Combinations of Searches for SM Higgs at the Tevatron

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On behalf of the CDF and D0 Collaborations

Rencontres de Moriond QCD and High Energy Interactions
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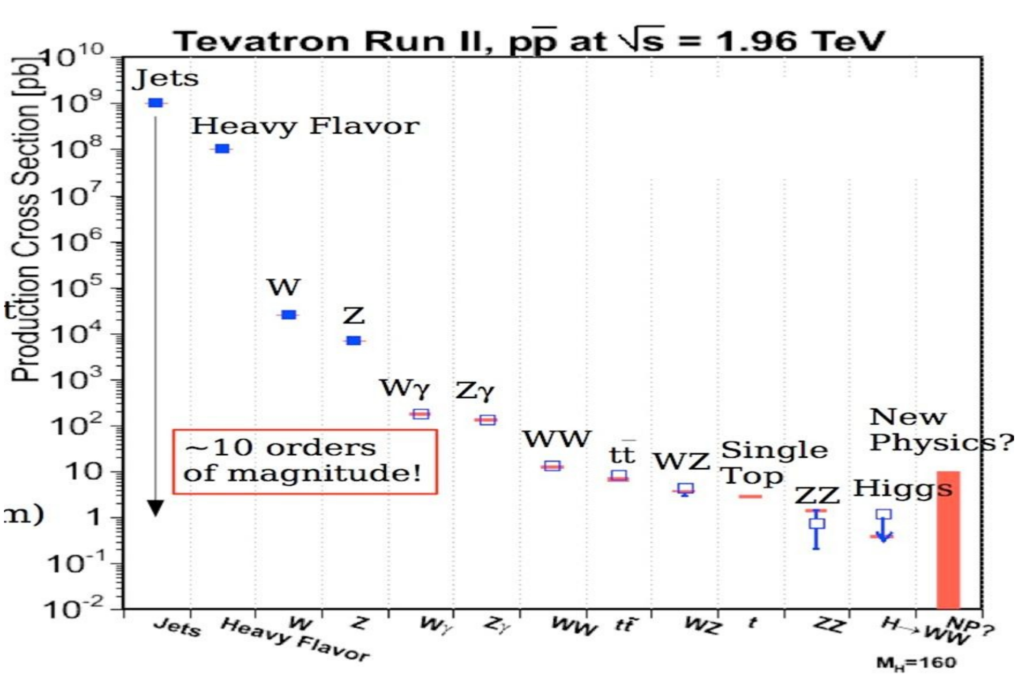
Outline

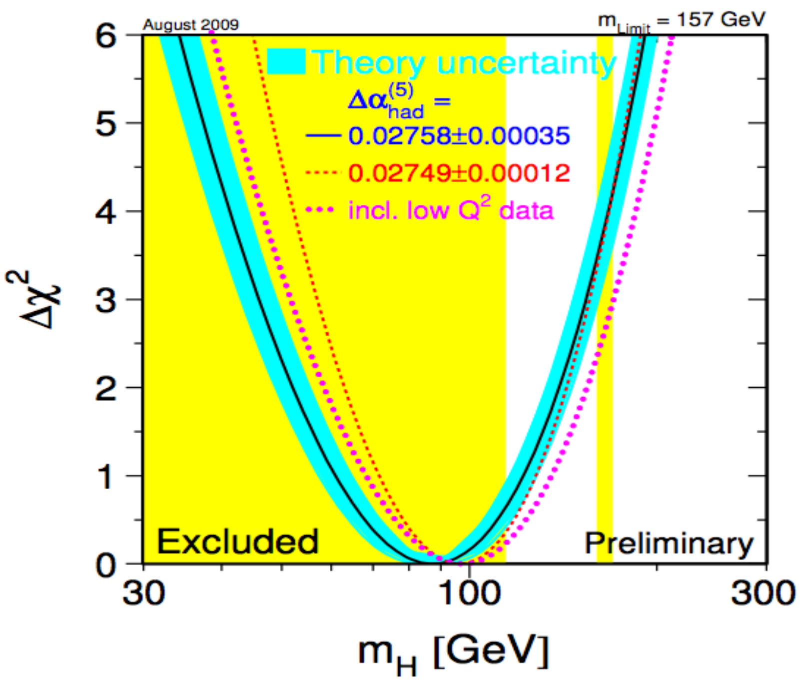
- Higgs Search Analyses Overview
- Combination Strategies
- Results based on 2.0-4.8 fb^{-1} (CDF) and 2.1-5.4 fb^{-1}(D0) of Data
- New limits on gg→H→WW and Constraints on 4th Generation
- Plans for Summer and Beyond

More Details see: arXiv:0911.3930[hep-ex] and PRL 104, 061802(2010)

Opportunity to SM Higgs and Beyond

- **Higgs search is a major goal of HEP, central part of Tevatron Program.**
- With recent observations of single top and WW/WZ→lνjj Tevatron is closing in on the SM Higgs boson.
- Direct search & EW fit set: **$114.4 < m_H < 186$ GeV @ 95 % C.L.**
- **The SM Higgs is now within Tevatron reach !**

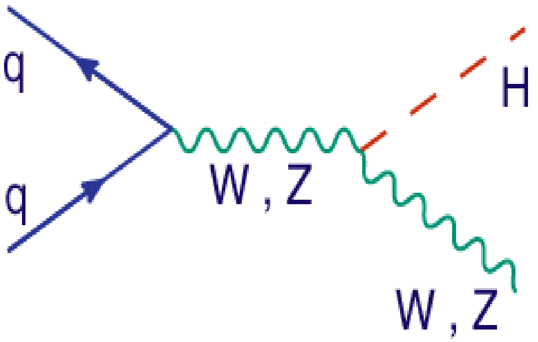




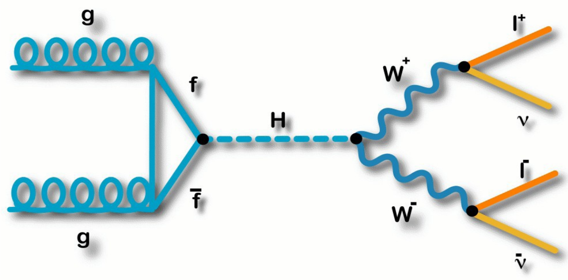
Higgs Search Strategies

- Event selections are similar for the corresponding CDF and D0 analyses.

- **Search for H→bb in association with W and Z:**
  - Main low mass channels
  - Identify Higgs as two jets with 1 or 2 btags
  - W, Z identified as leptonic or hadronic decays



- **Search for H→WW→lνlν in inclusive production:**
  - Main high mass channel
  - Selects on two charged leptons + missing et



- **Search for H→ττ, γγ in inclusive production:**
  - Minor channels for Tevatron, but important for LHC
  - Identify Higgs as a pair of τ or a pair of γ

- Employing "**no channel too small**" strategies to gain signal acceptances while reducing backgrounds with advanced analysis technique(**NN,ME,BDT**).

Higgs Search Channels

- **Total 90 mutually exclusive final states (D0:54 and CDF:36).**

D0 Channels	Luminosity(fb^{-1})	Tech
$WH \to \ell\nu b\bar{b}$ 2x(ST,DT)	5.0	NN
$VH \to \tau\tau b\bar{b}/q\bar{q}\tau\tau$	4.9	m_{jj}
$ZH \to \nu\bar{\nu}b\bar{b}$ (ST,TLDT)	5.2	BDT
$ZH \to \ell^+\ell^- b\bar{b}$ 2x(ST,DT)	4.2	NN
$WH \to WW^+W^- \to \ell^\pm\nu\ell^\pm\nu$	3.6	Likelihood
$H \to W^+W^- \to \ell^\pm\nu\ell^\mp\nu$	5.4	NN
$H \to \gamma\gamma$	4.2	$m_{\gamma\gamma}$
$t\bar{t}H \to t\bar{t}b\bar{b}$ 2x(ST,DT,TT)	2.1	H_T

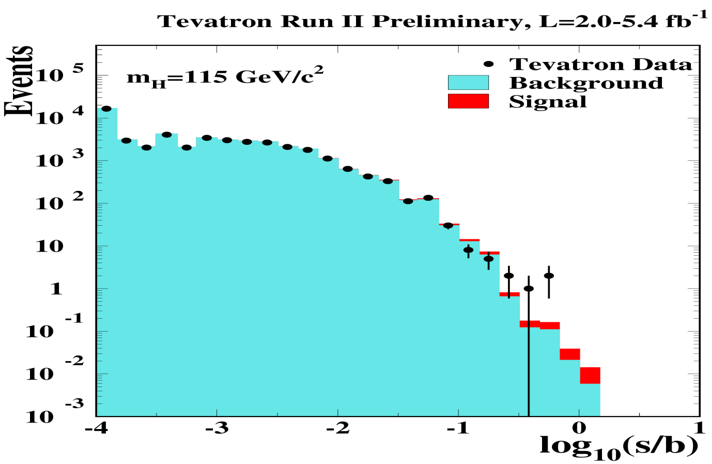
CDF Channels	Lum.(fb^{-1})	Tech
$WH \to \ell\nu b\bar{b}$ 2-jet 3x(TDT,LDT,ST,LDTX)	4.3	NN
$WH \to \ell\nu b\bar{b}$ 3-jet 2x(TDT,LDT,ST)	4.3	ME
$ZH \to \nu\bar{\nu}b\bar{b}$ (TDT,LDT,ST)	3.6	NN
$ZH \to \ell^+\ell^- b\bar{b}$ (L,H s/b)x(TDT,LDT,ST)	4.1	NN+ME
$H \to W^+W^-$ (L,H s/b)x(0,1, 2 jets)+Low-$m_{\ell\ell}$	4.8	NN+ME
$WH \to WW^+W^- \to \ell^\pm\nu\ell^\pm\nu$	4.8	NN
$H + X \to \tau^+\tau^- + 2$ jets	2.0	NN
$WH + ZH \to jjb\bar{b}$	2.0	ME

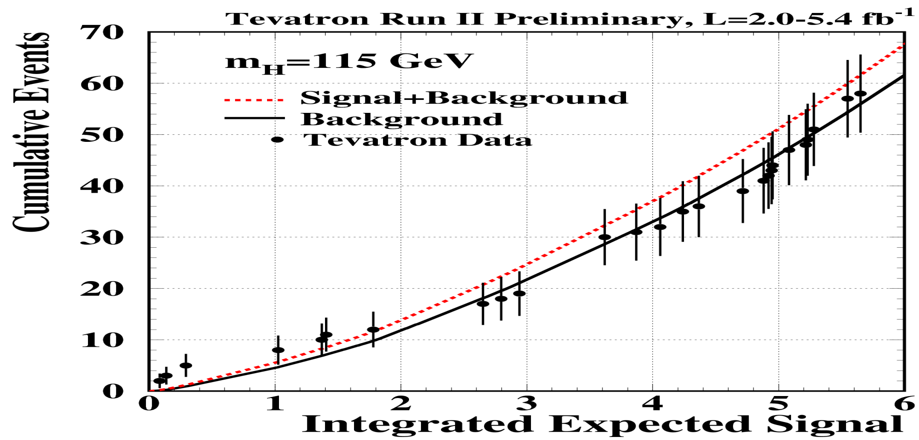
Systematic Uncertainties

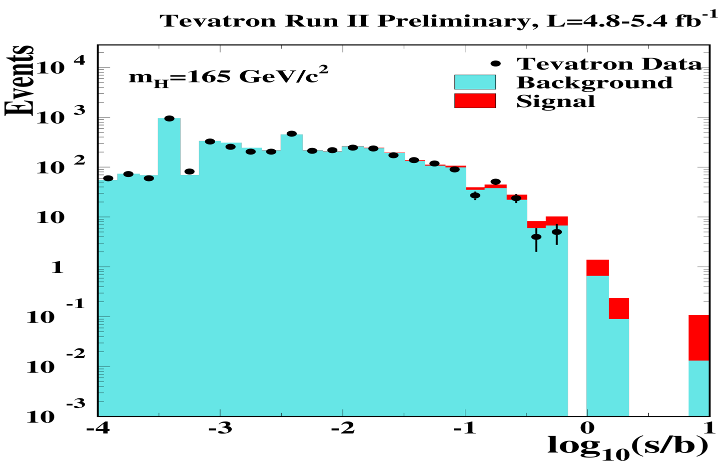
- Two types of systematics on estimated signal and background:
  - Rate systematics: only affect overall normalization
  - Shape systematics: change differential distribution, i.e. due to JES, MC modeling
- Systematics correlated between CDF and D0:
  - Integrated luminosity (4% correlated out of 6%)
  - Theoretical cross sections for signal and backgrounds (5-10%)
- Other Sources correlated within experiment:
  - Lepton ID, 2-4%
  - Btag SF, JES, FSR/ISR, 5-10%
  - Jet/Missing Et modeling
  - MC simulated backgrounds (W/Z+HF)
  - instrumental backgrounds(non-W, mistag)

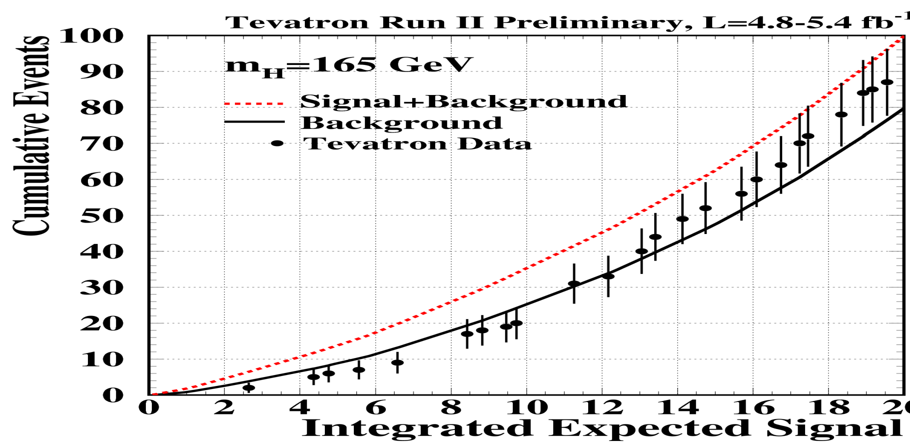
Data Distributions

- Rebin histograms of the final discriminant variable in log(S/B)
- Data with similar S/B may be added with no loss in sensitivity



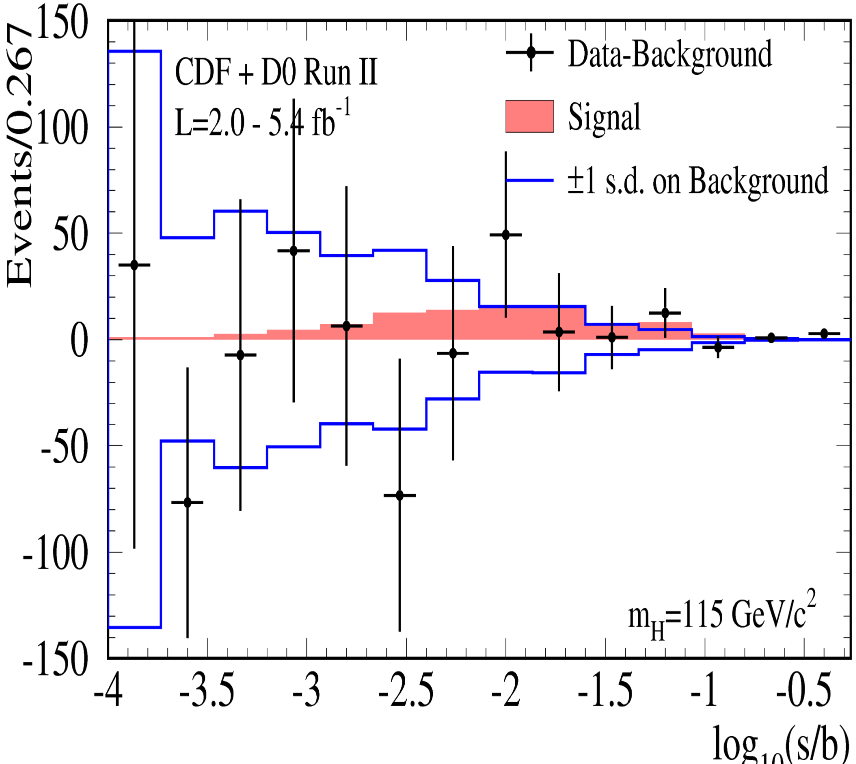


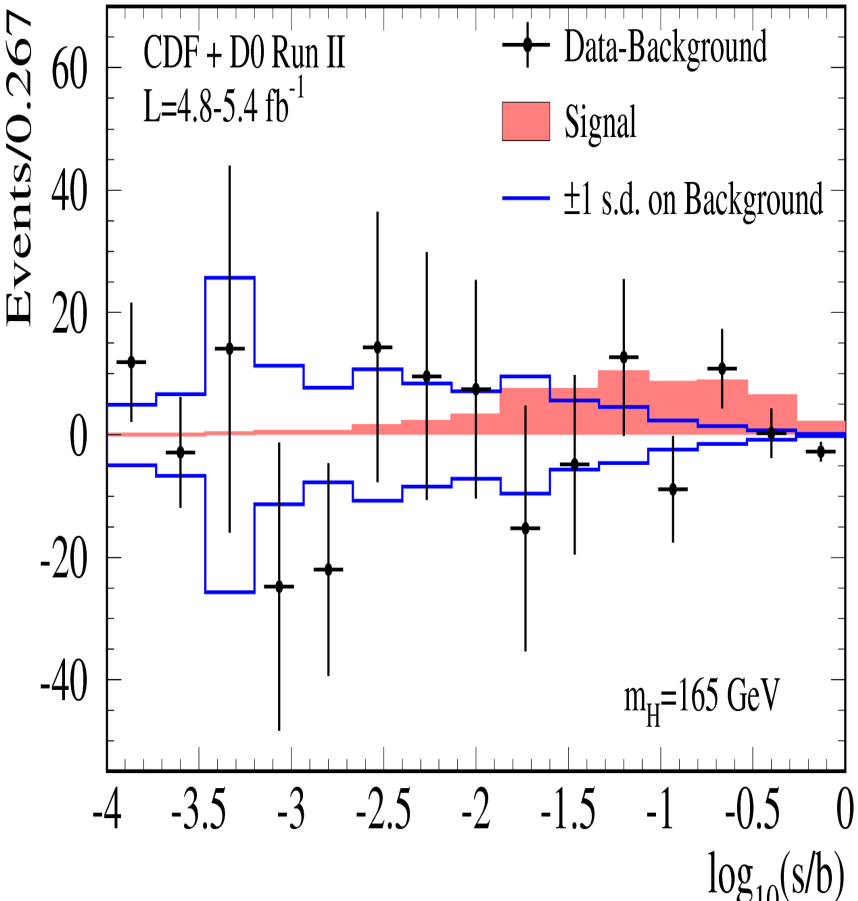




Data after Background Subtraction

- **Using background model that has been fit to the data.**
- **No excess of events observed in the highest S/B bins.**





Combination Methods

- Two limit setting methods used and provide cross check(<10%).
- Using distributions of final discriminant, not just event yields.
- Using Poisson statistics for all bins.
- Systematic as nuisance parameters with truncated Gaussian.
- **Bayesian Method (CDF), integrating over likelihoods:**
  - based on credibility, uses a prior
  - “How likely is the real value below limit?”
- **Modified Frequentist Method (DØ), CLs test statistics:**
  - comparing 'b-only' & 's+b' hypotheses
  - based on coverage, using pseudo-experiments
  - “How likely is the limit above the real value?”

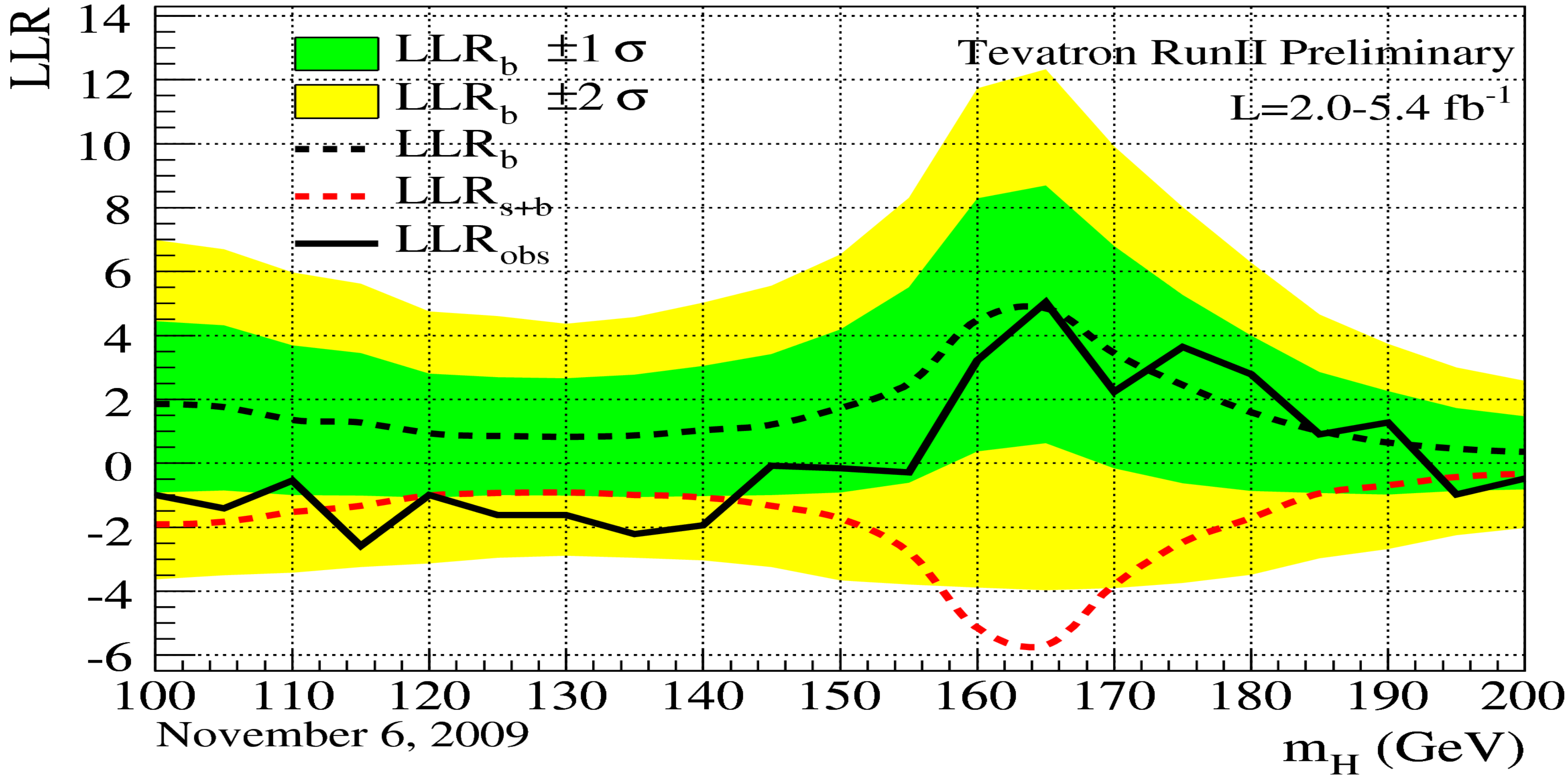
Production Xsec and Branching Ratio

- Normalized to SM predictions including most recent gg→H calculation:
  - ➔ NNLL + 2-loop EW + MSTW2008 NNLO PDF (Grazzini & Florian arXiv:0901.2427; Anastasiou et al arXiv:0811.3458)

m_H (GeV/c^2)	$\sigma_{gg\to H}$ (fb)	σ_{WH} (fb)	σ_{ZH} (fb)	σ_{VBF} (fb)	$B(H\to b\bar{b})$ (%)	$B(H\to\tau^+\tau^-)$ (%)	$B(H\to W^+W^-)$ (%)
100	1861	286.1	166.7	99.5	81.21	7.924	1.009
105	1618	244.6	144.0	93.3	79.57	7.838	2.216
110	1413	209.2	124.3	87.1	77.02	7.656	4.411
115	1240	178.8	107.4	79.07	73.22	7.340	7.974
120	1093	152.9	92.7	71.65	67.89	6.861	13.20
125	967	132.4	81.1	67.37	60.97	6.210	20.18
130	858	114.7	70.9	62.5	52.71	5.408	28.69
135	764	99.3	62.0	57.65	43.62	4.507	38.28
140	682	86.0	54.2	52.59	34.36	3.574	48.33
145	611	75.3	48.0	49.15	25.56	2.676	58.33
150	548	66.0	42.5	45.67	17.57	1.851	68.17
155	492	57.8	37.6	42.19	10.49	1.112	78.23
160	439	50.7	33.3	38.59	4.00	0.426	90.11
165	389	44.4	29.5	36.09	1.265	0.136	96.10
170	349	38.9	26.1	33.58	0.846	0.091	96.53
175	314	34.6	23.3	31.11	0.663	0.072	95.94
180	283	30.7	20.8	28.57	0.541	0.059	93.45
185	255	27.3	18.6	26.81	0.420	0.046	83.79
190	231	24.3	16.6	24.88	0.342	0.038	77.61
195	210	21.7	15.0	23	0.295	0.033	74.95
200	192	19.3	13.5	21.19	0.260	0.029	73.47

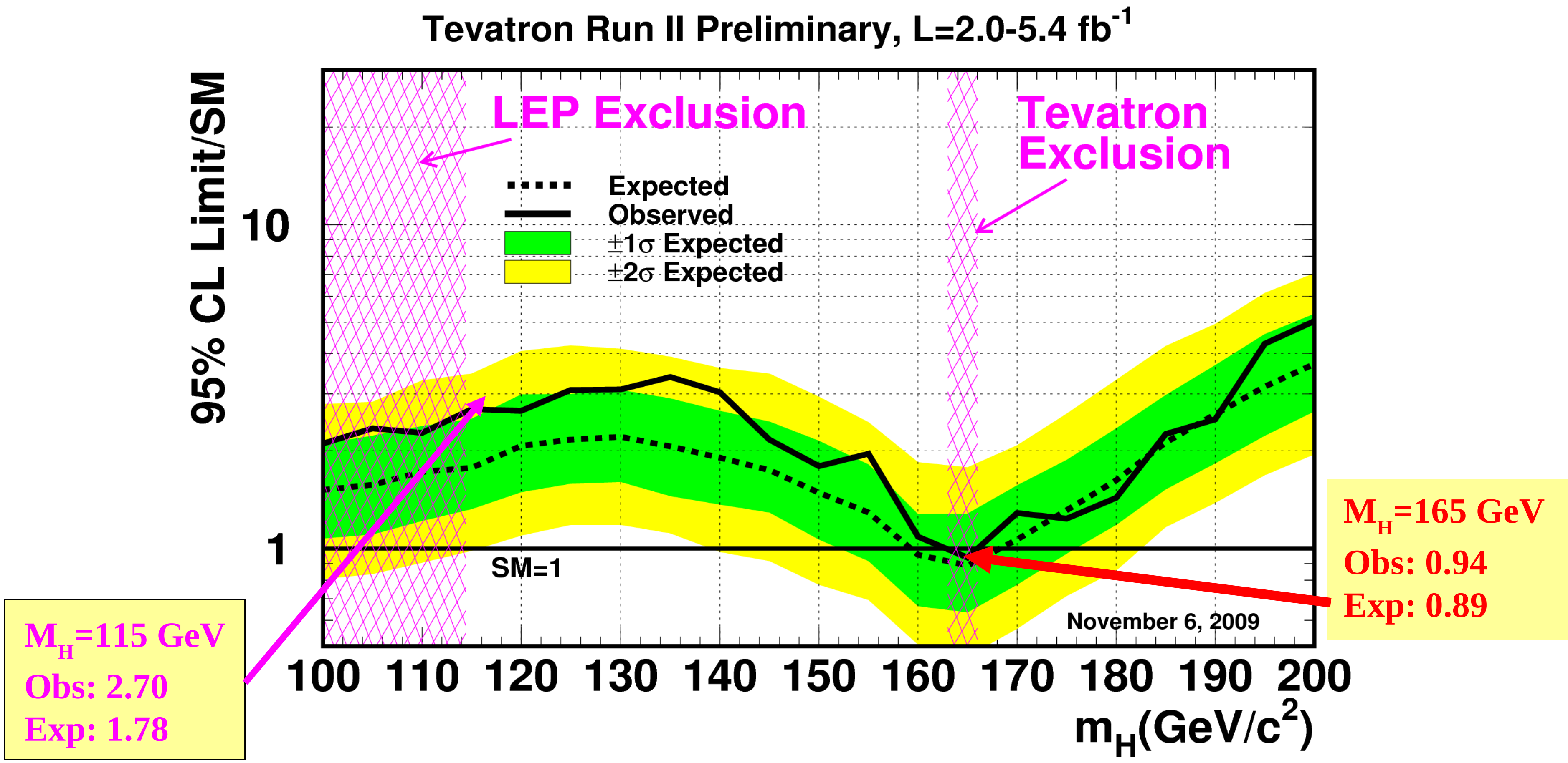
Tevatron Sensitivity

- **Log-likelihood Ratios (LLR): LLR_b, LLR_{s+b}, LLR_{obsv}**
- **Separation between LLR_b and LLR_{s+b} is the search sensitivity**



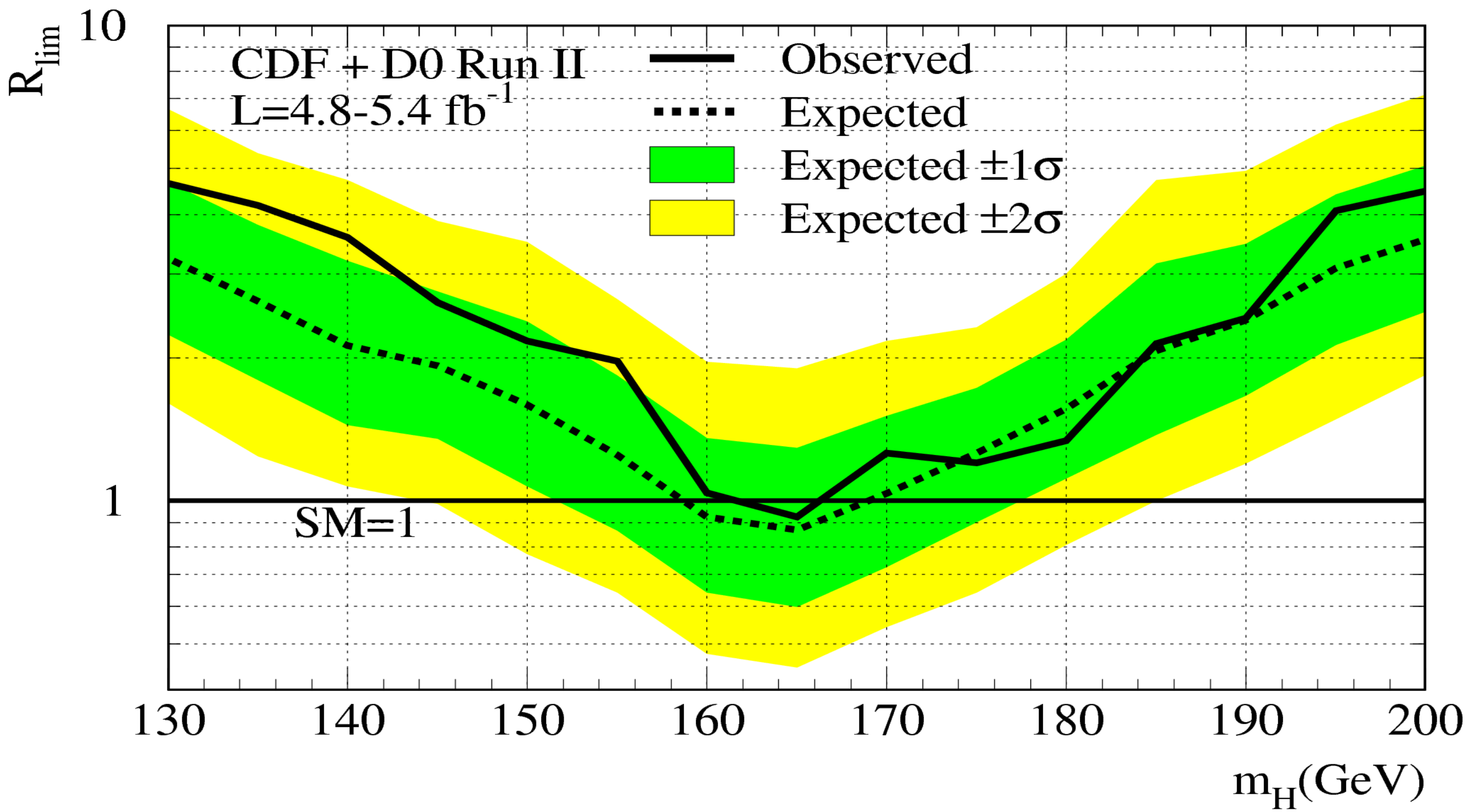
Tevatron Combination

- **Combining CDF and D0 for maximum sensitivity**



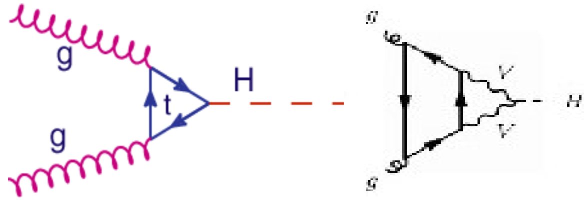
Tevatron Combination for H→WW

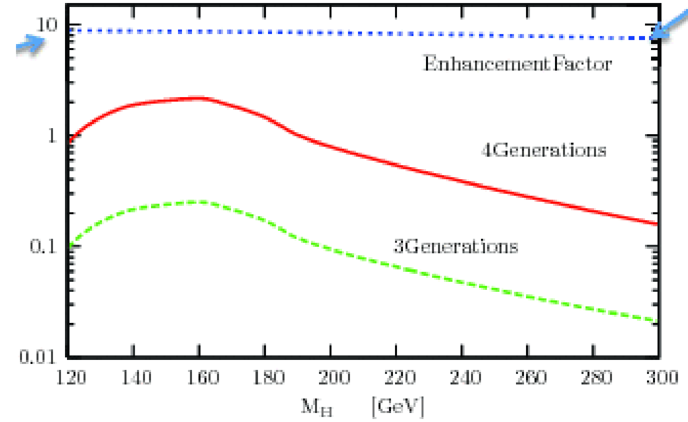
- **First joint CDF&D0 publication on SM Higgs search(PRL 104 061802 2010)**
- **Set 95% CL mass exclusion: 162<m_H<166 GeV/c^2 (159<m_H<169 expected)**

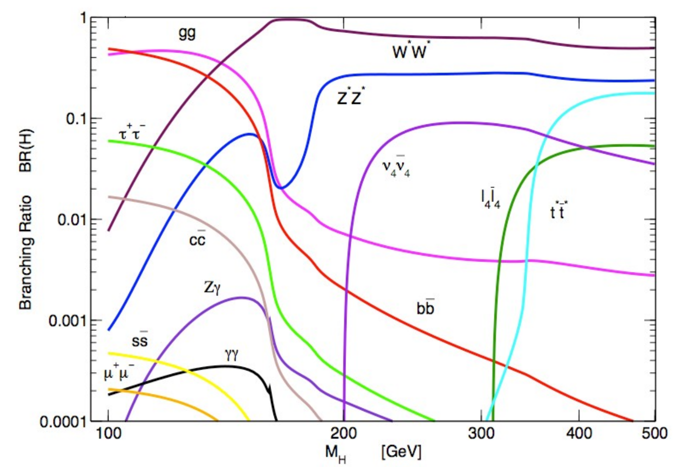


Tevatron Limit on gg→H→WW and Constraints on 4^{th} Generation

- Above current lower mass limits, the existence of 4^{th} generation is still a possibility.
- In this scenario gg→H coupling is enhanced by a factor of K~3 with additional quarks in the loop.
- **$\sigma_{4G}(gg\rightarrow H)=K^2\sigma_{SM}(1-\delta_{EW})+K\delta_{EW}\sigma_{SM}$**
- Higgs branching fractions are also modified due to the presence of 4^{th} generation.
- Two 4^{th} Generation Scenarios considered:
  - **Infinite-mass: $m_{l4,q4}$=1 TeV**
  - Low-mass: $(m_{l4}, m_{\nu4}, m_{u4}, m_{d4})$=(100, 80, 256, 128) GeV
  - **G. Kribs et al (arXiv:0706/3718)**

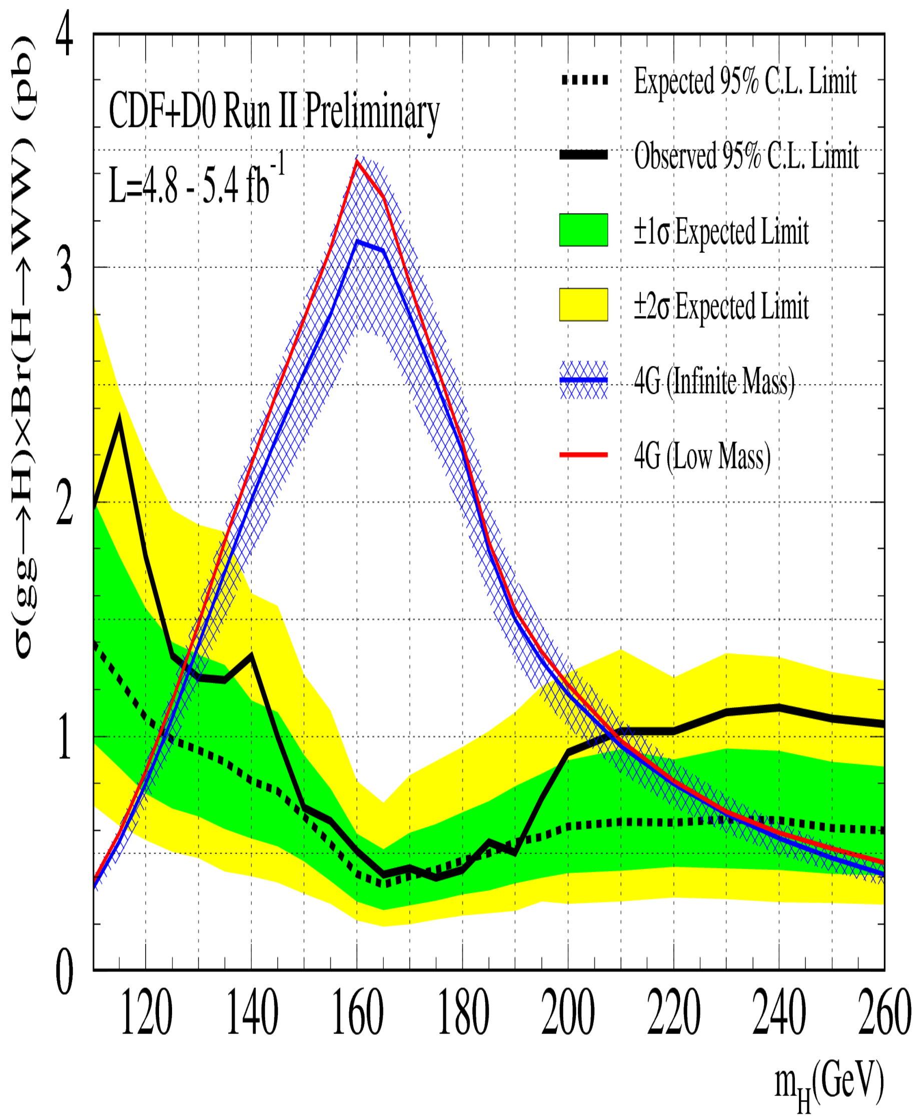






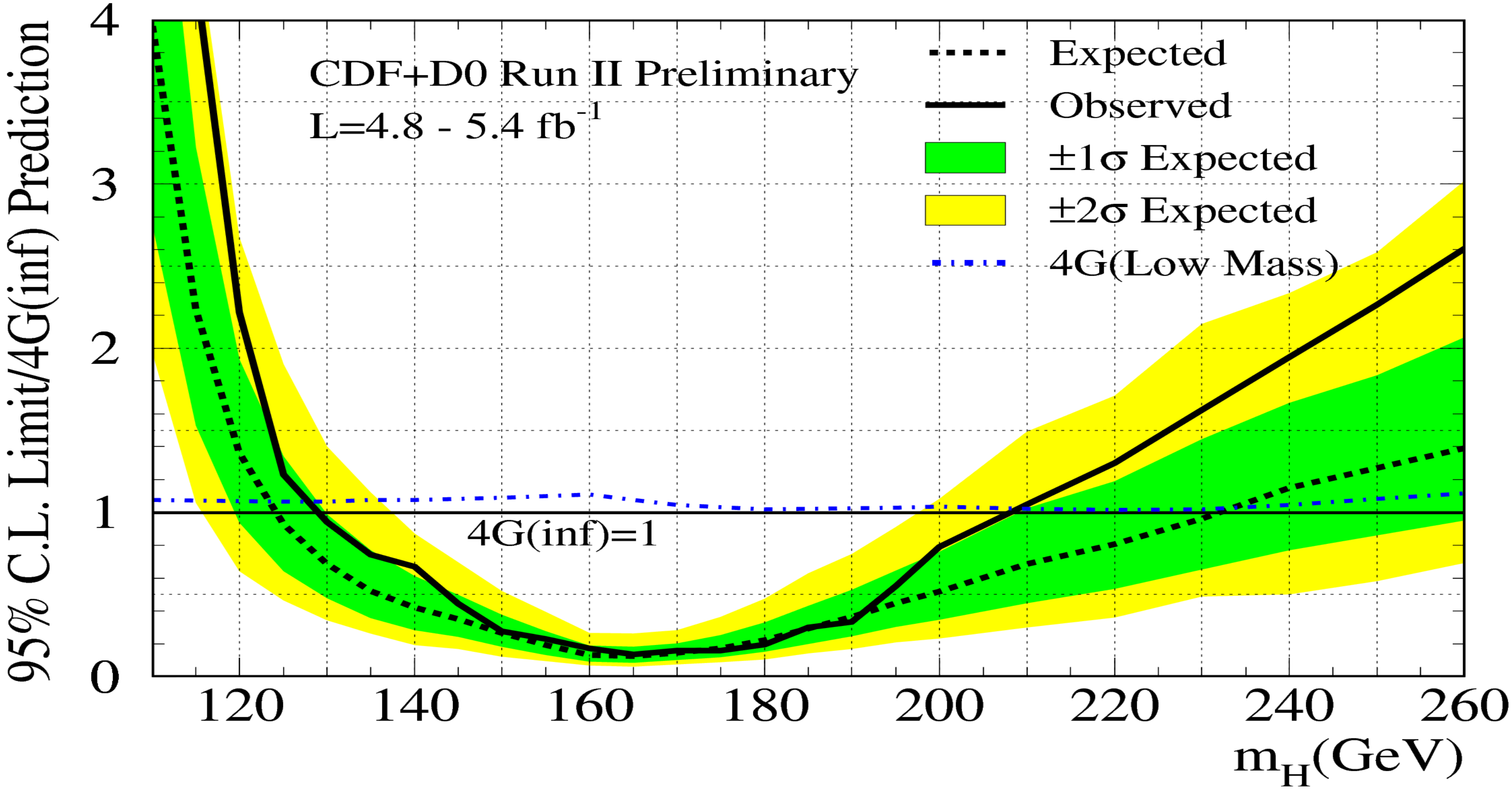
Analysis Strategy

- Consider gg→H→WW signal only.
- Standard HWW selections:
  - Ignore signal contributions from WH,ZH,VBF
  - Loosen $\Delta\varphi_{ll}$ cuts (D0) to gain acceptance for large m_H
  - Extend search to m_H=260 GeV
- Redo NN training for each mass.
- Same background predictions.
- Same Combination procedures.
- Set limit on σ(gg→H)xBR(H→WW):



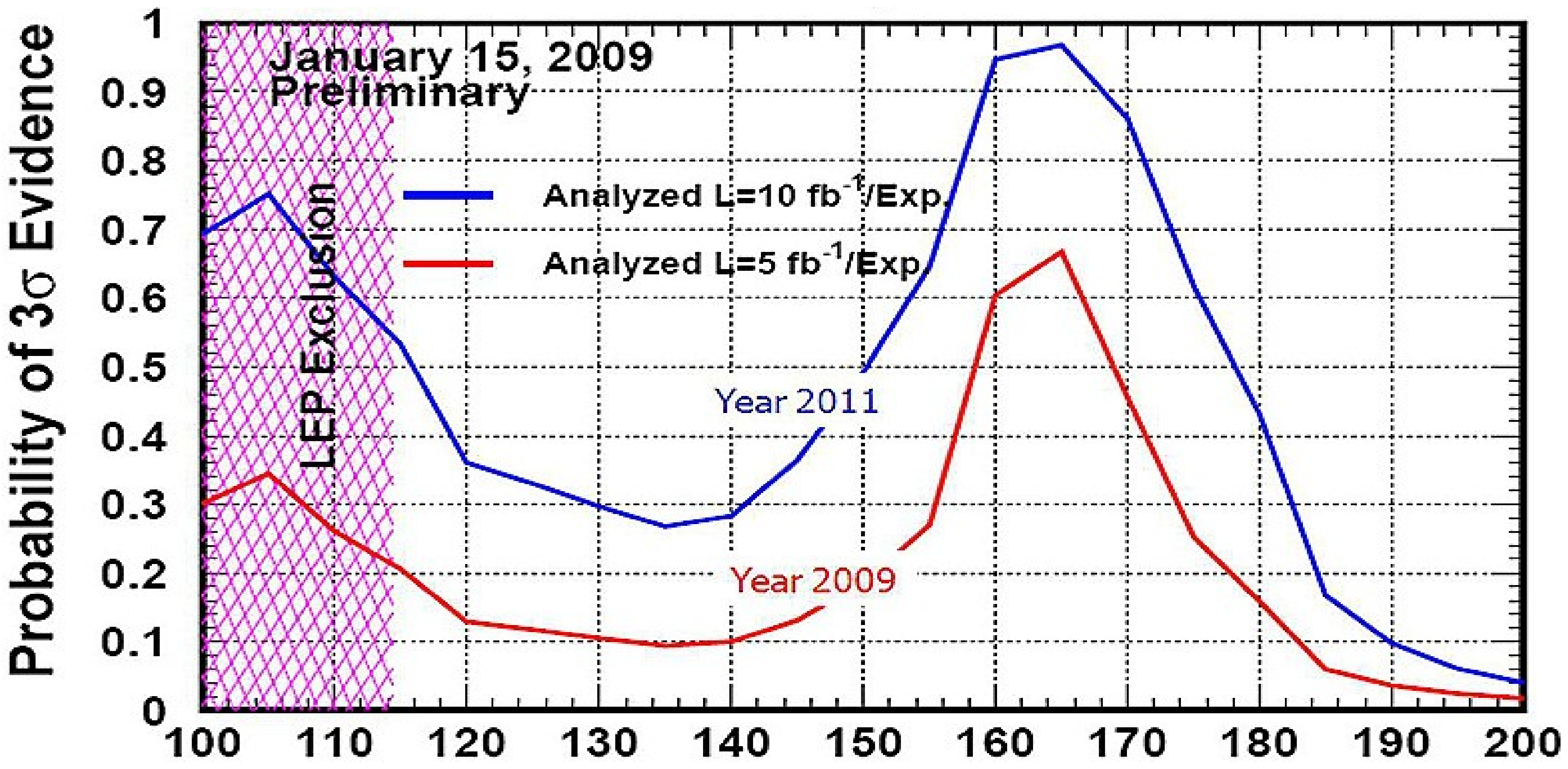
4th Generation Interpretation - Results

- Assuming the presence of a 4th generation with very large masses, Tevatron excludes a SM-like Higgs with mass: **$130<m_H<210$ GeV/c^2.**



Future Prospects

- With 10 fb^{-1} data, Tevatron has 1/3 of chance to see some hints of SM Higgs for all m_H<180 GeV/c^2.



Conclusion

- We excluded a Higgs mass range between 162 and 166 GeV/c^2 @ 95% CL for the first time and expect this range to glow when incorporating more data and improved analysis techniques.

- "No channel too small" strategy seems work well for both CDF and D0 and the sensitivity will continue to improve over time.

- By this summer, we aim to publish the combined searches in full mass region and each experiment should reach individual exclusion sensitivity near M_H=165 GeV.

- With 12 fb^{-1} by 2012, Tevatron would either exclude Higgs mass up to 180 GeV/c^2 @ 95%CL or find some evidence.

- The absence of $gg \rightarrow H \rightarrow WW$ can also be used to constrain some new physics such as 4th Generation models.

Backup Slides

Main Higgs Discriminant