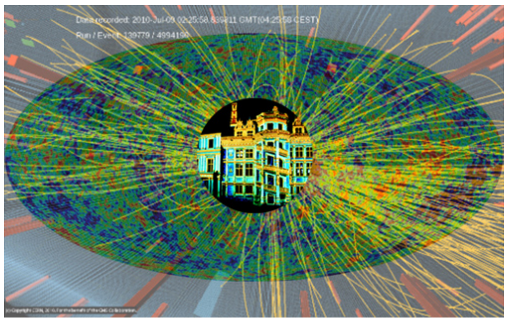
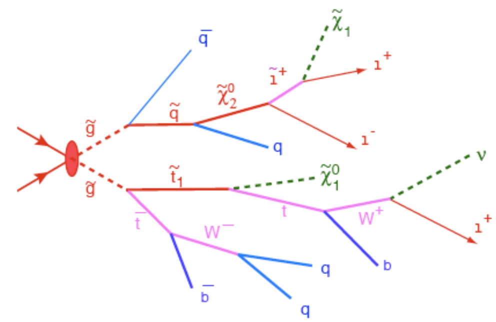
Searches for SUperSYmmetry



Oliver Buchmüller
(Imperial College London)

23rd Rencontres de Blois

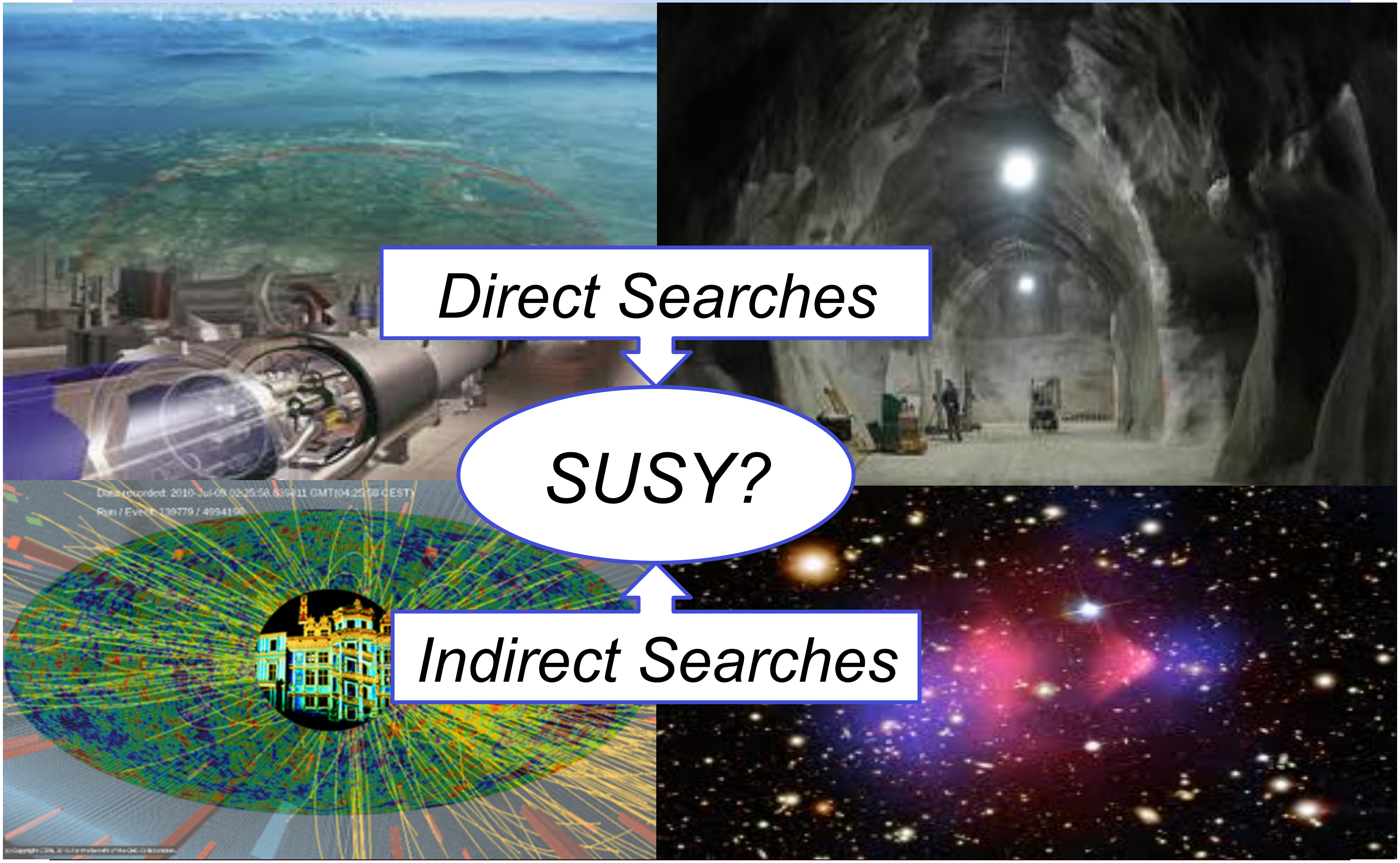


- *Landscape of SUSY searches*
- *SUSY searches at ATLAS and CMS*
- *Putting it all together – where are we today?*

31 May 2011

Imperial College London

Searches for SUSY



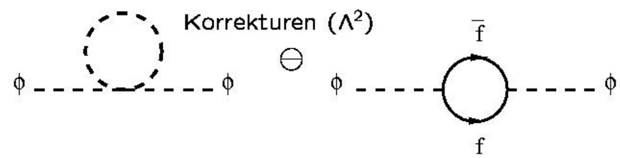
Searches for SUSY

Why is SUSY so Attractive?

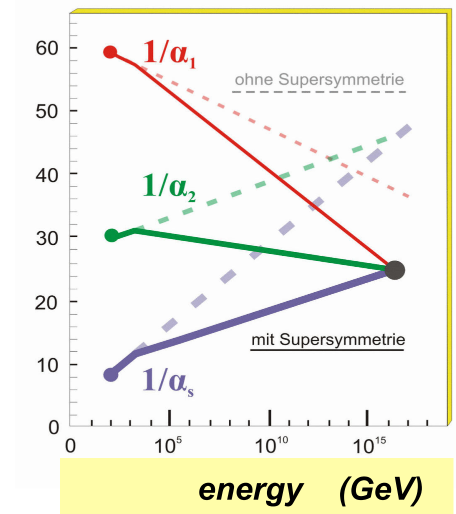
$m_{SUSY} \sim 1$ TeV

1. *Quadratically divergent quantum corrections to the Higgs boson mass are avoided*

$$\Delta m_H = f(m_B^2 - m_f^2)$$



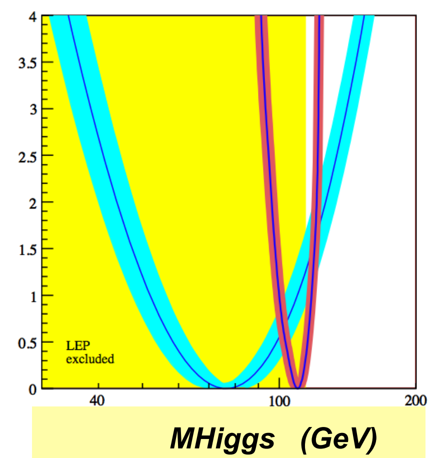
(Hierarchy or naturalness problem)



2. *Unification of coupling constants of the three interactions seems possible*

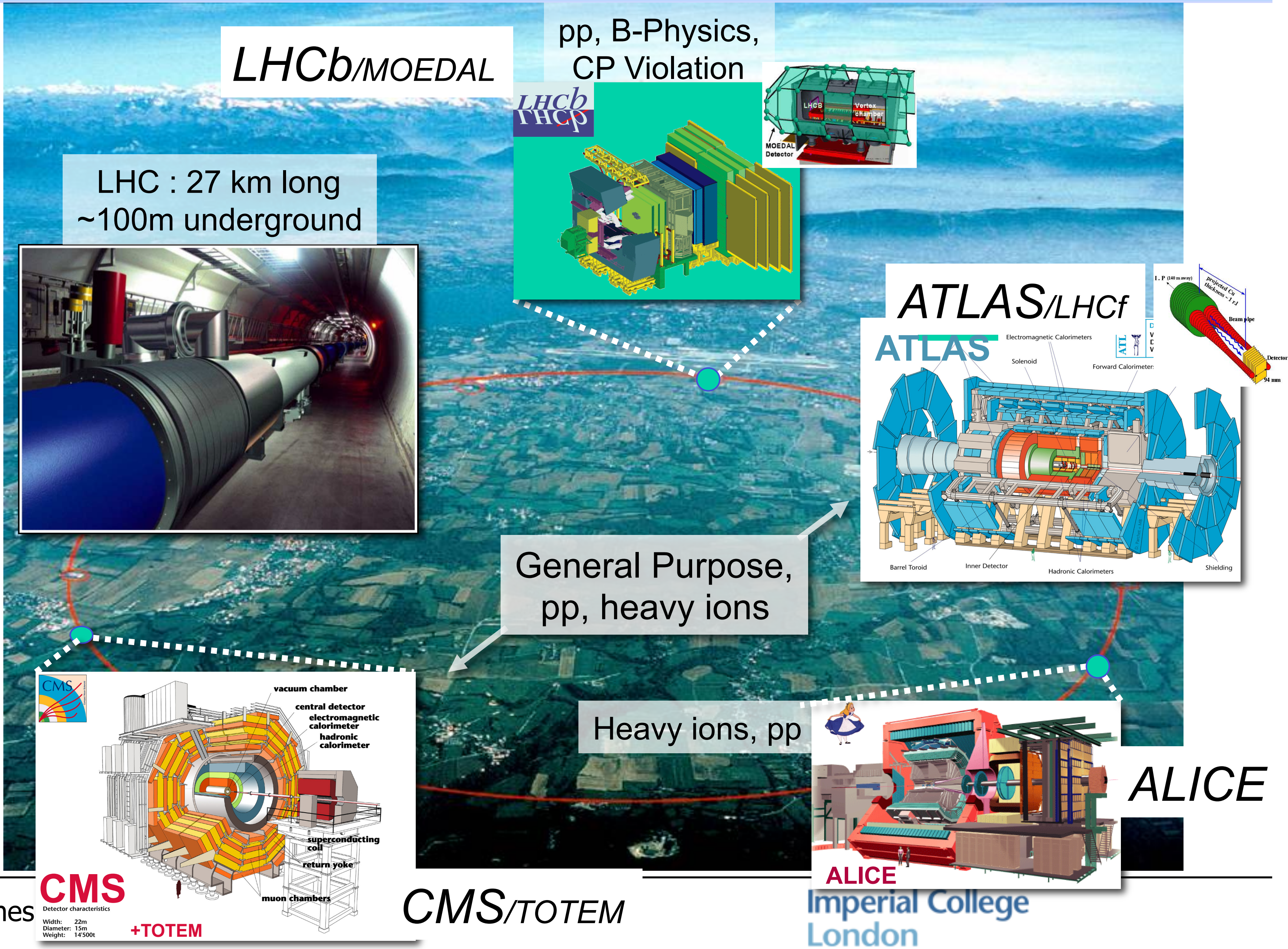
3. *SUSY provides a candidate for dark matter,*

The lightest SUSY particle (LSP)



4. *A SUSY extension is a small perturbation, consistent with the electroweak precision data*

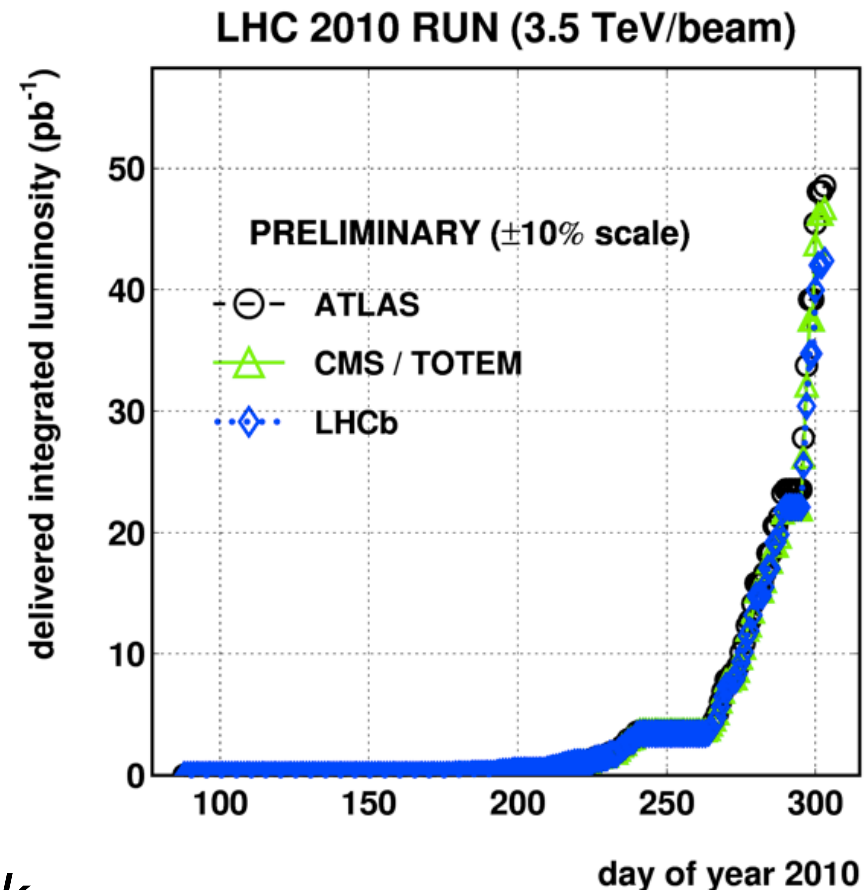
The Large Hadron Collider at CERN



LHC: Run Year 2010

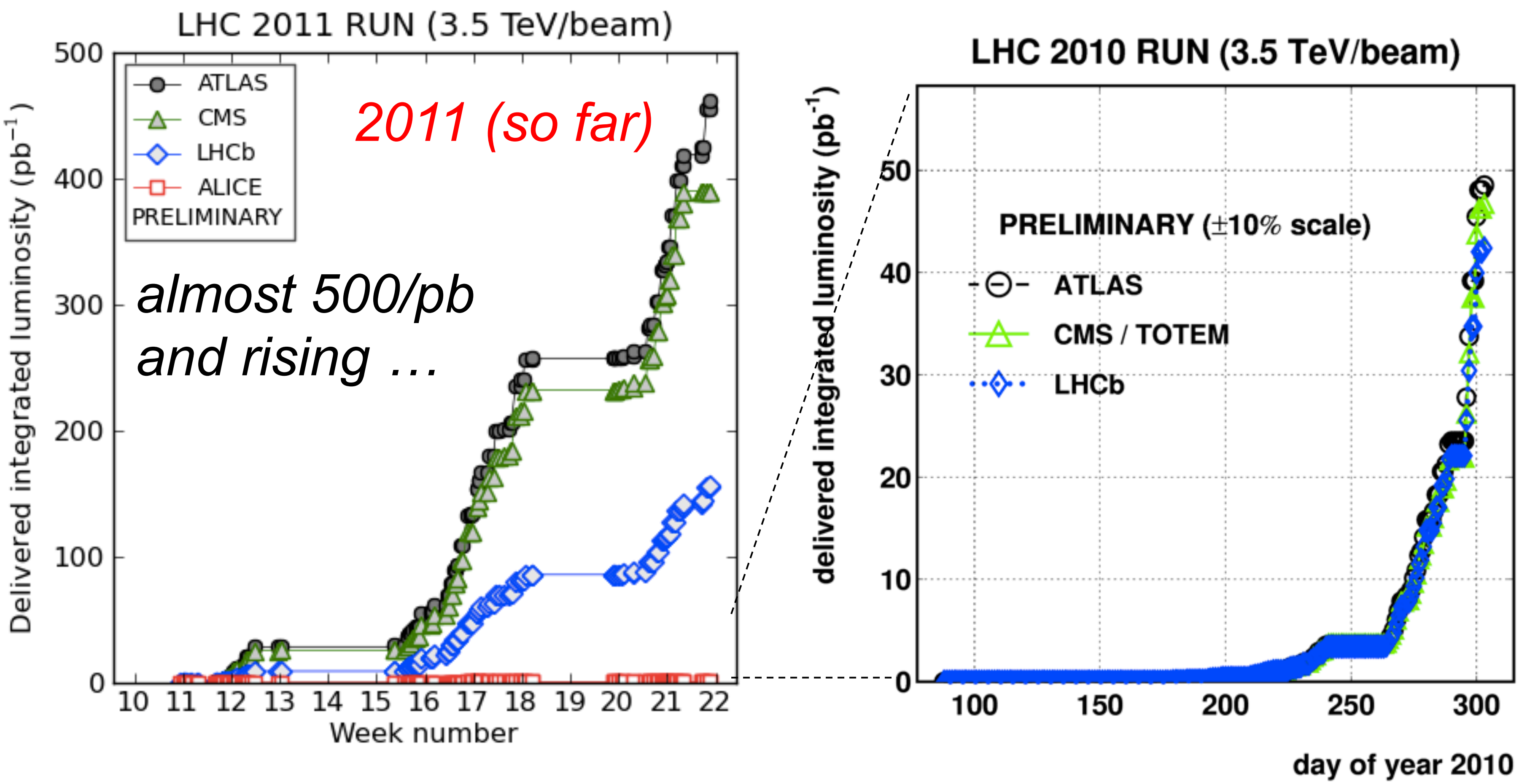
Almost 50/pb delivered
Data taking efficiency
>90% for the experiments

A Very Good Start!



Note:
All LHC results show in this talk are based on the 2010 data set.

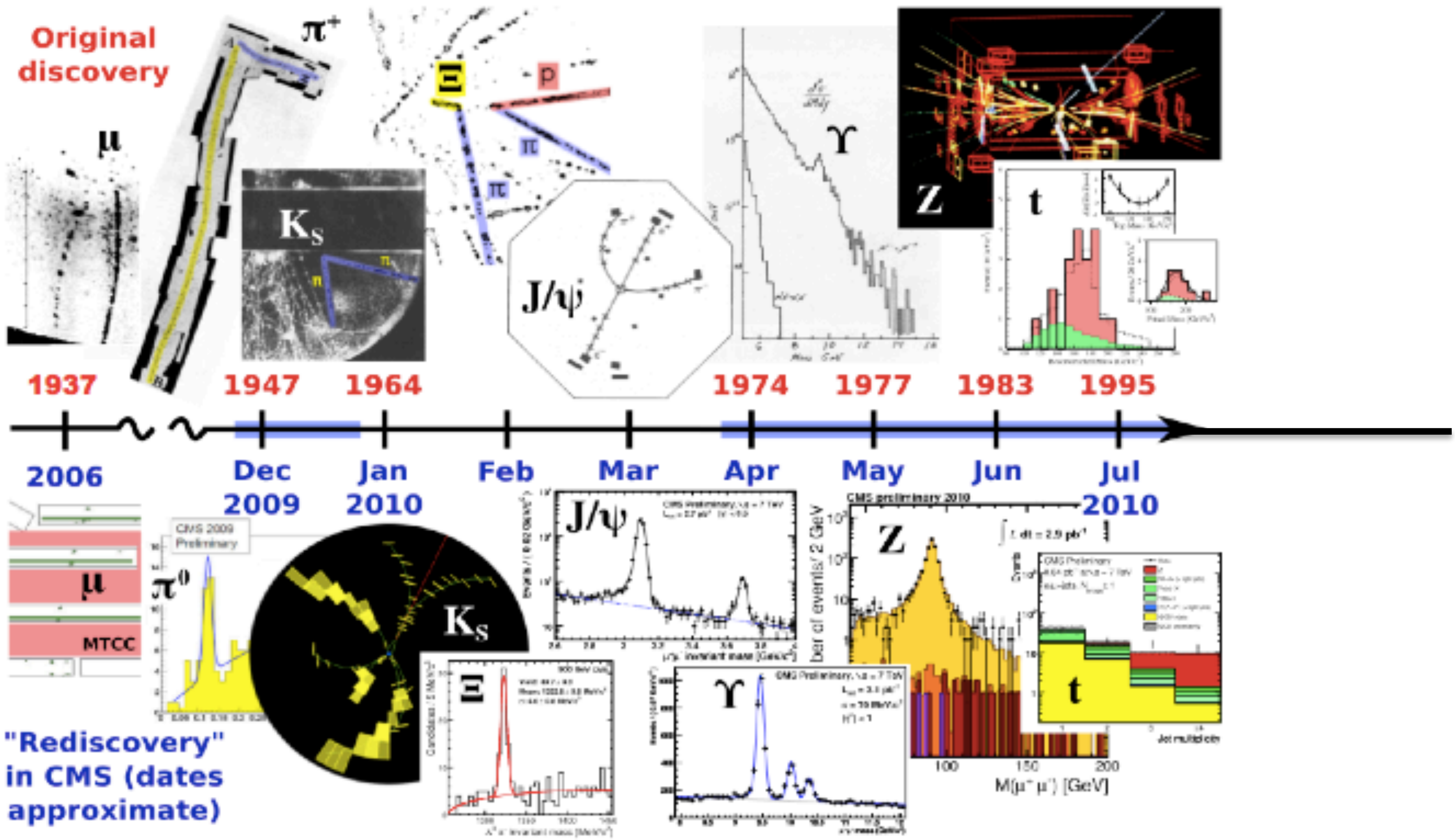
2011 Run Year – So Far



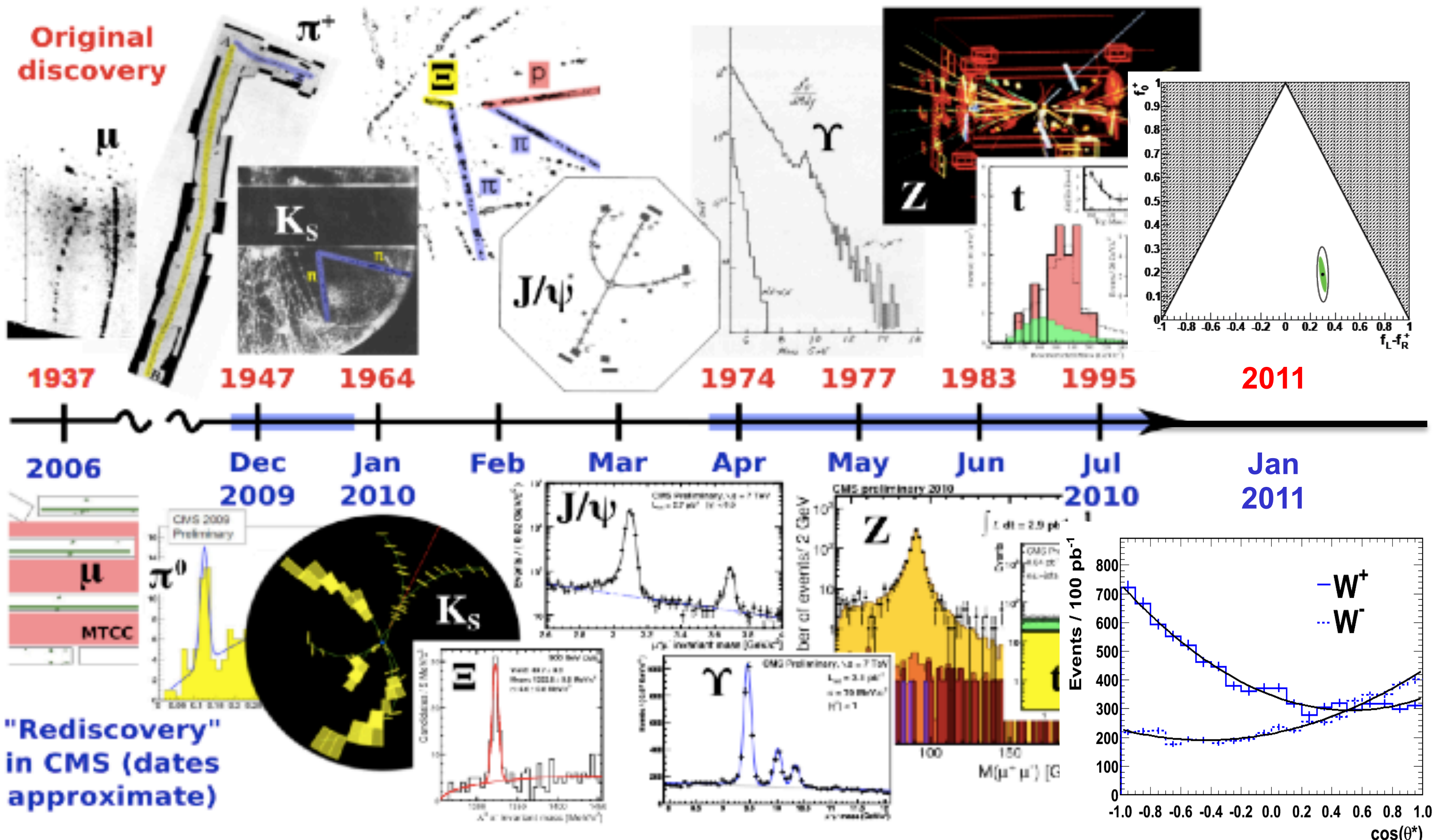
Early Searches at the LHC

- Step1: commissioning of machine and detectors of unprecedented complexity, technology and performance
- 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.
- Step3: perform the search

Re-Discovery of the Standard Model



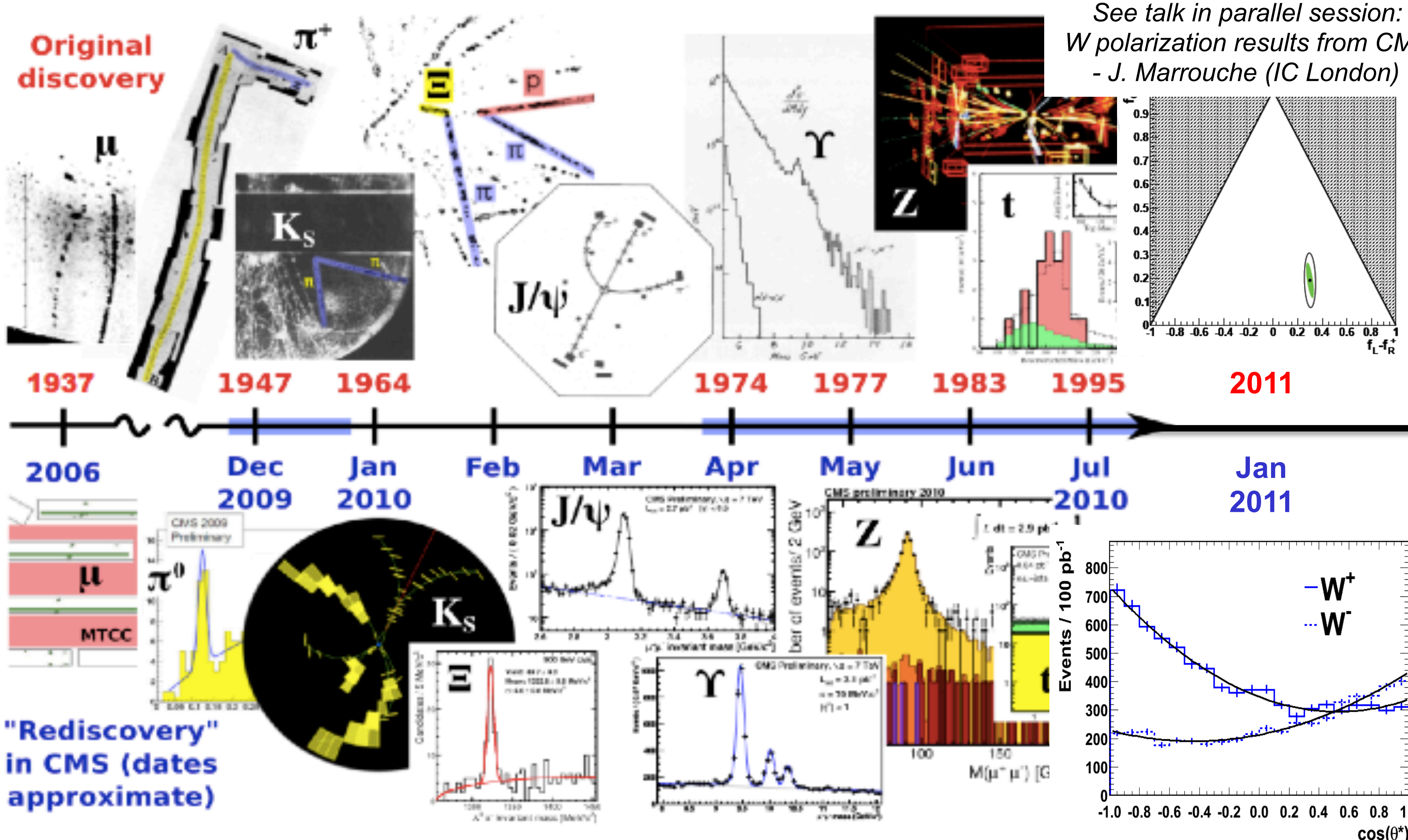
Re-Discovery of the Standard Model



W are mainly produced Left-handed in pp

Re-Discovery of the Standard Model

See talk in parallel session:
W polarization results from CMS
- J. Marrouche (IC London)



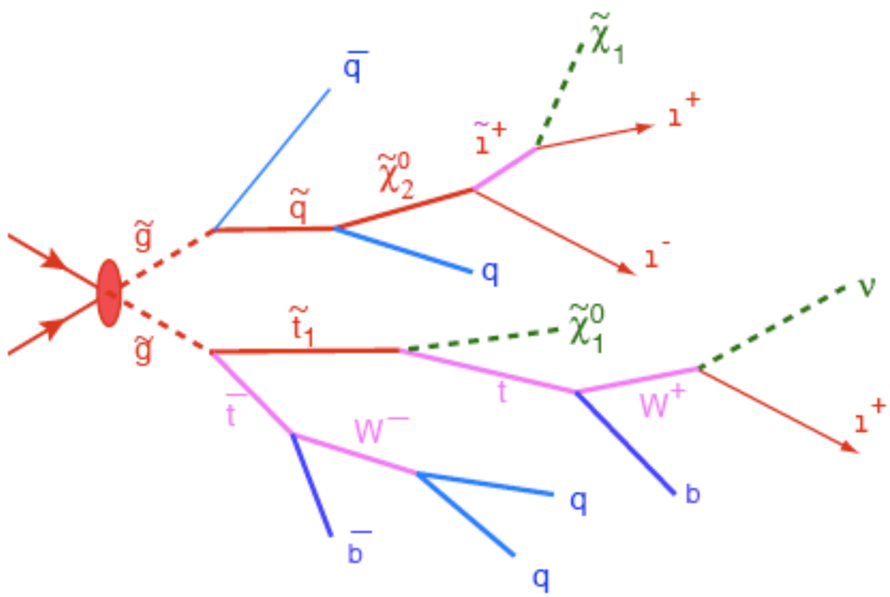
W are mainly produced
Left-handed in pp

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*

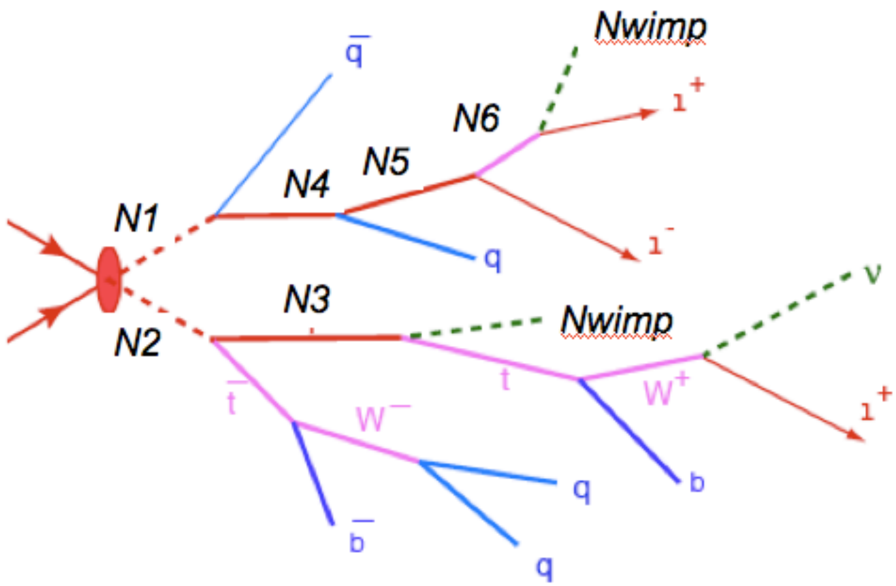
Multi-Jet:
- *from cascade decay (gaugino)*

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

Model examples are Extra dimensions, Little Higgs, Technicolour, etc but a more generic definition for this signature is as follows.

Search strategy

0-leptons	1-lepton	OSDL	SSDL	≥3 leptons	2-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

Search strategy

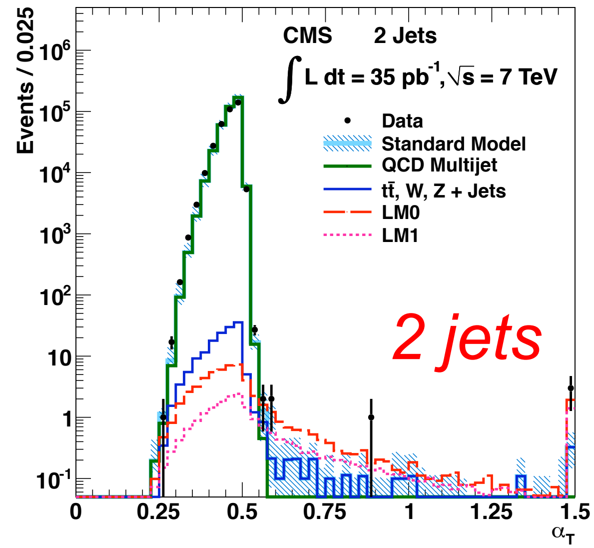
0-leptons	1-lepton	OSDL	SSDL	≥3 leptons	2-photons	γ+lepton
Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton	Di-photon + jet + MET	Photon + lepton + MET

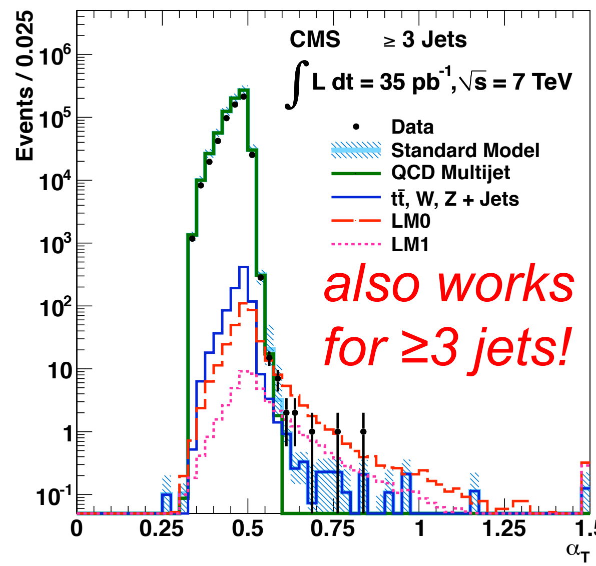
- Very challenging due to large amount and wide range of backgrounds
- However most sensitive search for strongly produced SUSY
- CMS pursues several complementary strategies based on kinematics and detector understanding
- Extend to b, τ and top-tagged final states

First SUSY Search of the LHC

The "QCD killer" $a_T = \frac{E_{T\,j2}}{M_{T\,j1j2}} = \frac{\sqrt{E_{T\,j2}/E_{T\,j1}}}{\sqrt{2(1-\cos\Delta\varphi)}} \leq 0.5$

- Event selection:
  - Require >=2 jets with p_T>50 GeV
  - *leading 2 jets with p_T > 100 GeV*
  - Scalar sum of jet p_T, H_T > 350 GeV
  - Explicit veto on
    - isolated el/mu with p_T>10 GeV
    - photons with p_T > 25 GeV
  - α_T > 0.55
- QCD multijet events eliminated

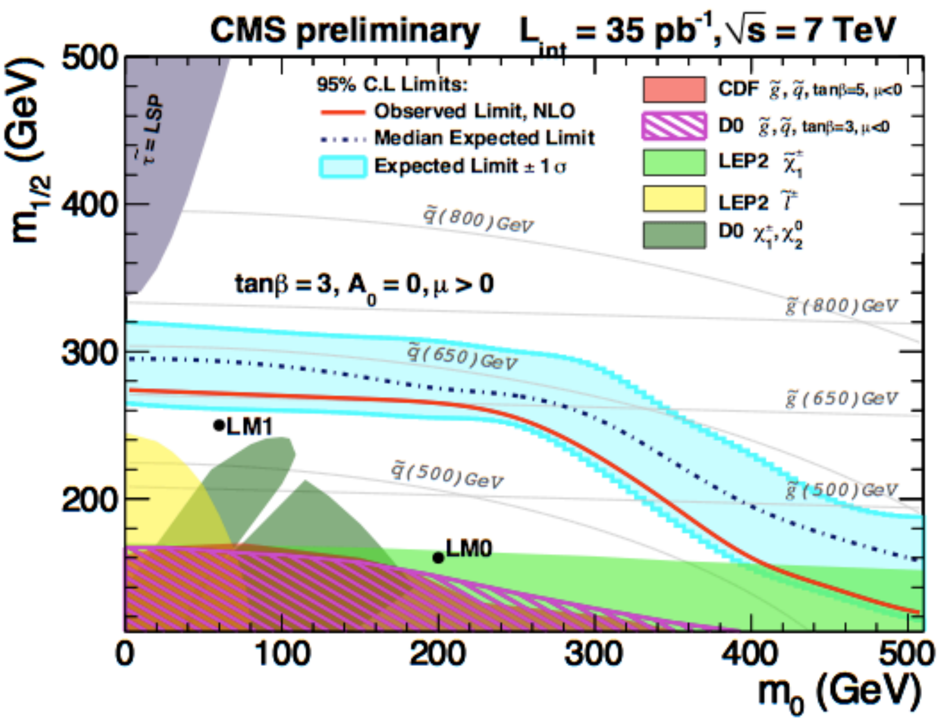


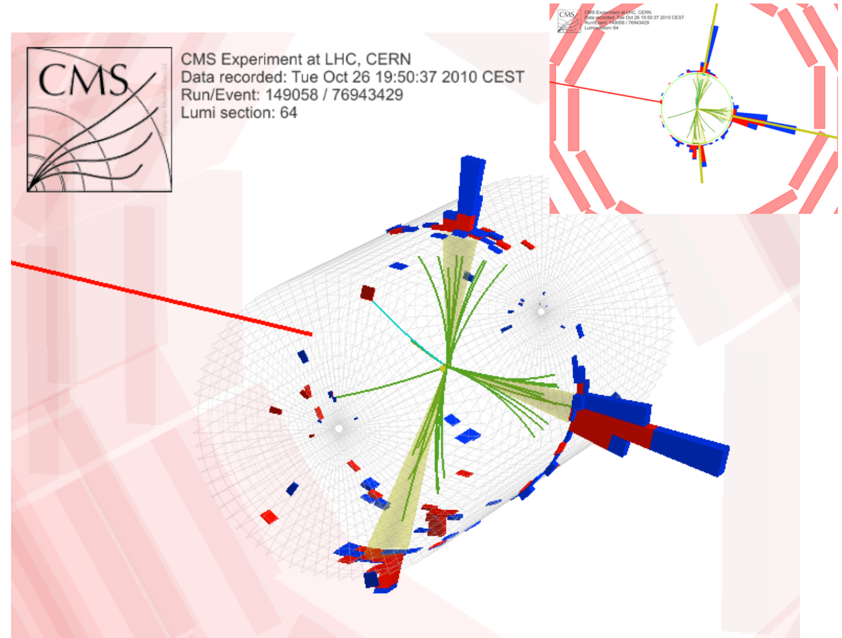


Selection	Data	SM	QCD multijet	$Z \to \nu\bar{\nu}$	W + jets	$t\bar{t}$
$H_T > 250$ GeV	4.68M	5.81M	5.81M	290	2.0k	2.5k
$E_T^{j2} > 100$ GeV	2.89M	3.40M	3.40M	160	610	830
$H_T > 350$ GeV	908k	1.11M	1.11M	80	280	650
$\alpha_T > 0.55$	37	30.5±4.7	19.5±4.6	4.2±0.6	3.9±0.7	2.8±0.1
$\Delta R_{ECAL} > 0.3 \vee \Delta\phi^* > 0.5$	32	24.5±4.2	14.3±4.1	4.2±0.6	3.6±0.6	2.4±0.1
$R_{miss} < 1.25$	13	9.3±0.9	0.03±0.02	4.1±0.6	3.3±0.6	1.8±0.1

Exclusion in the CMSSM

- CMSSM: 4 parameter model assuming common gaugino and scalar masses at GUT scale ($m_{1/2}$, m_0)
- *In absence of signal, calculate* 95% CL exclusion limit using Feldman-Cousins
- *tanβ independent exclusion*
- *Exclude squark and gluino masses of ~550-650 GeV in CMSSM*



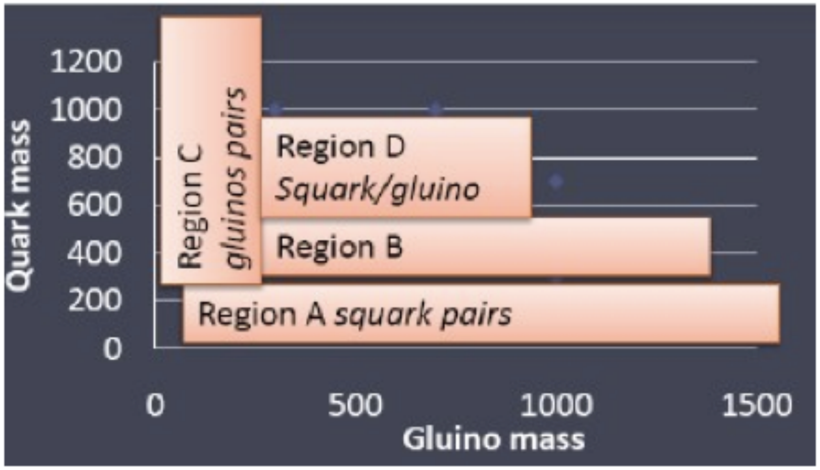


- Selection efficiency approximately production-process independent

Production mechanism	Yields for 35 pb^{-1}	ϵ_{total}(%)	$\epsilon_{signature}$(%)
$\tilde{q}\,\tilde{q}$	9.7±0.1	16.0±0.1	22.2±0.4
$\tilde{q}\,\tilde{g}$	8.8±0.1	14.4±0.1	23.0±0.5
$\tilde{g}\,\tilde{g}$	0.71±0.02	12.0±0.4	22.5±2.0

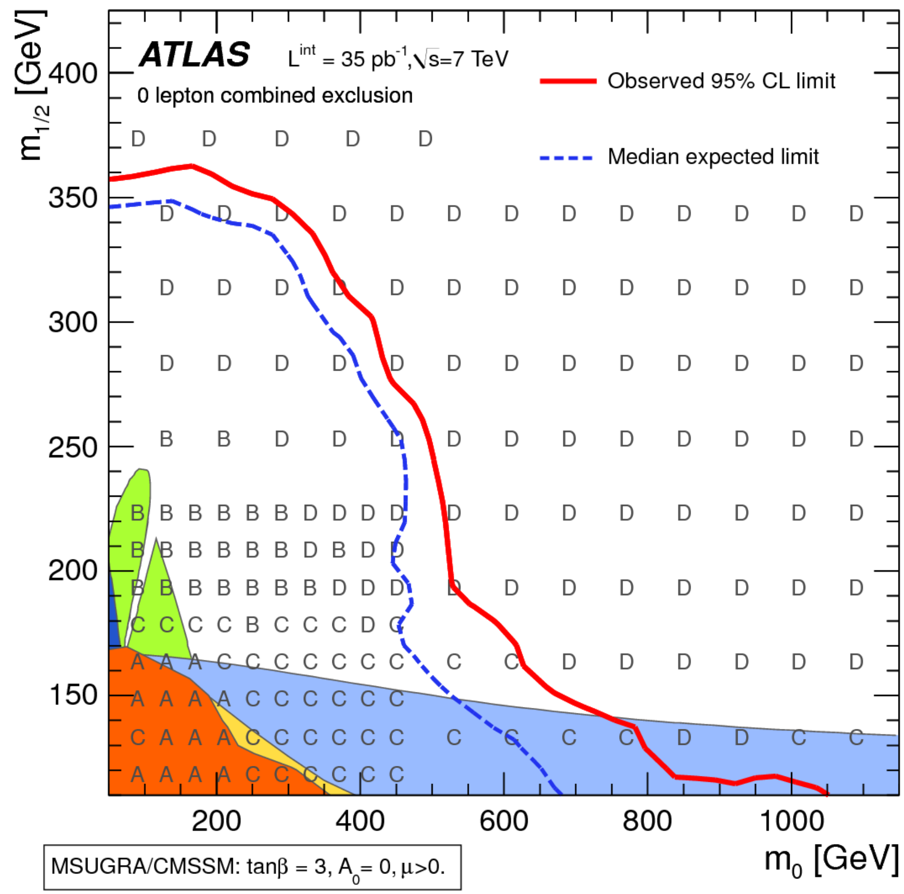
- *12% uncertainty on signal efficiency, dominated by 11% luminosity uncertaint*

ATLAS: Jets+E_T^{mis}



		A	B	C	D
Pre-selection	Number of required jets	≥ 2	≥ 2	≥ 3	≥ 3
	Leading jet p_T [GeV]	> 120	> 120	> 120	> 120
	Other jet(s) p_T [GeV]	> 40	> 40	> 40	> 40
	E_T^{miss} [GeV]	> 100	> 100	> 100	> 100
Final selection	$\Delta\phi(\text{jet}, \vec{P}_T^{miss})_{min}$	> 0.4	> 0.4	> 0.4	> 0.4
	E_T^{miss}/m_{eff}	> 0.3	–	> 0.25	> 0.25
	m_{eff} [GeV]	> 500	–	> 500	> 1000
	m_{T2} [GeV]	–	> 300	–	–

Define search in categories to cover different signatures and to improve sensitivity (e.g. in CMSSM).



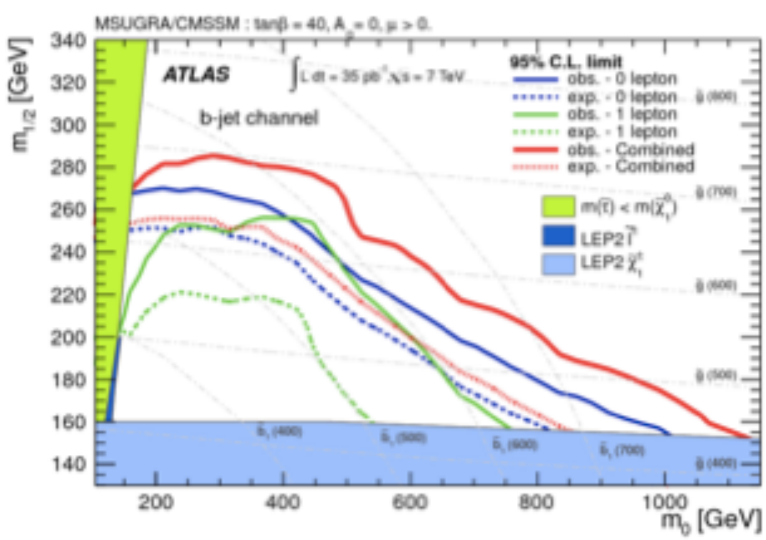
Jets+E_T^{mis} (plus b's)

$\geq$ 3 jets, with at least 1 btag
Two analyses: with/without 1 lepton

MET & HT define the signal region

estimated bkg

	0-lepton	1-lepton Monte Carlo	1-lepton data-driven
$t\bar{t}$ and single top	12.2 ± 5.0	12.3 ± 4.0	14.7 ± 3.7
W and Z	6.0 ± 2.0	0.8 ± 0.4	-
QCD	1.4 ± 1.0	0.4 ± 0.4	$0^{+0.4}_{-0.0}$
Total SM	19.6 ± 6.9	13.5 ± 4.1	14.7 ± 3.7
Data	15	9	9



$\geq$ 2 jets, with at least 1 btag

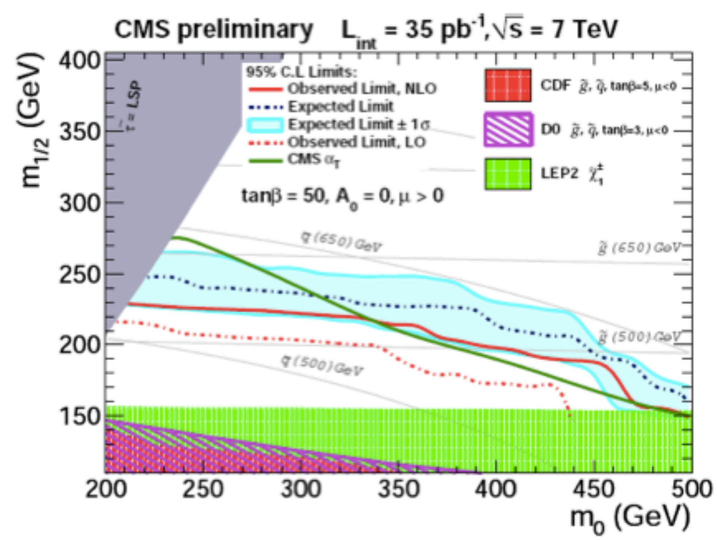
α_T & HT define the signal region

bkg from MC

N-jets	QCD	$t\bar{t}$	W	$Z \to \nu\bar{\nu}$	$Z \to l^+l^-$	total
2	0 ± 0.11	0.01 ± 0.01	0 ± 0.1	0 ± 0.09	0 ± 0.09	0.01 ± 0.21
≥ 3	0.05 ± 0.05	1.08 ± 0.07	0.10 ± 0.10	0.38 ± 0.18	0 ± 0.09	1.61 ± 0.26

bkg from data

N-jets	MC	Background Prediction	Data	LM0
≥ 2	1.61 ± 0.26	$0.33^{+0.43}_{-0.33}$ (stat) ± 0.13 (syst)	1	14.2 ± 0.3



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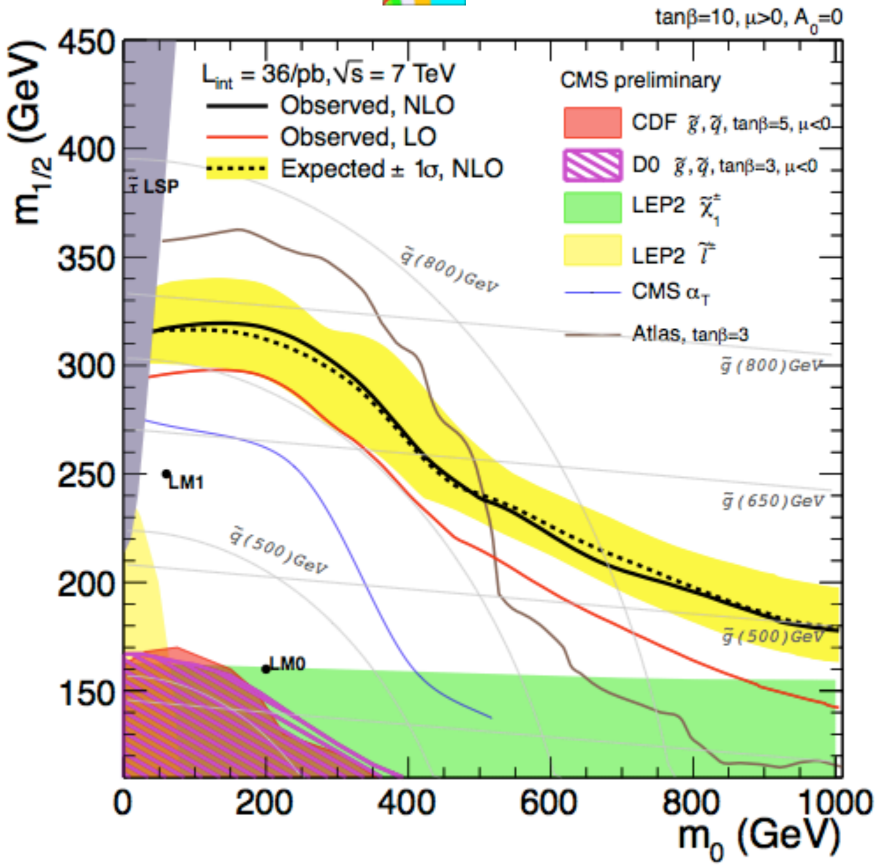
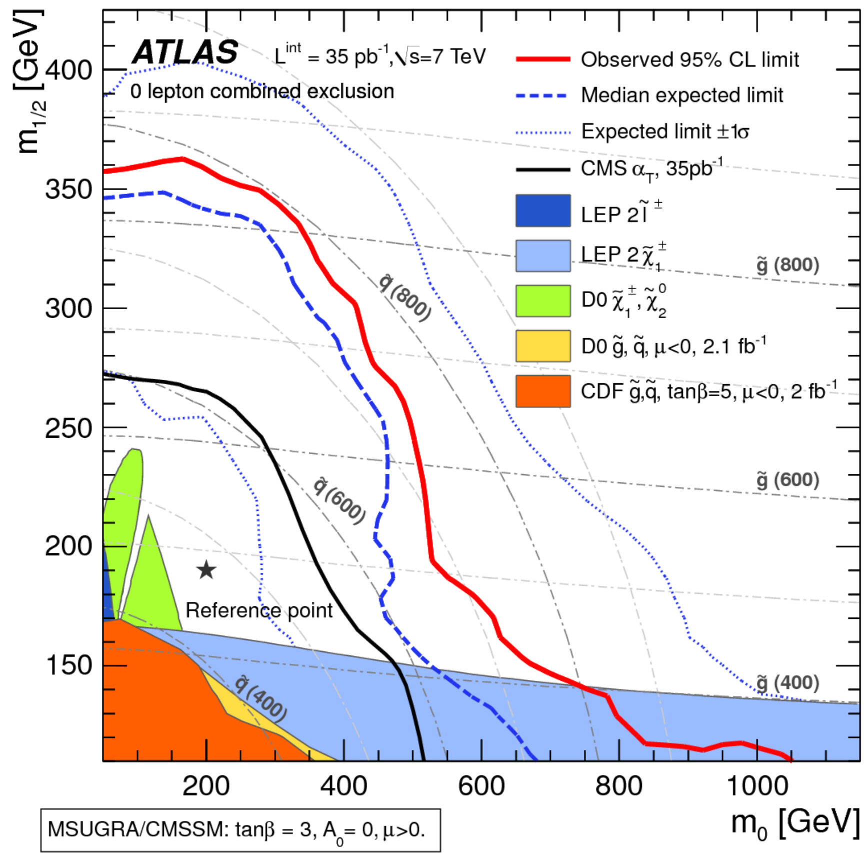
Jets+E_T^{mis}: 2010

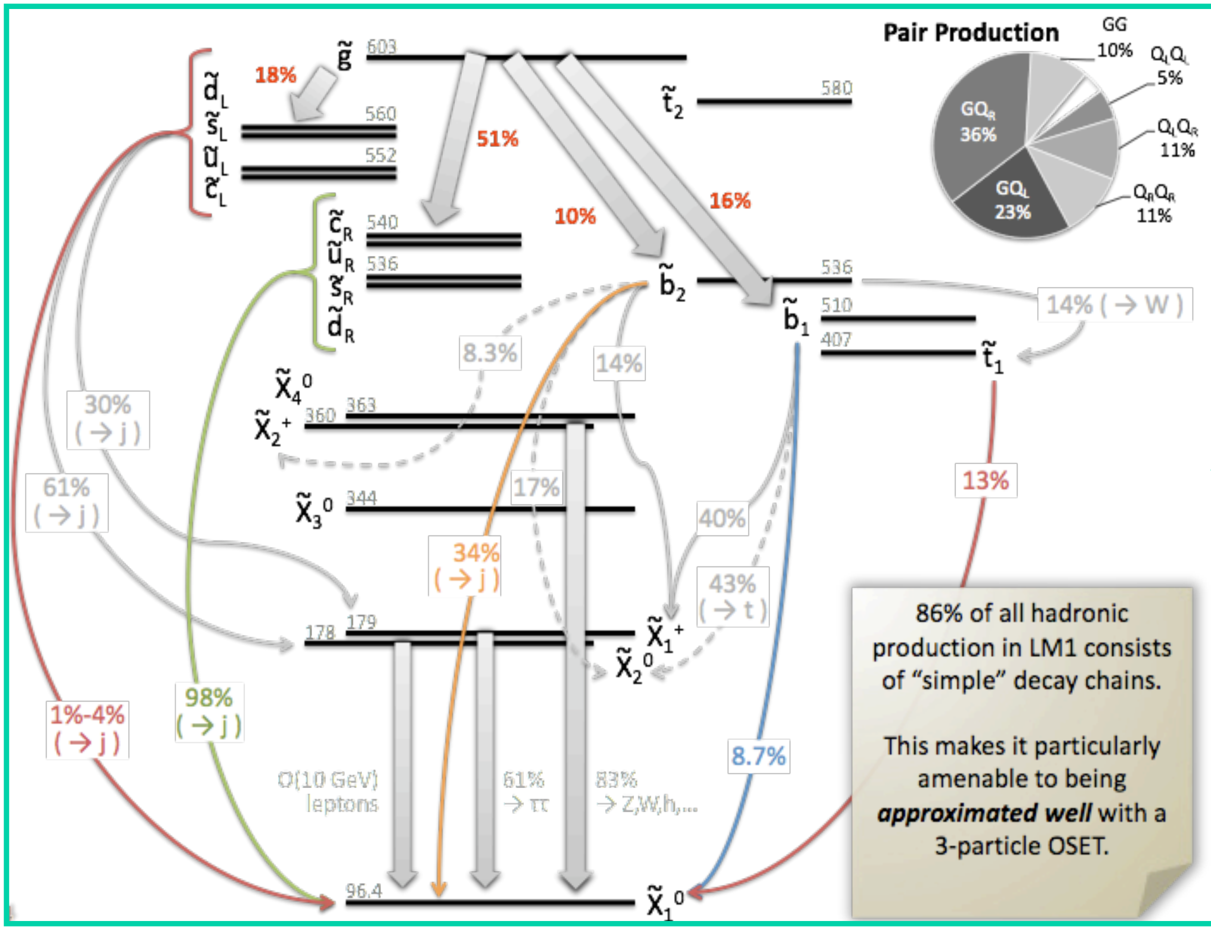


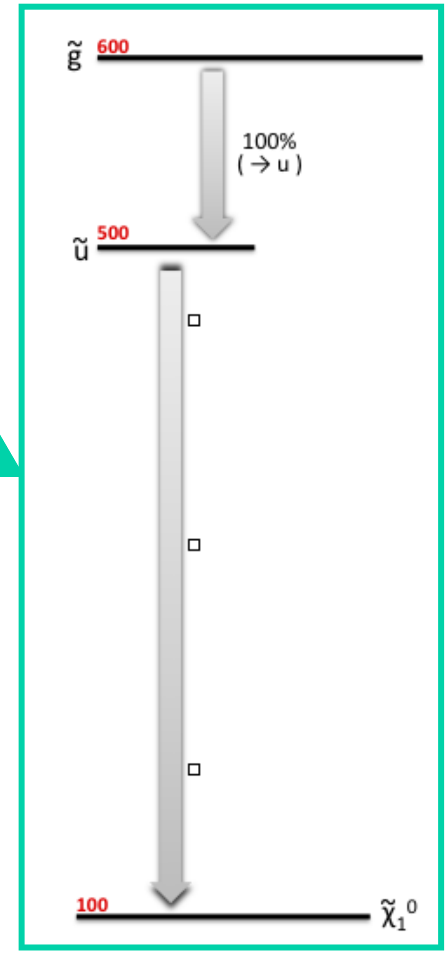


Additional Interpretation

CMSSM

What we see is much more simple…

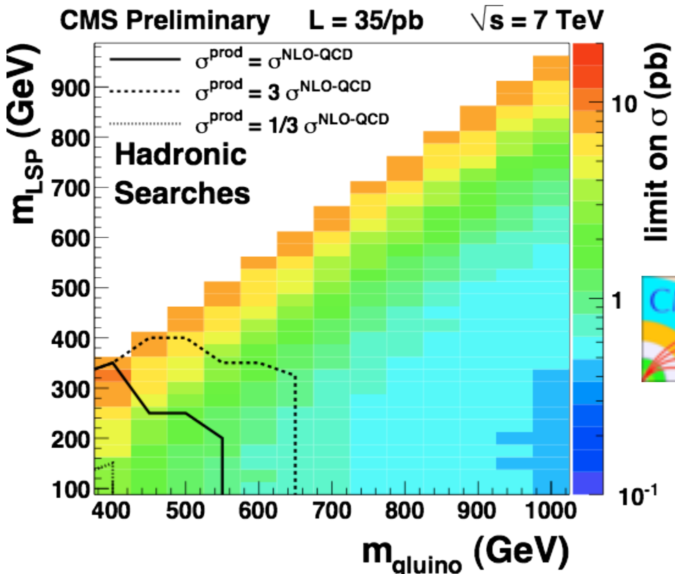


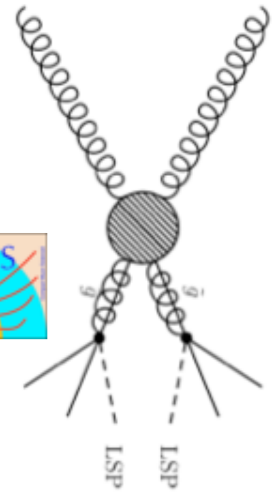


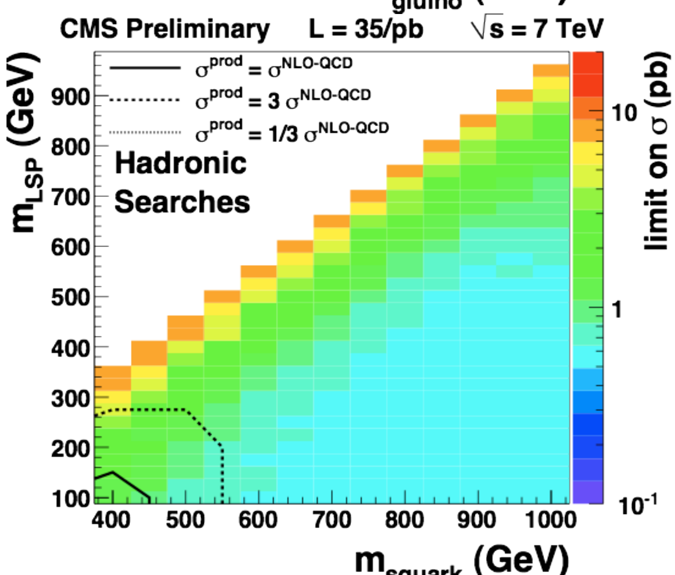
Simplified model spectrum or sms

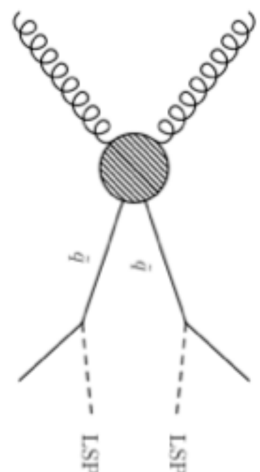
with 3 particles, 2 decay modes

Simplified Model Spectra

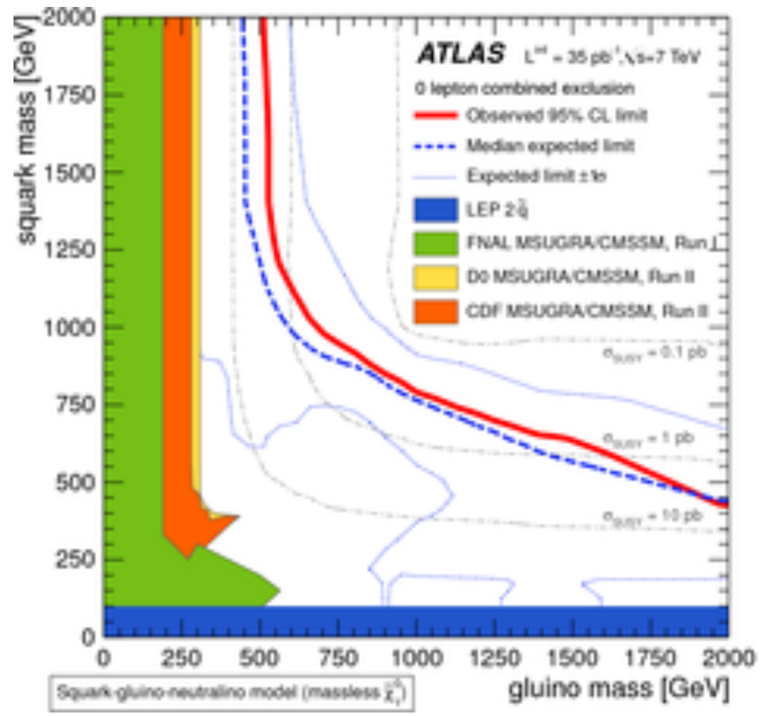








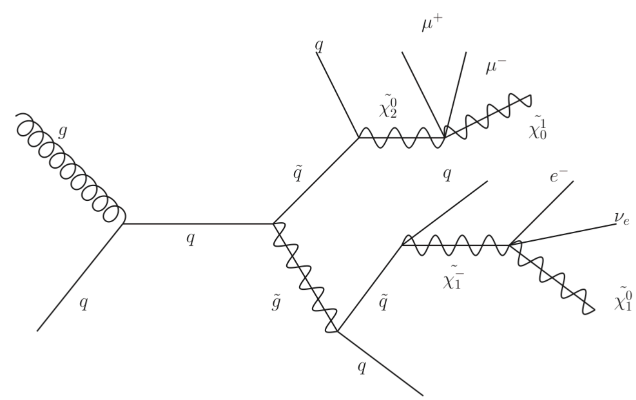
Going beyond the CMSSM



ATLAS: average squark and gluino mass in combination with mass LSP (neutralino)

Search strategy

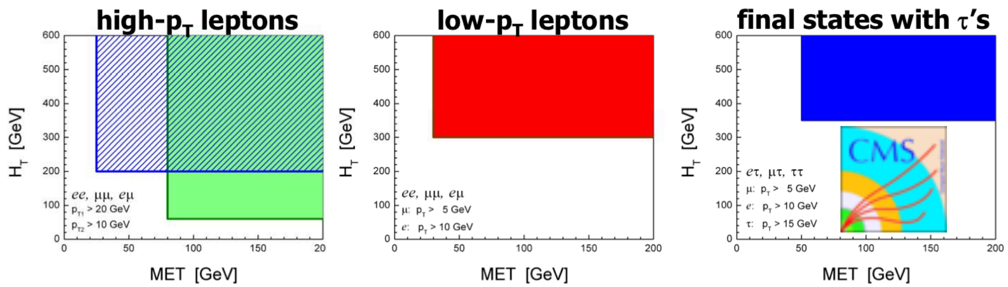
0-leptons	1-lepton	OSDL	SSDL	≥3 leptons	2-photons	γ+lepton
Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton	Di-photon + jet + MET	Photon + lepton + MET

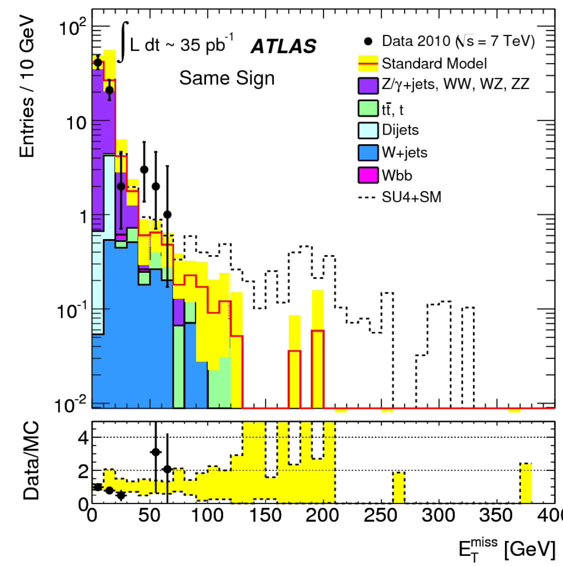


- A natural SUSY signature
- Very small Standard Model backgrounds
- Include all three generations of leptons and all cross channels

Same-sign dilepton search

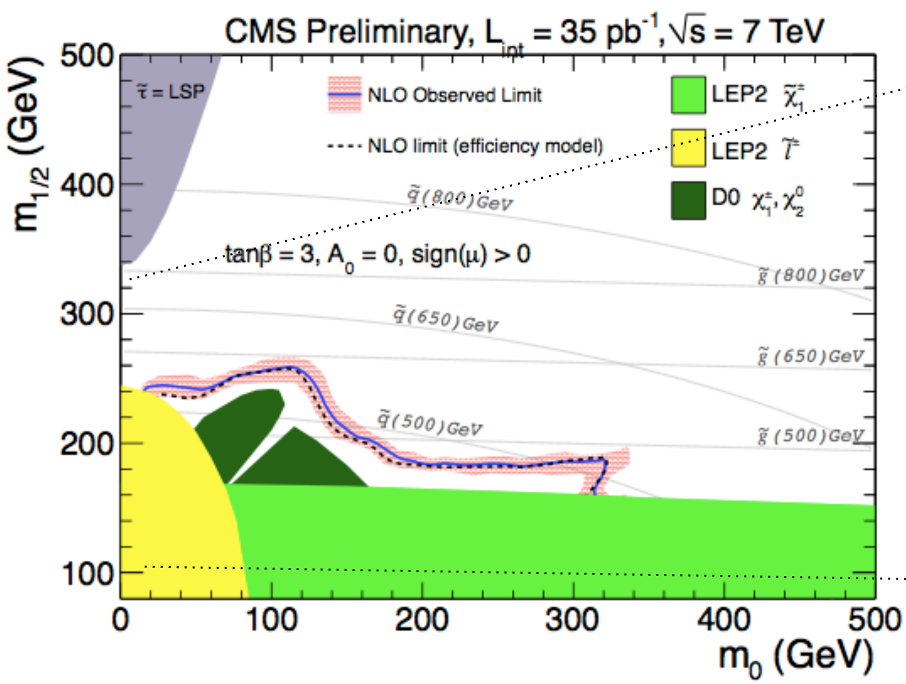
- *Isolated same-sign lepton signature essentially absent in the SM*
- *Search in all three lepton species and four search regions*

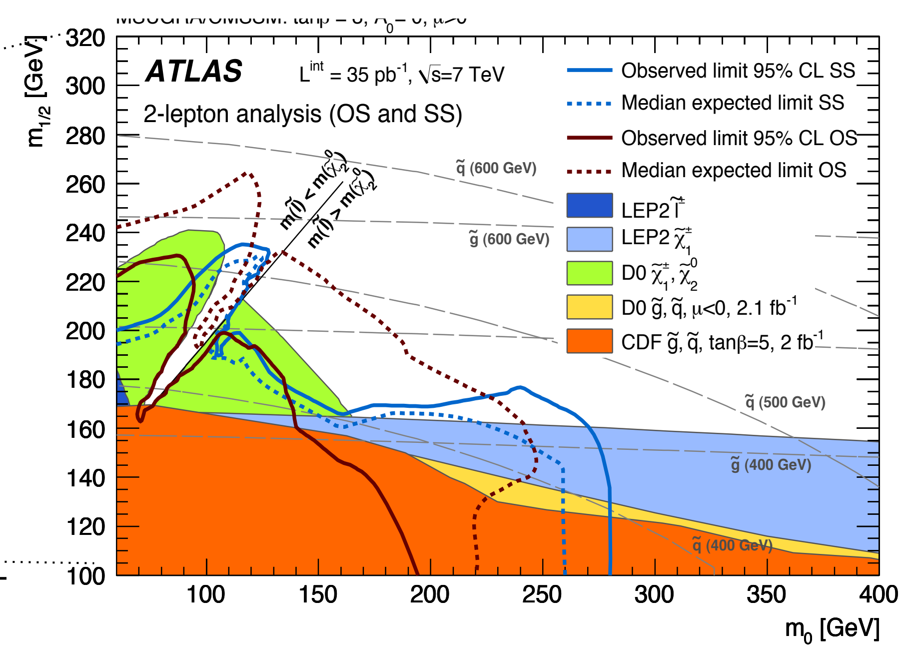




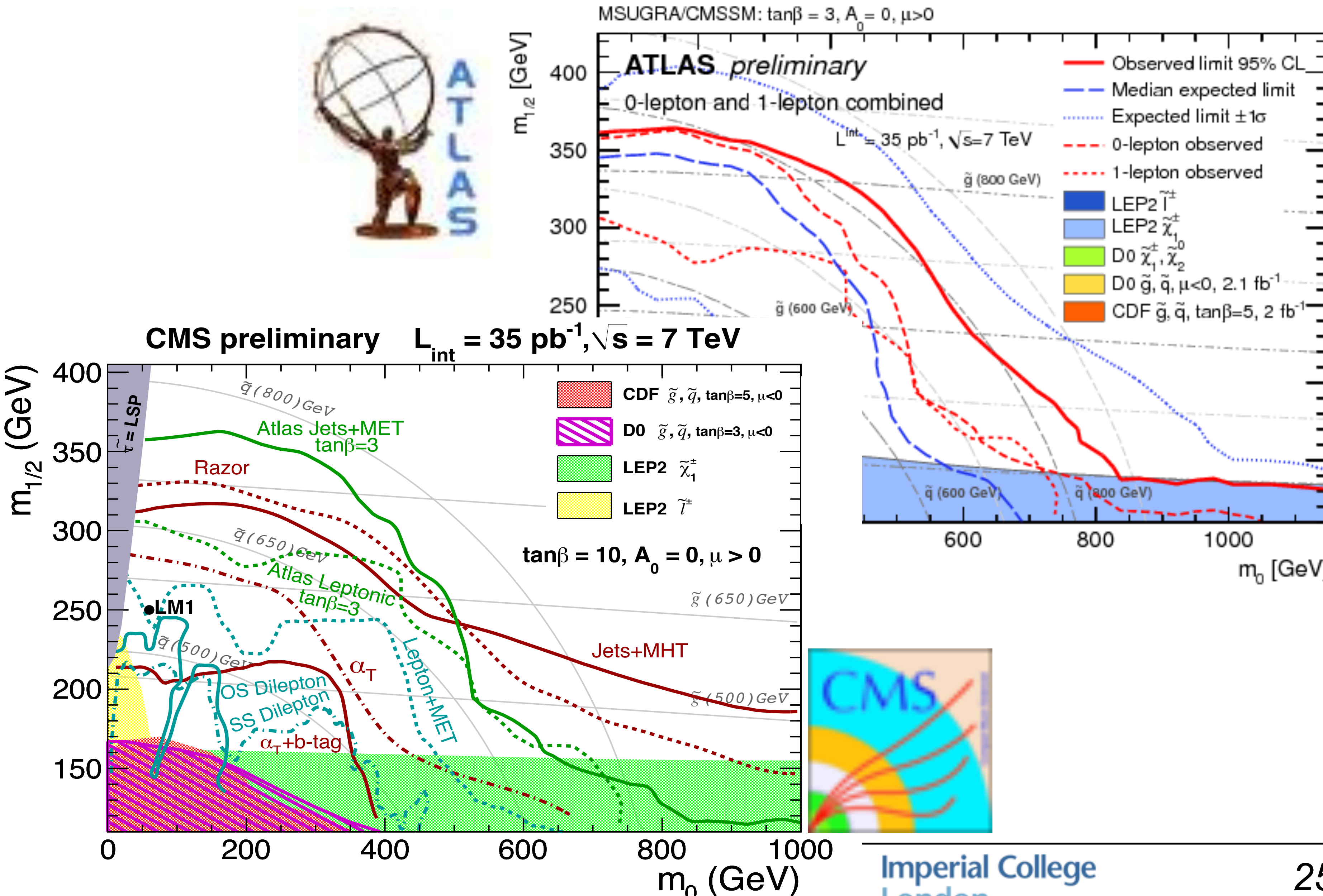
No excess seen

- *Dominant backgrounds:*
- *ttbar: one isolated lepton from W, one from semi-lep b/c decay*
- *QCD: larger for hadronic τ final states*

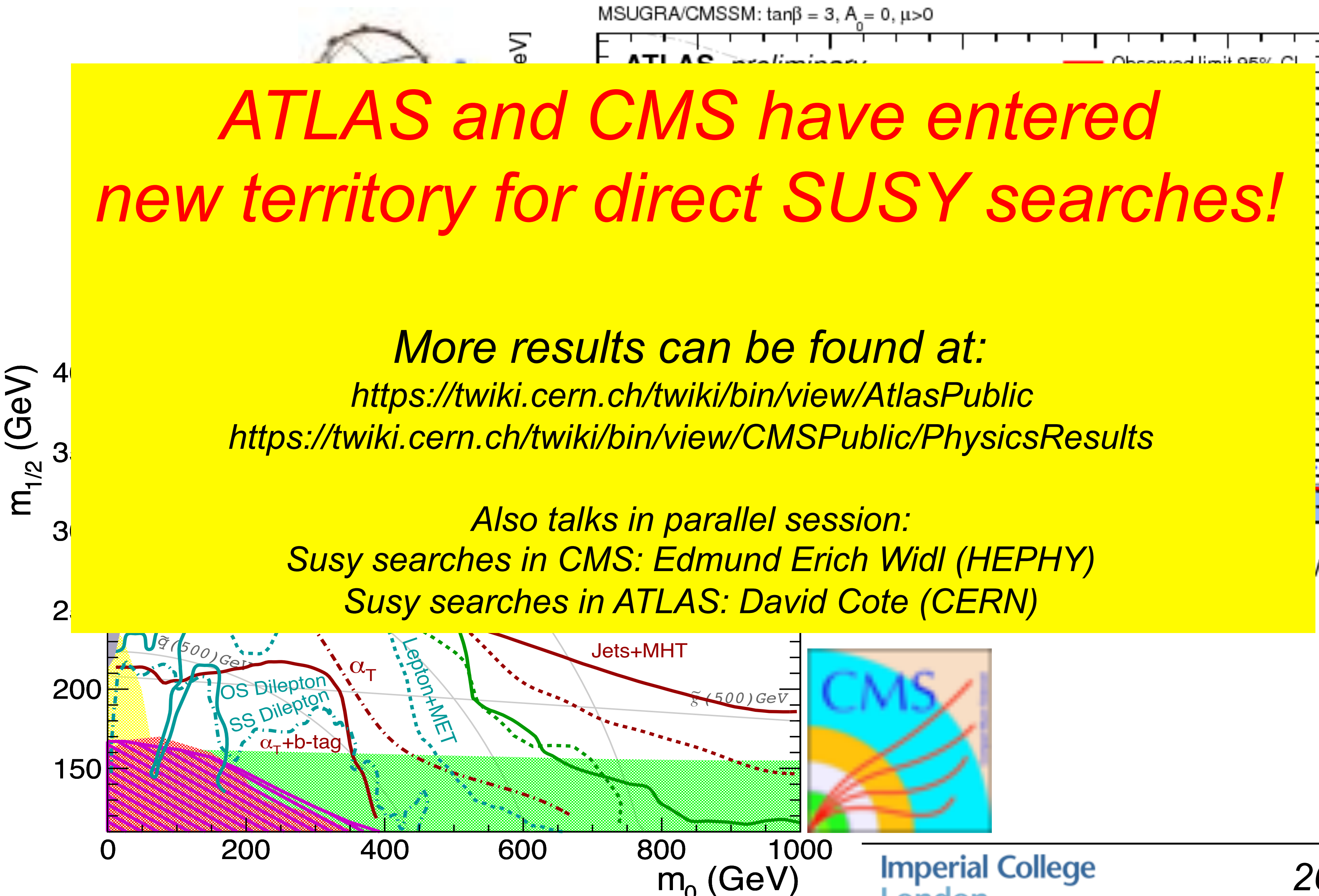




SUSY: All Together



SUSY: All Together



ATLAS and CMS have entered new territory for direct SUSY searches!

More results can be found at:

https://twiki.cern.ch/twiki/bin/view/AtlasPublic

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

Also talks in parallel session:

Susy searches in CMS: Edmund Erich Widl (HEPHY)

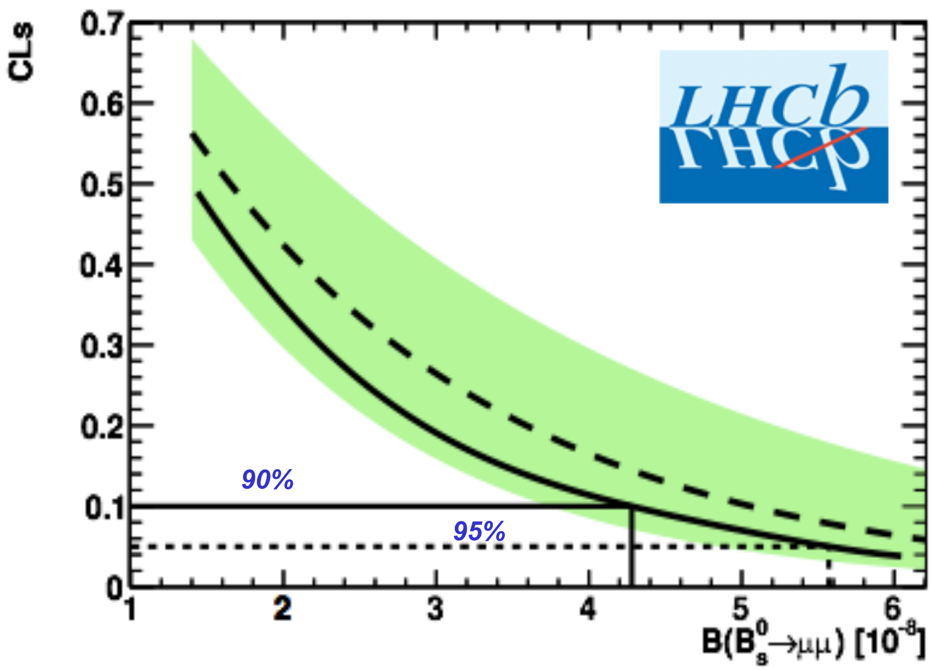
Susy searches in ATLAS: David Cote (CERN)

$B_s \to \mu\mu$

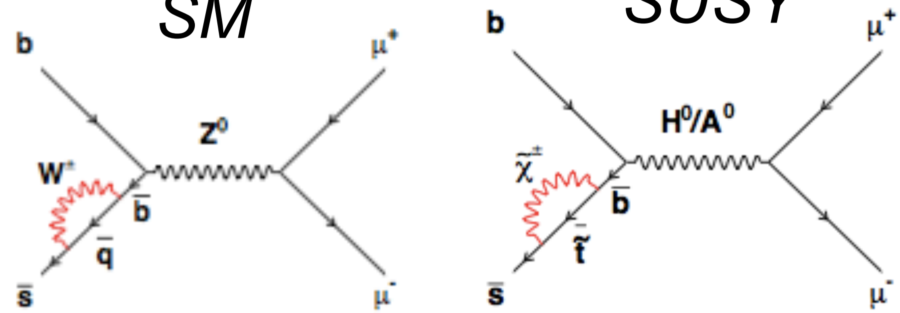
Also B-Physics provides powerful constraints on SUSY.

Example: $B_s \to \mu\mu$

Recent result from LHCb: arXiv:1103.2465



SM SUSY



For comparison:
SM: ~4×10^{-9}

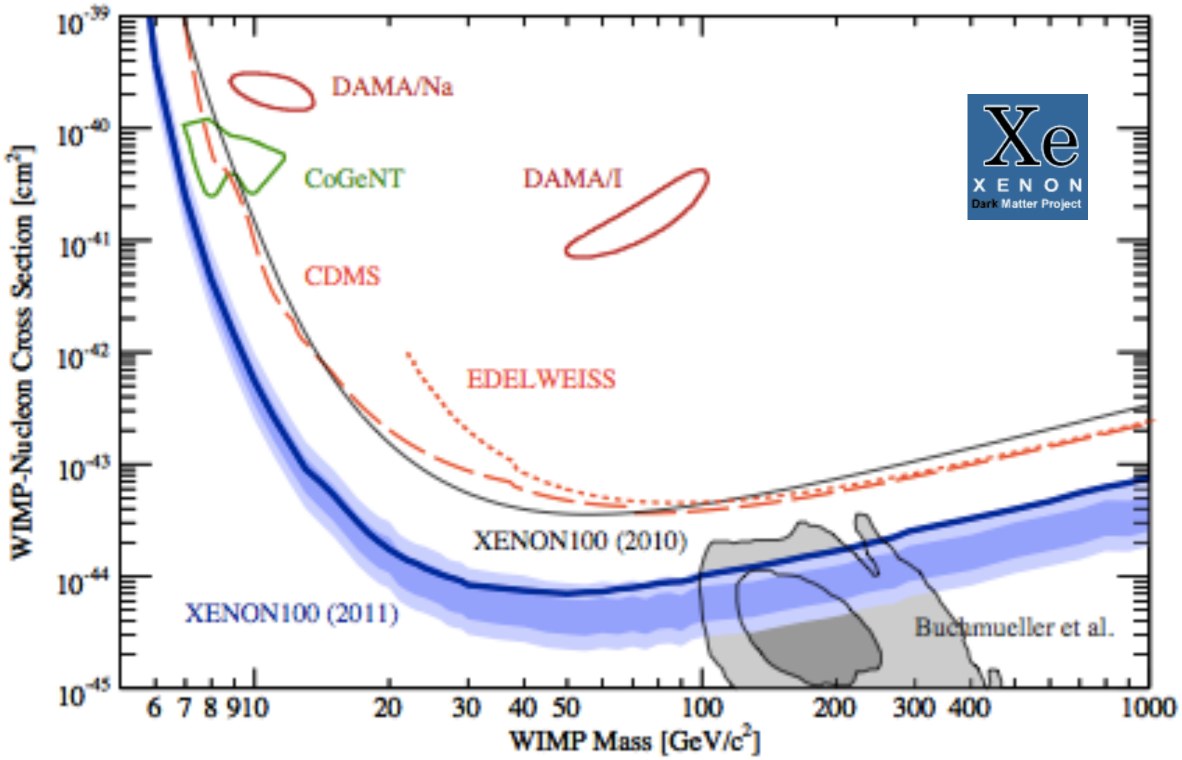
$BR(B_s \to \mu\mu)$ [10^{-9}]	90% CL	95% CL
LHCb	43	56
D0	42	51
CDF	36	43
Combined*	21	26

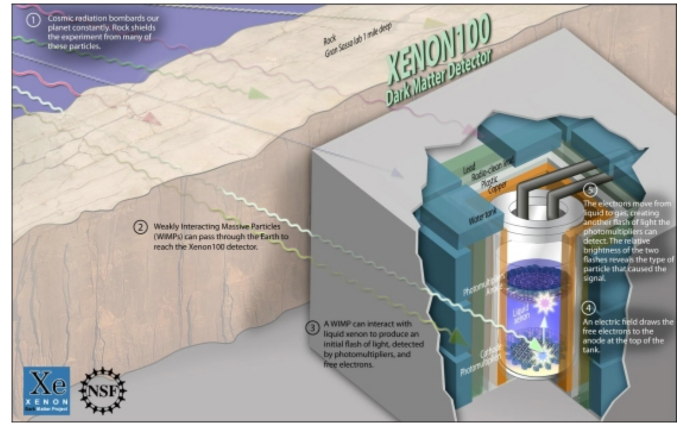
**) Private average performed for MasterCode studies*

Direct Dark Matter Searches

Example: Xenon100

New result: arXiv:1104.2549



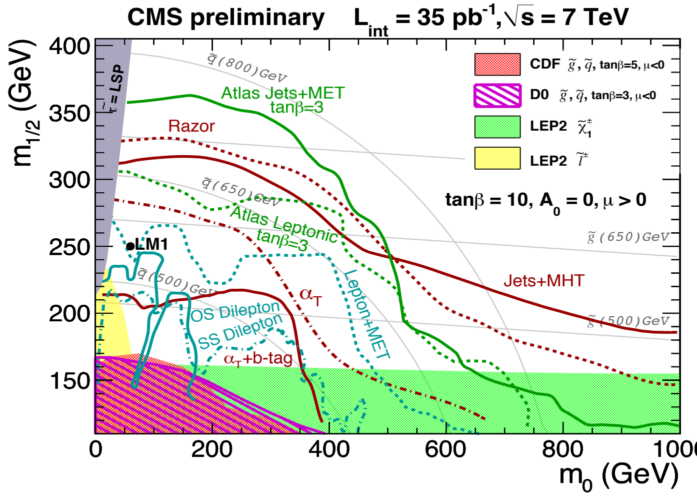


The XENON100 experiment is located deep underground at the Gran Sasso National Laboratory in Italy.

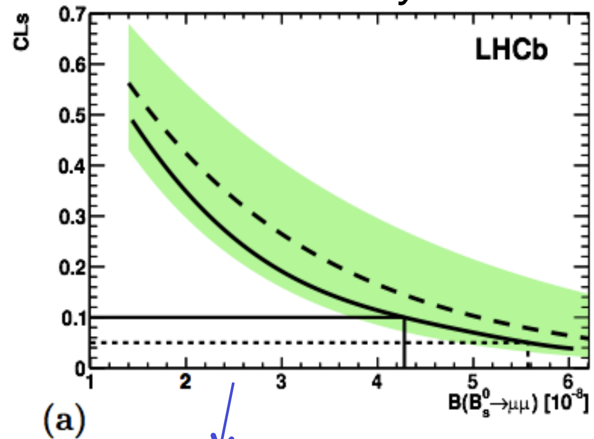
62 kg liquid Xenon target
100 days of data taking
1.8±0.6 events expected
3 events observed
$\Rightarrow$Exclude 7.0×10^{-45} cm^2
for a M_{WIMP} = 50 GeV at 90% CL.

Putting it all Together – Where are Toady?

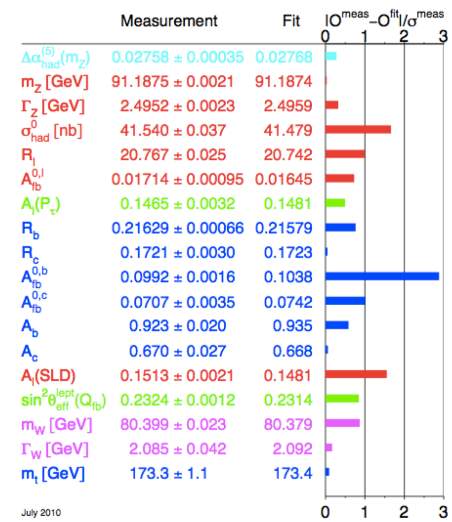
Direct Searches



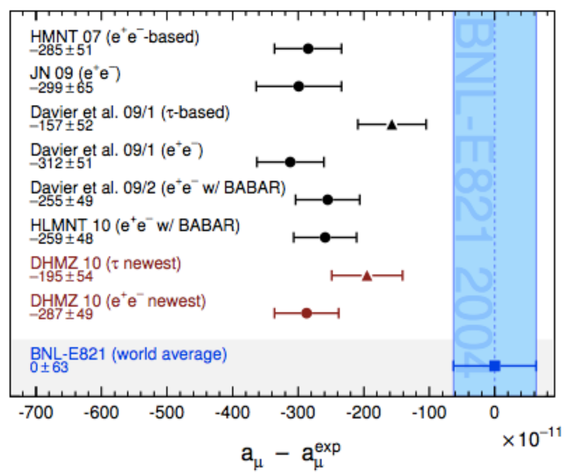
Flavour Physics



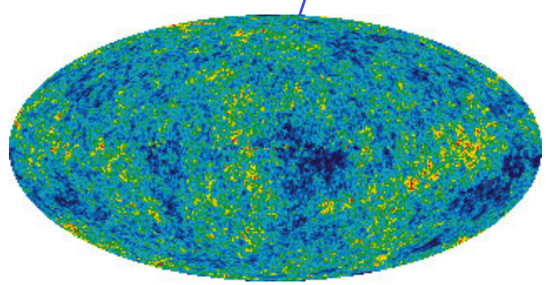
EWK results



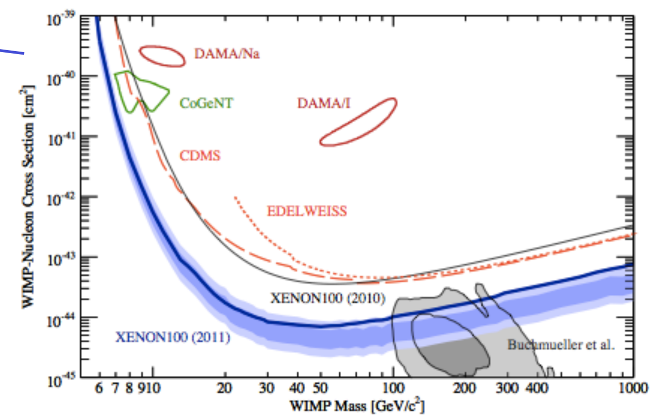
SUSY



Low Energy Data e.g. g-2



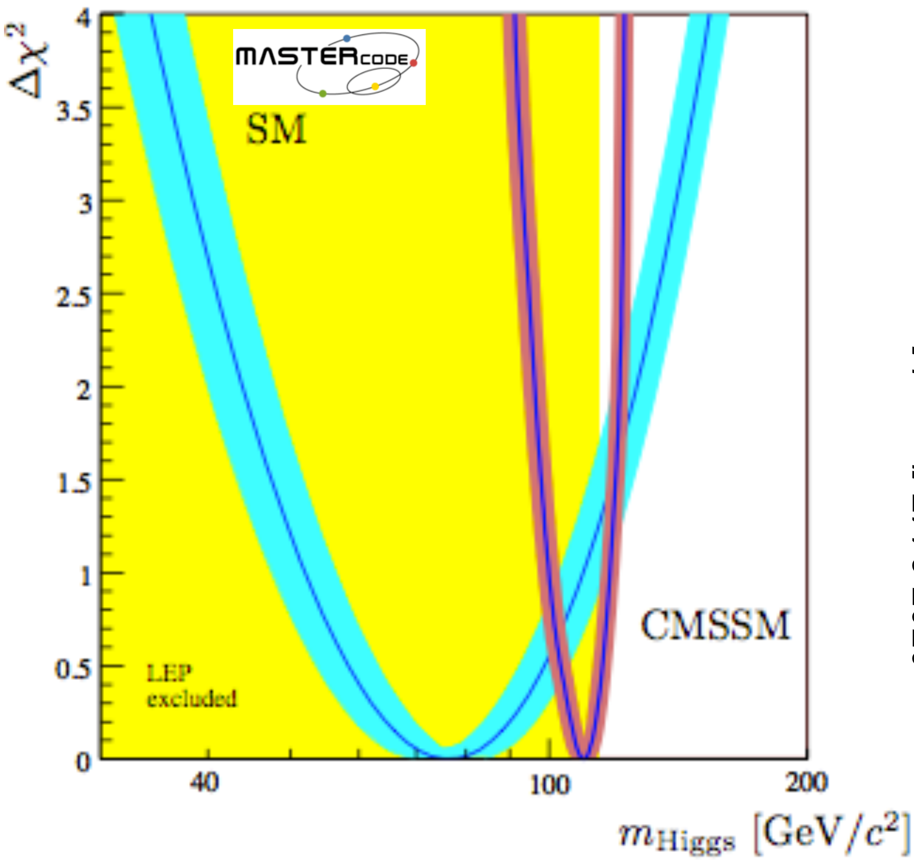
Cosmology



Dark Matter Searches

Confronting Data with Theory: New Physics

Global SUSY Fit



Example: "redo" SM fit in SUSY predicting the lightest higgs boson mass in the Constraint Minimal Supersymmeteric Standard Model (CMSSM)

MasterCode Collaboration

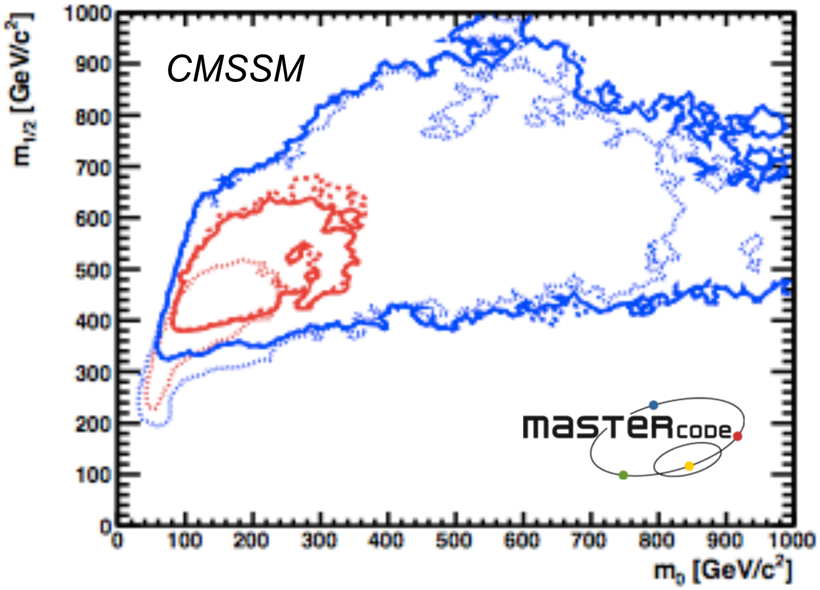
OB (Exp), R. Cavanaugh (Exp), A. De Roeck (Exp), J. Ellis (Theo), H. Flaecher (Exp), S. Heinemeyer (Theo), G. Isidori (Theo), K. Olive (Theo), P. Paradisi, (Theo), F. Ronga (Exp), G. Weiglein (Theo)

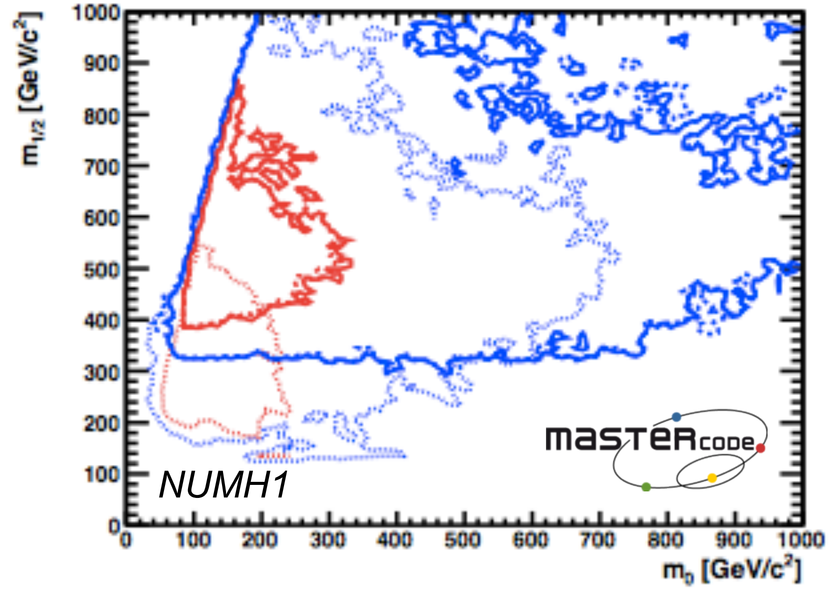
0707.3447 [hep-ph]

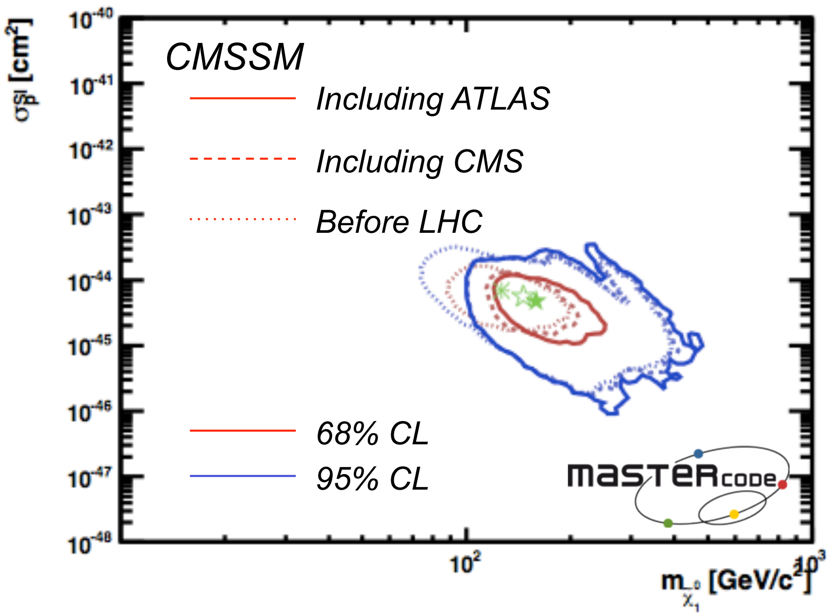
Pull for CMSSM fit

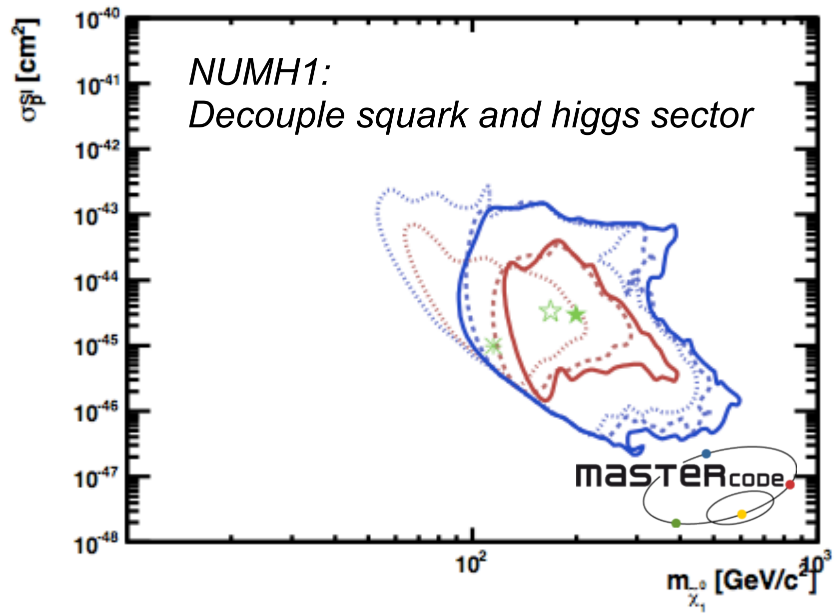
Variable	Measurement	Fit	$\lvert O^{meas}-O^{fit}\rvert/\sigma^{meas}$
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02774	
m_Z [GeV]	91.1875 ± 0.0021	91.1873	
Γ_Z [GeV]	2.4952 ± 0.0023	2.4952	
σ^0_{had} [nb]	41.540 ± 0.037	41.486	
R_l	20.767 ± 0.025	20.744	
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01641	
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1479	
R_b	0.21629 ± 0.00066	0.21613	
R_c	0.1721 ± 0.0030	0.1722	
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1037	
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0741	
A_b	0.923 ± 0.020	0.935	
A_c	0.670 ± 0.027	0.668	
A_l(SLD)	0.1513 ± 0.0021	0.1479	
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314	
m_W [GeV]	80.398 ± 0.025	80.382	
m_t [GeV]	170.9 ± 1.8	170.8	
$R(b\to s\gamma)$	1.13 ± 0.12	1.12	
$B_s\to\mu\mu$ [$\times10^{-8}$]	< 8.00	0.33	N/A (upper limit)
Δa_μ [$\times10^{-9}$]	2.95 ± 0.87	2.95	
Ωh^2	0.113 ± 0.009	0.113	

LHC & SUSY Parameter Space

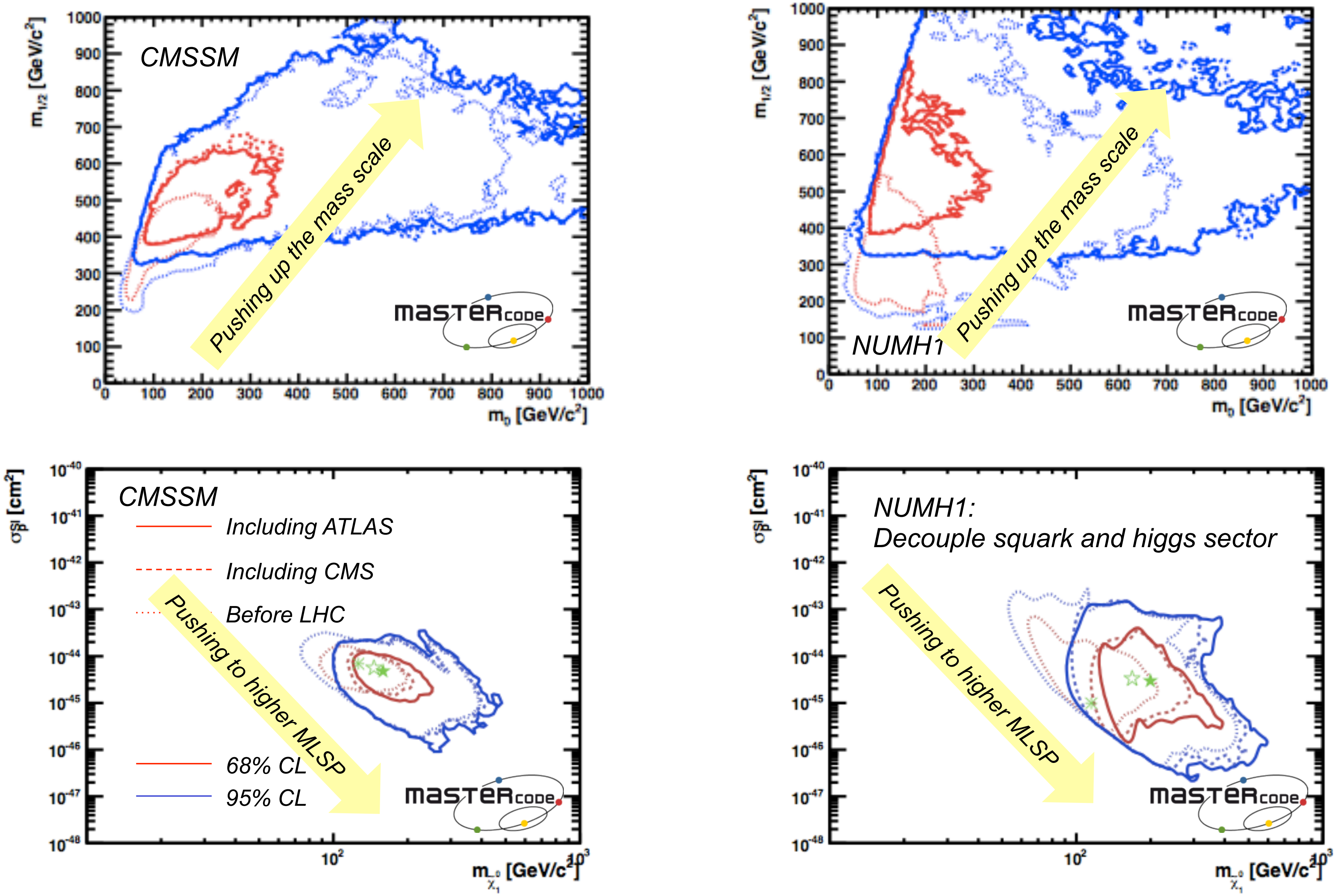




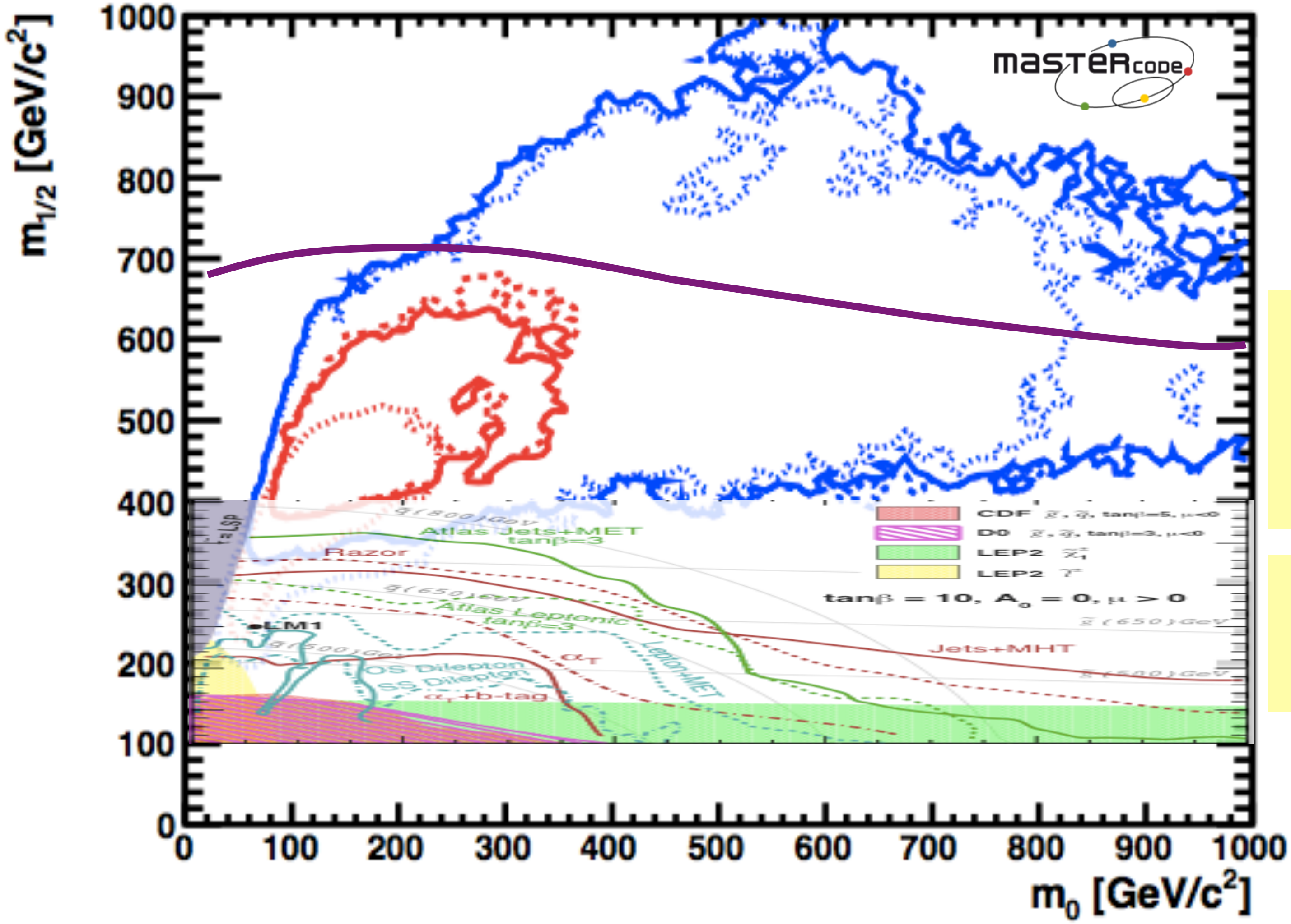




LHC & SUSY Parameter Space



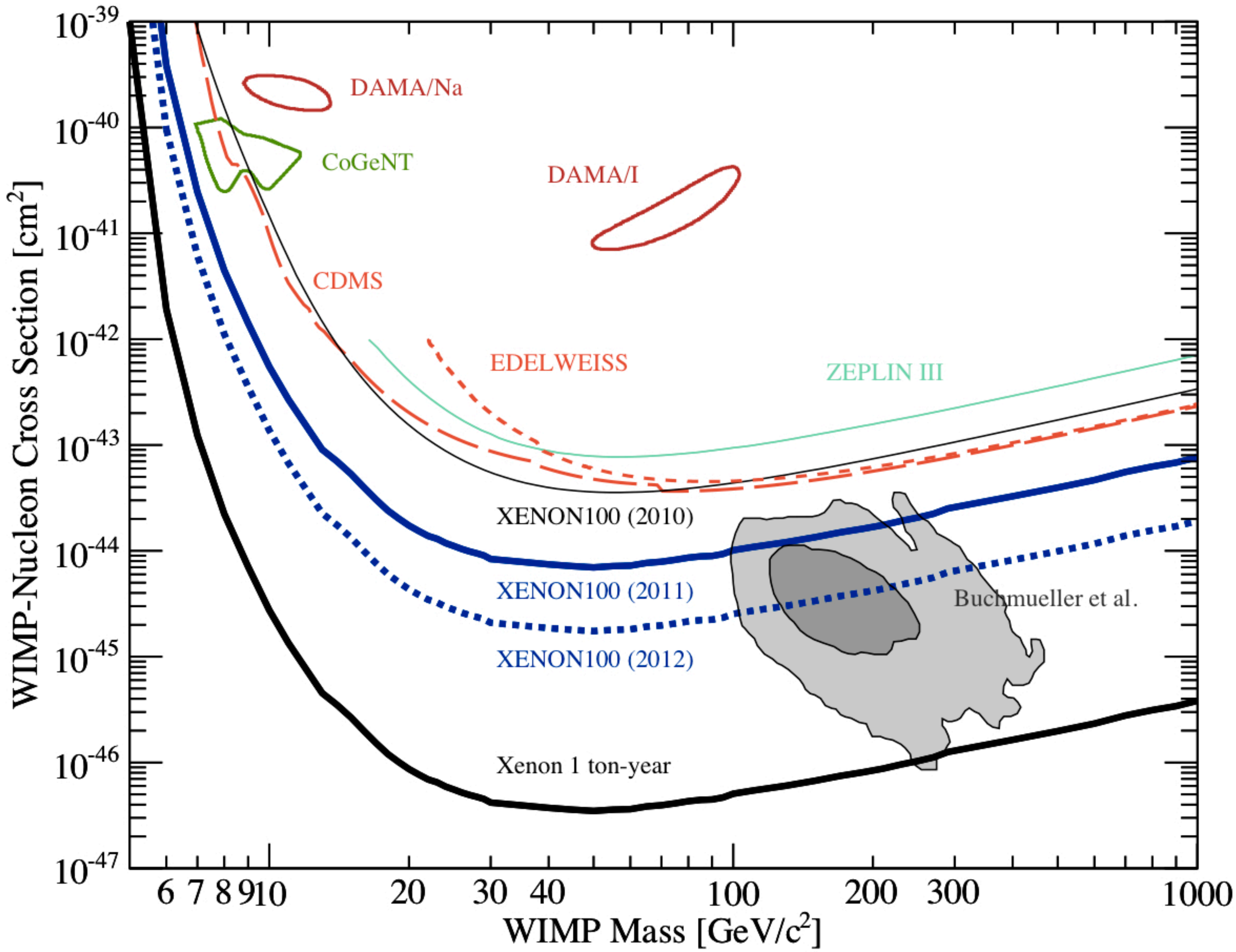
Where might we be in 2012?



2012
95% CL
Simple scaling
for ~3/fb

2010
95% CL

Where might we be in 2012?



Summary

- The experimental landscape for SUSY searches is multifaceted!
  - Several very powerful direct searches but also a lot of indirect information
  - Many of the direct searches are pursued on similar times scales.
- Already in 2010 the LHC has enter new territory for almost all low mass searches and has pushed the SUSY mass scale to almost 1 TeV
  - No observation so far – set limits
  - In 2011 - first signals might emerge very early but it might also take more time and ingenuity before we can claim a discovery
- The outcome of the direct searches in 2012/13 will have crucial implications.
  - With ~3fb^{-1} the LHC reach will extend significantly beyond the 1 TeV mass scale
  - Continue to explore detection of a dark matter candidate signal
- *So far SUSY has not revealed itself but with many of the powerful direct searches continuing to push the limits, discovery of a SUSY-like signal could now happen almost every day! The next two years will be very important!*

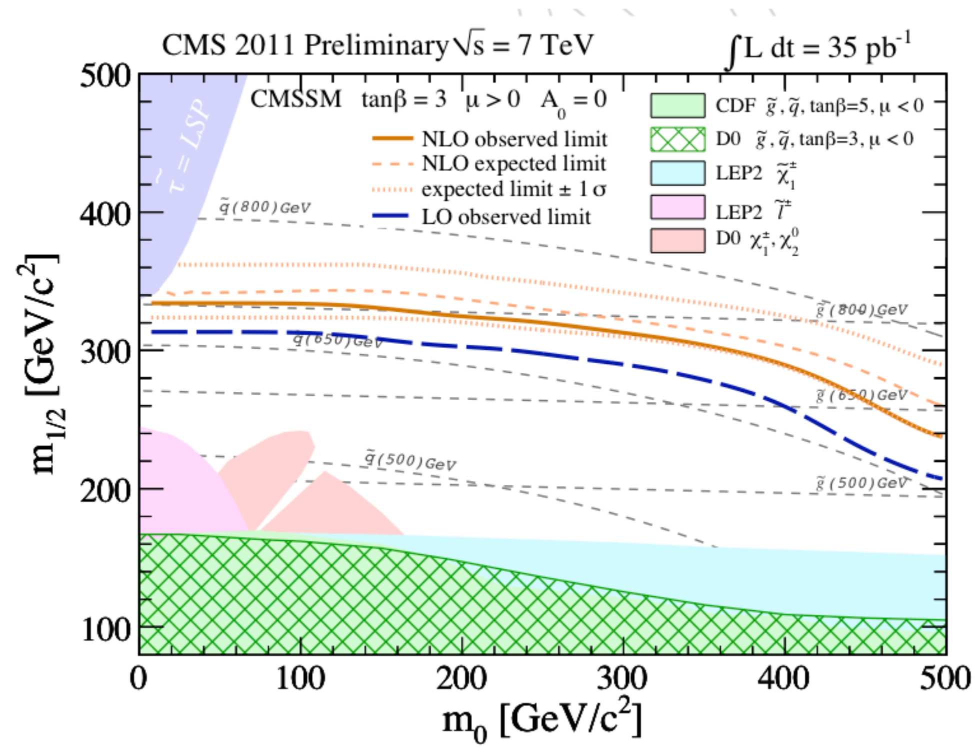
Backup Material

LHC SUSY Searches
- additional material -

Hadronic search with "Razor"

Another interesting all-hadronic search based on kinematics.

R>0.5	Predicted	Observed
M_R>500 GeV	5.5 ± 1.4	7

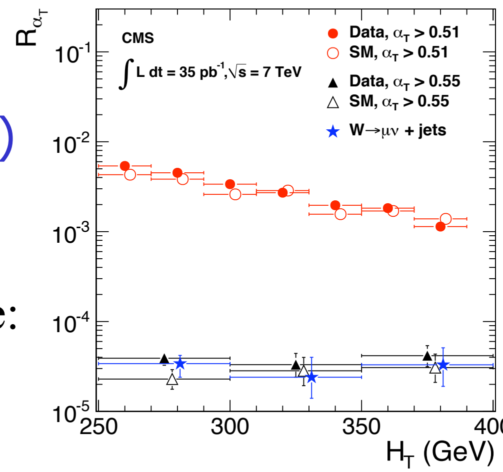


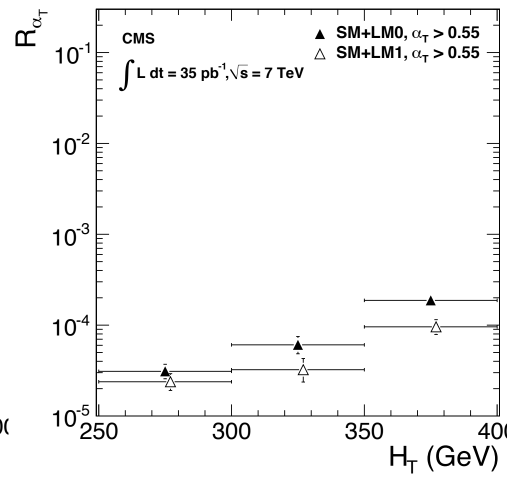
- Similar limits to jets+MHT analysis
- Complementary use of kinematics instead of detailed detector understanding

First SUSY search of the LHC

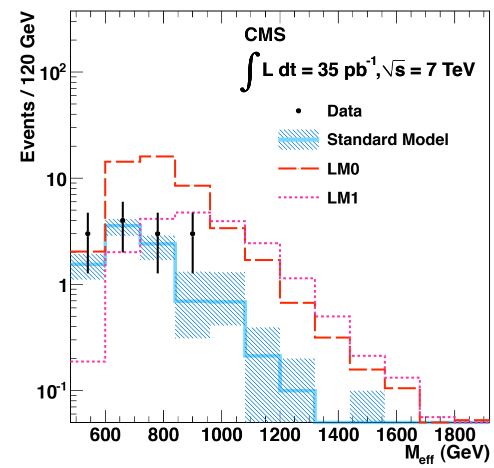
SM backgrounds predicted with 3 data-driven methods

- Total background (QCD, W/tt, Z→νν) extrapolating α_T ratio ($R_{\alpha T}$) from low H_T to high H_T region
  - *Two methods based on data only:*
    - 1) exponential H_T dependence: $9.4^{+4.8}_{-4.0\ stat} \pm 1.0_{syst}$
    - 2) No HT dependence (const. $R_{\alpha T}$) $12.5 \pm 1.9_{stat} \pm 0.7_{syst}$
- W/tt background from muon control sample
  - *invert muon veto*
  - $6.1^{+2.8}_{-1.9stat} \pm 1.8_{syst}$
- Z→νν background from photon control sample
  - *invert photon veto*
  - $4.4^{+2.3}_{-1.6stat} \pm 1.8_{syst}$





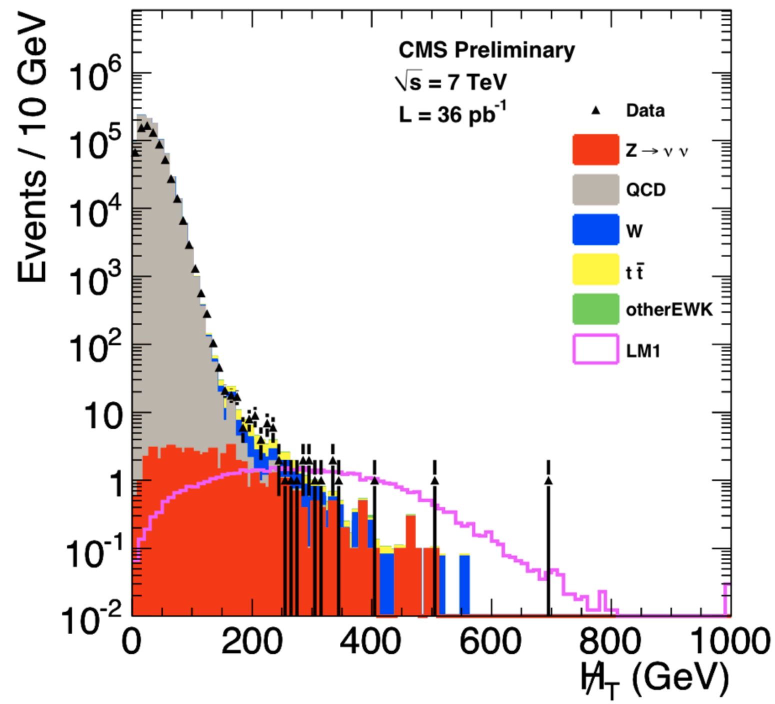
- 13 events in data after full selection
  - *kinematic properties compatible with SM expectation*
  - $M_{eff} = H_T + MH_T$



Hadronic search with missing energy

CMS-SUS-10-005

- Analysis based on understanding the detector response in detail
- Complementary to kinematics-based searches
- Baseline selection
  - At least 3 jets with E_T>50 GeV & | η | <2.5 anti-kT (0.5)
  - H_T>300 GeV and MHT > 150 GeV
  - Veto isolated electrons and muons



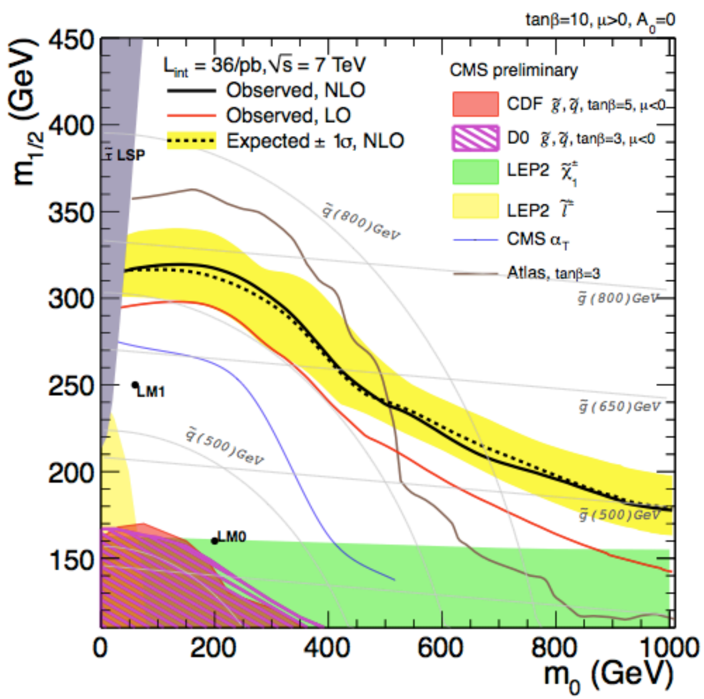
- *Backgrounds from*
  - *Multi-jet QCD, Z ➔ νν, W+jets, ttbar*
  - *All determined from data-driven techniques ➔*

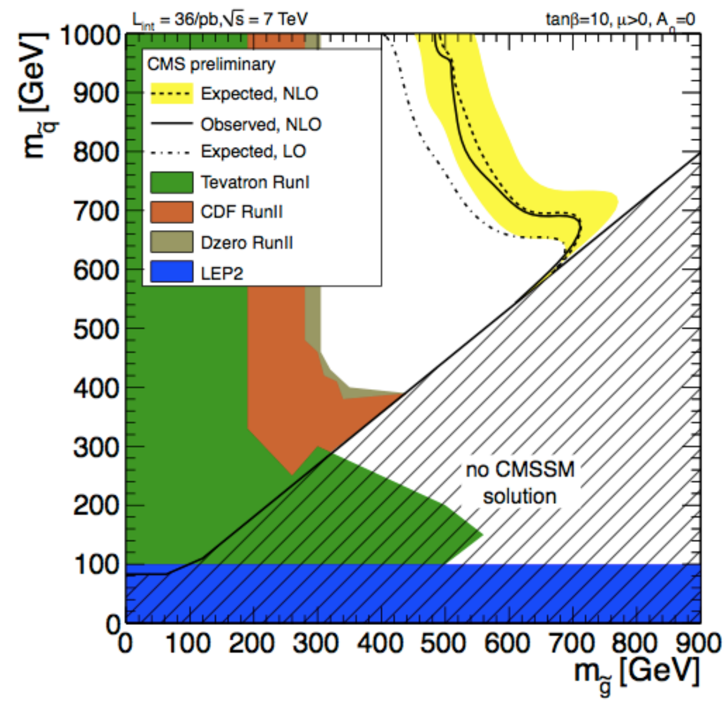
MC backgrounds (illustrative)

Hadronic search with missing energy

	Predicted	Observed
MHT > 250 GeV	18.8 ± 3.5	15

	Predicted	Observed
H_T > 500 GeV	43.9 ± 8.8	40





- Results expressed in terms of 95% C.L. in CMSSM
- Extends limit from α_T search and Tevatron

CMS-SUS-10-005

Search strategy (what and how?)

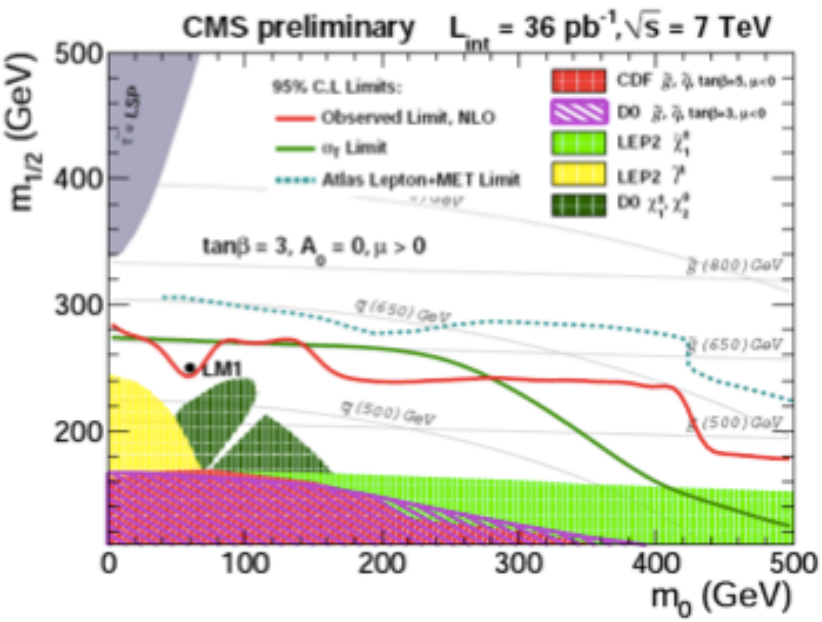
0-leptons	1-lepton	OSDL	SSDL	≥3 leptons	2-photons	γ+lepton
Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton	Di-photon + jet + MET	Photon + lepton + MET

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

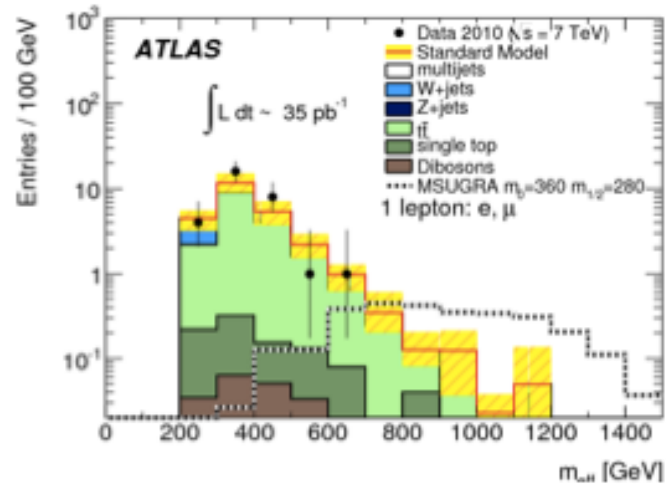
Jets+E_T^{mis} + 1 Lepton

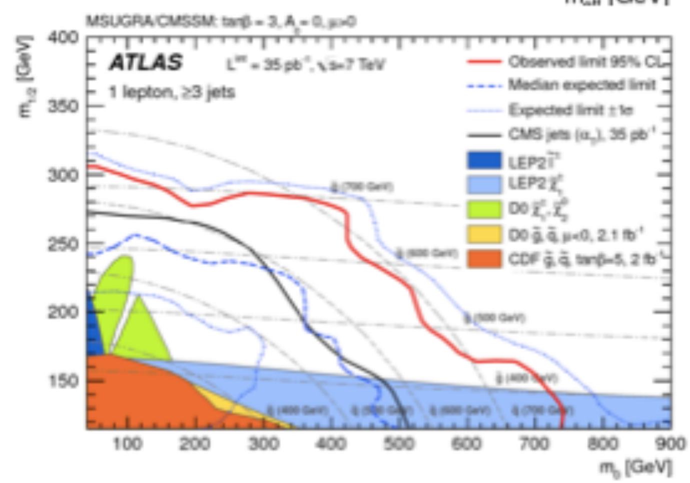
1 e or μ (pt > 20)
≥ 4 jets, pt > 30
MET > 250, HT > 500

Sample	$\ell = \mu$	$\ell = e$
Predicted SM 1 ℓ	1.7 ± 1.4	1.2 ± 1.0
Predicted SM dilepton	$0.0^{+0.8}_{-0.0}$	$0.0^{+0.6}_{-0.0}$
Predicted single τ	0.29 ± 0.22	$0.32^{+0.38}_{-0.32}$
Predicted QCD background	0.09 ± 0.09	$0.0^{+0.16}_{-0.0}$
Total predicted SM	2.1 ± 1.5	1.5 ± 1.2
Observed signal region	2	0



1 e or μ (pt > 20)
≥ 3 jets, pt > (60,30,30)
MET > 125, Meff > 500





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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

? Adding a second lepton (electron or muon) reduced W background

? Two analyses here: inclusive and Z peak search

? Several techniques including opposite-sign opposite-flavour subtraction

? Shape information and mass edges

Opposite-sign dilepton search

- Adding a second lepton rejects W+jets leaving mostly top background

arxiv:1103.1348

- Baseline selection
  - Two isolated leptons (e or μ); one with p_T>20 GeV, other with p_T>10 GeV
  - Veto same-flavour pairs in Z mass window and m_{ll}<10 GeV
  - At least 2 jets with p_T>30 and $|\eta|$<2.5

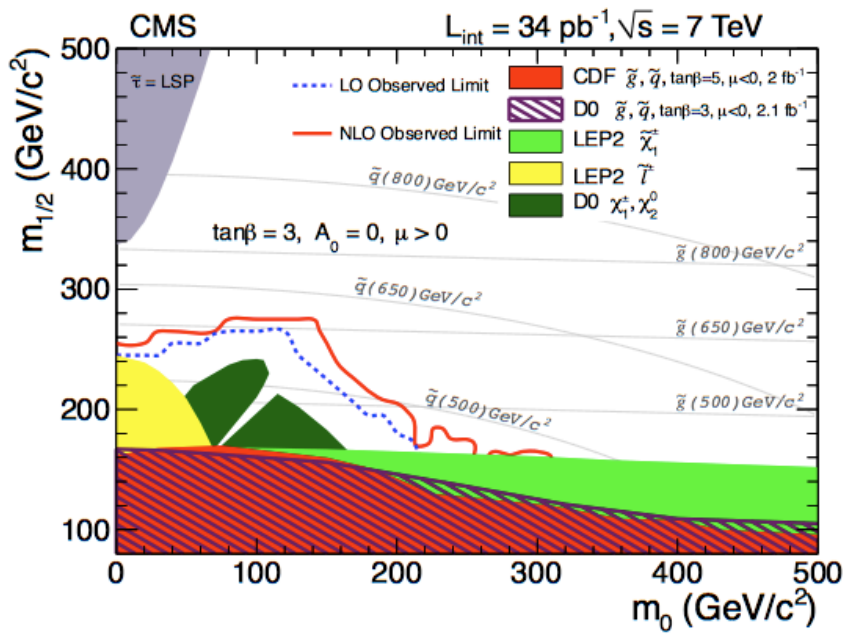
- Study selected events
  - Simulation predicts background from top
  - General event properties well understood

- Determine backgrounds from data ➔

Opposite-sign dilepton result

arxiv:1103.1348

	Predicted	Observed
Region D	1.3 ± 0.8	1

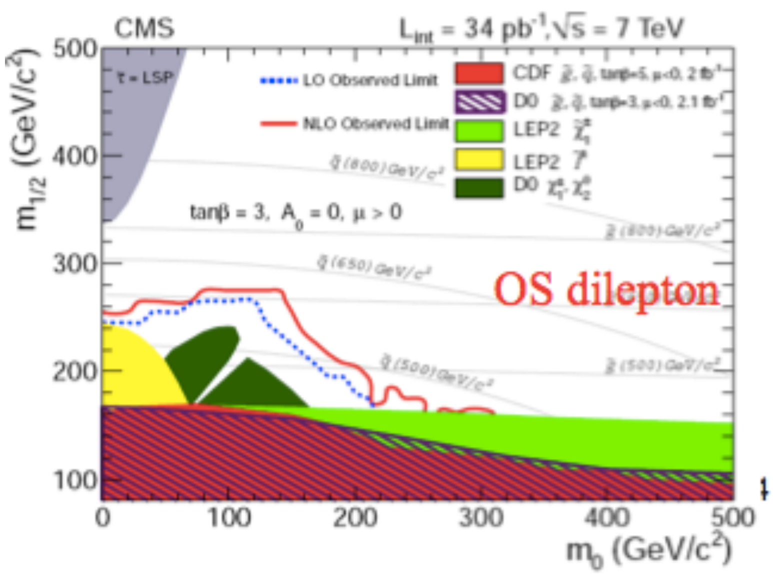


- Limit in CMSSM beyond previous Tevatron searches
- Also result from opposite-sign opposite-flavour subtraction
  - Observed in data: ee:0 $\mu\mu$:0 Predicted background: ee: $0.1^{+1}_{-0.4}$ $\mu\mu$: $0.5^{+1.2}_{-0.4}$
  - Powerful technique to obtain mass edge in the case of SUSY

Jets+E_T^{mis} + OS-Lepton

2 leptons, pt > (20,10), OS, Z veto
≥ 2 jets, pt > 30
HT > 300, MET/√HT > 8.5

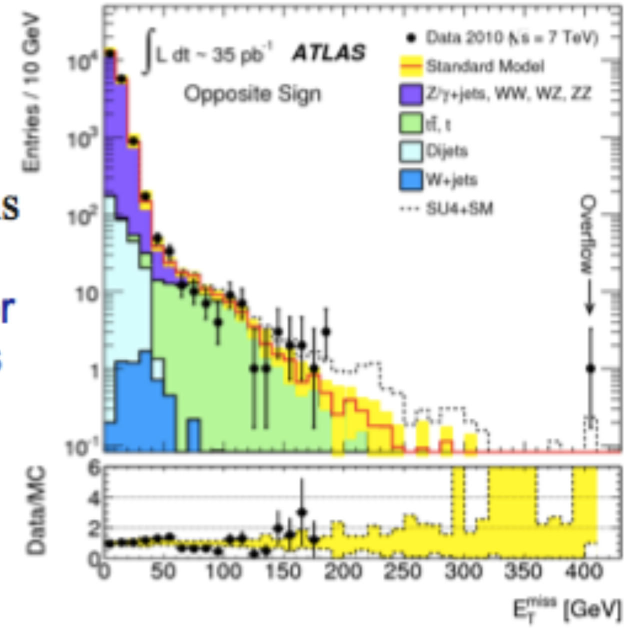
sample	N_A	N_B	N_C	N_D	$N_A \times N_C / N_B$
$t\bar{t} \to \ell^+\ell^-$	8.44 ± 0.18	32.83 ± 0.35	4.78 ± 0.14	1.07 ± 0.06	1.23 ± 0.05
$t\bar{t} \to$ other	0.12 ± 0.02	0.78 ± 0.05	0.16 ± 0.02	0.02 ± 0.01	0.02 ± 0.01
Drell Yan	0.17 ± 0.08	1.18 ± 0.22	0.04 ± 0.04	0.12 ± 0.07	0.01 ± 0.01
$W^{\pm}$ + jets	0.00 ± 0.00	0.09 ± 0.09	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
W^+W^-	0.11 ± 0.01	0.29 ± 0.02	0.02 ± 0.01	0.03 ± 0.01	0.01 ± 0.00
$W^{\pm}Z$	0.01 ± 0.00	0.04 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
ZZ	0.01 ± 0.00	0.02 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
single top	0.29 ± 0.01	1.04 ± 0.03	0.04 ± 0.01	0.01 ± 0.00	0.01 ± 0.00
total SM MC	9.14 ± 0.20	36.26 ± 0.43	5.05 ± 0.14	1.27 ± 0.10	1.27 ± 0.05
data	12	37	4	1	1.30 ± 0.78
LM0	4.04 ± 0.19	4.45 ± 0.20	13.92 ± 0.36	8.63 ± 0.27	12.63 ± 0.88
LM1	0.52 ± 0.02	0.26 ± 0.02	1.64 ± 0.04	3.56 ± 0.06	3.33 ± 0.27

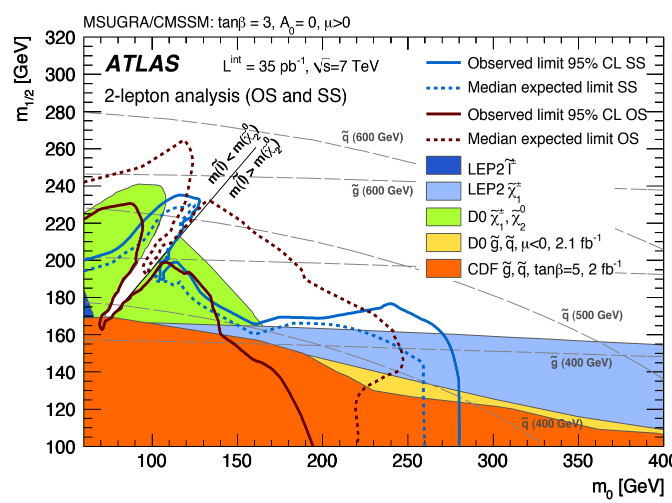


2 OS leptons, pt > 20, MET > 150 (100 for FS analysis), no jet requirement

Consistent with expectations

See next slide for example of limits





Search strategy (what and how?)

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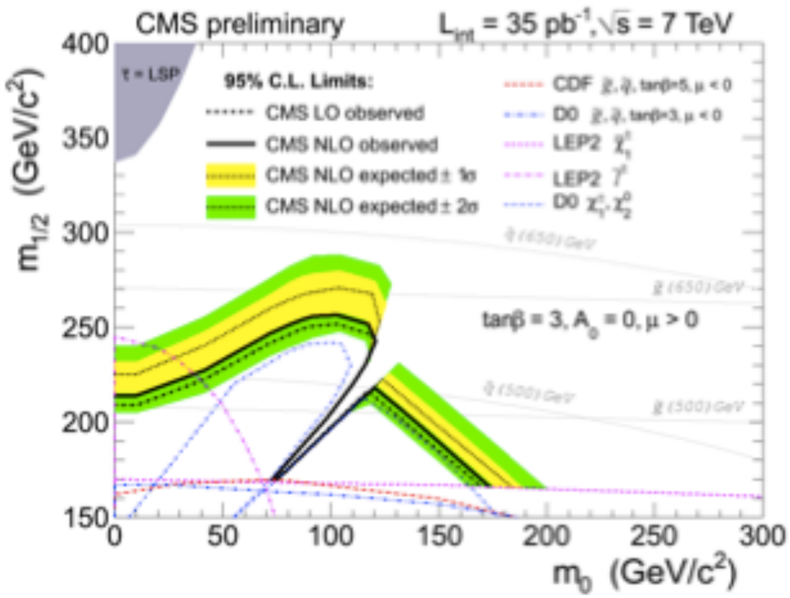
Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton	Di-photon + jet + MET	Photon + lepton + MET

? 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

Jets+E_T^{mis} + Multi-Lepton

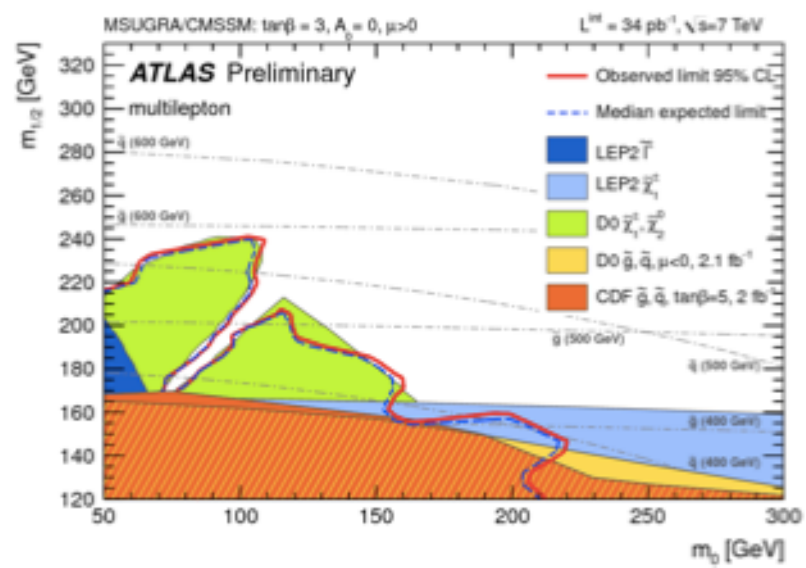
≥ 3 leptons, including taus! pt from 8 GeV
Tau: full tau ID; also isolated track
MET > 50 or H_T > 200

Complex analysis: many exclusive search channels



e and μ, pt > 20,20,20(e) or 10(μ)
Z veto, m(ℓℓ) < 20 also vetoed
≥ 2 jets, pt > 50
MET > 50

- 19 events with 3 leptons (before other cuts). 0 events after cuts
- 0 events with 4 or more leptons



Search strategy (what and how?)

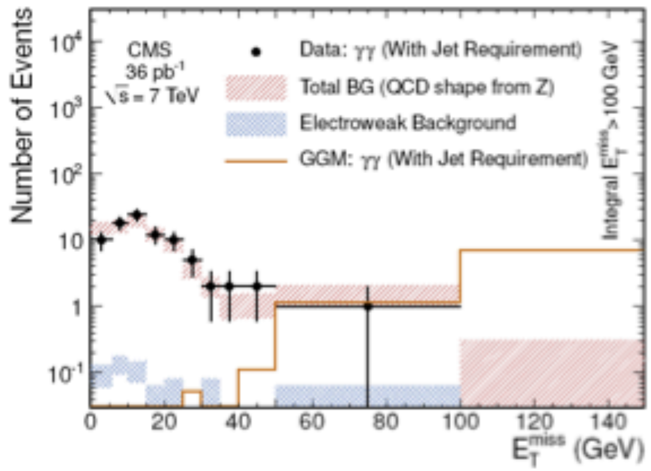
0-leptons	1-lepton	OSDL	SSDL	≥3 leptons	2-photons	γ+lepton
Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton	Di-photon + jet + MET	Photon + lepton + MET

? Many gauge-mediated models predict photons in final state

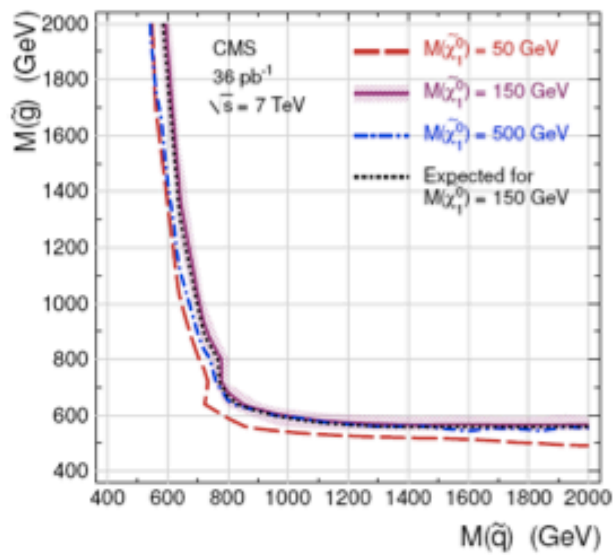
? Di-photon searches dominated by QCD multijet and γ +jet backgrounds

Jets+E_T^{mis} + Di-Photon

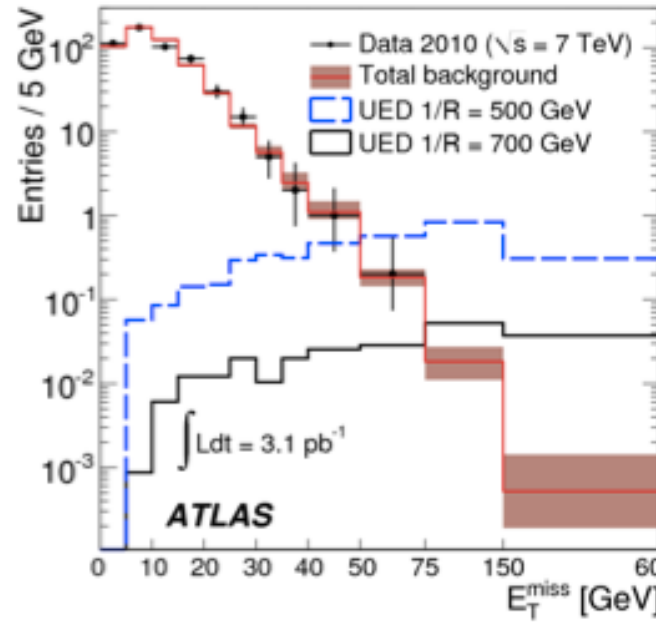
2 photons, Et > 30
≥ 1 jets, Et > 30
MET > 50



Set limits in a simplified General Gauge Mediation model



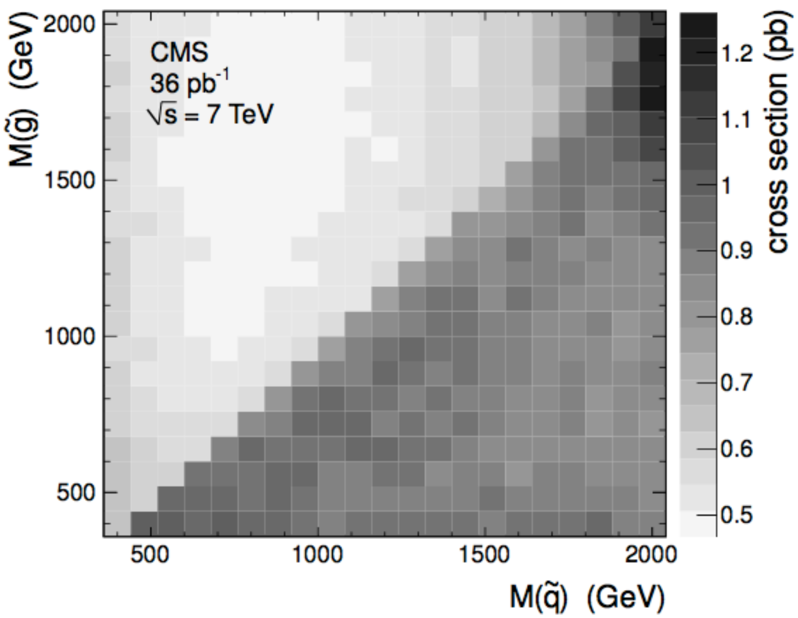
2 photons, Et > 25
No jet requirement
MET > 75

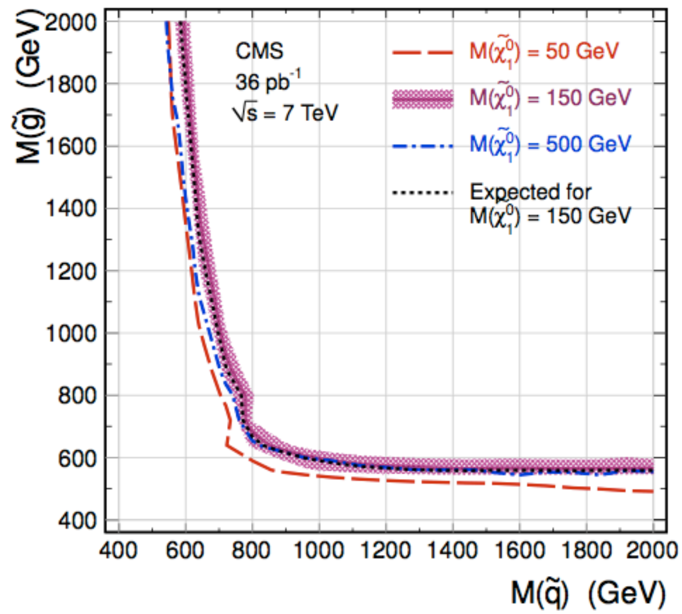


Set limits on UED model:
1/R < 729 GeV at 95% CL

Diphoton search

- *Observe 1 event MET >50 GeV consistent with 1.2 ± 0.8 background*

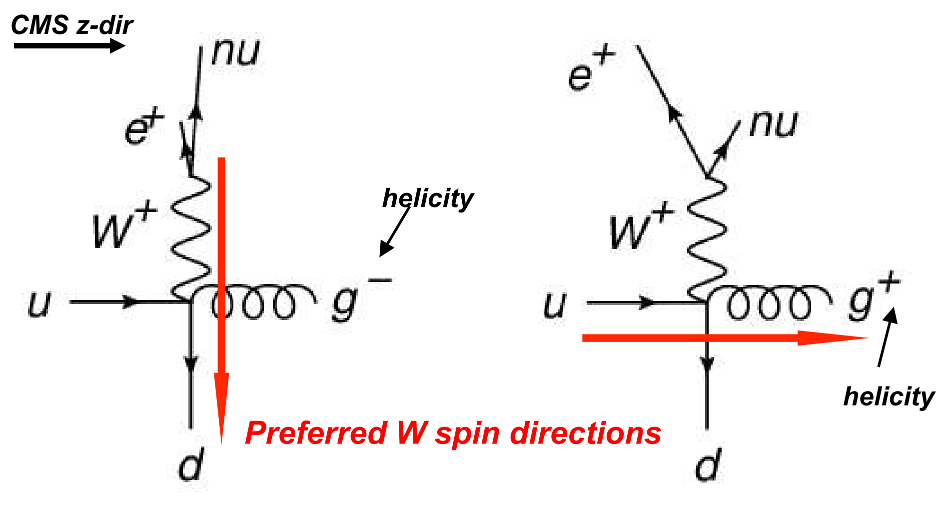




- Consider GGM model with neutralino (bino), gluino, and squark decaying to jets + two photons + two Gravitinos
- 95% CL upper limit this simple model for neutralino mass = 150 GeV
- Upper limits between 0.5 and 1.1 pb depending on masses
- Beyond previous experiments

W Polarisation in pp

- Dominant production of high P_T (e.g. >50 GeV) W-bosons:
  - Valence quark-gluon dominating from low P_T(W) at the LHC



W+1jet dominant production mechanism at LHC (not a Feynman diagram)

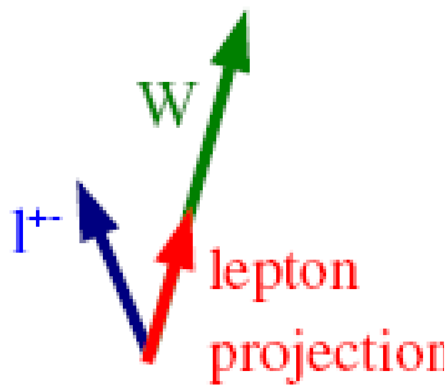
- *Strong polarisation effects in transverse plane*
- *SM predicts predominant left-handedness for both charges*
- *Initial states and CP counterparts not present in equal amounts at pp collider in contrast to $p\bar{p}$*
- *Robust with jet multiplicity*

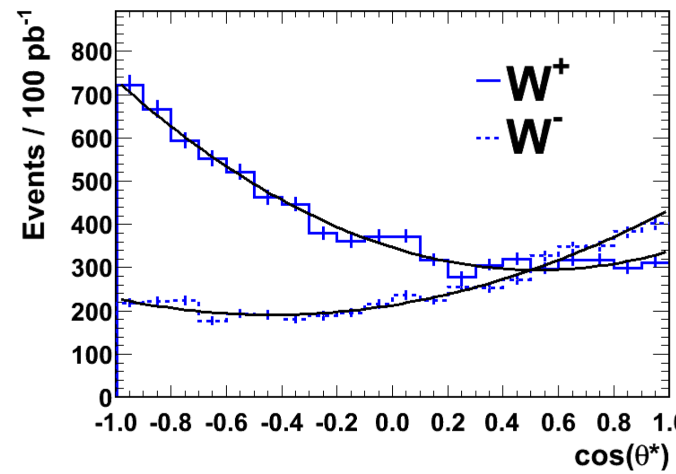
Strong polarisation effects in transverse plane at LHC expected.
➔ W's are mainly produced left-handed in pp.

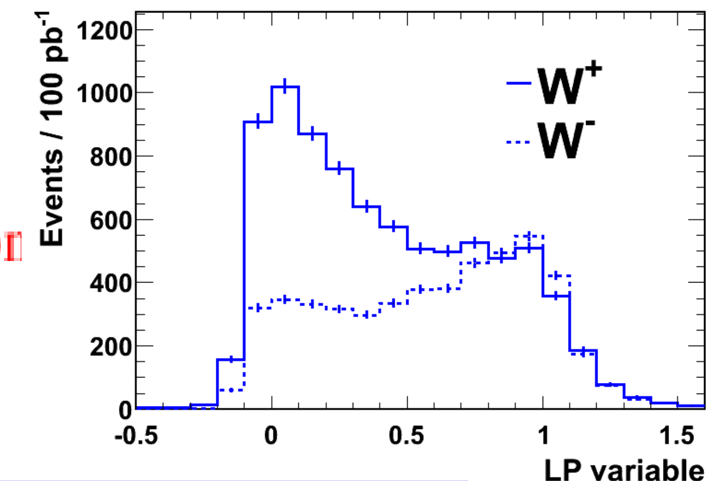
LP Variable

- *Fraction of W momentum imparted to a lepton solely depends on cos θ* (Lorentz boost)*
- *Given that $P_Z(W)$ cannot be uniquely determined, the polarisation variables can only include transverse quantities*
- *Define a transverse variable highly correlated to cos θ**

$$\mathrm{LP} = \frac{\vec{P}_T(\ell)\cdot\vec{P}_T(W)}{\left|\vec{P}_T(W)\right|^2}$$



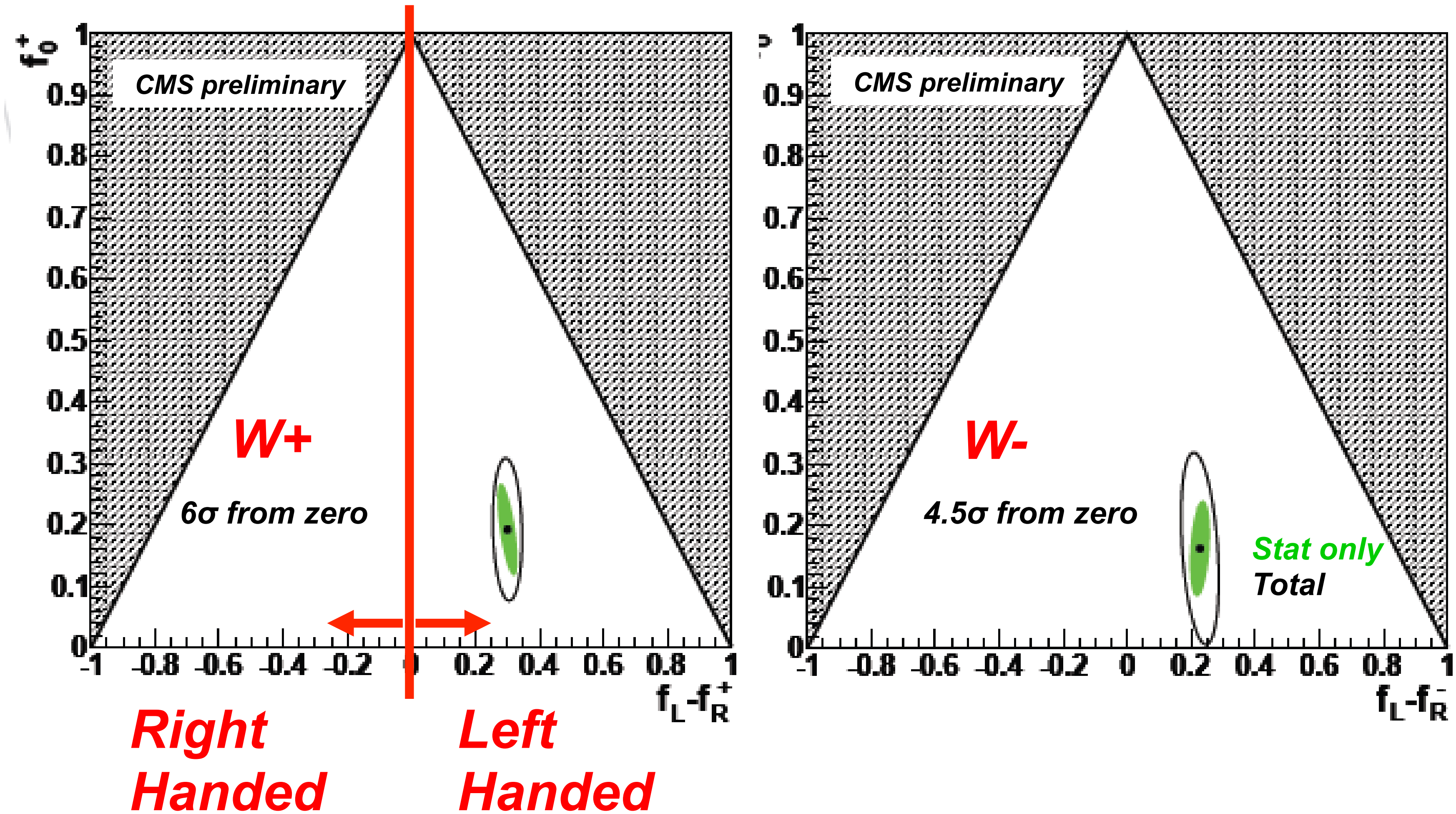




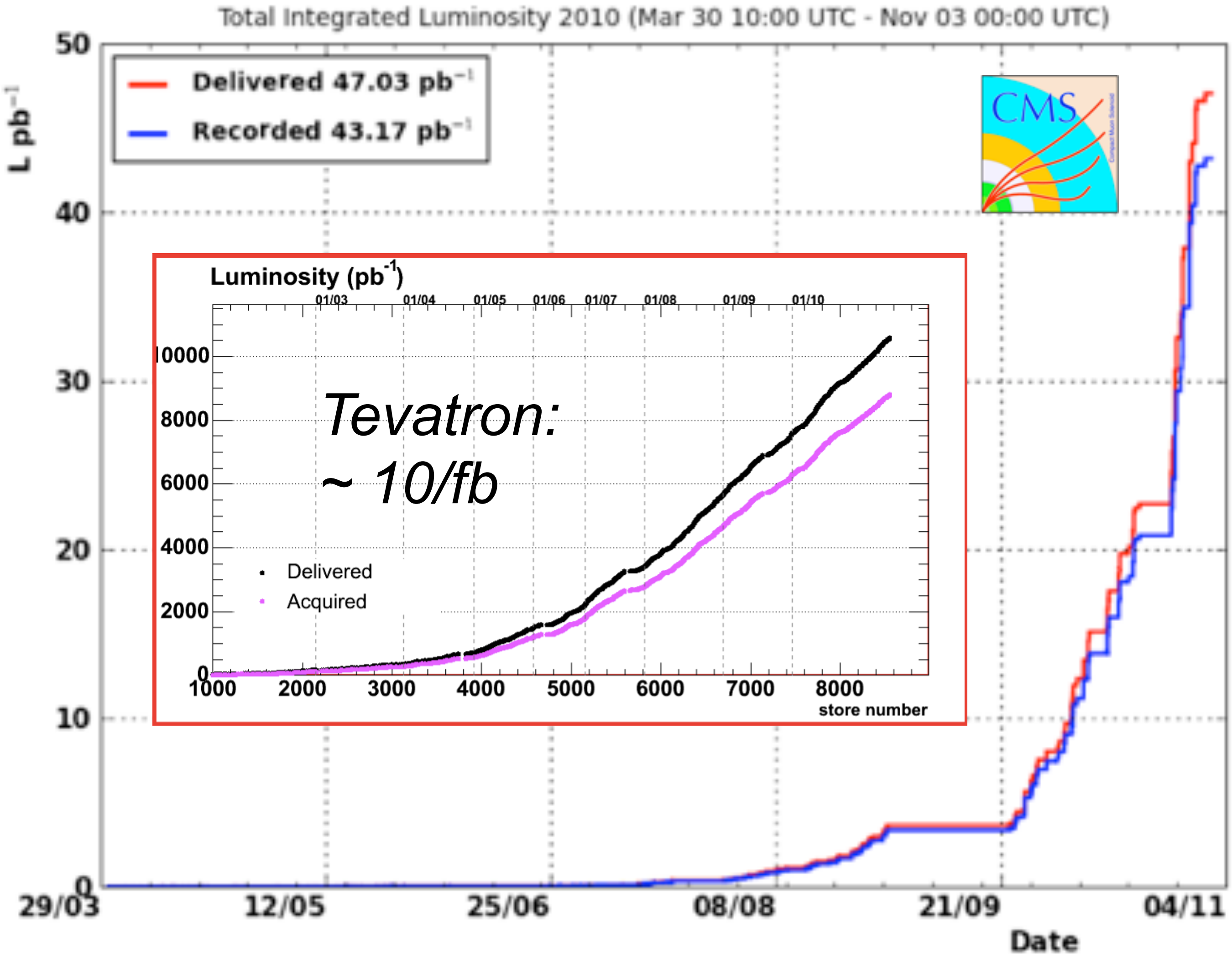
Use LP to measure W polarisation at large $P_T(W)$

Electron and Muon Channels Combined

68% confidence level contours shown in the (f_L-f_R, f_0) plane



~40/pb (LHC) vs. ~10/fb (Tevatron)



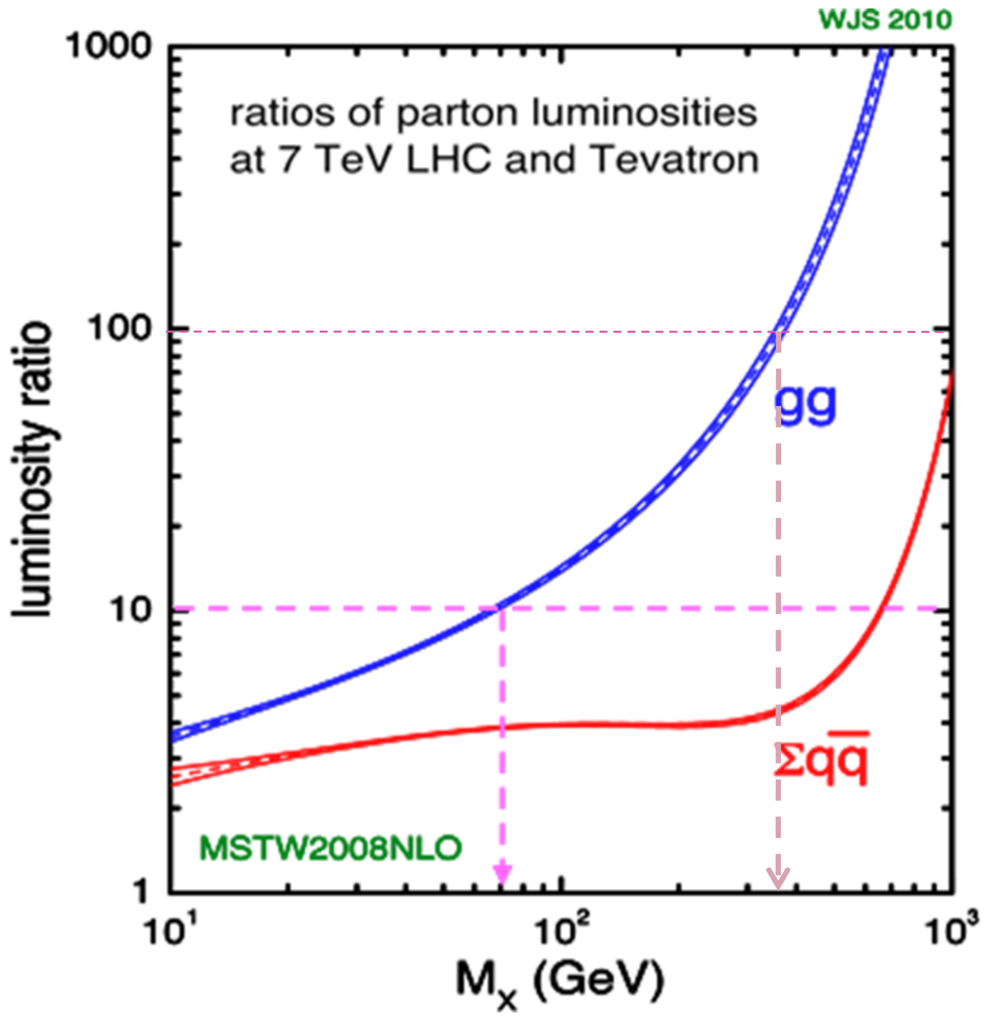
How much do we Gain?

Use parton luminosties to illustrate the gain:

<u>Example: mainly gg</u>
Higgs: pp → H, H→WW and ZZ
Factor ≈15

<u>Example: gg and qq</u>
Top: (85% qq, 15% gg at Tevatron)
Factor: 0.85 x 5 + 0.15 x 100
➔ ≈ 20
Squarks: (assume top):
350 GeV: 0.85 x 10 + 0.15 x 1000
➔≈150 to ≈200
500 GeV: 0.85 x 50 + 0.15 x 5000
➔≈500 to ≈1000

Z': ~1 TeV (qq)
Factor: ≈50 to ≈100

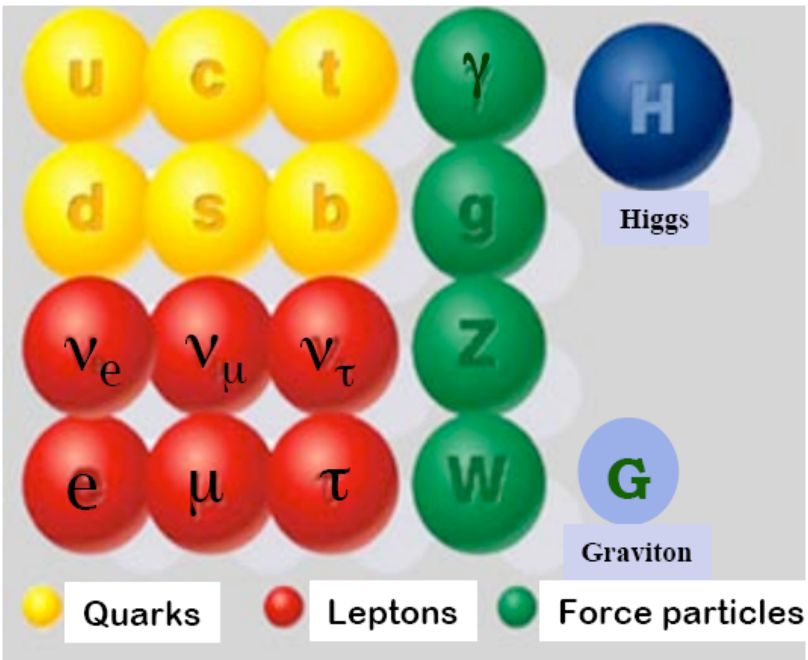


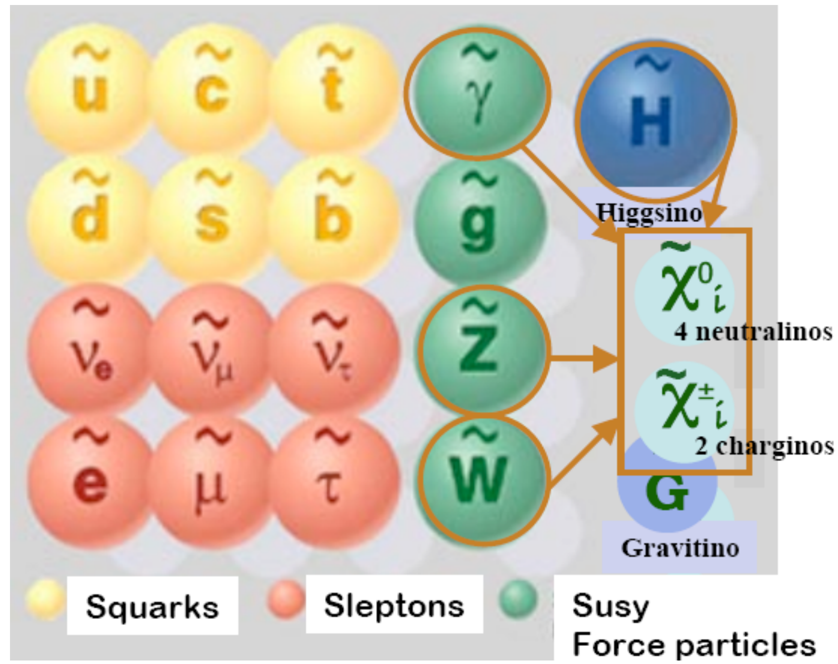
Supersymmetry

Extension of the Standard Model: Introduce a new symmetry

Spin ½ matter particles (fermions) ⇔ Spin 1 force carriers (bosons)

Standard Model particles | **SUSY particles**





New Quantum number: R-parity: $R_p = (-1)^{B+L+2s}$ = *+1 SM particles*, *- 1 SUSY particles*

R-parity conservation:

- *SUSY particles are produced in pairs*
- *The lightest SUSY particle (LSP) is stable*