Searches for New Physics with ATLAS and CMS at 7 TeV

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LHCC/A101

Open Session “Physics Reach with 0.1 to 1fb^{-1} at 7 TeV

- ***Prerequisites for New Physics searches***
- ***Expectations: Higgs/SUSY/Exotica***
- ***New Physics searches @ 7 TeV: Summary***

Introduction

Prerequisistes for Early Searches

- Step1: commissioning of machine and detectors of unprecedented complexity, technology and performance *[see morning session]*

- Step2: Rediscovery of the Standard Model at 7 TeV. Establishing (i.e. measuring) its properties at a new energy frontier is essential for the searches! After all, Standard Model process are THE background to the New Physics Searches. *[see talk from Tom]*

Commission and SM rediscovery are already well underway meaning that we are getting ready for searches as we speak!

Overview

Part I: Higgs @ 7 TeV

➔ *The most wanted and expected*

Part II: Supersymmetry @ 7 TeV

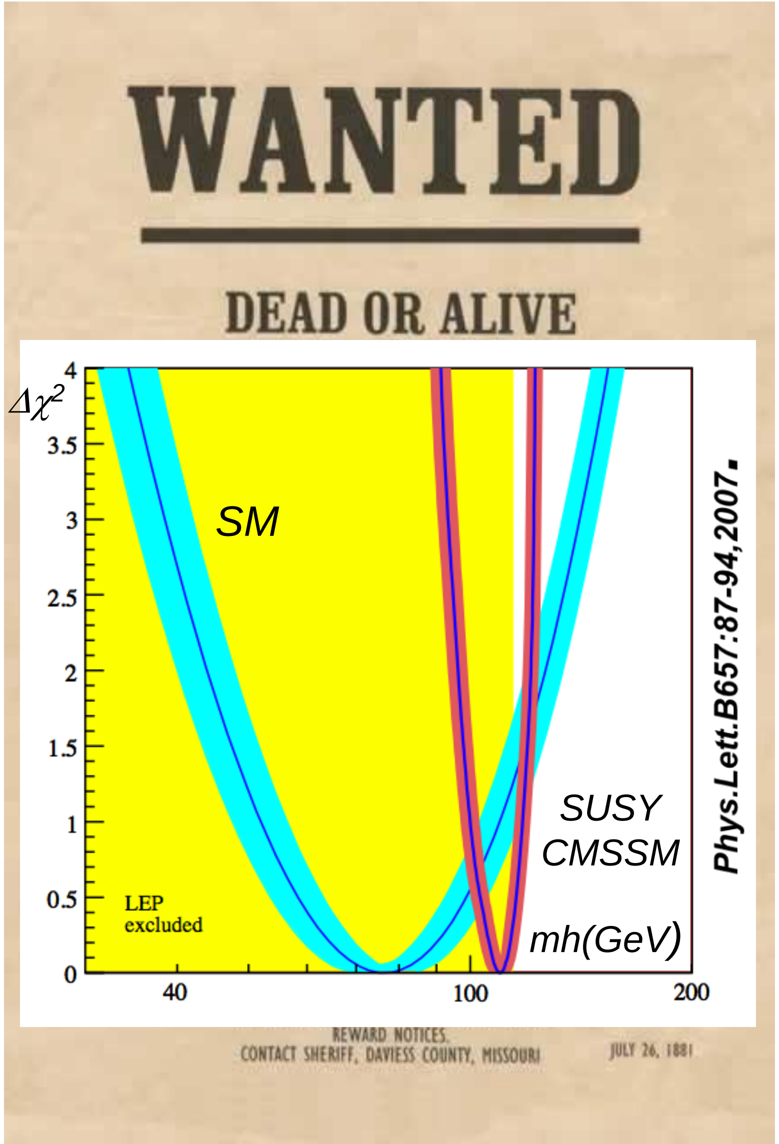
➔ *Still the best motivated extension to the SM*

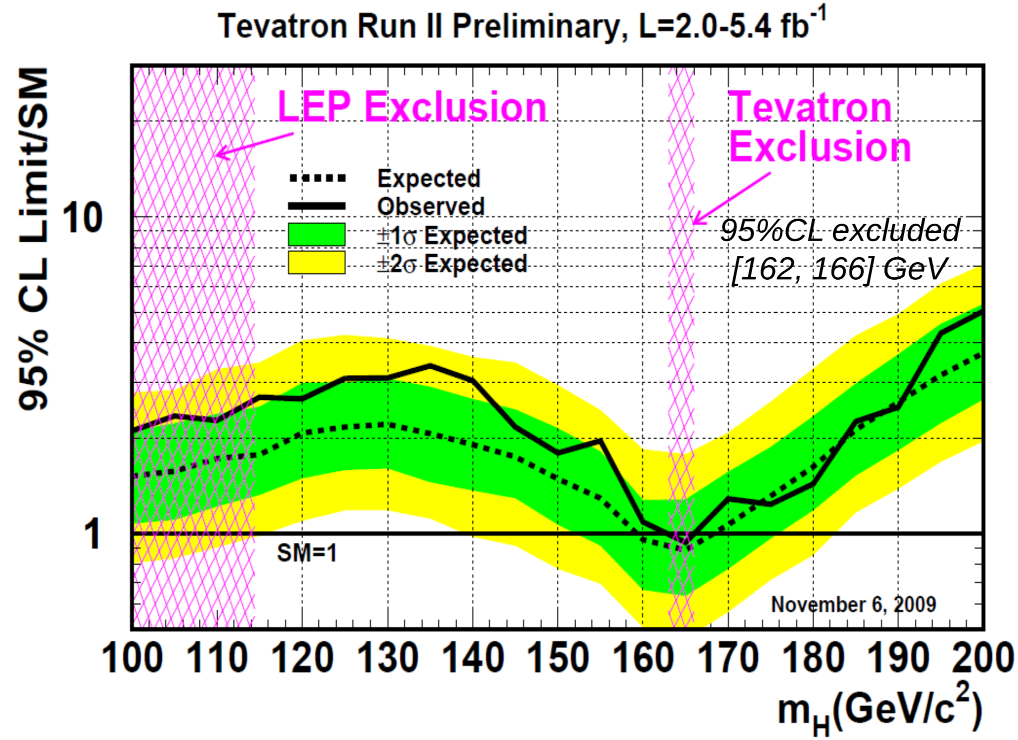
Part III: Exotica @ 7 TeV

➔ *From possible to unexpected – (almost) anything goes*

HIGGS

Standard Model(like) Higgs





Tevatron is the benchmark for comparison!

Not only for Higgs but also for SUSY and Exotica

(Comparison: 10 fb^{-1} vs. 1 fb^{-1})

Gaining a Factor 10 (or more)

Use parton luminosties to illustrate the gain:

Example: mainly gg

Higgs: pp → H, H→WW and ZZ

Factor ~15

Example: gg and qq

Top: (85% qq, 15% gg at Tevatron)

Factor: 0.85 x 5 + 0.15 x 100

➔ ~ 20

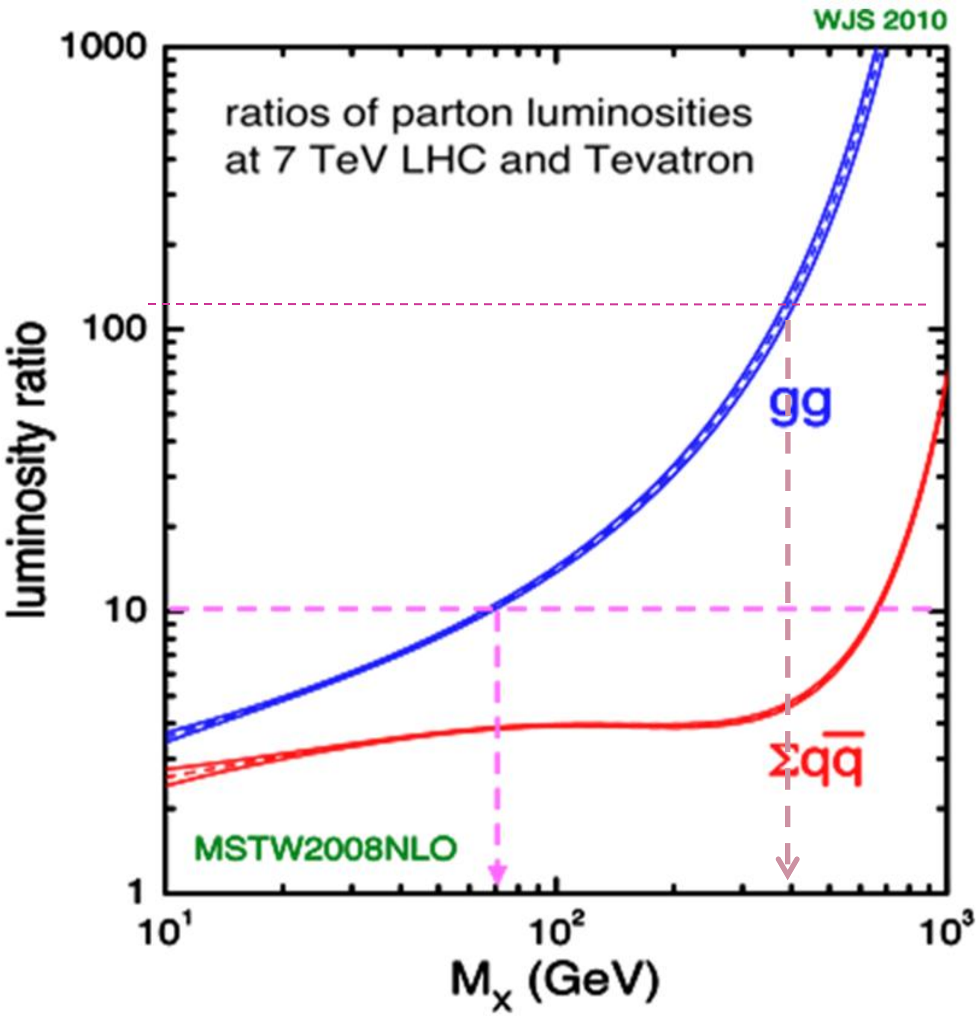
Squarks: ~350 GeV (assume top):

Factor: 0.85 x 10 + 0.15 x 1000

➔ ~ 150 to 200

Z′: ~1 TeV (qq)

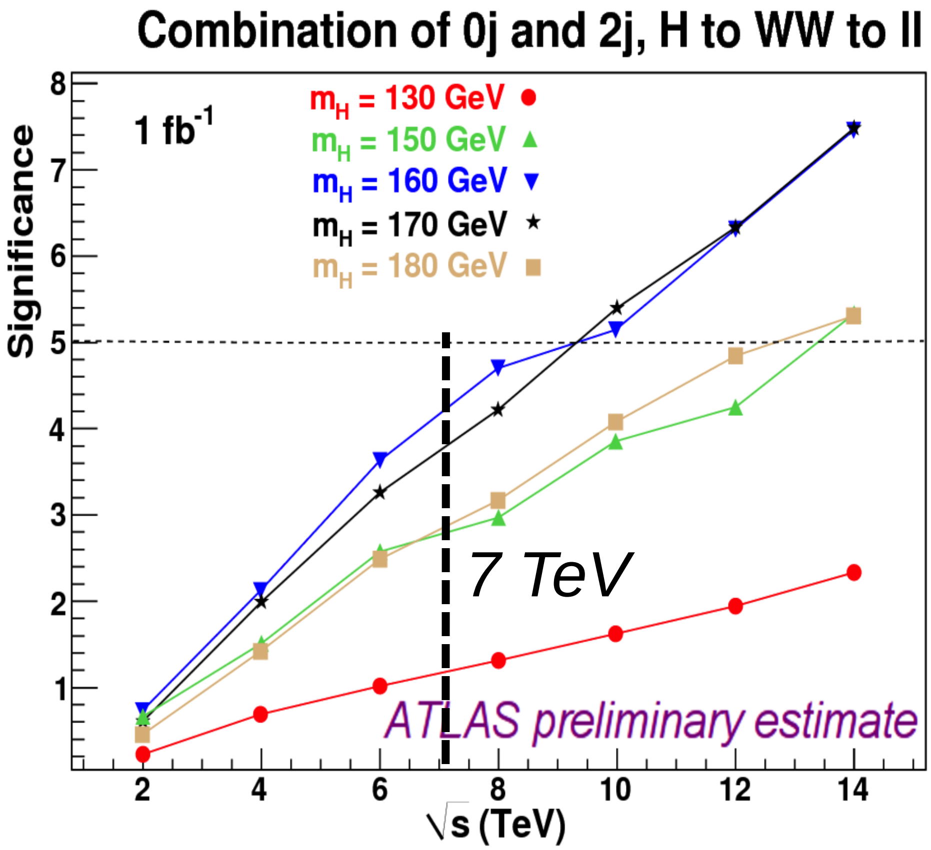
Factor: ~ 50 to 100

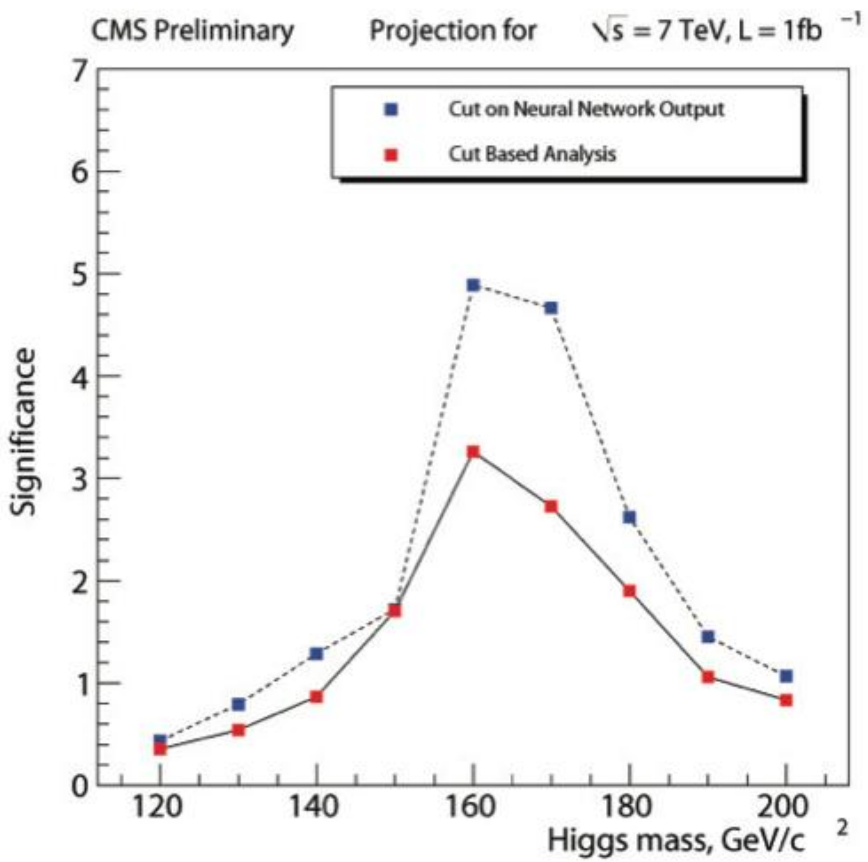


Standard Model Higgs: One Experiment

*1fb^-1^*

ATLAS H→WW→ll **CMS H→WW→ll**



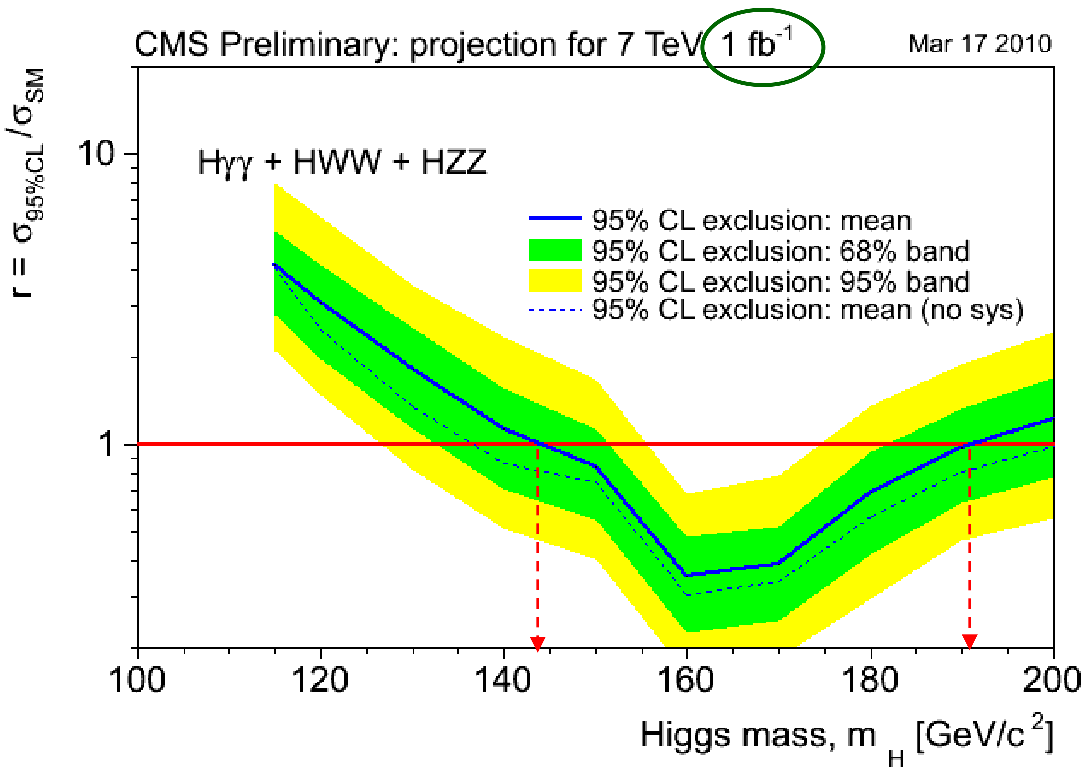


Depending on the analysis technique used 3 to almost 5 Sigma for **M_h~165 GeV** is possible.
Adding other channels like H→ZZ and H→γγ helps to improve in the high and low mass region

Standard Model Higgs: One Experiment

1fb^{-1}

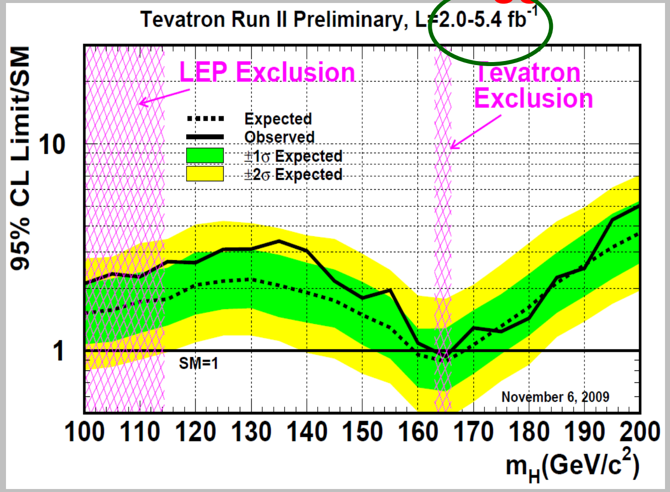
Exclusion: One experiment only



SM Higgs expected excluded range approx: **145-190 GeV**
3 to 5 Sigma at: ~**160 GeV**

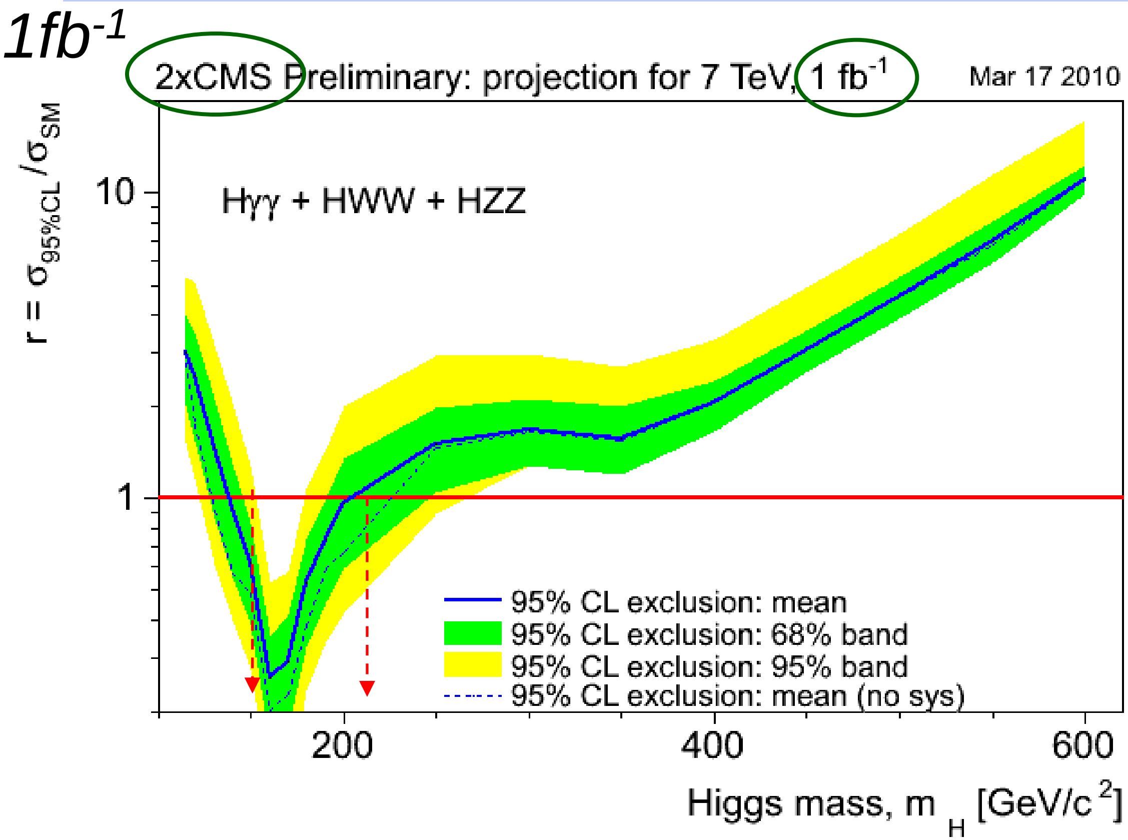
TEVATRON CDF+D0

Standard Model Higgs



Tevatron 95% exclusion today: [162 to 166] GeV

Standard Model Higgs: Combined



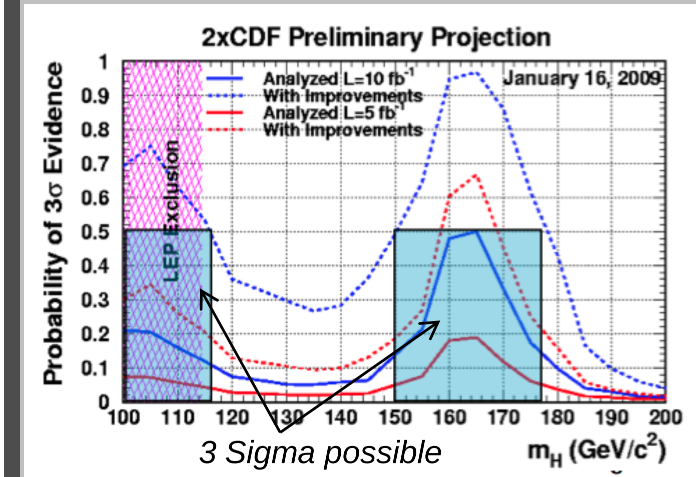
SM Higgs expected excluded range approx: **140-200 GeV**

discovery range approx: **160-170 GeV**

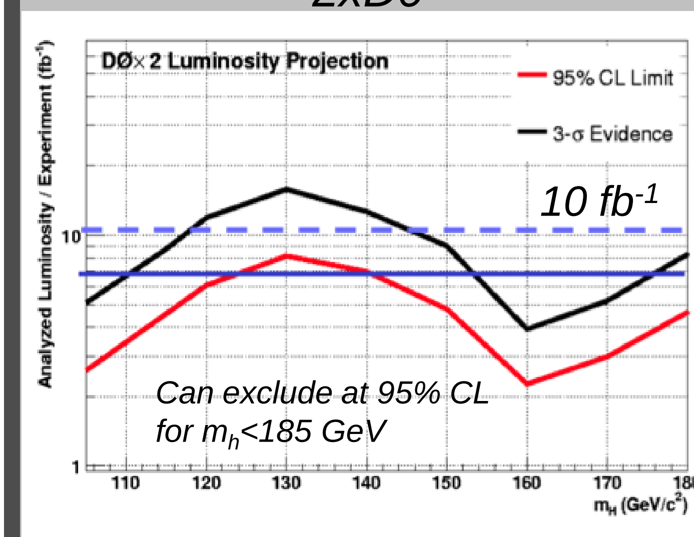
LHC starts to take over from the Tevatron at Higgs masses above 140 GeV!

TEVATRON Projection

2xCDF



2xD0



MSSM Neutral Higgses

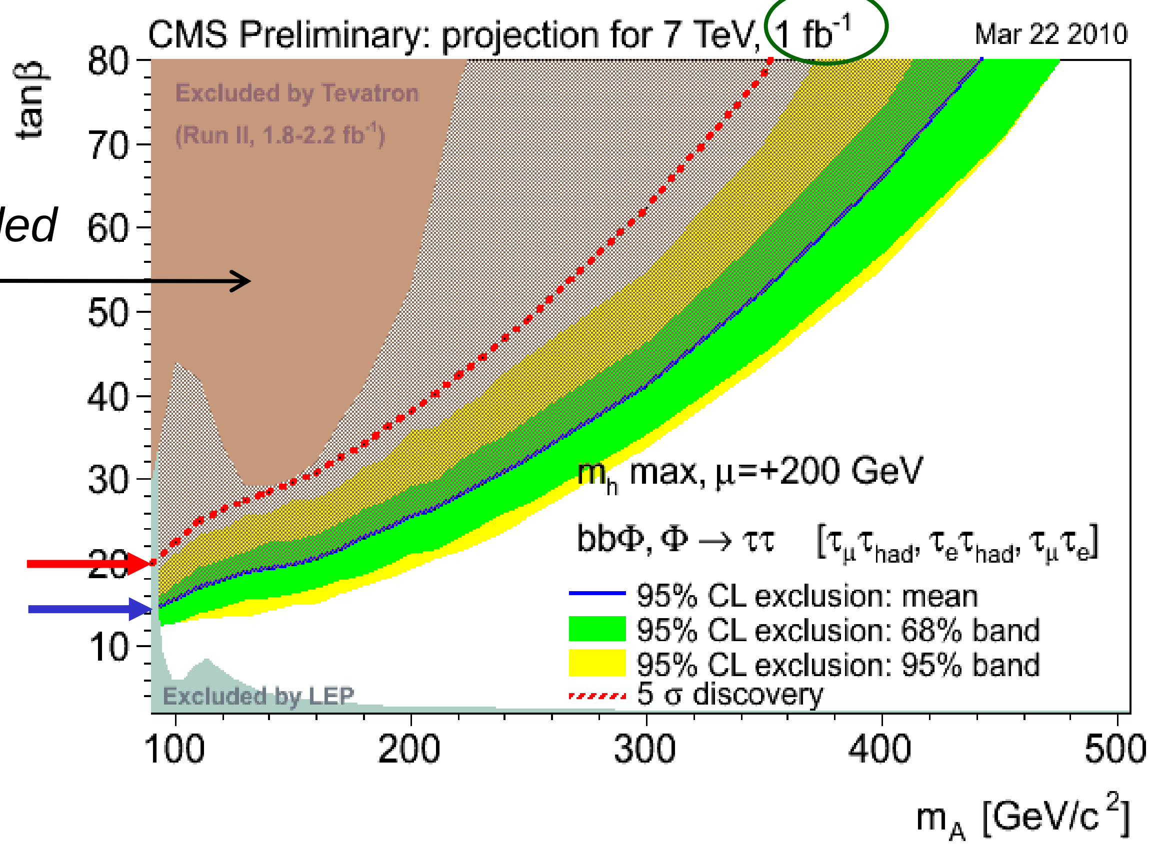
1fb⁻¹

One experiment only

Tevatron excluded today

discover

exclude

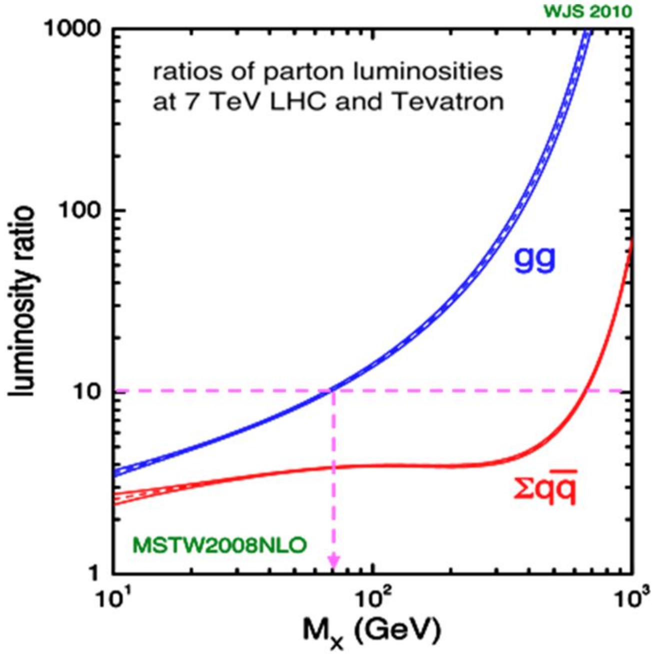


Potential to discover in not-yet-probed phase space: **down to tanβ~20 at low m_A**
Exclusion phase space even larger: **down to tanβ~15 at low m_A**

Higgs Searches: Summary

With 1 fb^{-1} at 7 TeV, LHC will surpass Tevatron's sensitivity at 10 fb^{-1} and enter terra incognita in searches for:

- **High mass SM Higgs searches**
  pp → H, H→WW and ZZ *predominantly gg-fusion*
- **MSSM neutral Higgs searches**
  pp → bbΦ, Φ→ττ *predominantly gg-fusion*
- **MSSM charged Higgs searches**
  pp → tt → (Wb)($H^{\pm}$b) *factor of 20 in cross section*
- **Beyond SM/MSSM Higgs searches**
  Higgs with 4 generations *predominantly gg-fusion*
  fermiophobic H→γγ *gains in qqH+VH cross section and better $m_{\gamma\gamma}$-resolution*



ATLAS and CMS intend to combine results once searches are performed by each collaboration and have been published

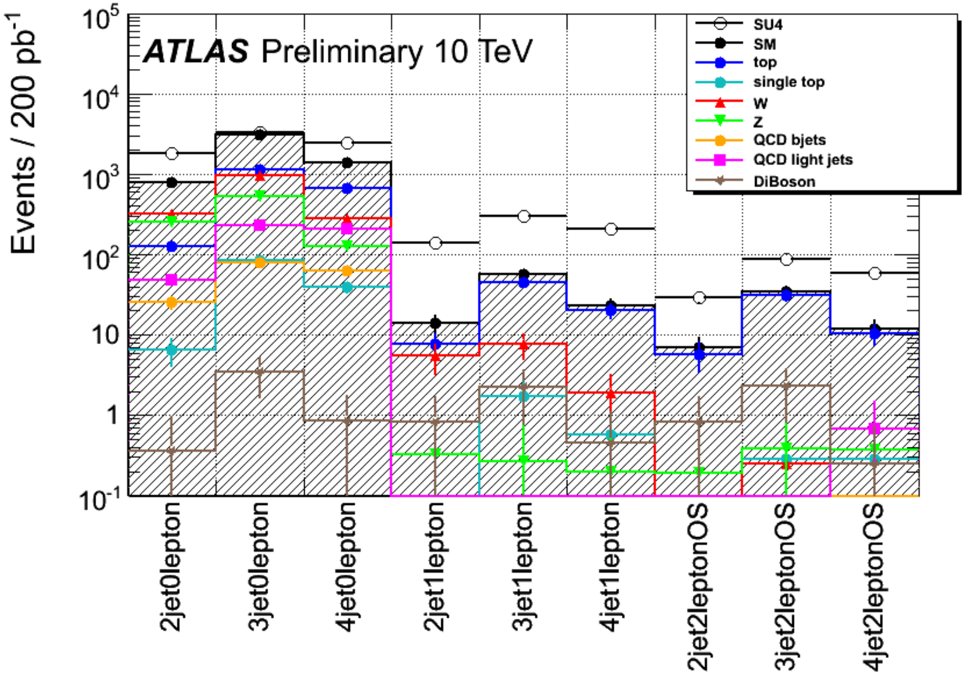
SUSY

SUSY Topology Searches

- Define Topologies

ATL-PHYS-PUB-2009-084

  - Simple categorisation in numbers of leptons and jets

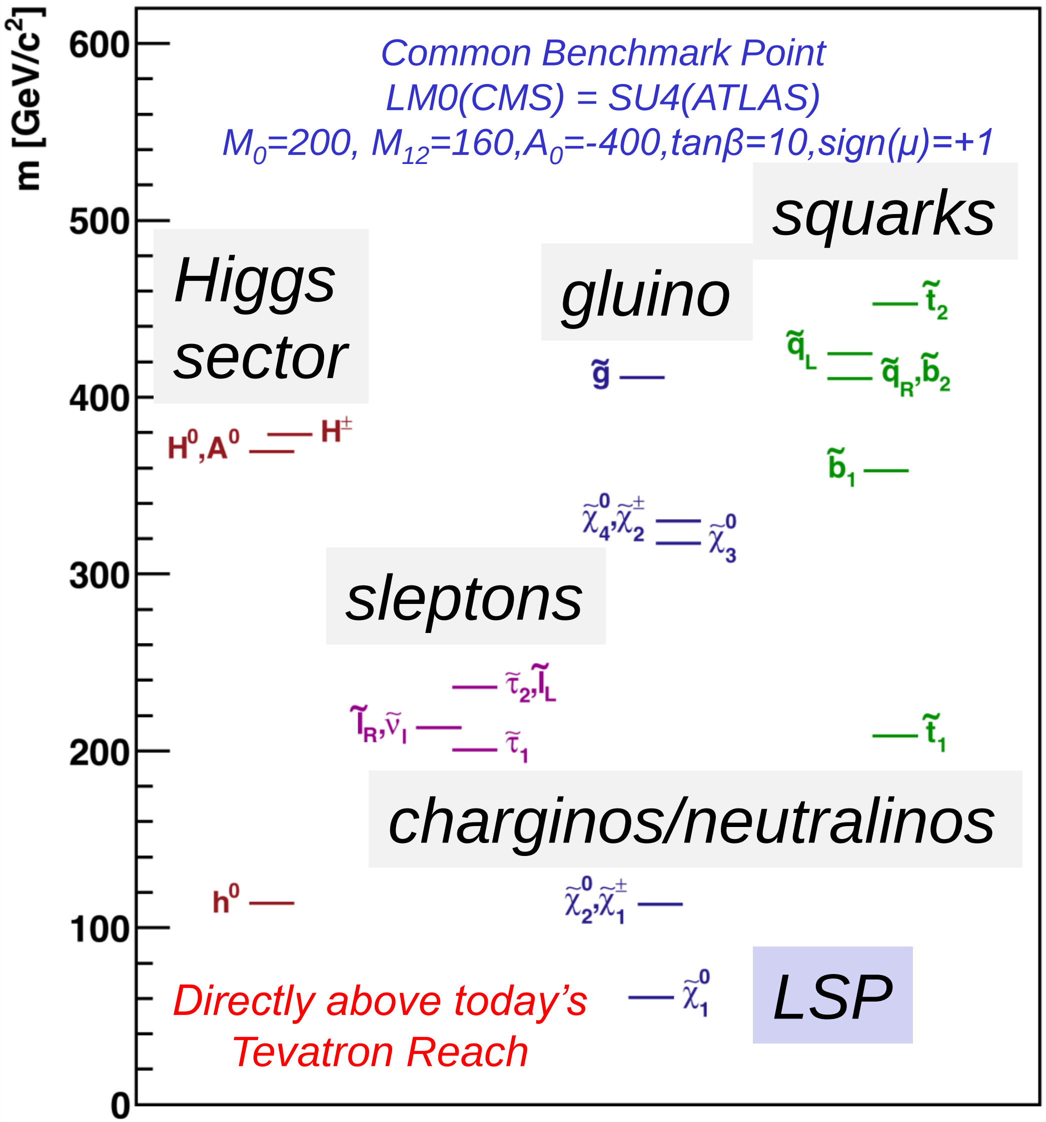


Pre-selection Cuts:

- *Jet E_T > 100 (40) GeV*
- *$\Delta\Phi(jet_i, MET)$ > 0.2 rad*
- *Lepton E_T > 20 (10) GeV*
- *MET > 80 GeV*
- *Meff = $\Sigma E_T^{jet} + \Sigma E_T^{lep}$ + MET*
- *MET > 0.2-0.3 x M_{eff}*
- *M_T > 100 GeV*

  - Even after pre-selection cuts a good S/B for most channels (200 pb^{-1} @ 10 TeV ~ 700 pb^{-1} @ 7 TeV) can be achieved but...
  - Backgrounds straight from Monte Carlo
- Key is measuring SM backgrounds from data with systematics

Characterise SUSY Search Reach



CMSSM

$$m_0, m_{1/2}, \tan\beta, A_0, sign(\mu)$$

Advantage:

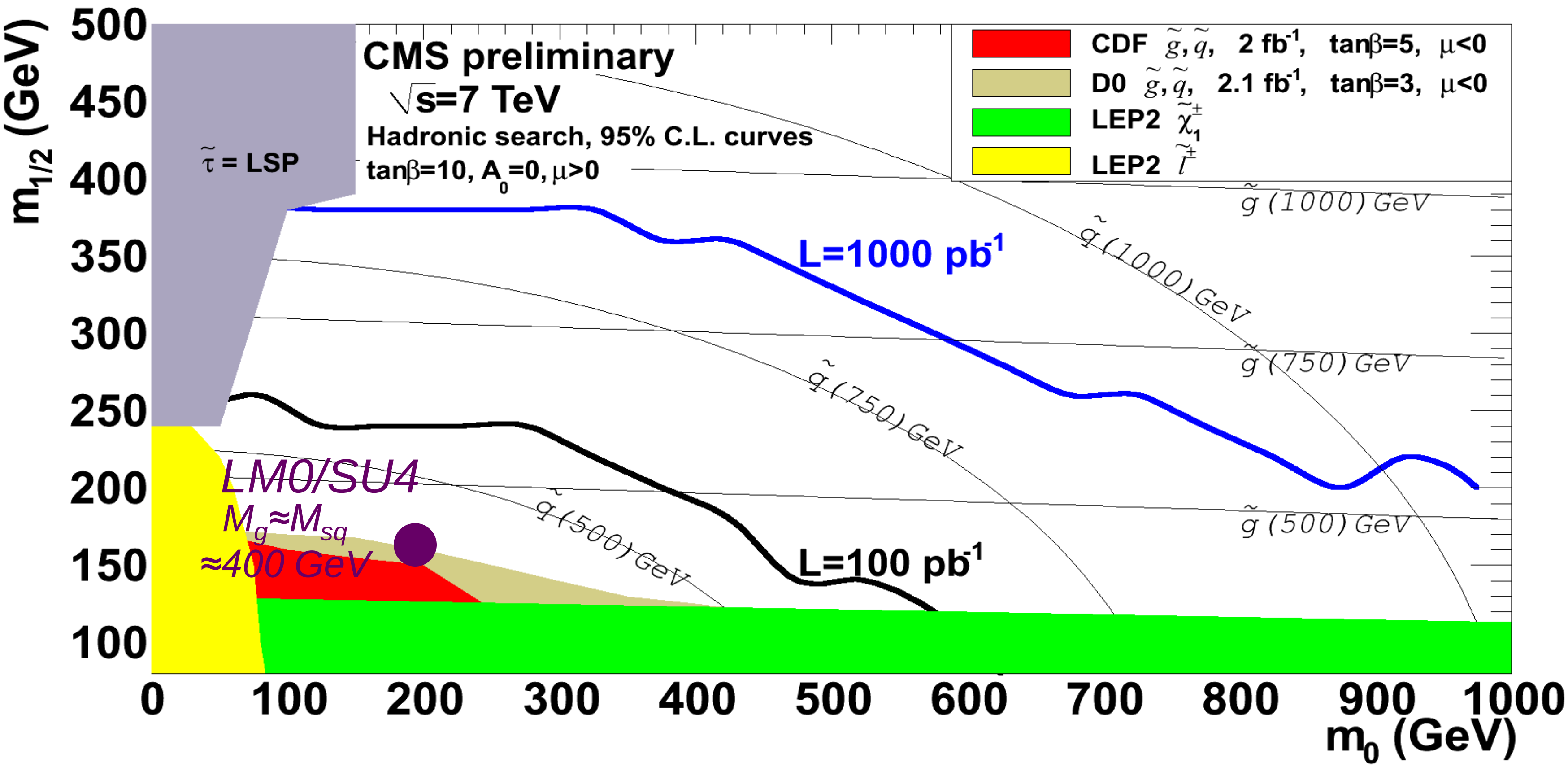
- *Only four free parameters (when sign(μ) fixed)*
- *One of the most studied incarnations of the MSSM*
- *Not yet ruled out by data*

Disadvantage:

- *Not fully representative of SUSY (e.g. fixed mass relation between M_{gluion} and M_{LSP})*

Note: The alternative approach of using M_{gluino} vs M_{squark} exploits the same mass relation and thus is also very CMSSM-like!

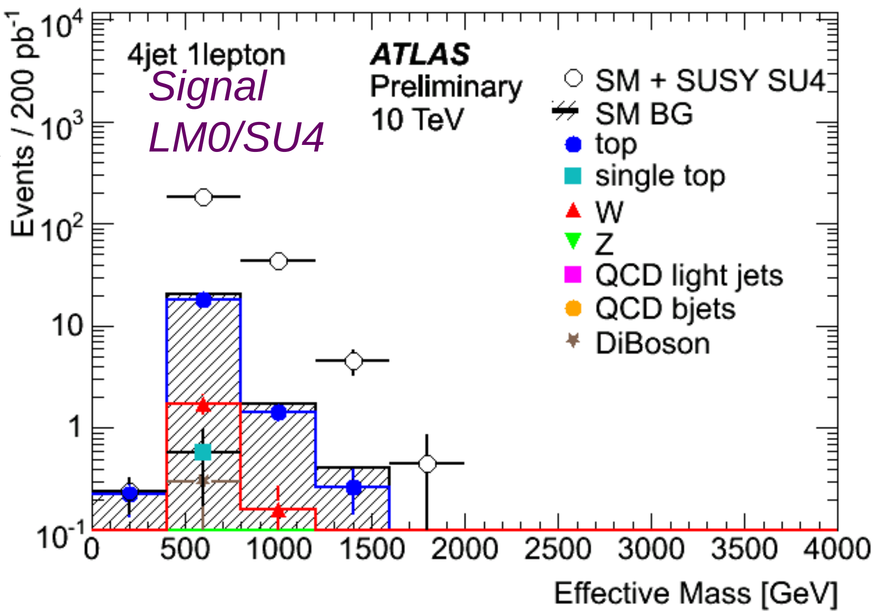
Jets+E_T^{miss} Signature

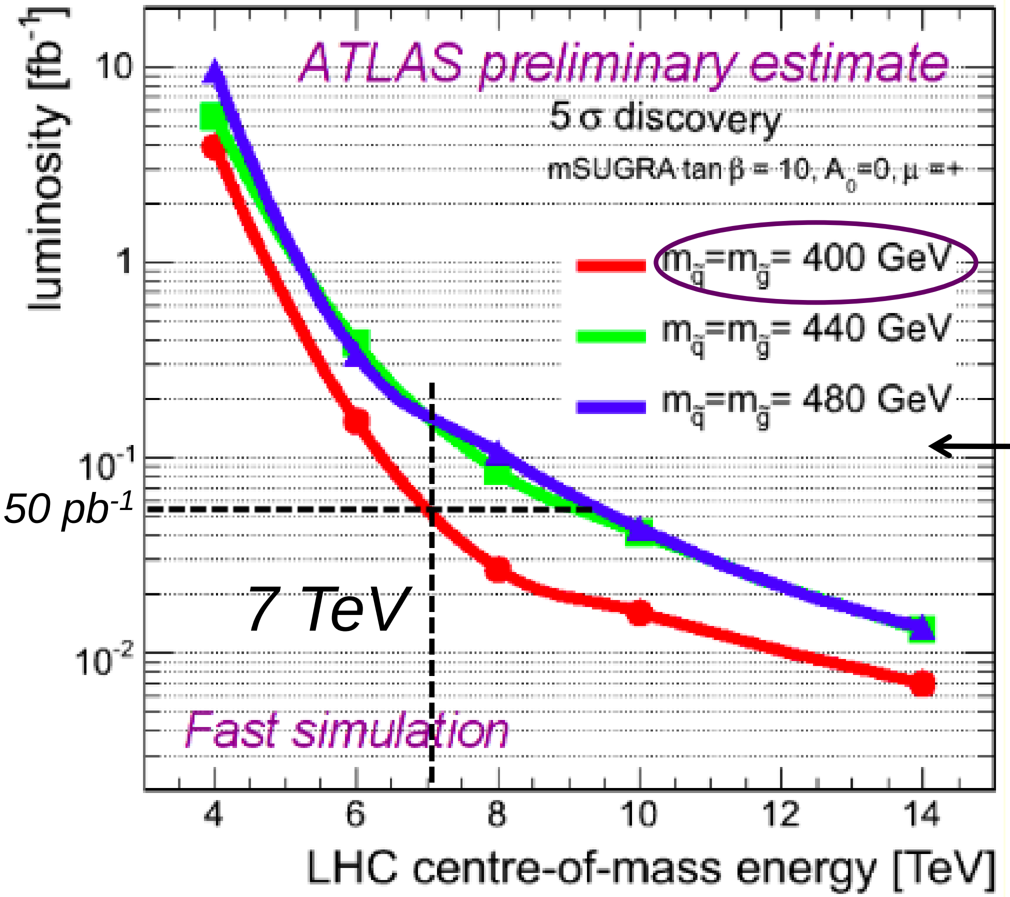


- 95% CL exclusion for all-hadronic search (≥ 3 jets + MET + e/μ veto)
- Systematic uncertainty of 50% assumed on Standard Model background
- *Sensitivity significantly beyond previous experiments (~50/pb to surpass Tevatron)*

Jets+1 Lepton+E_T^{miss} Signature

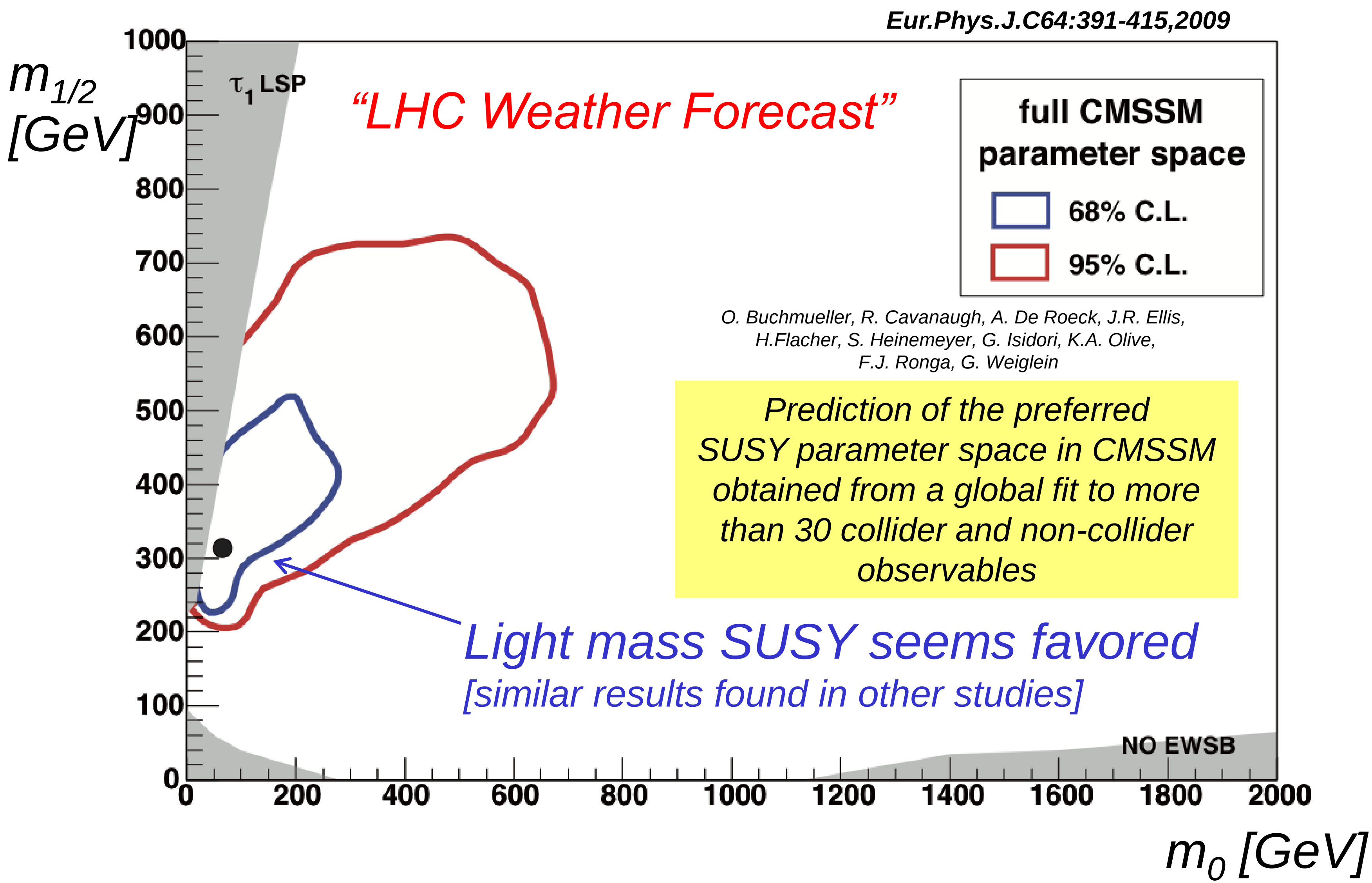
Example: 200 pb^{-1} @10 TeV
(~ 700 pb^{-1} @ 7 TeV)



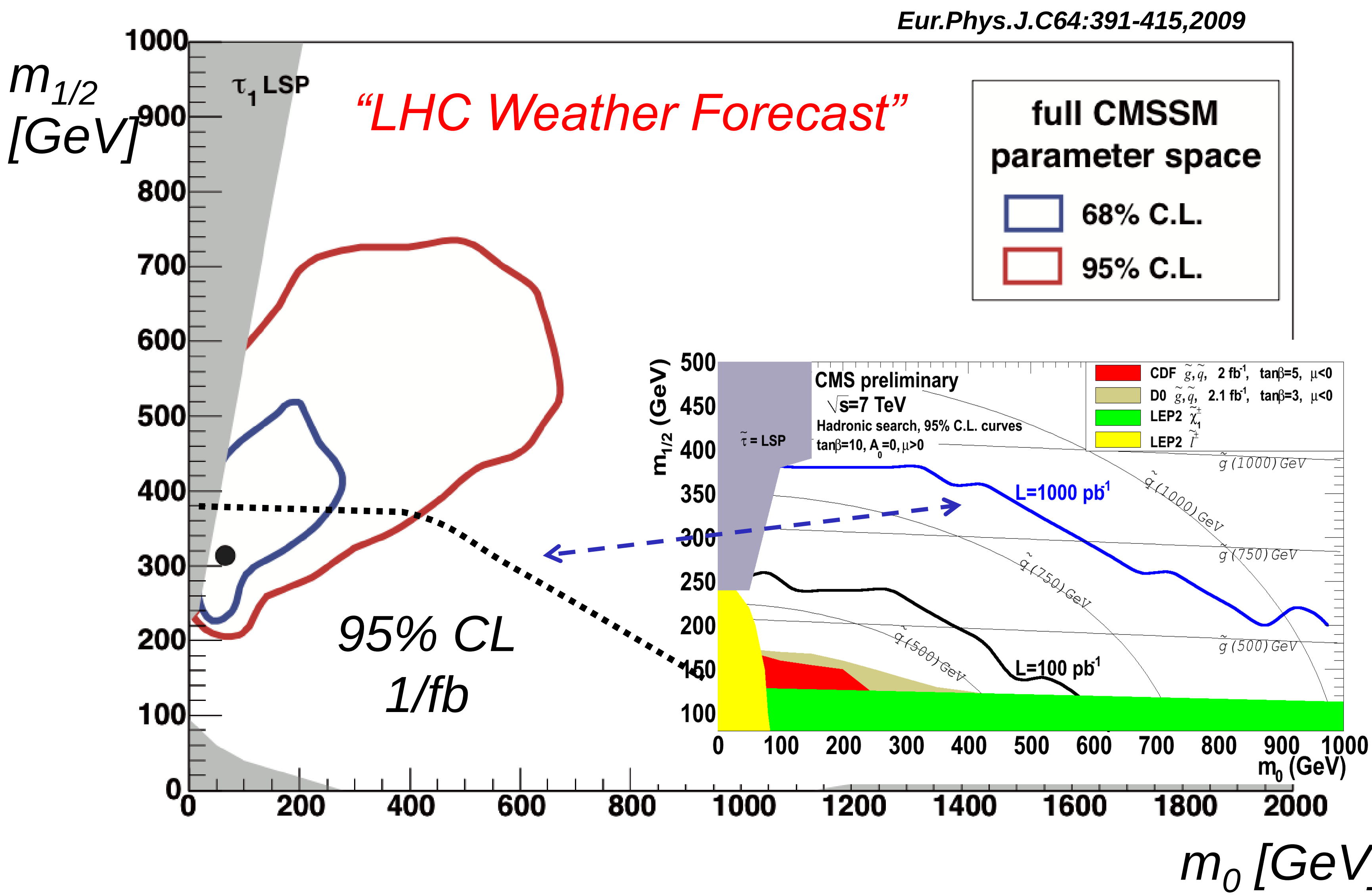


- *Exact reach depends strongly on assumed systematic – here 100%*
- *Discovery sensitivity beyond Tevatron from 50 pb^{-1} onwards.*
- *Channels combined discovery up to squark masses of ~750 GeV with 1 fb^{-1}*

What can be covered - Example



What can be covered - Example



SUSY Summary

• *Sensitivity studies demonstrate that we will be entering at new territory with less than 100 pb^{-1} of integrated luminosity at 7 TeV.*

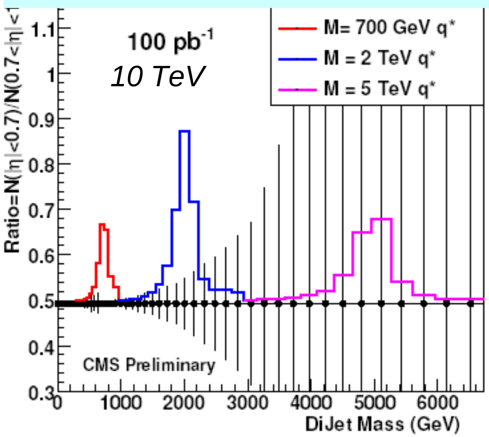
• *With 1 fb^{-1} @ 7 TeV will be able to discover squark masses significantly above 500 GeV. This goes far beyond previous experiments but but higher energies and more luminosity will be required to go beyond the 1 TeV mass scale.*

• *First results will likely be presented in constrained model hypotheses (e.g. CMSSM, M_g vs. M_{sq}, etc) but ATLAS and CMS are actively pursuing alternative, less model-dependent, ways of presenting results and interpretation*

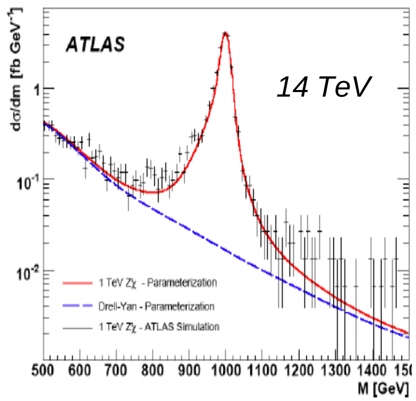
From the Possible to the Unexpected

Large zoo of models that predict different incarnations of New Physics at the LHC

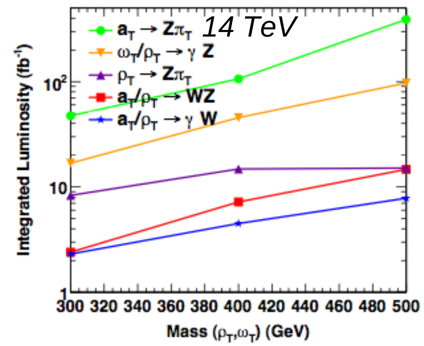
Contact Interaction /Excited Quarks?



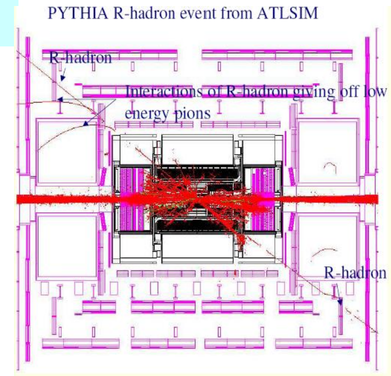
New Gauge Bosons?



Technicolour?



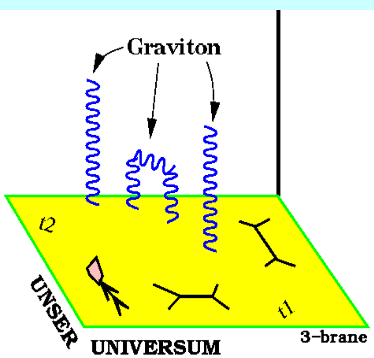
Split Susy?



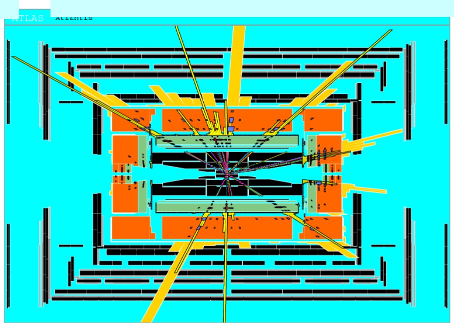
Little Higgs?

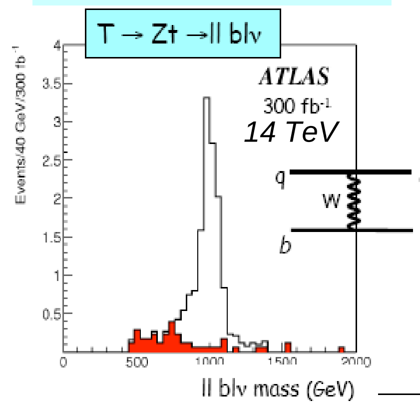
Hidden Valley??

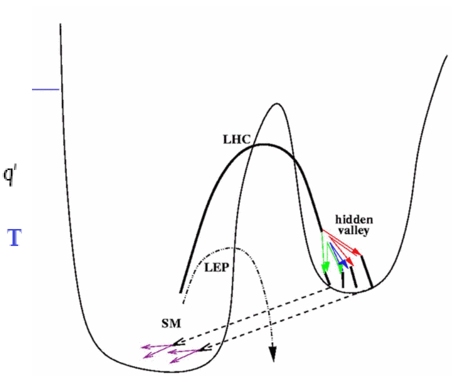
Extra Dimensions?



Black Holes???





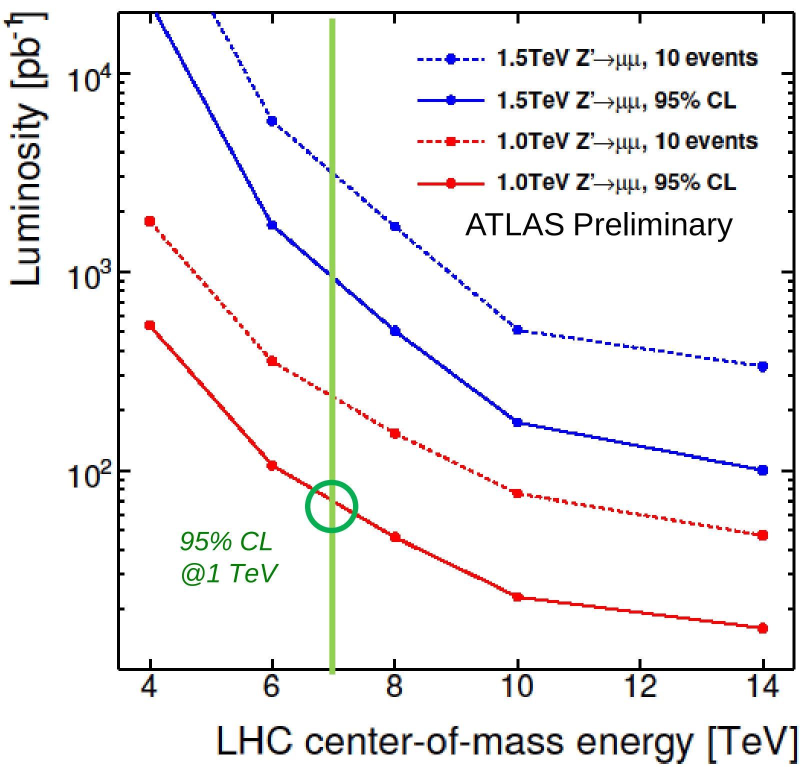


Non exhaustive list (by far)

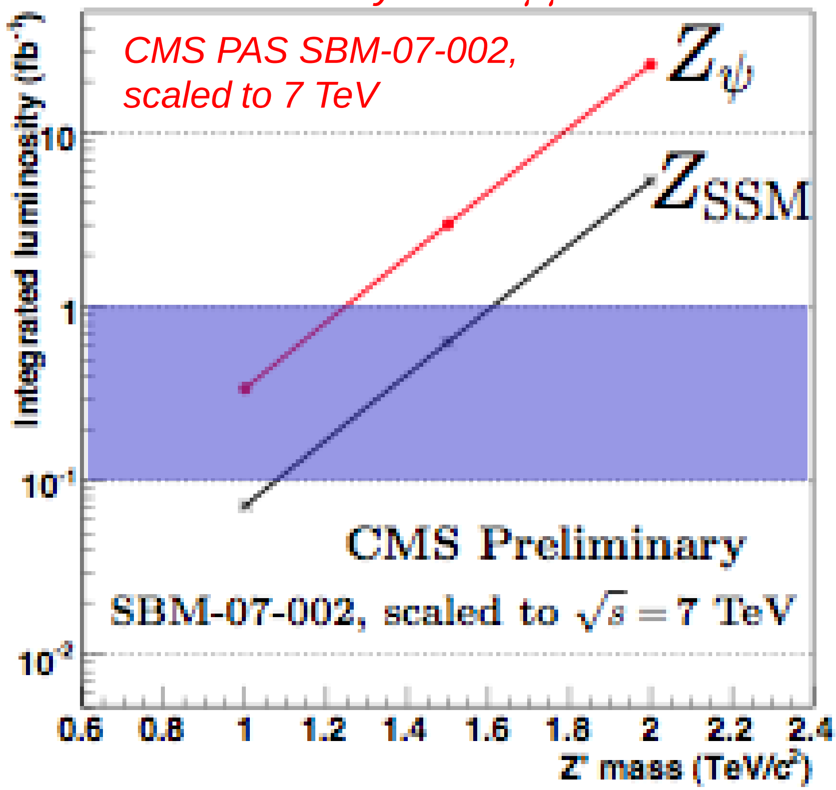
Dilepton Resonances (Example Z')

- Predicted in many SM extensions (Extra Dimensions, Technicolour, Little Higgs)
- Low, well understood background dominated by DY
- 95% CL exclusion O(100/pb) at 1 TeV
- Sensitivity beyond the Tevatron (1 TeV SSM Z') with ~100 pb^{-1}

95% exclusion in $\mu\mu$

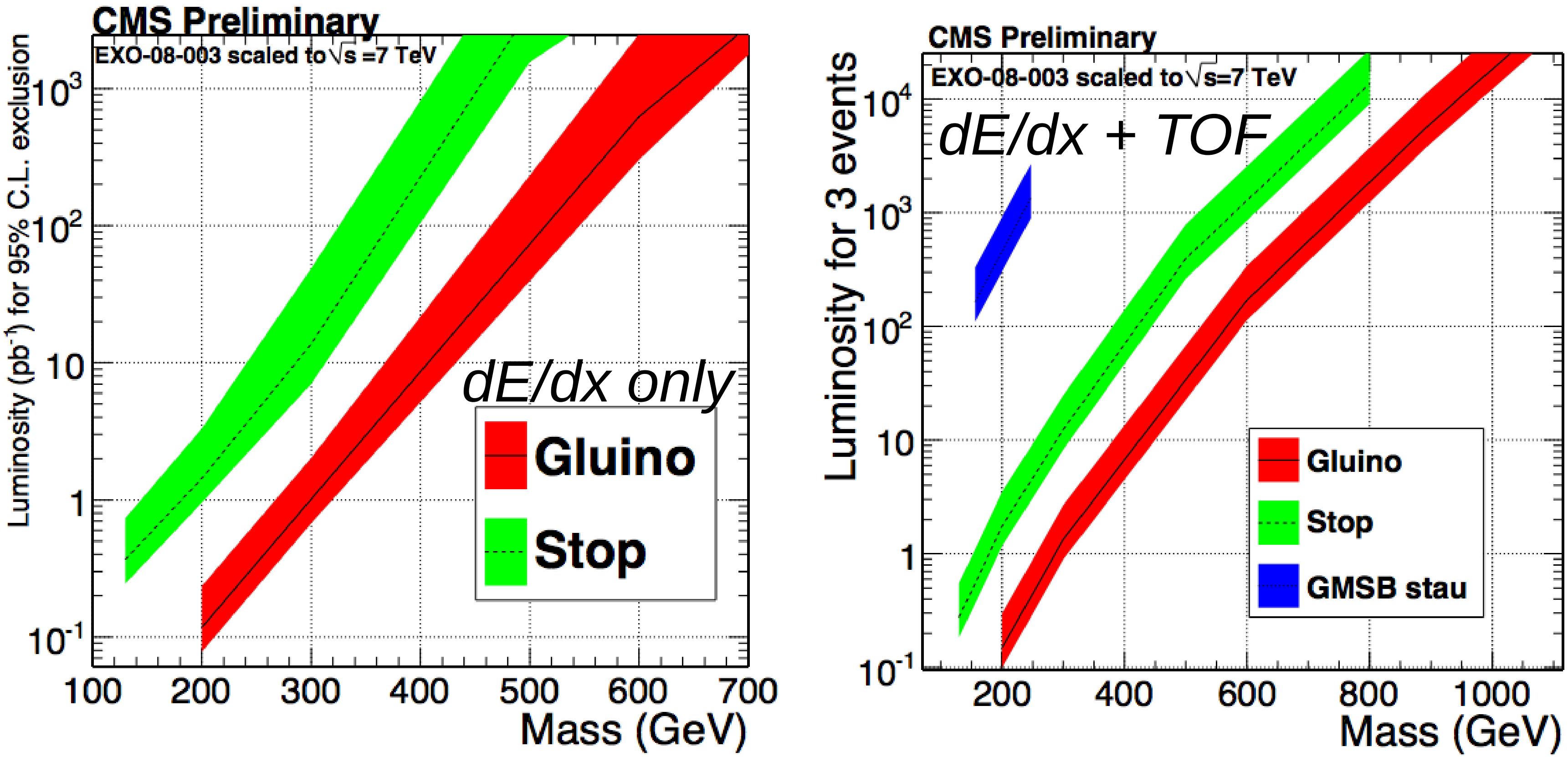


5σ discovery in the $\mu\mu$ channel



Heavy Slow Charged Particles

- A very early analysis: dE/dx and possibly TOF based
- dE/dx part is well understood from cosmics running
- Sensitivity beyond the Tevatron with as little as 1 pb^{-1} of data



CMS PAS EXO-08-003, scaled to 7 TeV

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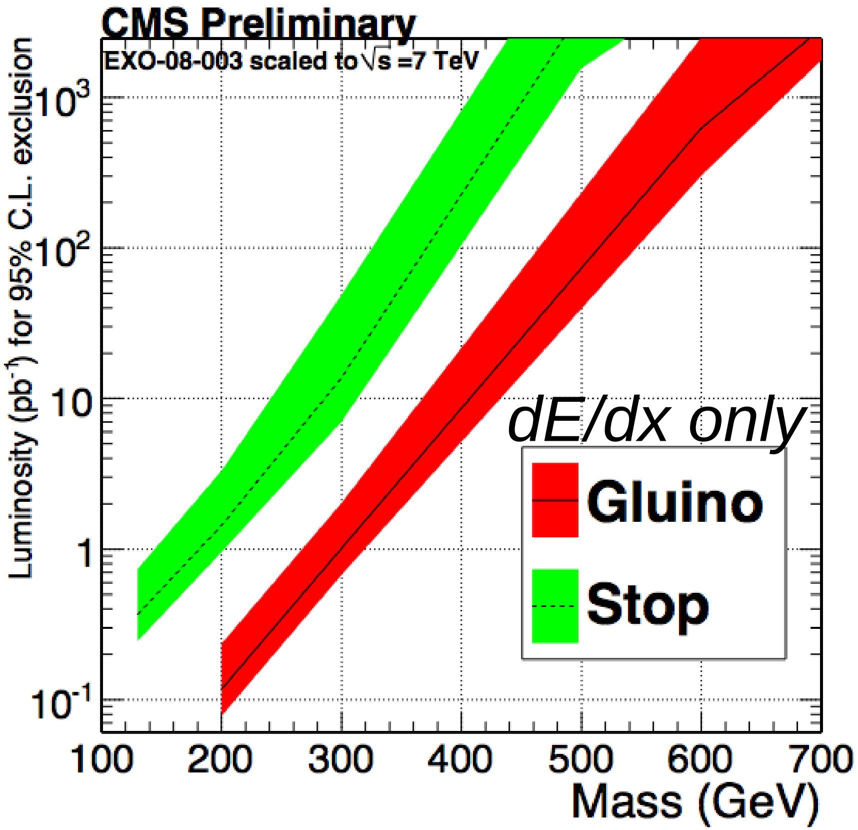
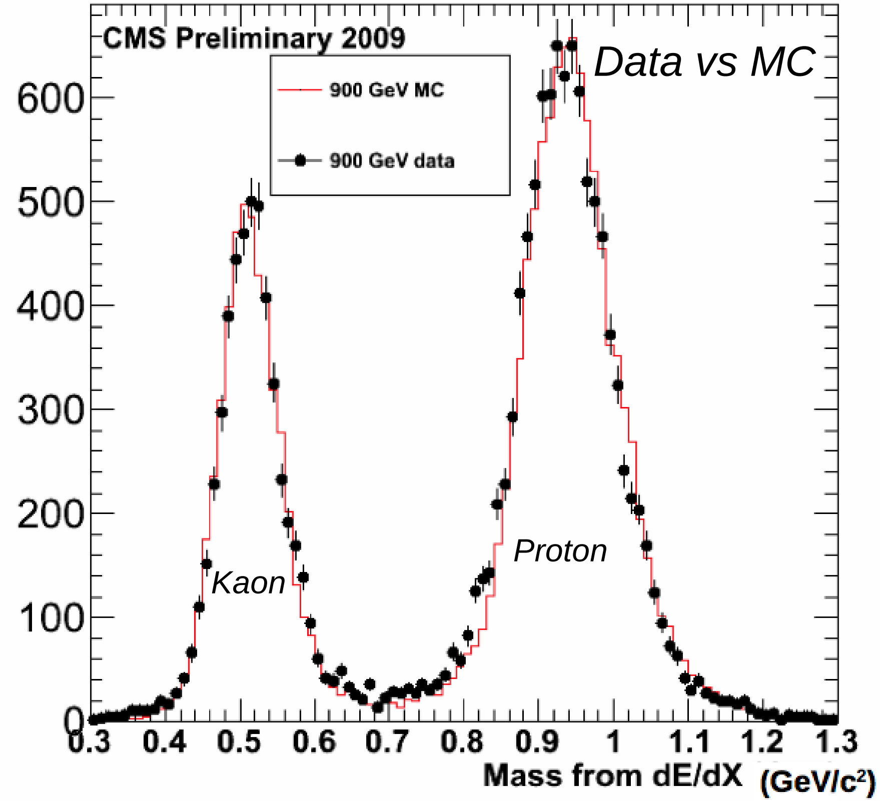
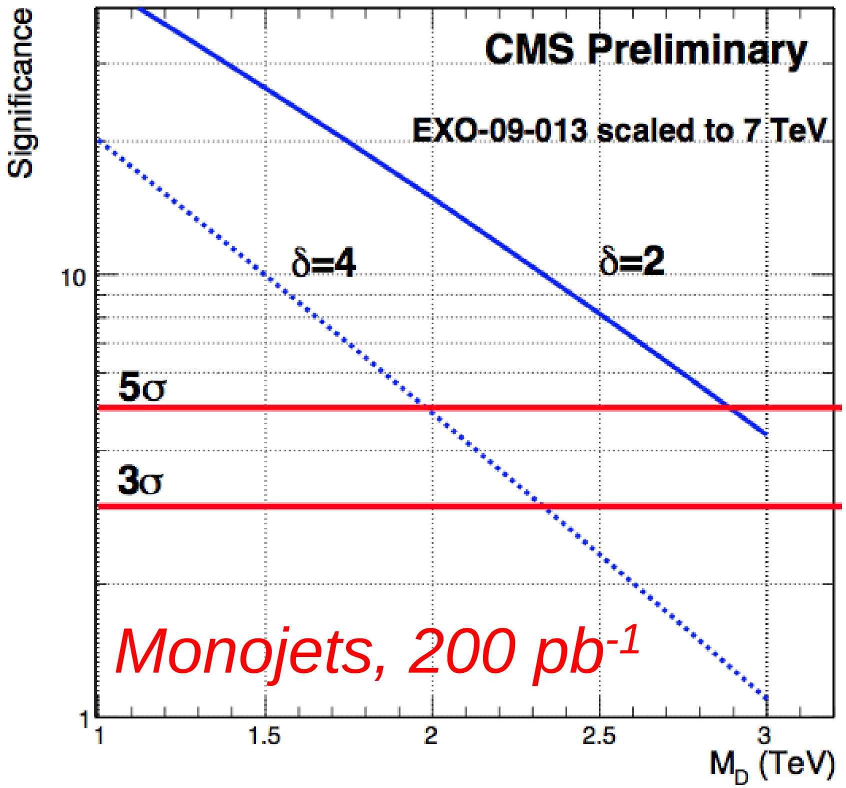




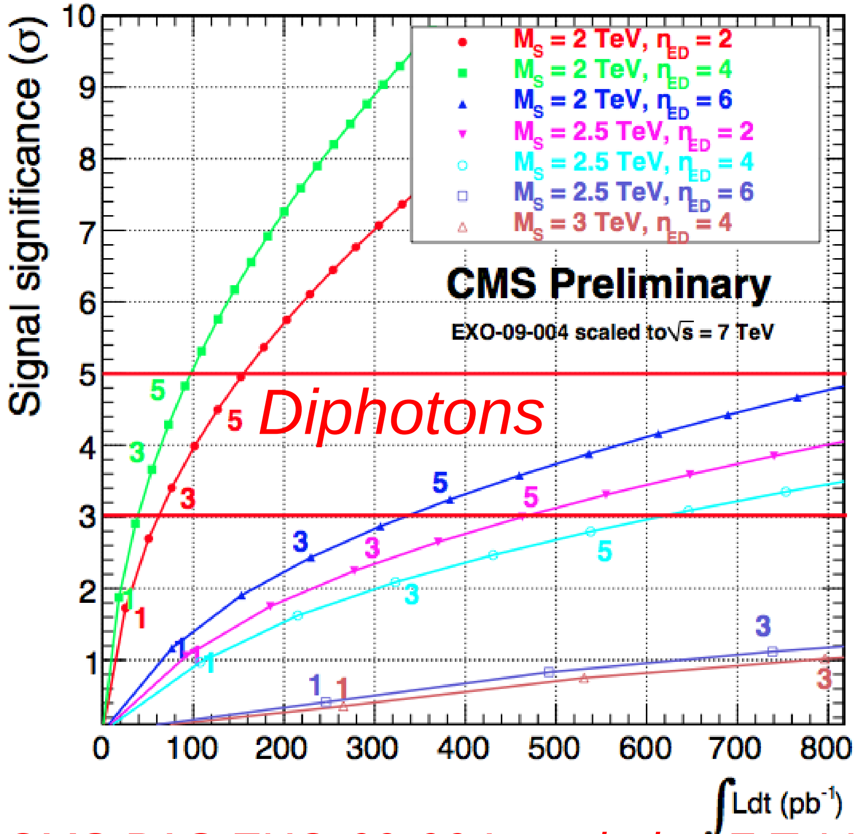
CMS PAS EXO-08-003, scaled to 7 TeV

Large Extra Dimensions

- Several channels offer doubling and tripling sensitivity compared to the Tevatron limits with 0.1-1.0 fb^{-1} at 7 TeV
- Classical signatures: monojets and photon pairs



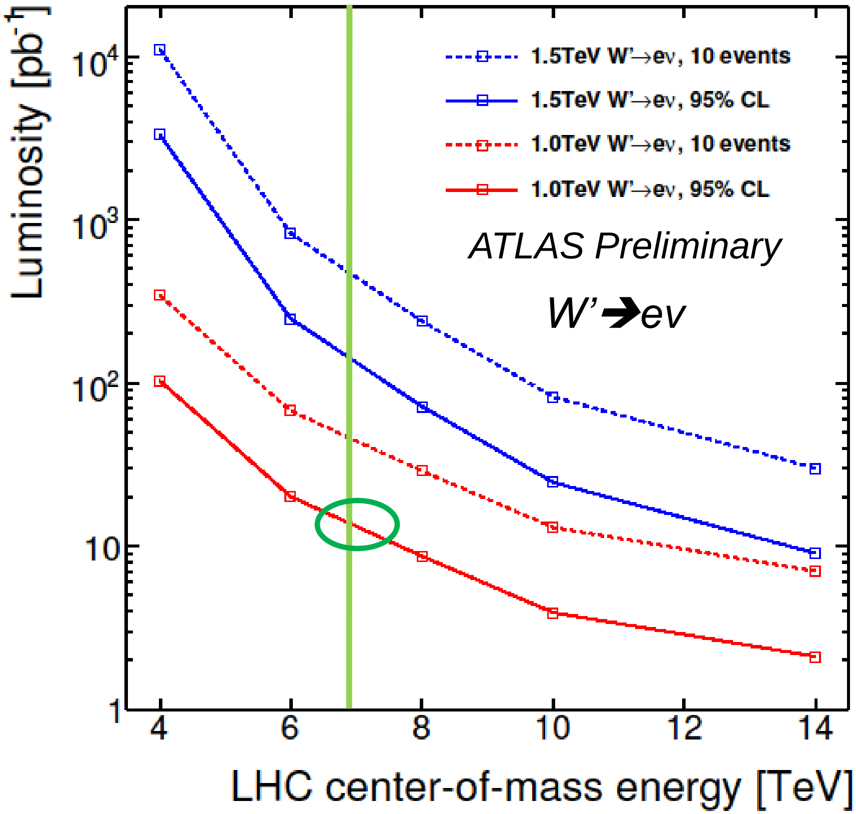
CMS PAS EXO-09-013, scaled to 7 TeV



CMS PAS EXO-09-004, scaled to 7 TeV

… and more …

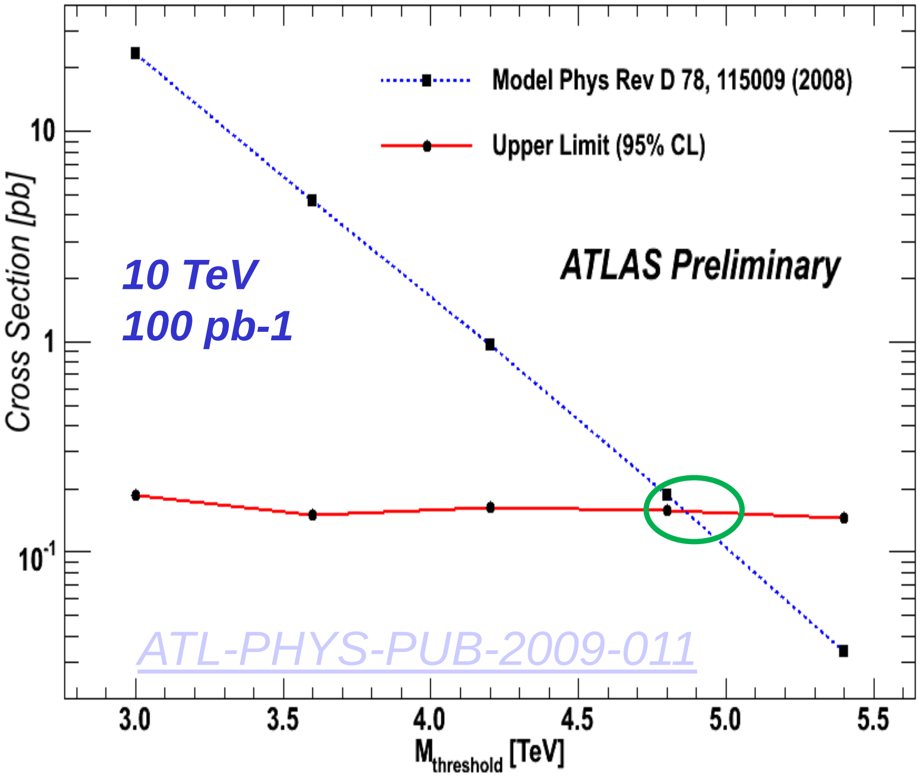
W'



95% CL limit per channel:

O(10/pb) at 1 TeV @ 7 TeV

String Balls



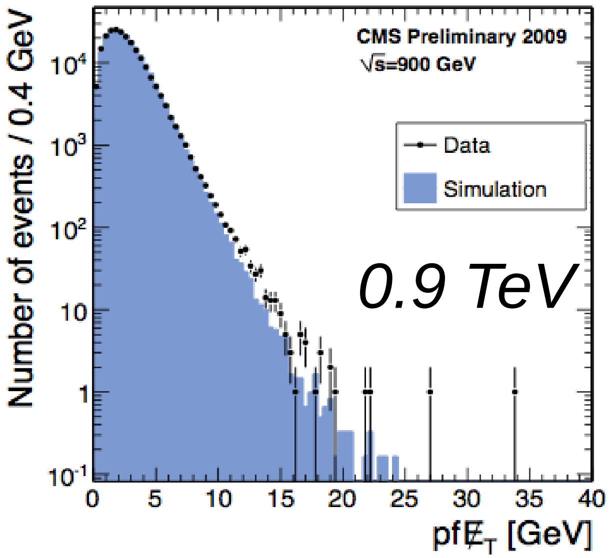
For 10 TeV: exclude M_{th} below 4.8 TeV
For 7 TeV: exclude M_{thh} below ca. 4 TeV

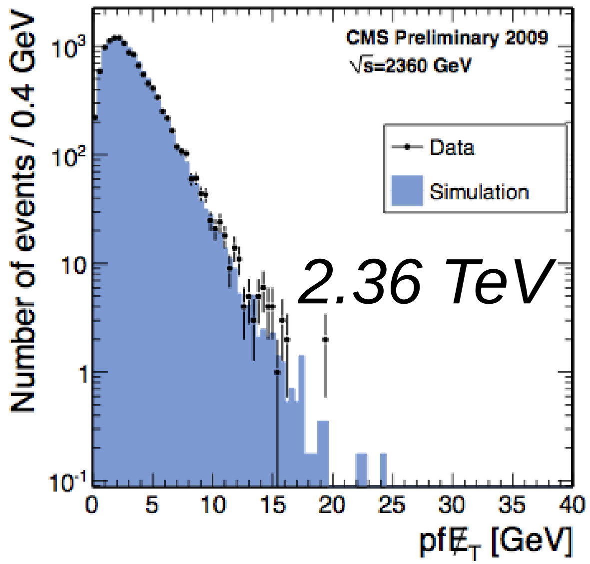
and even more!

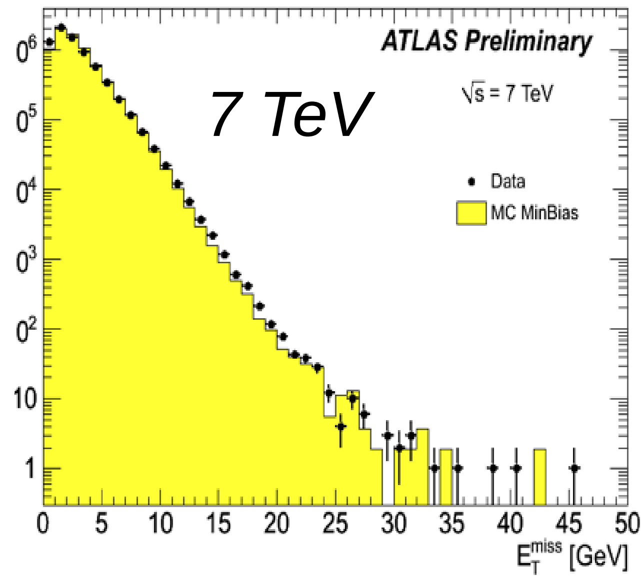
- Even more Exotica searches will enter new territory with 0.1-1.0 fb^{-1} of data:
  - Randall-Sundrum graviton searches in the diphoton channel:
    - ✓ *Exceeds the Tevatron reach with 50 pb^{-1}*
  - Dijet resonance and compositeness searches:
    - ✓ *Discovery possible with as little as 10 pb^{-1}*
  - Excited electron or muon search:
    - ✓ *Breaks new ground with 50 $pb^{-1:}$*
  - Searches for 4th generation quarks
    - ✓ *Exceed Tevatron sensitivity with 200-500 pb^{-1}*
  - Searches for stopped gluinos:
    - ✓ *Instantaneous luminosity is the key: discovery is possible as soon as the machine reaches 10^{32} $cm^{-2}s^{-1}$*
  - Several more searches, including Black Holes, RPV SUSY, Model-Independent Searches

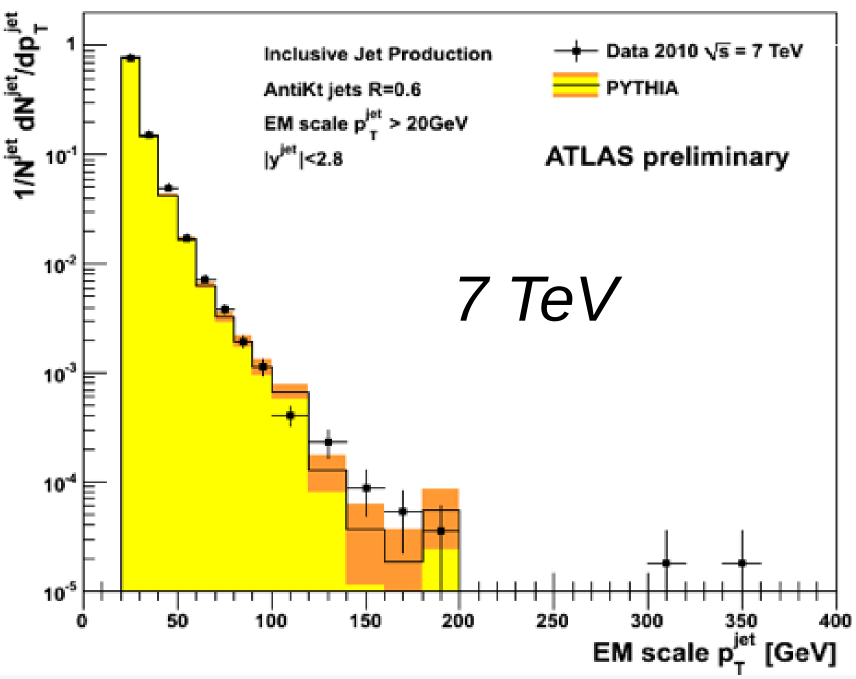
Impressive list of discovery possibilities for 1 fb^{-1} @ 7 TeV

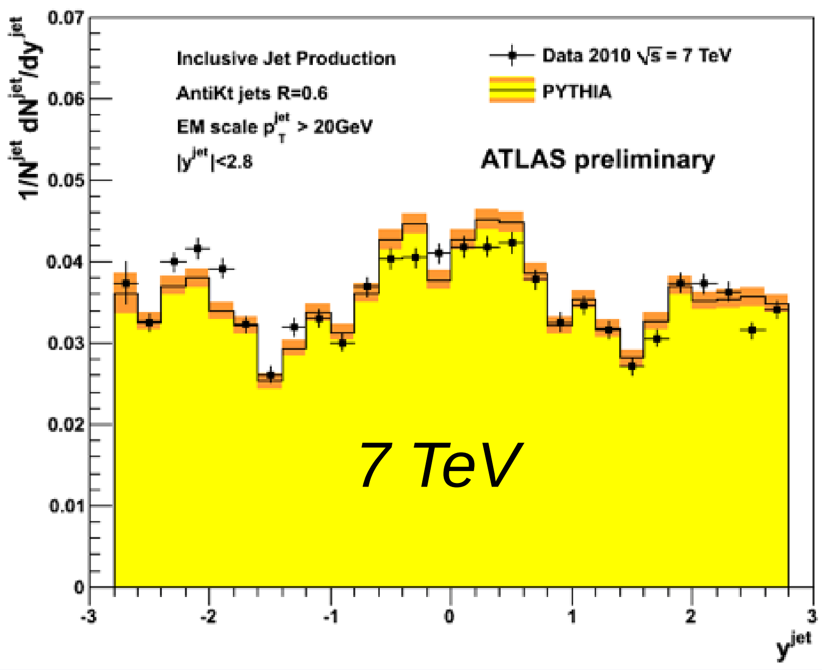
Data – MC Comparison











Summary: New Physics @ 7 TeV

- Establishing prerequisites for New Physics search well underway
  - Commissioning of detectors of unprecedented complexity and performance
  - Rediscovery of the SM at a new energy frontier
- The LHC will surpass Tevatron’s sensitivity for several SM and MSSM Higgs searches with $1fb^{-1}$
  - E.g. SM Higgs (M_h >140 GeV), 4th generation Higgs, MSSM neutral Higgs
- The LHC will enter new territory with less than 100 pb^{-1} for almost all low mass SUSY searches
  - First signals might emerge very early but it might also take more time and ingenuity before we can claim a discovery
  - With $1fb^{-1}$ the reach extends to almost 1 TeV in SUSY mass scale
- The LHC will have discovery potential with as little as 10 to 100 pb^{-1} for many new physics models
  - Black hole, Extra Dimensions,Little Higgs, Split Susy, New Bosons, Technicolour, etc …

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- Establishing prerequisites for New Physics search well underway
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We are about to enter new Territory!

Backup Material

SUSY Benchmark points

Low mass (LM) mSUGRA benchmarks

Benchmark	m0	m1/2	A0	tanb	sgn(mu)	Notes
LM0	200	160	−400	10	1	
LM1	60	250	0	10	+	
LM2	185	350	0	35	+	
LM2mhf360	185	360	0	35	+	
LM3	330	240	0	20	+	
LM4	210	285	0	10	+	
LM5	230	360	0	10	+	
LM6	85	400	0	10	+	
LM7	3000	230	0	10	+	
LM8	500	300	−300	10	+	
LM9	1450	175	0	50	+	
LM9p	1450	230	0	10	+	
LM9t175	1450	175	0	50	+	mtop = 175
LM10	3000	500	0	10	+	
LM11	250	325	0	35	+	
LM12						TBD
LM13						focus point, TBD

High mass (HM) mSUGRA benchmarks

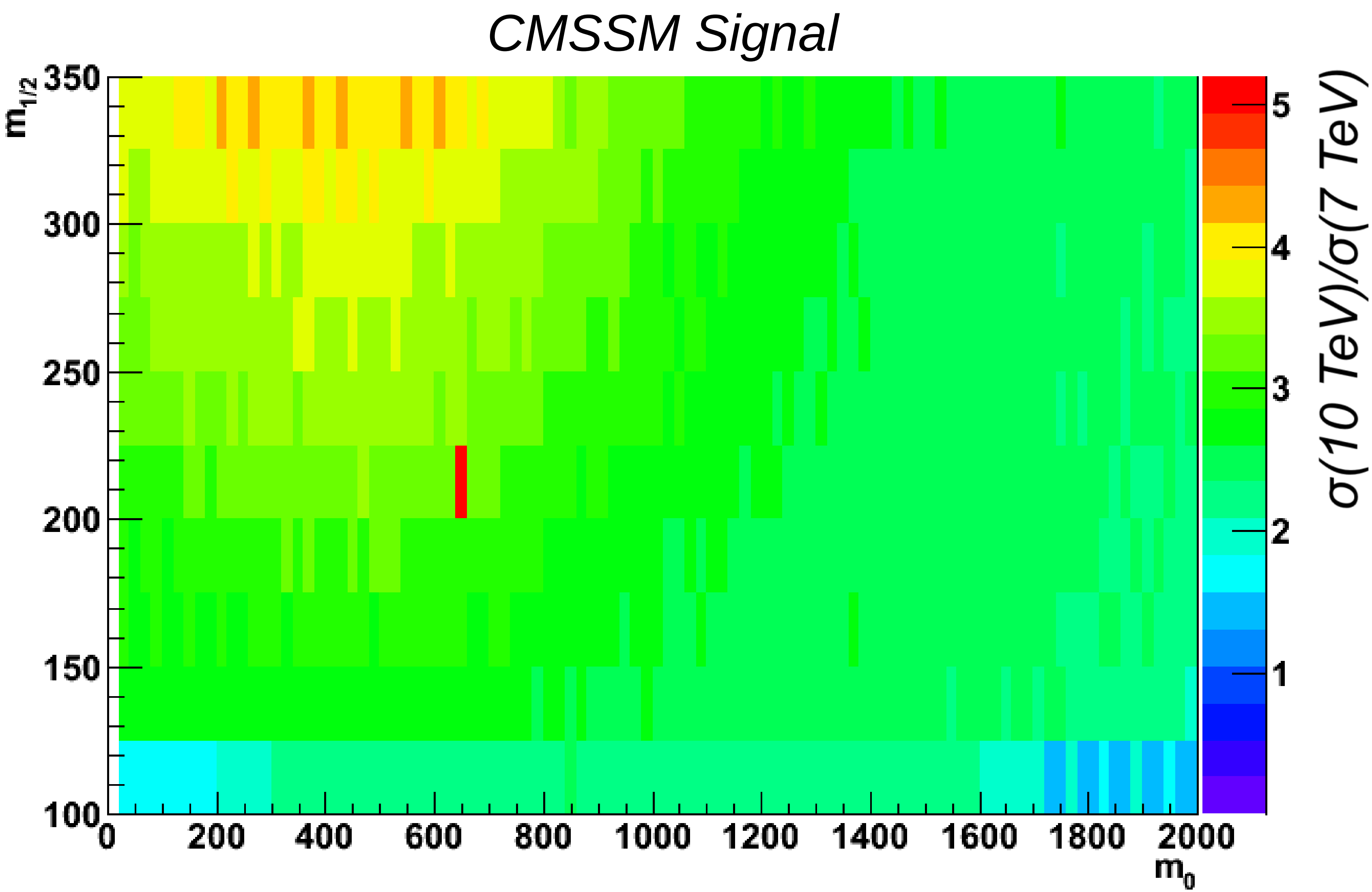
Benchmark	m0	m1/2	A0	tanb	sgn(mu)	Notes
HM1	180	850	0	10	+	
HM2	350	800	0	35	+	
HM3	700	800	0	10	+	
HM4	1350	600	0	10	+	

GMSB (GM) benchmarks

Benchmark	Lambda	M_mess	N5	C_Grav	tanb	sgn(mu)	Notes
GM1b	80	160	1	1	15	+	
GM1c	100	200	1	1	15	+	
GM1d	120	240	1	1	15	+	
GM1e	140	280	1	1	15	+	
GM1f	160	320	1	1	15	+	
GM1g	180	360	1	1	15	+	

Particle	SU1	SU2	SU3	SU4	SU6	SU8.1	SU9
$\tilde{d}_L$	764.90	3564.13	636.27	419.84	870.79	801.16	956.07
$\tilde{u}_L$	760.42	3563.24	631.51	412.25	866.84	797.09	952.47
$\tilde{b}_1$	697.90	2924.80	575.23	358.49	716.83	690.31	868.06
$\tilde{t}_1$	572.96	2131.11	424.12	206.04	641.61	603.65	725.03
$\tilde{d}_R$	733.53	3576.13	610.69	406.22	840.21	771.91	920.83
$\tilde{u}_R$	735.41	3574.18	611.81	404.92	842.16	773.69	923.49
$\tilde{b}_2$	722.87	3500.55	610.73	399.18	779.42	743.09	910.76
$\tilde{t}_2$	749.46	2935.36	650.50	445.00	797.99	766.21	911.20
$\tilde{e}_L$	255.13	3547.50	230.45	231.94	411.89	325.44	417.21
$\tilde{\nu}_e$	238.31	3546.32	216.96	217.92	401.89	315.29	407.91
$\tilde{\tau}_1$	146.50	3519.62	149.99	200.50	181.31	151.90	320.22
$\tilde{\nu}_\tau$	237.56	3532.27	216.29	215.53	358.26	296.98	401.08
$\tilde{e}_R$	154.06	3547.46	155.45	212.88	351.10	253.35	340.86
$\tilde{\tau}_2$	256.98	3533.69	232.17	236.04	392.58	331.34	416.43
$\tilde{g}$	832.33	856.59	717.46	413.37	894.70	856.45	999.30
$\tilde{\chi}_1^0$	136.98	103.35	117.91	59.84	149.57	142.45	173.31
$\tilde{\chi}_2^0$	263.64	160.37	218.60	113.48	287.97	273.95	325.39
$\tilde{\chi}_3^0$	466.44	179.76	463.99	308.94	477.23	463.55	520.62
$\tilde{\chi}_4^0$	483.30	294.90	480.59	327.76	492.23	479.01	536.89
$\tilde{\chi}_1^+$	262.06	149.42	218.33	113.22	288.29	274.30	326.00
$\tilde{\chi}_2^+$	483.62	286.81	480.16	326.59	492.42	479.22	536.81
h^0	115.81	119.01	114.83	113.98	116.85	116.69	114.45
H^0	515.99	3529.74	512.86	370.47	388.92	430.49	632.77
A^0	512.39	3506.62	511.53	368.18	386.47	427.74	628.60
H^+	521.90	3530.61	518.15	378.90	401.15	440.23	638.88
t	175.00	175.00	175.00	175.00	175.00	175.00	175.00

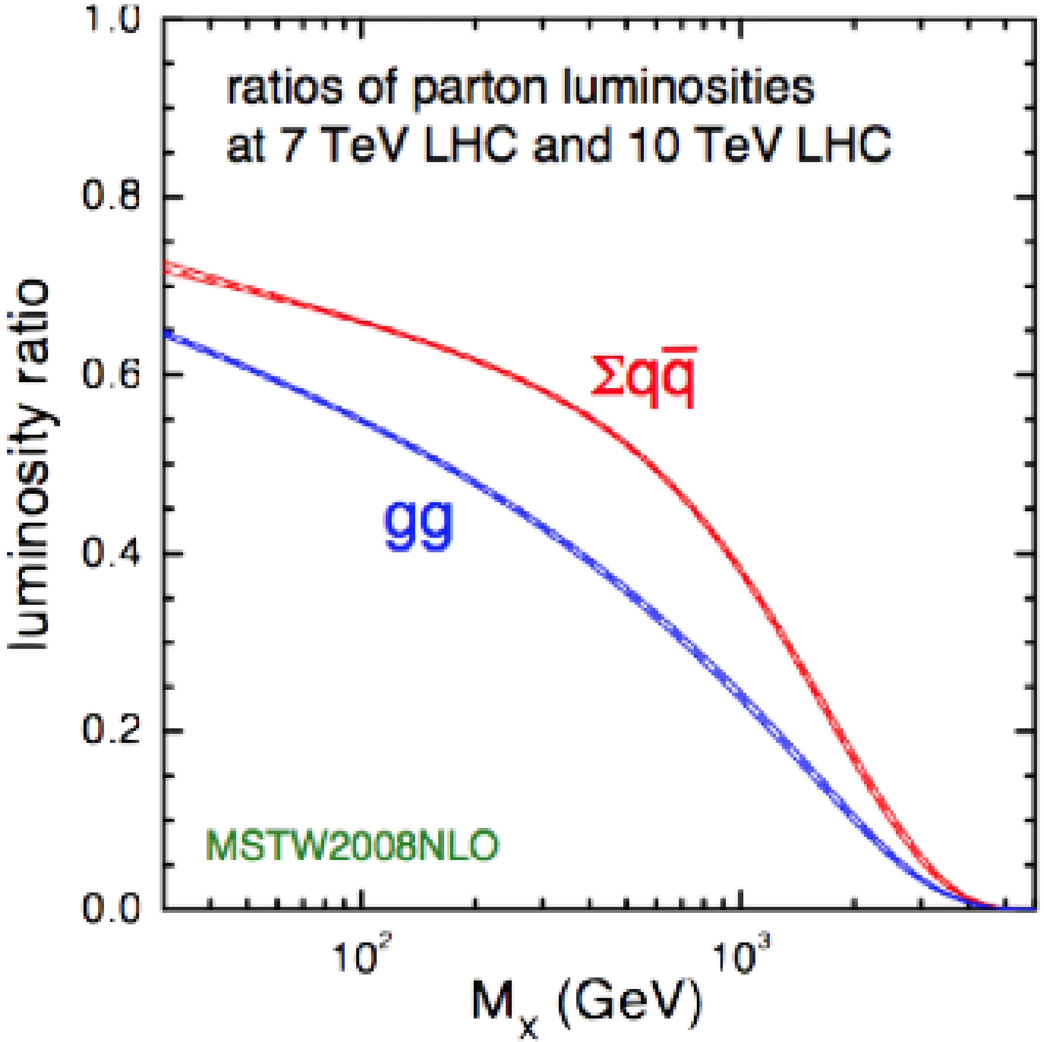
SUSY: 10 TeV vs. 7 TeV



Simple Scaling from 10 to 7 TeV

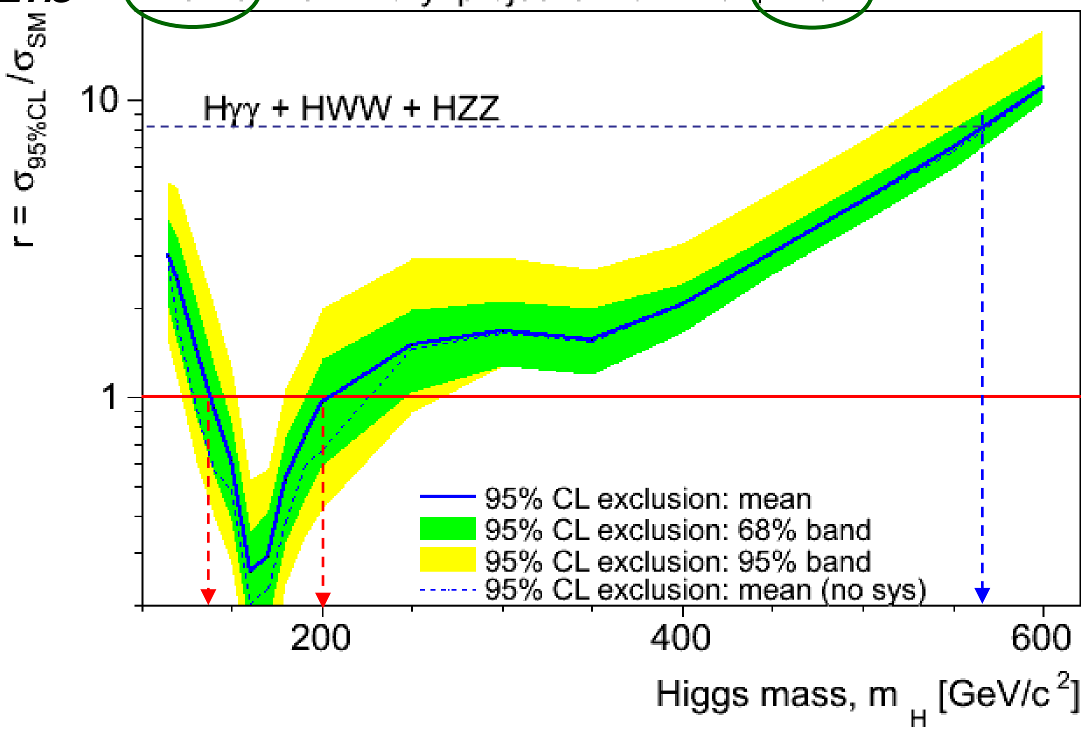
- Scaling of 10 TeV results to 7 TeV by using parton luminosities ratio.

- This simple scaling has been validated with fill simulation and found to be appropriate for the reach studies



Standard Model Higgs: Combined

1fb⁻¹

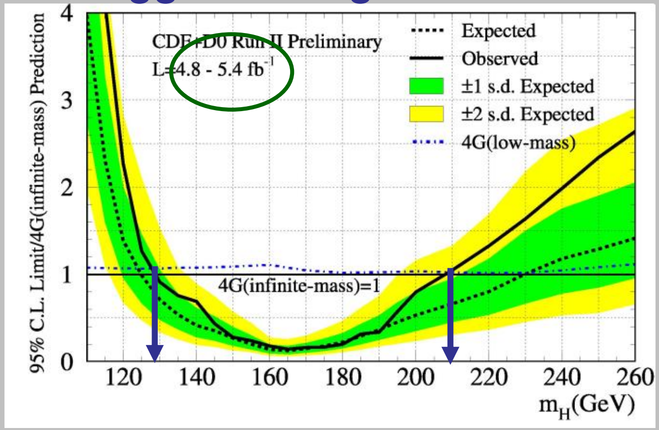


SM Higgs expected excluded range approx: **140-200 GeV**
discovery range approx: **160-170 GeV**

4th generation: gg→H goes up by factor of 9:
SM Higgs with 4 generations, exclusion: **<570 GeV**

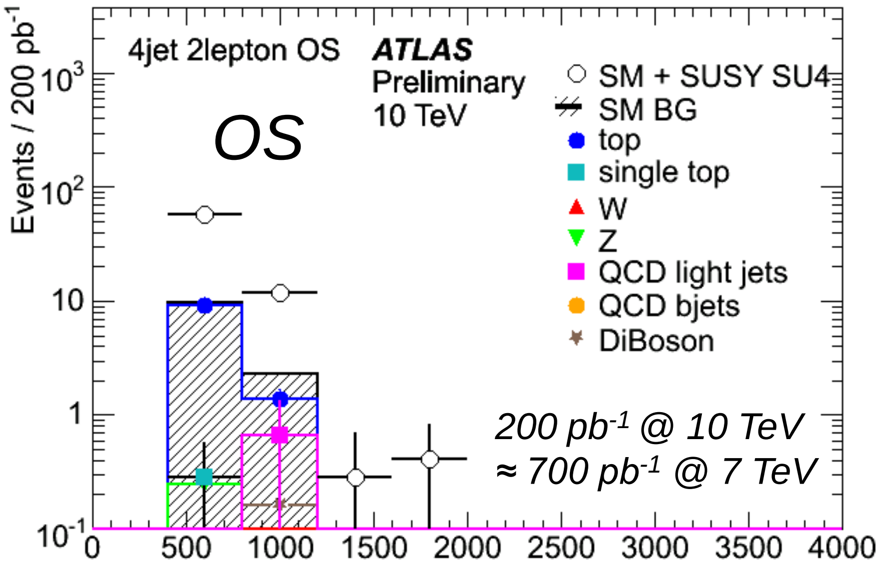
TEVATRON Today

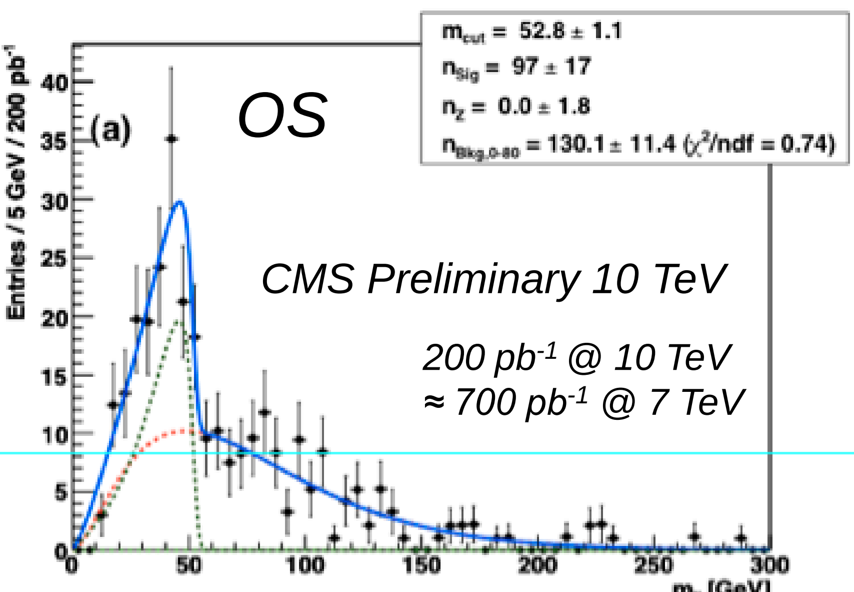
Higgs with 4 generations

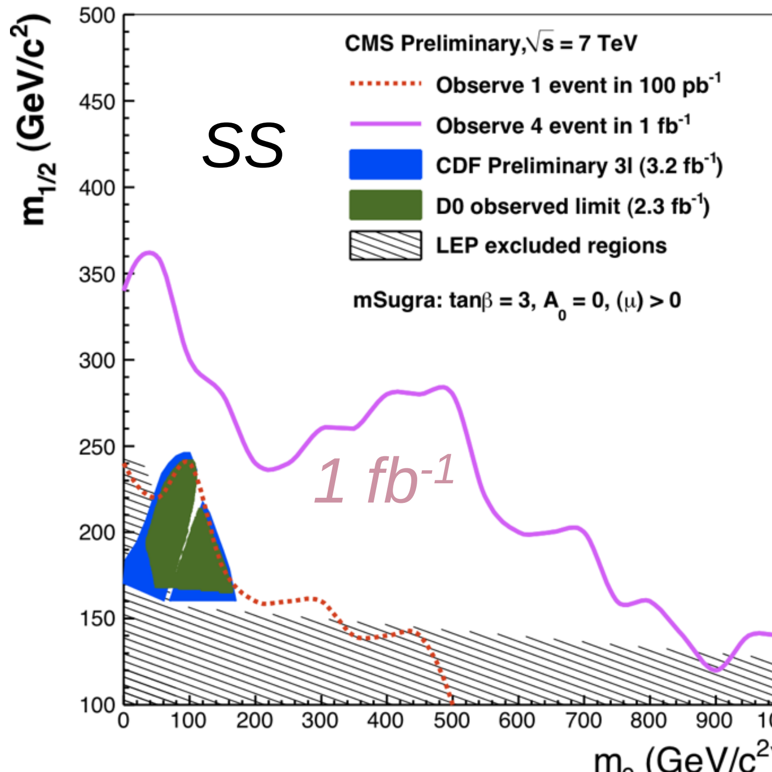


Tevatron exclusion today: [130 to 210]

Di-leptons E_T^{miss} Signature



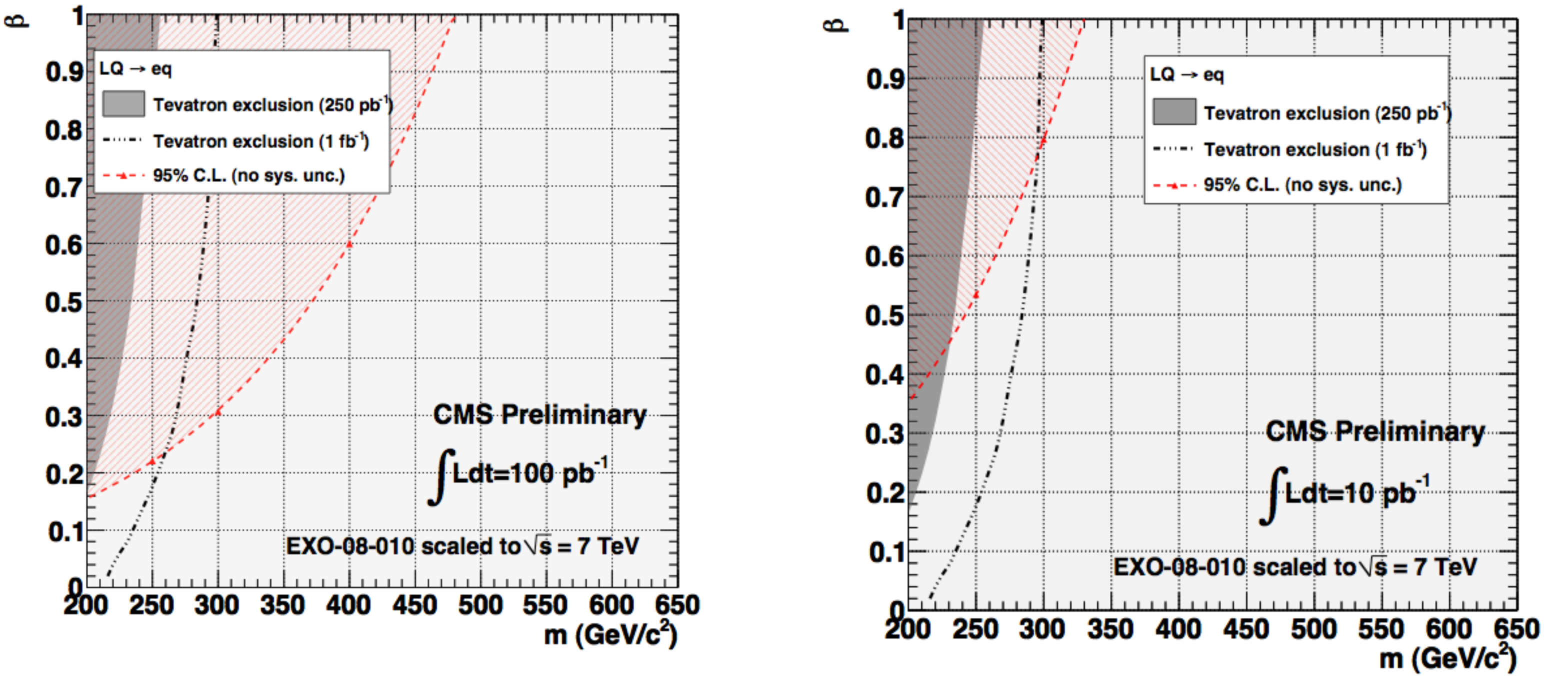




- *95% CL for same-sign di-lepton search (ee, eμ and μμ channels)*
- *Systematic uncertainty of 50% assumed on Standard Model background*
- *Sensitivity beyond previous experiments*

First Generation LQ's

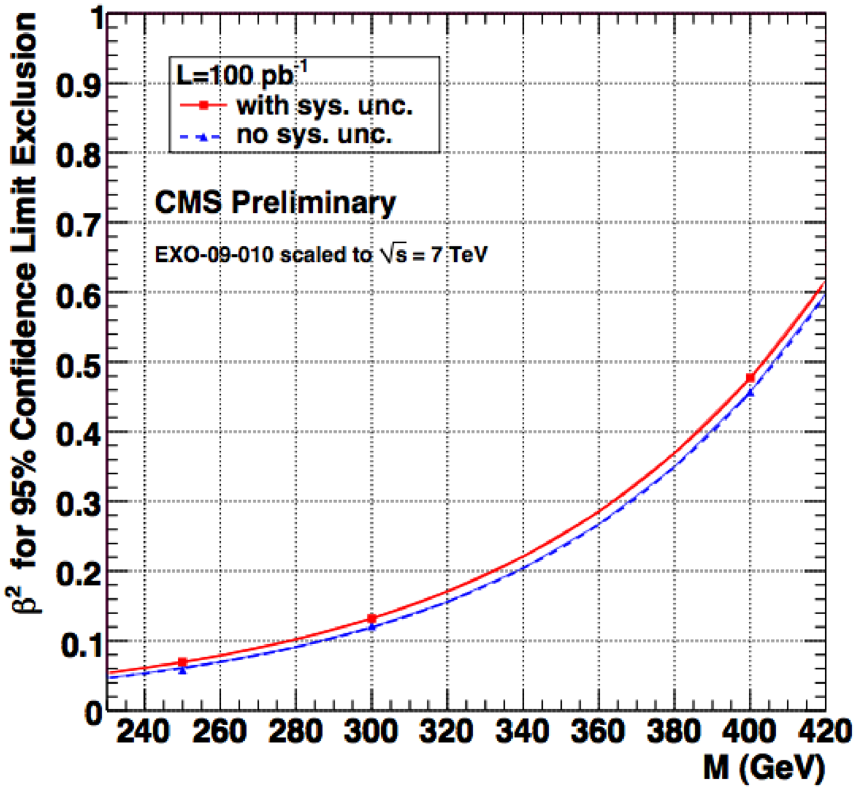
- Leptoquarks are predicted in many GUT models
- Strongly produced in pairs at the LHC
  - Significant reach beyond the Tevatron with as little as ~10 pb^{-1}
- This final state is also sensitive to diquarks $D \to 2j + \ell^+\ell^-$

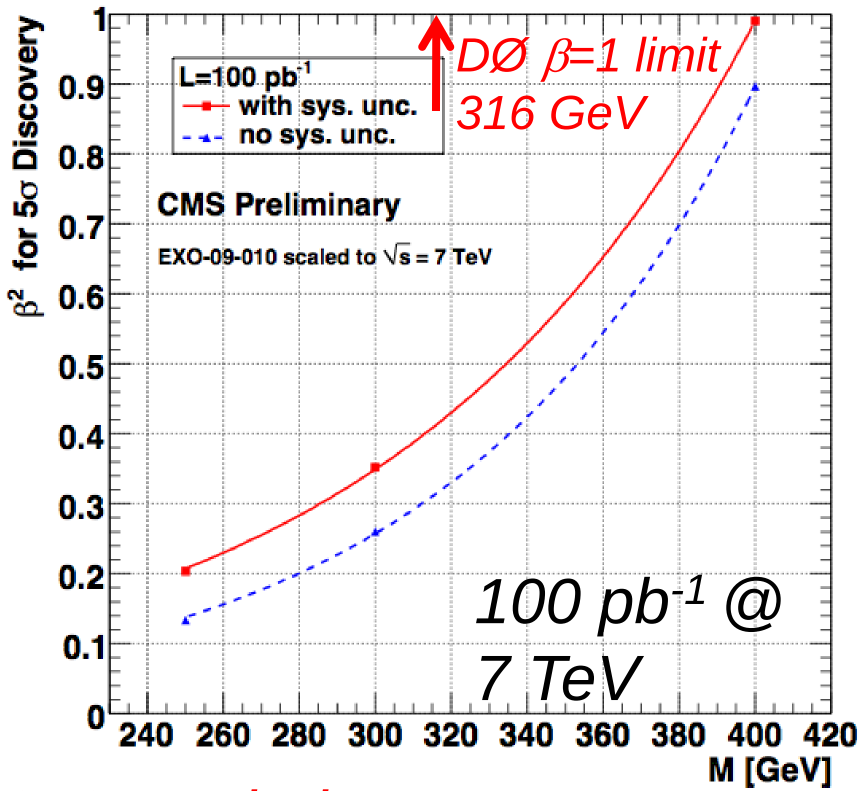


CMS PAS EXO-08-010, scaled to 7 TeV

Second Generation LQ's

- Similar situation to LQ1
  - Sensitivity beyond the Tevatron with ~10 pb^{-1}
- Effort to expand analyses to include eνjj/μνjj modes





CMS PAS EXO-09-010, scaled to 7 TeV

Sources of Material

ATLAS

- https://twiki.cern.ch/twiki/bin/view/Atlas/AtlasResultsEcmDependence
- Private communication

CMS

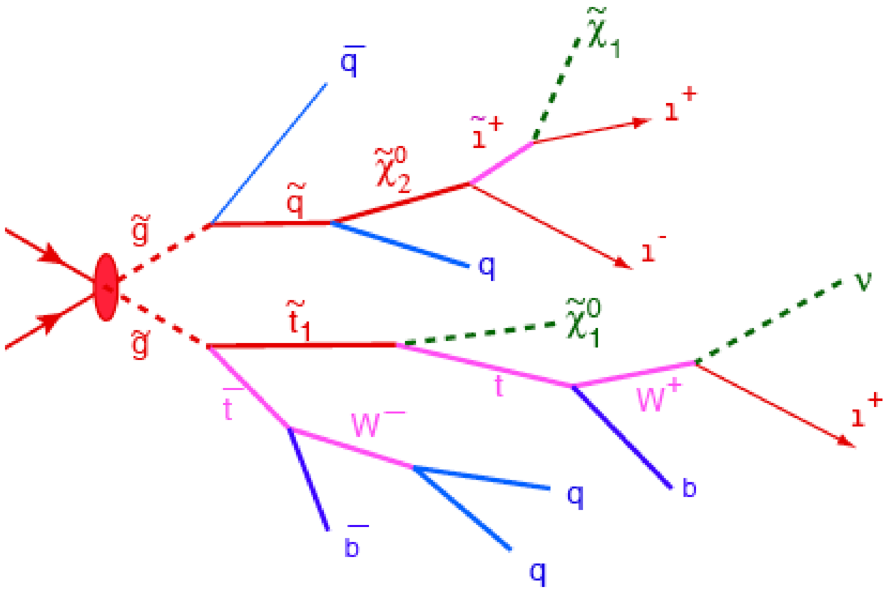
- http://cms.cern.ch/iCMS/jsp/openfile.jsp?type=NOTE&year=2010&files=NOTE2010_008.pdf
- Private communication

What do we call a “SUSY search”?

The definition is purely derived from the experimental signature.

Therefore, a “SUSY search signature” is characterized by

Lots of missing energy, many jets, and possibly leptons in the final state



Missing Energy:
- *from LSP*

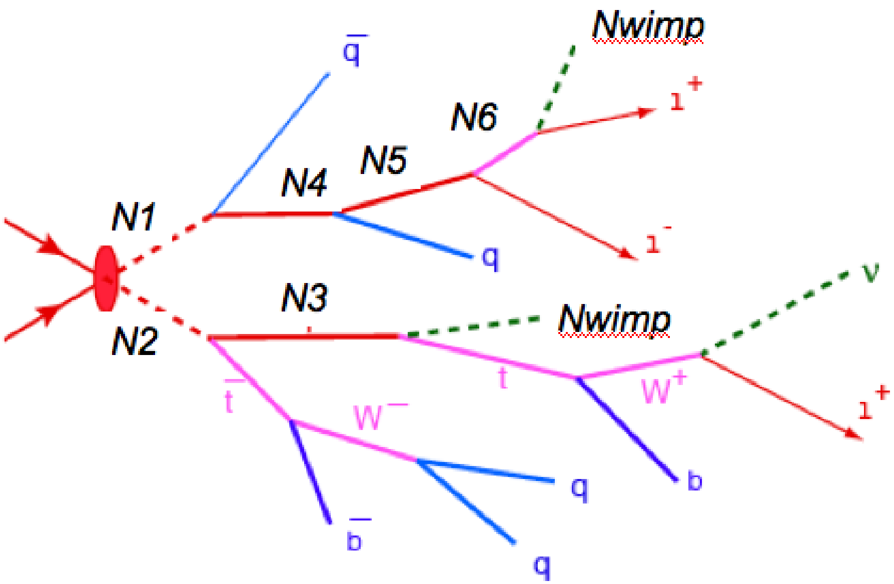
Multi-Jet:
- *from cascade decay (gaugino)*

Multi-Leptons/photons:
- *from decay of charginos/neutralios*

RP-Conserving SUSY is a very prominent example predicting this famous signature but …

What is its experimental signature?

… by no means is it the only New Physics model predicting this experimental pattern. Many other NP models predict this genuine signature



Missing Energy:
• *Nwimp - end of the cascade*

Multi-Jet:
• *from decay of the Ns (possibly via heavy SM particles like top, W/Z)*

Multi-Leptons/photons:
• *from decay of the N's*

SUSY, however, is a convenient tool to characterize this important search topology. One could also call it a "Dark Matter Candidate" search.