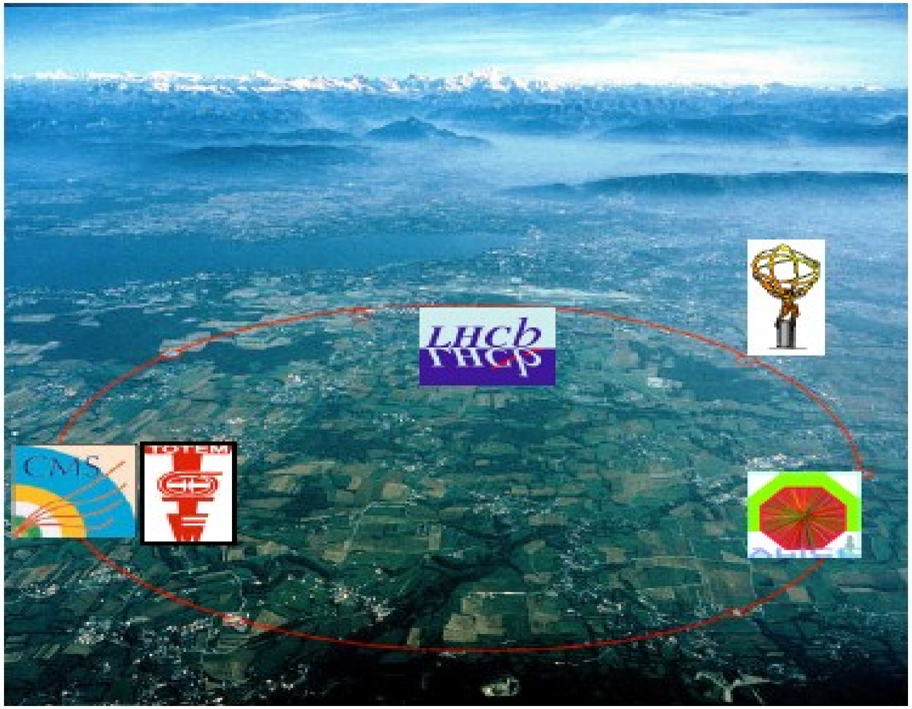
Physics with first fb^{-1}

at Large Hadron Collider

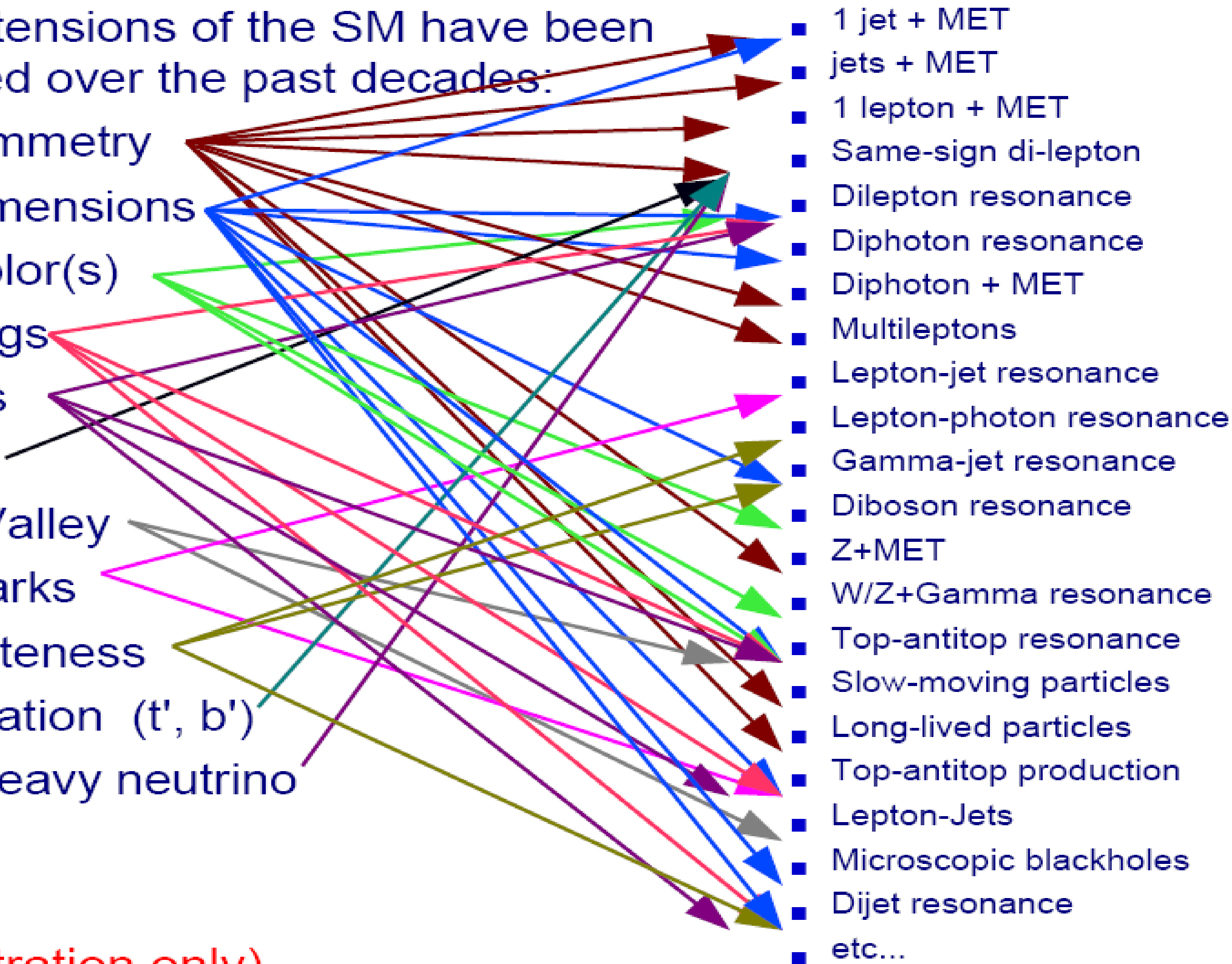
Today:

- **Searches for New Physics**
  - **SUSY**
  - **Heavy resonances**
  - **Exotica**



Long list of models and signatures

- Many extensions of the SM have been developed over the past decades:
- Supersymmetry
- Extra-Dimensions
- Technicolor(s)
- Little Higgs
- No Higgs
- GUT
- Hidden Valley
- Leptoquarks
- Compositeness
- 4^{th} generation (t', b')
- LRSM, heavy neutrino
- etc...



(for illustration only)

Long list of models and signatures

- Many extensions of the SM have been developed over the past decades:
- Supersymmetry
- Extra-Dimensions
- Technicolor(s)
- Little Higgs
- No Higgs
- GUT
- Hidden Valley
- Leptoquarks
- Compositeness
- 4th generation (t', b')
- LRSM, heavy neutrino
- etc...

(for illustration only)

- 1 jet + MET
- jets + MET
- 1 lepton + MET
- Same-sign di-lepton
- Dilepton resonance
- Diphoton resonance
- Diphoton + MET
- Multileptons
- Lepton-jet resonance
- Lepton-photon resonance
- Gamma-jet resonance
- Diboson resonance
- Z+MET
- W/Z+Gamma resonance
- Top-antitop resonance
- Slow-moving particles
- Long-lived particles
- Top-antitop production
- Lepton-Jets
- Microscopic blackholes
- Dijet resonance
- etc...

A complex 2D problem

Experimentally, a **signature standpoint** makes a lot of sense:

→ Practical

→ Less model-dependent

→ Important to cover every possible signature

Supersymmetry

Cascade ending with LSP
→ large MET

1 Jets+MET: Gluino and Squark prod. dominate

2 Leptons(+jets)+MET: lower branching ratio/cross-section but complementary

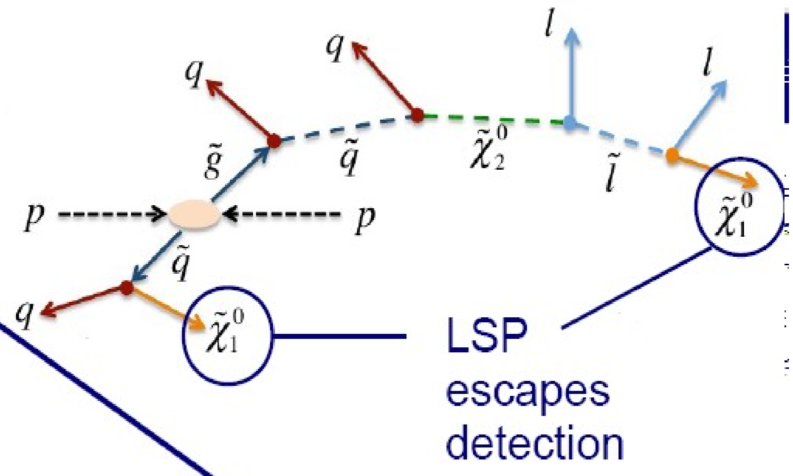
3 3rd generation (b or t)+MET:

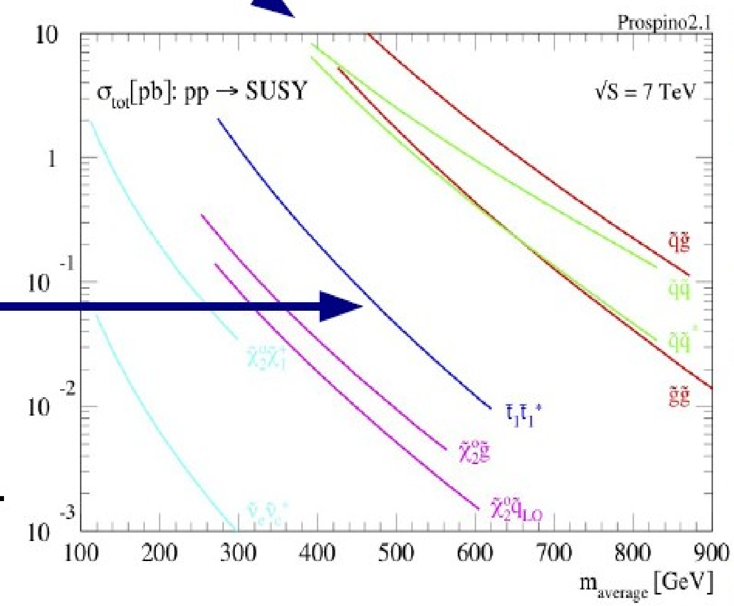
- → in cascade
- → direct production requires > 1 fb^{-1}
  → coming soon

4 Photon(s)+MET: GMSB models

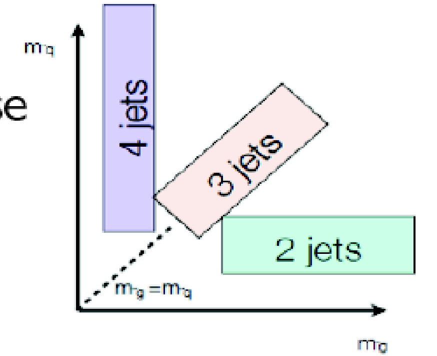
---

5 "Exotic" SUSY: long-lived, no MET

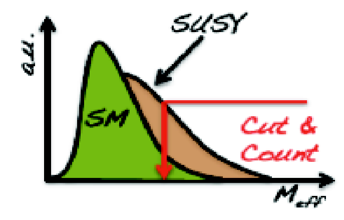


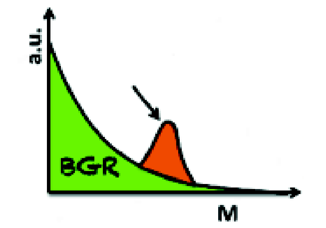


General search strategy



- Definition of **Signal Regions** (SRs) that maximise sensitivity to different models
  - → based on **discriminating variables**
- Identification and estimation of **SM backgrounds**
  - → different techniques (preferably data-driven)
- Search for **non-SM excess**
  - → cut & count
  - → resonances



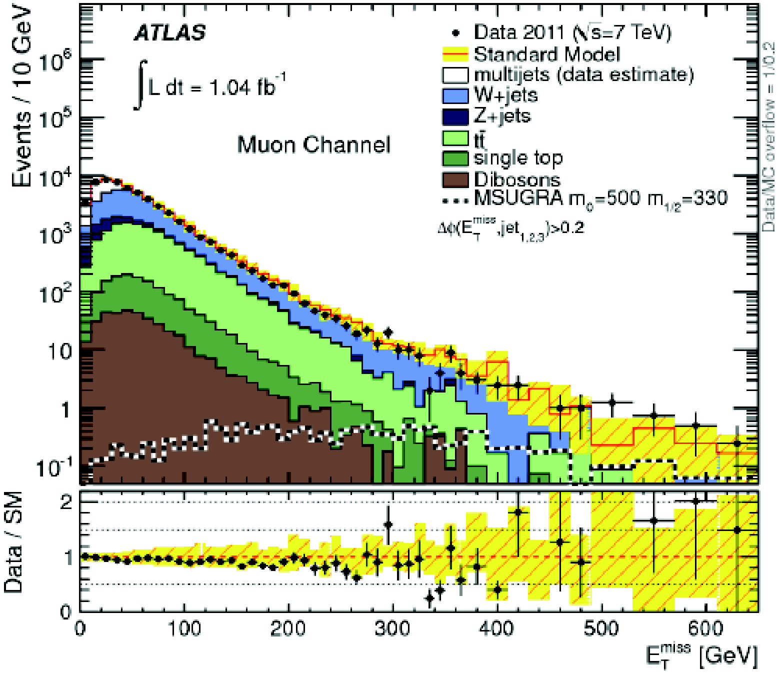


- If no excess, **model independent limits** set
  - → different stat. methods
  - → different interpretations

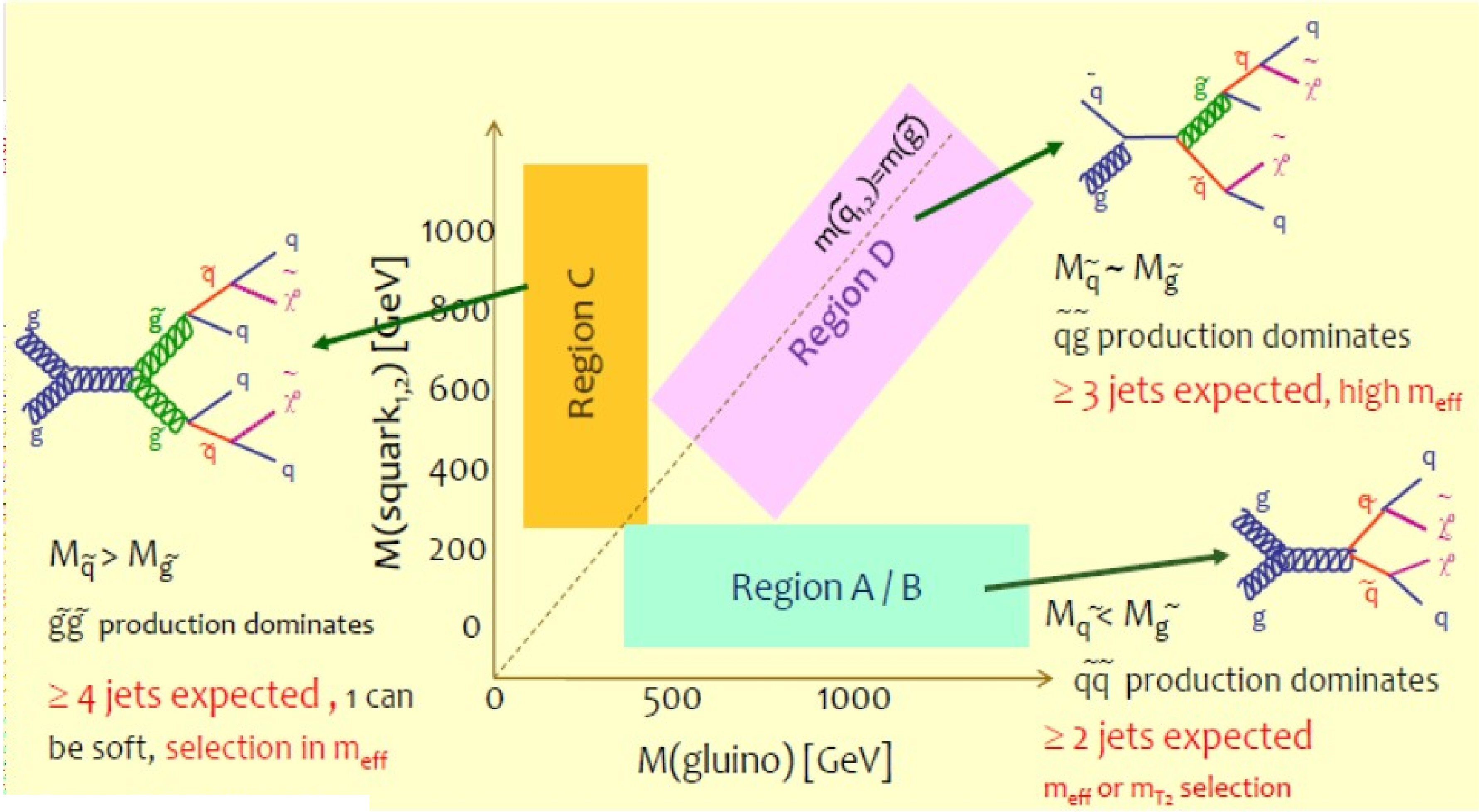
$$\sigma_{\text{BSM}} \times \varepsilon \times A$$

SUSY search results

- Searching for SUSY:
  - Sum all energy in the detector
  - Compute the energy balance in the plane transverse to the beam axis (E_T^{miss})
- E_T^{miss} distribution well described within 5 orders of magnitude:
  - Very good understanding of the detector!



0-lepton + Jets + E_T^{miss}

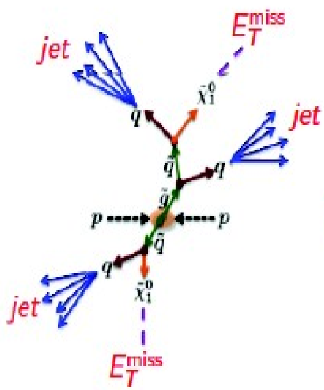


0-lepton signature

Cornell University Library

arXiv.org 1109.6572

1.04 fb^{-1}



$\tilde{q}\tilde{q}$: ≥ 2-jet; $\tilde{q}\tilde{g}$: ≥ 3-jet; $\tilde{g}\tilde{g}$: ≥ 4-jet and High mass

	Signal Region	≥ 2-jet	≥ 3-jet	≥ 4-jet	High mass
Trigger requirements	E_T^{miss}	> 130	> 130	> 130	> 130
	Leading jet p_T	> 130	> 130	> 130	> 130
Channel definition	Second jet p_T	> 40	> 40	> 40	> 80
	Third jet p_T	–	> 40	> 40	> 80
	Fourth jet p_T	–	–	> 40	> 80
QCD rejection	$\Delta\phi(\text{jet}, \vec{P}_T^{miss})_{min}$	> 0.4	> 0.4	> 0.4	> 0.4
	E_T^{miss}/m_{eff}	> 0.3	> 0.25	> 0.25	> 0.2
Enhance signal	m_{eff}	> 1000	> 1000	> 500/1000	> 1100

$\Delta\phi$ cut up to 3rd leading jet

≥ 2-jet, ≥ 3-jet, ≥ 4-jet: $m_{eff} = E_T^{miss} + \sum_{\text{SR jets}} p_T$

High mass: $m_{eff}^{incl} = E_T^{miss} + \sum_{\text{jets } p_T > 40} p_T$

R-parity conservation assumed

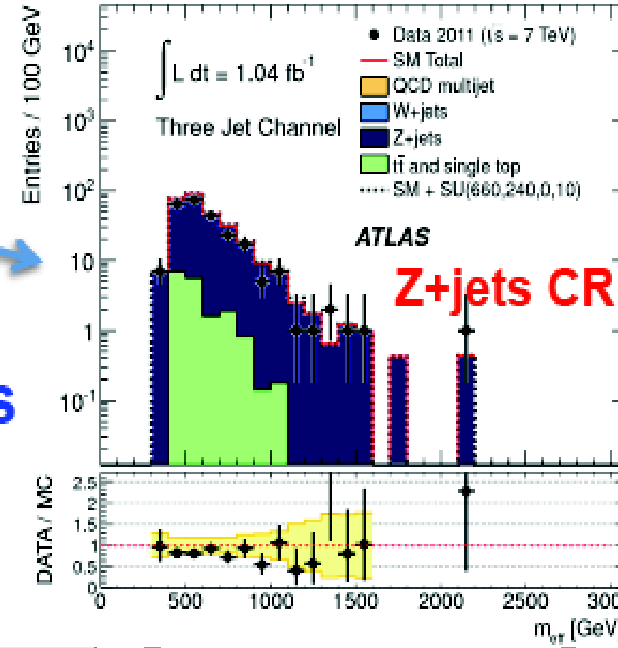
0-lepton signature

Cornell University Library

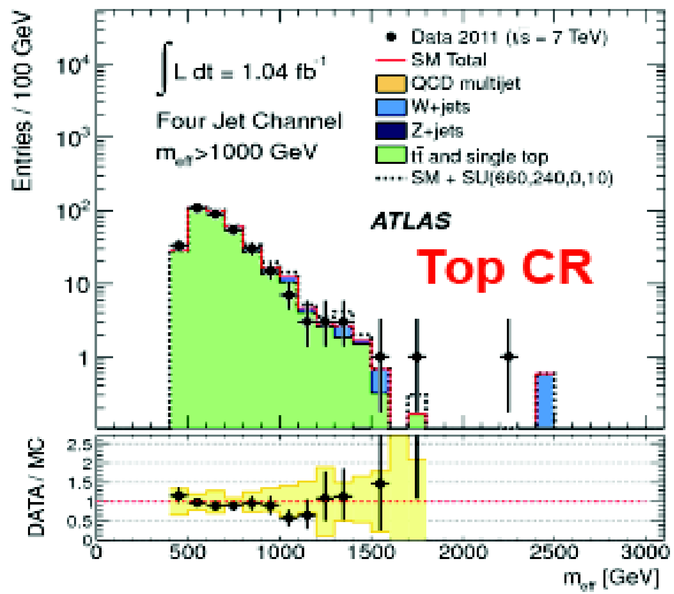
arXiv.org 1109.6572

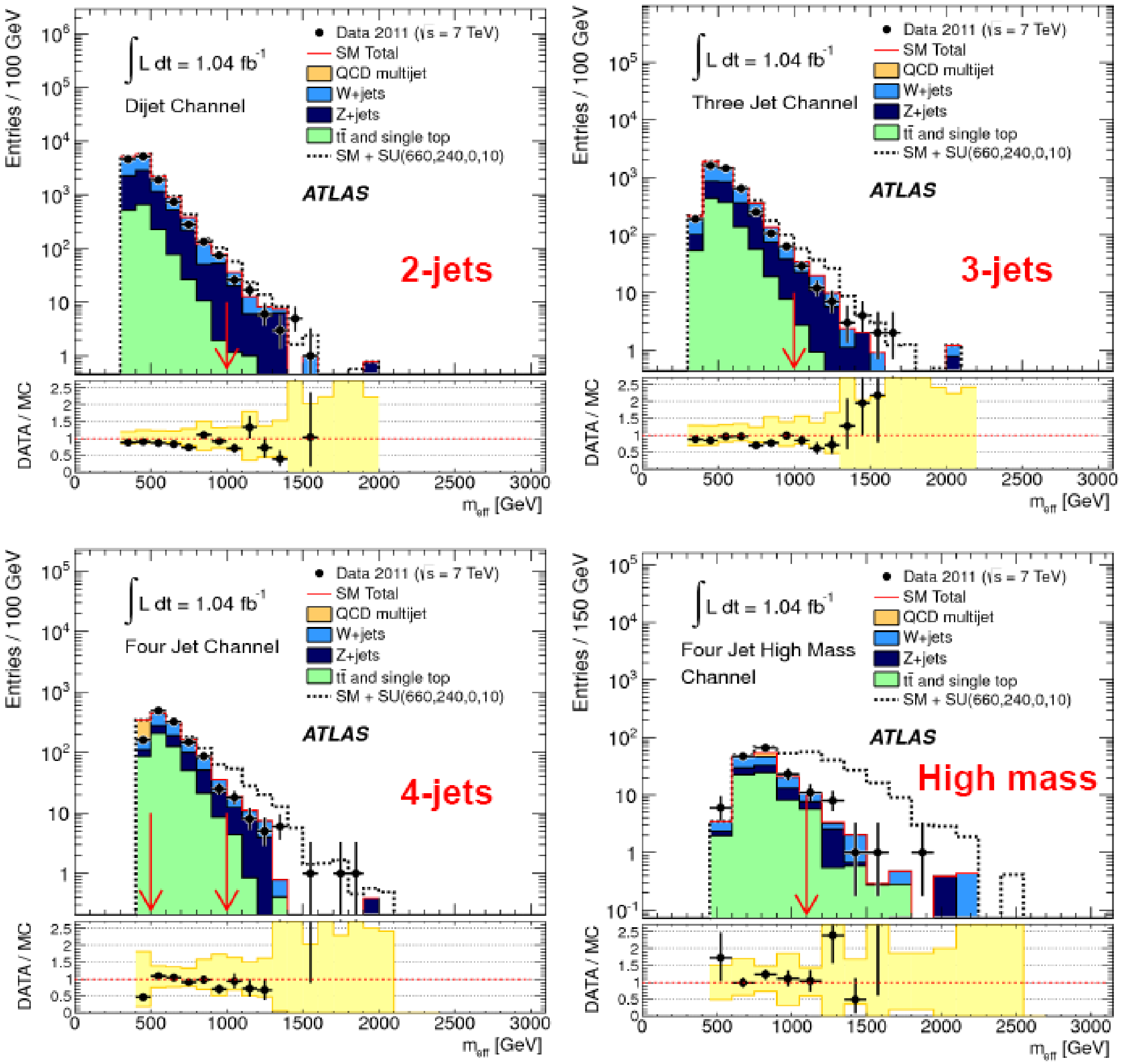
Backgrounds: ttbar, Z+jets, W+jets multijet

control regions



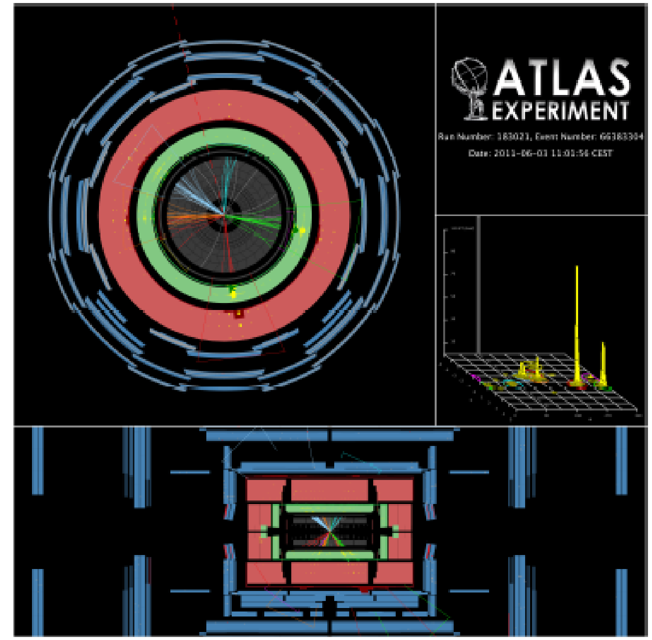
reverse $\Delta\Phi(\mathrm{jet}, p_T^{miss})$ cut





Cornell University Library

arXiv.org 1109.6572

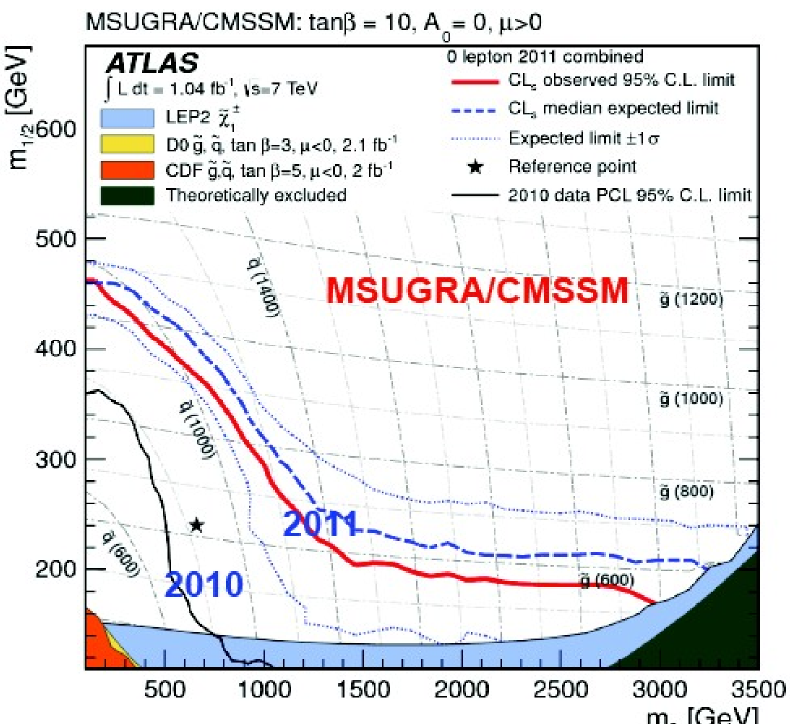


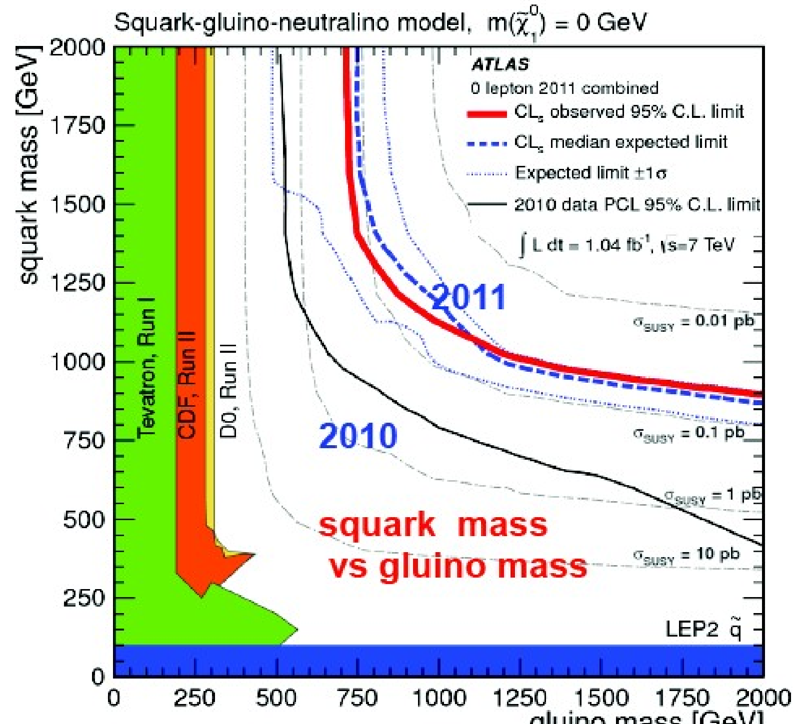
Highest m_{eff} event
m_{eff} = 1.81 TeV
E_T^{miss} = 460 GeV

Effective mass (m_{eff}) distributions in signal regions.

No excess observed: limits set (CL_s method, profile likelihood technique))

Process	Signal Region				
	$\geq$ 2-jet	$\geq$ 3-jet	$\geq$ 4-jet, $m_{\rm eff}$ > 500 GeV	$\geq$ 4-jet, $m_{\rm eff}$ > 1000 GeV	High mass
Z/γ+jets	32.3 ± 2.6 ± 6.9	25.5 ± 2.6 ± 4.9	209 ± 9 ± 38	16.2 ± 2.2 ± 3.7	3.3 ± 1.0 ± 1.3
W+jets	26.4 ± 4.0 ± 6.7	22.6 ± 3.5 ± 5.6	349 ± 30 ± 122	13.0 ± 2.2 ± 4.7	2.1 ± 0.8 ± 1.1
$t\bar{t}$+ single top	3.4 ± 1.6 ± 1.6	5.9 ± 2.0 ± 2.2	425 ± 39 ± 84	4.0 ± 1.3 ± 2.0	5.7 ± 1.8 ± 1.9
QCD multi-jet	0.22 ± 0.06 ± 0.24	0.92 ± 0.12 ± 0.46	34 ± 2 ± 29	0.73 ± 0.14 ± 0.50	2.10 ± 0.37 ± 0.82
Total	62.4 ± 4.4 ± 9.3	54.9 ± 3.9 ± 7.1	1015 ± 41 ± 144	33.9 ± 2.9 ± 6.2	13.1 ± 1.9 ± 2.5
Data	58	59	1118	40	18
εσA limit (fb):	22	25	429	27	17

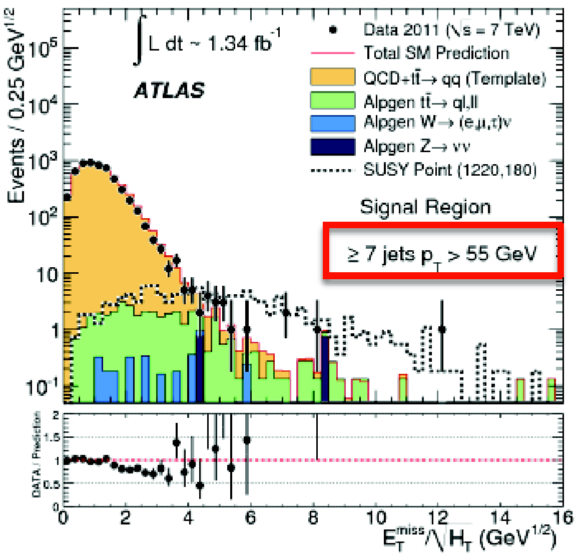


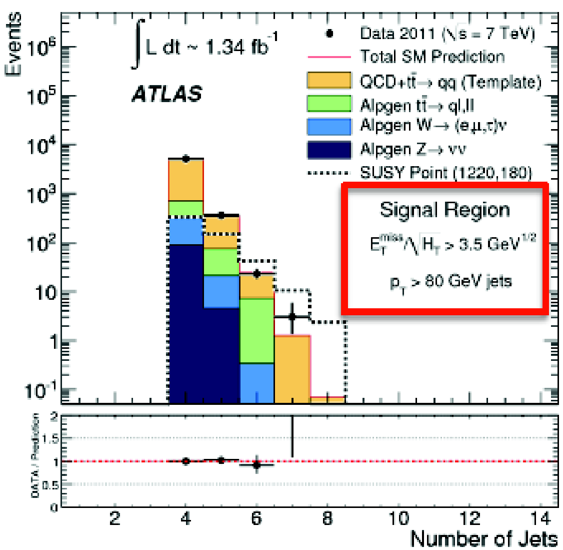


Long decay chain

Cornell University Library
arXiv.org 1110.2299

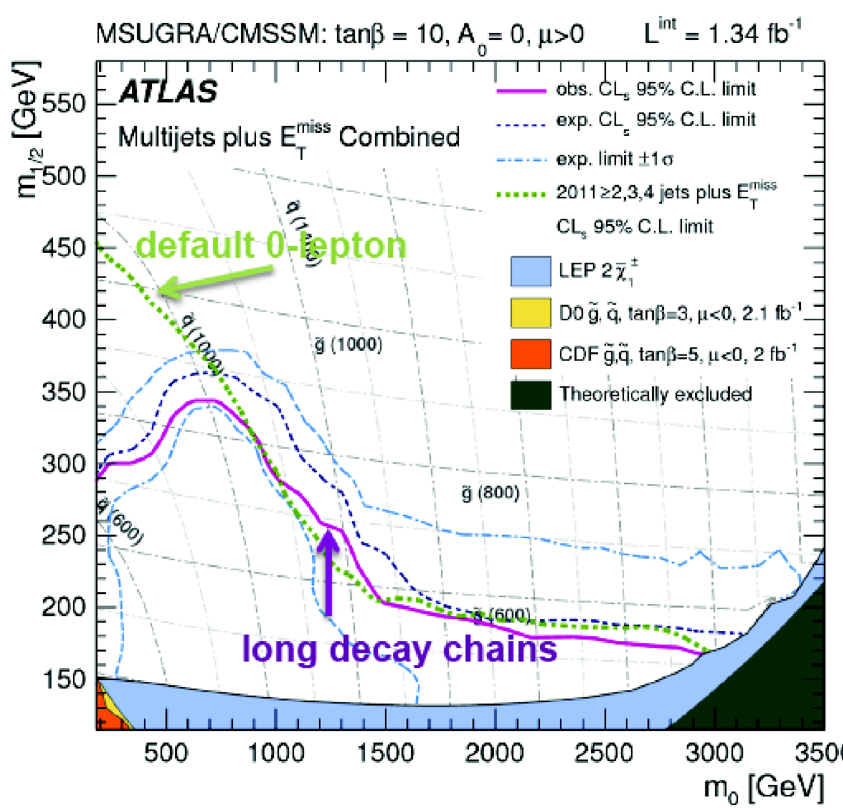
1.34 fb^{-1}





Signal region	7j55	8j55	6j80	7j80
Jet p_T	> 55 GeV		> 80 GeV	
Jet $\|\eta\|$	< 2.8			
ΔR_{jj}	> 0.6 for any pair of jets			
Number of jets	≥ 7	≥ 8	≥ 6	≥ 7
$E_T^{miss}/\sqrt{H_T}$	> 3.5 GeV$^{1/2}$			

Signal region	7j55	8j55	6j80	7j80
Total Standard Model	39 ± 9	$2.3^{+4.4}_{-0.7}$	26 ± 6	$1.3^{+0.9}_{-0.4}$
Data	45	4	26	3



1 lepton+Jets+E_T^{miss}

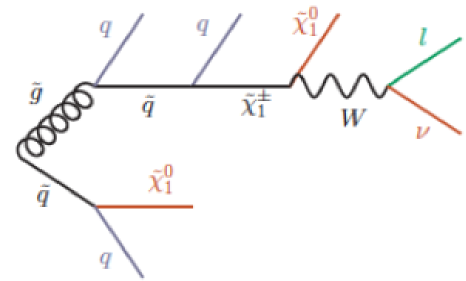
Cornell University Library

arXiv.org 1109.6606

1.04 fb^{-1}

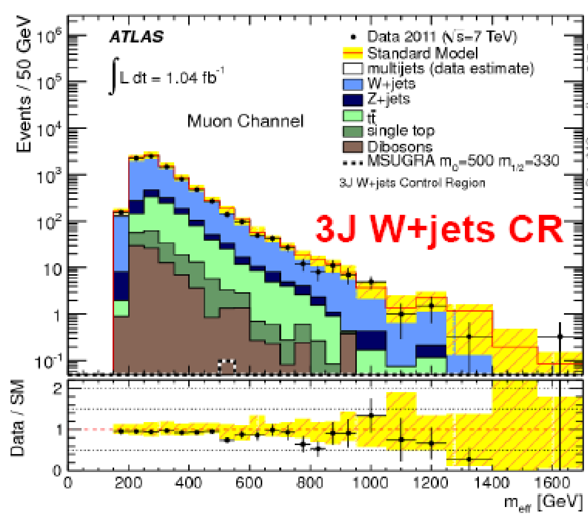
Selection	Signal Regions				Control Regions	
	3JL	3JT	4JL	4JT	3J	4J
Number of Leptons	= 1					
Lepton p_T (GeV)	> 25(20) for electrons (muons)					
Veto lepton p_T (GeV)	> 20(10) for electrons (muons)					
Number of jets	≥ 3		≥ 4		≥ 3	≥ 4
Leading jet p_T (GeV)	60	80	60	60	60	60
Subsequent jets p_T (GeV)	25	25	25	40	25	25
$\Delta\phi(\vec{\text{jet}}_i, \vec{E}_T^{miss})$	[> 0.2 (mod.π)] for all 3 (4) jets					
m_T (GeV)	> 100				$40 < m_T < 80$	
E_T^{miss} (GeV)	> 125	> 240	> 140	> 200	$30 < E_T^{miss} < 80$	
E_T^{miss}/m_{eff}	> 0.25	> 0.15	> 0.30	> 0.15	–	–
m_{eff} (GeV)	> 500	> 600	> 300	> 500	> 500	> 300

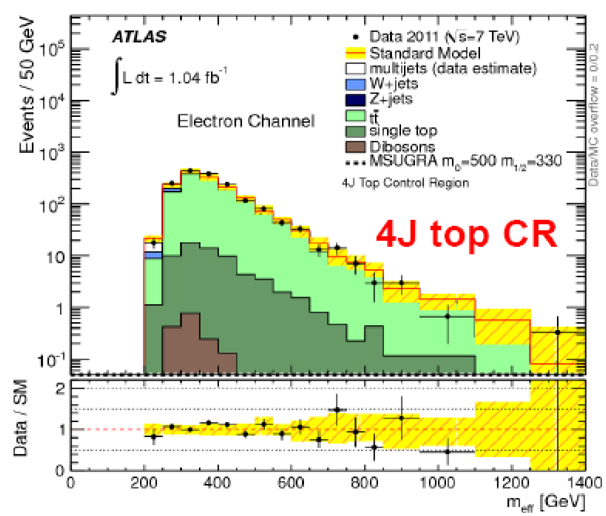
Example 1-lepton signature



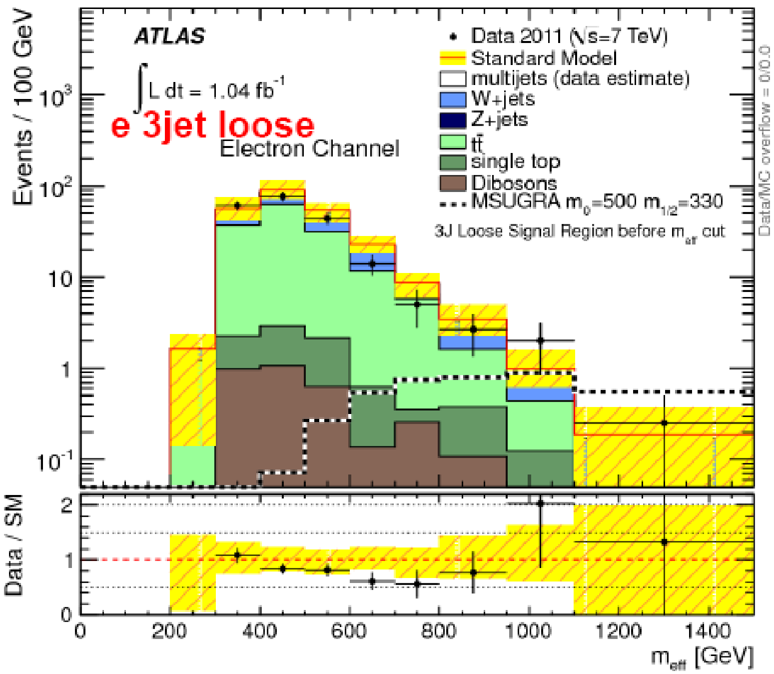
Backgrounds: W+jets, ttbar
(multijet negligible)

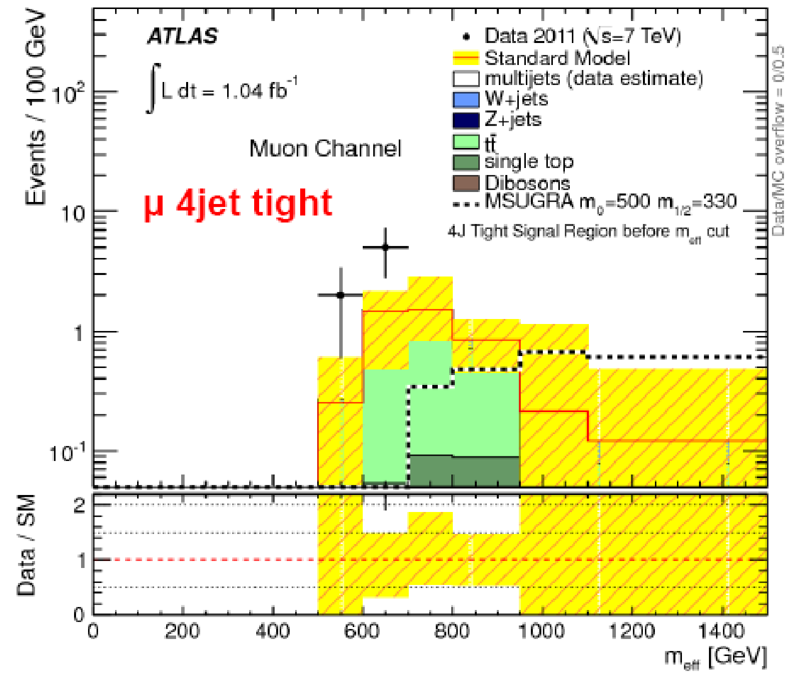
BG estimation using
control regions





E,

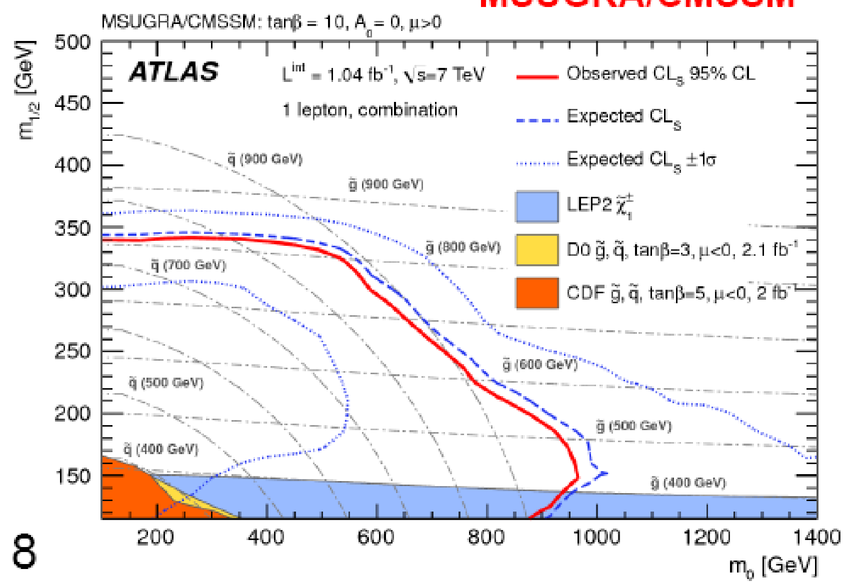




m_{eff} in signal regions: no excess

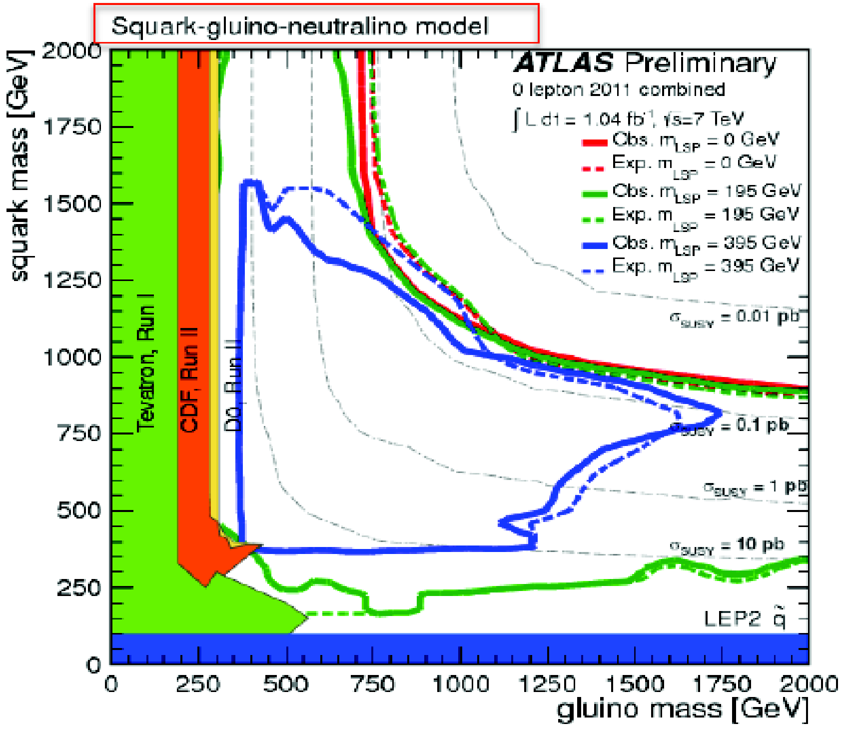
Electron channel	3JL SR	3JT SR	4JL SR	4JT SR
Observed events	71	14	41	9
Fitted background events	98 ± 28	18.5 ± 7.4	48 ± 18	8.0 ± 3.7
Muon channel	**3JL SR**	**3JT SR**	**4JL SR**	**4JT SR**
Observed events	58	11	50	7
Fitted background events	64 ± 19	13.9 ± 4.3	53 ± 16	6.0 ± 2.7
εσA limits (fb) e:	**50**	**14**	**33**	**10**
μ:	**36**	**10**	**31**	**9**

MSUGRA/CMSSM



SUSY : simplified models

MSSM-inspired models of well-defined production and decay modes
Explore dependence of free parameters
Introduce complexity progressively

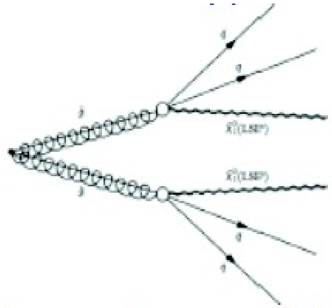


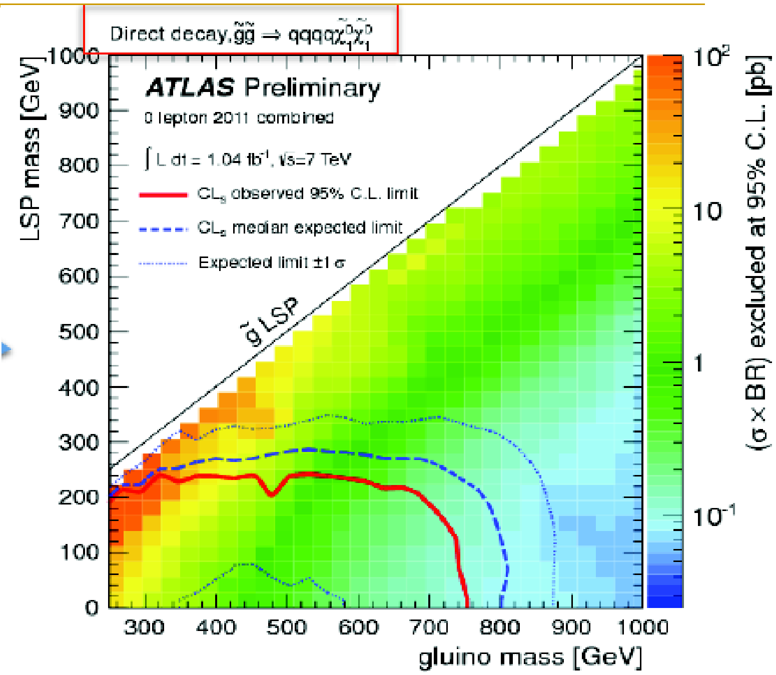
- Simplified models for 0-lepton channels

red: massless LSP
green: LSP 195 GeV
blue: LSP 395 GeV

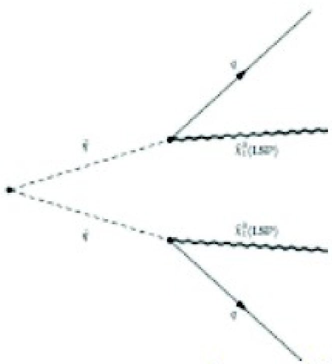
ATLAS-CONF-2011-155

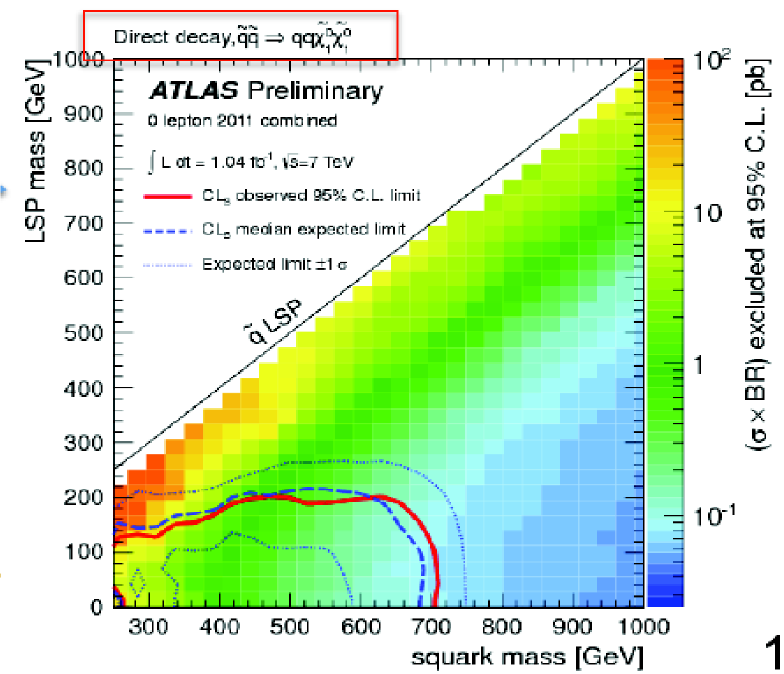
Simplified models for 0-lepton channel





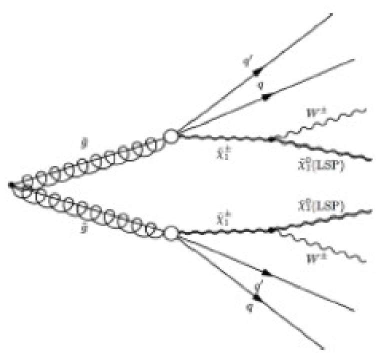
Free parameters: gluon and LSP mass





Free parameters: squark and LSP mass

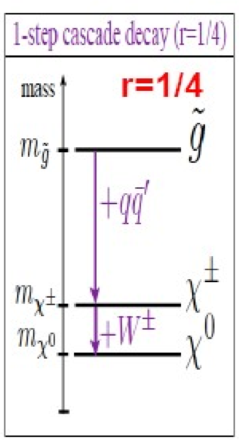
1 lepton simplified model

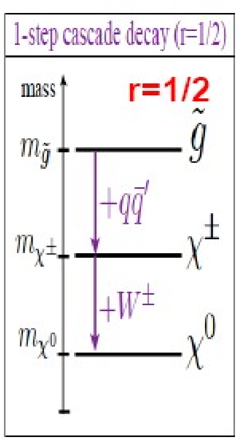


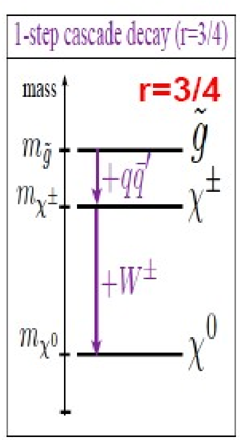
1-step via intermediate chargino

Cornell University Library

arXiv.org 1109.6606

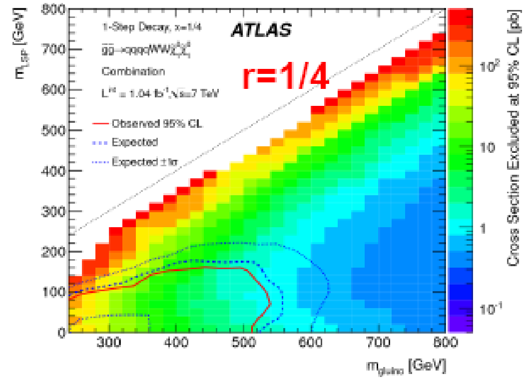


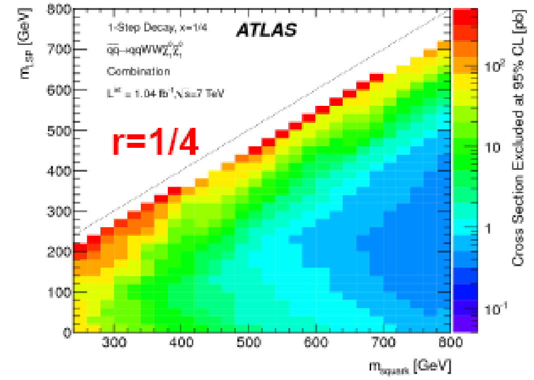


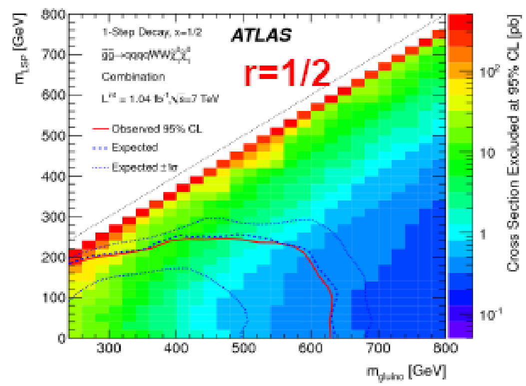


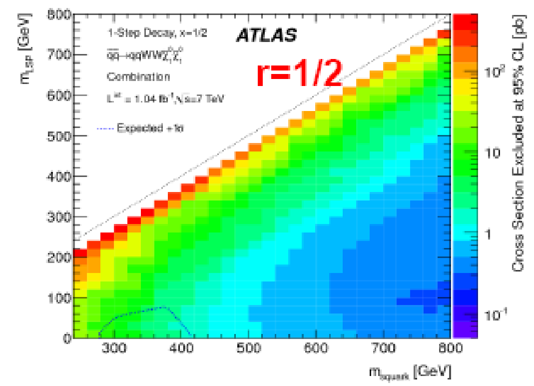
gluino decay

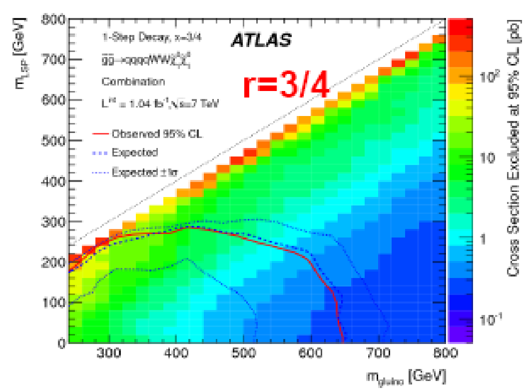
squark decay

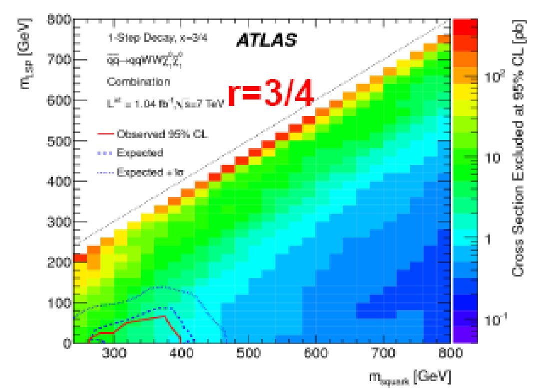












(Colours represent cross section upper limits)

Null searches so … (after 2 years of LHC with 1fb^{-1} analysed data)

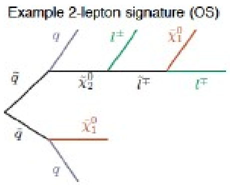
- Null searches also for any other BSM signal
- **What next…**
  - Generalize away from (over) constrained scenarios
  - Gaugino sector and sleptons: multi-leptons, photons
  - Stop (and sbottom and stau) sectors (major motivation for SUSY at low energies)
  - Non- “canonical” scenarios:
    - semi-stable SUSY particles, R-parity violation

Dileptons

Cornell University Library

arXiv.org 1110.6189

1.04 fb^{-1}



Common cuts

- Preselection (Data Quality, Trigger, Primary Vertex)
- 2 leptons: electron $p_T > 25/20$ GeV, muon $p_T > 20/10$ GeV, $m_{ll} > 12$ GeV

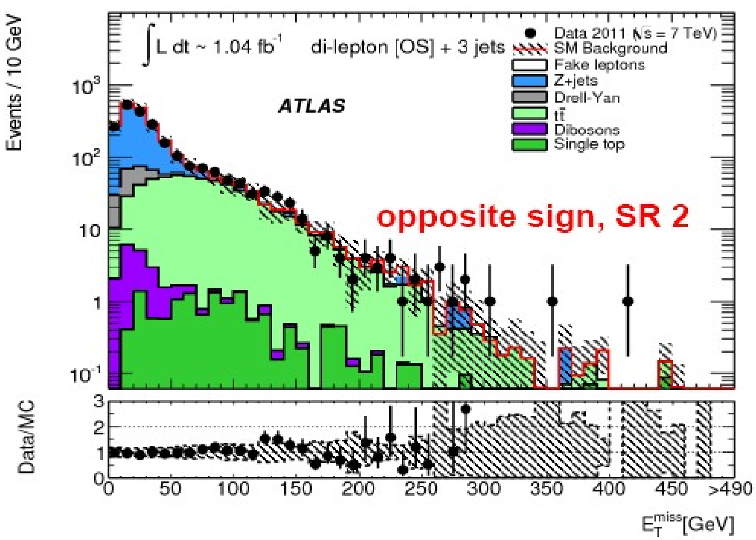
Opposite Sign

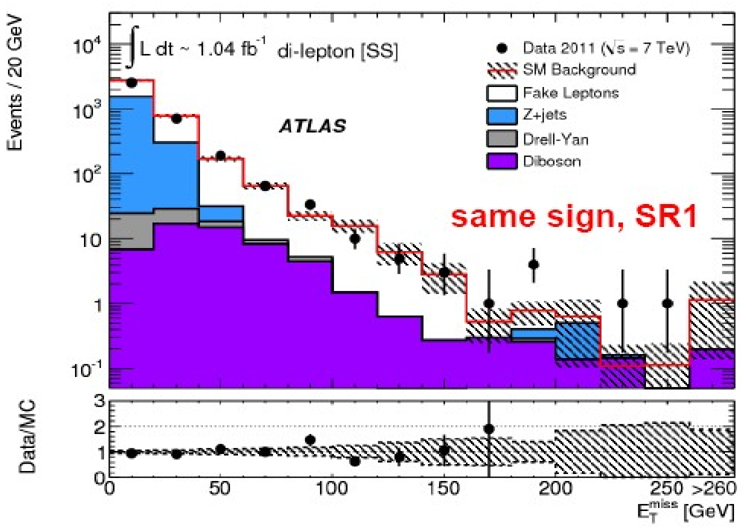
- **SR1** $\not{E}_T > 250$ GeV
- **SR2** 3 jets $p_T > 80, 40, 40$ GeV, $\not{E}_T > 220$ GeV (gluino 2-body decays)
- **SR3** 4 jets $p_T > 100, 70, 70, 70$ GeV, $\not{E}_T > 100$ GeV (gluino 3-body decays)

Same Sign

- **SR1** $\not{E}_T > 100$ GeV (weak gaugino production)
- **SR2** 2 jets $p_T > 50, 50$ GeV, $\not{E}_T > 80$ GeV (mSUGRA/CMSSM)

	Background	Obs.	95% CL
OS-SR1	15.5 ± 4.0	13	9.9 fb
OS-SR2	13.0 ± 4.0	17	14.4 fb
OS-SR3	5.7 ± 3.6	2	6.4 fb
SS-SR1	32.6 ± 7.9	25	14.8 fb
SS-SR2	24.9 ± 5.9	28	17.7 fb





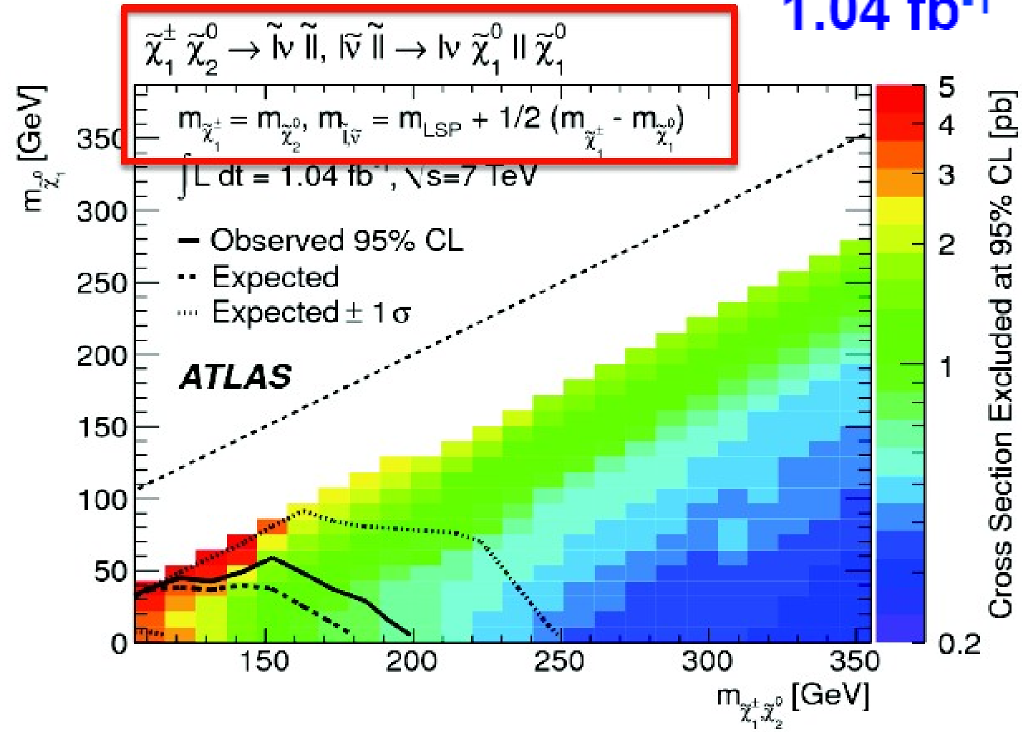
Dileptons

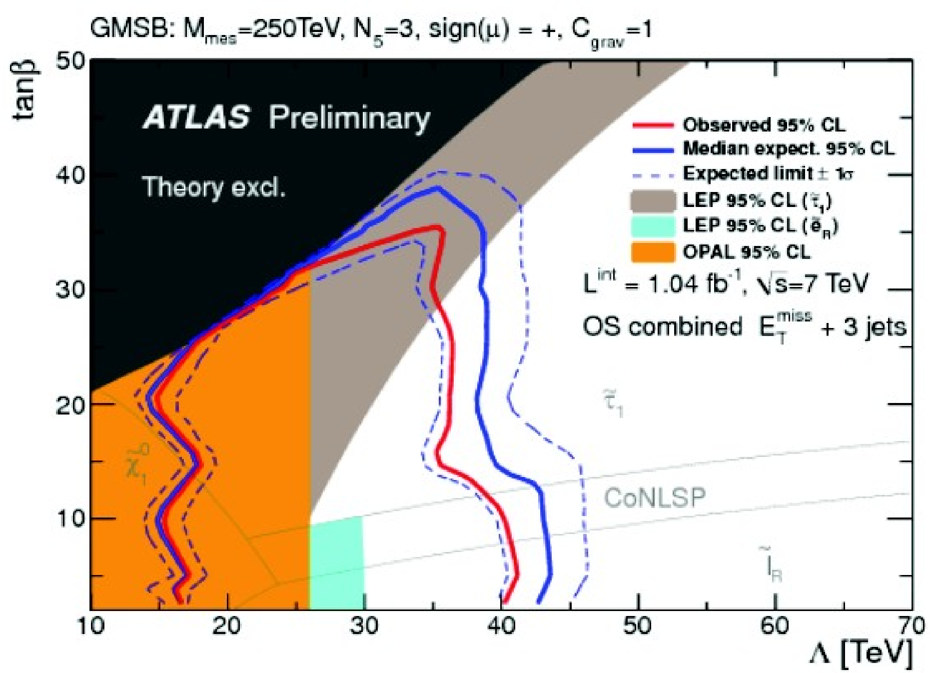
1.04 fb^{-1}

Same sign dilepton interpretation in simplified model of weak gaugino production: $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$

Cornell University Library

arXiv.org 1110.6189





Interpretation in GMSB

(opposite sign SR2)

ATLAS-CONF-2011-156

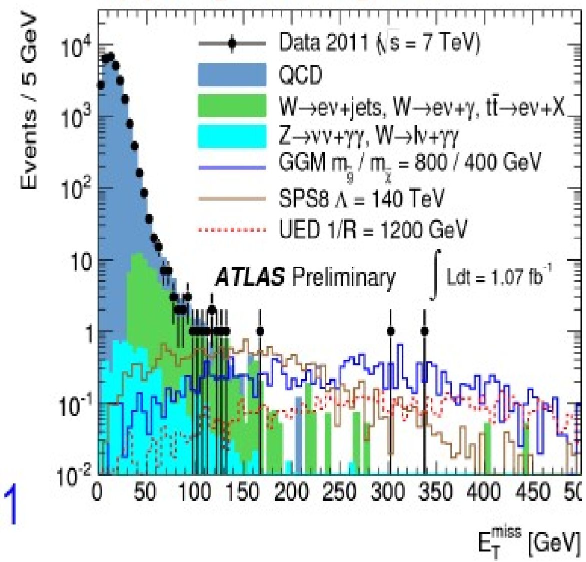
$\gamma\gamma + E_T^{miss}$

1.07 fb^{-1}

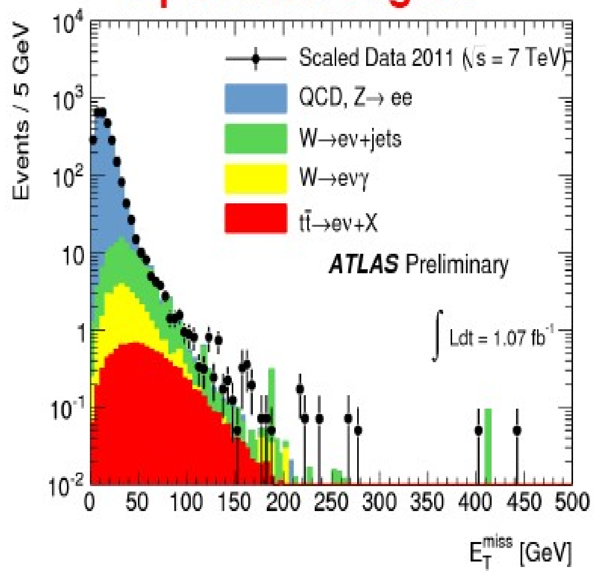
Gauge mediation with
bino-like NLSP:
$\tilde{\chi}^0 \rightarrow \gamma \tilde{G}$

Selection: 2 tight γ
E_T > 25 GeV, isolated,
|η|<1.37 or 1.52<|η|<1.81

γγ signal region



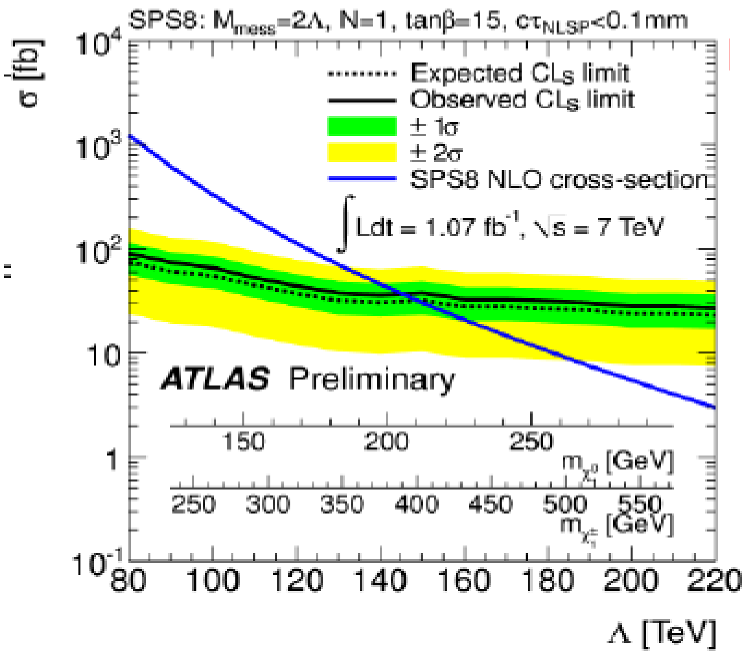
eγ control region



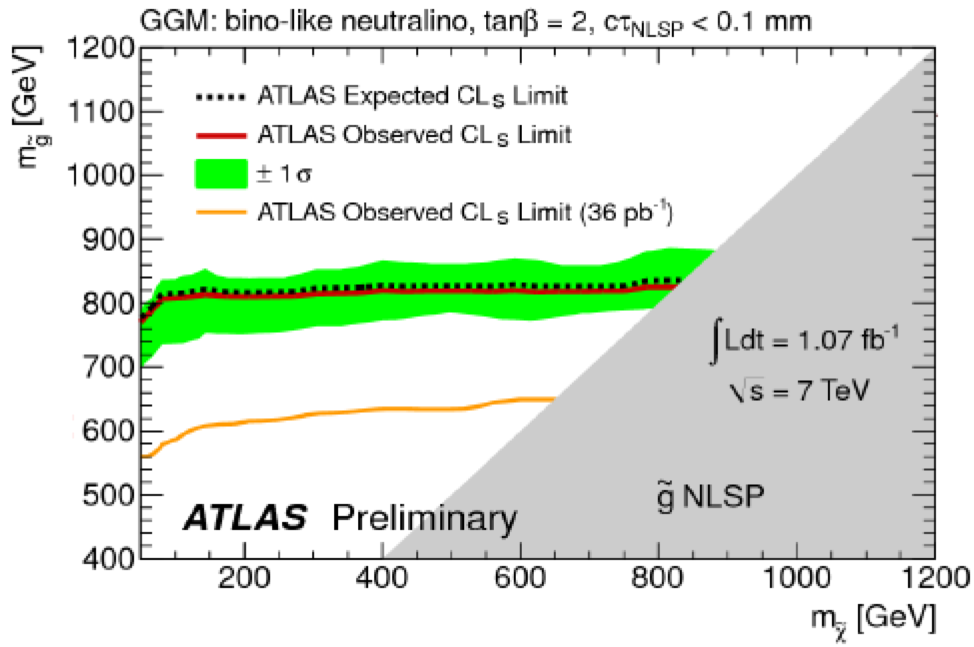
E_T^{miss} range [GeV]	Data events	Predicted background events: Total	QCD	$W/t\bar{t}(\rightarrow e\nu)+X$	Irreducible	Expected signal events: GGM	SPS8	UED
75 - 100	11	14.7 ± 1.2	6.7 ± 0.9	7.4 ± 0.8	0.52 ± 0.10	0.8 ± 0.1	2.1 ± 0.1	0.15 ± 0.01
100 - 125	6	4.9 ± 0.7	1.6 ± 0.4	3.0 ± 0.5	0.23 ± 0.05	1.2 ± 0.1	2.5 ± 0.1	0.29 ± 0.02
> 125	5	4.1 ± 0.6	0.8 ± 0.3	3.1 ± 0.5	0.15 ± 0.01	17.2 ± 0.5	13.0 ± 0.3	9.67 ± 0.11

$\gamma\gamma + E_T^{miss}$

1.07 fb^{-1}



Interpretation in minimal gauge mediation: SPS 8 benchmark slope



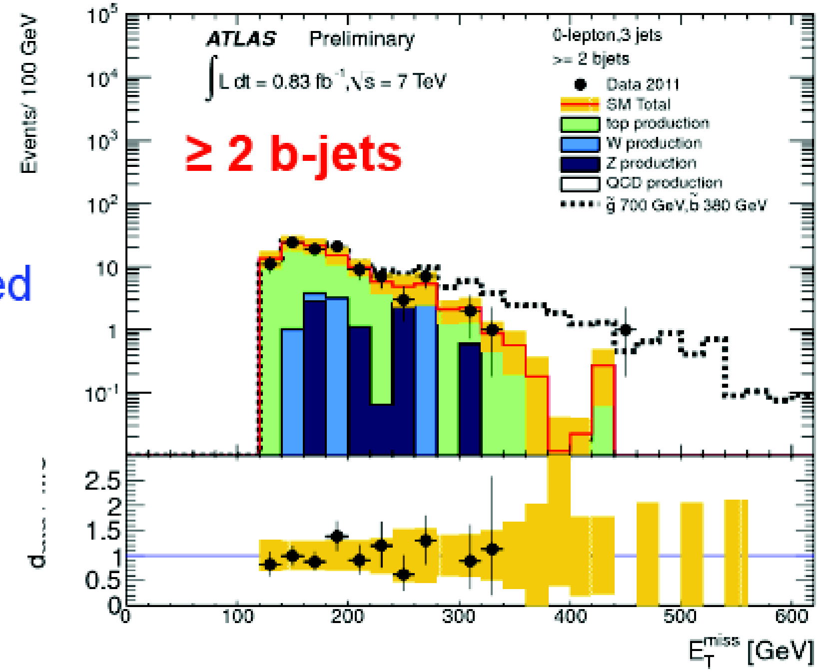
Interpretation in general gauge mediation: gluino and $\tilde{\chi}^0$ mass free, bino-like $\tilde{\chi}^0$

Sbottom production in gluino decays

0.83 fb^{-1}

$\geq$3 jets, p_T > 130, 50, 50 GeV, $\geq$1 jet b-tagged
3 jets $\Delta\Phi$(jet,E_T^{miss}) > 0.4
Veto events with isolated e or μ
E_T^{miss} > 130 GeV, E_T^{miss}/m_{eff} > 0.25

$\tilde{g}$-$\tilde{g}$ production, $\tilde{g} \to 2b+\tilde{\chi}_1^0$

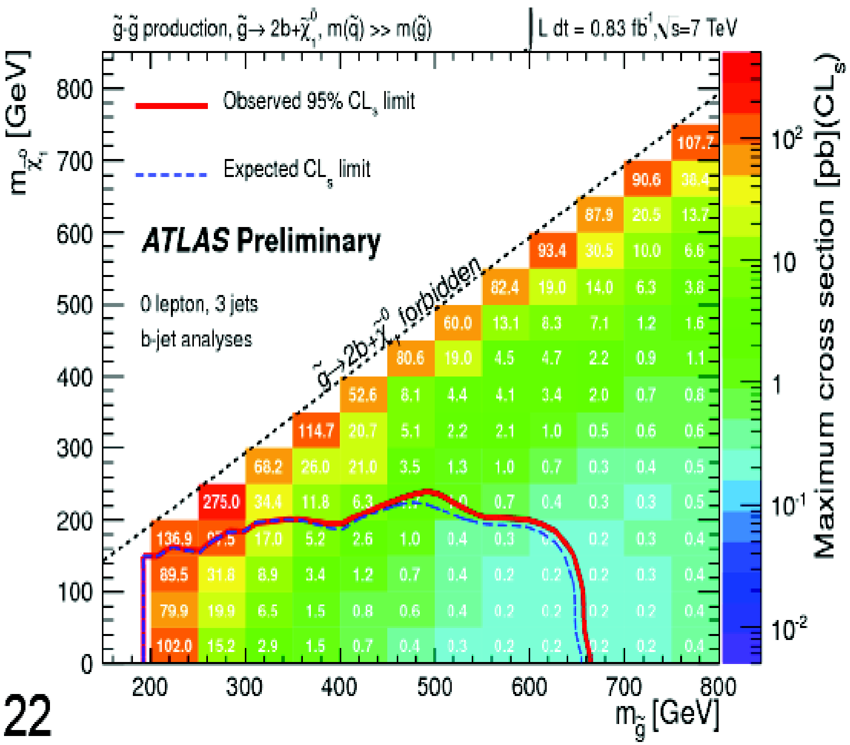


Sig. Reg.	Data (0.83 fb^{-1})	Top	W/Z	QCD	Total
3JA (1 btag m_{eff} >500 GeV)	361	221^{+82}_{-68}	121 ± 61	15 ± 7	356^{+103}_{-92}
3JB (1 btag m_{eff} >700 GeV)	63	37^{+15}_{-12}	31 ± 19	1.9 ± 0.9	70^{+24}_{-22}
3JC (2 btag m_{eff} >500 GeV)	76	55^{+25}_{-22}	20 ± 12	3.6 ± 1.8	79^{+28}_{-25}
3JD (2 btag m_{eff} >700 GeV)	12	$7.8^{+3.5}_{-2.9}$	5 ± 4	0.5 ± 0.3	$13.0^{+5.6}_{-5.2}$

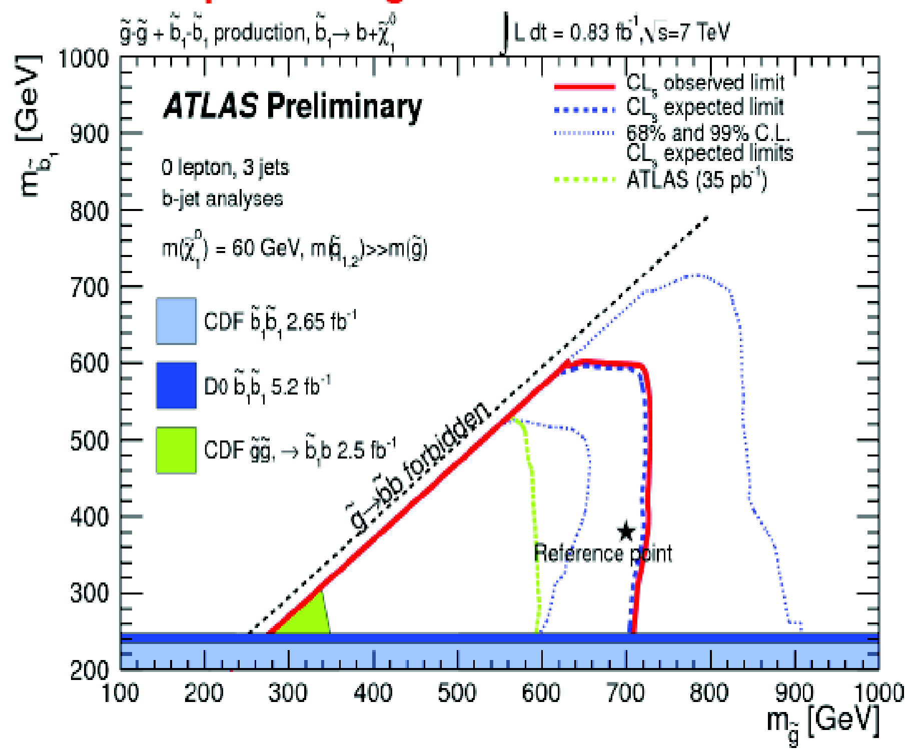
Sbottom production in gluino decays

ATLAS-CONF-2011-098

Interpretation: gluino → 2b + LSP



Interpretation: gluino → sbottom + bottom

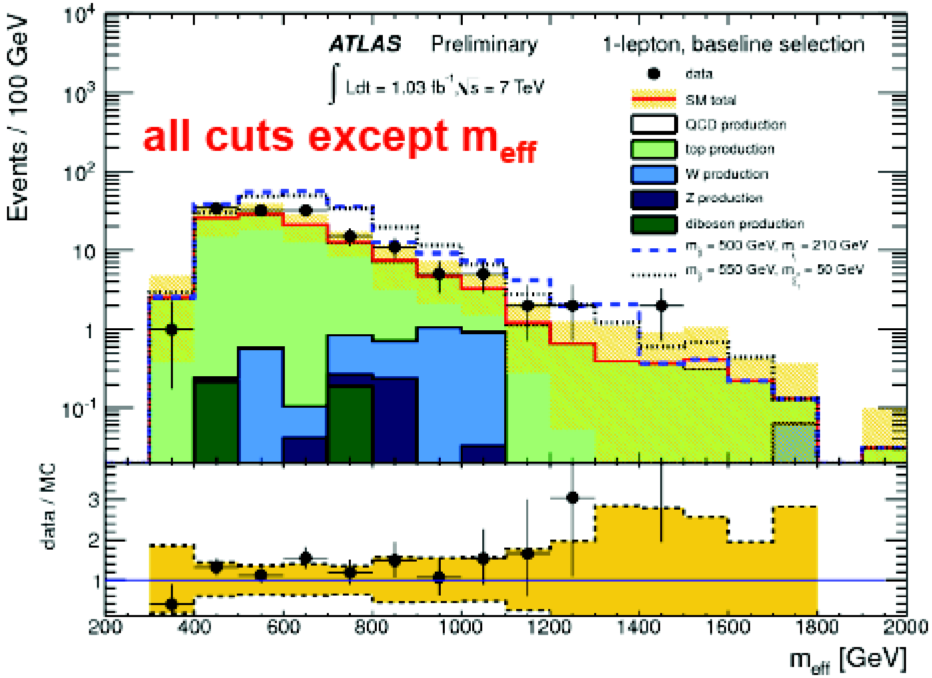


Stop production in gluino decays

ATLAS-CONF-2011-130

1.03 fb^{-1}

$\tilde{g}$-$\tilde{g}$ production, $\tilde{g} \to 2t+\tilde{\chi}_1^0$, $\tilde{g} \to \tilde{t}_1+t$, $\tilde{t}_1 \to b+\tilde{\chi}_1^{\pm}$



Analysis: b-jets plus isolated lepton signature

One e or μ with p_T > 20 GeV

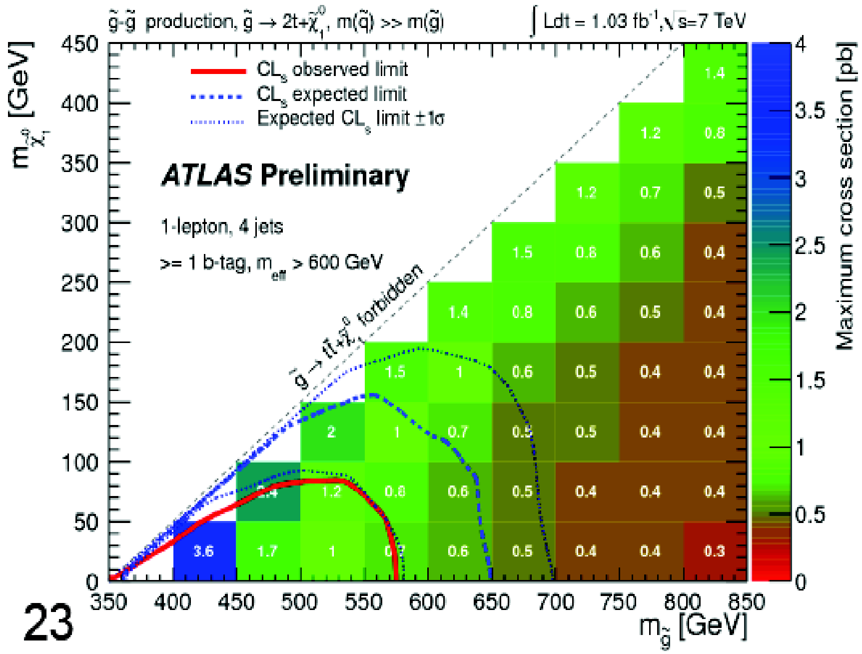
At least four jets with p_T > 50 GeV

Cuts	≥ 4 jets	≥ 1 b jet	$E_T^{miss} > 80$ GeV	$m_T > 100$ GeV	$m_{eff} > 600$ GeV
SM (MC) SM (d-d)	6574 ± 1870	3096 ± 1042	881 ± 356	109 ± 55	52 ± 28 54.9 ± 13.6
data	6659	3361	989	141	74

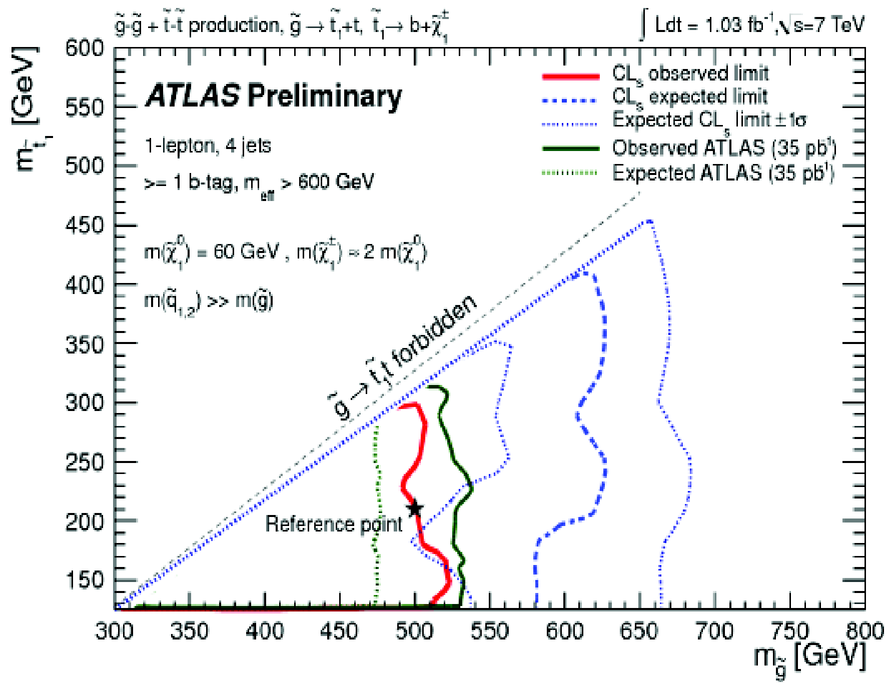
Stop production in gluino decays

ATLAS-CONF-2011-098

Interpretation: gluino → 2t + LSP

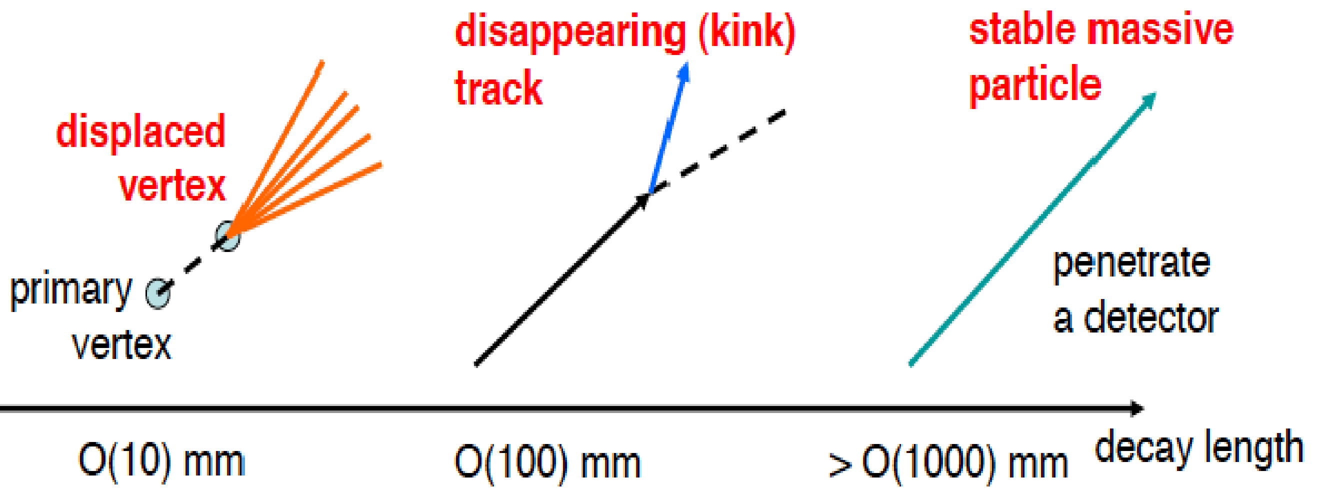


Interpretation: gluino → stop (→ b χ̃±) + top



Special final states

Long-living supersymmetric particles: very well possible in SUSY!



R-hadrons, R-parity violation, compressed spectra (AMSB)

Final results

$E_T^{miss}+X$:

- 0/1/2 lep+jets
- multijets
- $\gamma\gamma$

$sg \to 4$ jets

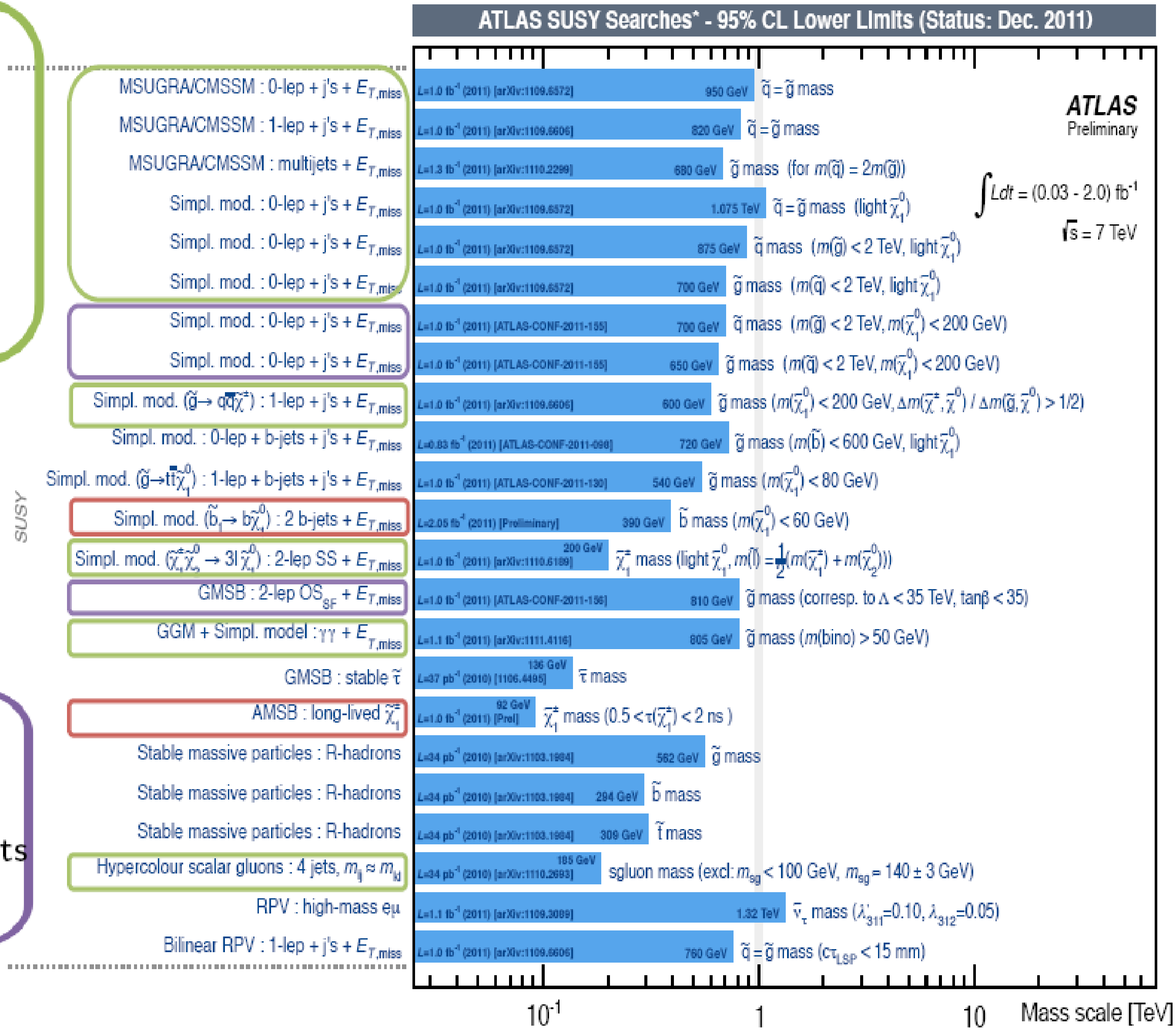
Preliminary

$E_T^{miss}+X$: $\tilde{b}/\tilde{t}$

long-lived: $\tilde{\chi}_1^{\pm}$

New interpret.

$E_T^{miss}+X$: 0/2 lep+jets



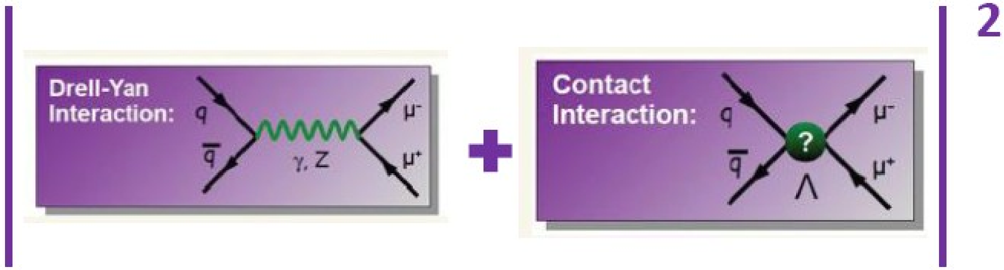
Search for contact interactions

Motivations: 4-fermion contact interaction (CI) can be a low-energy description of:

- Large Extra Dimension ADD model
- Quark-lepton compositeness

Analysis strategy:

Look for excess over Drell-Yan production selecting high-quality leptons



Context of left-left isoscalar model:

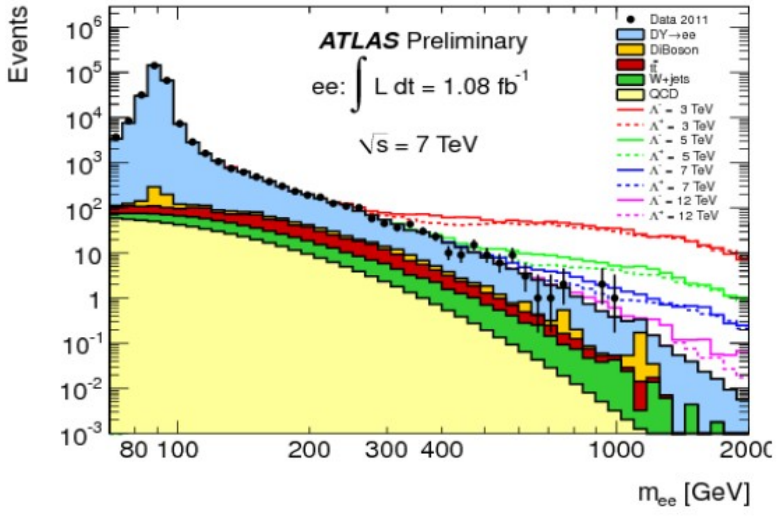
$$\frac{d\sigma}{dm_{\ell\ell}} = \frac{d\sigma_{DY}}{dm_{\ell\ell}} - \eta_{LL}\frac{F_I(m_{\ell\ell})}{\Lambda^2} + \frac{F_C(m_{\ell\ell})}{\Lambda^4}$$

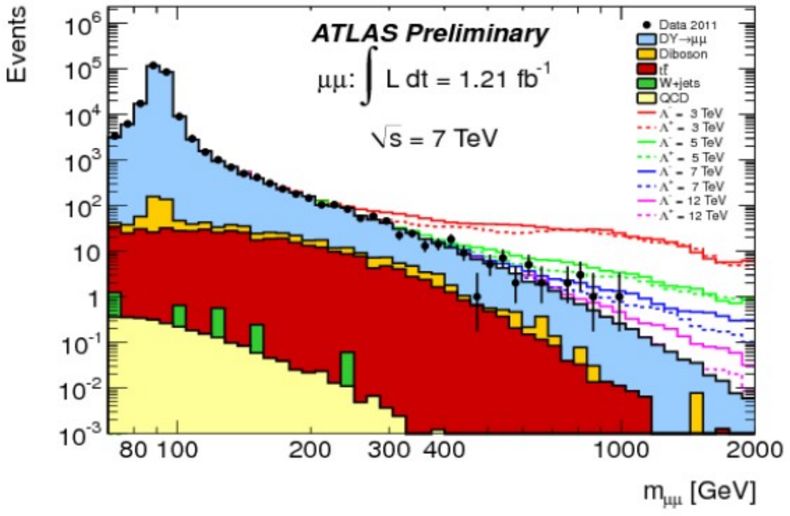
- F_I: interference interaction
- η_{LL} ±1
- F_C: pure contact interaction

- **Λ: Energy scale below which fermion constituents are bound**

Search for contact interactions

Results: **Electron channel** **Muon channel**





Lower limits on scale Λ at 95% of Credibility Level:

Channel	Prior	Expected limit (TeV) Constr.	Expected limit (TeV) Destr.	Observed limit (TeV) Constr.	Observed limit (TeV) Destr.
e^+e^-	$1/\Lambda^2$	9.6	9.3	10.1	9.4
	$1/\Lambda^4$	8.9	8.6	9.2	8.6
$\mu^+\mu^-$	$1/\Lambda^2$	8.9	8.6	8.0	7.0
	$1/\Lambda^4$	8.3	7.9	7.6	6.7
Combined	$1/\Lambda^2$	10.4	10.1	10.2	8.8
	$1/\Lambda^4$	9.6	9.4	9.4	8.4

Most stringent limits to date

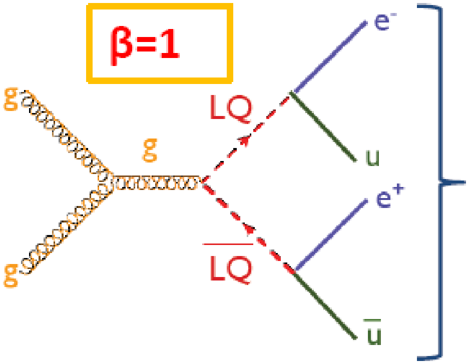
Leptoquarks

Motivations: **Leptoquarks (LQ) are color-triplet bosons that carry both lepton and baryon numbers, and fractional electric charge**

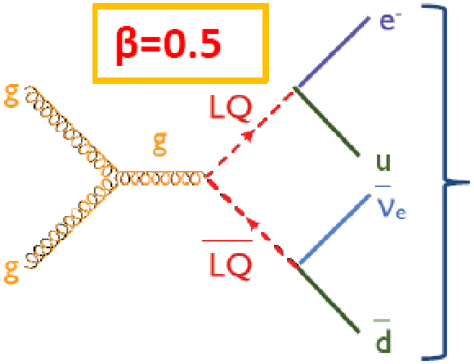
- Introduced by various extension of the SM (technicolor, GUTs, etc)
- Could explain **similarities between the 3 generations of leptons and quarks in the SM**, and lead to some **symmetry at high energy scale**

Analysis strategy: **Search for pair-produced LQs assumed to couple only to quarks and leptons of the same SM generation**

→ Focus here on 1st generation for 2 scenarii: β=BR(LQ→eq)

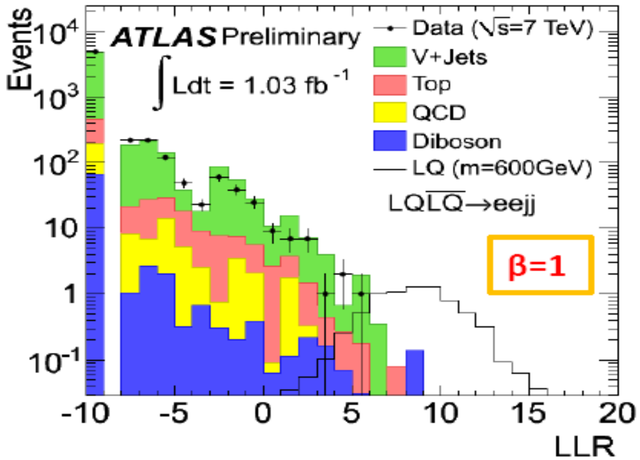


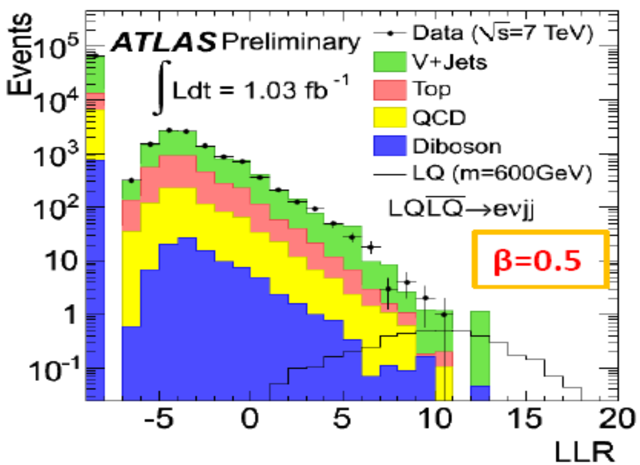
Select:
- **2 electrons**
- **2 jets**



Select:
- **1 electron**
- **2 jets**
- **Missing energy**

Search for first generation of scalar leptoquarks

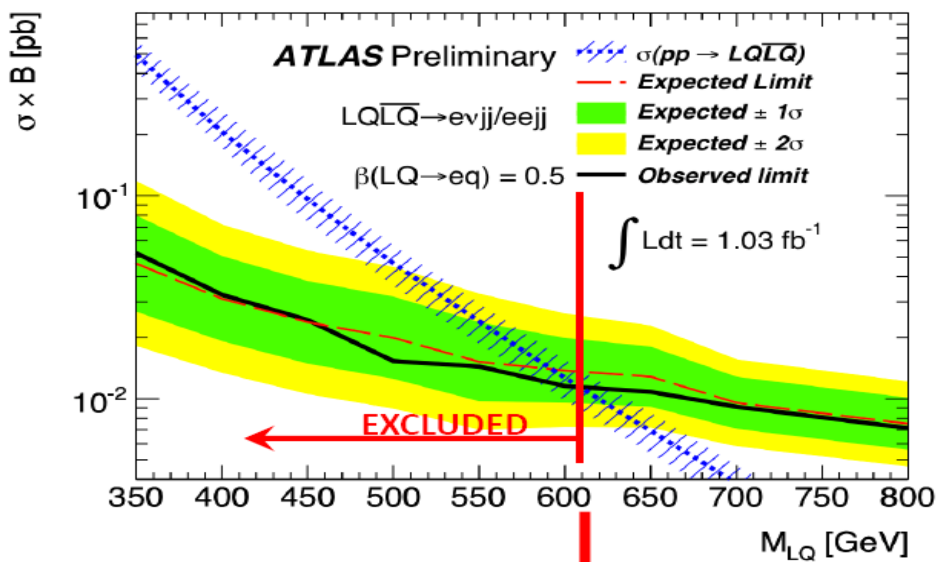




Analysis strategy cont'd:

Use of Likelihood ratio method to discriminate signal from SM backgrounds

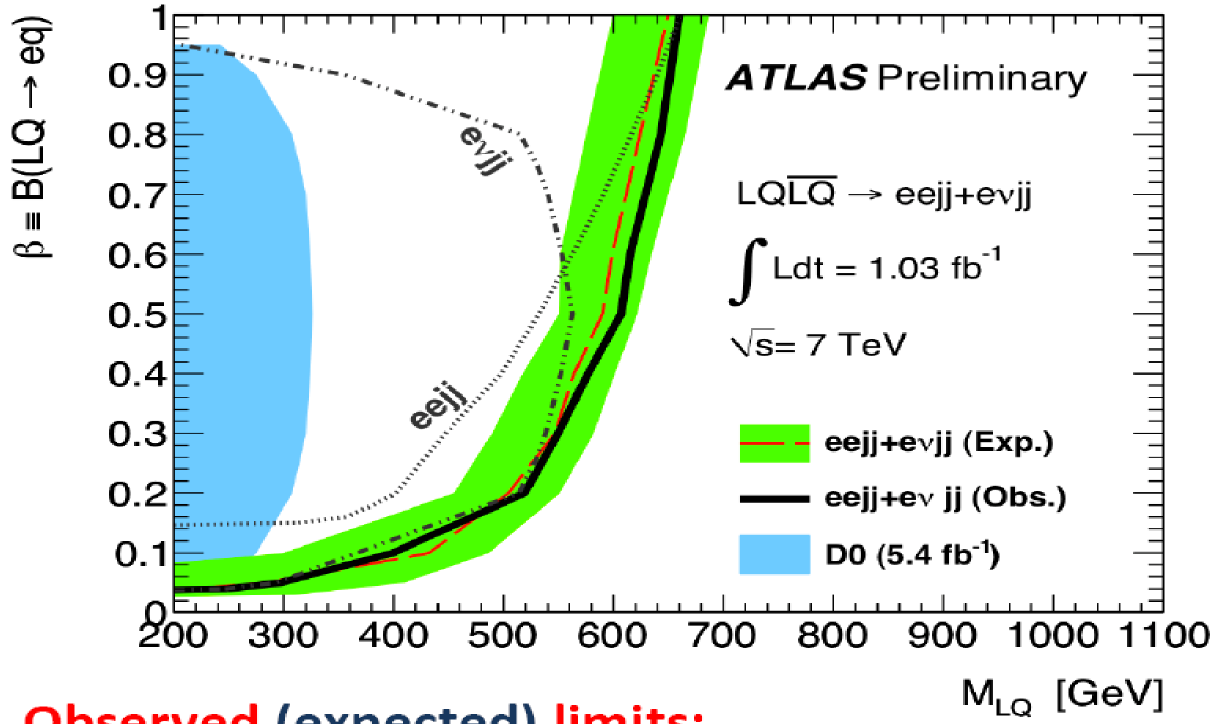
… then put 95% CLs upper limits on σxBR:



m_{LQ} > 607 GeV

Search for first generation of scalar leptoquarks

Results: 95% CL exclusion regions



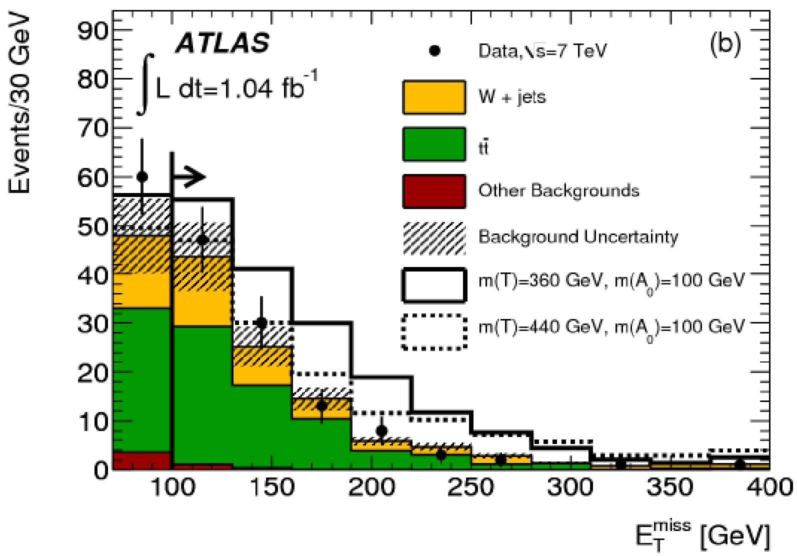
Observed (expected) limits:

- $\beta=1$: $m_{LQ} > 660(650)$ GeV
- $\beta=0.5$: $m_{LQ} > 607(587)$ GeV

Search for exotic top partners with large E_T^{miss}

Motivations: Top quark is the main contributor to quadratic divergence in the Higgs mass → *light* top partners T (m_T<1TeV) could allow to cancel part of this divergence, and provide solutions to the hierarchy problem

Analysis strategy: Search for $T\bar{T} \rightarrow t\bar{t} A_0 A_0$ with A_0 a stable, neutral weakly-interacting particle



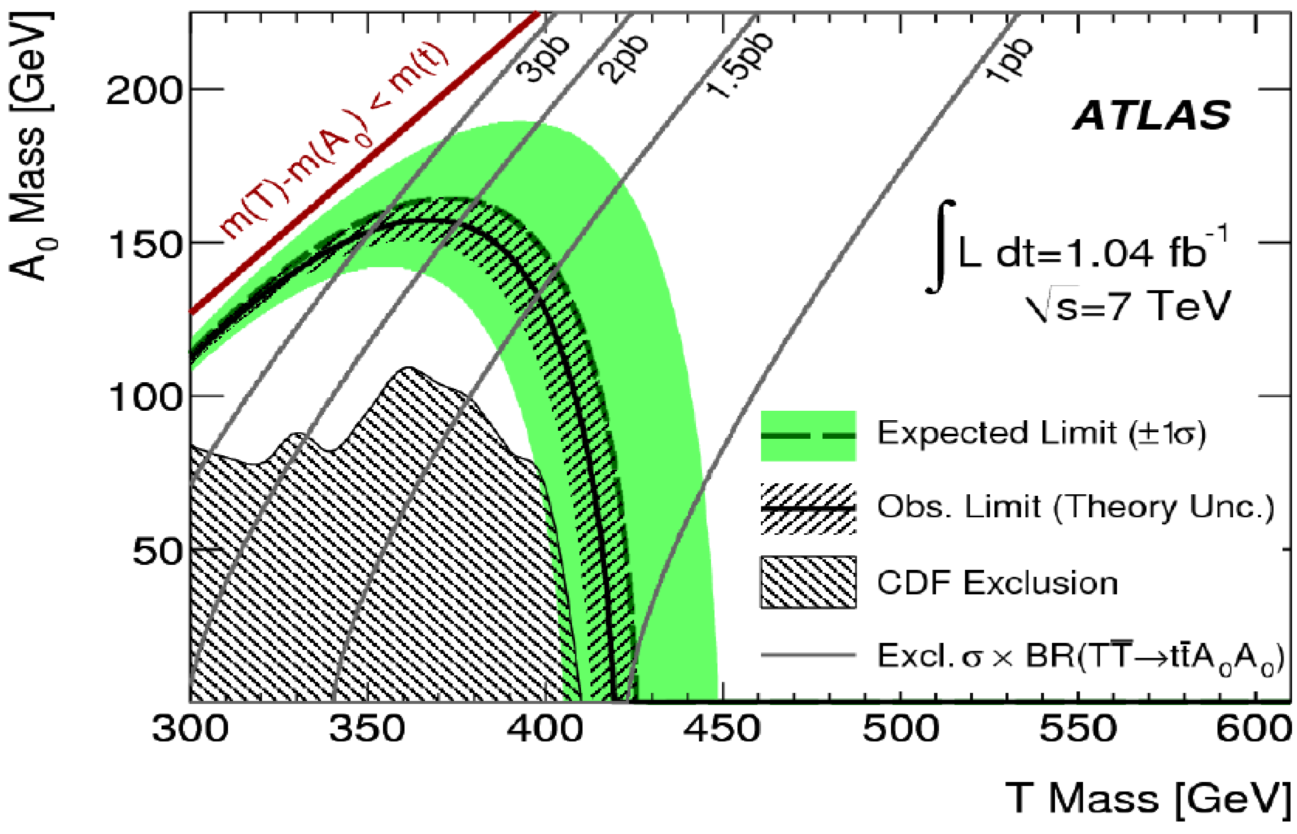
→**Introduced by many models, *e.g.:***
SuSy, little Higgs, 3rd generation of leptoquarks, extra dimension, etc

➢**Many provide mechanism for EWSB, and dark matter candidates**

→Signature identical to $t\bar{t}$, with larger amount of E_T^{miss} (focus here on single-lepton channel)

Search for exotic top partners with large E_T^{miss}

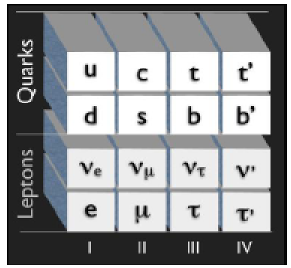
Results: 95% CL exclusion regions assuming B.R.($T\bar{T} \rightarrow t\bar{t} A_0 A_0$)=100%

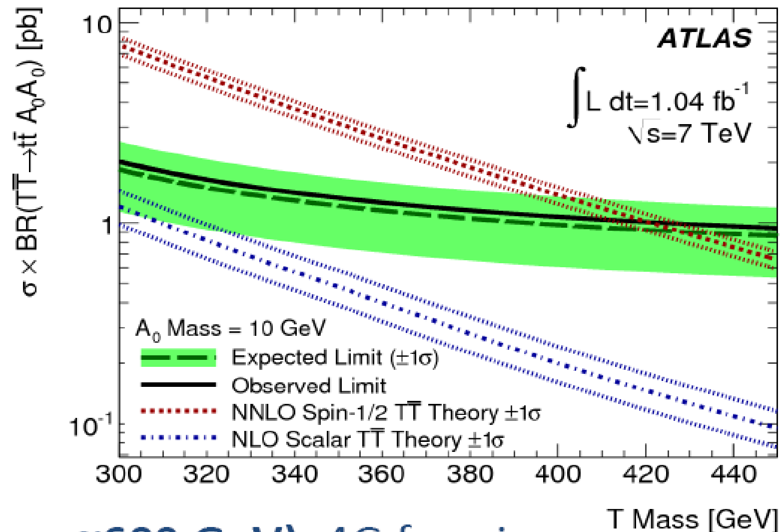


Interesting interpretation

Interesting interpretation:

4^{th} generation (l4,v4,u4,d4) is a natural and simple extension of the SM





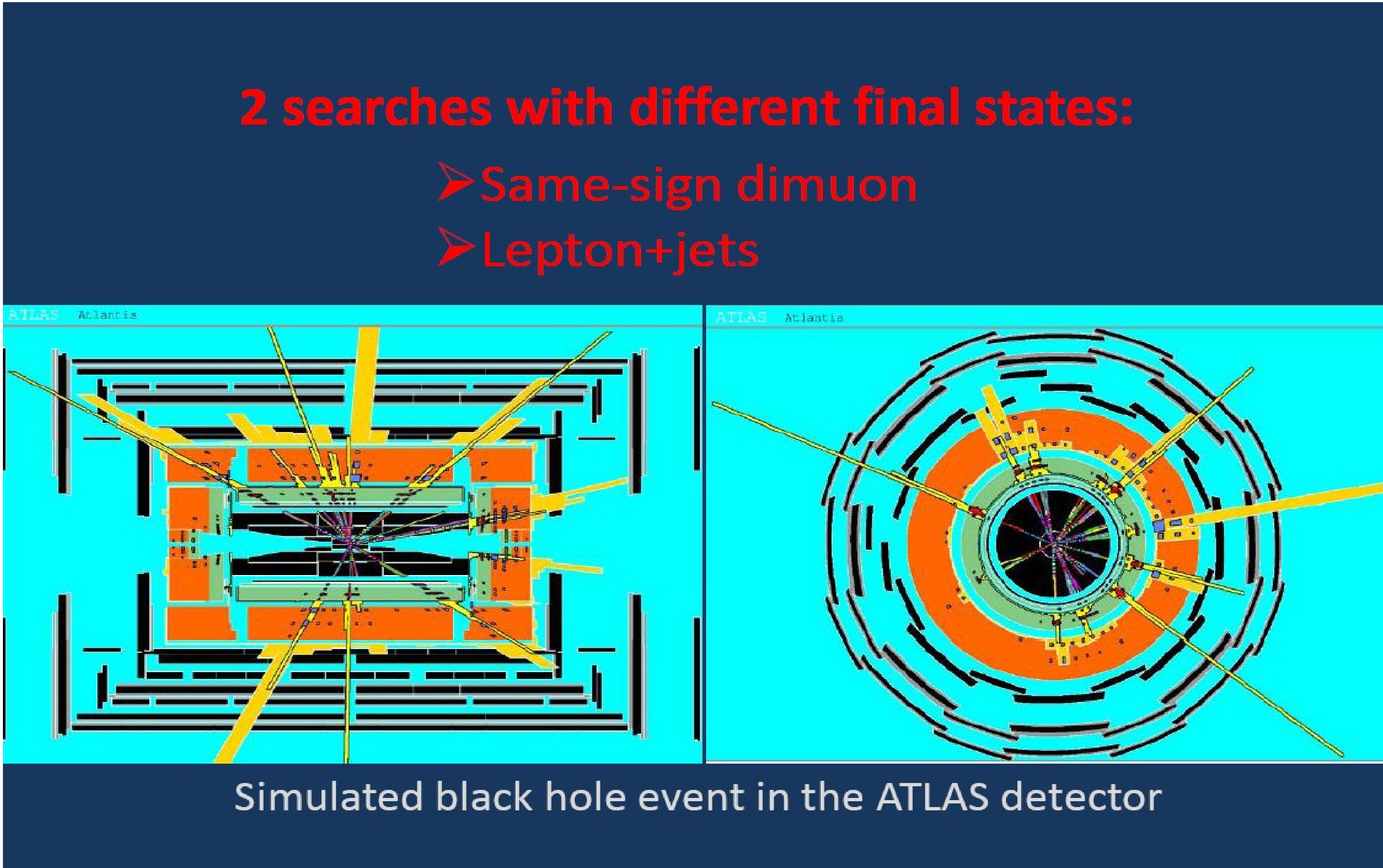
Would have major implications:

- Can **allow a heavy Higgs**
- **If there is no Higgs and u4 is heavy (e.g. ~600 GeV)**, 4G fermion condensates could play the **role of the Higgs via some strong interactions !**
- **In 5D** AdS space, K-K excitations of gauge bosons interacting with 4G fermions **give rise to Yukawa couplings** and to the **mass hierarchy**
- Could provide 10^{13} to 10^{15} more CP Violation to **solve the Baryon Asymmetry of the Universe problem**

→ m_{u4} > 420 GeV @ 95% CL ; σxBR < 1.1 pb (with m_{A_0}=10 GeV)

N.B.: limits in blue also ~valid for scalar models, e.g. stop quark pair production

Black holes

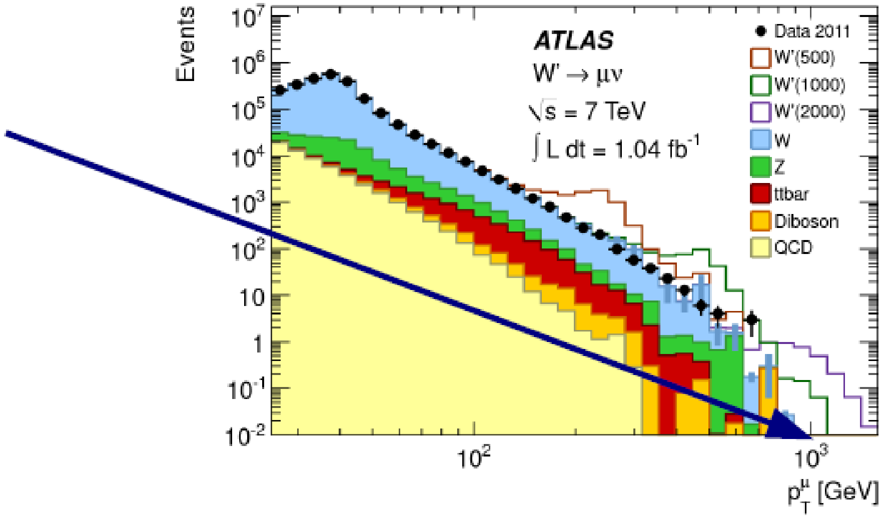


Simulated black hole event in the ATLAS detector

Search for heavy resonances

- Predicted by numerous extensions of the Standard Model:
  - → GUT-inspired theories, Little Higgs → heavy gauge boson(s) Z' (W')
  - → Technicolor → narrow technihadrons
  - → Randall-Sundrum ED → Kaluza-Klein graviton
- Experimental challenge: understand detector performance (resolution, efficiency) for a signal with (almost) no control sample at very high momentum → confidence in alignment, simulation, etc…
- Electrons and muons:

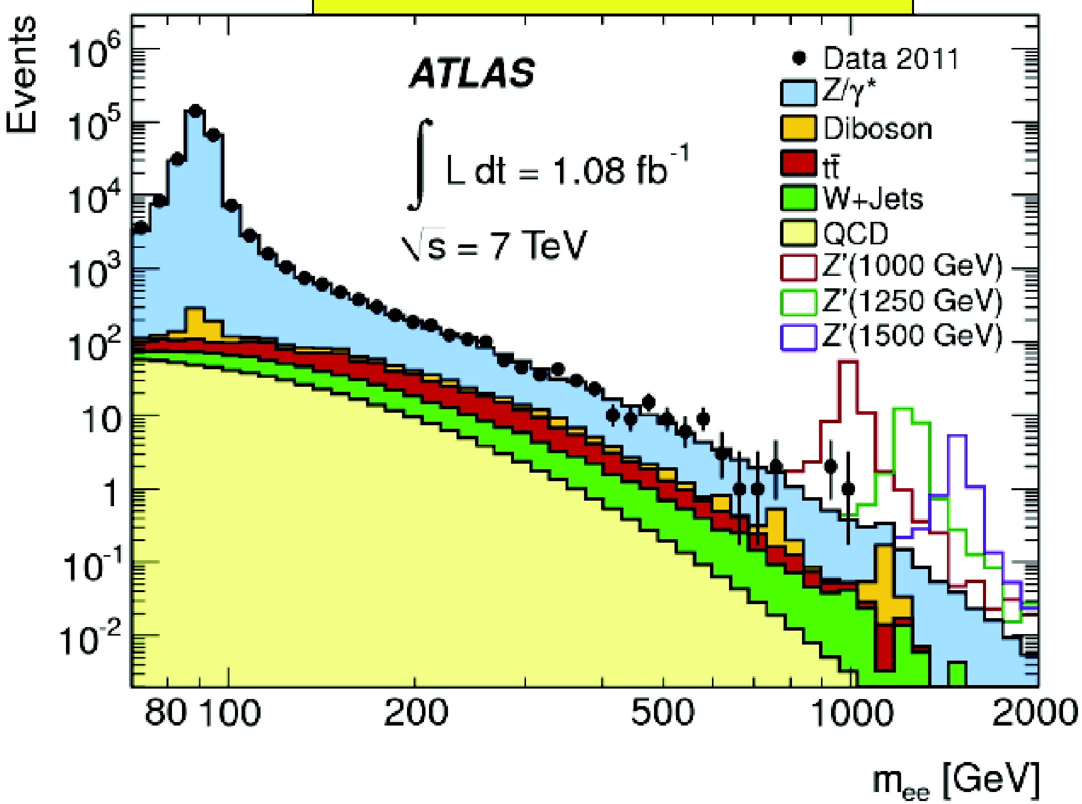
  Rapidly approaching 1 TeV!



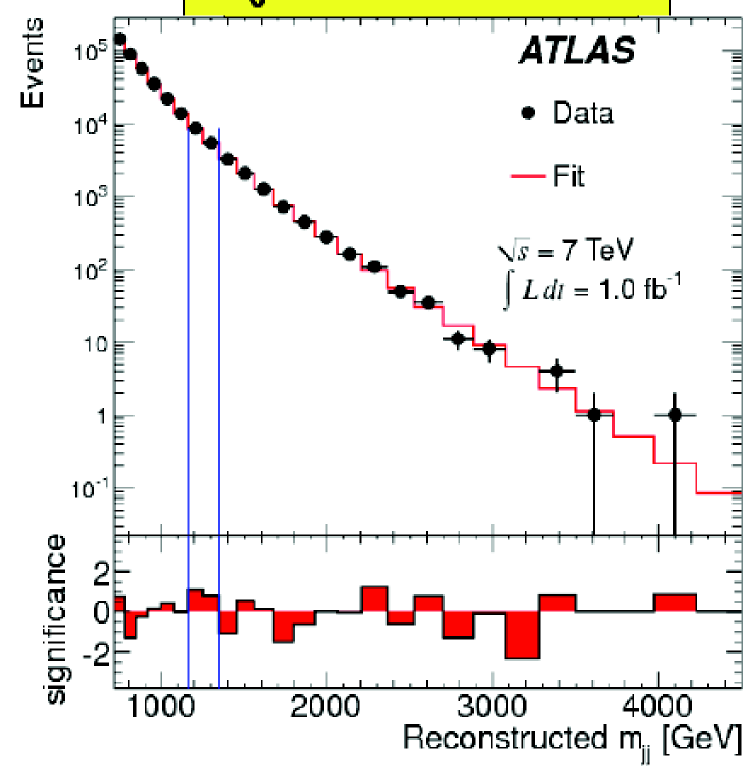
Search for heavy particles-resonances

- Search for peaks in different spectra
  - Reached very high masses: ~4TeV (m_{jj}) and 1 TeV (m_{ee})

2 electrons invariant mass



2 jets invariant mass



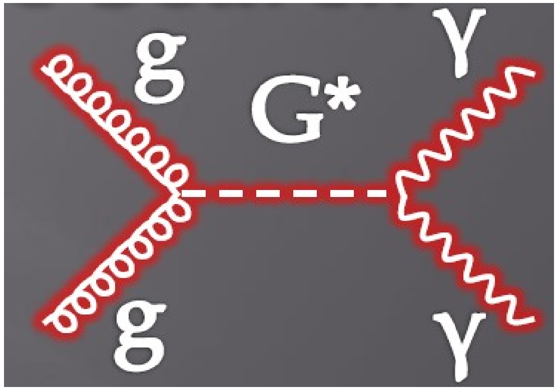
This allows to put more stringent lower mass limits to heavy new particles

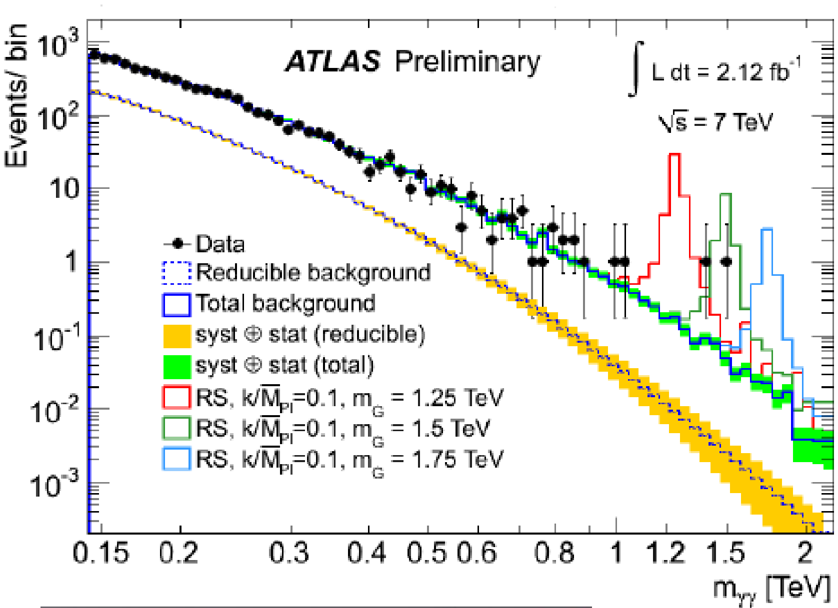
Diphoton resonances search

- No excess in the $m_{\gamma\gamma}$ spectrum

2.12 fb^{-1}

arXiv:1112.2194v1

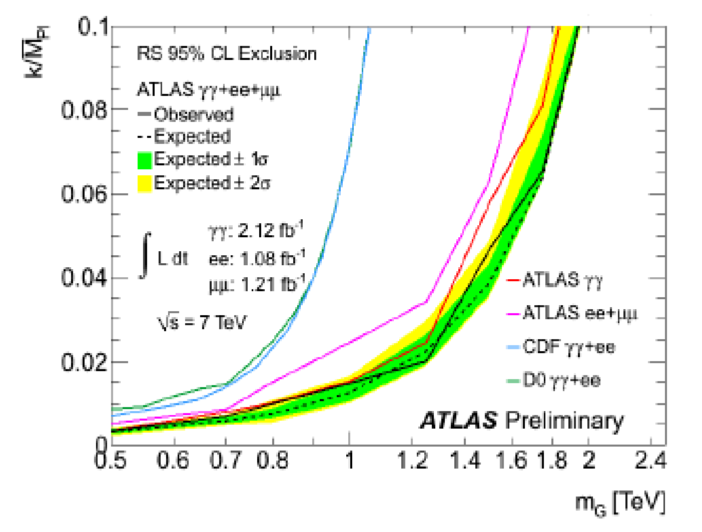


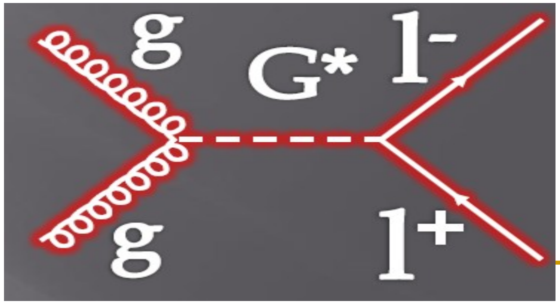


Bayesian approach using templates

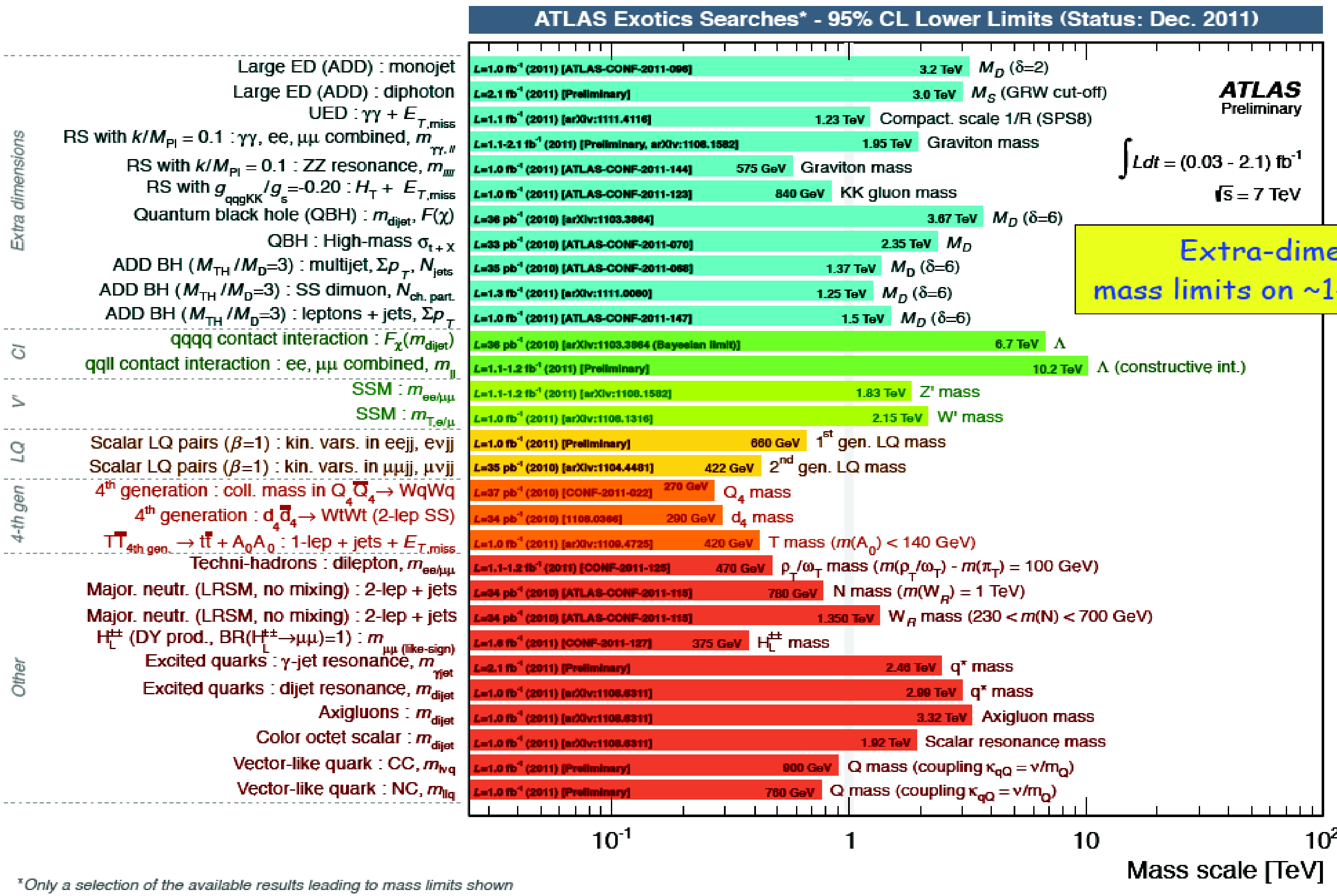
RS G* limits (γγ+ll):

- m_{G^*}>1.95 TeV ($k/\bar{M}_{PL}$=0.1)
- m_{G^*}>0.8 TeV ($k/\bar{M}_{PL}$=0.01)



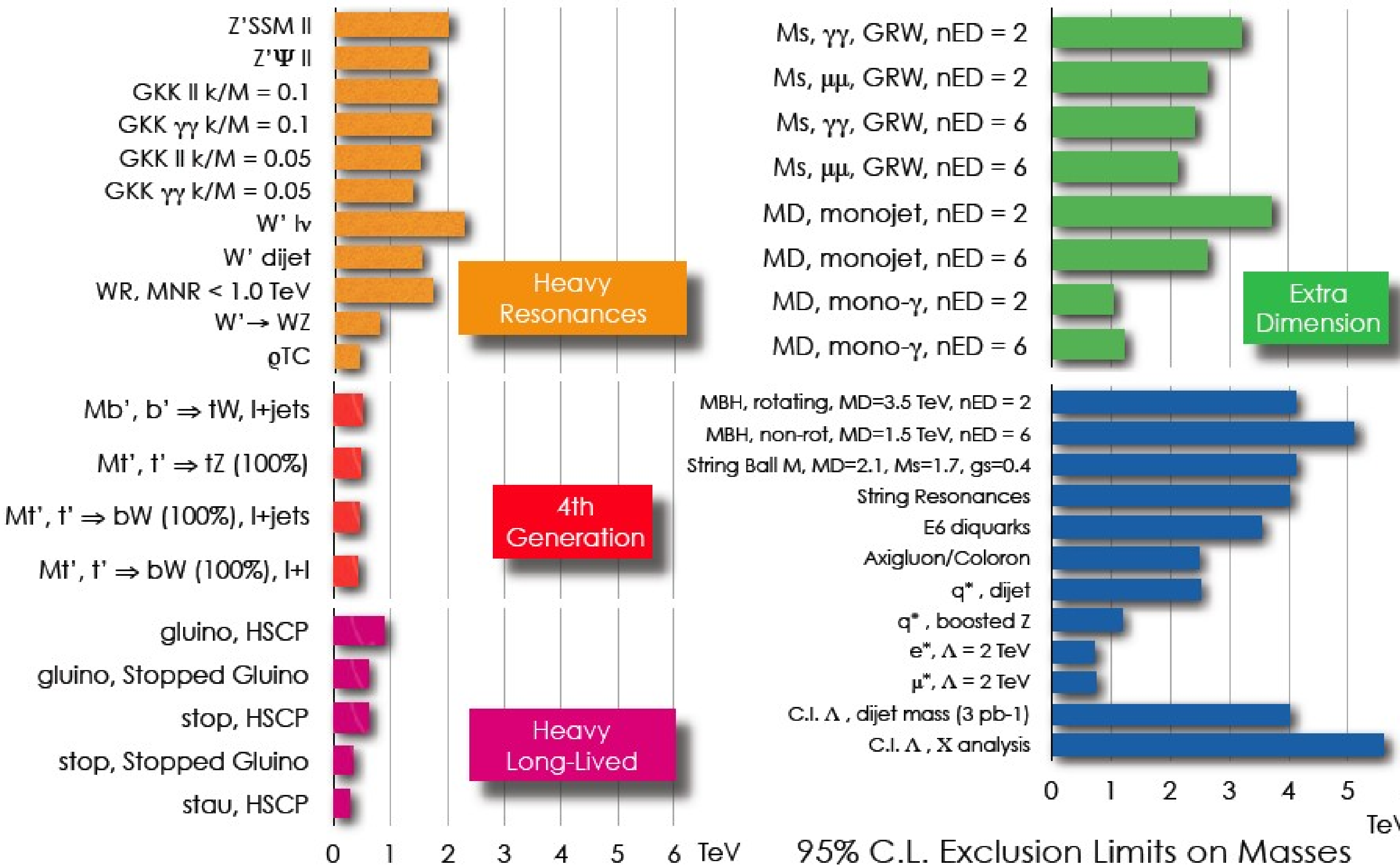


New exotic physics search result summary



Extra-dimensions:
mass limits on ~1-3 TeV range

(NULL) searches in CMS

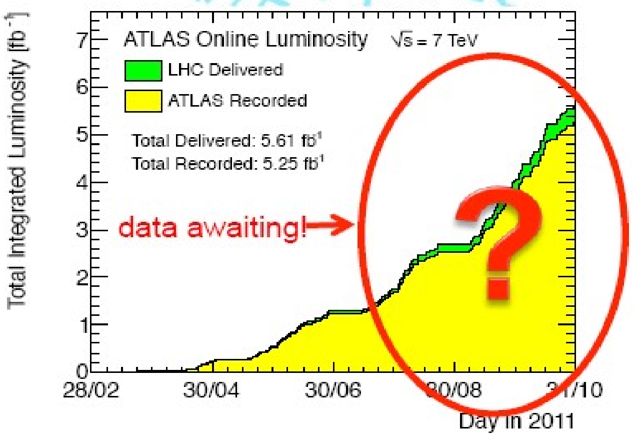


Summary on BSM searches

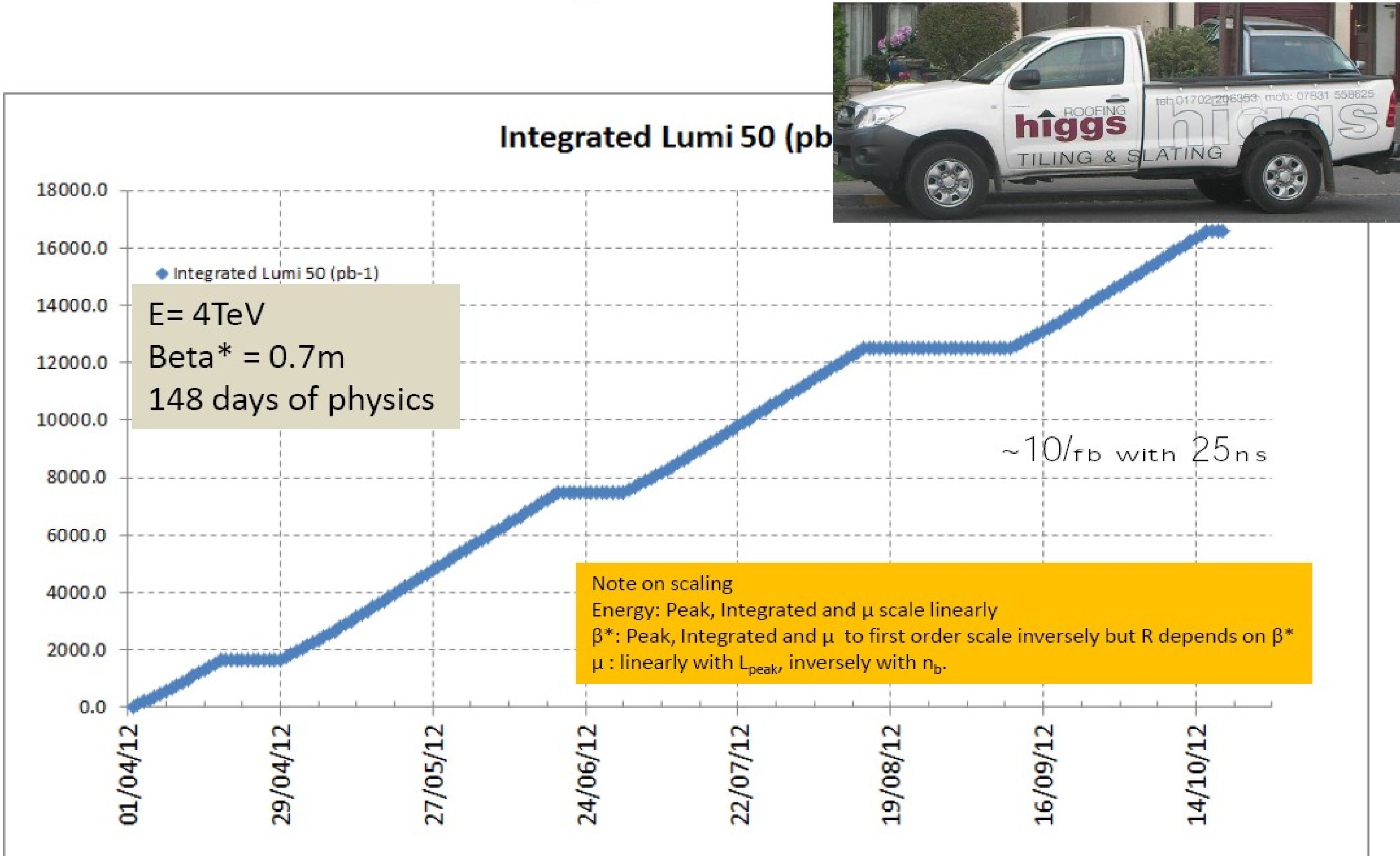
- ATLAS has performed many different BSM searches
- So far, no indication of BSM physics in any
  - $\rightarrow$ most stringent limits set on popular models

Outlook

- analyse rest of 2011 data $\sim 4\ \mathrm{fb}^{-1}$
- + upcoming data in 2012!
- Searches for other signatures coming
- Present searches will keep going
  - more and refined SRs
  - refined background estimates



2012 Integrated with 50ns



December 13, 2011 S. Myers for DG SPC 27

LHC running in 2012: 8 TeV [?]

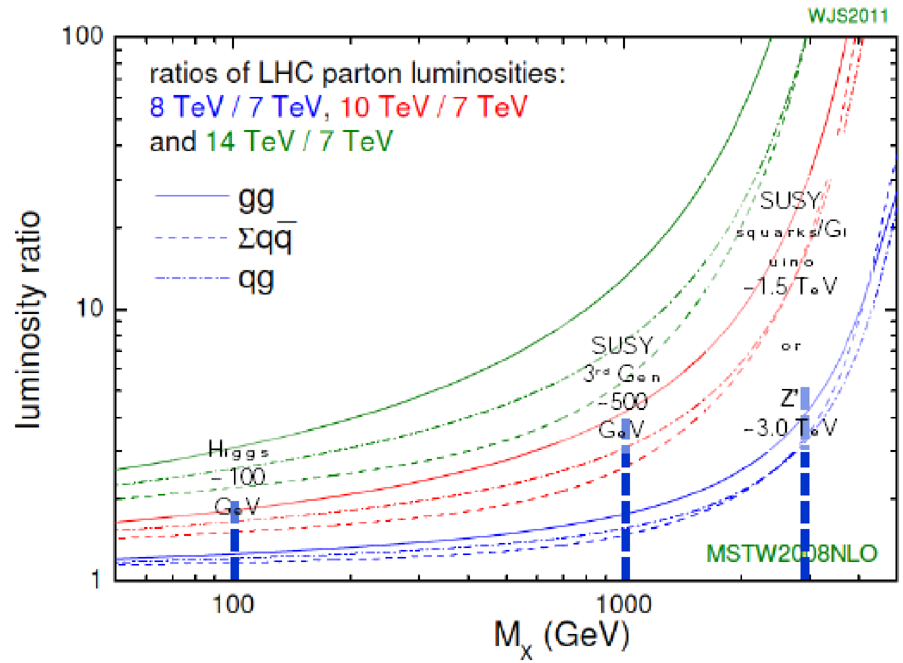
- **Enhances physics reach in two ways:**
  - Higher cross-sections for new physics in full mass range

Higgs: pp → H, H→ WW, ZZ & γγ
mainly gg: Factor ~1.2

SUSY: 3rd Gen Mass ~ 0.5 TeV
qq and gg: Factor ~1.5

SUSY: Squarks/Gluino M~1.5TeV
qq,gg,qg: Factor ~4.0

Z′ : Mass ~ 3.0 TeV
qq: Factor ~3.5



- More integrated luminosity
  - **@ 8 TeV: 10 – 16fb^{-1} expected (25/50 ns bunch crossing)**

The predictable future: LHC Time-line

2009 — Start of LHC

Run 1: 7 TeV centre of mass energy, luminosity ramping up to few 10^{33} cm^{-2} s^{-1}, few fb^{-1} delivered

2013/14 — LHC shut-down to prepare machine for design energy and luminosity

Run 2: Ramp up luminosity to design (10^{34} cm^{-2} s^{-1}), ~50 to 100 fb^{-1}

2017 or 18 — Injector and LHC Phase-I upgrades to go to ultimate luminosity

Run 3: Ramp up luminosity to 2.2 x design, reaching ~100 fb^{-1} / year accumulate few hundred fb^{-1}

~2021/22 — Phase-II: High-luminosity LHC. New focussing magnets and CRAB cavities for very high luminosity with luminosity levelling

Run 4: Collect data until > 3000 fb^{-1}

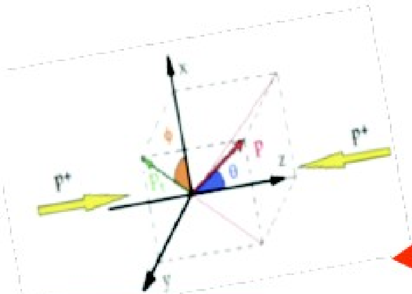
2030

Kick-Off meeting for HL-LHC: Nov 2011

Summary and Outlook

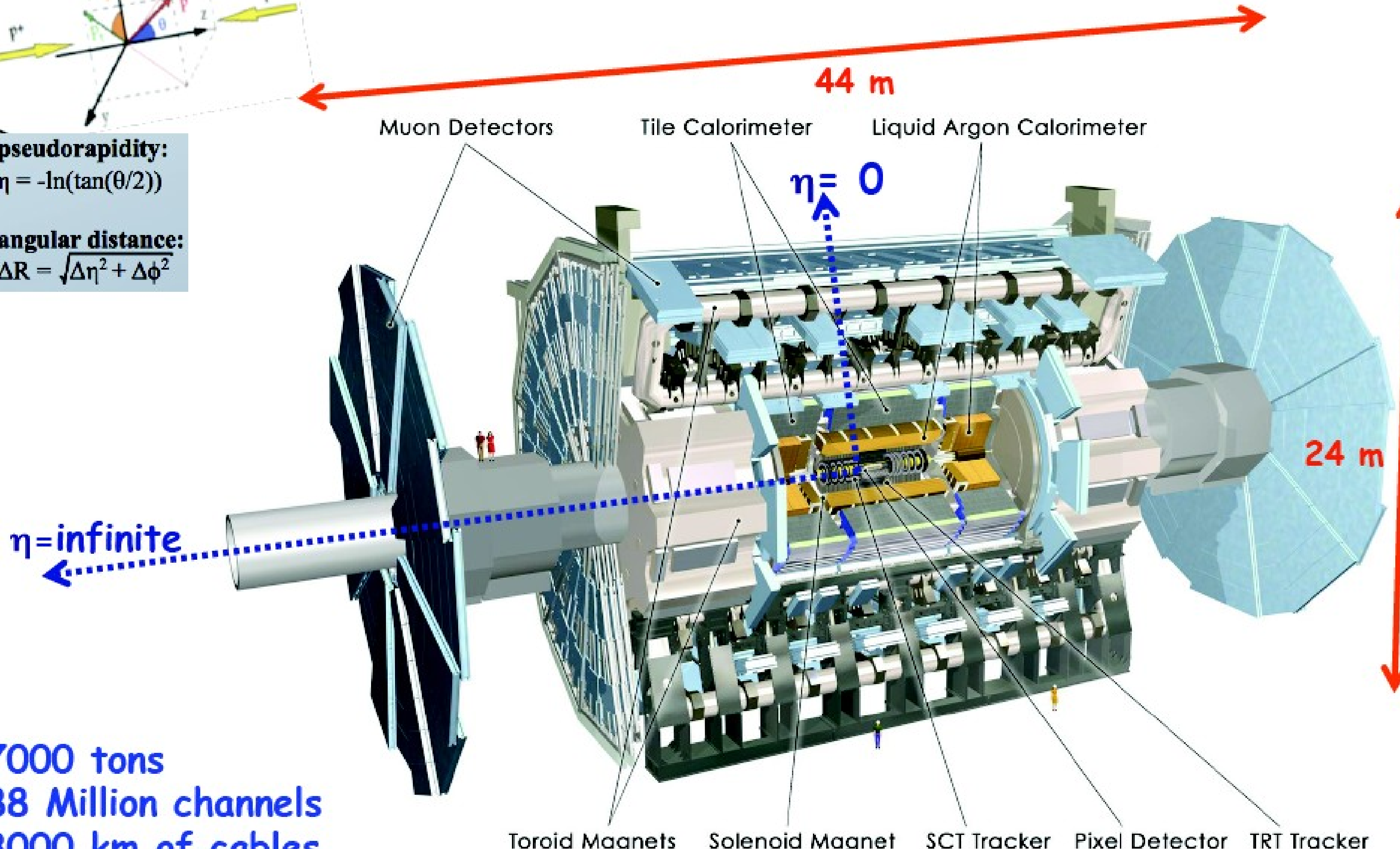
- **LHC and experiments' run at 7 TeV truly impressive**
  - By now detectors are fully functioning scientific instruments;
- **With ~40pb^{-1} the LHC observed all particles of the Standard Model**
  - Solid base for understanding the "background" to searches at higher mass and transverse energy scales
- **With 5 fb^{-1} we entered a true discovery era**
  - (null) searches so far
- **With 10-15 fb^{-1}**
  - SUSY explorable over very large area; possible new resonances; very large reach for other new physics;
- **The journey has just started.**

The ATLAS detector



pseudorapidity:
$\eta = -\ln(\tan(\theta/2))$

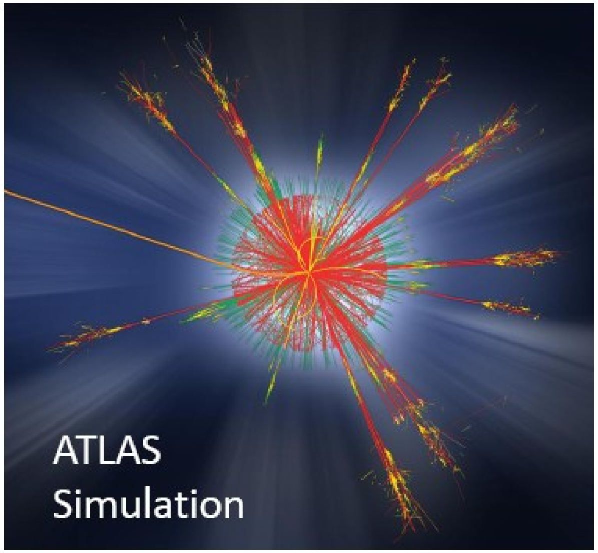
angular distance:
$\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$



7000 tons
88 Million channels
3000 km of cables
2T solenoid
Toroid (B ~ 0.5T in barrel;~1T end-cap)

Black holes

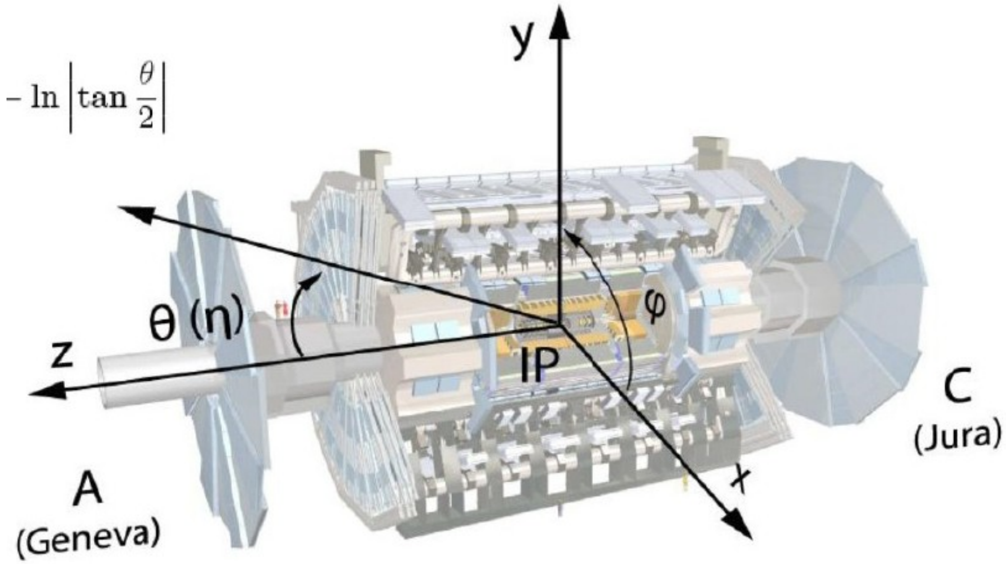
Motivations: Models introducing extra dimensions can provide a solution to the hierarchy problem (M_{Pl} ~10^{16}GeV >> M_{EW})
→The Planck scale in (n+4)-dimensions, M_D, would be much smaller than in 4D, because gravity propagates in all dimensions



If M_D is in the TeV range, **microscopic black-holes** could appear @LHC!...
... **and evaporate by Hawking radiation**

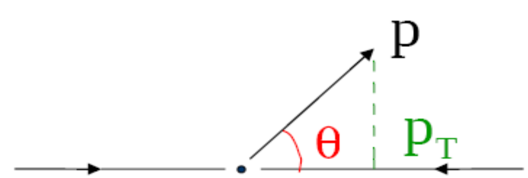
Large uncertainties on models due to our ignorance of quantum gravity, but semi-classical approximation assumed valid for: m(B.H.) > $M_{Threshold}$ >> M_D

ATLAS Detector



The ATLAS Detector is really big!

- Length : ~ 46 m
- Radius : ~ 12 m
- Weight : ~ 7000 tons
- $\sim 10^8$ electronic channels
- 3000 km of cables



Transverse momentum

(in the plane perpendicular to the beam)

$$p_T = p \sin\theta$$

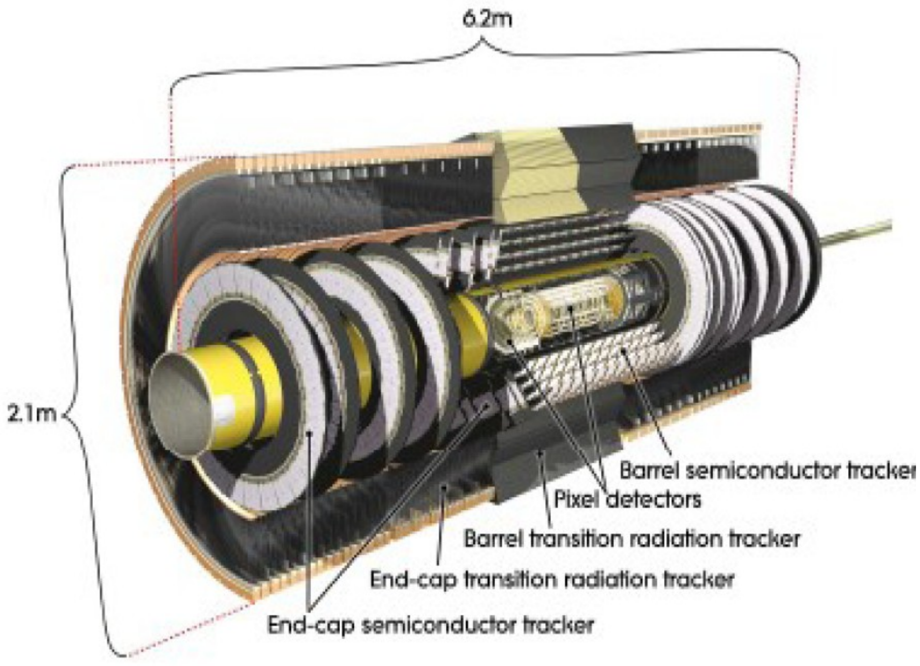
Rapidity: $\eta = -\log(\mathrm{tg}\,\frac{\theta}{2})$

$\theta = 90^\circ \rightarrow \eta = 0$

$\theta = 10^\circ \rightarrow \eta \cong 2.4$

$\theta = 170^\circ \rightarrow \eta \cong -2.4$

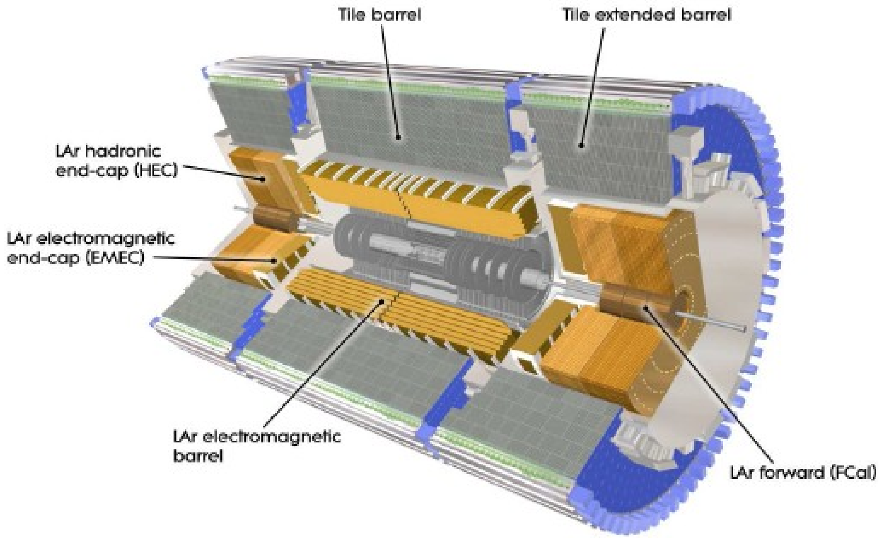
ATLAS Inner Detector



The inner detector $|\eta| < 2.5$ consists of

- Pixel detectors, semi-conductor tracker (SCT), transition radiation tracker
  - $\approx$ 87 million readout channels
  - Immersed in 2T solenoidal magnetic field
- Resolution of $\sigma/p_T = 5 \times 10^{-4} \oplus 0.015$

ATLAS Calorimeters



Electromagnetic and hadronic calorimeters

- Subsystem technology and granularity $\leftrightarrow$ shower characteristics
- Transverse and longitudinal sampling $\approx$ 200000 readout cells up to $|\eta| < 4.9$

Electromagnetic Calorimeters:

- Fine granularity $\Delta\eta \times \Delta\phi = 0.025 \times 0.025$ in central region
- Energy resolution $10\%/\sqrt{E}$

Hadronic Calorimeters:

- Granularity $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ in central region, less segmented in forward region
- Energy resolution $50\%/\sqrt{E} \oplus 0.03$