Imperial College London

Searches for Supersymmetry with the CMS detector at the LHC

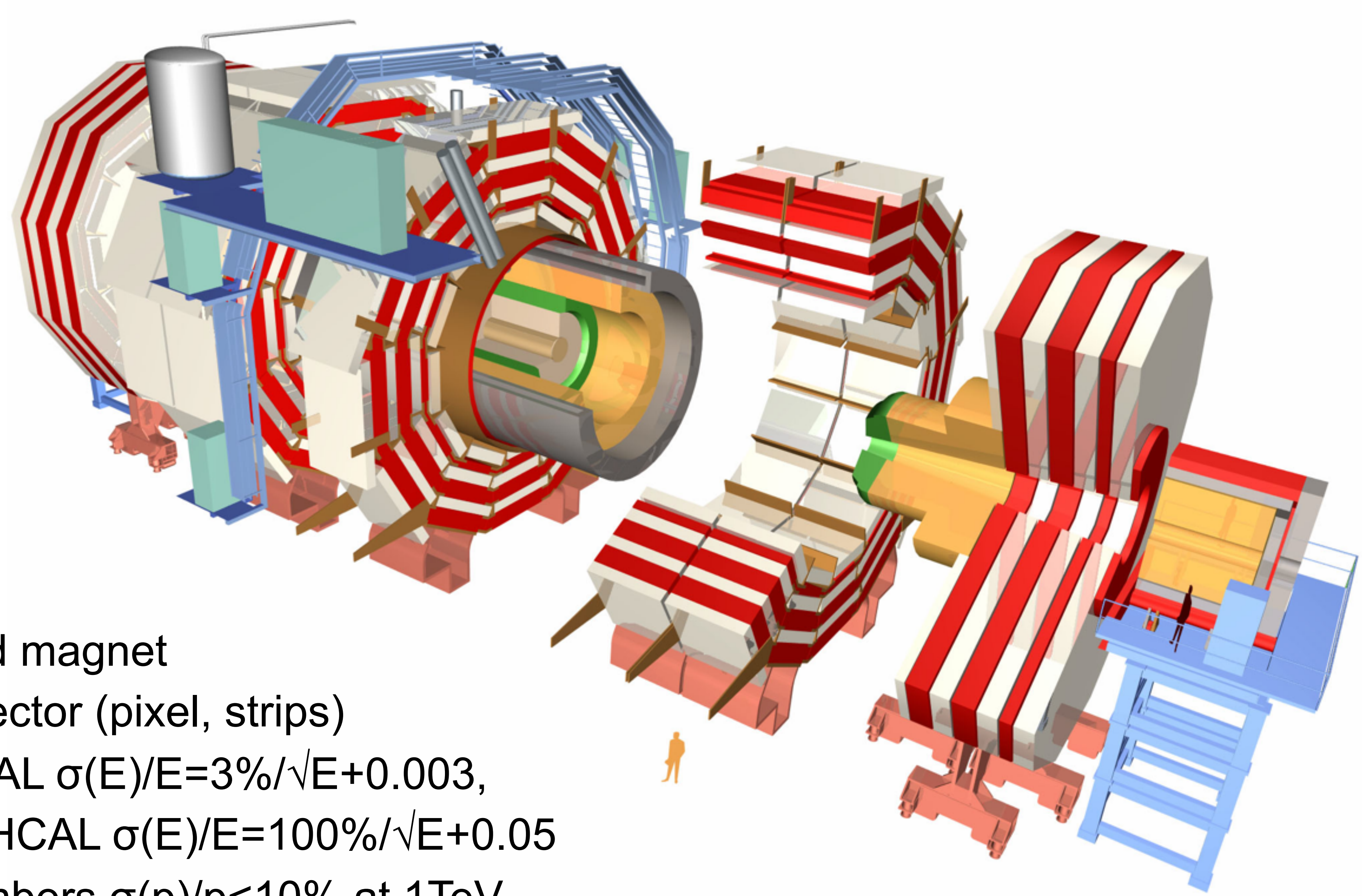
Alex Tapper

Outline

- Introduction
- SUSY search programme
  - What to look for and how to look for it
  - All-hadronic searches
  - Searches with leptons
  - Searches with photons
- Summary and conclusions

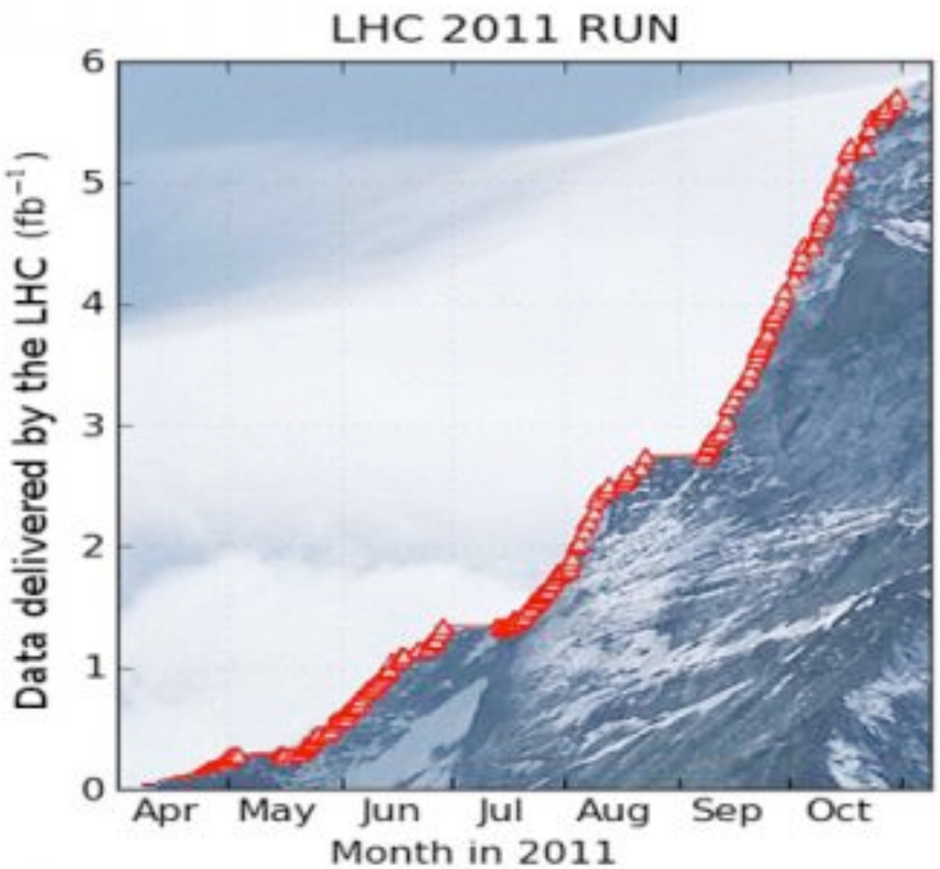
The CMS detector

JINST3:S08004 (2008)

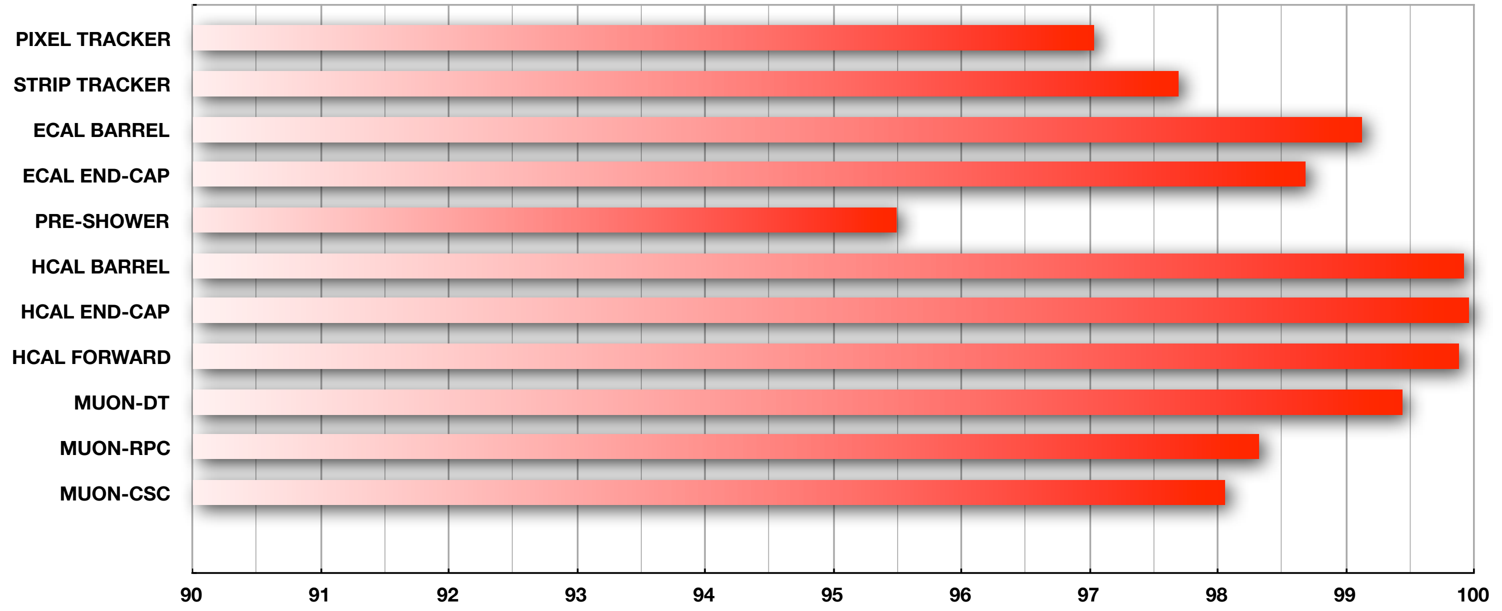


- 4T solenoid magnet
- Silicon detector (pixel, strips)
- Crystal ECAL $\sigma(E)/E=3\%/\sqrt{E}+0.003$,
- Brass/sci. HCAL $\sigma(E)/E=100\%/\sqrt{E}+0.05$
- Muon chambers $\sigma(p)/p<10\%$ at 1TeV

The CMS detector in 2011



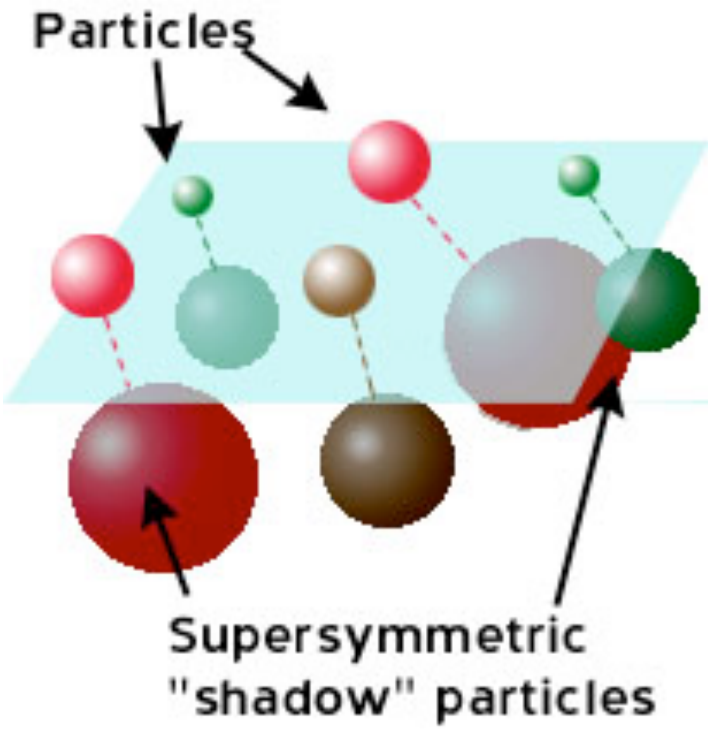
- LHC delivered ~6 fb^{-1} (thanks!)
- CMS collected ~5.6 fb^{-1} (93%)
- Results based on ~5 fb^{-1} (83%)



- Average fraction of functional detector channels > 98.5%
- Lowest still > 95%

Supersymmetry

- The theory hypothesises a relationship between bosons and fermions
  - Leads to the prediction that every fermion has a bosonic super-partner and vice versa



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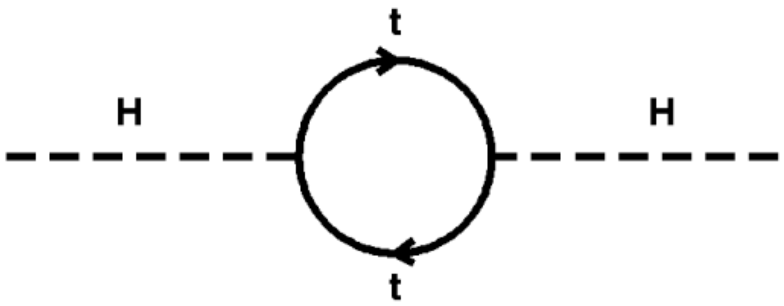
  - It provides a solution to the hierarchy problem



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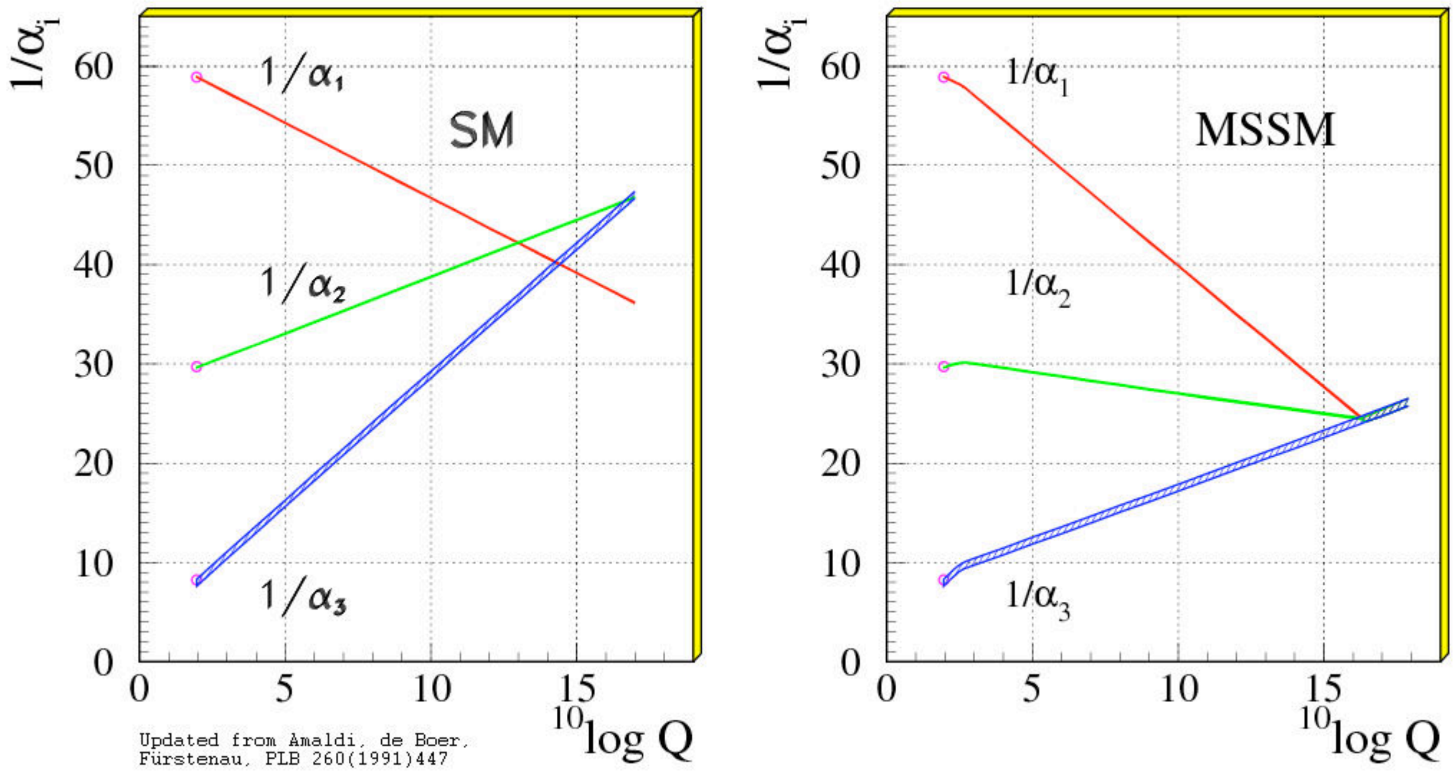

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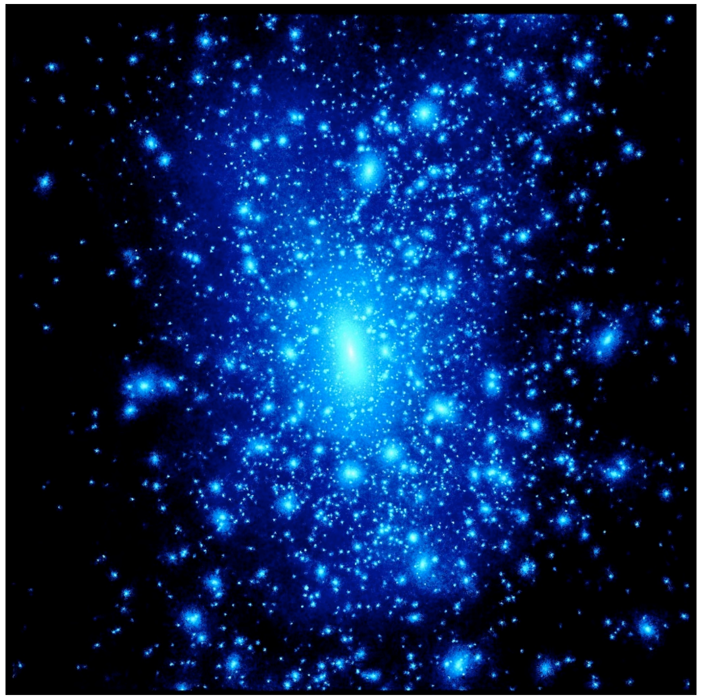

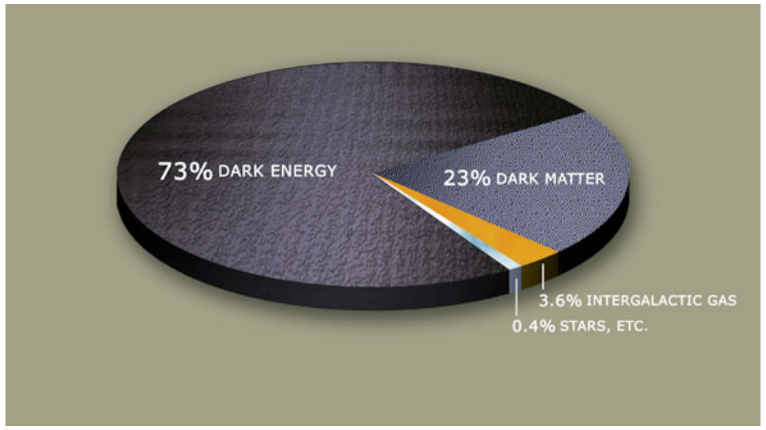

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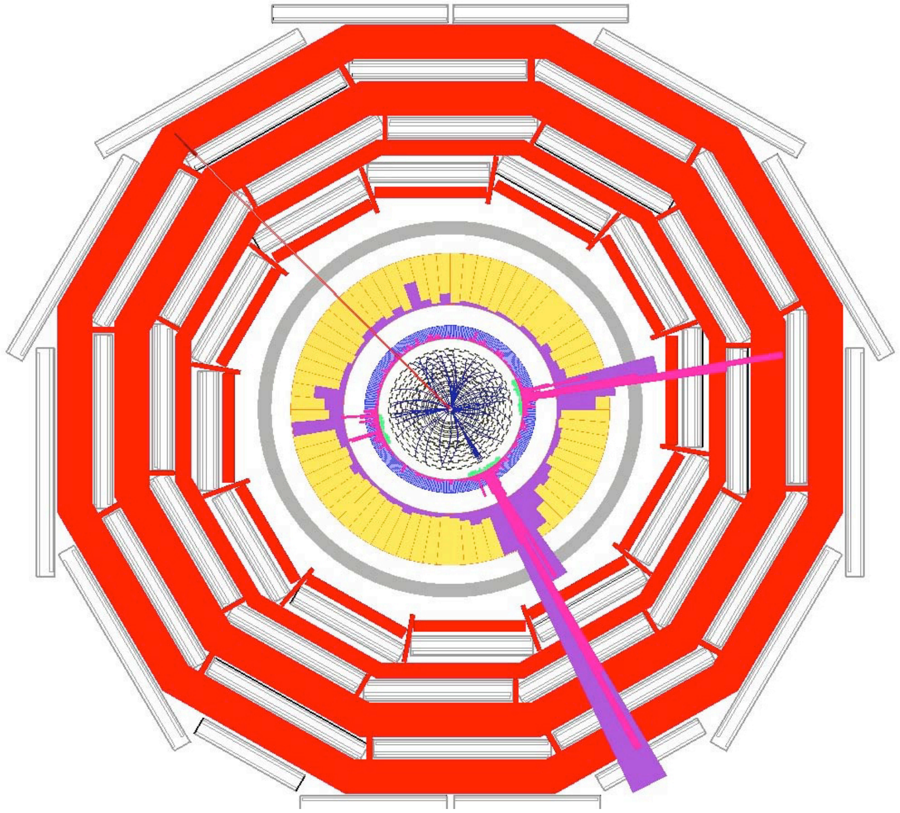
- Experimentalists love it because:
  - Plethora of new particles to discover and measure



Supersymmetry

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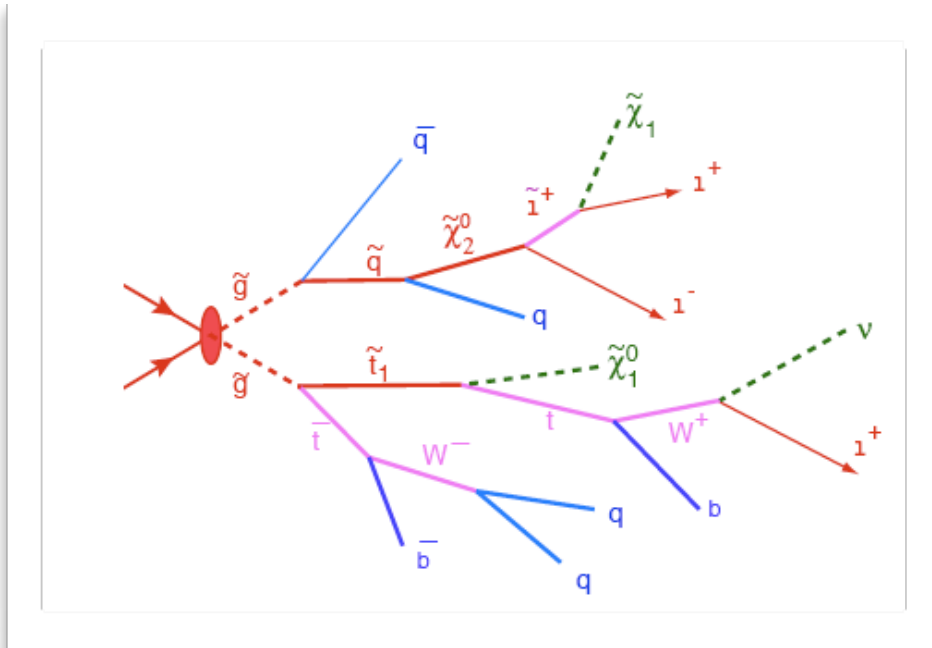
  - It provides a solution to the hierarchy problem
  - It allows unification of the gauge couplings at high scales and therefore a GUT?
  - It can provide a dark matter candidate
- Experimentalists love it because:
  - Plethora of new particles to discover and measure
- Symmetry not exact
  - SUSY and Standard Model particles have different masses
  - SUSY is broken ➔ what does it look like and how do we search?

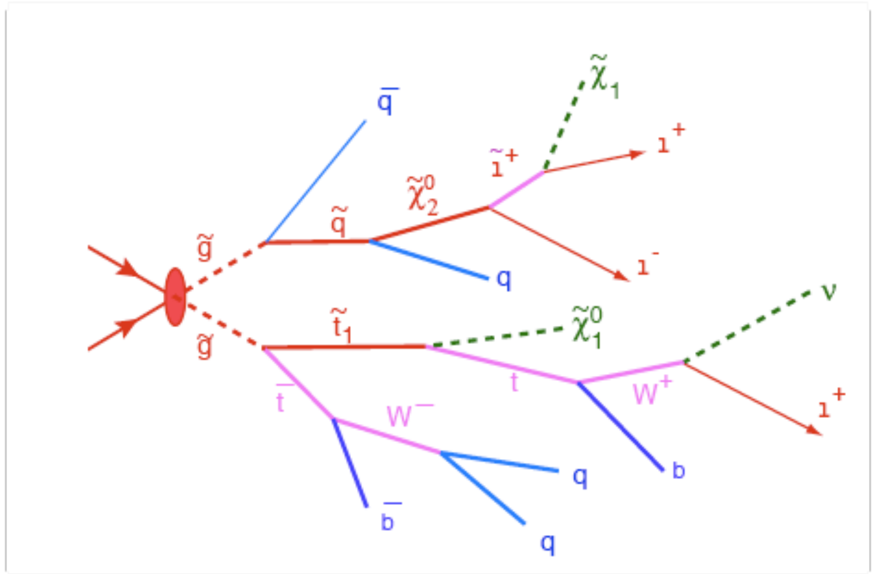
SUSY search strategy



- Production
  - Squark and gluino expected to dominate*
  - Strong production so high cross section
  - Cross section depends only on masses
  - Approx. independent of SUSY model

* I will cover electroweak production too ➔ possible with current luminosities

SUSY search strategy



- Production
  - Squark and gluino expected to dominate
  - Strong production so high cross section
  - Cross section depends only on masses
  - Approx. independent of SUSY model
- Decay
  - Details of decay chain depend on SUSY model (mass spectra, branching ratios, etc.)
  - Assume R_P conserved ➔ decay to lightest SUSY particle (LSP)
  - Assume squarks and gluinos are heavy ➔ long decay chains
- Signatures
  - **MET** from LSPs, **high-E_T jets** and **leptons** from long decay chain
- Focus on simple signatures
  - Common to wide variety of models
  - Let Standard Model background and detector performance define searches not models

The key: backgrounds

- Physics
  - Standard Model processes that give the same signatures as SUSY
  - Cannot/do not (yet?) rely on Monte Carlo predictions ➔ measure in data
- Detector effects
  - Detector noise, mis-measurements etc. that generate MET or extra jets
  - Commissioning and calibration ➔ good performance
- Other
  - Beam-halo muons and cosmic-ray muons, beam-gas events
  - Data and simulation already ➔ measure in situ too

Search strategy (what and how?)

0-leptons	1-lepton	OSDL	SSDL	≥3 leptons	photons	γ+lepton
Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton	(Di-)photon + jet + MET	Photon + lepton + MET

- Generic missing energy signatures
- Categorised by numbers of leptons and photons
- Many include jet requirement ➔ strong production
- Transition from simple counting experiments to shape-based analyses

Search strategy (what and how?)

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- Very challenging due to large amount and wide range of backgrounds
- However most sensitive search for strongly produced SUSY
- CMS pursues several complementary strategies based on kinematics and detector understanding
- Extended to b, τ and top-tagged final states (Alfredo's talk)

Search strategy (what and how?)

0-leptons	1-lepton	OSDL	SSDL	≥3 leptons	photons	γ+lepton
Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton	(Di-)photon + jet + MET	Photon + lepton + MET

- Lepton (electron or muon) requirement reduces background considerably
- Only ttbar and W+jets left ➔ topological information

Search strategy (what and how?)

0-leptons	1-lepton	OSDL	SSDL	≥3 leptons	photons	γ+lepton
Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton	(Di-)photon + jet + MET	Photon + lepton + MET

- Adding a second lepton (electron or muon) reduces W background
- Two analyses here: inclusive and Z peak search
- Several techniques including opposite-sign opposite-flavour subtraction
- In the case of discovery provide mass edges

Search strategy (what and how?)

0-leptons	1-lepton	OSDL	SSDL	≥3 leptons	photons	γ+lepton
Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton	(Di-)photon + jet + MET	Photon + lepton + MET

- A natural SUSY signature
- Very small Standard Model backgrounds
- Include all three generations of leptons and all cross channels

Search strategy (what and how?)

0-leptons	1-lepton	OSDL	SSDL	≥3 leptons	photons	γ+lepton
Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton	(Di-)photon + jet + MET	Photon + lepton + MET

- Very clean events with very low Standard Model background
- Include all three generations of leptons and all combinations
- Search inclusively, on the Z peak, with and without MET
- Some striking Standard Model events observed already

Search strategy (what and how?)

0-leptons	1-lepton	OSDL	SSDL	≥3 leptons	photons	γ+lepton
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- Many gauge-mediated models predict photons in final state
- Single and di-photon searches dominated by QCD multijet and γ+jet backgrounds

Search strategy (what and how?)

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- Many gauge-mediated models predict photons in final state
- Lepton reduces QCD multijet and γ+jet backgrounds

Search strategy (what and how?)

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Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton	(Di-)photon + jet + MET	Photon + lepton + MET

RPV	"Exotic"
R-Parity violating searches	Long-lived particles etc.

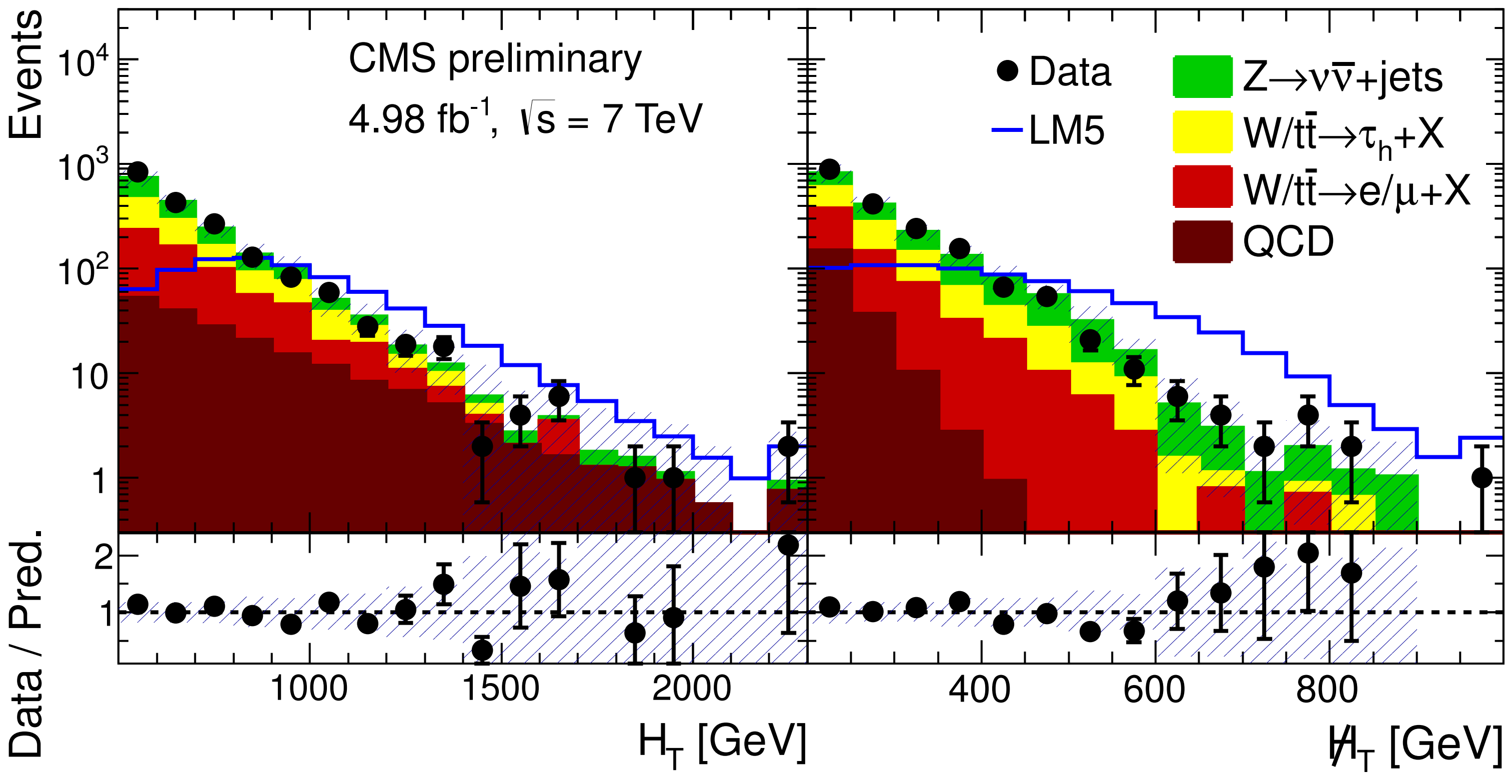
- Non-MET based searches
- R-parity conserving and "exotic" SUSY
- Examples are long-lived particles
- Not covered in this talk but well-studied in CMS
- See https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO

Jets + MET

- All hadronic channel, just jets and missing energy in event
  - Very challenging due to large amount and wide range of backgrounds
  - However most sensitive search for strongly produced SUSY
  - CMS pursues several complementary strategies based on kinematics and detector understanding ➔ this analysis the "classic" version

SUS-12-011

- Selection
  - No leptons (e or μ)
  - At least 3 jets > 50 GeV
  - Δφ between jets and MET
  - Examine data in bins
    - H_T^{miss} (MET from jets)
    - H_T (∑ of jet p_T)



Jets + MET

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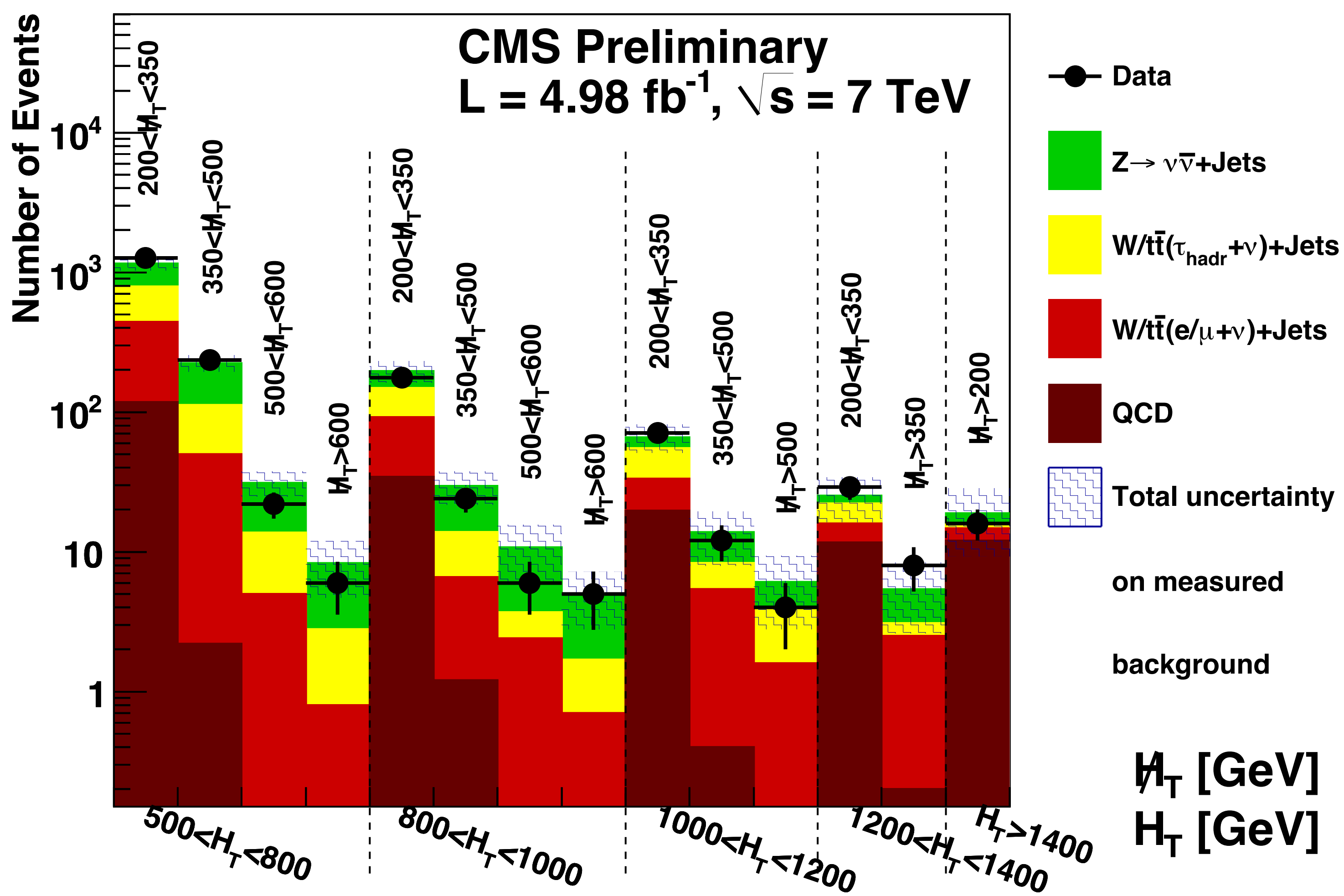
- All background estimates taken from **data**
- Multi-bin approach in H_T^{miss} and H_T
  - Wide sensitivity
  - Bins combined for final limits

No excess seen in data
→ set limits



Jets + MET

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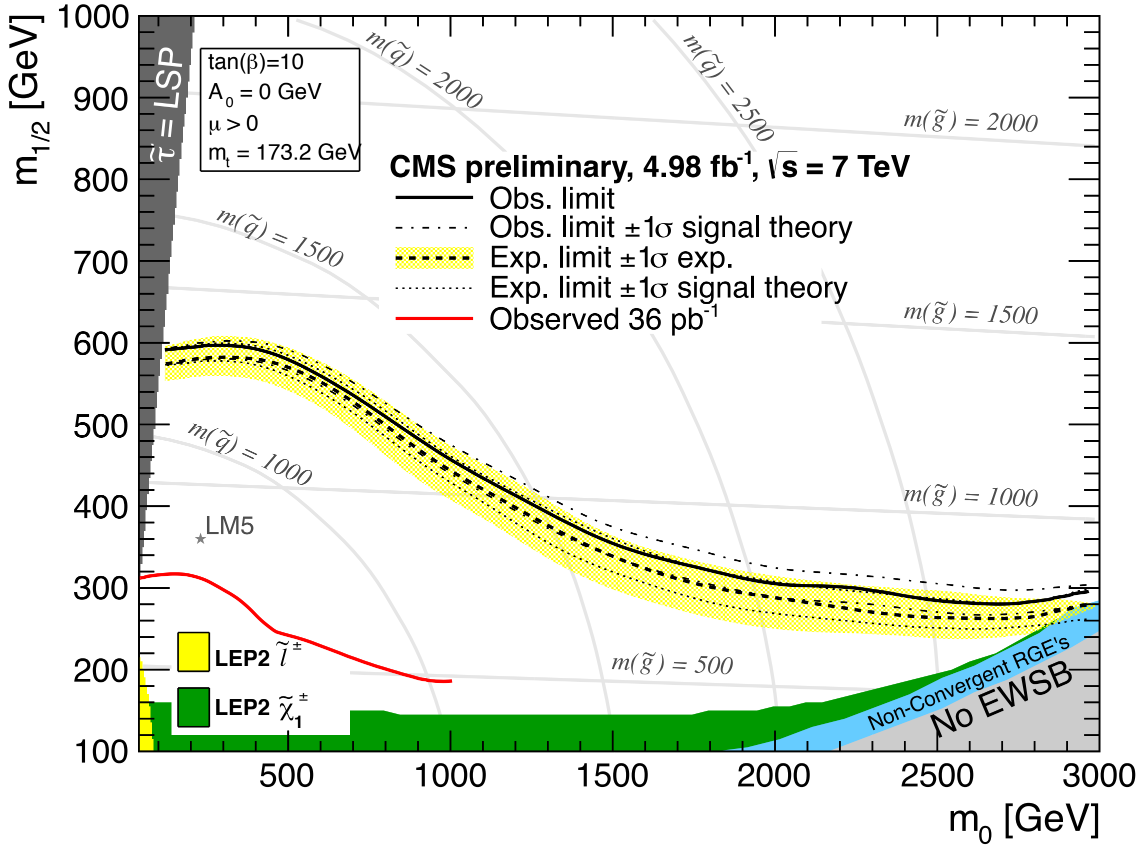
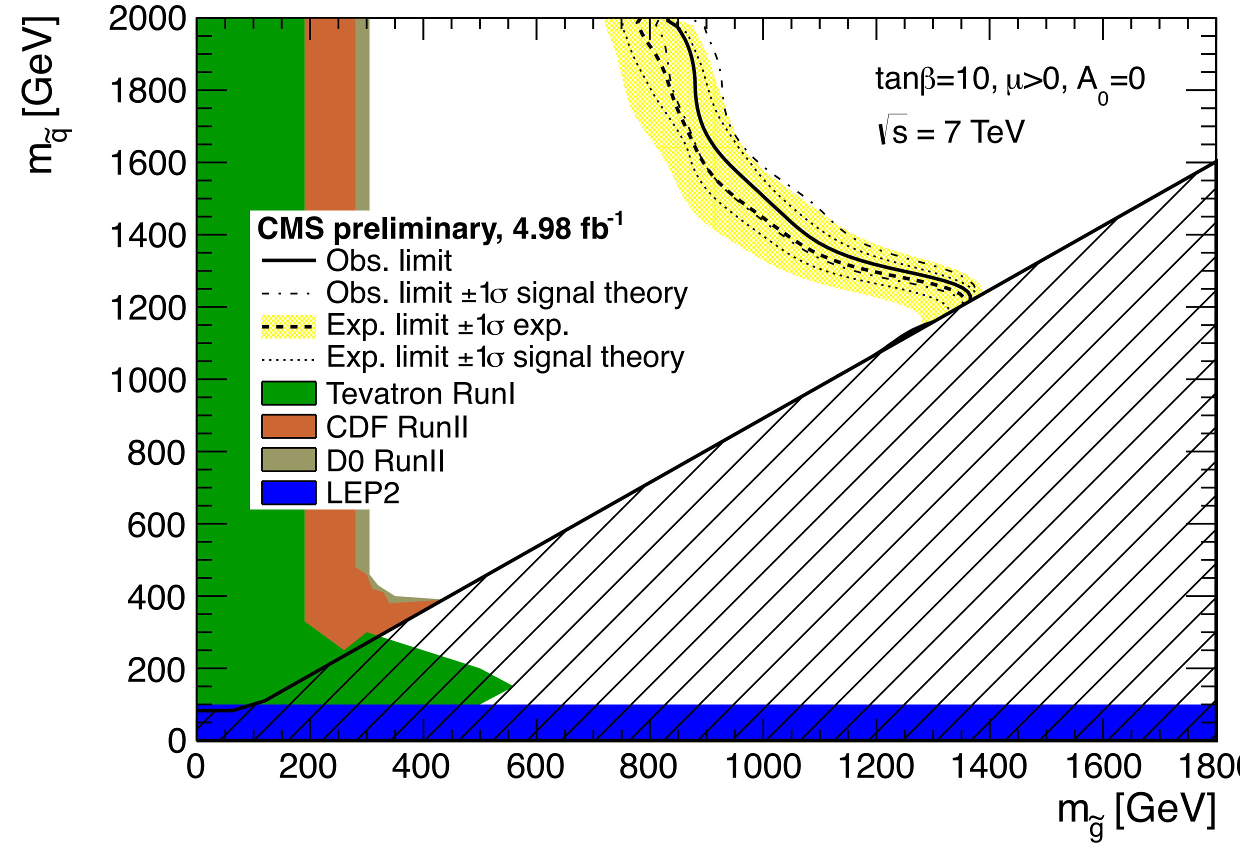
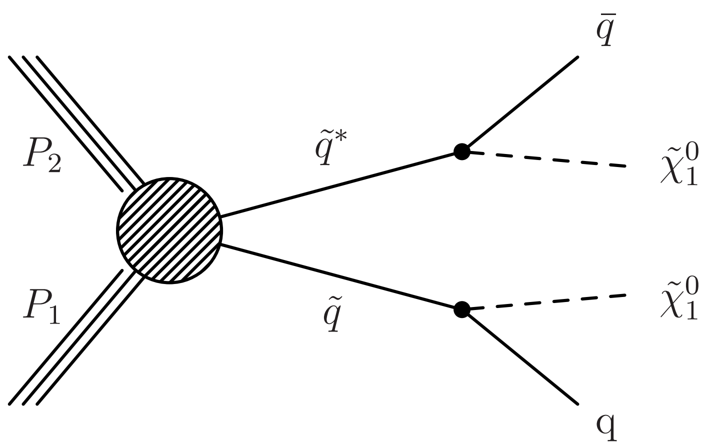




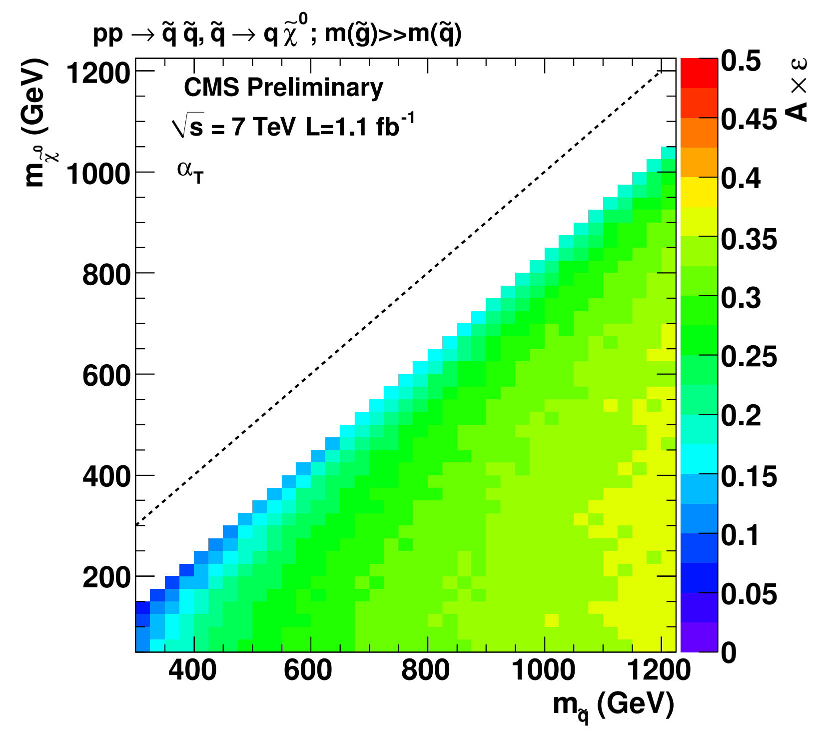
- Limit in the usual CMSSM plane (tanβ=10, A_0=0, μ>0)

Interpretation Intermezzo

- Simplified Model Spectra
  - Limited set of hypothetical particles and decays
  - Less specific mass patterns and signatures
  - Give acceptance x efficiency and cross-section limit
  - Models proposed at: http://www.lhcnewphysics.org



- Hadronic searches
  - Squark anti-squark pair production with decay
    - squark → quark + χ^0
  - Kinematics specified by masses
  - Direct case m_{squark} vs m_{LSP} 2D plot
  - For cascade decays (arbitrary but sensible) slices of intermediate particle
  - "Reference" cross sections (from PROSPINO) given to illustrate limits



Jets + MET

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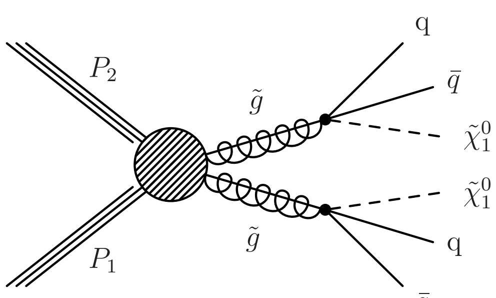
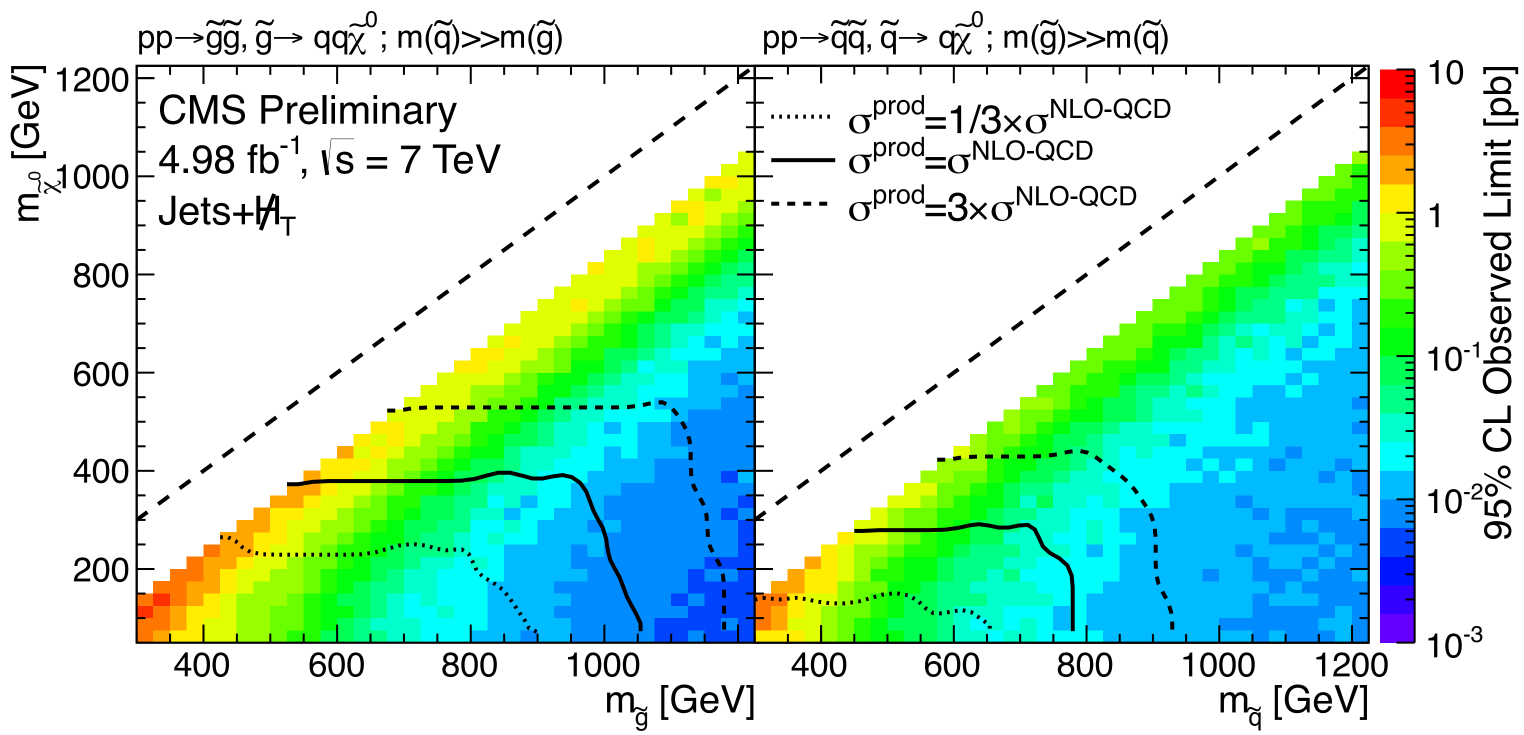
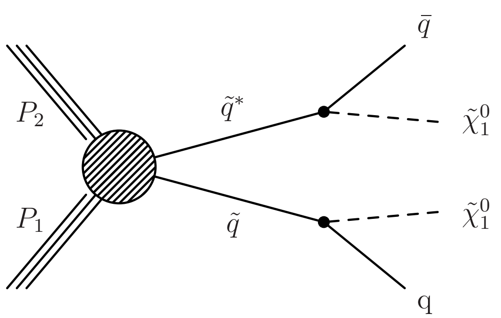






- Clean way to communicate results of our searches and compare different channels ➔ no hidden theory dependence
- Reference cross section scaled by 1/3 and 3 to demonstrate differences from spin or branching ration assumptions
- Areas of small mass splittings removed to reduce sensitivity to signal modelling

Dilepton searches

- Dilepton production:
  - In cascade decays of strongly produced particles
  - Directly via weak pair-production
- Several searches
  - Opposite-sign leptons ➔ On/off Z peak, same-flavour lepton pairs
  - Same-sign leptons ➔ strong and weak production
- Properties
  - Invariant mass of lepton pair can give mass information in the case of a discovery

Z+jets+MET

arXiv1204.3774

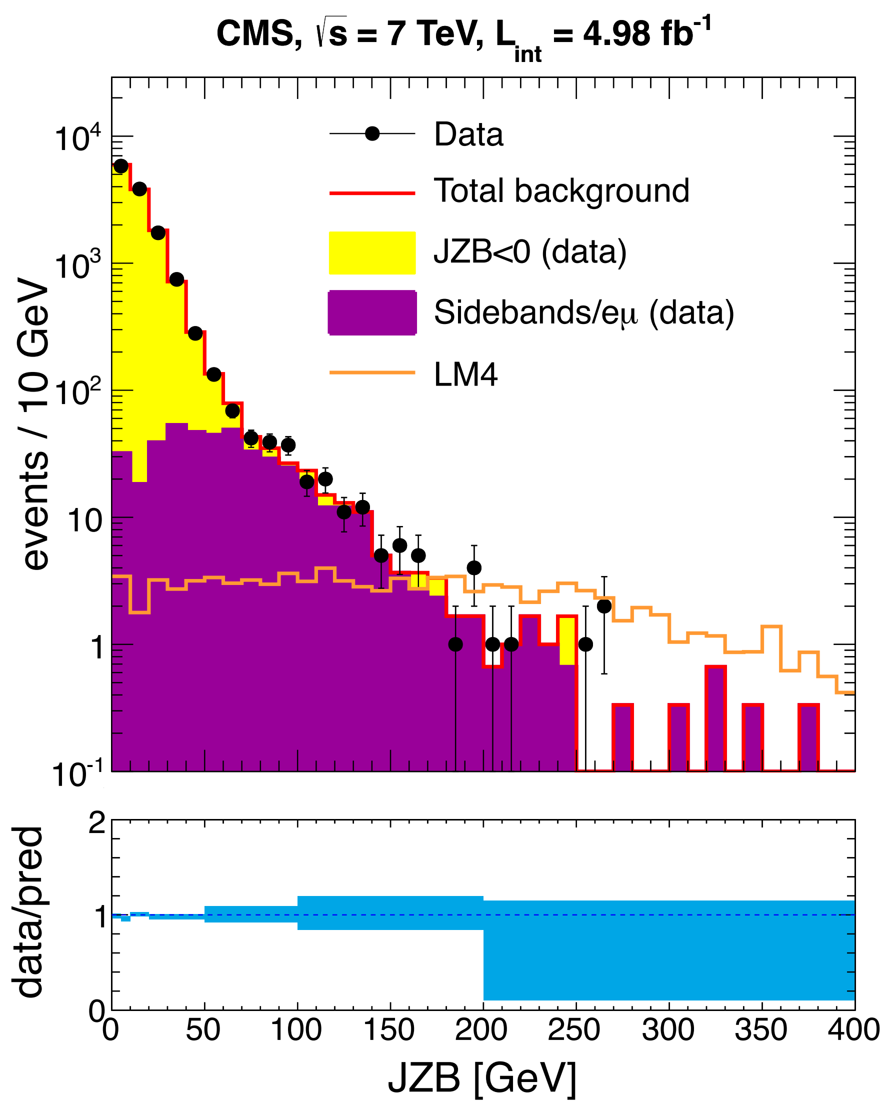
- Reconstruct Z boson mass in e^+e^- or $\mu^+\mu^-$ decay channels

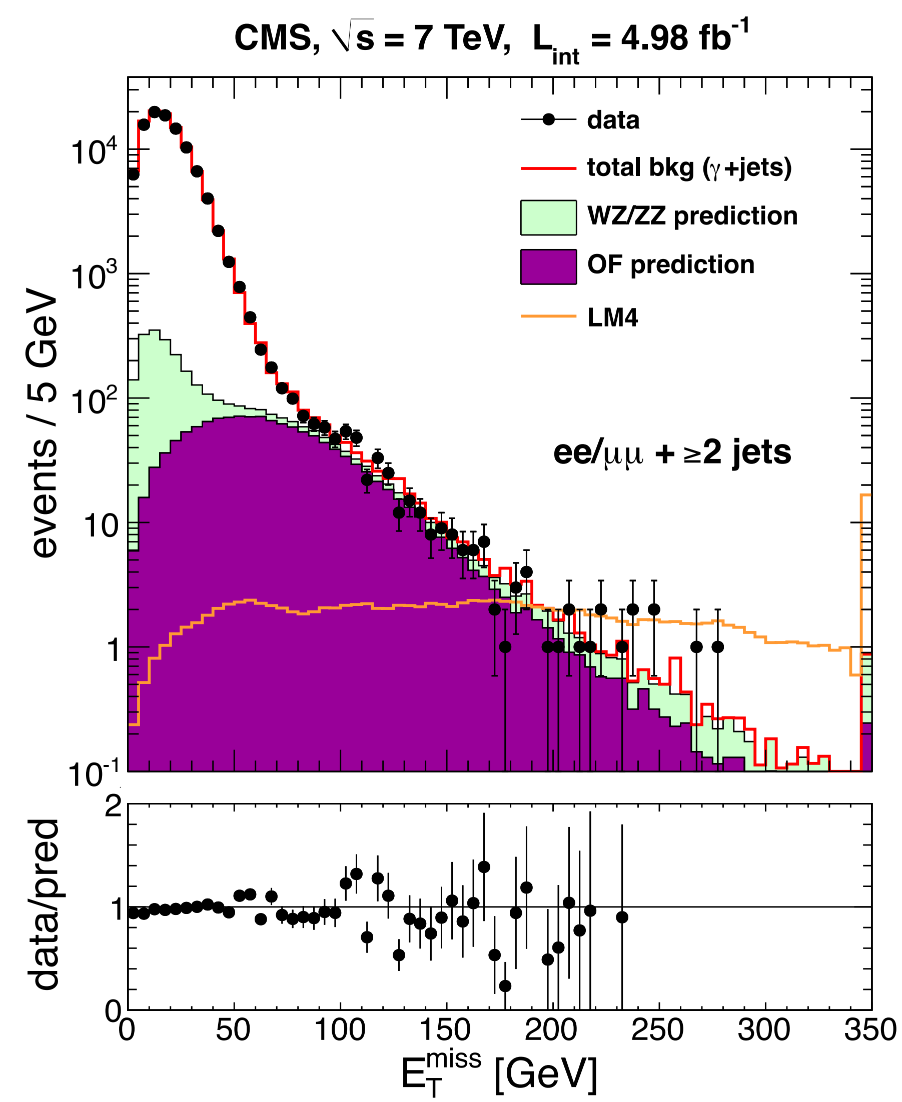
- Backgrounds
  - Z + jets ➔ mis-measured jets give false missing energy signature
  - Top pair-production ➔ leptonic decays in Z mass window

- Two complementary techniques for Z + jets
  - Model instrumental mis-measurement with templates from data
  - Use kinematic properties of events to estimate backgrounds

- For top background use opposite flavour subtraction
  - Top decays same amount of time to $e^\pm\mu^\mp$ as e^+e^- and $\mu^+\mu^-$

Z+jets+MET





JZB = |∑ jet p_T| - |p_T(Z)|

Imbalance of p_T between jets and Z boson ➔ symmetric for background - asymmetric for signal

Jet mis-measurement measured in γ +jet events and applied to signal sample to predict MET distribution

arXiv1204.3774

Comparison of analyses

- Can compare Z + MET with all-hadronic analyses
  - $Z \rightarrow l^+l^-$ here vs $Z \rightarrow qq$

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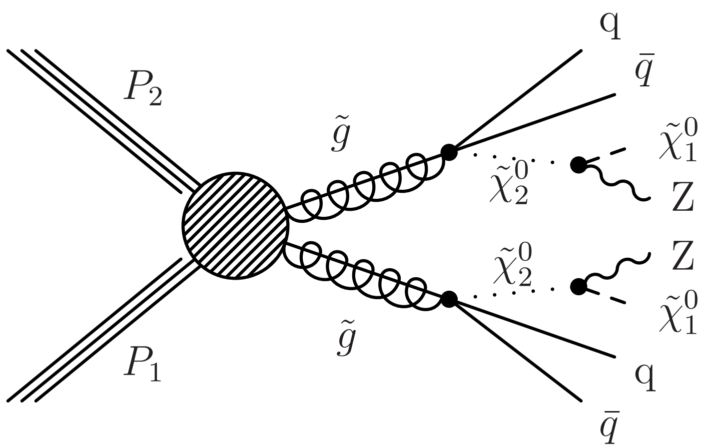
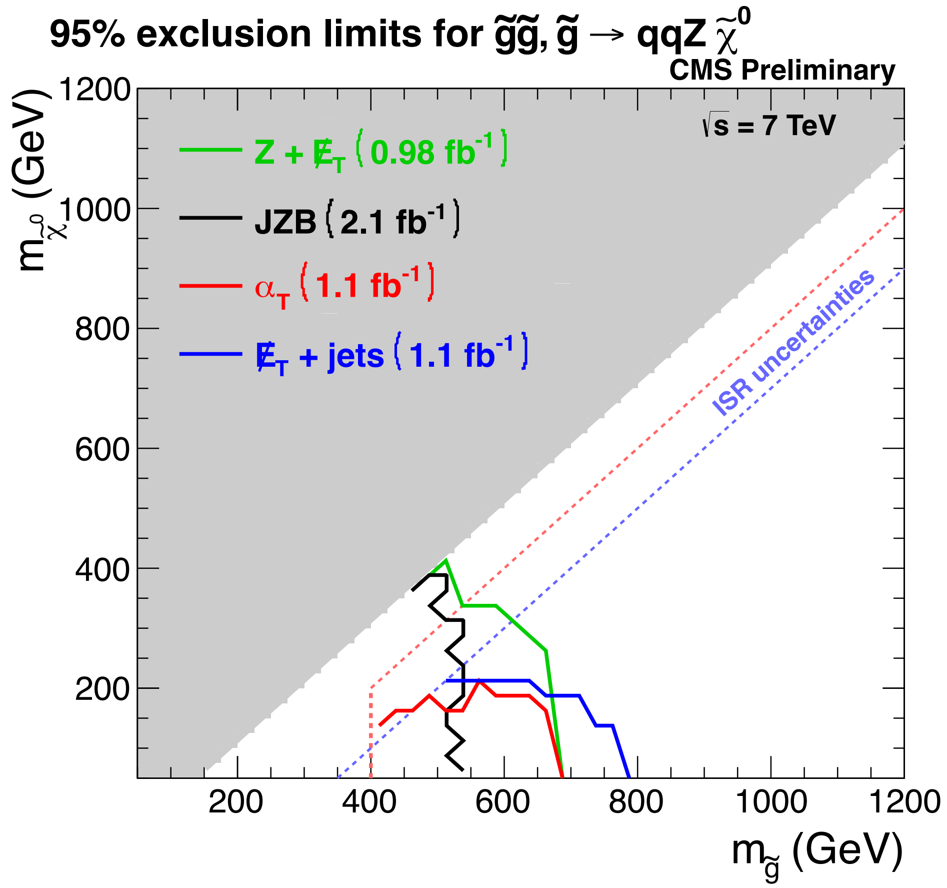




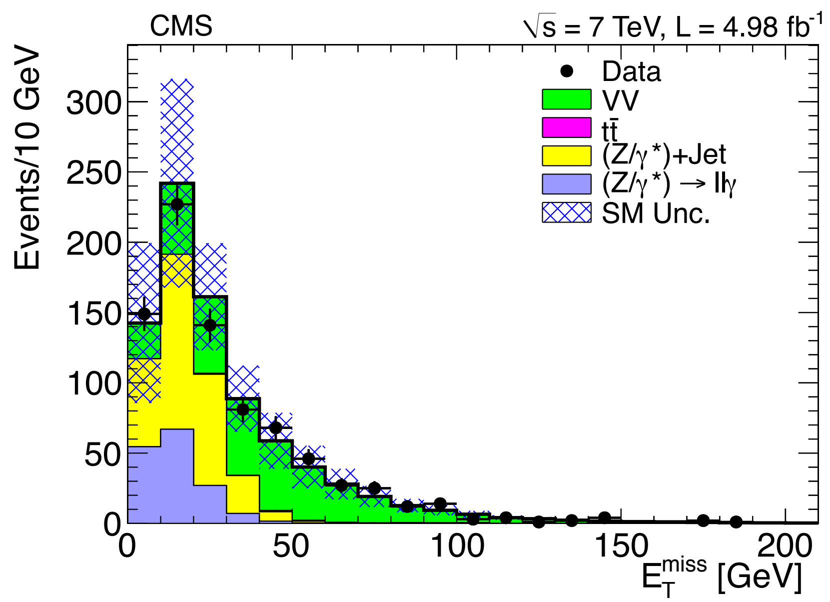
- Complementary
  - Hadronic channel large gluino mass - leptonic channel lower mass splittings

- In general helps to understand our coverage and spot holes

Multileptons

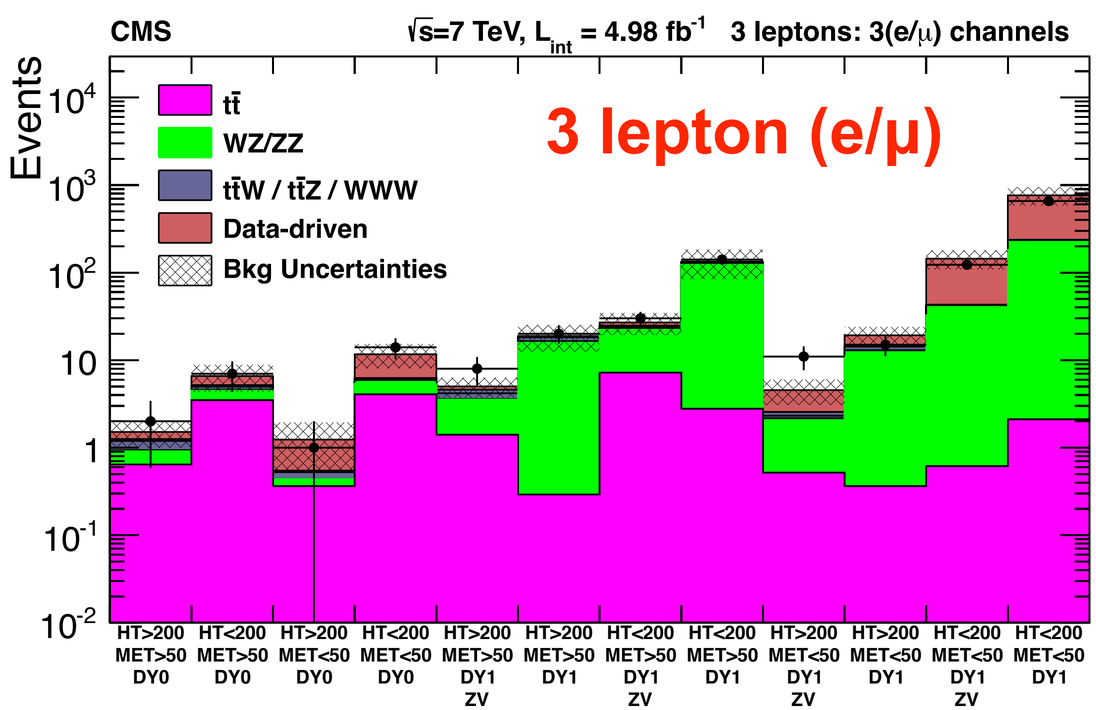
arXiv:1204.5341

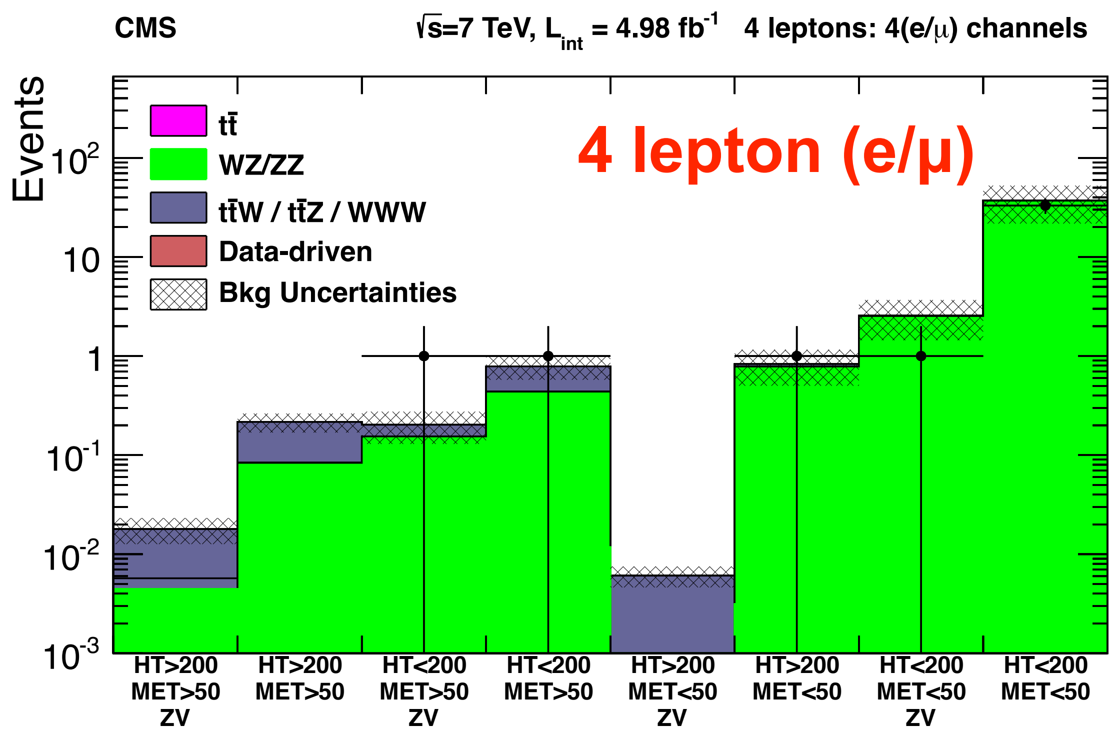
- At least three high p_T leptons e, μ and τ (require at least one e or μ)
  - Many signal/control boxes considered:
    - MET (50 GeV)/ no MET, on/off Z peak, high H_T (200 GeV)/no H_T, same-sign/opposite-sign/flavour
  - MET threshold determines control/signal for RPC/RPV search
  - Statistically combined for final limit



- Backgrounds
  - Irreducible: WZ+jets, ZZ+jets ➔ estimated from simulation
  - ttbar ➔ simulation with study in control regions
  - Z+jets, WW+jets, W+jets, QCD ➔ data-driven fake rate

Multileptons



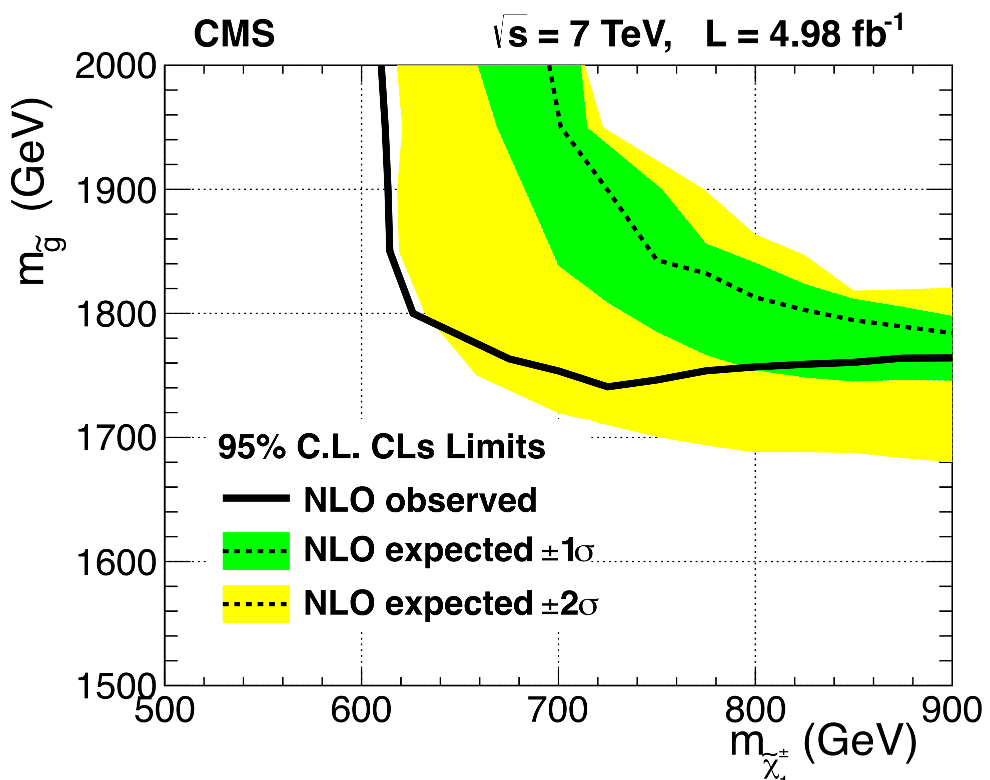


GGM inspired model

- Gravitino LSP
- Mass degenerate slepton co-NLSPs
- χ^0 (bino-like) NNLSP

Multilepton signatures from:

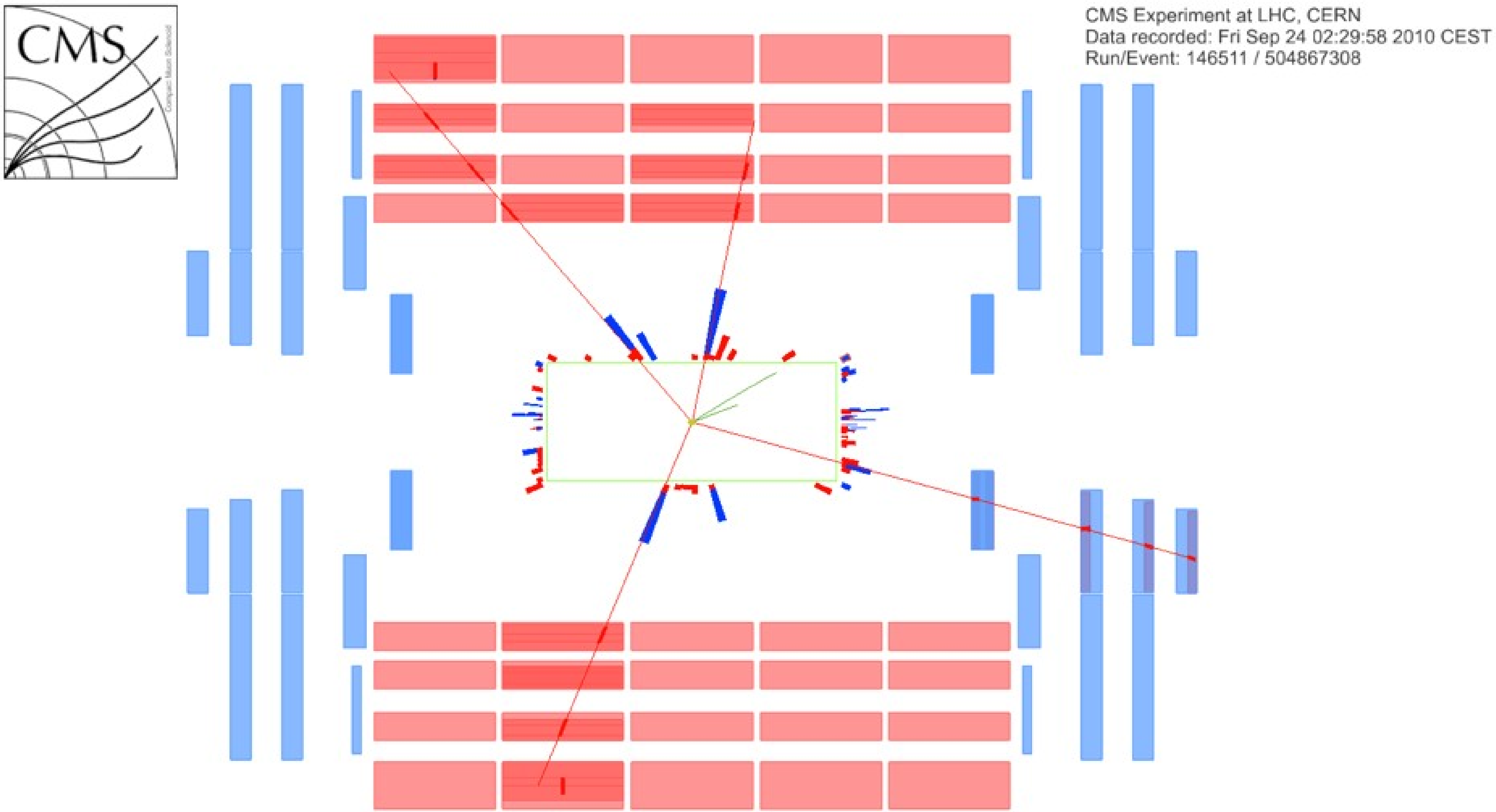
$$\chi^0 \to \tilde{l}^{\pm} l^{\mp} \to l^{\mp} + l^{\pm} + \tilde{G}$$



arXiv:1204.5341

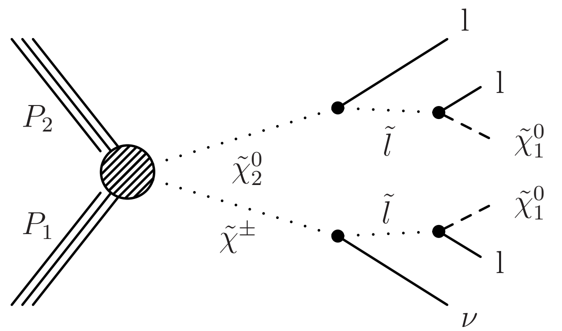
RPV interpretation in backup

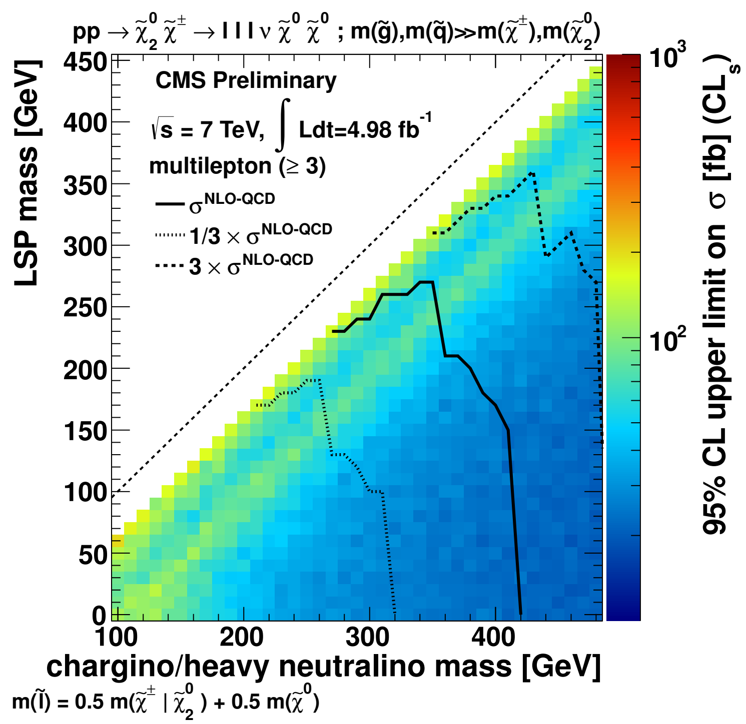
Multileptons



Multileptons

Multilepton searches constrain electroweak pair-production of SUSY particles





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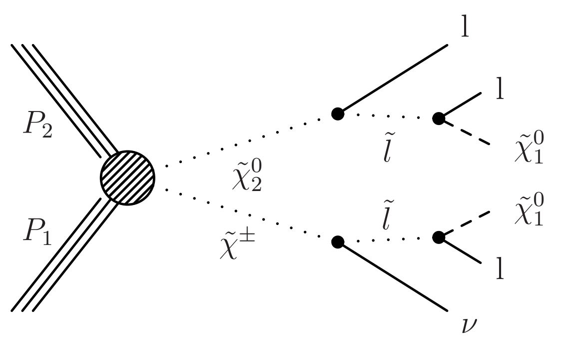

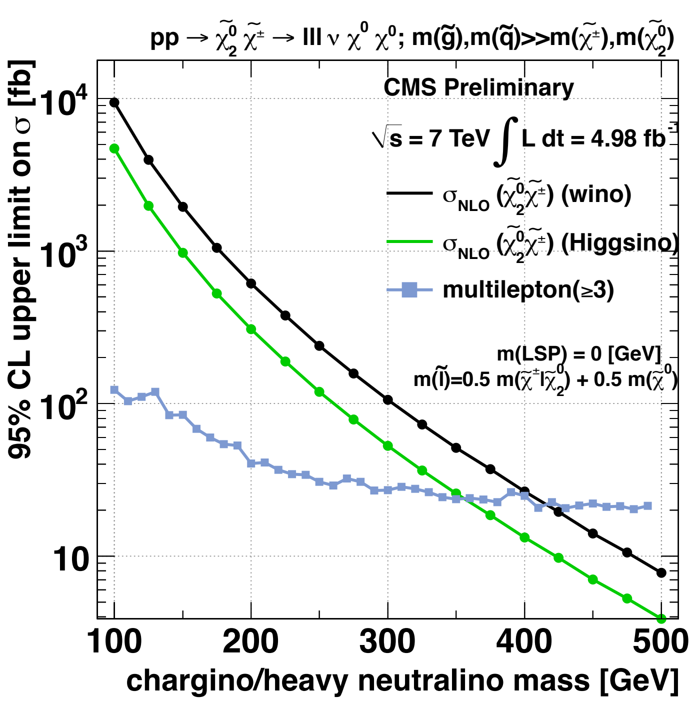

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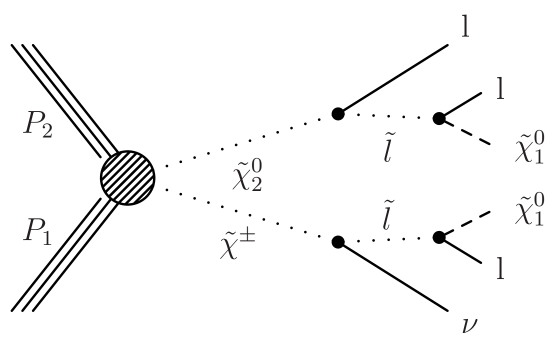

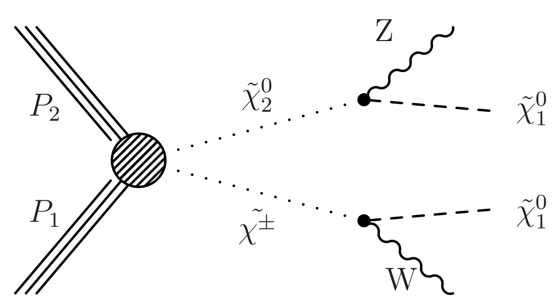

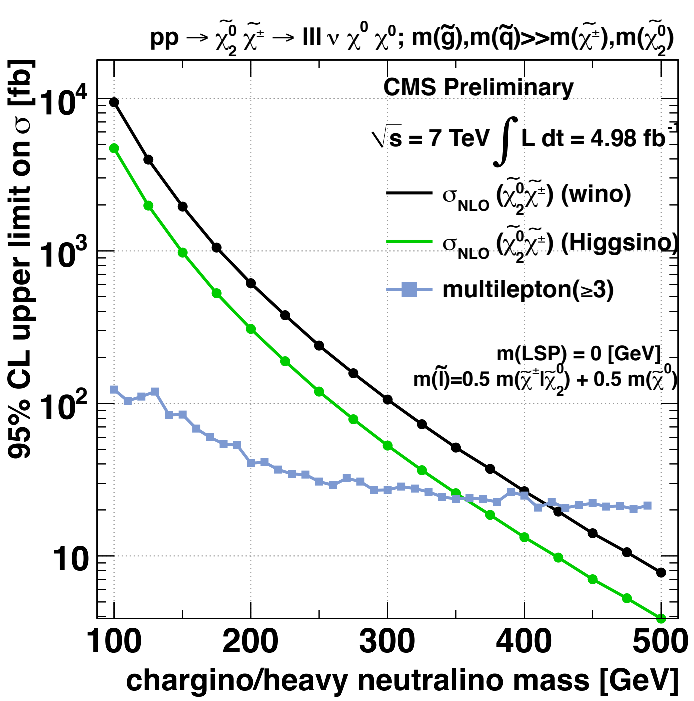

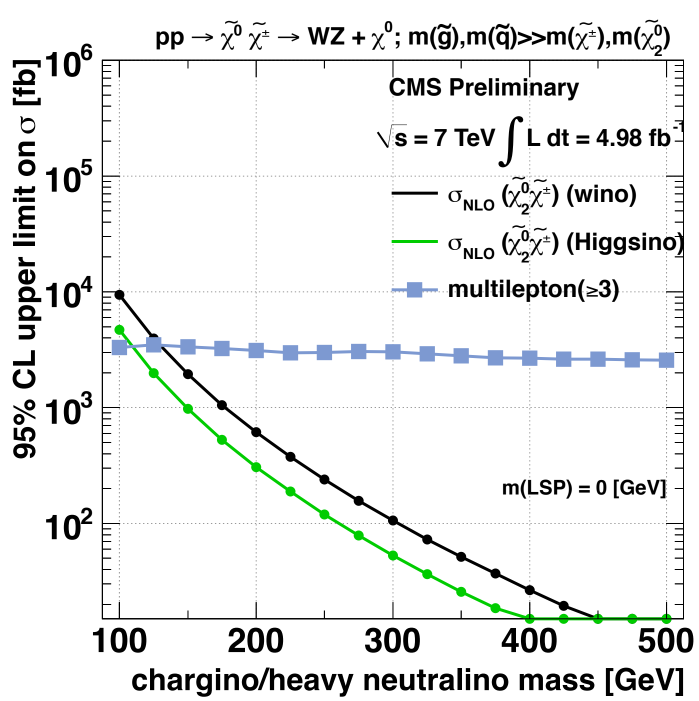

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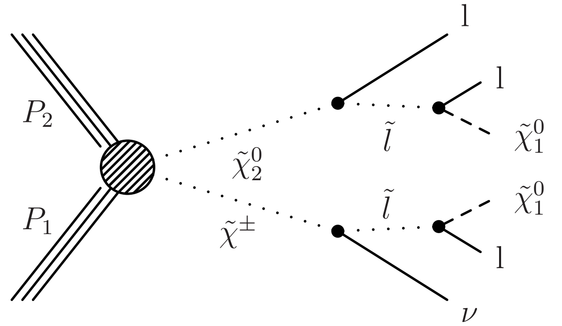
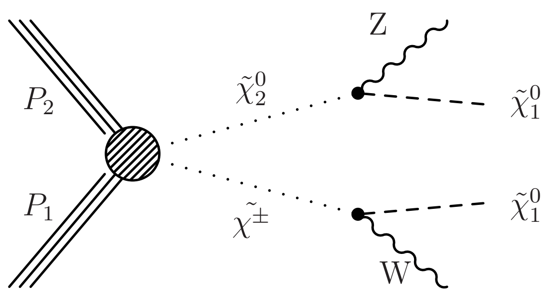
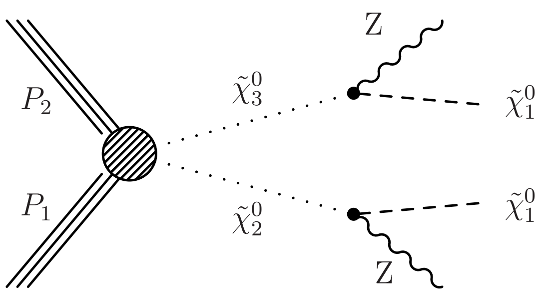
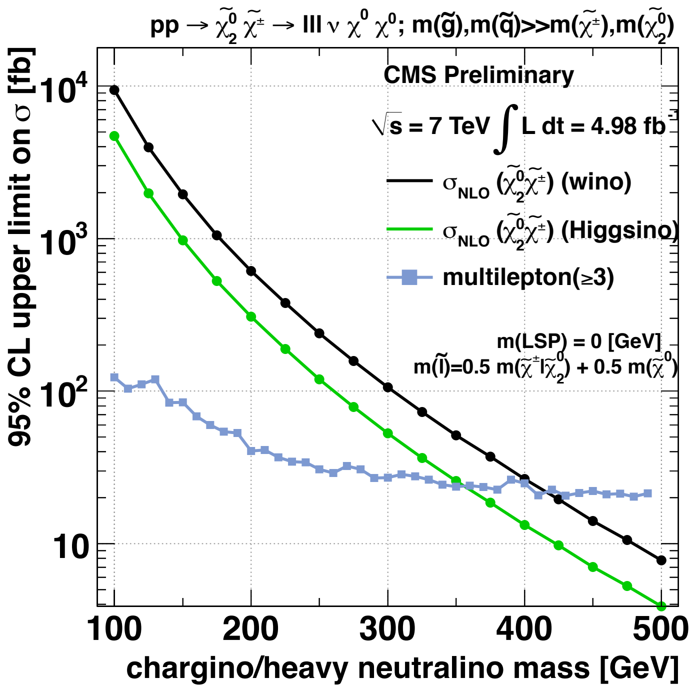
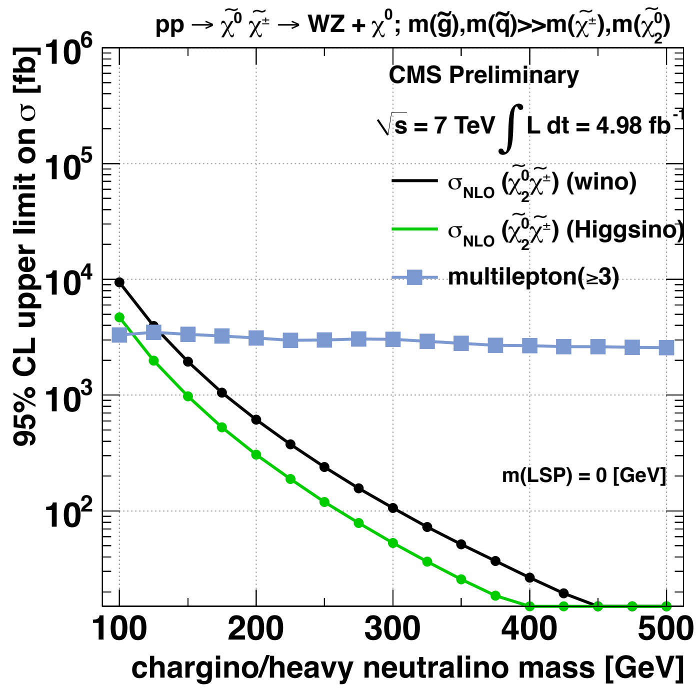
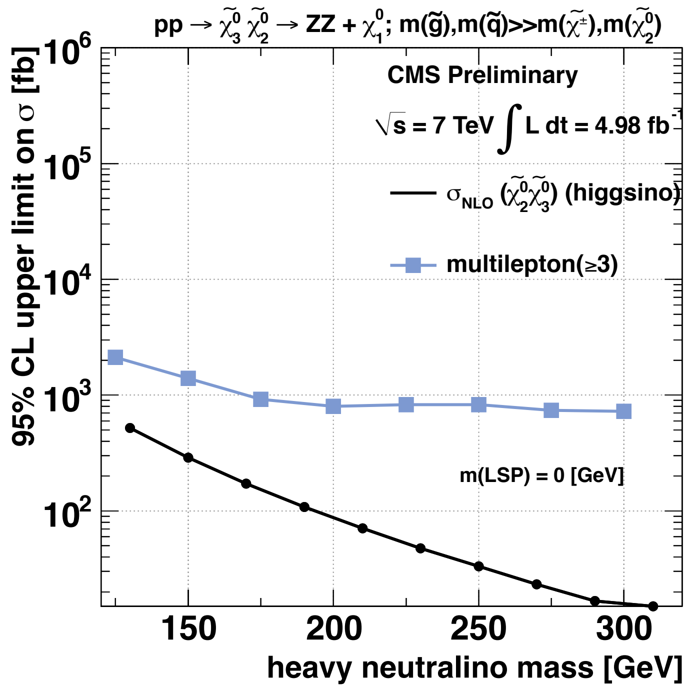






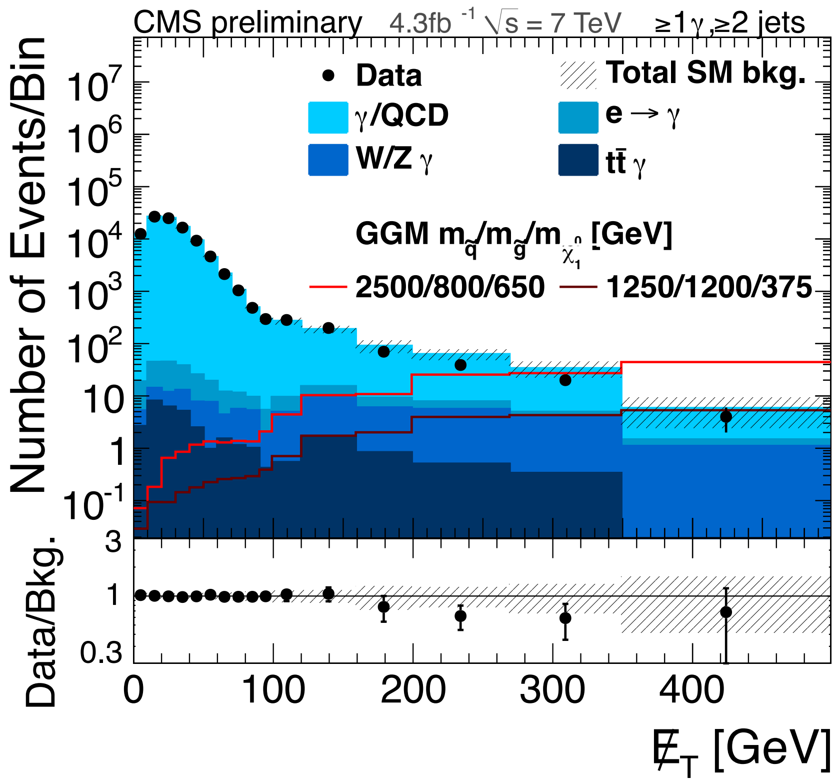


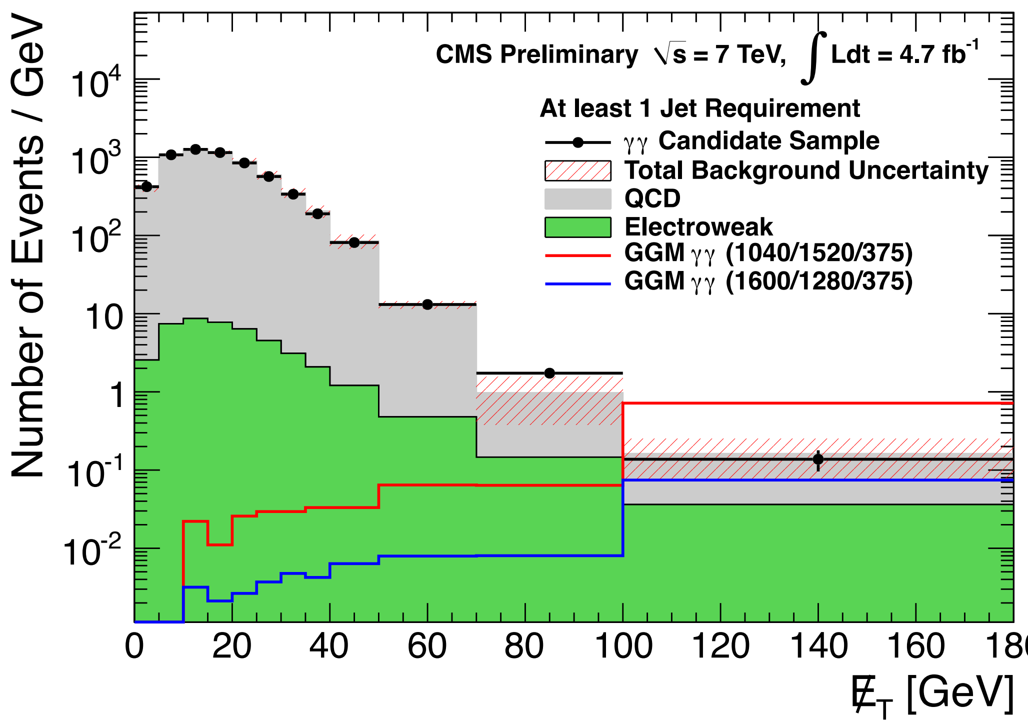




SUS-11-016

Photon(s) + MET





Single photon + jets + MET:

$P_{T\gamma}$ > 80 GeV
H_T (≥2 Jets) > 450 GeV
MET > 100 GeV

Diphoton + jet + MET:

$P_{T\gamma}$ > 40/25 GeV
At least one jet
MET > 50 GeV

- QCD bkgd. dominant ➔ shape from control samples - norm. at low MET
- e ➔ γ fake rate measured on Z peak and used to estimate EWK bkgds.

SUS-12-001

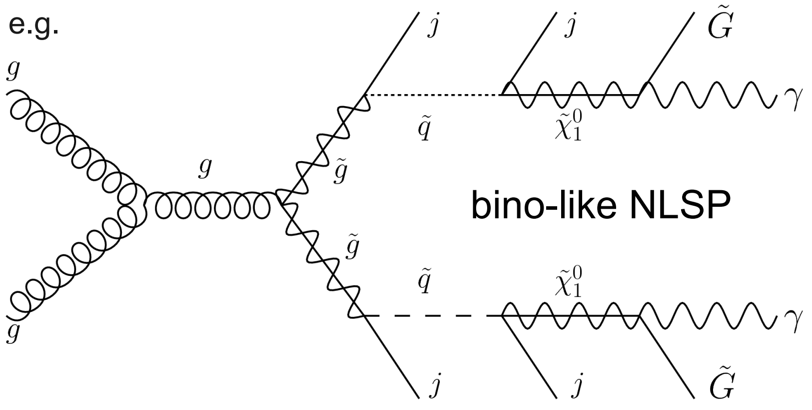
Photon(s)+MET

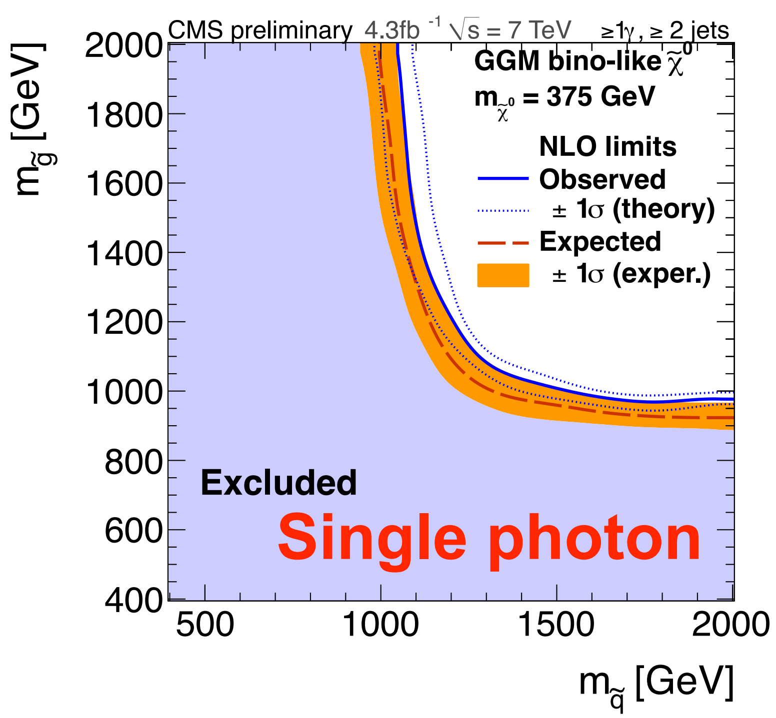
SUS-12-001

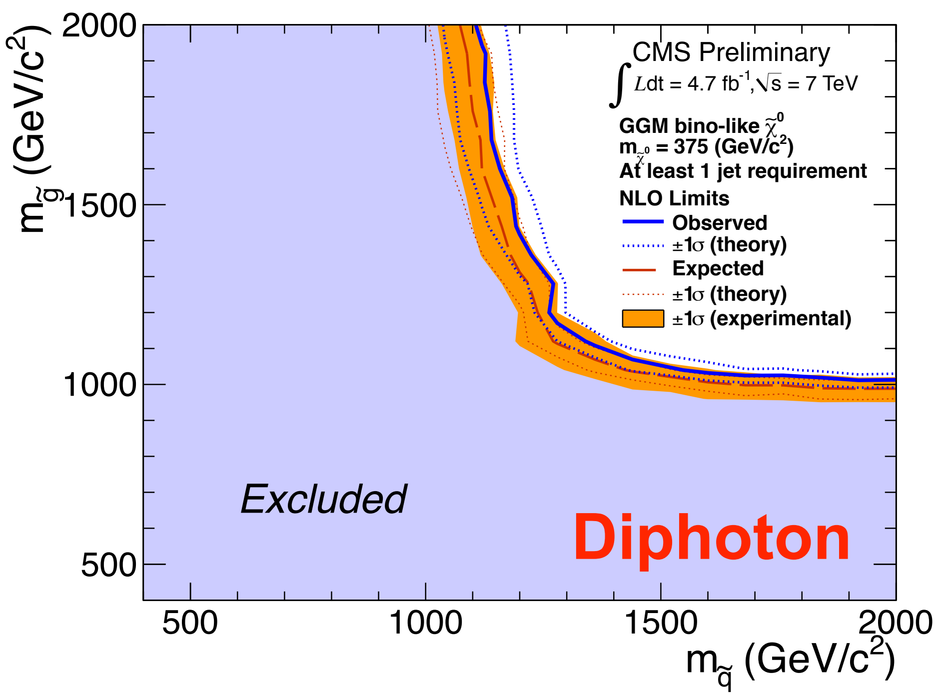
	2γ MET > 100 GeV	γ MET > 350 GeV
Data	11	4
SM	13.0 ± 4.3	8.7 ± 4.2 ± 2.5

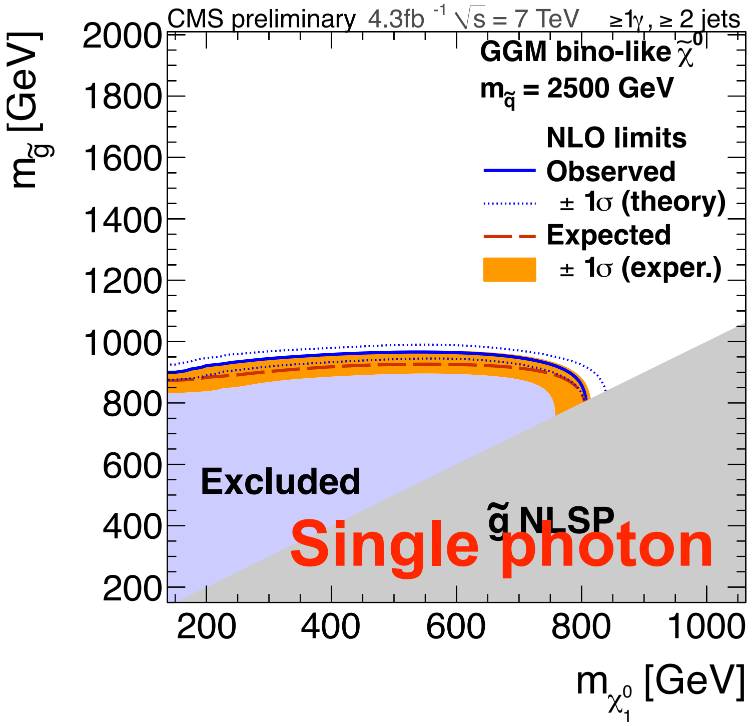
GGM model (J. Ruderman, D.Shih arXiv:1103.6083)

- Gravitino LSP
- Neutralino NLSP
- χ^0 (bino/wino-like) gives > 1 photon (BR γ vs Z^0)
- Limit for fixed χ^0 mass of 375 GeV









Photon(s)+MET

SUS-12-001

	2γ MET > 100 GeV	γ MET > 350 GeV
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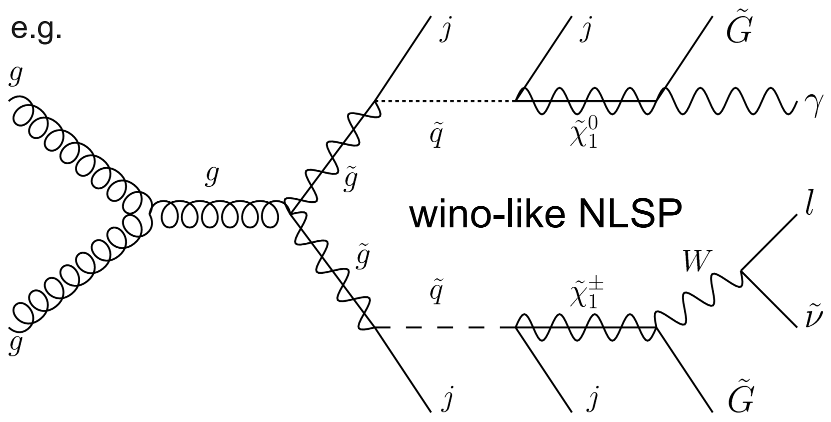
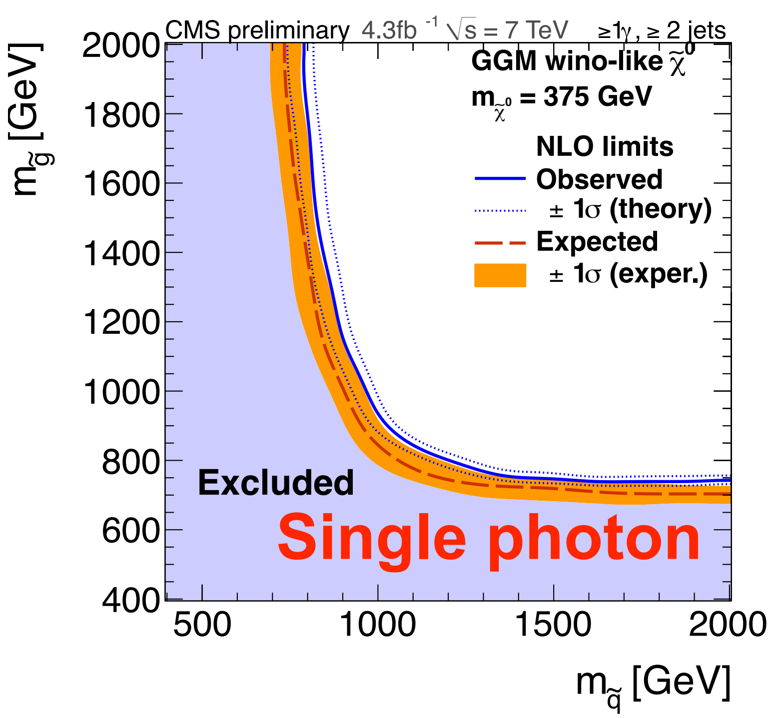
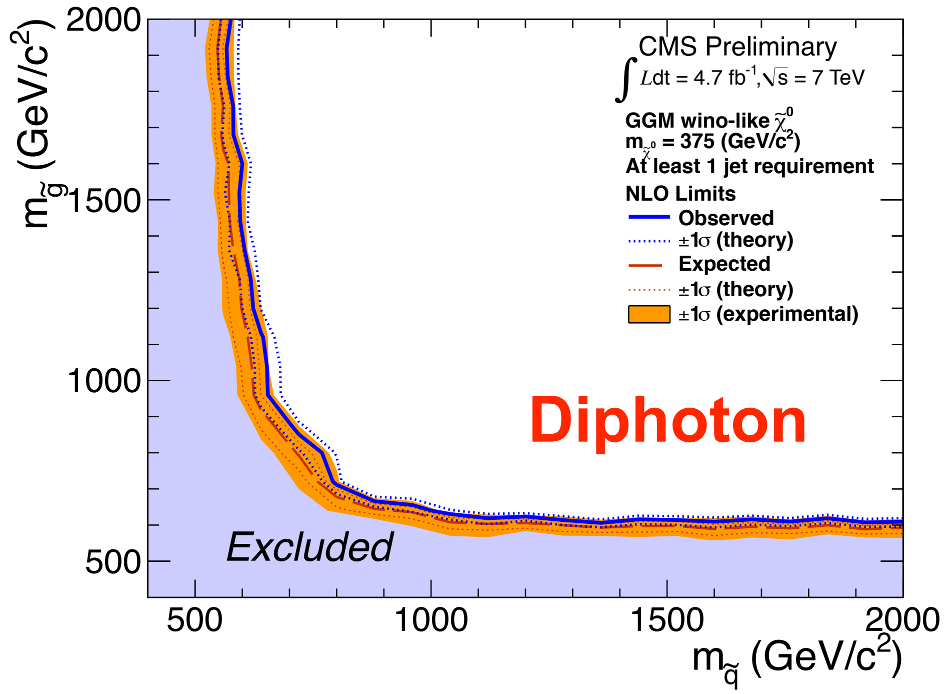
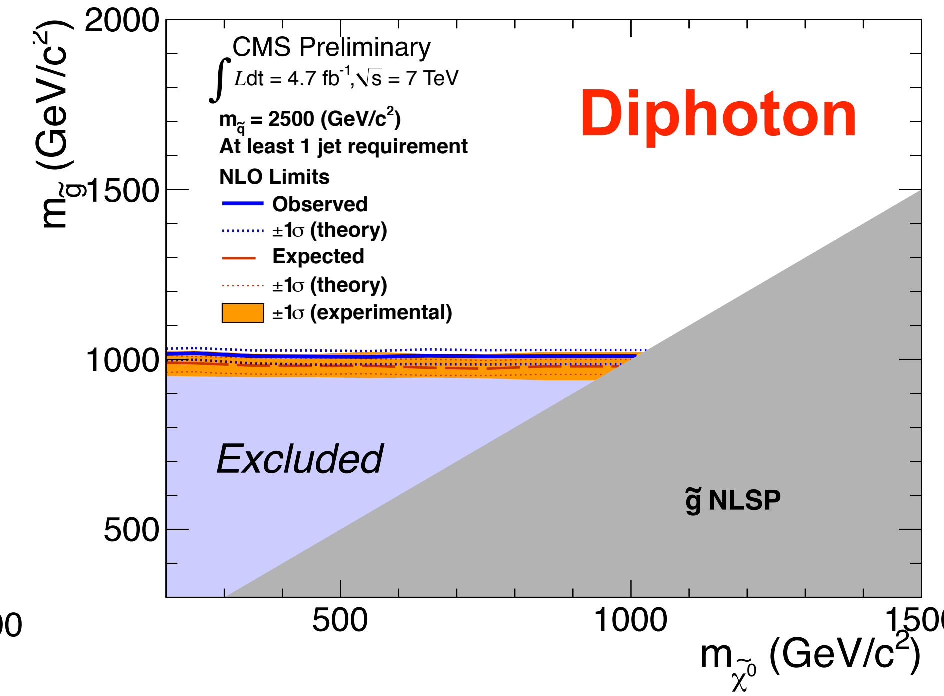


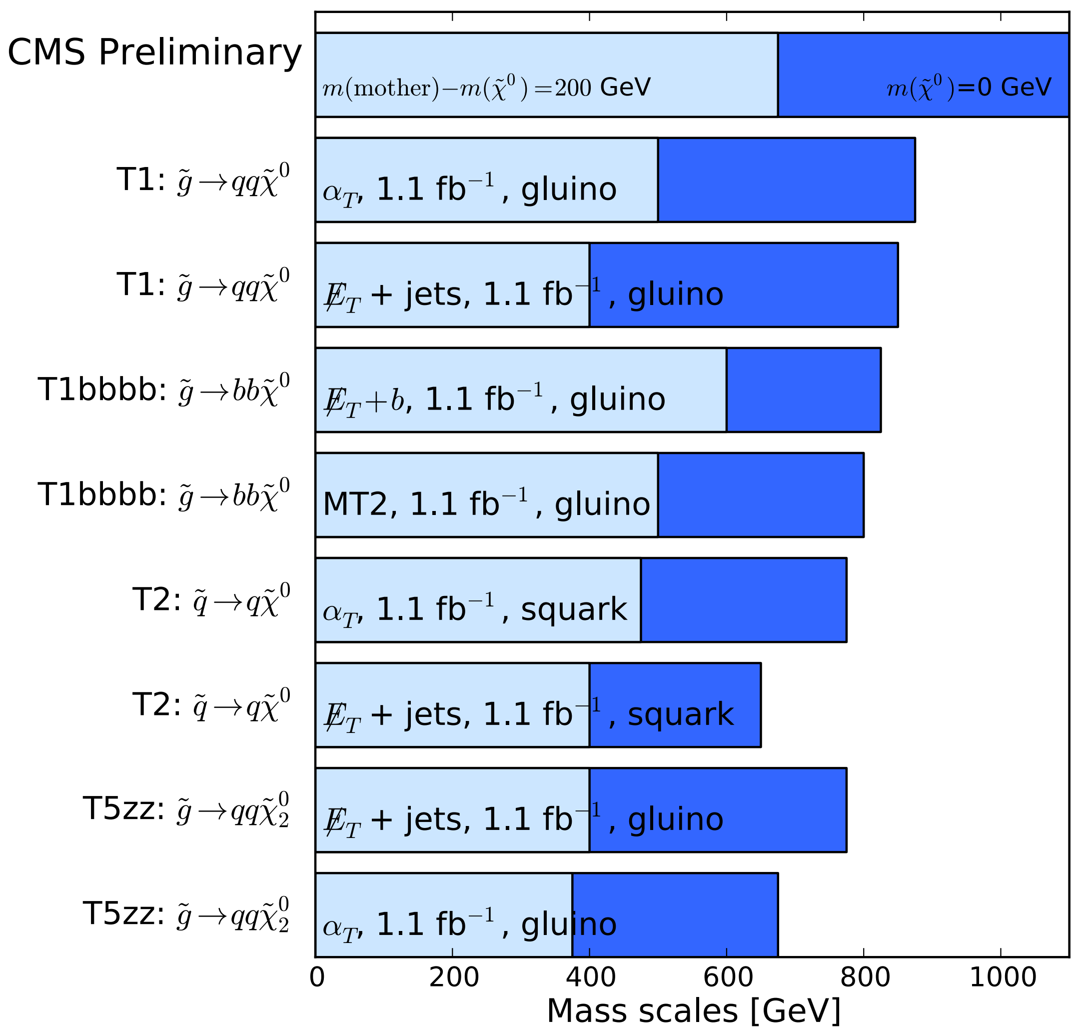




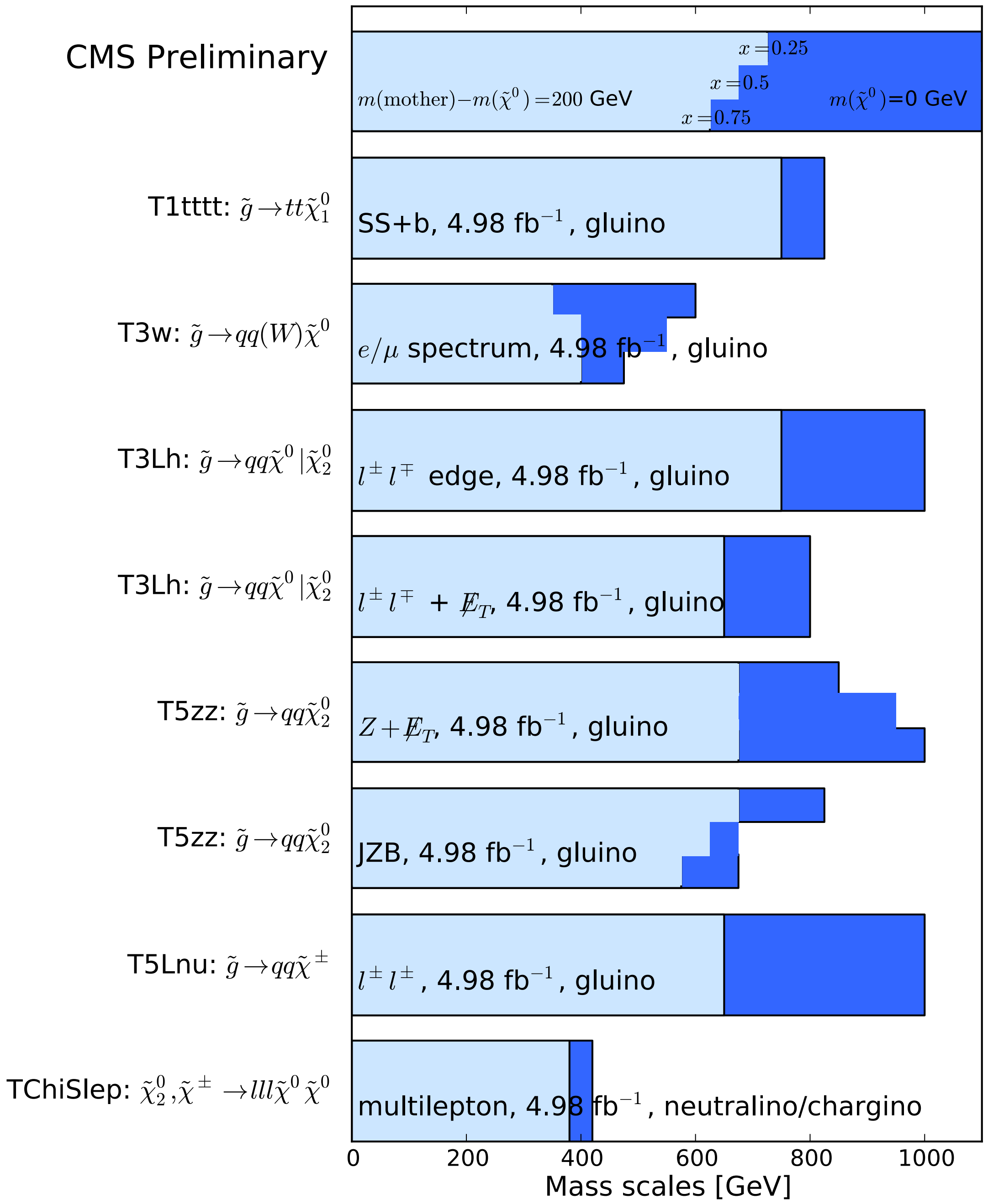


Results at a glance

Hadronic searches



Leptonic searches

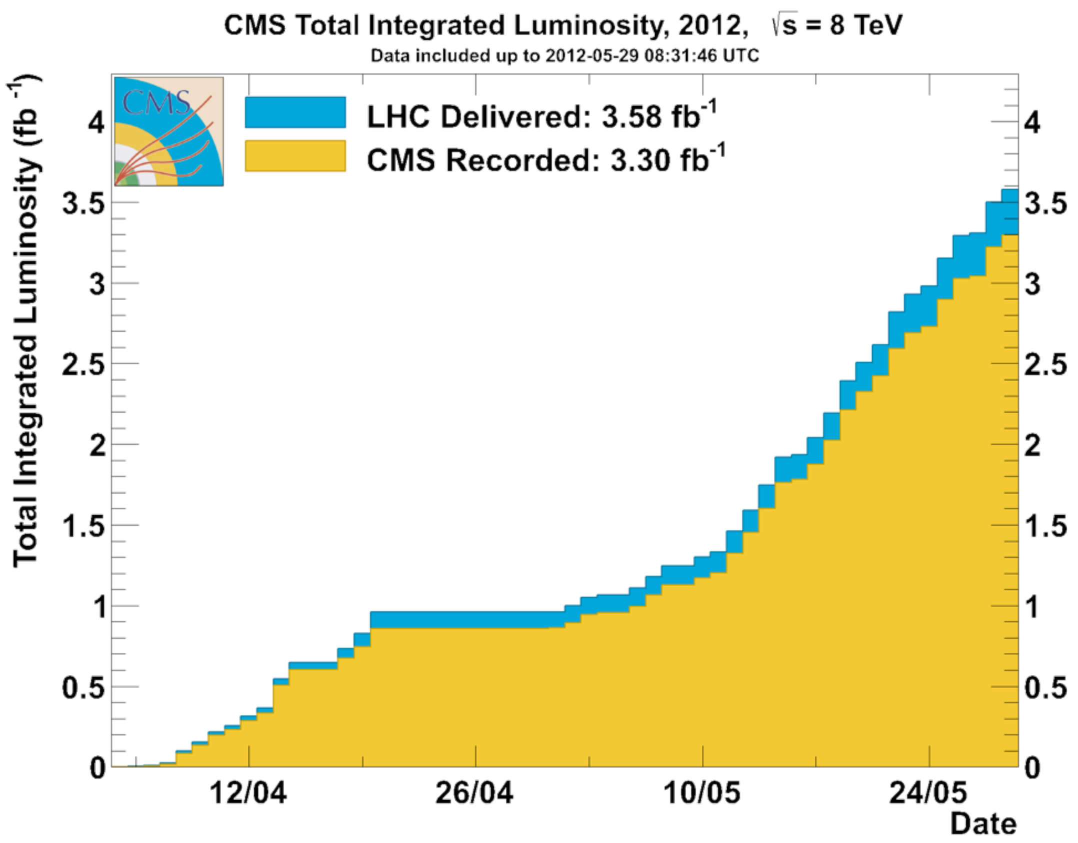


SUS-11-016

Summary

- Wide range of SUSY searches performed with 5 fb^{-1} 2011 data
  - Focused on strong production ➔ high cross section, rich phenomenology
  - No significant deviation from the Standard Model

- Larger data samples
  - Exclusive production modes
  - Electroweak production $\chi^{0}/\chi^{\pm}$
  - Third generation ➔ mixing/naturalness



- LHC running well in 2012

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

Backup

Jets + MET results

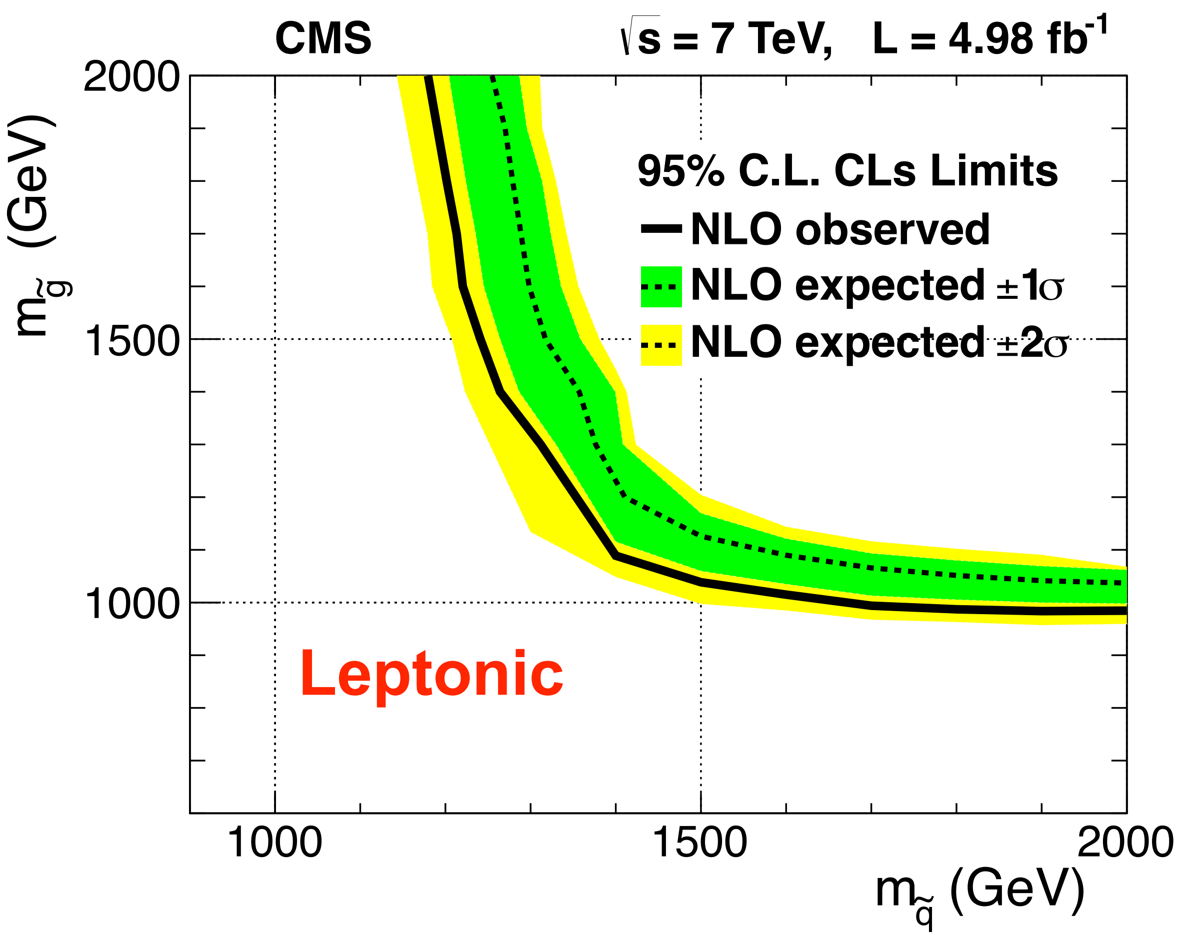
Selection H_T (GeV)	$\not{H}_T$ (GeV)	$Z \to \nu\bar{\nu}$ from γ+jets		$t\bar{t}/W \to e, \mu$+X		$t\bar{t}/W \to \tau_{hadr}$+X		QCD multijets		Total background		Data
500–800	200–350	359.2	± 82.2	326.5	± 47.0	348.5	± 40.1	118.6	± 76.9	1152.8	± 128.4	1269
500–800	350–500	112.3	± 27.4	47.8	± 9.2	62.5	± 8.7	2.2	± 2.2	224.8	± 30.3	236
500–800	500–600	17.6	± 5.6	5.0	± 2.2	8.7	± 2.5	0.0	± 0.1	31.3	± 6.5	22
500–800	>600	5.5	± 3.1	0.8	± 0.8	2.0	± 1.8	0.0	± 0.0	8.3	± 3.6	6
800–1000	200–350	48.4	± 19.1	57.7	± 15.3	56.3	± 8.3	34.6	± 24.0	197.0	± 35.3	177
800–1000	350–500	16.0	± 7.3	5.4	± 2.3	7.2	± 2.0	1.2	± 1.3	29.8	± 8.0	24
800–1000	500–600	7.1	± 4.5	2.4	± 1.5	1.3	± 0.6	0.0	± 0.2	10.8	± 4.8	6
800–1000	>600	3.3	± 2.0	0.7	± 0.7	1.0	± 0.3	0.0	± 0.1	5.0	± 2.2	5
1000–1200	200–350	10.9	± 5.5	13.7	± 3.8	21.9	± 4.6	19.7	± 13.3	66.2	± 15.5	71
1000–1200	350–500	5.5	± 3.5	5.0	± 4.4	2.9	± 1.3	0.4	± 0.7	13.8	± 5.8	12
1000–1200	>500	2.2	± 2.9	1.6	± 1.2	2.3	± 1.0	0.0	± 0.2	6.1	± 3.3	4
1200–1400	200–350	3.1	± 2.0	4.2	± 2.1	6.2	± 1.8	11.7	± 8.3	25.2	± 9.0	29
1200–1400	>350	2.3	± 2.3	2.3	± 1.4	0.6	± 0.8	0.2	± 0.6	5.4	± 2.9	8
>1400	>200	3.2	± 2.4	2.7	± 1.6	1.1	± 0.5	12.0	± 9.1	19.0	± 9.6	16

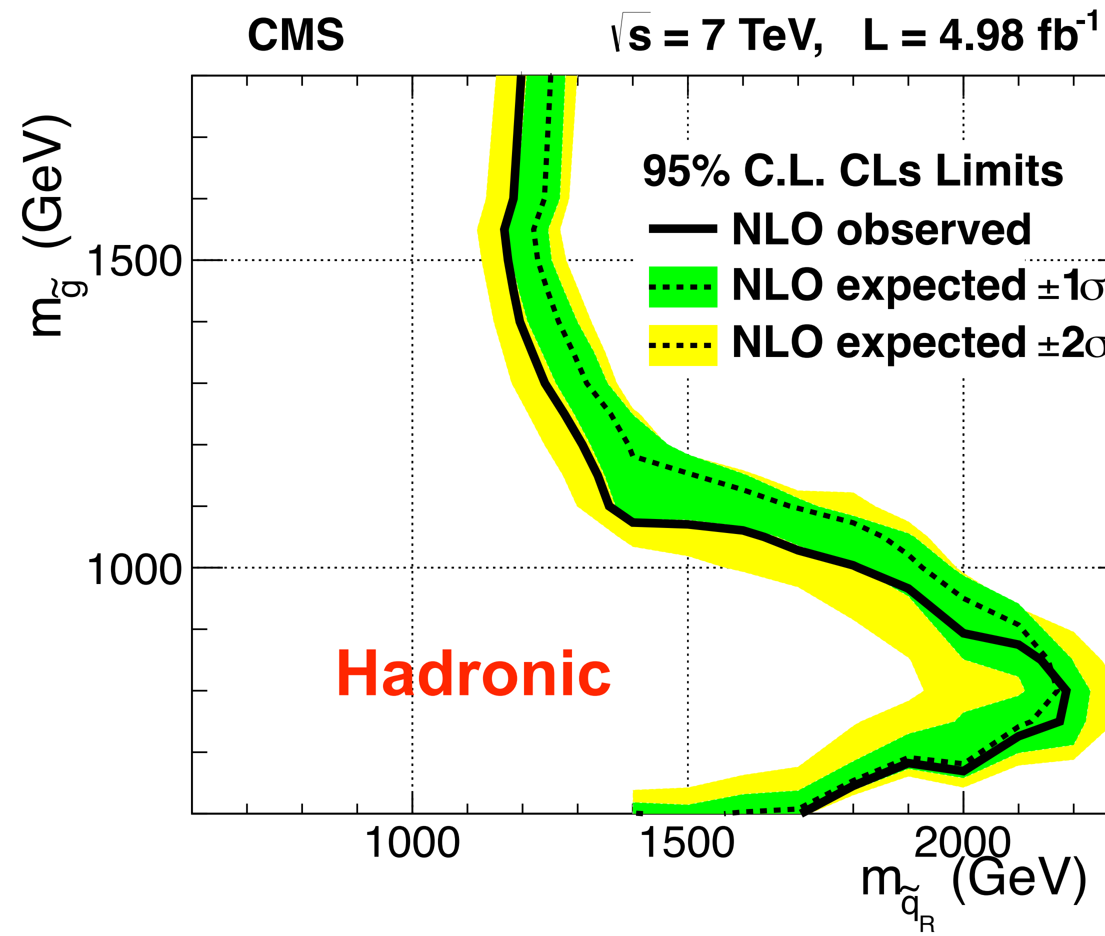
Multilepton results

Selection	N(τ)=0		N(τ)=1		N(τ)=2	
	obs	expect	obs	expect	obs	expect
4ℓ Lepton Results						
4ℓ (DY0) S_T(High)	0	0.0010 ± 0.0009	0	0.01 ± 0.09	0	0.18 ± 0.07
4ℓ (DY0) S_T(Mid)	0	0.004 ± 0.002	0	0.28 ± 0.10	2	2.5 ± 1.2
4ℓ (DY0) S_T(Low)	0	0.04 ± 0.02	0	2.98 ± 0.48	4	3.5 ± 1.1
4ℓ (DY1, no Z) S_T(High)	1	0.009 ± 0.004	0	0.10 ± 0.07	0	0.12 ± 0.05
4ℓ (DY1, Z) S_T(High)	1	0.09 ± 0.01	0	0.51 ± 0.15	0	0.43 ± 0.15
4ℓ (DY1, no Z) S_T(Mid)	0	0.07 ± 0.02	1	0.88 ± 0.26	1	0.94 ± 0.29
4ℓ (DY1, Z) S_T(Mid)	0	0.45 ± 0.11	5	4.1 ± 1.2	3	3.4 ± 0.9
4ℓ (DY1, no Z) S_T(Low)	0	0.09 ± 0.04	7	5.5 ± 2.2	19	13.7 ± 6.4
4ℓ (DY1, Z) S_T(Low)	2	0.80 ± 0.34	19	17.7 ± 4.9	95	60 ± 31
4ℓ (DY2, no Z) S_T(High)	0	0.02 ± 0.01	–	–	–	–
4ℓ (DY2, Z) S_T(High)	0	0.89 ± 0.34	–	–	–	–
4ℓ (DY2, no Z) S_T(Mid)	0	0.20 ± 0.09	–	–	–	–
4ℓ (DY2, Z) S_T(Mid)	3	7.9 ± 3.2	–	–	–	–
4ℓ (DY2, no Z) S_T(Low)	1	2.4 ± 1.1	–	–	–	–
4ℓ (DY2, Z) S_T(Low)	29	29 ± 12	–	–	–	–
3ℓ Lepton Results						
3ℓ (DY0) S_T(High)	2	1.14 ± 0.43	17	11.2 ± 3.2	20	22.5 ± 6.1
3ℓ (DY0) S_T(Mid)	5	7.4 ± 3.0	113	97 ± 31	157	181 ± 24
3ℓ (DY0) S_T(Low)	17	13.5 ± 4.1	522	419 ± 63	1631	2018 ± 253
3ℓ (DY1, no Z) S_T(High)	6	3.5 ± 0.9	10	13.1 ± 2.3	–	–
3ℓ (DY1, Z) S_T(High)	17	18.7 ± 6.0	35	39.2 ± 4.8	–	–
3ℓ (DY1, no Z) S_T(Mid)	32	25.5 ± 6.6	159	141 ± 27	–	–
3ℓ (DY1, Z) S_T(Mid)	89	102 ± 31	441	463 ± 41	–	–
3ℓ (DY1, no Z) S_T(Low)	126	150 ± 36	3721	2983 ± 418	–	–
3ℓ (DY1, Z) S_T(Low)	727	815 ± 192	17631	15758 ± 2452	–	–
Total 4ℓ	37	42 ± 13	32.0	32.1 ± 5.5	124	85 ± 32
Total 3ℓ	1021	1137 ± 198	22649	19925 ± 2489	1808	2222 ± 255
Total	1058	1179 ± 198	22681	19957 ± 2489	1932	2307 ± 257

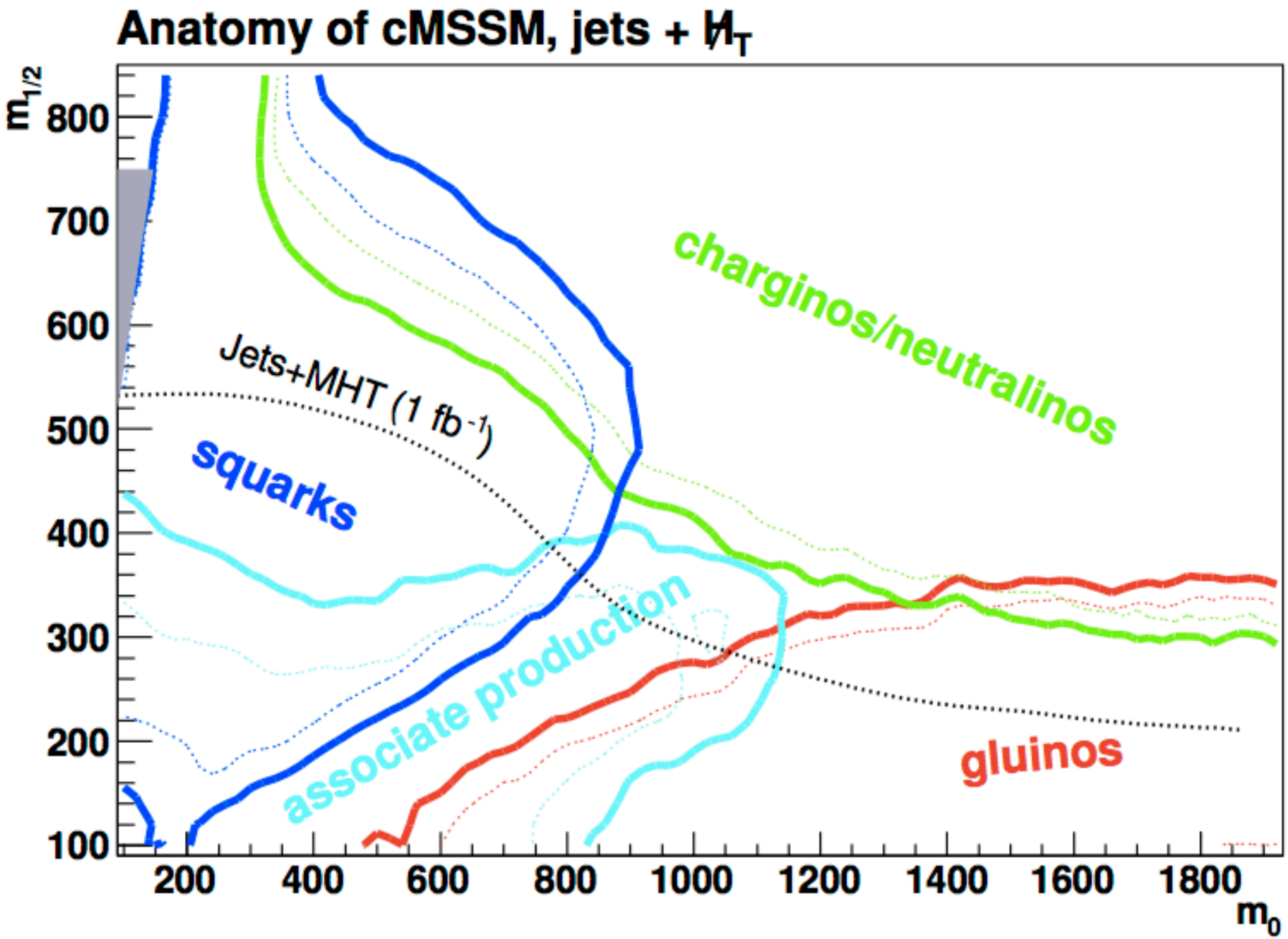
Selection	N(τ)=0		N(τ)=1		N(τ)=2	
	obs	expect	obs	expect	obs	expect
4ℓ Lepton Results						
4ℓ >50,>200, no Z	0	0.018 ± 0.005	0	0.09 ± 0.06	0	0.7 ± 0.7
4ℓ >50,> 200, Z	0	0.22 ± 0.05	0	0.27 ± 0.11	0	0.8 ± 1.2
4ℓ >50,<200, no Z	1	0.20 ± 0.07	3	0.59 ± 0.17	1	1.5 ± 0.6
4ℓ >50,<200, Z	1	0.79 ± 0.21	4	2.3 ± 0.7	0	1.1 ± 0.7
4ℓ <50,>200, no Z	0	0.006 ± 0.001	0	0.14 ± 0.08	0	0.25 ± 0.07
4ℓ <50,>200, Z	1	0.83 ± 0.33	0	0.55 ± 0.21	0	1.14 ± 0.42
4ℓ <50,<200, no Z	1	2.6 ± 1.1	5	3.9 ± 1.2	17	10.6 ± 3.2
4ℓ <50,<200, Z	33	37 ± 15	20	17.0 ± 5.2	62	43 ± 16
3ℓ Lepton Results						
3ℓ >50,>200,no-OSSF	2	1.5 ± 0.5	33	30.4 ± 9.7	15	13.5 ± 2.6
3ℓ >50,<200,no-OSSF	7	6.6 ± 2.3	159	143 ± 37	82	106 ± 16
3ℓ <50,>200,no-OSSF	1	1.2 ± 0.7	16	16.9 ± 4.5	18	31.9 ± 4.8
3ℓ <50,<200,no-OSSF	14	11.7 ± 3.6	446	356 ± 55	1006	1026 ± 171
3ℓ >50,>200, no Z	8	5.0 ± 1.3	16	31.7 ± 9.6	–	–
3ℓ >50,>200, Z	20	18.9 ± 6.4	13	24.4 ± 5.1	–	–
3ℓ >50,<200, no Z	30	27.0 ± 7.6	114	107 ± 27	–	–
3ℓ <50,>200, no Z	11	4.5 ± 1.5	45	51.9 ± 6.2	–	–
3ℓ >50,<200, Z	141	134 ± 50	107	114 ± 16	–	–
3ℓ <50,>200, Z	15	19.2 ± 4.8	166	244 ± 24	–	–
3ℓ <50,<200, no Z	123	144 ± 36	3721	2907 ± 412	–	–
3ℓ <50,<200, Z	657	764 ± 183	17857	15519 ± 2421	–	–
Total 4ℓ	37	42 ± 15	32.0	24.9 ± 5.4	80	59 ± 16
Total 3ℓ	1029	1138 ± 193	22693	19545 ± 2457	1121	1177 ± 172
Total	1066	1180 ± 194	22725	19570 ± 2457	1201	1236 ± 173

Multilepton RPV SUSY limits





CMSSM event topologies

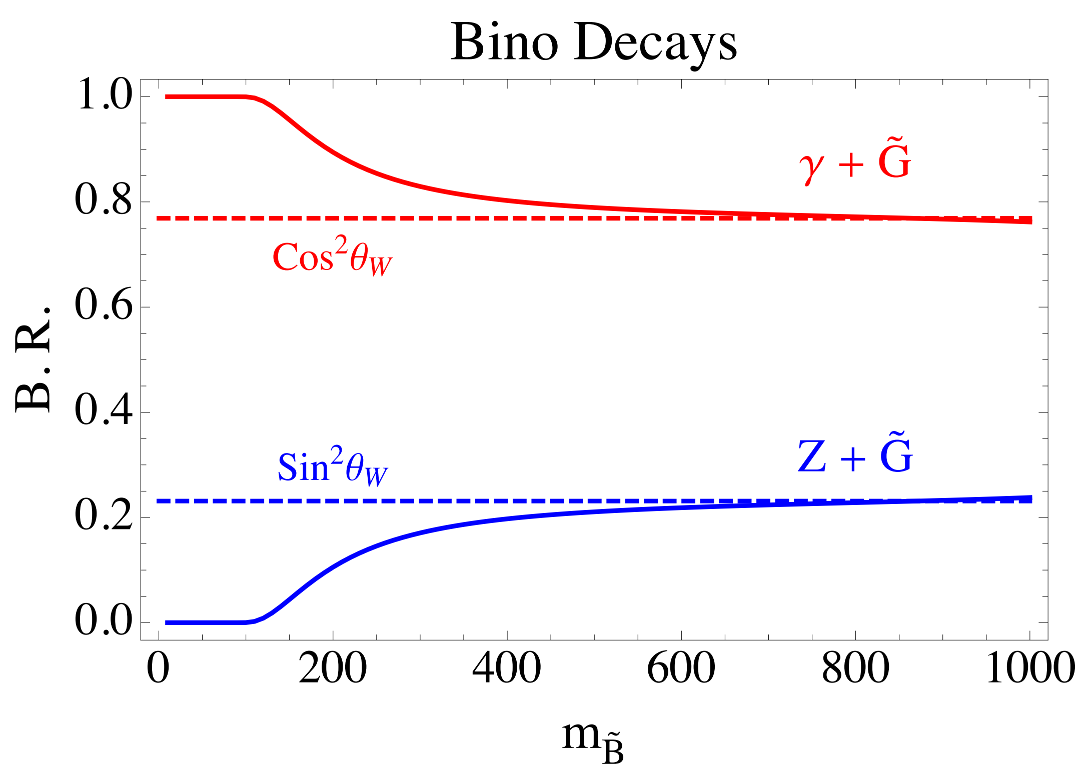


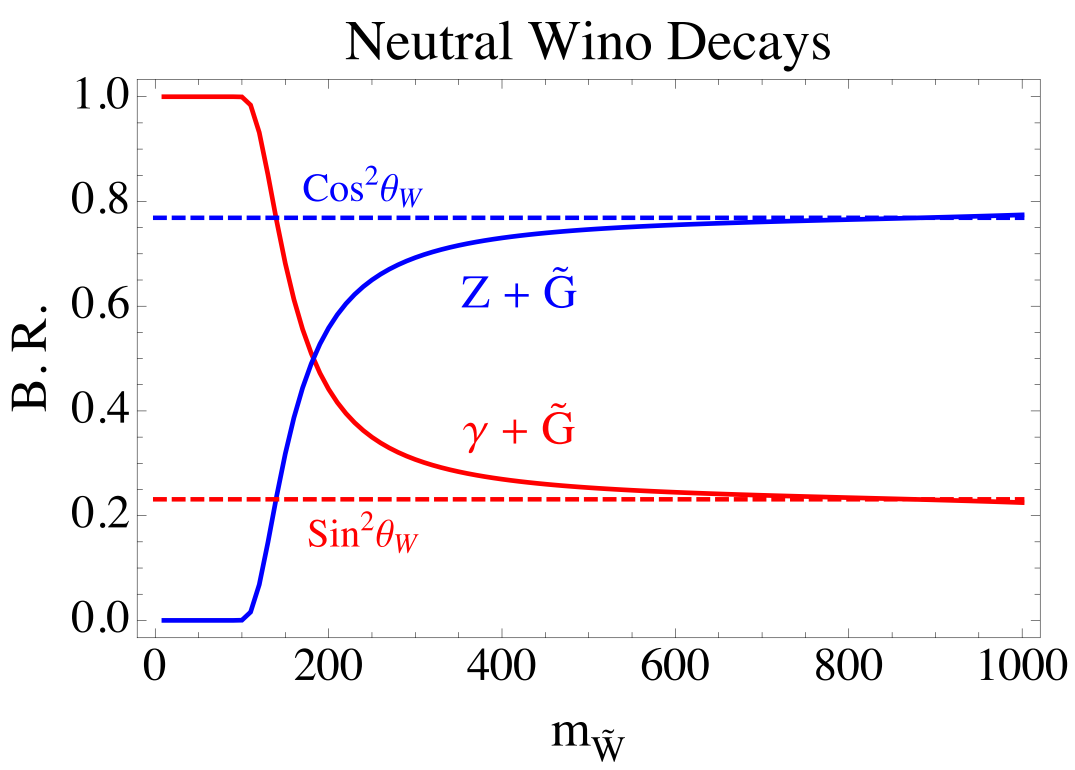
Multilepton co-NLSP Model

- Right-handed sleptons are flavour degenerate and NLSP
- Neutralino (bino-like) NNLSP
- Chargino mass twice neutralino mass
- Higgsinos are decoupled
- SUSY production proceeds mainly through pairs of squarks and/or gluinos.
- Cascade decays of these states eventually pass sequentially through the lightest neutralino ($\tilde{g}, \tilde{q} \rightarrow \chi^0 + X$)
- Decays into a slepton and a lepton ($\chi 0 \rightarrow \tilde{l}^{\pm} l^{\mp}$).
- Each of the degenerate right-handed sleptons decays to the Goldstino component of the massless and non-interacting gravitino and a lepton ($\tilde{l} \rightarrow \tilde{G}\ l$)

Photon GGM Model

- Gravitino LSP
- Neutralino NLSP
  - Bino-like gives BR(γ)>>BR(Z) ➔ two photons >> γ + Z (➔ jets, leptons)
  - Wino-like gives BR(Z)>>BR(γ) ➔ γ + Z (➔ jets, leptons)
  - Wino-like NLSP also chargino co-NLSP ➔ γ + W (➔ jets, leptons)
  - Higgsino gives h^0 or Z ➔ BR depends on tanβ and sign(μ)

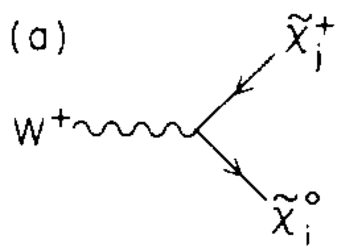




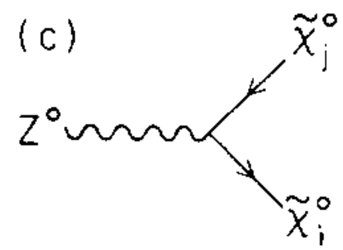
EWKino Model

Haber & Kane Physics Report Volume 117, pages 75-265 (1985)

[from Frank Wuerthwein]



$$\frac{ig}{2}\gamma^\mu\left[O^L_{ij}(1-\gamma_5)+O^R_{ij}(1+\gamma_5)\right]$$



$$\frac{ig}{2\cos\theta_W}\gamma^\mu\left[O''^L_{ij}(1-\gamma_5)+O''^R_{ij}(1+\gamma_5)\right]$$

Couples to all neutralino and chargino mass eigenstates

Couples to Higgsino neutralino mass eigenstates

- For WZ maximal Wino couplings (pure wino-like) and maximal Higgsino couplings (even split of two electroweak eigenstates)
- For ZZ maximal Higgsino couplings (even split of two electroweak eigenstates)
- Set chargino/heavy neutralino masses equal, light neutralino=0 and slepton mass in between