“Nuts and Bolts” of Combining Tevatron Higgs Search Results

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- Exchanging Experimental Results
- Bayesian Limits
- CL_s Limits
- Discovery Techniques
- Tevatron Combined Results

http://tevnphwg.fnal.gov
http://www-cdf.fnal.gov/physics/new/hdg/hdg.html
http://www-d0.fnal.gov/Run2Physics/WWW/results/higgs.htm

Exchanging Experimental Results for Combination

At LEP and at the Tevatron, we exchanged histograms of observed and predicted events.

Many advantages:

- Crosscheck analyzers' work:
  Signal and background checksum
  Limit/discovery recalculations
  check for "broken" bins
  - s>0 when b=0
  - any observation or prediction <0
- Can make control plots
- Can try a great variety of statistical treatments
  -- Profile Likelihood, Bayesian, CL_s and compare each one
- Can make expected limits/LLR distributions without approximations
- Can draw the $\pm 1\sigma$, $\pm 2\sigma$ bands on expected limits with MC
- Can point to excesses and deficits to explain why limits and p-values are as they are
- Can accommodate new cross sections and branching ratios by scaling
- Can pick and choose signals if more than one expected (e.g., do 4th gen analysis with $H \rightarrow WW$ without WH, ZH and VBF)
- Pre-binned histograms mean combiners don't have to choose binning, reducing mistakes, inconsistencies

Disadvantages:

- Lots of work/CPU!
- Have to share preliminary histos (your competitors may find your mistakes!)

Exchanging Experimental Results for Combination

Systematic uncertainties itemized by named source

- Asymmetric Rate errors on each predicted component

- Shape errors supplied as alternate shape histograms
  Alternate shapes normalized to predicted yield under parameter variation.
  (can have a different rate and shape from the best value)

-- practical difficulty: How to estimate 5σ systematics?

- Bin-by-bin independent uncertainties (MC statistics)

- Names used to categorize systematic uncertainties in a way easy to understand and check – and to implement correlations

Same name of uncertainty – 100% correlated. Different name: 0% correlated. Can always synthesize arbitrary correlations from mixtures of these.

Cross Section and Branching Ratio Alignment

SM b.r.'s from
HDECAY 3.15
(April 2010.
Reran the latest
from Jan 2011
and no changes)

We will update to
the b.r.'s in
arXiv:1101.0593v2
(Handbook of LHC
Cross Sections
1. Inclusive Observables)
For Summer 2011

Table 4: Higgs boson decay branching fractions computed with HDECAY

m_H GeV/c^2	$B(H \to b\bar{b})$ (%)	$B(H \to c\bar{c})$ (%)	$B(H \to \tau^+\tau^-)$ (%)	$B(H \to W^+W^-)$ (%)	$B(H \to ZZ)$ (%)	$B(H \to \gamma\gamma)$ (%)
100	80.33	3.542	7.920	1.052	0.1071	0.1505
105	78.57	3.463	7.821	2.307	0.2035	0.1689
110	75.90	3.343	7.622	4.585	0.4160	0.1870
115	71.95	3.169	7.288	8.268	0.8298	0.2029
120	66.49	2.927	6.789	13.64	1.527	0.2148
125	59.48	2.617	6.120	20.78	2.549	0.2204
130	51.18	2.252	5.305	29.43	3.858	0.2182
135	42.15	1.854	4.400	39.10	5.319	0.2077
140	33.04	1.453	3.472	49.16	6.715	0.1897
145	24.45	1.075	2.585	59.15	7.771	0.1653
150	16.71	0.7345	1.778	68.91	8.143	0.1357
155	9.88	0.4341	1.057	78.92	7.297	0.09997
160	3.74	0.1646	0.403	90.48	4.185	0.05365
165	1.29	0.05667	0.140	95.91	2.216	0.02330
170	0.854	0.03753	0.0930	96.39	2.351	0.01598
175	0.663	0.02910	0.0725	95.81	3.204	0.01236
180	0.535	0.02349	0.0589	93.25	5.937	0.01024
185	0.415	0.01823	0.0459	84.50	14.86	0.008128
190	0.340	0.01490	0.0377	78.70	20.77	0.006774
195	0.292	0.01281	0.0326	75.88	23.66	0.005919
200	0.257	0.01128	0.0288	74.26	25.33	0.005285
210	0.207	0.00909	0.0259	72.50	27.16	0.004358
220	0.188	0.00756	0.0235	71.60	28.11	0.003677
230	0.146	0.00640	0.0197	71.05	28.70	0.003147
240	0.125	0.00550	0.0168	70.66	29.11	0.002720
250	0.109	0.00477	0.0145	70.36	29.43	0.002370
260	0.0953	0.00418	0.0127	70.12	29.70	0.002078
270	0.0843	0.00370	0.00999	69.91	29.92	0.001833
280	0.0750	0.00329	0.00895	69.72	30.12	0.001625
290	0.0672	0.00295	0.00807	69.56	30.29	0.001448
300	0.0605	0.00266	0.00732	69.40	30.45	0.001297

All channels must use consistent predictions

The New Br. Table

Numbers from arXiv:1101.0593v2

To be used Summer 2011

TABLE IV: Higgs boson decay branching fractions from the LHC Cross Section Handbook [12]

m_H GeV/c^2	$B(H \to b\bar{b})$ (%)	$B(H \to c\bar{c})$ (%)	$B(H \to \tau^+\tau^-)$ (%)	$B(H \to W^+W^-)$ (%)	$B(H \to ZZ)$ (%)	$B(H \to \gamma\gamma)$ (%)
90	81.2	3.78	8.41	0.209	0.0421	0.123
95	80.4	3.73	8.41	0.472	0.0672	0.140
100	79.1	3.68	8.36	1.11	0.113	0.159
105	77.3	3.59	8.25	2.43	0.215	0.178
110	74.5	3.46	8.03	4.82	0.439	0.197
115	70.5	3.27	7.65	8.67	0.873	0.213
120	64.9	3.01	7.11	14.3	1.60	0.225
125	57.8	2.68	6.37	21.6	2.67	0.230
130	49.4	2.29	5.49	30.5	4.02	0.226
135	40.4	1.87	4.52	40.3	5.51	0.214
140	31.4	1.46	3.54	50.4	6.92	0.194
145	23.1	1.07	2.62	60.3	7.96	0.168
150	15.7	0.725	1.79	69.9	8.28	0.137
155	9.18	0.425	1.06	79.6	7.36	0.100
160	3.44	0.159	0.397	90.9	4.16	0.0533
165	1.19	0.0549	0.138	96.0	2.22	0.0230
170	0.787	0.0364	0.0920	96.5	2.36	0.0158
175	0.612	0.0283	0.0719	95.8	3.23	0.0123
180	0.497	0.0230	0.0587	93.2	6.02	0.0102
185	0.385	0.0178	0.0457	84.4	15.0	0.00809
190	0.315	0.0146	0.0376	78.6	20.9	0.00674
195	0.270	0.0125	0.0324	75.7	23.9	0.00589
200	0.238	0.0110	0.0287	74.1	25.6	0.00526
210	0.192	0.00889	0.0234	72.3	27.4	0.00434
220	0.160	0.00740	0.0196	71.4	28.4	0.00367
230	0.136	0.00627	0.0168	70.8	28.9	0.00314
240	0.117	0.00539	0.0145	70.4	29.4	0.00272
250	0.101	0.00468	0.0127	70.1	29.7	0.00237
260	0.0889	0.00411	0.0112	69.9	29.9	0.00208
270	0.0786	0.00363	0.0100	69.7	30.2	0.00184
280	0.0700	0.00323	0.00898	69.5	30.4	0.00163
290	0.0627	0.00290	0.00809	69.3	30.5	0.00145
300	0.0565	0.00261	0.00733	69.2	30.7	0.00130

Uncertainties in Higgs Boson Decay Branching Ratios

Baglio and Djouadi, arXiv:1012.0530

plus private communication to get the entire table

m_b – raising m_b increases the bb decay rate

m_c – same thing for charm

α_s – increasing this raises $Br(H \rightarrow gg)$.

Sum Br.=1 means $Br(H \rightarrow WW)$ is impacted accordingly.

“Up” uncertainty corresponds to a positive shift in the named parameter.

m_H (GeV/c^2)	$\delta Br(H \to W^+W^-)$ (α_s) (%)	$\delta Br(H \to W^+W^-)$ (m_b) (%)	$\delta Br(H \to W^+W^-)$ (m_c) (%)
100	$^{-1.57}_{+1.67}$	$^{-7.61}_{+2.78}$	$^{-0.74}_{+0.93}$
105	$^{-1.67}_{+1.75}$	$^{-7.55}_{+2.66}$	$^{-0.72}_{+0.83}$
110	$^{-1.60}_{+1.68}$	$^{-7.29}_{+2.60}$	$^{-0.68}_{+0.80}$
115	$^{-1.52}_{+1.57}$	$^{-6.91}_{+2.44}$	$^{-0.65}_{+0.75}$
120	$^{-1.43}_{+1.43}$	$^{-6.38}_{+2.24}$	$^{-0.61}_{+0.68}$
125	$^{-1.26}_{+1.26}$	$^{-5.75}_{+1.98}$	$^{-0.54}_{+0.58}$
130	$^{-1.02}_{+1.09}$	$^{-4.89}_{+1.70}$	$^{-0.45}_{+0.51}$
135	$^{-0.83}_{+0.88}$	$^{-4.04}_{+1.39}$	$^{-0.36}_{+0.44}$
140	$^{-0.66}_{+0.66}$	$^{-3.17}_{+1.06}$	$^{-0.29}_{+0.33}$
145	$^{-0.46}_{+0.49}$	$^{-2.33}_{+0.79}$	$^{-0.20}_{+0.25}$
150	$^{-0.33}_{+0.31}$	$^{-1.59}_{+0.51}$	$^{-0.14}_{+0.16}$
155	$^{-0.18}_{+0.19}$	$^{-0.94}_{+0.31}$	$^{-0.08}_{+0.10}$
160	$^{-0.07}_{+0.07}$	$^{-0.35}_{+0.11}$	$^{-0.03}_{+0.03}$
165	$^{-0.02}_{+0.02}$	$^{-0.12}_{+0.04}$	$^{-0.01}_{+0.01}$
170	$^{-0.02}_{+0.01}$	$^{-0.08}_{+0.02}$	$^{-0.01}_{+0.01}$
175	$^{-0.01}_{+0.01}$	$^{-0.06}_{+0.02}$	$^{+0.00}_{+0.01}$
180	$^{-0.01}_{+0.01}$	$^{-0.04}_{+0.02}$	$^{+0.00}_{+0.01}$
185	$^{-0.01}_{+0.01}$	$^{-0.04}_{+0.01}$	$^{+0.00}_{0.00}$
190	$^{+0.00}_{+0.01}$	$^{-0.03}_{+0.01}$	$^{+0.00}_{0.00}$
195	$^{+0.00}_{+0.01}$	$^{-0.03}_{+0.01}$	$^{+0.00}_{0.00}$
200	$^{+0.00}_{+0.01}$	$^{-0.01}_{+0.01}$	$^{+0.00}_{0.00}$
210	$^{+0.00}_{0.00}$	$^{-0.01}_{+0.01}$	$^{+0.00}_{0.00}$
220	$^{+0.00}_{0.00}$	$^{-0.01}_{0.00}$	$^{+0.00}_{0.00}$
230	$^{+0.00}_{0.00}$	$^{-0.01}_{+0.01}$	$^{+0.00}_{0.00}$
240	$^{-0.01}_{0.00}$	$^{-0.01}_{0.00}$	$^{+0.00}_{0.00}$
250	$^{+0.00}_{0.00}$	$^{+0.00}_{+0.01}$	$^{+0.00}_{0.00}$
260	$^{+0.00}_{0.00}$	$^{-0.01}_{0.00}$	$^{+0.00}_{0.00}$
270	$^{+0.00}_{0.00}$	$^{-0.01}_{0.00}$	$^{+0.00}_{0.00}$
280	$^{+0.00}_{0.00}$	$^{+0.00}_{0.00}$	$^{+0.00}_{0.00}$
290	$^{+0.00}_{0.00}$	$^{+0.00}_{+0.01}$	$^{+0.00}_{0.00}$
300	$^{+0.00}_{0.00}$	$^{-0.01}_{0.00}$	$^{+0.00}_{0.00}$

The Same Uncertainties for Br(H→bb)

Relative signs preserved with respect to the Br(H→WW) table on the previous page.

These only became available after our most recent low-mass limits were set. To be included next time. The WW uncertainties went into our high-mass limits.

Also have these tables for Br(H→cc), Br(H→ττ)

m_H (GeV/c^2)	$\delta Br(H \to b\bar{b})$ (α_s) (%)	$\delta Br(H \to b\bar{b})$ (m_b) (%)	$\delta Br(H \to b\bar{b})(m_c)(\%)$ (m_c) (%)
100	$^{+0.34}_{-0.35}$	$^{+1.99}_{-0.70}$	$^{-0.74}_{+0.88}$
105	$^{+0.40}_{-0.40}$	$^{+2.20}_{-0.77}$	$^{-0.72}_{+0.85}$
110	$^{+0.47}_{-0.49}$	$^{+2.47}_{-0.88}$	$^{-0.71}_{+0.81}$
115	$^{+0.58}_{-0.61}$	$^{+2.90}_{-1.02}$	$^{-0.66}_{+0.78}$
120	$^{+0.72}_{-0.75}$	$^{+3.47}_{-1.21}$	$^{-0.61}_{+0.71}$
125	$^{+0.90}_{-0.94}$	$^{+4.23}_{-1.45}$	$^{-0.54}_{+0.64}$
130	$^{+1.12}_{-1.14}$	$^{+5.12}_{-1.75}$	$^{-0.47}_{+0.55}$
135	$^{+1.32}_{-1.37}$	$^{+6.05}_{-2.07}$	$^{-0.40}_{+0.42}$
140	$^{+1.54}_{-1.54}$	$^{+7.04}_{-2.35}$	$^{-0.29}_{+0.35}$
145	$^{+1.71}_{-1.75}$	$^{+7.94}_{-2.68}$	$^{-0.26}_{+0.26}$
150	$^{+1.88}_{-1.94}$	$^{+8.74}_{-2.91}$	$^{-0.19}_{+0.13}$
155	$^{+2.03}_{-2.06}$	$^{+9.51}_{-3.08}$	$^{-0.10}_{+0.11}$
160	$^{+2.17}_{-2.17}$	$^{+10.17}_{-3.26}$	$^{-0.03}_{+0.06}$
165	$^{+2.23}_{-2.23}$	$^{+10.45}_{-3.34}$	$^{+0.00}_{+0.09}$
170	$^{+2.24}_{-2.25}$	$^{+10.45}_{-3.36}$	$^{-0.03}_{+0.03}$
175	$^{+2.25}_{-2.25}$	$^{+10.48}_{-3.37}$	$^{-0.03}_{+0.02}$
180	$^{+2.25}_{-2.27}$	$^{+10.48}_{-3.37}$	$^{-0.02}_{+0.02}$
185	$^{+2.26}_{-2.26}$	$^{+10.50}_{-3.36}$	$^{-0.03}_{+0.03}$
190	$^{+2.28}_{-2.28}$	$^{+10.49}_{-3.39}$	$^{-0.03}_{+0.03}$
195	$^{+2.31}_{-2.28}$	$^{+10.50}_{-3.38}$	$^{+0.00}_{+0.04}$
200	$^{+2.28}_{-2.28}$	$^{+10.51}_{-3.36}$	$^{+0.00}_{0.00}$
210	$^{+2.30}_{-2.30}$	$^{+10.52}_{-3.37}$	$^{+0.00}_{0.00}$
220	$^{+2.32}_{-2.32}$	$^{+10.55}_{-3.34}$	$^{+0.00}_{0.00}$
230	$^{+2.28}_{-2.35}$	$^{+10.48}_{-3.42}$	$^{+0.00}_{0.00}$
240	$^{+2.30}_{-2.39}$	$^{+10.52}_{-3.36}$	$^{+0.00}_{0.00}$
250	$^{+2.36}_{-2.35}$	$^{+10.51}_{-3.38}$	$^{-0.02}_{+0.02}$
260	$^{+2.36}_{-2.37}$	$^{+10.53}_{-3.38}$	$^{-0.02}_{+0.02}$
270	$^{+2.38}_{-2.37}$	$^{+10.54}_{-3.38}$	$^{-0.01}_{+0.03}$
280	$^{+2.38}_{-2.38}$	$^{+10.54}_{-3.37}$	$^{-0.01}_{+0.03}$
290	$^{+2.39}_{-2.39}$	$^{+10.53}_{-3.38}$	$^{-0.02}_{+0.02}$
300	$^{+2.40}_{-2.40}$	$^{+10.53}_{-3.37}$	$^{-0.02}_{+0.02}$

Baglio and Djouadi

Cross Section and Branching Ratio Alignment

gg→H production cross sections and uncertainties.

From M. Grazzini and D. de Florian
Similar calc. from Anastasiou, Boughezal, and Petriello

Updated: m_t=173.1 GeV, full m_t dependence.

In the main channels, we ignore the scale and PDF uncertainties in this table as they use n_{jet} categories, and the jet-by-jet uncertainties are larger.

33% relative uncertainty in the 2-jet bin smaller than the one recommended by Anastasiou, Dissertori, Grazzini, and Webber, because of a new NLO calculation of H+2j by Campbell, Ellis, and Williams

Table 3: The SM NNLO+NNLL production cross section for $gg \to H$ and the associated uncertainties. The PDF+α_s uncertainties are the full PDF4LHC prescription.

m_H (GeV/c^2)	$\sigma_{gg\to H}$ (fb)	scale (up) (%)	scale (down) (%)	PDF+α_s (up) (%)	PDF+α_s (down) (%)
90	2442.3	7.39	-8.17	8.70	-11.82
95	2101.1	7.33	-8.02	8.94	-11.84
100	1821.8	7.31	-7.88	9.17	-11.85
105	1584.7	7.28	-7.75	9.41	-11.86
110	1385.0	7.24	-7.64	9.64	-11.87
115	1215.9	7.20	-7.53	9.80	-11.94
120	1072.3	7.19	-7.43	9.96	-12.01
125	949.3	7.13	-7.32	10.07	-12.17
130	842.9	7.18	-7.24	10.18	-12.34
135	750.8	7.18	-7.15	10.39	-12.41
140	670.6	7.17	-7.07	10.59	-12.49
145	600.6	7.16	-7.00	10.80	-12.59
150	539.1	7.16	-6.93	11.01	-12.69
155	484.0	7.15	-6.86	11.23	-12.75
160	432.3	7.16	-6.79	11.45	-12.80
165	383.7	7.18	-6.73	11.62	-12.85
170	344.0	7.21	-6.66	11.79	-12.90
175	309.7	7.23	-6.60	11.90	-12.94
180	279.2	7.23	-6.55	12.00	-12.98
185	252.1	7.24	-6.49	12.10	-13.03
190	228.0	7.25	-6.44	12.20	-13.07
195	207.2	7.28	-6.39	12.26	-13.08
200	189.1	7.30	-6.37	12.31	-13.10
210	158.9	7.37	-6.37	12.26	-12.94
220	134.5	7.43	-6.37	12.53	-13.17
230	114.7	7.48	-6.36	12.61	-13.21
240	98.4	7.55	-6.37	12.64	-13.23
250	85.0	7.65	-6.39	12.81	-13.38
260	73.8	7.76	-6.42	13.02	-13.58
270	64.5	7.83	-6.43	13.22	-13.78
280	56.7	7.93	-6.44	13.75	-14.33
290	50.1	8.06	-6.48	14.27	-14.86
300	44.7	8.23	-6.53	14.90	-15.51
320	36.4	8.44	-6.60	16.05	-16.67
340	31.1	8.74	-6.76	17.62	-18.32
360	29.5	9.05	-6.94	19.93	-20.71
380	25.0	9.35	-7.23	22.34	-23.23
400	19.8	9.66	-7.47	24.81	-25.85

gg→H: No Jet Veto, but there is Classification by Jet Count

WW+0 jets

CDF Run II Preliminary	$\int \mathcal{L} = 7.1$ fb^{-1}		
$M_H = 165$ GeV$/c^2$			
$t\bar{t}$	2.60	±	0.79
DY	271	±	74
WW	673	±	66
WZ	30.3	±	4.6
ZZ	45.4	±	6.4
W+jets	273	±	64
$W\gamma$	169	±	25
Total Background	1470	±	140
$gg \to H$	19.7	±	3.0
WH	0.487	±	0.083
ZH	0.493	±	0.070
VBF	0.166	±	0.033
Total Signal	20.8	±	3.0
Data	1465		

AllSB-0JOS

WW+1 jet

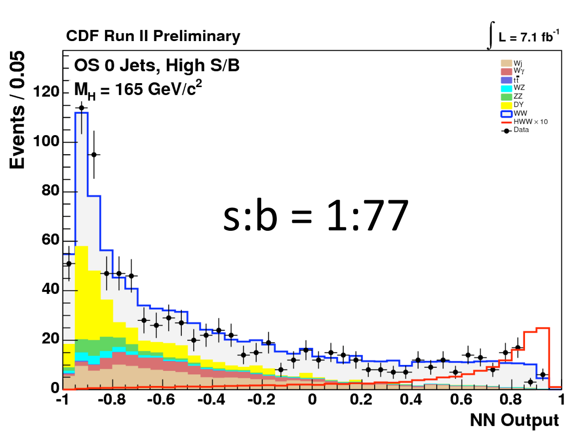
CDF Run II Preliminary	$\int \mathcal{L} = 7.1$ fb^{-1}		
$M_H = 165$ GeV$/c^2$			
$t\bar{t}$	68	±	14
DY	264	±	59
WW	181	±	23
WZ	30.1	±	4.2
ZZ	12.3	±	1.8
W+jets	94	±	24
$W\gamma$	27.5	±	4.7
Total Background	676	±	84
$gg \to H$	9.7	±	3.0
WH	1.34	±	0.21
ZH	0.521	±	0.079
VBF	0.88	±	0.15
Total Signal	12.4	±	3.1
Data	637		

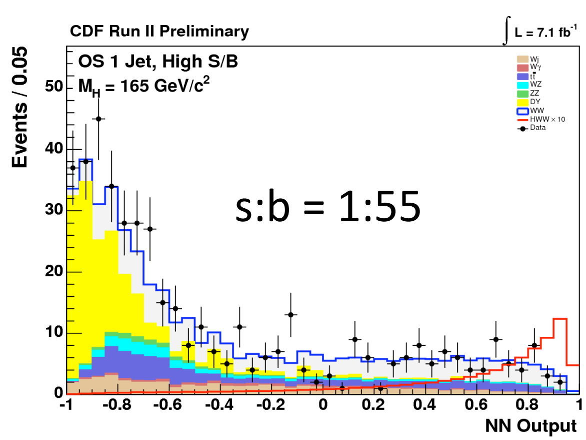
AllSB-1JOS

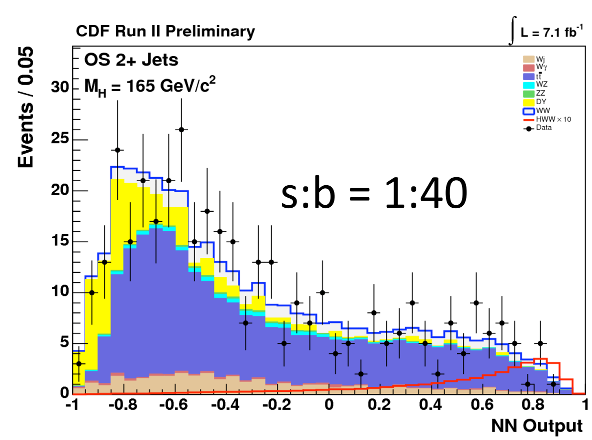
WW+2 or more jets

CDF Run II Preliminary	$\int \mathcal{L} = 7.1$ fb^{-1}		
$M_H = 165$ GeV$/c^2$			
$t\bar{t}$	194	±	32
DY	96	±	38
WW	40.2	±	8.0
WZ	8.2	±	1.5
ZZ	3.71	±	0.68
W+jets	34.7	±	9.7
$W\gamma$	4.9	±	1.3
Total Background	382	±	61
$gg \to H$	3.4	±	2.6
WH	2.97	±	0.41
ZH	1.52	±	0.21
VBF	1.63	±	0.27
Total Signal	9.5	±	2.8
Data	369		

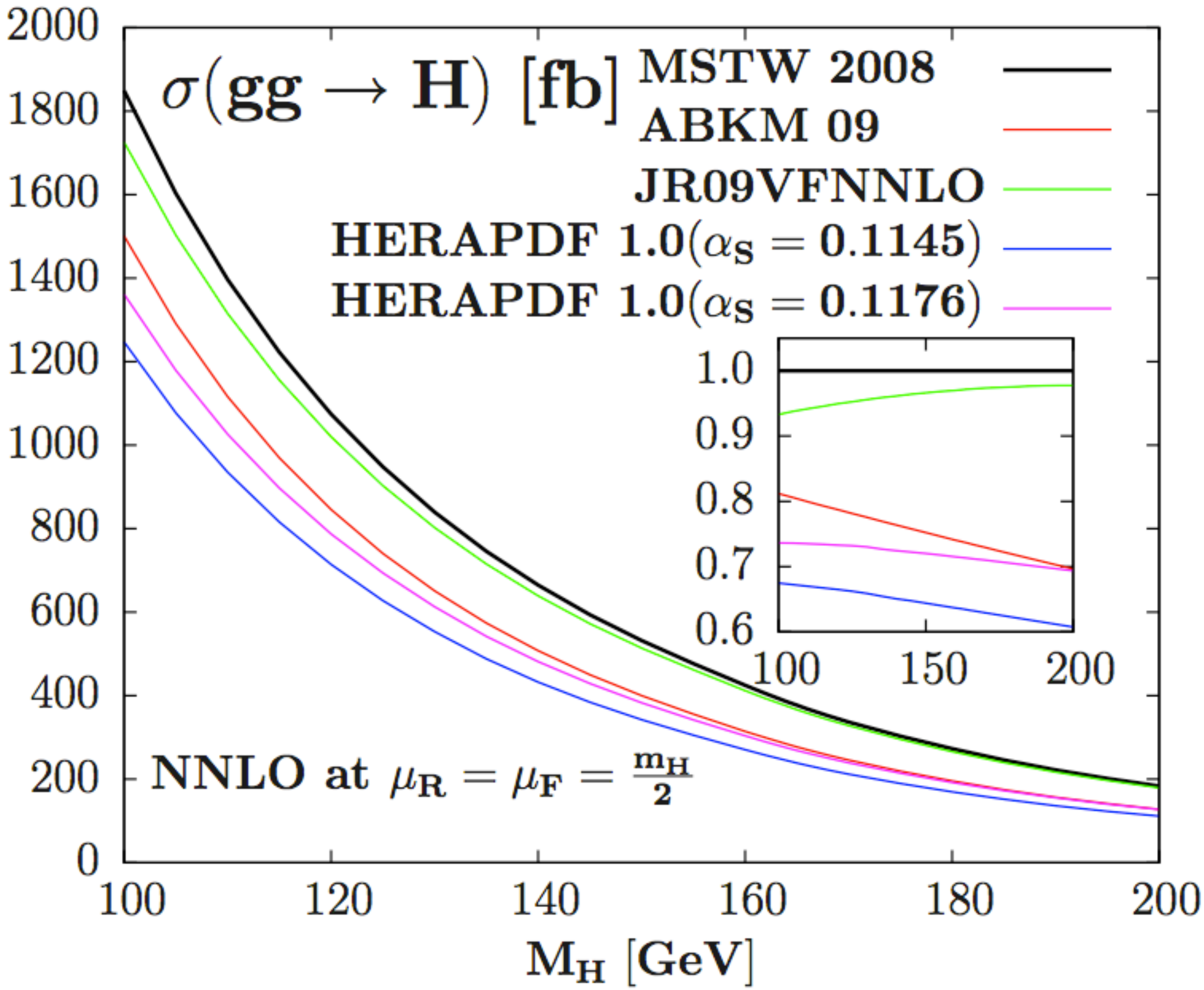
AllSB-2JOS



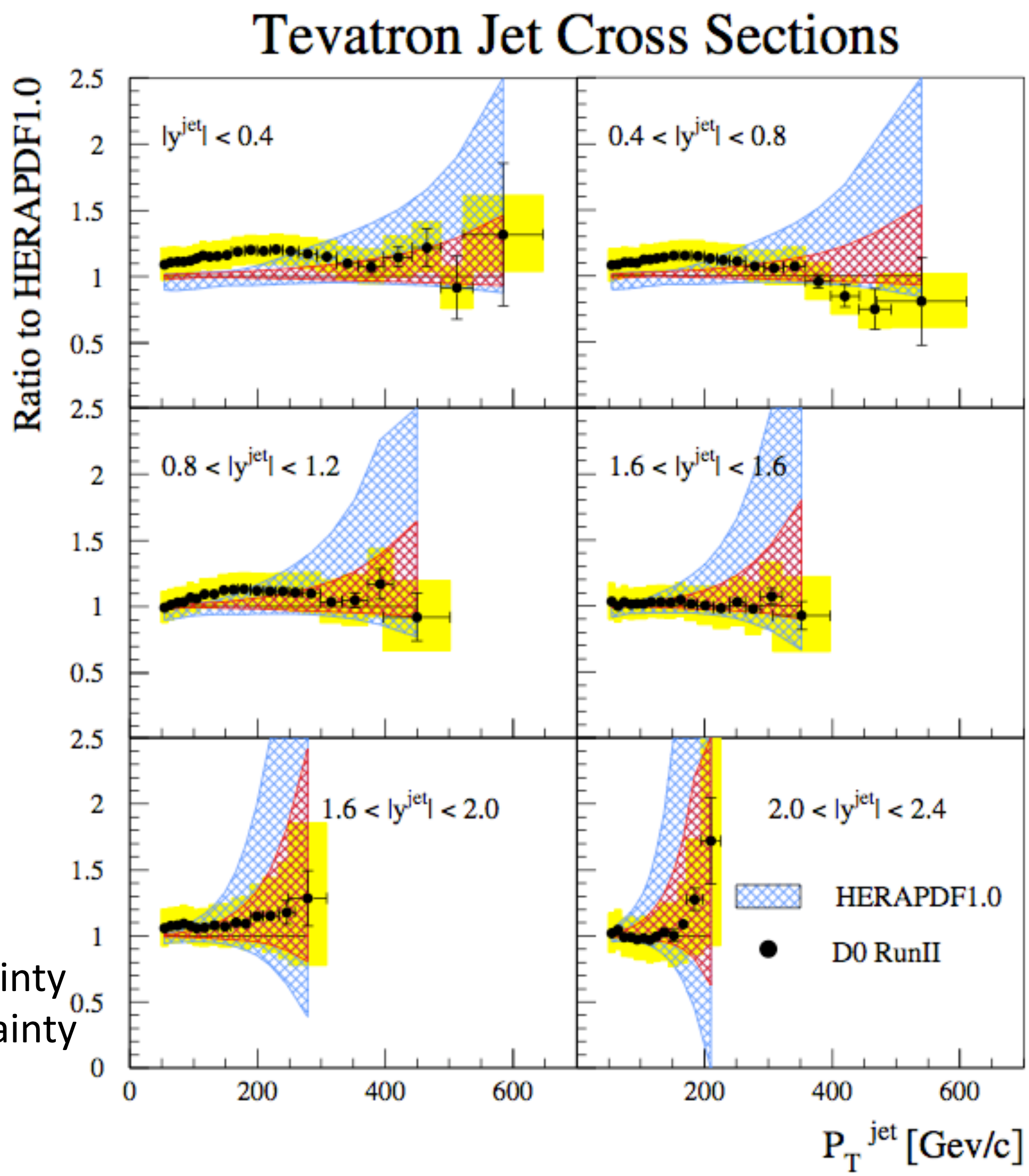




Baglio and Djouadi, arXiv:1101.1832

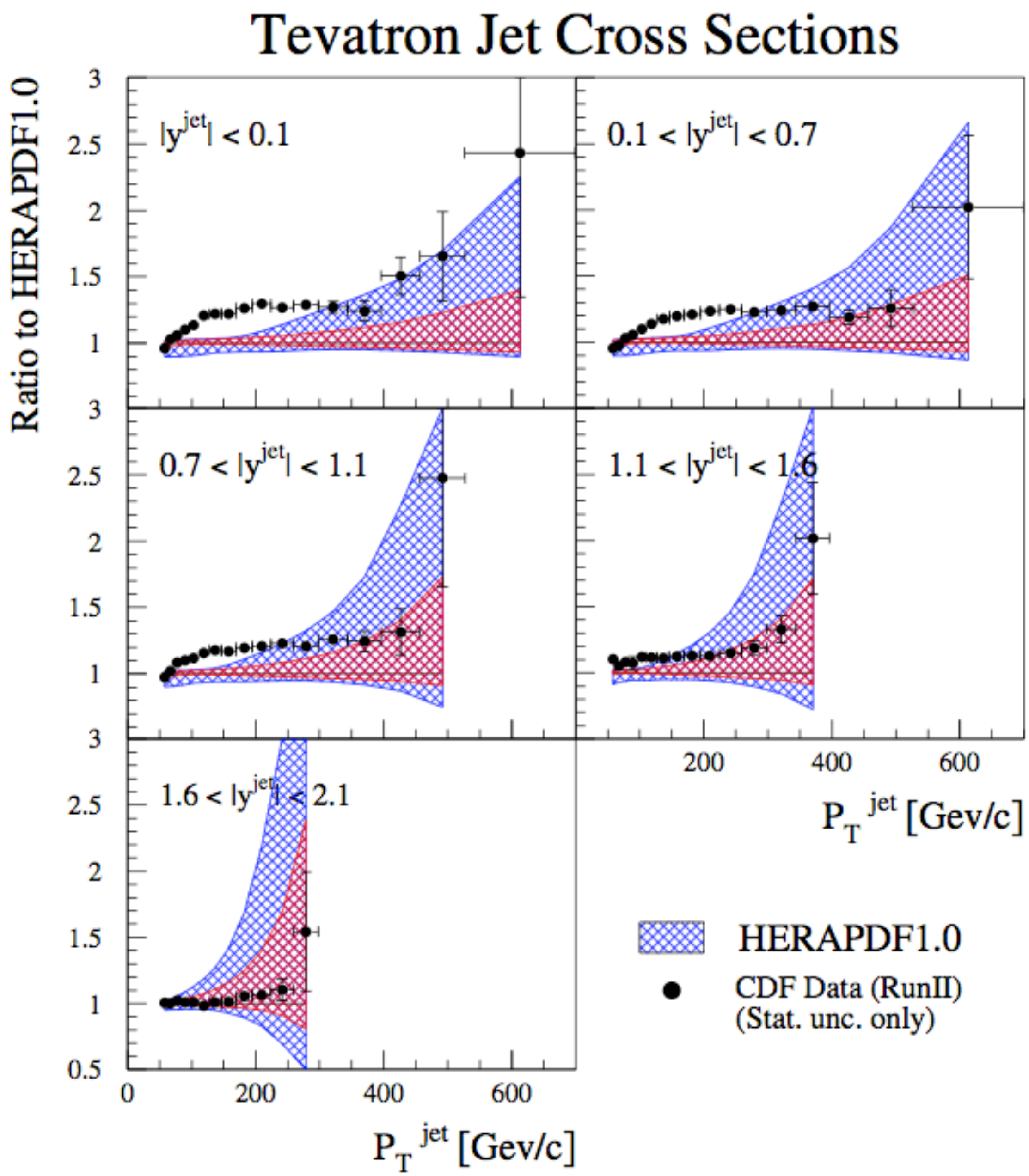


HERAPDF1.0 Predictions of Tevatron (D0) High-E_T jet data

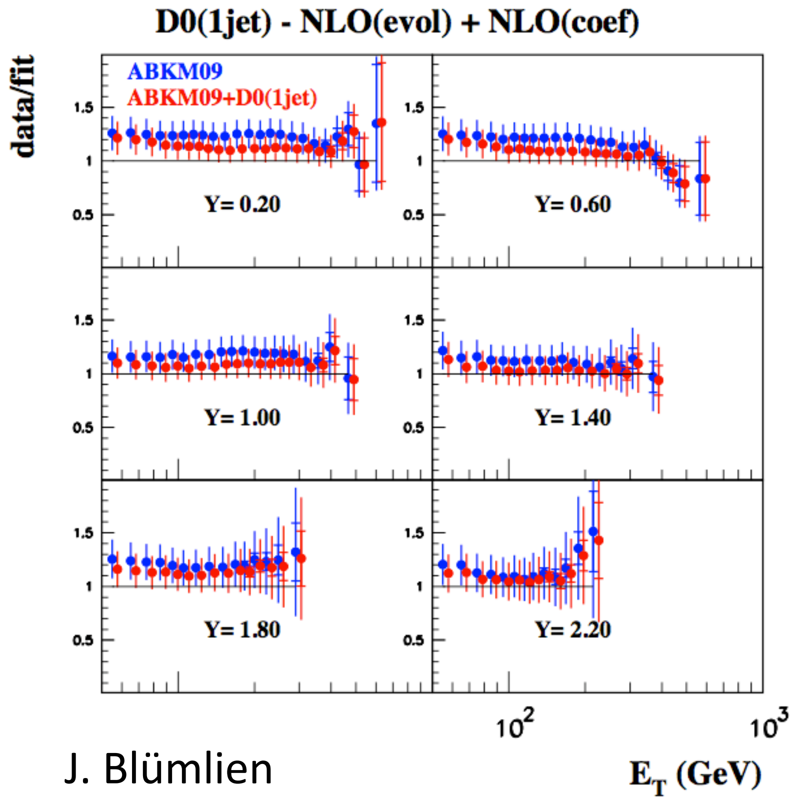


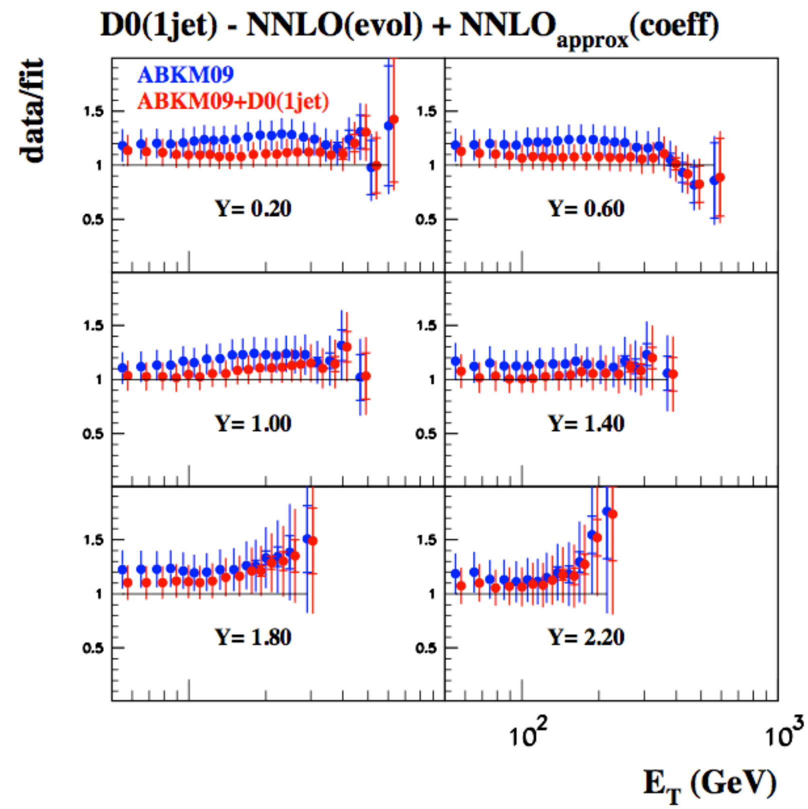
Blue: Total uncertainty,
Red: Experimental Uncertainty
Yellow: D0 jet data uncertainty

HERAPDF1.0 Predictions of Tevatron (CDF) High-E_T jet data



ABKM09 fit including D0 Run II Jet Data





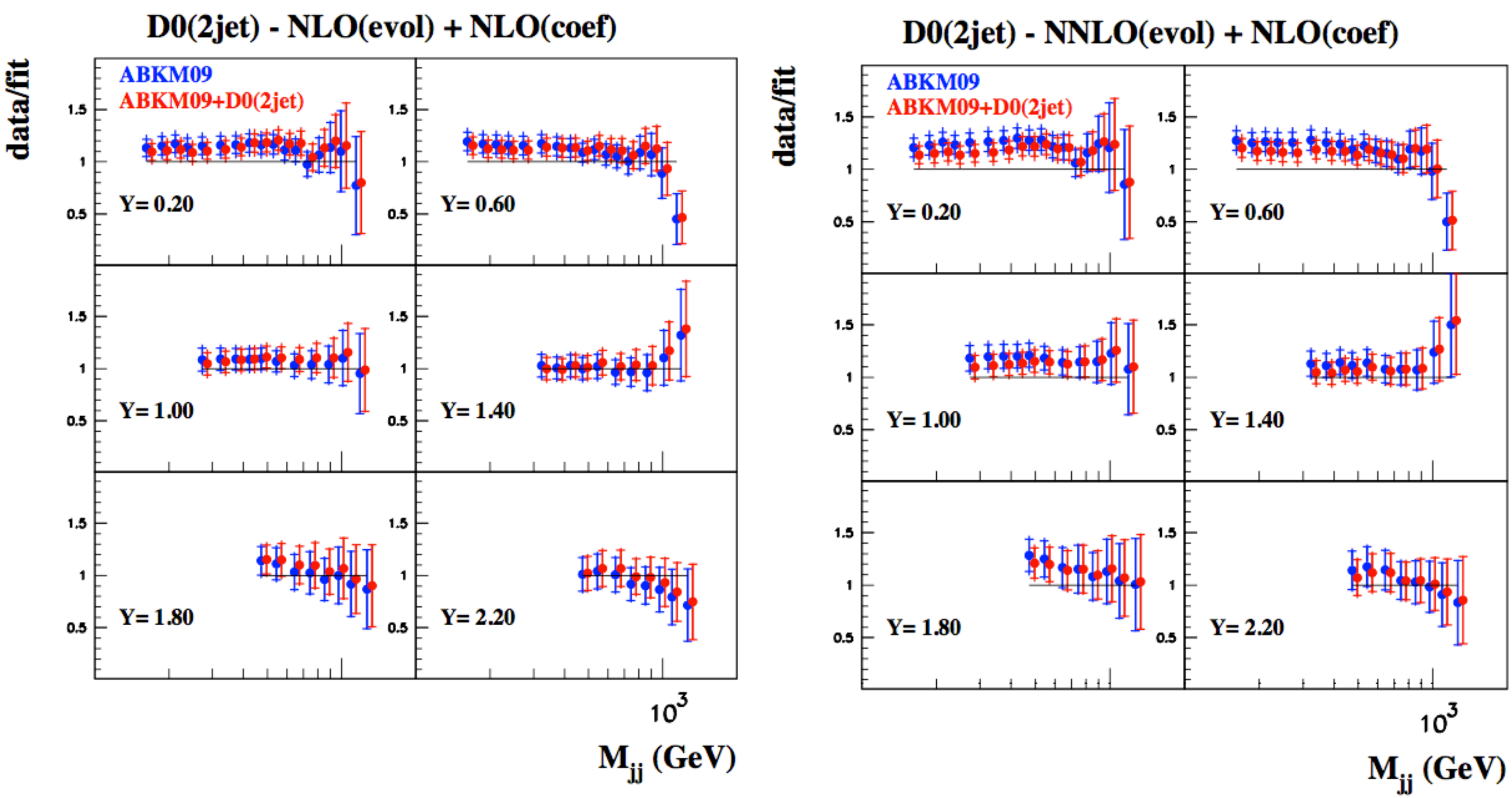
J. Blümlien

m_H=165 GeV Tevatron Higgs production cross sections from ABKM

$\sigma(H)$	ABKM PDFs	1-jet inclusive data	di-jet data
NLO	0.206(17) pb	0.235(10) pb	0.212(9) pb
NNLO	**0.253(22) pb**	0.297(12) pb	0.278(13) pb

c.f. NNLO with MSTW08: 0.341 pb, HERAPDF: 0.269 pb

ABKM09 Fitted with D0 Run II Dijet m_{jj} Data



MSTW08 Fits to CDF and D0 run II Jet Data

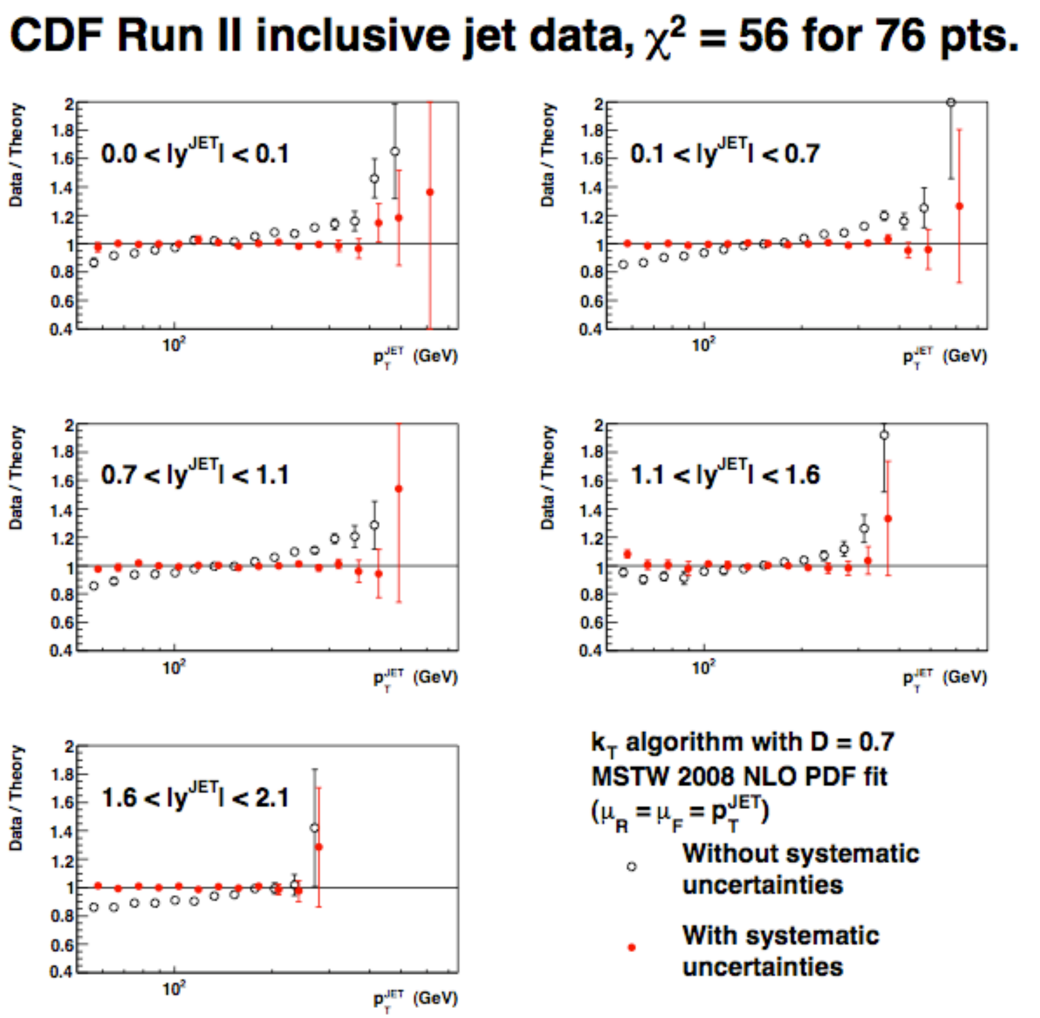
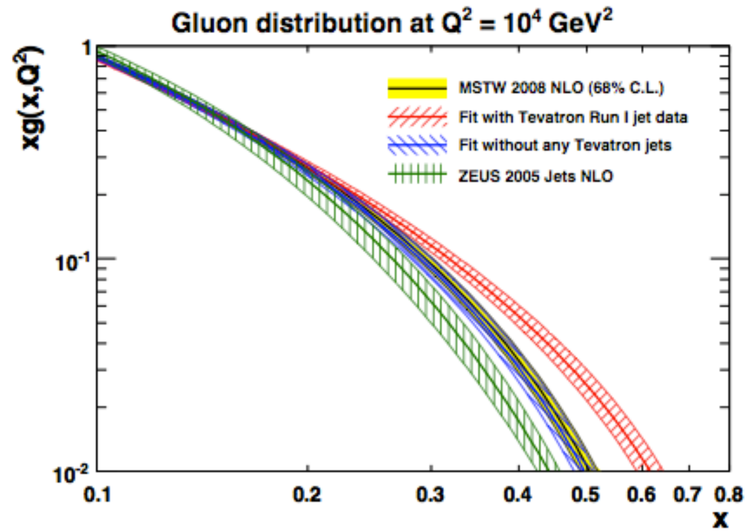
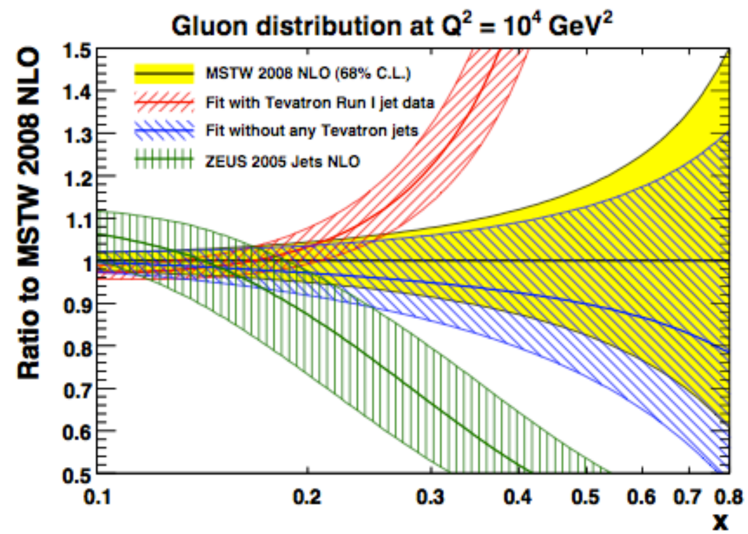


Figure 48: Data/theory ratio for the CDF Run II data obtained using the k_T jet clustering algorithm [54] and the MSTW 2008 NLO fit.





arXiv:0901.0002 Martin, Thorne, Stirling, and Watt Eur.Phys.J.C63:189-285,2009

Jet production predicted with FastNLO; MSTW estimate NNLO corrections to be small. Errors incurred in omitting this data are expected to be much bigger than those incurred by using only NLO predictions in making NNLO PDFs.

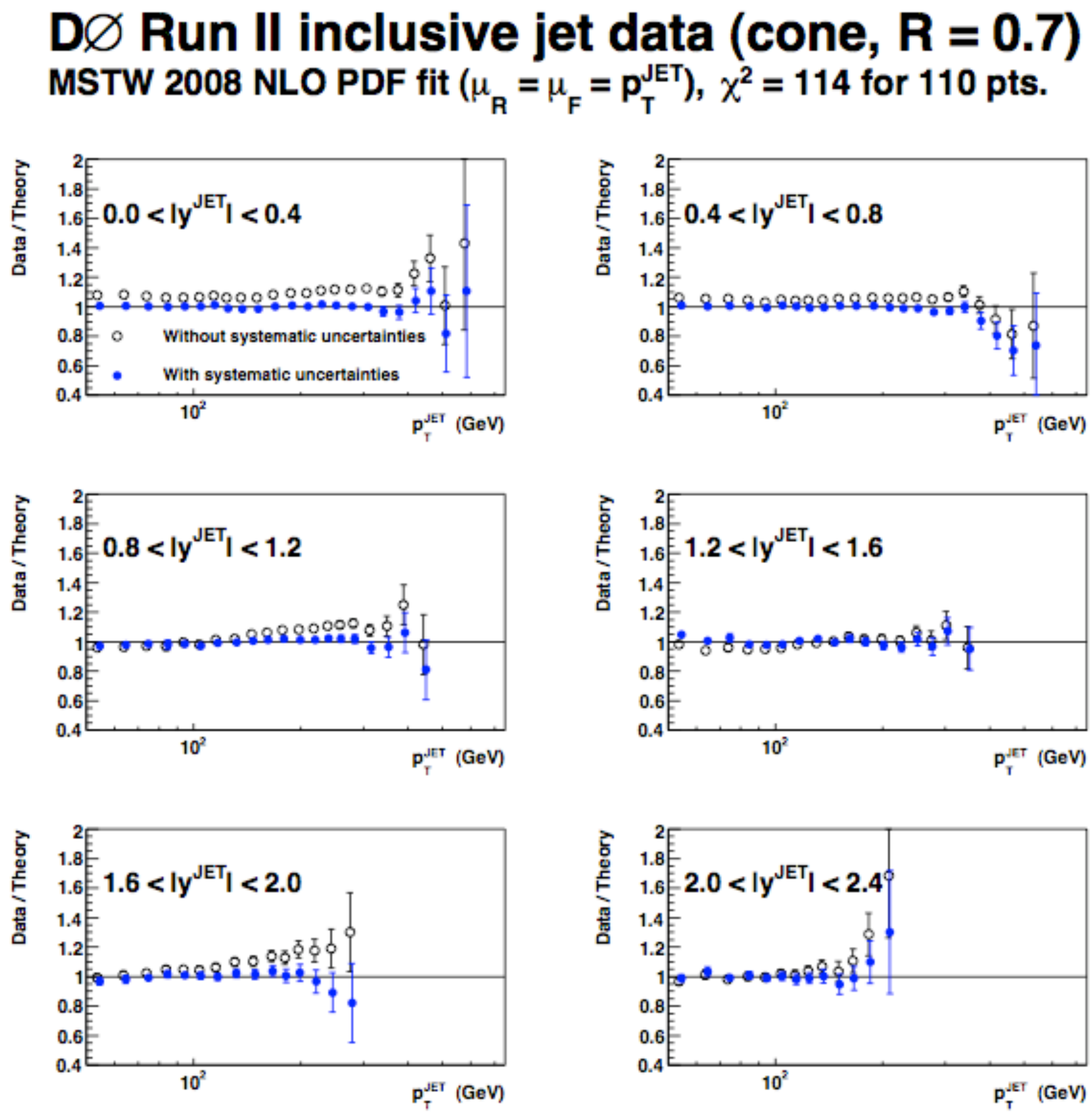


Figure 49: Data/theory ratio for the DØ Run II data [56] and the MSTW 2008 NLO fit.

arXiv:0901.0002 Martin, Thorne, Stirling, and Watt   Eur.Phys.J.C63:189-285,2009

Ahrens, Becher, Neubert, Yang: arXiv:1008.3162 (PLB 698, 271 (2011))

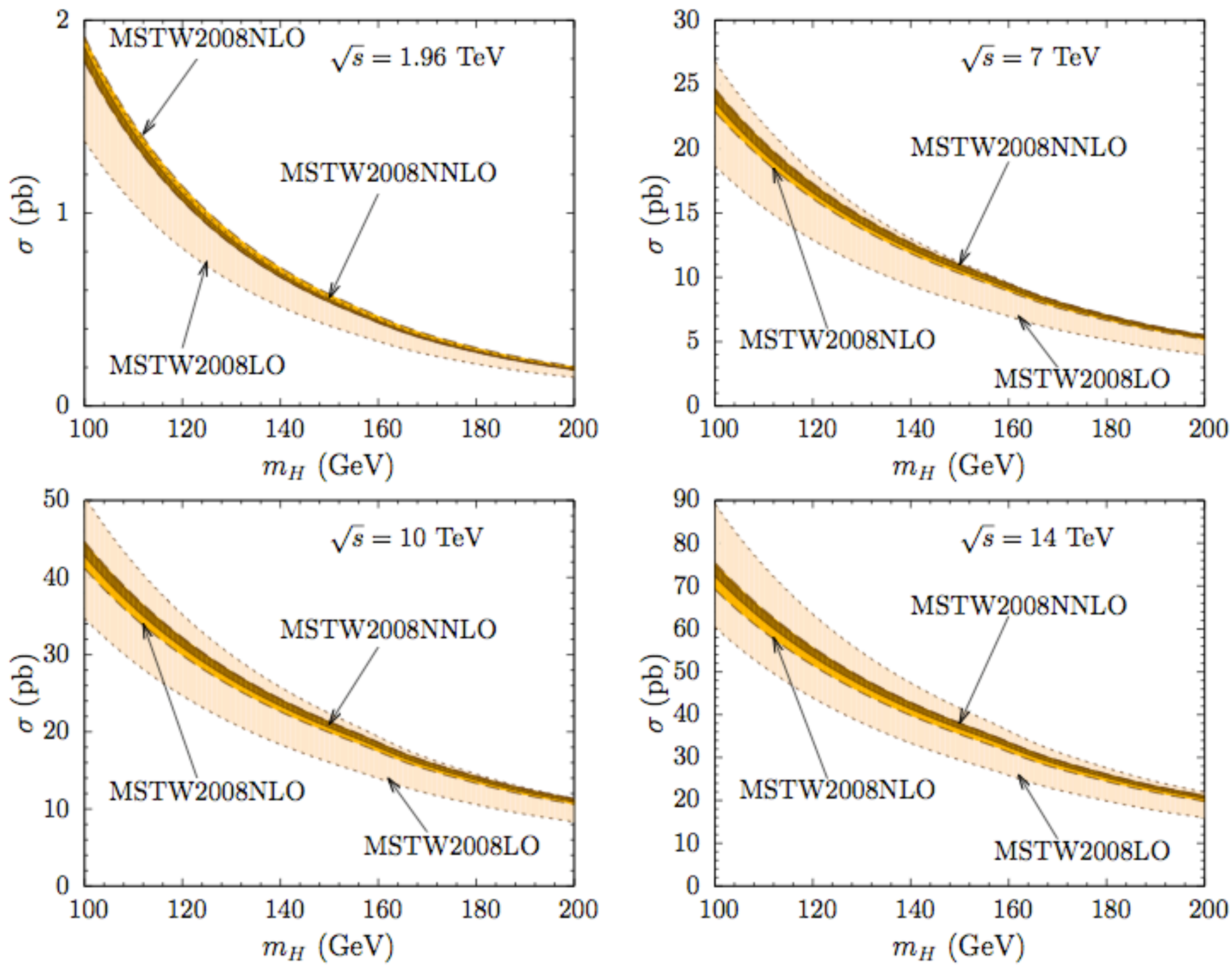


Figure 1: Cross sections at the Tevatron for $\sqrt{s} = 1.96$ TeV and the LHC for $\sqrt{s} = 7, 10, 14$ TeV. Bands indicate scale uncertainties. Light, medium and dark bands represent LO (NLL), NLO (NNLL) and NNLO (N^3LL) in RG-improved perturbation theory, respectively.

Rapid convergence of perturbative series with resummation.

A Stand-In for a Jet Veto that can be Calculated at NNLO+NNLL

$$\tau = \frac{\mathcal{T}_{\rm cm}}{m_H}\,, \qquad \mathcal{T}_{\rm cm} = \sum_k |\vec{p}_{kT}|\, e^{-|\eta_k|} = \sum_k (E_k - |p_k^z|)\,.$$

Low Beam thrust means no jets. (converse?)

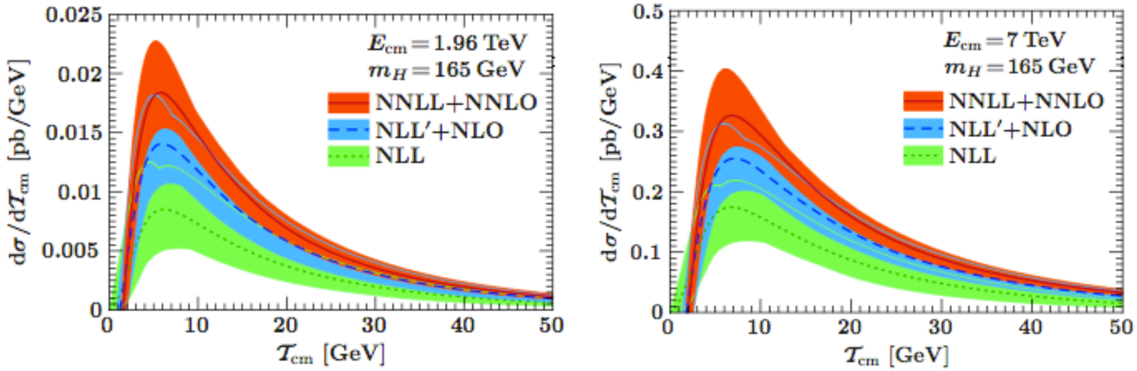


Figure 9. The beam thrust spectrum for Higgs production for $m_H = 165$ GeV at the Tevatron (left) and the LHC for $E_{\rm cm} = 7$ TeV (right). The bands show the perturbative scale uncertainties as explained in section 2.6.

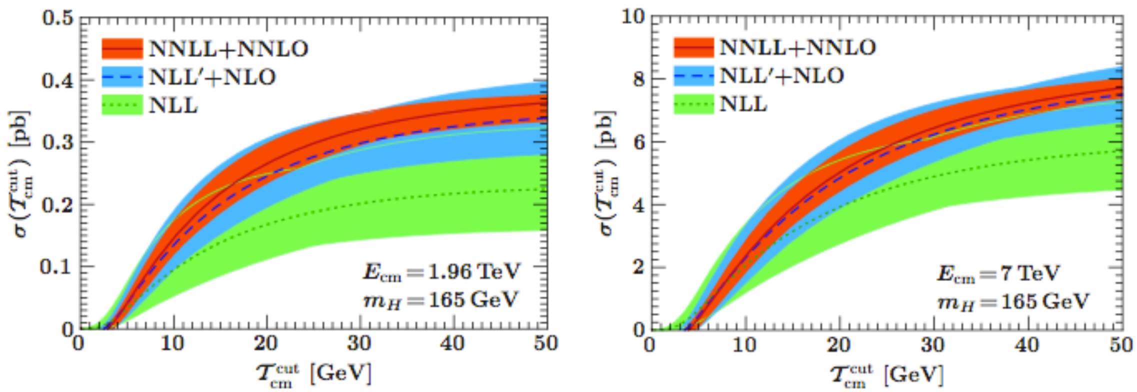
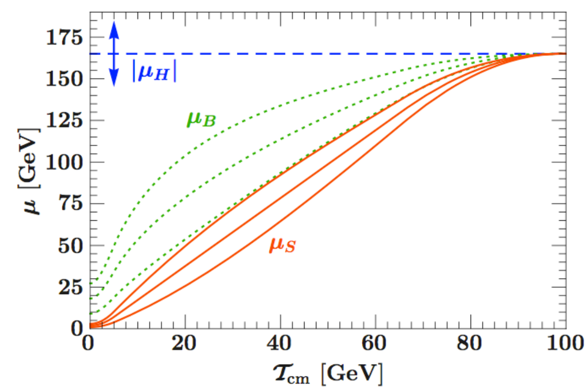


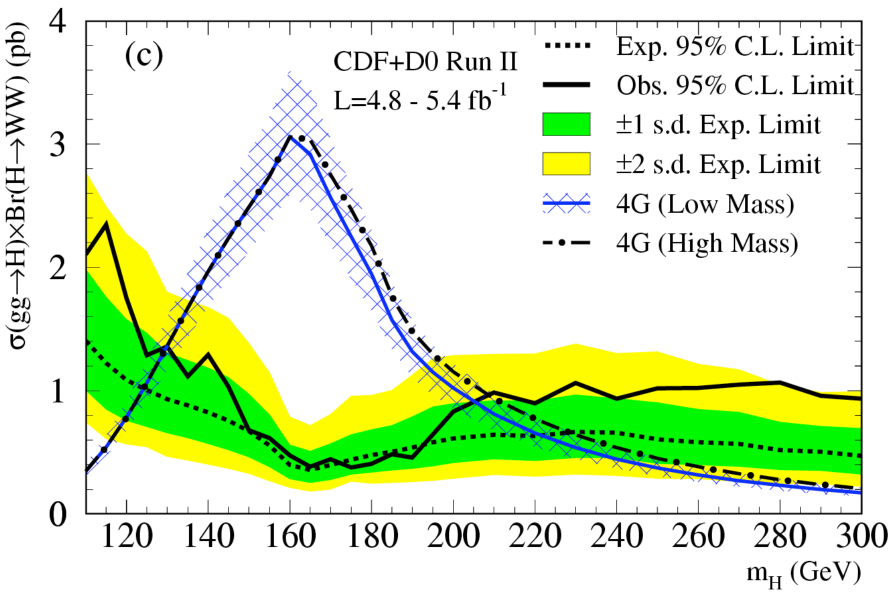
Figure 10. Higgs production cross section as a function of $\mathcal{T}_{\rm cm}^{\rm cut}$ for $m_H = 165$ GeV at the Tevatron (left) and the LHC with $E_{\rm cm} = 7$ TeV (right). The bands show the perturbative scale uncertainties as explained in section 2.6.

Three scales!



Berger, Marcantonini, Stewart, Tackmann, and Waalwijn, arXiv:1012.4480

Setting a Limit on σ(gg→H)xBr(H->W^+W^-)



T. Aaltonen et al., Phys. Rev. D 82, 011102(R) (2010)

- Model-"Independent"!
- No total uncertainty on the cross section or b.r. from PDF or scale needed when setting this limit.

- But: We need acceptance for our selection! 0j, 1j, 2+ jets have relative predictions that depend on scale (and less on PDF)

Our procedure: take the jet-category uncertainties and subtract off the common total amount from each one, so that we preserve the uncertainties in the jet categories while removing the total uncertainty.

Cross Section and Branching Ratio Alignment

WH and ZH Production rates at the Tevatron

Baglio and Djouadi
JHEP 1010, 064 (2010)
arXiv:1003.4266v2

Updated from v1:
Proper CKM elements in WH
More precise integrations
Reductions of cross sections of 4-6%

Table 1: The NNLO production cross section for WH, ZH, and the associated uncertainties

m_H (GeV/c^2)	σ_{WH} (fb)	σ_{ZH} (fb)	scale (%)	PDF+$\alpha_s^{\rm exp}$ (%)	$\alpha_s^{\rm th}$ (%)
100	291.90	169.8	$^{+0.7}_{-0.8}$	$^{+5.0}_{-5.0}$	$^{+0.5}_{-0.4}$
105	248.40	145.9	$^{+0.7}_{-0.8}$	$^{+5.4}_{-5.4}$	$^{+0.6}_{-0.4}$
110	212.00	125.7	$^{+0.7}_{-0.9}$	$^{+5.8}_{-5.8}$	$^{+0.6}_{-0.5}$
115	174.50	103.9	$^{+0.7}_{-0.9}$	$^{+6.1}_{-6.1}$	$^{+0.7}_{-0.5}$
120	150.10	90.2	$^{+0.7}_{-0.9}$	$^{+6.4}_{-6.3}$	$^{+0.8}_{-0.6}$
125	129.50	78.5	$^{+0.7}_{-1.0}$	$^{+6.6}_{-6.7}$	$^{+0.8}_{-0.6}$
130	112.00	68.5	$^{+0.7}_{-1.0}$	$^{+6.4}_{-6.7}$	$^{+1.0}_{-0.7}$
135	97.20	60.0	$^{+0.7}_{-1.0}$	$^{+6.9}_{-6.8}$	$^{+1.0}_{-0.7}$
140	84.60	52.7	$^{+0.7}_{-1.1}$	$^{+6.9}_{-6.7}$	$^{+1.1}_{-0.8}$
145	73.70	46.3	$^{+0.7}_{-1.1}$	$^{+7.3}_{-7.1}$	$^{+1.2}_{-0.9}$
150	64.40	40.8	$^{+0.8}_{-1.1}$	$^{+6.8}_{-6.7}$	$^{+1.2}_{-0.9}$
155	56.20	35.9	$^{+0.7}_{-1.1}$	$^{+7.5}_{-7.3}$	$^{+1.2}_{-1.1}$
160	48.50	31.4	$^{+0.8}_{-1.2}$	$^{+7.4}_{-6.8}$	$^{+1.4}_{-1.0}$
165	43.60	28.4	$^{+0.7}_{-1.1}$	$^{+7.8}_{-7.6}$	$^{+1.4}_{-1.1}$
170	38.50	25.3	$^{+0.8}_{-1.0}$	$^{+7.8}_{-7.0}$	$^{+1.6}_{-1.3}$
175	34.00	22.5	$^{+0.9}_{-1.2}$	$^{+7.9}_{-7.6}$	$^{+1.5}_{-1.2}$
180	30.10	20.0	$^{+0.7}_{-1.3}$	$^{+7.3}_{-7.3}$	$^{+1.7}_{-1.3}$
185	26.90	17.9	$^{+0.7}_{-1.1}$	$^{+7.8}_{-7.8}$	$^{+1.9}_{-1.5}$
190	24.00	16.1	$^{+0.8}_{-1.2}$	$^{+7.5}_{-7.5}$	$^{+1.7}_{-1.2}$
195	21.40	14.4	$^{+0.9}_{-1.4}$	$^{+8.4}_{-7.9}$	$^{+1.9}_{-1.4}$
200	19.10	13.0	$^{+1.0}_{-1.0}$	$^{+7.9}_{-7.3}$	$^{+2.1}_{-1.6}$
210	15.20	10.5	$^{+0.7}_{-0.7}$	$^{+7.2}_{-7.2}$	$^{+1.3}_{-1.3}$
220	12.30	8.5	$^{+0.3}_{-0.3}$	$^{+7.4}_{-7.4}$	$^{+1.1}_{-1.3}$
230	9.90	7.0	$^{+0.4}_{-0.4}$	$^{+7.6}_{-7.6}$	$^{+1.2}_{-1.4}$
240	8.03	5.7	$^{+0.2}_{-0.2}$	$^{+7.7}_{-7.7}$	$^{+1.4}_{-1.5}$
250	6.53	4.7	$^{+0.3}_{-0.3}$	$^{+7.8}_{-8.0}$	$^{+1.4}_{-1.5}$
260	5.33	3.9	$^{+0.2}_{-0.2}$	$^{+8.1}_{-8.1}$	$^{+1.5}_{-1.7}$
270	4.37	3.2	$^{+0.2}_{-0.2}$	$^{+8.0}_{-8.2}$	$^{+1.6}_{-1.6}$
280	3.59	2.7	$^{+0.3}_{-0.3}$	$^{+8.1}_{-8.4}$	$^{+1.7}_{-1.7}$
290	2.96	2.2	$^{+0.3}_{-0.3}$	$^{+8.4}_{-8.8}$	$^{+1.7}_{-1.7}$
300	2.45	1.9	$^{+0.0}_{0.0}$	$^{+8.6}_{-8.6}$	$^{+1.6}_{-2.0}$

Cross Section and Branching Ratio Alignment

Weak Vector Boson Fusion (VBF)

NNLO Calc from
P. Bolzoni, F. Maltoni,
S.-O. Moch, and M. Zaro

http://vbf-nnlo.phys.ucl.ac.be/vbf.html

Very close to the NLO calculation.

We checked the NLO EW corrections from
HAWK: Denner, Dittmaier, Mück
and found that they are of order -3%

m_H (GeV/c^2)	σ_{VBF} (NNLO) (fb)	scale (%)	PDF+α_s (%)	σ_{VBF} (HAWK) (fb)
100	100.1	$^{+0.7}_{-0.3}$	$\pm$ 4.8	98.6
105	92.3	$^{+0.7}_{-0.3}$	$\pm$ 4.9	90.8
110	85.1	$^{+0.8}_{-0.3}$	$\pm$ 4.9	83.8
115	78.6	$^{+0.8}_{-0.3}$	$\pm$ 4.9	77.3
120	72.7	$^{+0.6}_{-0.4}$	$\pm$ 4.9	71.4
125	67.1	$^{+0.7}_{-0.3}$	$\pm$ 5.0	66.0
130	62.1	$^{+0.7}_{-0.4}$	$\pm$ 5.0	61.0
135	57.5	$^{+0.7}_{-0.4}$	$\pm$ 5.0	56.5
140	53.2	$^{+0.7}_{-0.4}$	$\pm$ 5.0	52.3
145	49.4	$^{+0.7}_{-0.4}$	$\pm$ 5.1	48.5
150	45.8	$^{+0.7}_{-0.5}$	$\pm$ 5.1	44.9
155	42.4	$^{+0.7}_{-0.5}$	$\pm$ 5.1	41.5
160	39.4	$^{+0.7}_{-0.5}$	$\pm$ 5.1	38.5
165	36.6	$^{+0.7}_{-0.5}$	$\pm$ 5.1	36.2
170	34.0	$^{+0.7}_{-0.6}$	$\pm$ 5.2	33.6
175	31.6	$^{+0.7}_{-0.6}$	$\pm$ 5.2	31.2
180	29.4	$^{+0.7}_{-0.6}$	$\pm$ 5.2	28.9
185	27.3	$^{+0.7}_{-0.6}$	$\pm$ 5.2	27.0
190	25.4	$^{+0.7}_{-0.6}$	$\pm$ 5.2	25.1
195	23.7	$^{+0.8}_{-0.7}$	$\pm$ 5.3	23.4
200	22.0	$^{+0.8}_{-0.7}$	$\pm$ 5.3	21.7
210	19.1	$^{+0.7}_{-0.7}$	$\pm$ 5.3	18.8
220	16.6	$^{+0.7}_{-0.8}$	$\pm$ 5.3	16.3
230	14.5	$^{+0.8}_{-0.8}$	$\pm$ 5.4	14.2
240	12.6	$^{+0.8}_{-0.8}$	$\pm$ 5.4	12.3
250	11.0	$^{+0.8}_{-0.9}$	$\pm$ 5.4	10.7
260	9.6	$^{+0.8}_{-1.0}$	$\pm$ 5.5	9.4
270	8.4	$^{+0.8}_{-1.0}$	$\pm$ 5.5	8.2
280	7.4	$^{+0.8}_{-1.1}$	$\pm$ 5.5	7.1
290	6.4	$^{+0.8}_{-1.1}$	$\pm$ 5.6	6.2
300	5.6	$^{+0.8}_{-1.1}$	$\pm$ 5.6	5.4

Tevatron Correlated Systematic Errors I

Total Systematic error count: 129 (not counting bin-by-bin errors)

Note: correlation in errors on backgrounds between experiments helps sensitivity! One experiment is another experiment's control sample.

Luminosity: 3.8% Correlated CDF and DØ σ_{inel}(ppbar)
4.4% detector-specific

Diboson Cross Sections:
For WZ and ZZ, require
75 < m_{ll} < 105 GeV

$$\sigma_{W^+W^-} = 11.34^{+0.56}_{-0.49}\ (\mathrm{scale})\ ^{+0.35}_{-0.28}(\mathrm{PDF})\mathrm{pb}$$

$$\sigma_{W^\pm Z} = 3.22^{+0.20}_{-0.17}\ (\mathrm{scale})\ ^{+0.11}_{-0.08}\ (\mathrm{PDF})\ \mathrm{pb}$$

$$\sigma_{ZZ} = 1.20^{+0.05}_{-0.04}\ (\mathrm{scale})\ ^{+0.04}_{-0.03}\ (\mathrm{PDF})\ \mathrm{pb}$$

WW, WZ, and ZZ total cross section uncertainties considered 100% correlated with each other (Joey Huston computed PDF correlations and found they are nearly 100%). We measure the diboson background *in situ* with similar precision to the prediction.

ttbar Cross Section: Moch and Uwer, evaulated at (also measured *in situ*)
m_t=173 ± 1.2 GeV is (using MSTW2008 PDFs).

$$\sigma_{t\bar{t}} = 7.04^{+0.24}_{-0.36}\ (\mathrm{scale}) \pm 0.14(\mathrm{PDF}) \pm 0.30(\mathrm{mass}).$$

Tevatron Correlated Systematic Errors II

Signal Cross Section uncertainties (using MSTW PDFs)

WH, ZH: ± 5%

gg→H: ±~20% (weighted scale over jet samples)

± 12.5% (weighted PDF). Pt spectra reweighted to NNLO+NNLL predictions

Errors taken from Anastasiou, Grazzini, Dissertori, Stockli, and Webber, for H+0, 1 jets

VBF: ± 10%

Theory errors applied to SM interpretations, but taken off for cross-section times branching ratio limits.

CDF-DØ Uncorrelated errors:

- K-factors (data driven)
- trigger efficiency
- b-tag efficiency and mistags
- jet energy scale
- lepton ID, fakes and conversions
- MET modeling

Correlated *within* CDF and D0 where appropriate

Including Higher-Order Calculations

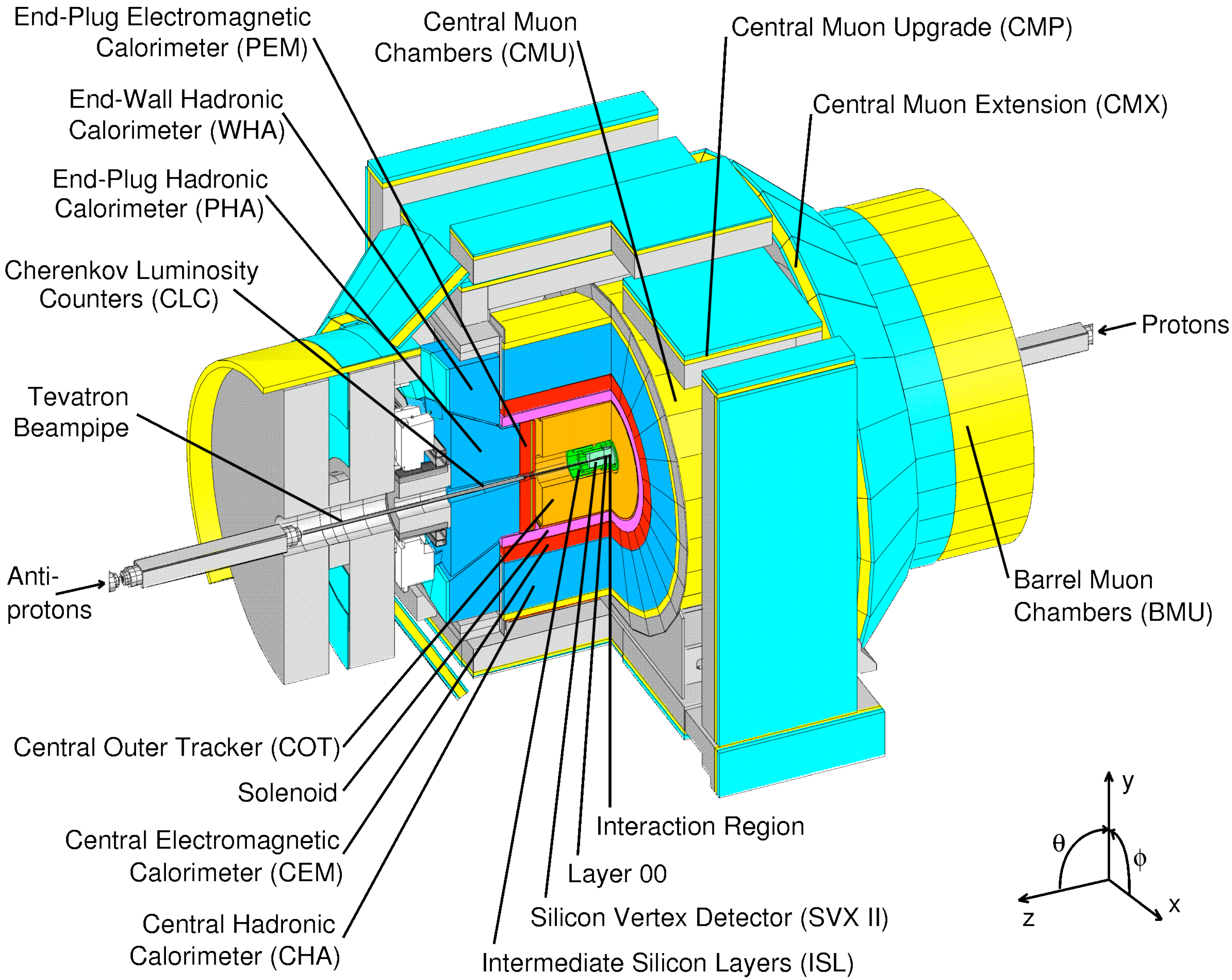
We like theoretical work which addresses our selections and use the resulting systematic uncertainties.

But we realize that the mapping between partons and measurements is not perfect.

- showering, hadronization (available to everyone)
- Detector acceptance, efficiency, resolution (not available to everyone)

- Need fully simulated Monte Carlo – happy to adjust the underlying physics of the generator though.

The CDF Detector



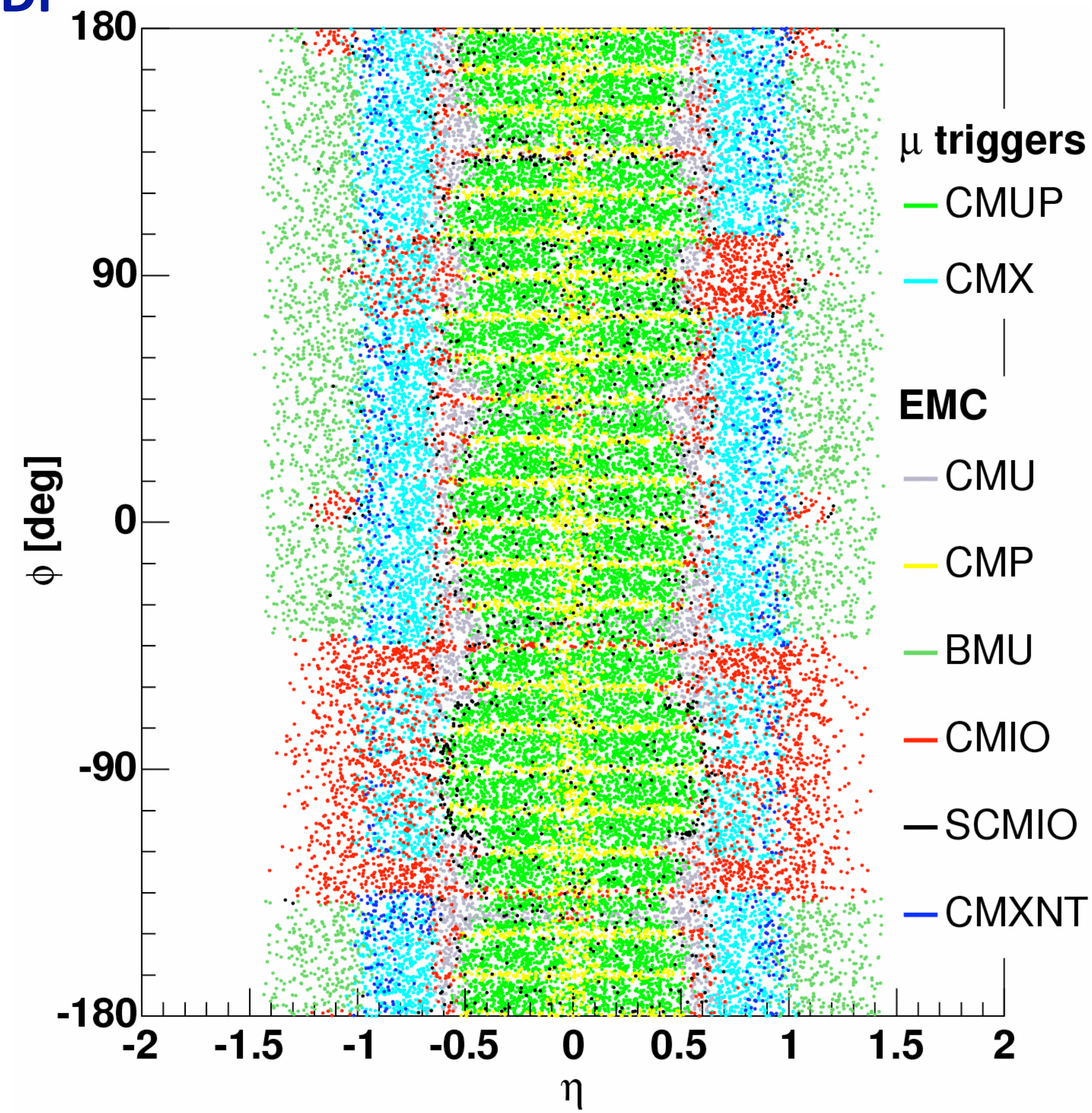
Muon Detection in CDF

requires looking at many different detectors and categories of muons.

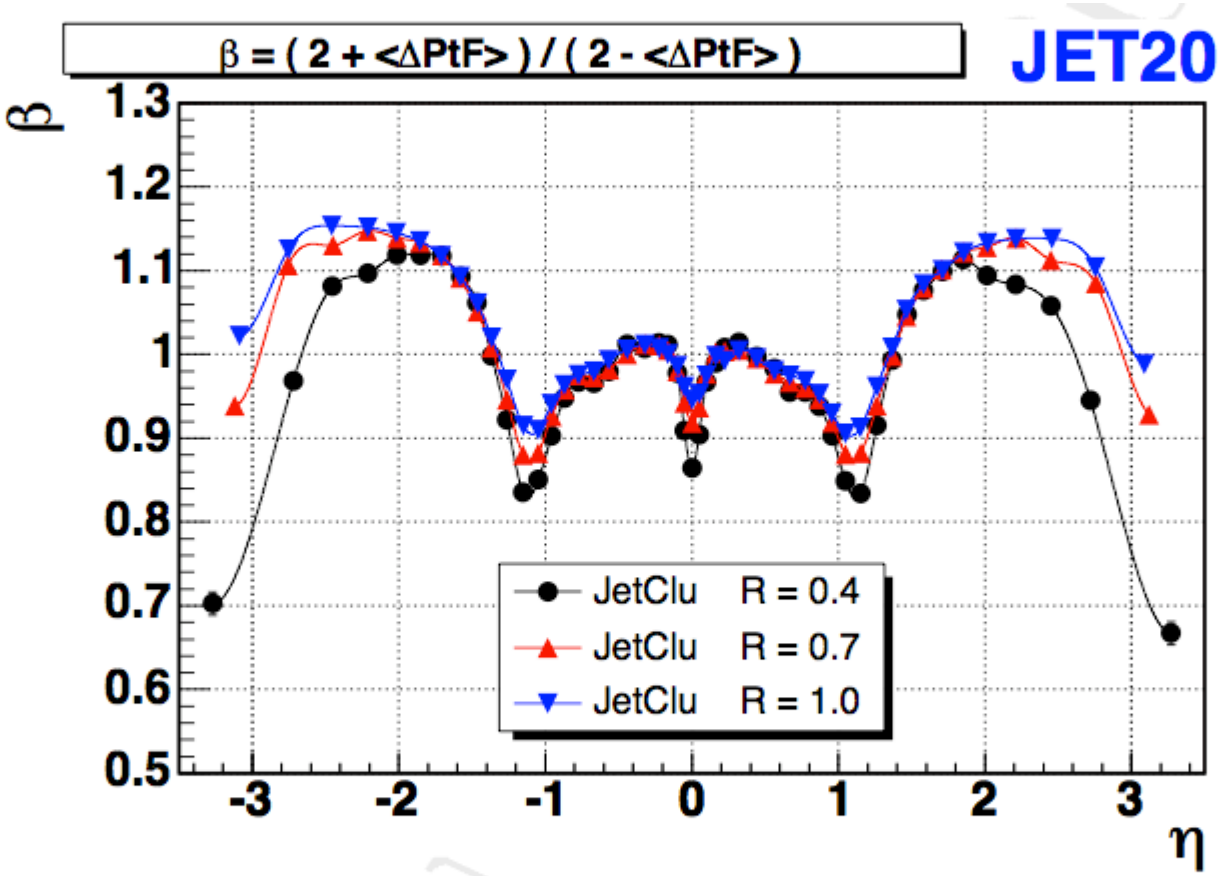
Detailed detector simulation + data-calibrated identification rate scale factors and resolutions required.

Calibrated with Z→μμ

Latest iteration have even more categories "crack tracks"



Uncorrected Jet Response is Highly angle dependent



This is corrected out, but then the jet resolution is highly angle dependent.

Steps Required for Combination

Before Exchanging data, quality control:

- Check stacked histograms and systematic tables with analysis documentation total counts:
  data, signal, background
  - look for bins with b=0 and have data events (bad!)
- Repeat individual channel limits -- compare against approved results.

CDF and DØ teams each do three combinations, using Bayesian and CL_s techniques.

CDF
DØ
Tevatron
Consistency at the better than 10% level required for all combinations at all test masses. Quote Bayesian limits (historical)

Mini-Review: Bayesian Limits

$$L(r,\theta) = \prod_{channels} \prod_{bins} P_{Poiss}(data \mid r,\theta)$$

Where r is an overall signal scale factor, and θ represents all nuisance parameters.

$$P_{Poiss}(data \mid r,\theta) = \frac{(rs_i(\theta) + b_i(\theta))^{n_i} e^{-(rs_i(\theta)+b_i(\theta))}}{n_i!}$$

where n_i is observed in each bin i, s_i is the predicted signal for a fiducial model (SM), and b_i is the predicted background. Dependence of s_i and b_i on θ includes rate, shape, and bin-by-bin independent uncertainties.

Tests models that scale (unphysically) WH, ZH, VBF, ggH all together, holding decay b.r.'s fixed

Mini-Review: Bayesian Limits

Including uncertainties on nuisance parameters θ

$$L'(data \mid r) = \int L(data \mid r, \theta)\pi(\theta)d\theta$$

- $\pi(\theta)$ encodes our prior belief in the values of the uncertain parameters.

- Nuisance parameters have correlated impacts on multiple predictions.
- Integral is a convolution for uncertainties that add: “quadrature” for uncorrelated uncertainties, “linear” for correlated uncertainties.
- Some uncertainties are multiplicative, and their impacts are propagated as such to the predictions.
- Rate, shape, bin-by-bin uncertainties handled together

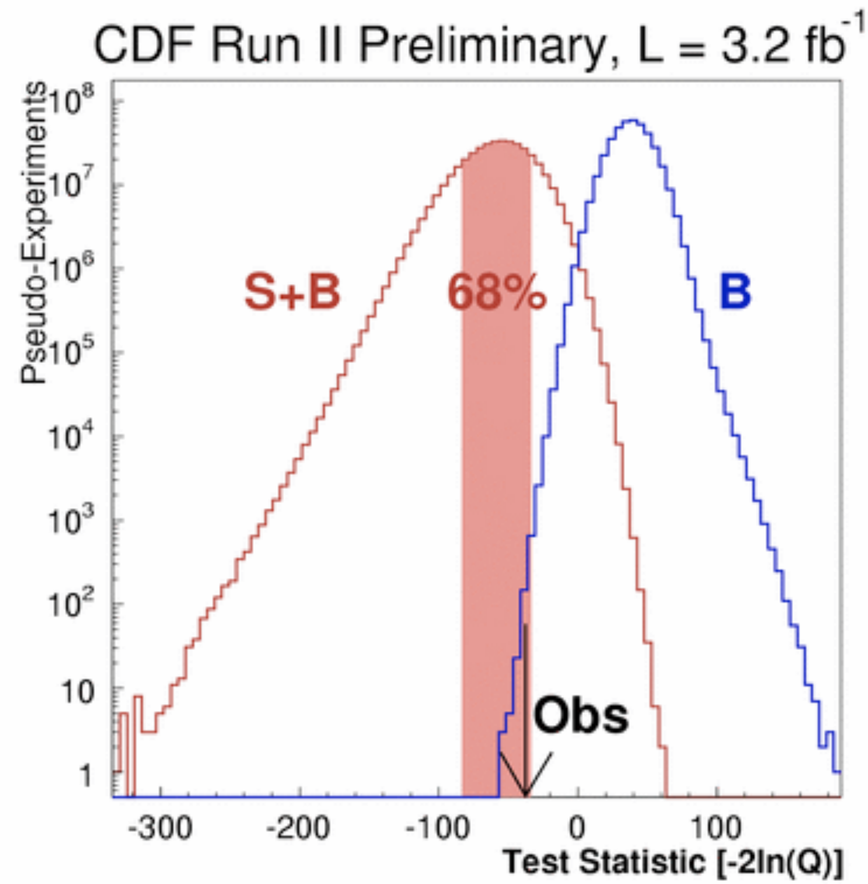
Useful for a variety of results:

Limits: $$0.95 = \int_0^{r_{\lim}} L'(data \mid r)\pi(r)dr$$

Typically $\pi(r)$ is constant
Other options possible.
Sensitivity to priors a concern.

Measure r: $$0.68 = \int_{r_{low}}^{r_{high}} L'(data \mid r)\pi(r)dr \quad r = r_{\max - (r_{\max} - r_{low})}^{+(r_{high} - r_{\max})}$$

Discovery with p-Values



Example: CDF single top.

$$-2\ln Q \equiv LLR \equiv -2\ln\left(\frac{L(\text{data}\mid s+b,\hat{\theta})}{L(\text{data}\mid b,\hat{\hat{\theta}})}\right)$$

100 M s+b and b-only pseudoexperiments,
each with fluctuated nuisance parameters, and fit twice.

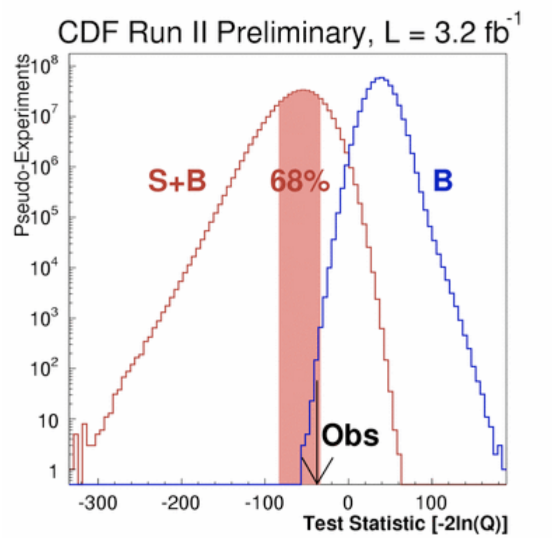
5σ: p-value of 2.77×10^{-7} or less.

3σ: p-value of 1.35×10^{-3} or less

2σ: p-value of 2.28% or less

Buzzword: “Prior Predictive ensemble”

Fitting and Fluctuating



$$-2\ln Q \equiv LLR \equiv -2\ln\left(\frac{L(\text{data}\,|\,s+b,\hat{\theta})}{L(\text{data}\,|\,b,\hat{\hat{\theta}})}\right)$$

- Monte Carlo pseudoexperiments are used to get p-values.
- Test statistic -2lnQ is not uncertain for the data.
- Distribution from which -2lnQ is drawn is uncertain!

- Nuisance parameter fits in numerator and denominator of -2lnQ **do not incorporate systematics into the result**.
  Example -- 1-bin search; all test statistics are equivalent to the event count, fit or no fit.
- Instead, we fluctuate the probabilities of getting each outcome since those are what we do not know. Each pseudoexperiment gets random values of nuisance parameters.
- Can also try values of nuisance parameters that maximize the p-value, but that's very conservative (called the supremum p-value, still needs choices of parameter ranges).
- Why fit at all? It's an optimization. Fitting reduces sensitivity to the uncertain true values and the fluctuated values. For stability and speed, you can choose to fit a subset of nuisance parameters (the ones that are constrained by the data). Or do constrained or unconstrained fits, it's your choice.
- If not using pseudoexperiments but using Wilk's theorem, then the fits are important for correctness, not just optimality.

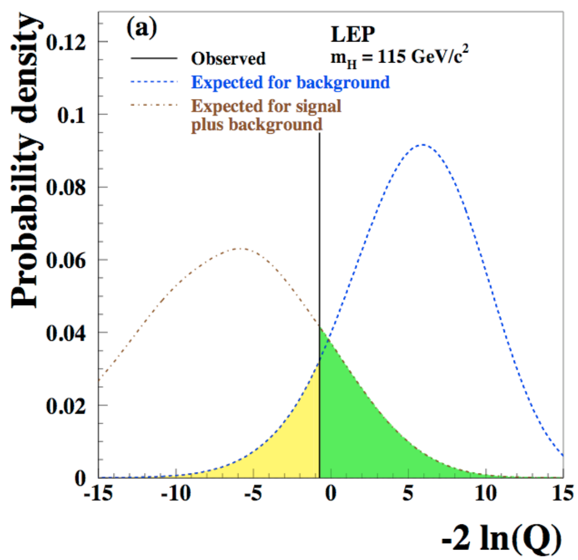
Mini-Review: CL_s Limits

- Based on p-values using the log likelihood ratio as the test statistic. Neyman-Pearson lemma says LLR is the uniformly most powerful test statistic, although the Neyman-Pearson one fits for the parameter of interest, not just the nuisance parameters, making the null hypothesis a subset of the test hypothesis

$$-2\ln Q \equiv LLR \equiv -2\ln\left(\frac{L(\text{data}\,|\,s+b,\hat{\theta})}{L(\text{data}\,|\,b,\hat{\hat{\theta}})}\right)$$

Pearson's LLR also fits for s (actually $r \times s$) in the numerator, while $r = 0$ in the denominator

Mini-Review: CL_s Limits

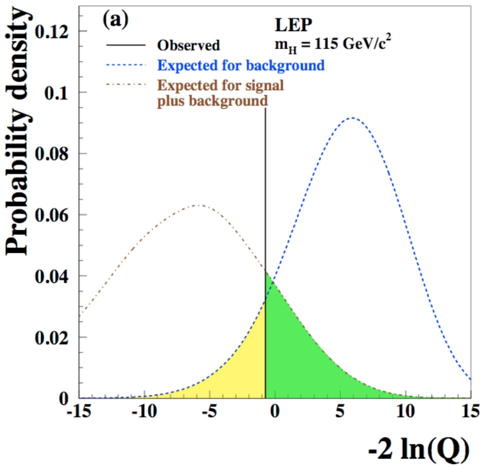


p-values:
Yellow area = $1-CL_b = 1-P(-2\ln Q > -2\ln Q_{obs} \mid b \text{ only})$
Green area = $CL_{s+b} = P(-2\ln Q > -2\ln Q_{obs} \mid s+b)$

$CL_s \equiv CL_{s+b}/CL_b \geq CL_{s+b}$
Exclude if $CL_s < 0.05$
Vary r until $CL_s = 0.05$ to get r_{lim}

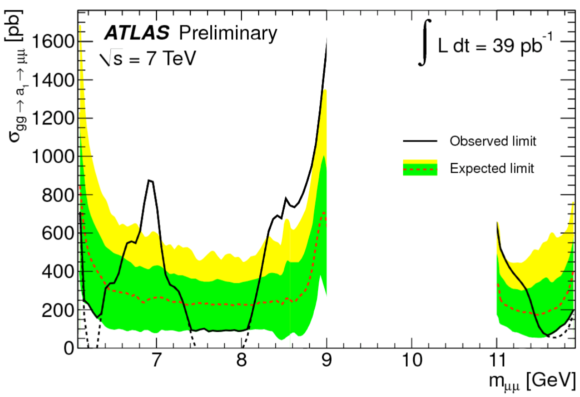
- Advantages:
  - Exclusion and Discovery p-values are consistent. Example -- a 2σ upward fluctuation of the data with respect to the background prediciton appears both in the limit and the p-value as such
  - Does not exclude where there is no sensitivity (big enough search region with small enough resolution and you get a 5% dusting of random exclusions with CL_{s+b})

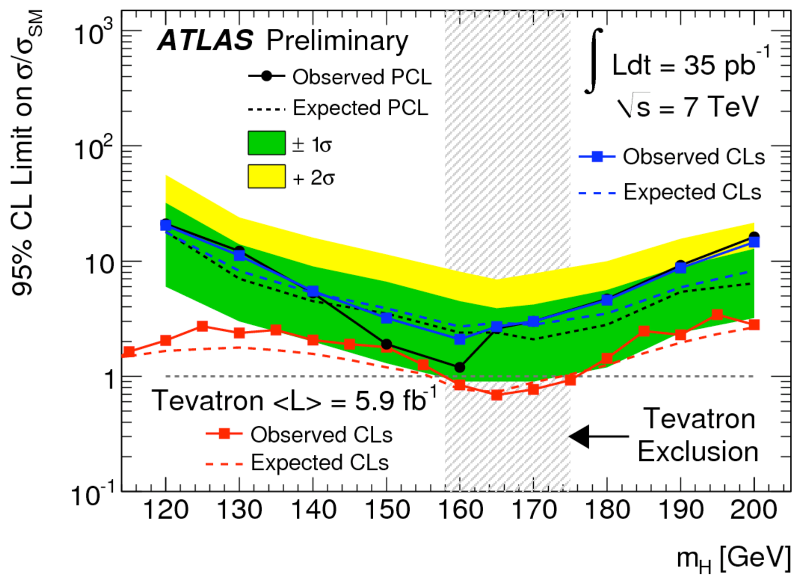
Power Constrained Limits (PCL)



Just use CL_{s+b}<0.05 to determine exclusion.

But if the resulting limit is more than 1σ more stringent than the median expectation, quote the 1σ limit instead



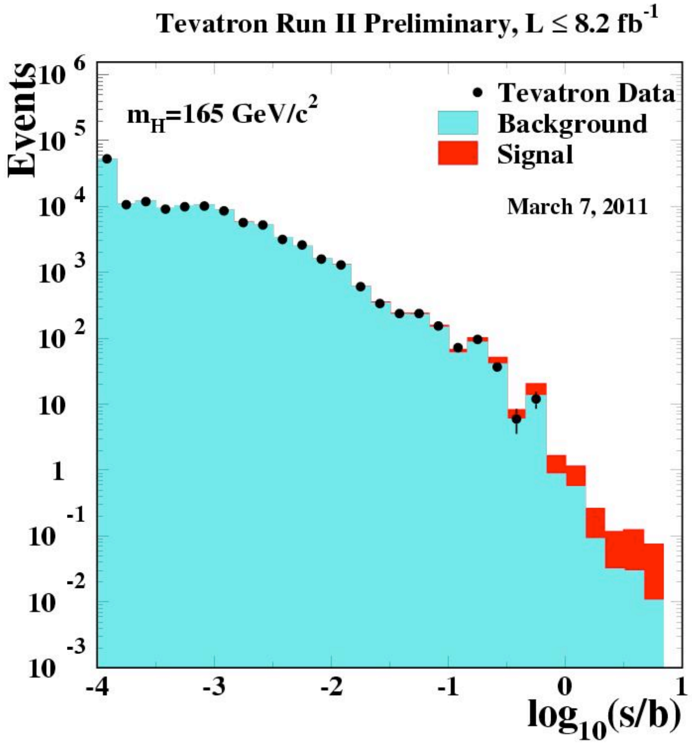


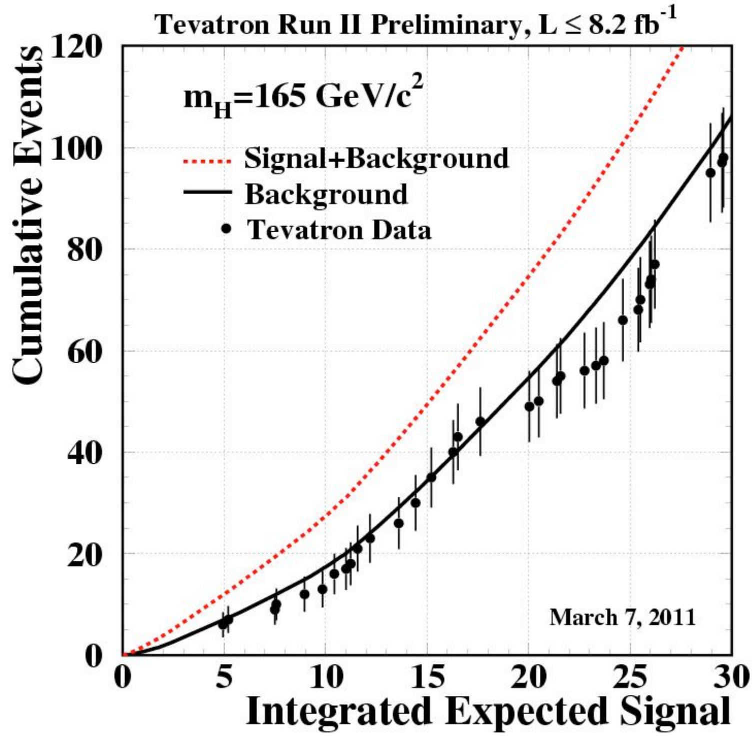
Advantages:

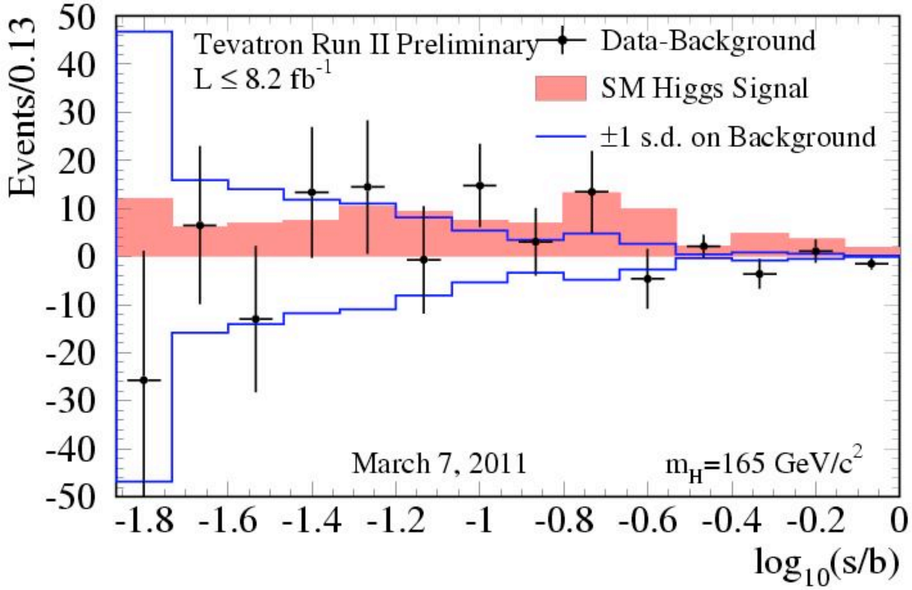
- More powerful than CL_s or Bayesian limits while still covering
- Does not exclude where there is no sensitivity

Disadvantage:

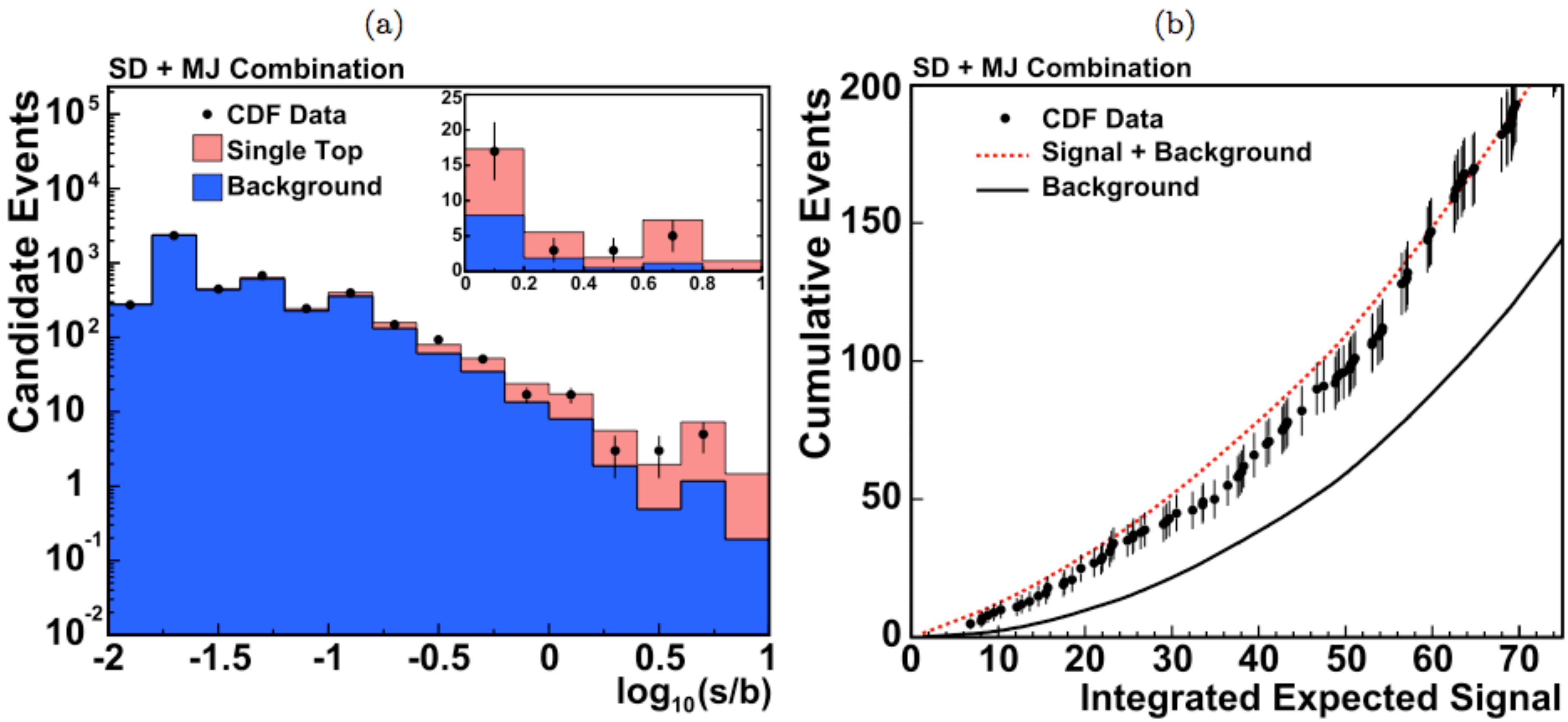
- 1σ constraint is arbitrary – balance desire for a more powerful method with acceptability of limits. A 2σ constraint defeats the purpose entirely for example.


Tevatron Run II Preliminary, L ≤ 8.2 fb^{-1}
m_H=165 GeV/c^2
Tevatron Data
Background
Signal
March 7, 2011
Events
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
-4
-3
-2
-1
0
1
$\log_{10}$(s/b)


Tevatron Run II Preliminary, L ≤ 8.2 fb^{-1}
m_H=165 GeV/c^2
Signal+Background
Background
Tevatron Data
March 7, 2011
Cumulative Events
120
100
80
60
40
20
0
0
5
10
15
20
25
30
Integrated Expected Signal

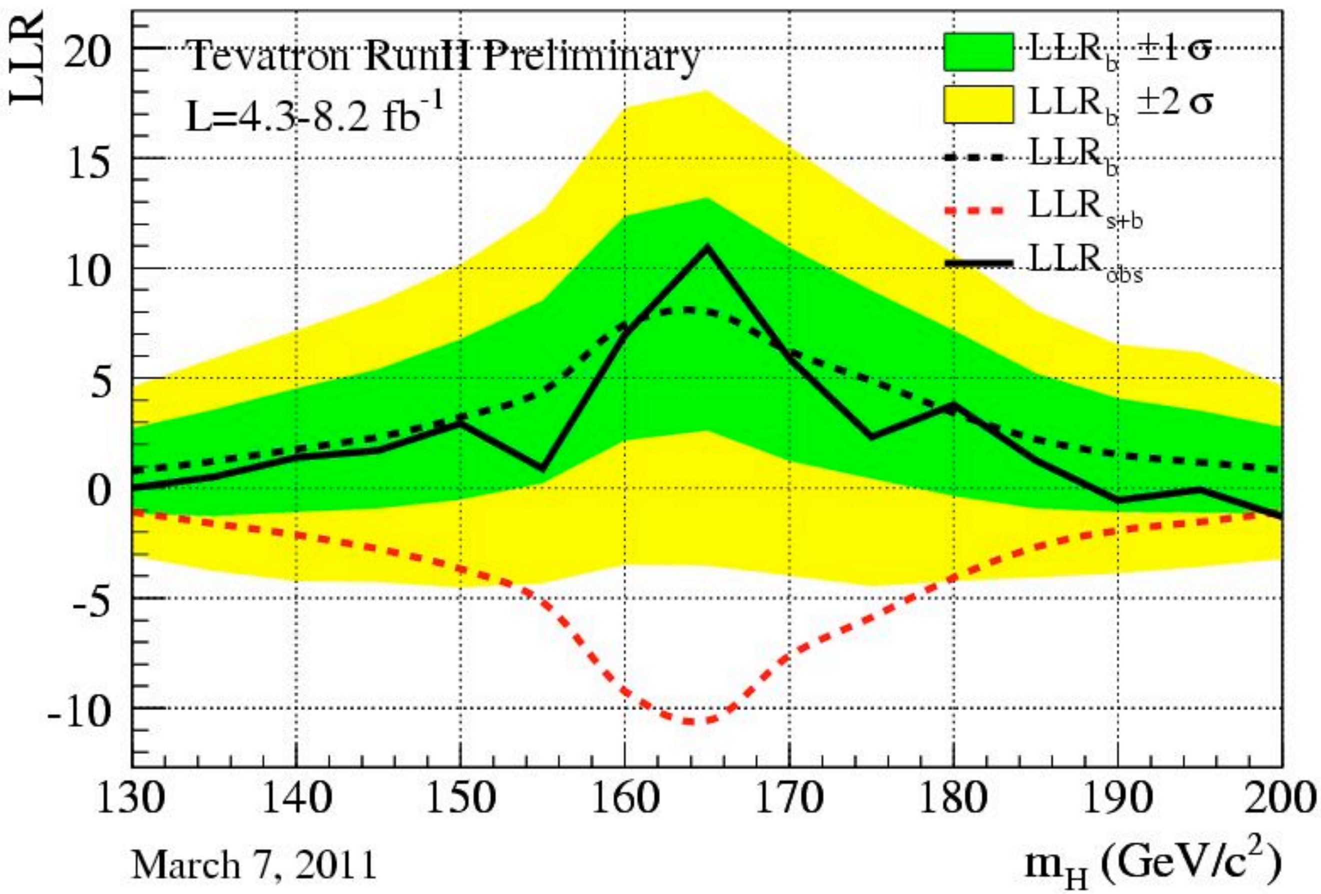

Tevatron Run II Preliminary
L ≤ 8.2 fb^{-1}
Data-Background
SM Higgs Signal
±1 s.d. on Background
March 7, 2011
m_H=165 GeV/c^2
Events/0.13
50
40
30
20
10
0
-10
-20
-30
-40
-50
-1.8
-1.6
-1.4
-1.2
-1
-0.8
-0.6
-0.4
-0.2
0
$\log_{10}$(s/b)

What These Look Like for a 5.0σ Observation



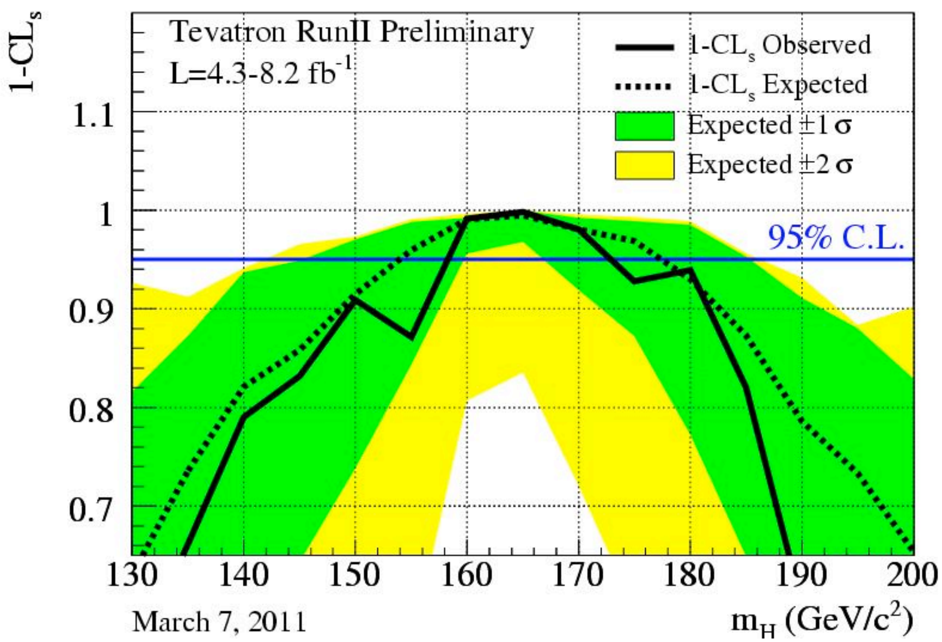
CDF Single Top, 3.2 fb^{-1}

Looking for a Signal



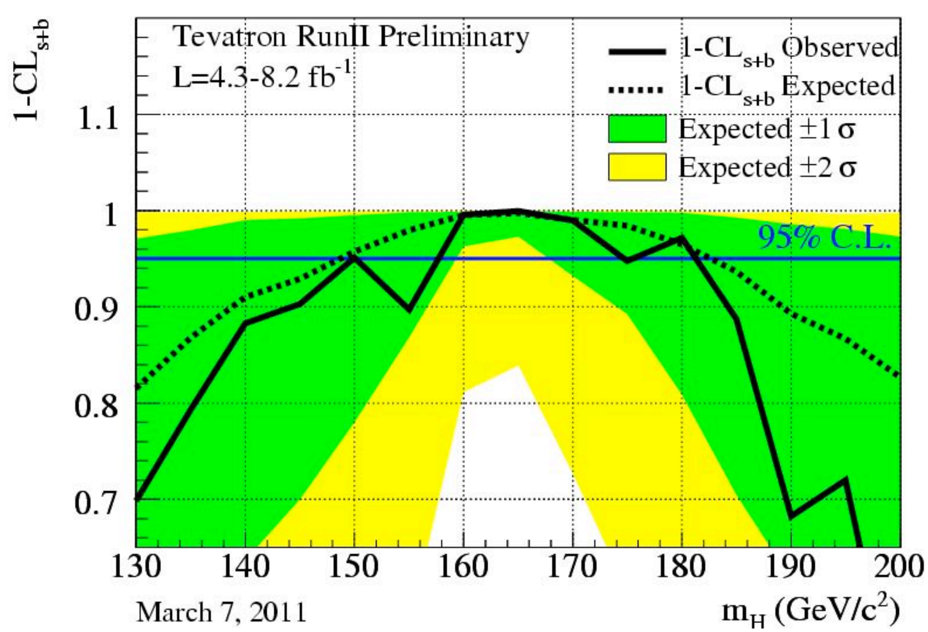
$$-2\ln Q \equiv LLR \equiv -2\ln\left(\frac{L(\text{data}\mid s+b,\hat{\theta})}{L(\text{data}\mid b,\hat{\hat{\theta}})}\right)$$

CL_s vs. CL_{s+b}



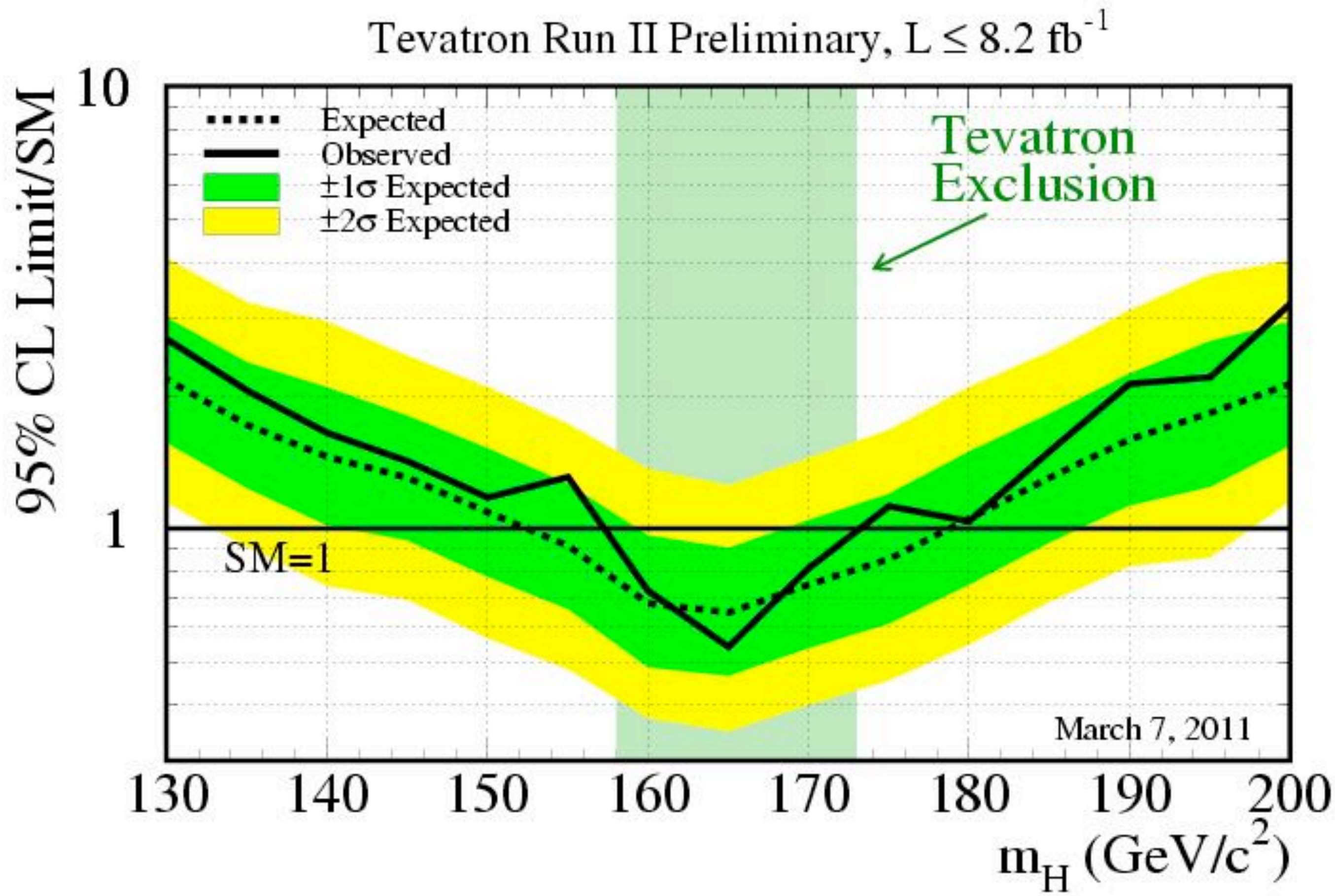
CL_s matches the Bayesian limits very well

CL_{s+b} and PCL give a ~40% larger expected m_H exclusion



Tevatron Observed and Expected Limits

Bayesian (chosen a priori)



Excluded regions:

158 < m_H < 173 GeV

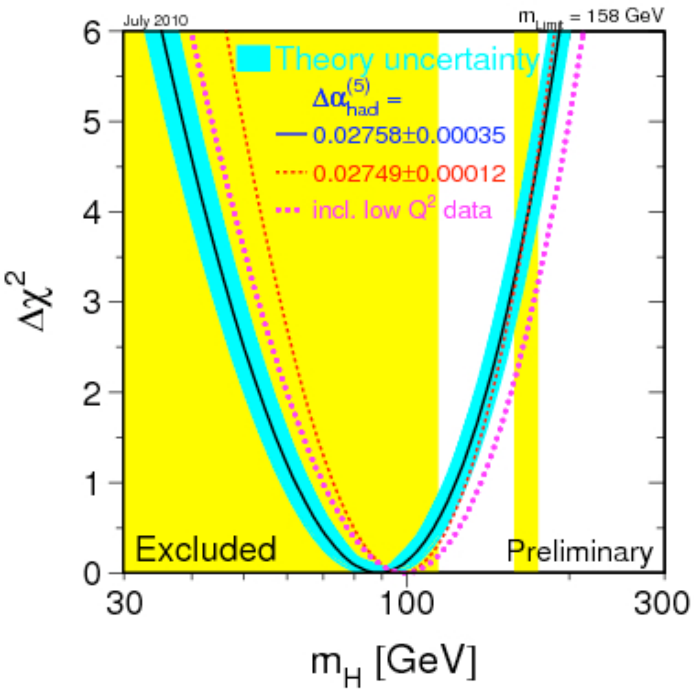
Expected Exclusion (if no signal is present):

153 < m_H < 179 GeV

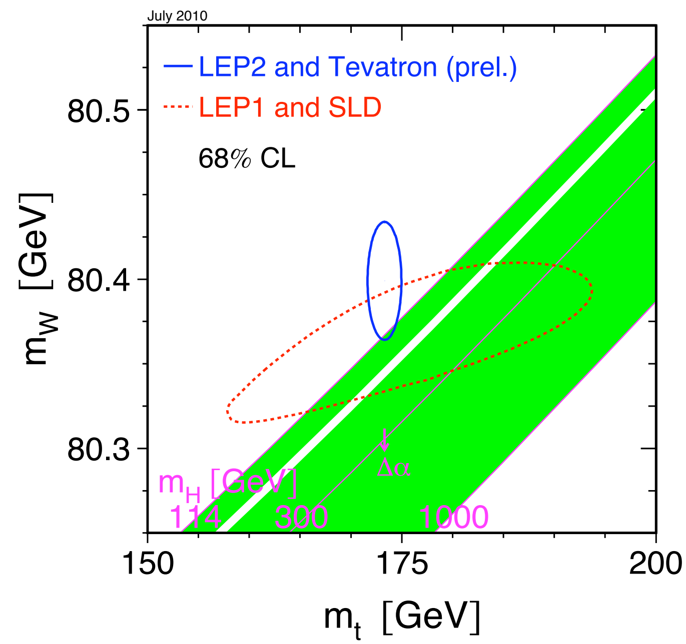
With CL_{s+b} 149<m_H<185 expected exclusion

Does not include H→bb channels – almost all H→WW goes into this plot. Some H→ττ and H→γγ is in there however)

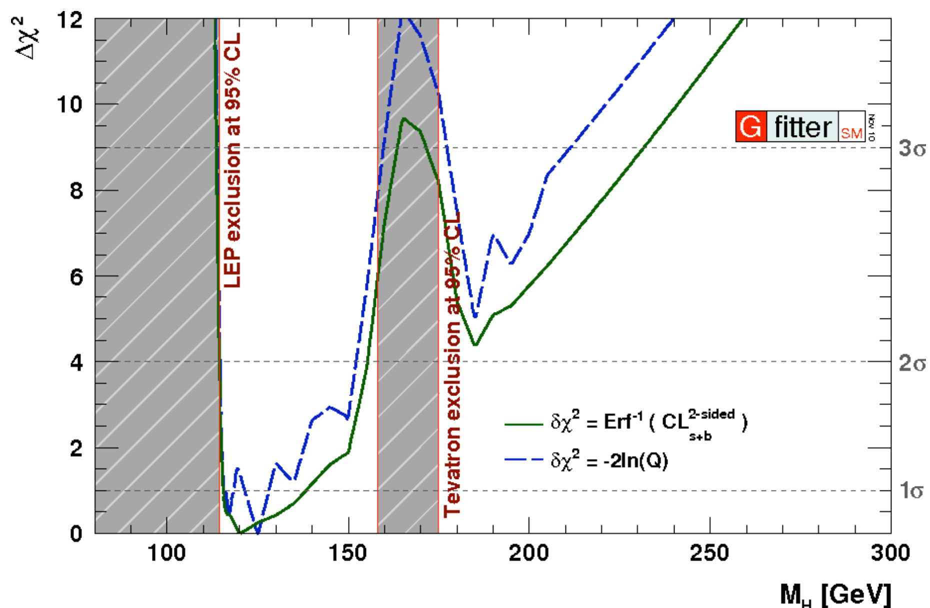
We have a large impact on the Global Fits



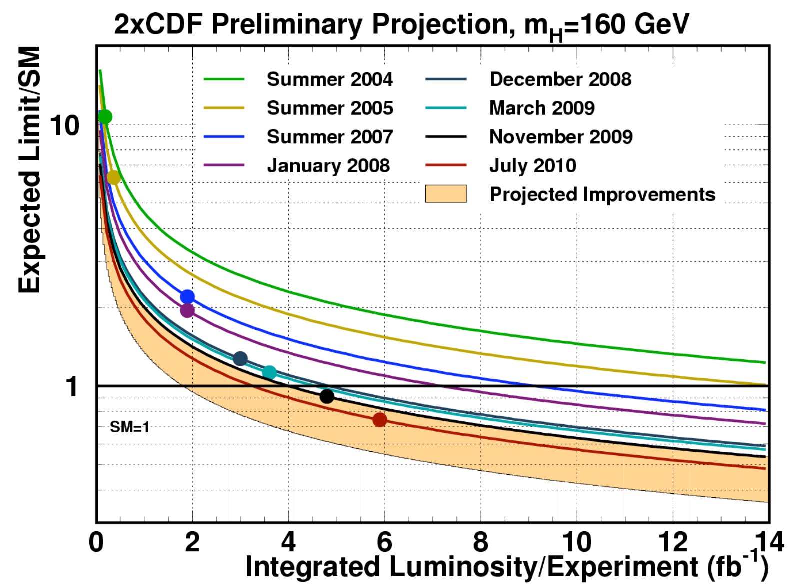
(LEPEWWG plots not updated yet)

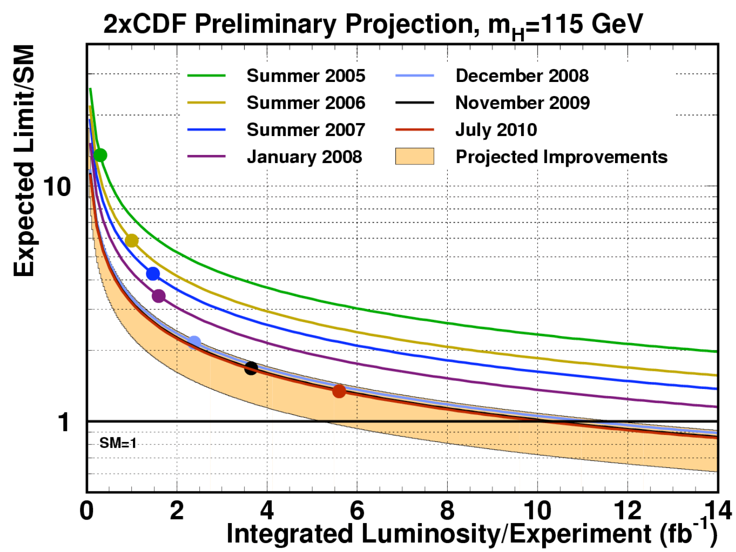


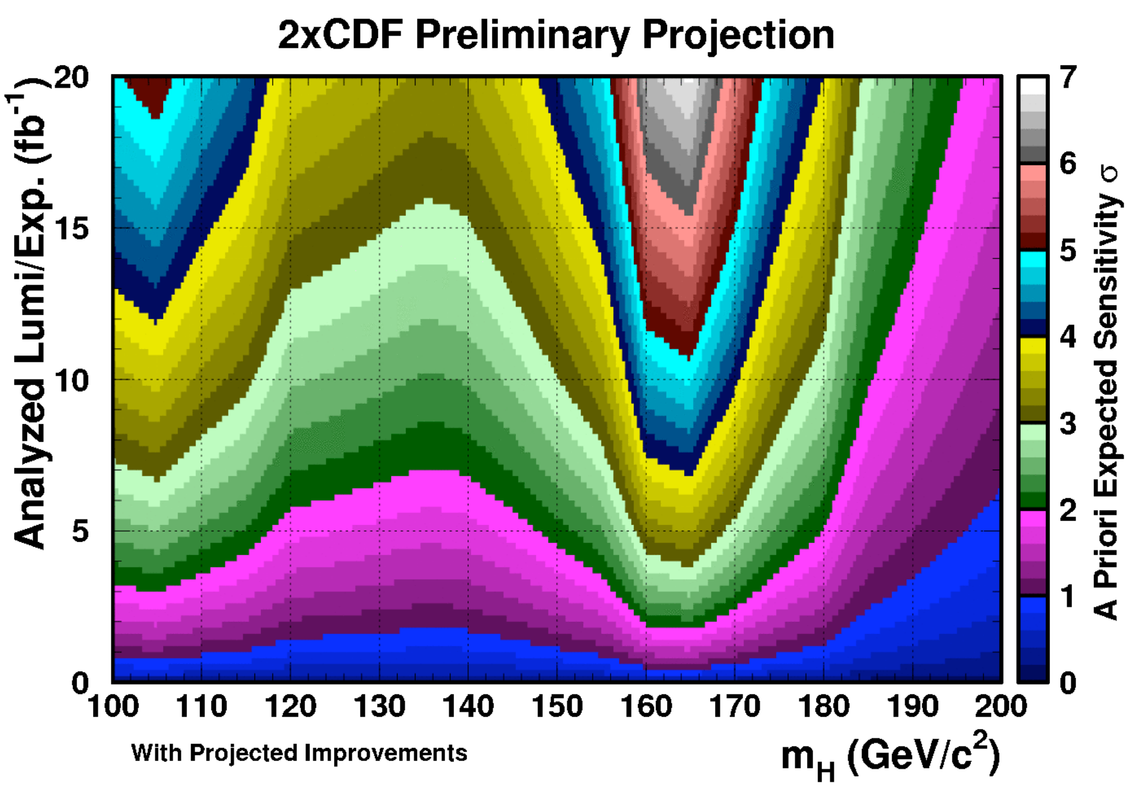
Gfitter Collaboration:



Projections for Future Performance

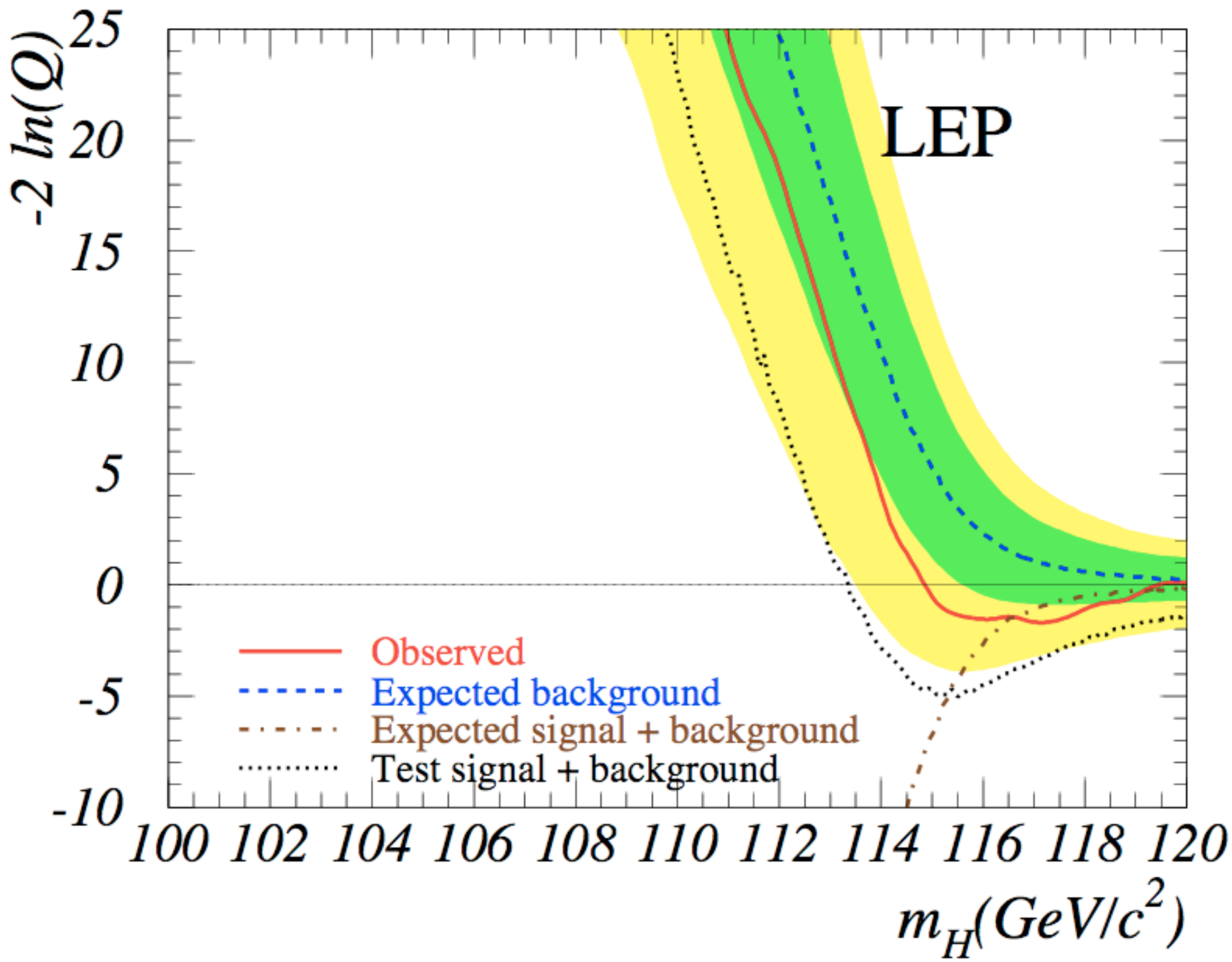






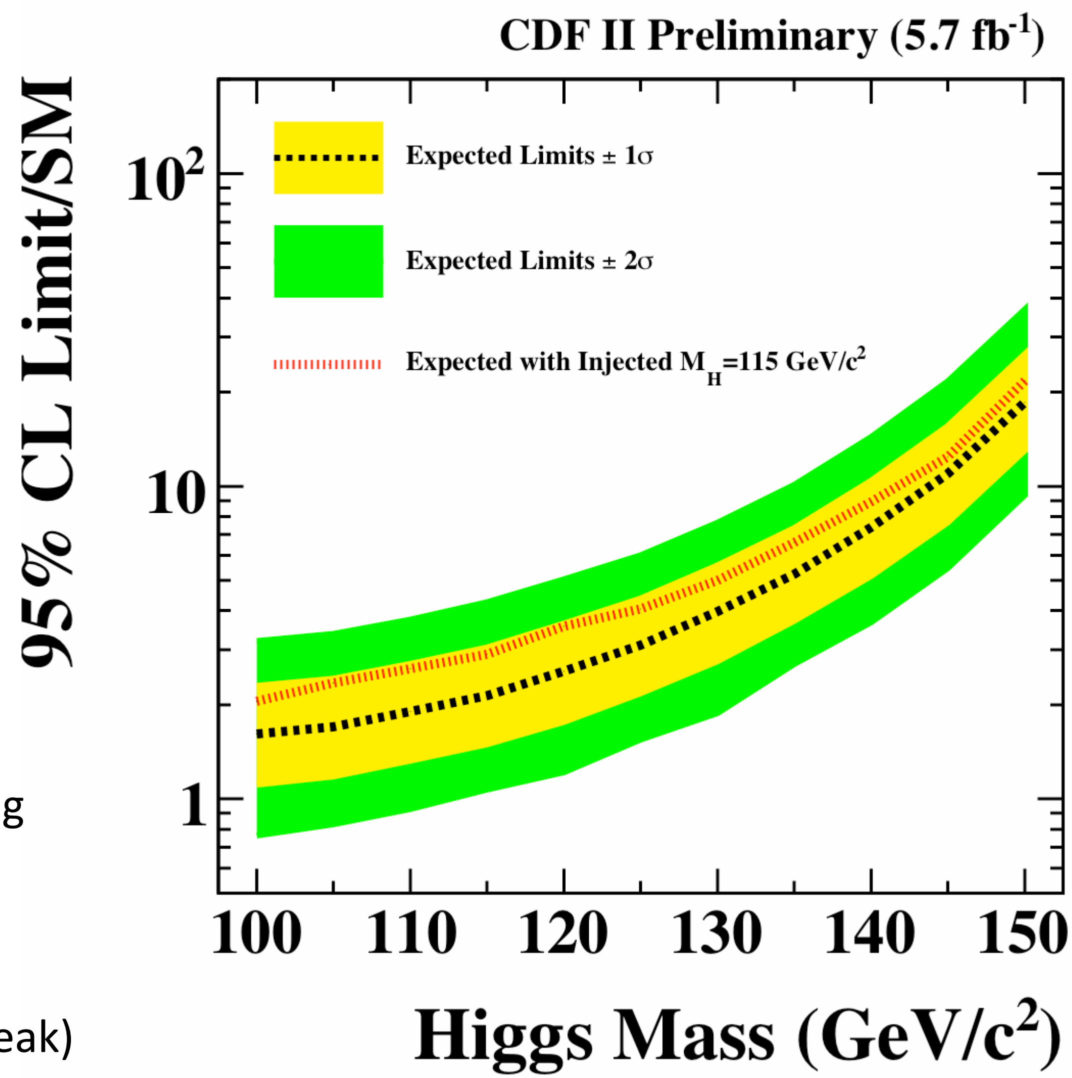
Look-Aside Histograms

What does a signal with $m_H = m_1$ look like when seeking $m_H = m_2$?
So far, not done at Tevatron. Not needed to study the trials factor, but needed to make this plot:



Studies of Injecting a Signal at m_H=115 GeV

- lvbb, METbb, and llbb channels included
- Inject SM*1.0 signal at m_H=115 GeV on top of SM backgrounds, and generate pseudoexperiments with that.
- Analyze 115 signal+background pseudoexperiments at other test masses – 100 GeV to 150 GeV
- Find the median expected limit assuming signal is there (compute it just as you would without the signal) and compare with the distribution of limits assuming the signal is completely absent.



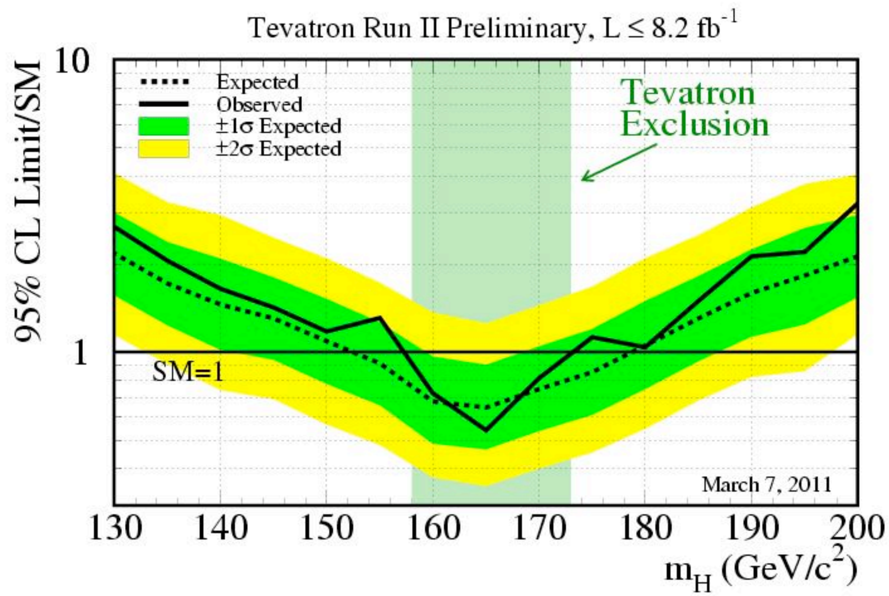
- MVA's are less sensitive to mass than m_{rec} (fold over different sides of the peak) -- good for hypothesis testing, but not so goodat measuring m_H.

Summary

The Tevatron
is doing very well!

We expect to
run until the end
of September 2011

Low- and high-mass
updates planned for
Summer 2011
conferences



Excluded regions:

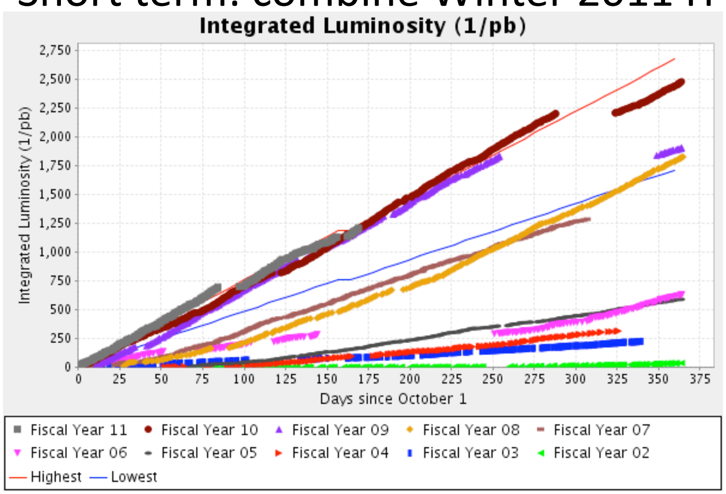
$158 < m_H < 173$ GeV

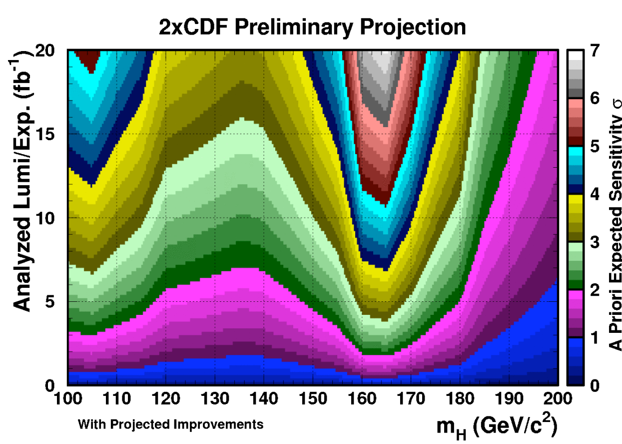
Expected Exclusion
(if no signal is present):

$153 < m_H < 179$ GeV

(summer 2010
expectation:
$156 < m_H < 173$ GeV)

Short term: combine Winter 2011 H→γγ Tevatron results





Extras

Commonly Used Tools for Setting Limits and Discovering New Processes in use at the Tevatron

- Bayesian limits -- common at CDF
  - genlimit code by Joel Heinrich, added to mclimit code by Tom Junk. Newer Metropolis-Hastings integrator is more numerically stable on big problems
  - Implements posterior integrated over systematic uncertainties with a flat prior in cross section in 1D
  - Method described in PDG statistics reveiw
  - Extra feature -- "correlated prior"

- CL_s limits -- common at D0, but used at CDF as well.
  - Collie code by Wade Fisher in use at D0
  - Method described in PDG statistics review
  - mclimit was originally designed to do CL_s and still does.
  - TLimit in ROOT is out of date -- no fits for nuisance parameters, no shape errors or bin-by-bin errors

Measurement and Discovery are Very Different

Buzzwords:

- Measurement = “Point Estimation”
- Discovery = “Hypothesis Testing”

You can have a discovery and a poor measurement!
Example: Expected b=2×10^{-7} events, expected signal=1 event, observe 1 event, no systematics.

p-value ~2×10^{-7} is a discovery! (hard to explain that event with just the background model). But have ±100% uncertainty on the measured cross section!

In a one-bin search, all test statistics are equivalent. But add in a second bin, and the measured cross section becomes a poorer test statistic than the ratio of profile likelihoods.

In all practicality, discriminant distributions have a wide spectrum of s/b, even in the same histogram. But some good bins with b<1 event

Sociological Issues

- Discovery is conventionally 5σ. In a Gaussian asymptotic case, that would correspond to a ±20% measurement.

- Less precise measurements are called "measurements" all the time

- We are used to measuring undiscovered particles and processes. In the case of a background-dominated search, it can take years to climb up the sensitivity curve and get an observation, while evidence, measurements, etc. proceed.

- Referees can be confused.

The Trials Factor

- Also called the "Look Elsewhere Effect"
- Bump-hunters are familiar with it.

What is the probability of an upward fluctuation as big as the one I saw *anywhere* in my histogram?

-- Lots of bins → Lots of chances at a false discovery
-- Approximation: Multiply smallest p-value by the number of "independent" models sought (not histogram bins!).
Bump hunters: roughly (histogram width)/(mass resolution)
Criticisms:
Adjusted p-value can now exceed unity!
What if histogram bins are empty?
What if we seek things that have been ruled out already?

It's not bins, but the number of independent hypotheses being tested that matters!

Low mass resolution at the Tevatron – not very many independent excesses possible.

The Trials Factor

More seriously, what to do if the p-value comes from a big combination of many channels each optimized at each m_H sought?

- Channels have different resolutions (or is resolution even the right word for a multivariate discriminant?
- Channels vary their weight in the combination as cross sections and branching ratios change with m_H

Proper treatment -- want a p-value of p-values!
(use the p-value as a test statistic)
Run pseudoexperiments and analyze each one at each m_H studied. Look for the distribution of smallest p-values.

Difficult but possible.
No trials factor associated with limits. -- random oscillations tend to make excluded regions shorter the better the resolution is.

At m_H=165 GeV, 133 named sources of systematic uncertainty

LUMI 0.0265679 +- 0.824895
D0_Lumi 0.185264 +- 0.85186
D0_MUID 0.0416735 +- 0.599
D0_muontrig 0.116747 +- 0.796573
D0_TauES -0.0423805 +- 0.771668
D0_tautrk -0.0168425 +- 0.995416
D0_TAUID 0.0078644 +- 0.941757
D0_VCJ 0.36824 +- 0.550693
ggHpT 0.00397764 +- 0.997253
D0_jetpt -0.0299649 +- 0.919487
D0_JES -0.665801 +- 0.245962
D0_JSSR 0.392235 +- 0.190582
D0_JetID 0.294897 +- 0.278994
XS_VH -0.00377098 +- 0.99713
XS_qqH 0.00628008 +- 1.00377
XS_ggH_Scale -0.0678625 +- 1.00207
XS_ggH_PDF -0.0157159 +- 1.00043
XS_ttbar 0.228554 +- 0.732712
XS_wjets 0.214818 +- 0.98896
XS_Zlp -0.949734 +- 0.750922
DIBOSON 0.447481 +- 0.701948
D0_MJnorm -0.279252 +- 0.98592
D0_MJshape 1.12234 +- 0.782589
D0_pdf1 0.553438 +- 0.791879
XS_Wlp 0.00432005 +- 0.610897
D0_hwwmnjj2BQCD -0.678378 +- 0.620833
D0_AlpMLM -1.00197 +- 0.934272
D0_AlpScale 0.714022 +- 0.837994
D0_AlpUE -2.12227 +- 0.876342
D0_hwwlnjj_WPT -1.52096 +- 0.852375
D0_hwwlnjj_DR -0.790806 +- 0.990347
D0_hwwlnjj_JET1 0.216373 +- 0.991425
D0_hwwlnjj_JET0 0.118625 +- 0.996596
D0_hwwmnjj_TRGS 0.190183 +- 0.949918
D0_TOPJES -0.00946262 +- 0.997783

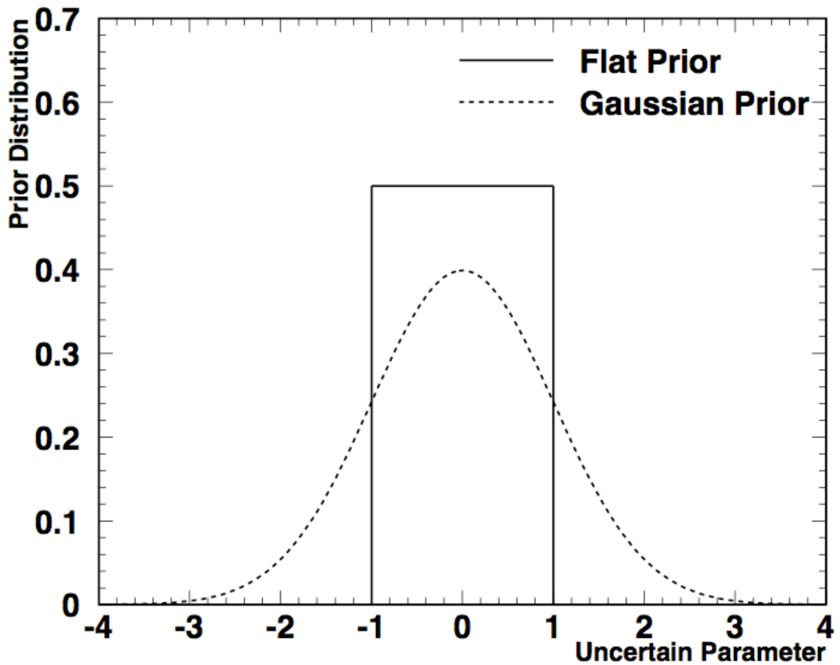
XS_Whf -0.177845 +- 0.843819
XS_Zhf -0.285996 +- 0.994315
D0_BJES 0.0390238 +- 0.997961
D0_hwwmnjj2AQCD -0.455895 +- 0.741364
D0_EMID 0.0374239 +- 0.601478
D0_hwwenjj2BQCD -1.63739 +- 0.773738
D0_hwwenjj2AQCD -1.09734 +- 0.884494
D0_SurfNorm_ee2B 0.238707 +- 0.688714
D0_btagOthers 1.01058 +- 0.510168
D0_btagTtbar -0.57316 +- 0.901125
D0_gg2ww 0.0436752 +- 0.979943
XS_W+lp_jets -0.385794 +- 0.984607
D0_njet2Scale2B_wjets -0.749523 +- 0.73994
D0_QCD_hwwee2B_2jet 0.00997179 +- 1.00411
D0_njet2Scale2B_zjets -0.205457 +- 0.422965
D0_SurfNorm_ee2A -0.0796919 +- 0.805764
ggHpt -0.00172292 +- 1.00173
D0_njet2Scale2A_wjets -0.106497 +- 0.993165
D0_QCD_hwwee2A_2jet -0.0548321 +- 0.99015
D0_njet2Scale2A_zjets -0.269128 +- 0.612472
D0_njet1Scale2B_wjets -0.880726 +- 0.709565
D0_QCD_hwwee2B_1jet -0.124923 +- 0.990662
D0_njet1Scale2B_zjets -0.765128 +- 0.486429
D0_njet1Scale2A_wjets 0.293885 +- 0.90222
D0_QCD_hwwee2A_1jet 0.00914123 +- 1.00193
D0_njet1Scale2A_zjets 1.26167 +- 0.728984
D0_WWrew -0.0471792 +- 0.991735
XS_W+lp_0jet -0.50853 +- 0.961063
D0_njet0Scale2B_wjets -0.0928367 +- 0.783232
D0_QCD_hwwee2B_0jet -0.129048 +- 0.997128
D0_njet0Scale2B_zjets -0.0250646 +- 0.910985
D0_njet0Scale2A_wjets -1.61098 +- 0.700075
D0_njet0Scale2A_zjets -0.0828907 +- 0.986453
D0_SurfNorm_mumu2B -0.469062 +- 0.625648
D0_QCD_hwwmumu -0.106863 +- 0.795989
D0_Wpt -0.184552 +- 0.96306
D0_Zpt 0.188088 +- 0.927037

D0_SurfNorm_mumu2A -0.0179862 +- 0.733734
D0_MUJSSR -0.121202 +- 0.948451
D0_etrig -0.0351927 +- 0.985838
D0_WH_JET2B -0.00347408 +- 0.99674
D0_WH_WJET2B -0.0523859 +- 0.958982
D0_WHME_QCD2B -0.112805 +- 0.934644
D0_WHMM_QCD2B 0.00983068 +- 0.988268
D0_WHMM_FLIP2B -0.228278 +- 0.747162
D0_WHEE_QCD2B 0.0364418 +- 0.984796
D0_WHEE_FLIP2B 0.0224206 +- 1.00059
D0_WH_JET2A -0.020881 +- 0.996993
D0_WH_WJET2A -0.111409 +- 1.00083
D0_WHME_QCD2A 0.414989 +- 0.912829
D0_WHMM_QCD2A 0.0119617 +- 0.938078
D0_WHMM_FLIP2A -0.00789962 +- 0.650085
D0_WHEE_QCD2A -0.225438 +- 0.940028
D0_WHEE_FLIP2A 0.0202663 +- 0.930071
D0_HWWemmu_trigger -0.0584725 +- 0.878939
D0_SurfNorm_em2B -0.0717138 +- 0.816335
D0_QCD_hwwem2B_2jet -0.360772 +- 0.97699
D0_EMJSSR -0.00838239 +- 1.00116
D0_QCD_hwwem2B_1jet 0.10249 +- 0.982492
D0_WJETS_SHAPE_ss2B_0jet 1.36122 +- 0.50868
D0_QCD_hwwem2B_0jet -1.00002 +- 0.897224
D0_EMUTrigger 0.284582 +- 0.95415
D0_CMID 0.144334 +- 0.986427
D0_QCD_hwwemu 0.110679 +- 0.986306
D0_njet2Scale 0.104044 +- 0.960317
D0_njet1Scale 0.135863 +- 0.777831
D0_njet0Scale 0.608654 +- 0.685043
D0_Triggers -0.00535372 +- 1.00348
D0_Wjet_mutau 0.298426 +- 0.490672
D0_QCD_mutau 0.518902 +- 0.622592
TrigID 0.020004 +- 0.895659
WWptScale -0.196794 +- 0.981869
WWptPDF 0.00458475 +- 0.961389
CDFLUMI 0.0382205 +- 0.866633

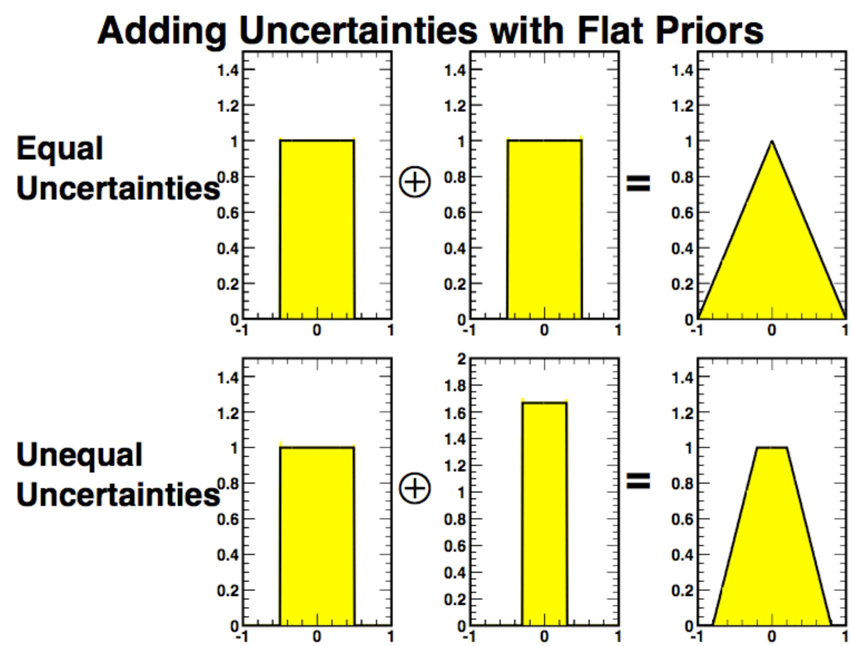
At m_H=165 GeV, 133 named sources of systematic uncertainty

CDFLEPTONID 0.000794111 +- 0.994515
CDFJES 0.370398 +- 0.37521
CDFHWW_TopAcc 0.731538 +- 0.806684
CDFHWW_DiboAcc 1.16657 +- 0.906918
WgamScale 0.792679 +- 0.76395
CDFHWW_WgamAcc 0.359372 +- 0.92247
CDFHWW_FakeRate -0.0250224 +- 0.475505
METModel -0.951287 +- 0.388791
HetaPDF -0.0155761 +- 0.996384
HptPDF 0.00182511 +- 0.994836
ALPHAS 0.000351948 +- 1.0022
MB 5.43305e-05 +- 1.00693
MC 0.00971472 +- 1.00016
ttbar_bfake 0.0156202 +- 0.971993
XS_Vgamma -0.0833847 +- 0.995168
ZgamAcc -0.114853 +- 0.973599
TauJetFake 0.189097 +- 0.83341
XS_Wjet -0.1286 +- 0.678103
TauLepFake 0.0505157 +- 1.0017
XS_DY -0.0257132 +- 0.99126
CDFHWW_DYAcc -0.0609454 +- 0.950461
TauID 0.12933 +- 0.998585
WW_CFR -0.277979 +- 0.911791
CDFHWW_BTagVeto 0.0775033 +- 0.972641

Constraints checked twice
1) MINUIT output
2) Bayesian posterior (by-product of Markov Chain integration)

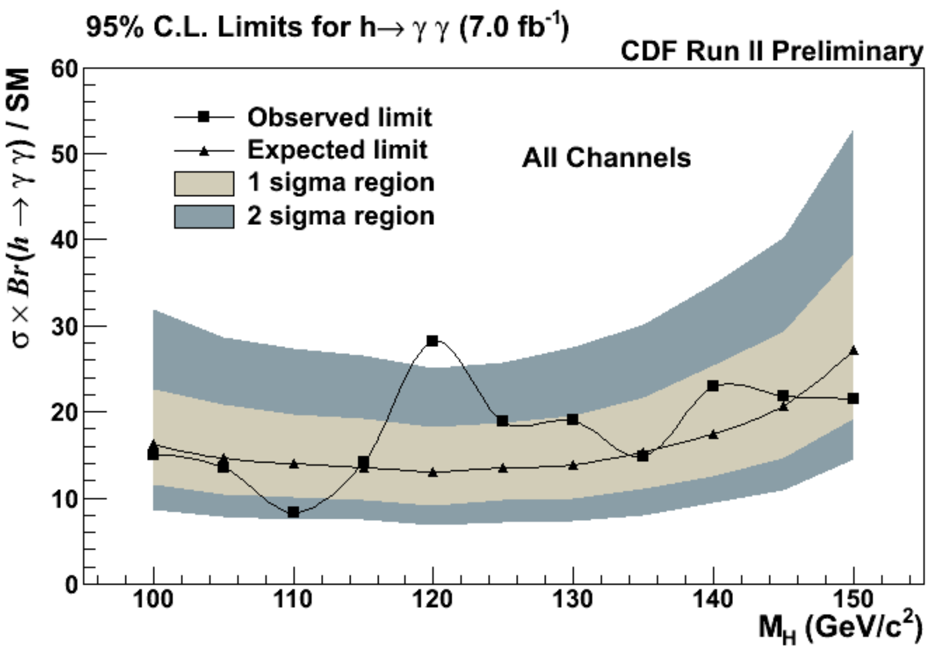


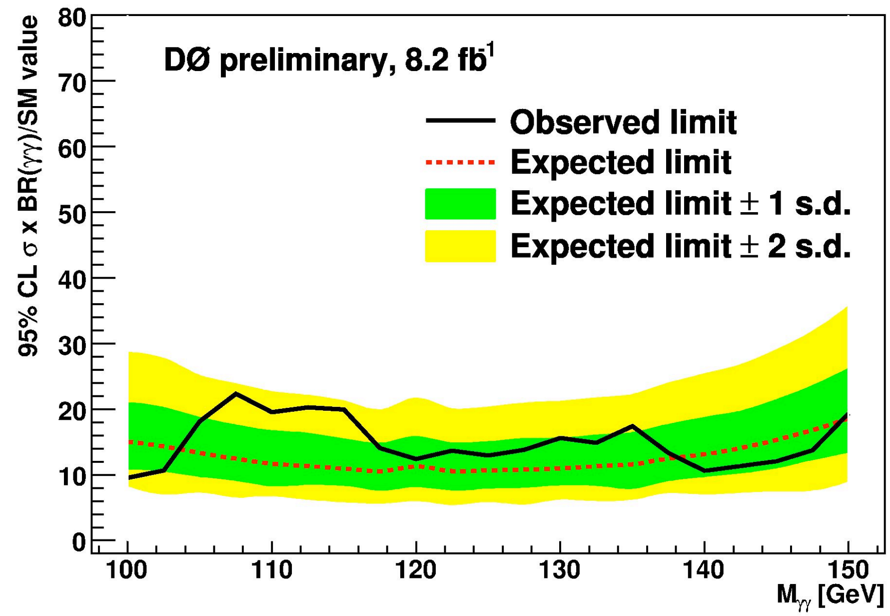
Prior Distribution
Flat Prior
Gaussian Prior
Uncertain Parameter



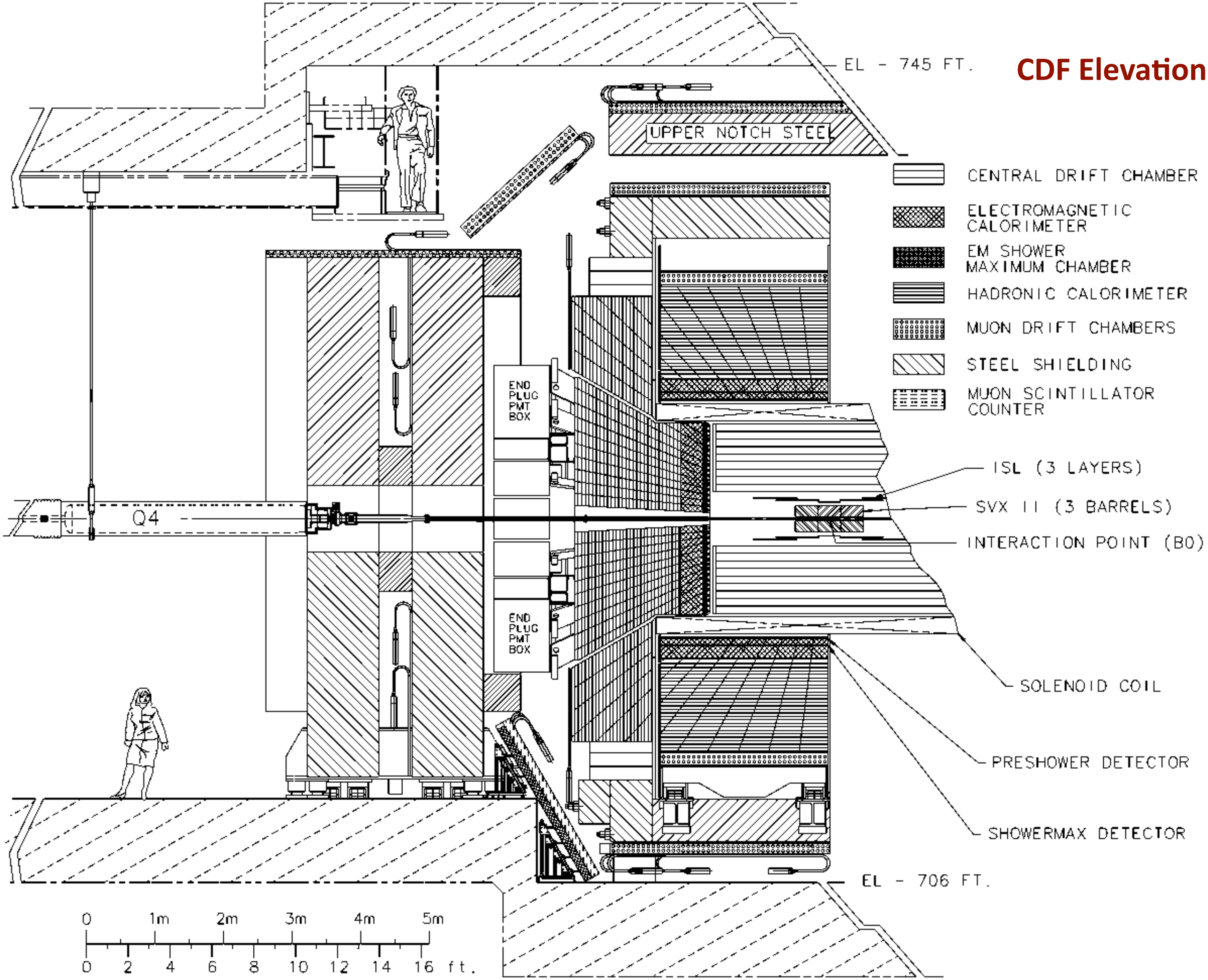
Adding Uncertainties with Flat Priors
Equal
Uncertainties
Unequal
Uncertainties

CDF and D0 H→γγ Limits





CDF Elevation



Integrating the Posterior to Other Values than 95%