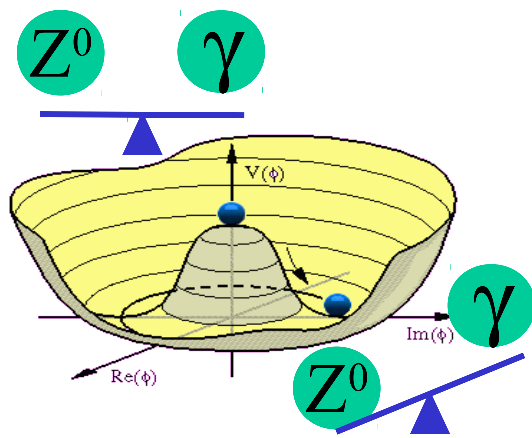
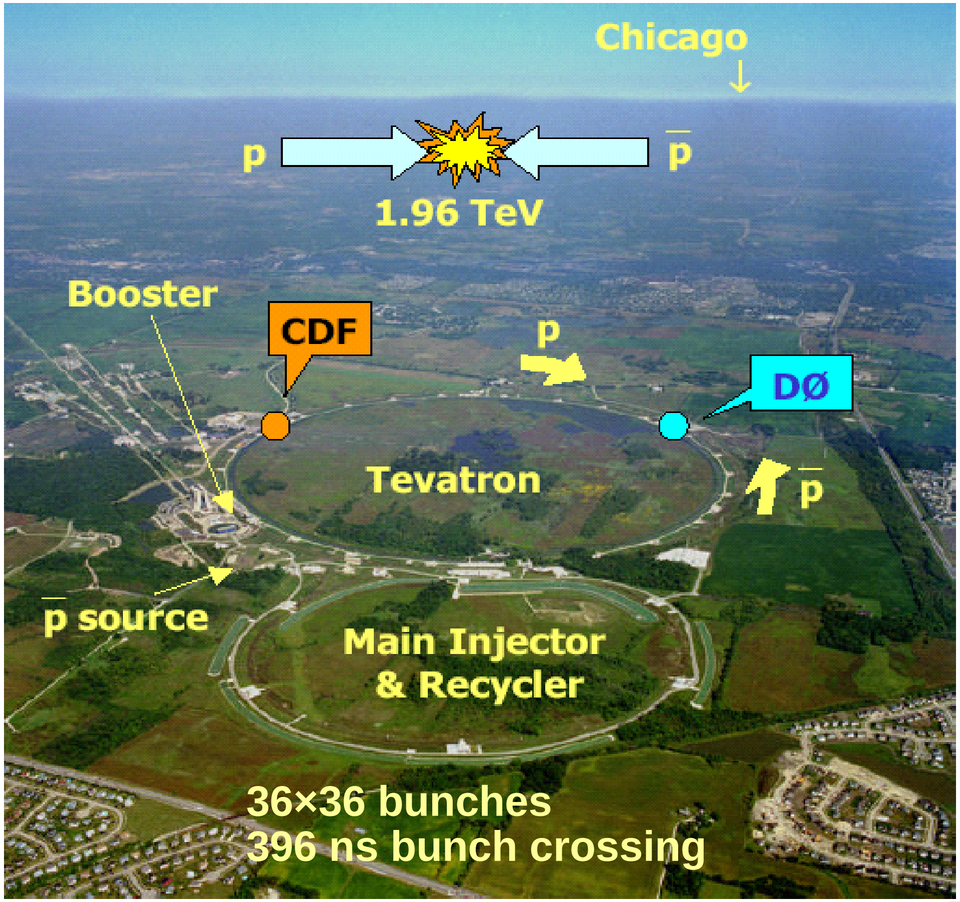
Search for high mass standard model Higgs boson at D0

Boris Tuchming - CEA Saclay
On behalf of D0 collaboration



The Tevatron



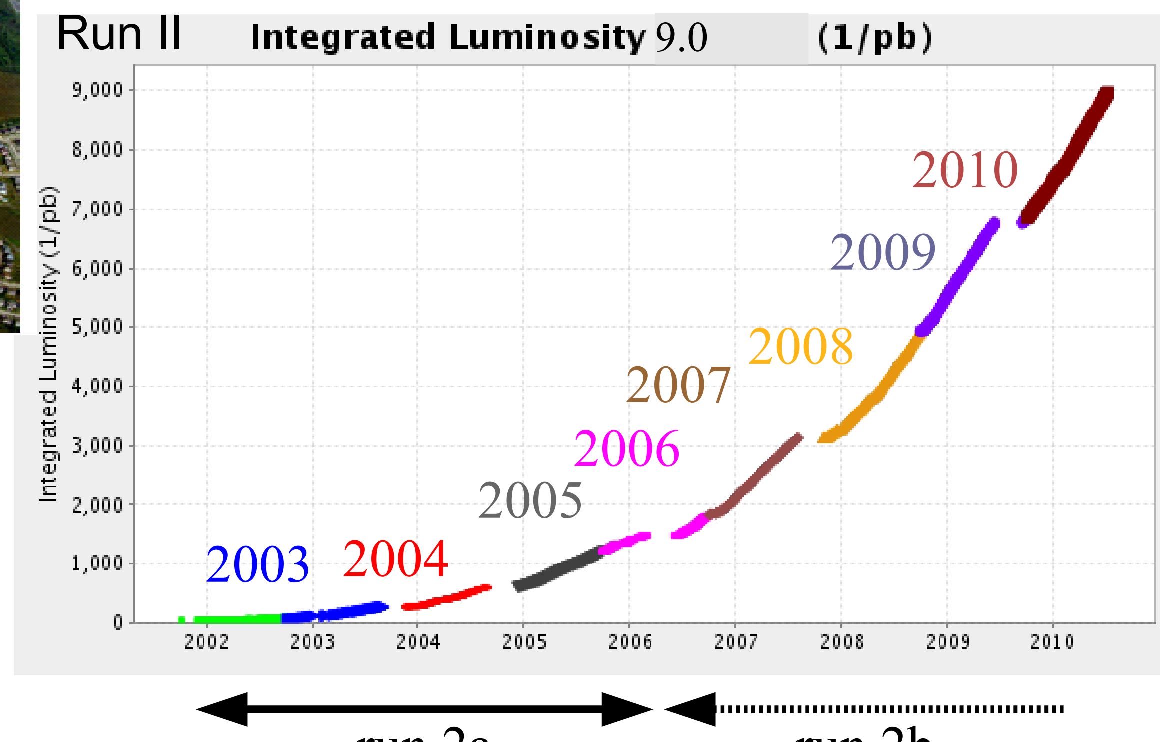
Run I (1993-1996)

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

Run II: (2002-201xx)

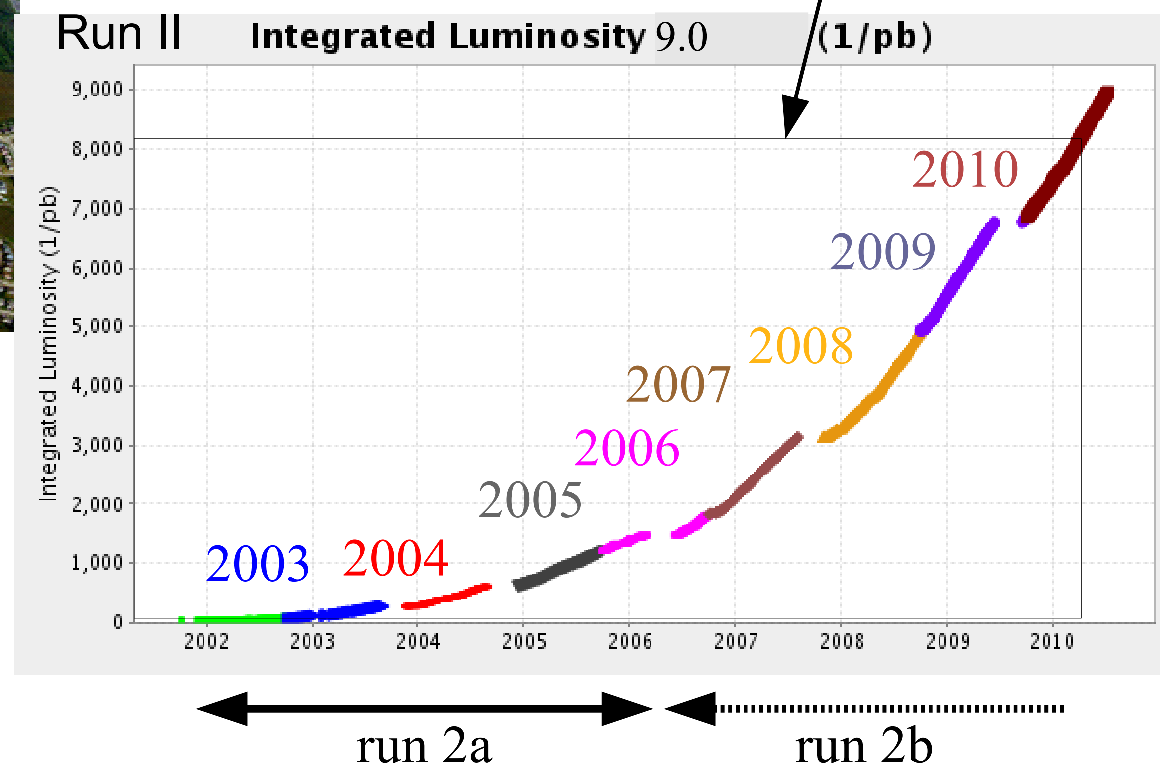
~ 9 fb^{-1} delivered per experiment

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



The Tevatron and D0

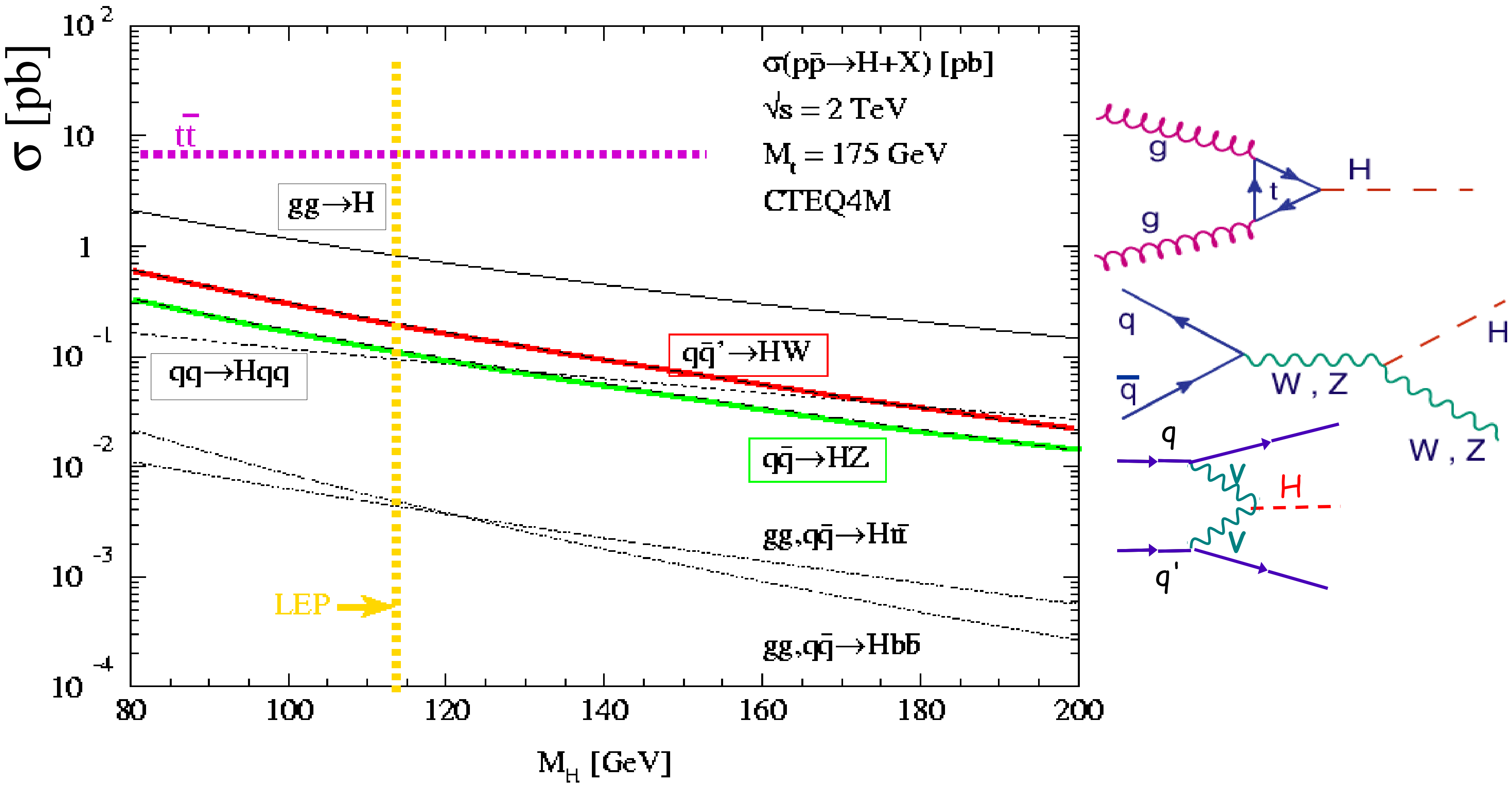
Run I (1993-1996)
~120 pb^{-1} per experiment-top quark discovery
Run II: (2002-201xx)
~ 9 fb^{-1} delivered per experiment
Tevatron now delivers >2 fb^{-1} per year
D0 most recent results are based on 6.7 fb^{-1}
(data recorded up to spring 2010)



Higgs production at the Tevatron

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

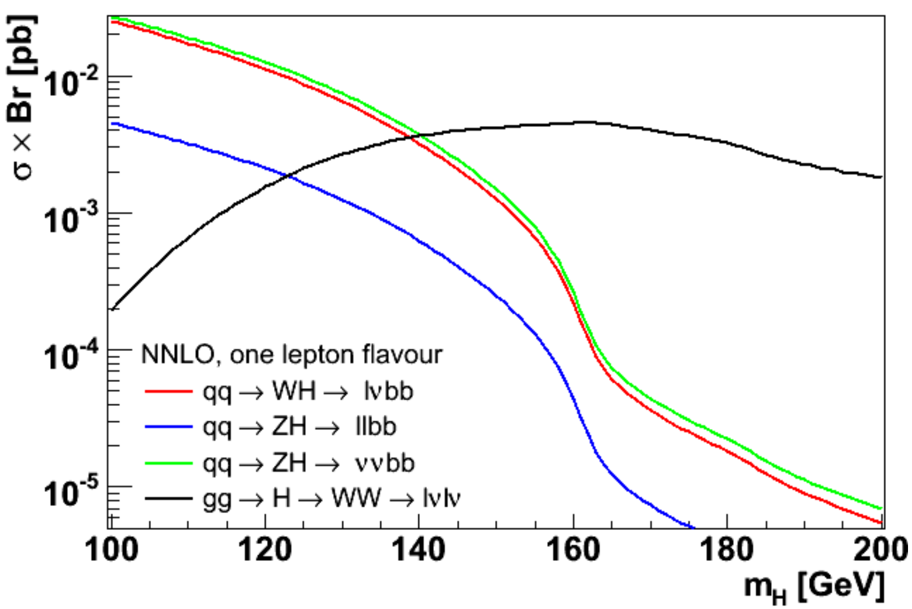
- in the 1200-300 fb range for gluon fusion gg → H
- In the 200-30 fb range for WH associated vector boson production
- In the 80-30 fb range for the vector boson fusion qq → Hqq

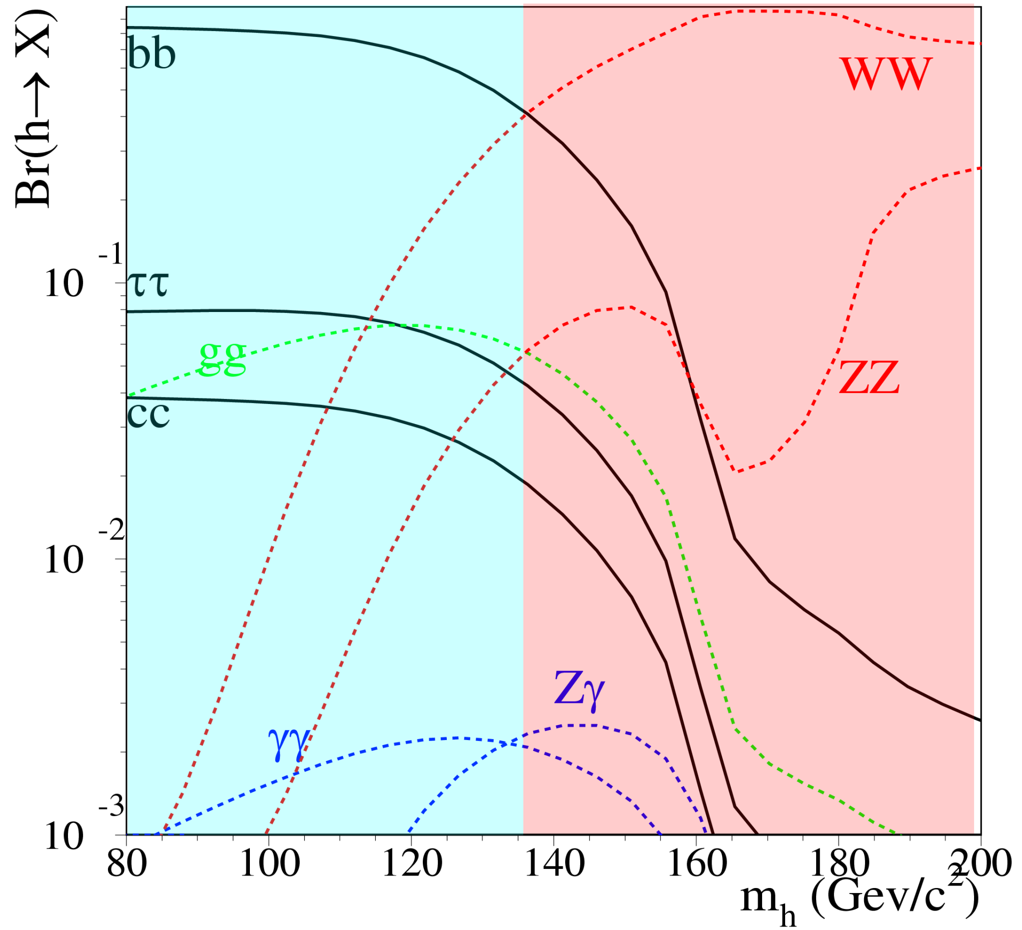


Low Mass vs High Mass

- 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.



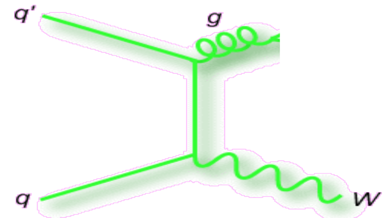


m_H<135 GeV
H → bb
H → ττ

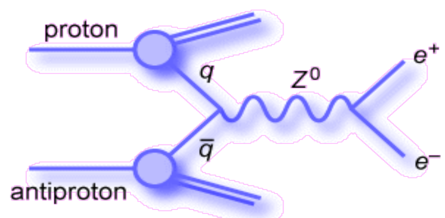
m_H>135 GeV
H → WW*

Backgrounds to WW final states

- W+jets

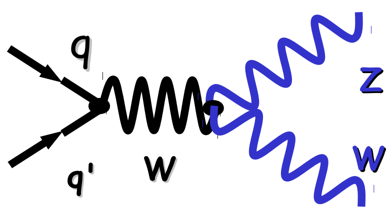


- Z/γ

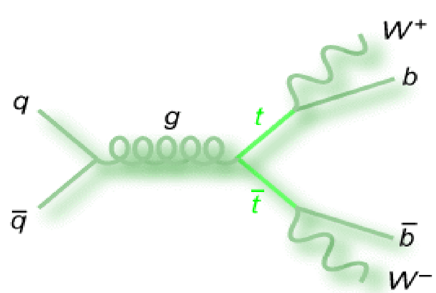


- WW

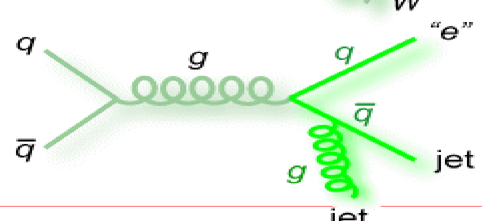
- WZ



- Top



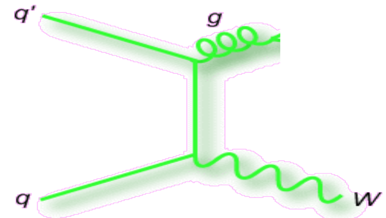
- multijet



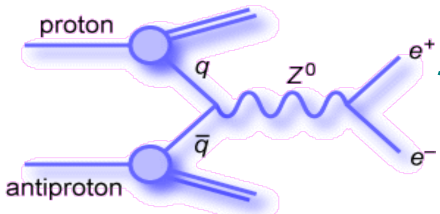
- W+jets, Z/γ +jets
  - Alpgen MC+ pythia showering
  - NNLO cross-sections
  - corrections to model $p_T(W)$,$p_T(Z)$
- Di-boson WW, WZ, ZZ
  - NLO calculation for cross-sections
  - for WW: NLO correction for p_T and di-lepton opening angle
- Top pair and single top
  - cross-section normalized at NNLO
- QCD multijet events

Backgrounds to WW final states

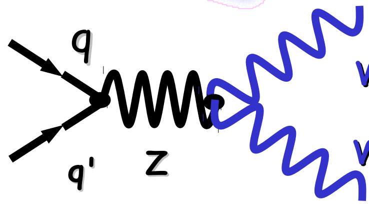
- W+jets



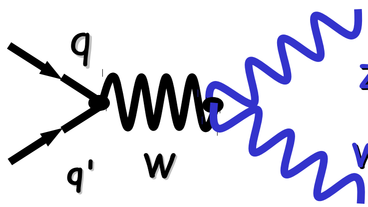
- Z/γ



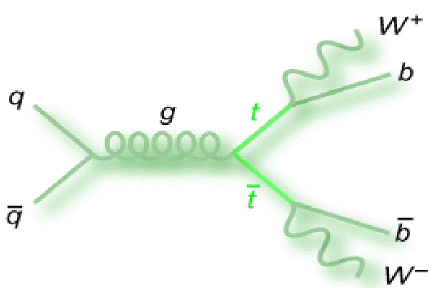
- WW



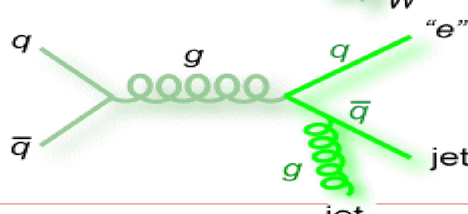
- WZ

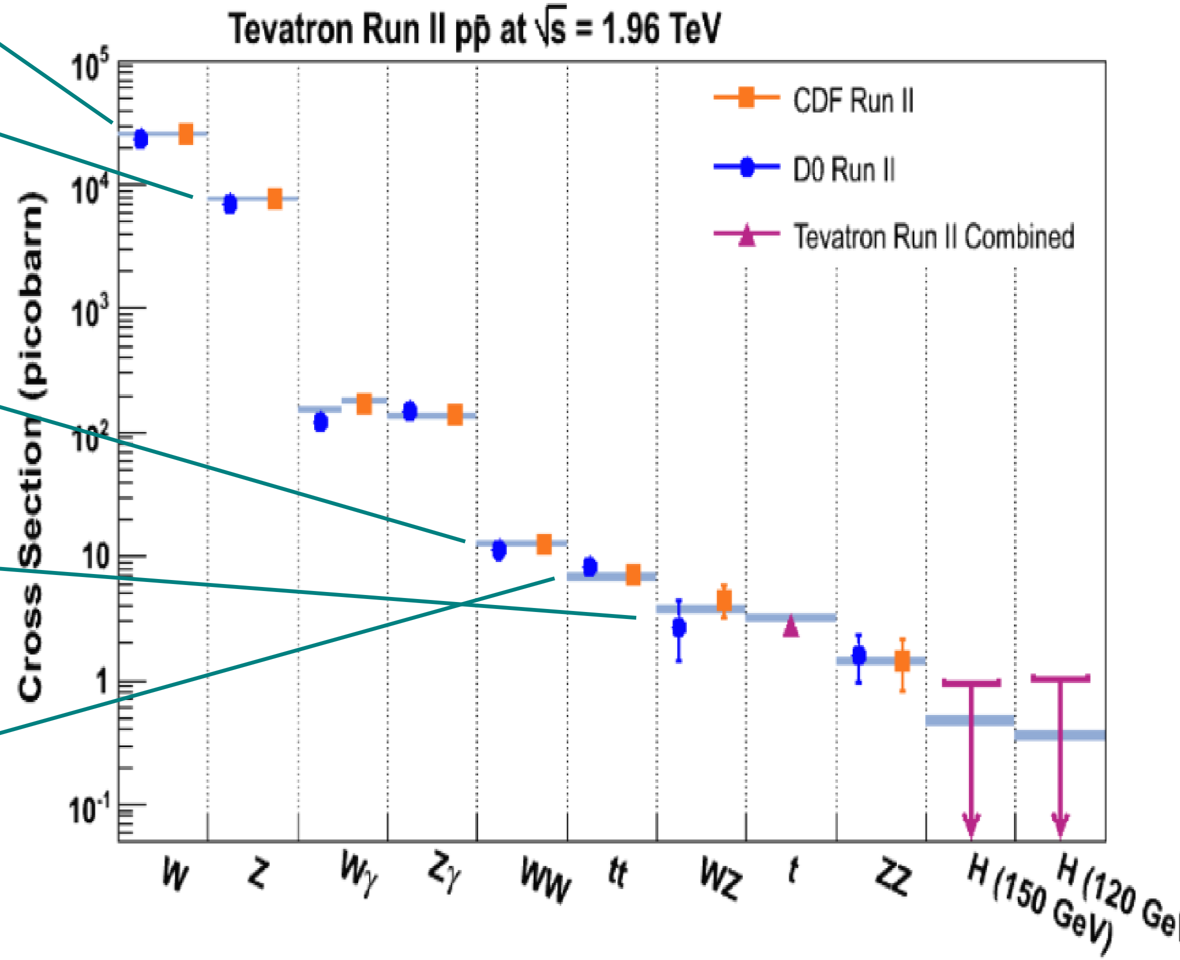


- Top



- multijet

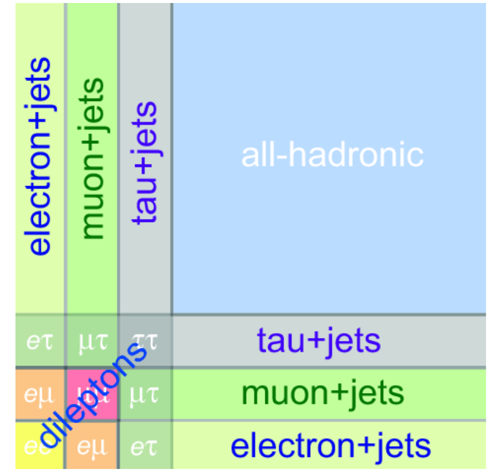




The Higgs signal is several order of magnitude below backgrounds

Looking for H → WW*

- W decay modes determine the final states
  - W → hadrons ~68%
  - W → lepton+neutrino ~ 3 x11%



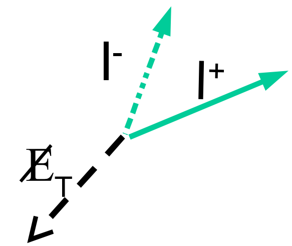
W vs W decays

- At hadronic collider: need for lepton and/or missing E_T signature because of overwhelming QCD background

- Di-lepton + missing E_T signature
  - Small Br~6% (ee, eμ, μμ)
  - Clean signal

new

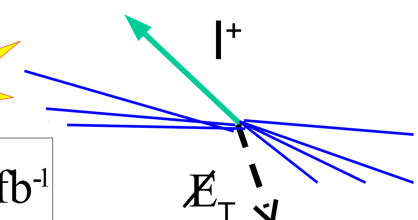
eμ 5.4 → 6.7 fb^{-1}



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

new

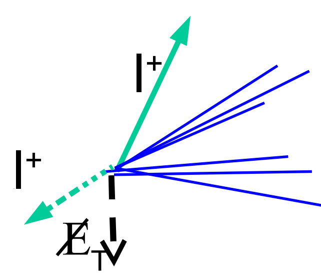
new channel 5.4 fb^{-1}



- Special case of associated production: HW → W W W
  - Same sign charged leptons are a very clean signature
  - But small σxBr

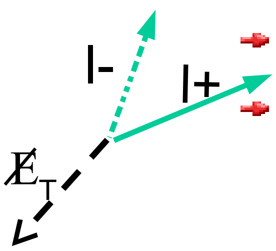
new

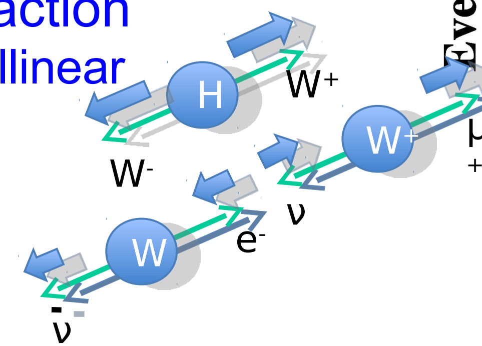
3.6 → 5.4 fb^{-1}

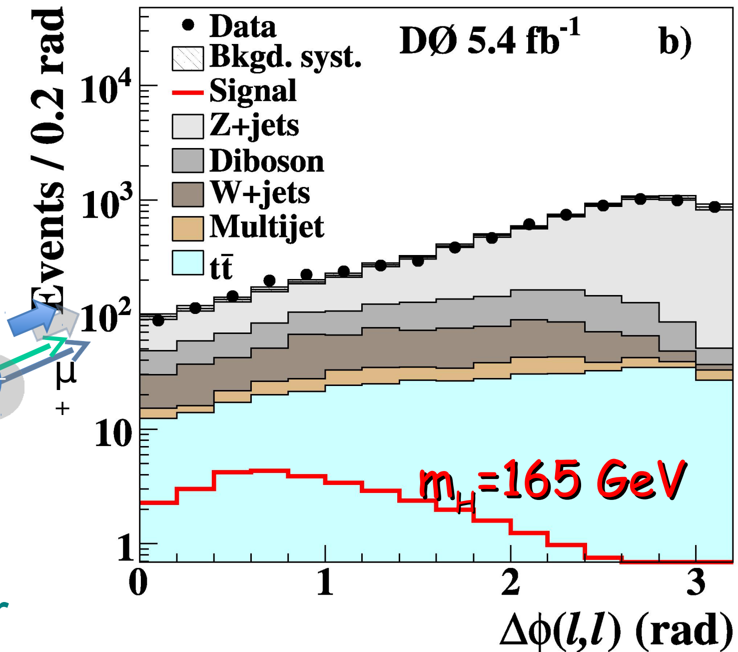


Di-lepton + $\not{E}_T$ channel

- Signature:
  - 2 isolated high p_T leptons
  - Large missing E_T
  - Higgs is scalar + V-A interaction
    - The leptons tend to be collinear
    - Small di-lepton mass
    - Small $\Delta\phi(l,l)$







- Strategy
  - Split analysis according to lepton flavor
    - Different instrumental (fake) background
    - Different lepton momentum resolution
      - typically 4% for electrons, 10% for muons
    - Different background composition
  - split eμ analysis according to jet multiplicity (0, 1, ≥2)
    - Better discrimination against top events (also use b-tagging)
    - Better sensitivity to H+jets final states: qqH, WH, ZH (important for low mass)
  - For new eμ *analysis*: more optimized lepton-id criteria ~+15% acceptance

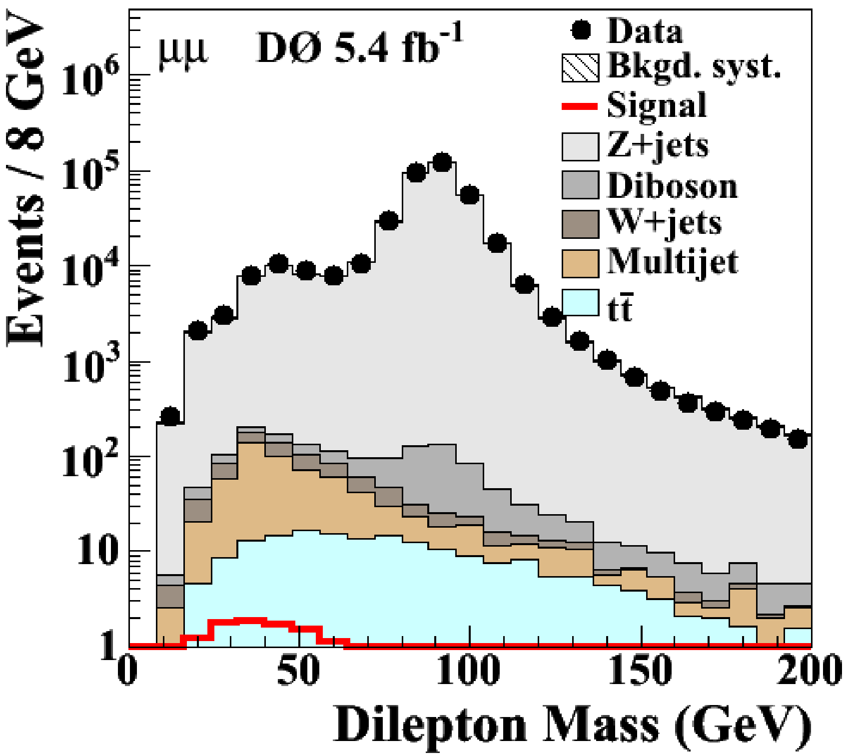
ee+eμ+μμ 5.4 fb^{-1}
PRL. 104, 061804 (2010)

new

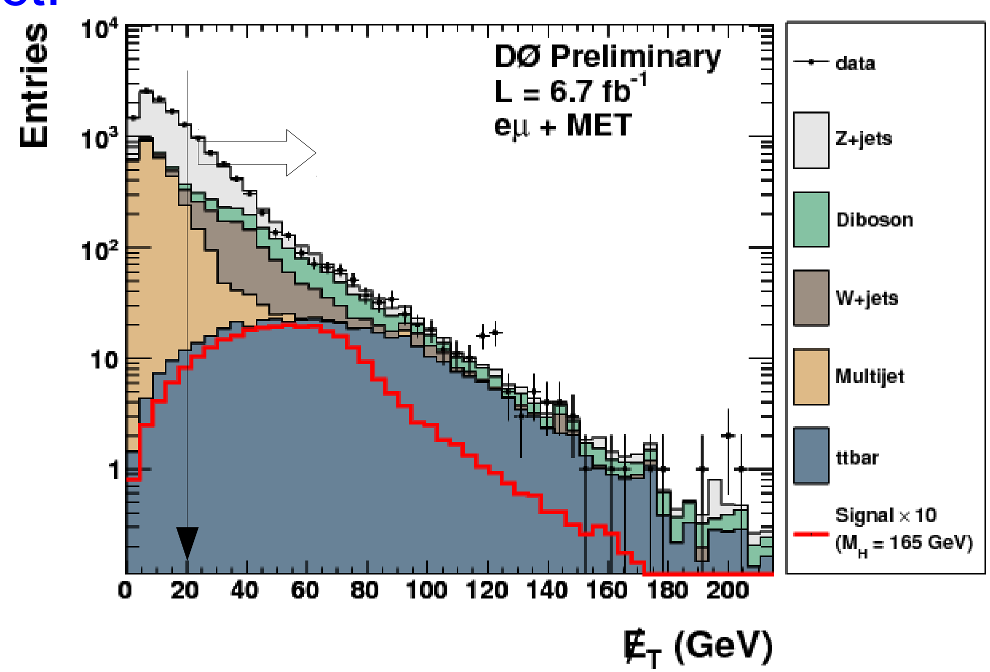
preliminary
eμ 6.7 fb^{-1}

Di-lepton + $\not\!E_T$ selection

- Preselection:
  - p_T(lepton)>10-20 GeV
  - Isolation, opposite charge, $M_{l1,l2}$ >15 GeV
- Selection
  - loose kinematics cuts to get rid of the dominant background



- Cut on Δφ(l,l), $\not\!E_T$, $\not\!E_T^{spec}$, $\not\!E_T^{scale}$, M_T(lep, $\not\!E_T$)
- $\not\!E_T$ based variables to ensure $\not\!E_T$ is significant and not due to mismeasured object.



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

Irfu cea saclay

- Still large background after selection
  - For μμ (m_H=165 GeV)
    - S/B ~ 9/1600
    - S/√B ~ 0.22
  - For ee (m_H=165 GeV)
    - S/B ~ 7/423
    - S/√B ~ 0.34

ee+μμ 5.4 fb^{-1}

	e^+e^- Preselection	e^+e^- Final selection	$\mu^+\mu^-$ Preselection	$\mu^+\mu^-$ Final selection
$Z/\gamma^* \to e^+e^-$	274886	158 ± 13	–	–
$Z/\gamma^* \to \mu^+\mu^-$	–	–	373582	1247 ± 37
$Z/\gamma^* \to \tau^+\tau^-$	1441	0.7 ± 0.1	2659	12.0 ± 0.7
$t\bar{t}$	159	47.0 ± 4.4	184	74.6 ± 6.8
W + jets/γ	308	122 ± 11	236	91.5 ± 6.5
WW	202	73.9 ± 6.4	272	107 ± 9
WZ	137	11.5 ± 1.0	171	21.5 ± 2.0
ZZ	117	9.3 ± 0.9	147	18.0 ± 1.8
Multijet	1370	1.0 ± 0.1	408	53.8 ± 10.3
Signal (m_H = 165 GeV)	11.2	7.2 ± 0.8	12.7	9.0 ± 1.0
Total background	278620	423 ± 19	377659	1625 ± 41
Data	278277	421	384083	1613

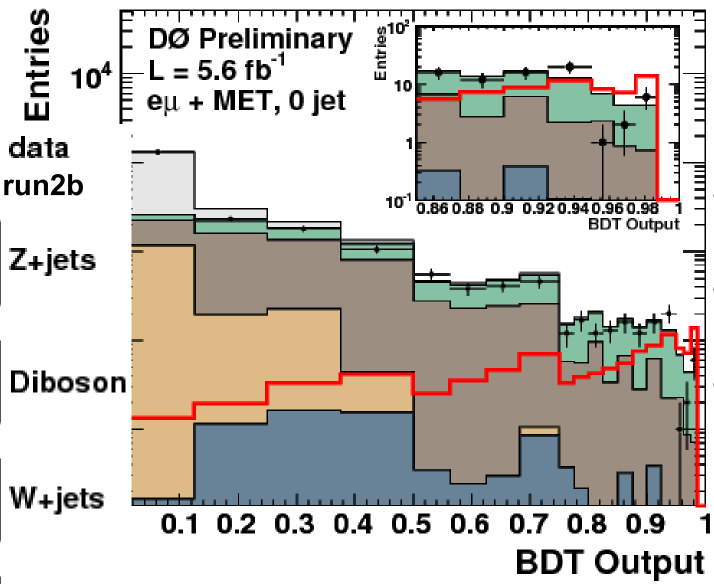
- eμ channel benefits from splitting in jet multiplicity bins
  - For eμ (m_H=165 GeV)
    - S/B ~ 13/2800 , 8/1100, 5/600
    - S/√B ~0.24, 0.24, 0.20

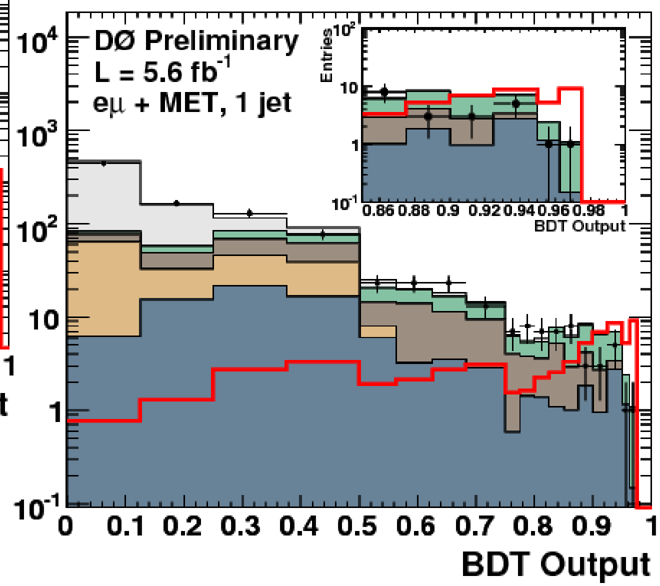
eμ 6.7 fb^{-1}

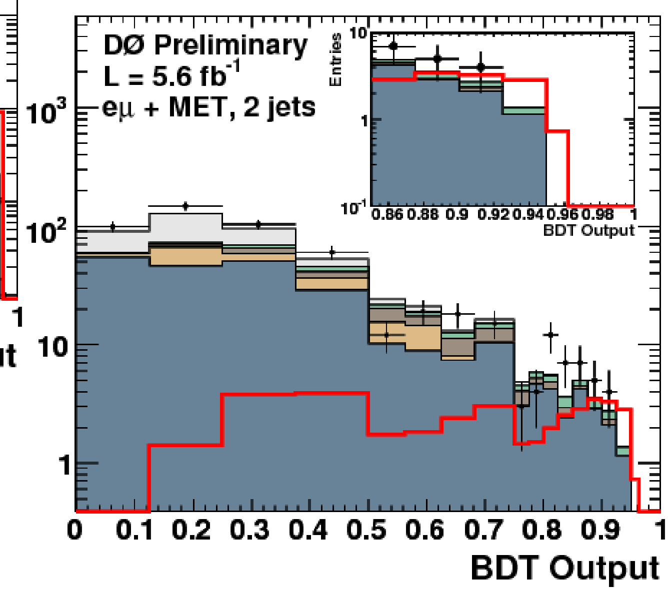
	Data	Signal	Total Background	$Z \to ee$	$Z \to \mu\mu$	$Z \to \tau\tau$	$t\bar{t}$	$W + jets$	WW	WZ	ZZ	Multi-jet
	$e^\pm\mu^\mp$ channel											
0 jets	2662	13.2	2838	8.9	172.2	1318	10.8	684.2	447.0	16.5	2.2	177.8
1 jet	1164	7.9	1132	4.8	40.6	585.5	107.6	147.6	99.0	6.5	1.6	138.4
$\geq$ 2 jets	636	4.8	593.6	2.3	14.4	162.8	300.6	38.1	21.9	2.7	1.4	49.2

Last step: multivariate analysis

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







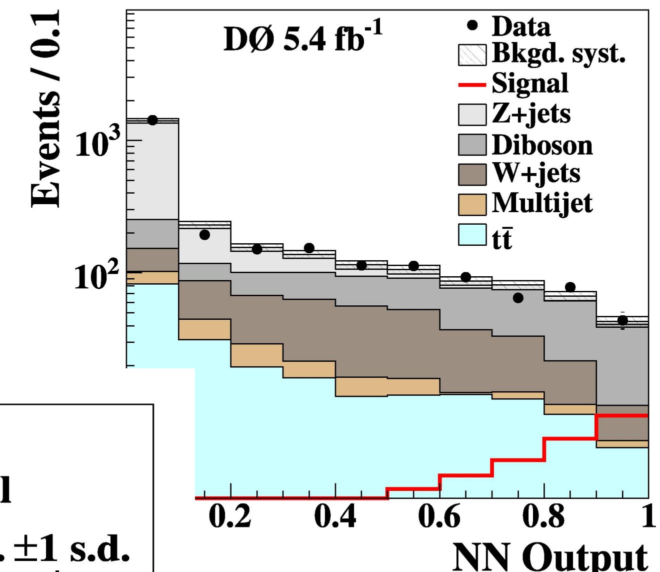
new

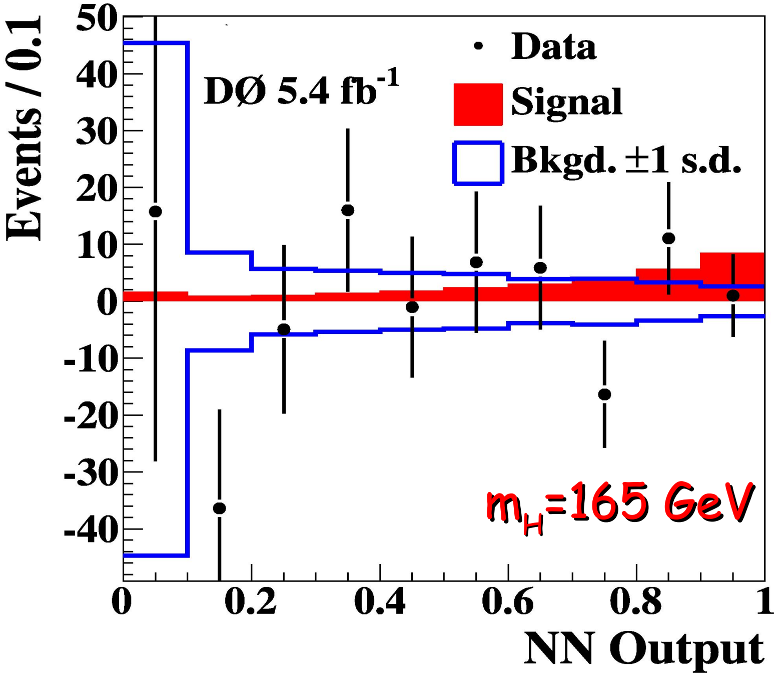
Splitting and dedicated training in different jet multiplicity bins to fight against different backgrounds

Di-lepton + $\not{E}_T$: systematic uncertainties

- Flat systematics: affect overal normalization
- Shape systematics: modifiy output of final discriminant
- Impact of systematics is reduced thanks to profiling techniques (~fit procedure in background dominated region)

Main systematics	Signal	Bkg
Lepton id (flat)	3-6%	3-6%
Luminosity (flat)	6.1%	6.1%
Cross-section (flat)	11%	6-10%
pT(Z) pT(W) pT(WW)pT(H)	1.5%	1-5%
Jet modeling	1-18%	1-18%
Jet calibration	1-5%	1-5%



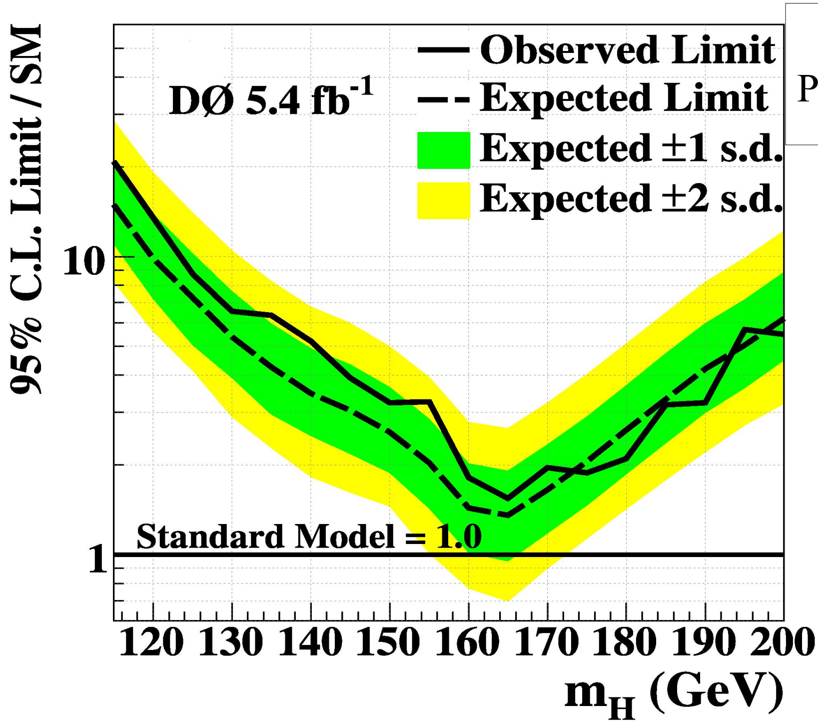


PRL. 104, 061804 (2010)
ee+eμ+μμ

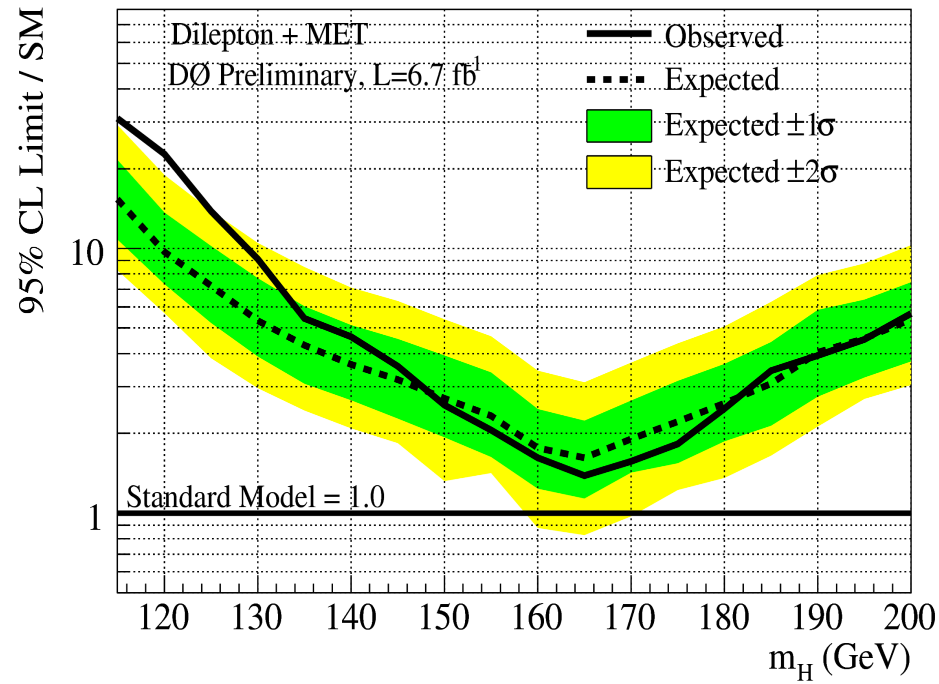
Di-lepton + $\not{E}_T$: results

- Limits @95% CL in SM cross-section unit

ee+eμ+μμ 5.4 fb^{-1}
PRL. 104, 061804 (2010)



eμ only 6.7 fb^{-1}



For m_H=165 GeV and 5.4 fb^{-1}
ee+μμ+eμ: $\sigma_{95}/\sigma(SM)$ = 1.55 (1.36 expected)

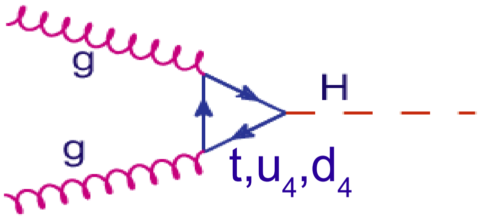
For m_H=165 GeV and 5.4 fb^{-1}
eμ only: $\sigma_{95}/\sigma(SM)$ = 1.99 (1.93 expected)

For m_H=165 GeV and 6.7 fb^{-1}
eμ only: $\sigma_{95}/\sigma(SM)$ = 1.39 (1.62 expected)

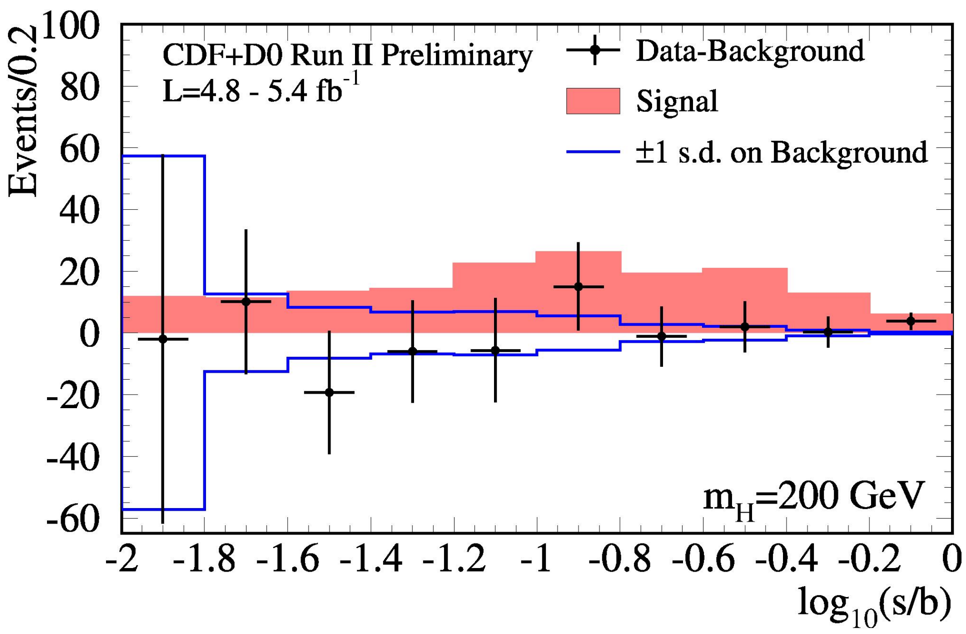
expected sensitivy increased by ~18%

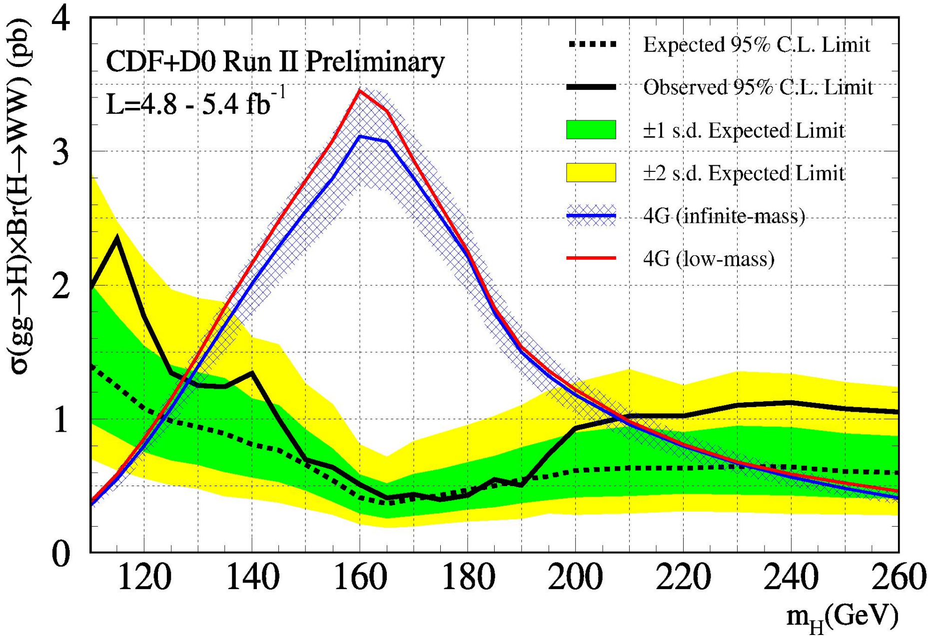
Higgs search within 4th generation model

- New heavy generation of quarks
  - ggH coupling is multiplied by 3 compared to SM
  - Production is enhanced by 9



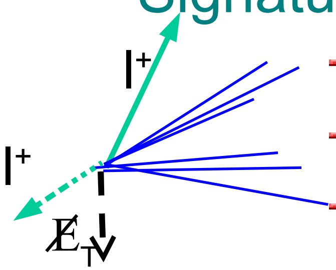
- Search in di-lepton +MET channel can be recycled
  - Some analysis tuning required because of extended mass reach (eg $\Delta\phi$(l,l) cut not applicable when W's are boosted)





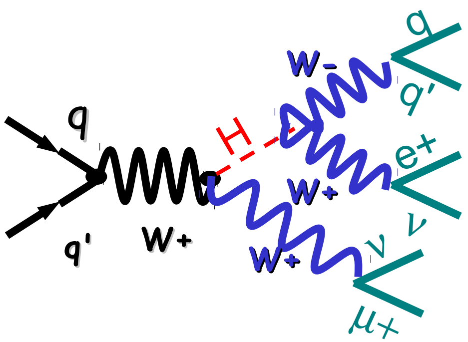
CDF+D0 combined exclusion: $130<m_H<210$ GeV @95%CL (infinite mass scenario)

Like-sign leptons : signature and background



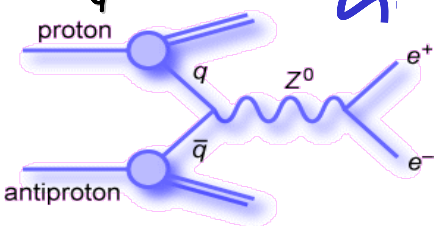
Signature:

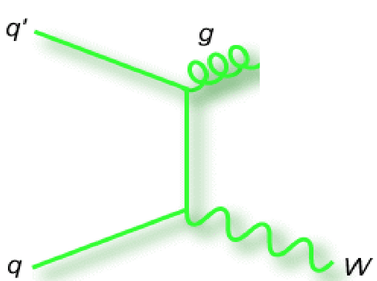
- 2 isolated high p_T leptons
- same charge
- Large missing E_T



Backgrounds

- Di-boson WZ, ZZ
- Drell-Yan Z/γ
  - mis-measurement of lepton charge (charge flip)
- W+jet
  - Jet mis-identified as lepton
- QCD multijet events
  - Jets mis-identified as leptons



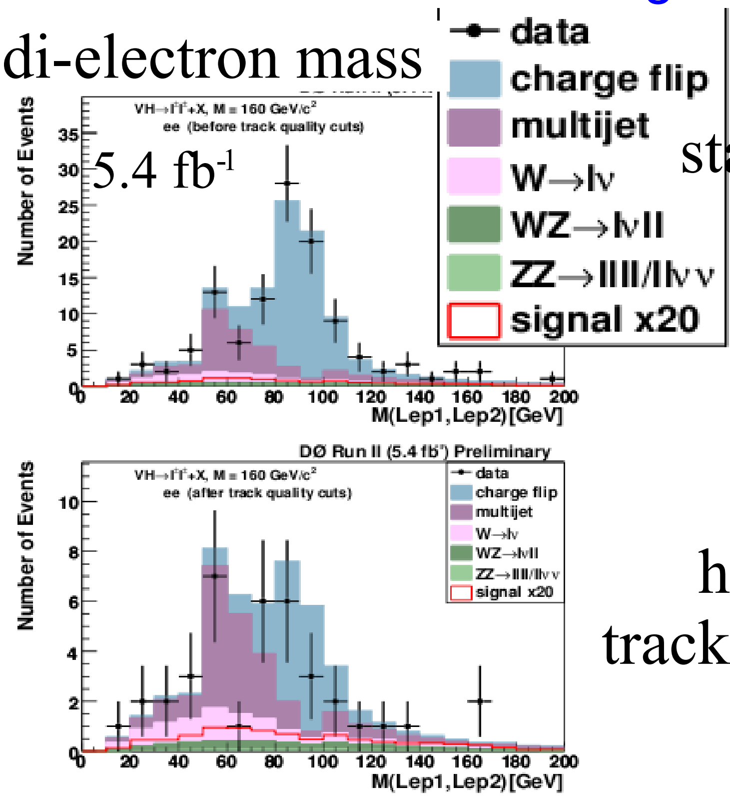


Like-sign leptons: analysis strategy

- Split into ee, eμ, μμ, to increase sensitivity
  - Different Background composition
  - Different rate of jets faking lepton
  - Different charge mis-id rate

di-electron mass

5.4 fb^{-1}



standard

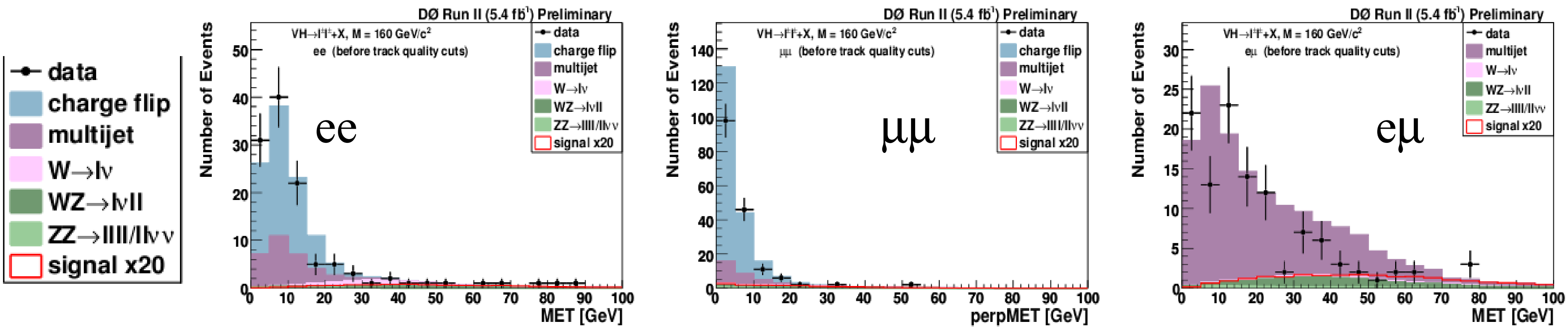
high track quality

- Selection
  - 2 isolated leptons, p_T>15 GeV, same charge
  - High quality track to reduce charge flip bkg
  - Reject events from background control region
    - $85<M_{l1,l2}<100$ GeV, $\Delta\phi(l1,l2)>2.8$
    - $30<M_{l1,l2}<50$ GeV, $\Delta\phi(l1,l2)>2.5$

- Last steps: multivariate analysis (new compared to 3.6 fb^{-1} analysis)
  - Decision Trees specifically trained against instrumental bkg
  - Decision Trees specifically trained against W+jet and di-boson bkg

Like-sign leptons: backgrounds

- Determine instrumental background from data
  - charge flip :
    - μμ channel exploits redundancy between tracking and mu spectrometer
    - ee channel exploits Z-peak reconstructed by calorimetry
    - Charge mis-id rate from control region
    - Event kinematic from opposite sign data
  - QCD multijet background
    - rate from background control region
    - QCD kinematic from inverting tight lepton criteria (isolation, em shower shape discriminant)

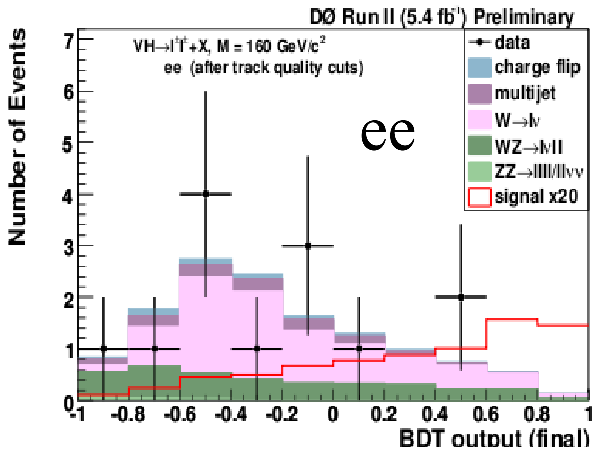


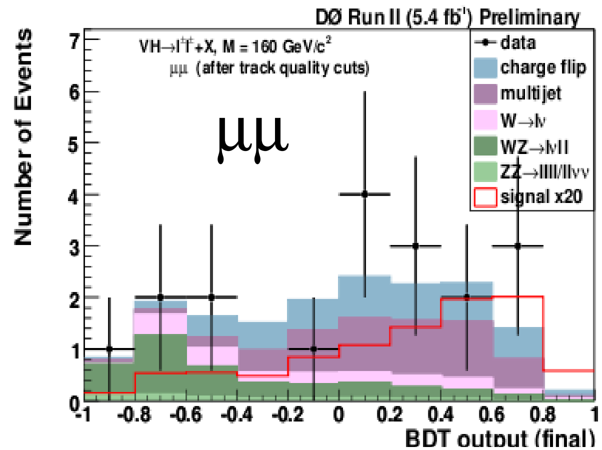
After final selections

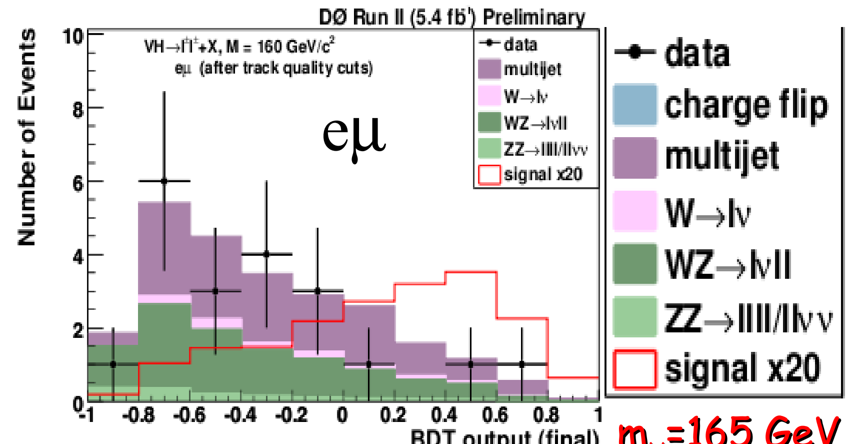
channel	ee	μμ	eμ
background	12.0±1.5	17.2±3.3	24.1±2.6
data	13	18	20
mH=160 GeV	0.39	0.56	0.93
S/√B	0.11	0.14	0.19

Like-sign leptons: results

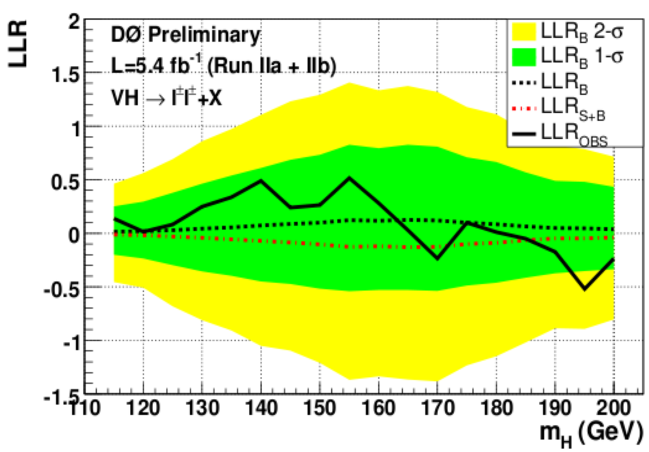
- Final multivariate discriminants to derive limits
  - Exploit: Event topology, lepton kinematics, jet content, relation between lepton and $\not{E}_T$

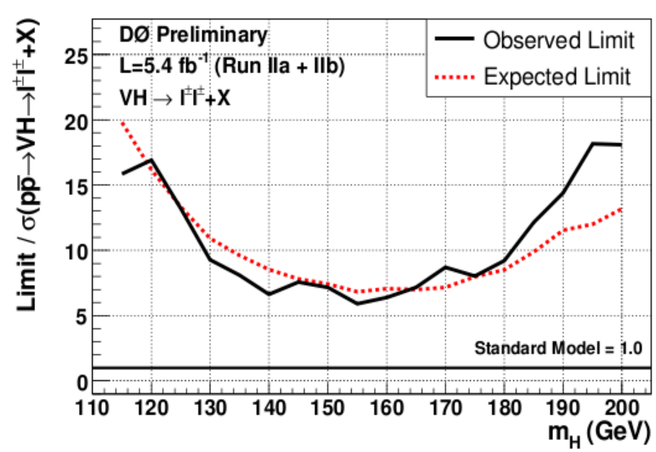






m_H=165 GeV





Main systematic uncertainties

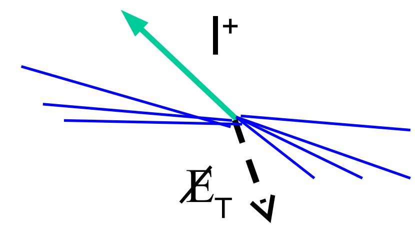
- 10-12% for acceptance
- 20% on W+jet background
- 20-150% on instrumental background

Limit for m_H=165 GeV and 5.4 fb^{-1} : $\sigma_{95}/\sigma(SM)$ =7.2 (7.0 expected)

expected sensitivity in 3.6 fb^{-1} analysis was 10.5σ(SM)

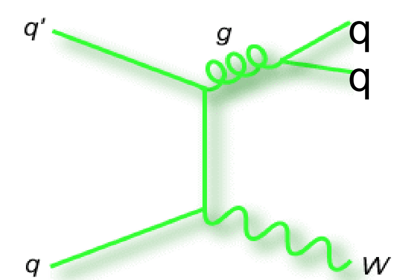
lepton+jets: signature and background

- Signature from WW → lνqq
  - 1 isolated high p_T lepton
  - Large missing E_T
  - 2 jets



- Selection:
  - One isolated high p_T(lepton)>15 GeV
  - 2 well reconstructed jets
  - Require $\not{E}_T$ >15 GeV , $M_T(W)+0.5 \not{E}_T$>40 GeV

- Backgrounds
  - Main background : W+ 2 jets



  - Top production
  - Di-boson WW,WZ, ZZ
  - QCD multijet events with jets identified as leptons

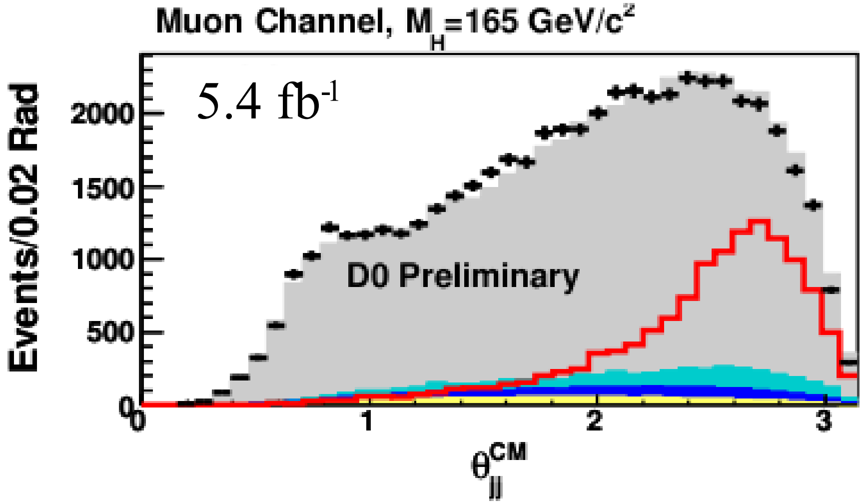
lepton+jets after selection

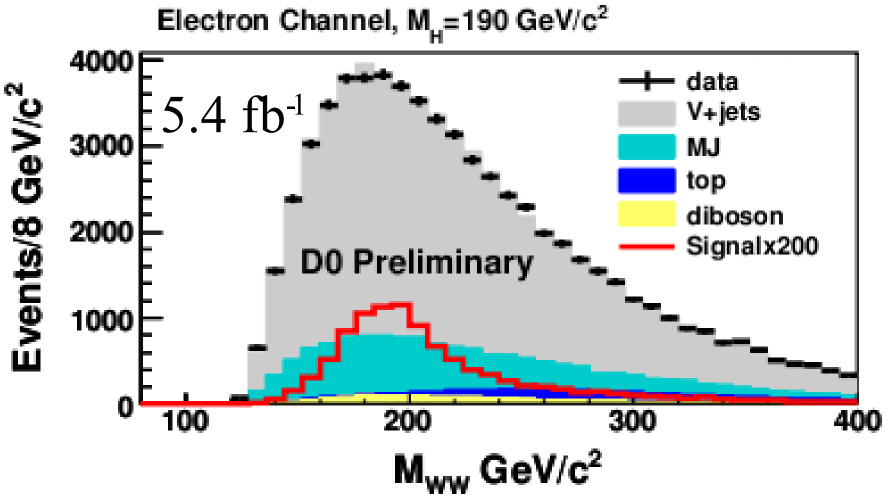
Large overwhelming W+jets background after selection

- $S/\sqrt{B} \sim 0.22$ (m_H=165 GeV)

Channel	$H \to WW$	V+jets	Multijet	top	VV	data
electron	45.2	52156	11453	2433	1585	67627
muon	32.2	47201	2409	1598	1225	52433

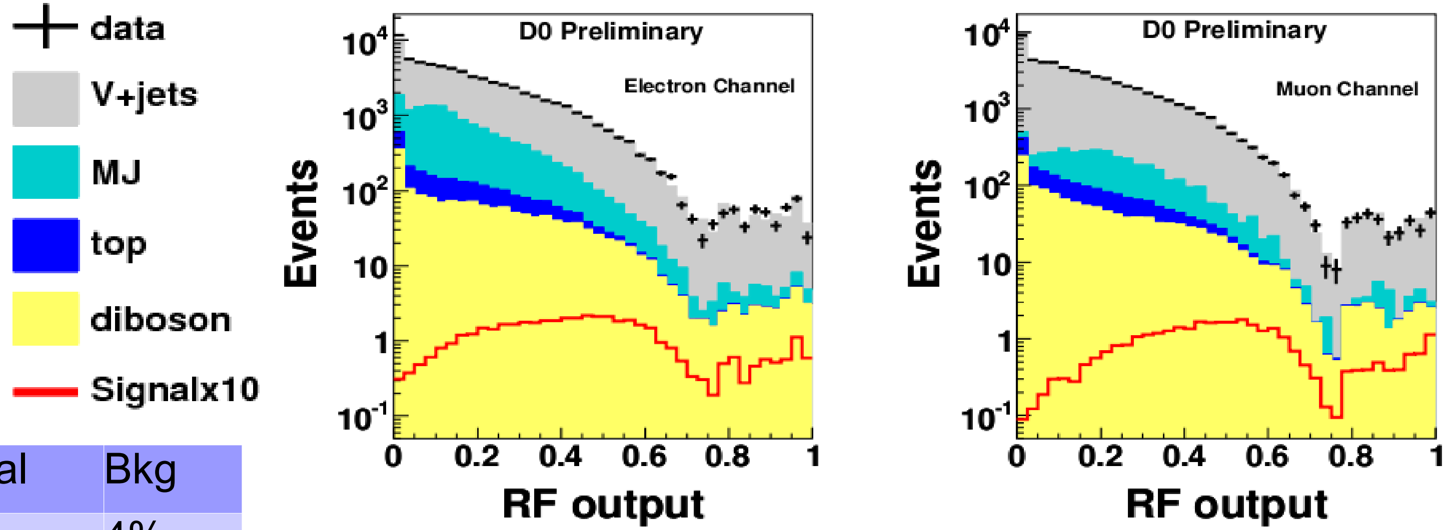
- Further discrimination needed with help of kinematic variables.
  - Use W mass constraint to reconstruct neutrino p_z
  - Exploit full event kinematics and topology by means of Decision Trees
    - Trained separately for e and μ channels and for each tested Higgs mass



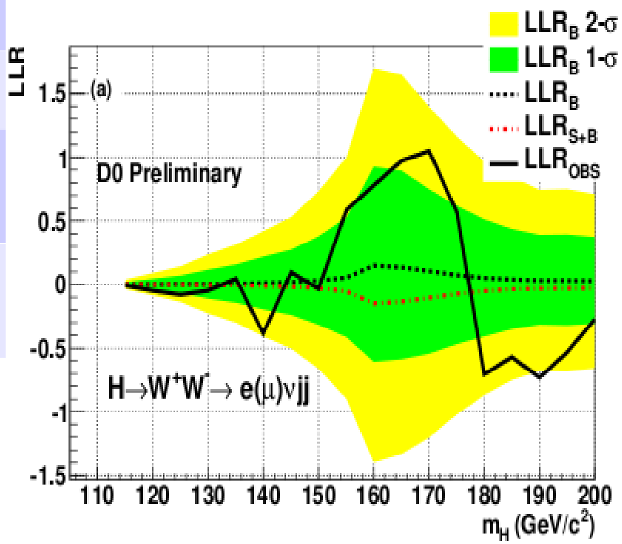


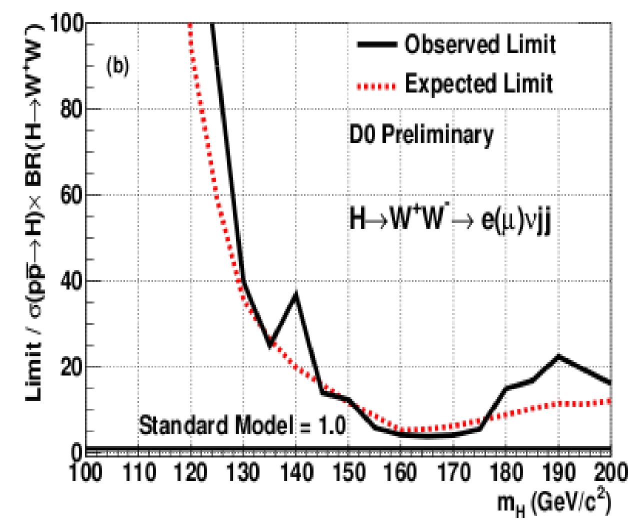
lepton+jets: results

- Final multivariate (Random Forest) discriminants to derive limits



Main systematics	Signal	Bkg
Lepton id (flat)	4%	4%
Luminosity (flat)	6.1%	6.1%
Cross-section (flat)	10%	6-10%
Jet calibration and resolution	5%	4-7%



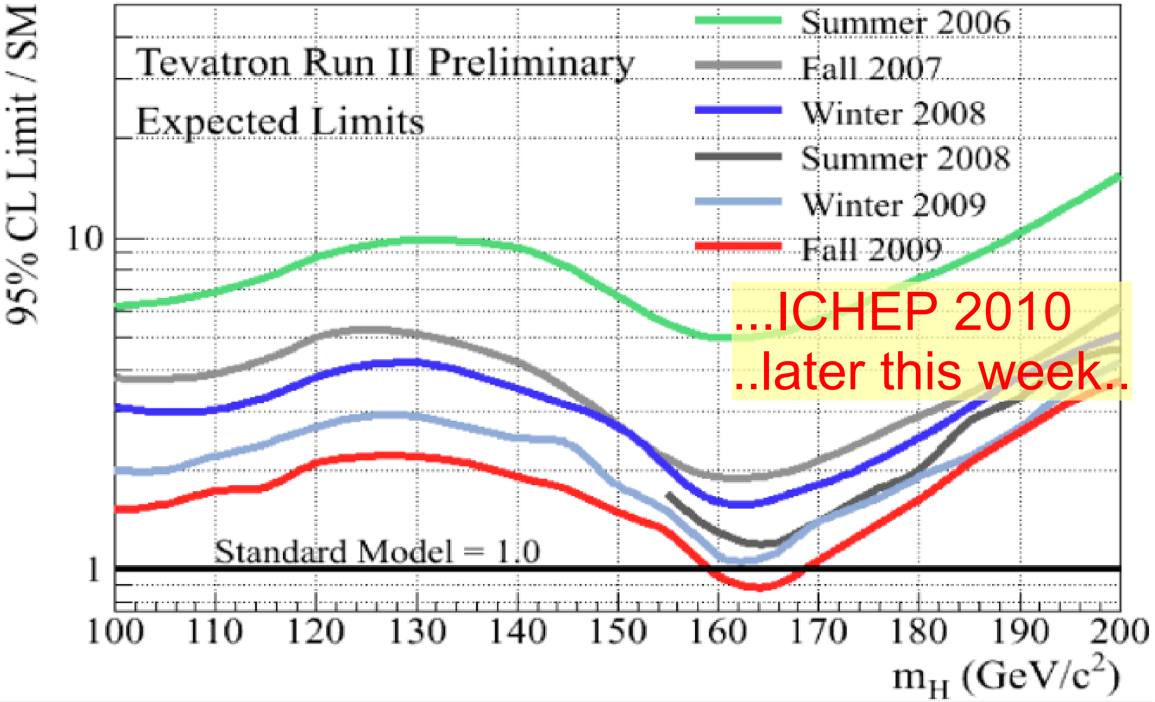


eνjj+μνjj: 5.4 fb^{-1}

Limit for m_H=165 GeV $\sigma_{95}/\sigma(SM)$ =3.8 (5.5 expected)

Conclusions

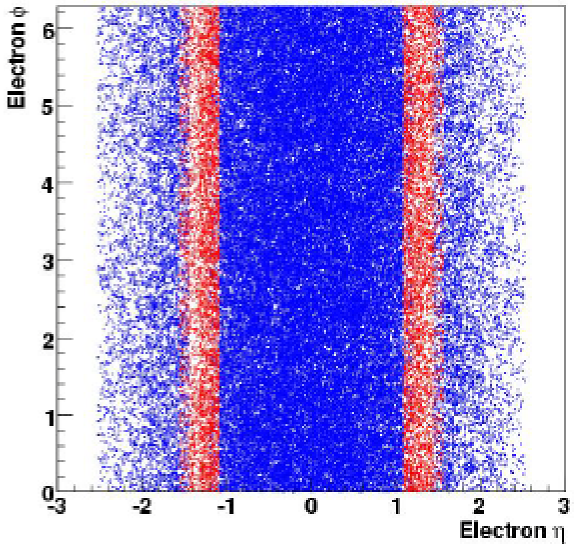
- Search for Standard Model high mass Higgs at D0
  - 2 channels: updated samples and improved analysis techniques
  - 1 channel completely new
  - Sensitivity improves faster than √L
- The results need to be combined to reach sensitivity to SM Higgs
  - Dzero combination: M. Mulhearn's talk tomorrow
  - Tevatron combination: B. Kilminster's talk on Monday
- Many improvements forseen for near future
  - More data, more efficiency, more channels
- Exciting times ahead



Support slides

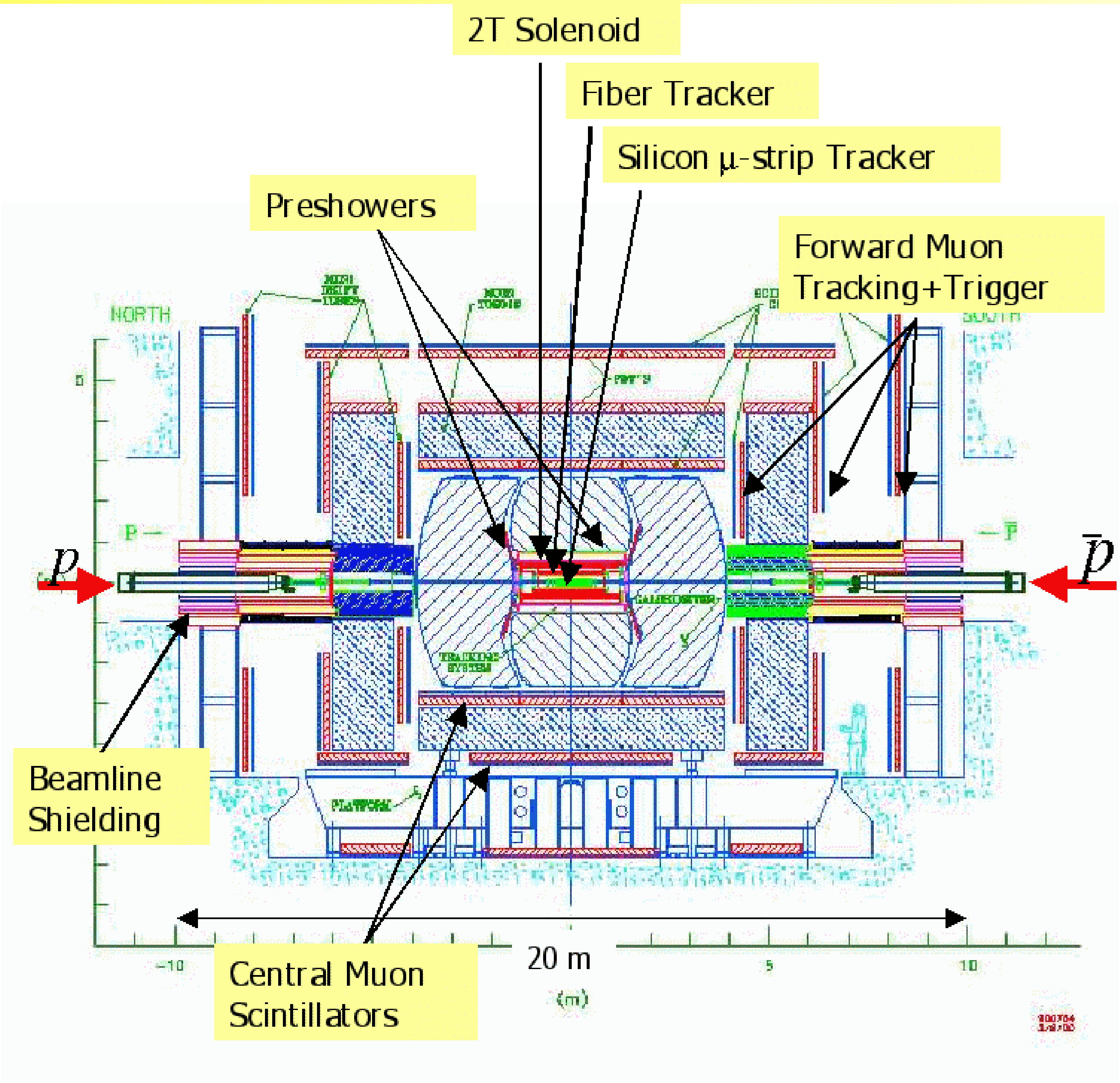
Prospects

- Many improvements are foreseen for near future
  - More than 10 fb^{-1} by the end of 2011
  - More optimized lepton id criteria
    - already in WW → eμ ~+15%
  - Increased lepton acceptance
    - already +15% in ZH → eebb
  - New channels
    - WW → e + tau, WW → mu + tau
    - tri-lepton signatures (from HW → WWW and H → ZZ)
  - Reduced systematic uncertainties
  - Better multivariate techniques



- Most of these improvements will also extend reach of « high mass » channels toward lower mass
- On the verge of being sensitive to Higgs production with D0 only data
- Exciting times ahead

The D0 Experiments at RunII



- New in RunII
  - Tracking in B-field
  - Silicon detector
  - fiber tracker
- Upgraded for Run II
  - Calorimeter,
  - muon system
  - DAQ/trigger
- RunIIb (2006):
  - Silicon layer 0
  - Cal Trigger
- Typical coverage
  - Muons $\eta < 2$
  - Electrons
    - $\eta<1.1$
    - $1.5<\eta<2.5$
  - Jets $\eta< 2.5$

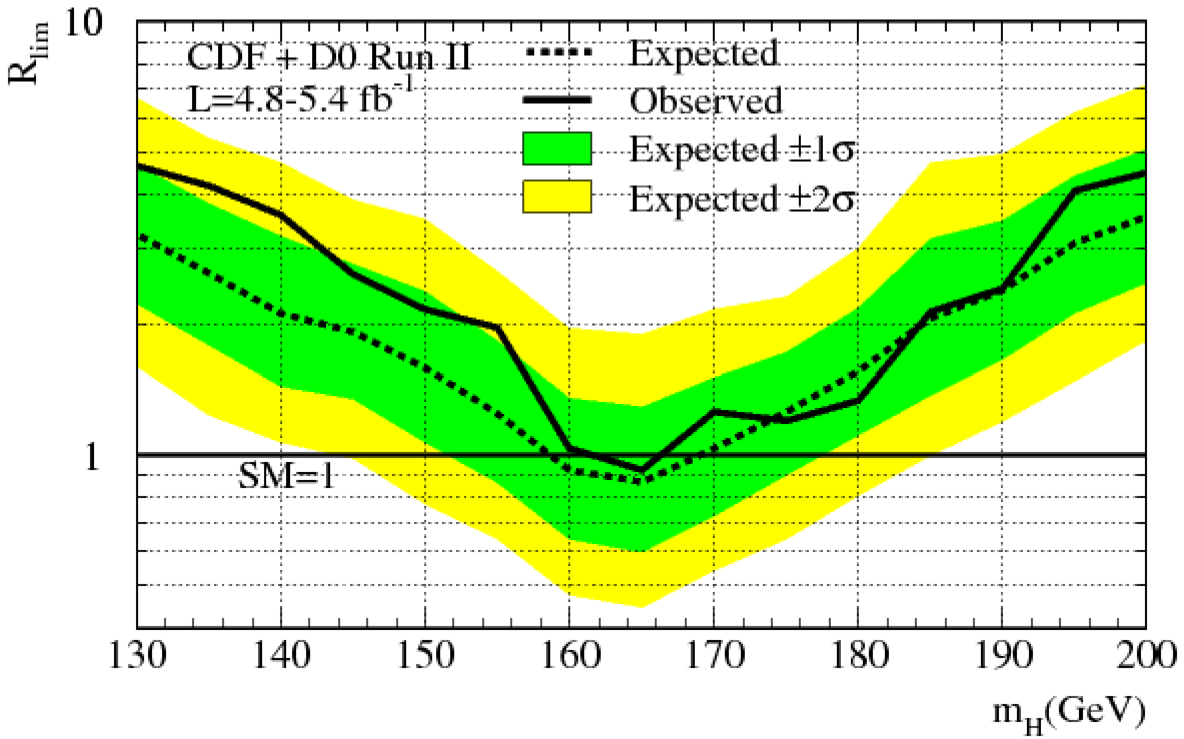
D0+CDF combined results

- First D0+CDF joint publication on Higgs search.

  Phys. Rev. Lett. 104, 061802 (2010)

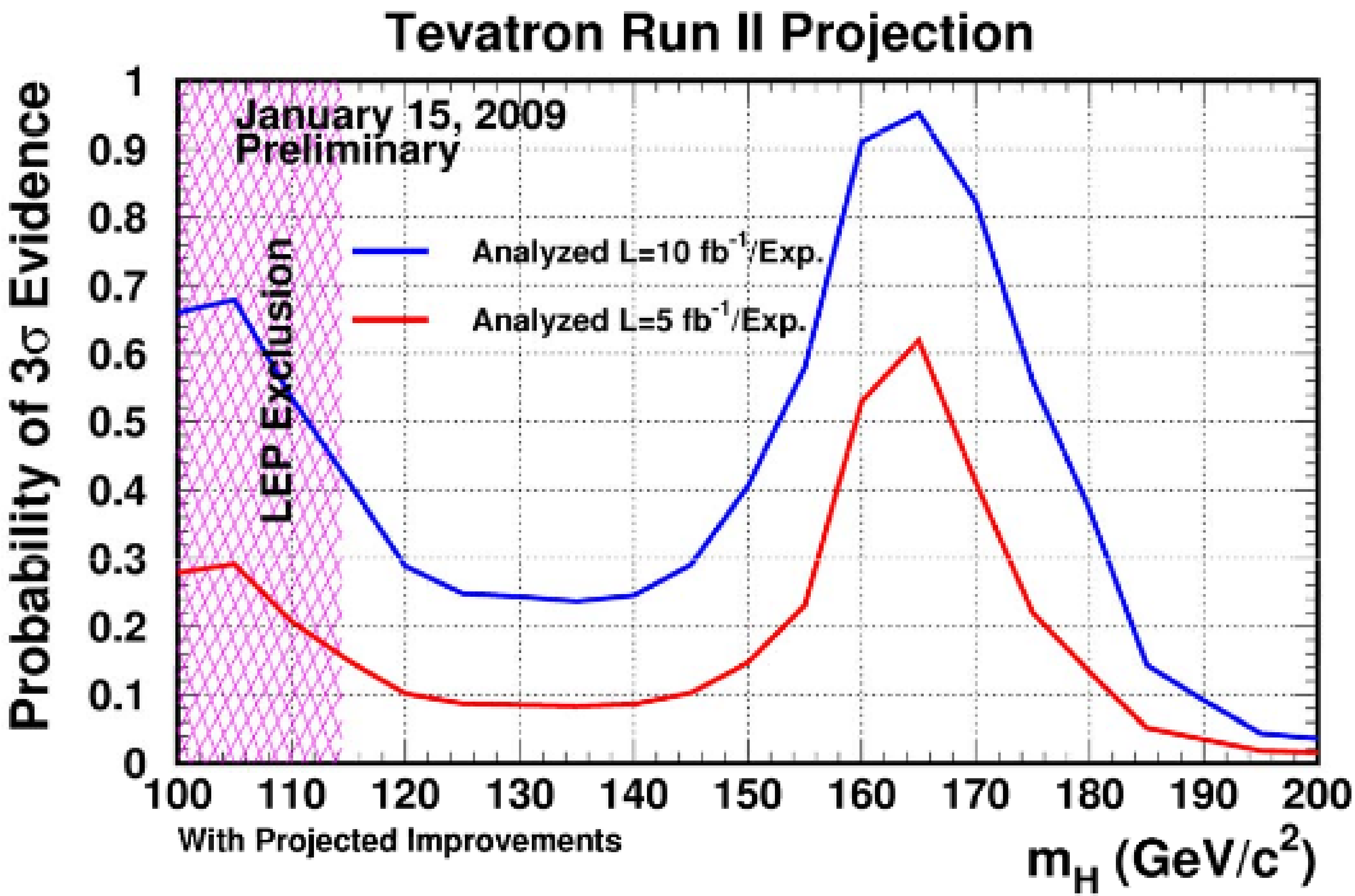
- Exclusion 162-166 GeV @95CL

  (Expected sensitivity for exlcusion 159-169 GeV)



TeVatron discovery potential

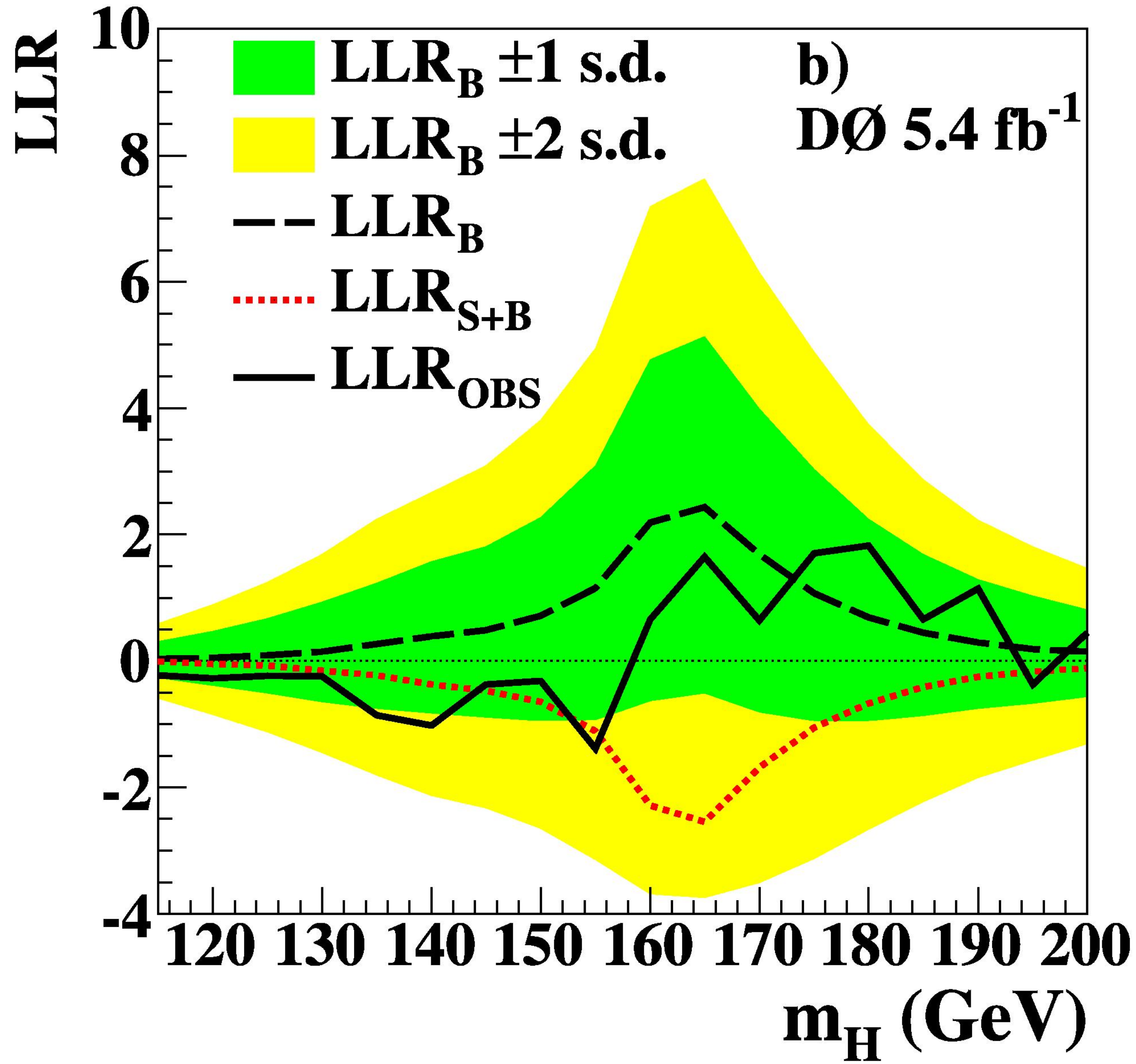
Extrapolation assuming analysis improvements underway



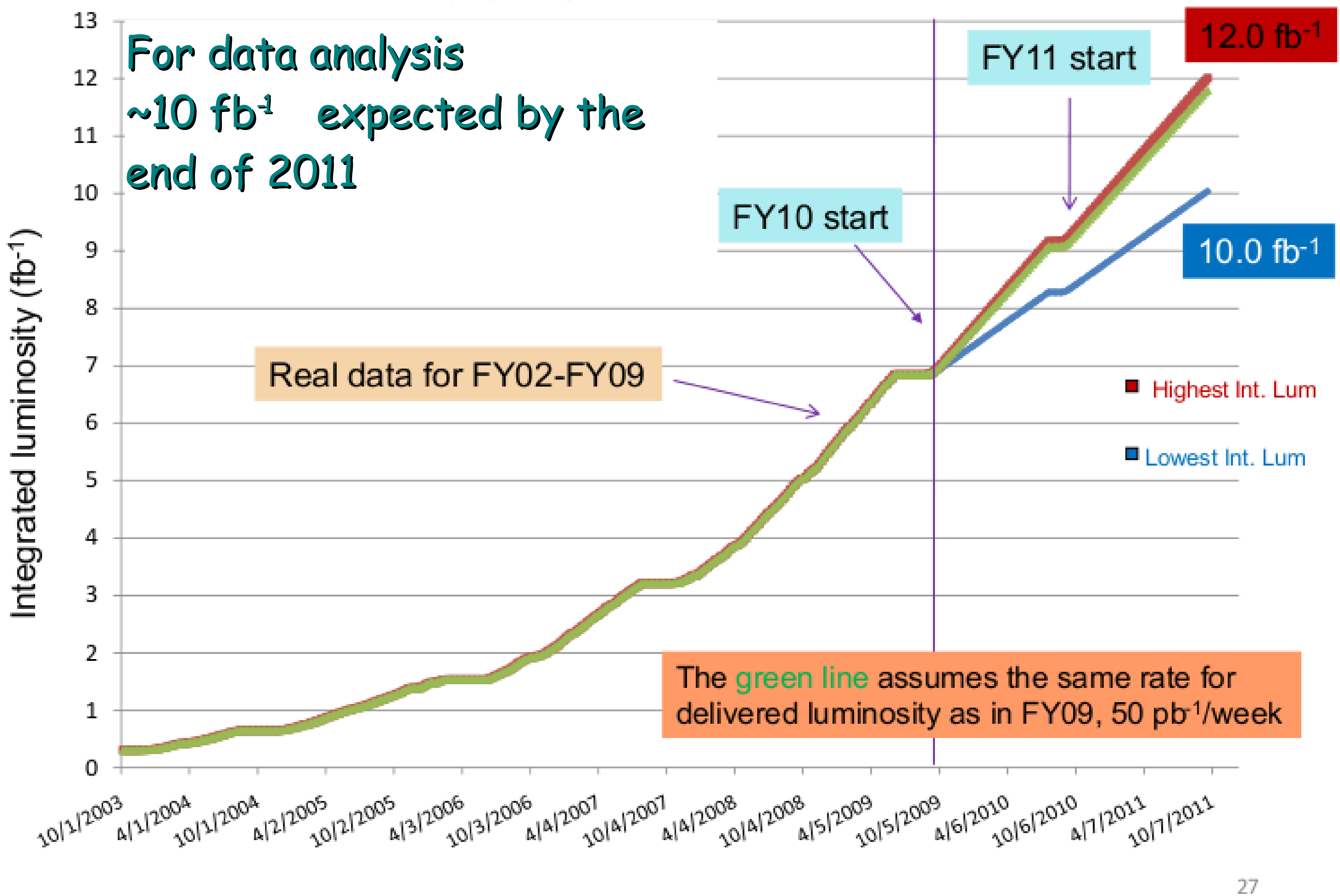
- At low mass Prob < 30%.
- Need to be somewhat lucky to see low mass Higgs.

– Log Likelihood Ratio

separation between LLR_b and LLR_{s+b} give the power to exclude or discover a Higgs

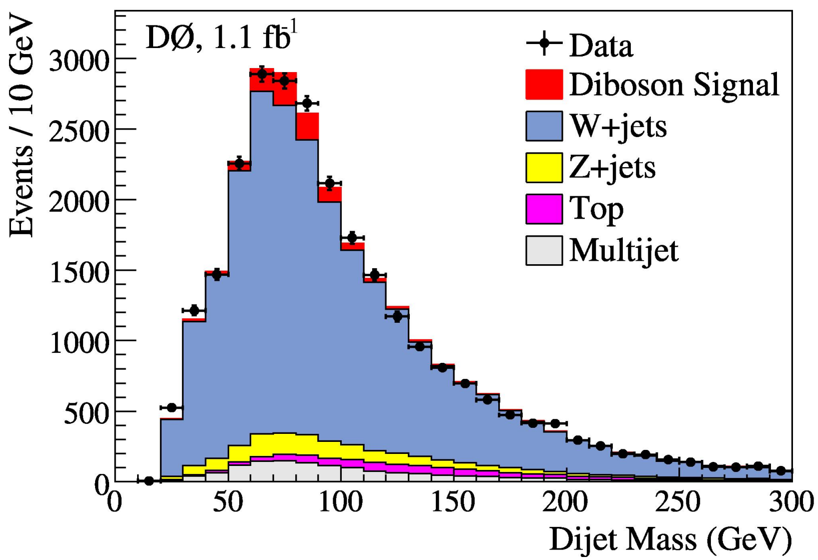


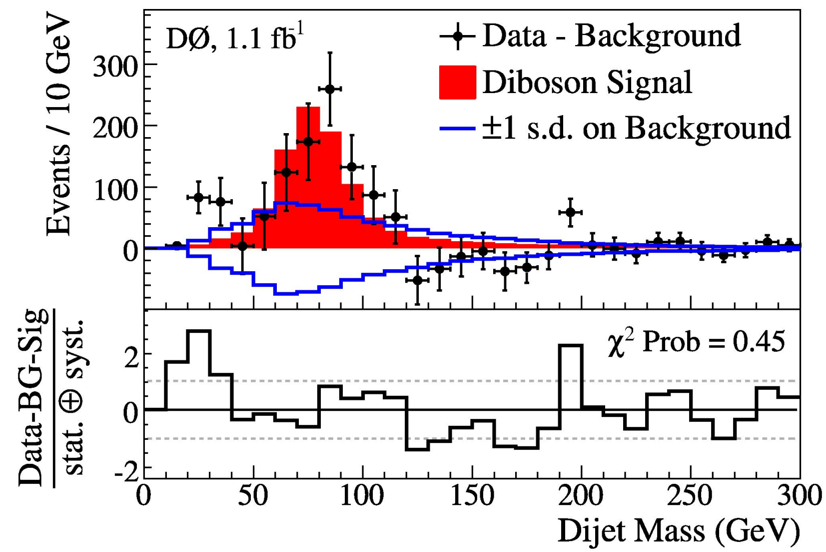
Luminosity prospects



WW and WZ signal in lepton+jet channels

With 1.1 fb^{-1}, D0 saw evidence at 4.4 σ
for W(W/Z) production in the $(W \to l\nu)(W/Z \to jj)$ channel





Phys. Rev. Lett. 102 , 161801 (2009)

Evolution of sensitivity