Forschungsseminar des Fachbereichs Physik
Universität Siegen, Germany, December 16, 2005

Properties of the Top Quark

Ulrich Husemann
University of Rochester

Outline

- The Road to the Top
- The CDF-II Detector at the Tevatron
- How to Find Top Quarks
- Top Properties
- Summary

The Road to the Top

The CDF-II Detector at the Tevatron

How to Find Top Quarks

Top Properties

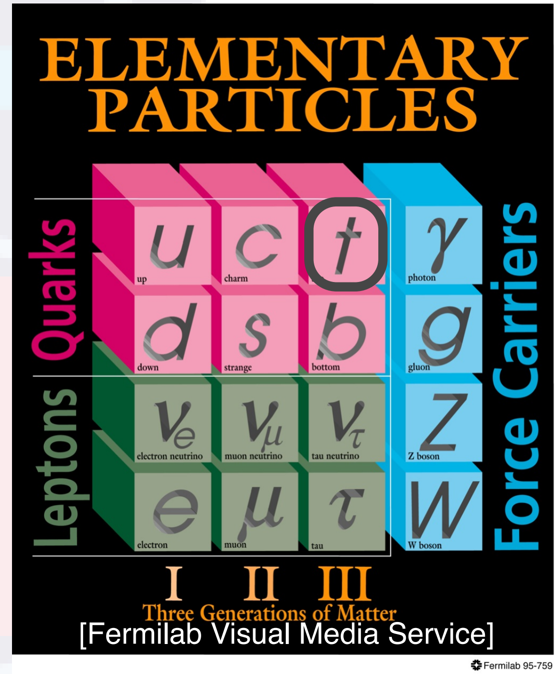
Summary

The Top in the Standard Model

- The top is heavy: $m_t \approx 175$ GeV/c^2 (40× m_b, approx. mass of gold atom)
- Mass close to scale of electroweak symmetry breaking (EWSB)

$$\mathscr{L}_{Y,t} = f \frac{v}{\sqrt{2}} \bar{t}_L t_R \equiv m_t \bar{t}_L t_R$$

→ Important role in EWSB models (vacuum expectation value of Higgs field: $v/\sqrt{2} \approx 178$ GeV):



- The only "free" quark: lifetime shorter than hadronization time

$$\tau = \frac{1}{\Gamma} \approx (1.5\,\mathrm{GeV})^{-1} < \frac{1}{\Lambda_{\mathrm{QCD}}} \approx (0.2\,\mathrm{GeV})^{-1}$$

→ No spectroscopy of bound states
→ Spin transferred to decay products

Theory & Early Discoveries

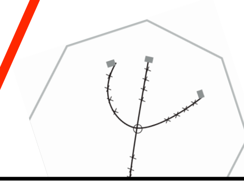
GIM mechanism: a fourth quark is required

Weak Interactions with Lepton-Hadron Symmetry*

S. L. Glashow, J. Iliopoulos, and L. Maiani†
Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts 02139
(Received 5 March 1970)

We propose a model of weak interactions in which the currents are constructed out of four basic quark fields and interact with a charged massive vector boson. We show, to all orders in perturbation theory, that the leading divergences do not violate any strong-interaction symmetry and the next to the leading divergences respect all observed weak-interaction selection rules. The model features a remarkable symmetry between leptons and quarks. The extension of our model to a complete Yang-Milis theory is discussed.

J/ψ discovery: the fourth quark is found



CKM matrix: CP violation only with three generations

Progress of Theoretical Physics, Vol. 49, No. 2, February 1973

***CP*-Violation in the Renormalizable Theory of Weak Interaction**

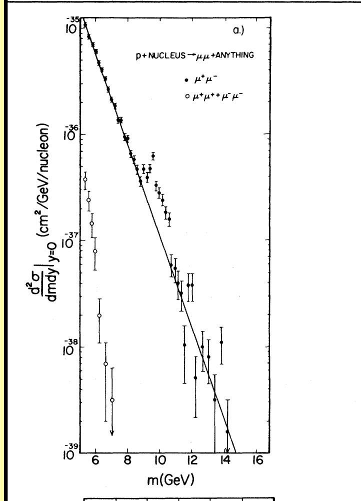
Makoto Kobayashi and Toshihide Maskawa
Department of Physics, Kyoto University, Kyoto

(Received September 1, 1972)

In a framework of the renormalizable theory of weak interaction, problems of *CP*-viola are studied. It is concluded that no realistic models of *CP*-violation exist in the qua scheme without introducing any other new fields. Some possible models of *CP*-violation also discussed.

Υ discovery: the first quark of the third generation

LETTERS 1 August 1977

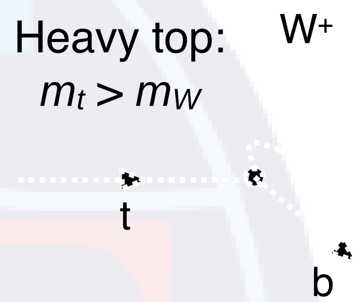


1970 — 1973 — 1974 — 1977

Searches ...

PETRA (DESY): e^+e^-, $\sqrt{s} \leq 45$ GeV
$m_t > 23$ GeV/c^2

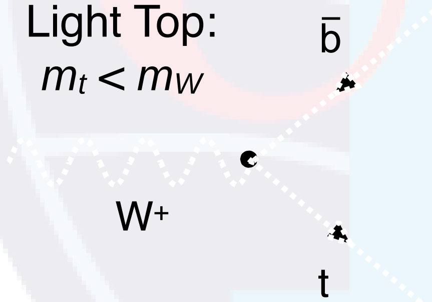
Heavy top:
$m_t > m_W$



Sp$\bar{p}$S (CERN): $p\bar{p}$, $\sqrt{s} \leq 630$ GeV
$m_t > 70$ GeV/c^2

CDF Run 0 (FNAL)
$m_t > 70$ GeV/c^2

Light Top:
$m_t < m_W$



LEP I (CERN): e^+e^-, $\sqrt{s} = 90$ GeV
$m_t = 173$ GeV/c^2 (EW fit)

Tevatron Run I:
Discovery

1979 – – – – – – – 1985 – – – – – – – 1990 – 1992 – 1994

Top Turns Ten

- The last mile to the top:
  - 1992:
    Tevatron Run I starts
  - January 1993:
    "Event 417" (D0)
  - August 1993:
    Evidence for top
    (CDF, published September 1994)
  - March 2, 1995:
    Discovery officially announced (CDF, D0)

The Road to the Top

The CDF-II Detector at the Tevatron

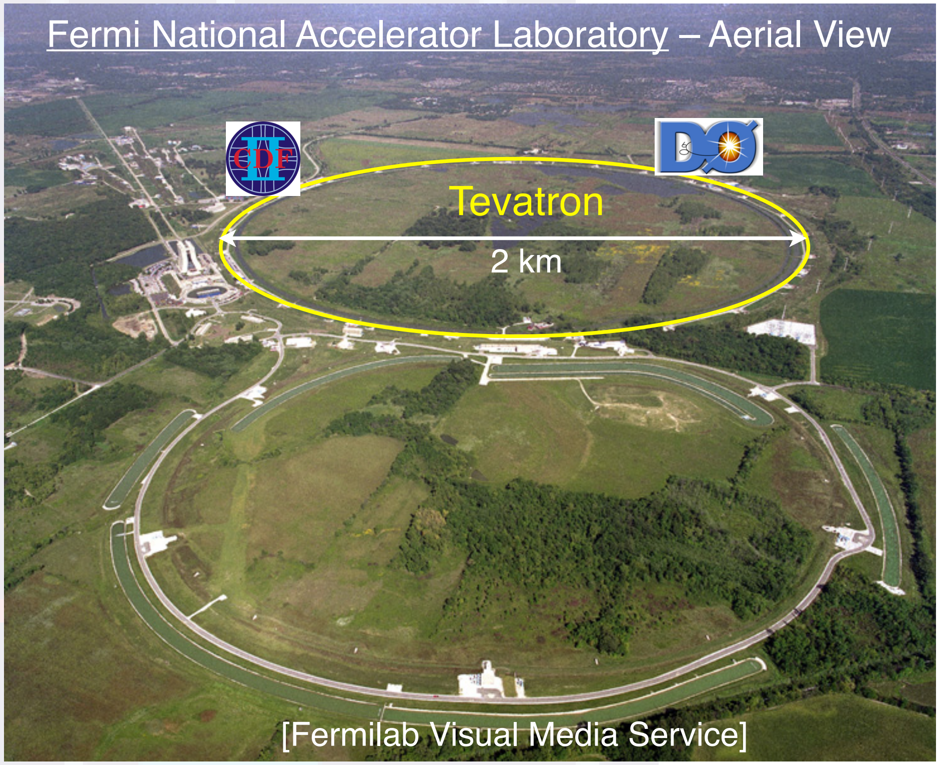
How to Find Top Quarks

Top Properties

Summary

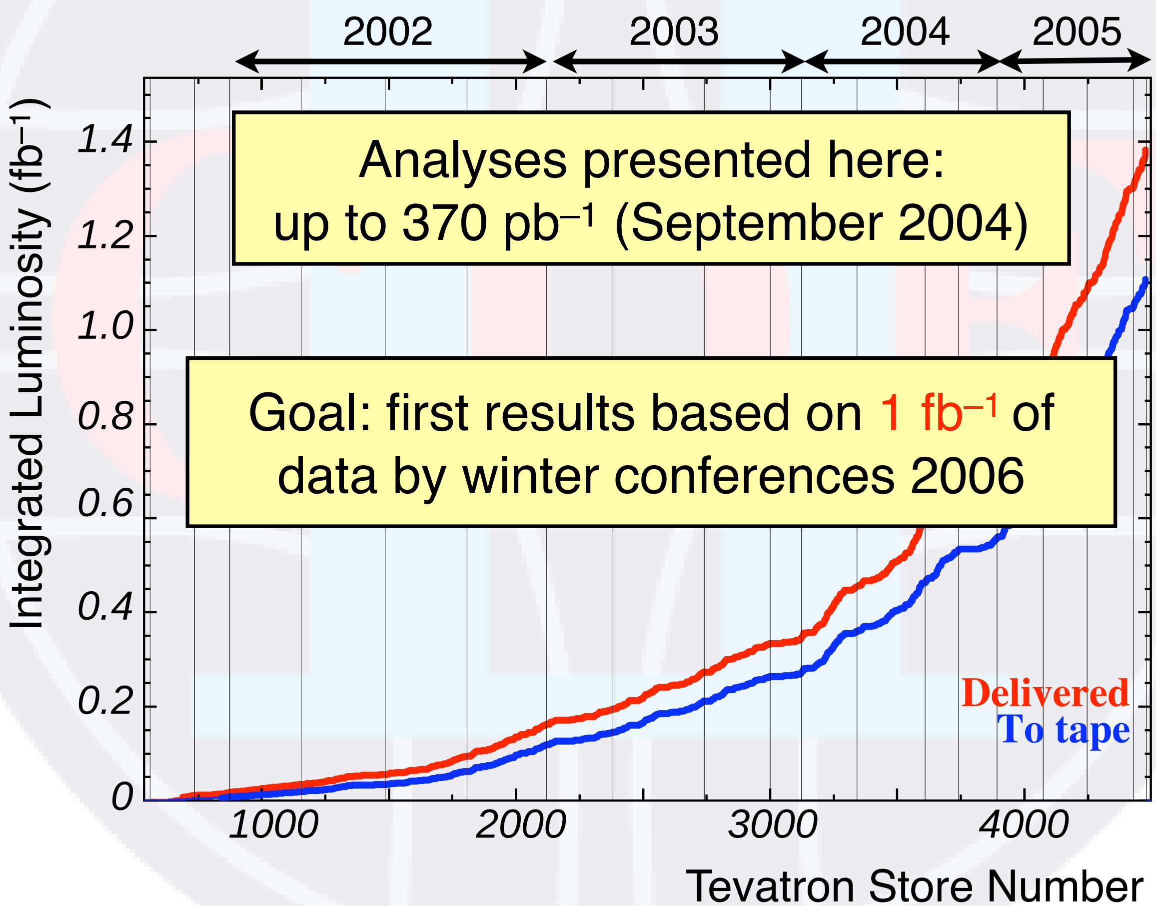
Tevatron Run II

- Proton-antiproton collider, $\sqrt{s}$ = 1.96 TeV
- 36×36 bunches
- Collisions every 396 ns
- Record instantaneous peak luminosity: $1.67 \times 10^{32}\ cm^{-2}\ s^{-1}$ → 3 top pairs/hour
- Luminosity goals:
  - Instantaneous: $(2–4) \times 10^{32}\ cm^{-2}\ s^{-1}$
  - Integrated: 4–8 fb^{-1} until 2009
- Two multi-purpose experiments: CDF & D0



Integrated Luminosity

- More than 1.4 fb^{-1} delivered, more than 1.1 fb^{-1} recorded by CDF



The CDF II Collaboration

CDF authorlist:
544 authors from 53 institutions in 11 nations

Canada
McGill Univ.
Univ. of Toronto

USA
Argonne National Laboratory
Brandeis Univ.,MS
Univ. of Chicago,IL
Davis UC,CA
Duke Univ.,NC
FNAL,IL
Univ. of Florida,FL
Harvard Univ.,MA
Univ. of Illinois,IL
The Johns Hopkins Univ.,MD
LBNL,CA
MIT,MA
Michigan State Univ.,MI
Univ. of Michigan,MI
Univ. of New Mexico,NM
The Ohio State Univ.,OH
Univ. of Pennsylvania,PA
Univ. of Pittsburgh,PA
Purdue Univ.,IN
Univ. of Rochester,NY
Rockefeller Univ.,NY
Rutgers Univ.,NJ
Texas A&M Univ.,TX
Texas Tech Univ.,TX
Tufts Univ.,MA
UCLA,CA
Univ. of Wisconsin,WI
Yale Univ.,CT

Russia
JINR, Dubna
ITEP, Moscow

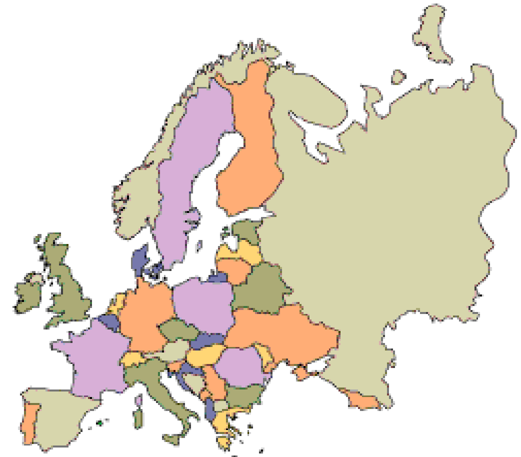
Germany
Univ. Karlsruhe

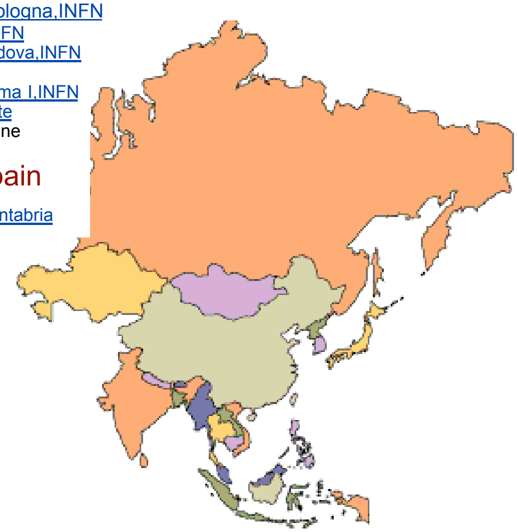
Switzerland
Univ. of Geneva

UK
Glasgow Univ.
Univ. of Liverpool
Univ. of Oxford
Univ. College London

Italy
Univ. of Bologna,INFN
Frascati, INFN
Univ. di Padova,INFN
Pisa, INFN
Univ. di Roma I,INFN
INFN-Trieste
Univ. di Udine

Spain
Univ. of Cantabria



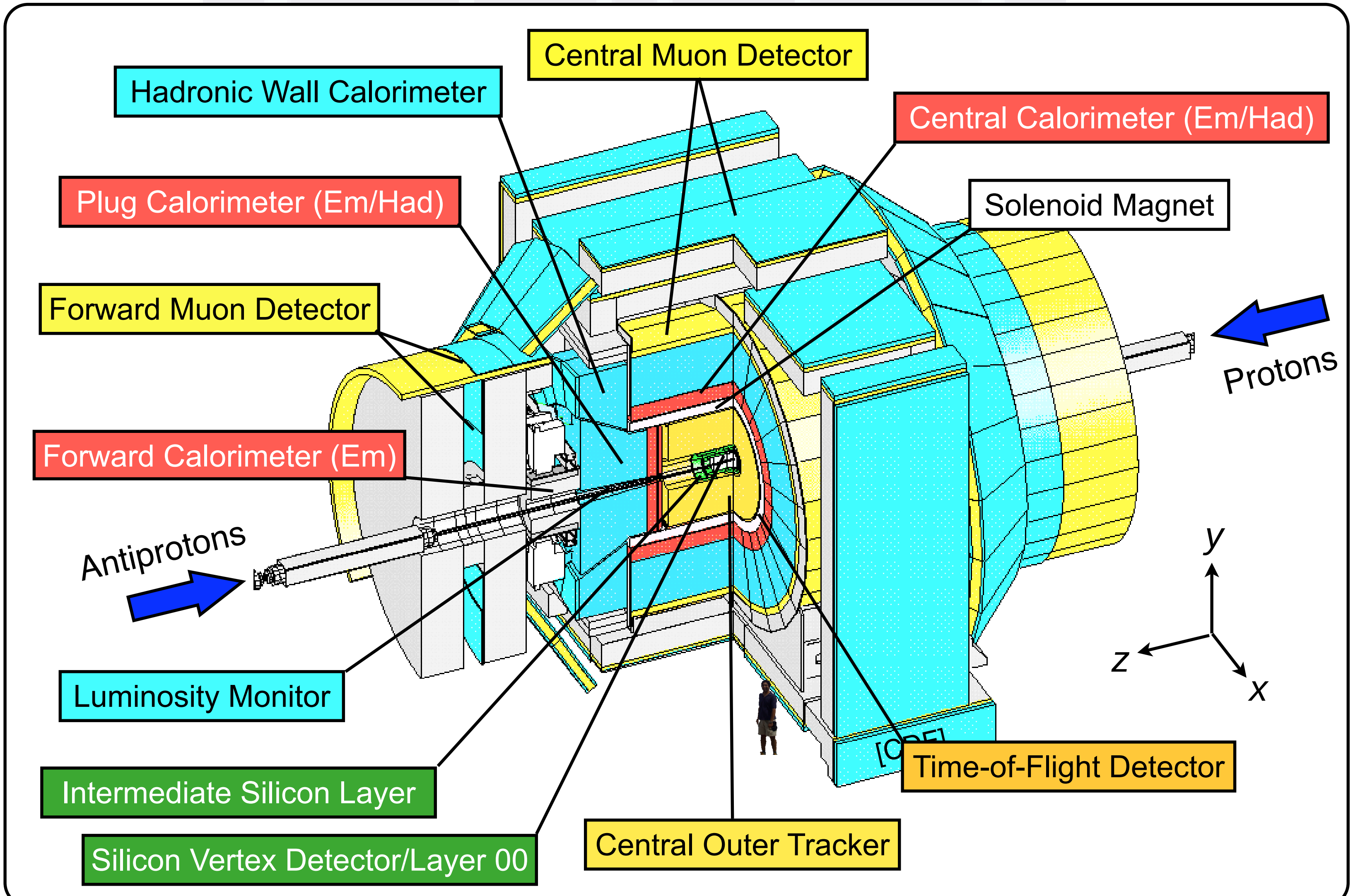


Korea
KHCL

Japan
Hiroshima Univ.
KEK
Osaka City Univ.
Univ. of Tsukuba
Waseda Univ., Tokyo

Taiwan
Academia Sinica, Taipei

The CDF Detector



The Road to the Top

The CDF-II Detector at the Tevatron

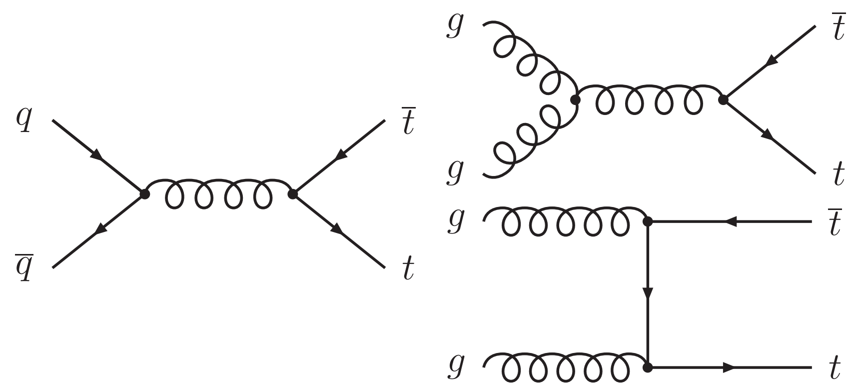
How to Find Top Quarks

Top Properties

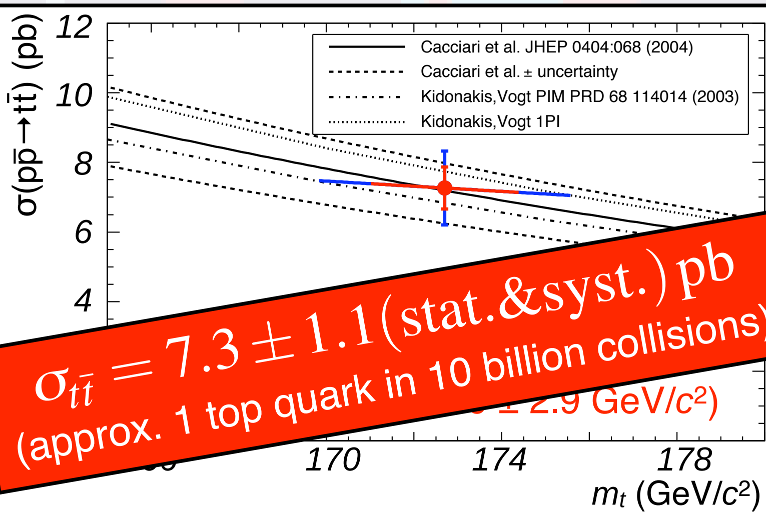
Summary

Top Pair Production: QCD

$p\bar{p}$ collisions at $\sqrt{s}$ = 1.96 TeV:

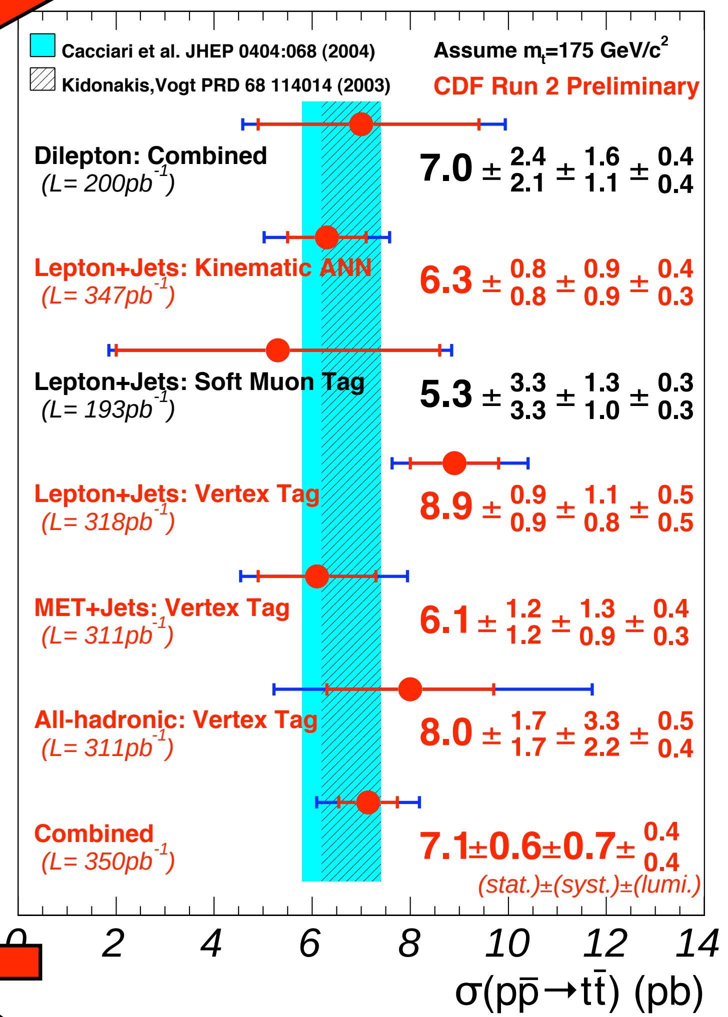


85% $q\bar{q}$ annihilation   15% gluon-gluon fusion



$$\sigma_{t\bar{t}} = 7.3 \pm 1.1\,(\text{stat.\&syst.})\ \text{pb}$$

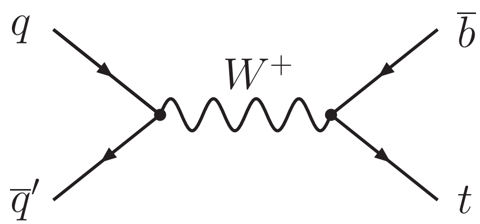
(approx. 1 top quark in 10 billion collisions)



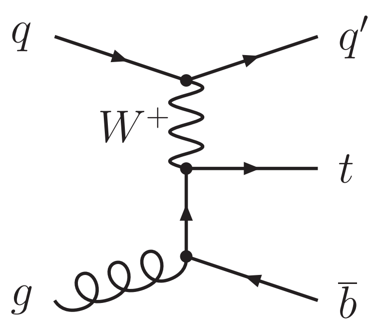
Single Top Production

Theoretical Predictions:

s channel: $\sigma_s = 0.88 \pm 0.11\,\text{pb}$

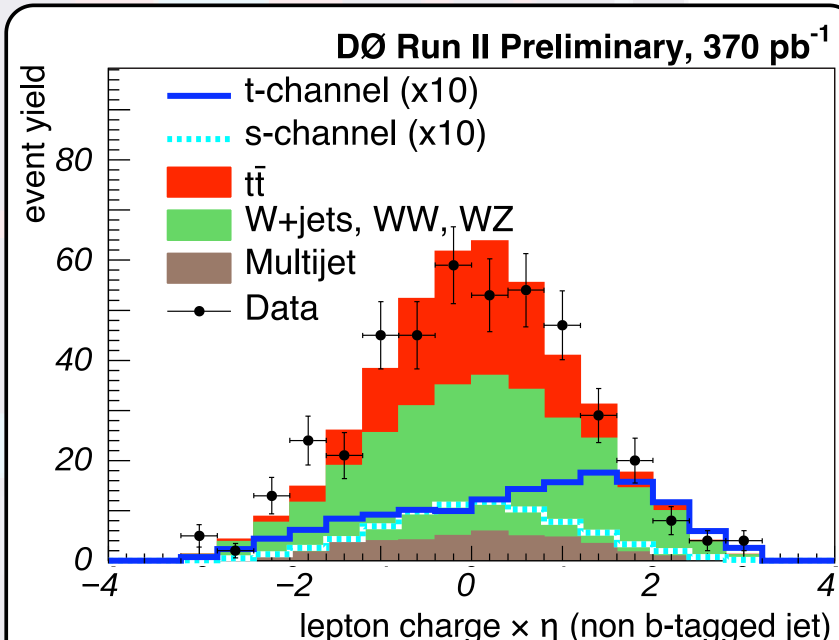


t channel: $\sigma_t = 1.98 \pm 0.25\,\text{pb}$

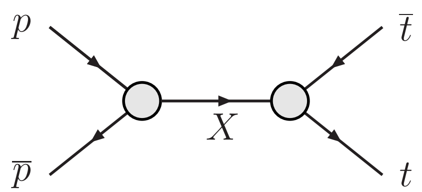


Heading for discovery:
3σ evidence expected
with 1–2 fb^{-1}

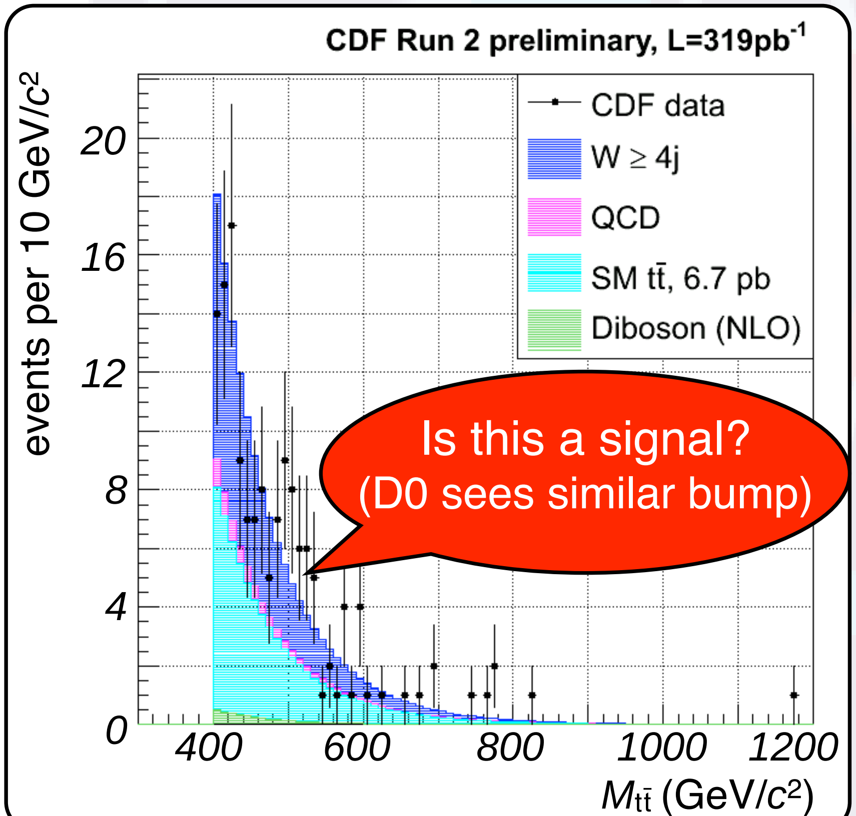
- Electroweak single top production: not yet observed
- Current best cross-section limits at 95% C.L. (D0):
  $\sigma_s < 5.0\,\text{pb}$ $\sigma_t < 4.4\,\text{pb}$



Decay of a Heavy Resonance?



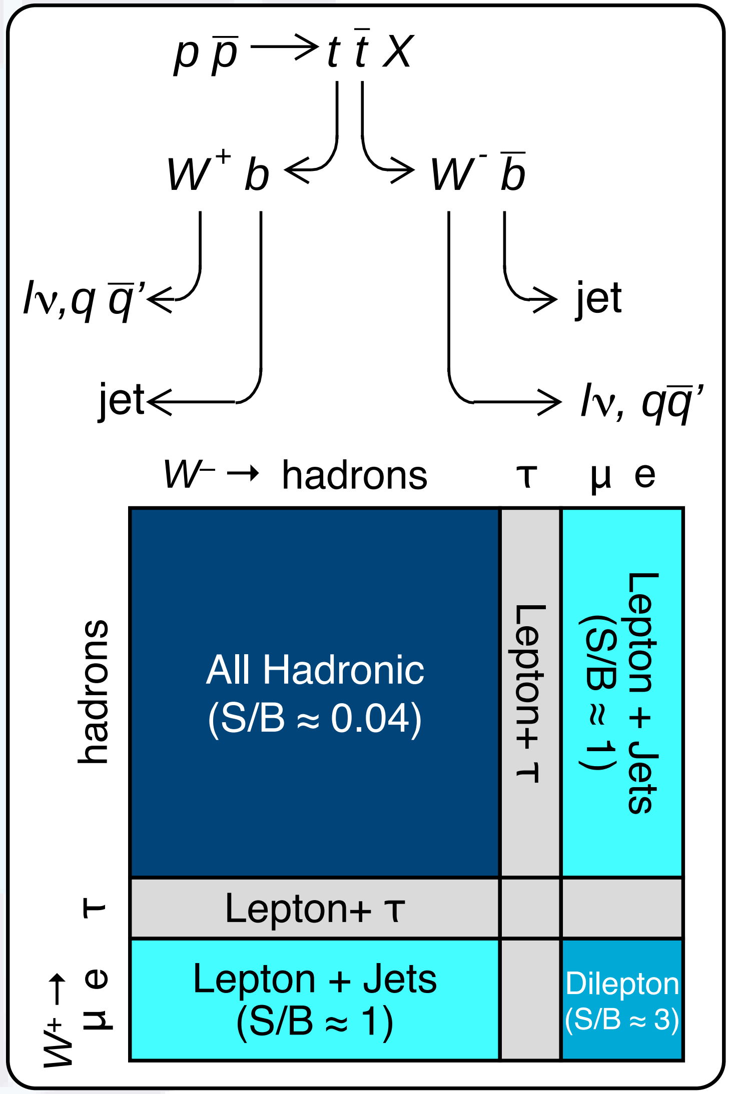
$t\bar{t}$ production from heavy resonance X



- Top quark important for electroweak symmetry breaking:
  - Heavy top due to new strong dynamics? → $t\bar{t}$ condensate
  - Example: top-color assisted technicolor models (C.T. Hill, Phys. Lett. **B345** (1995) 483)
- CDF: measure $t\bar{t}$ mass spectrum by matrix element method

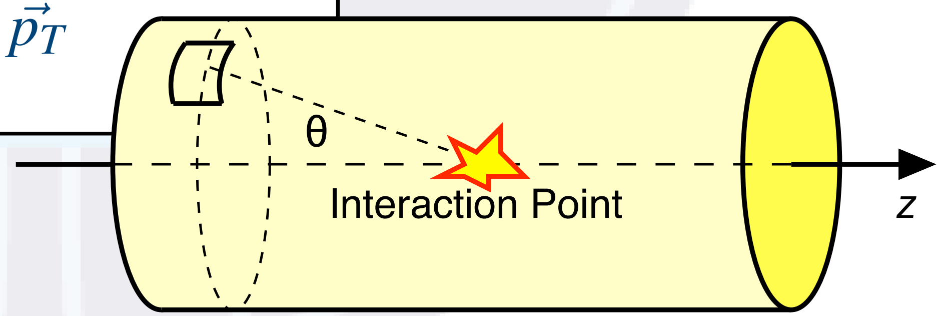
Top Decay Channels

- Standard Model:
  BR(t →Wb) ≥ 99.8%
- Final state: 2 W, 2 b jets
- Decay signatures characterized by W decays:
  - All hadronic: large BR, but large background
  - Tauonic: challenge of τ reconstruction
  - Lepton + jets: clean, kinematics fully determined
  - Dilepton: very clean, low BR



Hadron Collider Kinematics

- Cylindrical coordinate system:
  - θ: polar angle w.r.t. to proton direction
  - ϕ: azimuthal angle
  - Pseudorapidity:
    $\eta = -\ln\tan(\theta/2)$
  - Transverse energy:
    $$\vec{E}_T = \sum_{\text{cal towers}} E_i(\sin\theta_i, \phi_i)$$
  - Missing transverse energy ("MET"):
    $$\vec{\not{E}}_T = -\sum_{\text{jets}} \vec{E}_T - \sum_{\text{leptons}} \vec{p}_T$$

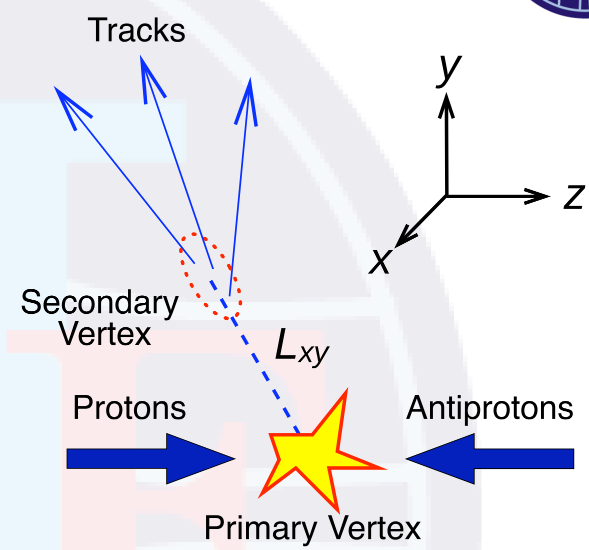


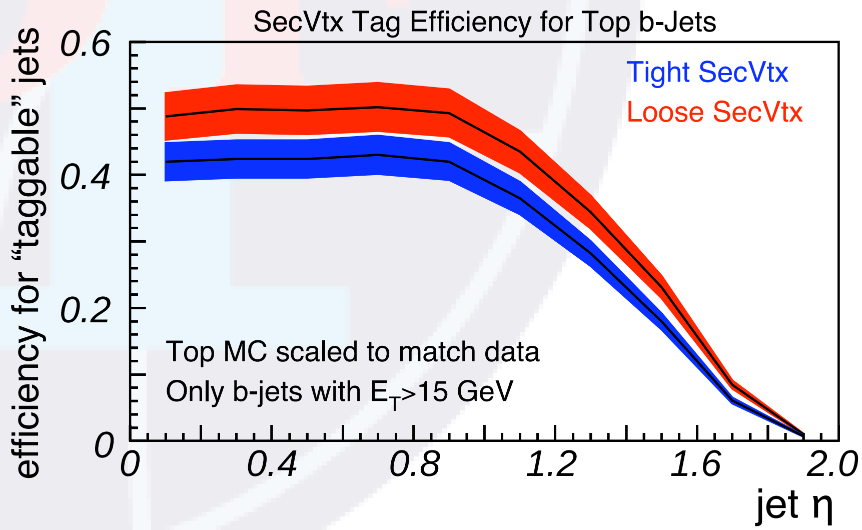
Typical Selection Criteria

- Lepton + Jets: $t\bar{t} \rightarrow Wb\ Wb \rightarrow l\nu b\ qq'b$
  - Isolated lepton with $p_T > 20$ GeV/c
  - Neutrino: missing E_T (“MET”) > 20 GeV
  - 3 jets within $|\eta| < 2$ with $E_T > 15$ GeV, 4th jet: $E_T > 8$ GeV
  - 0, 1, ≥ 2 identified jets from b quarks (“b-tags”)
- Dilepton: $t\bar{t} \rightarrow Wb\ Wb \rightarrow l\nu b\ l\nu b$
  - Two oppositely charged leptons with $p_T > 20$ GeV/c
  - Two neutrinos: MET > 25 GeV
  - ≥ 2 jets within $|\eta| < 2.5$ with $E_T > 15$ GeV
  - Scalar sum of lepton p_T’s, jet E_T’s and MET: $H_T > 200$ GeV
  - 0, 1, ≥ 2 b-tags

B-Tagging in CDF

- Main algorithm: "SecVtx"
  - Long lifetime of B mesons: detect secondary vertex
  - Discriminants: Significance of displacement in *xy* plane (L_{xy}) and impact parameter
- Further algorithms:
  - Jet probability tagger: probability of jet to come from primary vertex, derived from signed impact parameters of tracks
  - Soft lepton tagger: soft leptons from semileptonic *B* decays





The Road to the Top

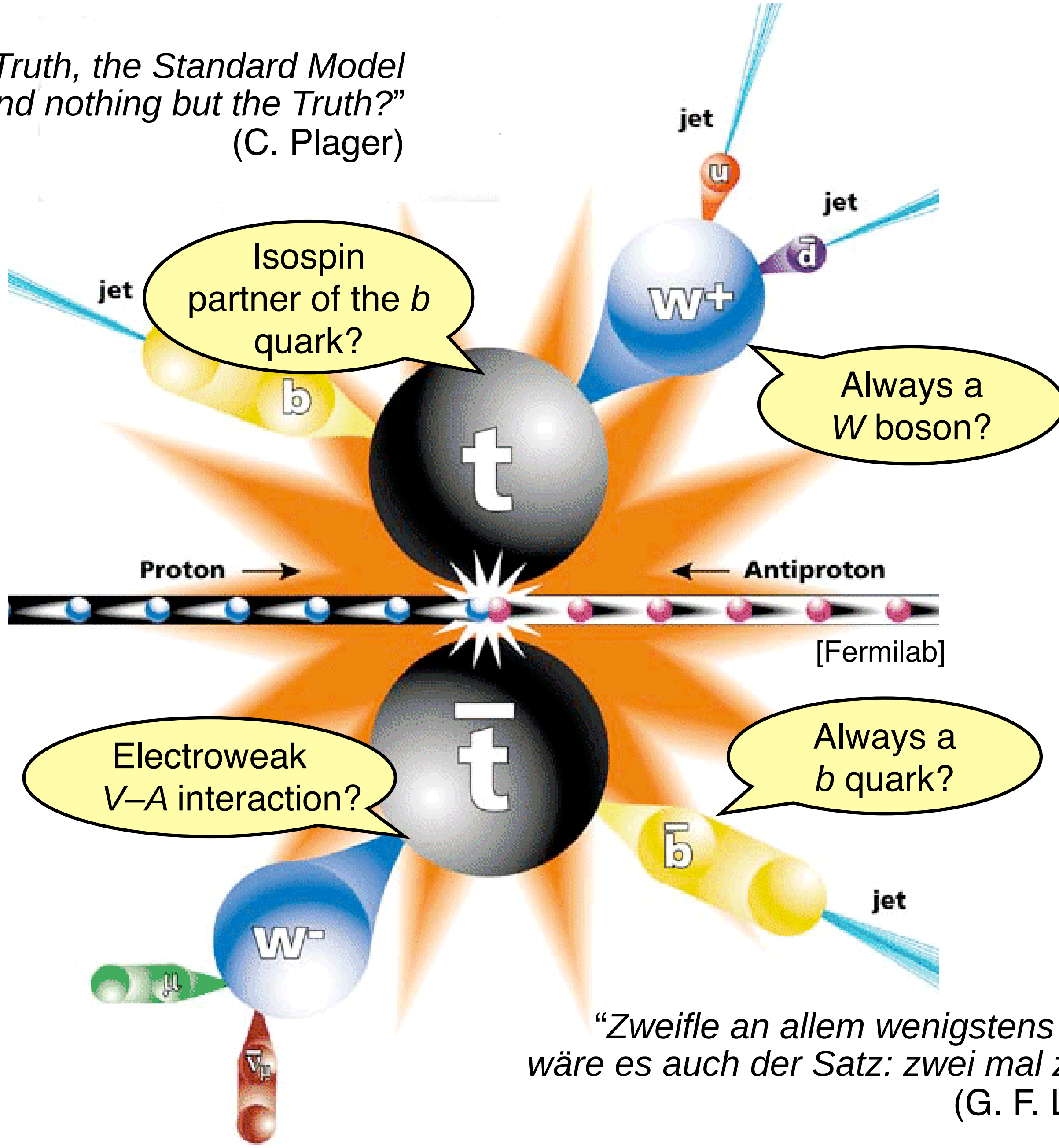
The CDF-II Detector at the Tevatron

How to Find Top Quarks

Top Properties

Summary

"Is it the Truth, the Standard Model Truth, and nothing but the Truth?"
(C. Plager)

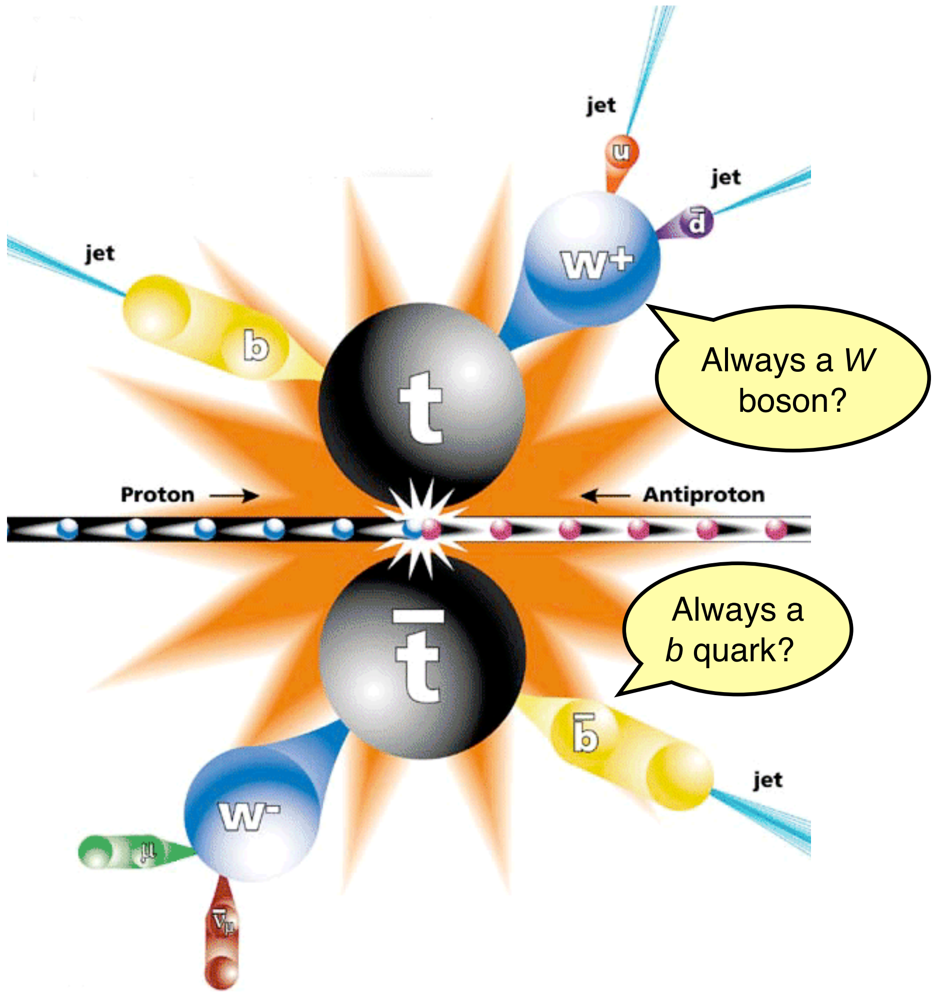


[Fermilab]

"Zweifle an allem wenigstens einmal, und wäre es auch der Satz: zwei mal zwei ist vier"
(G. F. Lichtenberg)

Questions: Part I

- Does top decay to Wb most of the time, i.e. the value of the CKM matrix element $|V_{tb}|$ close to unity?
- Does top sometimes decay into charged Higgs, as predicted in many SUSY models: $t \rightarrow H^+ b$?
- Are there anomalous couplings, e.g. top flavor-changing neutral currents (FCNC)



Measurement of V_{tb}

- $|V_{tb}|$ derived from unitarity of CKM matrix: $|V_{ub}|^2 + |V_{cb}|^2 + |V_{tb}|^2 = 1$
  - $|V_{ub}|$ and $|V_{cb}|$ known precisely from B meson decays
  - Unitary $|V_{tb}| = 0.999$ (90% C.L.)

The CKM Matrix

$$V_{\mathrm{CKM}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

- Tevatron: direct measurement of $|V_{tb}|$ from top decays:

$$R \equiv \frac{\mathrm{BR}(t \to Wb)}{\mathrm{BR}(t \to Wq)} = \frac{|V_{tb}|^2}{|V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2} \stackrel{?}{=} |V_{tb}|^2, \text{ with } q = d, s, b$$

- Idea: measure ratio R from relative rates of events with 0, 1, or 2 b-tags:
  - Any two ratios determine $R\,\epsilon_b$
  - Largely independent of cross section
  - Measure b-tagging eff. ϵ_b separately

Assuming no background:

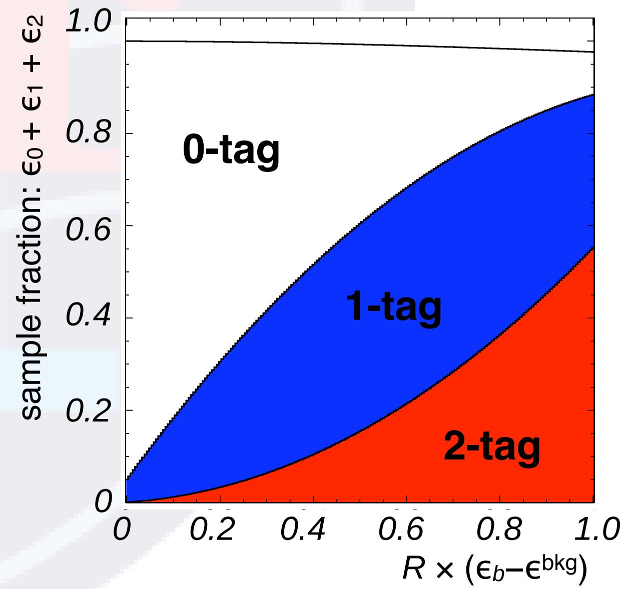
$$N_0 = N^{t\bar{t}} \varepsilon_0 = N^{t\bar{t}} (1 - R\varepsilon_b)^2$$
$$N_1 = N^{t\bar{t}} \varepsilon_1 = N^{t\bar{t}} (2R\varepsilon_b)(1 - R\varepsilon_b)$$
$$N_2 = N^{t\bar{t}} \varepsilon_2 = N^{t\bar{t}} (R\varepsilon_b)^2$$

Measurement of V_{tb}

- Data samples: Dilepton and Lepton + Jets with 0,1,2 jets, integrated luminosity: $\int L\,dt = 162\ \text{pb}^{-1}$
- Construct likelihood function: compare number of observed and expected events for i = 0,1,2 b-tags

$$N_i^{\text{exp}} = N^{t\bar{t}} \cdot \varepsilon_i(R) + N_i^{\text{bkg}} \quad \text{with } N^{t\bar{t}} = \sum_i N_i^{\text{obs}} - N_i^{\text{bkg}}$$

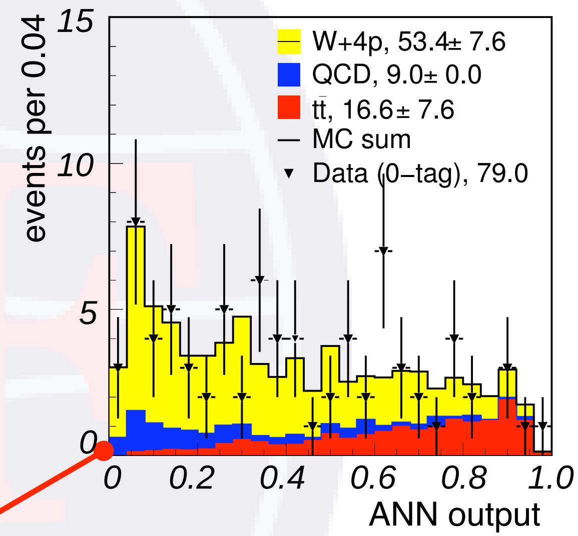
- Challenge 1: Determine efficiency $\epsilon_i(R)$ to observe i b-tags
  - Ingredients: efficiencies to tag b-jets, c-jets, QCD background, ...
  - Parametrization of $\epsilon_i(R)$: $R \times (\epsilon_b - \epsilon^{\text{bkg}})$



V_{tb}: Background Estimate

- Challenge 2: estimate expected number of background events, N_i^{bkg}
  - A-priori estimate: collection of data-driven and Monte Carlo methods
  - 0-tag sample in Lepton + Jets: no a-priori estimate available by construction → artificial neural network (ANN)

ANN Output for 0-tag L+J

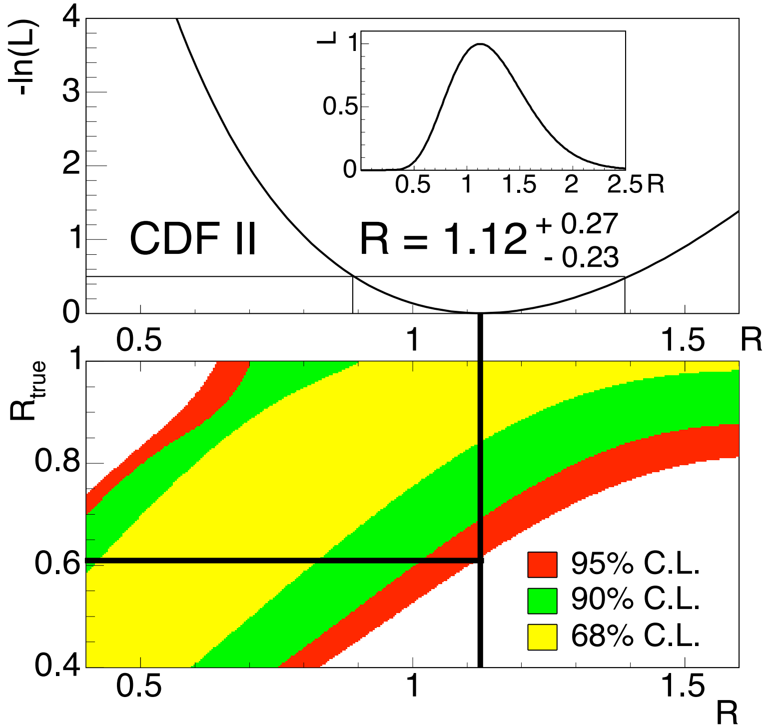


Dilepton	**0-tag**	**1-tag**	**2-tag**
$\varepsilon_i(R=1)$	0.47 ± 0.03	0.43 ± 0.02	0.10 ± 0.02
N^{bkg} (a priori)	2.0 ± 0.6	0.2 ± 0.1	< 0.01
N^{exp}	6.1 ± 0.4	4.0 ± 0.2	0.9 ± 0.2
N^{obs}	5	4	2

Lepton + Jets	**0-tag**	**1-tag**	**2-tag**
$\varepsilon_i(R=1)$	0.45 ± 0.03	0.43 ± 0.02	0.12 ± 0.02
N^{bkg} (a priori)	N/A	4.2 ± 0.7	0.2 ± 0.1
N^{bkg} (ANN)	62.4 ± 9.0	5.8 ± 5.1	$0.1^{+1.0}_{-0.1}$
N^{exp}	80.4 ± 5.2	21.5 ± 4.1	5.0 ± 1.4
N^{obs}	79	23	5

Very good agreement

V_{tb}: Results



[D. Acosta *et al.*,
Phys. Rev. Lett. **91** (2005) 102002]

- Maximum of likelihood function driven to unphysical value > 1 by mild excess in double-tagged sample:

$$R = 1.12^{+0.21}_{-0.19}(\text{stat.})^{+0.17}_{-0.13}(\text{syst.})$$

- Feldman-Cousins limit:

$$R > 0.61 \ (95\% \ \text{C.L.})$$

- Assuming three generations of quarks and leptons:

$$|V_{tb}| > 0.78 \ (95\% \ \text{C.L.})$$

Questions: Part I

- Does top decay to Wb most of the time, i.e. the value of the CKM matrix element $|V_{tb}|$ close to unity?
- Does top sometimes decay into charged Higgs, as predicted in many SUSY models: $t \rightarrow H^{+}b$?
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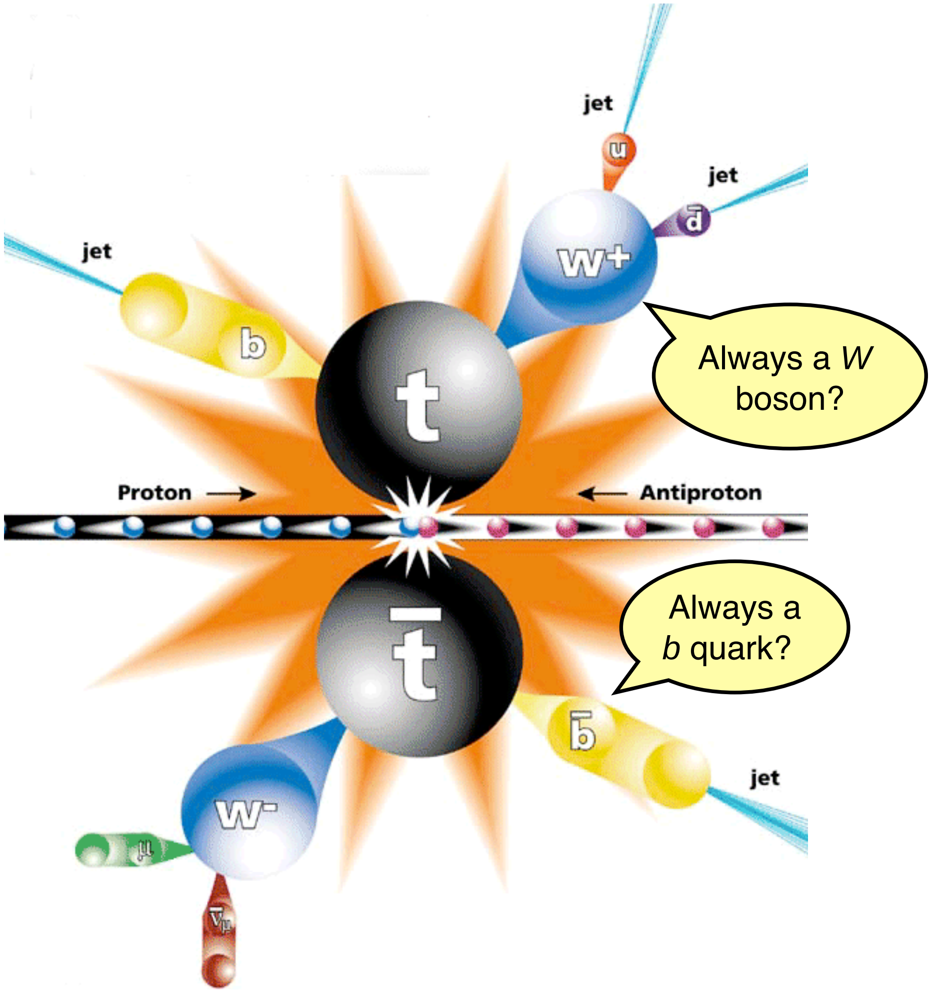
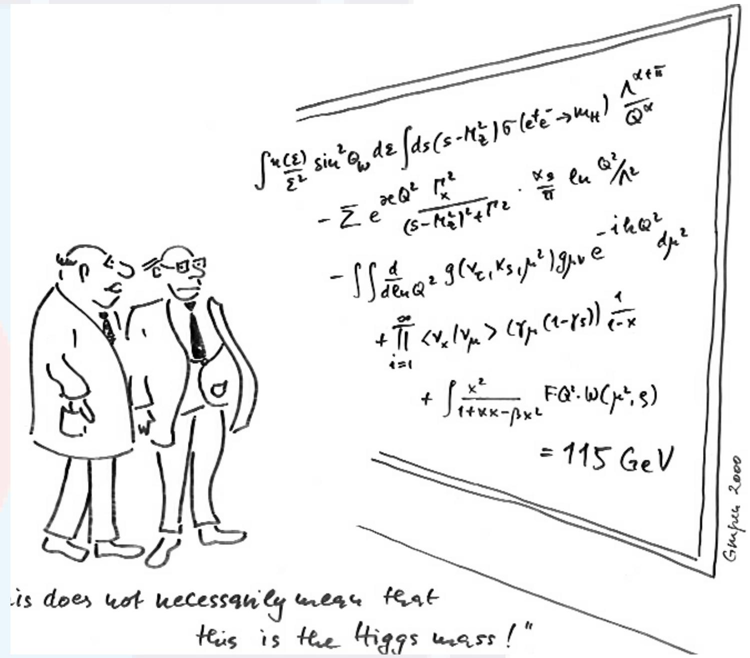


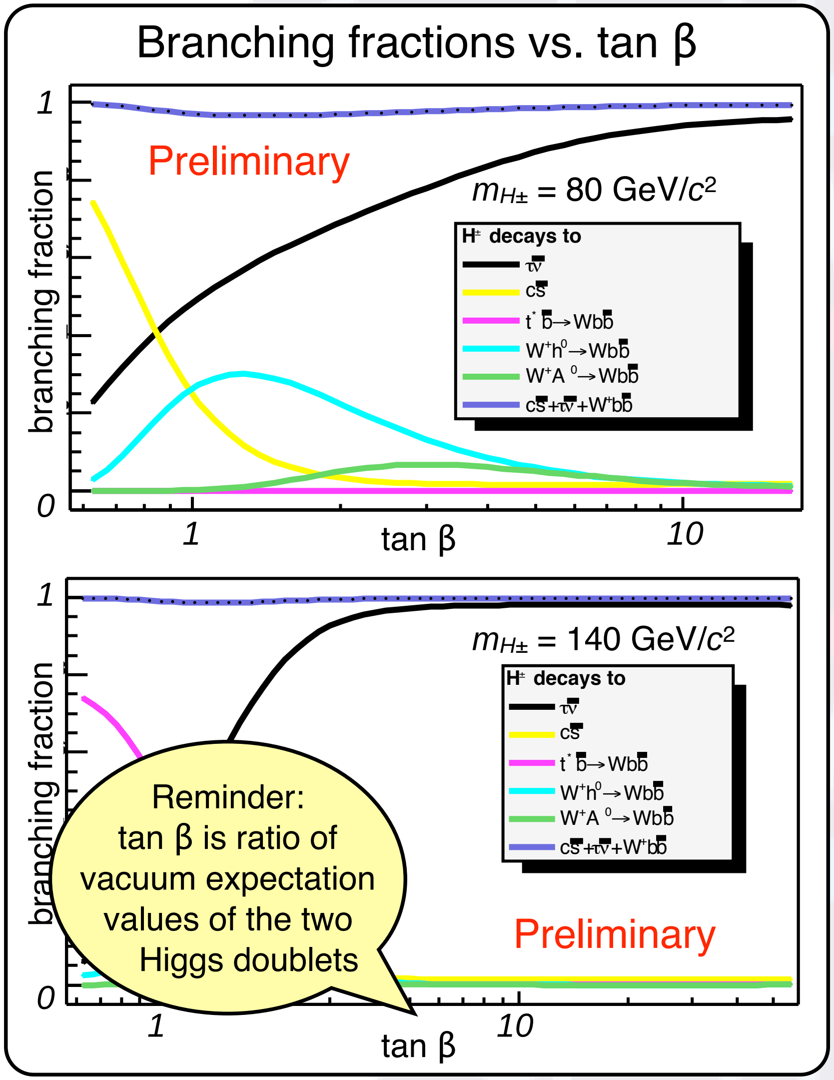
Search for Charged Higgs (I)

- Charged Higgs bosons appear in models with two Higgs doublets (MSSM etc.)
  - 5 physical Higgs bosons after electroweak symmetry breaking:
    - 3 neutral: h^0, H^0, A^0
    - 2 charged: $H^\pm$
  - Many new decay channels, e.g. $H^+ \to t^*\bar{b}$, $\tau^+\nu$, $c\bar{s}$, W^+h^0



- Presence of H^+ would change branching fractions of top decay channels → search for excesses or deficits:
  - $H^+ \to \tau^+\nu$: enhancement of Lepton + Tau channel
  - $H^+ \to c\bar{s}$: deficits in Lepton + Jets and Dilepton channels

Search for Charged Higgs (II)



- Assume 5 decay modes:
  - $t \to W^+b$ (Standard Model)
  - $t \to H^+b \to t^*\bar{b}b \to W^+b\bar{b}b$
  - $t \to H^+b \to \tau^+\nu b$
  - $t \to H^+b \to c\bar{s}b$
  - $t \to H^+b \to W^+h^0\bar{b}b \to W^+b\bar{b}b$
- Branching fractions for decay modes predicted for MSSM benchmark scenarios: CPsuperH
  - Important: includes full QCD, SUSY-electroweak and SUSY-QCD corrections
  - J.S. Lee *et al.*, Comput .Phys. Commun.156 (2004) 283

Charged Higgs: Results

- Data sample: Dilepton, Lepton + Jets (1 b-tag or ≥ 2 b-tags), Lepton + hadronic Tau
- Luminosity: $\int L\,dt = 193\ \text{pb}^{-1}$
- Calculation of expected number of events per channel:

$$N^{\text{exp}} = \varepsilon_{t\bar{t}}\, \underbrace{\sigma_{t\bar{t}}}_{\text{Theory}} \int L dt + \underbrace{N^{\text{bkg}}}_{\sigma_{t\bar{t}}\text{ Measurement}}$$

$$\varepsilon_{t\bar{t}} = \sum_{i,j=1}^{5} \underbrace{\text{BR}_i\,\text{BR}_j}_{\text{CPsuperH}}\ \underbrace{\varepsilon_{ij}(\Gamma_t, \Gamma_H, m_{H^\pm}, m_{h^0})}_{\text{Monte Carlo Simulation}}$$

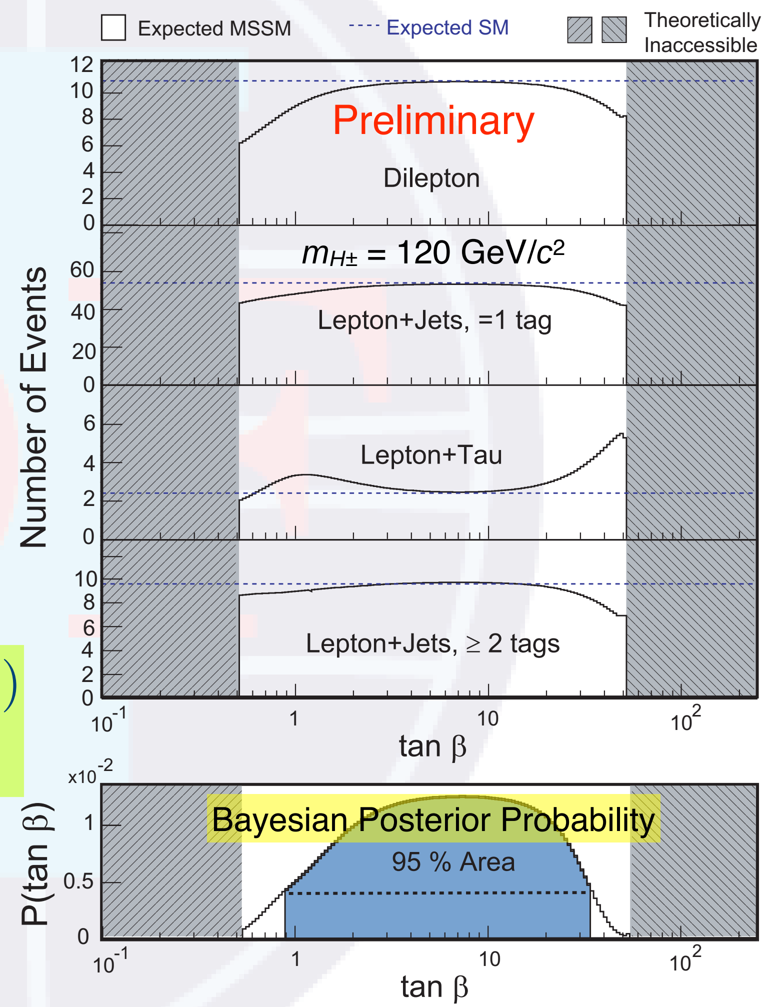
- SUSY scenario chosen:

$M_{\text{SUSY}} = 1000\,\text{GeV}/c^2$, $\mu = -500\,\text{GeV}/c^2$

$A_t = A_b = 2000\,\text{GeV}/c^2$, $A_\tau = 500\,\text{GeV}/c^2$

$M_2 = M_3 = M_Q = M_U = M_D = M_E = M_{\text{SUSY}}$,

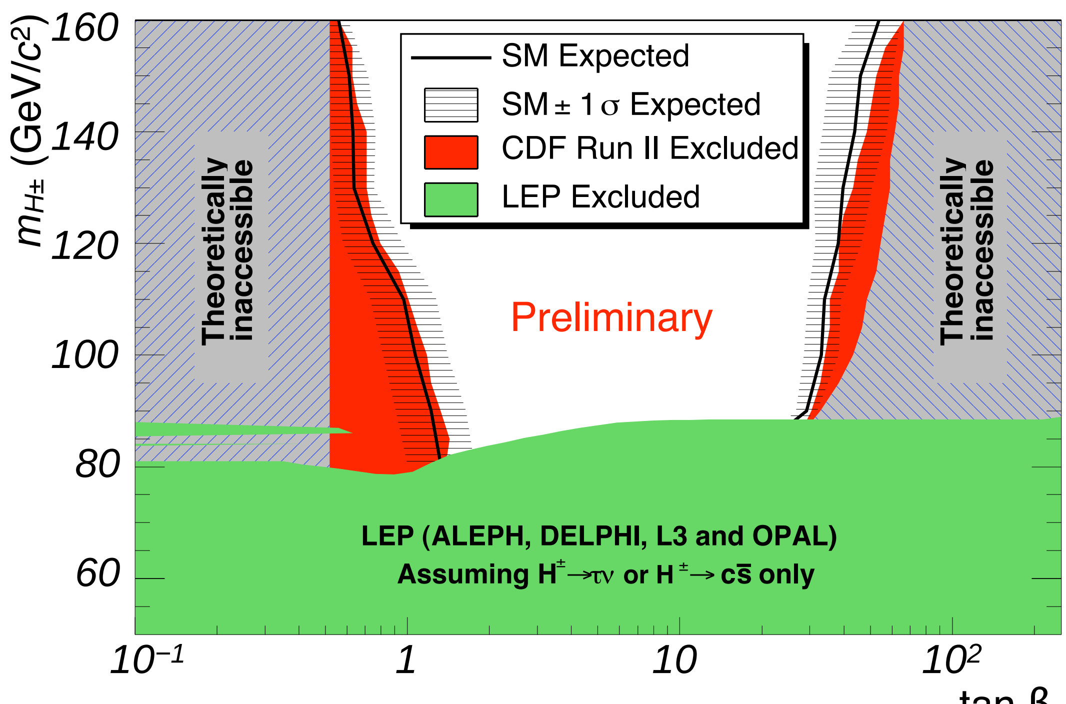
$M_1 = 0.498 M_2$



[hep-ex/0510065, submitted to PRL]

Charged Higgs: Limits

- No evidence of signal in 80 GeV/c^2 < $m_{H\pm}$ < 160 GeV/c^2
- Exclusion limits in ($m_{H\pm}$, tan β) plane:

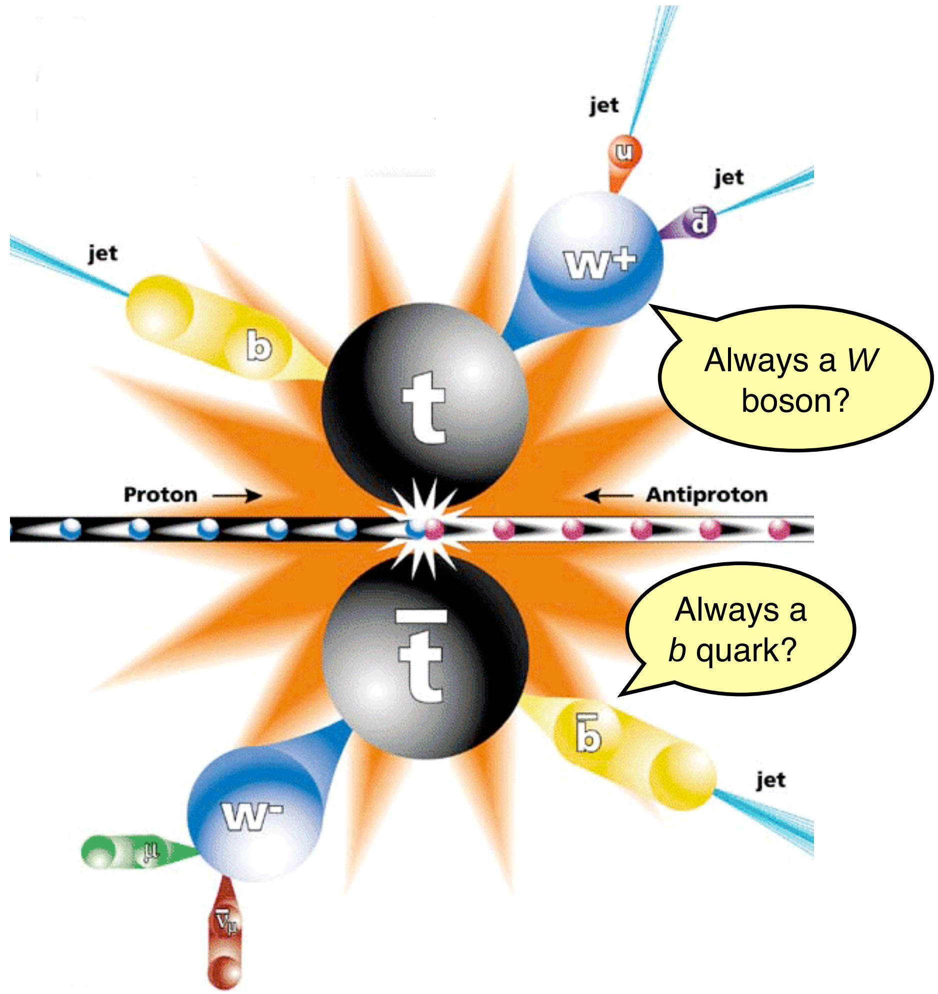


[hep-ex/0510065, submitted to PRL]

- Low tan β region excluded in all scenarios considered

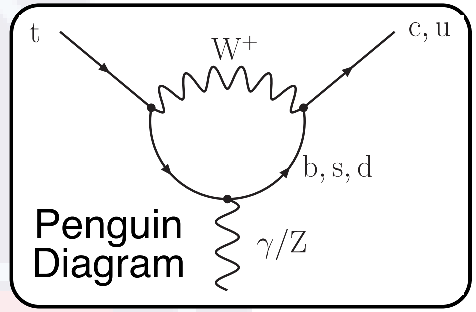
Questions: Part I

- Does top decay to Wb most of the time, i.e. the value of the CKM matrix element $|V_{tb}|$ close to unity?
- Does top sometimes decay into charged Higgs, as predicted in many SUSY models: $t \to H^+ b$?
- Are there anomalous couplings, e.g. top flavor-changing neutral currents (FCNC)



Search for FCNC

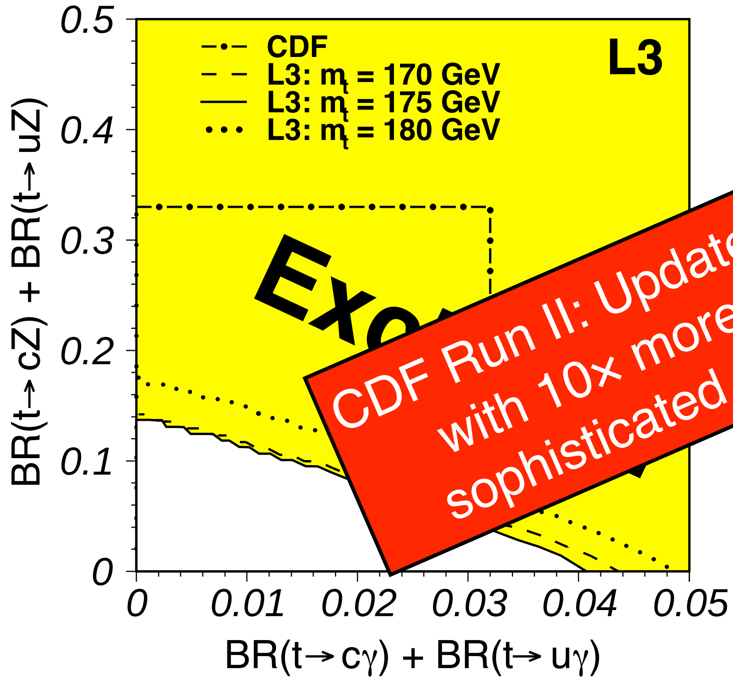
- Flavor-changing neutral currents (FCNC) are suppressed in the Standard Model:
  - Forbidden at tree level; suppressed by GIM mechanism, Cabibbo angle
  - FCNC possible e.g. via penguin diagrams, example: expected branching fraction for $t \to Zc$: as small as 10^{-14}
  - Any signal at the Tevatron: New Physics



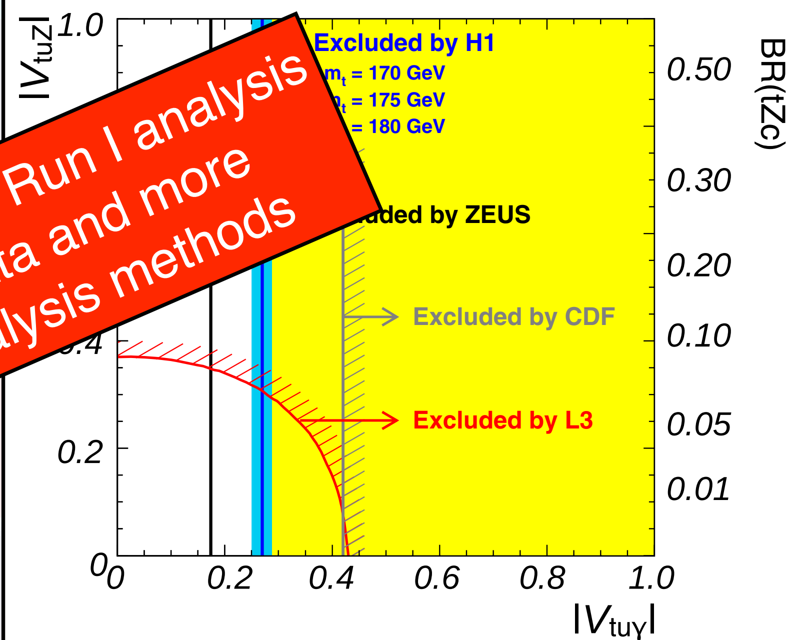
- CDF Run I: search for FCNC decays $t \to Zc$ (and $t \to \gamma c$):
  [F. Abe *et al.*, Phys. Rev. Lett. **80** (1998) 2525]
  - Decay channel: $t\bar{t} \to Zc\ Wb$; $W \to qq'$, $Z \to l^+l^-$
  - Limit: < 6.5 events at 95% C.L. → $BR(t \to Zc) < 33\%$
- Meanwhile: better limits from searches for single top production at LEP and HERA

FCNC: Current Best Limits

LEP: L3



HERA:



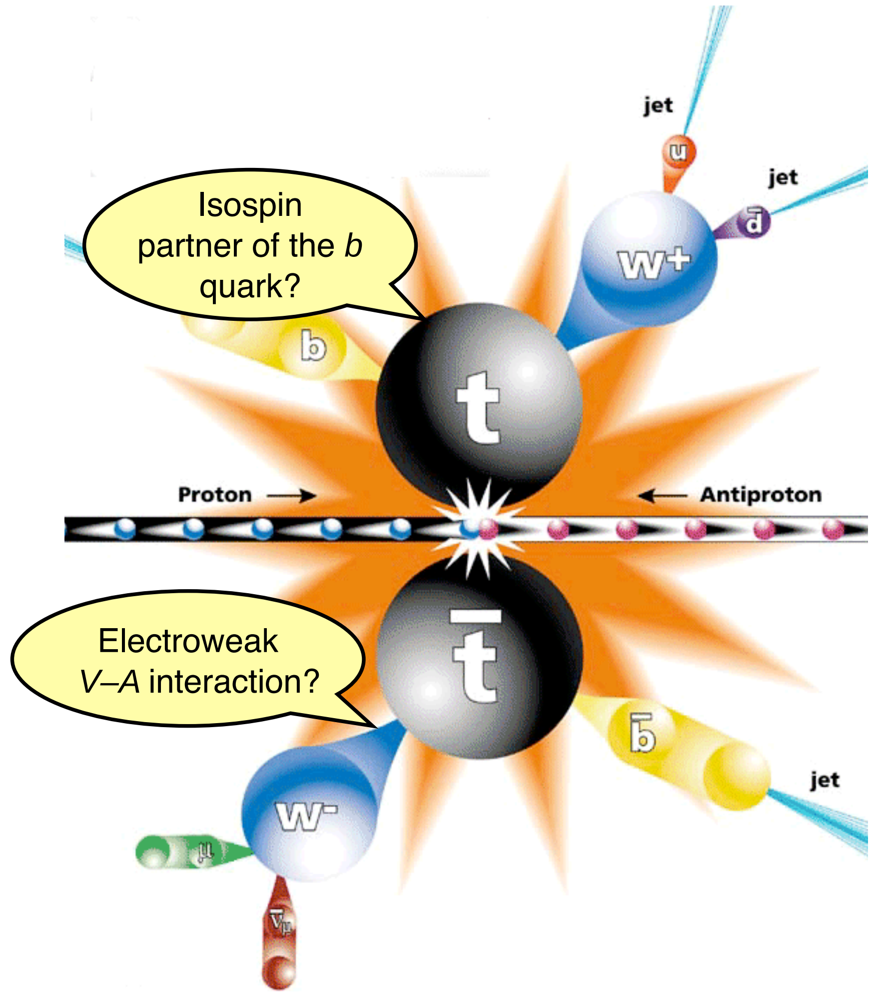
CDF Run II: Update of Run I analysis with 10× more data and more sophisticated analysis methods

From H1 paper:

Abstract. [...] In the leptonic channel, 5 events are found while 1.31 ± 0.22 events are expected from the Standard Model background. In the hadronic channel, no excess above the expectation for Standard Model processes is found. [...]

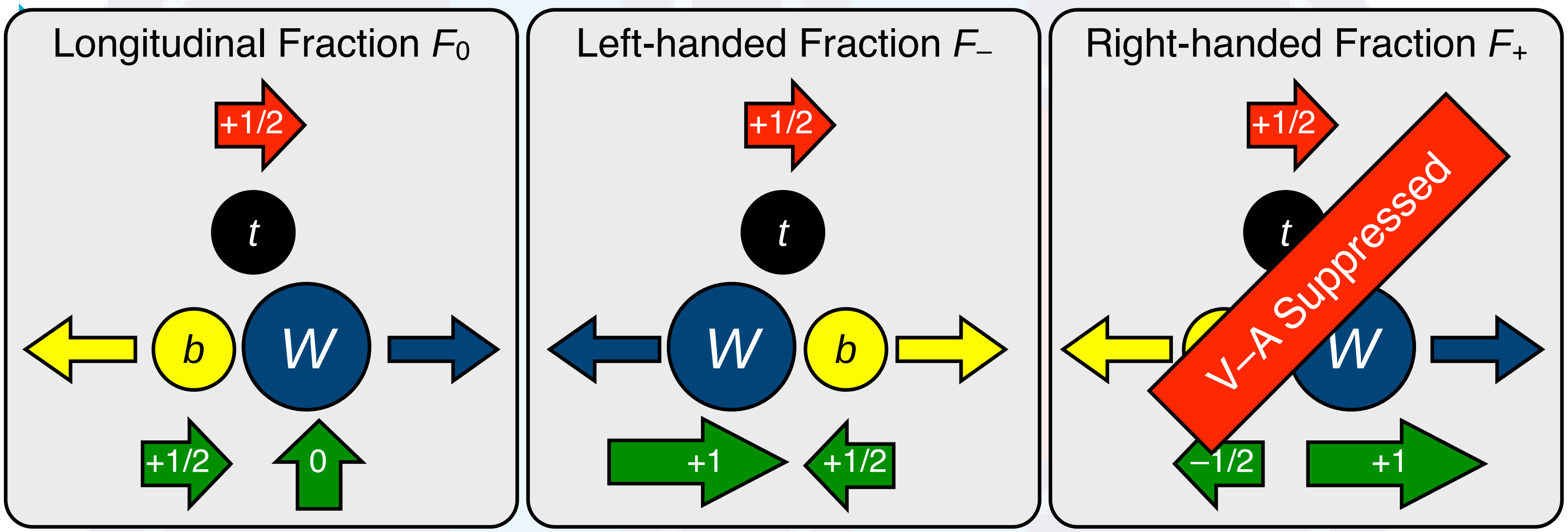
Questions: Part II

- Is the *W* helicity as expected in the Standard model (70% longitudinal, 30% left-handed)?
- More generic: are the kinematics of top events consistent with the Standard Model?



W Helicity in Top Decays

- Measurement of W helicity: stringent test of V–A structure of Standard Model close to EWSB scale

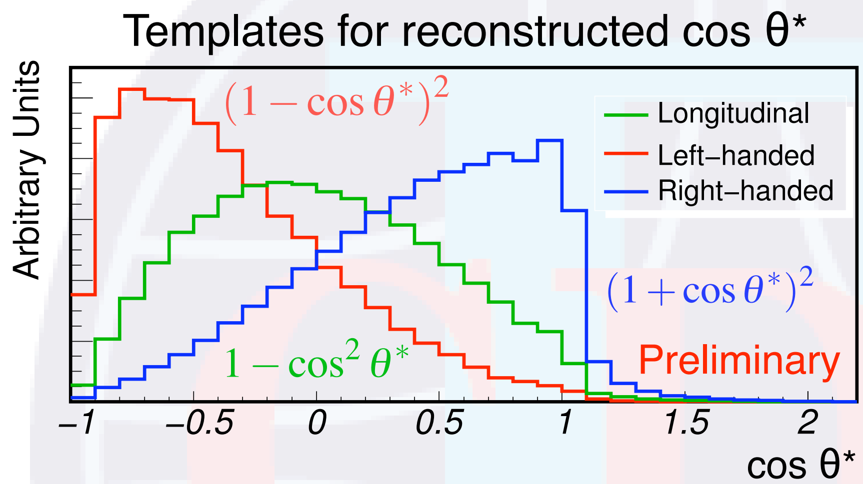


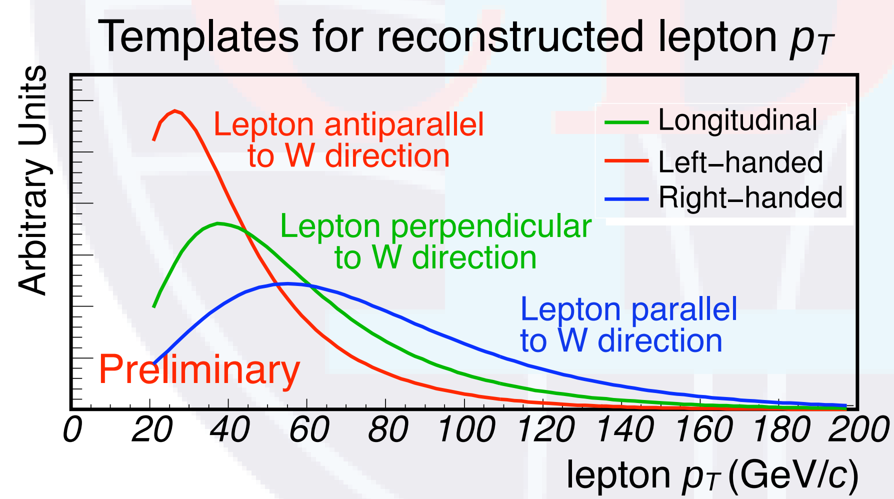
Standard Model: 0.7	Standard Model: 0.3	Standard Model: 0.0

$$F_0 = \frac{m_t^2}{2M_W^2 + m_t^2}$$

Longitudinal degree of freedom:
Goldstone mode of Higgs field
→ strong Yukawa coupling to top quark

How to Measure W Helicity





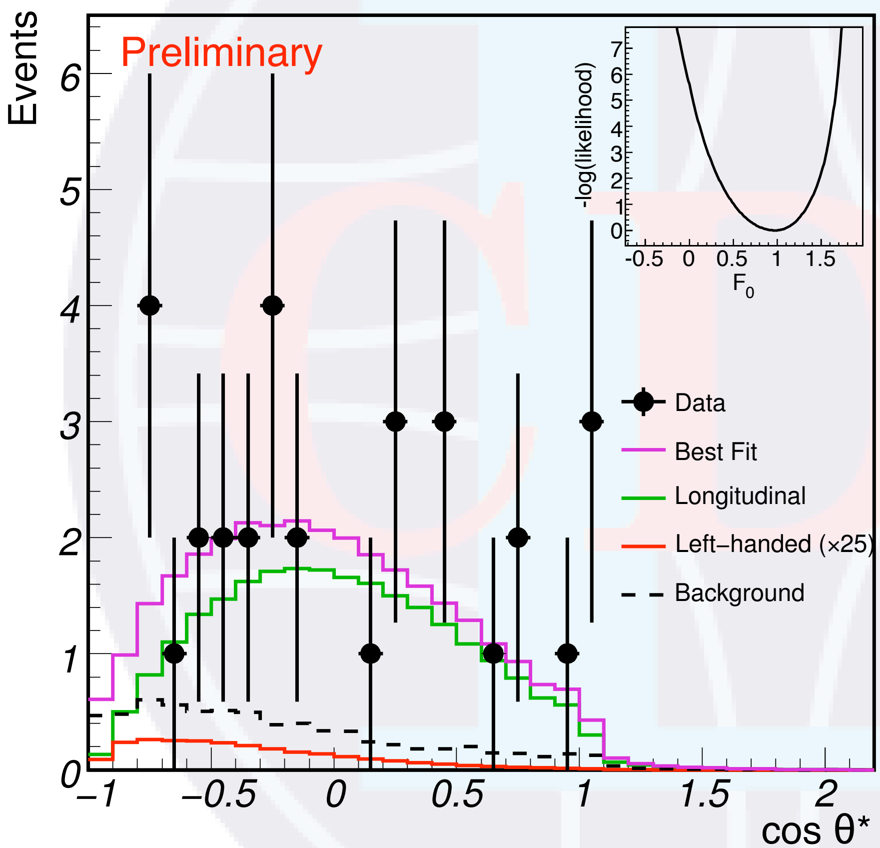
[hep-ex/0511023, submitted to PRL]

- Based on charged lepton from $W \to l\nu$
  - Method 1: distribution of decay angles θ* of charged lepton w.r.t. top direction in W rest frame, approximated by lepton–b-jet mass:

$$\cos\theta^* \approx \frac{2M_{lb}^2}{m_t^2 - M_W^2}$$

  - Method 2: transverse momentum spectrum of charged lepton in laboratory frame

W Helicity: cos θ* Results



[hep-ex/0511023, submitted to PRL]

- cos θ* results based on Lepton + Jets sample ($\int L\,dt = 200\ \mathrm{pb}^{-1}$, 31 events)
- Analysis limited by statistics: fix one parameter to Standard model value, fit other parameter, results:

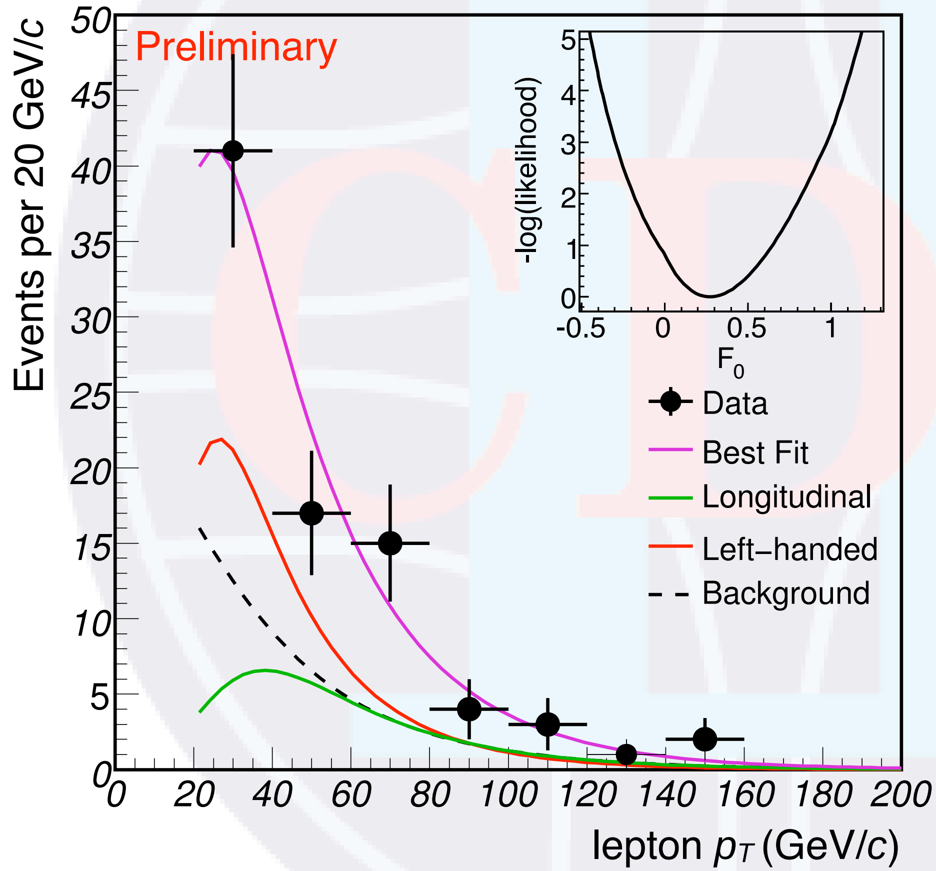
$$F_0 = 0.99^{+0.29}_{-0.35} \pm 0.19$$

$$F_+ = 0.23 \pm 0.16 \pm 0.08$$

(Standard Model: F_0 = 0.7, F_+=0.0)

W Helicity: Lepton p_T Results

Combined (Lepton + Jets & Dilepton):
fit to F_0 (F_+ fixed to 0%)



[hep-ex/0511023, submitted to PRL]

- Dilepton and Lepton + Jets, $\int L\, dt$ = 200 pb⁻: 83 events
- Fit results (also here: other parameter fixed to Standard Model value):

$$F_0 = 0.31^{+0.37}_{-0.23} \pm 0.17$$

$$F_+ = -0.18^{+0.14}_{-0.12} \pm 0.12$$

- Reason for unphysical negative value of F_+: lepton p_T spectrum in dilepton sample too soft

W Helicity: Combined Result

- Combination of cos θ* and lepton p_T results (including correlations in statistical and systematic uncertainties):

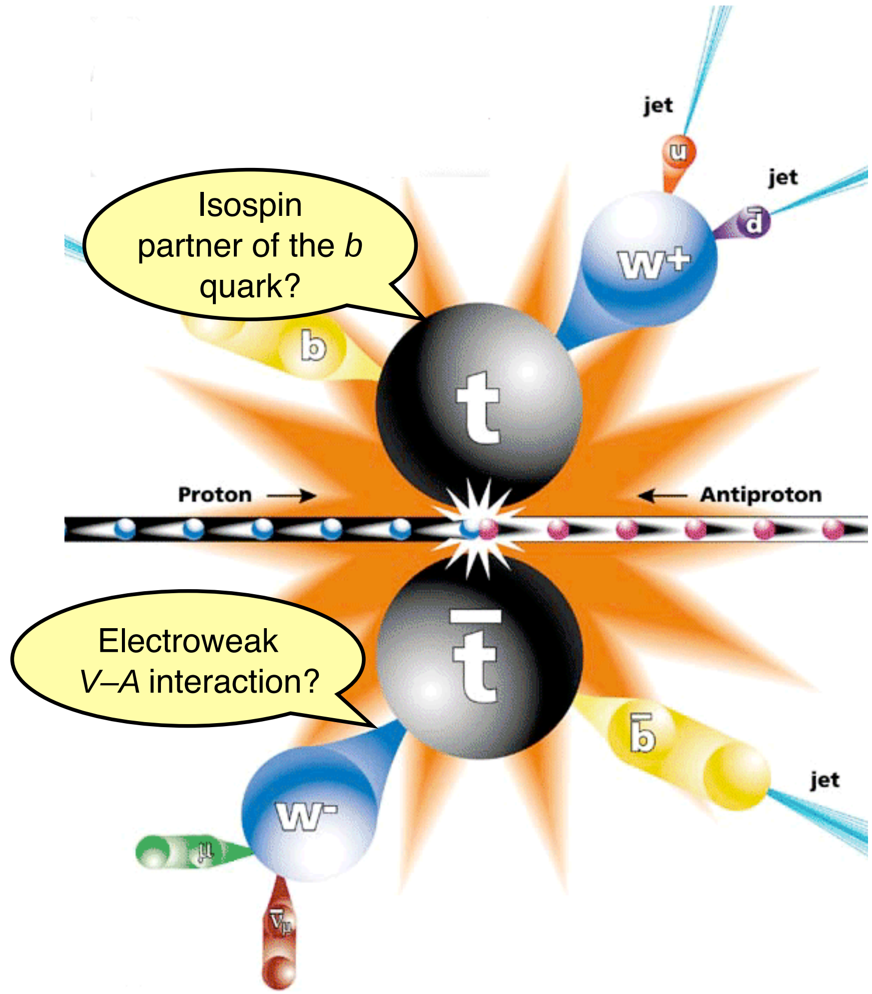
$$F_0 = 0.74^{+0.22}_{-0.34}(\text{stat.}\,\&\,\text{syst.})$$
$$F_+ = 0.00^{+0.20}_{-0.19}(\text{stat.}\,\&\,\text{syst.})$$

→ consistent with Standard Model values (F_0 = 0.7, F_+=0.0)

- Feldman-Cousins upper limit on F_+: $F_+ < 0.27\,(95\%\,\text{C.L.})$
- Other results:
  - D0 Lepton + Jets (230 pb^{-1}): $F_+ < 0.25$ (95% C.L.)
    [V. M. Abazov *et al.*, Phys. Rev. **D72** (2005) 011104]
  - CDF Run I combination (109 pb^{-1}): $F_+ < 0.18$ (95% C.L.)
    [D. Acosta *et al.*, Phys. Rev. **D71** (2005) 031101]

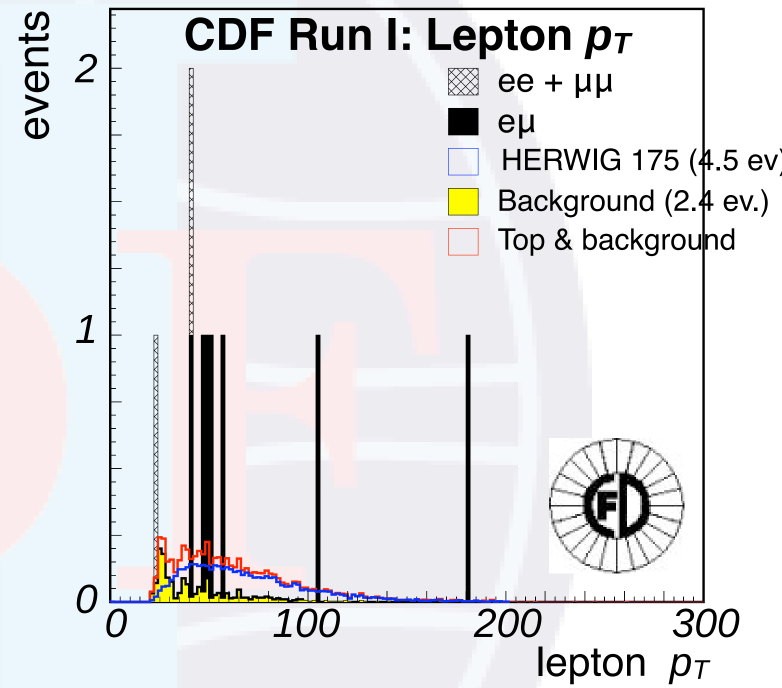
Questions: Part II

- Is the *W* helicity as expected in the Standard model (70% longitudinal, 30% left-handed)?
- More generic: are the kinematics of top events consistent with the Standard Model?



Anomalous Kinematics?

- Anomalies observed in CDF Run I:
  - Excess of large missing transverse energy and large lepton p_T
  - Flavor asymmetry in dilepton sample: excess of eμ combinations

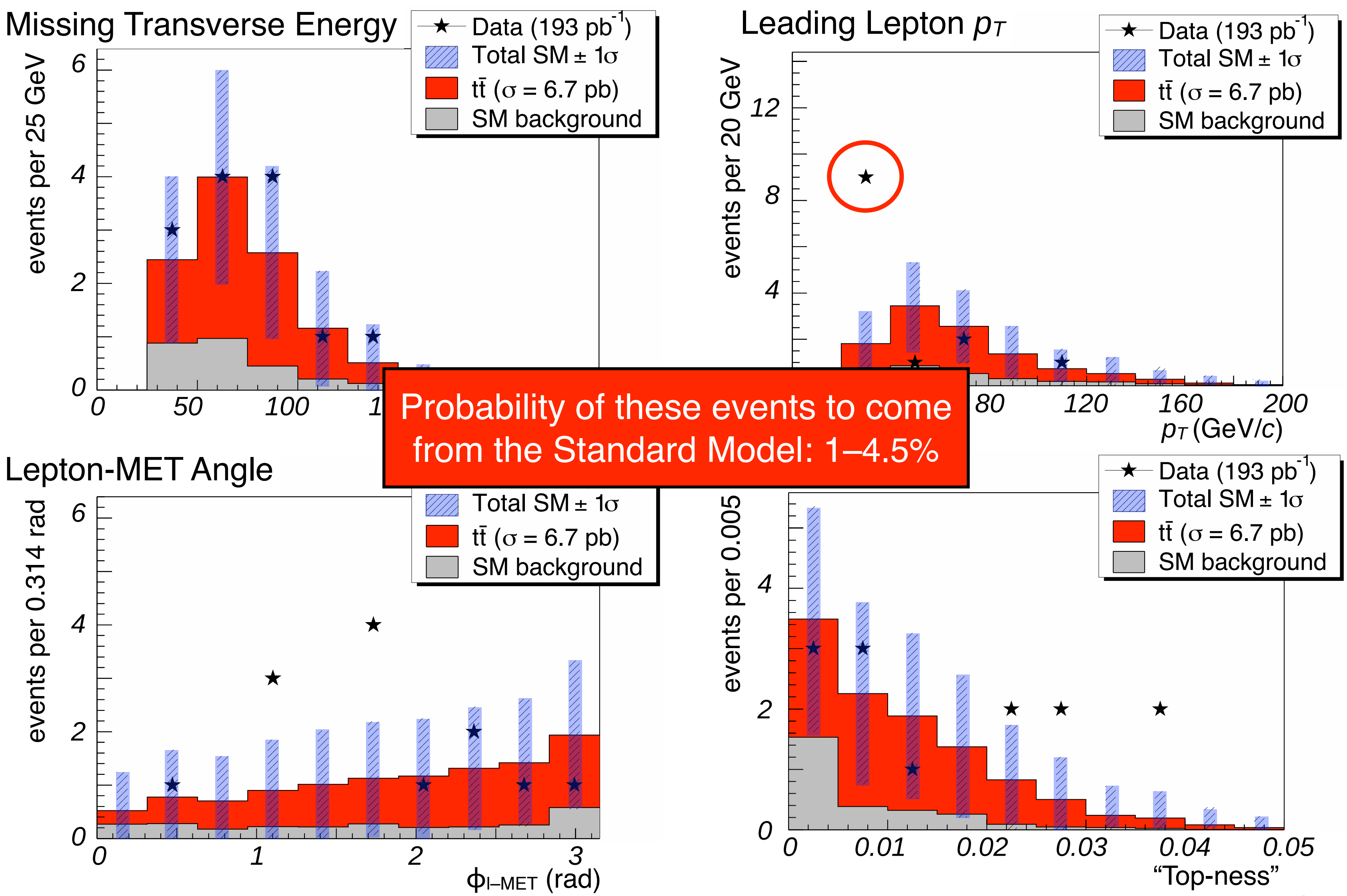


- Conjecture:
  Data more compatible with 300 GeV/c^2 squarks (SUSY partner of quarks) than with Standard Model
  [R. M. Barnett, L. J. Hall, Phys. Rev. Lett. **77** (1996) 3506]

Anomalous Kinematics?

- Strategy for Run II: model-independent search
  - Choose kinematics variables sensitive to New Physics a priori:
    - Missing transverse energy
    - Transverse momentum of "leading" (i.e. highest p_T) lepton
    - Angle between MET and p_T,
    - "Top-ness" (based on MET): $T = \int d\vec{\not{E}}_T \exp\left[-\frac{(\vec{\not{E}}_T{}^{\text{pred}} - \vec{\not{E}}_T{}^{\text{obs}})^2}{2\sigma^2_{\not{E}_T}} \right]$
  - Perform Kolmogorov-Smirnov test to check consistency between data and Monte Carlo expectation
  - Isolate subset of events most incompatible with the Standard Model
- Data: dilepton sample, integrated luminosity $\int L\,dt = 200\ \text{pb}^{-1}$, 13 events isolated

Anomalous Kinematics?



Probability of these events to come from the Standard Model: 1–4.5%

Summary

- Tevatron: currently only top factory in the world
  → Training ground for LHC operations and data analysis
- Searching for answers to the question: is the top quark we observe really the Standard Model top?
  - Branching fraction $t \to Wb$
  - Searches for charged Higgs bosons and FCNC
  - Helicity of W bosons from top quark decays
  - Search for anomalous kinematics
- Analyses with 370 pb^{-1}, first results with 1 fb^{-1} soon
- No evidence for physics beyond the Standard Model

Stay tuned for exciting new results from the Tevatron