SEARCH FOR SUPERSYMMETRY AT CMS

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Overview

➜ **Motivation and Introduction of Supersymmetry**

Indirect Searches

Direct Searches for Supersymmetry
- Inclusive all-hadronic searches
- "Natural-SUSY" stop, sbottom searches
- Search for gauge-mediated SUSY with photons
- Electroweak produced Supersymmetry
- Stealth models

The dilepton mass-edge analysis

Conclusion

New physics beyond the Standard Model: Supersymmetry

- **After the discovery of a Higgs Boson:**
  - **Hierarchy problem** has become a real problem!
  - What mechanism is responsible for the Higgs mass?

- **Supersymmetry can provide viable dark matter candidates:**
  - Implies stable lightest (neutral) supersymmetric particles (LSP) leading to missing transverse energy (MET) in the detectors
  - Corollary, limits on SUSY from MET searches do not apply if SUSY LSPs aren't (exclusively) responsible for dark matter

- **Unification of Gauge couplings at the GUT scale**
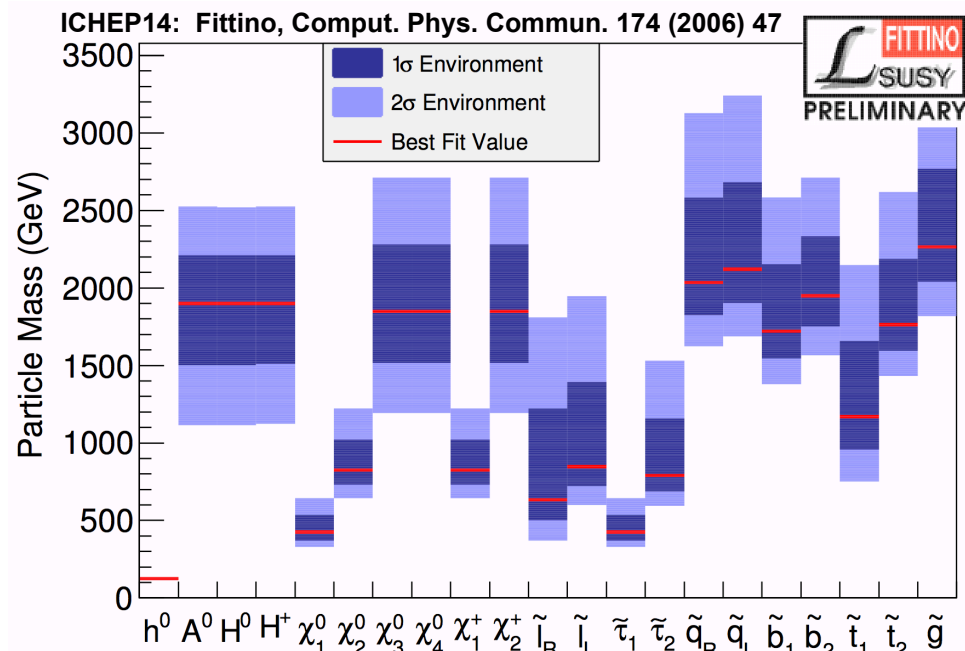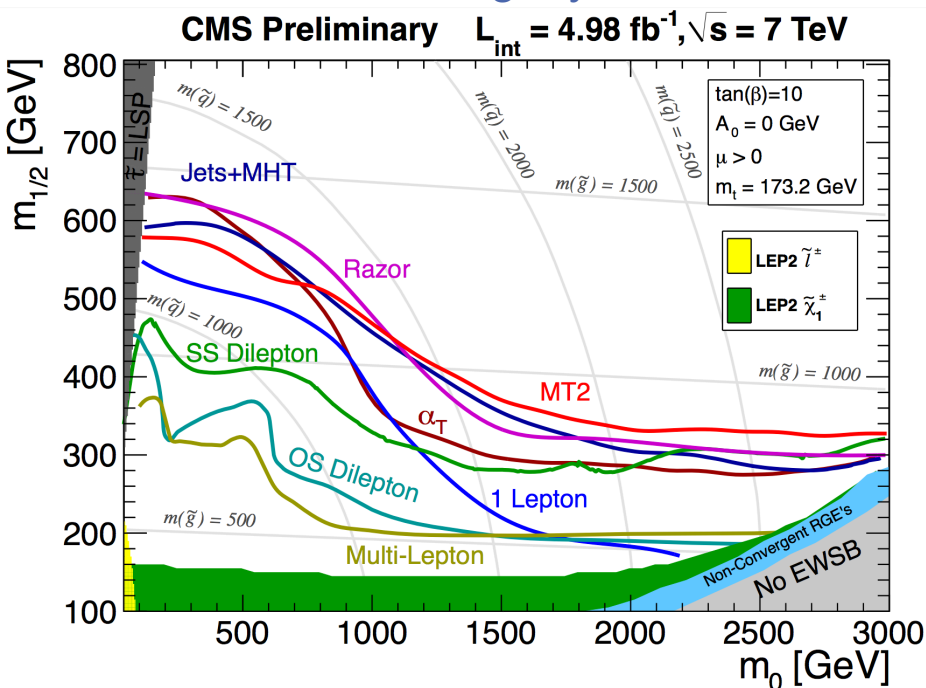
- **Local space-time symmetry naturally includes Gravity**

(Broken) Symmetries can be elegant!
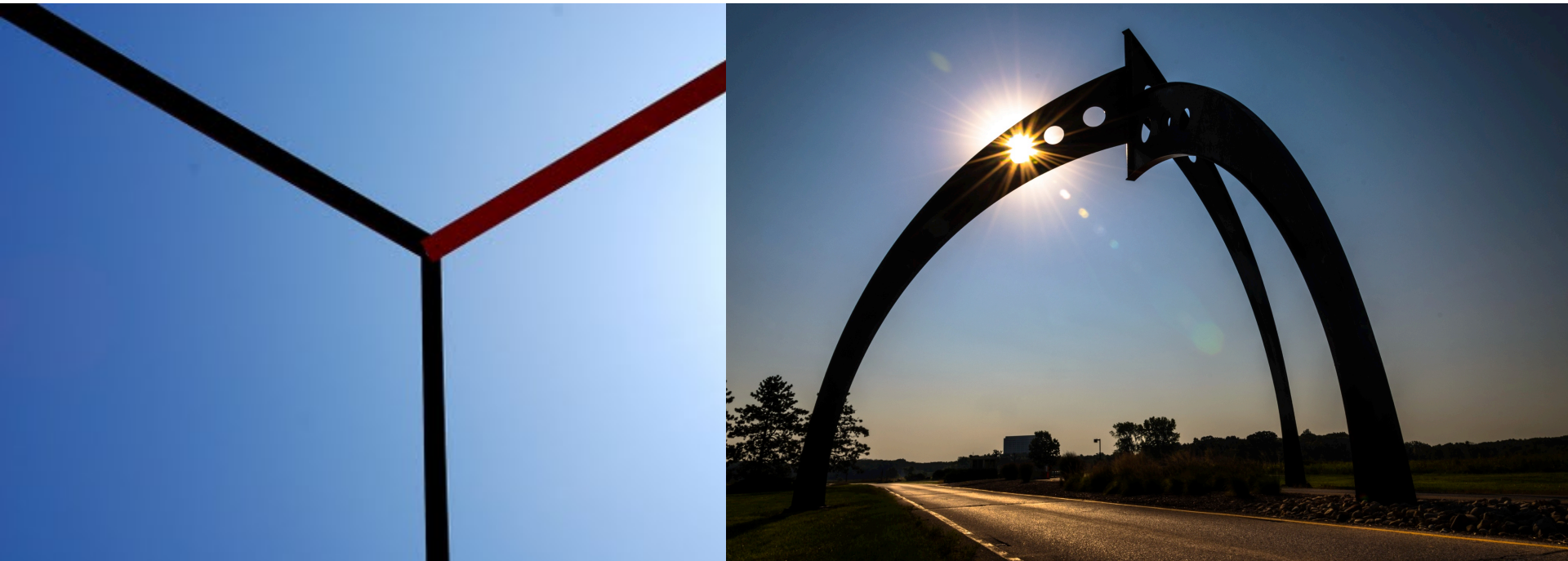
Entrance of Fermi National Laboratory (Fermilab FNAL), near Chicago

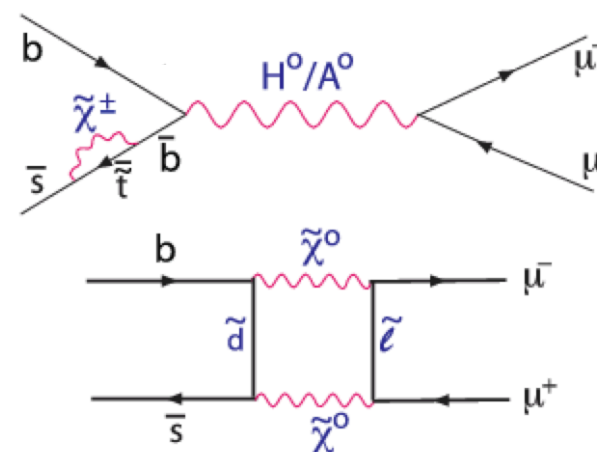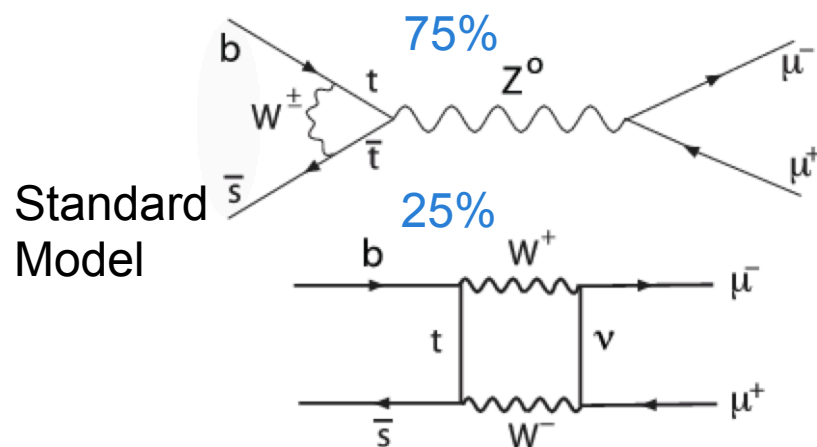# What is the status of the search for Supersymmetry?

7 TeV legacy:

- Simplest models like cMSSM (constrained minimal supersymmetric standard model) basically out of the game
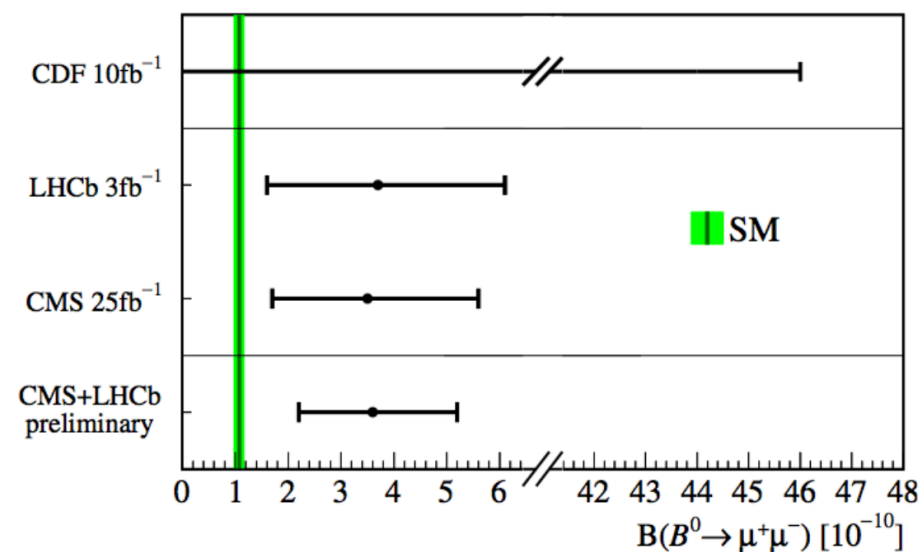- "Natural SUSY" has to have decoupled spectra
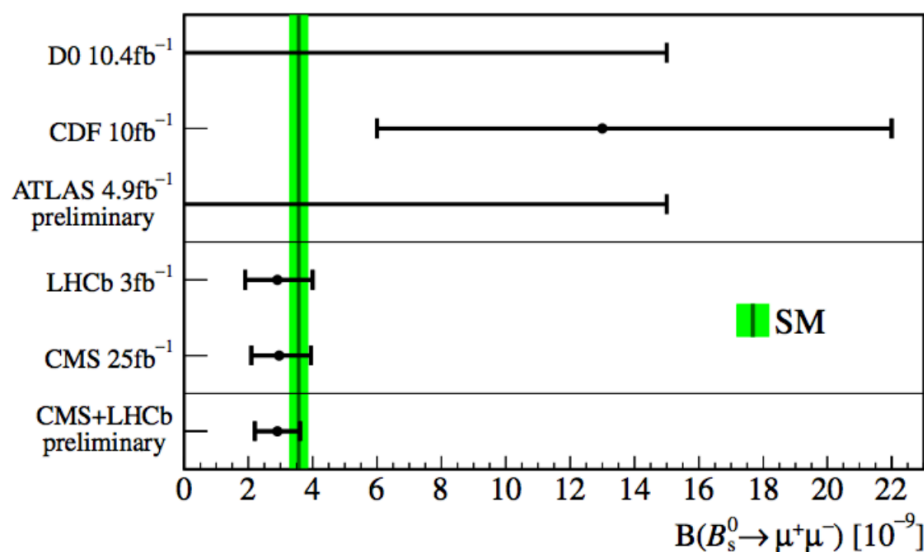
B⁰, B⁰ₛ →µµ: Indirect searches

branching fraction to µµ has sensitivity to "new physics" like Supersymmetry

Standard Model

75%

25%

New Physics

Results: Consistent with Standard Model ➔   Constraints allowed "New Physics"

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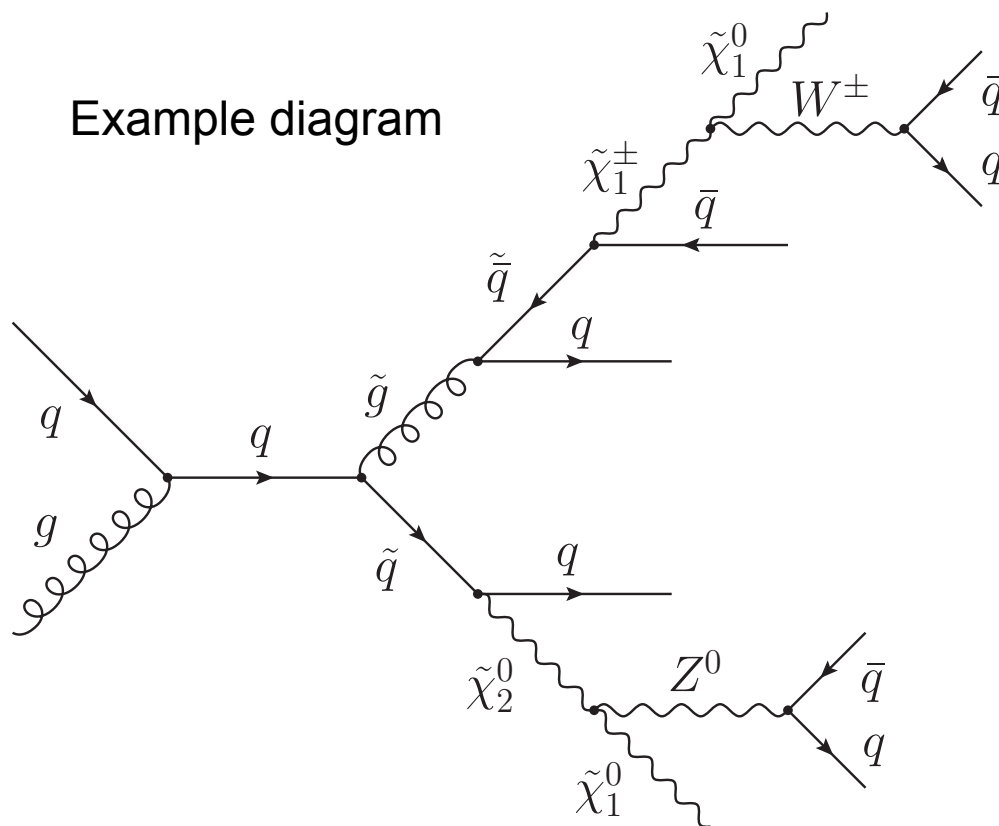- Electroweak produced Supersymmetry
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The dilepton mass-edge analysis

Conclusion

Inclusive search for SUSY in the MET and jets final state

Example diagram

$\sqrt{s}$ = 8 TeV,
19.5 fb^{-1} luminosity
(full 2012)

- Dominant squark and gluino pair/ associated production
- Stable neutralino LSP

Final state
- MHT

  missing transverse Energy

$$\mathcal{H}_T = \left| -\sum_i^{jets} \vec{p}_T,i \right|$$

- Jets
  - High multiplicity or
  - High H$_T$ (scalar sum jet p$_T$)

$$H_T = \sum_i^{jets} \left| \vec{p}_T,i \right|$$

➔ Very little model assumptions

Selection

- 3 jets pT > 50 GeV, |η| < 2.5
- ΔΦ(MHT, jets$_{1,2,3}$) > 0.5, 0.3, 0.3
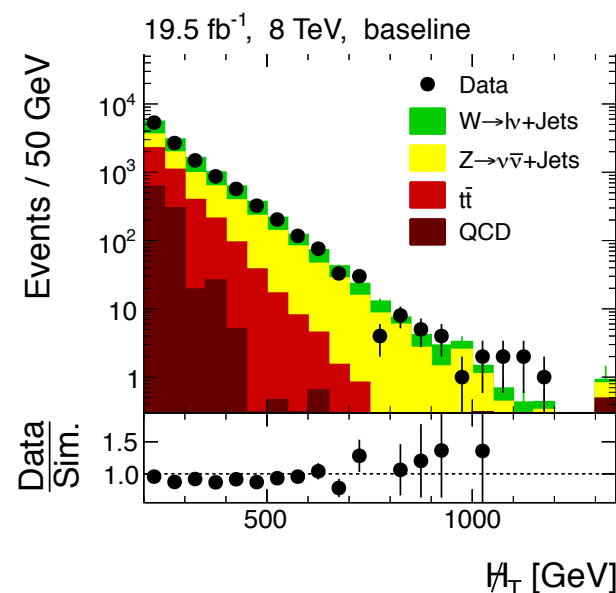- Veto events with isolated e, μ with p$_T$ > 10 GeV

Variable	baseline	36 signal search regions				
Jet-multiplicity	3 -	3 - 5		6 - 7		8 -
HT [GeV]	500 -	500-800	800-1000	1000-1250	1250-1500	1500 -
MHT [GeV]	200 -	200-300		300-450	450-600	600 -

Backgrounds

- QCD multi-jet production
  MHT from jet resolution and mis-measurements
- W/tt➔(e/μ)+jets
  Lepton is not reconstructed
- Z➔νν
- W+jets➔τ+jets

➔ All are estimated using data-driven methods

Baseline selection:

19.5 fb^{-1}, 8 TeV, baseline

Events / 50 GeV

- Data
- W→lν+Jets
- Z→νν̄+Jets
- tt̄
- QCD

Data / Sim.

500   1000

H̸$_T$ [GeV]

Background estimation

- ## QCD multijet estimation
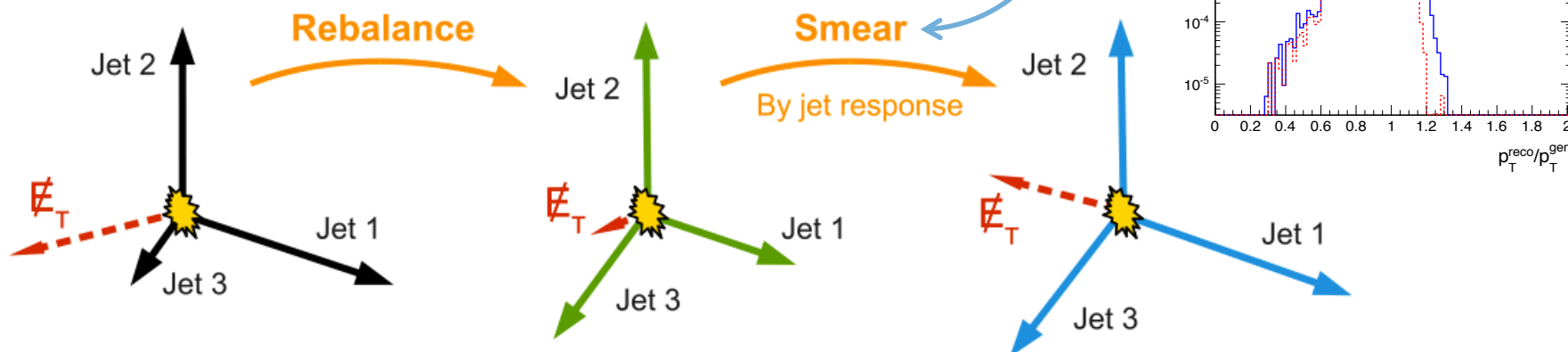
- ## tt/W ➜ (e/μ) + jets, where the lepton is lost
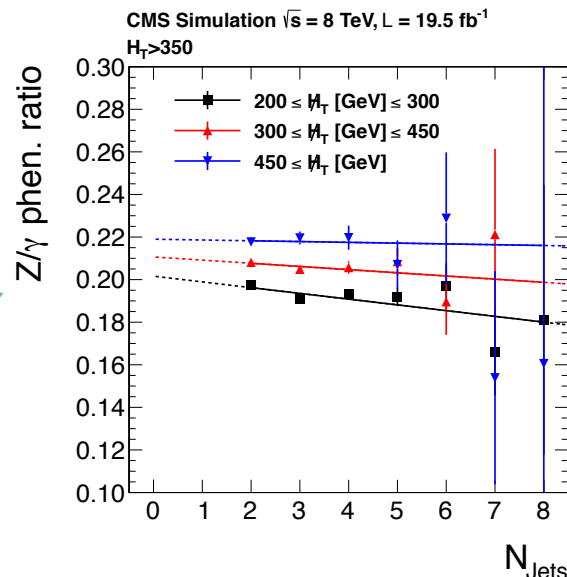

➜ Control sample (isolated muon)

Weighted according to lepton acceptance, isolation, and recon-struction efficiencies
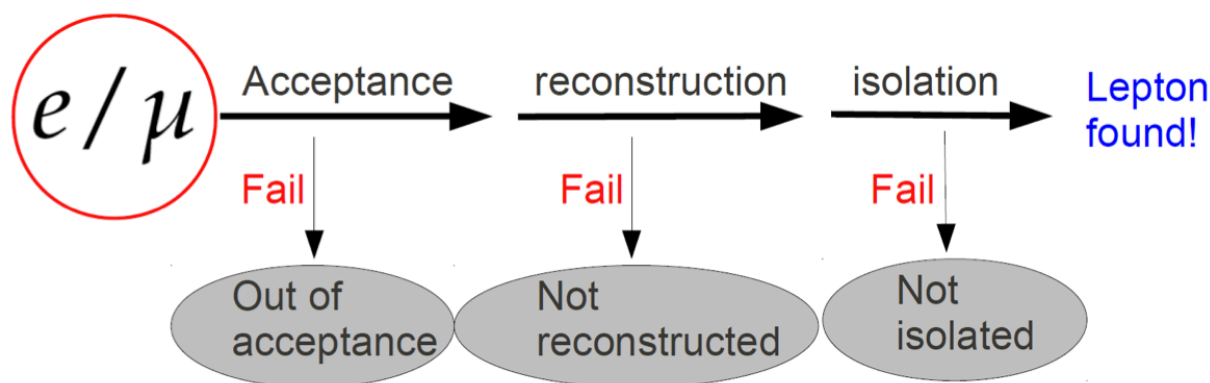
➜ Signal selection (lepton-veto)

Background estimation

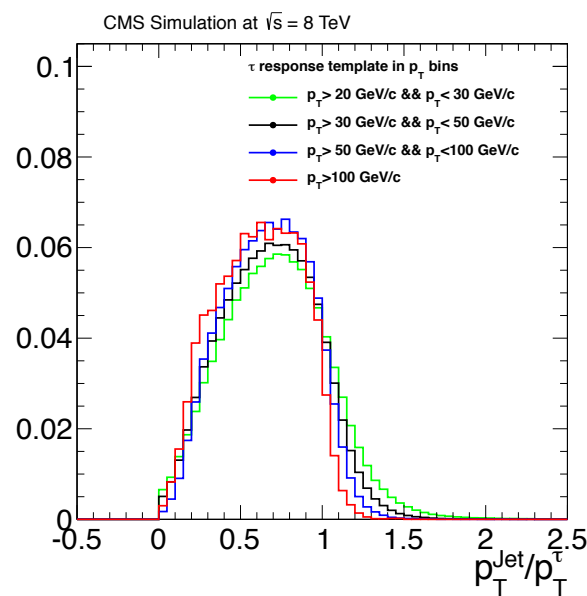- ## Z ➜νν from γ+jets
  - Z/γ similar at high boson pT
  - Replace γ with MET
  - Correct Z/γ ratio using simulation
  - Apply γ acceptance & efficiency corrections

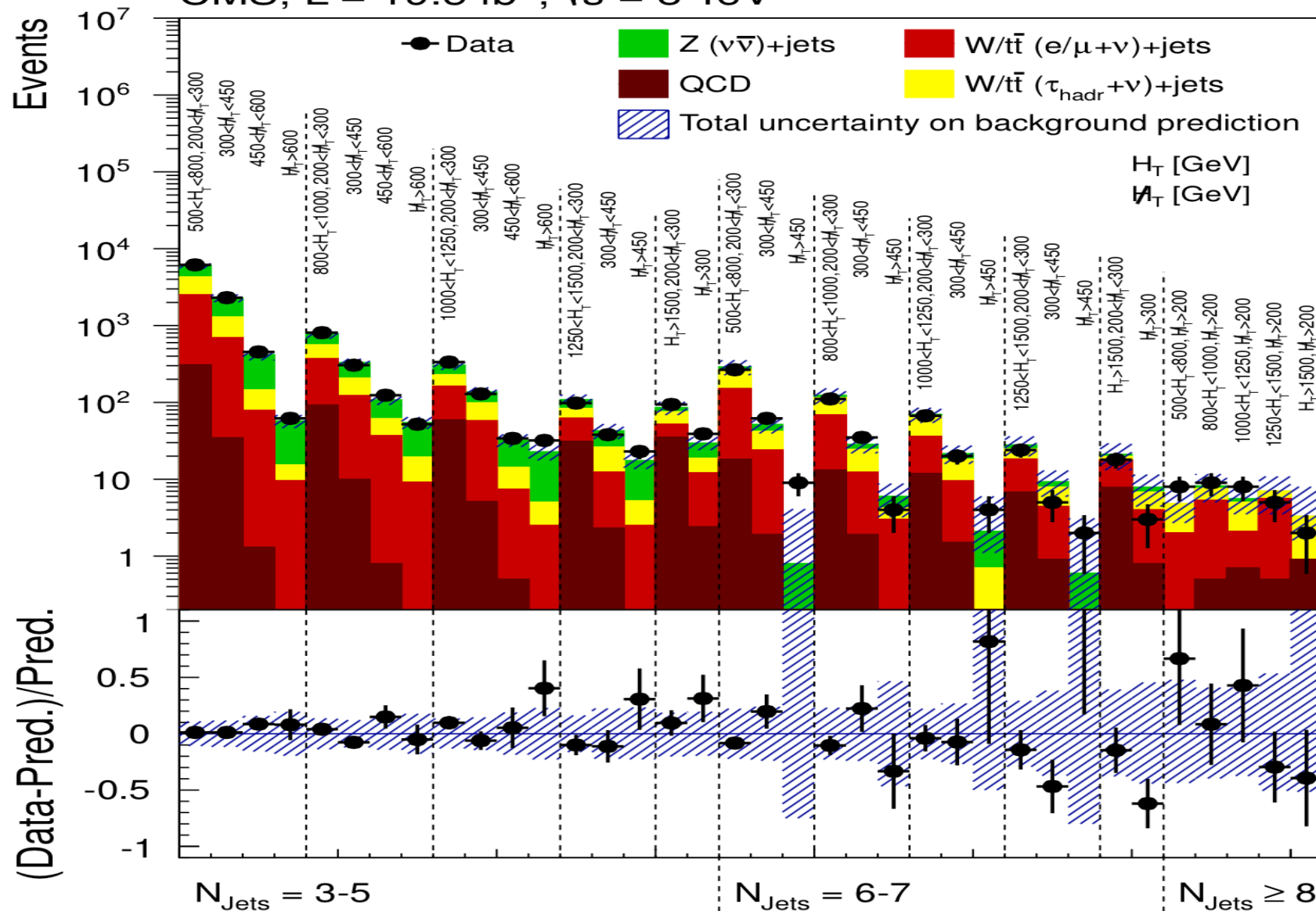- ## tt/W ➜ τ(➜hadrons) + jets
  - Isolated μ control sample
  - μ replaced by tau response according to template (each μ sampled 100 times)
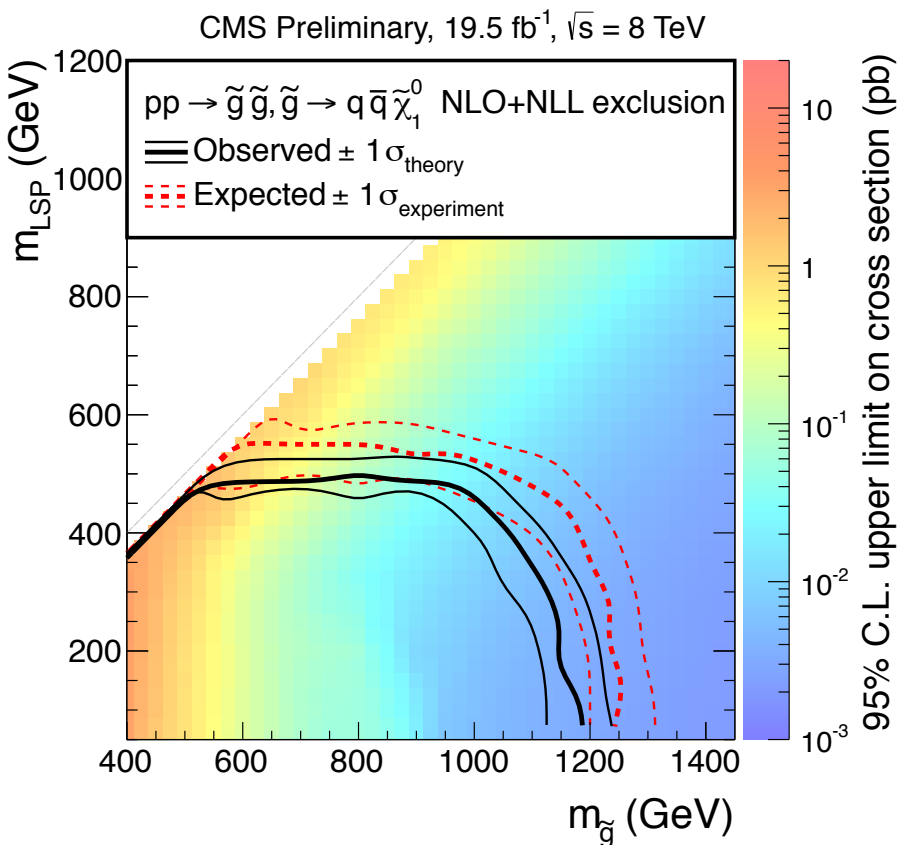 - μ trigger, acceptance, efficiency, and branching ratio μ / ν corrections

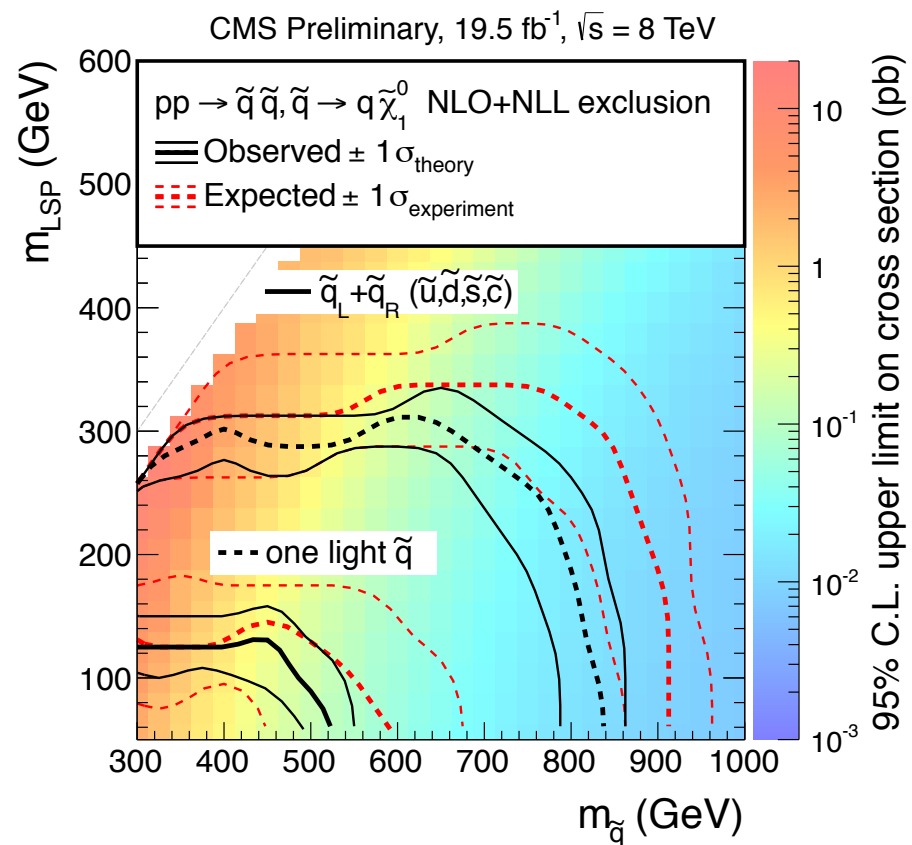# Results of the Jets plus MET search

Cross section limit and Interpretation in SMS

Gluino-gluino pair-production

Squark-squark pair-production

- First two squark generations mass degenerate
- Only one accessible squark

CMS Preliminary, 19.5 fb^{-1}, $\sqrt{s}$ = 8 TeV

$pp \rightarrow \tilde{g}\tilde{g}$, $\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0$ NLO+NLL exclusion
Observed ± 1σ_{theory}
Expected ± 1$\sigma_{experiment}$

CMS Preliminary, 19.5 fb^{-1}, $\sqrt{s}$ = 8 TeV

$pp \rightarrow \tilde{q}\tilde{q}$, $\tilde{q} \rightarrow q\tilde{\chi}_1^0$ NLO+NLL exclusion
Observed ± 1σ_{theory}
Expected ± 1$\sigma_{experiment}$

$\tilde{q}_L + \tilde{q}_R$ ($\tilde{u},\tilde{d},\tilde{s},\tilde{c}$)
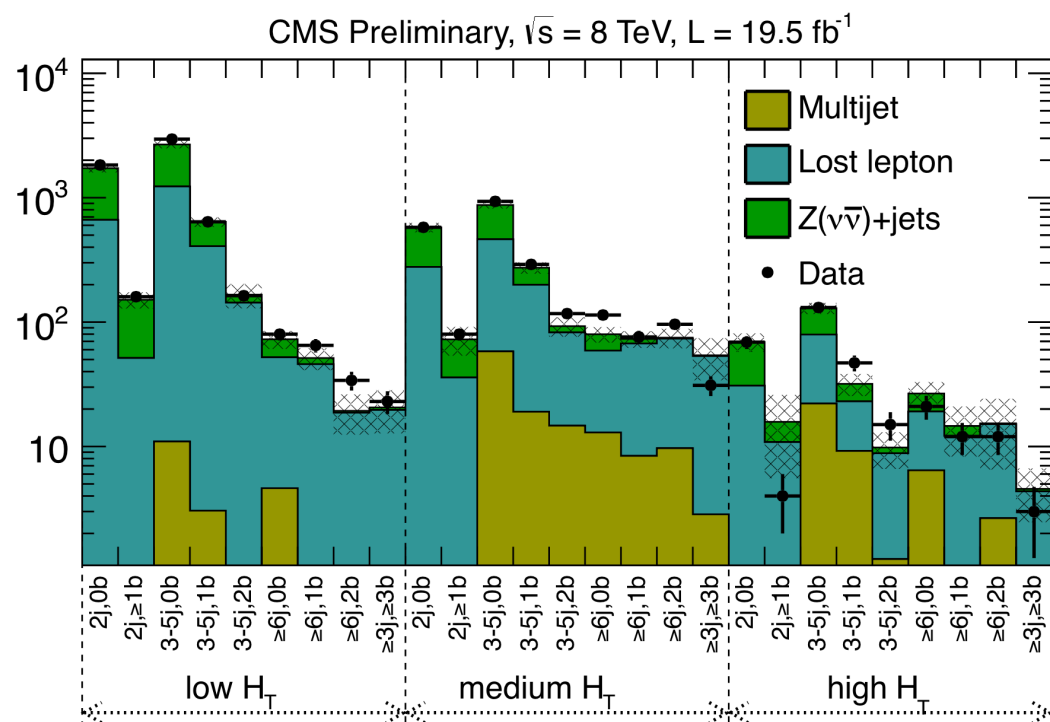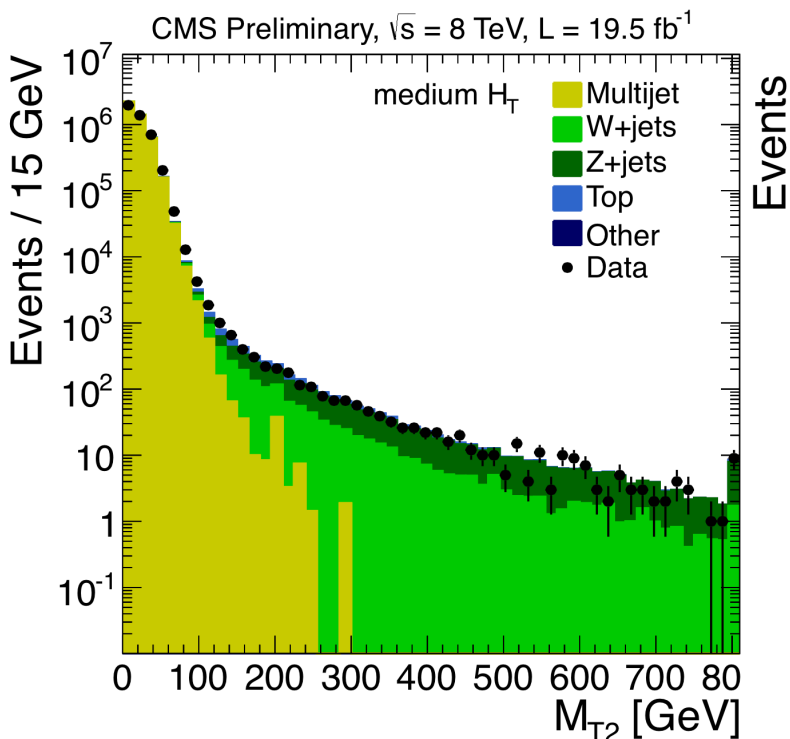
one light $\tilde{q}$

SUSY search with MT2

- Analysis carried out in the HT, jet-multiplicity, MT2 plane

$$(M_{T2})^2 = 2 p_T^{vis(1)} p_T^{vis(2)} (1 + cos\phi_{12})$$

- Backgrounds from data control regions

CMS Preliminary, $\sqrt{s}$ = 8 TeV, L = 19.5 fb^{-1}

medium H_T

Multijet
W+jets
Z+jets
Top
Other
Data

Events / 15 GeV

M_{T2} [GeV]

CMS Preliminary, $\sqrt{s}$ = 8 TeV, L = 19.5 fb^{-1}

Events

Multijet
Lost lepton
Z($\nu\bar{\nu}$)+jets
Data

low H_T · medium H_T · high H_T

signal region

MT2: Results
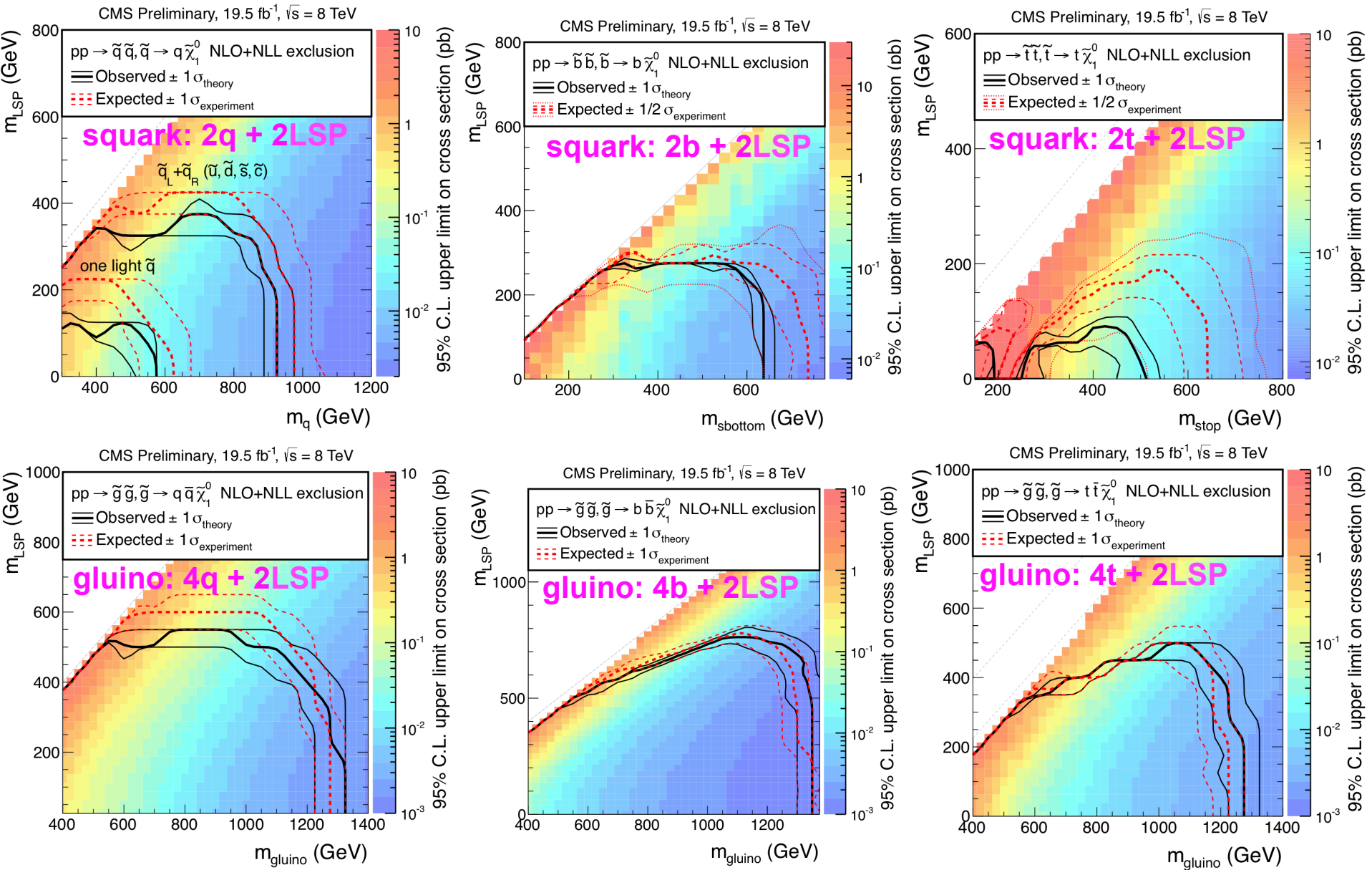
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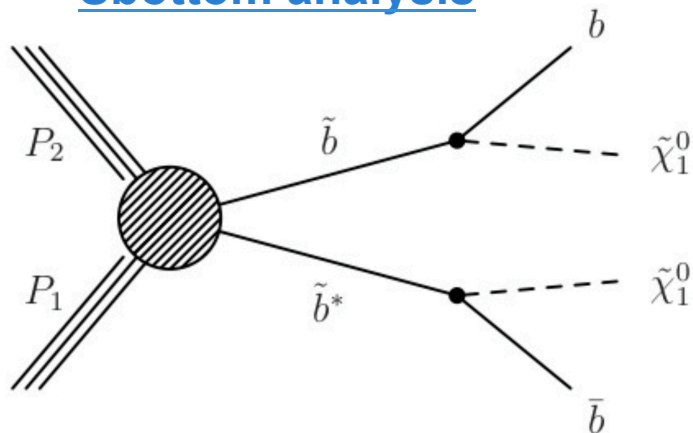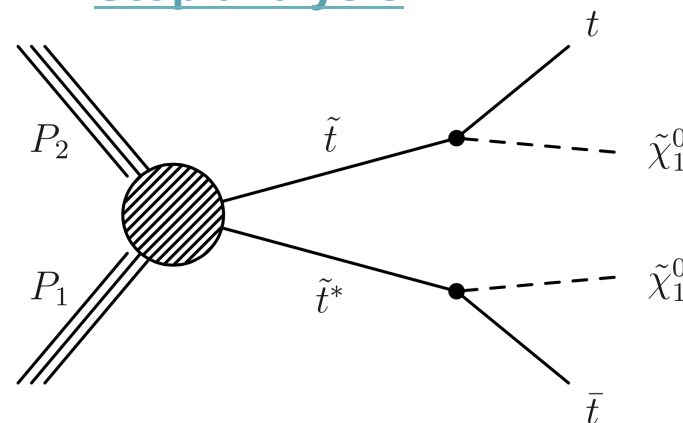- Stealth models

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Conclusion

Direct stop / sbottom searches

Sbottom analysis

Stop analysis

- MET > 175 GeV

- 2 jets pT > 70 GeV, Δφ<2.5 to supress QCD bb

- 1, 2 b-tags, veto leptons

- veto 3rd jet pt > 50 GeV to suppress ttbar

- MET > 200 GeV

- ≥ 2 jets, pT > 70 GeV and

- ≥ 4 jets, pT > 40 GeV and

- ≥ 5 jets, pT > 30 GeV

- at least 1 b-tag, veto leptons

- Δφ(jet, MET) > 0.5, 0.5, 0.3

- top-reconstruction

Direct stop / sbottom searches

Backgrounds:

- Z ➜ vv from W ➜ vl enriched data

- ttbar, W decaying to one lepton escaping detection ➜lost lepton

- QCD negligible (data sidebands)

Backgrounds:

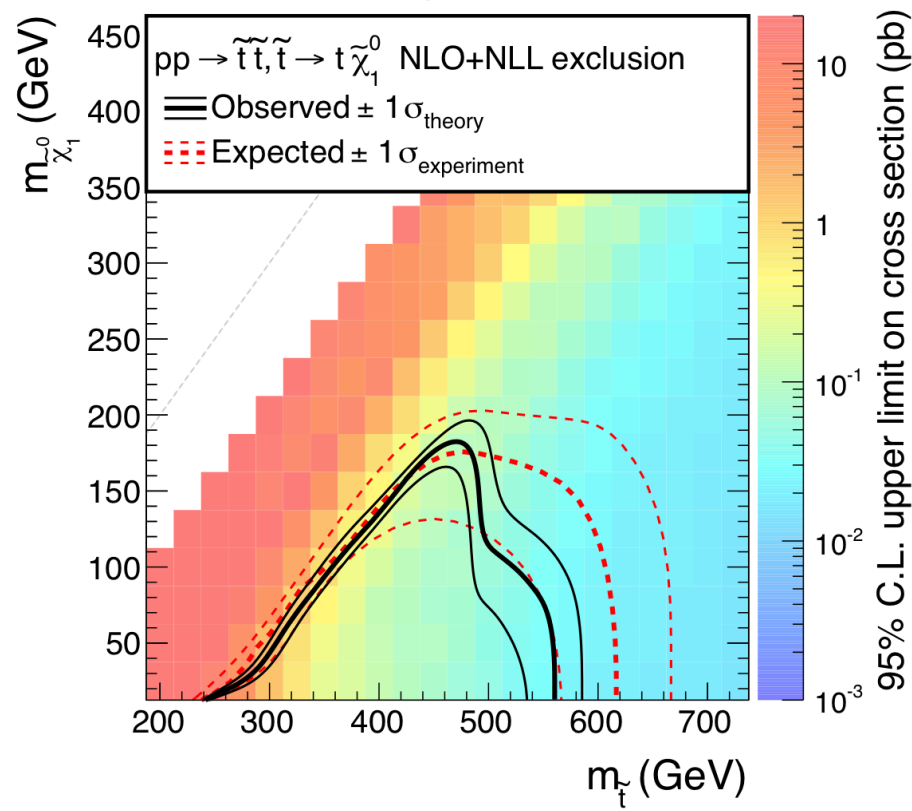- ttbar, W decaying to one lepton escaping detection ➜lost lepton method

- Z ➜ vv from MC, corrected by data

- QCD from data side-bands

CMS Preliminary, 19.4 fb^{-1}, $\sqrt{s}$ = 8 TeV

$pp \rightarrow \tilde{b}\,\tilde{b}, \tilde{b} \rightarrow b\,\tilde{\chi}_1^0$ NLO+NLL exclusion

Observed $\pm$ 1σ_{theory}

Expected $\pm$ 1$\sigma_{experiment}$

m_{LSP} (GeV)

$m_{sbottom}$ (GeV)

95% CL upper limit on cross section (pb)

CMS Preliminary, 19.4 fb^{-1}, $\sqrt{s}$ = 8 TeV

$pp \rightarrow \tilde{t}\,\tilde{t}, \tilde{t} \rightarrow t\,\tilde{\chi}_1^0$ NLO+NLL exclusion

Observed $\pm$ 1σ_{theory}

Expected $\pm$ 1$\sigma_{experiment}$

$m_{\tilde{\chi}_1^0}$ (GeV)

$m_{\tilde{t}}$ (GeV)

95% C.L. upper limit on cross section (pb)

Summary stop and sbottom searches

$\tilde{t}$-$\tilde{t}$ production, $\tilde{t} \rightarrow t\, \tilde{\chi}_1^0 / c\, \tilde{\chi}_1^0$

CMS Preliminary
$\sqrt{s} = 8$ TeV
ICHEP 2014

—— Observed
- - - Expected

SUS-13-011 1-lep (MVA) 19.5 fb^{-1}
SUS-14-011 0-lep + 1-lep + 2-lep (Razor) 19.3 fb^{-1}
SUS-14-011 0-lep (Razor) + 1-lep (MVA) 19.3 fb^{-1}
SUS-13-009 (monojet stop) 19.7 fb^{-1} ($\tilde{t} \rightarrow c\, \tilde{\chi}_1^0$)
SUS-13-015 (hadronic stop) 19.4 fb^{-1}

LSP mass [GeV]

stop mass [GeV]
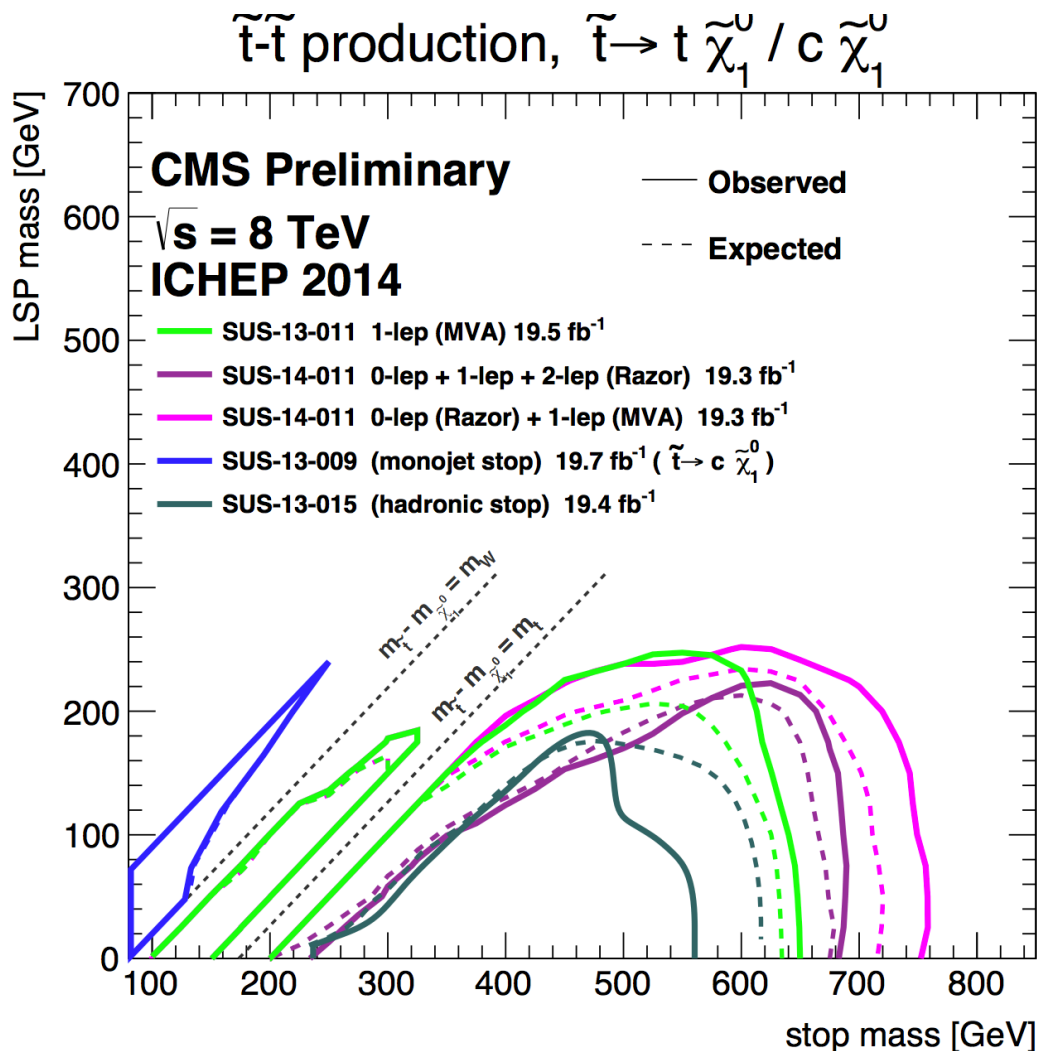
- Several dedicated searches for "natural SUSY"

- Reinterpretations of inclusive searches

- Several "blind spots"

- Still room for natural SUSY to hide

  ←→

  room for (new) sophisticated search strategies

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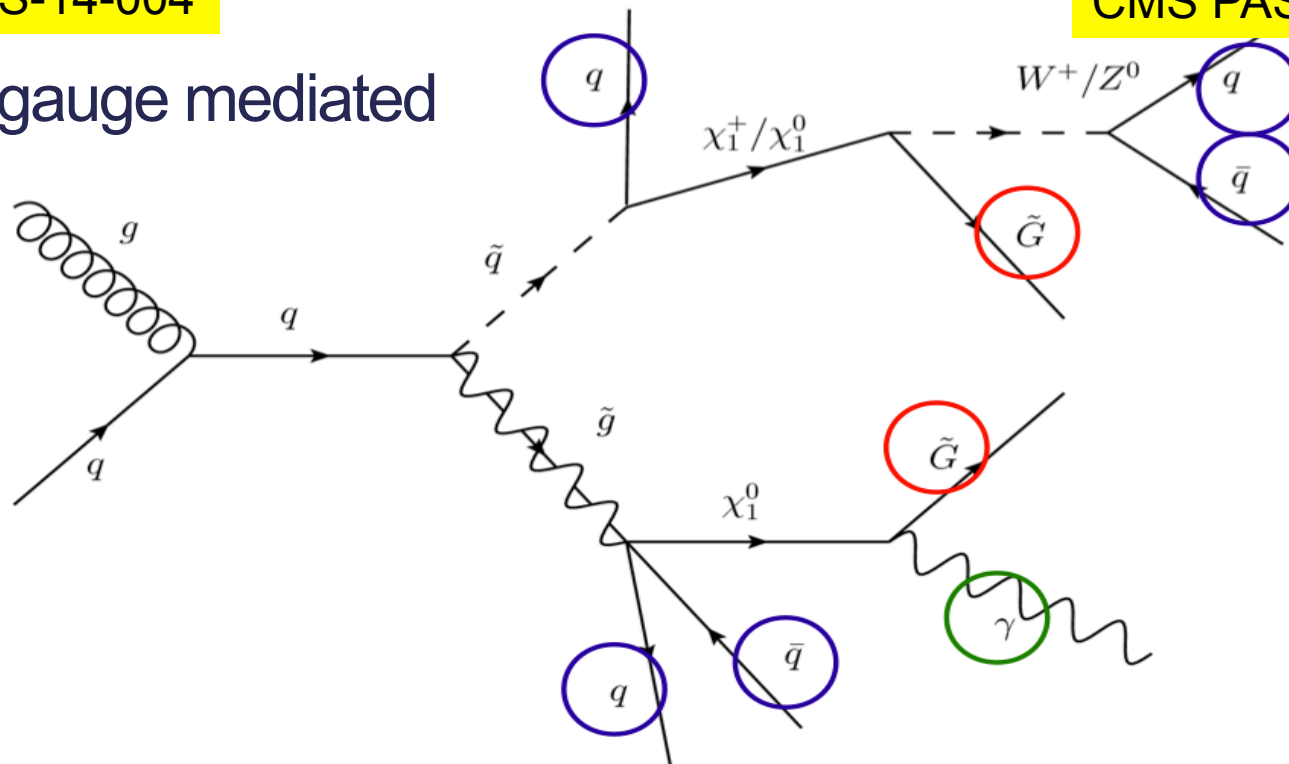
Direct Searches for Supersymmetry
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General gauge mediated breaking

Single-Photon Analysis
➔ Wino-like neutralinos

≥ 1 photon with pT > 110 GeV
≥ 2 jets with pT > 30 GeV
HT > 500 GeV
Particle-flow MET > 100 GeV

6 exclusive bins in MET

Di-Photon "Razor" Analysis
➔ Bino-like neutralinos

≥ 2 photon with pT > 36 (26) GeV
≥ 1 jets with pT > 40 GeV
no MET, but MR > 600 GeV, R^2>0.02

Analyses strategies

Single Photon

1. QCD photon-jet and QCD photon-fakes (jet→ɣ)

   MET from jet resolution and mismeasurements

   → Estimation from data: jet-control sample

2. Electro-weak backgrounds where an electron fakes a photon (e→ɣ)

   → Estimation from data: electron sample weighted by

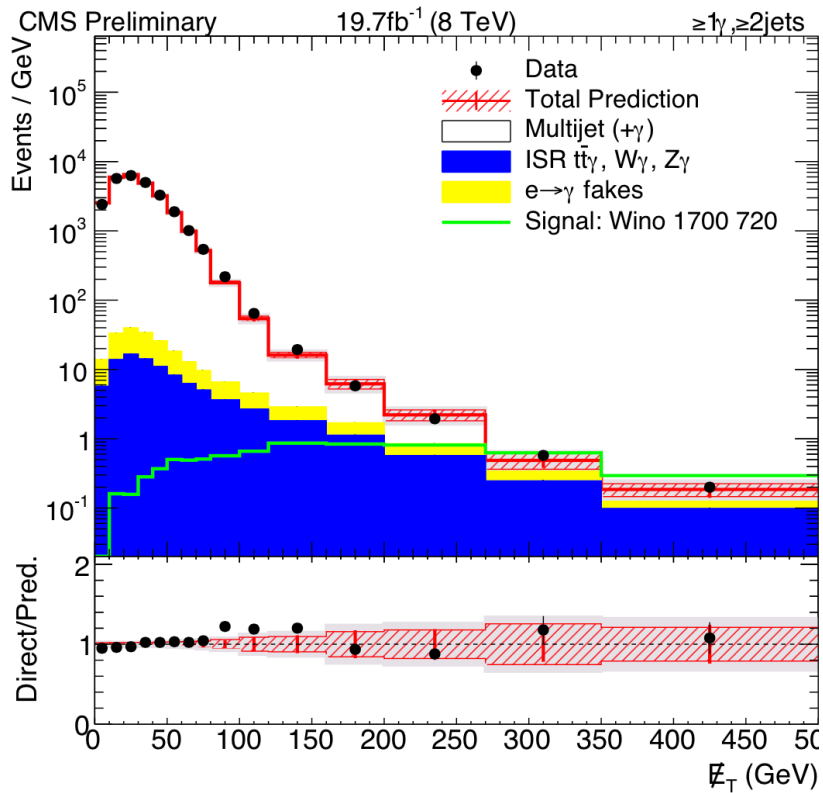   electron, photon conversion rate measured on Z→ee

Diphoton "Razor" Analysis

$$M_R \equiv \sqrt{(|\vec{p}_{j_1}| + |\vec{p}_{j_2}|)^2 - (p_z^{j_1} + p_z^{j_2})^2}$$

$$M_T^R \equiv \sqrt{\frac{E_T^{miss}(p_T^{j_1} + p_T^{j_2}) - \vec{E}_T^{miss} \cdot (\vec{p}_T^{j_1} + \vec{p}_T^{j_2})}{2}}$$

$$R \equiv \frac{M_T^R}{M_R}$$
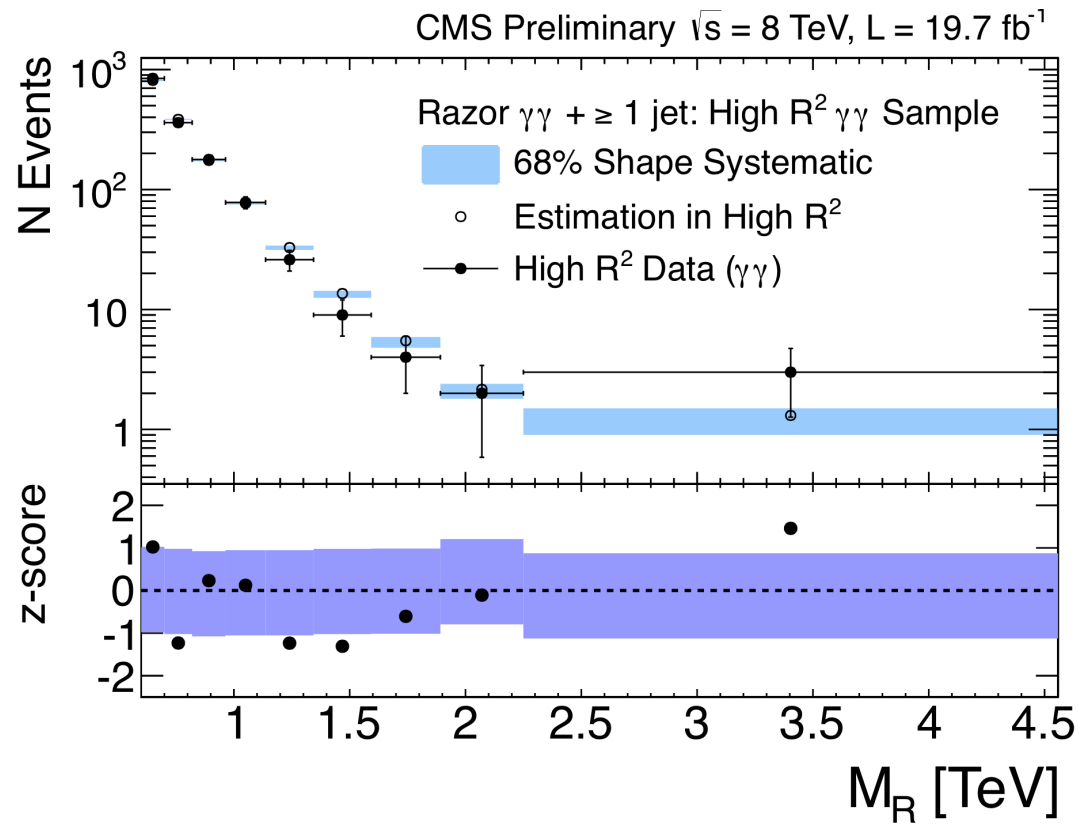
Signal region M_R > 600 GeV, R^2 > 0.02,

M_R shape from data control region 0.01 < R^2 < 0.02
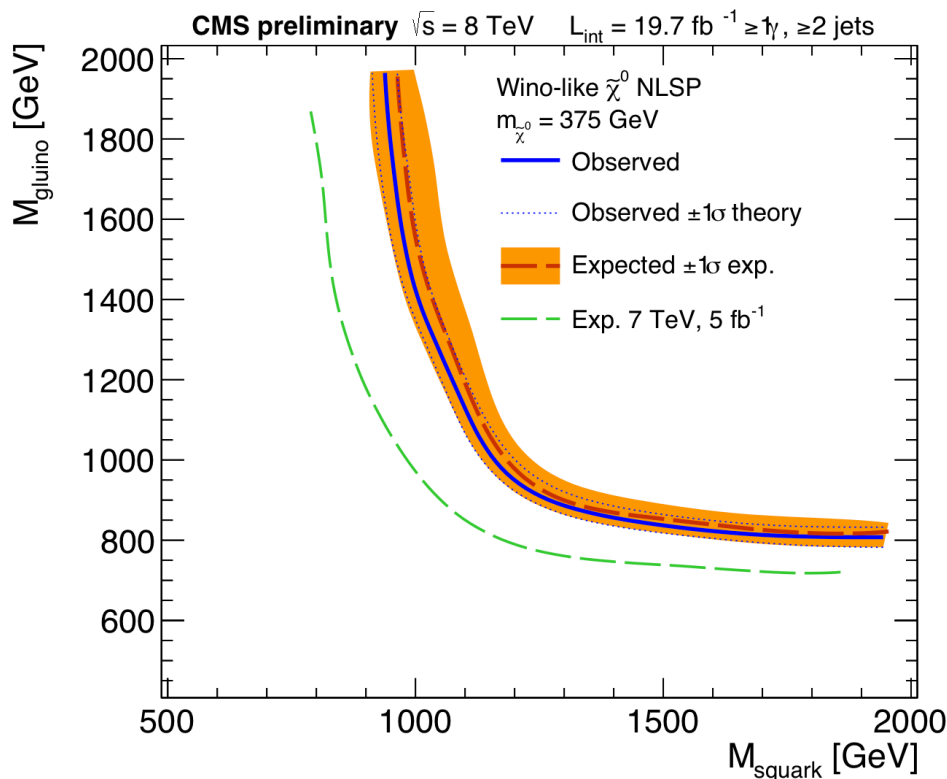
Results

Single-Photon

Di-Photon

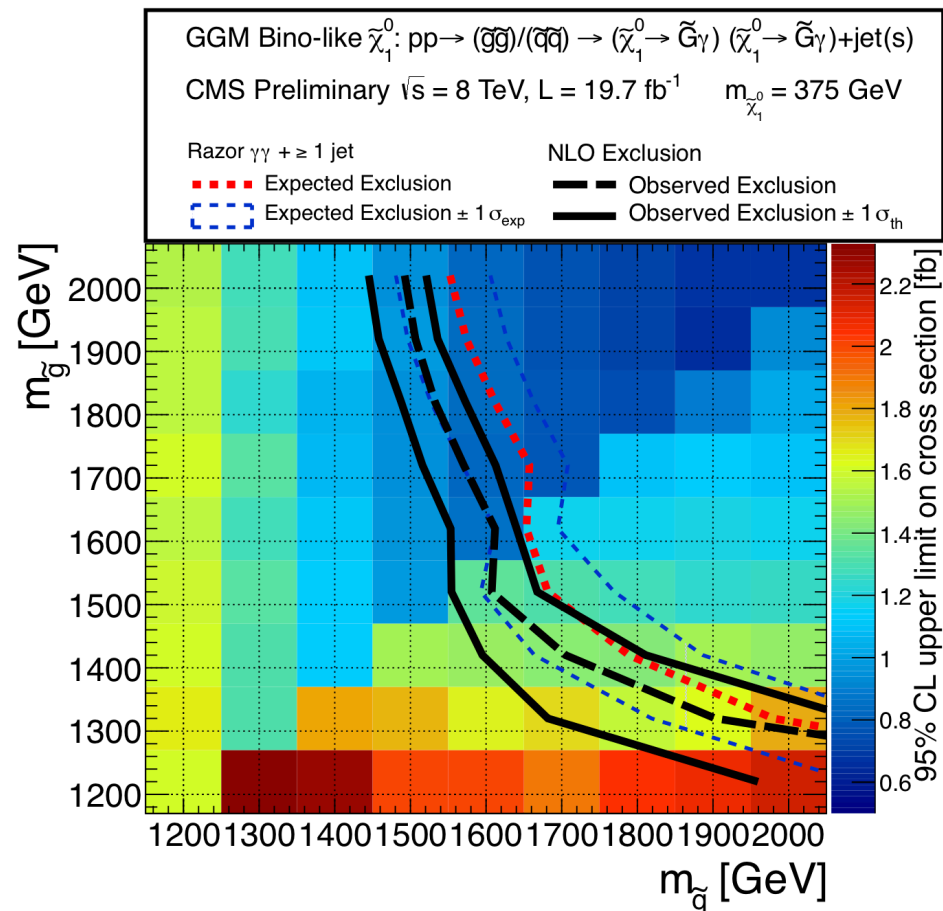# Interpretation in a General Gauge Mediated Scenario

Single-Photon
• Wino-like neutralino

Di-Photon
• Bino-like neutralino

Paper covering both analyses in preparation

Search for stop and higgsino production using diphoton Higgs decays

- "Natural" SUSY scenario with gauge mediated symmetry breaking

- Right-handed stop and higgsino are assumed to be only accessible sparticles

- Electroweak pair production of higgsinos or strong pair production of right-handed stop
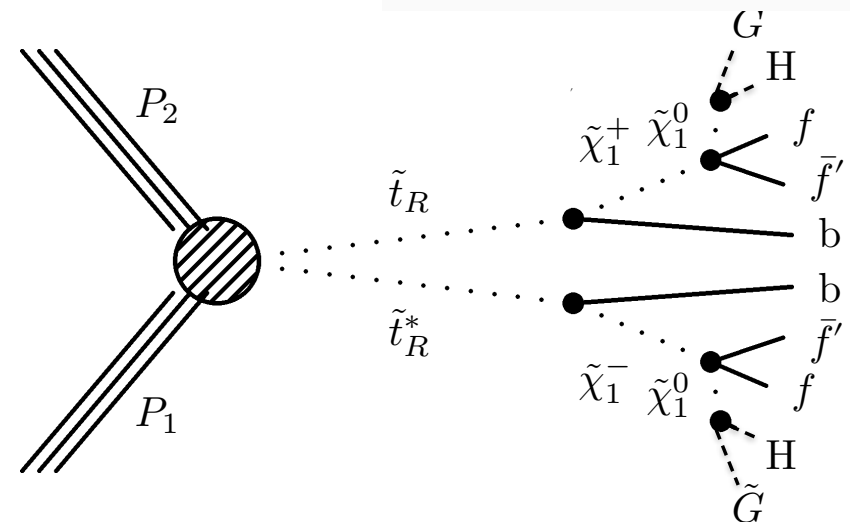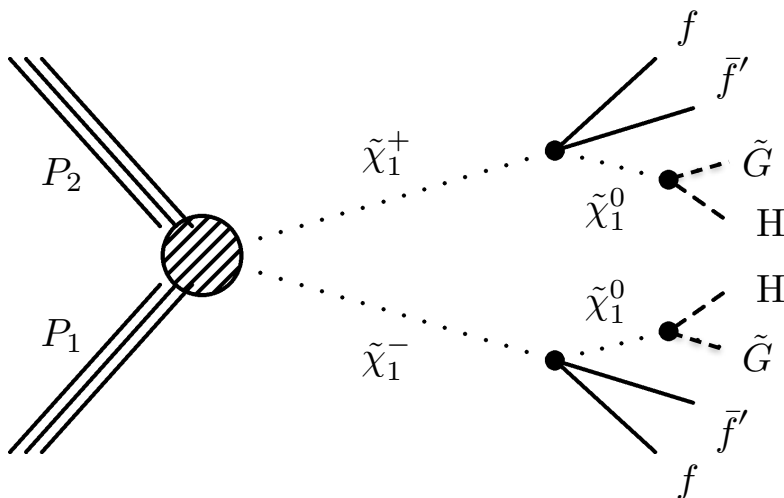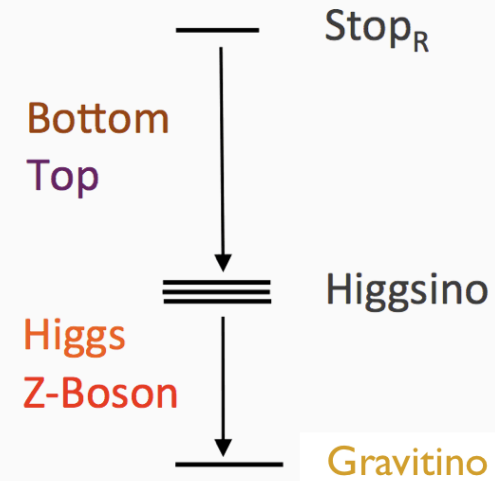
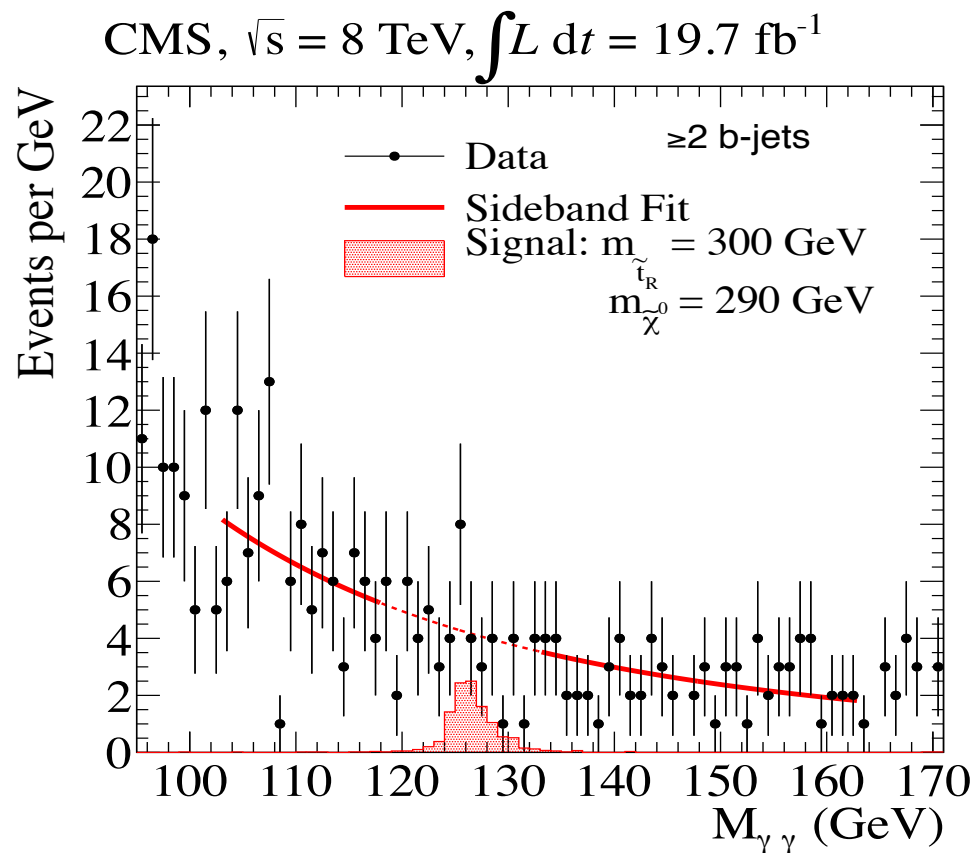Final state: H H + MET   (+ 2b or 2t in case of strong production)

Selection

- 2 photons γ: pT > 40, 25 GeV, | η | < 1.4442
- 2 b-tagged jets: combined-secondary-vertex, particle-flow jets d=0.5, pile-up subtracted, pT > 30 GeV, | η | < 2.4

Signal selection	Lower control region	Upper control region
120 < m(γγ) < 131 GeV	103 < m(γγ) < 118 GeV	133 < m(γγ) < 163 GeV

- Three signal categories (increases sensitivity up to 35%)

    i.   ≥ 3 b-tagged jets   ➔ strong production

    ii. 95 < m(bb) < 155 GeV: "on-H"   ➔ ewk production or small stop
                                                             neutralino mass difference

    iii. all other events: "off-H"   ➔ strong & ewk production

Background estimation

- SM background from di-photon inv. mass sidebands
  - SM Higgs background (peaking) found to be negligible
- Fit performed using lower and upper control region for each category
  - Systematics due to fit-function studied
  - Correlation to other variables by independent fits to lower and upper sideband
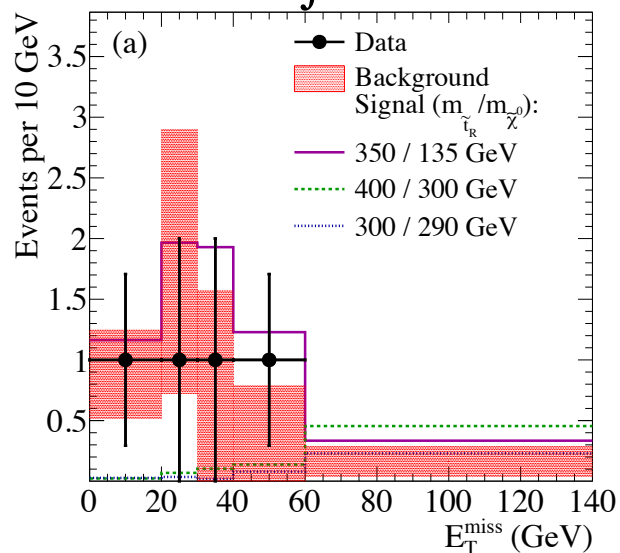

CMS, $\sqrt{s} = 8$ TeV, $\int L\,\mathrm{d}t = 19.7$ fb^{-1}

≥2 b-jets

Data
Sideband Fit
Signal: $m_{\tilde{t}_R} = 300$ GeV
$m_{\tilde{\chi}^0} = 290$ GeV

(Plot: sum of the three catego-
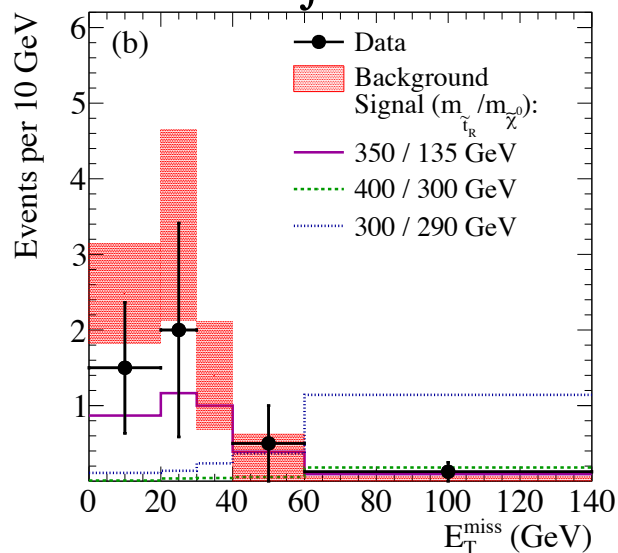ries: ≥3 b-jets, on-H, off-H)

Results for the three categories

i. : ≥3 b-jets

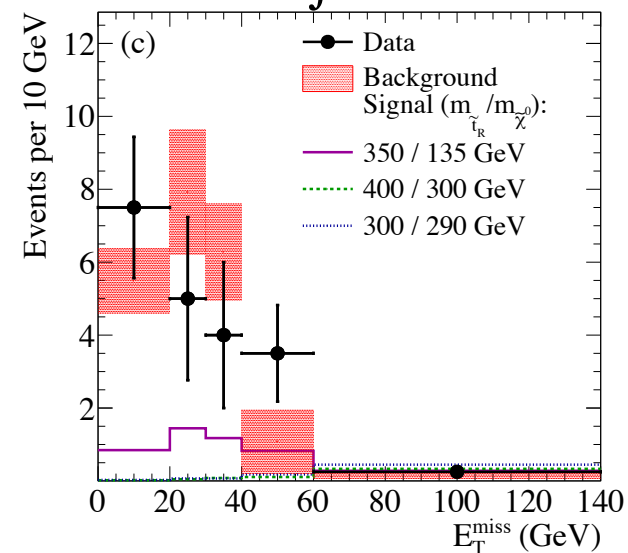CMS, $\sqrt{s}$ = 8 TeV, $\int L\, dt$ = 19.7 fb^{-1}

ii. on-H

CMS, $\sqrt{s}$ = 8 TeV, $\int L\, dt$ = 19.7 fb^{-1}

iii. off-H

CMS, $\sqrt{s}$ = 8 TeV, $\int L\, dt$ = 19.7 fb^{-1}

Event yields

Category	(i)	(ii)	(iii)
signal 350 / 135	10.7	2.0	6.8
signal 300 / 290	2.1	10.1	3.9
signal 400 / 300	4.0	1.4	2.8
expected background	6.7 ± 1.4	10.5 ± 1.8	29.7 ± 2.8
observed	6	7	33

$\sqrt{s}$ = 8 TeV
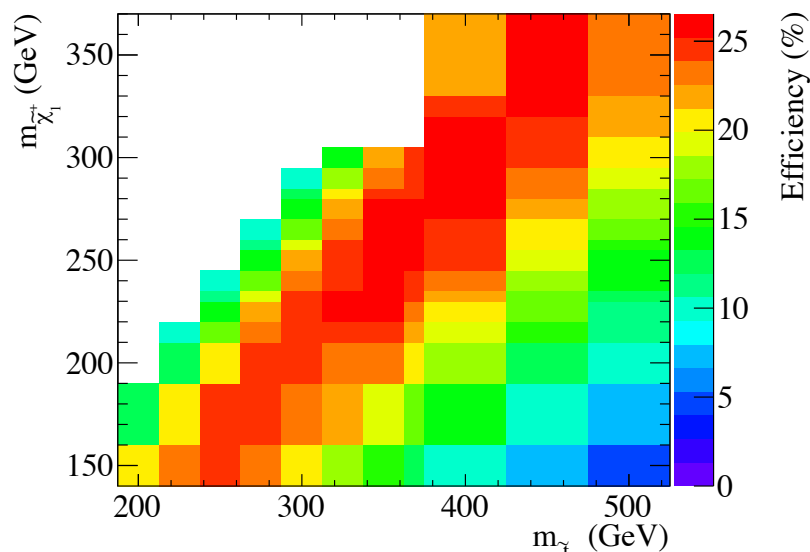L_{int} = 19.7 fb^{-1}

Dominant uncertainties:
- Background statistics
- B-tagged jet identification 1-17%
- Jet energy scale 7-43%

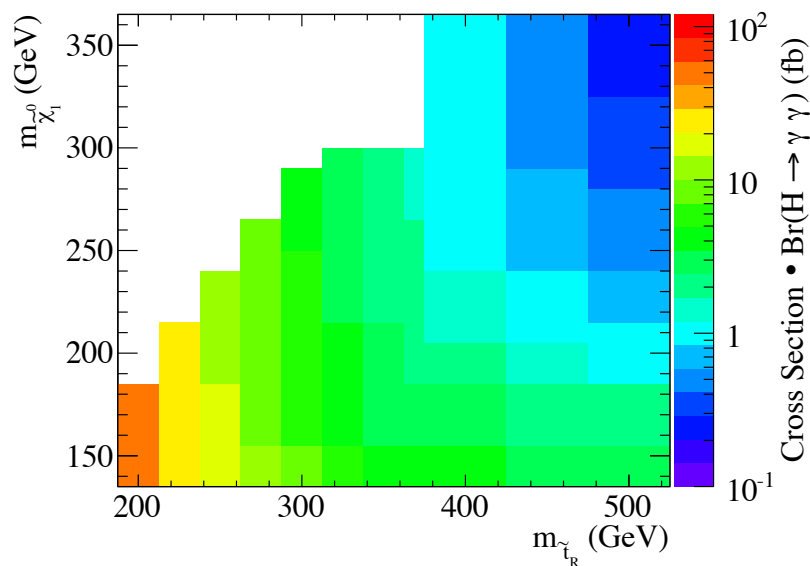## Acceptance ≥ 2b jets, ewk & strong prod.

CMS Simulation, $\sqrt{s}$ = 8 TeV
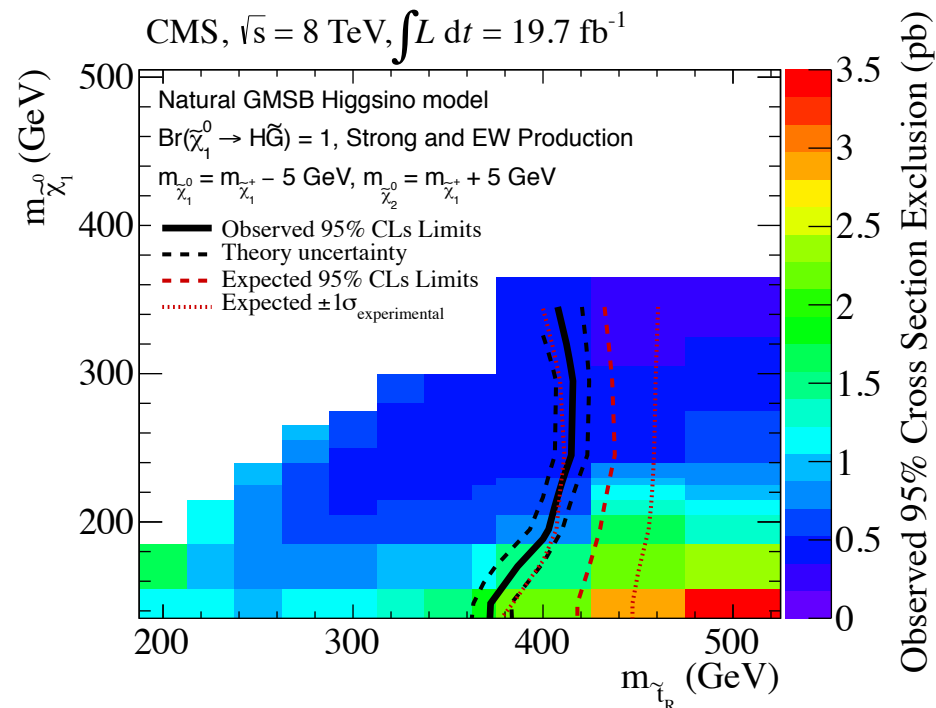
Total cross section × BF(H→γγ)

CMS Simulation, $\sqrt{s}$ = 8 TeV

Results and Interpretation

- CLs limits at 95% confidence level
  - LHC-style profiled likelihood test-statistics
- stop masses < 360 – 410 GeV excluded, depending on the neutralino mass

CMS, $\sqrt{s}$ = 8 TeV, $\int L\, dt$ = 19.7 fb^{-1}

Natural GMSB Higgsino model
Br($\tilde{\chi}_1^0 \to H\tilde{G}$) = 1, Strong and EW Production
$m_{\tilde{\chi}_1^0} = m_{\tilde{\chi}_1^+} - 5$ GeV, $m_{\tilde{\chi}_2^0} = m_{\tilde{\chi}_1^+} + 5$ GeV

— Observed 95% CLs Limits
-- Theory uncertainty
-- Expected 95% CLs Limits
⋯ Expected ±1σ$_{experimental}$

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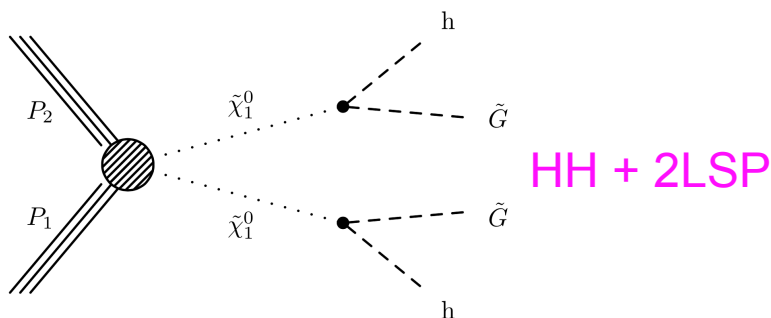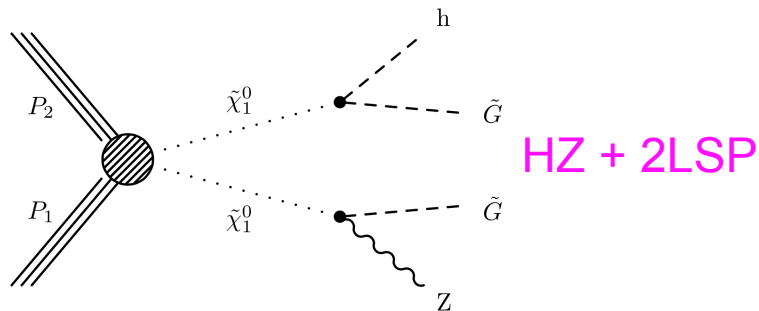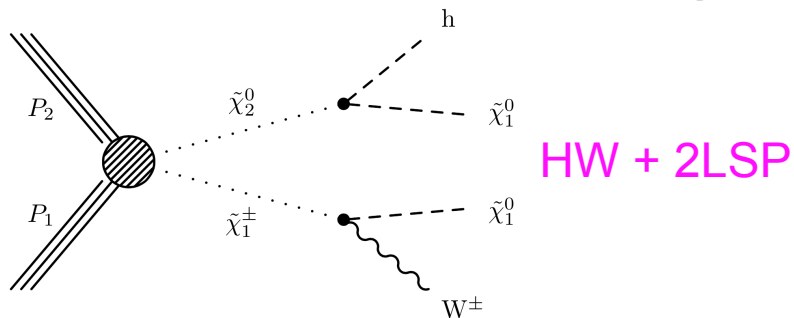Direct Searches for Supersymmetry
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Search for electroweak production of neutralinos, charginos and higgsinos

HW + 2LSP

HZ + 2LSP

HH + 2LSP

- Probing decay channels
  H ➜ bb / γγ / multileptons
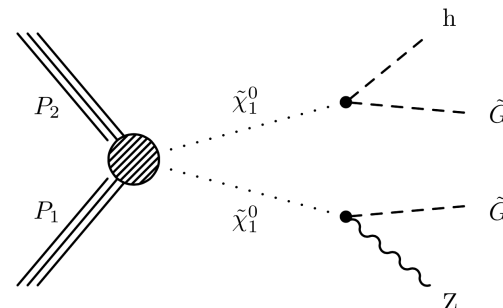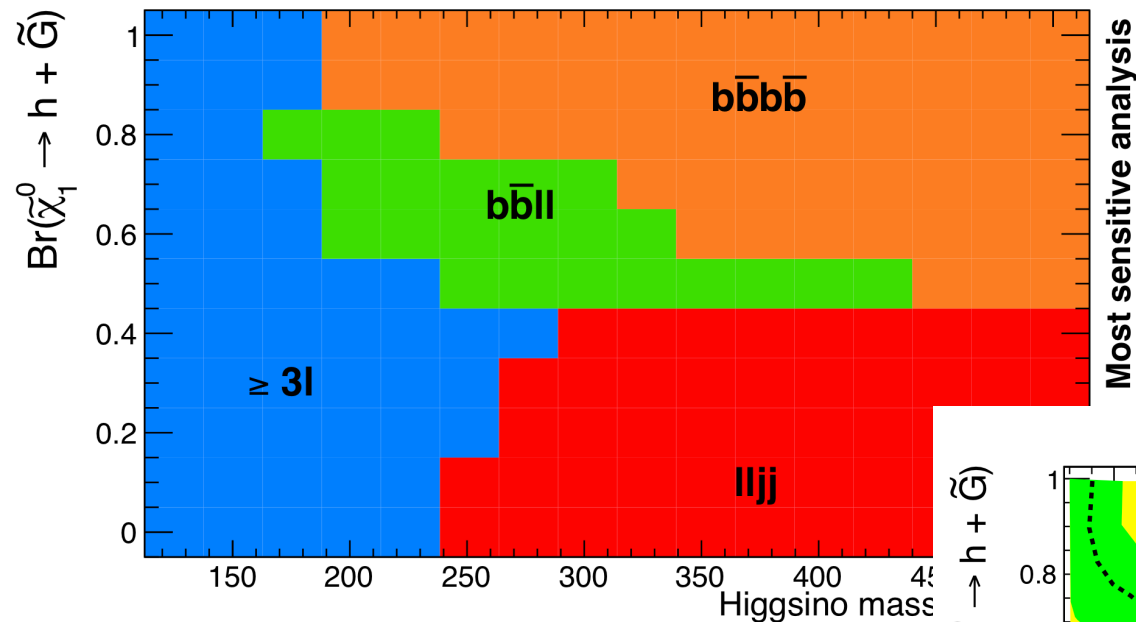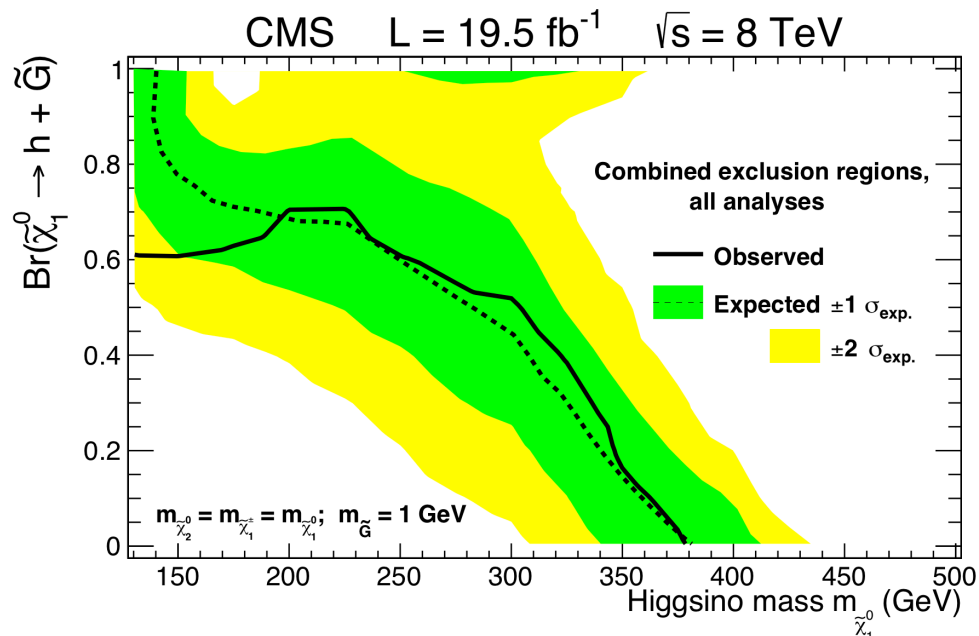 Z ➜ ll / jj, W ➜ lv / jj

- using Higgs mass similar as Z, W

- large MET, transverse mass MT, scalar energy sum ST, depending on the analysis

Search for electroweak production of neutralinos, charginos and higgsinos

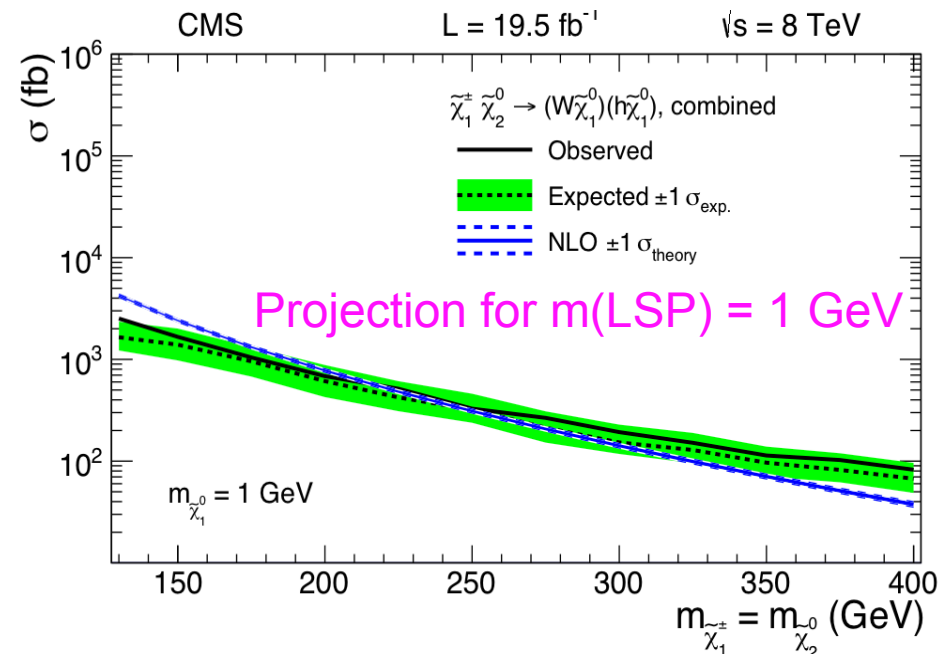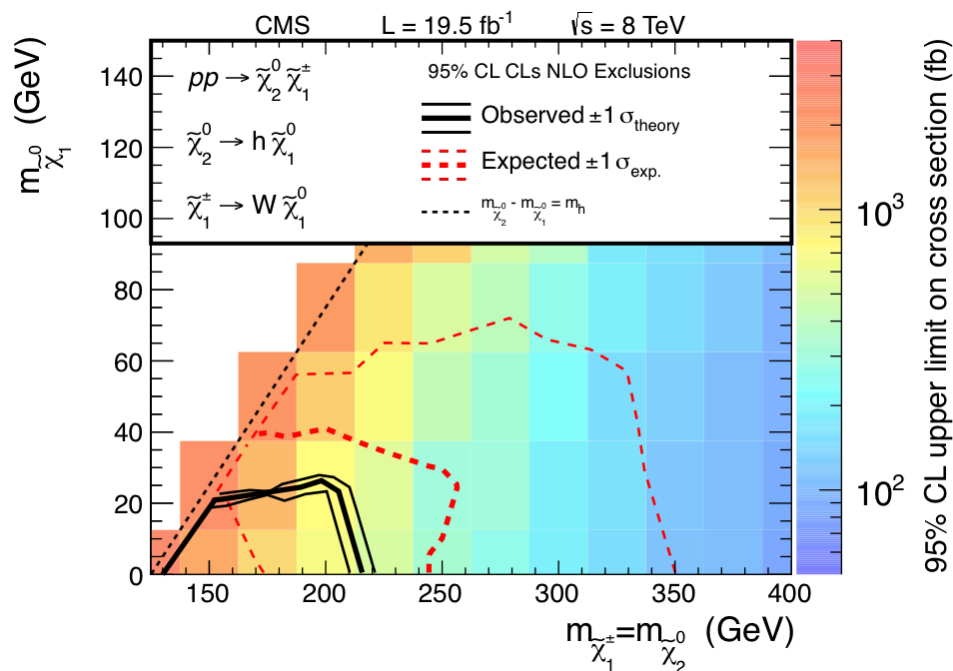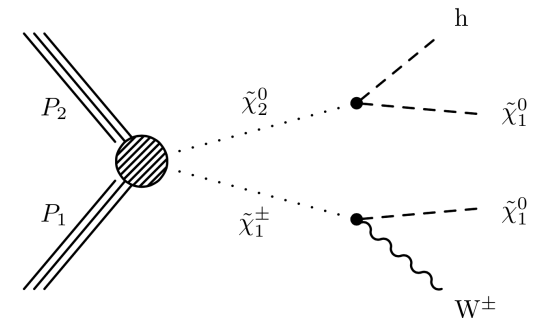CMS   L = 19.5 fb^{-1} √s = 8 TeV

- Channels have complementary sensitivity

- Higgsino mass vs BR of LSP to H

- Channels combined to single limit

Search for electroweak production of neutralinos, charginos and higgsinos

Combined limits on
chargino-neutralino pair-production

Projection for m(LSP) = 1 GeV

➔ Talk by David Morse, Friday afternoon

Overview

Motivation and Introduction of Supersymmetry

Indirect Searches

Direct Searches for Supersymmetry
- Inclusive all-hadronic searches
- "Natural-SUSY" stop, sbottom searches
- Search for gauge-mediated SUSY with photons
- Electroweak produced Supersymmetry
➔ - Stealth models

The dilepton mass-edge analysis

Conclusion

CMS PAS SUS-14-009

Search for Stealth Supersymmetry
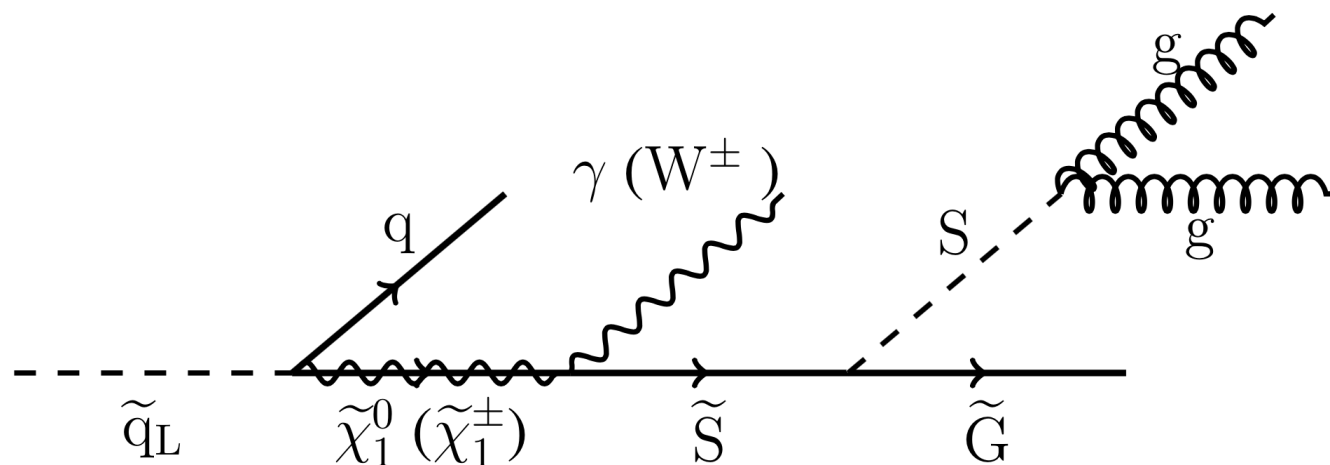
- Stealth SUSY benchmark model for no-MET signatures
  - New hidden sector of particles at the weak scale with nearly mass-degenerate superpartners

- **Diphoton channel**
  - Background from S_T side-bands
    (S_T: scalar sum of pT of all accepted physics objects i.e. jets, photons, leptons, MET)

- **Lepton channel**
  - Dominant backgrounds ttbar, single-top, Z taken from Monte Carlo simulation, using corrections from data-control regions

Search for Stealth Supersymmetry

- ## ST photon analysis
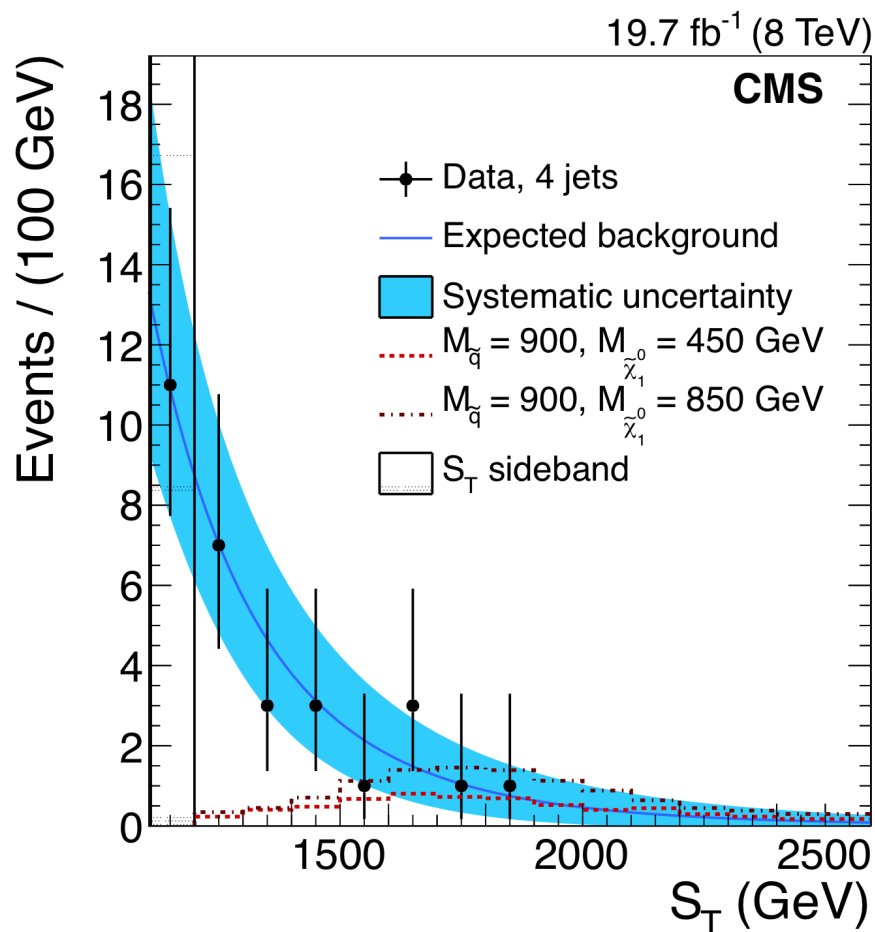
- ## Lepton analysis

Search for Stealth Supersymmetry
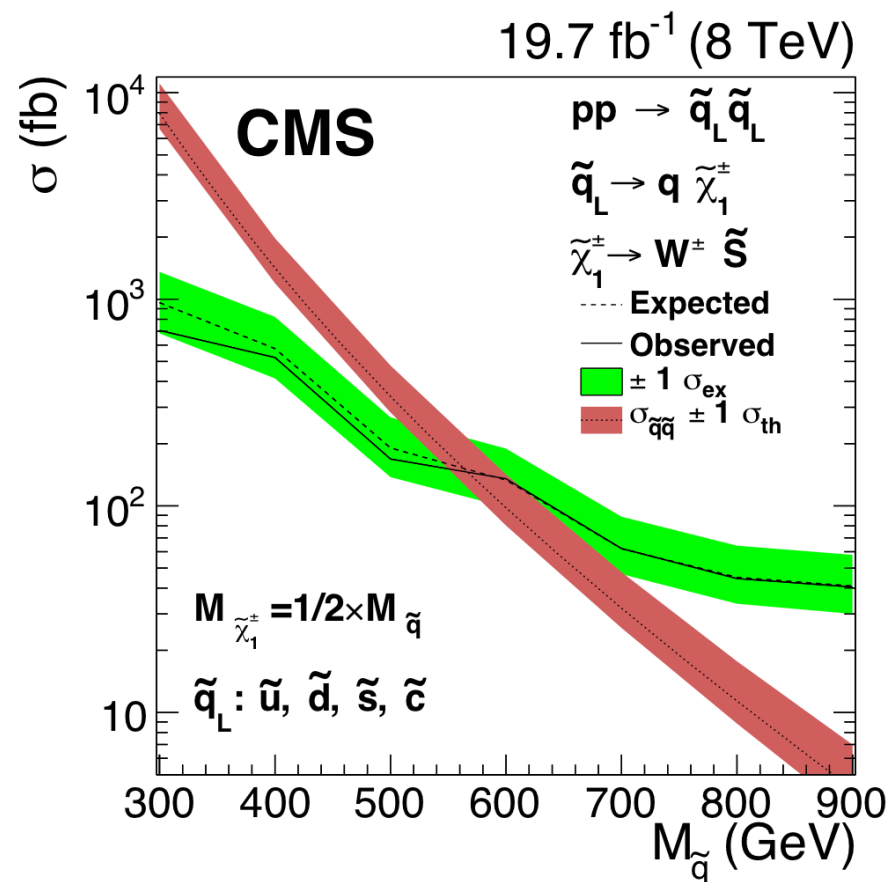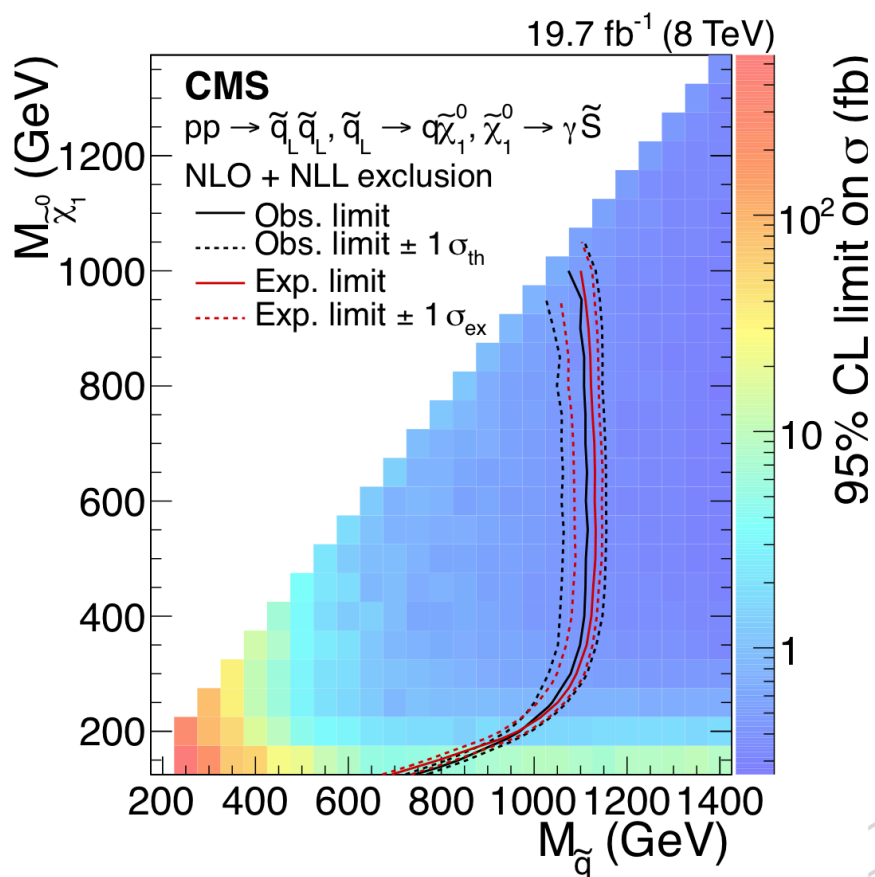
Summary of CMS SUSY Results* in SMS framework — ICHEP 2014

CMS Preliminary

For decays with intermediate mass,
$m_{intermediate} = x \cdot m_{mother} + (1-x) \cdot m_{lsp}$

*Observed limits, theory uncertainties not included
Only a selection of available mass limits
Probe *up to* the quoted mass limit

Mass scales [GeV]

Overview

Motivation and Introduction of Supersymmetry

Indirect Searches

Direct Searches for Supersymmetry
- Inclusive all-hadronic searches
- "Natural-SUSY" stop, sbottom searches
- Search for gauge-mediated SUSY with photons
- Electroweak produced Supersymmetry
- Stealth models

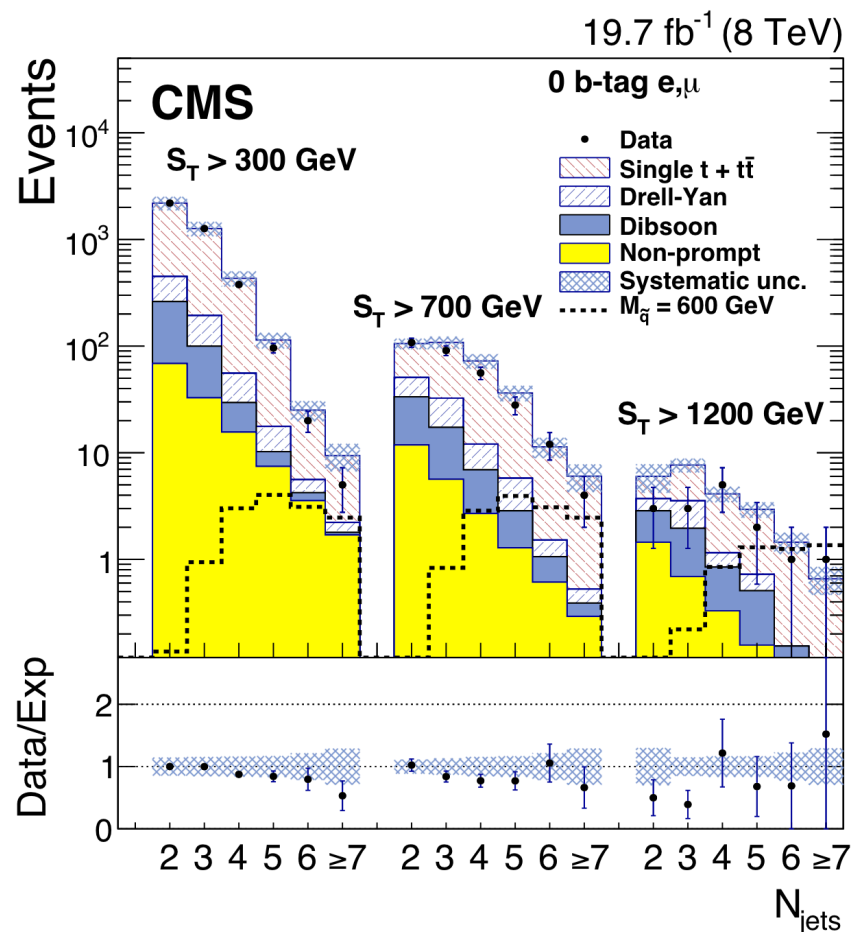➜ The dilepton mass-edge analysis

Conclusion

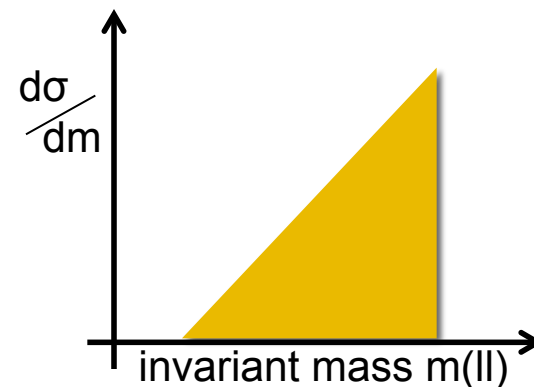# Search for Supersymmetry: Dilepton mass edge
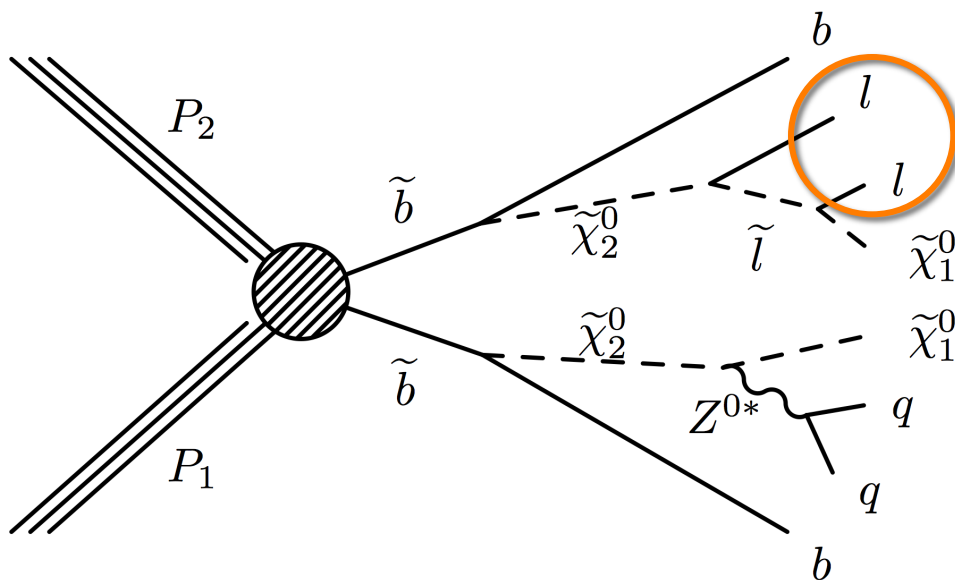
- Upper mass edge: $M_{max} = M(\chi^0_2) - M(\chi^0_1)$

- $$\frac{d\sigma}{dm_{ll}} = \frac{\pi^2 m_{ll}}{2m^2_{\tilde{\chi}^0_2}} \sqrt{\left(m^2_{\tilde{\chi}^0_2} - (m_{\tilde{\chi}^0_2} + m_{ll})^2)\right)\left(m^2_{\tilde{\chi}^0_2} - (m_{\tilde{\chi}^0_2} - m_{ll})^2)\right)}$$

  for a direct 3-body decay and pure Lorentz invariant phase space

Search for Supersymmetry: Dilepton mass edge

invariant dimuon mass of 4% of all recorded CMS events
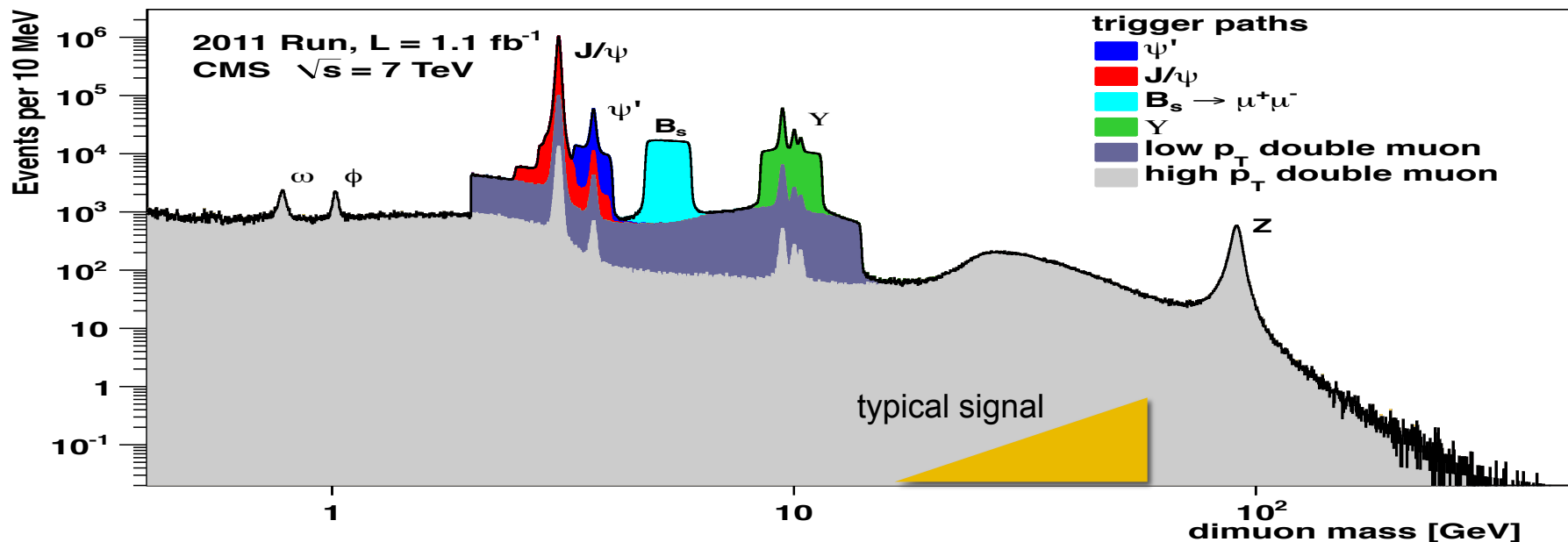
- 2 isolated leptons (e, μ) pT > 20 GeV, |η|<2.4
- ≥ 2 jets pT > 40 GeV and MET > 150 GEV   or
  ≥ 3 jets pT > 40 GeV and MET > 100 GEV
- m(ll) > 20 GeV

Search for Supersymmetry: Dilepton mass edge

99% dominant background: ttbar
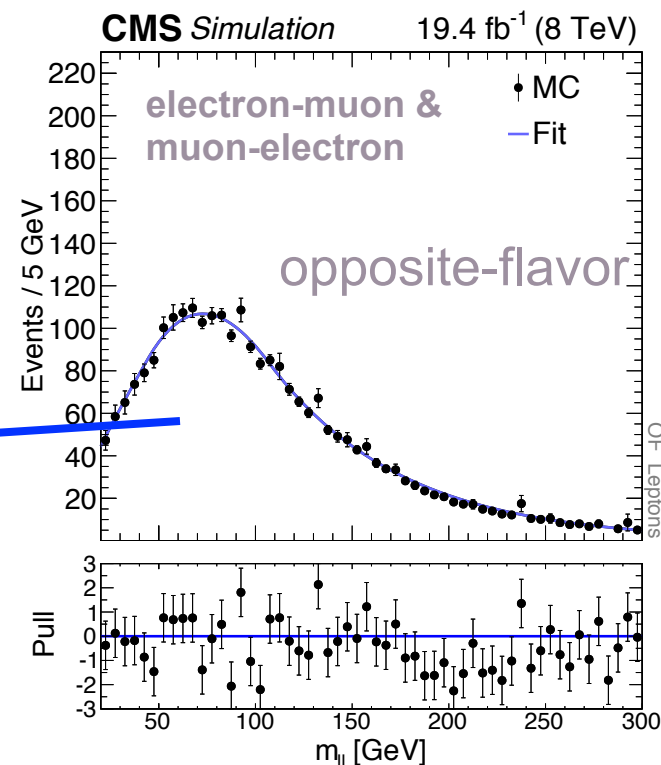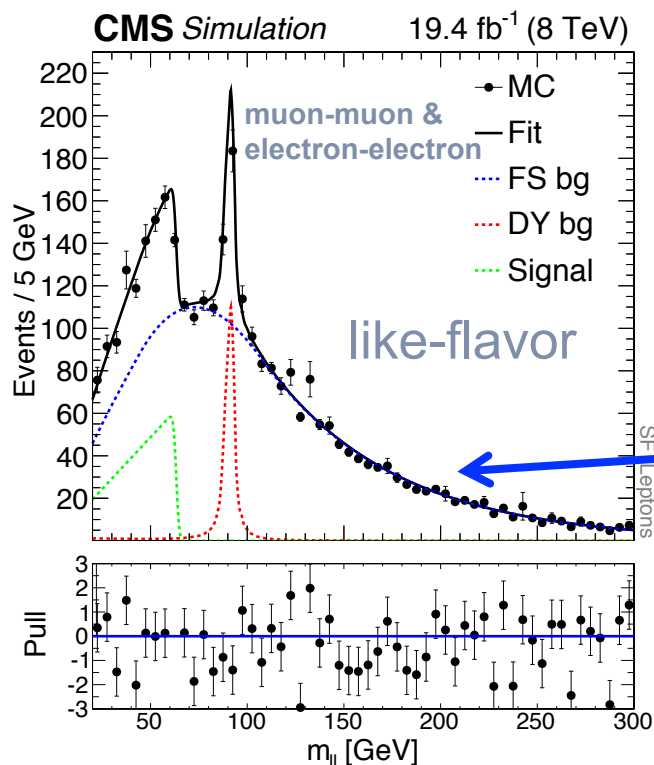
Bkgd: • Use <u>opposite lepton flavor events (e μ)</u> events to model the like flavor events in the signal selection (ee, μμ)

• Correct for differences of electron and muon efficiencies

Result: • A <u>highly precise Standard model background expectation</u>

Results of the dilepton search
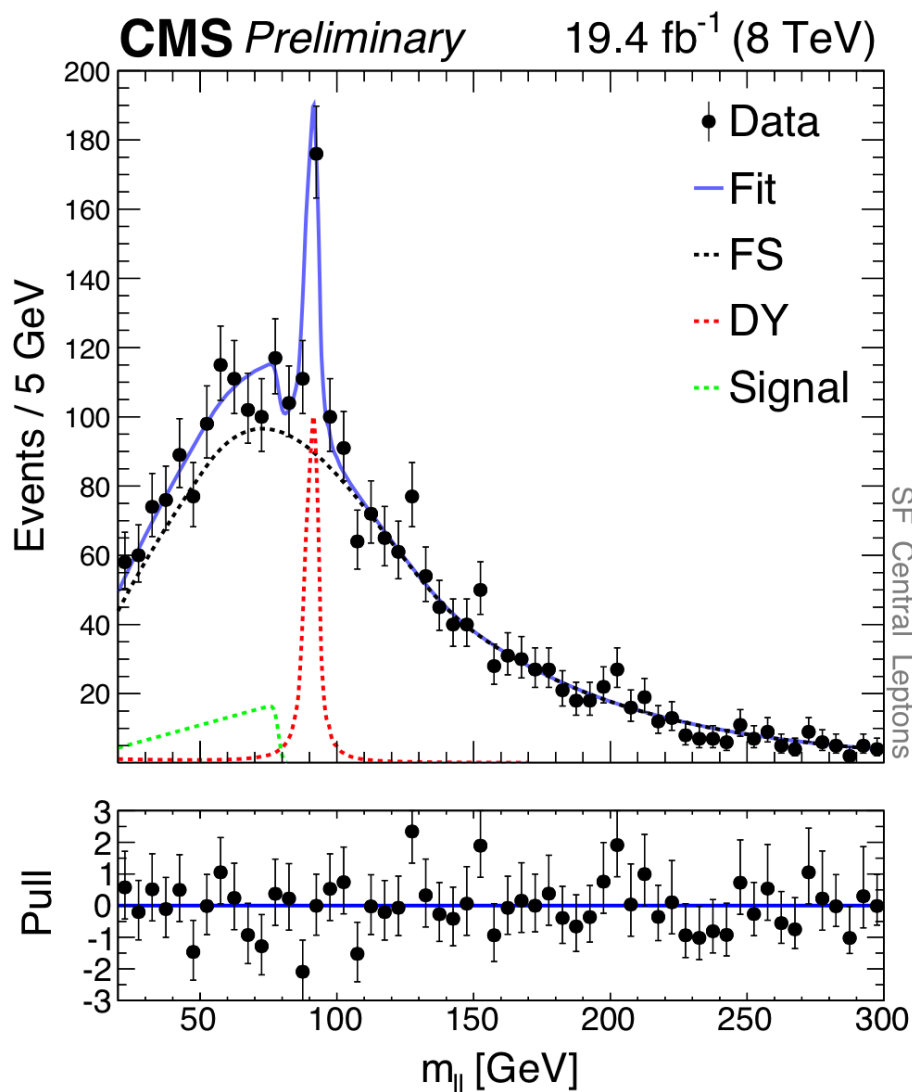
Paper in preparation
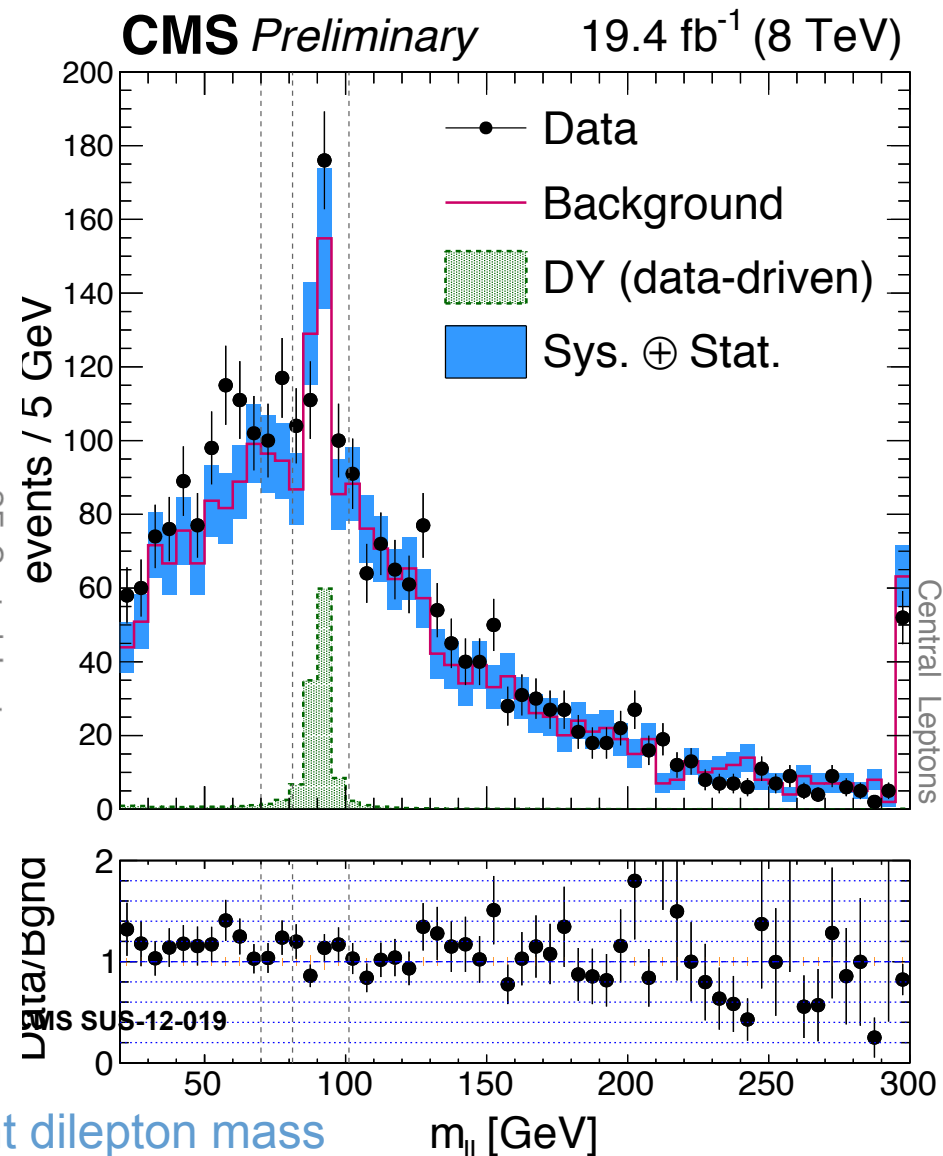
Invariant dilepton mass

Significance of the dilepton search results

Observed and expected event yields	
Observed data events	860
Background expectation	730 ± 40
Observed – Expected	$130\,^{+48}_{-49}$

Cut & Count, central region

Red area corresponds to **~1%** or to **2.6 σ**

observation:

130^{+48}_{-49}

$(\,\mu \pm 1\,\sigma\,)$

expectation

Global fit:
2.4σ significance excl. LLE

-3σ   -2σ   -1σ   μ   +1σ   +2σ   +3σ

event yields
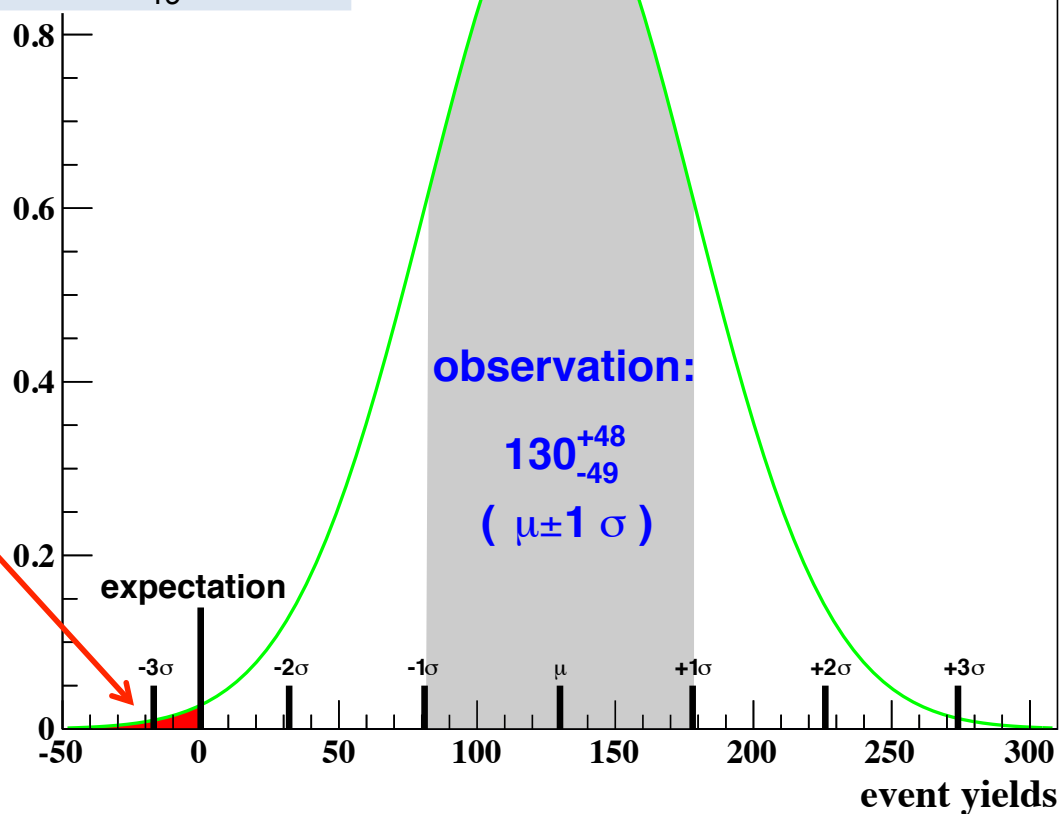
Analysis was carried out as "blind analysis"
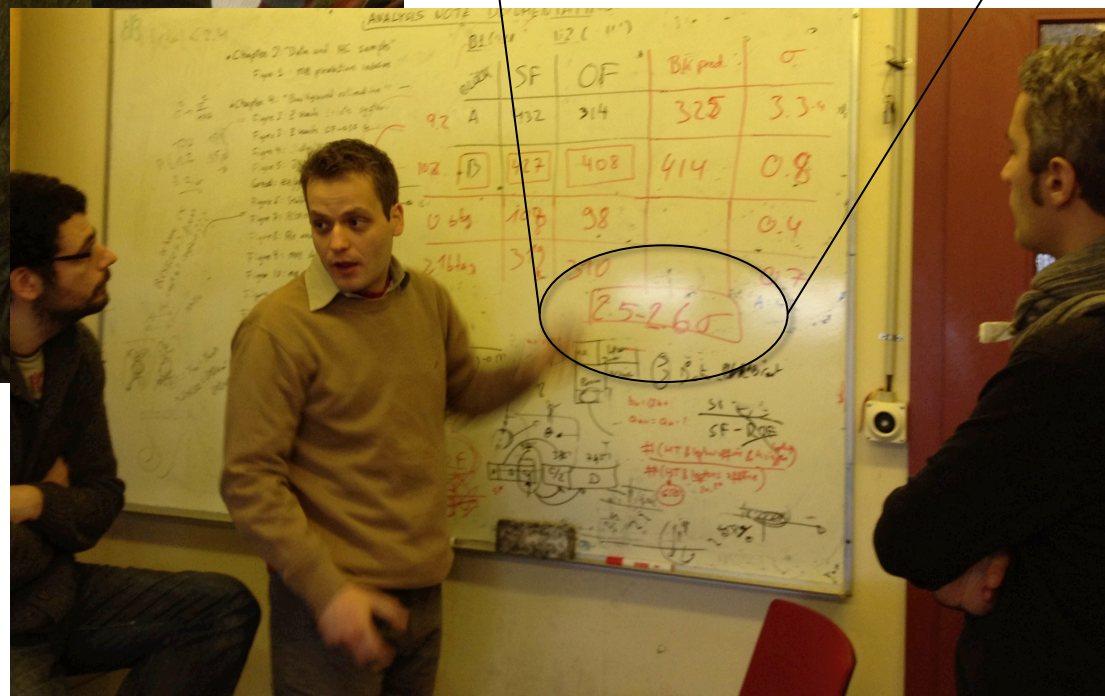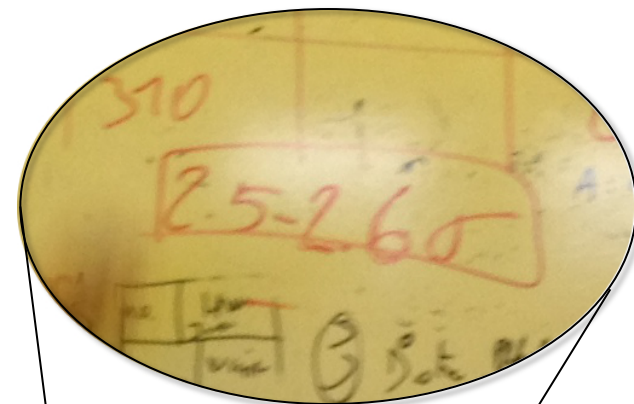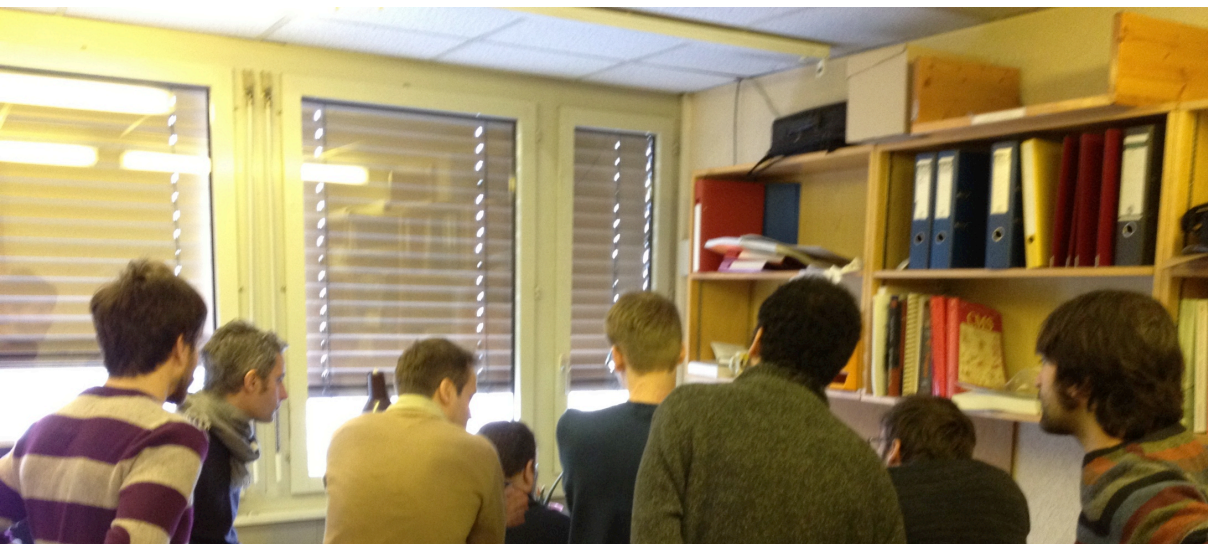
Unblinding the full 19.4 fb^{-1} of data

CERN, 12.12.2013

First indication of Supersymmetry?

- Most likely explanation is still statistical fluctuation
- Other systematic effects in the data were not found

But…

- …this was real?
  …the excess grows with new data?
- What would the Supersymmetry properties look like?
- Can this be studied / validated / ruled out by other analyses or experiments?

➔ Paper with interpretation in preparation

Ambulance chasing...

- B. Allanach, A. R. Raklev, A. Kvellestad, ``Interpreting a CMS lljj MET Excess With the Golden Cascade of the MSSM'', hep-ph:1409.3532.

- P. Huang, C. Wagner, ``CMS kinematic edge from s-bottoms'', hep-ph:1410.4998.

scenario A

scenario B

Allanach, Kvellestad, Raklev, 2014

example signal
background
observed
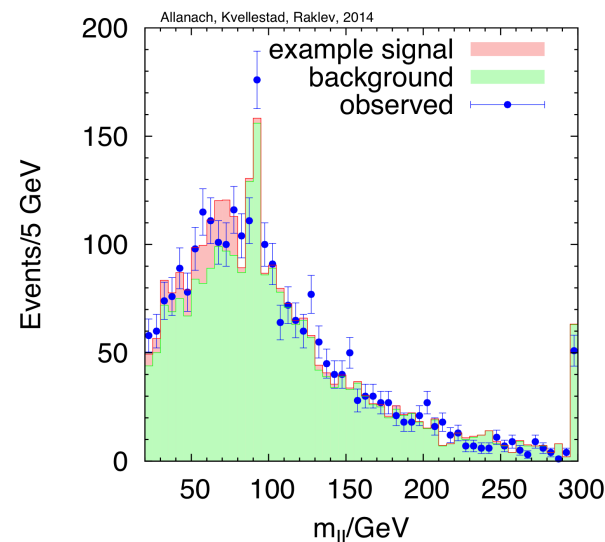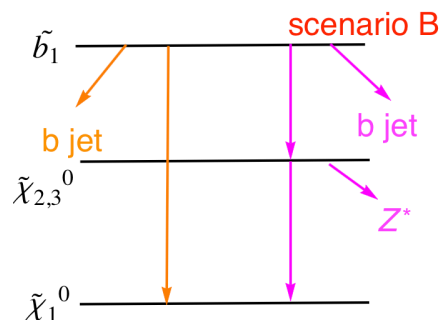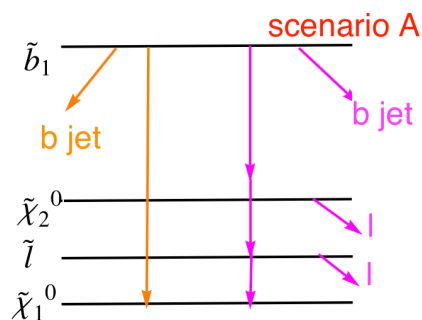
Future prospects

- **Lessons learned:** We have accumulated enough luminosity and sensitivity to make searches for rare signatures in decay chains worthwhile

- **Future analyses** at center-of-mass energies of 13 TeV will push limits on Supersymmetry much further, especially from inclusive hadronic and leptonic search channels

- **More sophisticated** specialized algorithms will be necessary to target more difficult accessible Supersymmetry phase space regions

Future challenges:

- **Boosted topologies** only one challenge out of many at the future √s = 13 TeV high luminosity LHC
  - ➔ jet substructure algorithms

- **"Pile-up"** from simultaneous and high-frequency pp-collisions
  distorted energy reconstruction, increased trigger threshold, jet multiplicit
  - ➔ requires sophisticated subtraction algorithms

- **Compressed** spectra
  small Supersymmetry particle mass differences
  - ➔ only little visible energy, requires e.g. specialized triggers

- **Electroweak** production
  low jet multiplicity and energies
  - ➔ specialized analyses

- **Model** fits
  - ➔ combine search results
  - ➔ derive matching parameters, exclude phase space regions

Conclusion

- CMS has searched for New Physics using 19.5 fb^{-1} of 8 TeV data of the full 2012 dataset

- Searching for Supersymmetry requires complex analysis tools

- Also 'negative' search results can be interesting

- CLs limits at 95% C.L. on the signal cross section have been calculated

- Interpretation in various simplified model spectra (SMS)

References
CMS public results: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

Additional material

M. Strassler 2011

The Exactly-Supersymmetric Standard Model

Higgs/Higgsino

H $\tilde{H}$

Higgs Field

quarks/**squarks**

$\tilde{t}$ t $\tilde{t}$

Weak Nuclear Force

W⁺ W⁻   Z⁰
Wino⁺ H⁺ H⁻ **Wino⁻** A⁰ **Zino**

up-type

down-type

$\tilde{b}$ b $\tilde{b}$

$\tilde{c}$ c   c

$\tilde{\tau}$ τ $\tilde{\tau}$

$\tilde{\mu}$ μ $\tilde{\mu}$

charged
leptons/**sleptons**

$\tilde{e}$ e $\tilde{e}$

$\tilde{s}$ s $\tilde{s}$

$\tilde{d}$ d $\tilde{d}$

$\tilde{u}$ u $\tilde{u}$

Heavier

neutrinos/
sneutrinos

$\tilde{\nu}_3$ ν_3 $\tilde{\nu}_2$ ν_2
$\tilde{\nu}_1$ ν_1

h $\tilde{h}$

Higgs/Higgsino

Electromagnetic Force
Photon, **Photino**

Strong Nuclear Force
Gluons (8 types), **Gluinos**
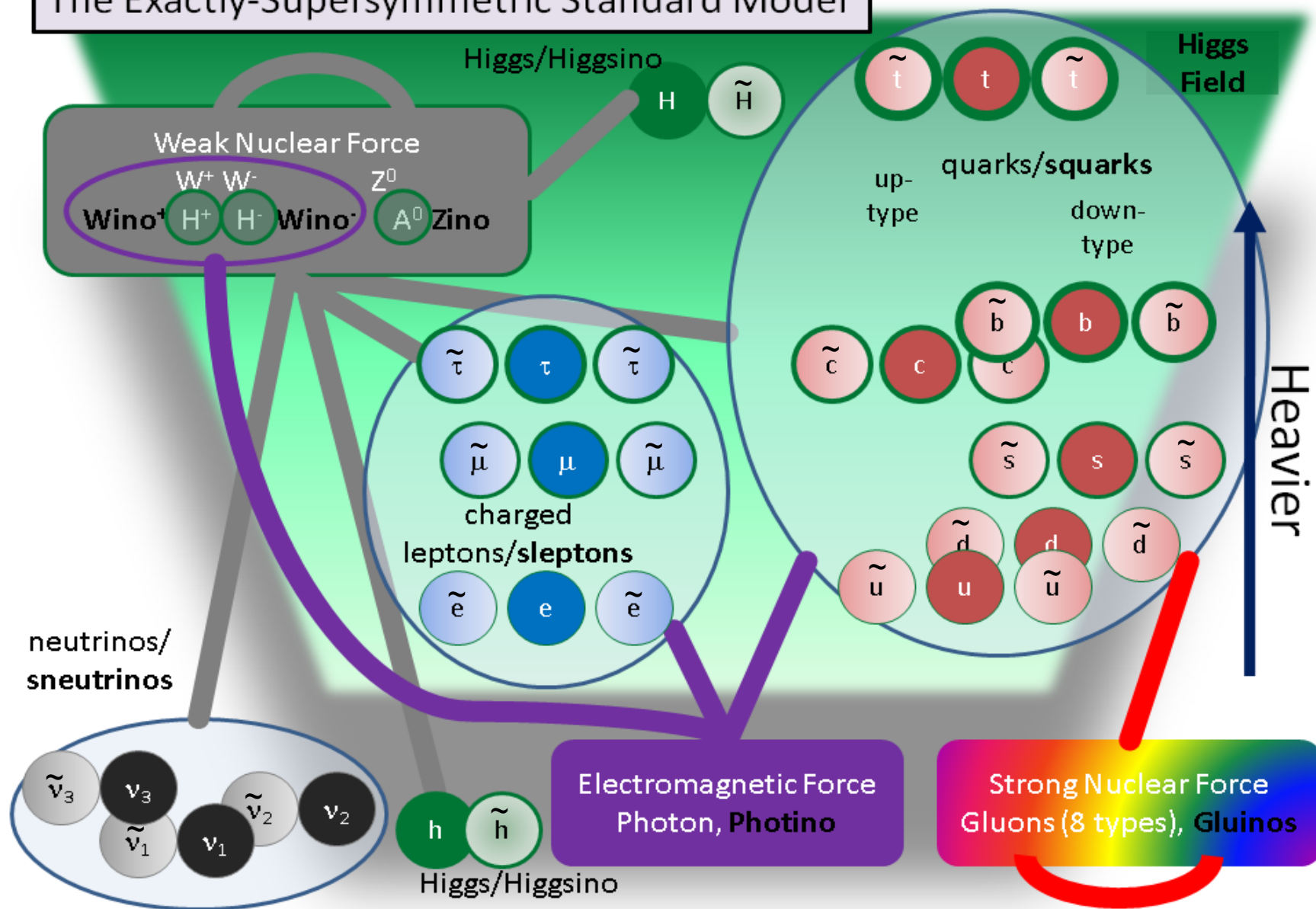
Inclusive search for SUSY with multi-leptons plus b

- Generic search, lepton requirement to suppress background
- Targeting possibly light third generation squarks (natural SUSY requires light 3rd generation)

Model A2

Model C1
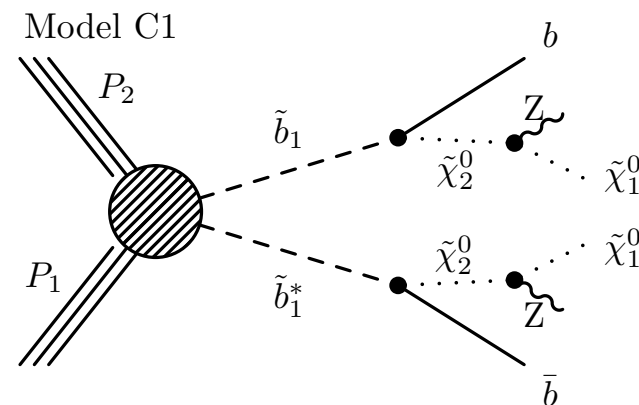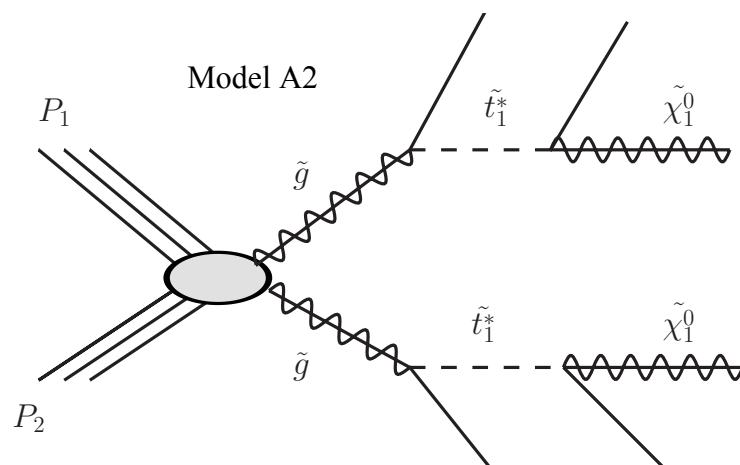
Sensitivity to SUSY scenarios with at least
- Three light isolated leptons (e, μ),
- One b-tagged jet
- Missing transverse energy (MET)
- Hadronic activity

$\sqrt{s}$ = 8 TeV,
19.5 fb^{-1} luminosity (full 2012)

Selection

- 3 leptons with pT > 20, 10, 10 GeV
- $m(l^+l^-) > 12$ GeV
- ≥ 1 b-tagged jet with pT > 30 GeV
- No lepton with ΔR(l, b-jet) < 0.4
- no jet with ΔR(l, jet) < 0.4

29 signal regions

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

<u>On-Z</u>: Opposite-sign same-flavor
di-lepton mass with m(Z) ± 15 GeV

<u>Off-Z</u>: all other events

Bin rather than cut

Standard Model background

- Top – anti-top plus boson production: ttW, ttZ, ttWZ
- Single-top plus Z production: tbZ
- Di-boson production: WZ, ZZ
- Triple-boson production, WWW, WWZ, WZZ

Monte Carlo simulation
Validated in data control
Region

- Non-prompt lepton (e.g. from b-decays)

Data side-band with
1 non-isolated lepton

- On-shell and off-shell photon conversions $\gamma \rightarrow l^+l^-$
  - Measured in low MET data control region

HT: scalar sum of jet pT


90 events

73 events
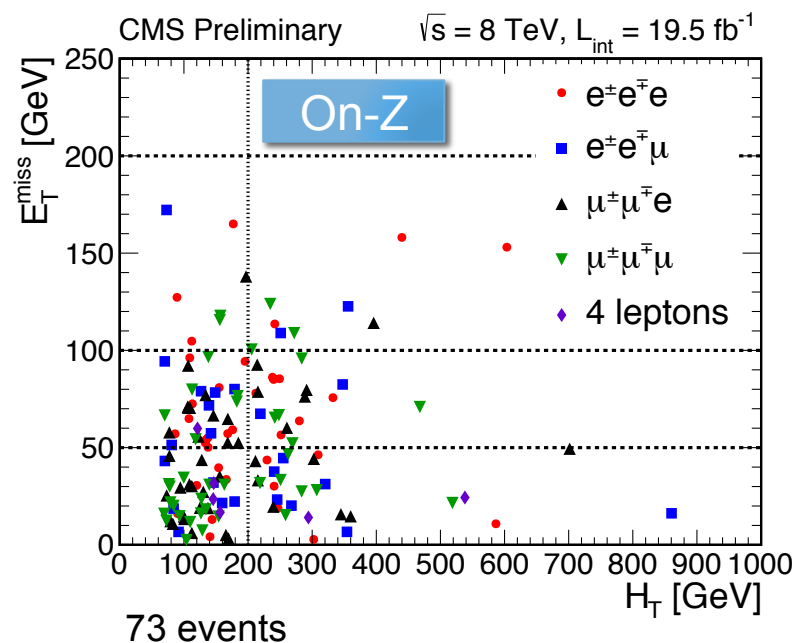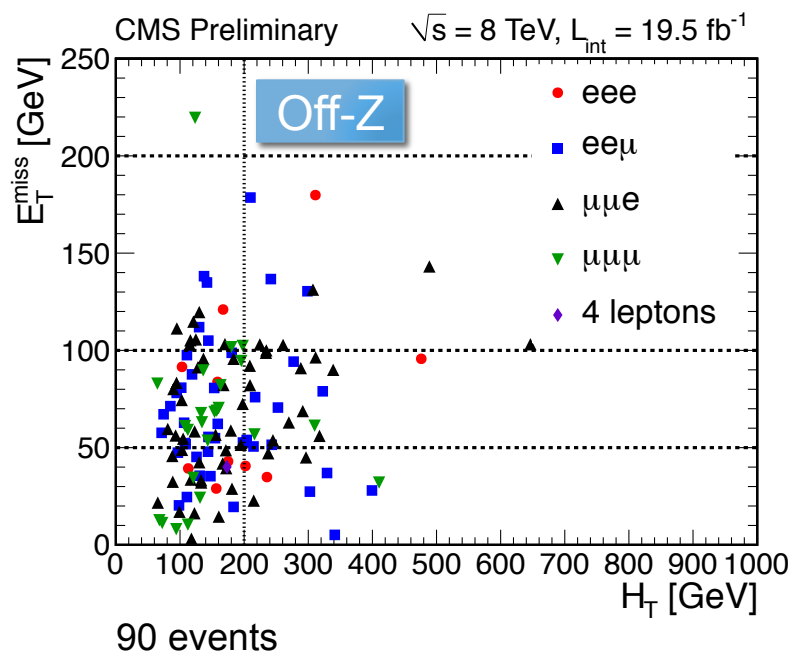
Results

- Non-prompt lepton background dominant – this is extracted from data

- Simultaneous multi-bin fit to obtain final cross-section limits

- Lepton reconstruction and isolation efficiency uncertainties measured in data control sample on the Z peak

Off-Z events   CMS Preliminary $\sqrt{s}$ = 8 TeV, L_{int} = 19.5 fb^{-1}

On-Z events   CMS Preliminary $\sqrt{s}$ = 8 TeV, L_{int} = 19.5 fb^{-1}
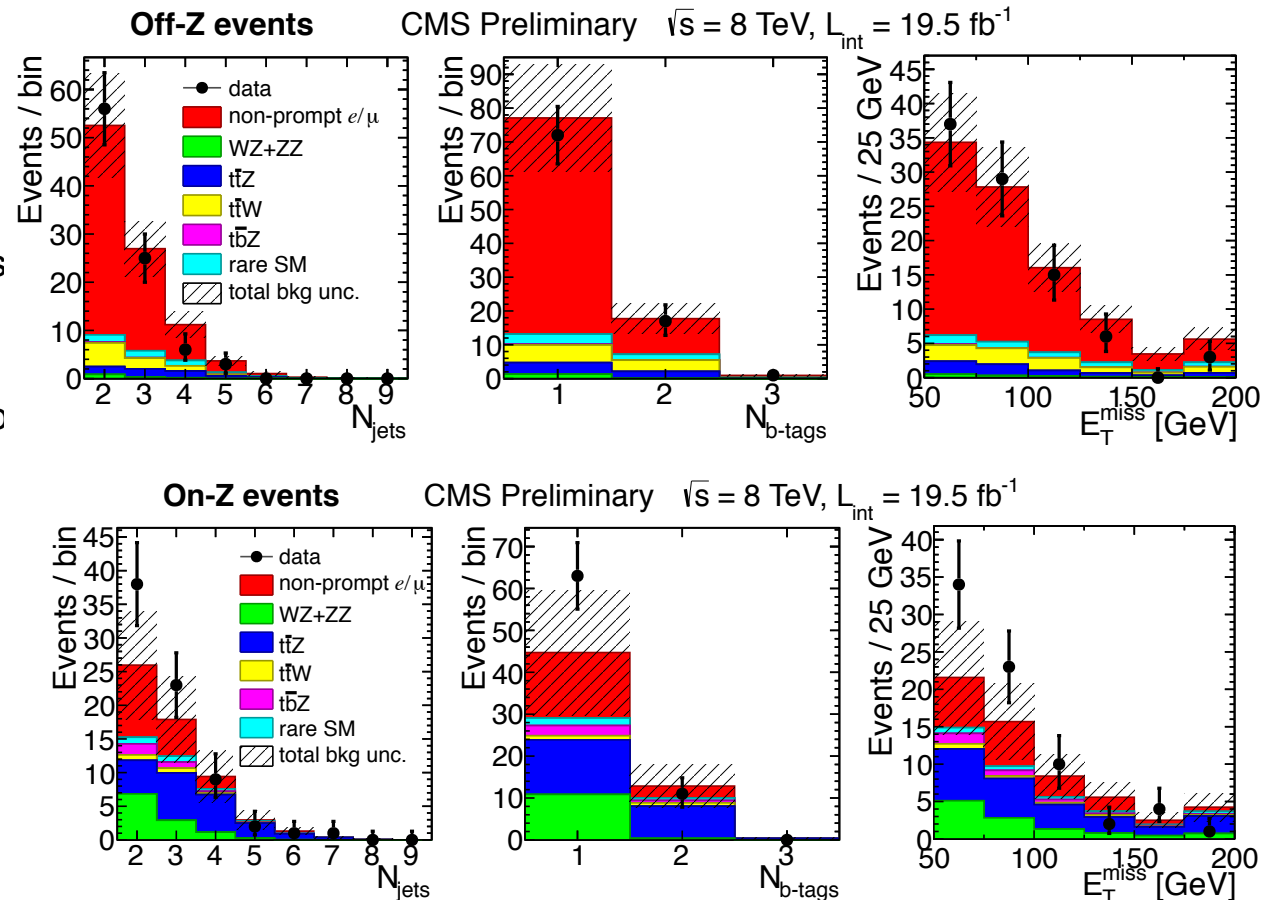
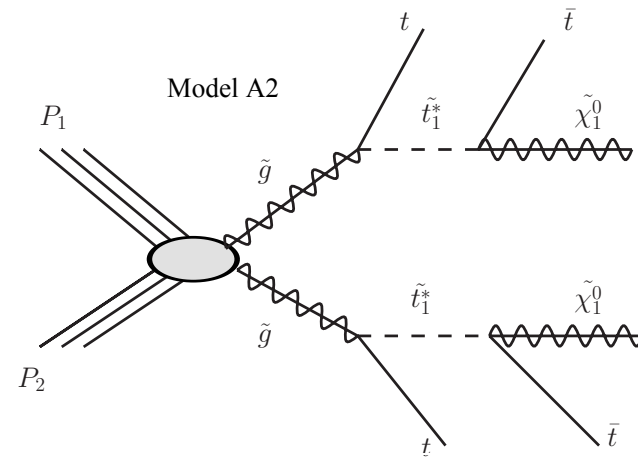| Source	Uncertainty, %
Luminosity	4.4
Modeling of lepton reconstruction, ID, $I_{\rm rel}$ based on Z-events	12
Jet energy scale	5–15
Unclustered energy and lepton effects on $E_{\rm T}^{\rm miss}$	5
Modeling of b-jet multiplicity	5–20
Trigger	5
Total systematic uncertainty	15–30

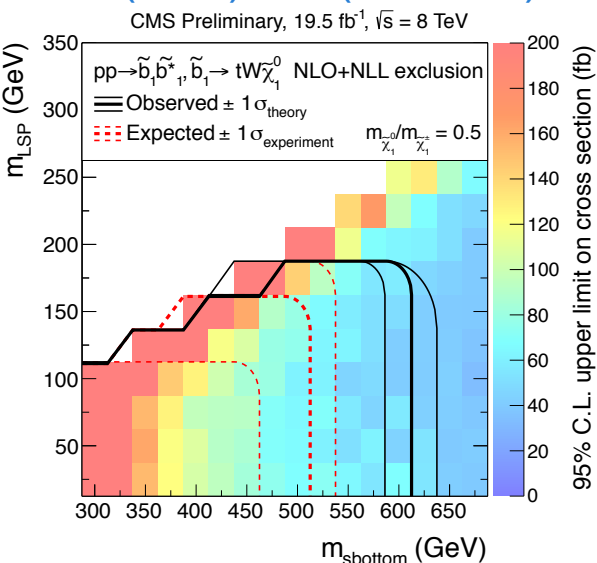# Cross section limit and interpretation in simplified model spectra (SMS)
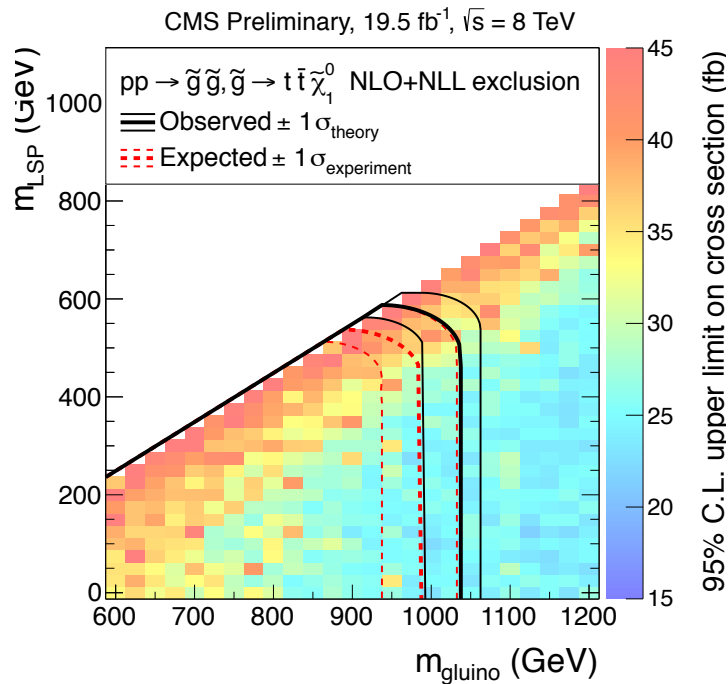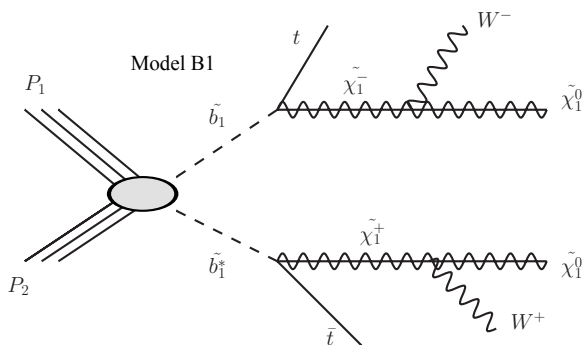

Off-shell stop
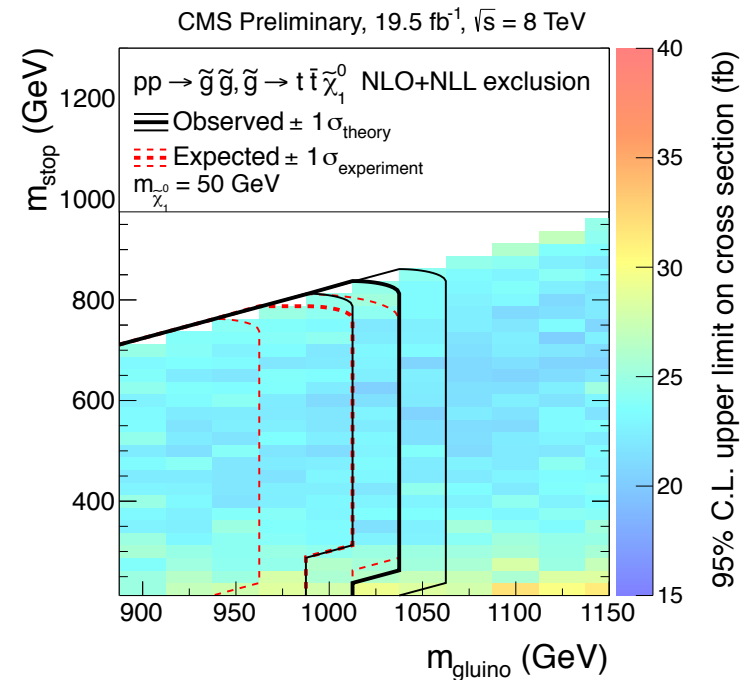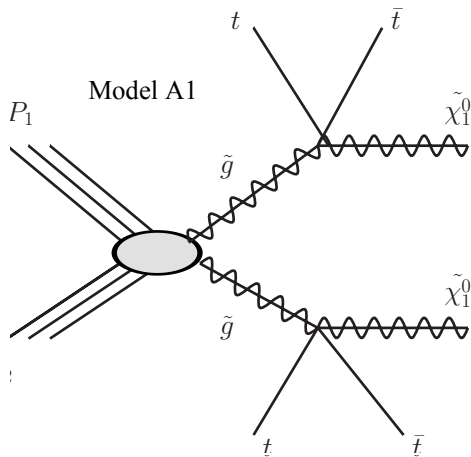
m(neutralino 1) = 50 GeV
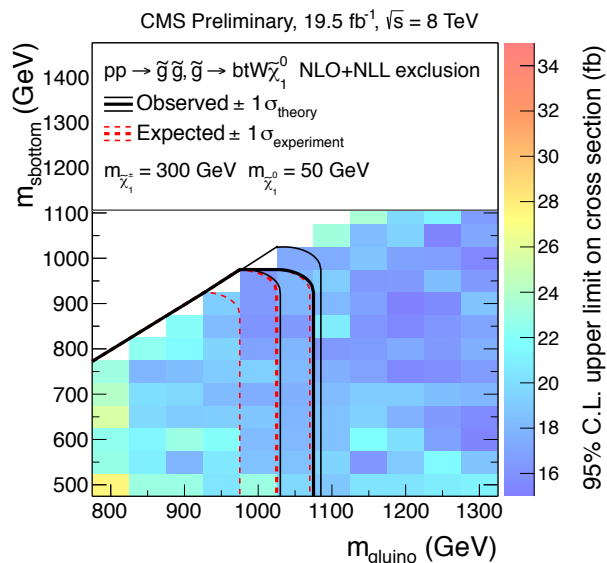
Cross section limit and interpretation in SMS

m(LSP) – m(sbottom)

CMS Preliminary, 19.5 fb^{-1}, $\sqrt{s}$ = 8 TeV

$pp \to \tilde{b}_1 \tilde{b}^*_1, \tilde{b}_1 \to tW\tilde{\chi}^0_1$ NLO+NLL exclusion

Observed ± 1 σ_{theory}
Expected ± 1 $\sigma_{experiment}$ $m_{\tilde{\chi}^0_1}/m_{\tilde{\chi}^\pm_1}$ = 0.5

95% C.L. upper limit on cross section (fb)

m(sbottom) – m(gluino)

CMS Preliminary, 19.5 fb^{-1}, $\sqrt{s}$ = 8 TeV

$pp \to \tilde{g}\tilde{g}, \tilde{g} \to btW\tilde{\chi}^0_1$ NLO+NLL exclusion

Observed ± 1 σ_{theory}
Expected ± 1 $\sigma_{experiment}$
$m_{\tilde{\chi}^\pm_1}$ = 300 GeV $m_{\tilde{\chi}^0_1}$ = 50 GeV

95% C.L. upper limit on cross section (fb)

m(LSP) – m(sbottom)

CMS Preliminary, 19.5 fb^{-1}, $\sqrt{s}$ = 8 TeV

$pp \to \tilde{b}_1 \tilde{b}^*_1, \tilde{b}_1 \to bZ\tilde{\chi}^0_1$ NLO+NLL exclusion

Observed ± 1 σ_{theory}
Expected ± 1 $\sigma_{experiment}$
$m_{\tilde{\chi}^0_2} - m_{\tilde{\chi}^0_1}$ = 110 GeV

95% C.L. upper limit on cross section (fb)

$m(\chi^\pm) / m(\chi^0)$ = 0.5

$M(\chi^\pm_1)$ = 300 GeV

$M(\chi^0_2) - M(\chi^0_1)$ = 110 GeV

Inclusive multi-leptons search

$\sqrt{s}$ = 8 TeV
9.2 fb^{-1} luminosity

- More general focus on all possible three-lepton signatures
- Not optimized for a particular SUSY scenario
- Multiple search regions binned in MET, HT rather than cut

Selection

- ≥ 3 isolated leptons, from same primary vertex
    - pT > 10 GeV, |η| < 2.4 for e, μ
    - At most one or three prong τ, pT > 20, |η| < 2.3
- Z-mass ± 15 GeV and m(ll)<12 GeV veto for opposite-charge same-flavor lepton pairs

Signal search channels

- Bins of number of opposite-sign same-flavor dilepton pairs
- Separate channels for events containing a hadronic tau
- No b-jet or ≥ 1 b-jets
- HT < 200 GeV or HT > 200 GeV
- Five MET bins 0 – 50 – 100 – 150 – 200 GeV, ≥ 200 GeV

Backgrounds

- (same as for 3 lepton + b)

Results

Gluino pair-production and decay via off-shell stop

Slepton co-NLSP scenario