Constraints on New Physics from ATLAS, CMS and LHCb

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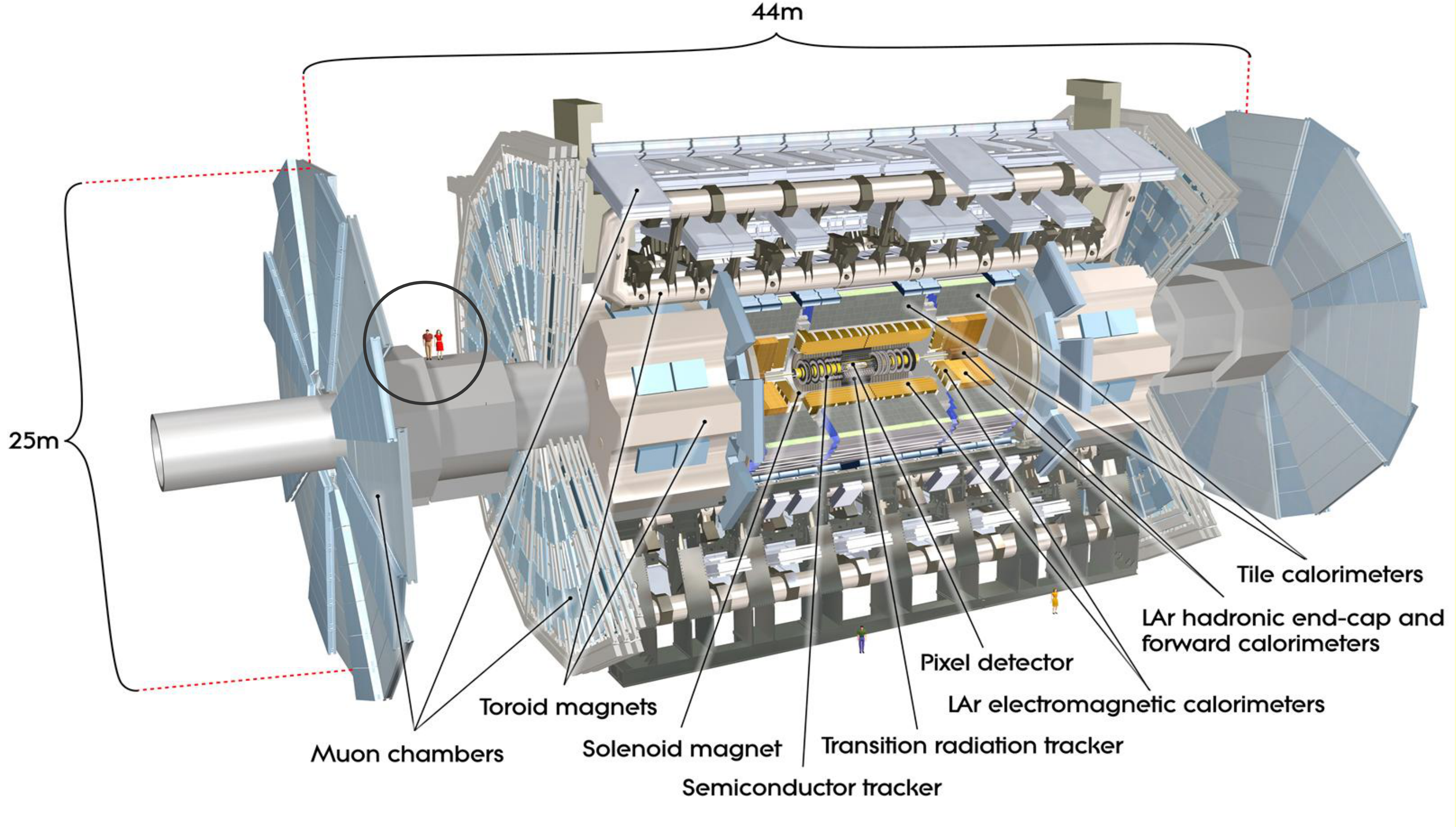
The LHC and the detectors

The LHC and the detectors

ATLAS: General purpose
large and light

38 countries, 174 institutions, 3000 scientists, 1000 students

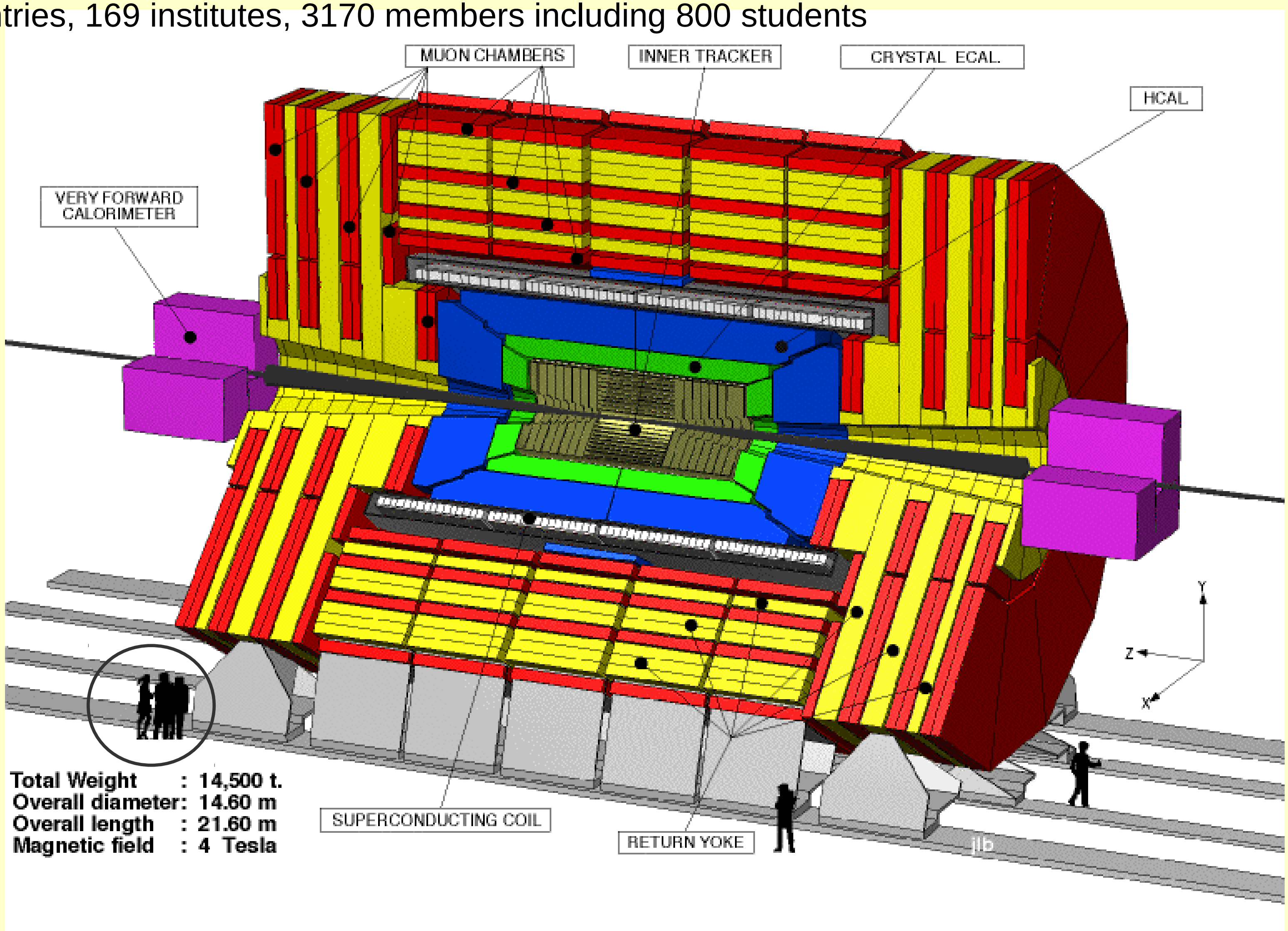
7000 tons



The LHC and the detectors

CMS: General purpose *small and heavy*

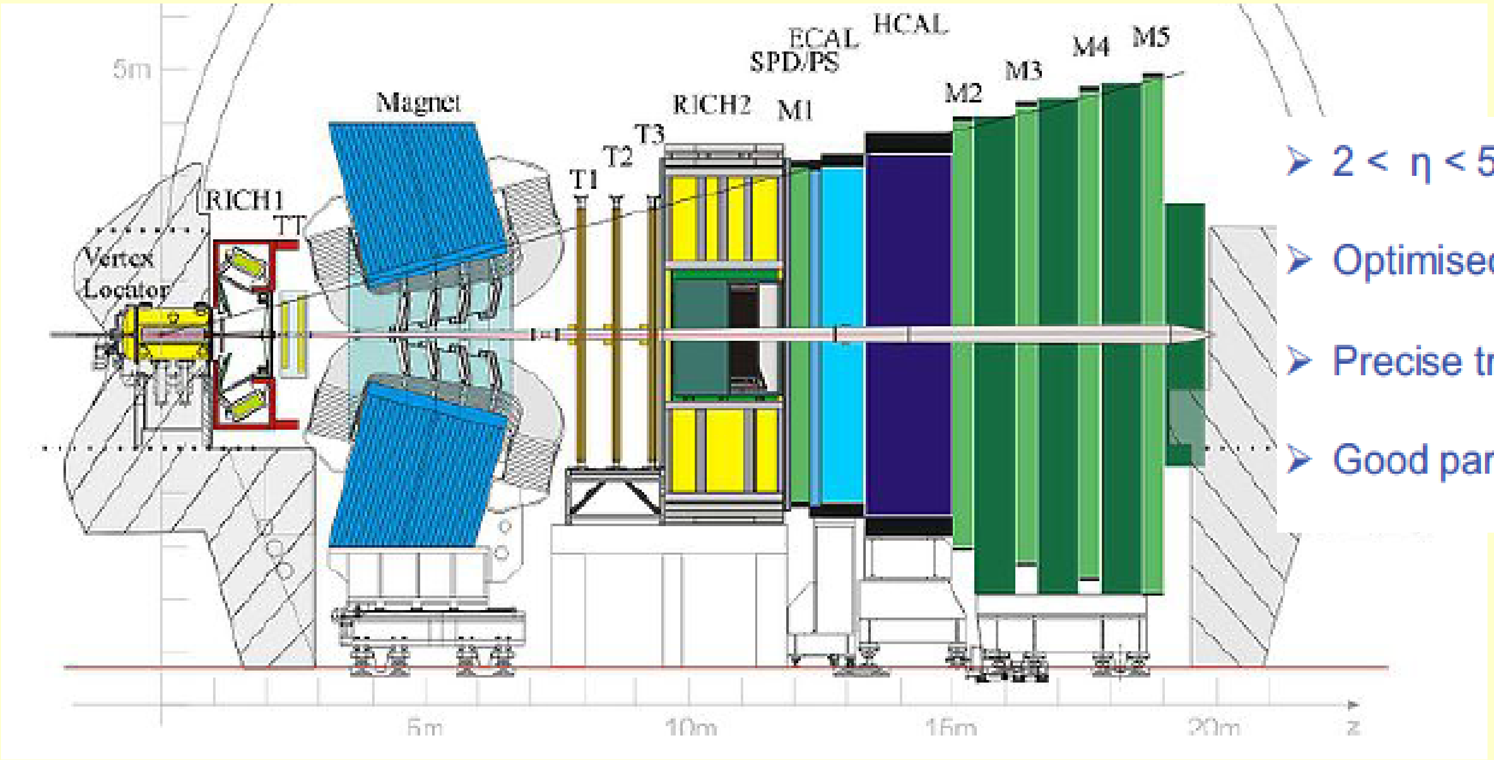
39 countries, 169 institutes, 3170 members including 800 students



The LHC and the detectors

LHCb: one arm forward spectrometer

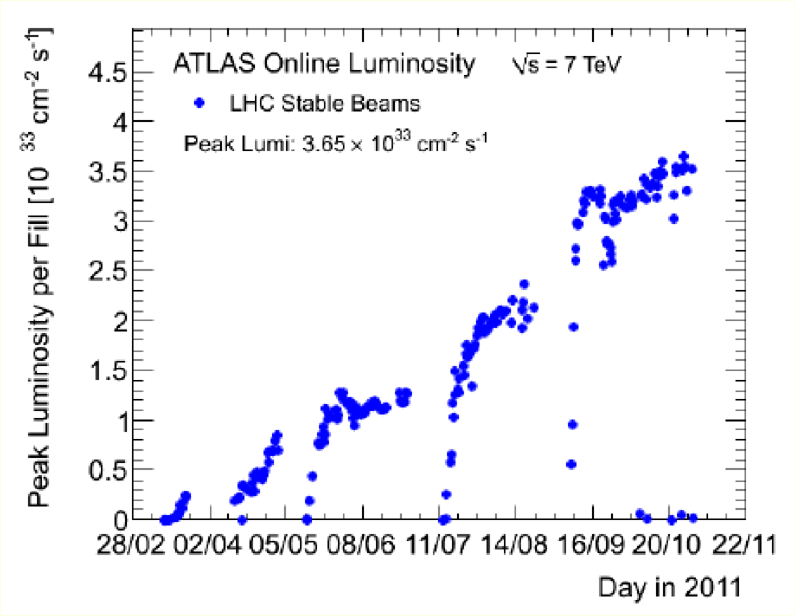
15 countries, 55 institutes, 804 members

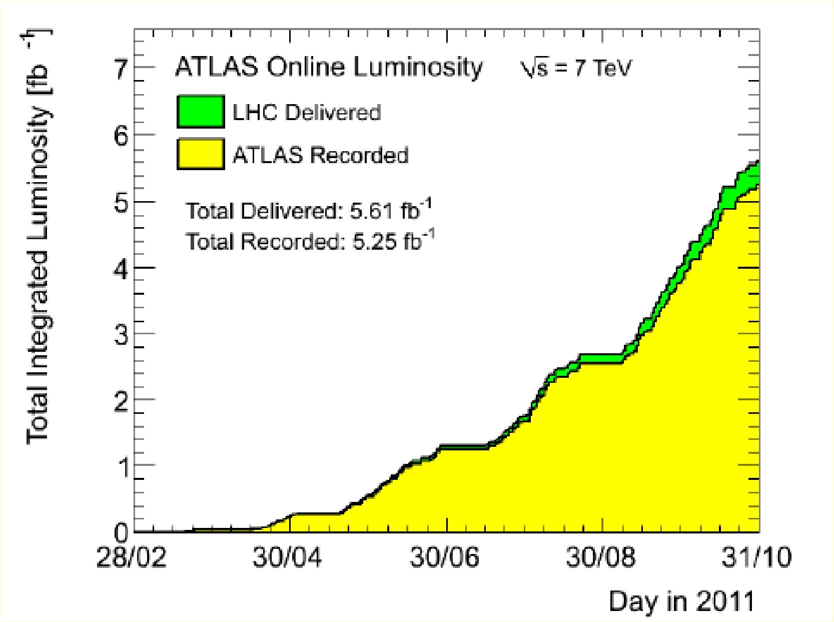


- $2 < \eta < 5$
- Optimised for *b* and *c* physics
- Precise tracking and decay vertex finder
- Good particle ID

The LHC in 2011

	2011/ Design
Colliding bunches	1331 / 2808
Energy/beam	3.5 / 7 TeV
Bunch spacing	50 / 25 ns
Luminosity	3.6 x 10^{33} / 10^{34} cm^{-2} s^{-1}

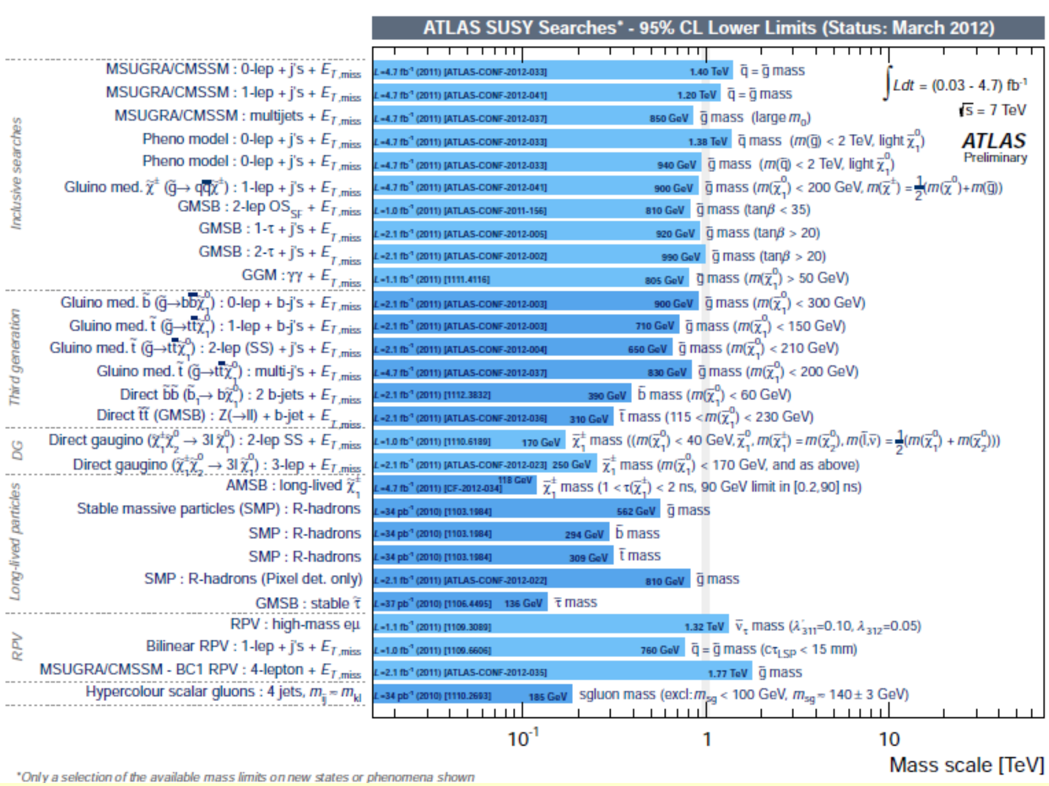


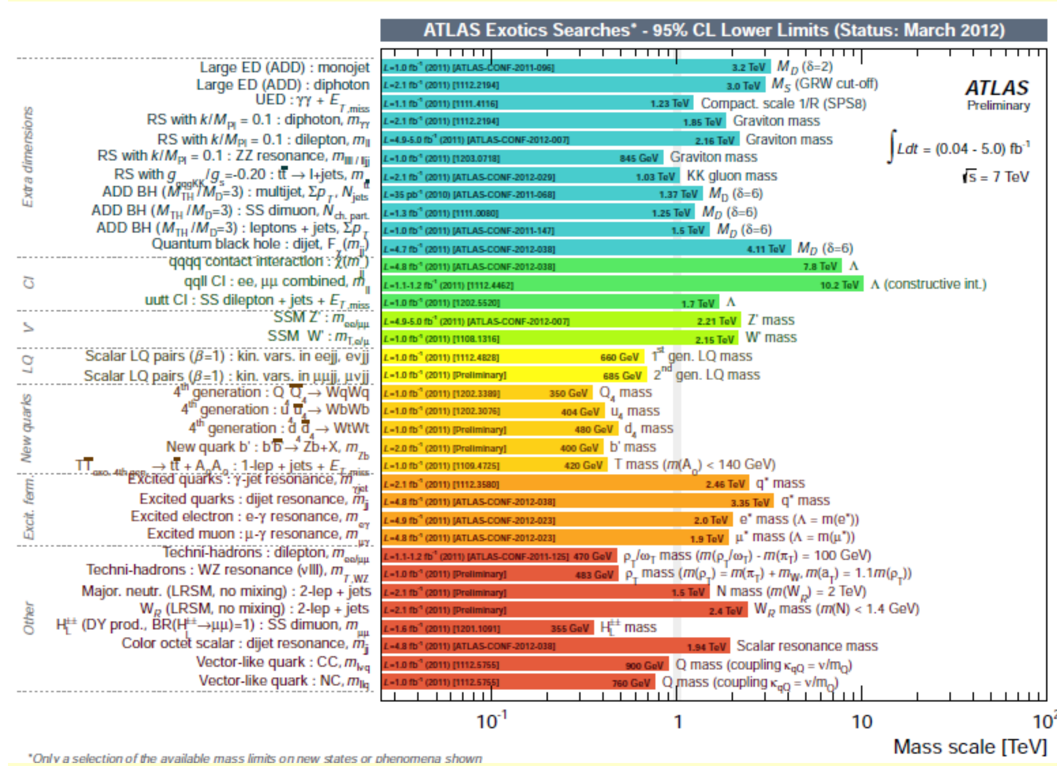


Searches for new physics...

are too many to review all in this talk!

To give you an idea, here are some ATLAS-only summary plots of BSM searches, with selected results from SUSY (left) and non-SUSY (right) models...





Searches for new physics

- I will thus focus mainly on what I am most familiar with, that is some SUSY searches

- Here are the links for more results from ATLAS, CMS and LHCb:

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

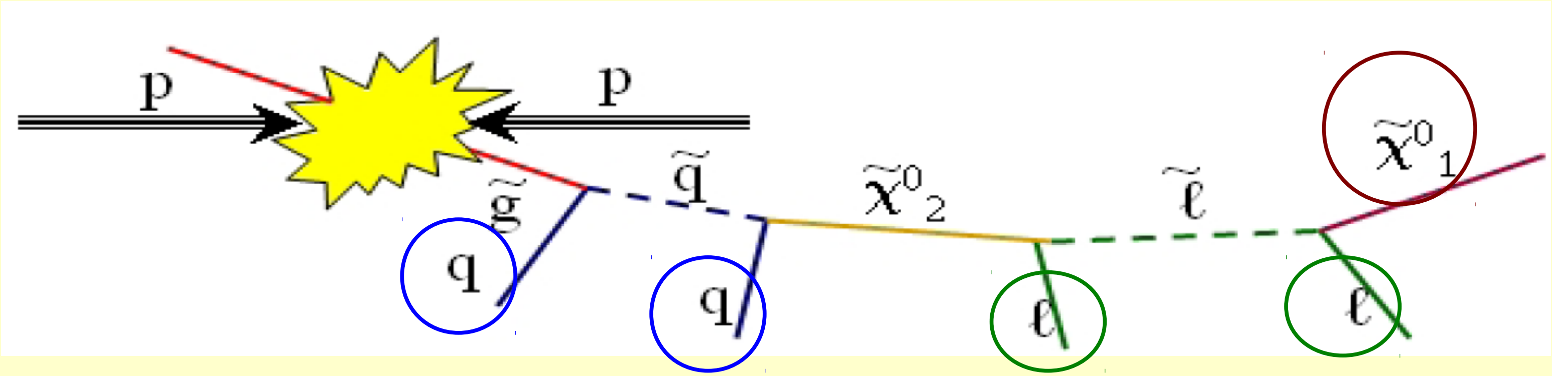
  https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

  http://lhcb.web.cern.ch/lhcb/Physics-Results/LHCb2012_Winter_Results.html

- There are also many clickable links throughout the talk, to get more information on the searches presented

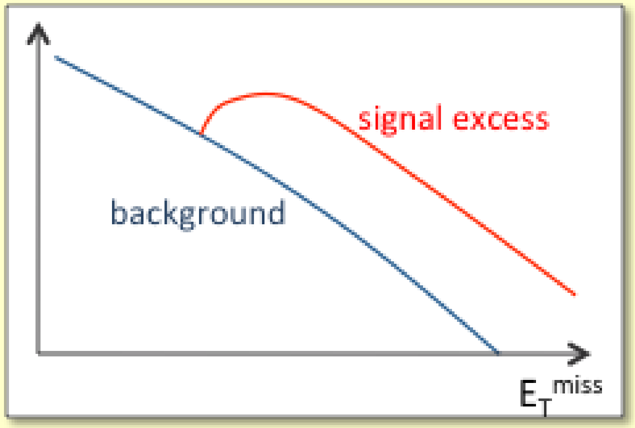
Inclusive SUSY searches

Is BSM physics around the corner?

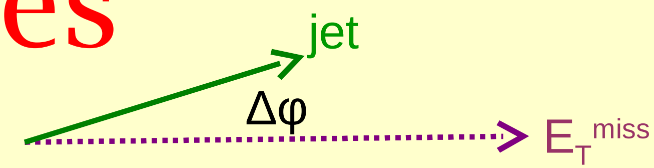


multi–Jets + n leptons + E_T^{miss}

Standard Model backgrounds: tt, W+jets, Z+jets, QCD jets, dibosons...



Other signal/BG discrimination variables



- Azimuthal angle ($\Delta\phi$) between jets and E_T^{miss}
- Scalar pT sum of objects: $H_T \equiv \sum_i p_T^{\text{jet},i} + \sum_i p_T^{\text{lepton},i} + \sum_i p_T^{\text{photon},i}$
- Effective mass: $m_{\text{eff}} = H_T + E_T^{\text{miss}}$

There are also more complex event variables offering discrimination, for example the razor variable:

Searches for the pair production of two heavy particles, each decaying to an unseen LSP plus jets, using the idea of event hemispheres. All the reconstructed objects in each hemisphere are combined into a single "mega-jet" (-> dijet topology). Introduce a frame R, which is the longitudinally boosted frame that equalizes the magnitude of the two mega-jets 3-momenta and construct the observables:

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

Peaks at $M_\Delta = \dfrac{M_S^2 - M_{\text{LSP}}^2}{M_S}$

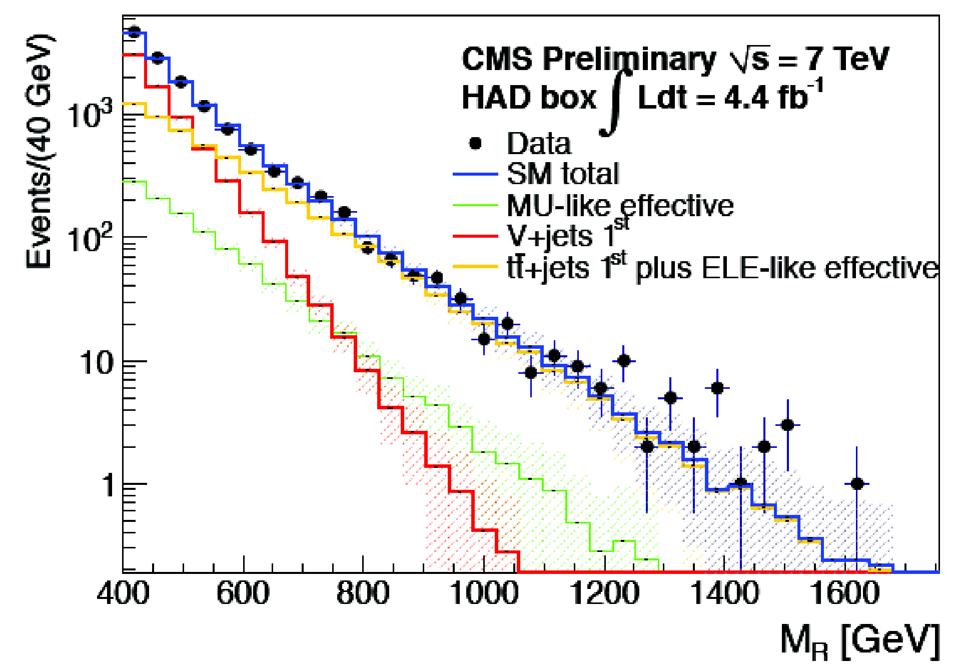
$$M_T^R = \sqrt{\frac{E_T^{miss}(p_T^{j_1} + p_T^{j_2}) - \vec{E}_T^{miss} \cdot (\vec{p}_T^{j_1} + \vec{p}_T^{j_2})}{2}}$$

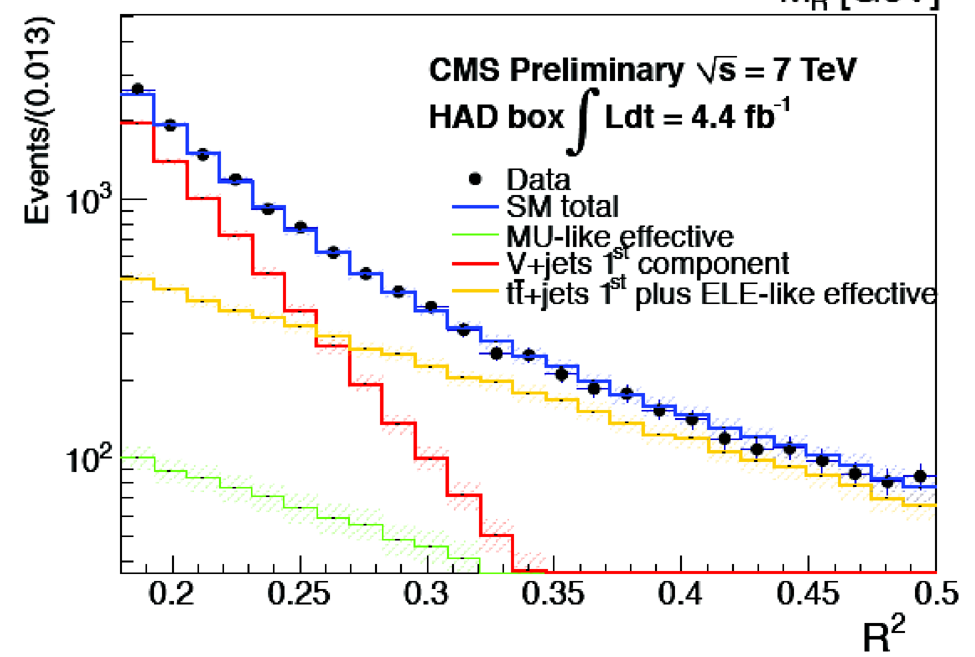
Edge at M_Δ

$$R = \frac{M_T^R}{M_R}$$

Ratio of two estimators of SUSY scale – describes transverse shape of event

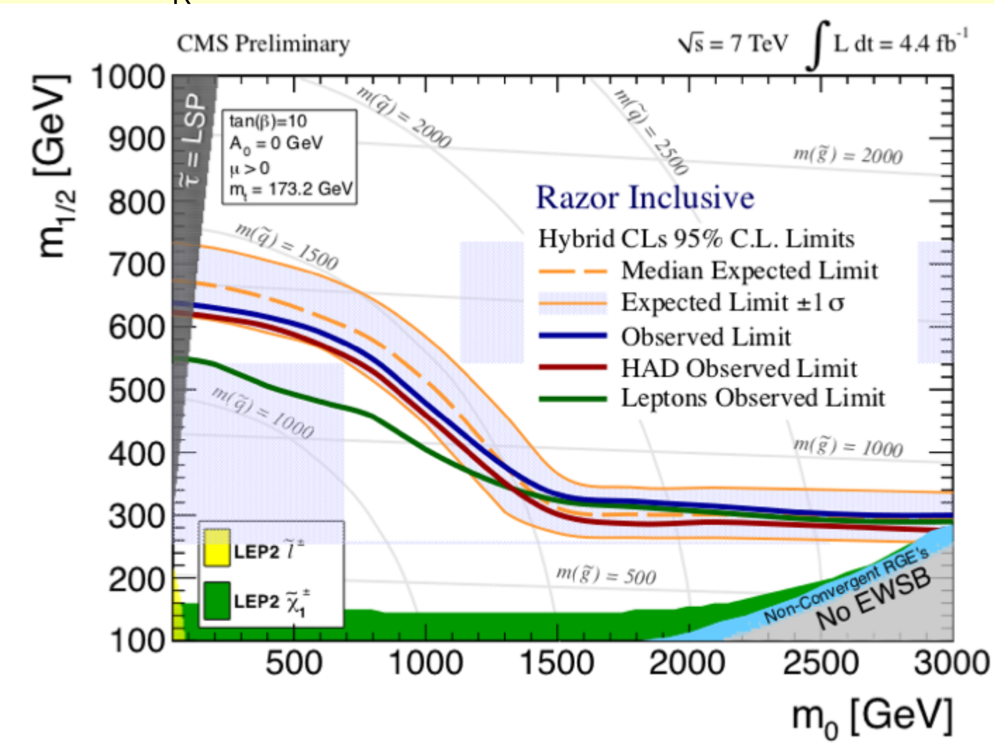
Razor analysis





CMS-PAS-SUS-12-005

Various signal regions defined in the M_R vs R plane, with or without leptons

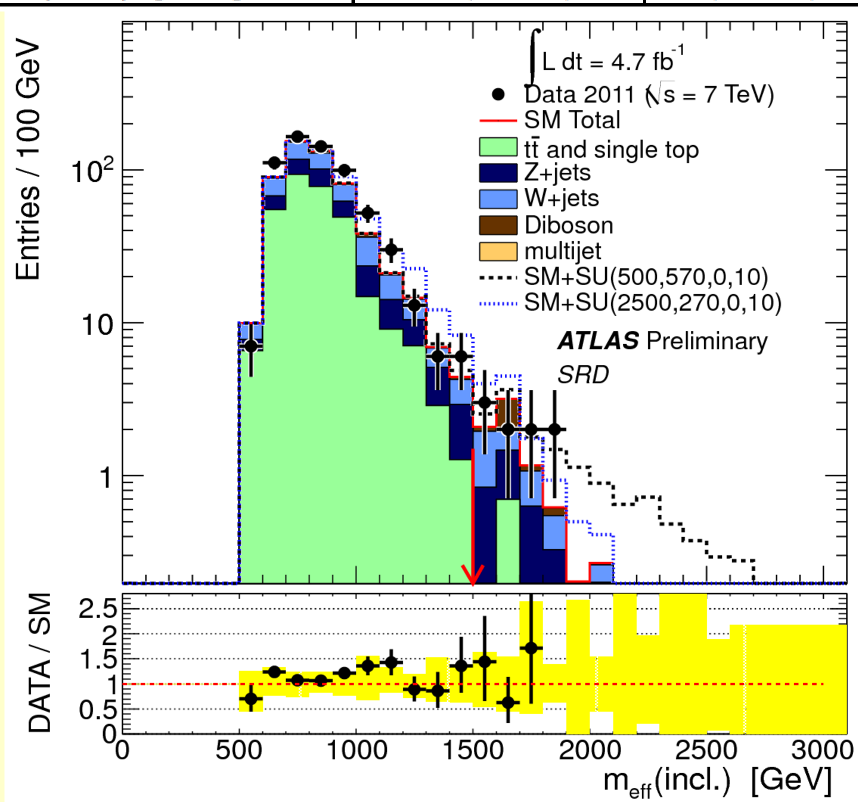


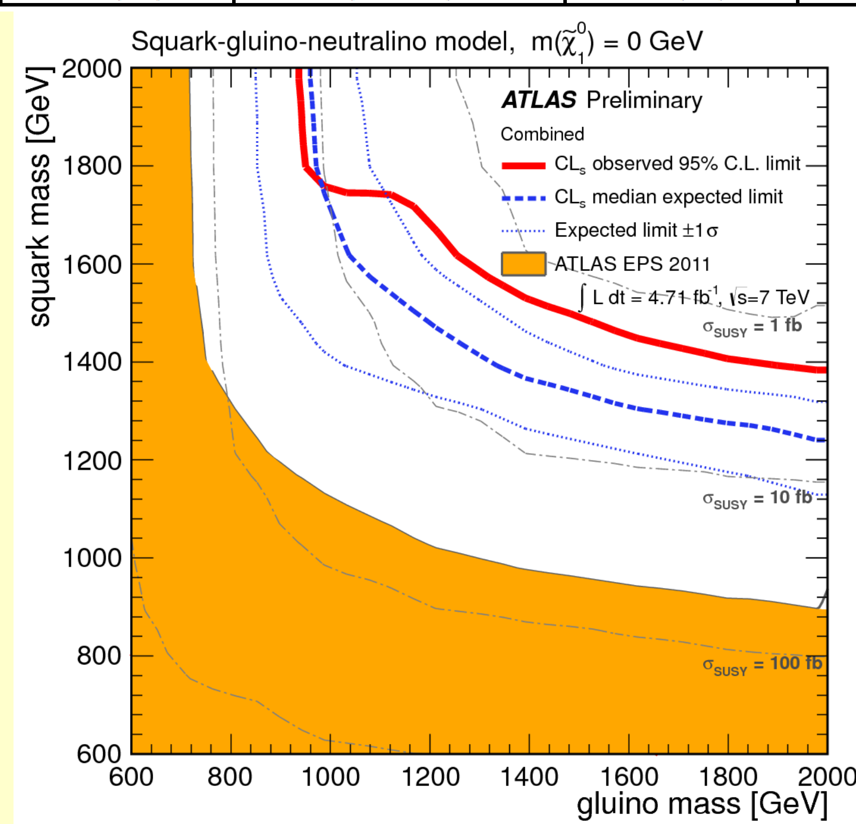
Exclude up to 1.35 TeV squarks and gluinos for $m_{gluino} \sim m_{squark}$

Jets + missing ET

ATLAS-CONF-2012-033

Requirement	Channel					
	2 jet	2 jet (soft)	3 jet	4 jet	5 jet	6 jet
E_T^{miss} [GeV] $>$	160					
$\Delta\phi(\text{jet}, E_T^{\text{miss}})_{\text{min}} >$	$0.4(i = 1, 2, (3))$			$0.4(i = 1, 2, (3))$, $0.2(p_T > 40$ GeV jets)		
$E_T^{\text{miss}}/m_{\text{eff}}(Nj) >$	0.3(2j)	0.4(2j)	0.25(3j)	0.25(4j)	0.2(5j)	0.15(6j)
$m_{\text{eff}}(\text{incl.})$ [GeV] $>$	1900/1400/–	–/1200/–	1900/–/–	1500/1200/900	1500/–/–	1400/1200/900



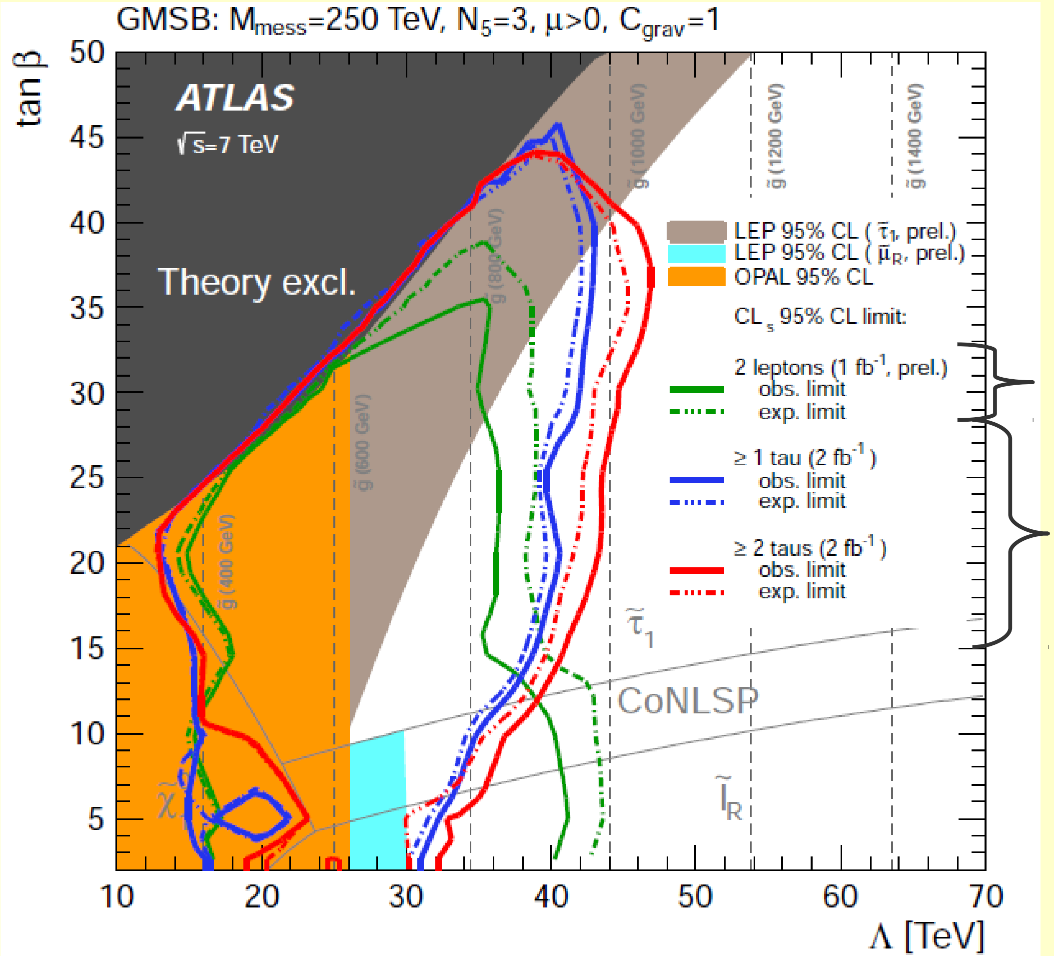


No discrepancy with respect to SM predictions

Degenerated 1st & 2nd generation squarks, LSP mass set to 0 (results hold up to ~200 GeV).

Probing GMSB

- In GMSB models, the LSP is the gravitino, the next–to–lightest SUSY particle (NLSP) determines phenomenology



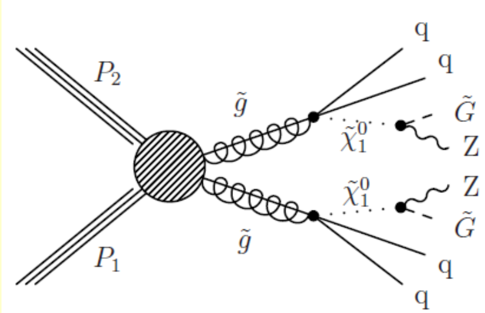
990 GeV limit on $\tilde{g}$ mass for tan $\beta > 20$

Neutralino or slepton NLSP : 2-lepton + jets + MET

ATLAS-CONF-2011-156

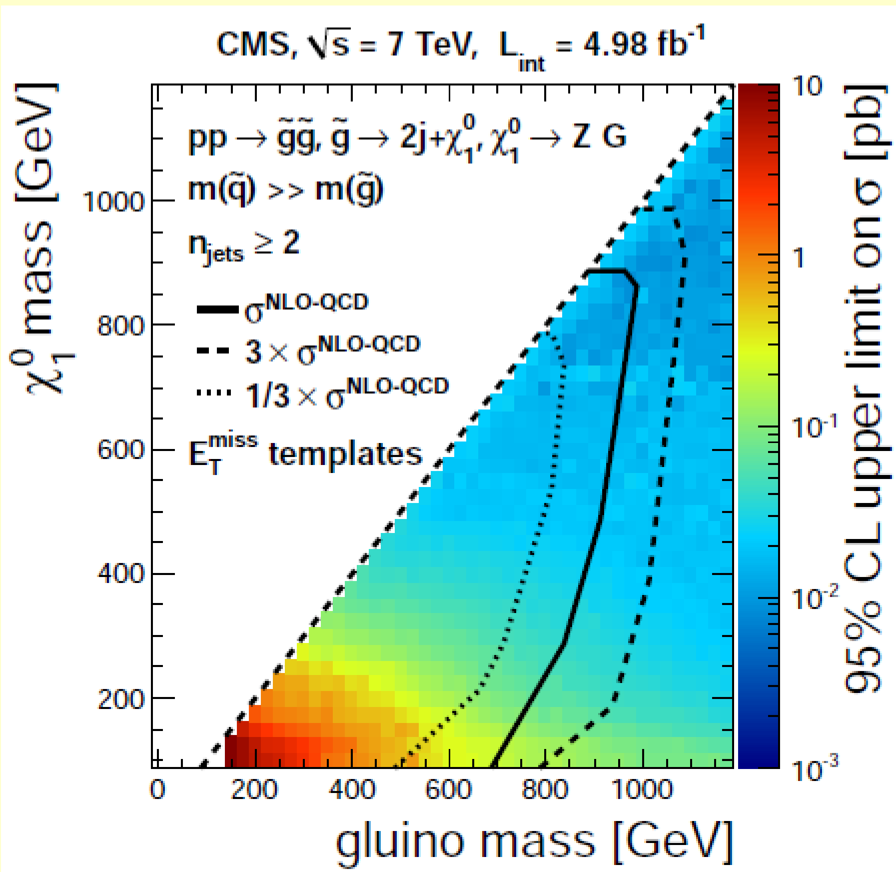
Stau NLSP: tau(s) + jets + E_T^{miss}

1204.3852
1203.6580

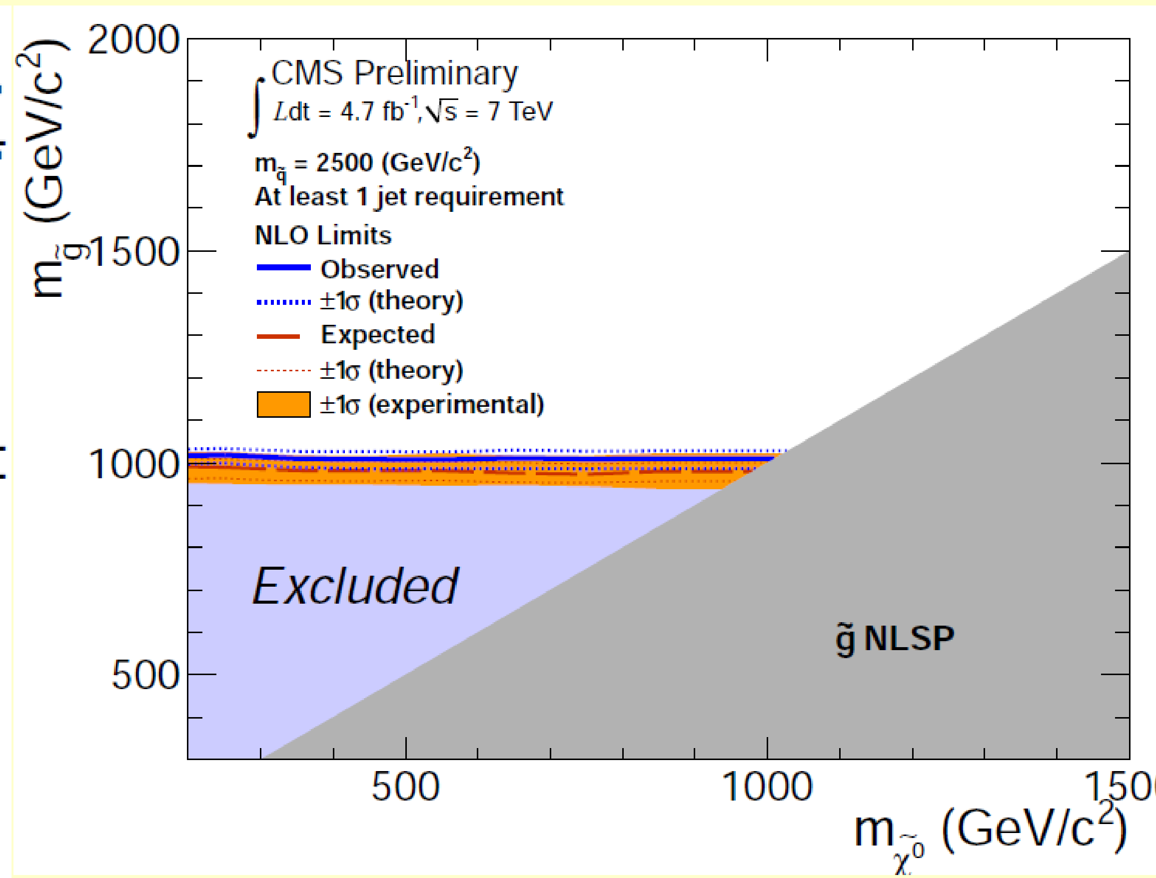


Probing GMSB

1204.3774



PAS-SUS-12-001



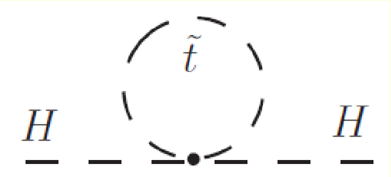
wino / higgsino NLSP:

Z + jets + E_T^{miss}

Bino NLSP:

2 photons + jet + E_T^{miss}

In this case as well, the limits on the gluino mass are rather stringent...

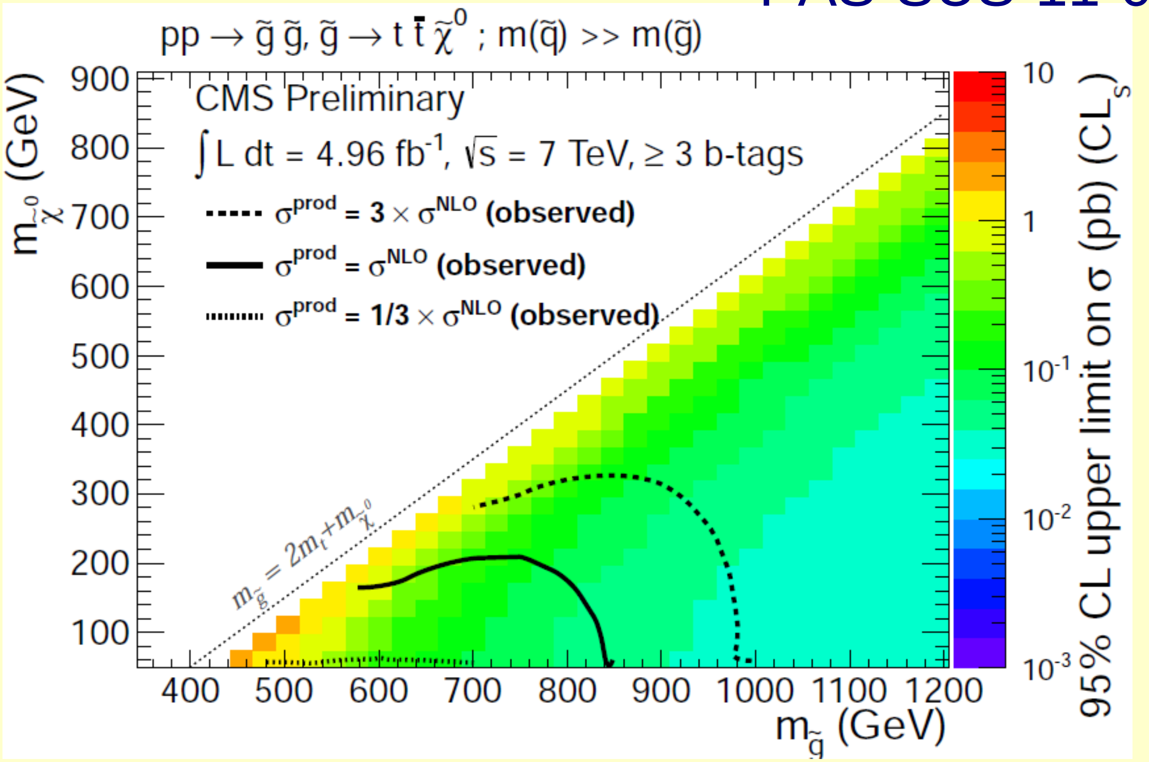


3rd generation

Can be lighter than the other two, naturalness points to a light third generation

Gluino-mediated searches

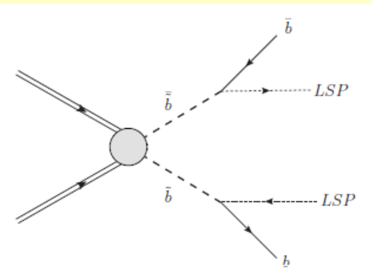
PAS-SUS-11-028



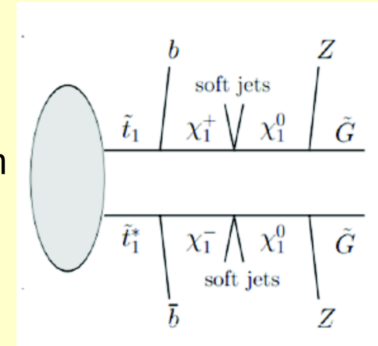
Lepton + b-jets + E_T^{miss} final state

3rd generation

Direct searches



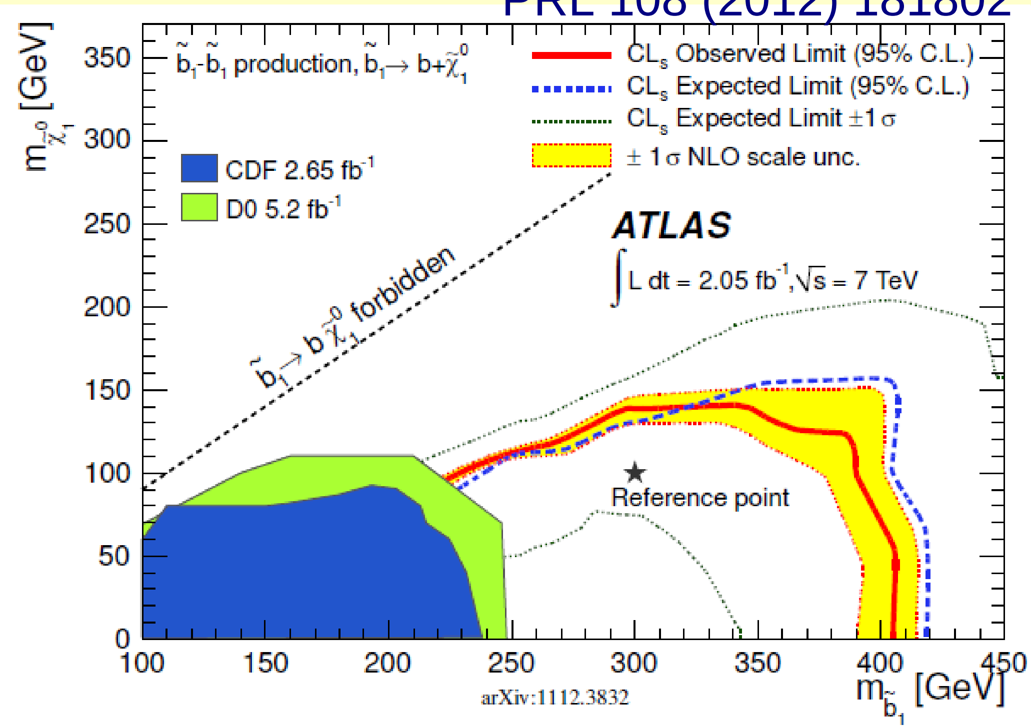
2 b-jets + MET + MCT*
* cotransverse mass of the bjet system



GMSB model

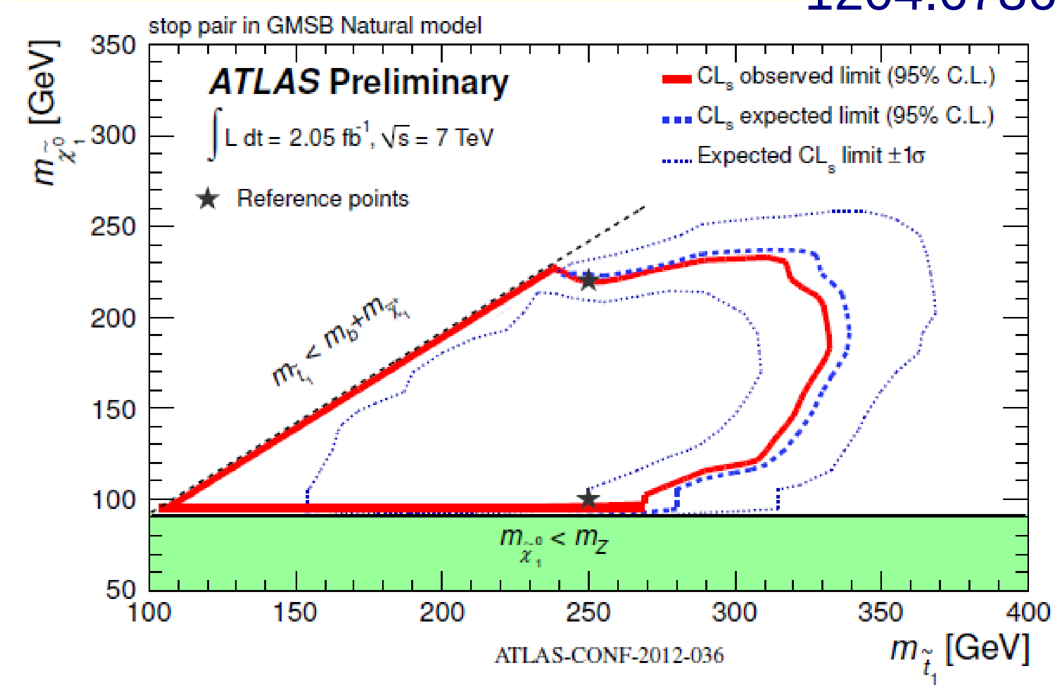
Z->ee,μμ + jets (1b) + MET

PRL 108 (2012) 181802



$m(\tilde{b}_1) < 390$ GeV excluded for
$m(\tilde{\chi}^0) < 60$ GeV

1204.6736



m(t_1) < 310 GeV for 115 GeV < m(LSP) < 230 GeV

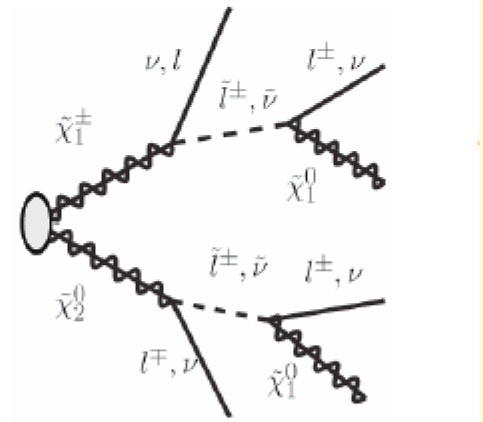
m(t_1) < 330 GeV for m(LSP)=190 GeV

m(t_1) < 240 GeV for m(LSP)>m(Z)

Direct gaugino

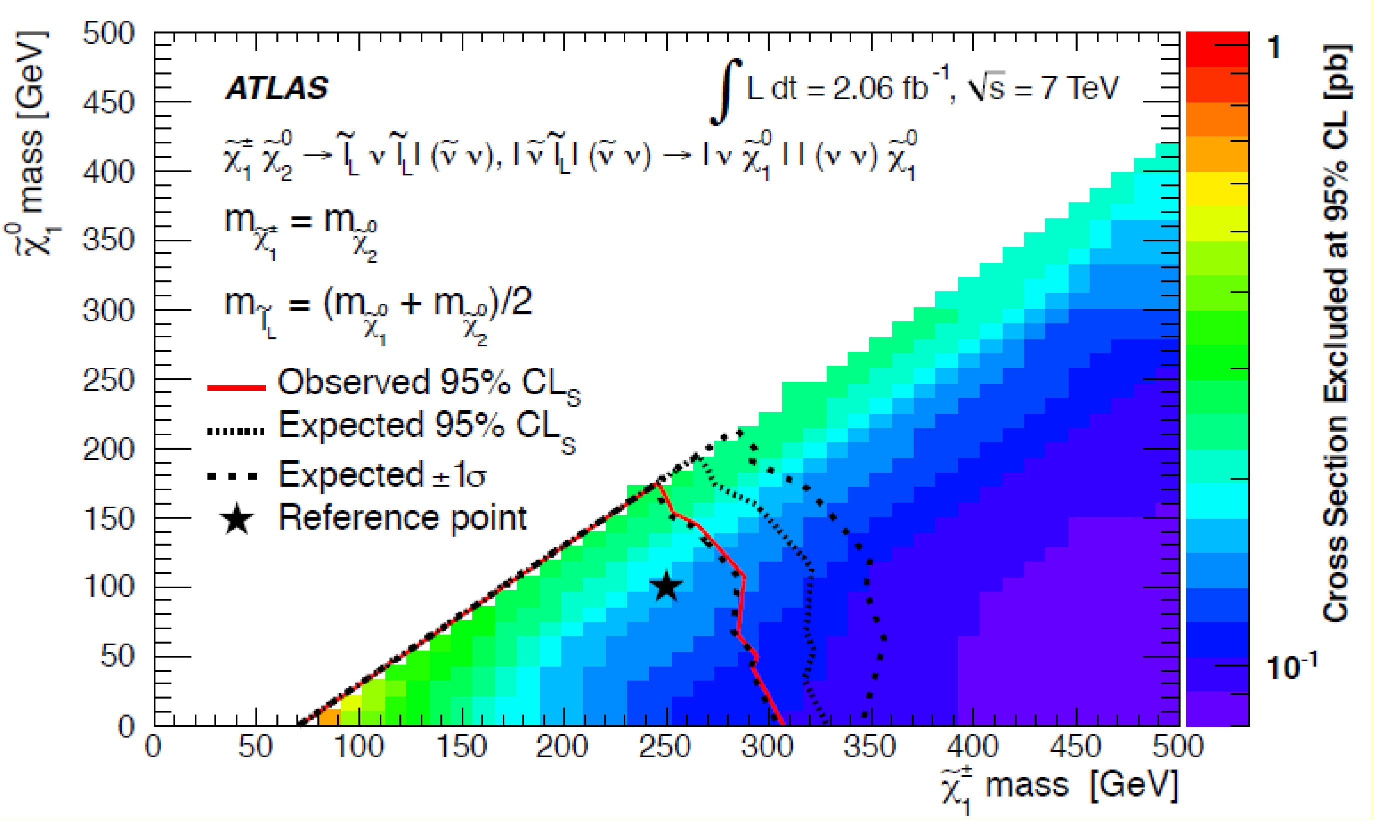
What about the electroweak sector?

1204.5638



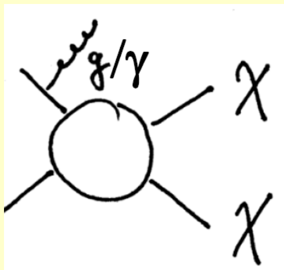
$\mathrm{BR}(\tilde{\chi}_1^\pm \to \tilde{l}^\pm \nu) = \mathrm{BR}(\tilde{\chi}_1^\pm \to l^\pm \tilde{\nu}) = 50\%$

$\mathrm{BR}(\tilde{\chi}_2^0 \to \tilde{l}^\pm l^\mp) = \mathrm{BR}(\tilde{\chi}_2^0 \to \tilde{\nu}\nu) = 50\%$



3-lepton + E_T^{miss} + Z-veto + b-jet veto

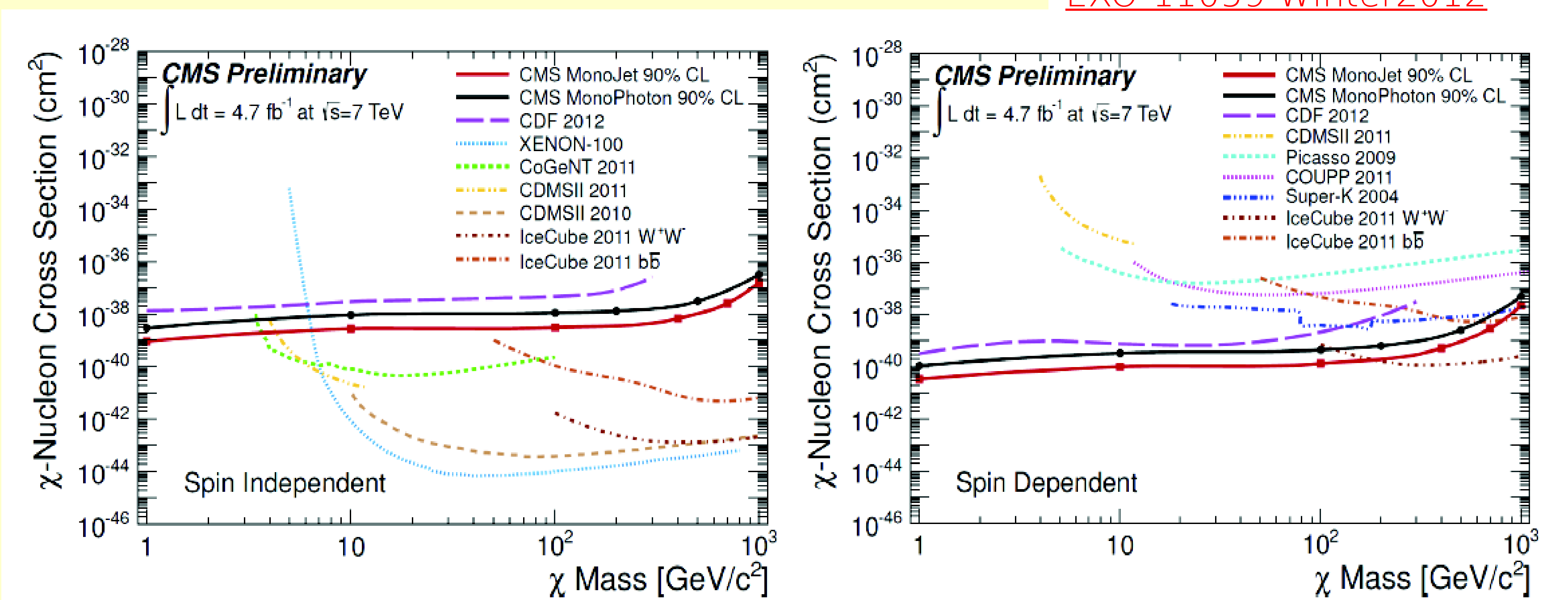
Probing 'invisible' production



Two search channels:
Jet + E_T^{miss}
γ + E_T^{miss}

arXiv:1204.0821

EXO-11059-Winter2012

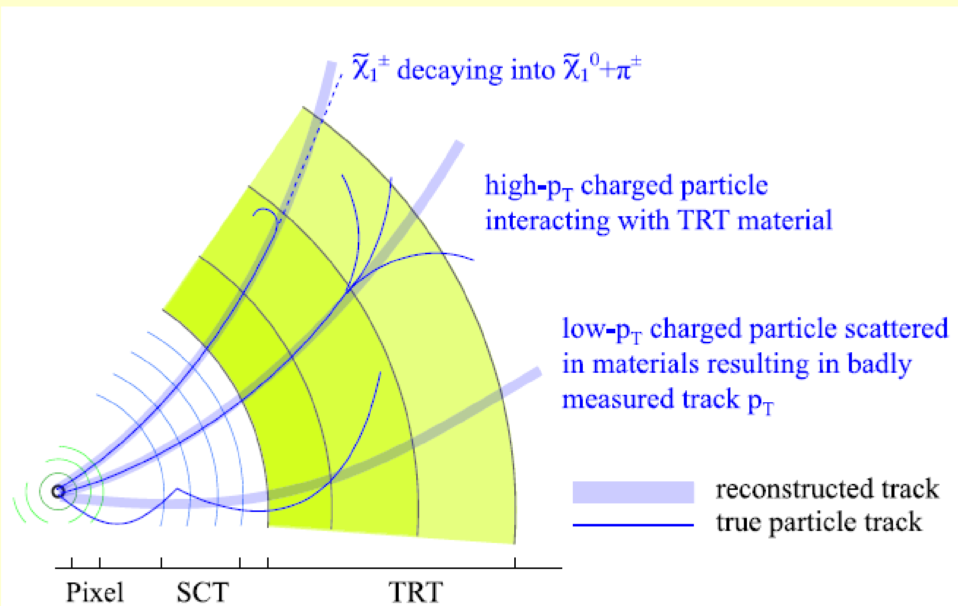


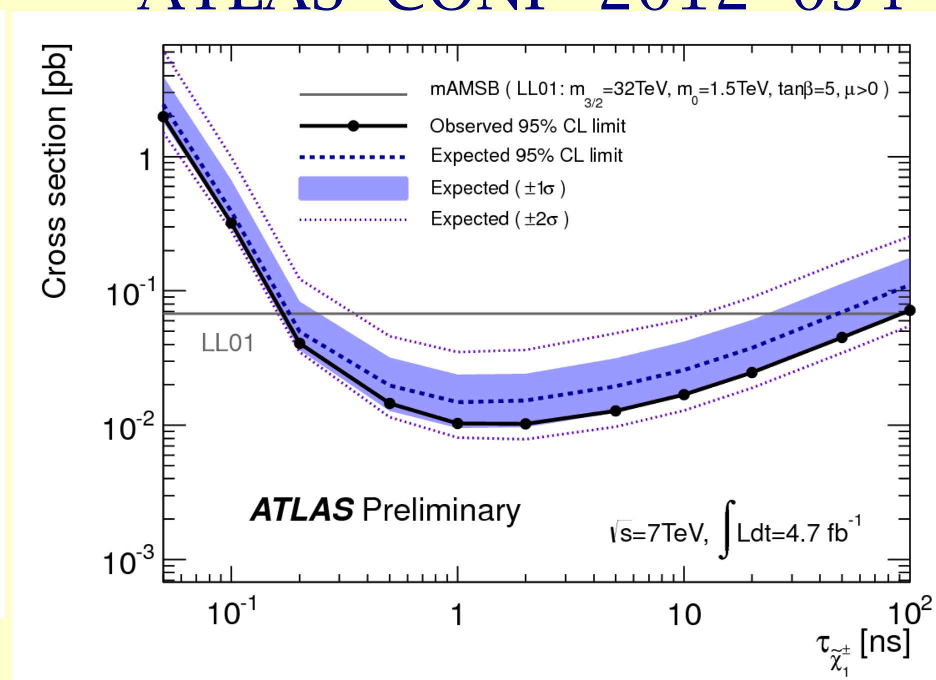
Assumptions:
– Dirac particles
– heavy particle mediating interactions with dark sector can be integrated out

Long-lived particles

- If the mass gap between NLSP and LSP is very small, metastable NLSP can be produced
- Search for high-pt tracks that stop in outer TRT in jets+MET events

ATLAS-CONF-2012-034





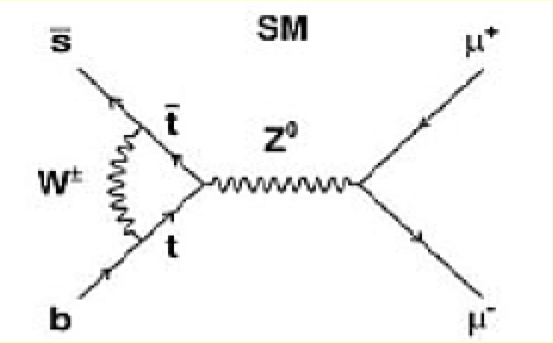
Exclude AMSB models with $m(\chi_1^+) < 90$ (118) GeV and 0.2 (1) $< \tau < 90$ (2) ns

Precision measurements: B–>μμ

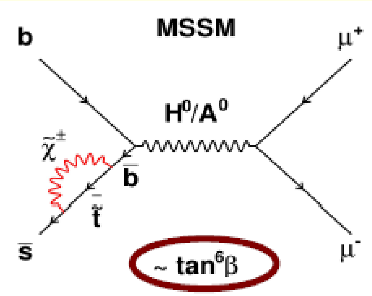
SM prediction:

SM $B(B_s \to \mu\mu) = (3.2 \pm 0.2) \times 10^{-9}$

SM $B(B \to \mu\mu) = (0.1 \pm 0.01) \times 10^{-9}$



Branching ratio very sensitive to new physics



$$BR(B_s \to \mu^+\mu^-) \propto \tan^6\beta / m_A^4$$

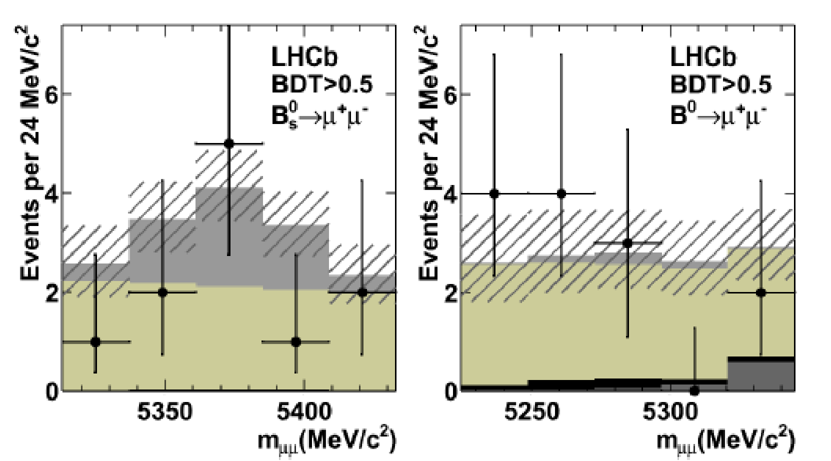
CDF has an excess (10 fb^{-1}):
Link
$B(B_s \to \mu\mu) = (1.3^{+0.9}_{-0.7}) \times 10^{-8}$

CMS limit at 95% CL (5 fb^{-1}) :
1203.3976
$B(B_s \to \mu\mu) < 7.7 \times 10^{-9}$

$B(B \to \mu\mu) < 1.8 \times 10^{-9}$

Precision measurements: B–>μμ

1203.4493

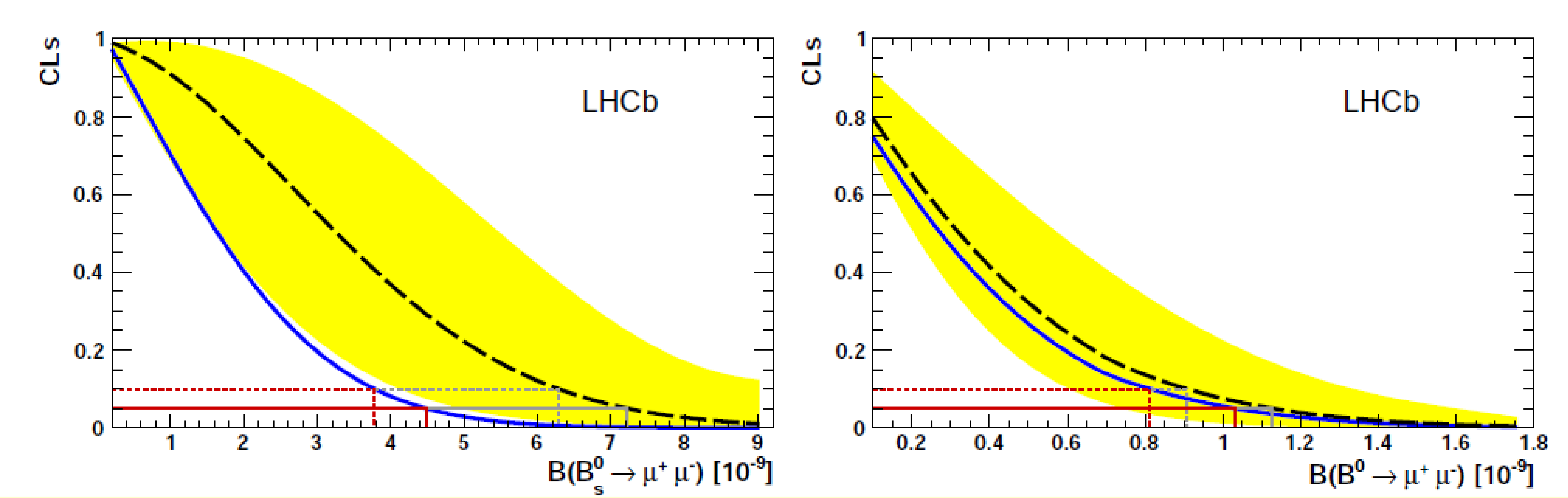


Set the most stringent upper limits to date at 95% CL:

$B(B_s \to \mu\mu) < 4.5 \times 10^{-9}$

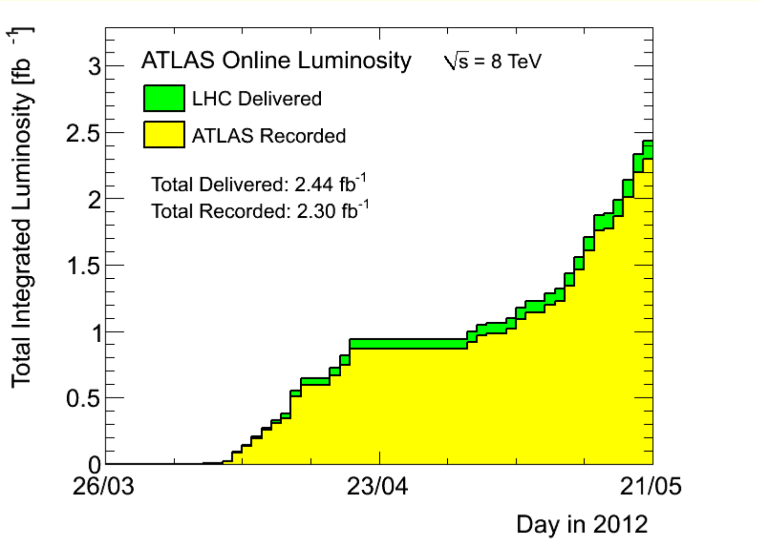
$B(B \to \mu\mu) < 1.03 \times 10^{-9}$

With the 2012 data, expect a 3σ evidence if BR($B_s \to \mu\mu$) is SM [X. Vidal, Pheno12]

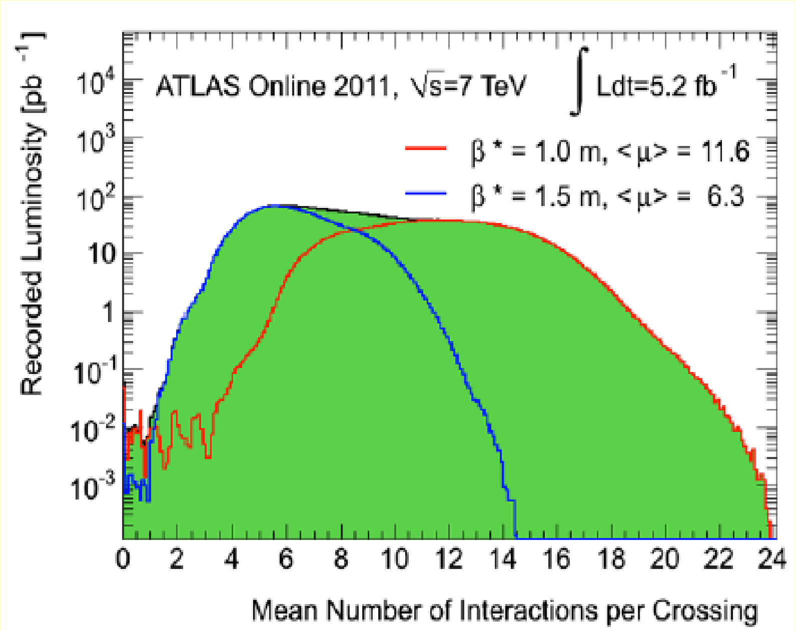


And the search continues...

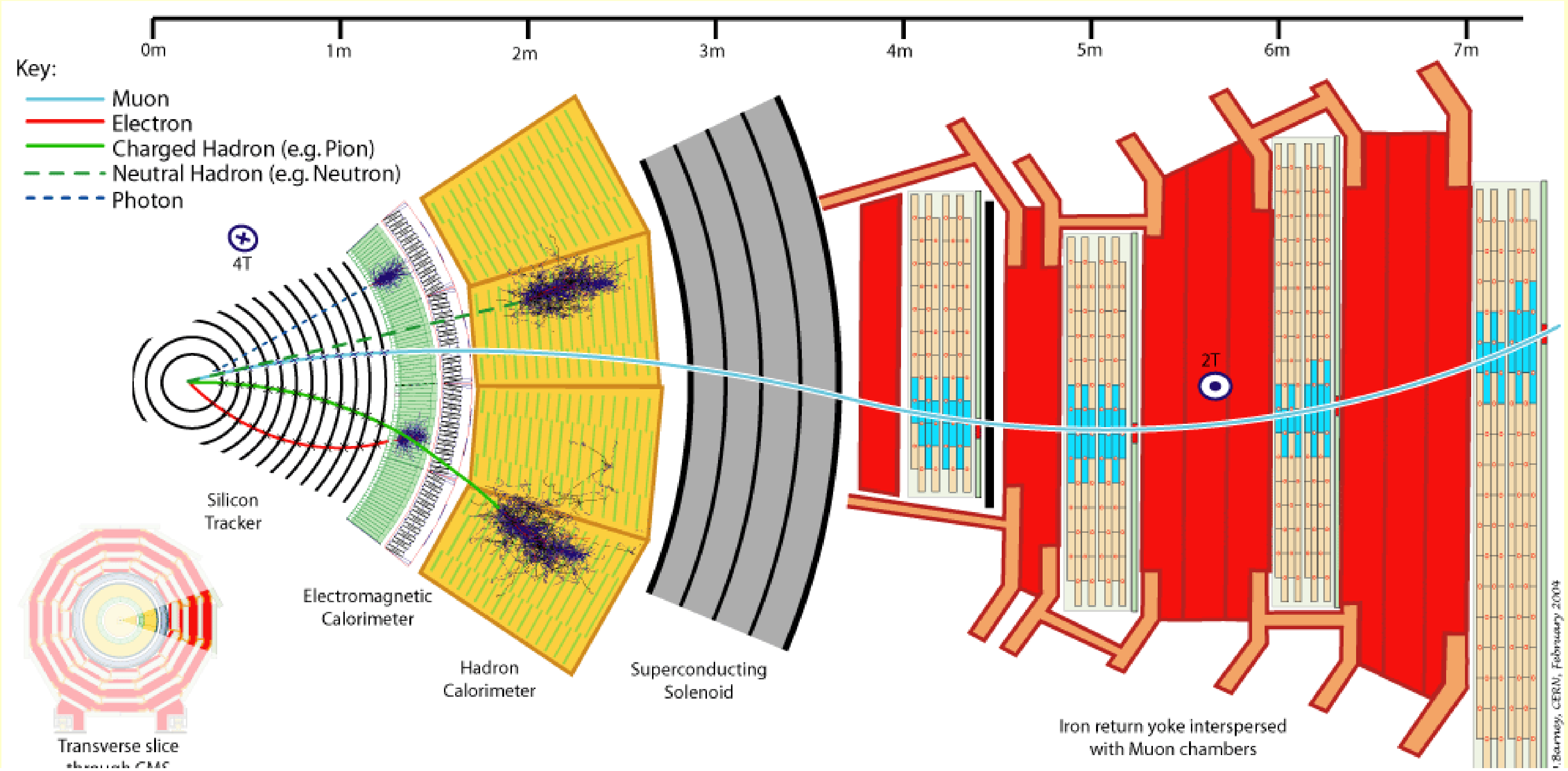
- The searches are now becoming very diversified, the accumulation of statistics allow new channels to open up
- But so far, in the new physics searches, it's been limits, limits, limits
- 2012:
  - 4 TeV / beam
  - already more than 2 fb^{-1}
  - luminosity at 6.0 x $10^{33} cm^2 s^{-1}$
  - 15 fb^{-1} by the end of the year



BACKUP slides...

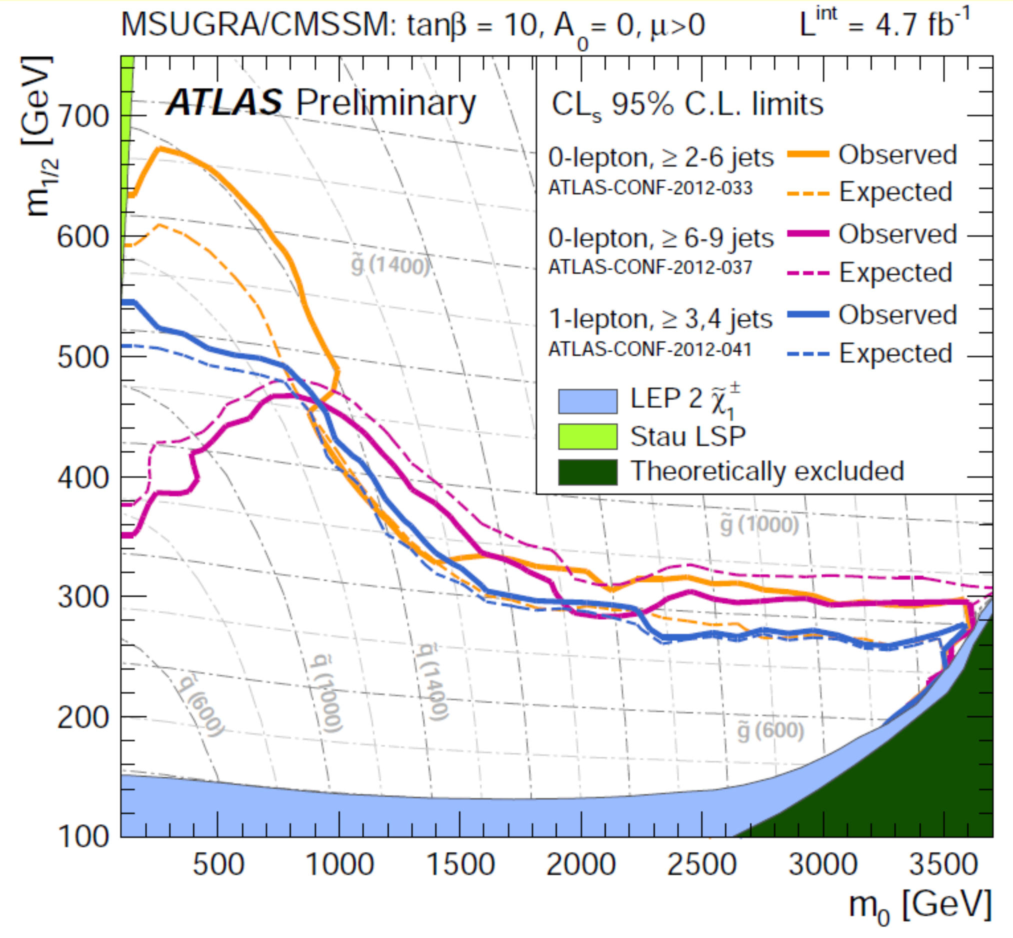

ATLAS Online 2011, √s=7 TeV
∫Ldt=5.2 fb⁻¹
β * = 1.0 m, <μ> = 11.6
β * = 1.5 m, <μ> = 6.3
Recorded Luminosity [pb⁻¹]
Mean Number of Interactions per Crossing

Object identification



j	Jet	Cluster in EM and hadronic calorimeters (and inner tracker)
γ	Photon	EM cluster without matching track
e	Electron	EM cluster with matching track
μ	Muon	Matching tracks in inner and muon trackers
τ	Tau lepton	Narrow jet with matching track(s)
MET	Missing E_T	pT required to balance all of the above (and more)

The cMSSM plane with 4.7 fb^{-1}



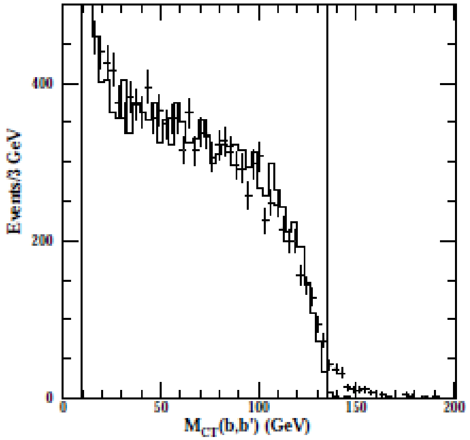
ATLAS-CONF-2012-033
Up to 6 jets + ETmiss

ATLAS-CONF-2012-037
Up to 9 jets + ETmiss

ATLAS-CONF-2012-041
1 lepton + jets + ETmiss

Inclusive searches are already producing stringent limits on gluinos and the first two generations of squarks...
If it exists, where could SUSY be hiding?

$t\bar{t}$ $m_{CT}(b, b)$ from JHEP 1003:030,2010:



Contransverse Mass

$$m_{CT}^2 = [E_T(b_1) + E_T(b_2)]^2 - [\vec{p_T}(b_1) - \vec{p_T}(b_2)]$$

- $\tilde{b}_1 \tilde{b}_1$ events: Endpoint at $\frac{m(\tilde{b}_1)^2 - m(\tilde{\chi}_1^0)^2}{m(\tilde{b}_1)}$
- $t\bar{t}$ events: Endpoint at ≈ 135 GeV