Searches for New Physics with Same-sign dileptons at ATLAS

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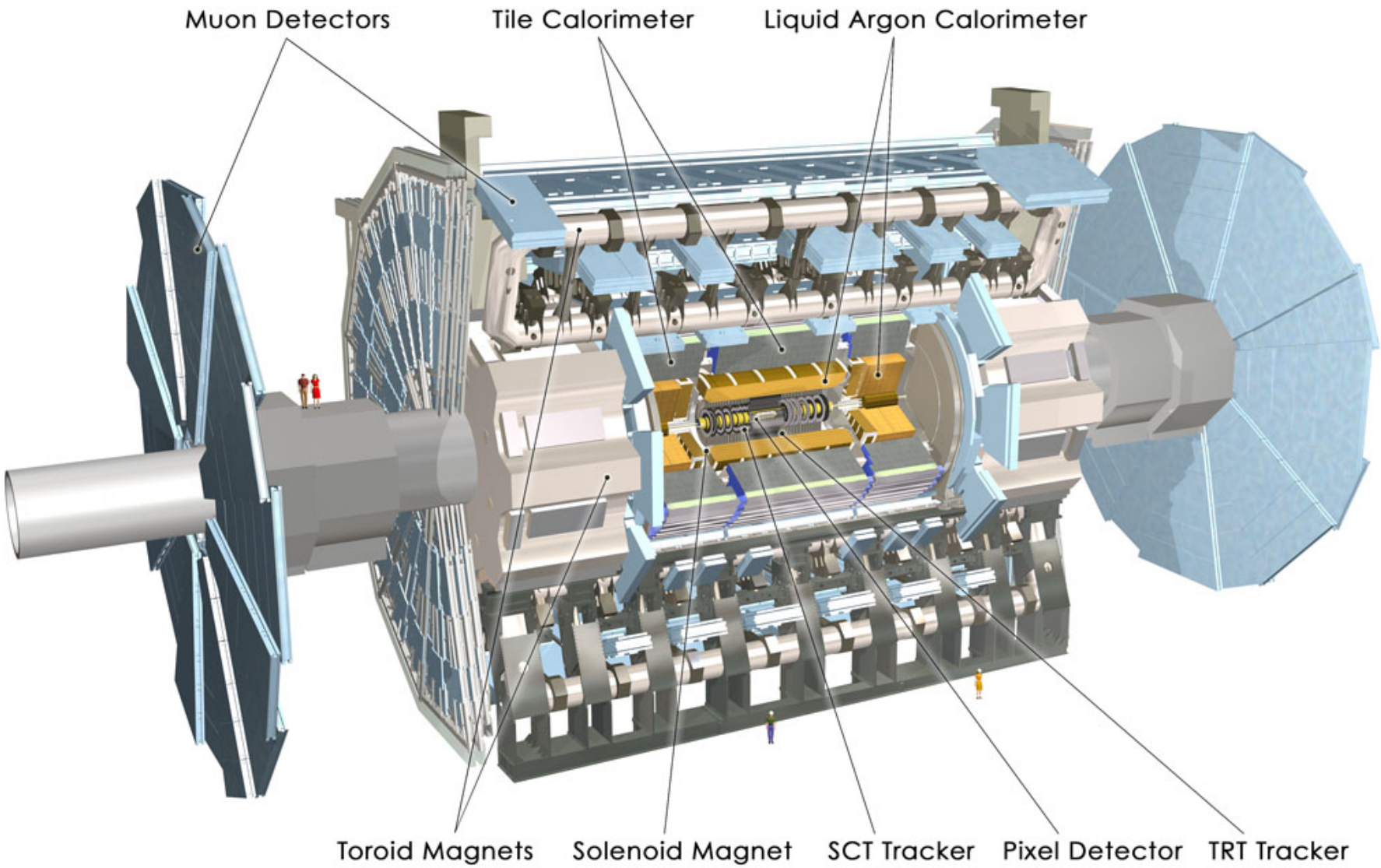
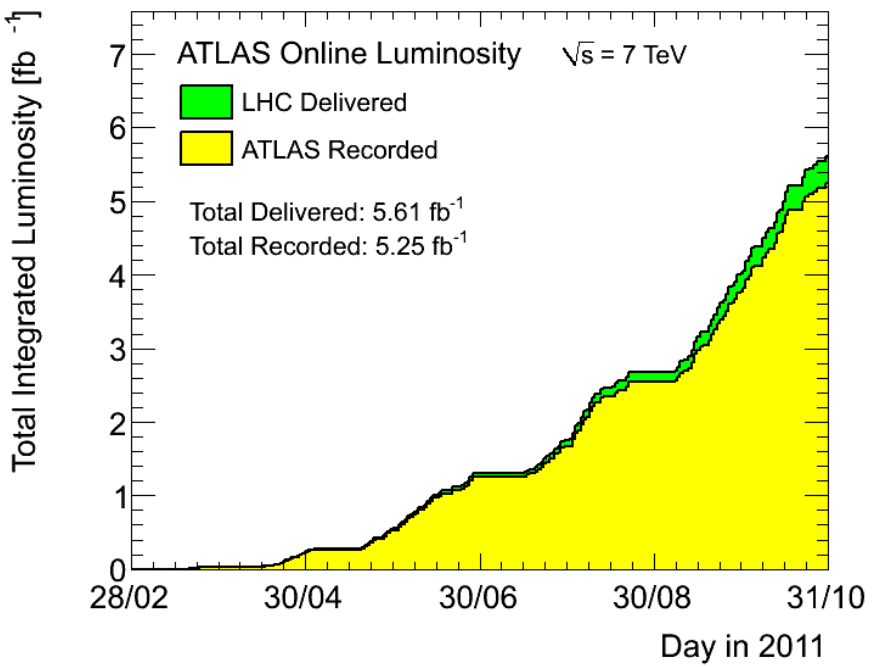
The ATLAS Detector



ATLAS

- 2011: Collected 5.25 fb^{-1} of data
  - Most analyses shown today based on 1-2 fb^{-1}
  - Luminosity known to 3.9% precision in 2011
- ATLAS detector operating very well



ATLAS 2011 p–p run

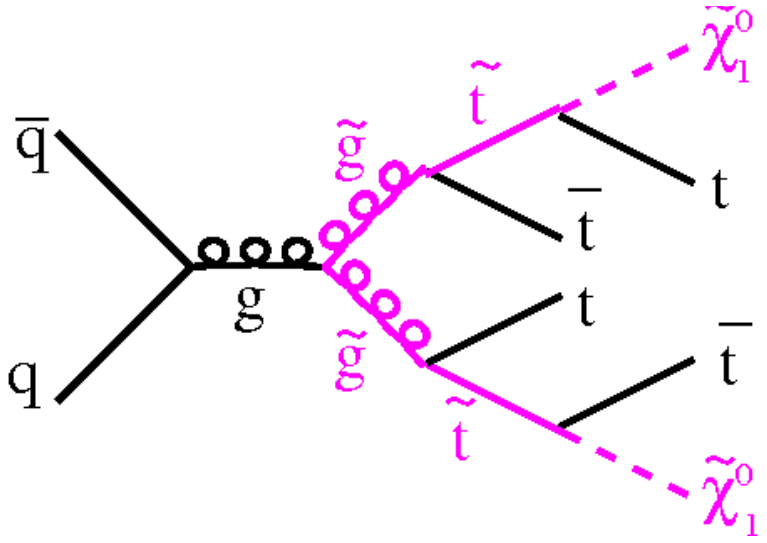
Inner Tracking			Calorimeters				Muon Detectors				Magnets	
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.8	99.6	99.2	97.5	99.2	99.5	99.2	99.4	98.8	99.4	99.1	99.8	99.3

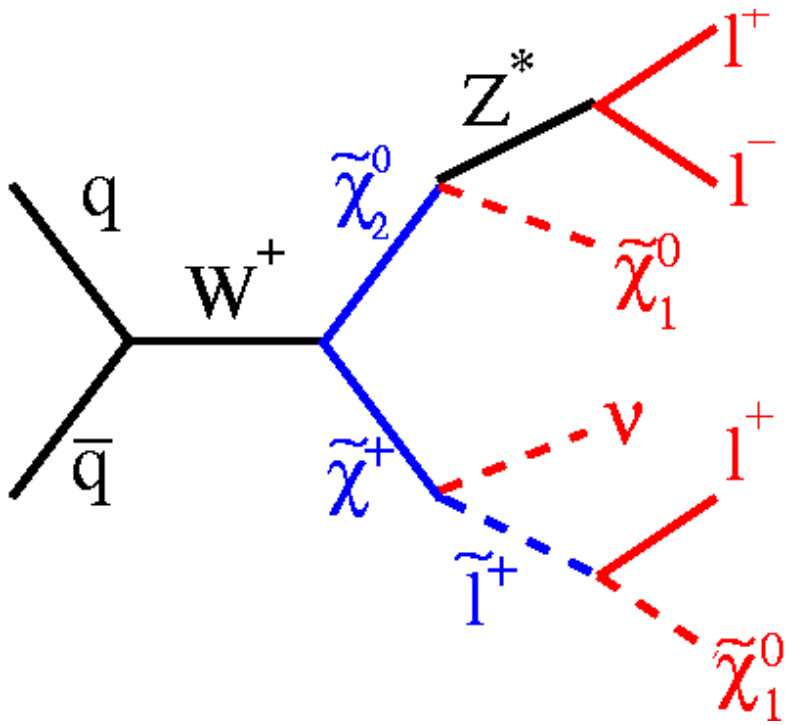
Luminosity weighted relative detector uptime and good quality data delivery during 2011 stable beams in pp collisions at √s=7 TeV between March 13th and October 30th (in %), after the summer 2011 reprocessing campaign

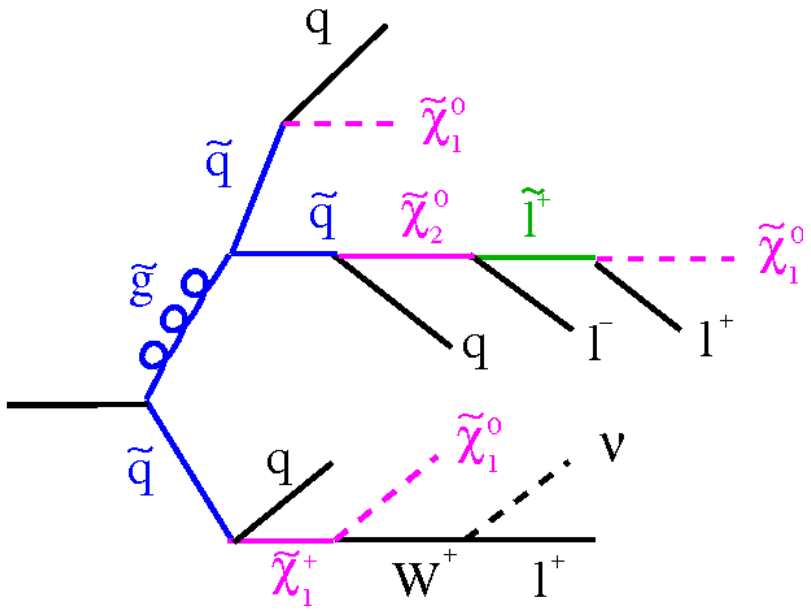
Why Same-sign leptons?

Supersymmetry

- Like-sign leptons occur from cascade-decays via sleptons and/or W- and Z bosons

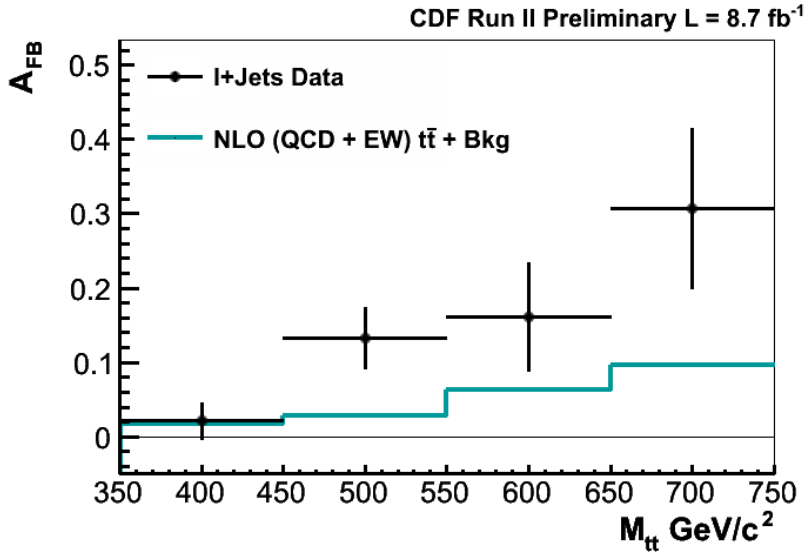


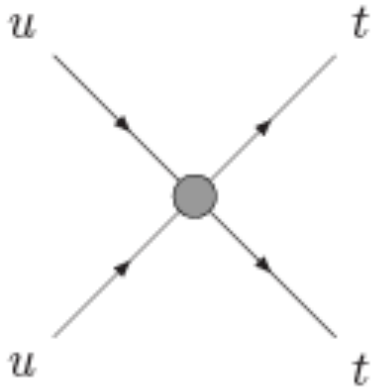


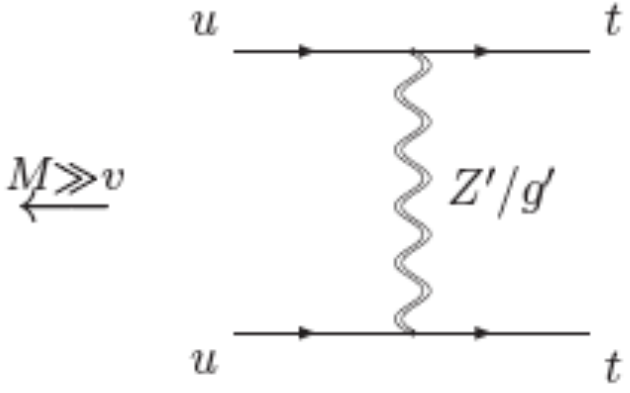


Like-sign top pairs

- Forward-background asymmetry in ttbar production observed at CDF
- Could be explained by Z' boson with FCNC coupling (utZ)
  - Would result in like-sign top pairs

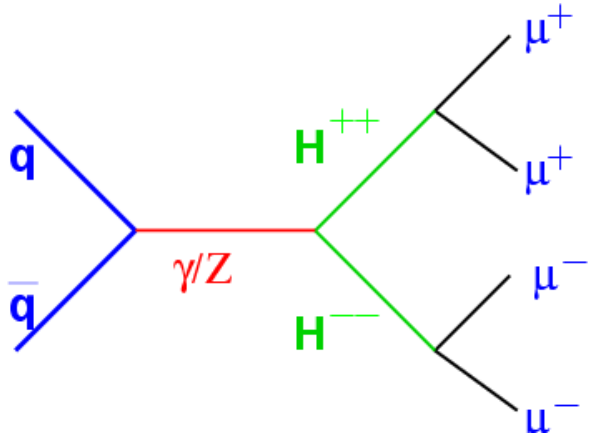




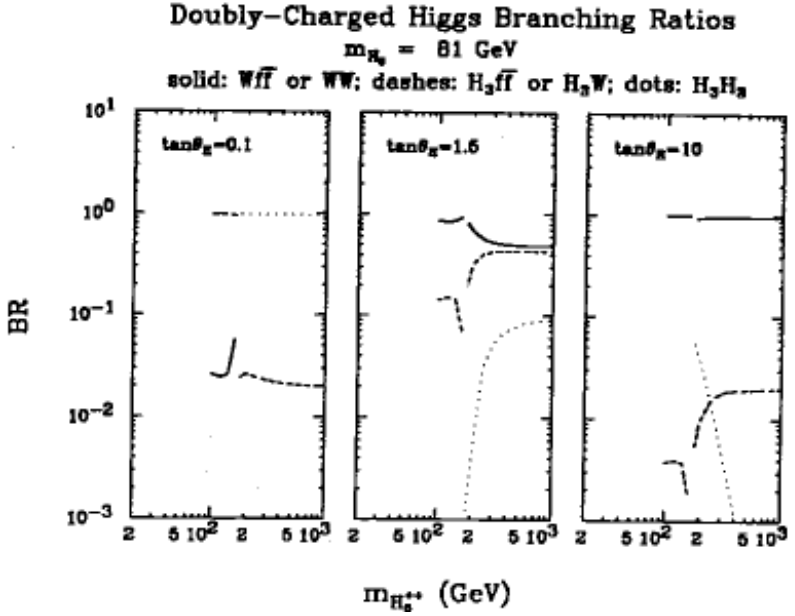


Doubly-Charged Higgs

$$\phi = \begin{pmatrix} \phi^{0*} & \phi^{+} \\ \phi^{-} & \phi^{0} \end{pmatrix} \quad \chi = \begin{pmatrix} \chi^{0} & \xi^{+} & \chi^{++} \\ \chi^{-} & \xi^{0} & \chi^{+} \\ \chi^{--} & \xi^{-} & \chi^{0*} \end{pmatrix}$$



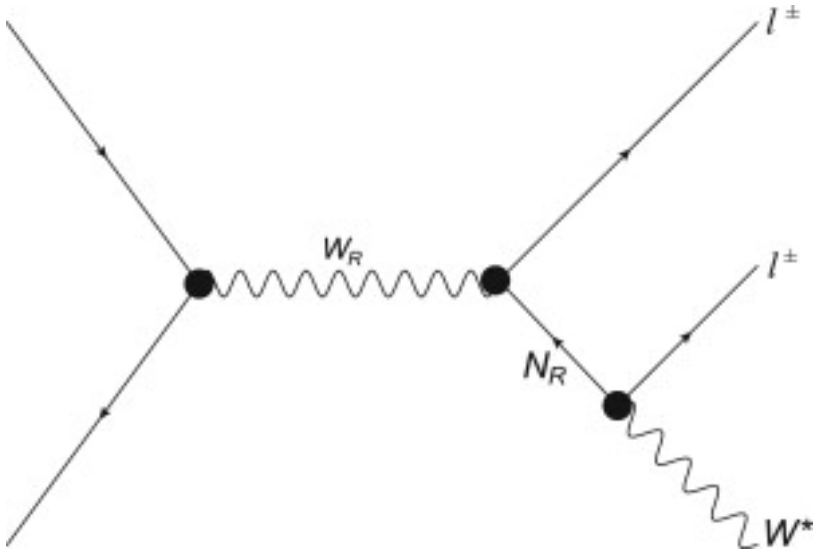
- Extended Higgs sectors predict charged Higgs bosons, e.g.
  - Little Higgs
  - Left-right-symmetric models
- Can generate neutrino masses via type-2 seesaw mechanism
- Significant branching ratio to two leptons possible
  - Left- or right-handed fermions
  - Otherwise decays to W's or other Higgs bosons



Gunion, Vega, Wudka, PRD 42 (1990) 1673

Righthanded W's and Majorana Neutrinos

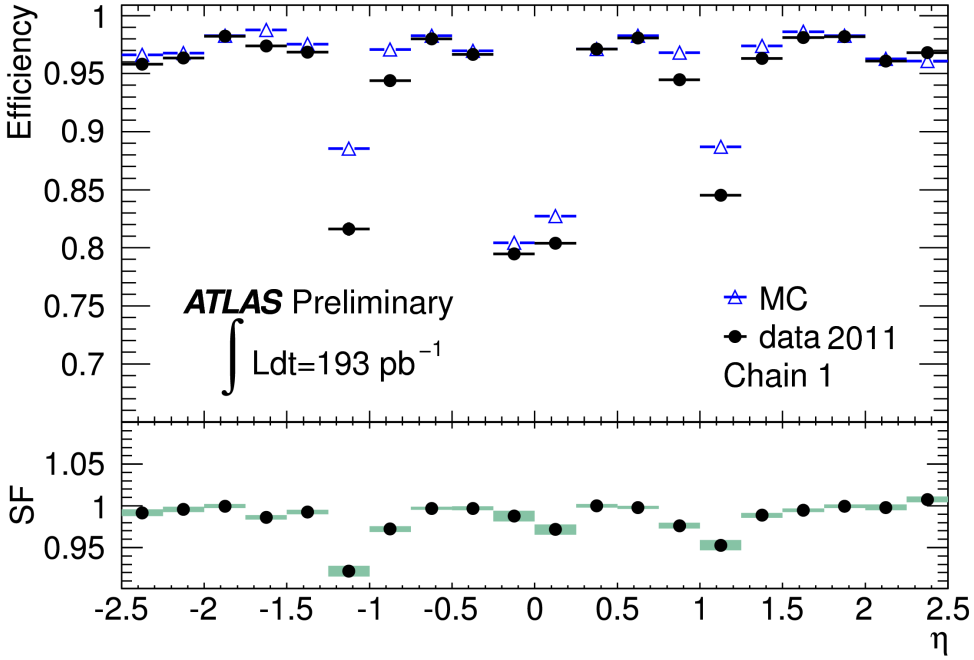
- If right-handed neutrinos (N_R) and right-handed W's have mass ~TeV they can be produced at LHC
  - Branching ratio depends on mass difference
  - Typically about 4-8% in search range
- Results in like-sign dilepton signature plus 1-2 jets from W* decay
  - for large m(N_R) 2nd jet often not resolved / W appears as one jet

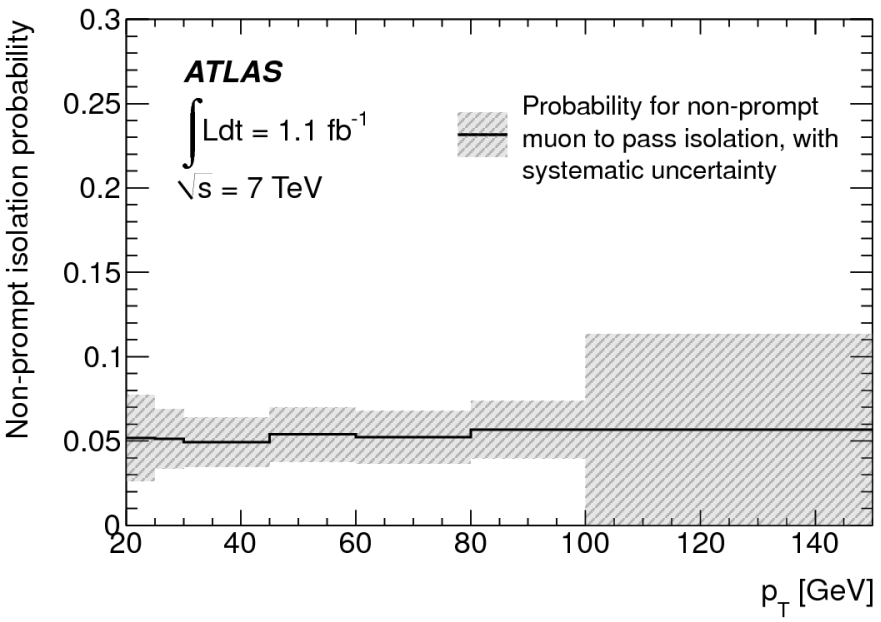


Standard Model Bcakgrounds

- WZ and ZZ production
  - Generated with Herwig
  - Cross section: σ(WZ)~20 pb, σ(ZZ)~5 pb
- ttW, ttZ production
  - Generated with Madgraph
  - Cross sections: σ(ttW)~0.17 pb, σ(ttZ)~0.12 pb
- $W^{\pm}W^{\pm}$ production
  - Generated using Madgraph
  - Cross section: ~0.29 pb
- Leptons from hadron decays (e.g. semi-leptonic b-decays etc.)
  - Estimated from data
- Charge misidentification

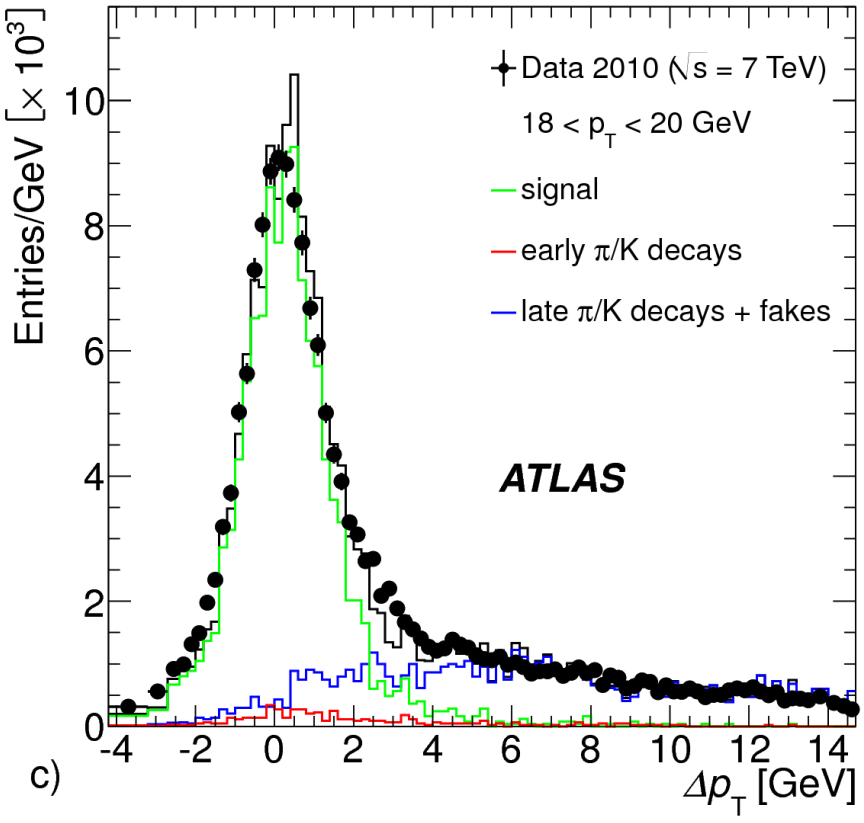
Muons





- Efficiency for reconstructing muons ~95%
  - Inefficiencies mostly due to small holes in coverage
- Fraction of muons from hadron decays that appear isolated ~5%
  - Dominated by b-hadrons
- Charge mis-ID negligible in relevant p_T range

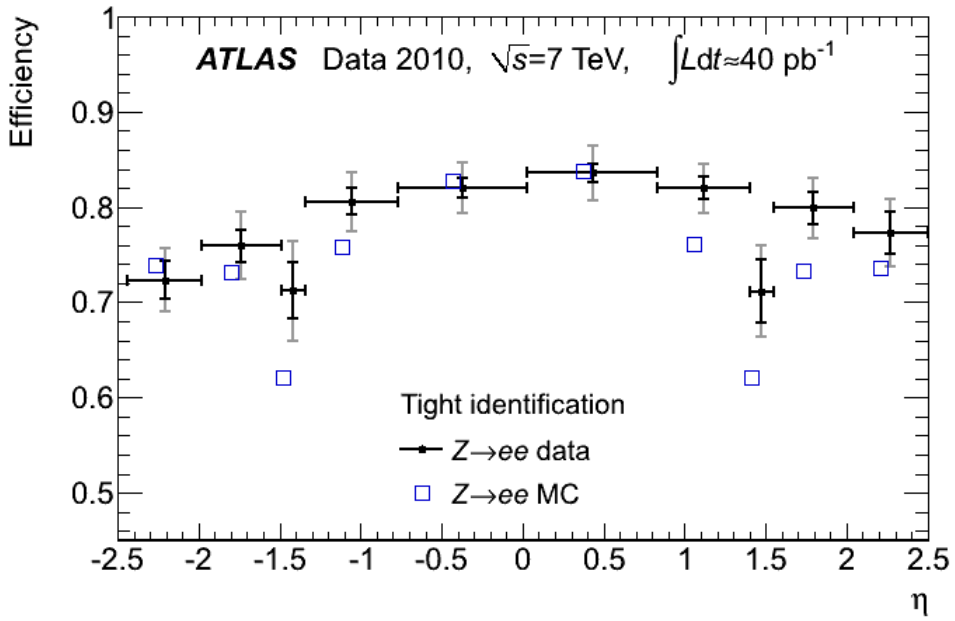
Inclusive Muons

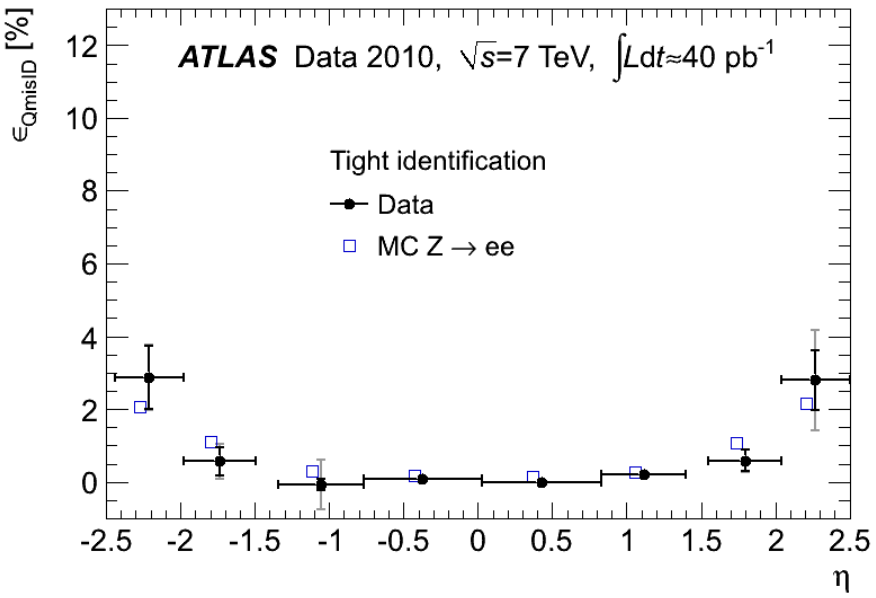


arXiv: 1109.0525

- Decay-in-flight from pion/kaon decays studied using momentum loss between inner tracking and muon system: $(p_{ID}-p_{MS})/p_{ID}$
- For p_T>20 GeV muons are dominated by heavy quark decays before isolation cuts

Electrons

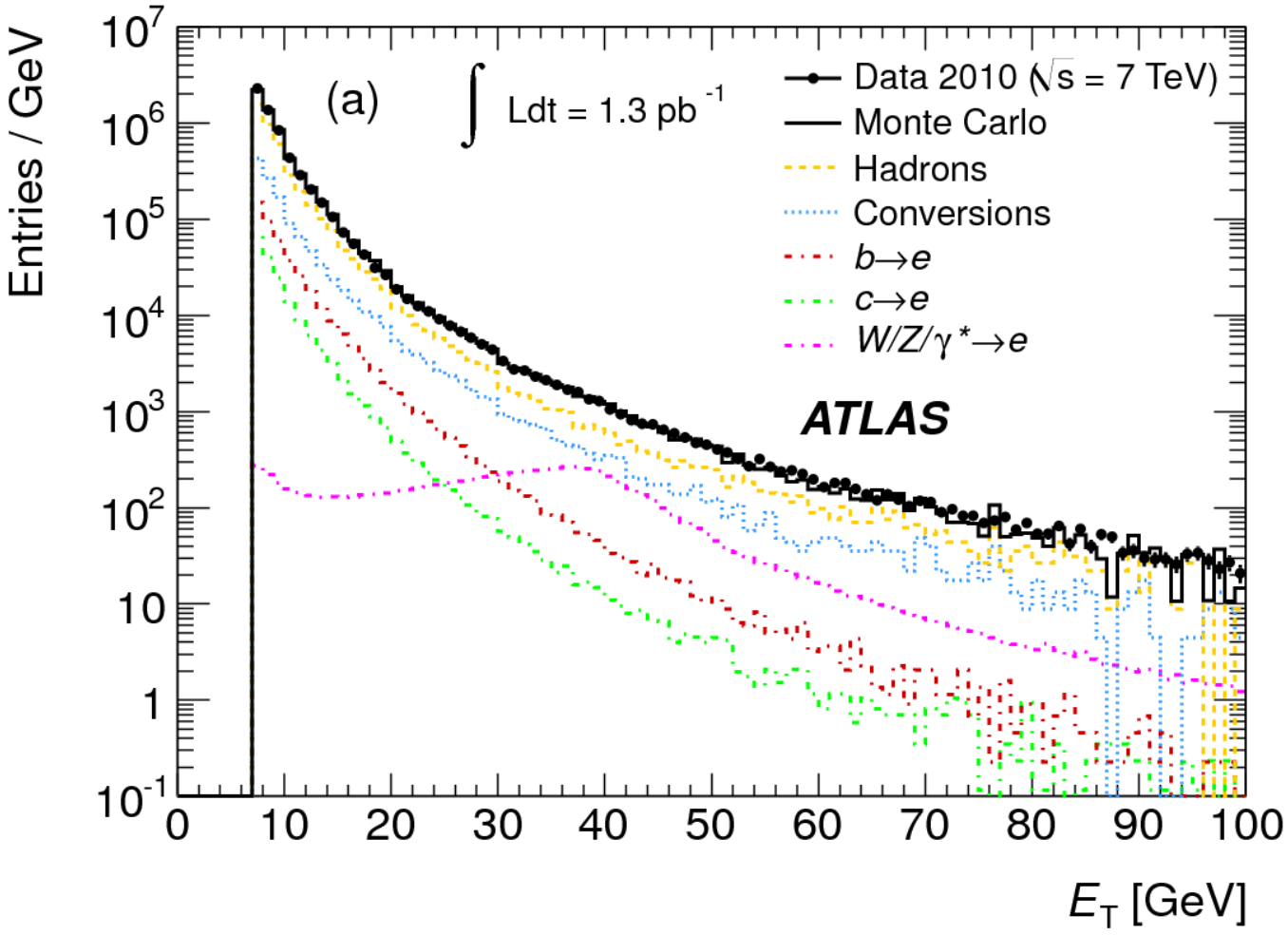




- Reconstruction efficiency for “tight” cuts ~70-80%
- Charge mis-ID depends on η: ~0.2-3%
- Fake lepton background typically 10 times larger than for muons

Inclusive Electrons

arXiv: 1109.0525

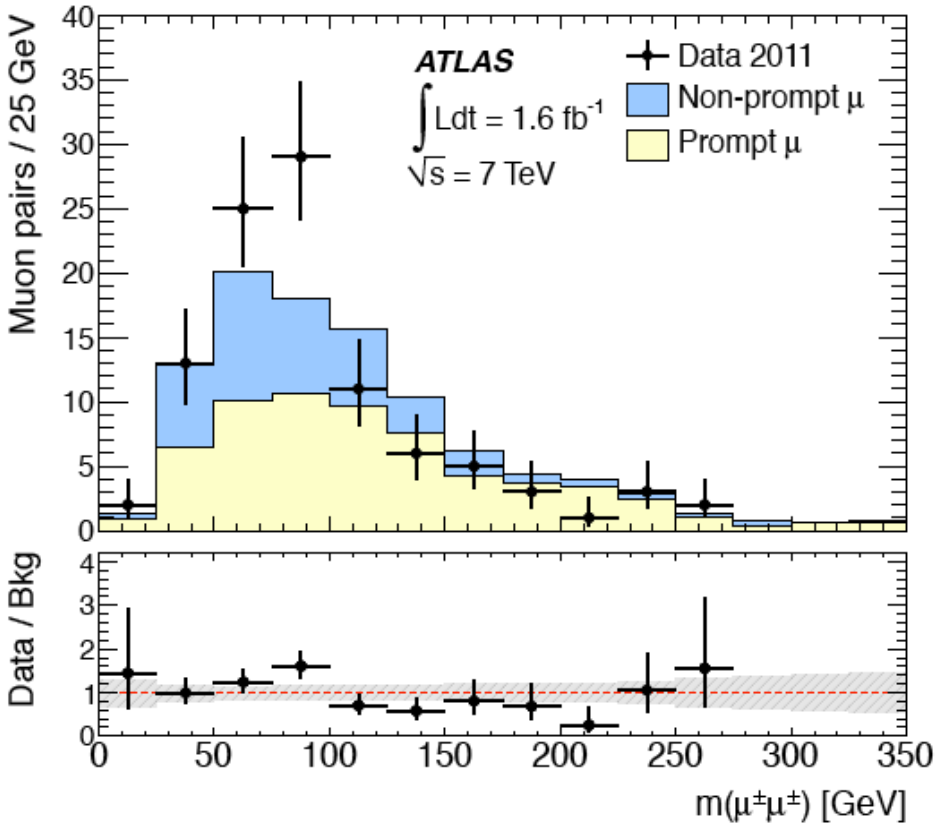


- Dominated by misidentified hadrons and photon conversions
  - Although here looser cuts used than in most analyses

Results

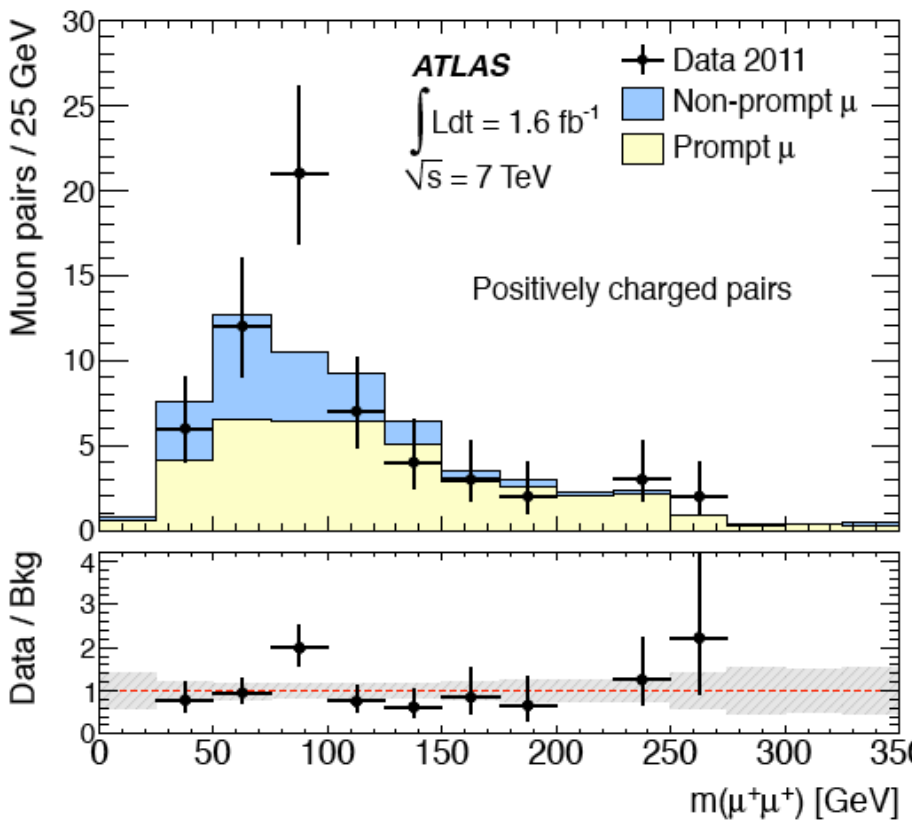
Inclusive same-sign dimuon search

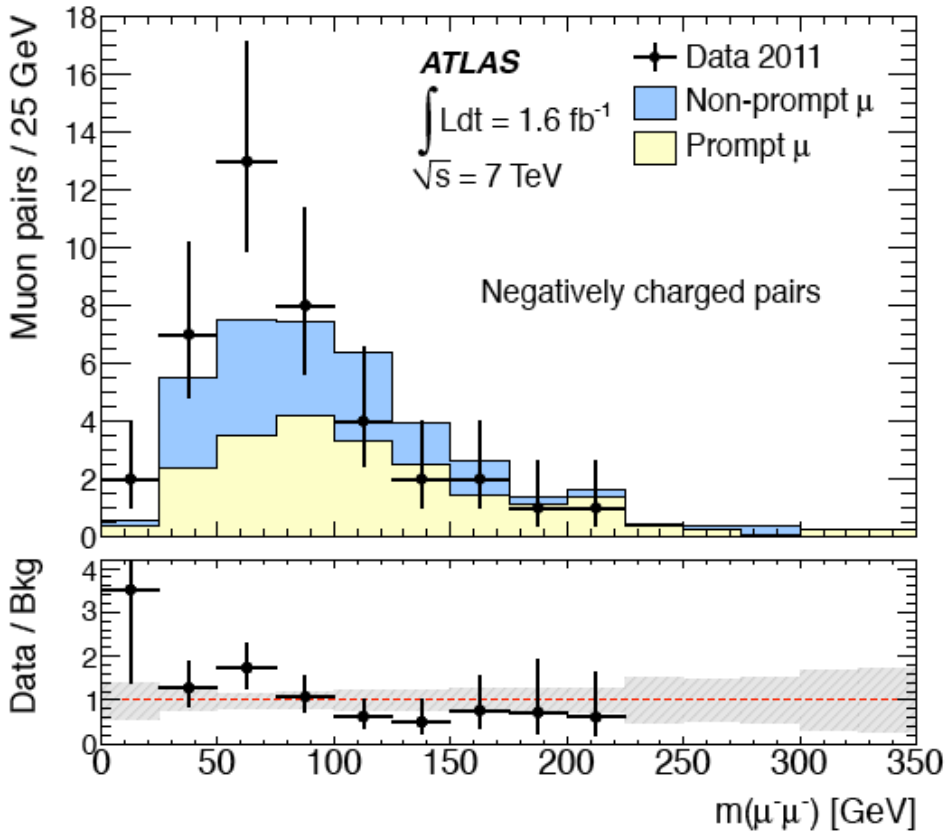
- 2 muons of same charge
  - p_T>20 GeV and |η|<2.5
- Prompt
  - σ(d_0)/d_0<3 and |d_0|<0.2 mm
  - Efficiency ~100% for prompt muons / ~ 70% for muons from tau-decays
- Isolated: Iso/p_T<0.08
  - Iso = sum of track p_T values in a cone of 0.4 around muon



arXiv: 1201.1091

++ and -- pairs





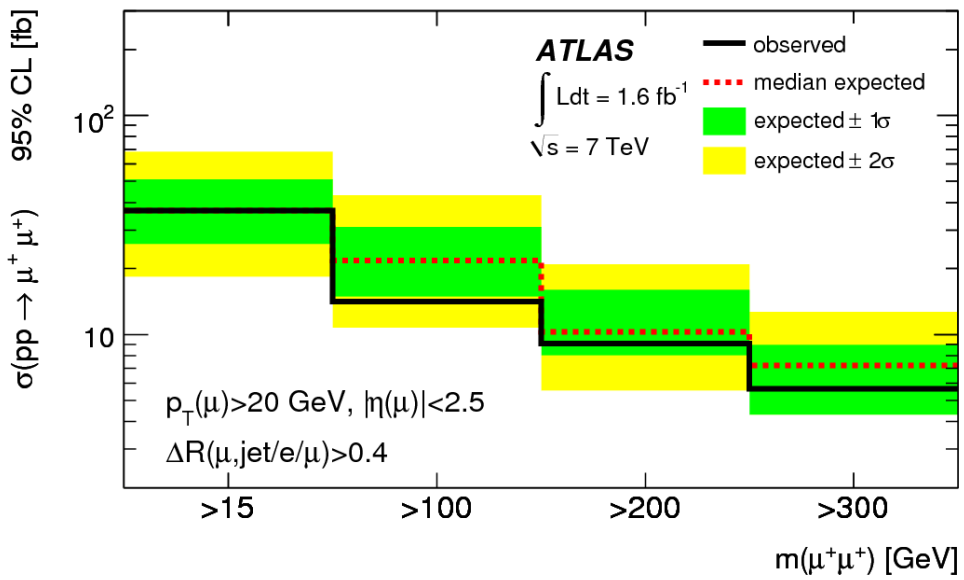
- Good agreement both for $\mu^+\mu^+$ and $\mu^-\mu^-$ pairs

Fiducial Cross Section limit

- Provide model-independent cross-section limit in fiducial region as function of dimuon mass:
  - p_T>20 GeV, |eta|<2.5, ΔR(μ,jet)>0.4
- Use large variety of models and take model with lowest efficiency
  - Models: $H^{\pm\pm}$, W_R, tt, b' at various masses
  - Efficiencies vary between 43.9% and 72.5%
- Cross section limits range from 4-60 fb
  - *Should* also apply to *future* physics models as long as prompt muons are involved in kinematic range

Mass range [GeV]	σ_{95}^{fid} [fb] expected	observed
All muon pairs		
$m(\mu^{\pm}\mu^{\pm}) > 15$	58^{+19}_{-17}	58
$m(\mu^{\pm}\mu^{\pm}) > 100$	30^{+11}_{-9}	16
$m(\mu^{\pm}\mu^{\pm}) > 200$	$13.7^{+5.7}_{-4.4}$	8.4
$m(\mu^{\pm}\mu^{\pm}) > 300$	$8.0^{+3.3}_{-2.6}$	5.3
Positively charged muon pairs		
$m(\mu^{+}\mu^{+}) > 15$	37^{+14}_{-11}	37
$m(\mu^{+}\mu^{+}) > 100$	$21.8^{+9.1}_{-6.9}$	14.1
$m(\mu^{+}\mu^{+}) > 200$	$10.3^{+5.7}_{-2.2}$	9.1
$m(\mu^{+}\mu^{+}) > 300$	$7.2^{+1.8}_{-2.9}$	5.6
Negatively charged muon pairs		
$m(\mu^{-}\mu^{-}) > 15$	29^{+11}_{-8}	30
$m(\mu^{-}\mu^{-}) > 100$	$17.0^{+6.5}_{-5.1}$	9.5
$m(\mu^{-}\mu^{-}) > 200$	$8.7^{+3.1}_{-2.5}$	5.2
$m(\mu^{-}\mu^{-}) > 300$	$5.9^{+1.8}_{-1.6}$	4.3

Fiducial Cross Section limit



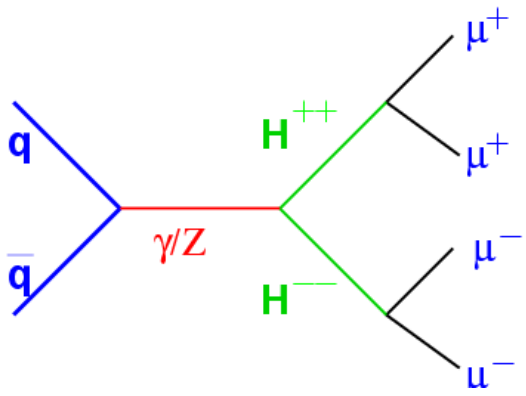
$m(Z')$	$\sigma_{95}(t_R t_R)$ [pb]	
	expected	observed
100 GeV	$4.2^{+2.3}_{-0.9}$	3.7
150 GeV	$3.3^{+1.9}_{-0.7}$	3.0
200 GeV	$2.9^{+1.6}_{-0.6}$	2.6
$\gg 1$ TeV	$2.5^{+1.4}_{-0.5}$	2.2

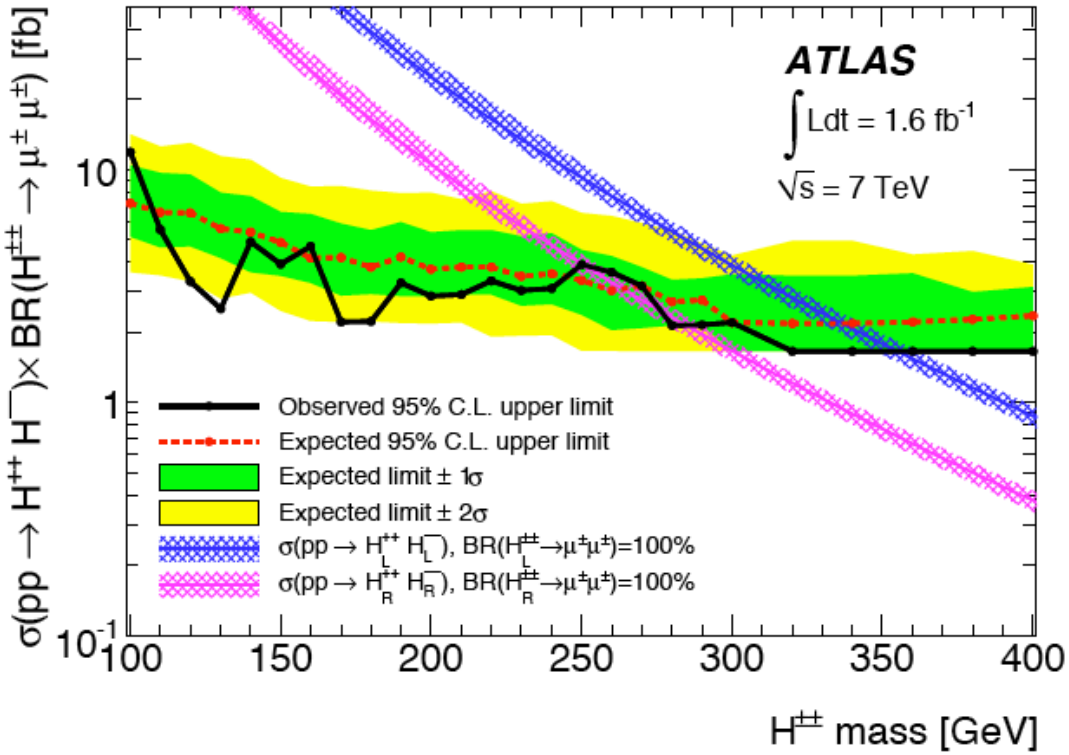
- Can use this directly to constrain new physics
  - E.g. tt production constrained by $\mu^+\mu^+$ limit
    - Acceptance of fiducial cuts for m>200 GeV:
      - 0.25-0.41 % depending on Z' mass
    - Upper limit on pp-> tt cross section:
      - 2.2-3.7 pb depending on Z' mass

$$\sigma_{95} = \frac{\sigma_{95}^{fid}(\mu\mu)}{A_{fid}}$$

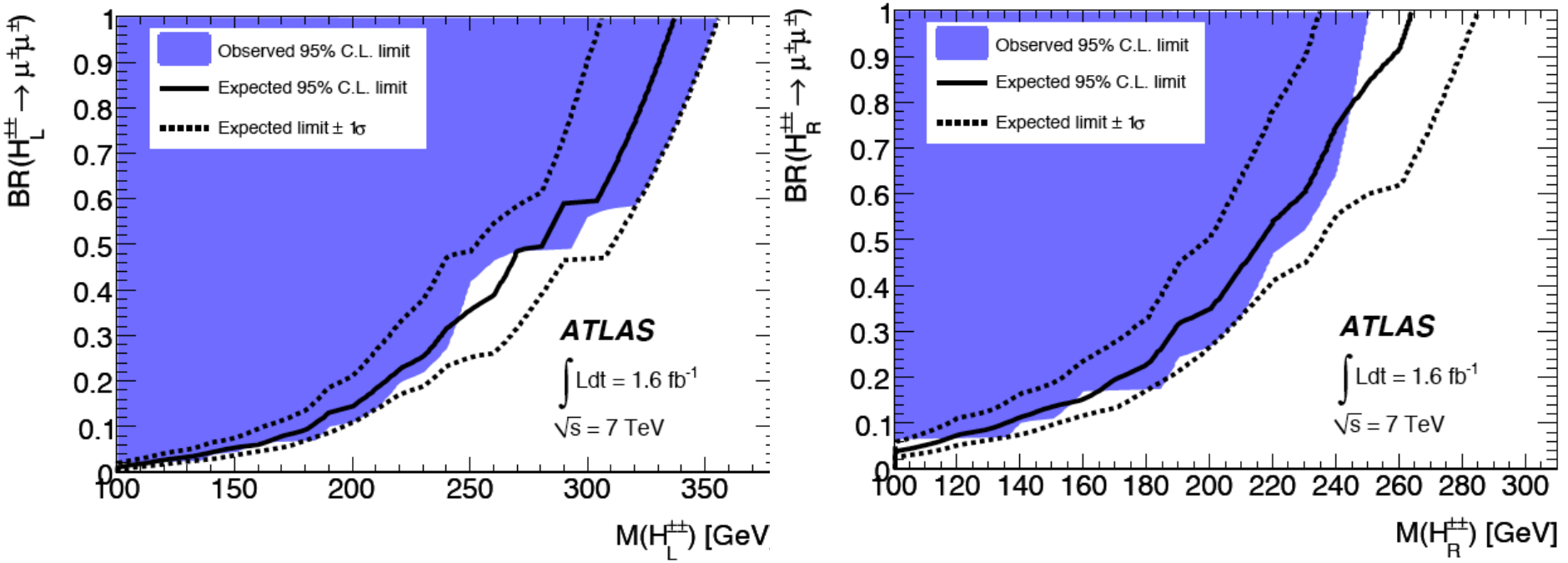
$H^{\pm\pm}$ Search

- Search for narrow resonance decaying to two muons
  - Mass window: 10% of mass value
- Only consider Drell-Yan production to minimize model-dependence of limit
  - Independent of H+ mass





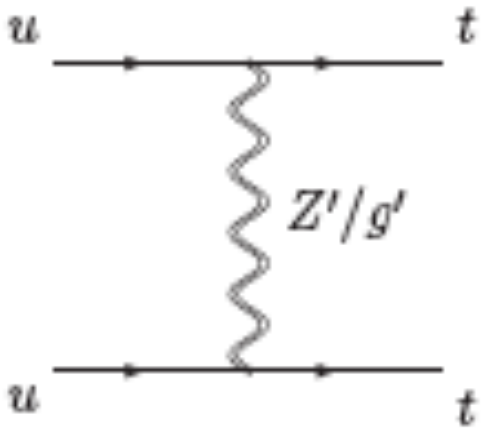
$H^{\pm\pm}$ Mass Limit versus branching ratio



- BR=100%: m($H^{\pm\pm}_L$)>355 GeV, m($H^{\pm\pm}_R$)>251 GeV
  - Recently superseded by preliminary CMS analysis with 4.6 fb^{-1}: 391 GeV for left-handed case
- BR=33%: m($H^{\pm\pm}_L$)>244 GeV, m($H^{\pm\pm}_R$)>209 GeV

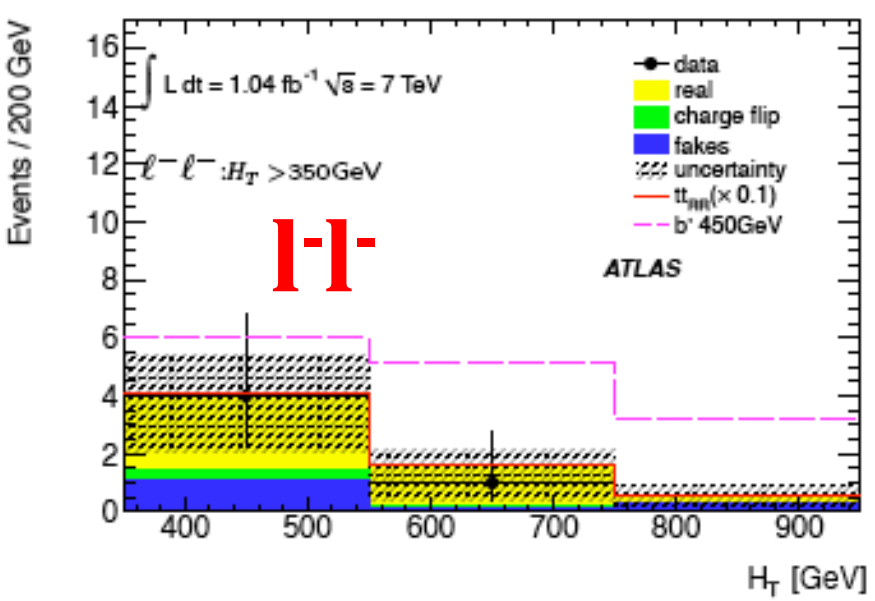
Dedicated tt Search

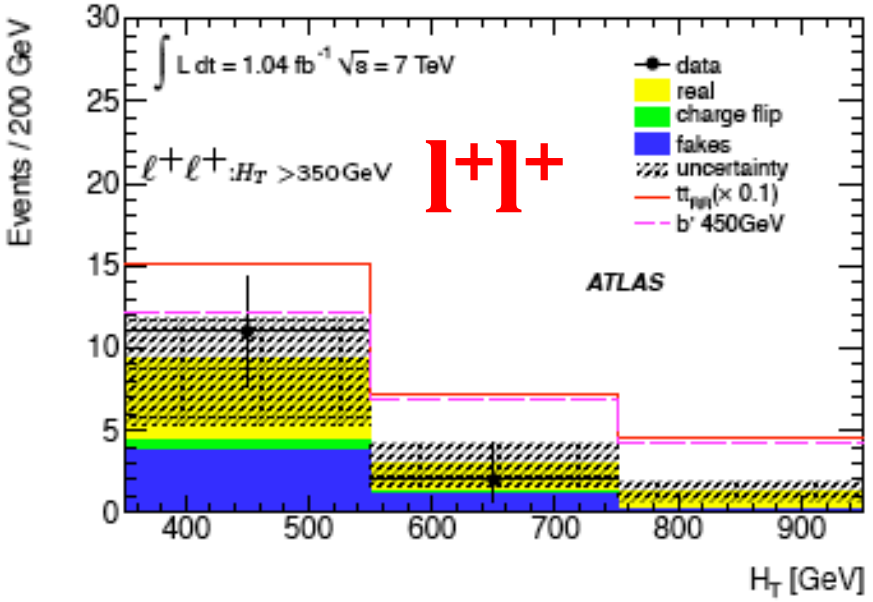
- 2 leptons with p_T>20 GeV (muons) / 25 GeV (electrons)
  - m(ll)> 15 GeV
  - ee and μμ veto 81<m(ee)<101 GeV
- 2 jets with p_T>20 GeV and |η|<2.5
- E_T^{miss}>40 GeV
- Both leptons must have positive charge
  - As mostly up quarks in proton (little anti-up)
- Two signal regions:
  - H_T> 350 GeV , H_T>150 GeV and m(ll)>100 GeV
- Selection efficiency ~0.7-1.0%

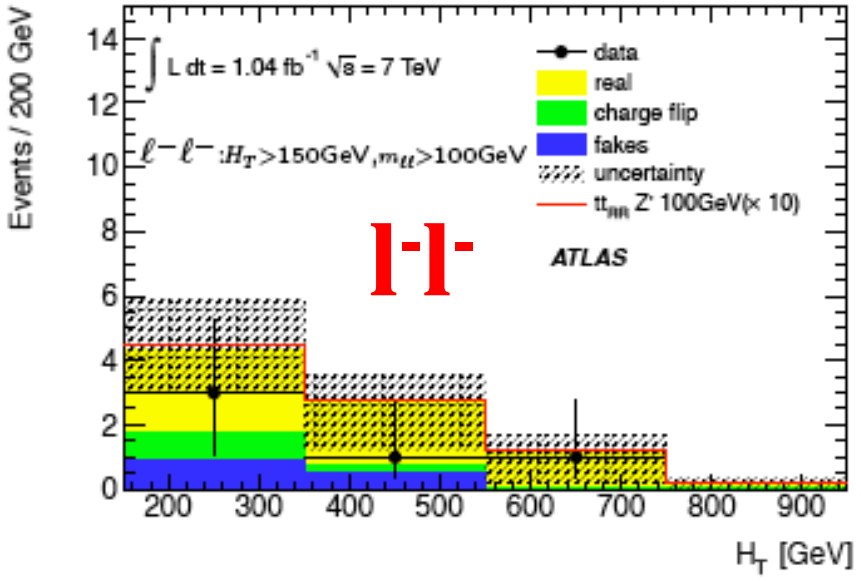


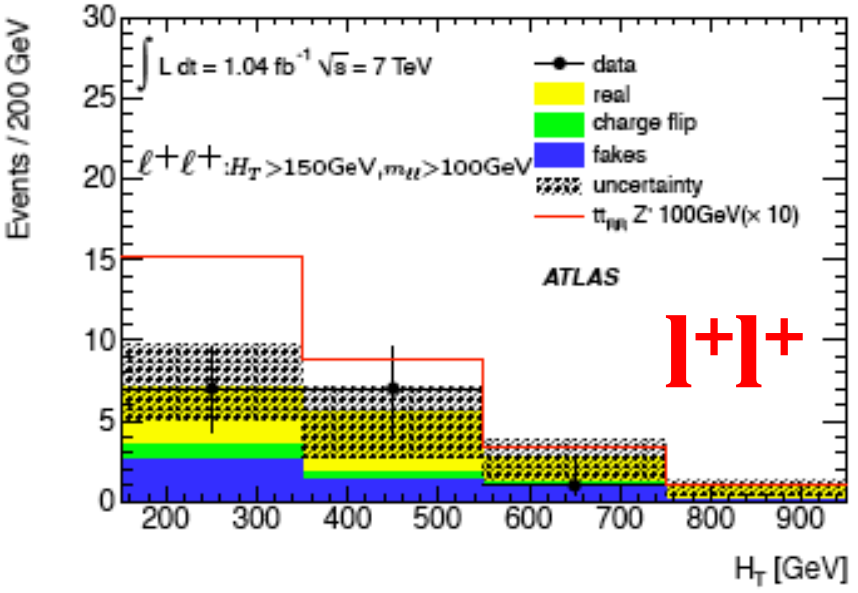
arXiv:1202.5520

Data in Signal Regions

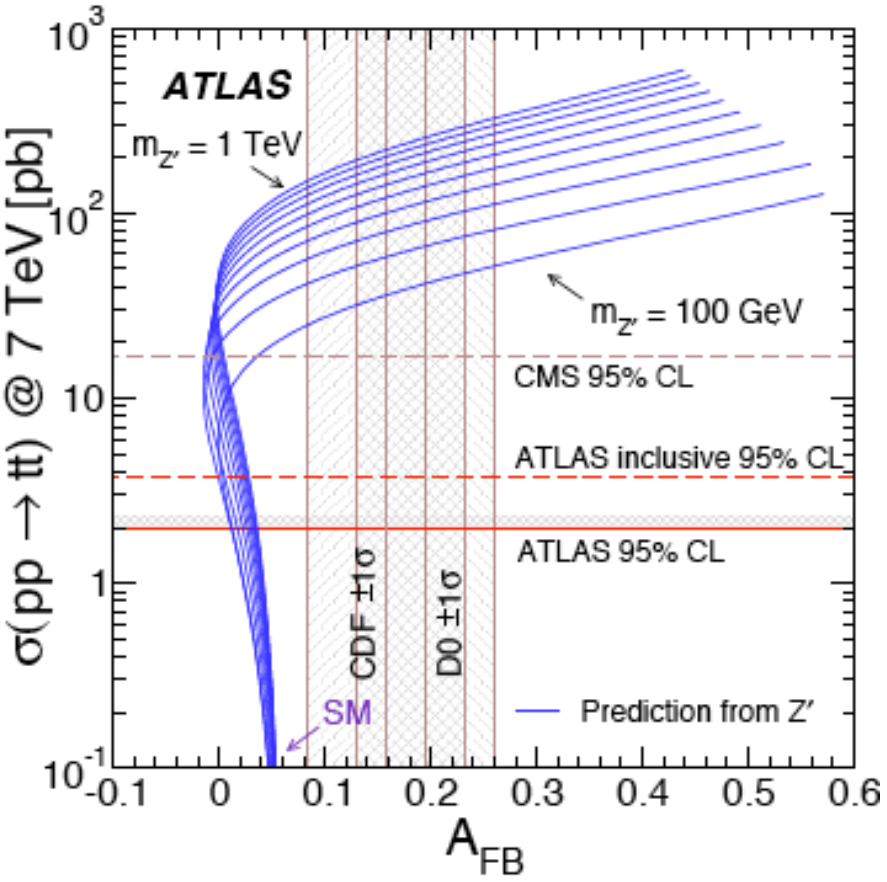


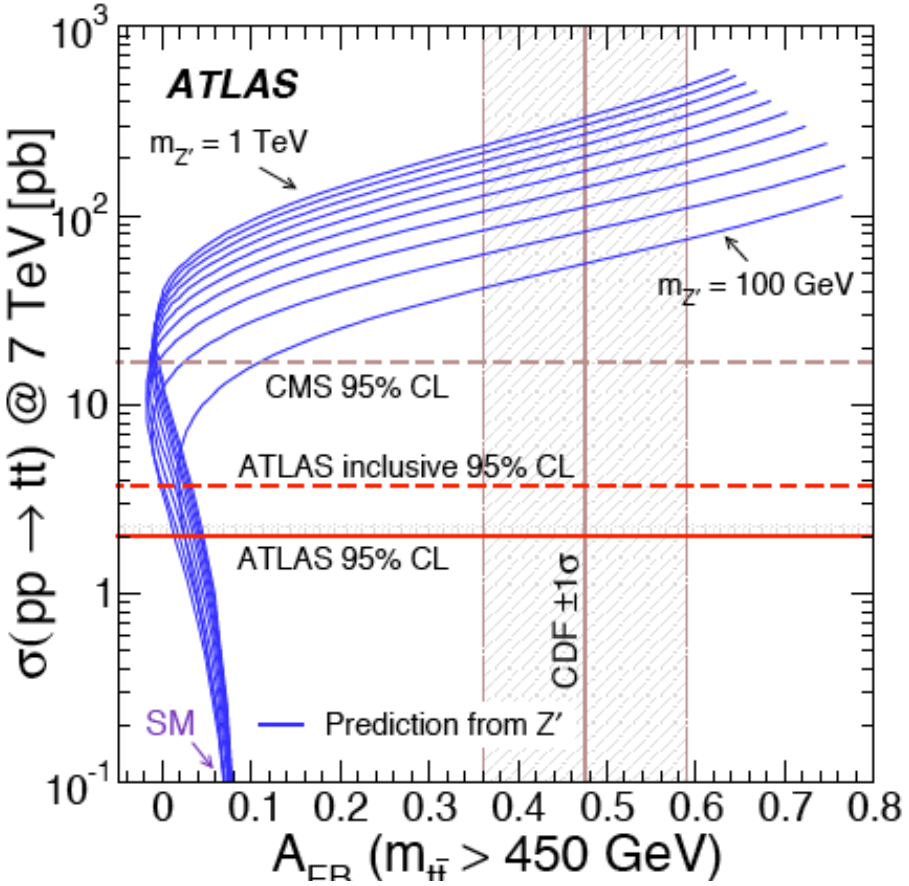






Limits on tt Production





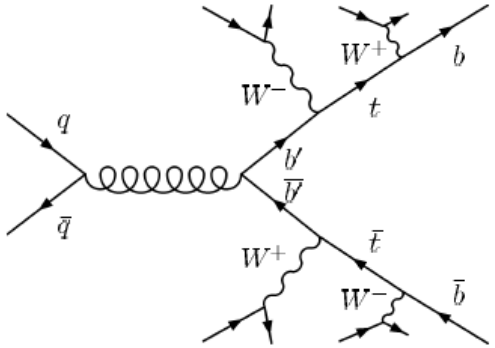
CDF Collaboration, Phys. Rev. D **83**, 112003 (2011).

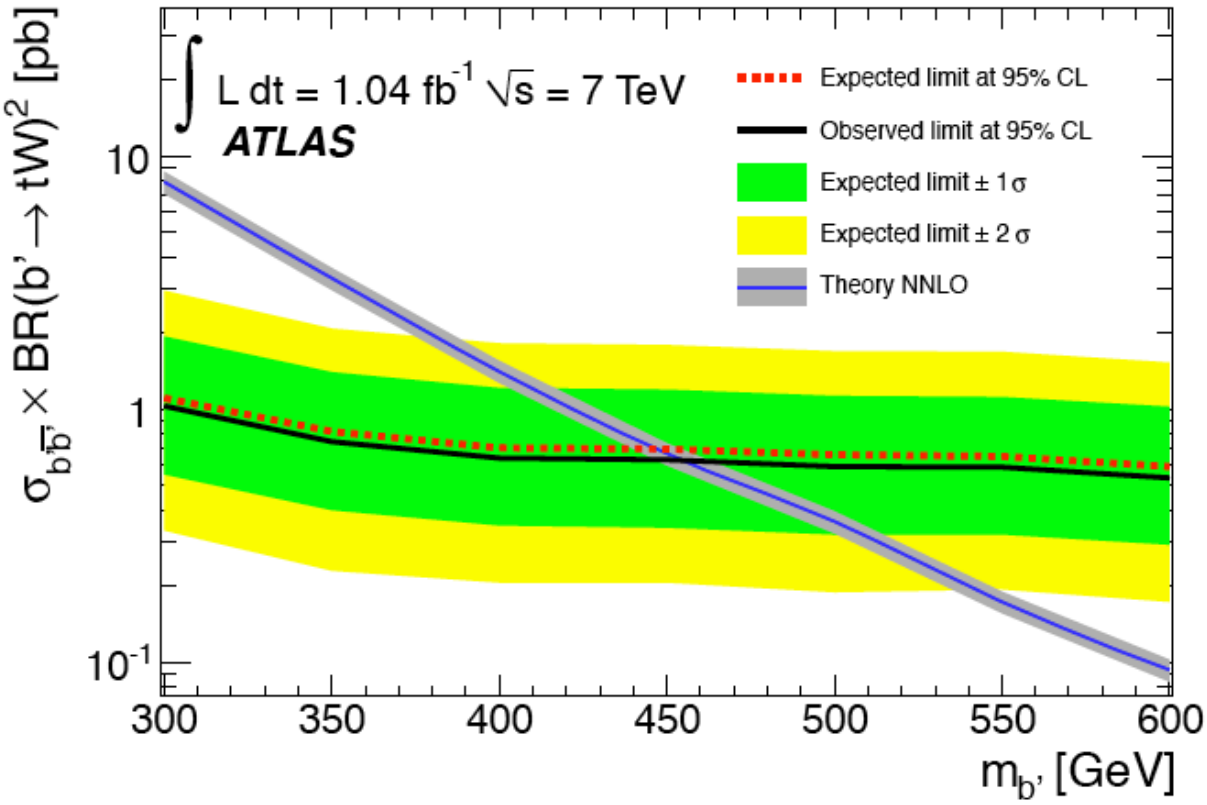
D0 Collaboration, Phys. Rev. D **84** 112005 (2011).

- This model is ruled out as explanation for Tevatron A_{FB} anomaly

Constraints on a b'

- Same analysis used to constrain 4th generation down-type quark decaying to tW
- Now use both ++ and -- pairs

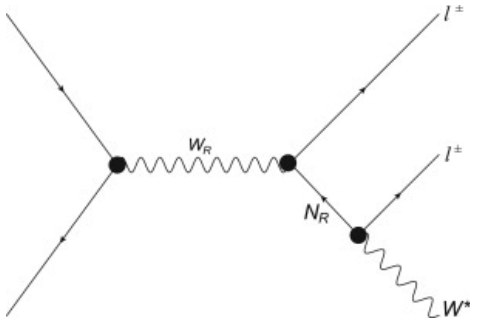




arXiv:1202.5520

W_R and N_R search

- Selection similar to inclusive analysis but
  - 2 leptons (e or μ) with p_T>25 GeV
    - looser isolation cuts
  - Require ≥1 jet with p_T>20 GeV



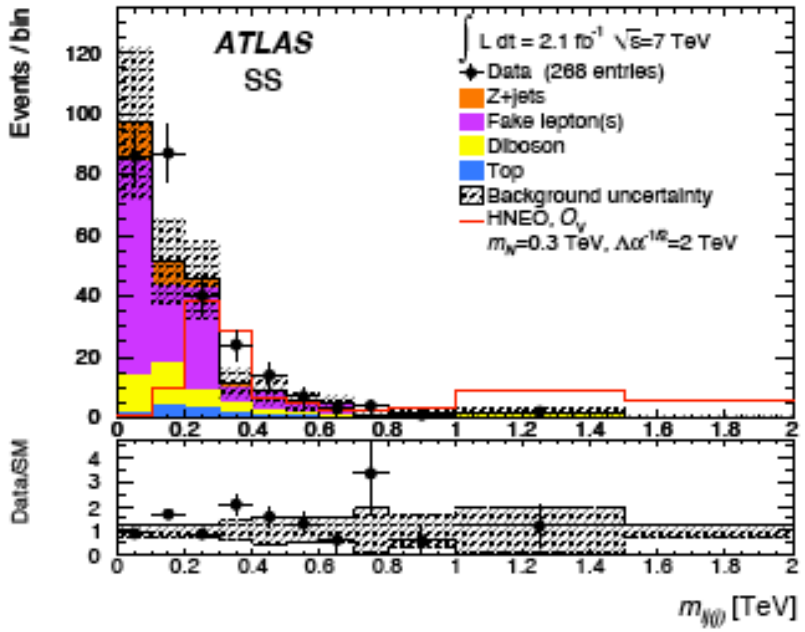
- Fake lepton background dominates for electrons

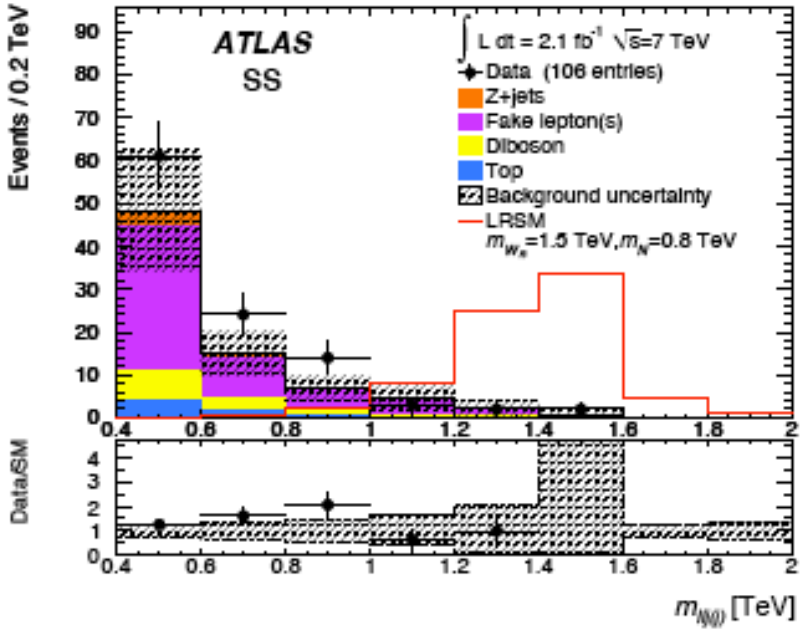
arXiv:1203.5420

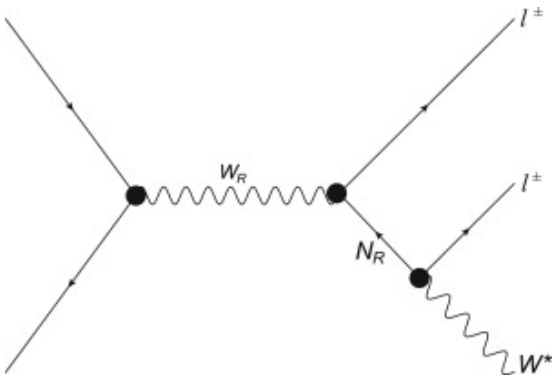
- Data agree with background estimate

Physics Processes	$e^\pm e^\pm$	$\mu^\pm\mu^\pm$	$e^\pm\mu^\pm$	Total
Z/γ^*+jets	26.1 ± 5.6	0.0 $^{+1.6}_{-0}$	1.2 ± 0.7	27 ± 6
Diboson	12.7 ± 2.3	7.2 ± 1.7	18.8 ± 3.0	39 ± 6
Top	5.8 ± 1.3	0.7 ± 0.3	6.8 ± 1.6	13 ± 3
Fake lepton(s)	93.6 ± 35.7	3.1 ± 1.6	53.8 ± 20.3	151 ± 50
Total Background	138.3 ± 36.5	11.0 $^{+2.9}_{-2.5}$	80.7 ± 20.8	230 ± 52
Observed events	155	14	99	268
	$m_{\ell\ell j(j)} \geq 400$ GeV			
Total Background	48.4 ± 16.1	4.4 $^{+2.1}_{-1.3}$	24.6 ± 7.6	77 ± 21
Observed events	59	8	39	106

W_R and N_R Search

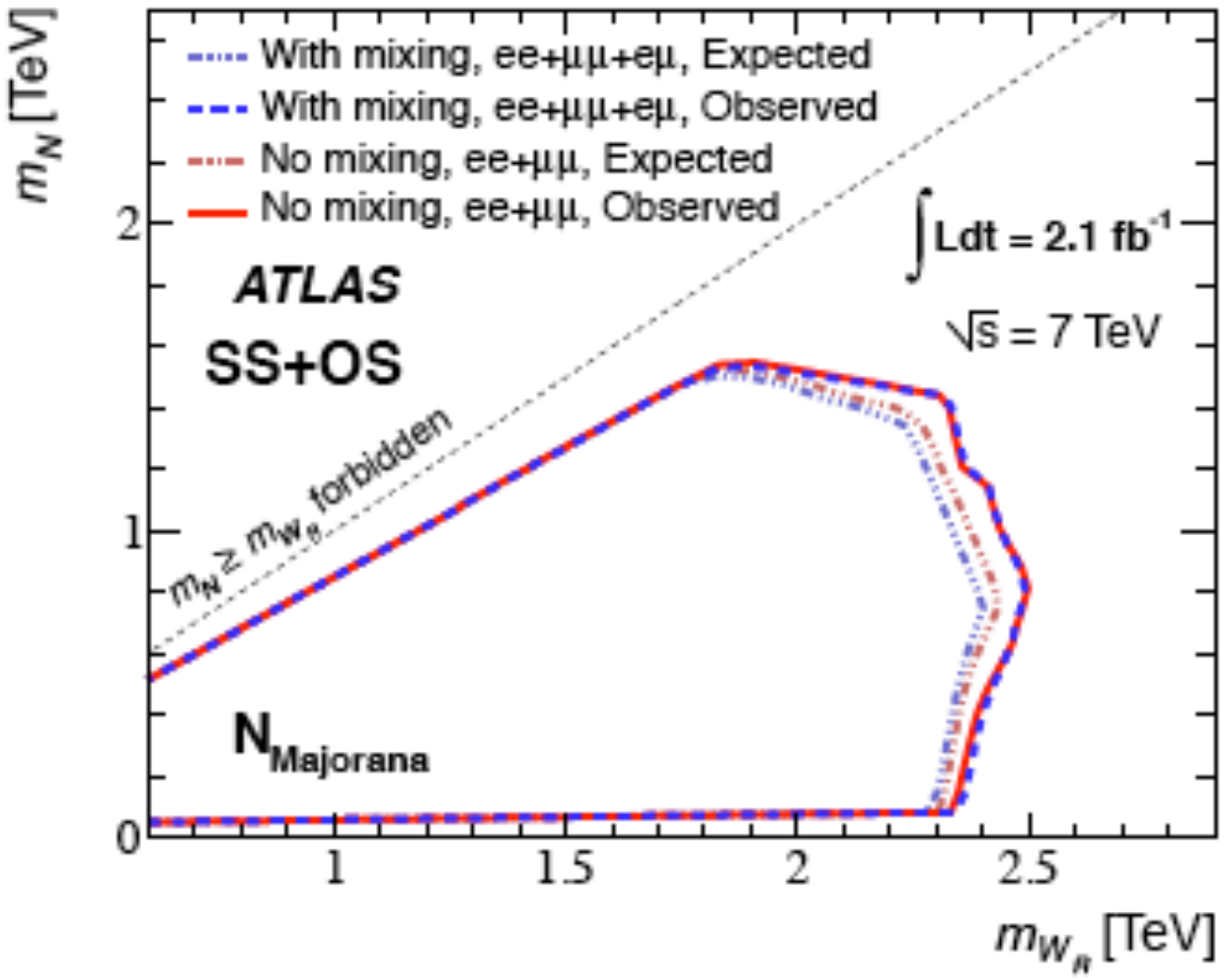






- Scan invariant mass of lj(j) and llj(j) systems
  - Correspond to N_R and W_R systems
- set limits in 2D parameter space

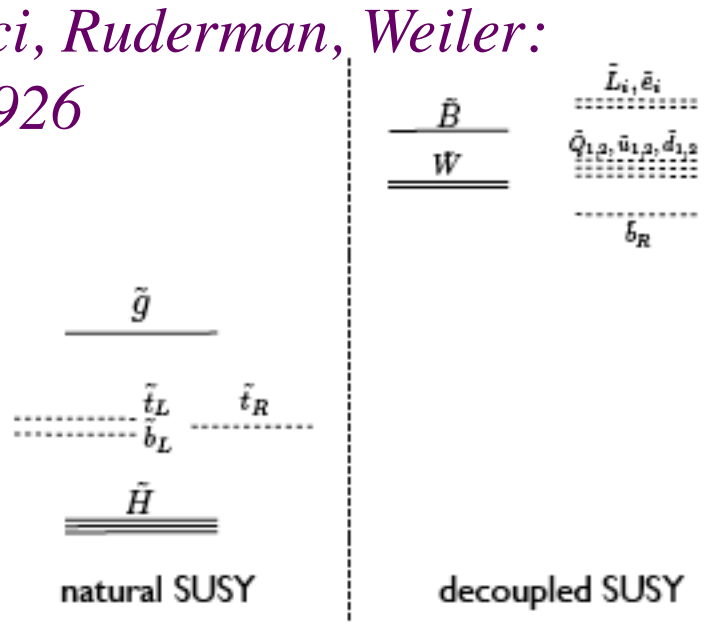
Limits on W_R and N_R production

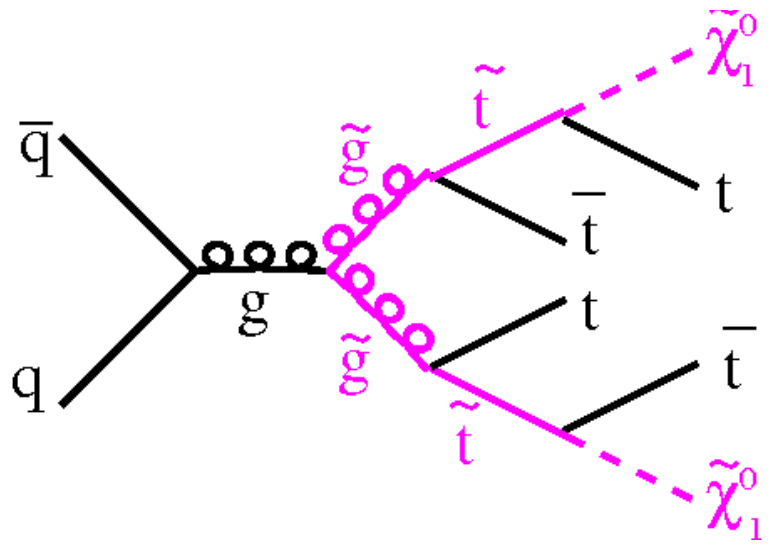


- Exclude up to $m(W_R)<2.4$ TeV and $m(N_R)<1.4$ TeV

Gluinos decaying via stop quarks

Papucci, Ruderman, Weiler: 1110.6926

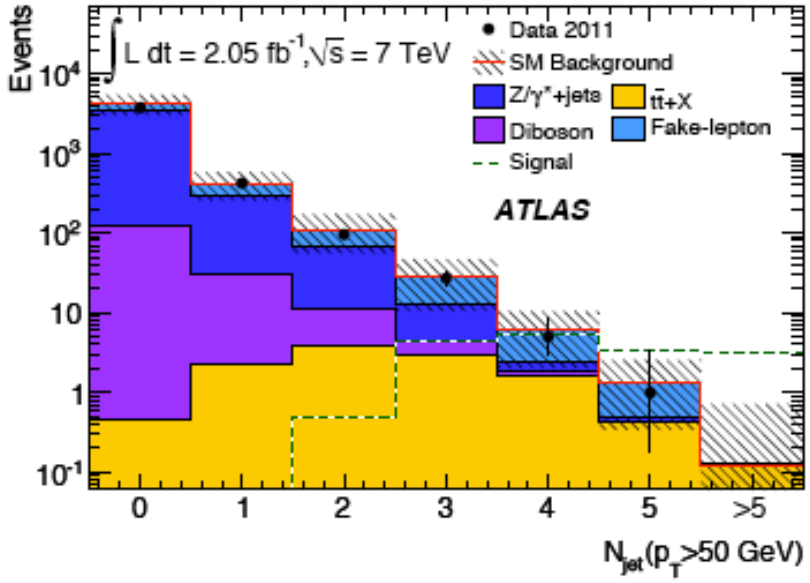


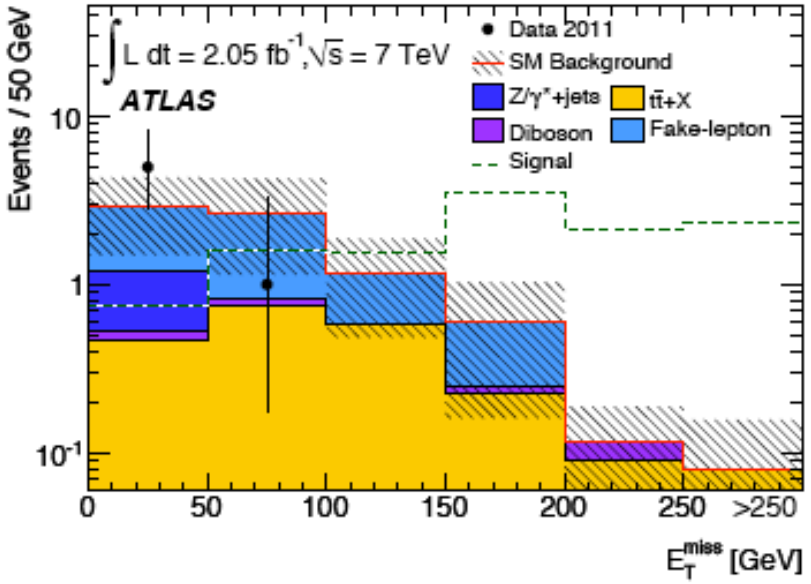


- Received a lot of attention as stop quark most critical for preserving natural SUSY
- Final state contains 4 W-bosons and 4 b-jets
  - Like-sign signature promising avenue due to small SM backgrounds

Same-sign search for gluino->stop

- Selection SR1:
  - 2 electrons or muons with p_T>20 GeV
  - 4 jets with p_T>50 GeV
  - E_T^{miss}>150 GeV
- Selection SR2:
  - As SR1 +
  - m_T>100 GeV



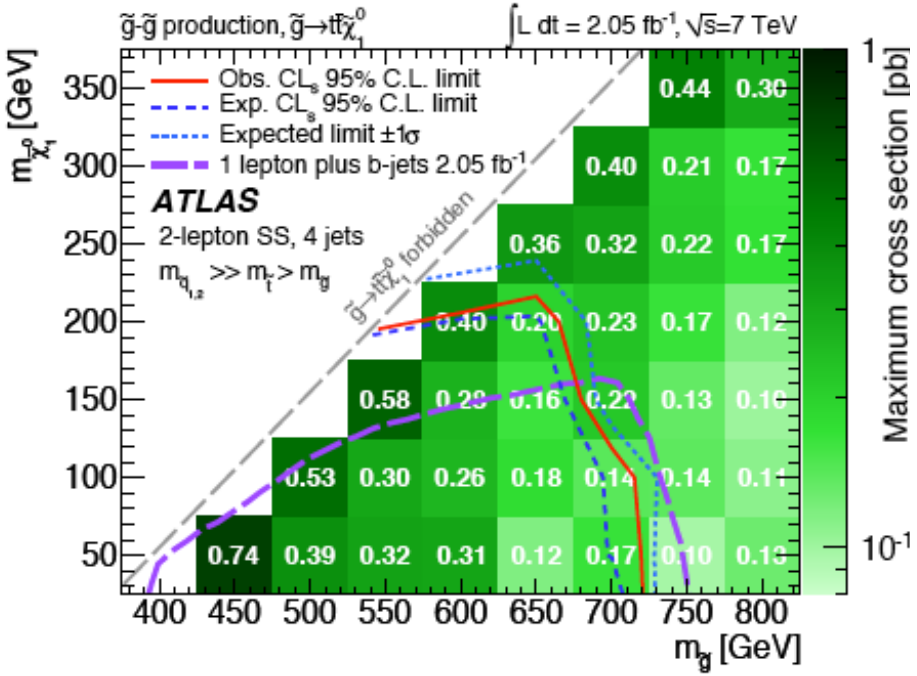


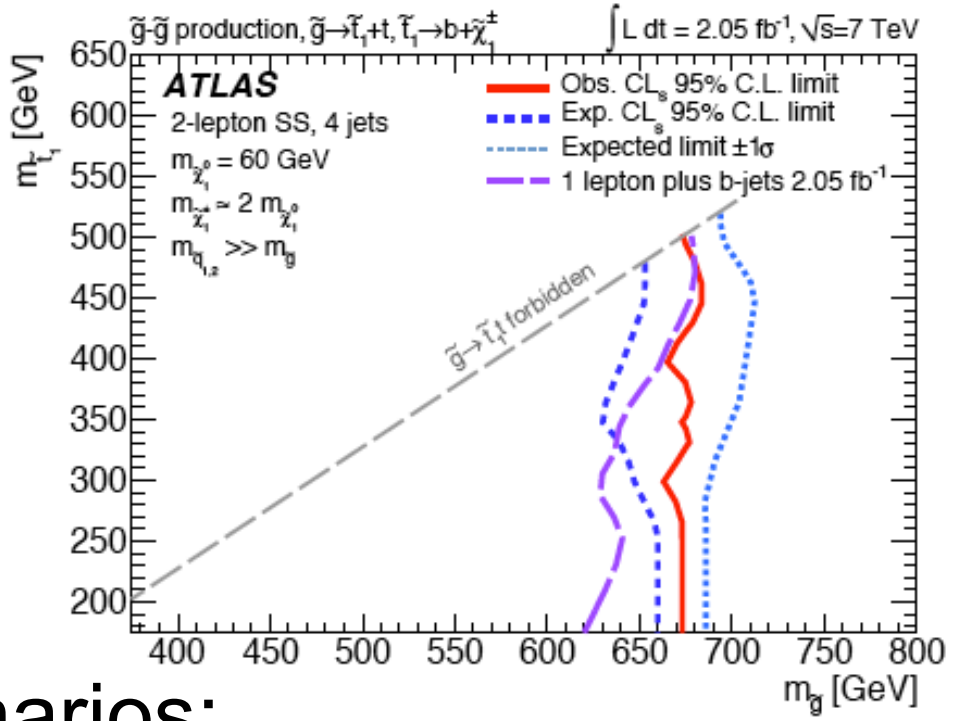
Results of Same-sign Gluino->stop search

	SR1	SR2
$t\bar{t}$ +X	0.37 ± 0.26	0.21 ± 0.16
Diboson	0.05 ± 0.02	0.02 ± 0.01
Fake-lepton	0.34 ± 0.20	< 0.17
Charge mis-ID	0.08 ± 0.01	0.039 ± 0.007
Total SM	0.84 ± 0.33	0.27 ± 0.24
Observed	0	0
$\sigma_{\text{vis}}^{\text{obs}}$ [fb]	<1.6	<1.5
$\sigma_{\text{vis}}^{\text{exp}}$ [fb]	$<1.7^{+0.5}_{-0.1}$	$<1.6^{+0.2}_{-0.1}$

- Largest background from ttW production
  - Only very recently calculated at NLO by K. Ellis and J. Campbell (thanks!!)
- No data events observed after cuts

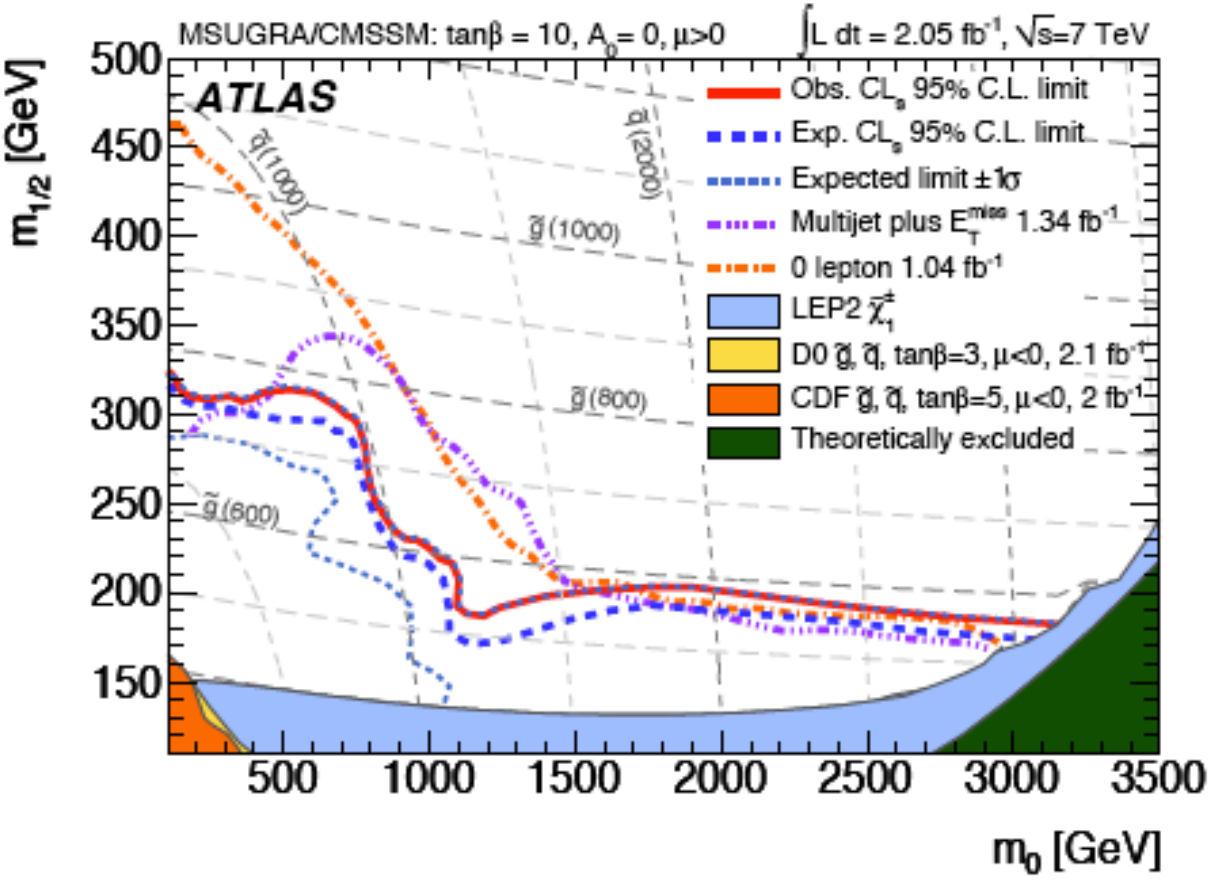
Results of Same-sign Gluino->stop search





- Interpreted in two scenarios:
  - a) M(stop)>m(gluino)>m(LSP)
    - constraints on gluino mass versus m(LSP)
  - b) M(gluino)>m(stop)>m(LSP)
    - constraints on gluino mass versus m(stop) at fixed m(LSP)

mSUGRA Interpretation



- Like-sign gluino/stop search also interpreted in mSUGRA
- Limits quite competitive in large m_0 region

Conclusions and Outlook

- The same-sign dilepton signature is a sensitive probe of new physics
- ATLAS has carried out many searches for a broad range of models
- Data agree with the background expectation in all cases based on 1-2/fb
  - Final $\sqrt{s}$=7 TeV 2011 data analysis of 5/fb is ongoing
  - 2012 data at $\sqrt{s}$=8 TeV is poring in!