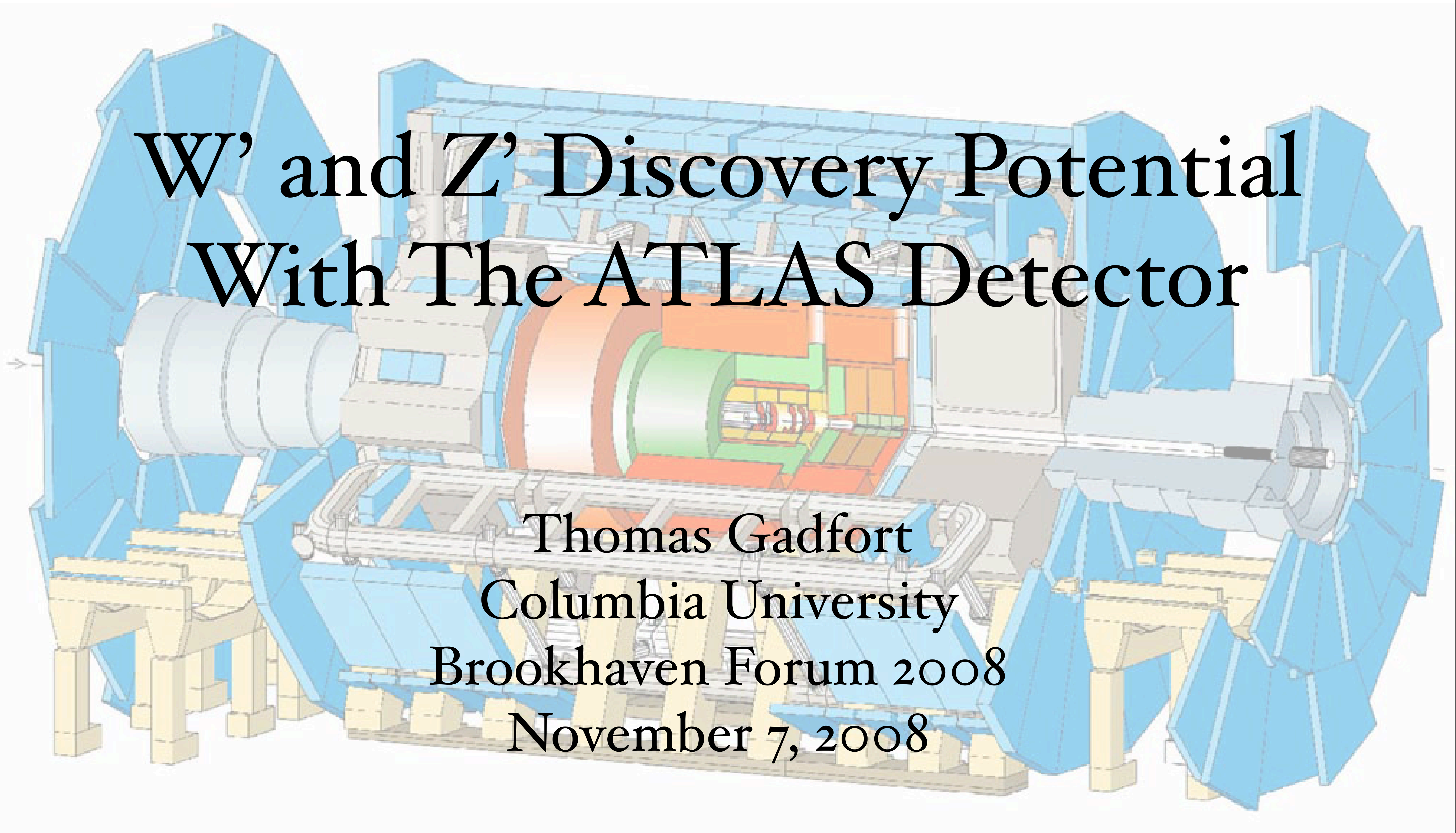
W' and Z' Discovery Potential With The ATLAS Detector



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Outline

- Experimental Signature of BSM Physics with W' and Z' Bosons.
- Lepton Identification at ATLAS
- ATLAS Z' & W' Discovery Potential
- Projections with 10 fb^{-1}

BSM Physics w/ W' & Z'

- There is much evidence that the Standard Model (SM) is only an effective low energy approximation to some higher energy theory.

- Many BSM theories predict massive resonances at the TeV-scale.
  - Sequential SM Z' (SSM) ; Left-Right Symmetric Model W'/Z' (LRSM) ; GUT E_6 (Z'_ψ , Z'_χ , Z'_η) ; Technicolor (ρ_T , ω_T) ; KK modes of RS Graviton.

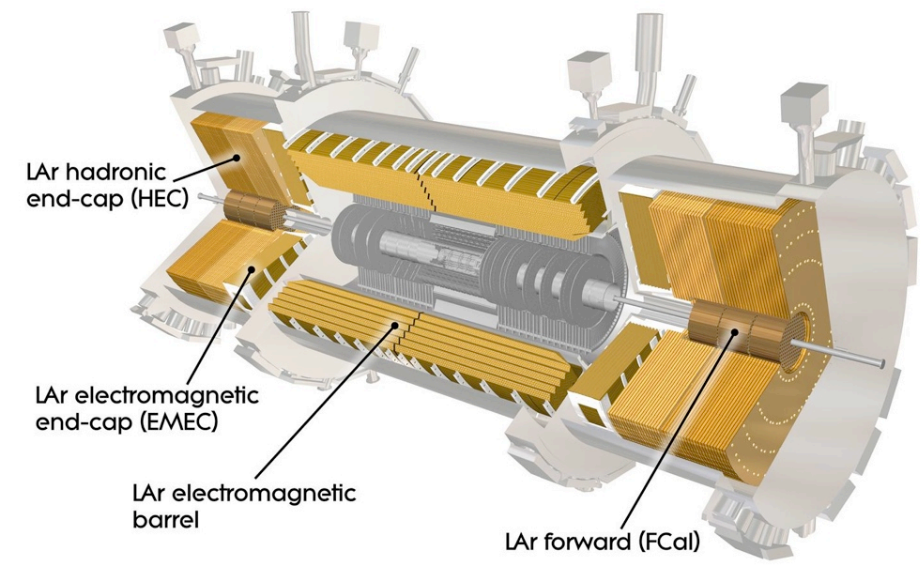
- We search for these resonances through their decay to leptons.
  - Advantages: excellent mass resolution, low backgrounds.
    Disadvantages: lower branching ratio compared to quarks.

- If the new particle is electrically-neutral we call it a **Z'**
  - Signature: two high p_T isolated leptons ; "bump" in the di-lepton mass spectrum (**Z'** $\rightarrow ll$)

- If the new particle is a electrically-charged we call it a **W'**
  - Signature: one high p_T isolated lepton + large missing energy ; Jacobian edge in transverse mass (m_T) spectrum (**W'** $\rightarrow l\nu$)

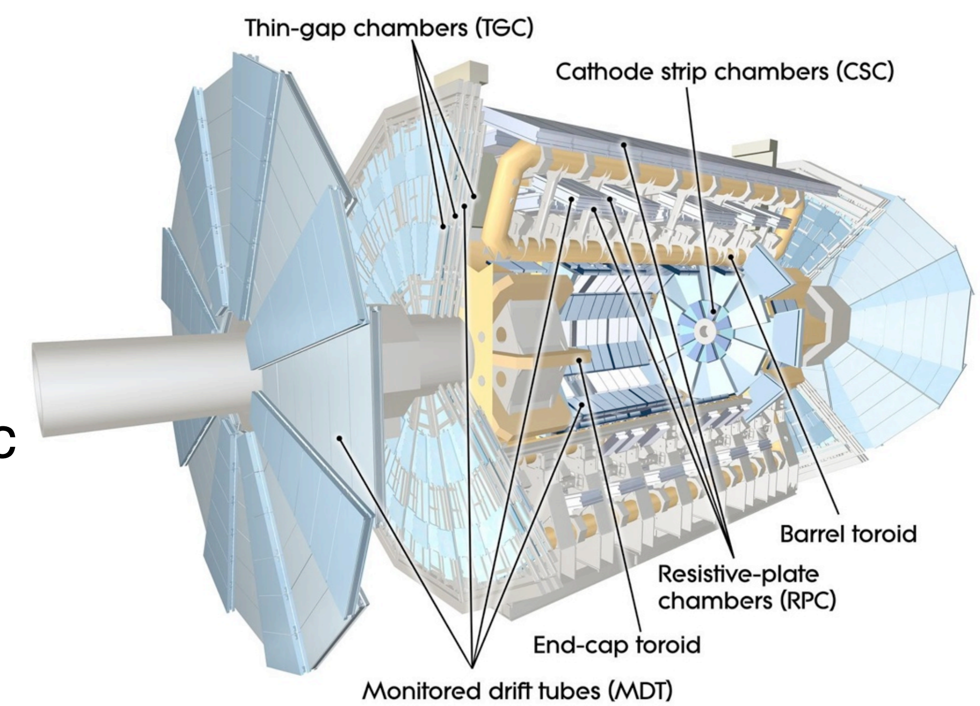
Lepton Identification at ATLAS

- **Electrons:** Utilize finely segmented EM calorimeter for energy measurement and inner tracking detector for momentum/charge.
  - (***loose***) Low hadronic activity + electron-like shower shape to reject $\pi^{\pm}$ and (***medium***) tight track requirements to reject π^0
  - $p_T(e) > 50$ GeV: $\varepsilon \sim 70\%$ and ~1% resolution
    Charge mis-ID ~ 1-5% for 100 GeV < $p_T(e)$ < 1 TeV.



- **Muons:** Combine hits in muon spectrometer with inner detector track to form muon candidate.
  - $p_T(\mu) = 500$ GeV: $\varepsilon \sim 95\%$ and ~5% resolution.

- **Taus**: Create tau-likelihood by combining EM+Hadronic shower shape with inner detector tracks to reject jets.
  - $p_T(\tau) > 60$ GeV: $\varepsilon \sim 50\%$ for hadronically decaying taus.

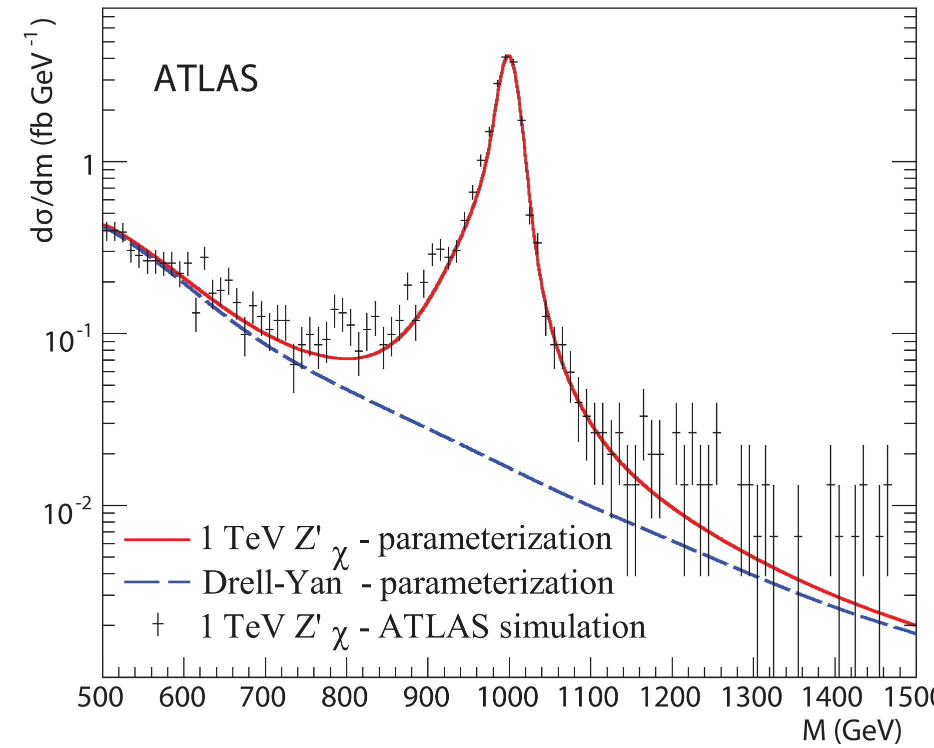


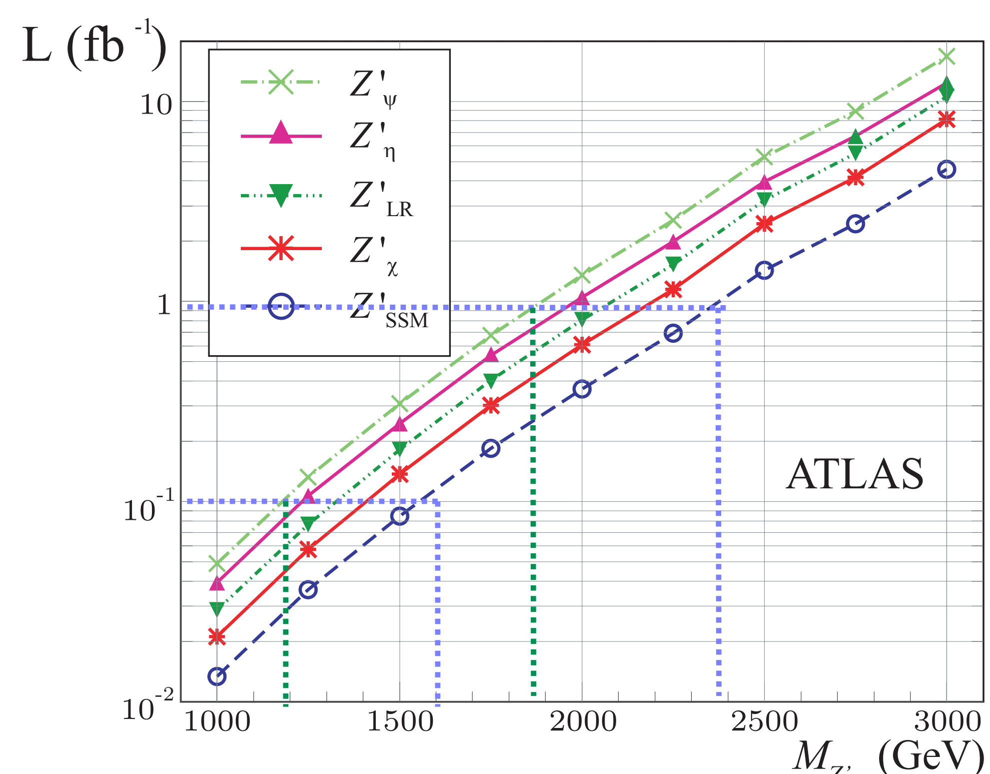
Z' in di-electron Final State

- Select events with single electron trigger
  - Expect 80-90% efficiency for 1 TeV signal
- The di-electron final state
  - Two oppositely charged *loose* electrons ; leading electron must have pT(e) > 65 GeV.
- Background dominated by high mass Drell-Yan and di-jet production
  - Simulate background and signal with Pythia Normalize to theory w/ 1.6 k-factor.
- Select events in $\pm 4\Gamma_{Z'}$ surrounding $M_{Z'}$ Expected Yields for 1 fb^{-1}

	1 TeV	2 TeV	3 TeV
$Z_\chi' \rightarrow e^+e^-$	166	6.2	0.43
$Z/\gamma^* \rightarrow e^+e^-$	1.70	0.07	0.007

  - w/ 100 pb-1: M ~ 1.2-1.5 TeV
    w/ 1 fb-1: M ~ 1.9-2.4 TeV
  - PDFs (~5-10%), ID (5%), Luminosity (20% with 100 pb^{-1}, 3% with 10 fb^{-1})



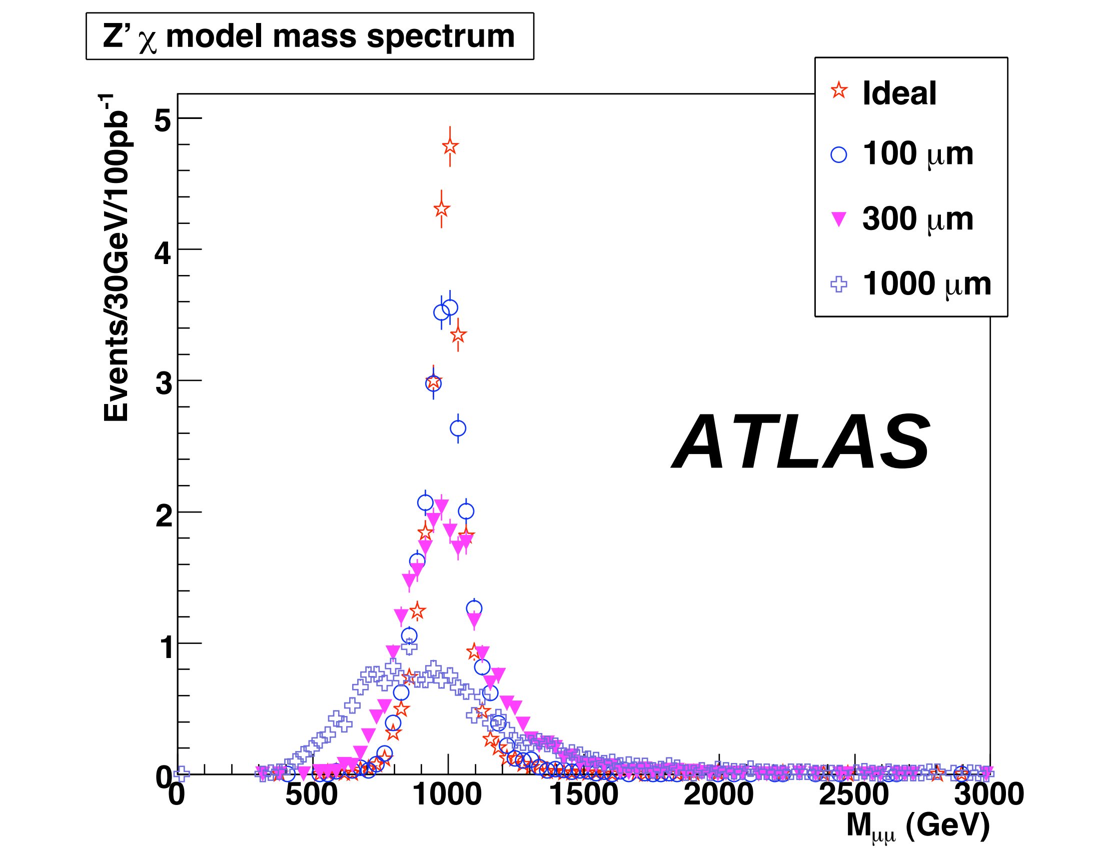


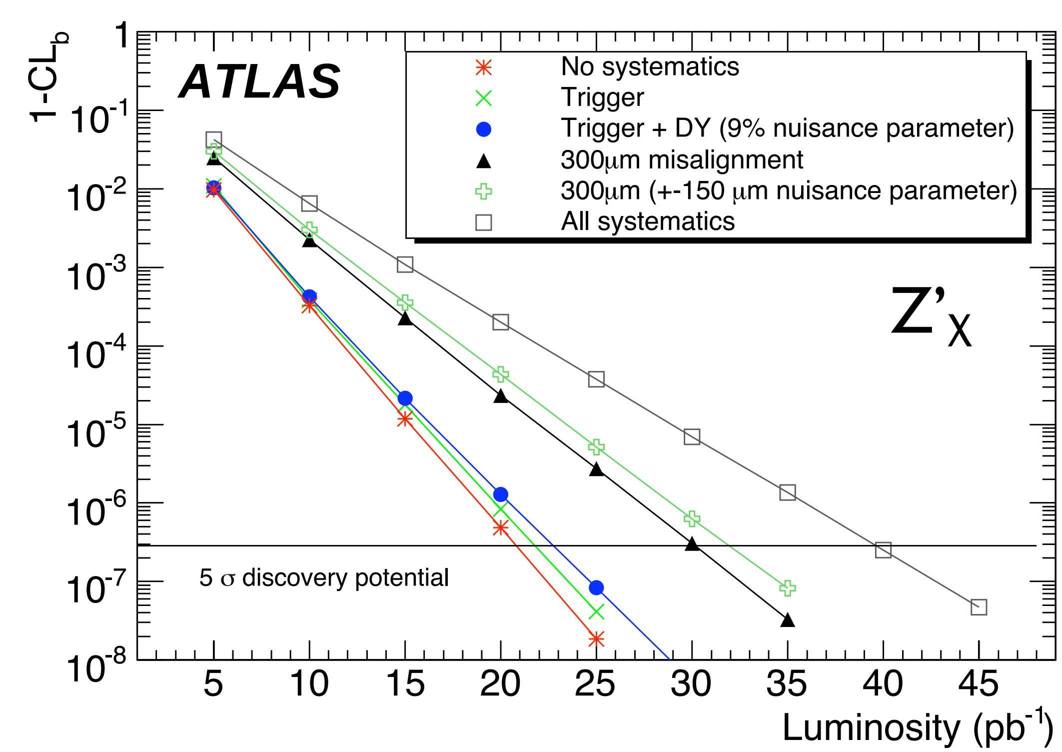
Z′ in di-muon Final State

- Di-muon events selected with single-muon trigger with 95% efficiency
- Early alignment is crucial for this analysis
  - Ideal uncertainty of σ = 40 μm.
    Initially expect σ = ~150 μm.
- Event Selection
  - Two oppositely charge muons with p_T > 30 GeV and |η| < 2.5 ; M($\mu^+\mu^-$) > 800 GeV.
- Select events with ±50 GeV surrounding $M_{Z'}$
  Expected yields for $M_{Z'}$ = 1 TeV with 1 fb^{-1}
  - w/ ~50 pb^{-1} will move beyond Tevatron limit.

$Z'_{SSM} \rightarrow \mu^+\mu^-$	324
$Z'_{\chi} \rightarrow \mu^+\mu^-$	243
$Z/\gamma^* \rightarrow \mu^+\mu^-$	9.6

- Systematics
  - PDFs (~5-10%), ID (5%),
    Luminosity (20% with 100 pb^{-1}, 3% with 10 fb^{-1})
    Mis-alignment raises required luminosity by 50%

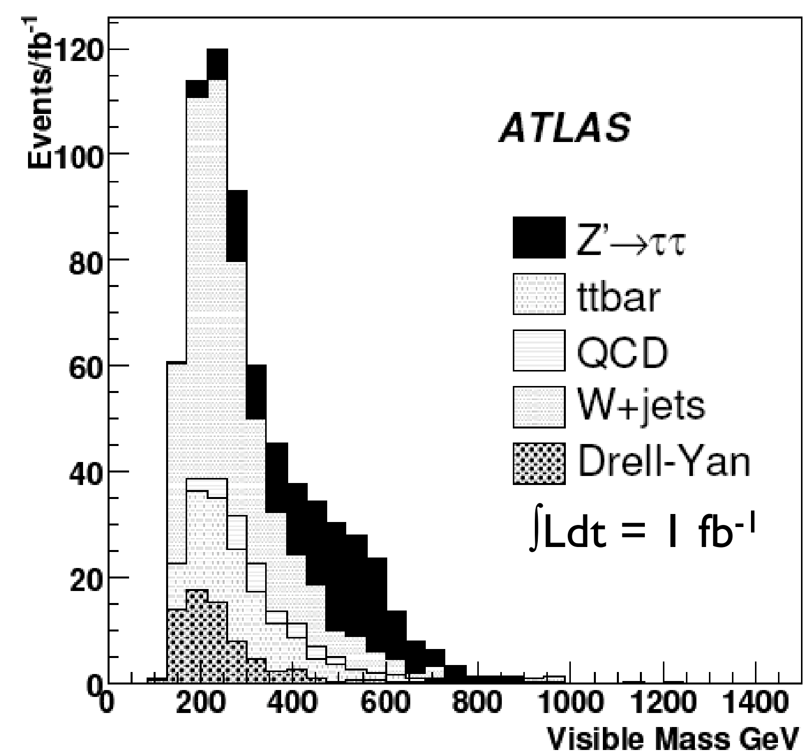




Z’ in di-tau Final State

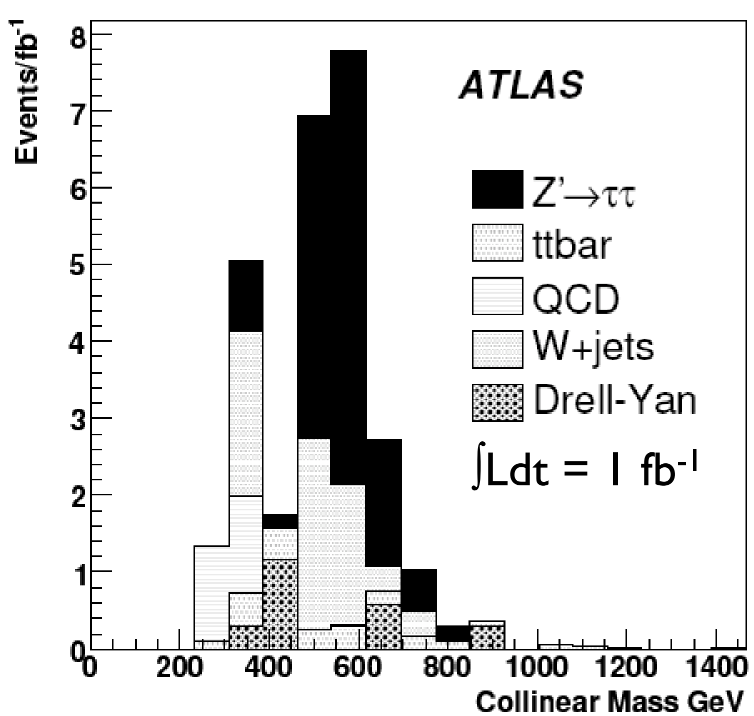
- Di-tau events are selected when one tau decays to an electron or muon and the other decays hadronically ($Z' \to \tau\tau \to \{e,\mu\}\tau_h$) to reduce QCD background.
- Use single muon or single electron triggers with 60-70%
- Event selection
  - $p_T(e) > 27$ GeV or $p_T(\mu) > 22$ GeV ;
    $p_T(\tau) > 60$ GeV w/ p_T-dependent likelihood requirement.
    $\varepsilon \sim 50\%$ for $M_{Z'} = 600$ GeV
  - Missing $E_T > 30$ GeV ; $M_T < 35$ GeV ; $p_T^{tot} < 70$ GeV.
    $M_{vis} > 300$ GeV

$$m_{vis} = \sqrt{(\underline{p_\ell} + \underline{p_h} + \underline{\not{p}_T})^2}$$



Collinear approximation if tau-lepton are not back-to-back

$$m_{\tau\tau} = \frac{m_{\ell,h}}{\sqrt{x_\ell x_h}}$$

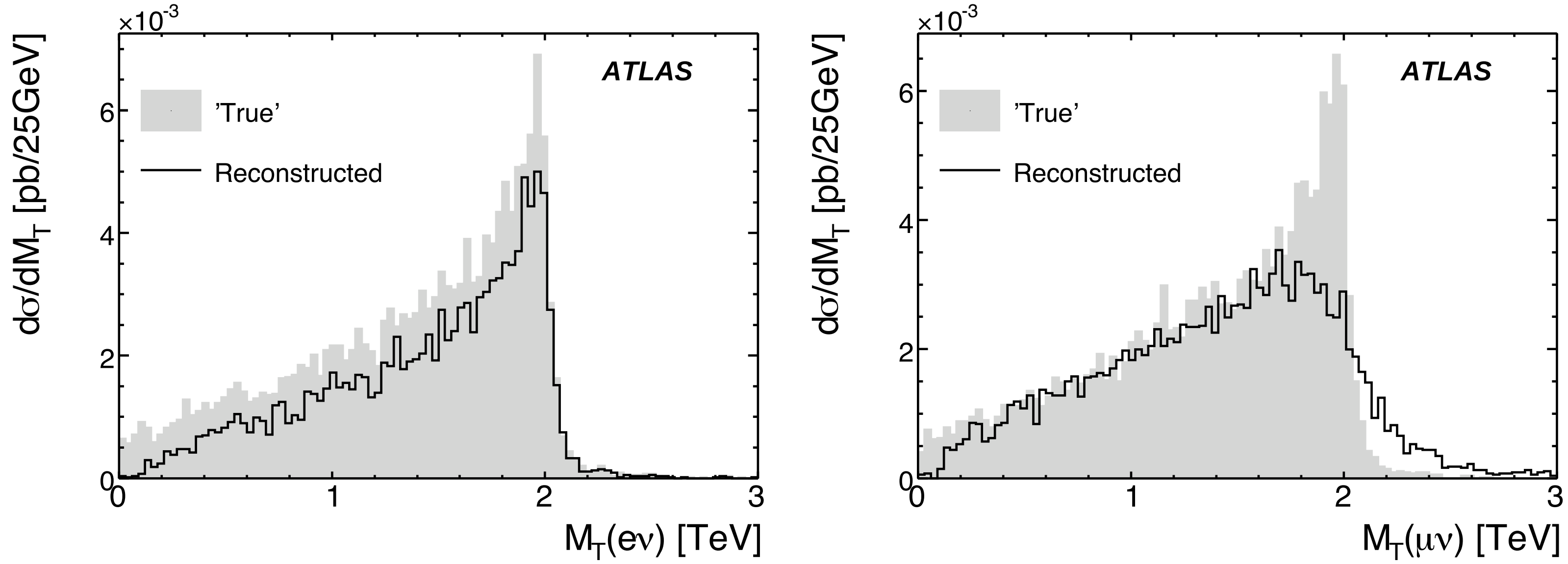


- Expect to see evidence for a 600 GeV Z’ with 3.4σ significance with 1 fb^{-1}
  - Systematics dominated by luminosity (18%) and tau energy scale (10%)

W' Search

- Many BSM theories predict a massive electrically charged boson (W')
    - Ex. Left-right symmetric model, GUT models.
- The channel with the highest early discovery potential is W' → lν
- Final state characterized by one isolated high p_T lepton and large missing energy.
- Reconstruct W' mass in the transverse plane (M_T) due to known system P_z boost

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



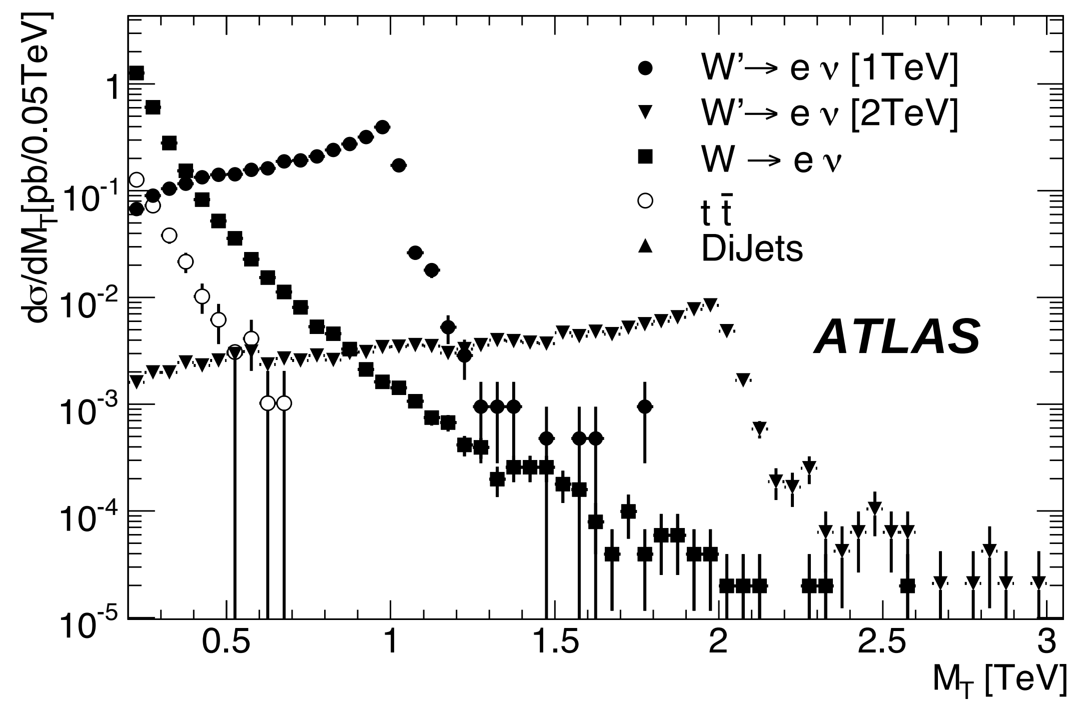
- Electron channel: $\sigma(M_T)$ ~ 12.3 GeV for $M_{W'}$ = 1 TeV and 23.4 GeV for $M_{W'}$ = 2 TeV
- Muon channel: $\sigma(M_T)$ ~ 18.4 GeV for $M_{W'}$ = 1 TeV and ~84 GeV for $M_{W'}$ = 2 TeV

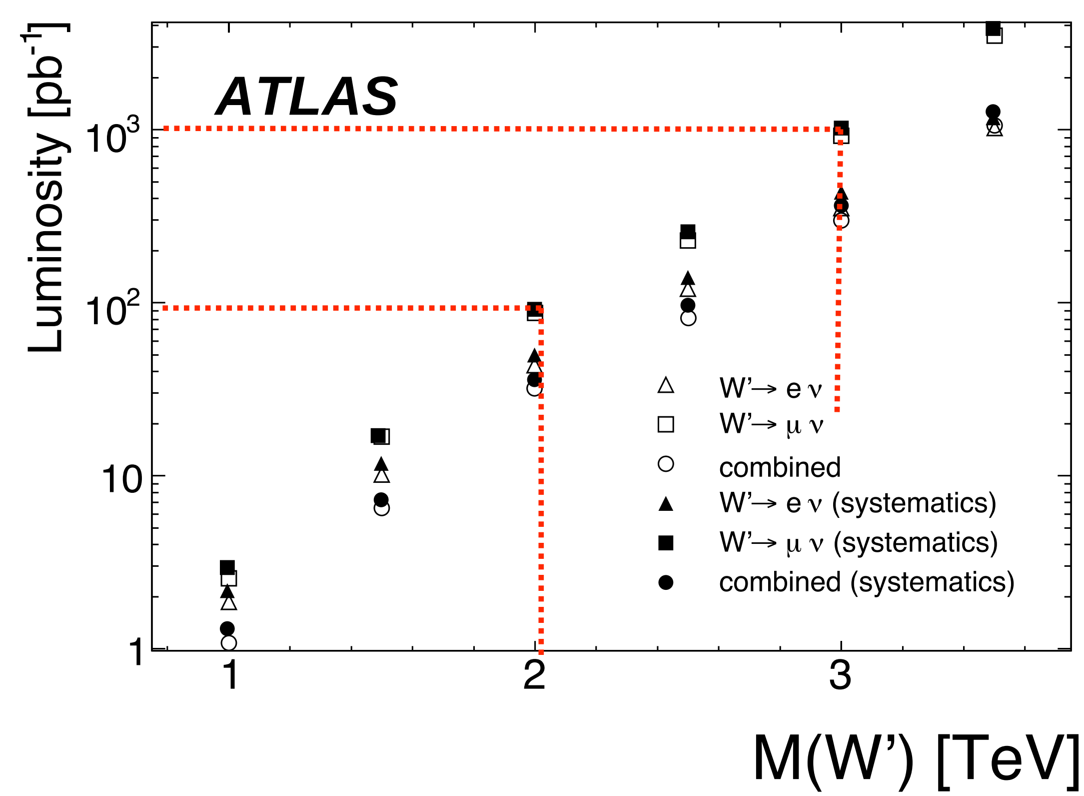
W' Discovery Potential

- Event Selection
  - Isolated lepton with $p_T(e,\mu) > 50$ GeV
    Missing $E_T > 50$ GeV
- Signal and background modeled with MC@NLO with 1.37 k-factor (δ=8%)
- Backgrounds a mix of ttbar, W+jets.
  - Select events with $M_T > 0.7*M_{W'}$;
    Veto events with leading jet $E_T > 200$ GeV.
- Events with 1 fb^{-1}

$M(\rho_T) = M(\omega_T)$	$M_{W'}$ = 1 TeV	$M_{W'}$ = 2 TeV
W' → lν	4060	168
W → lν + jets	74	4.5

  - w/ 100 pb-1: M ~ 2 TeV
    w/ 1 fb-1: M ~ 3 TeV
- Systematics
  - PDFs (5-10%), JES (7%), Luminosity (3%).

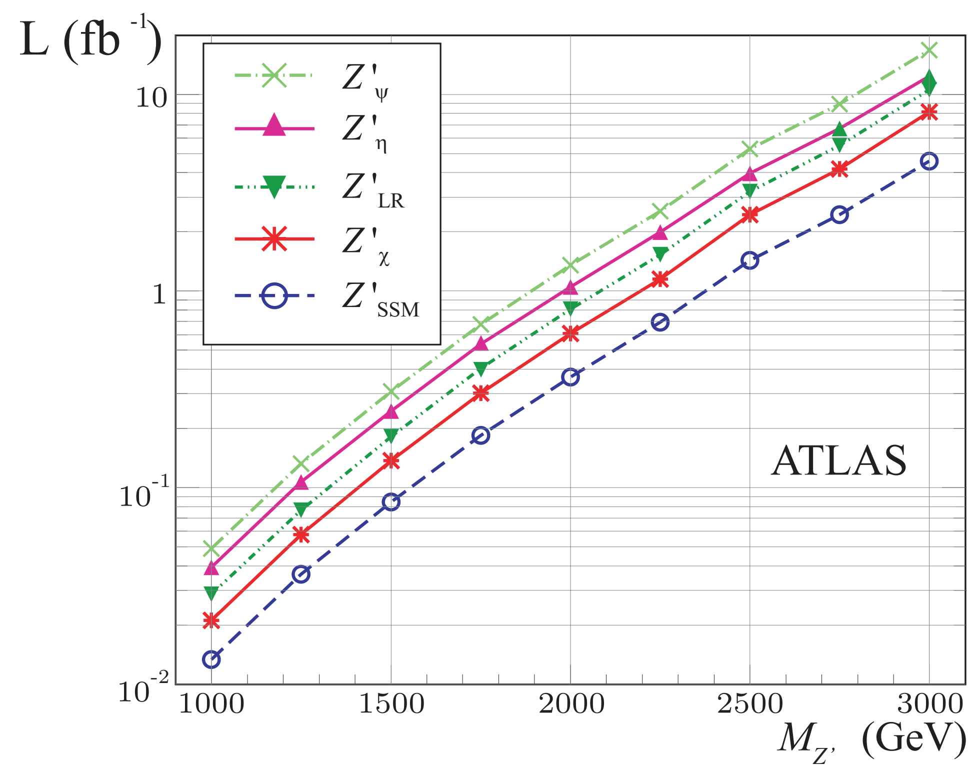


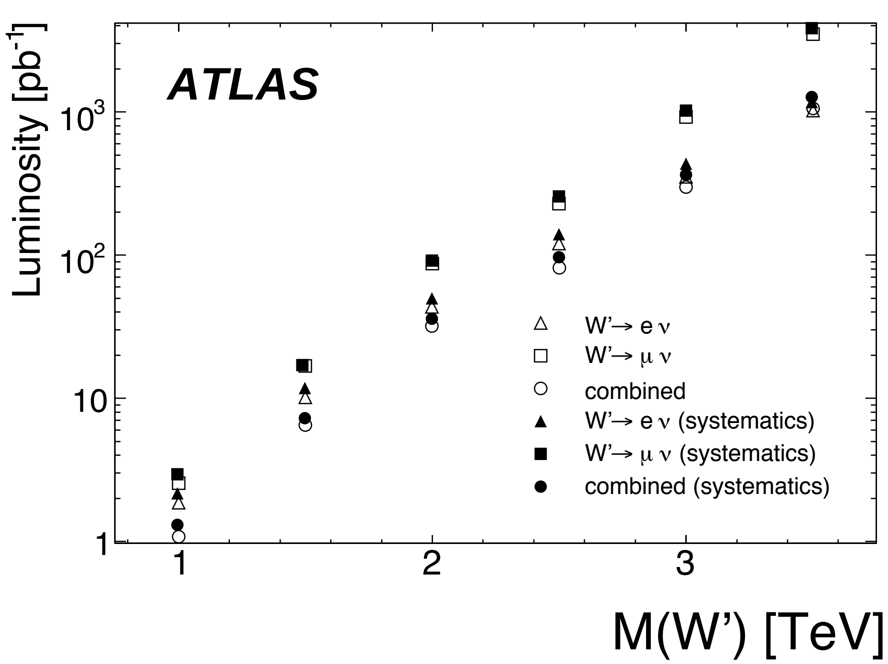


Summary

- W' and Z' are candidates for early discovery at the LHC.

- Z' : ATLAS will move beyond the Tevatron reach with the first 100 pb^{-1}
  - Discovery potential is model-dependent
  - Expect to discover a Z' with masses between 1 and 3.5 TeV with 10 fb^{-1}

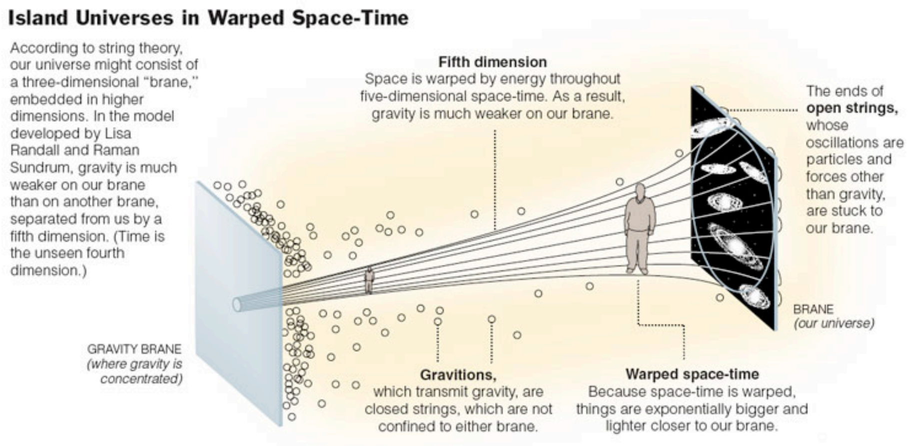




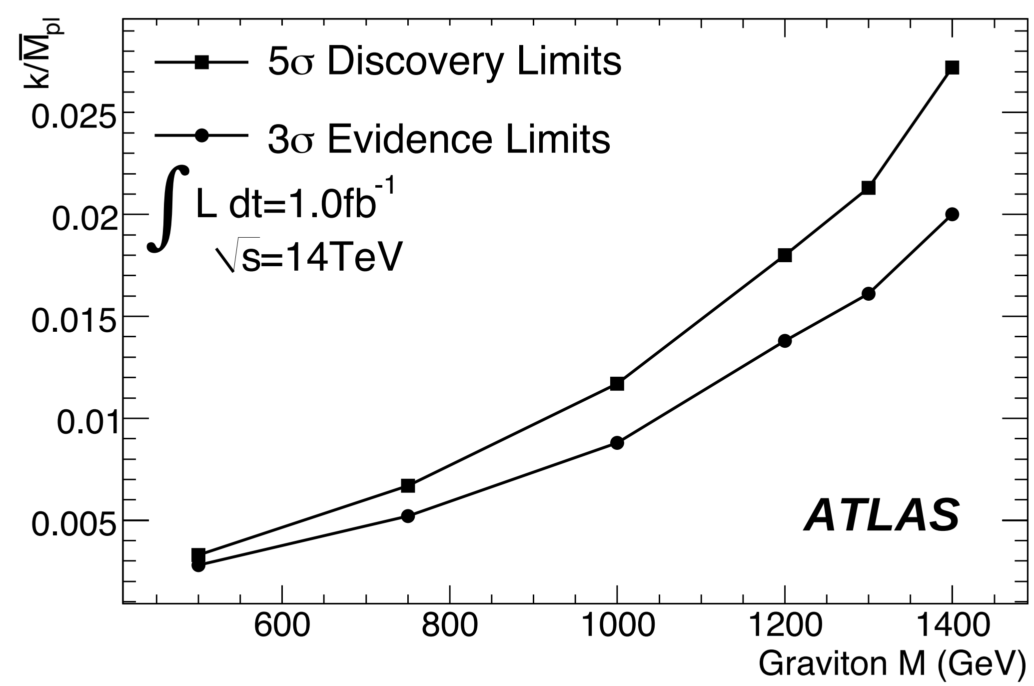
- W' : With only a few pb^{-1}, ATLAS will go beyond the currently excluded mass range ($M_{W'} < 1$ TeV).
  - With 10 pb^{-1} ATLAS can discover a W' with mass ~ 2 TeV.
  - Projecting with the current sensitivity, we will be sensitive to W' masses up to 4 TeV with the first 10 fb^{-1}.

Randall-Sundrum Graviton

- The Randall-Sundrum graviton is also studied through its decay to lepton pairs.
  - Gravity is allowed to propagate in a warped 5th dimension with curvature $\boldsymbol{k}^{-1}$.
  - KK modes of the graviton couple to fermions on the TeV brane with strength $\boldsymbol{k/M}_{\mathrm{pl}}$.
  - The mass of these KK modes is expected to be O(TeV).
  - Decays to a pair of leptons will mimic a Z' signal.



- Event Selection
  - $p_T(e) > 65$ GeV. No explicit charge requirement. Back-to-back electrons → $\cos(\Delta\Phi_{ee}) < 0$
  - Select events in $\pm 4\sigma_m$ mass window.



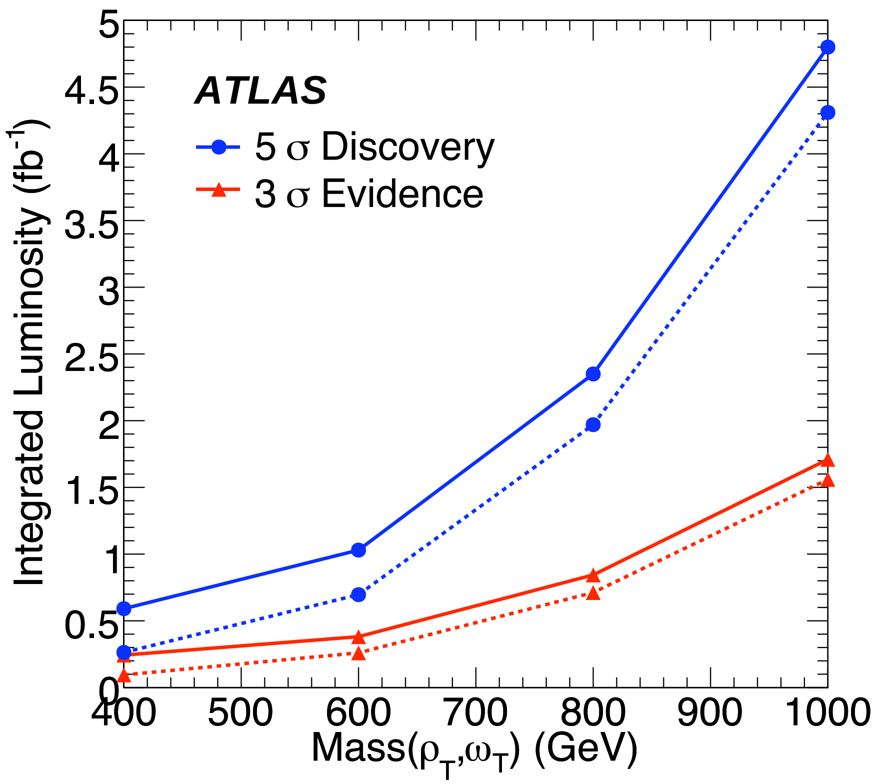
- Expected Yields with 1 fb^{-1}

	M_G = 500 GeV k/M_{pl} = 0.01	M_G = 1 TeV k/M_{pl} = 0.02	M_G = 1.4 TeV k/M_{pl} = 0.05
$G \to e^+e^-$	123	16.0	14.4
$Z/\gamma^* \to e^+e^-$	13.4	0.85	0.33

Topcolor-Assisted Technicolor

- Topcolor-assisted technicolor with a "walking" coupling strength provides an alternative method for EWSB.
  - Theory predicts broad spectrum of bound-states at the TeV-scale called technihadrons.
  - Lowest spin-1 bound-states ($\rho^{\pm,0}_T$ and ω_T) are expected to couple with fermion pairs. Masses expected to be O(100 GeV - 1 TeV)
- Studied through the Technicolor Strawman Model (TCSM)
  - Assume degenerate mass states → $M(\rho_T) = M(\omega_T)$
  - Simulate signal with Pythia w/ default TCSM settings
- Select events in ±1.5σ mass window

$M(\rho_T) = M(\omega_T)$	$\rho_T / \omega_T \to \mu^+\mu^-$	$Z/\gamma^* \to \mu^+\mu^-$
600 GeV	26.3	14.9
800 GeV	10.3	6.1
1000 GeV	4.7	2.8



- Expect to exclude 600 GeV mass states with first fb^{-1}