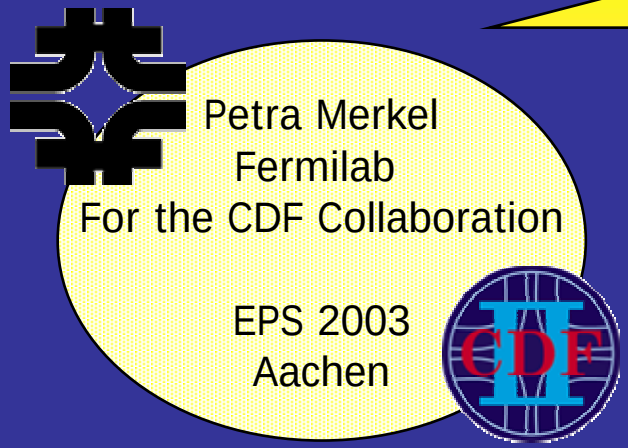
Search for Physics Beyond the Standard Model in $t\bar{t}$ Production



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Fermilab
For the CDF Collaboration

EPS 2003
Aachen

Run1 results

Kinematics of $t\bar{t}$ events

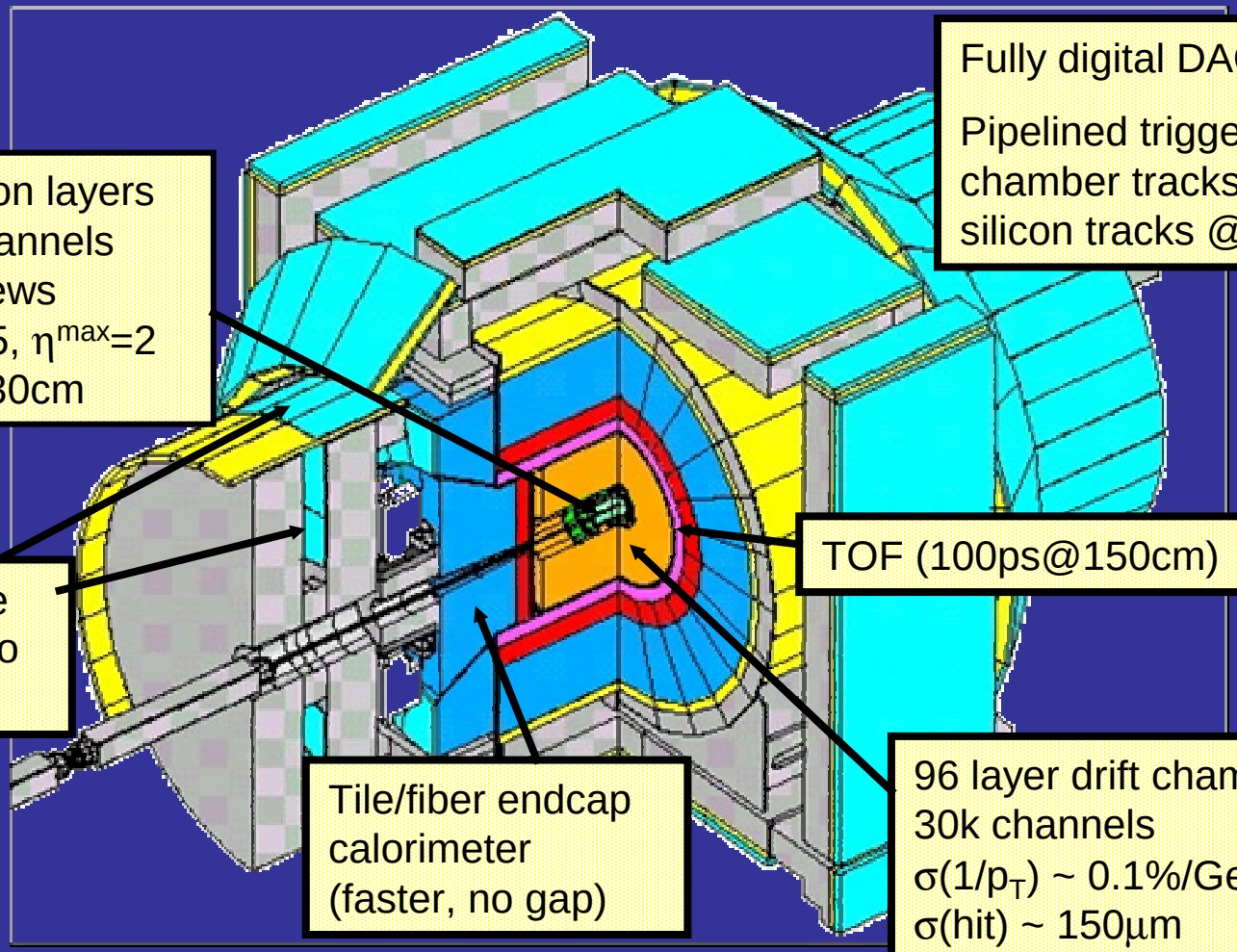
Jet multiplicity

Search for V+A, H^+,

Resonances, rare decays...

Run2 prospects

The New CDF Detector



Fully digital DAQ (132ns)

Pipelined trigger (drift chamber tracks @ L1, silicon tracks @ L2)

7-8 silicon layers
722k channels
rϕ, rz views
z_0^{max}=45, η^{max}=2
1.3<R<30cm

μ coverage extended to η=1.5

TOF (100ps@150cm)

Tile/fiber endcap calorimeter (faster, no gap)

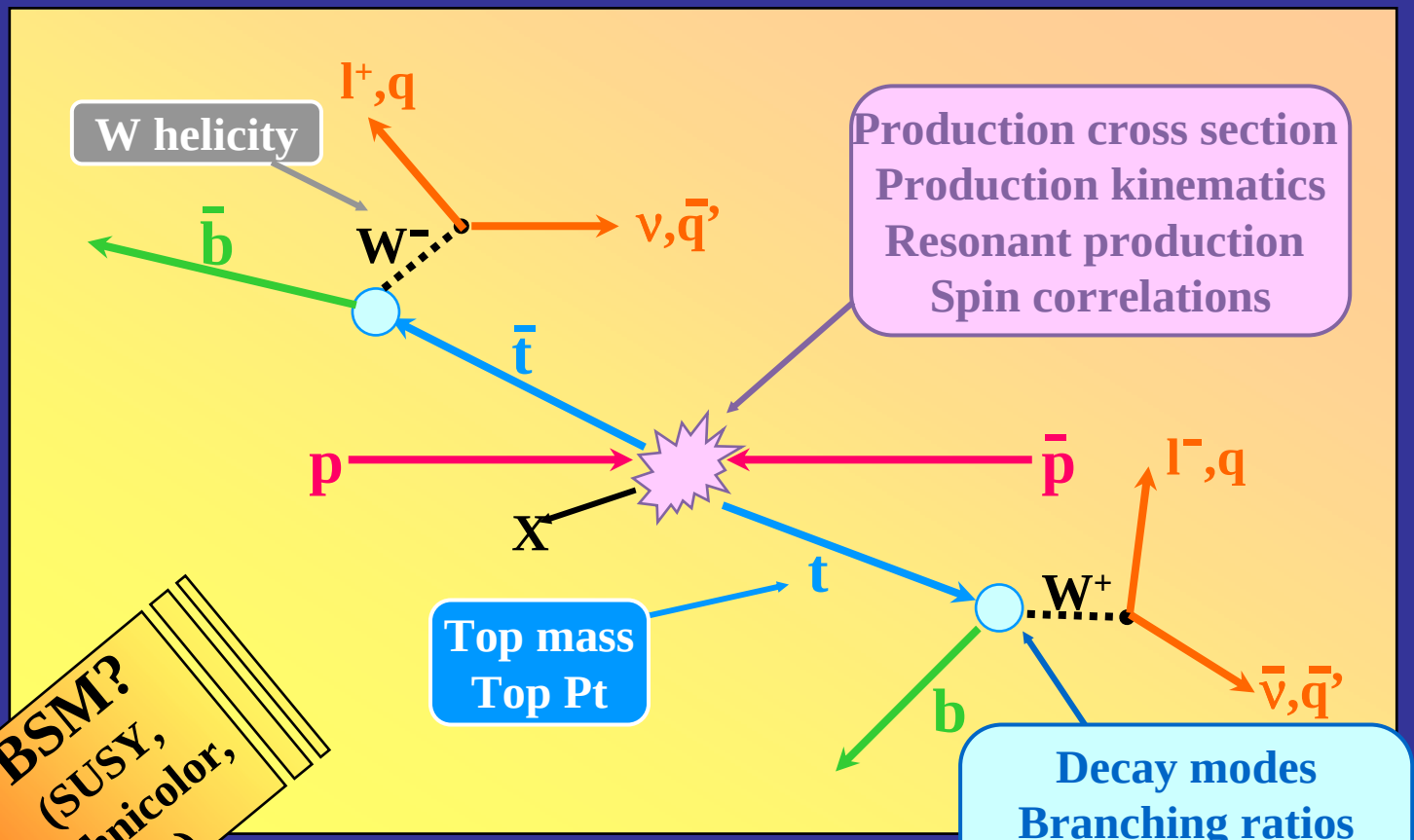
96 layer drift chamber
30k channels
$\sigma(1/p_T)$ ~ 0.1%/GeV
σ(hit) ~ 150μm

Top Physics

Exciting possibilities

Third generation, high mass...

➔ Special role in EW symmetry breaking?



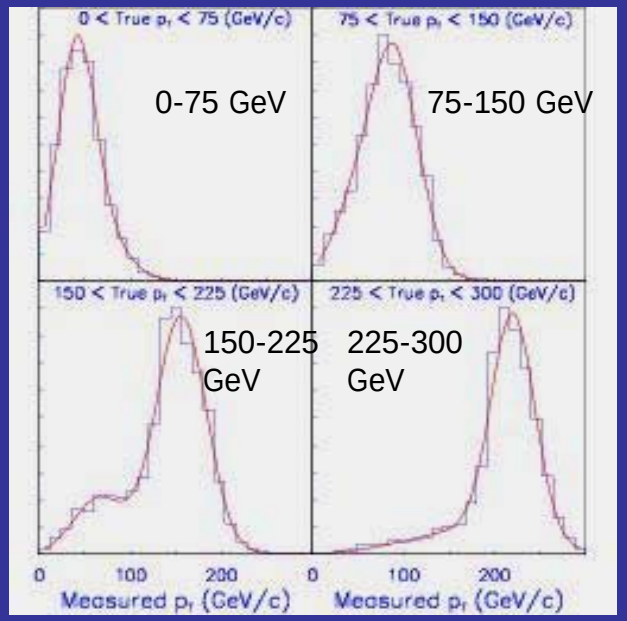
Kinematics of Top Events

- It is important to compare various distributions of the reconstructed top quark and especially of the $t\bar{t}$ system, with SM predictions. Discrepancies could indicate new physics.
- A list of some of the distinctive features that were seen in the RunI dataset (no significant effects observed yet):
  - increase of measured M_t w/ jet multiplicity?
  - slight excess of W+2jet events where 1 jet is tagged by 2^{nd}-vertex AND soft-lepton-tag (Phys.Rev.D65 (2002) 052007)
  - 2/9 di-lepton evts have unexpectedly large $E_t+E_t(l_1)+E_t(l_2)$ (compare Hall and Barnett, hep-ph/9609313)
  - measured M(tt) seems to deviate a little from expected distribution
  - measured P_t(tt) seems a bit harder than expected (but difficult measurement)
  - measured rapidity of tt system has different shape than expected

P_t(top)

Phys.Rev.Lett. 87, 102001 (2001)

- Measure P_t of hadronically decaying top in l+jets tt channel
- Constrain M_{top}=175 GeV, perform kinematic fit
- In 106 pb-1: 61 evts found
- BG estimate: 31.9+-4.6 evts
- Use unsmearing procedure and unbinned likelihood fit to extract true P_t(top)



CDF Run I

True p_T Bin	Parameter	Measurement	SM Expectation
$0 \le p_T \le 75$ GeV	R_1	$0.21^{+0.22}_{-0.21}(\text{stat})^{+0.10}_{-0.08}(\text{syst})$	0.41
$75 \le p_T \le 150$ GeV	R_2	$0.45^{+0.23}_{-0.23}(\text{stat})^{+0.04}_{-0.07}(\text{syst})$	0.43
$150 \le p_T \le 225$ GeV	R_3	$0.34^{+0.14}_{-0.12}(\text{stat})^{+0.07}_{-0.05}(\text{syst})$	0.13
$225 \le p_T \le 300$ GeV	R_4	$0.000^{+0.031}_{-0.000}(\text{stat})^{+0.024}_{-0.000}(\text{syst})$	0.025
$0 \le p_T \le 150$ GeV	R_1+R_2	$0.66^{+0.17}_{-0.17}(\text{stat})^{+0.07}_{-0.07}(\text{syst})$	0.84

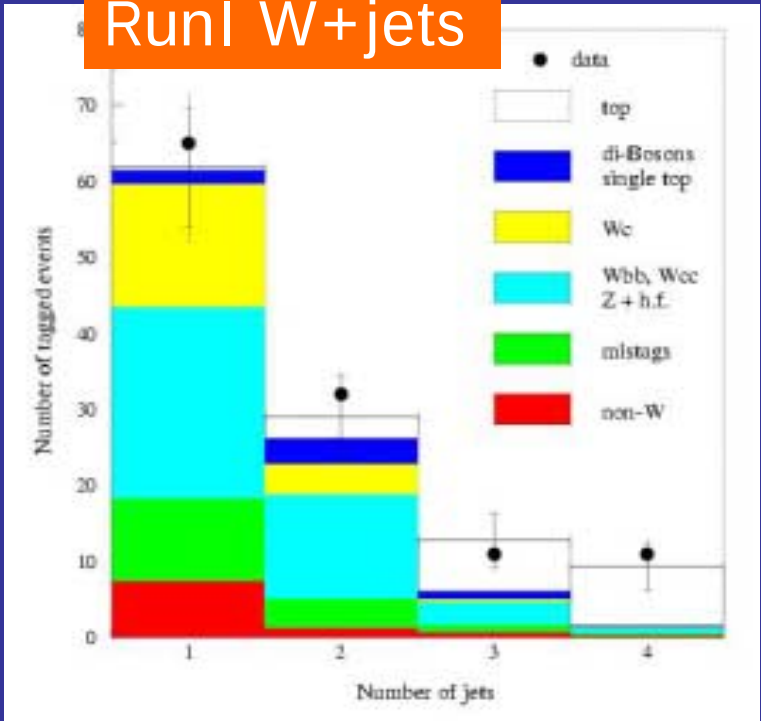
Upper limit:

$R_4(225<P_t<425\text{GeV/c}) < 0.16$ @ 95% C.L.

Search for Higgs in W+2jets Events

Search for $p\bar{p} \rightarrow W+X \rightarrow l\nu+b\bar{b}$ in $109pb^{-1}$

RunI W+jets



- Most of the signal expected in W+2jets bin; use other bins to check BG calculation
- 1 or 2 b-tags required: 2nd-vertex and soft-lepton-tags
- W+3jets bin in reasonably good agreement; small excess in W+2jets bin
- increase sensitivity of search, look for resonant mass peak in Mjj
- No resonance seen in CDFI data
- Use binned max-likelihood fit, constraining QCD and $t\bar{t}$ contributions, to extract N_{WX}
- Use SM Higgs production ($p\bar{p} \rightarrow WH^0$) as a model to extract upper limit

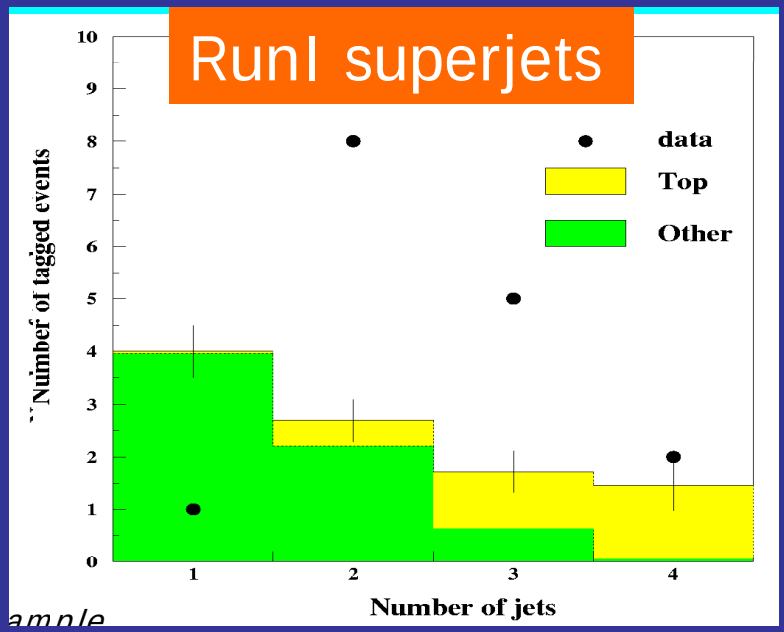
$$\sigma(p\bar{p} \rightarrow WX) \times B(X \rightarrow b\bar{b}) = [14,19]\,pb$$
$$\text{for } M_X = [70,120]\,GeV$$

- statistically compatible w/ no signal (SM Higgs)
- ~2 orders of magnitude away from sensitivity to SM Higgs

Heavy Flavor Content

Phys.Rev.D65, 052007 (2002)

- tt signal region: 3,4 jet bins
- We also looked for additional heavy flavor
- "Superjets": 2nd-vertex-tag AND soft-lepton-tag
- statistics limited: 14 evts observed, 4.4±0.6 expected in W+2,3 jets bin (while good agreement when integrating over all Njet bins)
- many checks performed in order to understand this slight excess
- either statistical fluctuation OR mis-undertsanding of detector OR new physics...
- Need more data from RunII to re-evaluate this analysis

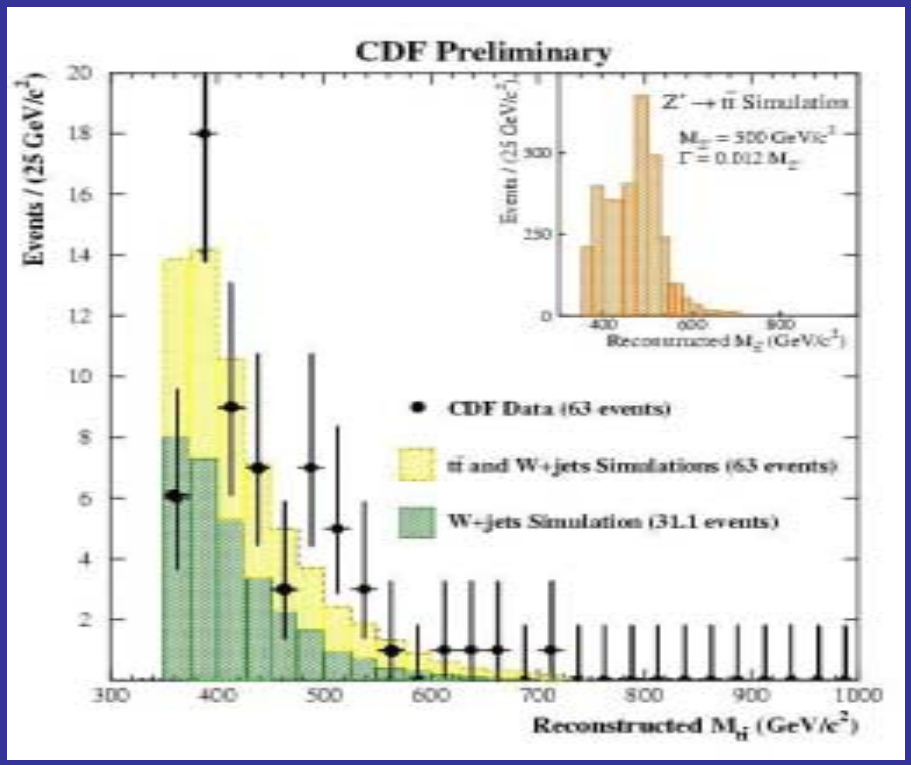


- 0.4% probability of consistency w/ SM in the 4 jet bins
- "a posteriori" probability of consistency in 2jet bin is $P=10^{-3}$

Search for $t\bar{t}$ Resonances

Phys.Rev.Lett. 85, 2062 (2000)

- Model independent search for narrow vector particle $X \rightarrow t\bar{t}$ in l+jets sample
- CDFI found no evidence for a $t\bar{t}$ resonance
- Establish upper limits on $\sigma_* B$ for narrow resonances
- Use limits to constrain a model of topcolor assisted technicolor ($Z' \rightarrow t\bar{t}$)



Expected sensitivity for Run II: $\delta(\sigma_* B) \sim 90$ fb

Exclude a narrow, leptophobic X boson with $m_X < 560$ GeV/c^2

Search for V+A

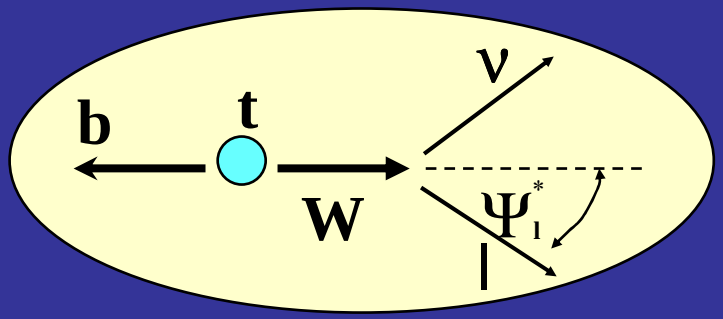
Phys.Rev.Lett. 84, 216 (2000)

Verify that this is the top quark of the SM...

SM V-A predicts W helicity:

F_0 = 70% longitudinal
F_- = 30% left-handed

[V+A: 70% long., 30% r.-h.]

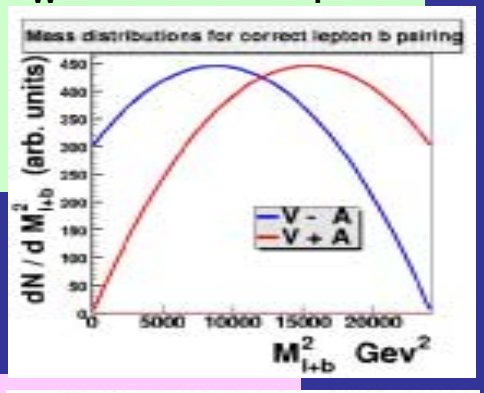


RunI

Use invariant mass of lepton and b quark (frame independent):

$M^2_{lb} = ½ (M^2_t - M^2_W)(1 + \cos\Psi^*_l)$

Fit for fraction of right-handed (V+A) component: f_{V+A}

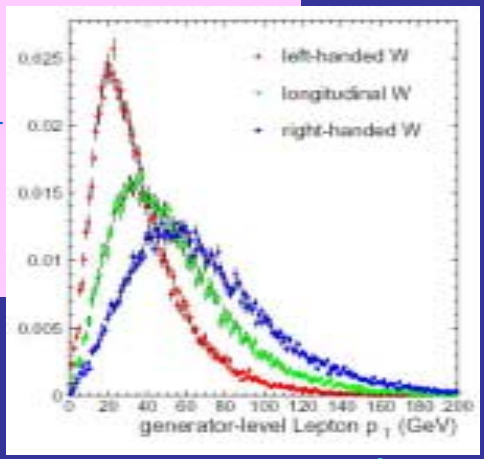


RunI & RunII

Use Pt of lepton:

Fit for F_0, then fit for F_+ while fixing F_0

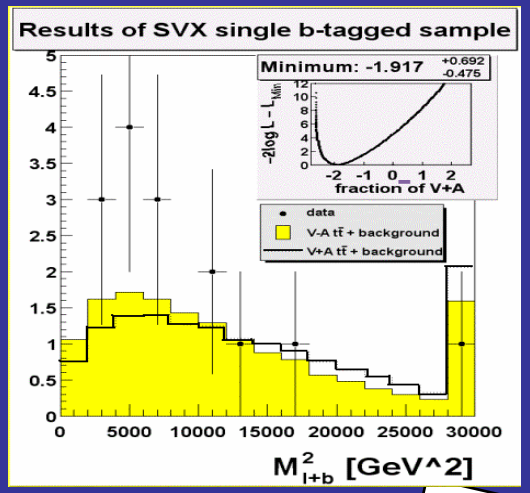
RunII measurement already more sensitive than in RunI!

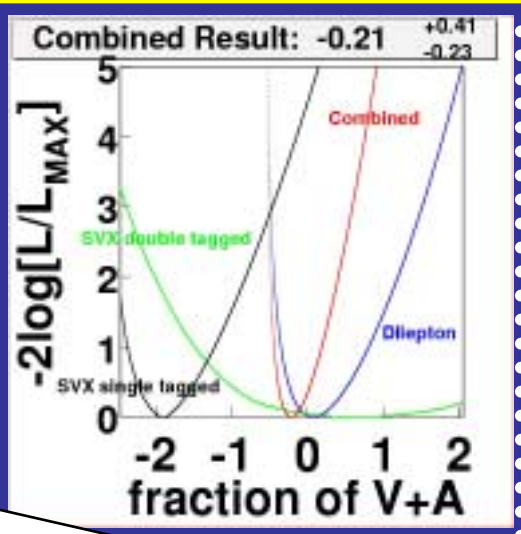


V+A Results

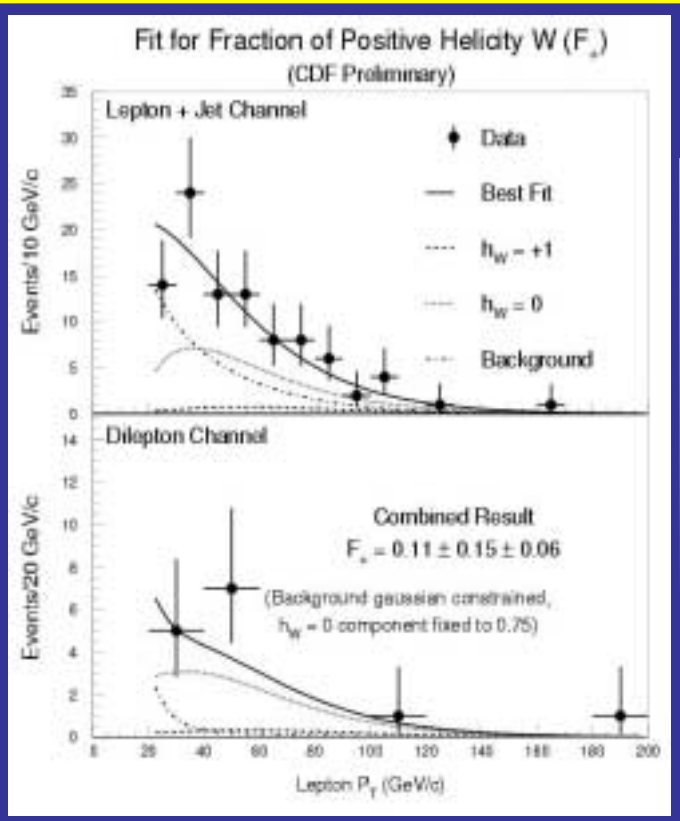
Using M^2_{l+b}

Using $P_t(l)$





CDF I preliminary



Expected sensitivity for Run II:
$\delta B(t \to W_0)$=5.5% ; $\delta B(t \to W_+)$=2.7%

CDFI Result (109pb^{-1}):
(Using tt dilepton, and lepton+jets events with 1 and 2 SVX b-tagged jets)

$$f_{V+A} = -0.21^{+0.42}_{-0.25} \pm 0.21$$

CDFI Result (106pb^{-1}):
$F_0 = 0.91 \pm 0.37 \pm 0.13$
$F_+ < 0.28$ @ 95% C.L.

Search for H^+:

Phys.Rev.D62, 012004 (2000)

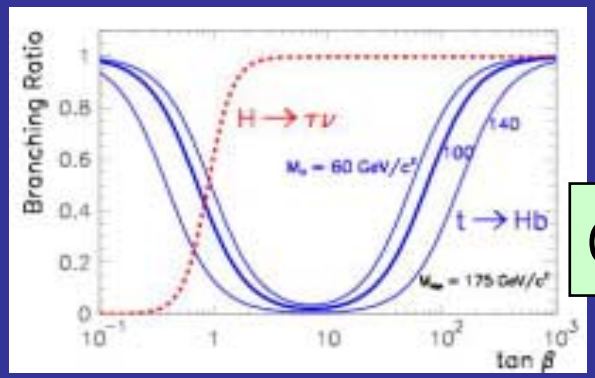
- 2-Higgs-doublet model, MSSM:
- $t \rightarrow H^+ b$ competes with SM $t \rightarrow W^+ b$, if $m_H < (m_{top} - m_b)$

➔ $t\bar{t}$ production/decay provides source of Higgs (strong interaction) :

$W^{\pm} H^{\mp} b\bar{b}$ $H^+ H^- b\bar{b}$

➔ Direct Higgs pair production (weak interaction) : $H^+ H^-$

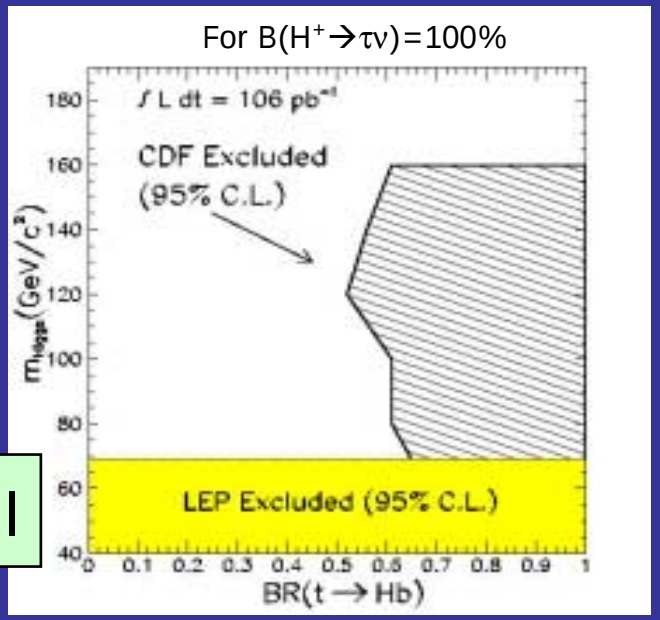
- In MSSM (for large tanβ) $H^+ \rightarrow \tau\nu$ dominant decay mode



CDF RunI

- Predict excess of top events with tau leptons!
- Direct search for signature of τ lepton in t decays → upper limit on B(t→H⁺b)
- Signature: $l+\tau+\not{E}_t+2jets+X$
- In 106pb^{-1} 4 candidates found
- Expect: 4.0+-0.6 from SM (BG+top)

For B($H^+ \rightarrow \tau\nu$)=100%



Expected sensitivity for RunII: δ(B(t→Wb)/B(t→Xb))=9%

Very interesting channel for RunII

Search for FCNC Decays

Phys.Rev.Lett. 80, 2525 (1998)

Unusual decays of the top quark might provide insight into the mechanism of EW symmetry breaking

CDF RunI

Rare decays: $t \to q\gamma$, $t \to qZ$

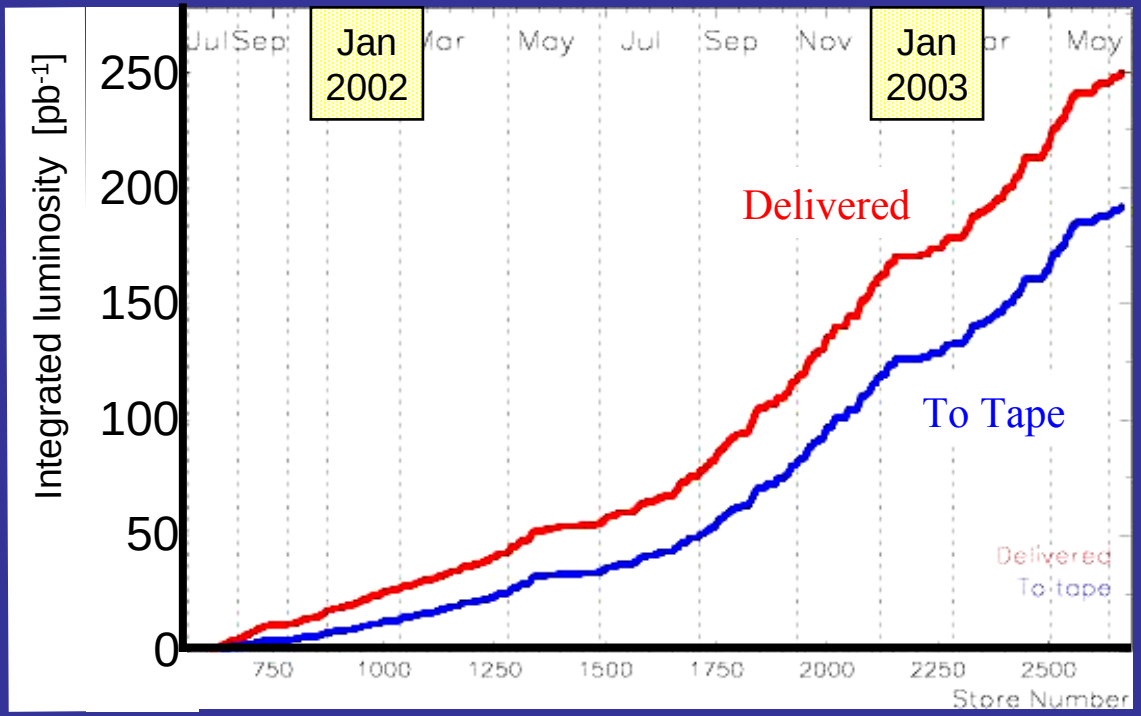
- Look for tt events w/ $t \to q\gamma$ and the other $t \to Wb(\to l\nu b$ or $\to qqb)$
  - <1 evt expected from SM BG sources
  - 1 evt found in 110pb^{-1}: $P_t(\mu)$=72GeV, $E_t(\gamma)$=88GeV, $\not{E}_t$=24GeV, 3 jets
  - Also kinematically consistent w/ $t \to W^+b$ & $t \to W^-b\gamma$, but $E_t(\gamma)$ exceptionally large!

  ➔ $B(t \to c+\gamma) + B(t \to u+\gamma) < 3.2\%$ @ 95% C.L.
- Look for tt events w/ $t \to qZ(\to qee$ or $\to q\mu\mu)$ and the other $t \to Wb(\to qqb)$
  - Less sensitive because B(Z→leptons) small
  - 1.2 evts expected from SM BG sources
  - 1 evt found in 110pb^{-1}: $Z \to \mu\mu$ + 4 jets
  - Kinematics fit better the Z+multijet hypothesis than FCNC decay

  ➔ $B(t \to c+Z) + B(t \to u+Z) < 33\%$ @ 95% C.L.

Tevatron Performance

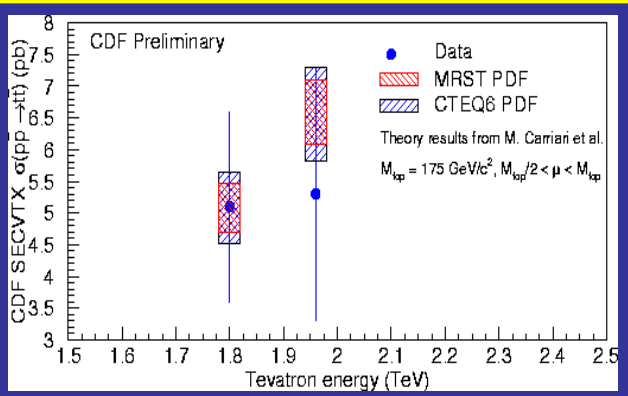
- $p\bar{p}$ collisions at $\sqrt{s}$=1.96 TeV
- Stable data-taking since June '02 shutdown ~ 200 pb^{-1} on tape
- ~ 5-8 pb^{-1}/wk @ > 90% efficiency
- Record instantaneous luminosity after January shutdown ~4.7-$10^{31}cm^{-2}s^{-1}$



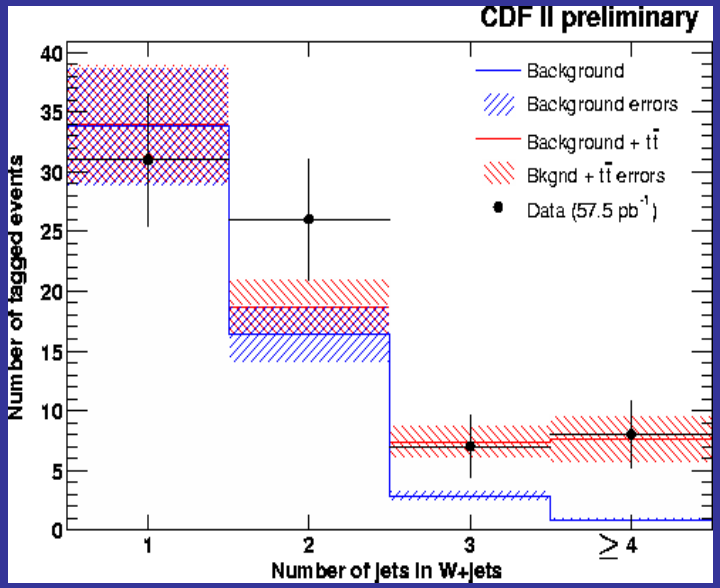
Most of the RunII results so far used 72 pb^{-1} (March '02 – January '03)
New results from ~120 pb^{-1} expected soon!

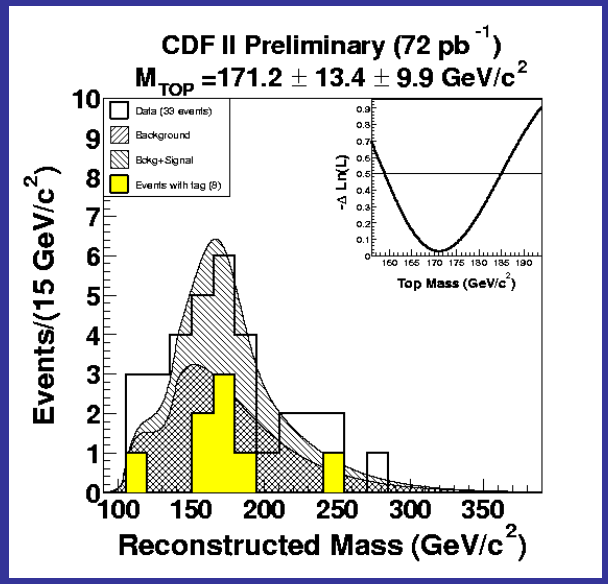
Top in RunII

- First cross section and M_{top} measurements using 72pb^{-1}
- New results from ~125pb^{-1} expected soon



Expected sensitivity for RunII: $\delta(\sigma_{tt})$=7%





Expected sensitivity for RunII: $\delta(M_t)$=2–3 GeV

Some searches are already on the way, like single top and V+A

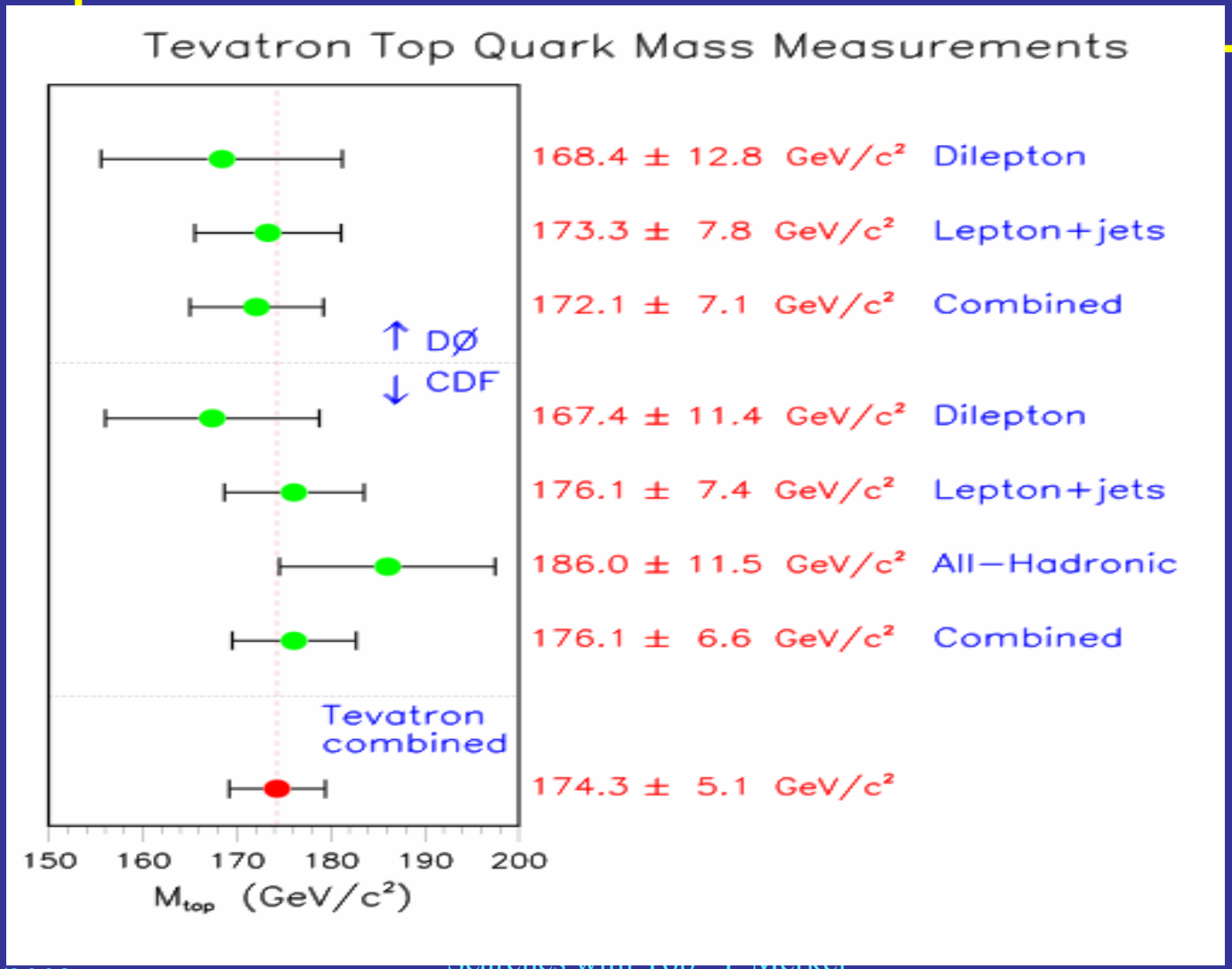
Summary & Outlook

- Many interesting and promising tests for new physics in the top sector
- Cross-section of CDF RunI results presented
- Standard top measurements established in RunII
- Some searches in $t\bar{t}$ events already started

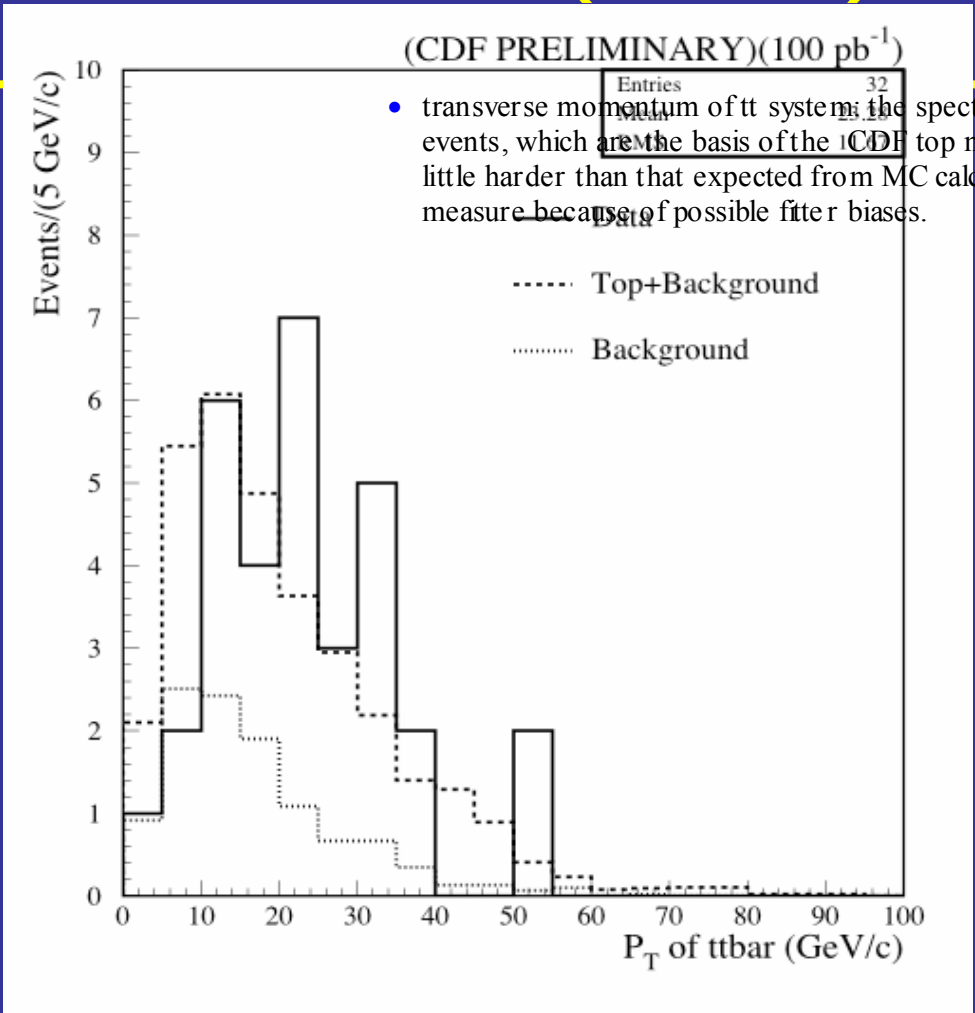
Measurement	Estim.uncertainty	Tests
M_t	2-3 GeV/c^2	Indirect M_H
σ_{tt}	7%	QCD couplings
σ_{ll}/σ_{l+j}	12%	Non-SM decays
$B(t\to Wb)/B(t\to WX)$	2.8%	"
$B(t\to Wb)/B(t\to Xb)$	9%	"
$B(t\to W_{long})$	5.5%	Non-SM couplings
$B(t\to W_{V+A})$	2.7%	"
$\sigma*B(Z'\to tt)$	~90 fb	exotics

BACKUP SLIDES:

Mtop versus # of jets

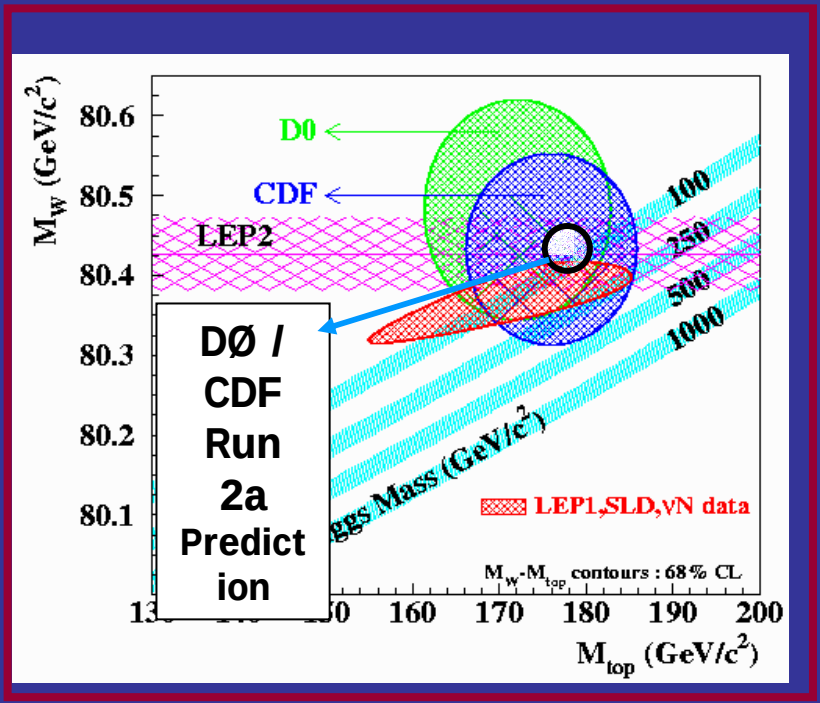


Pt(ttbar)



- transverse momentum of tt system: the spectrum based on 32 CDF tagged events, which are the basis of the CDF top mass measurement, seems to be a little harder than that expected from MC calculations; it is a difficult variable to measure because of possible fitter biases.

EWSB



DØ / CDF Run 2a Prediction

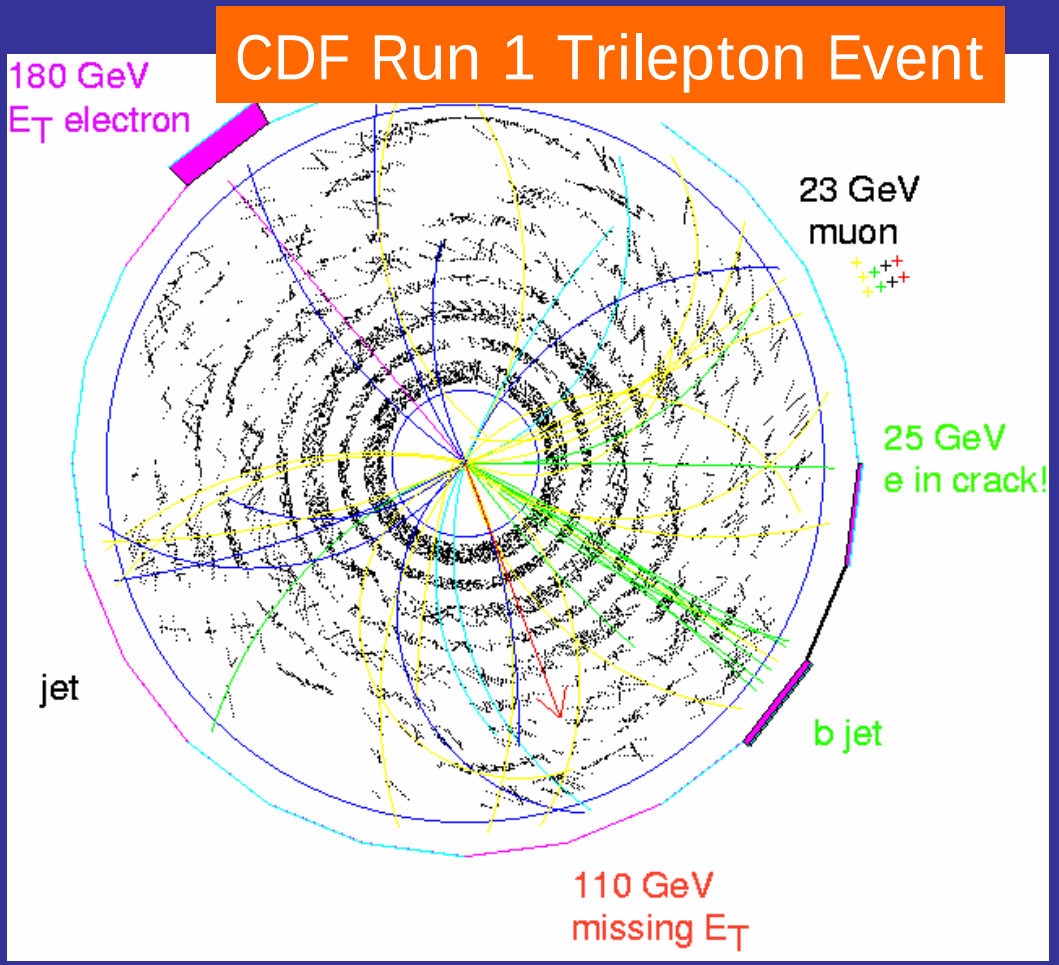
Precision measurements of top and W masses constrain the mass of the Standard Model Higgs

- M_W : CDF ⊕ DØ
  - σ_M ~ 30 MeV (2 fb^{-1})
  - σ_M ~ 20 MeV (10 fb^{-1})
- M_t : CDF or DØ
  - σ_M < 4 GeV (2 fb^{-1})
  - σ_M < 2 GeV (10 fb^{-1})

With only 2 fb^{-1} we may find a contradiction with the Standard Model Higgs direct search limit

Anomalies in the Top Quark Sample?

- found in dilepton sample
- electron in crack called jet
- 180 GeV E_T electron!
- 110 GeV missing E_T !

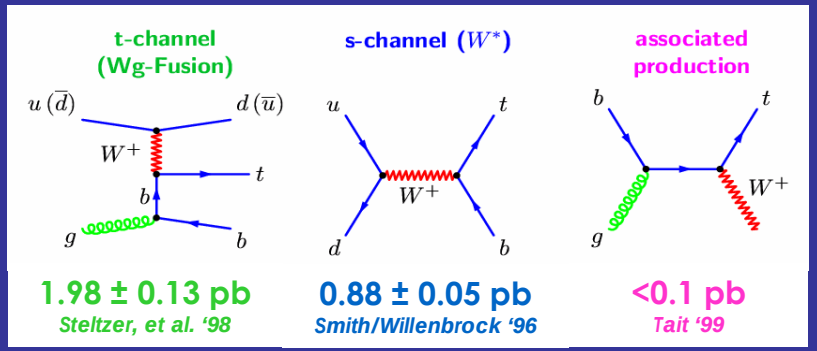


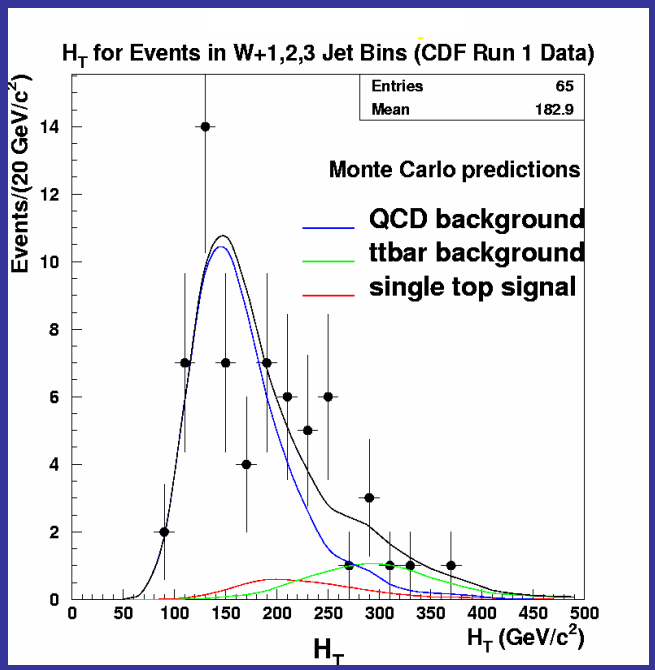
Search for Single top

Probe the electroweak Wtb vertex

Phys.Rev.D65, 091102 (2002)

- Search for anomalous couplings - large production rates or anomalous angular distributions
- Background to Higgs



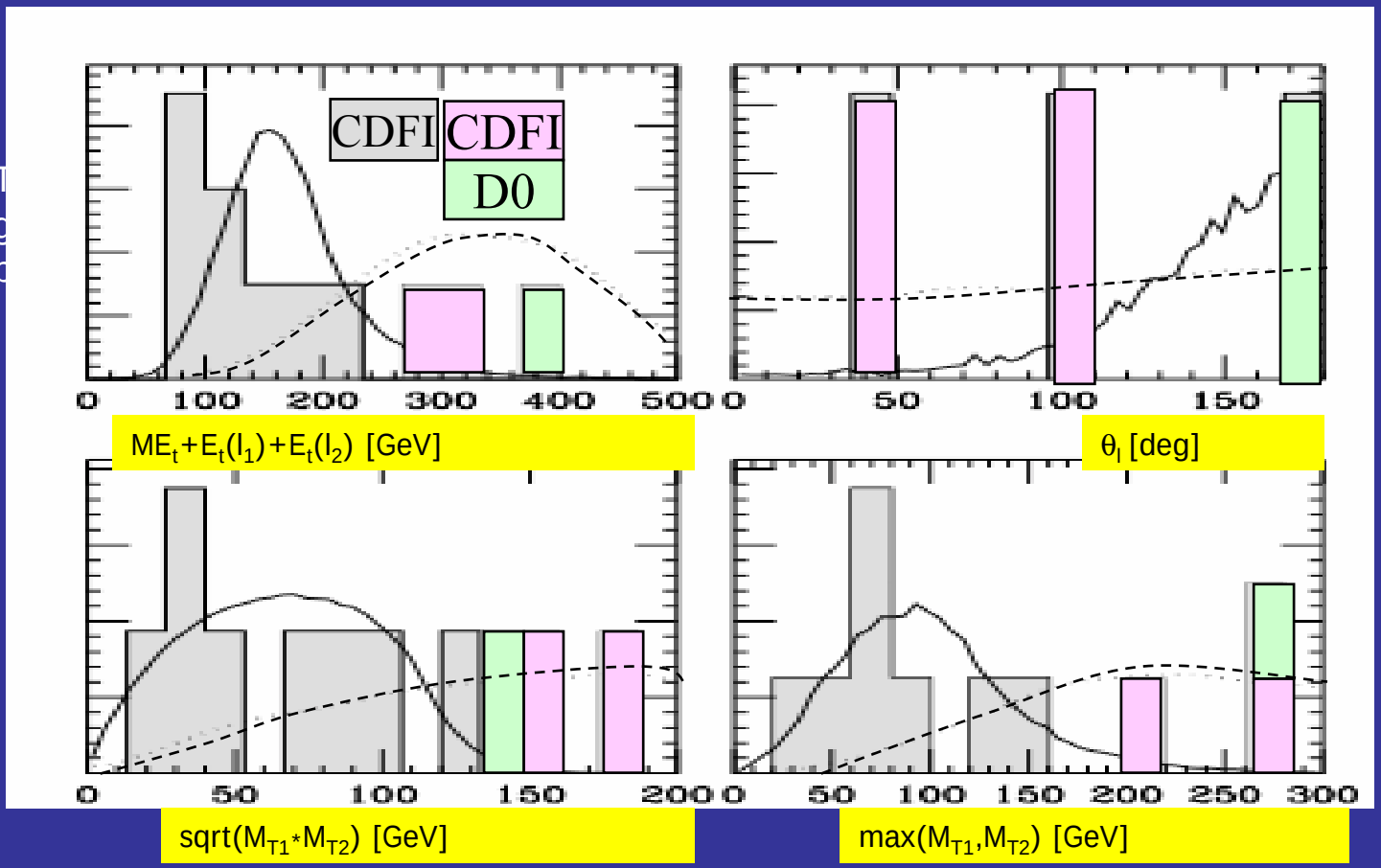


- CDF I has performed searches for s and t channels separately in RunI
- CDF I has also searched for combined process: $\sigma(t) < 14$ pb at 95% C.L.

- If SM is correct, observation in RunIIa
- Expect about 100-150 events in 2 fb^{-1}
- Measure $|V_{tb}|$ with 10-15% precision

Kinematics in Dilepton Events

hep-ph/9609313



$t\bar{t}$ or decay of SUSY quarks with masses around 300 GeV?