ATLAS Beyond the Standard Model

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LBNL

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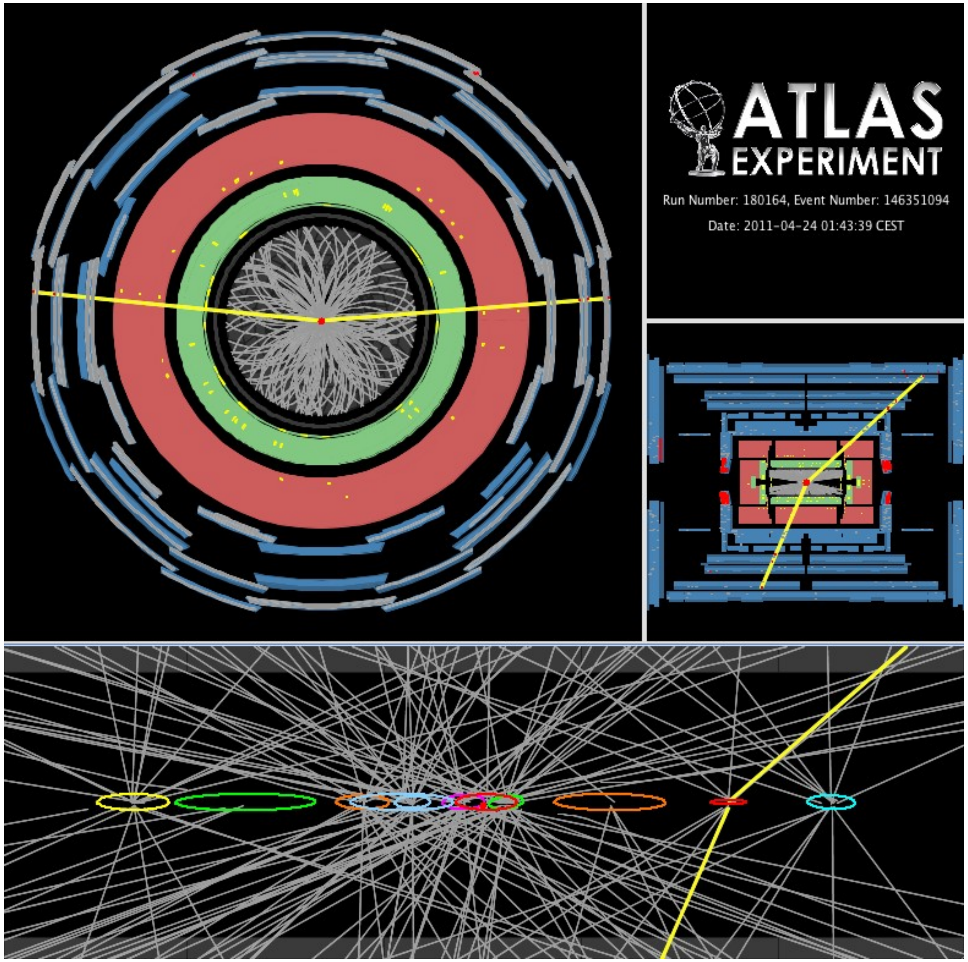
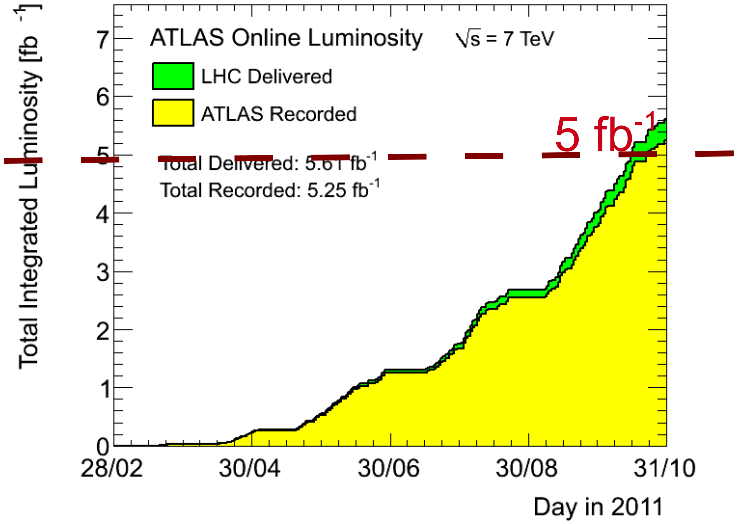
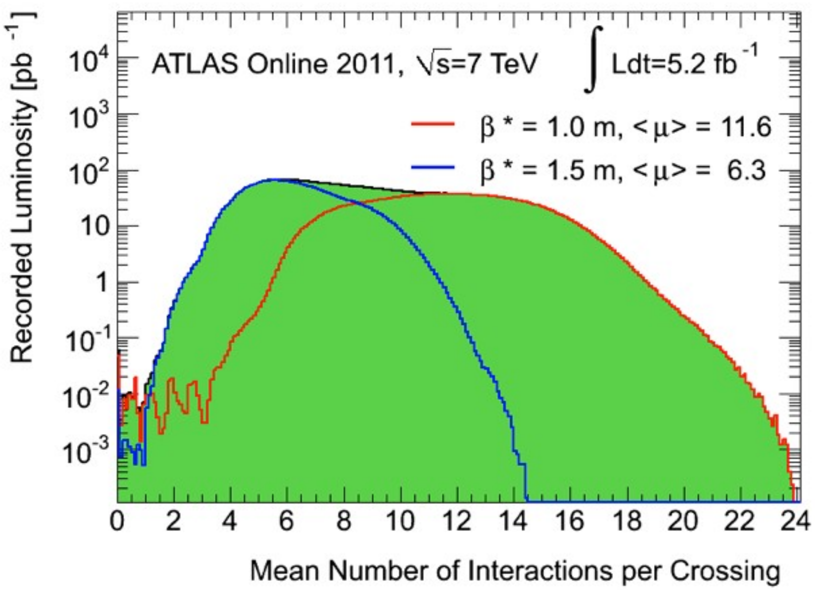


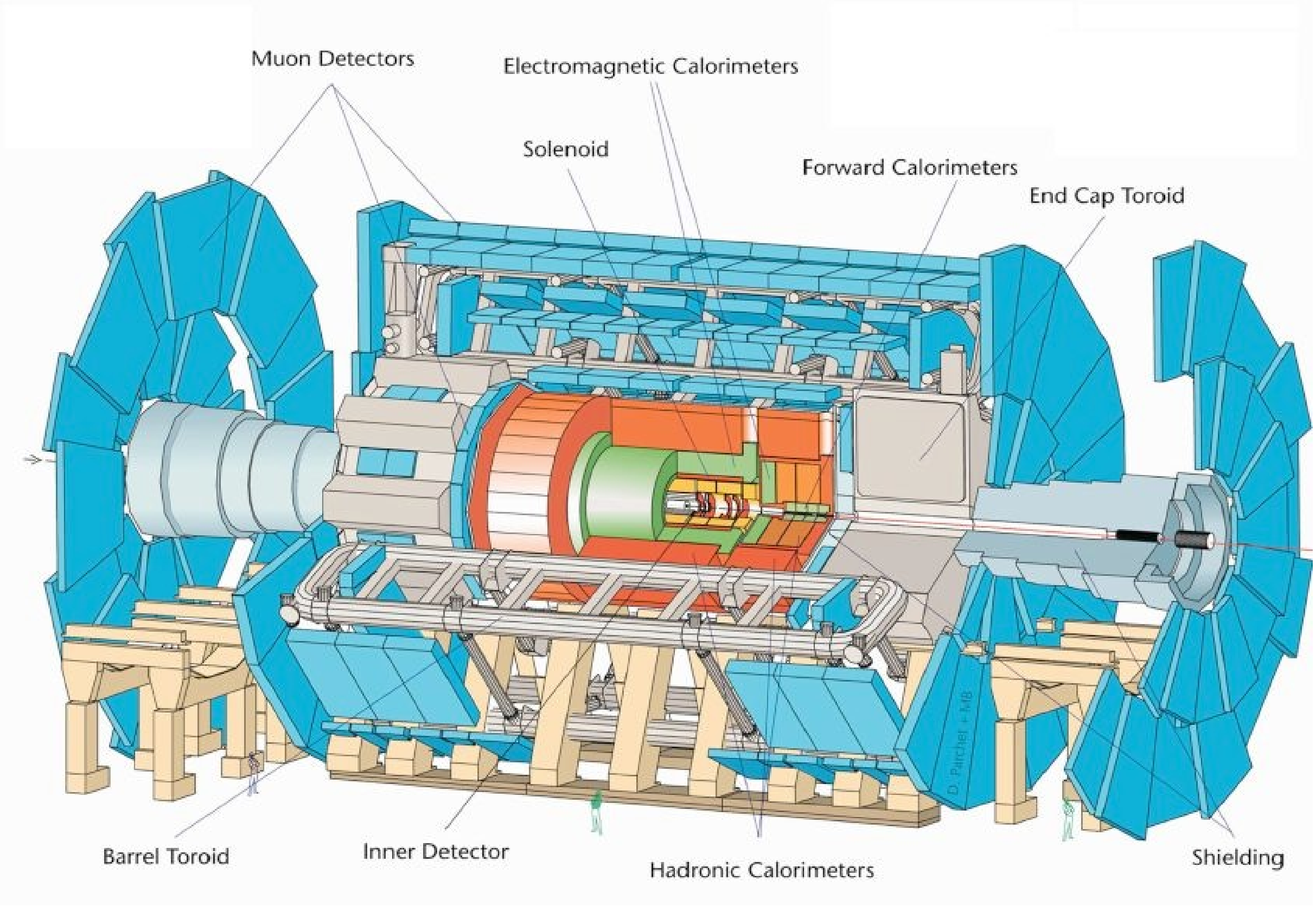
The Large Hadron Collider (LHC)

- pp collisions at $\sqrt{s}$ = 7 TeV
  (and PbPb at $\sqrt{s_{NN}}$ = 2.76 TeV, not covered in this talk)
- LHC has performed extremely well in 2011:
  - → 3.65 10^{33} /cm²/s peak luminosity
  - → 5.25 fb^{-1} delivered
- 50 ns bunch spacing
- ~ 12 collisions / crossing during last months of data-taking





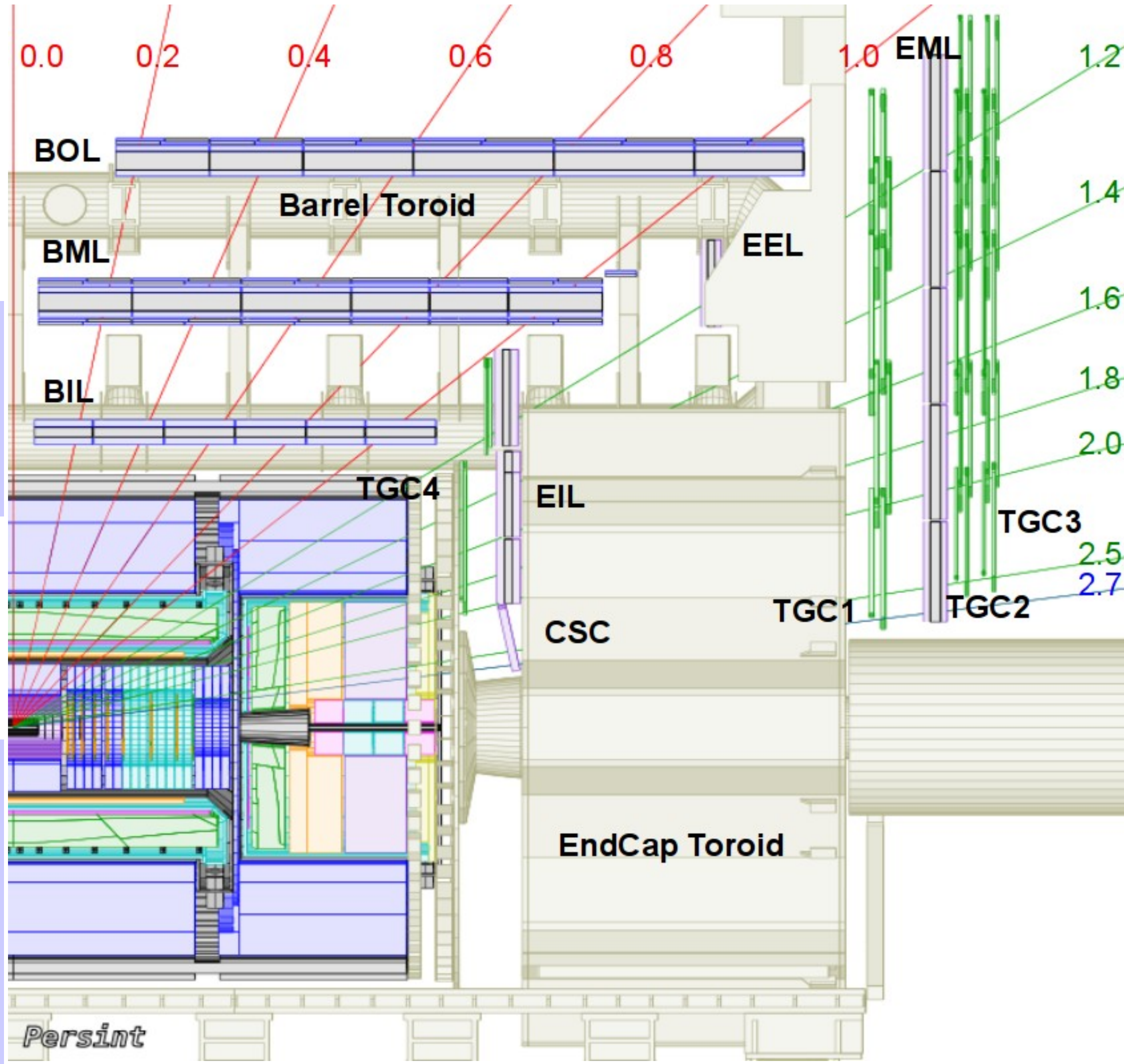
The ATLAS Detector



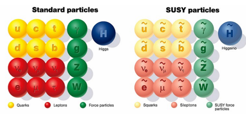
The ATLAS Detector

Already close to nominal performance!

Muon Spectrometer	Toroids B.dl ~ 1-7 T.m RPC + TGC: triggers MDT + CSC: precision σ/p_T = 2% @ 50 GeV σ/p_T ~ 13% @ 1 TeV
Hadronic Calorimeter	Fe+scint. or Cu/W+LAr $\sigma/E \sim 50\%/E^{1/2} \oplus 3\%$ Thickness ~ 10 λ
EM Calorimeter	Lead+LAr $\sigma/E \sim 10\%/E^{1/2} \oplus 1.5\%$ Thickness ~ 24 X_0
Inner Detector	2 Tesla solenoid Si pixels + strips TRT $\sigma/p_T = 5 \times 10^{-4}\, p_T \oplus 0.01$

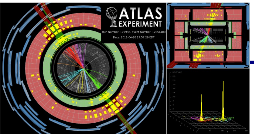


Outline (extended)



Supersymmetry (with MET)

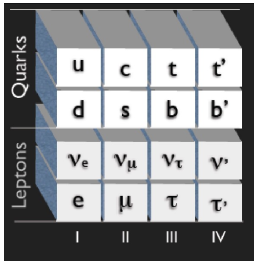
- → **Jets + MET**
- → Monojet + MET
- → Lepton(s) + MET
- → Tau's + MET
- → **3rd generation**
- → Photon(s) + MET



Heavy Resonances

- → **Dilepton, Dijet, top-antitop**
- → W', Diphoton, Photon-Jet
- → Doubly-charged Higgs
- → Heavy neutrinos
- → Dibosons
- → Excited leptons

4th generation and heavy "quarks"

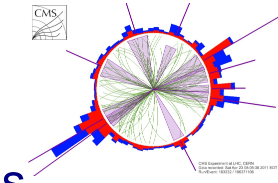


- → **t'**
- → **b'**
- → **Vector-like quarks**
- → Leptoquarks

Long-lived particles

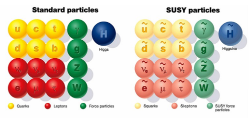
- → **Displaced vertices**
- → **Disappearing track**
- → Slow particles
- → Out-of-time decays

TeV-gravity



- → Black-holes
- → monojets, monophotons

Outline



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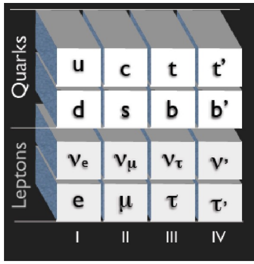

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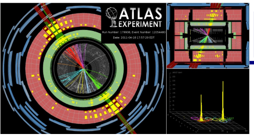


Heavy Resonances

→ **Dilepton**

→ **Dijet**

→ **Top-Antitop**

Long-lived particles

→ **Displaced vertices**

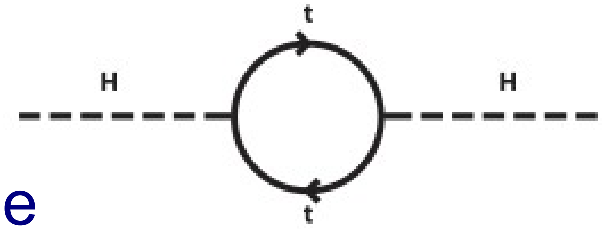
→ **Disappearing track**

This is my own selection of some of the most recent topics.

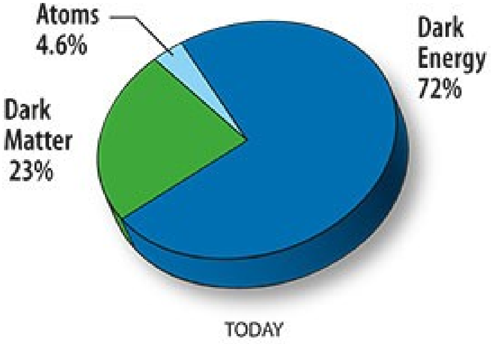
Not enough time to show you everything.

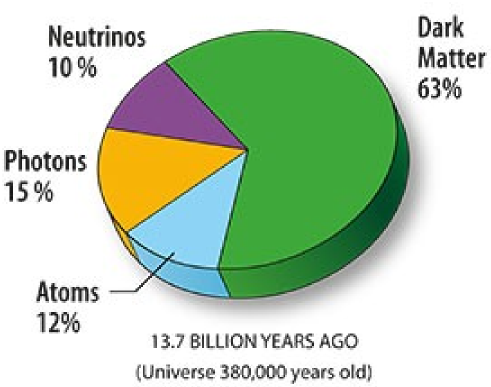
For more: https://twiki.cern.ch/twiki/bin/view/AtlasPublic

Why look "beyond" the Standard Model?



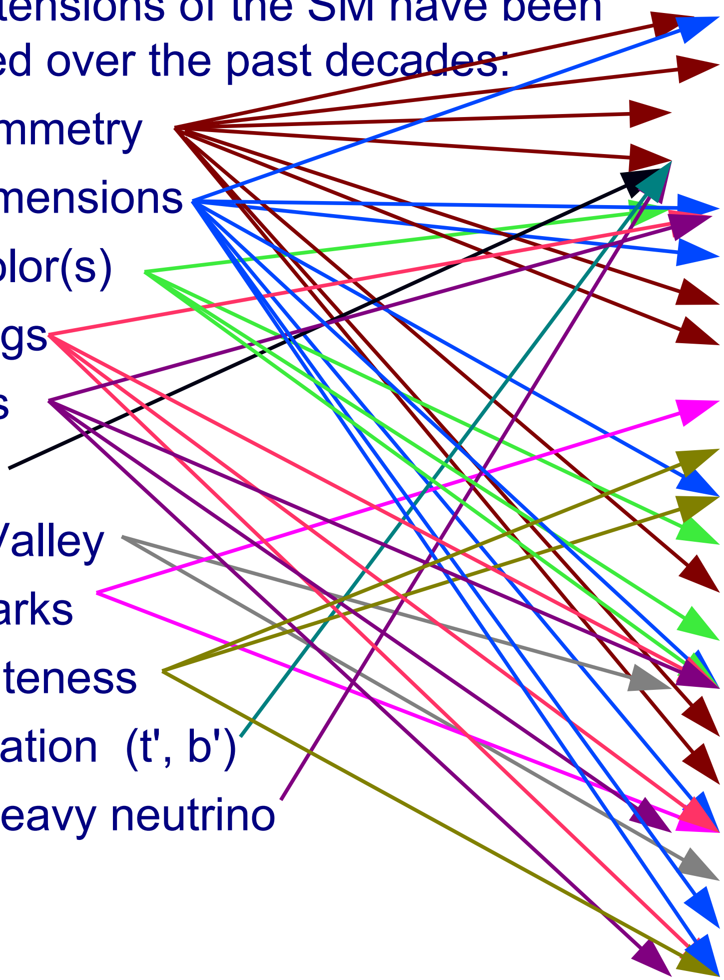
- The Standard Model is a (very) effective theory that breaks down at a certain scale
  - → Hierarchy: quadratic divergence of the Higgs mass, extremely fine-tuned
  - → What is the underlying nature of EWSB?
- Dark Matter
  - → cannot be explained by SM
- Neutrinos have mass
  - → where are the right-handed neutrinos?
- BSM models attempt to solve the SM limitations





A very long list of models x 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...



- 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...

(for illustration only)

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A complex 2D problem

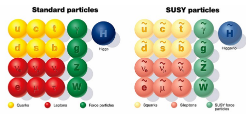
Experimentally, a **signature standpoint** makes a lot of sense:

→ Practical

→ Less model-dependent

→ Important to cover every possible signature

Outline



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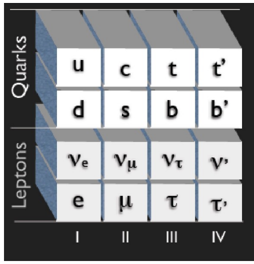
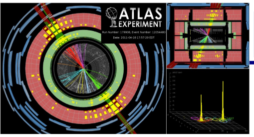
4th generation and heavy "quarks"

→ **t'**

→ **b'**





Heavy Resonances

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→ **Dijet**

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Long-lived particles

→ **Displaced vertices**

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Supersymmetry (with Missing Transverse Energy)

Cascade ending with LSP
→ large MET

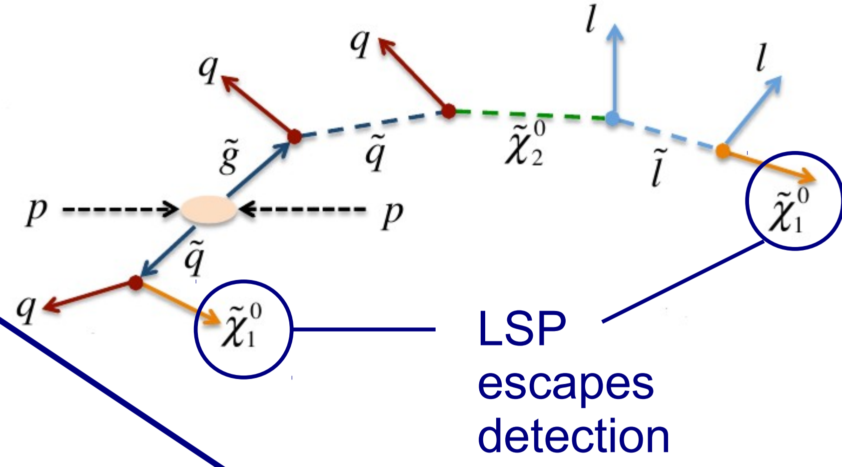
1 Jets+MET: Gluino and Squark production dominates

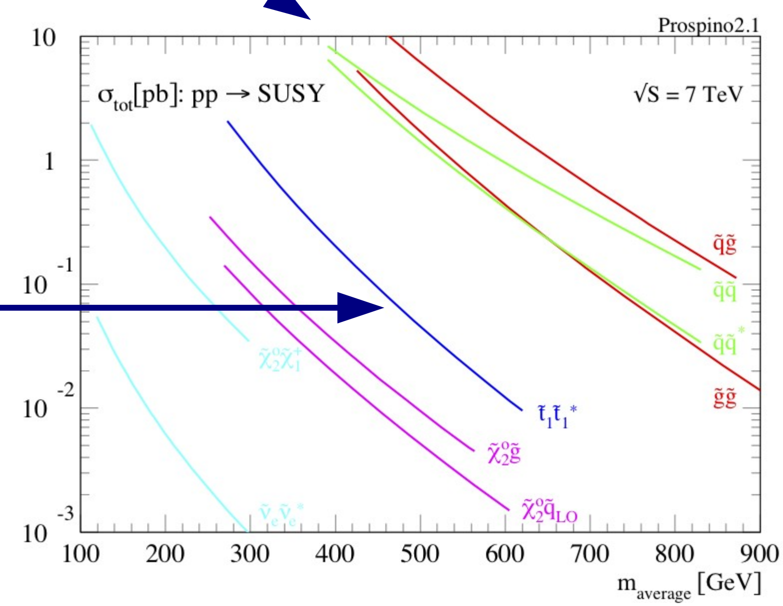
2 Leptons(+jets)+MET: lower branching ratio/cross-section but complementary

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

- → in cascade
- → direct production requires > 1 fb^{-1}
  several new results with 2 fb^{-1}

4 Photon(s)+MET: GMSB models





SUSY: Jets + Missing E_T

$\tilde{q} \to q\tilde{\chi}_1^0$

$\tilde{g} \to qq\tilde{\chi}_1^0$

- "Workhorse" analysis of SUSY+MET searches
- Select events with 2 to 6 jets
- Veto leptons and events with > 6 jets (left to dedicated high-multiplicity analysis)
- Trigger: Jet 75 + MET 55

  ε > 98% above turn-on
- Discriminant variables:
  - → H_T = sum of jet p_T (including jets with p_T > 40 GeV and $|\eta| < 2.8$)
  - → $m_{eff} = H_T$ + Missing E_T
- Optimize cut on m_{eff} and Missing ET for each jet multiplicity

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above trigger turn-on

Requirement	Channel					
	A	A'	B	C	D	E
E_T^{miss} [GeV] >	160					
$p_T(j_1)$ [GeV] >	130					
$p_T(j_2)$ [GeV] >	60					
$p_T(j_3)$ [GeV] >	–	–	60	60	60	60
$p_T(j_4)$ [GeV] >	–	–	–	60	60	60
$p_T(j_5)$ [GeV] >	–	–	–	–	40	40
$p_T(j_6)$ [GeV] >	–	–	–	–	–	40
$\Delta\phi(\text{jet}, E_T^{miss})_{min}$ >	$0.4\ (i = \{1, 2, (3)\})$			$0.4\ (i = \{1, 2, 3\}), 0.2\ (p_T > 40$ GeV jets)		
$E_T^{miss}/m_{eff}(Nj)$ >	0.3 (2j)	0.4 (2j)	0.25 (3j)	0.25 (4j)	0.2 (5j)	0.15 (6j)
m_{eff}(incl.) [GeV] >	1900/1400/–	–/1200/–	1900/–/–	1500/1200/900	1500/–/–	1400/1200/900

Jet p_T

ETmiss and m_{eff}

2 jets | 3 | 4 | 5 | 6

SUSY: Jets + Missing E_T

$$\tilde{q} \to q\tilde{\chi}_1^0$$
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- Low jet-multiplicity: sensitive to squark production
- High jet-multiplicity: sensitive to gluino production

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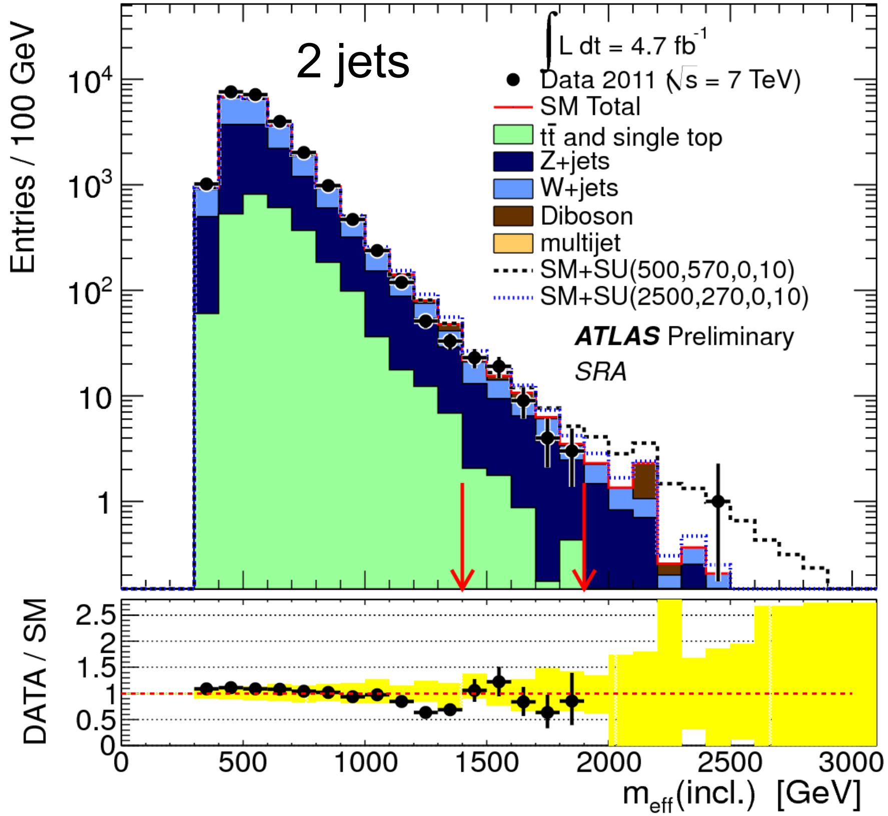

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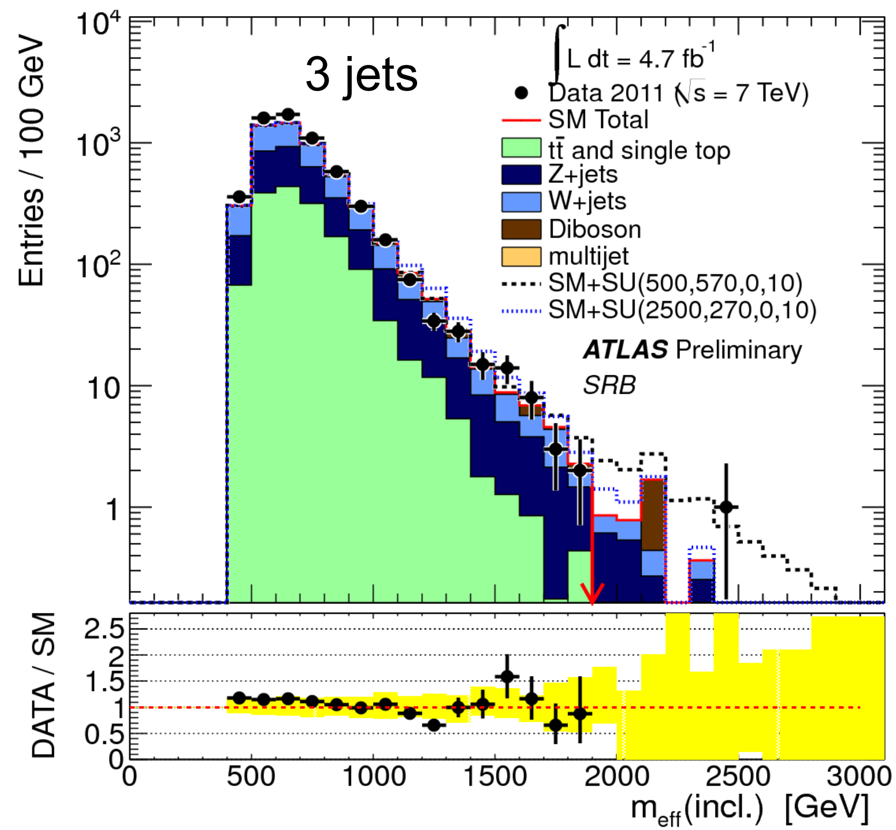

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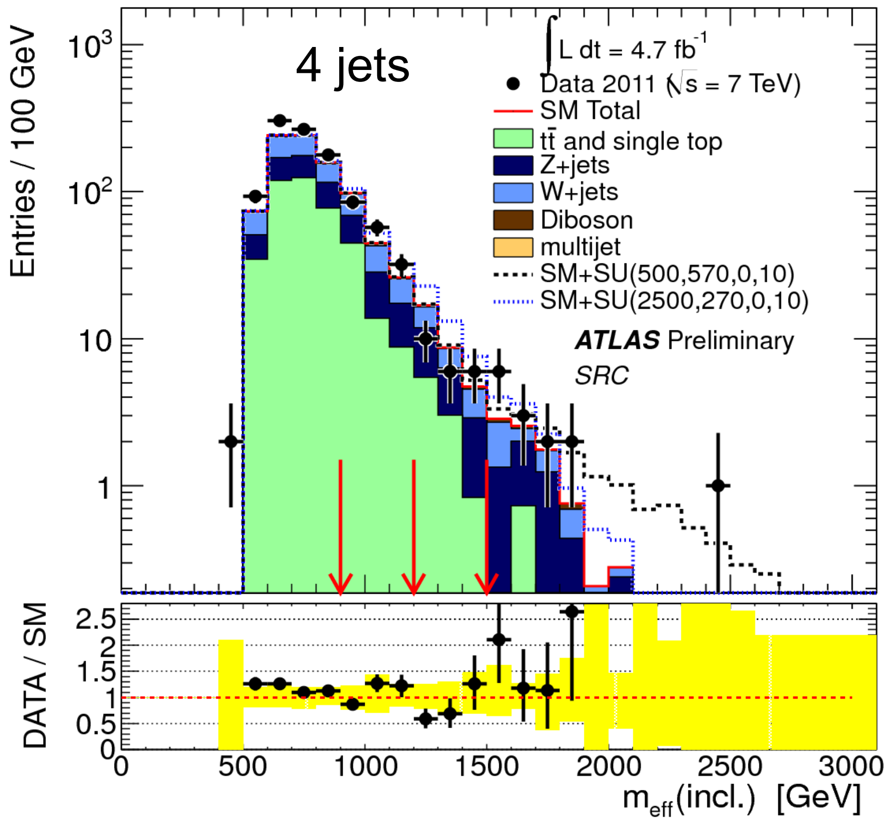

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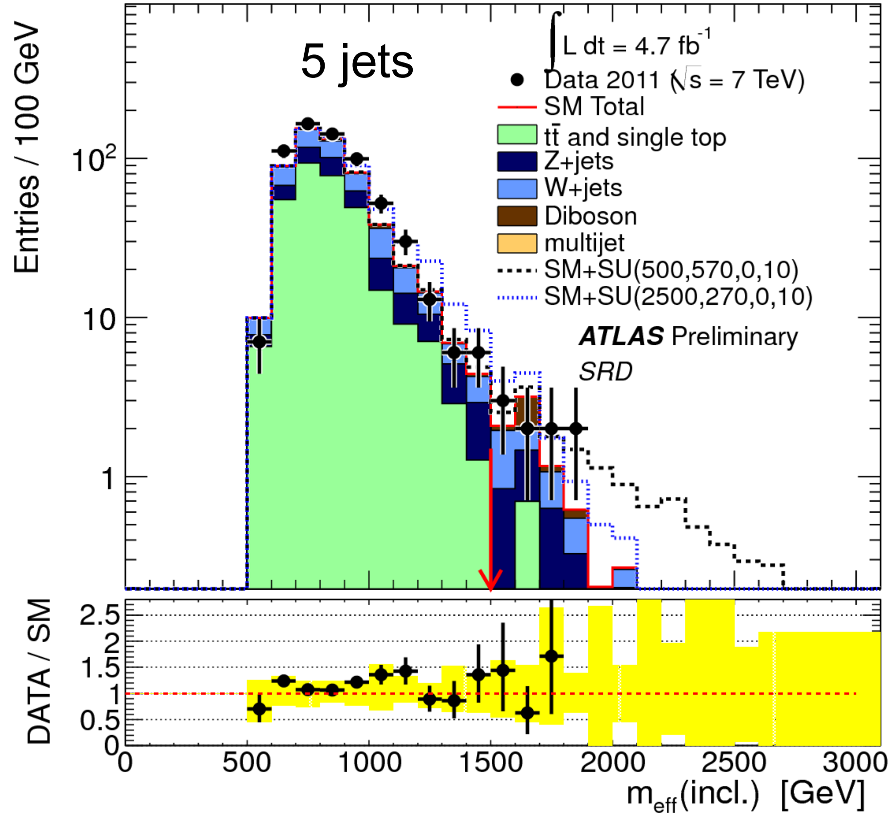

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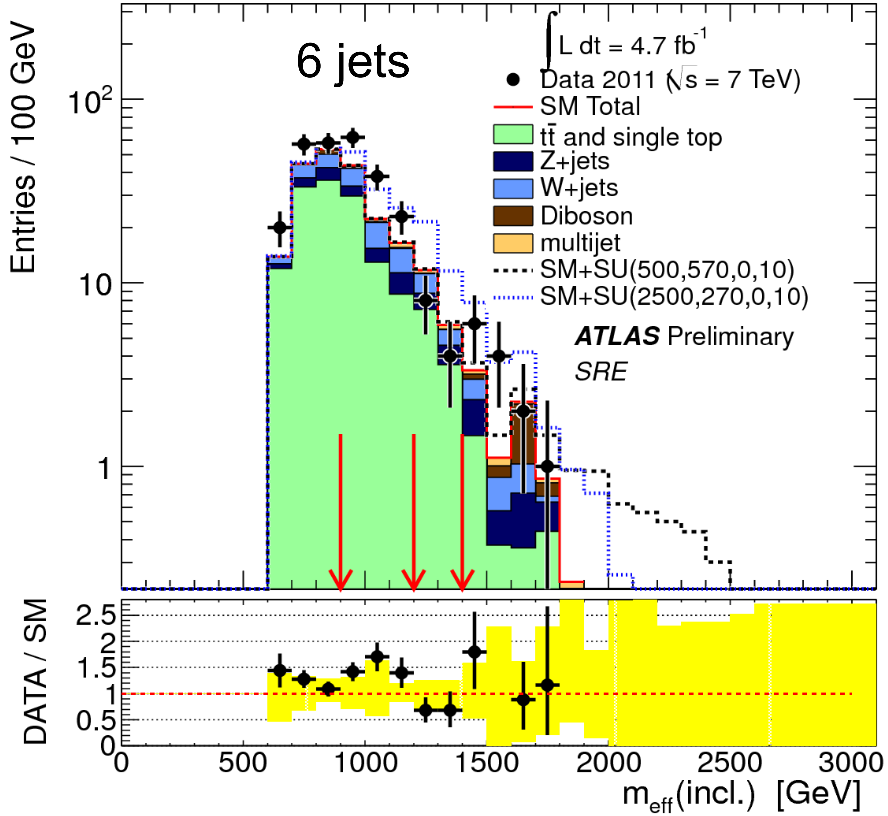

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SUSY: Jets + Missing E_T

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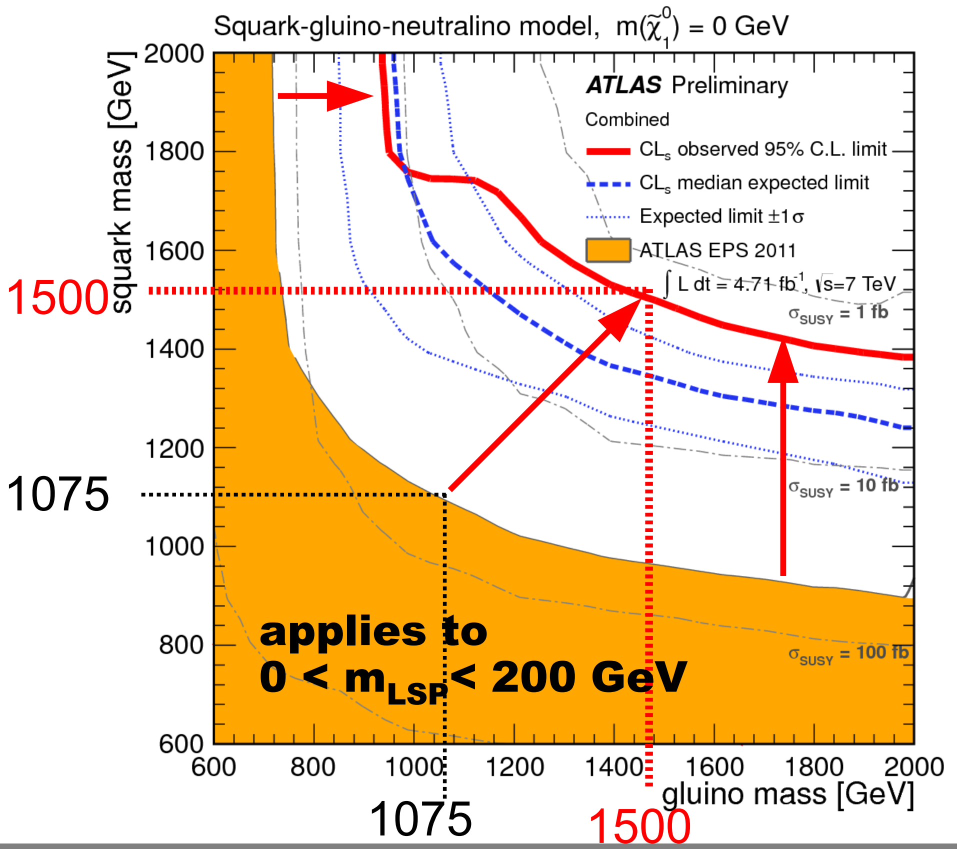
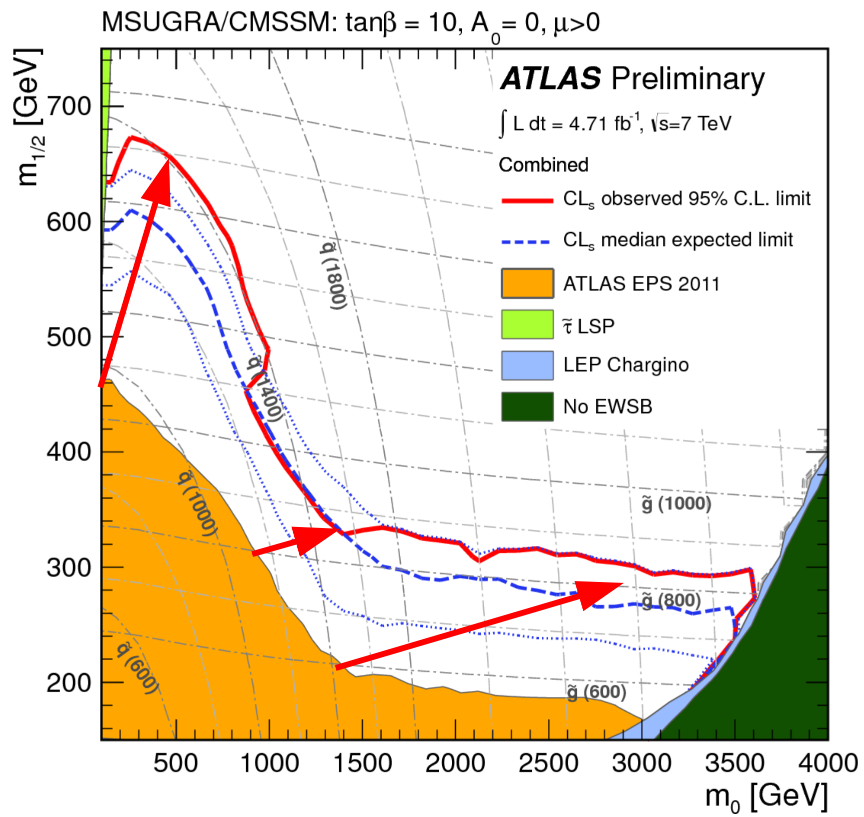
- Simplified model: m(squark) > 1.4 TeV, m(gluino) > 940 GeV
- CMSSM: m(squark) = m(gluino) > 1.4 TeV

Limit on simplified model:

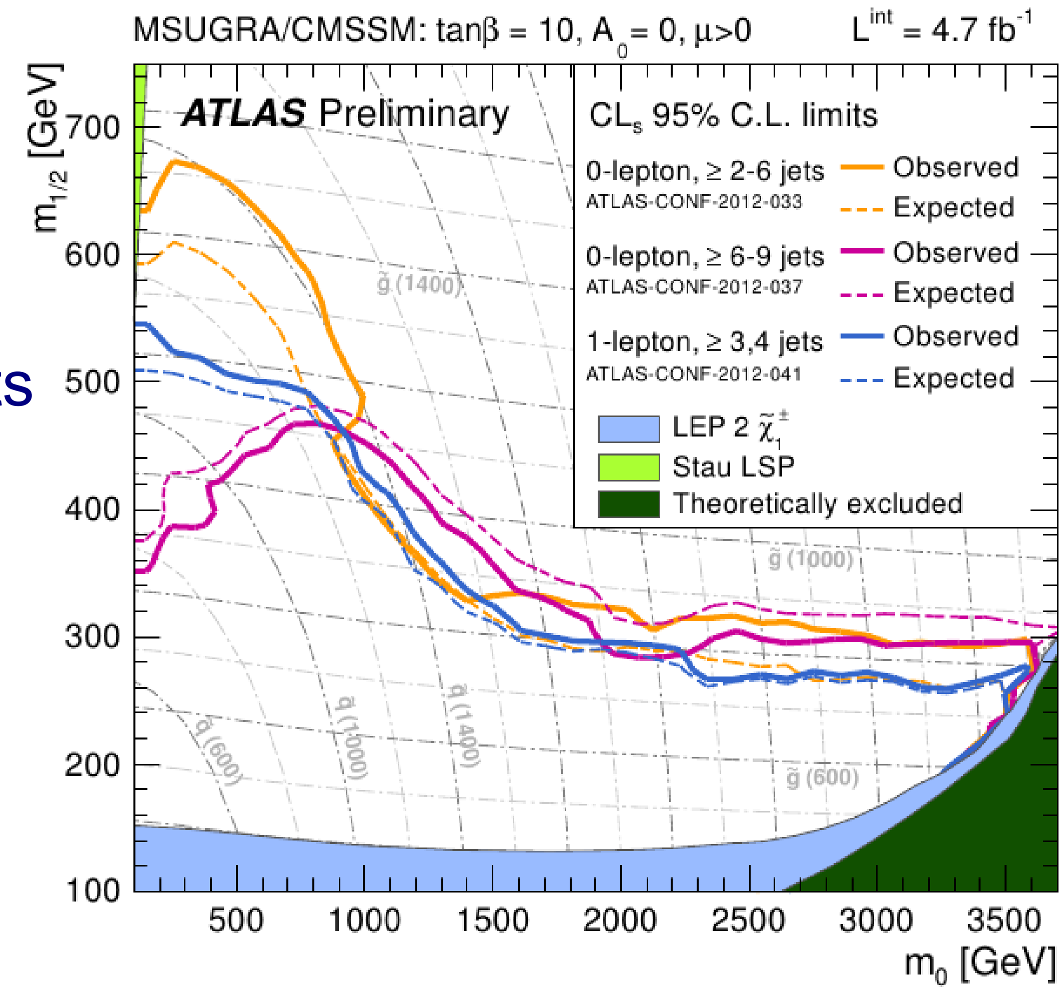


Limit on MSUGRA/CMSSM model:



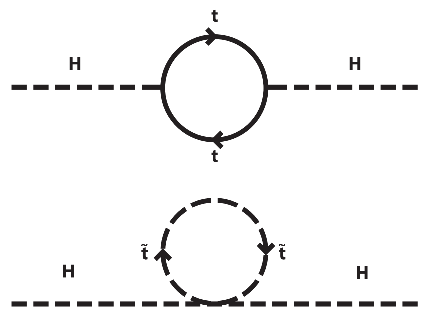
SUSY with MET: Summary

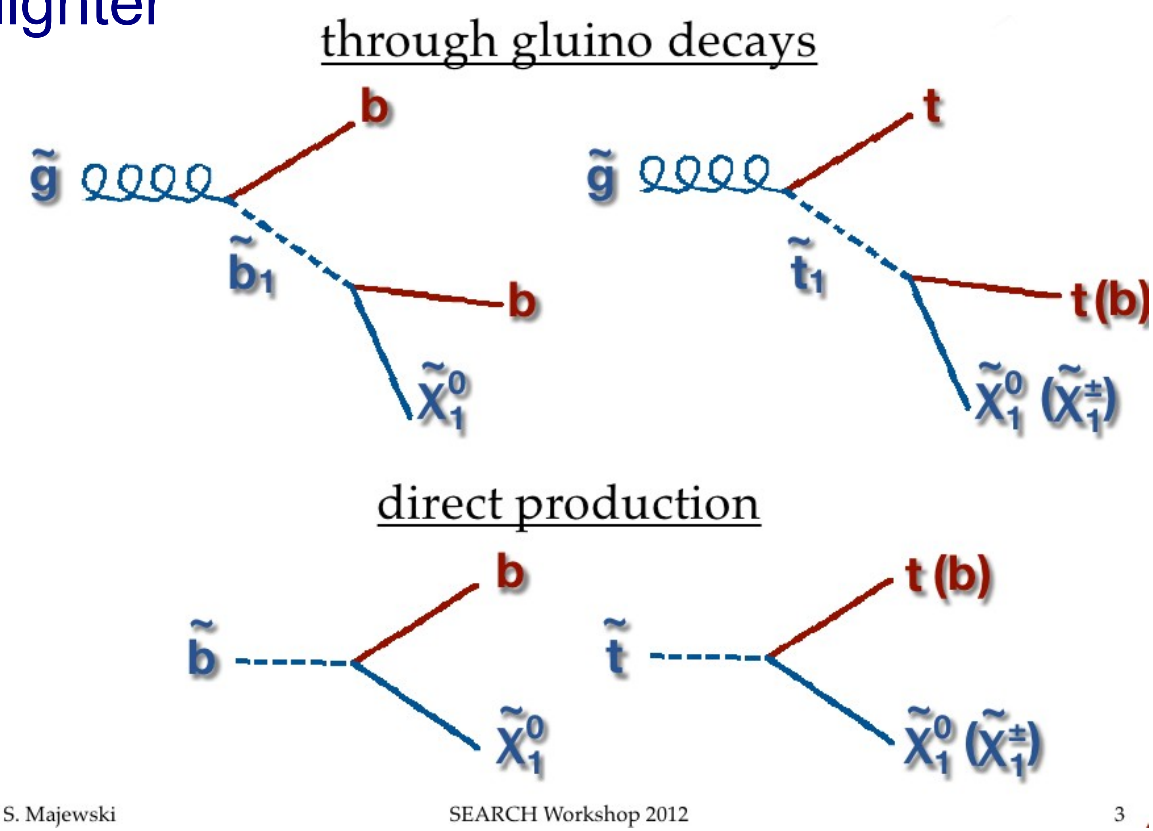
- Several other analyses updated with 5 fb^{-1} for Moriond 2012:
- High jet multiplicity 6-9 jets
- 1 lepton (e or μ) + jets



SUSY: a lighter 3rd generation?

- SUSY solves Higgs fine-tuning only if 3rd generation is “light”
  - → Other gen. can be heavier
- What if 3rd generation lighter than others?
- Look specifically for stop and sbottom
- Mostly through enhanced heavy flavour





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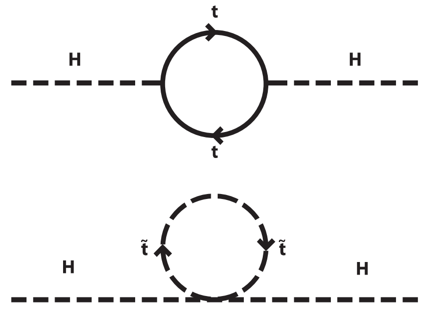
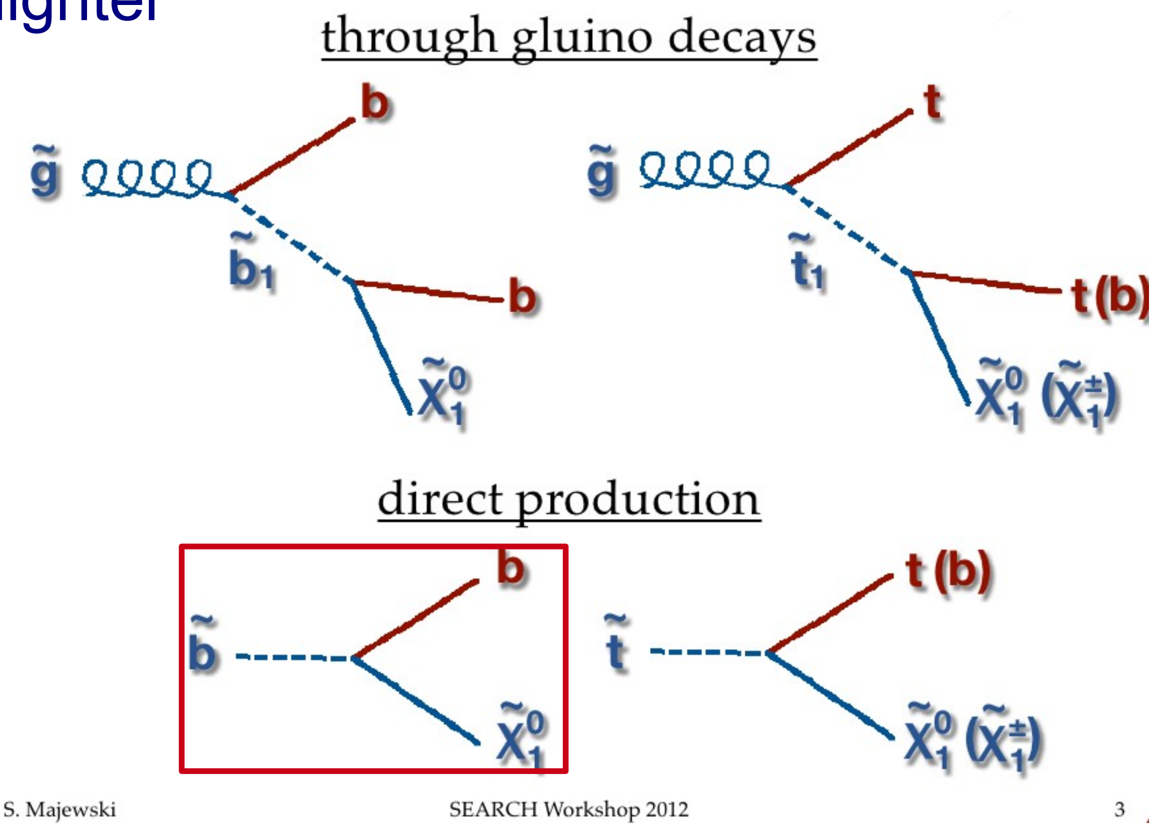
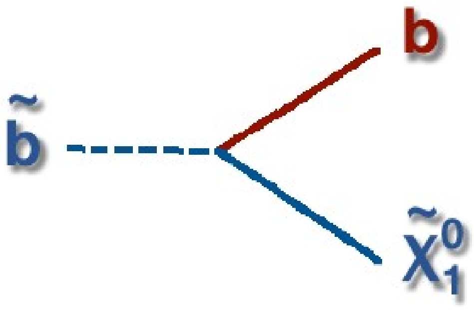




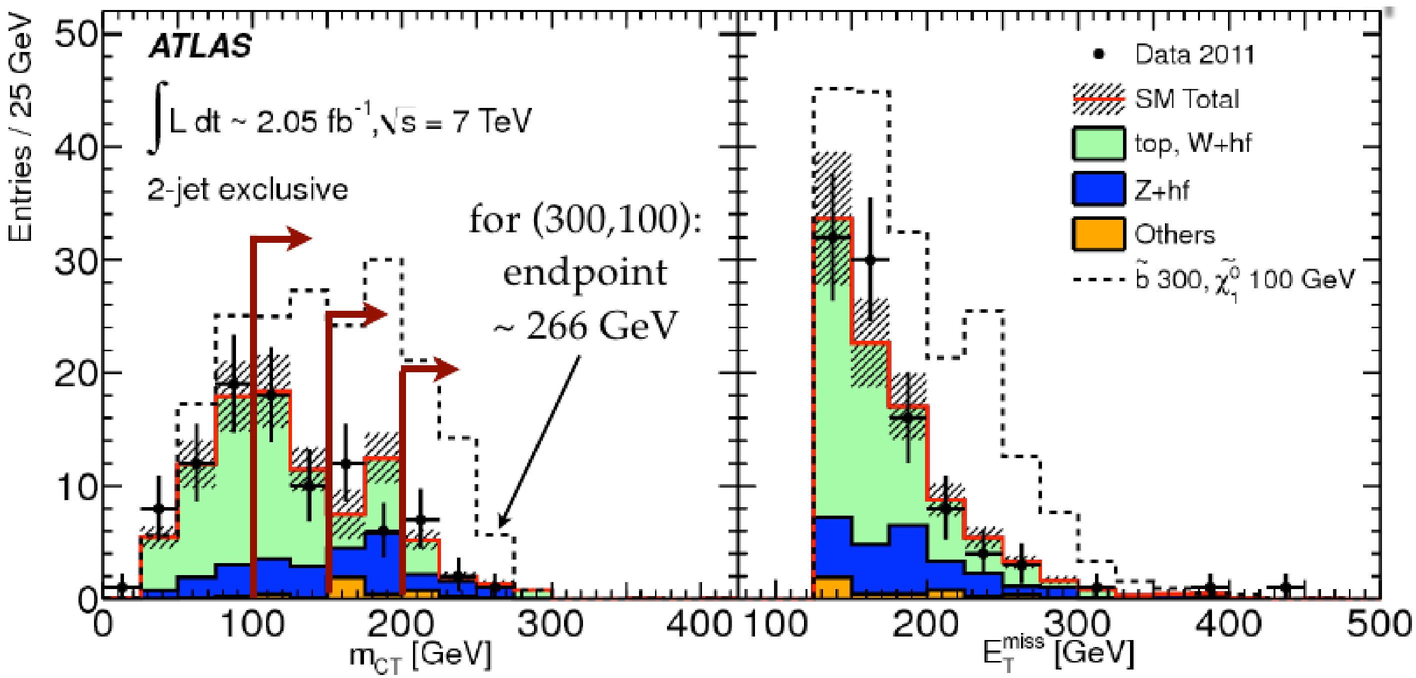
SUSY: Direct Sbottom Production

- 2 b-jets + Missing ET
- Use "contransverse mass":



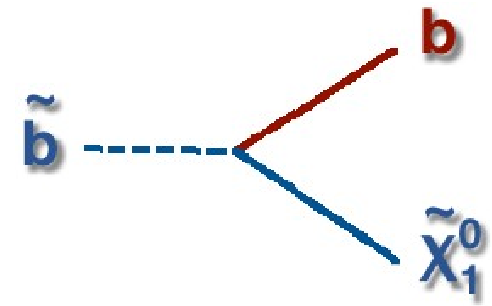
$$m_{\mathrm{CT}} = \sqrt{[E_T(b_1) + E_T(b_2)]^2 - [p_T(b_1) - p_T(b_2)]^2}$$

- Endpoint at: for ttbar ~ 135 GeV, for sbottom: $\frac{m_{\tilde{b}}^2 - m_{\tilde{\chi}_1^0}^2}{m_{\tilde{b}}}$

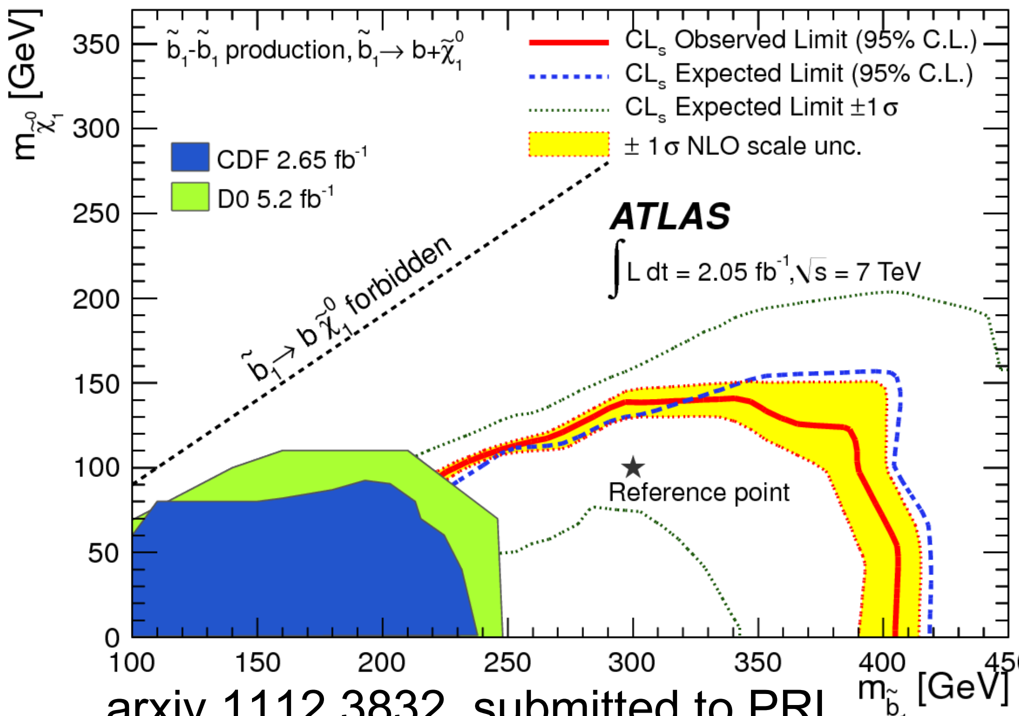


SUSY: Direct Sbottom Production

- Four thresholds to be sensitive over the entire (m(sbottom) ; m(neutralino)) plane
- m(sbottom) > 400 GeV for light neutralino



Signal Region	Expected Bkg	Data
$m_{CT} > 0$ GeV	94 ± 16	96
$m_{CT} > 100$ GeV	62 ± 13	56
$m_{CT} > 150$ GeV	27 ± 8	28
$m_{CT} > 200$ GeV	8.1 ± 3.5	10



arxiv 1112.3832, submitted to PRL

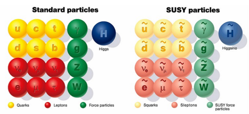
Supersymmetry: Summary

- SUSY CMSSM is starting to be fine-tuned
  - → Of course we will continue looking and increasing our reach
- With 5 fb^{-1}, more SUSY prod. mechanisms open up → exclusive chargino/neutralino and 3rd generation production
- Focusing more and more on non-CMSSM scenarii:

  “Split”, “squashed”, R-parity violation

  More exotic signatures:
  - → SUSY with low Missing ET
  - → Multi-jet resonances
  - → Long-Lived Particles (R-hadrons, staus)

Outline



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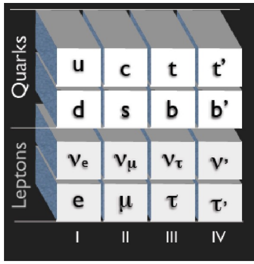
4[th] generation and heavy "quarks"



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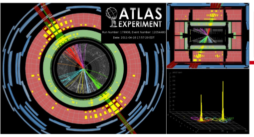

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Long-lived particles

→ **Displaced vertices**

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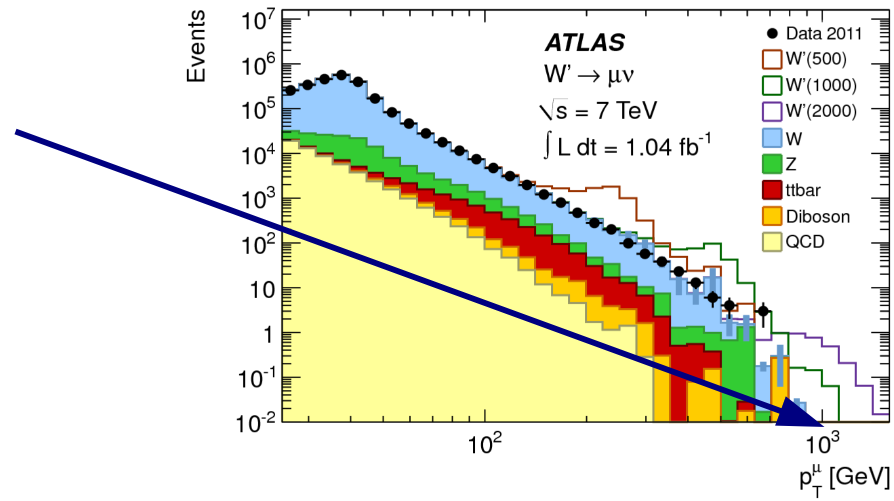
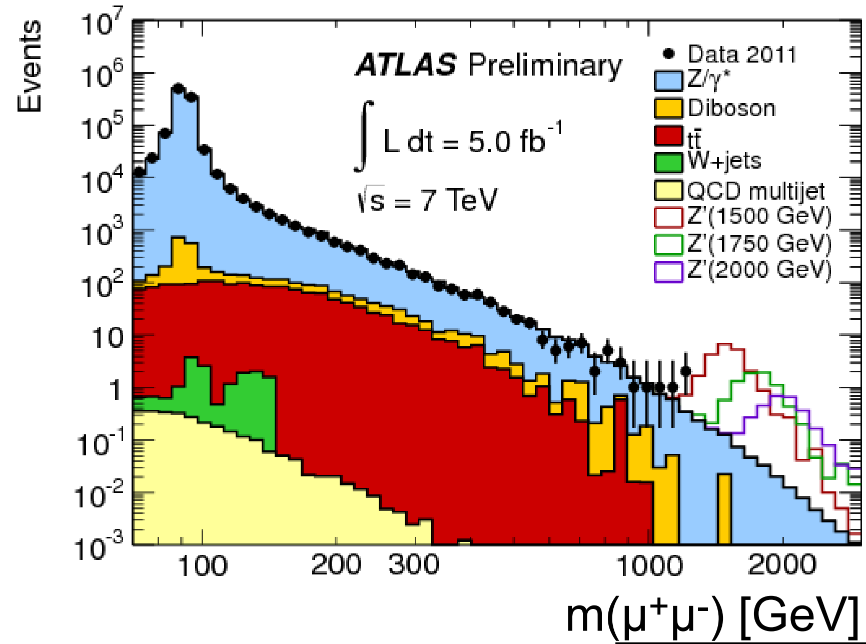
Search for Heavy Resonance

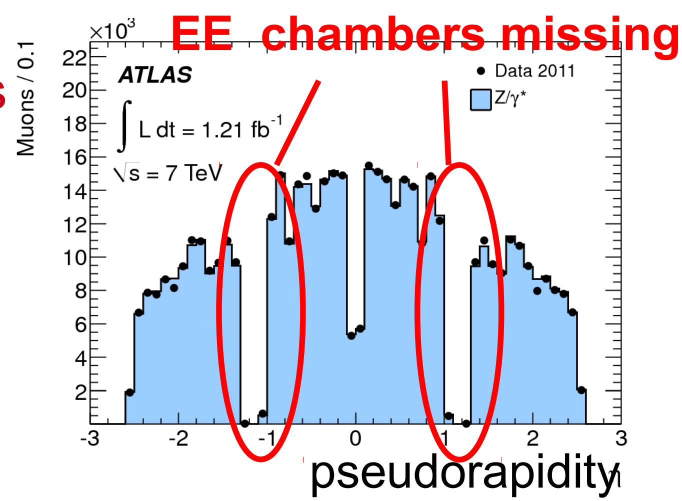
- Predicted by numerous extensions of the Standard Model:
  - → GUT-inspired theories, Little Higgs → heavy gauge boson(s) Z' (W')
  - → Technicolor → narrow technihadrons
  - → Randall-Sundrum ED → Kaluza-Klein graviton
- Experimental challenge: understand detector performance (resolution, efficiency) for a signal with (almost) no control sample at very high momentum → confidence in alignment, simulation, etc...
- Electrons and muons: reaching pT ~ 1 TeV!

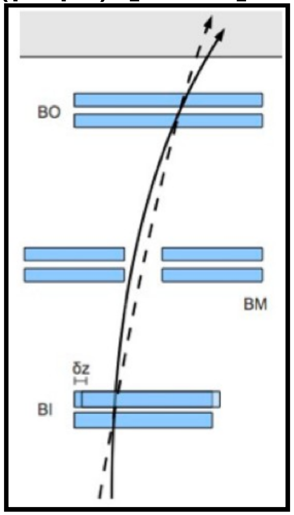


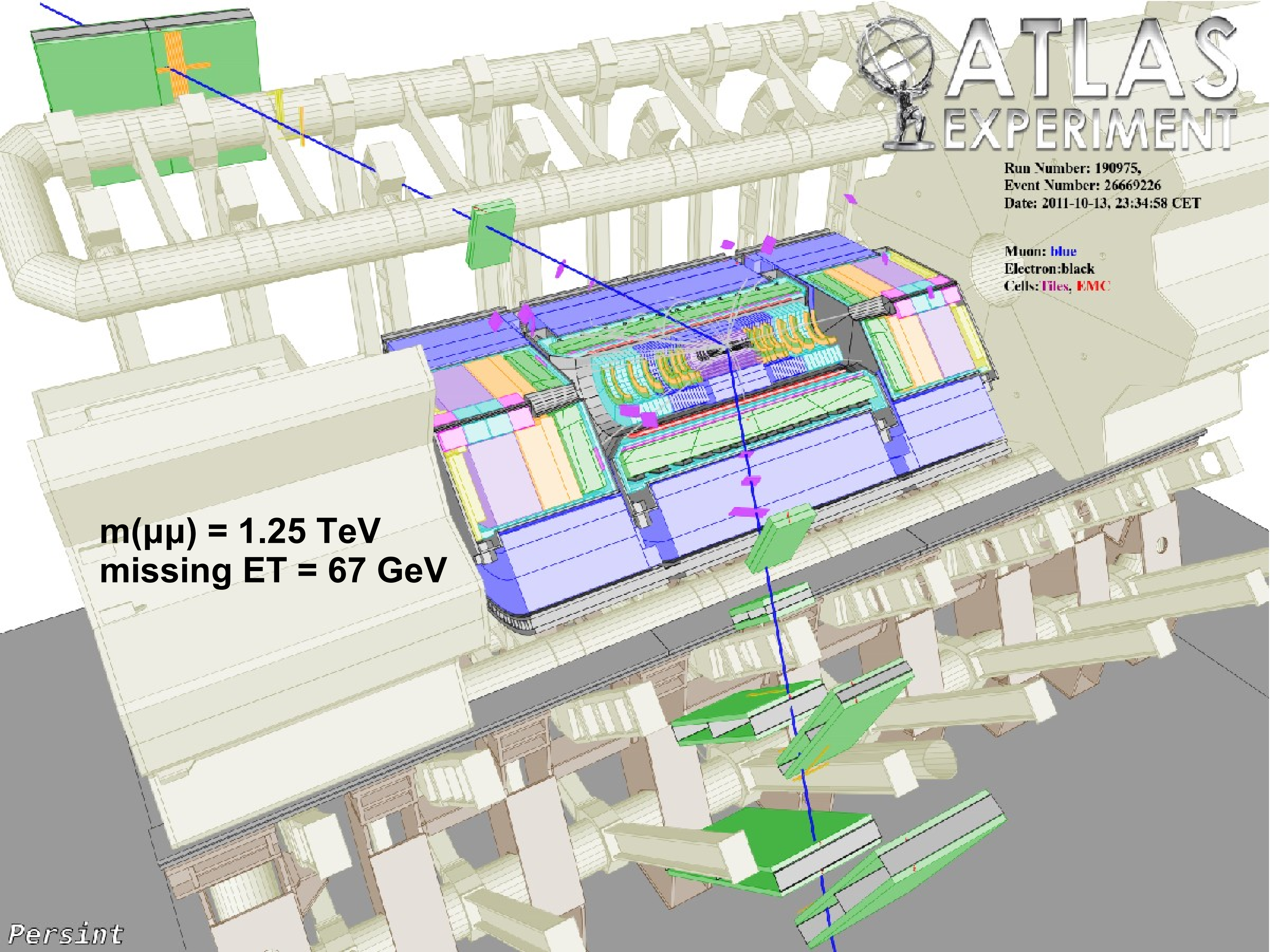
Search for Heavy Resonance: dilepton channel

- Dimuon channel
- Alignment critical
  - → Now close to nominal (30 μm) in most of the detector
  - → Resolution 13% at p_T = 1 TeV
- Require 3-station tracks for good resolution → loss of acceptance
  - → Now also using 2-station tracks in well-understood regions
  - → This Winter: installation of 75% of missing EEL's completed



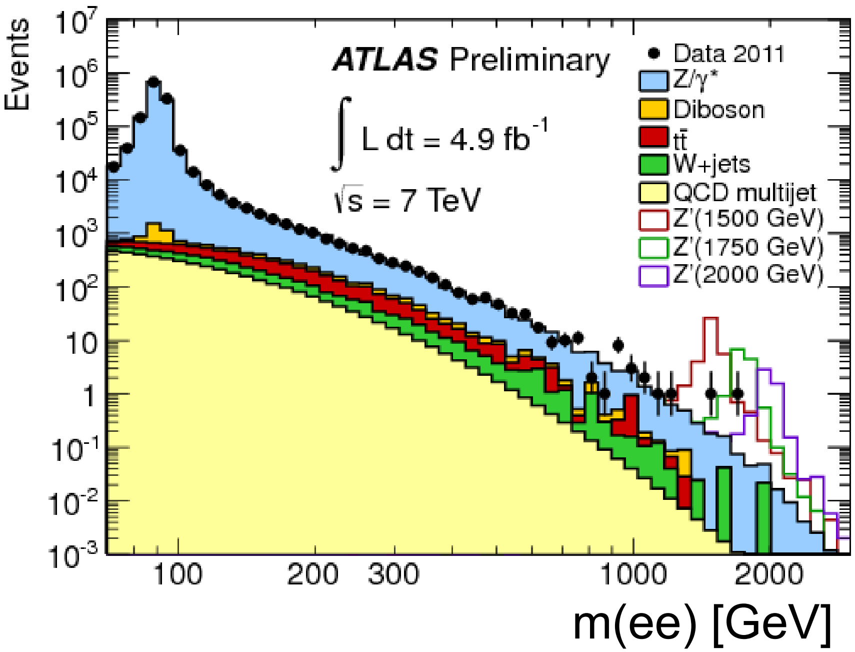





ATLAS EXPERIMENT
Run Number: 190975,
Event Number: 26669226
Date: 2011-10-13, 23:34:58 CET
Muon: blue
Electron:black
Cells:Tiles, EMC
m(μμ) = 1.25 TeV
missing ET = 67 GeV
Persint

Search for Heavy Resonance: dilepton channel

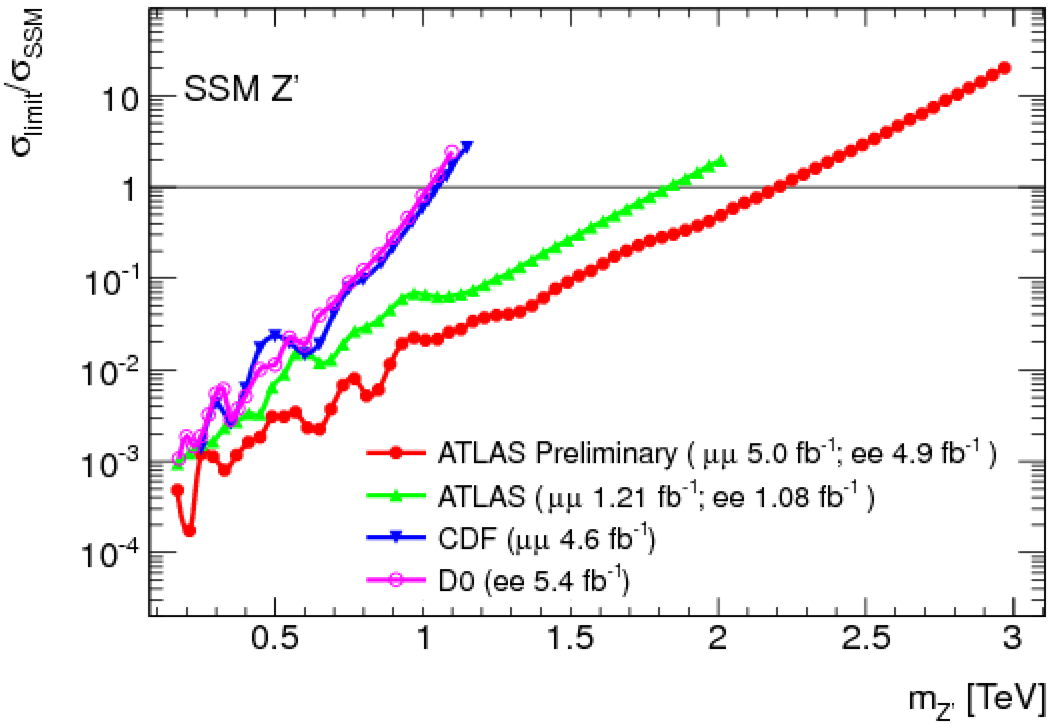
- Dielectron channel
- Excellent resolution: < 2% at high momentum
- Poor charge measurement → no charge requirement in the dielectron channel



Search for Heavy Resonance: dilepton channel

- No deviation from SM is observed
- Sequential SM: m(Z') > 2.21 TeV (exp. 2.26 TeV)

  RS graviton (k/M_{Pl} = 0.1): m(G^*) > 2.16 TeV



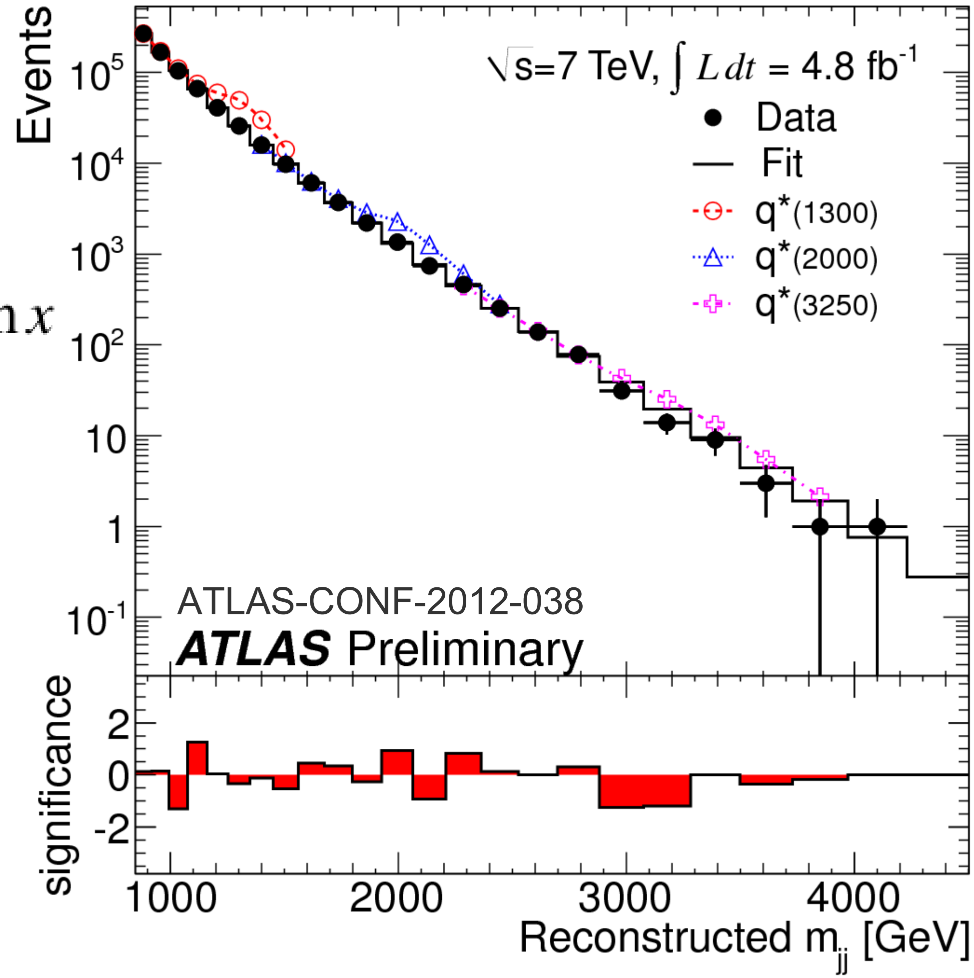
Search for Heavy Resonance: Dijet Resonance

- Excited quarks, strong gravity, contact interaction
- Look for resonance above phenomenological fit of the data:

$$f(x) = p_1 (1-x)^{p_2} x^{p_3 + p_4 \ln x}$$

$$x \equiv m_{jj}/\sqrt{s}$$

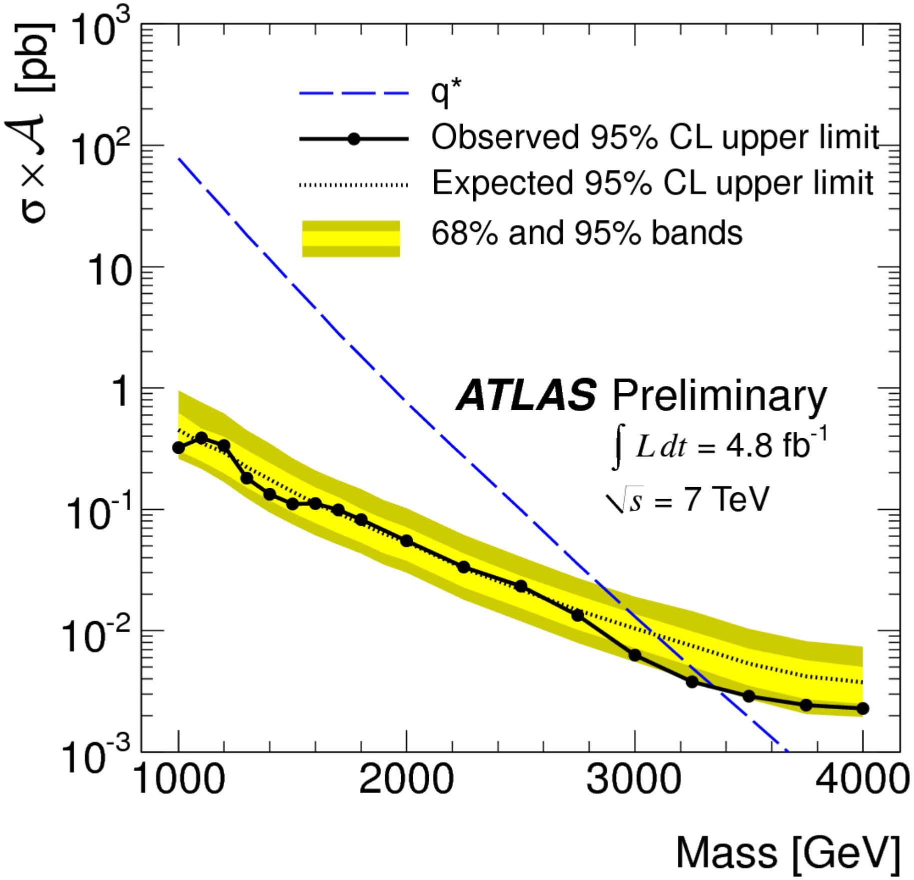
Probing the quark structure beyond 4 TeV



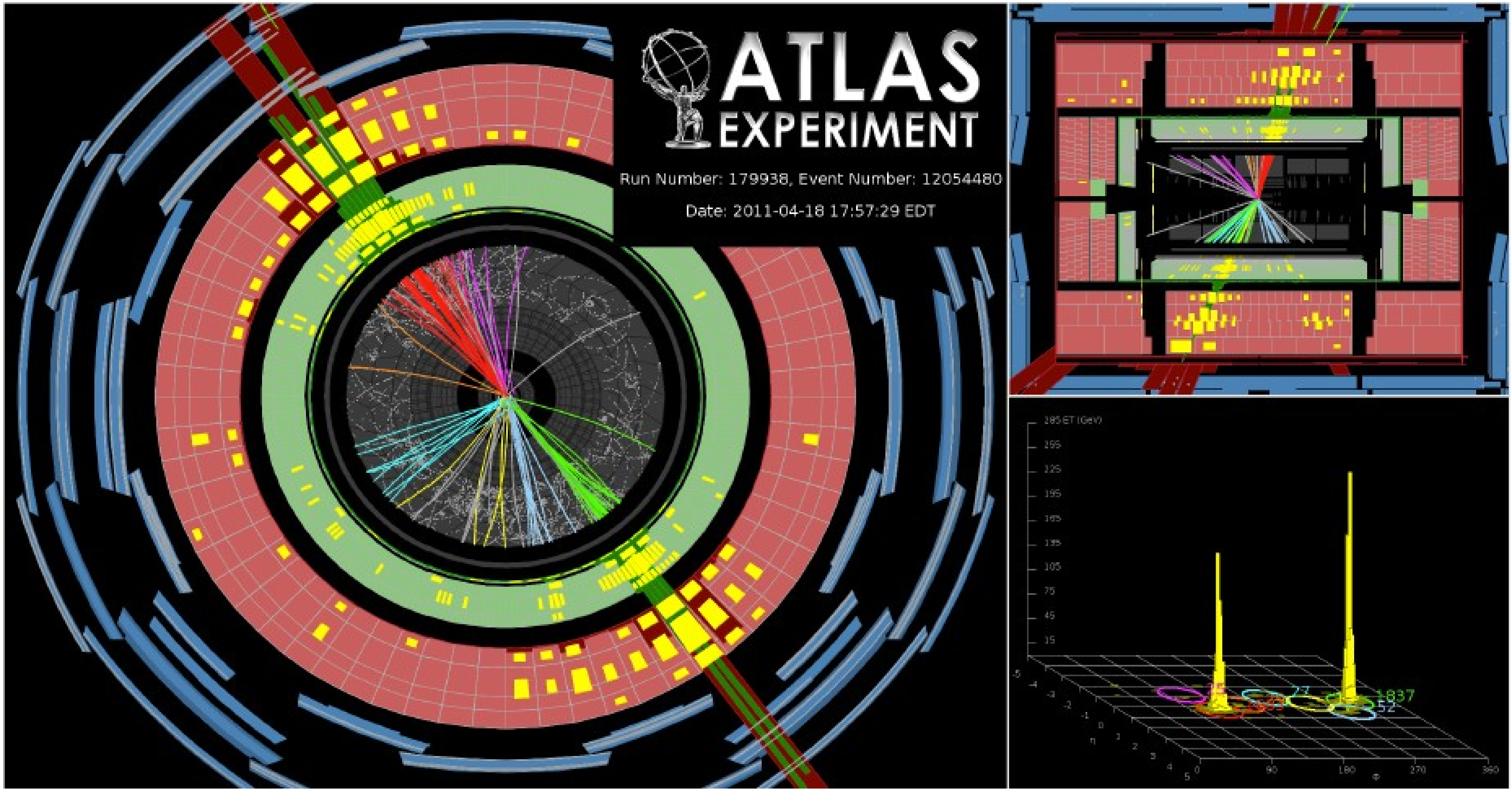
Search for Heavy Resonance: Dijet Resonance

- "Search phase": frequentist approach
  - → Binned likelihood (goodness of fit)
  - → "BumpHunter" looking for an excess of any width over the entire spectrum
- "Limit phase": Bayesian approach (flat cross-section prior)
- Excited quark:

  m > 3.35 TeV at 95% CL



Search for Heavy Resonance: Dijet



m(jet-jet) = 4.0 TeV **Missing E_T = 100 GeV**

Search for Heavy Resonance: Dijet Angular

- Most BSM signal are expected to be more central than QCD
- Study angular variable as a function of dijet mass
- Consider the two leading jets rapidity in their center of mass:

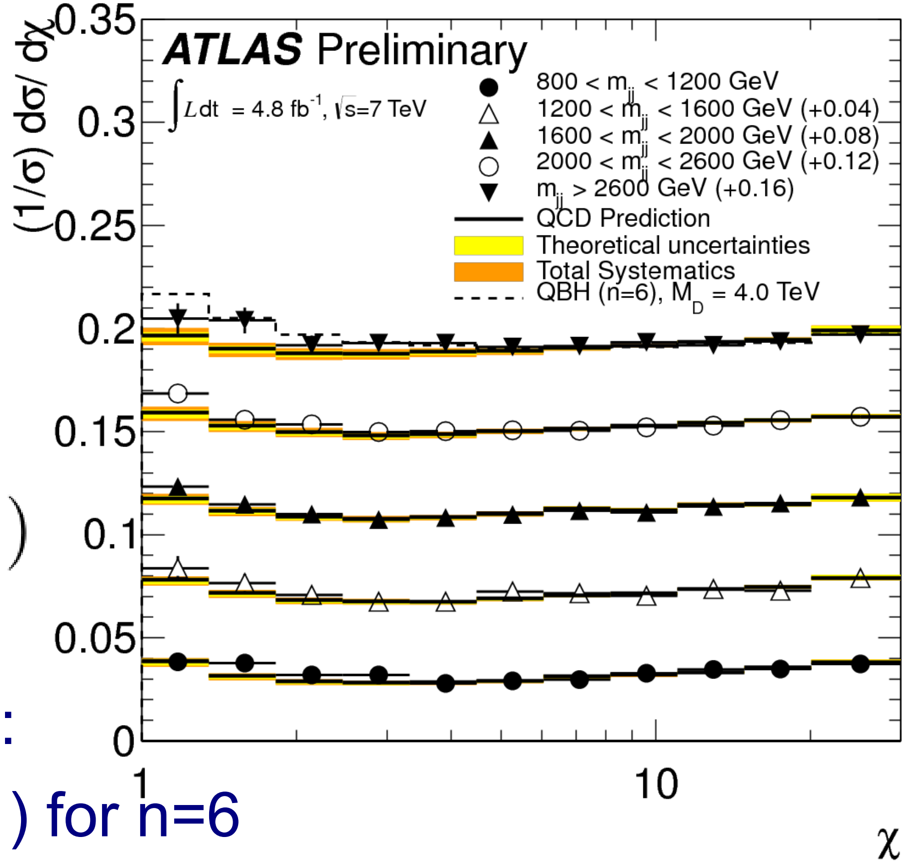
$$y^* = \pm\frac{1}{2}(y_1 - y_2)$$

- Variable chi defined as:

$$\chi \equiv \exp(|y_1 - y_2|) = \exp(2|y^*|)$$

as a function of m(jet-jet)

- Limit on Quantum Black Holes: m(QBH) > 4.14 TeV (exp. 4.11) for n=6



Search for Heavy Resonance: Dijet Angular

- Most BSM signal are expected to be more central than QCD
- Study angular variable as a function of dijet mass
- Alternatively, look at:

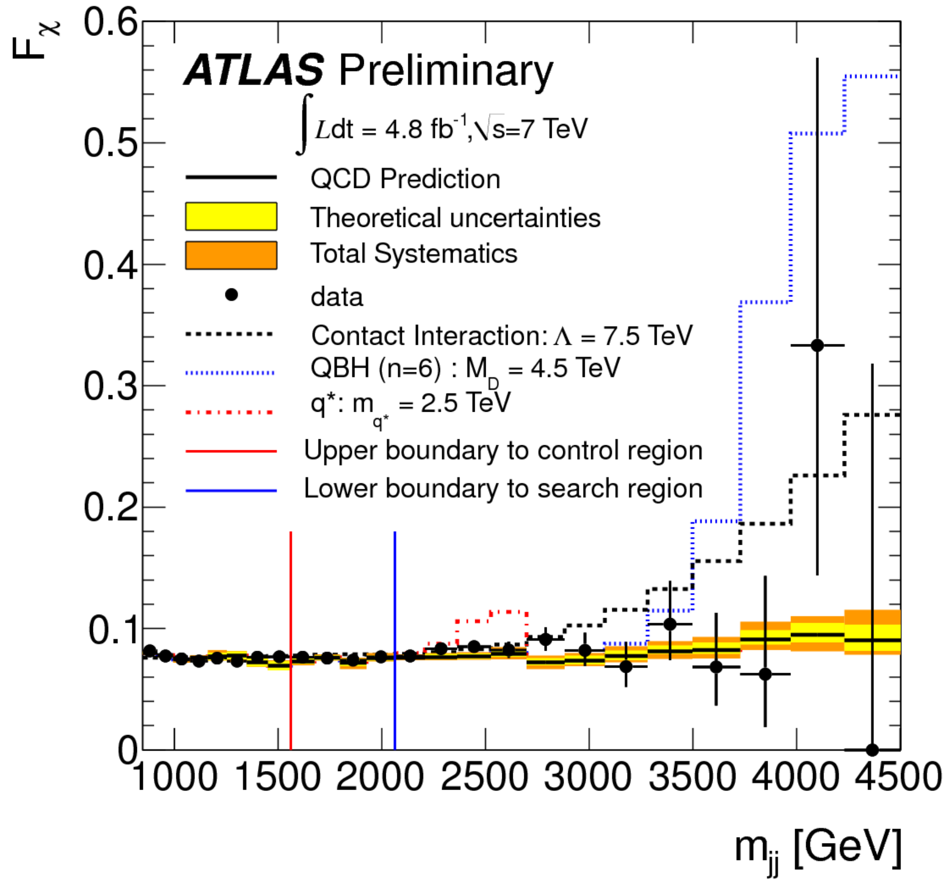
$$F_\chi = \frac{N_{\text{central}}}{N_{\text{total}}}$$

where $N_{central}$ is $|y^*| < 0.6$

- Limit on Contact Interaction:

  $\Lambda > 7.6$ TeV at 95% CL

  (expected: 8.2 TeV)



Search for Heavy Resonances: Top-antitop

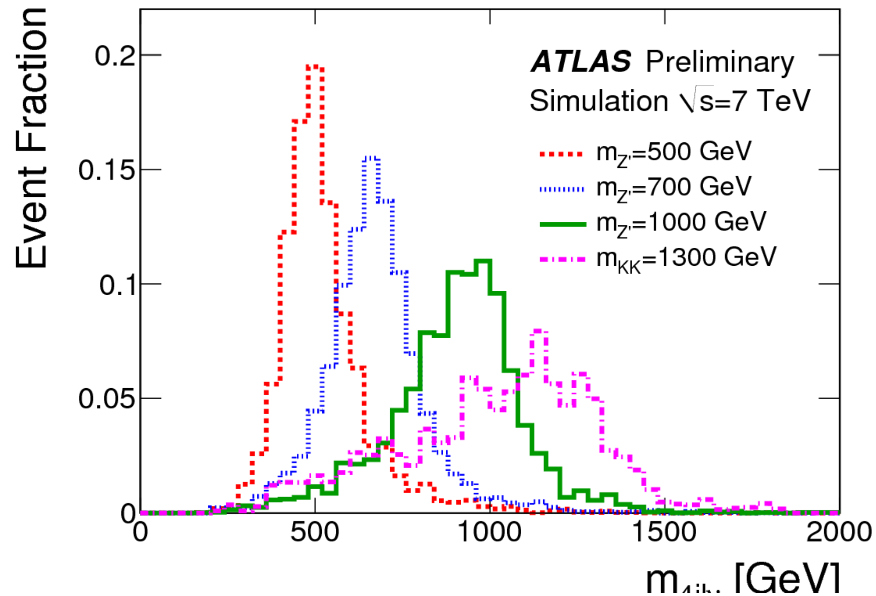
- While SSM Z' has same BR than SM Z, many models give Top a special role

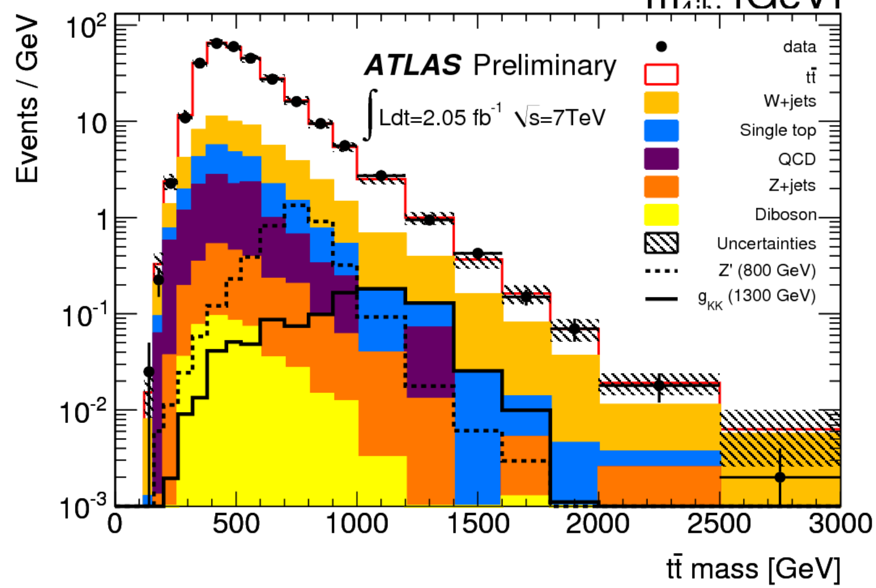
  - Top-color

  - RS KK gluon

  favor a decay to top-antitop

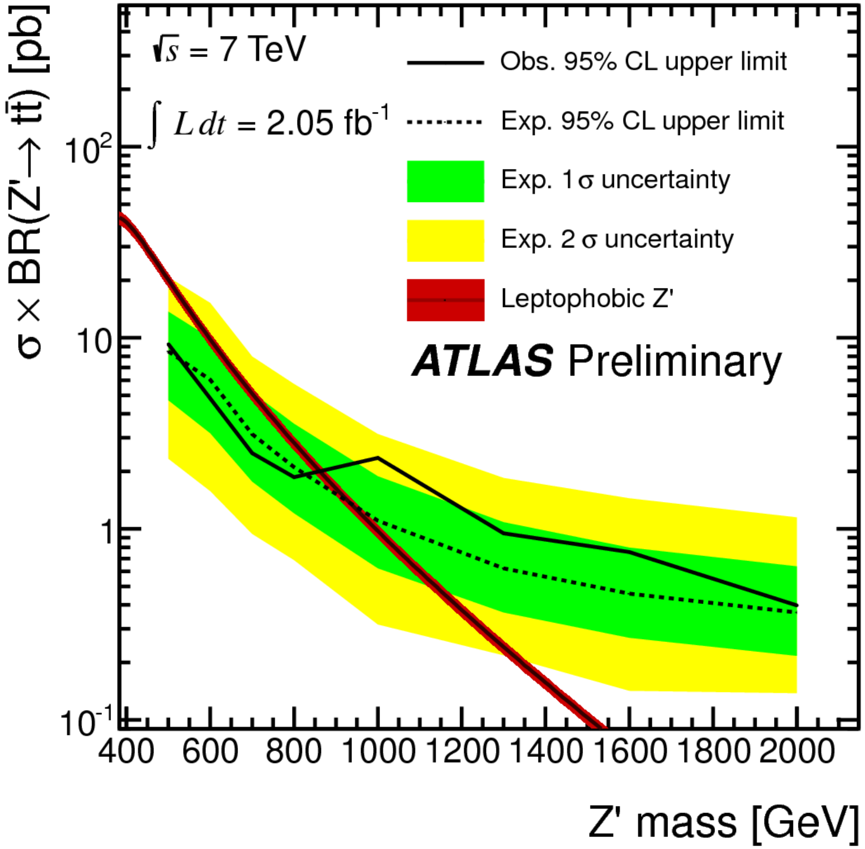
- tt → WbWb
- l+jets channel: lνb jjb
- Kinematic fit on W and top mass to find best jet combination

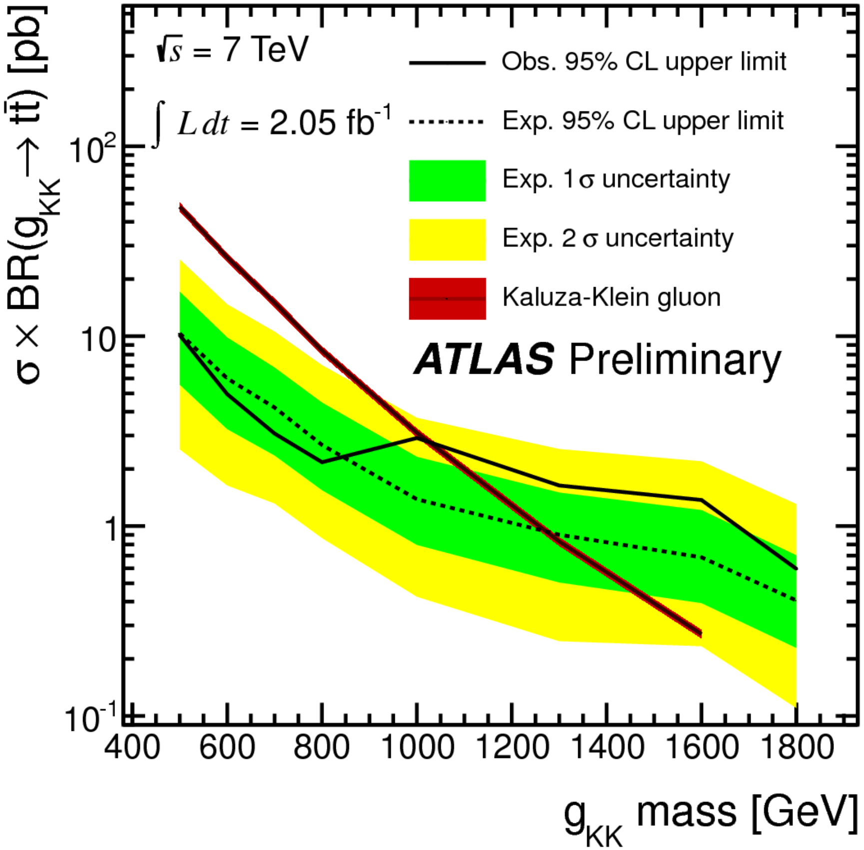




Top-antitop Resonance

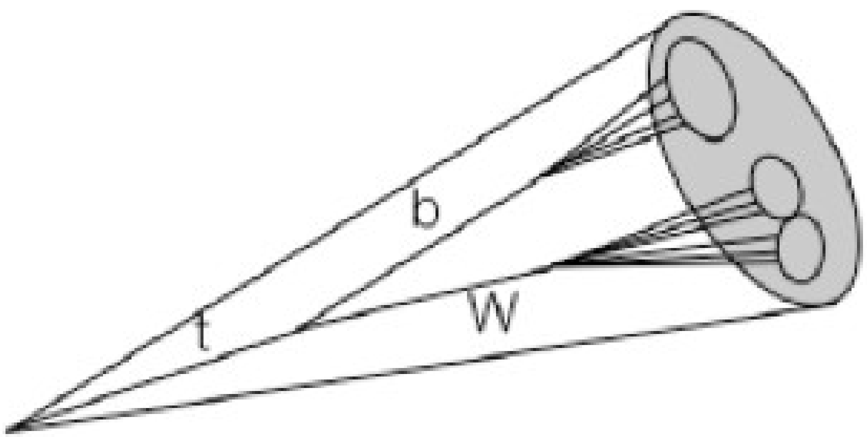
- RS model: m(KK gluon) > 1025 GeV
- Leptophobic top-color Z': m(Z') > 860 GeV

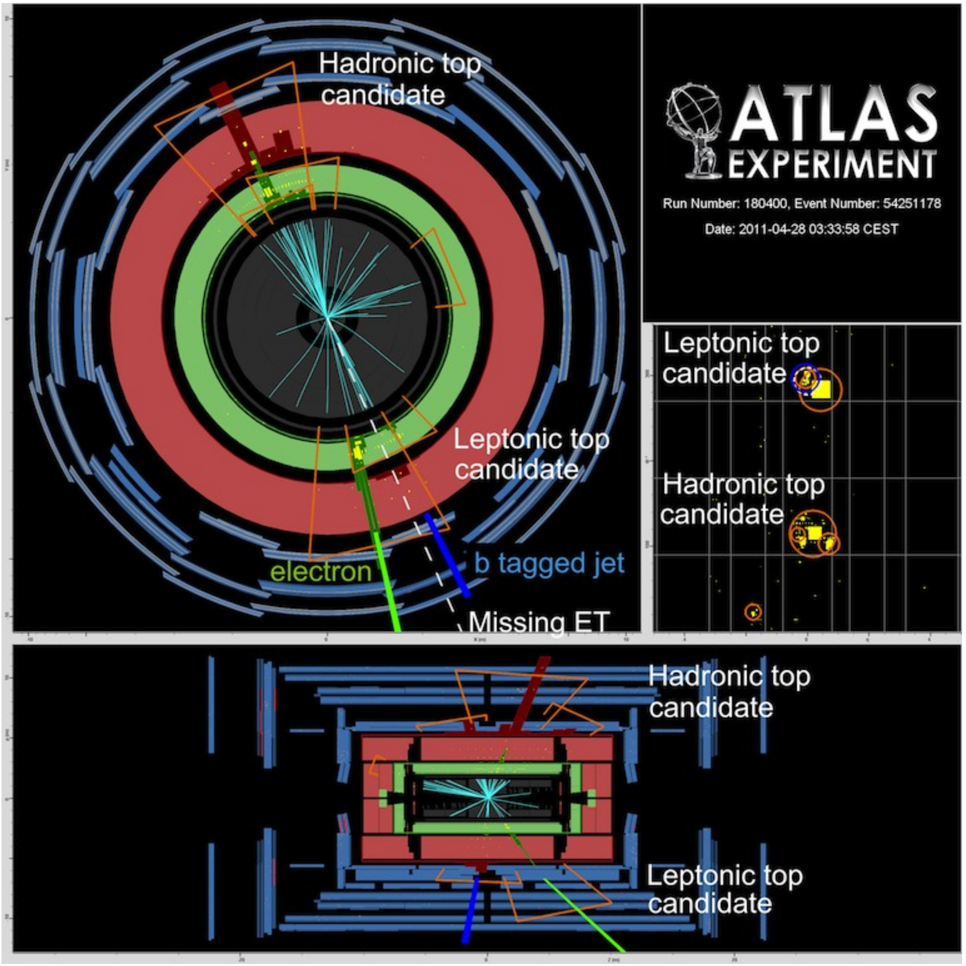




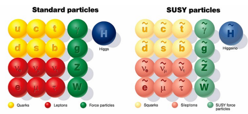
Top-antitop Resonance

- For m(ttbar) > 1 TeV, specific boosted top reconstruction needed
- No public result yet





Outline



Supersymmetry (with MET)

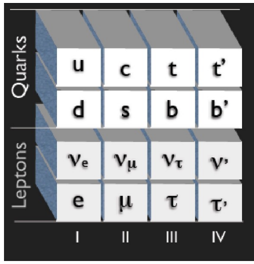
→ **Jets + MET**

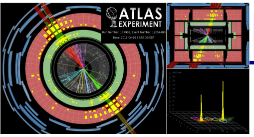
→ **3rd generation**

4th generation and heavy “quarks”

→ **t'**

→ **b'**





Heavy Resonances

→ **Dilepton**

→ **Dijet**

→ **Top-Antitop**

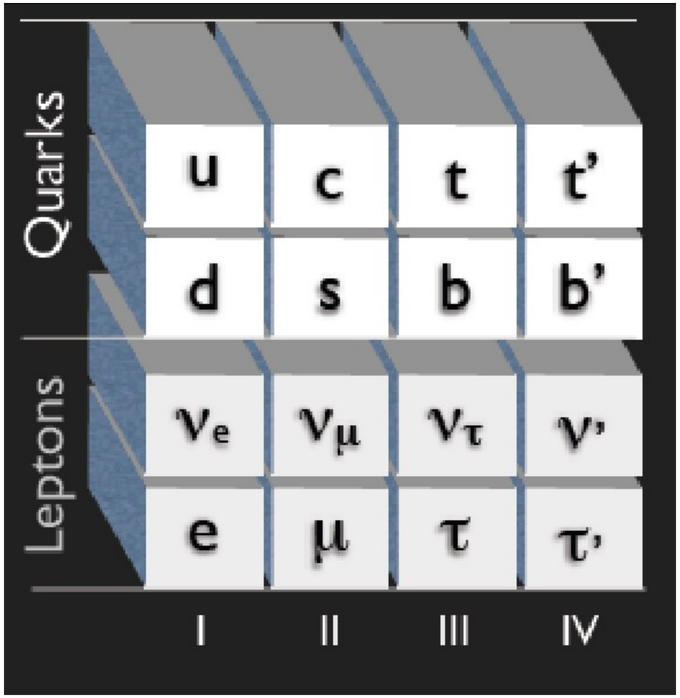
Long-lived particles

→ **Displaced vertices**

→ **Disappearing track**

4^{th} Generation Quarks

- Consistent with EW precision
- 4^{th} generation would significantly enhance Higgs production cross section
  - → Stringent constraint from Higgs search
- Can provide enough CP violation to explain matter-dominated universe
- Loose constraints on CKM4 → decays to light quarks possible!

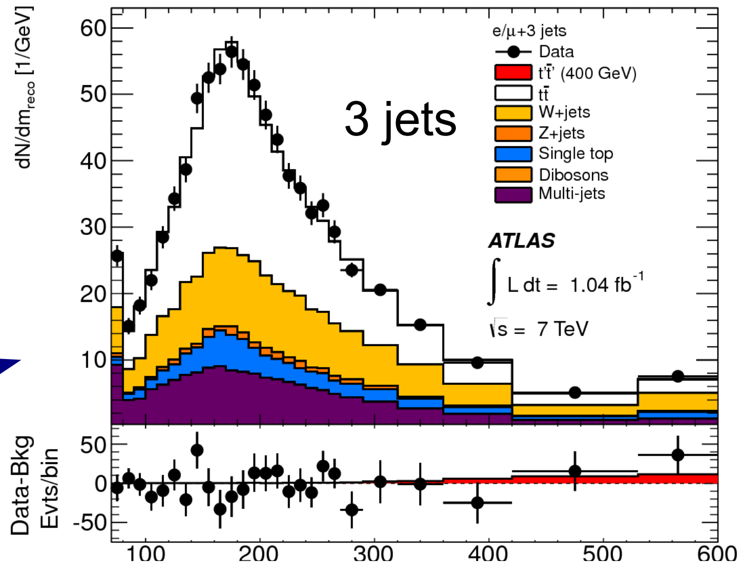


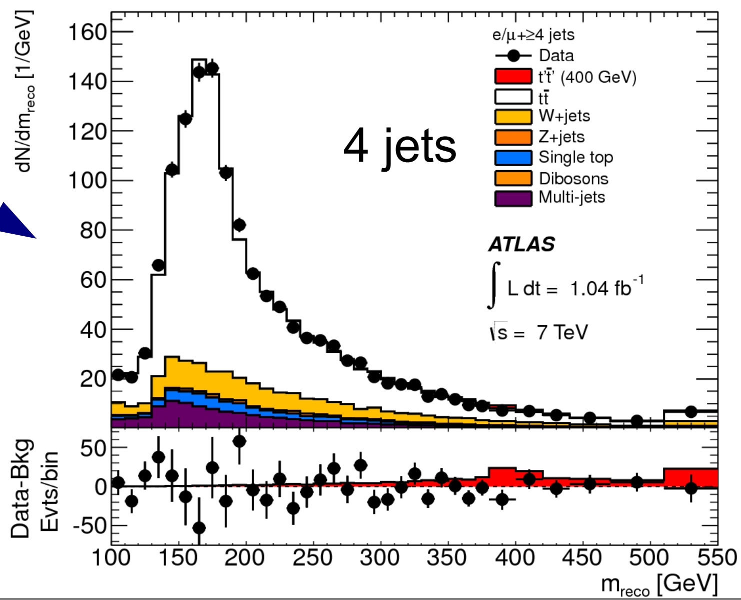
- t' or b' → Wq: like top, but heavier
- b' → tW: like top, but busier

Today focus on:
t't' → WbWb
b'b' → WtWt
in e or μ + jets channels

t't' → WbWb → lvbbqq (l+jets channel)

- Signature: l + ETmiss + ≥3 jets (l=e,μ) and b-tagging
- Main background: top
- Observable: reconstructed heavy quark mass
  - 3-jet events: m(jjj)
  - 4-jet events: kinematic fit
- Strategy:
  - → Combine 3-jet and 4-jet
  - → Constrain background systematics through *in situ* fit a.k.a. "profiling"
  - → Jet Energy Scale uncertainty improved by about factor 4 (!)

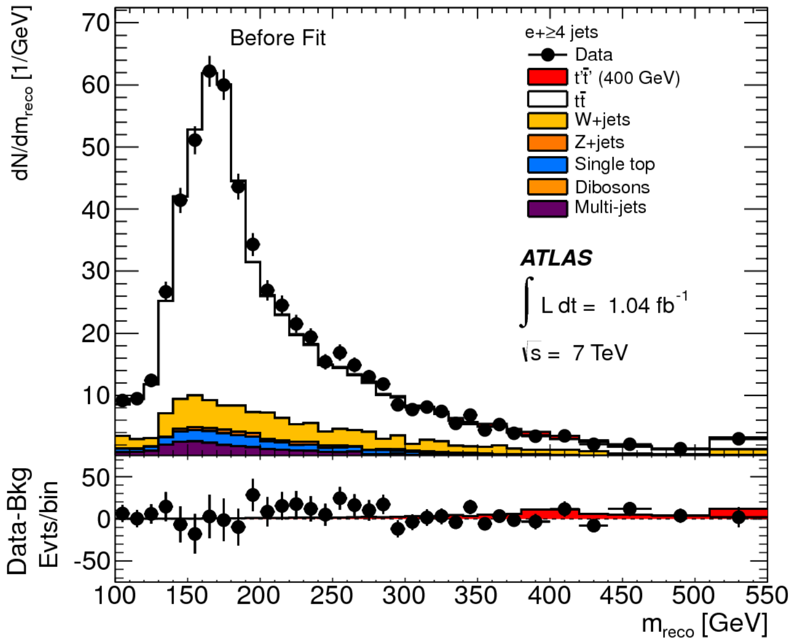




Constraining systematics *in situ*, a.k.a. "profiling"

- Powerful but requires careful understanding of syst. modelling!

BEFORE:

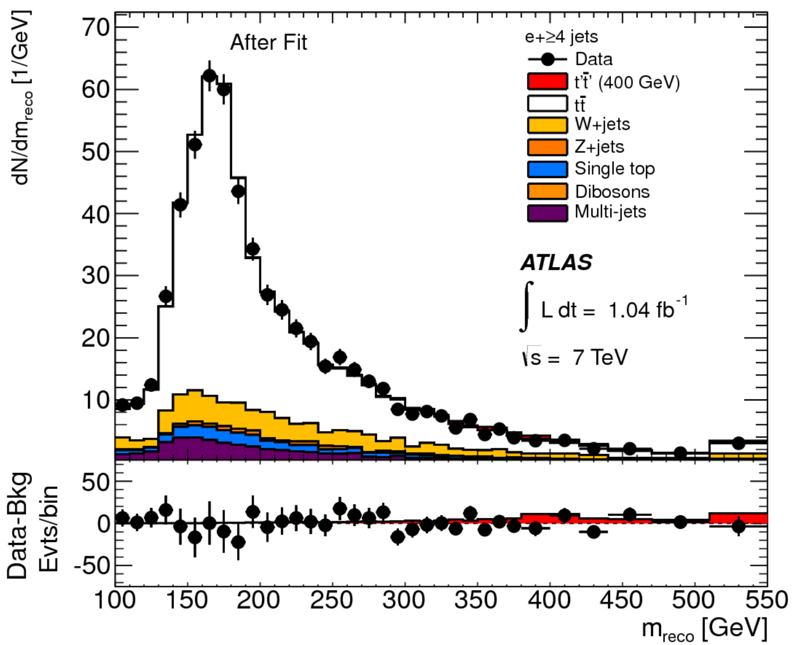


Source	Normalization	Shape	Fitted
$t\bar{t}$ cross section	YES	NO	YES
$t\bar{t}$ fragmentation model	YES	YES	NO
$t\bar{t}$ NLO MC generator	YES	YES	NO
Top quark mass	YES	YES	NO
Initial state QCD radiation	YES	YES	YES
Final state QCD radiation	YES	YES	YES
W+jets normalization	YES	NO	YES
Ratio of $W+\geq 4$ jets and $W+3$ jets normalizations	YES	NO	YES
W+jets matching/factorization scales	NO	YES	NO
Z+jets cross section	YES	NO	NO
Single top cross section	YES	NO	NO
Diboson cross section	YES	NO	NO
QCD multi-jet normalization (e+jets)	YES	NO	YES
QCD multi-jet normalization (μ+jets)	YES	NO	YES
QCD multi-jet shape (e+jets)	NO	YES	NO
QCD multi-jet shape (μ+jets)	NO	YES	NO
Electron identification and trigger efficiency	YES	NO	YES
Muon identification and trigger efficiency	YES	NO	YES
Jet reconstruction efficiency	YES	NO	NO
Jet energy scale (inclusive jets)	YES	YES	YES
b-quark jet energy scale	YES	NO	NO
Jet energy resolution	YES	NO	NO
E_T^{miss} modeling	YES	NO	NO
b- and c-quark tagging efficiency	YES	NO	YES
Light-quark tagging efficiency	YES	NO	NO
Hardware problem modeling	YES	NO	NO
Luminosity	YES	NO	YES

Constraining systematics *in situ*, a.k.a. "profiling"

- Powerful but requires careful understanding of syst. modelling!

AFTER:



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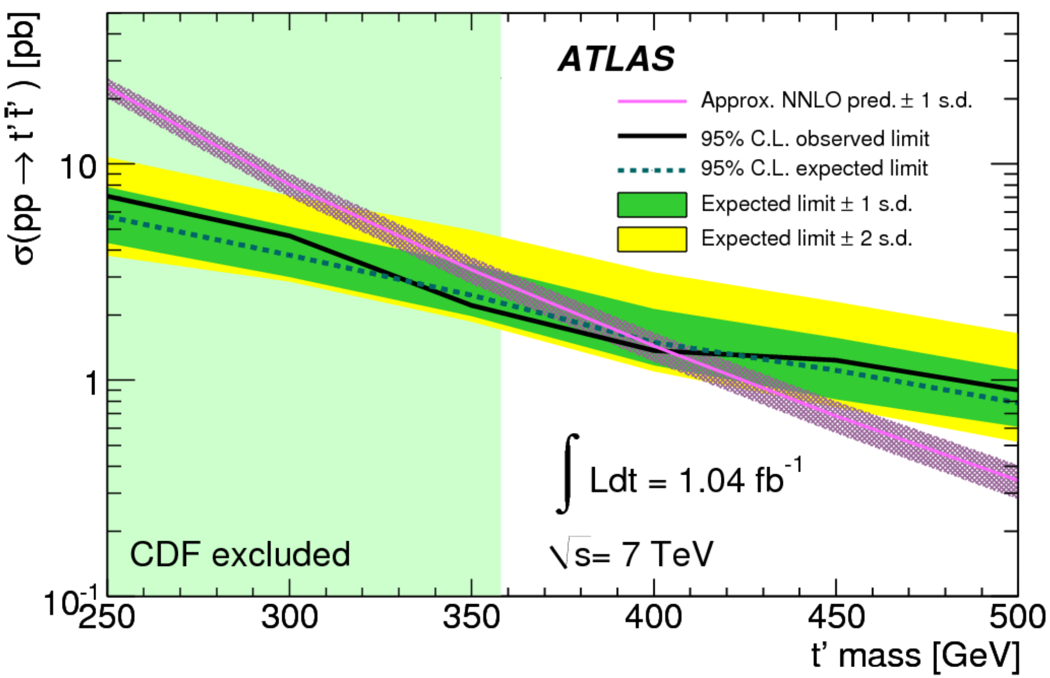
b- and c-quark tagging efficiency	YES	NO	YES
Light-quark tagging efficiency	YES	NO	NO
Hardware problem modeling	YES	NO	NO
Luminosity	YES	NO	YES

t't' → WbWb → lνbbqq (l+jets channel)

- Data in agreement with SM expectation
- Assuming BR(t' → Wb) = 100%, m(t') > 404 GeV at 95% CL (expected limit: 394 GeV)



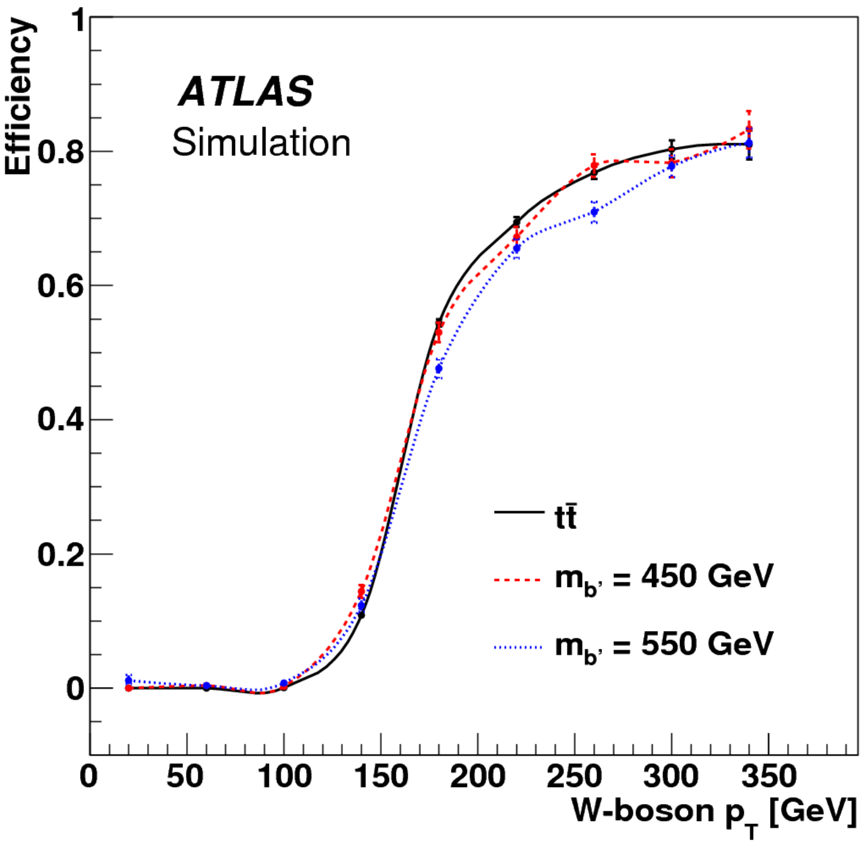
b'b' → WtWt → lνbbqq + qqqq (l+jets channel)

- Like top but messier
- Event selection: l + ETmiss + ≥6 jets (l=e,μ)
- Main background: top+jets (ALPGEN)
- Two additional W's decaying hadronically:

Identify high-pT (boosted) hadronic W's as pair of jets close to eachother:

$\Delta R(\text{jet-jet}) \sim 2m(W) / p_T(W)$

$\Delta R = \text{sqrt}(\Delta\eta^2 + \Delta\varphi^2)$



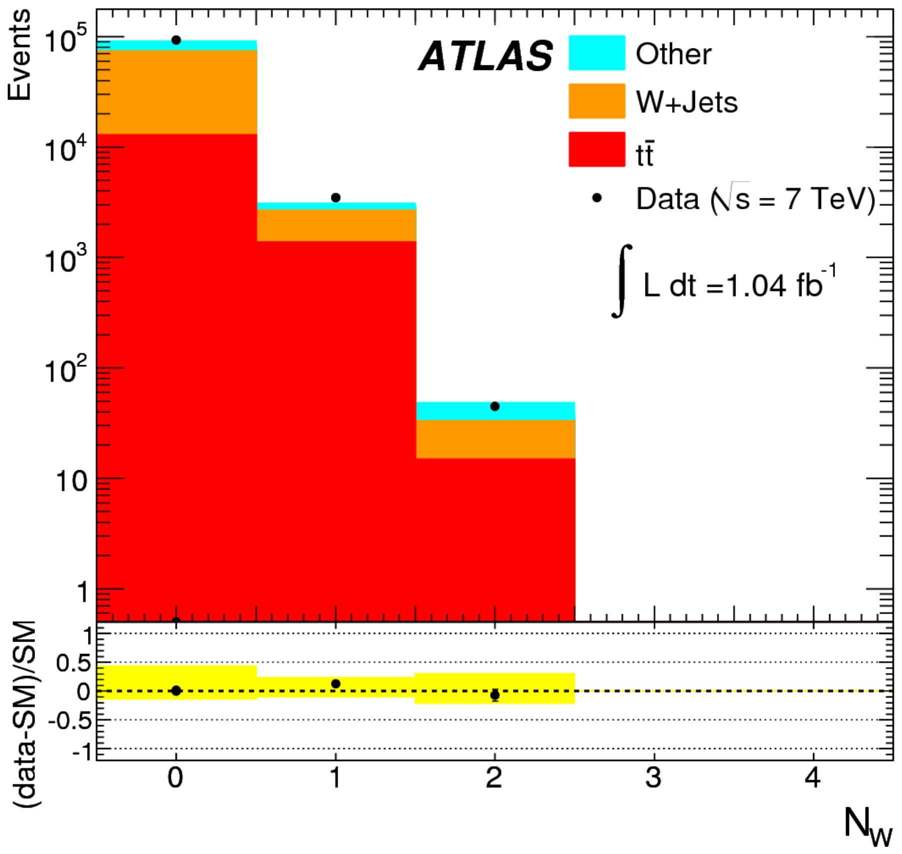
Select pairs of jets with:

$\Delta R < 1.0$

$70 < m(jj) < 100$ GeV

b'b' → WtWt → lvbbqq + qqqq (l+jets channel)

- Observables:
  - # jets
  - # identified hadronic W's
- Control region: # jets < 6 →
  dominated by top-antitop and W+jets
- # hadronic W's well-described by simulation



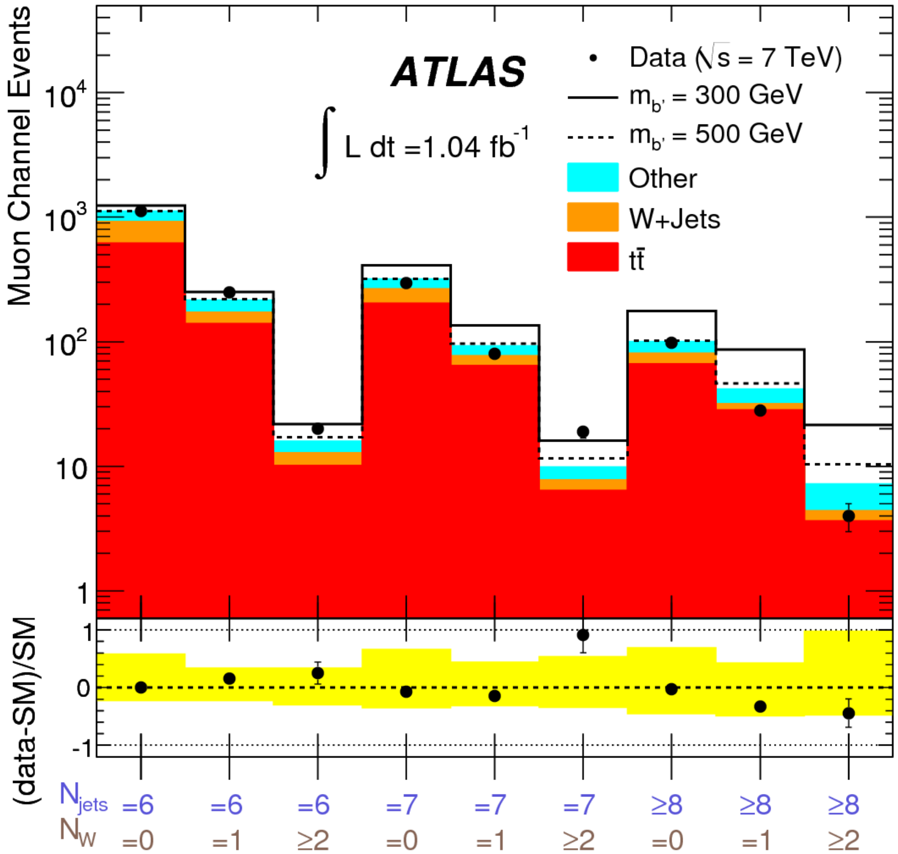
b'b' → WtWt → lvbbqq + qqqq (l+jets channel)

- Observables:

  # jets

  # identified hadronic W's
- Control region: # jets < 6

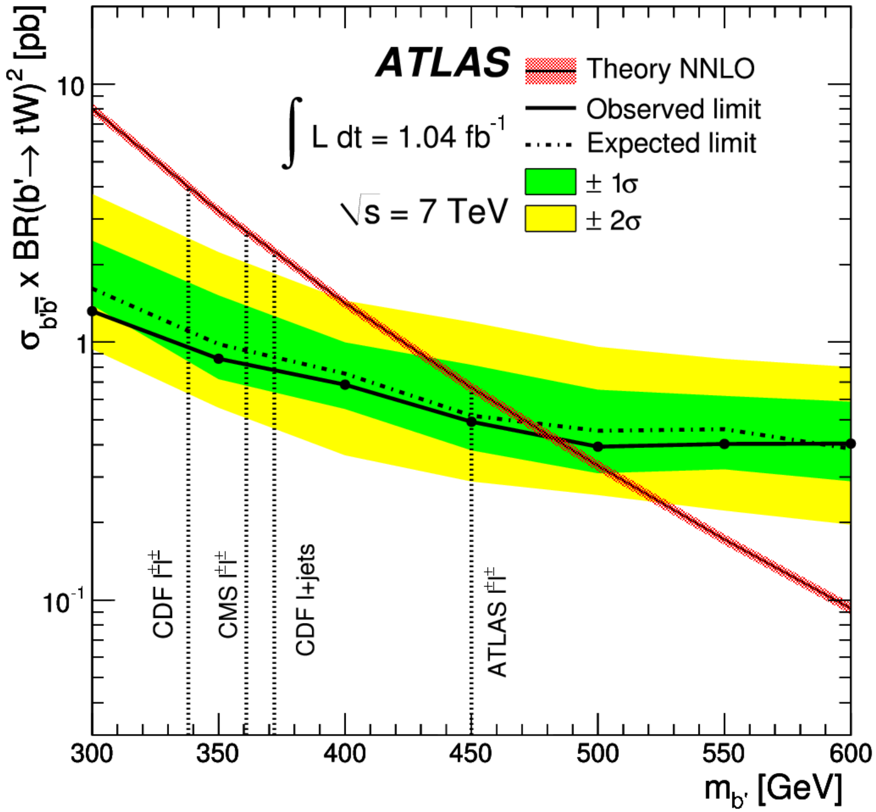
  dominated by top-antitop and W+jets
- # hadronic W's well-described by simulation
- Signal region: # jets ≥ 6
- Constrain background in low jet and W multiplicity bins



b'b' → WtWt → lνbbqq + qqqq (l+jets channel)

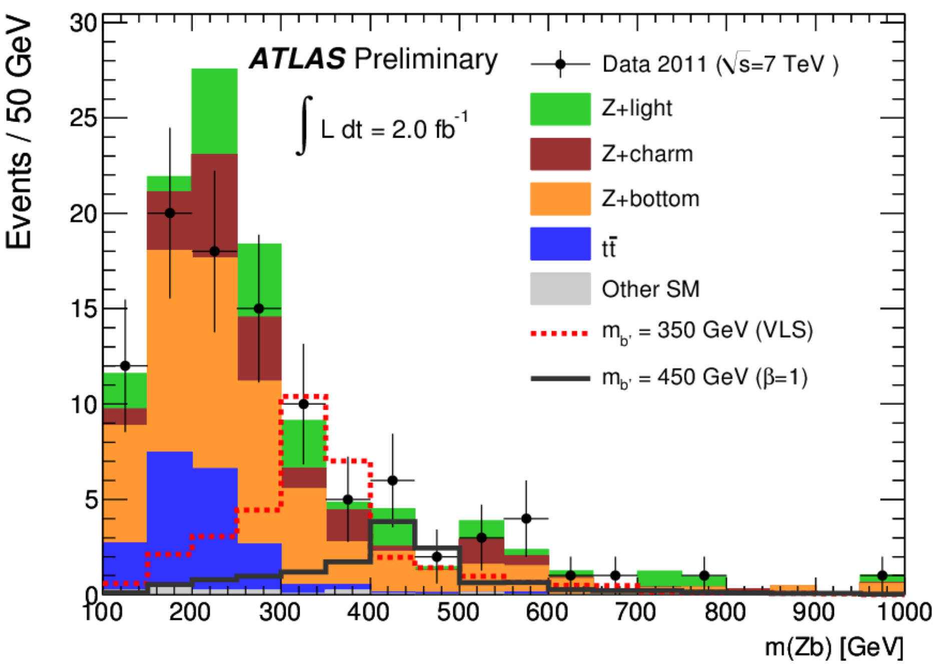
- Data in agreement with SM expectation
- Assuming BR(b' → tW) = 100% m(t') > 480 GeV at 95% CL

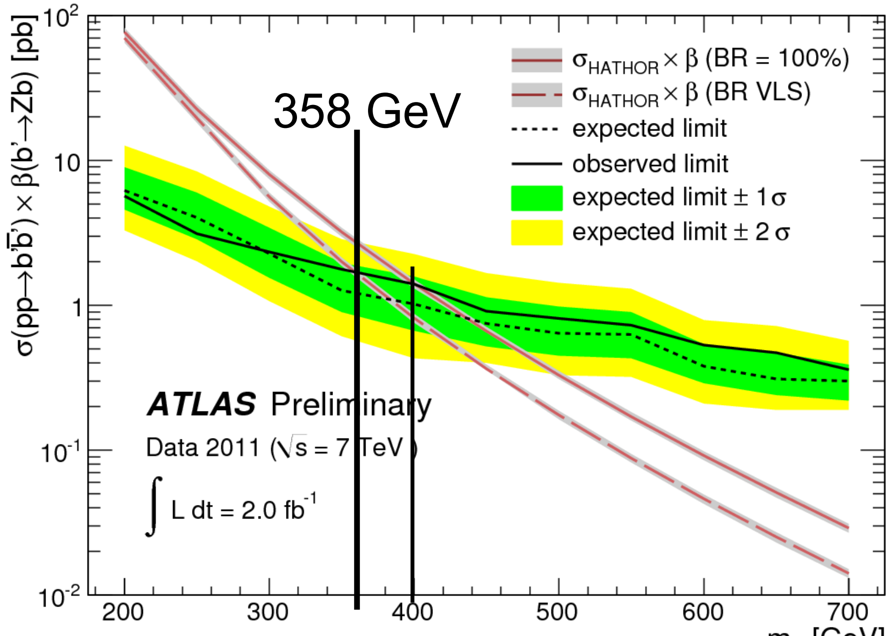
  (expected limit: 470 GeV)



b'b' → Zb + X

- Search for a resonance decaying to Z(→ee) + b-jet
- Inclusive search: reconstruc only one b' (other can decay to anything)
- Esp. relevant for Vector-Like Quarks
- Assuming VLQ coupling only to 3rd gen: m(b') > 358 GeV (95% CL)

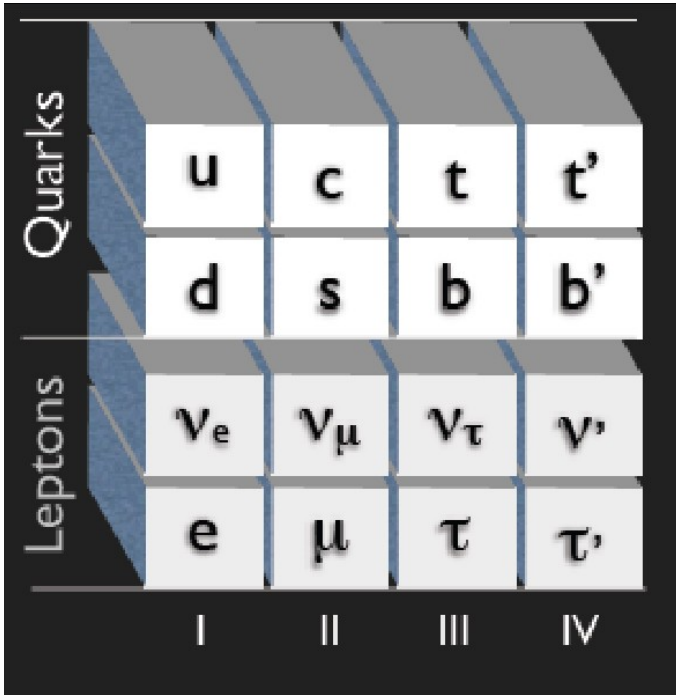




4^{th} Generation and Vector-Like Quarks: Summary

- No time to show other analyses:
  - → t' and b' dilepton searches (without b-tagging): sensitive to light quark decays
  - → Vector-Like Quark searches
- Here limits assume 100% BR:

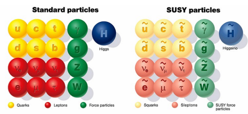
Analysis	Lower limit (95% CL)
t't' → WbWb (l+jets)	404 GeV
t't' → WqWq (dilepton)	350 GeV
b'b' → Wq Wq (l+jets)	480 GeV
b'b' → WqWq (dilepton)	450 GeV
QQ → Zb+X	400 GeV
Single Q → Wq	900 GeV
Signel Q → Zq	760 GeV



Still a lot to do!

Decays to Zt and involving Higgs not considered yet

Outline

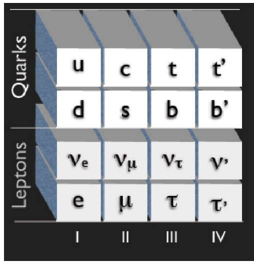


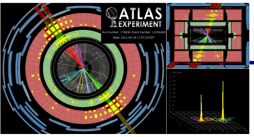
Supersymmetry (with MET)

- → **Jets + MET**
- → **3rd generation**

4th generation and heavy “quarks”

- → **t'**
- → **b'**





Heavy Resonances

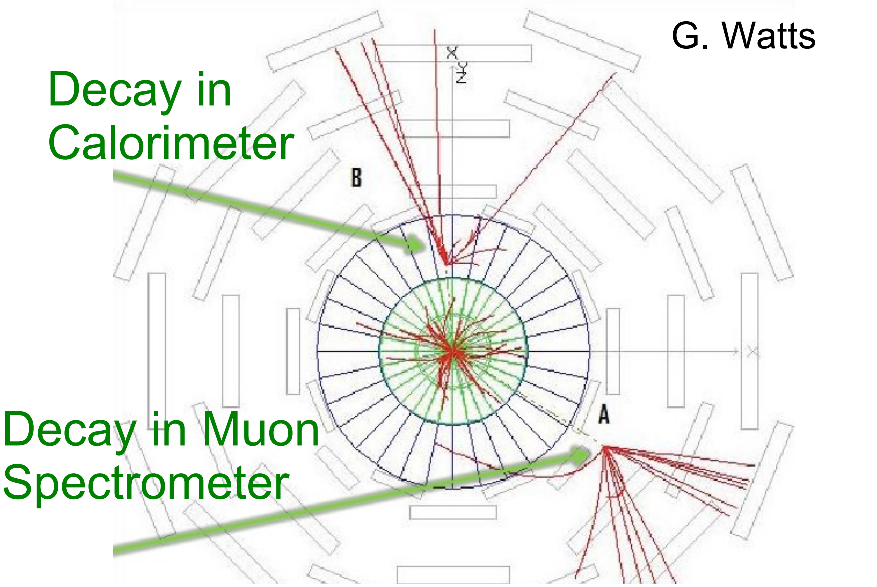
- → **Dilepton**
- → **Dijet**
- → **Top-Antitop**

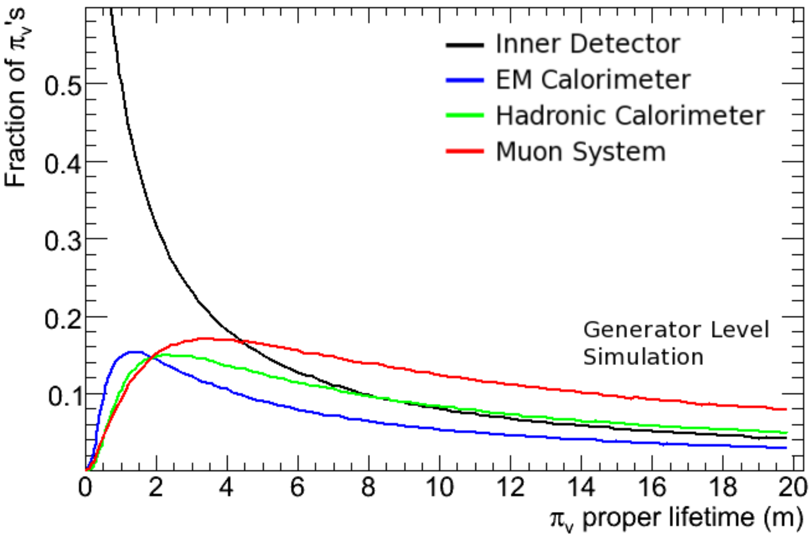
Long-lived particles

- → **Displaced vertices**
- → **Disappearing track**

Long-Lived Particles

- Predicted by:
  - → SUSY (R-parity violating or split/compressed mass spectra): stau, or gluino/stop hadronized into R-hadrons
  - → Hidden Valley
- Experimentally very diverse:
  - → Depends widely on particle's properties: life-time, charge, decay
  - → highly displaced vertices
  - → highly ionizing (dE/dx)
  - → slow (time-of-flight)
  - → kinked tracks
  - → disappearing tracks
  - → out-of-time (wrt collision) decay





Long-Lived Particles Triggers

- (b-tagging triggers)
- Trackless jet trigger:
  - → decays late in inner detector
  - → jet E T > 35 GeV
  - → no tracks with p T > 1 GeV near jet
  - → muon spectrometer activity
- Hadronic / EM (decays beyond the EM calorimeter)
  - → jet ET > 35 GeV
  - → no tracks with p T > 1 GeV near jet
  - → $E_{had} / E_{EM} > 10$
- Muon spectrometer cluster trigger
  - → 3 muon triggers close from each other
  - → no jets, no tracks

Typical decay length

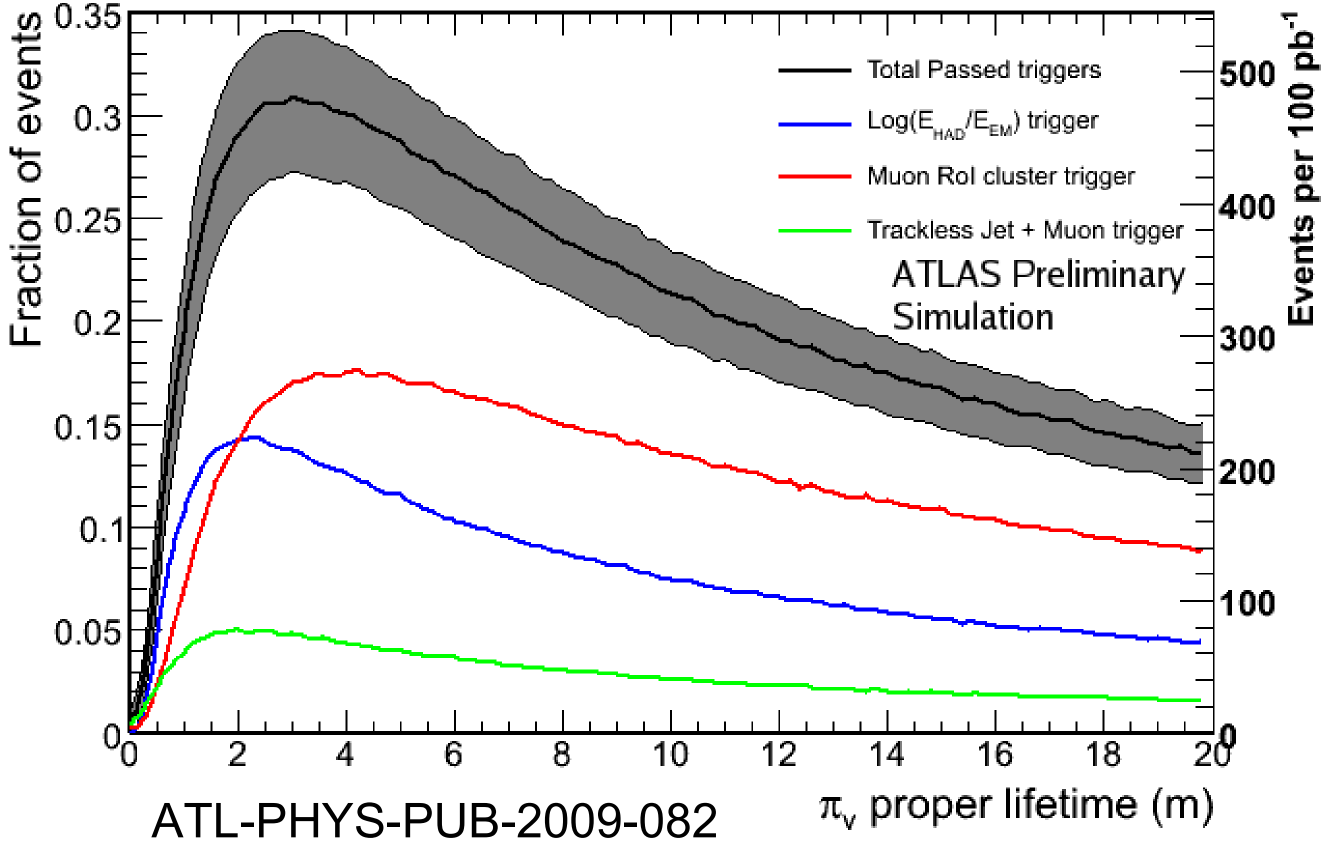
(1 mm - 5 cm)

1 - 3 m

2 - 3 m

4 - 7 m

Long-Lived Particles Triggers



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Long-Lived Particles Triggers

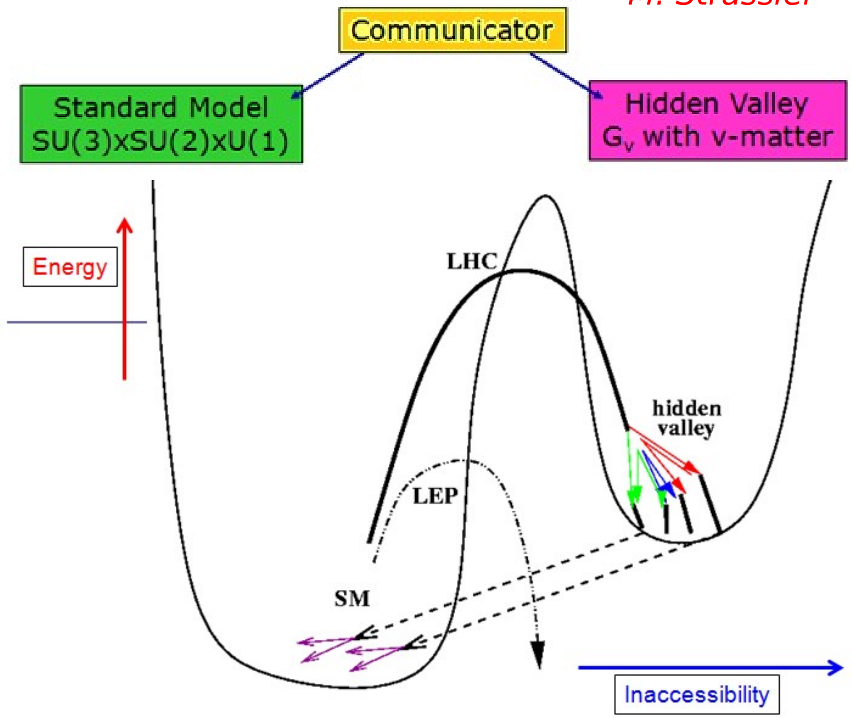
Typical decay length

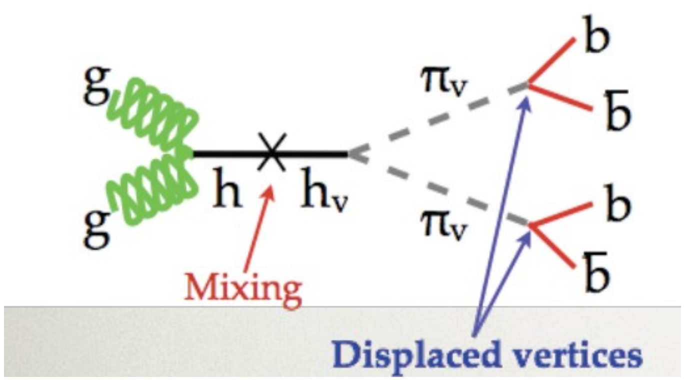
- (b-tagging triggers) — (1 mm - 5 cm)
- Trackless jet trigger: — 1 - 3 m
  - → decays late in inner detector
  - → jet E_T > 35 GeV
  - → no tracks with p_T > 1 GeV near jet
  - → muon spectrometer activity
- Hadronic / EM (decays beyond the EM calorimeter) — 2 - 3 m
  - → jet ET > 35 GeV
  - → no tracks with p_T > 1 GeV near jet
  - → $\log(E_{had}/E_{EM}) > 1.0$
- Muon spectrometer cluster trigger — 4 - 7 m
  - → 3 muon triggers close from each other
  - → no jets, no tracks

Long-Lived Particles: Decay in the Muon Spectrometer

- Hidden-Valley theories predict a hidden sector coupled to the SM only through some heavy communicator → weakly coupled → long-lived particles
- Ex: $h \rightarrow h_v \rightarrow \pi_v\ \pi_v \rightarrow$ 4b's
- Life-time of π_v is unknown
- Look for 2 pairs of b-jets appearing outside the calorimeter.
- Sort of b-tagging with the Muon Spectrometer!

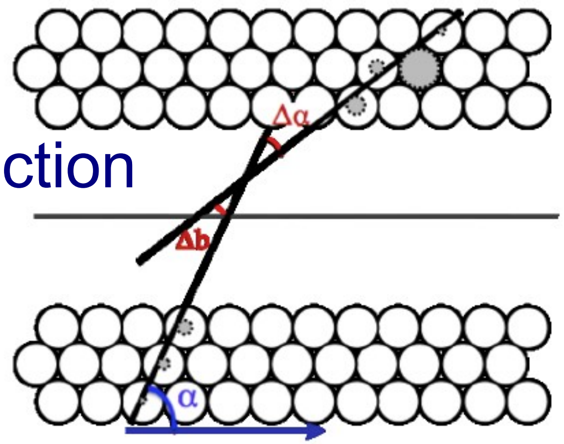
M. Strassler

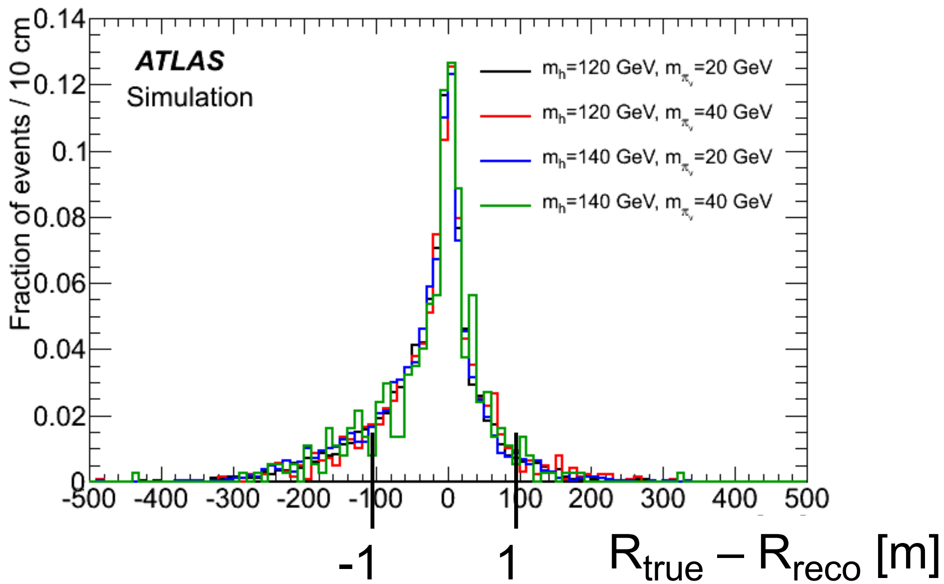


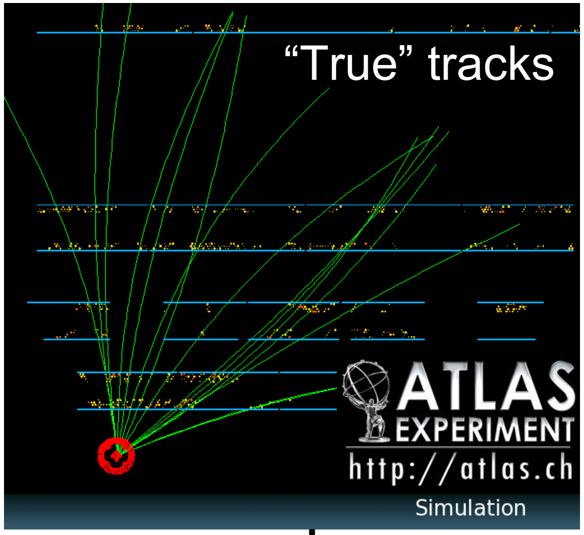


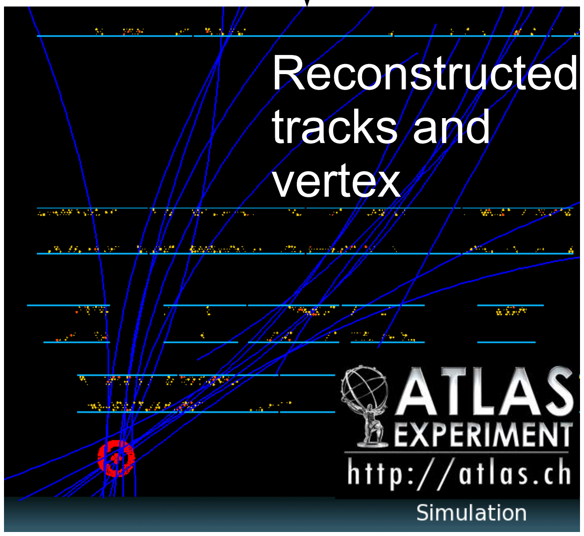
Long-Lived Particles: Vertex Reconstruction in the Muon Spectrometer

- Very high occupancy
- Partial track reconstruction
- Efficiency ~ 50%
- Very coarse spatial resolution:





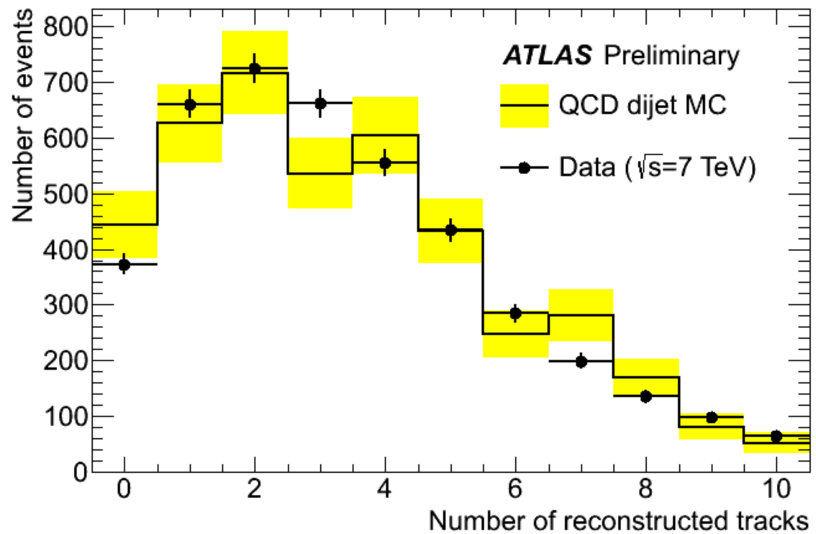


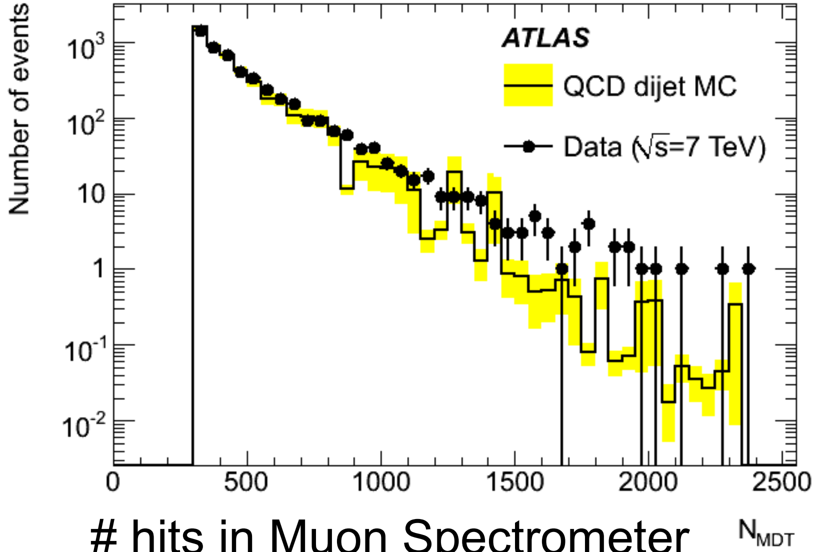


Long-Lived Particles: Decay in the Muon Spectrometer

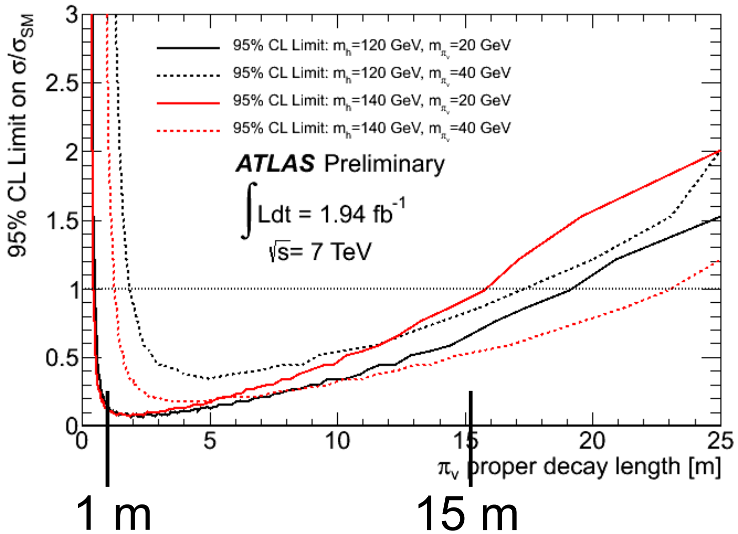
- Validation of simulation with punch-through events
- Note: punch-through's very well described by the simulation!
- After final selection: no event observed (exp: 0.03±0.02 ev.)

Tracks caused by jets in Muon Spectrometer



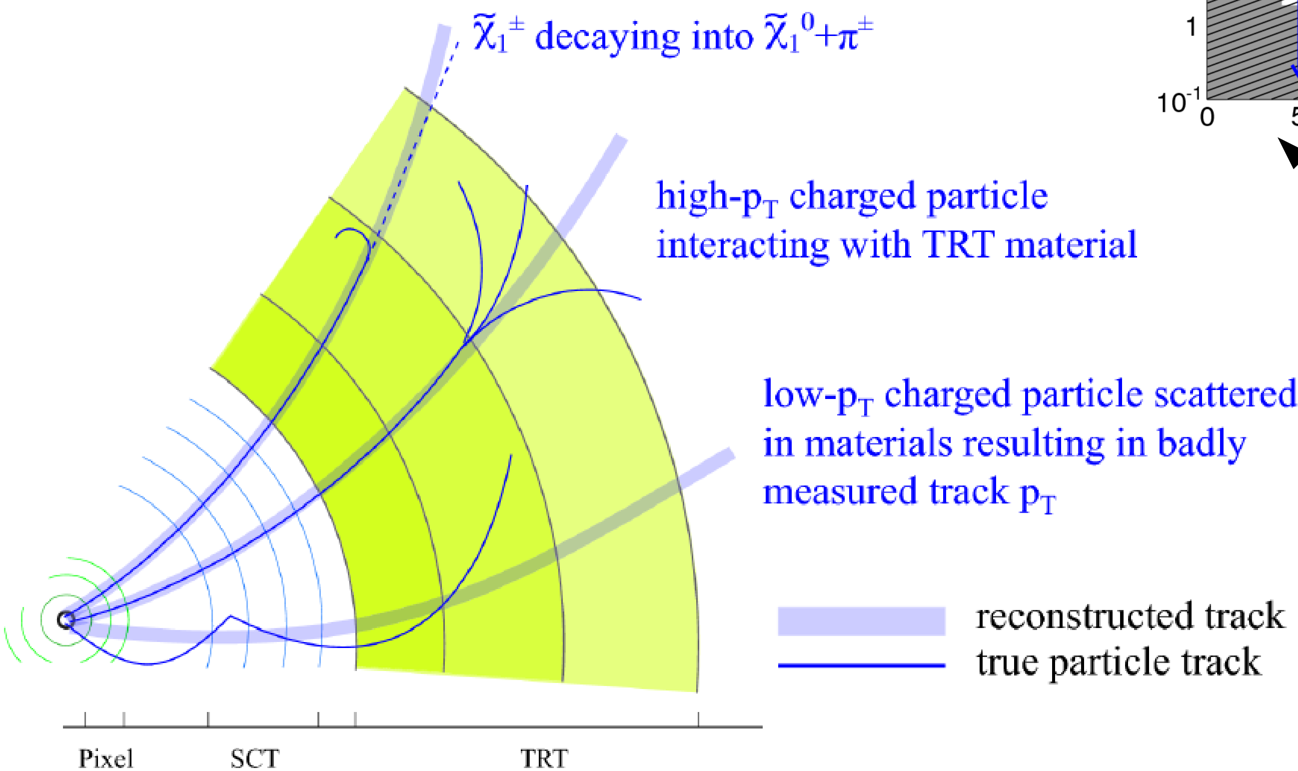


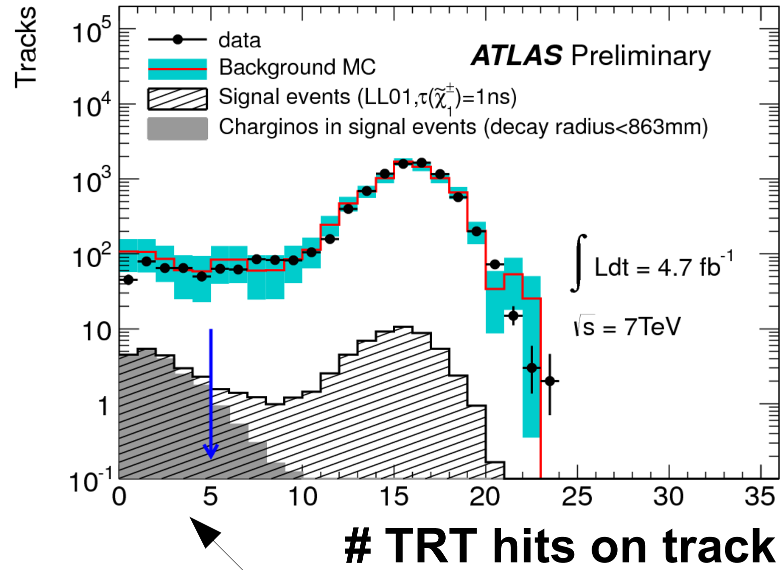
hits in Muon Spectrometer behind a jet



Long-Lived Particles: Disappearing Track

- Compressed spectrum: m(chargino) ~ m(neutralino)
- Chargino long-lived
- Chargino → neutralino + soft pion

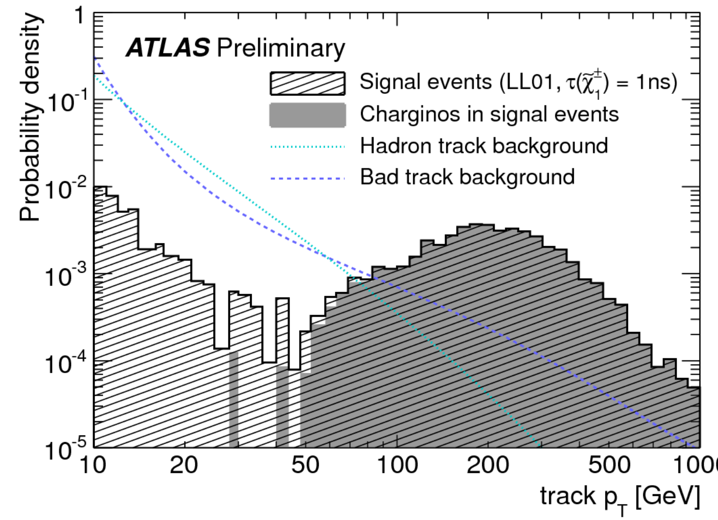


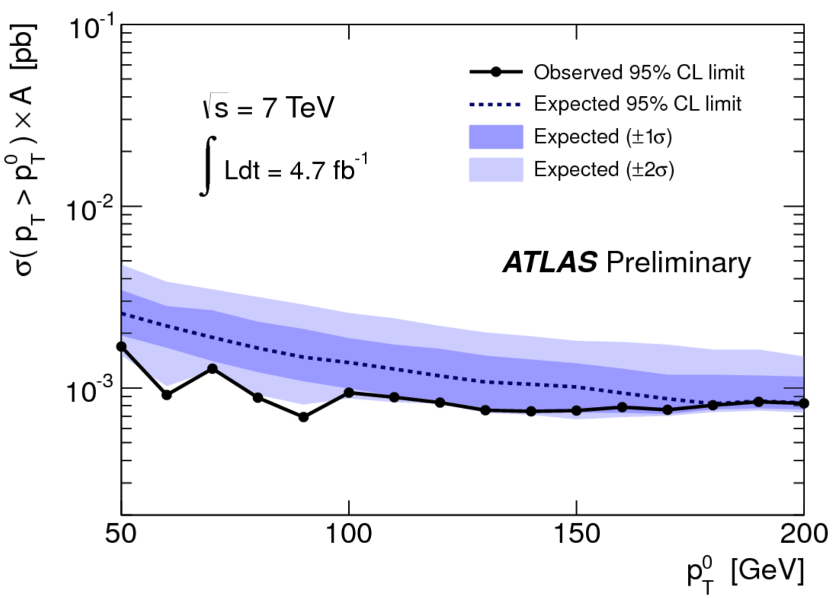


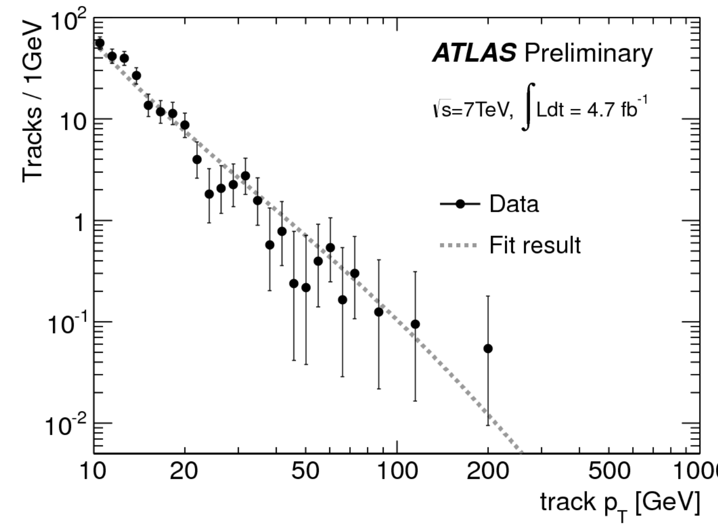
Select tracks
With less than
5 TRT hits

Long-Lived Particles: Disappearing Track

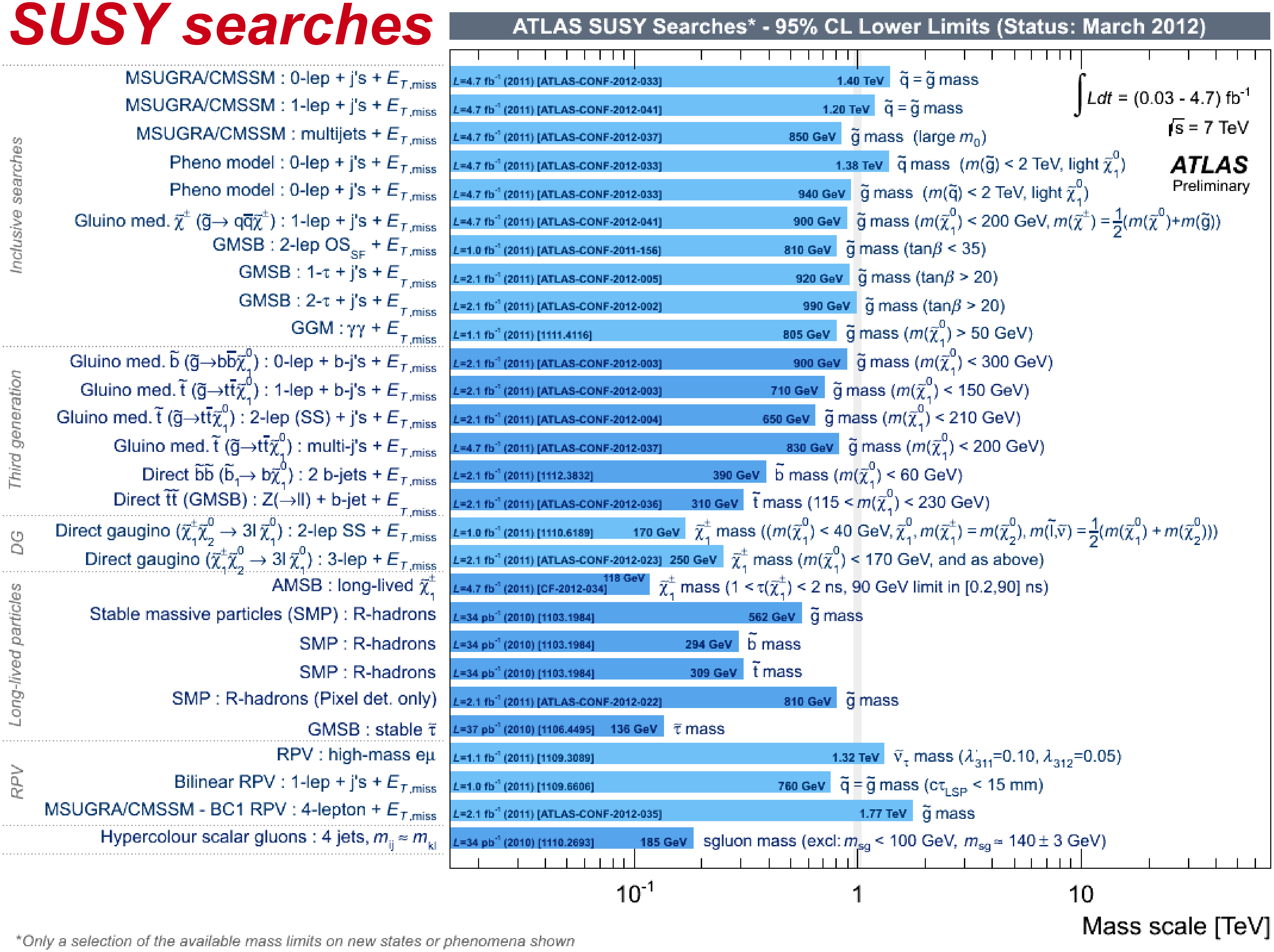
- Look at events with at least 3 jets and large missing ET
- Discr. Variable: pT of tracks with less than 5 TRT hits



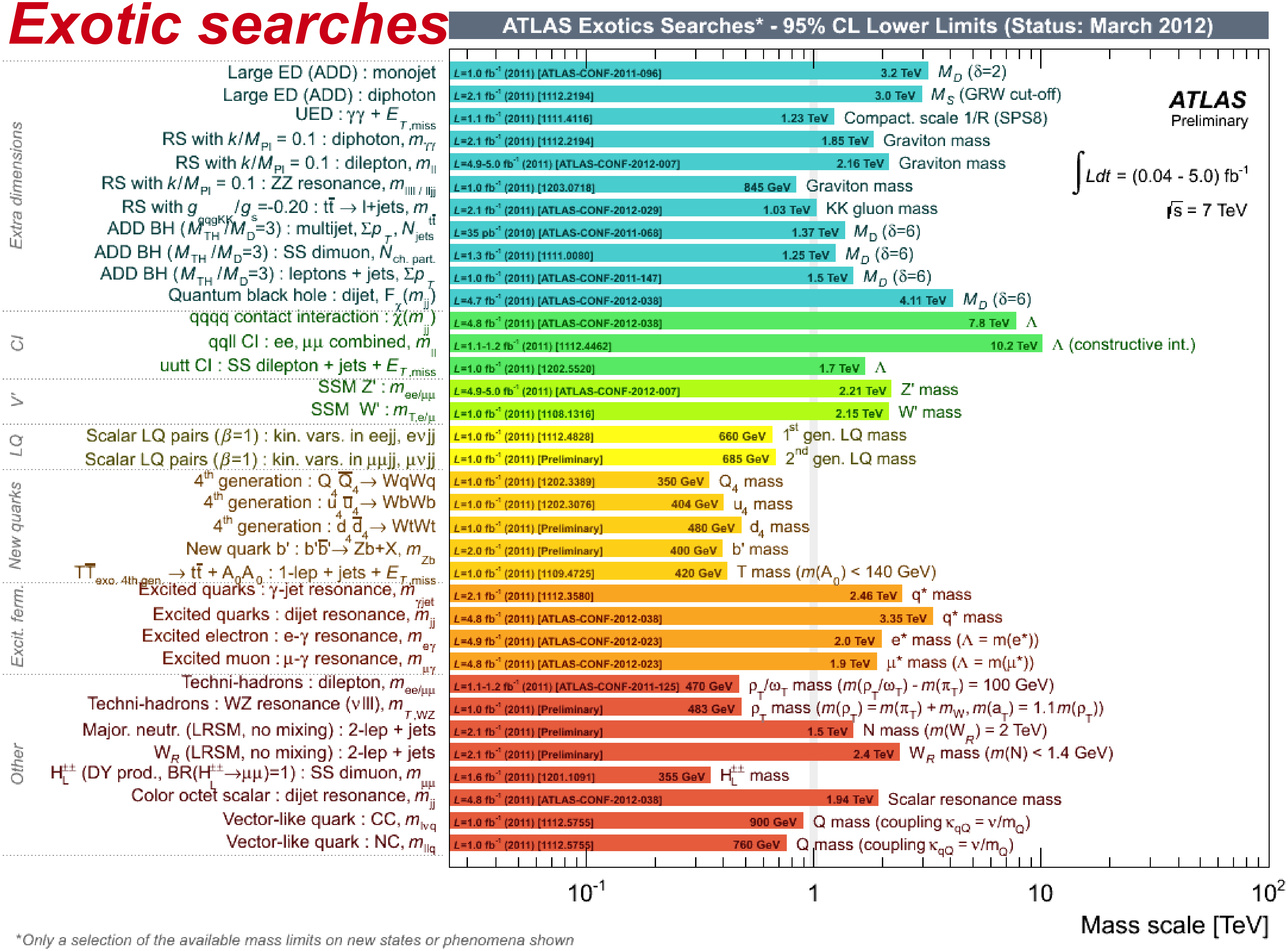




SUSY searches



Exotic searches



A very short summary of the first two years

Unfortunately, still no hint of New Physics in the LHC data...

95% CL lower limits	1 fb^{-1} (7/2011)	5 fb^{-1} (2011)
CMSSM ($m_{\tilde{q}} = m_{\tilde{g}}$)	1 TeV	1.4 TeV
Z' (SSM)	1.8 TeV	2.2 TeV
Excited quark	2.9 TeV	3.4 TeV

Outlook

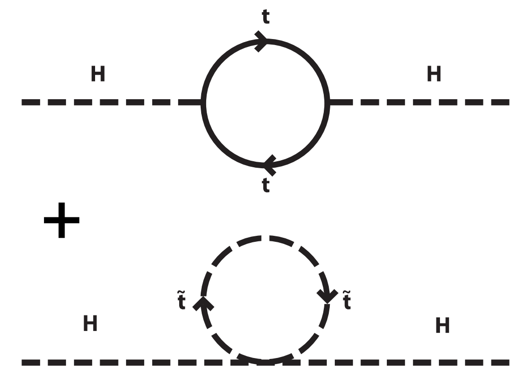
- Unfortunately, New Physics was not "around the corner"
- Experimental challenges as we enter further the Multi-TeV world:
  - → TeV leptons
  - → Boosted objects (W, top)
  - → Investigate less obvious signatures and pursue precision measurements
  - → Pile-up with ~ 30 interactions / crossing
- Expect 15-20 fb^{-1} **at 8 TeV** by the end of 2012

  followed by 300 fb^{-1} at 14 TeV by the end of the decade (?)
- It's only the beginning!

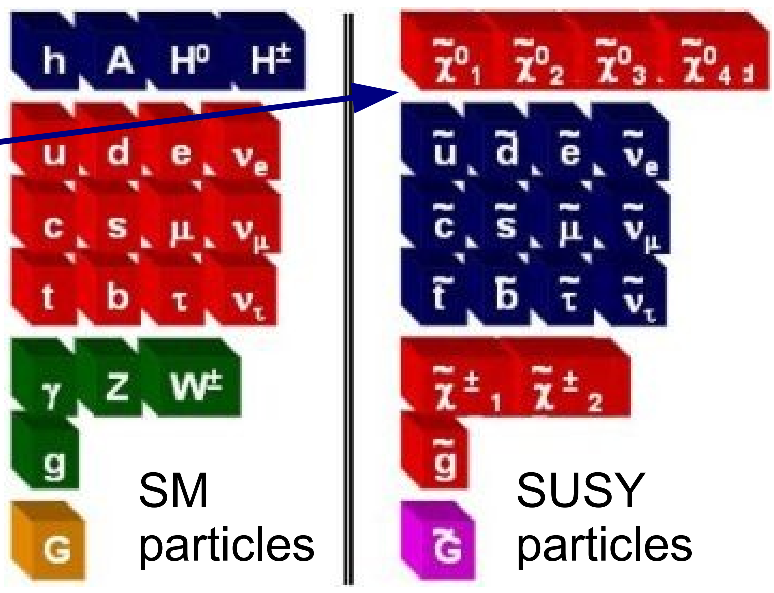
Backup

Supersymmetry

- Extension of the Poincaré algebra
- Fermion ↔ Boson symmetry
- Solves many problems of the SM, esp. stabilizes Higgs sector
- If R-parity ($R = (-1)^{3(B-L)+2s}$) is conserved, Lightest SUSY Particle (LSP) is an excellent Dark Matter candidate
- Phenomenology is **very** diverse



≈ 0 (if $\tilde{t}$ is light)



3. SUSY: b-Jets + lepton + Missing E_T

- What if gluinos decay preferentially to 3rd generation?
- Consider several pheno. scenarii, such as:

  Assume $m(\tilde{g}) << m(\tilde{t}_1) << m(\tilde{q}_{1,2}) \approx m(\tilde{b}_1)$

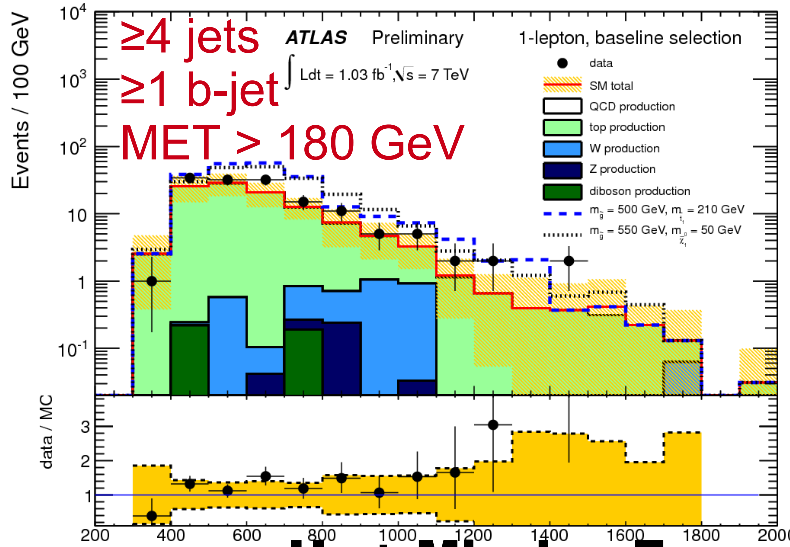
  Consider only gluino-gluino production followed by decay through off-shell stop:

  $$\tilde{g} \rightarrow \tilde{t}_1^* t \rightarrow t t \tilde{\chi}_1^0$$

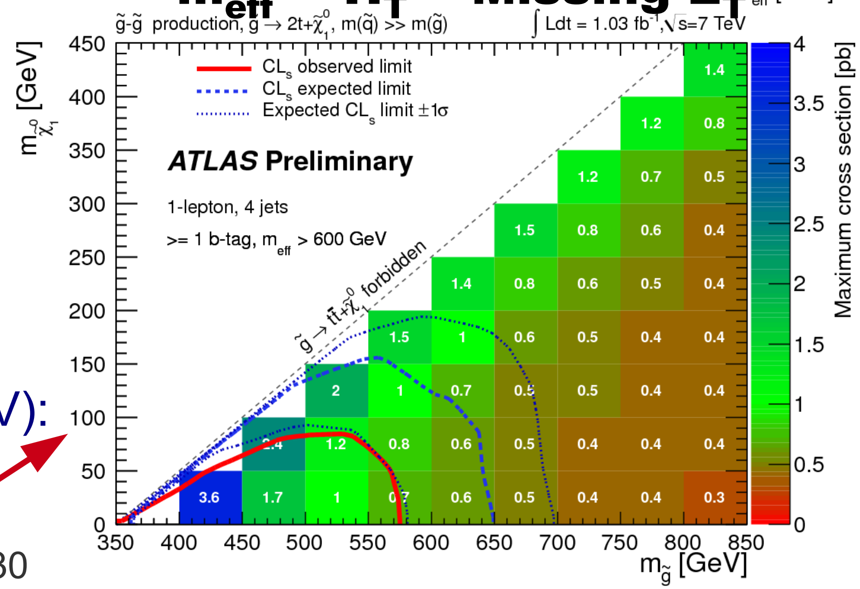
- Complex final states with lepton(s) and b-jets
- Limit on gluino mass ($m(\chi_1^0) < 80$ GeV):

  m(gluino) > 540 GeV at 95% C.L.

ATL-CONF-2011-130

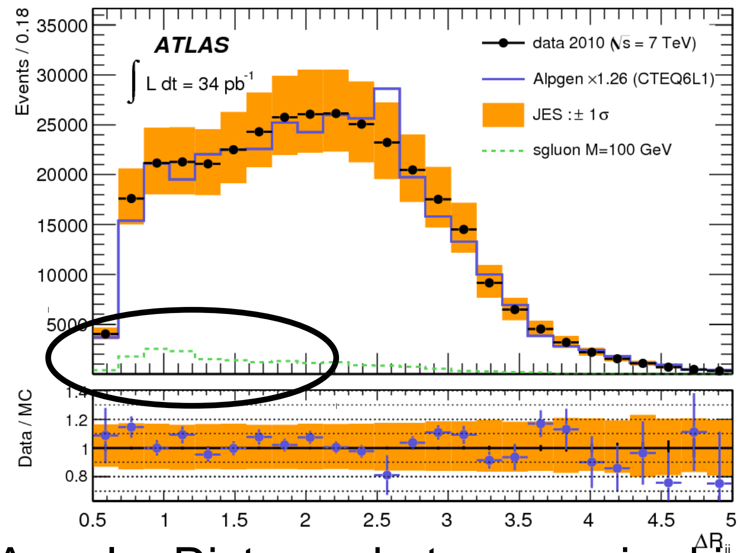


m_{eff} = H_T + Missing E_T

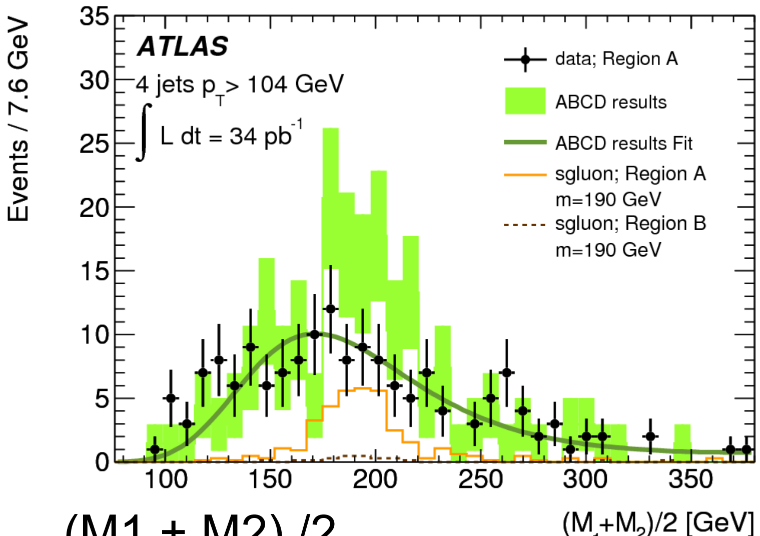


Supersymmetry without MET: an example

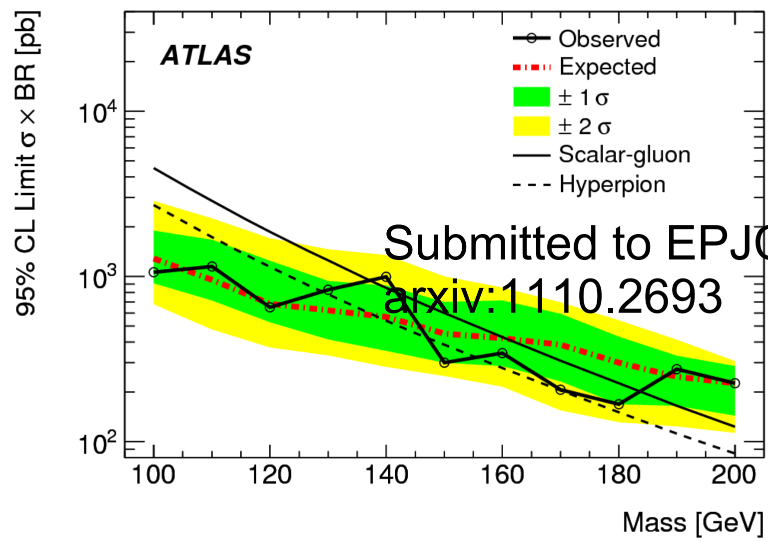
- Extended SUSY models
  - → Scalar gluon (not gluino!) has same R-parity as gluon → decay to pair of gluons
- Look for 2 back-to-back pairs of jets in 4-jet events



Angular Distance between paired jets



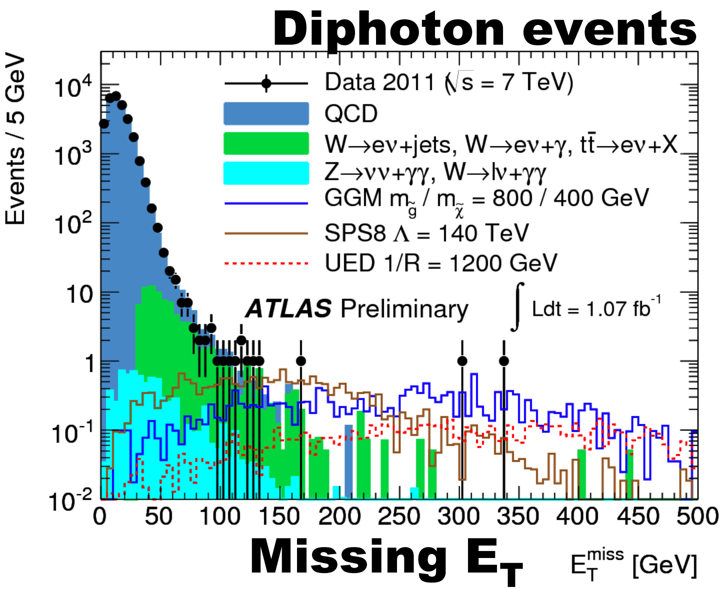
(M1 + M2) /2
Average mass of the two dijet pairs

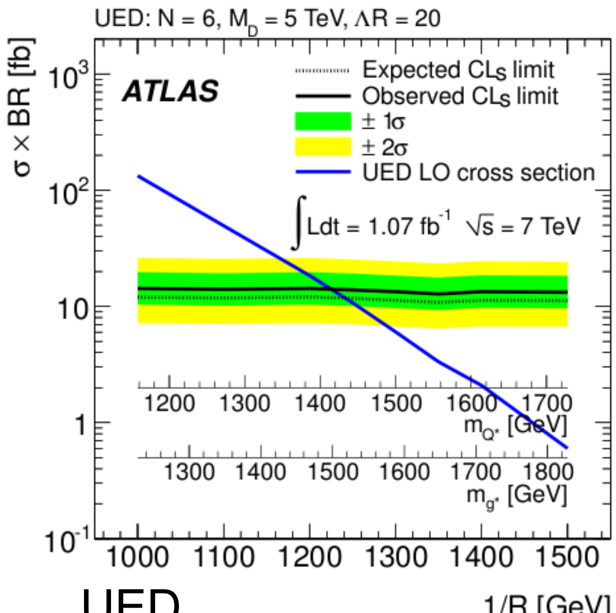


Submitted to EPJC
arxiv:1110.2693

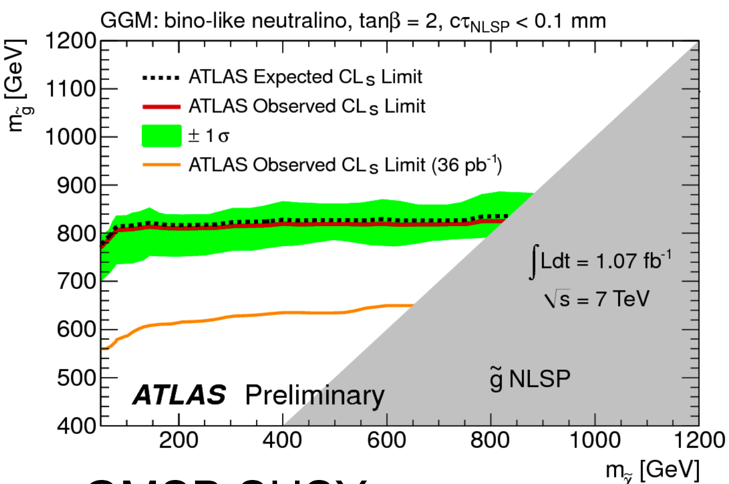
4. SUSY: diphoton + jet + Missing E_T

- Gauge-Mediated SUSY Breaking:
  - → LSP = Gravitino
  - → NLSP = Neutralino
  - → NLSP → LSP + Photon
- Also interpreted as Universal Extra-Dimension (UED)





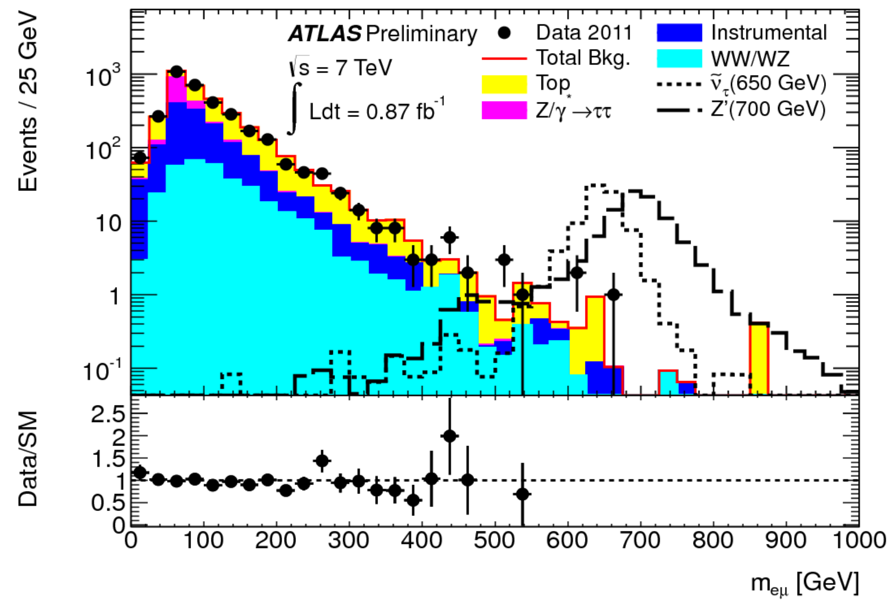
UED

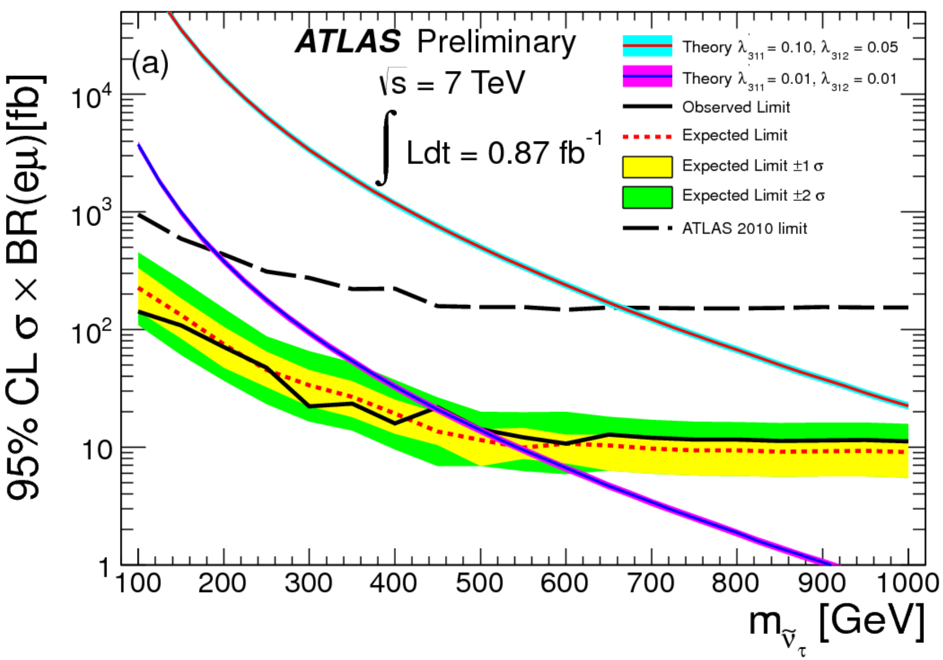


GMSB SUSY

Search for Heavy Resonance: eμ

- Lepton Flavor Violation occurs e.g. in RP-Violation SUSY
  - → sneutrino decaying to eμ
- Limit of 11 fb at high mass
- Constrains on RPV coupings



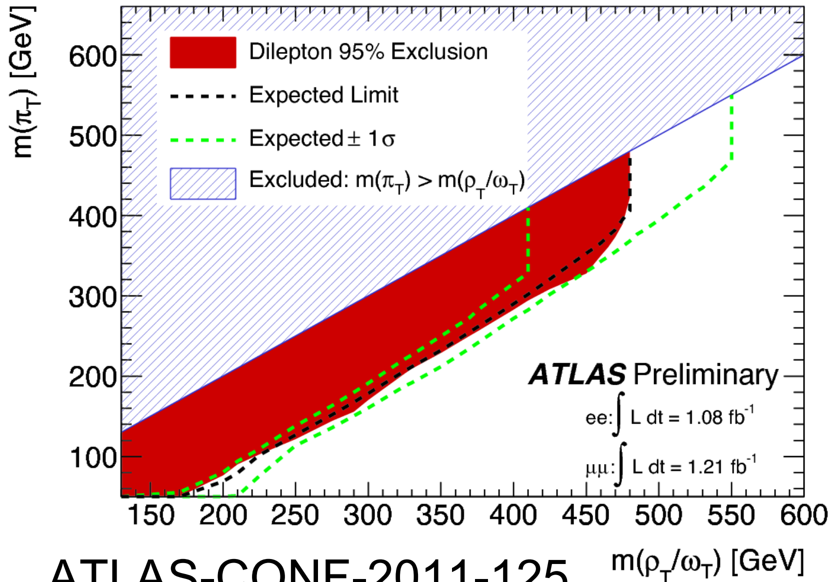


Search for Heavy Resonance: dilepton channel

- Neutral heavy gauge boson
- Randall-Sundrum KK graviton excitation
- Technihadron

Sequential SM:
m(Z') > 1.8 TeV at 95% C.L.
RS graviton (k/M_{Pl} = 0.1):
m(G) > 1.6 TeV at 95% C.L.

Accepted by PRL
arXiv:1108.1582



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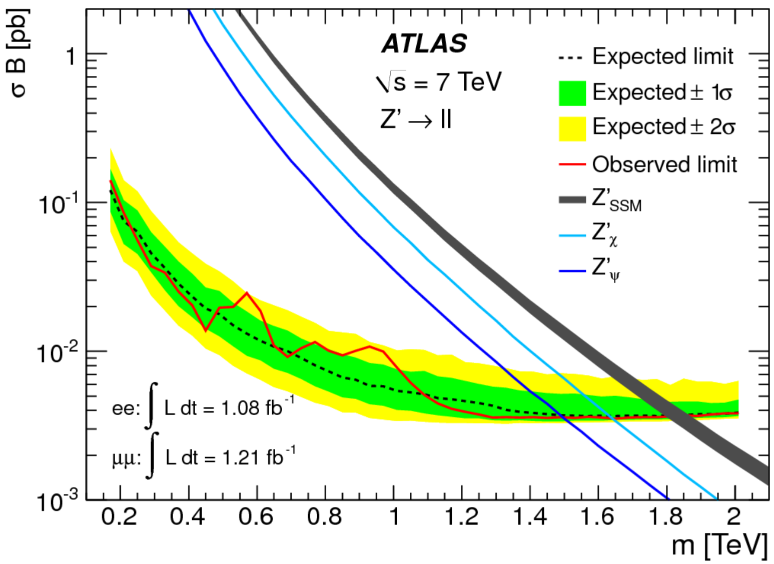
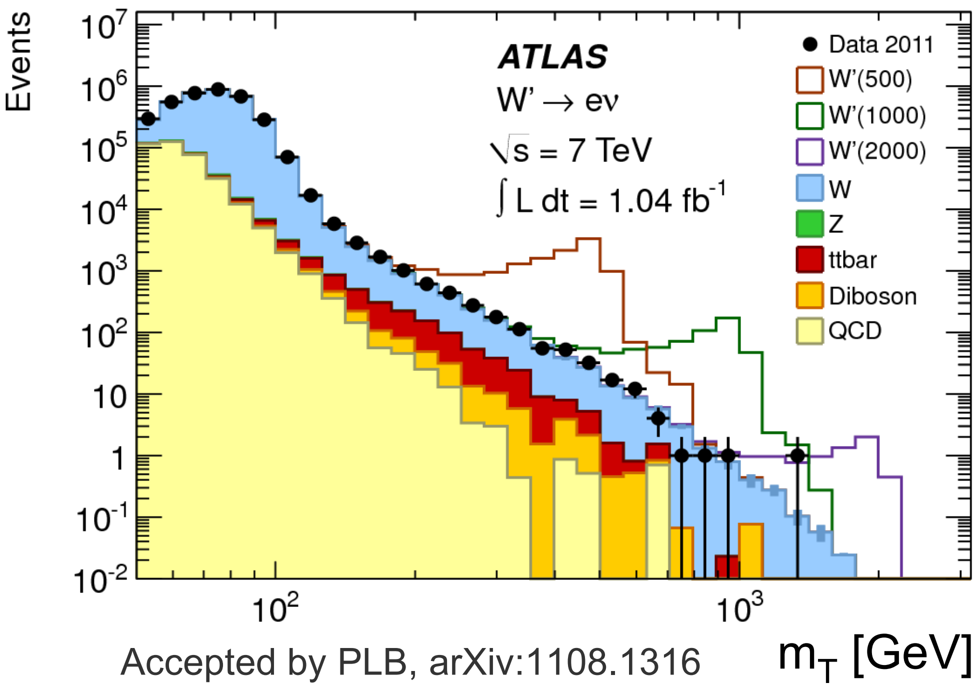


Search for Heavy Resonance: W' → lν

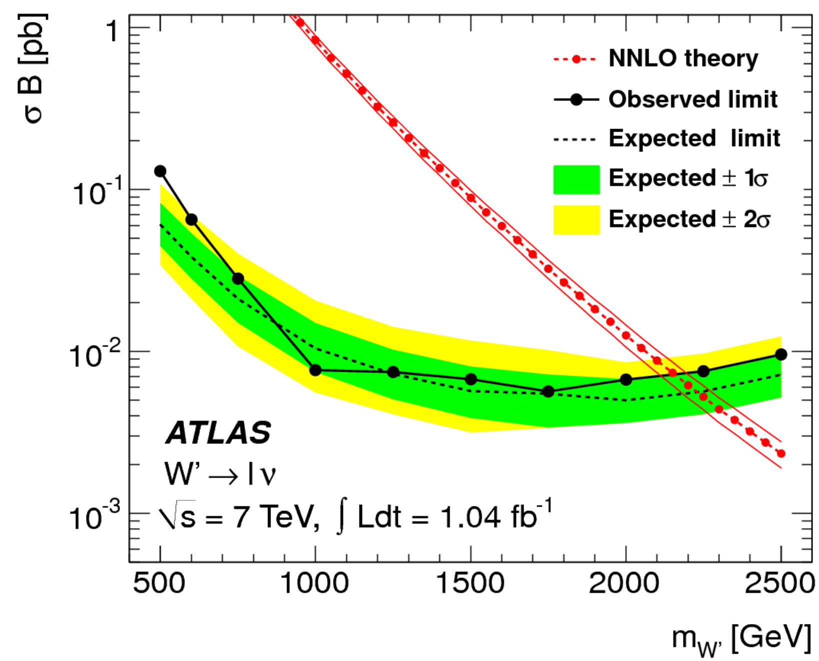
- Heavy charged gauge boson
- Technirho, Little Higgs
- 1 lepton + Missing E_T
- Look for Jacobian peak

$$m_T = \sqrt{2 p_T \not{E}_T (1 - cos\Delta\phi_{\ell,\not{E}_T})}$$

Sequential SM:
m(W') > 2.15 TeV at 95% C.L.

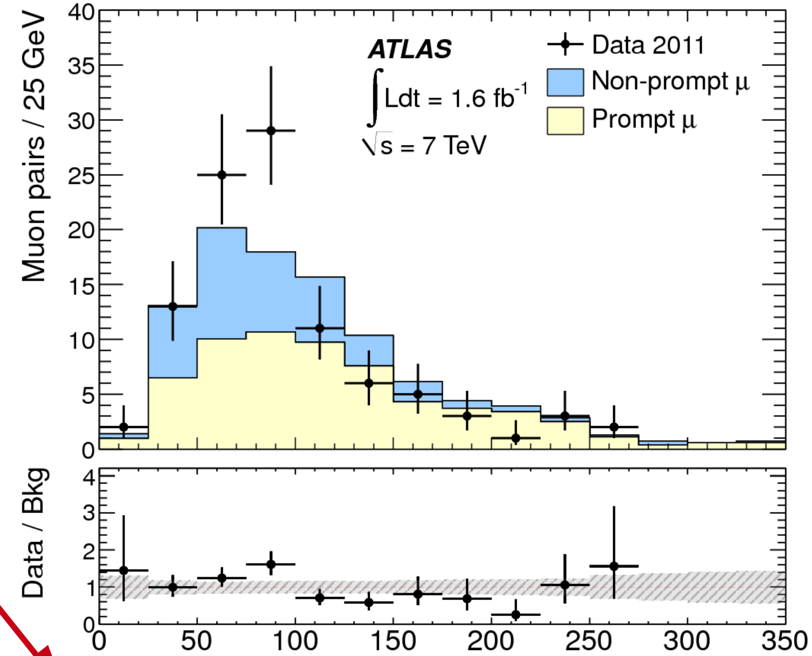


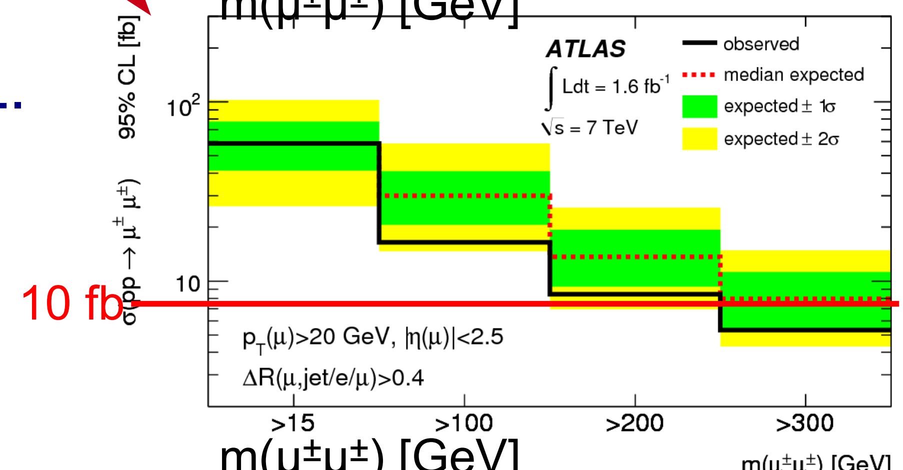
Accepted by PLB, arXiv:1108.1316



Search for ~~Heavy Resonance~~ Inclusive search: Same-Sign Dilepton

- Predicted by many models
- Very clean signature
- Inclusive, model-independent search:
  - Fiducial cross-section limit as function of m(μ±μ±)
- Interpretation in terms of same-sign top production: σ(tt) < 2.9 – 4.1 pb at 95% C.L.





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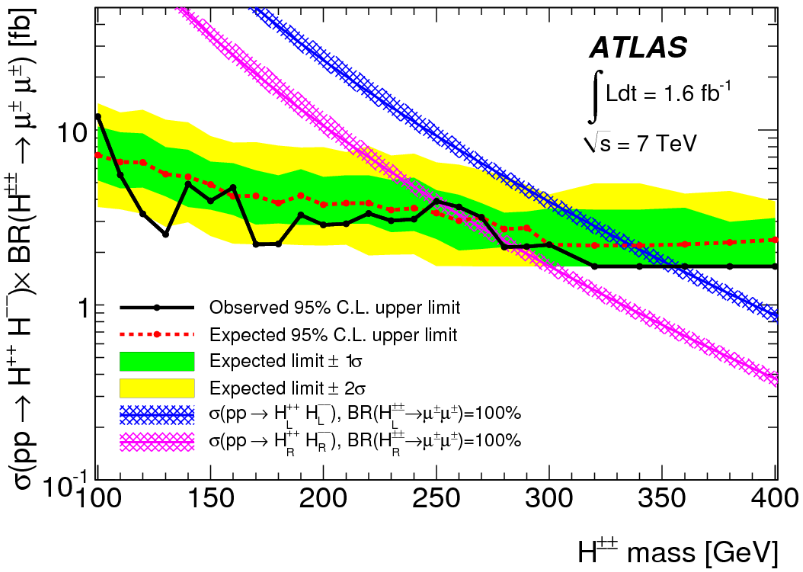
Search for Heavy Resonance: Same-Sign Dilepton

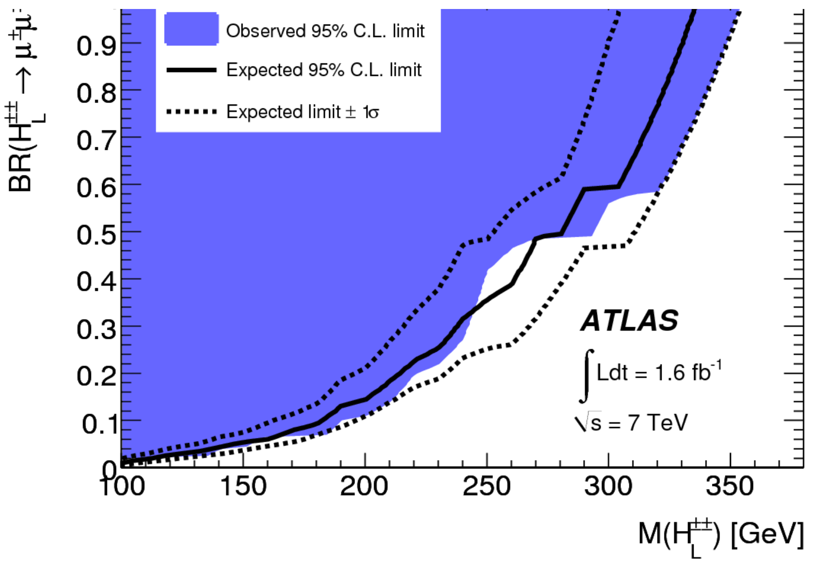
- Doubly-charged Higgs search
  - → based on same analysis as inclusive search
  - → window 10% around Higgs mass



Assuming BR($\mu^\pm\mu^\pm$) = 100%:

m(H_L) > ??? GeV (exp. ??? GeV)

m(H_R) > ??? GeV (exp. ??? GeV)



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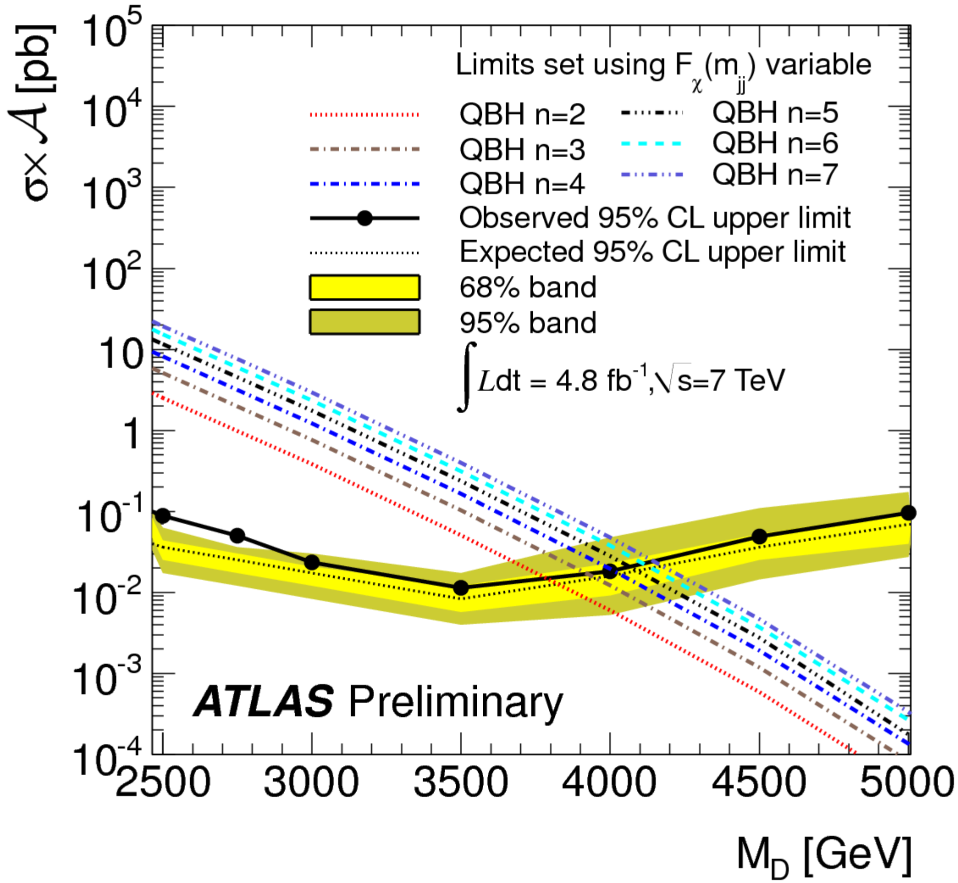
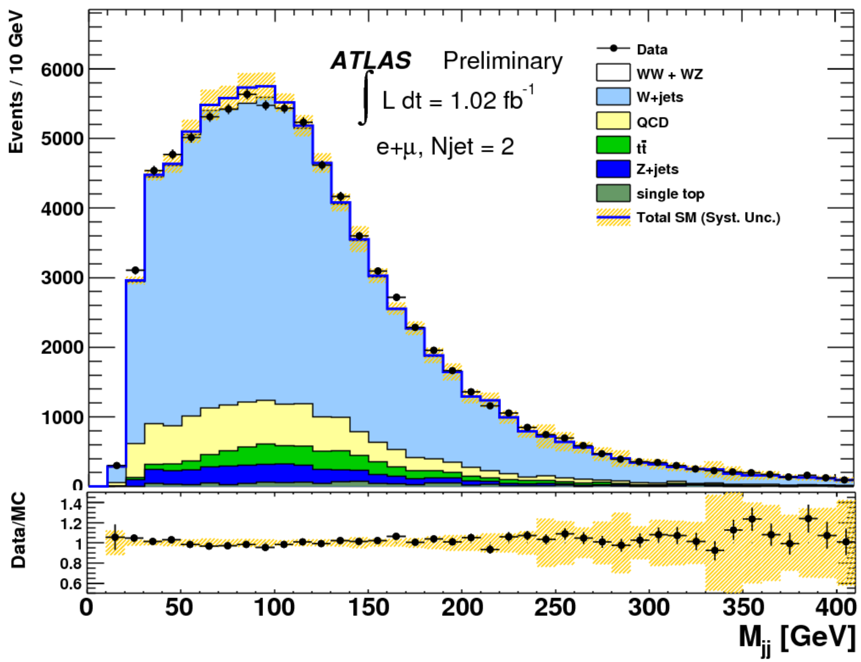
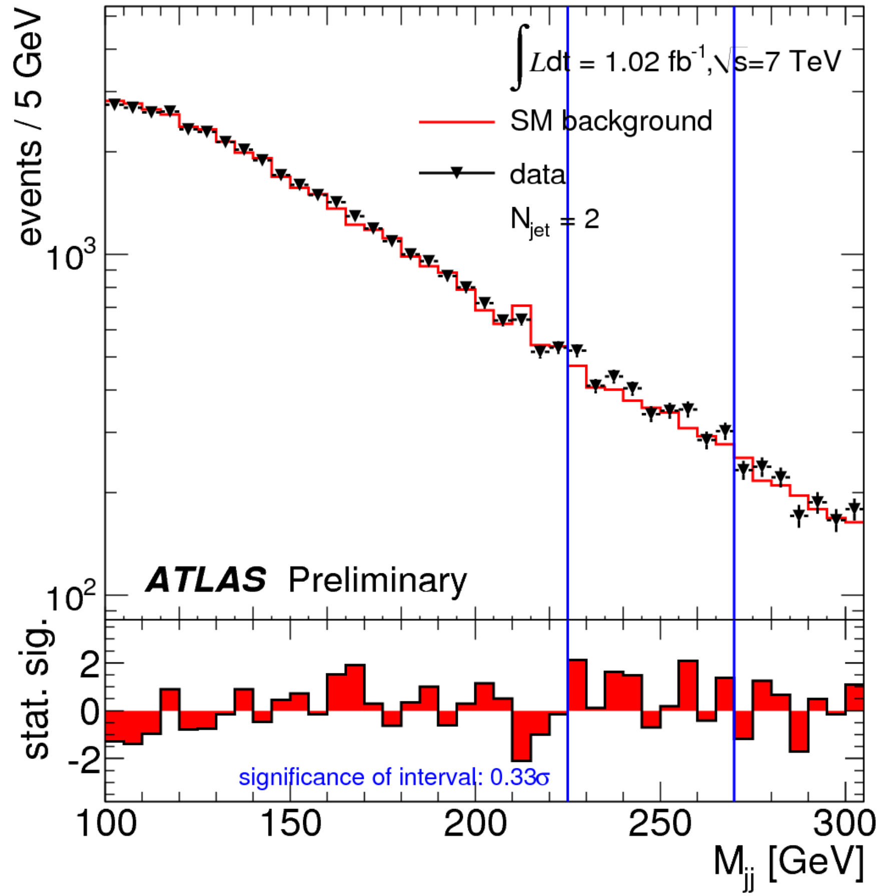
Search for Heavy Resonance: Dijet



Wjj

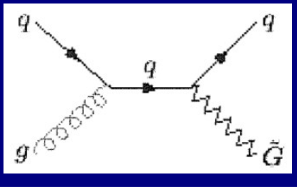


ATLAS Preliminary
∫ L dt = 1.02 fb⁻¹
e+μ, Njet = 2
Data
WW + WZ
W+jets
QCD
tt̄
Z+jets
single top
Total SM (Syst. Unc.)
Events / 10 GeV
Data/MC
M_jj [GeV]



∫Ldt = 1.02 fb⁻¹, √s=7 TeV
SM background
data
N_jet = 2
ATLAS Preliminary
events / 5 GeV
stat. sig.
significance of interval: 0.33σ
M_jj [GeV]

Search for Monojets

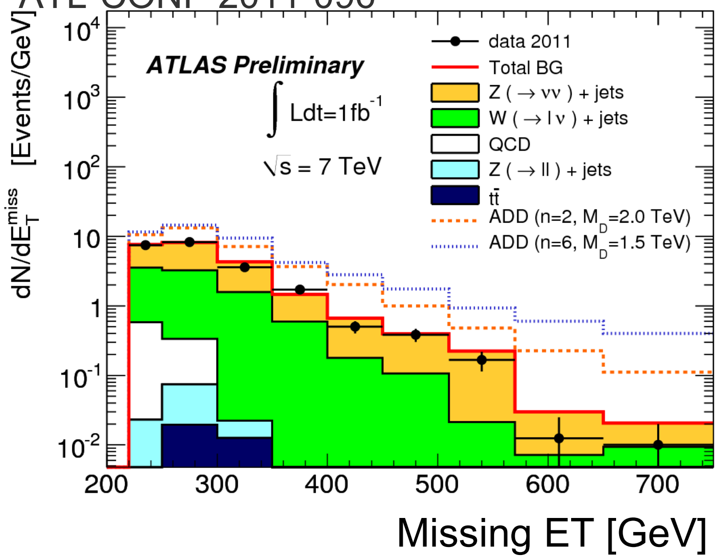


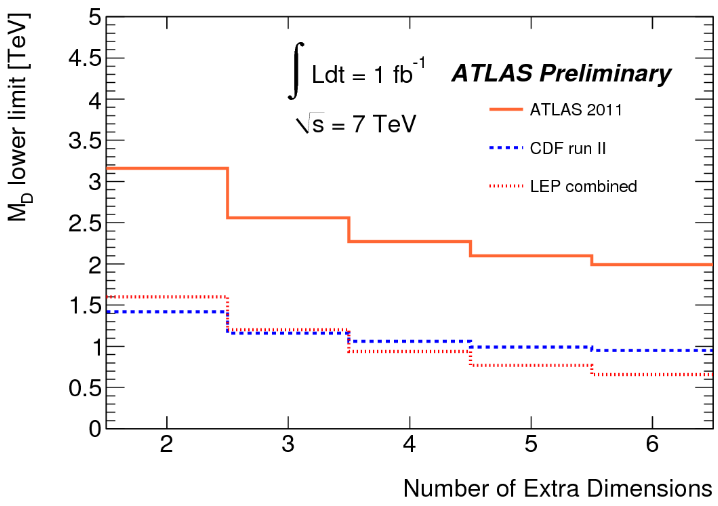
- Large Extra-D (ADD):
  - → Brings the Plank scale down to the TeV scale:

$$M_{Pl}^2 \sim M_D^{2+n} R^n$$

  - → Graviton escapes detector
- Also Split SUSY
- Look for a jet and ~ nothing else
- Challenge:
  - → Instrumental background
  - → Understanding Z(→ νν) + jets

ATL-CONF-2011-096



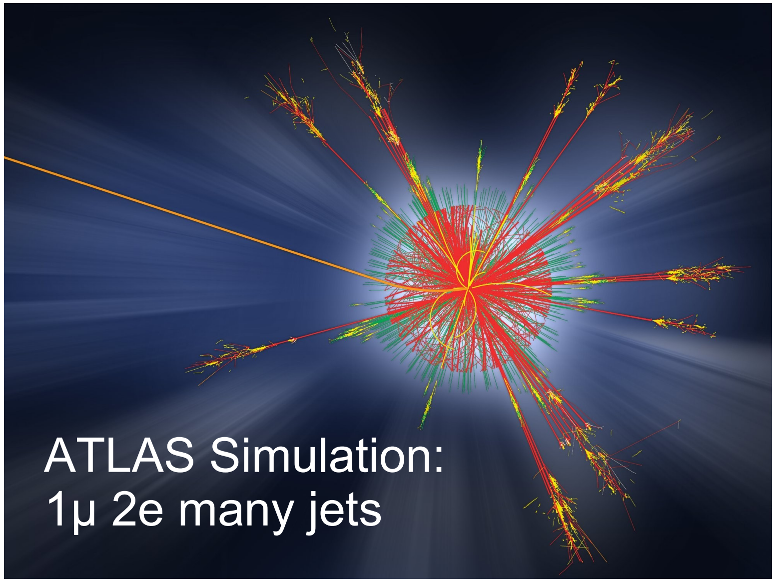


Strong Gravity at TeV-scale, Microscopic Black Holes

- Large Extra-D (ADD):
  - → Brings the Plank scale down to the TeV scale:

$$M_{Pl}{}^2 \sim M_D{}^{2+n} R^n$$

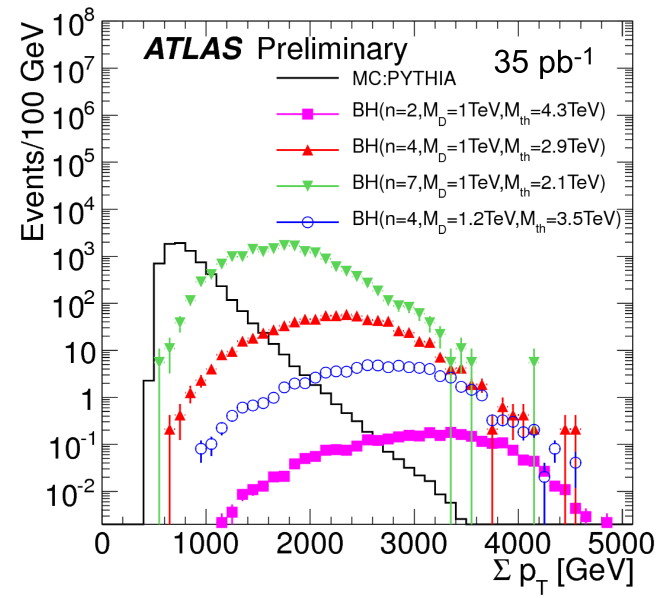
  - → Gravity becomes strong at TeV
- Microscopic black-holes decaying through Hawking radiation
- Large uncertainty on models due to our ignorance of quantum gravity

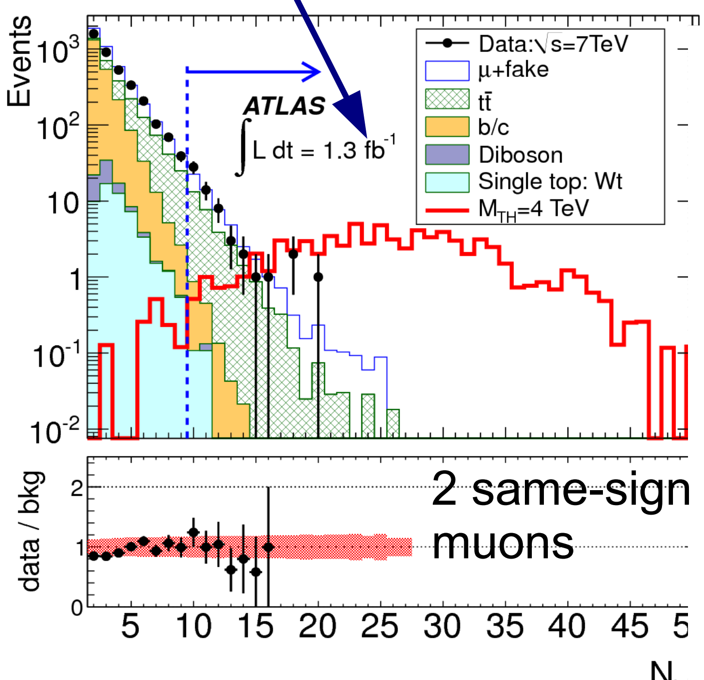


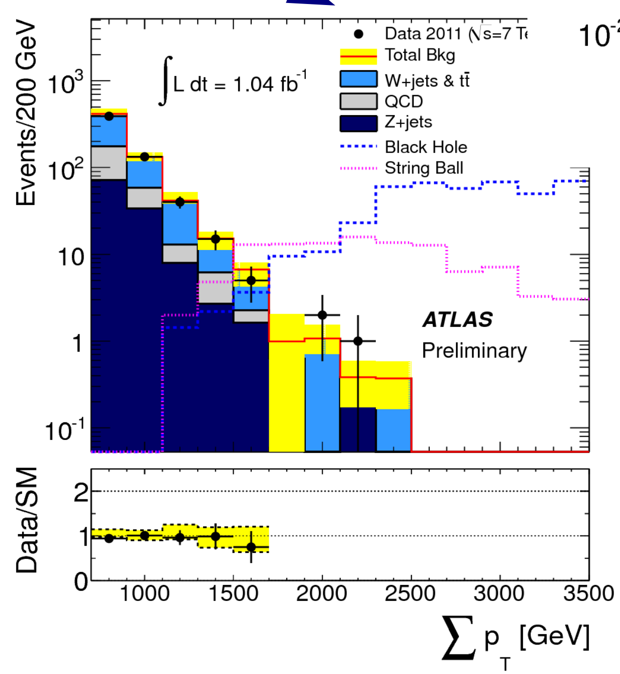
- Semi-classical models only for m(B.H.) >> m(threshold)
- A safe bet: decay is democratic and isotropic
- **Look for (many) jets and leptons at high mass**

Black Holes: Multi-Jets, Lepton+Jets, Same-Sign

- Multijet
- L+Jets
- Same-sign Dimuon



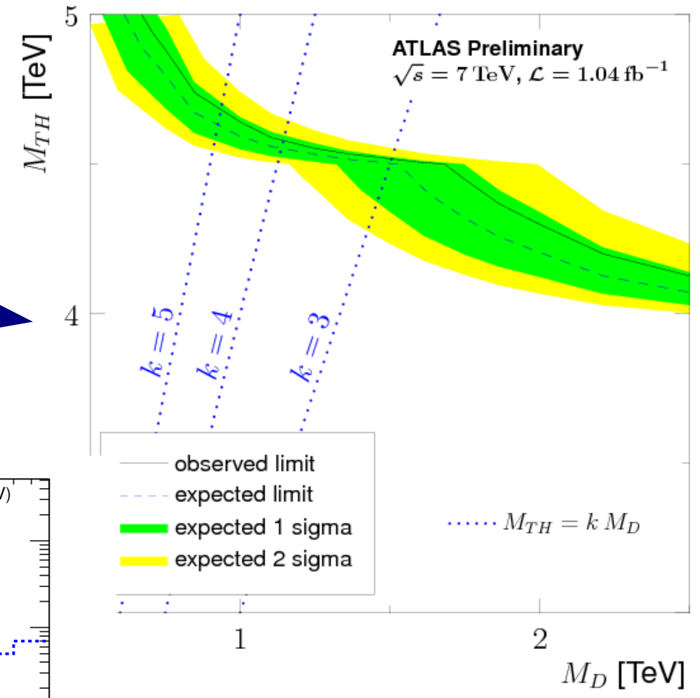


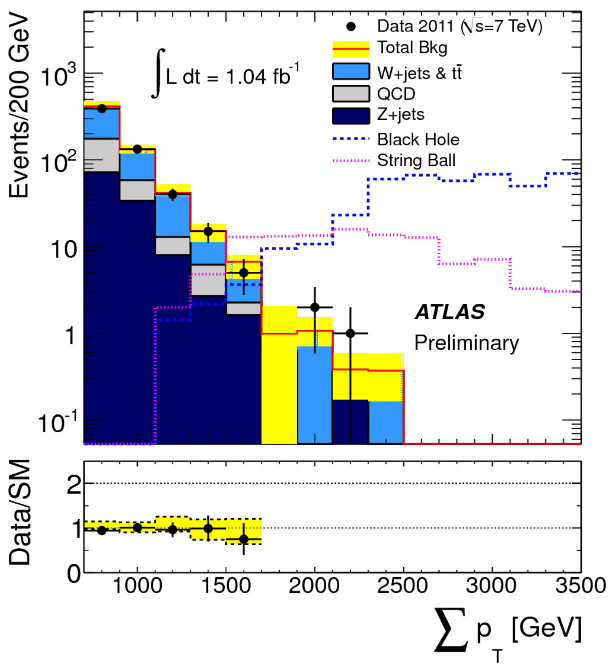


high-pT Tracks

Black Holes: Multi-Jets, Lepton+Jets, Same-Sign

- Multijet
- L+Jets
- Same-sign Dimuon





t't' → WbWb → lvbbqq (l+jets channel)

- Signature: l + ETmiss + ≥3 jets (l=e,μ) and b-tagging
- Main background: top
- Observable: reconstructed heavy quark mass
  - 3-jet events: m(jjj)
  - 4-jet events: kinematic fit
- Strategy:
  - → Combine 3-jet and 4-jet
  - → Constrain background systematics through *in situ* fit a.k.a. "profiling"
  - → Jet Energy Scale uncertainty improved by about factor 4 (!)

- Event selection:
- Exactly 1 e or μ with

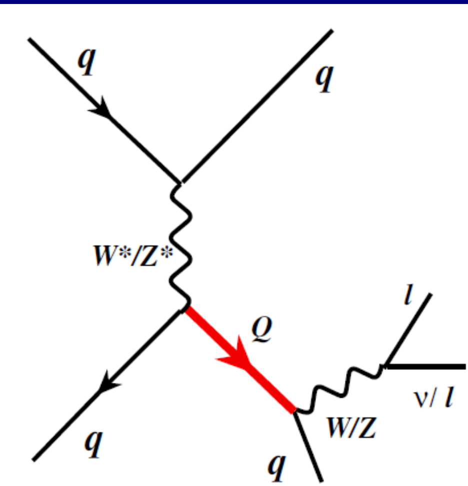
  pT(e)>25 GeV, pT(μ)>20 GeV
- e (μ) +jets: ETmiss>35(20) GeV
- ETmiss+MT(W)>60 GeV
- At least 3 jets with

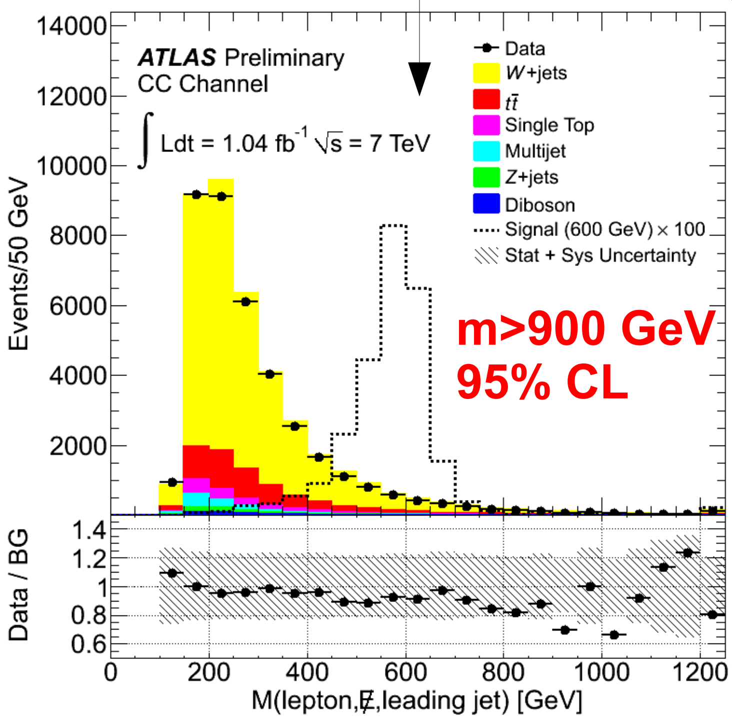
  pT>25 GeV, |η|<2.5

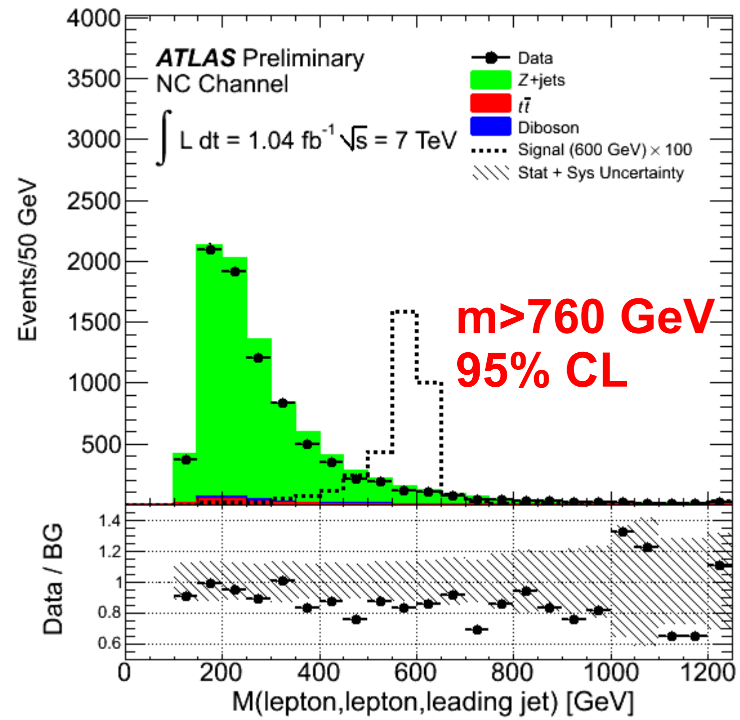
  Leading jet pT > 60 GeV
- At least one b-tagged jets

Vector-like Quarks

- Chiral fermions are seriously constrained, but room for vector-like quarks
- Look for Wq or Zq resonance



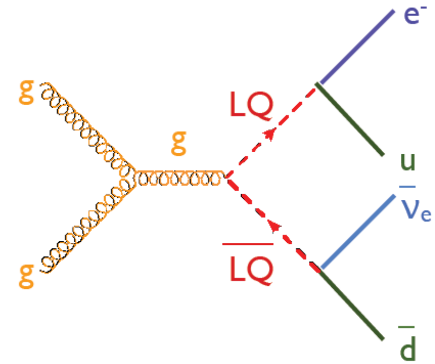




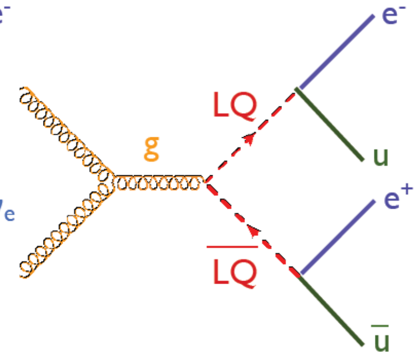
1st Generation Leptoquarks

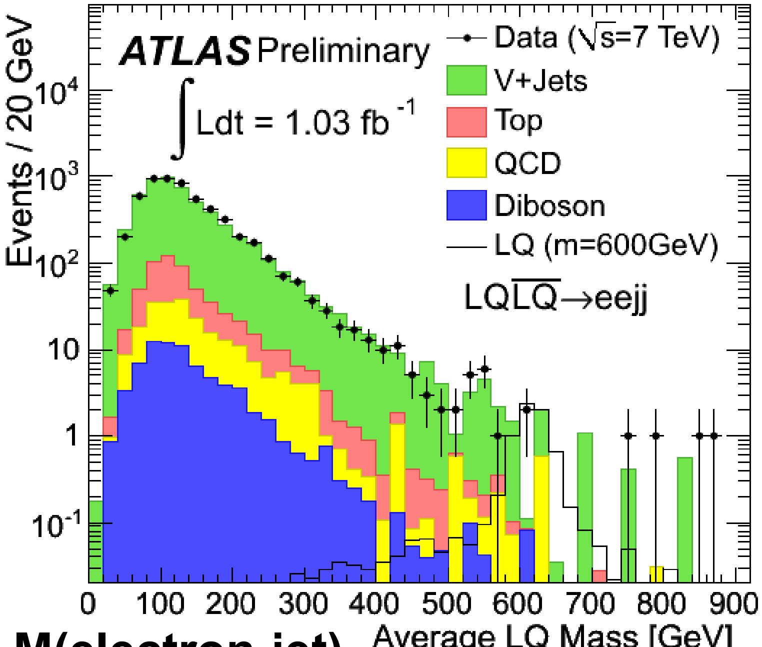
- LQs carry both lepton and baryon number → decay to lepton-quark
- 1st generation: dielectron and electron neutrino channel
- Multivariate analysis, using mostly:

e-jet ν-jet:

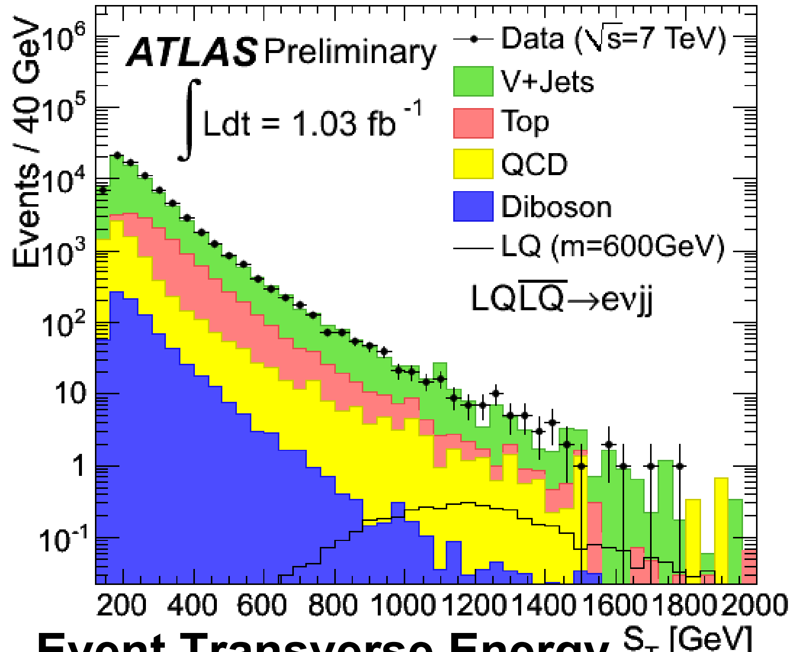


e-jet e-jet:





M(electron-jet)



Event Transverse Energy

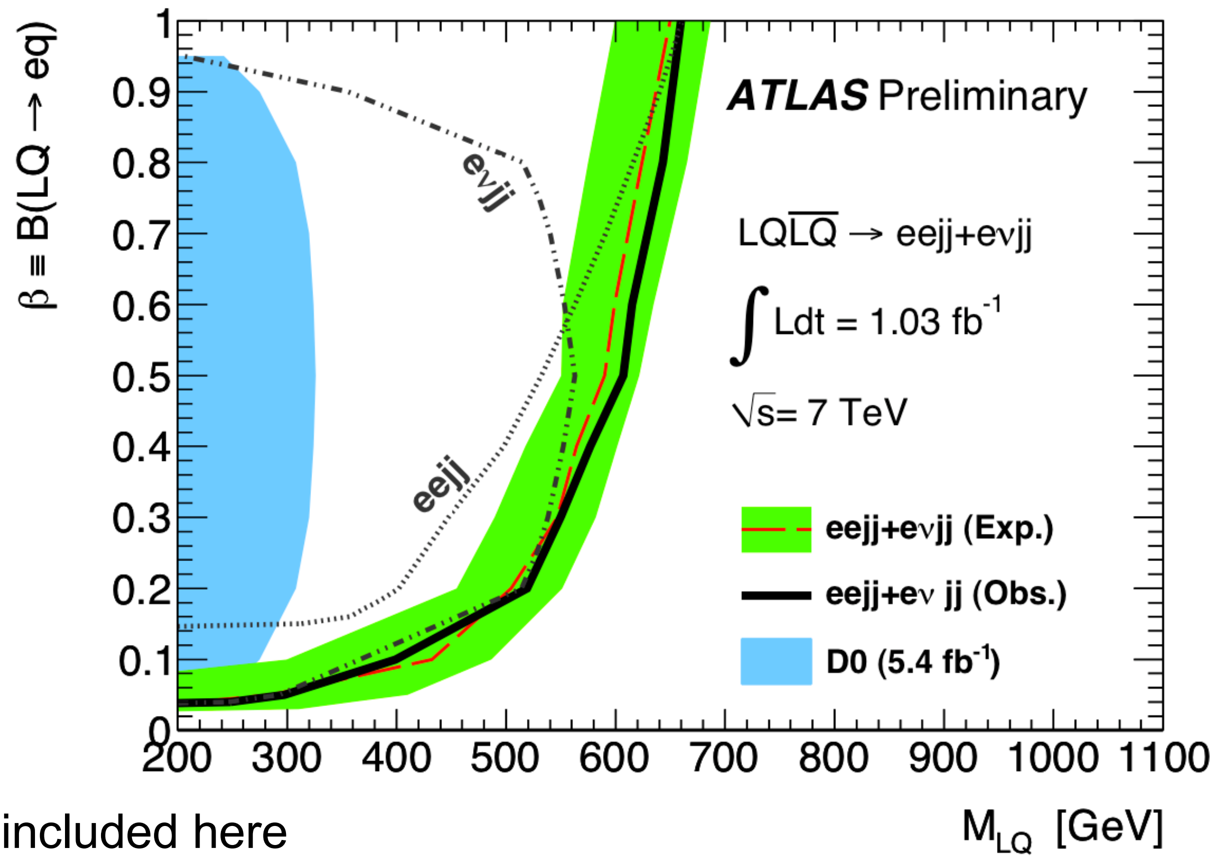
1st Generation Leptoquarks

- New limits clearly surpass TeVatron
- Now working on 2nd and 3rd generation...

β=1 : m > 660 GeV
β=0.5: m > 607 GeV

100% to eejj

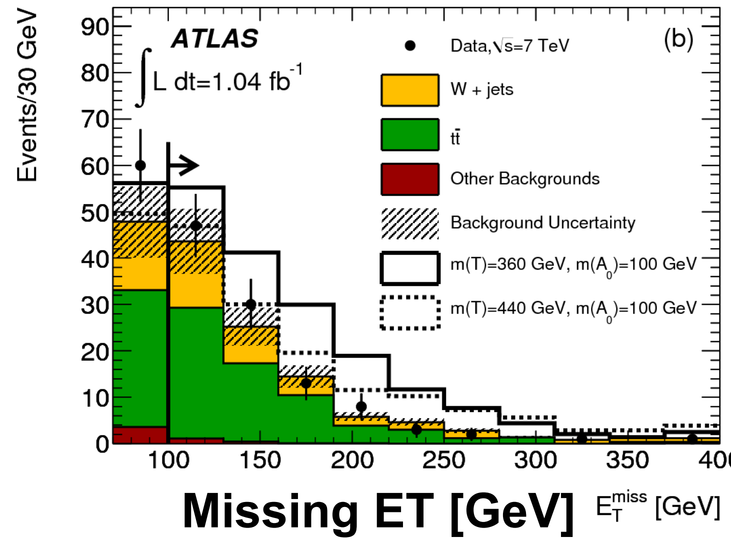
100% to vvjj

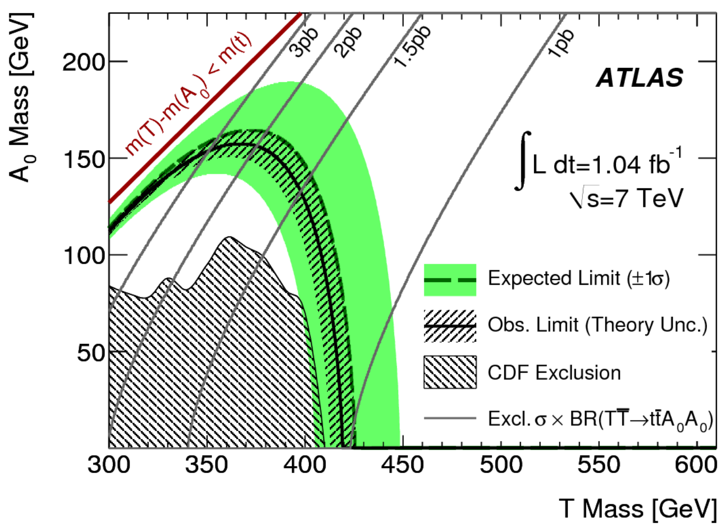


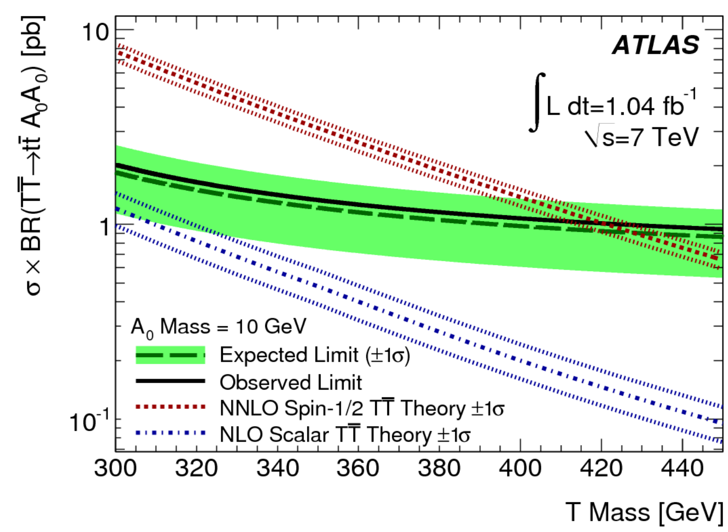
Channel not included here

Top-antitop + Missing Energy

- Look for topology: T T → tt A_0 A_0
- T can be:
  - → Spin ½: 4th generation top partner
  - → Scalar: stop, 3rd generation leptoquark





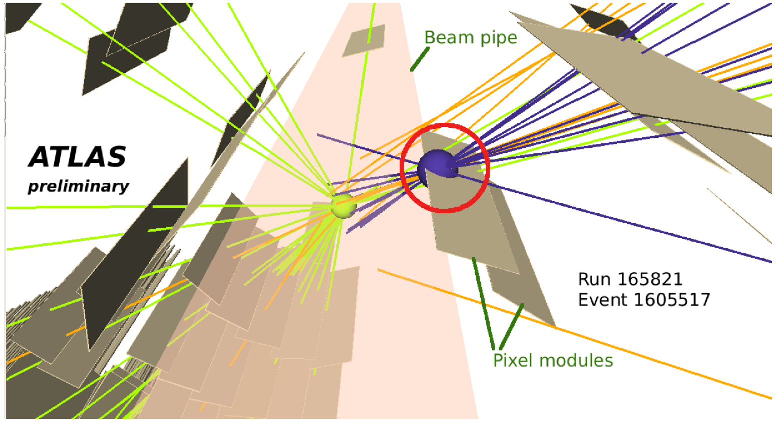


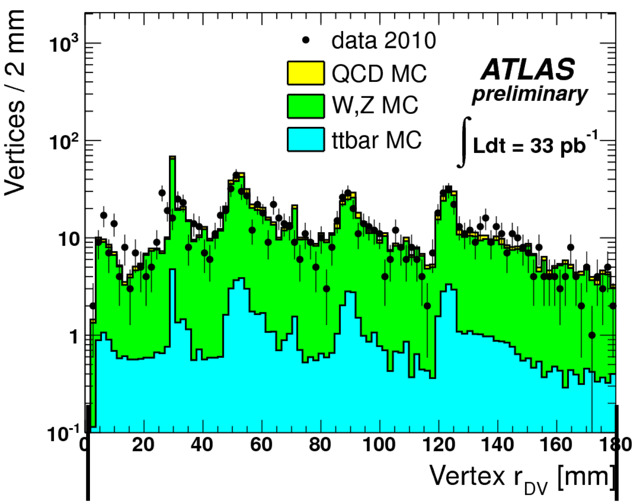
Submitted to PRL

arXiv:1109.4725

Long-Lived Particles: Decay in the Inner Detector

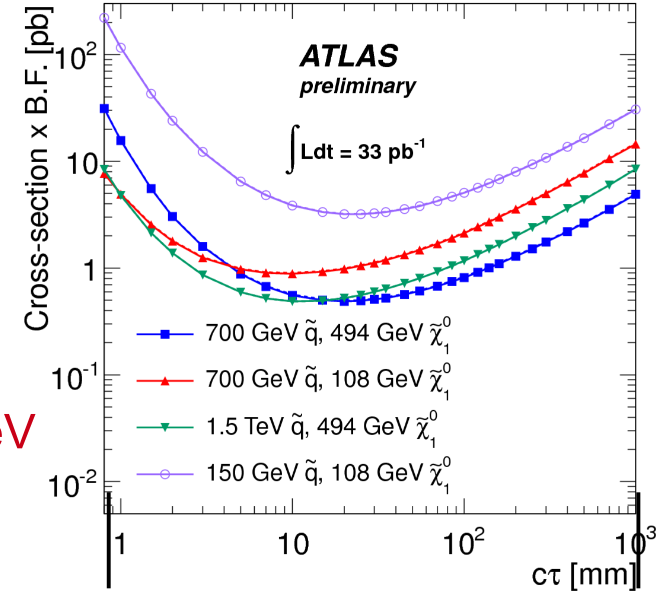
- R- hadrons (hadronized squarks or gluinos)
- Vertex outside the beampipe, in association with a high-pT muon
- Requires good understanding of tracking, detector passive material





0 cm Decay Radius 18 cm

Signal Region:
* Ntracks > 4
* Vertex Mass > 10 GeV



1 mm 1 m