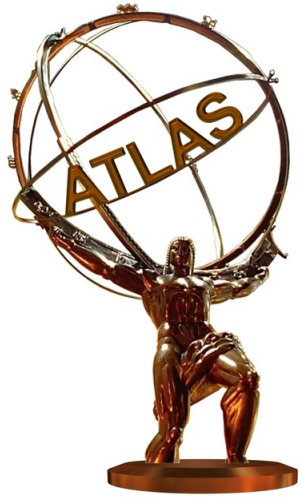
General Exotics review of ATLAS

Higgs Quo Vadis – Aspen 2013

Samuel Calvet
(LPC Clermont-Ferrand)
On behalf of Atlas Collaboration



Exotic Searches

- Higgs-like particle discovered
- But there are still open questions:
  - Hierarchy problem, dark matter, neutrino masses, ...
- The answers may come from exotic models, predicting new phenomena:
  - Excited lepton, graviton, 4^{th} generation, …
- Exotics on Atlas:
  - 60 papers published/submitted on 7TeV data,
  - New results going out with the 8TeV data
- Will review only 8TeV results except for Exotic Higgs for which 7TeV results will be presented as well

Dilepton resonances

NEW

ATLAS-CONF-2013-017

- Search for high mass dilepton resonance, using Z' or G* as benchmarks

- ee:
  - Diphoton trigger (for good background estimation)
  - 2 electrons with E_T>40GeV and 30GeV
  - Acc x eff =73% @ 2TeV
- μμ:
  - Single muon trigger
  - 2 muons with pT>25GeV, opposite charge
  - Acc x eff =46% @ 2TeV

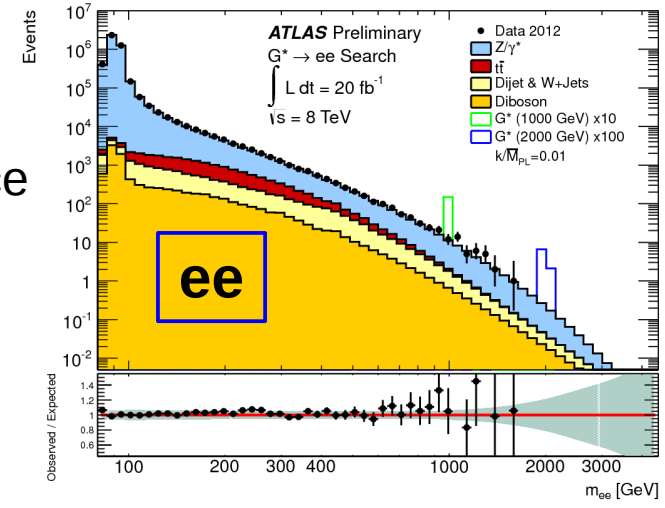
- Backgrounds from MC, apart for fake leptons
  - ee: multijet/W+jets from data
  - μμ: multijet/W+jets negligible
  - MC normalized to data in the Z peak region (80-110GeV)

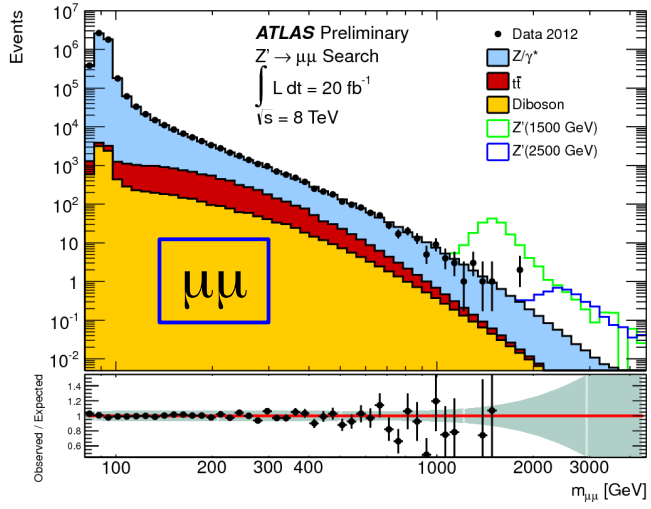
Dilepton resonances

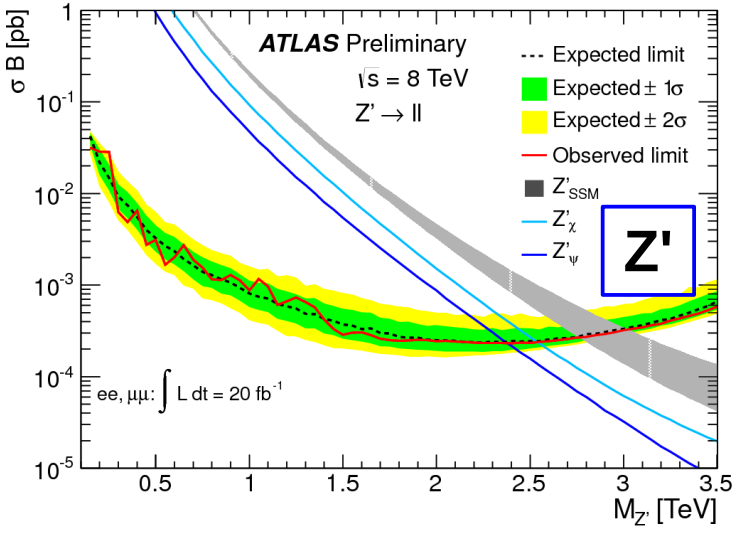
NEW

ATLAS-CONF-2013-017

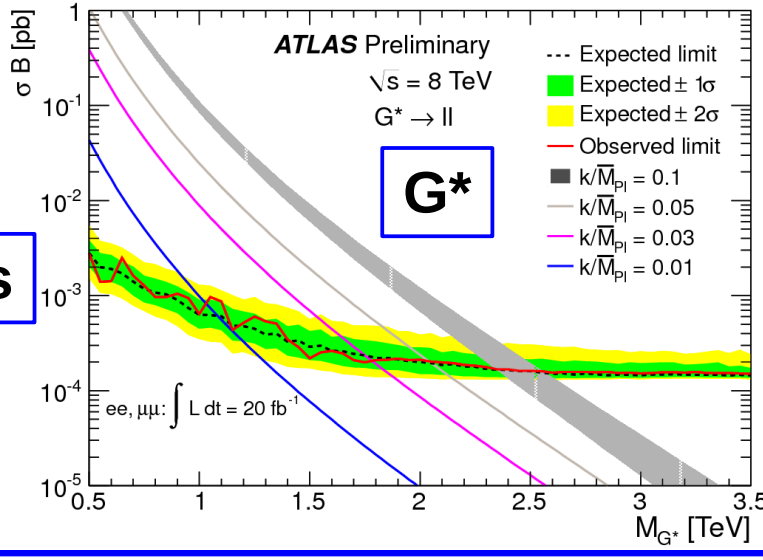
- Main systematic uncertainties:
  - Variation (15%) and choice (17%) of PDF
  - W+jets/multijet (9%)







Combined limits

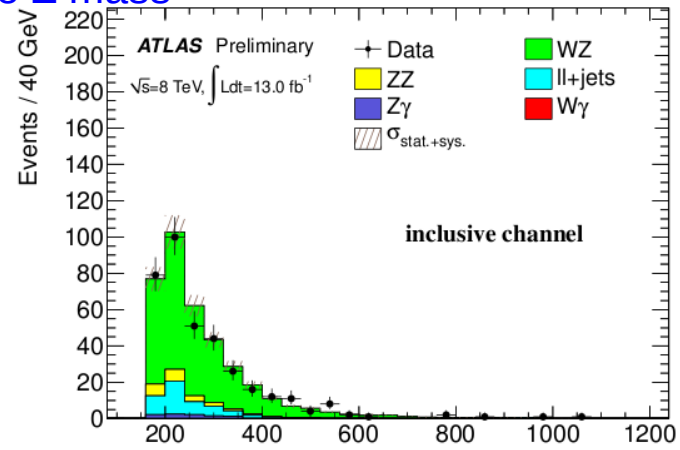


WZ resonances

NEW

ATLAS-CONF-2013-015

- Resonance decaying into WZ(lvl'l') search for with 2 benchmark models:
  - Extended gauge model (EGM), W': $g_{W'WZ}=g_{WWZ}x(m_W m_Z/m^2_{W'})$
  - Low Scale Technicolor (LSTC), $\rho_T \rightarrow WZ$
- Selection:
  - Single lepton trigger
  - Missing E_T (MET)>25GeV, exactly 3 leptons (e or μ), pT>25GeV
    - $e\nu ee$, $e\nu\mu\mu$, $\mu\nu ee$, $\mu\nu\mu\mu$
    - Same flavor leptons: opposite sign, within 20GeV of the Z mass
    - ν' s p_z recovered from W's mass constraint
  - $\Delta y(W,Z)<1.8$, $\Delta\phi(W,Z)>2.6$
- Backgrounds
  - WZ, ZZ, Zγ: from MC
  - Z+jets, ttbar, …: ll+fake lepton → fake rate from data
  - Backgrounds (apart WZ) from a fit for m(WZ)>300GeV
  - WZ from a fit for m(WZ)>500GeV

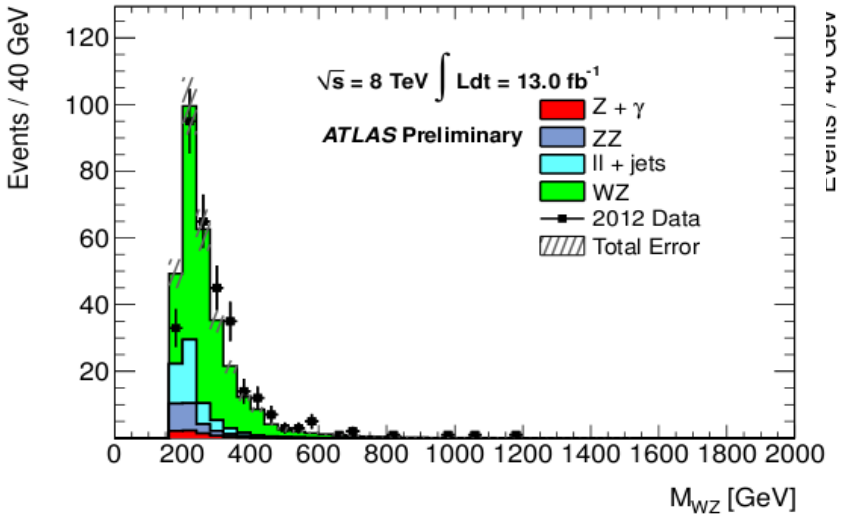


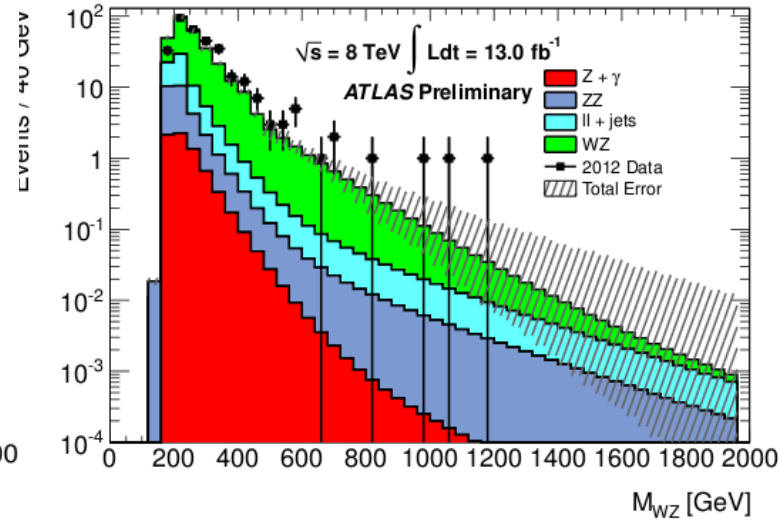
m(WZ), WZ control region

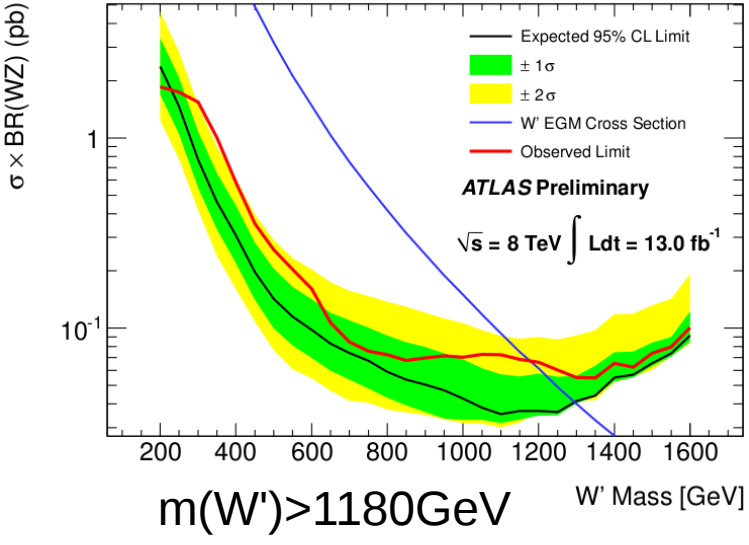
WZ resonances

NEW

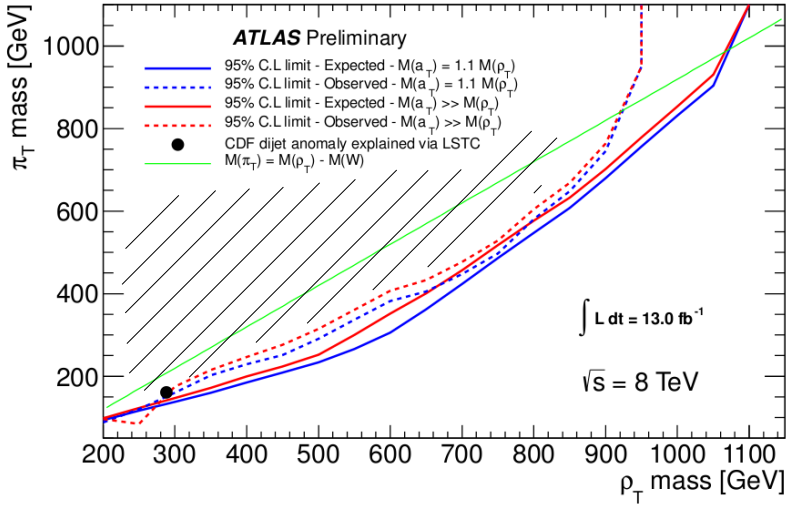
ATLAS-CONF-2013-015







m(W')>1180GeV

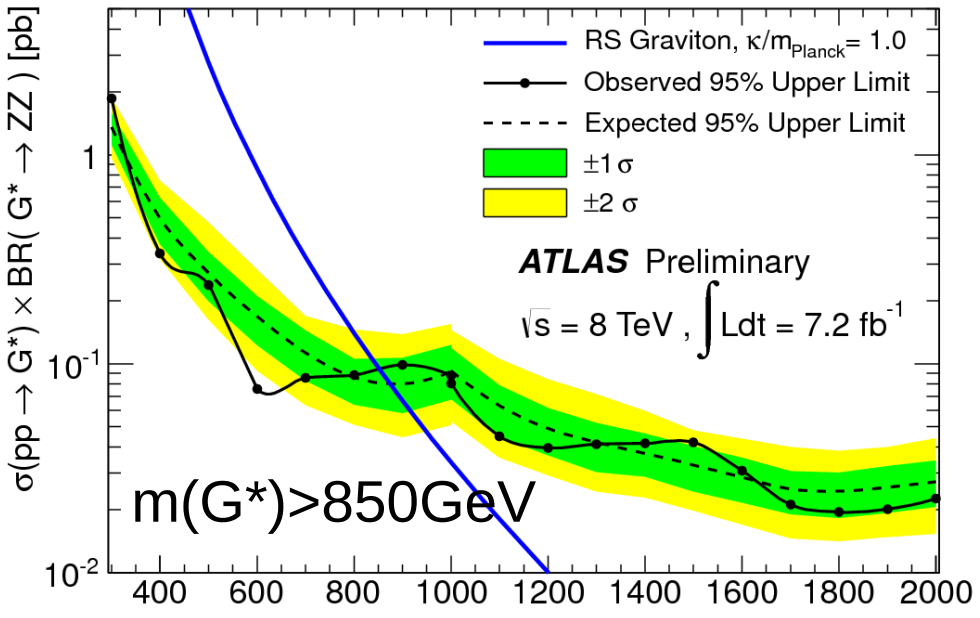


ZZ resonances

ATLAS-CONF-2012-150

- Use spin-2 Randall-Sundrum Graviton as benchmark model

- Select Z boson in ee/$\mu\mu$ events: $66<m_{ll}<116$GeV.
- Second Z depending on the topology: resolved or merged (2 quarks fall into the same jet)
  - Resolved selection (m<1TeV)
    - $pT_{ll}>50$GeV
    - $65<m_{jj}<115$GeV, $\Delta\varphi_{jj}<1.6$
  - Merged selection (m>1TeV)
    - $pT_{ll}>200$GeV
    - $pT_{j}>200$GeV, $m_{j}>40$GeV

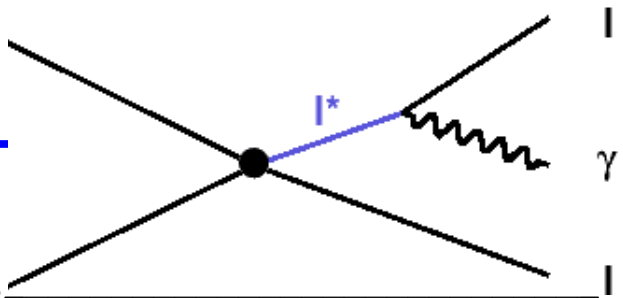


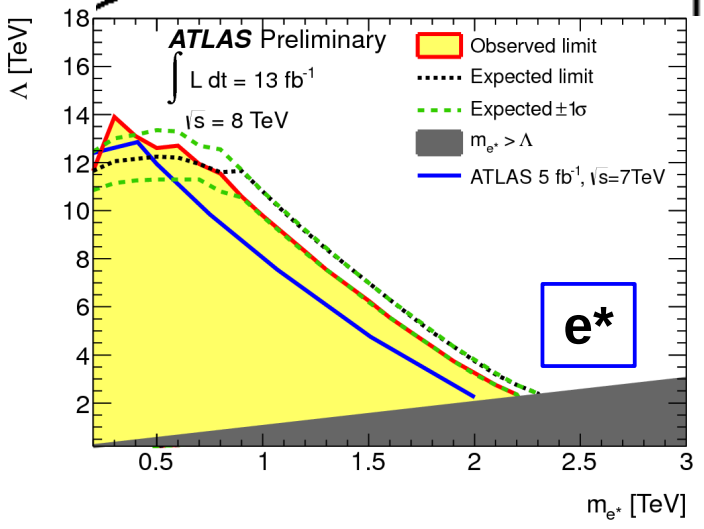
- Background estimated from a fit on the data :
  - If fit's χ^2 has probability<1%, exclude the region of disagreement → re-fit
  - Cross-checked with MC

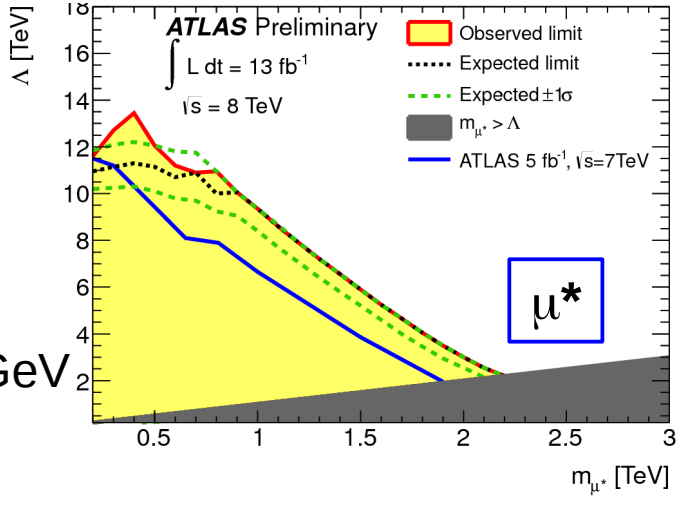
Excited leptons

ATLAS-CONF-2012-146

- Benchmark model: contact interaction
- Selection:
  - eeγ: 2 electrons with pT>40GeV and 35GeV
  - μμγ: 2 muons with 25GeV
  - pT_{γ}>30GeV, isolated from lepton
  - m_{ll}>100GeV
- Background from MC
  - Z+jets scaling from data
    $70<m_{ll}<110$ (correct fake-γ rate)
  - For $m_{ll\gamma}$>250GeV:
    - Low statistics for Z+X
    - Fits Z+jet and Z+γ in the range $110< m_{ll\gamma}<1050$GeV



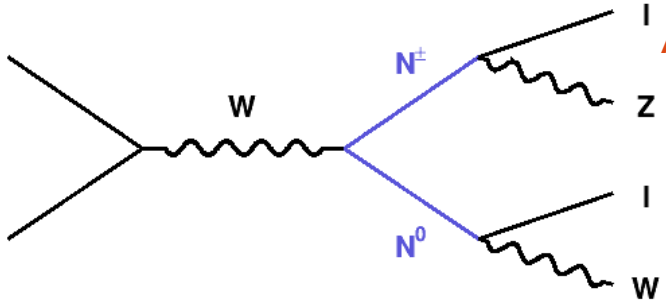




Type III Seesaw Model Heavy Fermions

NEW

- Type III seesaw (→neutrino masses) predicts heavy fermions N^0, $N^\pm$
  - $m(N^0) \sim m(N^\pm)$
  - Search for pair production

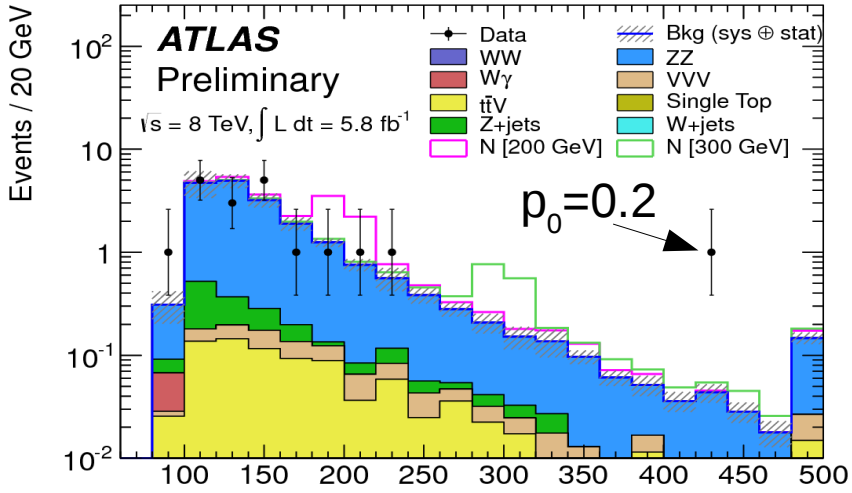


ATLAS-CONF-2013-019

- Selection:
  - Single lepton trigger
  - At least 4 leptons (e or μ), pT_1>25GeV, $pT_{2,3,4}$>10GeV
  - m(ll) within 10GeV of the Z mass.
  - Veto events with a second Z

- $N^\pm$ from the Z candidate + the closest lepton

- Backgrounds from MC
  - Z+jets (bb/cc): low statistics
    → reverse the isolation cut
    and normalize it in a control region



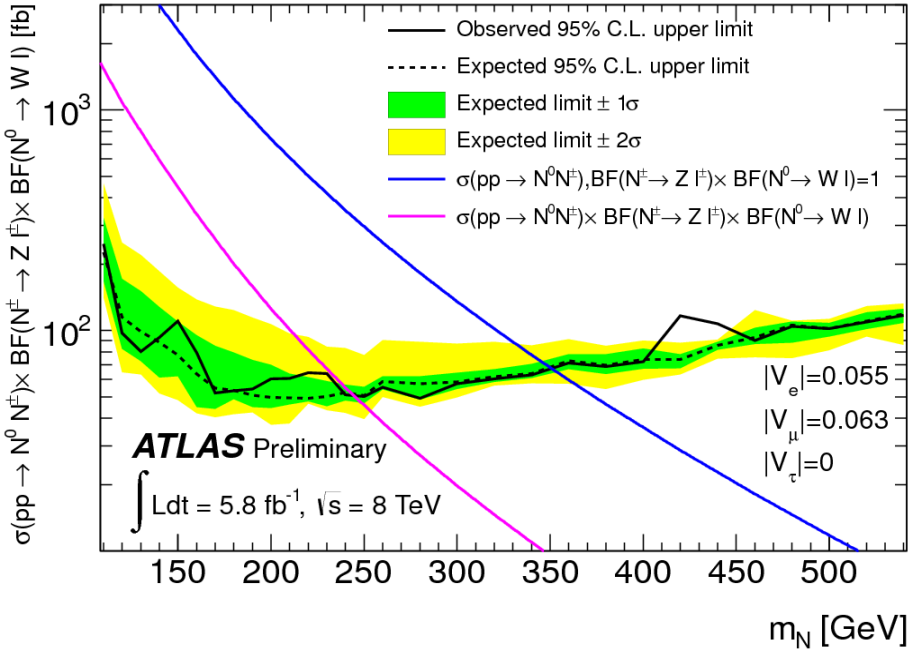
m($N^\pm$), signal region

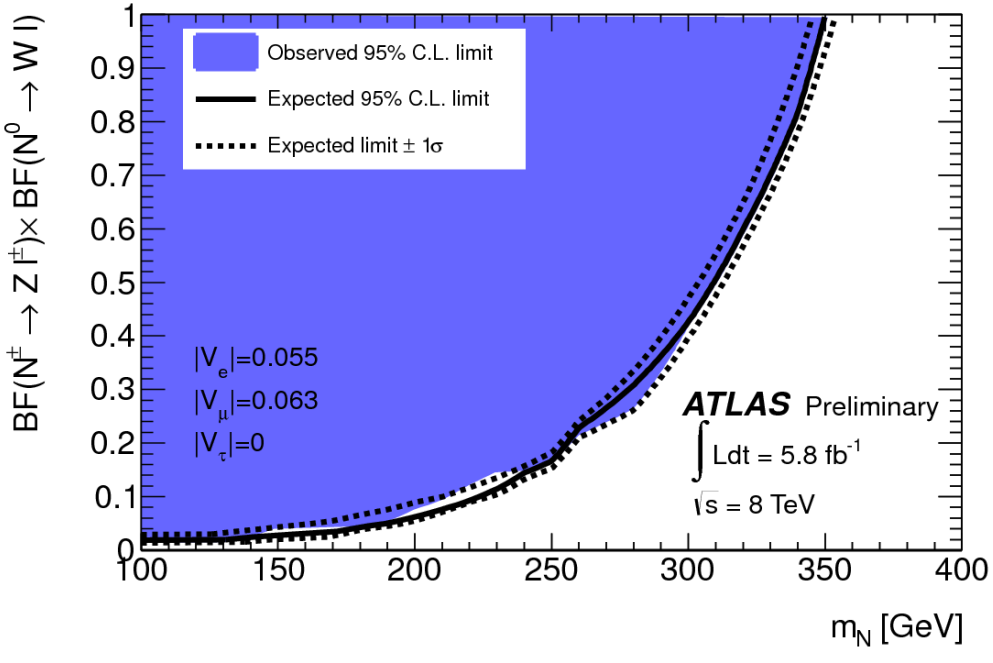
Type III Seesaw Model Heavy Fermions

NEW

- Main systematic uncertainties:
  - Electron identification (2.7%)
  - Fast simulation vs full G4 simulation: 6.8% on signal acceptance
  - Z+jets shape (100%) and normalization (370%)

ATLAS-CONF-2013-019





Top-like quarks

NEW

ATLAS-CONF-2013-018

- Top quark partner from addition of weak-isospin singlets/doublets/triplets
- 3 possible decay modes: t' → Wb, t' → Zt, t' → Ht
  - Focus on high jet and b-jet multiplicities: t't' → HtHt/ZtHt/WbHt (H → bb)
- Selection
  - Single lepton triggers, exactly one lepton (e or μ)
  - MET>20GeV, MET+ W transerve mass > 60GeV
  - At least 6 jets, then split into 3 channels
    - 2 b-tagged jets and H_T(=sum jet, lepton pT and MET)<700GeV
    - 3 b-tagged jets

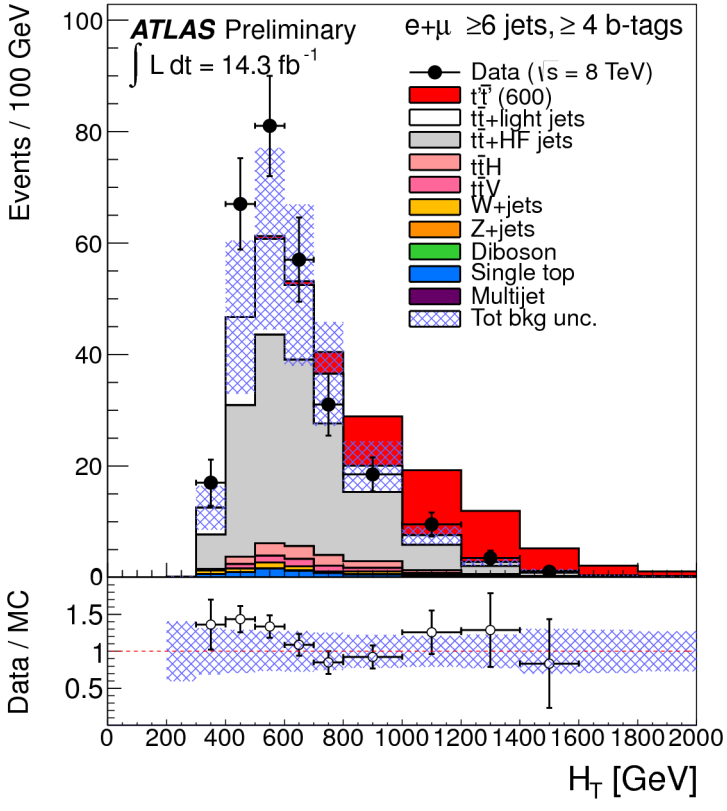
    } Constrain the systematic uncertainties
    - At least 4 b-tagged jets : drives the sensitivity
- Backgrounds:
  - tt+jets: MC, light and heavy flavor components of the jets fitted in a control region
  - Other backgrounds (small) MC apart for:
    - W+jets: MC, data-driven normalization
    - Multijet: data-driven

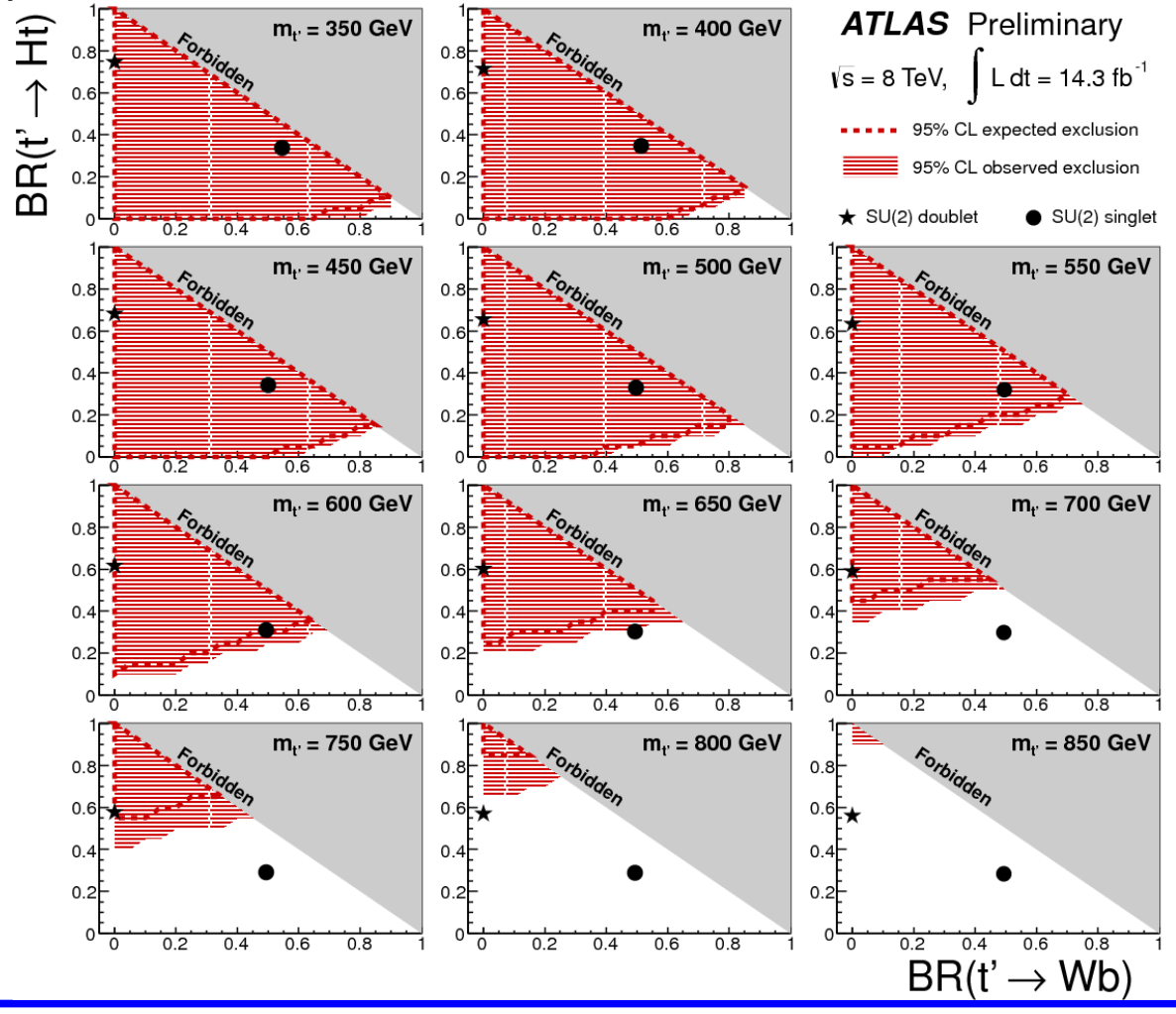
Top-like quarks

NEW

ATLAS-CONF-2013-018

- Dominant systematic uncertainties
  - Normalization of backgrounds (42%)
  - tt+heavy flavor fraction (32%)
  - b-/c-tagging (16%/11%)

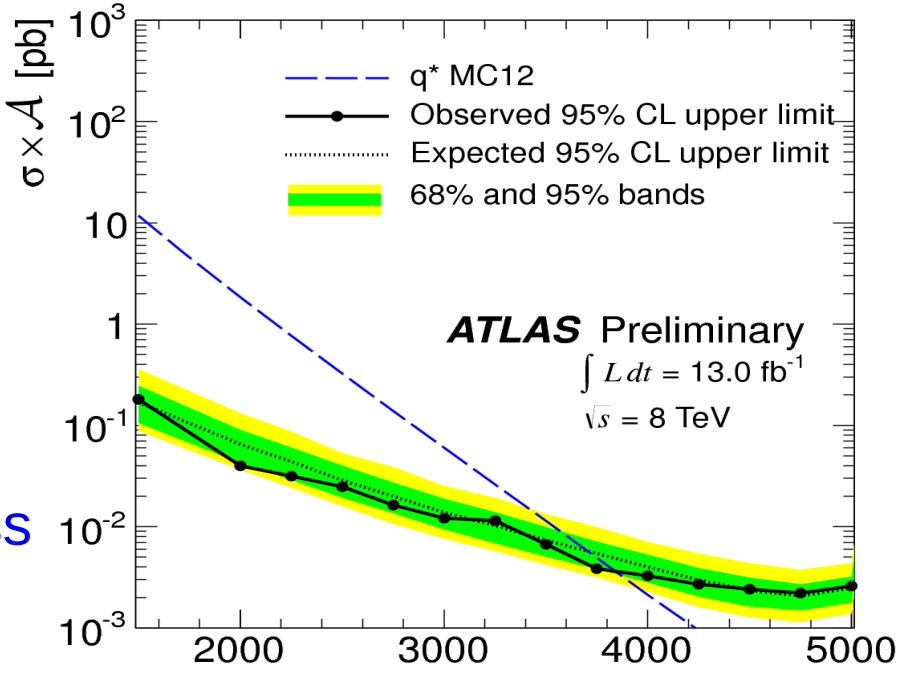




Di-jet resonance

ATLAS-CONF-2012-148

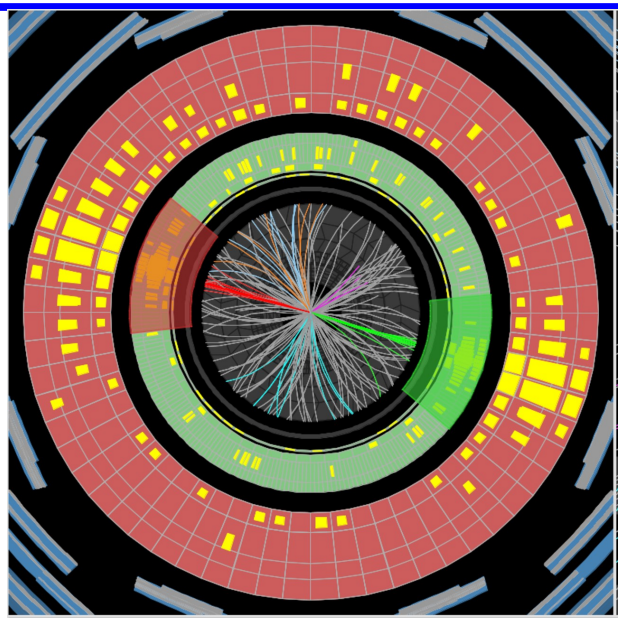
- Di-jet resonances predicted by many models (compositness, extra-dimensions,...)
- Selection
  - High pT jet trigger
  - 2 anti-kt jets with R=0.6, |y|<2.8, pT>150 GeV
  - $|y^*|=|y_1-y_2|/2 < 0.6$, $m_{jj}>1$ TeV
- Background fitted from data
- Search for excesses/deficits
  - Take care of Look-Elsewhere Effect
- Limits expressed as function of q* mass or simplified Gaussian model (backup)

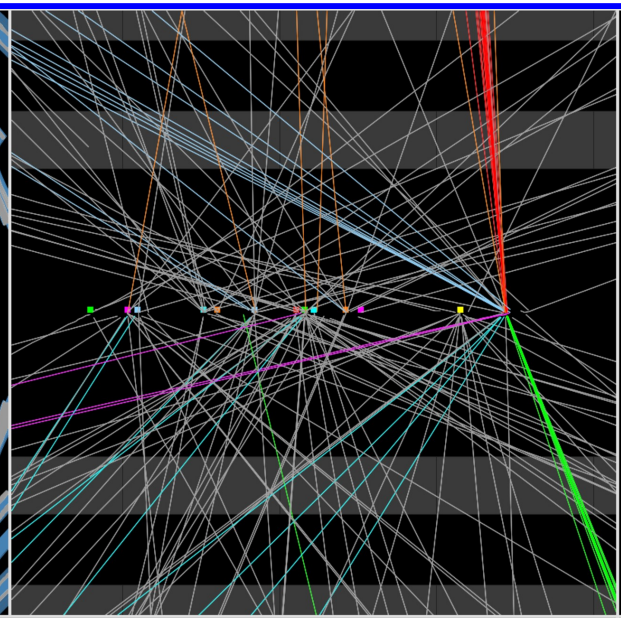


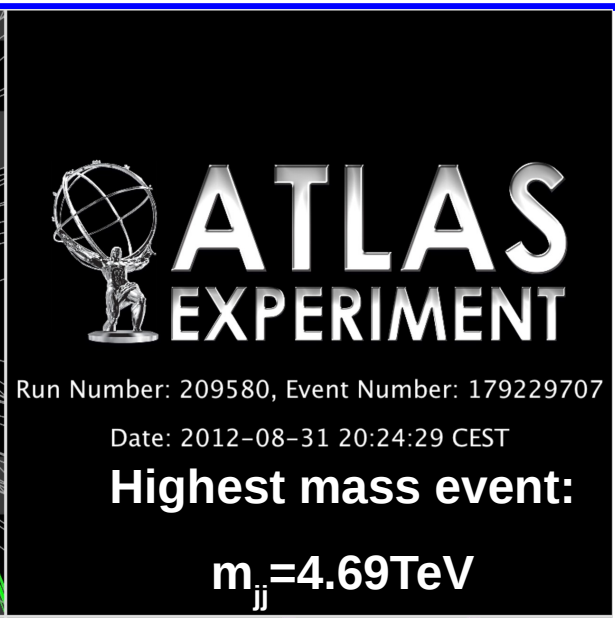
$m_{q^*}>3.84$TeV

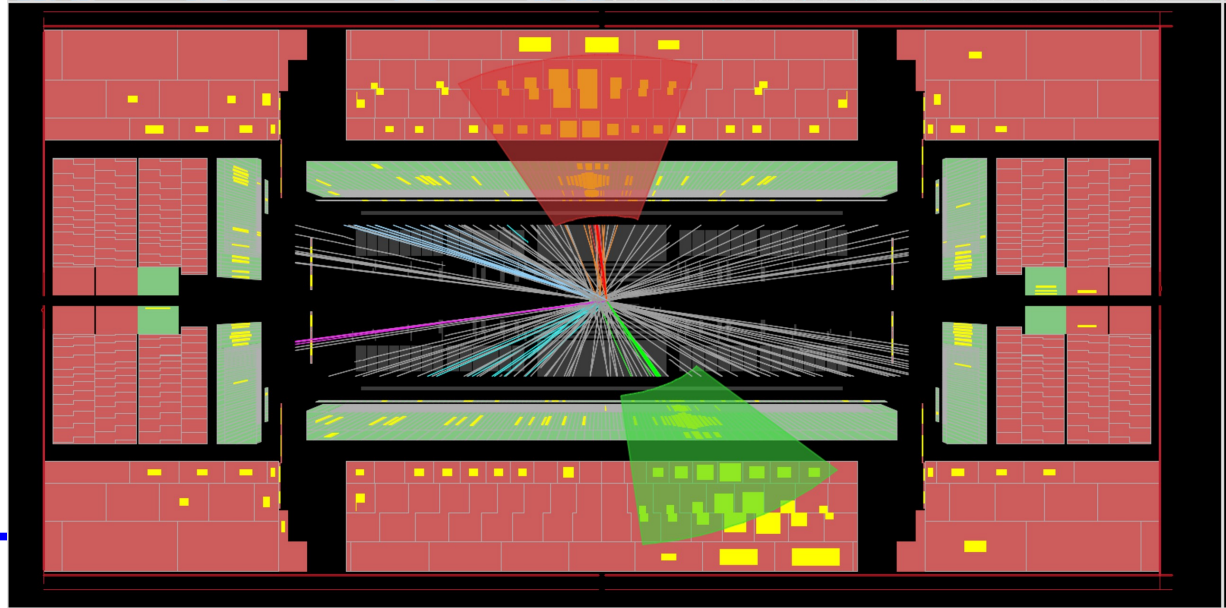
Di-jet mass

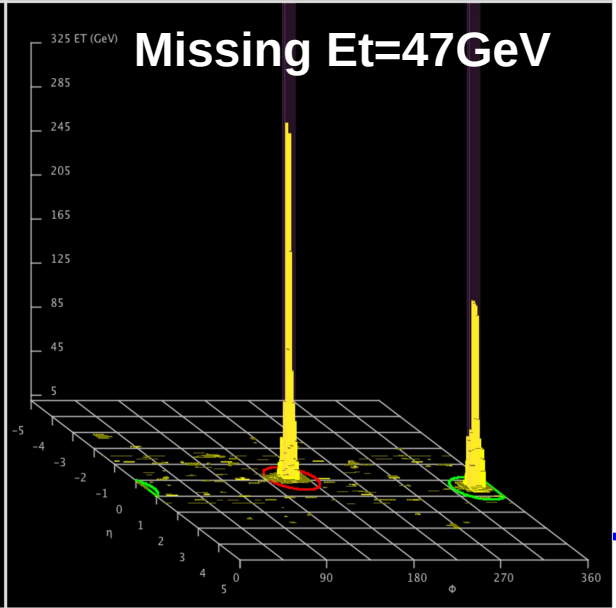
ATLAS-CONF-2012-148







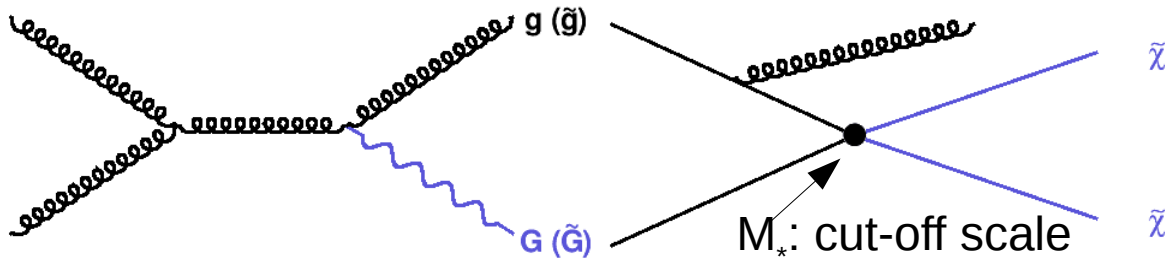




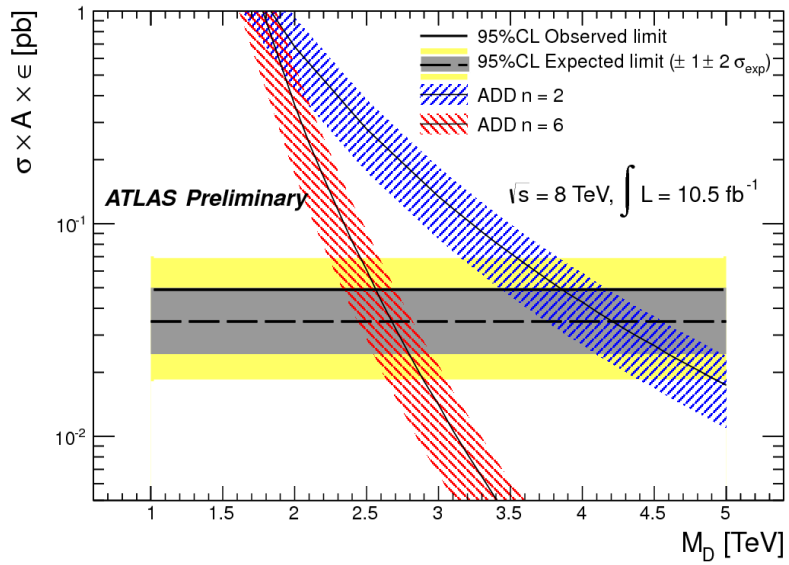
Monojet + missing E_T

ATLAS-CONF-2012-147

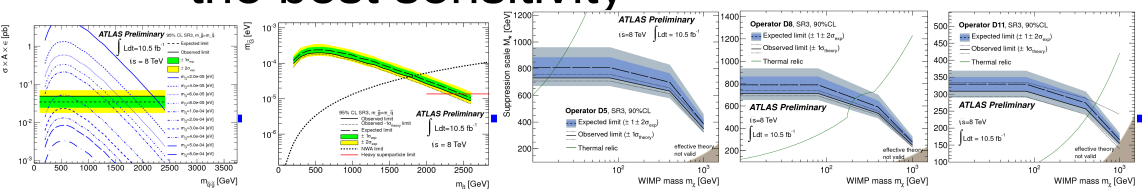
- Predicted by supersymmetry (gravitino), Large Extra Dimension (graviton), WIMPS …



- Selection:
  - missing E_T trigger,
  - MET>120GeV
  - At most 2 anti-Kt jets (R=0.4), pT>30GeV, $|\eta|<4.5$
  - Leading jet: pT>120GeV, $|\eta|<2$
  - $\Delta\varphi(2^{nd}$ jet, MET)>0.5
  - Lepton veto

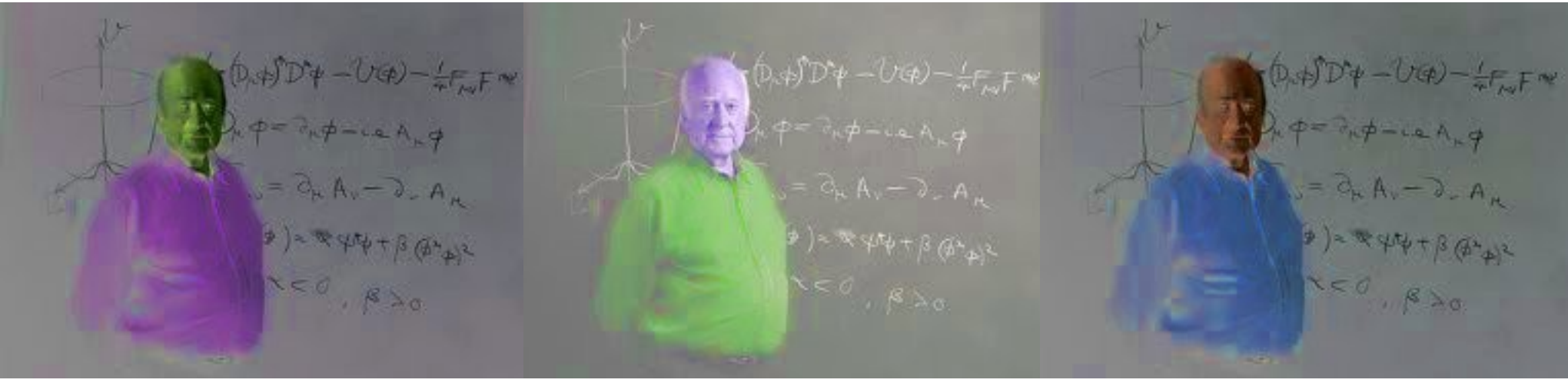


- 4 signal regions: MET and leading jet pT larger than 120, 220, 350, 500 GeV
  - 350 GeV working point gives the best sensitivity



(Much more limits in backup slides)

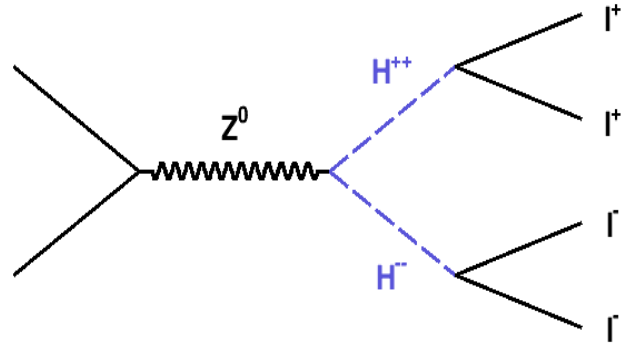
Exotics Higgs



Doubly-charged Higgs boson

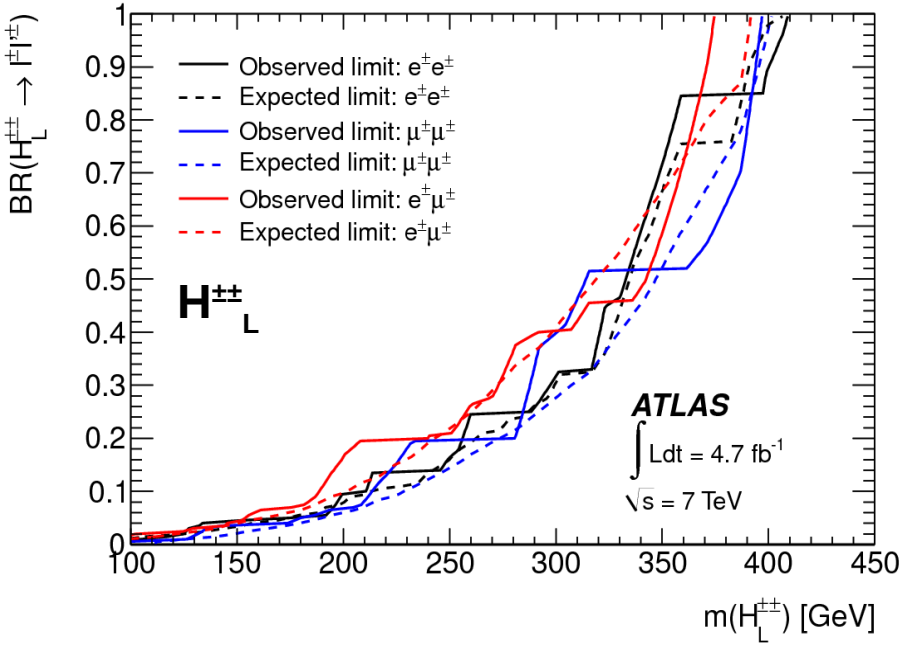
EPJC 72 (2012) 2244
EXOT-2012-18

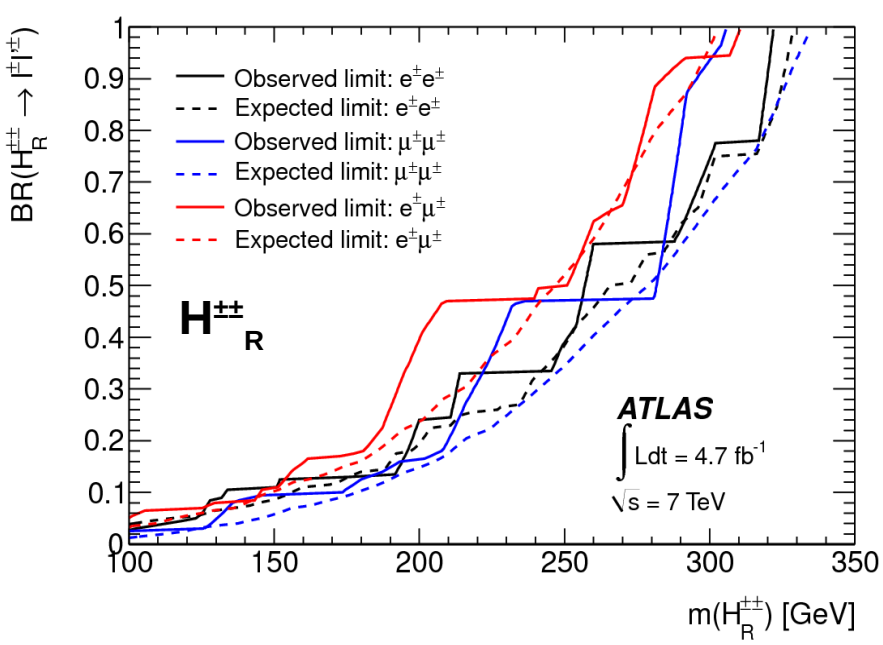
- Extensions (type II seesaw, ...) predict the Higgs sector is extended to a triplet (H^0, $H^{\pm}$, $H^{\pm\pm}$)
- $H^{\pm\pm}$: **narrow resonance**, pair-produced
  - $H^{\pm\pm}$ couples to left- or right-handed fermions
- Search for signals inside windows of ±4% [**ee**] or ±(6+0.007.m_H)% [**eμ**, **μμ**] of the tested m_H



Limits on BR($H^{\pm\pm}\rightarrow$**ee**), BR($H^{\pm\pm}\rightarrow$**eμ**), BR($H^{\pm\pm}\rightarrow$**μμ**) vs m($H^{\pm\pm}$)

See talk by E. Strauss

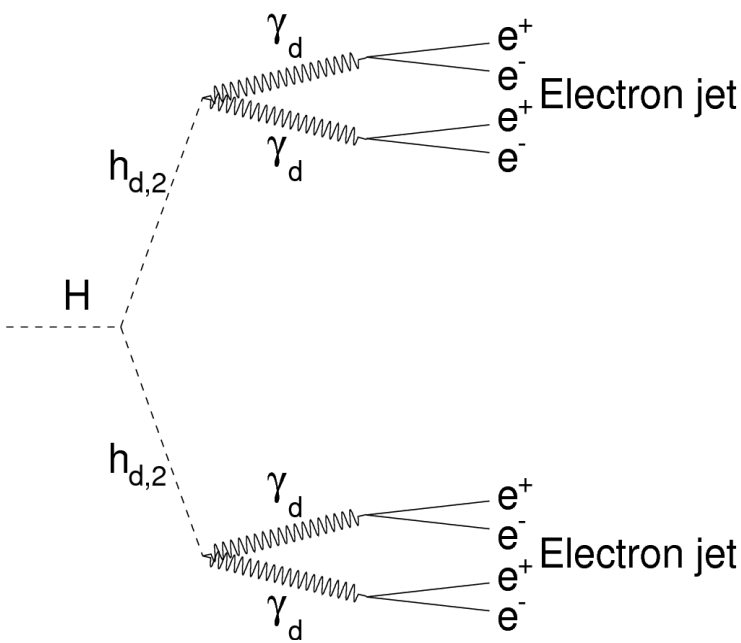


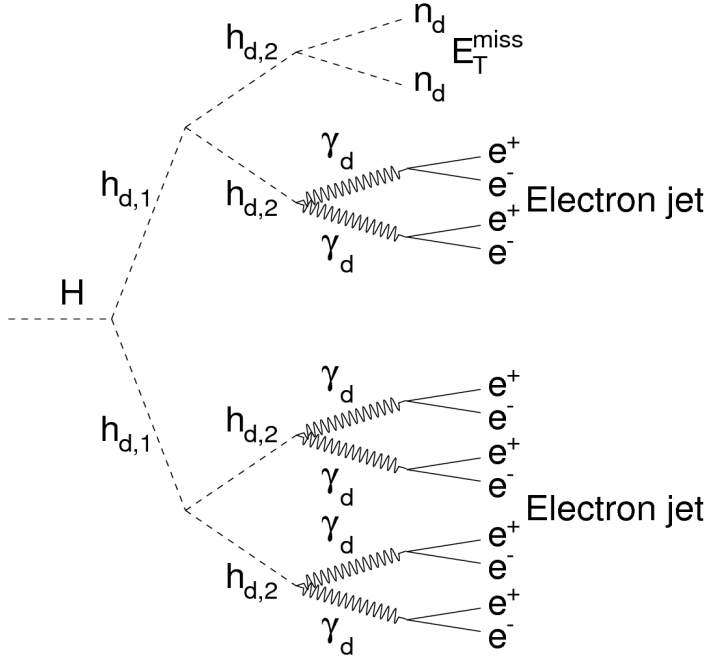


Higgs → hidden sector / electron jet

Accepted by NJP
EXOT-2011-01

- The Higgs boson could decay into hidden-sector particles (string theory, unparticle model)
- 2 models considered → 2- or 3-step decay chains
  - New particles assumed very light → decays are boosted → jet of electrons
    - $m(h_{d,1})$=10GeV, $m(h_{d,2})$=4GeV, $m(n_d)$=90MeV, $m(\gamma_d)$=100 or 200MeV
    - Results unchanged while $m(h_{d,1/2})$<10GeV and $BR(h_{d,2} \rightarrow n_d n_d)$<0.2

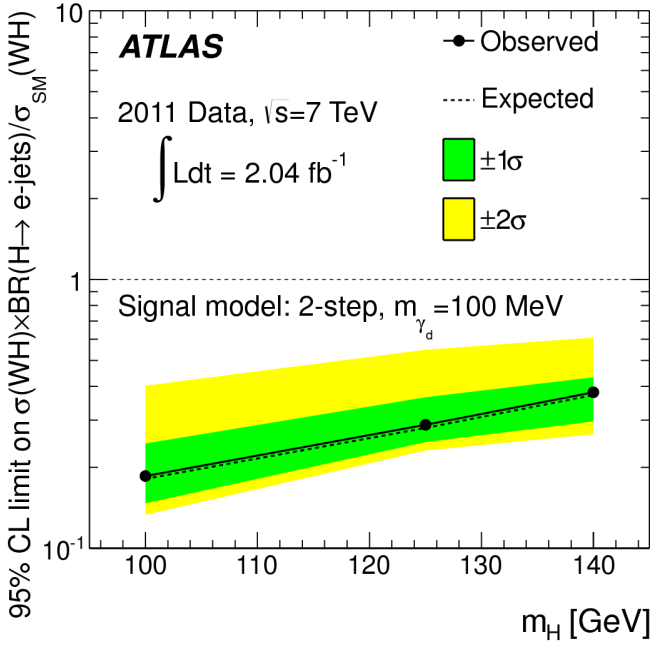


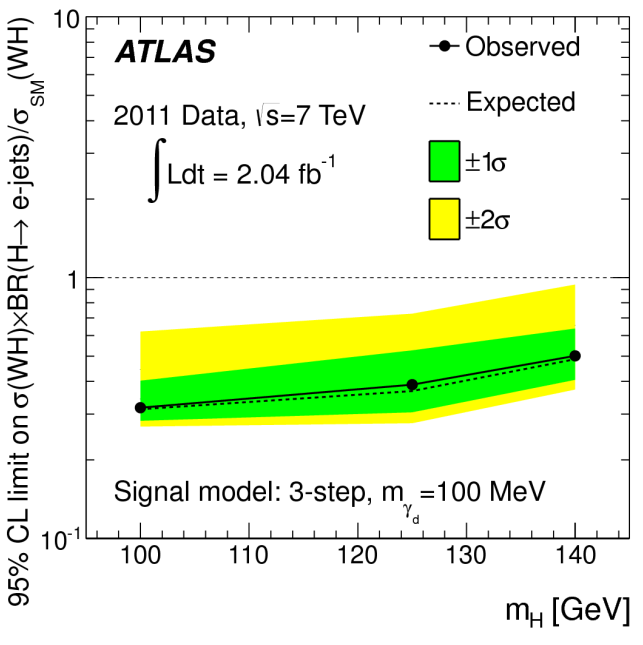


Higgs → hidden sector / electron jet

Accepted by NJP
EXOT-2011-01

- Search using the **HW(→e/μ ν)** production
- Single lepton trigger, one isolated lepton, MET>25GeV,
  at least 2 electron-jets (high electromagnetic and charged fractions, ...)
- Backgrounds :
  - Fake electron-jets, from final state photon radiation and π^0 decays
  - Fully data-driven
- Main systematic:
  80% on the background estimation
- Similar results for $m(\gamma_d)$=100 or 200MeV

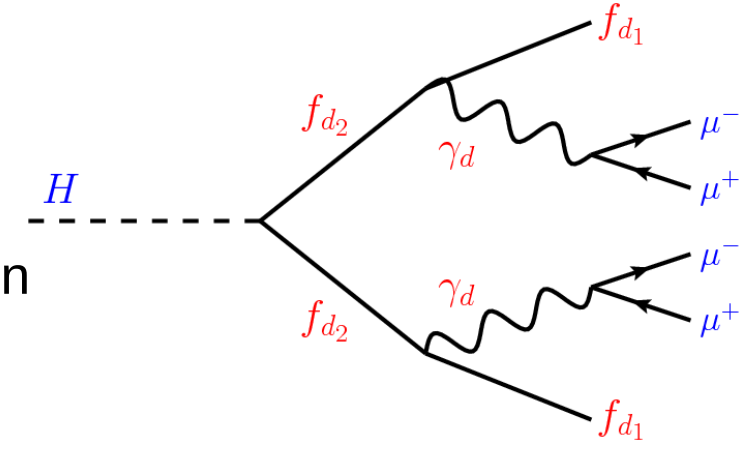




Higgs → hidden sector / muon jet

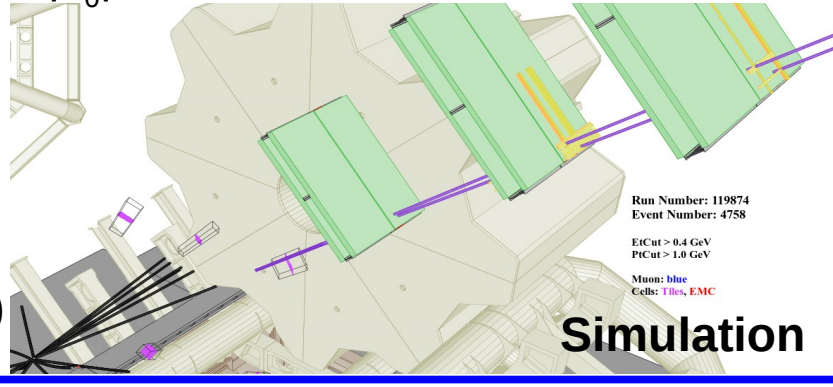
Accepted by PLB
EXOT-2011-12

- Assume
  - heavier γ_d: 400MeV, with $c\tau$~O(40mm)
  - m(f_{d2})=5GeV, m(f_{d1})=2GeV
    → muon jets, with high impact parameters (IP)
- Single production of H^0, f_{d1} escape to the detection
  - $\gamma_d \to \mu\mu$: 45%



- Selection:
  - Trigger with the muon spectrometer, large IP prevent the use of inner tracker
  - 2 isolated muon jets, back-to-back (Δφ>2), neutral
  - Not too far from the primary vertex $|d_0|$<200mm, $|z_0|$<270mm

- Backgrounds
  - Prompt muon: negligible
  - Multijet: data-driven
  - Cosmic-ray: from data (empty bunch crossing)

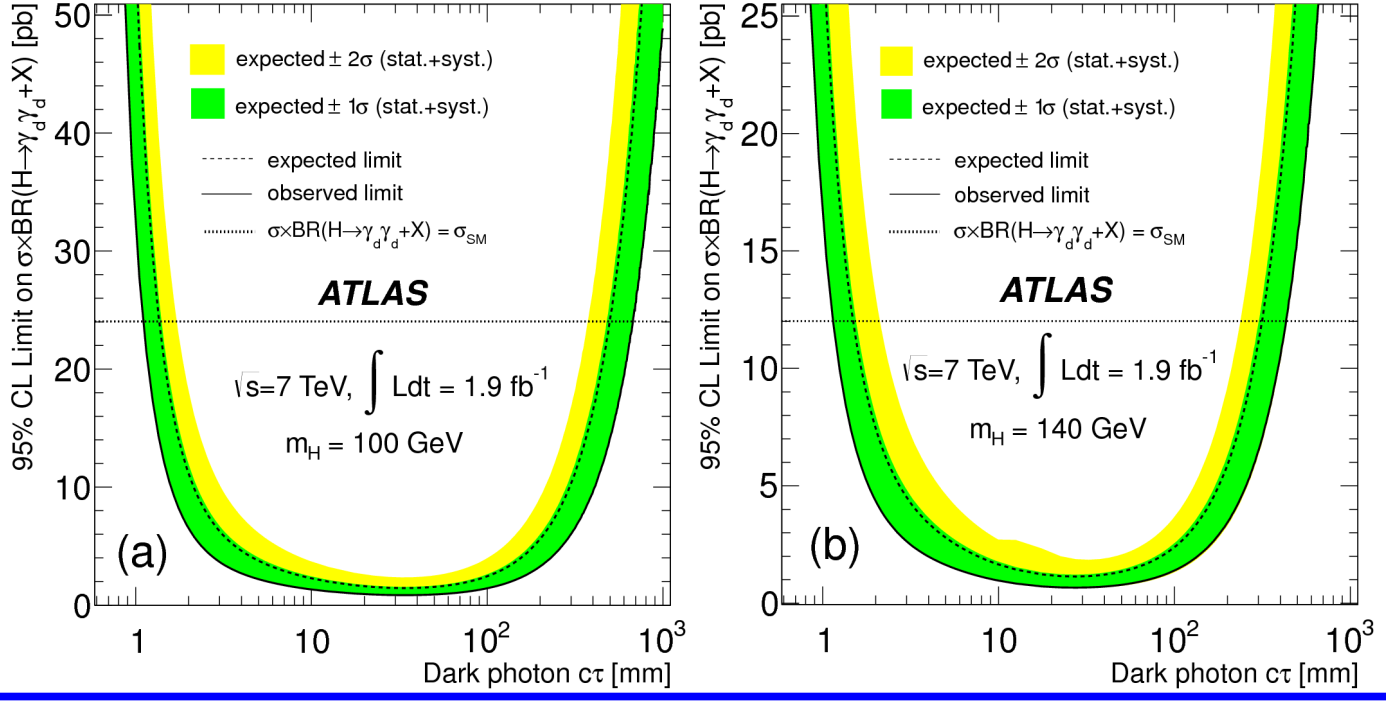


Higgs → hidden sector / muon jet

Accepted by PLB
EXOT-2011-12

- Main systematic uncertainties: trigger (17%), reconstruction of γ_d (13%)
- Almost no background at the end:

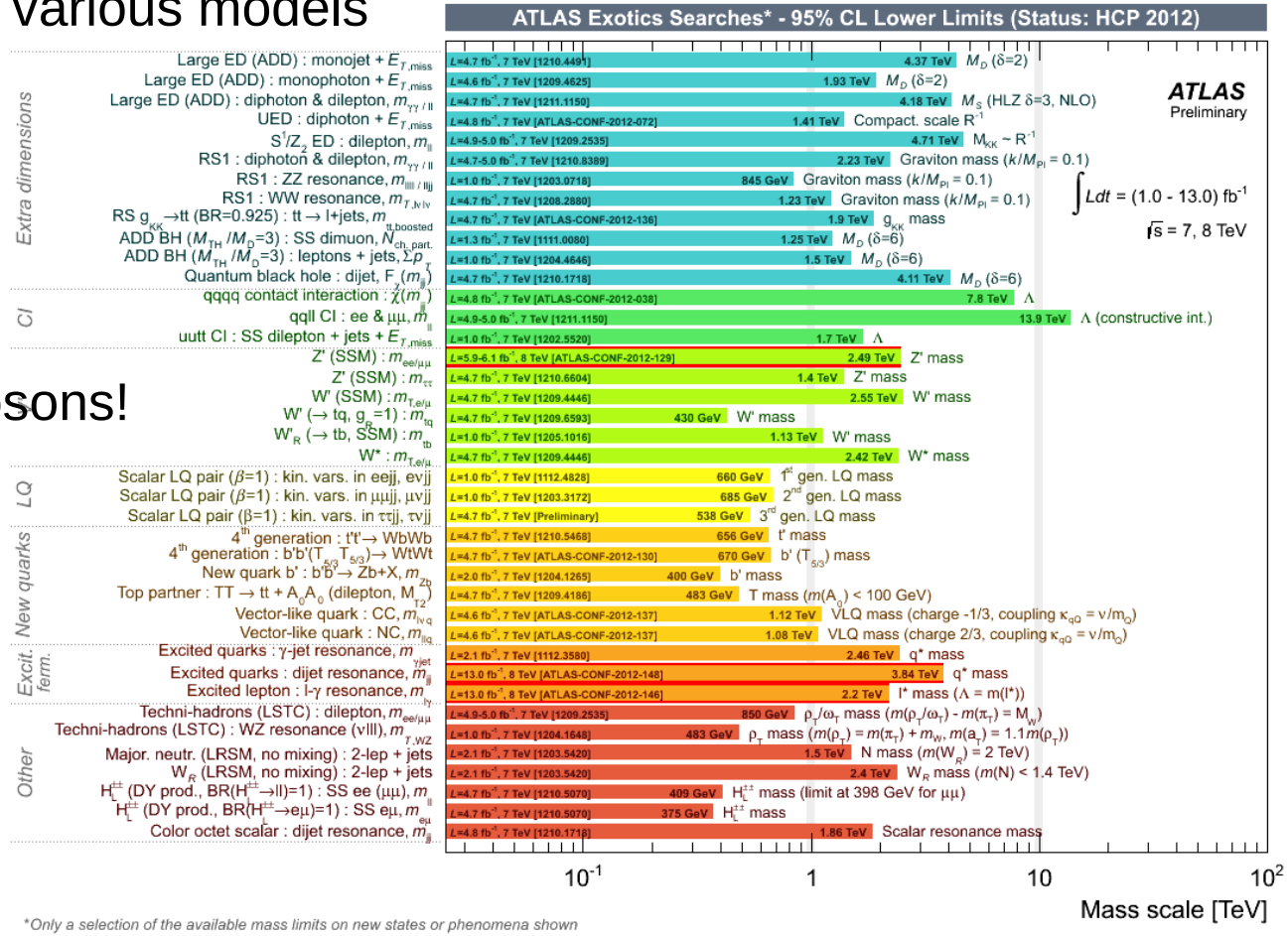
cut	cosmic-rays	multi-jet	total background	m_H = 100 GeV	m_H = 140 GeV	data
$N_{MJ} = 2$	3.0 ± 2.1	N/A	N/A	$135 \pm 11^{+29}_{-21}$	$90 \pm 9^{+17}_{-13}$	871
$E_T^{isol} \leq 5$ GeV	3.0 ± 2.1	N/A	N/A	$132 \pm 11^{+28}_{-21}$	$88 \pm 9^{+17}_{-13}$	219
$\lvert\Delta\phi\rvert \geq 2$	1.5 ± 1.5	$153 \pm 18 \pm 9$	$155 \pm 18 \pm 9$	$123 \pm 11^{+26}_{-19}$	$81 \pm 9^{+15}_{-12}$	104
$Q_{MJ} = 0$	1.5 ± 1.5	$57 \pm 15 \pm 22$	$59 \pm 15 \pm 22$	$121 \pm 11^{+26}_{-19}$	$79 \pm 8^{+15}_{-12}$	80
$\lvert d_0\rvert, \lvert z_0\rvert$	$0^{+1.64}_{-0}$	$111 \pm 39 \pm 63$	$111 \pm 39 \pm 63$	$105 \pm 10^{+22}_{-16}$	$66 \pm 8^{+12}_{-10}$	70
$\Sigma p_T^{ID} < 3$ GeV	$0^{+1.64}_{-0}$	$0.06 \pm 0.02^{+0.66}_{-0.06}$	$0.06^{+1.64+0.66}_{-0.02-0.06}$	$75 \pm 9^{+16}_{-12}$	$48 \pm 7^{+9}_{-7}$	0



Conclusion

- Searches with 8TeV dataset are closing in on many models
- Tighter and tighter limits on various models
  - Extra dimension
  - Compositeness
  - ...

But also on exotic Higgs bosons!



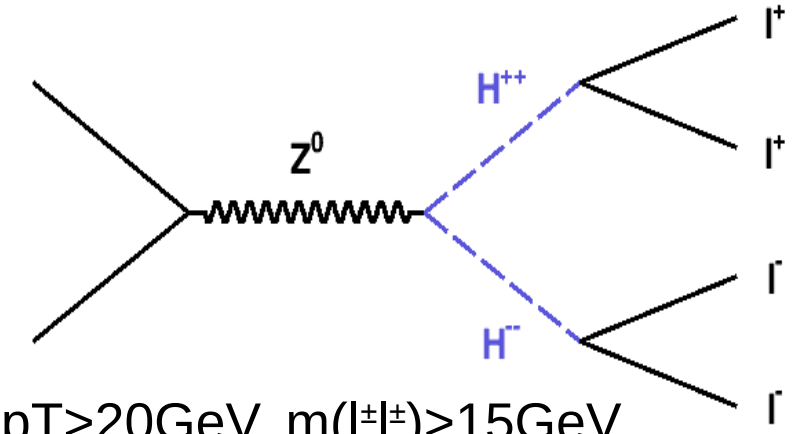
*Only a selection of the available mass limits on new states or phenomena shown

Backup

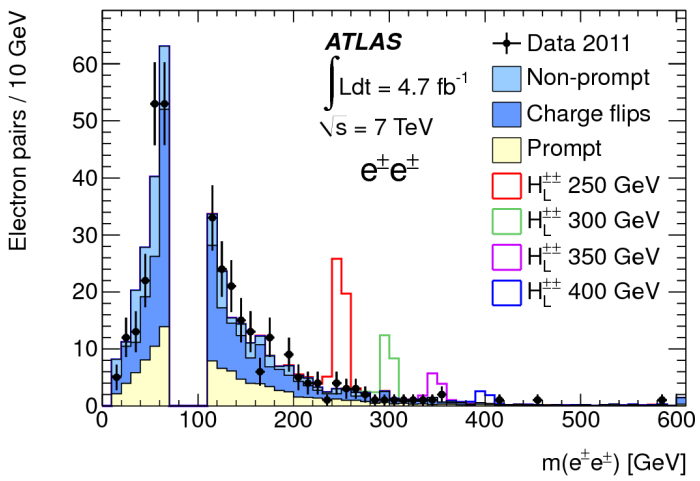
Doubly-charged Higgs boson

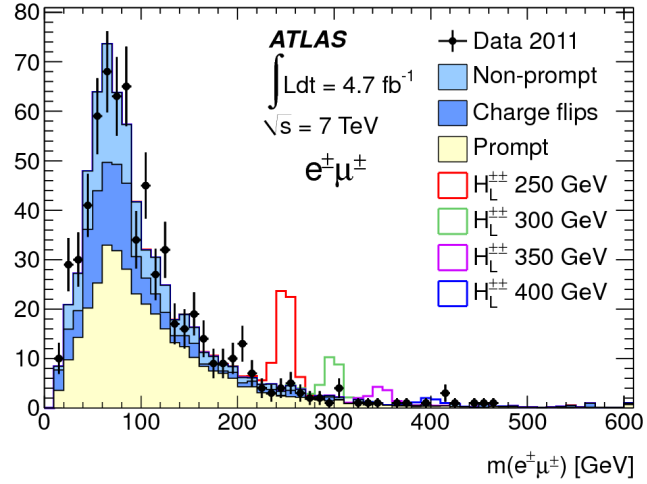
EPJC 72 (2012) 2244
EXOT-2012-18

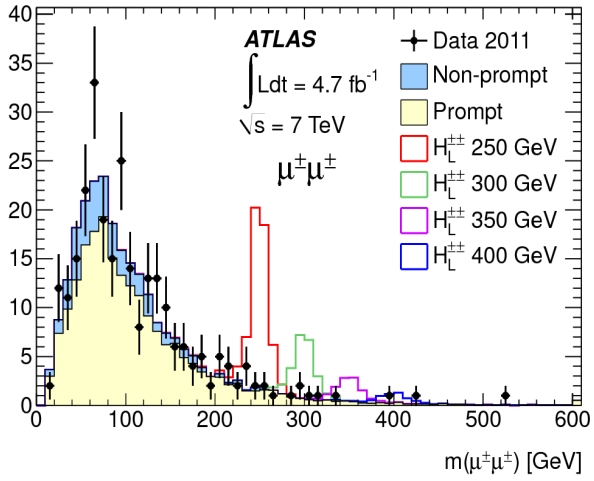
- Extensions (type II seesaw, ...) predict the Higgs sector is extended to a triplet (H^0, $H^{\pm}$, $H^{\pm\pm}$)
- $H^{\pm\pm}$: **narrow resonance**, pair-produced
  - $H^{\pm\pm}$ couples to left- or right-handed fermions
- Assume $H^{\pm\pm}$ decay only into **ee**, **eμ** or **μμ**



- Single lepton trigger, at least two leptons with pT>20GeV, m($l^{\pm}l^{\pm}$)>15GeV
- Search for signals inside windows of ±4% [**ee**] or ±(6+0.007.m_H)% [**eμ**, **μμ**] of the tested m_H







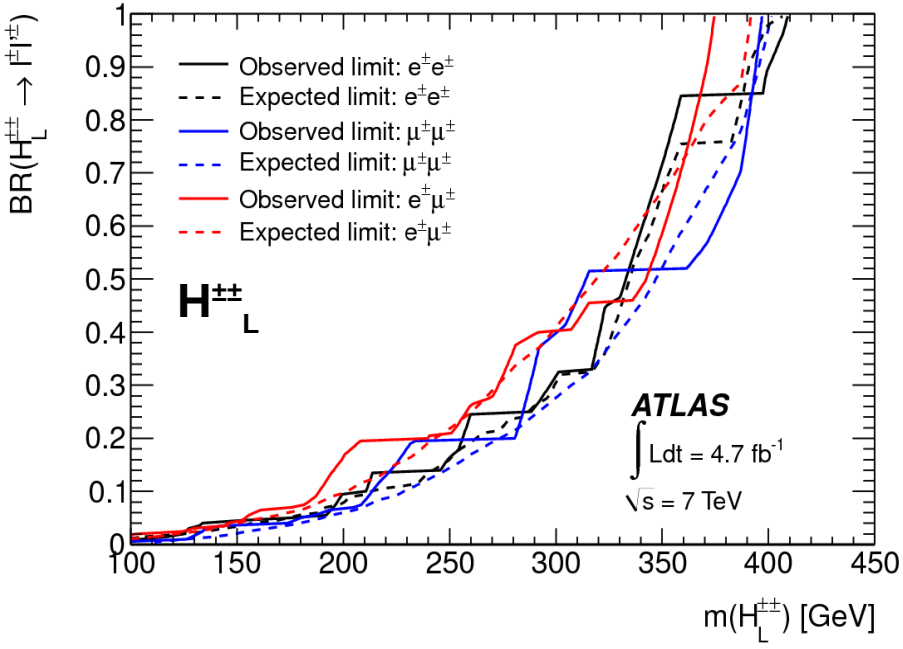
Doubly-charged Higgs boson

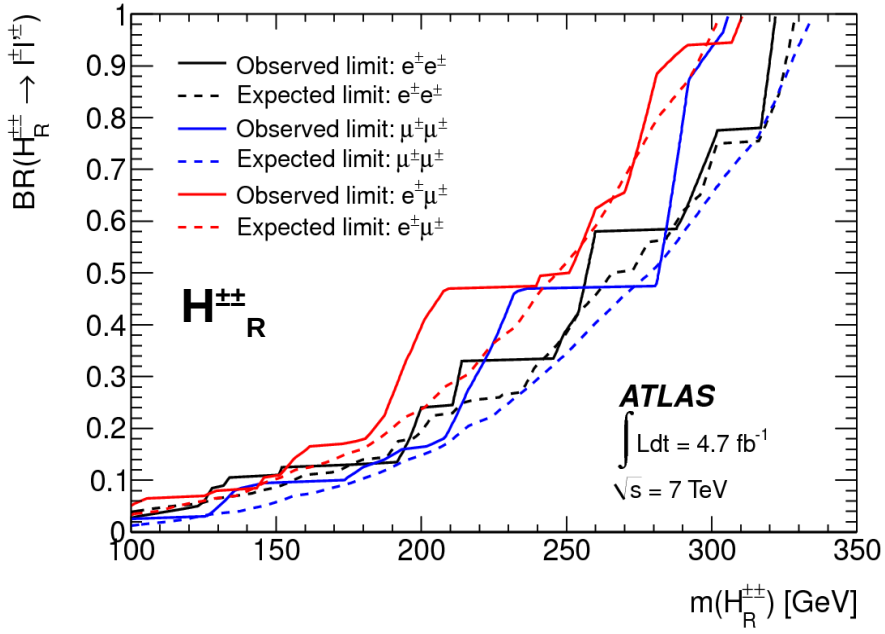
EPJC 72 (2012) 2244

EXOT-2012-18

- Limits depend on if the $H^{\pm\pm}$ couples to left- or right-handed fermions

Limits on BR($H^{\pm\pm} \to$ **ee**), BR($H^{\pm\pm} \to$ **eμ**), BR($H^{\pm\pm} \to$ **μμ**) vs m($H^{\pm\pm}$)





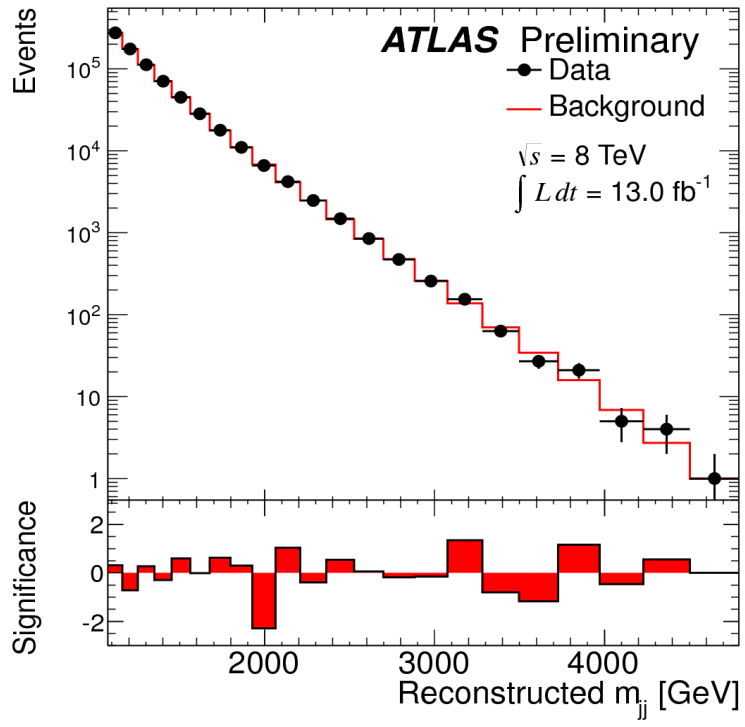
Dominant uncertainties:

- ±12% for WZ/ZZ cross-sections
- ±40% for non-prompt and charge flips
- Limited by the statistics at high mass

Di-jet mass

ATLAS-CONF-2012-148

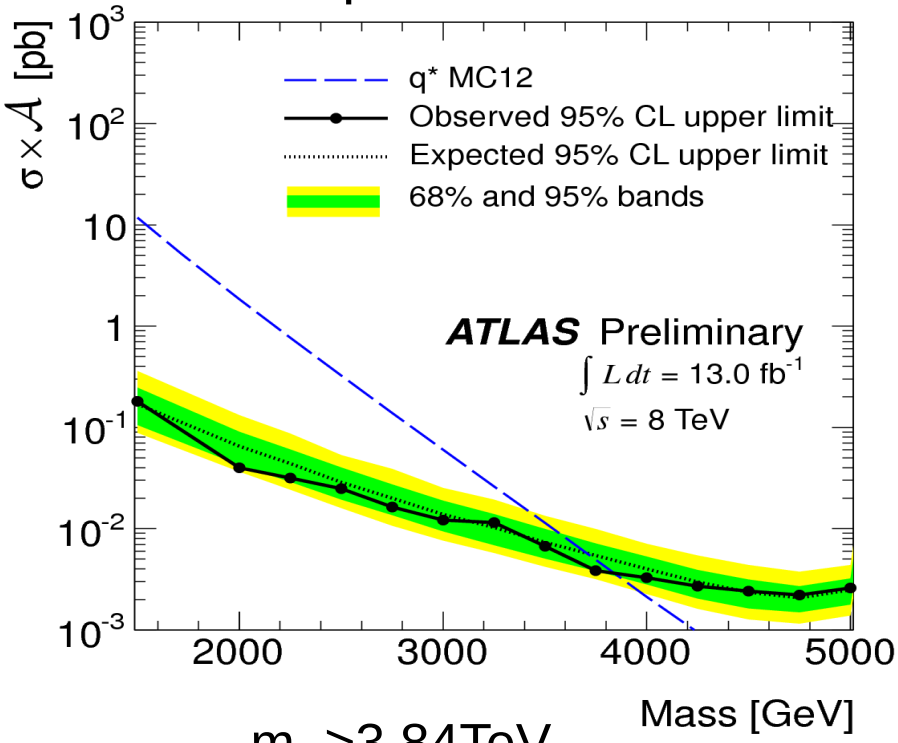
- Di-jet resonances predicted by many models (compositness, extra-dimensions,...)
- Selection
  - High pT jet trigger
  - 2 anti-kt jets with R=0.6, |y|<2.8, pT>150 GeV
  - $|y^*|=|y_1-y_2|/2 < 0.6$, $m_{jj}>1$ TeV
- Background fitted from data:
  - $f(x) = p_1(1-x)^{p_2} x^{p_3+p_4 \ln x}$
  - Assume Poisson statistics
    χ^2/NDF=15.5/18=0.86
- Search for excesses/deficits
  - Take care of Look-Elsewhere Effect



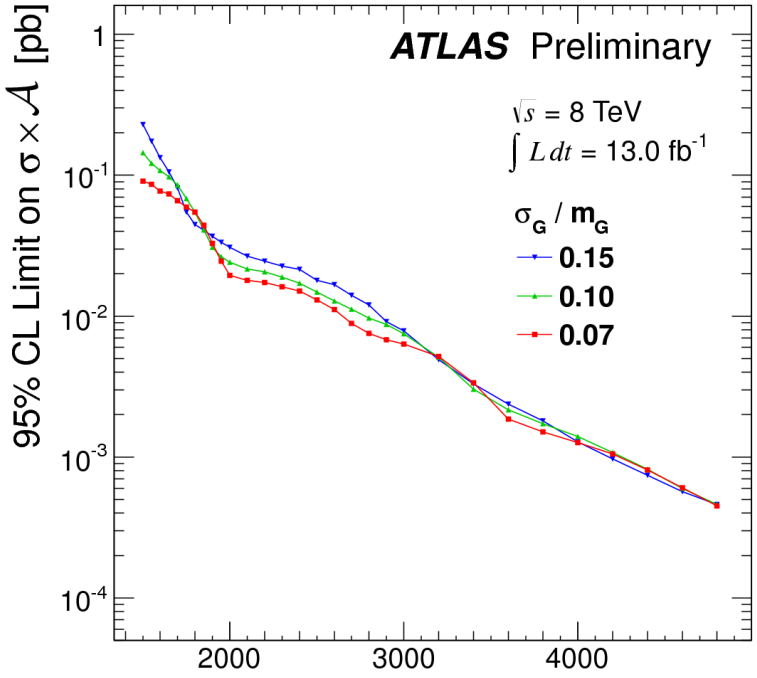
Di-jet mass

ATLAS-CONF-2012-148

- Jet energy scale is the main uncertainty (can be as low as 4%)
- Limits expressed as function of q* mass and simplified Gaussian model



m_{q^*}>3.84TeV



Gaussian distributions with Mass, m_G [GeV]
width of 7%, 10% or 15%

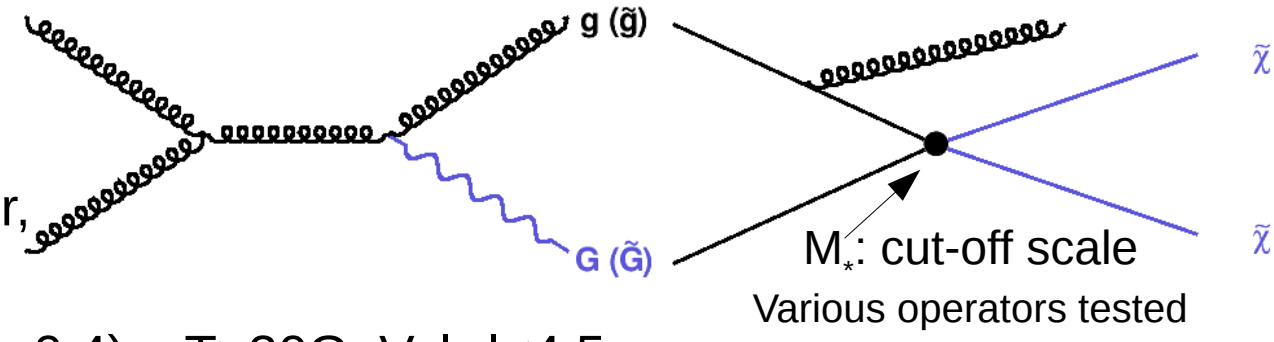
Detector resolution on m_{jj}

from 7% (1TeV) to 4% (3TeV)

Monojet + missing E_T

ATLAS-CONF-2012-147

- Predicted by supersymmetry (gravitino), Large Extra Dimension (graviton), WIMPS ...



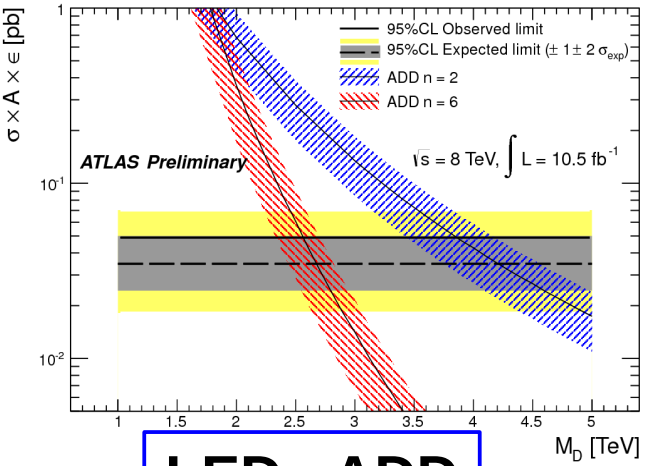
- Selection:
  - missing E_T (MET) trigger,
  - MET>120GeV
  - At most 2 anti-Kt jets (R=0.4), pT>30GeV, $|\eta|<4.5$
  - Leading jet: pT>120GeV, $|\eta|<2$
  - $\Delta\varphi(2^{nd}$ jet, MET)>0.5
  - Lepton veto

- Main backgrounds (W/Z+jets, multijet, ...) are data-driven, apart from top and dibosons

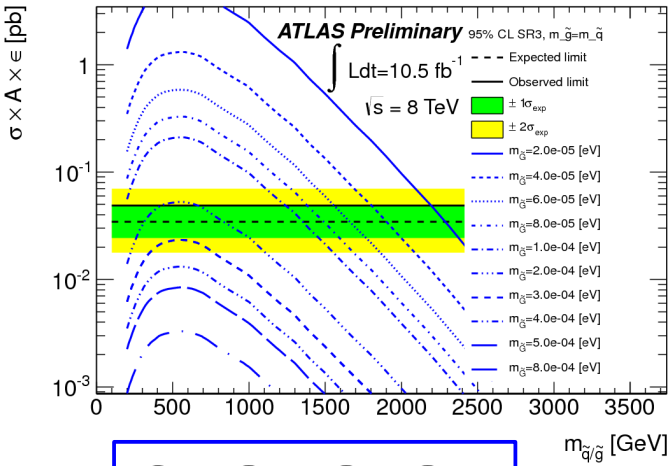
- 4 signal regions: both MET and leading jet pT larger than 120, 220, 350, 500 GeV
  - 350 GeV working point gives the best sensitivity

Monojet + missing E_T

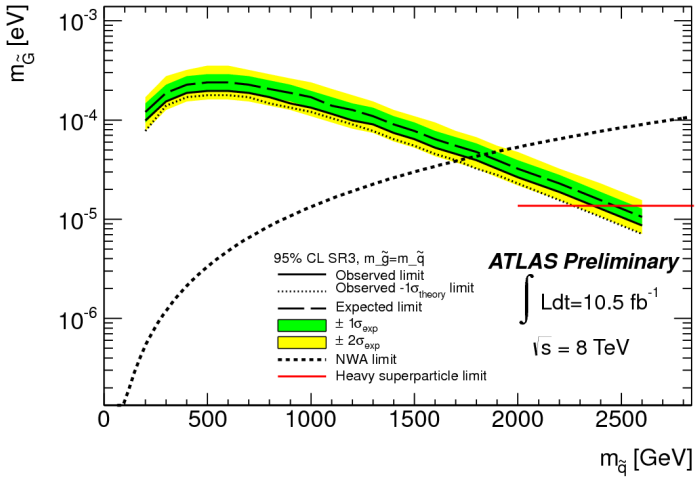
ATLAS-CONF-2012-147

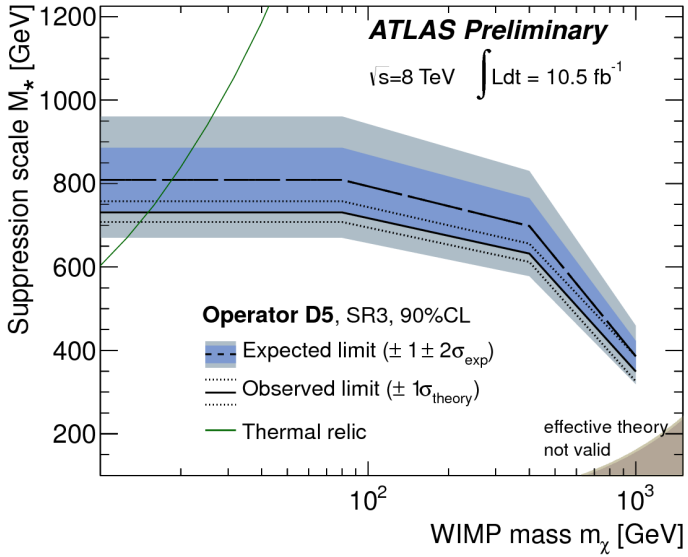


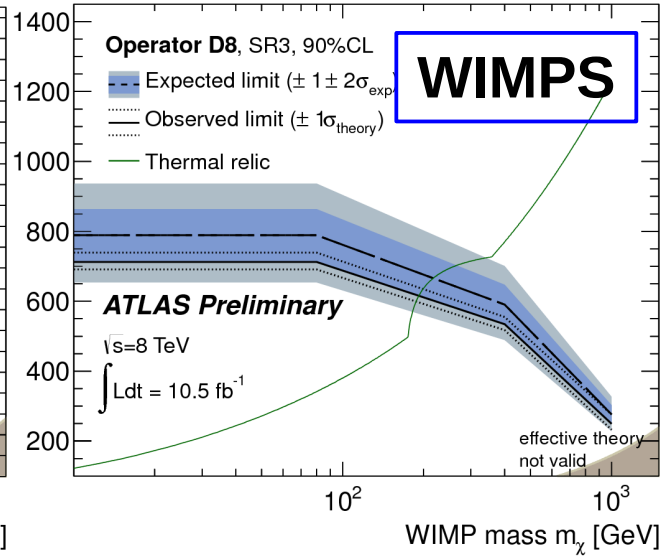
LED - ADD



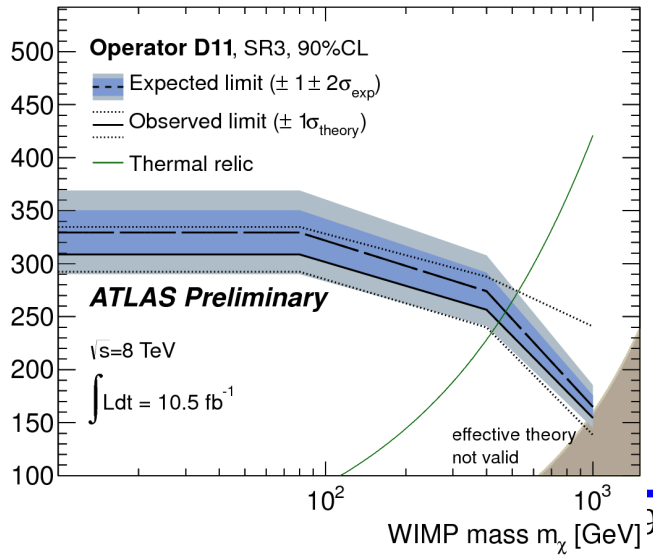
GMSB SUSY





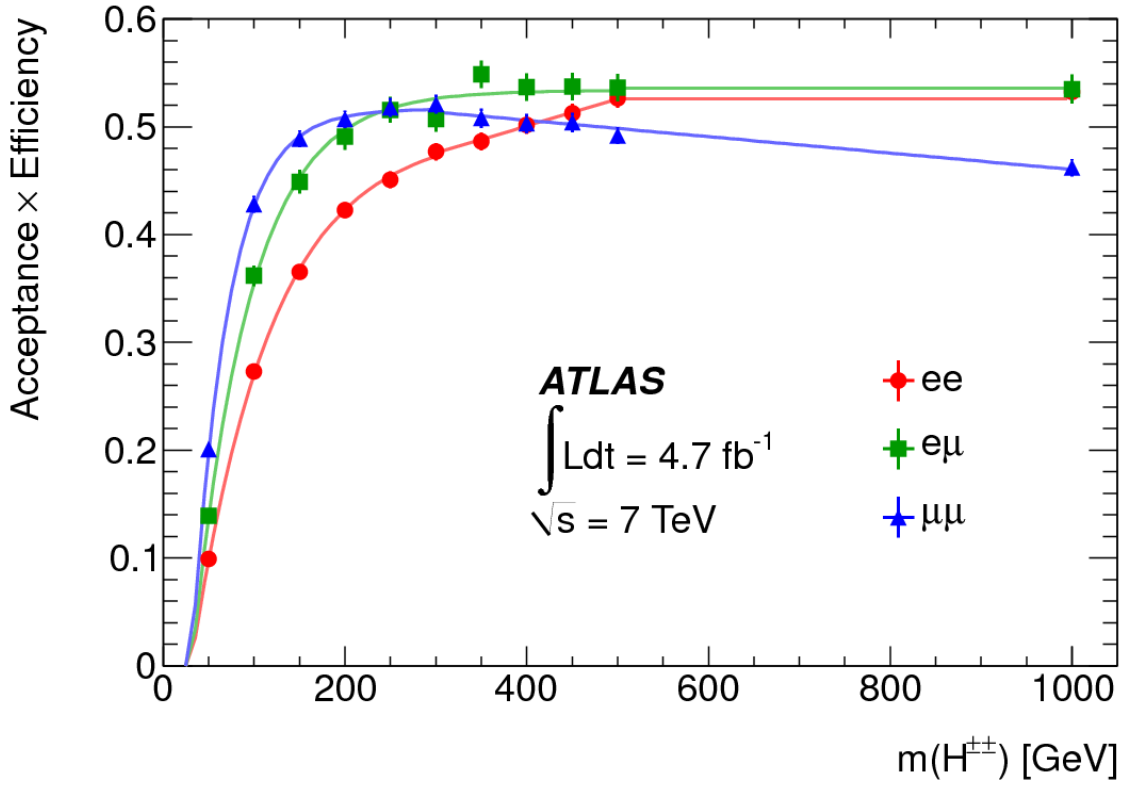


WIMPS

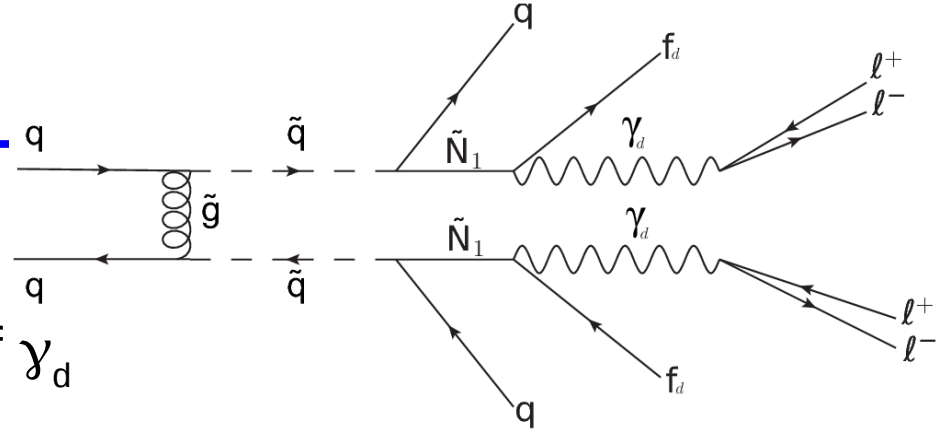


Doubly-charged Higgs boson

- Acceptance x Efficiency



Hidden valley

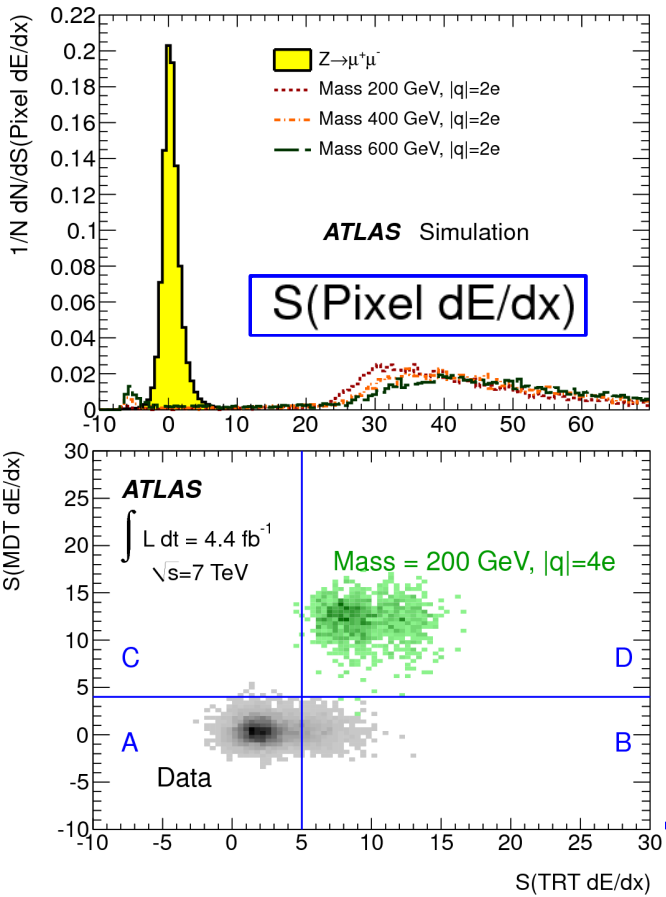


- Squark pair production
- f_d can radiate γ_d, depending on the coupling a_d, increasing the number of γ_d
- Selections
  - Single muon jet with at least 4 muons,
  - Pairs of muon jet, with at least 2 muons,
  - Or pairs of electron jets, with at least 2 electrons
- Background
  - Mainly mulitjets and gamma+jets
  - Data driven

Signal Parameters		Electron LJ	1 Muon LJ	2 Muon LJ
α_d	m_{γ_D}[MeV]	Obs (Exp) pb	Obs (Exp) pb	Obs (Exp) pb
0.0	150	0.082 (0.082)	-	-
0.0	300	0.11 (0.11)	0.060 (0.035)	0.017 (0.011)
0.0	500	0.20 (0.21)	0.15 (0.090)	0.019 (0.012)
0.10	150	0.096 (0.10)	-	-
0.10	300	0.37 (0.37)	0.064 (0.036)	0.018 (0.011)
0.10	500	0.39 (0.39)	0.053 (0.035)	0.018 (0.011)
0.30	150	0.11 (0.11)	-	-
0.30	300	0.40 (0.40)	0.099 (0.055)	0.020 (0.012)
0.30	500	1.2 (1.2)	0.066 (0.043)	0.022 (0.015)

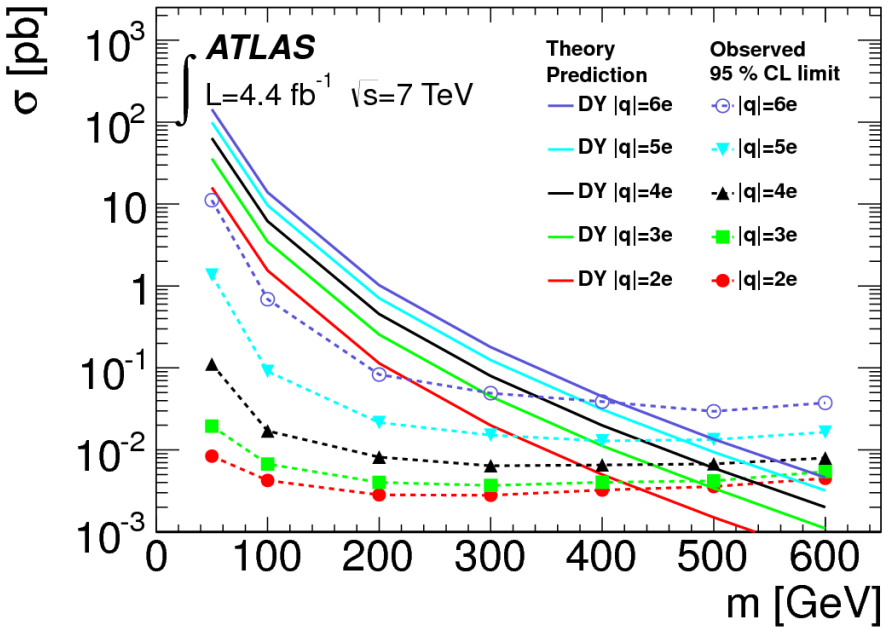
Long-lived, multi-charged particles

- Particles predicted by many models (magnetic monopoles, long-lived micro black holes, Q-balls)
- Search for 2e≤|q|≤6e particles: highly ionizing → large dE/dx
- Select events with “muon” pairs (assuming Drell-Yan production),
- Request large deviation of dE/dX in the various sub-detectors



$$S(\mathrm{d}E/\mathrm{d}x) = \frac{\mathrm{d}E/\mathrm{d}x_{\mathrm{track}} - \langle \mathrm{d}E/\mathrm{d}x_{\mu} \rangle}{\sigma(\mathrm{d}E/\mathrm{d}x_{\mu})}$$

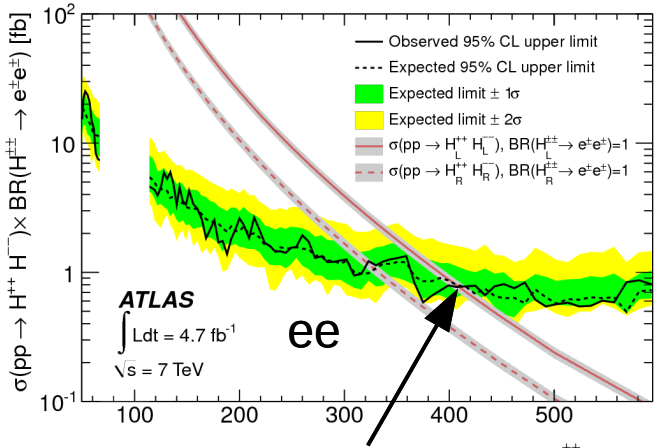
- Limits dominated by the statistic uncertainty



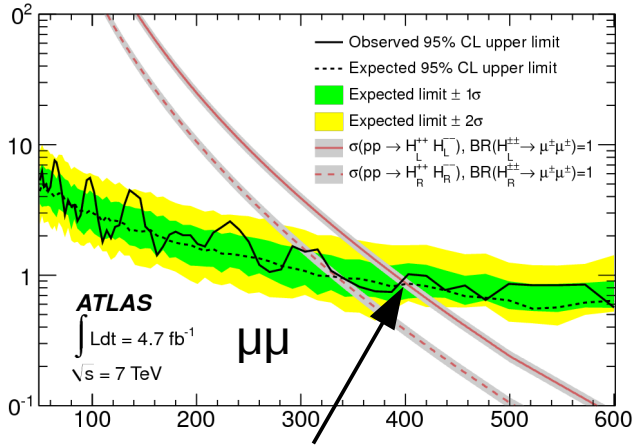
Doubly-charged Higgs boson

EXOT-2012-18

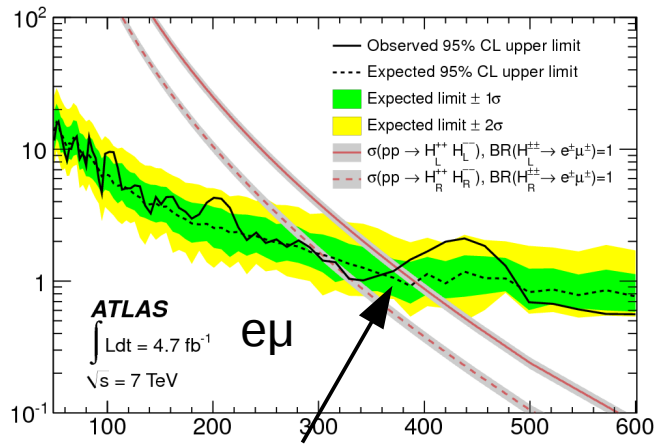
- Limits depend on if the $H^{\pm\pm}$ couples to left- or right-handed fermions



$m(H^{\pm\pm}_L) > 409\,GeV$



$m(H^{\pm\pm}_L) > 398\,GeV$

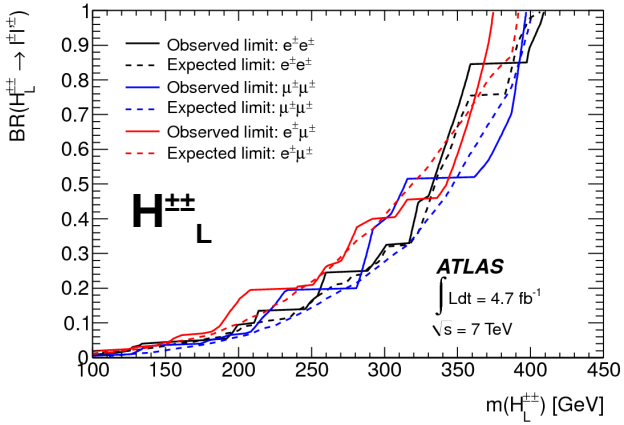


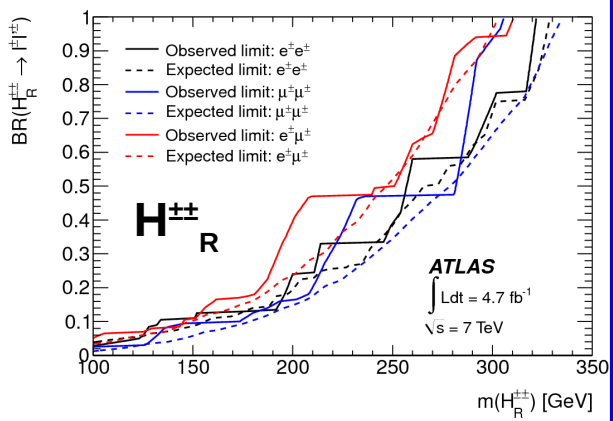
$m(H^{\pm\pm}_L) > 375\,GeV$

Dominant uncertainties:

- ±12% for WZ/ZZ cross-sections
- ±40% for non-prompt and charge flips
- Limited by the statistics at high mass

Limits on BR($H^{\pm\pm} \rightarrow$ **ee**), BR($H^{\pm\pm} \rightarrow$ **eμ**), BR($H^{\pm\pm} \rightarrow$ **μμ**) vs $m(H^{\pm\pm})$





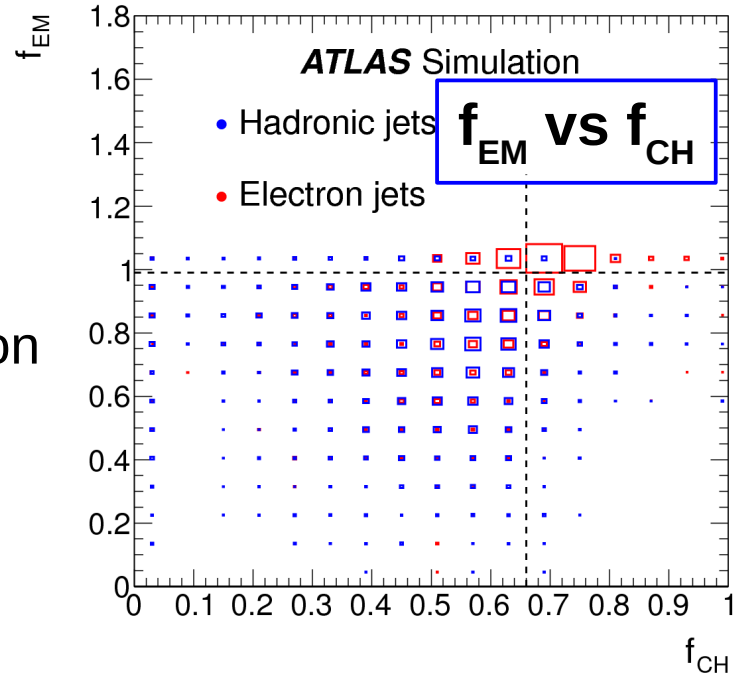
Higgs → hidden sector / electron jet

EXOT-2011-01

- Search using the **HW(→e/μ ν)** production

- Single lepton trigger, one isolated lepton, MET>25GeV, at least 2 electron-jets:
  - $|\eta|<2$, pT>30GeV
  - High electromagnetic fraction $f_{EM}>0.99$
  - High charged fraction $f_{CH}>0.66$
  - At least 2 tracks, likely to come from electron

- Background :
  - Fake electron-jets, from final state photon radiation and π^0 decays
  - Fully data-driven



Higgs → hidden sector / electron jet

EXOT-2011-01

Signal	three-step model		two-step model	
m_H (GeV)	$m_{\gamma_d} = 100$ MeV	$m_{\gamma_d} = 200$ MeV	$m_{\gamma_d} = 100$ MeV	$m_{\gamma_d} = 200$ MeV
100	$14.3 \pm 1.7 \pm 0.8$	$12.4 \pm 1.6 \pm 0.7$	$22.6 \pm 2.1 \pm 1.2$	$23.5 \pm 2.1 \pm 1.2$
125	$11.3 \pm 1.0 \pm 0.6$	$10.7 \pm 1.1 \pm 0.6$	$16.2 \pm 1.2 \pm 0.9$	$18.1 \pm 1.4 \pm 1.0$
140	$9.6 \pm 0.8 \pm 0.5$	$9.0 \pm 0.8 \pm 0.4$	$13.7 \pm 0.9 \pm 0.8$	$13.9 \pm 0.9 \pm 0.8$
Background	$0.41 \pm 0.29 \pm 0.12$			
Data	1			

- Main systematic:

  80% on the background estimation
- Similar results for $m(\gamma_d)$=100 or 200MeV