# Combined CDF-D0 Limits on SM Higgs Production
# ReBlessing

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## OutLine of Talk

- Introduction
- Input Data, Acceptance, and Backgrounds
- Combination Procedures and systematics
- Combination Results
- Cross Checks
- Conclusion

Documented in CDF-8384 and supported by CDF-8403 and D0-5056.

# Introduction

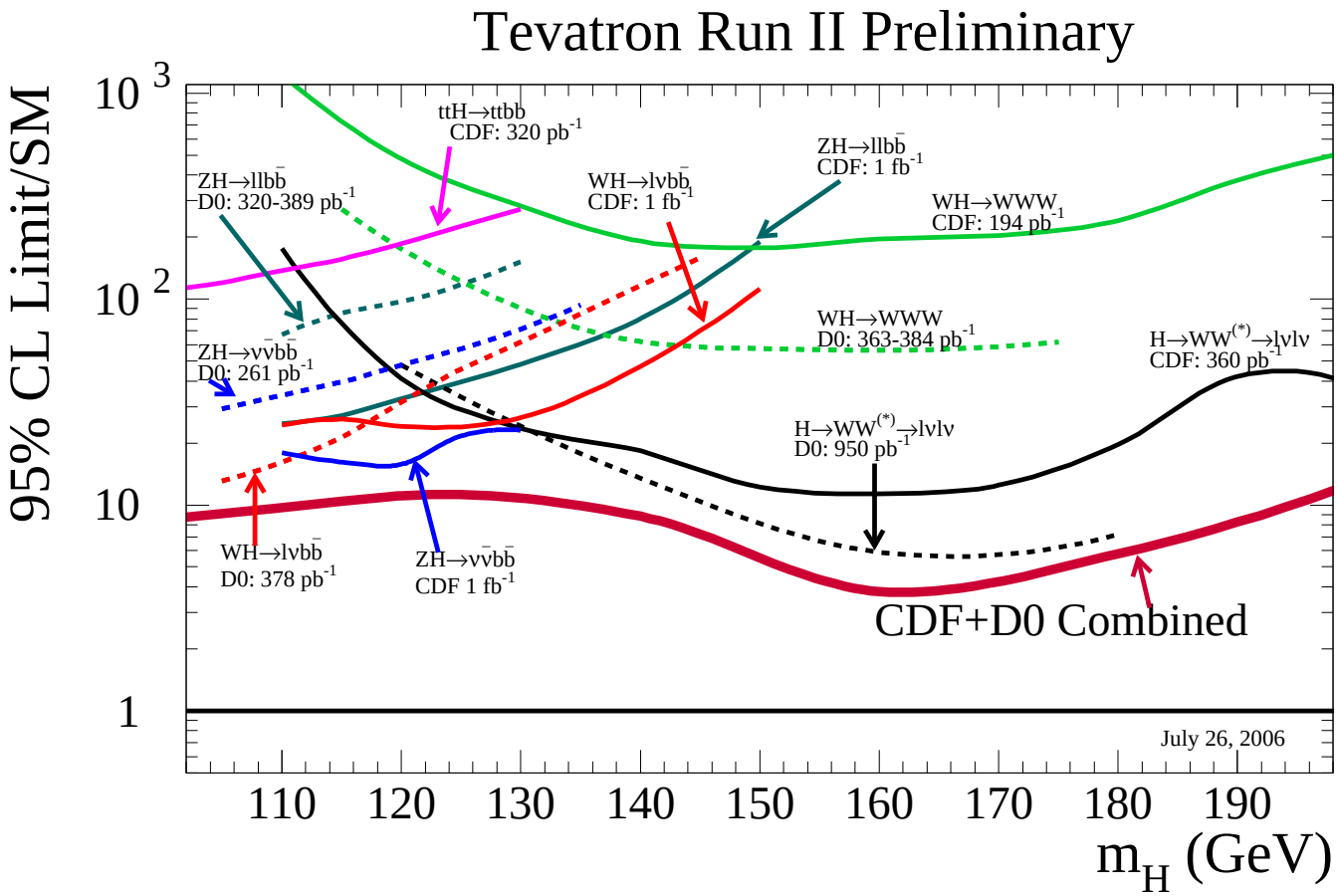
- CDF and D0 have reported direct searches for SM Higgs production in many different final states with sufficient integrated luminosity ($\approx 1fb^{-1}$)
  - $WH \rightarrow l\nu b\bar{b}$
  - $ZH \rightarrow \nu\bar{\nu}b\bar{b}$
  - $ZH \rightarrow l^+l^-b\bar{b}$
  - $gg \rightarrow H \rightarrow W^+W^-$
- A combined limit would significantly improve the individual limits for each experiment.

# Inputs

- CDF results included:
  - $WH \to l\nu b\bar{b}$ with 1 fb$^{-1}$ (ST, DT)
  - $ZH \to \nu\bar{\nu}b\bar{b}$ with 1.0 fb$^{-1}$ (ST, DT)
  - $ZH \to l^+l^-b\bar{b}$ with 1.0 fb$^{-1}$ ($\geq 1$ tag)
  - $gg \to H \to W^+W^- \to l^+l^-\nu\bar{\nu}$ with 0.4 fb$^{-1}$

- D0 results included:
  - $WH \to l\nu b\bar{b}$ with 0.4 fb$^{-1}$ (e, $\mu$, DT, ST)
  - $ZH \to \nu\bar{\nu}b\bar{b}$ with 0.3 fb$^{-1}$ (DT, ST)
  - $ZH \to l^+l^-b\bar{b}$ with 0.4 fb$^{-1}$ (DT only)
  - $H \to WW \to l^+l^-\nu\bar{\nu}$ with 1 fb$^{-1}$ ($e^\pm e^\mp$, $e^\pm\mu^\mp$, $\mu^\pm\mu^\mp$)
  - $WH \to WWW$ with 0.4 fb$^{-1}$ ($e^\pm e^\pm$, $e^\pm\mu^\pm$, $\mu^\pm\mu^\pm$)

# Summary of Tevatron Higgs Results (Tom)



# Source of Correlated Systematic (CDF)

| Channels | $l\nu b\bar{b}$ | | $\nu\bar{\nu}b\bar{b}$ | | $l^+l^-b\bar{b}$ | $W^+W^-$ |
|---|---|---|---|---|---|---|
| | Single | Double | Single | Double | | |
| Acceptance | | | | | | |
| Luminosity (%) | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 |
| btag SF (%) | 5.3 | 16.0 | 8.0 | 16.0 | 8 | 0.0 |
| Lepton ID (%) | 2.0 | 2.0 | 2.0 | 2.0 | 1.4 | 3.0 |
| JES (%) | 3.0 | 3.0 | (1-20) | (1.6-20) | 6.0 | 1.0 |
| MC modeling (%) | 4.0 | 10.0 | 4.0 | 5.0 | 2.0 | 5.0 |
| Trigger (%) | 0.0 | 0.0 | 3.0 | 3.0 | 0.0 | 0.0 |
| Shapes (%) | 0.0 | 0.0 | 0.0 | 0.0 | -20.0 | 0.0 |
| Backgrounds | | | | | | |
| Mistag (%) | 22 | 15 | 17 | 17 | 17 | 0.0 |
| QCD (%) | 17 | 20 | -10 | -44 | -50 | 0 |
| W/Z+HF(I) (%) | 33 | 34 | 12 | 12 | 40 | 0 |
| W+HF(II) (%) | 0 | 0 | -10 | -42 | 0 | 0 |
| Z+HF(II) (%) | 0 | 0 | -6 | -19 | 0 | 0 |
| Top(I) (%) | 13.5 | 20 | 12 | 12 | 20 | 0 |
| Top(II) (%) | 0. | 0. | -2 | -3 | 0 | 0 |
| Diboson(I) (%) | 16 | 25 | 12 | 12 | 20 | 11 |
| Diboson(II) (%) | 0 | 0 | -5 | -10 | 0 | 0 |
| Other (%) | 0 | 0 | 0 | 0 | 0 | -(12-18) |

- The positive value means correlated, the negative value means uncorrelated
- The results seems insensitive to these correlations changing from 100% to 0%

# Source of Correlated Systematic (D0)

| Channels | $e\nu b\bar{b}$ DT(ST) | $\mu\nu b\bar{b}$ DT(ST) | $\nu\nu b\bar{b}$ DT(ST) | $e^+e^-b\bar{b}$ DT | $\mu$ |
|---|---|---|---|---|---|
| Luminosity (%) | 6.5 | 6.5 | 6.5 | 6.5 | |
| JES (%) | 4 | 5 | 6 | 7 | |
| Jet ID (%) | 6.8 | 6.8 | 7.1 | 7 | |
| Electron ID (%) | 6.6 | 0 | 0 | 8 | |
| Muon ID (%) | 0 | 4.9 | 0 | 0 | |
| b-jet Tagging (%) | 8.5(5) | 8.5(5) | 9.6(6.7) | 12 | |
| Backgrounds $\sigma$ (%) | 6-33 | 6-25 | 6-33 | 6-19 | |

- Common Systematic between CDF and D0:
  - Luminosity: 4.5%
  - Top xsec (8%), Diboson xsec (6%), and 10% for $gg \to H$

# Technique for Limit Combination

- CLs Method with Log-Likelihood Ratio (LLR) - D0

$$\chi_n = 2 \times \sum_{i=1}^{N_C} \sum_{j=1}^{Nbins} (s_{ij} - n_{ij} Log(1 + s_{ij}/b_{ij}))$$

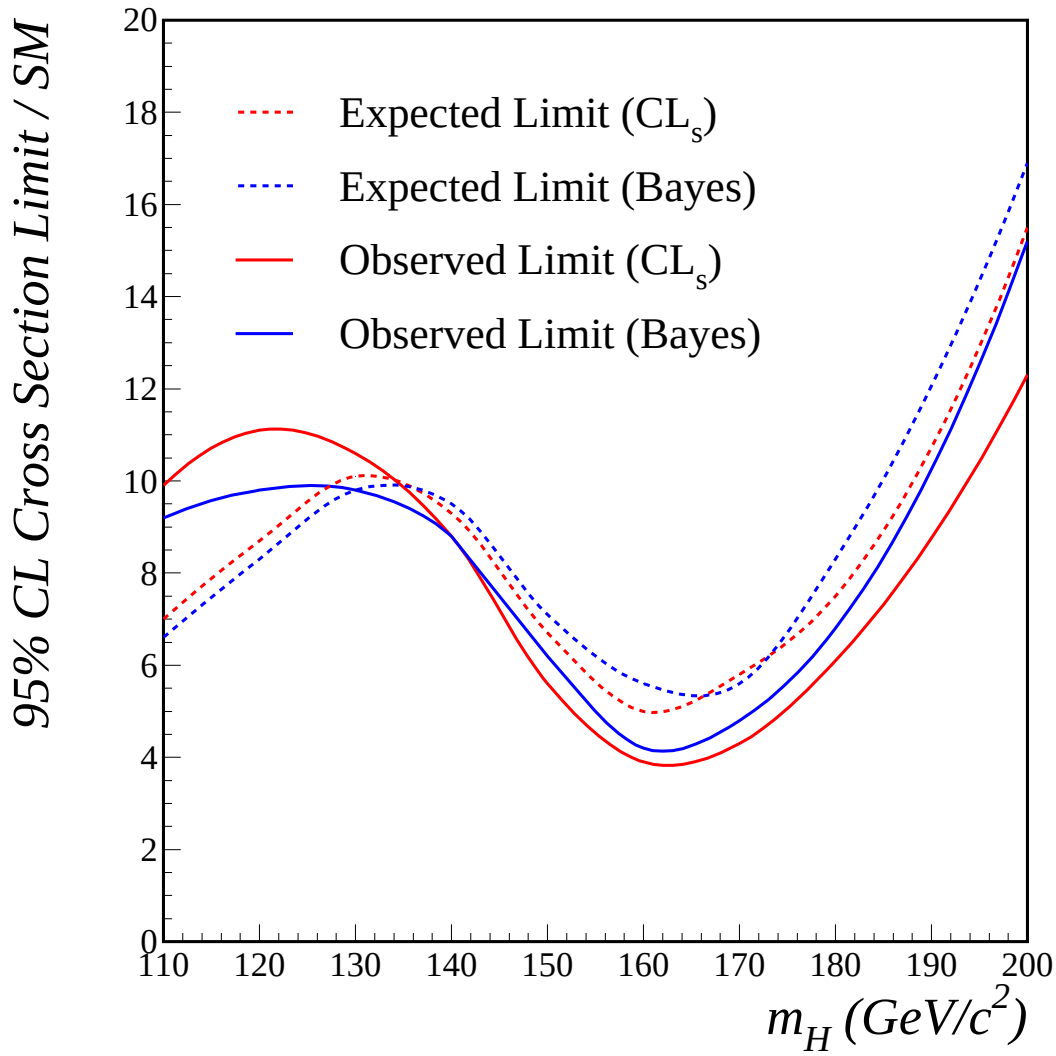
  - $CL_s = CL_{s+b}/CL_b$

- Bayesian framework - CDF
  - Use Bayesian posterior probability
  - Assume flat prior density for the number of Higgs events
  - Combined Binned Poisson Likelihood:

$$\mathcal{L}(R, \vec{s}, \vec{b}|\vec{n}) = \prod_{i=1}^{N_C} \prod_{j=1}^{Nbins} \mu_{ij}^{n_{ij}} e^{-\mu_{ij}}/n_{ij}!$$

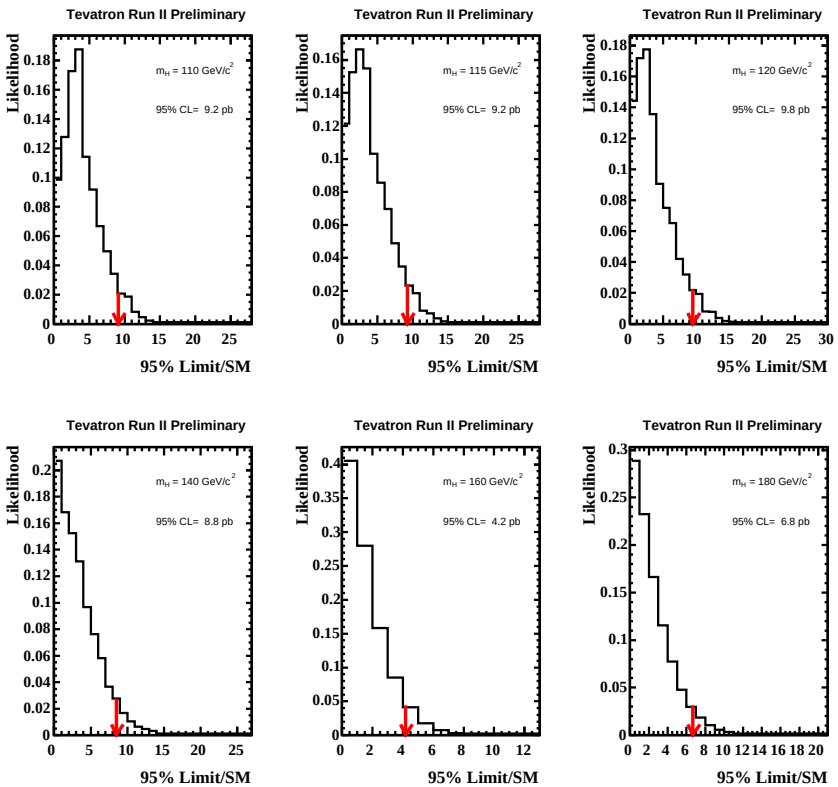
- Both methods agree within 10%

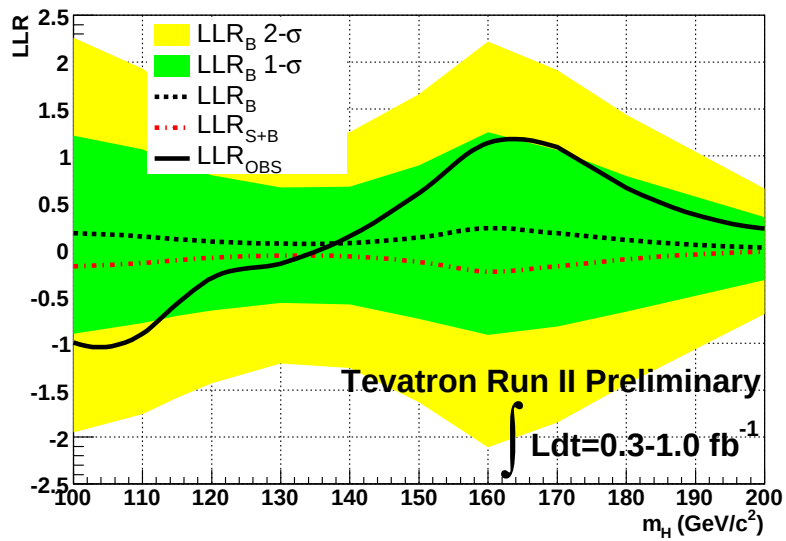
# Cross Checks between Two Methods



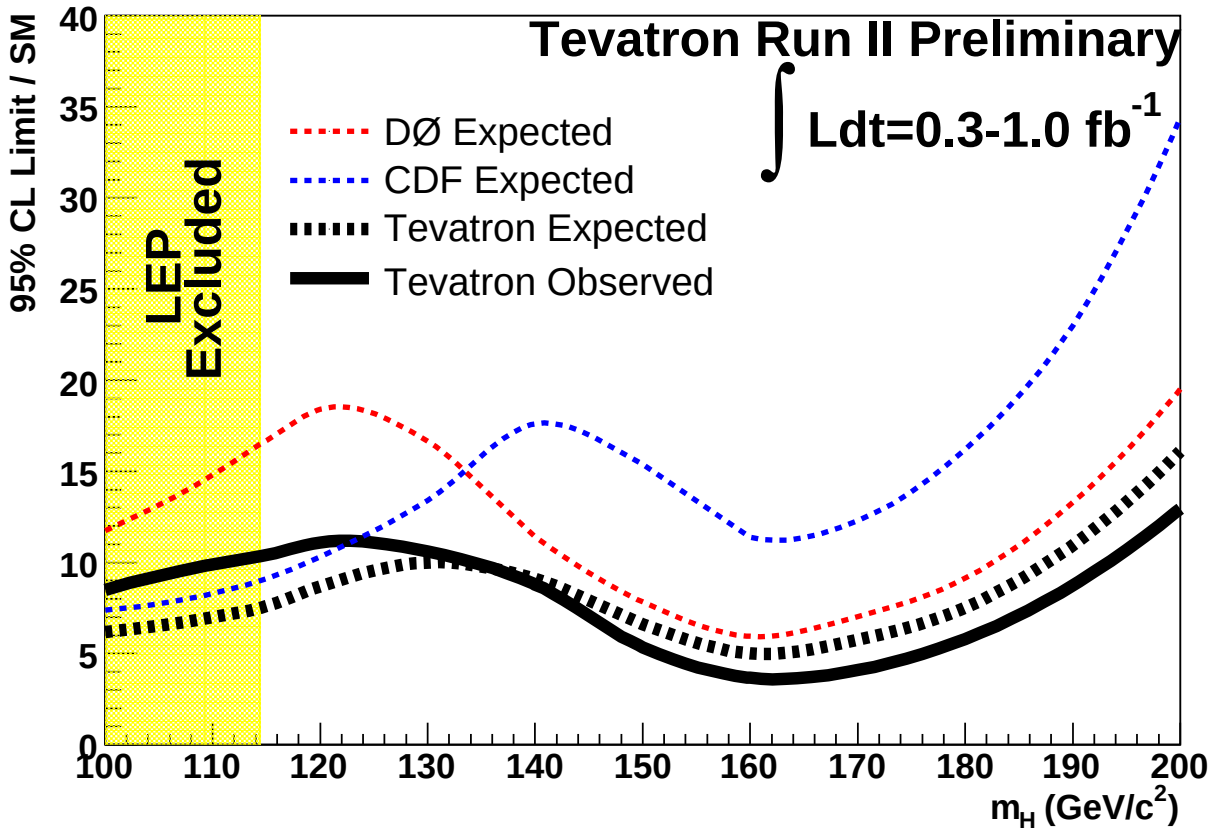

- At low mass the Bayesian procedure gives better limits while at high masses the $CL_s$ method yeilds a better limit.

# Tevatron Likelihood and Log-Likelihood Ratio (For Blessing)



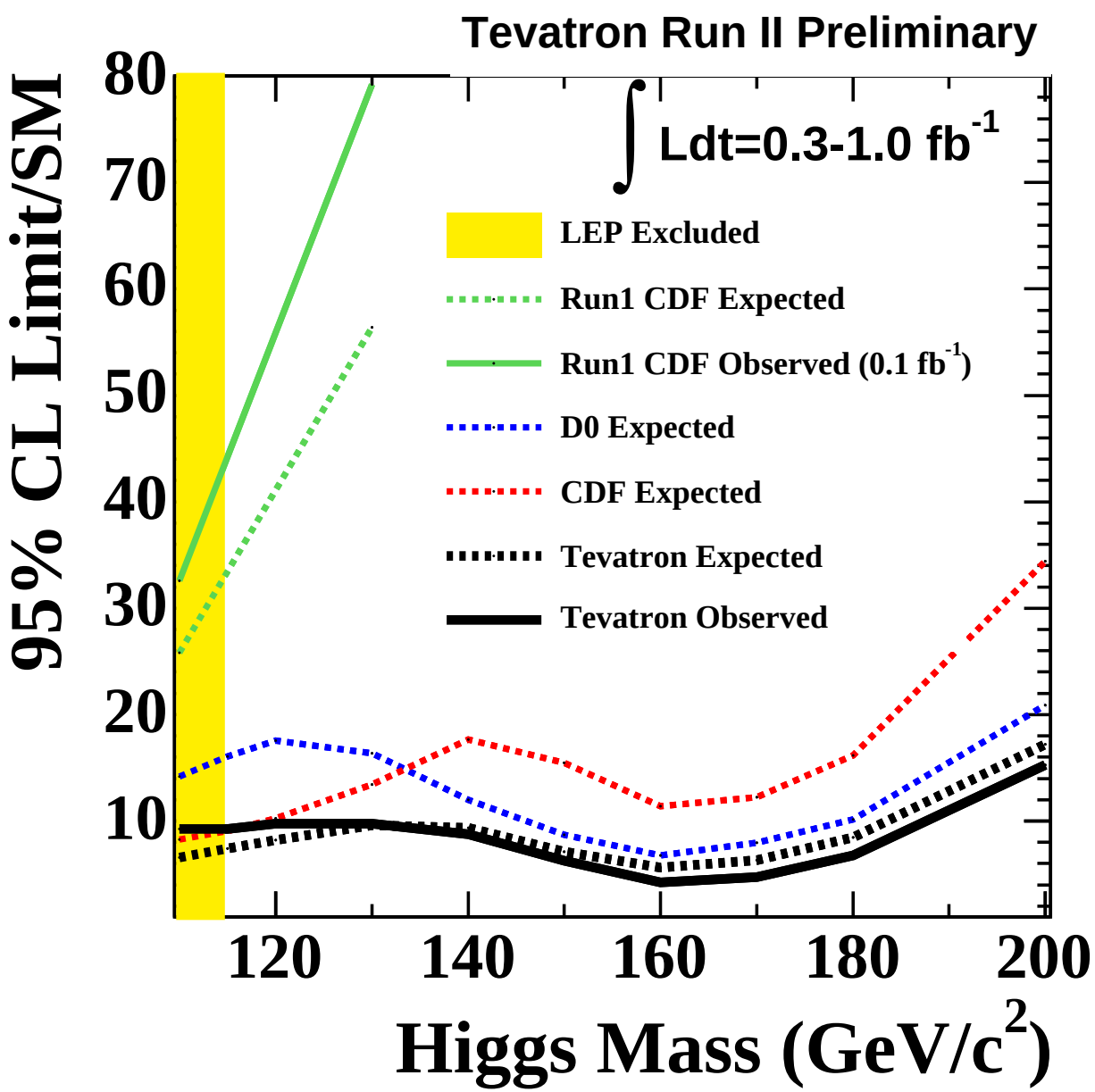
# Tevatron Combined Limit (For Blessing)



# Conclusion

- We have developed two techniques to combine SM Higgs limit from CDF and D0
- The 95% CL upper limits are a factor of 10.4(3.8) higher than the standard Model cross section at $m_H = 115(160)$ GeV/c$^2$.
- This result significantly improves the individual limits for each experiments
- Once the method established, we should be able to include all the latest Higgs results into combination quickly.
- Will see where we are after all the channels are updated to 1 fb$^{-1}$
- ...

# Tevatron Combined Limit (For Blessing)


Tevatron Run II Preliminary
∫ Ldt=0.3-1.0 fb-1
LEP Excluded
Run1 CDF Expected
Run1 CDF Observed (0.1 fb-1)
D0 Expected
CDF Expected
Tevatron Expected
Tevatron Observed
95% CL Limit/SM
80
70
60
50
40
30
20
10
120
140
160
180
200
Higgs Mass (GeV/c2)