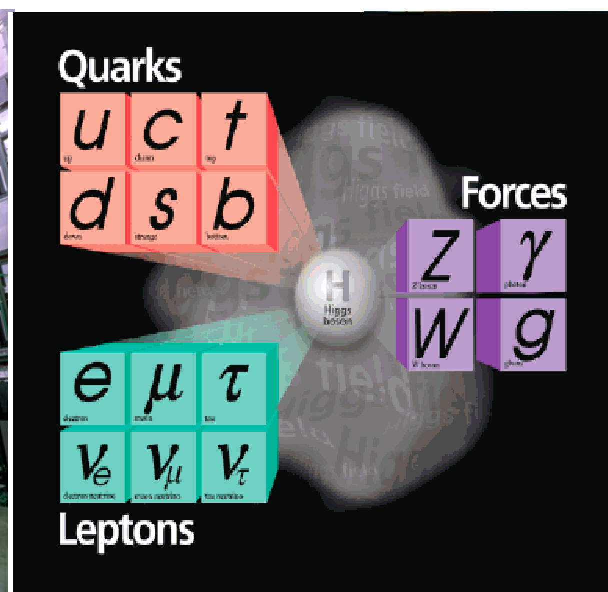
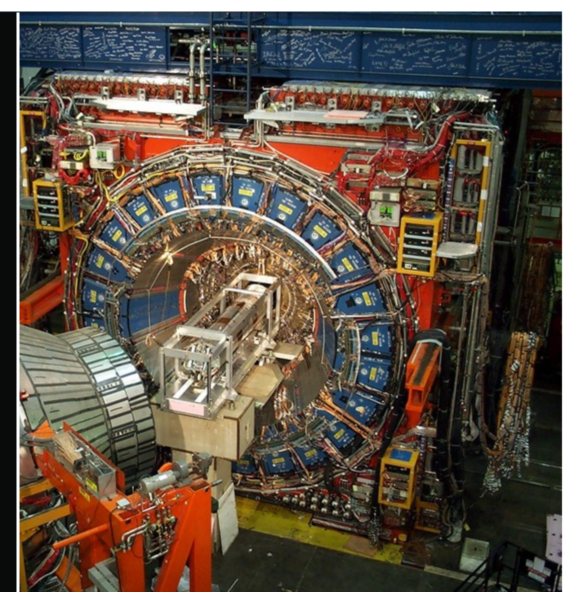
Search for high mass standard model Higgs boson at Tevatron in di-lepton channels

Boris Tuchming – Irfu/Spp CEA Saclay

on behalf of the CDF and DØ collaborations

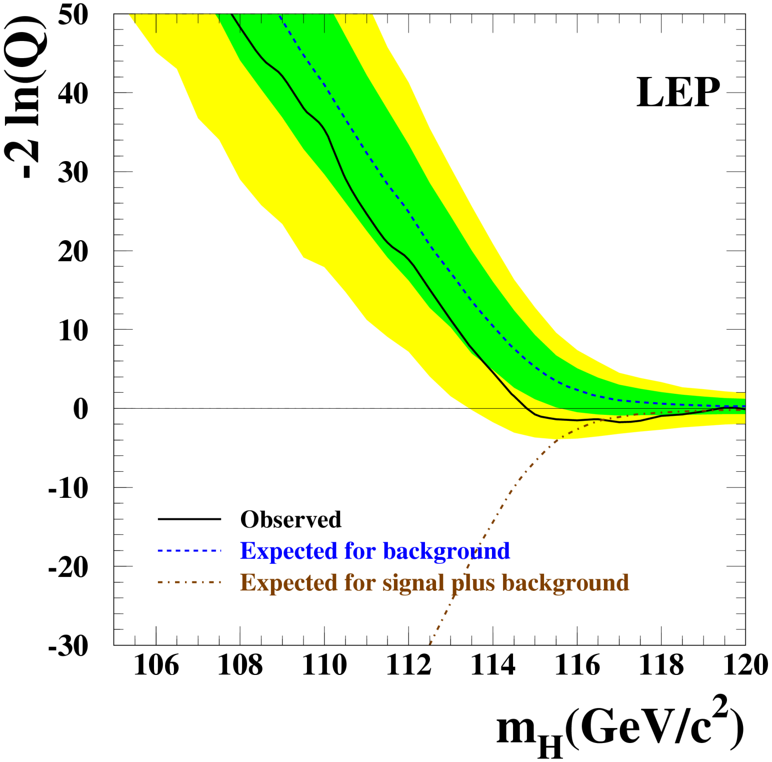


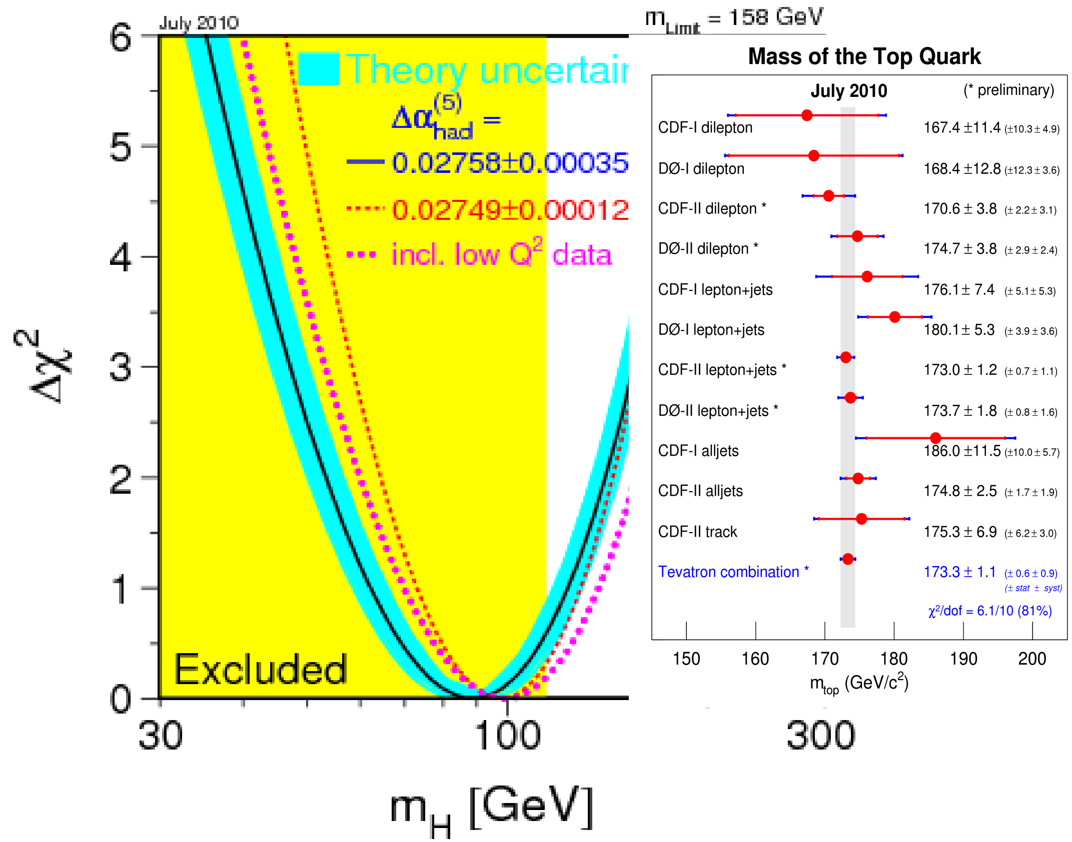


What do we know about Higgs boson ?

Direct constraints from LEP

Indirect (contributions from Tevatron)





$$M_H = 89^{+35}_{-26}\,GeV$$

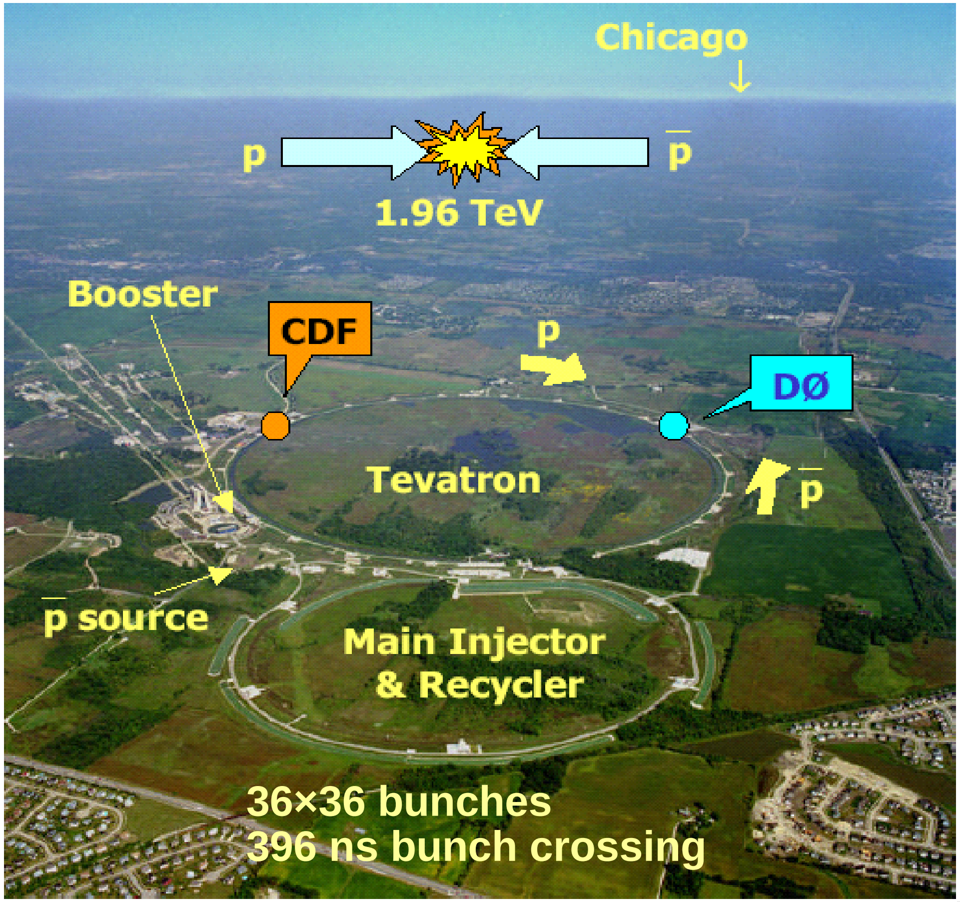
M_H > 114.4 GeV @95%

M_H < 185 GeV @95%

Light mass Higgs is favoured

- Region accessible to Tevatron

The Tevatron proton-antiproton collider



Run I (1993-1996)

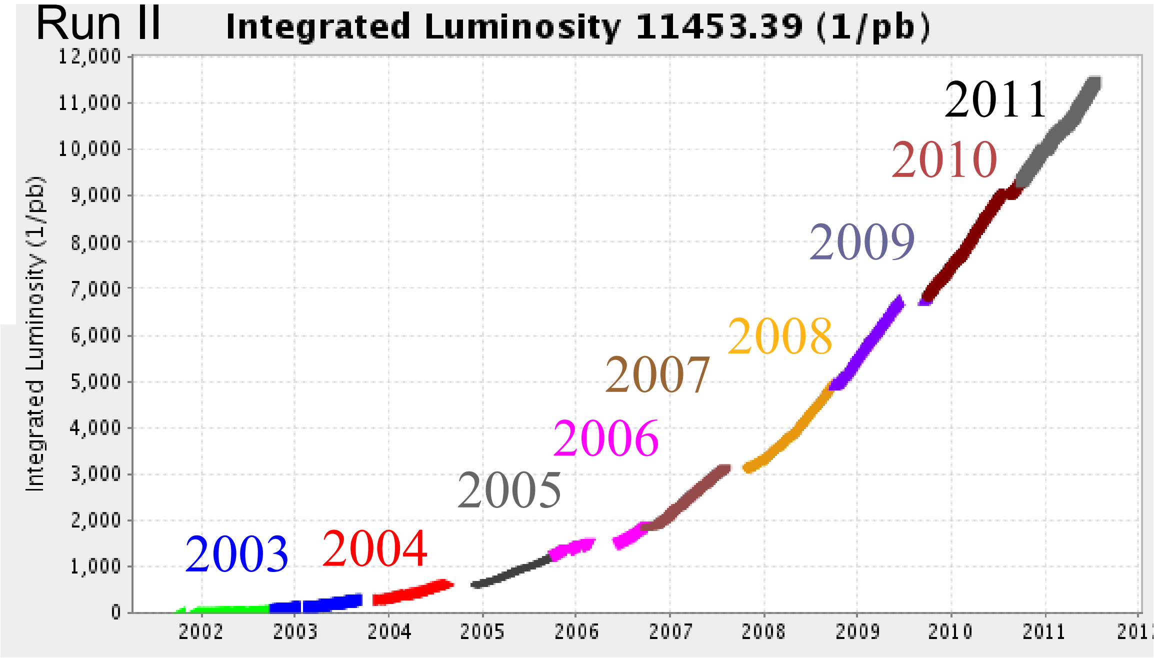
~120 pb^{-1} per experiment-top quark discovery

Run II: (2002-2011)

Tevatron now delivers >2 fb^{-1} per year

Shutdown forseen end september 2011

~11.5 fb^{-1} delivered per experiment

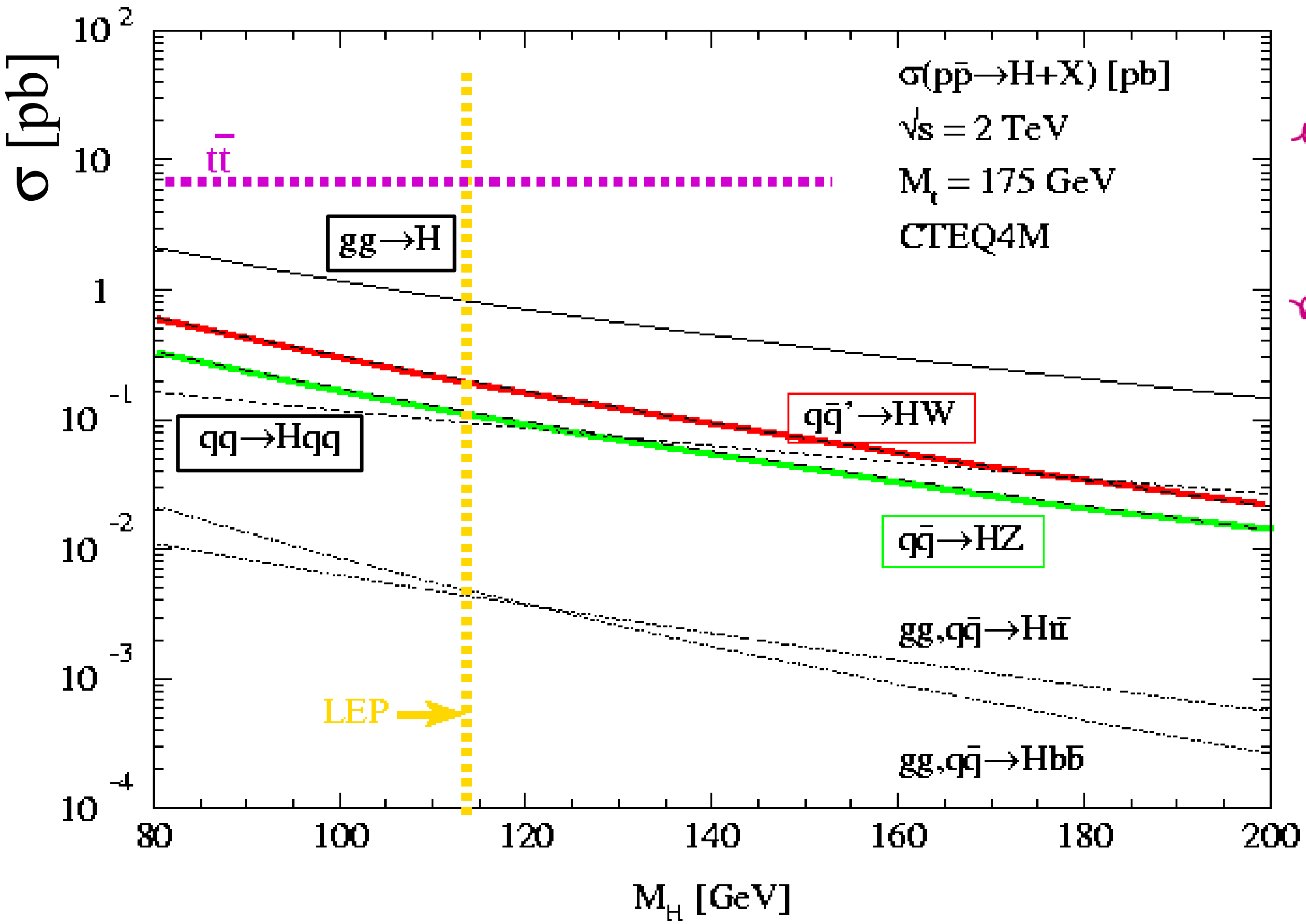


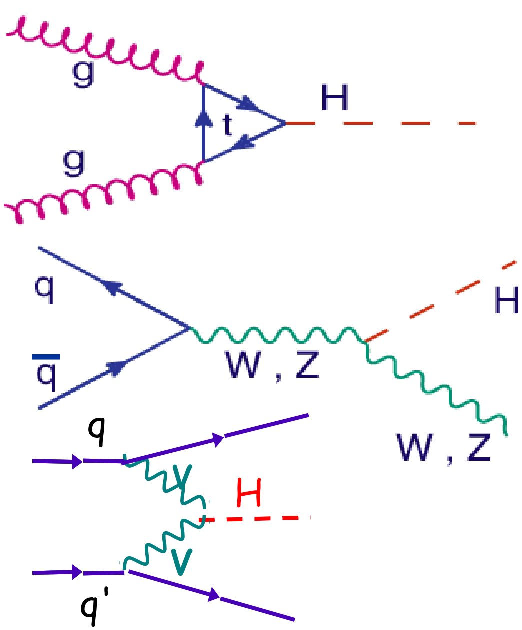
Most of the Higgs results today rely on: 5.3-8.2 fb^{-1}

Higgs production at the Tevatron

Production cross section (for $115 < m_H < 180$ GeV)

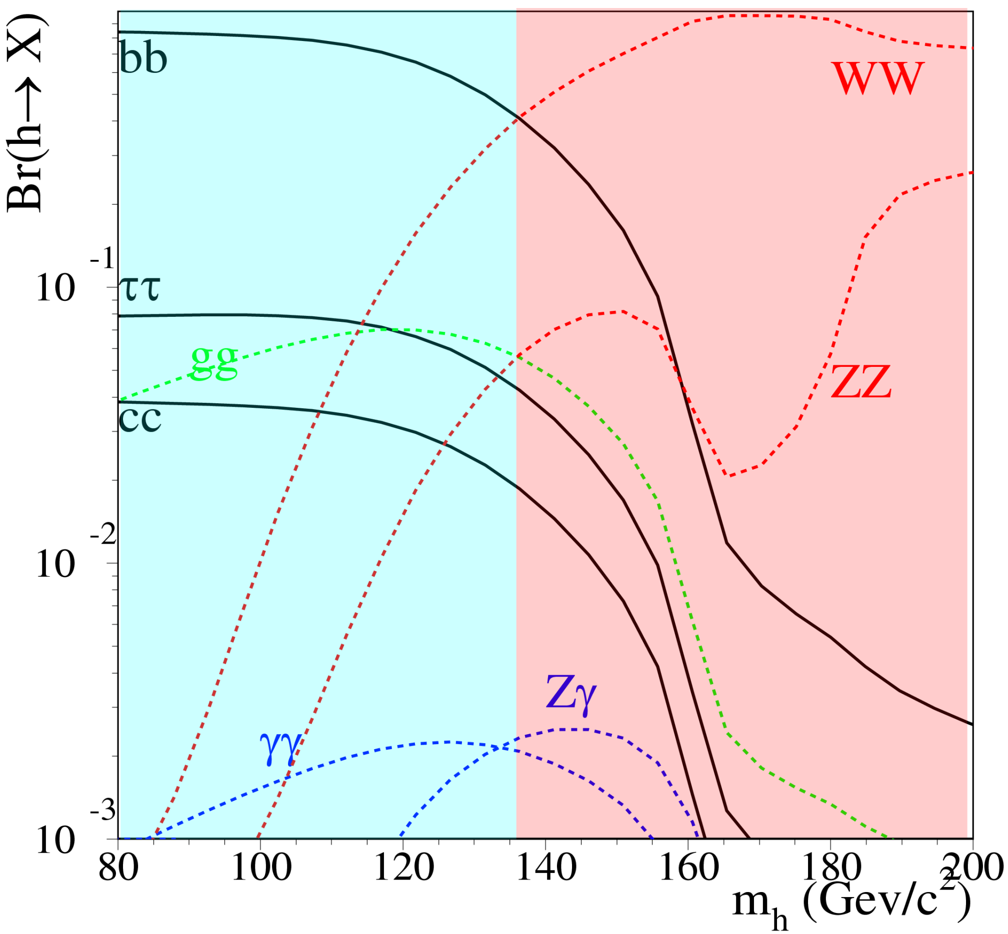
- in the 1.2-0.3 pb range for gluon fusion $gg \rightarrow H$
- In the 0.2-0.03 pb range for WH associated vector boson production
- In the 0.08-0.03 pb range for the vector boson fusion $qq \rightarrow Hqq$

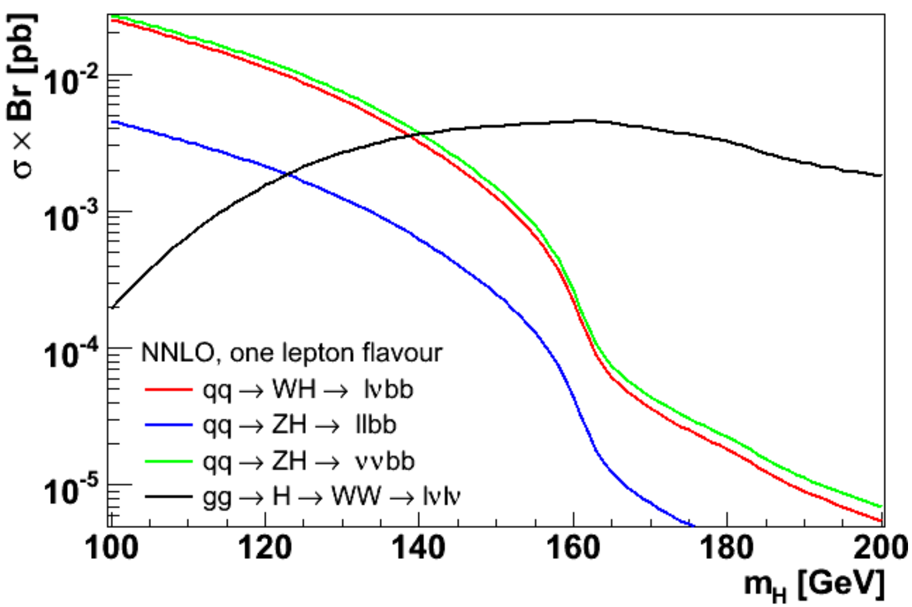




Low Mass vs High Mass

- Decay modes depend on the Standard Model Higgs mass
- At high mass :
  - Look for W decay products
  - Peak sensitivity just above threshold M_H~165 GeV.





m_H<135 GeV

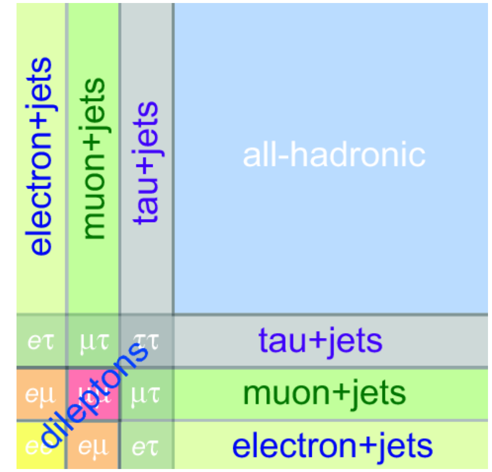
$H \to bb$

$H \to \tau\tau$

m_H>135 GeV

$H \to WW^*$

Looking for H → WW*



W vs W decays

W decay modes determine the final states

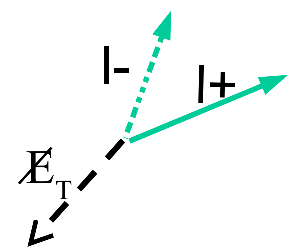
- W → hadrons ~68%
- W → lepton+neutrino ~ 3 x11

Overwhelming QCD background in hadron colliders

Need for lepton and/or missing E_T signature

Di-lepton of opposite signs (OS) + missing E_T signature

- Small Br~6% (ee +eμ + μμ)
- Clean signal

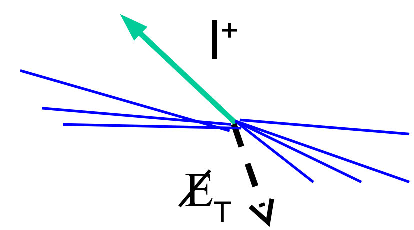


Lepton+ tau+ missing E_T signature

- small Br~4% (eτ+ μτ)
- Difficulty to reconstruct hadronic taus

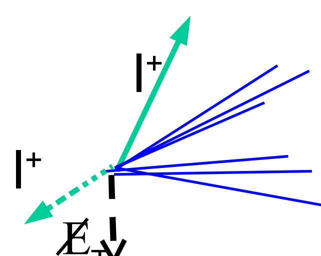
Lepton + jets + missing E_T signature

- Larger Br ~ 30% (e+jets, μ+jets)
- Large W+jets background, hard to model

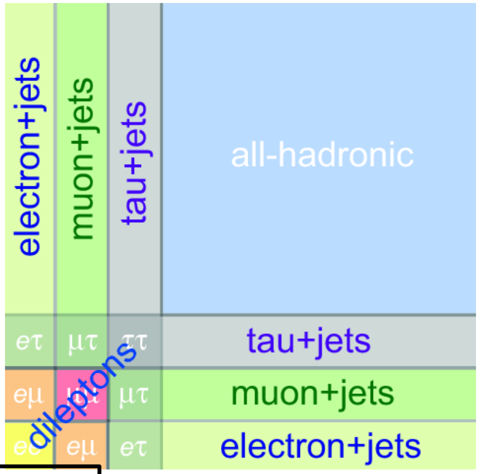


Di-lepton of same signs + missing E_T signature

- arises from the associated production: HW → W W W
- Same charge leptons are a very clean signature
- But small σxBr



Looking for H → WW* in di-lepton channels



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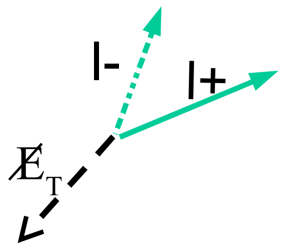

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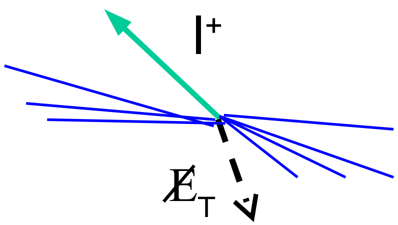

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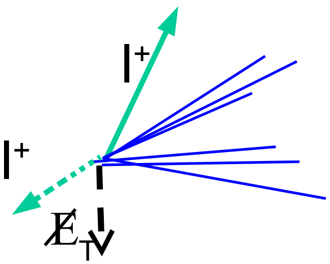


Di-lepton channels : new since winter 2011

CDF

- Add more data: 7.1 → 8.2 fb^{-1}
  - both Standard Model and 4th generation results
- Increased acceptance with additional lepton definitions and triggers
- Modified lepton isolation algorithm to prevent self-spoiling of narrowly separated lepton pairs

DØ

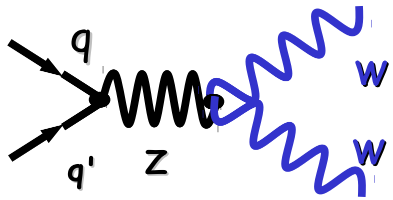
- Opposite sign channels : No new data, same 8.1 fb^{-1} sample
  - eμ: Improved systematic treatment, improved selection cut.
  - Analysis within 4th generation model.
- Same sign channels: No new data, 5.3 fb^{-1} analysis finalized and submitted to PRD (arXiv:1107.1268 [hep-ex])

Both

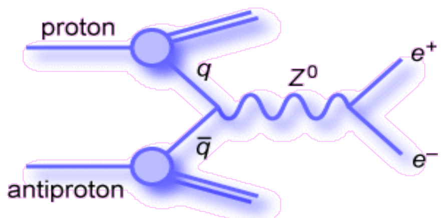
- Update signal Branching ratios*
- Anti-correlations between jet bins for the gg → H cross-section scale uncertainty

* - S. Dittmaier et al. [LHC Higgs Cross Section Working Group], “Handbook of LHC Higgs Cross Sections: 1. Inclusive Observables”, arXiv:1101.0593v2 (2011).

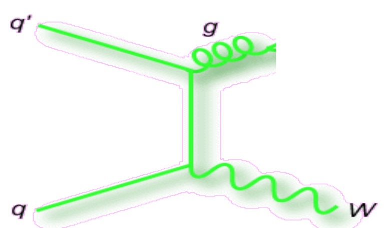
Backgrounds to H → WW



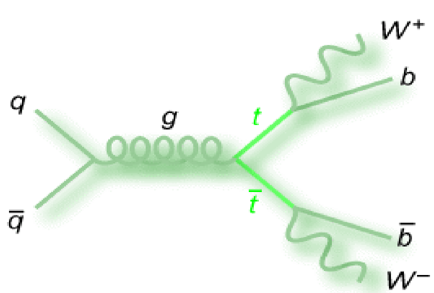
- Di-boson WW, WZ, ZZ
  - WW = irreducible background
  - NLO calculation for cross-sections
  - for WW: NLO correction for p_T and di-lepton opening angle



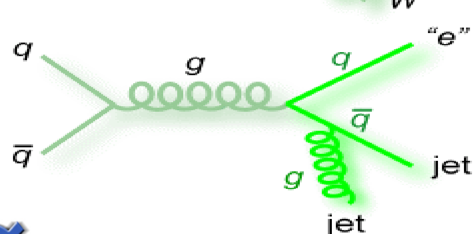
- Z/γ +jets
  - mismeasured jets or leptons yielding MET
  - NNLO cross-sections, data-based corrections to model $p_T(Z)$



- W+jets, W+γ
  - jets or γ faking lepton
  - Data driven model

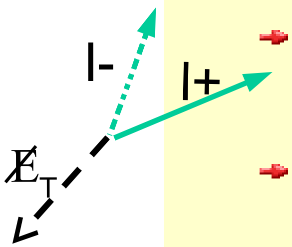


- Top pair and single top
  - cross-section normalized at NNLO



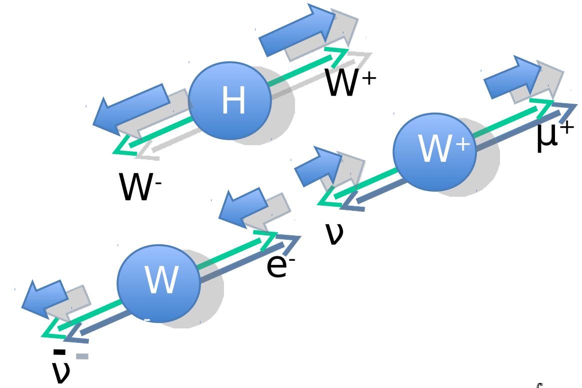
- QCD multijet events
  - jets faking leptons
  - mismeasured jets creating MET

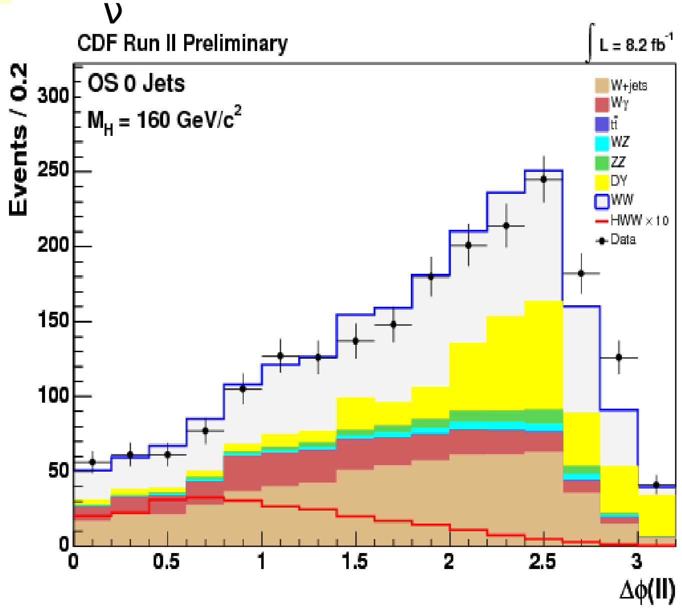
Di-lepton + $\not{E}_T$ channels

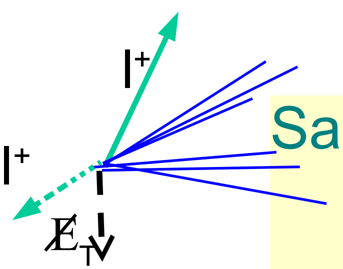


Opposite Sign Signature:

- 2 isolated high p_T leptons, opposite signs
  - unlike W+jets and QCD background
- Large missing E_T
  - unlike Drell-Yan background
- Higgs is scalar at rest + V-A interaction:
  - The leptons tend to be collinear
  - Small $\Delta\phi(l,l)$
  - unlike WW background







Same sign Signature:

- 2 isolated hight p_T leptons,Large missing E_T
- same charge (require high quality track)
  - unlike Drell-Yan and WW background
- Presence of jets (CDF)

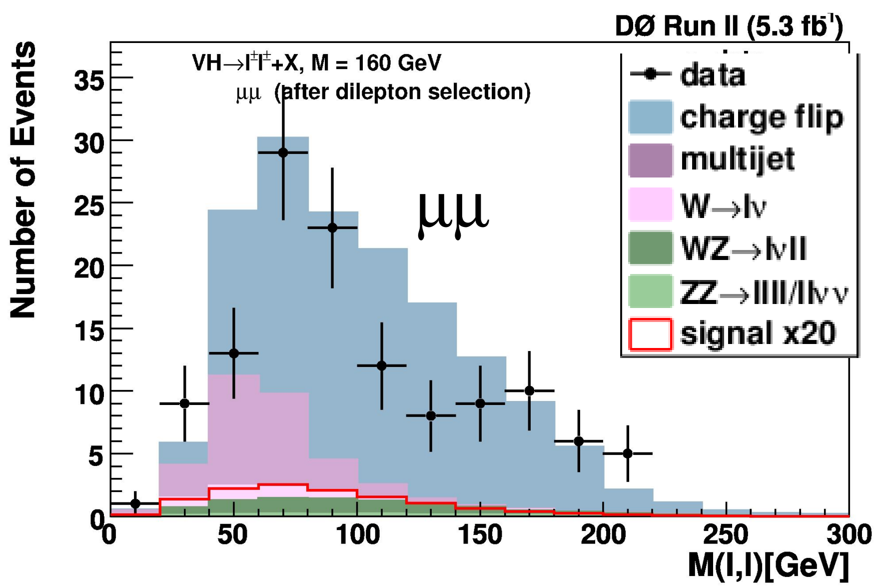
Strategy

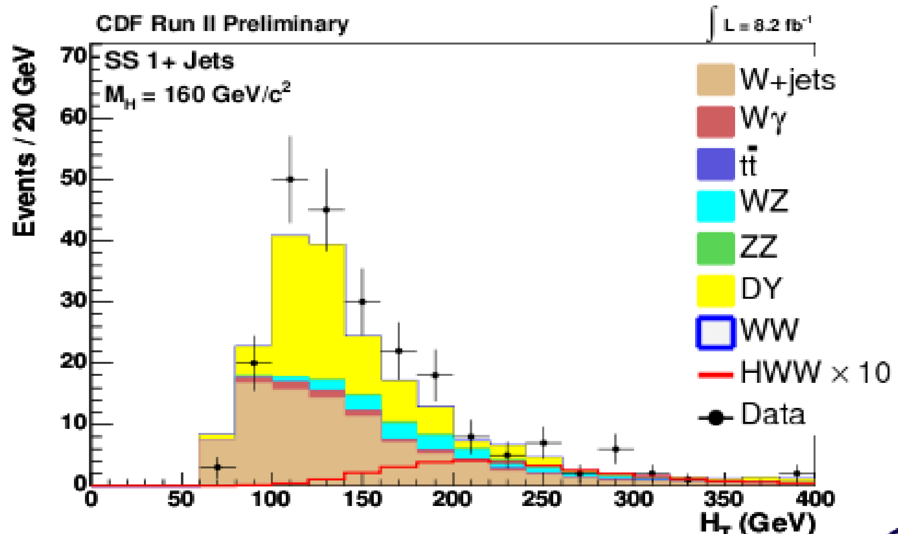
General strategy:

- Pre-selection of isolated high p_T di-lepton events
- Further selection to get rid of dominant Drell-Yan background
- Split analysis into subchannels with different signal/background to maximize discriminating power
- Multivariate techniques to maximize use of available information
  - Decision trees (BDT), Neural Networks (NN), Matrix Element (ME)
  - Trained for each subchannel and Higgs mass hypothesis.

Instrumental background needs to be determined on data

- jets faking leptons, photon faking electrons, charge mis-measurements

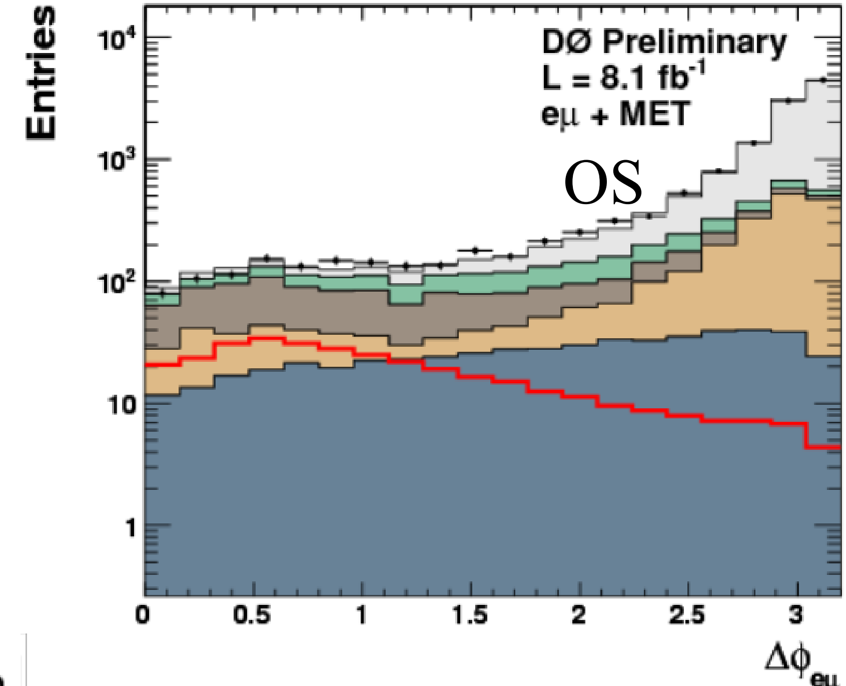


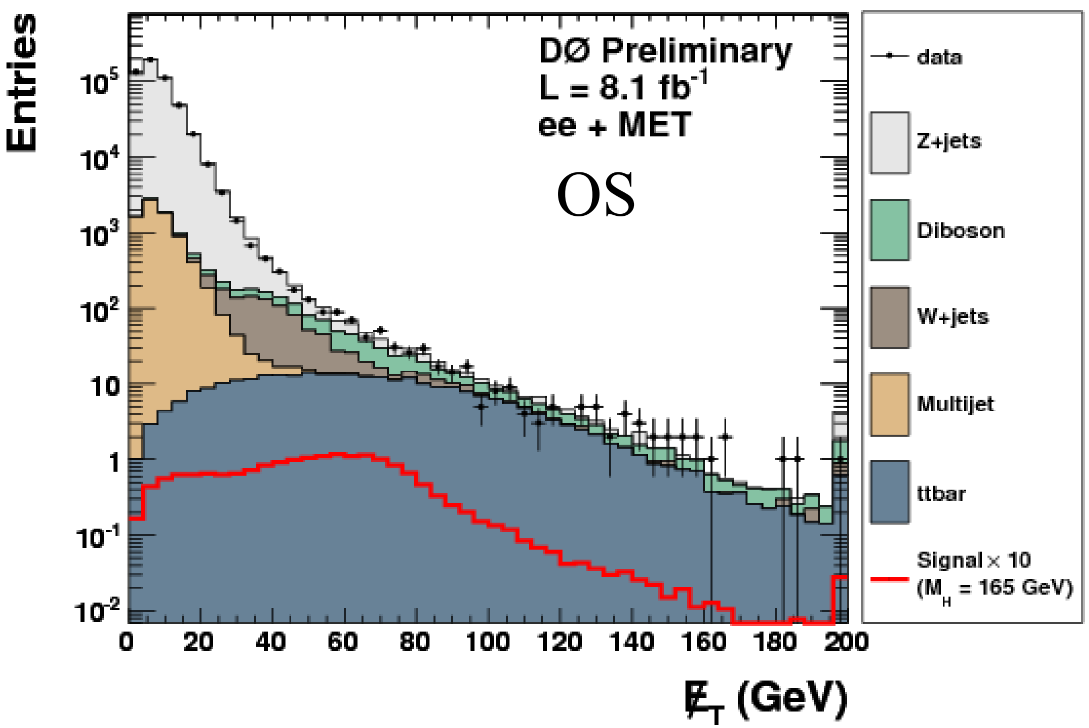


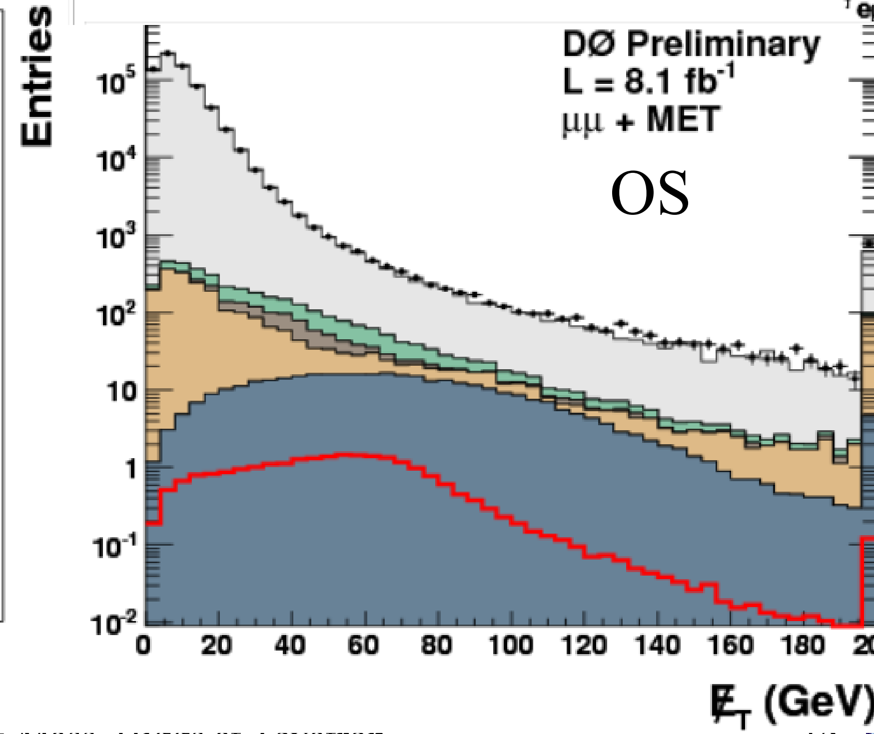
Di-lepton + $\not{E}_T$ Subchannels

Split analysis according to :

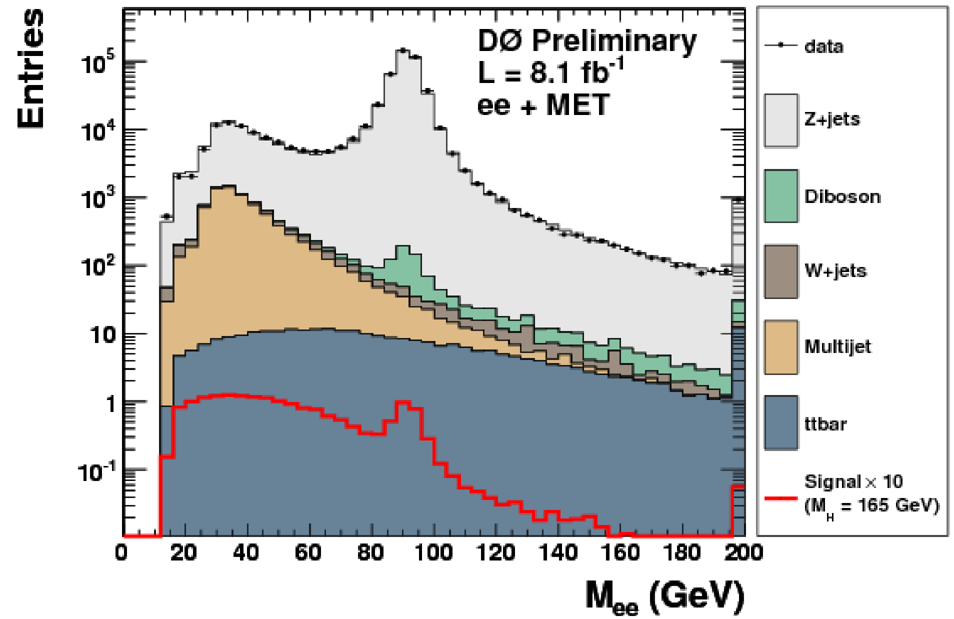
- Lepton flavor: ee, eμ, μμ (DØ)
- Signal purity based on lepton quality (CDF)
- Low (<16 GeV) di-lepton mass (OS channel at CDF)
  - Different instrumental (fake) background
  - Different lepton momentum resolution
    - typically 4% for electrons, 10% for muons at D0
  - Different background composition





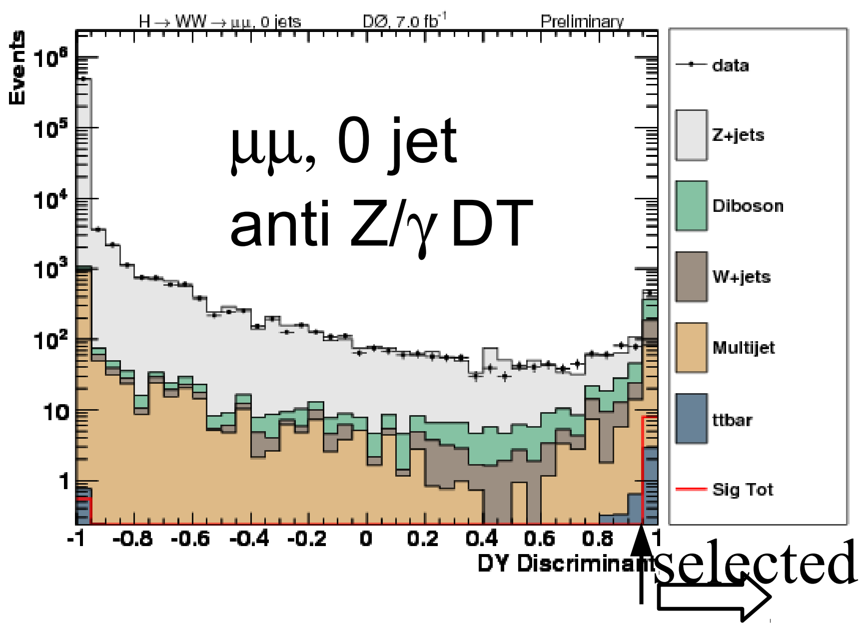


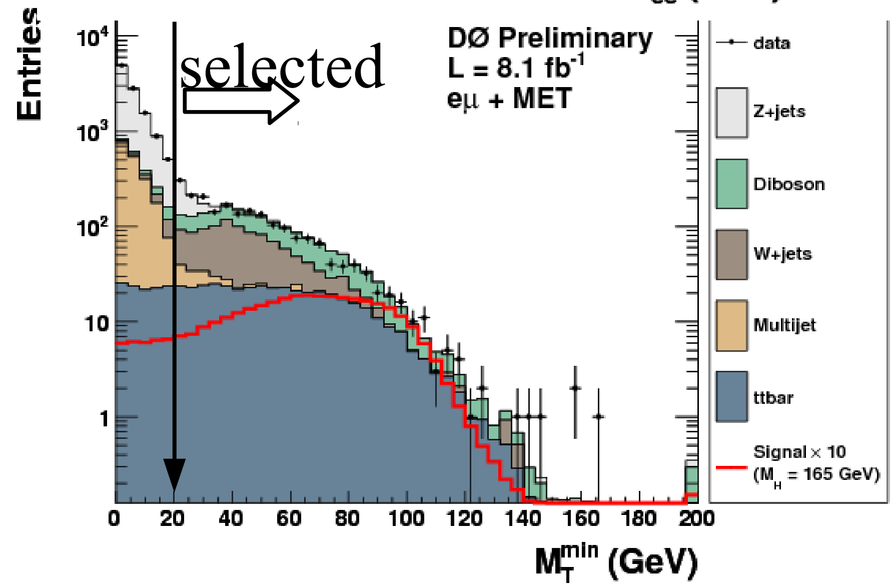
Di-lepton (OS) + $\not{E}_T$ selection



Get rid of the dominant Z/γ background.

- Use kinematics, in particular $\not{E}_T$ based variables that ensure $\not{E}_T$ is significant and not due to mismeasured object.
- DØ (ee, μμ) employs Decision Trees trained against Z/γ



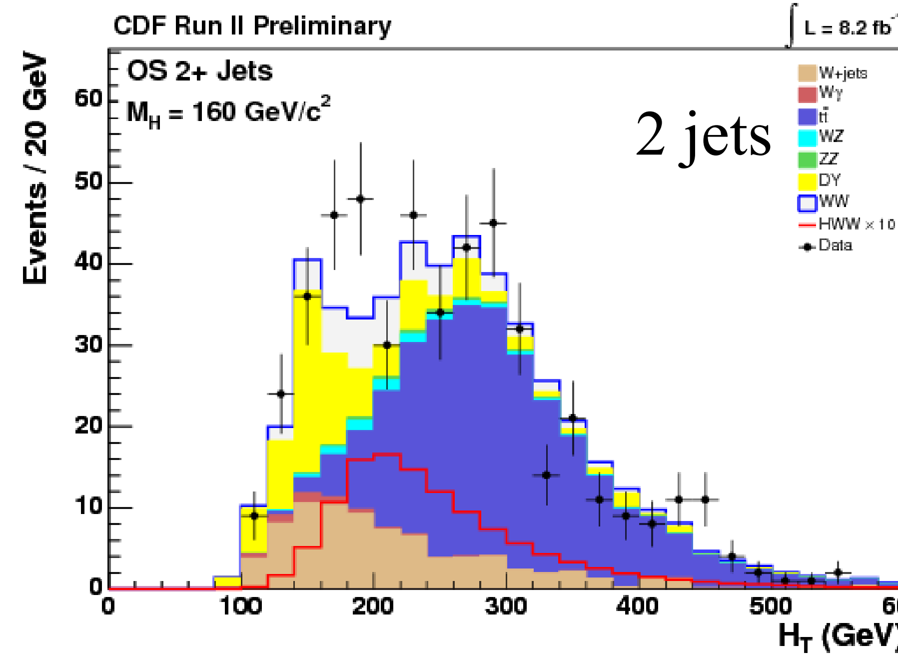


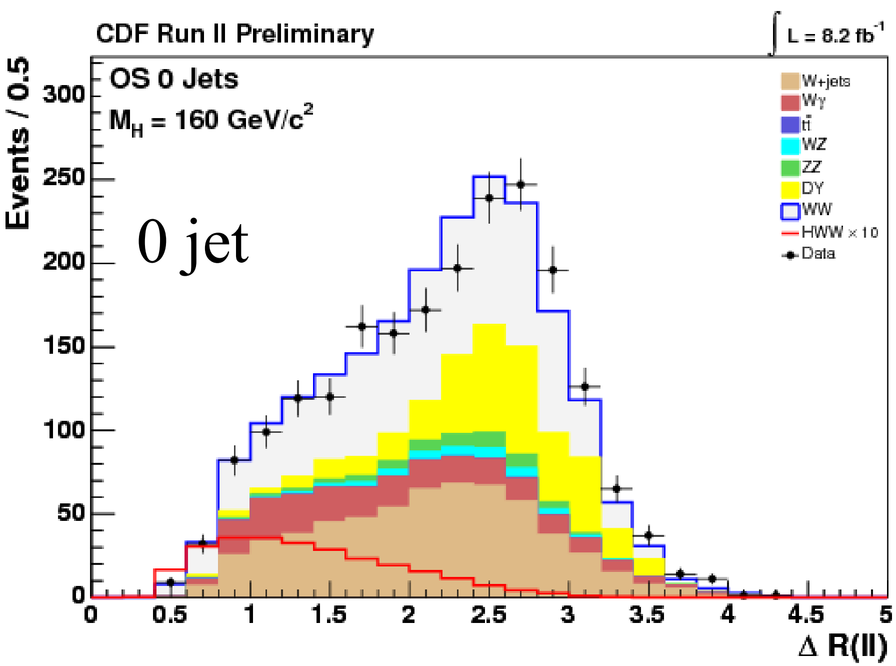
- Typically: - O(1000) events remains at this stage for each sub-selection
  - S/B is of order O(1/100)

Di-lepton + $\not{E}_T$ (OS) : More subchannels

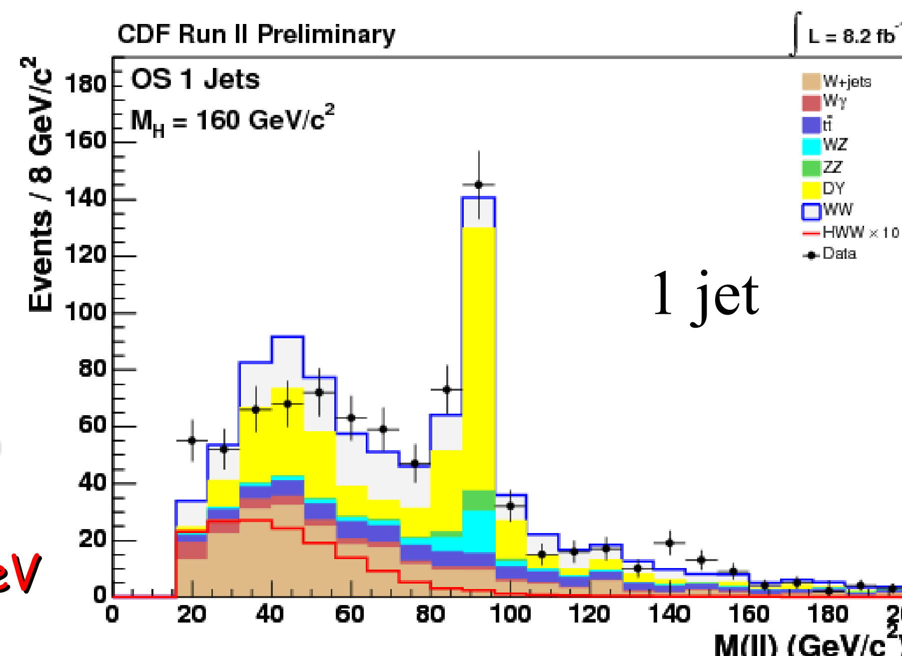
Split according to jet multiplicity

- Better sensitivity to H+jets final states: qqH, WH, ZH (important for low mass)
- Each multiplicity bin correspond to a different dominant background.
  - 0 jet: WW
  - 1 jet: WW + Z/γ
  - ≥2 jets: top pairs



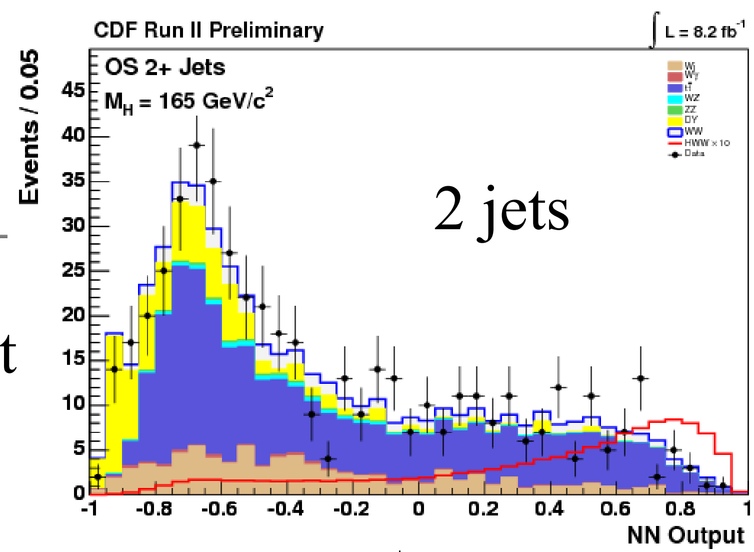


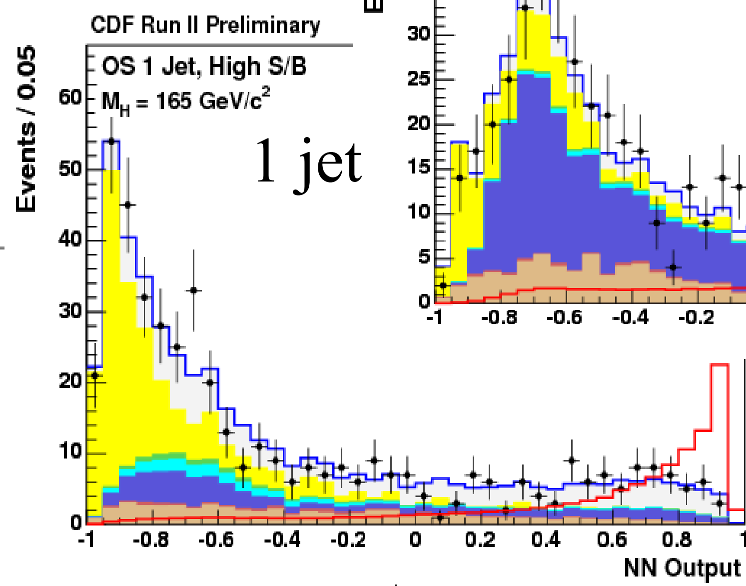
m_H=160 GeV

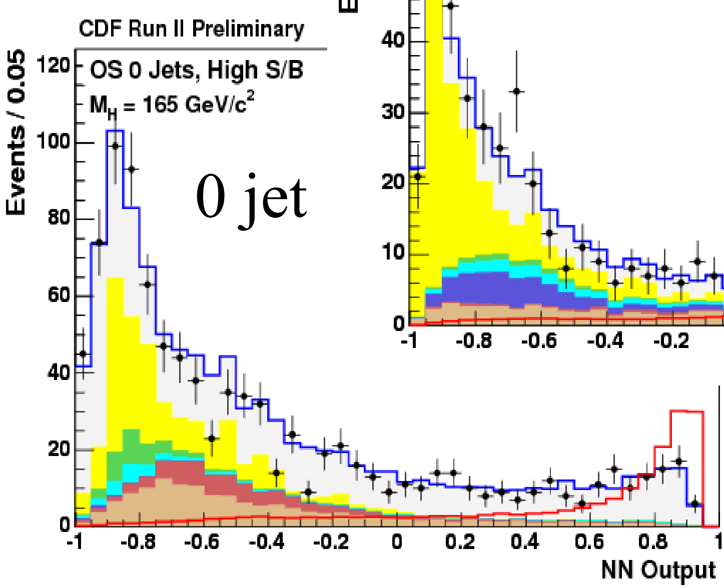


OS channels: multivariate analysis

- MVA optimized for each sub-channel and mass hypothesis.
- Input variables: event topology, lepton kinematics, quality of leptons, jet content, Matrix Element discriminant, relation between lepton and $\not{E}_T$, relation between jets and $\not{E}_T$
- Output discriminant is the input for statistical analysis of data



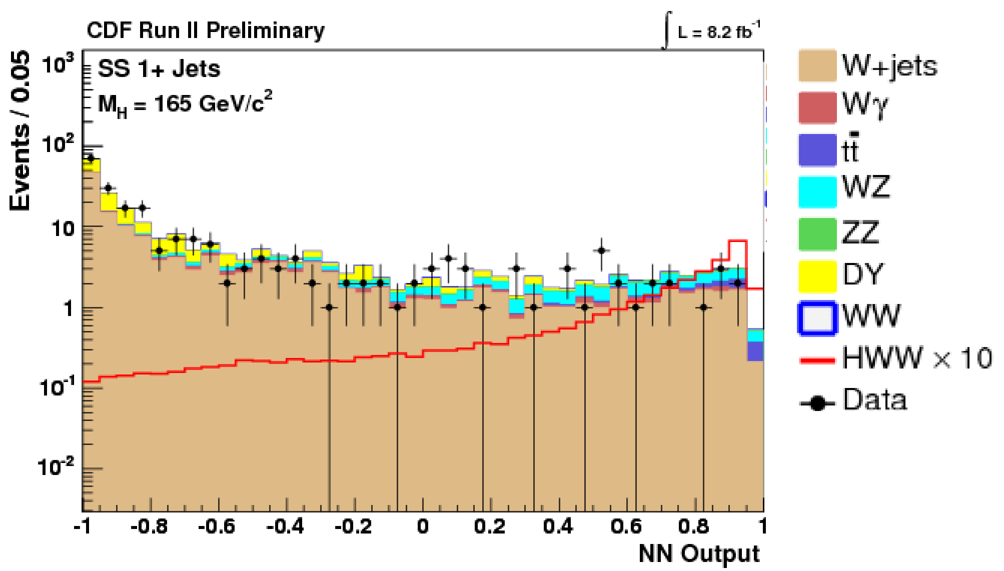


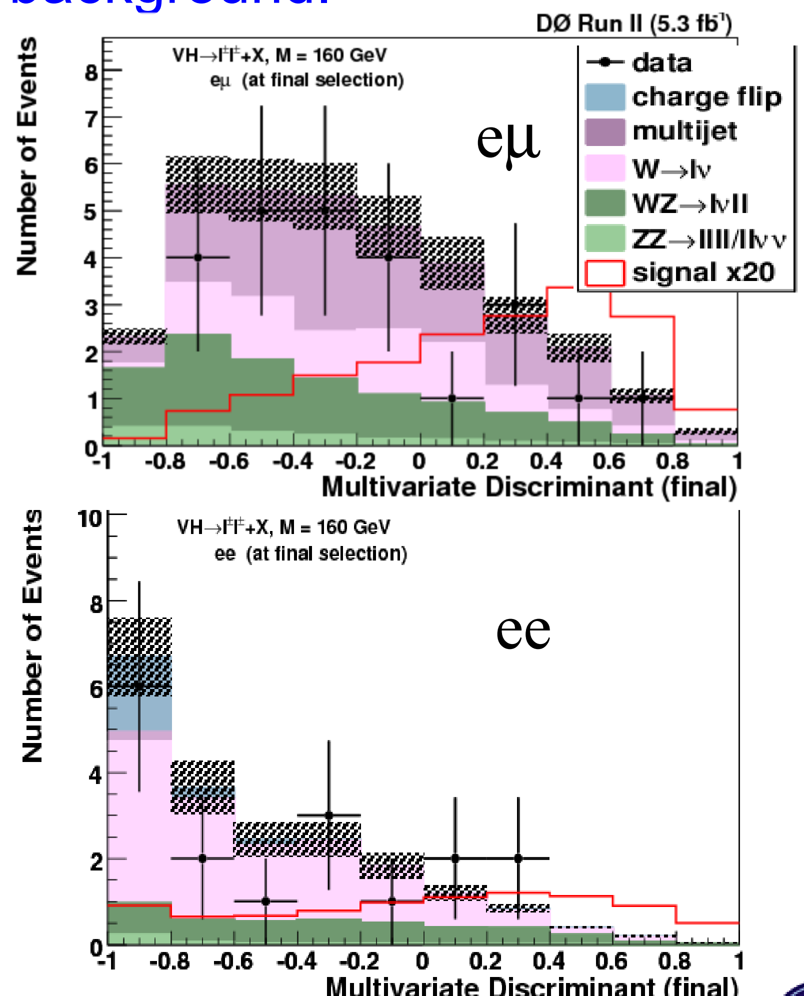


No excess above background
→ derive limits

Like-sign leptons : multivariate analysis

- Final multivariate (BDT, NN) discriminants to analyze data
  - Exploit: Event topology, lepton kinematics, jet content, relation between lepton and $\not{E}_T$
  - Two steps at DØ: against instrumental background
    against physics background.





No excess above background → derive limits

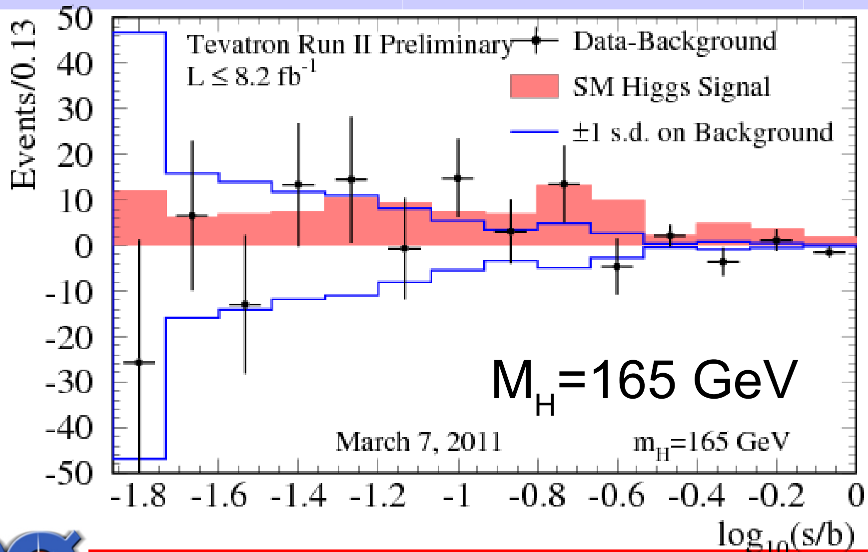
Systematic uncertainties

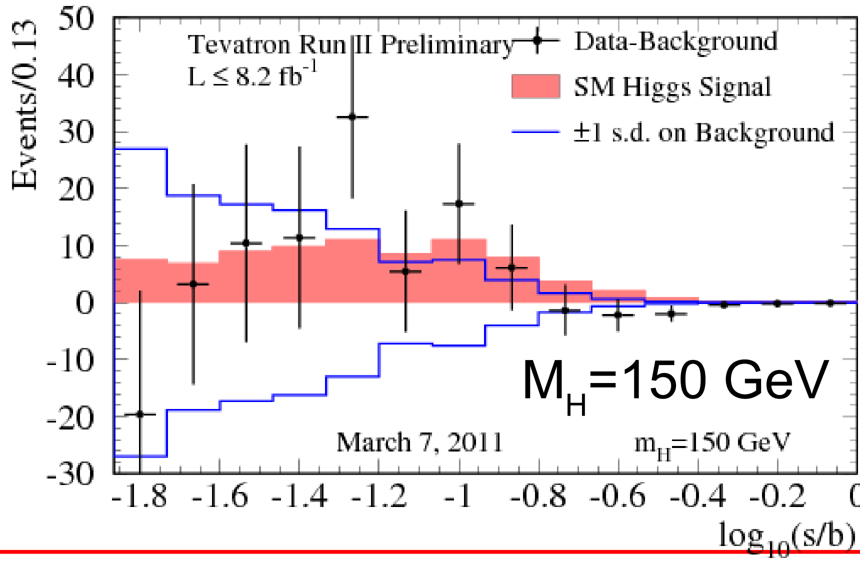
Main systematics	Signal	Bkg
Lepton id +trigger	2-5%	2-5%
Lepton/jet fakes	-	14-50%
charge mis-id		20-40%
Luminosity	5.9%	6.1%
Jet calibration	5-17%	3-30%
$\not{E}_T$ modeling	~20%	~20%
pT(Z) pT(W) pT(WW)pT(H)	1.5%	1-5%
Cross-sections	(VBF,VH) 5-10%	6-10%
gg → H production Scale PDF	(jet dependent) 7-33% 7.6-30%	-

Uncertainties have a sizable impact

- Flat : affect overall normalization
- Shape: modify output of final discriminant
- Have to account of correlations among channels and experiments
- Impact is reduced thanks to constraints from background dominated region
- Degrade sensitivity by ~15-25%

Goal to reduce uncertainties on background in particular to gain sensitivity for lower masses.





Results from both experiments

CDF and DØ achieved single experiment sensitivity in winter 2011

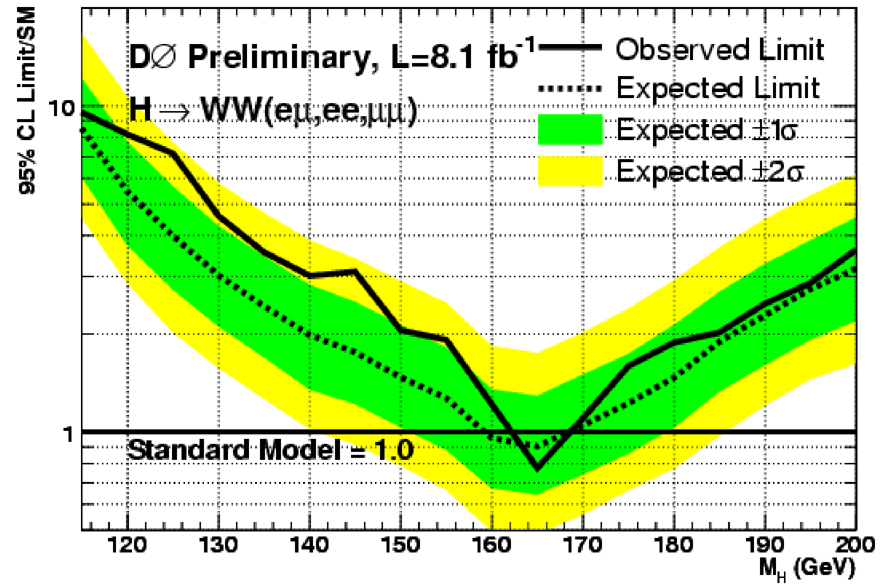
- DØ, 8.1 fb^{-1}, OS di-lepton

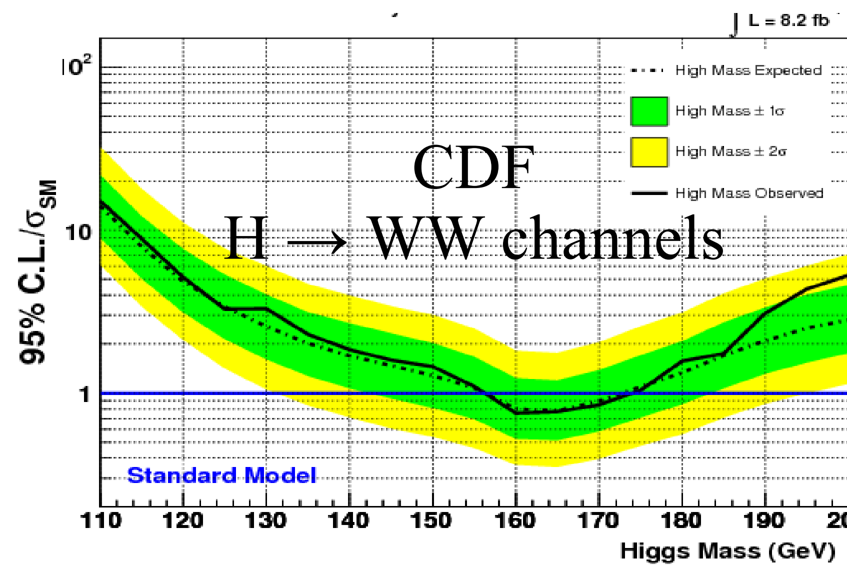
95% CL expected sensitivity range	
Winter 11	Summer 11
[~162,~165] GeV	[~159,~169] GeV

- CDF all WW channels

95% CL expected sensitivity range	
Winter 11	Summer 11
7.1 fb^{-1}	8.2 fb^{-1}
[~160,~167] GeV	[~156,~173] GeV

- Sensitivity continue to increase faster than just by adding more data.





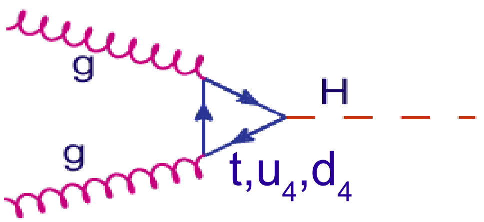
Limit for m_H=165 GeV

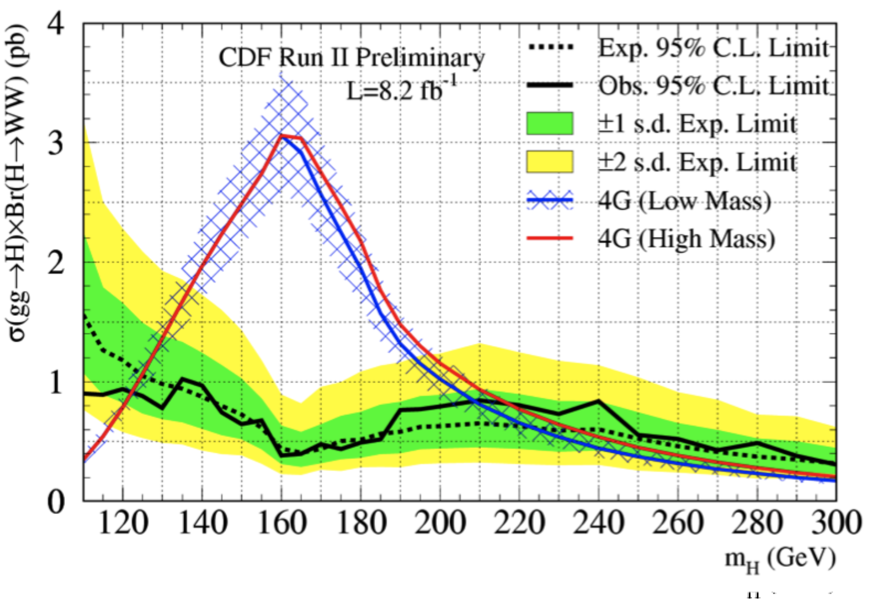
DØ OS di-lepton 8.1 fb^{-1} : $\sigma_{95}/\sigma(SM)$ =0.78 (0.90 expected (0.97 in winter))

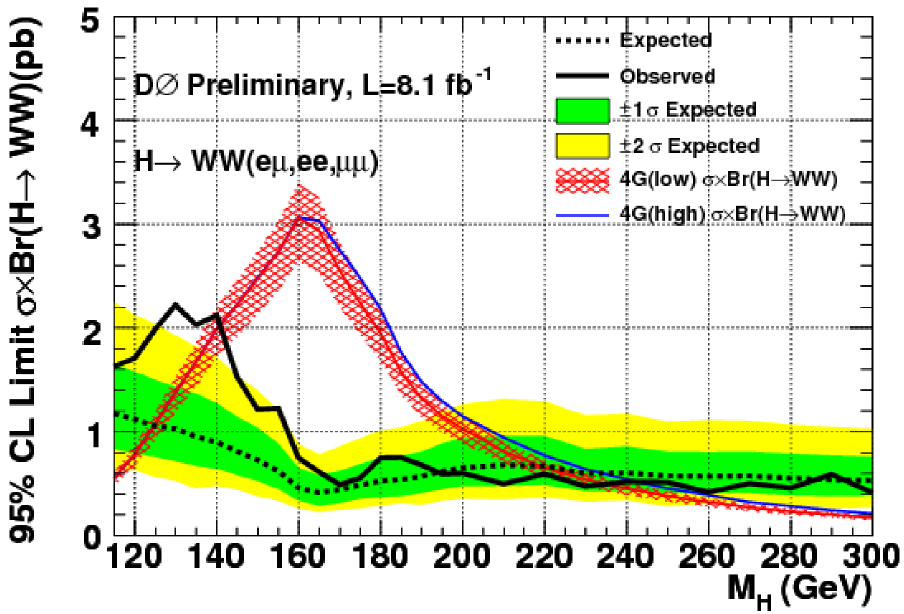
CDF H → WW 8.2 fb^{-1} : $\sigma_{95}/\sigma(SM)$ =0.77 (0.78 expected (0.93 in winter))

Higgs search within 4^{th} generation model

- New heavy generation of quarks
  - ggH coupling is multiplied by 3 compared to SM
  - Production is enhanced by 9
- Search in di-lepton +MET channel can be recycled
  - Some analysis tuning required because of extended mass reach (eg $\Delta\phi(l,l)$ cut not applicable when W's are boosted)







CDF only 8.2 fb^{-1} (summer 11) $123<m_H<215$ GeV @95%CL
DØ only 8.1 fb^{-1} (summer 11) $140<m_H<240$ GeV @95%CL

Conclusion

$H \rightarrow WW$ di-lepton channels are scrutinized by both CDF and DØ

- Sensitivity to Higgs boson around 165 GeV is achieved by each single experiment since winter 2011
- Sensitivity is still increasing faster than luminosity thanks to analysis improvements
- Able to probe 4th generation models

Have to focus on analysis improvements

- Tevatron will shut down in September
  - Cannot just « wait and see » new data
- More acceptance, more channels, reduced systematic uncertainties
- Goal to increase $H \rightarrow WW$ reach at lower masses ~130 GeV
- $H \rightarrow WW$ will help covering "low mass" ranges for the Higgs Searches

Di-lepton modes are part of the combined CDF/DØ results

- See next talk for the contributions of other decay modes
- See forthcoming parallel and plenary talks for combined results

Backup slides

gg →H (μ_R,μ_F) scale uncertainties

- Vary independently ggH +0jet, ggH+1jet, ggH+2jets scale uncertainties (s0, s1,s2).
- Account for migration between jet multiplicity bin.

	s0	s1	s2
0 jet	0.134	-0.230	0.0
1 jet	0.0	0.35	-0.127
2+jet	0.0	0.0	0.33

DØ and CDF limits

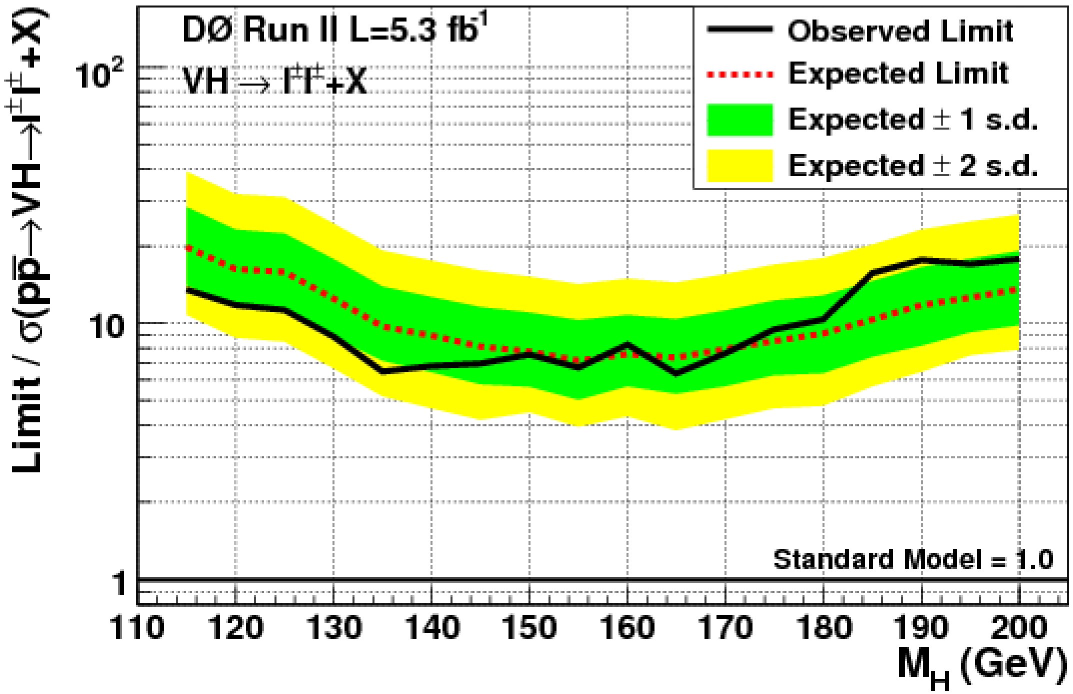
D0 H → WW opposite signs di-leptons
8.1 fb^{-1}

$M_H=$	115	120	125	130	135	140	145	150	155	160	165	170	175	180	185	190	195	200
Exp. all:	8.52	5.46	3.99	3.01	2.43	1.98	1.76	1.47	1.27	0.96	0.90	1.05	1.22	1.46	1.89	2.28	2.74	3.16
Obs. all:	9.54	8.18	7.14	4.59	3.55	3.01	3.10	2.05	1.92	1.22	0.78	1.10	1.59	1.88	2.02	2.47	2.86	3.62
Exp. $e\mu$:	13.54	8.02	5.74	4.41	3.67	2.93	2.64	2.23	1.95	1.44	1.31	1.53	1.79	2.22	2.73	3.40	3.91	4.78
Obs. $e\mu$:	21.34	12.77	13.72	7.74	5.76	4.52	3.66	2.67	2.10	1.21	1.10	1.68	1.98	2.79	3.00	3.91	3.83	4.73
Exp. ee:	18.97	13.25	9.22	7.01	5.44	4.55	3.90	3.37	2.84	2.18	2.08	2.28	2.78	3.26	4.10	5.04	6.05	6.77
Obs. ee:	12.20	13.69	8.36	8.54	5.72	6.41	6.06	4.39	4.58	3.23	2.62	2.96	3.42	3.13	4.09	4.74	6.17	7.62
Exp. $\mu\mu$:	19.09	13.15	9.28	6.71	5.49	4.41	3.87	3.37	2.78	2.17	2.18	2.60	2.96	3.50	4.56	5.30	6.41	7.39
Obs. $\mu\mu$:	26.09	15.95	11.13	7.77	7.02	6.05	7.17	5.06	4.66	3.60	2.15	2.47	4.35	4.69	5.58	5.71	8.89	10.29

CDF H → WW, 8.2 fb^{-1}

High Mass	110	115	120	125	130	135	140	145	150	155	160	165	170	175	180	185	190	195	200
$-2\sigma/\sigma_{SM}$	6.15	3.39	2.12	1.41	1.05	0.84	0.71	0.61	0.54	0.46	0.36	0.35	0.40	0.47	0.56	0.71	0.86	0.99	1.14
$-1\sigma/\sigma_{SM}$	8.96	5.03	3.13	2.14	1.61	1.27	1.07	0.93	0.81	0.69	0.52	0.51	0.58	0.71	0.85	1.07	1.31	1.54	1.75
Median/σ_{SM}	**14.03**	**7.86**	**4.86**	**3.38**	**2.57**	**2.01**	**1.69**	**1.48**	**1.27**	**1.07**	**0.80**	**0.78**	**0.89**	**1.09**	**1.33**	**1.70**	**2.09**	**2.49**	**2.81**
$+1\sigma/\sigma_{SM}$	21.81	12.11	7.63	5.31	4.02	3.12	2.68	2.33	2.02	1.66	1.24	1.19	1.38	1.70	2.08	2.71	3.34	4.01	4.59
$+2\sigma/\sigma_{SM}$	32.42	17.85	11.08	7.68	6.00	4.64	3.97	3.40	3.02	2.48	1.82	1.77	2.04	2.56	3.11	4.08	5.04	5.99	7.09
Observed/σ_{SM}	**15.07**	**8.82**	**5.12**	**3.28**	**3.29**	**2.28**	**1.85**	**1.59**	**1.45**	**1.09**	**0.75**	**0.77**	**0.84**	**1.04**	**1.57**	**1.75**	**3.08**	**4.34**	**5.26**

SS channel

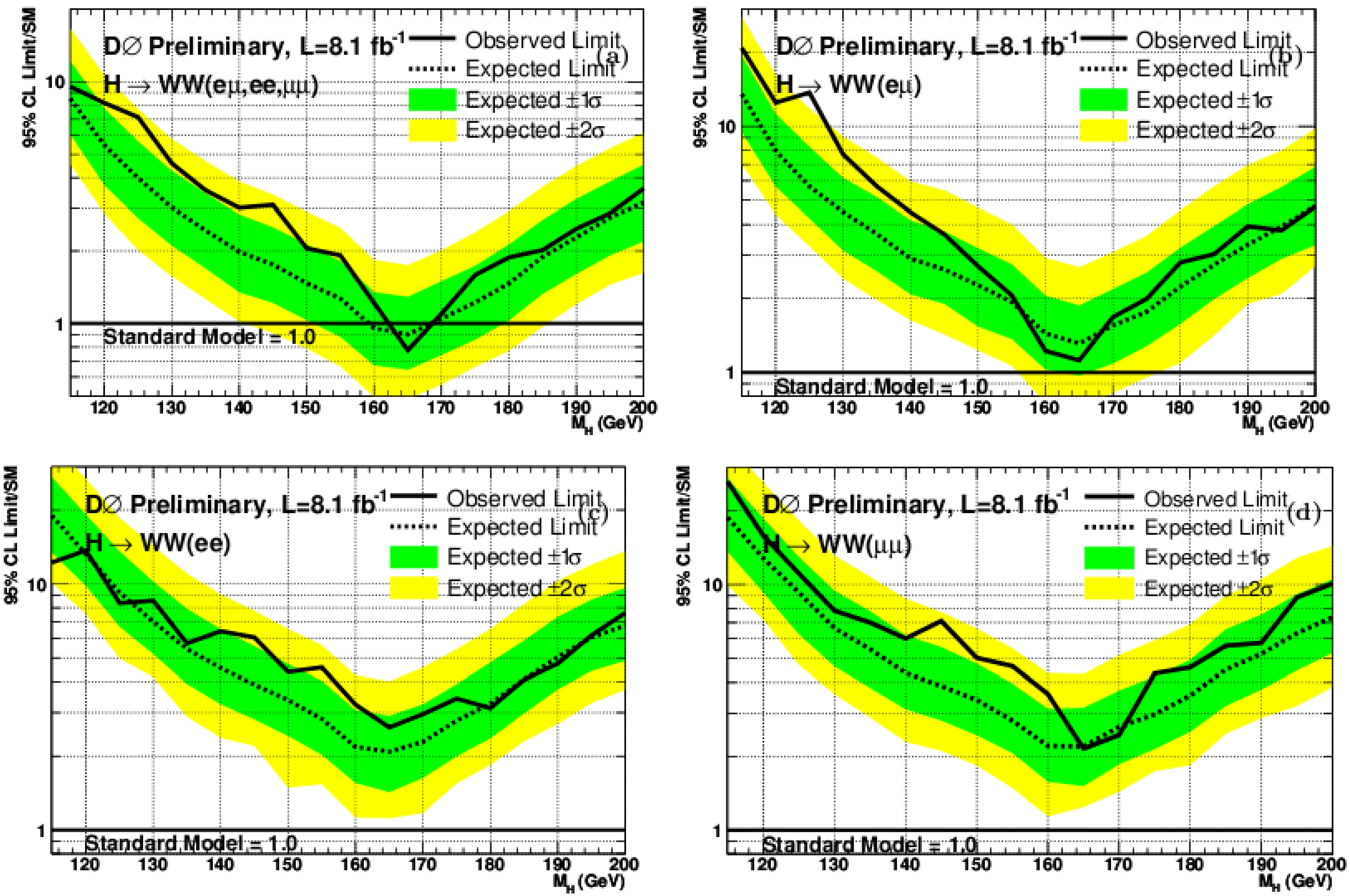


Limit for m_H=165 GeV

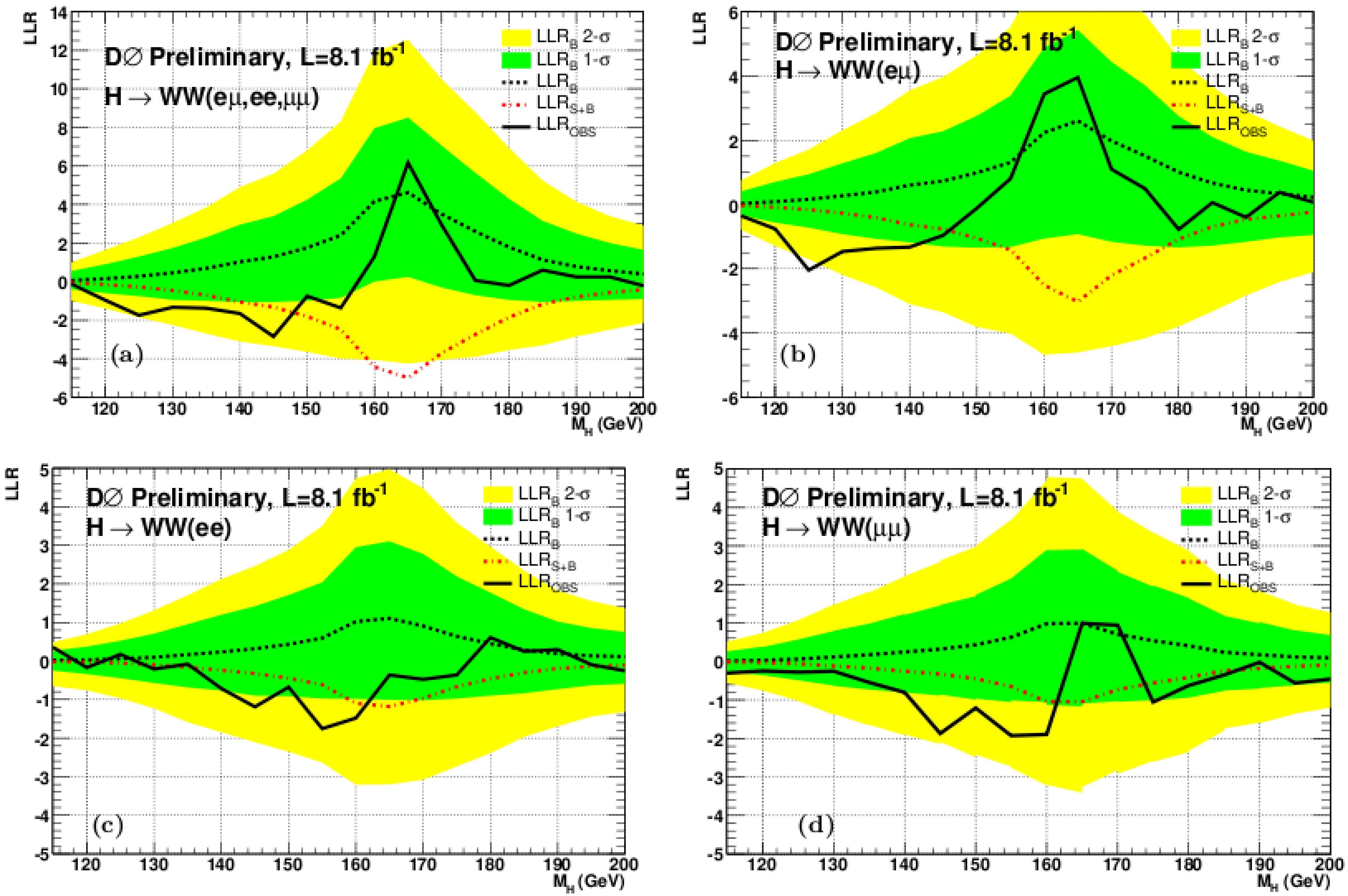
DØ 5.3 fb^{-1} : $\sigma_{95}/\sigma(SM)$ =6.4 (7.3 expected)

CDF 8.2 fb^{-1} : $\sigma_{95}/\sigma(SM)$ =3.7 (4.3 expected)

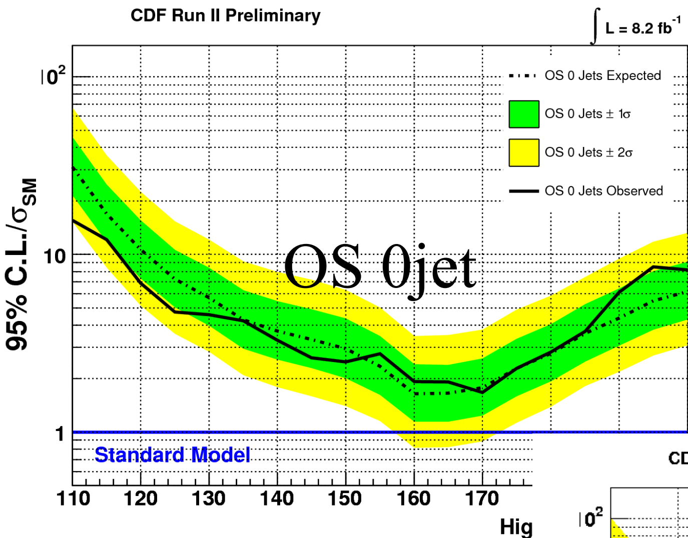
DØ OS subchannels

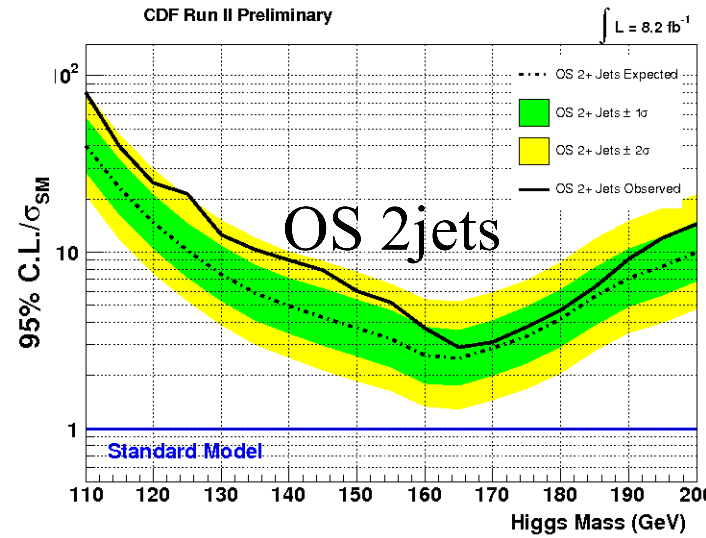


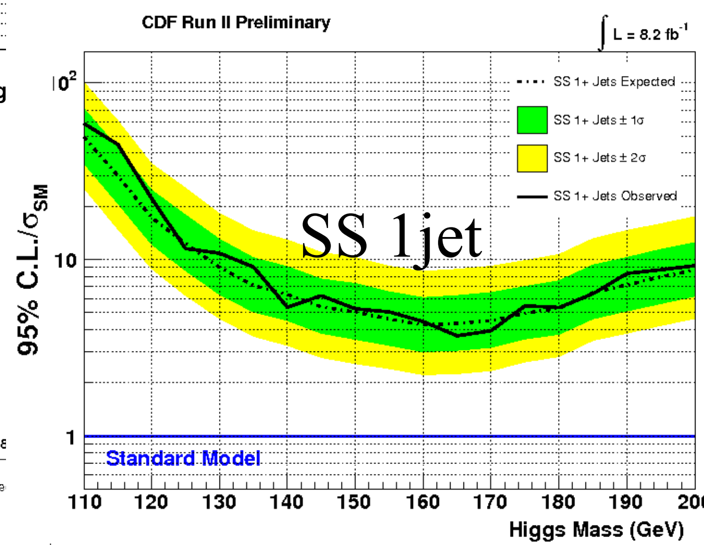
DØ OS subchannels

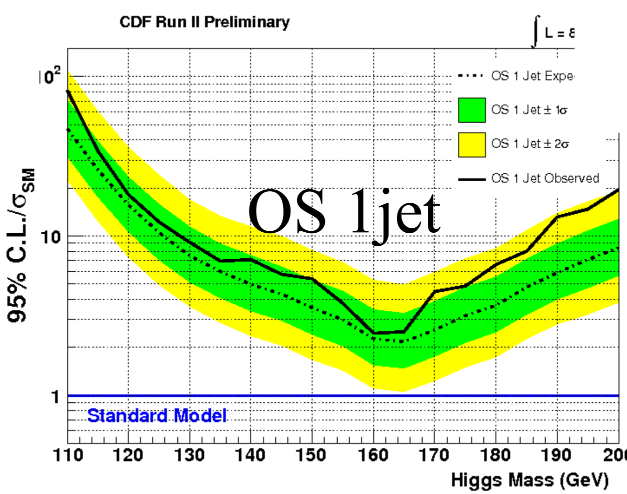


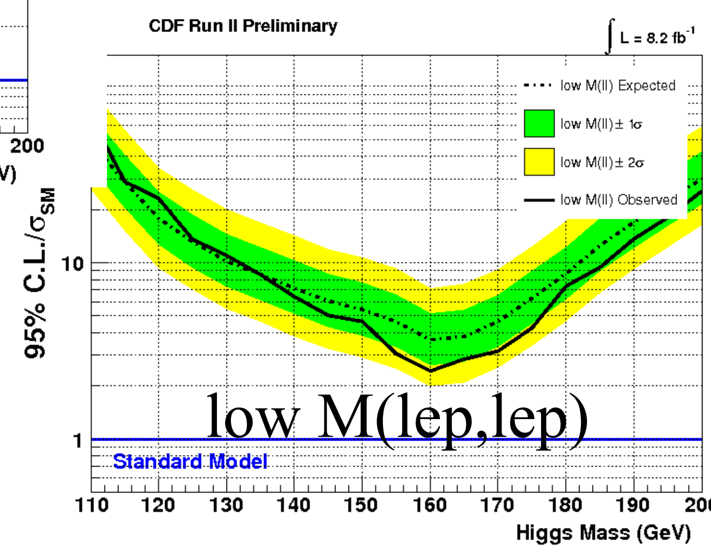
CDF subchannels







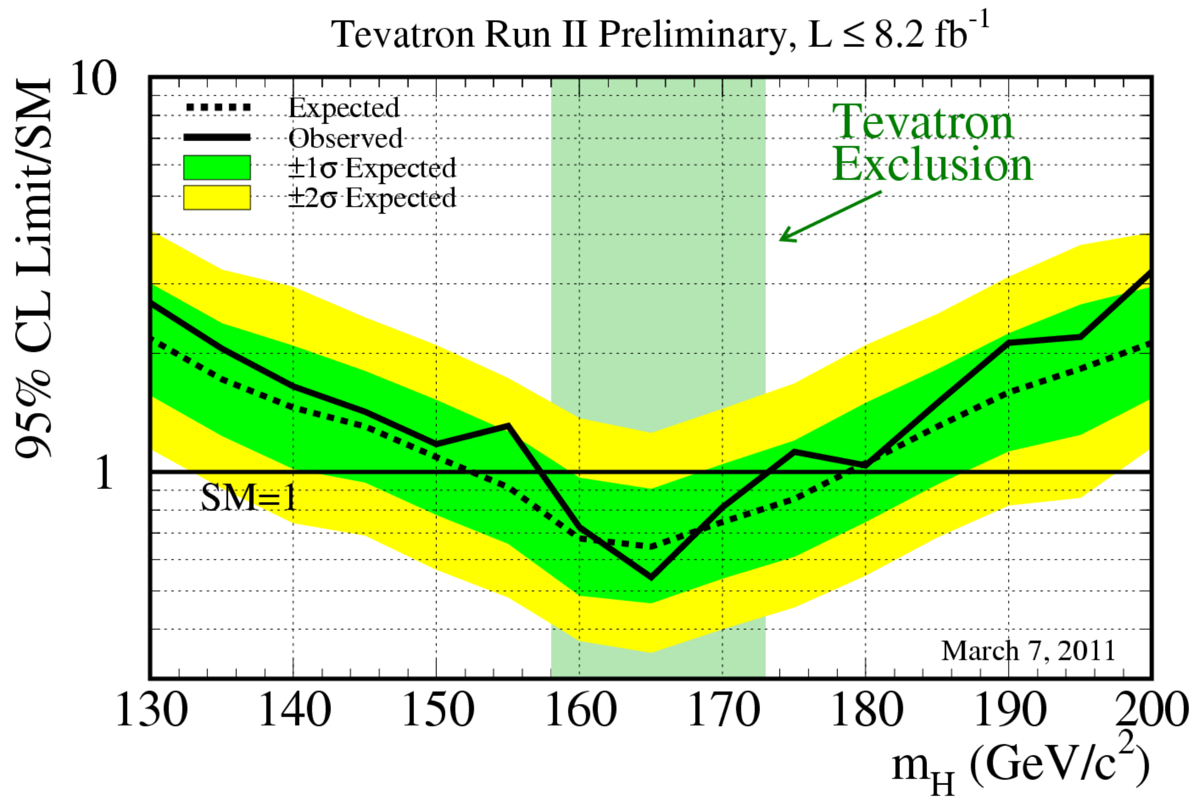


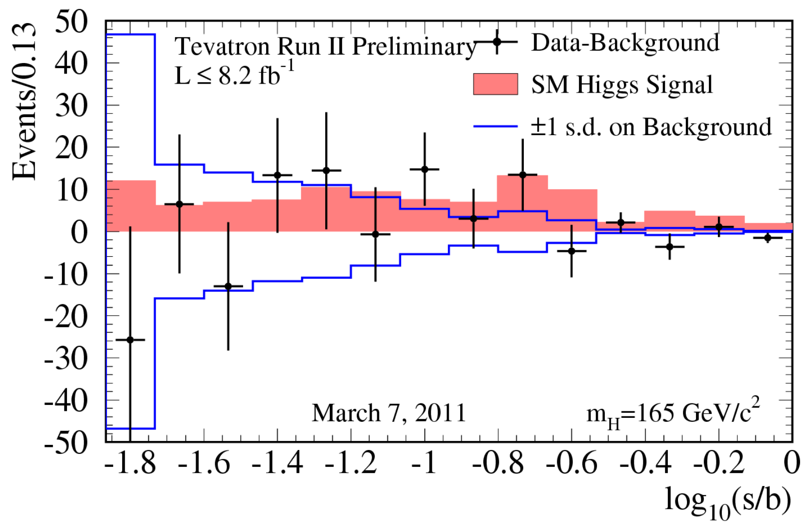


Combined update for high mass (Winter 2011)

High mass channels able to exclude SM Higgs @ 95% CL

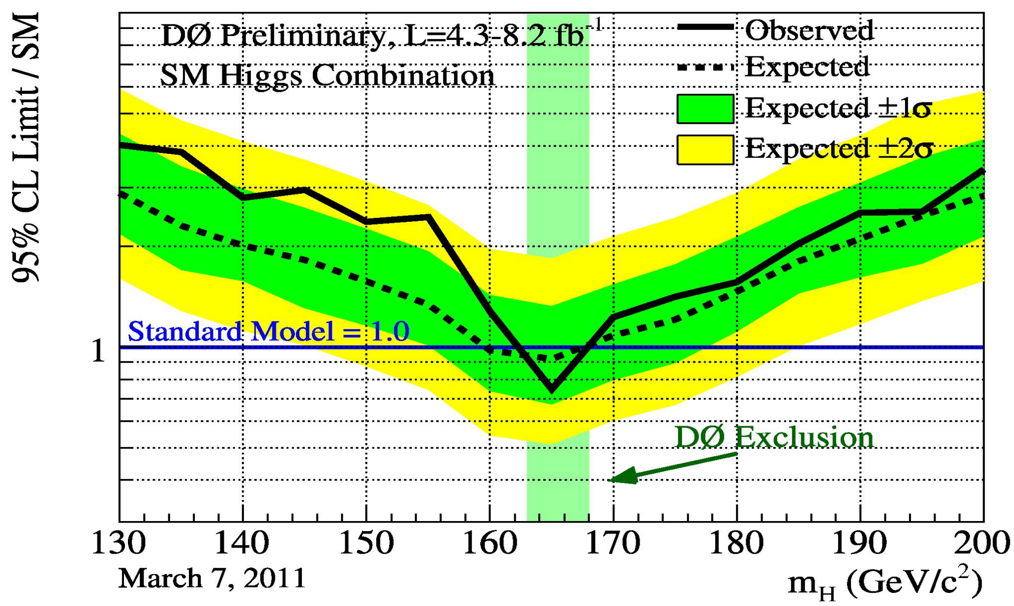
$158<m_H<173$ GeV is excluded
expected sensitivity $153<m_H<179$ GeV

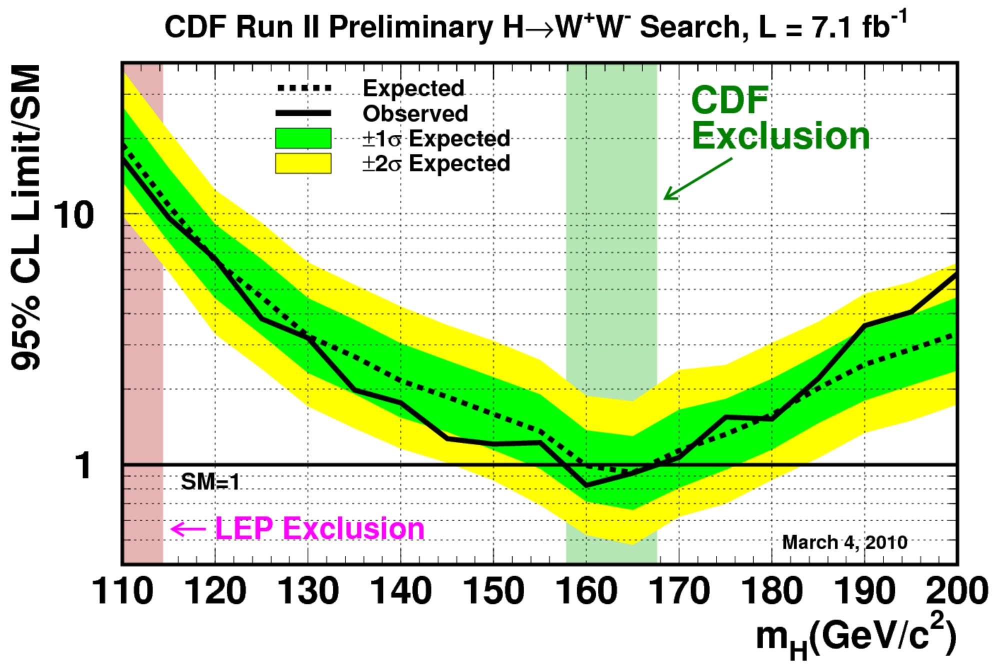




Status in Winter 2011

Each experiment has reached SM Higgs sensitivity

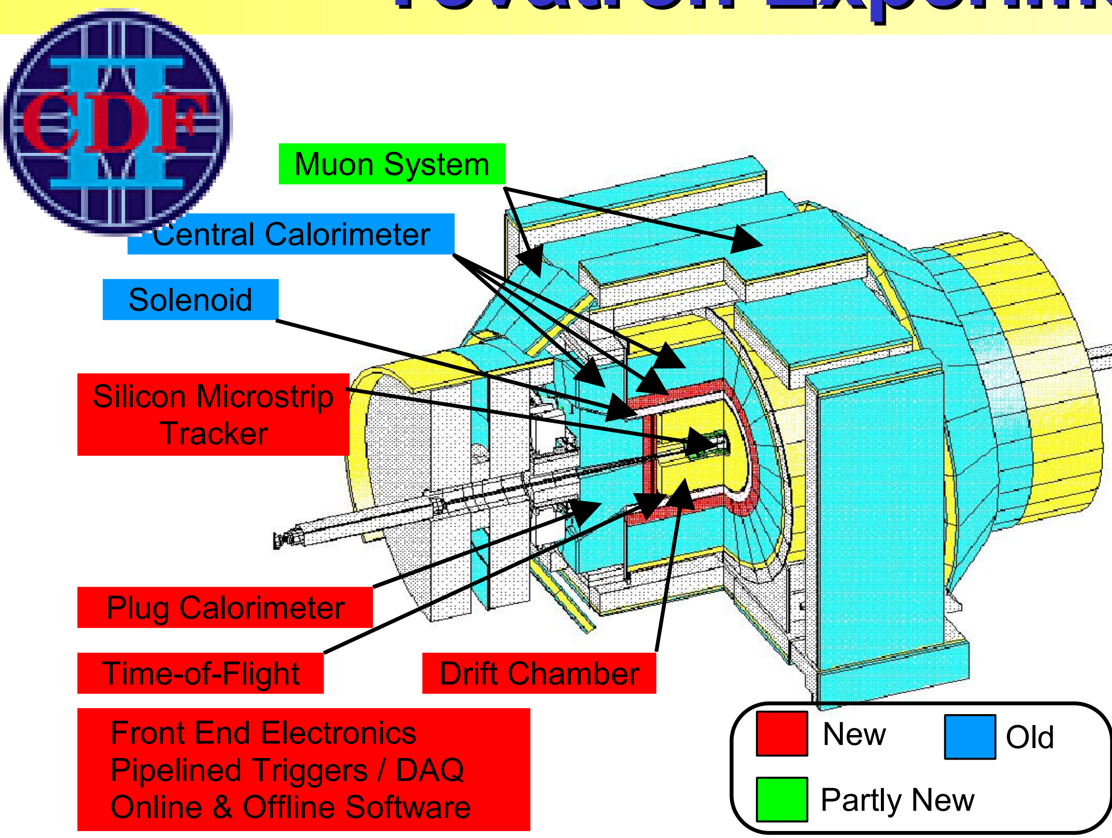


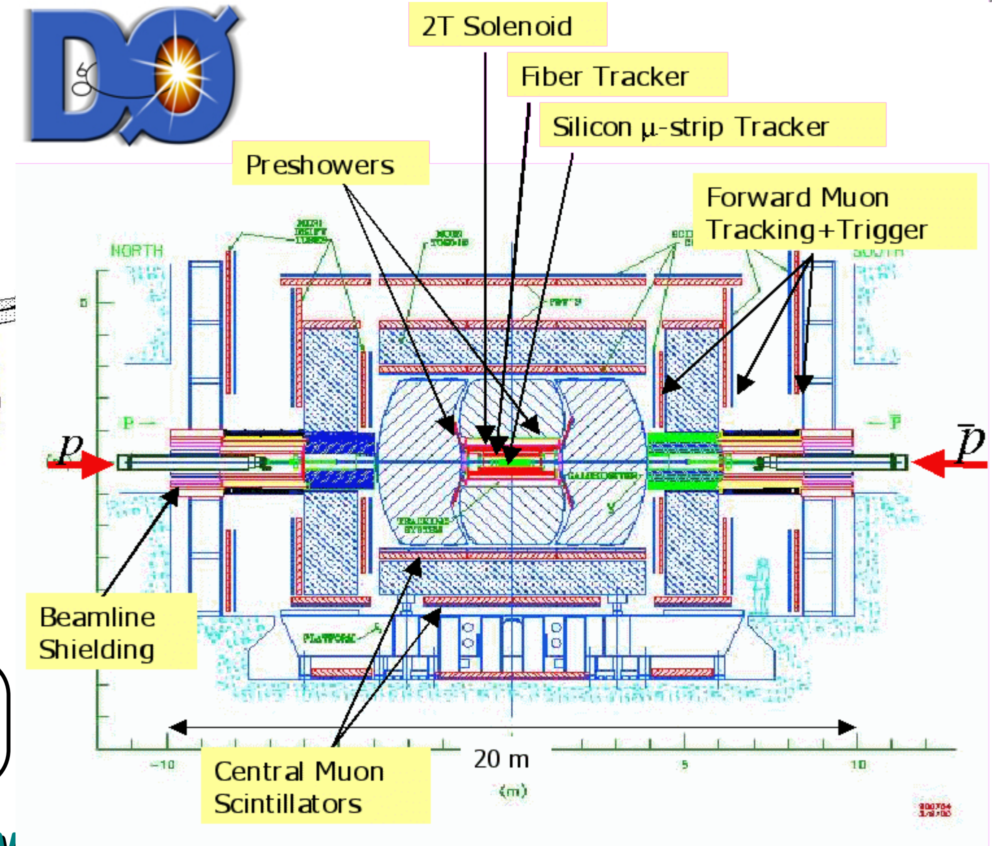


163<m_H<168 GeV is excluded
expected sensitivity 160<m_H<168 GeV

158<m_H<168 GeV is excluded
expected sensitivity 159<m_H<168 GeV

Tevatron Experiments at RunII





New

- silicon detector
- Drift chamber
- TOF PID system

Upgraded

- Calorimeter
- DAQ/trigger
- displaced-vertex trigger

New

- Tracking in B-field
- Silicon detector
- fiber tracker

Upgraded

- Calorimeter, muon system
- DAQ/trigger
- RunIIb: Silicon layer 0, Cal Trigger

Scale Variations (μ_R & μ_F)

- Is our treatment of assessing cross section uncertainties due to scale variations reasonable?
- We obtain our gluon fusion production cross sections from:

  D. de Florian, M. Grazzini, Phys. Lett. **B674**, 291-294 (2009). [arXiv:0901.2427 [hep-ph]].

  C. Anastasiou, R. Boughezal, F. Petriello, JHEP **0904**, 003 (2009). [arXiv:0811.3458 [hep-ph]].
- We use a scale variation of a factor of 2 from the central value ($\mu=m_H/2$) to estimate the magnitude of potential contributions from higher-order processes
- The authors confirmed that higher order corrections to these cross sections are small and that the standard $\kappa=2$ scale variations are perfectly reasonable for assigning uncertainties
- Another recent, independent publication argues for even smaller scale uncertainties than those being currently assigned in our searches:

  V. Ahrens, T. Becher, M. Neubert *et al.*, Eur. Phys. J. **C62**, 333-353 (2009). [arXiv:0809.4283 [hep-ph]];

  V. Ahrens, T. Becher, M. Neubert *et al.*, [arXiv:1008.3162 [hep-ph]].
- **Yes, our treatment is sufficient and supported by the theoretical community**

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Additional Theoretical Uncertainties

- Should there be an additional theoretical uncertainty assigned to our gluon fusion cross sections coming from the effective field theory (EFT) approach used to integrate electroweak contributions from heavy and light loop particles?
- Such an uncertainty is already included:

  C. Anastasiou, R. Boughezal, F. Petriello, JHEP **0904**, 003 (2009). [arXiv:0811.3458 [hep-ph]].

- Uncertainties on the gluon fusion cross section used in Tevatron Higgs searches incorporate a ~2% level component to account for this effect
- The same authors find that when they entirely remove corrections from light quark diagrams (clearly too conservative), the total cross section changes by less than 4%
- **Our current treatment of EFT effects is on solid ground**

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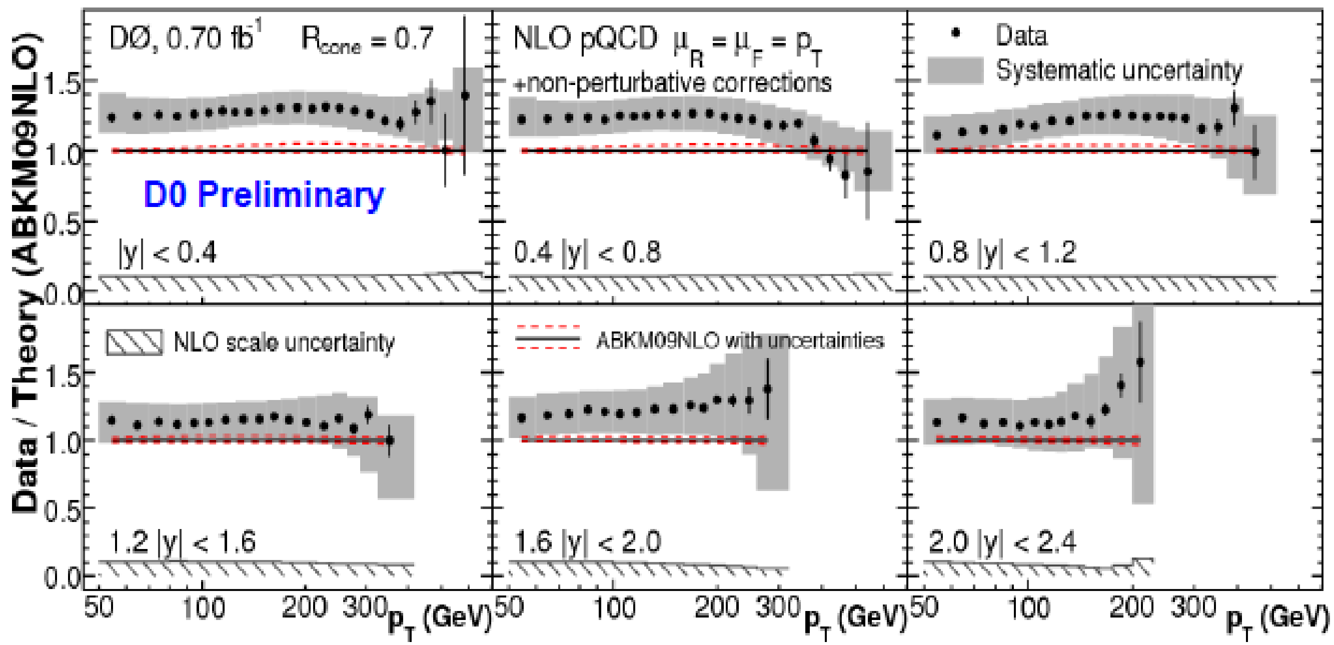
PDF Uncertainties

- Should our PDF uncertainties account for observed differences in cross sections obtained using our default MSTW model and ABKM/HERAPDF models?
- See Juan Rojo's talk on "Recent Developments and Open Problems in Parton Distributions" in the Tuesday afternoon session
- ABKM09 & HERAPDFs do not include Tevatron data, which provide the best constraints on the relevant high-x gluon distributions at Tevatron energies
- A comparison of high E_T Tevatron data with ABKM09 & HERAPDF shows large disagreement:

ABKM09 at the Tevatron:
Ratio of D0 High-ET jet cross-section to ABKM09 prediction (Data vs central PDF value)

(→ Uncertainty on ABKM Prediction)



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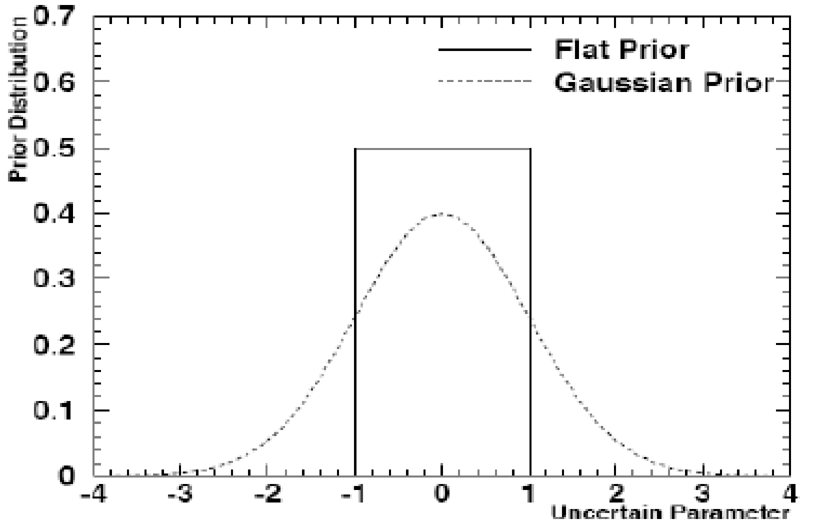
Treatment of Theoretical Uncertainties

- Most theoretical uncertainties are rather loosely stated. They are interpreted in terms of a maximum range of variations (*flat prior*)
- We treat theoretical uncertainties as gaussian (*gaussian prior*)
- Are we underestimating our uncertainties?
- We use the maximum bound as 1σ. This means we allow even larger variations than the given bounds. (See figure)
- We also tested the flat prior approach and found no significant change in our limits
- **We are not underestimating our uncertainties**



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Emulation of Tevatron Limit Calculation

- Care needs to be taken when trying to emulate Tevatron limits
- Correlations between different input channels need to be properly taken into account:
  - Our limit calculation uses these correlations to constrain the backgrounds
  - Our backgrounds are better constrained by the data, as compared to the theory. This can be viewed as a measurement of the true rate and the a posteriori uncertainty is an experimental determination of the true error.
- An estimation of the sensitivity increase due to MVA is not straightforward:
  - Our pre-selection cuts are kept as loose as possible to maximize signal acceptance and cannot be interpreted as an optimized cut-based analysis
  - MVAs are used to separate signal from background
  - To estimate MVA sensitivity gains: compare fully optimized cut-based results with MVA results
  - MVAs typically improve limits by ~30% over optimized cut-based
- Impact of theoretical uncertainties:
  - Theoretical uncertainties are statistically accounted for together with other systematics
  - Increasing theoretical cross section uncertainties is not equivalent to decreasing the central prediction

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