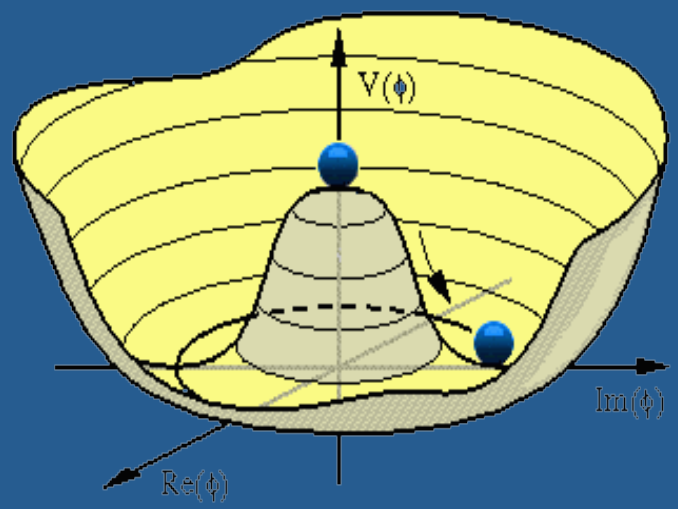
Physics Case for 'Beyond 2011'

The Missing Piece

In the Standard Model, the Higgs field is a complex scalar field, V(φ):

Through Electroweak Symmetry Breaking, the gauge bosons (W, Z) acquire mass.



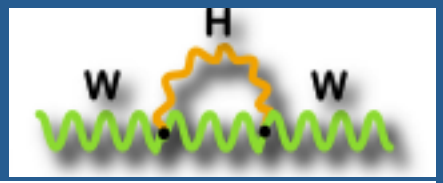
A single Higgs boson with spin 0 appears. The only free parameter is its mass.

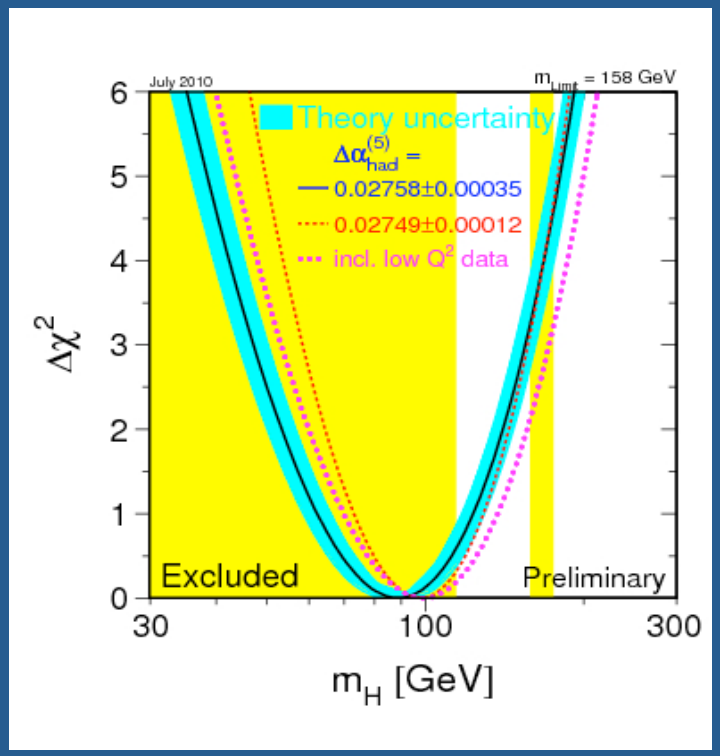
The Higgs is key to understanding Electroweak Symmetry Breaking,, the most important question in Particle Physics.

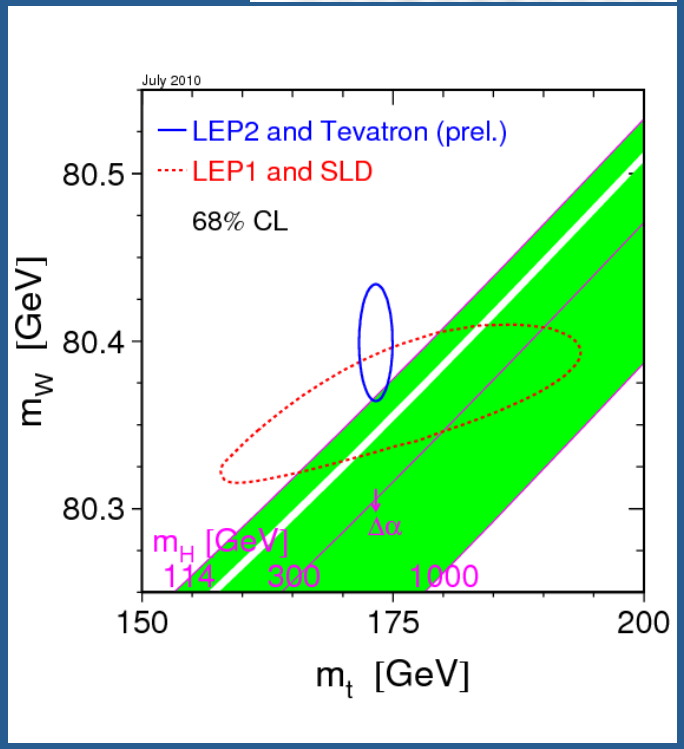
Not finding the Higgs boson will contradict the Standard Model and revolutionize particle physics…

Squeezing the Higgs

$M_H < 185$ GeV, incl. LEP limits

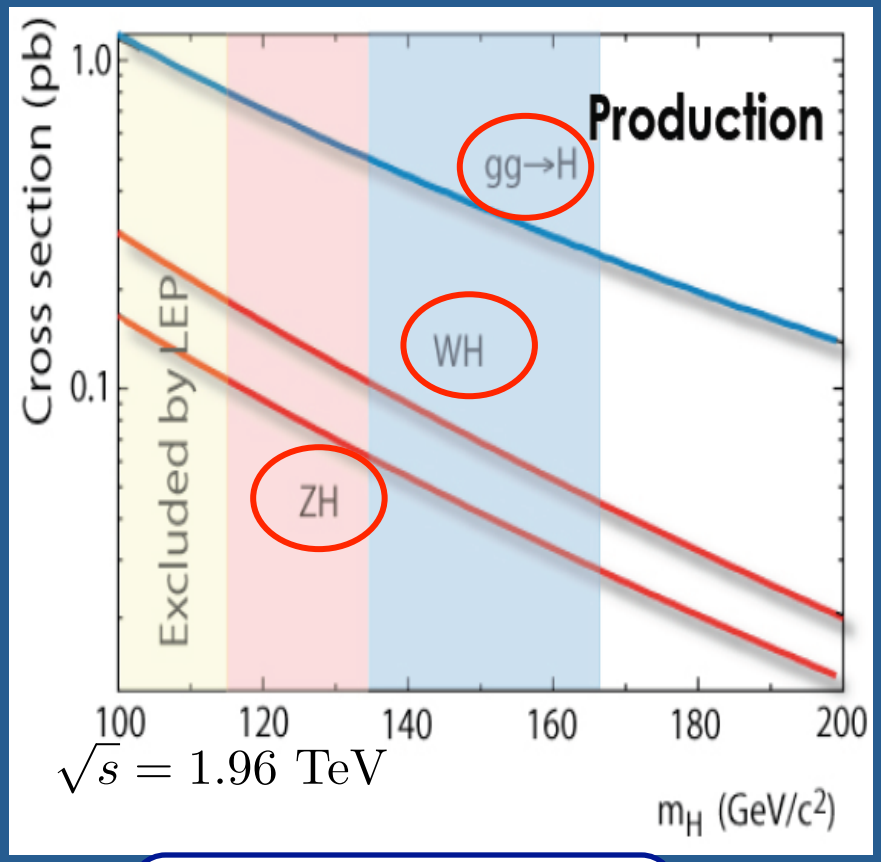


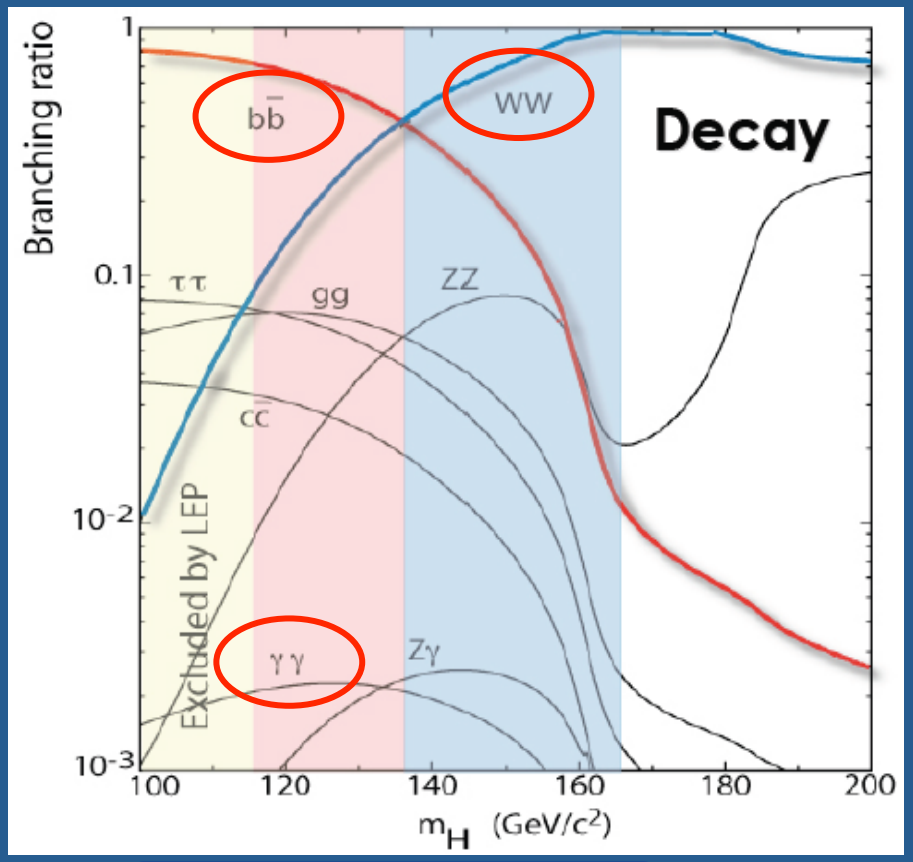


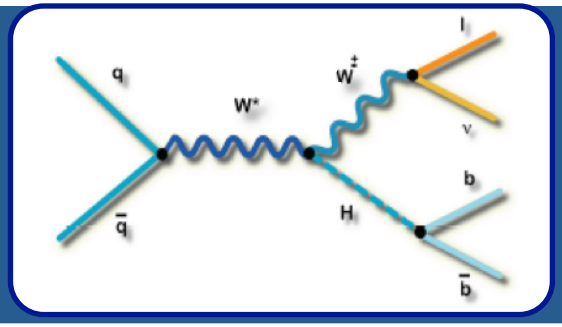


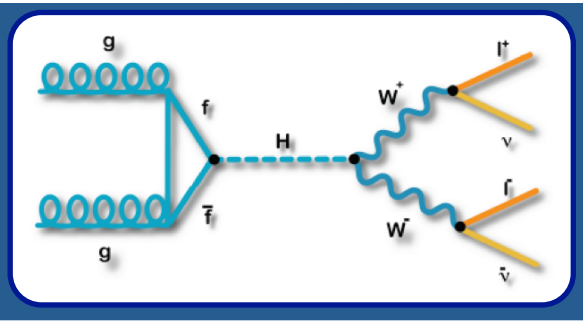
A light Higgs is favoured by the precision data.
Tevatron will be able to cover the full range

Higgs at the Tevatron

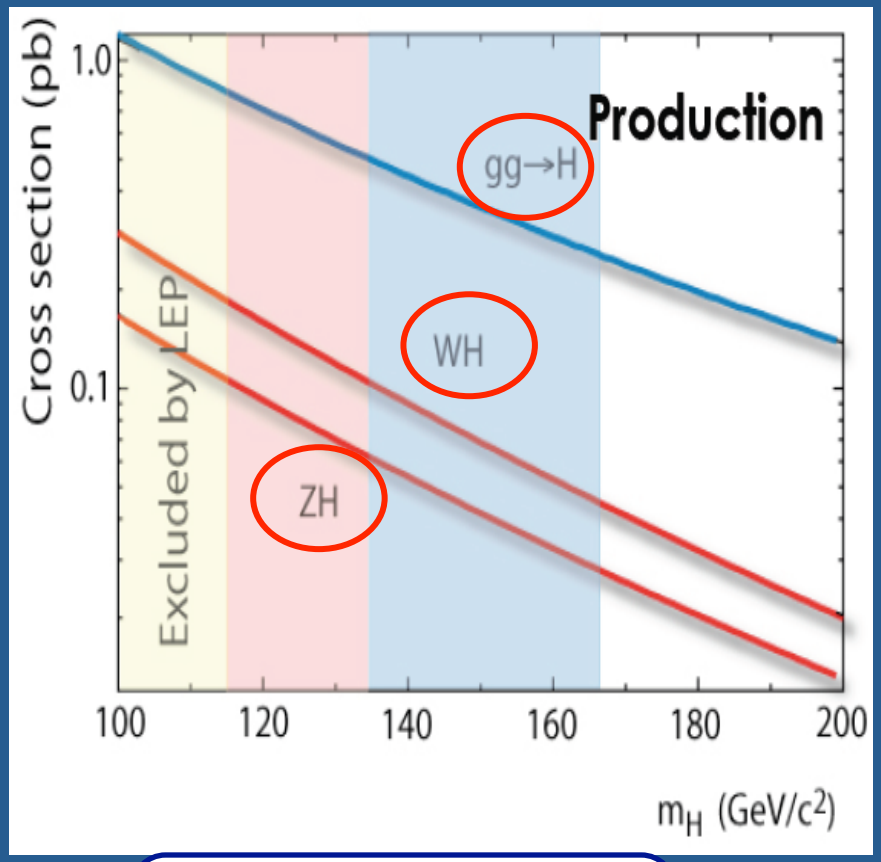


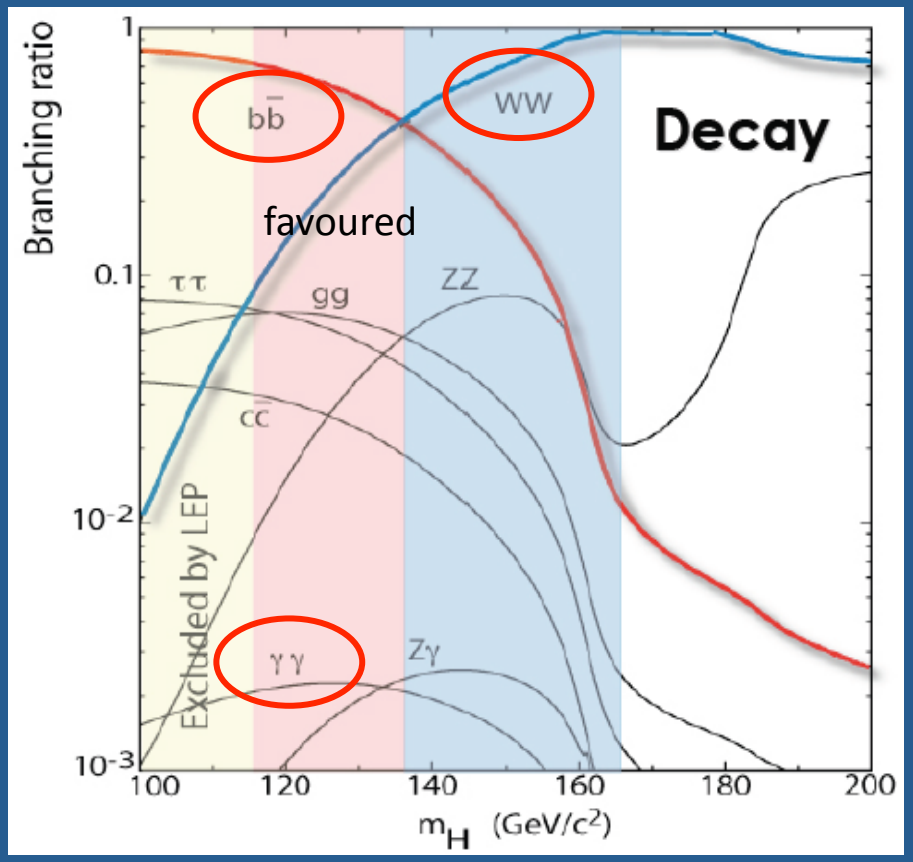


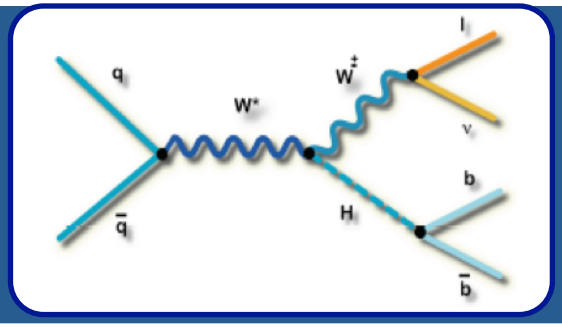




Higgs at the Tevatron

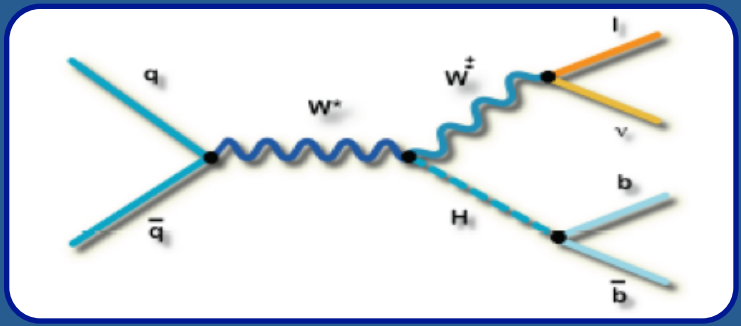


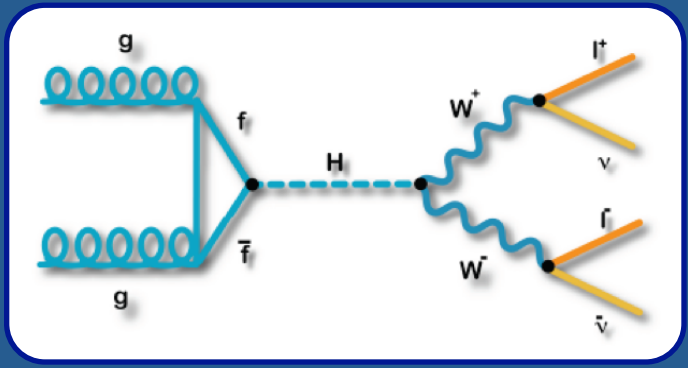




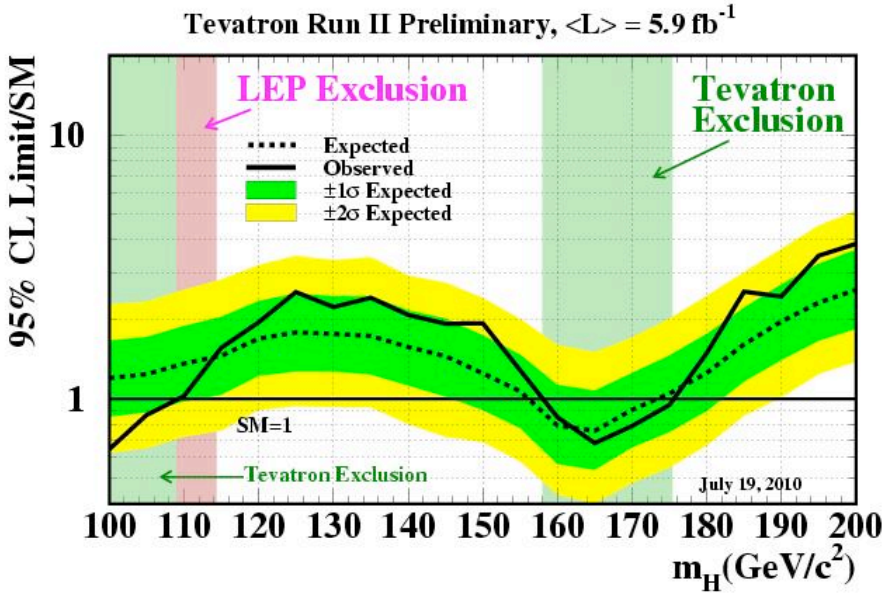
Coupling to gluons/photons via loops
Direct coupling to W boson and b quarks

Status of Higgs Searches

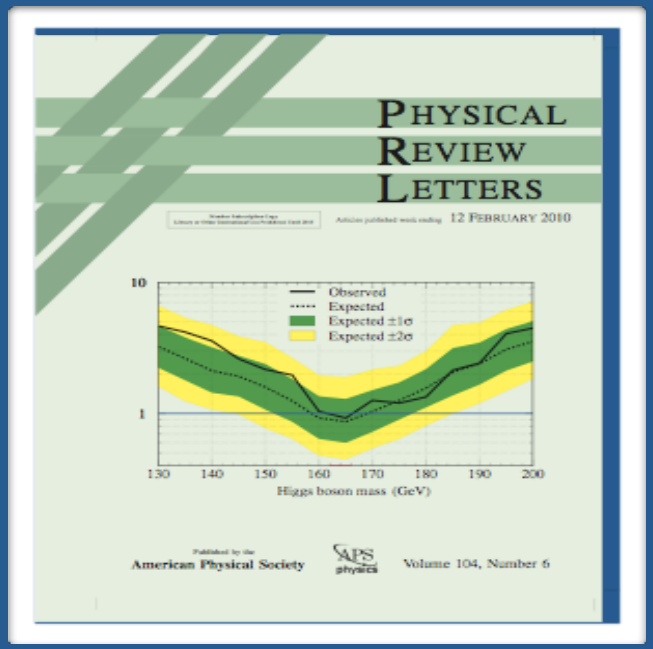




ICHEP 2010

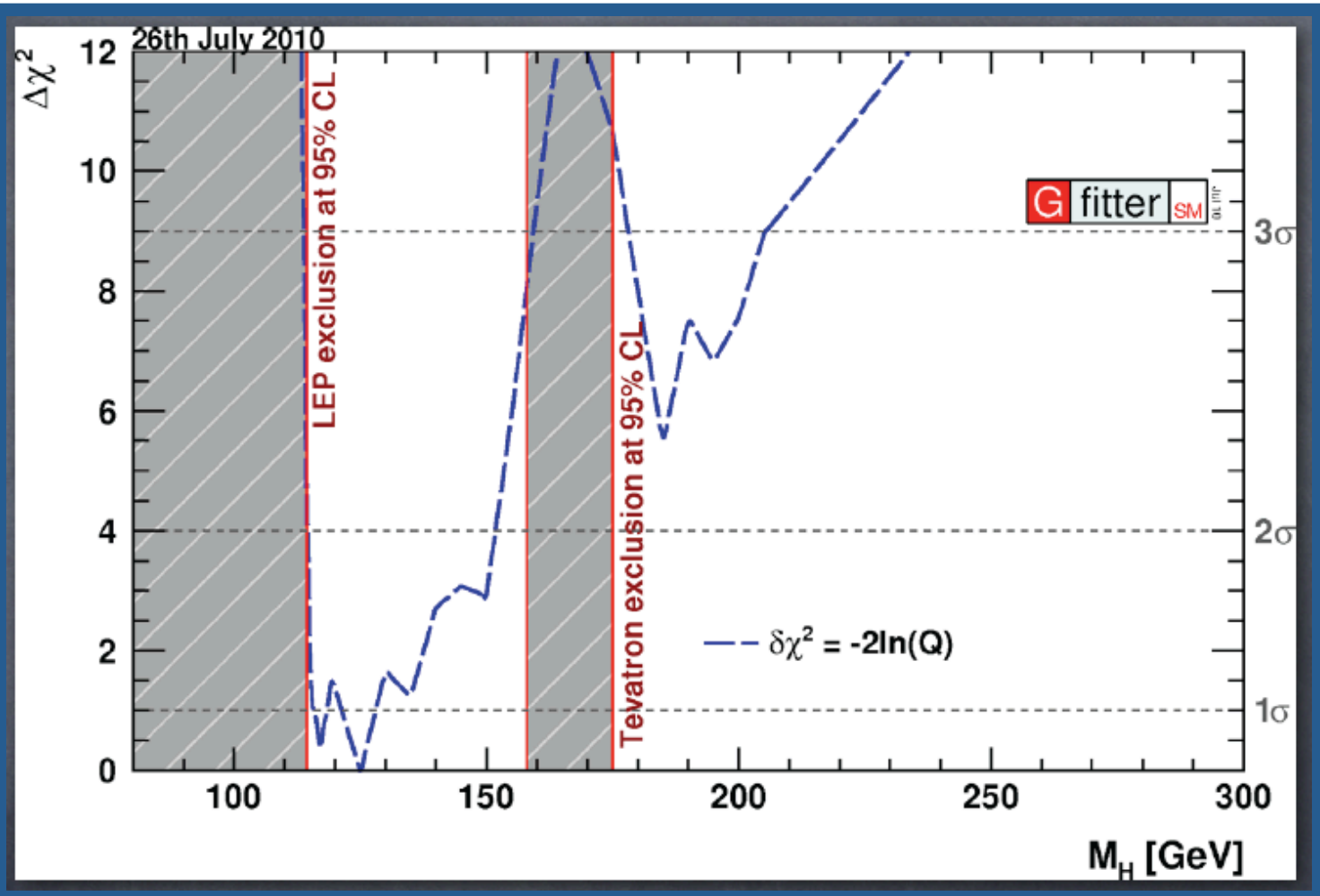


Sensitivity within a factor two up to 190 GeV



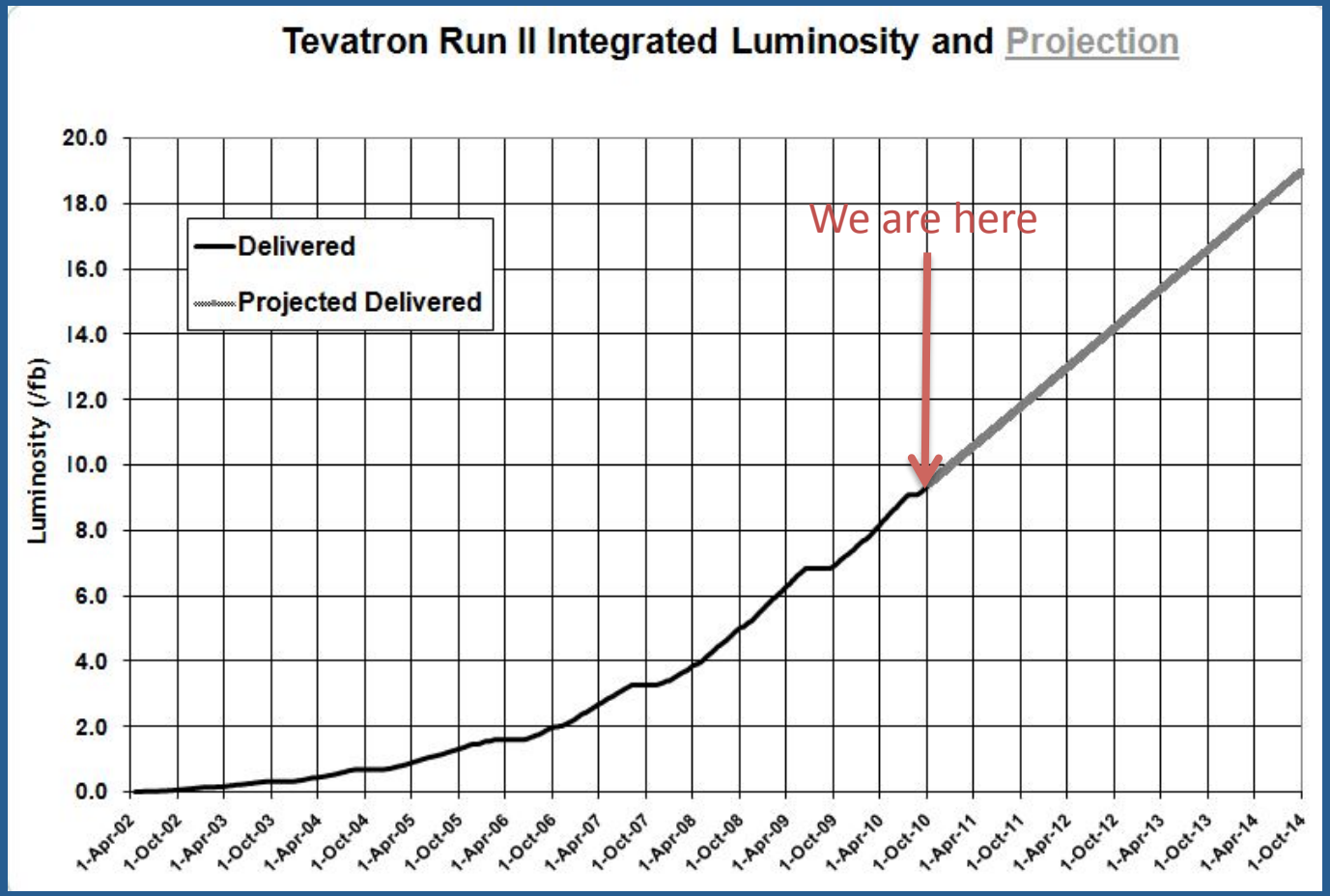
Joint CDF-DØ Publication

Combing Indirect & Direct Limits



- Gfitter combines direct and indirect constraints
- If SM is correct, light Higgs is almost unavoidable

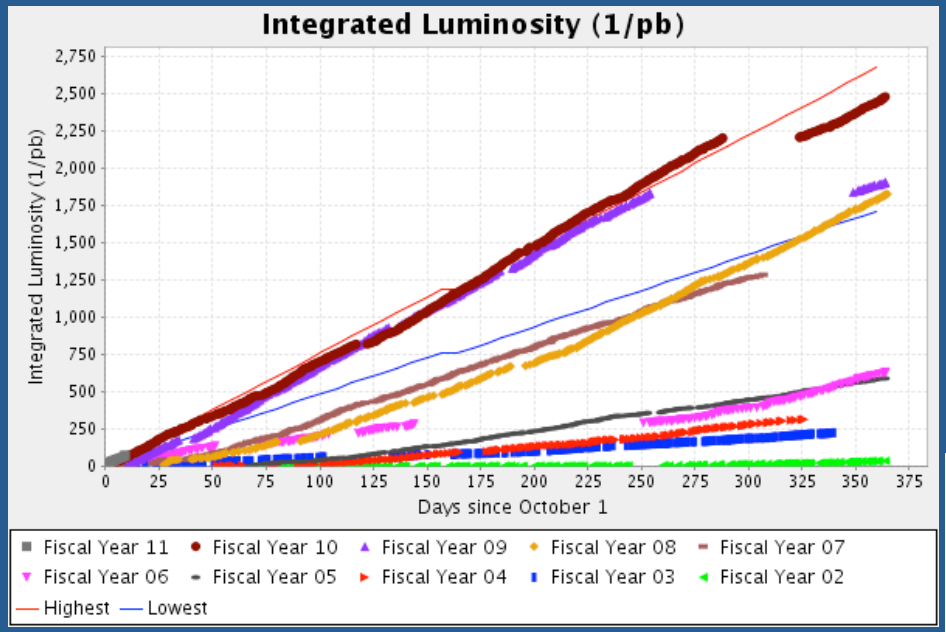
Tevatron Luminosity Projection



2002 2014

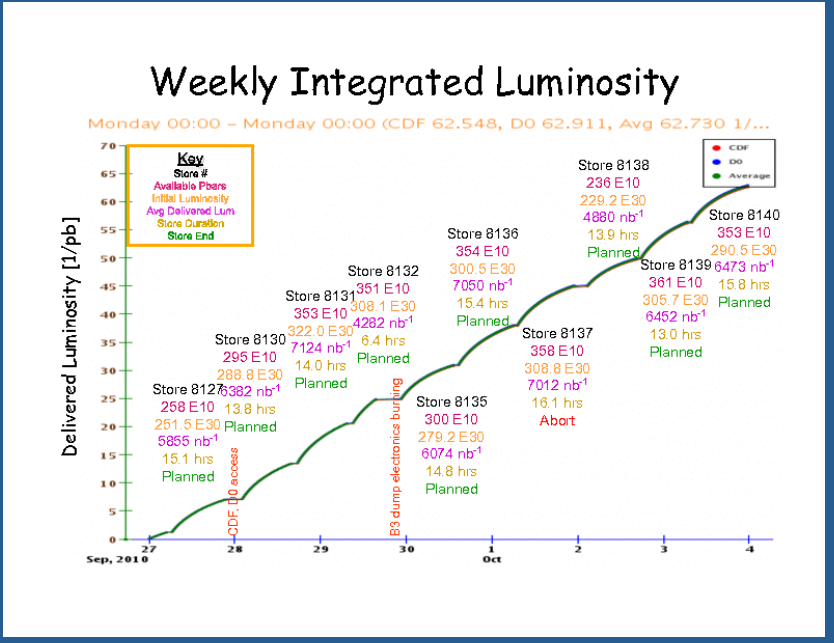
About L=19 fb^{-1} recorded and about L=16 fb^{-1} analysable in 2014.

Tevatron Operations



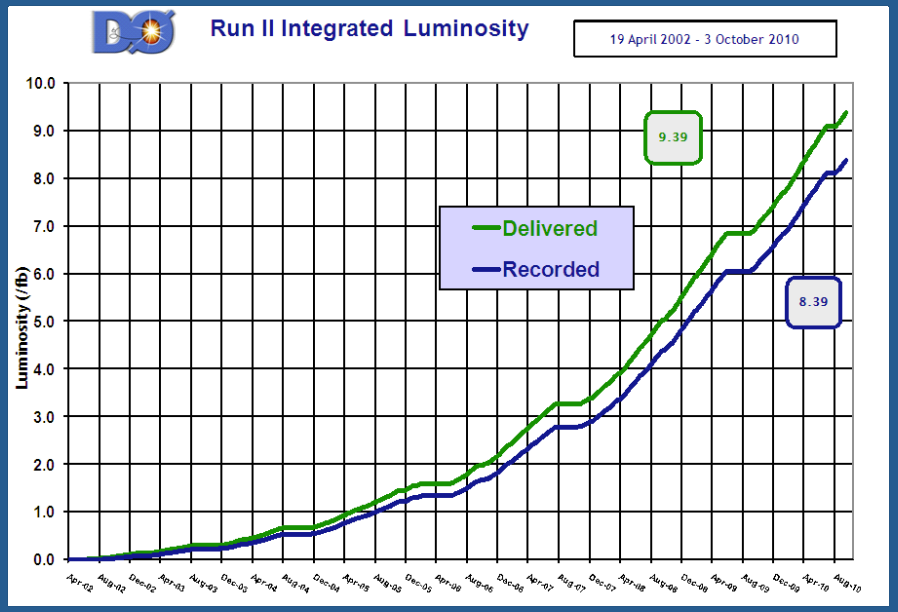
Tevatron operates stably in almost continuous operation

An example week (early October)

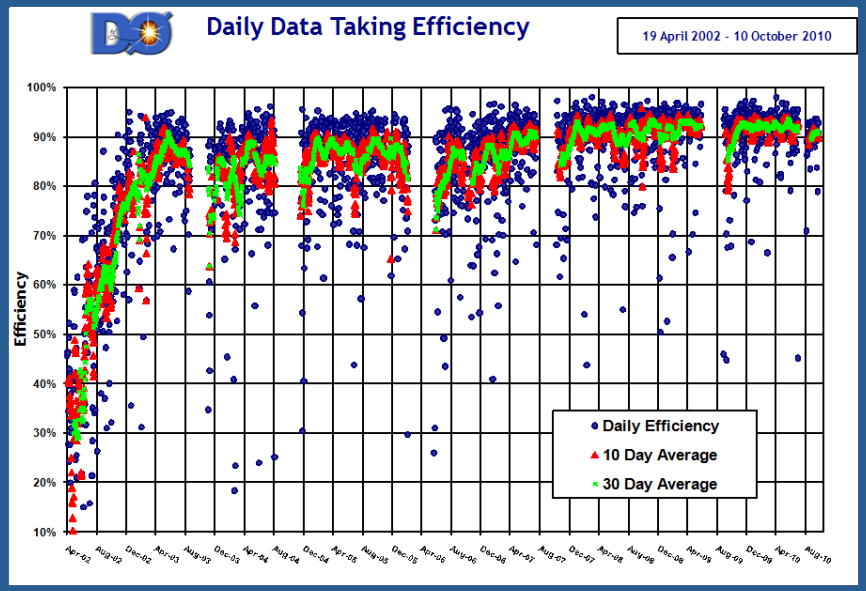


Extrapolations are based on the current rate of integrated luminosity provided by the Tevatron

Experiments Operations

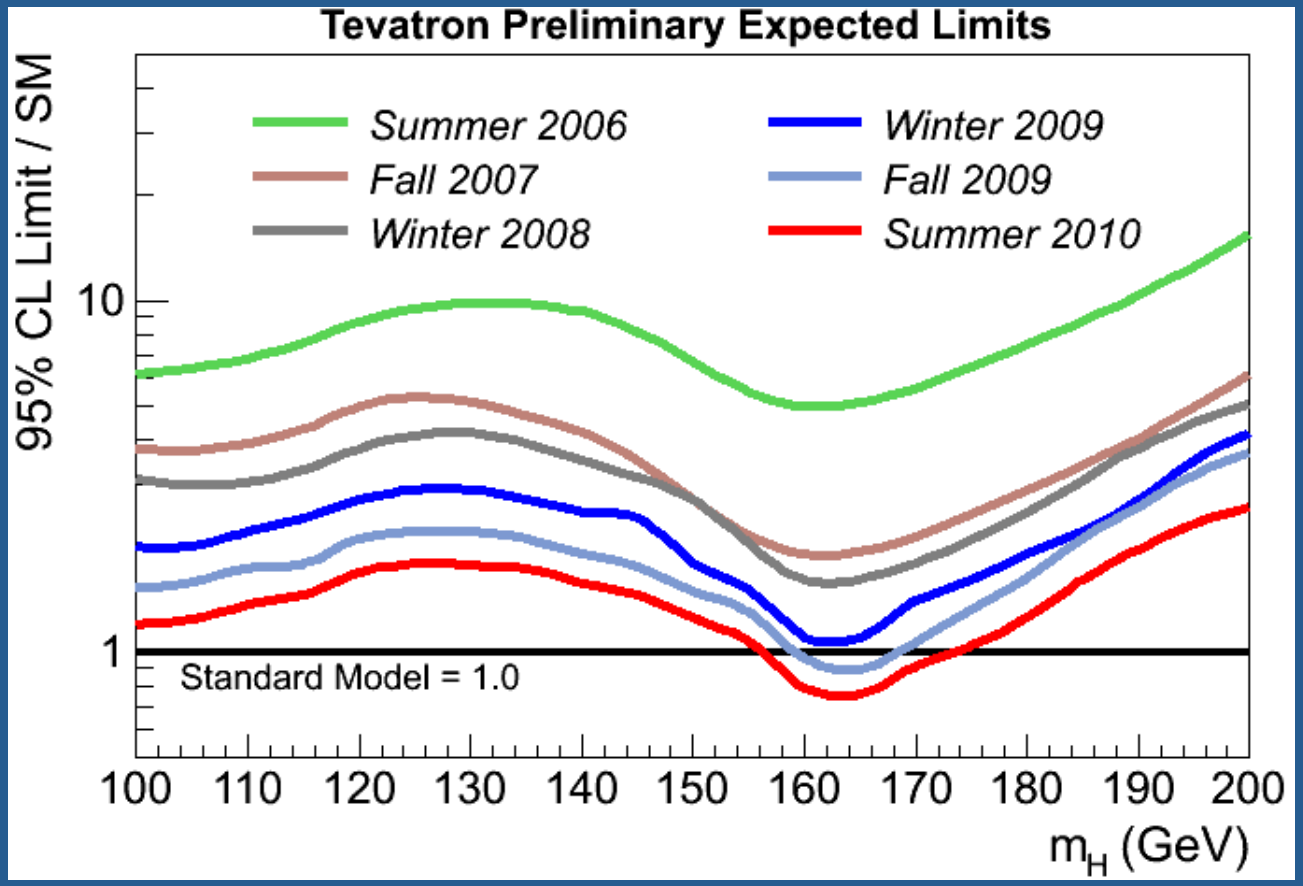


Both detectors operate with high efficiency (~90%) and without major interruptions.



High data quality ensures that almost all data is used in analysis.

A Historic Perspective

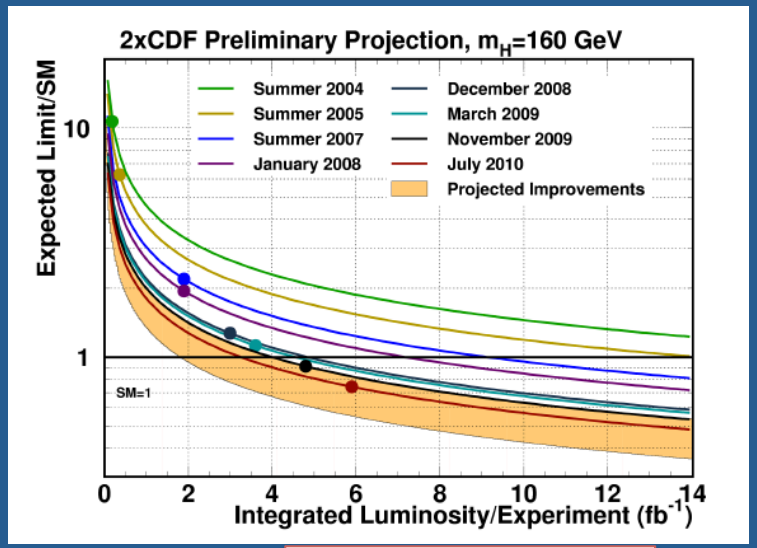


Sensitivity has always improved better than just expected from √L.
Further improvements needed to reach full sensitivity.

Improvements

Expected limits `sensitivity' have made impressive progress since 2006

- Dijet mass resolution
- b tagging
- lepton id
- more channels
-…



Status 2010, updated at ICHEP

Extrapolations assume improvements in analysis techniques.

Even with improvements, we need to go beyond 10 fb^{-1} to have significant probability for evidence.

Improvements (e.g. DØ)

Type	Projected Improvement	WH→lvbb	ZH→llbb	ZH→vvbb	H→WW	Other Channels
Lepton ID	MVA Electron ID	1%	5%	-1%	3%	3%
	Improved MuonID/tracking	4%	3%	-2%	Done	3%
	Add Isolated Tracks	2%	Done	-1%	3%	2%
	Add ICR Electrons	2%	Done	-1%	3%	2%
	Add EC Electrons	Done	Done		Done	2%
	Improved energy scale	1%	2%		2%	5%
Trigger / Reco	Trigger/Reconstruction Efficiency	5%	3%	Done	Done	5%
Jet Selection	Di-jet Mass Resolution	10%	10%	10%		
	MVA B-ID	5%	5%	5%		
	MVA Bottom vs Charm	4%	4%	4%		
MVA Analysis	Enhanced Techniques	10%	10%	10%	10%	10%
	New signal separation variables	5%	5%	5%	5%	5%
	MVA QCD Rejection	3%	1%	Done	3%	3%
	Matrix Element Discriminants	5%	5%	5%	5%	3%
	Kinematic Fitting	5%	Done			3%
Optimization	Track Variables	5%	3%	Done	5%	5%
	Optimized B-ID Usage	3%	3%	3%		
	Optimized Jet Treatment	3%	8%	Done		
New Channels	H→WW→e/mu+tau				5%	
	VH→etau+jj					3%
	H→ZZ					3%
	VH→VVV→trileptons					3%
	Additional Decay Modes	5%	5%	Done	5%	5%
	Existing Improvements:	57%	70%	29%	41%	
	Planned Improvements:	36%	27%	20%	18%	

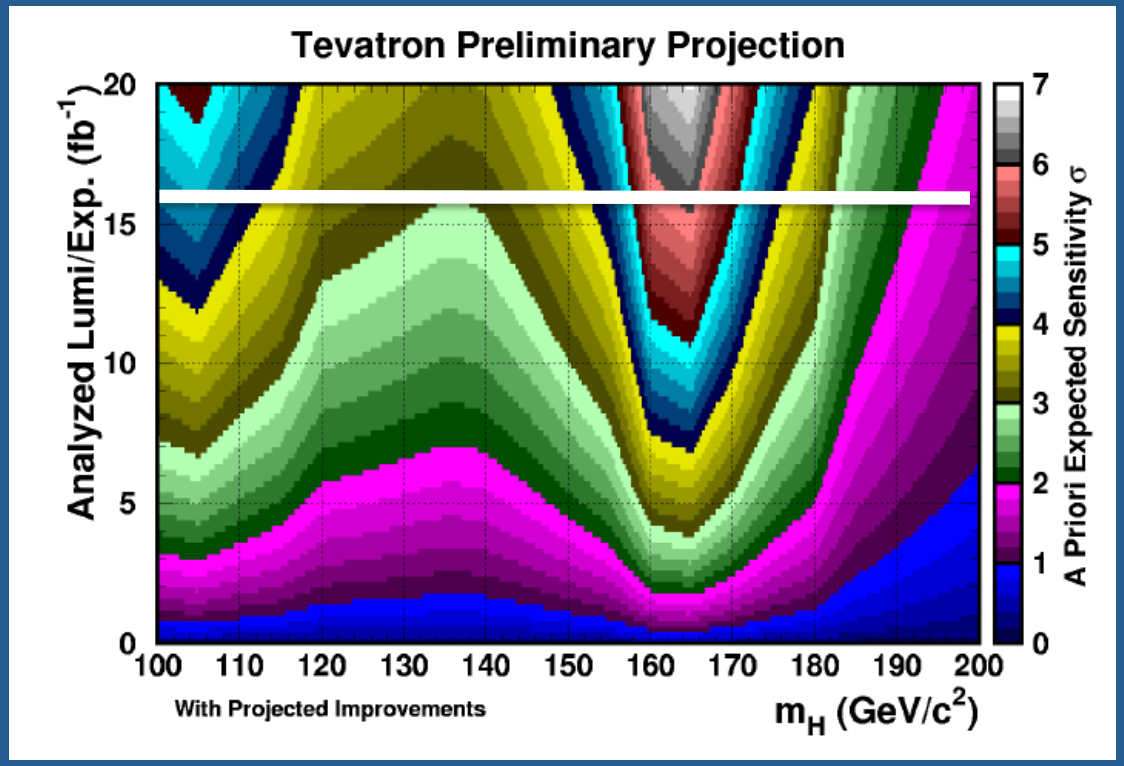
- Yellow cells are existing improvements to be propagated to final analysis.
- White cells with numbers are the areas the experiment is actively working on.

Young Scientists Letter

Letter to the Secretary of Energy, Steven Chu, signed by 220 young scientists:

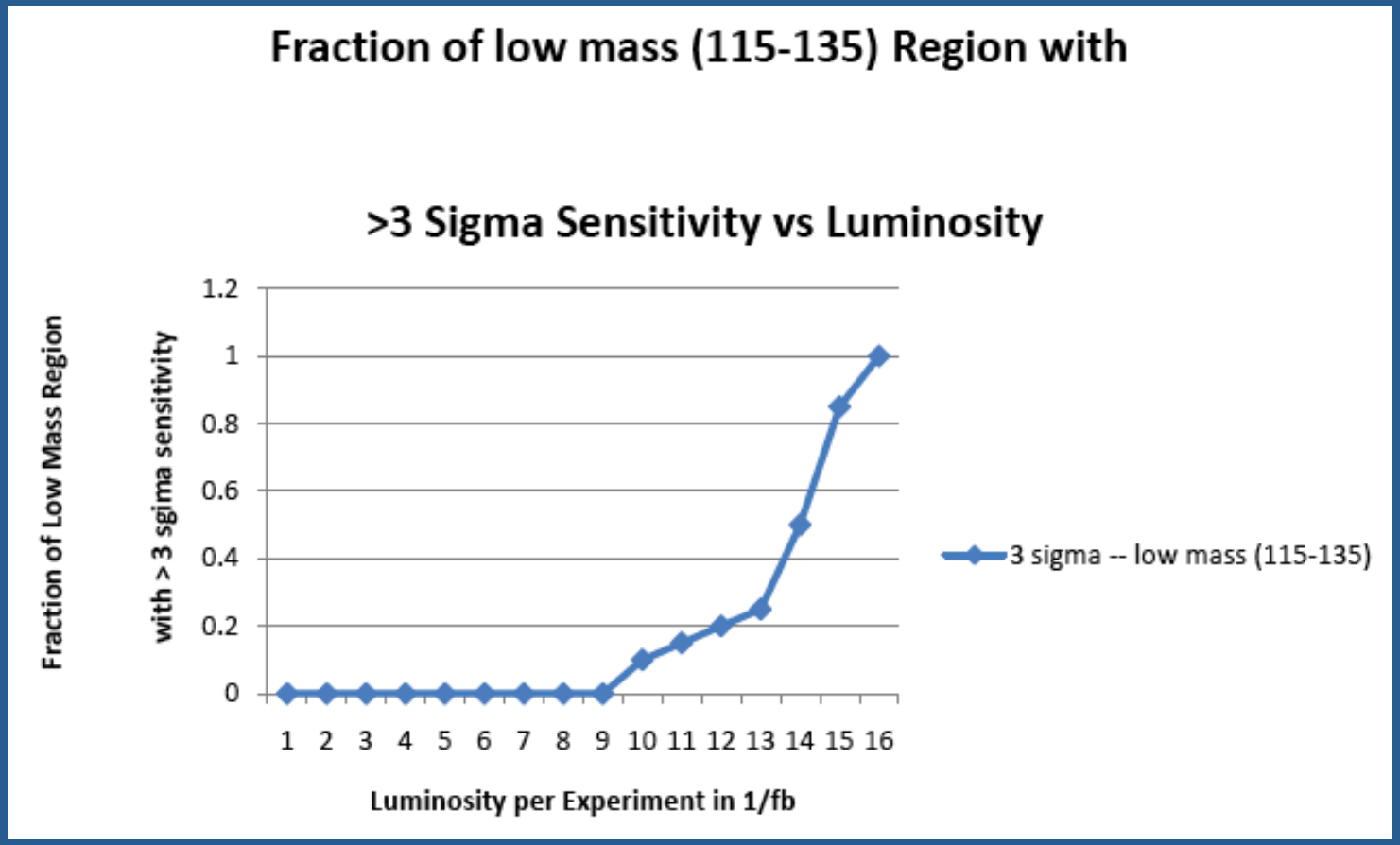
"We are the students, post docs, junior faculty and scientists who will be down in the trenches, driving the CDF and D0 experiments and delivering the results. We assure you that maximizing Higgs discovery potential would be our number one priority in an extended Tevatron run."

Higgs Projection



With 16 fb^{-1}, the Tevatron will have sensitivity to find at least 3 sigma evidence or to exclude the SM Higgs boson in the allowed region below ~190 GeV.

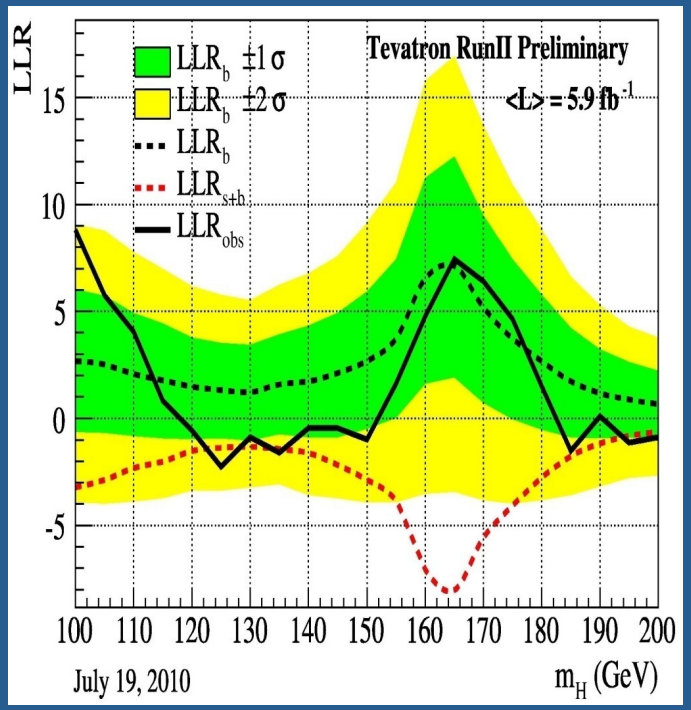
Reaching a Threshold

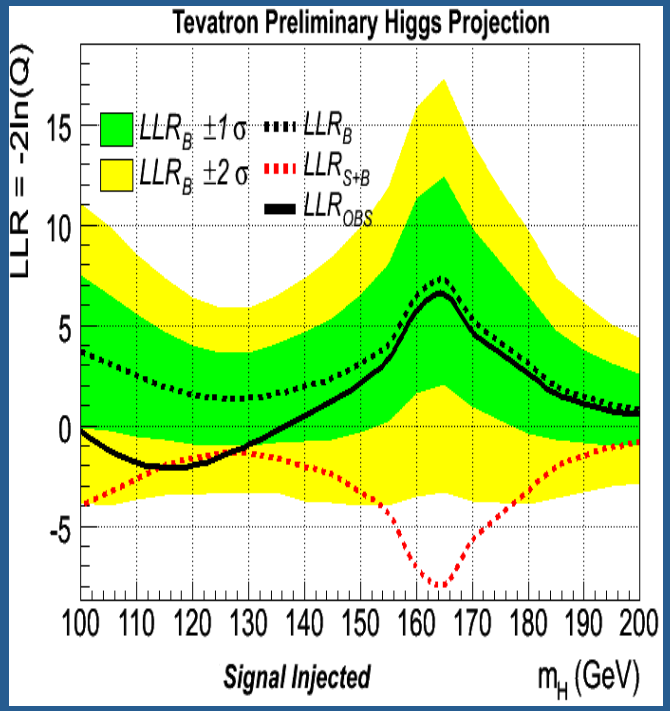


- We are crossing a threshold in the Higgs sensitivity.
- All these are 'a priori' extrapolations, not including observed limits.

Excess in the 115-150 GeV Region

We currently observe about one sigma 'excess' in the low mass region

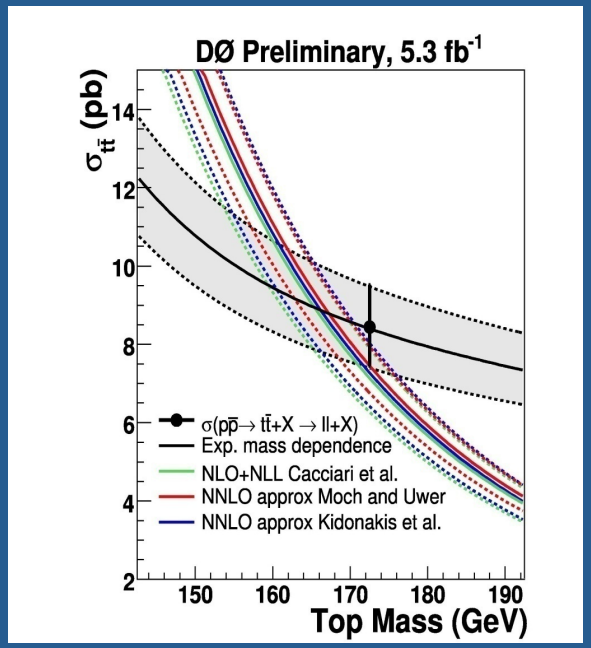


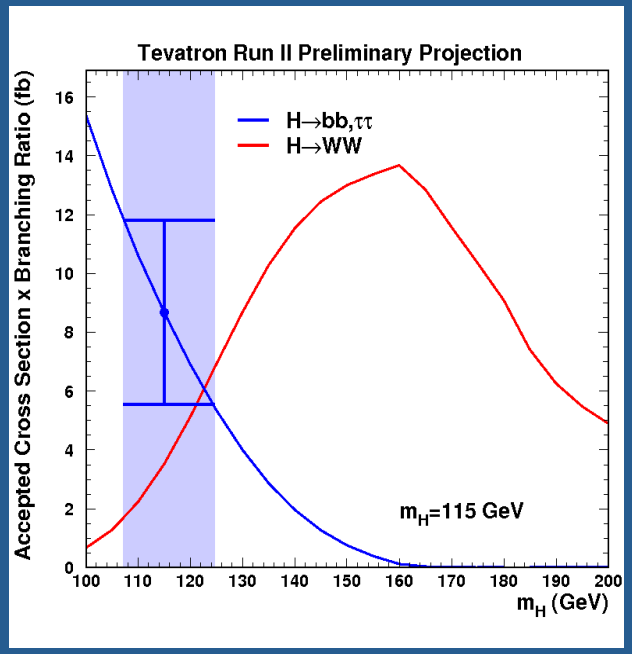


We injected Higgs signals at 115 GeV and calculated "observed" LLR curve.

Higgs Mass Resolution

Access to mass information through a) rate and b) kinematics.





top mass precision just from cross section ~ 5 GeV

Steeply falling cross sections allow to measure Higgs mass with high accuracy.

Higgs Mass Resolution

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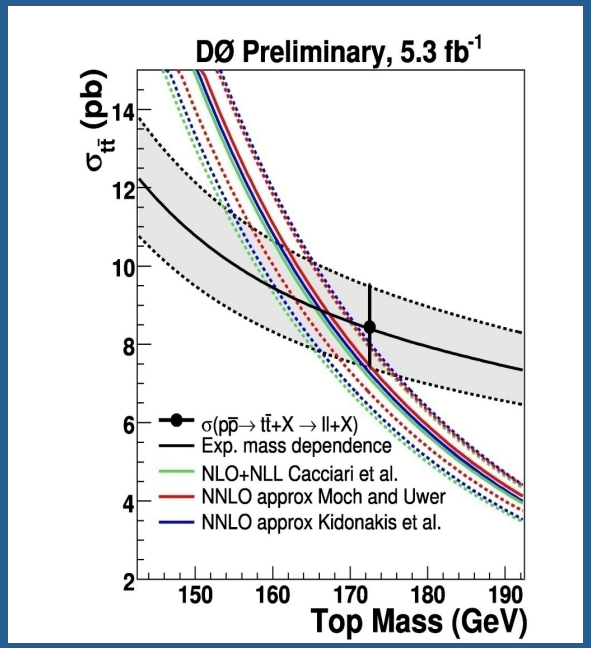

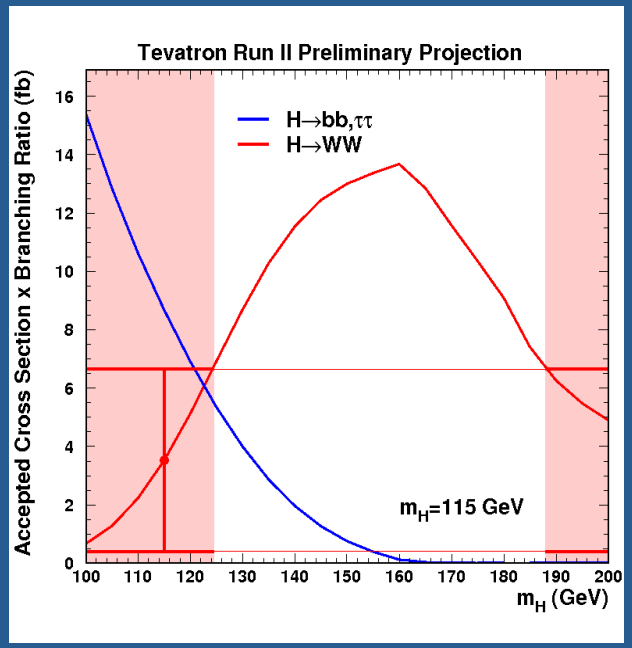

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Unique feature of H → bb channel at the Tevatron.

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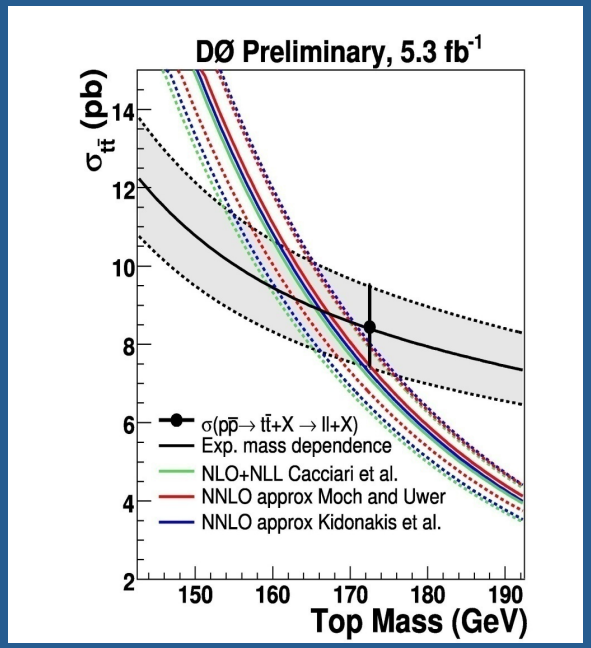

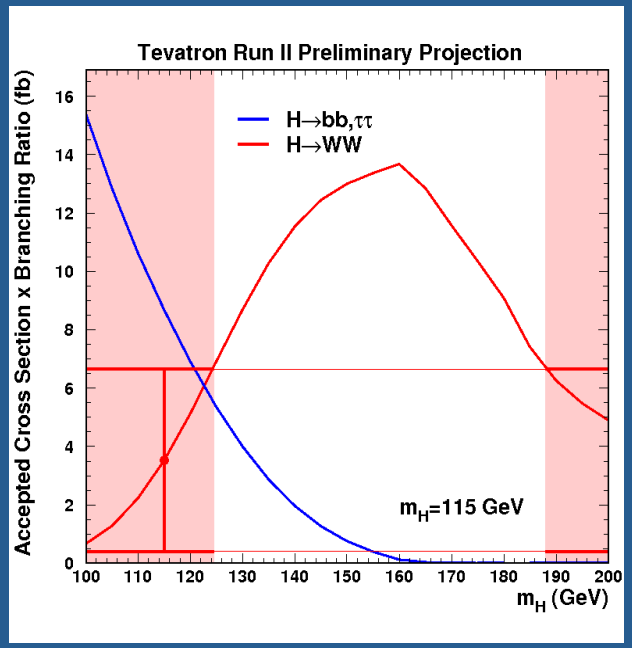

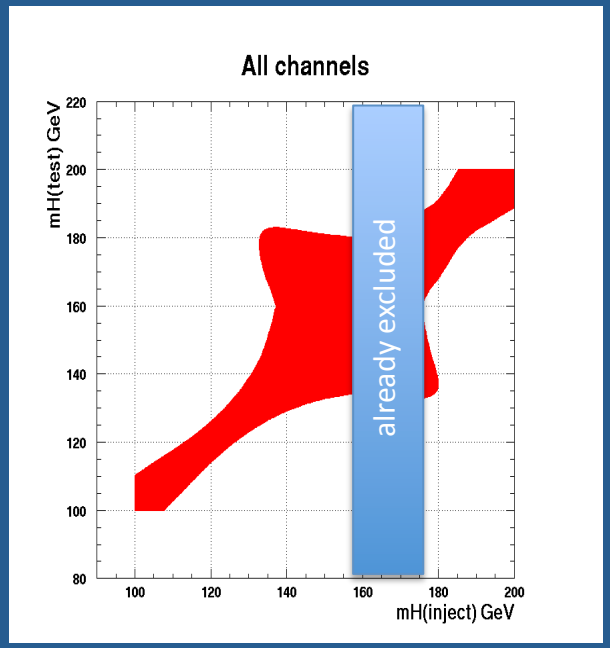

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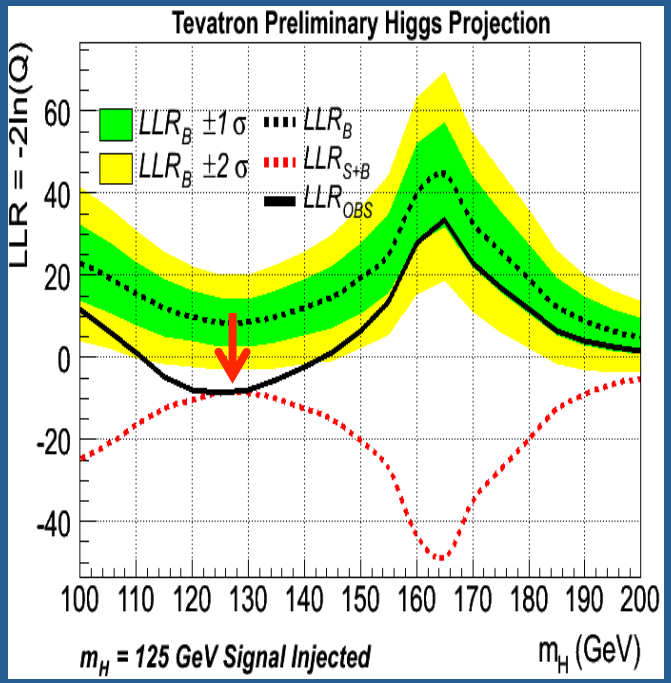
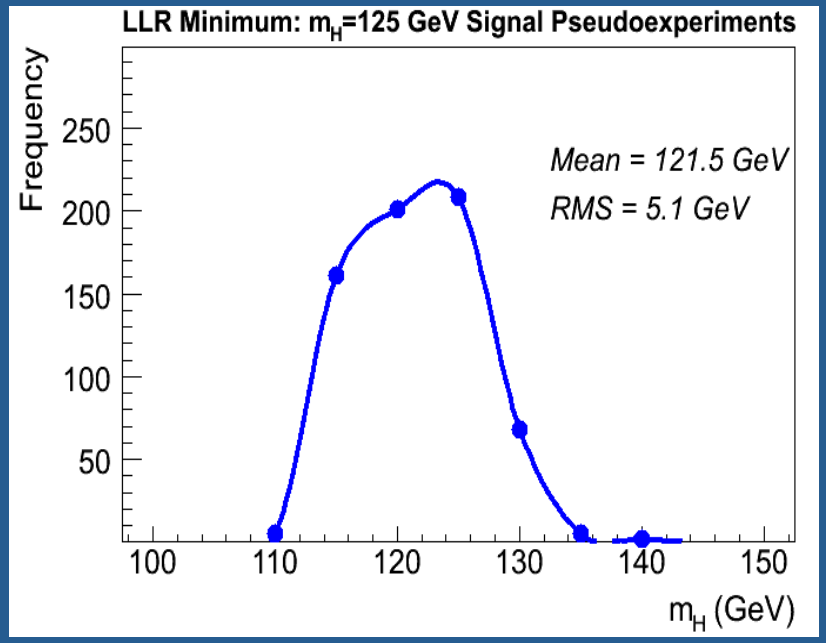
Unique feature of H → bb channel at the Tevatron.

Pseudo Experiments





Perform 800 injection pseudo-experiments with 3 sigma evidence set.

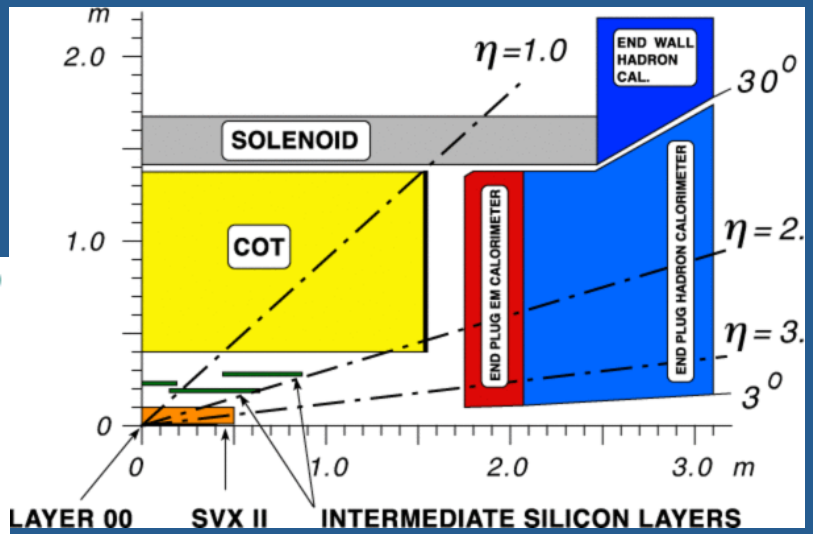
Mass resolution about 6 GeV up to a Higgs mass of 135 GeV

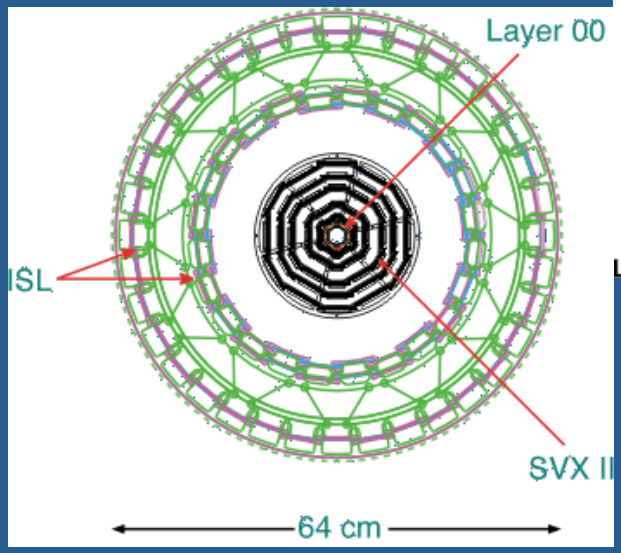
Ageing Review

- July 2010 – organized jointly with Fermilab and Tevatron experiments.
- Each collaboration presented
  - Overview of the experiment
  - Status of silicon detector
  - Status of outer tracker

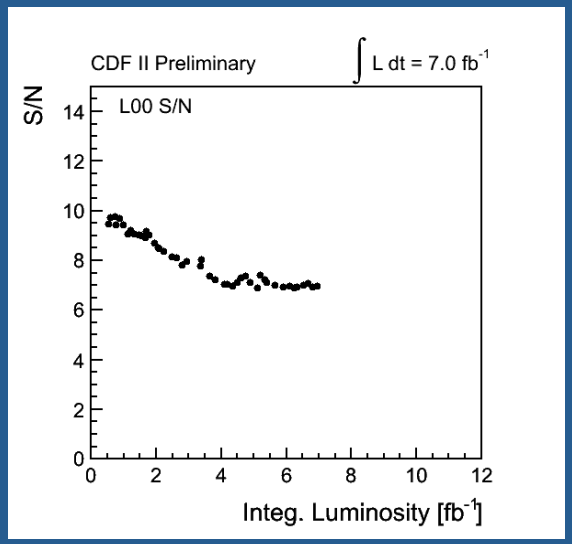
Detector Ageing (CDF)

Main effect expected in silicon detector – important for b tagging (tracks with large impact parameter, secondary vertices)





Some sensors will be underdepleted – but redundancy in tracking capability sufficient to compensate

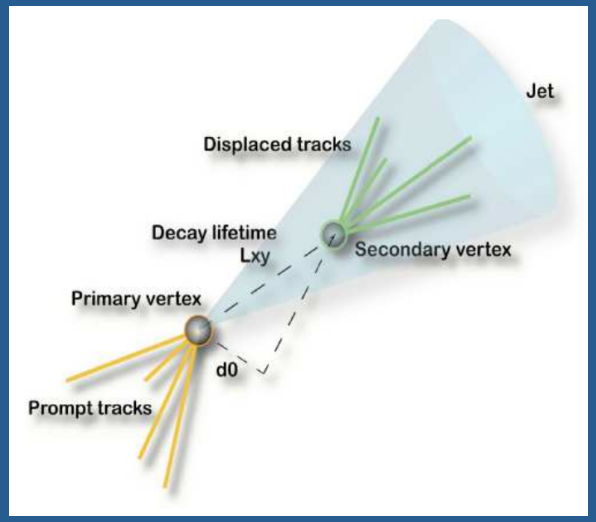


Detector Ageing (DØ)

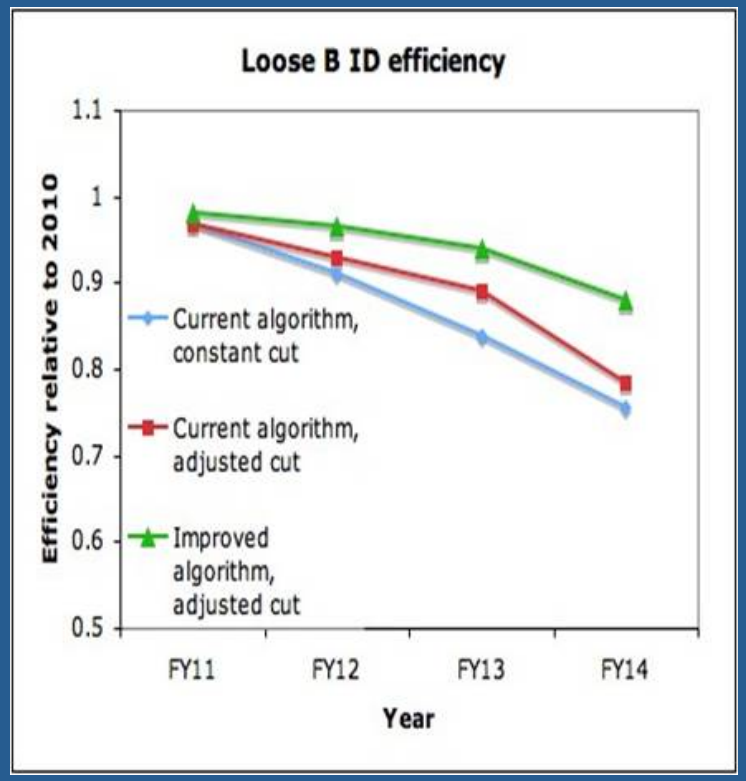
A detailed study was performed using the expectations for

- reduced charged collection efficiency in the silicon detector;
- reduced light yield in the Central Fiber Tracker.

Ageing effects can be mitigated by algorithm improvements.

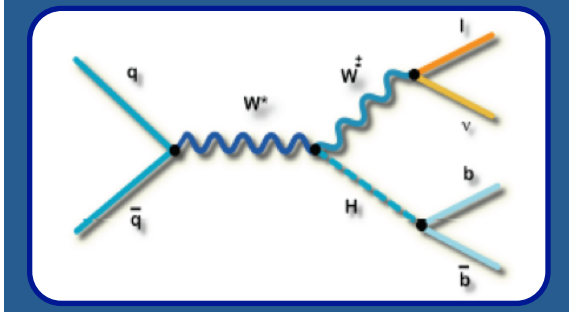


Efficiency to tag a b jet

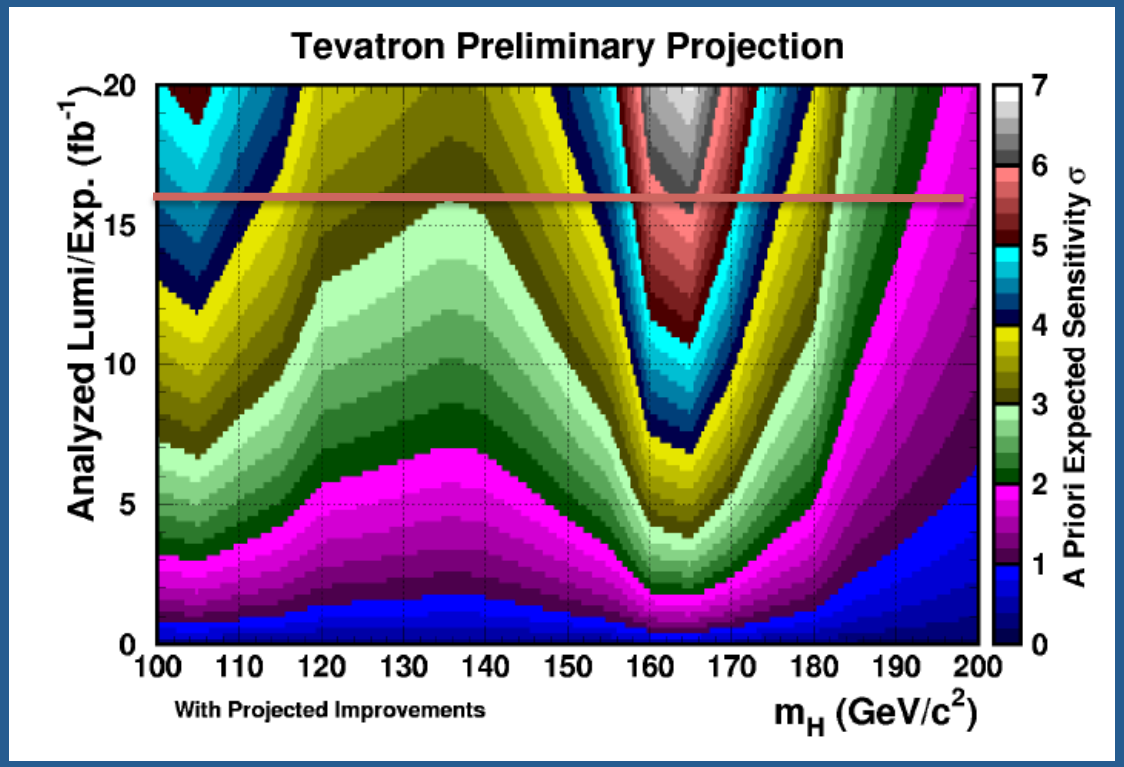


Three scenarios:
(green) Ageing w/o improvements
(red) Adjust cut on b-tagging variable to keep fake tag rate constant
(blue) Put in tracking improvements

Higgs Projection



Complementary to LHC: probes H coupling to bb

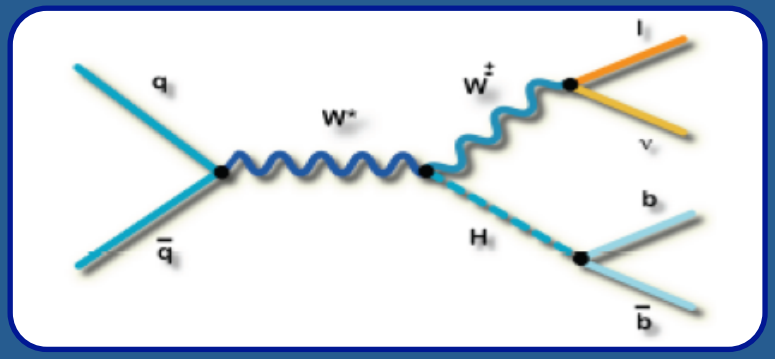


After repeating Higgs sensitivity study, we obtain similar expectations as previously, but now with radiation ageing effect included.

Some assumptions are conservative and further improvements are anticipated.

Tevatron – LHC Complementarity

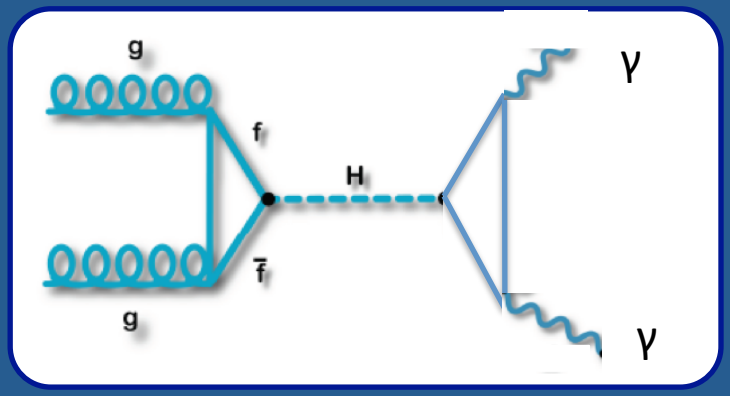
'Tevatron'



Tree level coupling to b quark and W boson

Associated production is dominant mode for Higgs masses below 135 GeV at the Tevatron. Significantly better S/B than at LHC.

'LHC'



Higgs couples to massless particles via loops with top and W, plus possibly new physics particles

Gluon fusion into di-photons dominates Higgs sensitivity at LHC.

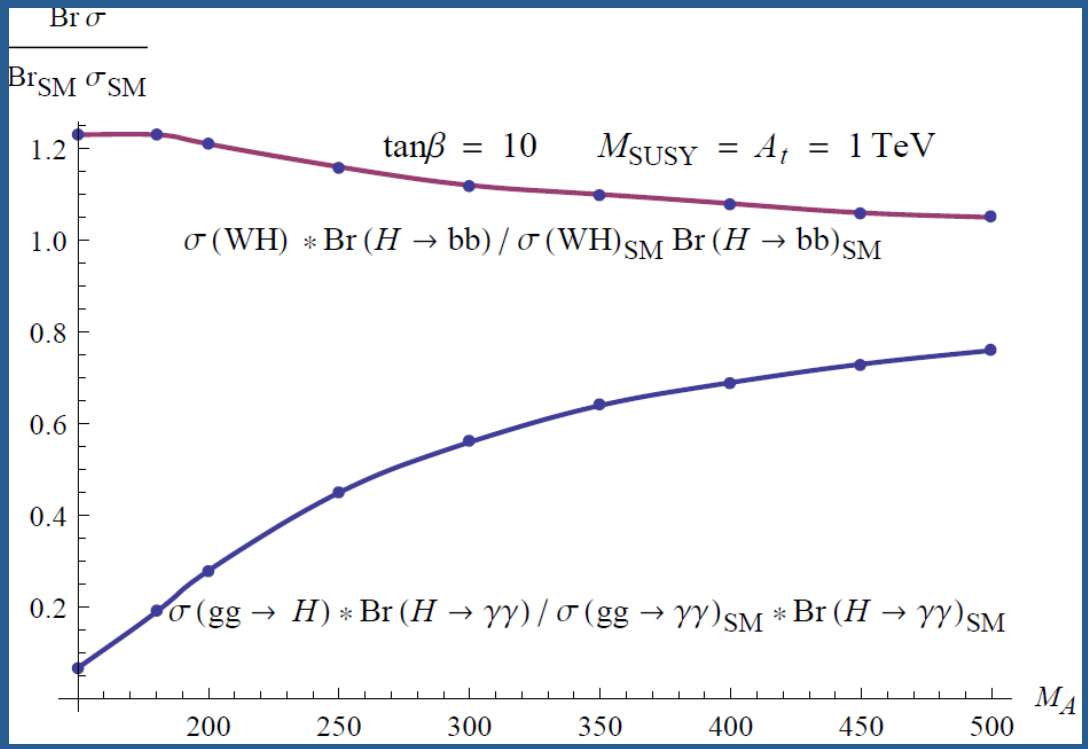
Gluon Fusion is also used for high mass exclusion at Tevatron in WW decays (direct coupling !).

Tevatron – LHC Complementarity

Generic 2 Higgs Doublet Model with M(Higgs)=120 GeV

Ratio to SM

Ratio is sensitive to physics beyond the Standard Model



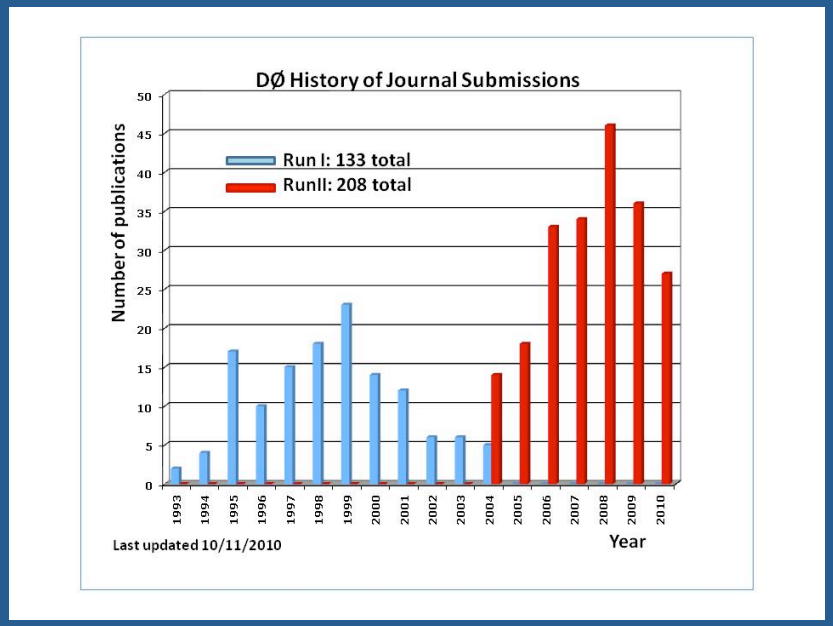
M(A) (GeV)

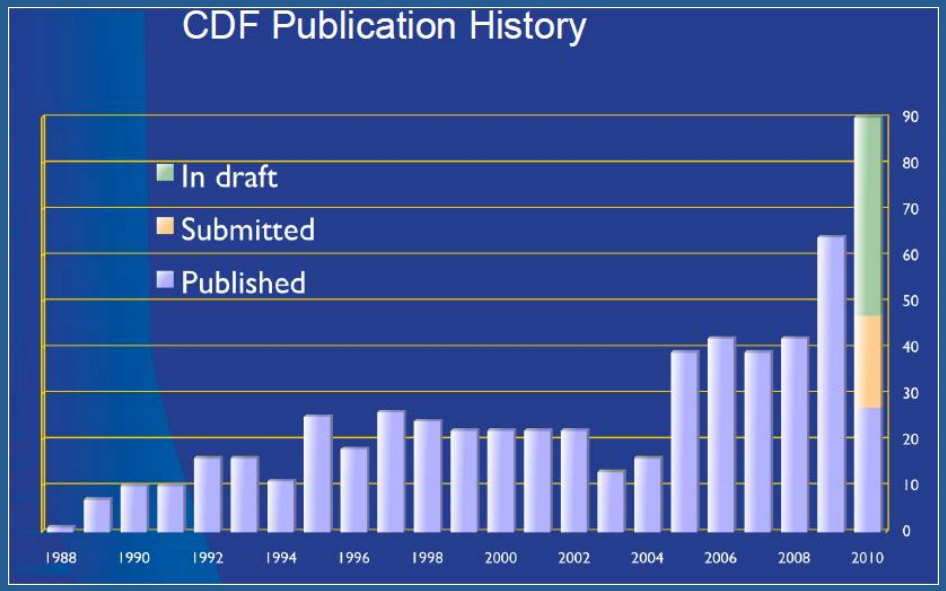
- Powerful tool to understand nature of Higgs.
- bb final at Tevatron dominant for 115-130 GeV.

There is more than the Higgs

About 80 journal publications per year

Publication rate constant at a high level

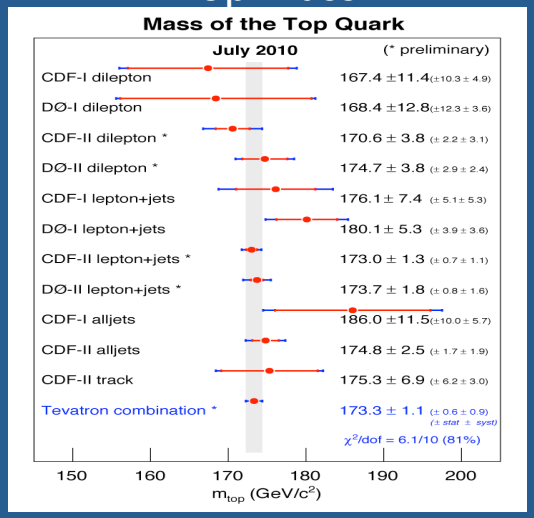




Highlights in 2010:
- "DØ Anomalous Dimuon Asymmetry" published in PRL & PRD , 58 citations
- "CDF/DØ Combination of Higgs Searches in WW decays", published in PRL, 35 citations

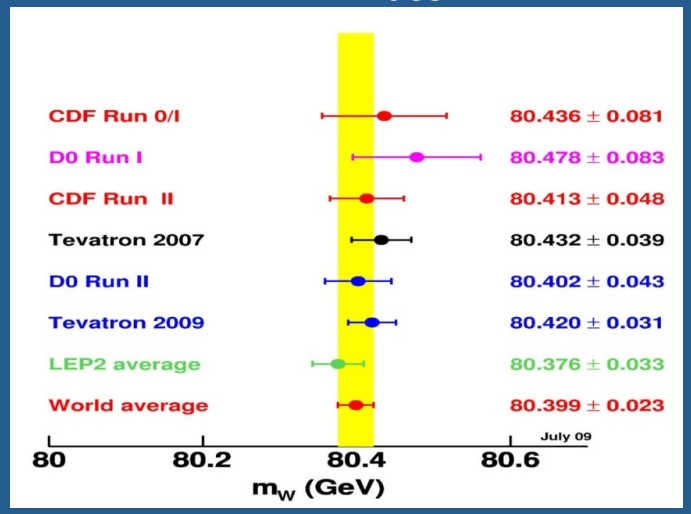
Legacy Measurements

Top mass

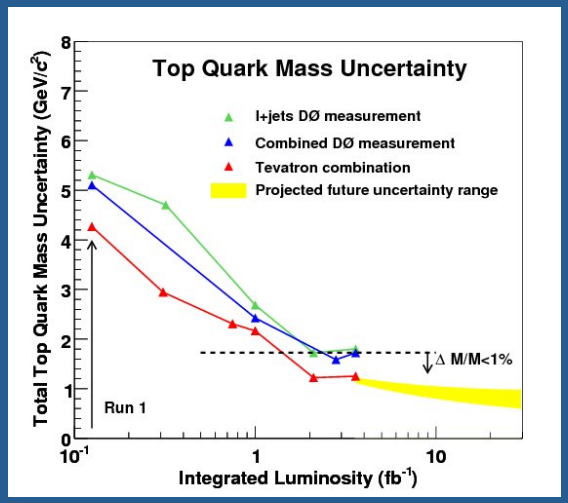


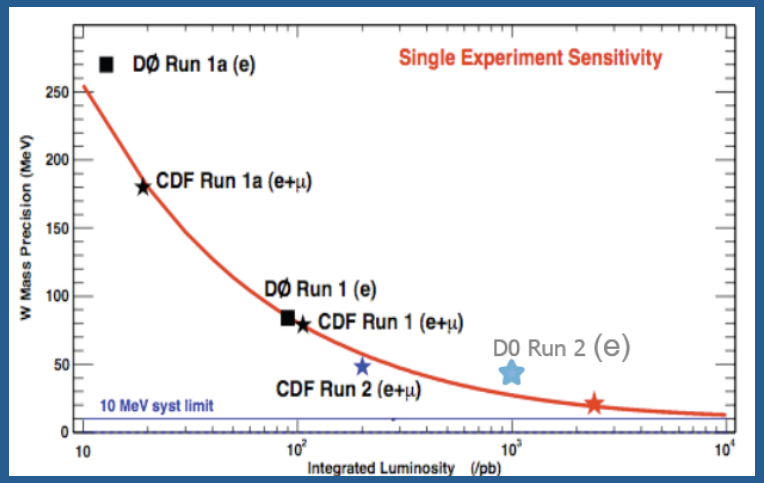
Current Tevatron precision: 0.7%

W mass

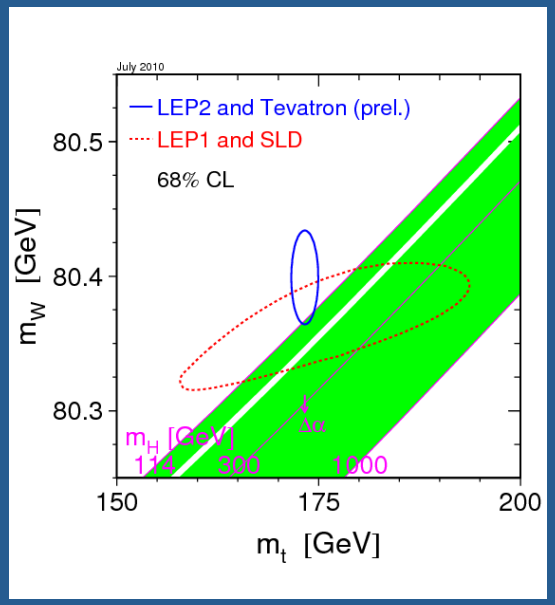


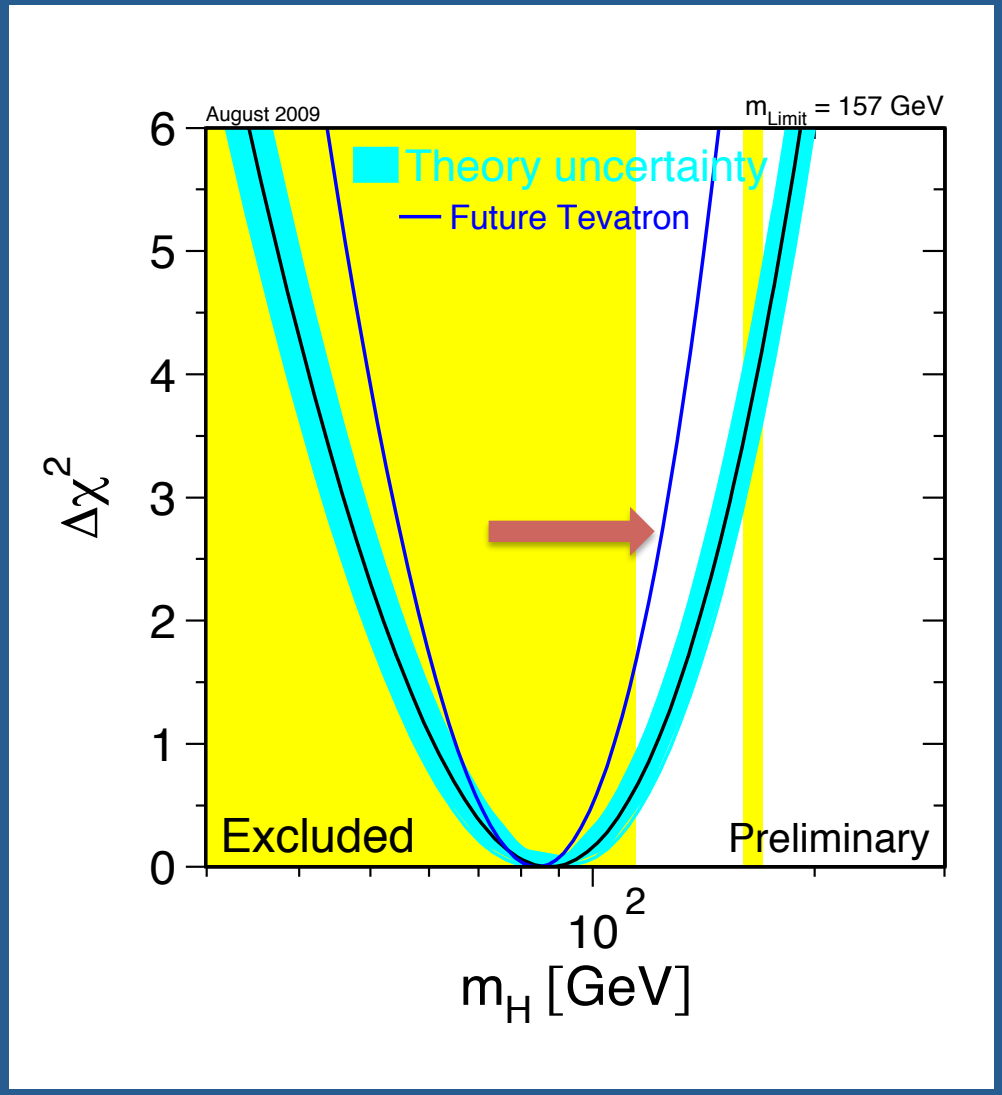
Current Tevatron precision: 31 MeV





Self-consistency of SM





Expected precision:
- 1 GeV for the top mass
- 15 MeV for W boson mass:

m_H < 117 GeV at 95% CL

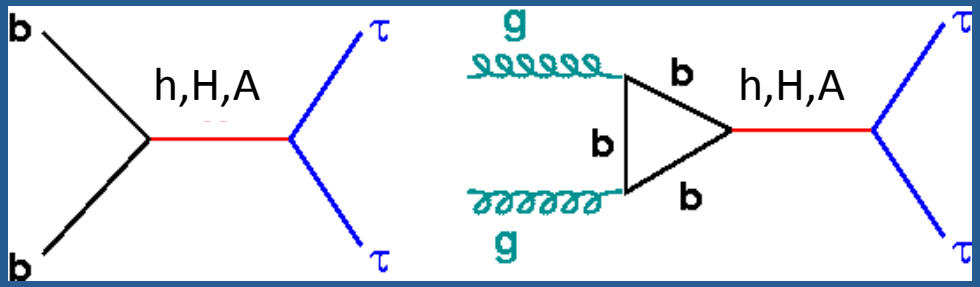
for current SM minimum.

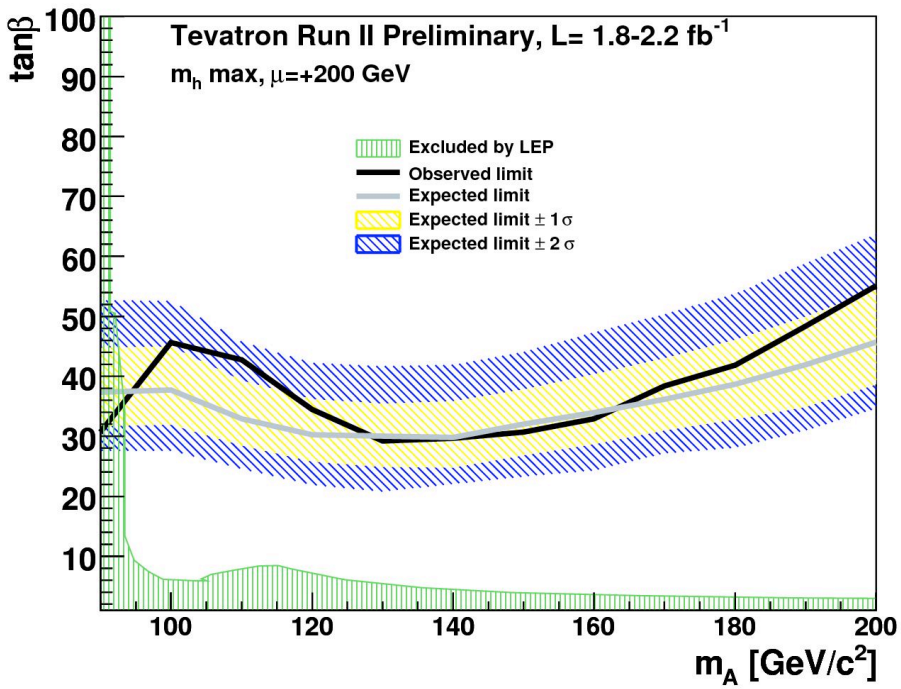
Supersymmetric Higgs

In the MSSM:

- two neutral CP-even Higgs (h,H)
- one neutral CP-odd Higgs (A)
- two charged ($H^{\pm}$)

- h should be light (<135 GeV)
- H,A nearly mass degenerate

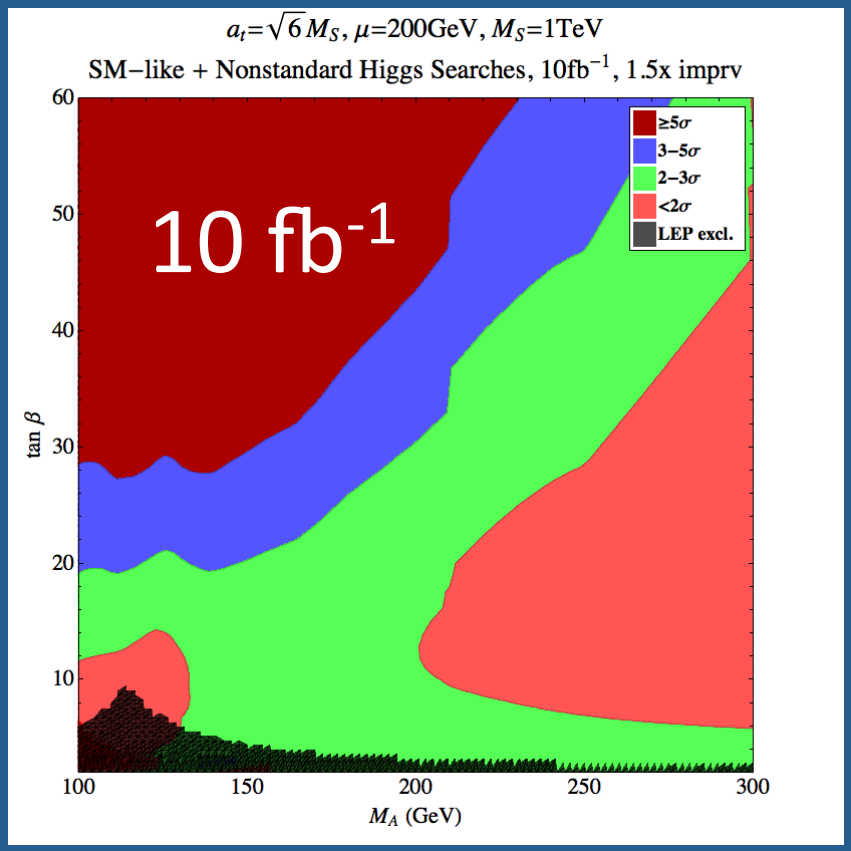


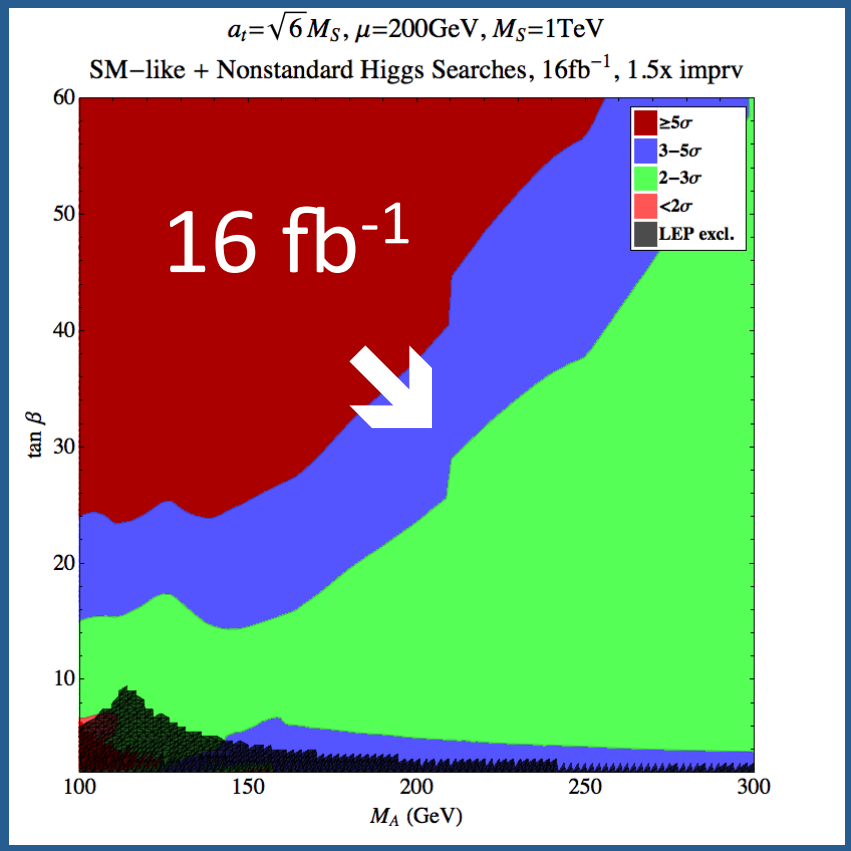


SM Higgs searches can also be used to constrain the SM-like Higgs in these models

MSSM Higgs Bosons

Example: Maximal Mixing Scenario





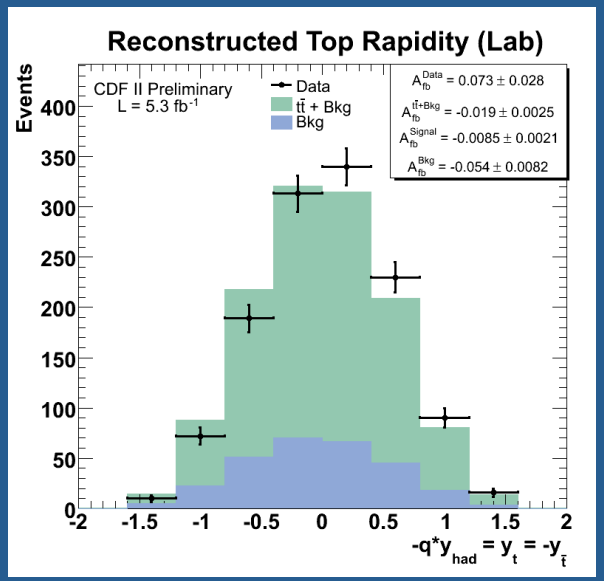
Interesting tanβ region around $m_t/m_b \approx 35$.

Complementarity

Proton-Antiproton Collisions

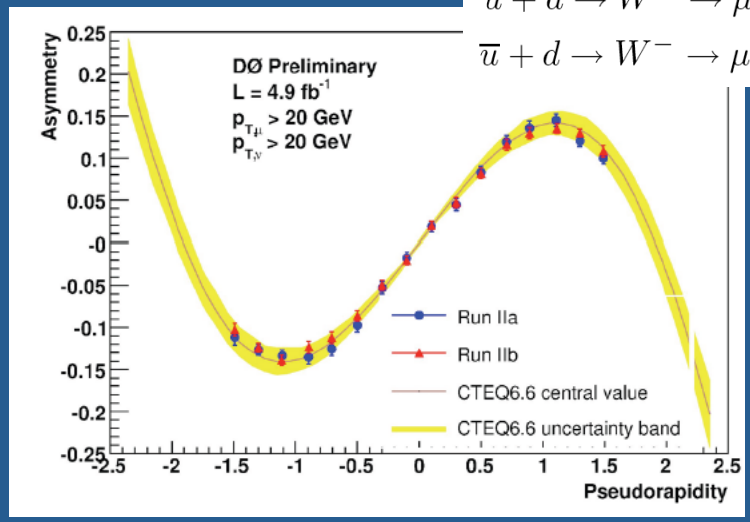
Some Examples

Forward-Backward
Top Asymmetry

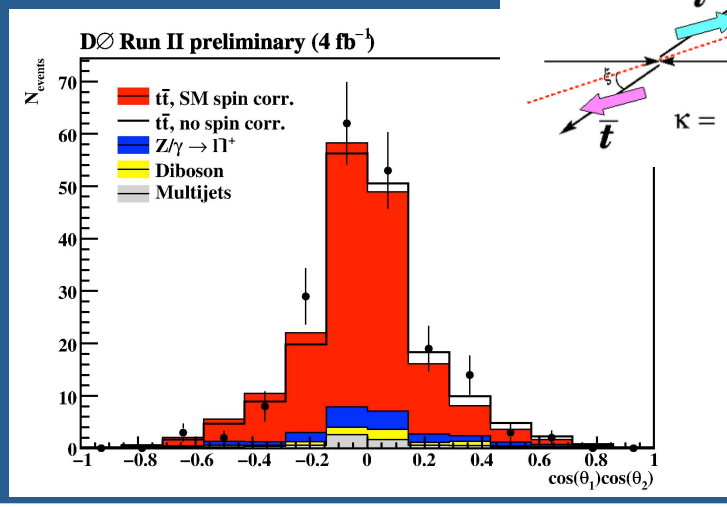


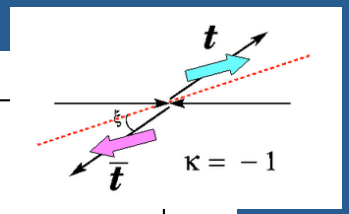
W Asymmetry

$$u + \overline{d} \rightarrow W^+ \rightarrow \mu^+ + \nu_\mu$$
$$\overline{u} + d \rightarrow W^- \rightarrow \mu^- + \overline{\nu}_\mu$$



Top Spin Correlations

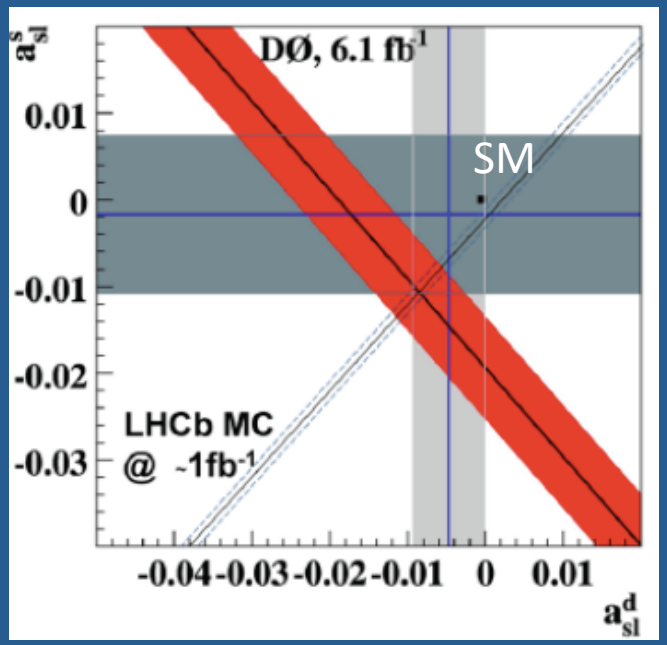




Complementarity

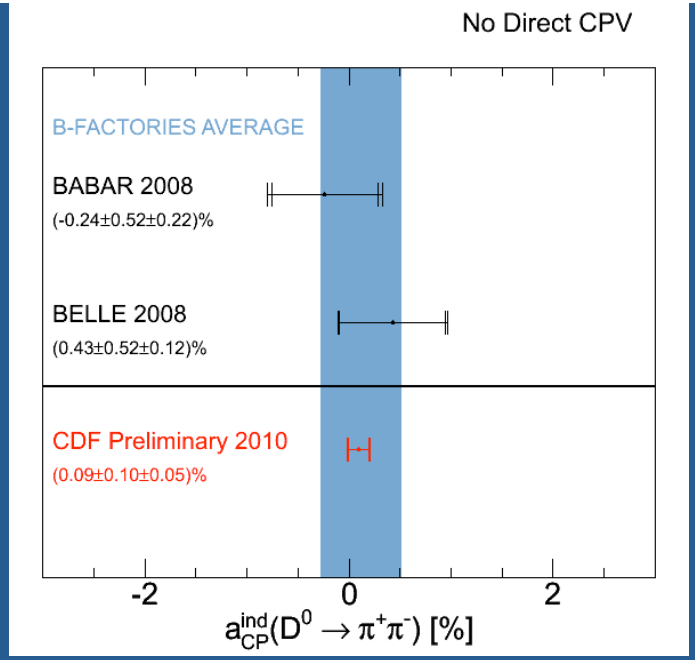
Proton-Antiproton Collisions enable high precision CP measurements due to symmetric initial state

CP Violation in B Decays



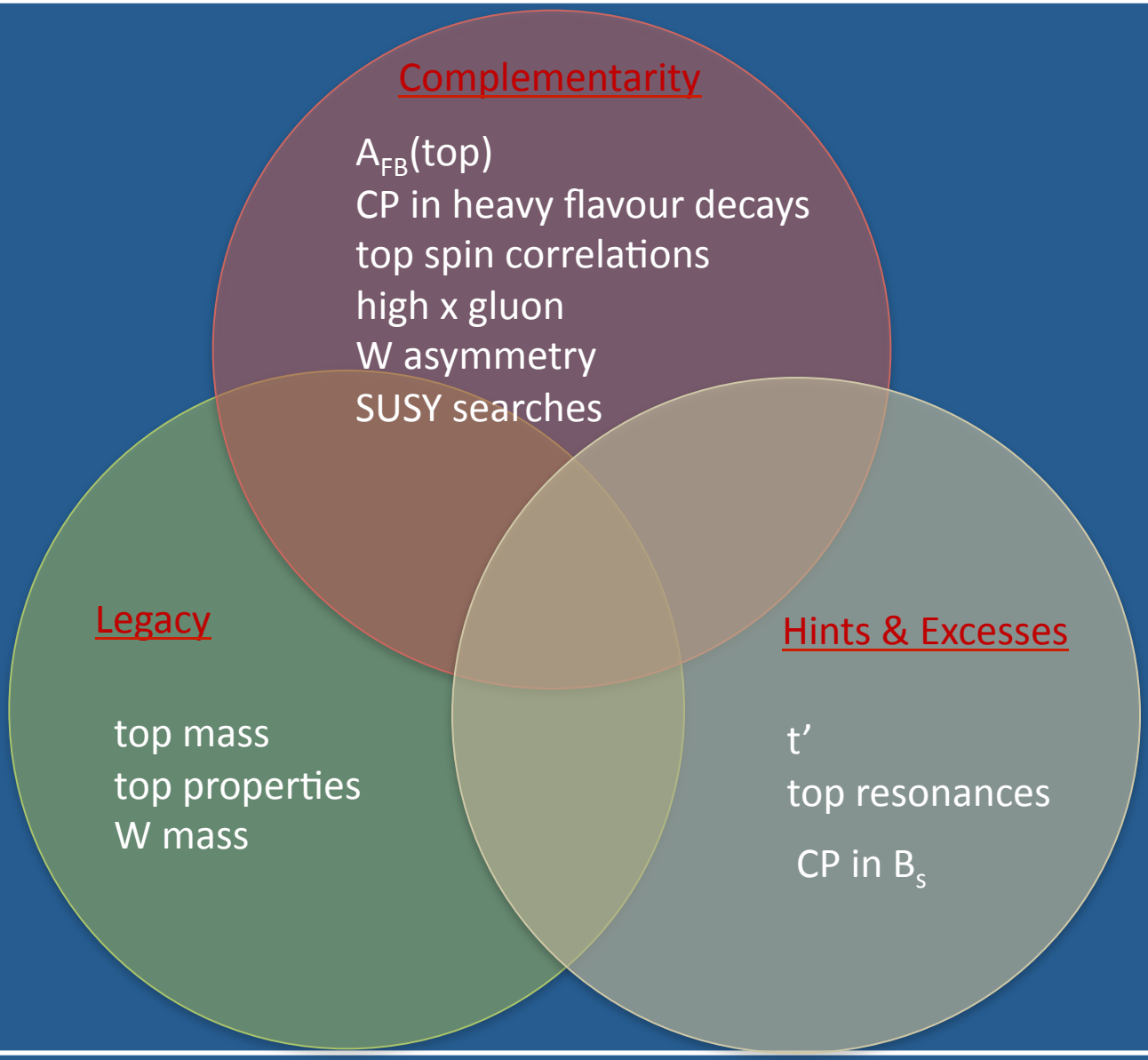
3.2 standard deviations from SM

$$A_{CP}(\pi^+\pi^-) = \frac{\Gamma(D^0 \to \pi^+\pi^-) - \Gamma(\overline{D}^0 \to \pi^-\pi^+)}{\Gamma(D^0 \to \pi^+\pi^-) + \Gamma(\overline{D}^0 \to \pi^-\pi^+)}$$



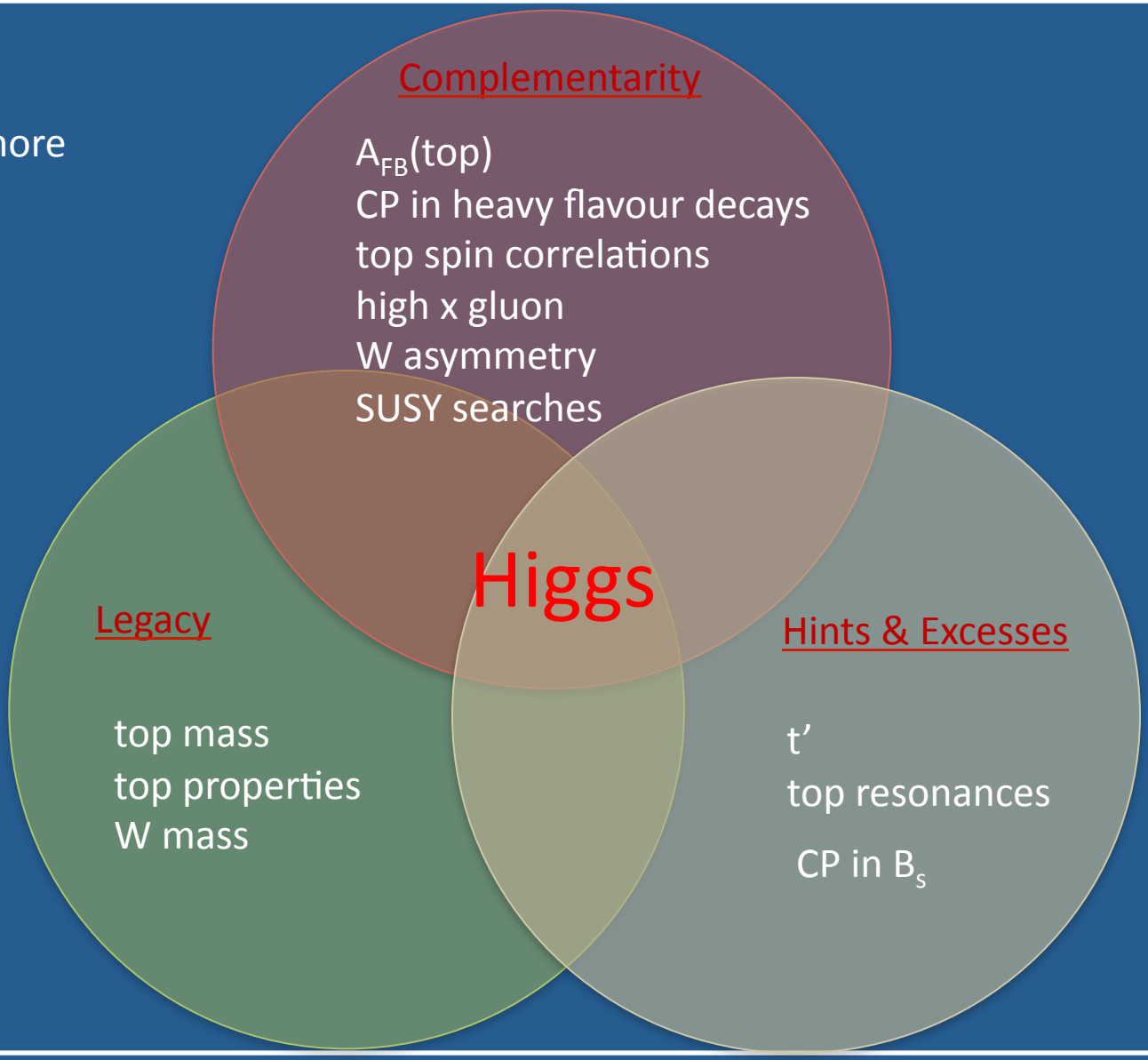
Most precise measurement of CP Asymmetry in charm sector

Beyond 2011 Tevatron Potential



Beyond 2011 Tevatron Potential

plus much more



Future Personpower (DØ)

A complete survey of all groups was performed asking them to provide manpower estimates for 2012-2014.
Groups were asked to assume that funding is available.
Effort reports for 2009: 277 FTEs, significantly above earlier predictions.

Category	2012	2013	2014
Academics/Senior Researcher	93	88	85
Postdocs	70	63	61
Students	80	76	73
Total FTEs	**243**	**227**	**219**

- Excellent return rate: 93% of the collaboration responded.
- Most of the collaboration committed for the full three years.
- Sufficient manpower for experiment operation (~100) and physics programme.
- Past experience shows that these estimates tend to be conservative.

Future Personpower (CDF)

2009 Survey/ Current Survey /Actual

"RUN III"

	2009	2010	2011	2012	2013	2014
Tot FTE	292	249/278	191	141/184	179	176
U.S.	46%	48%/51%	50%	46%	46%	46%
postdocs	71	65/72	47	29/48	46	45
students	100	77/91	51	33/60	57	55
fac. level	121	107/115	93	79/76	76	76

✸ Actual 2010 numbers turn out larger than projected in 2009, staying at 2009 level. This has always been the case in past surveys.

Notes:

- #'s are in FTE
- faculty level = teaching and non-teaching faculty + lab scientists

International and National Support

Examples:

"I believe the physics case, especially in terms of a low mass Higgs boson, is potentially strong."

Letter by the Director of the Science Programme, STFC, John Womersley

"We expect that many more exciting results may be achieved with longer machine operation."

Letter by the Director of JINR, Dubna, Mikhail Itkis

"Running the Tevatron through 2014 could produce the first direct evidence of a Higgs boson, a remarkable triumph for U.S. HEP and one of the most exciting scientific developments of this decade."

Letter by theorists to the Secretary of Energy, Steven Chu

Conclusions I

- CDF and DØ are enthusiastic about the physics opportunity of an extended Tevatron run – to solve the fundamental problem of EWSB.
- Tevatron and experiments are performing well and will continue to do so until 2014.
- We can find Higgs boson in all of the allowed mass range or demonstrate that SM is not internally consistent – both options are exciting.

Conclusions II

- Tevatron is currently unique – and complementary to the LHC - in having access to the bb decay mode.
- There is a wide range of `legacy' measurements that will be performed.
- Our extrapolations are based on experience and on data – we are confident that we can deliver.