Resonances in muons at the early LHC

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Work with Lisa Randall and Randall Kelley

August 13, 2010 • Implications of First LHC Data Workshop

Our work

GOAL: What **new physics** can the LHC find?

- Not already seen/excluded by Tevatron

- Resonances are a good first place to look
  - Generic prediction (Z’, RS, …)
  - Distinctive shape
- Consider **dimuon** final states
- Look at open regions of parameter space & techniques

Motivation

- LHC vs. Tevatron
  - Tevatron: p-pbar collider, more integrated luminosity
  - LHC: higher CM energy
- Where can the LHC beat the Tevatron?
  - Gluon fusion
  - High invariant mass
  - Need strong coupling to compensate for small luminosity → often leads to **broad resonance**

Example: Z'

- New heavy gauge boson specified at low energy by
  - Mass
  - Coupling $\epsilon = \frac{g_{Z'}}{g_Z}$
  - Charges

- General behaviour:

$$\sigma(pp \to Z' \to \mu\bar{\mu}) \sim \frac{\epsilon^2}{s}\frac{d\mathcal{L}}{d\tau}\left(\frac{M_{Z'}^2}{s}\right) \qquad \Gamma \sim M_{Z'}\,\epsilon^2\left[1 + \mathcal{O}\left(\frac{m^2}{M_{Z'}^2}\right)\right]$$

Example: Z'

- Only rigorous constraint is anomaly cancellation

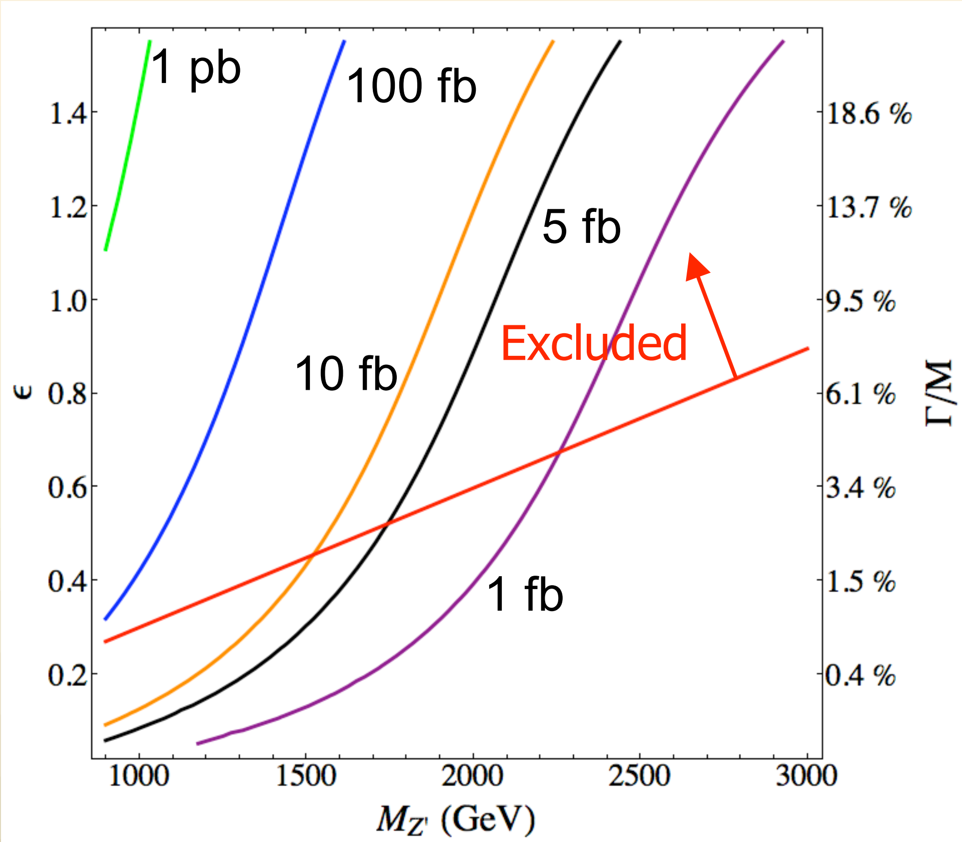
- We consider **minimal models** (no new fields except Z' and RH neutrinos)
  - Since RH υ are gauge singlets, only hypercharge, *B-L* are anomaly-free
  - Hypercharge constrained by mixing with SM Z
  - Consider only *B-L* type

Z′ Cross Sections

- Compute cross sections at $\sqrt{s} = 7\ \mathrm{TeV}$
  - Do not use narrow width approximation
  - Integrate over 4Γ window centred at mass peak
  - MSTW2008 PDF
  - Calculated at LO with invariant-mass-dependent K-factor
  - $|\eta|<2.5$ and $p_T > 20$ GeV, selection efficiency (CMS)
- Constraints:
  - Direct bounds from dimuon searches (minimal above 1 TeV) from Tevatron
  - Indirect bounds on contact interactions from LEP (electrons) and Tevatron (muons)

Z′ Signal Cross Sections

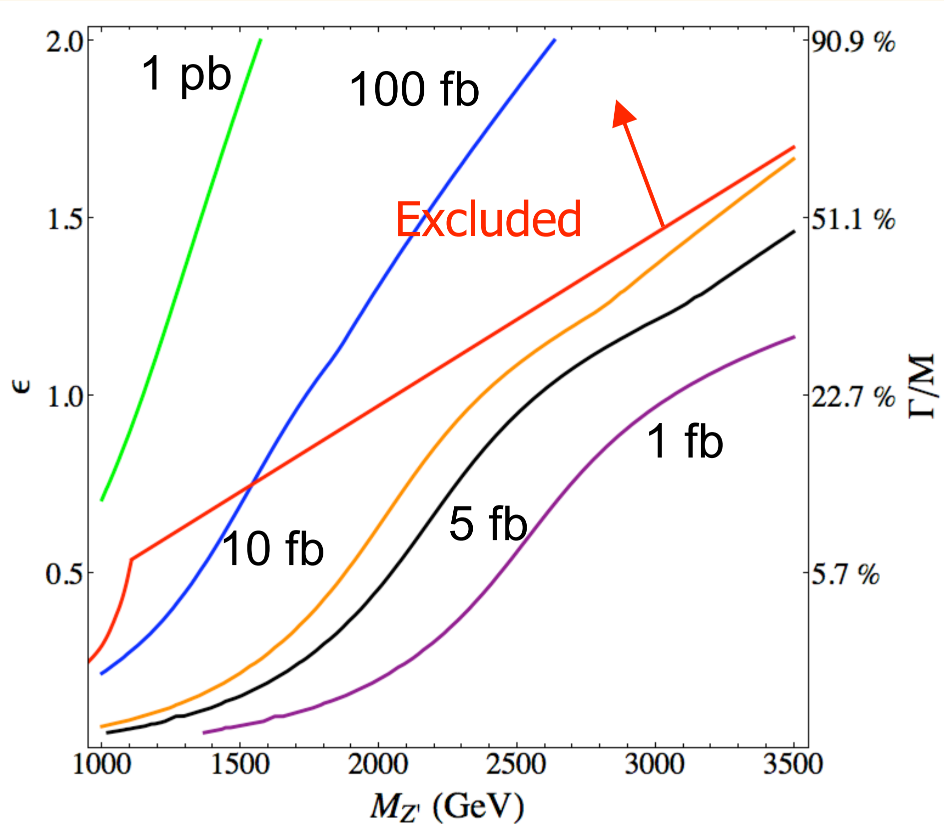
- Flavour-universal *B-L* constrained by LEP due to electron coupling



E. Salvioni *et al.*, JHEP **1003**, 010 (2010)

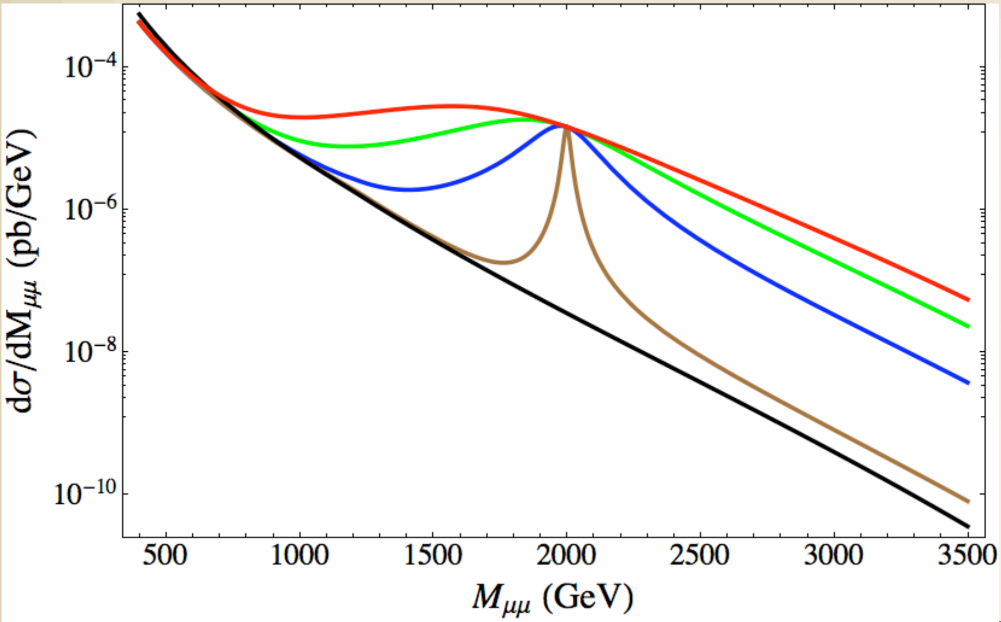
Z' Signal Cross Sections

- More parameter space open if we couple preferentially to muons, *B-3L*$_\mu$



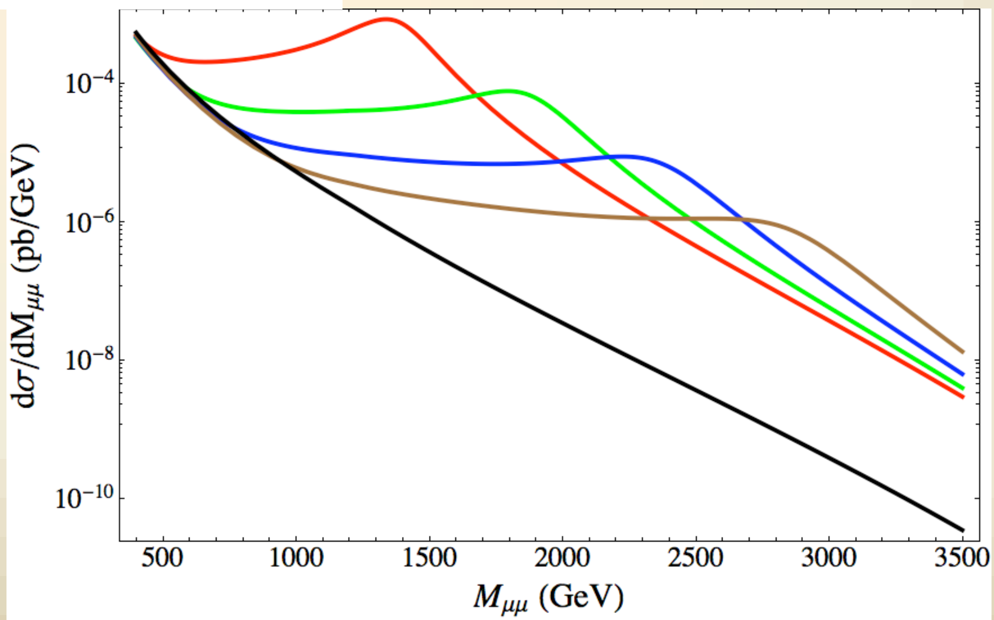
Back to Z':

7 TeV



Varying **coupling**

(ε=1.4, 1.1, 0.8, 0.5, 0 [SM])



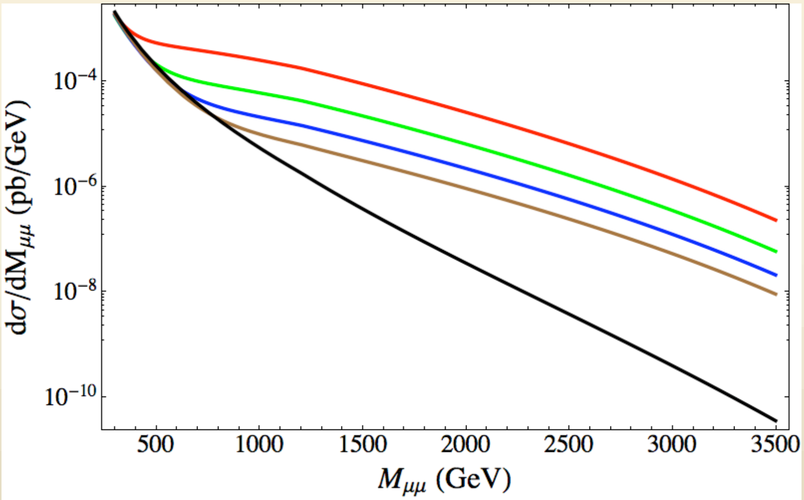
Varying **mass**

(1.4, 1.9, 2.4, 2.9 TeV, SM)

Shape Discrimination

- Easy to see narrow resonances
- As resonance gets broader, looks more like a contact interaction
- Contact interaction predicts excess events at high invariant mass in simply falling distribution

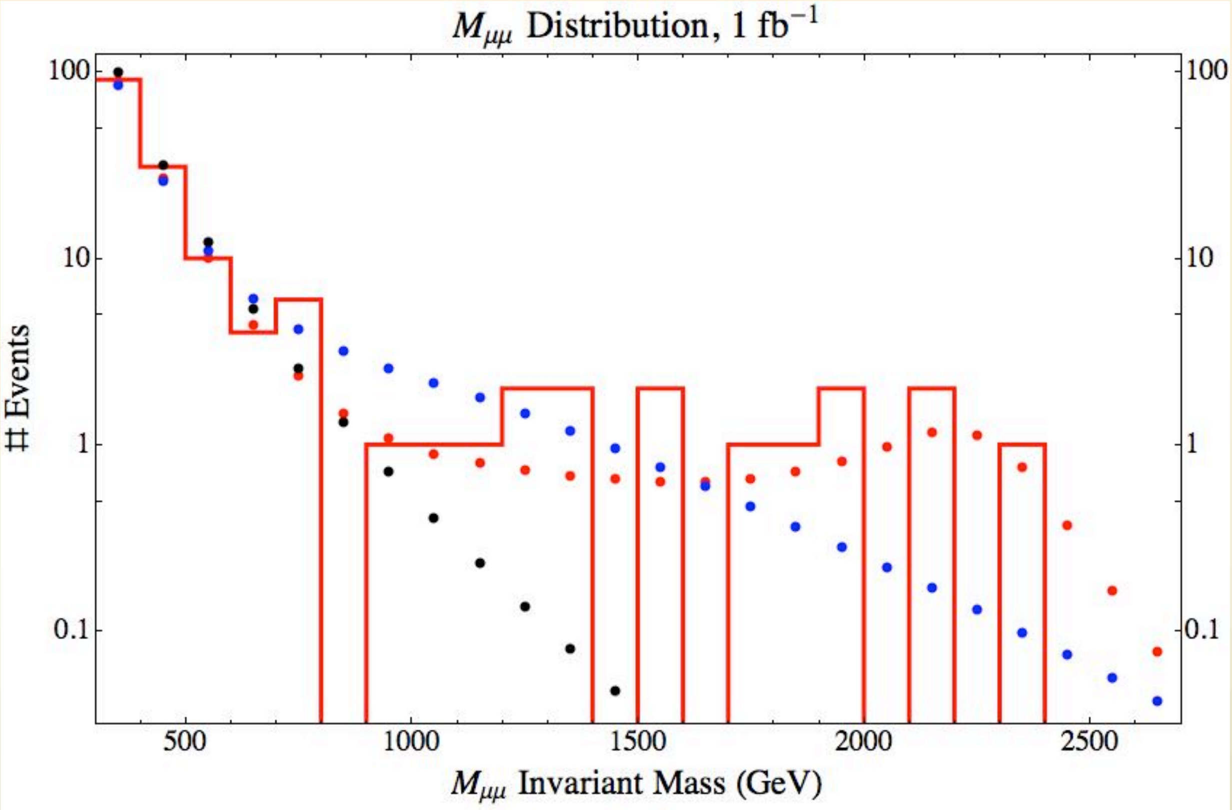
$$\mathcal{L} = \frac{4\pi}{\Lambda^2}(\bar{q}\gamma^{\nu}q)(\bar{\mu}\gamma_{\nu}\mu)$$



<u>Scales:</u>
5 TeV, 7 TeV, 9 TeV, 11 TeV,
SM ($\Lambda \rightarrow \infty$)

Shape Discrimination

- Statistical fluctuations can mask the underlying physics



Maximum Likelihood Analysis

- Perform **fits**, compare resonance and contact interaction using some statistic
  - Cannot use χ^2 at low statistics (Poisson)
  - Instead use log likelihood fit (statistic *Q*)

- Can be used to fit both contact & resonance
  - Compare the two fits using

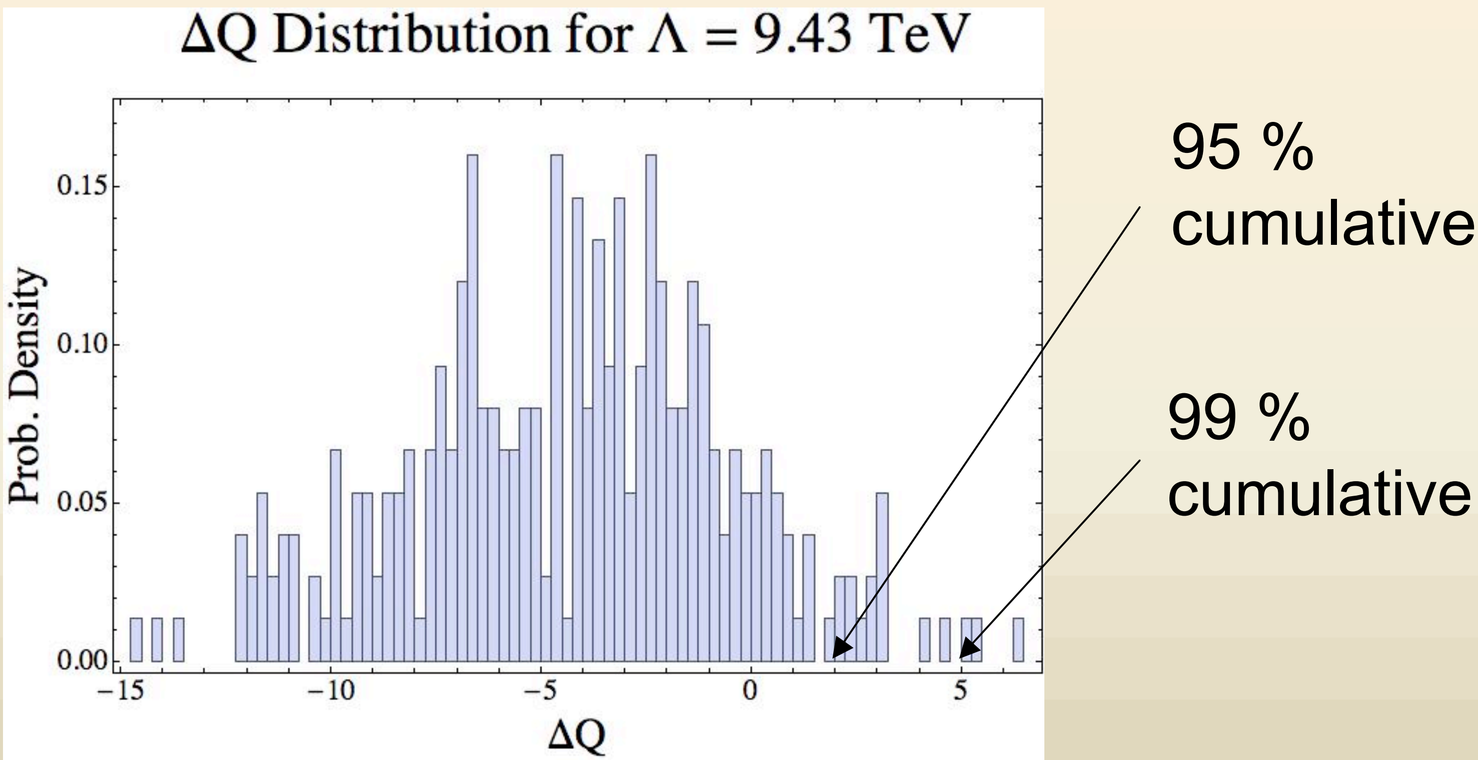
$$\Delta Q = Q_{\mathrm{c}} - Q_{\mathrm{r}} = 2 \sum_i \left(\mu_{i\,\mathrm{c}} - \mu_{i\,\mathrm{r}} + n_i \ln \frac{\mu_{i\,\mathrm{r}}}{\mu_{i\,\mathrm{c}}} \right)$$

Procedure

- Suppose we have some data. We want to show that it's a resonance and not a contact interaction
  1. Perform separate fits for resonance and contact models. Let the best-fit contact scale be Λ.
  2. Compute ΔQ from these fits.
  3. We need to show that this value of ΔQ is on the tail of the distribution of ΔQ computed from data arising from statistical fluctuations of a **contact interaction**. We generate this distribution by simulating many pseudoexperiments based on contact interaction with scale Λ, perform fits and compute the corresponding ΔQ.

Procedure

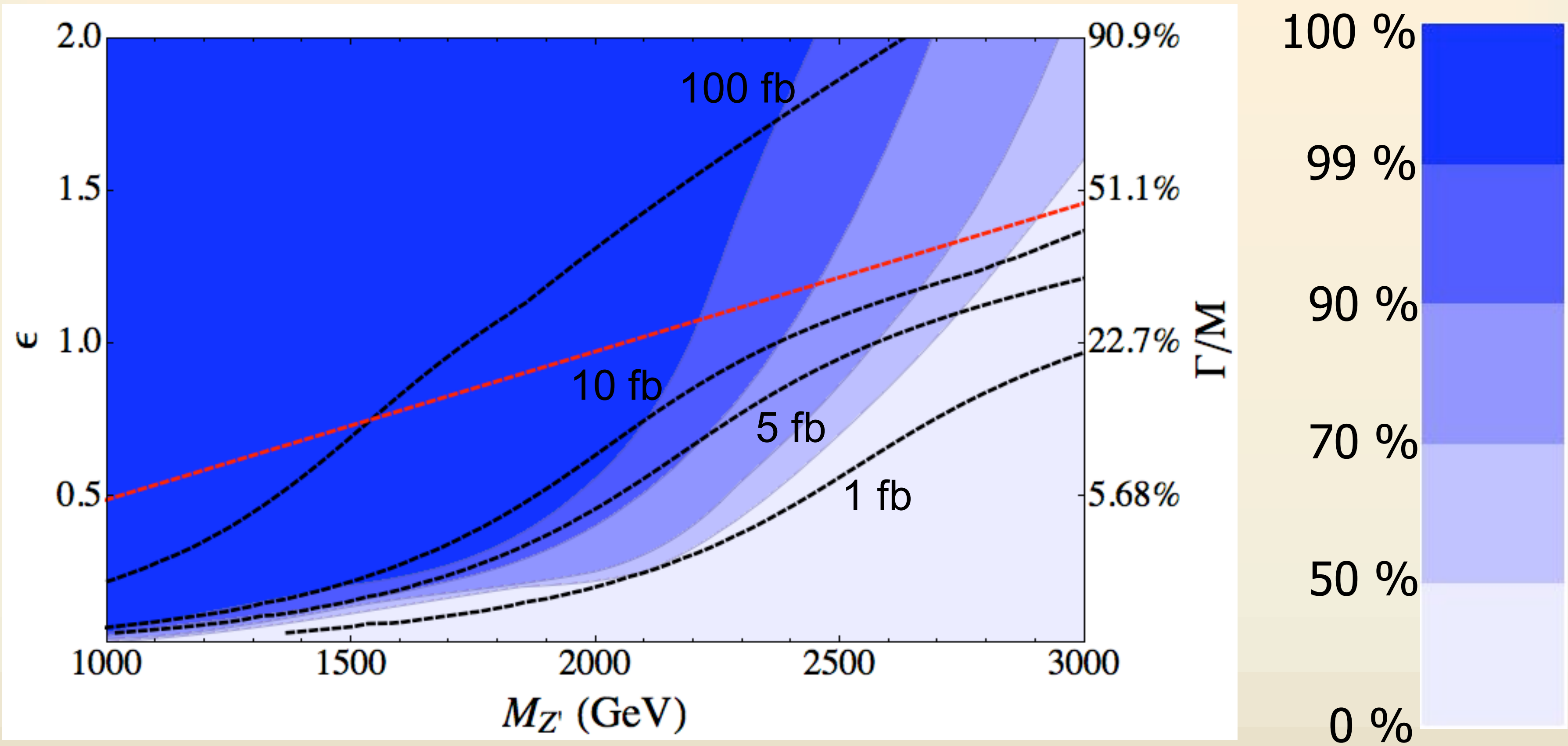
4. Compare the original value of ΔQ with the distribution. We say that we can distinguish resonance from contact at 95% CL if it is above the 95% point on the distribution.



Reliability

- We want to know for what parameters this analysis will work
  - Scan over parameter space. Simulate Z′ data and determine if we can distinguish from contact
  - Repeat many times. The probability that a given Z′ can be distinguished in any given experiment is the **reliability**
- Details of analysis:
  - Differential cross sections as before
  - Bin size of 100 GeV
  - Fit in range from 300 GeV to 4 TeV
  - Always at 1 fb^{-1}

Reliability - Results



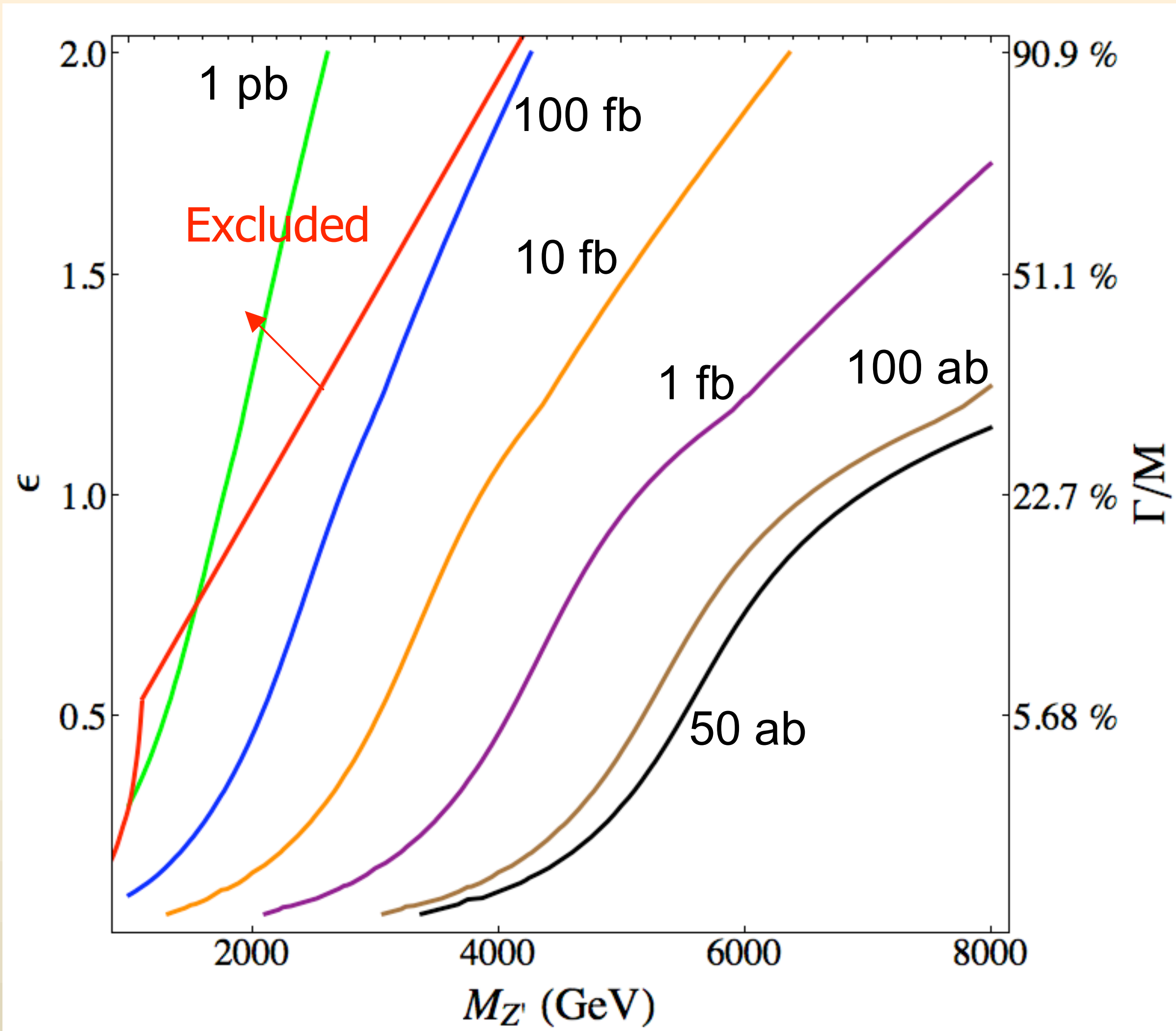
- Z′ compared to VV contact interfering destructively with SM

Conclusions

- Resonances are a good place to look for new physics, even early in the LHC running
- Muon final states allow clear detection
- Generically expect strongly-coupled physics!
- Counting experiments not always sufficient for discovery, particularly for broad resonances
- Statistical analysis of distribution shape can differentiate between resonances and background, other types of new physics

Back-up slides

Cross Sections - 14 TeV



$B\text{-}3L_\mu$