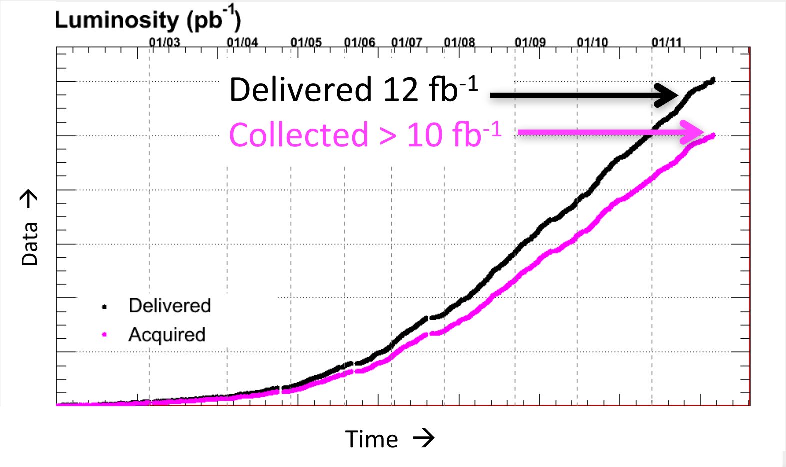
Latest results from Tevatron

Yuri Oksuzian on behalf of CDF&D0 collaborations

Tevatron

- p-pbar collider at Ecm = 1.96 TeV
- Two detectors: CDF & D0
- Records
  - Peak luminosity: 430×10^{30} cm^{-2} s^{-1}
  - Best week: 85/pb
- Run II: 2001-2011
  - 12 fb-1 delivered
  - 10 fb-1 collected



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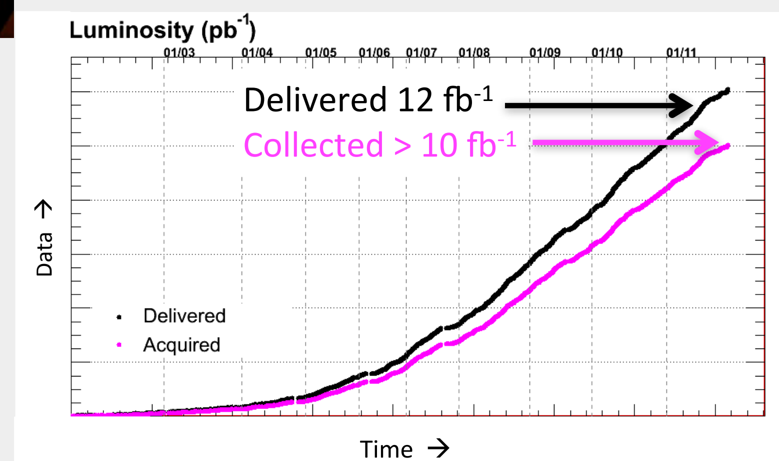
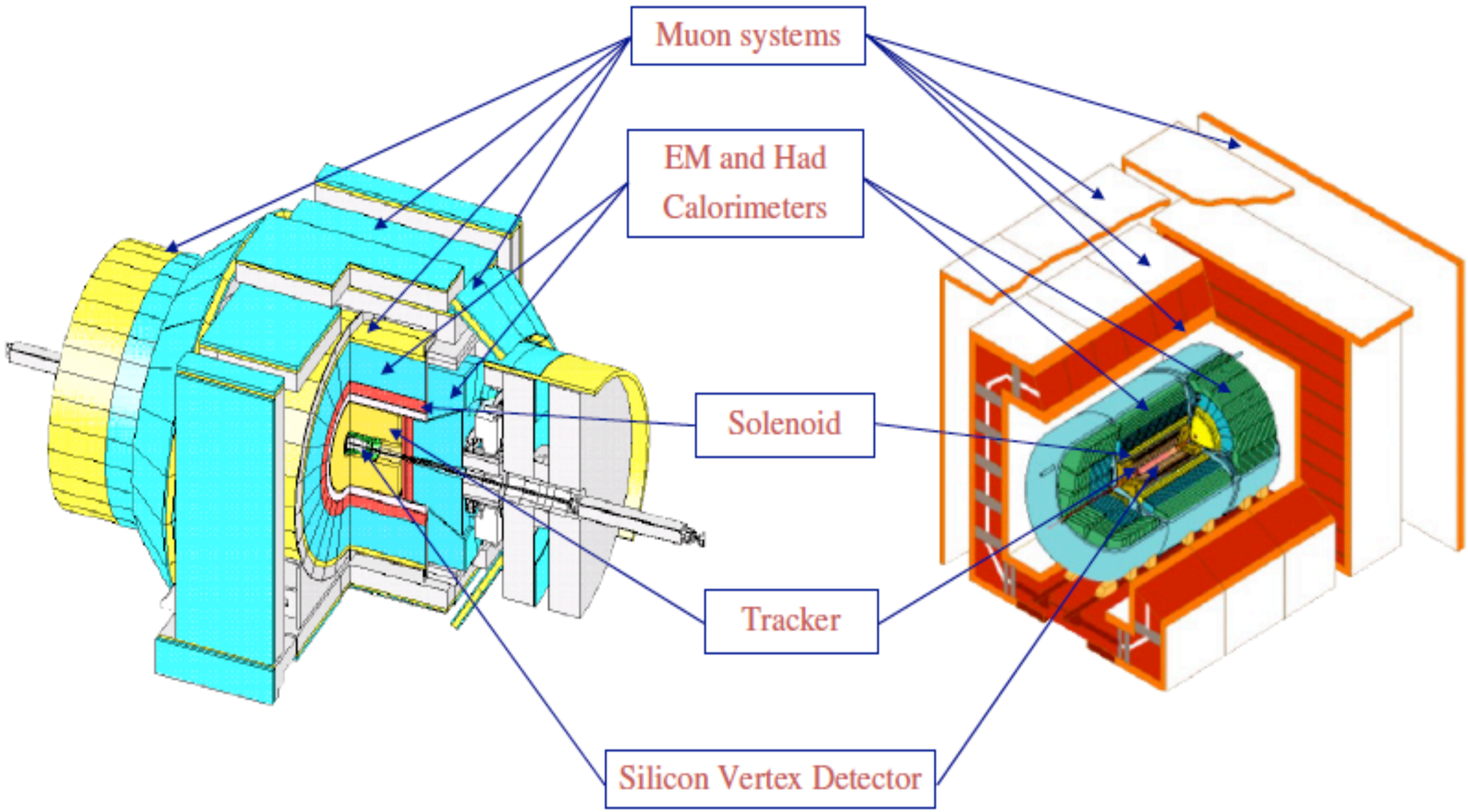
- Last collision on Sep 30th 2011
- 25 years of data-taking and exciting physics results



CDF & D0

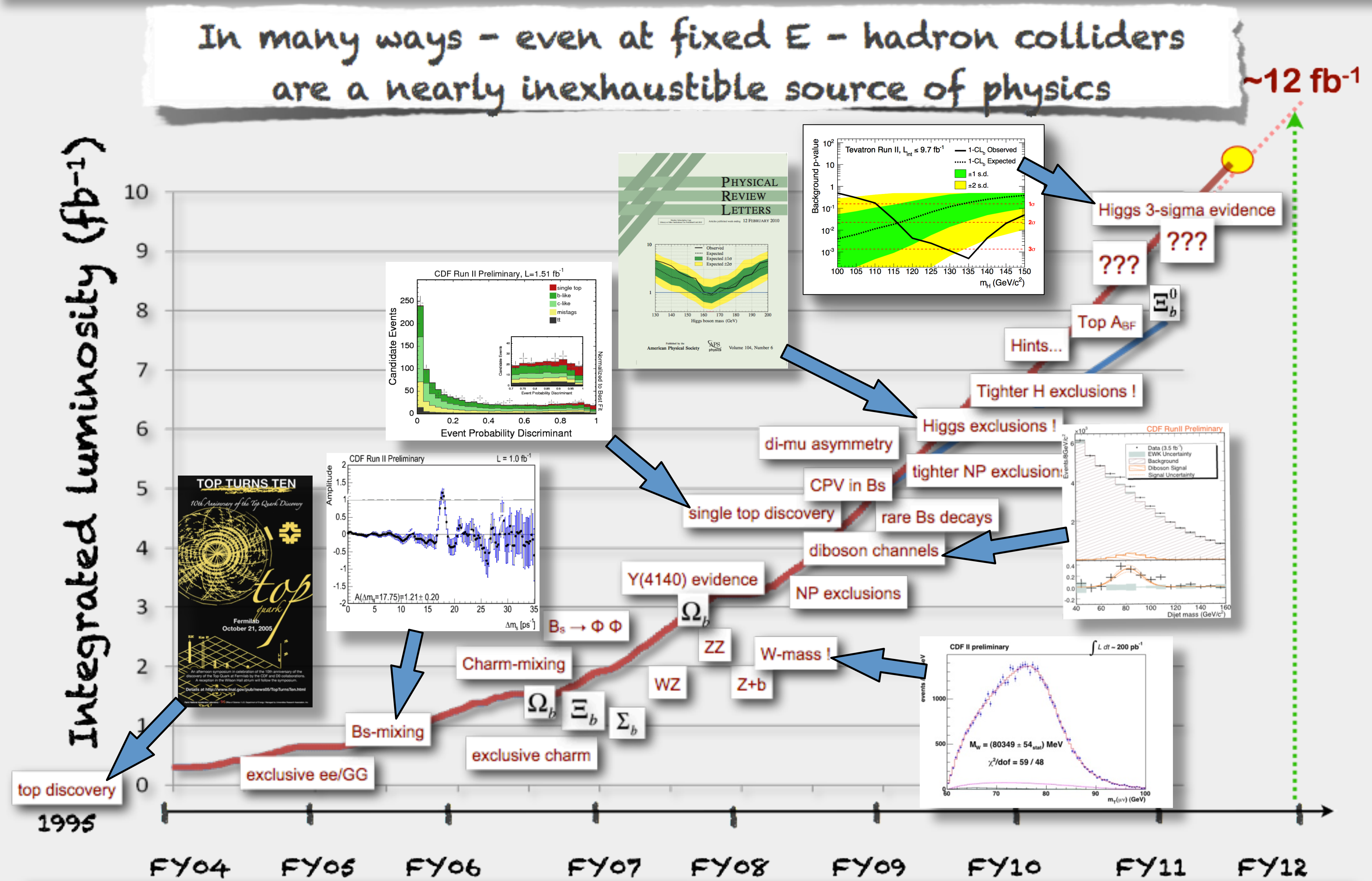


Muon systems
EM and Had
Calorimeters
Solenoid
Tracker
Silicon Vertex Detector

CDF & D0

- 1000 scientists from all over the world
  - from 25 countries
- 1000 papers published
- 1000 PhD theses

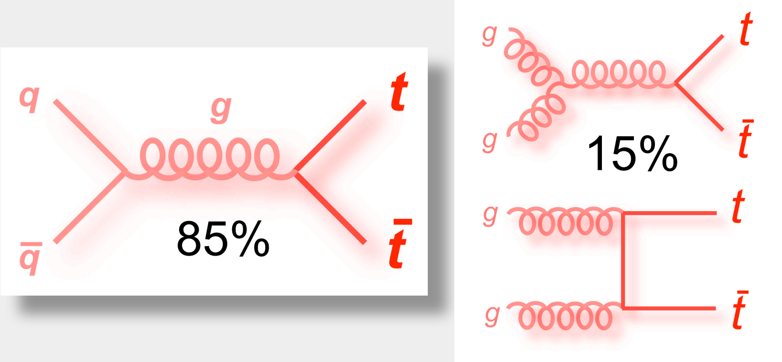
Tevatron milestones

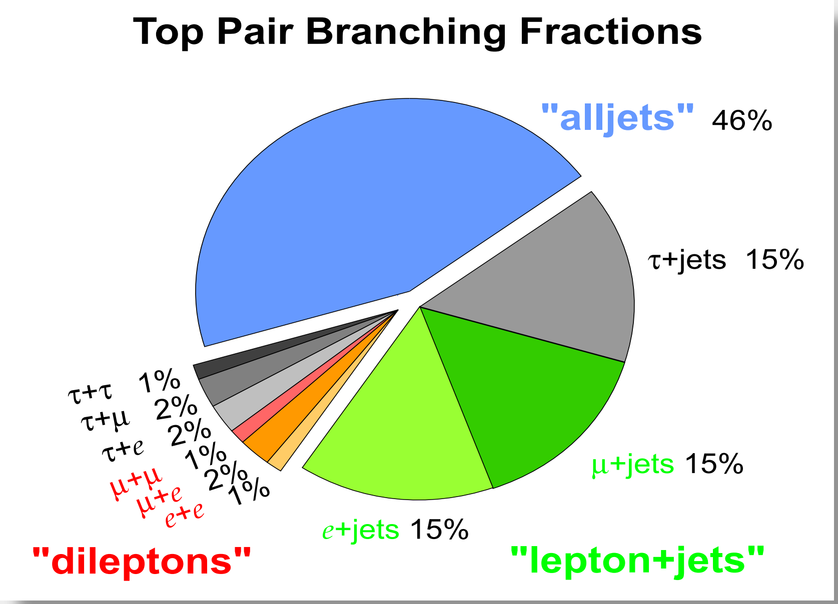


Top quark at Tevatron

- Observed and studied at Tevatron
- Strikingly large mass
  - $m_t = 173.20 \pm 0.87$ GeV/c^2
  - Strongest coupling to Higgs field
- $\sigma_{t\bar{t}} = 7.65 \pm 0.42$ pb
- Properties:
  - A_{FB} ,W helicity, Spin correlation, top-antitop mass difference, single top...
- Searches:
  - Z’, W’, b’, t’, t→Zq, anomalous coupling, dark matter...

Main production mechanism





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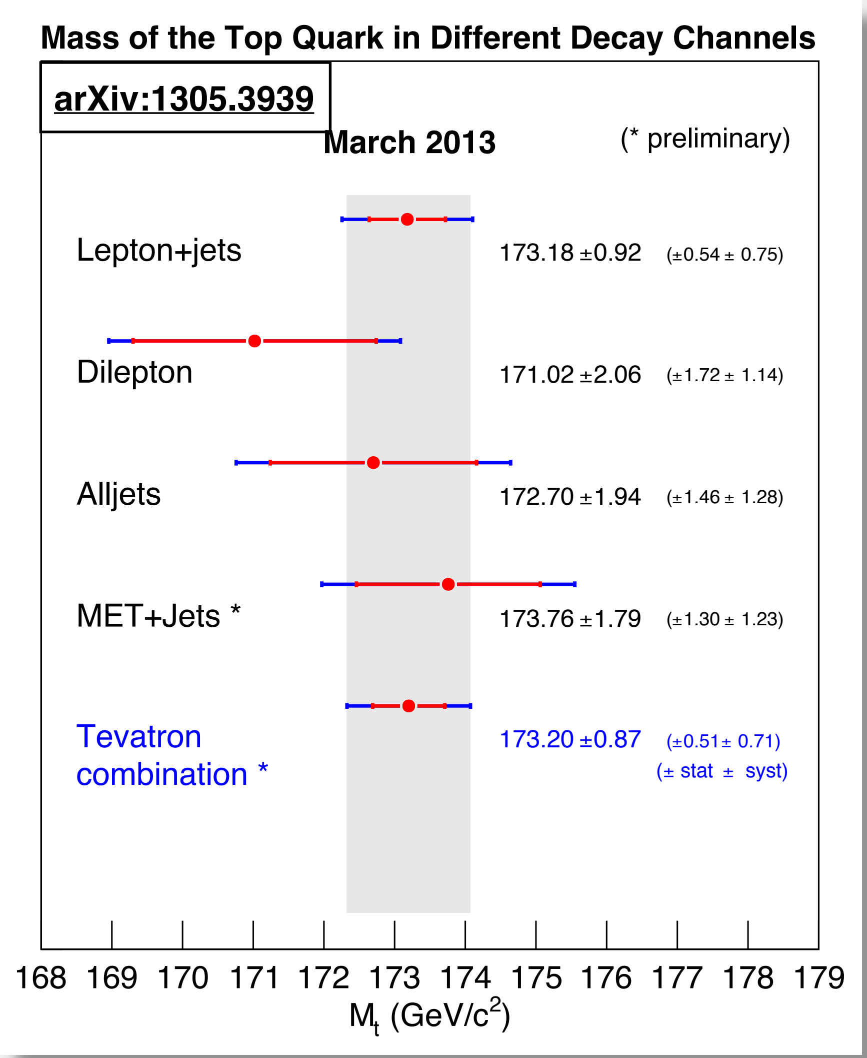

Top quark at Tevatron: σ_t

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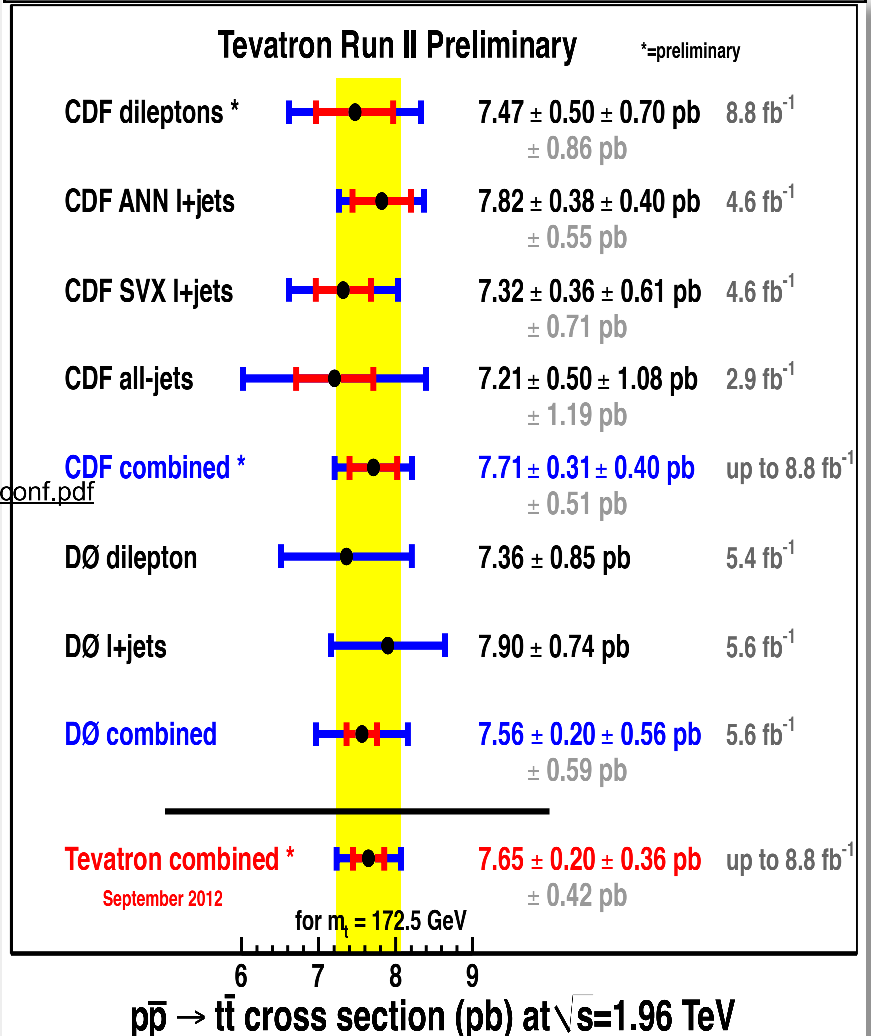
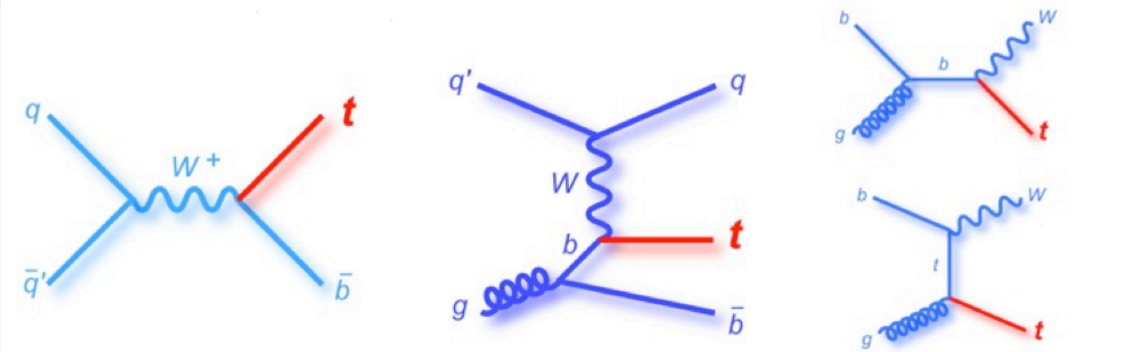


Single top



s-channel (tb) t-channel (tqb) Associated (tW)

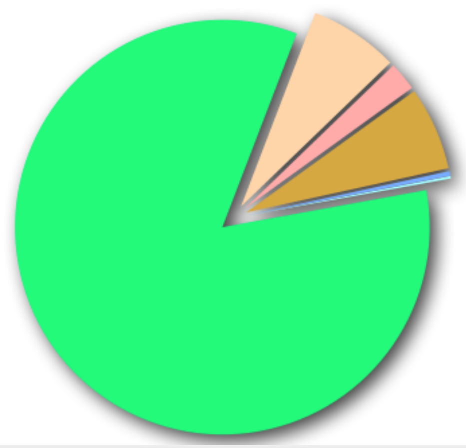
Cross section(pb)	$t\bar{t}$	s-channel	t-channel	tW-channel
Tevatron(1.96 TeV)	7.08	1.05	2.08	0.25
	30	5	40	90
LHC(8 TeV)	234	5.55	87.2	22.2

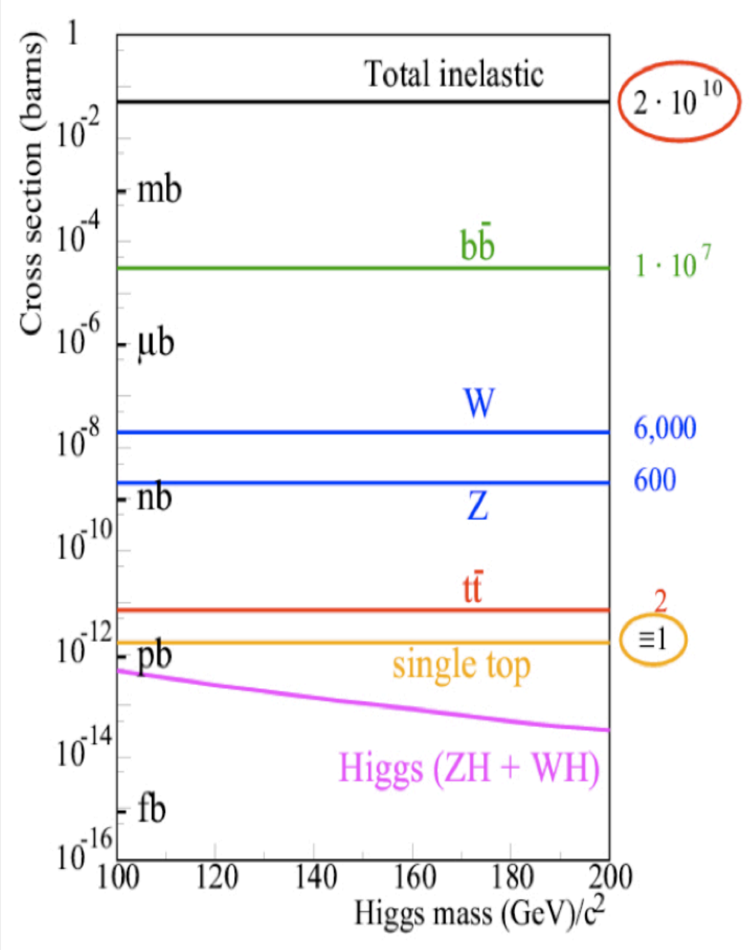
- Observed tb+tqb in 2009, ~15 years after top quark.
- Direct probe of $|V_{tb}|$
- Top quark decay width
- BSM models: gauge bosons, FCNC, anomalous couplings

Single top: Main challenge

- D0 analyzed full dataset in L+jets channel to measure s-channel xsec
- Single top is hidden below overwhelmed W+jets background

tb	423
tqb	793
W+jets	181721
Z+jets diboson	15115
top pair	4886
multijet	14164



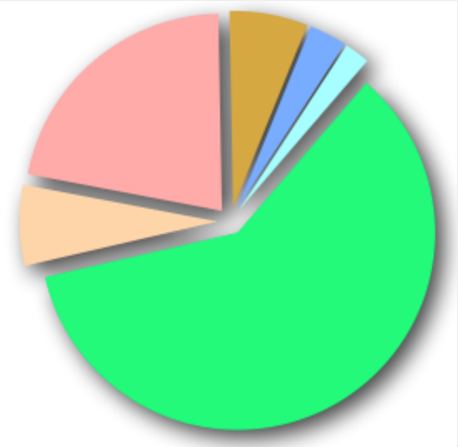


Single top: B-tagging

- D0 analyzed full dataset in L+jets channel
- Single top is hidden below overwhelmed W+jets background
- Multivariate b-tagging algorithm is applied to reduce W+light flavor jets

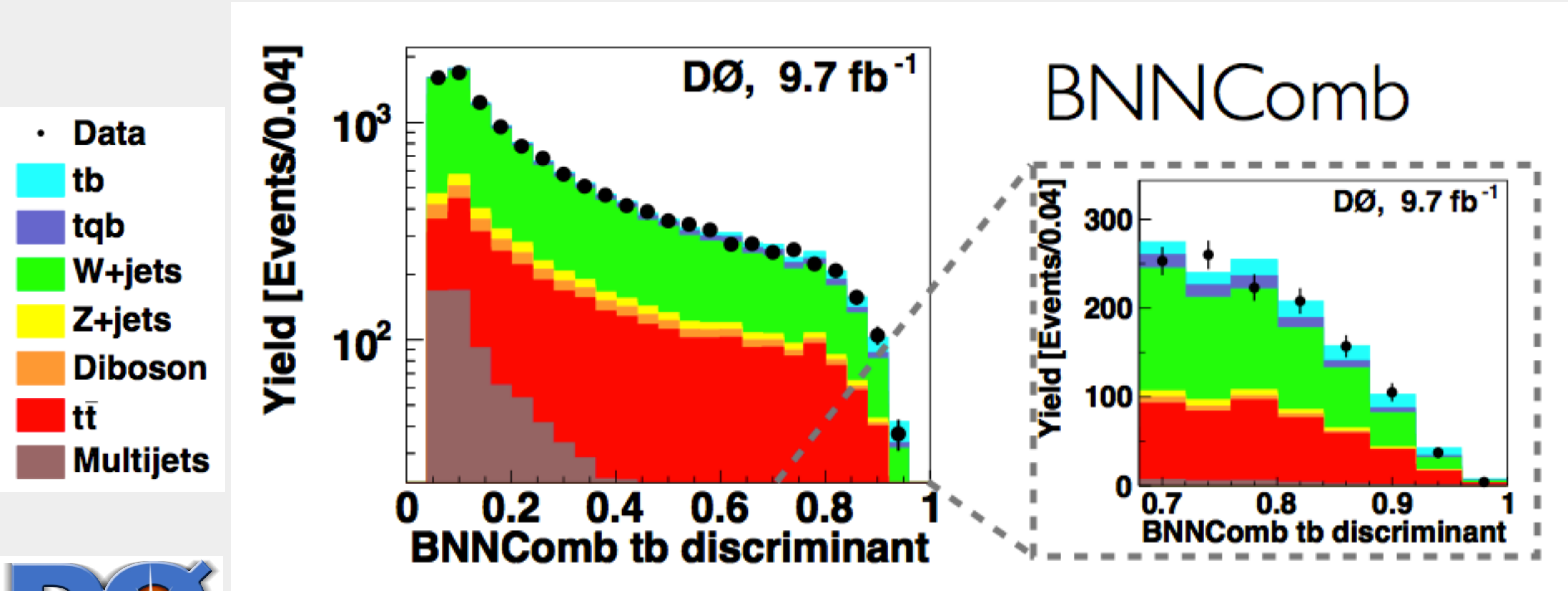
e, μ 2, 3-jets 1, 2 *b*-tags combined	
tb	257 ± 31
tqb	378 ± 53
W+jets	7394 ± 401
diboson, *Z*+jets	815 ± 71
top pair	2672 ± 284
multijet	789 ± 81
Total background	11669 ± 503
Data	12103 ± 110

tb: *tqb*: B = 1: 1.5: 45



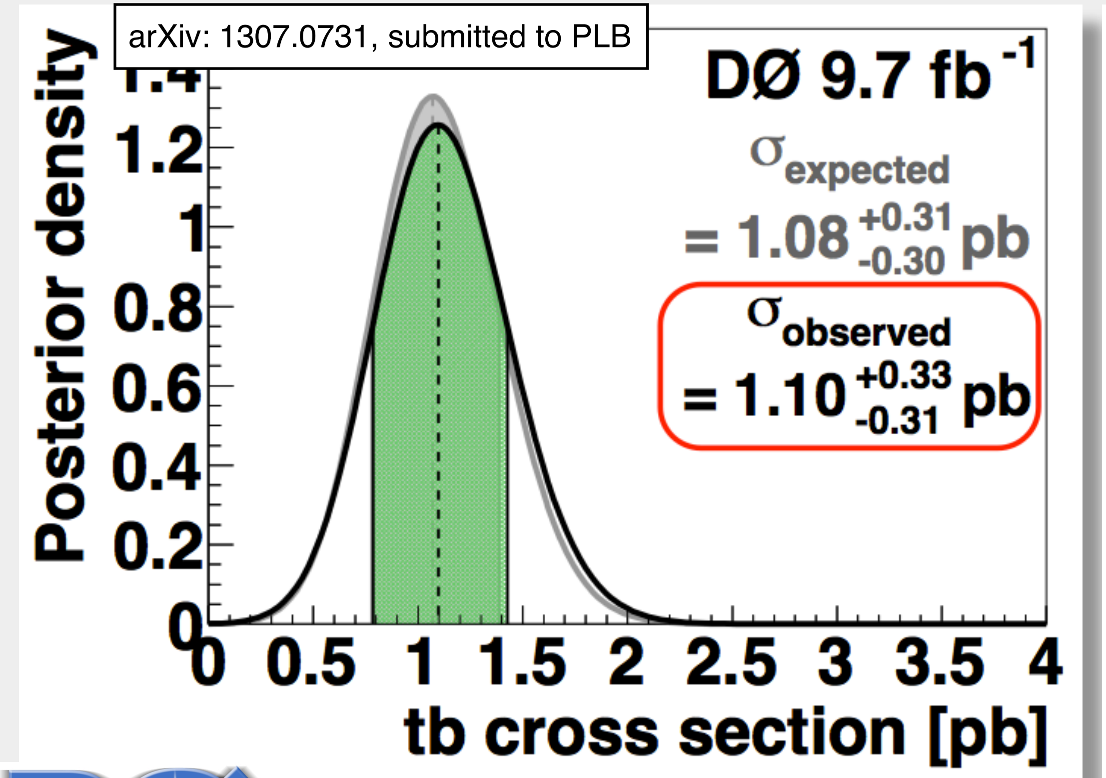
Single top: Final discriminant

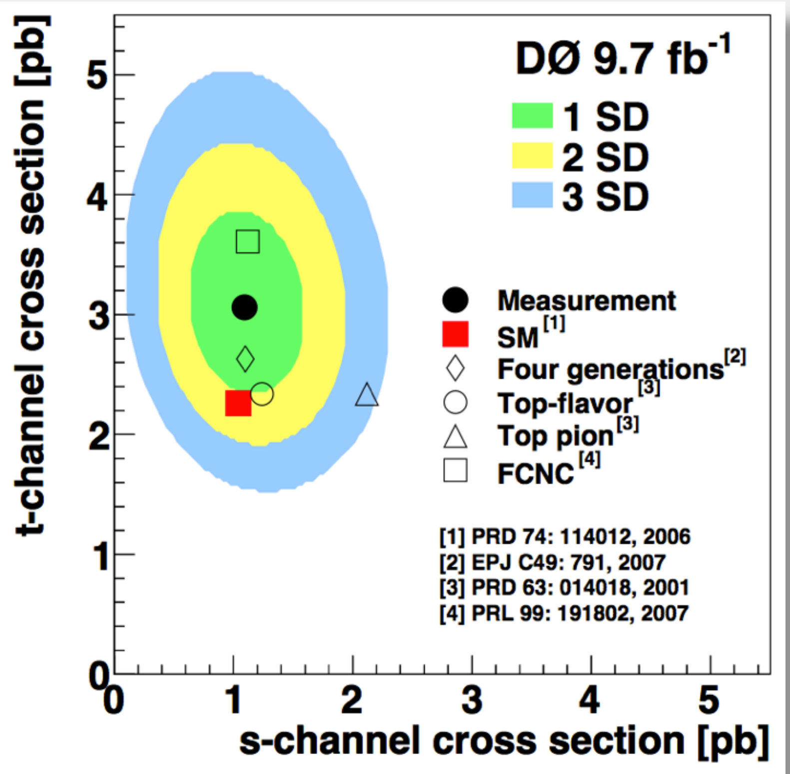
- D0 analyzed full dataset in L+jets channel
- Single top is hidden below overwhelmed W+jets background
- Multivariate b-tagging algorithm is applied to reduce W+light flavor jets
- Multivariate and Matrix Element algorithms are implemented to construct final discriminant.



Single top: Final result

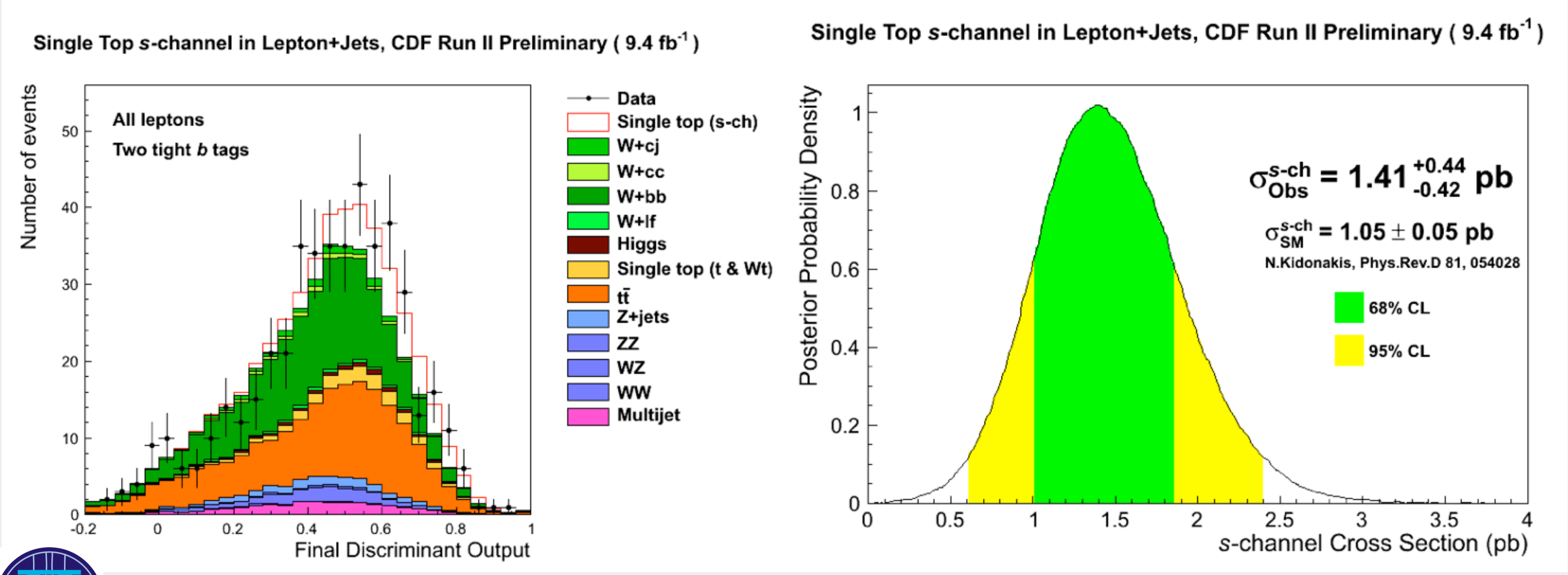
- s-channel single top cross-section, σ_{tb} = 1.10 ± 0.33 pb.
  - t-channel σ_{tqb} = 3.07 ± 0.53 pb
- Measurement significance is 3.7σ
- $|V_{tb}|$>0.92 at 95% confidence level.





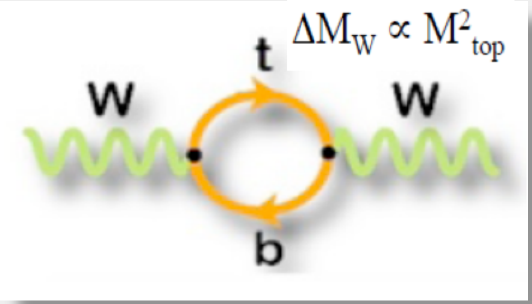
Single top: Final result

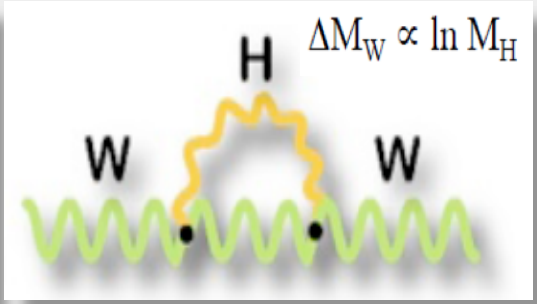
- Similar analysis is performed at CDF
- Multivariate techniques are used in: b-jet tagging, b-jet from top quark selector, final discriminant
- s-channel single top cross-section, $\sigma_{tb} = 1.41 \pm 0.44$ pb.
- Measurement significance is 3.8σ

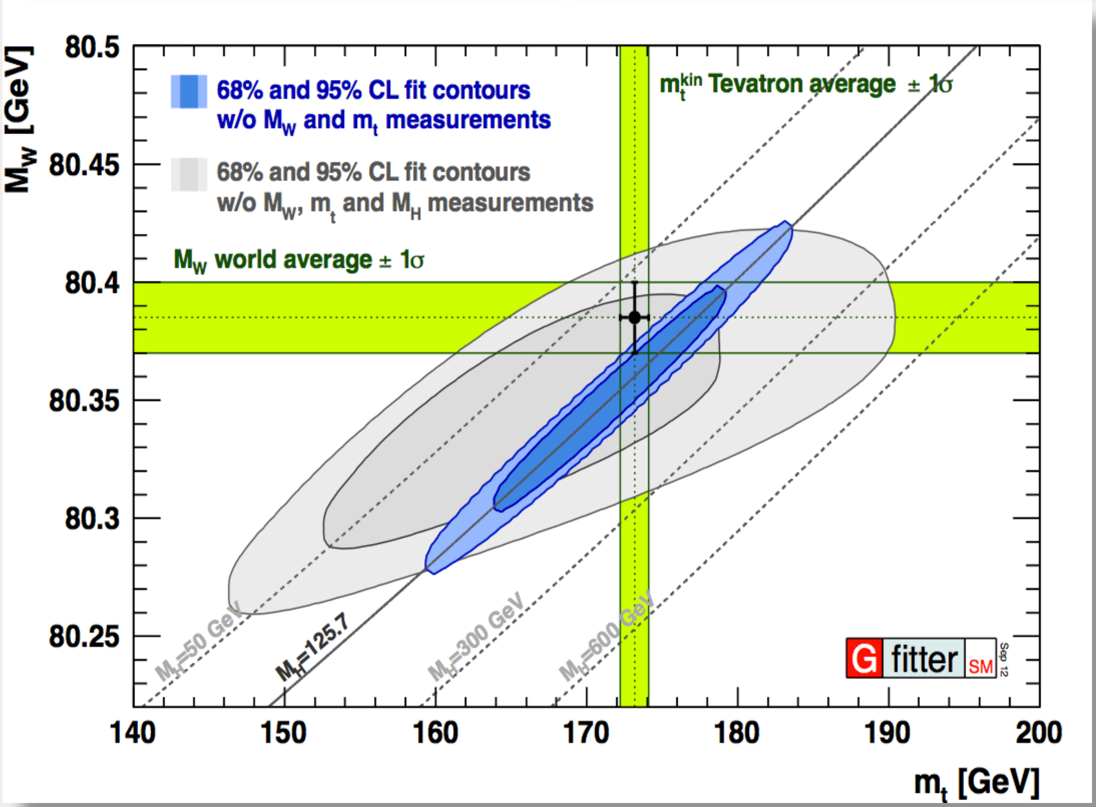


EW constraints from Tevatron

- Higgs mass is constrained from indirect EW measurements
- World best W boson mass measurement
  - $M_W = 80387 \pm 17$ MeV/c^2
- World best Top quark mass measurement:
  - $M_t = 173.2 \pm 0.9$ GeV/c^2
- Only direct discovery can prove EWK symmetry breaking due to Higgs mechanism

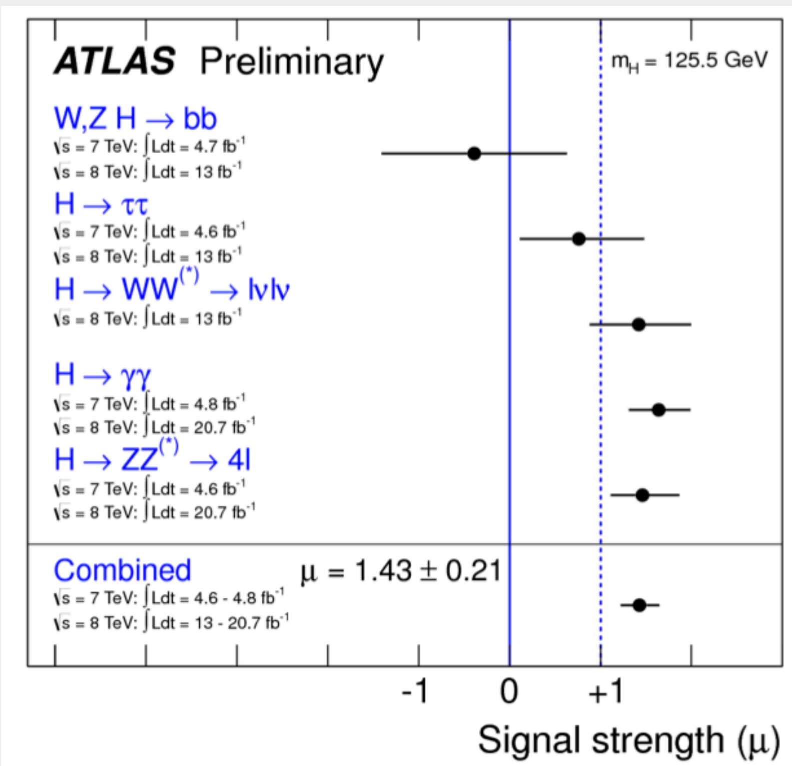


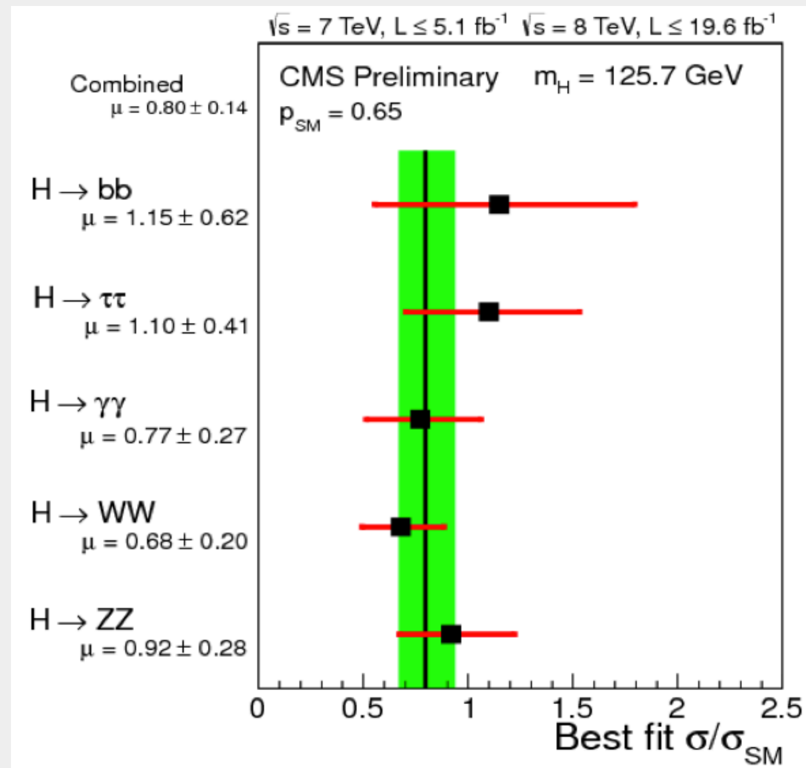




Higgs at LHC and Tevatron

- Higgs boson was discovered by LHC
- LHC sensitivity is driven by H→VV/ɣɣ
- Tevatron sensitivity is driven by H→bb

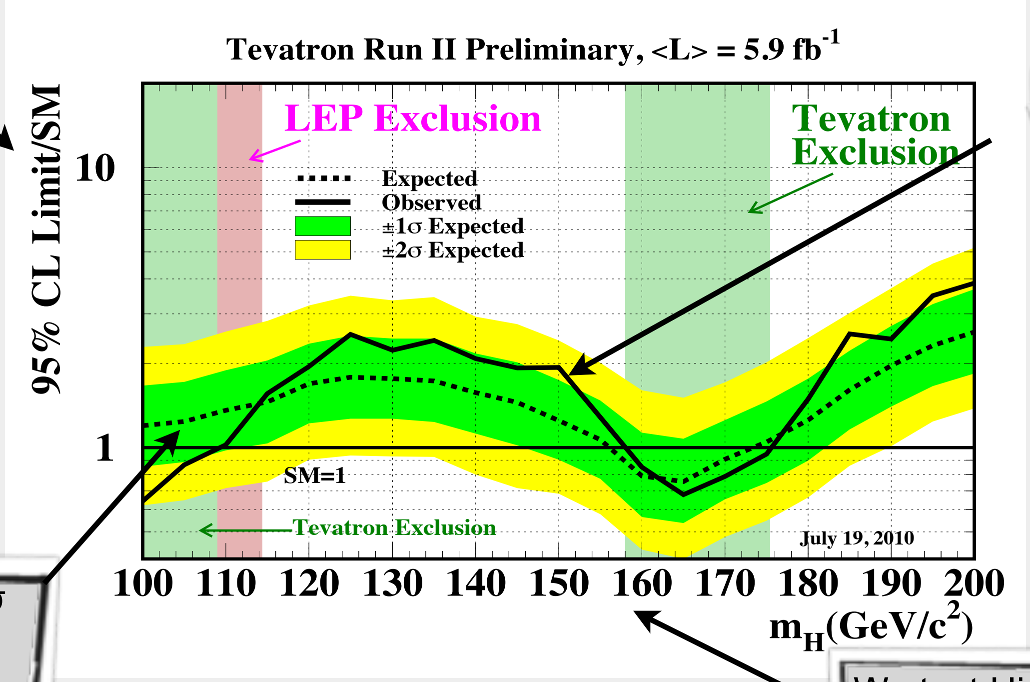




Previous results. Goals.

- Summer 2010, Tevatron sensitivity was <2xSM
- ~30% gain in sensitivity by using full dataset
- Crucial to improve the analysis technique
  - Luminosity only improvements were not sufficient

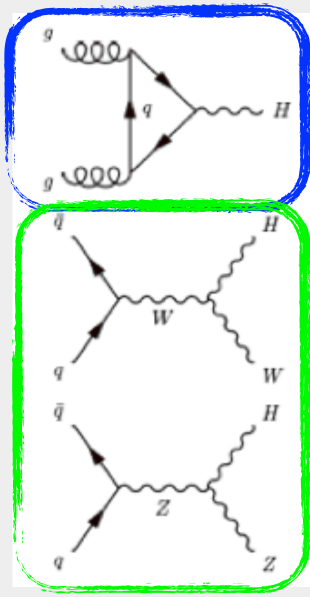
Upper limits on cross section for Higgs production relative to SM prediction

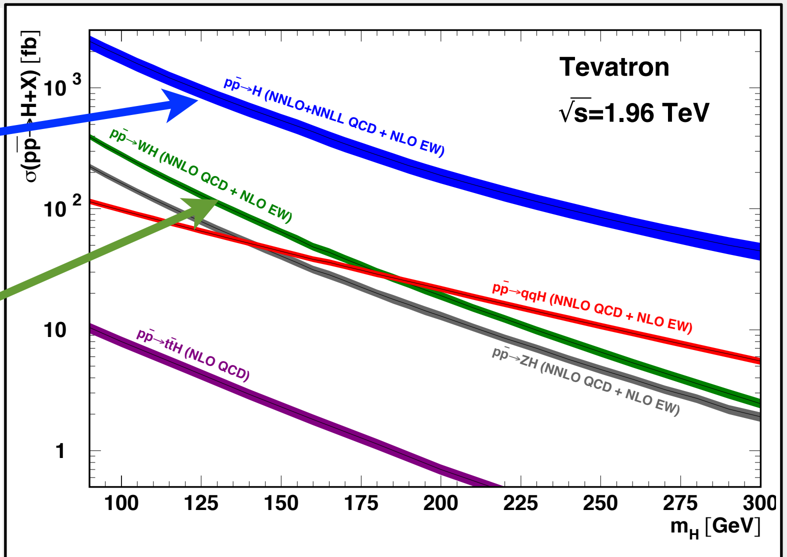


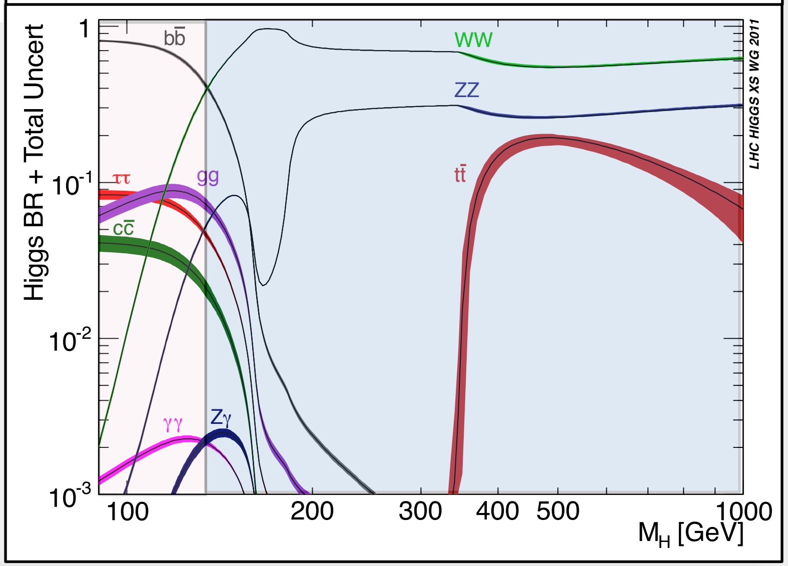
Observed limit from data

Expected limit and 1σ/2σ from background only pseudo-experiments

We test Higgs mass ranges of 100-200 GeV in 5 GeV steps

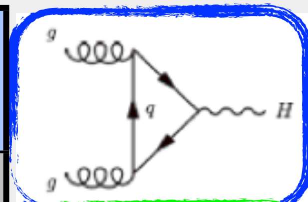

g
g
q
H
q̄
q
W
H
W
q̄
q
Z
H
Z

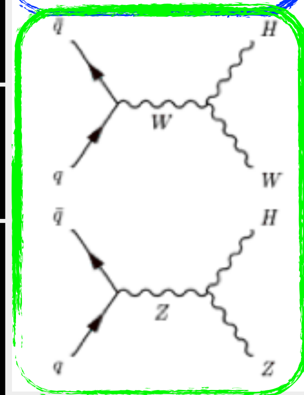

Tevatron
√s=1.96 TeV
pp̄→H (NNLO+NNLL QCD + NLO EW)
pp̄→WH (NNLO QCD + NLO EW)
pp̄→qqH (NNLO QCD + NLO EW)
pp̄→ZH (NNLO QCD + NLO EW)
pp̄→tt̄H (NLO QCD)
σ(pp̄→H+X) [fb]
m_H [GeV]

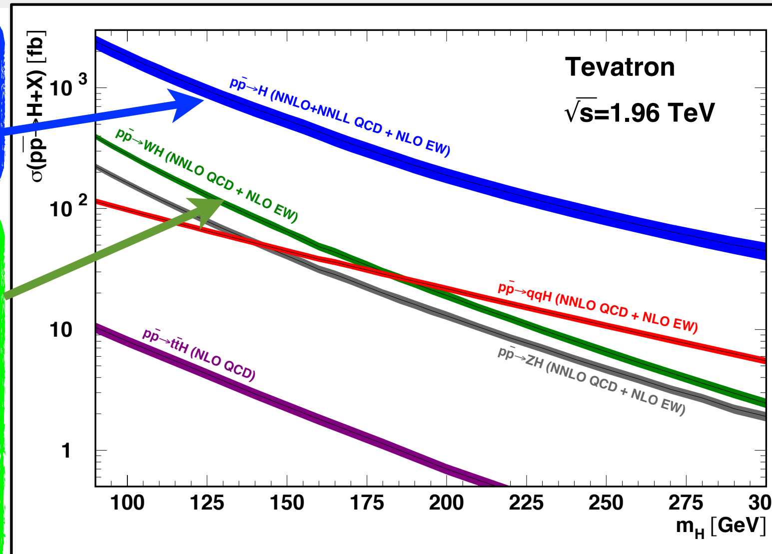

bb̄
WW
ZZ
ττ
gg
cc̄
tt̄
γγ
Zγ
Higgs BR + Total Uncert
M_H [GeV]
LHC HIGGS XS WG 2011

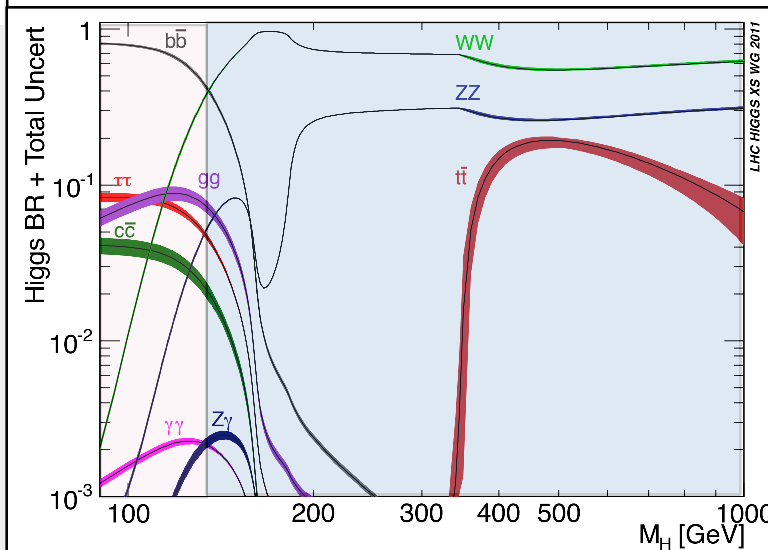
Higgs production

	Low mass	High mass
Production*	WH, ZH	gg→H
Decay	H→*bb*	H→WW
Main modes	*bb*+*ℓν* *bb*+*ℓℓ* *bb*+*νν*	*ℓℓ*+*νν*



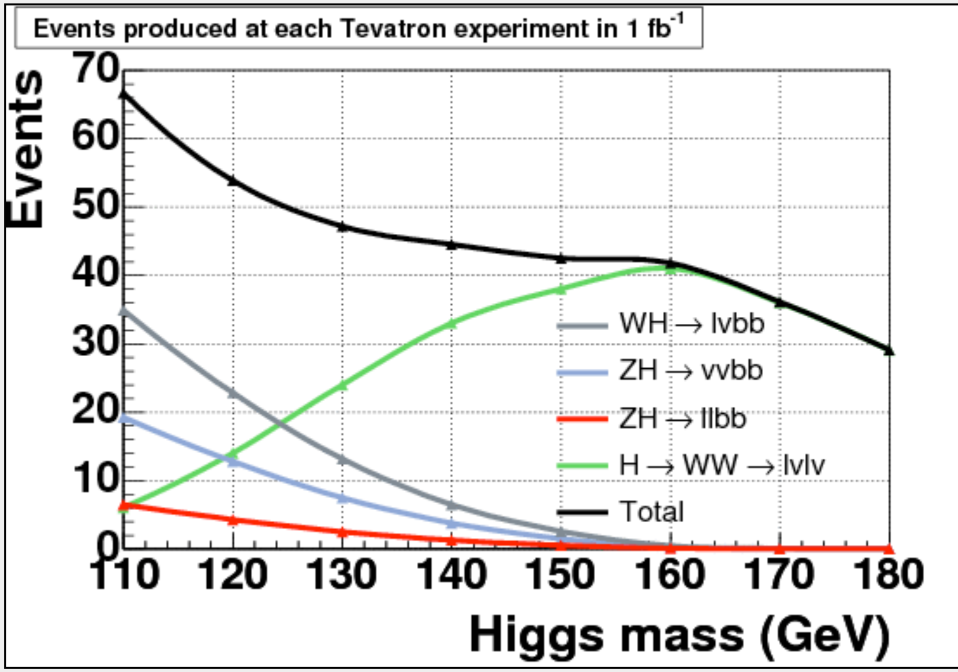


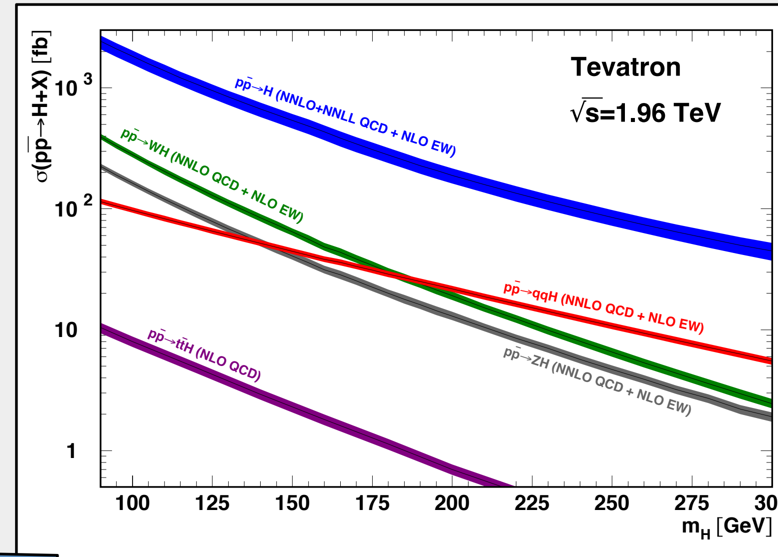


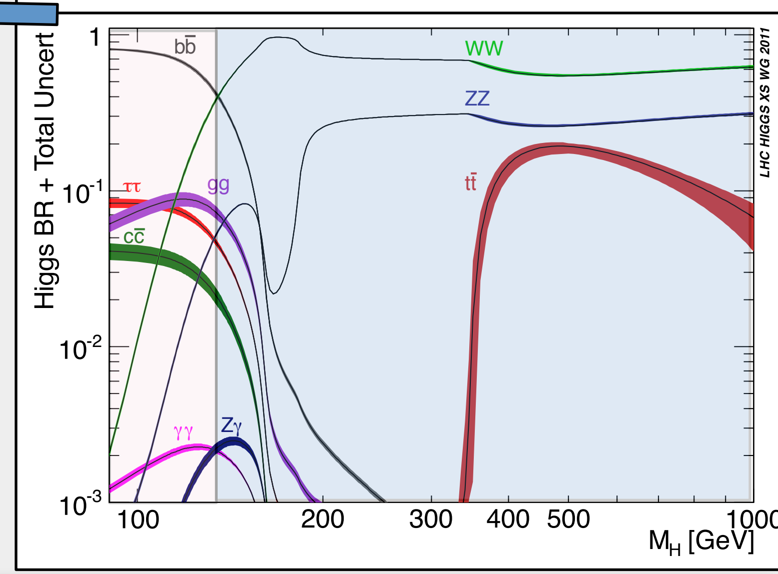


* No channel is left behind. LONG list of “secondary”channels with total weight of 10% to the final combination

Higgs production

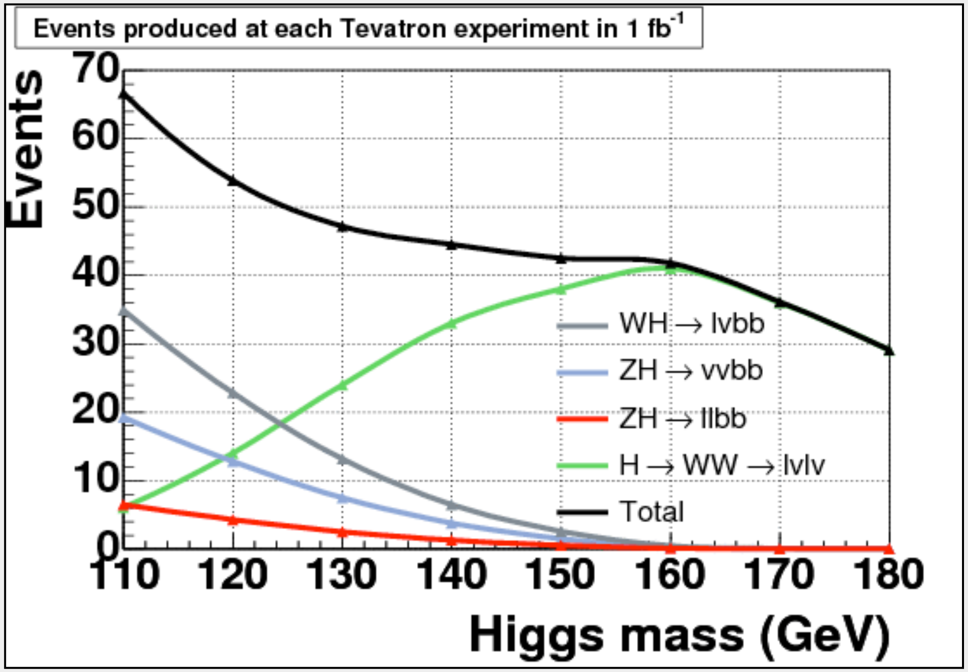




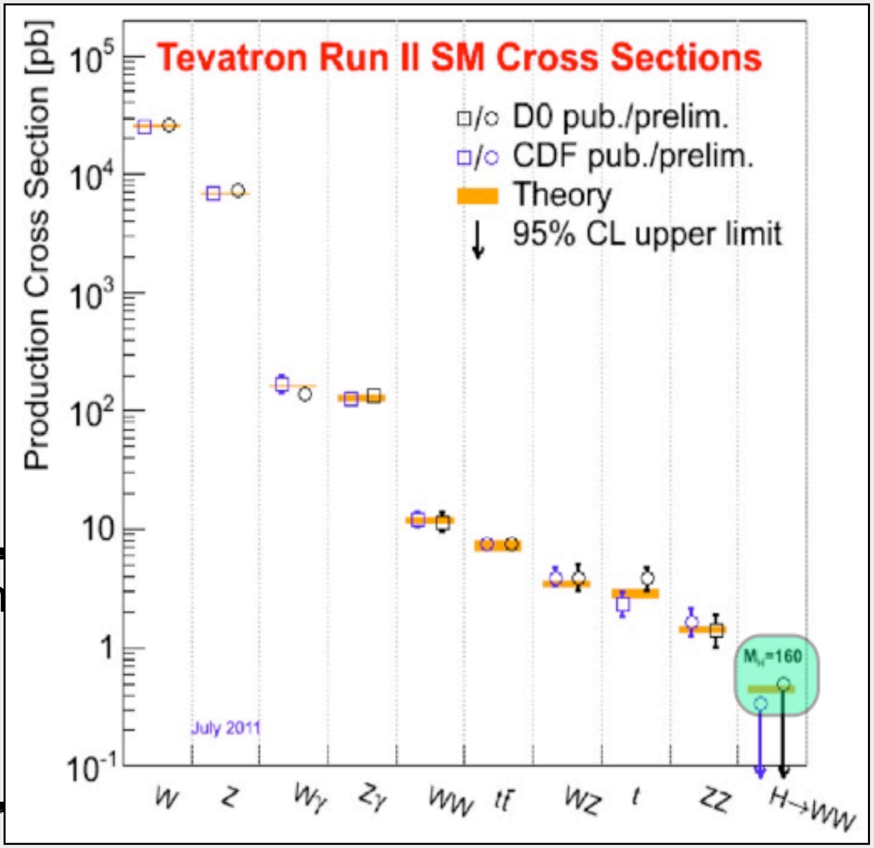


- About 1000 Higgs events expected in main channels of full Tevatron dataset (10 fb^{-1})
- 10-20% survive trigger+reconstruction +selection efficiency

Higgs production



- Higgs signal is buried under overwhelmed SM background processes
- Yesterday's signal is today's background



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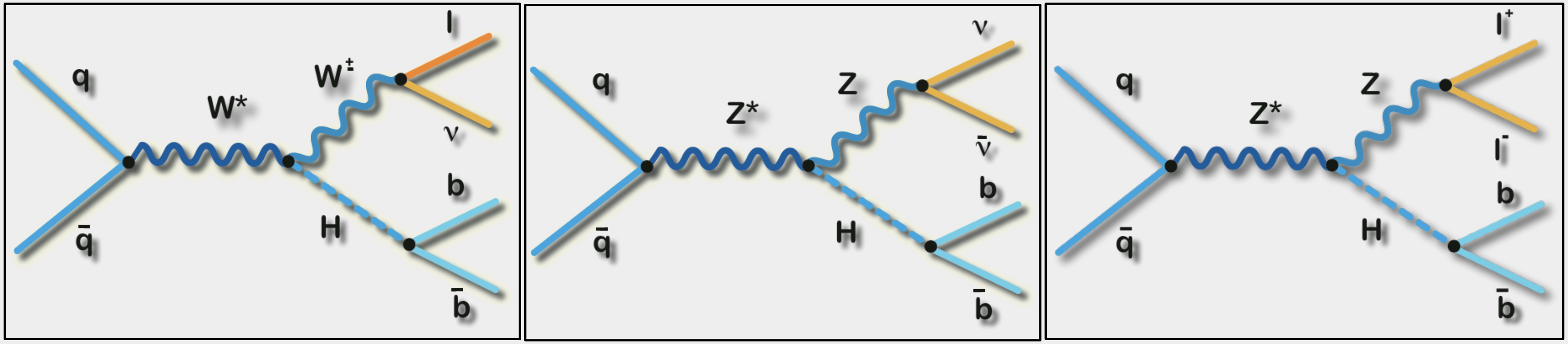
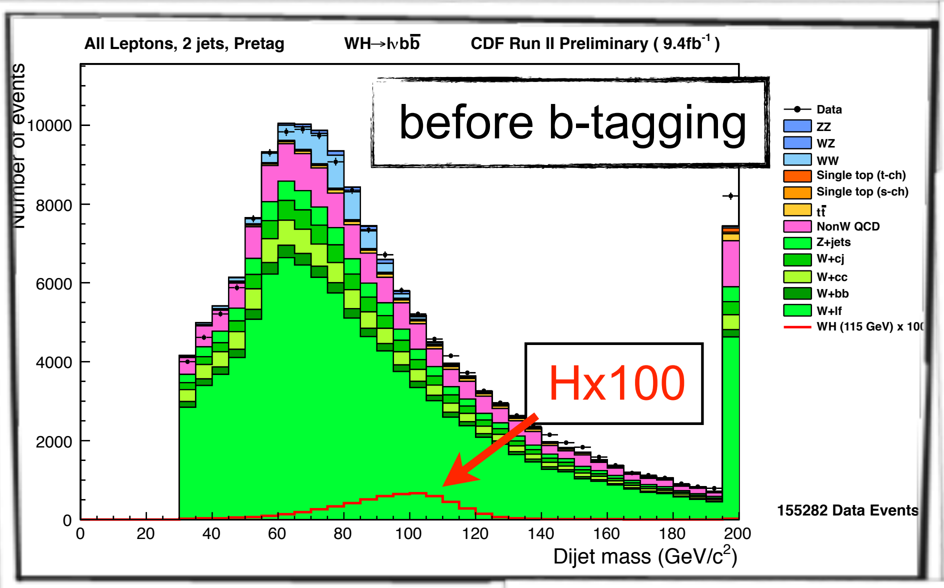
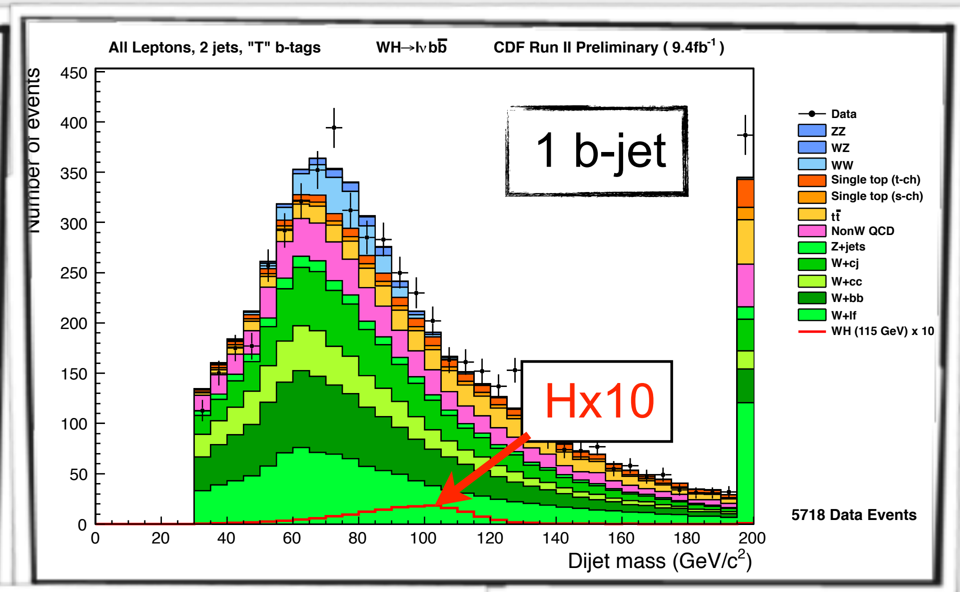
H→bb strategy

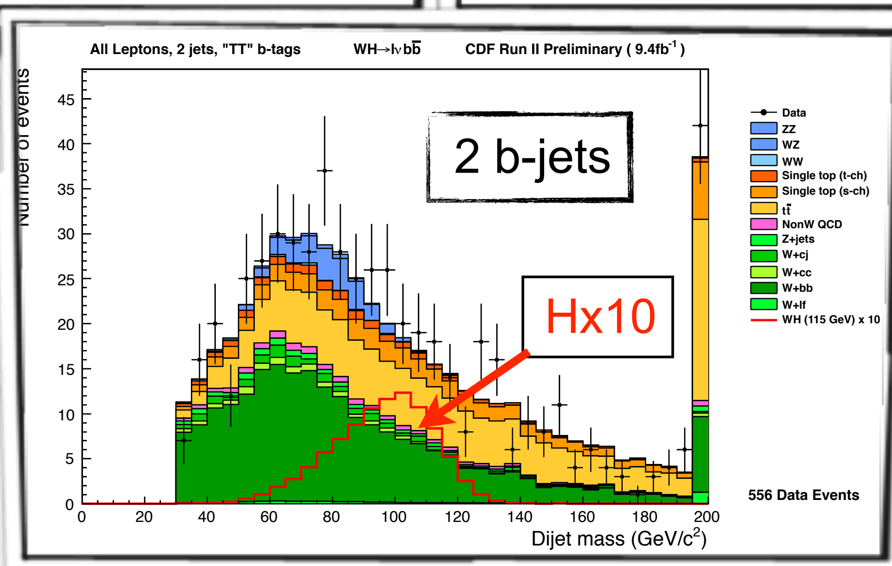


- To maximize sensitivity:
  - Optimize b-tagging ID efficiency
  - Improve di-jet mass resolution
  - Maximize lepton reconstruction and selection ID
- Use MVA analyses to discriminate between signal and background or various background components

Effect of b-tagging

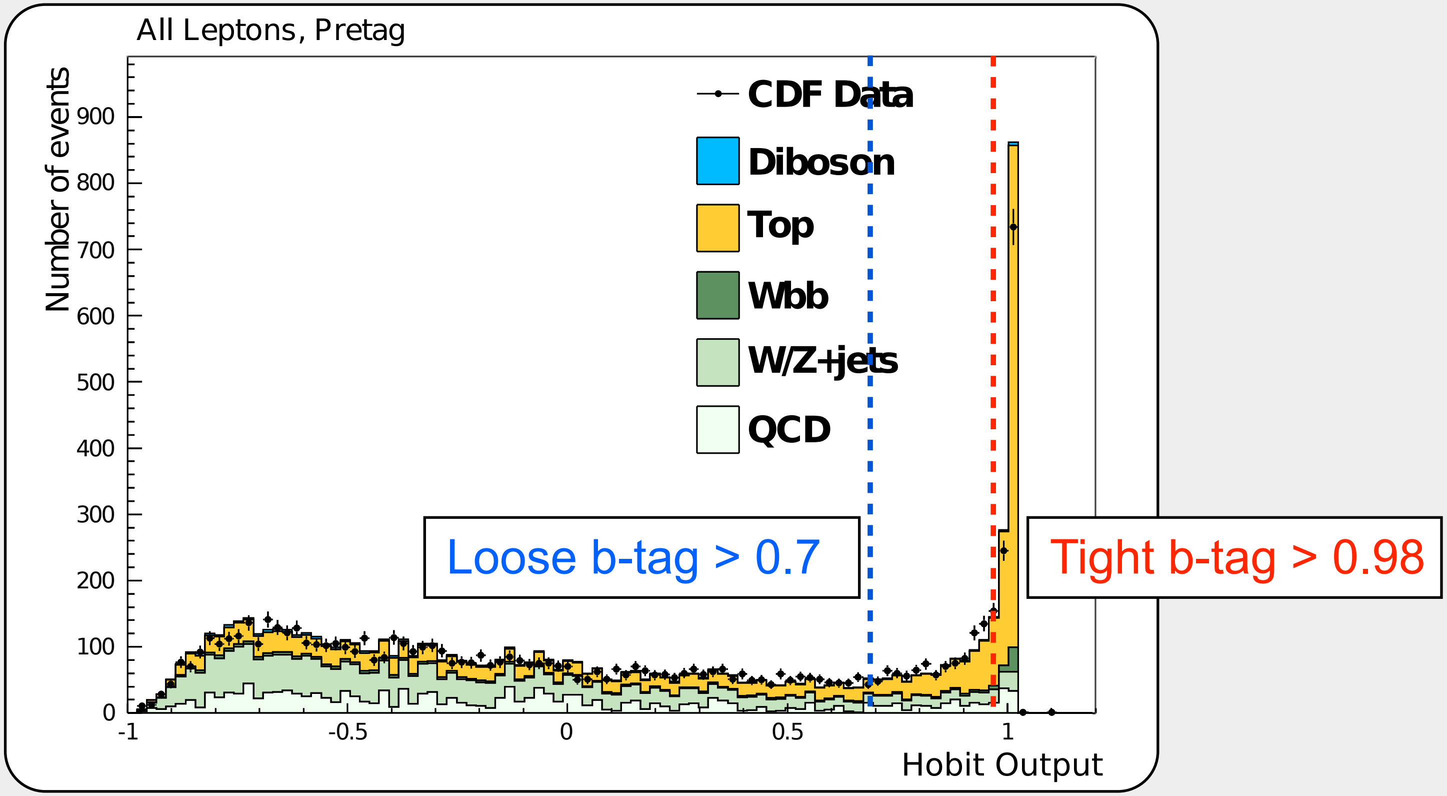






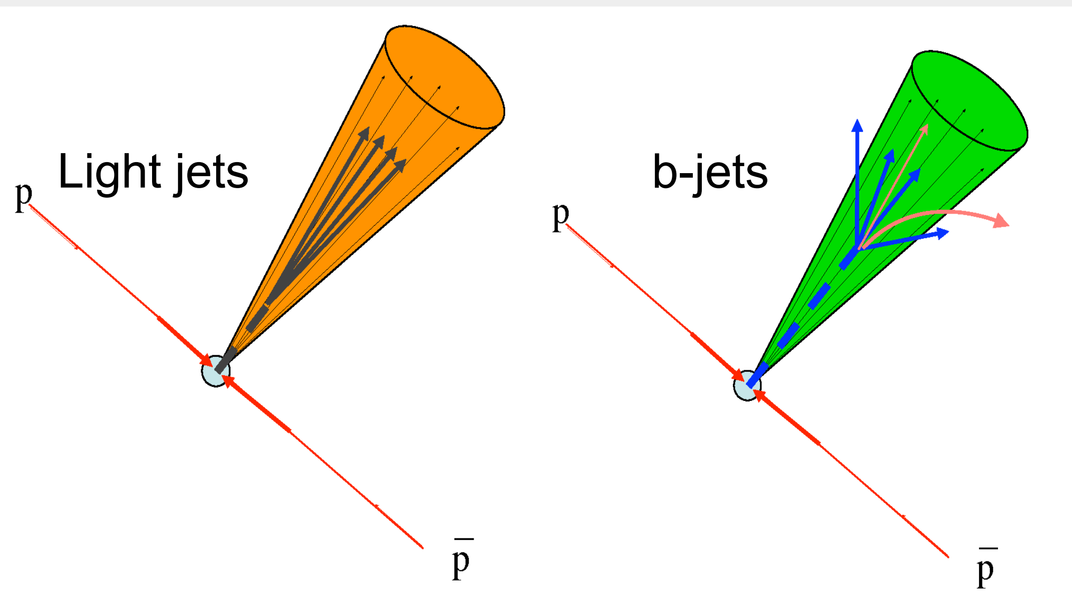
The Higgs-Optimized b-Identification Tagger(HOBIT)

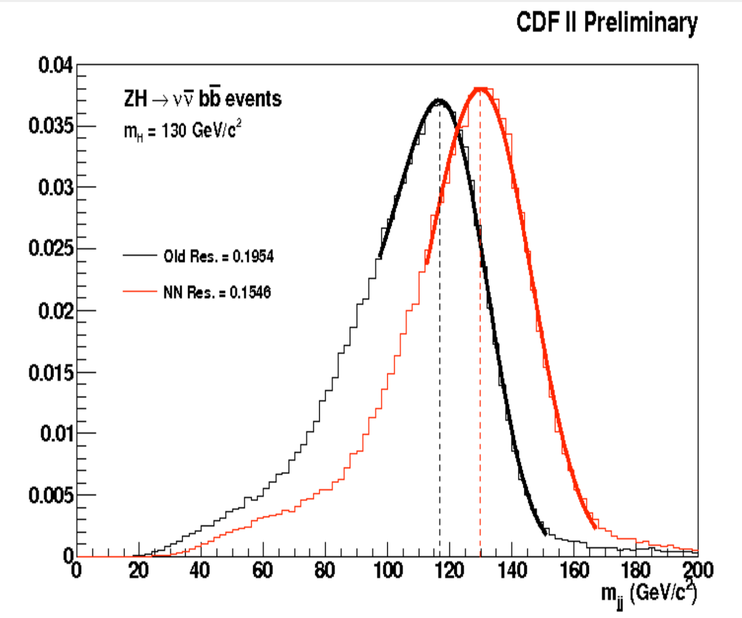
- Take advantage b-meson lifetime(displaced vertex) and soft lepton from semi-leptonic decays.
- We incorporate the knowledge from previous taggers into:
  - The Higgs-Optimized b-Identification Tagger (HOBIT)
- WH and ZH gained boost of >12% in sensitivity from HOBIT



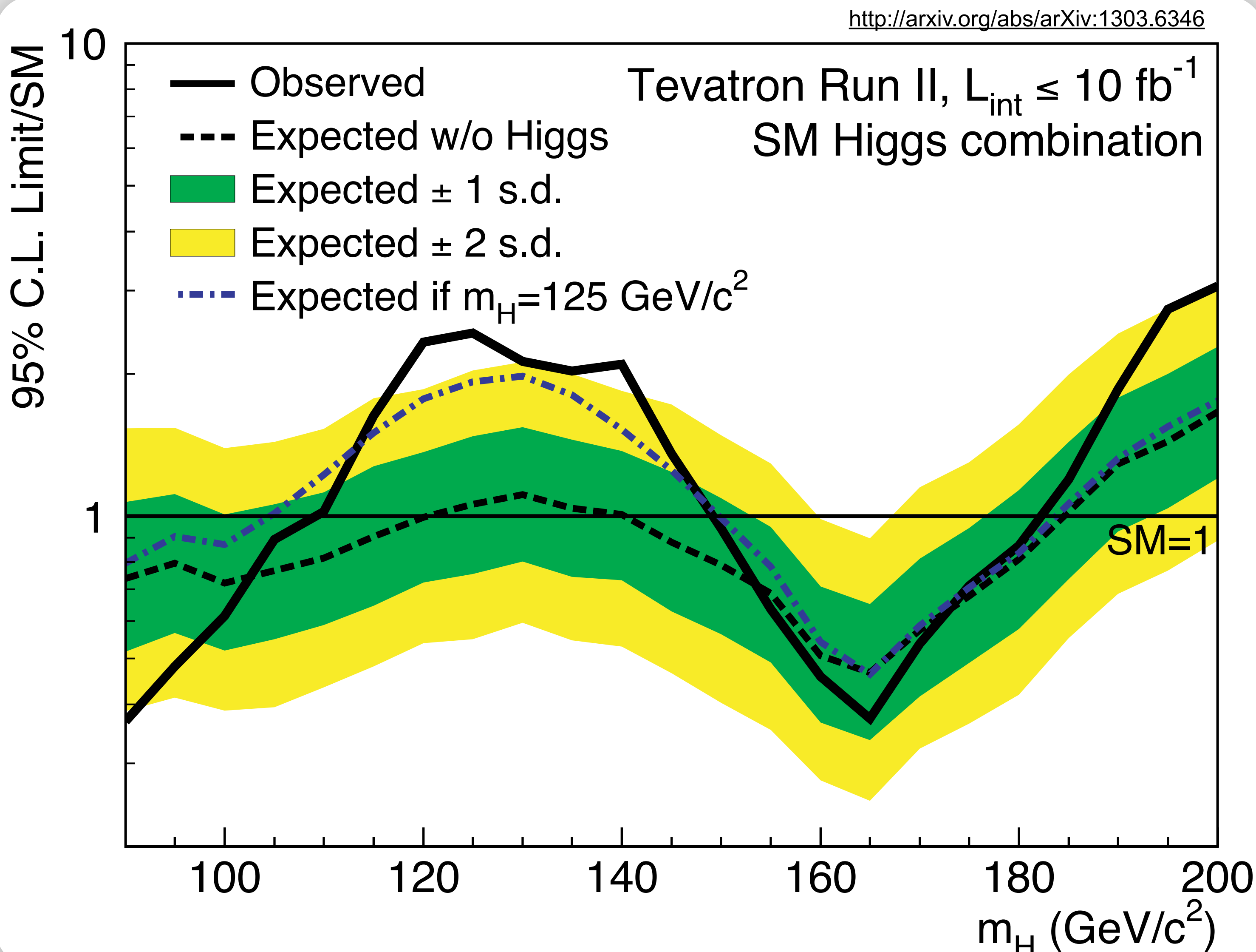
Mass Resolution

- Dijet mass is the most powerful variable
- Jet-energy corrections generally derived from light-quark jets
- b-jets are very different from light flavor quark jets
- MVA algorithms improves jet energy resolution by ~20%

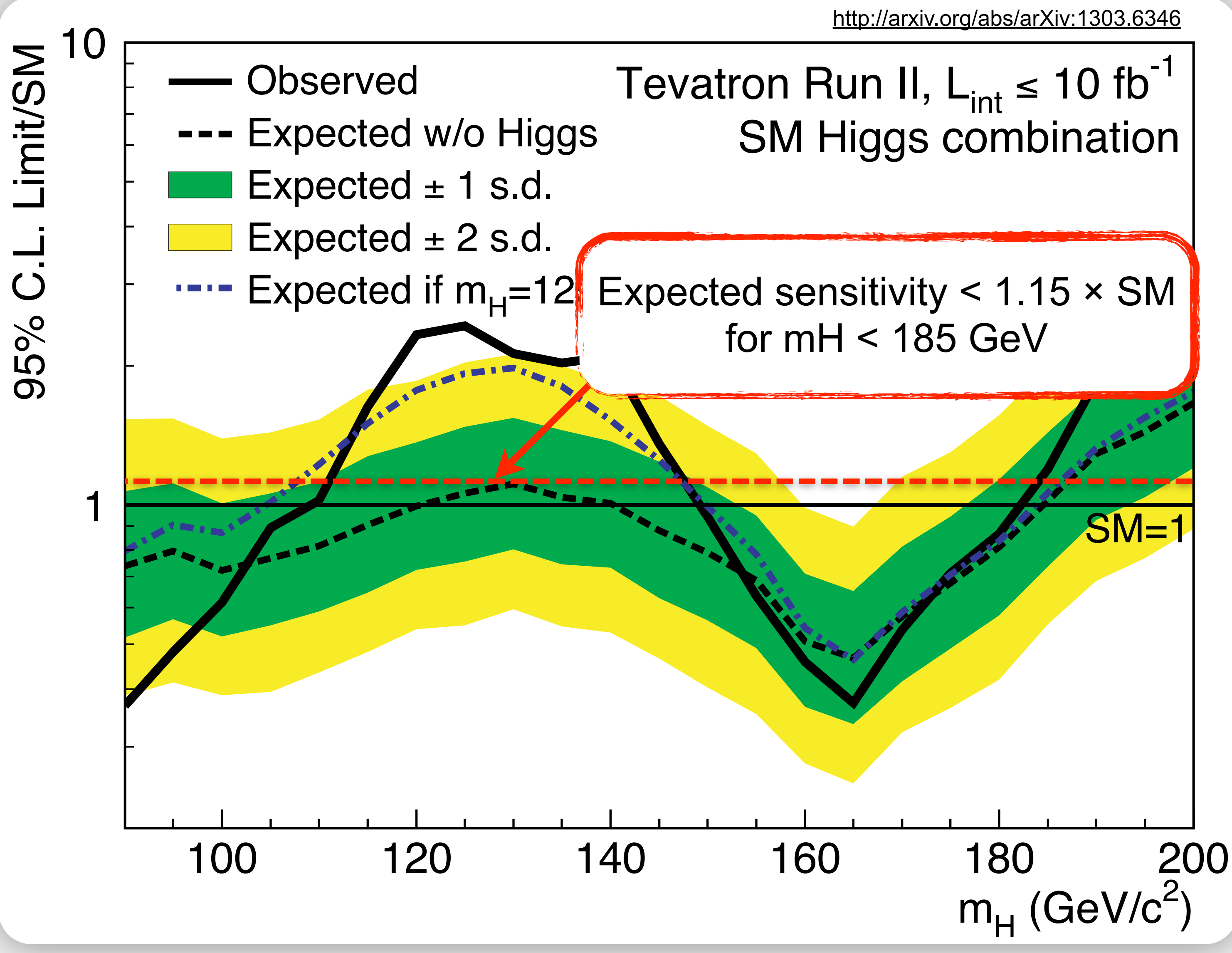




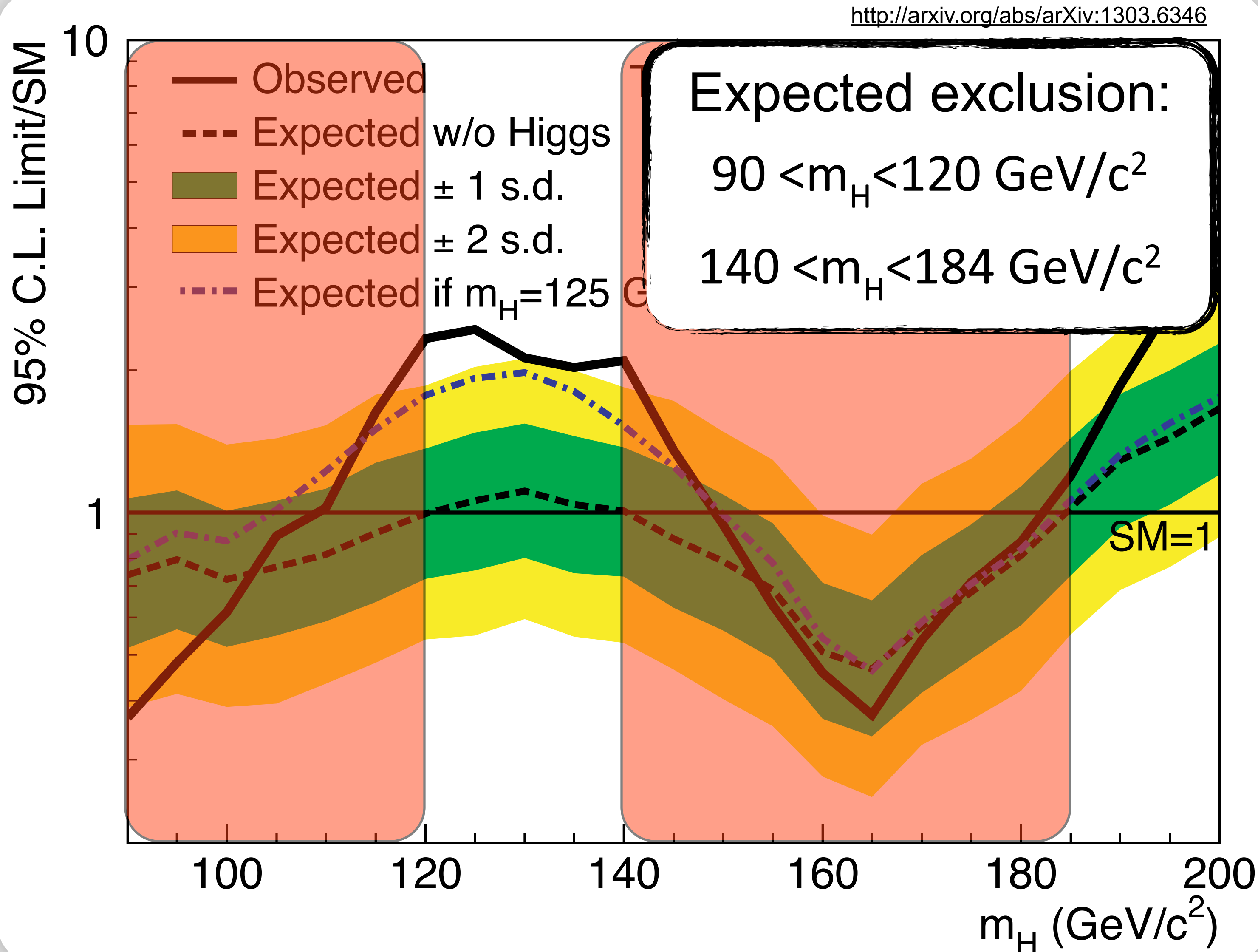
Combined limits



Combined limits



Combined limits

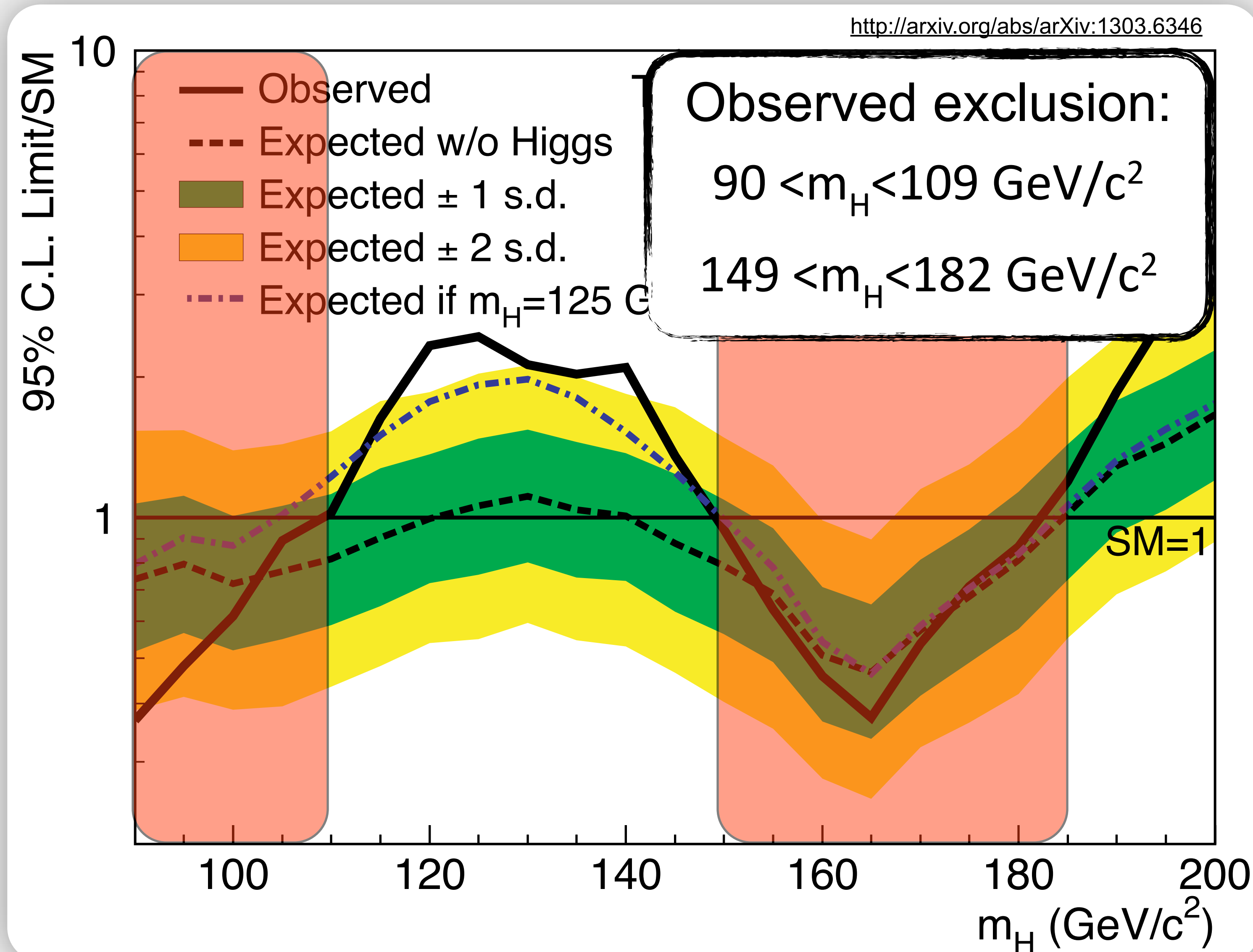


Expected exclusion:

$90 < m_H < 120$ GeV/c^2

$140 < m_H < 184$ GeV/c^2

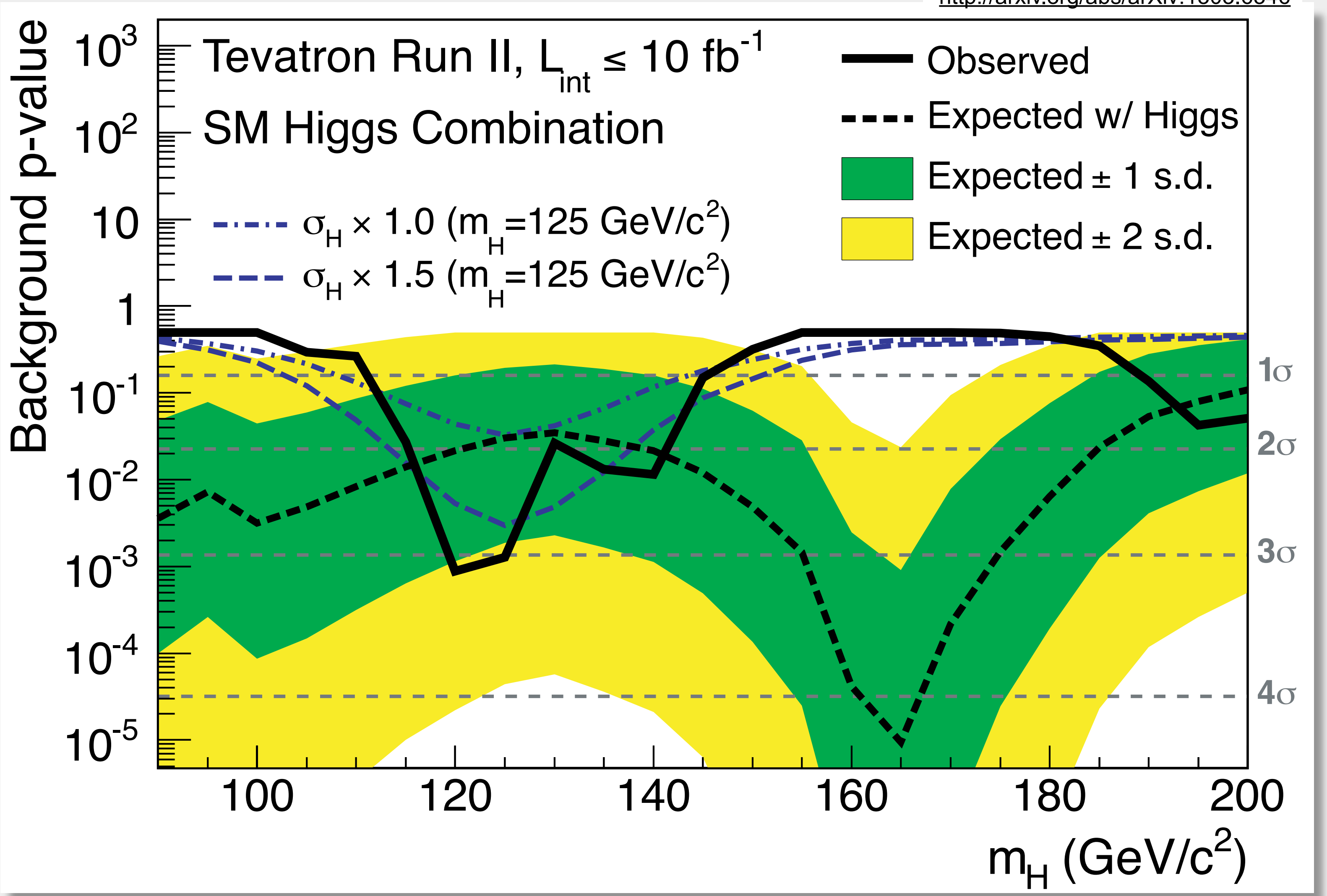
Combined limits



Excess significance

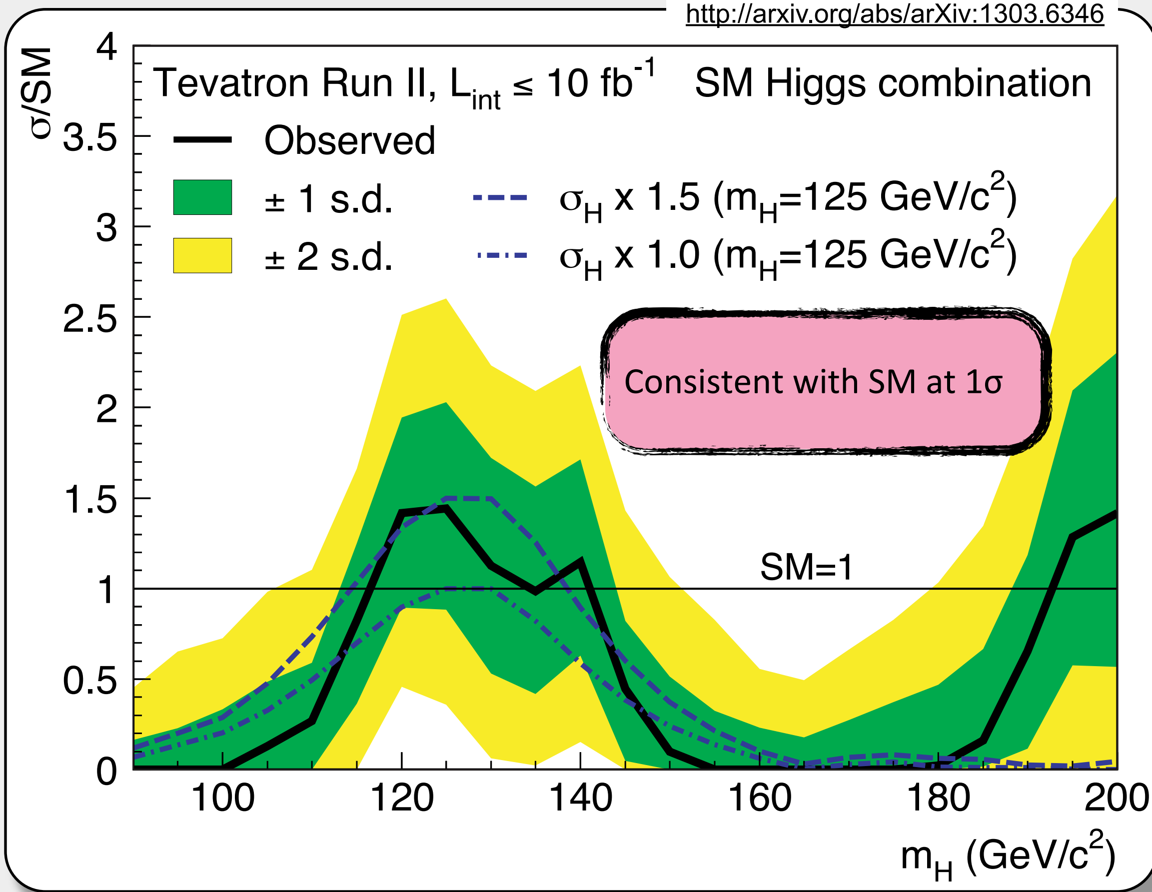
Is the excess consistent with background only assumption?

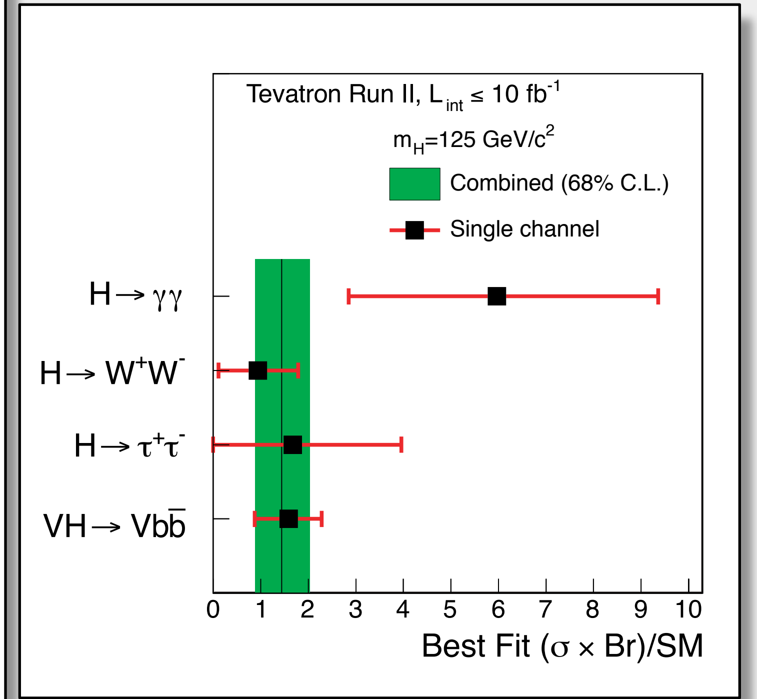
http://arxiv.org/abs/arXiv:1303.6346



Fitted σ_H

http://arxiv.org/abs/arXiv:1303.6346

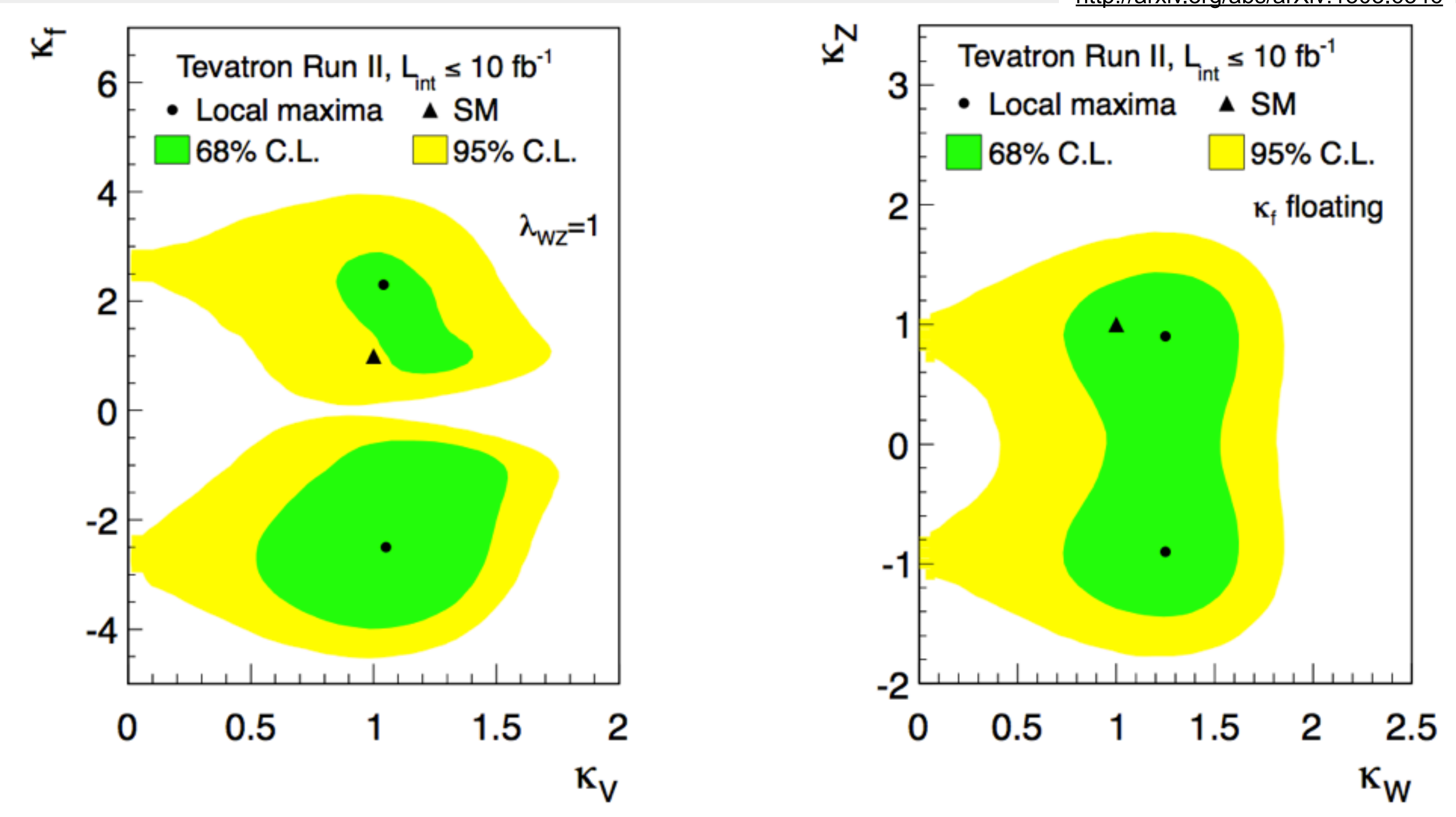




Couplings

- Coupling to fermions is scaled by k_f
- Coupling to bosons is scaled by k_W, k_Z, k_V

http://arxiv.org/abs/arXiv:1303.6346

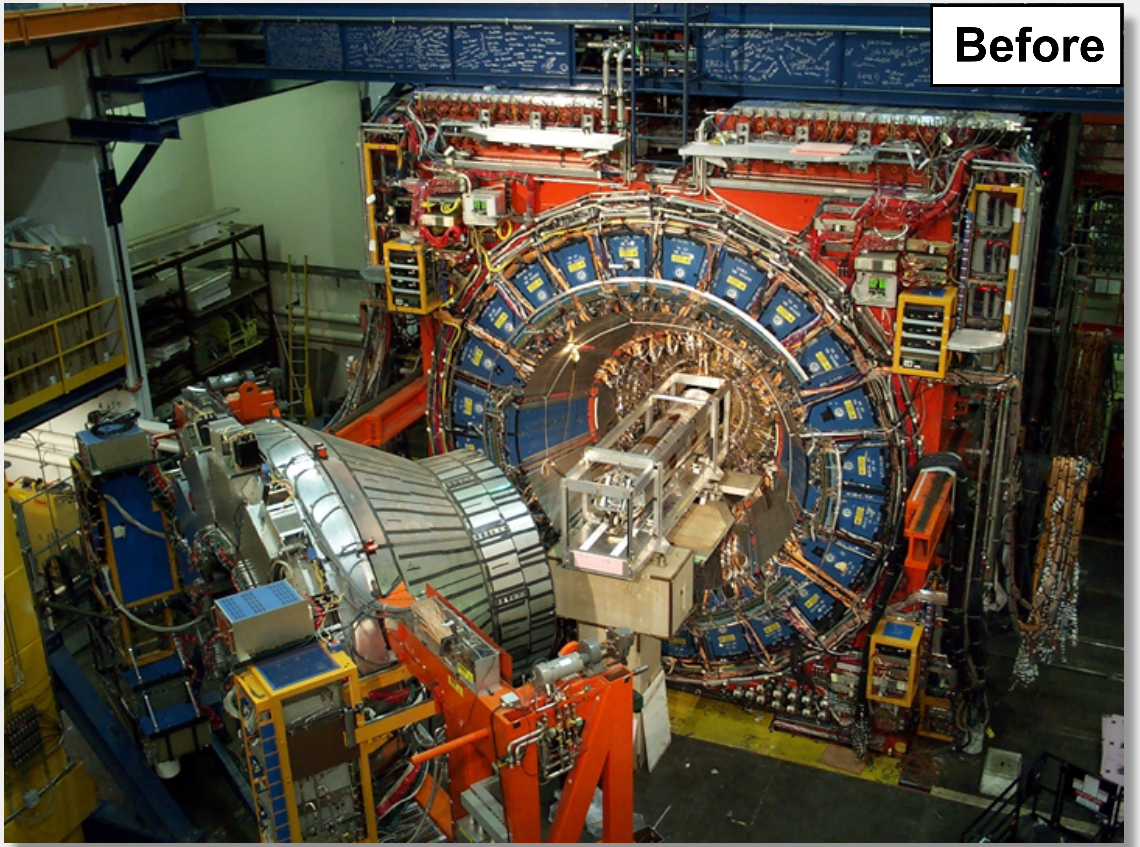


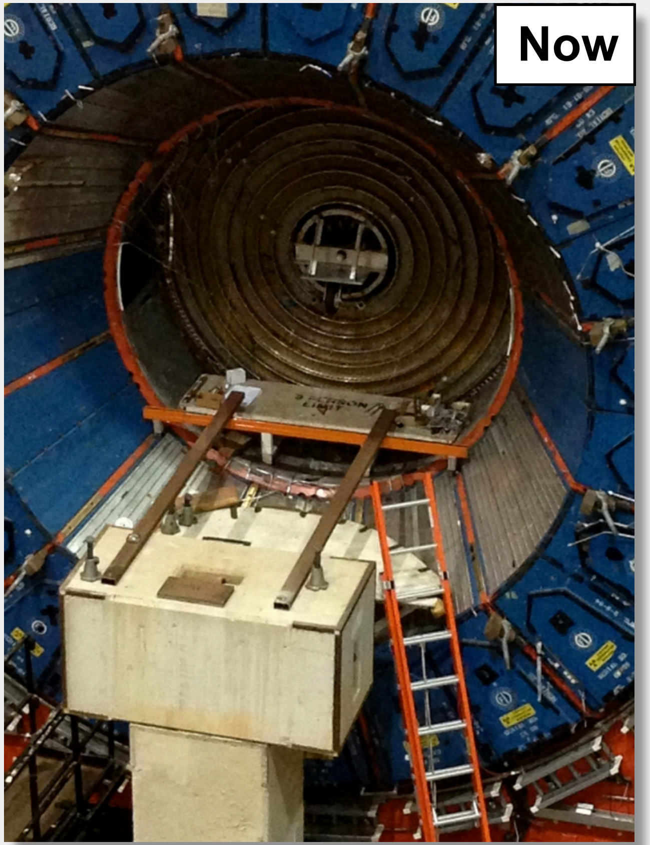
Conclusion

- Tevatron had a long and wide physics program
- Physicists extracted every bit of information in data delivered
- Strong legacy discoveries and measurements
- CDF and D0 observe an evidence Higgs boson production at 125 GeV.

- **Results:**
- **D0: http://www-d0.fnal.gov/results/**
- **CDF: http://www-cdf.fnal.gov/physics/physics.html**

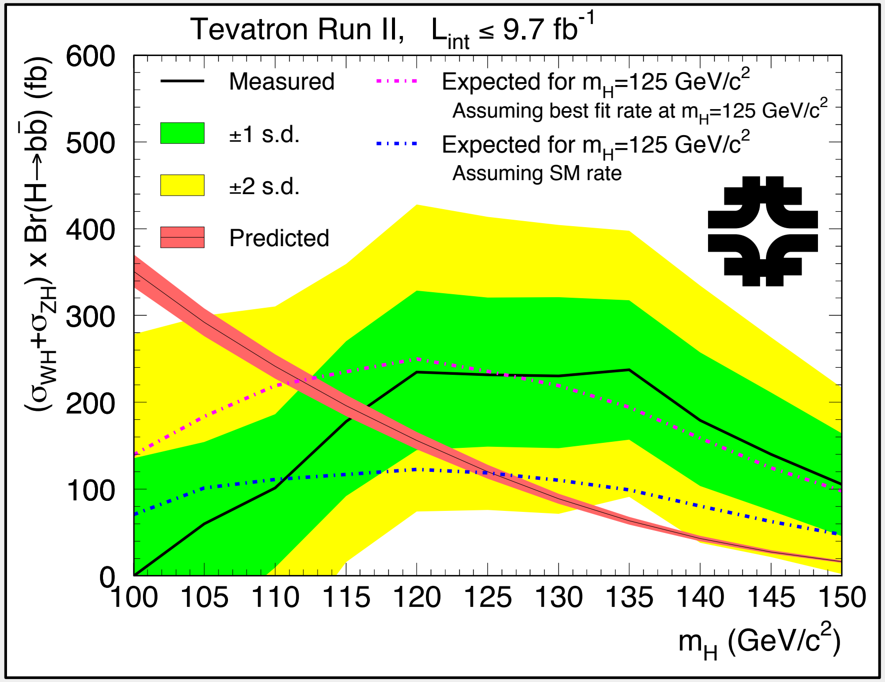
Conclusion

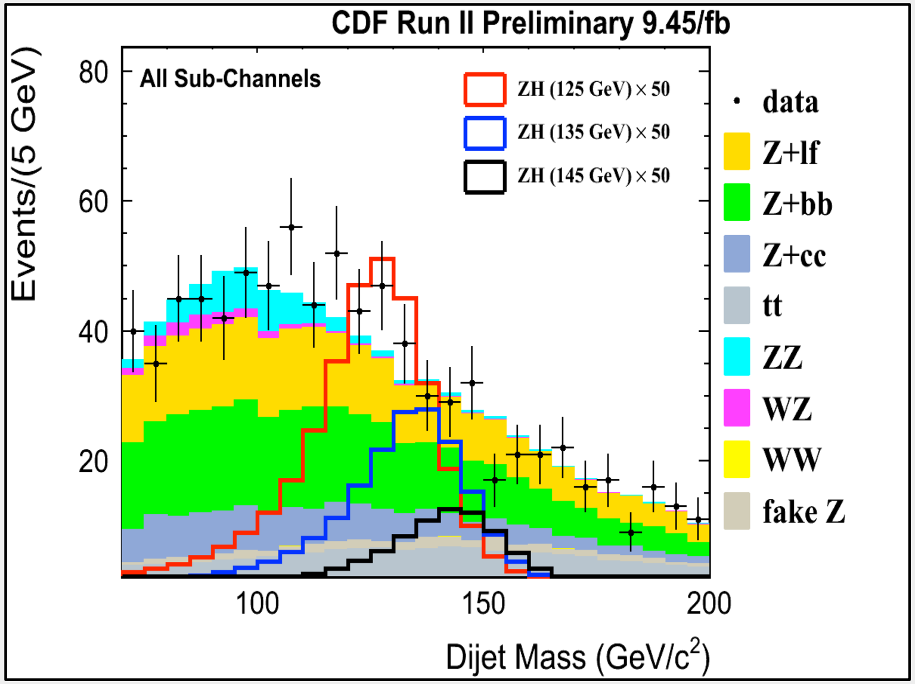




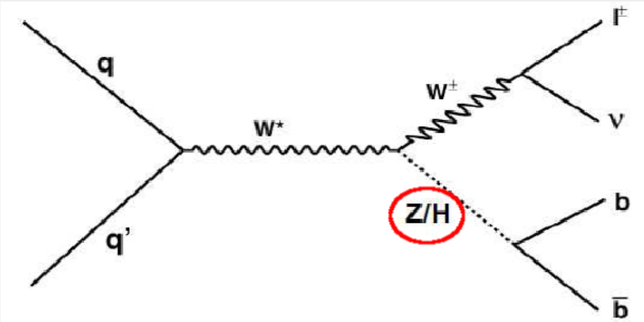
Backup

Best $\sigma_{H\rightarrow bb}$ fit

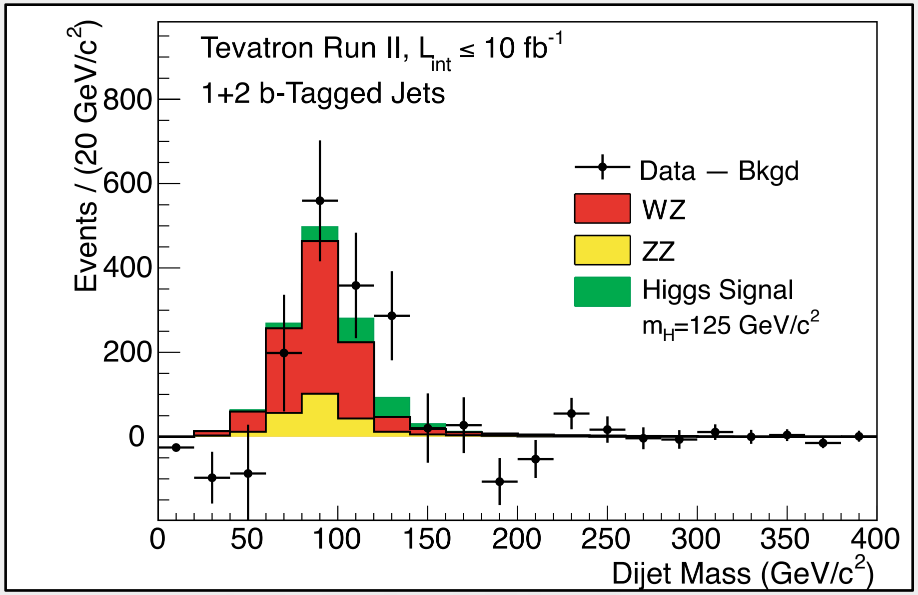




Diboson Fit



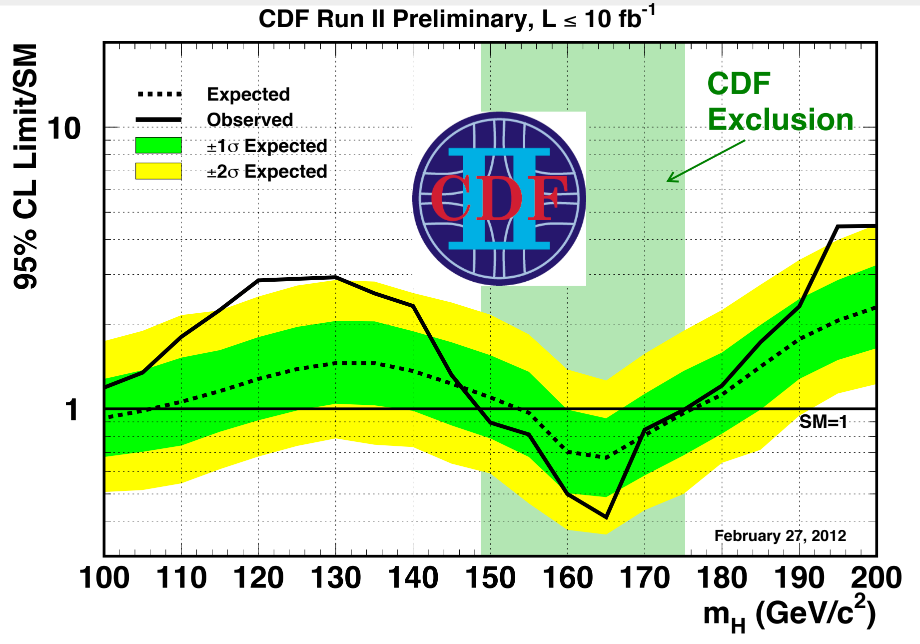
- We check the modeling
  - Each individual input to MVA is tested in the control regions
  - Well known SM processes: single top and diboson in particular
- σ(WZ+ZZ)*Br(Z→bb) =0.68±0.05pb (SM)
- σ(WH+ZH)*Br(H_{125}→bb) =0.12±0.01 pb
- We find perfect agreement with SM prediction

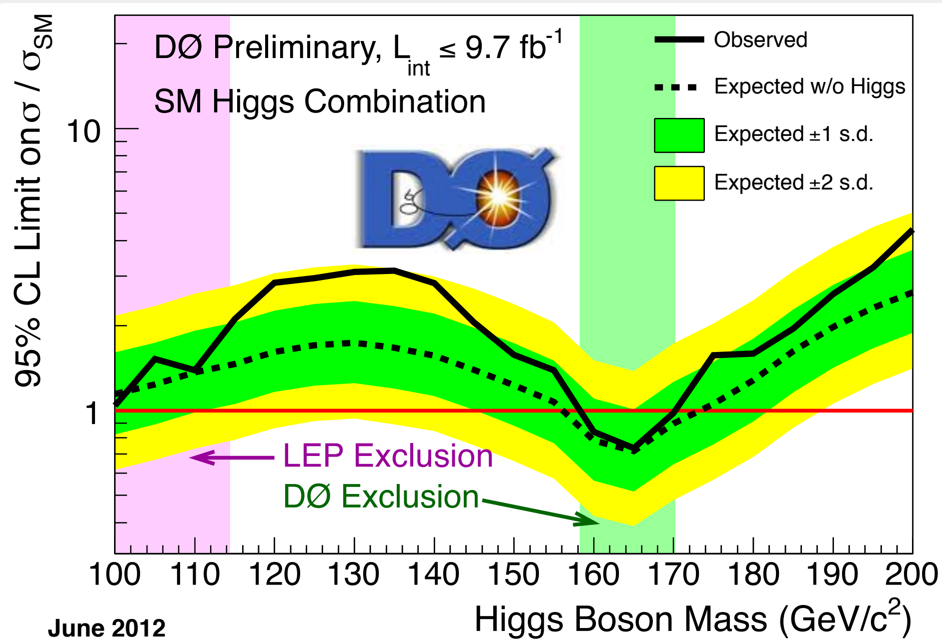


σ(WZ+ZZ)= 3.0 ± 0.6 (stat) ± 0.7 (syst) pb

(SM Prediction = 4.4 ± 0.3 pb)

Limits from CDF/D0

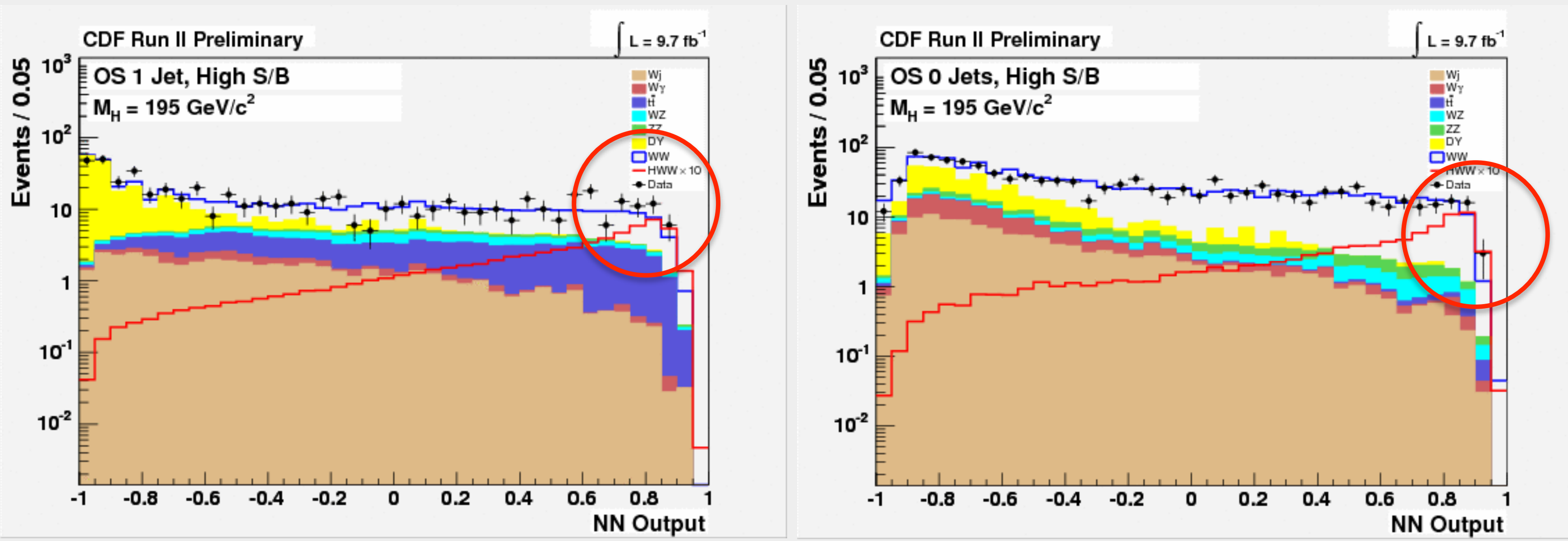




Exp. Exclusion: 154 < m_H < 176 GeV
Obs. Exclusion: 149 < m_H < 175 GeV

Exp. Exclusion: 156 < m_H < 173 GeV
Obs. Exclusion: 159 < m_H < 170 GeV

High mass excess



Behavior of observed limits driven by small event excesses in the high S/B regions of opposite-sign dilepton 0 and 1 jet channels

Nothing peculiar in the modeling of these distributions

Of course, ATLAS and CMS have ruled out a mH = 195 GeV/c2 SM Higgs based primarily on equivalent searches in H WW

CDF W+jets bump

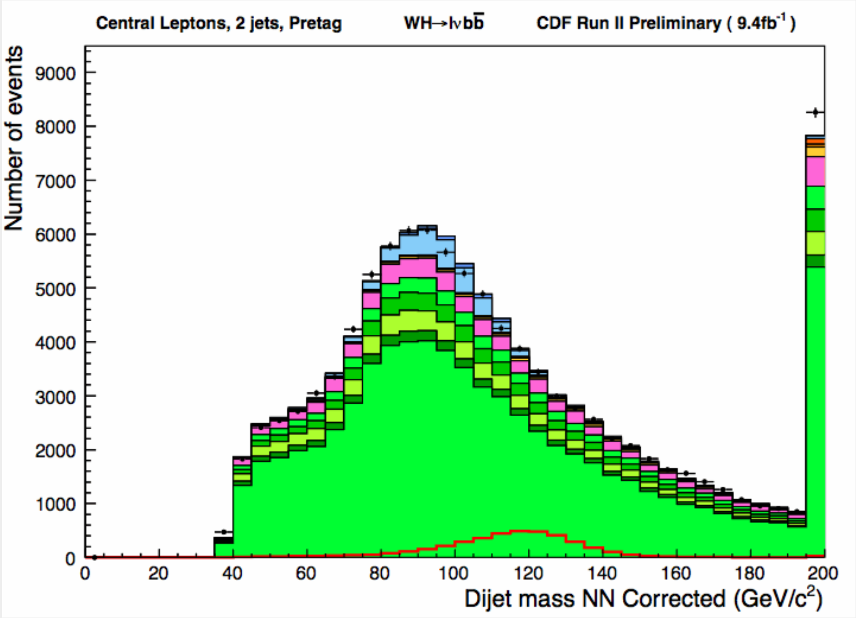
studies indicate that JES for gluon jets needs to be shifted by 2σ in MC to match with data

The JES for quark jets is good – not surprising since well constrained by top mass measurements

In CDF Higgs, -2σ JES corrections are applied to the gluon jets in the MC samples

In the end, since there are so few gluon jets in tagged samples, the effect is small

With these corrections in place modeling looks pretty good in the pre-tag region of the WH Higgs search



Likelihood

- We set limits on the Higgs boson production rate
- Use a combined binned likelihood fit:

$$L = \prod_{i=1}^{N_{\mathrm{channel}}} \prod_{j=1}^{N_{\mathrm{bins}}} \frac{\mu_{ij}^{n_{ij}}}{n_{ij}!} e^{-\mu_{ij}} \times \prod_{k=1}^{N_{\mathrm{np}}} e^{-\theta_k^2/2}$$

Expected events

Nuisance parameters

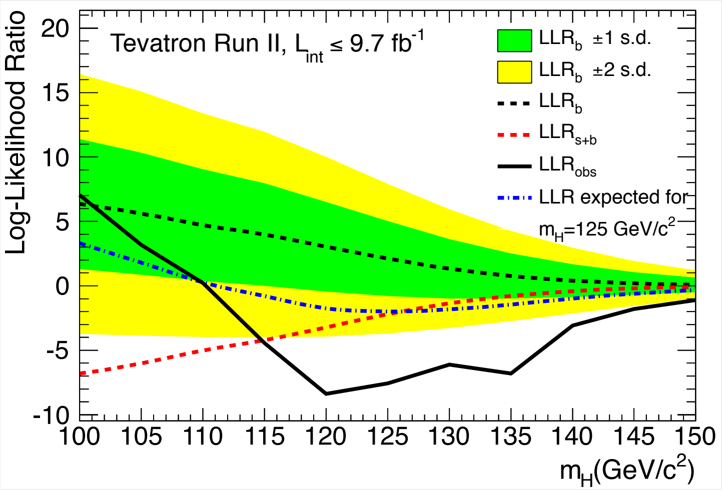
Observed events

- Uncertainties incorporated as nuisance parameters. Shape and normalization of background and signal
- Determine best-fit nuisance-parameters by maximizing likelihood

LLR

$$LLR = -2\ln\frac{p(\text{data} \mid s+b)}{p(\text{data} \mid b)}$$

LLR>0: Background-like experimental outcome
LLR<0: Signal-like experimental outcome



p-value

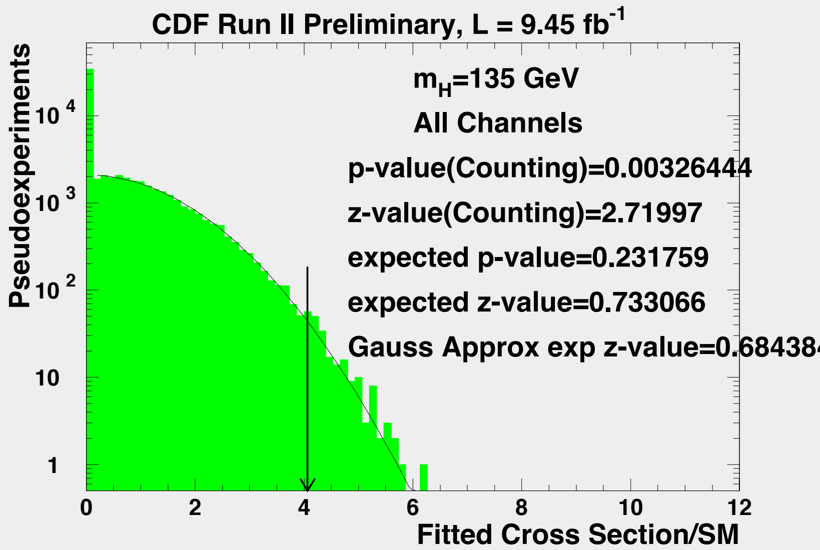
Strategy – Run the cross section fit on background-only pseudo-experiments

Count the pseudo-experiments with $R^{fit} \geq R^{fit,obs}$. The fraction is the p-value

Convert to a significance in "standard deviations".

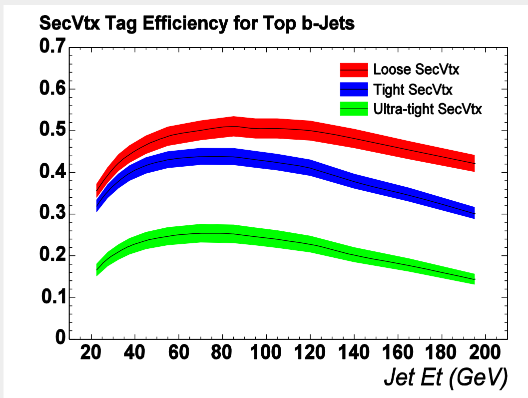
Do this at each mH value separately

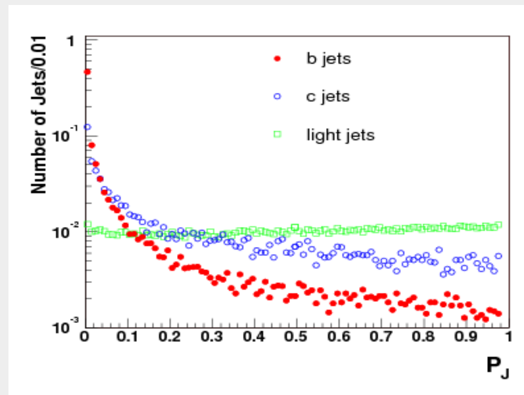
Using LLR instead of Rfit is supposed to be more optimal, cross section fits are better behaved.

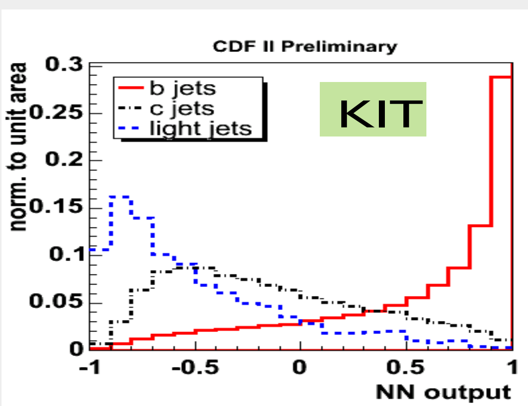


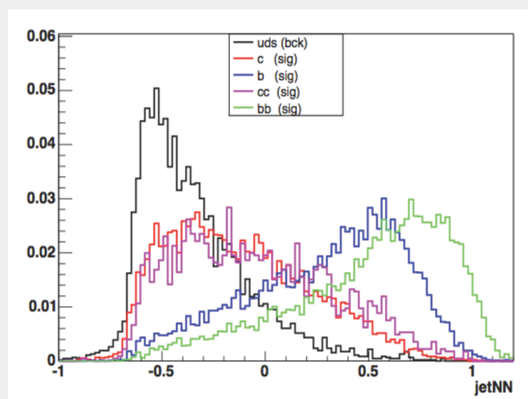
History of b-taggers at CDF

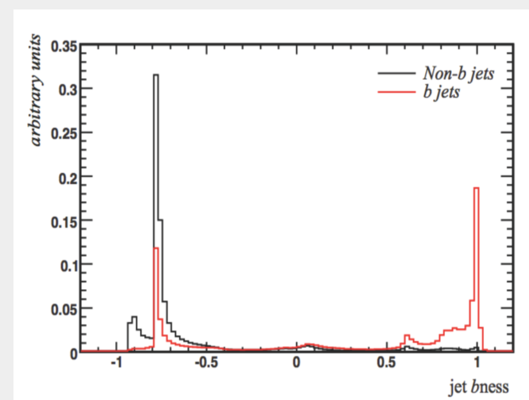
- Improvement in b-tagging efficiency are crucial to various high Pt analysis
  - By 2010 we had at least 5 types of b-taggers





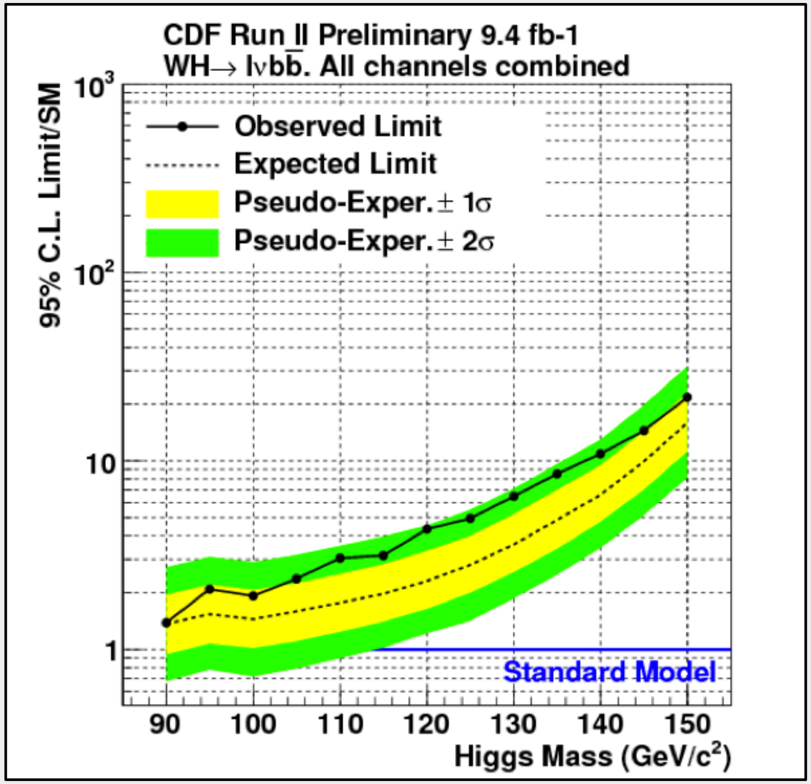




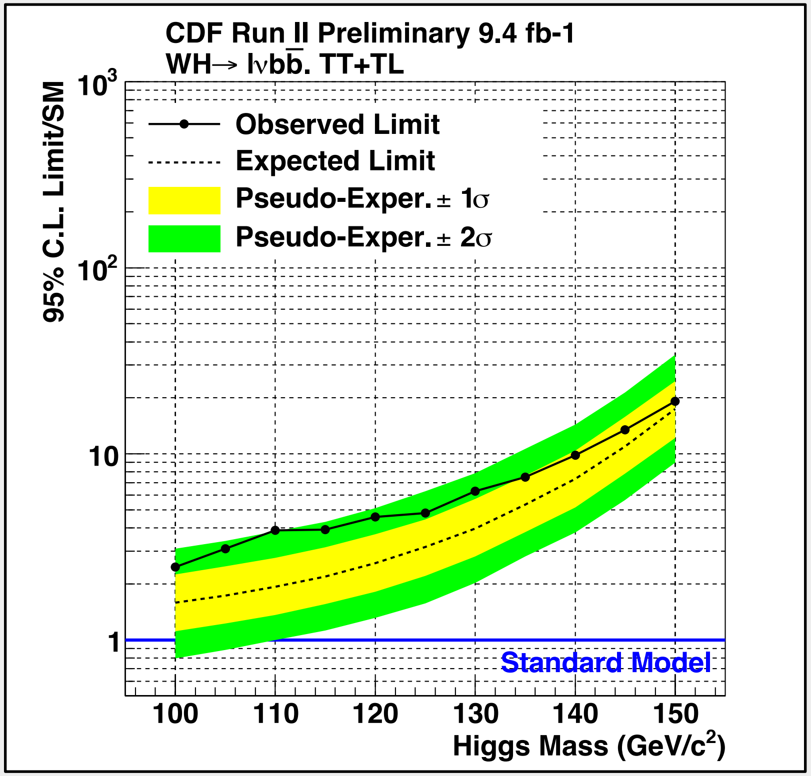


Tight b-tags only

All



TT+TL only



OLD vs NEW b-tagging strategy

- Previous version of WH analysis used 3 types of b-tagger by forming exclusive b-tagging categories:
  - SVTSVT, SVTJP05, SVTnoJPRoma, SVTnoJPnoRoma

Tagging Category	S/√B
SecVtx+SecVtx	0.228
SecVtx+JetProb	0.160
SecVtx+Roma	0.103
Single SecVtx	0.146
Sum	0.331

- The improvement in sensitivity ~scales with improvements in signal significance

NEW - HOBIT

Tagging Category	S/√B
Tight-Tight	0.266
Tight-Loose	0.200
Single Tight	0.143
Loose-Loose	0.053
Single Loose	0.044
Sum	0.369