Collider and Dark Matter Physics Workshop

Mitchell Institute for Fundamental Physics and Astronomy, Texas A&M University (TX)

18th May 2017

Probing compressed SUSY with low-pT leptons

a.k.a. “SUSY ~~around~~ in the cornerS”

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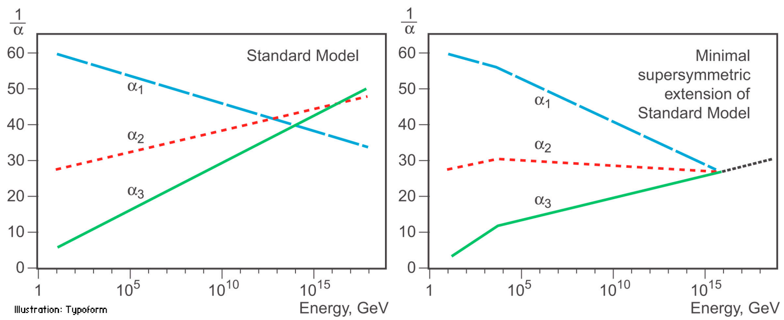
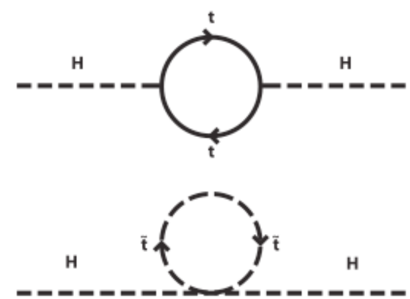
[Ref. CMS-PAS-SUS-16-048]

Why SUSY?

Many, many questions solved in one, natural, elegant theory



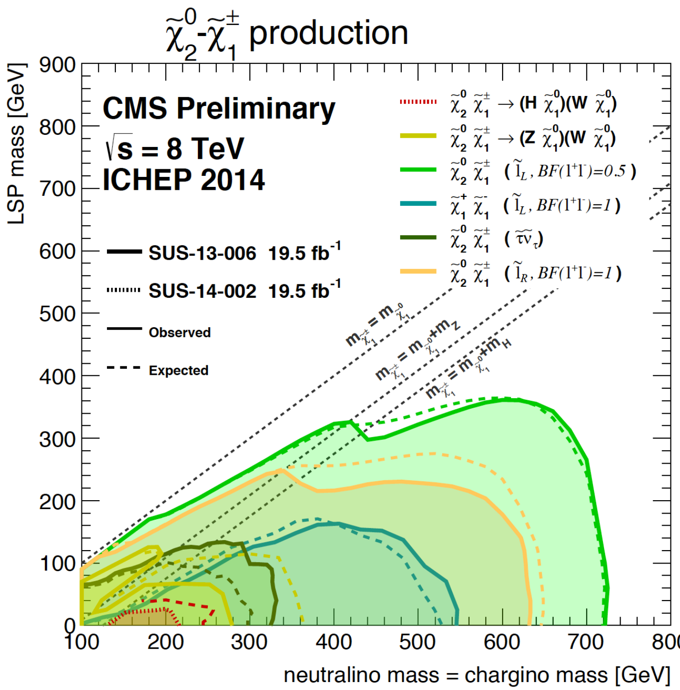
Unification of gauge couplings
Presence of sparticles changes running of couplings



Hierarchy problem
Low-mass top squarks cancel SM contributions to m(H)
(together with light higgsinos and gluinos)

WIMP Dark matter
Lightest SUSY particle can be massive, stable, and weakly interacting

The legacy of the past

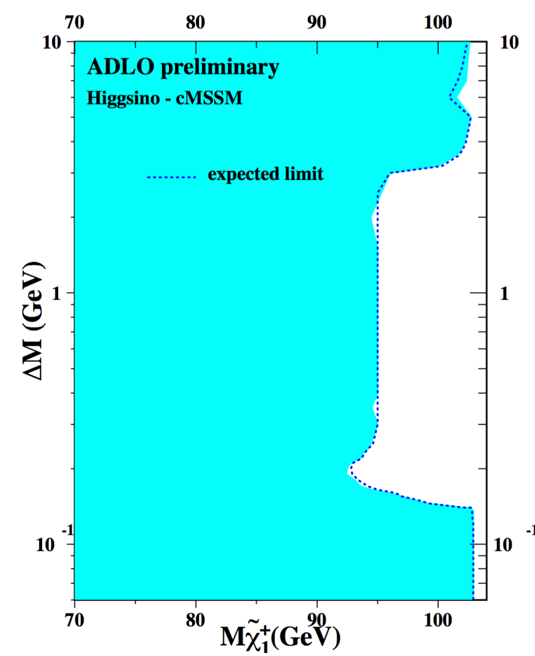


LHC8TeV: a broad range of searches

- Large number of signatures and final states
- No excesses, but limits

LEP: limits on Higgsino LSP

- Chargino masses excluded up to ~100 GeV
- How?
  - photon ISR and soft decay products down to Δm~200 MeV
  - for smaller Δm: displaced tracks or HSCP



Why we (still) look for SUSY?

"Sparticles within kinematic reach"

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- *Low couplings*: not enough luminosity for production
- *Low BR* for channels which can be separated from backgrounds

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- Little visible energy or long-lived decays
- Signal kinematics very similar to the major background
- Complex decays: suppressed MET (*stealth*) or compressed mass spectra

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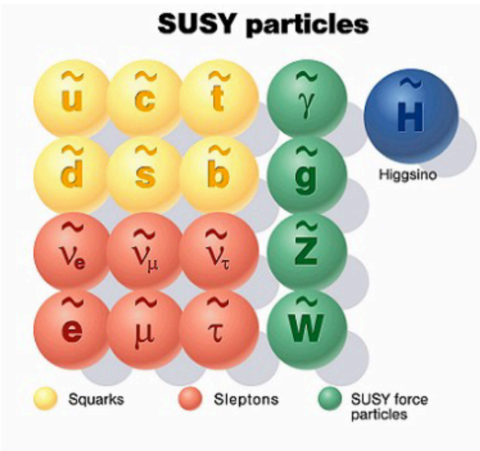
Solution: Work on improving experimental techniques. And keep calm.

#electroweakSUSY



Mixing: Superpartners (Winos, Bino, Higgsinos) mix to form mass eigenstates (EWKinos)

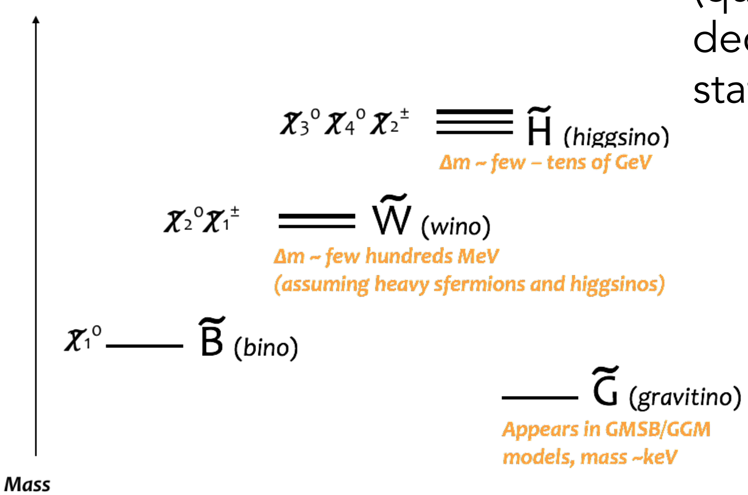
Neutralinos: $\chi_1^0 \chi_2^0 \chi_3^0 \chi_4^0$

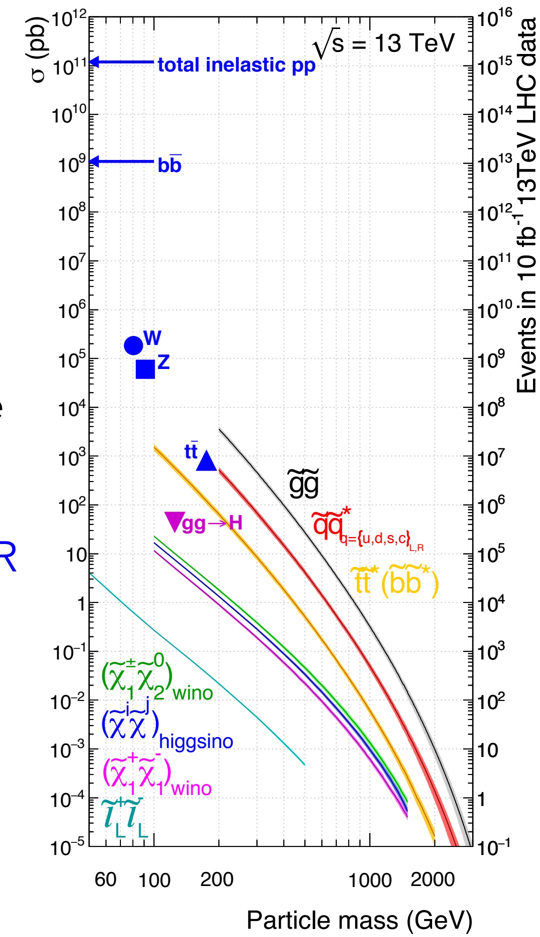
Charginos: $\chi_1^\pm \chi_2^\pm$

Production: low cross-section (quark induced) + W/Z/H in the decay chain, hadronic final states too much SM like

→ exploit leptonic BR

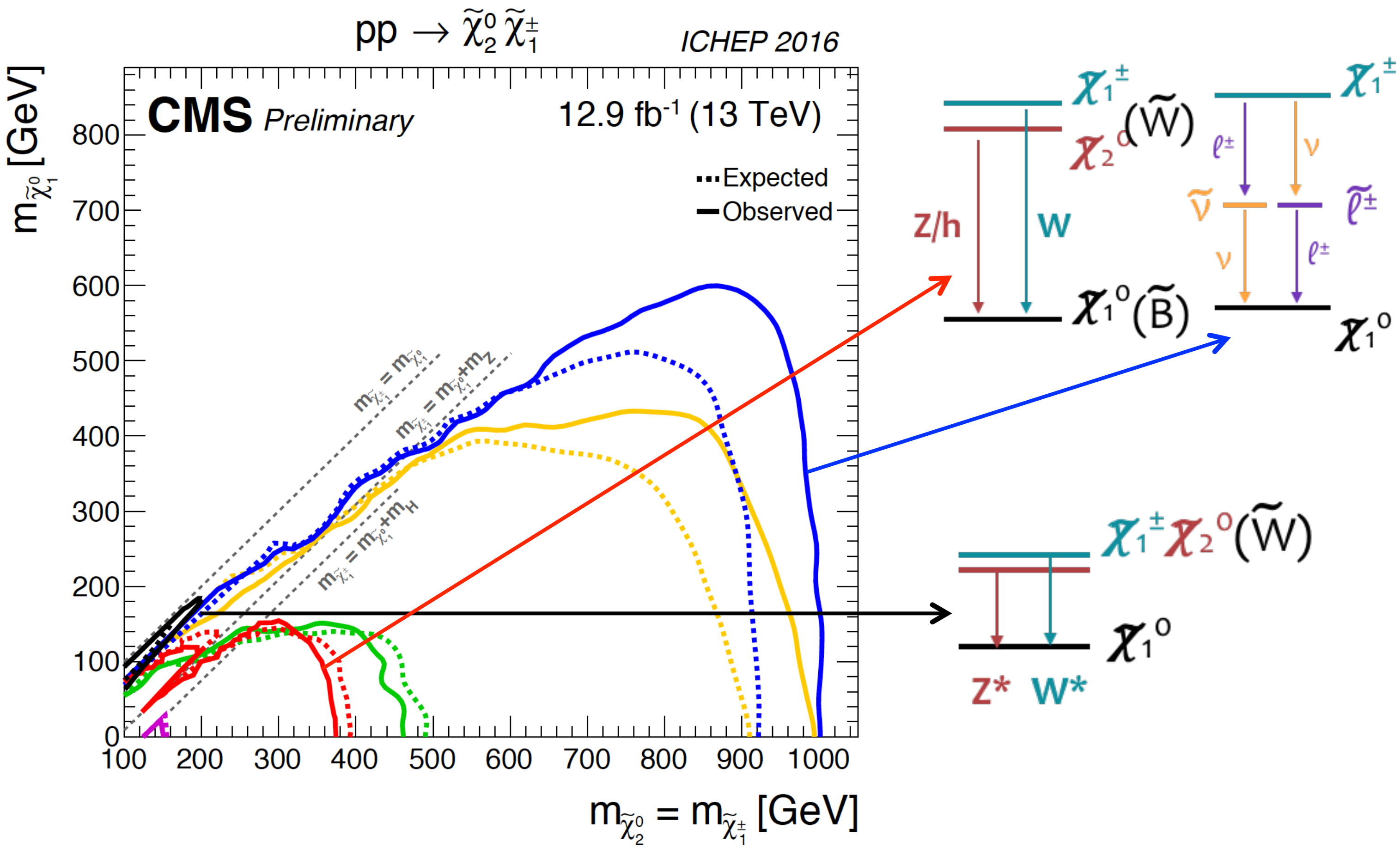
Spectrum: In principle, any hierarchy allowed, interesting when Higgsino is the lighest





#electroweakSUSY

CMS has a full program: covering large fraction of phase space



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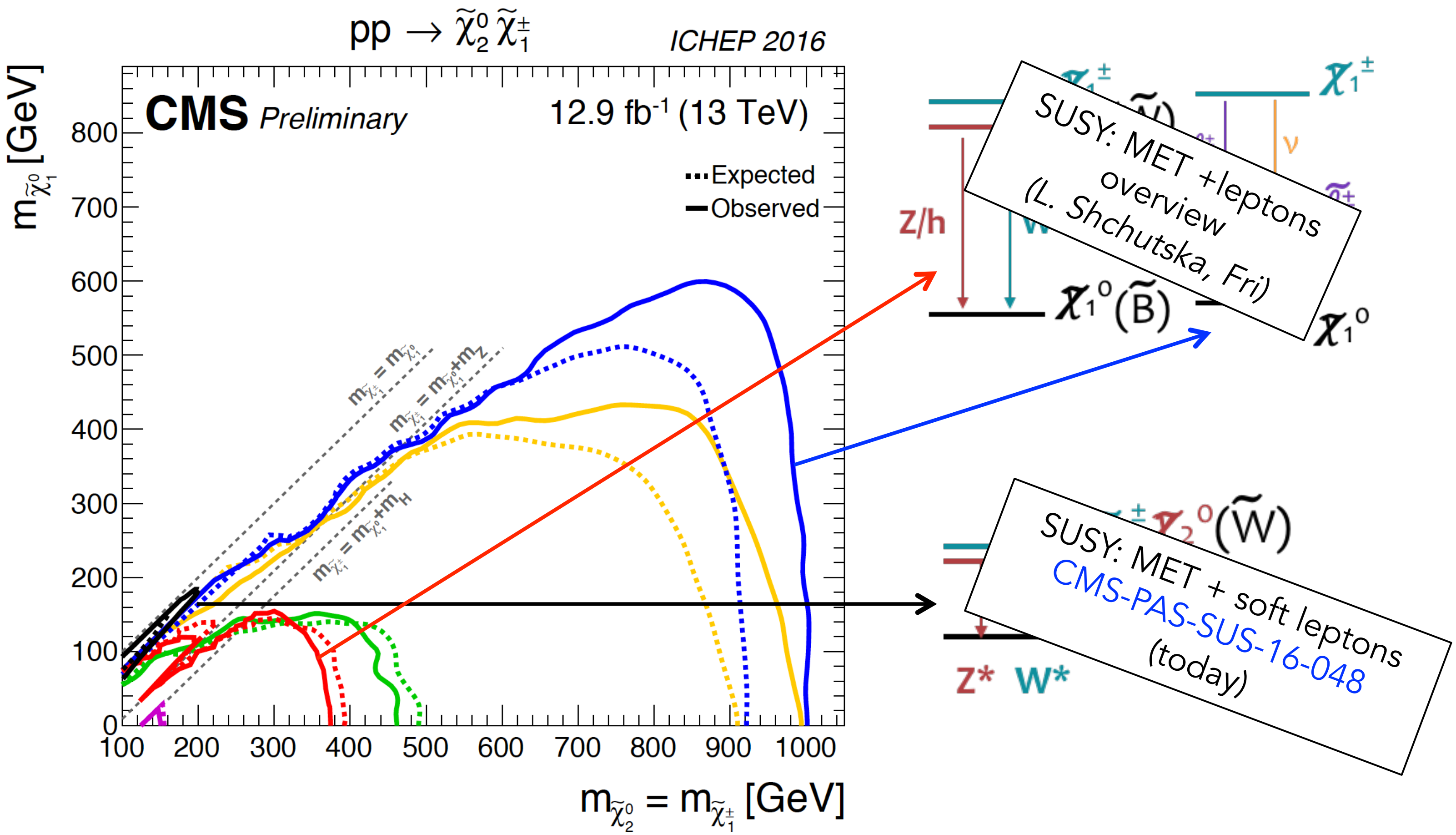

Why #compressedSUSY ?

#compressedSUSY and #Naturalness

- m(Higgsino)< 200-300 GeV (&& m(gluino)< 2 TeV, m(stop)< 1 TeV)
- Higgsino are likely mass-compressed

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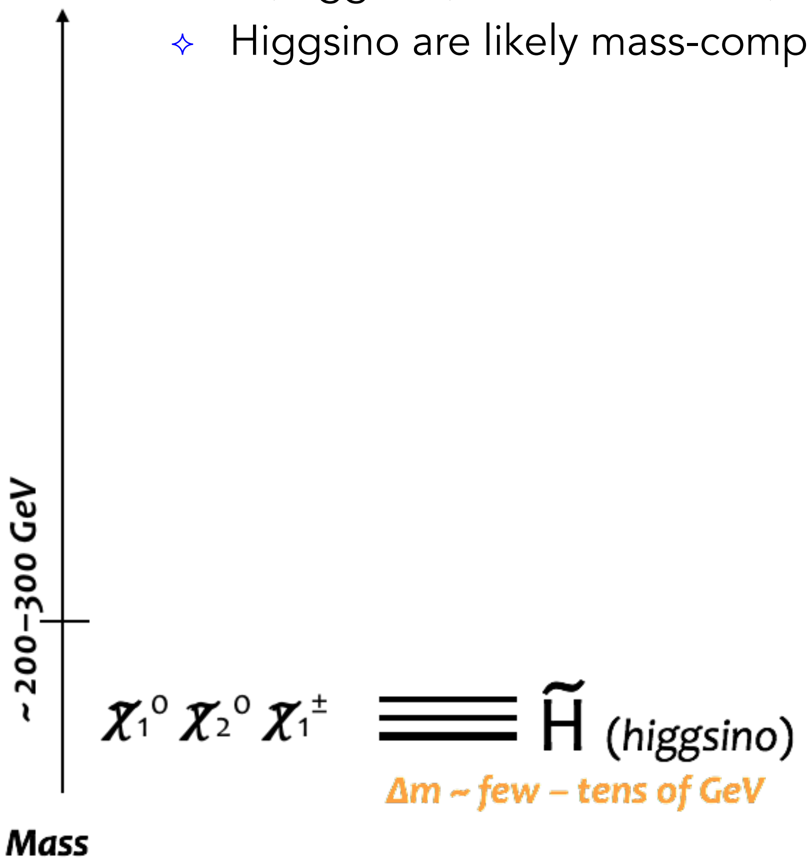

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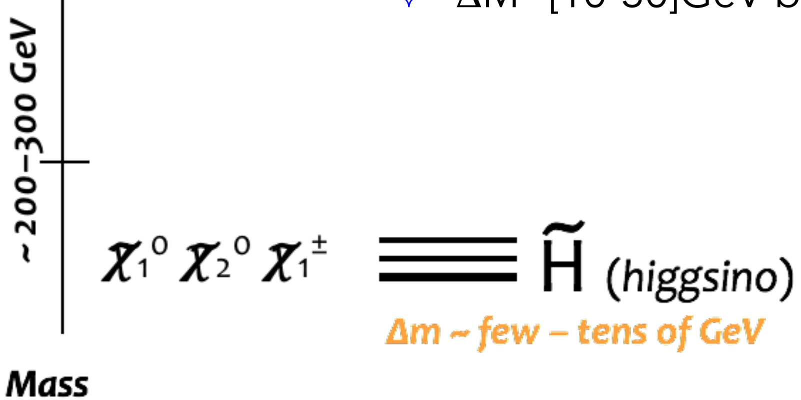
#compressedSUSY and #DarkMatter

- co-annihilation reduces DM and get right relic density
- ΔM=[10-30]GeV between co-annihilation partners

[Phys. Rev. D 70, 015007]



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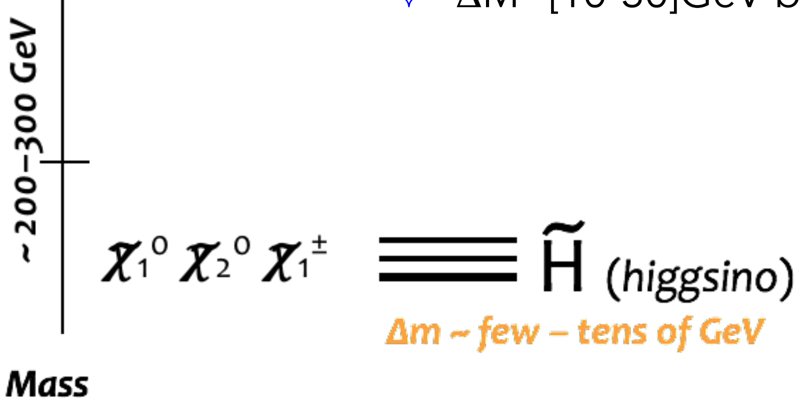
#compressedSUSY and #Stop

- Low ΔM between (light) stop and LSP motivated in literature

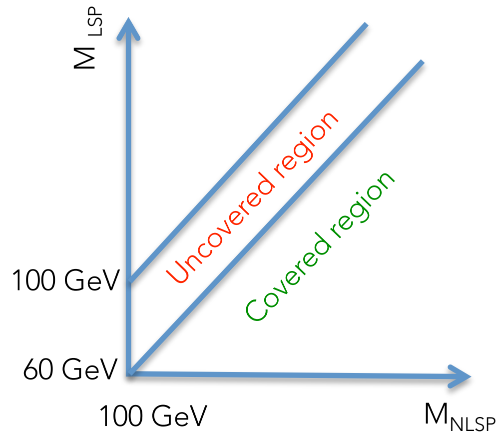
[https://arxiv.org/abs/1212.6847]



Compressed for experimentalists

Compressed can be used for ΔM(NLSP, LSP)<40 GeV

- LSP carries out most of invisible energy
- Small energy fraction left to visible decay products
  - off-shell leptonic W and Z for EWK SUSY sector



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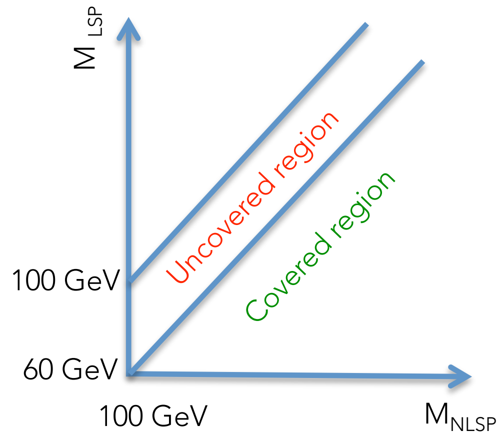

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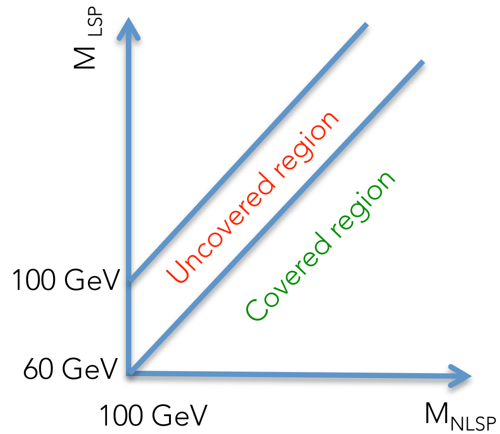

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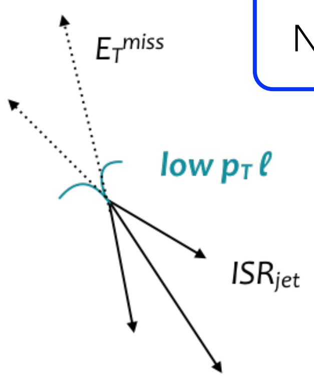
Need a boost in the transverse plane to see something → ISR jet



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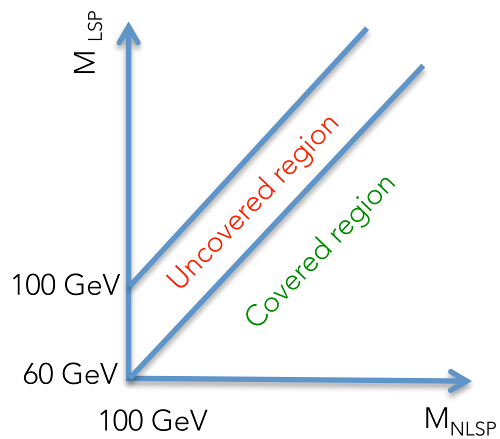

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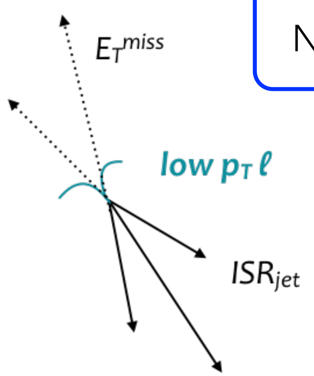

A challenging detector signature

- Low missing energy: less than ~200 GeV
- Low-pT leptons: pT~[3-30] GeV

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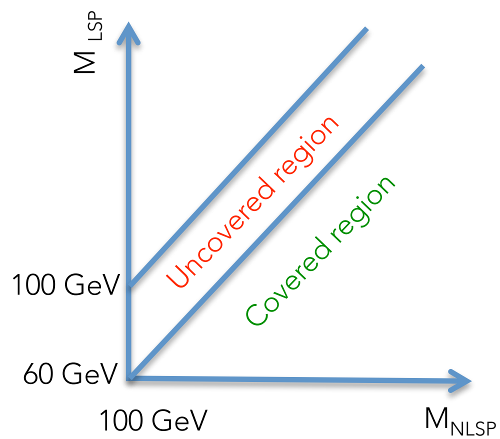

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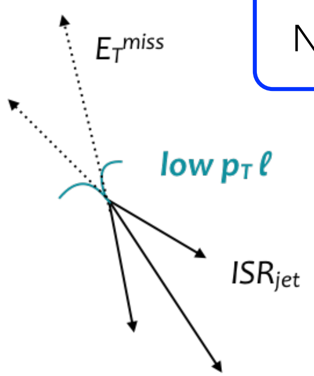

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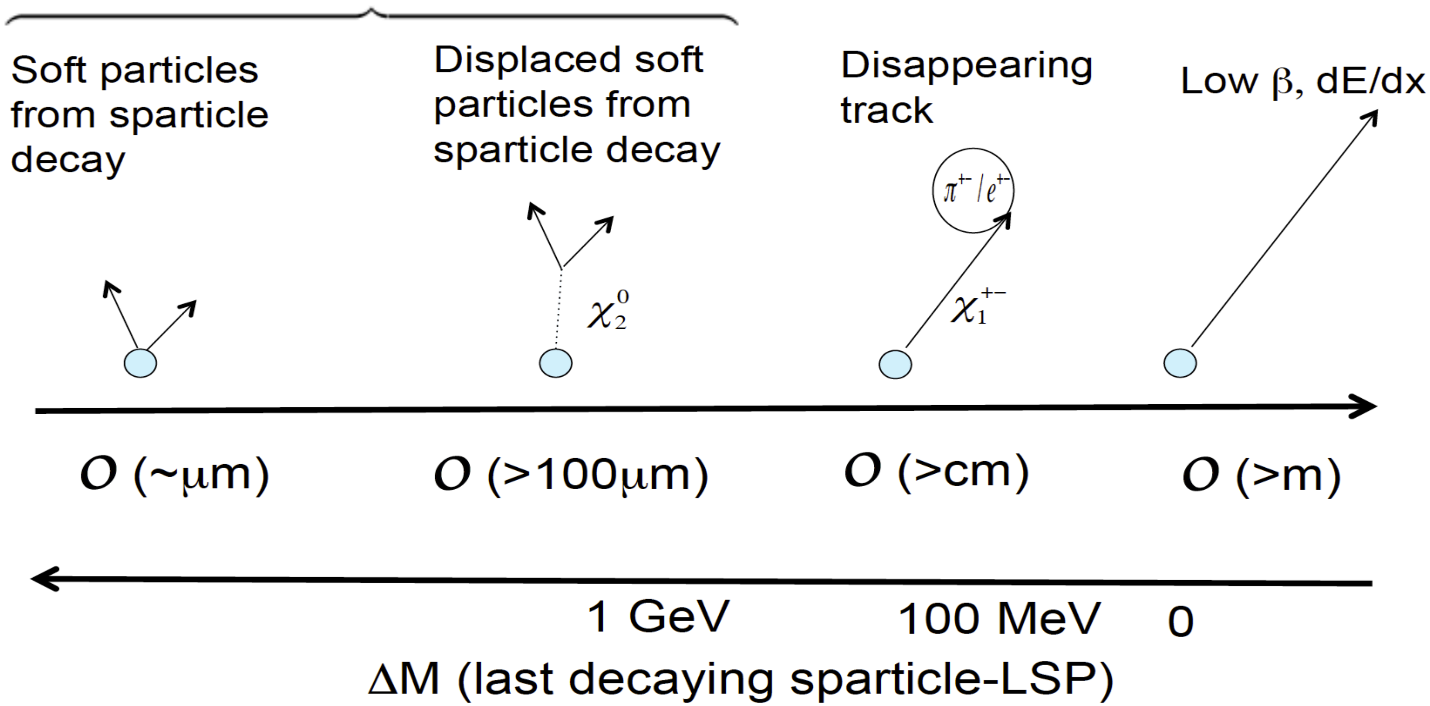
…pays back: O(100k) less bkg than pure monojet search! (for same MET)

Signatures vs strategy

Triggering on ISR or MET (monojet like topology)



But with the increasing of LHC instantaneous luminosity during Run2:

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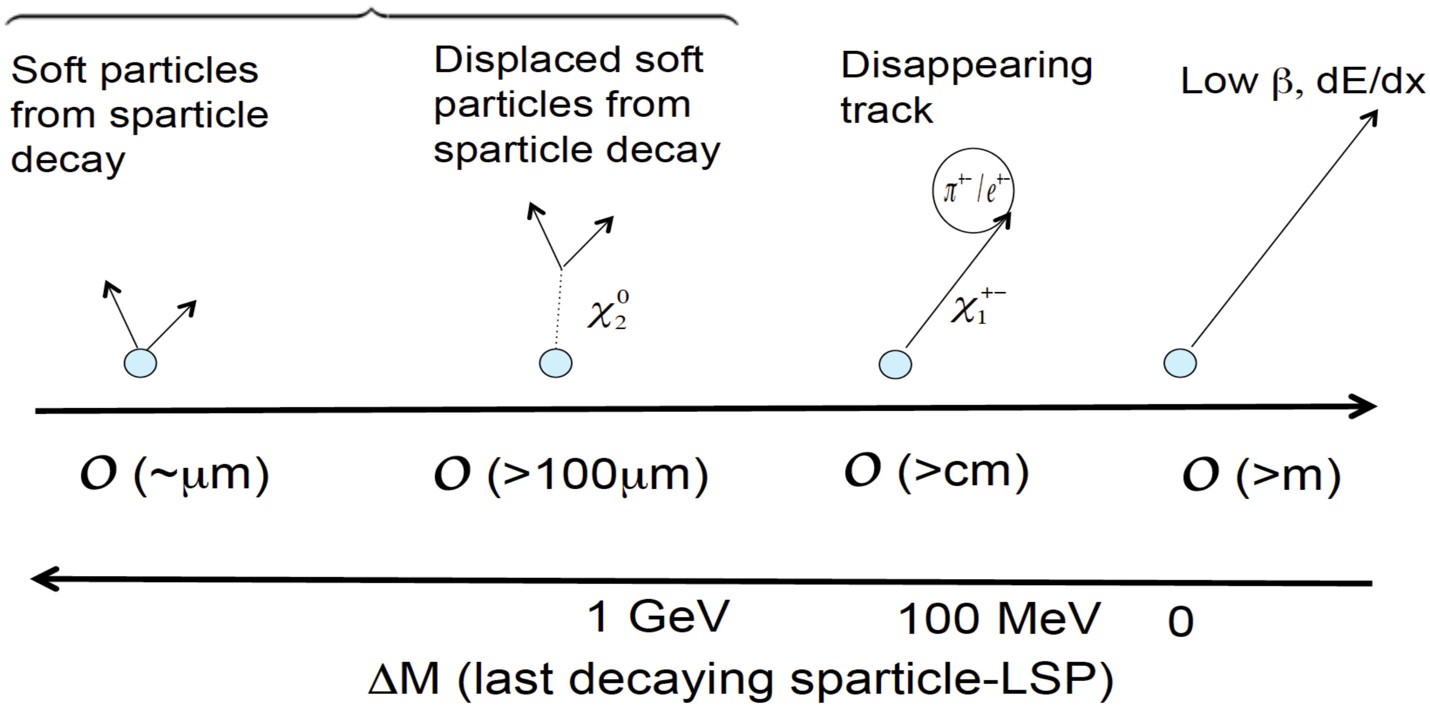

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New technique in CMS during Run2 : Triggering on soft leptons+ MET

The key: triggering

- Leptonic triggers: analyses require pT >20/25 GeV
  - No constraint on MET, can probe down to $\Delta M(ll)>30\text{-}40$ GeV
- MET/ISR triggers: hadronic analyses for non-compressed require MET>200 GeV

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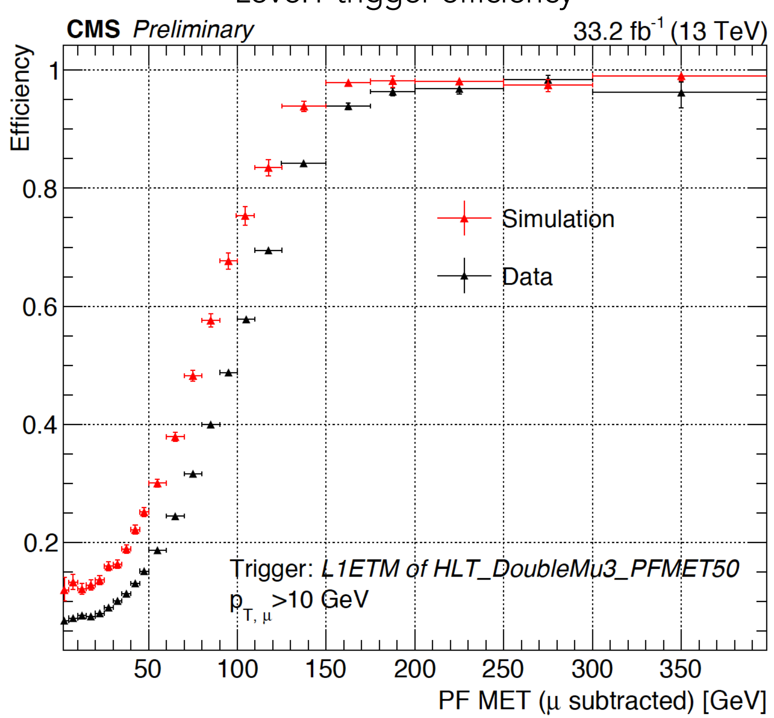
What's new in Run2

Trigger combining low pT muons (3 GeV) and low MET (50 GeV) already at Level1

- Increasing the acceptance:
  - 2 OS μ pT > 5 GeV
  - MET>125 GeV
- 80% trigger efficiency

Level1 trigger efficiency



- MET 200→125 GeV:
  - Almost a factor 2 more in sensistivity!

Designing the analysis

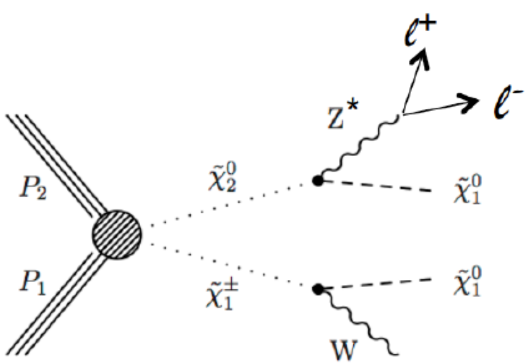
Focusing on the presence of Z*->ℓℓ, i.e. production of $\chi_2^0\chi_1^0, \chi_2^0\chi_1^\pm$

Non prompt leptons

QCD and Quarkonia

DY->tautau

Dileptonic TTbar



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Dileptonic TTbar

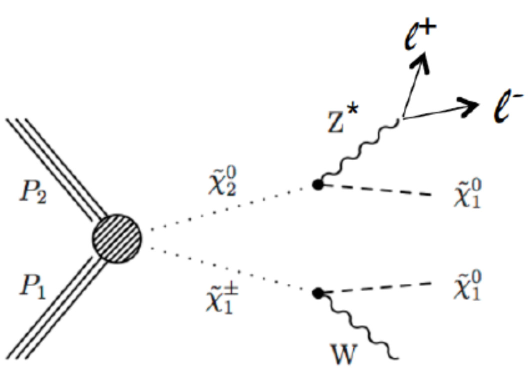
Two SF OS leptons (μ or e) w/ pT=[5-30] GeV
- ✧ Tight ID and lepton IP to reject non-prompt ℓ
  - ✧ Typical ID efficiency for μ(e) 80-90% (50-60%)

ISR jet and *MET* > 125 GeV, *Υ veto*

M(tautau) > 160 GeV, reduce boosted DY→tautau

B-jet veto: reduce TTbar dileptonic

MTmin(ℓ,MET) < 70 GeV: for signal MET *aligned*



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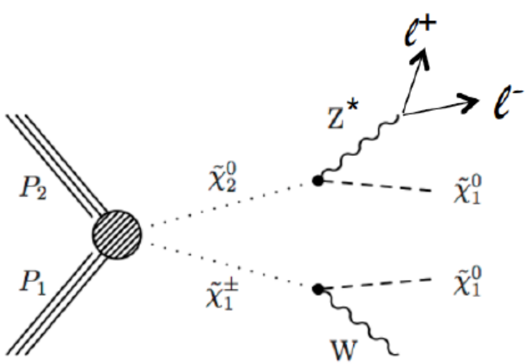
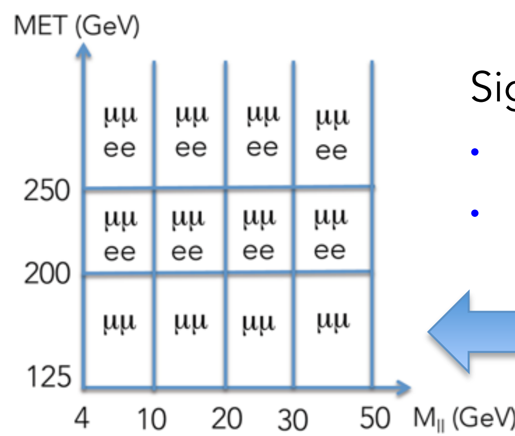




Signal region (SR) binned in:

- m(ℓℓ) (signal edge)
- MET (125-200-250-∞)

New trigger

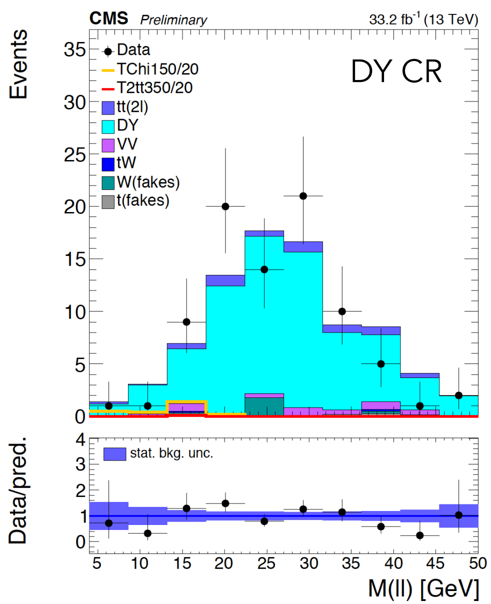
Backgrounds

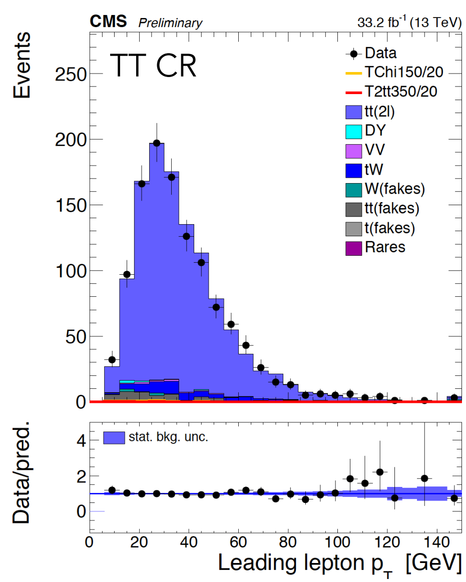
Define bkg-dominated control regions (CR) similar in phase space to SRs

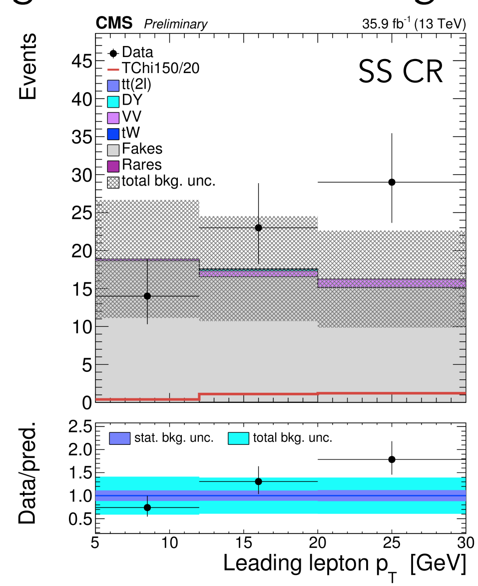
- Shapes validation in data
- CR fitted simultaneously to the SRs bins, to constrain normalization

- DY CR: inverted m($\tau\tau$) cut, relax ℓ IP and upper ℓ pT cuts
- TTbar CR: ≥ 1 b-jet, relax upper ℓ pT cuts
- VV (mainly WW): from simulation, normalization validated in dedicated CR
- Non prompt: probability for non prompt ℓ to pass ID measured in data

+ bkg-dominated *same-sign (SS)* CR

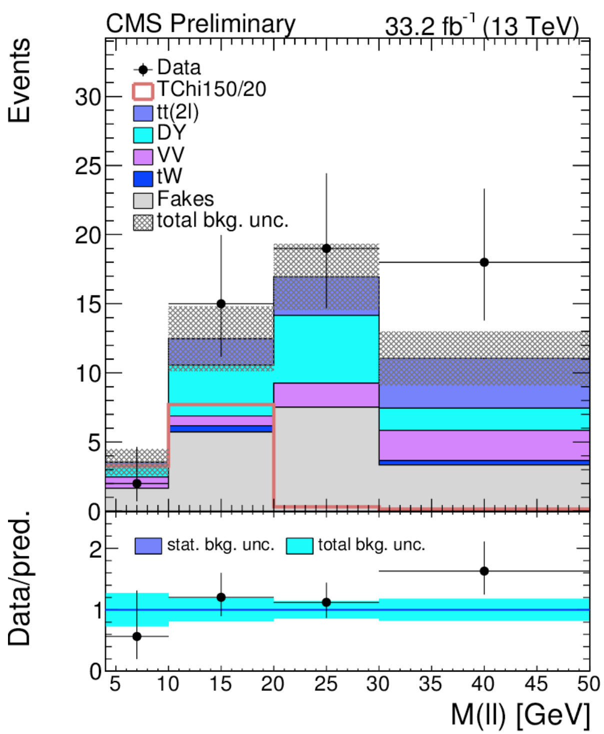




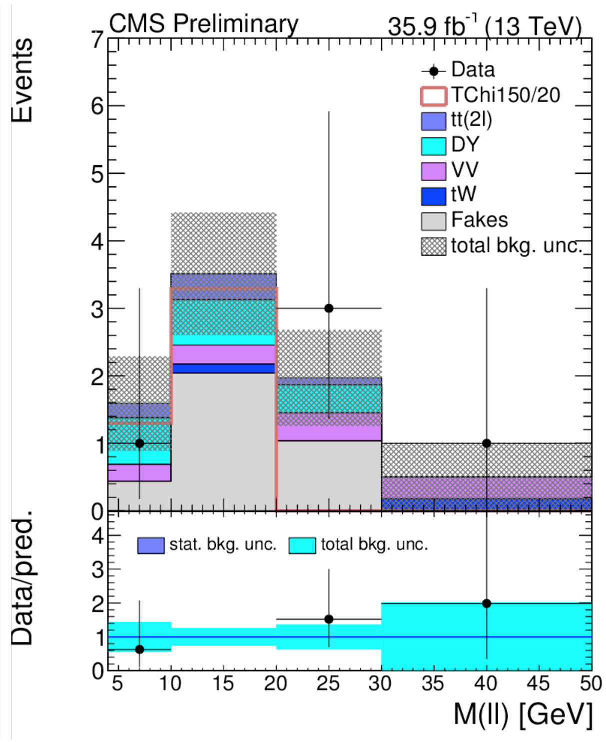


Opening the box

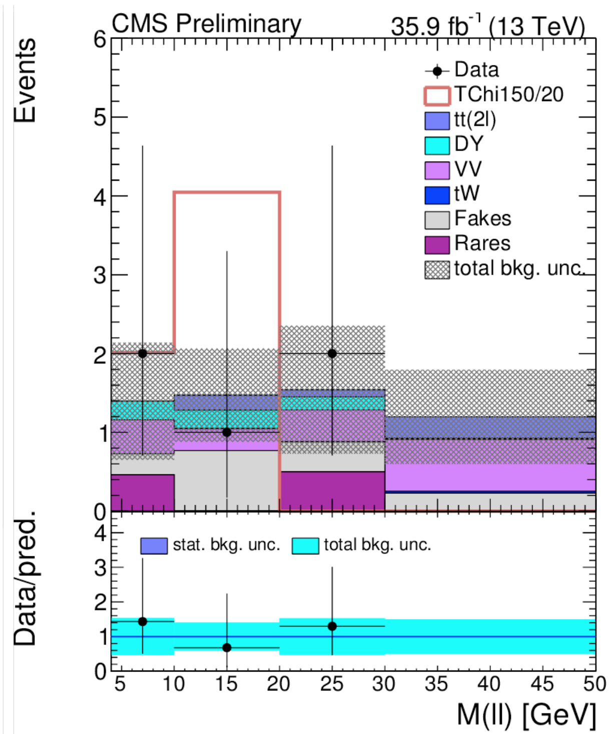
$125 < E_T^{miss} < 200$



$200 < E_T^{miss} < 250$



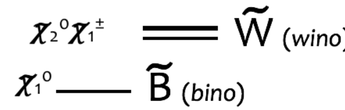
$E_T^{miss} > 250$



"No significant excess" [cit.]

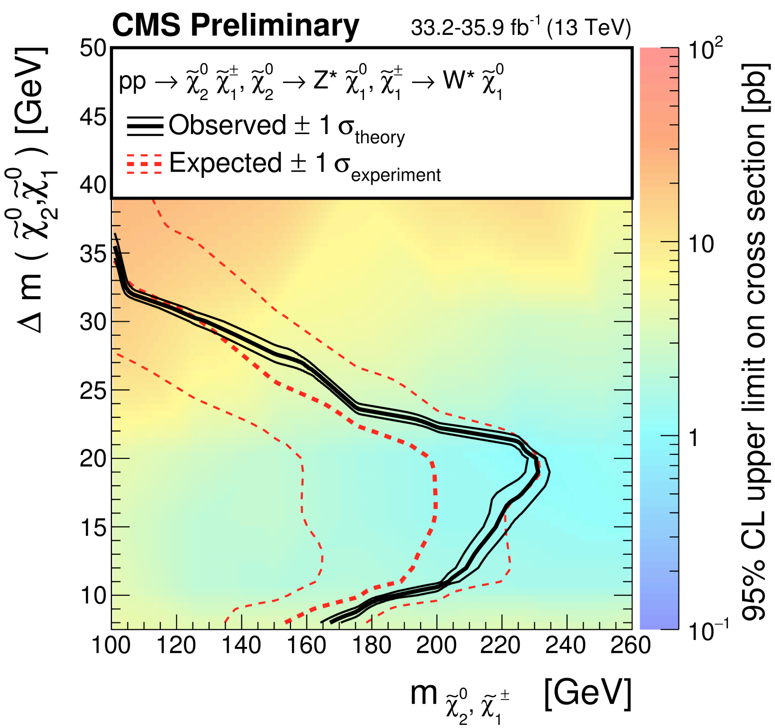
Interpretation

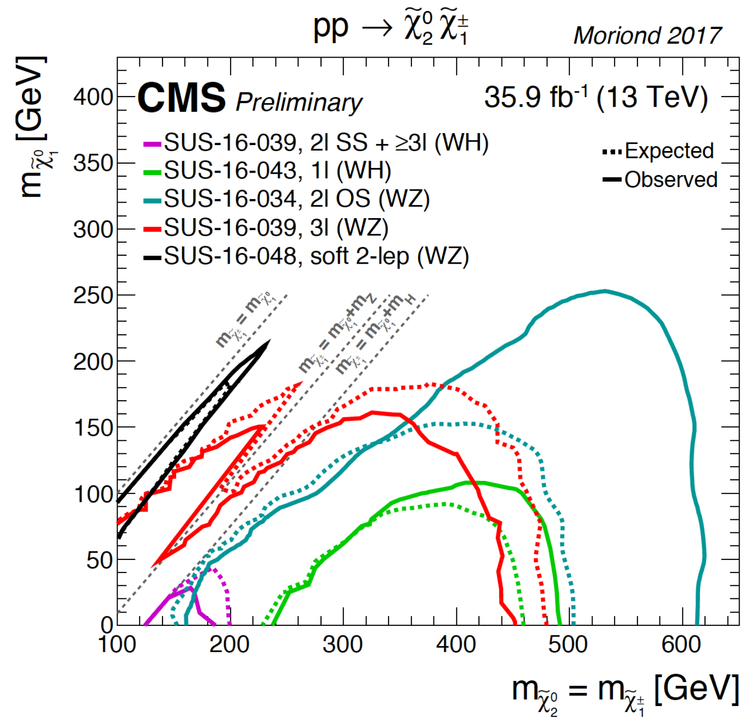
Results interpreted using NLO+NLL Wino pure cross-section
[Eur. Ph. J. C 73 (2013) 2480, JHEP 10 (2012) 081]



First coverage at LHC of region 7.5 GeV<Δm(NLSP,LSP)< 30 GeV

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





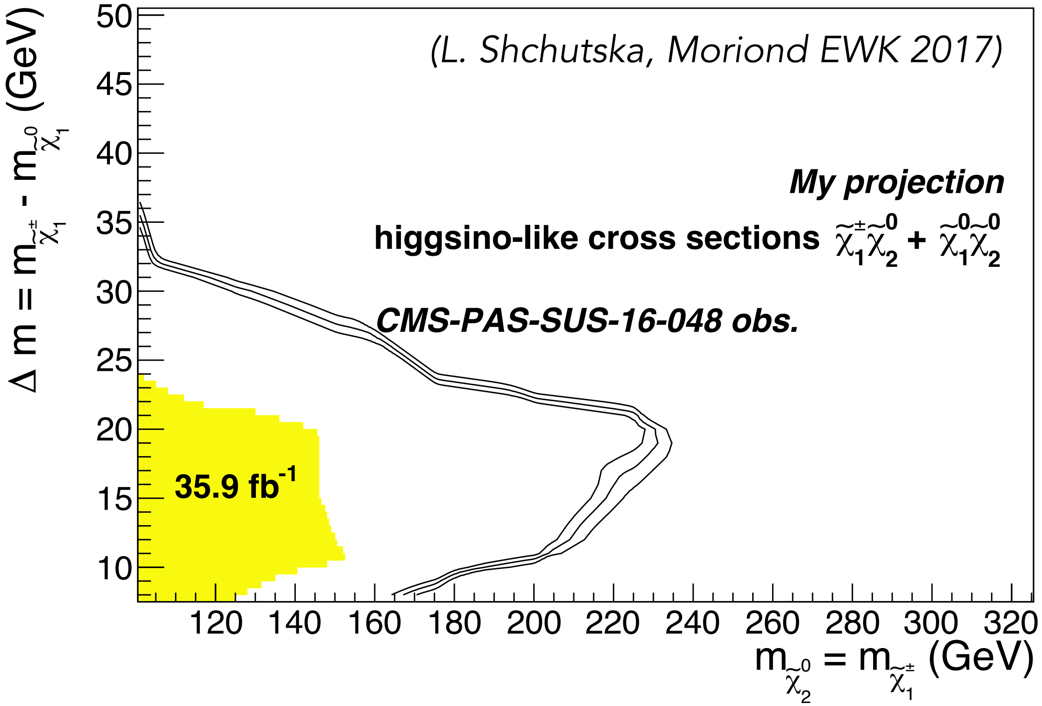
Nice complementarity with other SUSY EWK analyses

What if Higgsinos are DM?

Assuming instead of Wino the Higgsino x-sec for mode $\chi_2^0\chi_1^0 + \chi_2^0\chi_1^\pm$

Only projections so far, but results will be out soon

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



Will extend the limits for the first time after LEP!

Summary and thoughts

- LHC Run2 explores new territories in the *SUSY EWKino sector*
  - Low cross sections, leptonic final state powerful tool
- *Exclusion possible* for a large phase space and corners thanks to:
  - New ideas and improvement of exp. techniques (trigger, lepton ID,..)
- *Low pT leptons* have been used to probe corners *for the first time at LHC*:
  - Sensitive to light degenerate Higgsino (projections, soon results)

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- Adding more luminosity: no drastic improvements
- Should work on refining techniques and strategies
  - Adding a third soft lepton (e.g. we have a soft trilepton trigger, let's do it)
- Access even more *compressed* regions ($\Delta M < 4$GeV)
  - Displaced soft leptons, long lived disappearing tracks, etc..
    - Develop triggers with topological cuts
    - Synergy with analysis looking for generic *exotic* models w/ same topologies
    - AOI (Any Other Idea)

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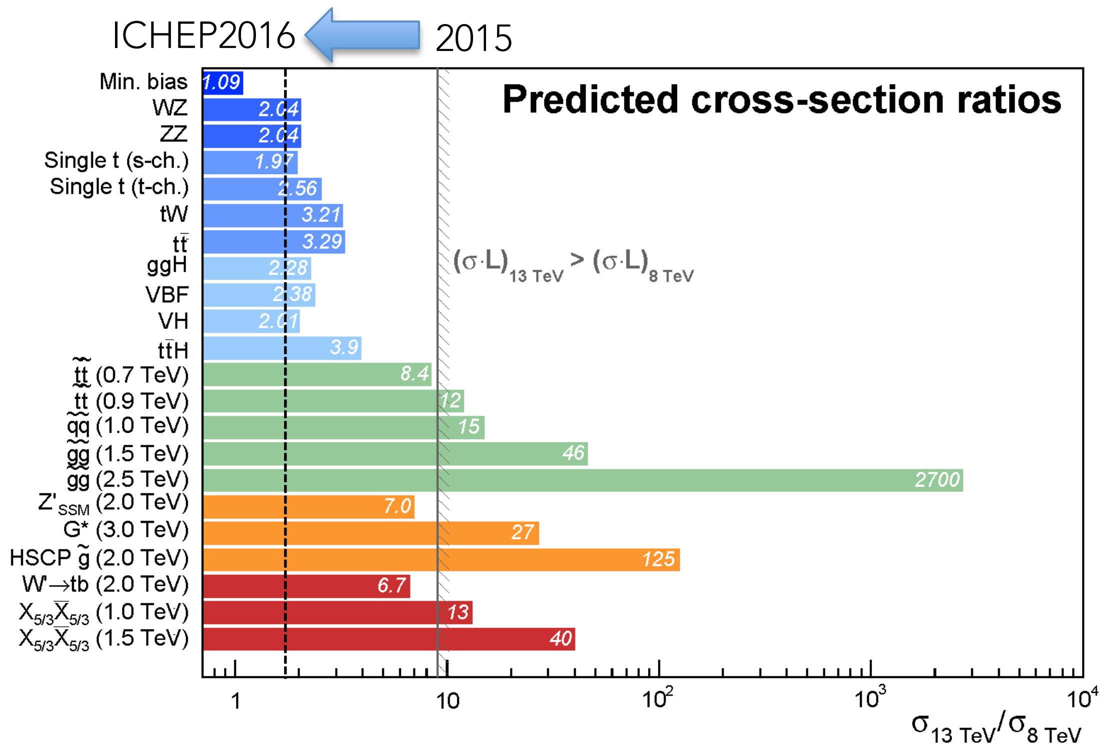
Thank you.

Extra slides

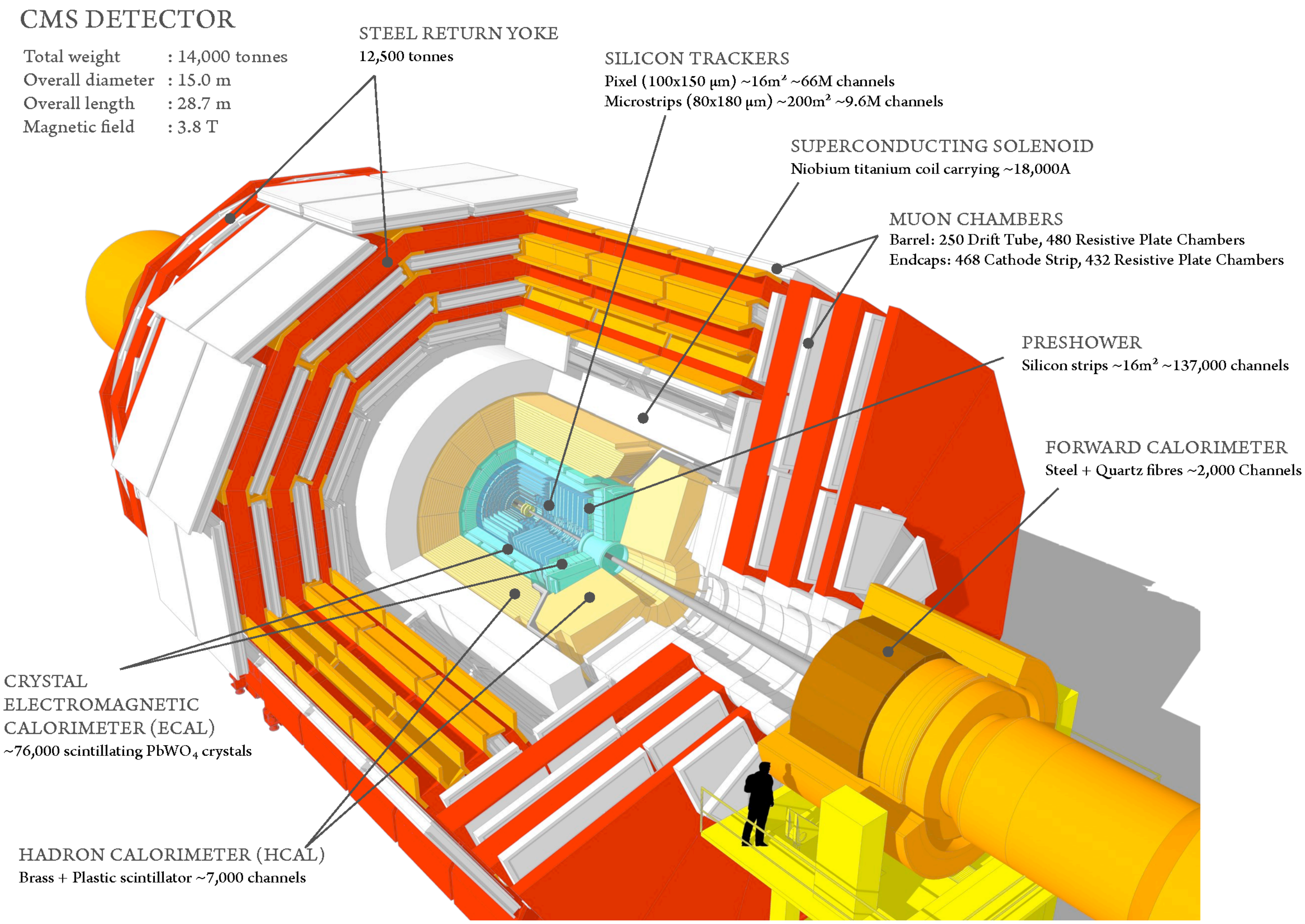
LHC: a tool for going beyond

- LHC8, CMS collected ~20/fb, Higgs boson discovery and its precise measurement
- LHC13 era started in 2015, ~36./fb collected for Moriond17(2.3/fb in 2015) by CMS



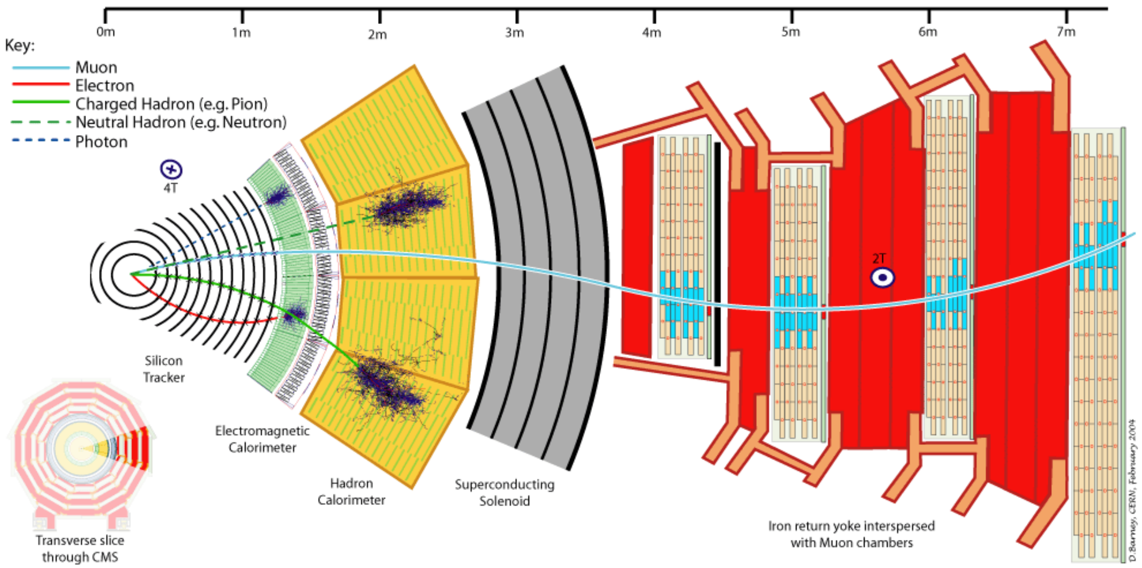
- Cross-section of many BSM benchmarks would significantly increase @LHC13
- E.g. gluino is what would be most abundantly produced (if exists)
- Sharp probes are need to scan all the challenging final states hiding NP

The CMS detector at LHC



The CMS detector

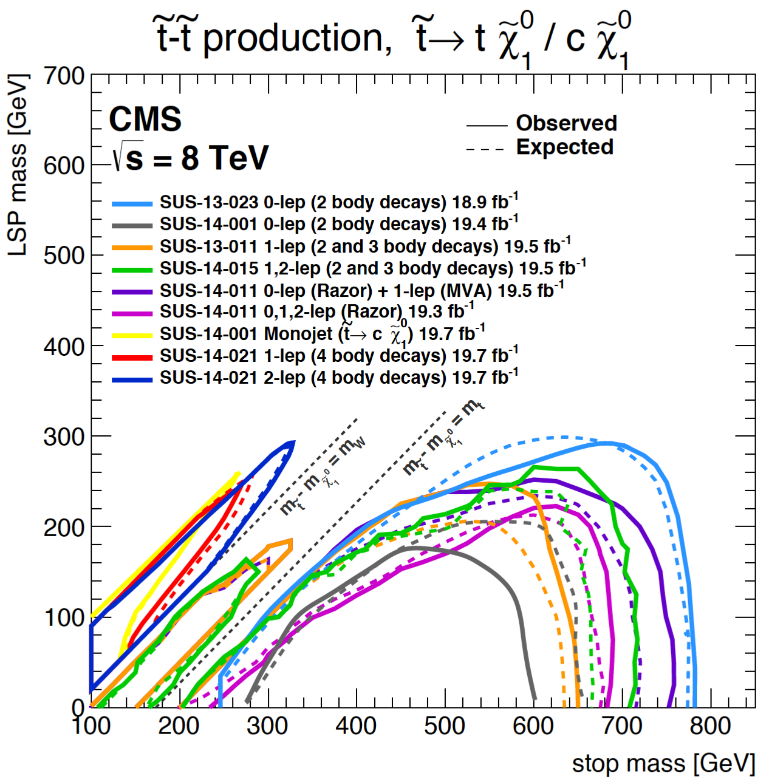
- From particle reconstruction: muons, electrons, hadrons (charged and neutral), photons



- … to physics objects: muons, electrons, jets, photons
- Excellent detector performance:
  - Track-finding efficiency is more than 99%
  - Transverse momentum resolution: $\sigma(pT)/pT$= 1.5 - 3% for tracks of pT ~ 100 GeV
  - Energy resolution for electrons and photons: $\sigma(E)/E$~ 1 %

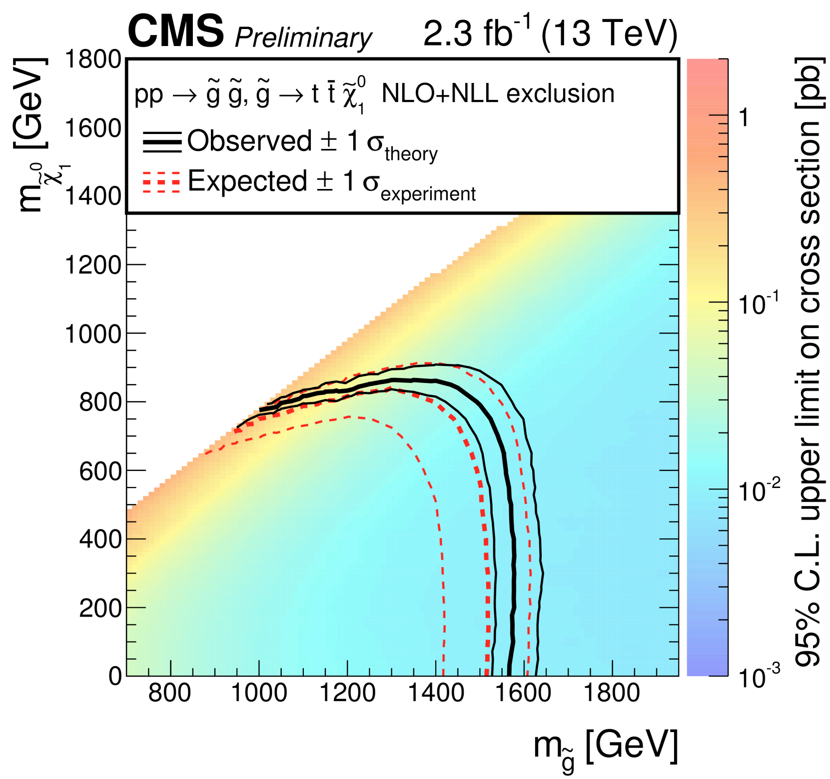
How to read all this?

- Showing the potential of the different final states in constraining a model



Bulk is proven by the hadronic, corners (*compressed*) mostly by leptonic final states

- Model independent limits on the cross section for a specific final state (+ specific benchmark contour)

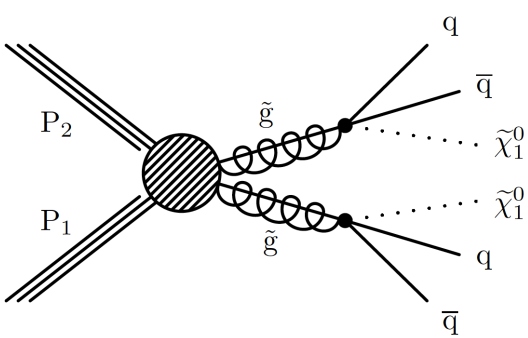


Can be reinterpreted in any other model with the same final state (modulo signal efficiency)

Hit parade of SUSY models (as of today)

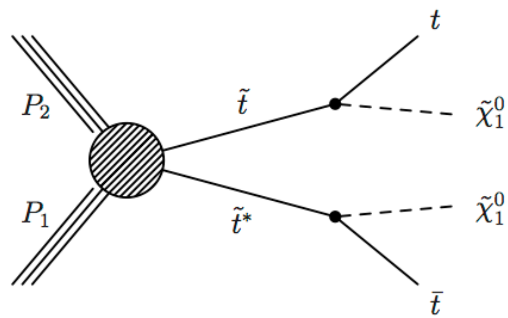
(assuming R-parity conservation)

Gluino pair production

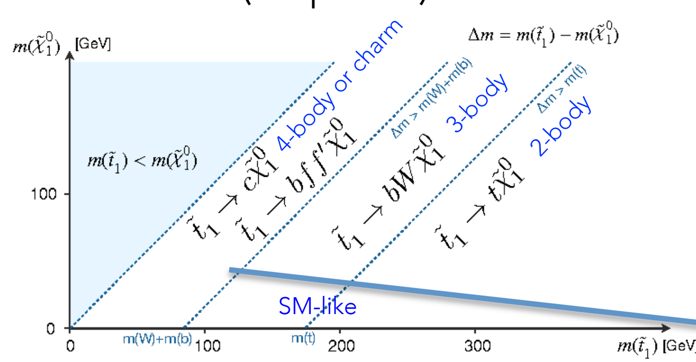


- Highest SUSY x-section
- Characterized by high hadronic activity in the event
- Can give access to other sparticles via decay chains

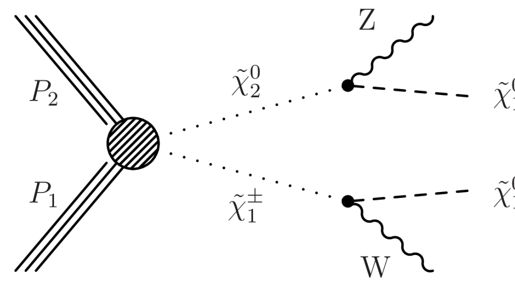
Stop pair production



- Low-mass stop required by natural SUSY (~<1TeV)
- Decays depend on the Δm(stop-LSP)



EWK production



- Few jets, many W,Z: high leptonic activity
- Small cross sections, accessible only now
- Small mass splitting in natural SUSY, Δm(C1-N1)~ few GeV

Compressed SUSY

The importance of being *lepton*

- In R-parity SUSY, LSP is stable and also a natural DM candidate
- LSP at rest = nothing in the detector, need a (transverse) boost

the key: Missing Transverse Energy (MET)

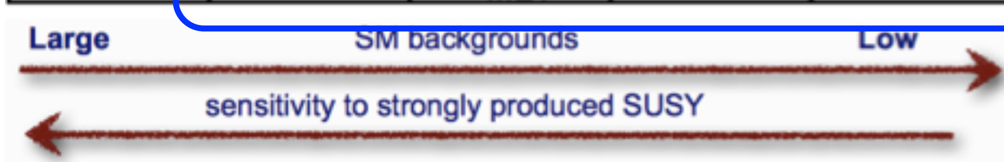
+ jets: purely hadronic final states, ideal for early discoveries

- High BR, very sensitive to strong productions
- Suffer of large backgrounds

+ leptons: leptonic final states

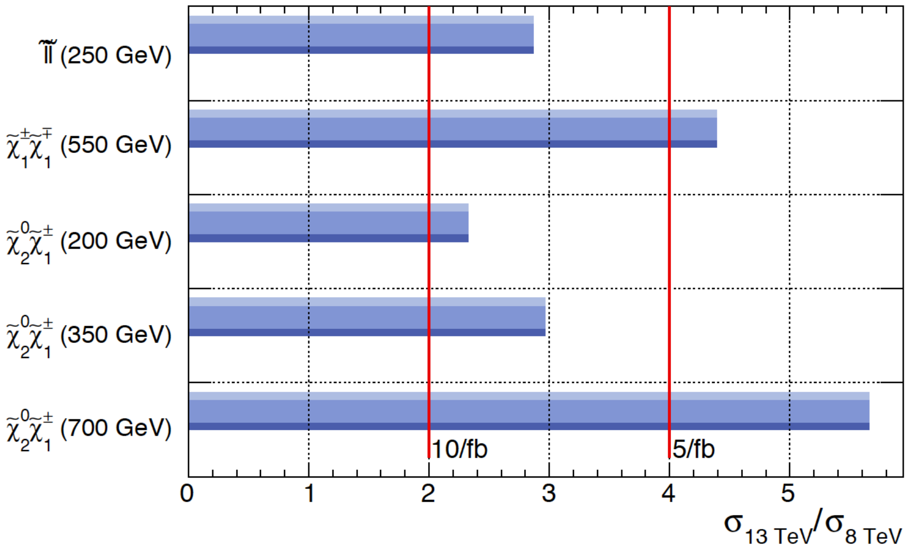
- Targeting generic decays but also corners of phase space (e.g. compressed)
- Smaller BR, but low SM background

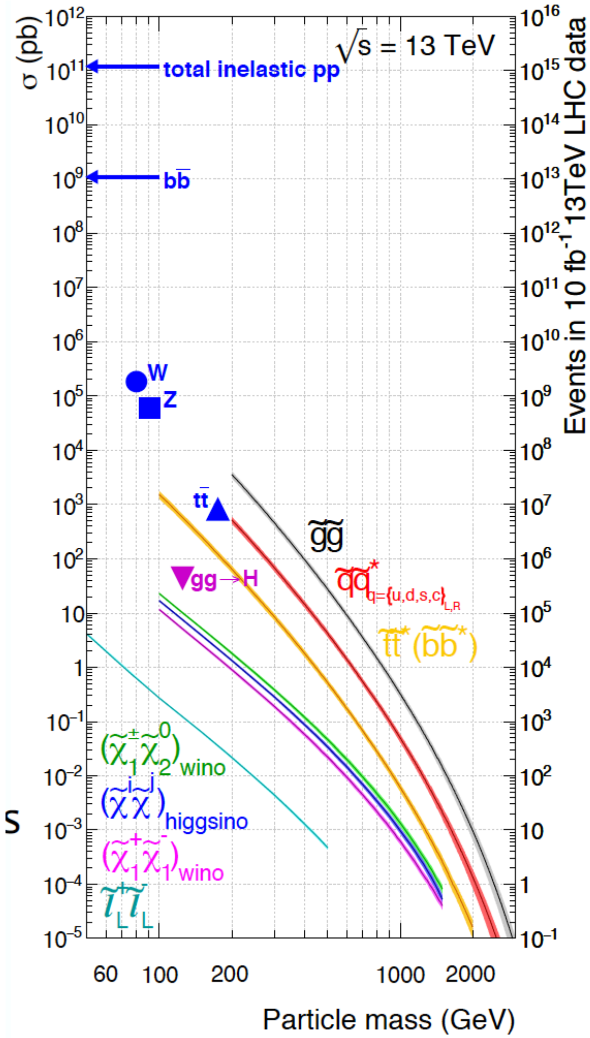
0-leptons	1-lepton	OSDL	SSDL	≥3 leptons
Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton



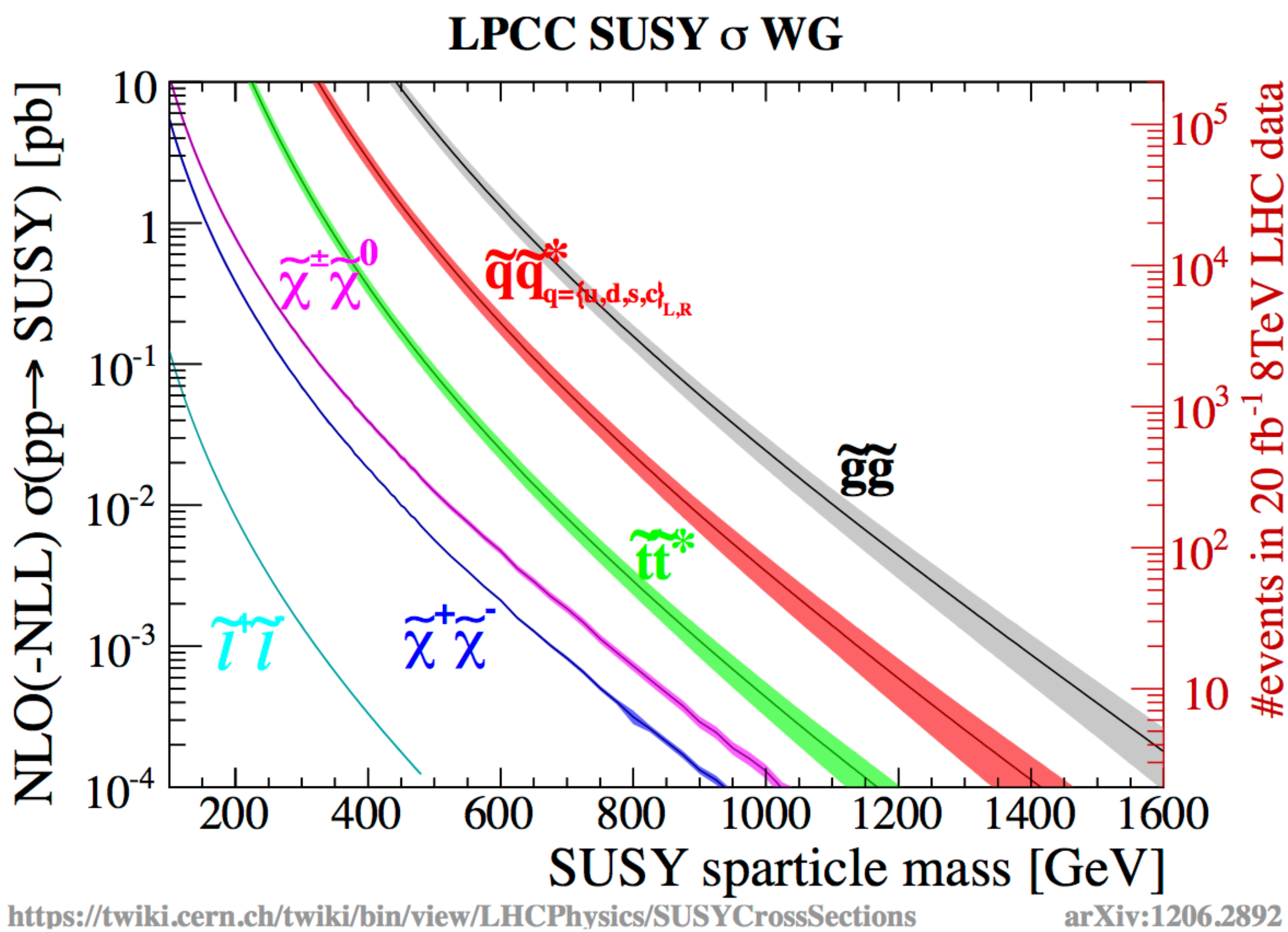
SUSY cross sections at LHC13

Electroweak signatures with the midsummer dataset:





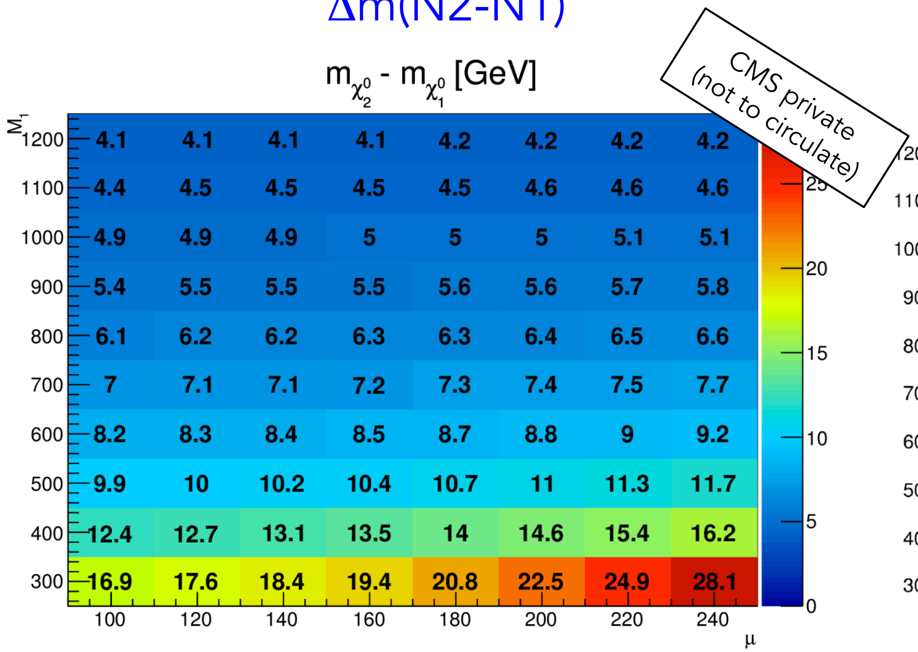
SUSY sparticle pair x-section



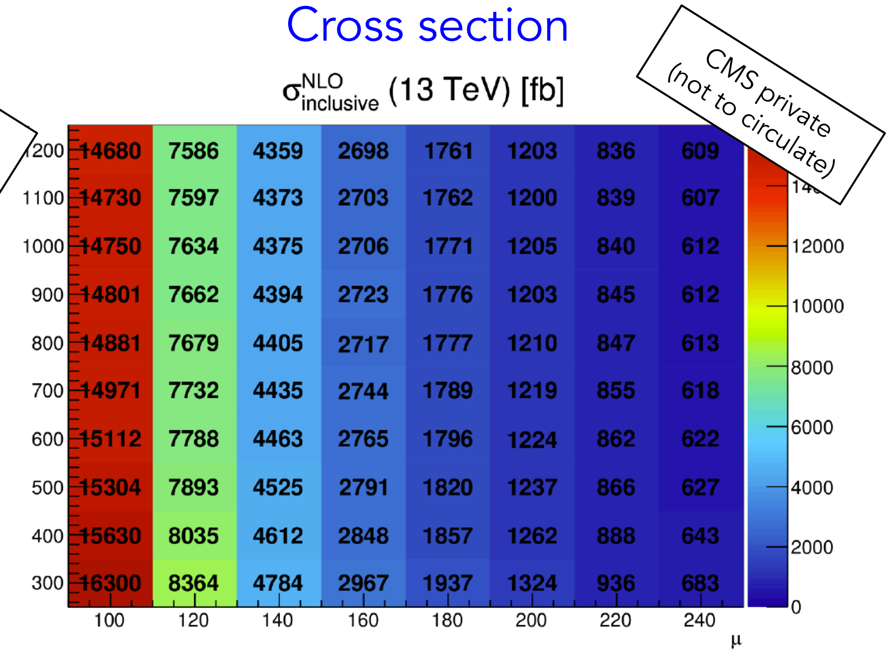
Higgsino full model (pMSSM)

- Δm can range from 2-4GeV (M1~1200 GeV) up to 20-30GeV (M1~300 GeV)
- To have gaugino unification at the GUT scale: M2=2xM1, M3 decoupled
- Ingredients are there: NLO inclusive cross section and 2L efficiency (~5%)

$\Delta m(N2-N1)$

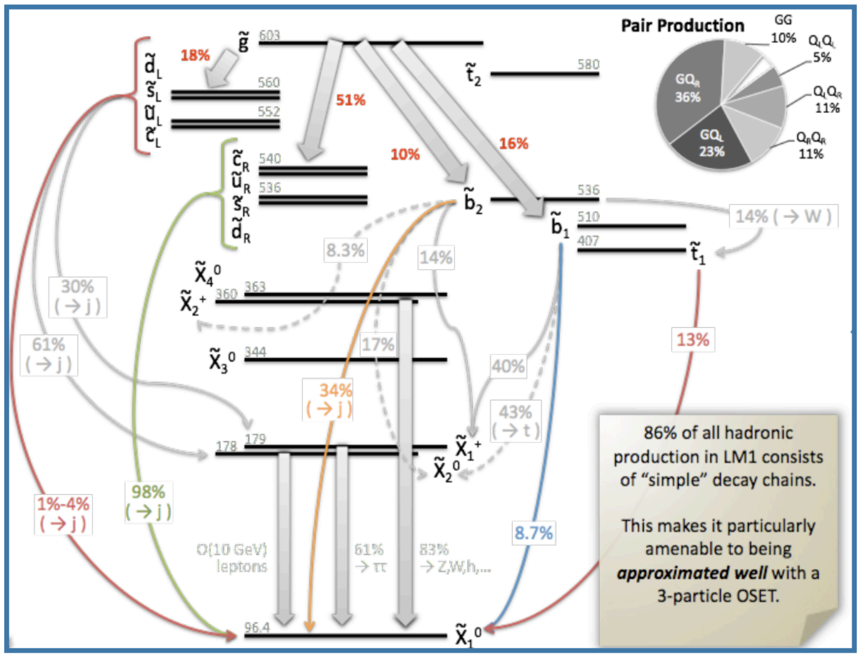


Cross section

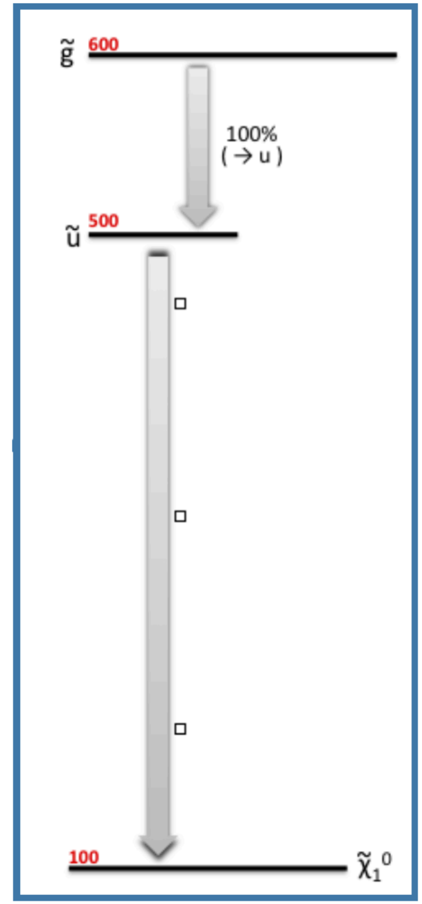


Different views in HEP

SUSY model for a theorist



SUSY model for an experimentalist



Mostly dealing with *simplified models*

- 2-3 particles, 1-2 decay modes at a time, 100% BR
- Not really a statement on theory, but rather showing potential for a specific kin.

Kinematics of the simplified model