Reproducibility In Particle Physics and possible applications to other sciences

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Talk Outline

- **Science & Experiments**
- **Case Studies to illustrate past problems**
  - **Wrong claims for discovery of top quark & SUSY.**
- **Lessons learned**
  - **How to minimise chances of wrong clams of discovery**
- **Example of procedures**
  - **Higgs boson discovery.**

- **Critical issues and possible applications to other sciences**
  - **Discussion session not a lecture**
  - **Aim to provoke discussion.**
  - **I will act as scientific secretary: document consensus (if any!).**

Science & Experiments

Very Naïve Philosophy of Science

- **Complex links between experiment & theory but need both!**
- **"It doesn't matter how beautiful your theory is, it doesn't matter how smart you are. If it doesn't agree with experiment, it's wrong." Richard P. Feynman**
- **Science requires reliable experimental results.**
  - **Discuss criteria for obtaining reliable results in this talk.**

2 Way Interactions

Experiments

Theory
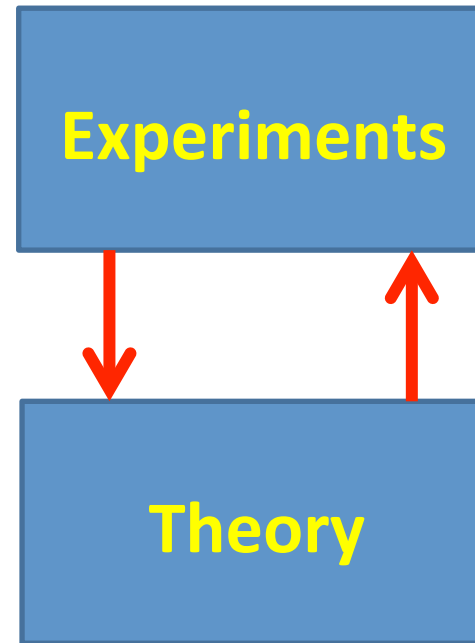
Wrong Top Discovery

- **G. Arnison et al., 1984, Physics Letters B, 147, p494.**
- **Claim for top quark discovery:**
  - **"The two-jet signal has an over-all invariant mass clustering around the W mass, indicating a novel decay of the W"**
  - **"They are, however, consistent with the process W $\rightarrow$ tb, where t is the sixth "top" quark of the Cabibbo current. If this is indeed the case, then the mass of the top is bounded between 30 and 50 GeV/c^2".**
- **Now known to be wrong, top quark mass ~ 175 GeV**
- **Fooled by statistical fluctuation.**

Wrong SUSY

- **Search for Supersymmetry (SUSY)** G. ARNISON, 1984, Phys. Lett B. 139, p115.
  - **Supersymmetry allows for Weakly Interacting Massive Particles**
  - **WIMPs candidate for dark matter in universe.**
  - **WIMPs don't interact in detector ➜ apparent violation of conservation of momentum.**
- **Discovery claim :**
  - **"We report the observation of five events in which a missing transverse energy larger than 40 GeV is associated with a narrow hadronic jet and of two similar events with a neutral electromagnetic cluster (either one or more closely spaced photons). We cannot find an explanation for such events in terms of backgrounds or within the expectations of the Standard Model."**
- **Result was wrong because backgrounds were not carefully evaluated.**

Right & Wrong Results in Particle Physics

- **Several correct discoveries in 1980s-1990s:**
  - **Overwhelmingly statistically significant.**
  - **Confirmed by multiple experiments.**
- **A few wrong results**
  - **Not confirmed by other experiments**
  - **Some discovered to be wrong by better background calculations.**
- **Problem hasn't gone away completely …**
  - **e.g. BICEP 2 claim for B mode polarization of CMB.**
  - **DAMA claim to observe dark matter.**

Rewards & Punishment

- **Fame and glory for scientists who are first to make big discoveries**
  - **Also £££ in some areas**

- **Wrong discoveries can be published in high impact journals ➜high citation index**

- **No sanctions for making wrong discoveries (unless fraudulent).**

How to avoid mistakes at LHC

- **Discussion between two general purpose experiments ATLAS and CMS before data taking.**
  - **High statistical power**
  - **Blind analysis**
  - **5 sigma significance for discovery claim**
  - **Rigorous checking of results before publication**
  - **Need two independent experiments**
- **Illustrate this approach with Higgs discovery.**
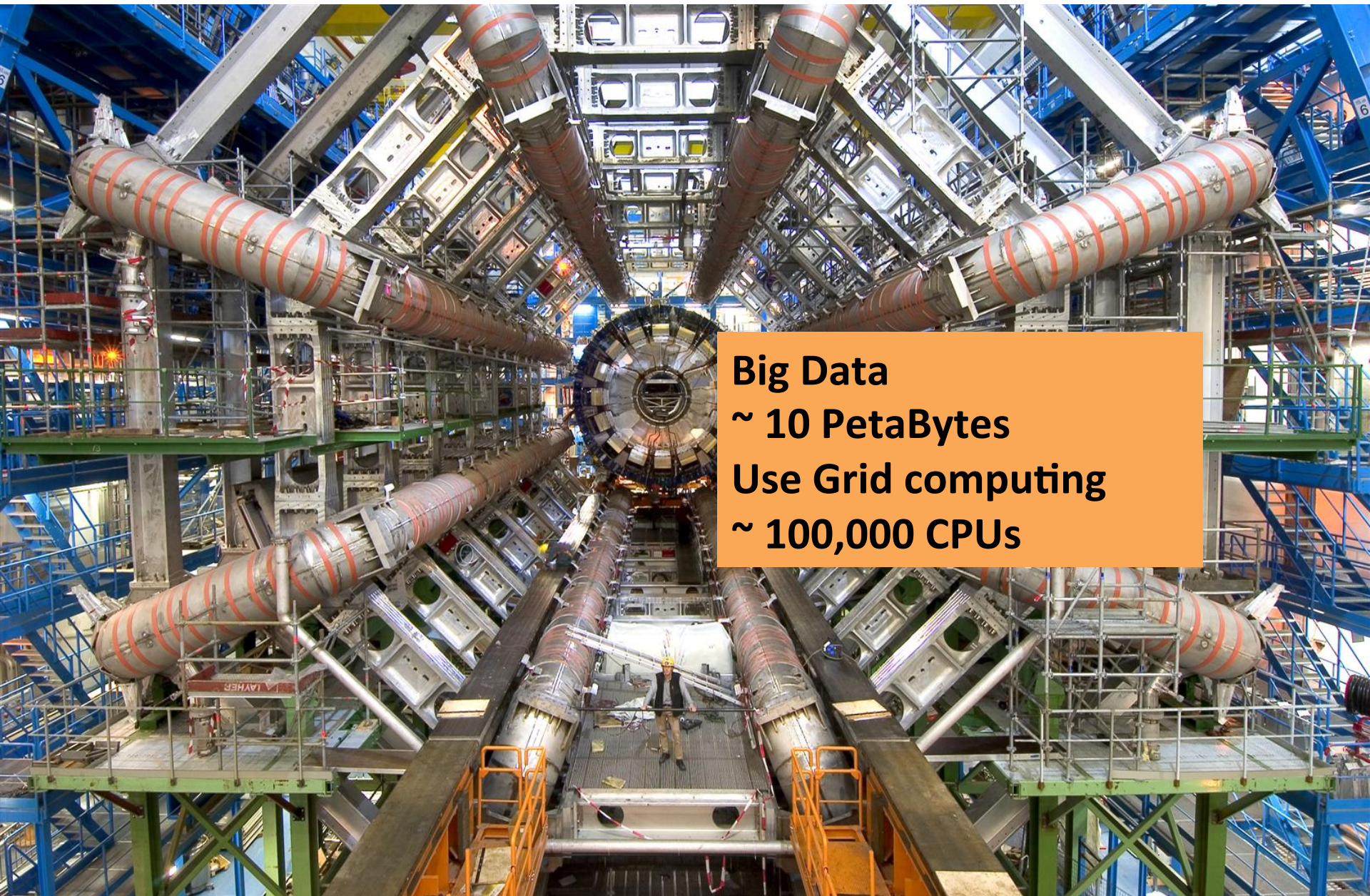
Big Data
~ 10 PetaBytes
Use Grid computing
~ 100,000 CPUs

Grid computing

Case study: Higgs boson discovery

- **Scientific procedures**
  - **Statistical**
  - **Blind analysis**
  - **5 sigma threshold for discovery**

- **Levels of checking**
  - **Low level x-checks**
  - **Sub-group**
  - **Working groups**
  - **Editorial Board**
  - **(Several further levels)**
  - **Collaboration**
  - **Refereed journals**
  - **Confirmation by another experiment.**

Statistical Power Higgs Search

- **Assume a value for the mass of the Higgs boson**

- **Detailed Monte Carlo for signal & background & detector response.**

- **Expected significance > 5σ.**

- **If experiment works as expected, either confirm or reject Standard Model Higgs boson theory.**
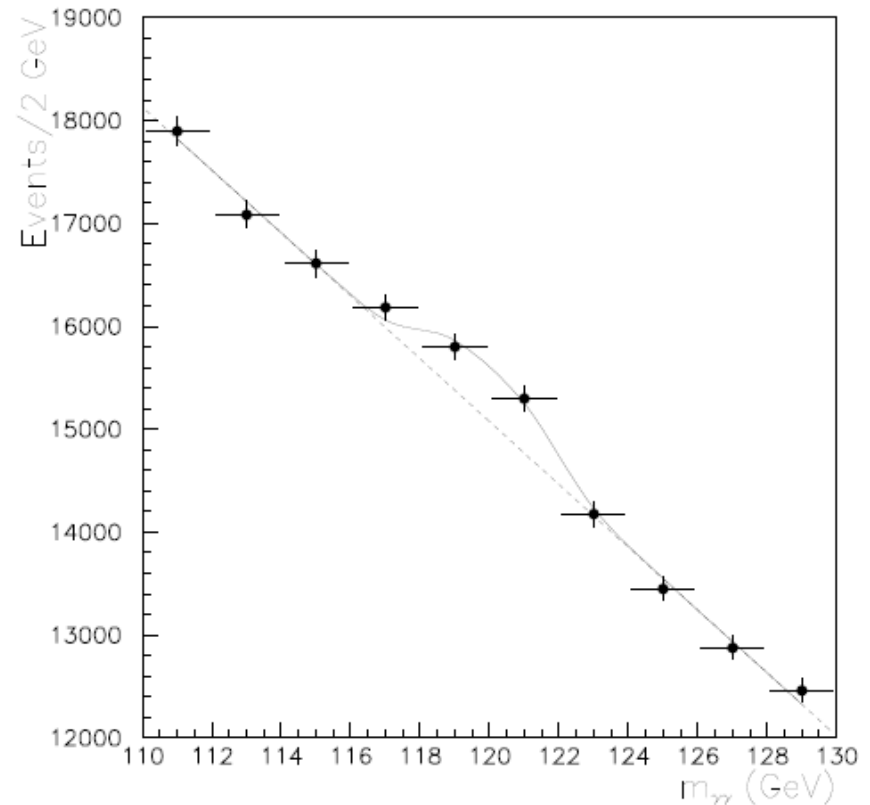

Expected mass spectrum for assumed m$_H$ Bump above smooth background.

Blind Analysis

- **Avoid finding spurious signals in very large data sets ➔ use blind analysis:**
  - **Monte Carlo simulations for signals and backgrounds**
  - **Optimise analysis (separation of signal from background) using Monte Carlo samples**
  - **Review analysis and then "open box" and look at data without changing analysis**
 - **Warning: this is a very simplified description!**

Higgs Boson

- **In the Standard Model of particle physics Higgs boson gives mass to other elementary particles.**

- **Use high energy proton-proton collisions to try to produce Higgs bosons.**

- **Reconstruct decay products and use E=mc^2**

- **Look for peak in mass spectra at mass of Higgs boson (m$_H$)**
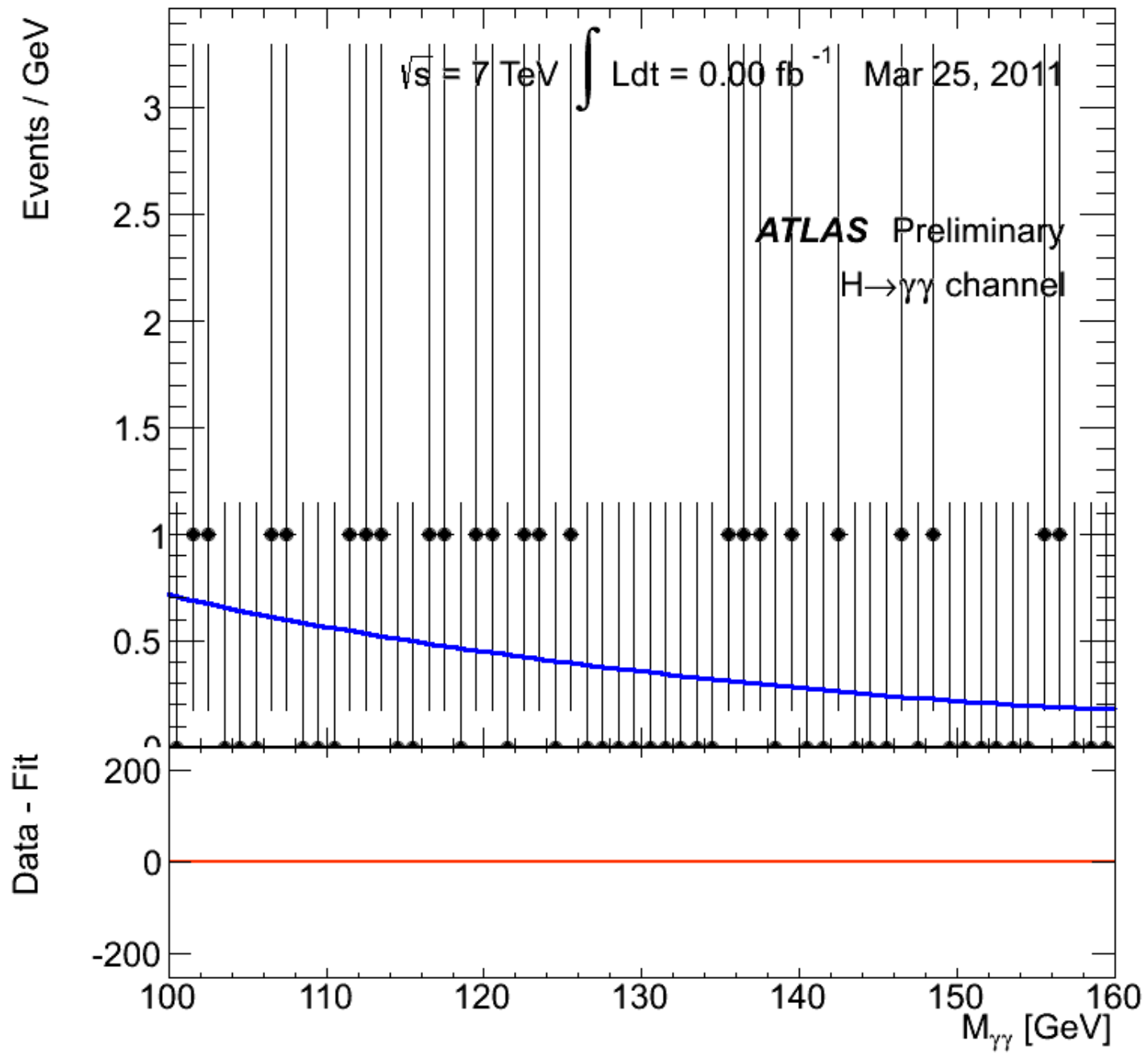
Higgs boson discovery

- **One channel: H→γγ is the "bump" a statistical fluctuation or significant evidence for a Higgs boson?**
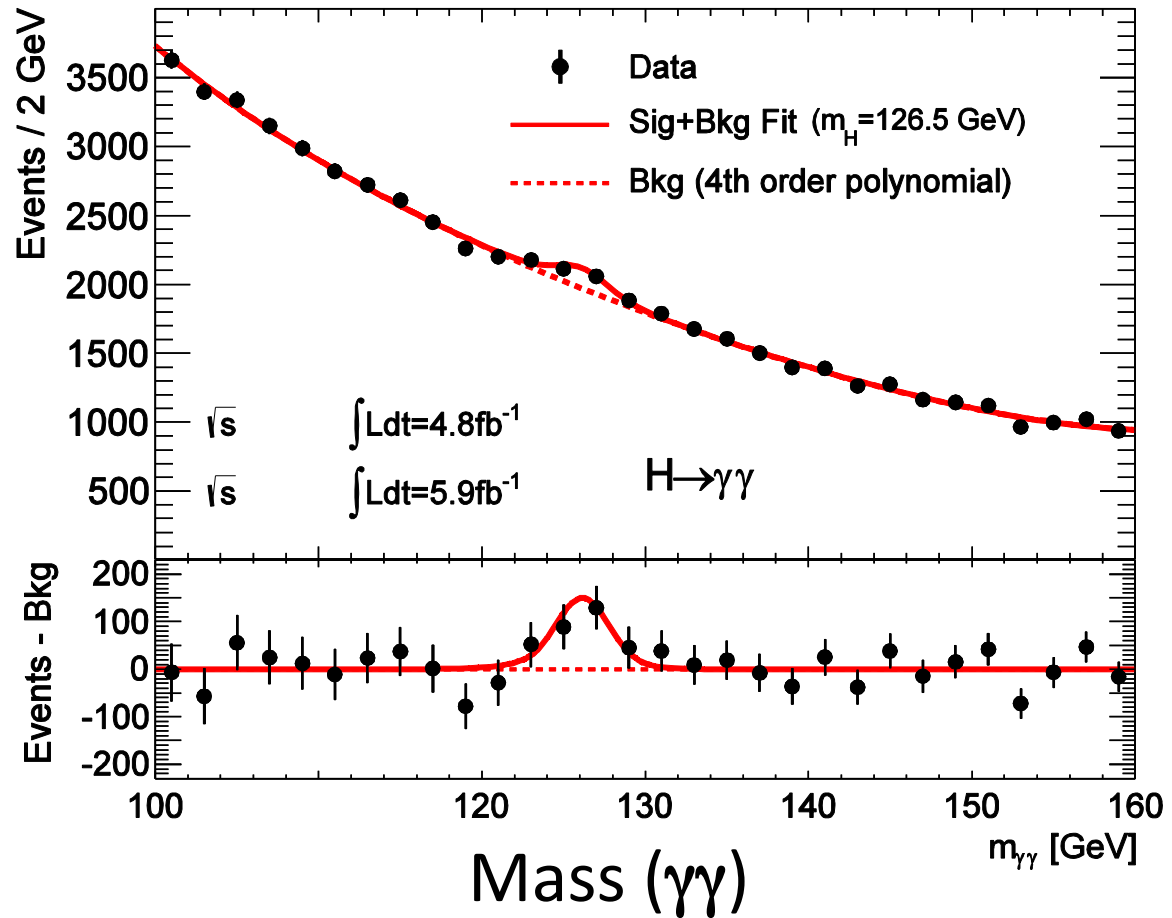
Statistical Procedures

- **Frequentist approach:**
  - Define probability p_0 that if experiment were repeated infinite number of times that we would see a larger discrepancy with the no-signal model than in the actual data set.

- **Combine all channels**

- **Plot p_0 vs Higgs mass (m_H)**

- **Look Elsewhere Effect → Global signficance.**

- **5 σ rule**
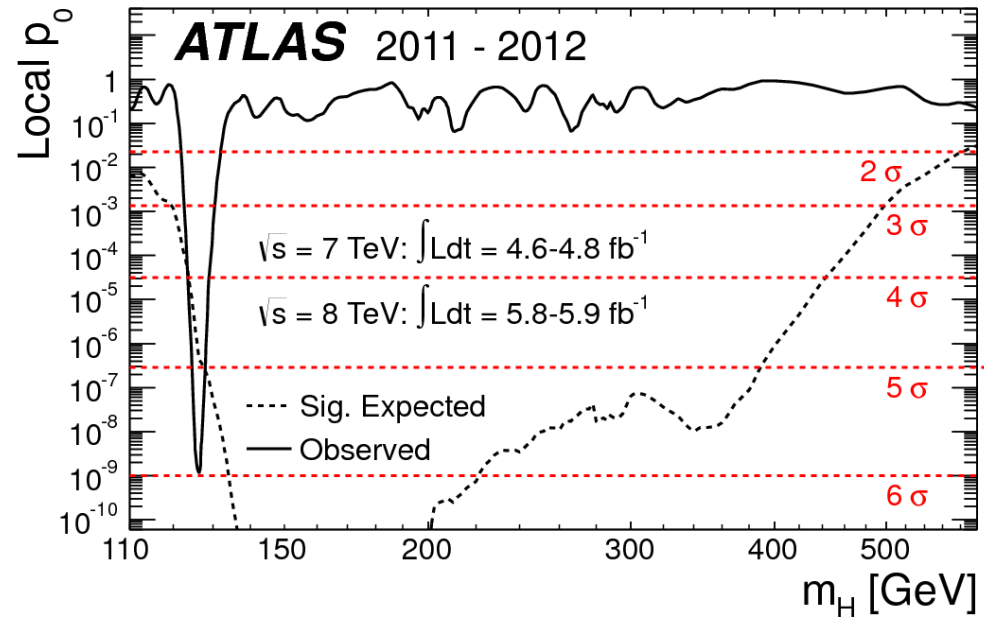
Checking Results

- **Internal**
  - **Low level x-checks**
  - **Sub-group**
  - **Working groups**
  - **Editorial Board**
  - **(Several further levels)**
  - **Collaboration**
- **Refereed journals**
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Works well because of scientific culture in which everybody is encouraged to give critical feedback

Applicability to other sciences (1)

- **Don't do low power experiments?**

Applicability to other sciences (2)

- **Blind analysis**

Applicability to other sciences (3)

- **High level of statistical significance for claiming discovery**
    - **5σ may be very high but is 95% c.l. appropriate?**

Applicability to other sciences (4)

- **Internal checking by collaboration before publication**
  - **Requires healthy scientific culture in which junior PhD student can criticize results.**

Applicability to other sciences (5)

- **Confirmation of claim by at least one other independent experiment**