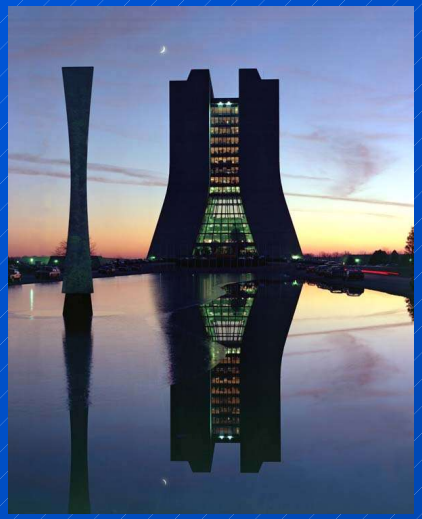
DØ Results on Electroweak, Top and Higgs Physics



Arnulf Quadt

for the DØ Collaboration

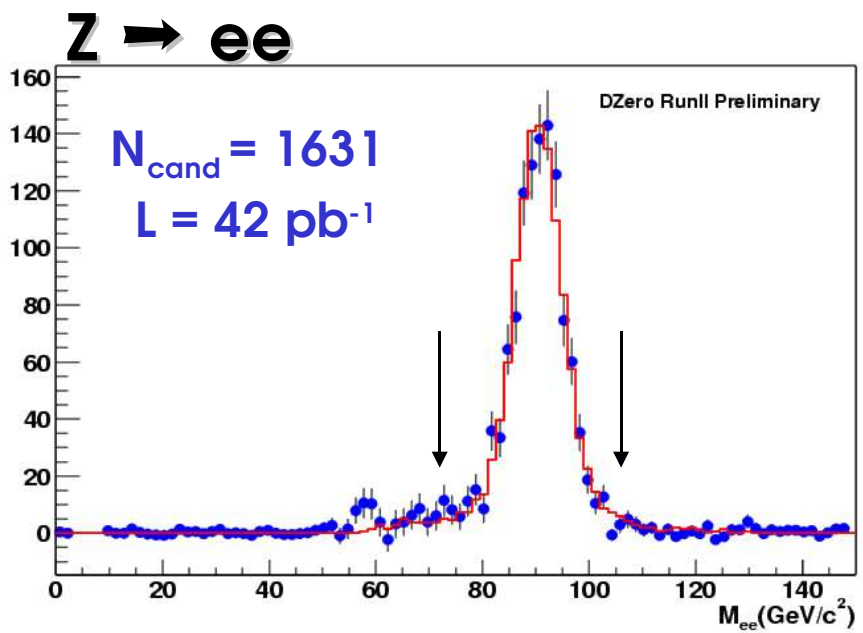
FNAL Users Meeting

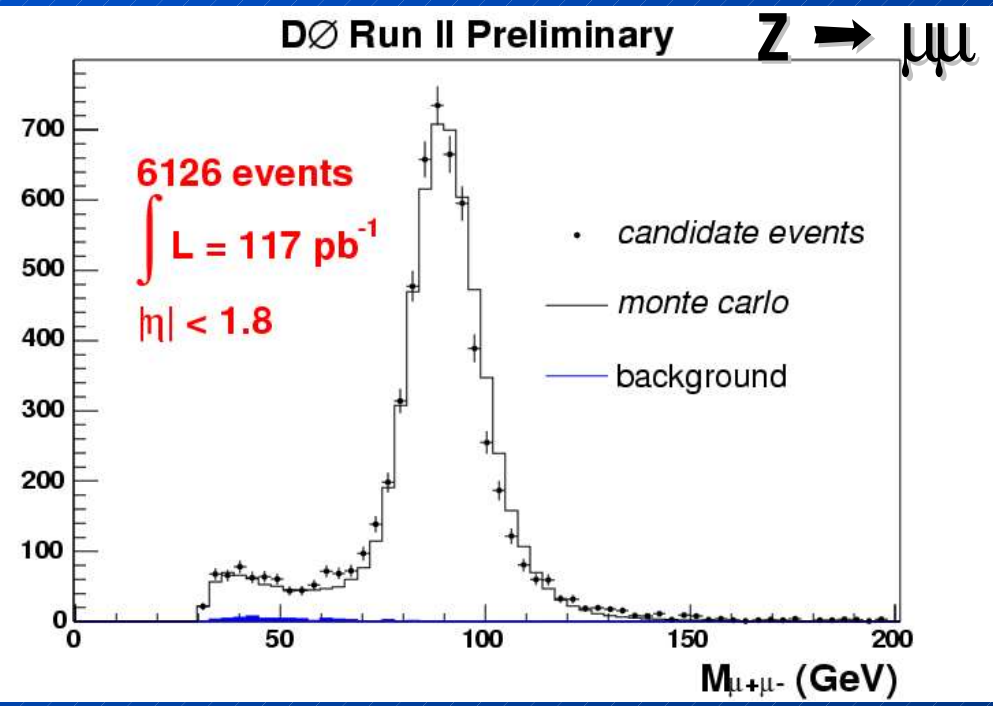
Outline

- **Electroweak Physics**
  - Z/W production
  - W width
  - Wγ production
  - other studies
- **Top**
  - ttbar production (strong)
  - single-top production (electroweak)
  - properties (mass, W-helicity ...)
- **Higgs**
  - Standard Model Higgs Search
  - MSSM Higgs
  - 2HDM Higgs
  - Double Charged Higgs

Z → ee, μμ Production

- select 2 opposite charged high-p_T leptons
- backgrounds: Z → ττ and qq/bb production for ee/μμ
- systematics: lepton-ID, PDF, acceptance, background
- correct from Z*/γ* to Z using MC





$$\sigma_Z \cdot Br(Z \to \mu^+ \mu^-) = 261.8 \pm 5.0(stat) \pm 8.9(syst.) \pm 26.2(lumi)\, pb$$

$$\sigma_Z \cdot Br(Z \to e^+ e^-) = 275 \pm 9(stat) \pm 9(syst.) \pm 28(lumi.)\, pb$$

... also starting to measure WZ bosons differential cross section ...

W → eν, μν Production

$P_T(e) > 25$ GeV

$E_T^{miss} > 25$ GeV

$N_{cand} = 27370$

$\mathscr{L} = 42\ pb^{-1}$

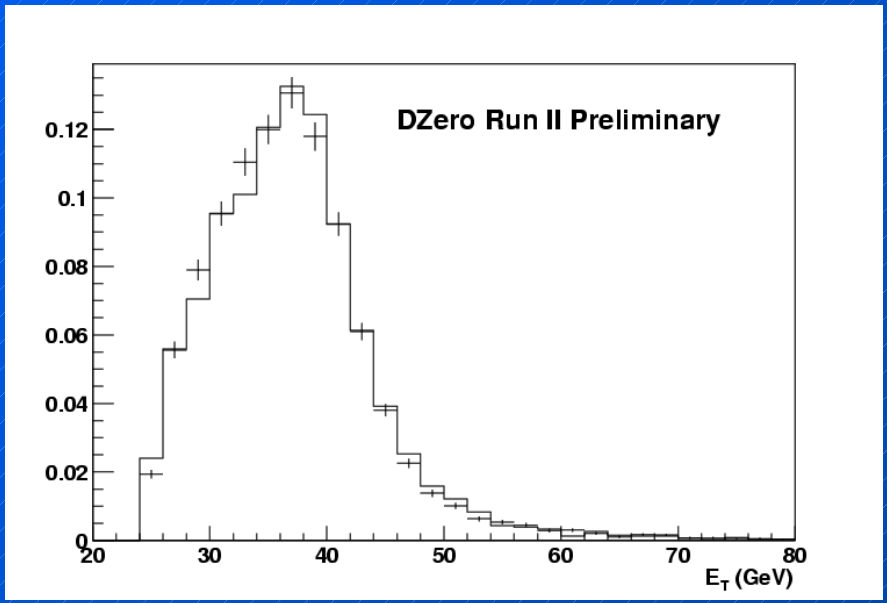
$P_T(\mu) > 20$ GeV

$E_T^{miss} > 20$ GeV

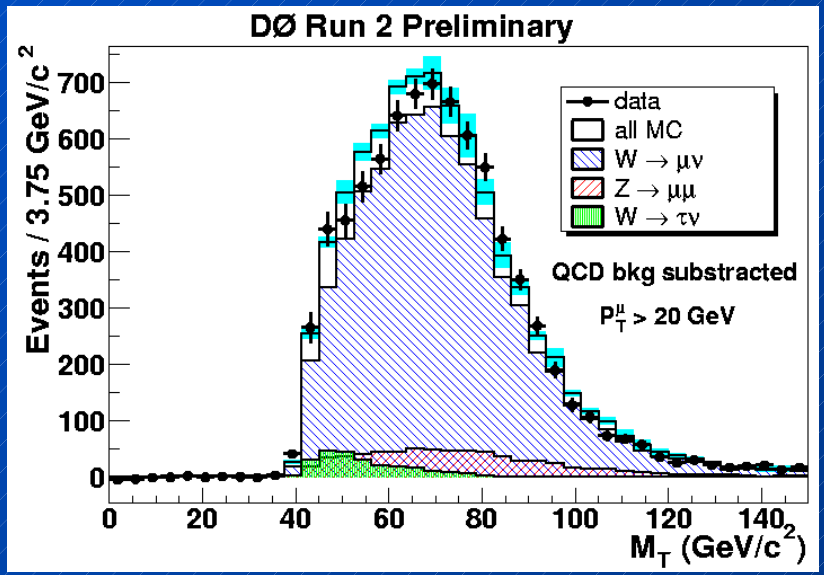
$N_{cand} = 8302$

$\mathscr{L} = 17\ pb^{-1}$

W → eν



W → μν



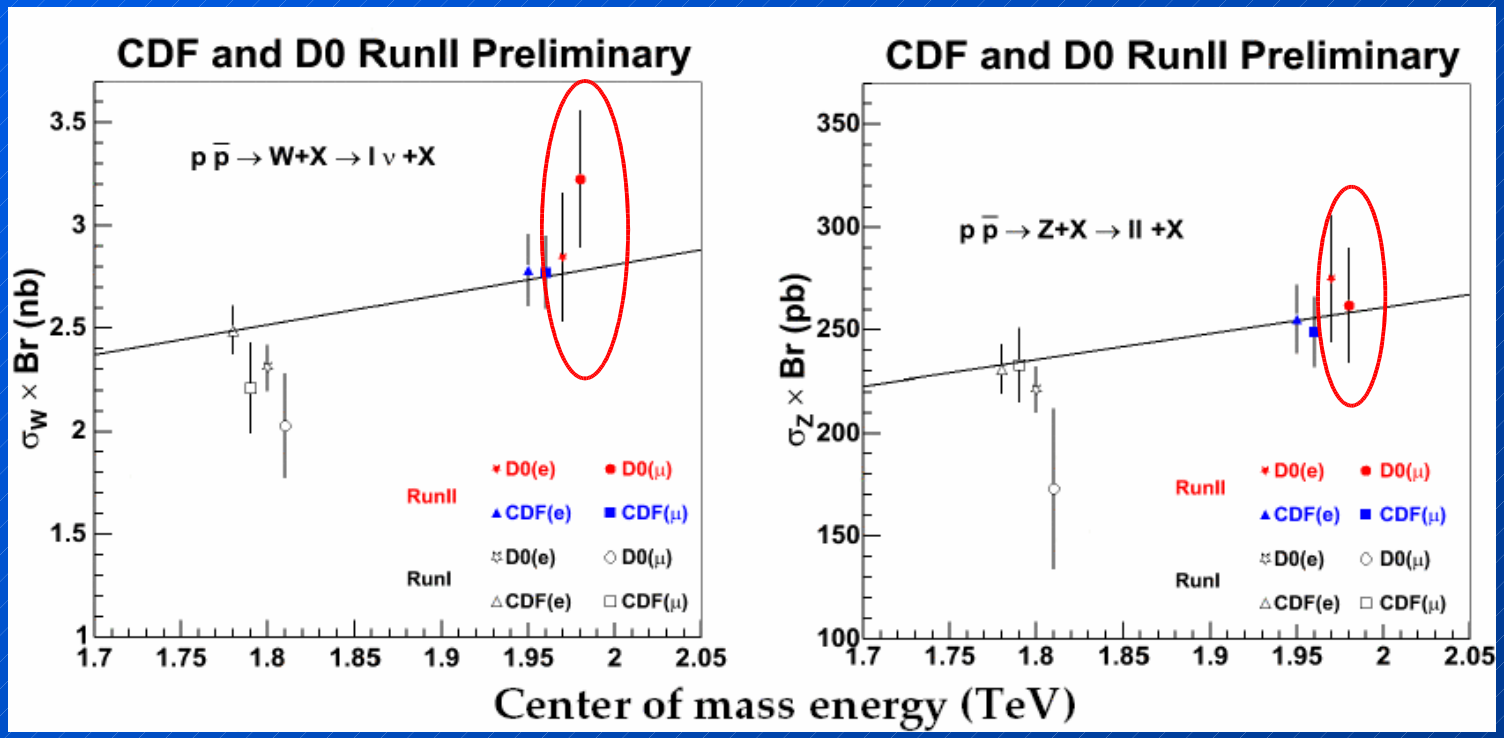
$$\sigma_W \cdot Br(W \to e\,\nu) = 2.884 \pm 0.021\,(stat.) \pm 0.128\,(syst.) \pm 0.284\,(lumi.)\,nb$$

$$\sigma_W \cdot Br(W \to \mu\,\nu) = 3.226 \pm 0.128\,(stat.) \pm 0.100\,(syst.) \pm 0.322\,(lumi.)\,nb$$

... can use this analysis as luminosity measurement; goal $\Delta\sigma = \pm 1\%$ ...

... update of Z/W cross sections with much increased statistics in preparation ...

Summary of W/Z Production Cross Sections



here CDF and DØ use different normalization
common normalization agreed recently for Run-II
... combination of results easier ...

Indirect Measurement of Γ_W

measurement :

$$R = \frac{\sigma_W \cdot Br(W \to l\,\nu)}{\sigma_Z \cdot Br(Z \to l^+ l^-)}$$

interpretation :

$$R = \frac{\sigma_W}{\sigma_Z} \cdot \frac{Br(W \to l\,\nu)}{Br(Z \to l^+ l^-)}$$

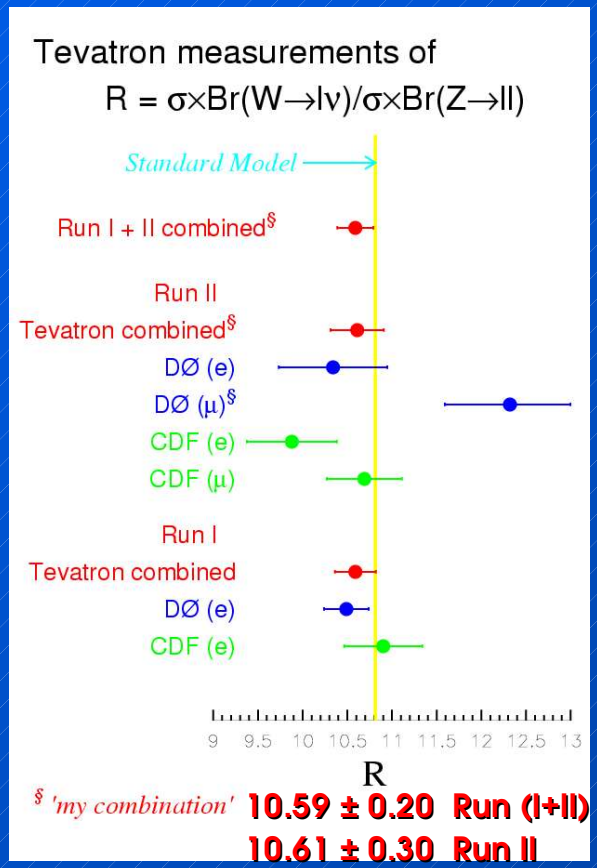
measurement

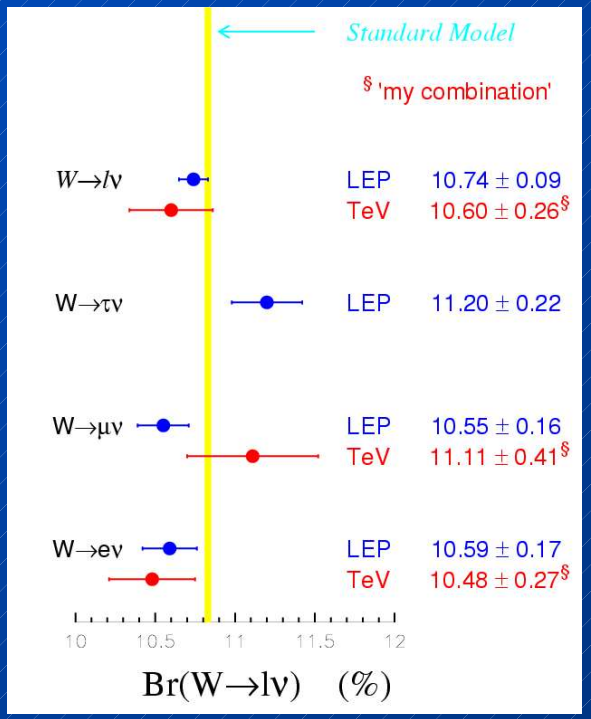
NNLO calc.

from LEP

- luminosity error cancels
- other systematics partially cancel:
  - PDFs
  - experi.: high pT, isolated leptons

LP'03





$Br(W \to l\nu) = \Gamma(W \to l\nu) / \Gamma_W$

Tevatron combined : $\Gamma(W \to l\nu) = 2.135 \pm 0.053$ GeV

LEP & Tevatron direct: $\Gamma(W \to l\nu) = 2.139 \pm 0.069$ GeV

direct measurement of Γ_W coming soon

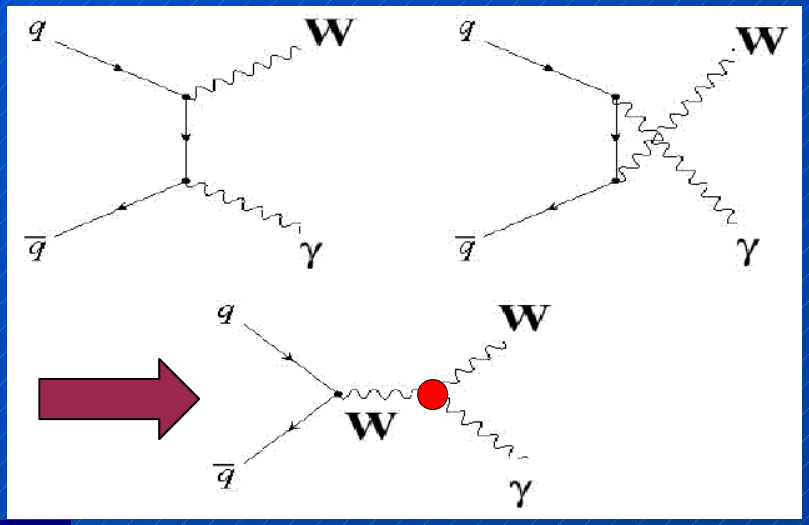
... consistency test of direct and indirect Γ_W ...

$W\gamma$ Production

Trilinear Gauge Couplings
- small in SM
- sensitive to new physics

	$W \to e\nu$	$W \to \mu\nu$
expected background	87.1 ± 7.5	37 ± 10
observed	146	77

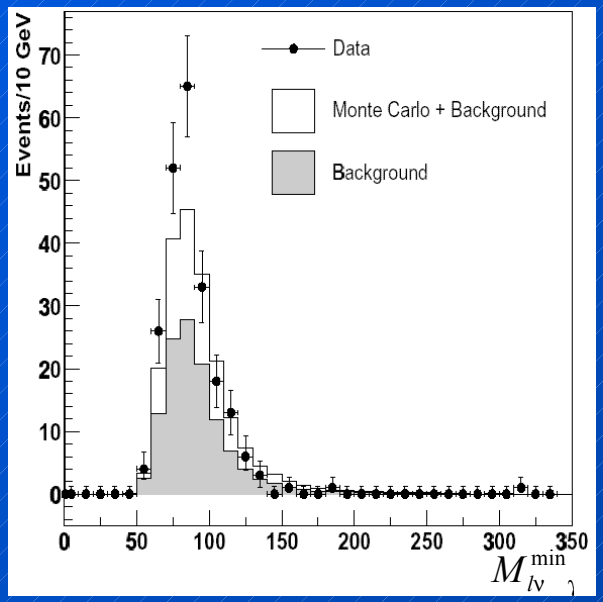
signal eff. calculated using Baur MC + Pythia



$\sigma(pp \to W\gamma \to l\nu\gamma + X) = 19.3 \pm 6.7 \pm 1.2$ (lumi) pb

Theory (Baur + K factor) = 16.4 ± 0.4 pb

e channel: 162.3 pb-1
μ channel: 82.0 pb-1



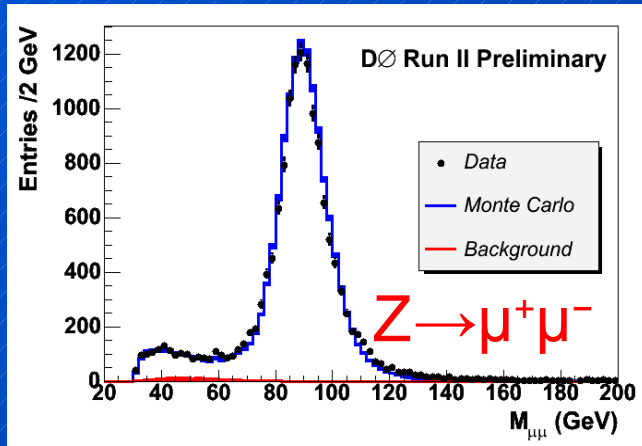
... only first step ...

With increased data detailed $W\gamma$ & $Z\gamma$ kinematic studies will be possible

limits on anomalous couplings
measurement of radiation zero
...

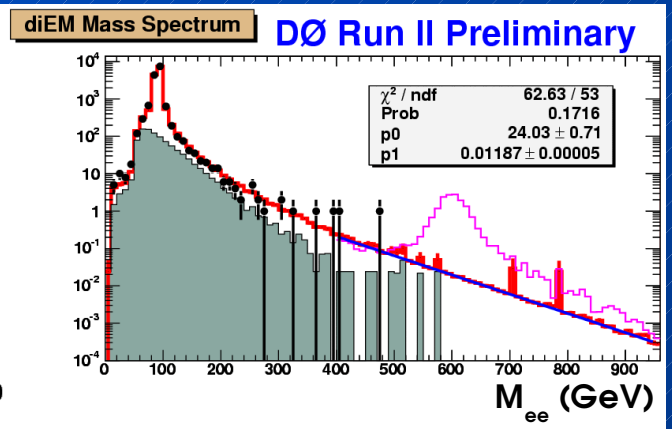
Other Measurements with W, Z Events

- Promising future for Γ_W ... **measurements** with 2 fb^{-1}:
  - $O(10^6)$ $W \rightarrow l\nu$ events per channel
  - $O(10^5)$ $Z \rightarrow l^+l^-$ events per channel (for calibration)
  - LEP2: $O(10^3)$ $W \rightarrow l\nu$ decays per channel per experiment
- **High mass tail of Z**:
  - **A_{FB} Z-charge asymetry**
  - Z'/anomalous couplings
  - $\sin^2\Theta_W$ sensitivity
  - PDF
- **$p_T(Z)$, $\eta(Z)$**
  - PDF
- **W charge asymmetry**
  - ... only at Tevatron ...
  - PDF
- **$Z \rightarrow \tau\tau$** cross section measurement in preparation
- **W-mass** measurement



14790 Z/γ^* events in 147 pb-1

eff*acc ~ 16 – 29% !!!



200 pb^{-1} of $Z \rightarrow ee$

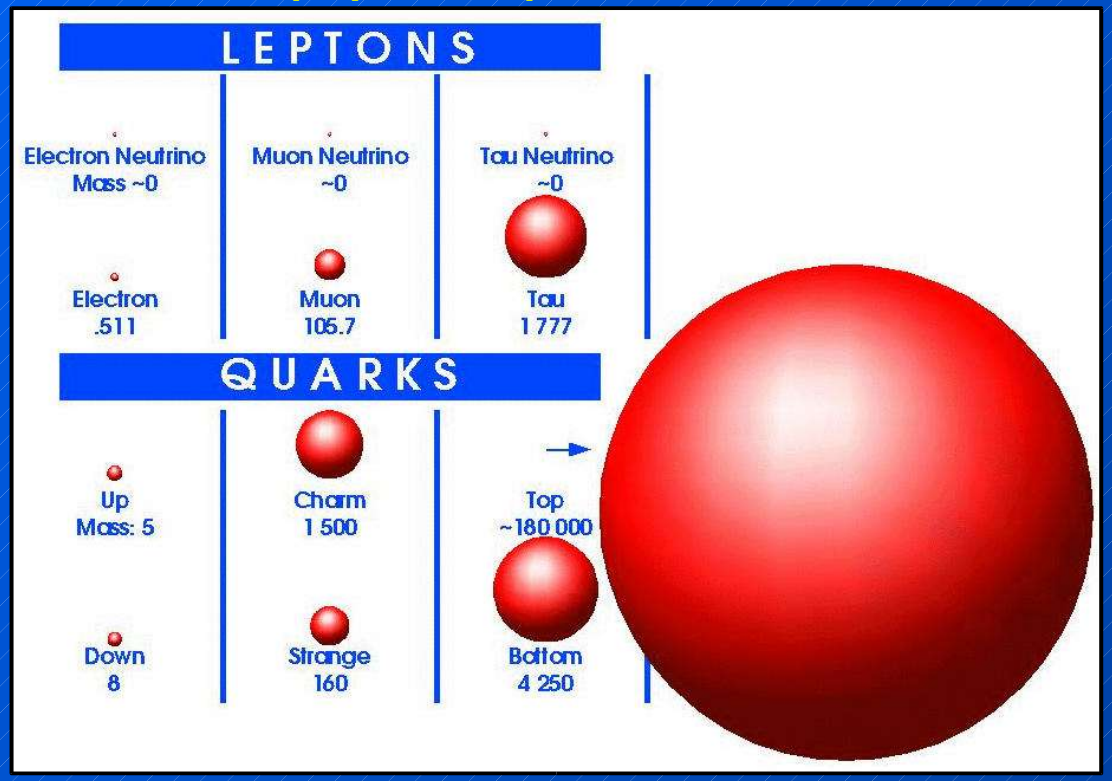
m(Z') > 780 GeV @ 95% CL

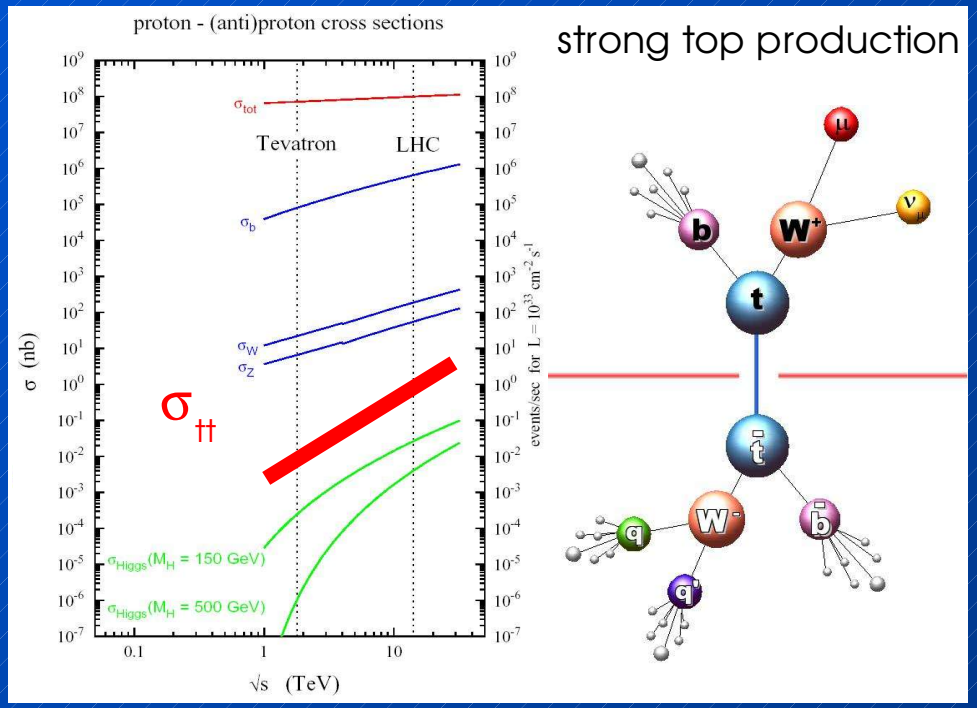
... analyses ongoing, more luminosity included, new results soon ...

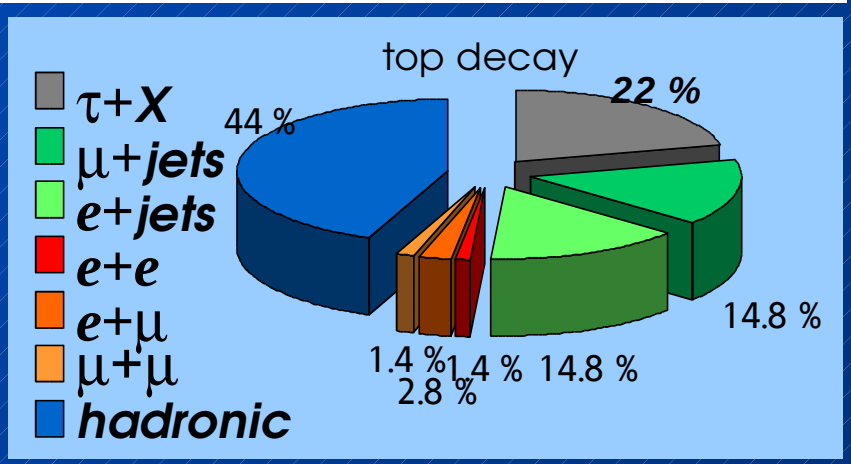
Top Quark in the Standard Model

Why is the Top Quark so interesting ?

- completes the quark sector
- large mass $m_{top} \sim 180\ GeV / c^2$
- short lifetime $\tau \sim 5 \cdot 10^{-25} s$
- sensitive to physics beyond the Standard Model







Discovery of the Top Quark in 1995 by the CDF and DØ Collaborations.

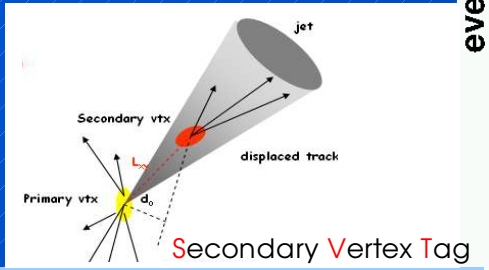
Higgs-Boson coupling to fermions : $g \sim m_f$

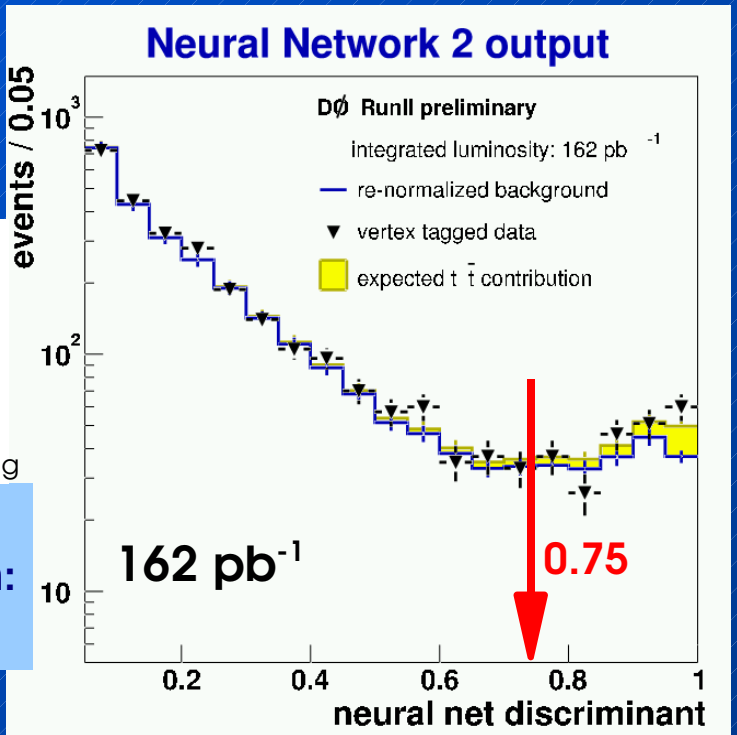
$g_t \sim 1$

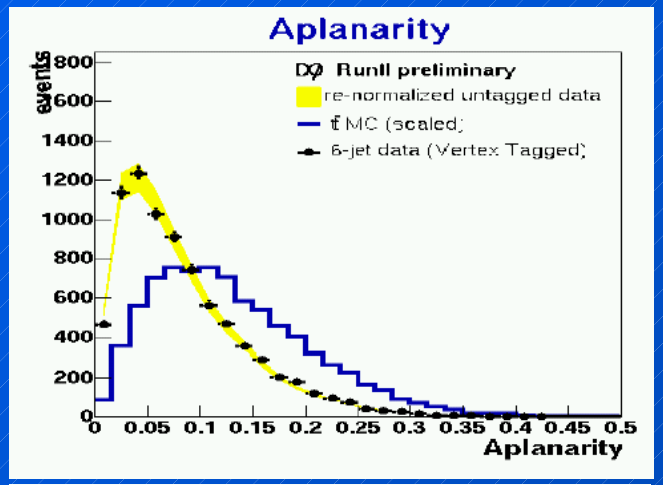
... measure top production cross section (strong and weak) and properties ...

All Jets Channel

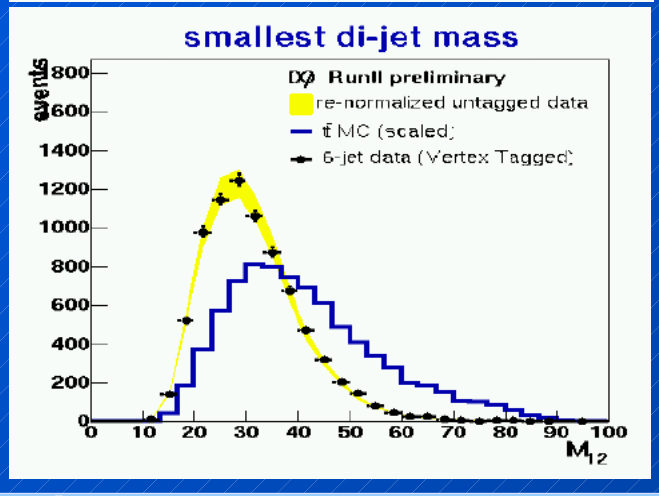
- signature: 6 jets, 2 being b-jets (46% of top production)
- background: large QCD multijet background
  ➜ need b-tagging
- use secondary vertex tagger (SVT)
- combine various kinematical variables into 3 neural networks (trained on data)

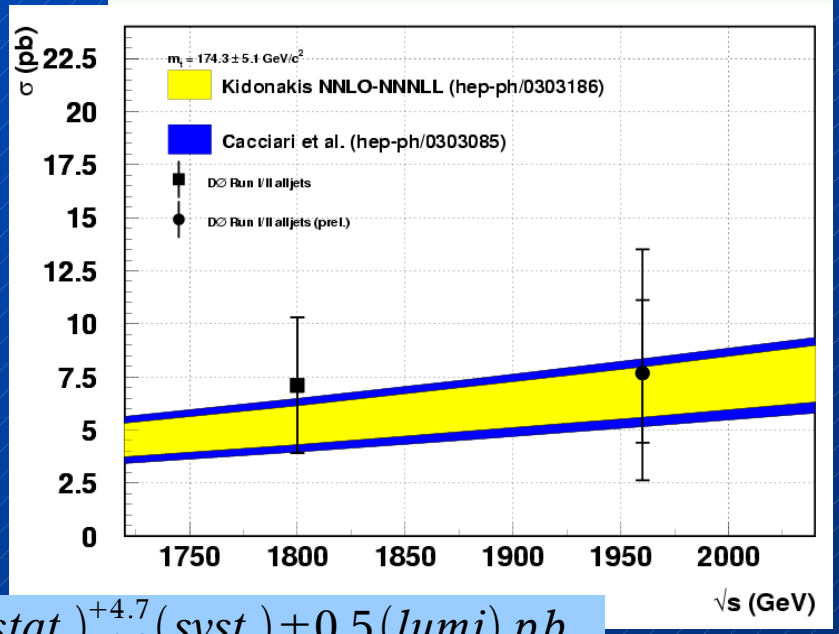






select 220 events
background expectation:
186 ± 5(stat.) ± 7.6(syst.)





$$\sigma(t\bar{t}) = 7.7^{+3.4}_{-3.3}(stat.)^{+4.7}_{-3.8}(syst.) \pm 0.5(lumi)\ pb$$

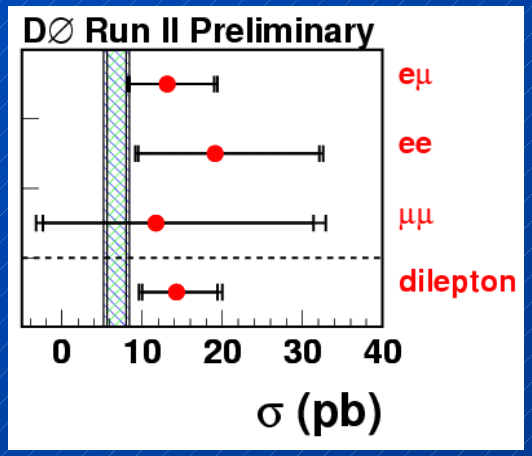
Di-Lepton Channels

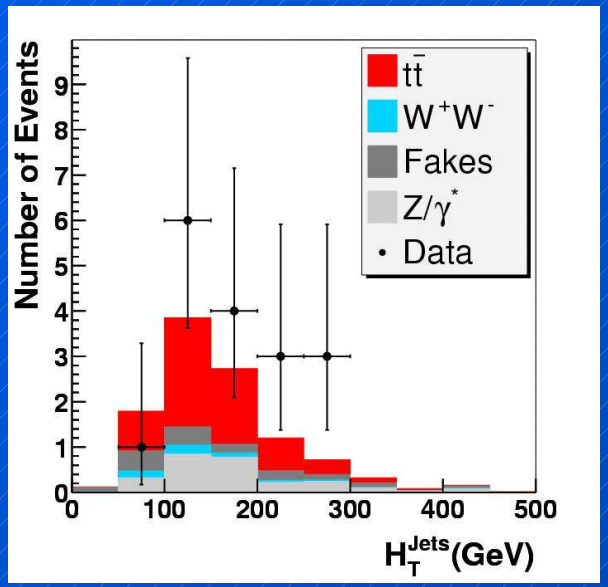
- signatures: isolated high p_T ee, μμ, eμ with high transverse p_T, ≥2 Jets, MET
- small branching ratios to ee, μμ, eμ
- background:
  - WW(→ ee, μμ ,eμ) + Jets
  - Z (→ ee, μμ) + Jets
  - Z (→ ττ → eμ) + Jets
  - W + Jets (Jet fakes isolated e,μ)
  - (bb +) Multijet-Production (Jets fake isolated e, μ)

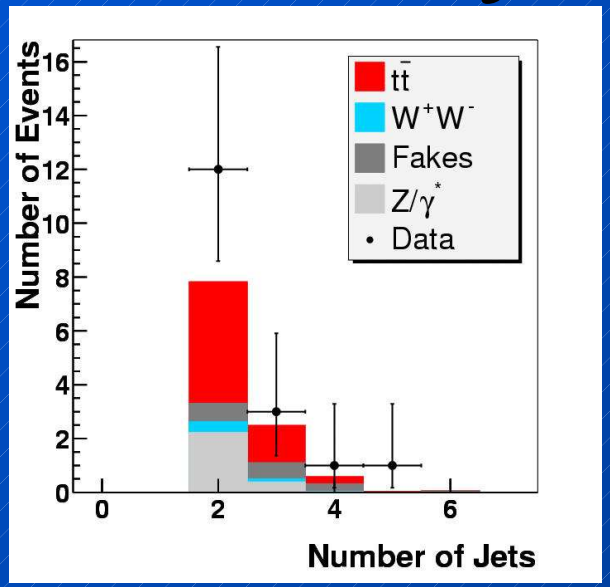
} from MC

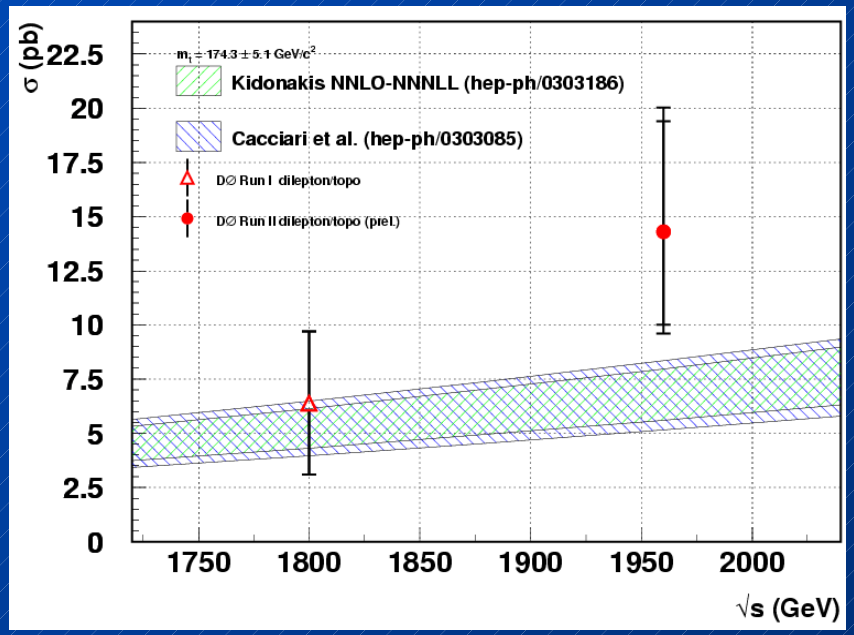
} from data

ee: 156 pb^{-1}
eμ: 140 pb^{-1}
μμ: 143 pb^{-1}









$$ee: \quad \sigma_{t\bar{t}} = 19.1^{+13.0}_{-9.6}\ (\text{stat})\ ^{+3.7}_{-2.6}\ (\text{syst})\ \pm 1.2\ (\text{lumi})\ \text{pb};$$

$$\mu\mu: \quad \sigma_{t\bar{t}} = 11.7^{+19.7}_{-14.1}\ (\text{stat})\ ^{+7.9}_{-5.0}\ (\text{syst})\ \pm 0.8\ (\text{lumi})\ \text{pb};$$

$$e\mu: \quad \sigma_{t\bar{t}} = 13.1^{+5.9}_{-4.7}\ (\text{stat})\ ^{+2.2}_{-1.7}\ (\text{syst})\ \pm 0.9\ (\text{lumi})\ \text{pb};$$

$$\text{dilepton}: \quad \sigma_{t\bar{t}} = 14.3^{+5.1}_{-4.3}\ (\text{stat})\ ^{+2.6}_{-1.9}\ (\text{syst})\ \pm 0.9\ (\text{lumi})\ \text{pb}.$$

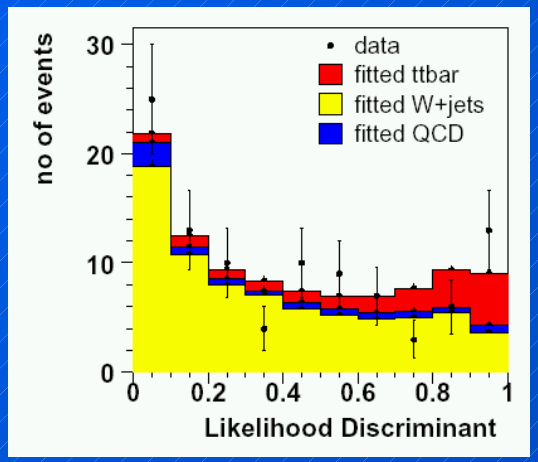
DØ conf-note 4421

Lepton+Jets Channels

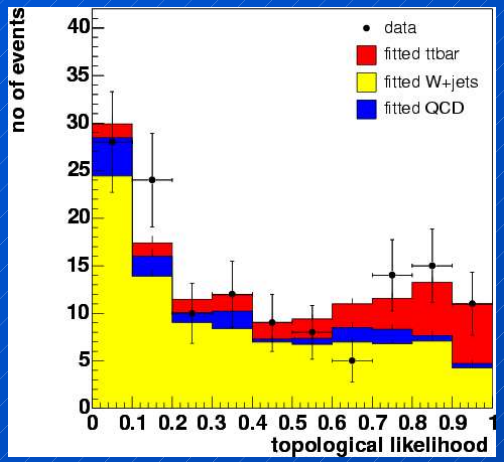
- topology: isolated high p_T lepton, large MET, ≥4 jets (no b-tagging)
- preselection removes all but W+jets
- form topological likelihood discriminant, optimized for total precision
- fit linear combination of QCD (poor-electron selection in data), W+4jet and ttbar to data

DØ conf-note 4423

μ+jets: 144 pb^{-1}

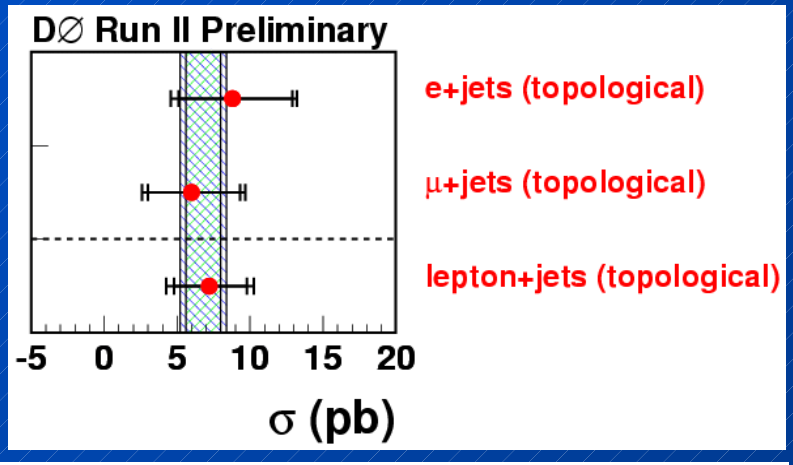


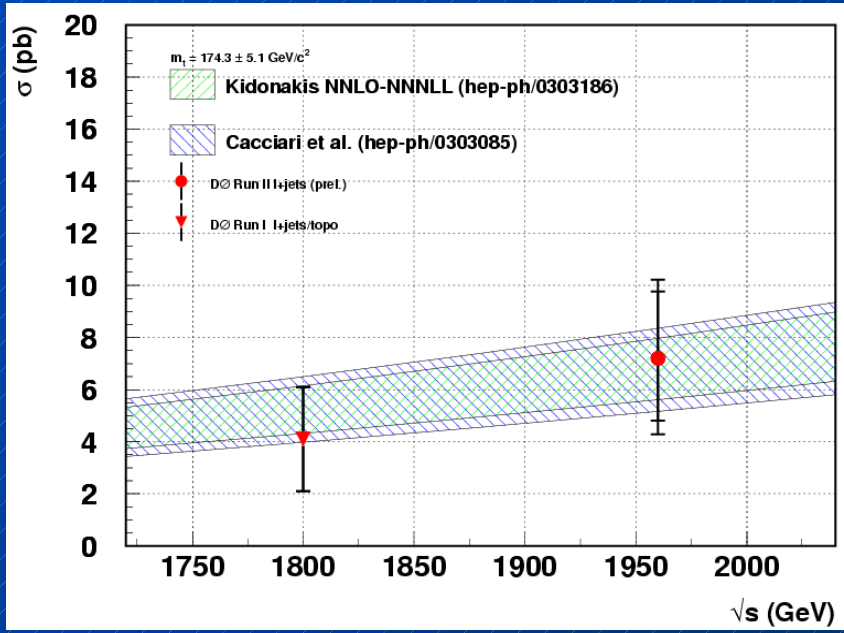
e+jets: 141 pb^{-1}



	muons	electrons
Nev	100	136
fitted N^W	74.7 + 12.7 – 12.0	94.6 + 15.8 - 15.0
fitted N^{QCD}	7.1 + 0.9 – 0.9	14.1 + 1.2 - 1.2
fitted N^{tt}	17.8 + 9.9 – 8.7	27.5 + 12.7 - 11.7

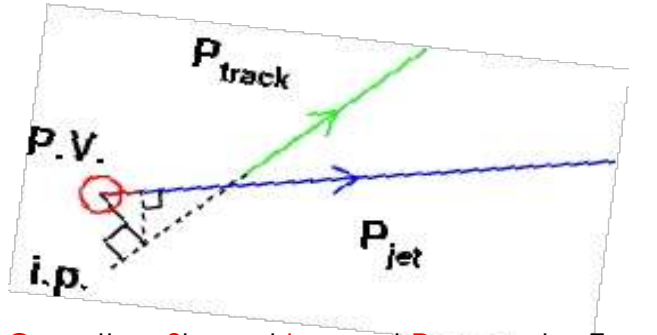
e+jets	$8.8^{+4.1}_{-3.7}(\text{stat})^{+1.6}_{-2.1}(\text{syst}) \pm 0.6\ (\text{lumi})\ \text{pb}$
μ+jets	$6.0^{+3.4}_{-3.0}(\text{stat})^{+1.6}_{-1.6}(\text{syst}) \pm 0.4\ (\text{lumi})\ \text{pb}$
lepton+jets	$7.2^{+2.6}_{-2.4}(\text{stat})^{+1.6}_{-1.7}(\text{syst}) \pm 0.5\ (\text{lumi})\ \text{pb}$



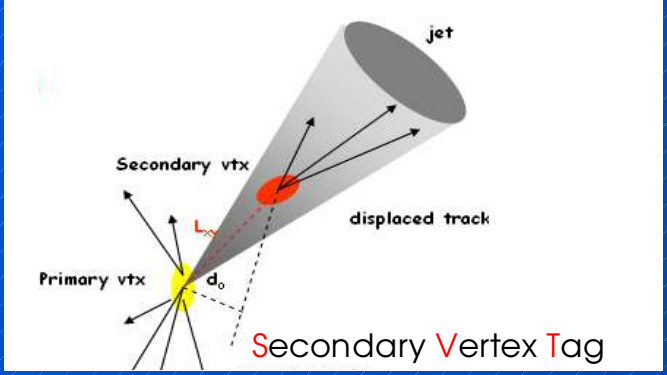


... lepton+jets with soft-mu tag coming soon ...

Lepton+Jets Channels with b-tagging



Counting Signed Impact Parameter Tag

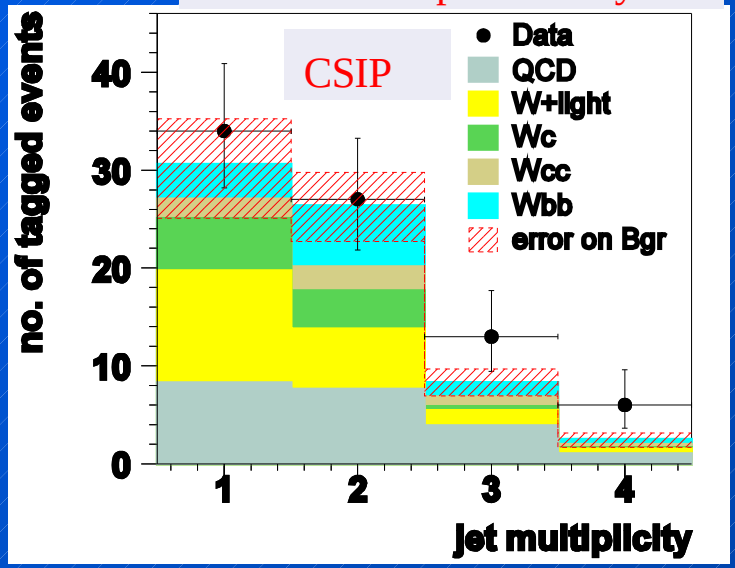


Secondary Vertex Tag

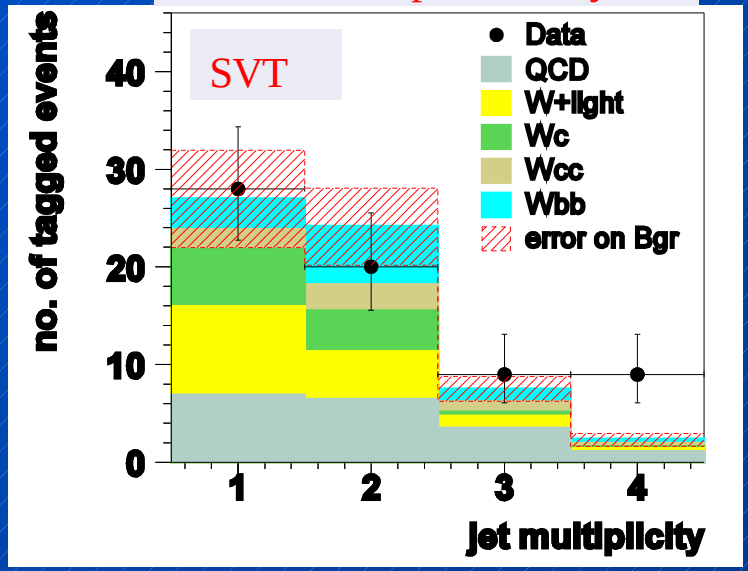
44.75 pb^{-1}

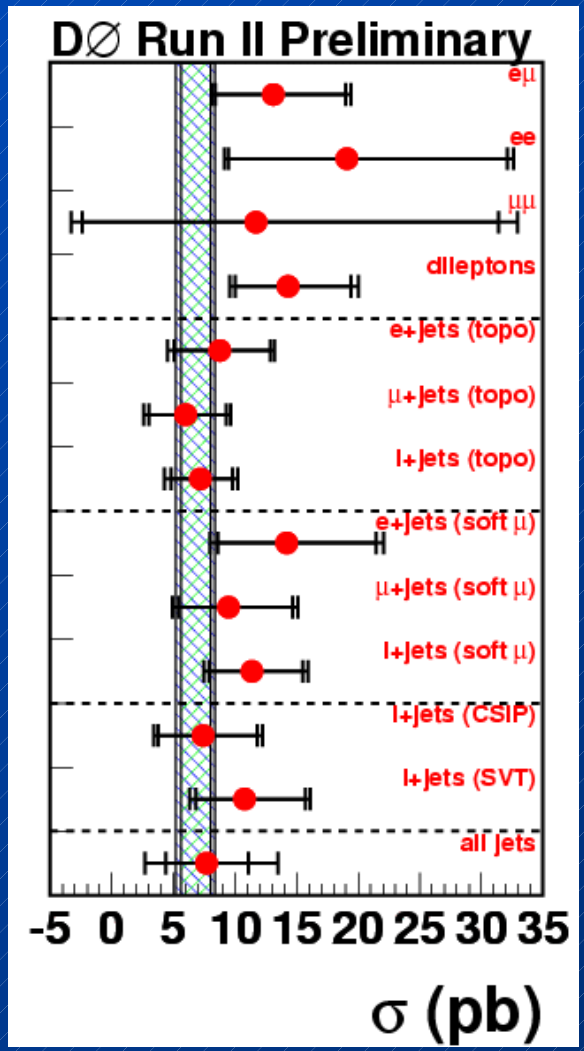
# of tags	W+1 jet	W+2 jet	W+3 jet	W+≥ 4 jet
CSIP	34	27	13	6
SVT	28	20	9	9

D0 Run II preliminary



D0 Run II preliminary



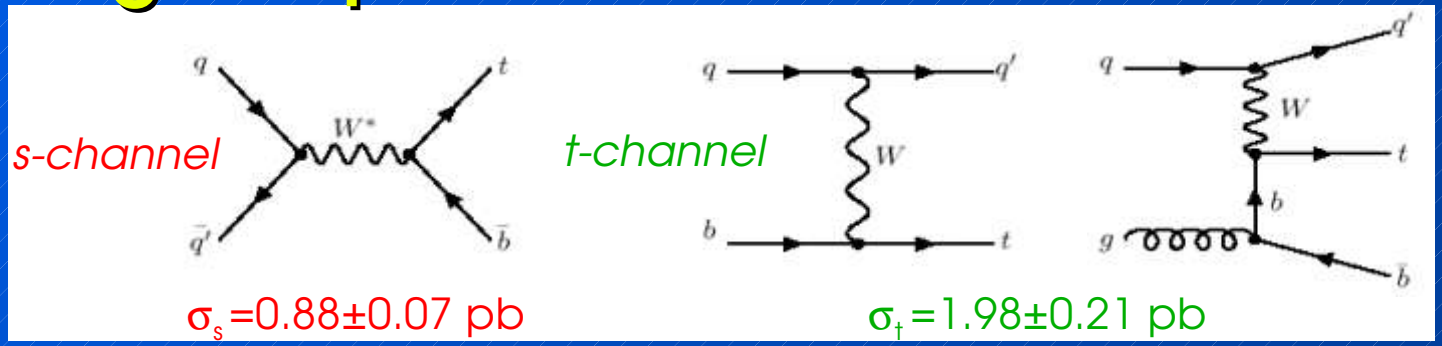


... update with > 4-fold data in preparation ...

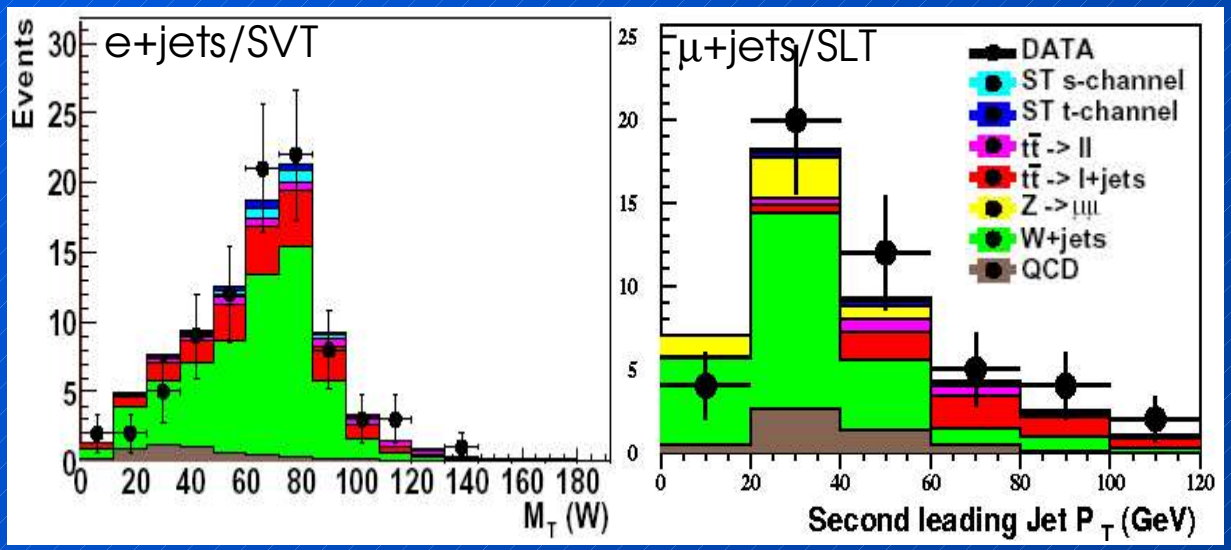
Single-Top Production

- electroweak top interaction
- $|V_{tb}|$
- ...

- not yet observed, despite `large' rate ~40% σ_{tt}
- DØ Run-I upper limit (@ 95% CL): $\sigma_s < 17$ pb, $\sigma_t < 22$ pb
- signature: similar to tt l+jets but lower multiplicity (preselection ➪ b-tagging ➪ topological cuts)
- backgrounds: W+jets, tt, multijets (fake leptons), dibosons



... not yet applied ...



expected limits

	Without Systematics	With Systematics
σ_s (pb)	< 6.4	< 13.8
σ_t (pb)	< 9.0	< 19.8
σ_{s+t} (pb)	< 7.9	< 15.8

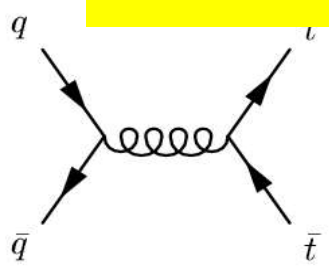
sensitivity already better than Run-I but this is only half of the analysis !

... update coming soon ...

Measurement of the Top Mass in l+jets Channel

- re-analysis of Run-I data (125 pb^{-1}); improvement corresponds to 2.4-times statistics !
- form event likelihood based on top and background probability
- obtain probabilities by folding differential cross section with object resolutions: (Matrix Element Method)

$$P_m(\alpha, x) = \underbrace{Acc(x)}_{\text{Acceptance (selection, trigger,...)}} \times \frac{1}{\sigma} \int \underbrace{d^n\sigma(y;\alpha)}_{\text{LO-Matrix element} \cdot \text{phase space}} dq_1\, dq_2\, \underbrace{f(q_1)\, f(q_2)}_{\text{PDF's}}\, \underbrace{W(x,y)}_{\text{Transfer Functions (Probability to measure x when y was produced)}}$$



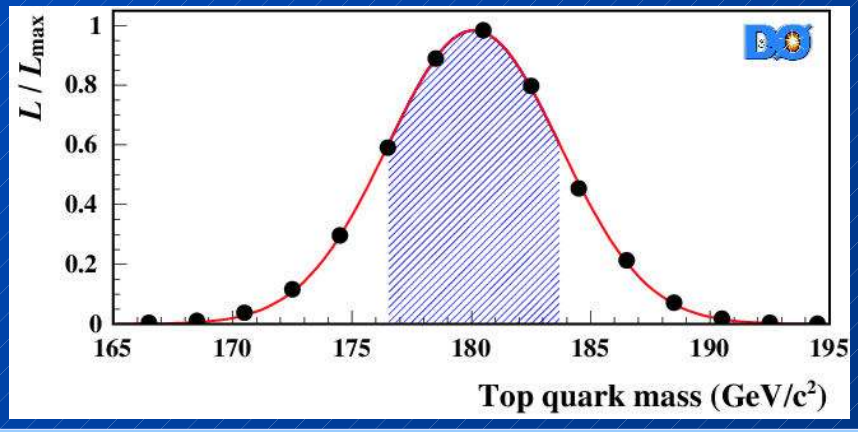
Signal (No ISR or FSR)

Background (VECBOS-ME)
W+ 4 Jets
(also found adequate for QCD bkg.)

- 22 events after final selection
- uncertainty dominated by jet energy scale

$M_T = 180.1 \pm 3.6_{stat} \pm 4.0_{sys}$ GeV

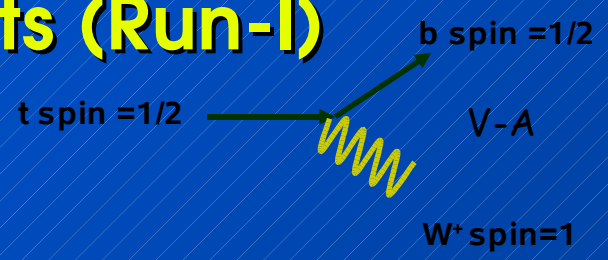
accepted by Nature

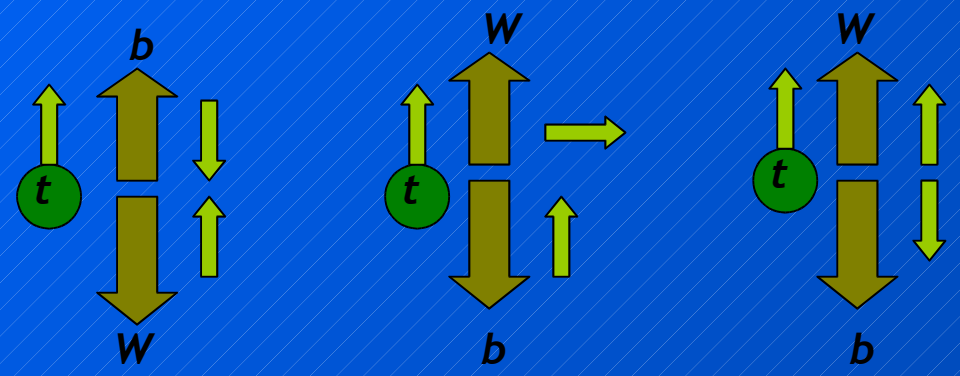


... Run-II top mass measurement ongoing ...

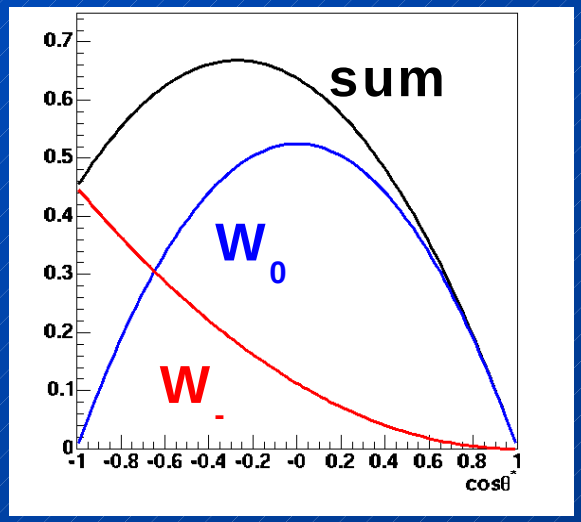
Helicity of the W in Top Events (Run-I)

Top Standard Model weak decay ⇨
V-A coupling as it is for all the other fermions





Suppressed by the V-A coupling



W_- Left-Handed fraction F_-

W_0 Longitudinal fraction F_0

W_+ Right-Handed fraction F_+

$$w(\cos\phi_{l\bar{b}}) = F_- \cdot \frac{3}{8}(1-\cos\phi_{l\bar{b}})^2 + F_0 \cdot \frac{3}{8}(1-\cos^2\phi_{l\bar{b}}) + F_+ \cdot \frac{3}{8}(1+\cos\phi_{l\bar{b}})^2$$

In SM (with m_b=0, M_{top} = 175 GeV and m_W = 80.4 GeV),

$$F_- = \frac{2\frac{m_W^2}{M_{top}^2}}{1+2\frac{m_W^2}{M_{top}^2}} \approx 0.30$$

We want to extract

$$F_0 = \frac{1}{1+2\frac{m_W^2}{M_{top}^2}} \approx 0.70$$

$$F_+ = 0$$

- Integrate over M_{top}
- 22 events pass our cuts ⇨ from fit, 12 signal + 10 background events

$F_0 \pm \delta F_0$(Stat+ M_{top}) = 0.558 ± 0.306

submitted to PRL

further top properties measurements in preparation:

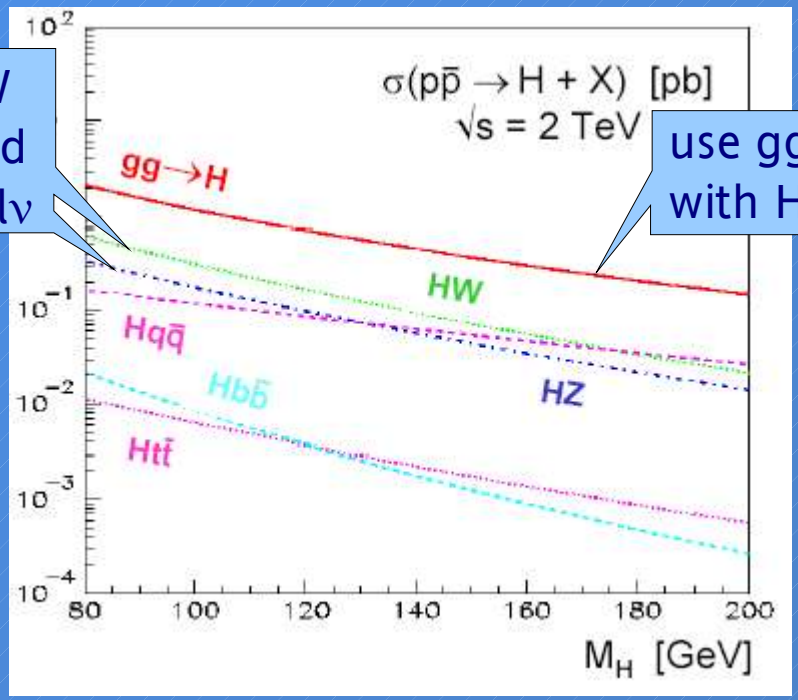
- top coupling
- branching ratios
- top charge
- ...

Search for the Standard Model Higgs at DØ

- Last missing particle in SM (EW symmetry breaking – mass)
- Light SM Higgs preferred
- Key to understand beyond-SM-physics (in MSSM m_H < 135 GeV)
- Search strategy a function of production and decay channel ...
- b-tagging a crucial tool

use HZ and HW with H→ bb and Z→ ll/νν, W→ lν

use gg → H with H → WW



$H \to b\bar{b}$

$H \to WW^{(*)}$

Dominant decay modes

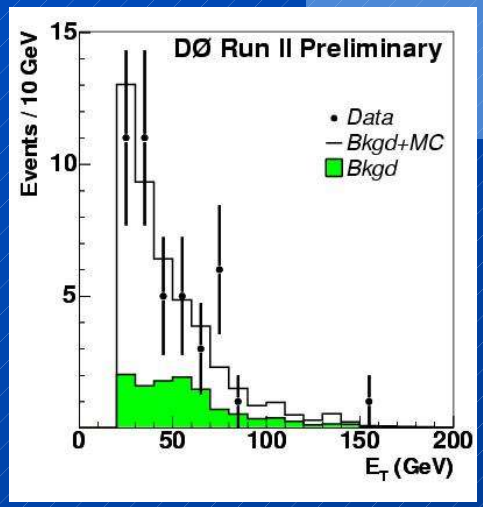
Example: Z(→ee/μμ) b associated production

- background to ZH production
- probes PDF of b-quark
- data lumi: 184 (ee), 152 (μμ) pb^{-1}

QCD and mistag bkgd. estimated from data

E_T spectrum of b-tagged jets

⇒ good match !



DØ conf-note 4388

$$R = \frac{\sigma(p\bar{p} \to Z b)}{\sigma(p\bar{p} \to Z j)} = 0.024 \pm 0.005\,(stat.)^{+0.005}_{-0.004}\,(syst.)$$

$$Theory: R \sim 0.02$$

hep-ph/0312024
J. Campbell et al.

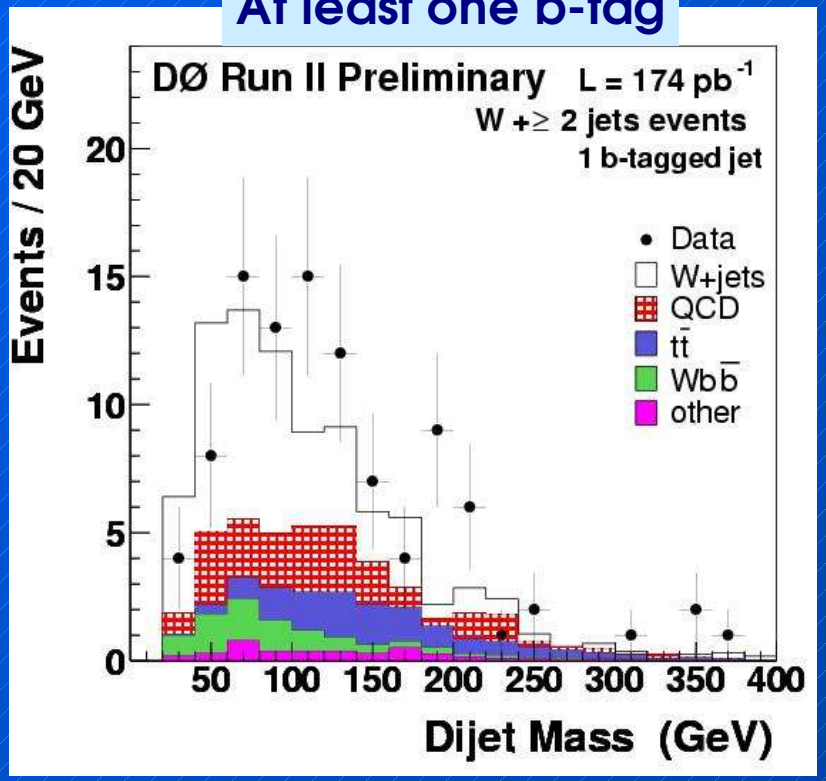
... Z(→νν) bb also coming ...

Search in the WH → eνbb Channel

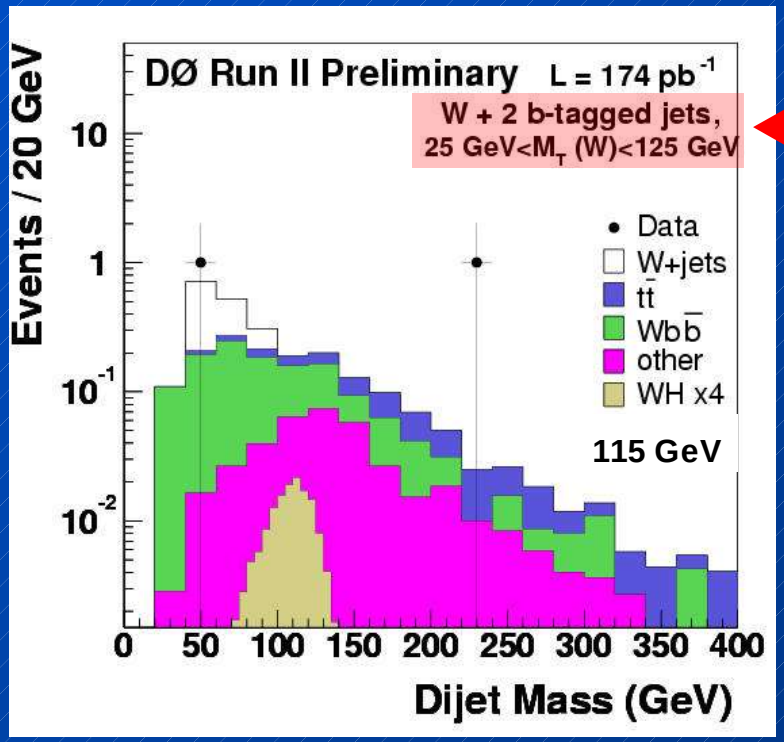
Event selection:

- central isolated $p_T(e) > 20$ GeV
- MET > 25 GeV
- ≥ 2 jets $E_T > 20$ GeV, $|\eta| < 2.5$
- require jets to be b-tagged

At least one b-tag



- require exactly 2 b-tagged jets to suppress top bgd
- observe 2 events, expect 2.5 ± 0.5



limits (@ 95% CL) on the production of

- $\sigma(Wbb) < 20.3$ pb
- $\sigma(WH)\ B(H \to bb) < 12.4$ pb for $m_H = 115$ GeV

JES and MC simulation dominant syst.errors

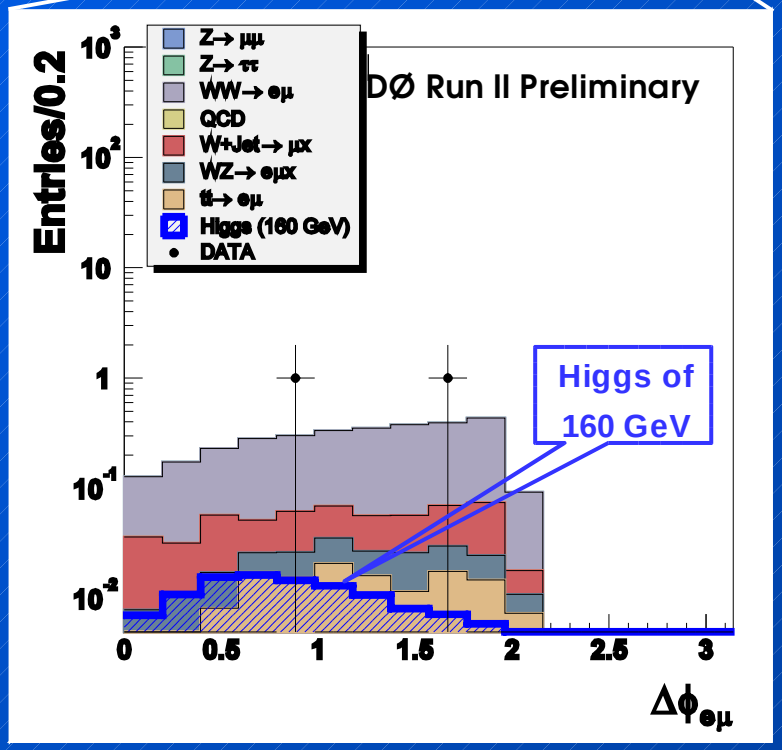
... ($W \to \mu\nu$) -channel coming soon ...

Search in the H → WW* → ll$\nu\nu$ Channel

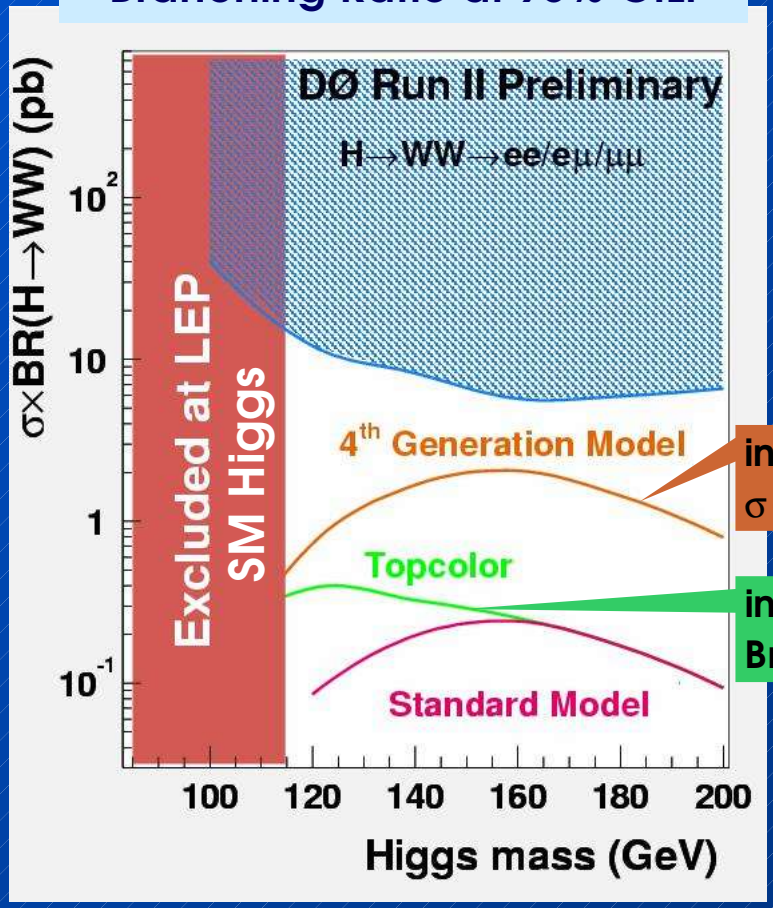
- data set: ~ 180 (ee), 160 (eμ) and 150 ($\mu\mu$) pb^{-1}
- cannot reconstruct Higgs mass due to 2 ν
- exploit $\Delta\phi$(ll) spin correlations to suppress the bgd.

after full selection

	ee	eμ	$\mu\mu$
Observed	2	2	5
Expected	2.7±0.4	3.1±0.3	5.3±0.6



Excluded cross section times Branching Ratio at 95% C.L.



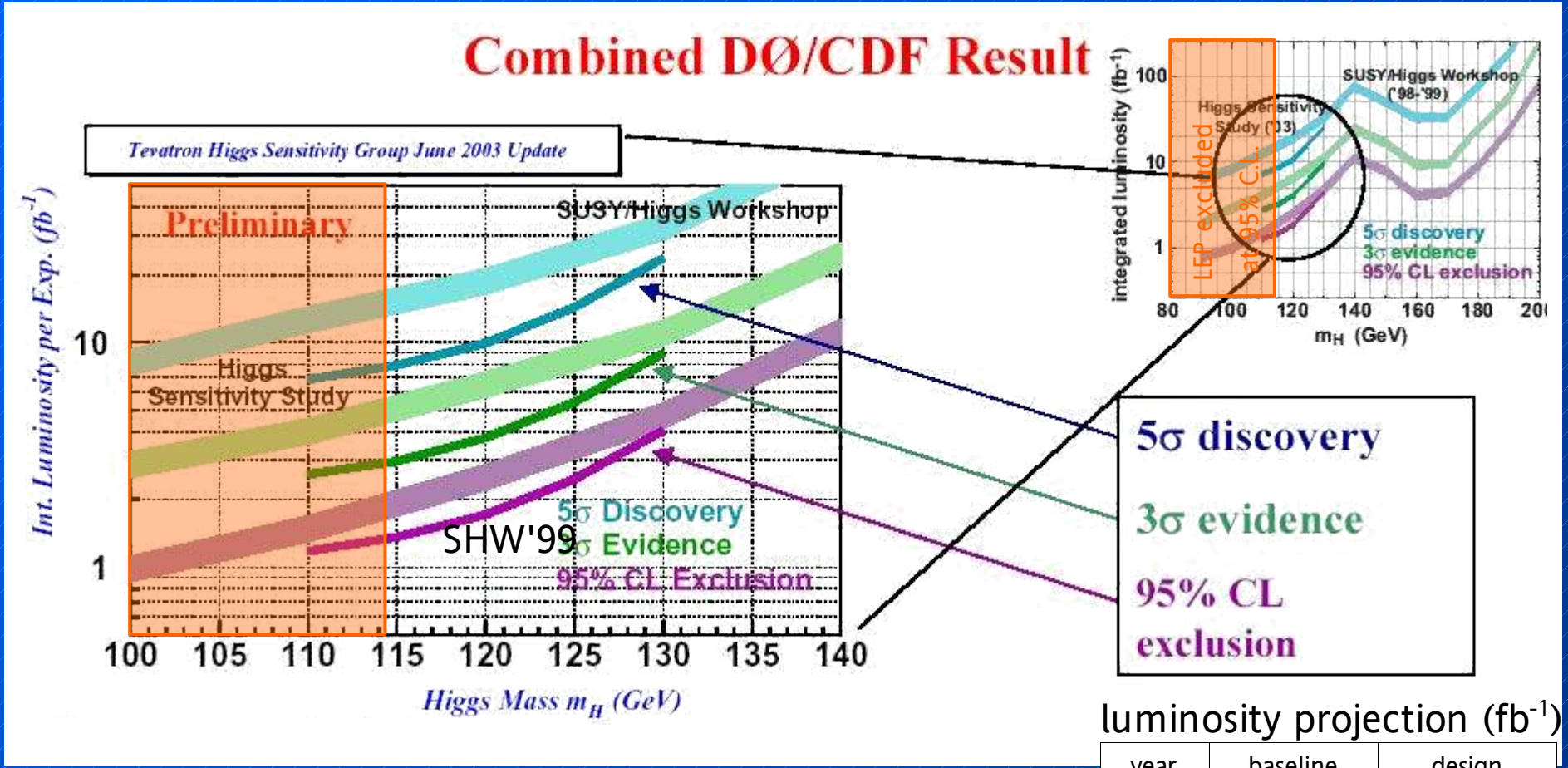
increased σ(H)

increased Br(H → WW)

... first Higgs sensitivity at high masses !

... extended models in reach soon ...

Prospects on Sensitivity to SM Higgs



luminosity projection (fb^{-1})

year	baseline	design
2003	0.28	0.3
2004	0.59	0.68
2005	0.98	1.36
2006	1.48	2.24
2007	2.11	3.78
2008	3.25	6.15
2009	4.41	8.57

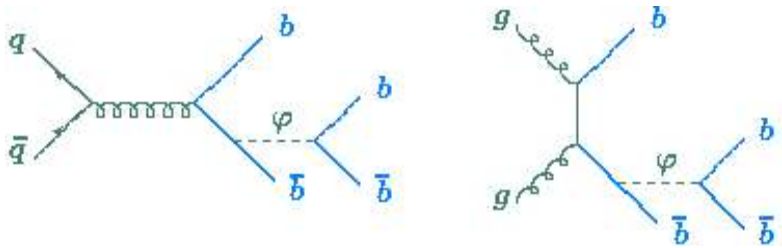
- combined ll, νν, lν channels
- no systematics included yet
- no H → WW* channel; impacts m_H > 125 GeV
- assumes upgraded detector

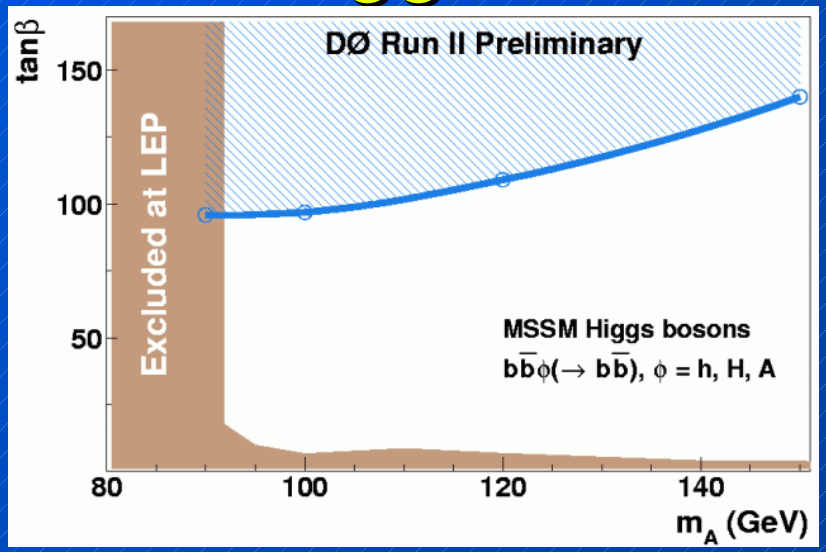
Search for MSSM Higgs

Two Higgs Doublets $\mathcal{H}_1, \mathcal{H}_2$ and 5 physical states

2 CP-even neutral Higgses	h^0, H^0	$m_h < m_H$
1 CP-odd neutral Higgs	A^0	
2 charged Higgses	$H^\pm$	
Free parameters:	$\tan\beta = v_2/v_1$	(VEV ratio)
	α	(mixing angle of h, H)
	μ	Higgs mass parameter
	A_0	common trilinear Higgs-sfermion coupling
tree level:	$m_h < m_Z < m_H$	
rad.corrected:	$m_h < 130$ GeV	

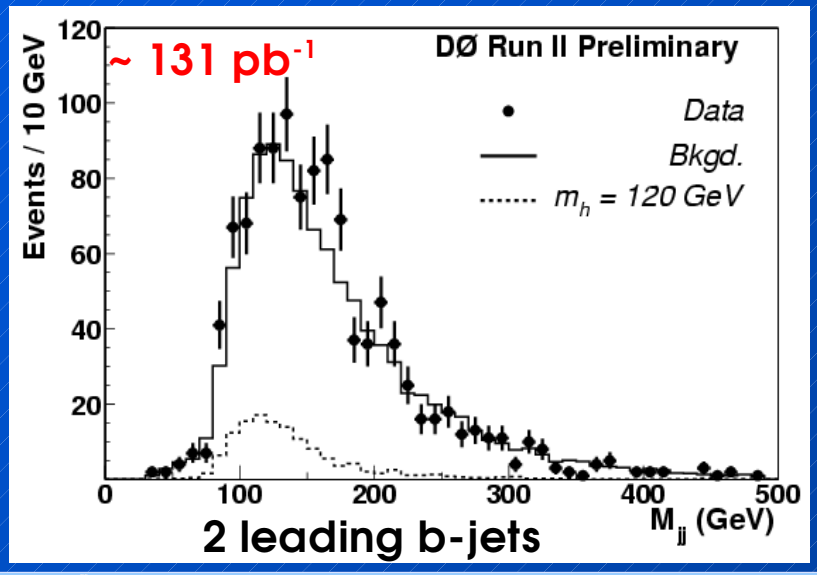
$Br(\phi \to b\bar{b}) \sim 90\,\%$

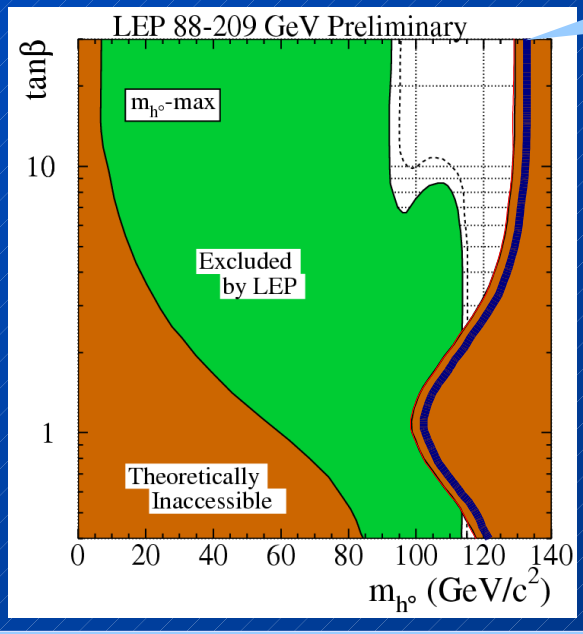




- significant improvements expected from reprocessing
- ... bbττ coming next year ...

- multi-jet sample (≥3 b-tagged jets)
- E_T cuts on jets optimized for Higgs masses





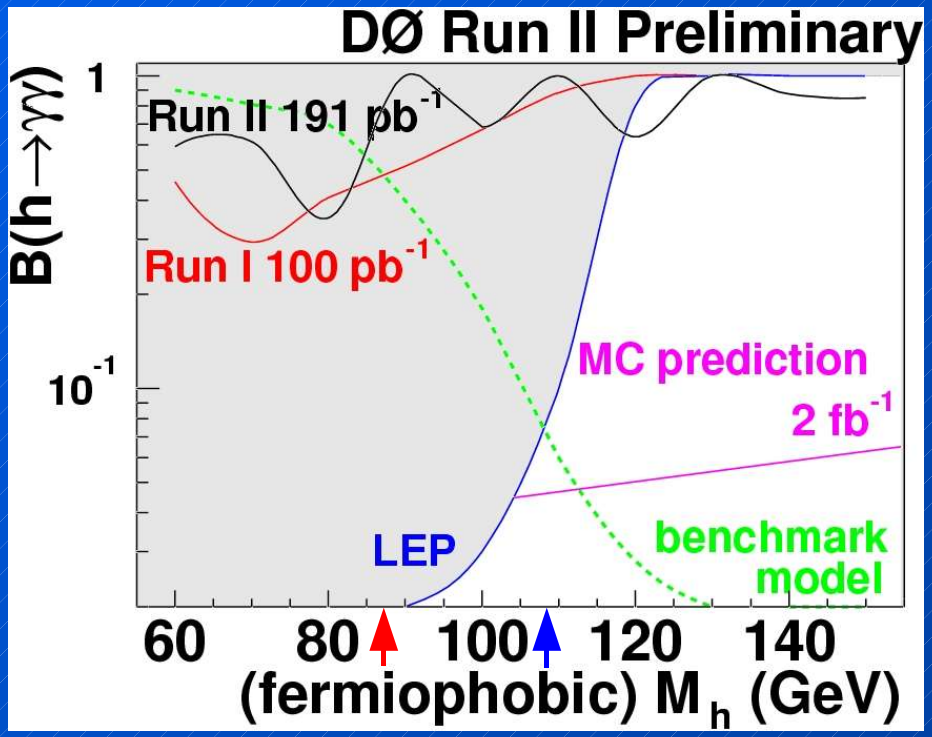
$$\Delta m_h^2 \sim \frac{m_t^4}{m_W^2} \times \left(\log \frac{m_{\tilde{t}_1}^2 m_{\tilde{t}_2}^2}{m_t^4} + \ldots \right)$$

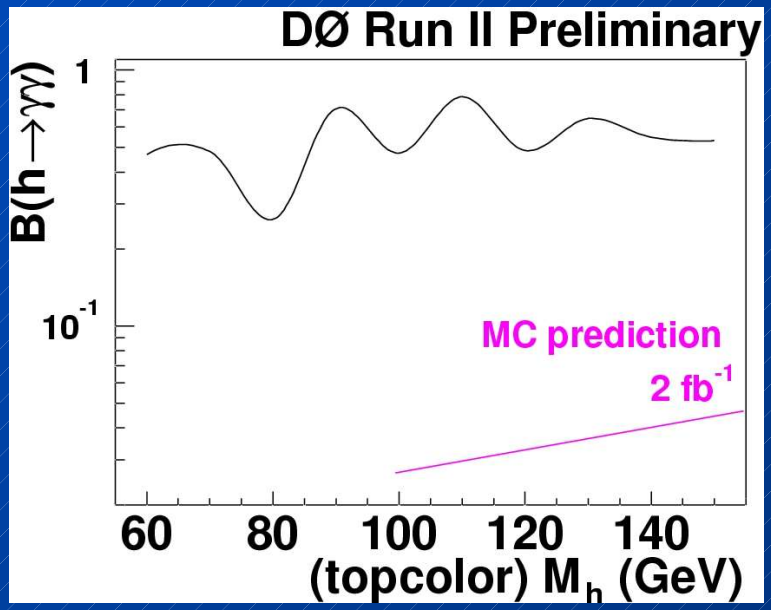
re-interpretation of LEP data due to new m_{top}

Higgs Search in 2-Higgs Doublet Models

- In **2HDM - type I** Higgs coupling to fermions $g_{Hff} \sim \cos\alpha$ can go to zero ($\rightarrow$ `**fermiophobic Higgs**')
- **Topcolor Higgs**: only top has non-zero fermion coupling
- $\Rightarrow$ increase of bosonic Higgs decays (in SM $Br(H \rightarrow \gamma\gamma) \approx 0.1\%$ for m_h=90 GeV)

- **Search:** $h \rightarrow \gamma\gamma$
- 2 isolated γ with P_T > 25 GeV in central/endcap cal.
- $P_T^{\gamma\gamma}$ > 35 GeV
- γ mis-ID dominant uncertainty





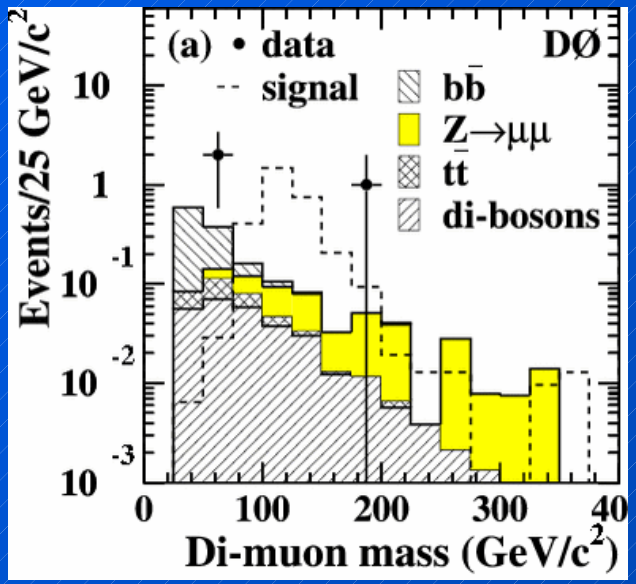
- counting experiment in sliding-mass window
- will be combined with $H \rightarrow WW^*$
- sensitivity improves with luminosity (no kinematic limit)

Search for Doubly-Charged Higgs Bosons

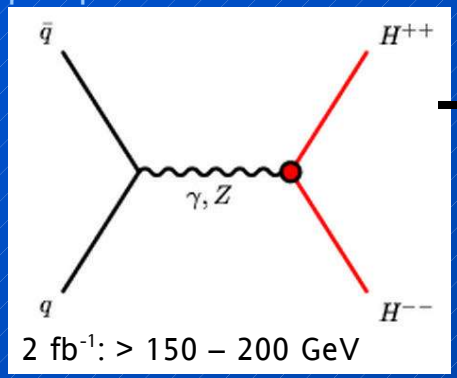
H^{++}/H^{--} predicted in models that contain Higgs triplets

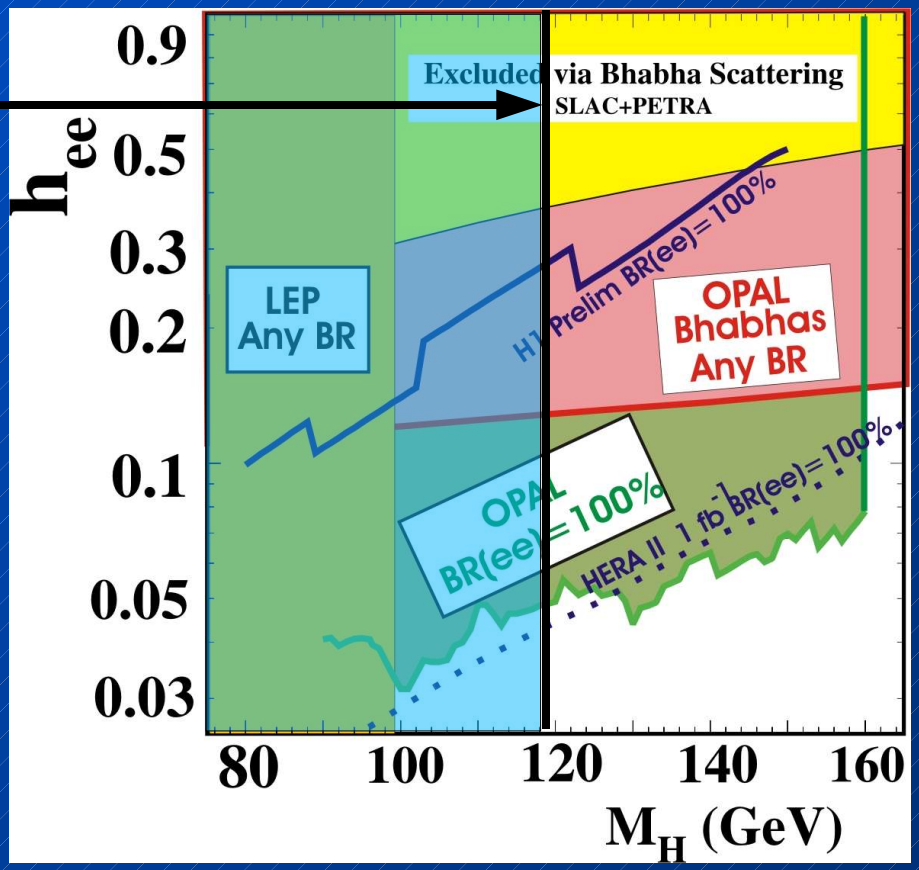
- Left-Right (LR) symmetric models
- SUSY LR models: low mass (~ 100 GeV – 1 TeV)

- search: $H^{++/--} \rightarrow \mu^{\pm}\mu^{\pm}$ (same sign di-muons in 113 pb^{-1})



pair production at TEVATRON



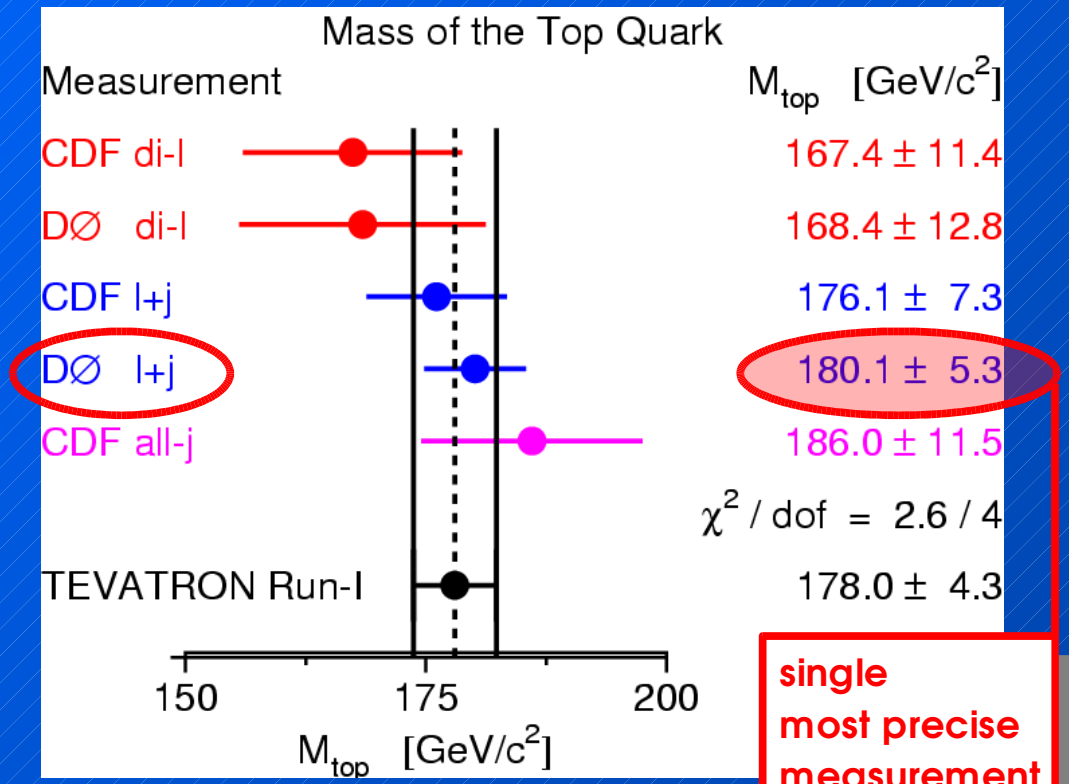


$M(H_L^{\pm\pm}) > 118.4$ GeV

$M(H_R^{\pm\pm}) > 98.2$ GeV

submitted to PRL

Electroweak Fits of m_H with new World-Average m_{top}

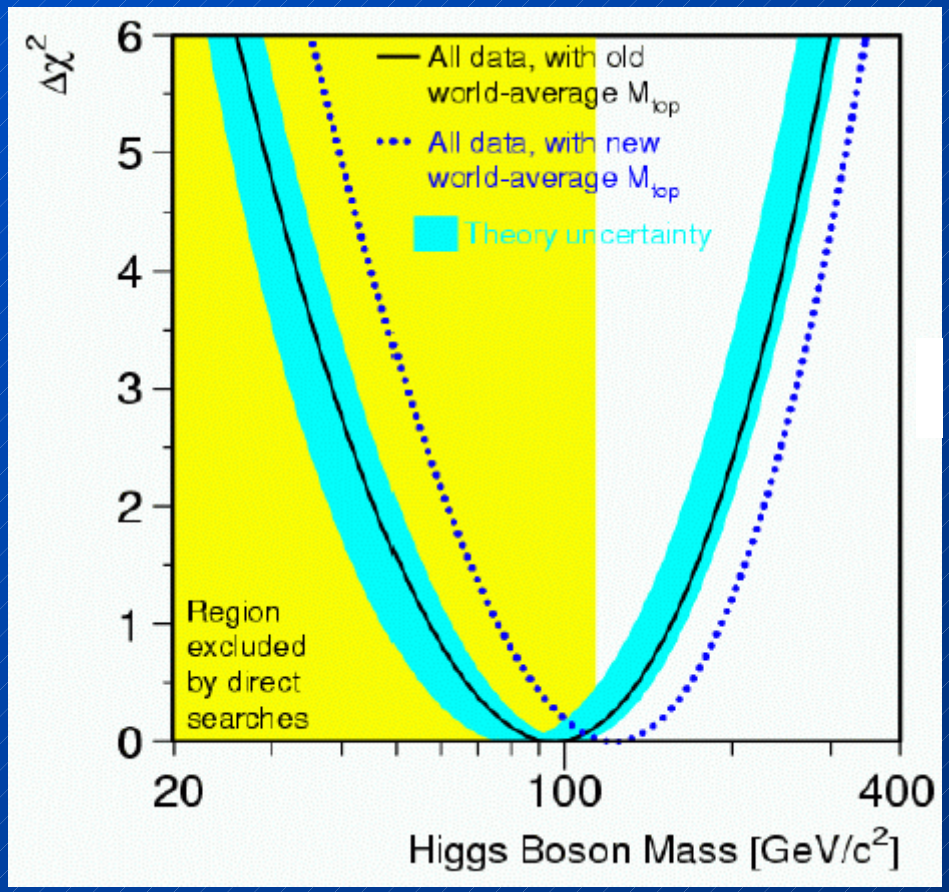


single most precise measurement

$$\log M_H = 2.07^{+0.20}_{-0.21}$$

$$M_H = 117^{+67}_{-45}\ \text{GeV}$$

$$< 251\ \text{GeV (95\% CL)}$$



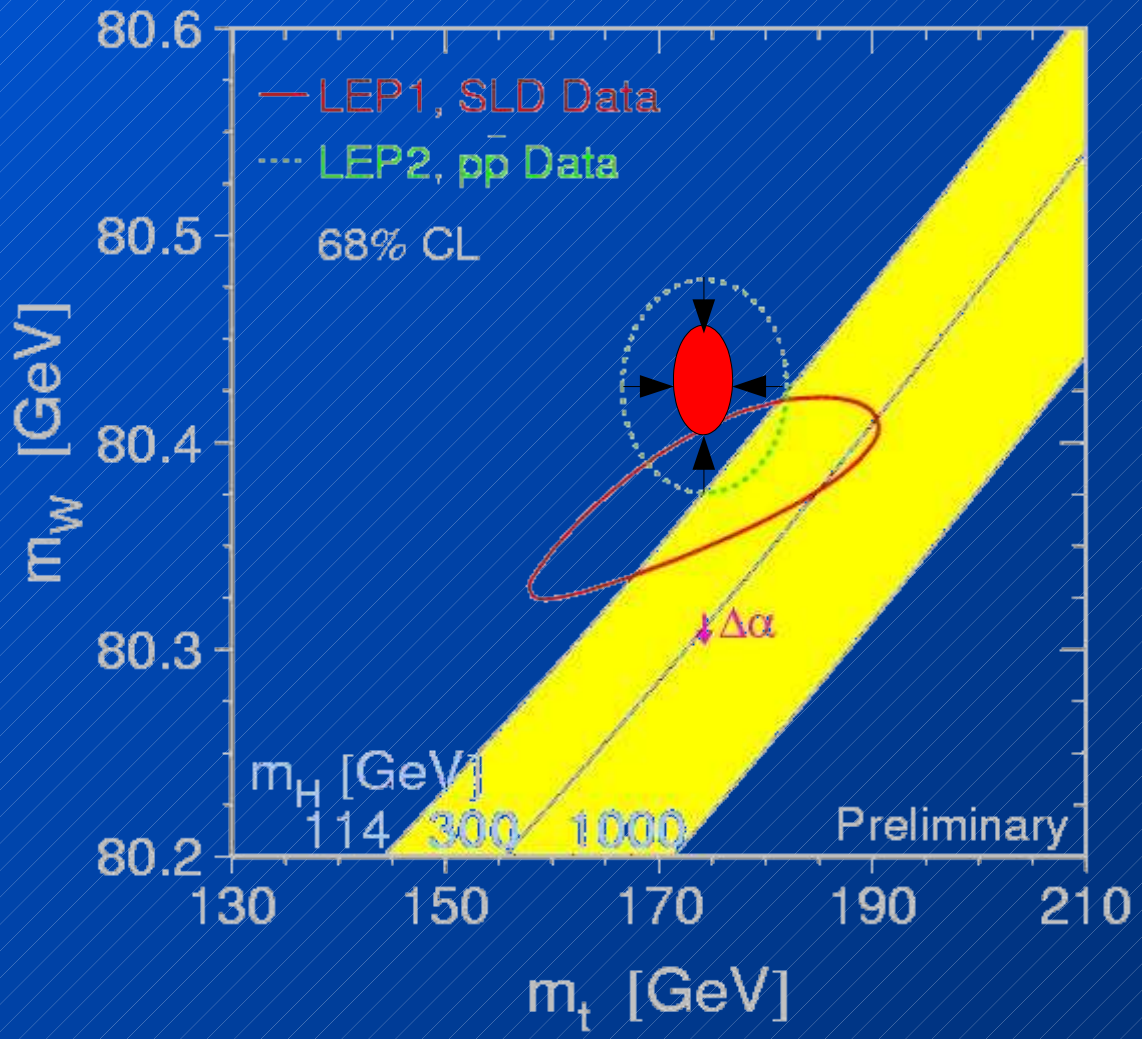
new world average

(TeV EW/TOP working group, 1.April'04):

$178.0 \pm 4.3\ \text{GeV/c}^2$

Summary : Electroweak-Top-Higgs

- A wealth of data being analyzed
- Numerous cross section and properties studies in W/Z, top and Higgs being pursued, many unique and cutting edge
- Precision already better than in Run I
- Getting ready for large luminosity ...



goal for Tevatron in Run II:

Δm_{top} = 2 GeV

Δm_W = 20 MeV

Higgs discovery