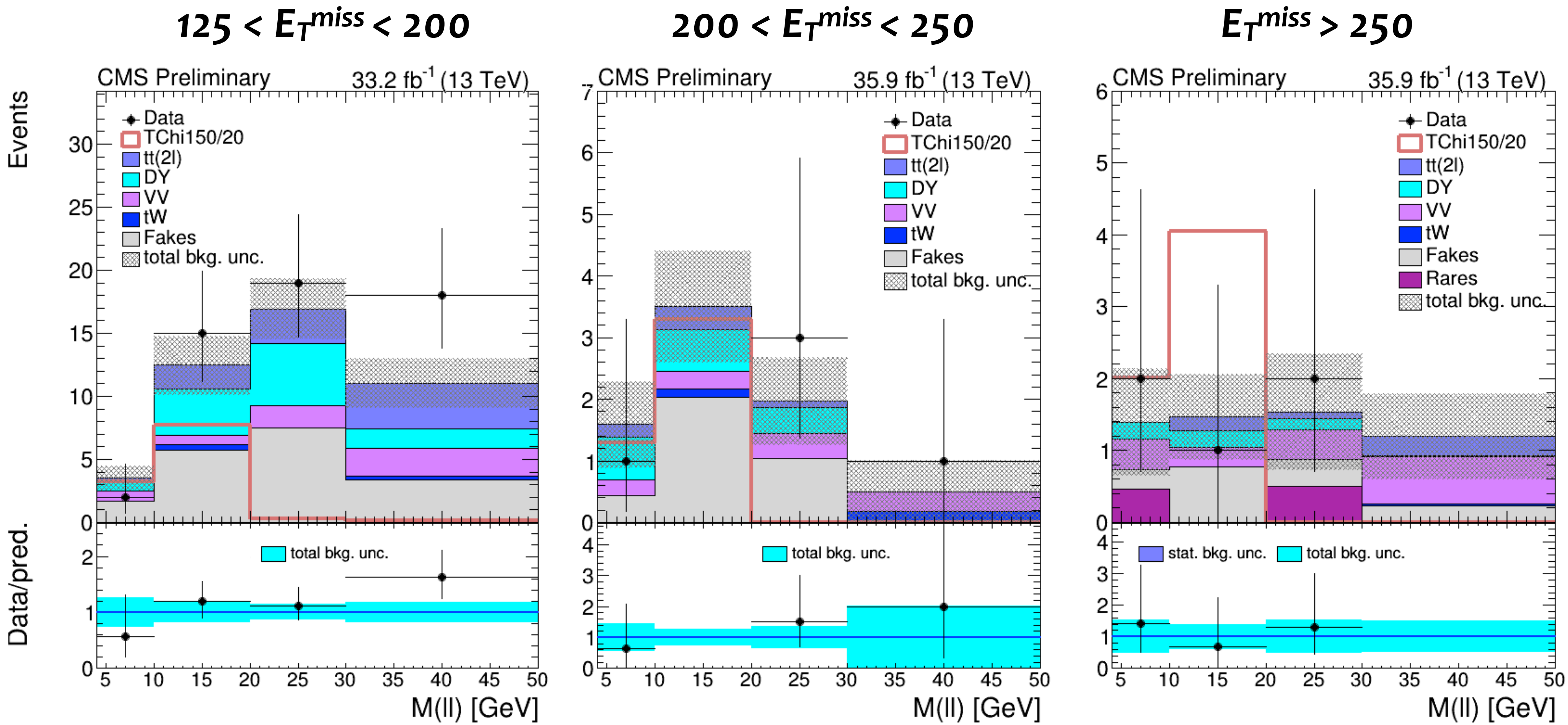
Non prompt leptons

- **Sources:** *real lepton in jets (μ,e), jet mis-identification (e)*
- **Processes:** *W+jets*
- ***Data driven estimation: "fake-rate" method***
  - *measure in data probability for non prompt lepton to pass lepton ID (fake-rate ratio)*
  - *extrapolate to event yields based on the number of lepton failing the tight selection*
  - *closure within 40% in simulation*

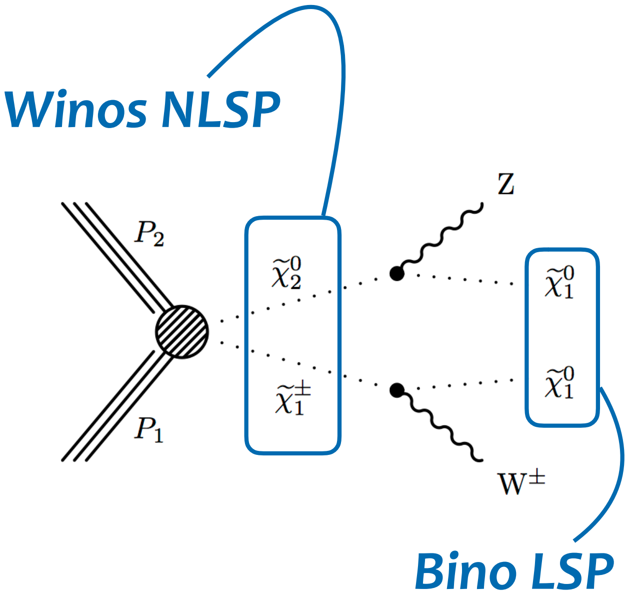
- *To validate the prediction define a bkg dominated control region similar in phase space to SRs*
  - *CR* ***fitted simultaneously to the SRs bins****, to constrain normalisation*
  - ***Non-prompt control region***
    - *same-sign leptons in high E_T^{miss}*

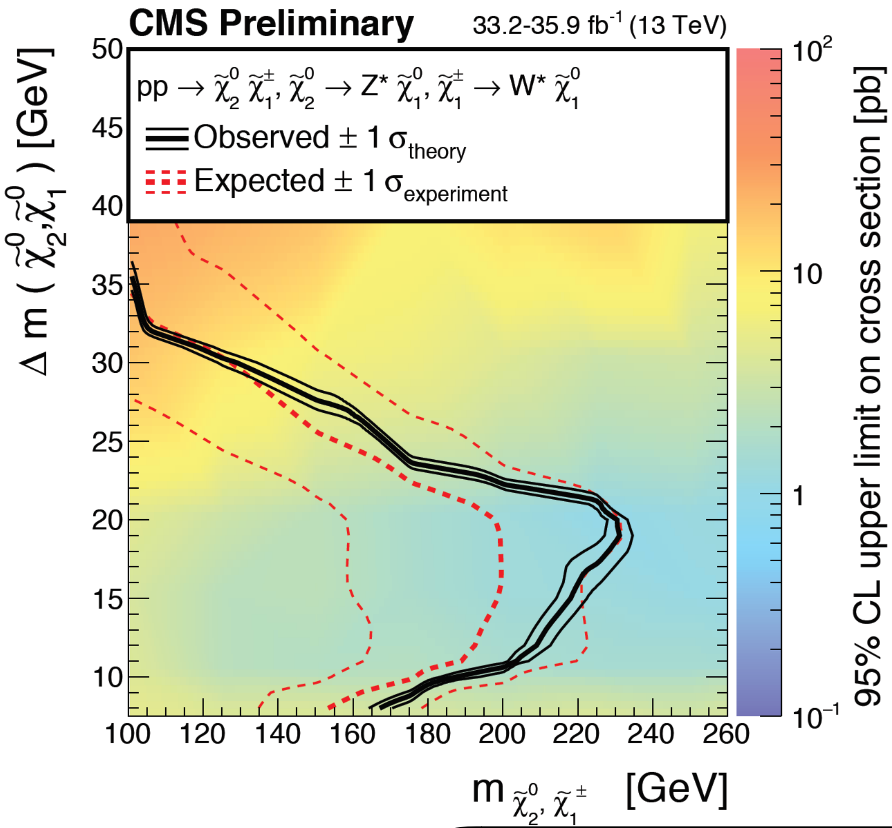


Results

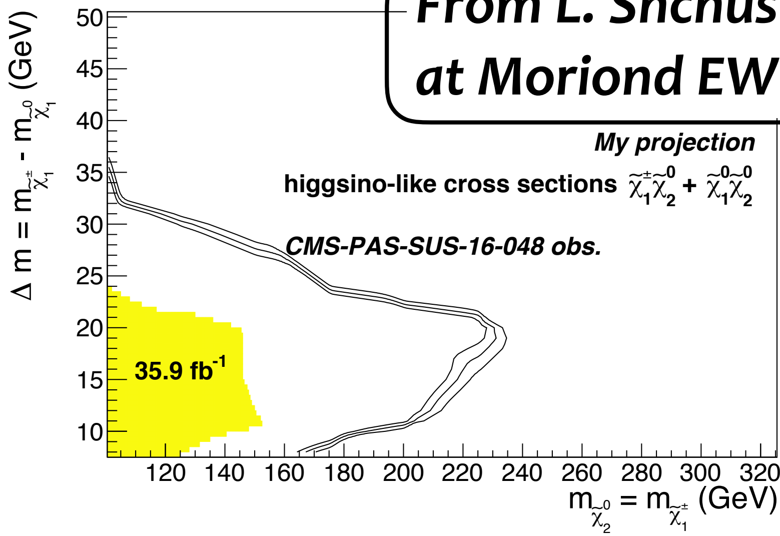

125 < E_T^{miss} < 200
200 < E_T^{miss} < 250
E_T^{miss} > 250
CMS Preliminary
33.2 fb^{-1} (13 TeV)
35.9 fb^{-1} (13 TeV)
Events
Data/pred.
Data
TChi150/20
tt(2l)
DY
VV
tW
Fakes
Rares
total bkg. unc.
stat. bkg. unc.
M(ll) [GeV]

Interpretation





From L. Shchustka's talk at Moriond EWK



First coverage of Δm 7.5-30 GeV

exclusion up to 175 GeV for Δm=7.5, 230 GeV for ΔM= 20 GeV

Assuming instead ***Higgsino production cross section*** *for production modes $\chi_2^0\chi_1^0$, $\chi_2^0\chi_1^\pm$*

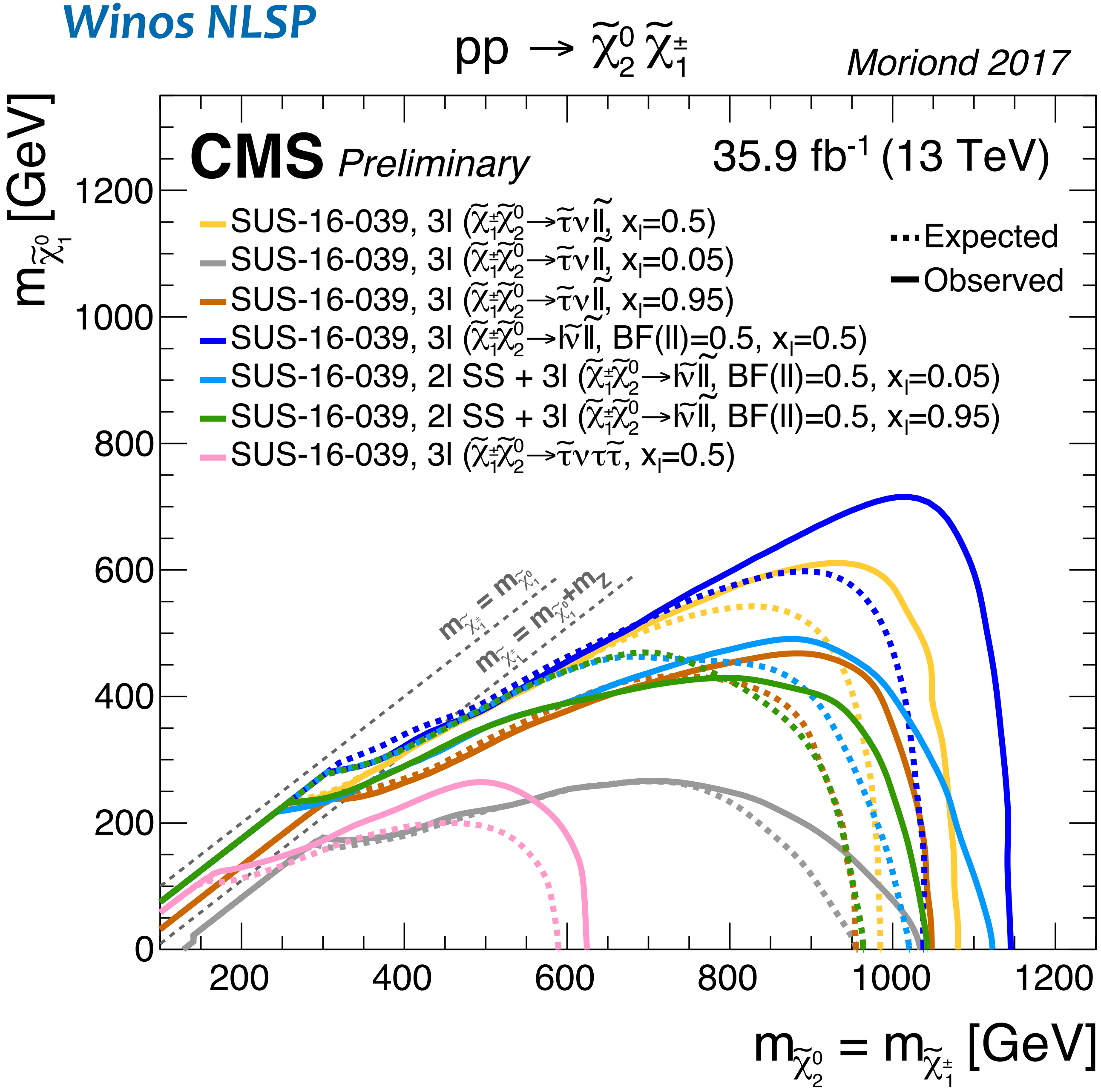
ONLY PROJECTION SO FAR:

exclusion up to ~120 GeV for Δm=7.5, ~150 GeV for Δm= 20 GeV

Summary and conclusions

Everything together

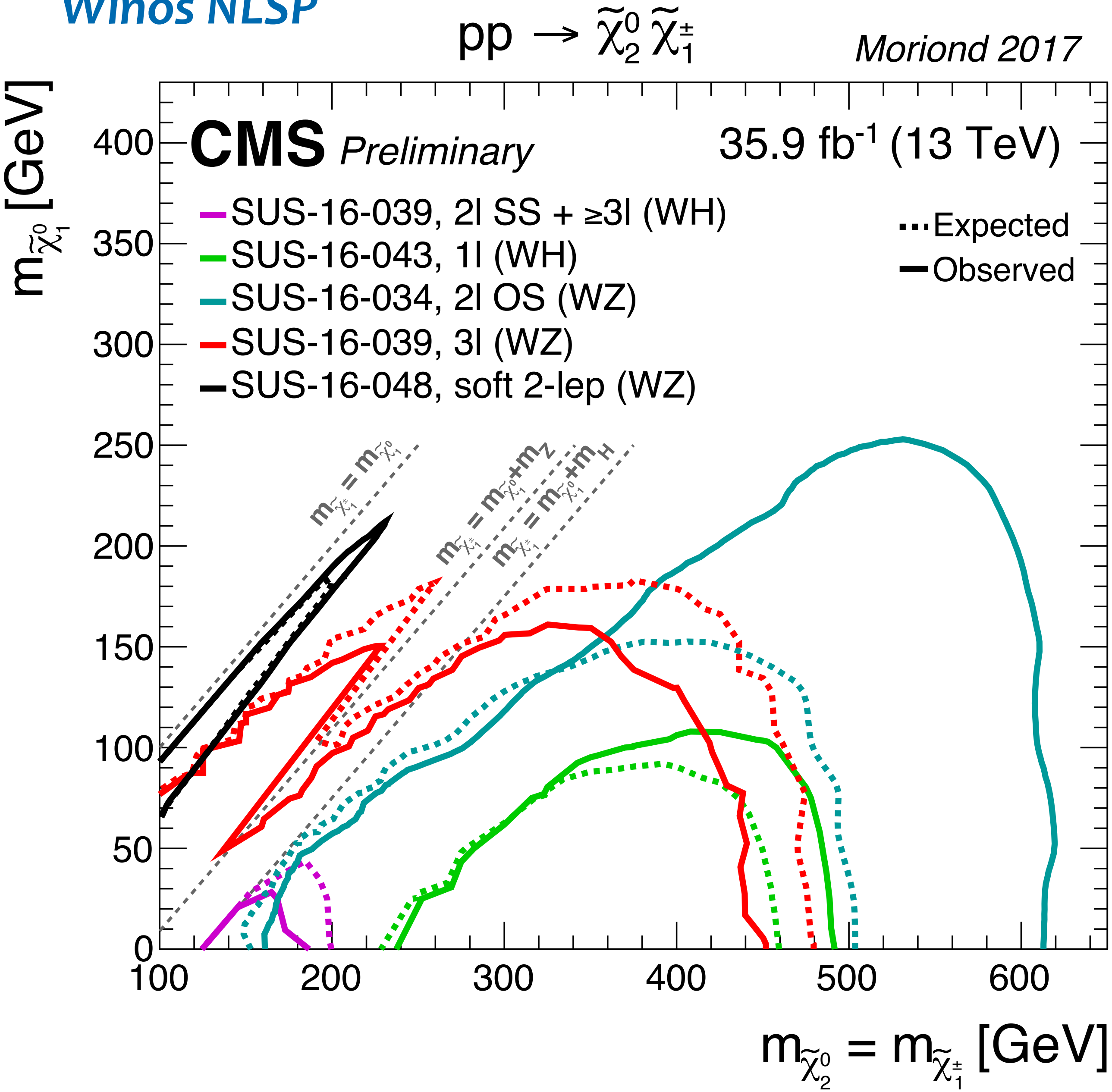
Winos NLSP



- ***Assuming decay through sleptons:***
  - *in 'tau enriched' and 'flavour democratic' scenarios limits up to* ***1020-1150 for massless LSP (was 630-720 in Run I)***
- *Different slepton mass assumptions lead to different exclusions in LSP mass (up to 400/500/700 for flavour democratic)*

Everything together

Winos NLSP



3ℓ search, decay through ***WZ***
Coverage of critical region where the signal is very similar to WZ production

Z->ℓℓ+jets, *decay through* ***WZ***
push limit up to ~620 GeV for massless LSP thanks to higher acceptance
Due to tighter kinematics cuts against bkg, less coverage in the compressed region

Multilepton *search, decay through* ***WH***

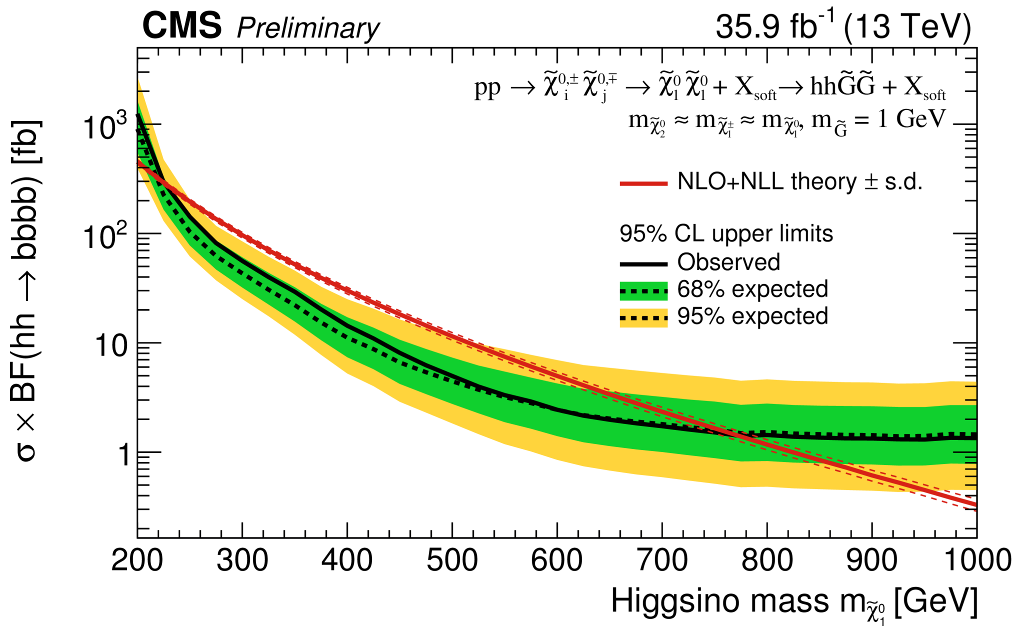
1ℓ + H->bb *search, decay through* ***WH***

2ℓ OS soft, *decay through* ***WZ***
first coverage of dM 7.5-30 GeV

Everything together

Higgsino NLSP ($\tilde{\chi}_1^\pm\tilde{\chi}_1^\pm$, $\tilde{\chi}_2^0\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\tilde{\chi}_1^\pm$,$\tilde{\chi}_2^0\tilde{\chi}_1^\pm$), GMSB Gravitino LSP

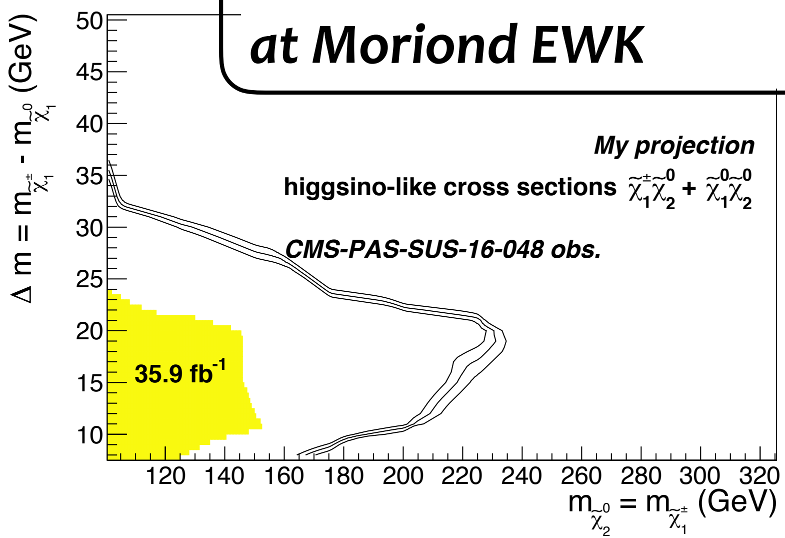
- *Assuming decay through* ***HH:***
  - *exclusion in [230-770] GeV mass range from the h->bb+h->bb final state*



Higgsino LSP ($\tilde{\chi}_2^0\tilde{\chi}_1^0$,$\tilde{\chi}_2^0\tilde{\chi}_1^\pm$), decay through Z* into $\tilde{\chi}_1^0$

- ***Soft OS dilepton:***
  - *milestone for Higgsino LSP searches at LHC*
- ***Just projection !!!*** *real results coming soon:*
  - *limit at ~120 GeV for dM=7.5,*
  - *limit at ~150 GeV for dM = 20 GeV*

From L. Shchustka's talk at Moriond EWK



Conclusions

- ***The EWK SUSY production happens with very low rates***
  - *low cross section*
  - *need leptonic final states or Higgs boson tagging*
- *The 2016 dataset gave us the possibility to* ***explore new territories in the EWKino sector***
- *With an extensive search program covering diverse topologies,* ***CMS extended the RunI searches*** *with the increased luminosity and center of mass energy*
  - ***No hint of new physics has been observed, and larger regions of the phase space have been excluded***
- ***New ideas and final states are being developed to cover all the possible corners of the phase space, especially in the Higgsino sector***
  - *Thanks to the search with soft-lepton for the first time at LHC we will be sensitive to light degenerate Higgsinos, results coming soon.*