The Tevatron and the Higgs

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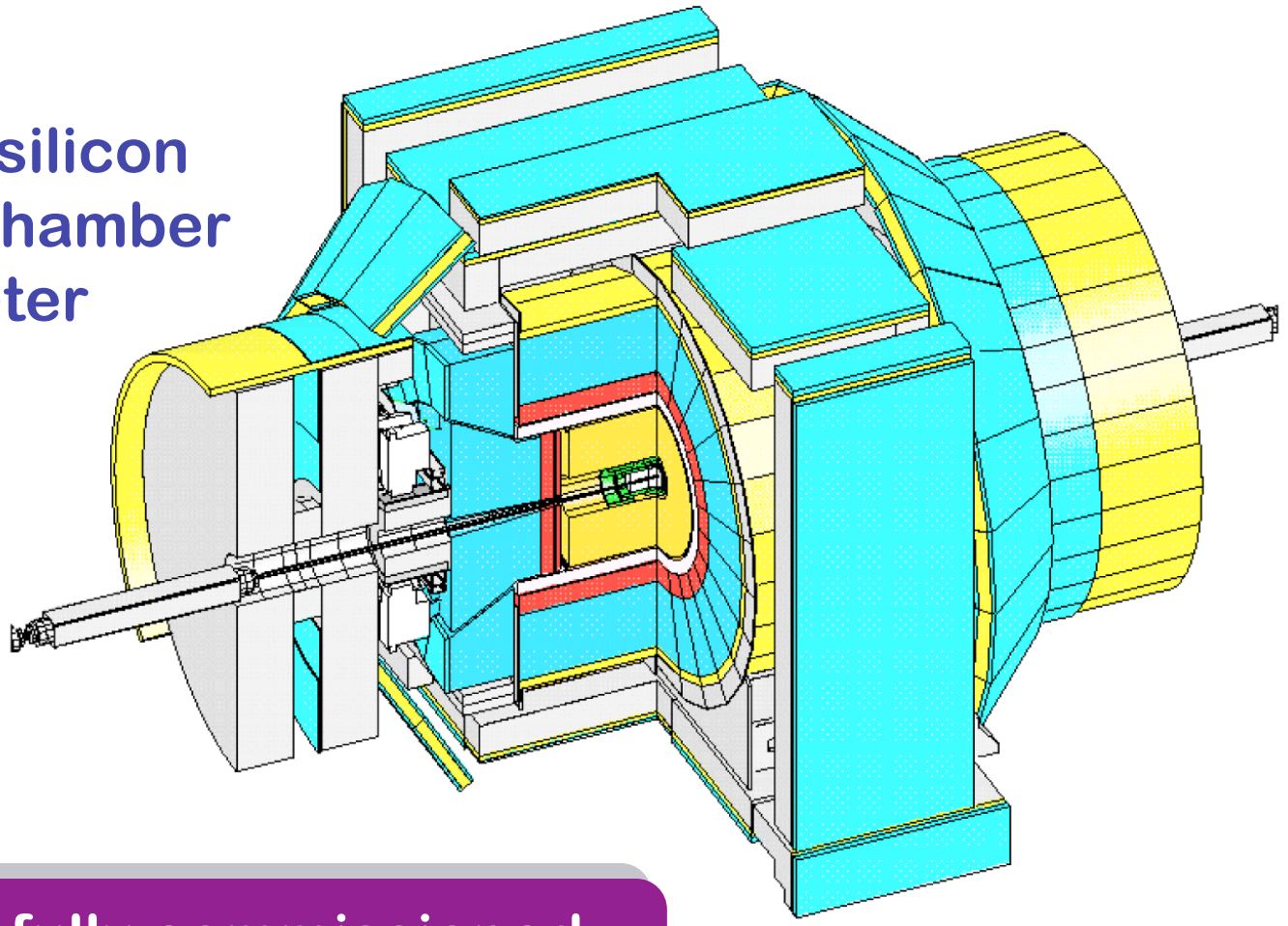
Rutgers University
LHC Advanced Study - Prague
July 2003

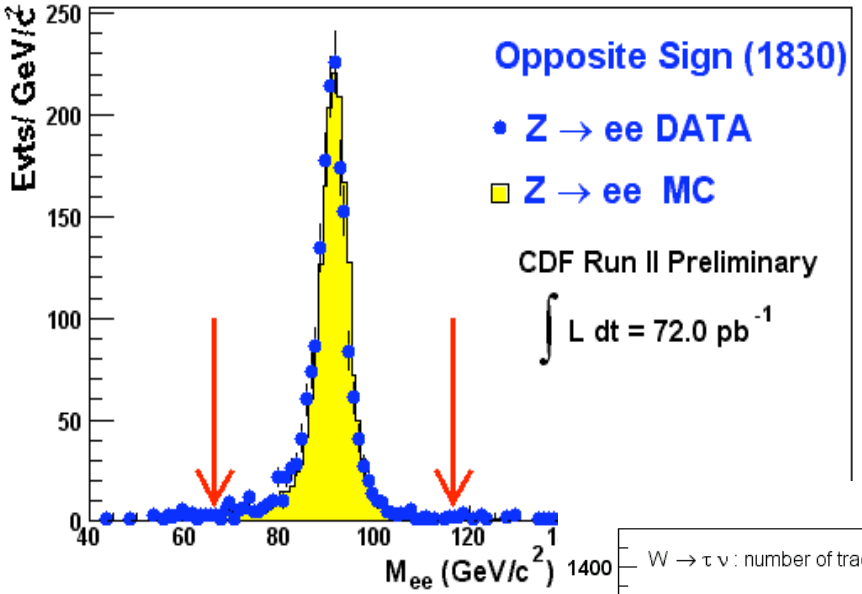
CDF

New
- double sided silicon
- central drift chamber
- plug calorimeter
- DAQ system
- trigger
- front end

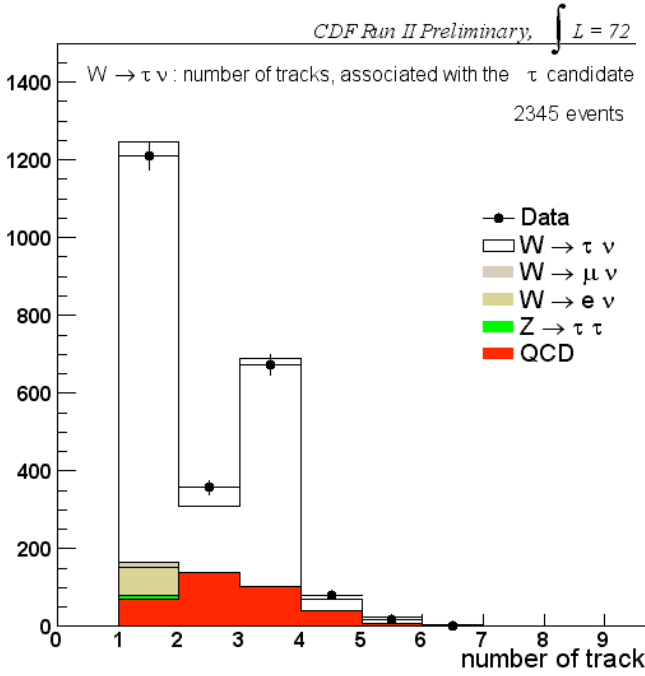


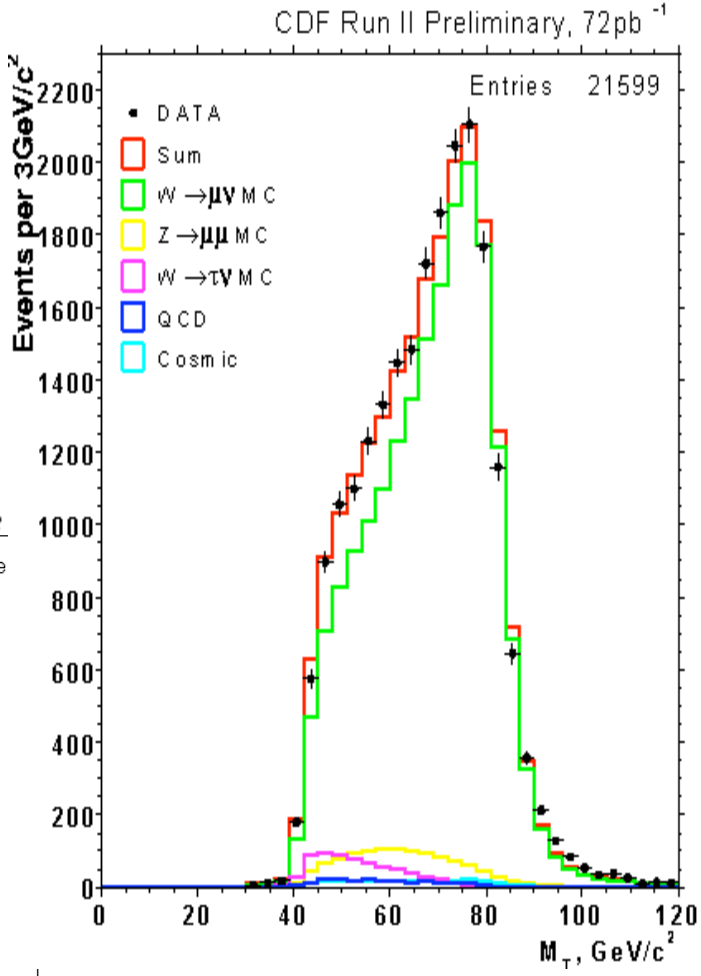
Detector fully commissioned and working well!

CDF performance - leptons



e

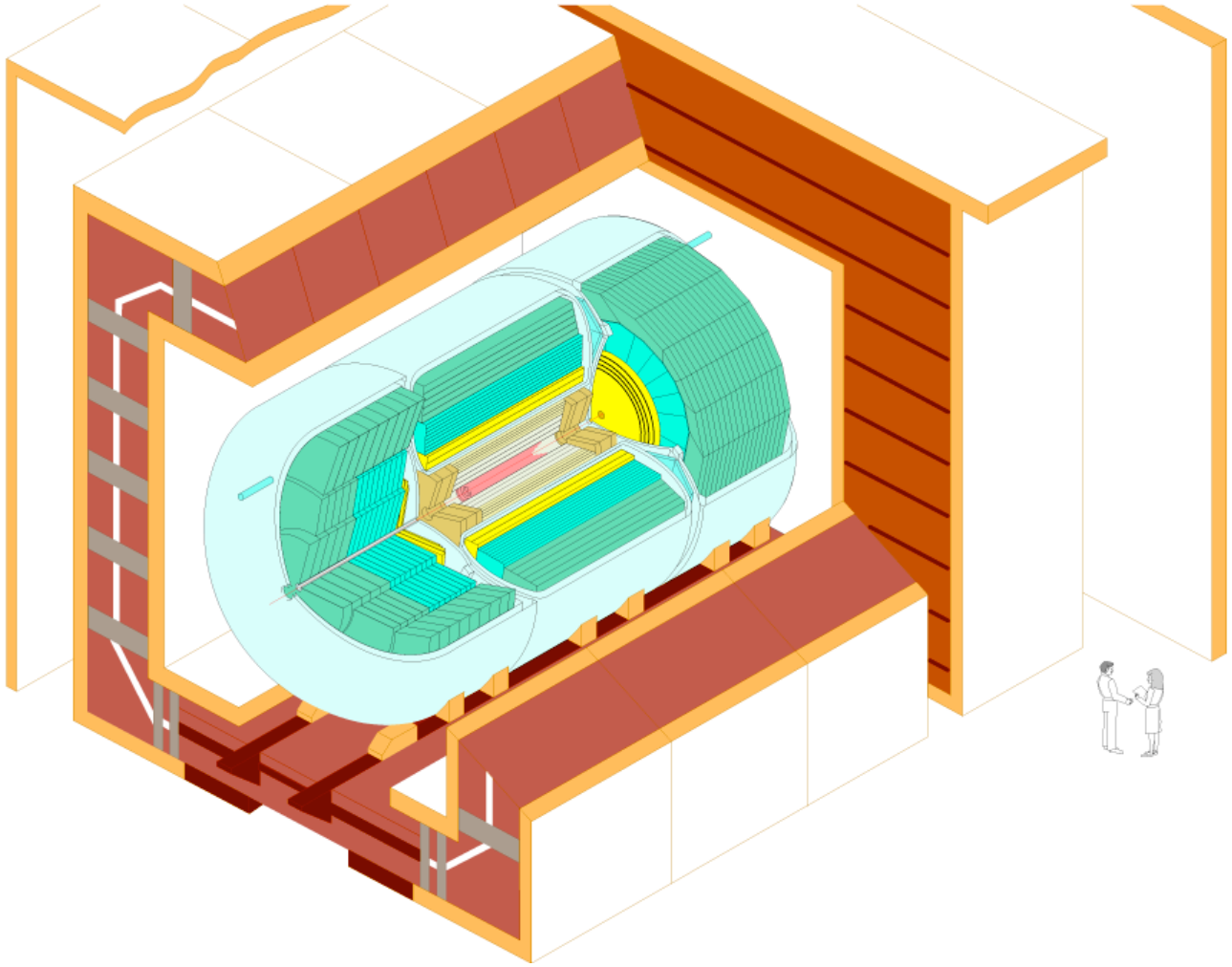




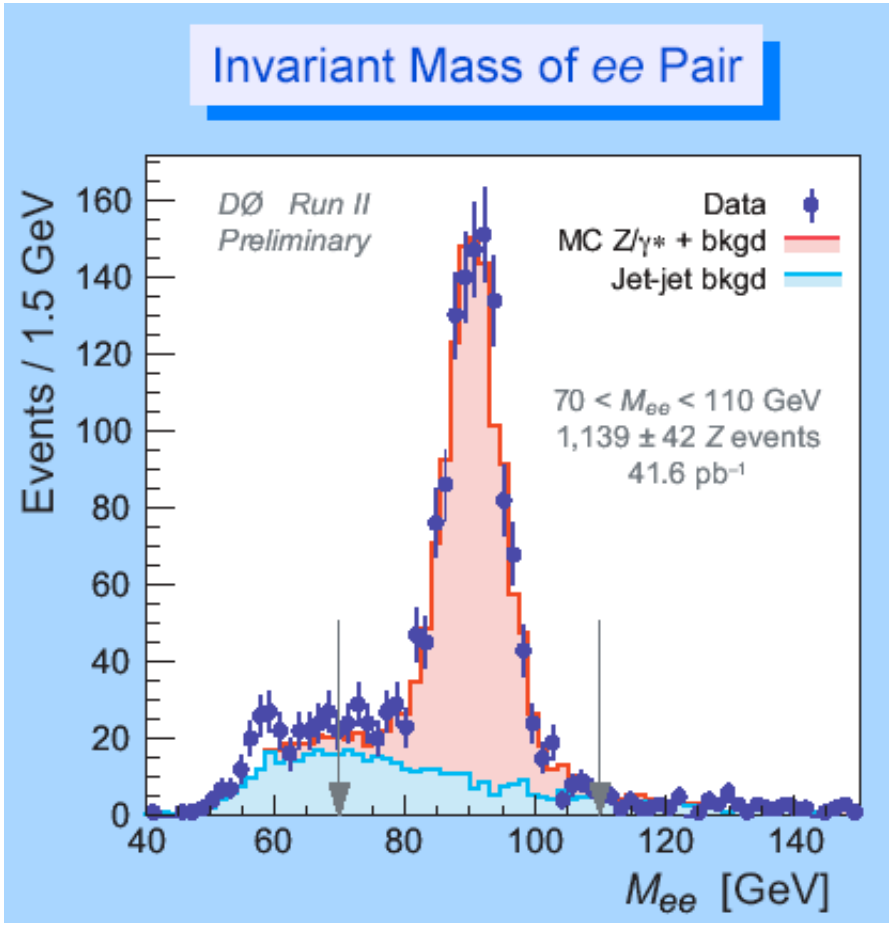
DØ

New:

- magnet!
- silicon vertex
- vertex trigger
- fiber tracker
- DAQ system

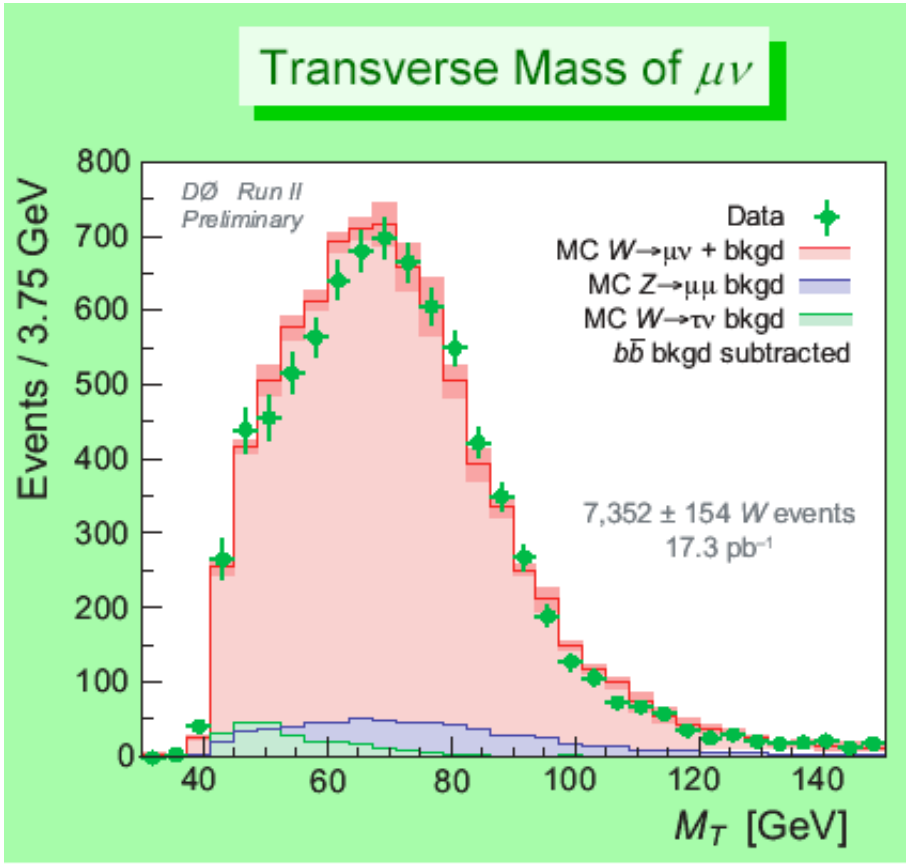


D0 - electrons and muons



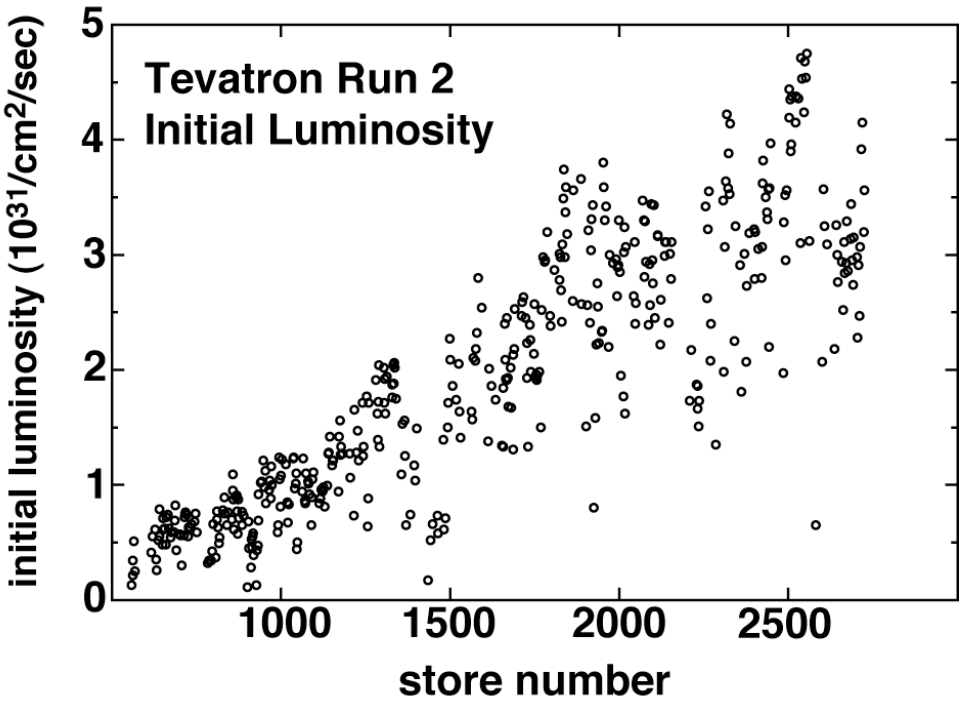
Z□ ee

W□ □□



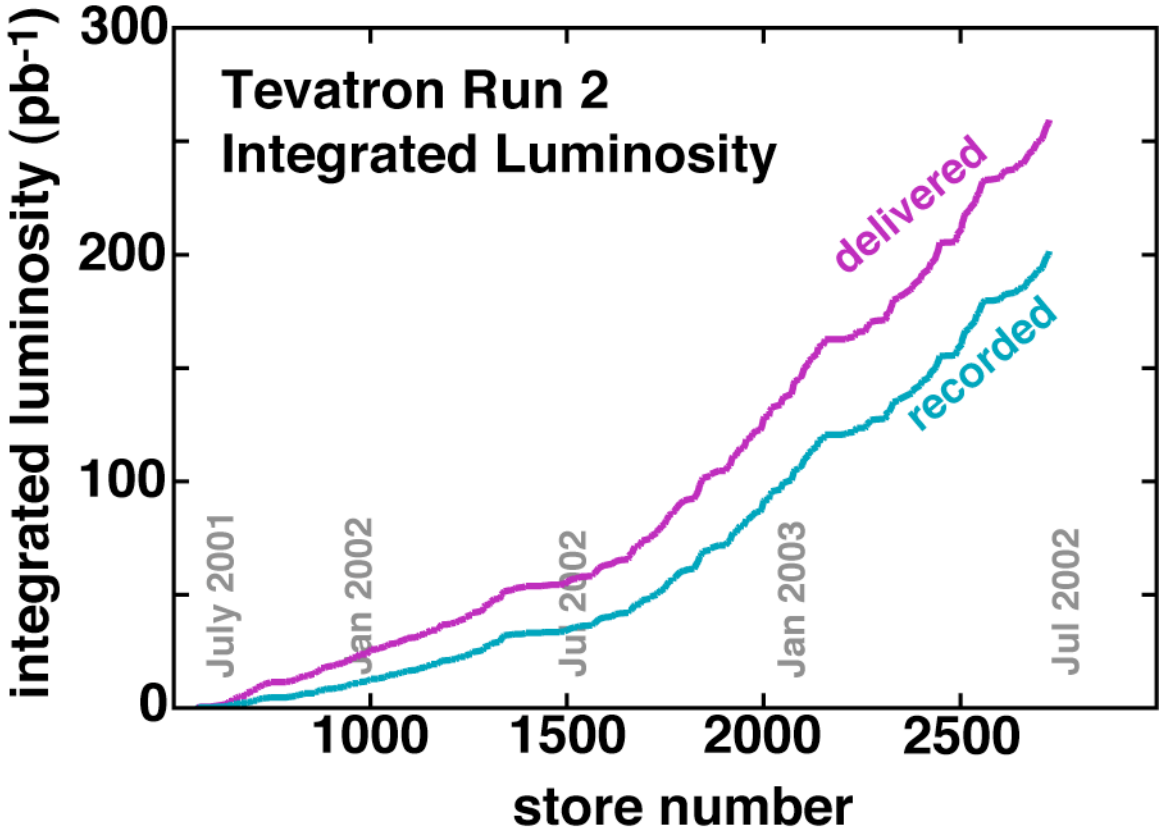
Tevatron Run 2

- Run 2 began in earnest mid-2001
- new Main Injector
- new Recycler ring
- 1.96 TeV cm energy
- 396 ns bunch crossing
- 36x36 bunches
- initial L: 3-5 x 10^{31} $cm^{-2}s^{-}$



Shutdowns, maintenance, beam-beam interactions, aperture restrictions, magnet alignment…nevertheless we have doubled the luminosity in the past year!

Tevatron performance

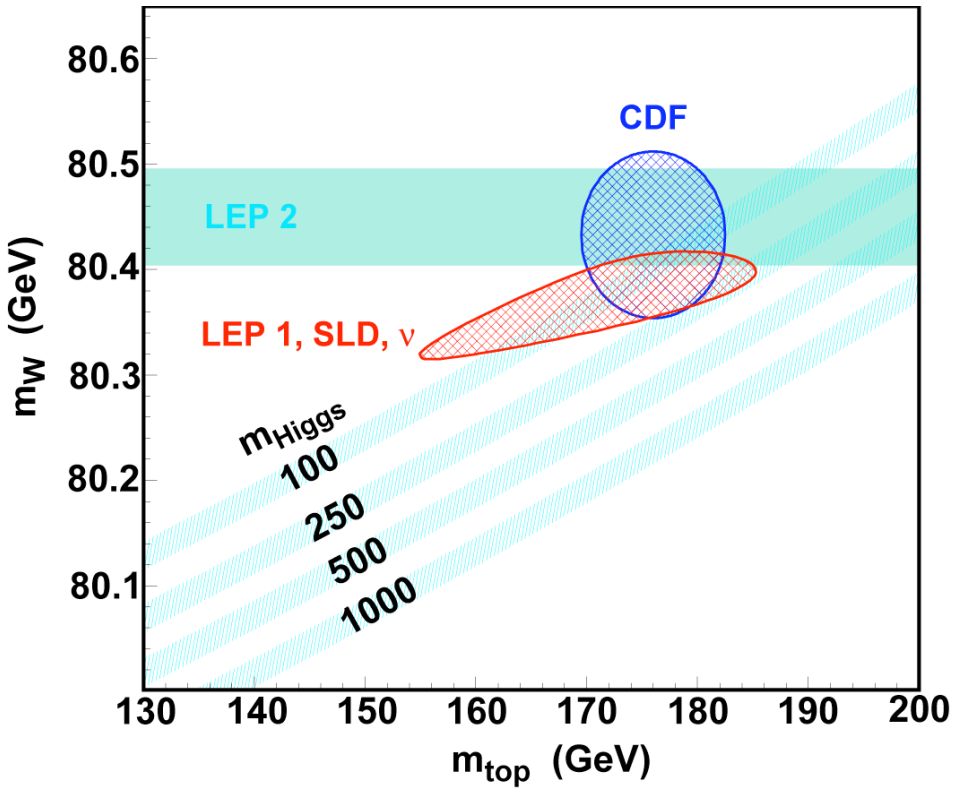


Seven week shutdown for NuMI construction, magnet alignment, maintenance starting 25 Aug 2003.

Hope for 5-6x10^{31} before then, double analyzable sample!

Top and W Masses

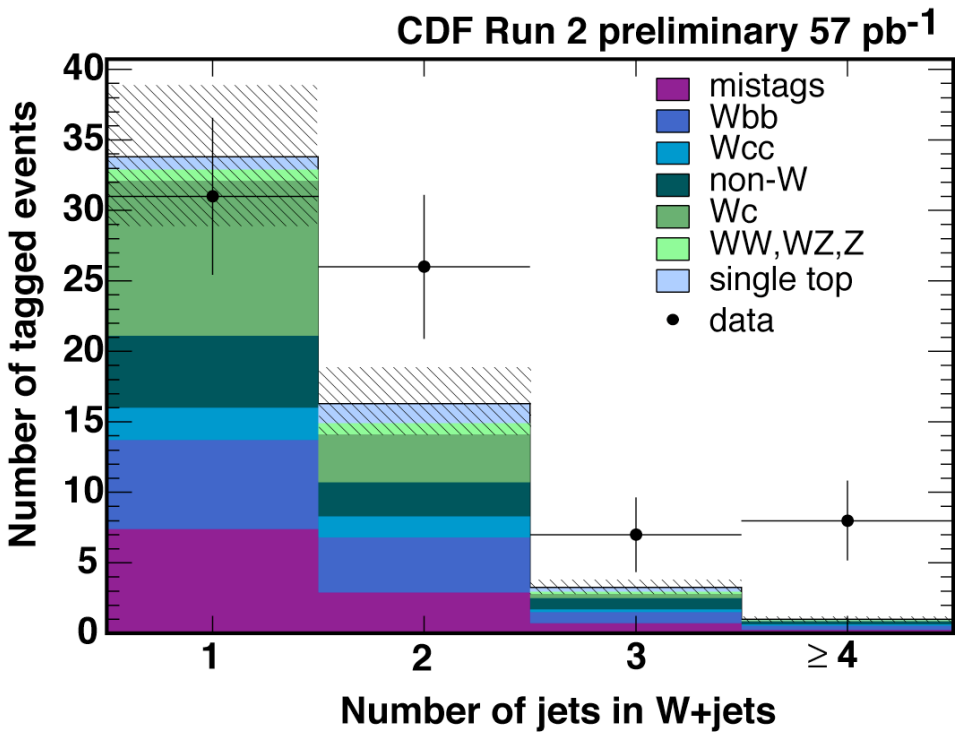
- initially at the Tevatron, we focus on measuring the mass of the W and top quark
- tight constraints on Higgs mass
- this is what CDF and D0 do best!

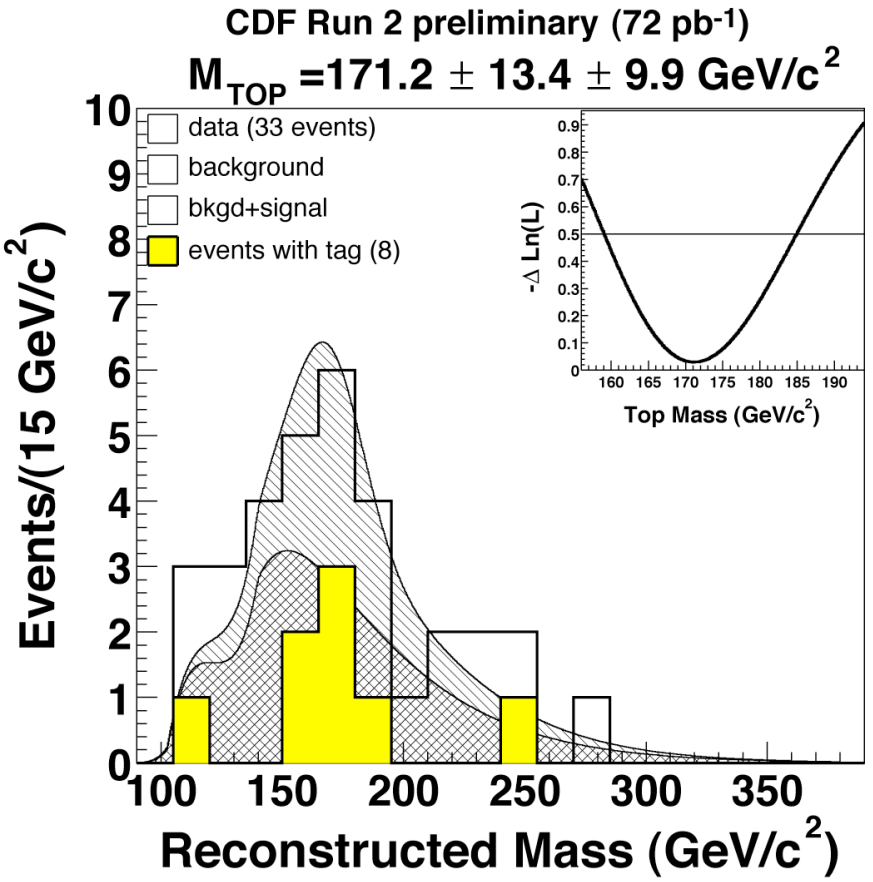


Lots of work to do on b tagging, jet energy reconstruction, mass reconstruction, understanding background…all of which is preparation for the direct Higgs search!

Top mass

✓"lepton plus jets" channel with b tagging is most sensitive to top

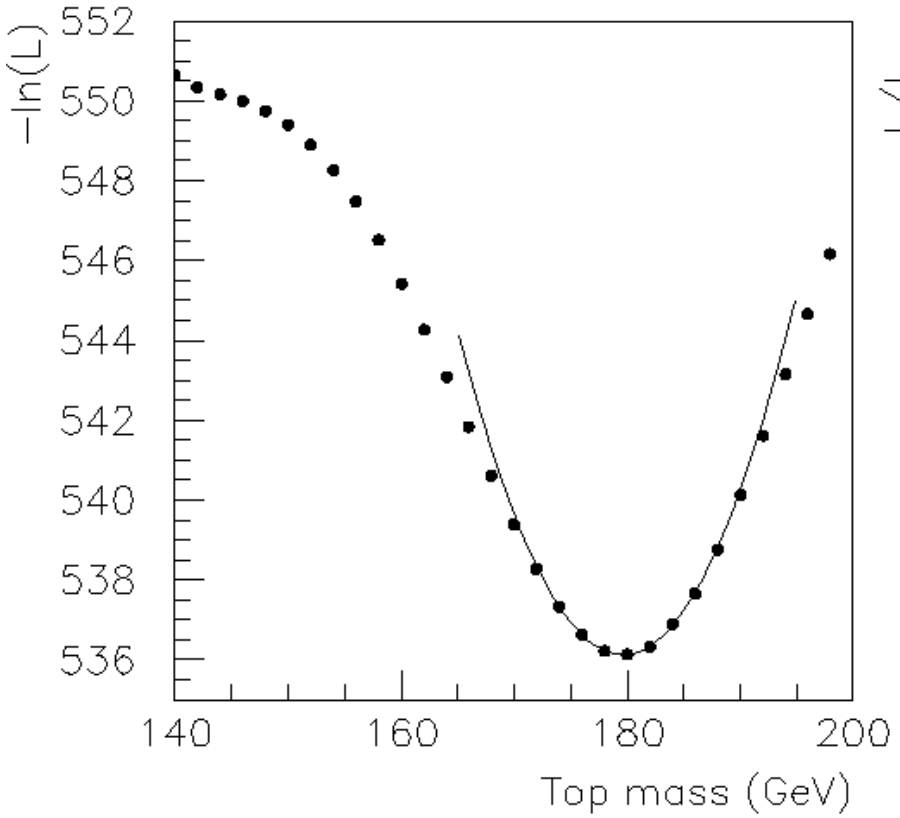


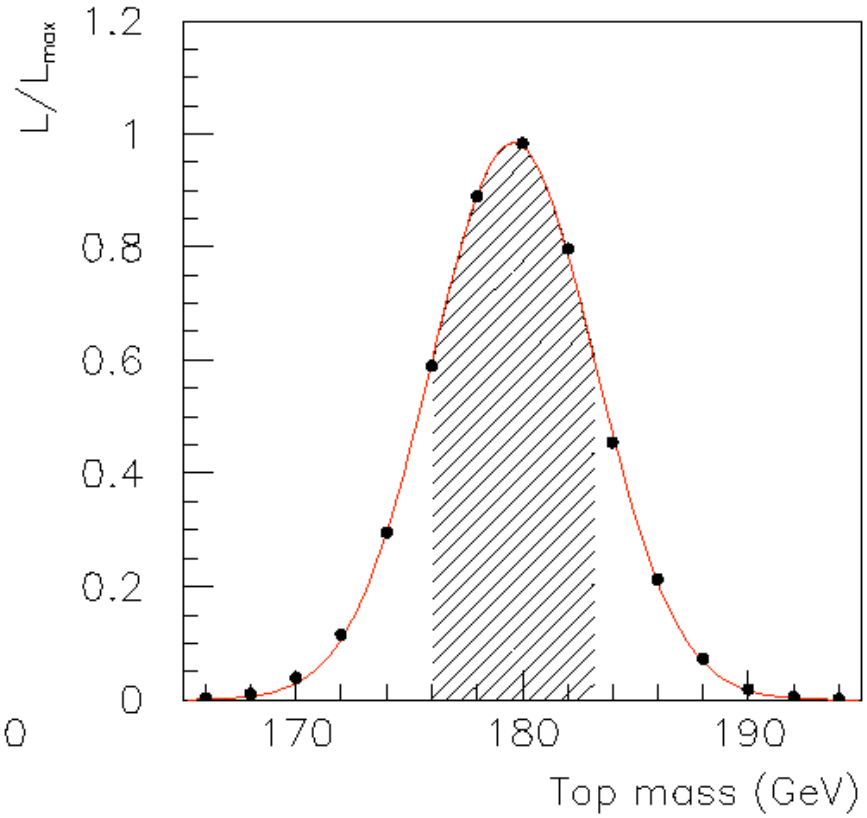


errors large now; due to calorimeter calibration

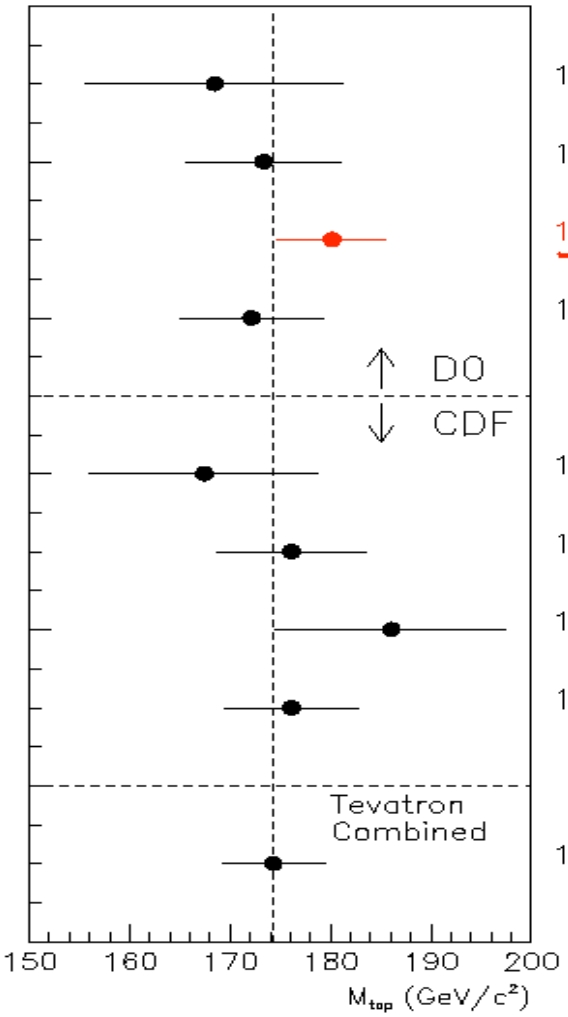
Top mass - new methods

- new method of top mass determination from D0
- uses multidimensional “transfer function” to correct
- improves D0 Run 1 error from 5.6 to 3.6 GeV!





Combined top mass (still Run 1)



single best measure

In Run 2a (2 fb^{-1}) we hope to get the total error, CDF+D0, down to about 2 GeV (?)

m_t=174±5 GeV

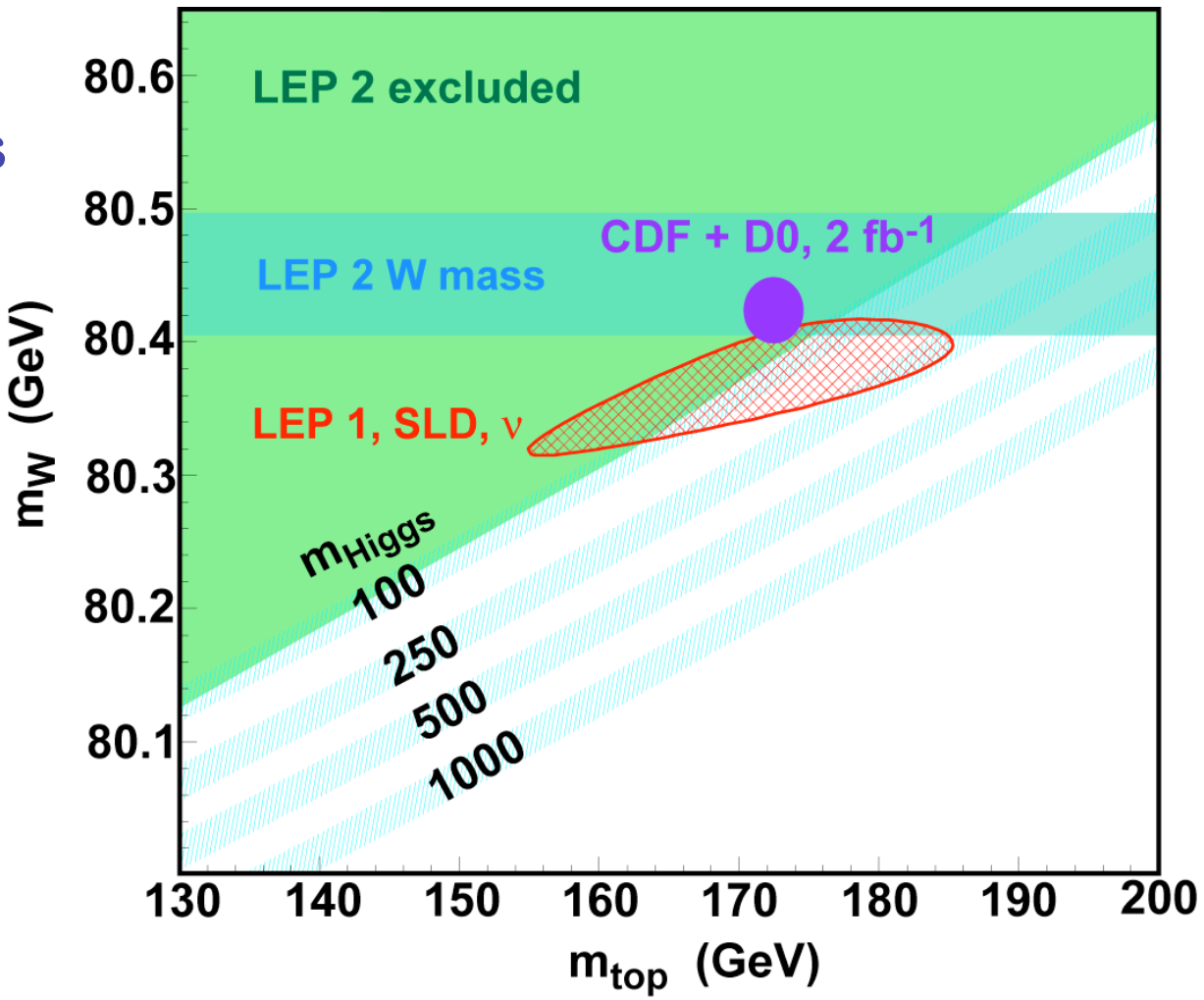
J. Estrada, F. Canelli theses

Combined Top/W Mass Projection

Suppose CDF and D0 measure the top and W masses as shown here:

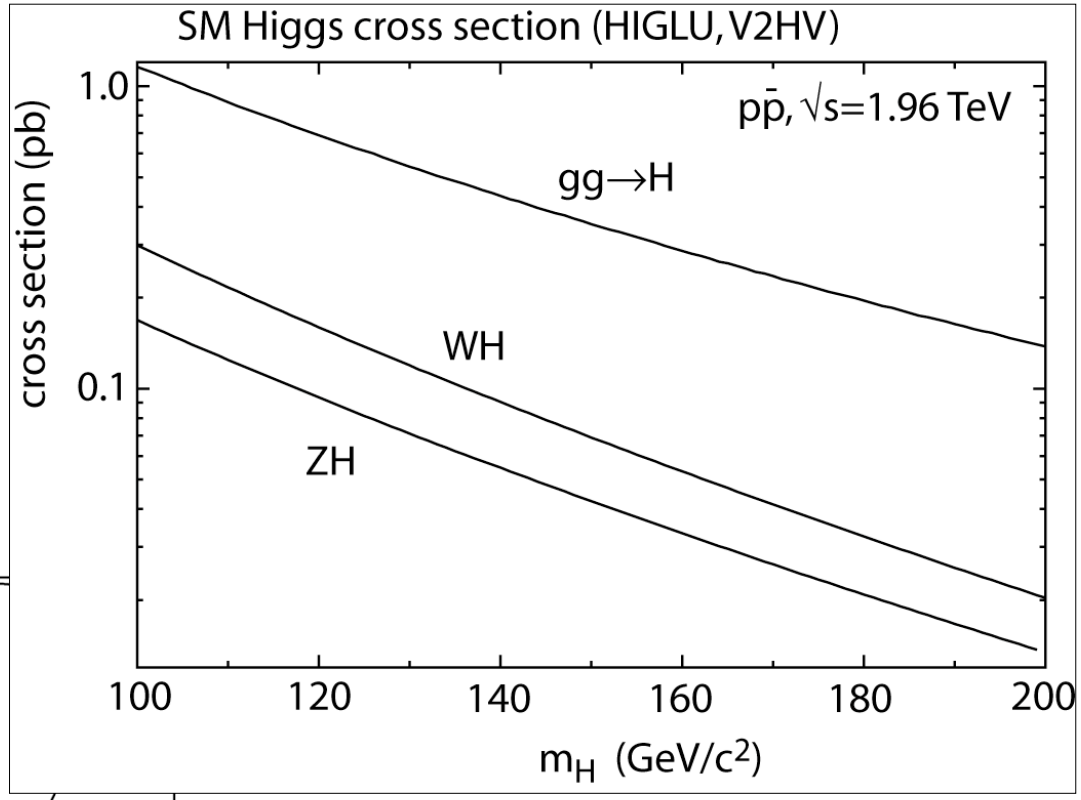
This would be evidence for new physics!

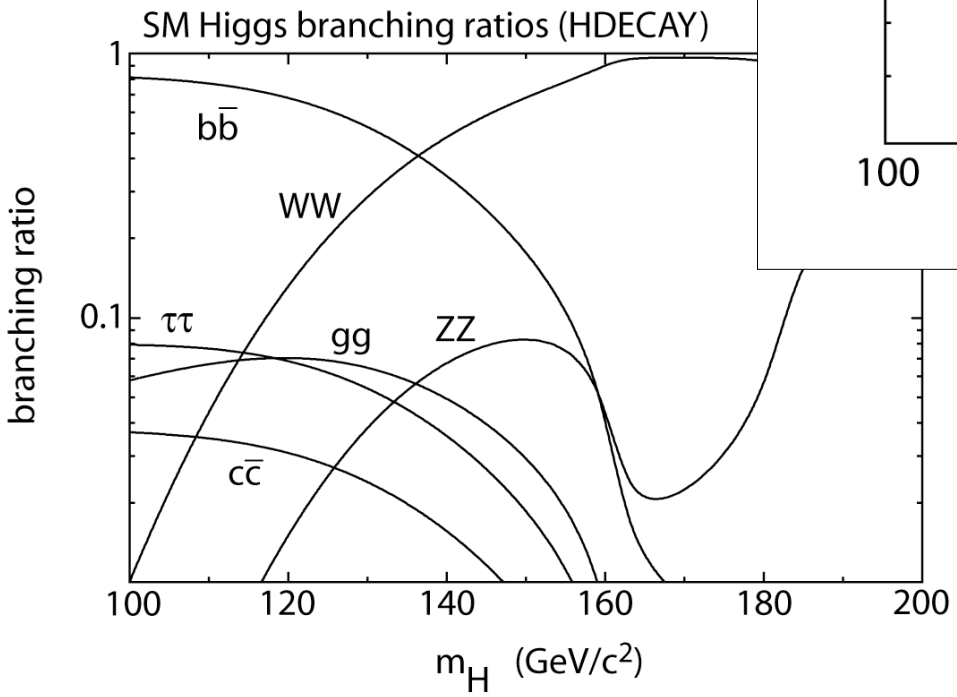
Lots of work to do to get to this point…exciting prospect!



SM Higgs Production

- gg H dominates but dijet background too big…
- bb decay modes are best!

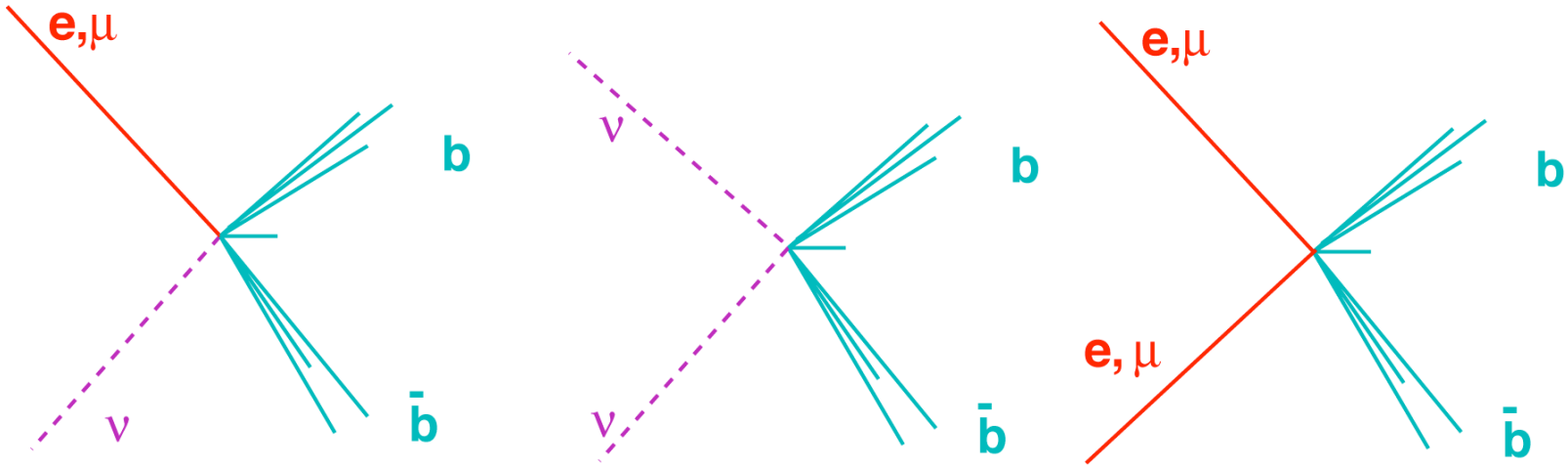




WH+ZH ~300 fb at 115 GeV

Search Channels - Low Mass

For m_H<135 GeV, bb decays dominate:



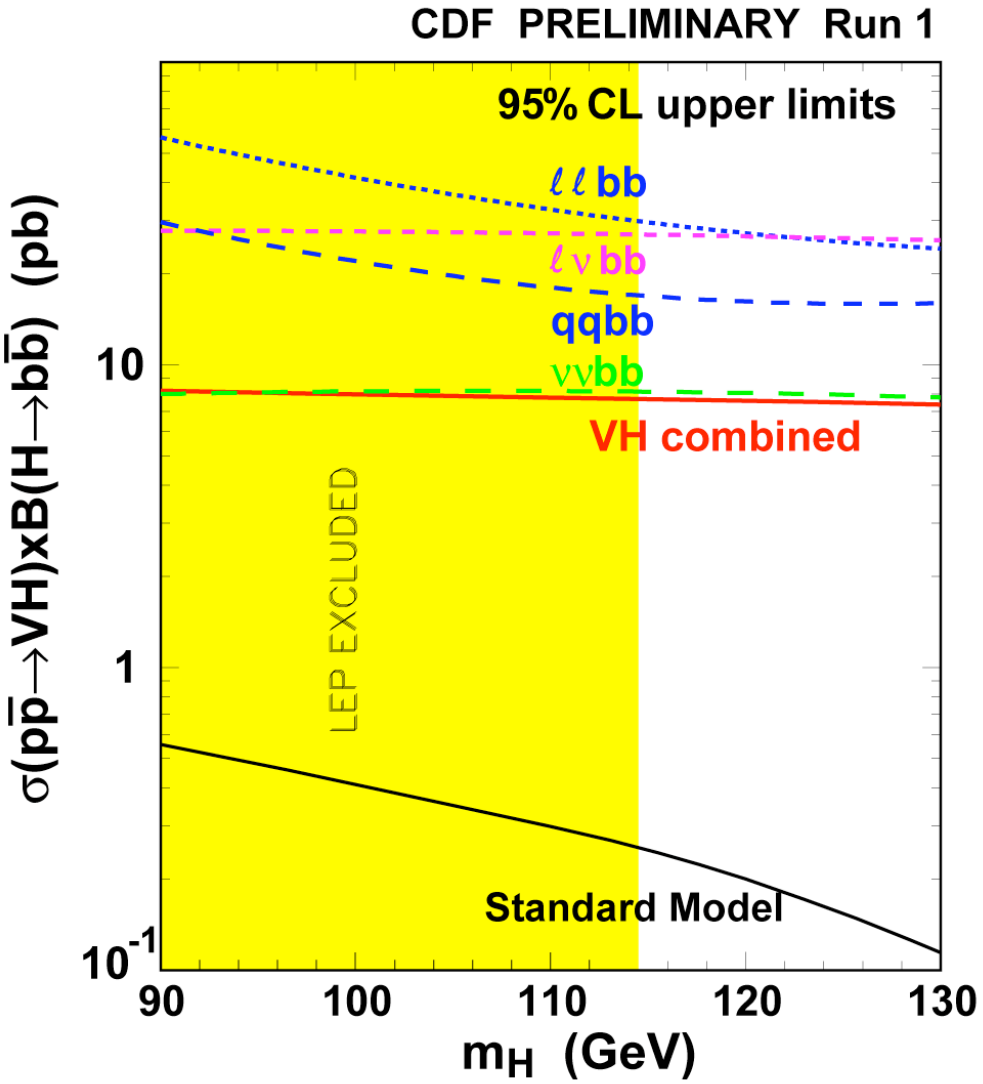
WH ZH

- clearly need excellent b tagging!
- need optimal bb mass resolution!
- need to understand background shapes!

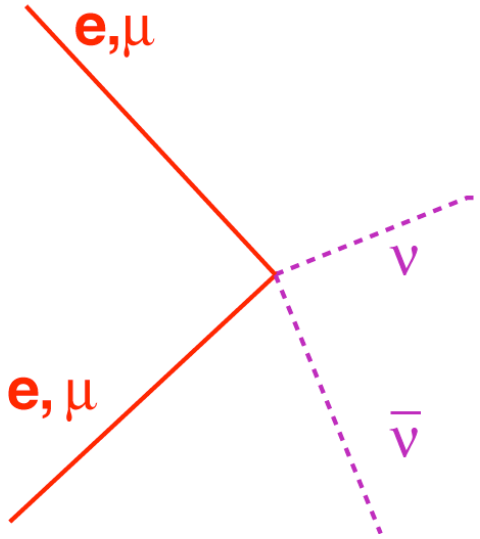
Run 1 combined limits - CDF

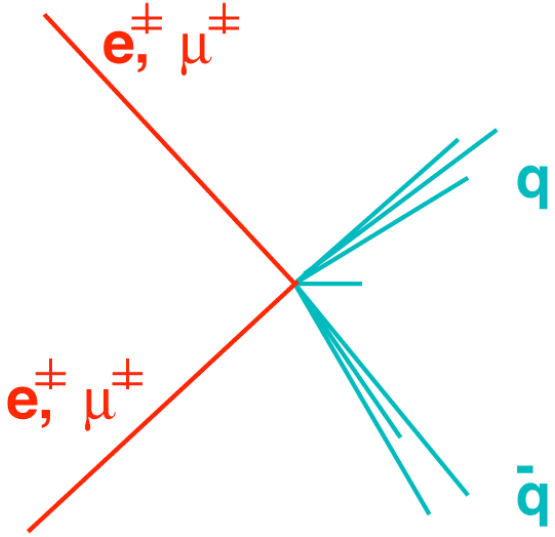
Slight fluctuation up in $\ell\nu$bb channel led to higher limit…

Still very far from SM cross section



Search Channels - High Mass

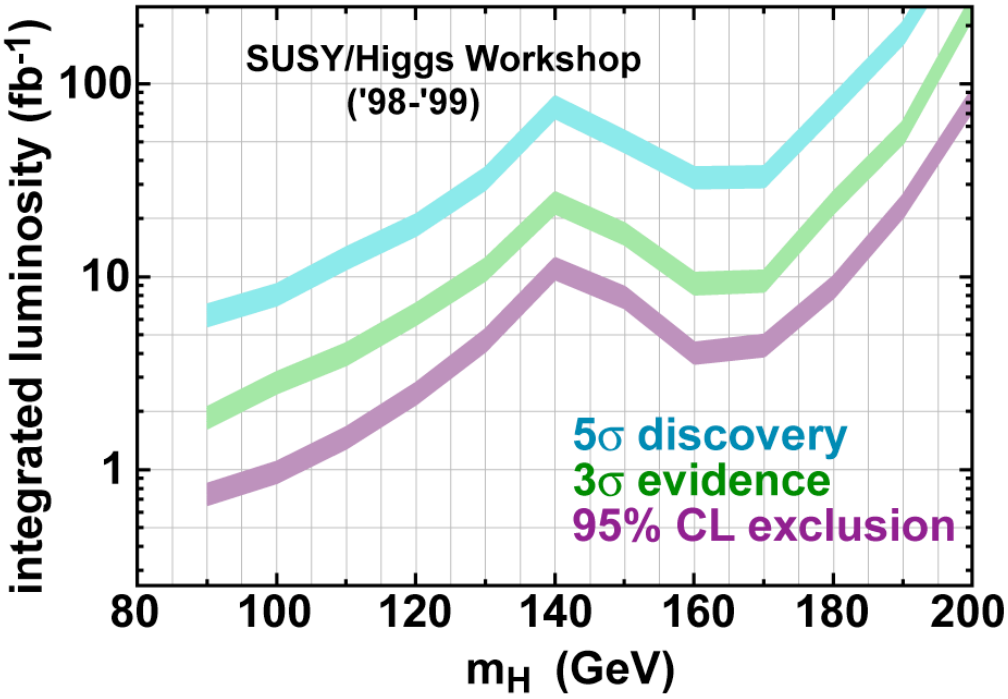




gg H WW ℓℓ ZH/WH WWW/ZWW

(trileptons: rate too low)

98/99 Run 2 SUSY/Higgs Workshop



- parametrized fast Monte Carlo (no magnet or multiple interaction effects)
- neural network selection
- 10% mass bb mass resolution
- single-bin counting experiment
- nominal systematics

(see hep-ph/0010338)

2003 Higgs Sensitivity Study

- Asked by DOE Office of Science to review the previous study and re-evaluate our SM Higgs reach
- Now have full Monte Carlo, real data experience to draw upon
- Short time: split work between CDF and D0 along lines of “WH” and “ZH” channels
- Study completed two weeks ago and presented to DOE

VERY PRELIMINARY! RESULTS MAY CHANGE!

Neural Net Selection

Since SHW study, have performed an analysis in CDF to see if we can reproduce enhancement in the $\ell\nu$bb channel. (Chris Neu, OSU, thesis in prep.)

Find that application of NN in this channel reduces integrated luminosity required by x1.6.

ZH channel: D0 HSC study group finds big improvement in missing energy channel:

Required integrated luminosity reduced by x2.25.

b Tagging

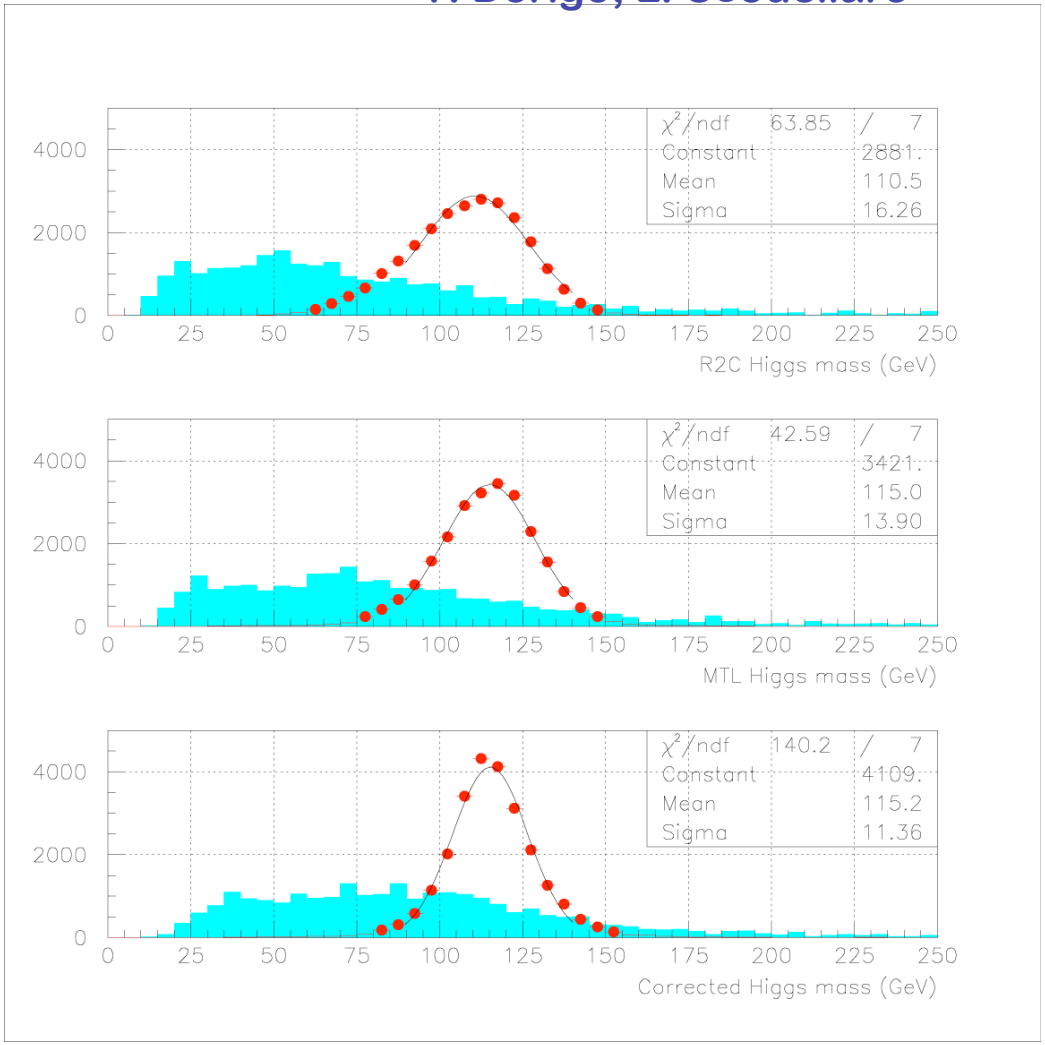
Higgs Mass (GeV/c^2)	110	115	120	130	140
$\geq$ 1 Secvtx (Win 2003)	0.484	0.491	0.496	0.492	0.499
Double Secvtx (Win 2003)	0.089	0.087	0.090	0.089	0.101
$\geq$ 1 Secvtx	0.552	0.554	0.557	0.568	0.579
1 Secvtx + 1 Secvtx.OR.JetPrb<0.05	0.185	0.184	0.191	0.194	0.202
$\geq$ 1 Secvtx (Extended η)	0.661	0.664	0.664	0.677	0.686
Double Secvtx.OR.JetPrb<0.05	0.279	0.279	0.290	0.300	0.314
SHWG Tight (No Eta Dependence)	0.712	0.712	0.710	0.721	0.723
SHWG Loose (No Eta Dependence)	0.347	0.343	0.351	0.359	0.372

- efficiency rises with jet p_T
- SHW assumed flat efficiency out to |□|=2
- HSC assumes drop-off at large □
- these efficiencies require new detectors!

Mass Resolution

T. Dorigo, L. Scodellaro

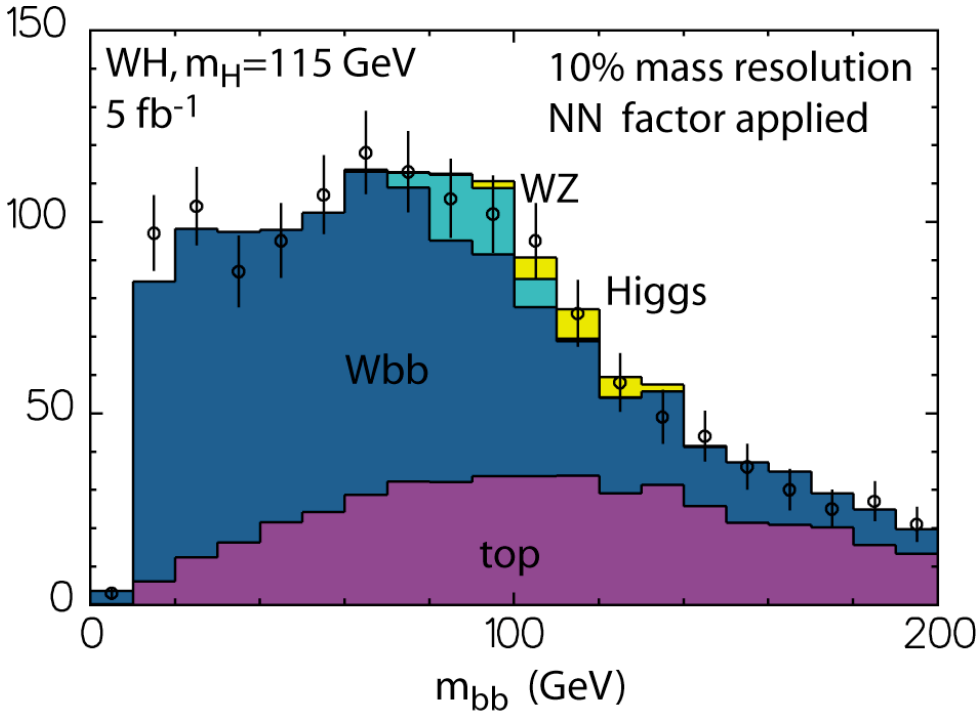
- "hyperball" algorithm: make mass correction in N-dimensional space of kinematic variables
- can get ~10% mass resolution!
- but need to find optimal point in sensitivity…



This study (and SHW) assumes 10% resolution

WH channel

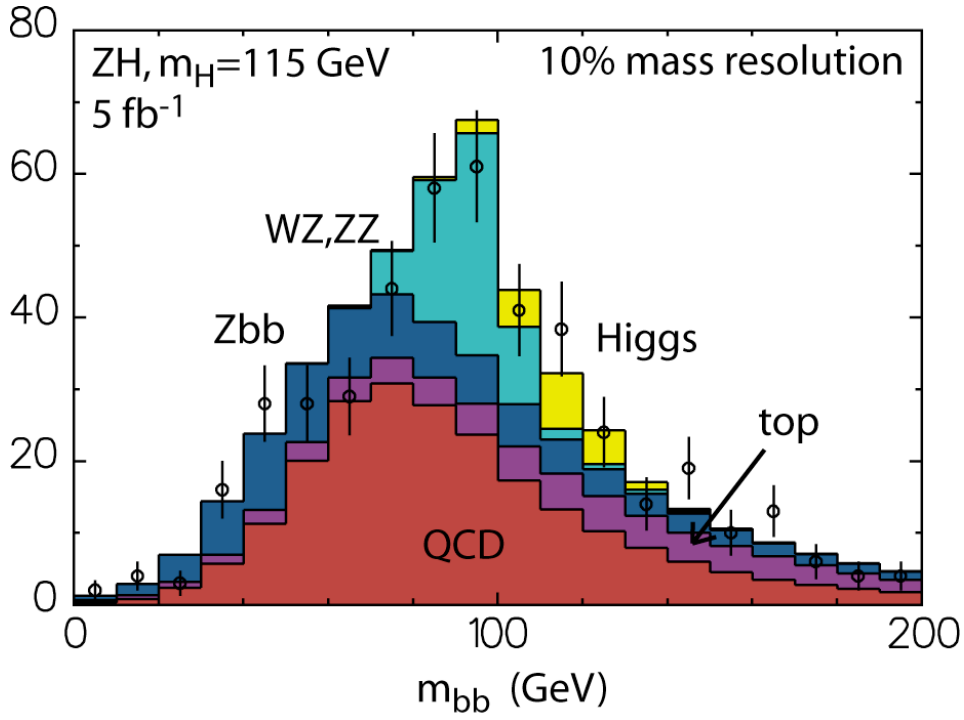
- assume SHW-level b tagging but declining at large eta
- 10% mass resolution
- signal and background scaled by a factor of 1.6 to account for effect of neural network-type selection



To do this channel, need to control background shape very accurately.

ZH channel

- incorporate $\ell\ell$bb by scaling signal and background by 1.33
- use NN for selection
- QCD background from real data!
- sensitivity a bit better than SHW report
- significant acceptance from WH process!



Need to ensure that there is no acceptance overlap with ℓ□bb channel

Final Result Combining Channels

Perform pseudoexperiments in which CDF and D0 each have WH and ZH outcomes.

Form joint likelihood using full m(bb) distributions in both channels. (Can integrate out systematics.)

Scan in luminosity, determine fraction of experiments meeting 95% CL exclusion, 3- and 5-sigma discovery.

Two methods used in determining statistical level:

- Bayesian with flat prior (as in SHW report)
- CL_s a la LEP 2 Higgs search

The two methods agree within ~10% in luminosity.

Likelihood function

Joint likelihood formed from product of Poisson probability in each bin (i) in the mass spectrum over all channels (j), with Gaussian constraints on the source cross sections (k) in each channel:

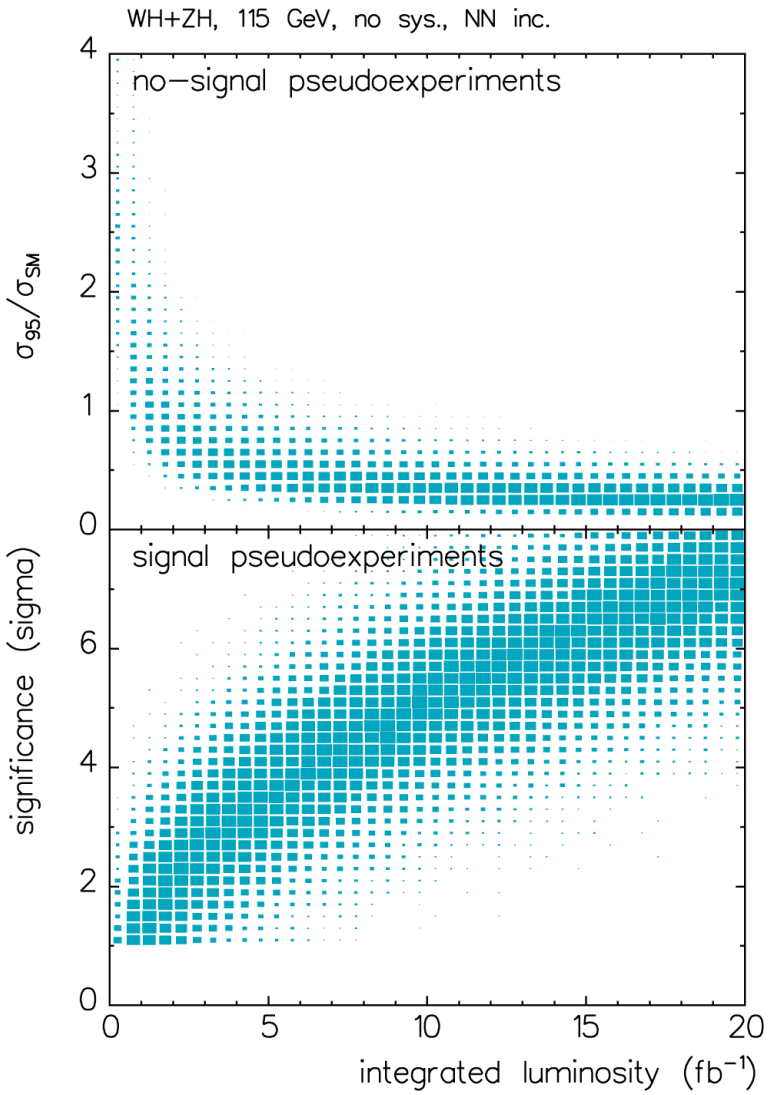
$$L(s) = \prod_{j=1}^{n_{ch}} \prod_{i=1}^{n_j} P(n_{ji} \mid \mu_{ji}) \prod_{k=1}^{n_{jk}} G(\theta_{jk}, \tilde{\theta}_{jk})$$

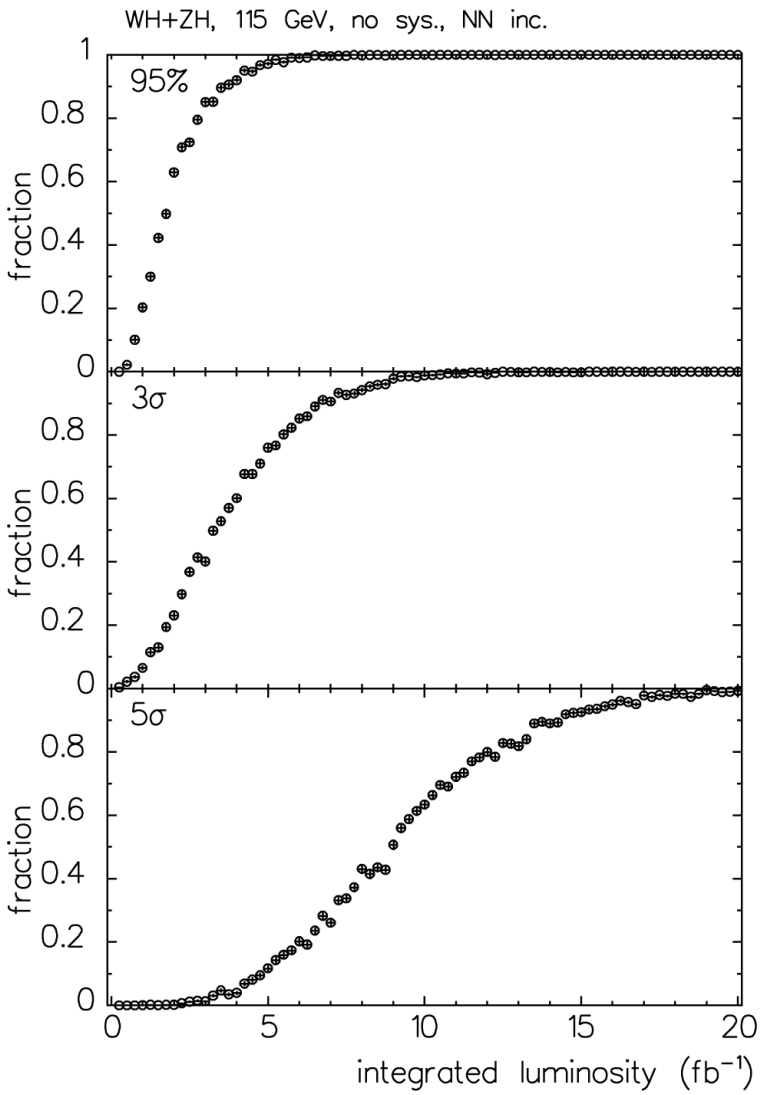
where the number expected in each bin (ji) is

$$\mu_{ji} = \sum_{k=1}^{n_{jk}} L\sigma_{jk}\varepsilon_{jki} \quad \text{with } \mu_{j1} = s \ \text{(Higgs signal rate)}$$

Bayes method: integrate out everything except Higgs cross section

Pseudoexperiments at 115 GeV

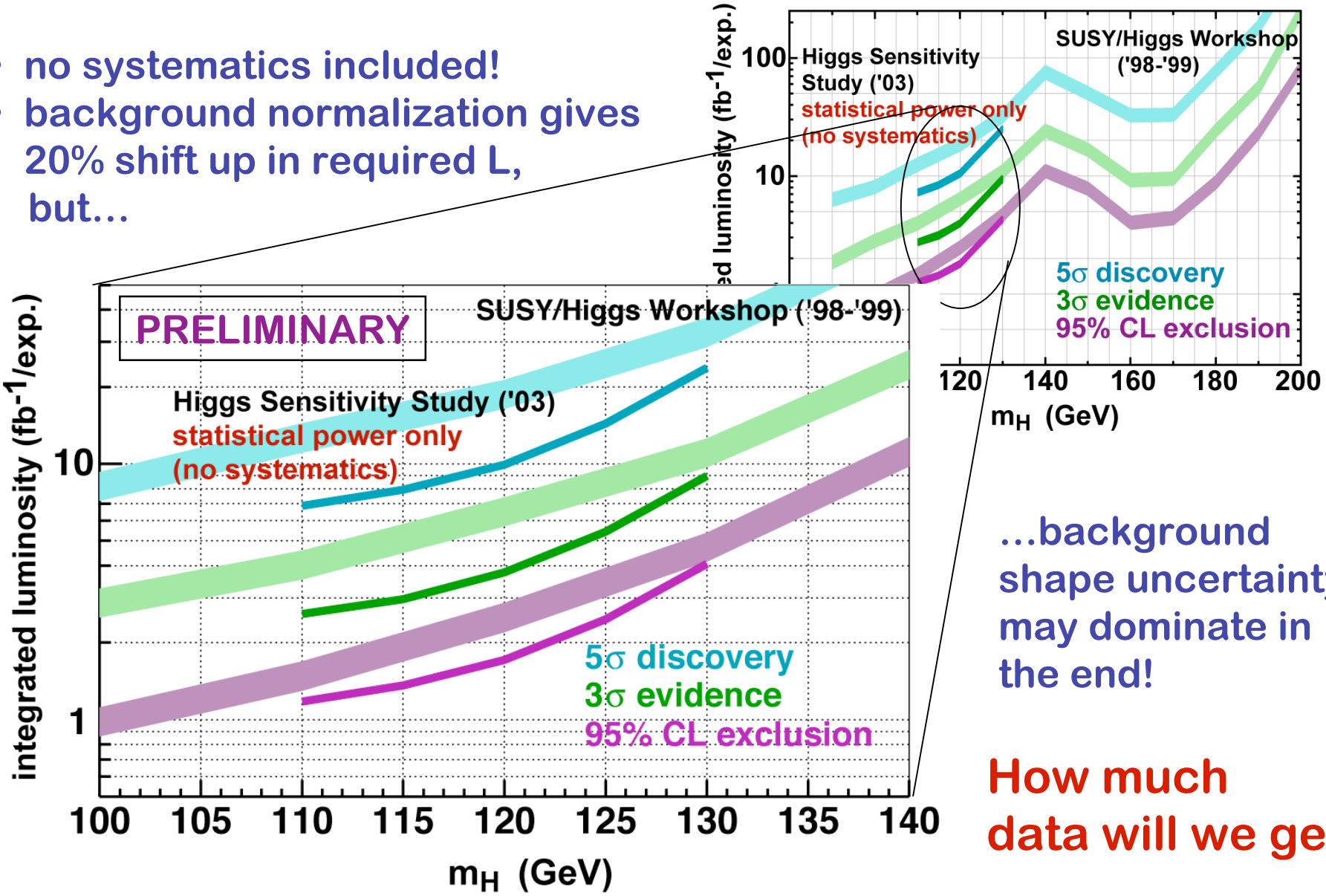




Turn-on occurs over a rather broad range!

Revised SM Higgs Reach Estimate

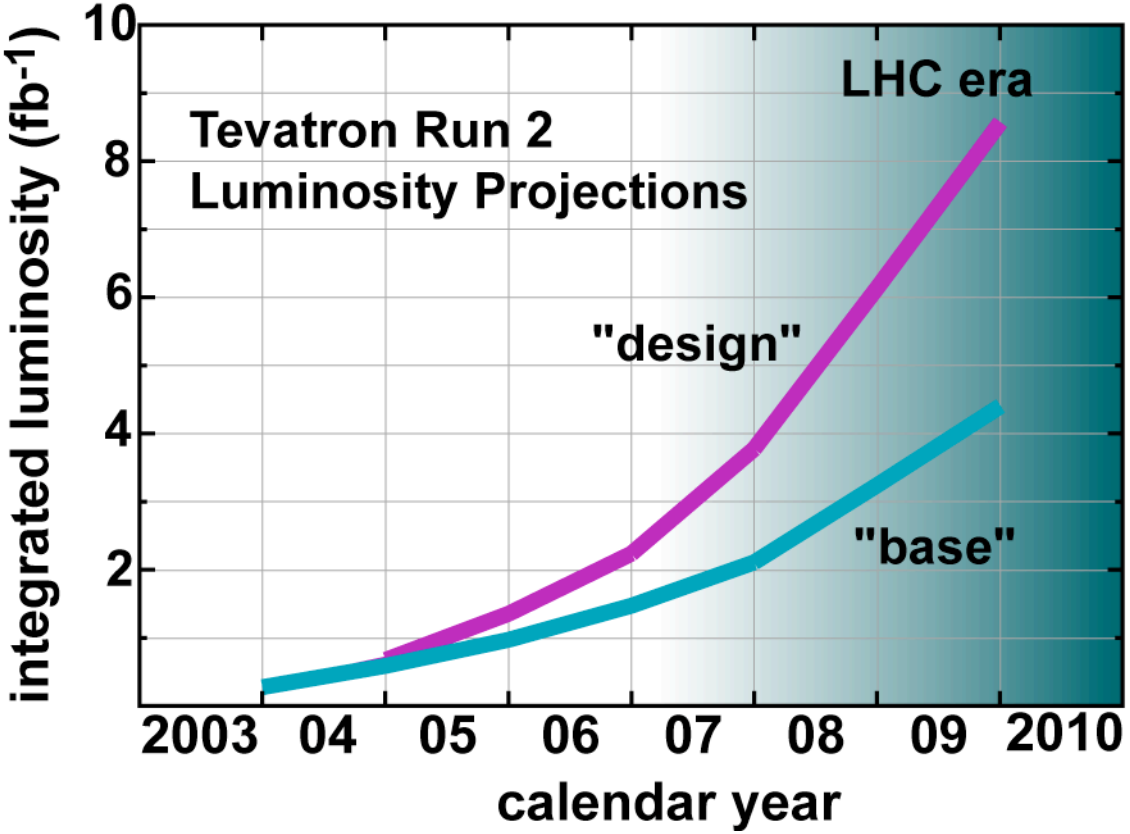
- no systematics included!
- background normalization gives 20% shift up in required L, but…



…background shape uncertainty may dominate in the end!

How much data will we get?

Tevatron Run 2 Projections



- report presented June 15 to DOE
- basis for July Lehman review
- "design" goal requires electron cooling in Recycler
- includes shutdown for CDF/D0 silicon installation (2006)

4-5 fb^{-1} by LHC turn on?

Tevatron in the News

Key sub-atomic particle slips away again

10:00 30 June 03

Exclusive from New Scientist Print Edition. Subs

The most elusive particle in physics has skip
Pinning down the Higgs boson, or proving tha
huge step towards understanding why our Ur

But fresh predictions from Fermilab, home to
particle accelerator, have dashed hopes of a
the next six years.

Current understanding of the Universe is sur
standard model, but this lacks any explanatio
The popular Higgs theory says that a gooey
Universe and endows matter with mass throu

So finding the Higgs has become a matter of
confirm the theory, while disproving its existe
new theory, such as a slew of higher dimensi

"It is one of the most important discoveries in
former spokesman for one of the collaboratio
Tevatron accelerator in Batavia, Illinois.

Below-par performance hampers Fermilab quest for Higgs boson

Geoff Brumfiel, Washington

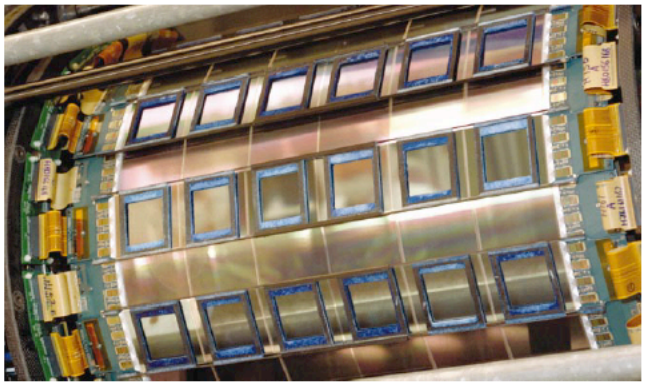
Physicists at the Tevatron particle accelerator near Chicago are steeling themselves for failure in their ambitious bid to detect the elusive Higgs boson.

Researchers working on the machine, at the Fermi National Accelerator Laboratory (Fermilab) in Batavia, Illinois, are searching for signs of the particle, thought to give other particles their mass, in the debris of high-energy particle collisions.

But they have now cut their estimate of the number of proton–antiproton collisions they expect to see by 2008 by 60–80%. As many collisions have to be studied to detect the Higgs boson, this is a serious blow to the lab's hopes of observing the particle.

The figures appear in a document prepared for Fermilab's sponsor, the US Department of Energy, and released on 15 June. Stephen Holmes, associate director for accelerators at the lab, says that problems have arisen with the equipment used to accelerate the protons and antiprotons. The Tevatron is 20 years old and its accelerators have been plagued by trouble during 'Run II', an upgraded second phase of operation that began in 2001.

The news is forcing Michael Witherell, Fermilab's director, to reconsider funding for Run II, which consumes nearly two-thirds of the lab's $300-million annual budget. "We have to make some tough choices," he says.



Poor results mean that Fermilab may not splash out on new silicon wafers for its particle detectors.

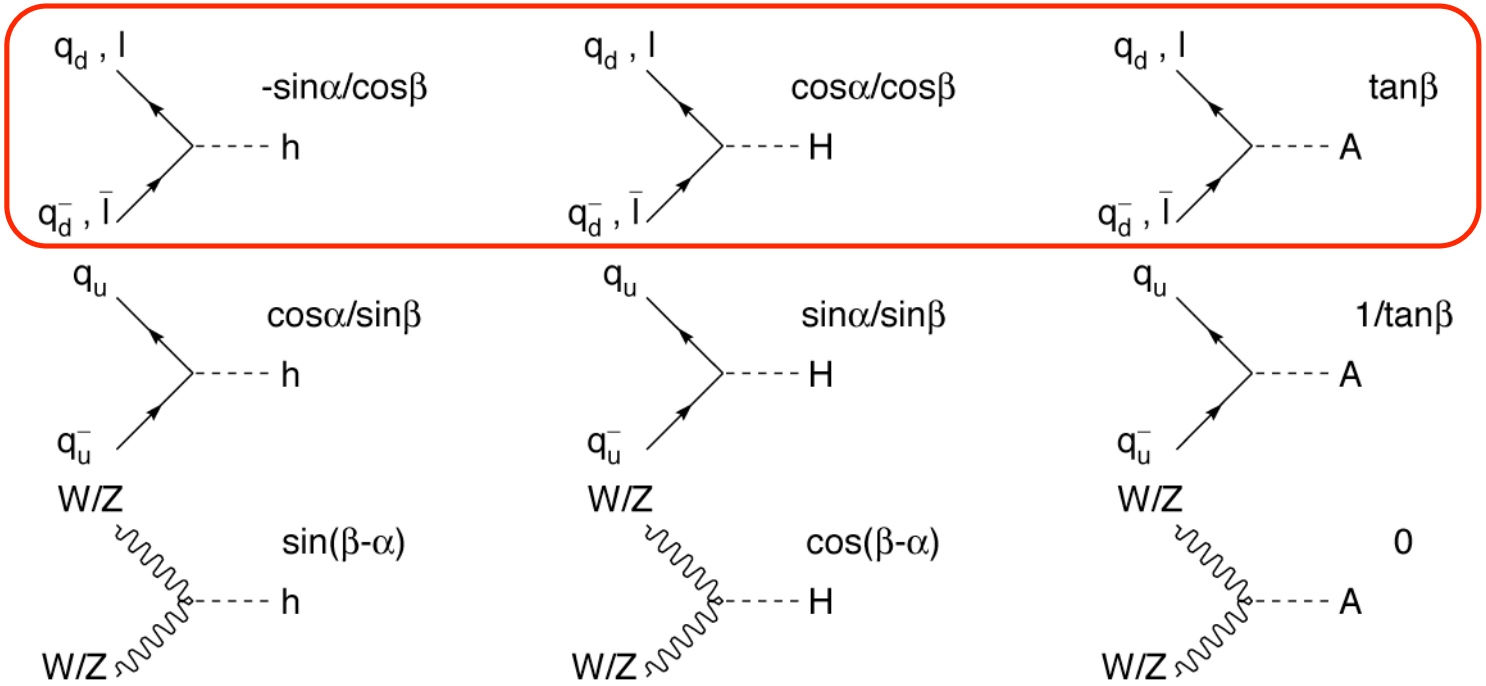
Witherell says he may have to withhold $25 million needed to replace the detectors' silicon wafers, which create electrical signals when hit by particles. Researchers warn that this could severely impair the detectors' performance.

Many observers doubt whether the Tevatron will be able to find the Higgs boson before the rival Large Hadron Collider comes online in 2007 at CERN, the European particle-physics lab near Geneva. Witherell puts the chance of spotting the Higgs at "something like 50%". Others disagree: "I don't think there's any chance they will find it," says CERN physicist Daniel Froidevaux.

Many Fermilab researchers admit that they placed too much emphasis on finding the Higgs. Now, they say, they need to draw attention to their other research, such as studies of the top quark, a subatomic particle that was discovered at the lab in 1995. "I think we need to get some buttons out there that say: 'Run II, it ain't just the Higgs'," says Holmes. ■

Grrrr….it's not all about the Higgs!

MSSM Higgs at the Tevatron

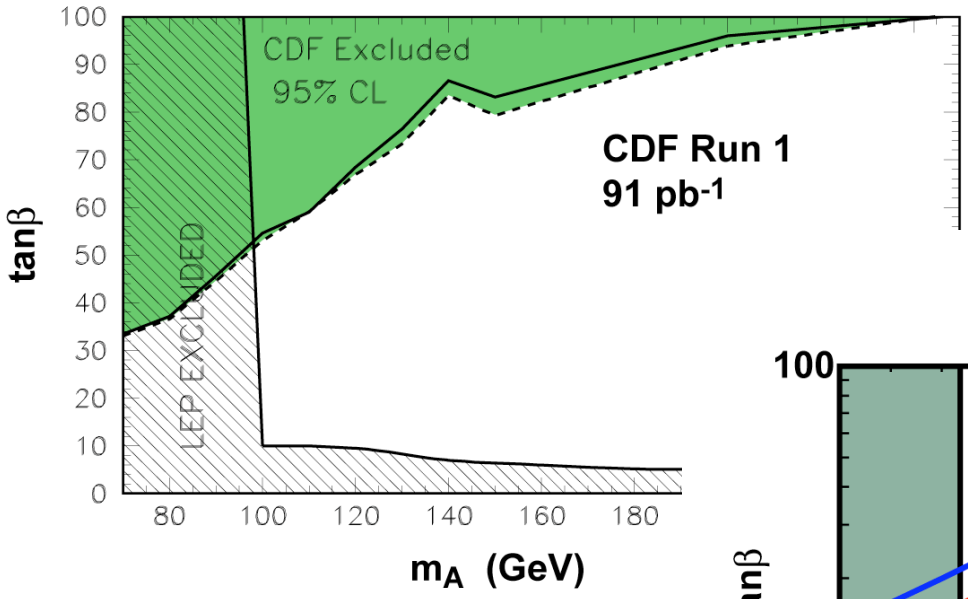


Top row leads to enhanced production at large tan

(pp bbH/bbA/bbh) μ tan^2

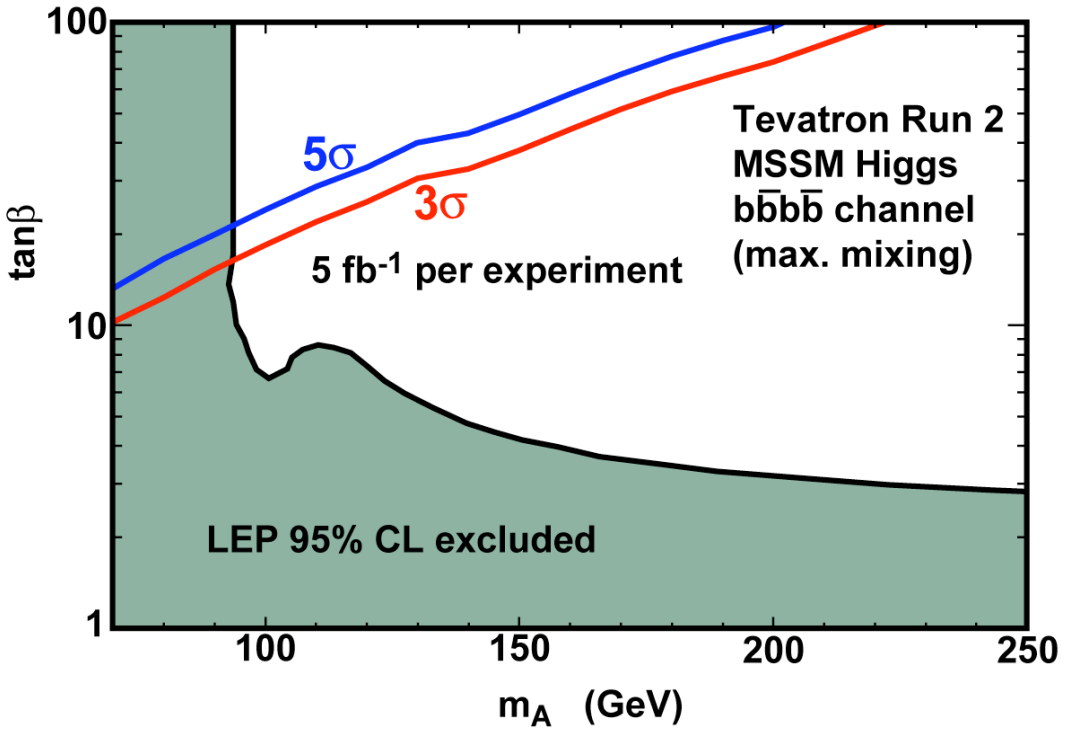
We are already probing new territory!

MSSM Higgs + b(b)



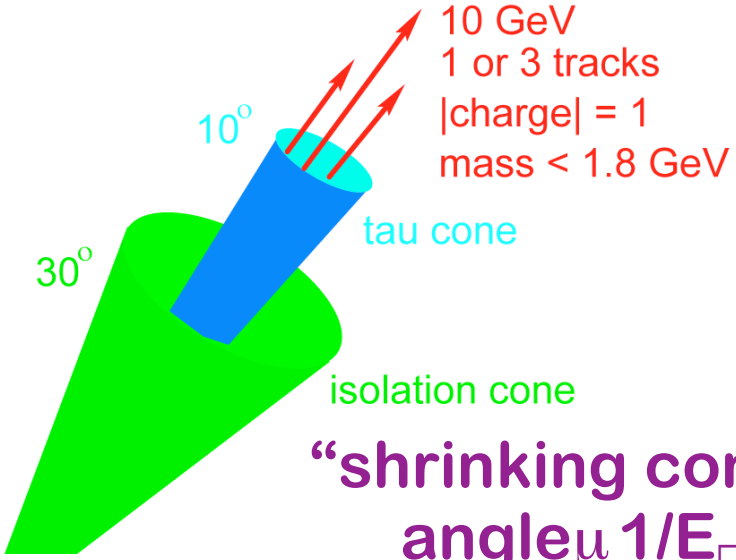
CDF Run 1 result from four-jet trigger; 3 tags

Run 2 projections based on same trigger; will likely do better win new three-jet trigger

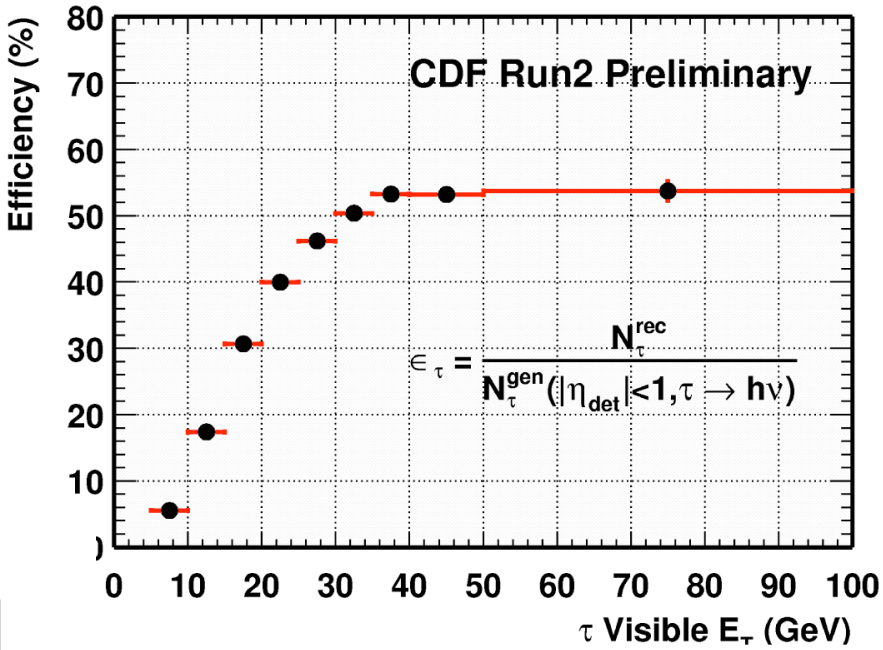


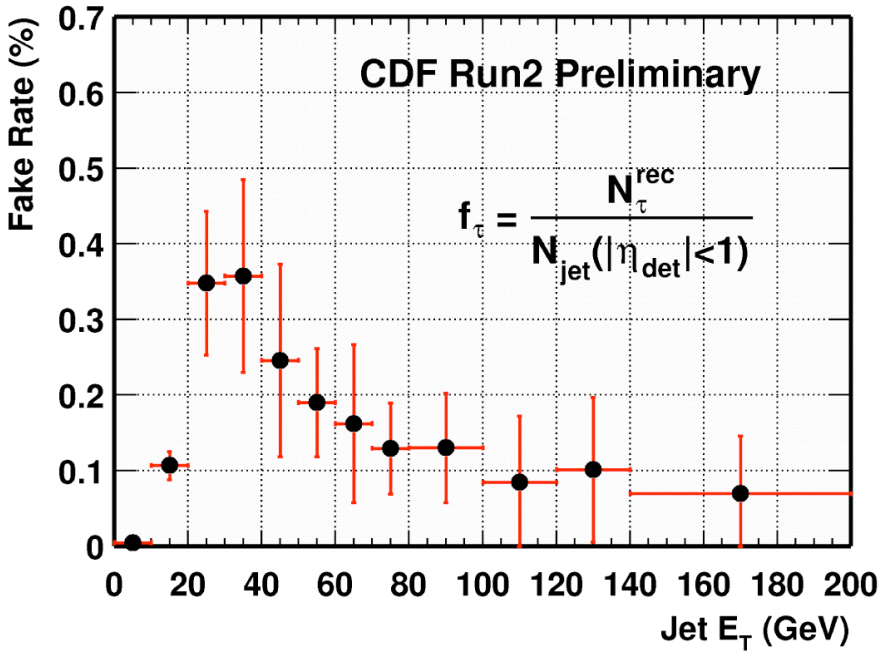
Willenbrock et al: enhancement for Higgs+b (hep-ph/0304035)

What about Taus?



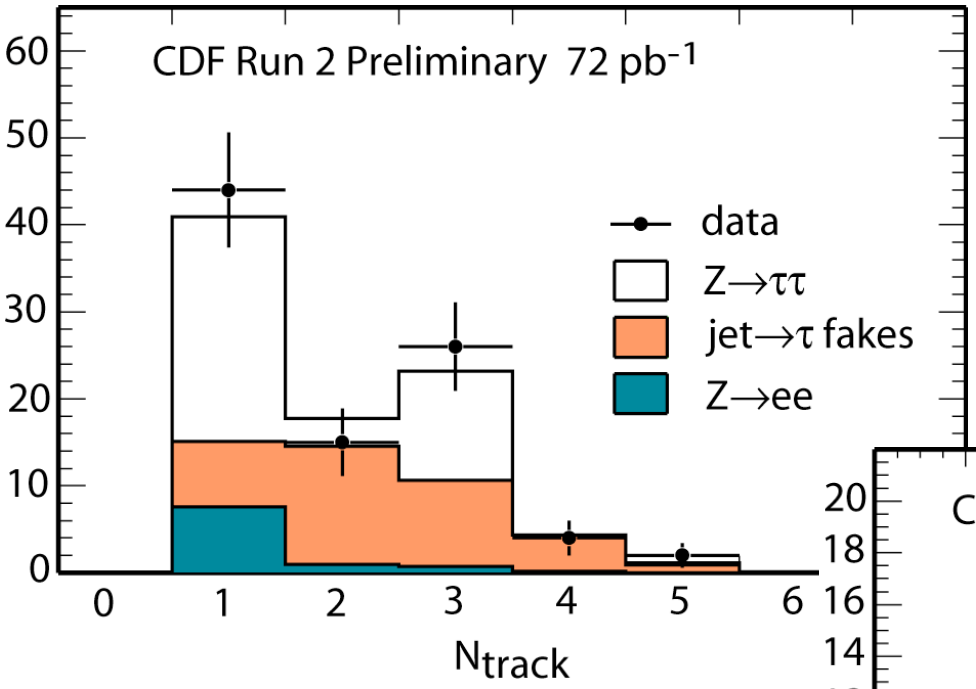
"shrinking cone" angle μ 1/E_{τ}





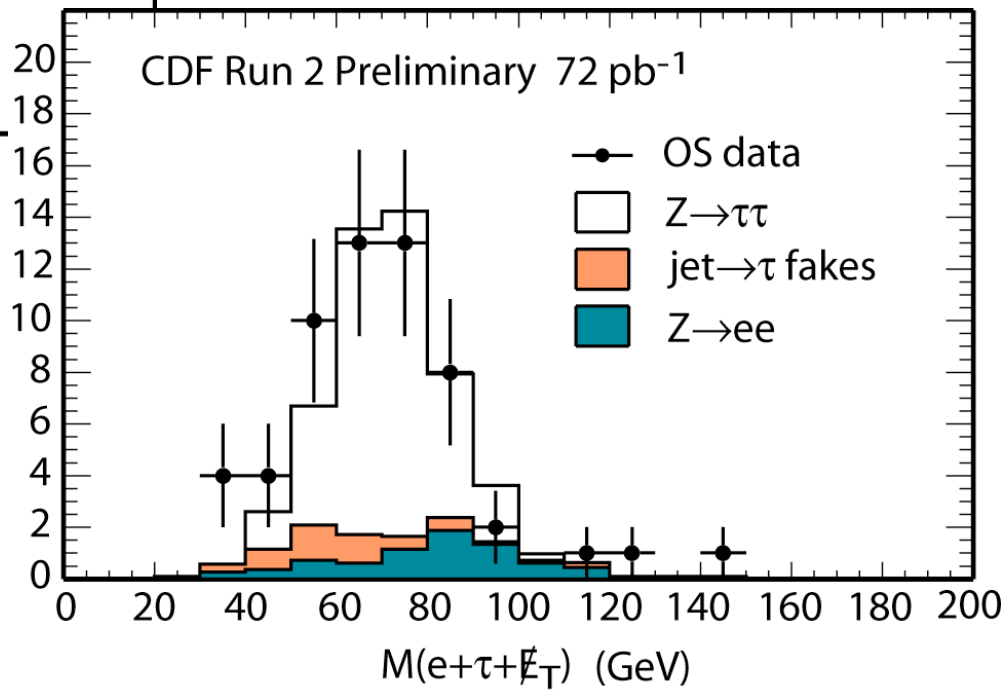
Greatly reduced fake rate compared with Run 1

H□ □□



e+□channel

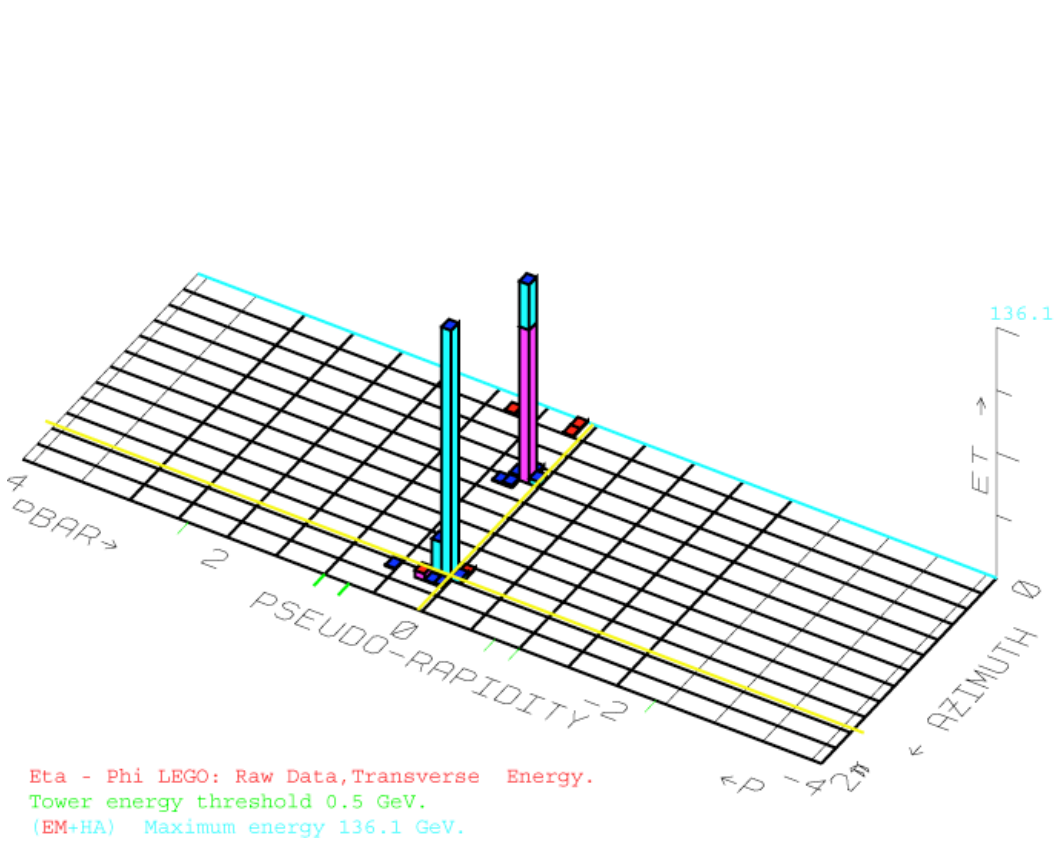
Use track multiplicity to constrain jet to tau fake rate

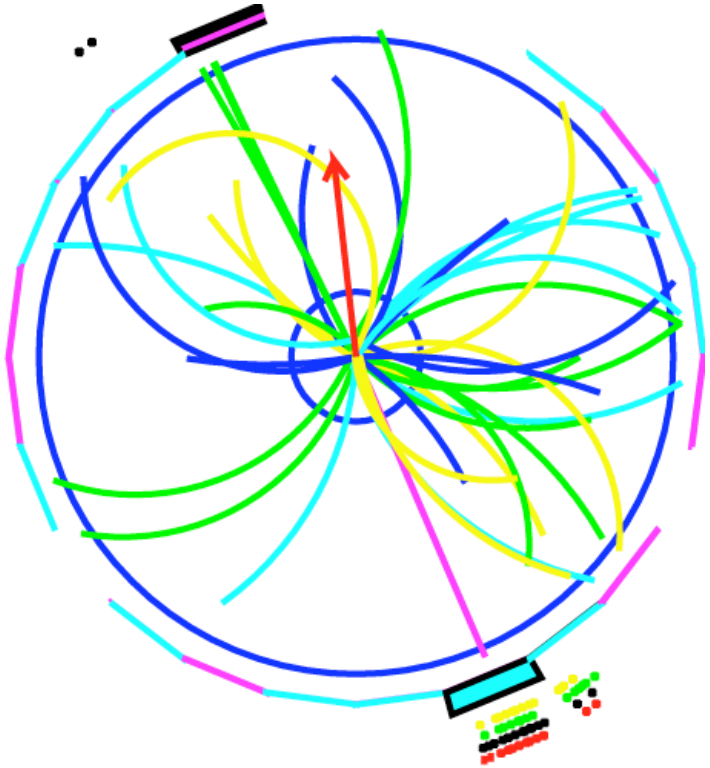


Plot mass of e, tau, and missing E_T

Results soon on high mass tau pair search!

Run 1 high mass tau pair





Extraordinary event! Will we see more?

Summary

- Tevatron experiments now nearing 2x Run 1 data sample, and running well: time to break new physics ground!

- First goal: measure top and W mass

- Reevaluated SM Higgs reach - similar to SHW study

  - need great b tagging (new detectors!)
  - need to develop excellent bb mass resolution
  - need to tightly control backgrounds
  - still will not have 5 sigma discovery…

- Can now start on MSSM Higgs!