SESAPS 2011
Roanoke, VA

Tevatron Higgs Boson Search Results in the LHC Era

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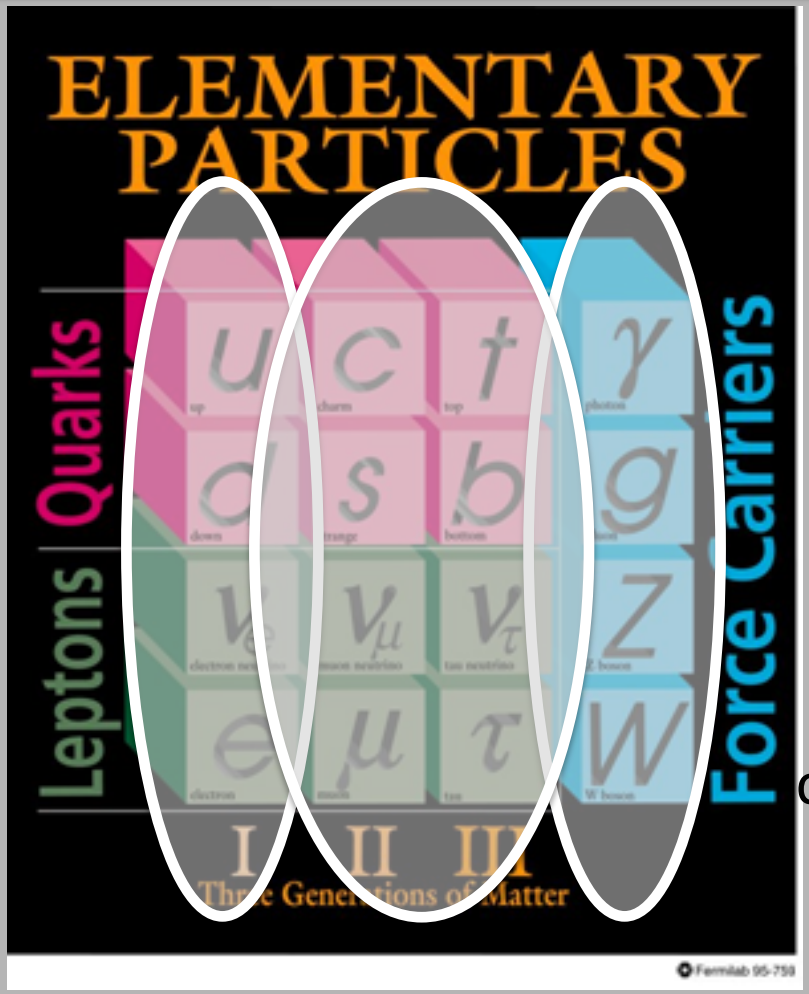
Are there undiscovered fundamental particles?

Make up all "regular" matter In the Universe



Force Carriers

Unstable matter created in high-energy collisions

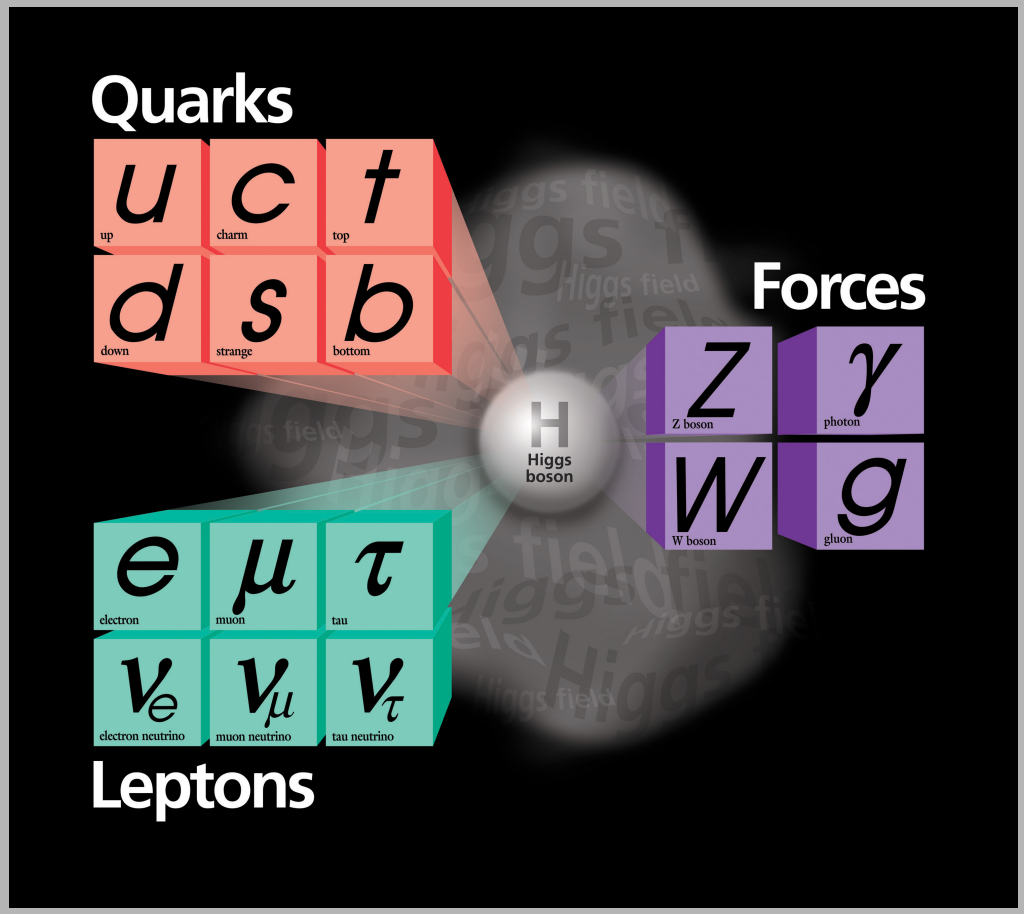
Standard Model (SM) of particle physics includes these experimentally observed particles and their interactions

What is the origin of Electroweak Symmetry Breaking?

- Consider the Electromagnetic and the Weak Forces
- Coupling at low energy: EM: ~α, Weak: ~$\alpha/(M_{W,Z})^2$
  - Coupling strength governed by the same dimensionless constant
  - Difference due to the mass of the W and Z bosons
    - Electroweak symmetry: $M_Y=M_Z=M_W$
    - But photons massless and W and Z are massive?
- SM postulates a mechanism of electroweak symmetry breaking via the Higgs mechanism
  - Results in massive vector bosons and mass terms for the fermions
  - Theory predicts a massive new particle called the Higgs boson!

Are there undiscovered fundamental particles?

The standard model really looks more like this!



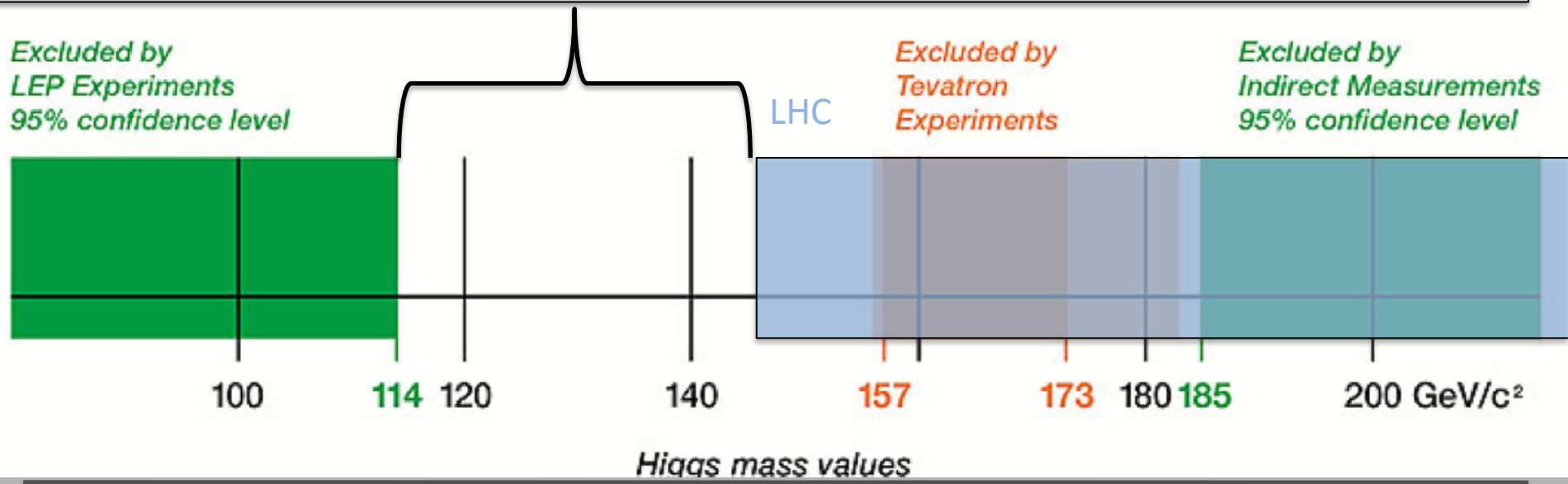
Discovery (or exclusion) of the Higgs boson, will shine light on the question of the origin of EWK symmetry breaking

Constraints on the Higgs Boson Mass

Higgs searches ongoing for 30 years!

- Direct searches from LEP:
  - Higgs mass > 114 GeV

If the Higgs boson exists in this mass range, we can produce it with high energy particle collisions !



The Tevatron at Fermilab

The Tevatron currently provides high energy proton-antiproton collisions:

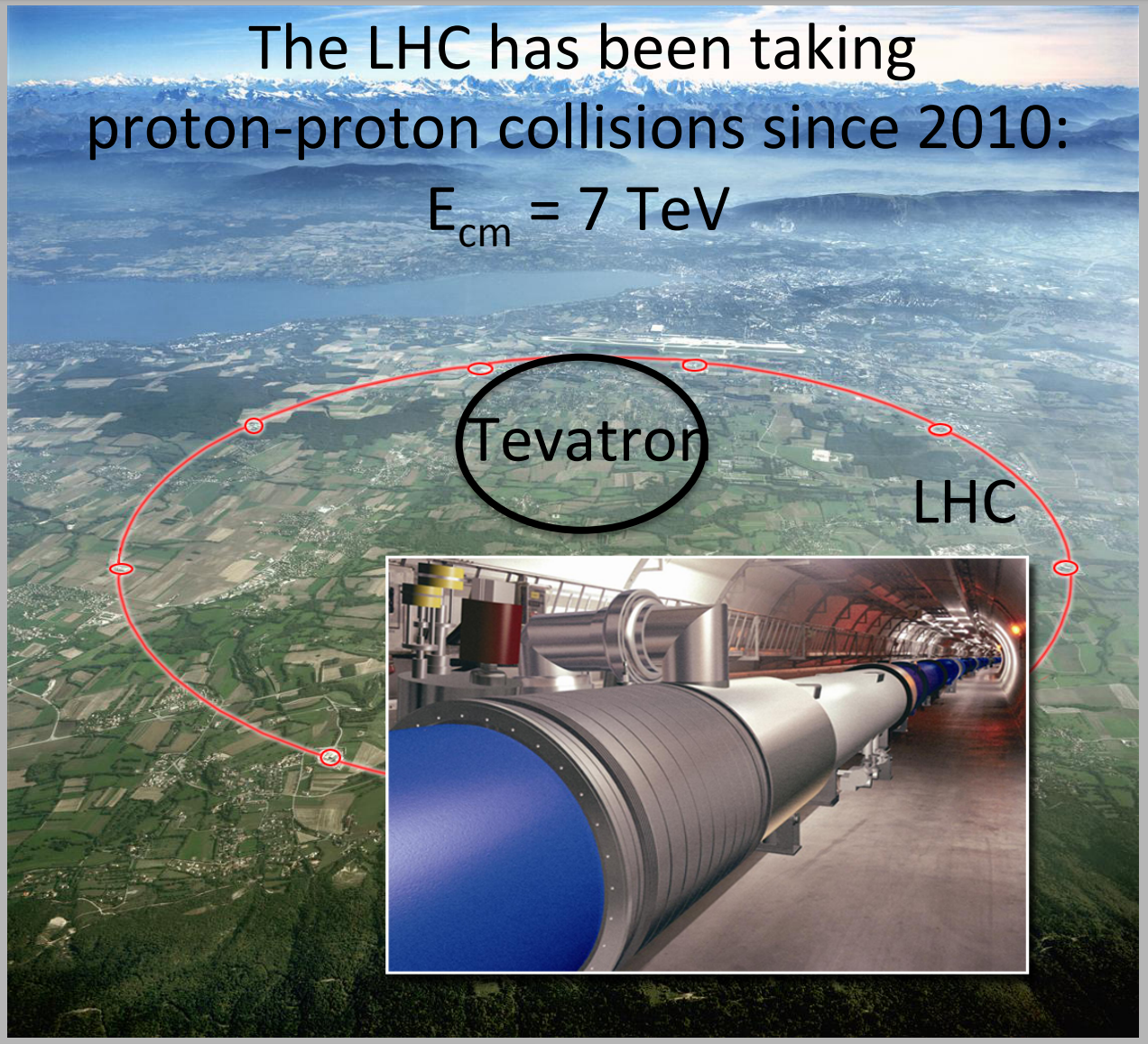
E_{cm} = 1.96 TeV

CDF

Tevatron

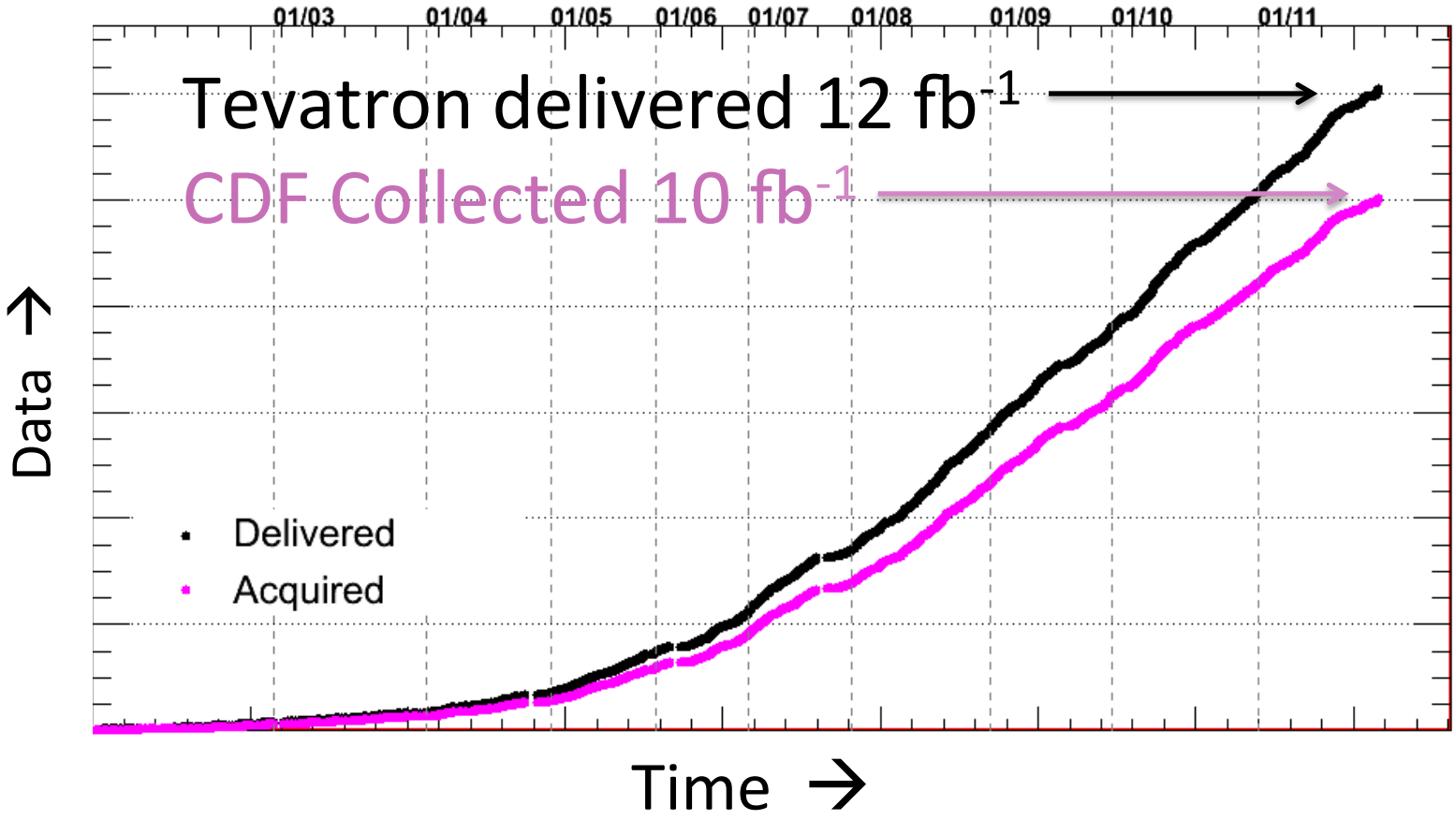
After a 26 year career, the Tevatron took its last collision on Sept. 30th 2011 !

The LHC at CERN



Tevatron Performance

An enormous thanks to the Fermilab Accelerator Division for an outstanding performance!



Summer 2011 CDF analyses contained up to 8.2 fb^{-1}

The CDF Experiment at FNAL

Collaboration

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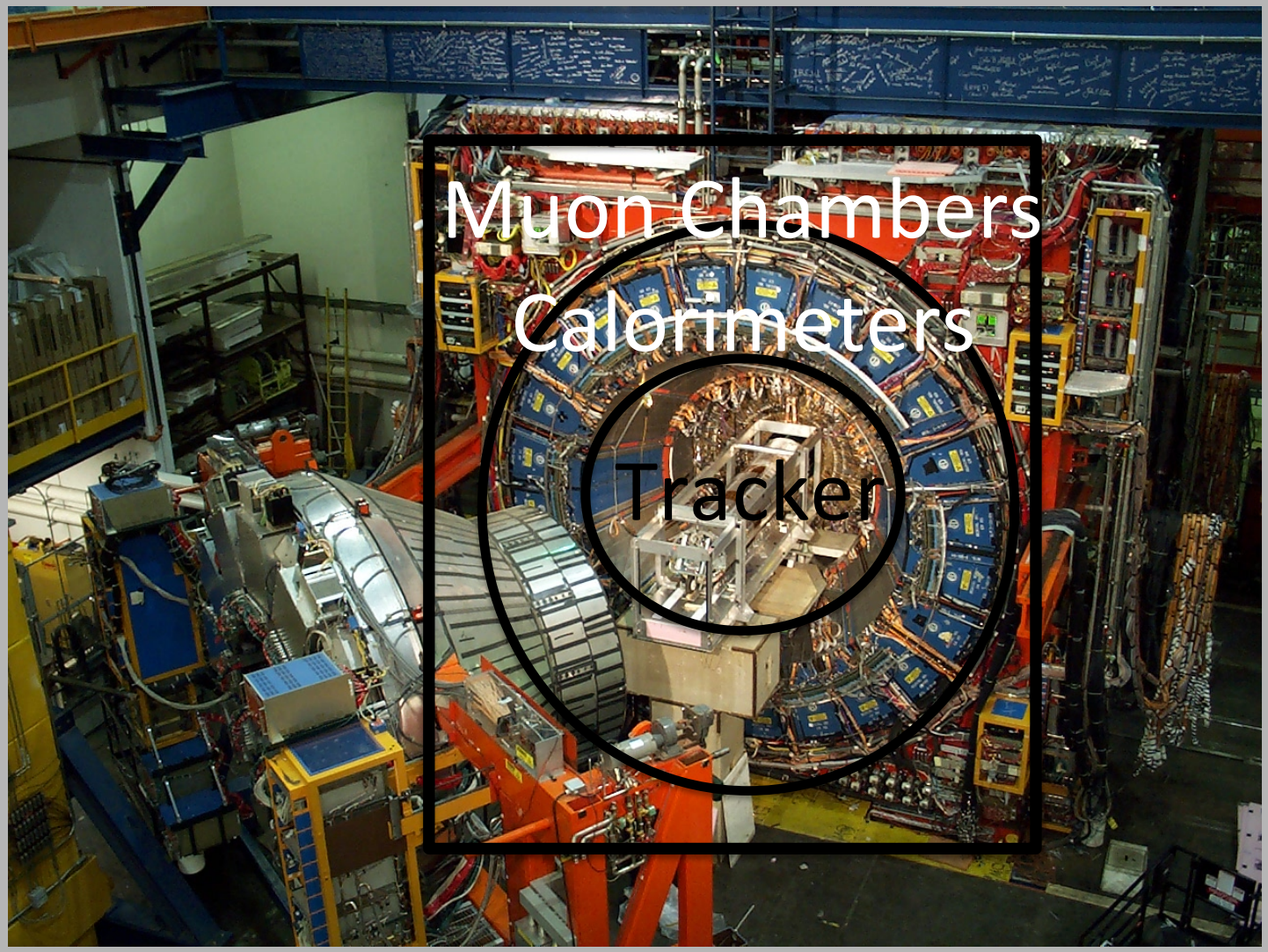
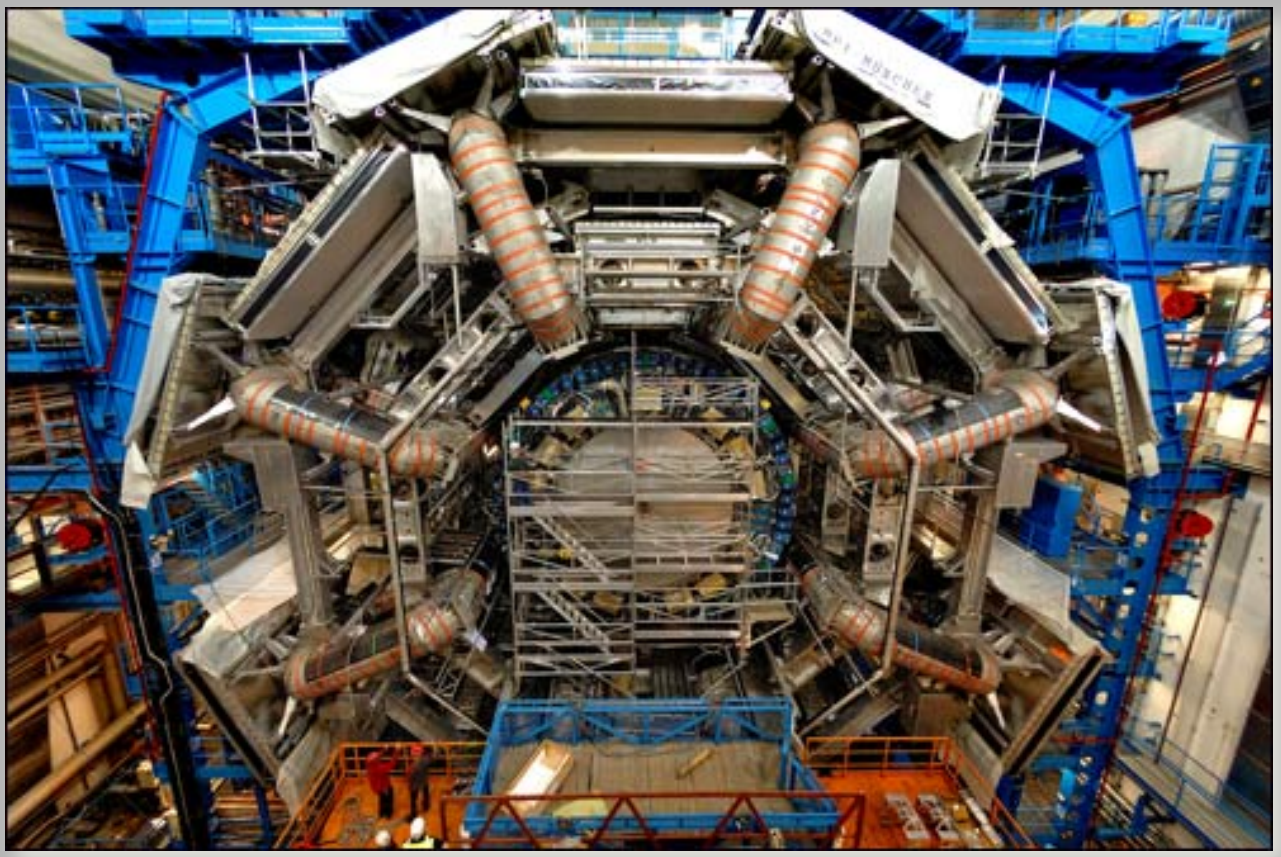
15 Countries
63 Institutions
602 Authors
~50 pubs/year



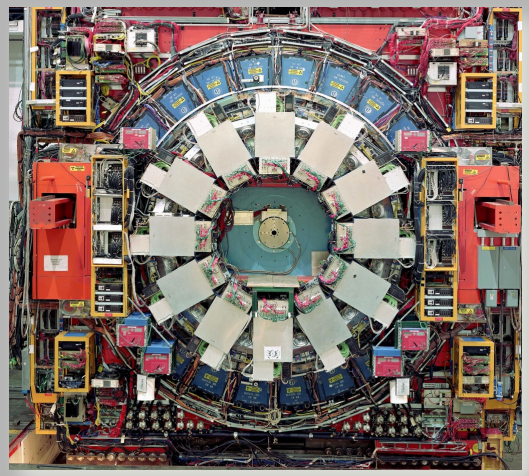
Detectors to Scale

diameter = 25 m
length = 46 m



ATLAS

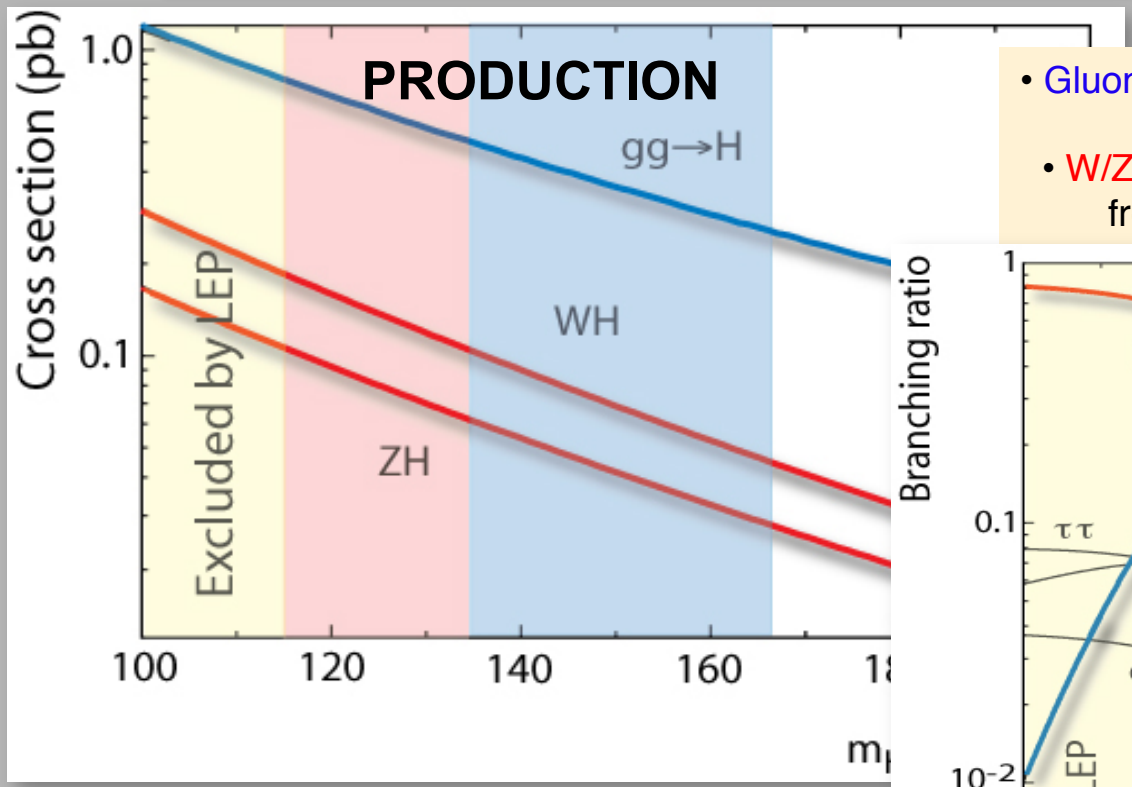
d = 12 m
l = 12 m



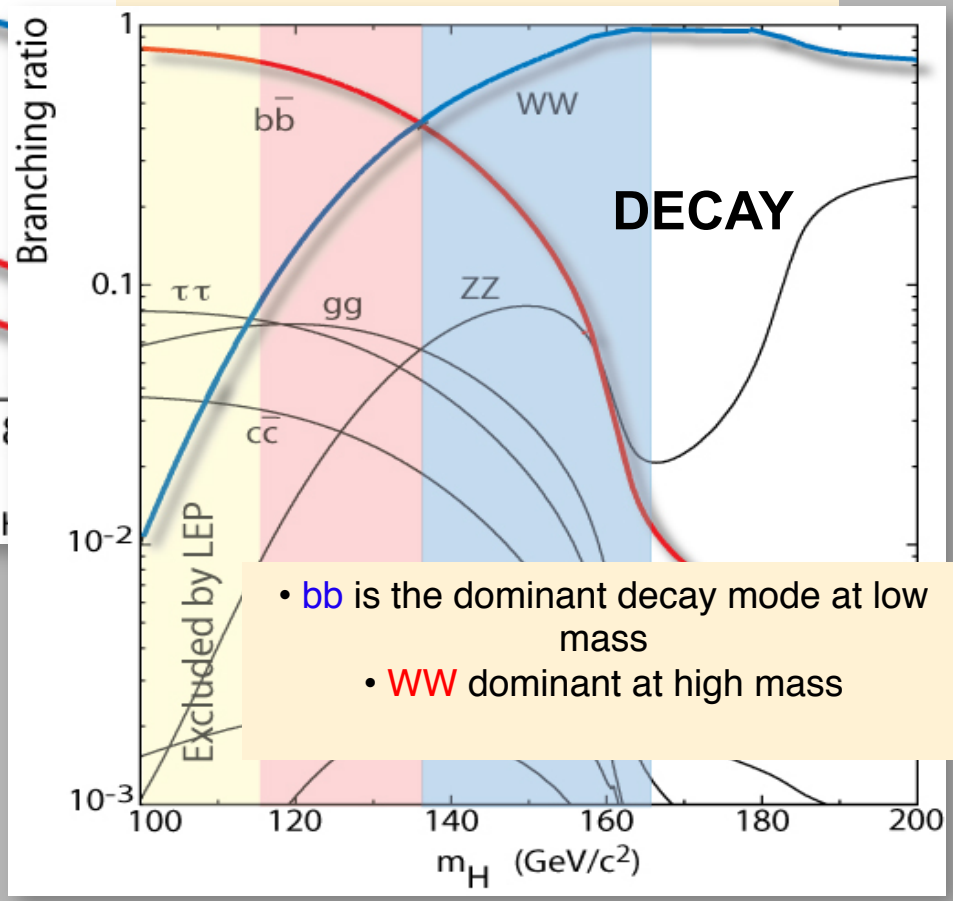
CDF

Cockroft-Walton
(Accelerator and Detector!)

Higgs Production and Decay (at the Tevatron)



- Gluon fusion is the dominant production mode: σ ~1.1-0.1 pb
- W/Z associated production next most frequent mode: σ ~0.2-0.01 pb

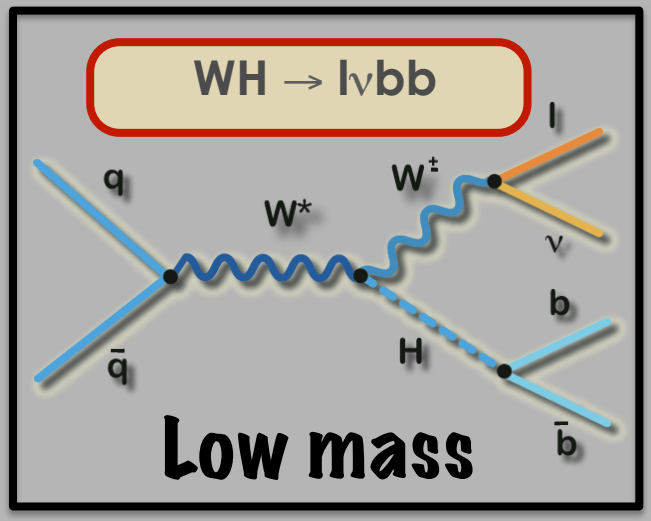


- bb is the dominant decay mode at low mass
- WW dominant at high mass

Low mass

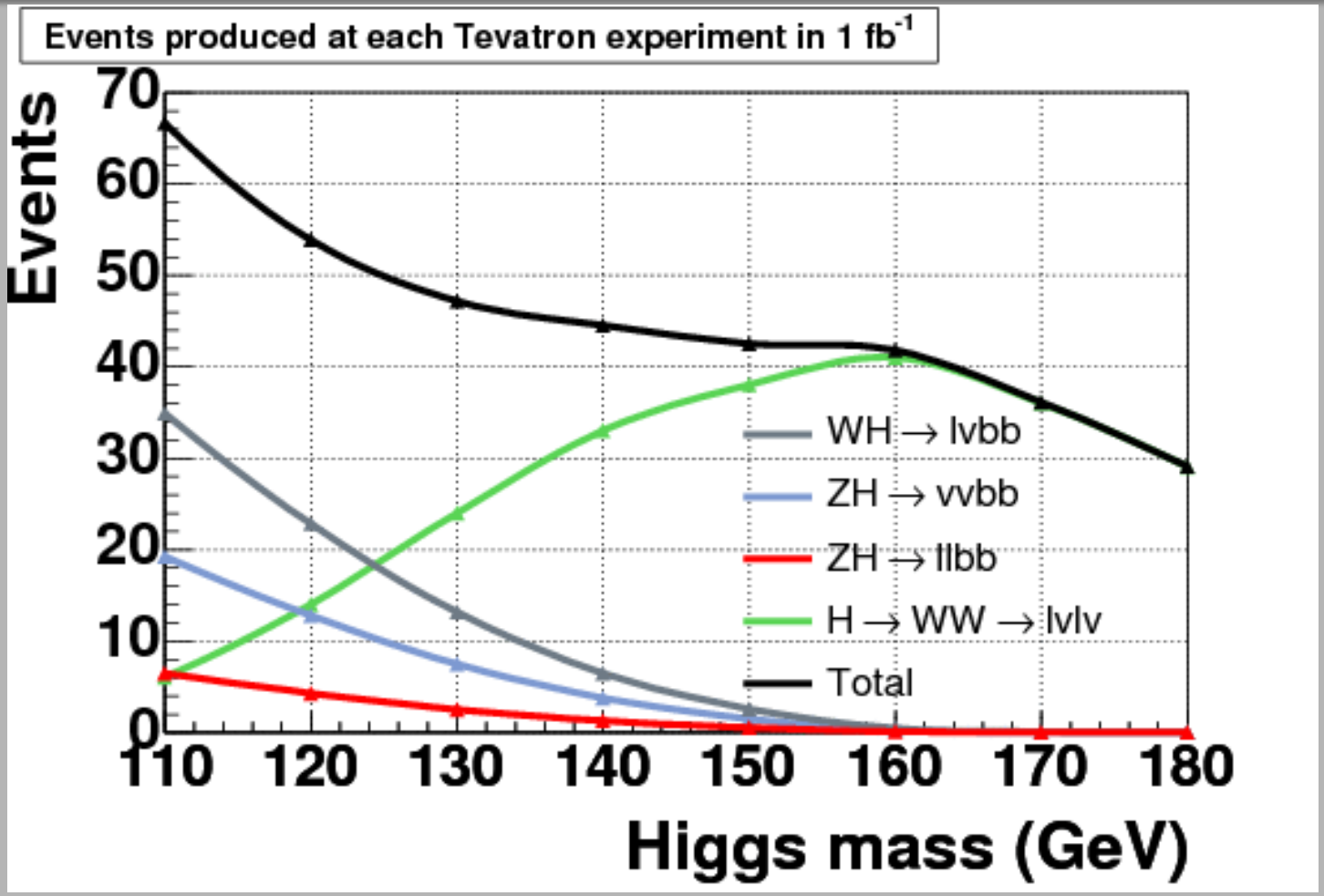
High mass

Main Search Channels



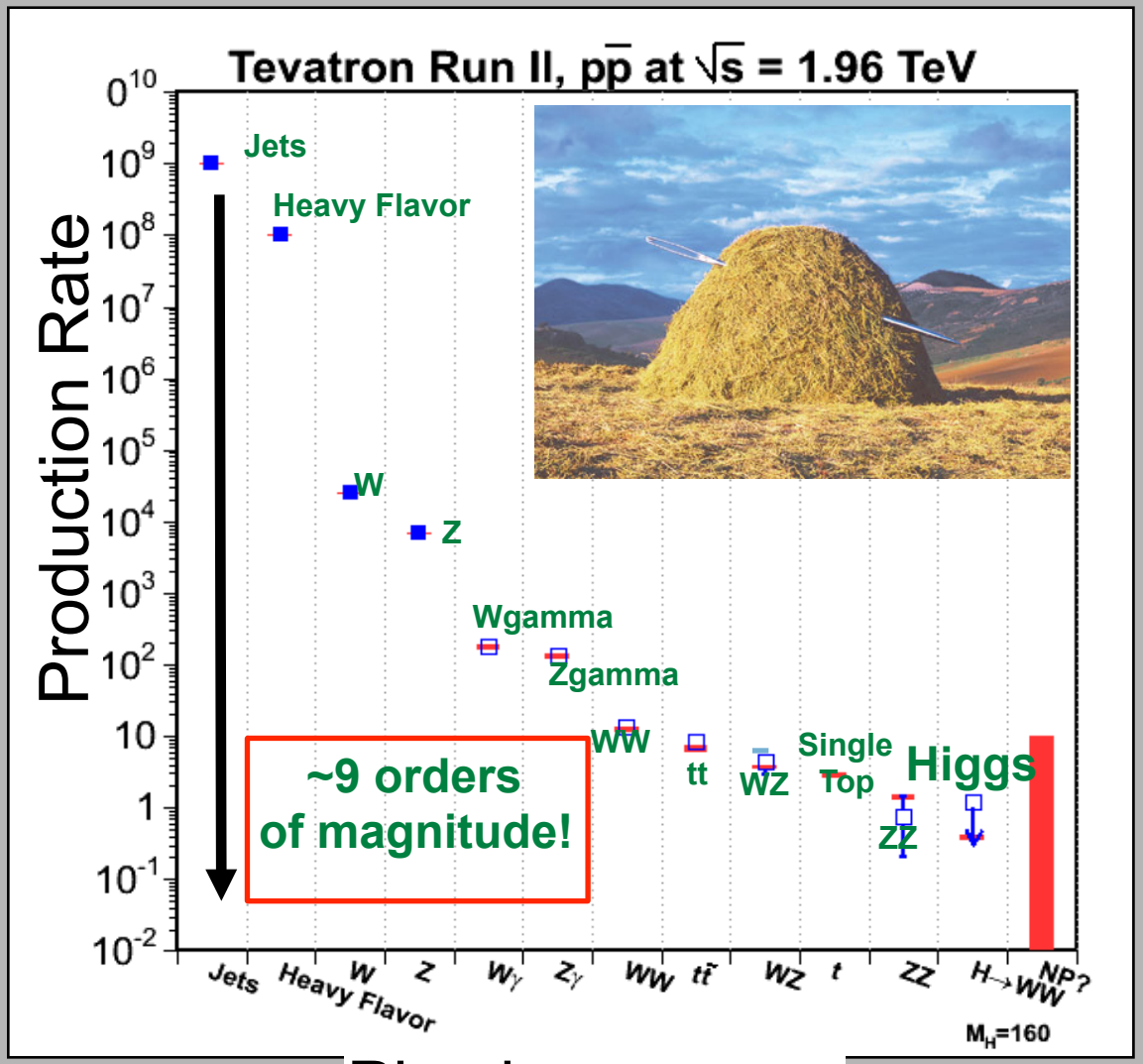
I will focus on low-mass and use the **WH → lνbb** analysis from CDF as an example

Higgs Production Rates



About 1000 Higgs events expected at the Tevatron in the with dataset (10 fb^-1)

Rates of Physics Processes at the Tevatron



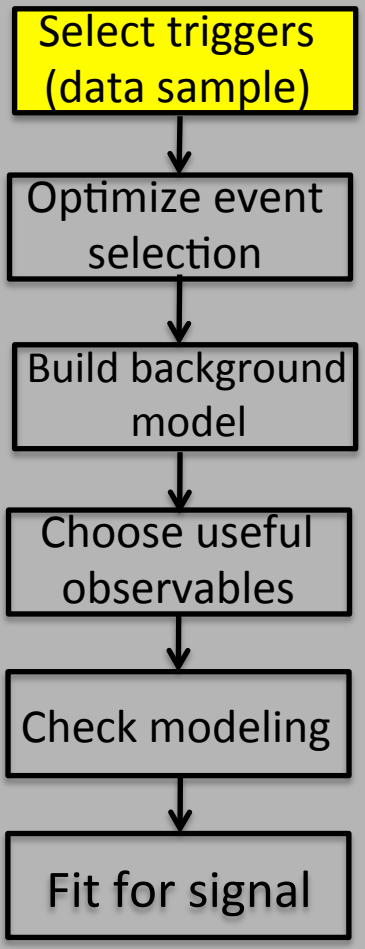
New Physics?

Triggers

- *Collisions occur at a rate of ~ 2.5 MHz!*
  - → More than 99.9% jet events
  - → We can't (and don't want to) store all events
- We select (trigger) potentially useful events and throw the rest away!
- There are many different triggers to choose from:

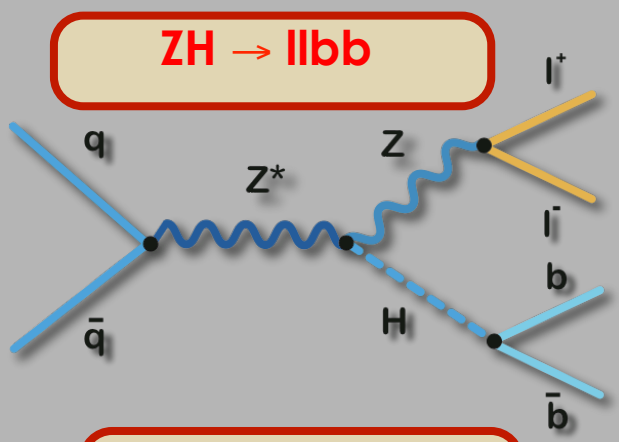
  We can trigger on the lepton (*e or μ):*
  - *WH → ℓνbb, ZH → ℓℓbb, H → WW*

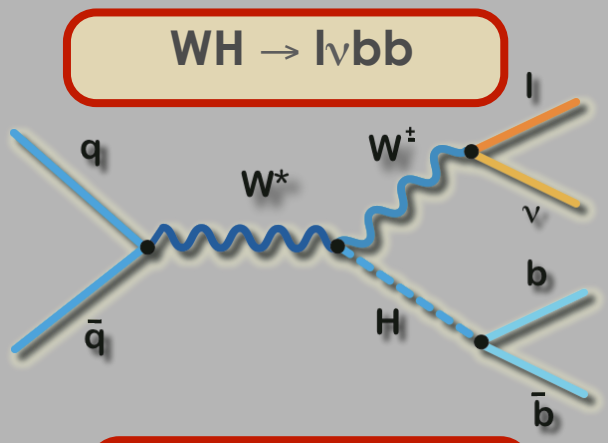
  Or, *MET + jets (MET= missing transverse energy):*
  - *WH → ℓνbb, ZH → ννbb*

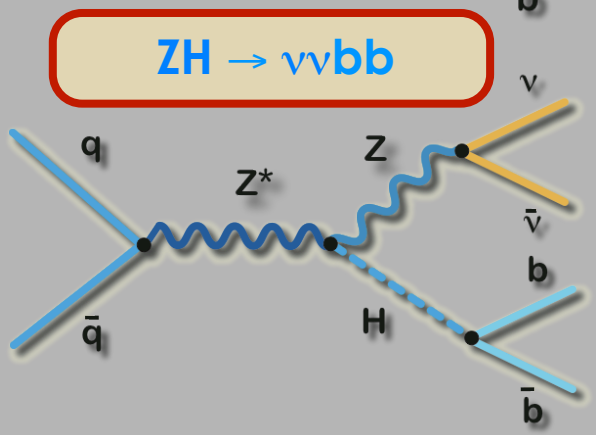


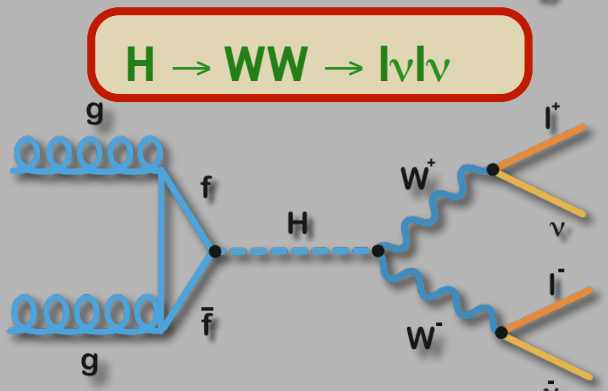
Event Selection

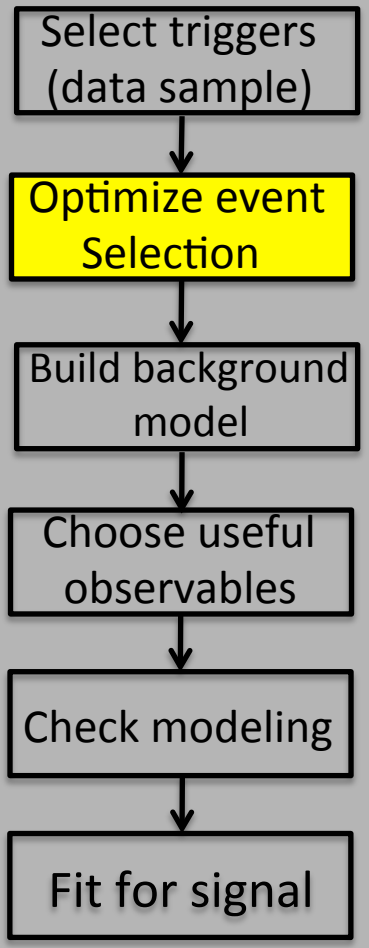
Based on the final state content, event selection is optimized to maximize signal acceptance and sample purity







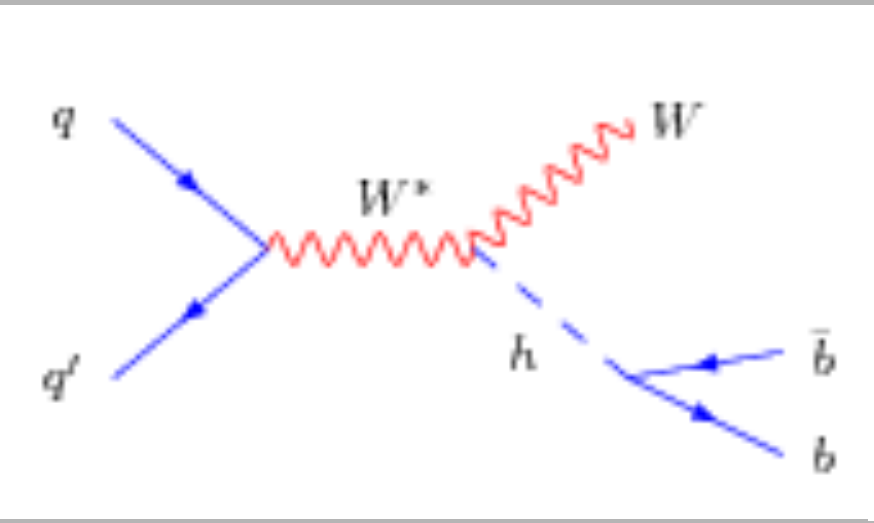




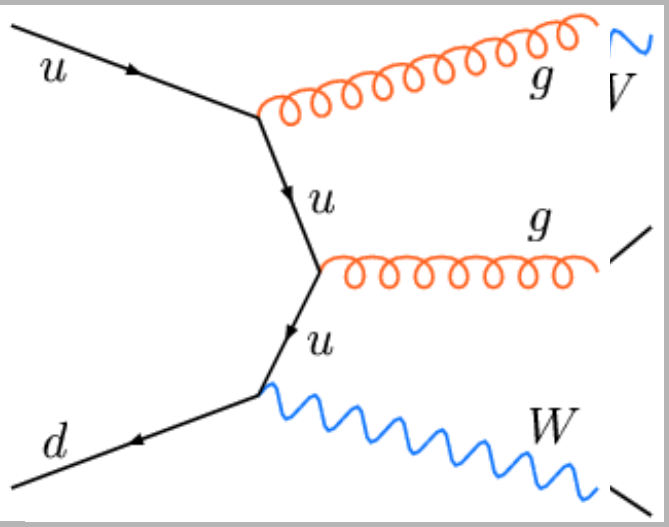
Backgrounds to the Higgs Boson Signal

Backgrounds are events from other processes that pass Higgs event selection.

Examples from WH → lνbb



Signal



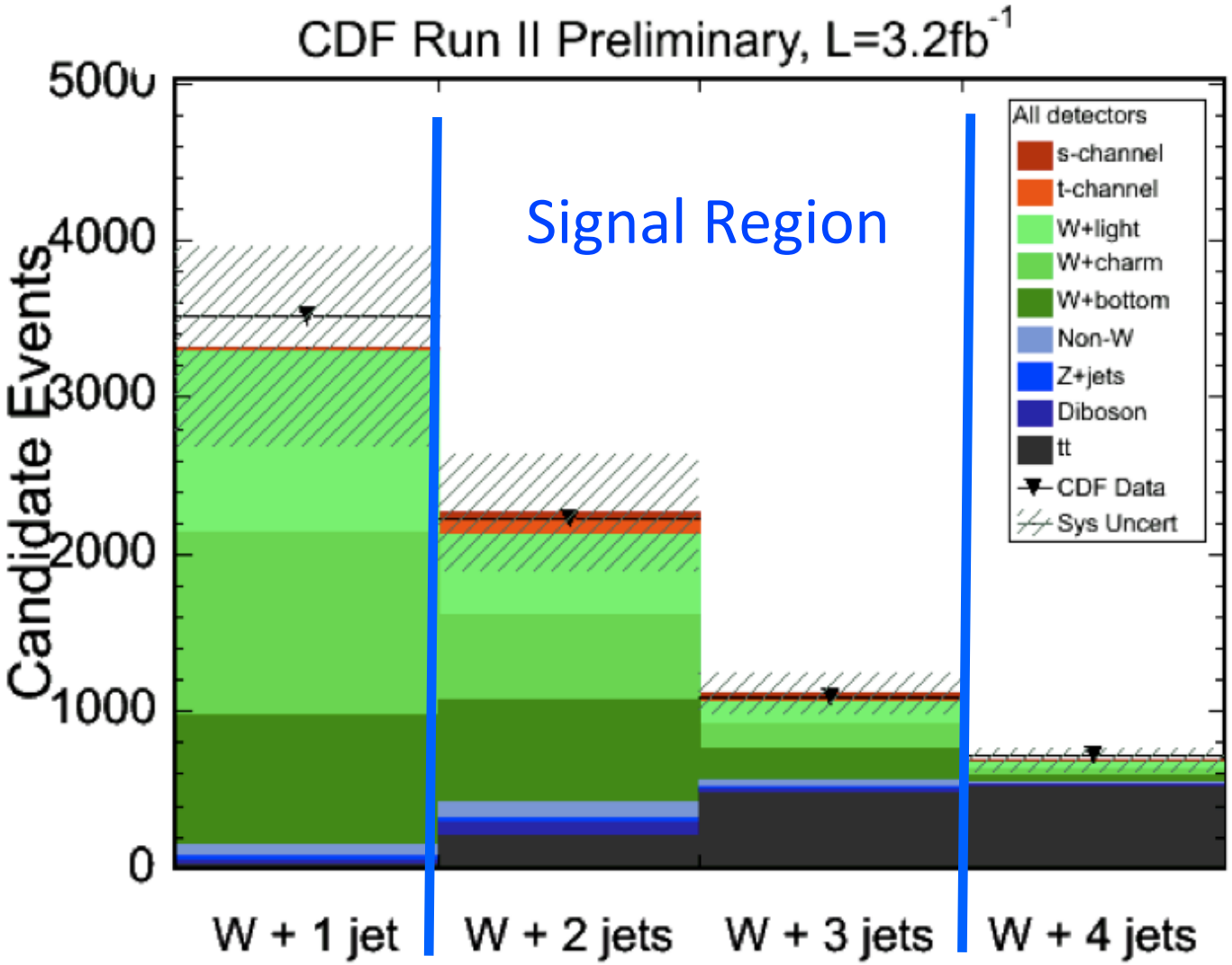
Physical Background

Instrumental Background

- Select triggers (data sample)
- Optimize event Selection
- Build background model
- Choose useful observables
- Check modeling
- Fit for signal

Other backgrounds from top, dibosons, …

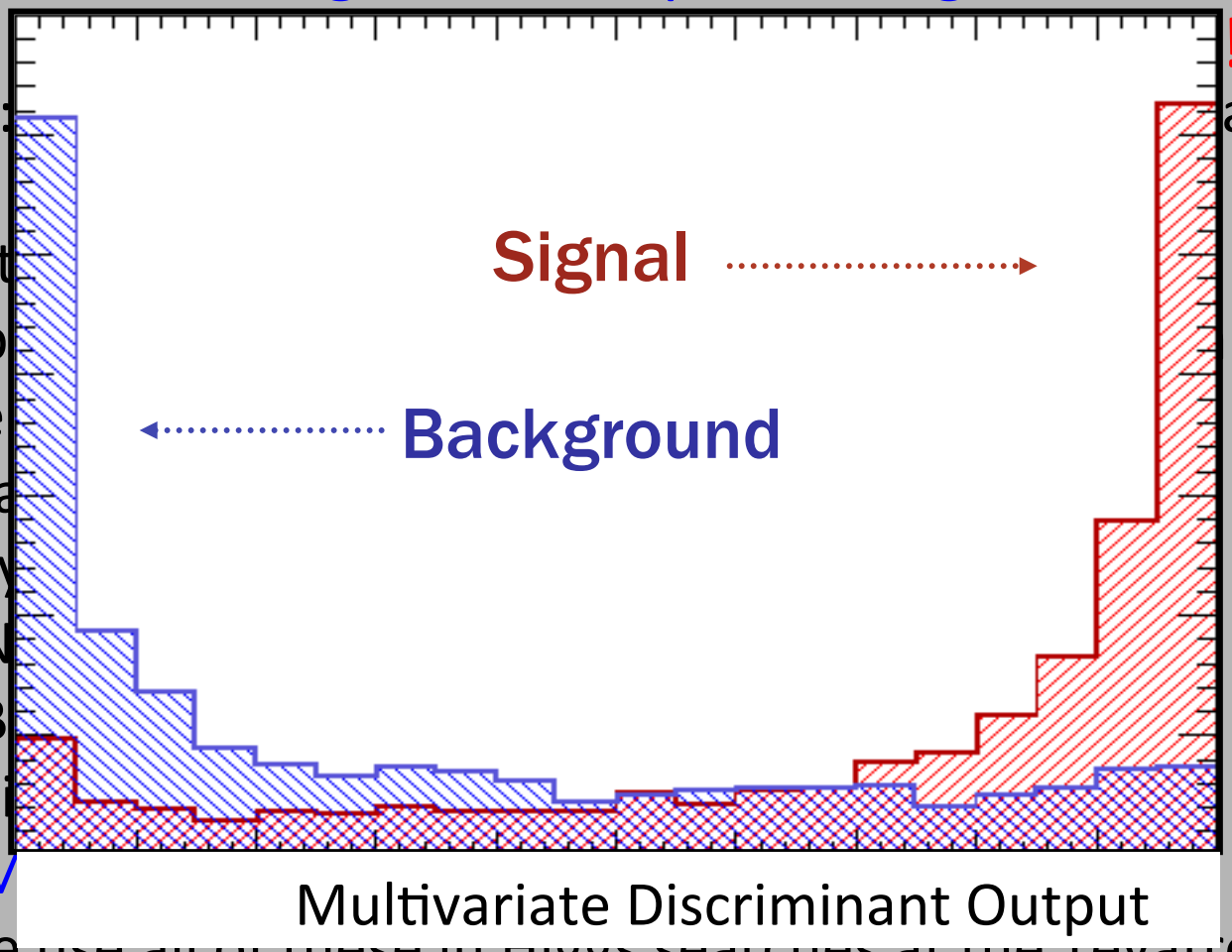
Background Estimate



- Select triggers (data sample)
- Optimize event Selection
- **Build background model**
- Choose useful observables
- Check modeling
- Fit for signal

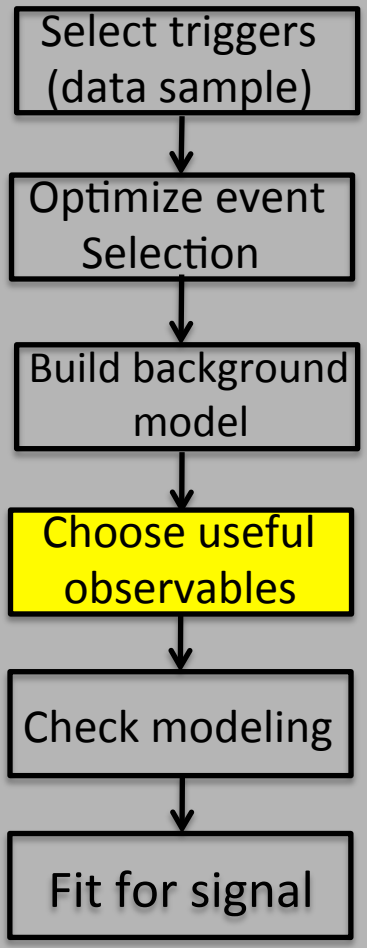
Multivariate Techniques

Uncertainties on background prediction are larger than expected signal

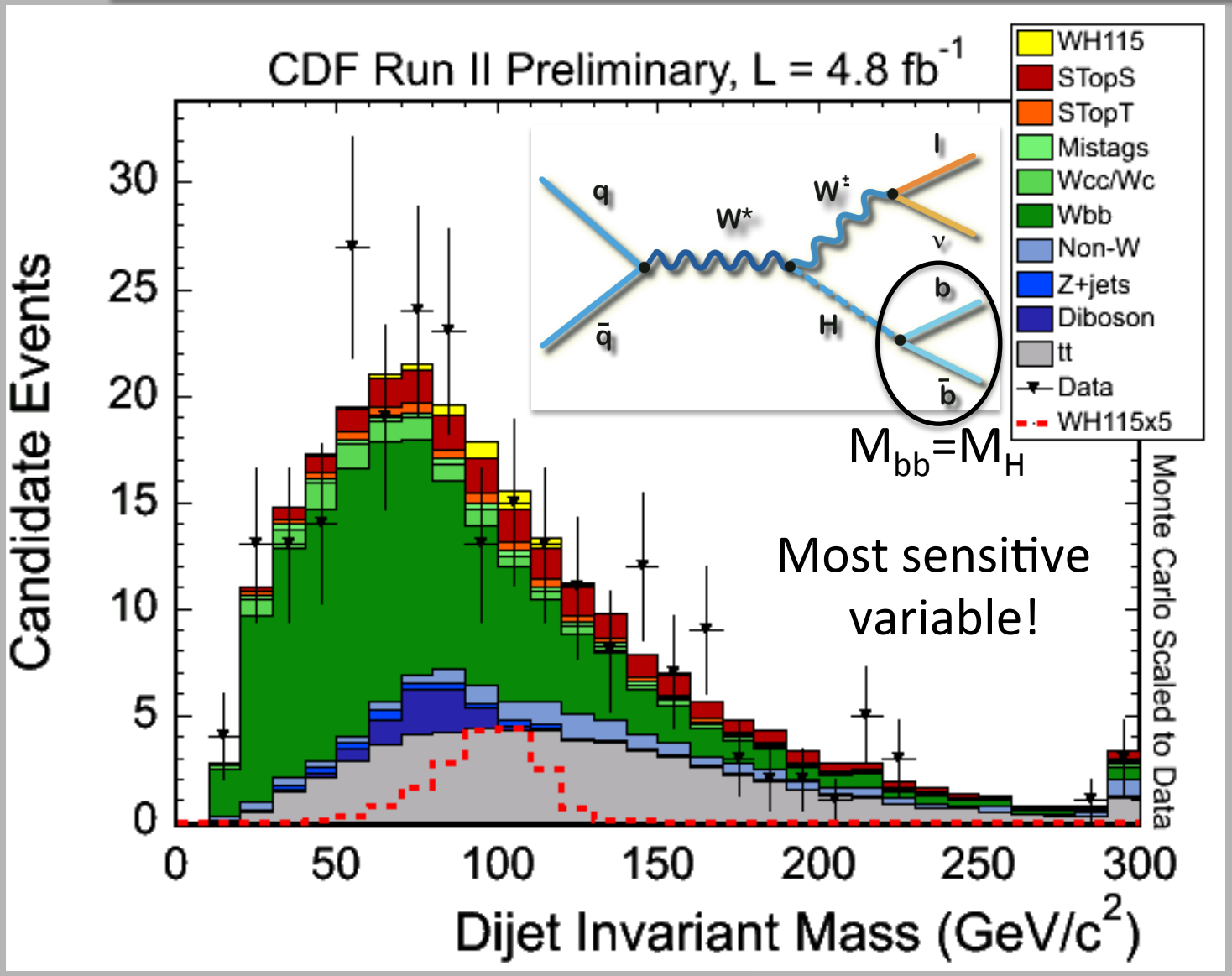


- Goal: …ate signal
- Input
- Outp… …ny single
- Just a
- Many
  - N
  - B
  - Li
  - M

→ We use all of these in Higgs searches at the Tevatron!



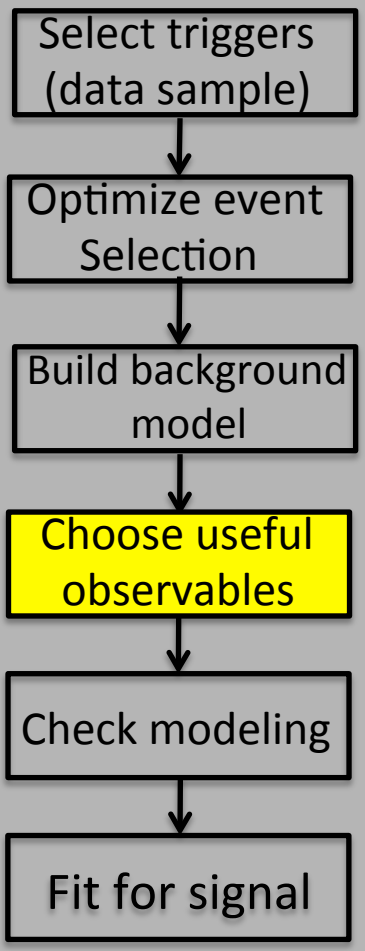
Variable Selection



- Select triggers (data sample)
- Optimize event Selection
- Build background model
- **Choose useful observables**
- Check modeling
- Fit for signal

Other Variables

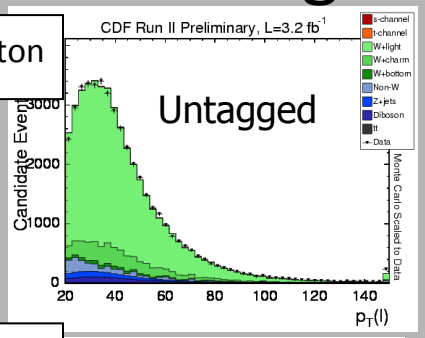
- M_{jj} is the most sensitive, but other variables can add separation power between signal and background
- For multivariate analyses we carefully choose variables that have separation power for at least 1 background
- Using multivariate techniques improves sensitivity by ~25% for WH over just using M_{jj}

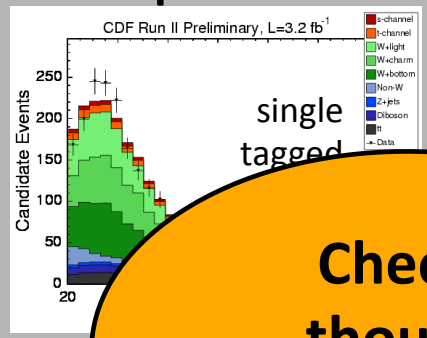


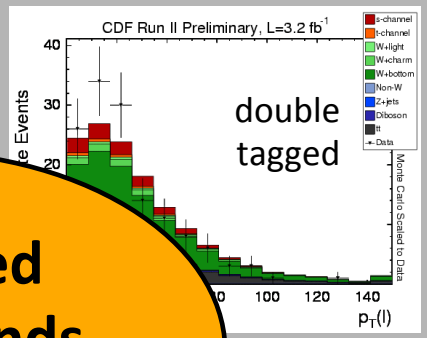
Check Background Modeling

Multivariate techniques are only as good as the modeling of the input variables…

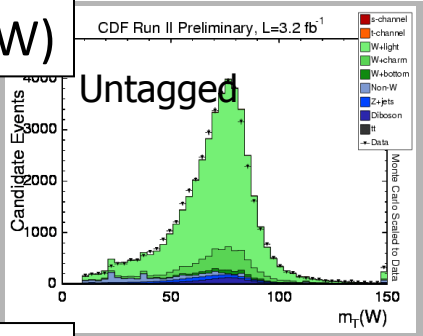
P_T^{lepton}

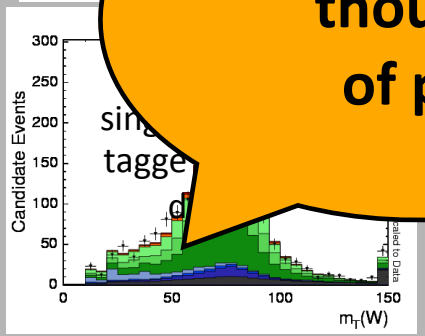


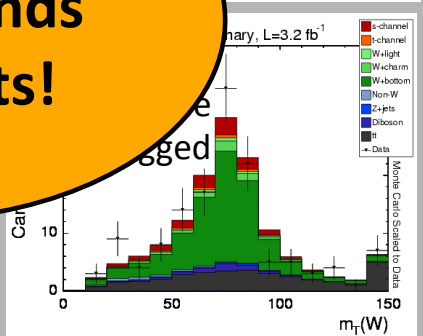




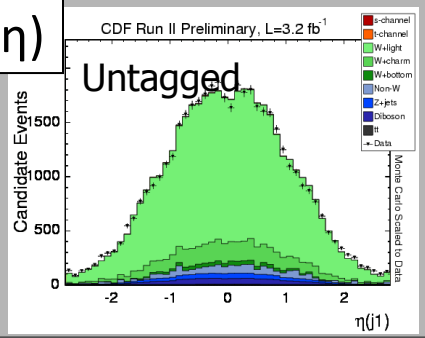
$M_T(W)$

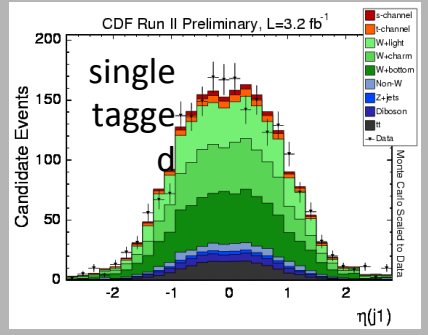


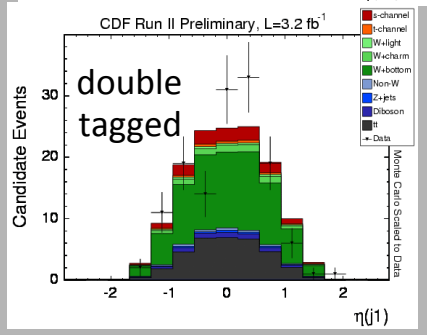




$J_1(\eta)$







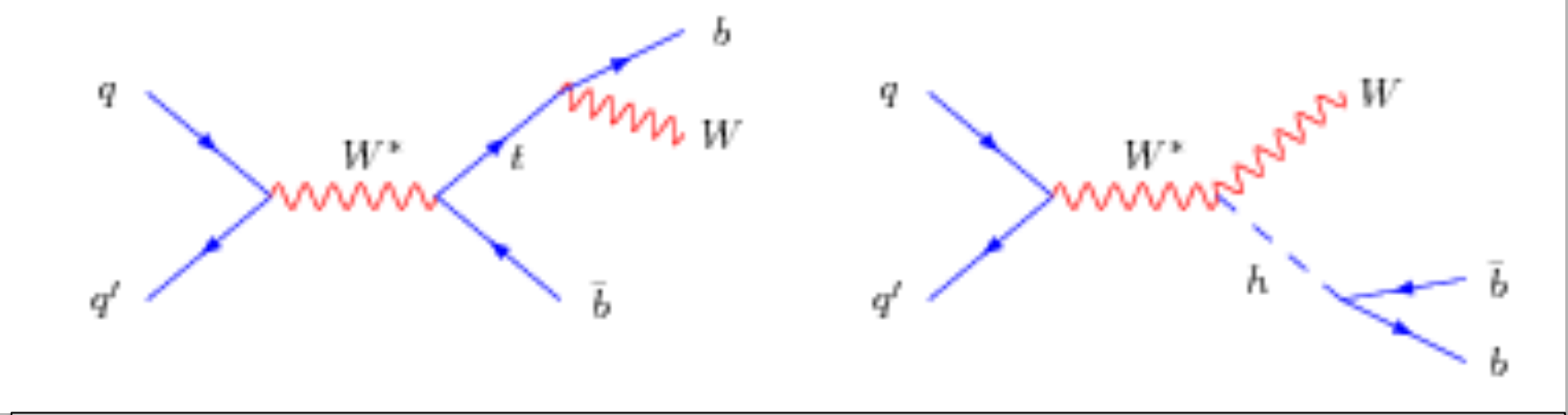
Checked thousands of plots!

- Select triggers (data sample)
- Optimize event Selection
- Build background model
- Choose useful observables
- **Check modeling**
- Fit for signal

WH Proofs of Principle

Single Top Quark Production

Measuring single top quark production is a benchmark for WH!



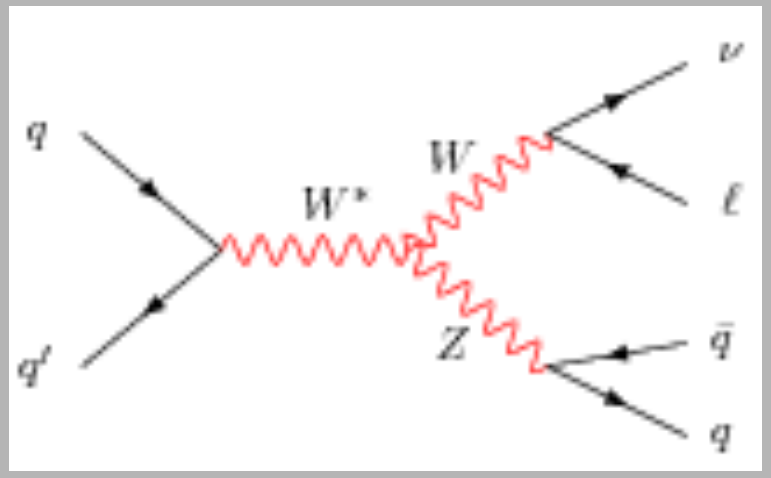
CDF first observation of single top:
Phys. Rev. Lett. 103, 092002 (2009)

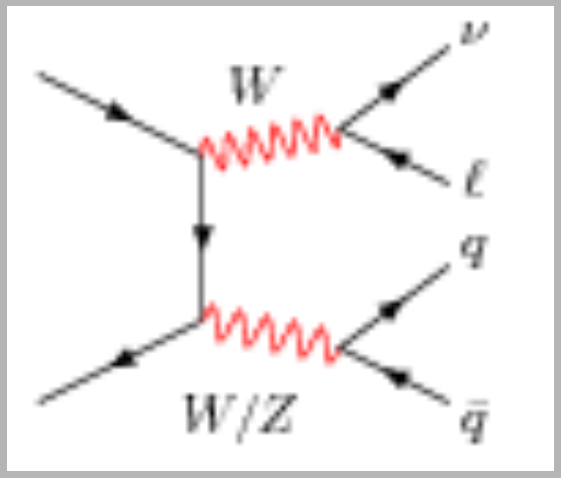
σ_{WH} 1/10 $\sigma_{Singletop}$

WH Proofs of Principle

Diboson Production (lvjj)

Measuring diboson production is a benchmark for WH!





- *lvjj final state also very similar to Higgs*
- *Small signal in large background*

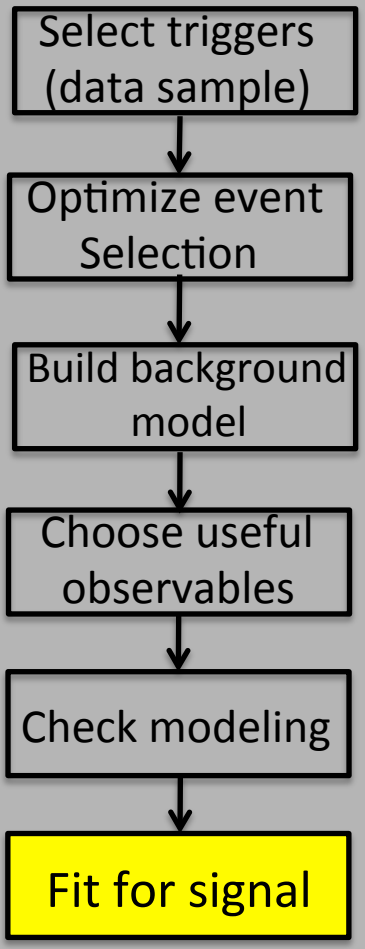
CDF first observation diboson (lvjj):
arXiv:0911.4449 (in PRL)

Fit For Signal

We don't see evidence for the Higgs boson yet!

- For now, we set limits on its rate of production
- These limits say:

If the true Higgs production rate was at the limit value, we would see evidence of the Higgs signal more significant than what we observed in 95 % of experiments



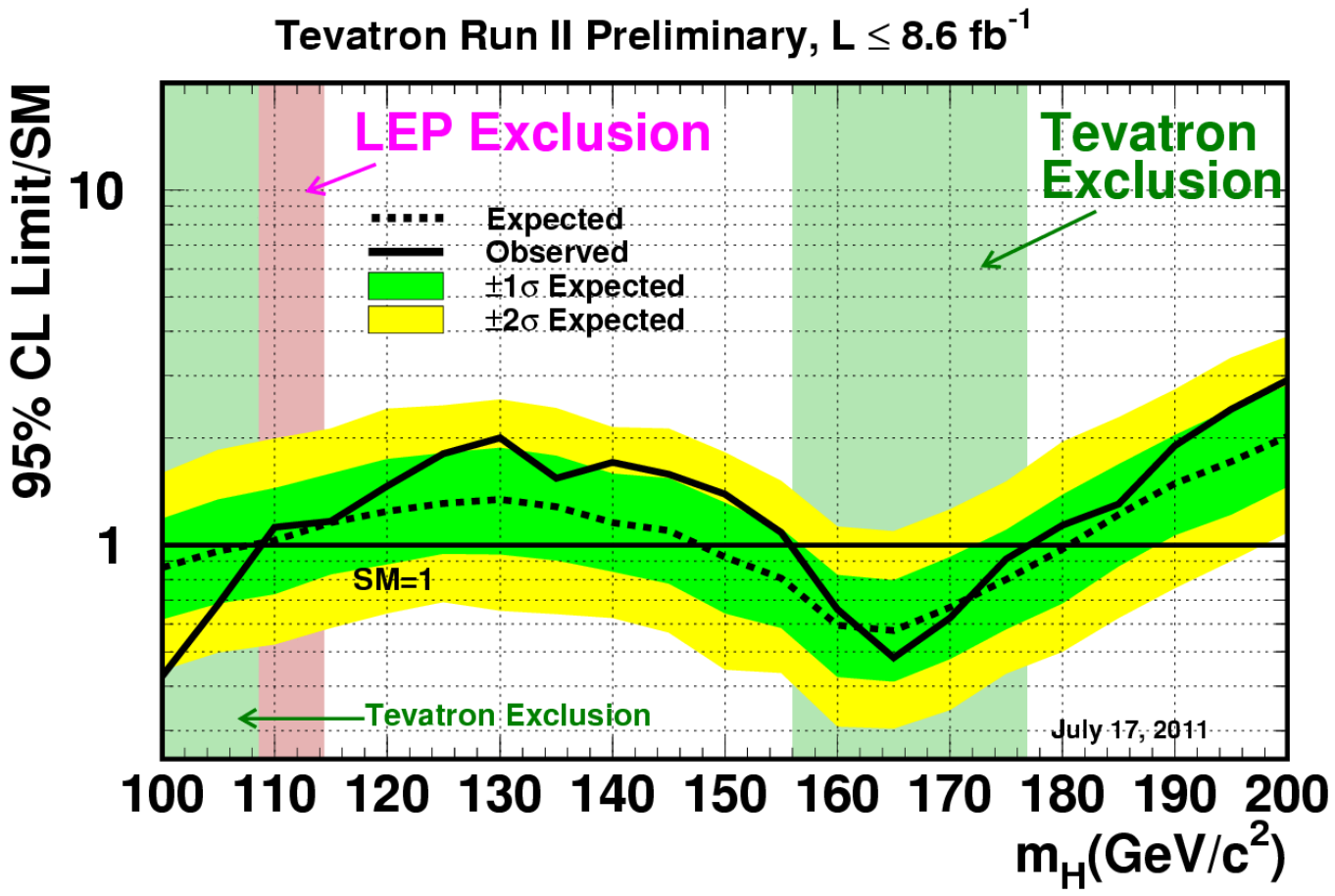
CDF Results: Main Channels

CDF limits at low mass ($M_H = 115\ GeV/c^2$)

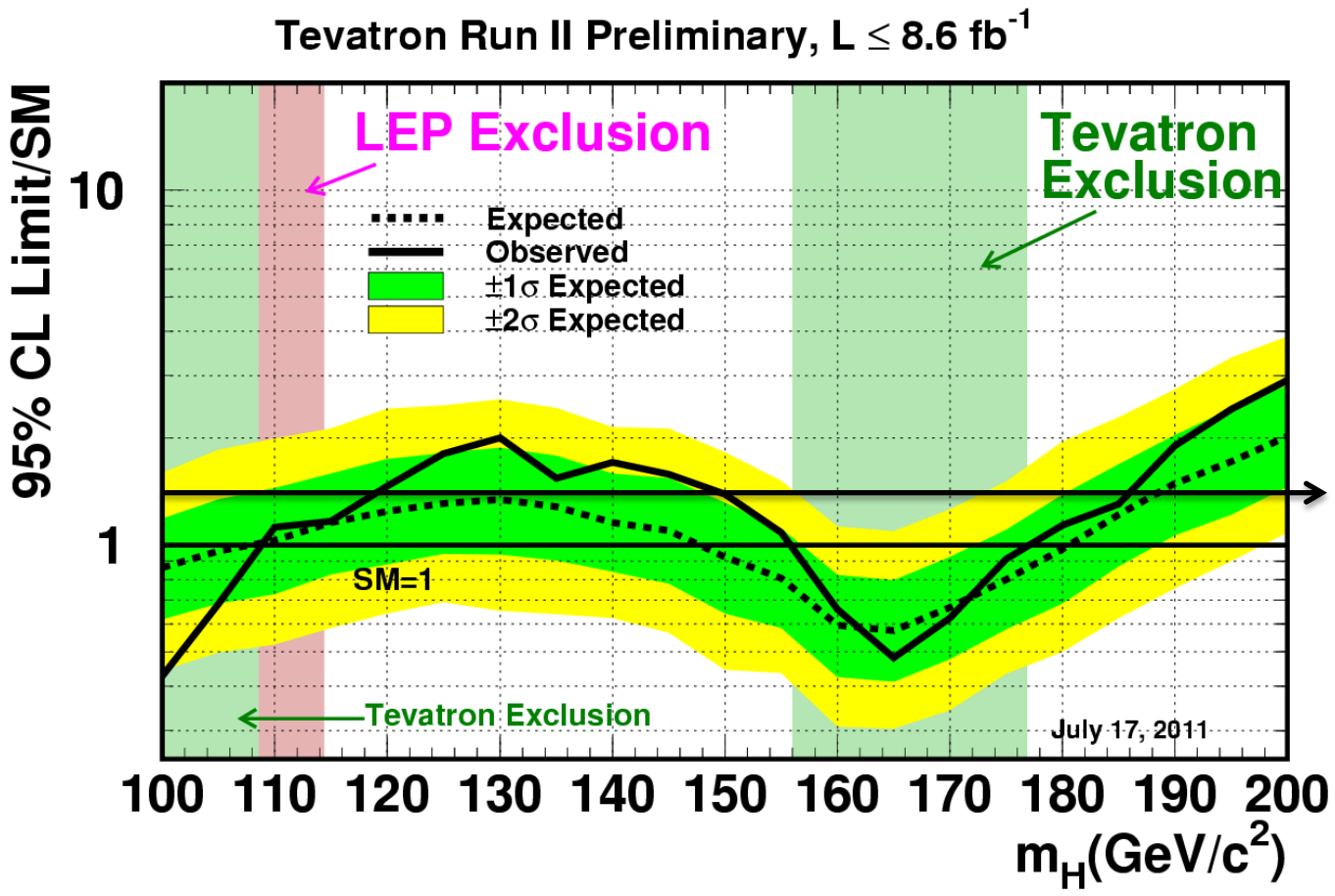
Channel	Limit x SM (expected)
$WH \rightarrow l\nu bb$	2.8
$ZH \rightarrow \nu\nu bb$	
$ZH \rightarrow llbb$	
$H \rightarrow WW$	7.9
	18
	12.6
$H \rightarrow \Upsilon\Upsilon$ (New!)	13.5
CDF combined	1.4

Next, we combine CDF and D0.

Tevatron Combined Results

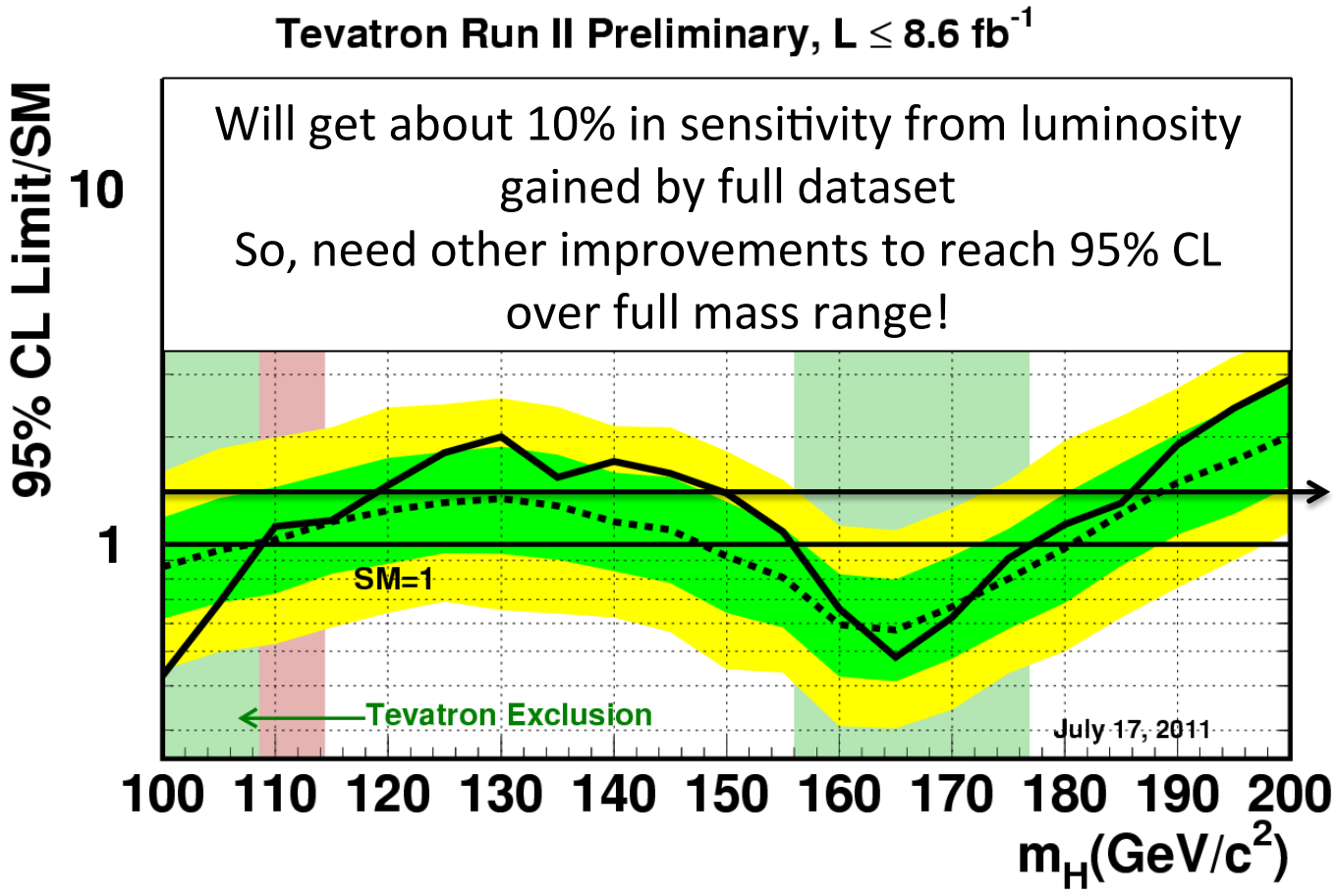


Tevatron Current Results

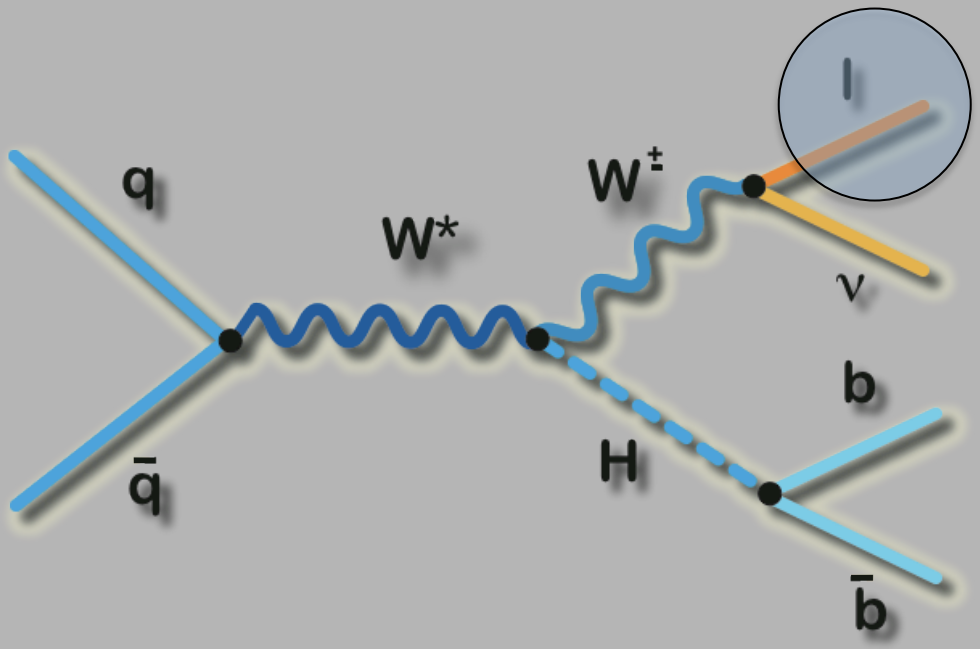


< 1.3xSM sensitivity everywhere

Tevatron Current Results



Improvement Examples

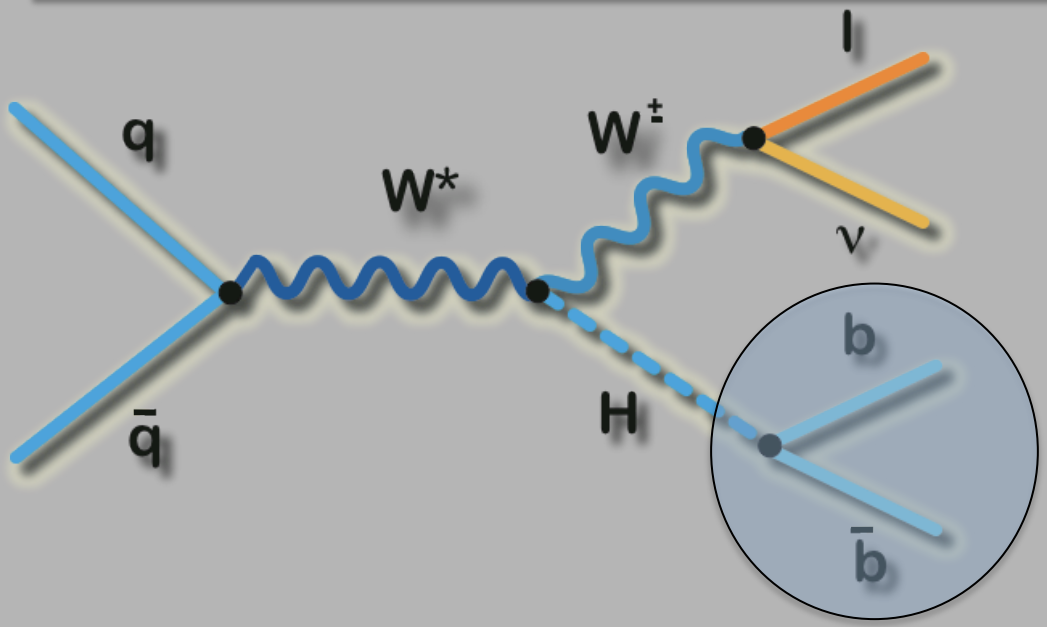


By improving lepton trigger efficiency we expect up to a 5% gain in sensitivity.

(See H. Liu's talk from Thurs.)

Improvement Examples

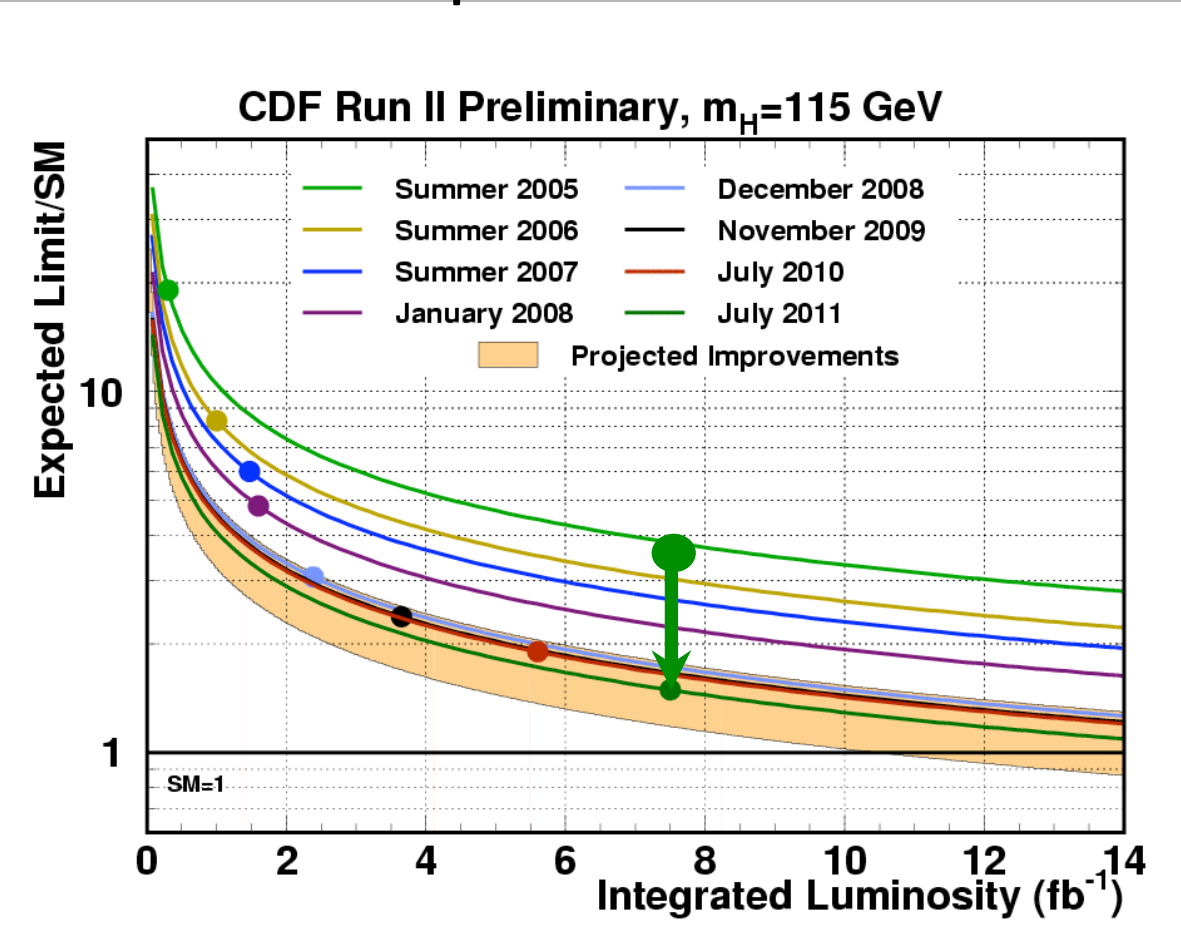
All CDF and D0 analyses working toward gains with the full Tevatron dataset.



By improving b-jet ID efficiency gains up to 10% in sensitivity are possible.
(Applies to all h-bb analyses)

A history of improvement…

More than a factor of 2 in improvement over what is expected from luminosity!

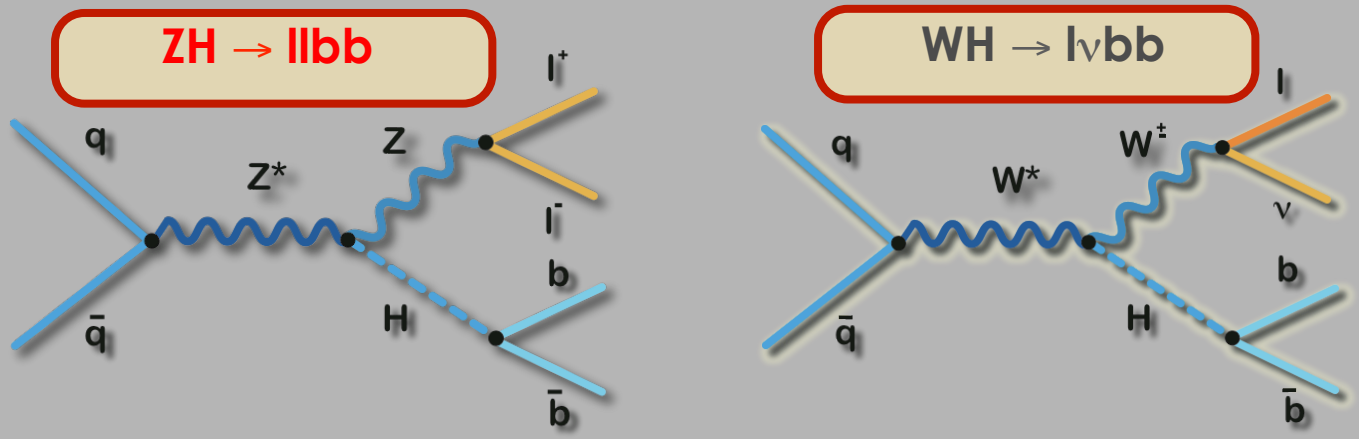


In the era of the LHC…

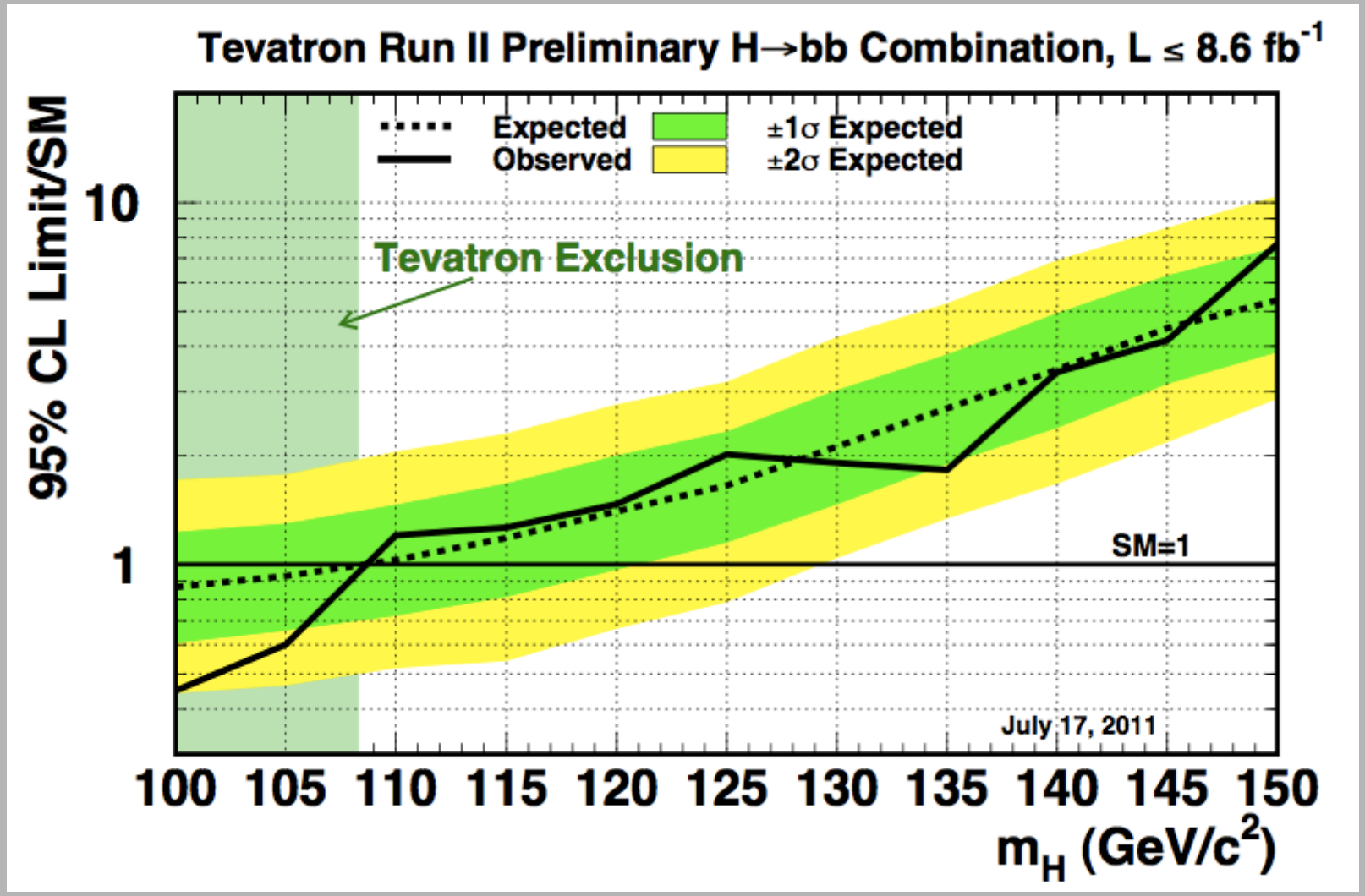
- The LHC has higher collision energy and will surpass the Tevatron in integrated Luminosity over the next year.
- Already, the LHC is more sensitive for high mass Higgs boson searches.
- At low mass the Tevatron and LHC are competitive and will be at least until early next year.
- Still, there are some areas where the Tevatron has an edge…

Quarks v/s gluons

- The Tevatron has an advantage in some quark antiquark initiated states – the LHC has limited antiquark content in the colliding protons.
- For example, backgrounds rate relative to signal rate for WH, and ZH associated production are higher at the LHC.



H-bb is harder at the LHC

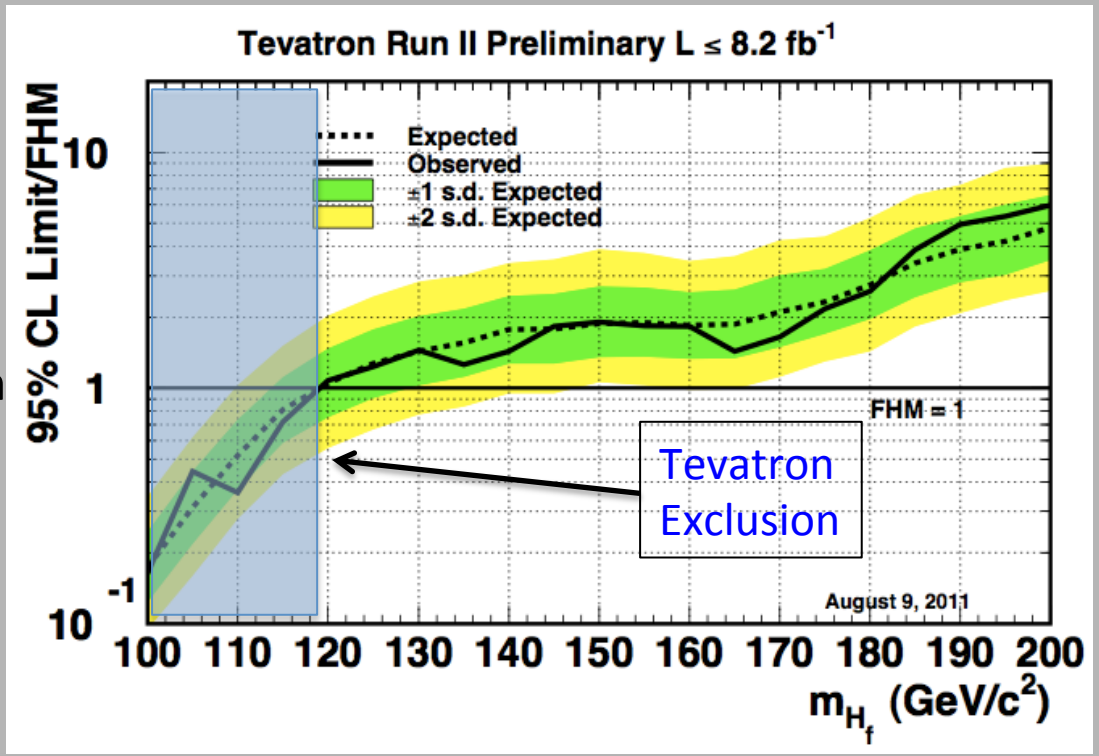


H-bb results from the Tevatron will be competitive for quite some time…

Fermiophobic Higgs

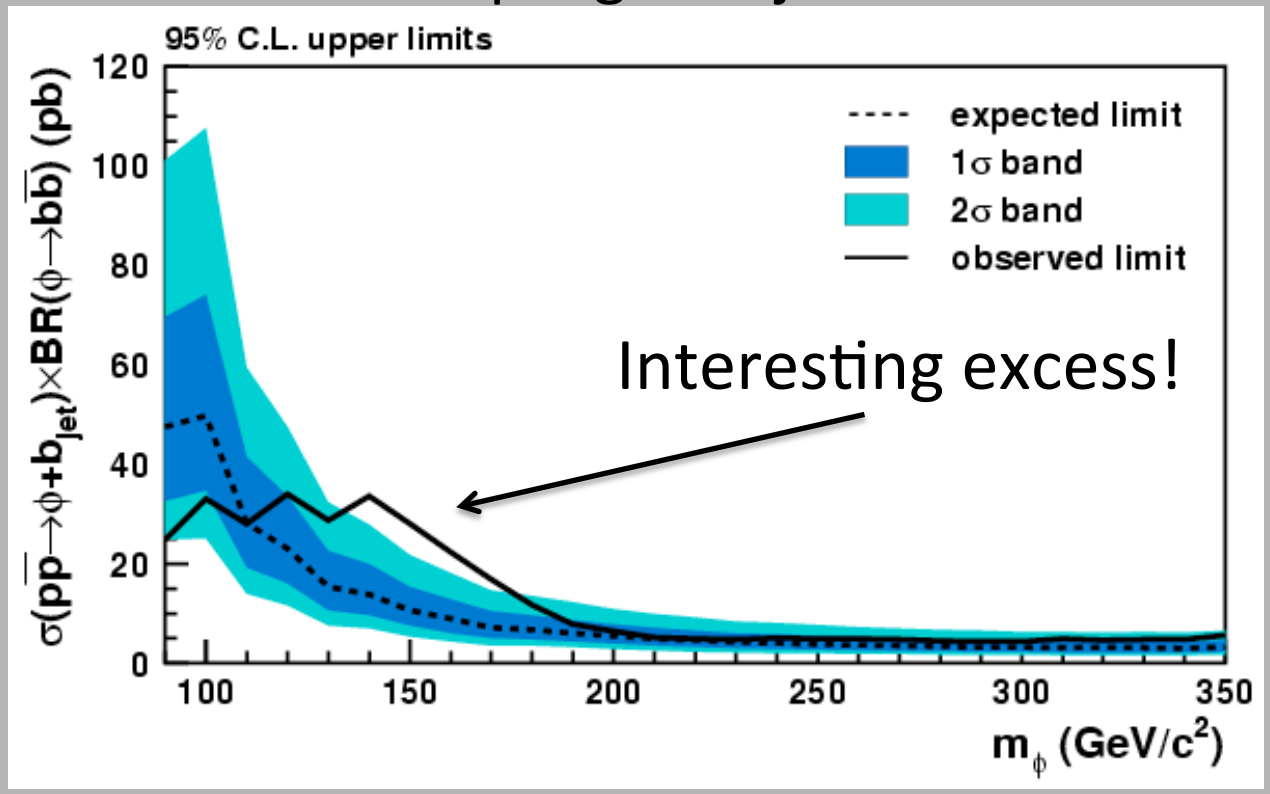
- If the Higgs doesn't couple to fermions then the dominant production mode (gluon fusion through a top quark loop) doesn't occur.
- Production through quark-antiquark initial states dominates.
- Fermiophobic Results:
  - CDF has best mass limit from any single experiment
  - Recent Tevatron combination

    $M_H < 118$ GeV



bbb

Supersymmetric Higgs bosons may have enhanced coupling to b-jets.



Triggering based on 'medium' energy jets with high efficiency is a challenge at the LHC.

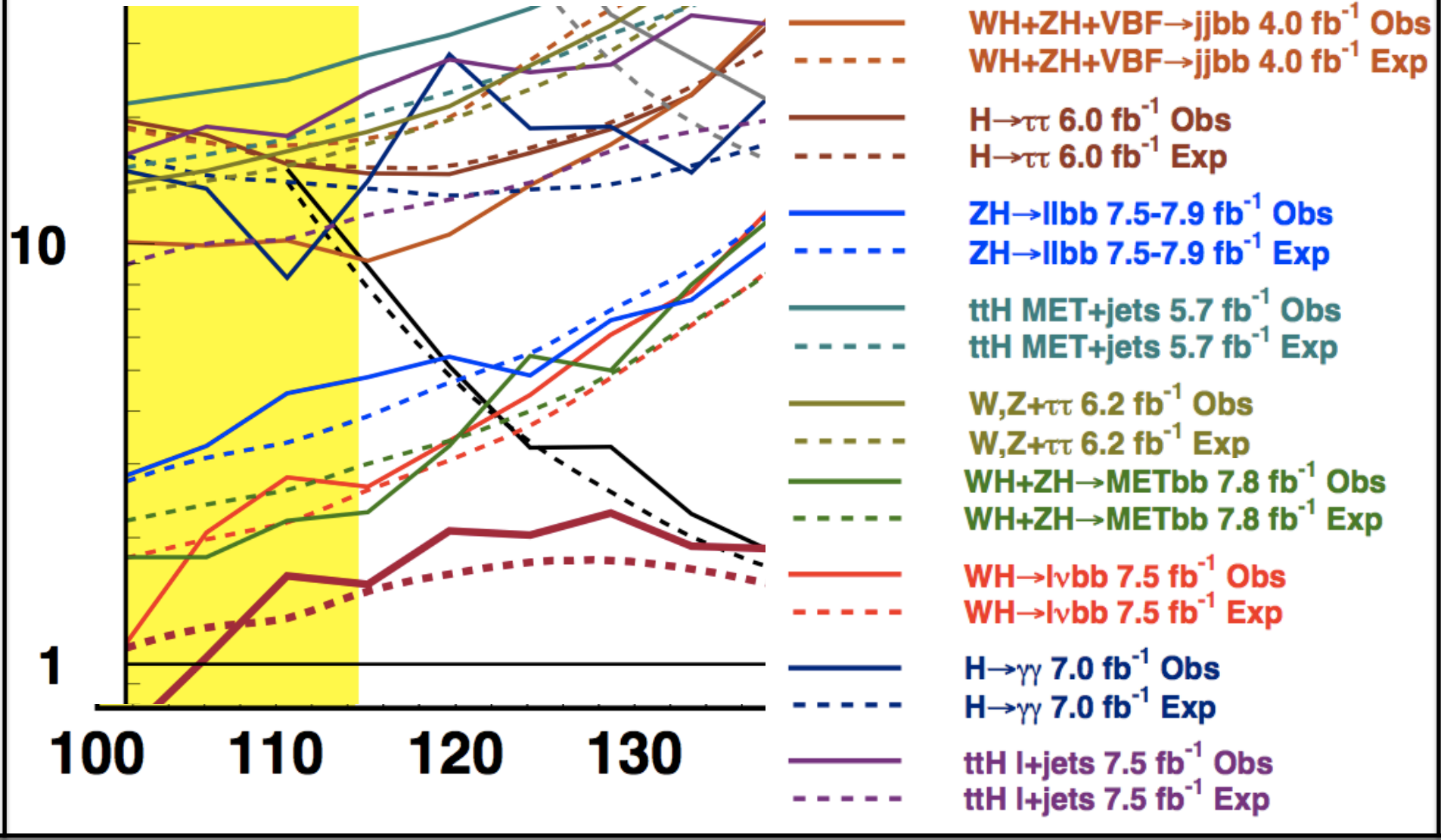
Conclusion

- We are working on the final Higgs statement from the Tevatron
- We don't have much time left: Glory's last shot!
- Each analysis has planned improvements that will be successful.
- The Tevatron will remain competitive in several searches for quite some time.


Higgs


Thank you!

The Low-Mass Spaghetti



WH Background Estimate

Top/EWK (WW/WZ/Z→ττ, ttbar)

- MC normalized to theoretical cross-section
- Modeled by Pythia Monte Carlo

MC driven

W+HF jets (Wbb/Wcc/Wc)

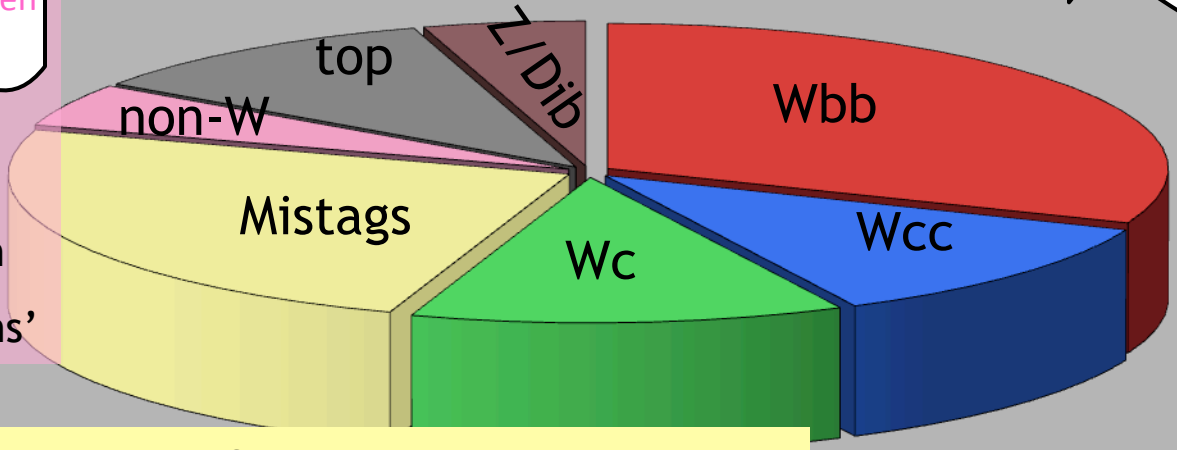
- W+jets normalization from data and heavy flavor (HF) fractions from ALPGEN Monte Carlo
- Modeled by Alpgen W+HF MC

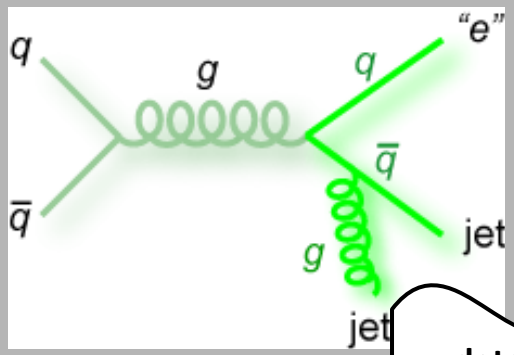
MC+ data driven

Non-*W (QCD)*

- Multijet events with semileptonic *b*-decays or mismeasured jets
- Fit low MET data and extrapolate into signal region
- Modeled by 'Anti/Jet-electons'

Data driven





Mistags (W+2jets)

- Falsely tagged light quark or gluon jets
- Mistag probability parameterization obtained from inclusive jet data
- Apply mistag probability to generic W +jets sample

data driven