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SM and BSM Higgs Searches at DØ

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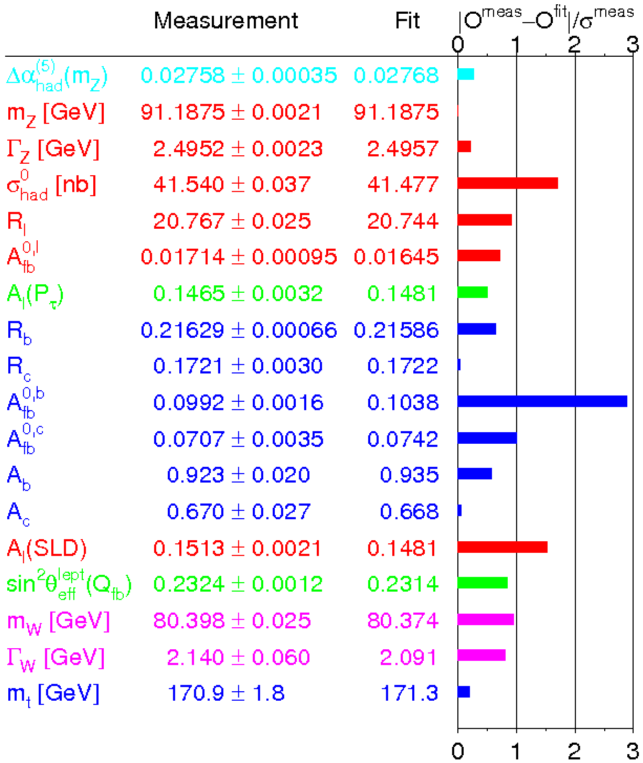
(For the DØ Collaboration)

The Success of the SM

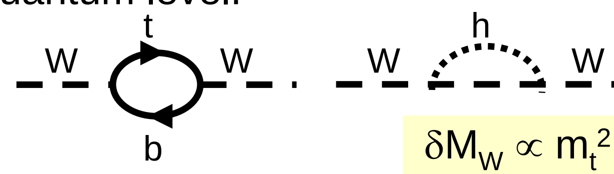
- During the last decade the SM has been confirmed experimentally beyond reproach.



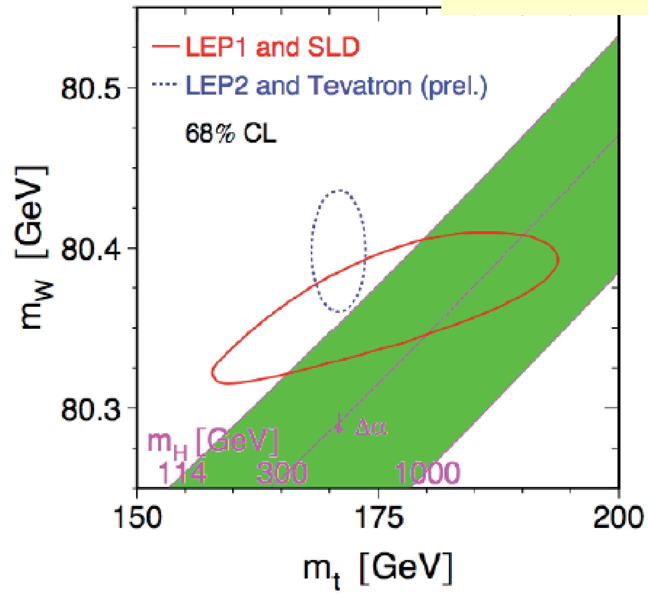
	Measurement	Fit	$\lvert O^{meas}-O^{fit}\rvert/\sigma^{meas}$
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02768	
m_Z [GeV]	91.1875 ± 0.0021	91.1875	
Γ_Z [GeV]	2.4952 ± 0.0023	2.4957	
σ^0_{had} [nb]	41.540 ± 0.037	41.477	
R_l	20.767 ± 0.025	20.744	
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01645	
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1481	
R_b	0.21629 ± 0.00066	0.21586	
R_c	0.1721 ± 0.0030	0.1722	
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1038	
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0742	
A_b	0.923 ± 0.020	0.935	
A_c	0.670 ± 0.027	0.668	
A_l(SLD)	0.1513 ± 0.0021	0.1481	
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314	
m_W [GeV]	80.398 ± 0.025	80.374	
Γ_W [GeV]	2.140 ± 0.060	2.091	
m_t [GeV]	170.9 ± 1.8	171.3	

- However, the dynamics for EWSB still awaits direct experimental verification.

- The high accuracy achieved (both experimental and theoretical) allows to perform tests at the quantum level:



$\delta M_W \propto m_t^2, \ln(m_h/M_W)$



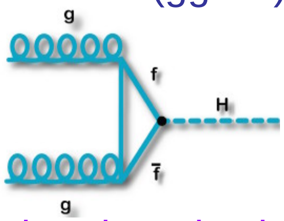
$\Rightarrow$ some sensitivity to the EWSB sector (requires careful interpretation)

- Current “experimental knowledge” on the SM-like Higgs:
  - Direct searches at LEP II: m_h>114.4 GeV @ 95% CL
  - Fits to precision EW data: m_h<144 GeV @ 95% CL

Data “favors” a light Higgs boson

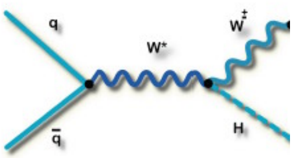
SM Higgs at the Tevatron

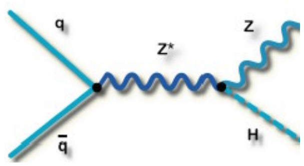
- Main production mechanisms (115<m_h<180 GeV):
  - Gluon fusion ($gg \rightarrow h$):



σ~0.8-0.2 pb

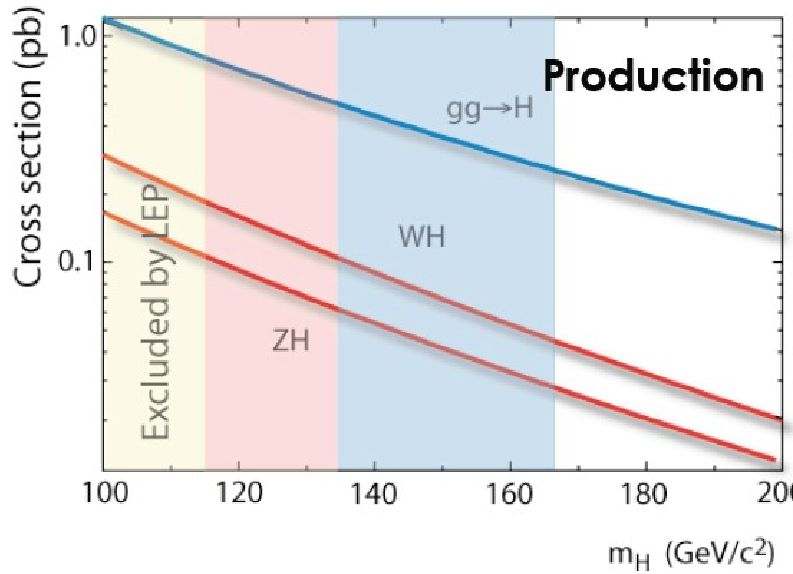
  - Associated production (Vh, V=W,Z):

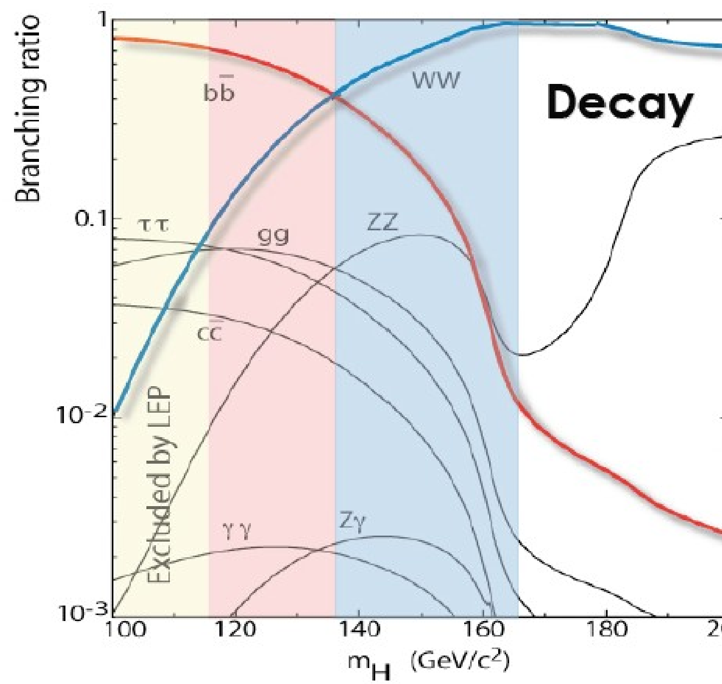




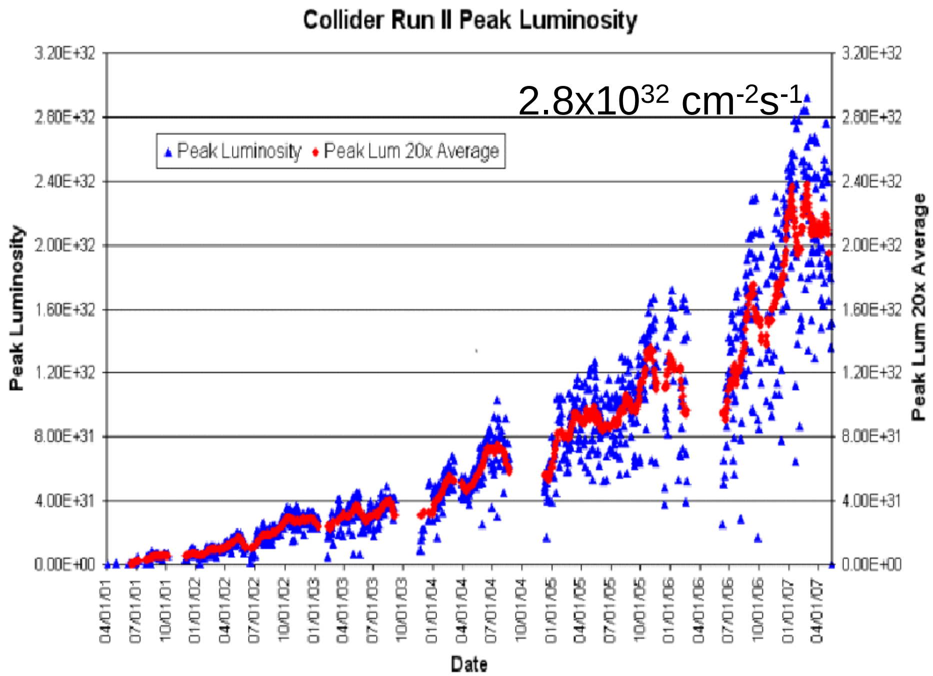
σ~0.2-0.03 pb σ~0.1-0.01 pb

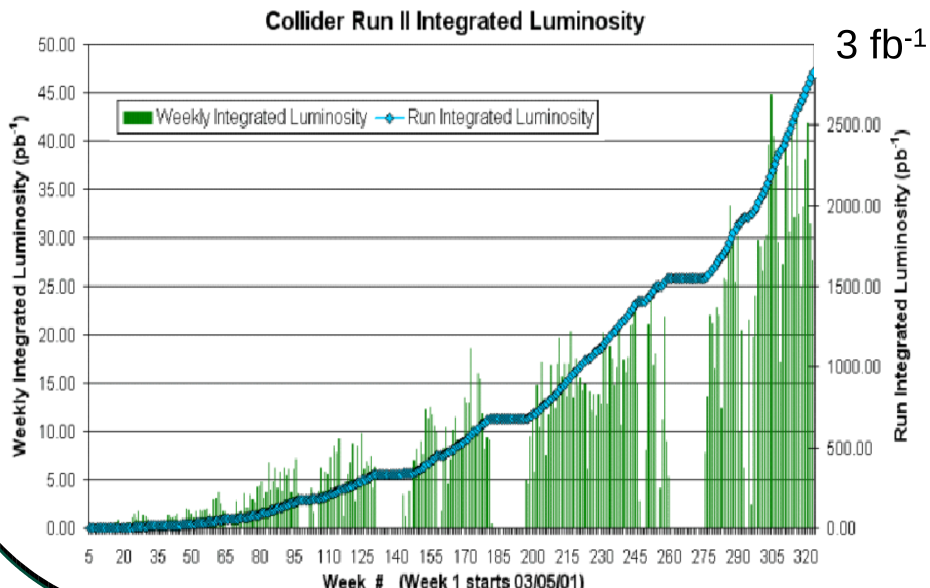
- Dominant decay channels:
  - m_h<135 GeV: $h \rightarrow bb$
  - m_h>135 GeV: $h \rightarrow WW^{(*)}$
- Search strategy:
  - Capitalizes on leptons to be able to trigger and select a sample enriched in EW instead of QCD processes.
  - Low mass region:
    dominated by $Wh \rightarrow l\nu bb$, $Zh \rightarrow l^+l^-bb$, $Zh \rightarrow \nu\nu bb$
  - High mass region:
    dominated by $gg \rightarrow h \rightarrow WW^{(*)} \rightarrow l^+\nu l'^-\nu$
  - Complement e.g. with $Wh \rightarrow WWW^{(*)}$





Tevatron Performance

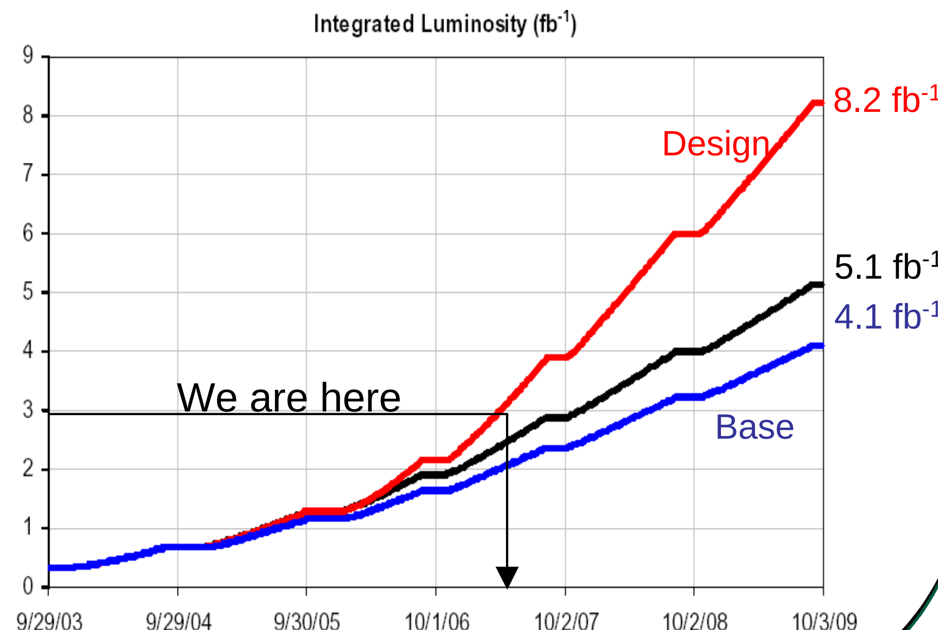




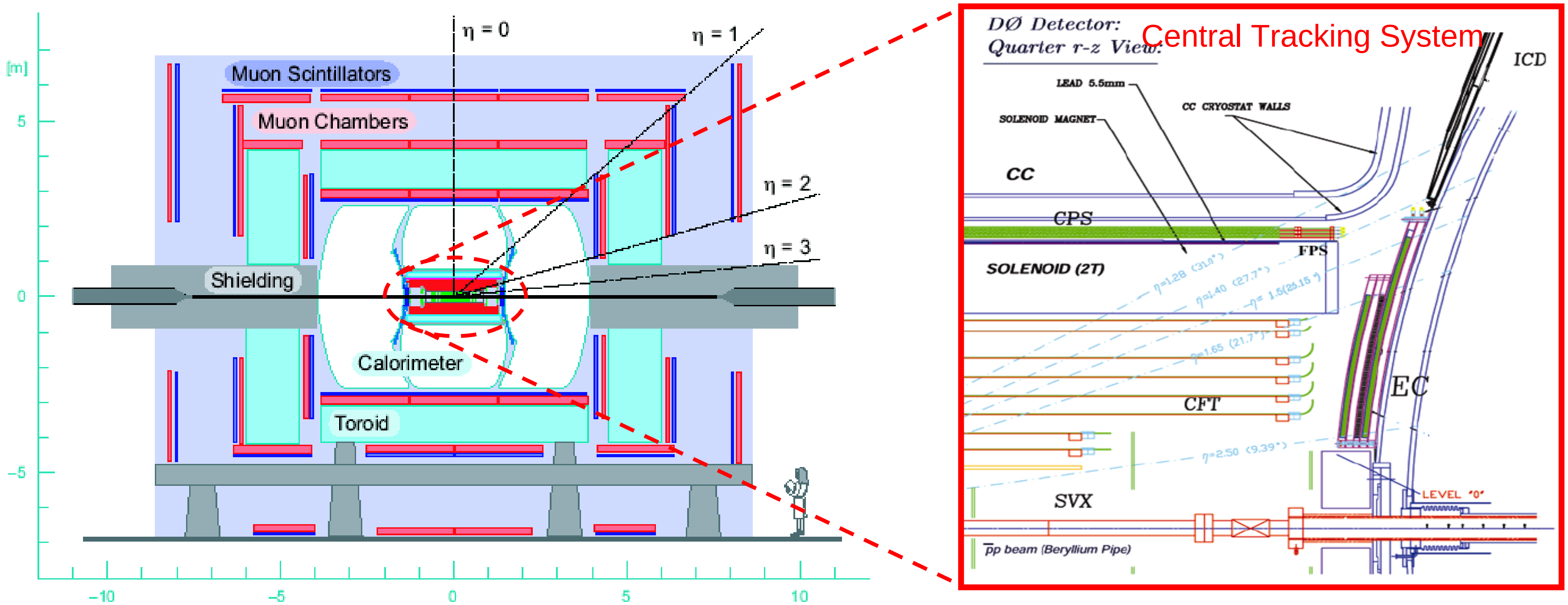
Excellent accelerator performance:

- Peak luminosity: $\geq 2\times10^{32}$ cm^{-2}s^{-1} (record: $\sim 3\times10^{32}$ cm^{-2}s^{-1})
- Weekly integrated luminosity: ~35 pb^{-1} (record: ~45 pb^{-1})
- Delivered integrated luminosity: ~3 fb^{-1}

- Performance is matching expectations for the design integrated luminosity of ~8 fb^{-1} by 2009.



DØ Detector

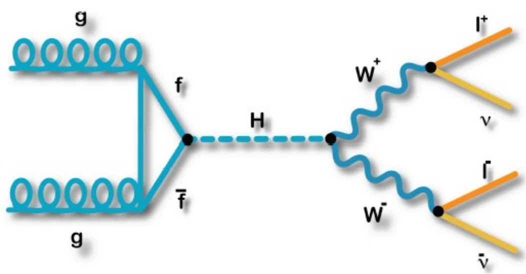


- Features:
  - Central tracking system in a 2 T solenoidal field:
    - Silicon Tracker (|η|<3)
    - Scintillating Fiber Tracker (|η|<1.5)
  - Central and forward preshowers
  - LAr/U calorimetry (|η|<4.2)
  - Muon system (3 layers, (|η|<2.0)
- Run IIb upgrades for further improved performance:
  - L1 trigger: CAL, Track and CAL+Track
  - Additional silicon layer (LØ) at R=1.6 cm.

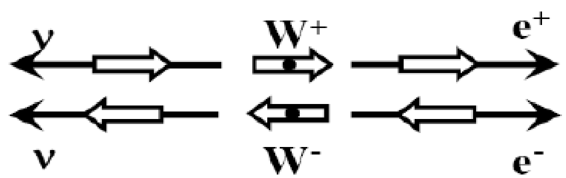
- Multipurpose detector well suited for Higgs search:
  - Lepton (e, μ, τ) identification
  - Jets and MET reconstruction
  - Jet flavor ID via displaced tracks and soft-leptons
- Data taking efficiency: 85-90%
- Recorded luminosity to date: ~2.5 fb^{-1}
- Results discussed here: ≤1 fb^{-1}

Gluon Fusion

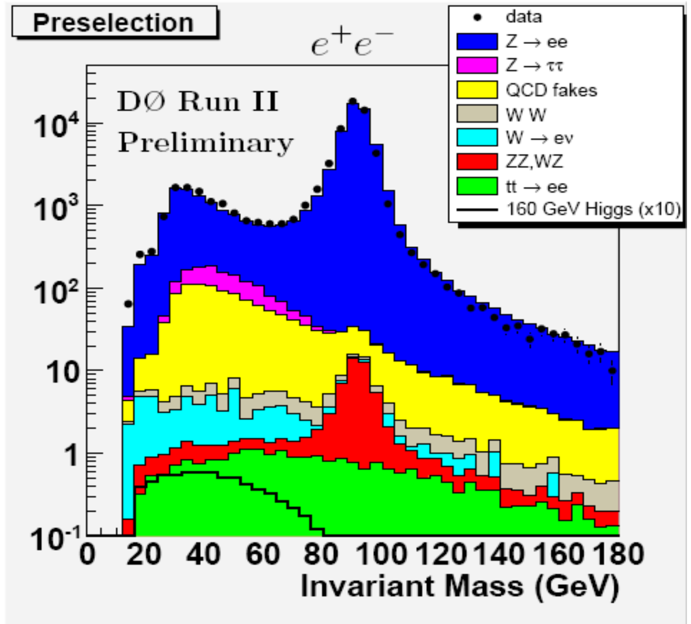
- Highest sensitivity channel for m_h>135 GeV.
- Experimental signature:

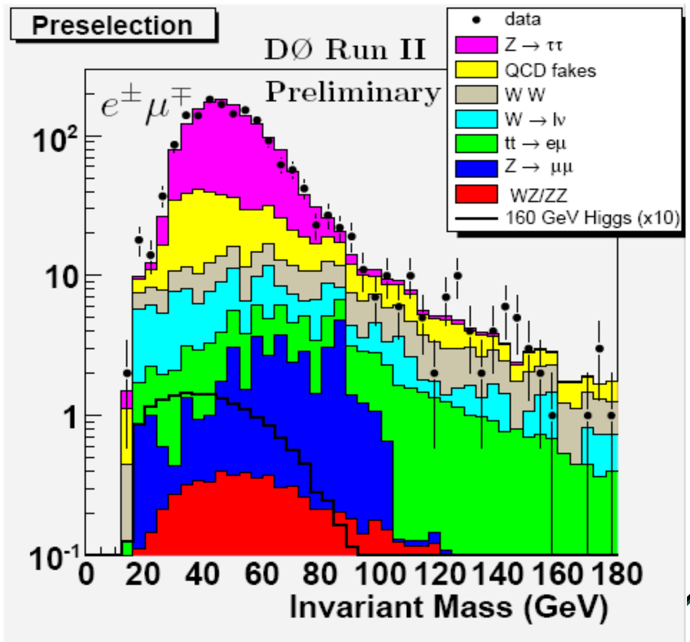


  - 2 high p_T leptons (ee,eμ,μμ) from W boson decays
  - Large MET from missing neutrinos
  - Low Δφ(l,l) because of spin-0 Higgs decay



- Backgrounds: Z/Drell-Yan, Diboson, W+jets, QCD, top
- Event selection:
  - Preselection: 2 opposite charge high p_T leptons
  - MET > 20 GeV
  - Additional kinematic cuts (e.g. m_{ll})
  - $\sum p_{T,jet}$< 100 GeV (ttbar veto)
  - Δφ(l,l)<2.0
- Main background after full selection is WW (~70%). Run II measurements agree with NLO calculations.

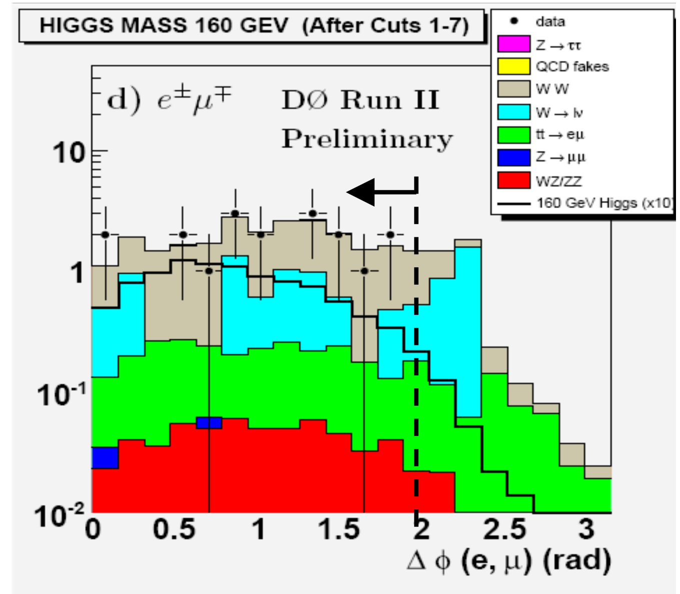




Gluon Fusion (cont'd)

Expected/Observed Events in 1 fb^{-1}

Channel	Signal (m_h=160 GeV)	Background	Data
ee	0.42	10.3	10
eμ	0.97	24.4	18
μμ	0.35	9.8	9
Total	1.74	44.5	37

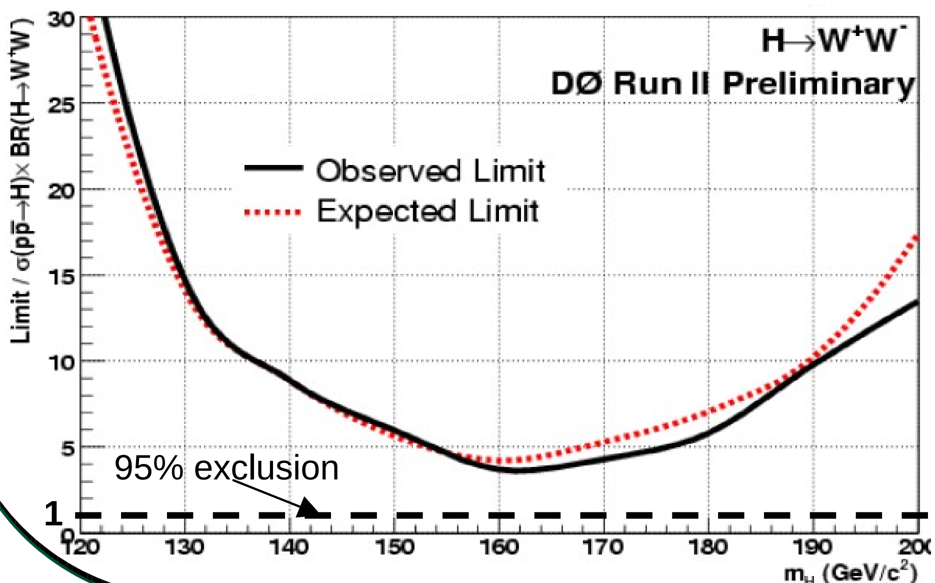


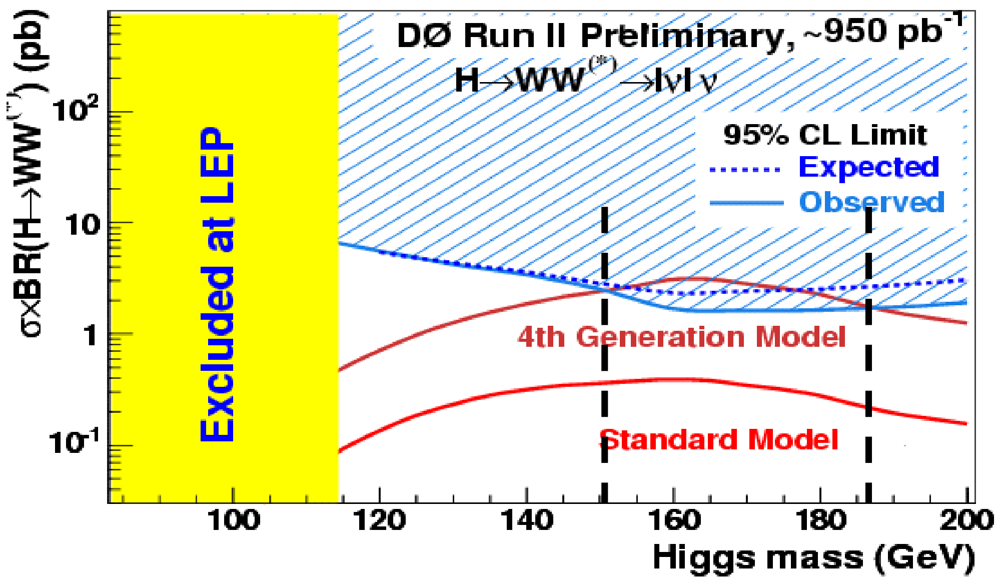
- Cross section limit based on counting experiment after full selection.
- 95%CL limit (m_h=160 GeV):

  $\sigma_{95} < 4\ \sigma_{SM}$ (expected)

  $\sigma_{95} < 4\ \sigma_{SM}$ (observed)

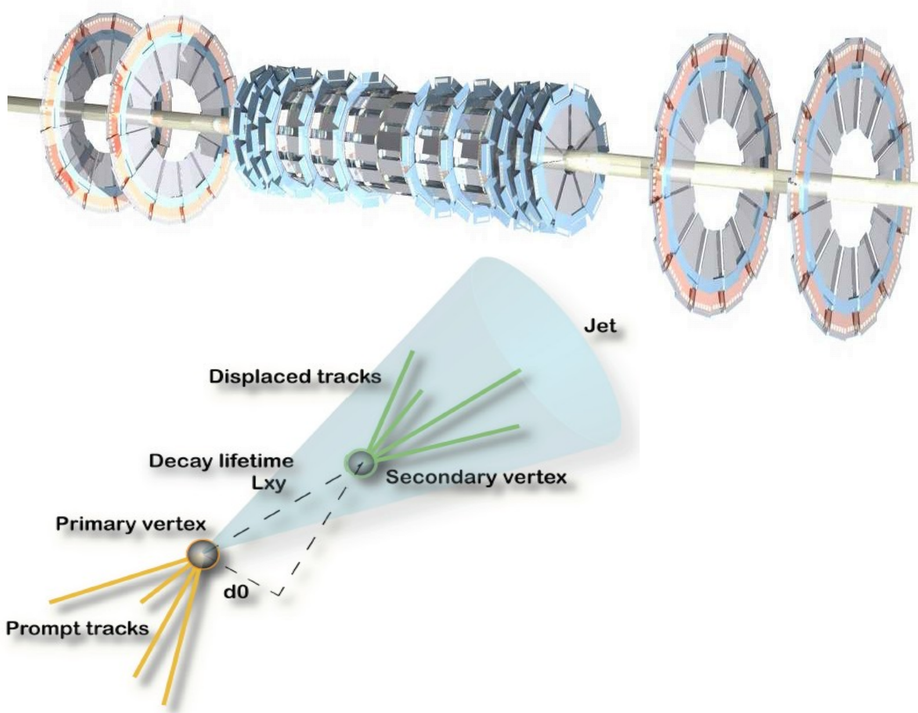
4th generation model excluded for m_h=150-185 GeV

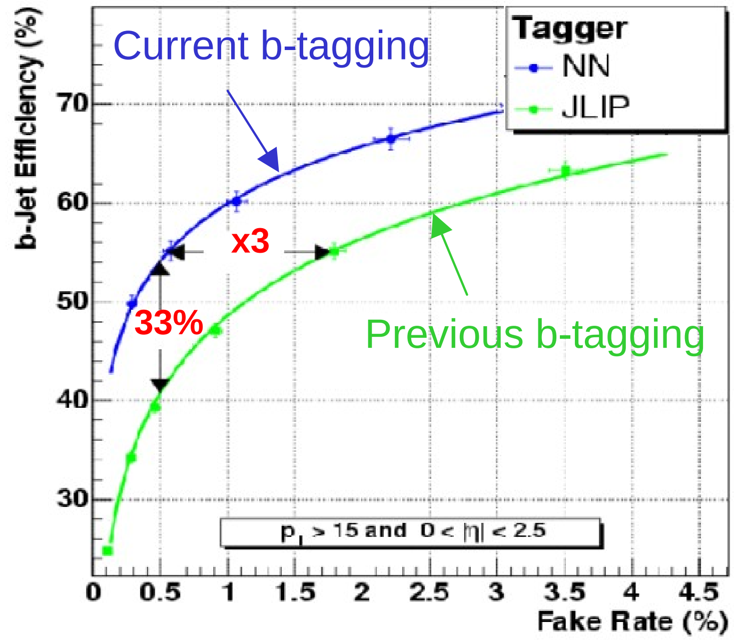




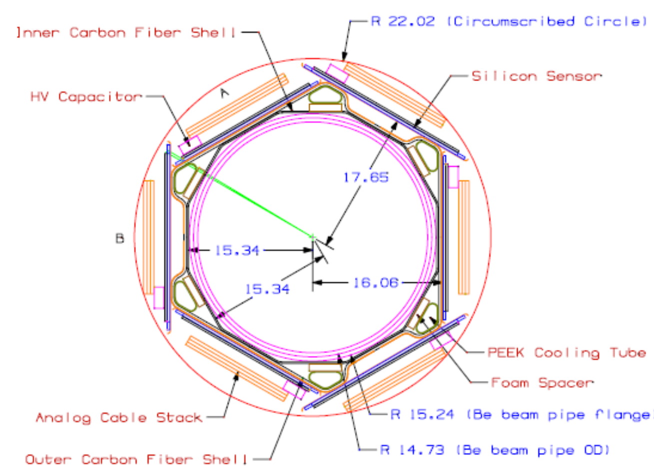
B-Tagging

- High b-tagging performance critical for searches involving h→bb.



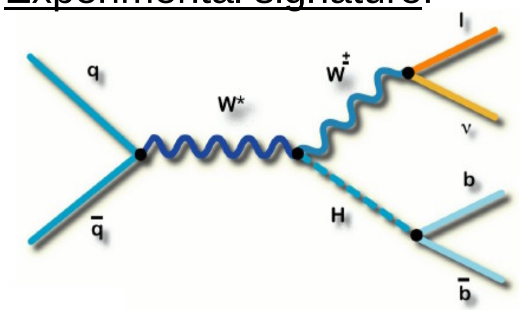


- Significantly improved performance for new NN b-tagger combining 7 variables based on previously existing secondary vertex and impact parameter taggers.
- Multiple operating points ranging from TIGHT (eff=50%, fake=0.4%) to LOOSE (eff=70%, fake=4.5%)
- Further improvements expected:
  - NN b-tagger including soft-lepton taggers.
  - Improved impact parameter resolution (by x2) from addition of Layer-Ø silicon detector.



Associated Production ($Wh \rightarrow l\nu bb$)

- Experimental signature:



  - High p_T isolated lepton
  - Large MET
  - 2 b-jets
- Event selection:
  - 1 isolated e(μ), p_T>20 GeV, $|\eta|$<1.1(2.0)
  - MET > 20 GeV
  - 2-3 jets, p_T>20 GeV, $|\eta|$<2.5
  - 1 tight b-tag (1-tag sample) OR

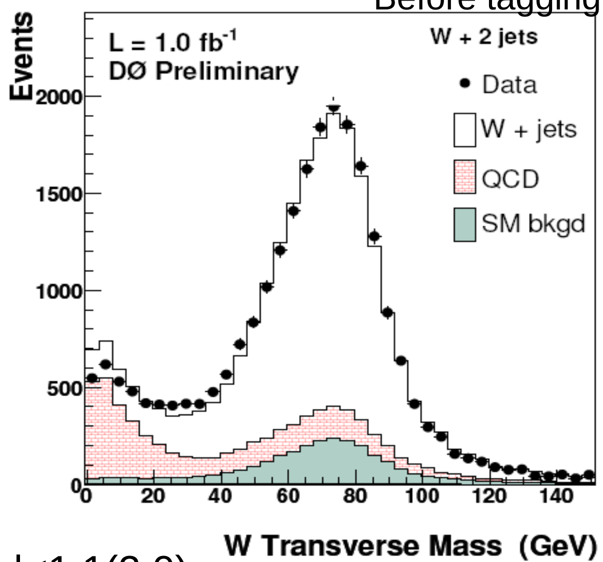
    2 loose b-tags (2-tag sample)

  With respect to previous analysis:

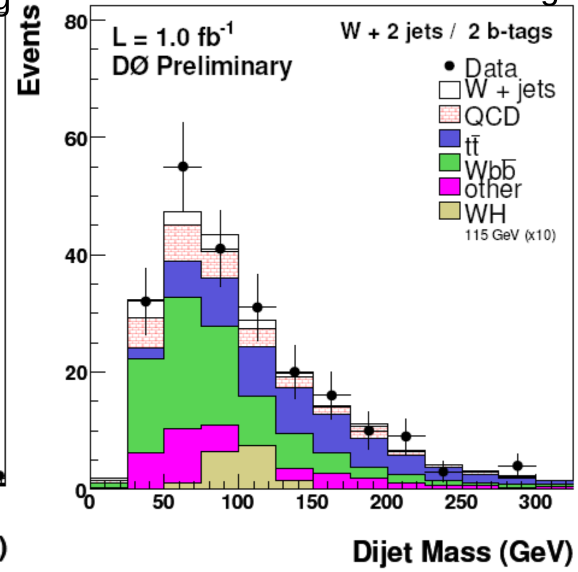
  ⇒ +47% sensitivity in μ channel from trigger OR (eff~100%)

  ⇒ +15% sensitivity from orthogonal 1-tag and 2-tag
- Backgrounds: W+jets (65-50%), top (15-30%), QCD
- Main discriminant variable: m_{jj} distribution.
- Multivariate analyses under development.
  E.g. matrix-element based discriminant as sensitive as cut-based analysis despite 30-40% less sensitive selection.

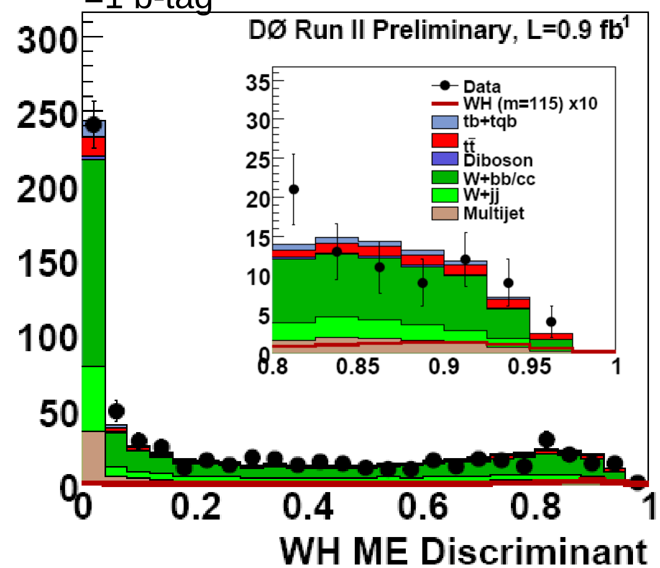
Before tagging



2 b-tags

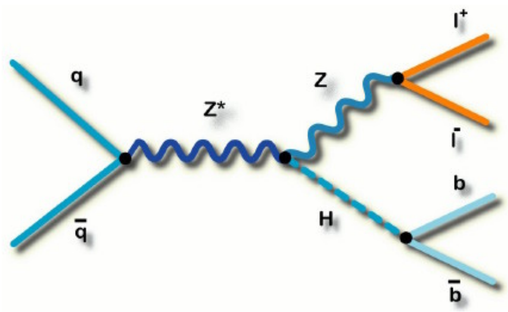


=1 b-tag



Associated Production ($Zh \rightarrow l^+l^-bb$)

- Experimental signature:

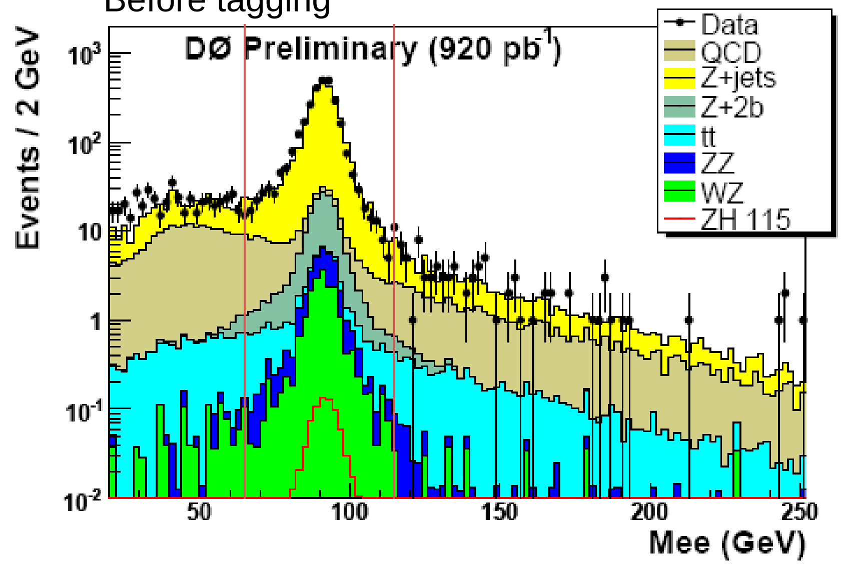


  - Two high p_T isolated leptons
  - Low MET
  - 2 b-jets

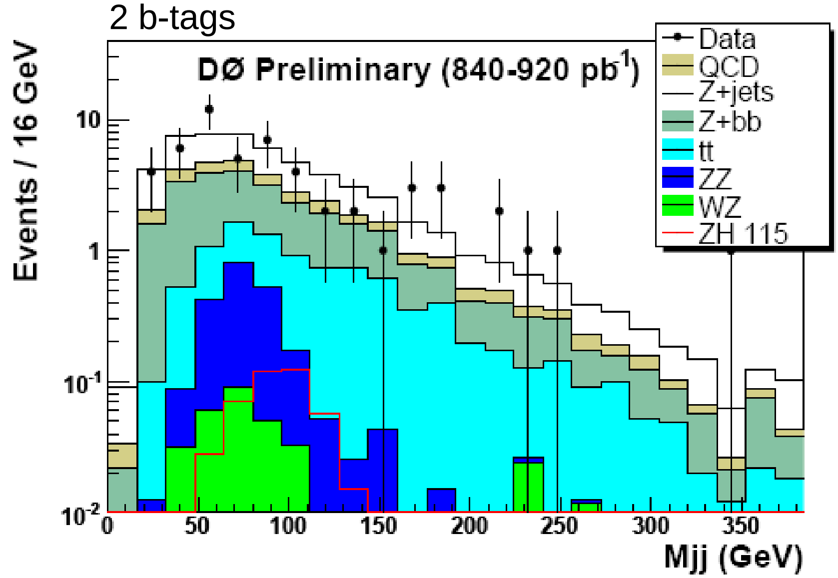
- Event selection:
  - 2 isolated e(μ), p_T>15 GeV, $|\eta|<1.1$ or $1.5<|\eta|<2.5$ ($|\eta|<2.0$)
  - Z mass window cut:
    ee: $65<m_{ll}<115$ GeV
    $\mu\mu$: $70<m_{ll}<110$ GeV
  - $\geq$2 jets, p_T>15 GeV, $|\eta|<2.5$
  - 2 loose b-tags (4% mistag rate)
- Backgrounds: Z+jets (~80%), top, dibosons

- Main discriminant variable: m_{jj} distribution.
- Multivariate analyses under development.

Before tagging

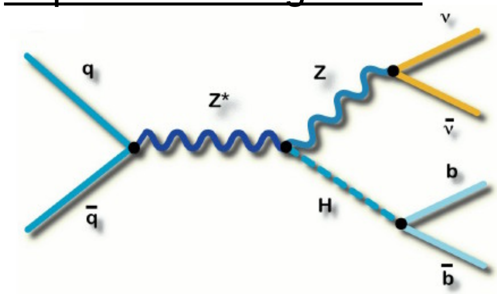


2 b-tags



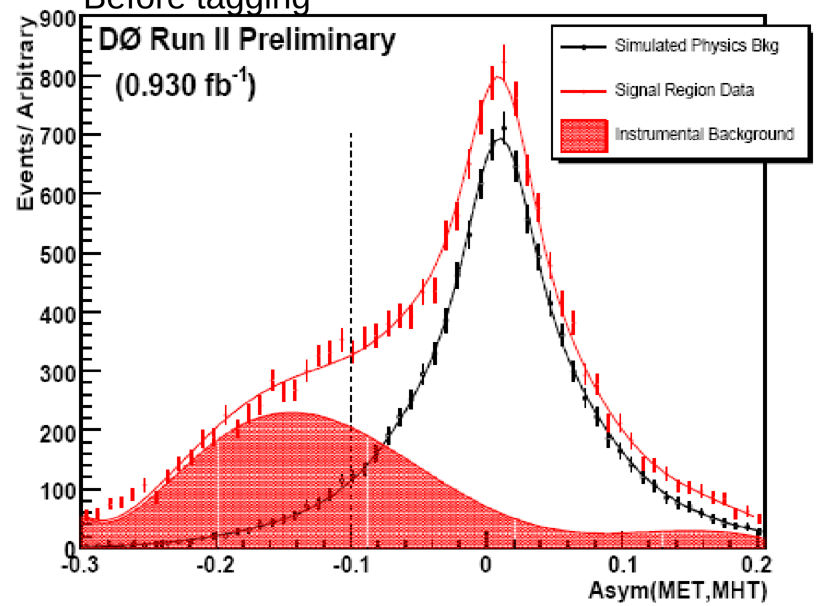
Associated Production (Zh→ννbb)

- <u>Experimental signature</u>:

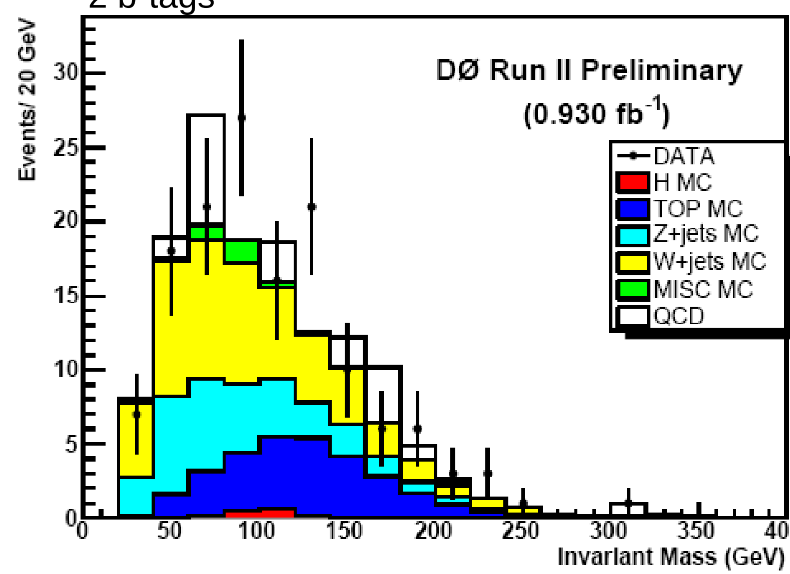


  - Large MET
  - 2 b-jets
- <u>Main event selection criteria</u>:
  - Trigger based on large vectorial missing H_T
  - MET>50 GeV
  - ≥2 jets, p_T>20 GeV, |η|<1.1 or 1.4<|η|<2.5
    Not back-to-back: Δϕ>165 deg
  - -0.1<Asymmetry(MHT,MET)<0.2
  - 2 b-tags: 1 tight + 1 loose b-tag
- <u>Backgrounds</u>:
  - Physics (87%): W+jets (40%), Z+jets, tt
  - Instrumental (13%): QCD multijets
    (estimated from sideband in data)
- Significant acceptance for Wh→lνbb with undetected e/μ or l=τ(→had).
- Main discriminant variable: m_{jj} distribution.
- Multivariate analyses under development.

Before tagging



2 b-tags

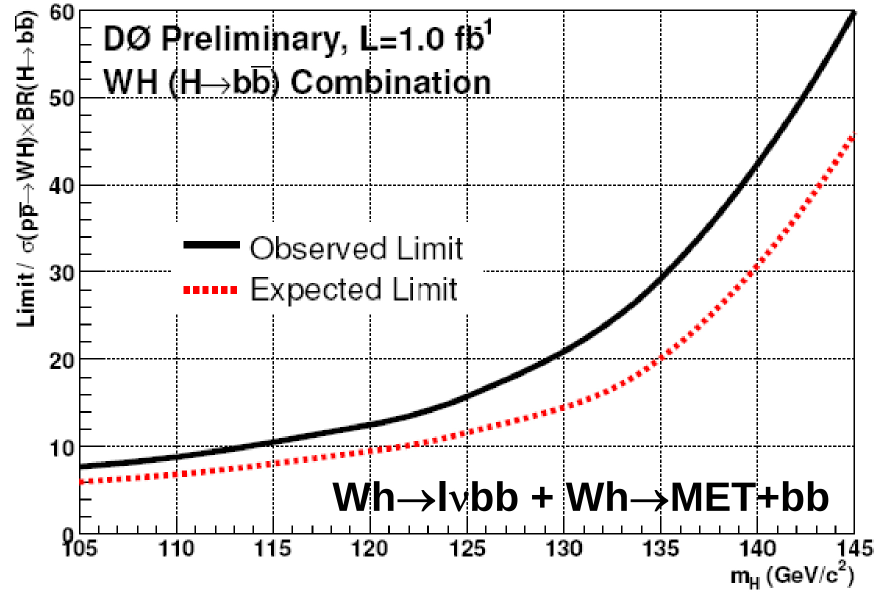


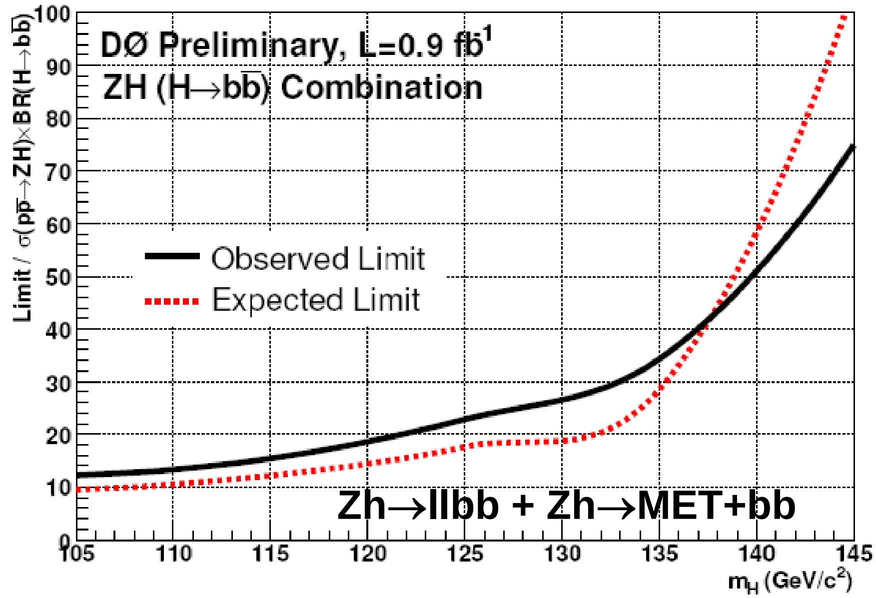
Associated Production Limits

Expected/Observed Events in 1 fb^{-1}
(m_h=115 GeV, *70<m_{jj}<130 GeV)*

Process	Signal	Bckg	Data	S/√B
Wh→lνbb(2-tag)	1.45	86.6	91	0.156
Wh→lνbb(1-tag)	1.48	365.2	339	0.077
Zh/Wh→MET+bb	0.83/0.54	55.3	63	0.184
Zh→llbb	0.37	19.8	17	0.083
Total	4.67	526.9	510	

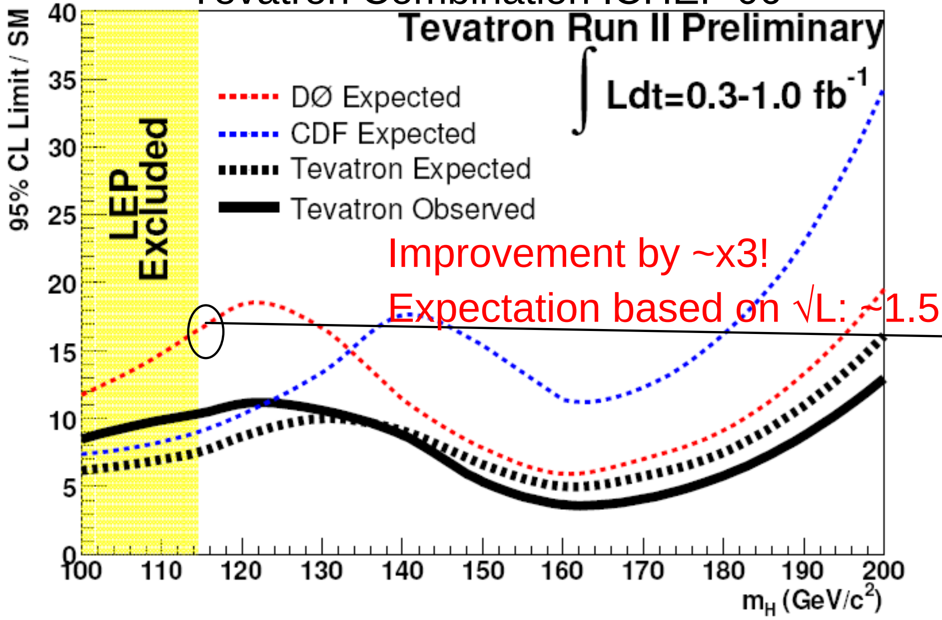
- Wh combined 95% CL limits (m_h=115 GeV):
  $\sigma_{95} < 8.1\ \sigma_{SM}$ (expected)
  $\sigma_{95} < 10.6\ \sigma_{SM}$ (observed)
- Zh combined 95% CL limits (m_h=115 GeV):
  $\sigma_{95} < 12.2\ \sigma_{SM}$ (expected)
  $\sigma_{95} < 15.4\ \sigma_{SM}$ (observed)
- Different channels have different sensitivity: important to keep separate in the combination.



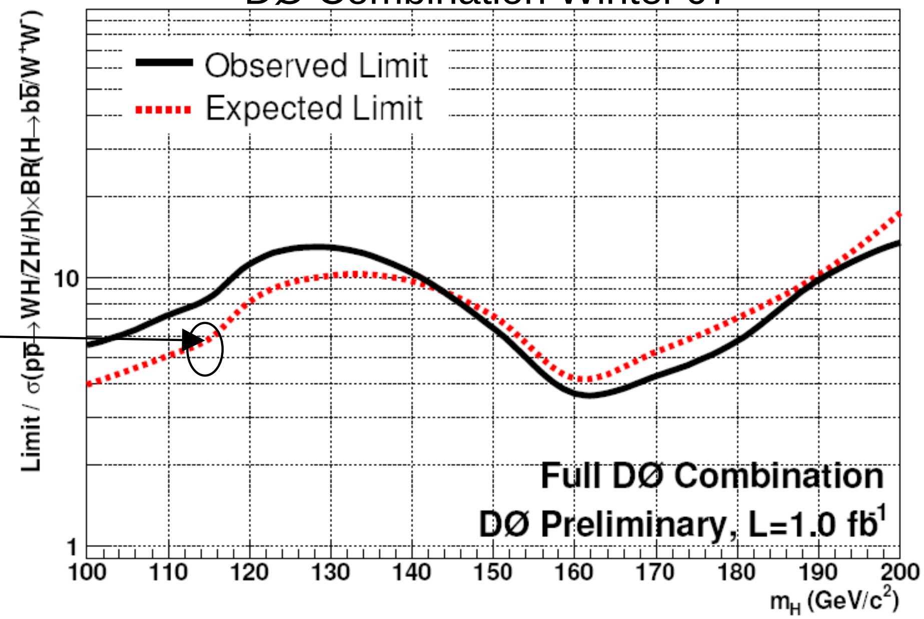


Combined Limits and Prospects

Tevatron Combination ICHEP'06



DØ Combination Winter'07



- Prospects:

(optimized operating point, improved b-tag NN, continuous b-tagging, layer-Ø,..) → B-tagging

(ME/NN discriminants,..) → Multivariate Techniques

(kinematic fiting, b-specific corrections,…) → Improved Mass Resolution

(Wh→WWW(*), Zh/1-tag, taus, h→WW(*) →lνjj,…) → New Channels

Ingredient	Equiv. Lumi. Gain	σ_{95}/σ_{SM} (m_h=115 GeV)	σ_{95}/σ_{SM} (m_h=160 GeV)
DØ (1 fb^{-1})	-	5.9	4.2
Lumi = 2 fb^{-1}	2	4.2	3.0
B-tagging	2	3.0	3.0
Multivariate Techniques	1.7	2.3	2.3
Improved Mass Resolution	1.5	1.8	2.3
New Channels	1.3/1.5	1.6	1.9
Reduced Systematics	1.2	1.5	1.7
Two Experiments	2	1.1	1.2

Luminosity needed for 95% CL exclusion: ~2.5 fb^{-1} ~3.0 fb^{-1}

(*) Potential improvements in acceptance (lepton ID, trigger, etc) not included in above table.

Higgs Boson(s) Beyond the SM

- The simple SM Higgs mechanism may not be realized in Nature.
- Many extended models of EWSB possess a limit in which they are indistinguishable from the SM ("decoupling limit"): e.g. 2HDM, extra dimensions, composite models, etc.

  ➔ SM-like Higgs searches provide useful information.

- In particular, within the generic (Type II) 2HDM:
  - Φ_u and Φ_d couple respectively to up- and down-type fermions; $\tan\beta = v_u/v_d$.
  - After EWSB, four massive scalars ($h^0, H^0, H^\pm$) and one massive pseudo-scalar (A^0)

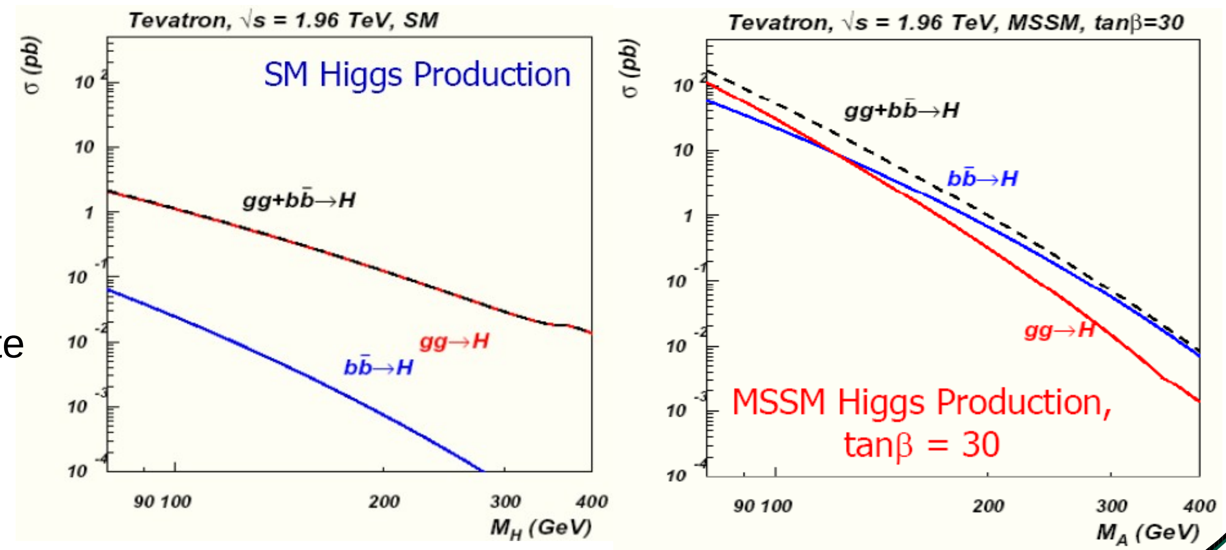
  Most successful of them is SUSY:
  - EWSB typically explained by radiative corrections
  - Requires light h: m_h<135-140 GeV
  - MSSM: described via a handful of additional parameters: $\tan\beta$, μ, A and gaugino masses

- MSSM at large $\tan\beta$:
  - $\Phi^0=\{h^0/H^0, A^0\}$ nearly degenerated in mass
  - $\sigma_{\Phi+X} \propto \tan^2\beta$

  $\Rightarrow$ Significant increase in production rate!!
  - For low and intermediate masses:

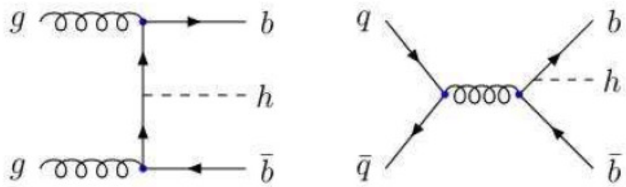
    BR($\Phi^0 \rightarrow$bb)~90%

    BR($\Phi^0 \rightarrow \tau^+\tau^-$)~10%

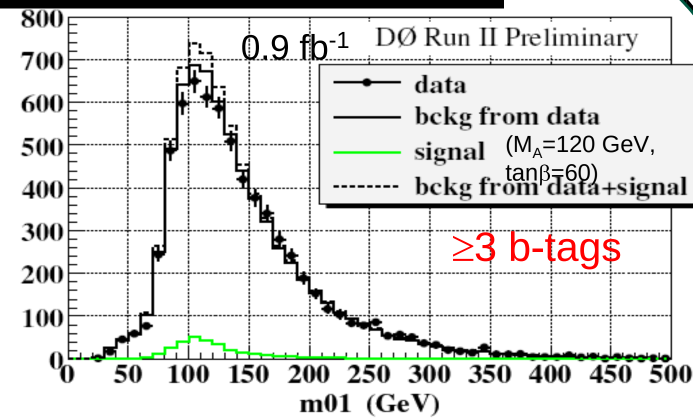


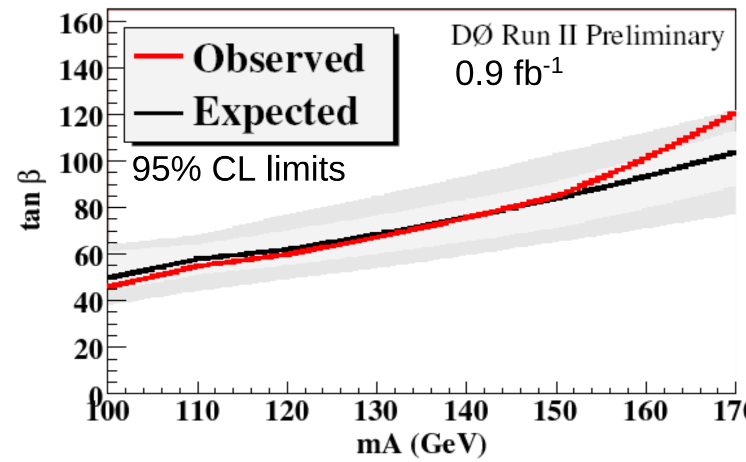
MSSM Higgs ($\Phi \rightarrow bb$)

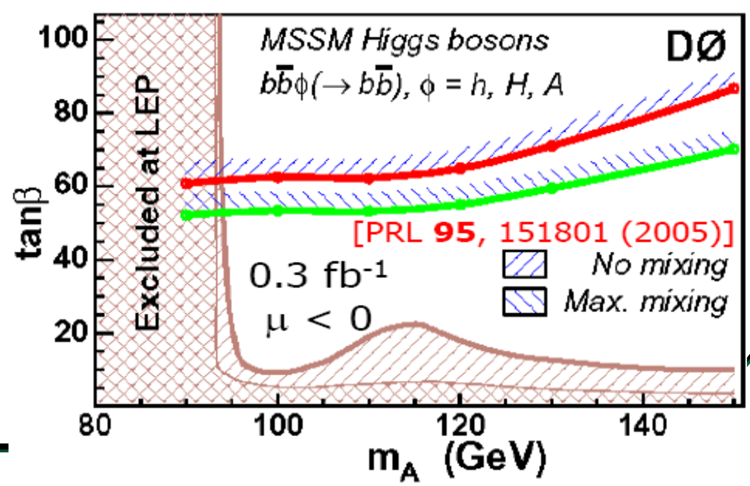
- Search for Φ+b(b) associated production with $\Phi \rightarrow bb$.



- Experimental signature:
  - $\geq$3 b-tagged jets with p_T>40, 25, 15 GeV.
  - Invariant mass of leading two jets peaks at M_Φ
- Backgrounds dominated by heavy flavor-enriched QCD multijets:
  - Shape extracted from 2-tag sample (including kinematic bias from 3rd b-tag)
  - Rate normalized outside the "signal region" (for each point in M_A and tanβ) plane.
- Good agreement between data and background model $\Rightarrow$ limits on $\sigma_{\Phi b(b)}$BR($\Phi \rightarrow bb$) set via the CL_s method.
- Interpret cross section limits as upper tanβ limits (currently using tree-level cross sections, i.e. w/o NLO and stop mixing effects – so not directly comparable to published 0.3 fb^{-1} result).
  - Moderate improvement (~15%) over published result despite not being as optimized.
  - Largest sensitivity expected for μ<0 and "maximum mixing".

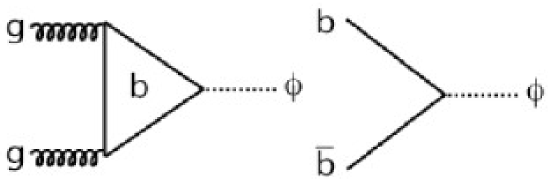






MSSM Higgs ($\Phi\to\tau^+\tau^-$)

- Search for $\Phi\to\tau^+\tau^-$ complementary to $\Phi\to bb$: lower BR but also lower backgrounds.



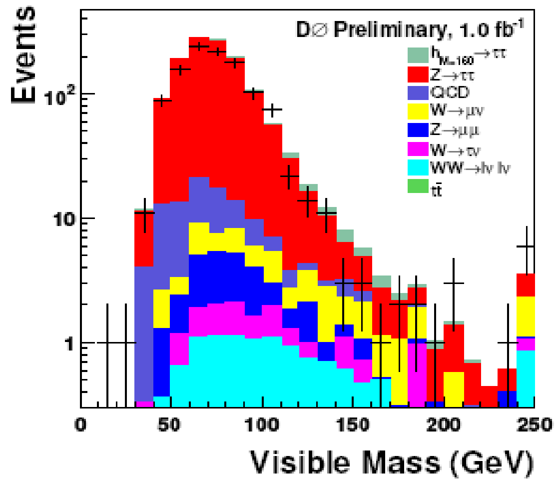
$\Phi\to\tau_\mu\tau$

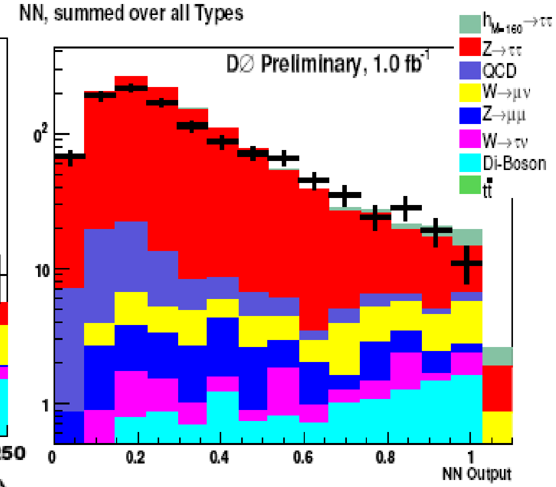
- <u>Main event selection criteria</u>:
  - One isolated μ, p_T>15 GeV
  - One τ candidate, p_T>15(20) GeV
  - NN_τ>0.9(0.95); $\Delta R_{\mu\tau}$>0.5
  - M_W^{vis}<20 GeV (reduce W+jets bckg)

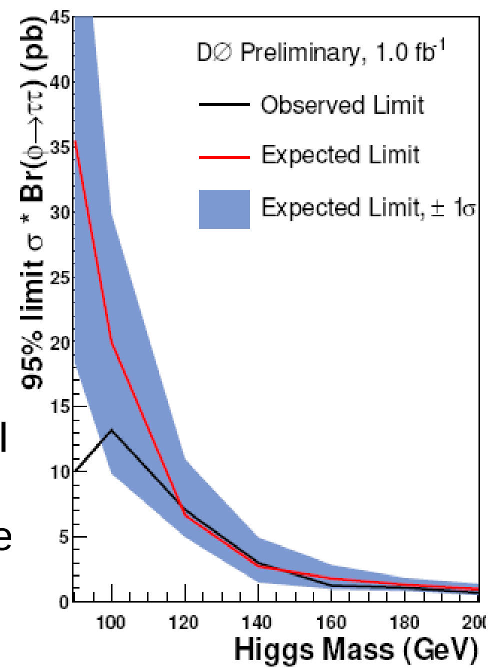
$$M_W^{vis} = \sqrt{2E_\mu \not{E}_T \frac{p_\mu}{p_{T,\mu}}(1-\cos\Delta\phi)}$$

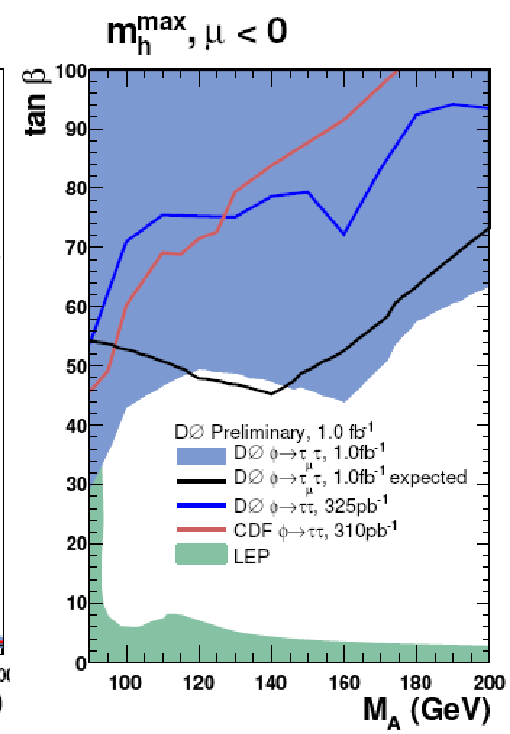
- <u>Dominant bckg after selection</u>: $Z\to\tau^+\tau^-$ (90%).
- Mass-dependent NN selection for optimal S/B separation (M^{vis}, μ and τ kinematic variables).

- Good agreement between data and bckg model $\Rightarrow$ limits on $\sigma_\Phi BR(\Phi\to\tau^+\tau^-)$ via the CL_s method.
- Interpret cross section limits within MSSM in the m_h^{max} and no-mixing scenarios.









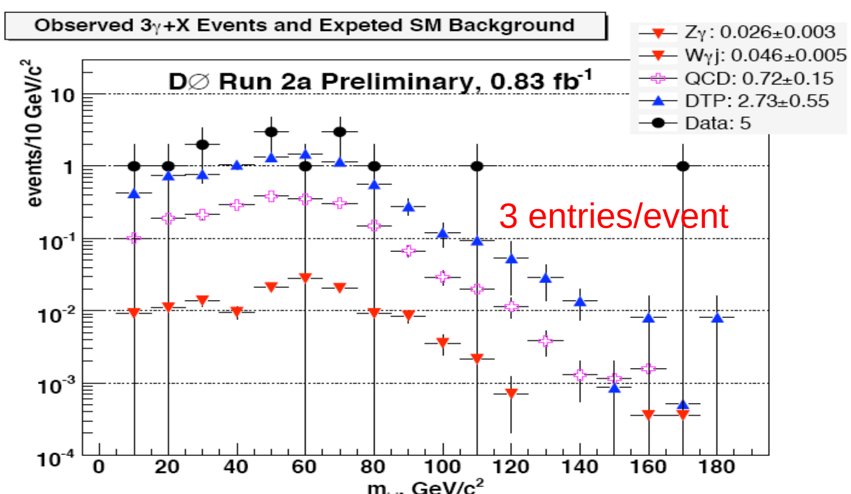
Fermiophobic Higgs

- In certain 2HDM, couplings of light Higgs to fermions is suppressed. If sufficiently light, $BR(h_f \to \gamma\gamma) \sim 1$.
- Search for associated $h_f H^\pm$ production via the $h_f W^\pm H^\pm$ interaction in the multi-photon final state.

$$p\bar{p} \to h_f H^\pm \to h_f h_f W^\pm \to \gamma\gamma\gamma(\gamma) + X$$

  - In 2HDMs, for $\tan\beta > 1$, $M_{H\pm} < 200$ GeV, $M_h < 90$ GeV: $BR(h_f \to \gamma\gamma) \sim 1$ and $BR(H^\pm \to h_f W^\pm) \sim 1$.
- Experimental signature:

  $\geq 3\ \gamma$, $E_T > 30, 20, 15$ GeV with $|\eta| < 1.1$
- Main background: direct 3γ production (78%); estimated from MC, corrected for the ratio of direct di-photons in data vs. MC.
- Good agreement between data (5 events) and background model (3.5±0.6).

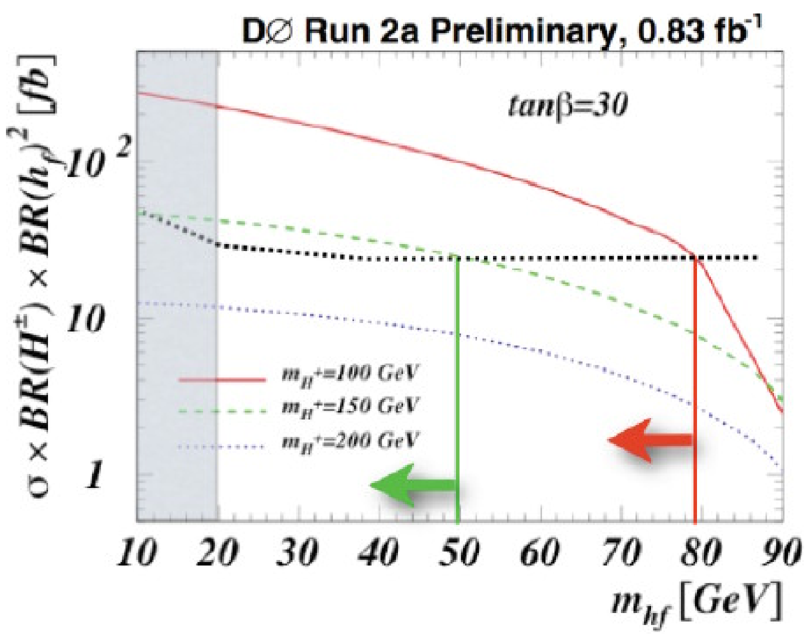


- No apparent structure in the di-photon mass spectrum. Further improve S/B by requiring $p_T(3\gamma) > 25$ GeV:

  observed: 0 events,

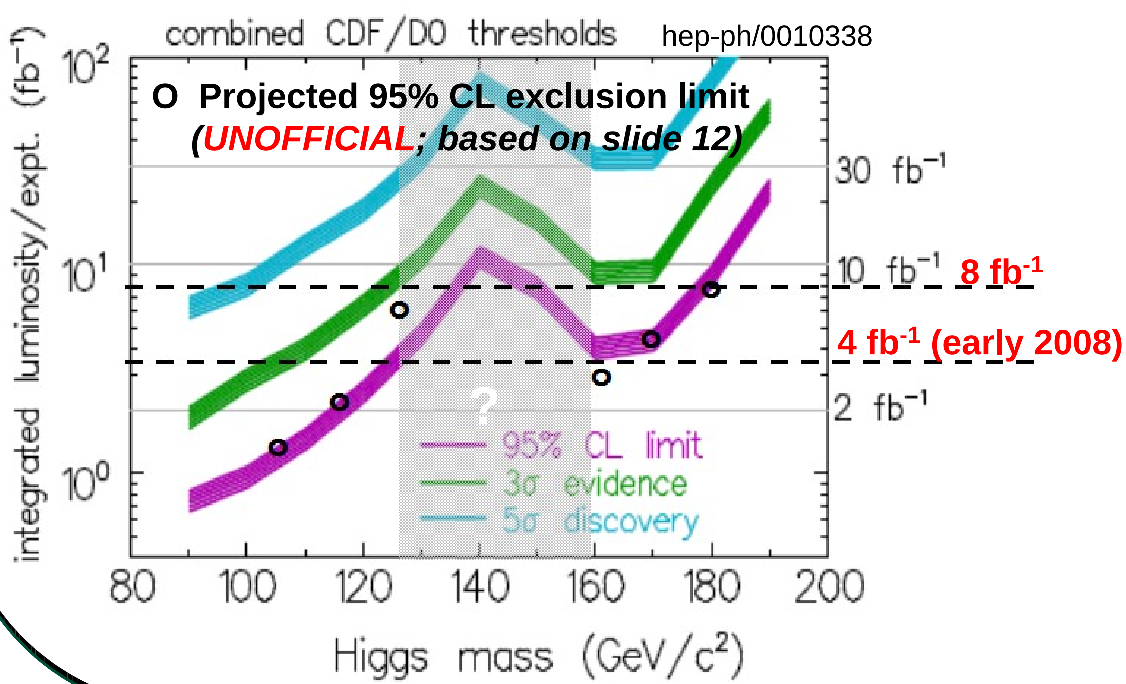
  expected: 1.1±0.2 events

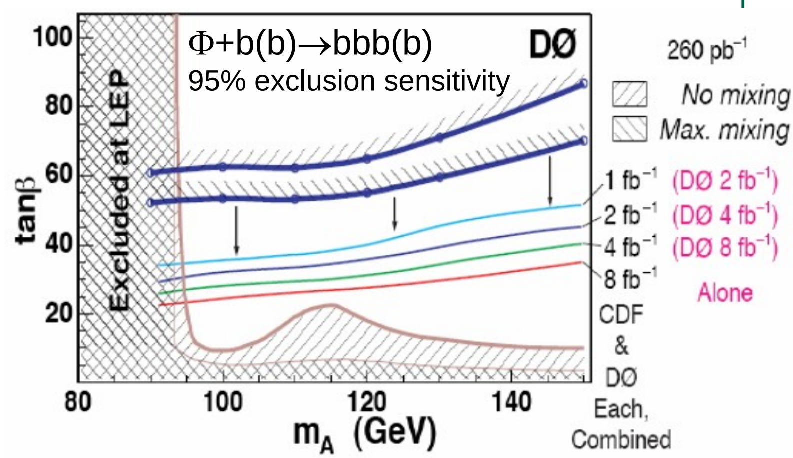
  $\Rightarrow \sigma(h_f H^\pm) < 25.3$ @ 95% CL.
- Limits presented as exclusion in M_h for different $M_{H\pm}$ and $\tan\beta$ values.
- Sensitivity depends strongly (weakly) on $M_{H\pm}$ ($\tan\beta$).

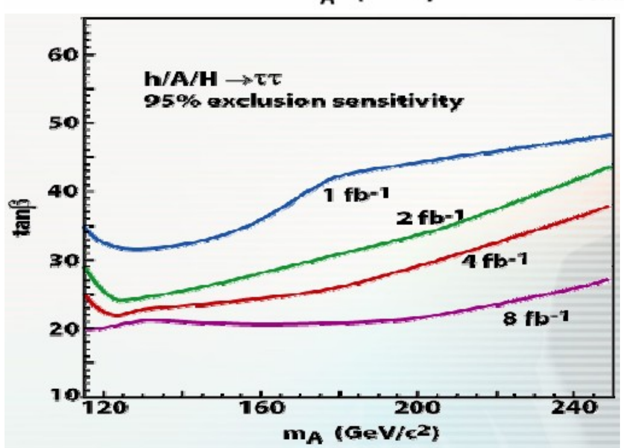


Conclusions and Outlook

- Wide variety of searches for SM or BSM Higgs with 1 fb^{-1} show no evidence of signal.
- The accelerator and the DØ detector are performing extremely well.
  - 2.5 fb^{-1} of data already recorded; expect ~4(8) fb^{-1} delivered by end of 2007(2009).
- We continue to learn how to squeeze the last drop of information out of the data.
  - Ongoing work to increase acceptance, add channels not considered before, invariant mass resolution improvements, sophisticated analysis techniques, etc.
  - Goal: continue to beat down √L scaling!
  - Analysis teams are growing!!
  - Very important: the same is happening at CDF!!!
- A very exciting time for the Higgs search at the Tevatron!!!!



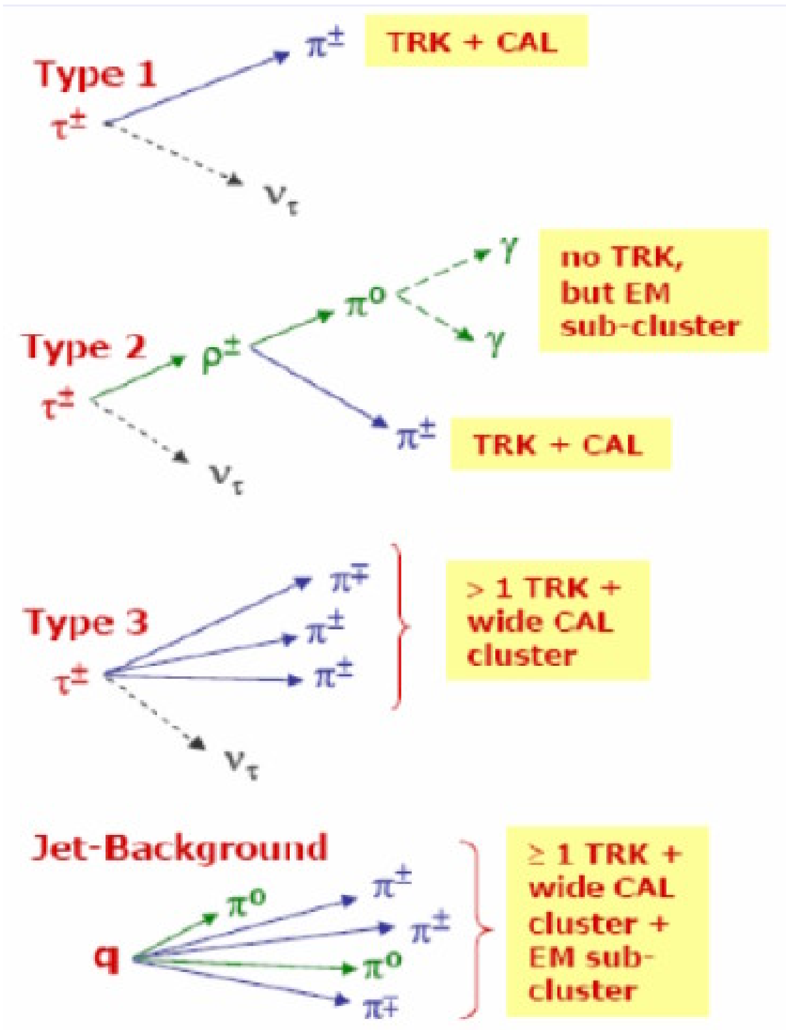


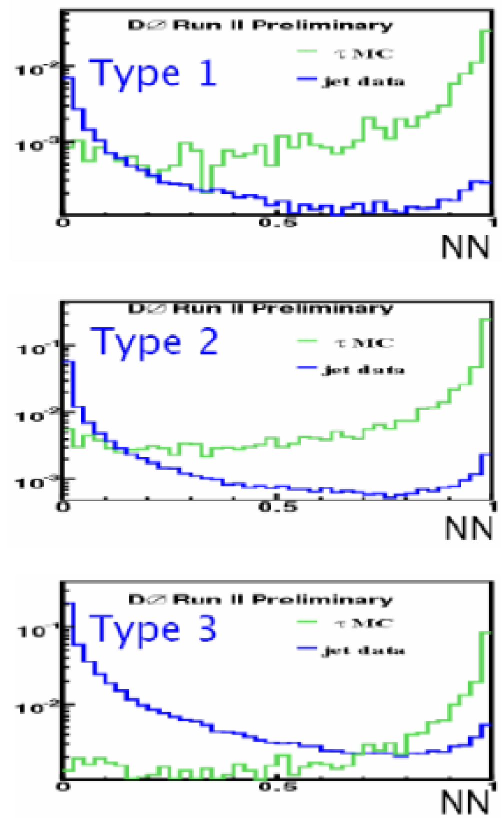


Backup

Tau Identification

- NN-based identification for each of three tau categories.





Performance (p_T>15 GeV)

Tau Type	1	2	3
Reconstruction			
Jets	1.5	10	38
Taus	9.1	50	20
NN > 0.9			
Jets	0.04	0.2	0.8
Taus	5.8	37	13

⇒ Validated in $Z \rightarrow \tau\tau$ cross section measurement.