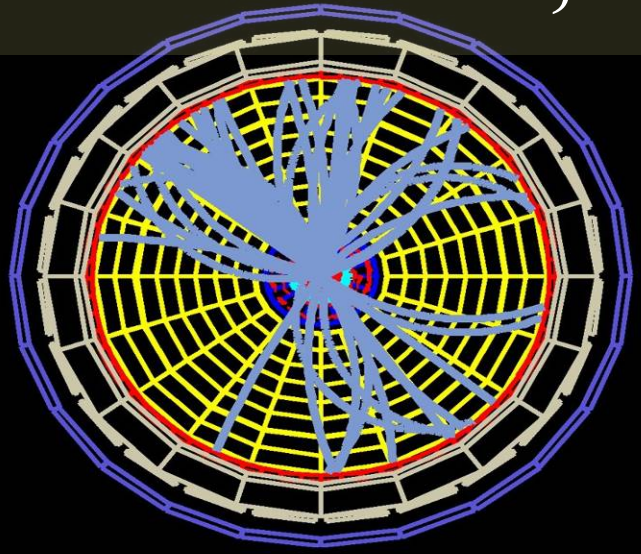
Experimental Particle Physics
PHYS6011
Joel Goldstein, RAL



1. Introduction & Accelerators
2. Particle Interactions and Detectors (2)
3. Collider Experiments
4. Data Analysis

Data Analysis

Extract physics from data

– Measure a quantity

– Search for new particles

1. Basic concepts
2. Monte Carlo methods
3. Signal
4. Backgrounds
5. Errors
6. Statistics

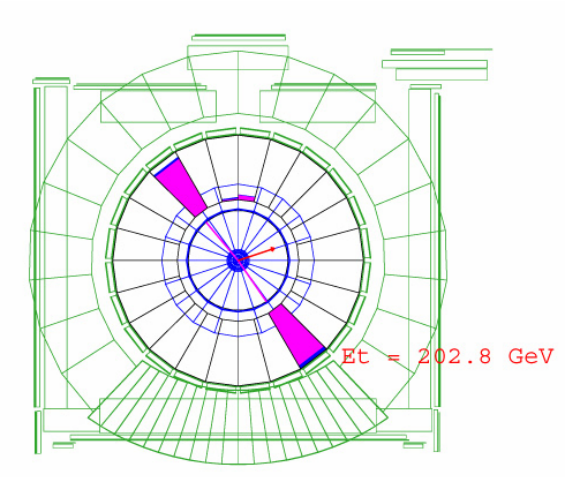
➢ Higgs search at CDF

Data Flow

Low S:B

High S:B

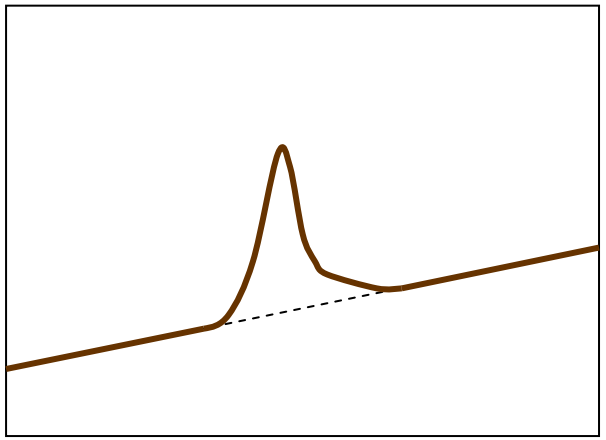
Detector → Trigger and DAQ → Storage → Event selection → Analysis



Elements of Analysis

No only *Data* but...

- **Detector response to signal**
- **Background estimates**
- **Errors**
  - **statistical**
  - **systematic**



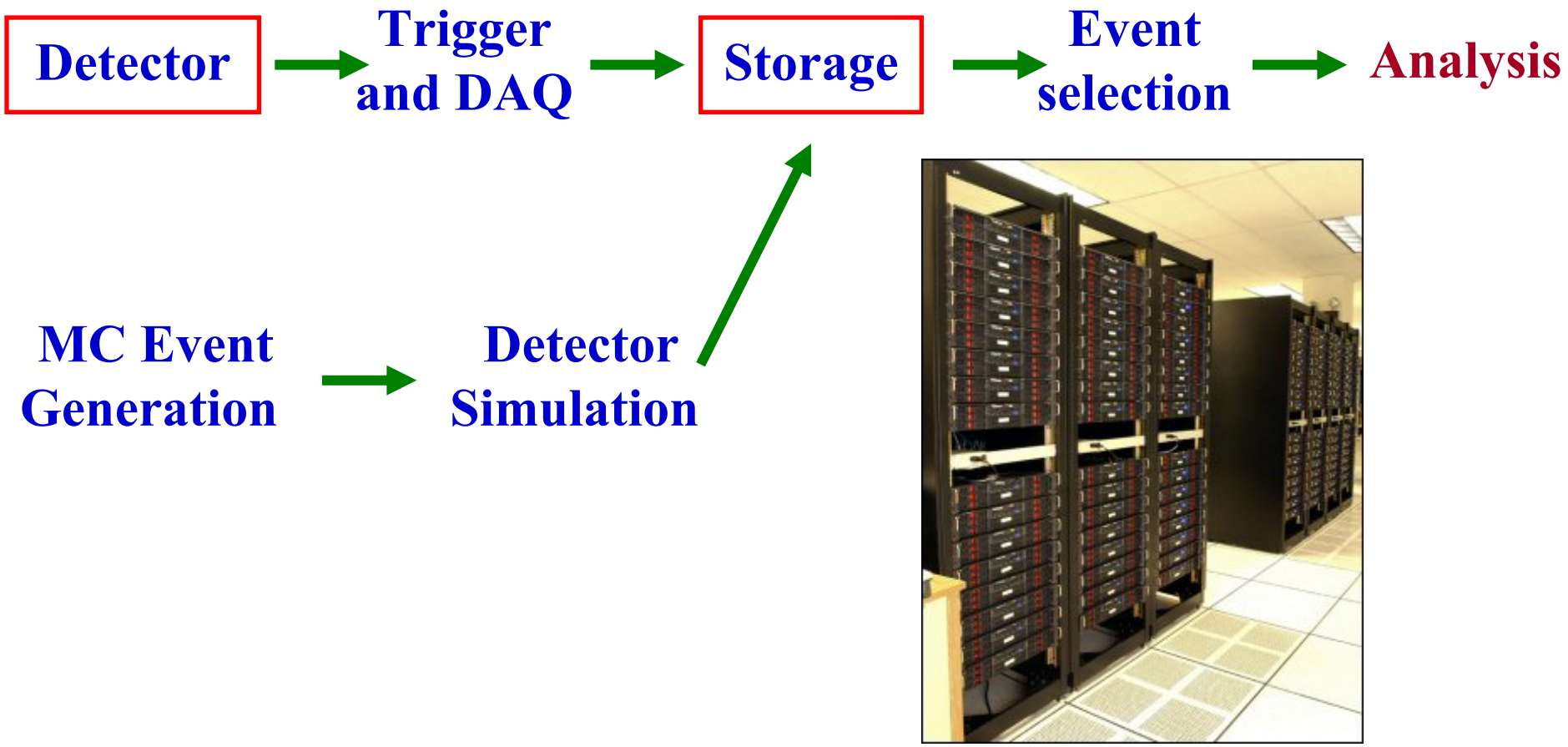
- **Try and evaluate from data**
- **Sometimes need more...**
  - ***Monte Carlo***

Monte Carlo

1. **Generate artificial data**
2. **Simulate detector response**
3. **Analyse simulated data as if it were real**
   - **Response to known input can be calculated**
   - ***Also used in detector design***

- **Computer intensive**
- **Must be carefully tuned and checked**

Data and Monte Carlo



Search for the Higgs

Higgs Boson **- missing piece of Standard Model**

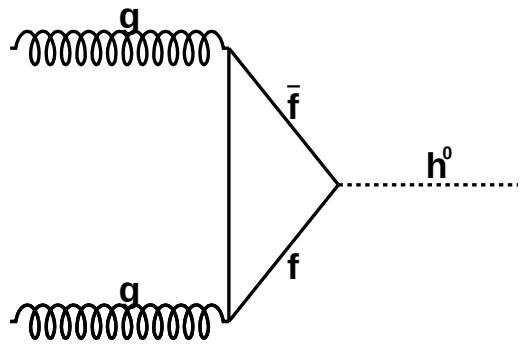
- **SM Higgs theory well understood**
  - **Mass is only free parameter**
  - **Clear predictions to test**
- **Most new physics theories have something similar**

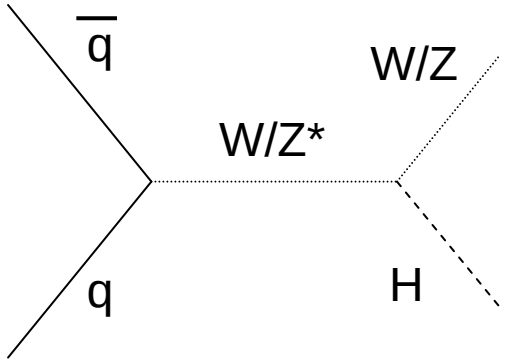
- **Current limit is mass > 115 GeV (LEP)**
  - ***Some evidence of signal just beyond limit***

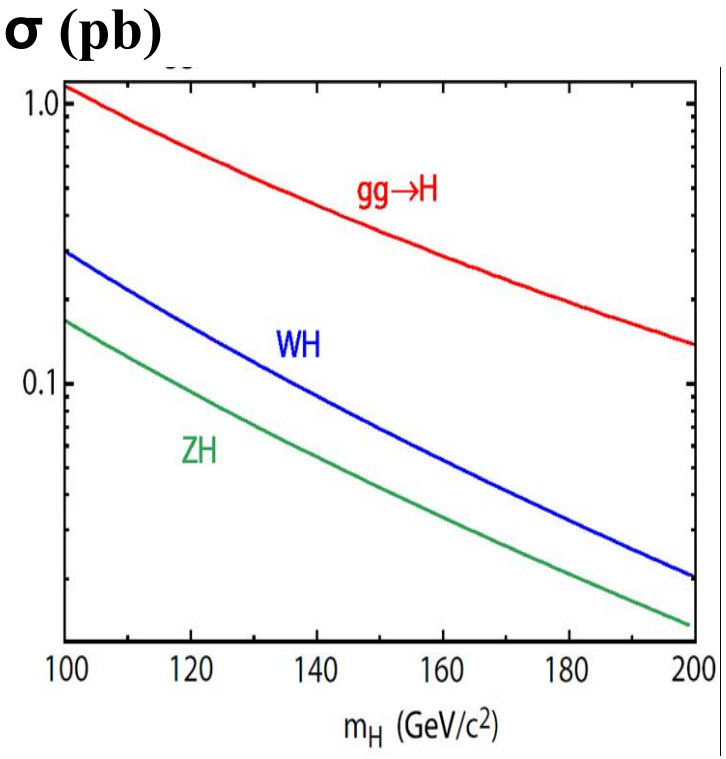
Can CDF see a Higgs at 120 GeV?

Higgs Production

First: *understand signal*

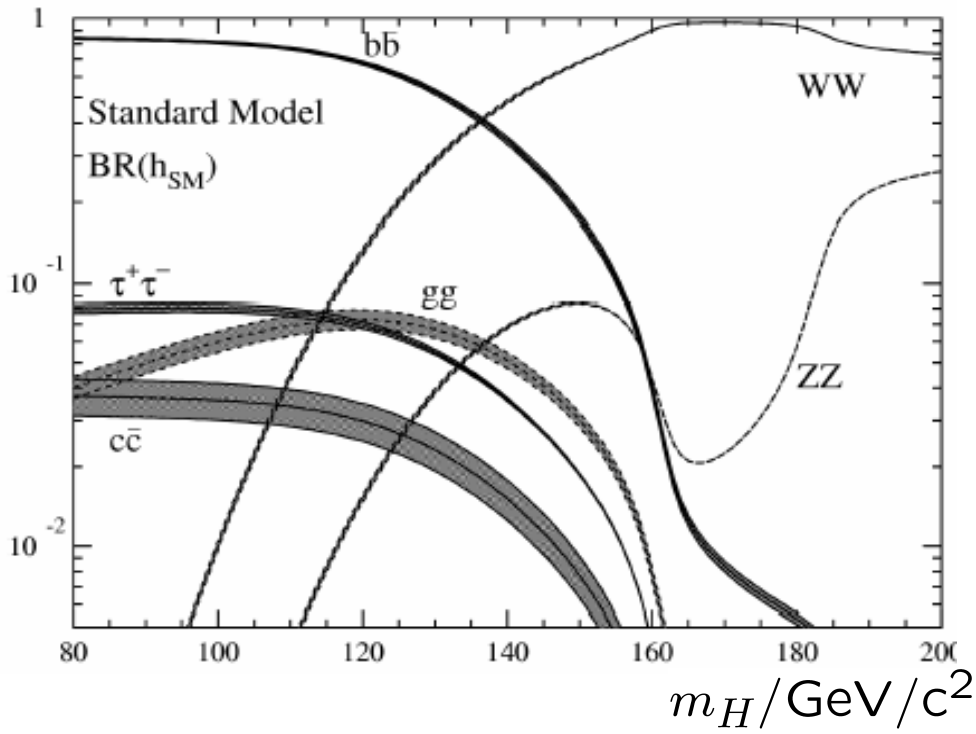






- **Gluon fusion most promising**

Higgs Decay

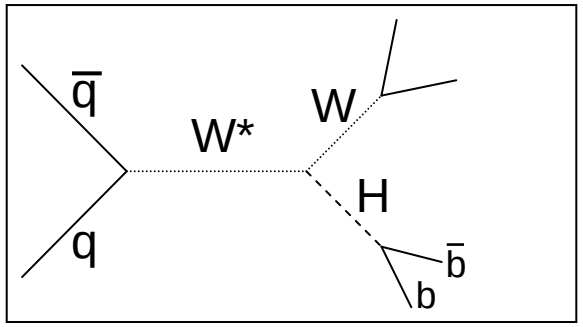


- **At 120 GeV *H→bb* dominates**
- **Signature *gg→H→bb*:**
  - **2 jets**
  - **One or two *b*-tags**

- **Swamped by dijet production**
  - ***bb*** **~ μb**
  - ***qq*** **~ mb** ***(fake b-tag rate small but not zero)***
- **Have to use *W/Z+H* channel**

Associated Production

$qq \to WH$ with $H \to bb$



$W \to qq$ 70%

- final state *qqbb*
- Four jet backgrounds still too large

$W \to e\nu_e$ 10% $W \to \mu\nu_\mu$ 10%

- Final state *lvbb*
  - One electron or muon
  - Missing transverse momentum
  - Two jets
  - One or two *b*-tags
- Easy to select in trigger and offline

$\sigma \times Br \approx 0.02$ pb

Efficiency

- **Nature provides 20 fb of *WH→lνbb* events – *a handful per year***
- **How many pass our trigger and analysis selection?**
  - ***Cleanly identified electron or muon in acceptance***
  - ***Two jets***
  - ***At least one b-tag***
  - ***Large missing momentum***
  - ***None overlapping***

➢ ***Run thousands of MC events***

➢ ***Efficiency*** $\epsilon = \frac{N_{selected}}{N_{generated}} \approx 10\%$

➢ ***Observe 2 fb - 1 per year***

Backgrounds

- **Anything with signature similar to signal**
  - $W+X$ (*X* can be *W*, *Z* or just 2 QCD jets)
  - $ZZ \rightarrow qqll$ (one lepton not identified)
  - $\tau\tau$
  - *b*-tags can be real, charm or fakes
- **Estimate how many pass signal selection $\Rightarrow$ *Monte Carlo***
- **Largest is $W+bb$: about 250 fb**
  - **Signal to background about 1:100**

Errors

Statistical

- **Mostly counting events (data or MC)**
- **Poisson distribution: $\sigma = \sqrt{\mu} \approx \sqrt{N}$**
  - ***NB fractional error ~ $1/\sqrt{N}$***
- **Efficiency follows binomial distribution:**

$$\sigma_\epsilon = \sqrt{\epsilon(1-\epsilon)/N}$$

Systematic

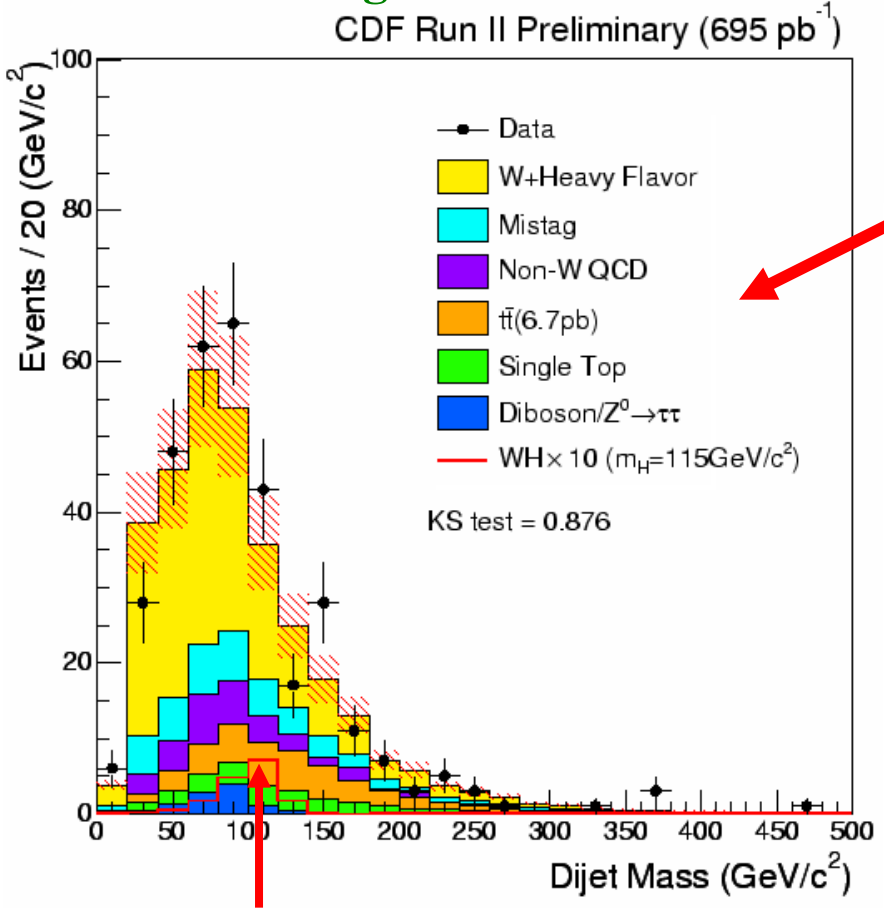
- **Anything not completely understood may affect result**
  - **Detector performance, background rates, MC modeling…**
- **Estimate range of parameter**
- **Propagate in MC**

Significance

- **In a given amount of data we expect:**
  - N_B **background events**
  - **Statistical error on background** $\approx \sqrt{N_B}$
  - **Systematic error on background** $= \sigma_{sys}$
  - **Add errors in quadrature to get** σ_{TOT}
- **Observe** $N(>N_B)$ **events in data. Could be:**
  - **random fluctuation in** $N_B \pm \sigma_{TOT}$ **background events**
  - N_B **background events &** N_S **signal events**
- **Significance** $S = N_S/\sigma_{TOT}$
  - **S = 3: probability of fluctuation ~10^{-3} – interesting...**
  - **S = 5: probability of fluctuation ~10^{-5} – discovery!!**

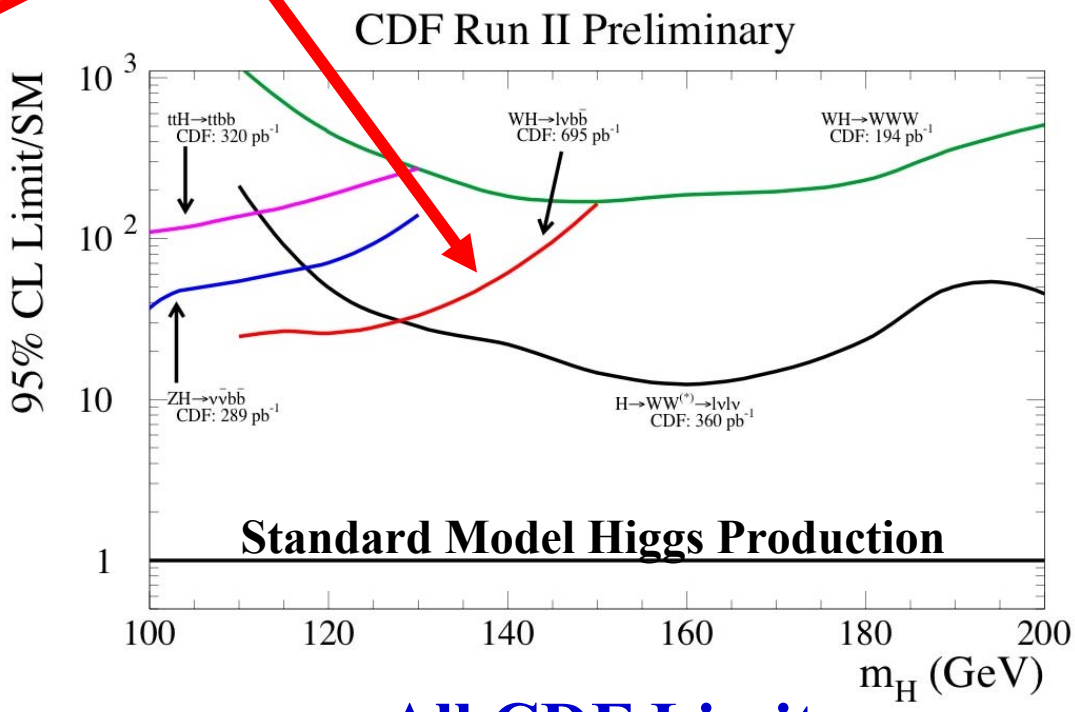
Latest CDF Results

- **Data and background as function of *bb* mass**



Expected signal × 10

$$WH \to l\nu b\bar{b}$$

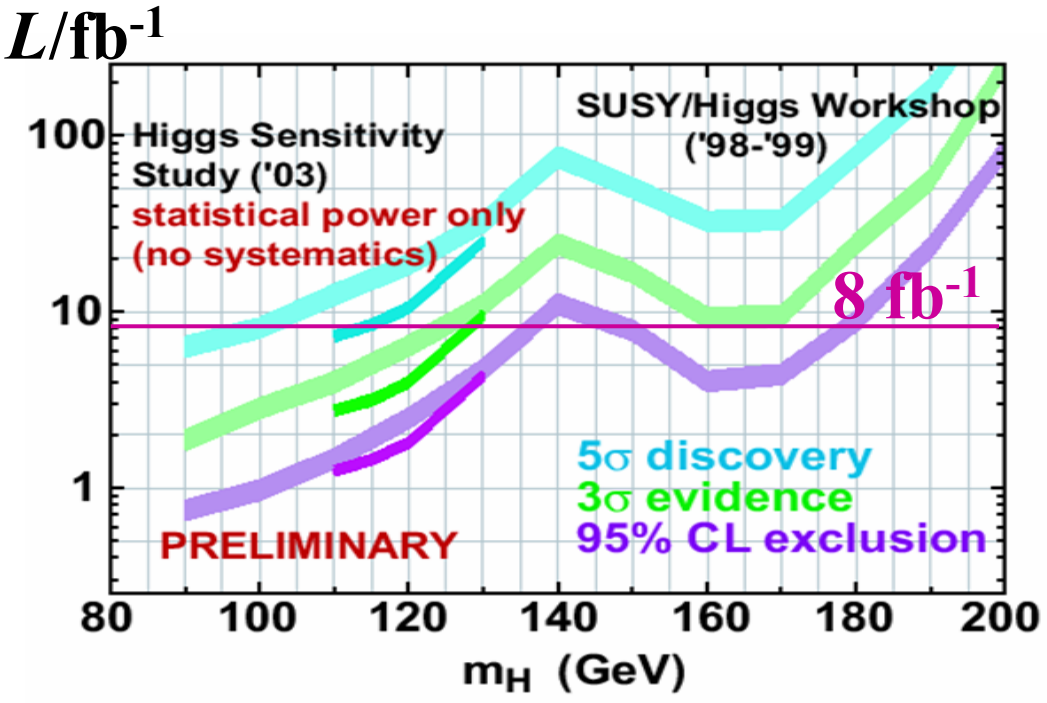


All CDF Limits

Predicted Sensitivity

- **CDF expects a maximum of 8 fb^{-1} by 2009**
  - **15-20 signal events**
  - **2000 background**
  - ***S = 0.3*** **(ignoring systematics)**

- **Optimistic, combine channels and experiments predict *S ≈ 3***
- **Higgs-like particles in new theories may be easier**
- ***Really need a new accelerator with higher energy and more luminosity…..***

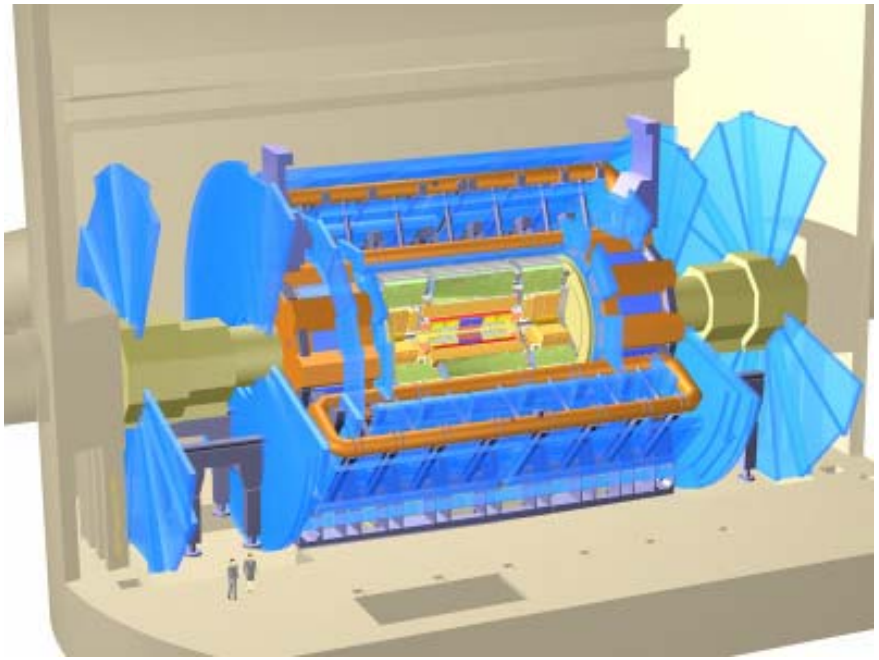


The LHC

- **The Large Hadron Collider**
- **First collisions in 2007**

- **$\sqrt{s}$ = 14 TeV**
- **$L \sim 10^{34}$ cm^{-2} s^{-1}**

LHC Experiments



- **ATLAS and CMS designed to find Higgs**
- ***Good experiments to work on for a PhD…..***

That's It!

Any questions?

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