Search for heavy resonances with the ATLAS detector

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on behalf of the ATLAS collaboration

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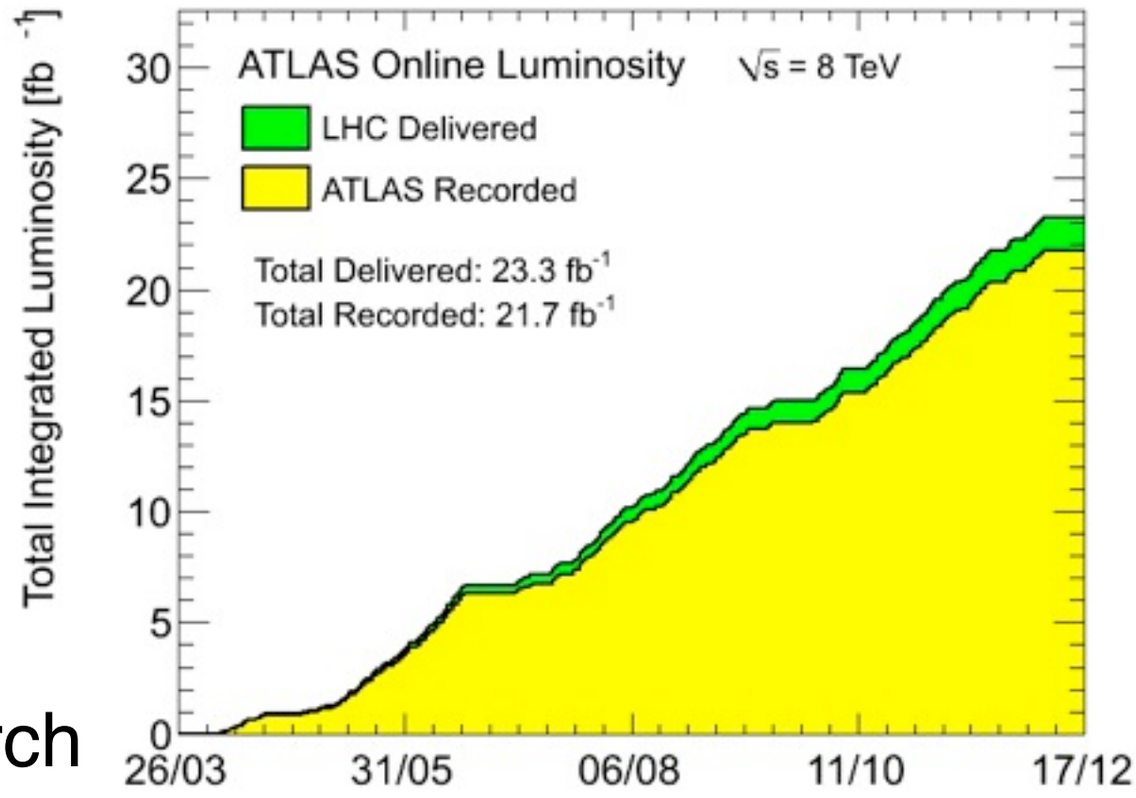
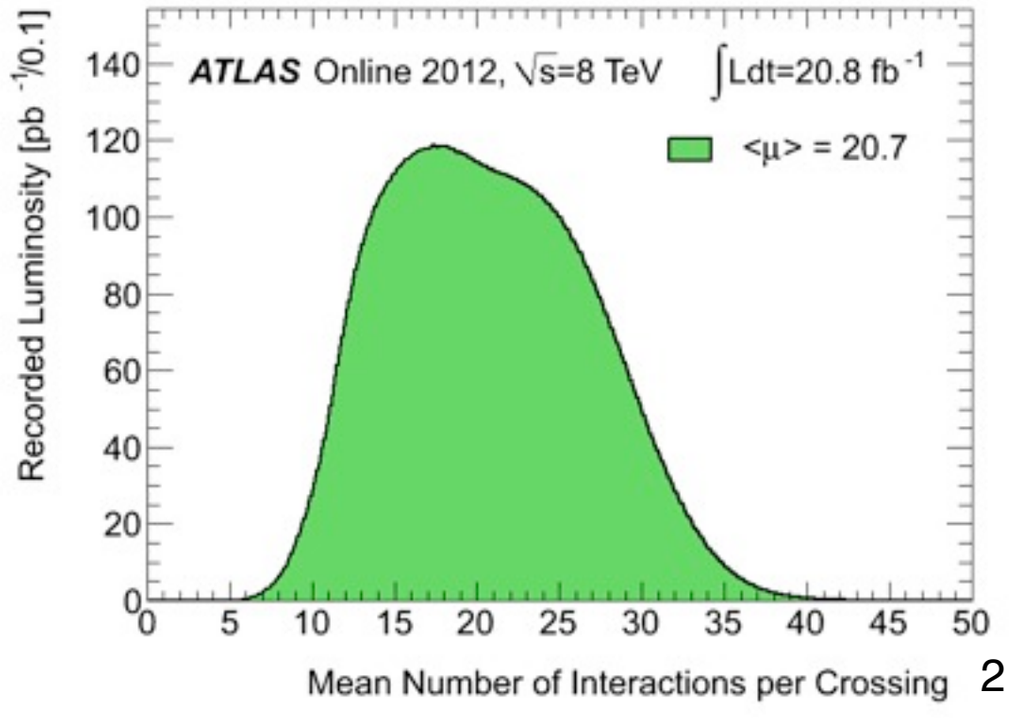
Outline

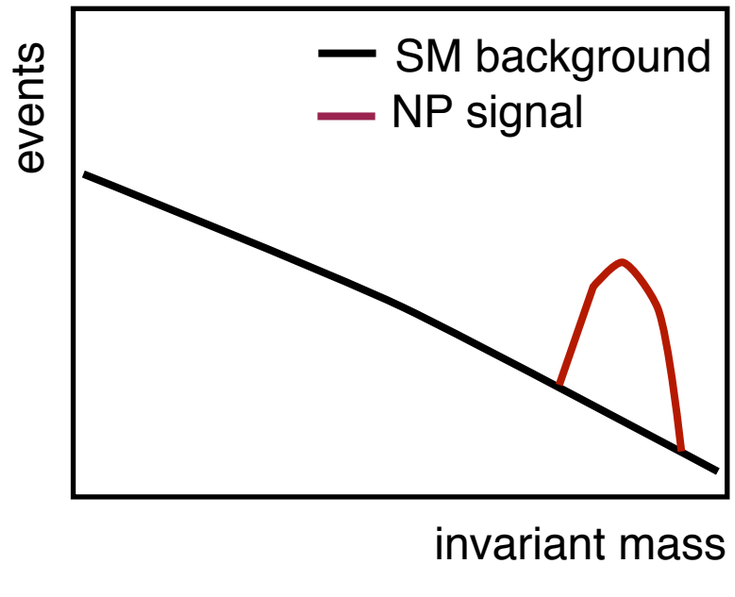
- 2012 data taking @ ATLAS
  $\sqrt{s}$ = 8TeV
  Searches for heavy resonances in events with
  - two jets
  - two leptons
- Review of $\sqrt{s}$ = 7TeV combination of dilepton and diphoton resonance search
- Considered models are
  - Excited quarks
  - Generic Gaussian Resonances
  - Z‘ from Sequential Standard Model and E_6 motivated models
  - Randall-Sundrum graviton G*





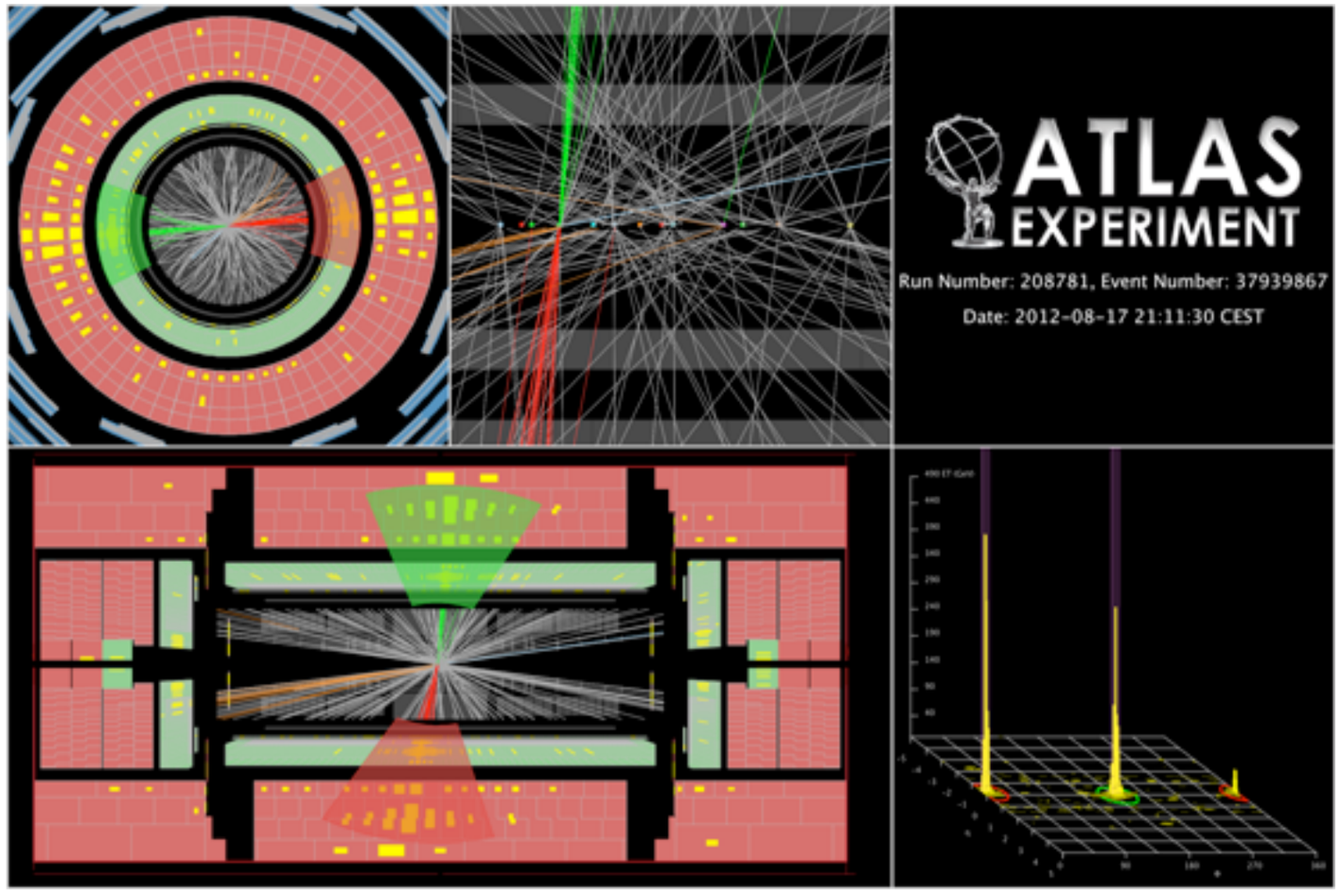
Dijet Analysis Idea

- Sensitive to highest mass scales accessible with hadronic final states
- Bump hunt
  - Search for resonances
  - Set limits in case of absence
- **Excited Quarks**
  - Test compositeness of quarks
  - Substructure scale $\Lambda > 1$ TeV similar to expected m_{q^*}
- **Generic Gaussian shaped signals**
  - Model independent limits
  - Can be used to set limits on models with resonant peak with Gaussian core



Selection

- 13.0 fb^{-1} of pp collisions
  - OR of two central single-jet triggers
  - two highest p_T jets in central region
    $|y| < 2.8$ $|y^*| < 0.6$
  - invariant mass of dijet system
    $m_{jj} > 1000$ GeV
  - jet $p_T > 150$ GeV
- Search for resonances above smooth QCD background



highest p_T jet event recorded until end of September 2012:

$m_{jj} = 4.47$ TeV

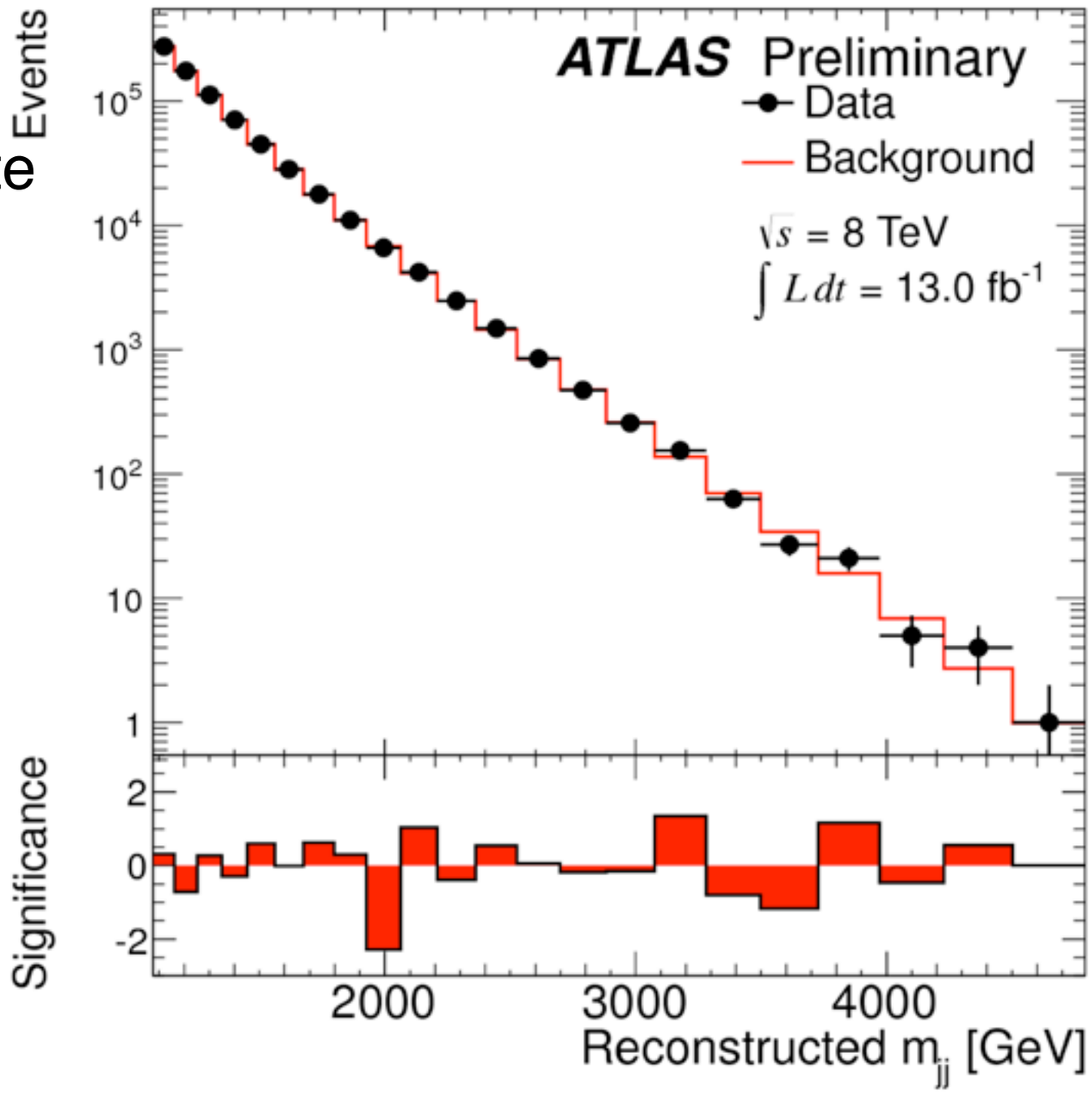
$p_T^1 = 2.34$ TeV $p_T^2 = 2.10$ TeV

Rapidity $y = 0.5 \ln((E+p_z)/(E-p_z))$

Rapidity in cms frame $y^* = \pm 0.5 (y_1 - y_2)$

Fit of m_{jj}

- Fit smooth background
  $f(x) = p_1(1-x)^{p2}\, x^{p3 + p4\ln x}$
- Binning motivated by absolute resolution of signal m_{jj} evaluated from MC
- Maximum-likelihood fit
- Significance
  - from bin by bin data-fit
  - difference in Gaussian standard deviations
  - positive values = excess
- Dominant systematic uncertainty: jet energy scale (p_T and η dependent, 4% in central region)



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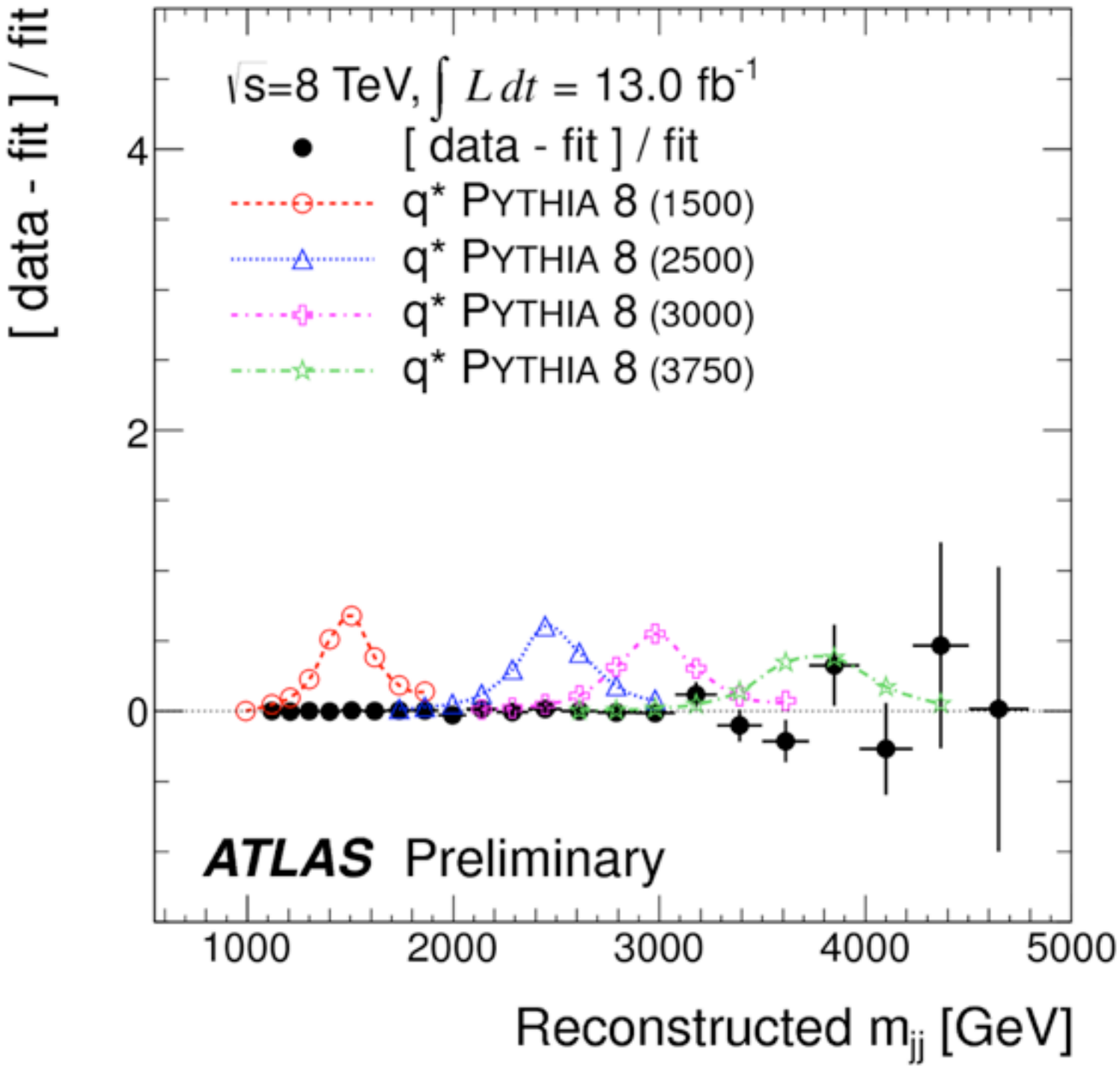
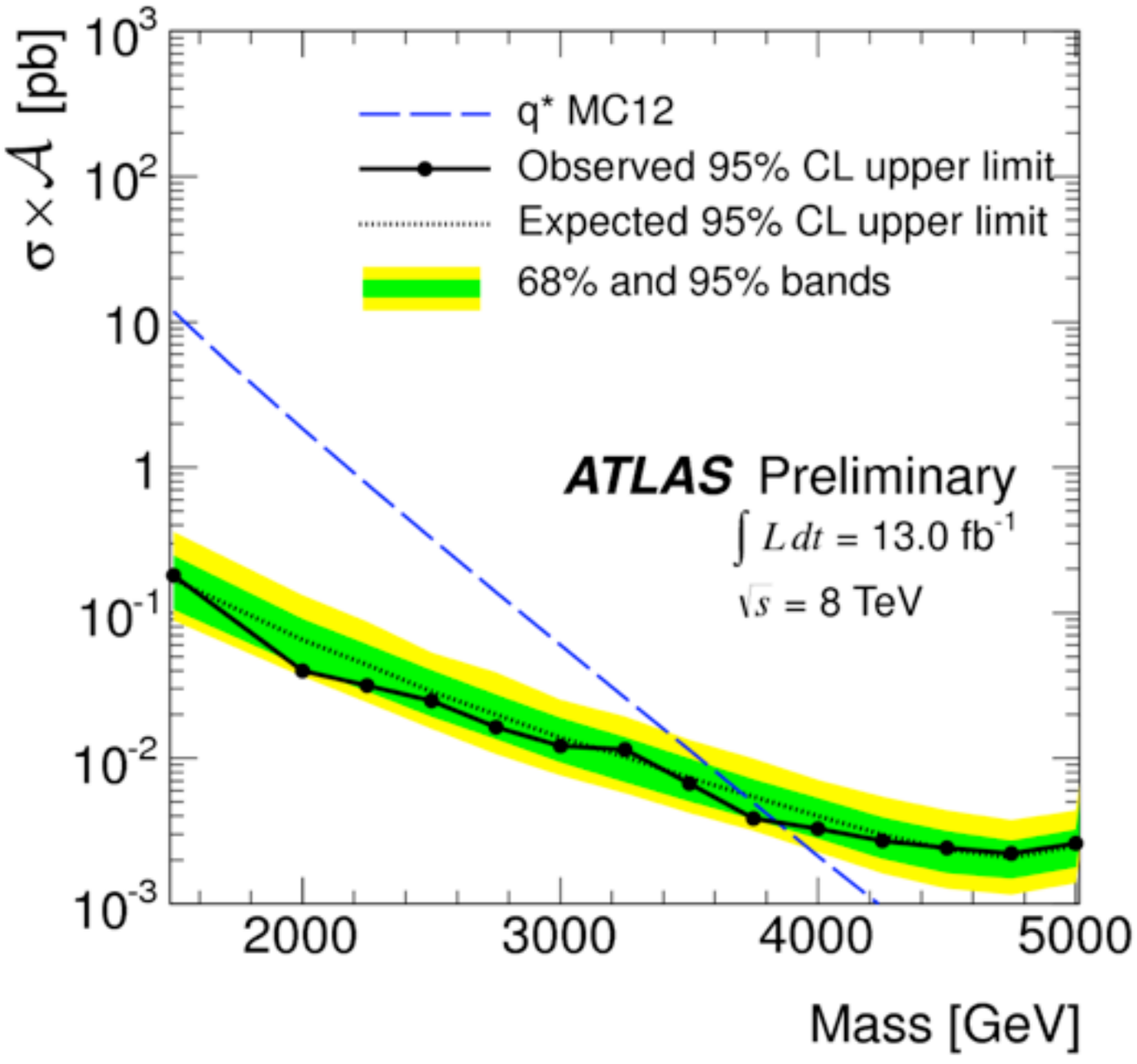
Excited quark signals

- Excited quark signals: bumps above smooth background
- Global p-value of fit 0.61
  - comparison of χ^2 from data and pseudo-experiments
  - good agreement of data and fit
- BumpHunter algorithm:
  - search localized resonances, assume Poisson statistics, look-elsewhere effect
  - no significant excess found



Excited quark limits

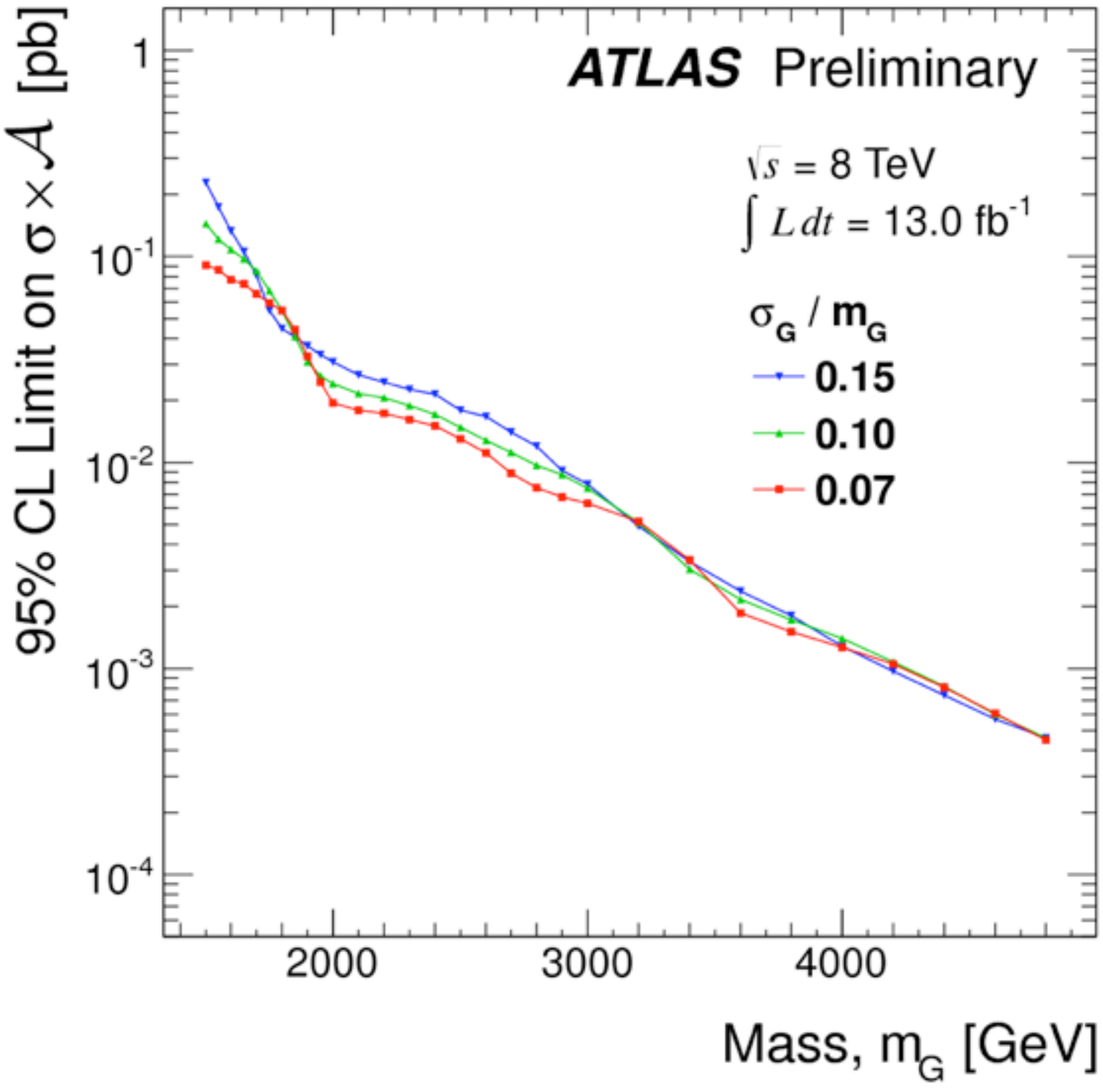


- Derive limits on cross section × acceptance ($\sigma \times \mathcal{A}$)
- Acceptance $\mathcal{A}$ 11% - 54% ($m_{q^*} > 2$TeV: $\mathcal{A} > 48\%$)
- Lower limit on **m_{q^*} = 3.84 TeV (3.70 TeV)**

q* MC12: Pythia 8, 8TeV, MC12 AU2 tune, CT10 PDFs

Simplified Gaussian Limits

- Generic Gaussian resonance:
  particles with mass m_G, width
  σ_G/m_G = 7%, 10% or 15%
- σ_G/m_G = 7% very sensitive to single-bin fluctuations
- NP signal needs to be Gaussian after selection cuts
- m_{jj} resolution ~5%
  smaller widths need to be compared to 7% result
- Limits on $\sigma \times \mathcal{A}$ in range
  0.1 - 0.003 pb



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Dilepton Analysis

- Search for neutral narrow width resonance gauge boson Z‘ with spin 1
- Two models considered
- Benchmark model: **Sequential Standard Model** (SSM): Z'_{SSM}
  - same couplings to leptons as SM Z
  - $\sigma_{Z'}/m_{Z'} = 3.1\%$
- **Grand Unification Model E_6 gauge group**
  - broken to SU(5) and two U(1)
  - 2 new neutral gauge bosons, lightest linear combination

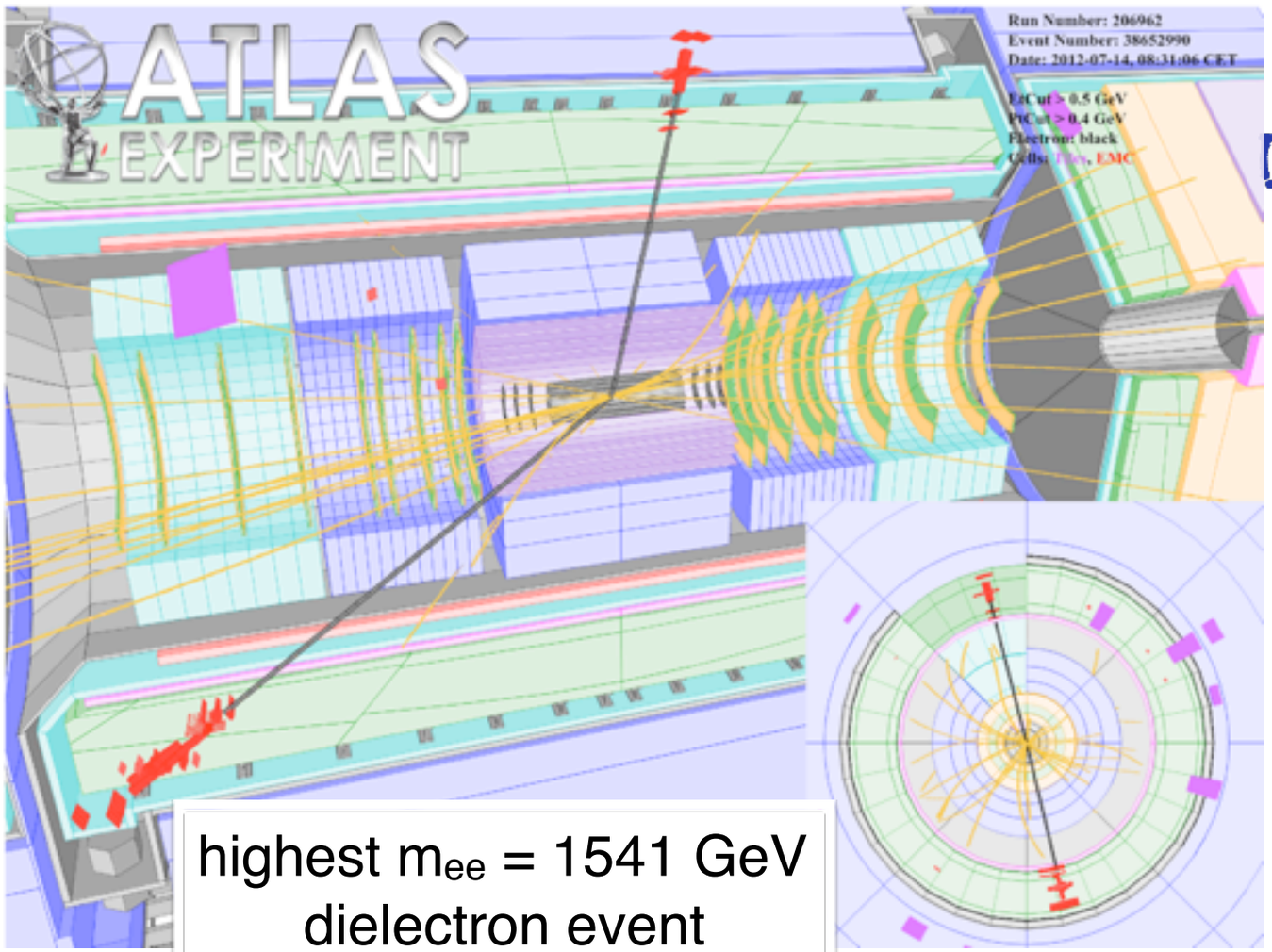
    $Z'(\theta_6) = Z'_{\psi} \cos\theta_6 + Z'_{\chi}\sin\theta_6$
  - couplings determined by θ_6 and pattern of EWSB
  - 6 different models considered
  - $\sigma_{Z'}/m_{Z'} = 0.5 - 1.3\%$

Dilepton Analysis

- **Randall-Sundrum model of extra spatial dimensions**
  - excited Kaluza-Klein modes of graviton
  - appear as spin 2 resonance
  - first excitation G*
  - narrow width 1.4% ($k/M_{Pl} = 0.1$)
  - cross sections scale ~ $(k/M_{Pl})^2$
- Search in two channels
  - $e^+ e^-$
  - $\mu^+ \mu^-$

Selection $e^+ e^-$

- 20.0 fb^{-1} of pp collisions
- ≥ 1 primary vertex with ≥ 2 tracks



highest m_{ee} = 1541 GeV dielectron event
p_T^1 = 588 GeV
p_T^2 = 584 GeV

- Diphoton trigger
  - $E_T > 35$ GeV, $E_T > 25$ GeV
  - advantages over e^- trigger for background estimation
- ≥ 2 e^- candidates with
  - $|\eta| < 2.47$ excluding transition region ($1.37 \leq |\eta| \leq 1.52$)
  - $E_T > 40$ GeV, $E_T > 30$ GeV
  - Isolation to suppress jets
  - select highest $\sum p_T$ pair
  - no opposite sign requirement

m_{ll} = 2TeV:
Acceptance × Efficiency = 73%

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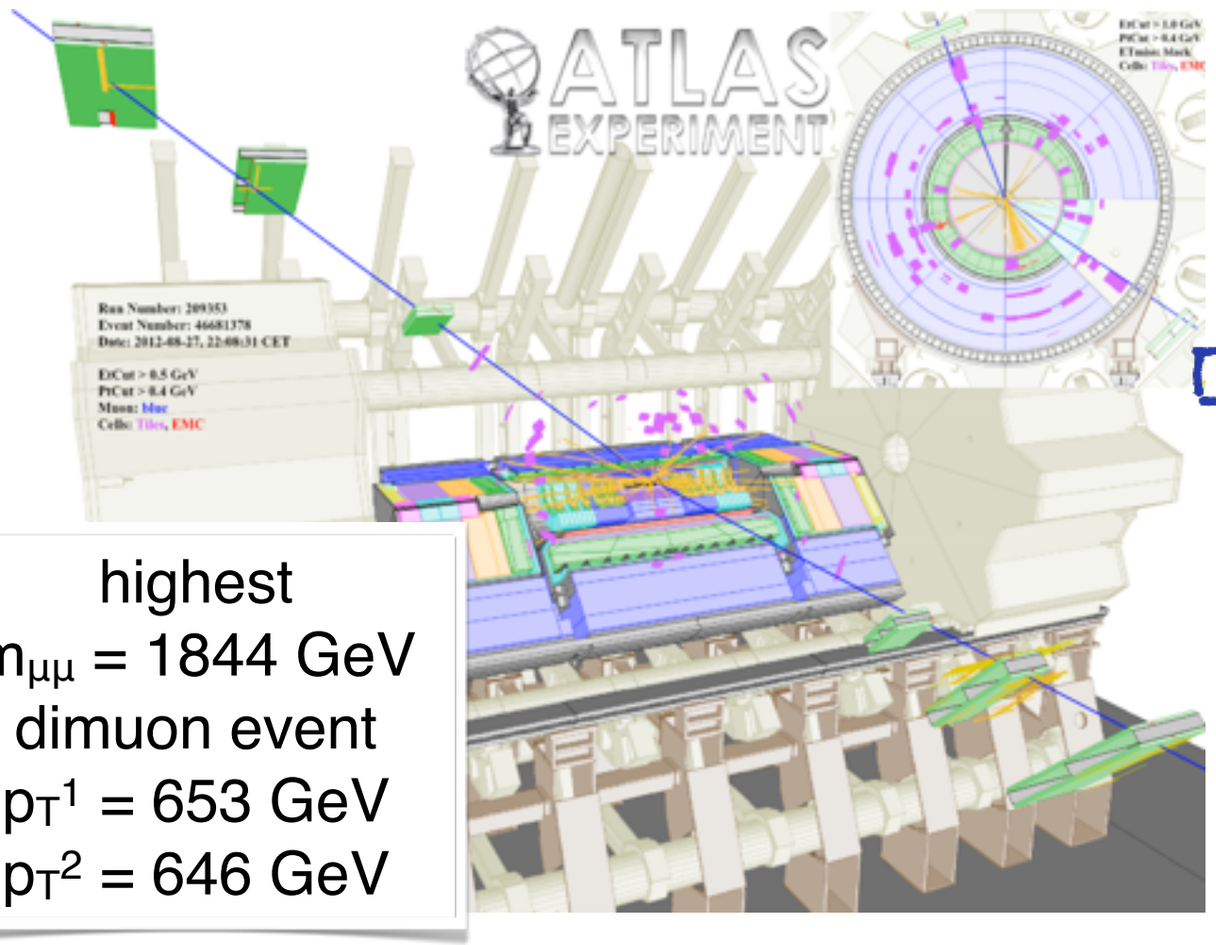
Selection $\mu^+\mu^-$

- in 20.0 fb^{-1}: ≥ 1 primary vertex with ≥ 2 tracks
- OR of two single muon triggers:
  isolated $p_T > 24$ GeV
  $p_T > 36$ GeV (no isolation)



highest
$m_{\mu\mu}$ = 1844 GeV
dimuon event
p_T^1 = 653 GeV
p_T^2 = 646 GeV

- Muons in MS and ID
  - $p_T > 25$ GeV, $|\eta| < 2.4$
  - 3-station muons
    ≥3 hits in inner, middle and outer station of MS
  - 2-station muons ($|\eta| < 1.05$)
    ≥5 precision hits in inner and outer station of MS
    ≥1 hit in one layer of trigger chambers
  - isolation (on $\sum p_T$ in cone around $p_T(\mu)$)
- highest $\sum p_T$ muon pair of either
  - 2 os 3-station muons (90%)
  - os 3-station & 2-station muon

m_{ll} = 2TeV:
Acceptance × Efficiency = 46%

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Backgrounds

- $qq \rightarrow Z/\gamma^* \rightarrow l^+ l^-$ (Drell-Yan) dominant & irreducible
- electron channel
  - QCD multijet (incl. heavy flavor quarks γ+jet production)
  - W + jets (incl. semi-leptonic decays of tt & single top)
  - diboson (WW, WZ, ZZ) production
  - electrons from dileptonic decay of tt
- muon channel
  - tt
  - diboson production
  - (QCD multijet & W + jets negligible!)

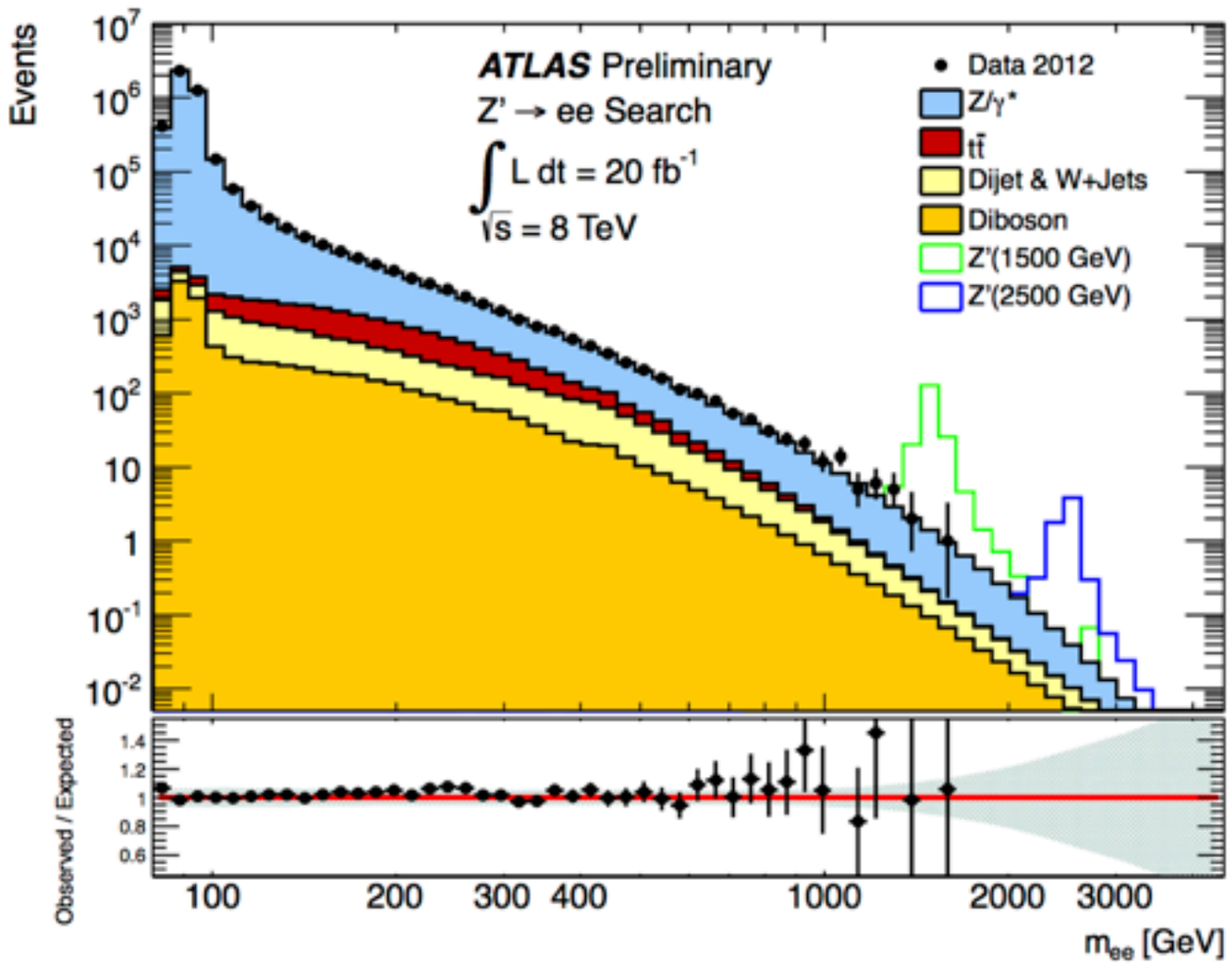
data-driven estimation from fake-rate studies

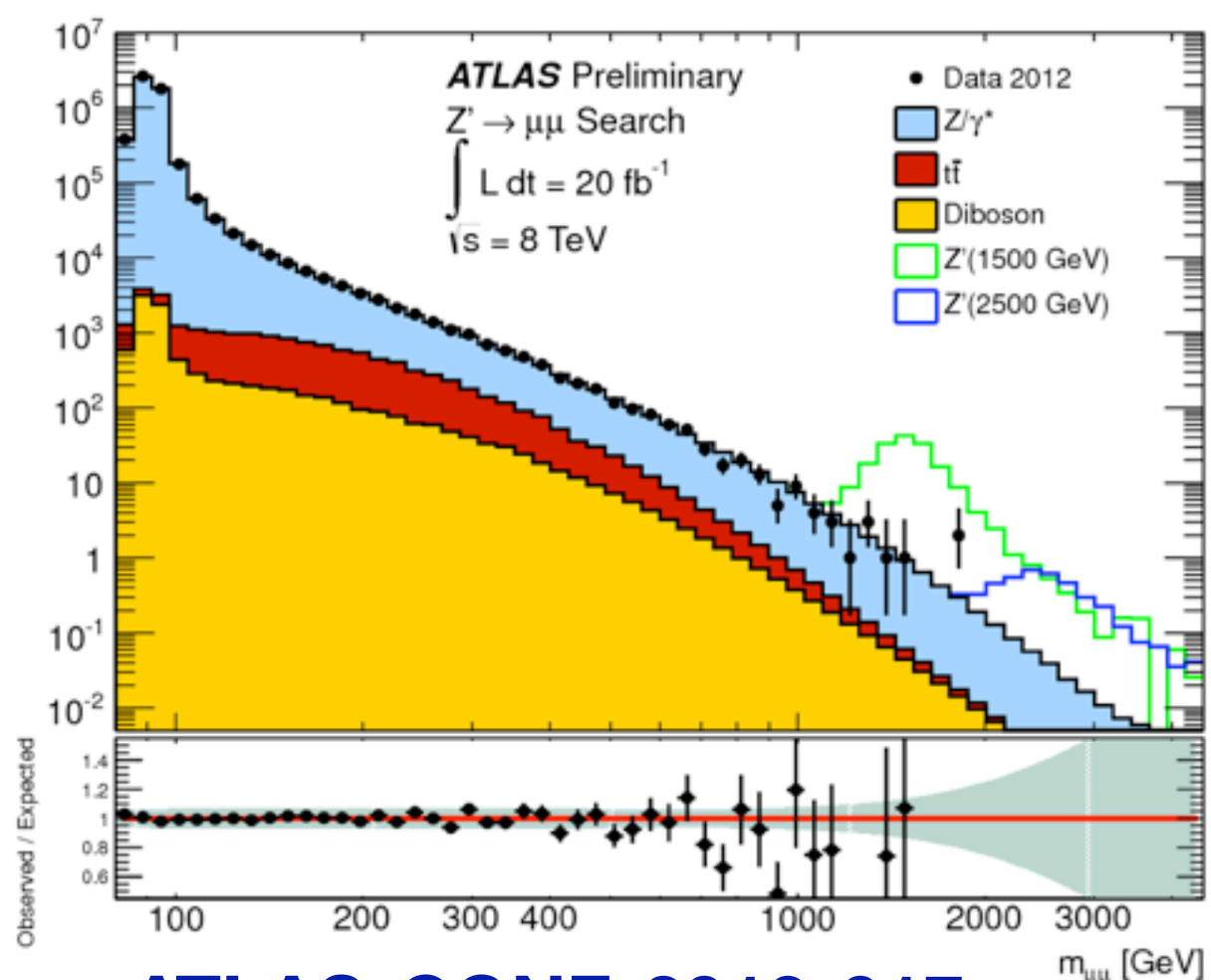
evaluated from MC with highest order σ predictions

estimated using reversed isolation method based on track isolation

Background Estimation

- Data-driven estimate of W+jet and QCD multijet background
- Sum of Drell-Yan, tt, diboson scaled to agree with data in normalization region 80 GeV < m_{ll} < 110 GeV
- Event yields agree within 1%





Systematic Uncertainties

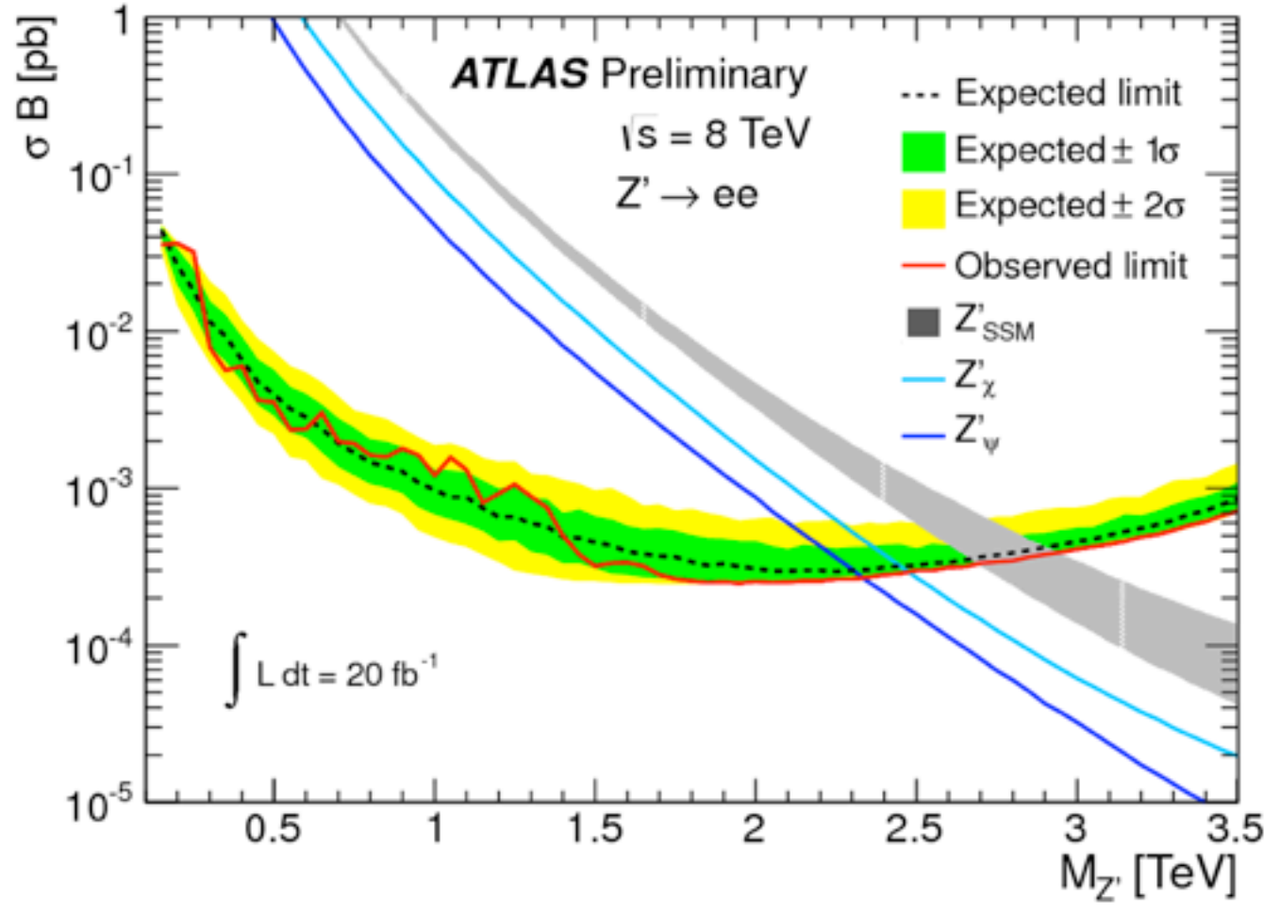
- Insensitive to luminosity and all mass-independent uncertainties due to scaling in normalization region
- 5% uncertainty on signal from normalization due to theoretical uncertainty on Z cross section
- In total 26% (e^+e^-) and 25% ($\mu^+\mu^-$) on background estimation (m_{ll} = 2 TeV)

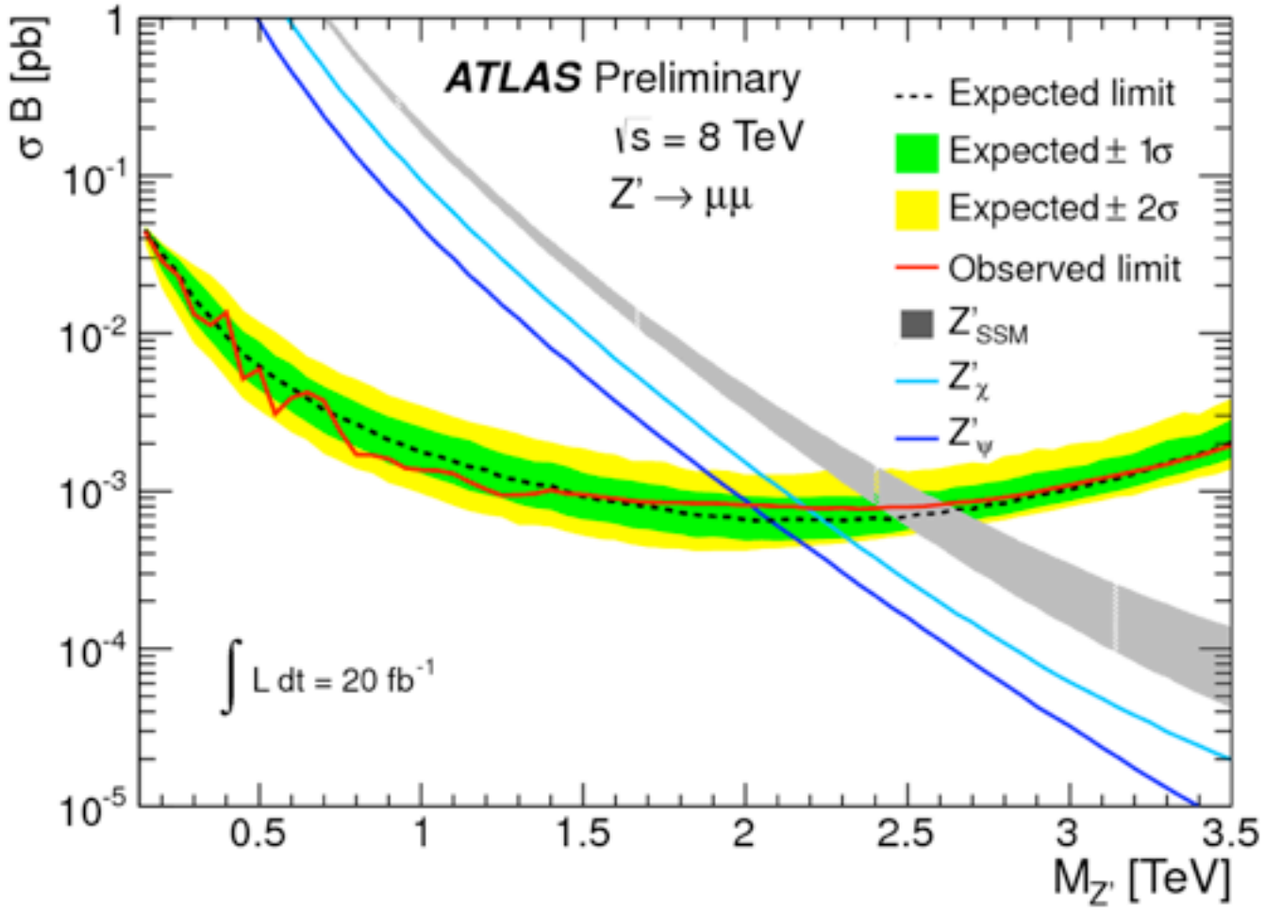
Uncertainties on expected number of events at m_{ll} = 2 TeV

Source	Dielectrons		Dimuons	
	Signal	Background	Signal	Background
Normalization	5%	NA	5%	NA
PDF variation	NA	15%	NA	15%
PDF choice	NA	17%	NA	17%
Scale	NA	-	NA	-
α_s	NA	4%	NA	4%
Electroweak corrections	NA	3%	NA	3%
Photon-induced corrections	NA	4%	NA	4%
Efficiency	-	-	6%	6%
Resolution	-	-	-	3% (7%)
W + jet and multi-jet background	NA	9%	NA	-
Diboson and ttbar extrapolation	NA	5%	NA	4%
Total	5%	26%	8%	25% (26%)

Z‘ Single Limits

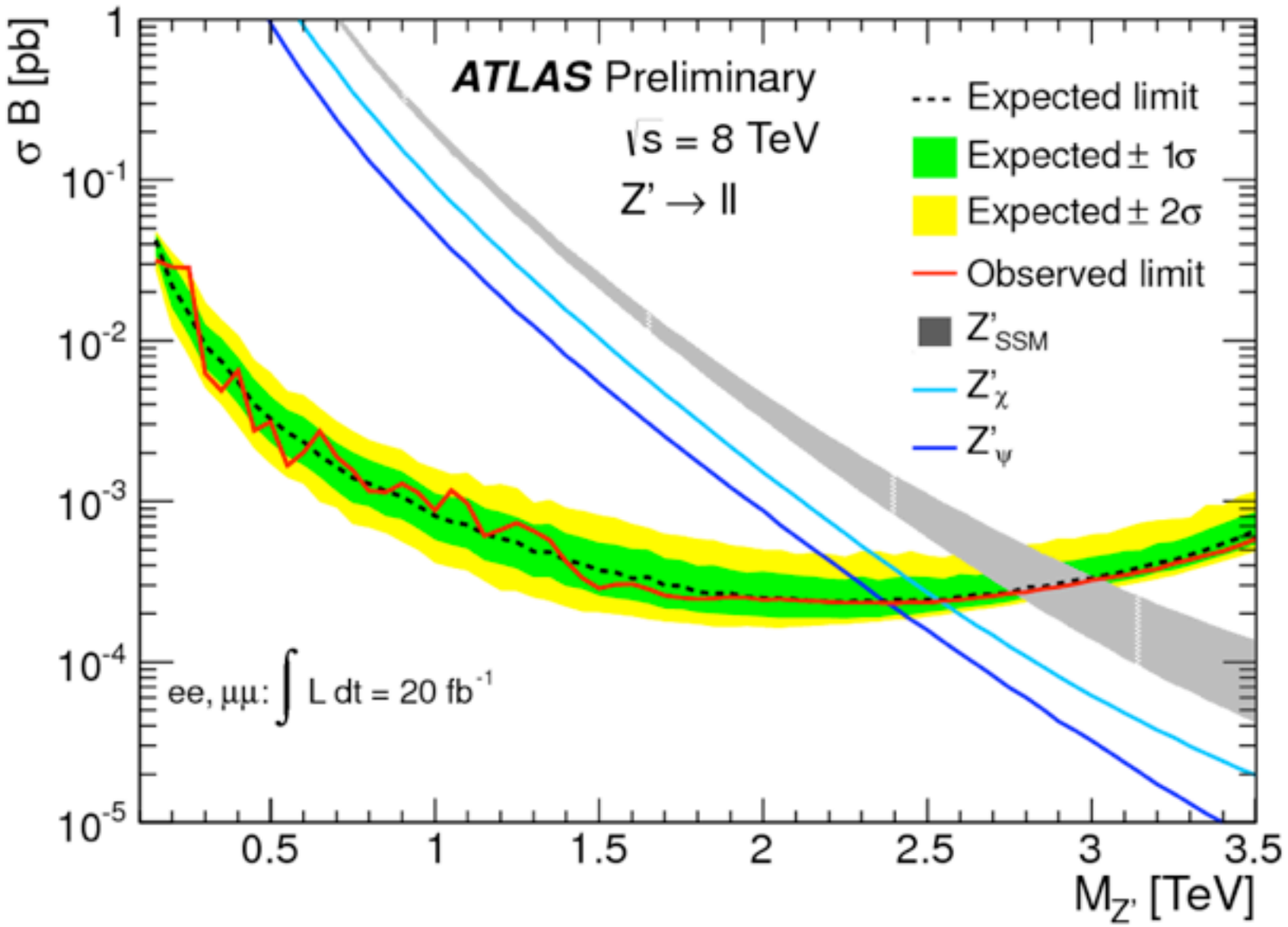
- Electron channel $M_{Z'} > 2.79$ TeV (2.76 TeV expected)
- Muon channel $M_{Z'} > 2.48$ TeV (2.52 TeV expected)





Z‘ Combined Limits

- Assume equal branching fractions to e and μ

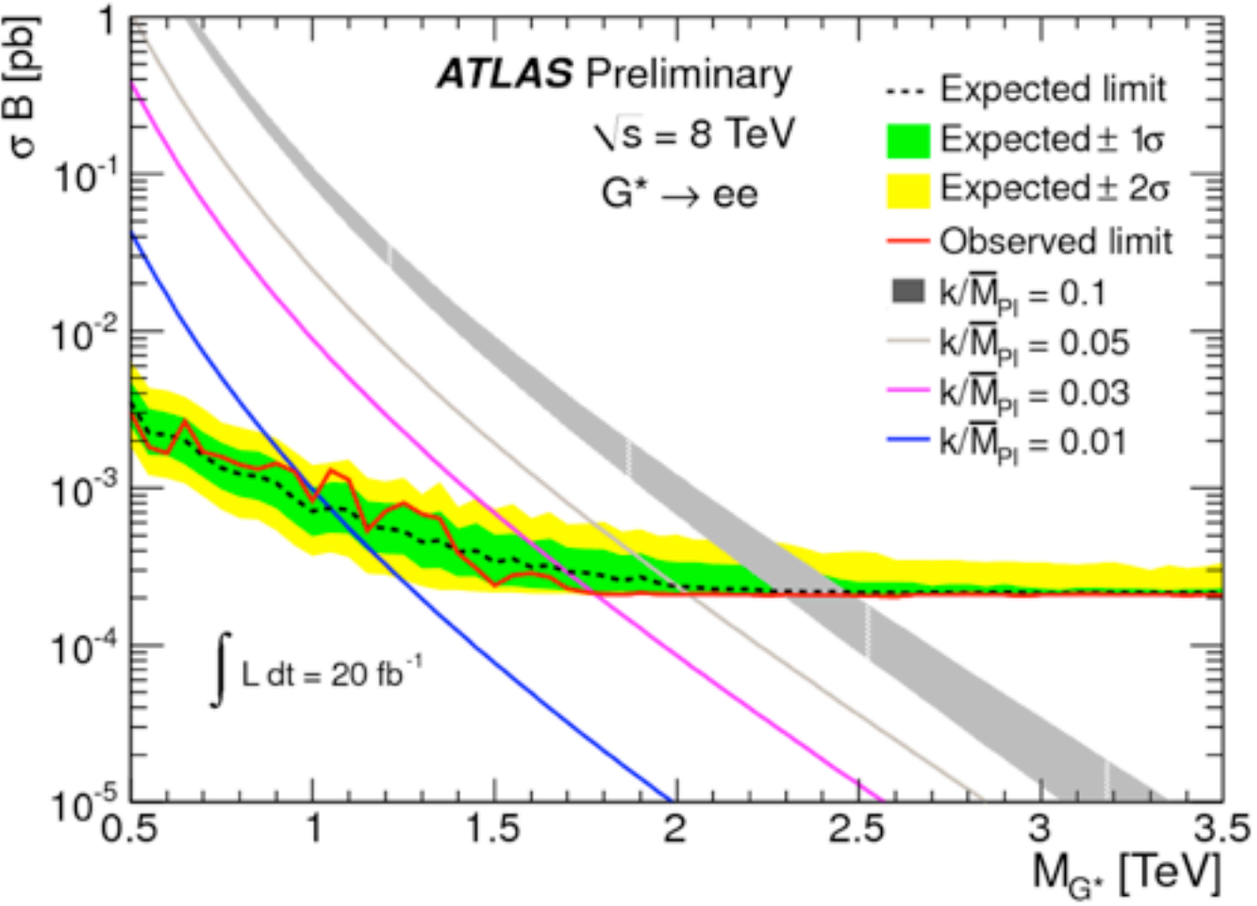


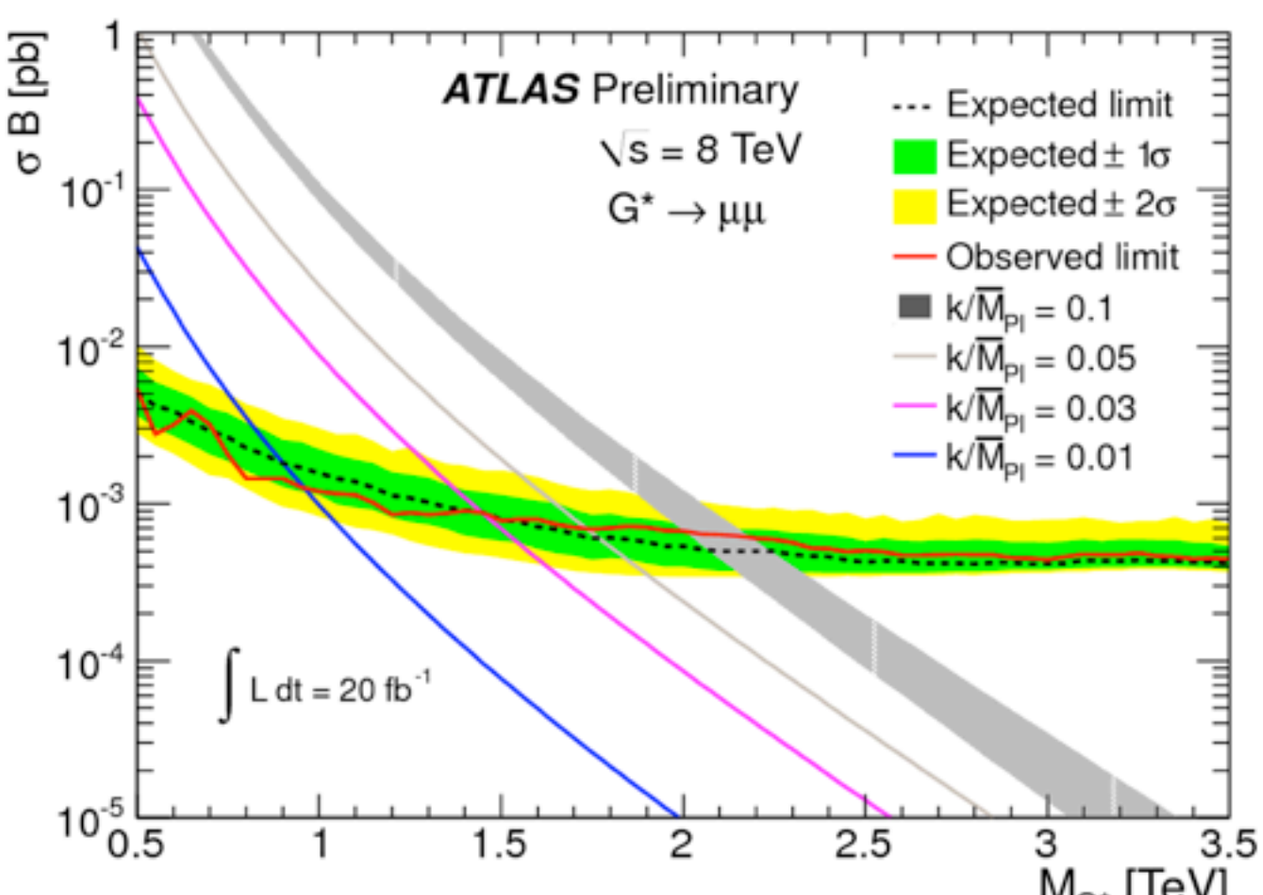
- SSM:
  $m_{Z'} > 2.86$ TeV
  (expected: 2.85 TeV)
- E_6-motivated Z‘ models:

model	Observed mass limit	Expected mass limit
Z'_ψ	**2.38 TeV**	2.37 TeV
Z'_η	**2.39 TeV**	2.38 TeV
Z'_S	**2.44 TeV**	2.43 TeV
Z'_I	**2.42 TeV**	2.40 TeV
Z'_S	**2.47 TeV**	2.46 TeV
Z'_χ	**2.54 TeV**	2.53 TeV

G* Single Limits

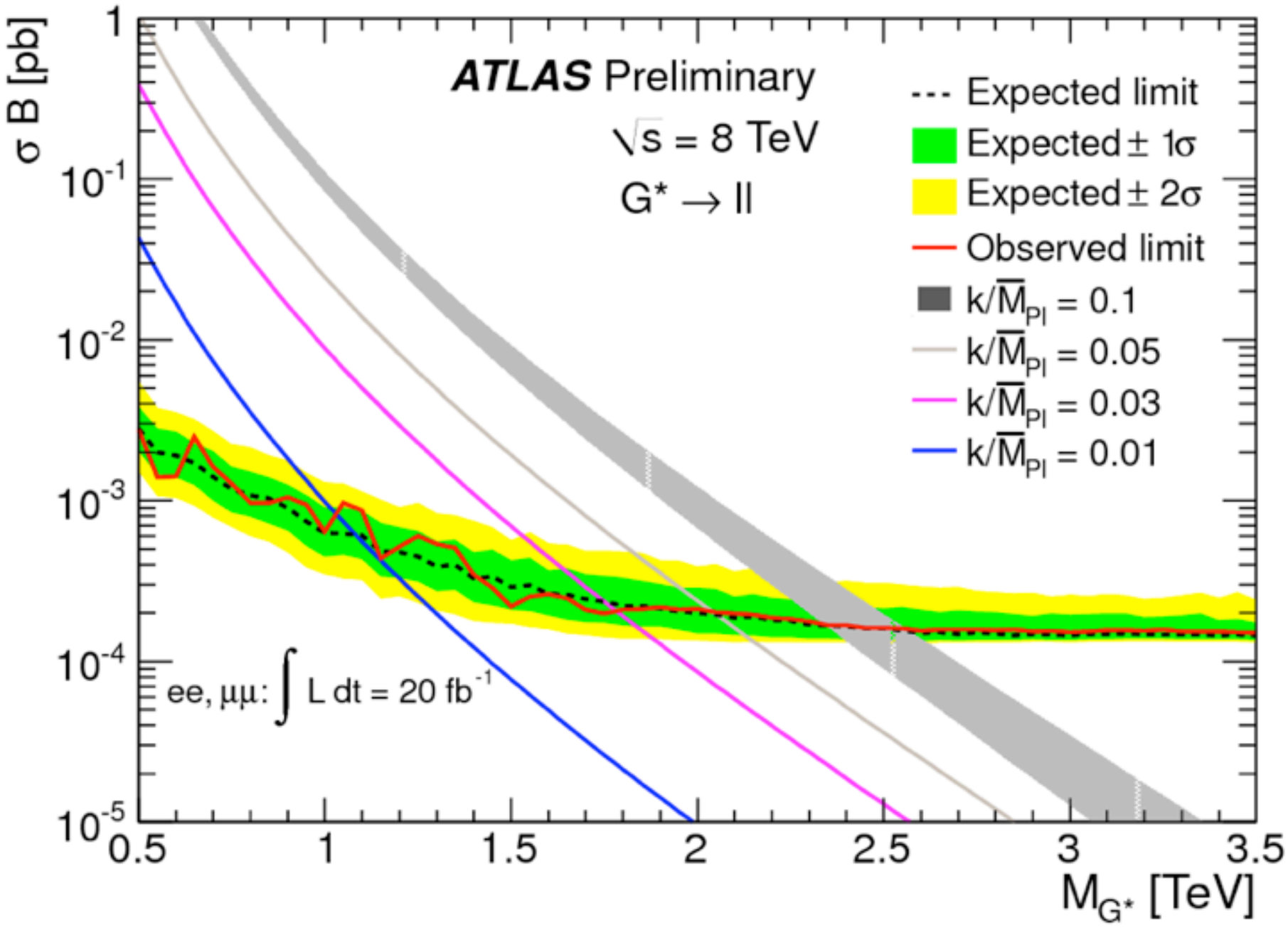
- $k/M_{Pl} = 0.1$ other limits proportional to factor $(k/M_{Pl})^2$
- Electron channel **$m_{G^*} > 2.40$ TeV** (2.40 TeV expected)
- Muon channel **$m_{G^*} > 2.10$ TeV** (2.17 TeV expected)





G* Combined Limit

- m_{G^*} **> 2.47 TeV** (2.47 TeV)



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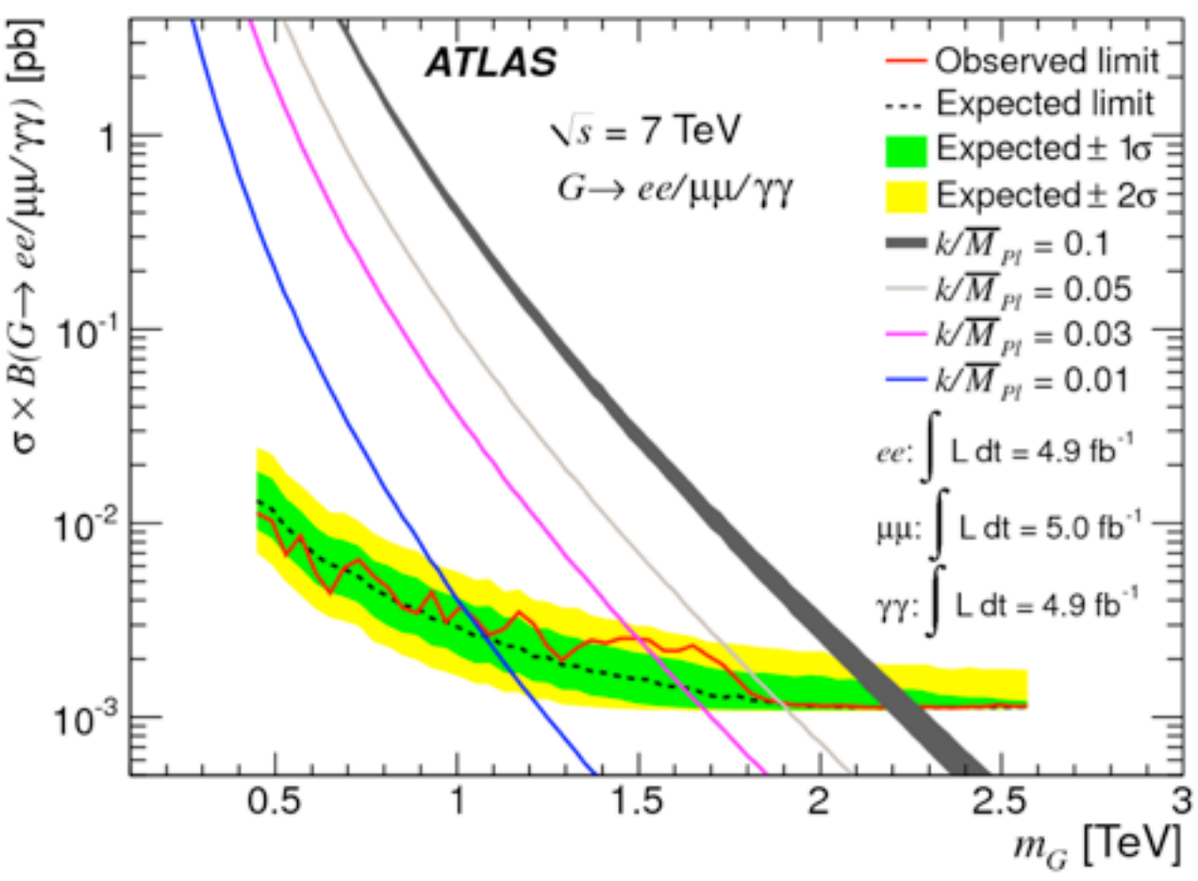
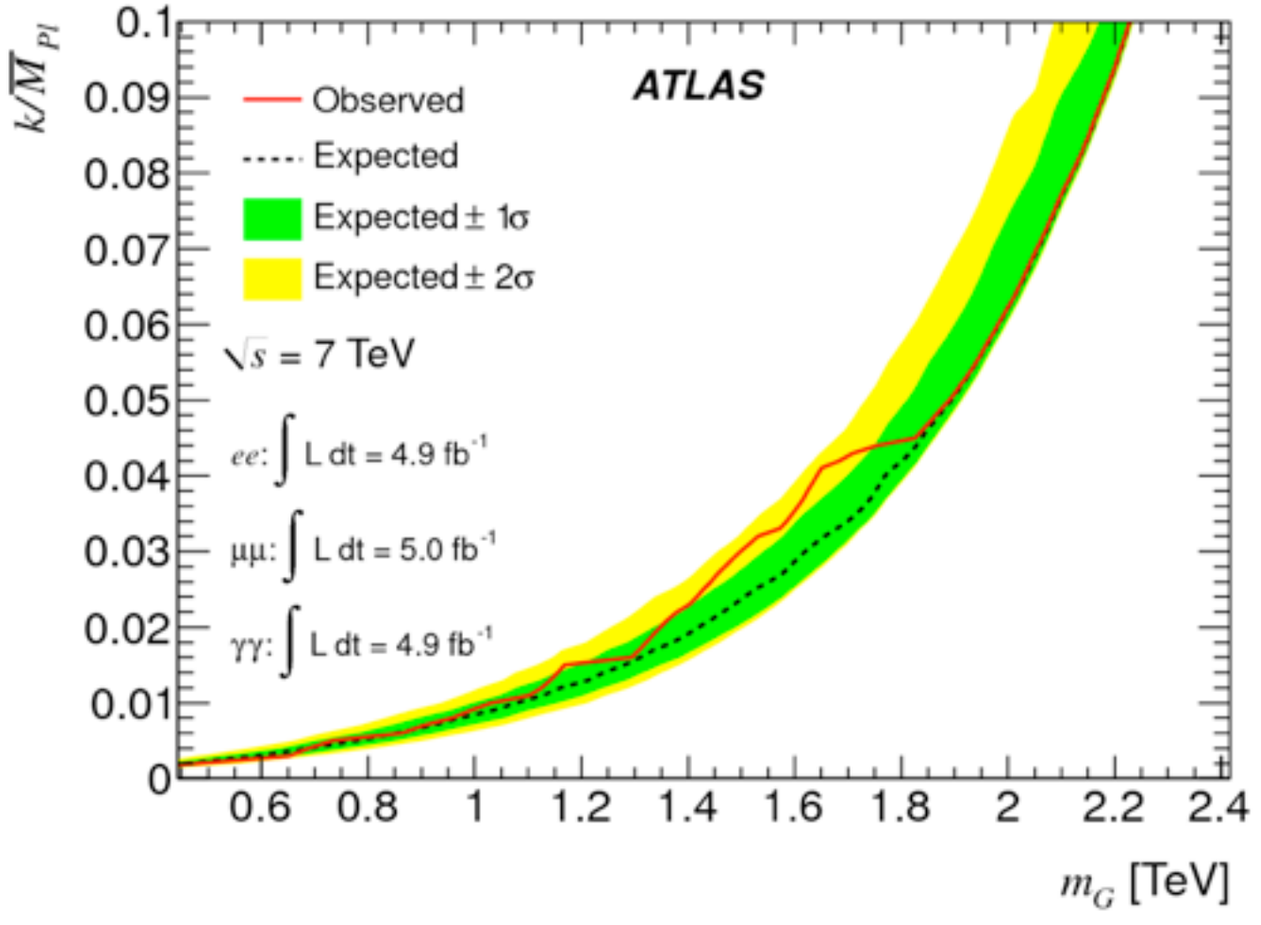
Review of 7 TeV Analyses

- Combination of analyses (2011 data at $\sqrt{s}$ = 7 TeV)
  - dilepton (ee/μμ) 4.9 fb^{-1} / 5.0 fb^{-1} **Phys. Rev. D 87, 015010 (2013)**
  - diphoton (γγ) 4.9 fb^{-1} **CERN-PH-EP-2012-289, submitted to NJP**
- **m_{G^*} > 2.23 TeV (1.00 TeV)** for k/M_{Pl} = 0.1 (0.01)
  Improve dilepton limits m_{G^*} > 2.16 TeV (0.92TeV) by ~100GeV





Summary

- Presented two **ATLAS searches for heavy resonances** at $\sqrt{s}$ = 8TeV based on 2012 *pp* collisions
- Reviewed combination of dilepton and diphoton analysis at $\sqrt{s}$ = 7TeV based on 2011 *pp* collisions
- Dijet Analysis (13.0 fb^{-1})
  - Extend limits on $\sigma \times \mathcal{A}$ of **excited quarks**, exclude below **m_{q^*} = 3.84TeV**
  - Extend limits on $\sigma \times \mathcal{A}$ for simplified Gaussian resonances
- Dilepton Analysis (20.0 fb^{-1})
  - Extend limits on **SSM Z‘ (E_6-motivated Z‘)**, exclude below **$m_{Z'}$ = 2.86 TeV (2.38 - 2.54 TeV)**
  - Extend limits on **Randall-Sundrum Graviton G***, exclude below **m_{G^*} = 2.47 TeV**

BACK UP

Corrections & cross-checks

- Check trigger efficiency as function of m_{jj}
  agrees within stat error for first and second half of data
- Dead calorimeter cells and modules
  - assess effect on jet energy scale
  - events with 1 jet in dead region
  - use p_T balance of dijet system
- Uncertainties from all corrections covered by jet energy scale uncertainties
- Luminonsity, acceptance and fit uncertainties taken into account
  more information in **ATLAS-CONF-2012-088**
- Uncertainty of jet energy resolution negligible

Data Driven Background Estimate

$$\begin{pmatrix} N_{TT} \\ N_{TL} \\ N_{LT} \\ N_{LL} \end{pmatrix} = \begin{pmatrix} r_1 r_2 & r_1 f_2 & f_1 r_2 & f_1 f_2 \\ r_1(1-r_2) & r_1(1-f_2) & f_1(1-r_2) & f_1(1-f_2) \\ (1-r_1) r_2 & (1-r_1) f_2 & (1-f_1) r_2 & (1-f_1) f_2 \\ (1-r_1)(1-r_2) & (1-r_1)(1-f_2) & (1-f_1)(1-r_2) & (1-f_1)(1-f_2) \end{pmatrix} \begin{pmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{pmatrix}$$

$$N_{TT} = r_1 r_2 N_{RR} + r_1 f_2 N_{RF} + f_1 r_2 N_{FR} + f_1 f_2 N_{FF}$$

Signal

Background

NRF, NFR, NFF from NTT, NTL, NLT, NLL via matrix inversion

- R : real electron
- F : fake electron
- T: tight selection
- L: loose selection and NOT tight

- r1 (r2): probability of a real electron in loose sample to pass selection and (sub)leading isolation (from MC)
- f1 (f2) fraction of (sub)leading electron candidates passing electron selection and isolation (weighted average from 11 background enriched data control samples)

Dilepton Monte Carlo Generators

- Signal:
  Pythia 8 reweighted to invariant-mass shape of resonance
  Z‘: MSTW2008LO, G*: CTEQ6L
- Drell-Yan:
  NLO Powheg, hadronization & parton showering Pythia 8, CT10
- Diboson: Herwig, CTEQ6L1
- tt: MC@NLO, Herwig, CT10

} extrapolated to higher mass regions with fits

- For all samples: Final state radiation with Photos, GEANT4 model of ATLAS detector