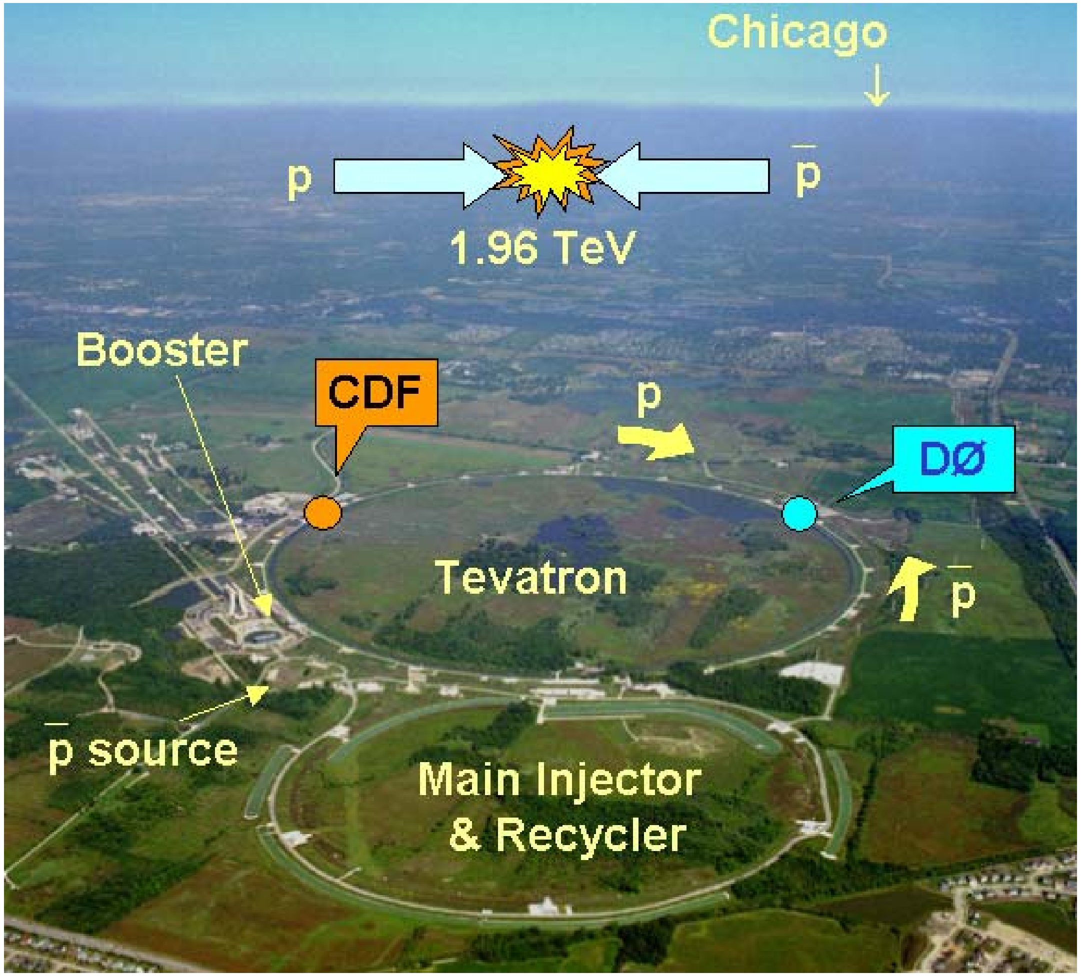
Results for Top and Higgs at Tevatron

Outline

- Tevatron
- CDF and DØ
- Top quark studies
- Search for Higgs
- Summary



ICHEP 2004, August 16-22, Beijing China

Dmitri Denisov, Fermilab

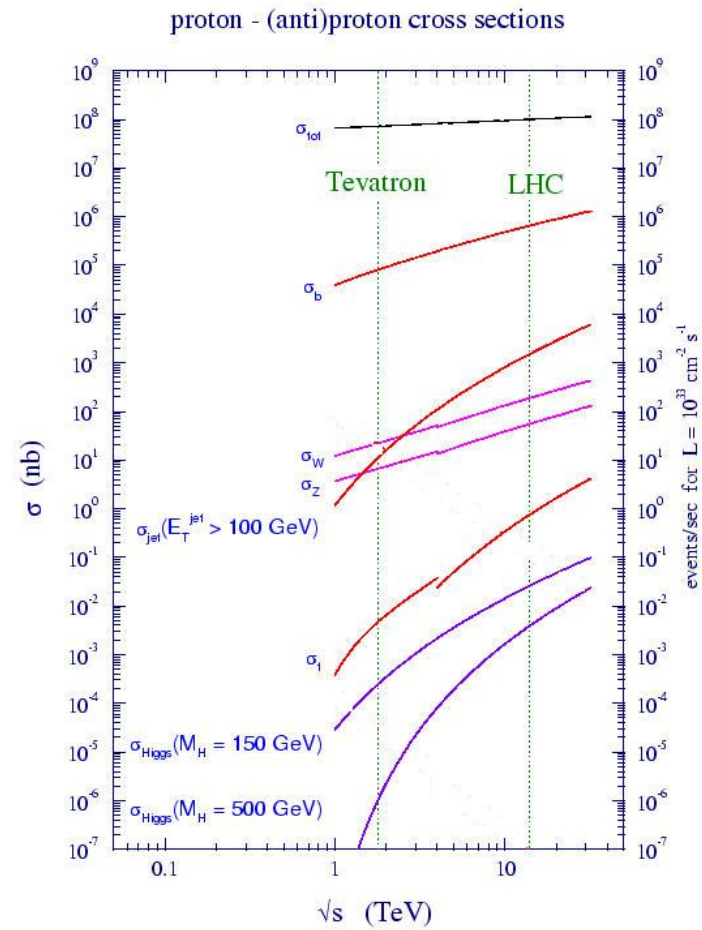
Top Quark Studies and Higgs Searches

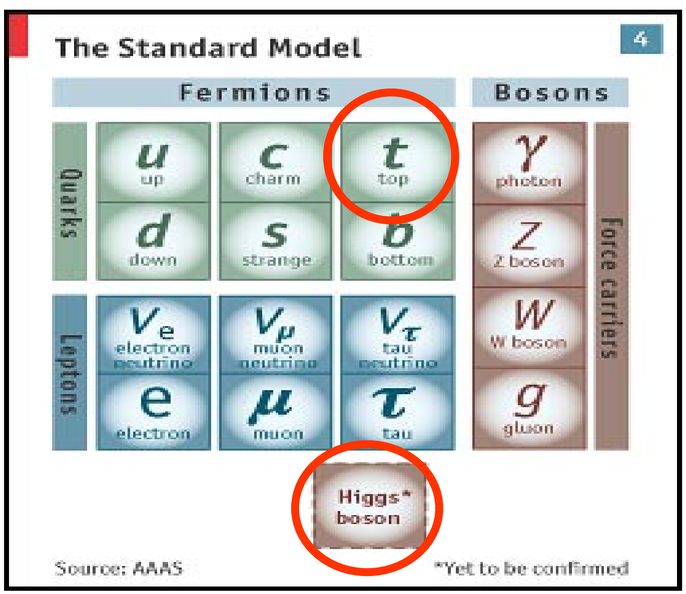
Discovery of top quark at Fermilab in 1995
- Completed SM Quark Sector

Studies of heaviest known elementary particle
- SM parameters/tests
- Beyond SM searches

Higgs is last missing particle in SM
- Describes EWSM – particle masses

Experimental challenges: low cross sections and backgrounds
- Accelerator
- Detectors
- Analysis





Tevatron currently is the only accelerator able to produce such heavy particles

Tevatron Parameters

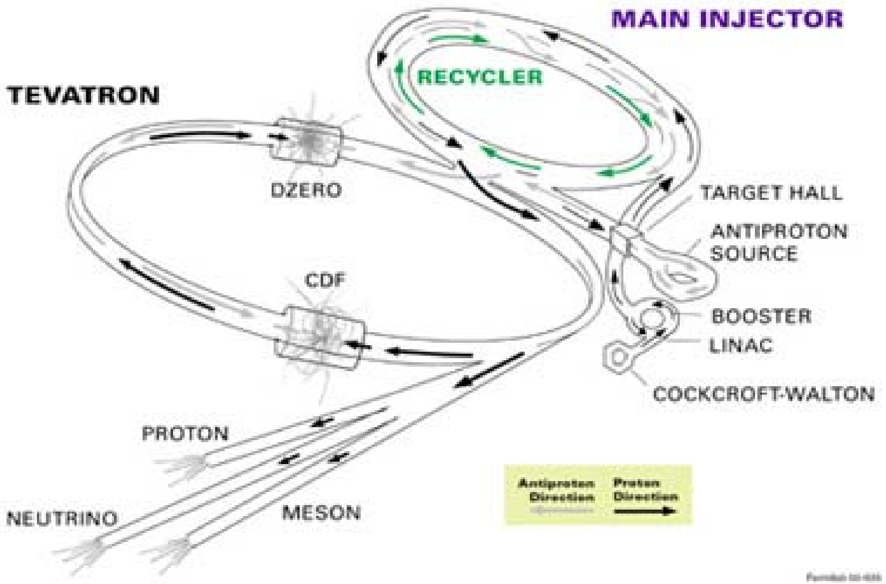
Substantial upgrades for Run II 2001-…

10% Energy increase → 30% higher σ_{top}

Integrated luminosity increase: x40

Major challenge is making antiprotons

FERMILAB'S ACCELERATOR CHAIN

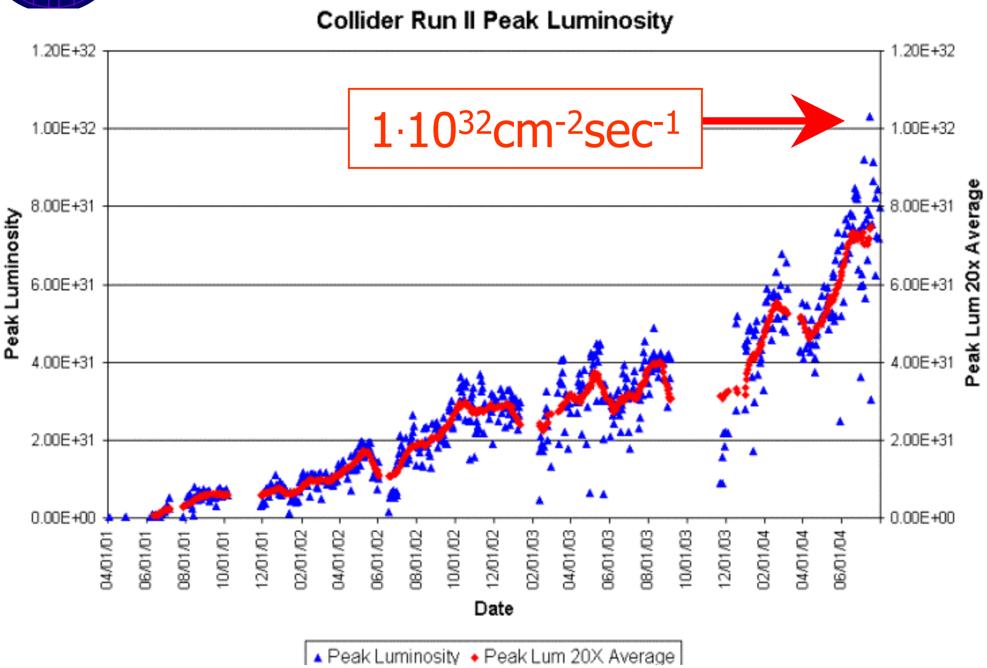


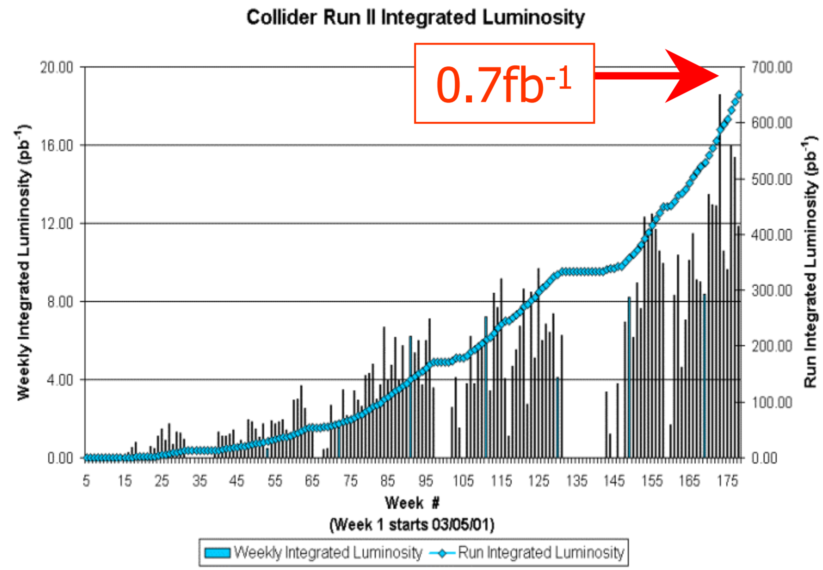
	Run I	Run IIa	Run IIb
Bunches in Turn	6 × 6	36 × 36	36 ×36
√s (TeV)	1.8	1.96	1.96
Typical L ($cm^{-2}s^{-1}$)	1.6 ×10^{30}	9 ×10^{31}	3 ×10^{32}
∫ Ldt (pb^{-1}/week)	3.2	17.3	50
Bunch crossing (ns)	3500	396	396
Interactions/ crossing	2.5	2.3	8

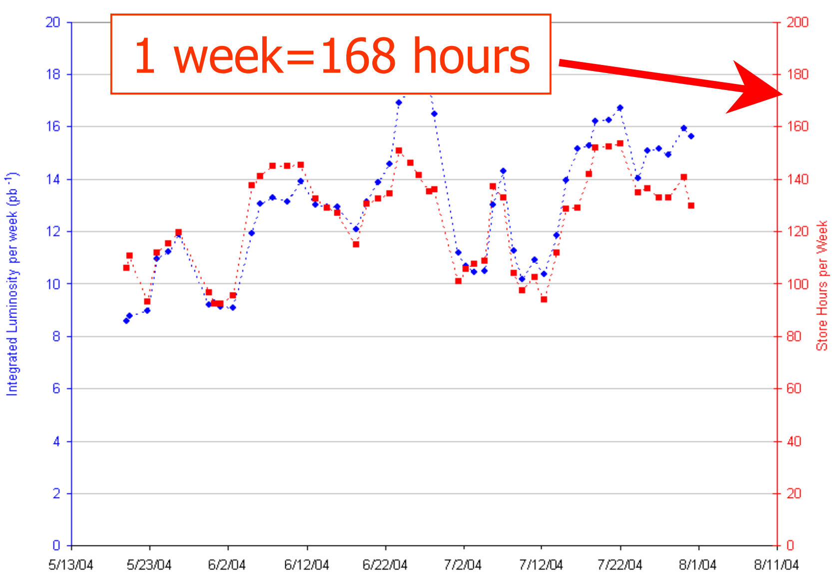
Run I → Run IIa → Run IIb
0.1 fb^{-1}

6 km Tevatron Ring

Tevatron Run II Performance







Tevatron delivering luminosity as planned

Peak luminosity above $1 \cdot 10^{32} cm^{-2} sec^{-1}$!

Reliable operation
→ in stores ~120hours/week

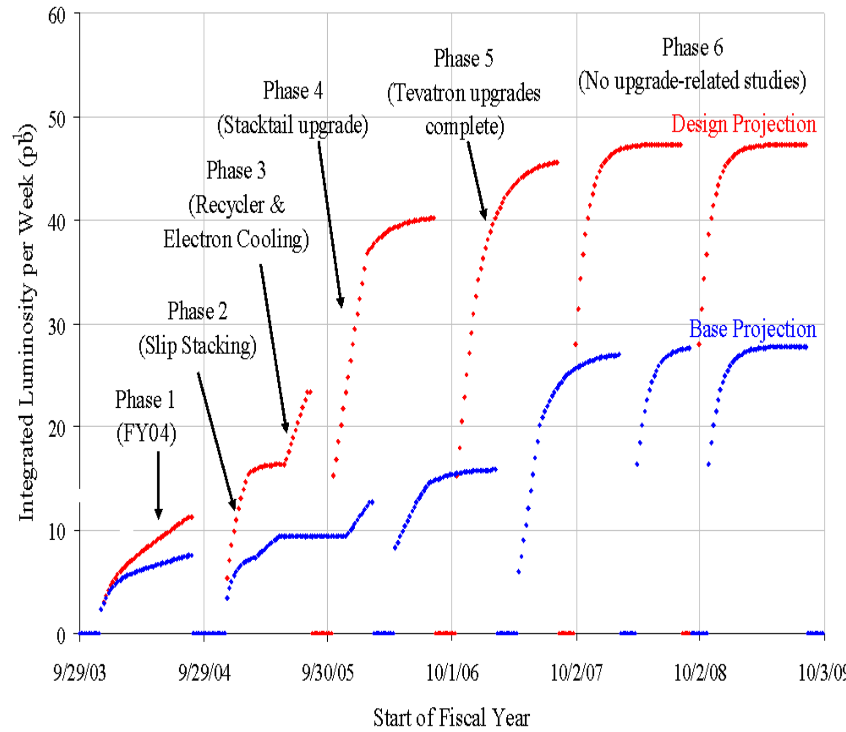
Total ~$0.7 fb^{-1}$ delivered in Run II

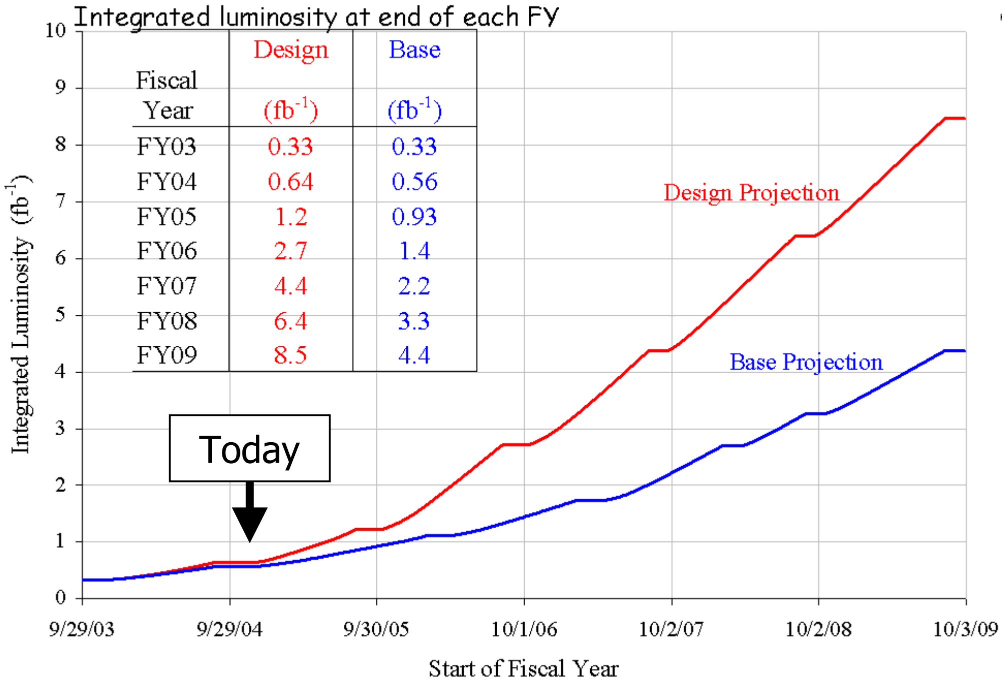
Tevatron Long Term Luminosity Plan

To reach higher masses with the same energy
→ more collisions

Increase in number of antiprotons
→ the key for higher luminosity

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



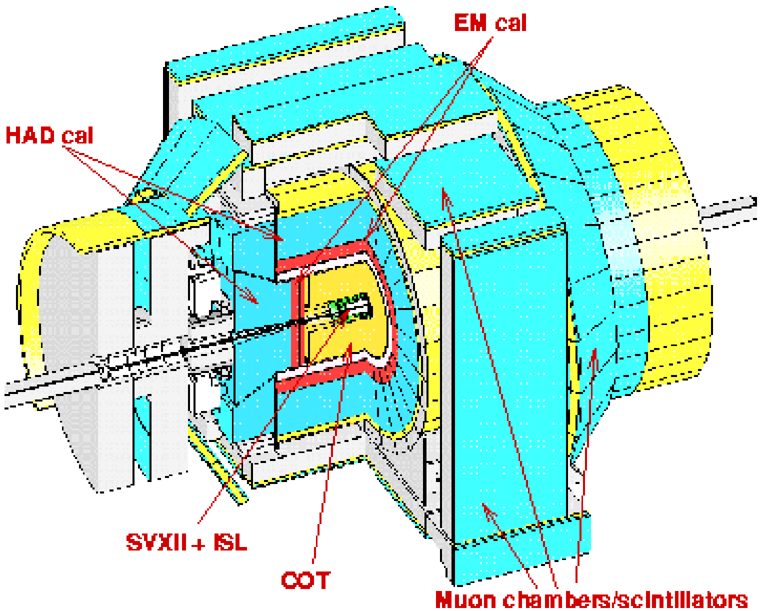


Fiscal Year	Design (fb^{-1})	Base (fb^{-1})
FY03	0.33	0.33
FY04	0.64	0.56
FY05	1.2	0.93
FY06	2.7	1.4
FY07	4.4	2.2
FY08	6.4	3.3
FY09	8.5	4.4

Currently expecting delivered luminosity to each experiment
→ 4-8 fb^{-1}
by end of 2009

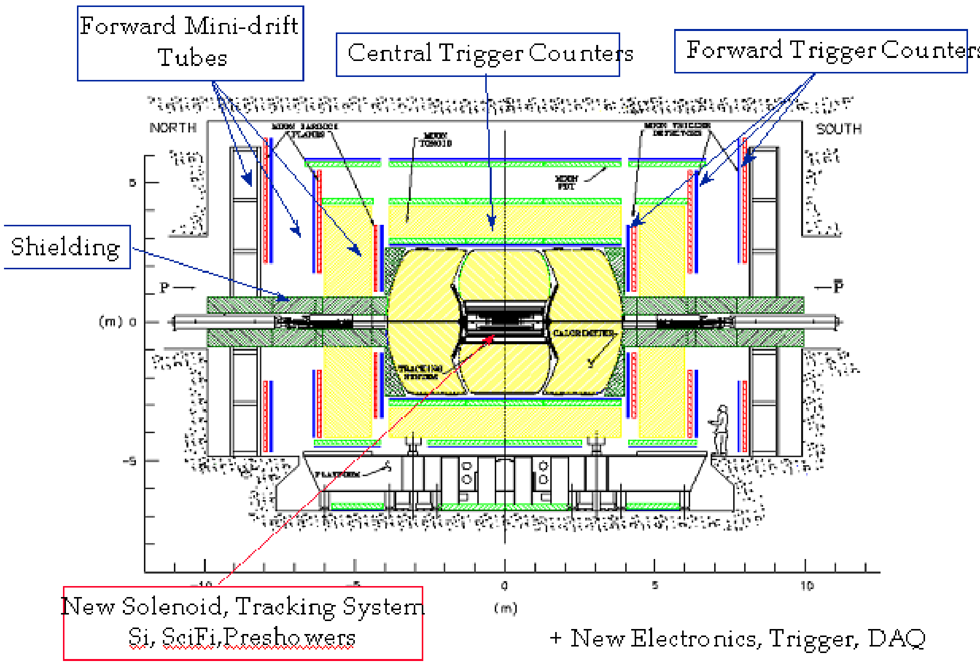
CDF and DØ Experiments

CDF



New Silicon Detector
New Central Drift Chamber
New End Plug Calorimetry
Extended muon coverage
New electronics

DØ



Silicon Detector
2 T solenoid and fiber tracker
Substantially upgraded muon system
New electronics

Driven by physics goals detectors are becoming “similar”:
silicon, central magnetic field, hermetic calorimetry and muon systems

Experimental Challenges

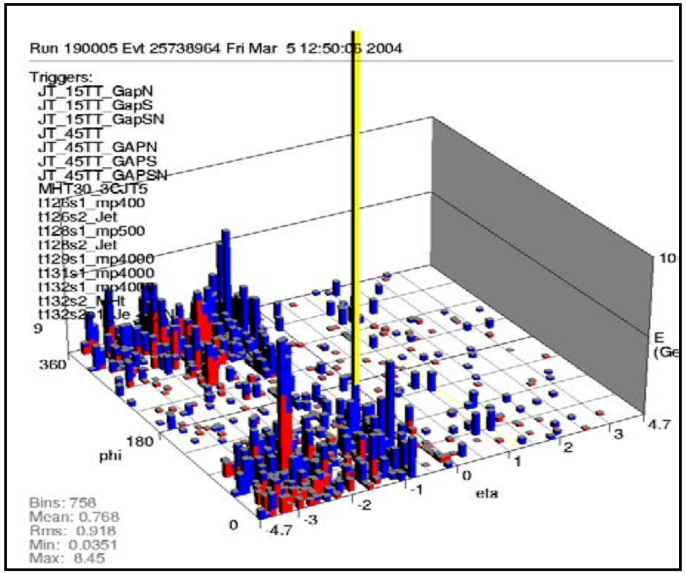
Collecting data at energy and luminosity frontiers is non-trivial

Large particle fluxes → irradiation issues

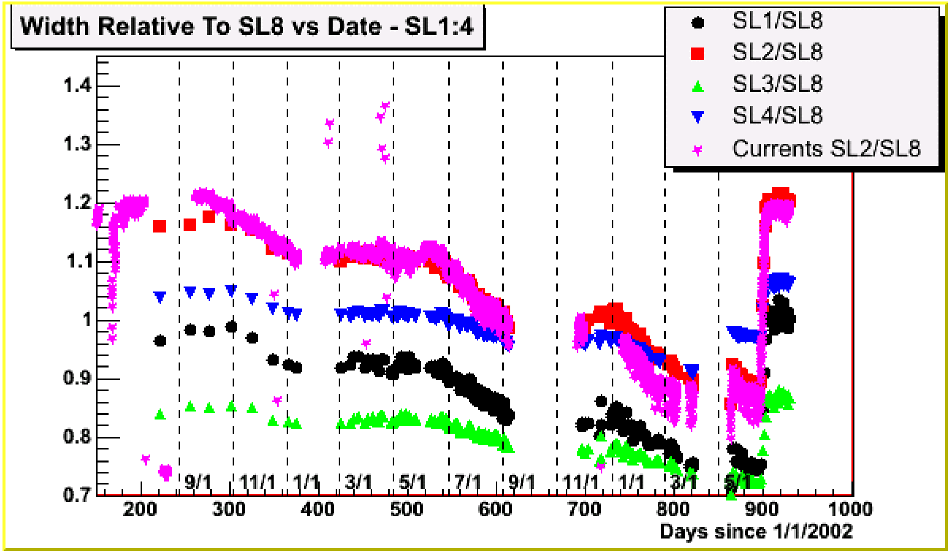
Small bunch spacing and large number of interactions per crossing
- Event synhronization
- Complex event topology

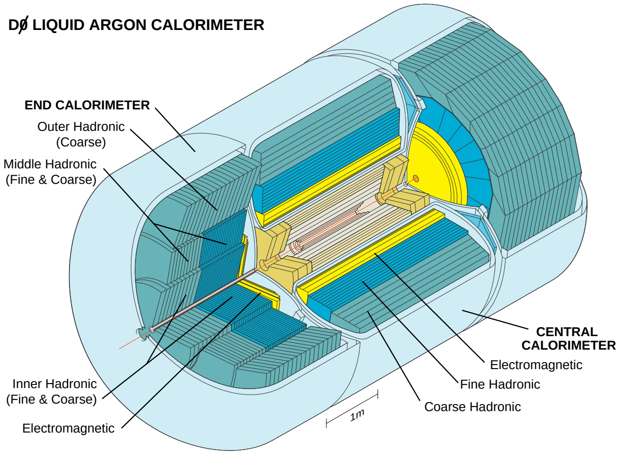
Unexpected…

Not new physics, just welding induced noise → resolved



CDF central tracking chamber → aging resolved





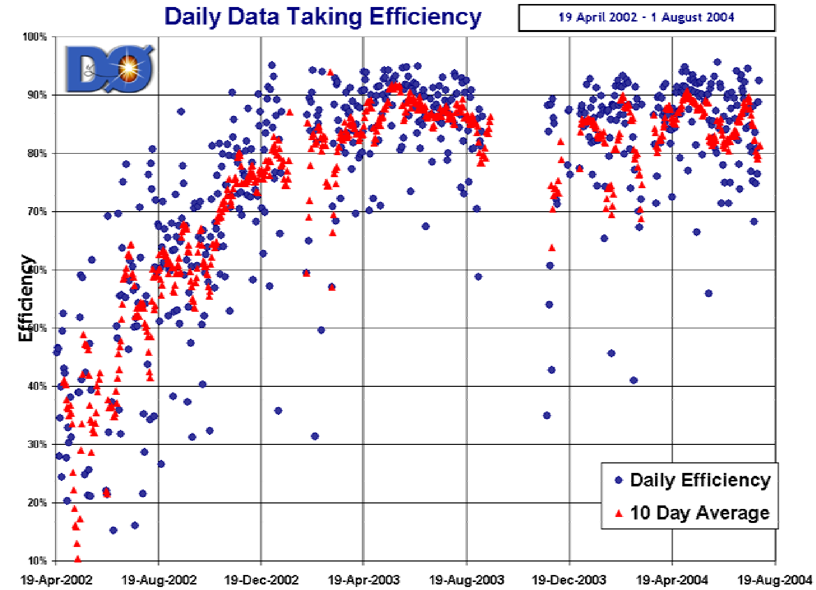
Data Collection by Experiments

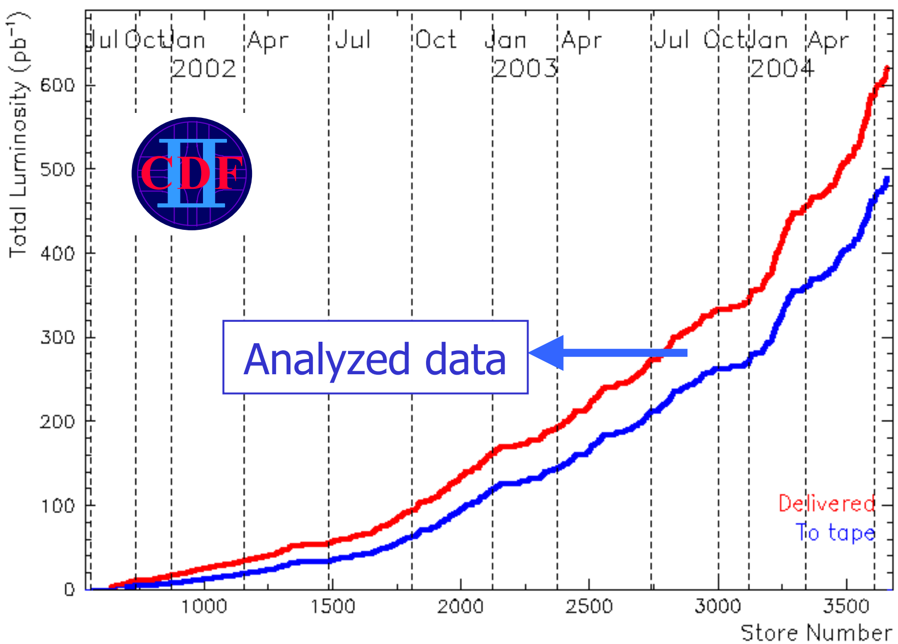
Both experiments are very complex

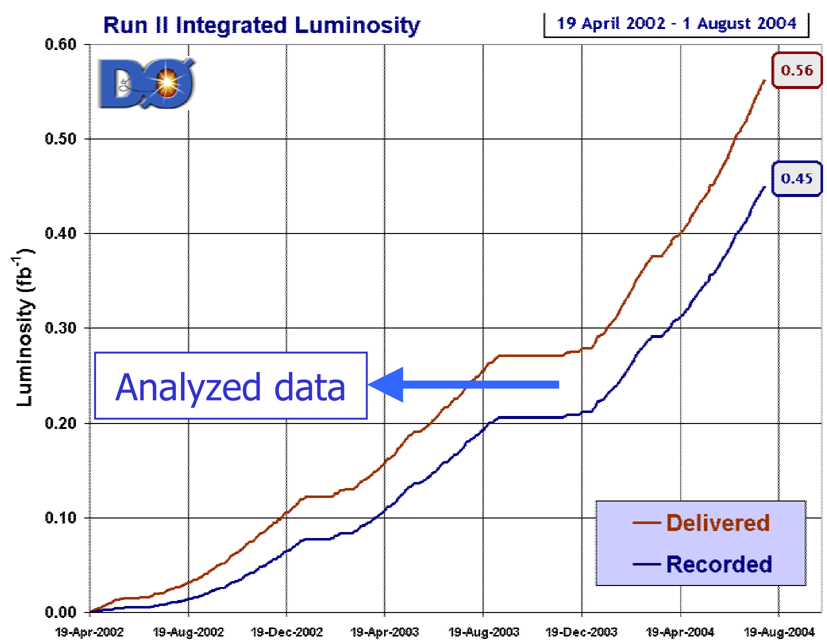
Typical ratio of “recorded” to “delivered” luminosity is 80%-90%

As of now both experiments collected ~0.5 pb^{-1}

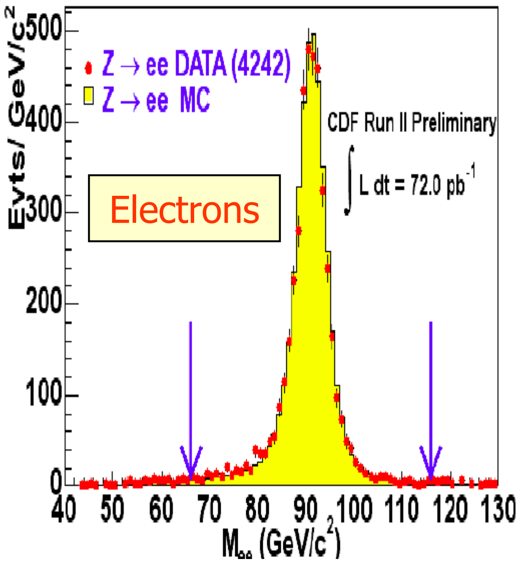
Results presented correspond to ~0.2 pb^{-1}

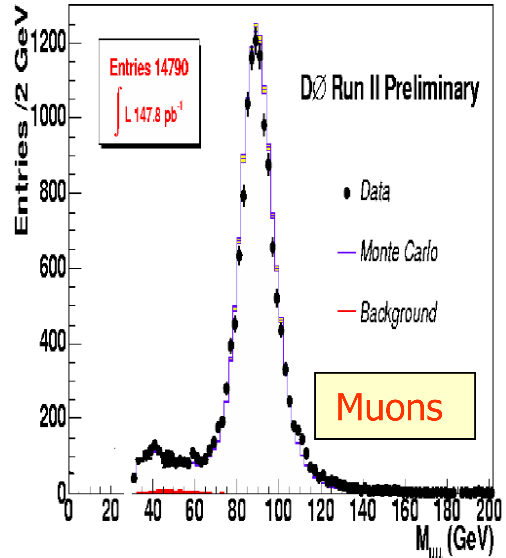


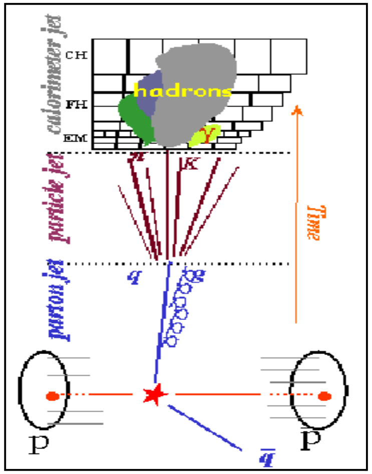


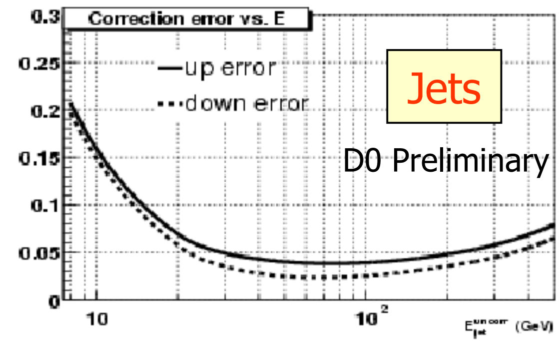


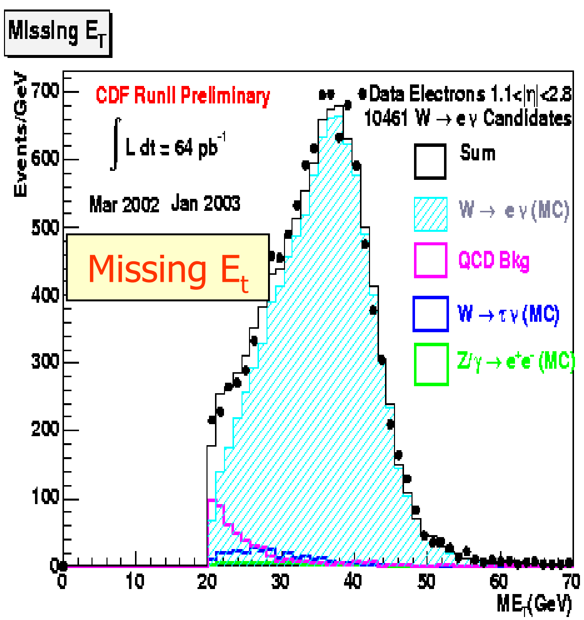
Detection of High P_t Objects











Top and Higgs final decay products

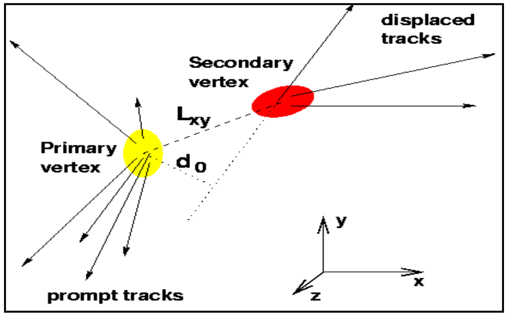
→ **electrons**

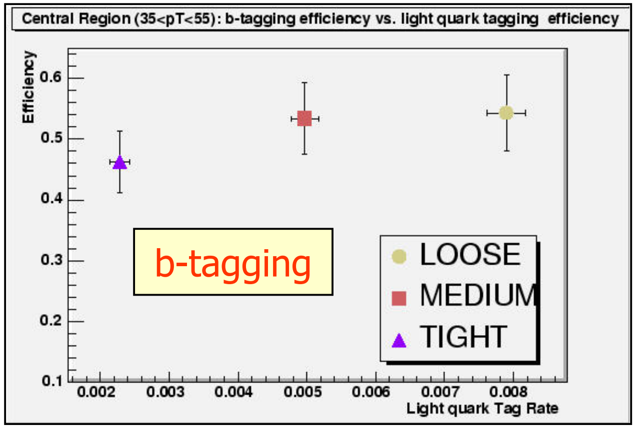
→ **muons**

→ **jets (b)**

→ **missing E_t (ν)**

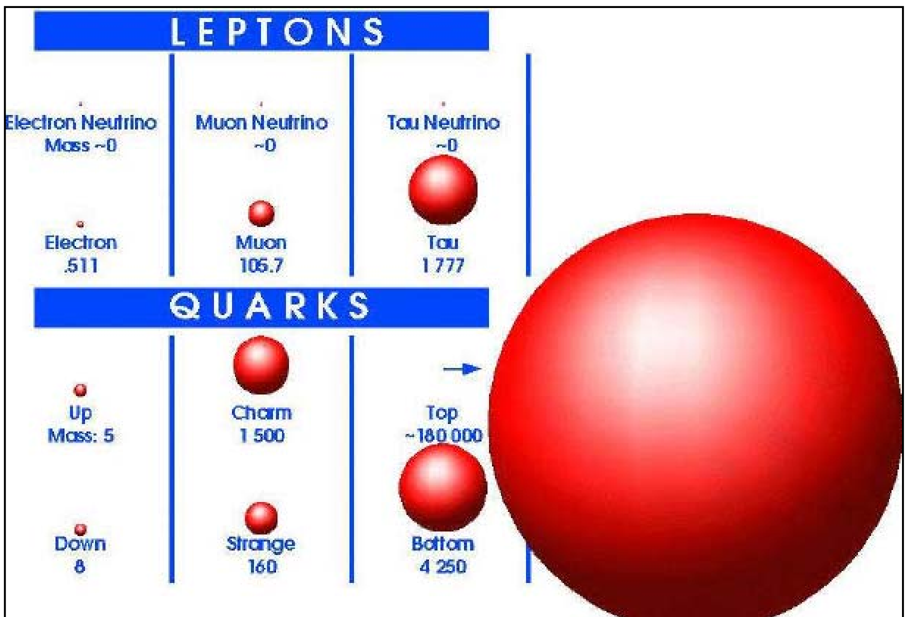
Detection and MC optimization using well known objects

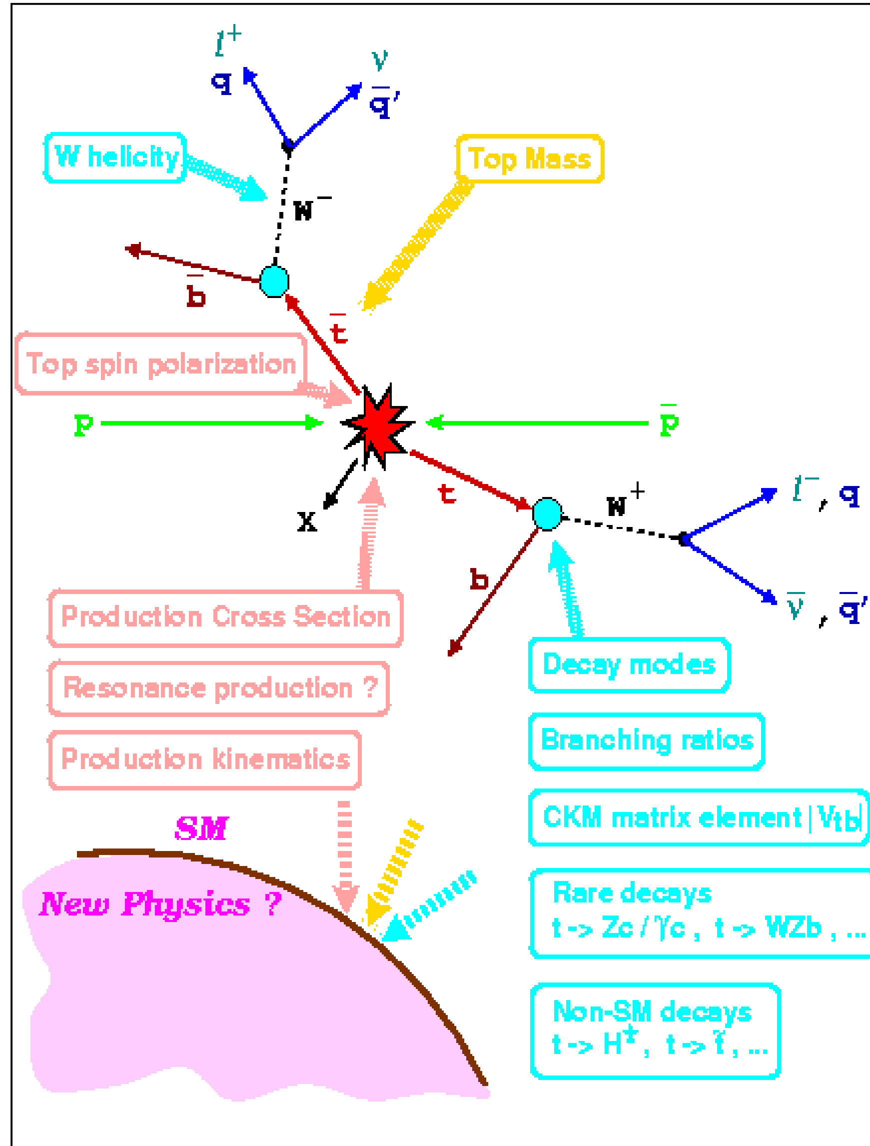




Top Quark Studies

- Heaviest known elementary particle
  - → ~180 GeV
  - → discovered at Fermilab in 1995
- Measure properties of least known quark
- Short life time → probe bare quark
- Sensitive to new physics
- Important for SM Higgs mass limit
- ….

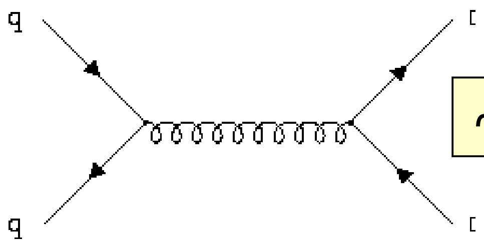




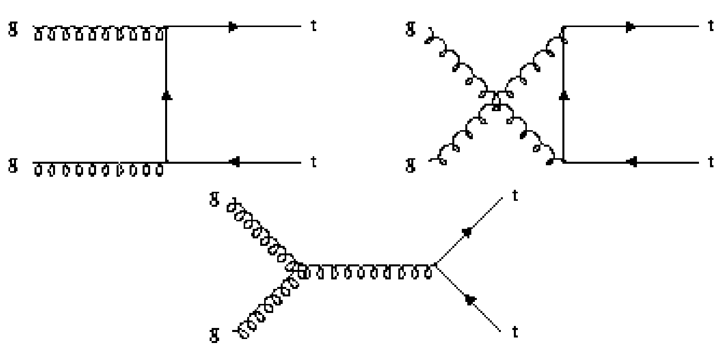
Top Quark Production and Decays

Production

Top quarks at Tevatron are (mainly) produced in pairs via strong interaction



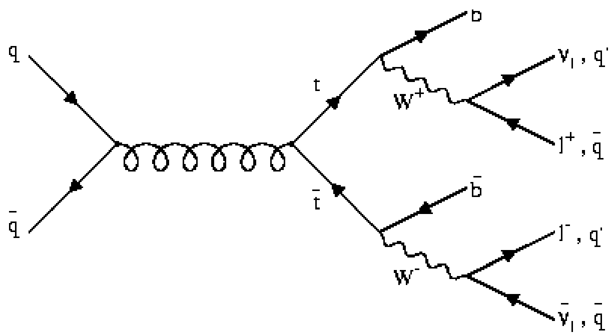
~85%



Top pair cross section at 1.96 TeV is 6.7 pb^{-1}
Many Run II Measurements

Decay

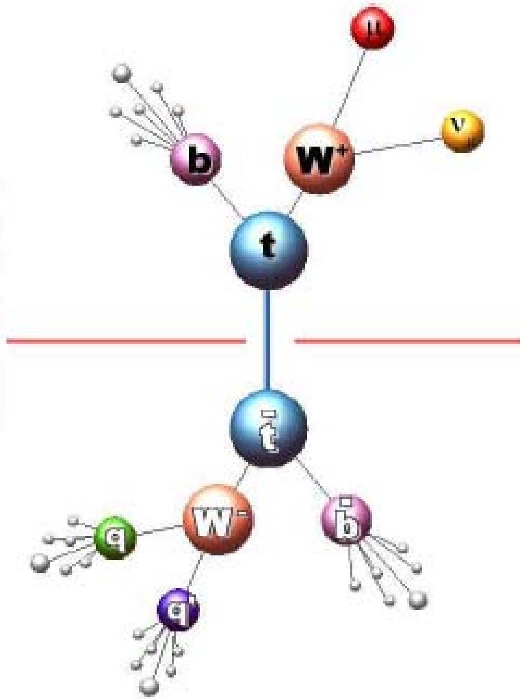
In SM top decays 100% to Wb
Classification of top decays
is based on Ws decays

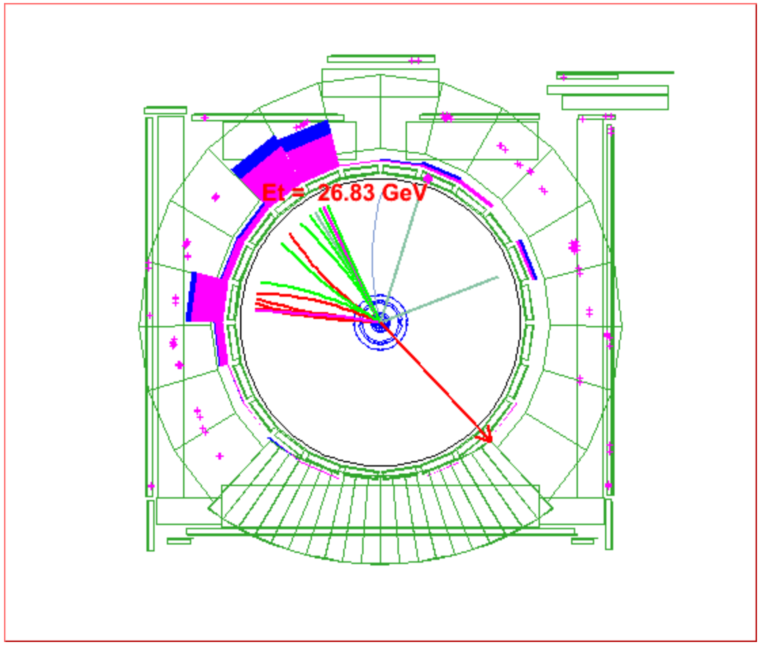


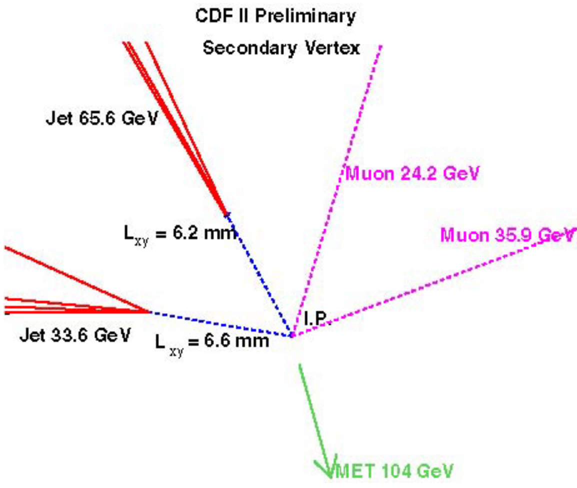
%	$e\nu$	$\mu\nu$	$\tau\nu$	*qq*
$e\nu$	1.2	2.5	2.5	14.8
$\mu\nu$		1.2	2.5	14.8
$\tau\nu$			1.2	14.8
qq				44.4

Top decays classification: di-lepton, lepton+jets, all jets

Selection of Top Quark Events







In triggering and analysis select events with

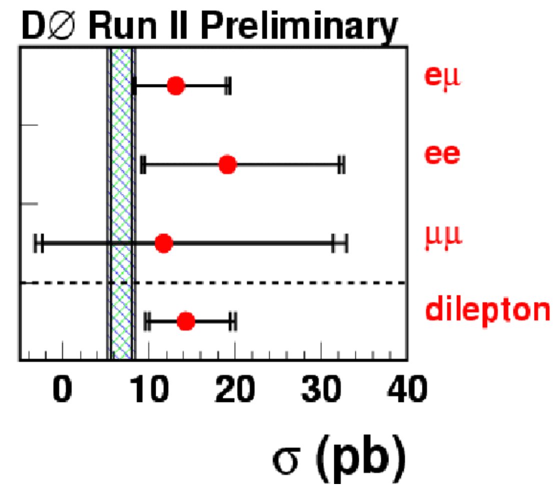
→ high P_t leptons
→ high E_t multiple jets
→ large missing E_t (ν)
→ displaced vertex for b jets

"Di-lepton" is golden mode
→ low backgrounds (di-bosons, Drell-Yan, ...)
→ low statistics (~6% for e, μ decays)
"Lepton+jets" very productive mode
→ ~5 times more events
→ main background W+jets
→ good purity after b tagging
" All jets"
→ ~50% branching
→ high QCD backgrounds, jets combinatoric

DØ Top Cross Section in di-lepton Channel

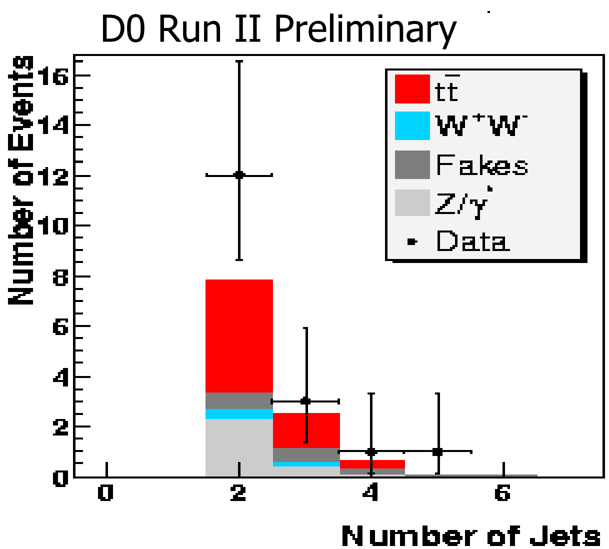
Golden mode signature (topological selection)
→ isolated (not in jet) high P_t ee(156 pb^{-1}), $\mu\mu$(140 pb^{-1}), eμ(143 pb^{-1}) pair
→ 2 or more jets
→ large missing E_t
Backgrounds: WW, Z+jets, W+jets, QCD jets, fakes

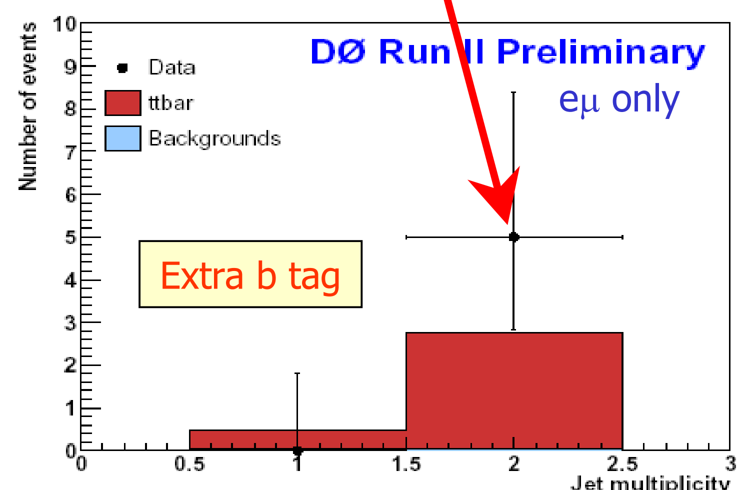
Category	ee	$\mu\mu$	$e\mu$	$\ell\ell$
Z/γ^*	0.15 ± 0.10	2.04 ± 0.49	0.47 ± 0.17	2.66 ± 0.53
WW	0.14 ± 0.08	0.10 ± 0.04	0.29 ± 0.06	0.53 ± 0.11
Fakes	0.91 ± 0.30	0.46 ± 0.20	0.19 ± 0.06	1.56 ± 0.36
Total background	1.20 ± 0.33	2.61 ± 0.53	0.95 ± 0.19	4.76 ± 0.65
Expected signal	1.39 ± 0.19	0.83 ± 0.15	3.77 ± 0.44	5.99 ± 0.50
SM expectation	2.59 ± 0.38	3.44 ± 0.55	4.73 ± 0.49	10.76 ± 0.83
Selected events	5	4	8	17



$$\sigma(t\bar{t}) = 14.3^{+5.1}_{-4.3}(stat)^{+2.6}_{-1.9}(syst)\text{ pb}$$

Ultra-pure sample of top events: S/N>50



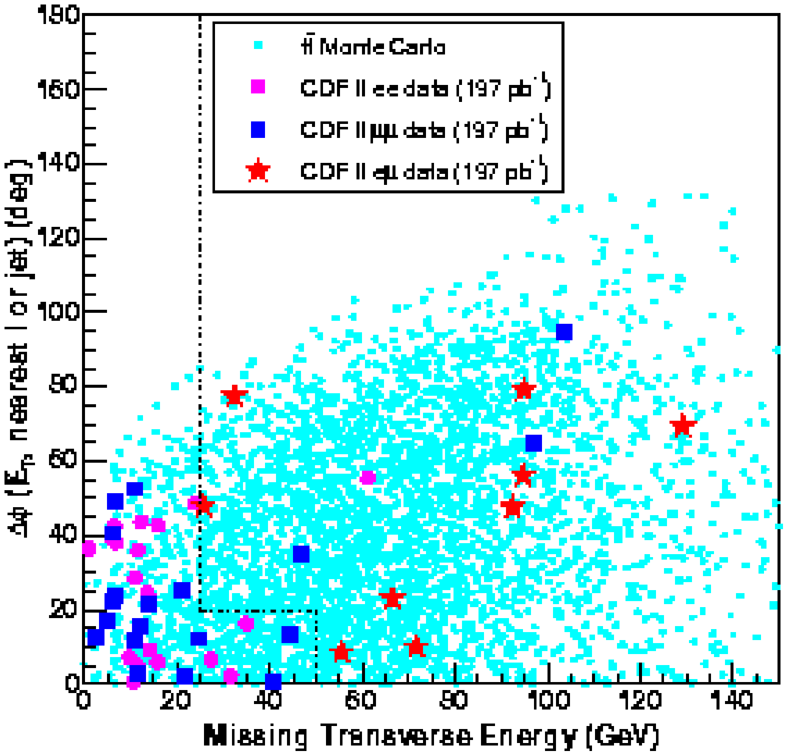


$$\sigma(t\bar{t}) = 11.1^{+5.8}_{-4.3}(stat)^{+1.4}_{-1.4}(syst)\text{ pb}$$

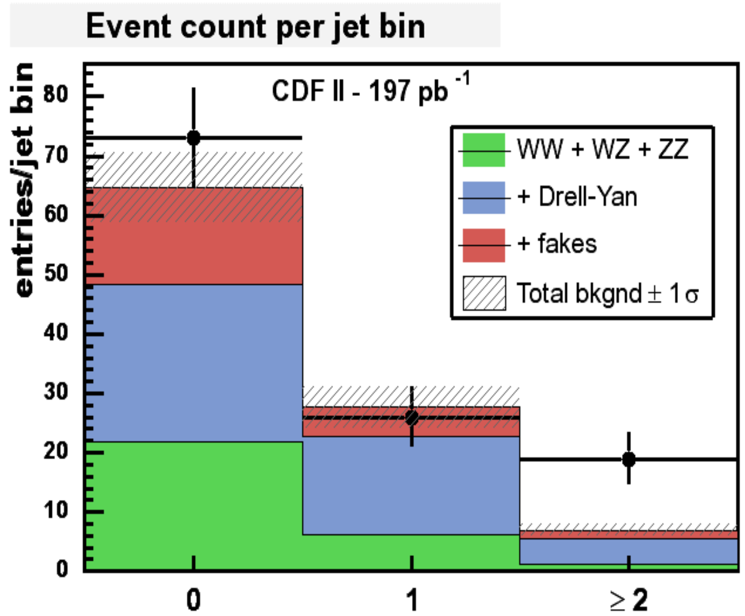
CDF Top Cross Section in di-lepton Channel

197 pb^{-1} data sample for all channels

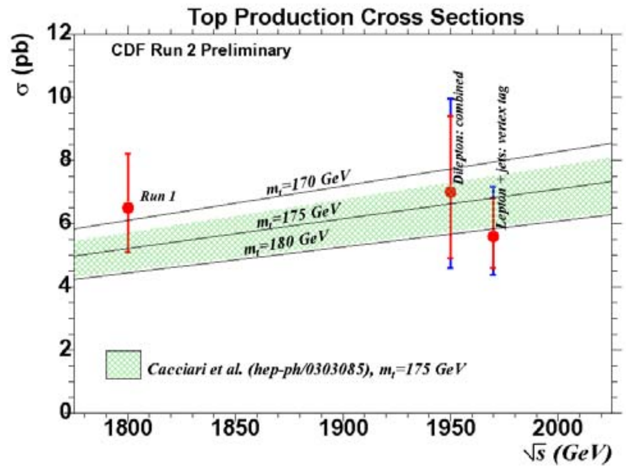
Combine ee, μμ and eμ channels for best precision



Accepted by PRL

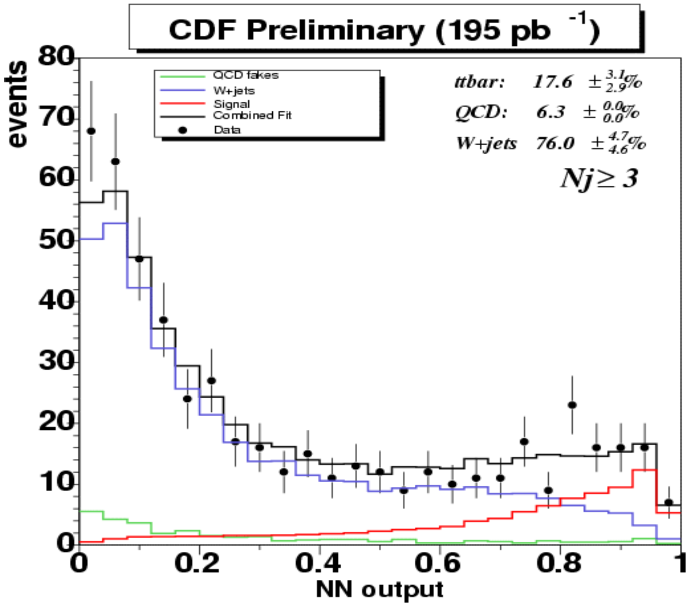


$$\sigma_{t\bar{t}} = 7.0^{+2.4}_{-2.1}(\text{stat.})^{+1.6}_{-1.1}(\text{syst.}) \pm 0.4(\text{lum.})$$



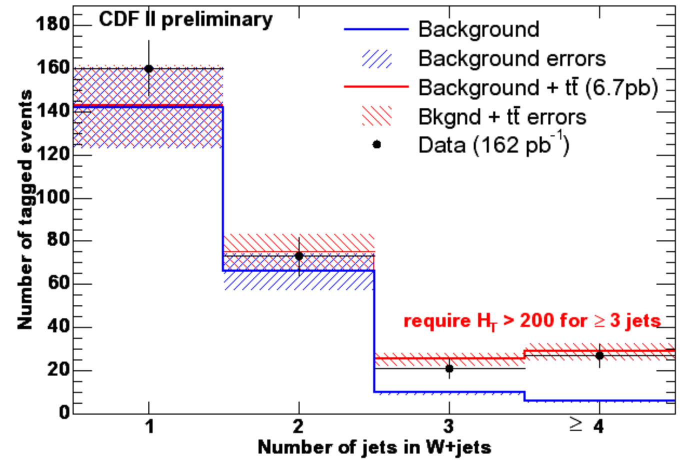
CDF Top Cross Section in lepton+jets Channel

l+jets topological



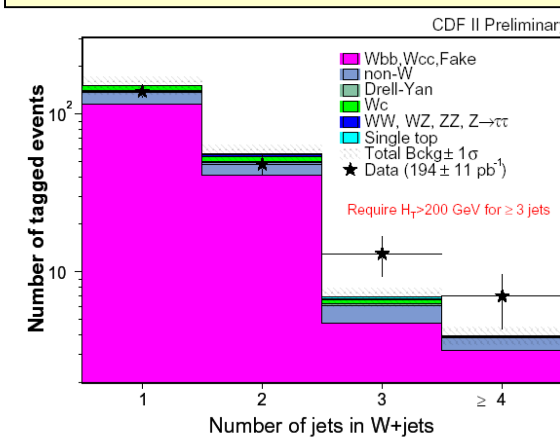
$$\sigma(t\bar{t}) = 6.7^{+1.1}_{-1.1}(stat)^{+1.6}_{-1.6}(syst)\ \text{pb}$$

l+jets with vertex b tagging



$$\sigma(t\bar{t}) = 5.6^{+1.2}_{-1.0}(stat)^{+1.0}_{-0.7}(syst)\ \text{pb}$$

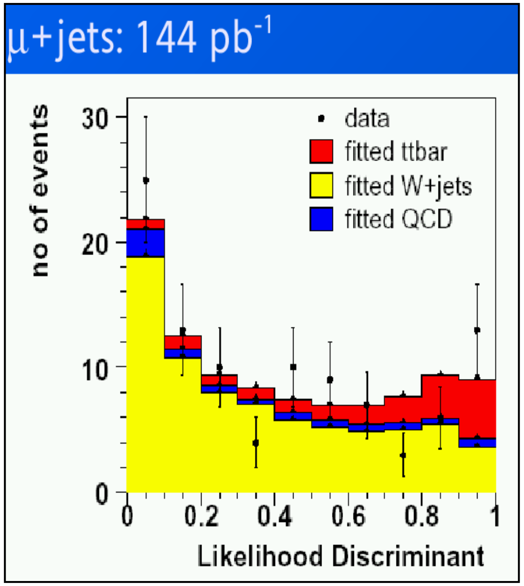
l+jets with soft lepton tagging

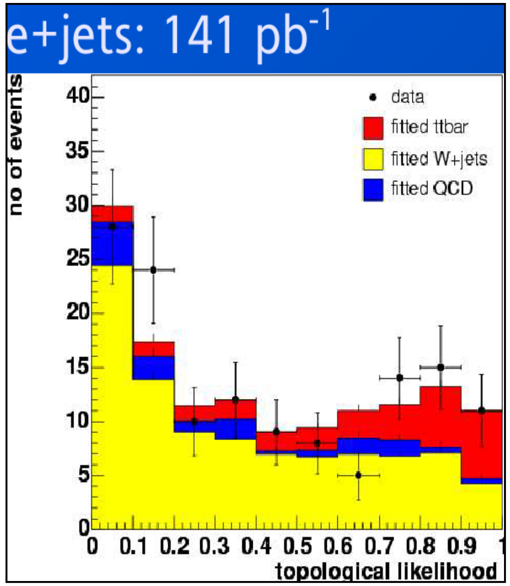


$$\sigma(t\bar{t}) = 4.2^{+2.9}_{-1.9}(stat)^{+1.4}_{-1.4}(syst)\ \text{pb}$$

Exploit different strategies
→ higher statistics – topological
→ b-jets tagging
→ displaced vertex
→ soft lepton (μ)

DØ Top Cross Section in lepton+jets Channel

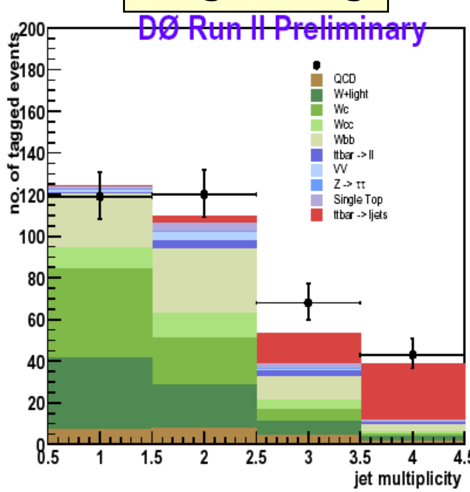




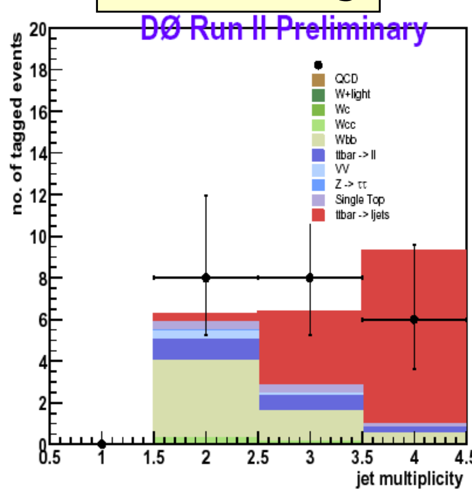
Selection of events
→ high P_t lepton
→ large missing E_t
→ 4 or more jets (no b tagging)
Pre-selection removes all but W+jets events
Form topological discriminant to optimize top events selection

$$\sigma(t\bar{t}) = 7.2^{+2.6}_{-2.4}(stat)^{+1.6}_{-1.7}(syst)\ \text{pb}$$

Single b tag



Double b tag

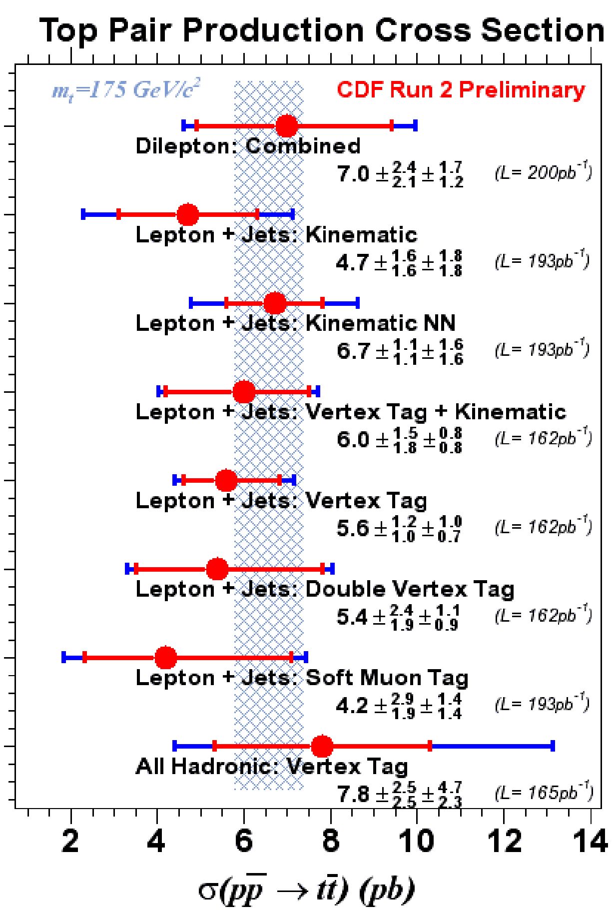


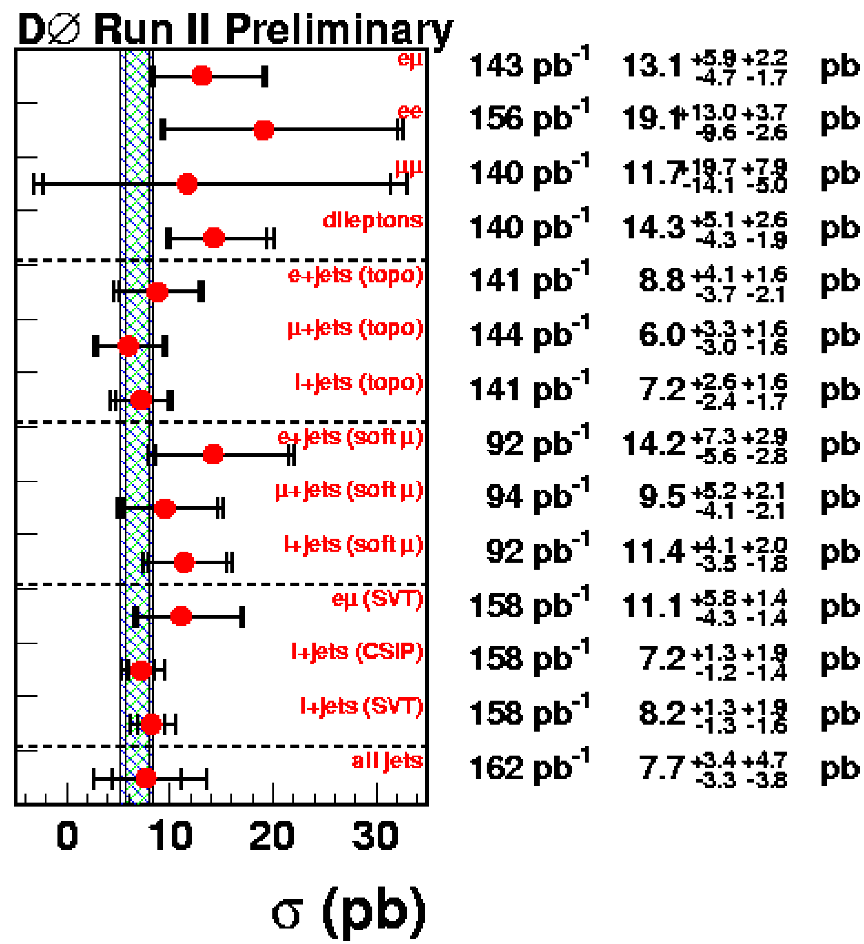
Tagging jets from b decays using displaced vertex algorithms reduces backgrounds substantially

$$\sigma(t\bar{t}) = 8.2^{+1.3}_{-1.3}(stat)^{+1.9}_{-1.6}(syst)\ \text{pb}$$

Run II Top Quark Cross Section: Summary

Errors between different channels are correlated





Measurements demonstrate success of multiple top detection techniques
Results within errors consistent with NNLO SM predictions for 1.96TeV of 6.7pb⁻¹

Top Quark Mass Measurement

Fundamental SM parameter
Top mass together with EW data constrain Higgs mass

Using Run I data l+jets events (125pb^{-1}) DØ developed "matrix element method"

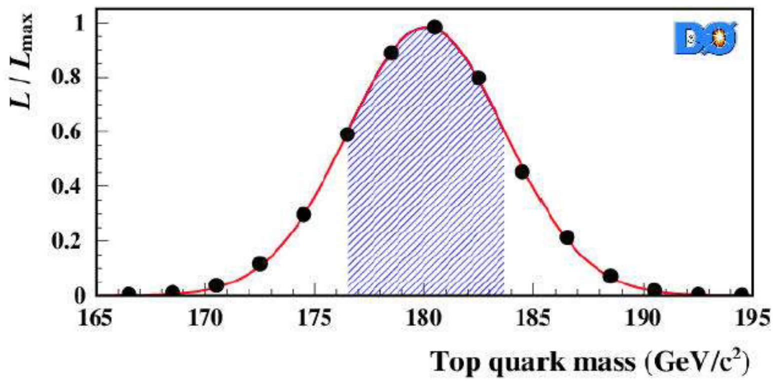
Detailed knowledge of top decays and detector response is required
→ event by event likelihood calculated vs m_t

$$P(x, m_t) = \frac{1}{\sigma(m_t)} \int d\sigma(y, m_t) dq_1 dq_2 f(q_1) f(q_2) W(x, y)$$

Phase space x LO ME

PDFs

Probability for observable x when y was produced (Ex: quark E_T → jet E_T)



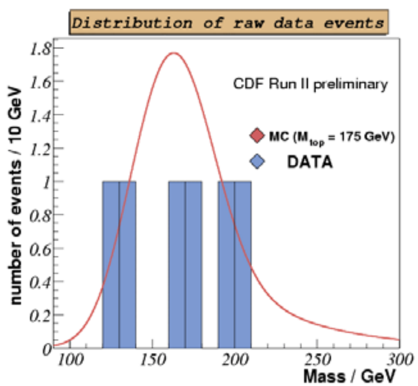
Single most precise top mass measurement
→ good detector understanding

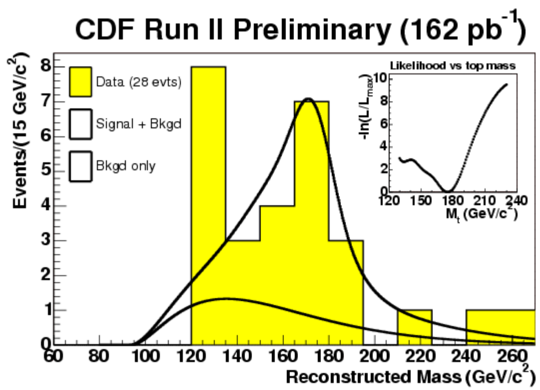
m_t = 180.1±3.6(stat)±3.9(syst) GeV

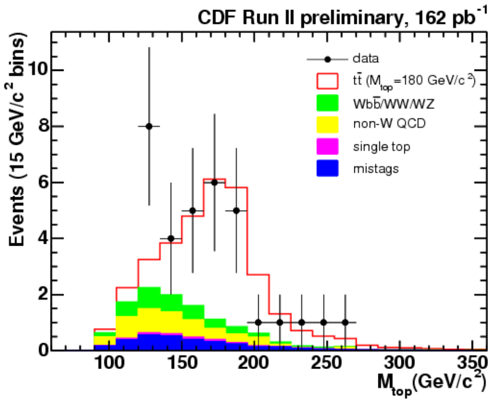
Run II Top Mass Measurement at CDF

Run I style “template” method is efficiently used

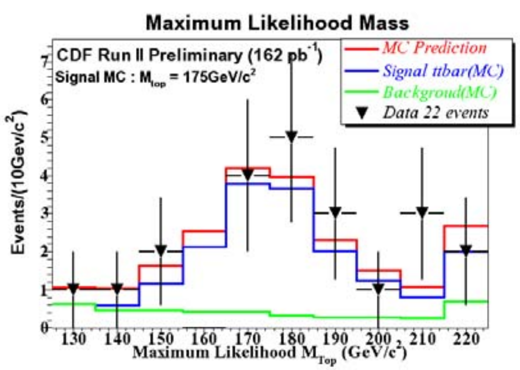
di-leptons | l+jets, b-tagged | l+jets, b-tag+jets E_t

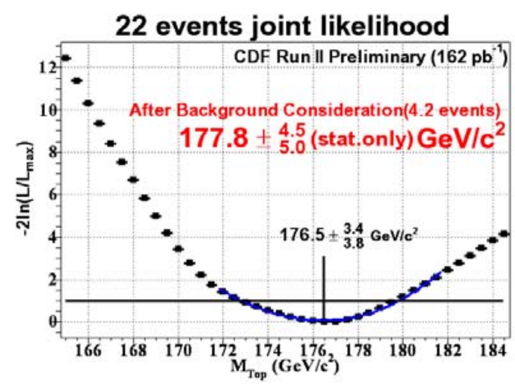






Dynamical Likelihood Method is similar to D0 “matrix element method”





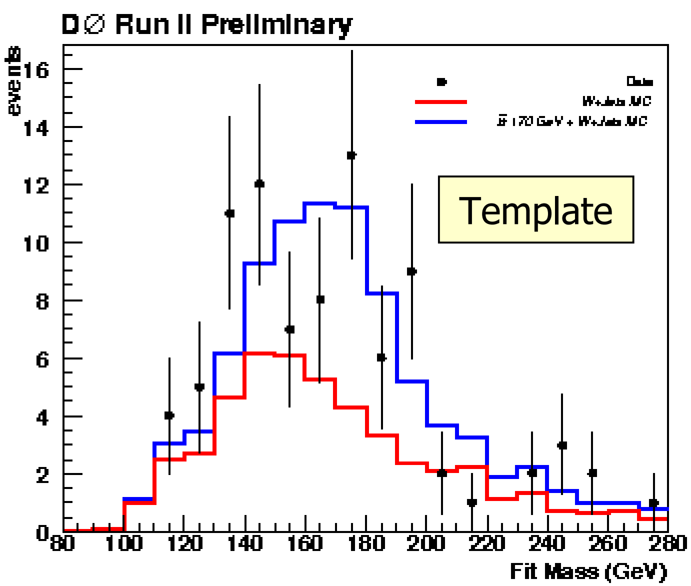
$$m_t = 177.8^{+4.5}_{-5.0}(stat) \pm 6.2(syst)\ \mathrm{GeV}/c^2$$

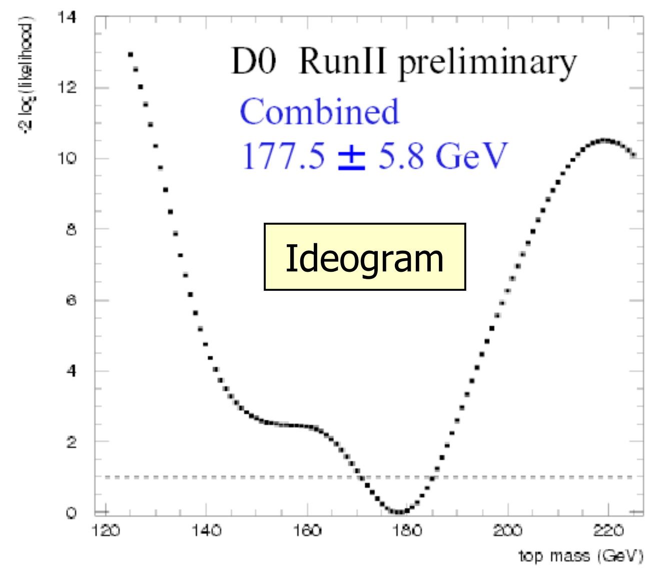
Single most precise Run II measurement

Top Quark Mass Measurement at DØ in Run II

Measurements in l+jets channel (~150 pb^{-1})

→ template method uses templates for signal and background mass spectra
→ ideogram method uses analytical likelihood for event to be signal or background for each event





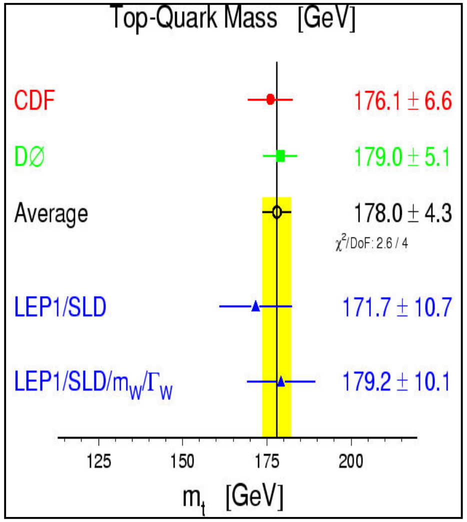
Template method m_t = 170±6.5(stat)+10.2/-5.7(syst) GeV

Ideogram method m_t = 177.5±5.8(stat)±7.1(syst) GeV

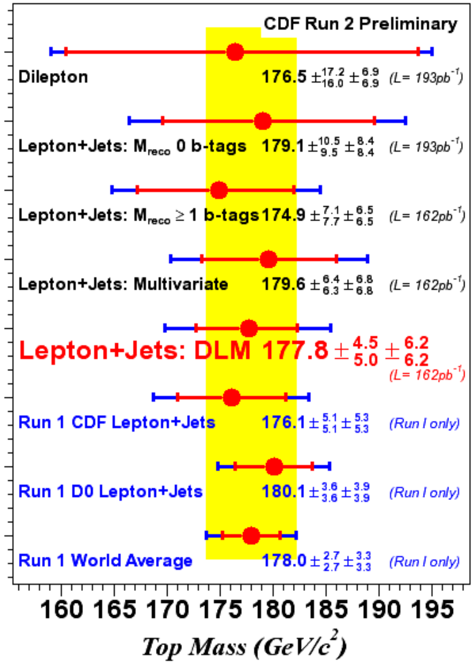
Tevatron Top Mass Measurement

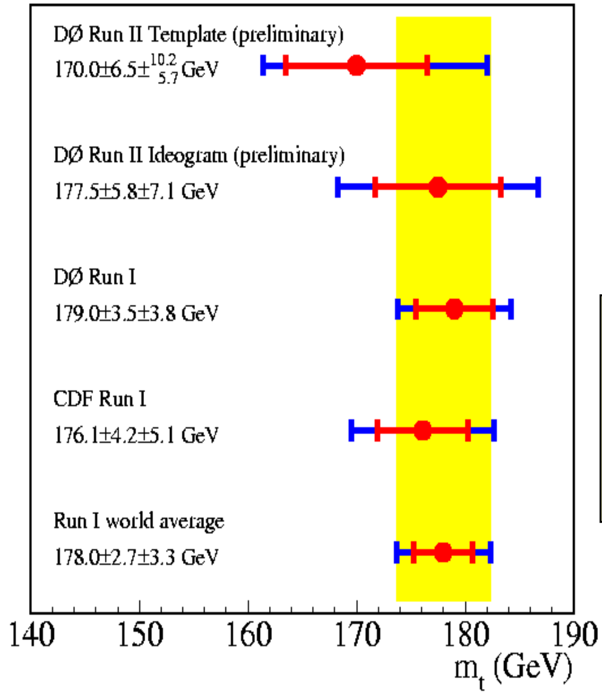
New combined Run I result →
(Was m_t = 174.3±5.1 GeV)

m_t = 178.0±4.3 GeV



Run II top quark mass results from both detectors are available



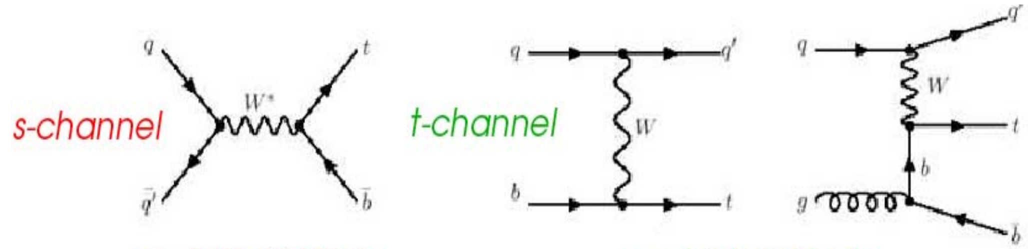


Systematic error
(mainly jet energy scale)
is becoming limiting accuracy
factor

TeV EWWG is working on combining Run II top mass measurement from CDF and DØ

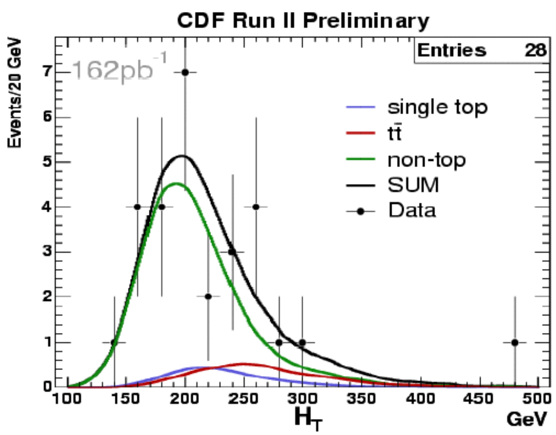
Search for Single Top Quark Production

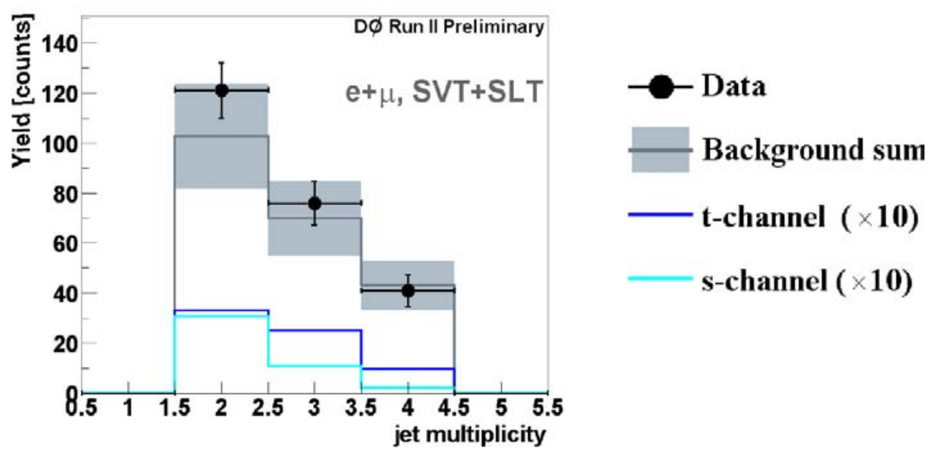
EW production of top quark
→ direct probe of $|V_{tb}|$



σ_s=0.88±0.07 pb σ_t=1.98±0.21 pb

Events selection: is similar to top pairs l+jets, but with lower jets multiplicity
-> backgrounds (W+jets, tt, dibosons…) are substantial





Need about 1 fb^{-1}
for observation

95% C.L. limits	CDF	DØ
σ (s-channel)	<13.6pb	<19pb
σ (t-channel)	<10.1pb	<25pb
σ (s+t channels)	<17.8pb	<23pb

Unexpected Top Quark Decay Modes?

Assuming three-generation CKM unitarity, $|V_{tb}|=0.999$

$R = BR(t\to Wb)/BR(t\to Wq) > 0.998$

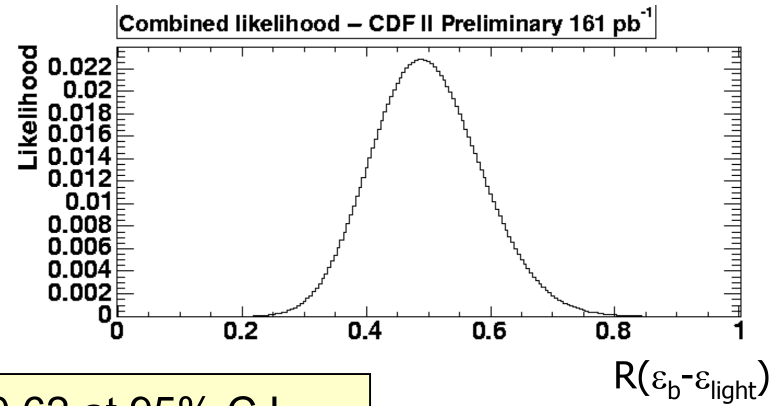
Can measure ratio by checking the b-quark content of the top sample decay products

If efficiency to tag a b-quark is ε_b (~0.45 at CDF), then

$\varepsilon_2=(b\varepsilon_b)^2$ "double-tagged"

$\varepsilon_1=2b\varepsilon_b(1-b\varepsilon_b)$ "single-tagged"

$\varepsilon_0=(1-b\varepsilon_b)^2$ "no-tag"



BR(t→Wb)/BR(t→Wq) >0.62 at 95% C.L.

Does top decays into something besides SM Wb?

→ Like Xb, where X → qq (100%) or Yb, where Y → lν (100%)?

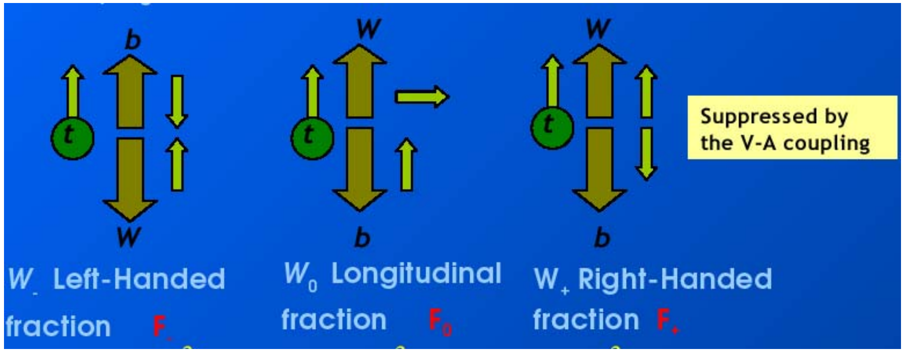
Estimate using ratio of top cross sections σ_{ll}/σ_{lj}

Br(t → Xb) <0.46 at 95% C.L. Br(t → Yb) <0.47 at 95% C.L. (CDF)

Is Top to Wb vertex SM? W Helicity

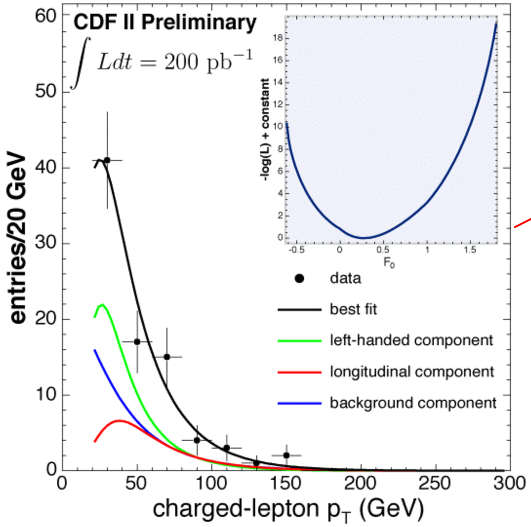
Test of V-A coupling in top decays: W couples only to LH particles

This together with angular momentum conservation allows top decays into LH (negative helicity) or longitudinally-polarized (0 helicity) W bosons



In SM F_-=0.30, F_0 =0.70, F_+ =0

Helicity of W manifests itself in decay product kinematics



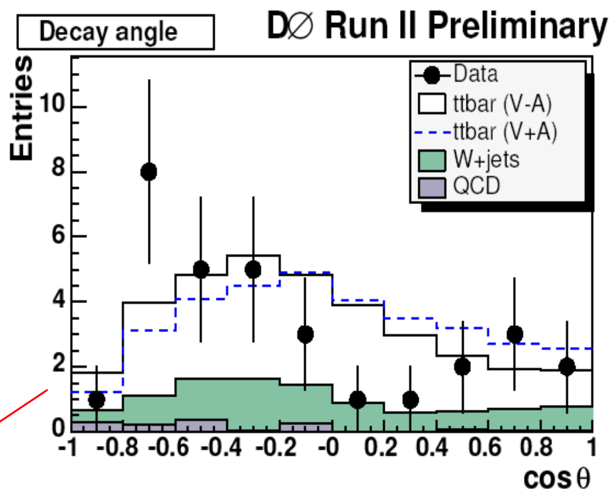
CDF (l+jets and di-lepton)

$F_0 = 0.27^{+0.35}_{-0.21}(stat) \pm 0.17(syst)$

DØ (μ+jets, $160 pb^{1}$)

F_+ < 0.262 at 90% C.L. topological

F_+ < 0.269 at 90% C.L. b-tagging



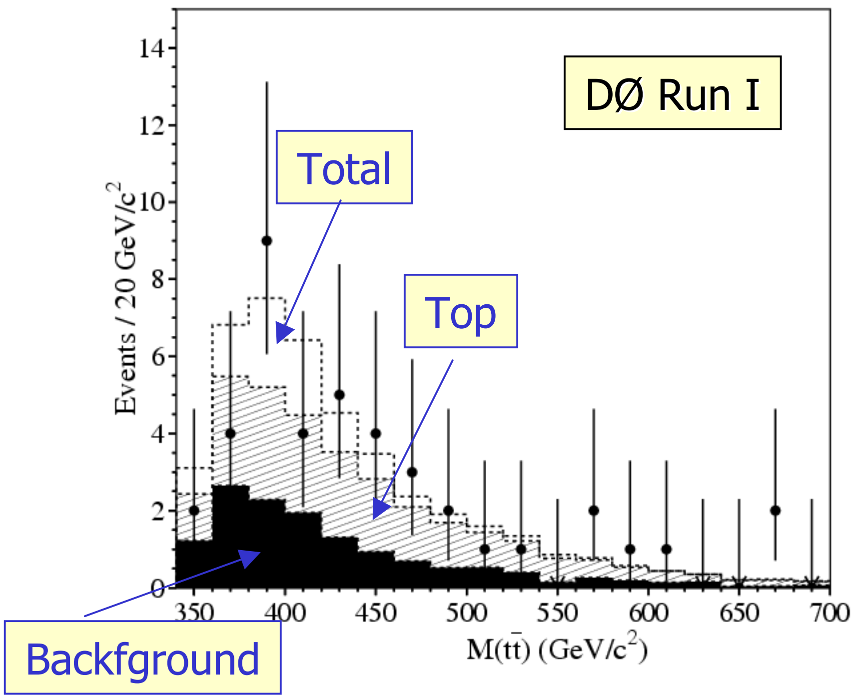
No deviations from SM predictions

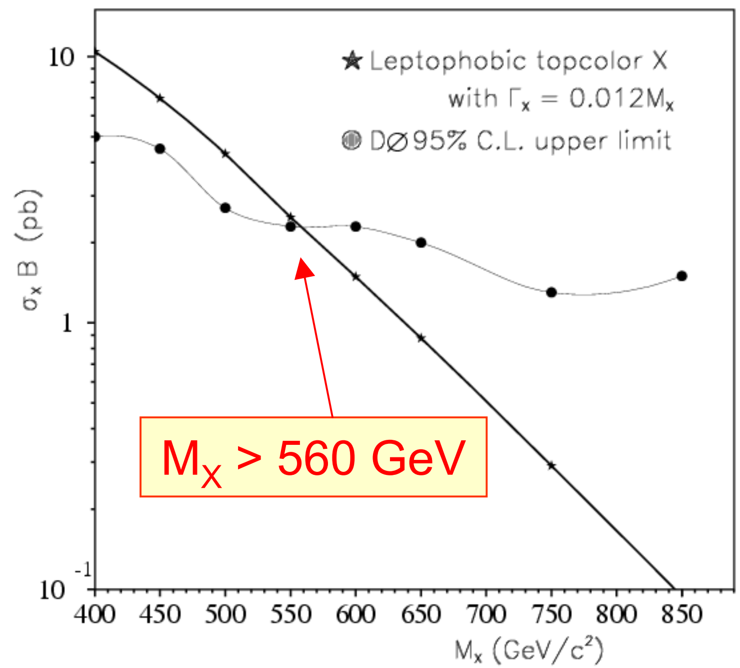
Resonances in tt system?

No resonance production in tt system is expected in SM (cc, bb,…)

Some models predict tt bound states, example: topcolor-assisted technicolor
→ predicts leptophobic Z' with strong 3rd-generation coupling

Experimental check: search for bumps in tt effective mass spectrum





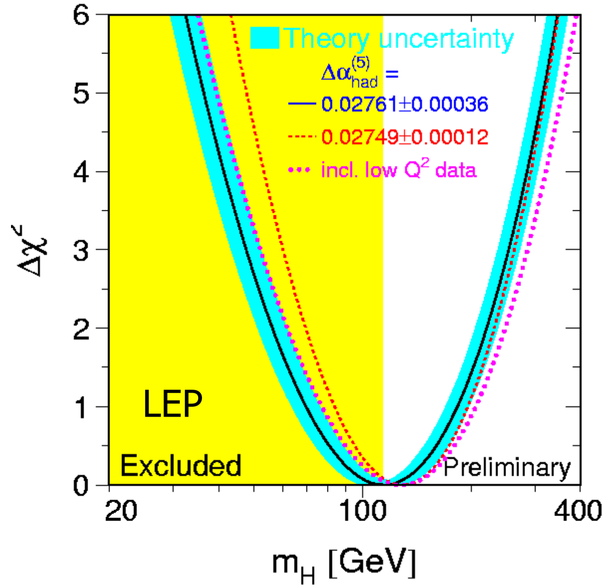
Experimental Limits on Higgs Mass

Last missing particle in SM
Explains EWSM → mass

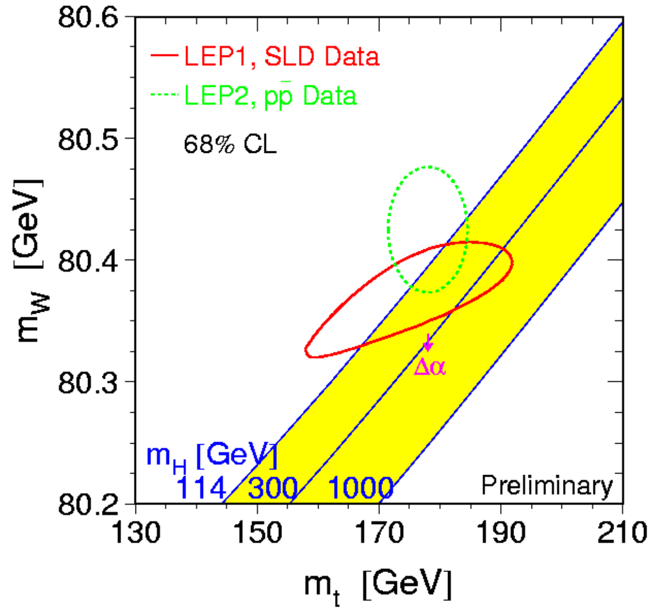
Available experimental limits
→ precision EW fits
→ direct searches at LEP (>114 GeV)
Light Higgs favored

$$m_H = 114^{+69}_{-45}\, GeV$$

$$m_H \leq 260 GeV$$ at 95% C.L.

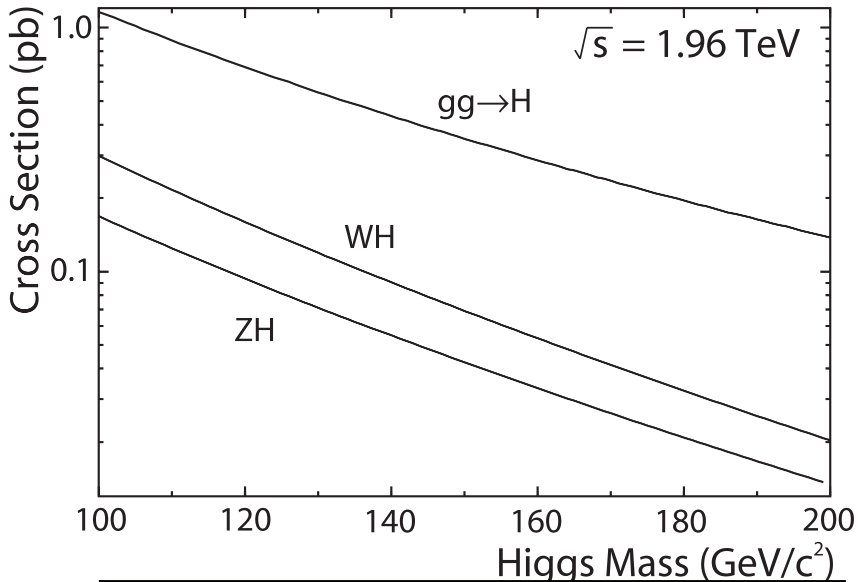


Tevatron provides
→ precision m_t and M_W measurements
Direct Searches
→ SM Higgs
→ non-SM Higgs



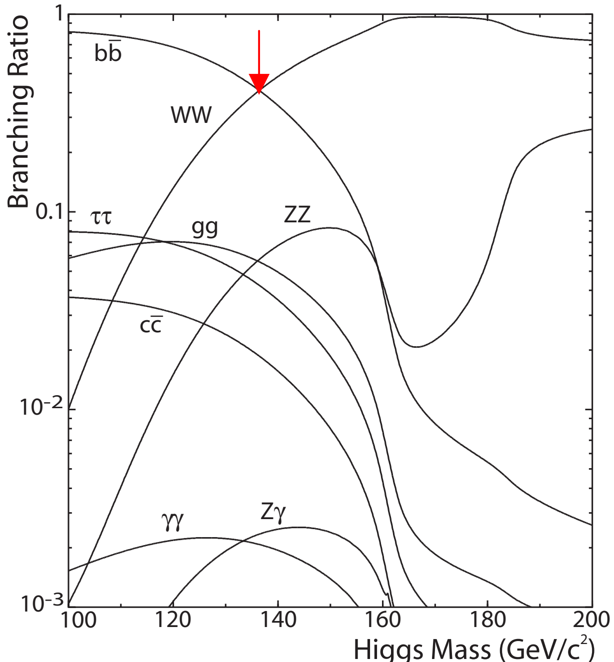
SM Higgs Production and Decays at Tevatron

Production



Production Cross Section
→ in the 1 pb range for gg → H
→ in the 0.1 pb range for associated vector boson production

Decay



Decays
→ bb for M_H < 140 GeV
→ WW for M_H > 140 GeV

Search strategy

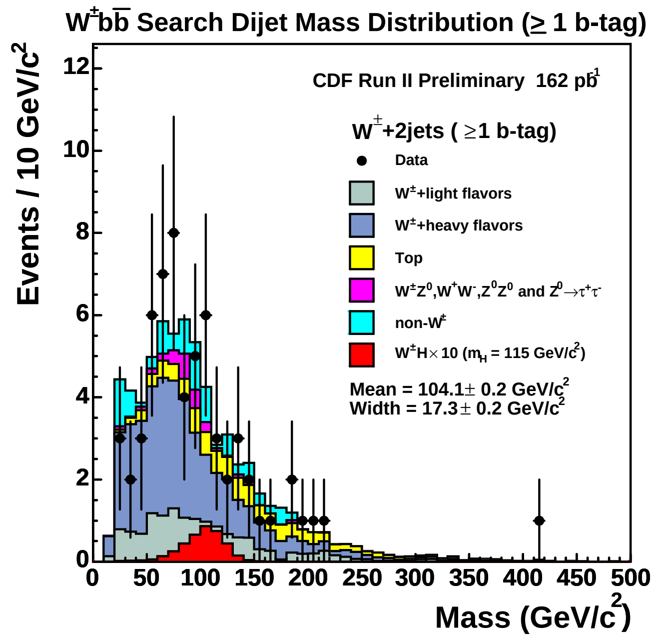
M_H <140 GeV associated production and bb decay W(Z)H → lν(l) bb
Backgrounds: top, Wbb, Zbb…

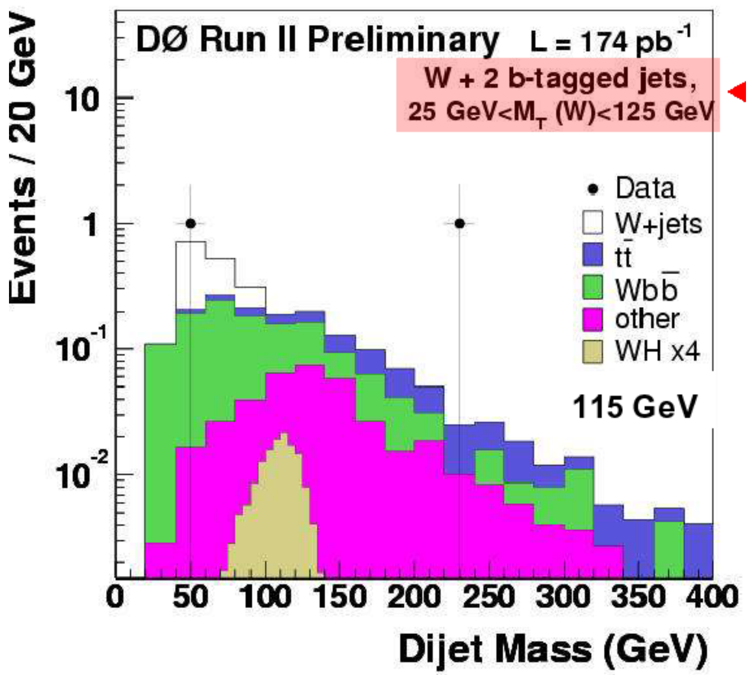
M_H >140 GeV gg →H production with decay to WW
Backgrounds: electroweak WW production…

SM Higgs Search: WH → lνbb (M_H<140 GeV)

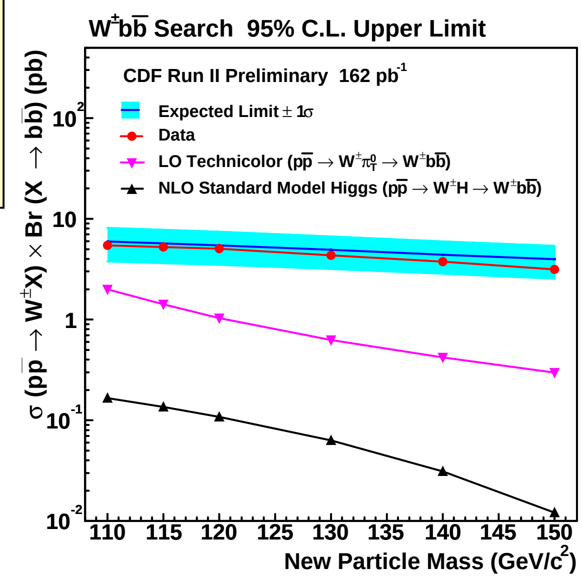
DØ is using sample of W(eν)+2 b tagged jets
→ Require exactly 2 jets to suppress top background
2.5 events expected and 2 events observed

σ(WH)xBR(H→bb) < 12.4pb^{-1} at 95% C.L.
For M_H =115 GeV





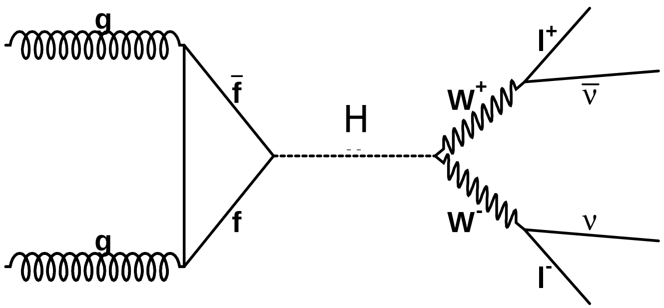
CDF uses e and μ channels
Requires at least 1 jet to be tagged



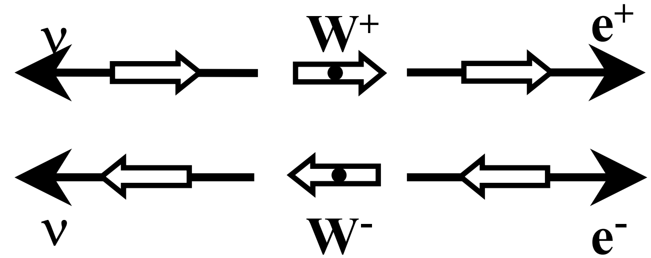
Future improvements

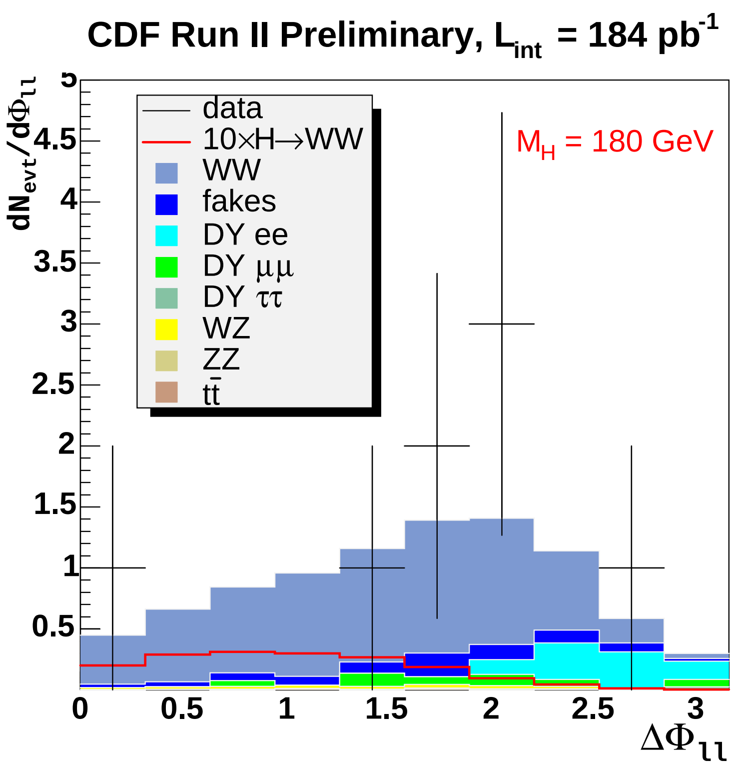
Extend b-tagging acceptance, efficiency.
Additional kinematic variables
Better M_{bb} resolution
Add ννbb channel

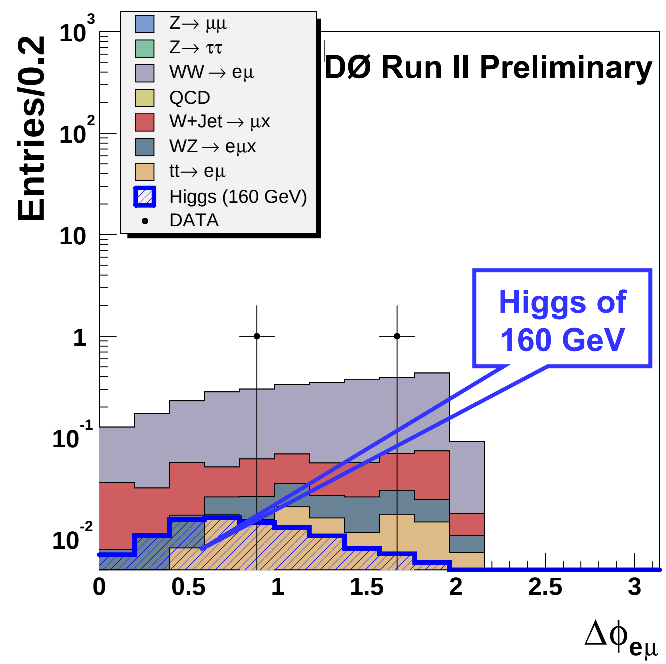
SM Higgs Search: H → WW → llνν (M_H >140 GeV)



Search strategy
→ 2 high P_t leptons + missing E_t
→ WW comes from spin 0 Higgs:
leptons prefer to point in the same direction

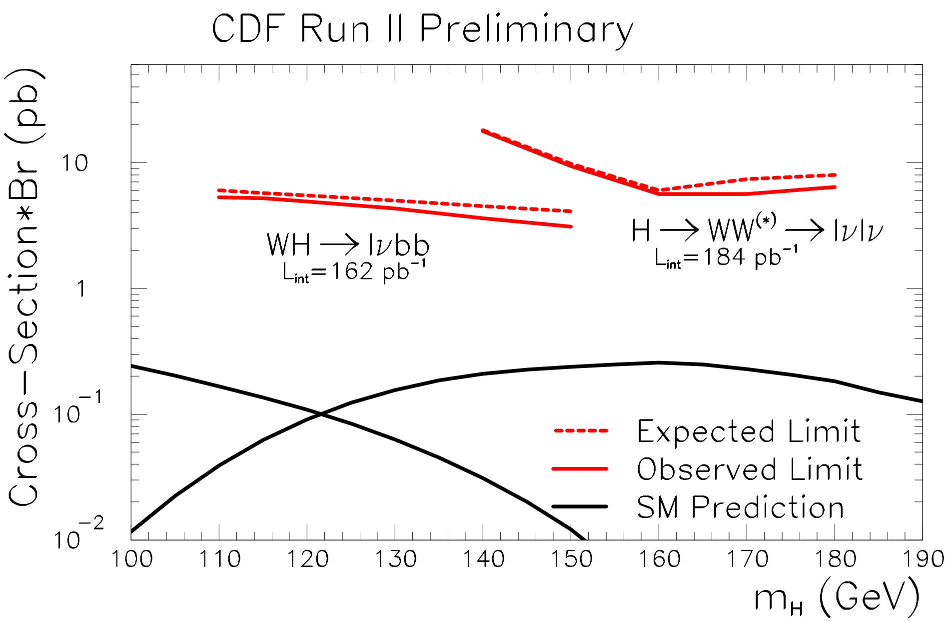


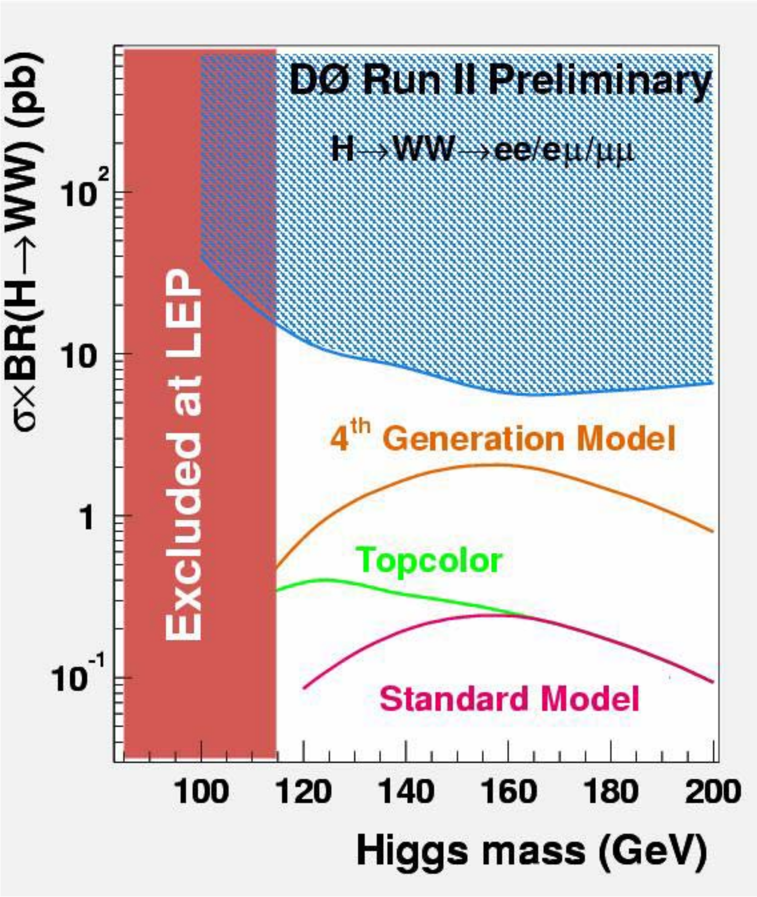




Current limits on SM Higgs Search

Both experiments set 95% C.L. on SM Higgs cross section x Br





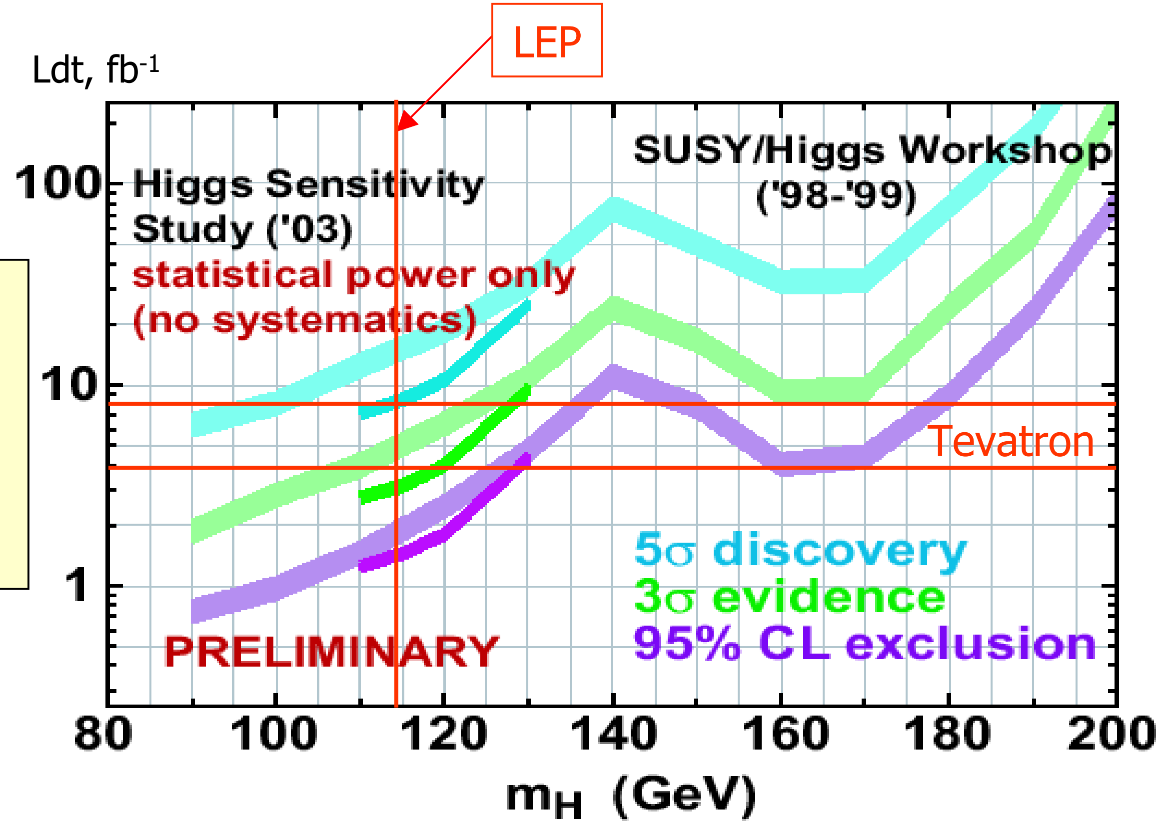
Limits already exceeding Run I results

DØ light (115 GeV) Higgs search limit
$\sigma(WH)xBR(H \rightarrow bb) < 12.4\ pb^{-1}$ at 95% C.L.

Tevatron SM Higgs Search: Outlook

Updated in 2003 in the low Higgs mass region W(Z)H->lν(νν,ll)bb to include

→ better detector understanding
→ optimization of analysis



Sensitivity in the interesting mass region starts at ~2 fb^{-1}

Meanwhile
→ optimizing analysis techniques
→ understanding detectors better
→ searching for non-SM Higgs with higher production cross sections or enhanced branching into modes with lower backgrounds

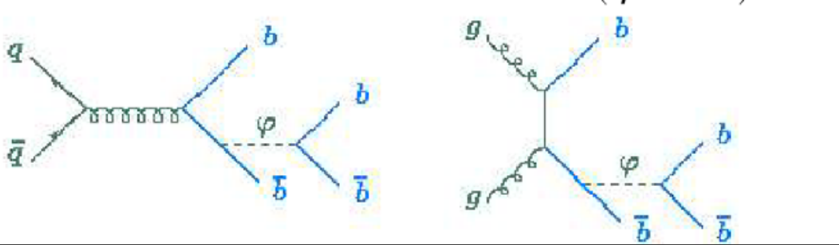
Search for MSSM Higgs

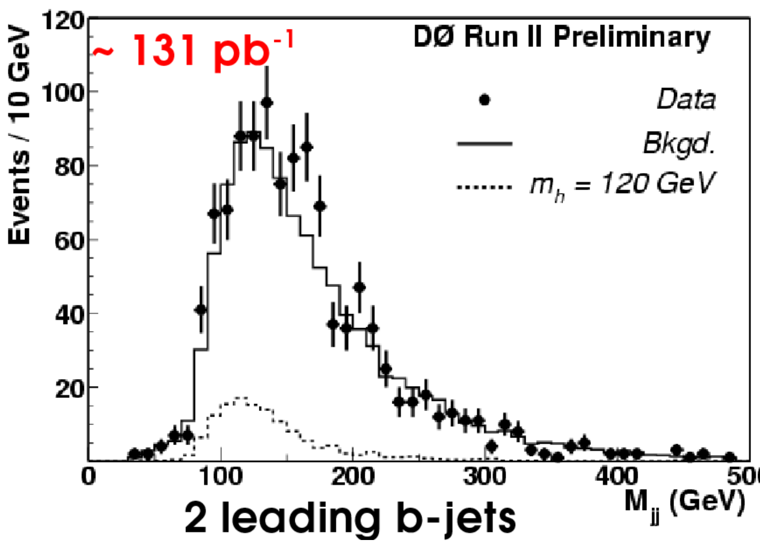
MSSM predicts larger Higgs cross sections for some values of parameter space then SM

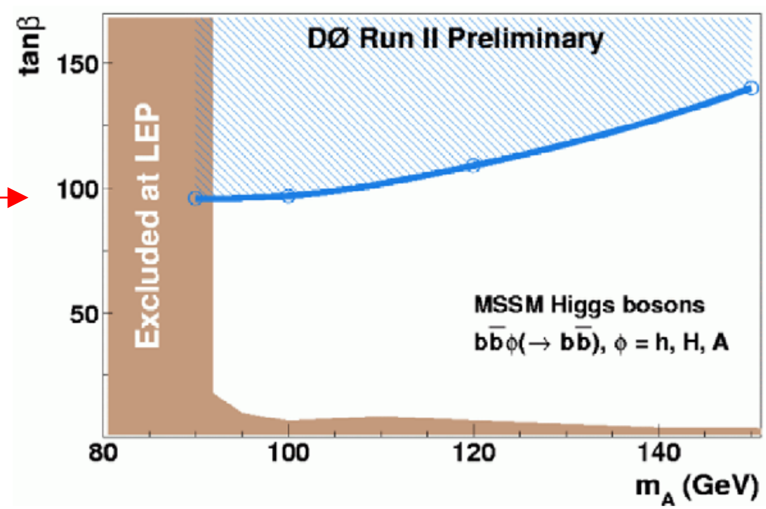
Using NLO cross section calculations and assuming no difference between A and h/H DØ performs search for MSSM Higgs
- → multi-jet high E_t sample
- →3 or more b tagged jets

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





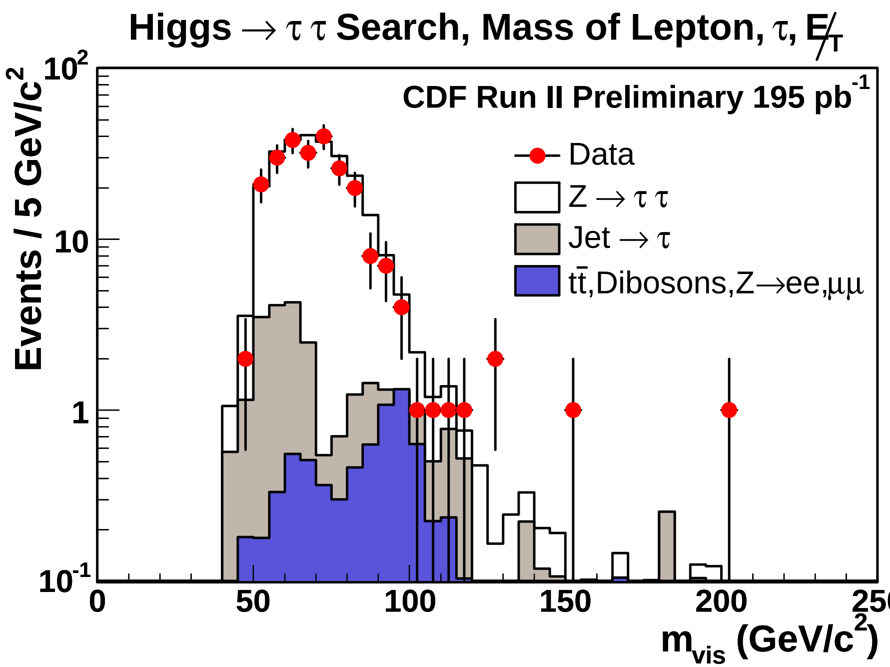


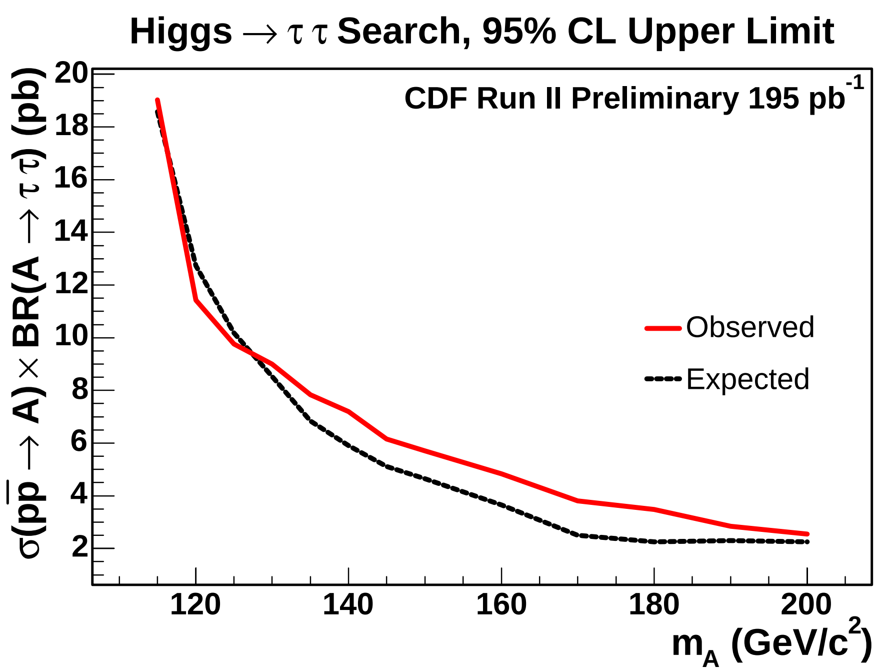
Search for MSSM Higgs

CDF searches for $p\bar{p} \to h / A + X$

With A decaying into ττ pair
→ ~8% branching at high tanβ
→ lower backgrounds then bb pairs
No excess seen over backgrounds

	$\tau_h \tau_e$	$\tau_h \tau_\mu$	Combined
$Z \to \tau\tau$	132.3 ± 17.1	104.1 ± 13.3	236.4 ± 29.5
$Z \to ll$	1.8 ± 0.2	4.9 ± 0.4	6.7 ± 0.6
$t\bar{t}, VV$	0.7 ± 0.1	0.8 ± 0.1	1.5 ± 0.1
$jet \to \tau$	12.0 ± 3.6	7.0 ± 2.1	19.0 ± 5.7
Total predicted	146.8 ± 17.5	116.8 ± 13.5	263.6 ± 30.1
Data	133	103	236



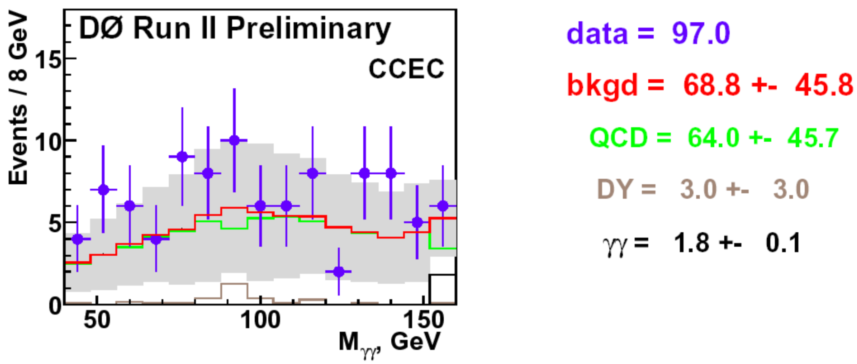


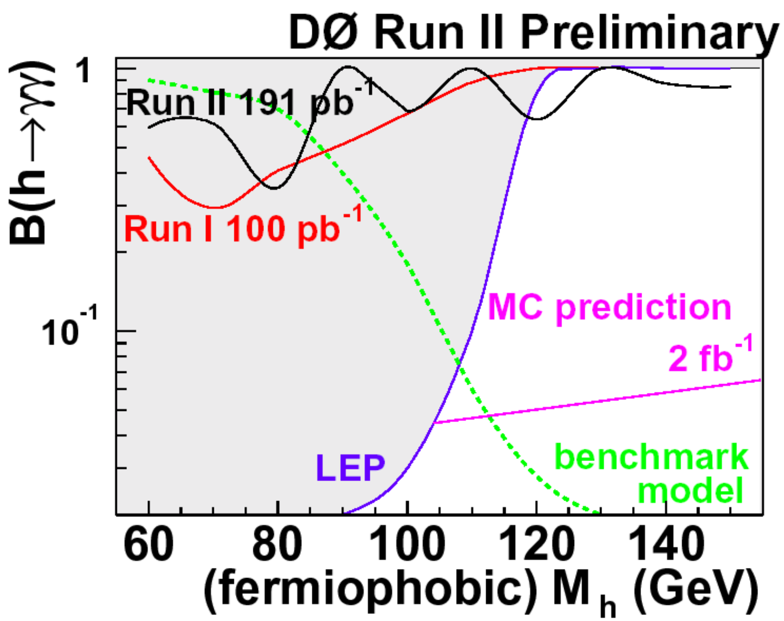
Search for H -> $\gamma\gamma$

In the SM Higgs → $\gamma\gamma$ has Br~10^{-3} at Tevatron energy
→ search for SM Higgs decaying to gamma pair is not hopeful

Many SM extensions allow enhanced gamma pair decay rate largely due to suppressed coupling to fermions
→ Fermiphobic Higgs
→ Topcolor Higgs

Looking for peaks in $\gamma\gamma$ mass spectrum for high P_t isolated γ's





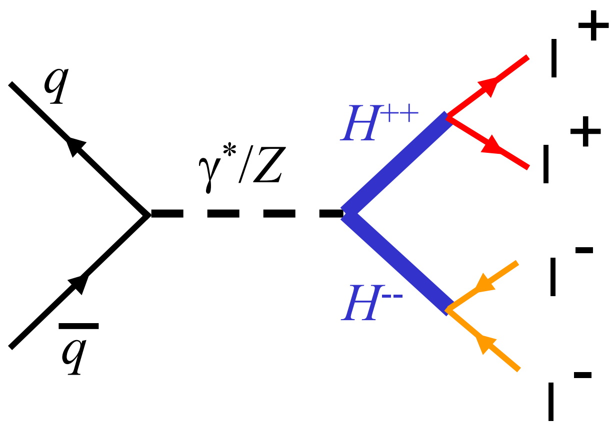
Search for H^{++}/H^{--}

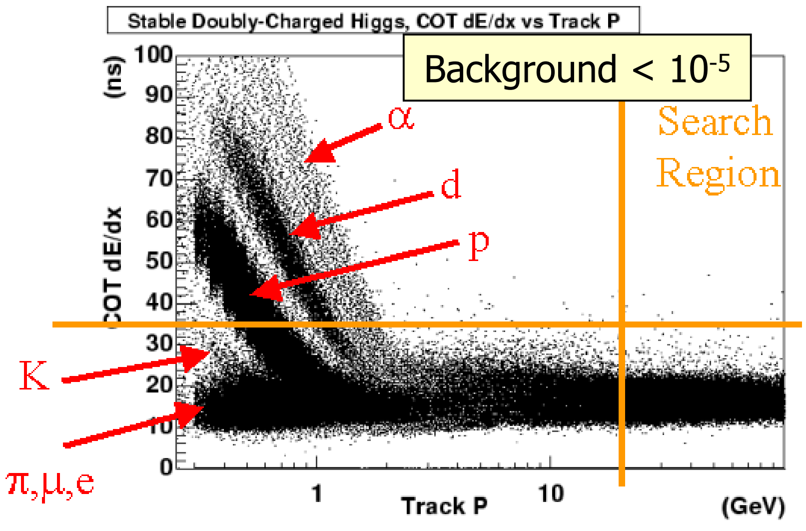
Predicted by Left-Right Symmetric Models

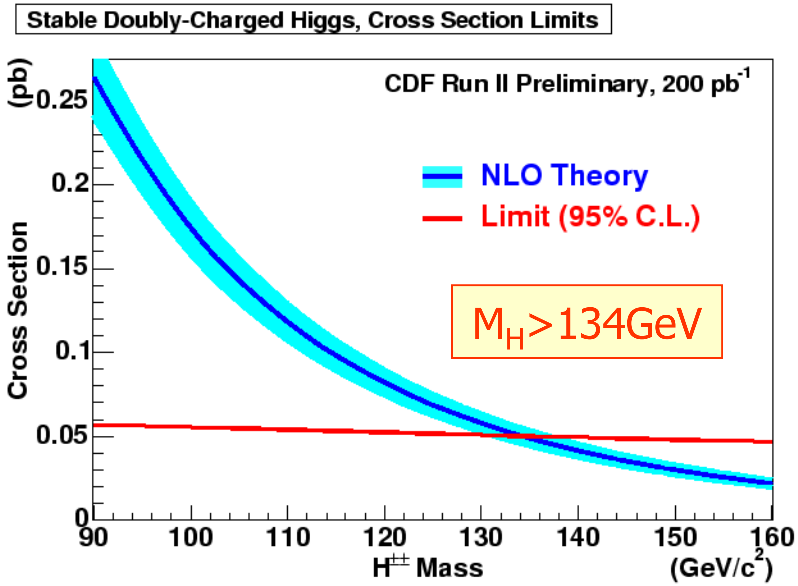
If short lived:
→ Very prominent signature – multiple high P_t leptons, like sign di-lepton mass peak
→ Backgrounds: WZ, W+jets, conversions (e)

D0 ($113pb^{-1}$) $M(H_L)$ > 118GeV ($\mu\mu$) at 95% CL
CDF ($240pb^{-1}$) $M(H_L)$ > 136GeV ($\mu\mu$) at 95% CL

If long lived:
→ two high ionization tracks







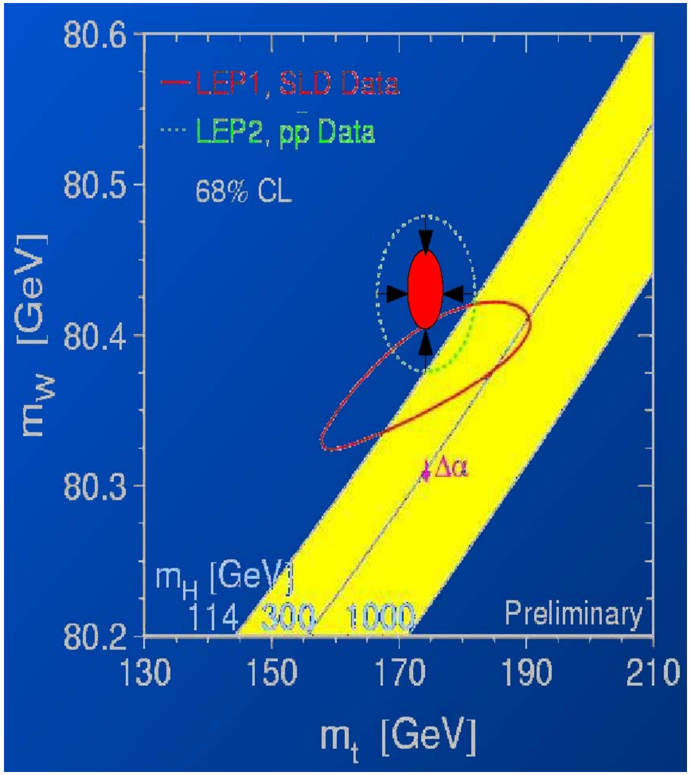
Tevatron Top and Higgs: Summary

Many excellent talks about top and Higgs studies at Tevatron are presented at ICHEP04
EW, Beyond SM, Heavy Quarks sessions

Top studies are actively progressing:
→ updated σ_t, m_t, limits on single top production
→ studies of SM predictions and beyond SM models
-> W helicity studies
-> decay modes: Wq, WX, Xq...
-> tt resonances,…

No deviations from SM observed (yet)

Higgs search is in progress:
→ SM Higgs
→ sensitivity (m_H >115 GeV) starts at ~2fb^{-1}
→ non-SM Higgs
→ many different models tested
→ already see reduction in allowed phase space (Run I, LEP)



Expect substantial improvements in top studies, Higgs hunting with
~0.5 fb^{-1} already on tapes
~8 fb^{-1} expected in Run II

Backup Slides