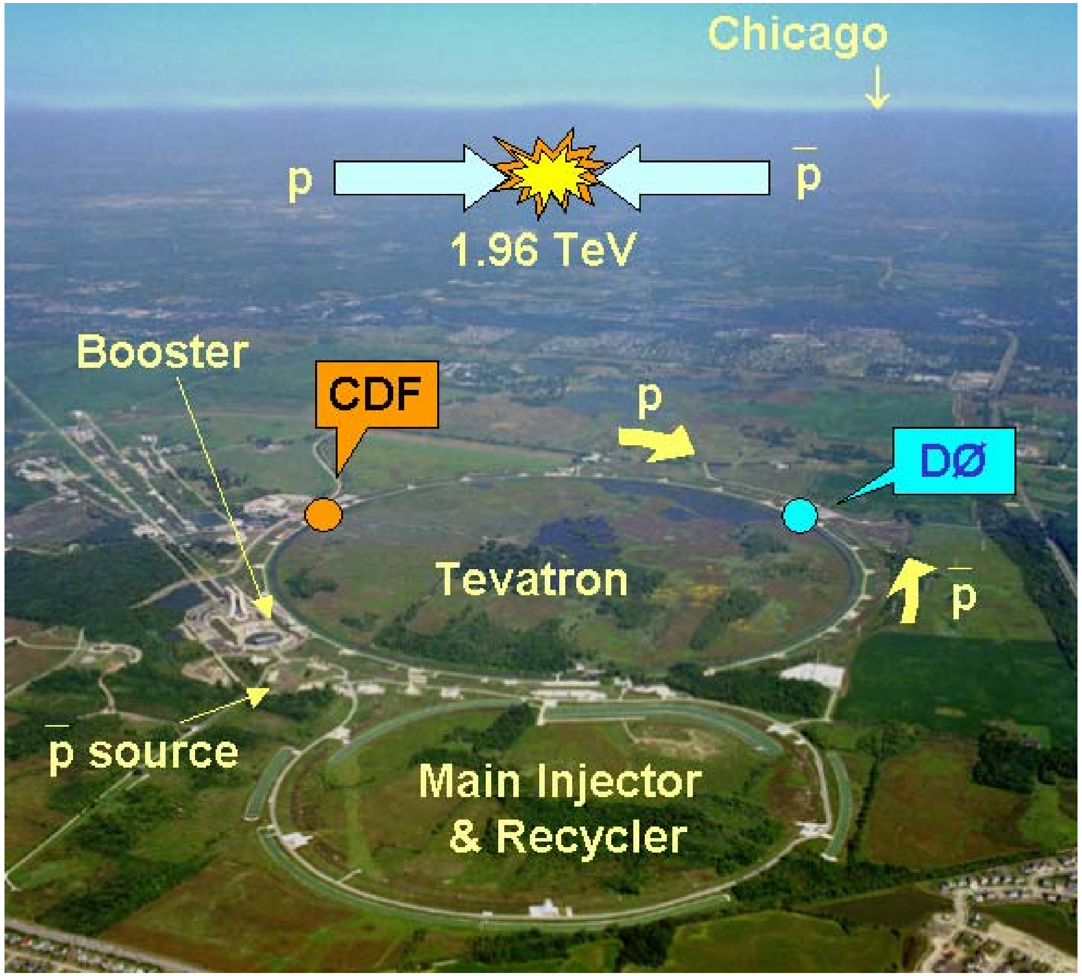
Results on Higgs Searches @Tevatron

Tev4LHC@CERN, April 2005,

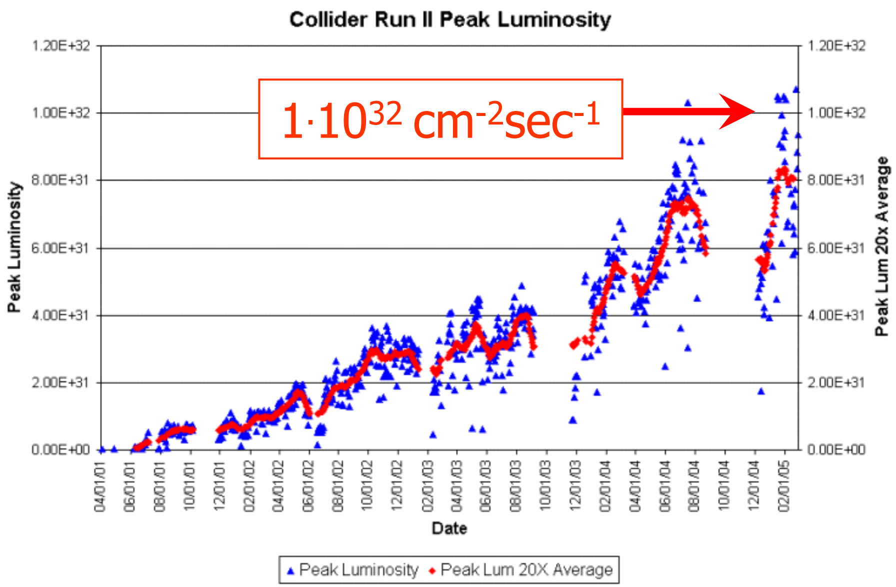
Gregorio Bernardi, Paris/FNAL

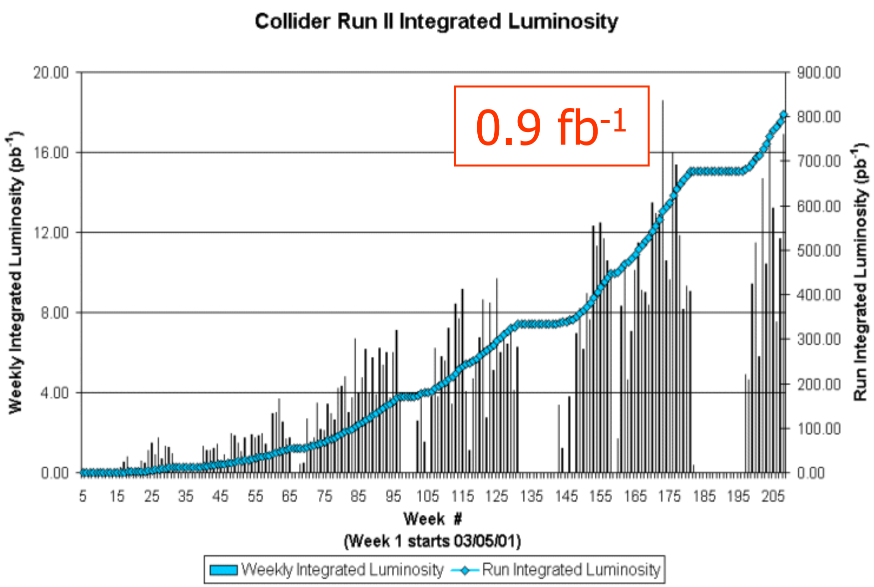
CDF and DØ Collaborations Results

- Tevatron/ Luminosity
- b-tagging
- SM Higgs Searches
- Summary

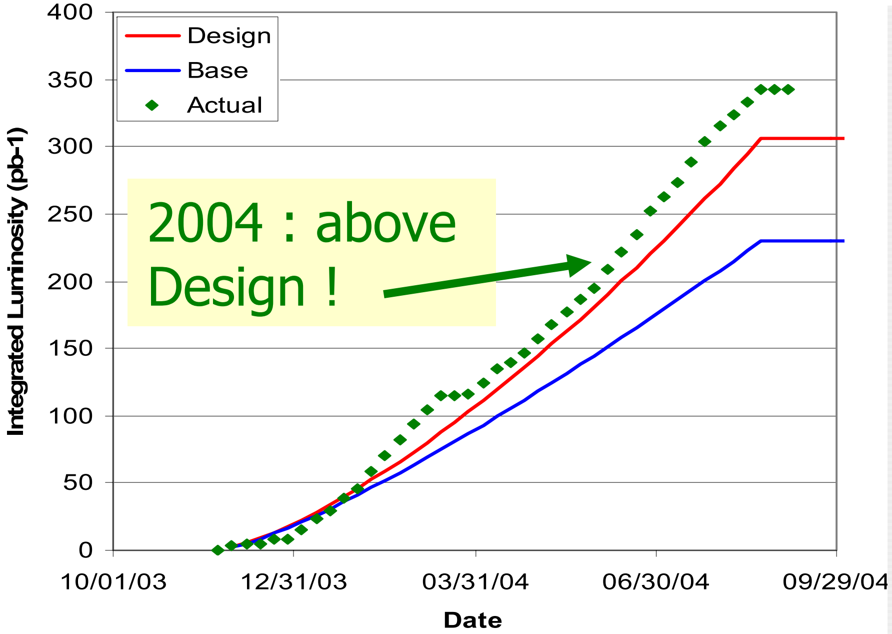


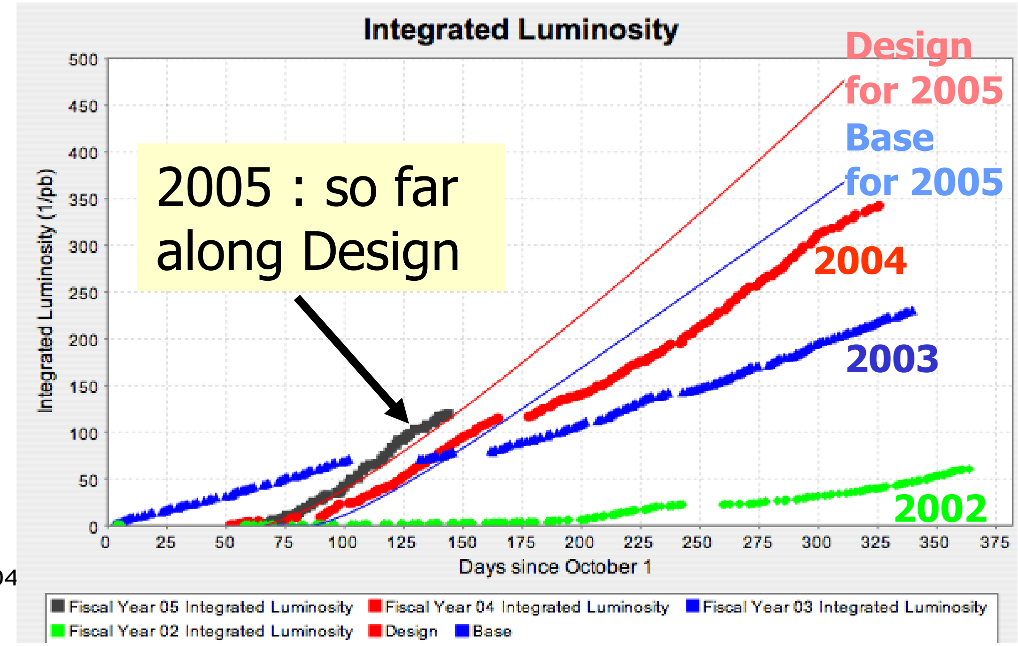
Tevatron Run II Performance





Peak luminosity is above $1.2 \cdot 10^{32}$ cm^{-2}sec^{-1} **Total ~0.9 fb^{-1} delivered in Run II**





Tevatron Long Term Luminosity Plan

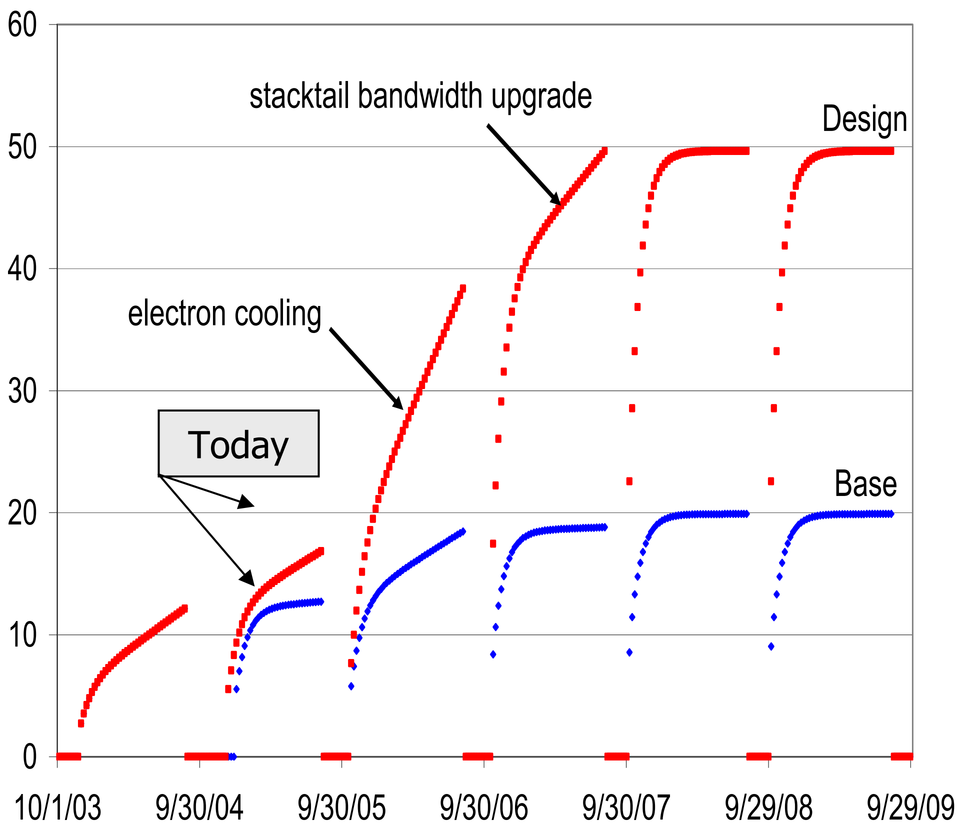
Increase in number of antiprotons
→ key for higher luminosity

Expected peak luminosity
→ $3{\cdot}10^{32}$ cm^{-2}sec^{-1} by 2007

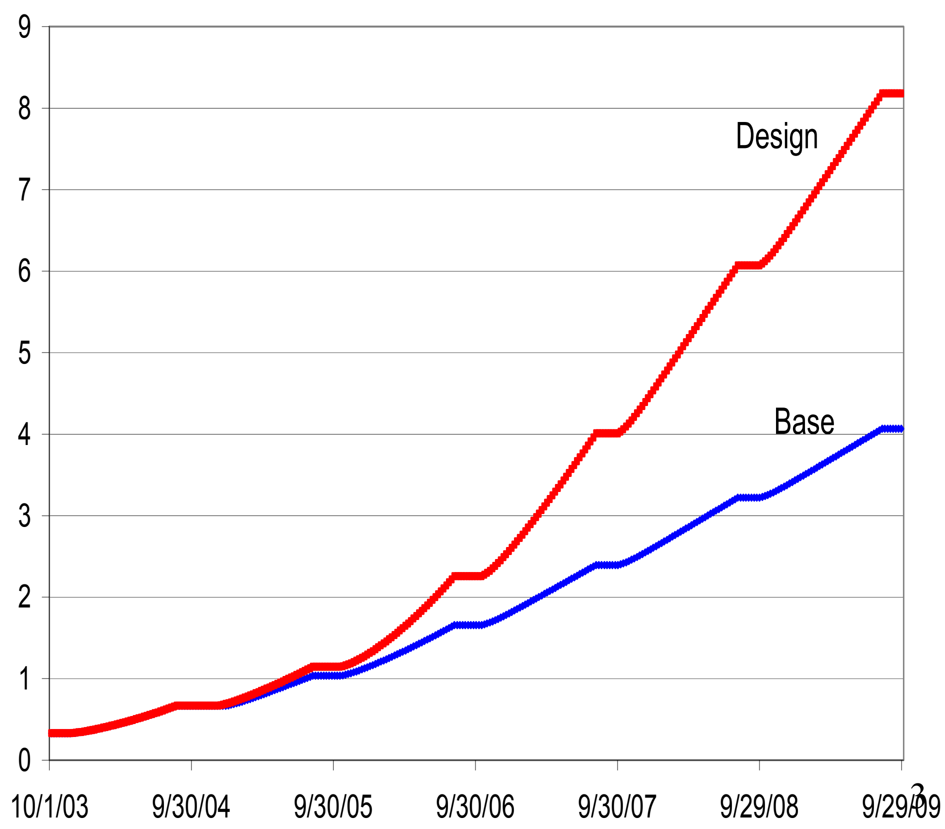
Currently expecting delivered luminosity to each experiment

→ 4 - 8 fb^{-1}
by the end of 2009

Integrated Weekly Luminosity (pb-1)

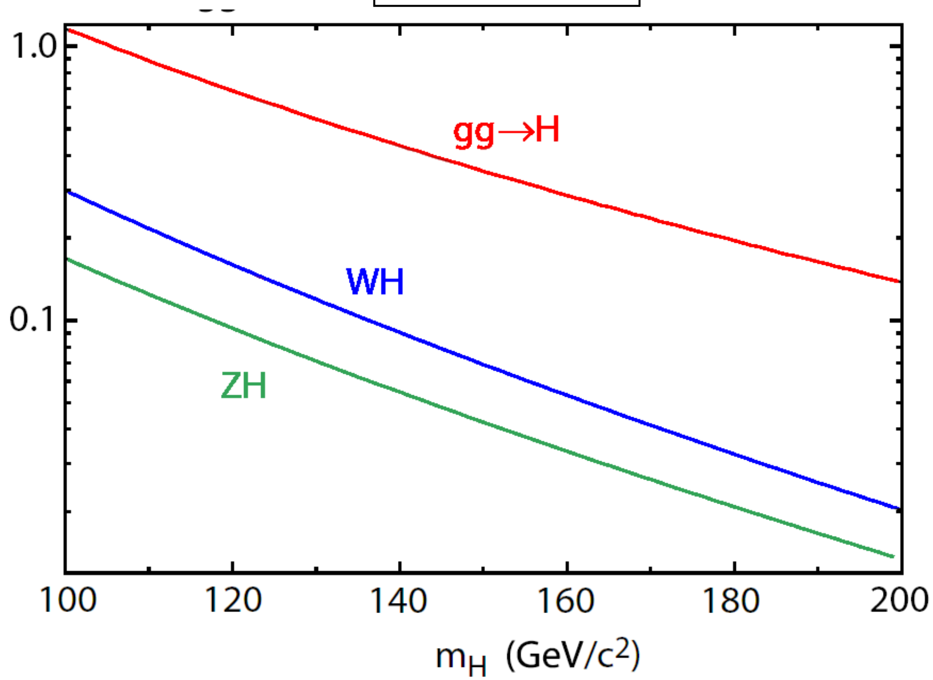


Total Luminosity (fb-1)

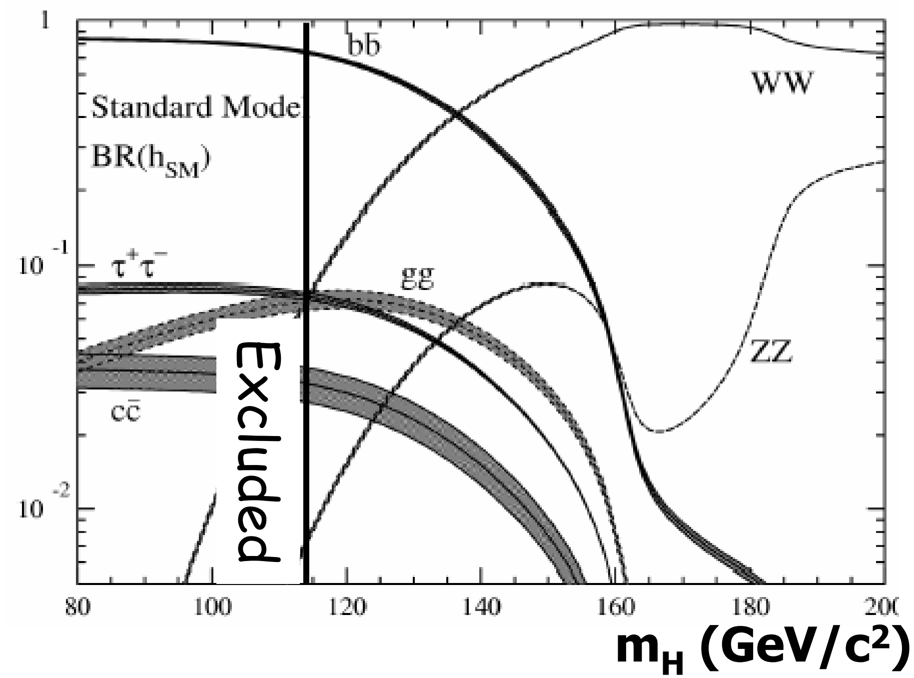


SM Higgs Production and Decays

Production



Decays



Production cross section
→ in the 1.0-0.2 pb range for gg → H
→ in the 0.2-0.03 pb range for associated vector boson production

Dominant Decays
→ $b\bar{b}$ for M_H < 135 GeV
→ WW^* for M_H > 135 GeV

Search strategy:

M_H <135 GeV associated production WH and ZH with H→bb decay
Backgrounds: top, Wbb, Zbb…

M_H >135 GeV gg →H production with decay to WW^*
Backgrounds: electroweak WW production…

Experimental Limits on Higgs Mass

→**direct searches at LEP**

M_H >114 GeV at 95% C.L.

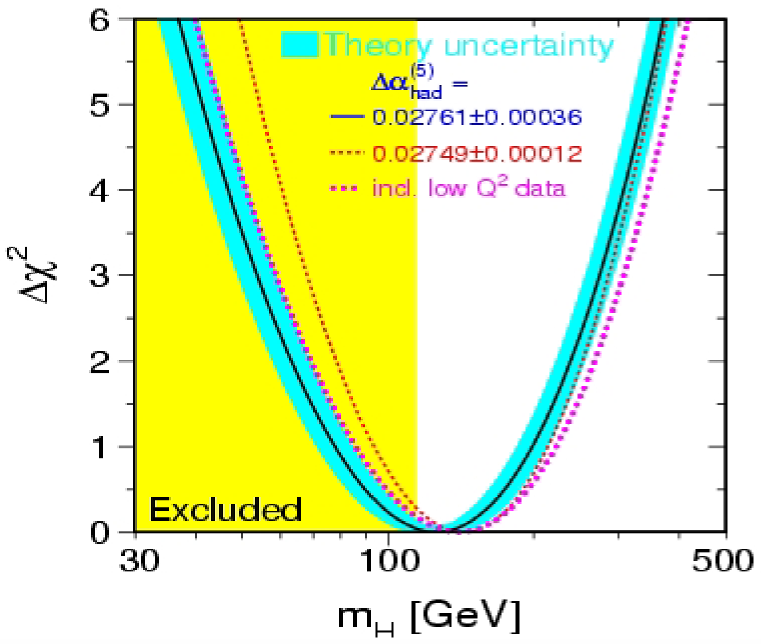
→**precision EW fits** (winter 2005)

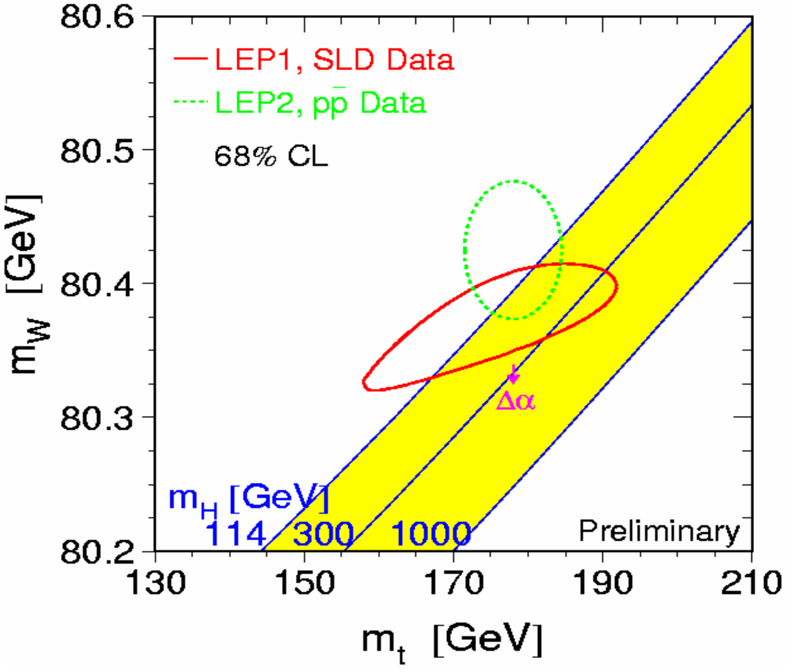
M_H= 126^{+73}_{-48} GeV

$M_H \leq$ 280 GeV @ 95% C.L.

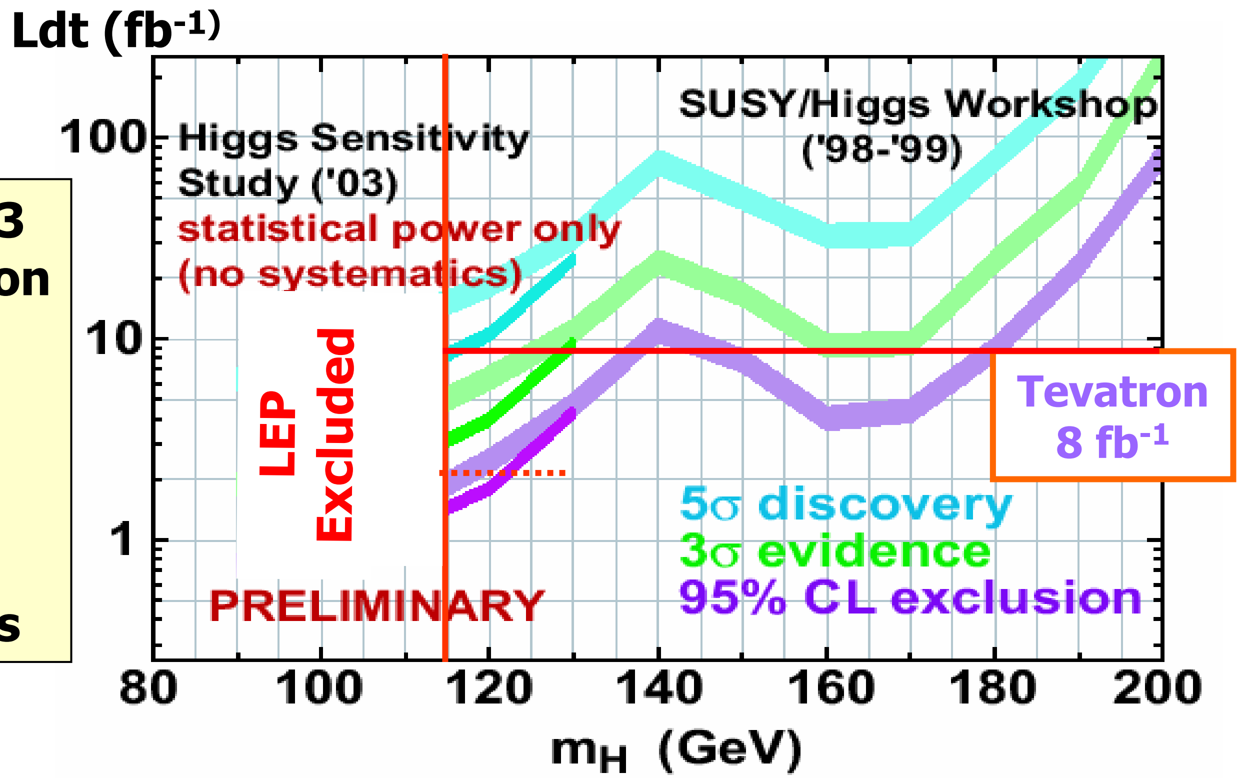
➔ **Light Higgs favored**

Tevatron provides:
Precision measurements of m_{top} & M_W
and
Direct searches:
→ **SM Higgs**
→ **non-SM Higgs**





Tevatron SM Higgs Search: Outlook



Prospects updated in 2003 in the low Higgs mass region

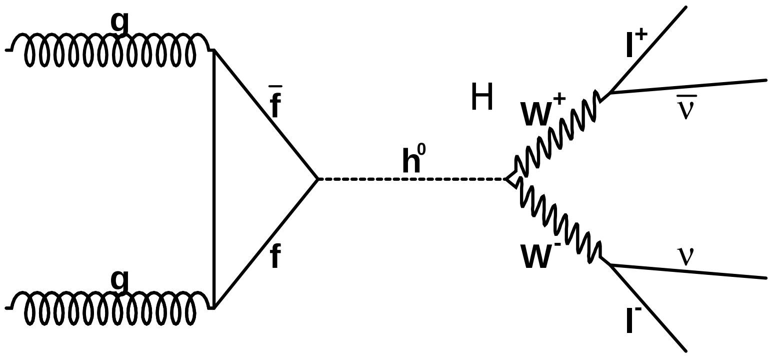
W(Z) H→ lν(νν,ll) $b\bar{b}$

→ better detector understanding
→ optimization of analysis

Sensitivity in the mass region above LEP limit (114 GeV) starts at ~2 fb^{-1}
With 8 fb^{-1}: exclusion 115-135 GeV & 145-180 GeV,
5 - 3 sigma discovery/evidence @ 115 – 130 GeV

Meanwhile
- **→ optimizing analysis techniques, understanding detectors better**
- **→ measuring SM backgrounds (Zb, Wbb, WW)**
- **→ Placing first Higgs limits which can be compared to the prospects**

SM "Heavy" Higgs: H → WW* → lνlν

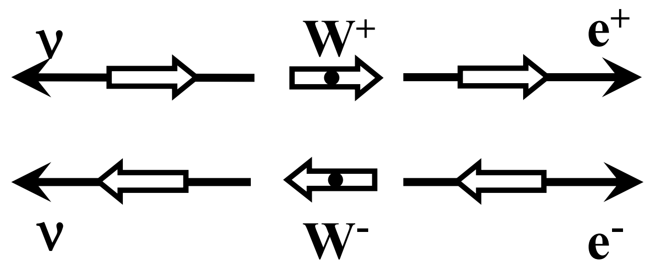


Search strategy:

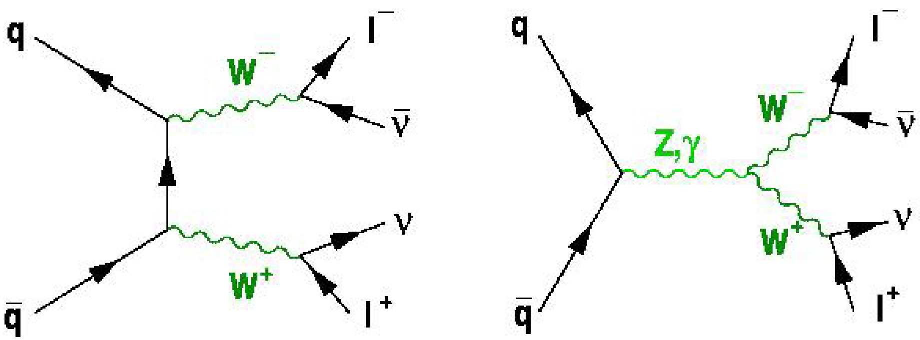
→ 2 high P_t leptons and missing E_t

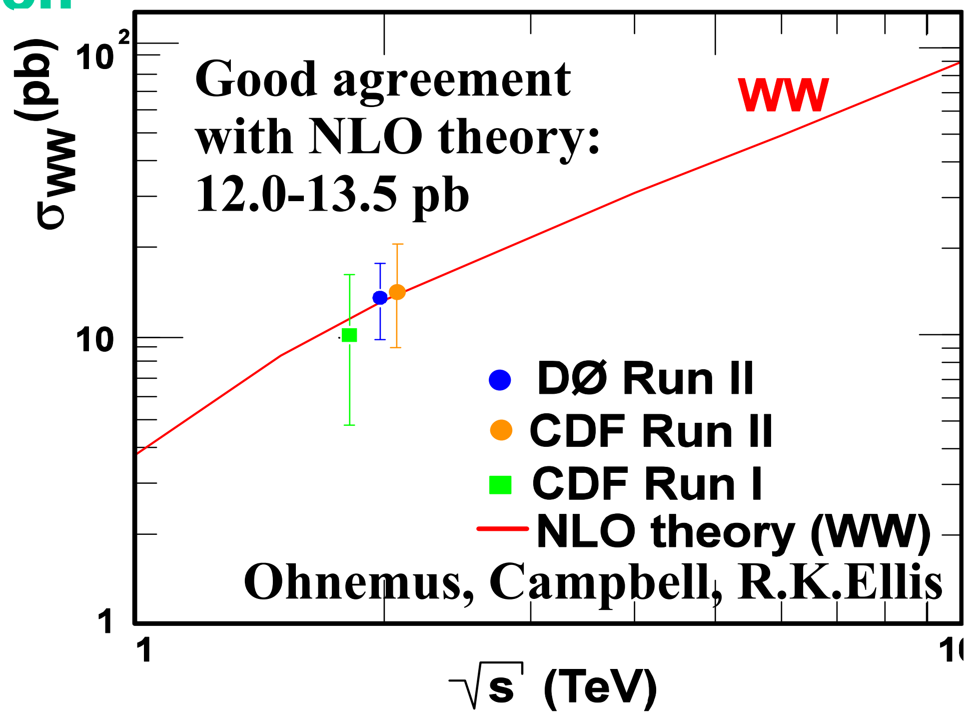
→ WW comes from spin 0 Higgs:

leptons prefer to point in the same direction



Main Background: WW Production





Now Measured at the Tevatron by both Experiments

DØ: PRL/ hep-ex/0410062

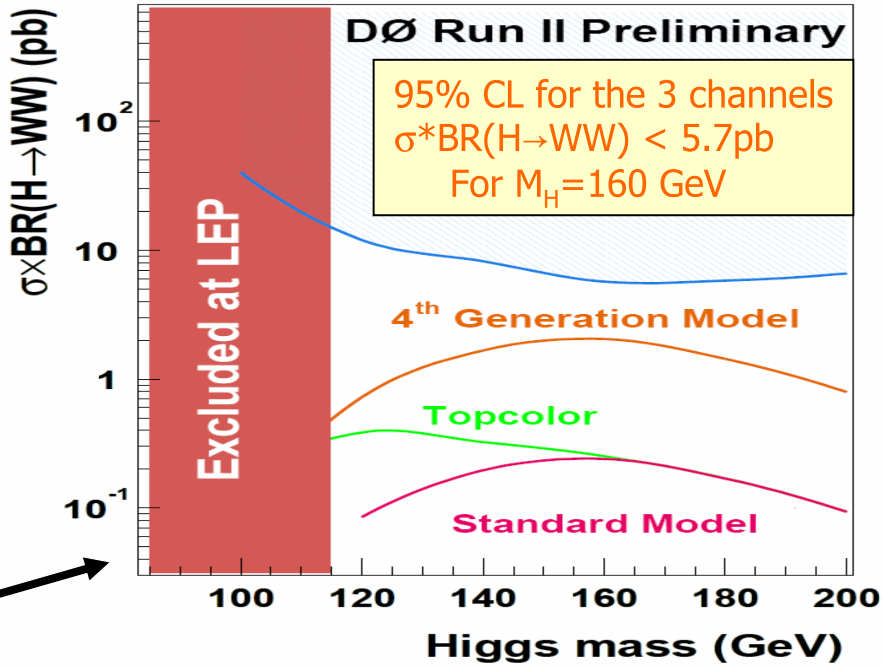
Search for H → WW*

Search in 3 channels: H→WW*→llνν

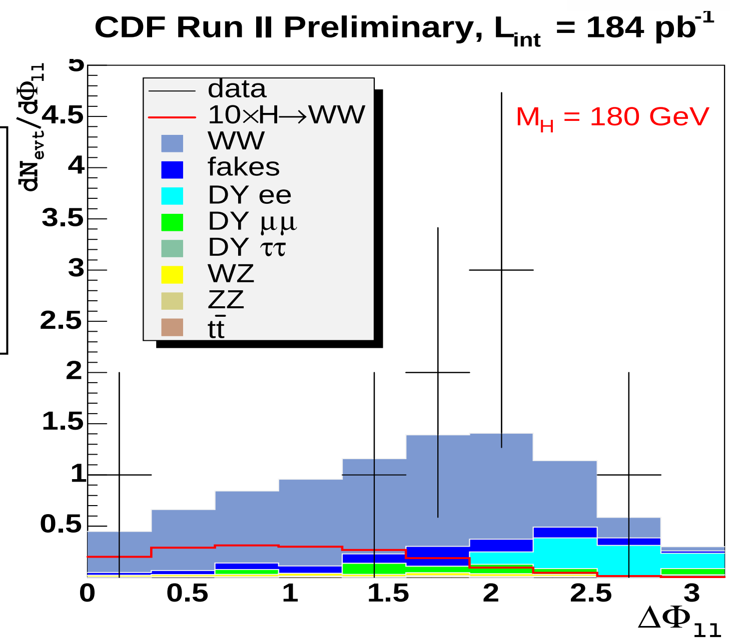
with l = ee,μμ,eμ →inclusive high p_T lepton triggers: integrated luminosity 184 pb^{-1} (CDF), 147-177 pb^{-1}(D0)

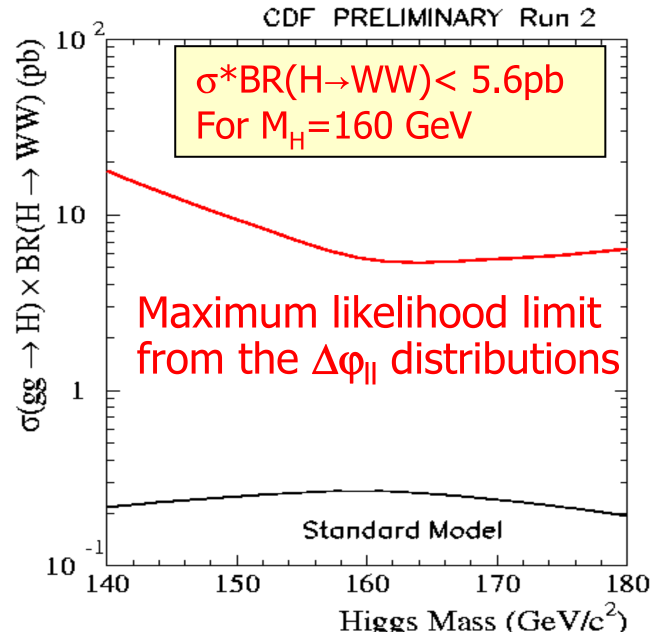
Data Selection: two isolated leptons with opposite charges with p_T > 20 GeV, $\not{E}_T$ >25 GeV, Δφ($\not{E}_T$, l or j) , veto on jets, light (<M_H/2) invariant dilepton mass

DØ: Obs: 9 evts; Bkgnd:11.1 ± 3.2
Signal: 0.27 ± 0.004 (m_H=160 GeV)

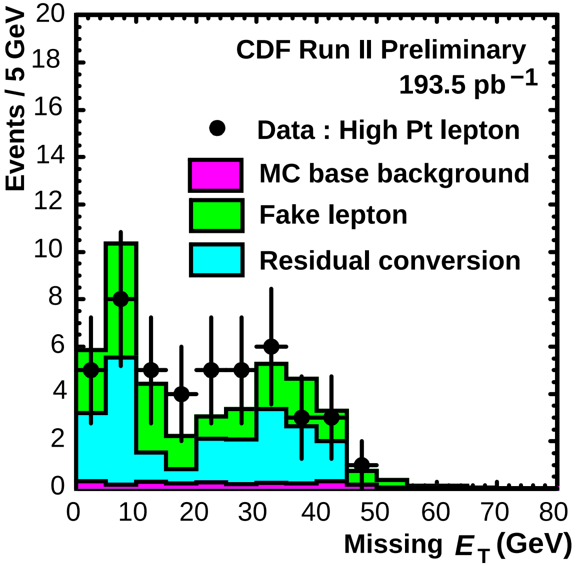


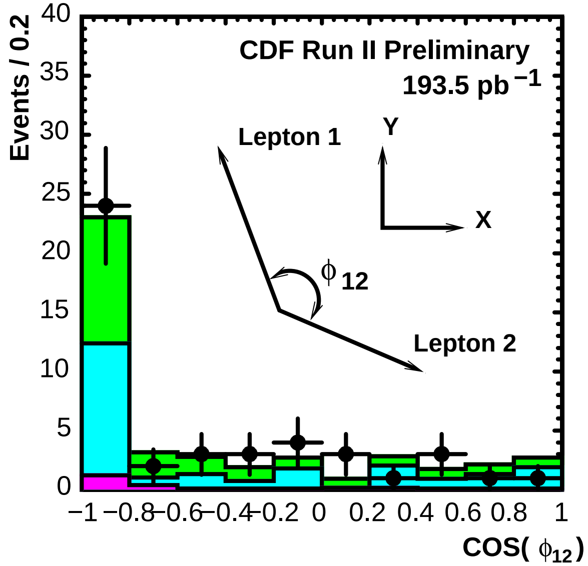
CDF: Obs: 8 evts;
Bkgnd: 8.9 ± 1
Signal: 0.17 ± 0.02
(m_H=180 GeV)

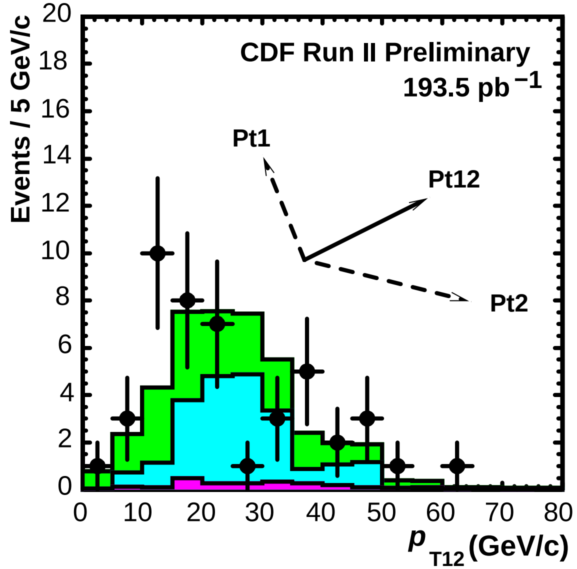




Search for WH → WWW*





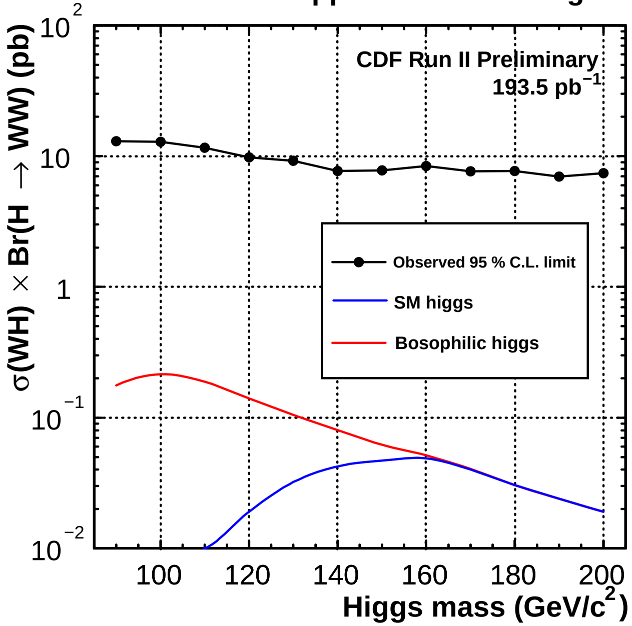


Search of high-pT isolated like-sign (LS) dilepton events in 193.5 pb^{-1} data.

leading lepton $p_{T,1}$ > 20 GeV, 2nd lepton p_{T2} > 16 GeV, p_{T12}= |vect.sum of 1,2| > 35 GeV. Search in the ($p_{T,2}$,$p_{T,12}$) plane:

- **0 events found**
- **total exp. Backgnd: 0.95 +- 0.61(stat) +- 0.18(syst)**
- **bosophilic Higgs (110 GeV) exp. to be about 0.06 evts (assuming same production x-section as SM Higgs)**
- **SM Higgs (160 GeV) expected to be about 0.03 evts.**

Cross section upper limit of WH signal



Low Mass (<135 GeV) Higgs Search

Also difficult at LHC (combination of several channels)

At Tevatron need to fully exploit associated productions:

WH and Z ($\rightarrow l^+l^-$ or $\nu\nu$) H with H $\rightarrow b\bar{b}$ ➔➔ b-tagging

Understand intrumental and SM backgrounds

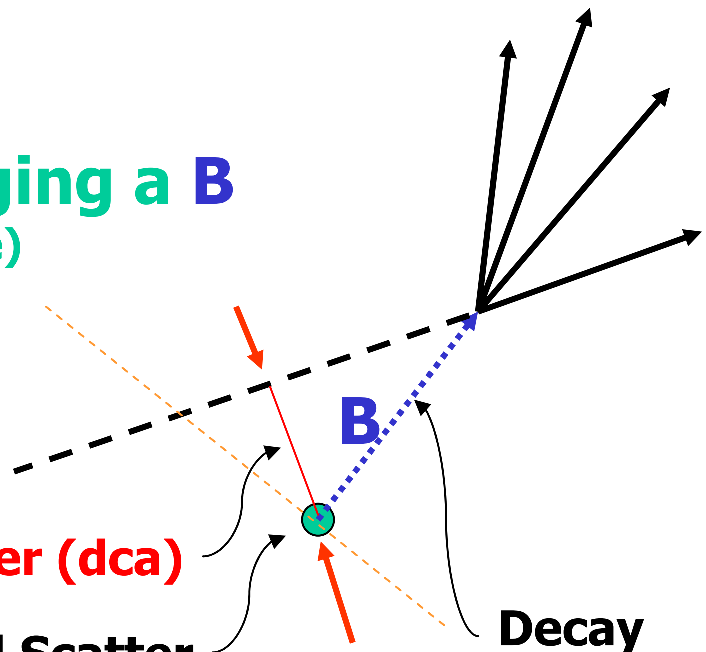
➔W,Z+heavy flavor are backgrounds to leptonic WH,ZH

➔instrumental background (QCD) is difficult for $\nu\nu$ H

Here after, b-tagging, WH, ZH and SM Higgs prospects

Tagging b-quarks (B-hadrons)

Vertex Tagging a B
(transverse plane)



- Top, Higgs have b-quark jets

→ contains a B hadron
  - Has finite life time
  - Travels some distance from the vertex before decaying
    - ~ 1mm
    - With charm cascade decay, about 4.2 charged tracks

→ can have leptons from B meson

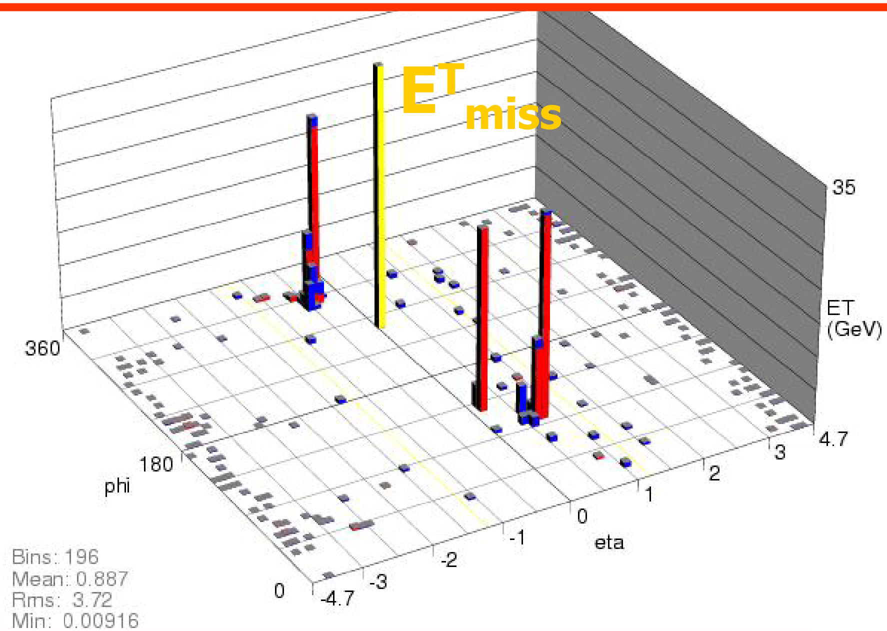
Several algorithms under development/improvement:

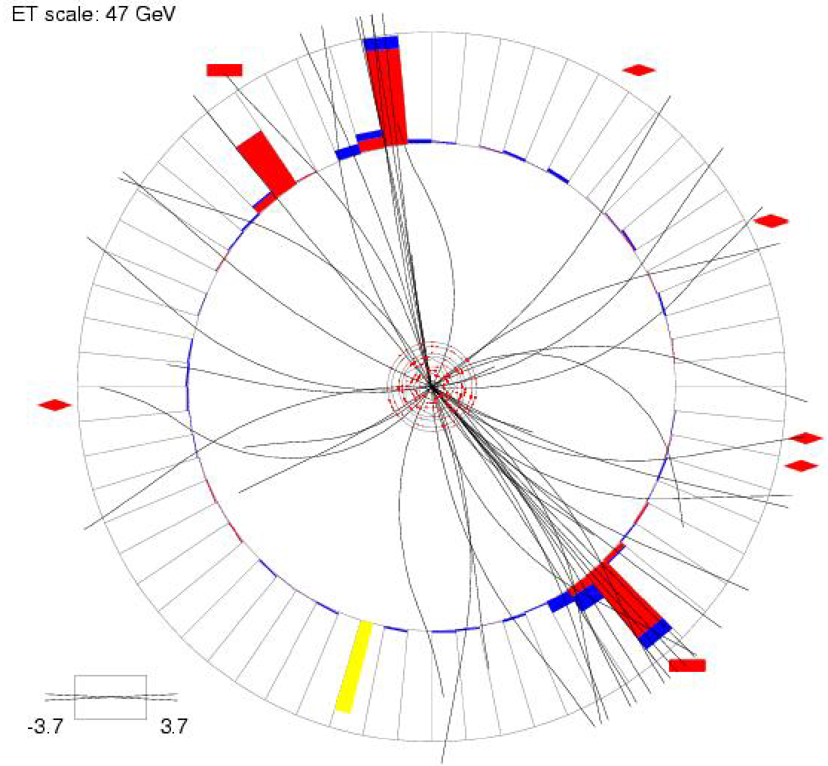
3 main categories:

- Soft-lepton tagging
- Impact Parameter based → Impact Parameter Resolution
- Secondary Vertex reconstruction → Decay Length Resolution

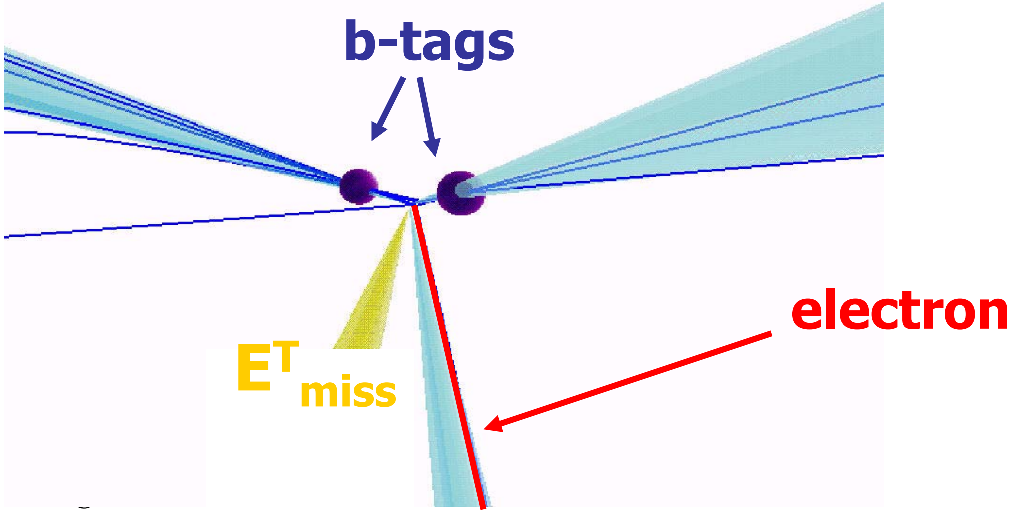
tt l+jets ~ 56%
Single Top ~ 52%
Wbb ~ 52%
Wj ~ 0.3%

3 views of a high dijet mass (220 GeV) Wbb (WH) candidate

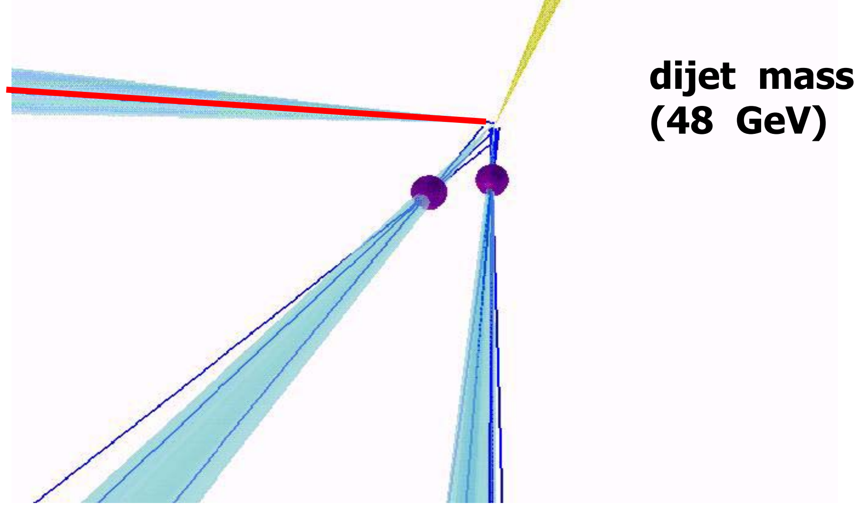




Clean Events! Mass Reconstruction?



Vertex view of a low mass candidate



Search for $Wb\bar{b}$/WH Production

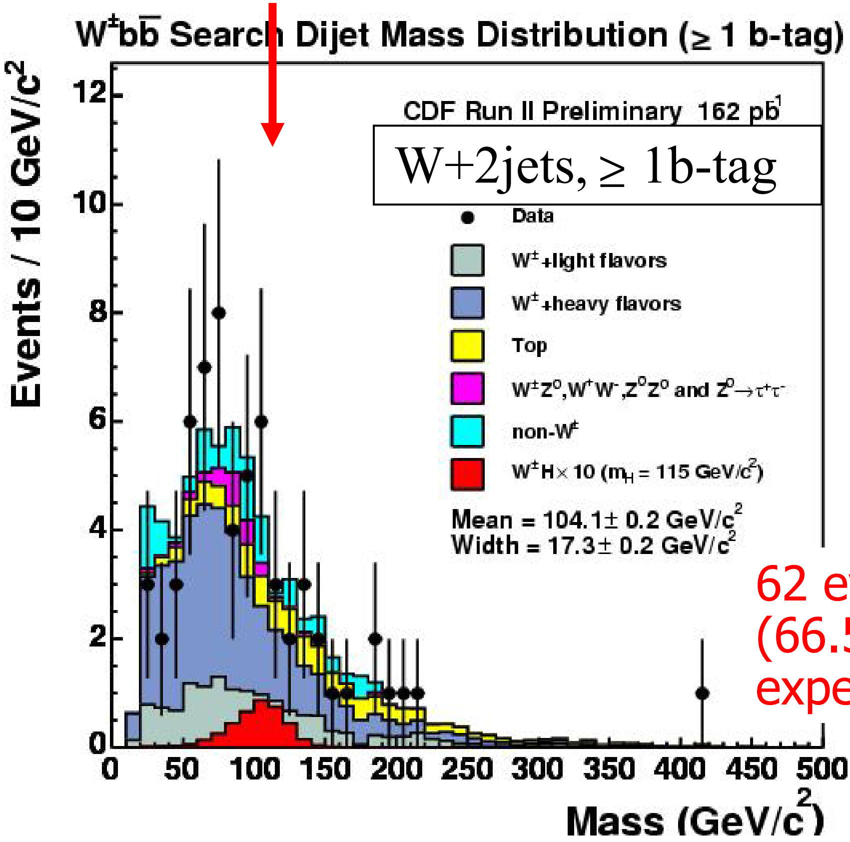
162pb^{-1} sample with one electron or muon and $\not{E}_T$ (single-tag search)

Electron or muon: p_T > 20 GeV/c
Missing E_T > 20 GeV
2 Jets: p_T > 15 GeV/c, $|\eta|$<2.0

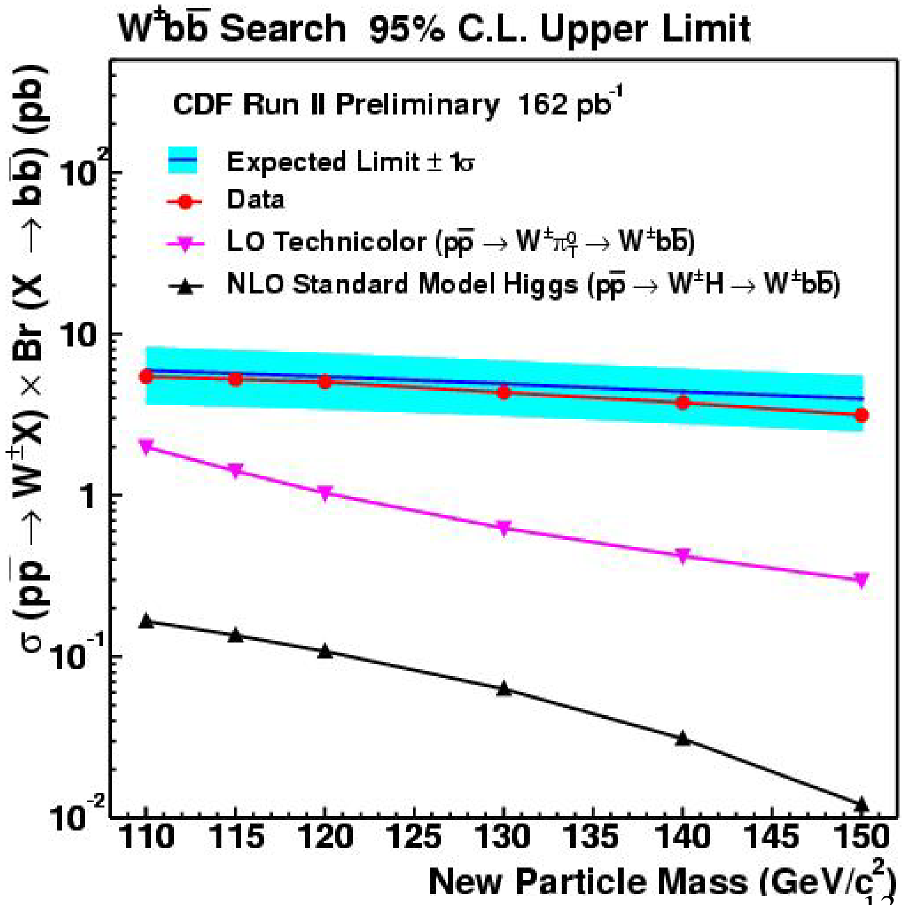
2540 evts before tagging

Total systematic error ~ 11%

No significant peak from Higgs



62 evts
(66.5 ± 9
expected)



Search for $Wb\bar{b}$/WH Production

174pb^{-1} sample e + 2 jets and $\not{E}_T$

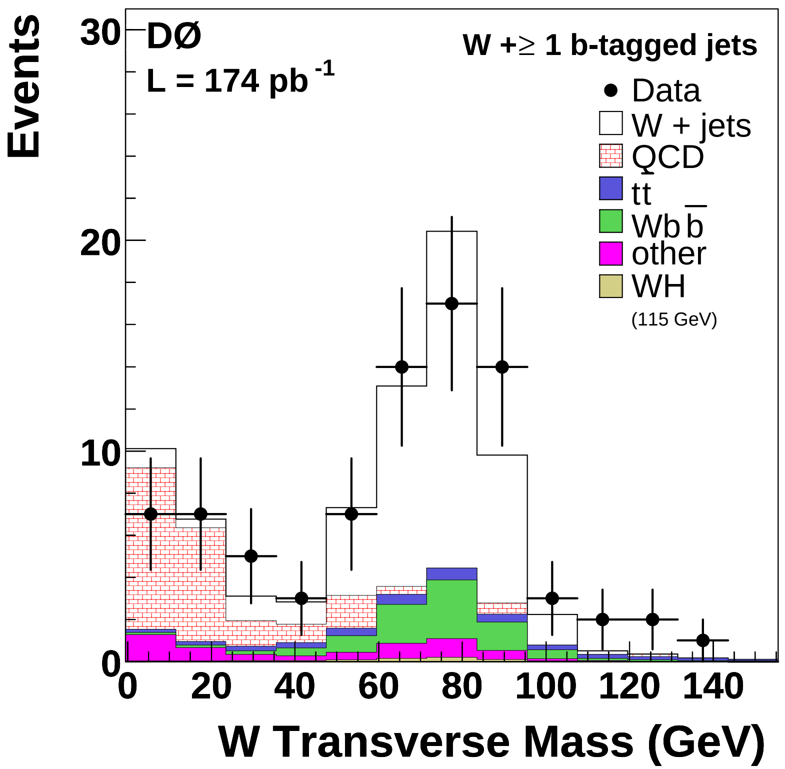
Electron: p_T > 20 GeV, |η|<1.1
Missing E_T > 25 GeV
2 Jets: p_T > 20 GeV/c, |η|<2.5

➔2540 evts (2580 ± 630 expected)

➔ ≥1 tag: 76 evts (72.6 ± 20 exp.)

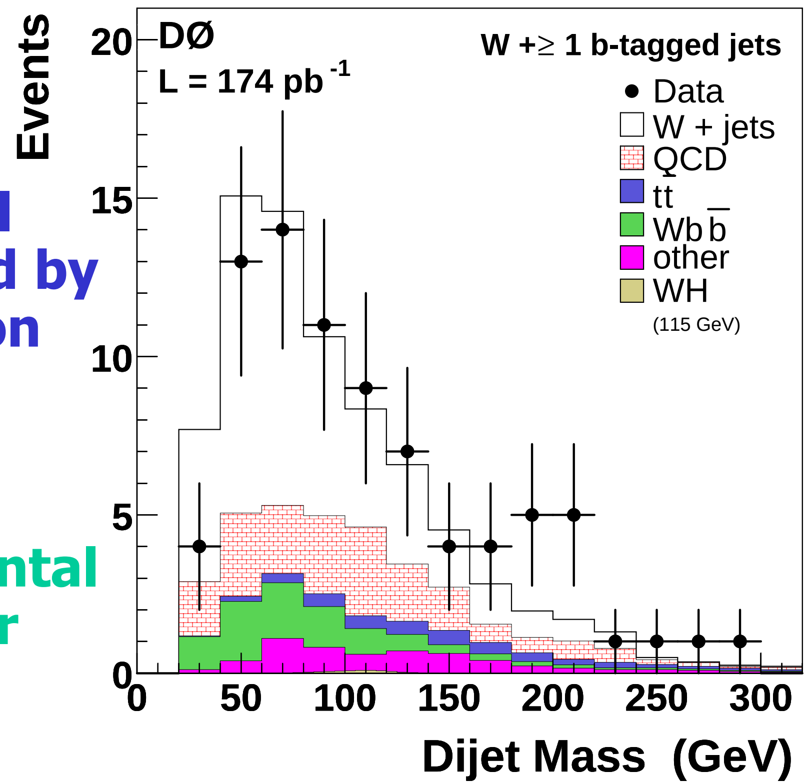
Wbb dominant backgd for WH

Compared to ALPGEN, PYTHIA showering, and full detector simulation. Normalized to NLO x-section (MCFM for W+jets)

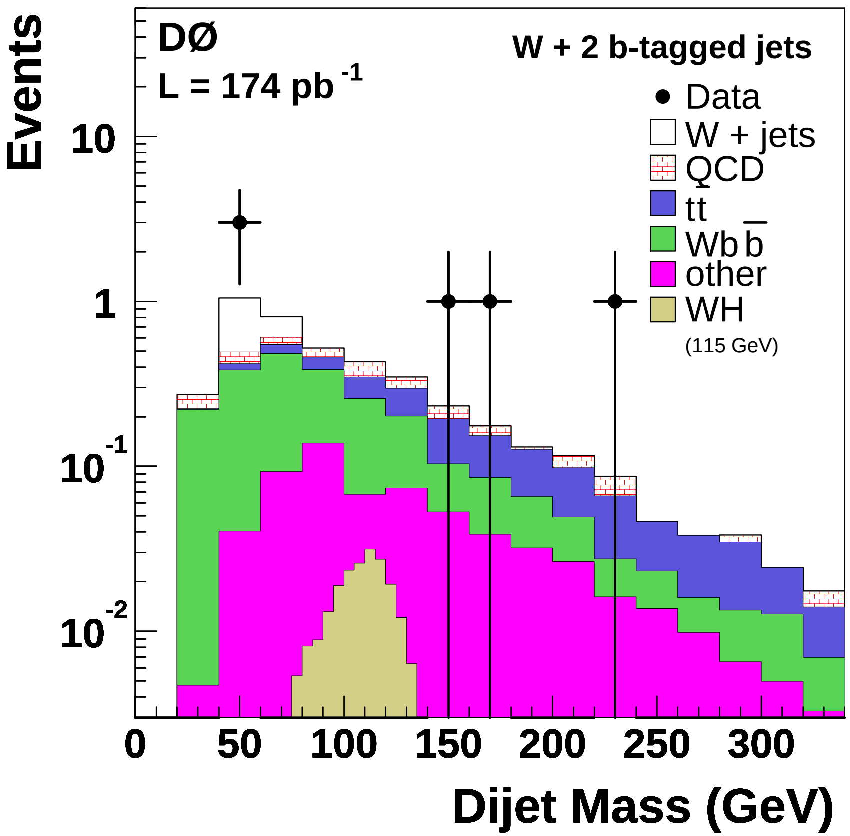


Data well described by simulation

Total experimental syst. Error ~15 %

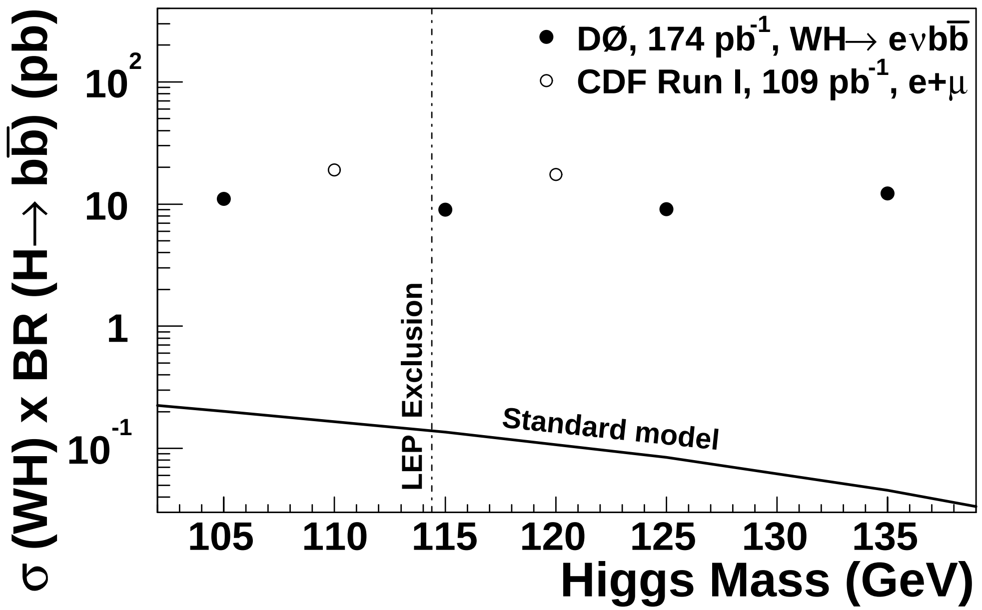


$Wb\bar{b}$ / WH Search



6 evts (4.4 ± 1.17 expected)

95% CL upper limit of 6.6 pb on $Wb\bar{b}$ production for b with p_T^b > 20 GeV and ΔR_{bb} >0.75



For 115 GeV Higgs, in a +-25 GeV mass window:

0 data, 0.05 exp Higgs, 1.07 bckgd

➔95% CL upper limit on WH production of 9.0 - 12.2 pb for Higgs masses of 105-135 GeV

Published Run II limit better than Run I ➔ detector improvements

published (PRL) - hep-ex/0410062

Comparison of WH Results with Prospective Study

	DØ Analysis (PRL '05) 174 pb^{-1} $WH \rightarrow e\nu bb$	Prospective Study ('03) normalized to 174 pb^{-1} and to $WH \rightarrow bbe\nu$	Ratio $\frac{\text{Prospective}}{\text{DØ Analysis}}$
Dijet mass window	[85,135]	[100,136]	R=0.72
Dijet mass resolution	14 +/- 1 %	10 %	R=0.71
Signal events (S)	0.049	0.145	R=3.0
Background evts (B)	1. 07	1.76	R=1.6
$S/\sqrt{B}$	0.045	0.11	R=2.4
S/B	0.046	0.082	R=1.8

We are currently missing a factor 2.4 in sensitivity

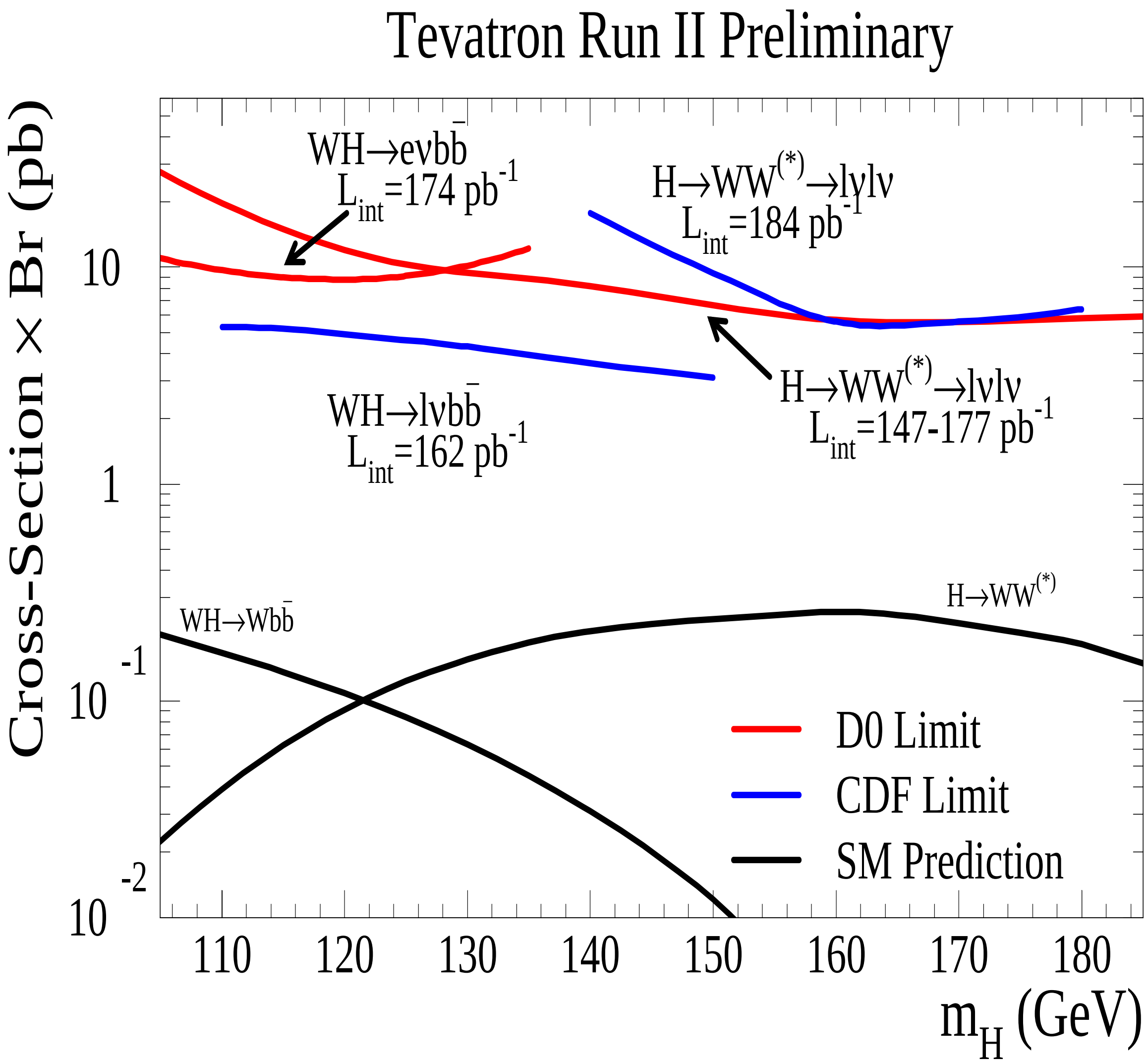
Prospective Study assumed: Larger ECAL coverage (+30%), improved em-id (+40%), extended b-tag efficiency (+50%, 2 tags) and 30% less backgd (better dijet mass resolution)

→ Factor 2 in $S/\sqrt{B}$ → 2.4/ 2 = 1.2 difference (only) in sensitivity

Apply Advanced techniques

Missing Factors can be recovered

SM Higgs Status/Prospects



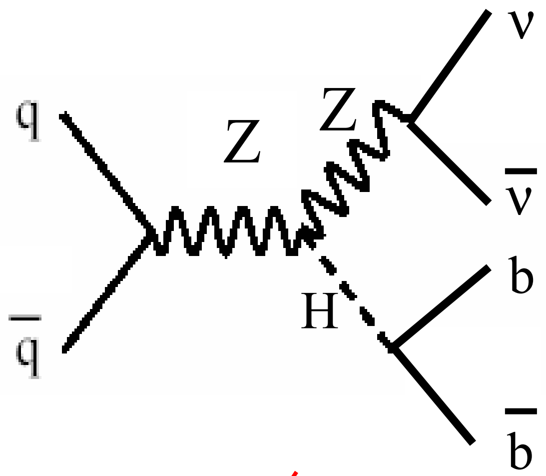
Future improvements:

- **Extend b-tagging acceptance**
- **Improve efficiencies**
- **Use Additional kinematic variables**
- **Better M_{bb} resolution**

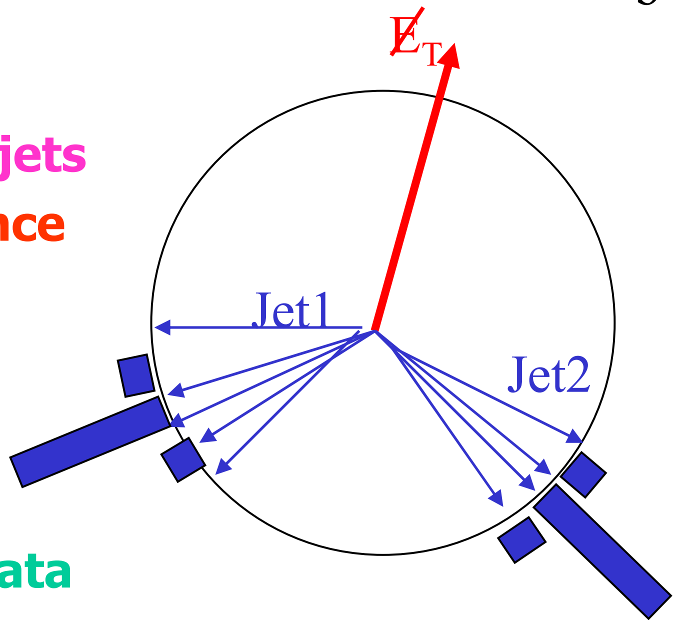
Add Zbb channels

ZH→ννbb searches

- Missing E_T from Z→νν and 2 b jets from H→bb
  - Large missing E_T > 25 GeV
  - 2 acoplanar b-jets with E_T > 20 GeV, $|\eta|$ < 2.5



- Backgrounds
  - "physics"
    - W+jets, Z+jets, top, ZZ and WZ
  - "instrumental"
    - QCD multijet events with mismeasured jets
      - Huge cross section & small acceptance

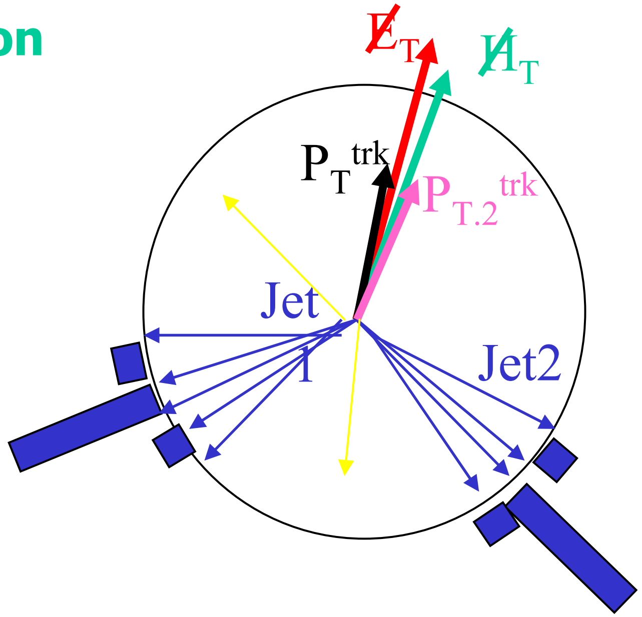


- Strategy
  - Trigger on events with large missing H_T
    - H_T defined as a vector sum of jets' E_T
  - Estimate "instrumental" background from data
  - Search for an event excess in di-b-jet mass distribution

More selection variables

Suppress "physics" background

- In addition to missing E_T > 25 GeV and two jets with E_T > 20 GeV
- Veto evts. with isolated tracks ← reject leptons from W/Z
- $H_T = \Sigma|p_T(\text{jets})|$ < 200 GeV ← for tt rejection



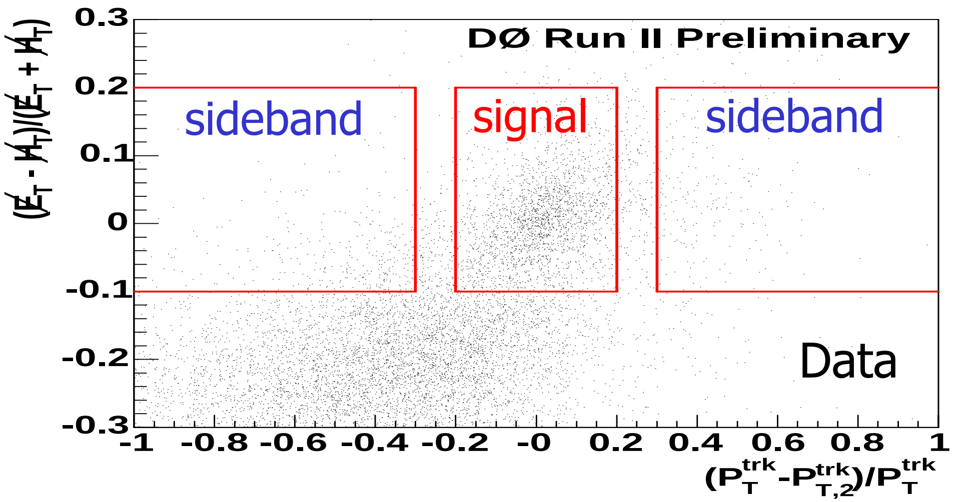
Reduce "instrumental" background

- Jet acoplanarity $\Delta\phi$(dijet) < 165°
- Various missing energy/momentum variables
  - $\not{E}_T$ calculated using calorimeter cells
  - $\not{H}_T = -|\Sigma p_T(\text{jet})|$ … jets
  - $P_T^{trk} = -|\Sigma p_T(\text{trk})|$ … tracks
  - $P_{T,2}^{trk} = -|\Sigma p_T(\text{trk in dijet})|$ … tracks in jets

Form various asymmetries

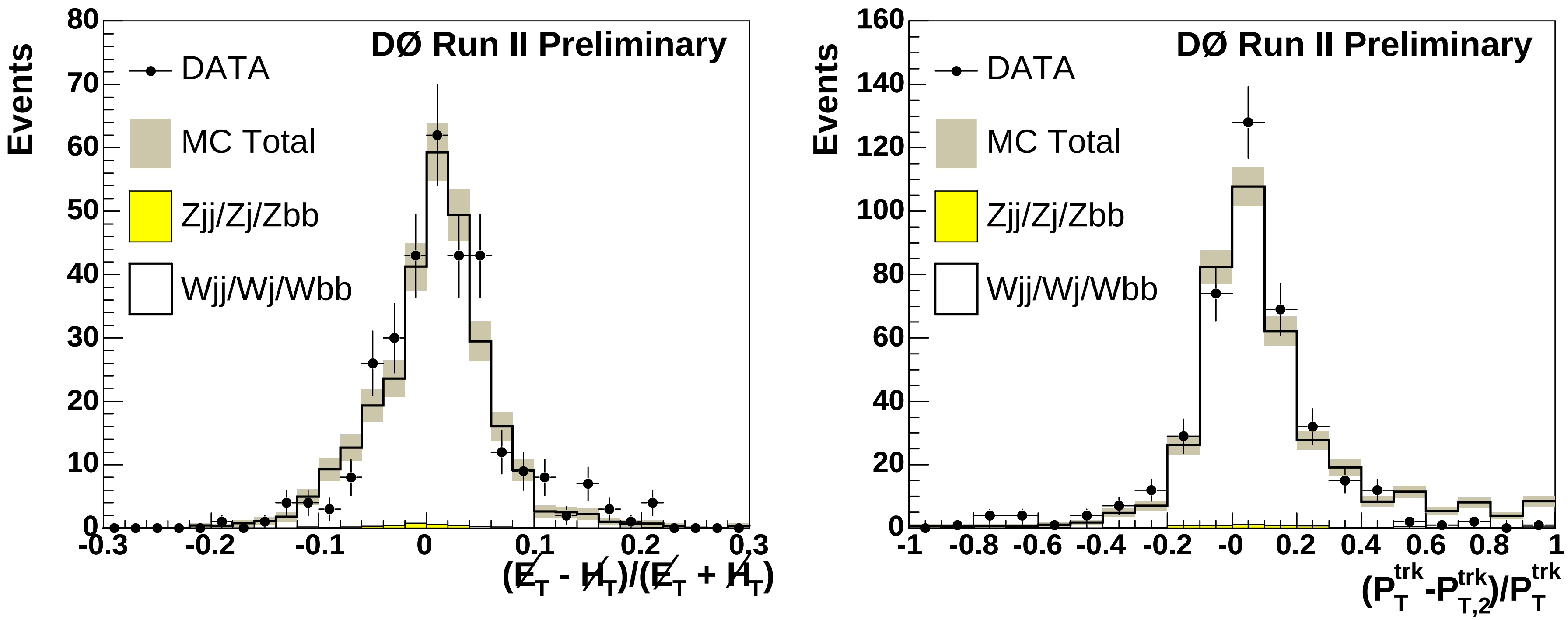
- $\text{Asym}(\not{E}_T,\not{H}_T) = (\not{E}_T - \not{H}_T)/(\not{E}_T + \not{H}_T)$
- $R_{trk} = |P_T^{trk} - P_{T,2}^{trk}| / P_T^{trk}$

→ In signal like events they all peak at ~ 0 and are aligned



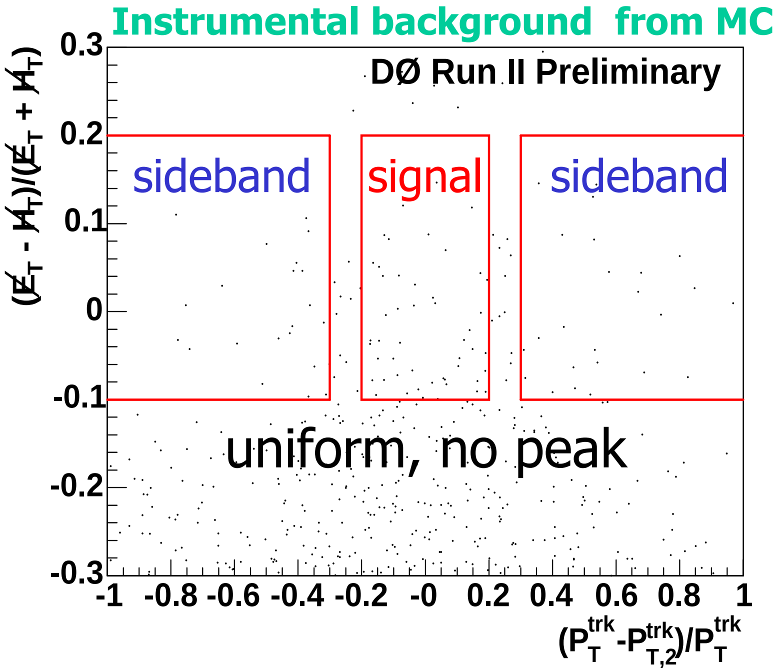
Cross Check on W+jets

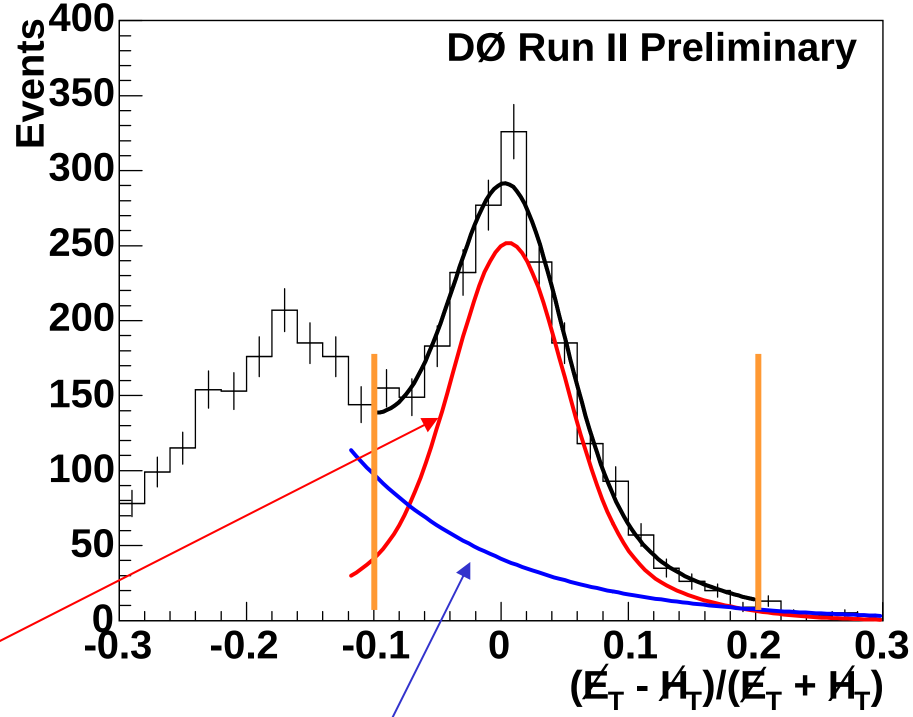
- **Cross-checked variables used by selections, using W+jets→μν+jets**
  - **Same data sets without isolated track veto**
  - **Very small instrumental backgrounds**
  - **If ignore muon, the final state is $\not{E}_T$ + jets → same as ZH→ννbb**
    - **Muon pT is removed from $\not{E}_T$, P_T^{trk} calculations**

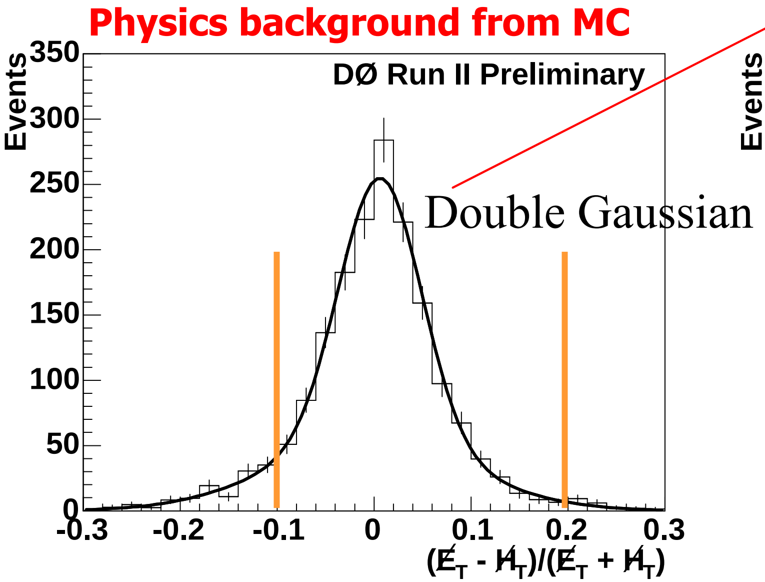


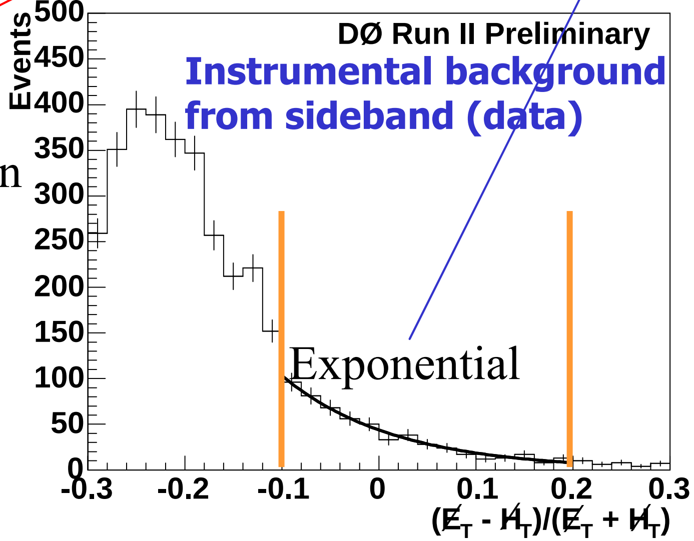
Variables are well modeled by simulation, indeed peak at 0 !!

Instrumental background estimation



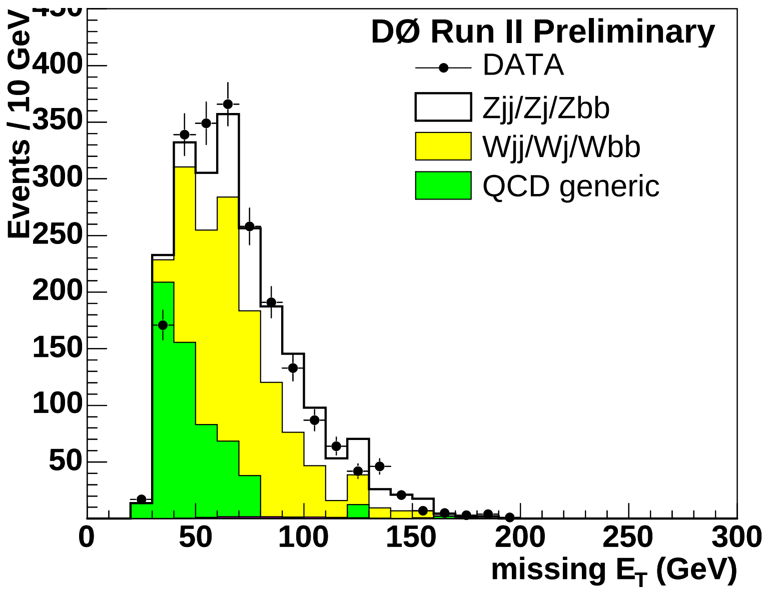


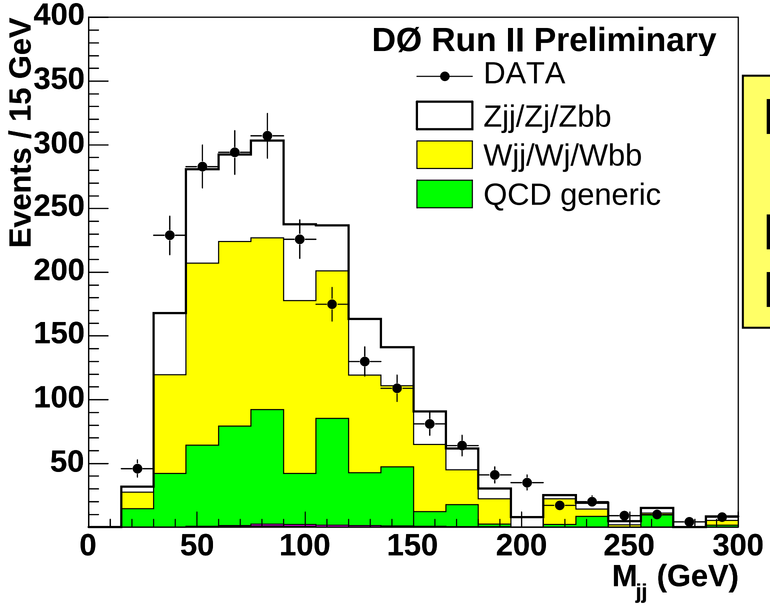




Physics …
1579 from fit
1600 from MC
Instrumental …
524 from fit

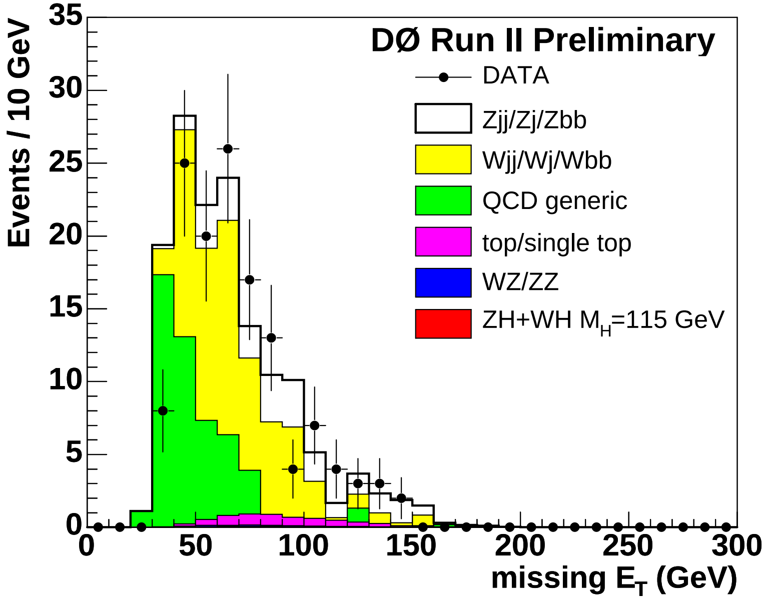
Distributions of $\not{E}_T$ + 2 jets (with-w/o tagging)

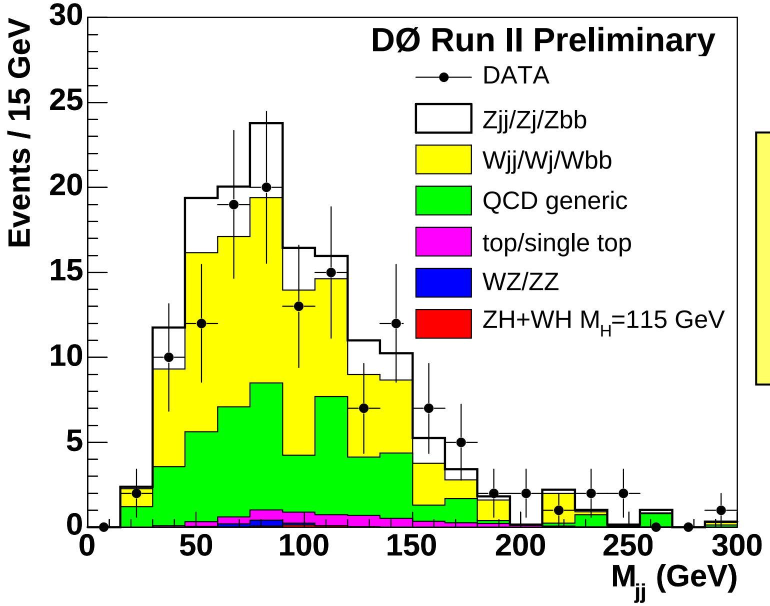




Before Tagging

Data : 2140
Expect : 2125

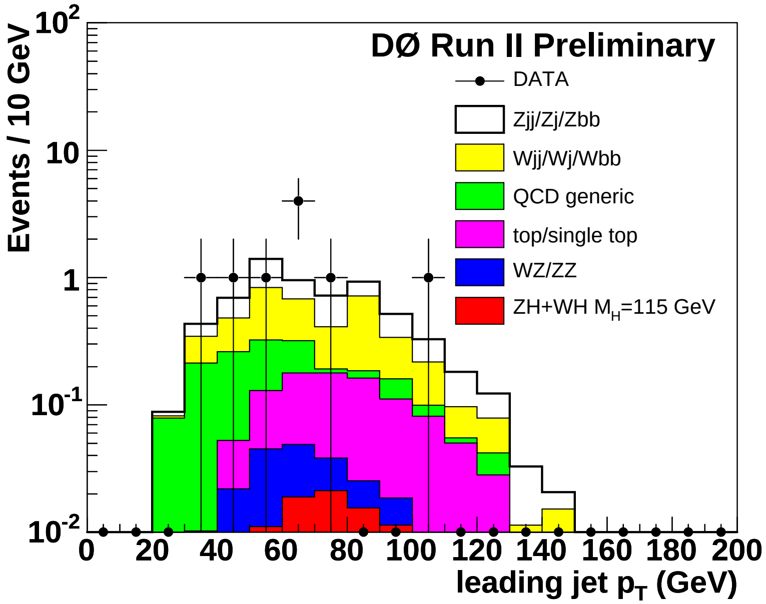


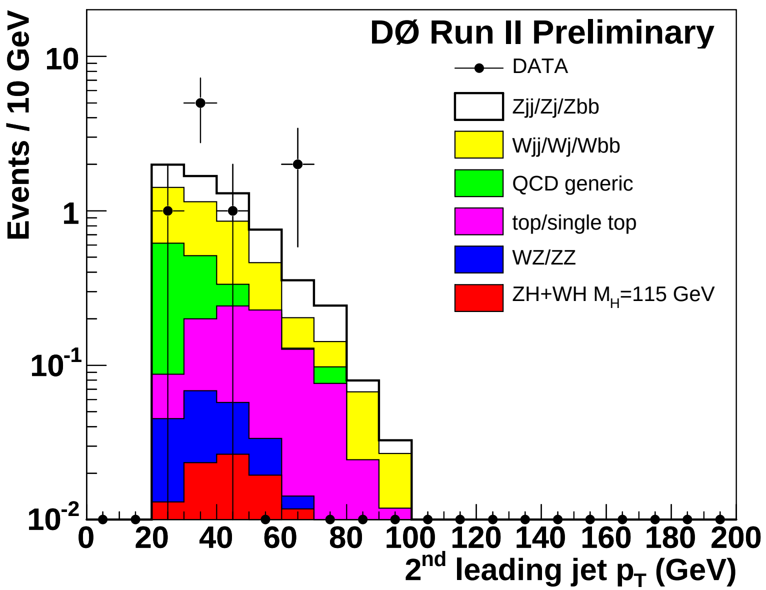


1 b-tag

Data : 132
Expect : 145

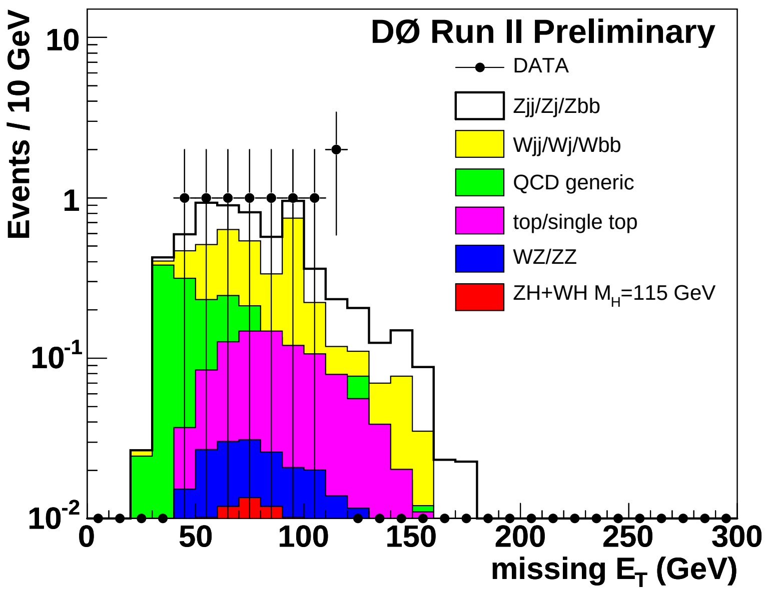
Distributions after double b-tagging

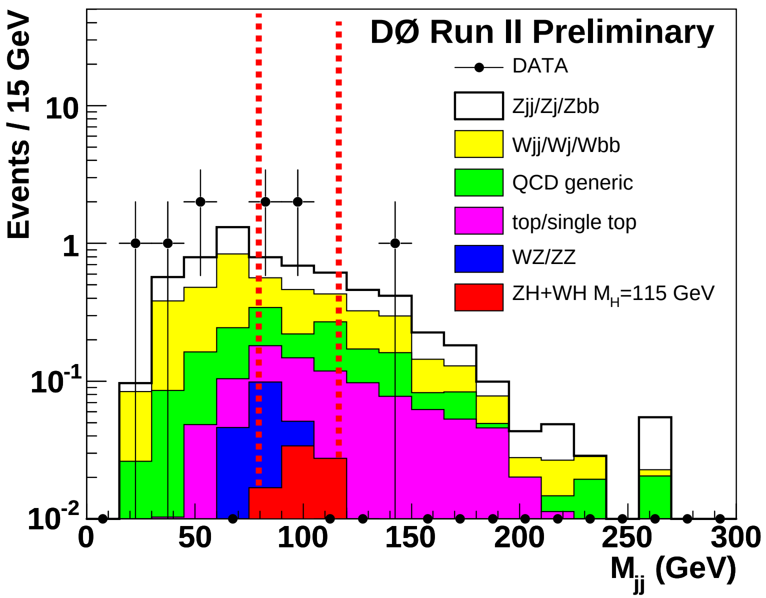




2 b-tags

Data : 9
Expect : 6.4





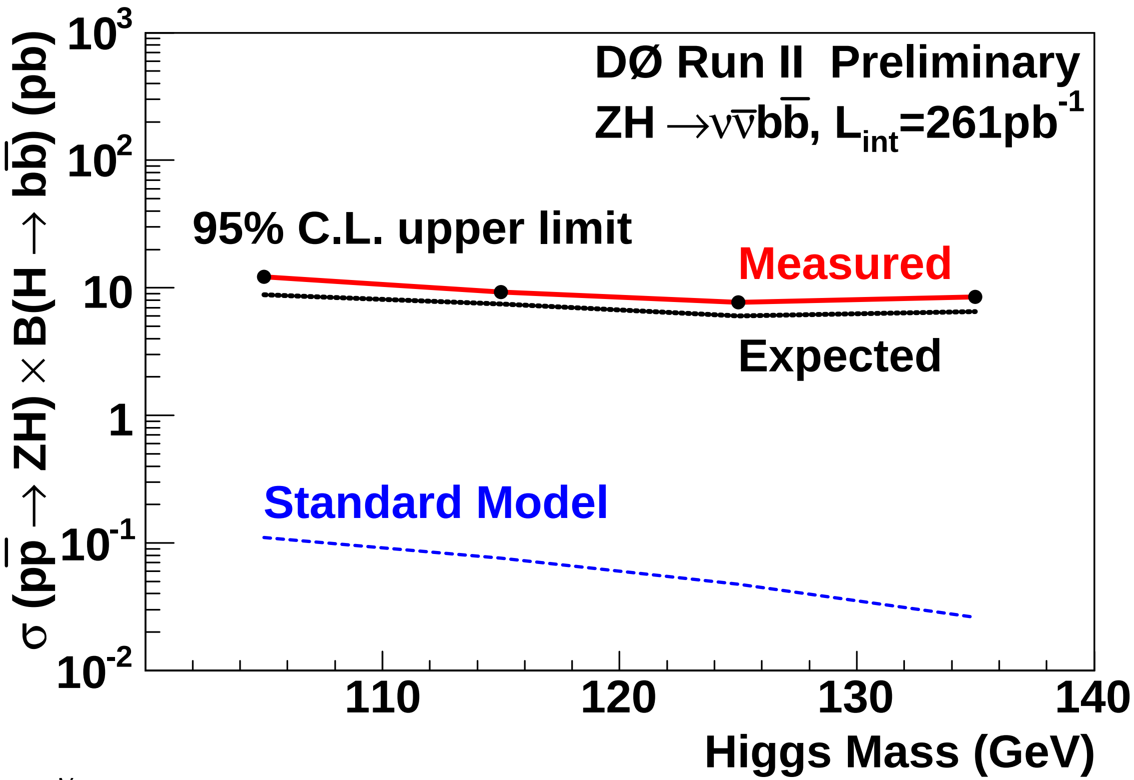
Dijet Mass Window @ 115 GeV

Data : 3
Expect : 2.2

First Run II Results for ZH → $\nu\nu bb$ (261 pb^{-1})

Mass Window	105GeV [70,120]	115GeV [80,130]	125GeV [90,140]	135GeV [100,150]
Detected Data	4	3	2	2
Acceptance (%)	0.29 ± 0.07	0.33 ± 0.08	0.35 ± 0.09	0.34 ± 0.09
Total BKG	2.75 ± 0.88	2.19 ± 0.72	1.93 ± 0.66	1.71 ± 0.57
Limit @95% C.L.	12.2 pb	9.3pb	7.7 pb	8.5 pb
Expected Limit	8.8 pb	7.5 pb	6.0 pb	6.5 pb

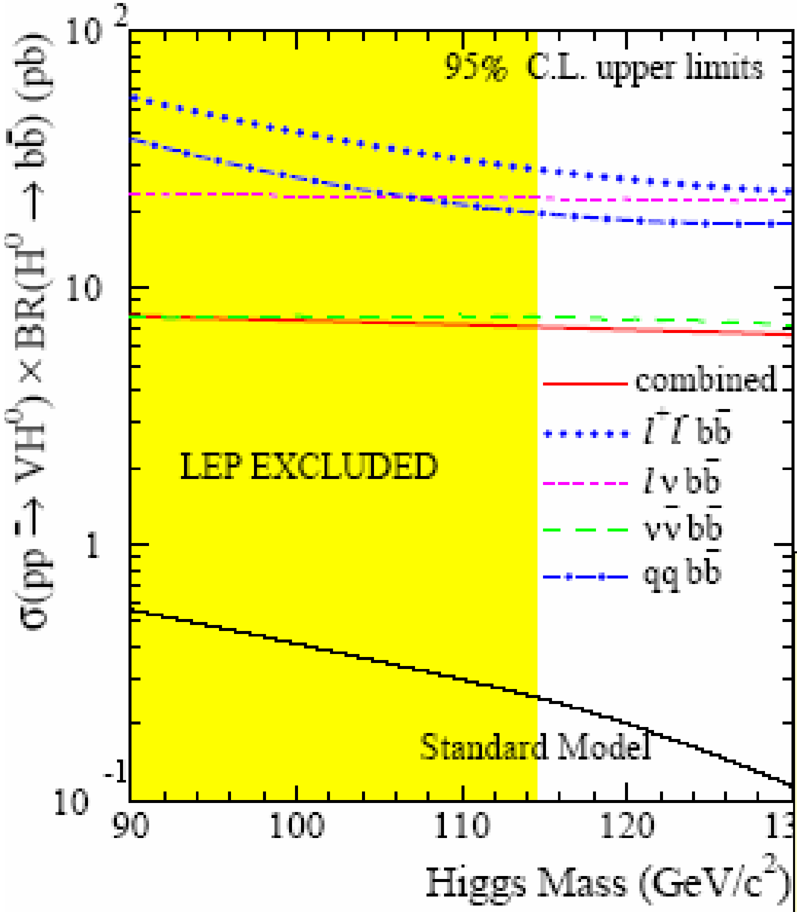
Wjj/Wbb	32%
Zjj/Zbb	31%
Instrumental	16%
Top	15%
WZ/ZZ	6%



Systematic Uncertainty

Source	Sig	Bkg
Jet ID	7%	6%
JES	7%	8%
Jet resolution	5%	3%
b-tagging	22%	25%
Instrumental bkg	-	2%
Bkg Cross Section	-	17%
Total	26%	33%

Run I Combination / Sensitivities



PRL - hep-ex/0503039

Channel	Measured (expected) upper limits (pb) $M_H = 90$	$M_H = 110$	$M_H = 130$
$\ell^+\ell^- b\bar{b}$	55.6 (36)	31.8 (24)	23.8 (25)
$\nu\bar{\nu}\, b\bar{b}$ (ST)	20.8 (30)	20.8 (21)	18.4 (17)
$\nu\bar{\nu}\, b\bar{b}$ (DT)	10.4 (17)	9.2 (14)	8.0 (12)
$\nu\bar{\nu}\, b\bar{b}$ (ST+DT)	7.6 (13)	7.8 (11)	7.4 (8.8)
$\ell\nu\, b\bar{b}$ (ST)	30.0 (18)	29.4 (15)	27.6 (12)
$\ell\nu\, b\bar{b}$ (DT)	31.0 (24)	26.6 (19)	24.2 (18)
$\ell\nu\, b\bar{b}$ (ST+DT)	23.2 (13)	22.6 (11)	21.6 (9.0)
$q\bar{q}'\, b\bar{b}$	38.2 (77)	21.2 (43)	17.8 (29)
All combined	7.8 (7.1)	7.2 (5.7)	6.6 (4.7)

Expected "sensitivity" similar for WH and ZH channels (@ m_H=110 GeV ➔limit of 11 pb for 106 pb^{-1} e+mu, SingleTag+DoubleTag)

Combination of all channels allows to go from 19 pb in a single channel (WH-DT) down to 6 pb

Run II vs Run I: expected limit 12 pb@ D0-RunII for WH-DT instead of 19 pb @CDF-Run I, with equivalent lumi (174 pb^{-1} e-chan. vs. 106 pb^{-1} e+mu-chan.)

- For WH-ST, expected limit 8 pb @ CDF-Run II vs. 15 pb @ CDF-Run I ➔ PROGRESS

Summary

No deviations from SM observed (yet)

Higgs search is in progress:

For the SM Higgs

→Most of the channels (WH, ZH, single/double tag) have already been studied with Run II data → no showstoppers, but we have to keep improving efficiencies.

→ sensitivity (m_H >114 GeV) starts at ~2 fb^{-1} (2007)
→ Expect exclusion or evidence for a low mass Higgs when LHC produces its first results

For non SM Higgs sensitivity could be higher, see A. Haas talk

Expect soon substantial improvements in Higgs hunting with ~0.8 fb^{-1} already on tape .....and with ~8 fb^{-1} expected in Run II