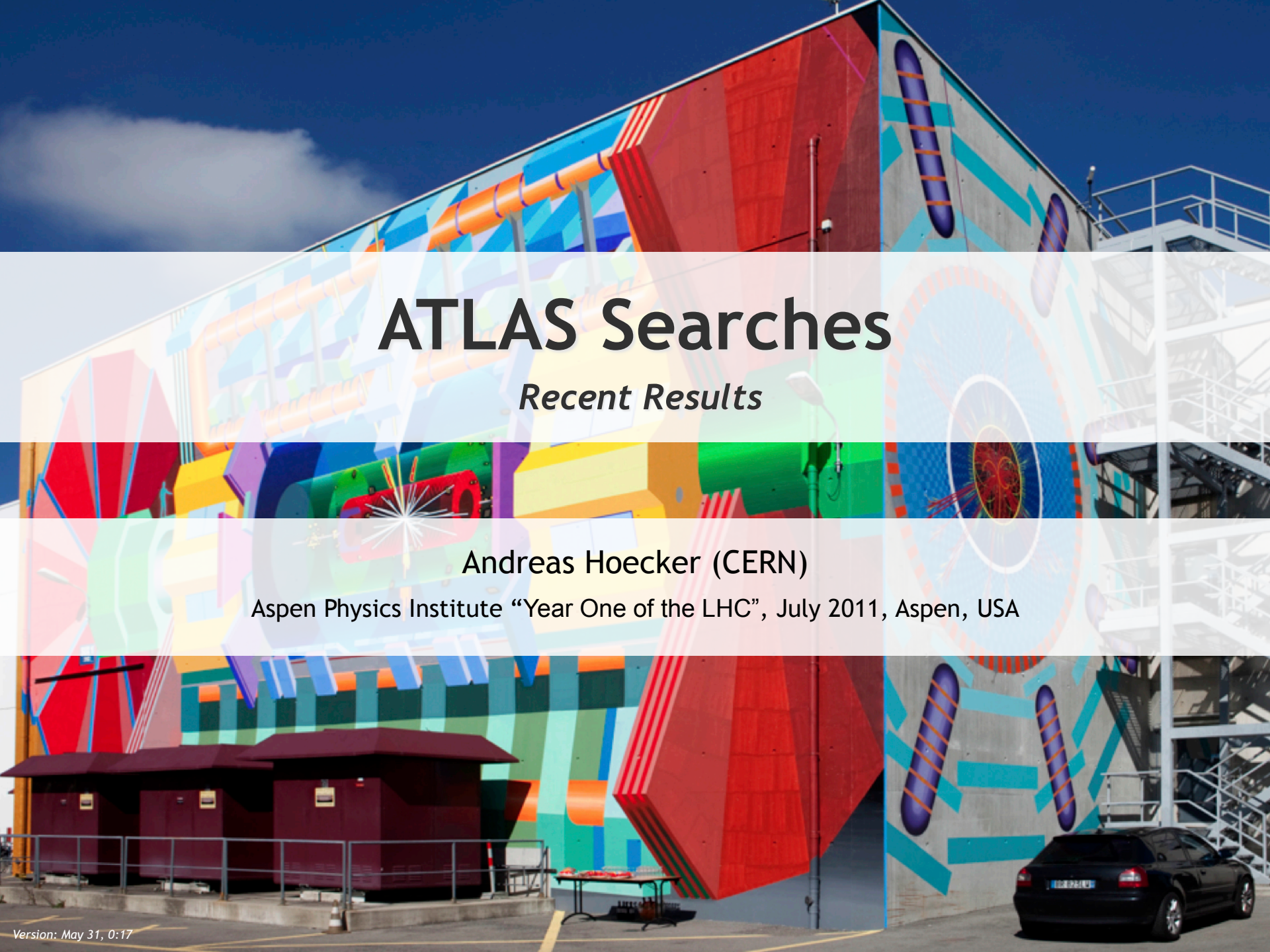




ATLAS Searches

Recent Results

Andreas Hoecker (CERN)

Aspen Physics Institute “Year One of the LHC”, July 2011, Aspen, USA

The LHC proton-proton Physics Programme

1. Mass and electroweak symmetry breaking

- Search for the Higgs Boson, measurement of its properties

2. Hierarchy in the TeV domain

- Search for new phenomena moderating the hierarchy problem
- Search for the unexpected at the high-energy frontier

3. Electroweak unification and strong interactions

- Precision measurements (M_W , m_{top}) and tests of the Standard Model
- Tests of perturbative QCD at the high-energy frontier

4. Flavour

- B , D mixing, rare decays and CP violation as tests of the Standard Model

The LHC proton-proton Physics Programme

This talk

1. Mass and electroweak symmetry breaking

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4. Flavour

- B , D mixing, rare decays and CP violation as tests of the Standard Model

Most results shown still based on 2010 dataset of 35-43 pb⁻¹ luminosity, though more and more analyses updated to 2011
→ EPS, LP !

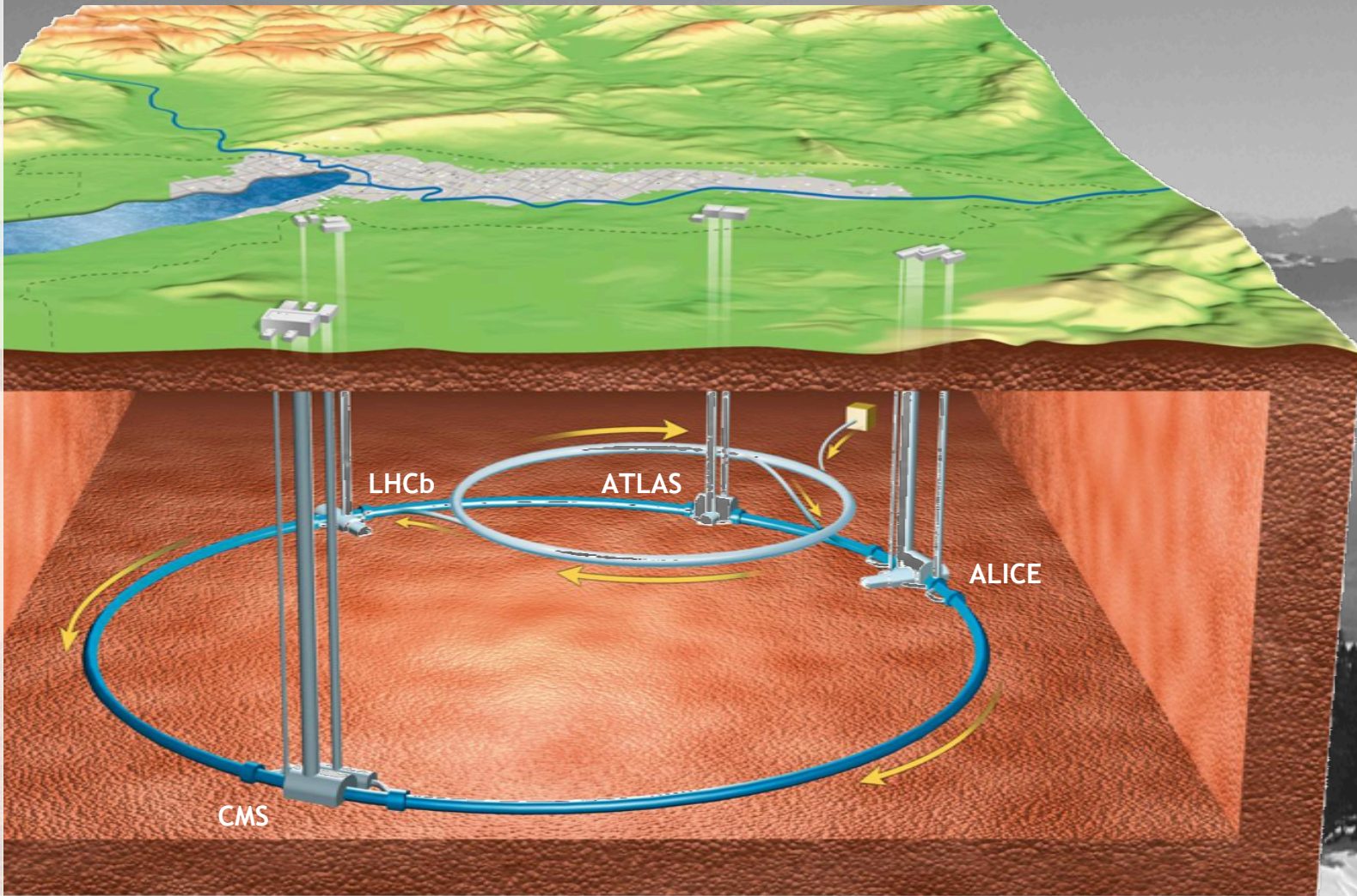
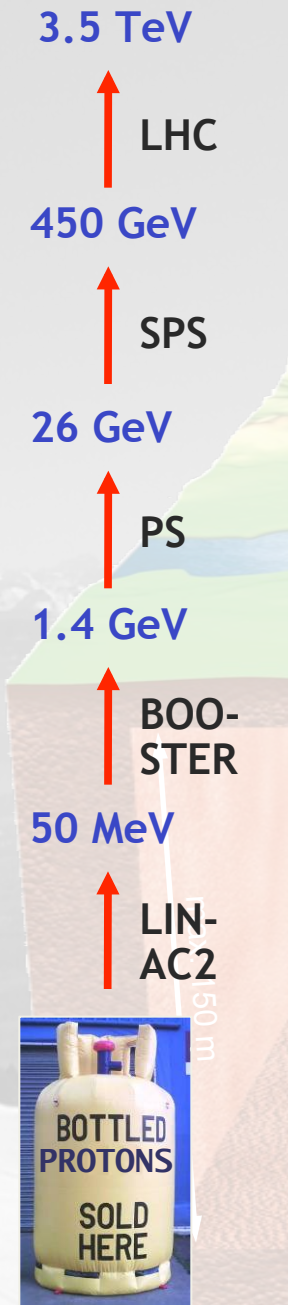
Almost all search analyses require data-driven estimates of backgrounds from data control regions and transfer functions using simulation → this is the primary analysis challenge!

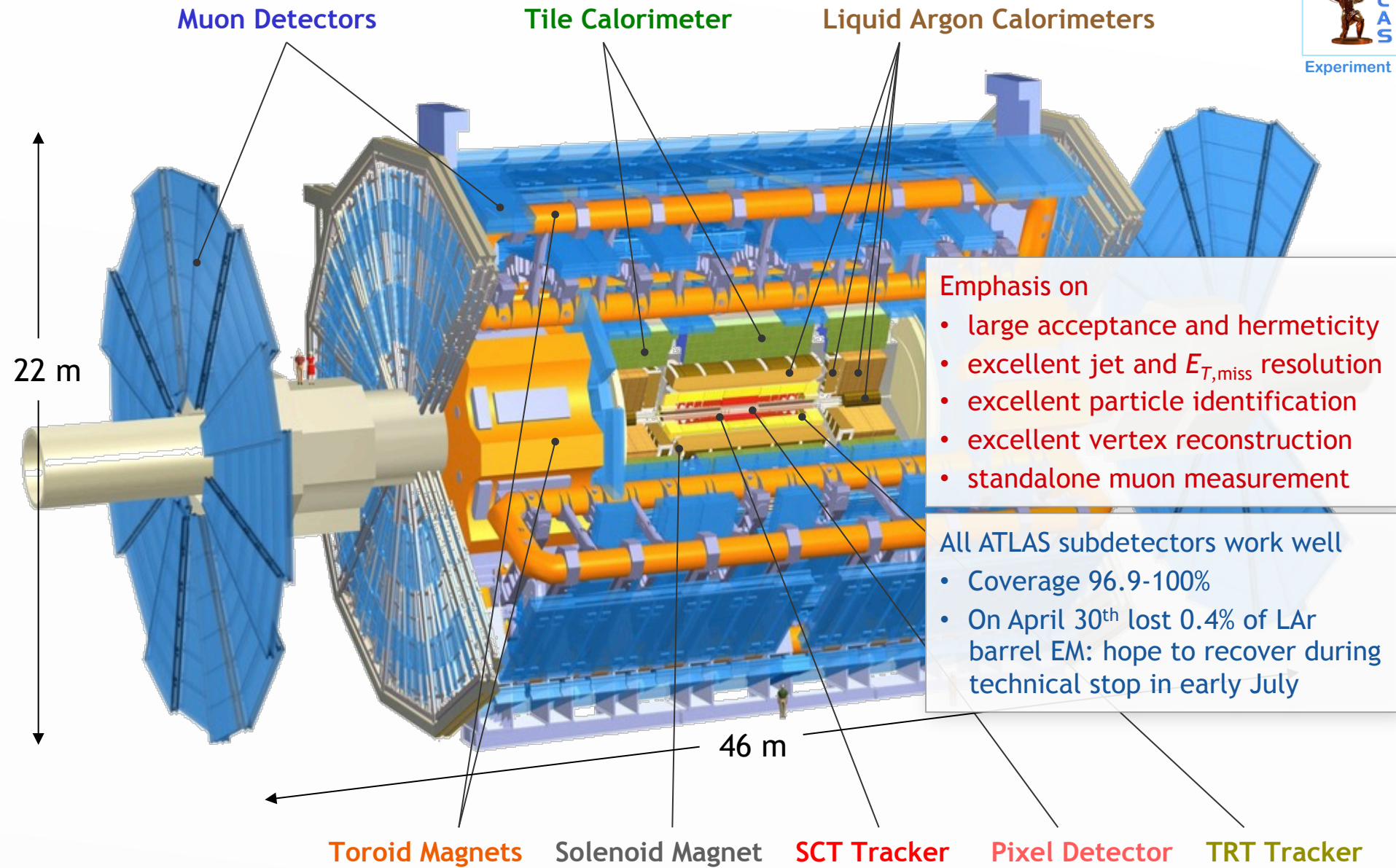
These estimates rely on pioneering Standard Model measurements in ATLAS and accurate preparation work by the ATLAS physics objects and trigger groups.

Full list of ATLAS results: <http://twiki.cern.ch/twiki/bin/view/AtlasPublic>

The LHC at CERN

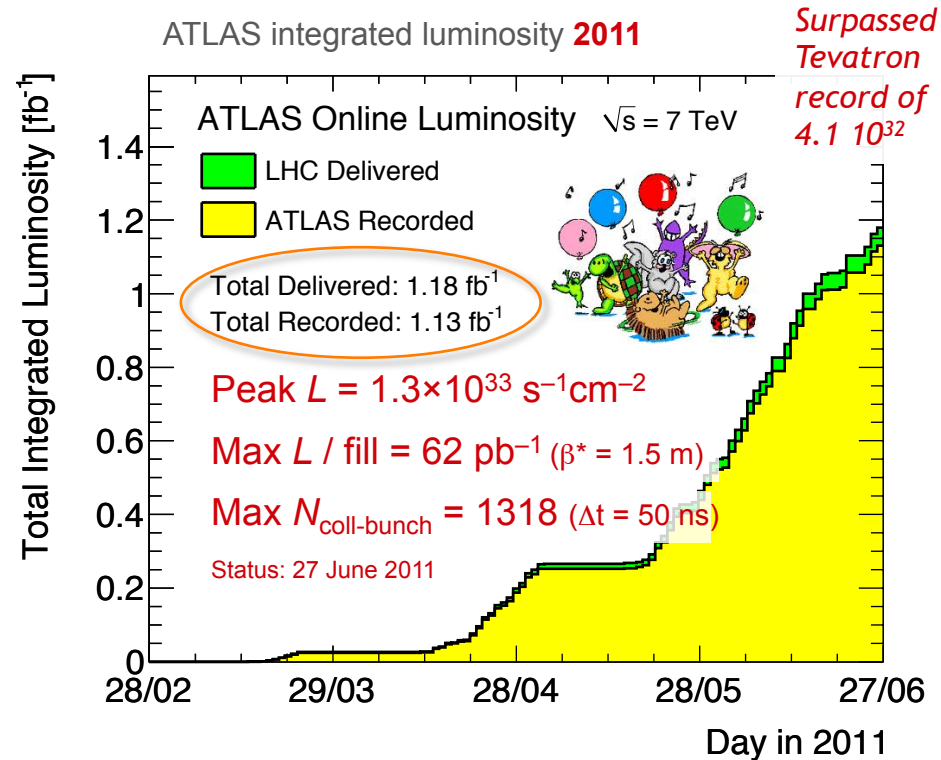
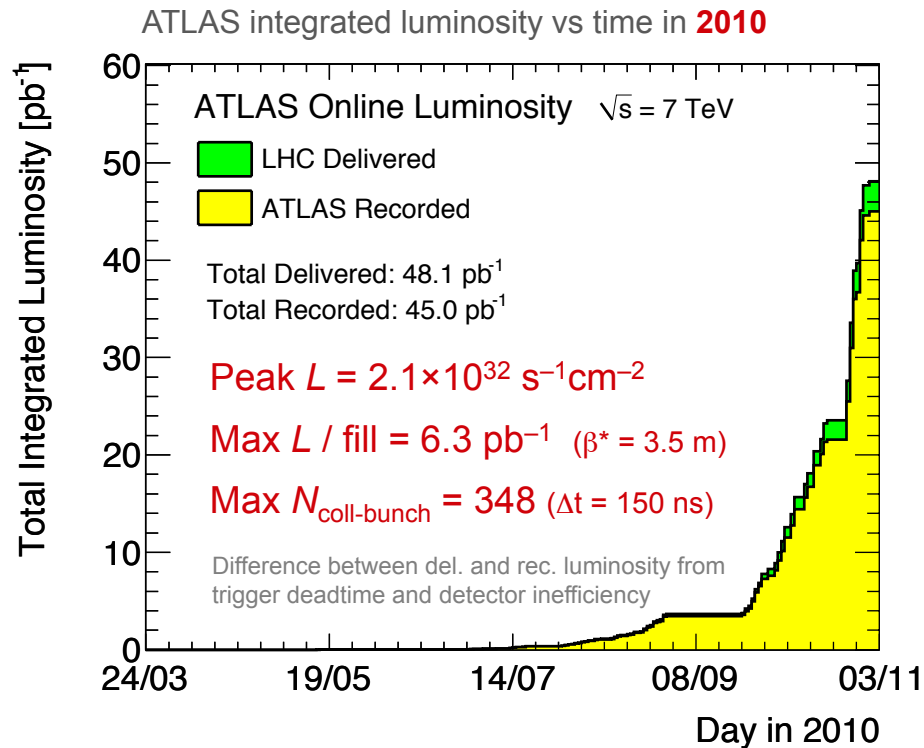
4 large experiments: ATLAS, CMS, LHCb, ALICE





Recorded Luminosity in 2010 and 2011

Measured with forward detectors, calibrated with beam separation scans



95.8% data-taking efficiency

- Loose 1.6% at turn-on at start of stable beams
- Loose 2.6% due to deadtime

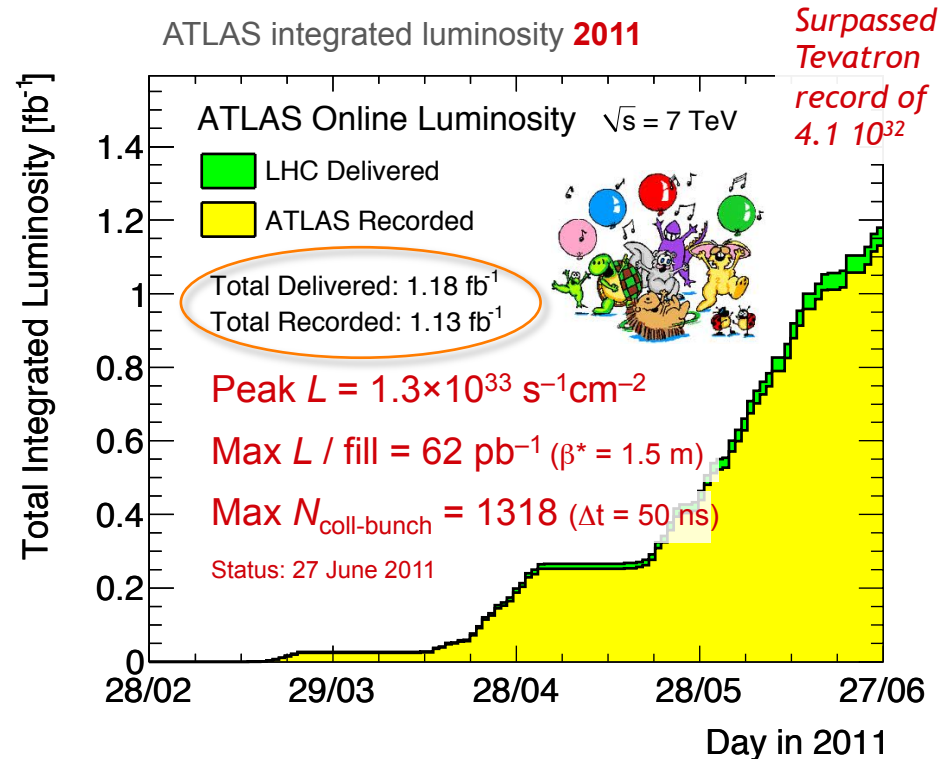
Recorded Luminosity in 2010 and 2011

Measured with forward detectors, calibrated with beam separation scans

At $L = 10^{33} \text{ s}^{-1}\text{cm}^{-2}$, produce 1 SM Higgs boson with 115 (150) GeV every 48 (83) seconds in ATLAS and CMS $\rightarrow$ 75 (43) Higgs bosons per hour

Tevatron @ 115 GeV: 2 per hour at max luminosity

$10^{33} \text{ cm}^{-2}\text{s}^{-1}$ instantaneous luminosity corresponds to an integrated luminosity of 3.6 pb^{-1} per hour $\rightarrow 1.8 \text{ fb}^{-1}$ per month (assuming design 70% LHC efficiency for physics – not presently achieved)



95.8% data-taking efficiency

- Loose 1.6% at turn-on at start of stable beams
- Loose 2.6% due to downtime

Pileup

The high luminosity comes to the price of multiple interactions per crossing

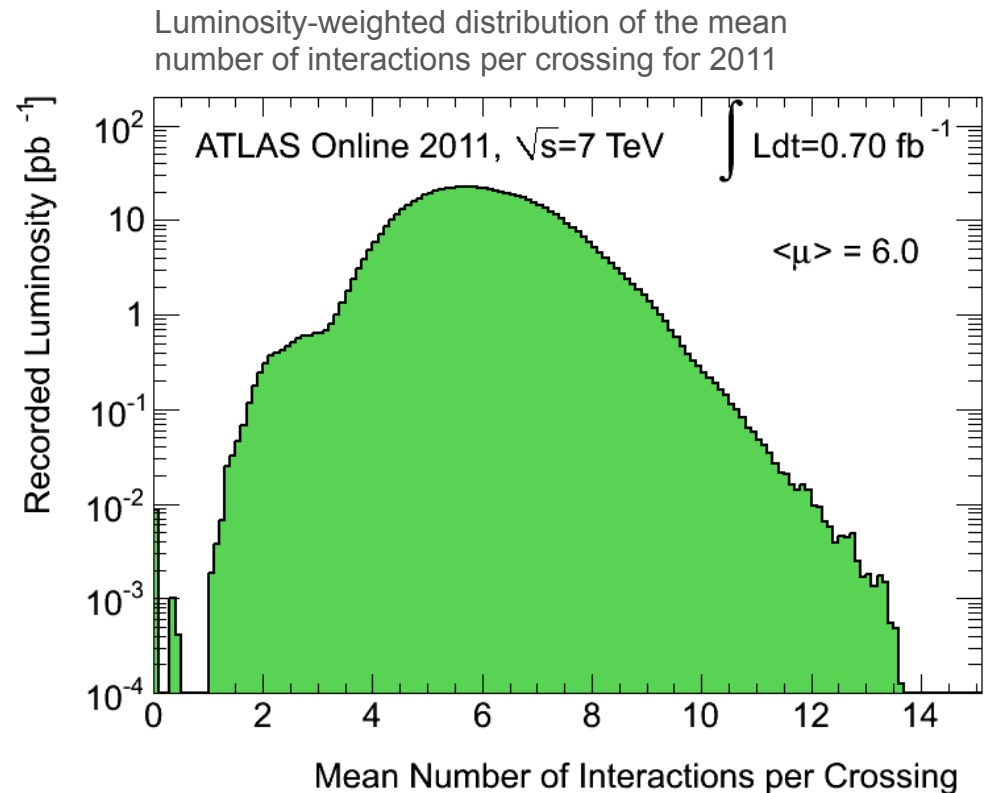
arXiv:1101.2185

Pileup in 2011 is on average $\langle\mu\rangle=6$ interactions per crossing

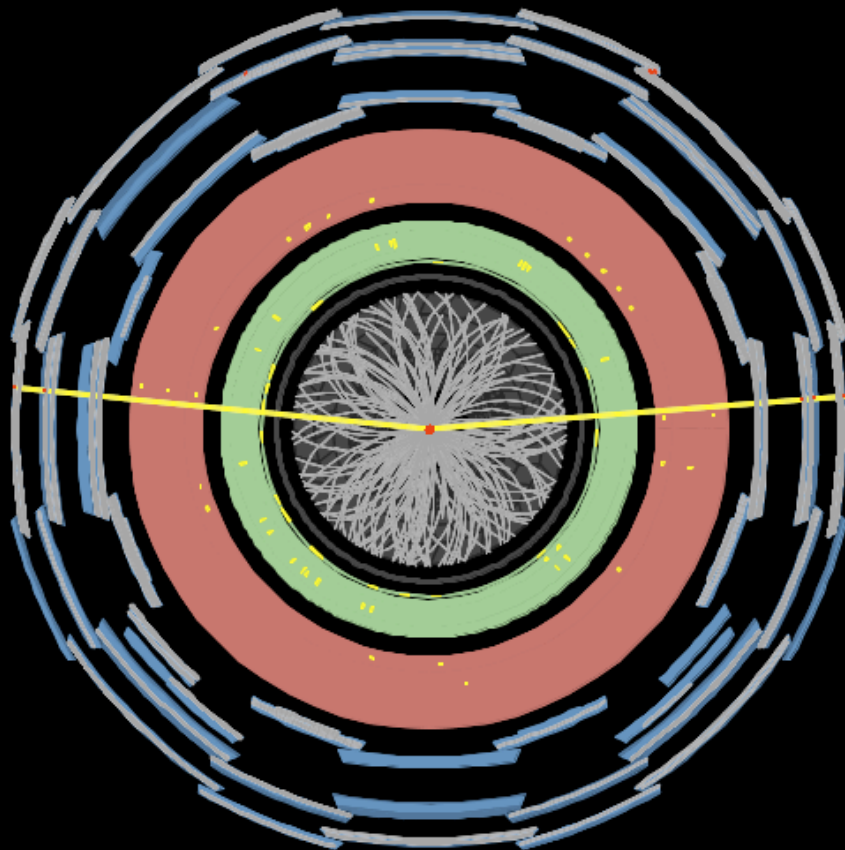
- Significantly higher than 2010
- Tails up to 14 interactions per crossing

Causes challenge for physics analyses and software

- Detailed simulation models both the $\langle\mu\rangle$ and the bunch train structure (*detailed enough?*)
- Software performance improved to accommodate Tier-0 resources (reco time 11-13s/event)
- Physics performance reasonably unaffected

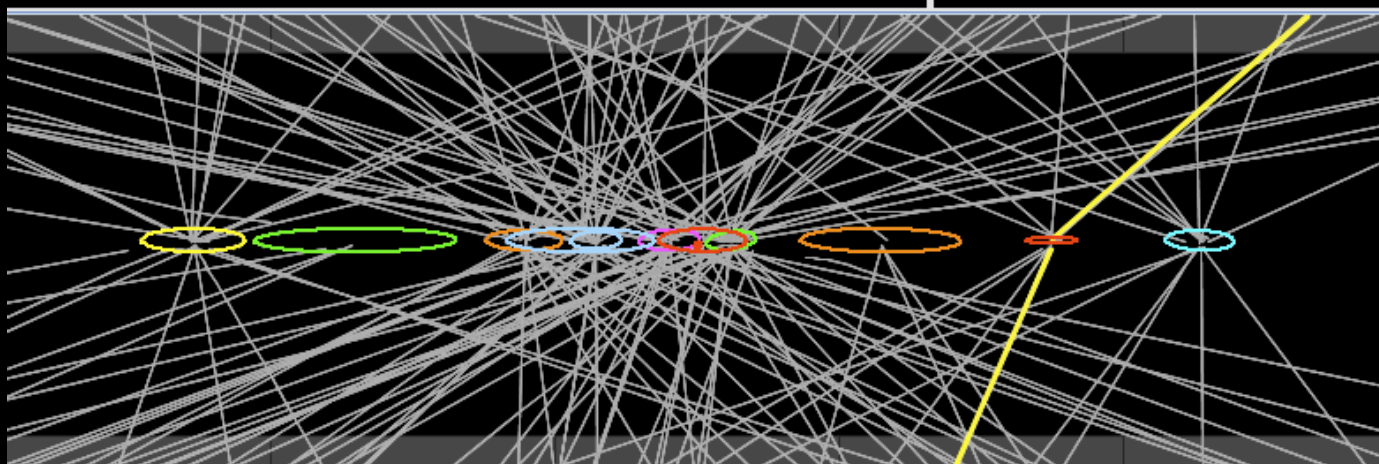
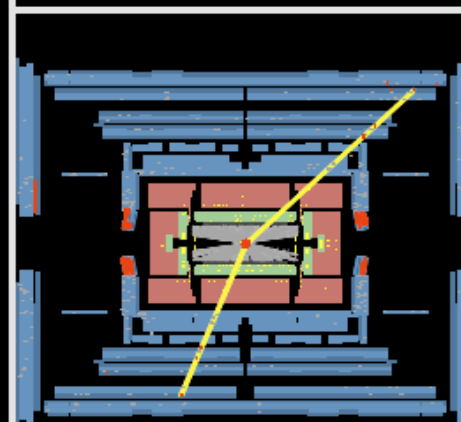


A candidate Z boson event in the dimuon decay with 11 reconstructed vertices



Run Number: 180164, Event Number: 146351094

Date: 2011-04-24 01:43:39 CEST



Trigger

Higher thresholds in 2011 than in 2010

Trigger menu kept stable

- Primary triggers never prescaled
- Supplemented by supporting and monitoring triggers

Typical output rates:

- L1: 60 kHz, L2: 5 kHz, EF: 300-400 Hz
- EF output rate constrained by offline resources
- Can predict rates with ~20% accuracy

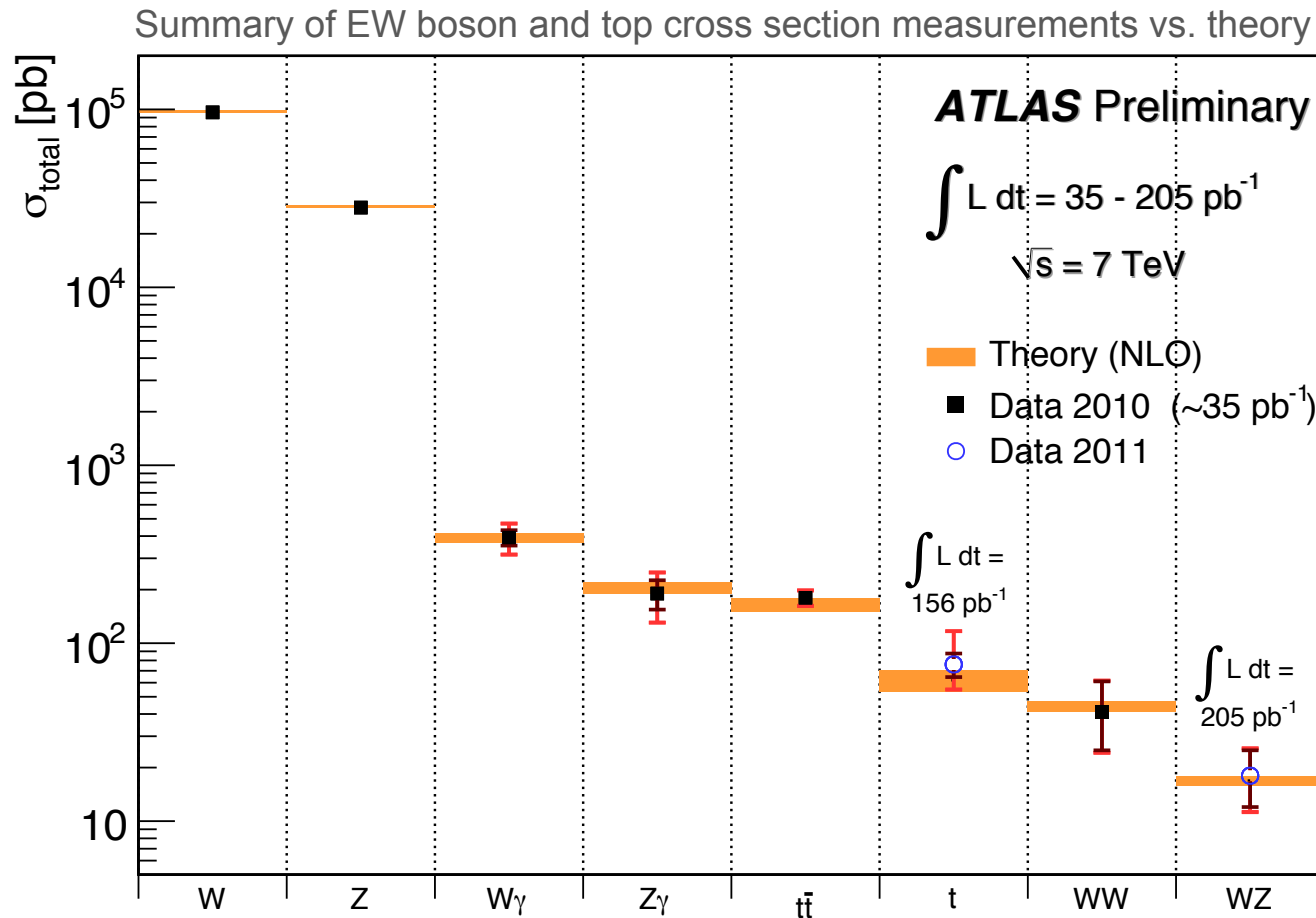
Performance of trigger well understood

Unprescaled trigger rates at $L=1 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$

trigger	L1 item	L1 Rate (Hz)	EF Rate (Hz)
E20_medium	EM14	8500	50
2e12_medium	2EM7	5700	1
g80_loose	EM30	700	3
2g20_loose	2EM14	750	2
mu18	MU10	5300	40
2mu10	2MU10	100	1
xe60	XE40	300	4
J180	J75	200	6
Tau29medium_xe35	TAU11_XE20	3800	6
Tau16_e15	TAU6_EM10	7500	6
J75_xe45	J50_XE20	500	10

Electroweak and QCD measurements

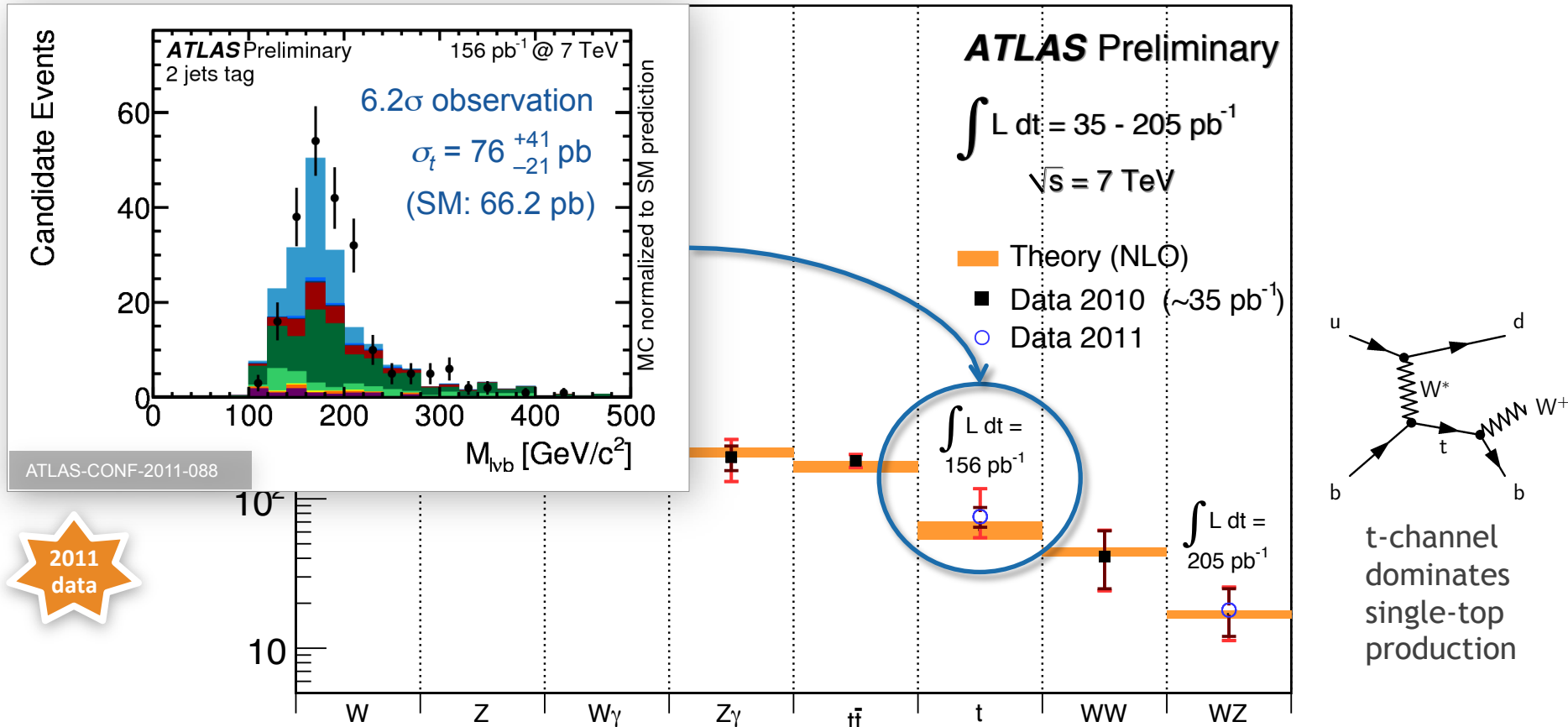
Lots of truly novel results at unexplored centre-of-mass energies



Electroweak and QCD measurements

Lots of truly novel results at unexplored centre-of-mass energies

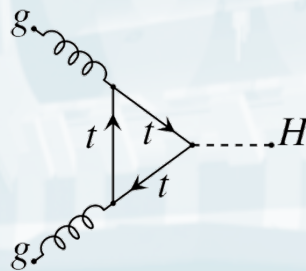
Summary of EW boson and top cross section measurements vs. theory



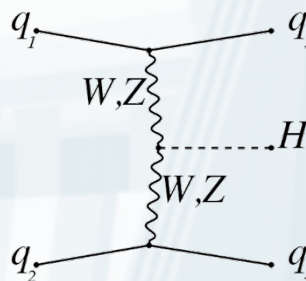
mass

Higgs boson searches

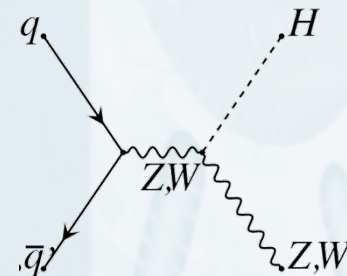
Standard Model and Beyond



$$\sigma_{M=120} = 16.6 \text{ pb (87\%)}$$



$$\sigma_{M=120} = 1.3 \text{ pb (7\%)}$$



$$\sigma_{M=120} = 1.0 \text{ pb (5\%)}$$

[arXiv:1101.0593]

$$\left. \begin{array}{l} \sigma(qq' \rightarrow W/Z + H) \sim 10 \\ \sigma(gg \rightarrow H) \sim 40 - 50 \end{array} \right\} \times \text{larger at LHC than Tevtron}$$

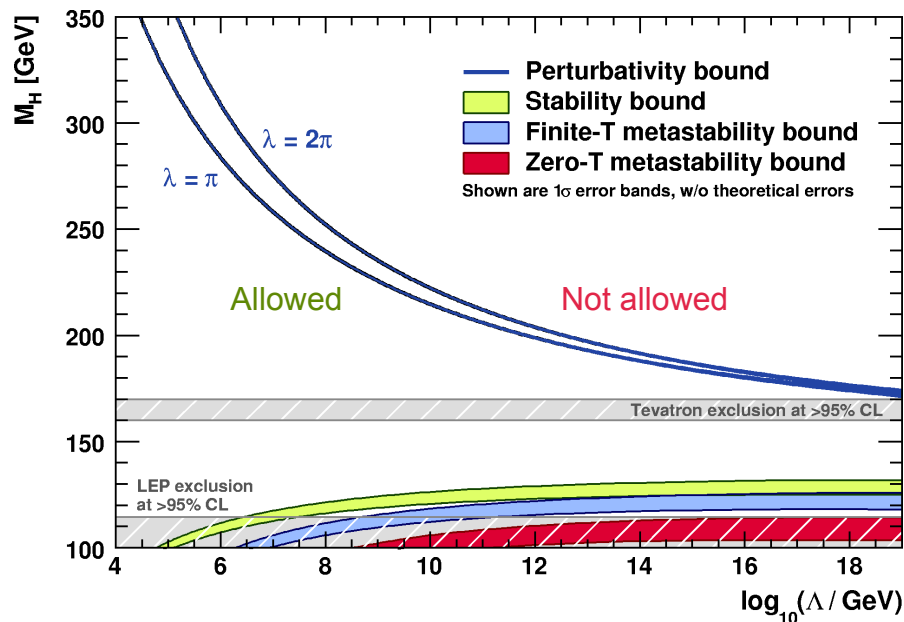
Theoretical and indirect exp. Higgs constraints

The Higgs boson should be light but not too light...

J. Ellis et al., arXiv:0906.0954

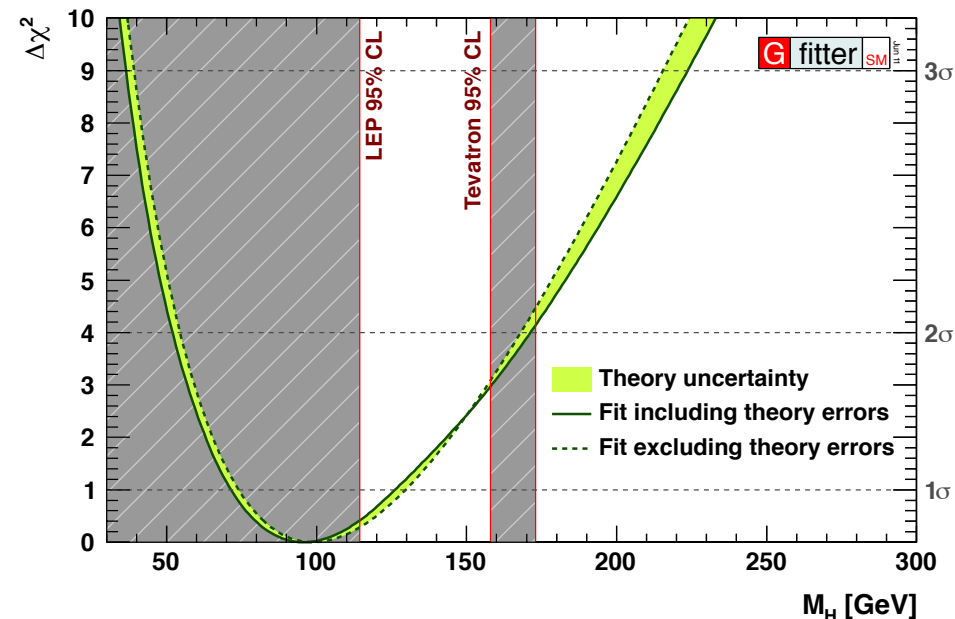
<http://cern.ch/gfitter>

Perturbativity and (meta)stability bounds
versus the SM cut-off scale Λ



The SM Higgs must steer a narrow course
between two disastrous situations if it is to
survive up to the Planck scale $M_P \sim 2 \times 10^{18}$ GeV

EW fit **not** including direct Higgs searches



Central value $\pm 1\sigma$: $M_H = 96^{+31}_{-24}$ GeV
95% CL upper limit: 169 GeV

Theoretical and indirect exp. Higgs constraints

The Higgs boson should be light but not too light...

In the Standard Model the Higgs must be light.

BUT: Beyond the Standard Model the Higgs can be heavy !

→ MUST ALSO search for a heavy Higgs boson !

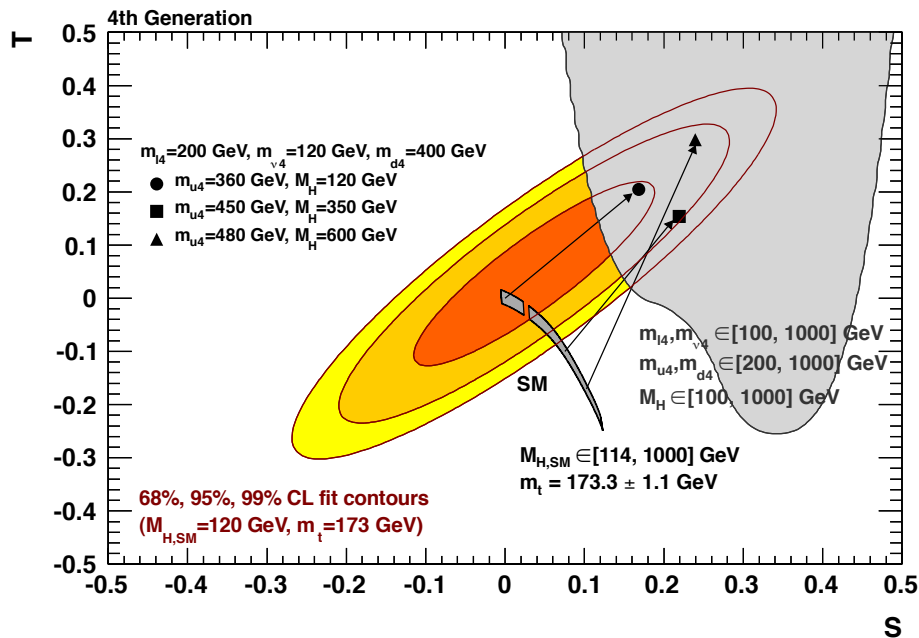
[New physics scale can be low, and weak-isospin violating new physics contributions may cancel heavy Higgs effects on electroweak precision data]

Higgs mass constraint in SM extensions

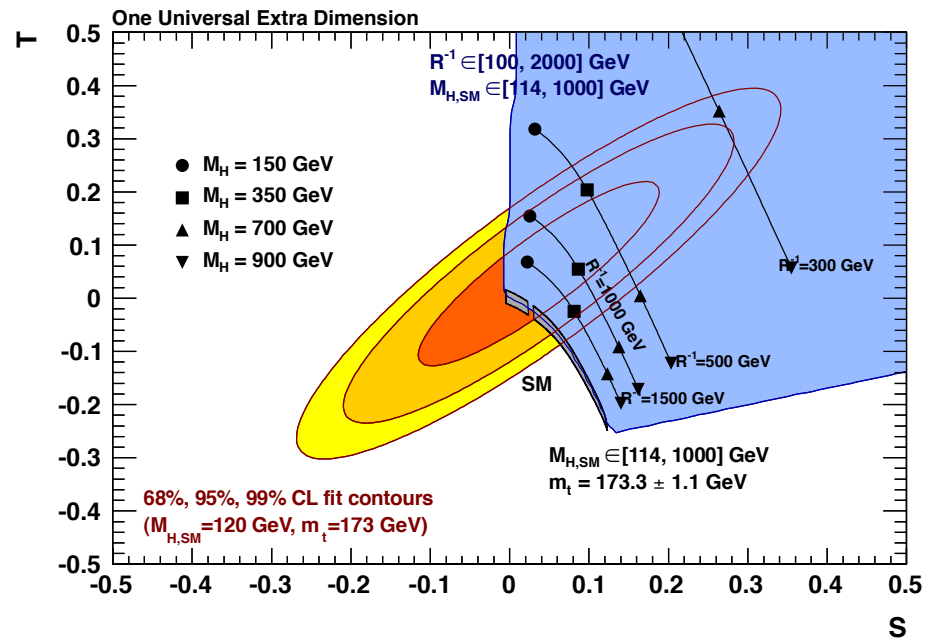
With sufficient weak isospin violation, Higgs can become heavy

<http://cern.ch/gfitter>

Constraint in S, T plane in sequential 4th gen.

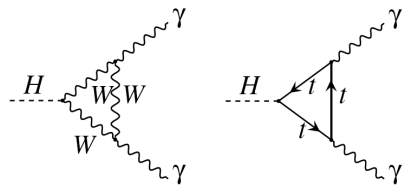
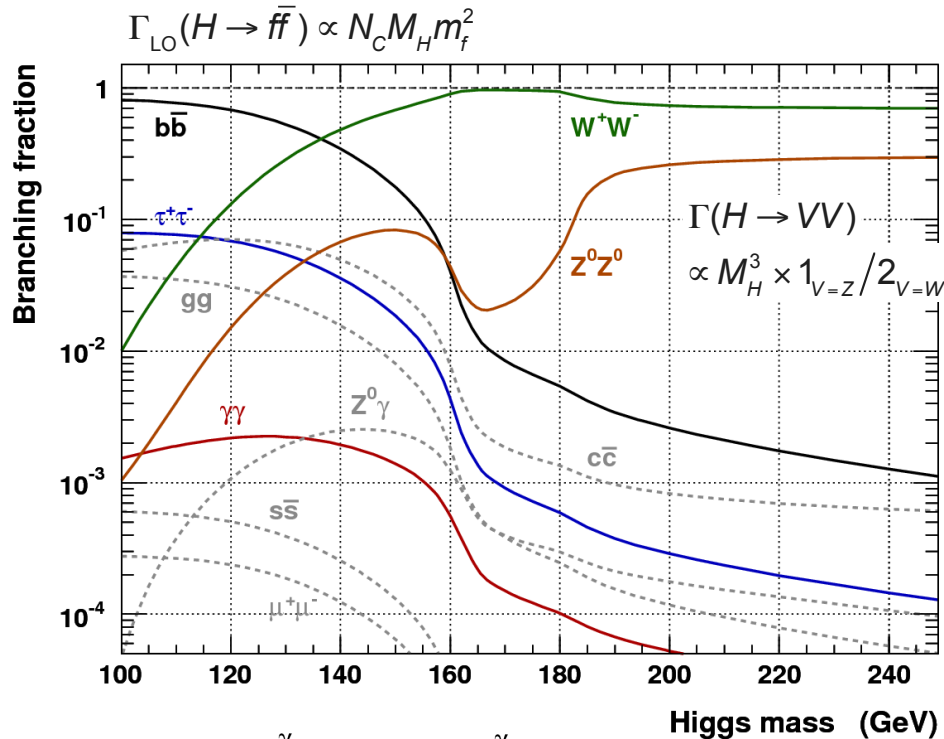


Constraint in S, T plane in UED



Higgs Searches at the LHC

Dependence of the branching fractions on M_H drives search strategy



$$\Gamma(H \rightarrow \gamma\gamma) \propto \alpha^2 \cdot M_H^3 \cdot \left| N_c Q_t^2 A_t^H + A_W^H \right|^2$$

For **heavy Higgs**:

- Lepton final states via $WW^{(*)}$, $ZZ^{(*)}$

For **light Higgs**:

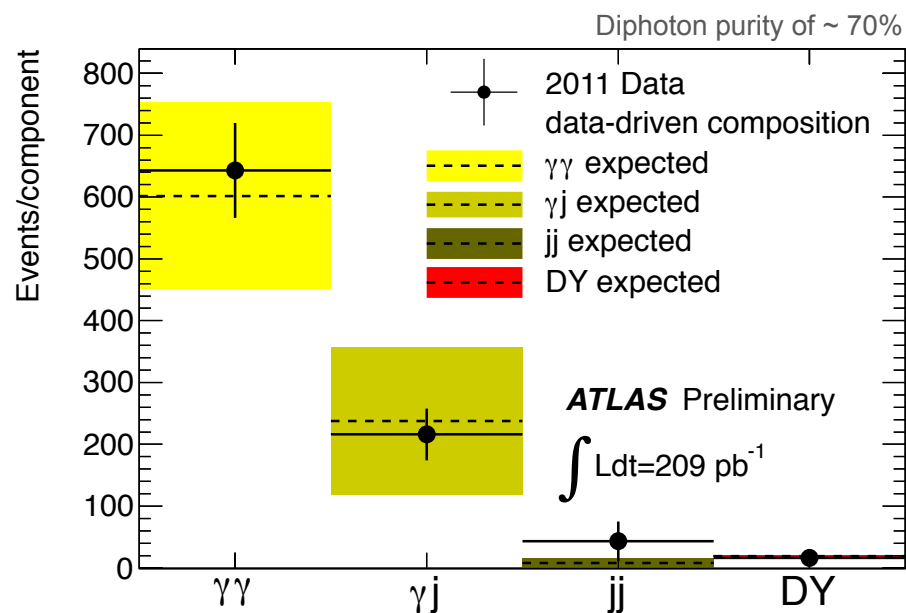
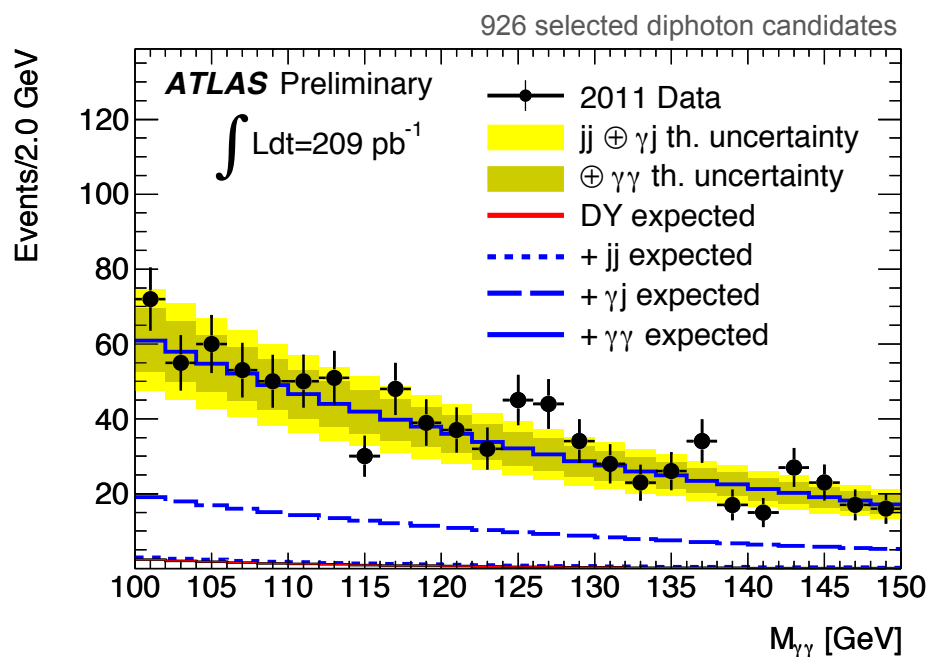
- Lepton final states via WW^* , ZZ^*
- Di-photon final state
- Di-tau final state

The dominant $H \rightarrow b\bar{b}$ mode is only exploitable in association with W/Z or $t\bar{t}$, also with strong Higgs boost

Associated leptons provide trigger signal as they help to reduce huge QCD background, $\sigma(bb) \sim \mathcal{O}(100 \text{ } \mu\text{b})$

Clean discovery channel for light Higgs: $\sigma \times \text{BR}$ (115 / 140 GeV | $\sqrt{s}=7$ TeV) $\approx 45 / 28$ fb

Select tight & isolated high- p_T photons; need excellent E_γ resolution, efficient & pure PID, primary vertex

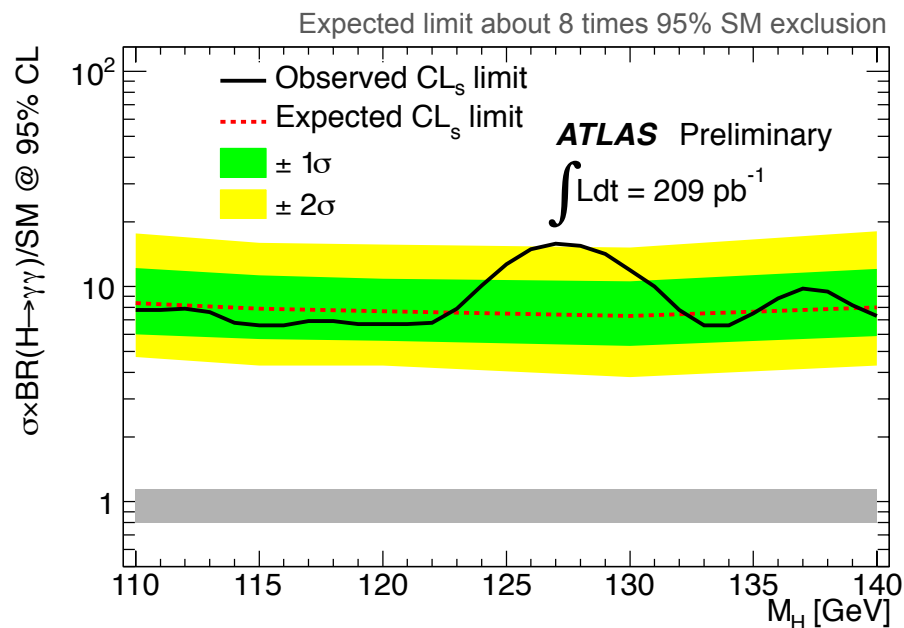
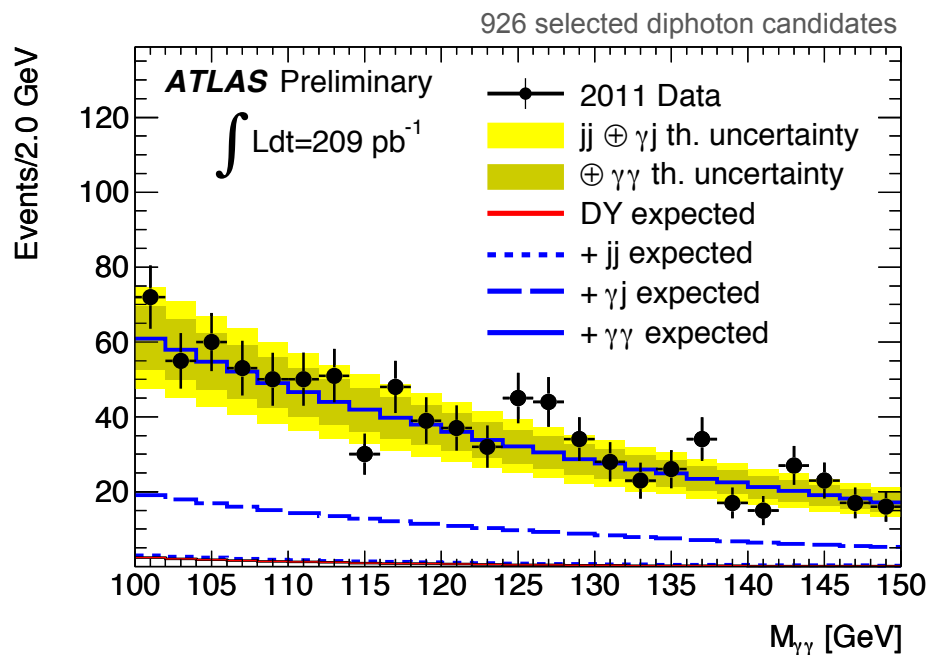


Total background shape and normalisation determined simultaneous with signal

Higgs signal would manifest itself as narrow peak [syst. error on signal yield $\sim 24\%$]

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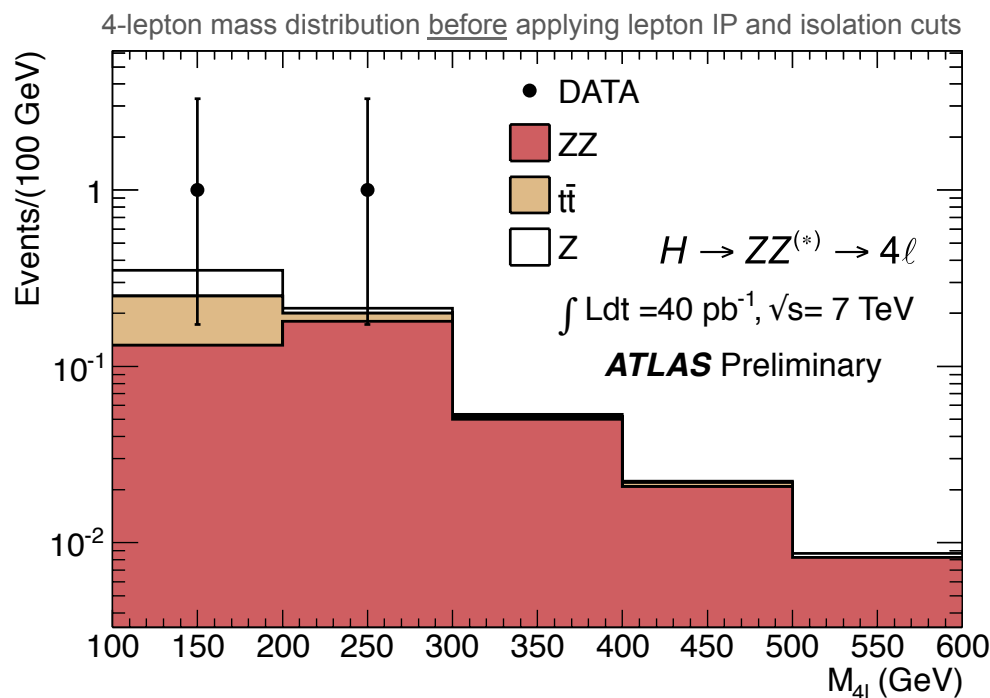
Higgs signal would manifest itself as narrow peak [syst. error on signal yield $\sim 24\%$]

$H \rightarrow ZZ^{(*)} \rightarrow 4 \text{ leptons } (e, \mu)$

ATLAS-CONF-2011-048

Very clean channel, low BR: $\sigma \times \text{BR}$ (140 / 200 / 600 GeV | $\sqrt{s}=7 \text{ TeV}$) $\approx 4.2 / 6.8 / 0.5 \text{ fb}$

Signal selection: $p_T > 15_e / 7_\mu \text{ GeV}$, isolated leptons, $M(1,2) \sim M_Z$, $M(3,4) > 15\text{--}60 \text{ GeV}$ (M_{4l} - dependent)



Backgrounds:

Dominant background after isolation cuts: **$ZZ^{(*)}$ continuum**

Top production

$$t\bar{t} \rightarrow WbWb \rightarrow \ell\nu \, c\ell\nu \, \ell\nu \, c\ell\nu$$

Also: associated Zbb production

$$Zbb \rightarrow \ell\ell \, c\ell\nu \, c\ell\nu$$

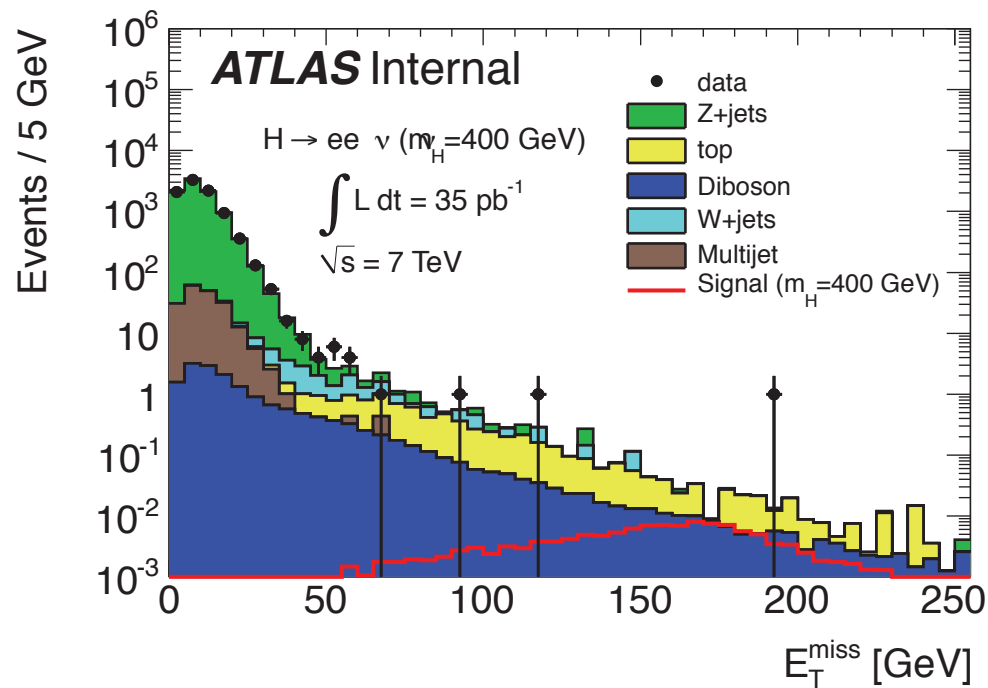
Reject by requiring leptons to be isolated and to match primary vertex

	$M_H = 130 \text{ GeV}$	$M_H = 150 \text{ GeV}$
Observed	0	0
Background	0.010 ± 0.002	0.090 ± 0.014
Signal	0.015 ± 0.003	0.095 ± 0.017

$$H \rightarrow ZZ^{(*)} \rightarrow 2l(e, \mu) + \nu\nu$$

Benefit for $M_H > 200$ GeV from 3 times larger $Z \rightarrow \nu\nu$ BR

Higgs to 4 leptons transverse mass reconstruction from leptons and $E_{T,\text{miss}}$ vector



Backgrounds:

Z + jets: require large $E_{T,\text{miss}}$ and veto back-to-back leptons

Top production: veto b -jets

Also: W + jets and diboson production

Verify MC background yields with dedicated control regions

	$M_H = 200 \text{ GeV}$	$M_H = 400 \text{ GeV}$
Observed	5	5
Background	5.8 ± 1.4	3.5 ± 0.9
Signal	0.19 ± 0.04	0.30 ± 0.06

Similarly powerful for $M_H > 400$ GeV : $H \rightarrow ZZ \rightarrow 2l + qq$ mode [also included in analysis]

$$H \rightarrow WW^{(*)} \rightarrow 2\ell(e, \mu) + 2\nu$$

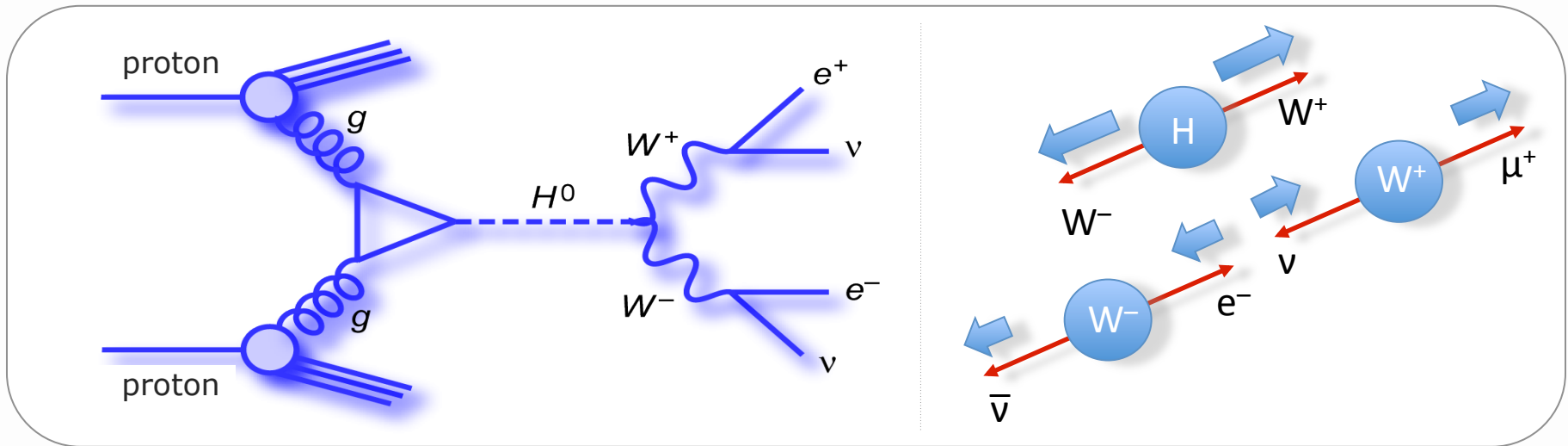
ATLAS-CONF-2011-005

No clean channel but large $\sigma \times \text{BR}$ (120 / 165 / 200 GeV | $\sqrt{s}=7$ TeV) $\approx$ 120 / 400 / 200 fb

Leptonic mode ($\ell\nu\ell\nu$) used for $120 < M_H < 220$ GeV, semi-leptonic mode ($\ell\nu qq$) for $220 < M_H < 600$ GeV

Signal selection: leptons, $M_T^2 = (E_{T,\ell} + E_{T,\text{miss}})^2 - (\mathbf{p}_{T,\ell} + \mathbf{p}_{T,\text{miss}})^2 \sim M_H^2$, exploit W polarisation, separate jets

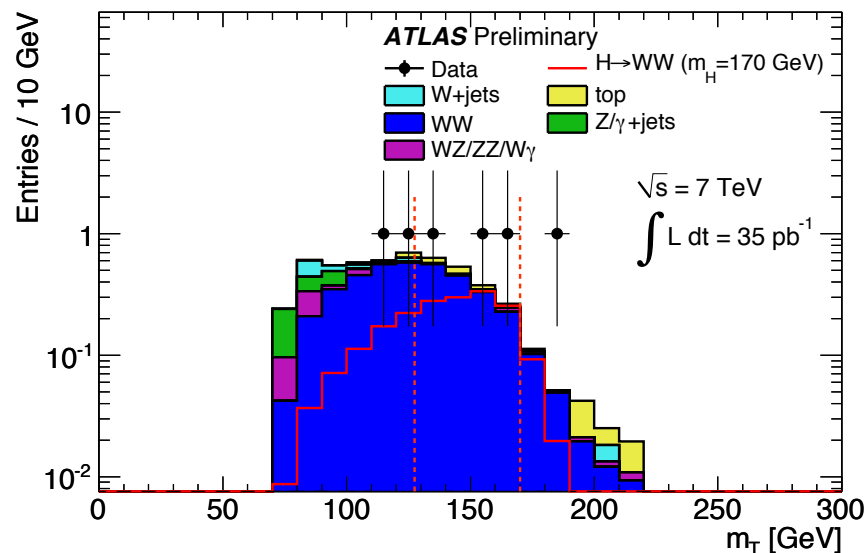
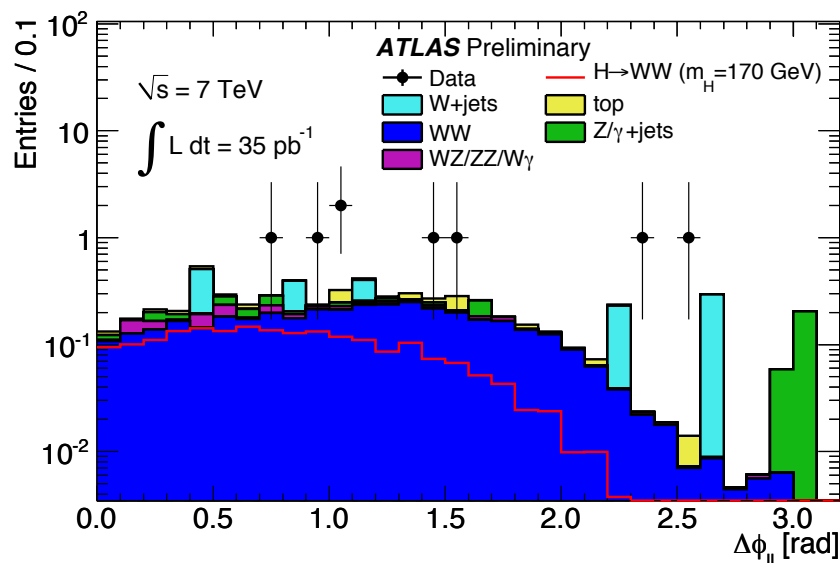
$$p\bar{p} \rightarrow H + X \rightarrow W^+W^- + X \rightarrow \ell^+\nu\ell^-\bar{\nu} + X: \text{leptons} + E_T^{\text{miss}} + \text{small } \Delta\phi_{\ell\ell}$$



Dominant backgrounds from
 WW continuum, W + jets, top...

W polarisation: correlated lepton emission
Dilepton opening angle is discriminant

- Data-driven background determination using background-enhanced control regions (*anti-cuts*)
- 0-jet channel: $S/B \sim 0.7$ at $M_H = 170$ GeV, after cuts on $\Delta\phi_{ll}$, m_{ll} , m_T , $E_{T,miss}$



Observed and expected num. of events
in $e\mu$ channel for $M_H = 170$ GeV

	0-jet	1-jet
Observed	1	0
Total Bkg.	0.83 ± 0.15	0.47 ± 0.18
(WW bkg.	0.71 ± 0.08	0.18 ± 0.04)
Signal	0.62 ± 0.18	0.31 ± 0.09

Higgs detection requires good
understanding of WW background

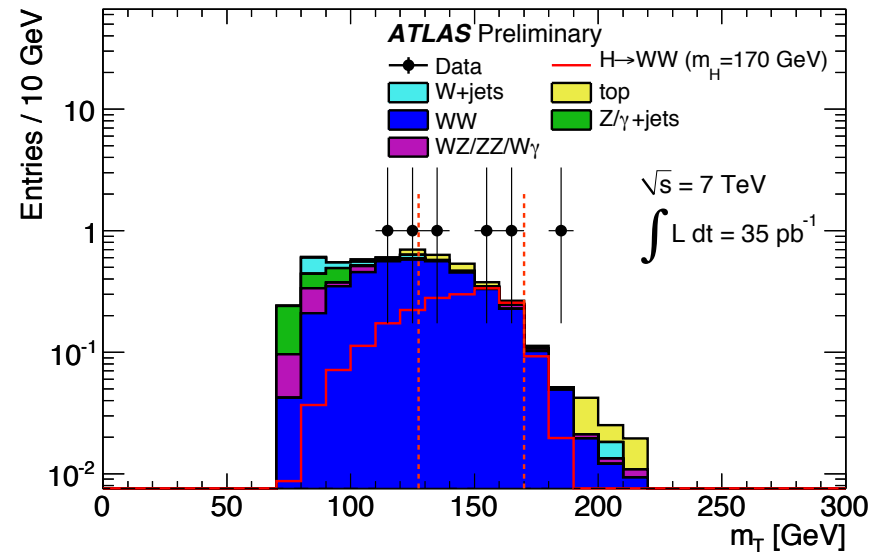
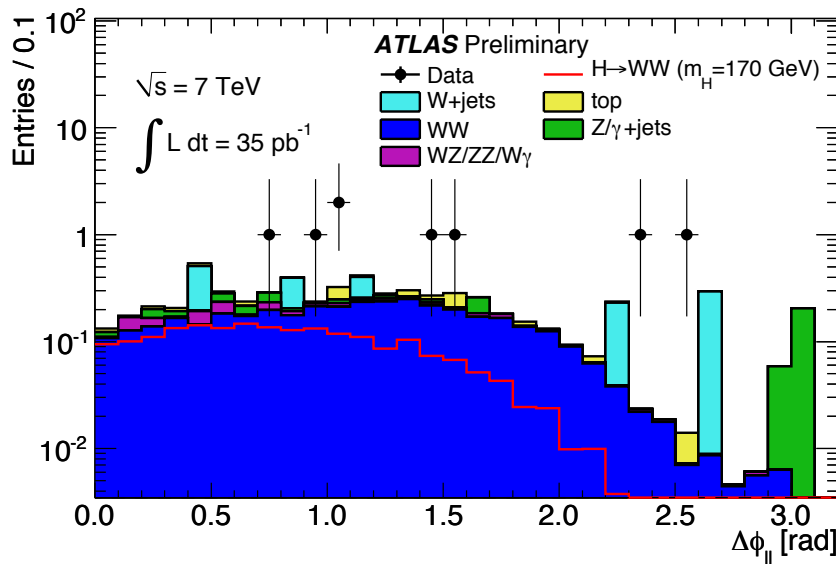
Recent ATLAS measurement finds:

$$\sigma(pp \rightarrow W^+W^-) = (41^{+20}_{-16} \pm 5) \text{ pb}$$

agreeing with NLO SM: $(44 \pm 3) \text{ pb}$

arXiv:1104.5225

- Data-driven background determination using background-enhanced control regions (*anti-cuts*)
- 0-jet channel: $S/B \sim 0.7$ at $M_H = 170$ GeV, after cuts on $\Delta\phi_{ll}$, m_{ll} , m_T , $E_{T,miss}$



(Almost) counting experiment only

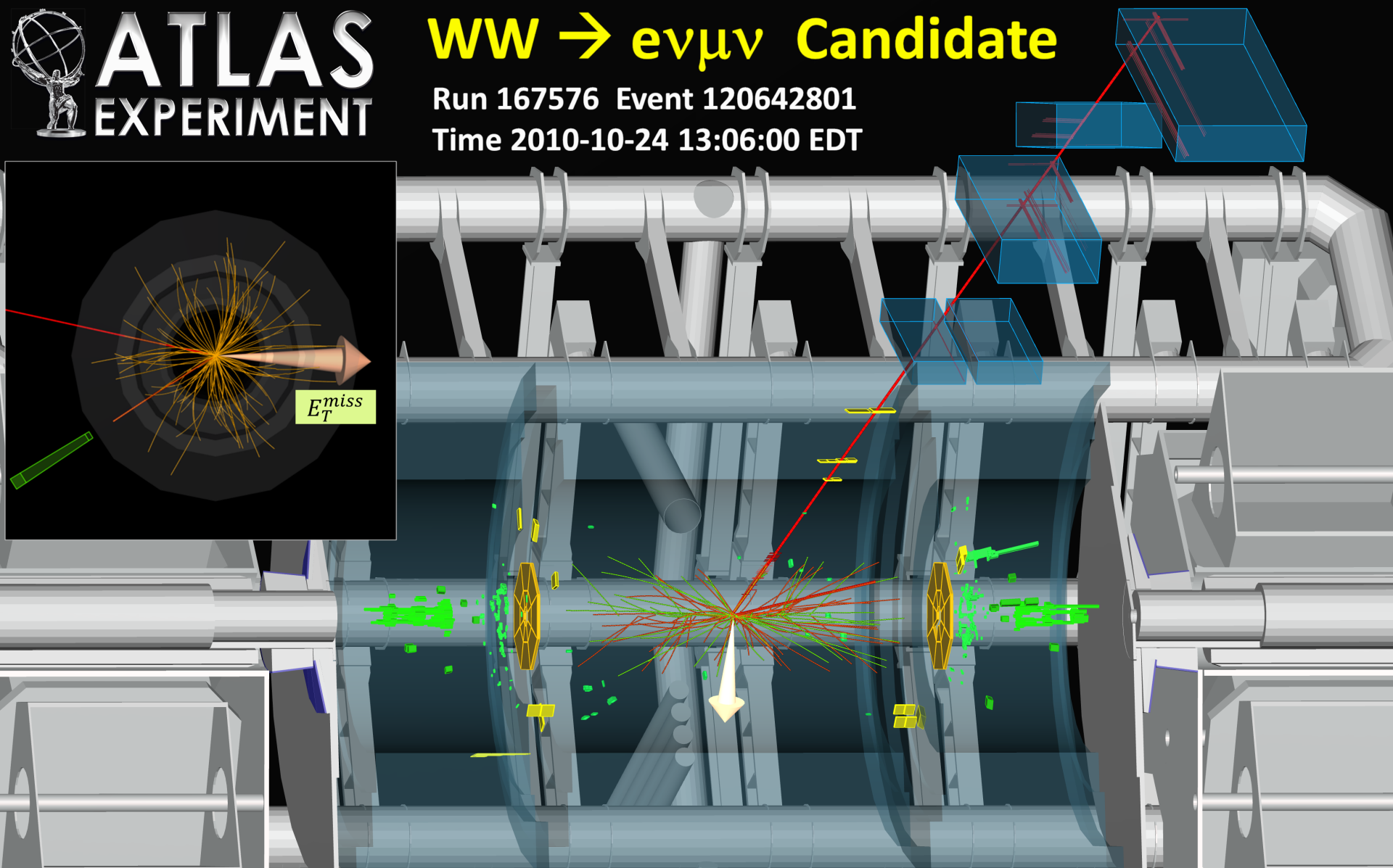
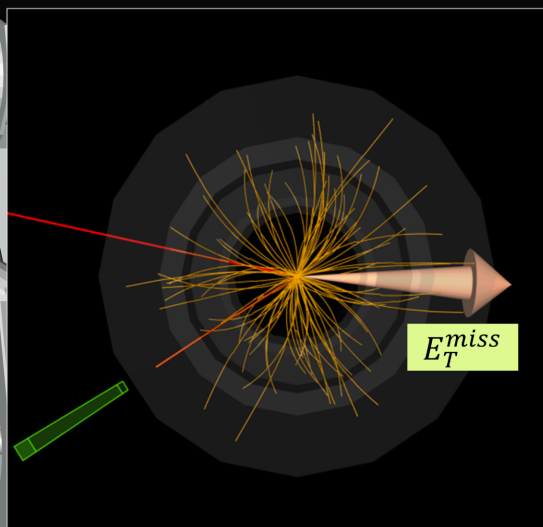
Requires accurate control of backgrounds in abundance and variable shapes

→ Hard work for experimentalists !

$WW \rightarrow e\nu\mu\nu$ Candidate

Run 167576 Event 120642801

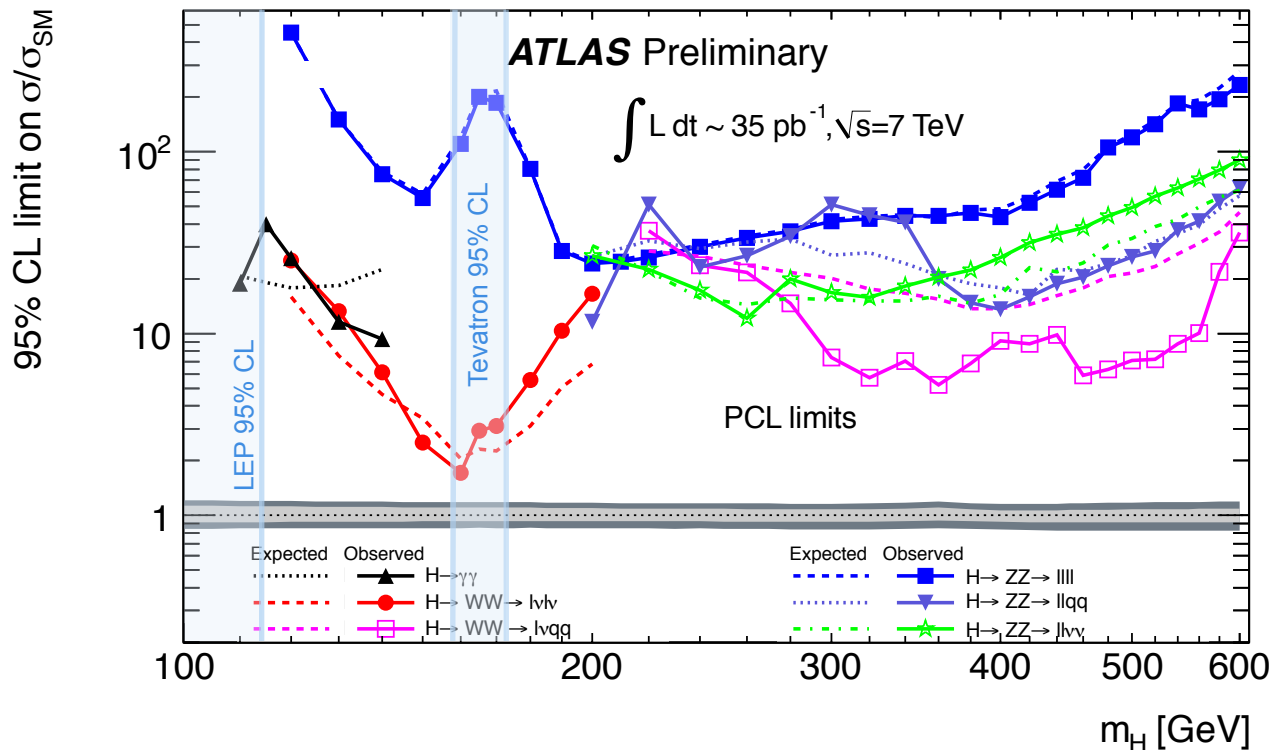
Time 2010-10-24 13:06:00 EDT



SM Higgs Exclusion

arXiv:1106.2748

Observed and expected 95% CL exclusion limits in units of SM cross section



At $M_H = 120$ GeV,
 WW competitive with $\gamma\gamma$

Almost 95% exclusion
at $M_H \sim 160$ GeV

Between $M_H \sim 210$ and
290 GeV $ZZ \rightarrow ll\nu\nu$ most
sensitive

Above $M_H \sim 290$ GeV
 $WW \rightarrow l\nu qq$ dominant

Above $M_H \sim 400$ GeV
 $ZZ \rightarrow llqq$ competitive

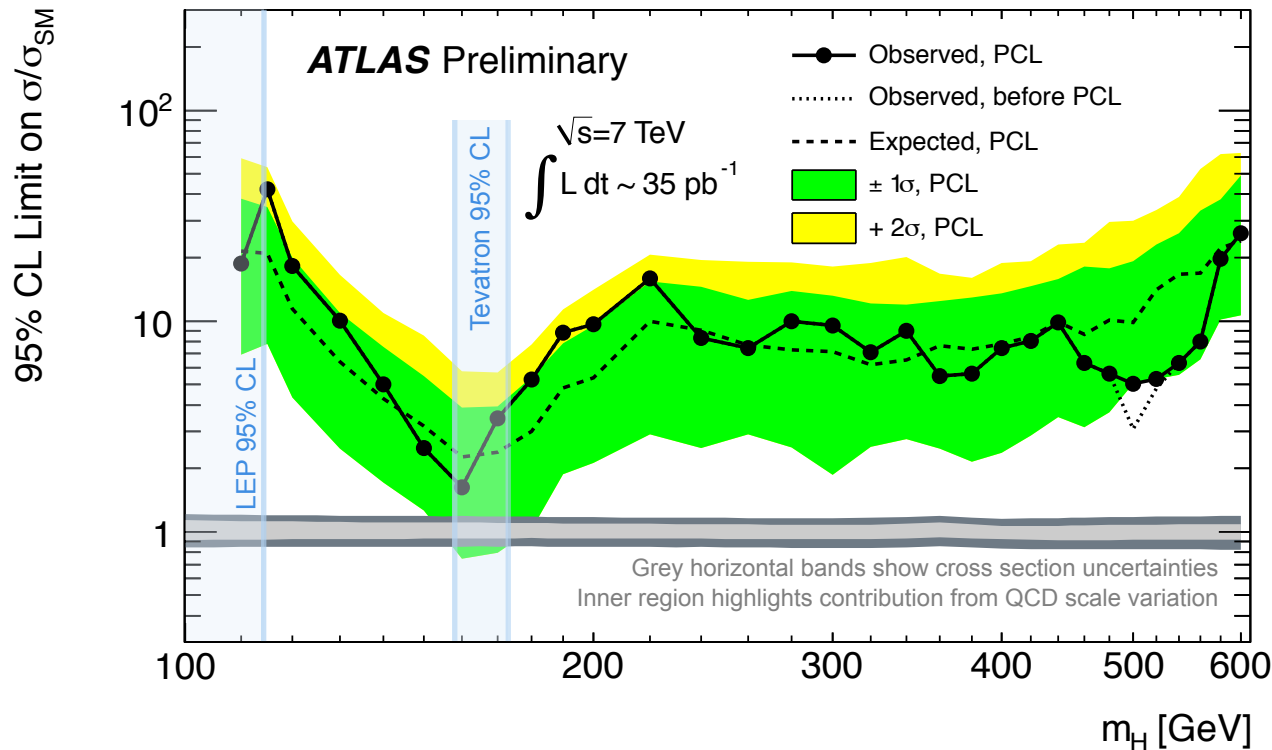
Power-constrained* limits (PCL) computed from CL_{s+b} of test statistics using toy MC

*Fluctuations below -1σ wrt. median of expected limits are not allowed
Corresponding CL_s limits provide reduced exclusion (overcoverage)

SM Higgs Exclusion

arXiv:1106.2748

ATLAS combination of individual channels for 2010 data



Combination using
maximum likelihood fit
taking into account
correlated nuisance
parameters

Uncertainty on cross
section included in SM
expectation

Not yet reached at Tevatron
who exclude 158–173 GeV
at 95% CL [arXiv:1103.3233]

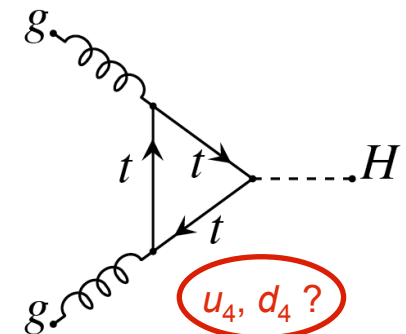
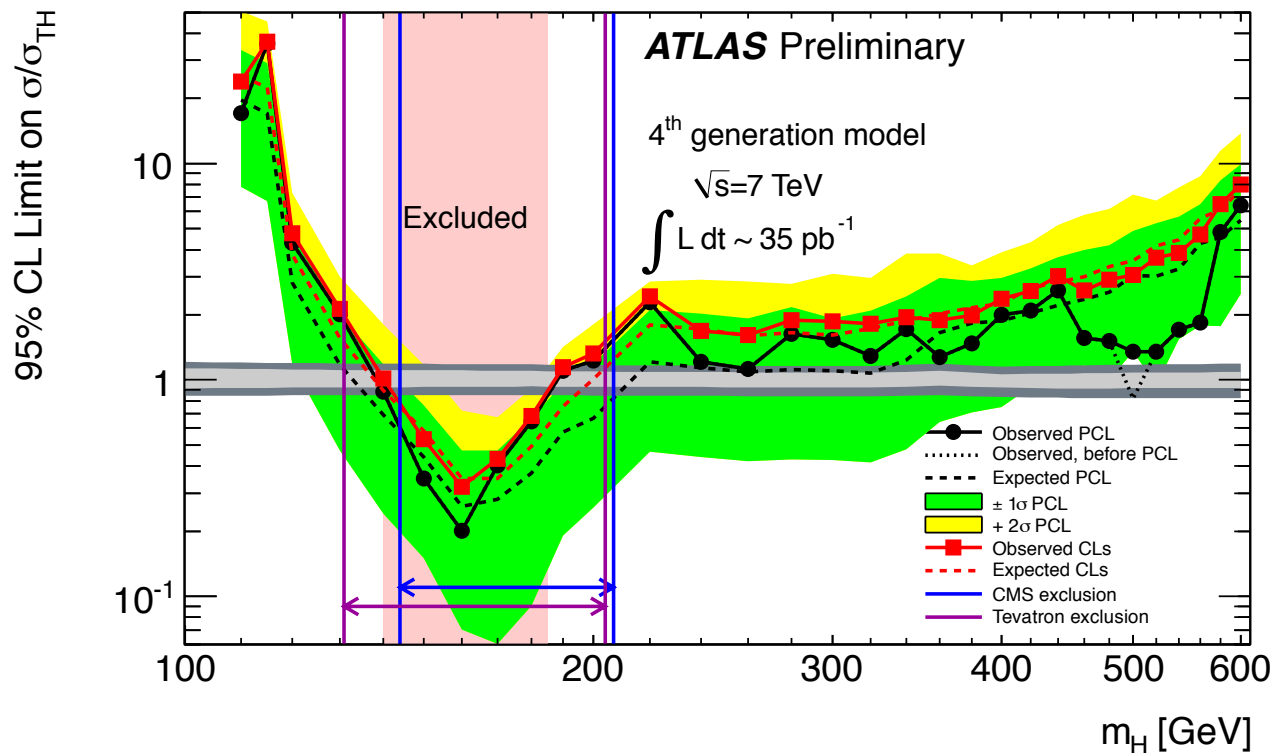
Power-constrained* limits (PCL) computed from CL_{s+b} of test statistics using toy MC

*Fluctuations below -1σ wrt. median of expected limits are not allowed
Corresponding CL_s limits provide reduced exclusion (overcoverage)

4-Gen SM Higgs Exclusion

arXiv:1106.2748

Gluon fusion to Higgs via triangular heavy-quark loop sensitive to 4th generation



4th generation ?
 K-factor of $\sim 3^2 = 9$
 using sequential model

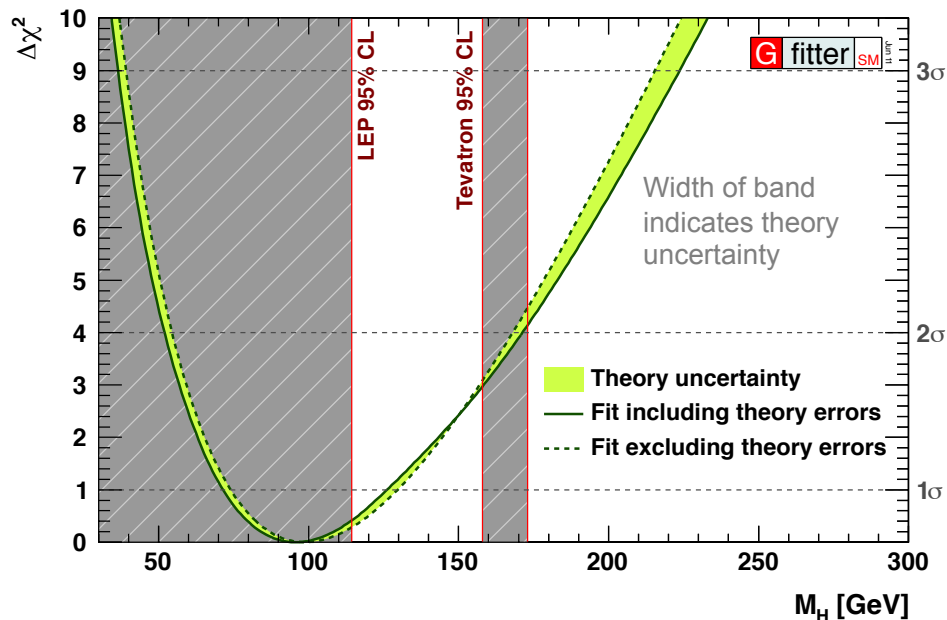
95% CL exclusion of $140 < M_H < 185$ GeV in SM4

Constraints on Higgs mass

Combining direct Higgs searches with EW fit

<http://cern.ch/gfitter>

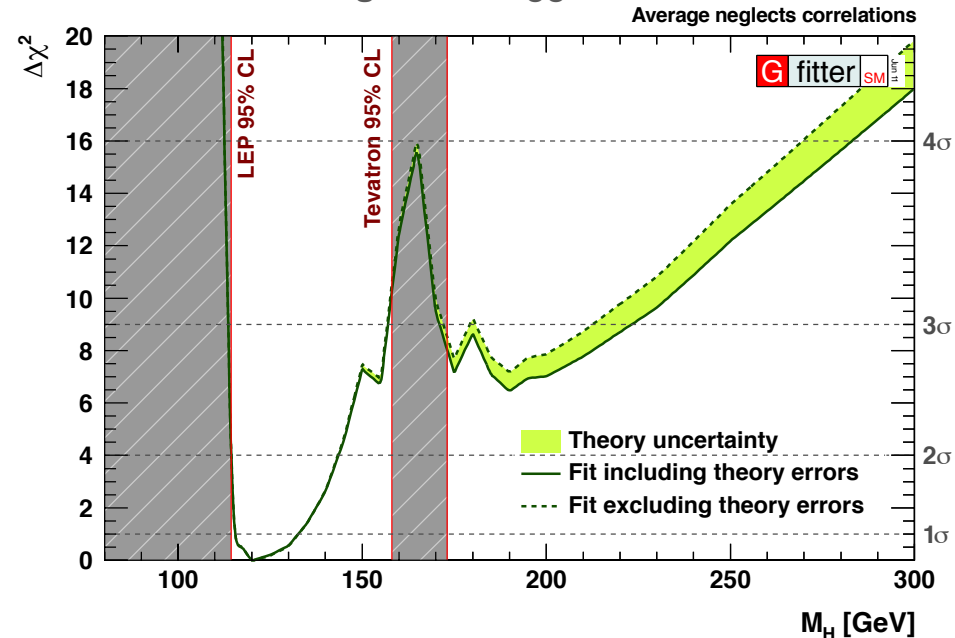
EW fit *not* including direct Higgs searches



Central value $\pm 1\sigma$: $M_H = 96^{+31}_{-24}$ GeV

95% CL upper limit: 169 GeV

EW fit *including* direct Higgs searches



Central value $\pm 1\sigma$: $M_H = 120^{+12}_{-5}$ GeV

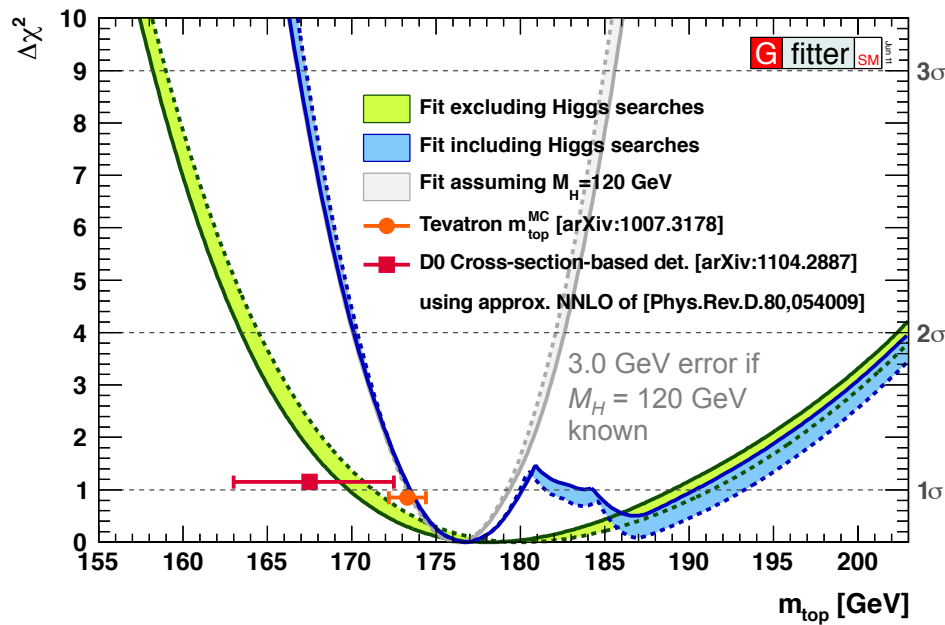
95% CL upper limit: 143 GeV

Constraints on other observables

Combining direct Higgs searches with EW fit to predict precision observables

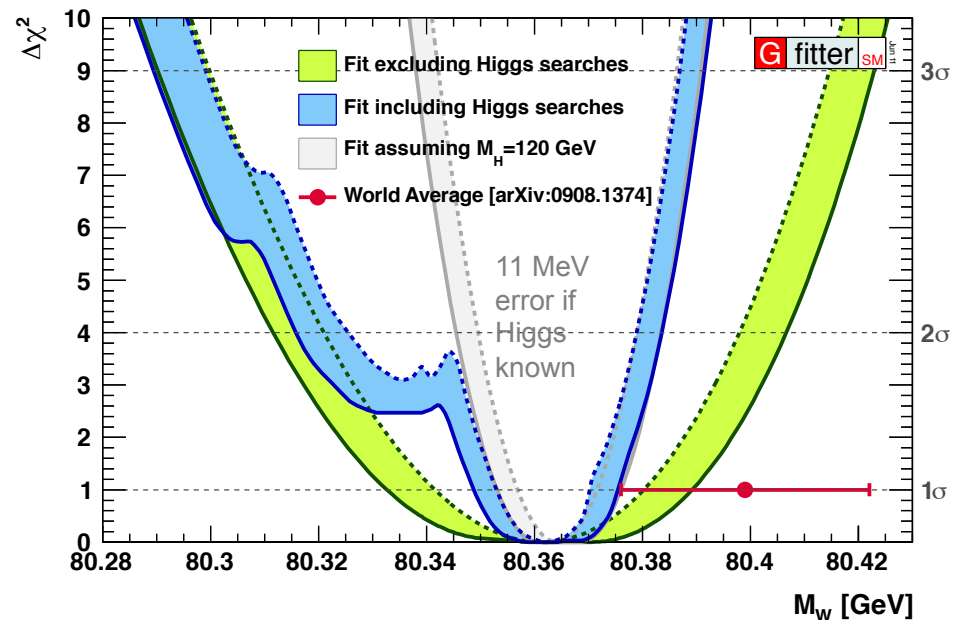
<http://cern.ch/gfitter>

Constraint on top mass



Central value $\pm 1\sigma$: $m_t = (176.8 \pm 3.3) \text{ GeV}$
 Direct measurement: $m_t = (173.3 \pm 1.1) \text{ GeV}$
 From cross section: $m_t = (167.5^{+5.0}_{-4.5}) \text{ GeV}$

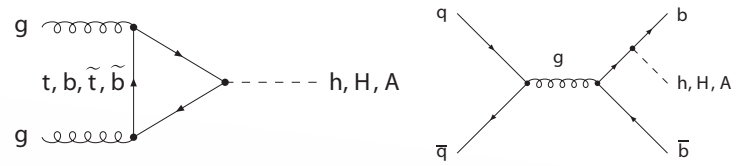
Constraint on W mass



Central value $\pm 1\sigma$: $m_t = (80.359^{+0.017}_{-0.010}) \text{ GeV}$
 Direct measurement: $m_t = (80.399 \pm 0.023) \text{ GeV}$

D0: arXiv:1104.2887

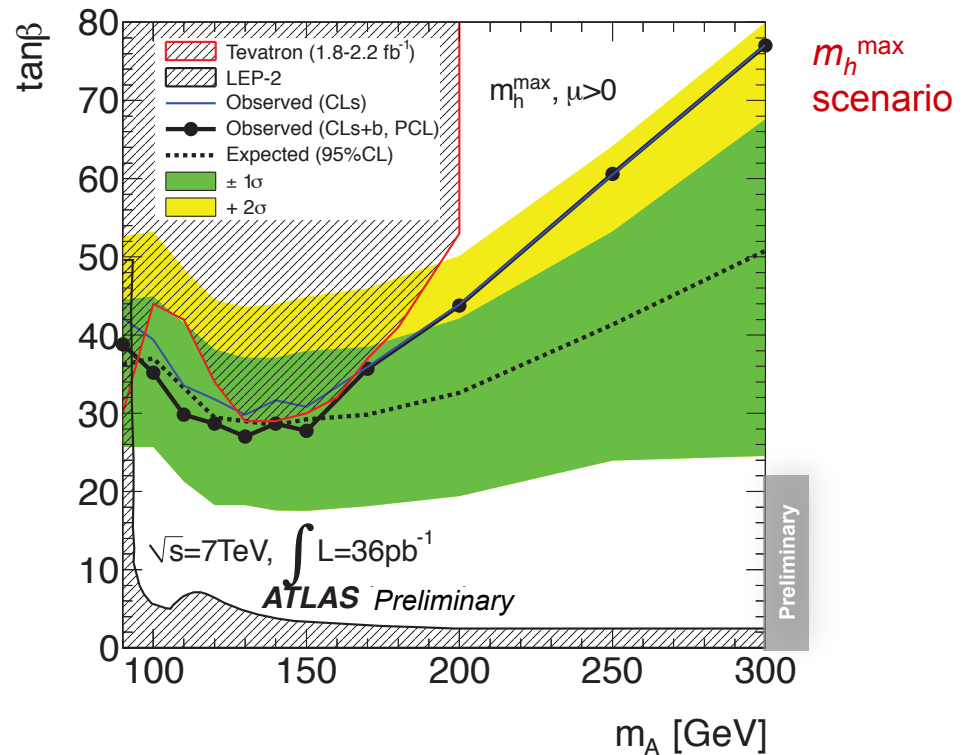
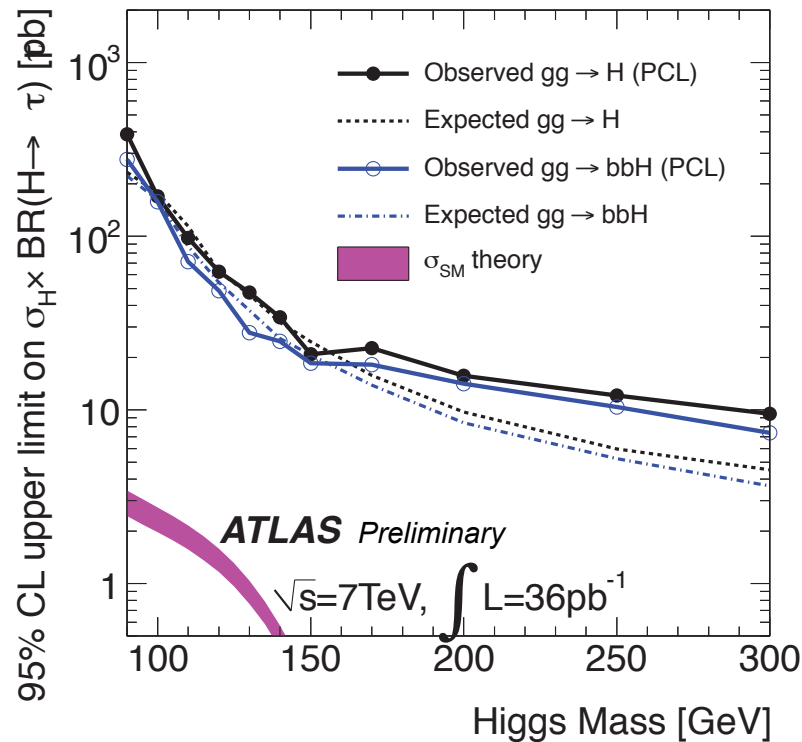
SM / SUSY Higgs to $\tau\tau$



2 Higgs doublets required in MSSM, leading to 5 Higgs bosons: $h, H, A, H^\pm$

Higgs coupling to down-type fermions can be strongly enhanced depending on $\tan\beta = v_d / v_u$ and m_A

Search for $h, H, A \rightarrow \tau\tau$ decays in $e-\mu$ & e/μ -had channels (52% BR), require $E_{T,\text{miss}} > 20$ GeV and low M_T



We also searched for CP -odd NMSSM Higgs $a_1 \rightarrow \mu\mu$ for masses 6–9, 11–12 GeV $\rightarrow$ 95% CL limits $O(250 \text{ pb})$

$$\begin{aligned}
 p_T(\mu) &= 18 \text{ GeV} \\
 p_T^{\text{vis}}(\tau_h) &= 26 \text{ GeV} \\
 m_{\text{vis}}(\mu, \tau_h) &= 47 \text{ GeV} \\
 m_T(\mu, E_T^{\text{miss}}) &= 8 \text{ GeV} \\
 E_T^{\text{miss}} &= 7 \text{ GeV}
 \end{aligned}$$

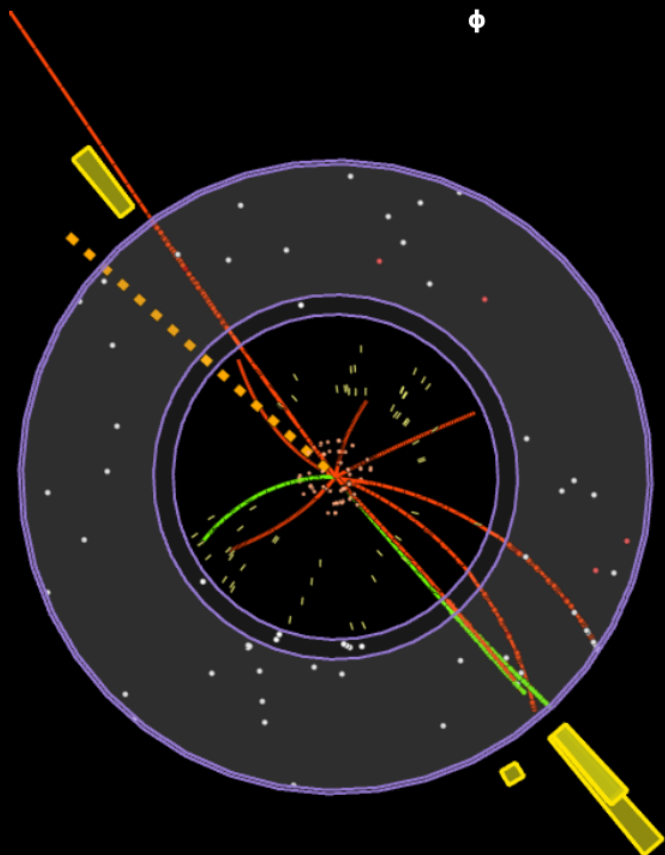
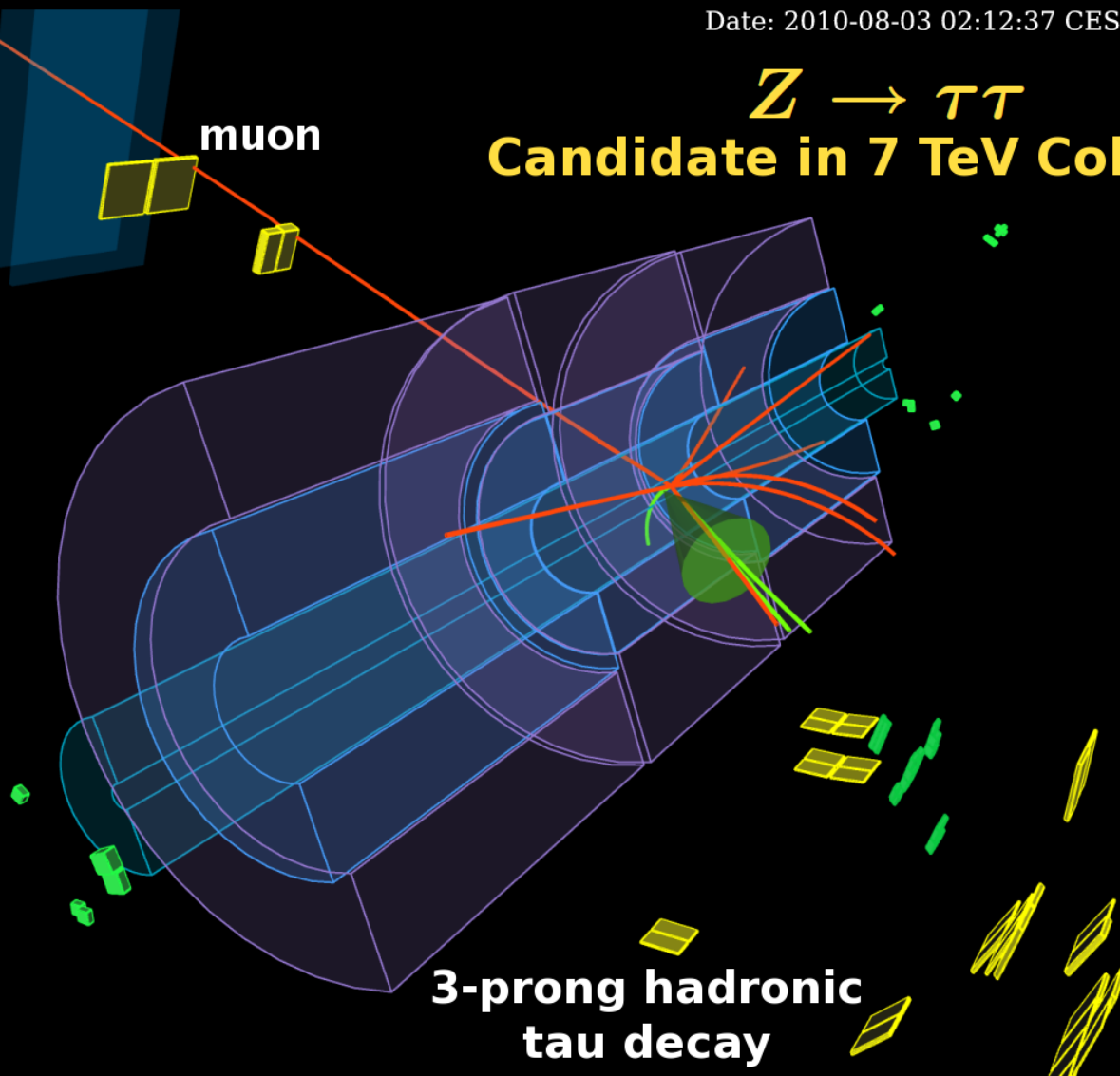
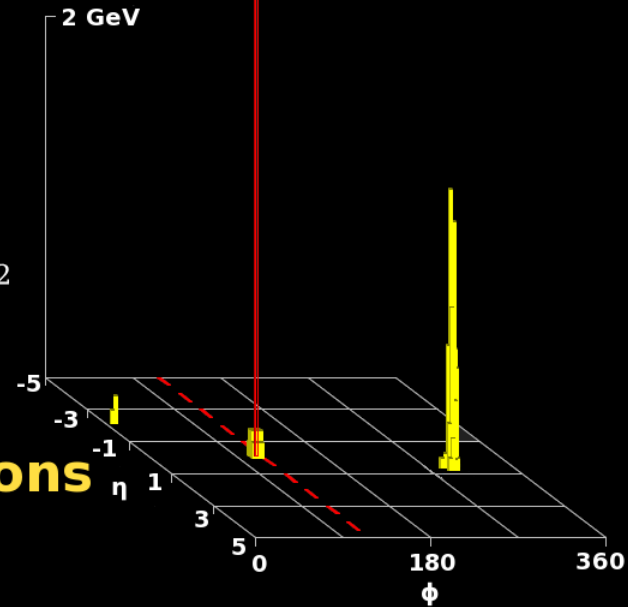


ATLAS EXPERIMENT

Run Number: 160613, Event Number: 9209492

Date: 2010-08-03 02:12:37 CEST

$Z \rightarrow \tau\tau$ Candidate in 7 TeV Collisions



3-prong hadronic
tau decay

hierarchy

Supersymmetry searches

SUSY searches also sensitive to many other new physics scenarios (and vice versa)

Spin 0	Spin 1/2	Spin 1
$\tilde{l}_1, \tilde{l}_2$	ℓ	SM
$\tilde{q}_1, \tilde{q}_2$	q	SUSY
$h^0, H^0, A^0, H^\pm$	$\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0$	
	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^\pm$	$\gamma, Z^0, W^\pm$
	$\tilde{g}_a$	g_a

+ gravitino ($S=3/2$)
and graviton ($S=2$)

Gauge-mixed physical states that propagate in space and time and can be observed

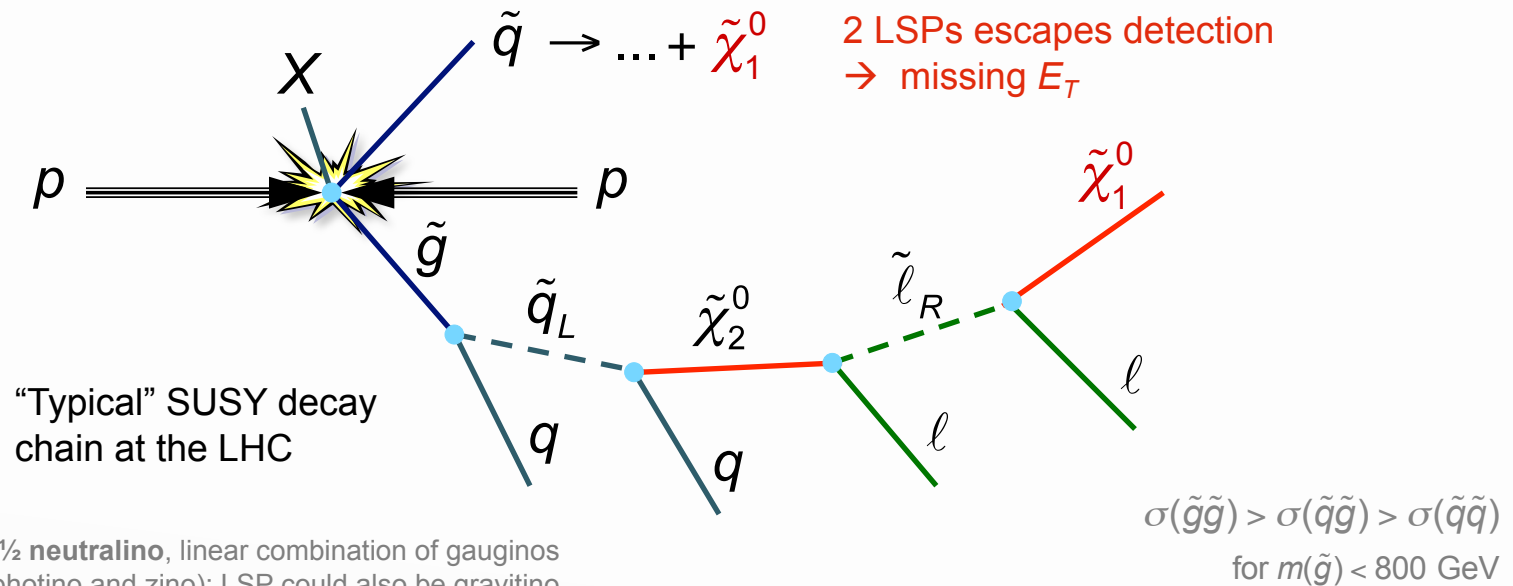
Characteristic SUSY Decay Cascades

R -parity conserving SUSY can cascade into high- p_T jets + leptons + $E_{T,\text{miss}}$

With R parity: SUSY production in pairs which requires energy $2 \times$ SUSY mass !

→ Incomplete event reconstruction

- SUSY evidence in tails of distributions
- Analysis concentrates on understanding backgrounds (top, W/Z +jets, QCD)
- Each background component is taken from / verified in control regions



Different Analyses for Various Scenarios

arXiv:1102.5290, arXiv:1102.2357, arXiv:1103.6214, arXiv:1103.6208, ATLAS-CONF-2011-039, arXiv:1103.4344

Channel	Signature	Main backgrounds
Monojet + $E_{T,\text{miss}}$	≥ 1 jet, large $E_{T,\text{miss}}$	$W / Z(\nu\nu) + \text{jets}$, top, QCD
0 leptons + jets + $E_{T,\text{miss}}$	$\geq 2\text{--}4$ jets, large $E_{T,\text{miss}}$, $m_{\text{eff}}^{(*)}$	$W / Z + \text{jets}$, top, QCD
1 lepton + jets + $E_{T,\text{miss}}$	≥ 3 jets, large $E_{T,\text{miss}}$, m_{eff} , m_T	top, $W / Z + \text{jets}$
2 leptons (SS / OS) + jets + $E_{T,\text{miss}}$ (also “flavour subtraction” OS analysis)	large $E_{T,\text{miss}}$	SS: Fakes, diboson; OS: top, $Z + \text{jets}$, also cosmics ($\mu\mu$)
≥ 3 leptons + jets + $E_{T,\text{miss}}$	≥ 2 jets, $E_{T,\text{miss}}$, $m_{l+l-} \neq m_Z$	top, $Z + \text{jets}$
(**) 0(1) lepton + b -jets + $E_{T,\text{miss}}$	$\geq 3(2)$ jets, $E_{T,\text{miss}}$, m_{eff} , (m_T)	top, $W / Z + \text{jets}$
2 photons + $E_{T,\text{miss}}$	$E_{T,\text{miss}}$	QCD, top, $W(\gamma) + \text{jets}$
+ more targeted analyses for SUSY scenarios with features not covered by above inclusive searches		

Incomplete list

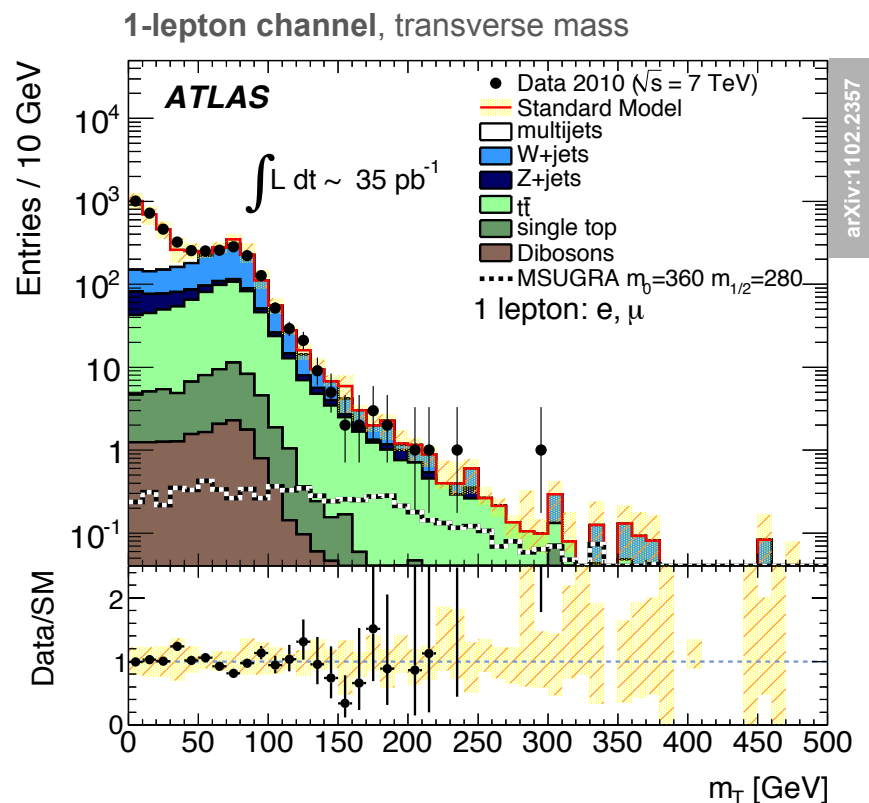
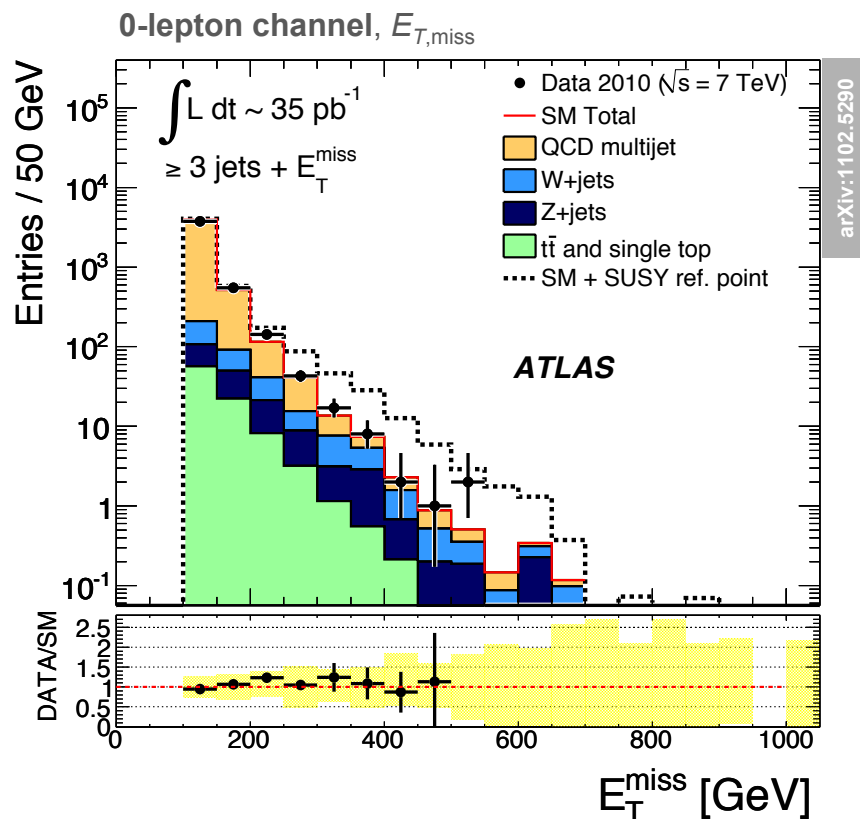
$$(*) m_{\text{eff}} = E_{T,\text{miss}} + \Sigma p_{T,\text{jets}}$$

(**) Large mixing scenario can give light sbottom, stop with: $\tilde{g} \rightarrow \tilde{b}_1 b$, $\tilde{g} \rightarrow \tilde{t}_1 t$

ATLAS monojet paper out today (arxiv:1106.5327)

→ Discussion of ATLAS and CMS monojet analyses by David Berge this week

- Data-driven background determination using background-enhanced control regions (*anti-cuts*)
- Extrapolation into signal region(s) using MC (include systematic errors in transfer functions)



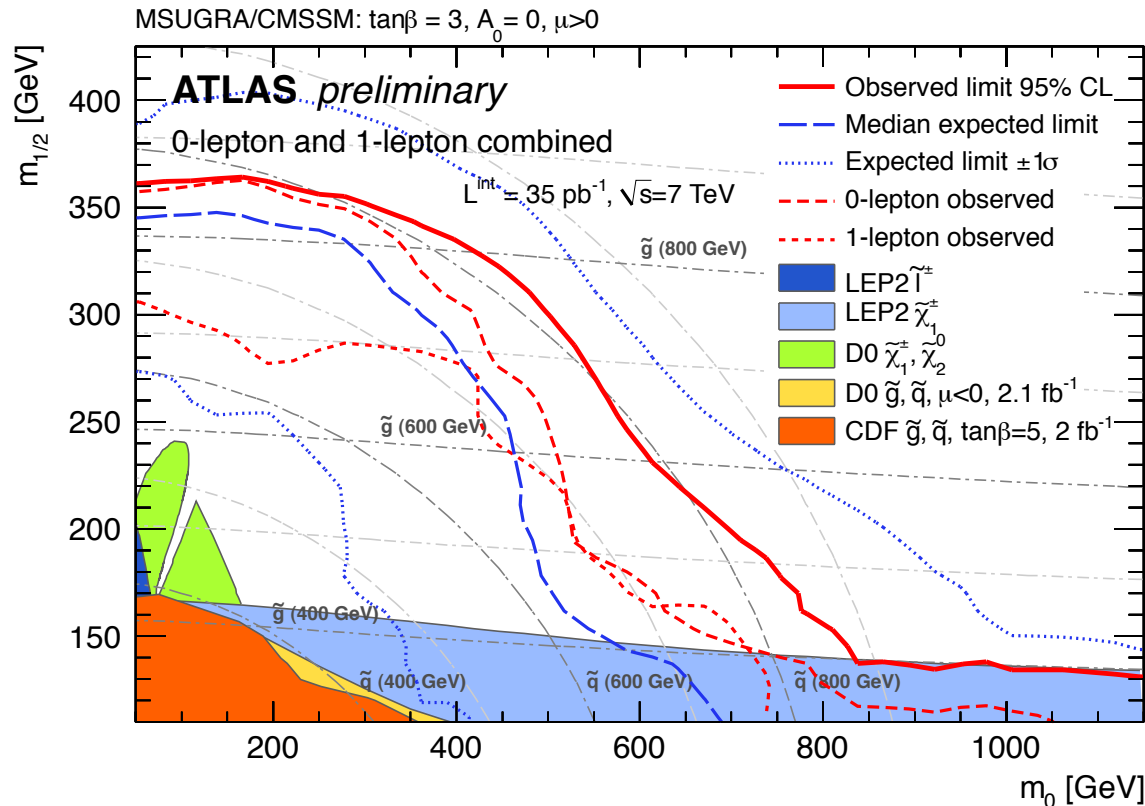
Example for observed and predicted events in signal regions; pure selection gives best sensitivity

	0-lepton (SR-D)	1-lepton (e)	1-lepton (μ)
Observed	2	1	1
Total SM background	$2.5^{+1.4}_{-1.1}$	1.81 ± 0.75	2.25 ± 0.94

SUSY Exclusion

ATLAS-CONF-2011-064

No signal evidence found → exclusion limits using CMSSM and simplified models



In CMSSM: combined
0 + 1-lepton analysis
achieves best sensitivity

b-jet analysis competitive
for large $\tan\beta$

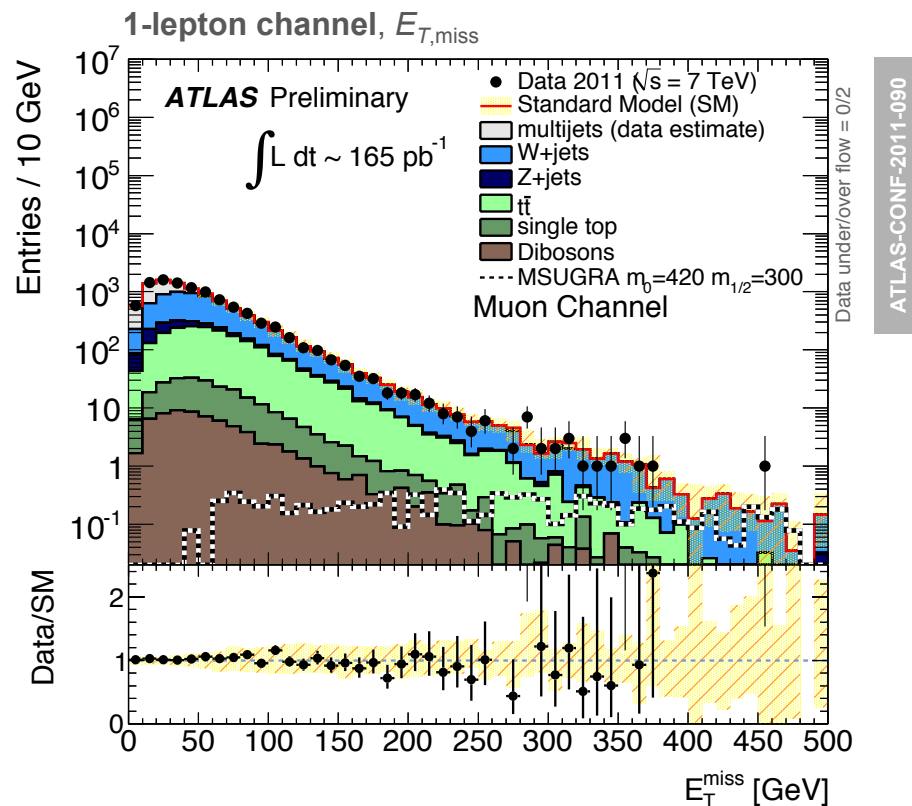
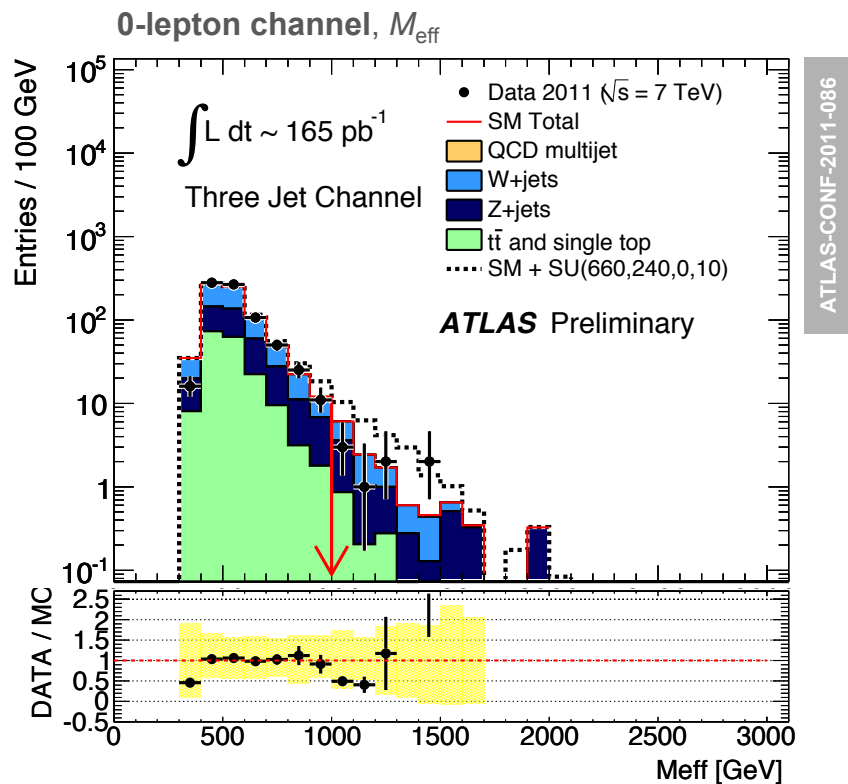
Exclude equal squarks and
gluino masses of **815 GeV**
at **95% CL**

Power-constrained* limits (PCL) computed from CL_{PCL} of test statistics using toy MC

*Fluctuations below -1σ wrt. median of expected limits are not allowed
Corresponding CL_s limits provide reduced exclusion (overcoverage)



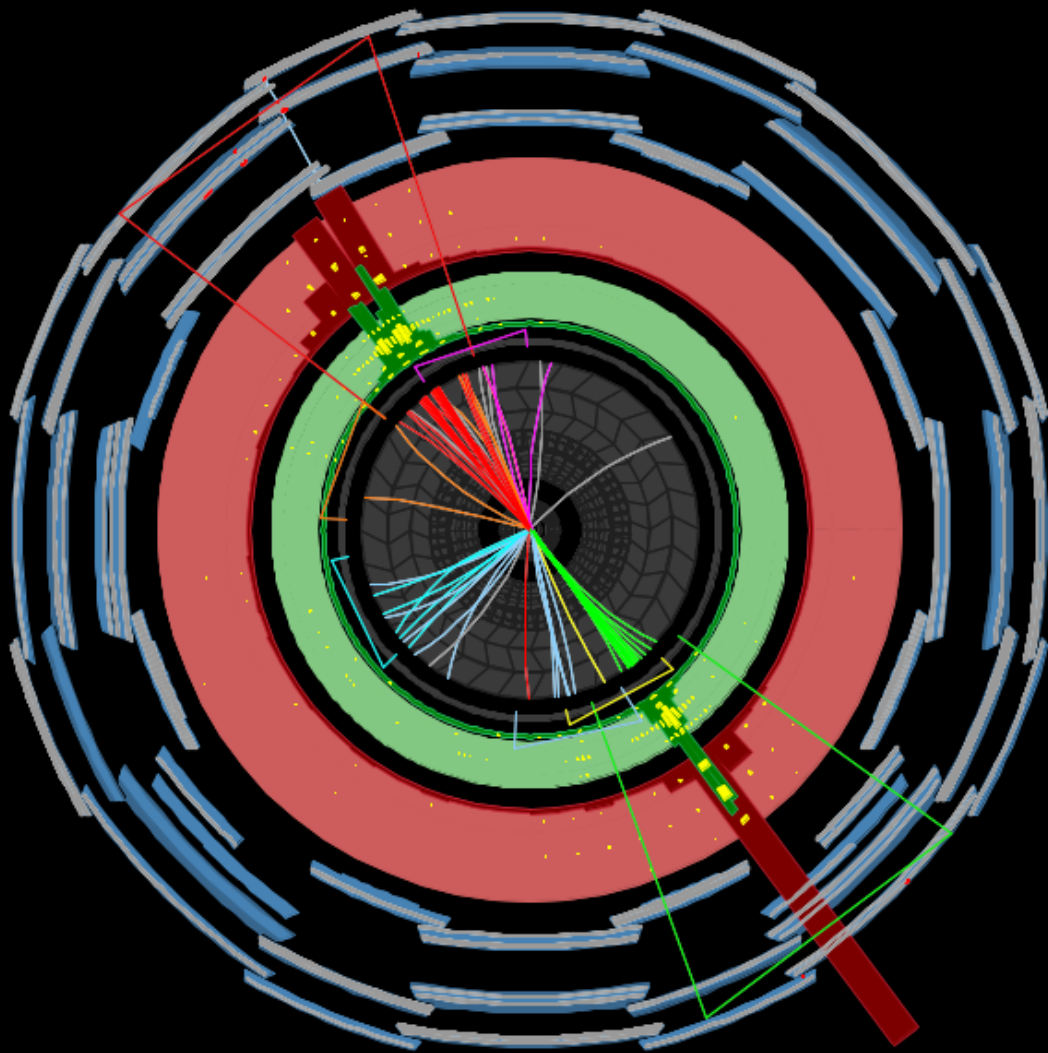
- 0/1-lepton analyses updated for PLHC with improved signal regions (2+, 3+, 4+ jets)
- Raised M_{eff} cut to 1 TeV in 0-lepton analysis (previously: 500 GeV)



Example for observed and predicted events in signal regions; pure selection gives best sensitivity

	0-lepton (≥ 3 -jet)	1-lepton (e)	1-lepton (μ)
Observed	8	10	12
Total SM background	10.1 ± 2.3	14.5 ± 5.2	12.2 ± 3.8

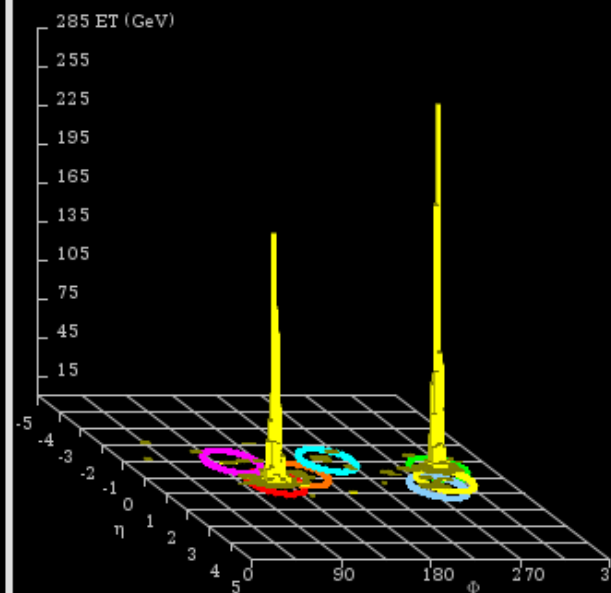
Event with 1.5 TeV effective mass and 550 GeV missing transverse energy



ATLAS EXPERIMENT

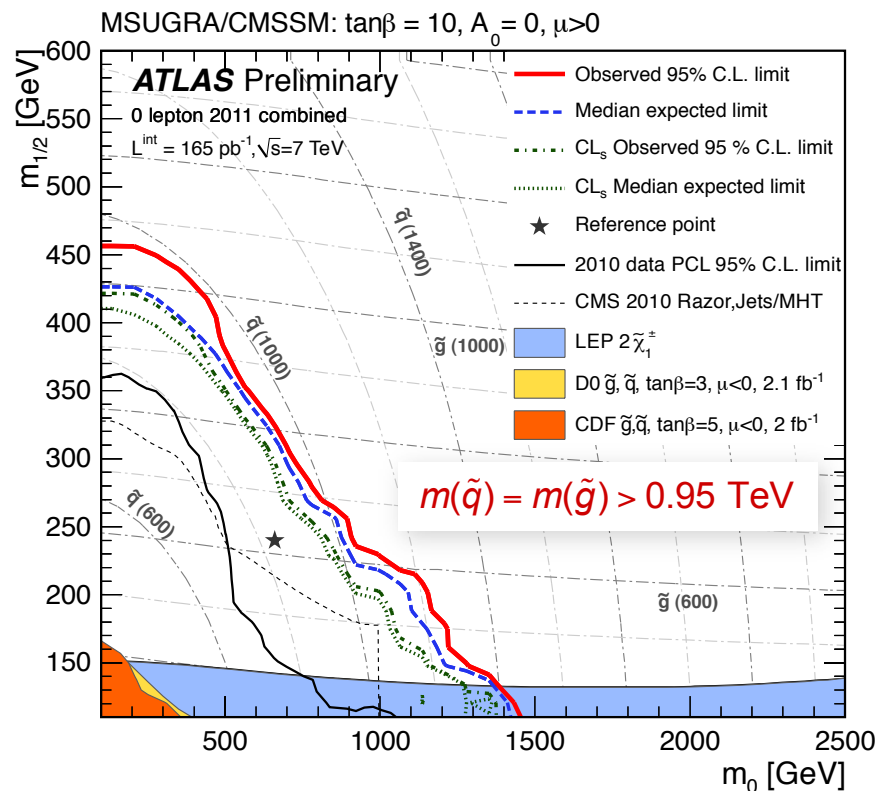
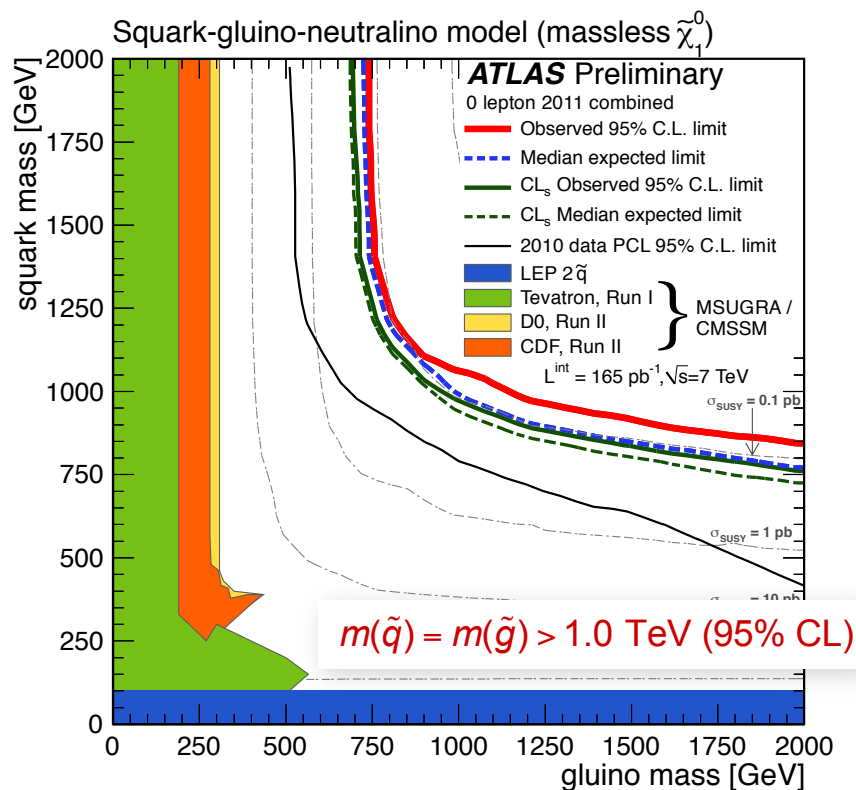
Run Number: 179938, Event Number: 12054480

Date: 2011-04-18 17:57:29 EDT



0/1-lepton analyses updated for PLHC with improved signal regions (2+, 3+, 4+ jets)

Raised m_{eff} cut to 1000 GeV in 0-lepton analysis (previously: 500 GeV) to optimise reach for increased statistics



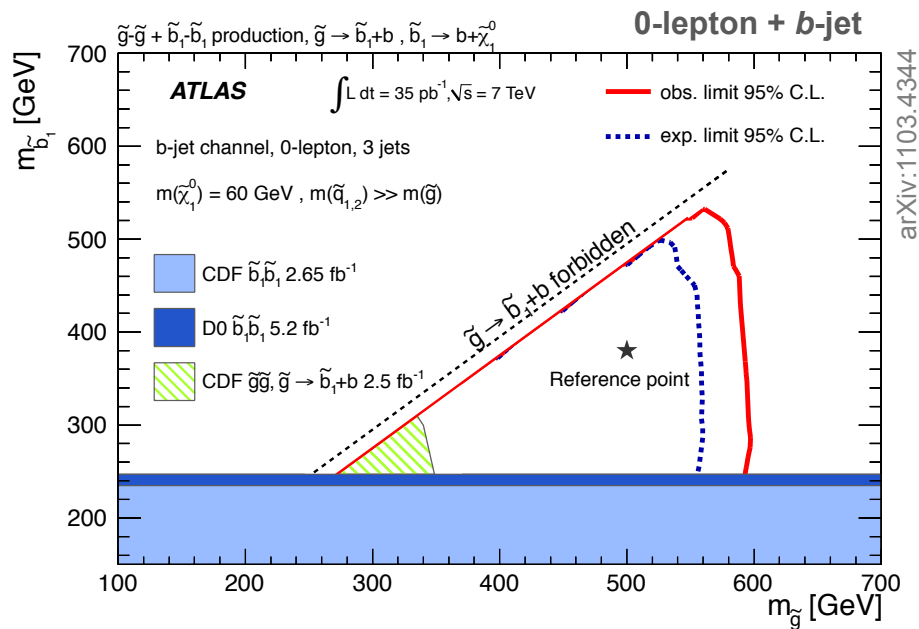
0-lepton limits on PhenoGrid and CMSSM combining all signal regions

SUSY Exclusion with Simplified Models

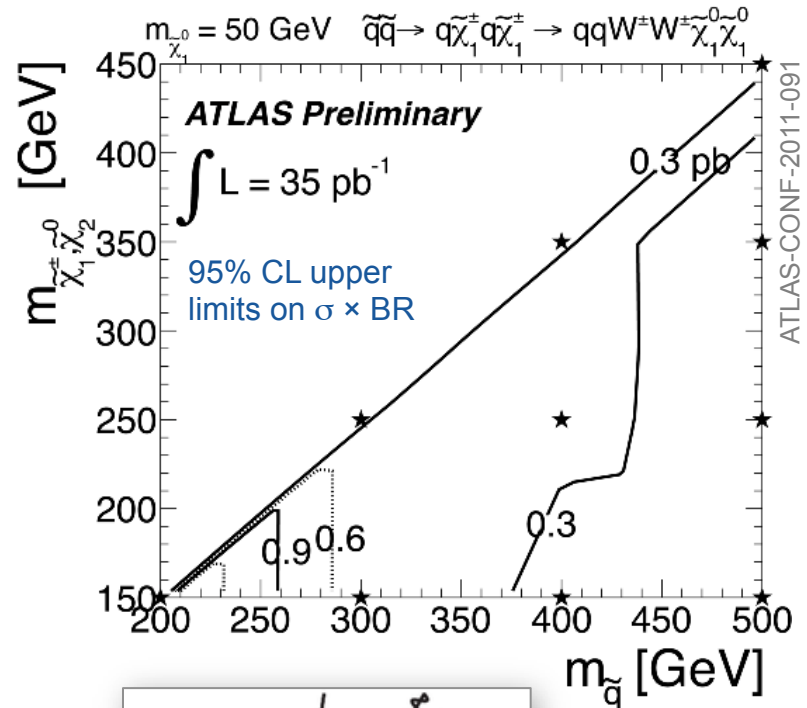
Simplified models compendium: arXiv:1105.2838

Limits in simplified models (“Pheno-grids”)

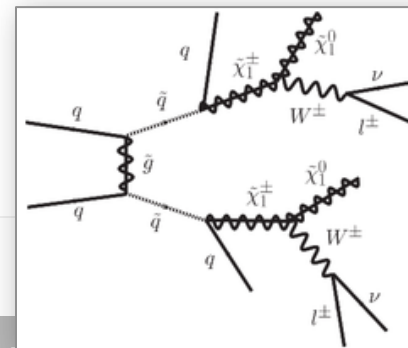
2-lepton channel (SS)



Exclude $m(\text{gluino}) < 590 \text{ GeV}$ for $m(\text{sbottom}) < 500 \text{ GeV}$



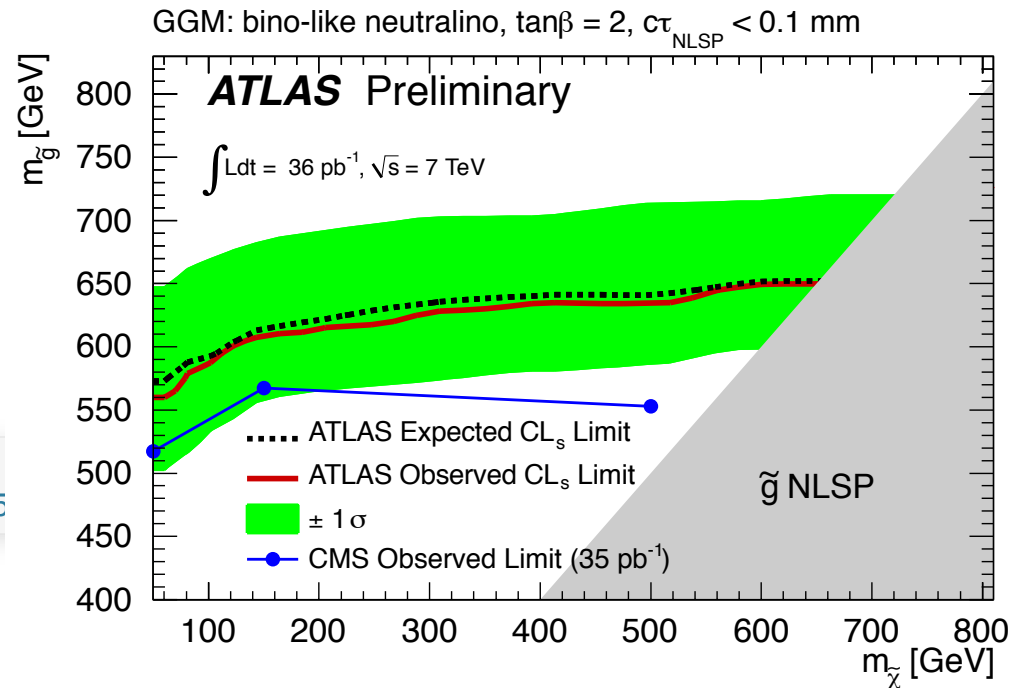
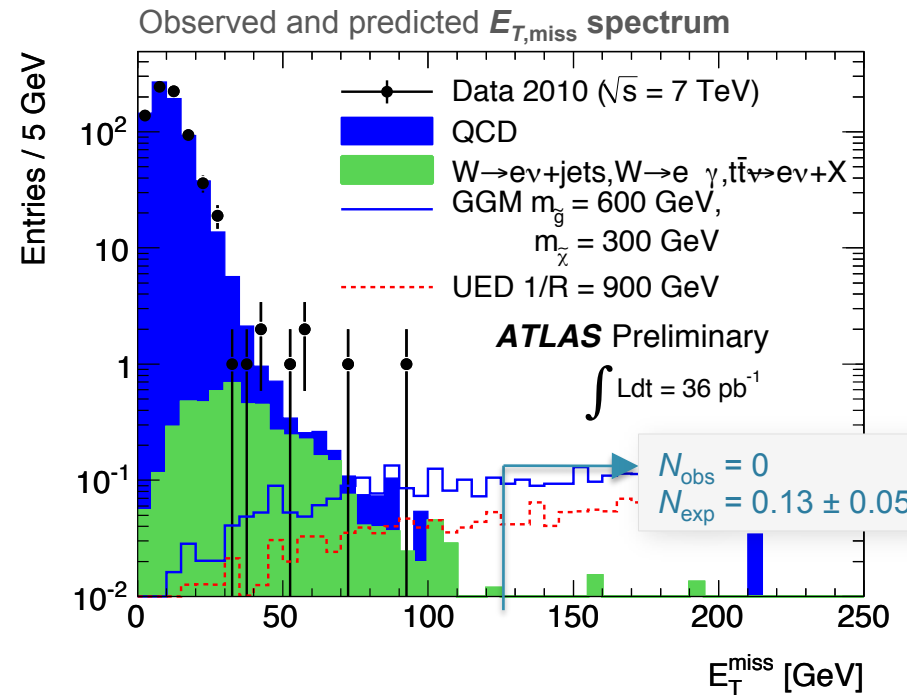
Useful to assess signature-driven performance,
and to discover holes in search strategy



Inclusive search with 2 photons and $E_{T,\text{miss}}$

Sensitive to gauge-mediated SUSY breaking and also UED models

Preliminary



Cut $E_{T,\text{miss}} > 125$ GeV sets 95% CL_s limits:

GGM gluino mass(*) > 560 GeV; UED compactification scale(**): $1/R_{\text{UED}} > 960$ GeV

(*) In GMSB: $\tilde{\chi}_1^0 \rightarrow \gamma + \tilde{G}$, giving $\gamma\gamma + E_{T,\text{miss}}$ signature

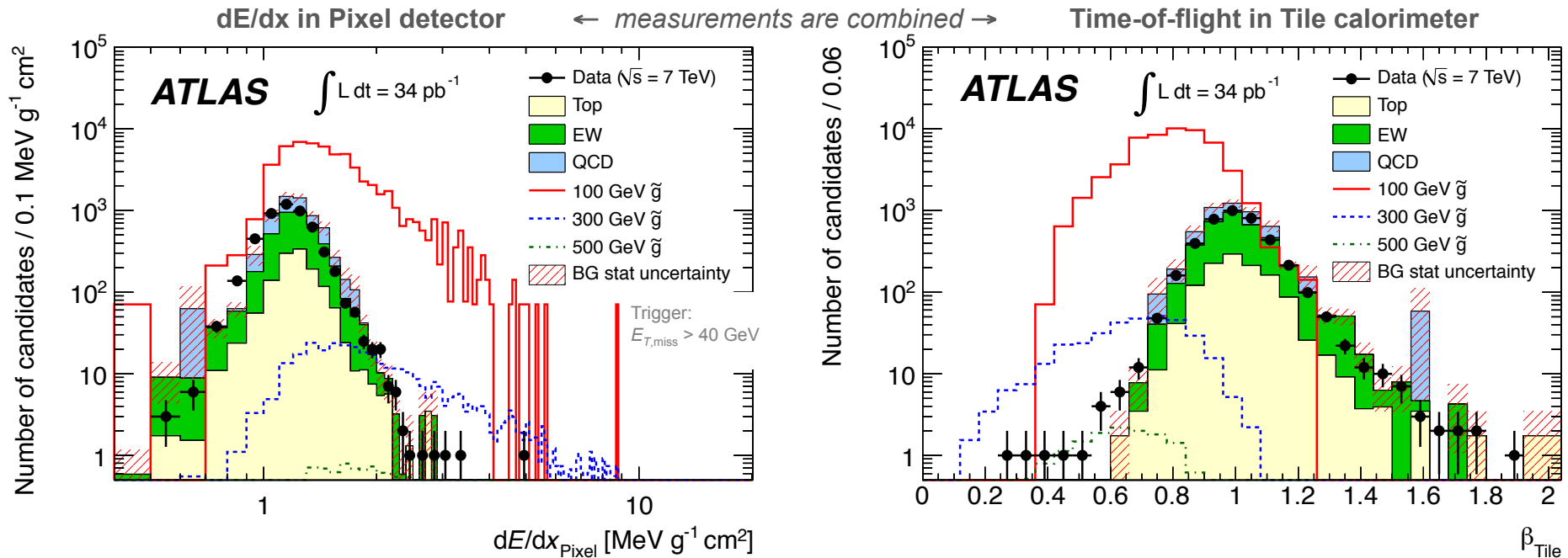
(**) LKP $\gamma^* \rightarrow \gamma + G$ (UED embedded in in eV^{-1} sized EDs)

Search for stable squarks and gluinos [$\tau \sim O(100-1000) \text{ sec}$]

Hadronize to e-neutral or charged colour-singlet R -hadrons: $\tilde{g}g$, $\tilde{g}u\bar{d}'$, $\tilde{t}\bar{d}$, ...

arXiv:1103.1984

Detection of charged R -hadrons through specific ionisation loss and time-of-flight



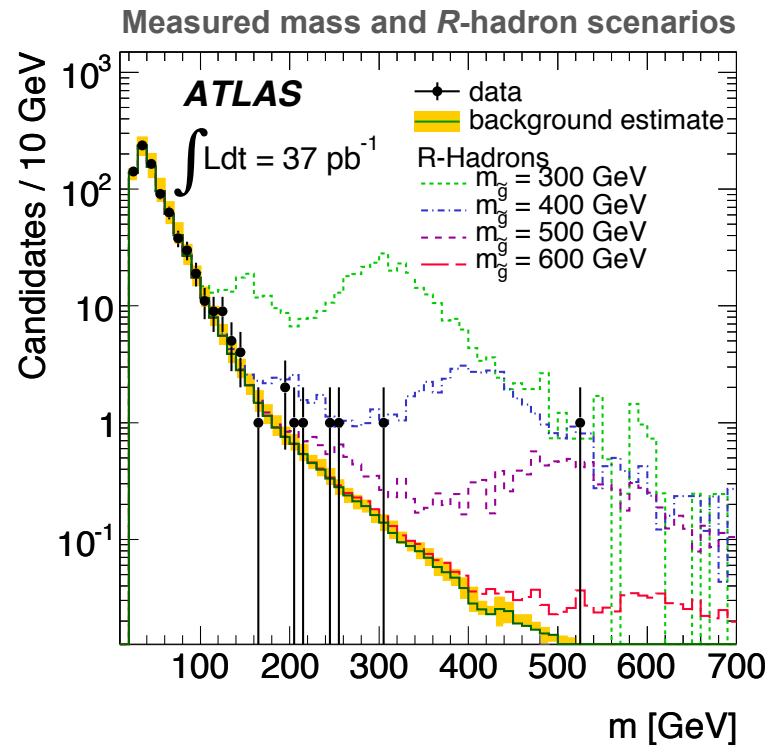
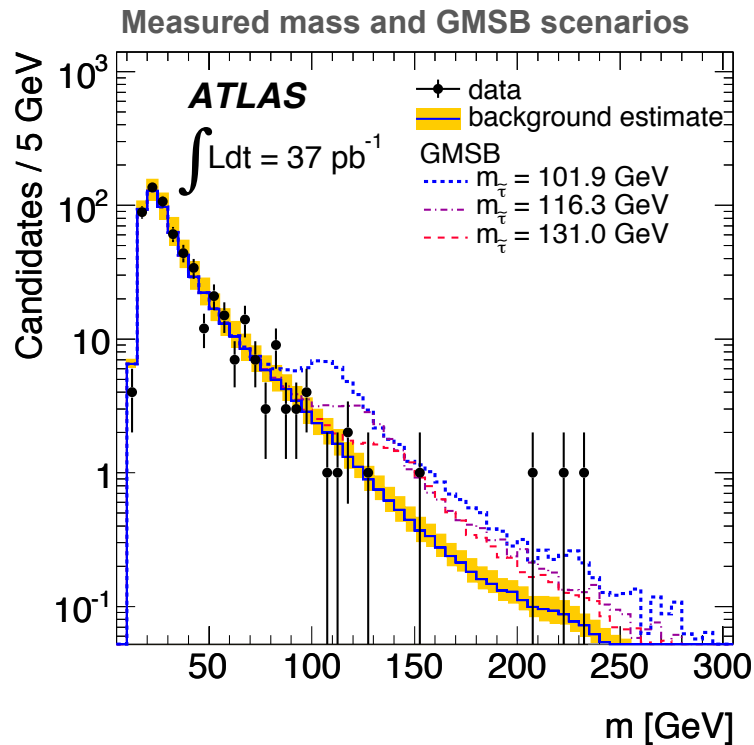
→ 95% CL: sbottom R -hadrons > 294 GeV; stop > 309 GeV; gluino > 562–586 GeV

Search for long-lived particles reaching muons system

Search for GMSB staus (“heavy muons”) and R -hadrons, ID and calo also used

arXiv:1106.4495

Detection of slow massive particles through time-of-flight $\rightarrow \beta$ (mass)



Model-dependent limits:

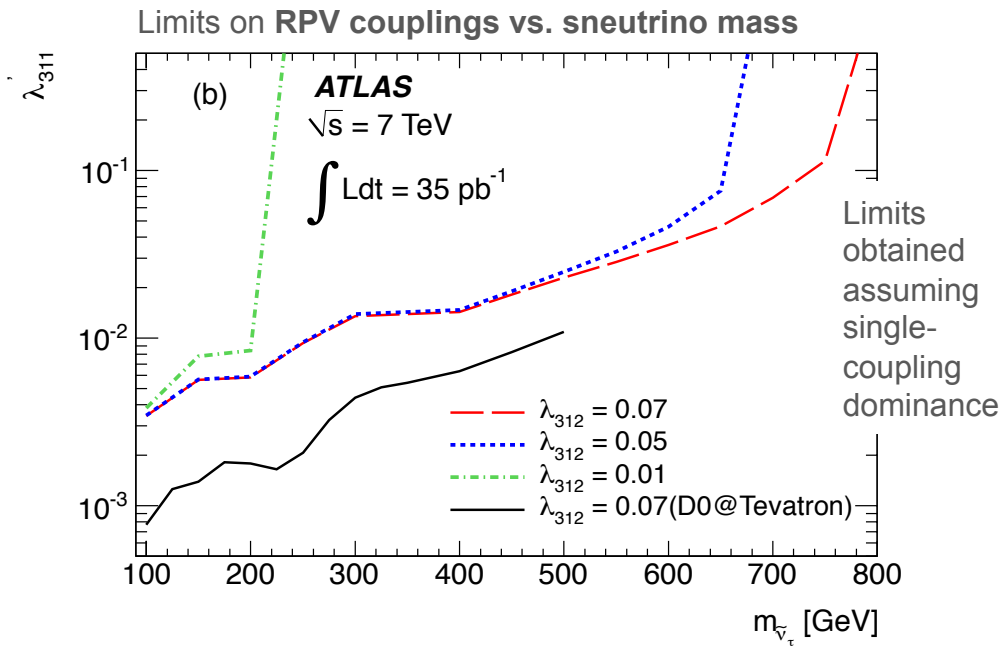
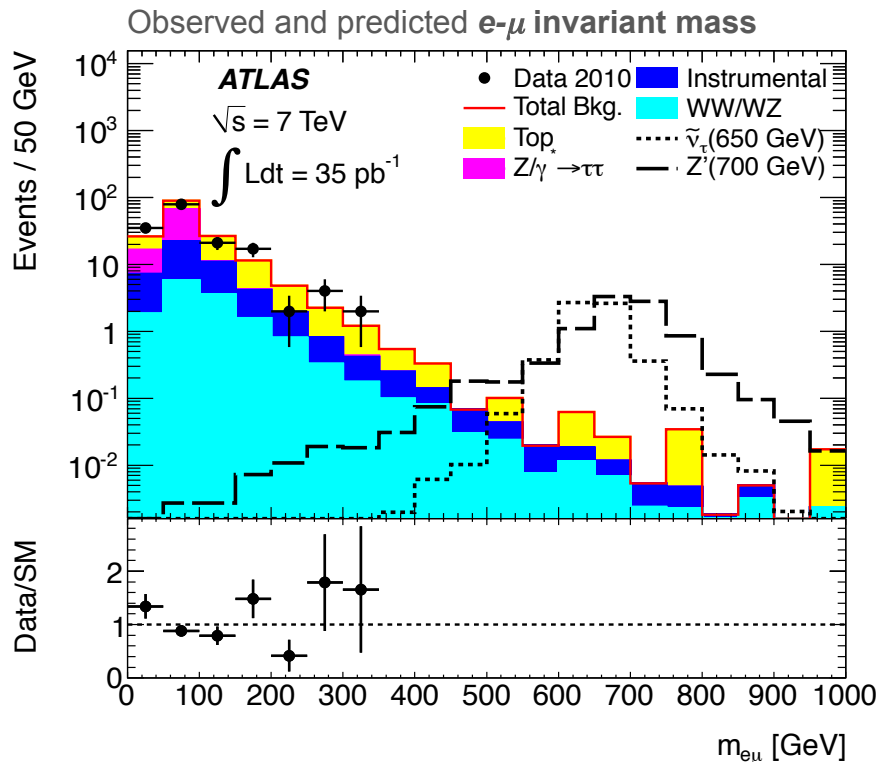
Exclude stable staus of 136 GeV in GMSB benchmark model

Exclude R -hadrons (depending on scattering model and gluino-ball fraction) up to 544 GeV

R-parity violating SUSY: single sparticles, LFV, no $E_{T,\text{miss}}$

Consider: $d\bar{d} \xrightarrow{\lambda'_{311}} \tilde{\nu}_\tau \xrightarrow{\lambda_{321}} e\mu$, search for high mass $e\mu$ signature

arXiv:1103.5559



Analysis also sensitive to Z' bosons with non-diagonal flavour coupling allowing LFV

Limits on RPV coupling: at 95% CL exclude: $m(\tilde{\nu}_\tau) < 750 \text{ GeV}$ for $\lambda'_{311} = 0.11$, $\lambda_{321} = 0.07$

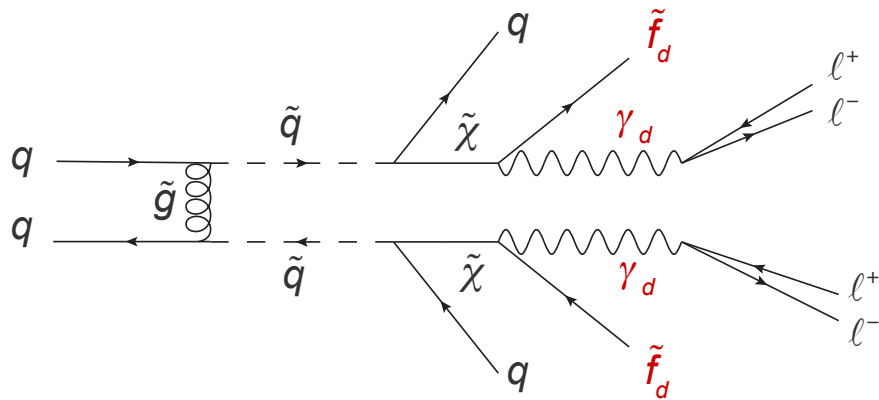
Lepton-jets from dark photon decays to lepton pairs

Hidden sector, weakly coupled to SM, allows for new light (GeV scale) boson

ATLAS-CONF-2011-076

Production of 2 lepton-jets from squark pairs

- dark photon g_d decays to lepton pairs
- dark fermion $\tilde{f}_d$ ("darkino") escapes undetected

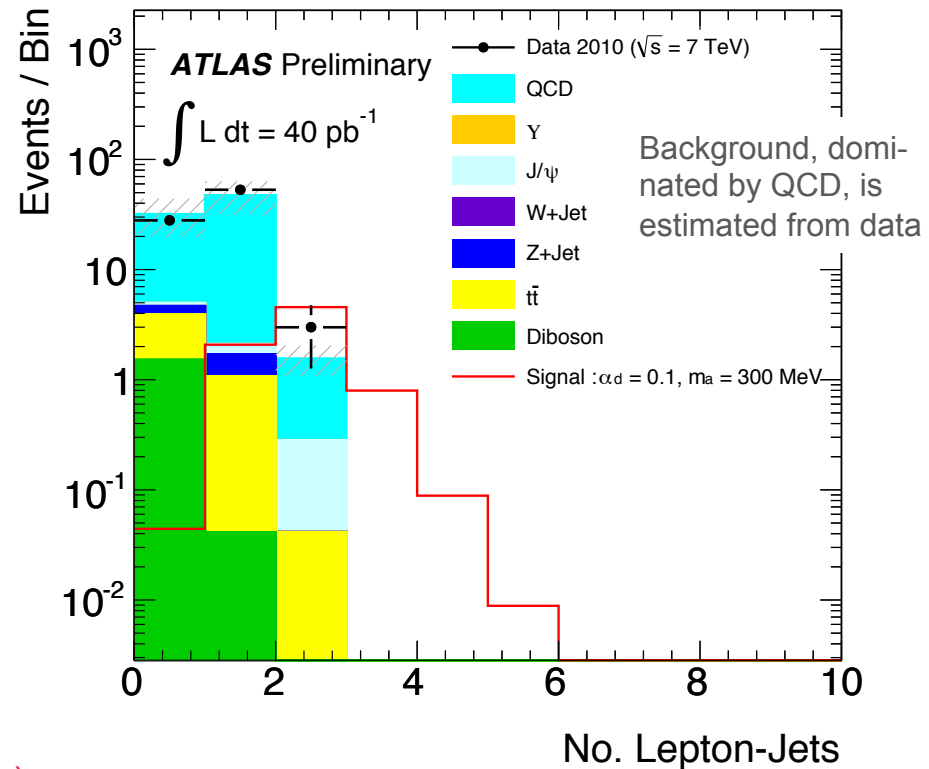


Search for ≥ 2 lepton-jets with ≥ 2 leptons

Zero events observed in signal region,
for 0.20 ± 0.19 expected background

→ model-dependent limits on cross section of $O(0.2 \text{ pb})$

Lepton-jets must have high-quality muons and be isolated



hierarchy

Searches for Other New Phenomena

Excited quarks, contact int., Z'/W' , Leptoquarks, 4th generation, Extra dimensions, ...

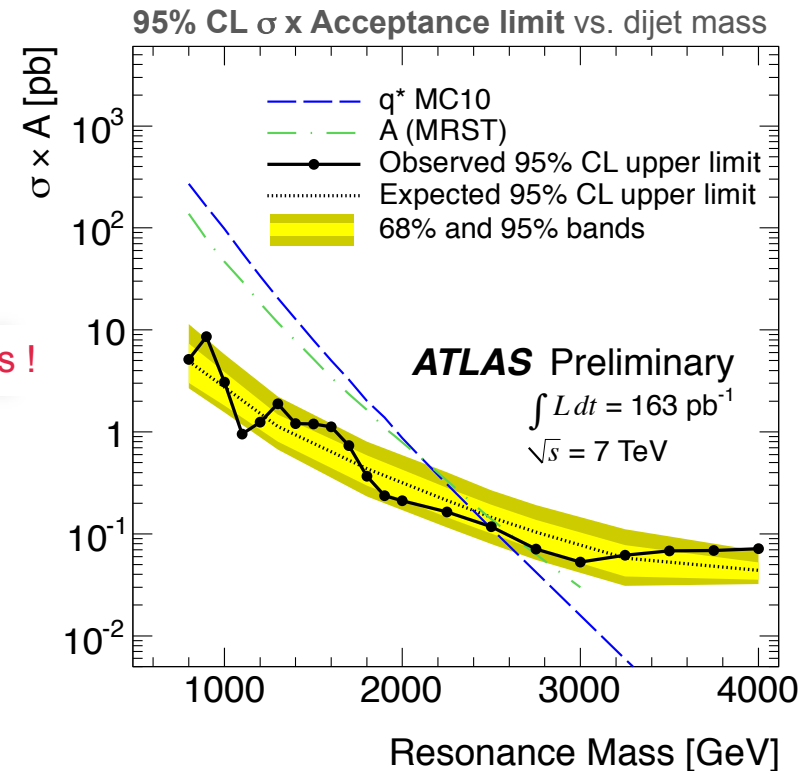
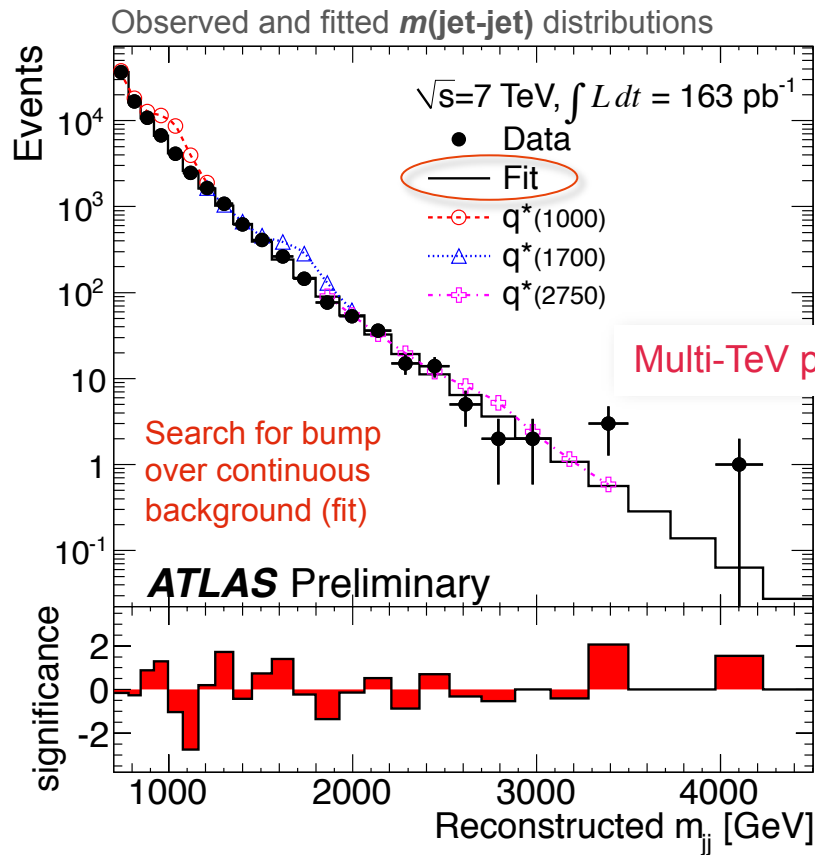


Dijet mass and angular distributions as probes of NP

Excited quarks, contact interactions, axiguons, strong gravity, ...

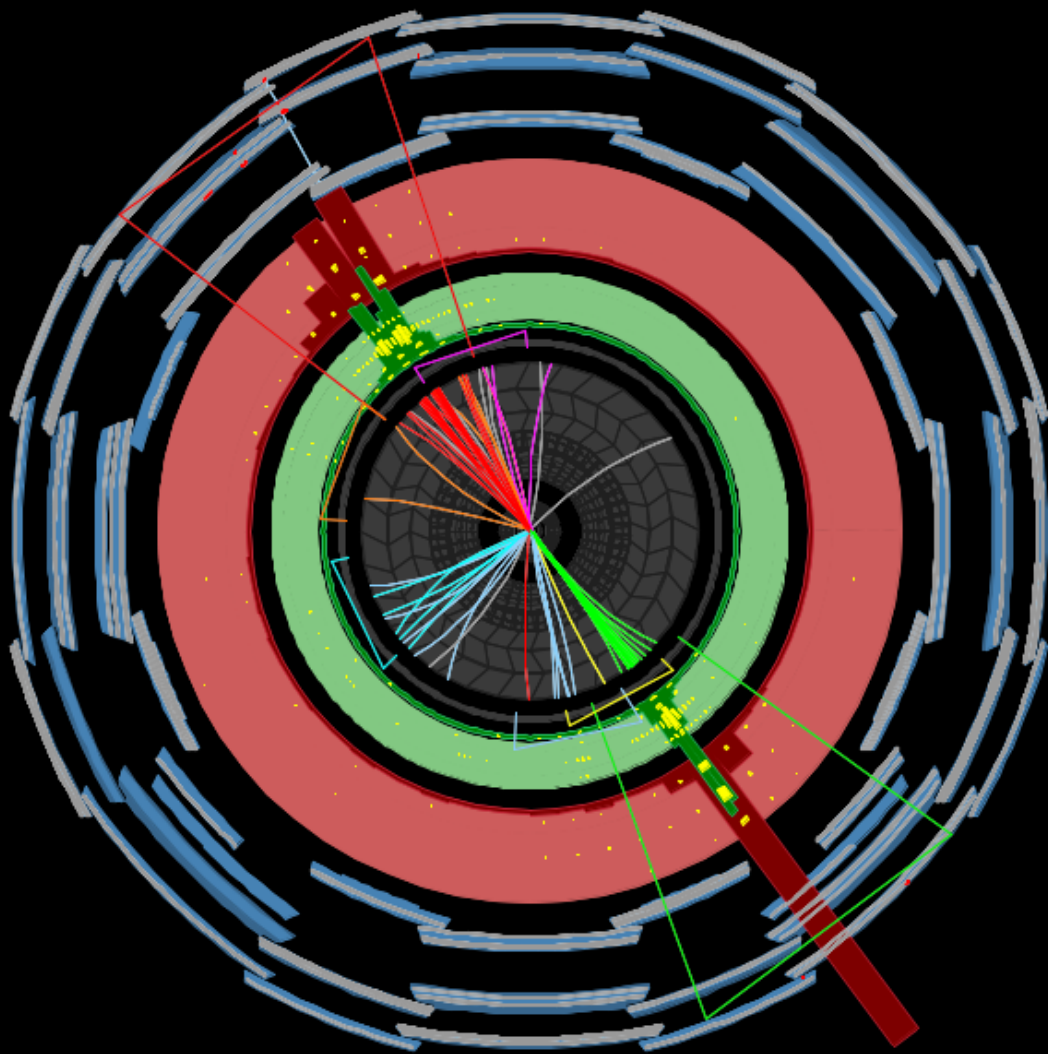
2011
data

ATLAS-CONF-2011-081



No deviations from SM seen → set limits

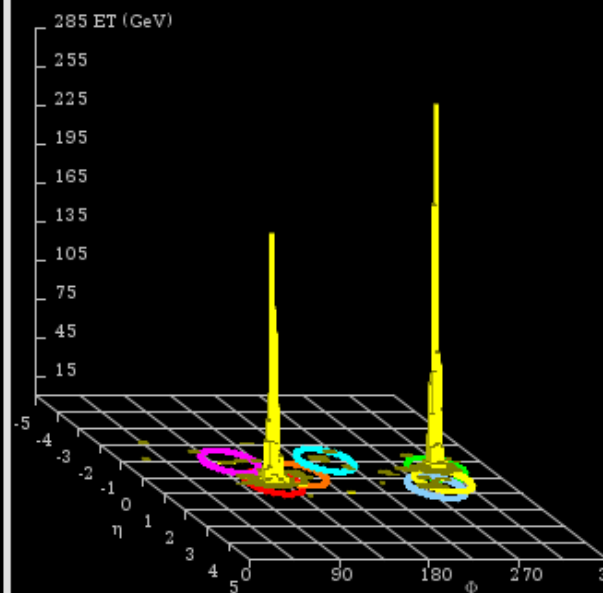
Event with 4.04 TeV dijet invariant mass



ATLAS EXPERIMENT

Run Number: 179938, Event Number: 12054480

Date: 2011-04-18 17:57:29 EDT



Dijet mass and angular distributions as probes of NP

Excited quarks, contact interactions, axigluons, strong gravity, ...

2011
data

ATLAS-CONF-2011-081

arXiv:1103.3864

	Benchmark model	Observed (expected) limit at 95% CL
Resonant	Excited quarks	$m(q^*) > 2.64$ (2.12) TeV
	Axigluons	$m > 2.67$ (2.48) TeV
Nonresonant	Quantum black hole ($\delta = 6$)	$M_D > 3.67$ (3.64) TeV
	4-quark contact interactions	$\Lambda > 6.7$ (5.7) TeV ^(*)

(*) Bayesian limit

Limit on $\mu\mu qq$ contact interactions derived from $m(\mu\mu)$
spectrum (42 pb⁻¹): $\Lambda > 4.9 / 4.5$ TeV at 95% CL
for constructive / destructive interference

arXiv:1104.4398

New limit on size of quark:
 < 2.1 (3.4) $\times 10^{-18}$ cm

For the record: limit on electron radius from $g - 2$:
 $R_g < 4 \times 10^{-11} \times 10^{-12}$ cm $\sim O(10^{-22})$ cm

Searches for W' and Z' resonances in decays to e/μ

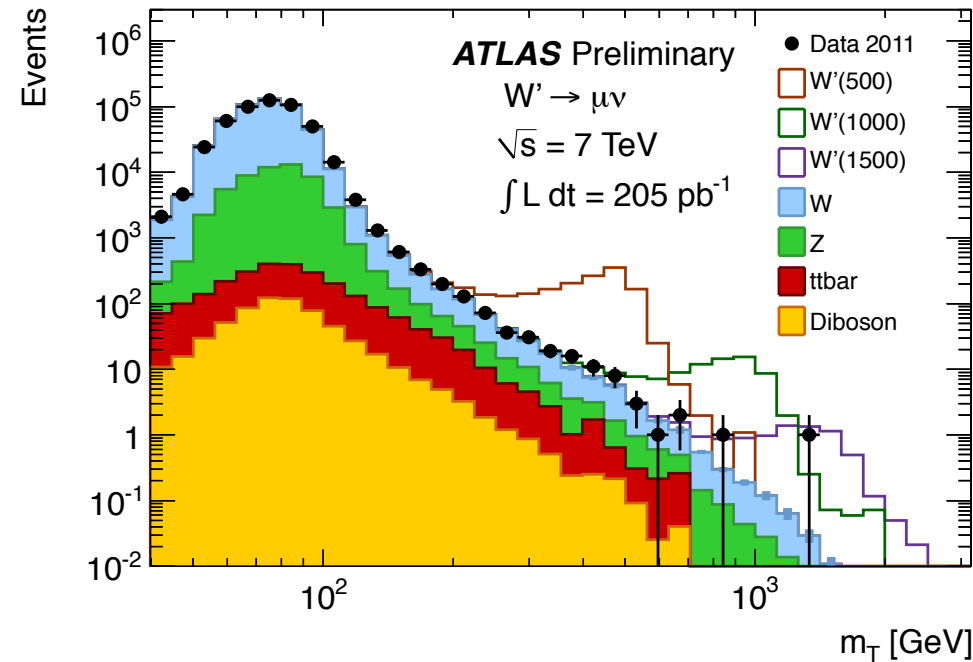
Use transverse / dilepton mass to search for excess over SM



arXiv:1103.1391, ATLAS-CONF-2011-082

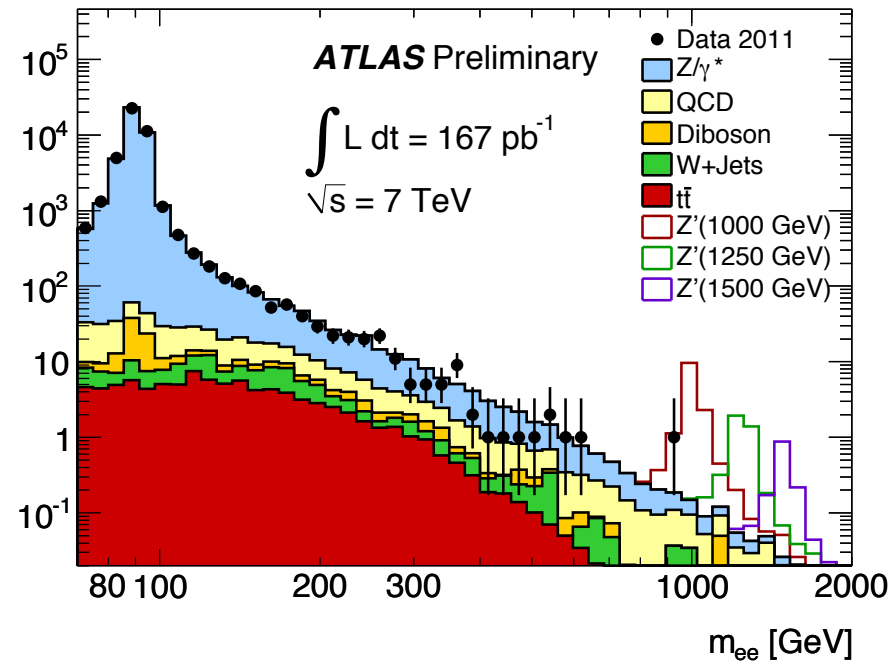
arXiv:1103.6218, ATLAS-CONF-2011-083

Observed and predicted **transverse mass**, **search bumps**



Combination of 2010+2011 ($W \rightarrow \mu\nu$ only) sets
 95% CL_s limit: $m(W'_{\text{SSM}}) > 1.70 \text{ (1.77) TeV}^{(*)}$

Observed and predicted **dilepton mass**



Likelihood fit sets limit at 95% $\text{CL}_{\text{Bayesian}}$:
 $m(Z'_{\text{SSM}}) > 1.41 \text{ (1.41) TeV}^{(*)}$

(*) limits for E_6 Z' models: $1.12_\psi - 1.26_\chi \text{ GeV}$; for Z^*

Searches for W' and Z' resonances in decays to e/μ

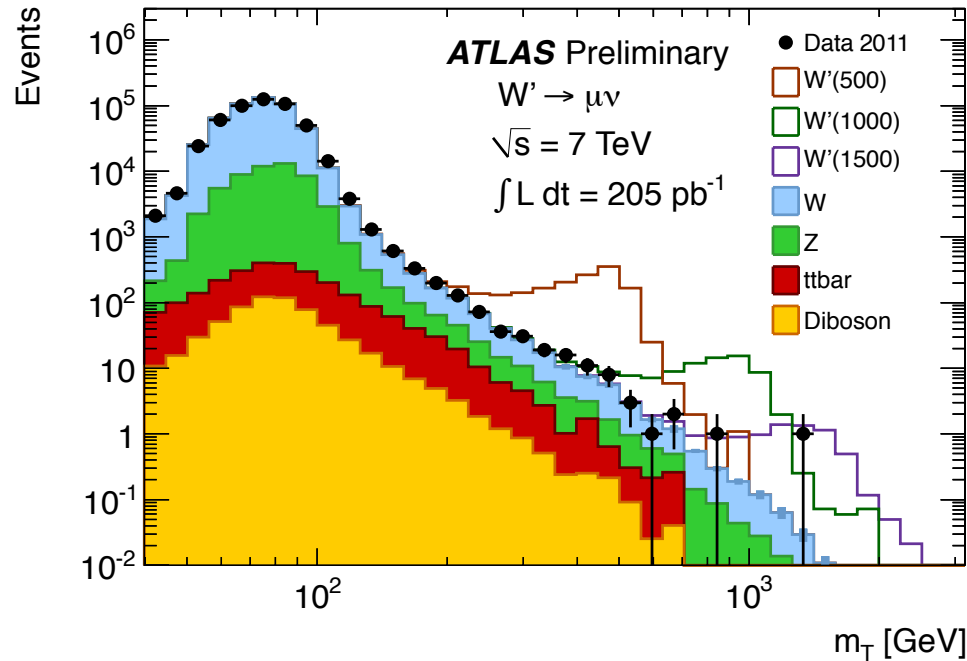
Use transverse / dilepton mass to search for excess over SM



arXiv:1103.1391, ATLAS-CONF-2011-082

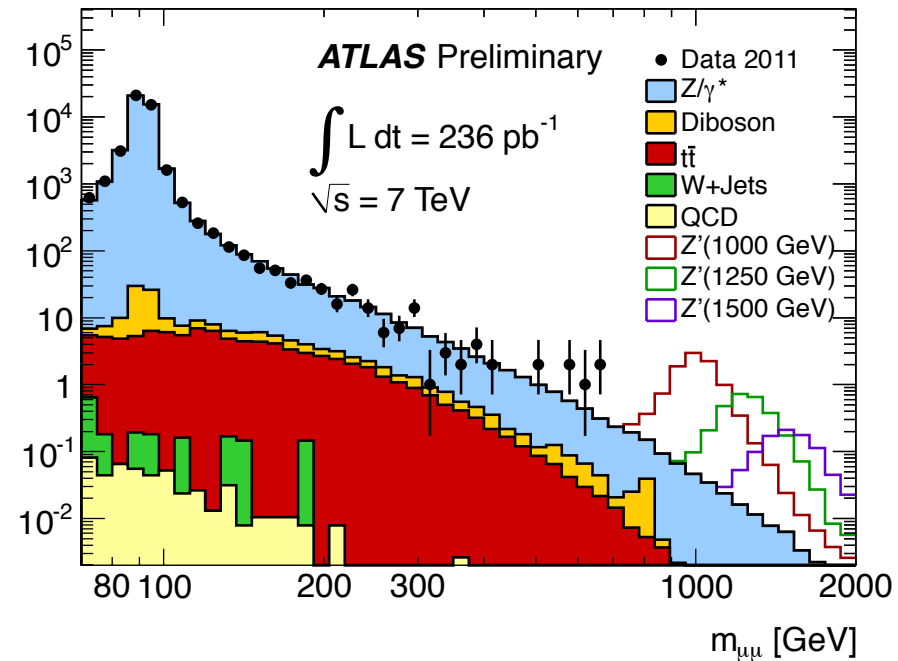
arXiv:1103.6218, ATLAS-CONF-2011-083

Observed and predicted **transverse mass**



Combination of 2010+2011 ($W \rightarrow \mu\nu$ only) sets
95% CL_s limit: $m(W'_{SSM}) > 1.70$ (1.77) TeV(*)

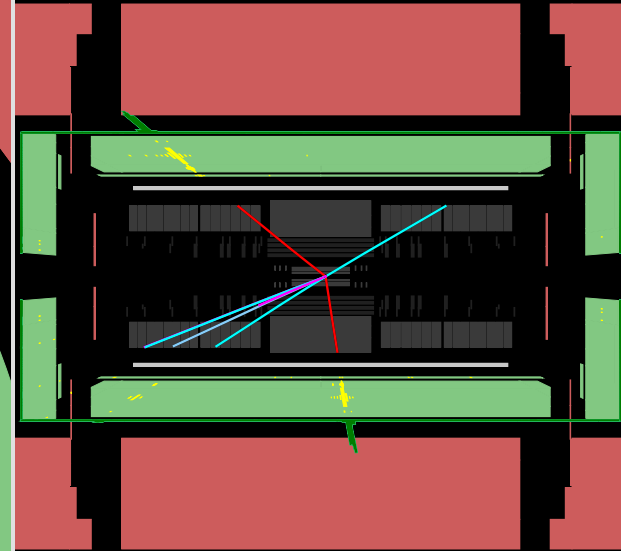
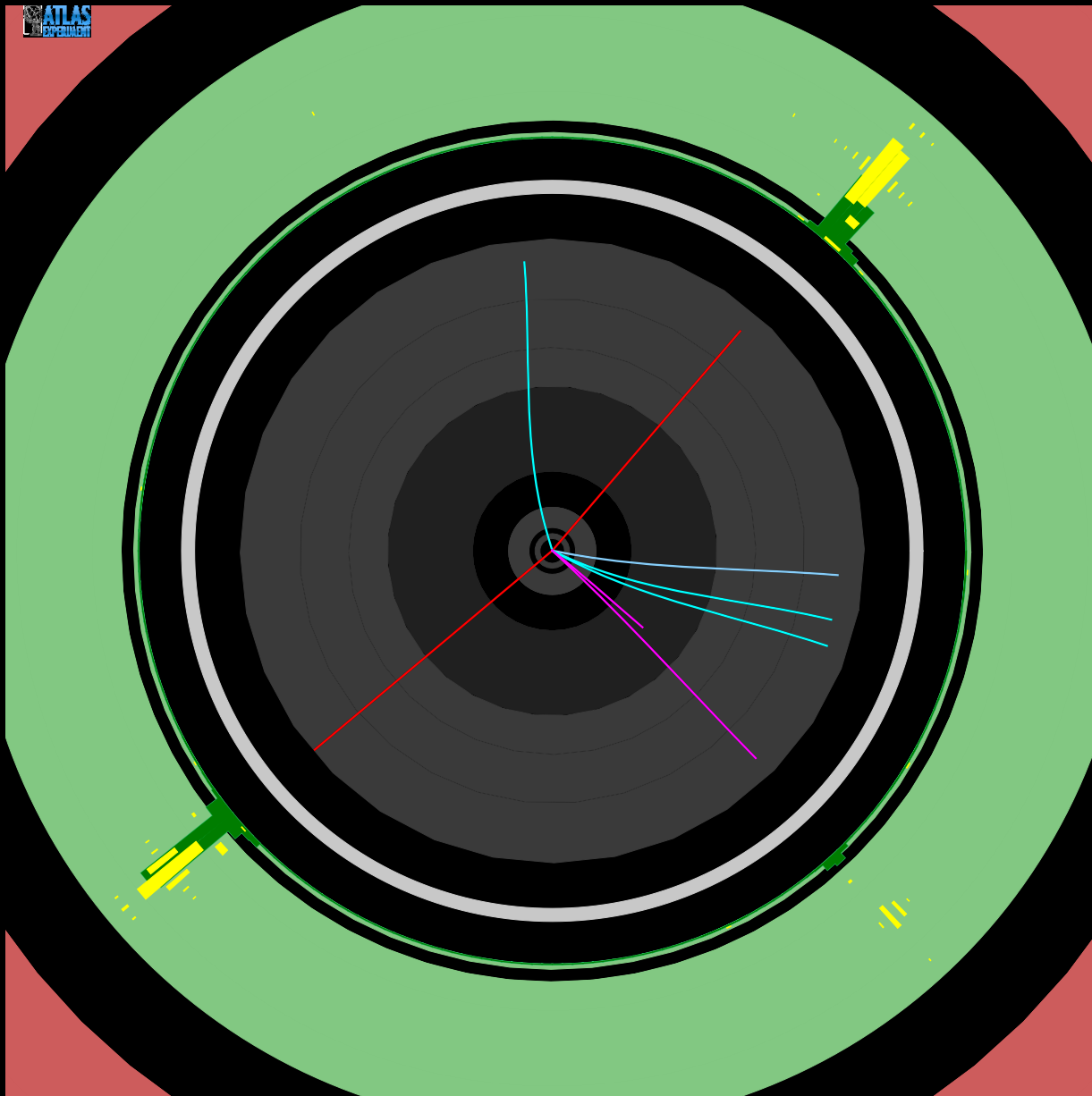
Observed and predicted **dilepton mass**



Likelihood fit sets limit at 95% CL_{Bayesian} :
 $m(Z'_{SSM}) > 1.41$ (1.41) TeV(*)

(*) limits for E_6 Z' models: $1.12_\psi - 1.26_\chi$ GeV ; for Z^*

Highest mass dielectron event with $m(ee) = 920$ GeV



ATLAS
EXPERIMENT

Run Number: 180400, Event Number: 77876087

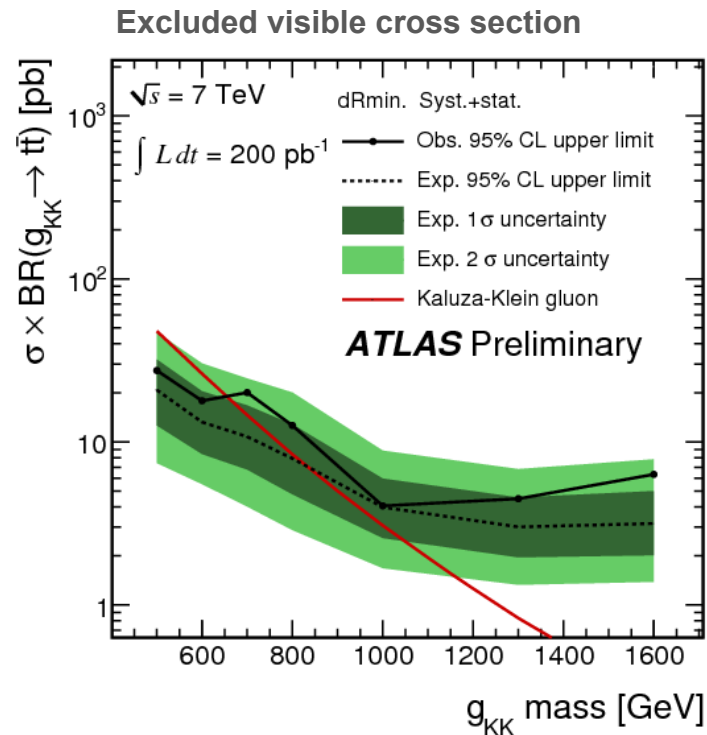
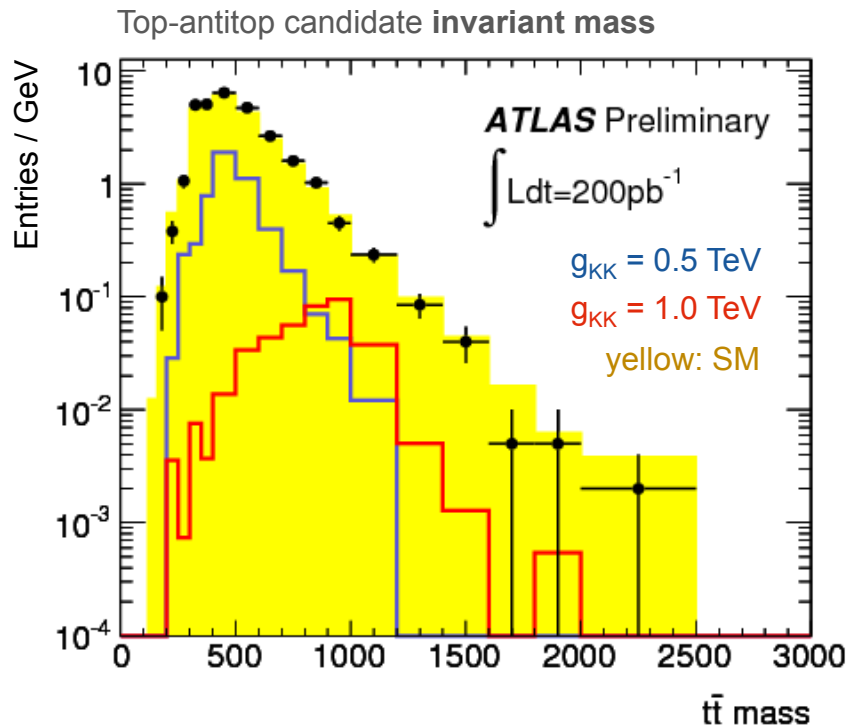
Date: 2011-04-27 23:35:05 EDT

Resonant $t\bar{t}$ production

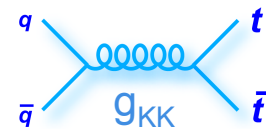
Study $t\bar{t}$ invariant mass spectrum in lepton + jets final states



ATLAS-CONF-2011-087



Limit for RS KK gluon

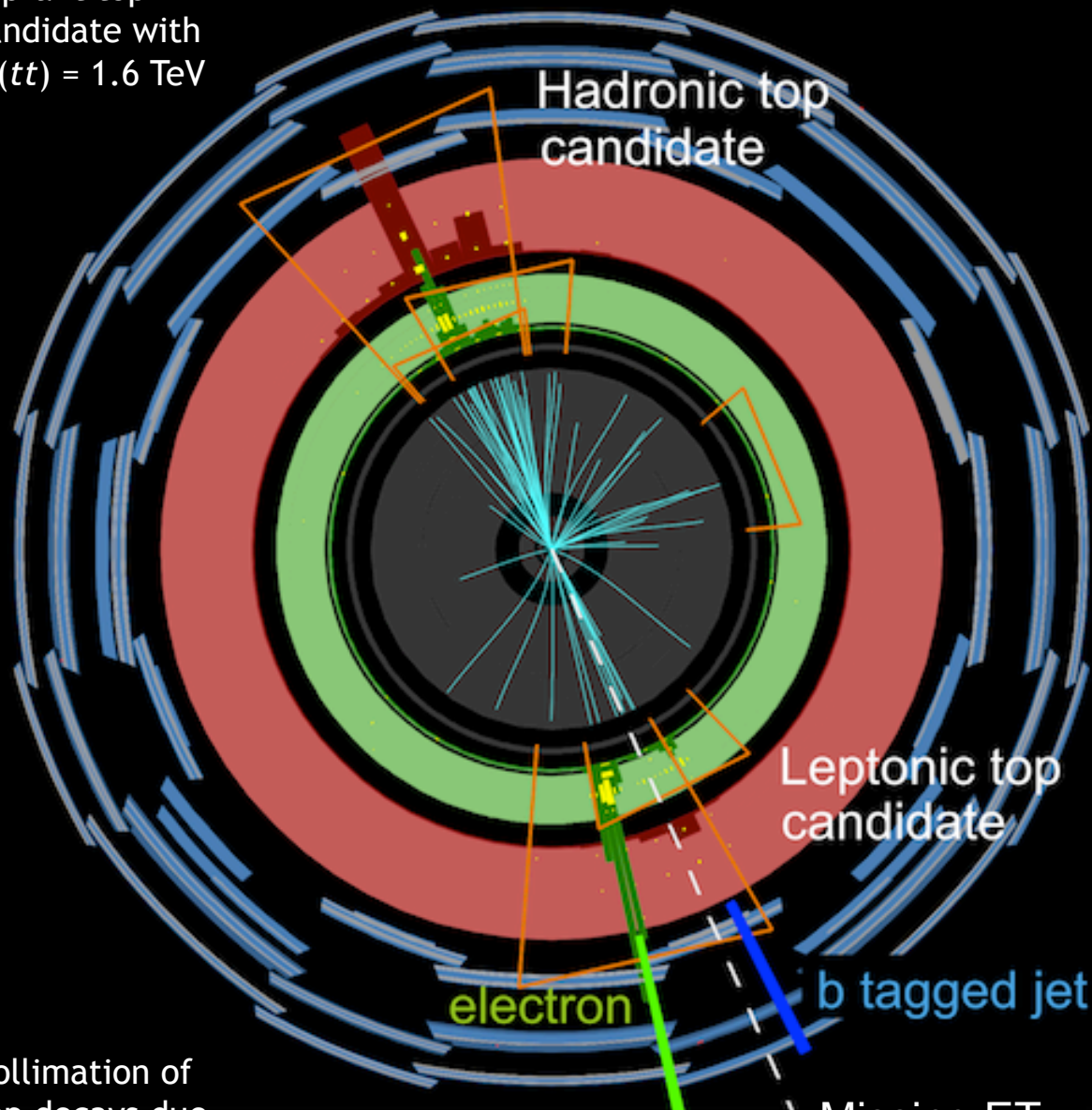


Analysis not yet sensitive to leptophobic Z' model chosen

95% $\text{CL}_{\text{Bayes.}}$ limits:

$\sigma \times \text{BR}(g_{KK} \rightarrow t\bar{t}) < 38 \text{ pb}$ ($m_{g_{KK}} = 500 \text{ GeV}$), $< 4.2 \text{ pb}$ (1300 GeV) $\rightarrow m(g_{KK}) < 650 \text{ GeV}$

Top-antitop
candidate with
 $m(tt) = 1.6 \text{ TeV}$



Collimation of
top decays due
to strong boost

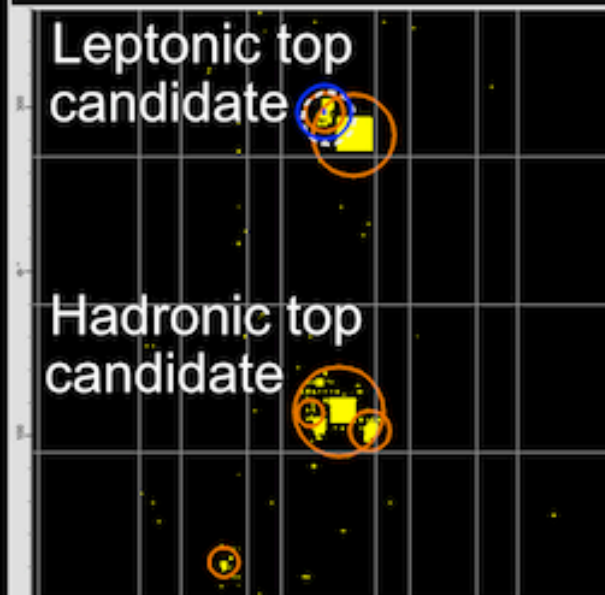


Run Number: 180400, Event Number: 54251178

Date: 2011-04-28 03:33:58 CEST

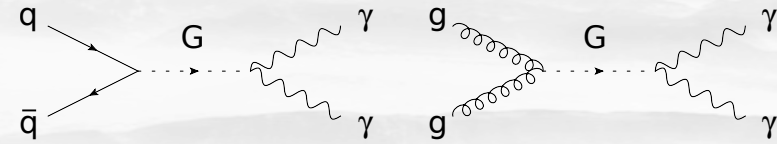
Leptonic top
candidate

Hadronic top
candidate

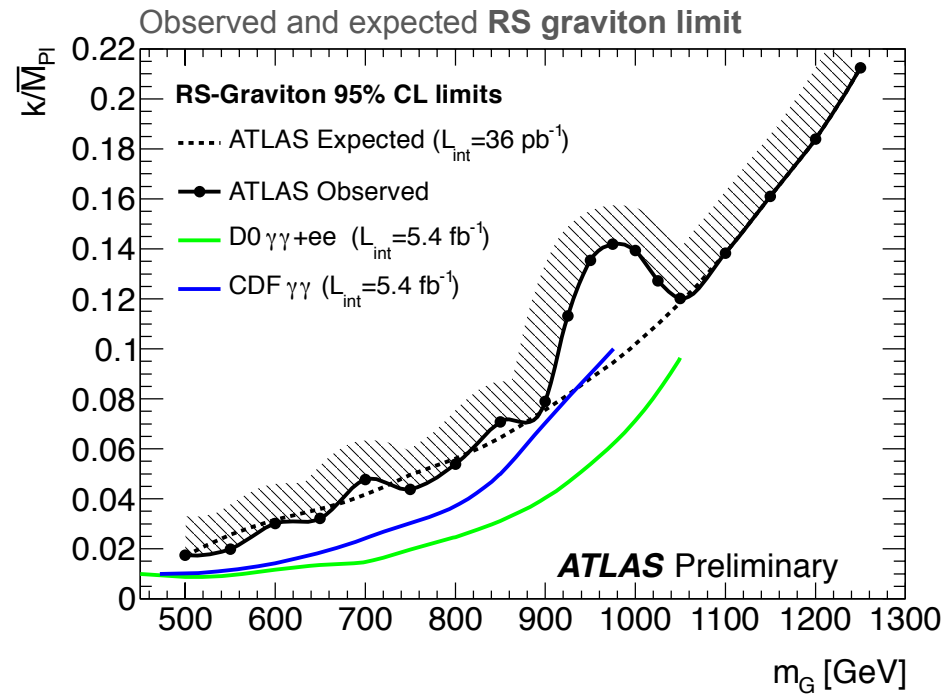
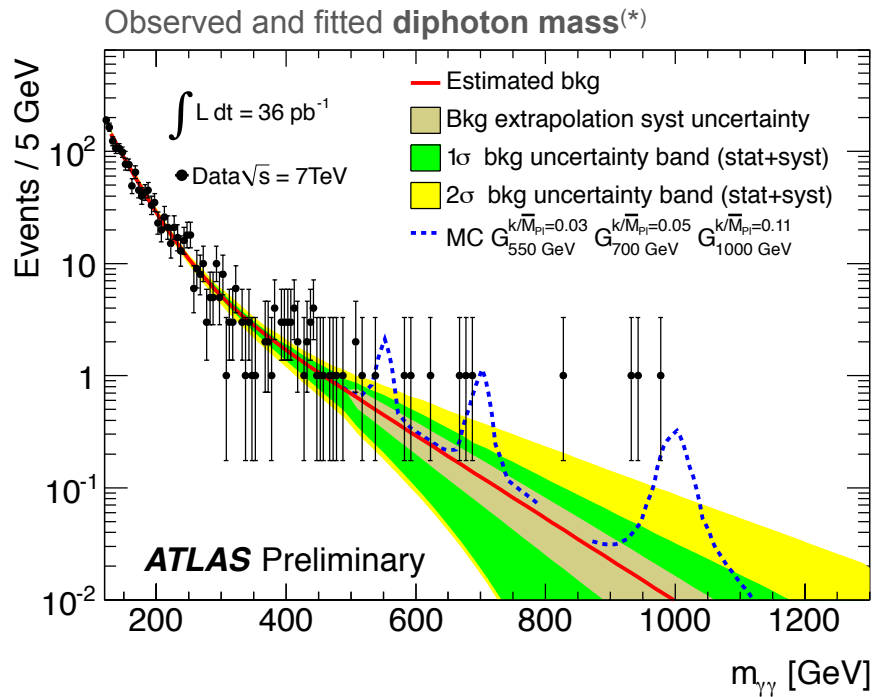


Search for extra dimensions

Randall-Sundrum KK graviton $G \rightarrow \gamma\gamma$



ATLAS-CONF-2011-044

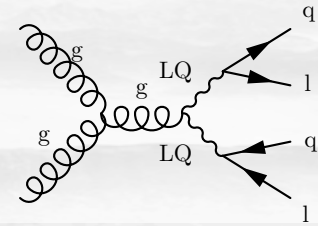


95% CL_s limit: $M_G > 545$ (920 GeV) for $k/M_{\text{Pl}} = 0.02$ (0.1)

(*)Preliminary analysis using loose photon identification

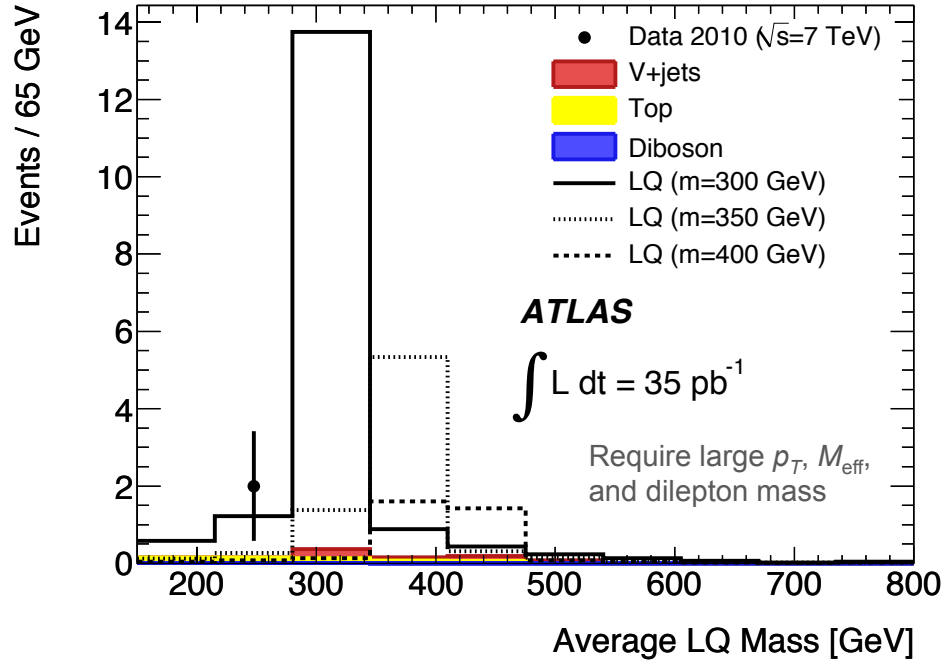
Search for 1st and 2nd gen. leptoquarks

Study scalar LQ pair production to $lljj$ and $l\nu jj$ final states

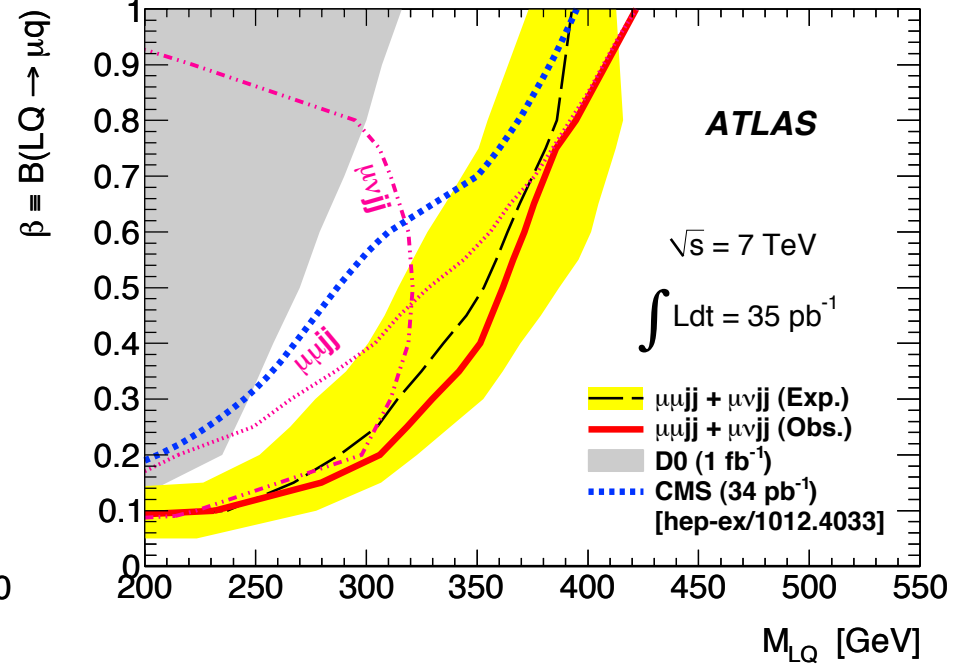


arXiv:1104.4481

Observed and predicted ave. $M(\text{LQ})$ in $eejj$ channel



Observed and expected 2nd generation LQ limit



95% CL_s limits on $M(\text{LQ})$ for 1st gen: > 376 (319) GeV; 2nd gen > 422 (362) GeV for $\beta = 1.0$ (0.5)

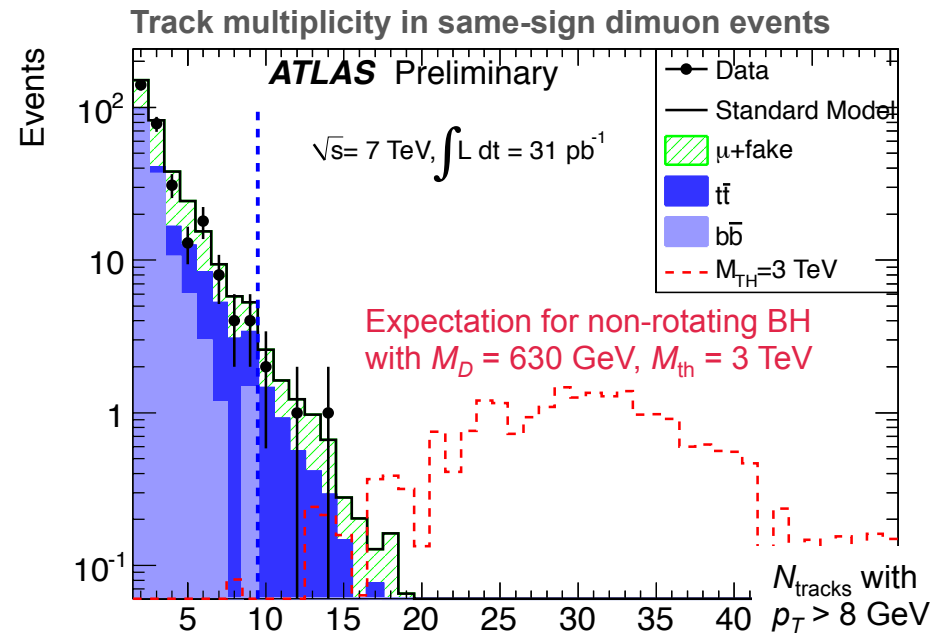
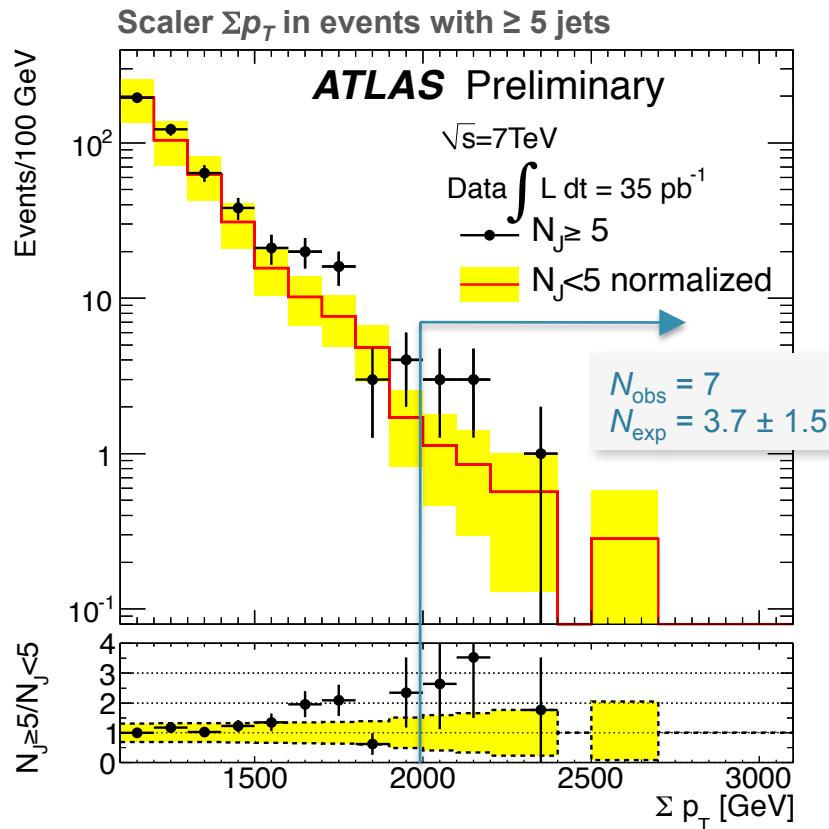
Search for extra dimensions - trans-Planck physics

Microscopic black hole search in multijet and same-sign dimuon events(*)

(*)BH signal simulated with BLACKMAX 2.01

ATLAS-CONF-2011-068

ATLAS-CONF-2011-065



Fiducial non-SM cross section limits :

- Multijet analysis: $\sigma \times \text{BR} \times A < 0.29 \text{ (0.19) pb}$
- SS dimuon analysis: $\sigma \times \text{BR} \times A < 0.18 \text{ (0.28) pb}$

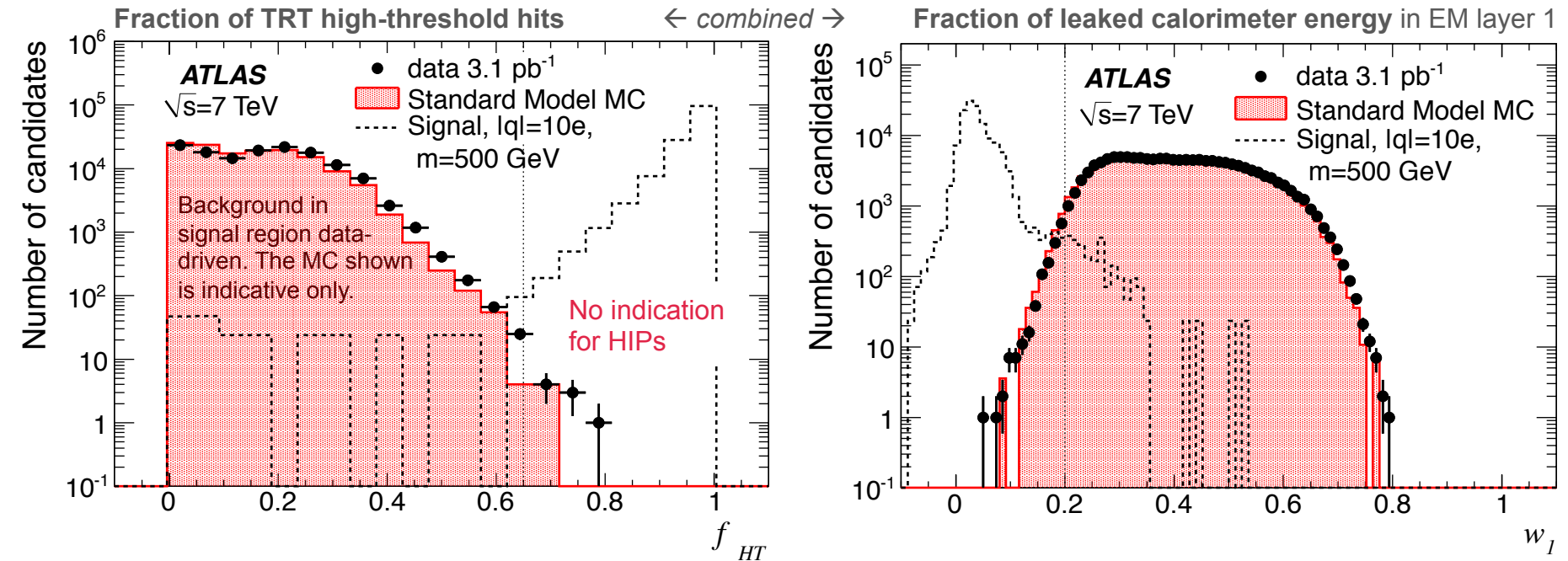
Also BH limit from $t + X$ cross section: $M_{\text{th}} > 2.35 \text{ TeV}$

ATLAS-CONF-2011-070

Search for long-lived highly ionising particles* (HIP)

Heavy particle with $Q_{\text{electric}} \sim \mathcal{O}(10e) \rightarrow$ large specific energy loss in detector

arXiv:1102.0459



Analysis on low-luminosity data only to benefit from 10 GeV E_T EM trigger threshold

95% CL_{Bayes} limits: $\sigma < 3\text{--}12$ pb (for DY mechanism) for $6e \leq |Q_e| \leq 17e$ and $0.2 < m_{\text{HIP}} < 1$ TeV

(**) Examples for models with HIPs: Q-balls, stable micro black-hole remnants, magnetic monopoles & dyons



Summary

... after (only) one year of 7 TeV data taking

ATLAS Searches* - 95% CL Lower Limits (June 6, 2011)

ATLAS
Preliminary

$$\int L dt = (31 - 236) \text{ pb}^{-1}$$

SUSY

MSUGRA : 0/1-lep + $E_{T,miss}$
 MSUGRA : 0-lep + $E_{T,miss}$
 Simplified model : 0-lep + $E_{T,miss}$
 Simplified model : 0-lep + $E_{T,miss}$
 Simplified model : 0/1-lep + b-jets + $E_{T,miss}$
 Pheno-MSSM (light $\tilde{\chi}_1^0$) : 2-lep SS + $E_{T,miss}$
 Pheno-MSSM (light $\tilde{\chi}_1^0$) : 2-lep OS_{SF} + $E_{T,miss}$
 GMSB (GGM) + Simpl. model : $\gamma\gamma$ + $E_{T,miss}$
 GMSB : stable $\tilde{\tau}$
 Stable massive particles : R-hadrons
 Stable massive particles : R-hadrons
 Stable massive particles : R-hadrons
 RPV ($\lambda'_{311}=0.11, \lambda_{321}=0.07$) : high-mass $e\mu$

Extra dimensions

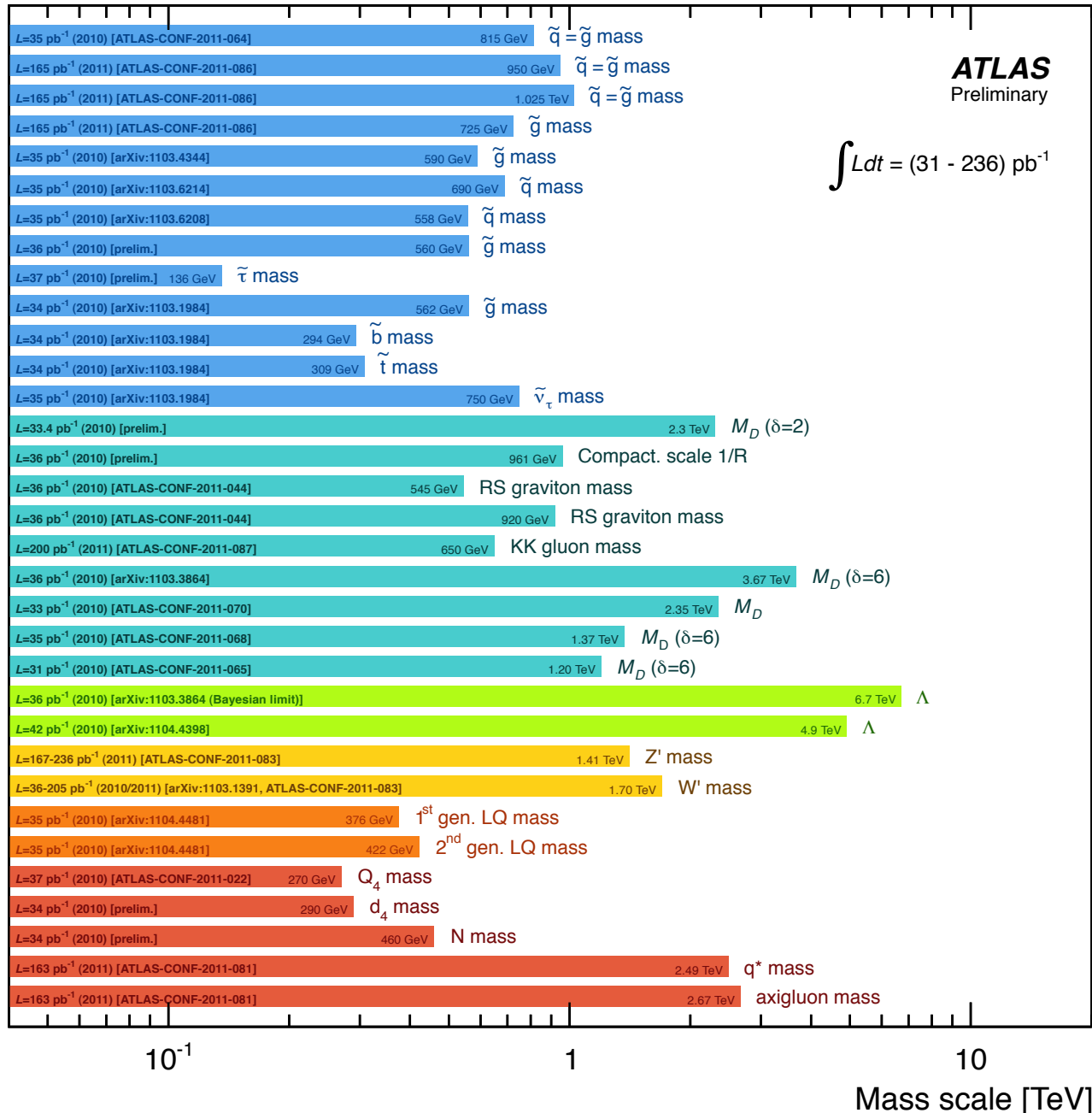
Large ED (ADD) : monojet
 UED : $\gamma\gamma$ + $E_{T,miss}$
 RS with $k/M_{Pl} = 0.02$: $m_{\gamma\gamma}$
 RS with $k/M_{Pl} = 0.1$: $m_{\gamma\gamma}$
 RS with top couplings $g_L=1.0, g_R=4.0$: $m_{t\bar{t}}$
 Quantum black hole (QBH) : $m_{dijet}, F(\chi)$
 QBH : High-mass $\sigma_{t+\bar{t}}$
 ADD BH ($M_{th}/M_D=3$) : multijet $\Sigma p_T, N_{jets}$
 ADD BH ($M_{th}/M_D=3$) : SS dimuon $N_{ch. part.}$
 qq qq contact interaction : $F_\chi(m_{dijet})$
 qq $\mu\mu$ contact interaction : $m_{\mu\mu}$

LQ : Z'/W: Ct. I.

SSM : $m_{ee/\mu\mu}$
 SSM : $m_{\tau e/\mu\tau}$
 Scalar LQ pairs ($\beta=1$) : kin. vars. in $eejj, e\nu jj$
 Scalar LQ pairs ($\beta=1$) : kin. vars. in $\mu\mu jj, \mu\nu jj$
 4th family : coll. mass in $Q_4 \bar{Q}_4 \rightarrow WqWq$
 4th family : $d_4 \bar{d}_4 \rightarrow WtWt$ (SS dilepton)
 Major. neutr. ($V_{4-ferm.}, \Delta=1 \text{ TeV}$) : SS dilepton

Other

Excited quarks : m_{dijet}
 Axigluons : m_{dijet}

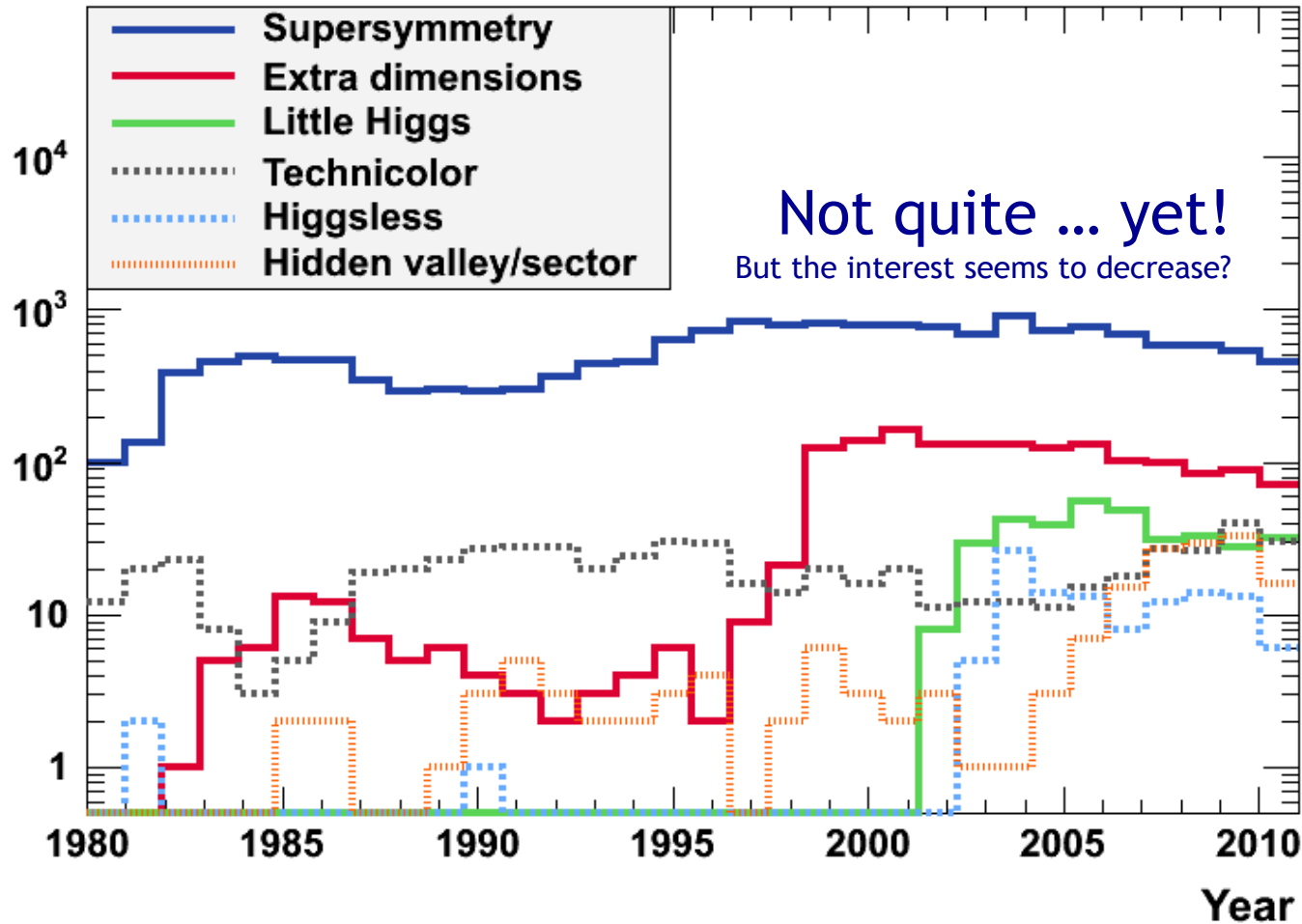


*Only a selection of the available results shown

Paper Statistics in SPIRES

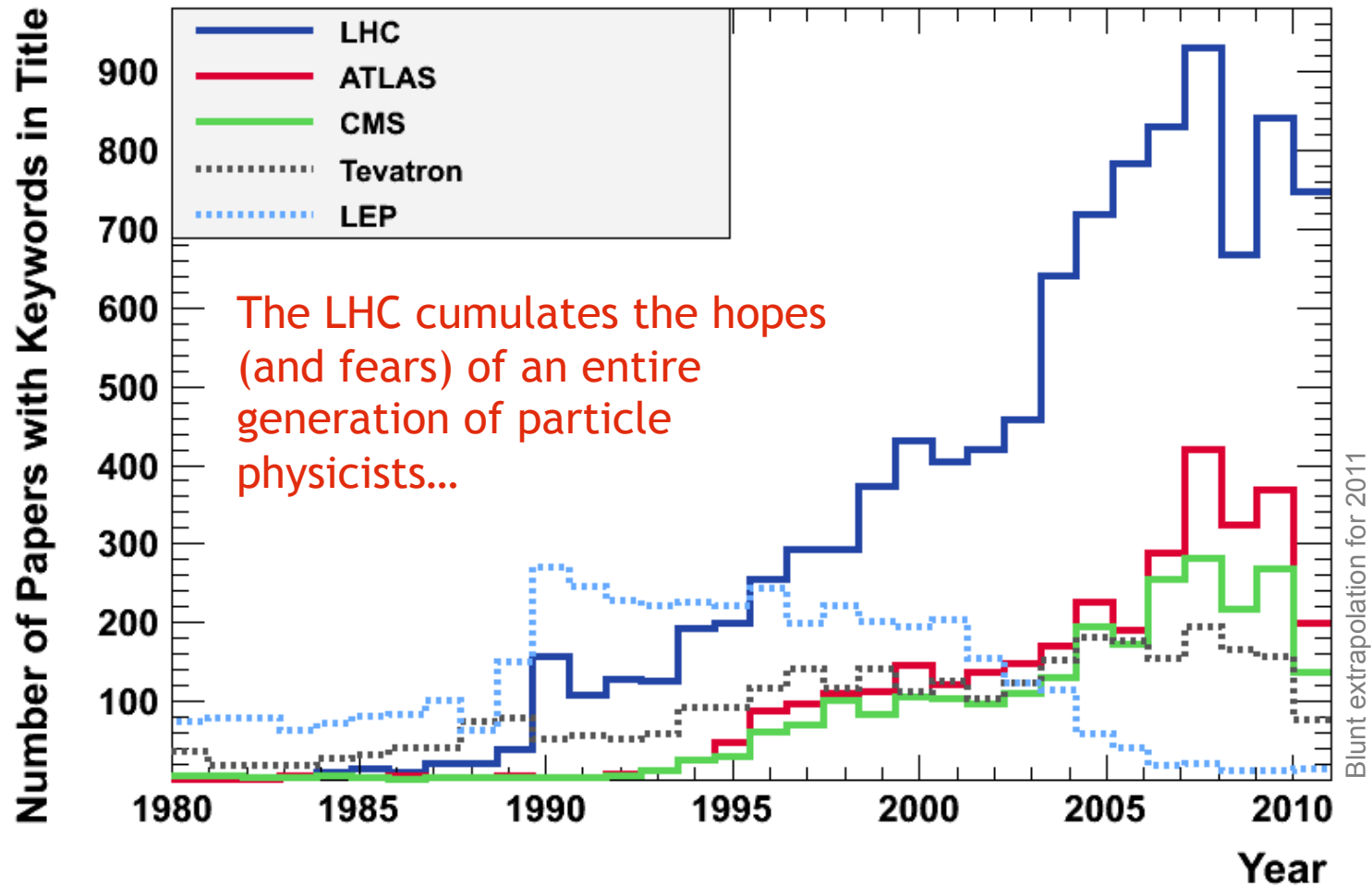
Is SUSY out already?

Number of Papers with Keywords in Title



Caution: serious science!

Paper Statistics in SPIRES



Caution: serious science!

10⁻¹

1

10

Mass scale [TeV]

Conclusions

ATLAS is mining its data for the expected and the unexpected

- 2010 data ~ fully analysed, strong effort on 2011 data → EPS, LP, ...

Search for the SM Higgs boson

- First full ATLAS maximum likelihood combination of 6 Higgs analyses
- Touching 95% CL exclusion at 160 GeV [expect 145-190 GeV with 1 fb⁻¹]

Searches for beyond-SM phenomena

- Large amount of search analyses performed, exclusion reach between 300 GeV and 6.7 TeV obtained, SUSY in MSUGRA excluded up to 950 GeV
- Intensive work on detector and background understanding pays off
- Analyses in “factory” mode, setup to fast conduct new searches

No new physics in 2010 → expect ~100 × more data in 2011

Luminosity potential of present LHC

How to go further?

$$L = \frac{f_{\text{rev}} n_b N_b^2}{4\pi\beta^* \varepsilon} \frac{1}{\sqrt{1 + \phi_{\text{piw}}^2}} \quad \phi_{\text{piw}} \equiv \frac{\sigma_z \theta_c}{2\sigma_{x,y}^*}$$

50 ns spacing:

n_b : 1092 $\rightarrow$ 1380, N_b : $1.2 \times 10^{11} \rightarrow 1.7 \times 10^{11}$ (double batch inj.)

β^* : 1.5 $\rightarrow$ 1.0 m

Total gain $\sim$ factor 4 $\rightarrow$ **$5 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$ at 3.5 TeV**

25 ns spacing (e- cloud in SPS & LHC!?):

n_b : 1092 $\rightarrow$ 2808, N_b : 1.2×10^{11}

β^* : 1.5 $\rightarrow$ 1.0 m, $\gamma\varepsilon$: 3 $\mu\text{m} \rightarrow$ 4 μm

Total gain $\sim$ factor 3 $\rightarrow$ **$4 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$ at 3.5 TeV**

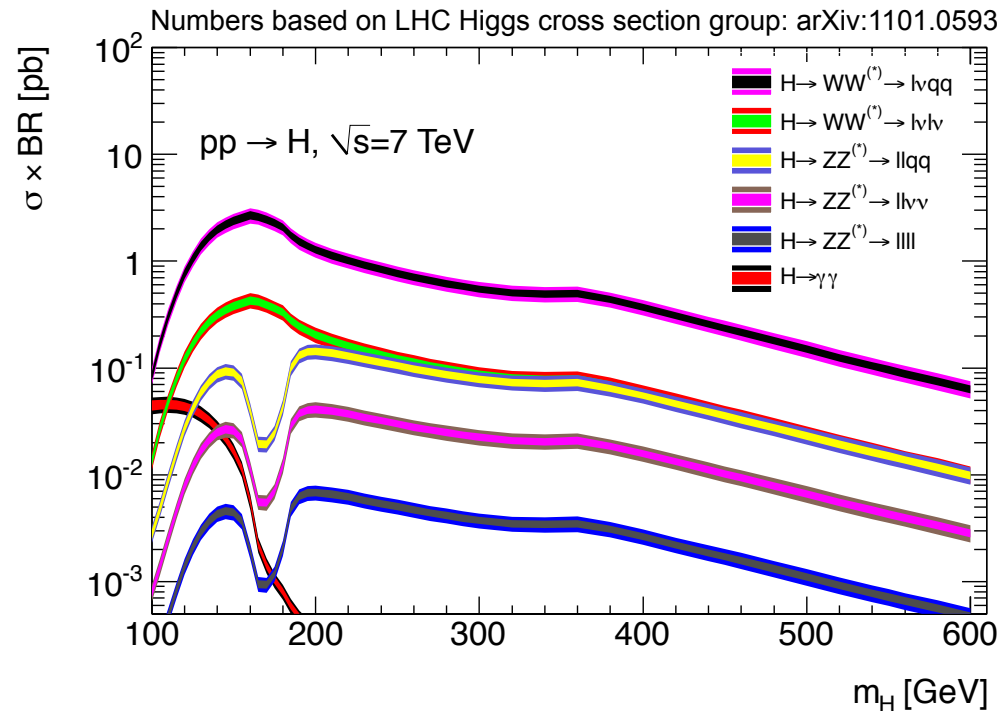
Another factor 4 from going to ~ 7 TeV ($\beta^* \sim 0.5$ m)

$2 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ at ~ 7 TeV does not appear impossible

Extra slides...

Higgs Searches at the LHC

Total Higgs cross section $\times$ BR versus M_H

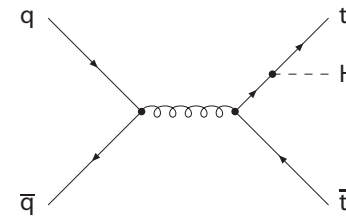
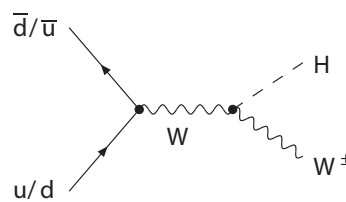
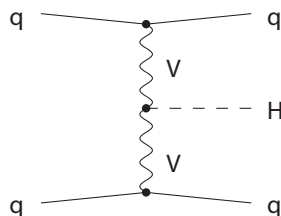
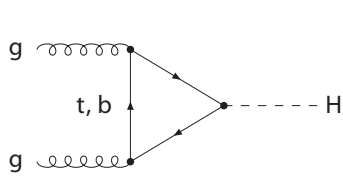


Cross section uncertainties include

- Missing higher-order corrections
- PDF uncertainties
- α_S uncertainty
- BRs: $< \sim 2\%$ (neglected)

Uncertainties per production mode

- $\pm (15\text{--}20)\%$ for $gg \rightarrow H$
- $\pm (3\text{--}9)\%$ for $qq \rightarrow qq + H$
- $\pm 5\%$ for $qq' \rightarrow H + W/Z$



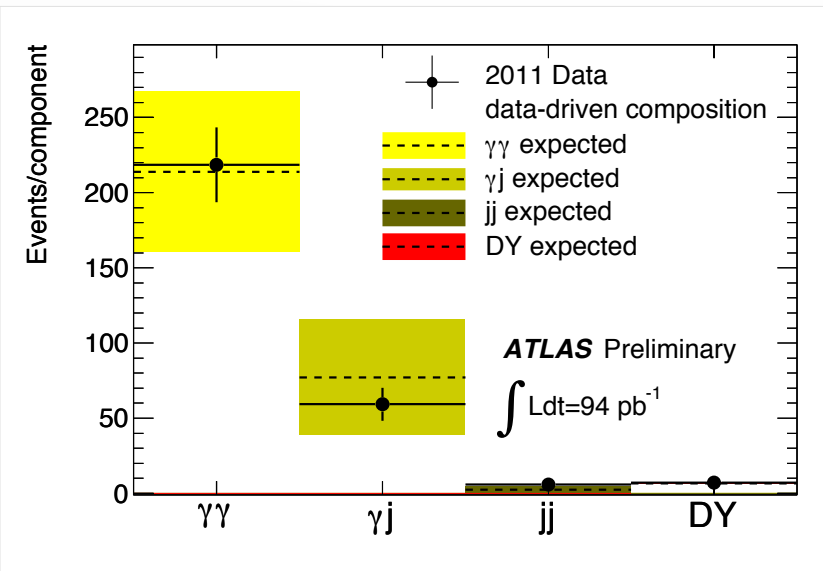
Incomplete list of graphs !

$H \rightarrow \gamma\gamma$

ATLAS-CONF-2011-071

Clean discovery channel for light Higgs: $\sigma \times \text{BR}$ (115 / 140 GeV | $\sqrt{s}=7$ TeV) $\approx 48 / 28$ fb

Select tight & isolated photons; requires excellent E_γ resolution, efficient & pure photon ID, primary vertex

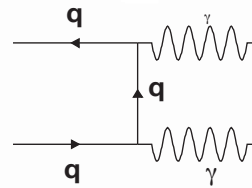


Backgrounds composition measurement with calorimeter sideband techniques

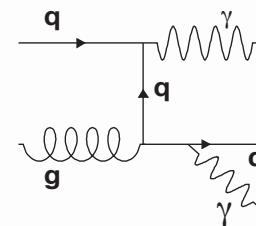
Agreement with (imprecise) theory predictions

Dominant backgrounds:

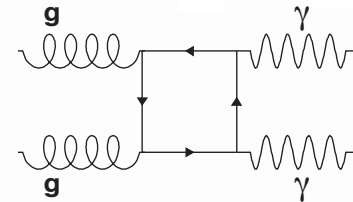
$\gamma + \gamma$ (“irreducible” – not quite)



Quark annihilation
(dominant: $O(\alpha^2)$)

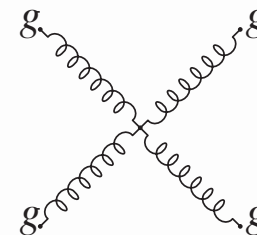
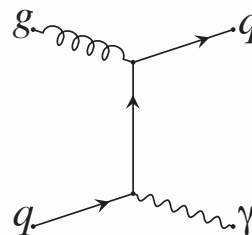


Bremsstrahlung, $O(\alpha^2\alpha_s)$
and quark fragmentation



Box diagram
 $O(\alpha^2\alpha_s^2)$, $\approx$ q-ann.

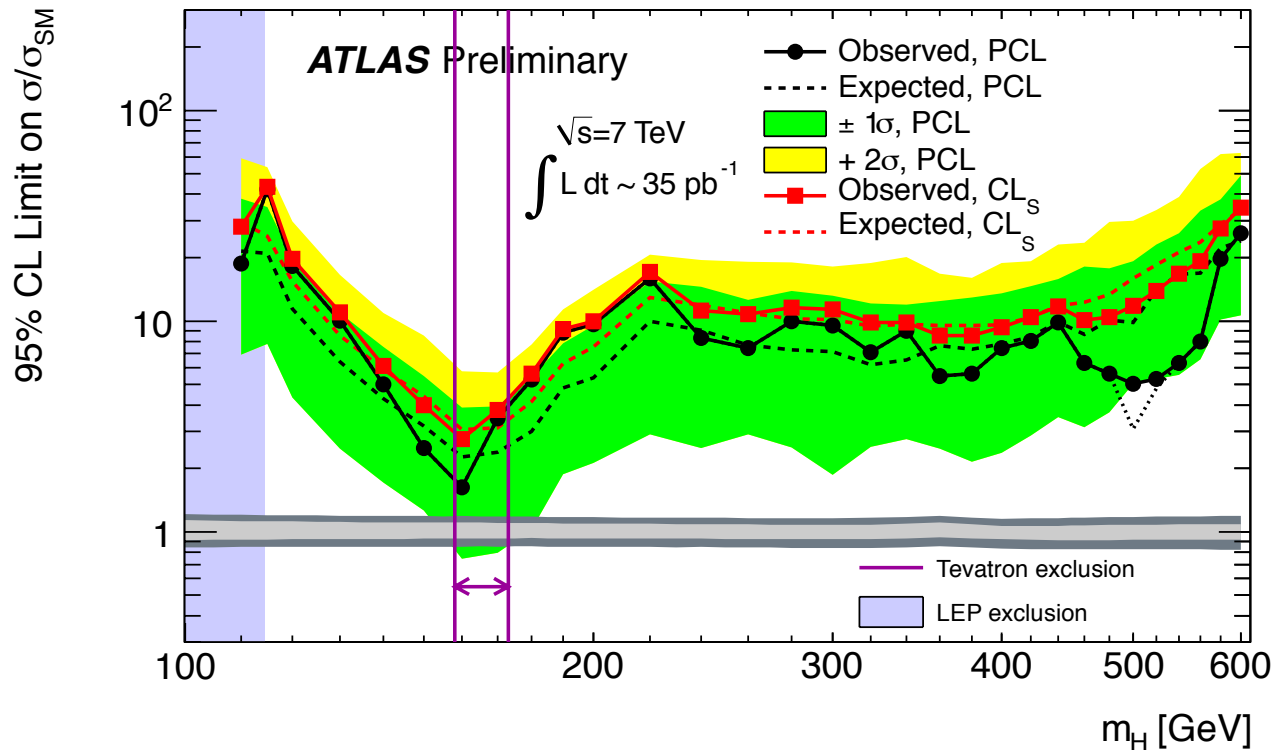
$\gamma + \text{jet}$ and $\text{jet} + \text{jet}$ (reducible, but $\sim 10^6 \times$ larger than $\gamma\gamma$)



QCD processes
suffering from
large uncertainties

SM Higgs Exclusion Potential

ATLAS combination of individual channels for 2010 data / statistics comparison



Combination using maximum likelihood fit taking into account correlated nuisance parameters

Uncertainty on cross section included in SM expectation

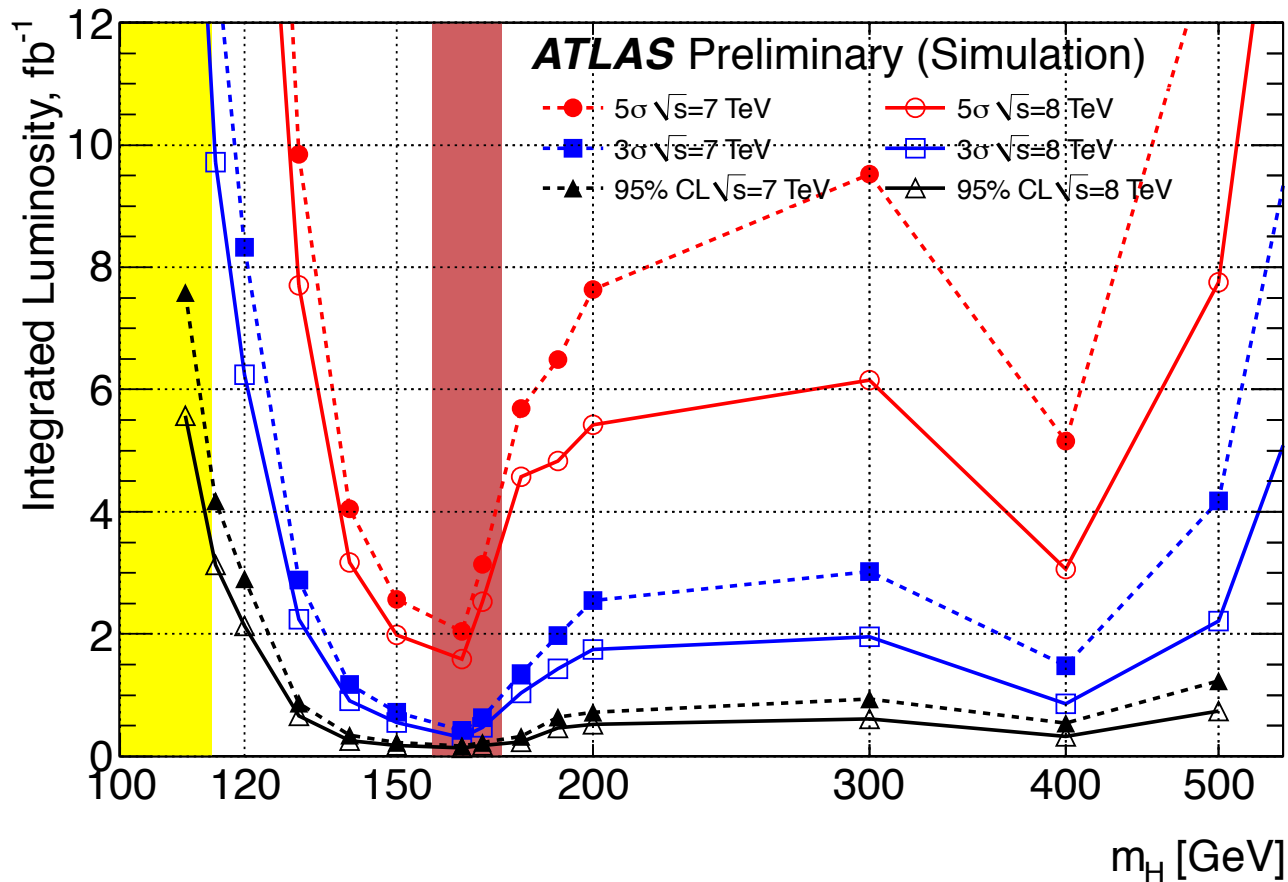
Also indicated are LEP and Tevatron 95% CL exclusion regions

Comparison of PCL with CL_s results for observed and expected exclusion limits

SM Higgs Exclusion / Discovery Potential

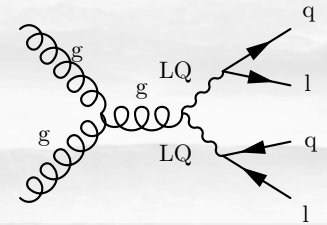
Luminosity required to exclude, see and discover an SM Higgs at $\sqrt{s} = 7, 8$ TeV

ATLAS-CONF-2011-022

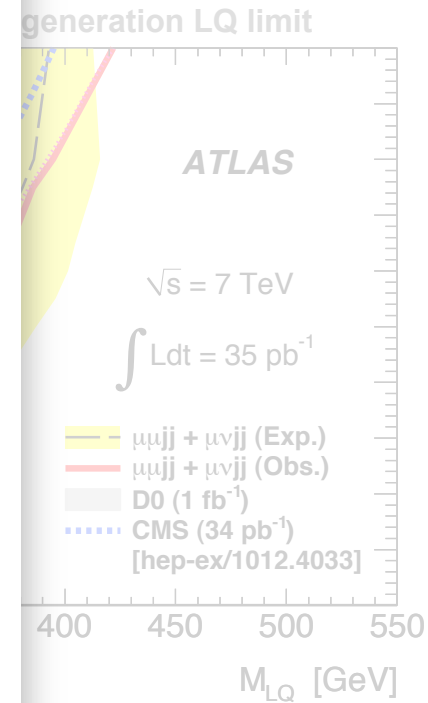
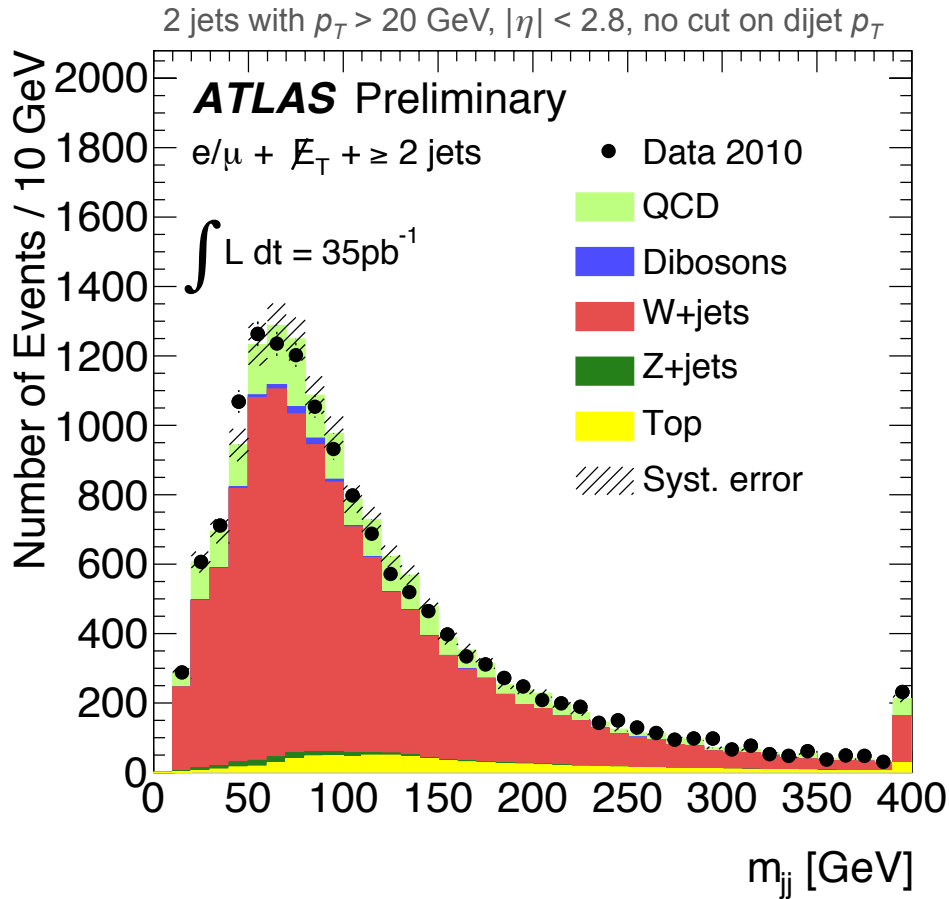
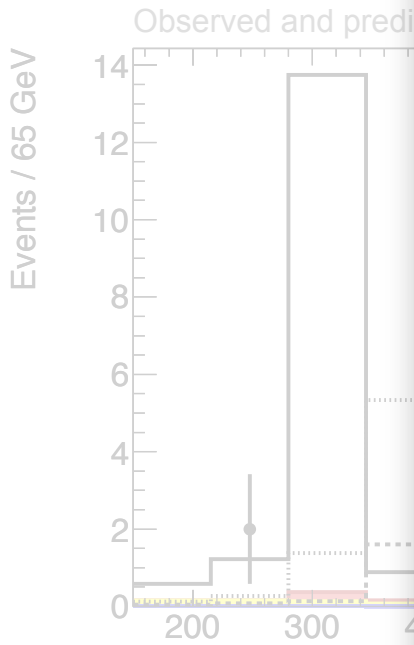


Search for 1st and 2nd gen. leptoquarks

Study scalar LQ pair production to $lljj$ and $l\nu jj$ final states

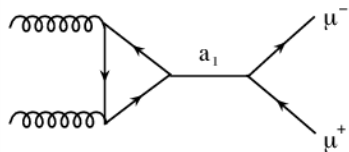


ATLAS-CONF-2011-069



95% CL_s limits on M_{LQ}

GeV for $\beta = 1.0$ (0.5)



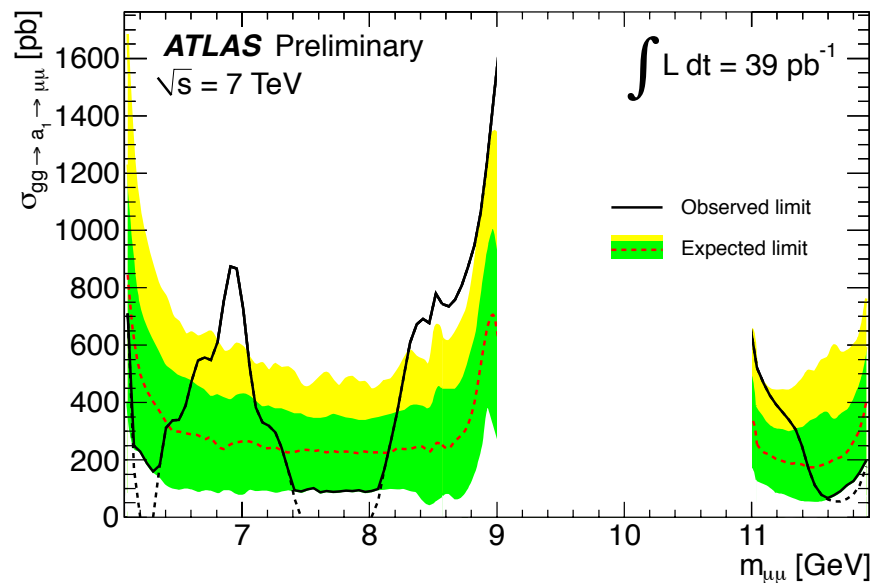
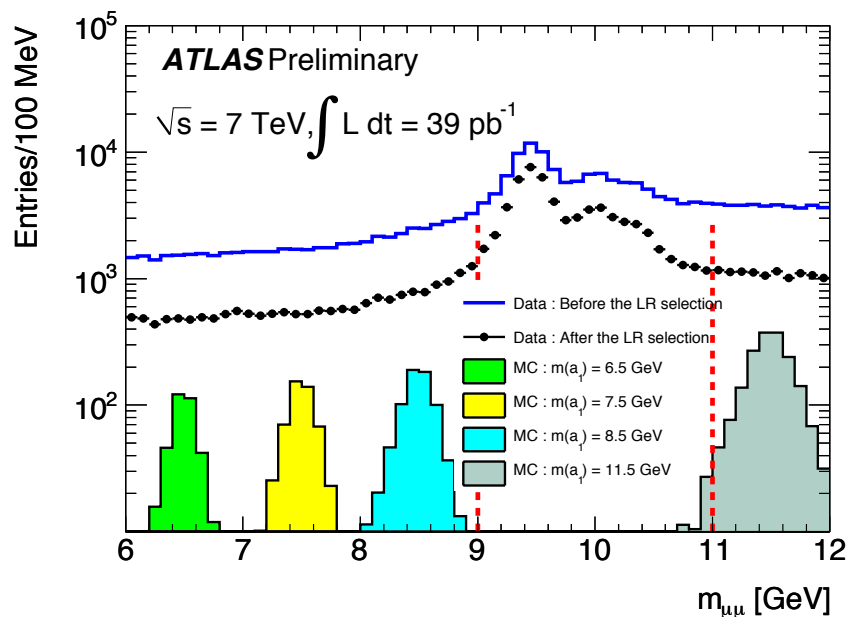
SUSY Higgs: $a_1 \rightarrow \mu\mu$

ATLAS-CONF-2011-020

NMSSM expands Higgs sector by scalar singlet $\rightarrow$ adds h_1, a_1 (CP -even/odd) fields

Higgs phenomenology dramatically altered if $h_1 \rightarrow a_1 a_1$ dominant. $\sigma \times \text{BR}$ depends on $\tan\beta$ and a_1 - a_2 mixing

Search for $a_1 \rightarrow \mu\mu$ ($\text{BR} \sim 0.5\%$) in mass ranges 6–9 and 11–12 GeV (cut out Y_{1-3S}), tight muon-pair selection



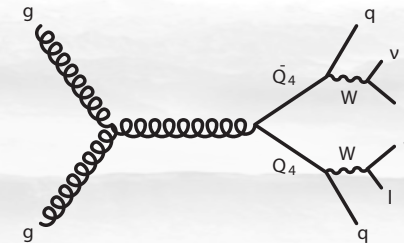
Upper limit on $\sigma(gg \rightarrow a_1 \rightarrow \mu\mu)$

Example:

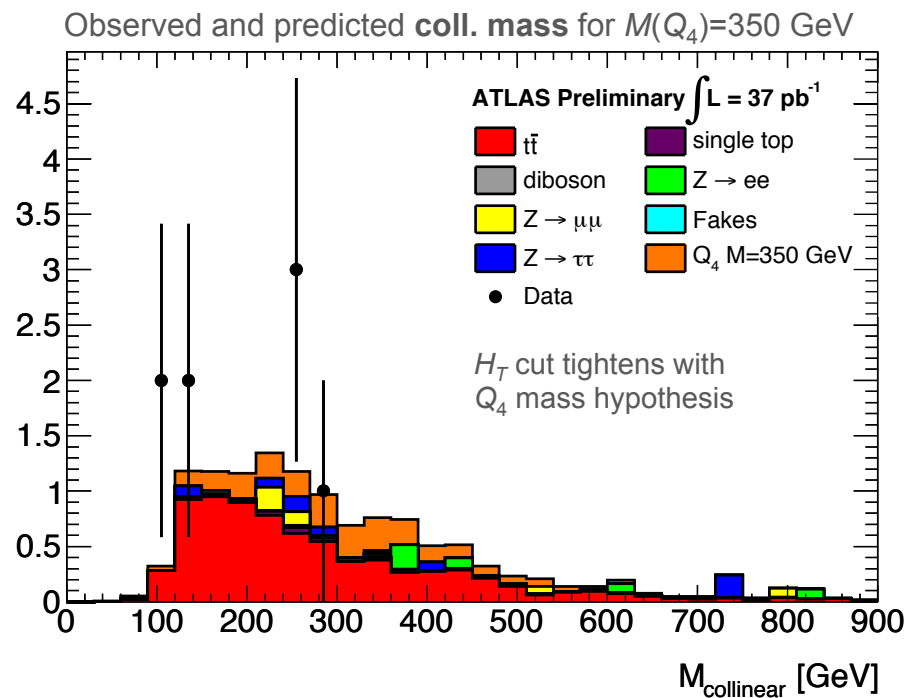
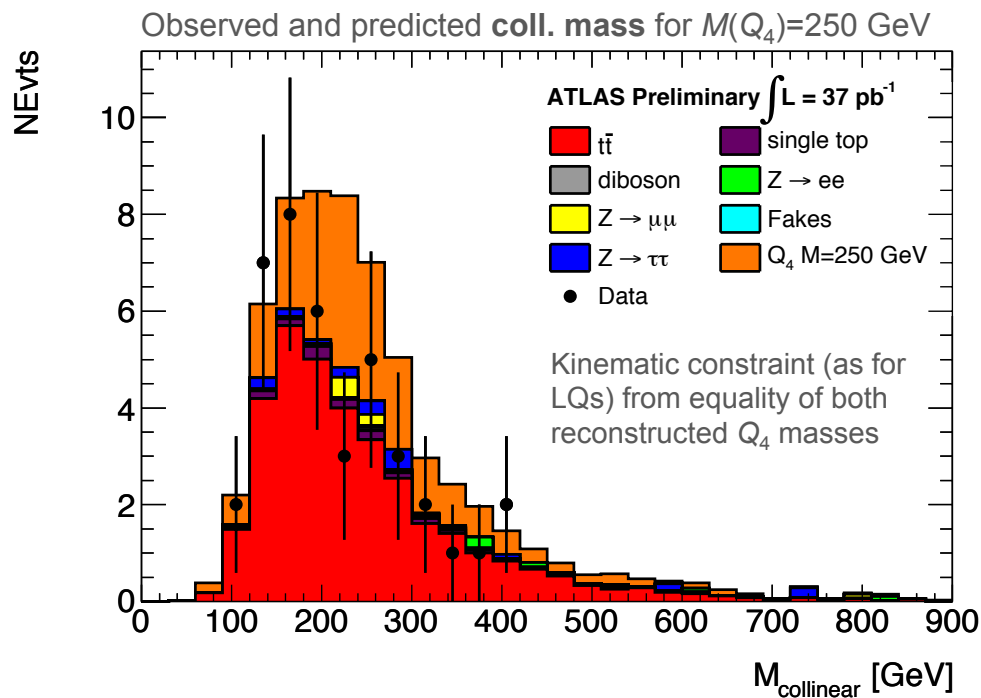
$\sigma \times \text{BR} \sim 3 \text{ pb}$ for $m(a) = 8 \text{ GeV}$, $\tan\beta = 10$, $\cos\theta = 0.1$

Search for 4th generation quarks

Study Q_4 pair production to $2 \times W(\rightarrow l\nu)q$ final state (OS)

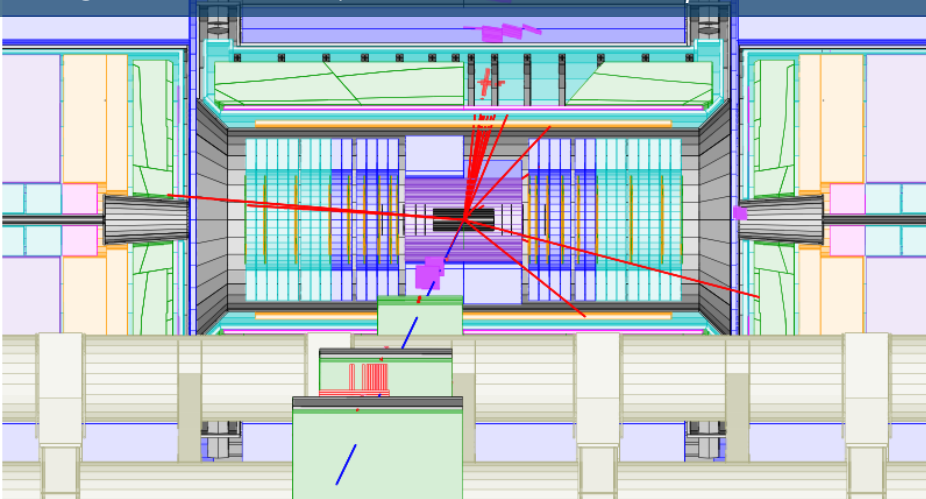


ATLAS-CONF-2011-022

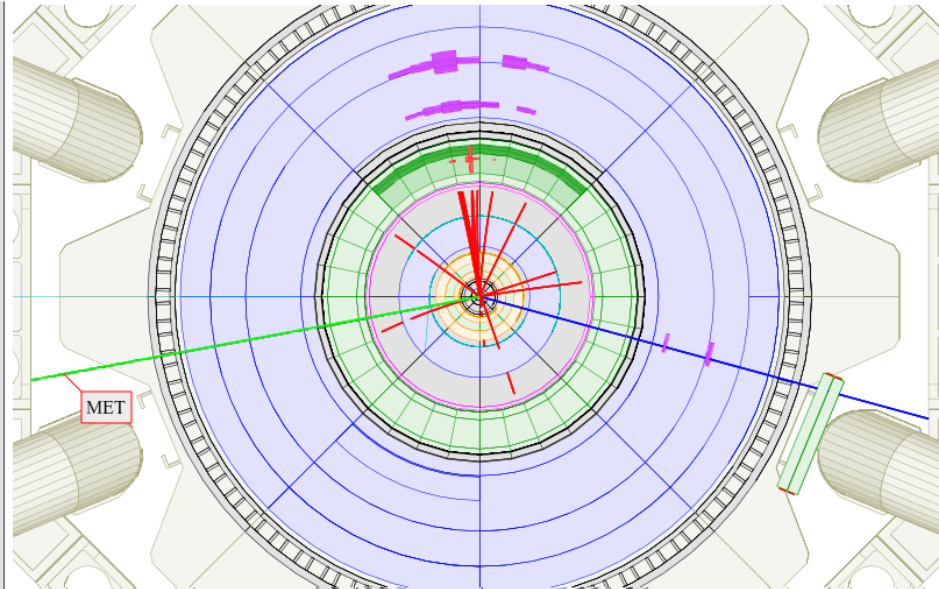


95% CL_{FC} limit $M(Q_4) > 270$ GeV, applicable to u_4 and other exotic Q_4 -like quark models

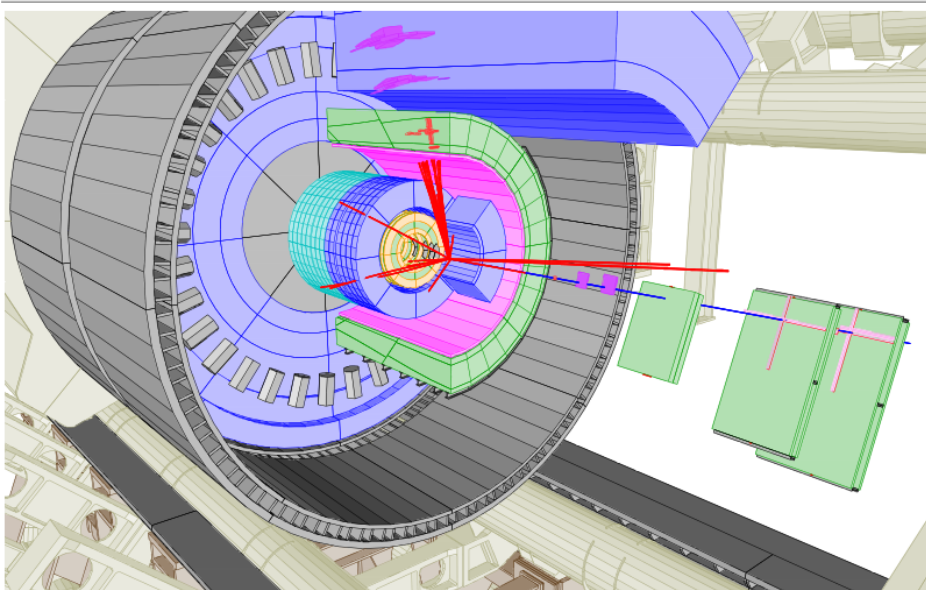
Highest mass $W \rightarrow \mu\nu$ candidate with $m_T = 1.35$ TeV



YZ view



XY view



Run Number: 180149, Cells: Tiles, EMC
Event Number: 25360846
Date: 2011-04-22, 20:17:34 CET

