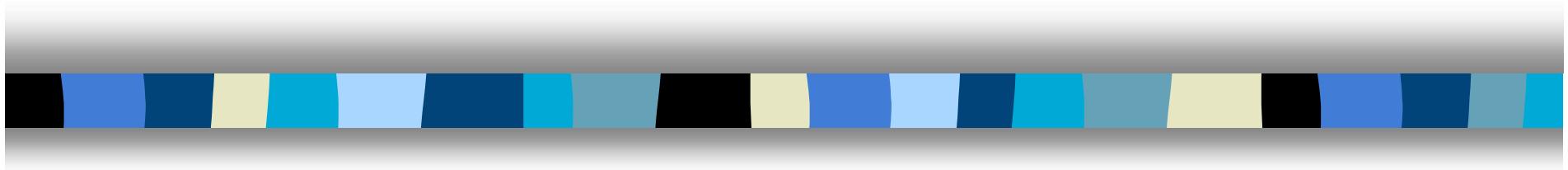


Lehrstuhlseminar Experimentelle Physik IV
Universität Dortmund, Germany, December 20, 2005

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

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Summary



The Top in the Standard Model

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

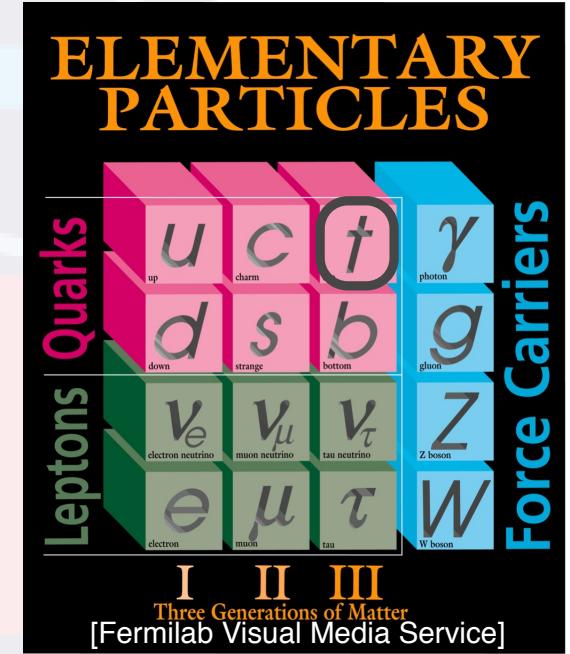
$$\mathcal{L}_{Y,t} = f \frac{v}{\sqrt{2}} \bar{t}_L t_R \equiv m_t \bar{t}_L t_R$$

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

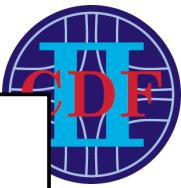
- ▶ The only “**free**” quark: lifetime shorter than hadronization time

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

→ 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. ILOPOULOS, 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.

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*-violation are studied. It is concluded that no realistic models of *CP*-violation exist in the quark scheme without introducing any other new fields. Some possible models of *CP*-violation also discussed.

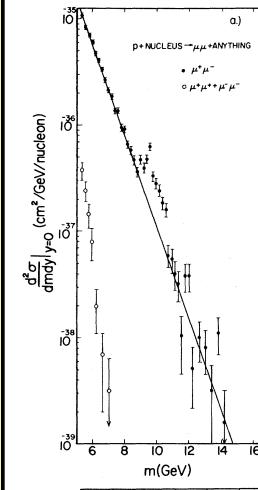
J/ψ discovery: the fourth quark is found



γ 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: W^+
 $m_t > m_W$

SppS (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

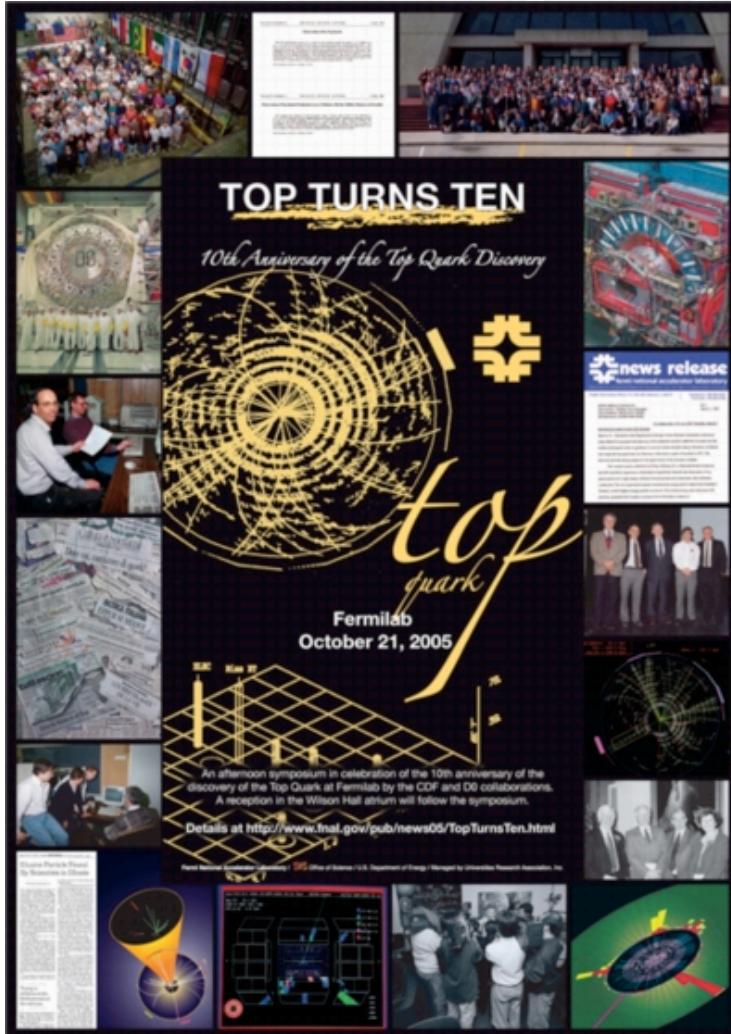
LEP I (CERN): e^+e^- , $\sqrt{s} = 90$ GeV
 $m_t = 173$ GeV/c 2 (EW fit)

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

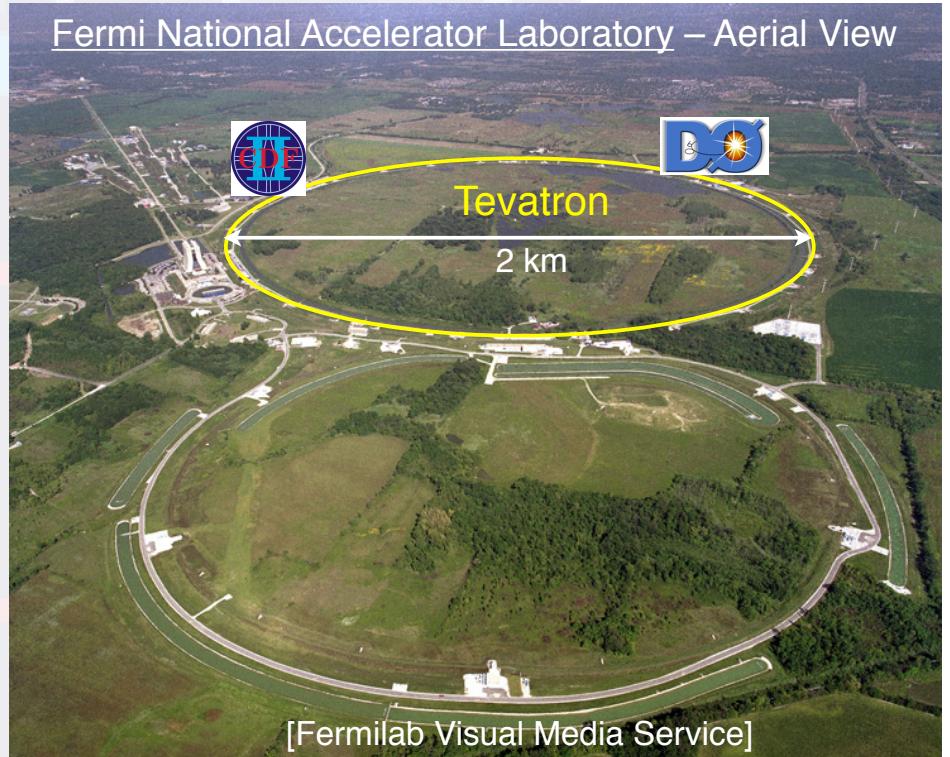
Top Properties

Summary



Tevatron Run II

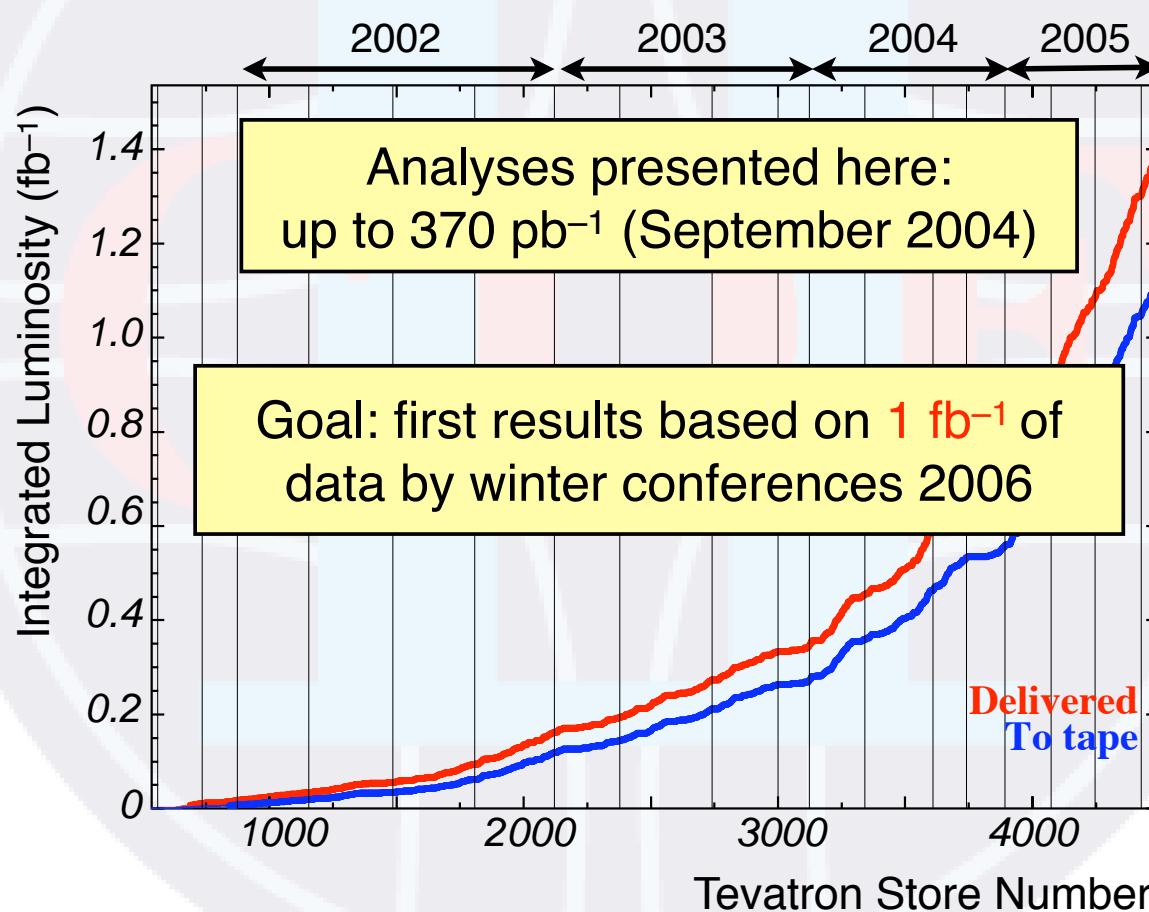
- ▶ Proton-antiproton collider, $\sqrt{s} = 1.96 \text{ TeV}$
- ▶ 36×36 bunches
- ▶ Collisions every 396 ns
- ▶ Record instantaneous peak luminosity:
 $1.67 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$
→ 3 top pairs/hour
- ▶ Luminosity goals:
 - Instantaneous: $(2\text{--}4) \times 10^{32} \text{ cm}^{-2}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





Integrated Luminosity

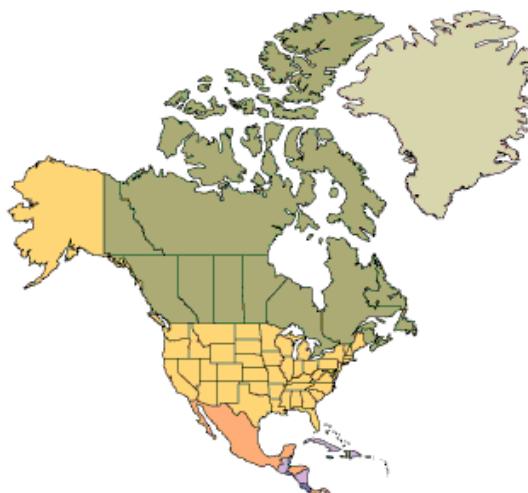
- More than 1.4 fb^{-1} delivered, more than 1.1 fb^{-1} recorded by CDF





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
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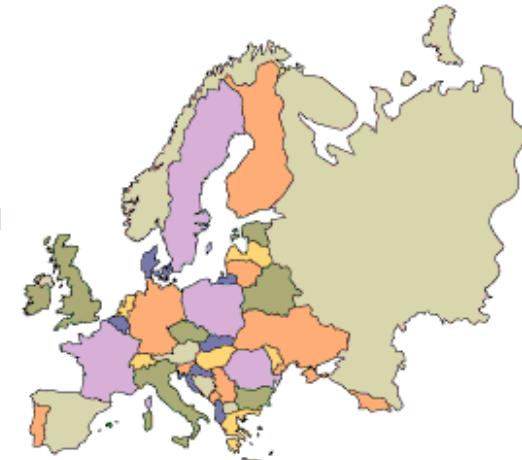
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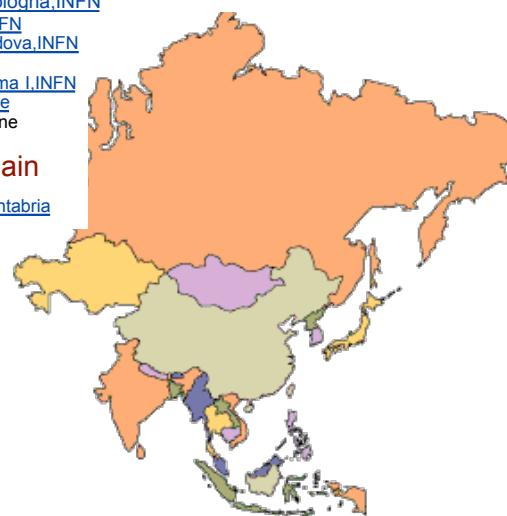
Spain
[Univ. of Cantabria](#)



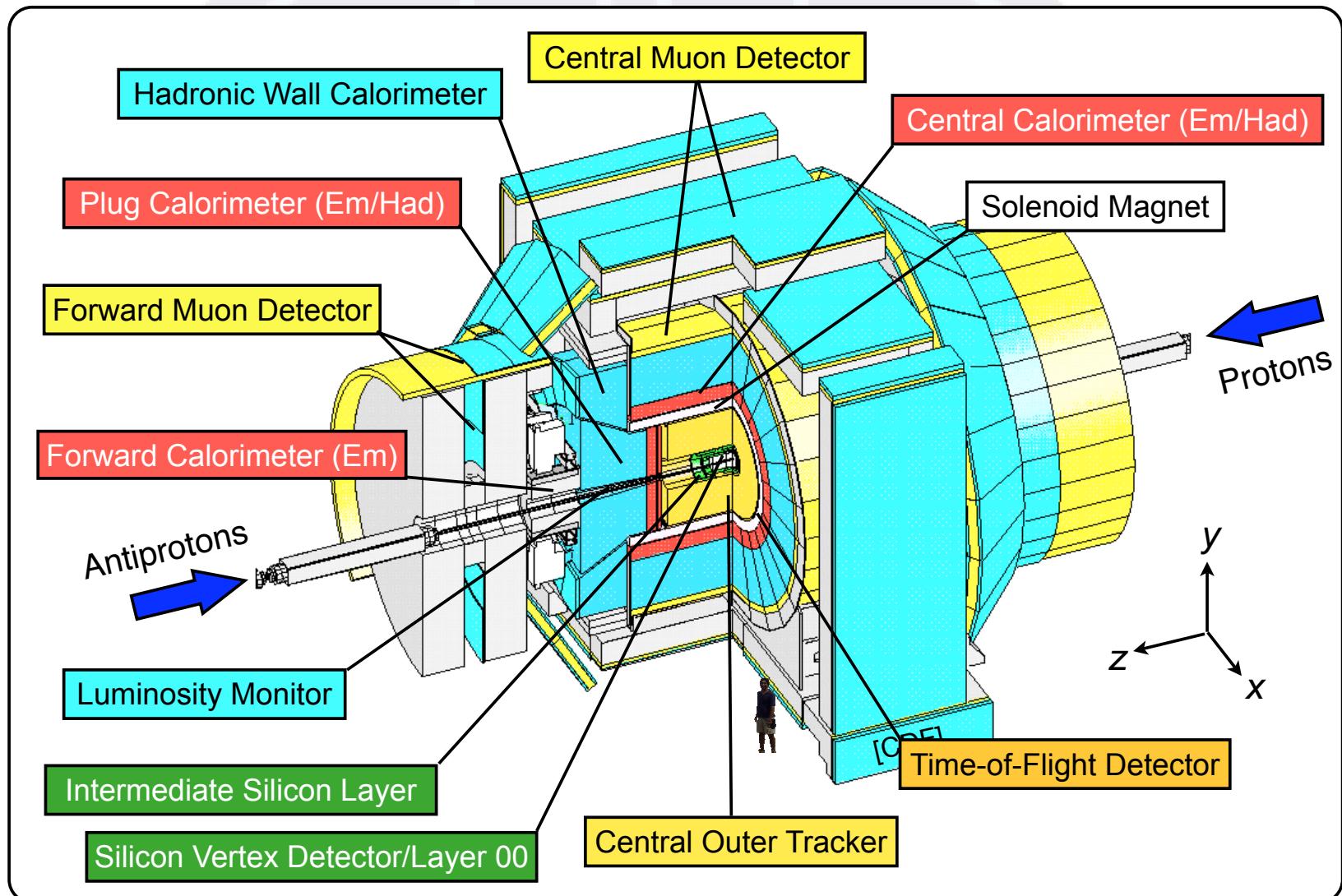
Korea
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[KEK](#)
[Osaka City Univ.](#)
[Univ. of Tsukuba](#)
[Waseda Univ.](#), Tokyo

Taiwan
[Academia Sinica](#),
Taipei



The CDF Detector





The Road to the Top

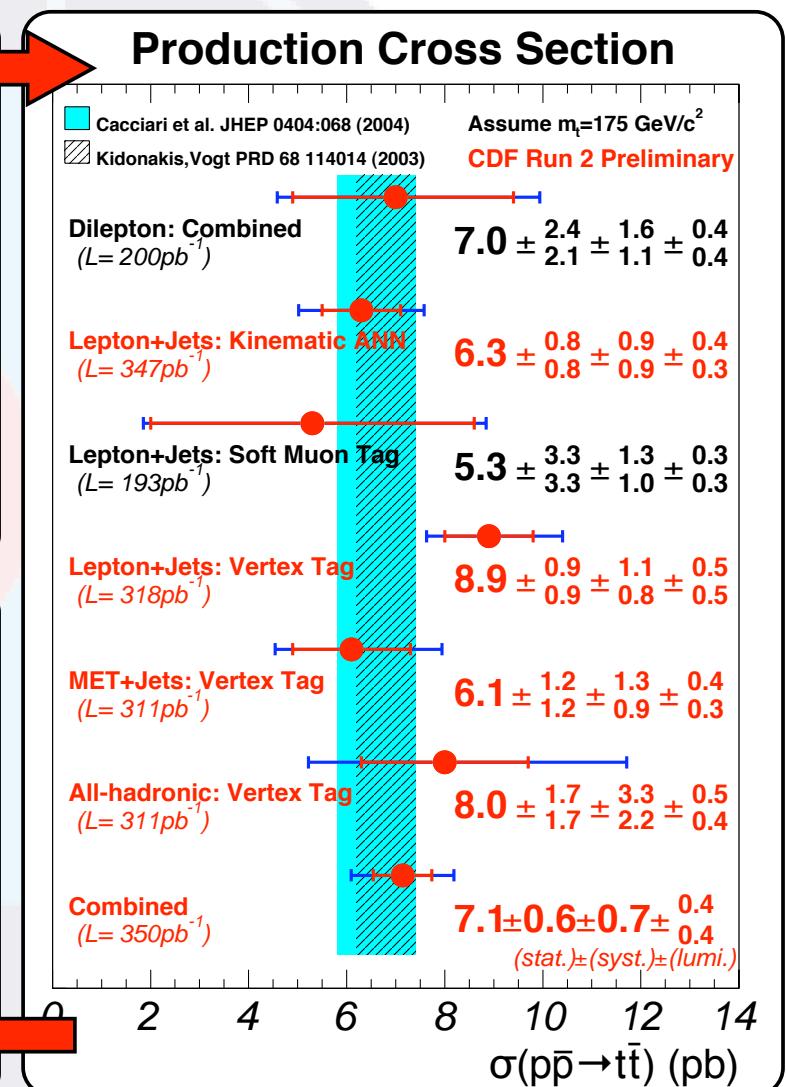
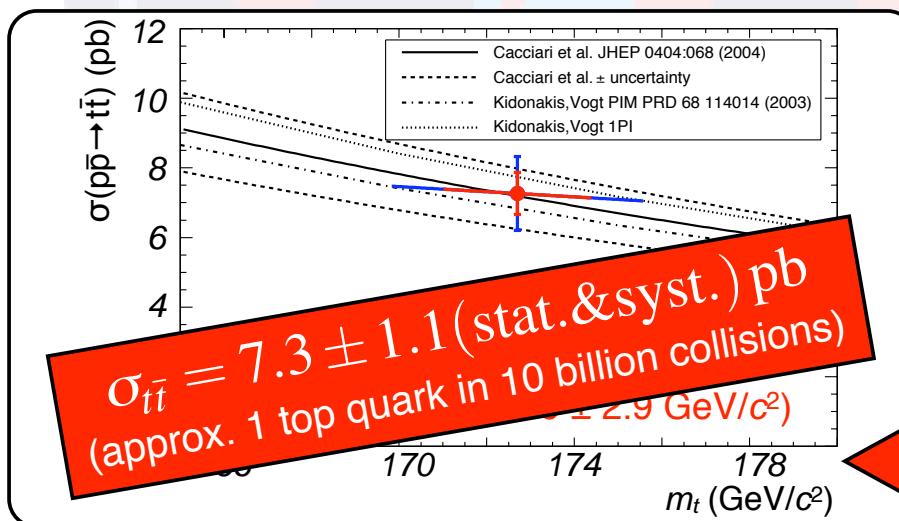
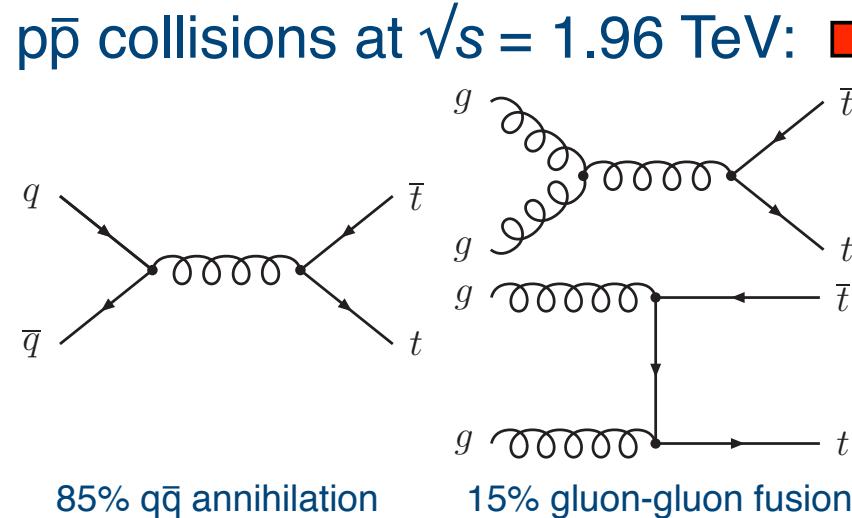
The CDF-II Detector at the Tevatron

How to Find Top Quarks

Top Properties

Summary

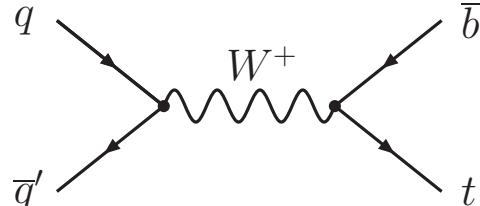
Top Pair Production: QCD



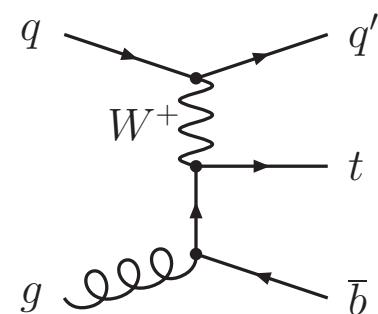
Single Top Production

Theoretical Predictions:

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



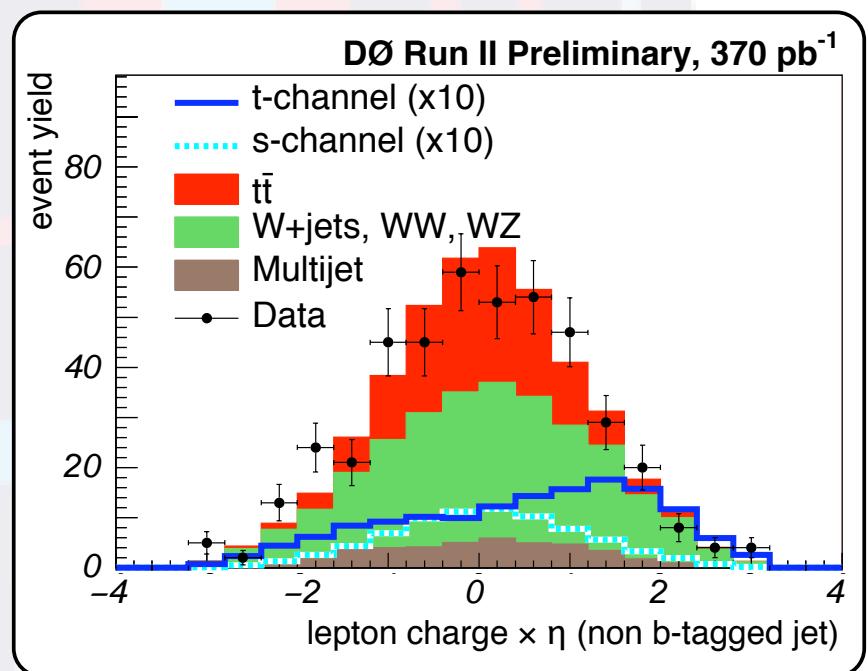
t channel: $\sigma_t = 1.98 \pm 0.25 \text{ pb}$



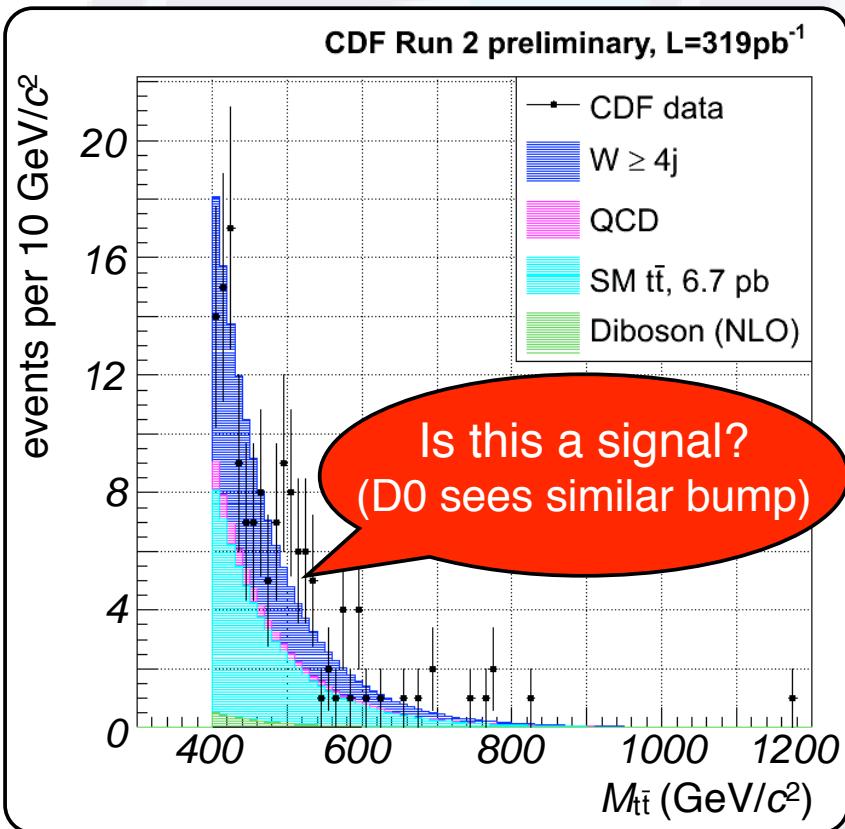
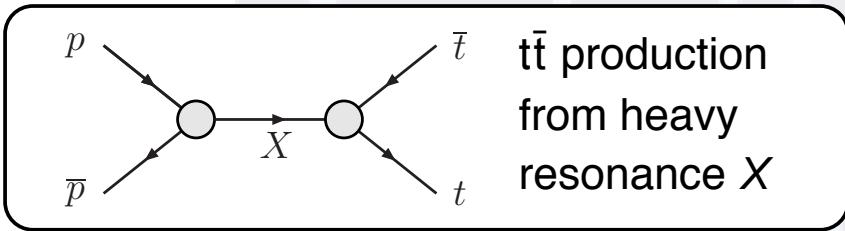
Heading for discovery:
3 σ evidence expected
with 1–2 fb^{-1}

- ▶ Electroweak single top production: **not yet observed**
- ▶ Current best cross-section limits at 95% C.L. (D0):

$$\sigma_s < 5.0 \text{ pb} \quad \sigma_t < 4.4 \text{ pb}$$



Decay of a Heavy Resonance?

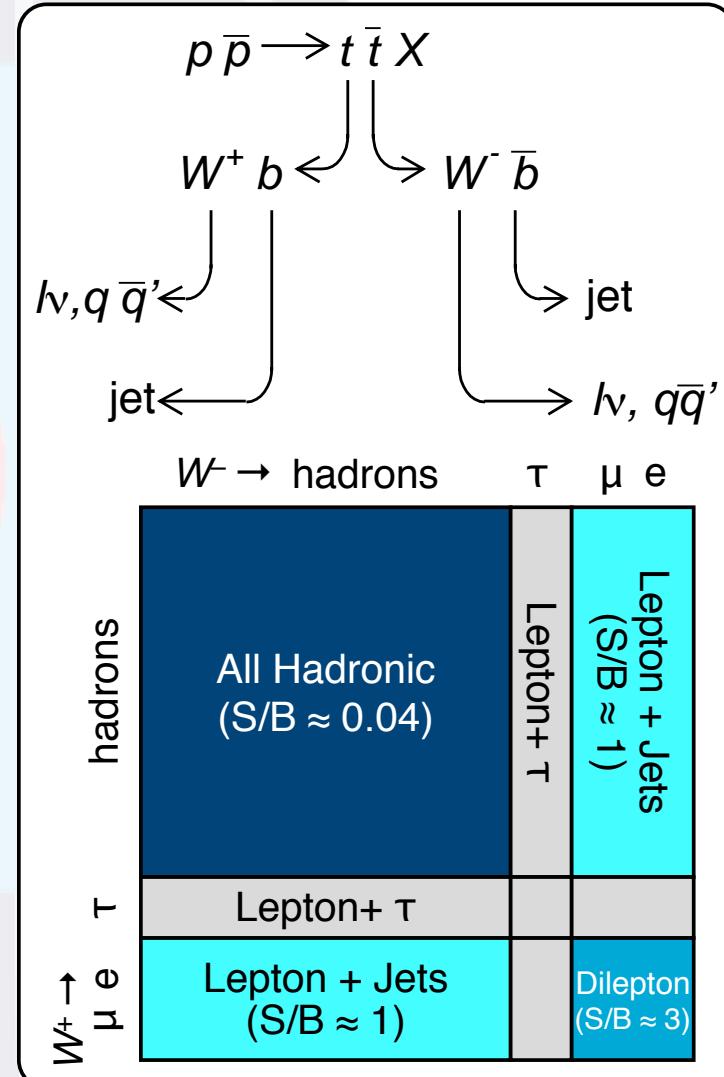


- ▶ Top quark important for electroweak symmetry breaking:
 - Heavy top due to new strong dynamics?
→ $t\bar{t}$ condensate
 - Example: top-color assisted technicolor models (C.T. Hill, Phys. Lett. **B345** (1995) 483)
- ▶ CDF: measure $t\bar{t}$ mass spectrum by matrix element method

Top Decay Channels



- ▶ Standard Model:
 $\text{BR}(t \rightarrow W b) \geq 99.8\%$
 - ▶ 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:

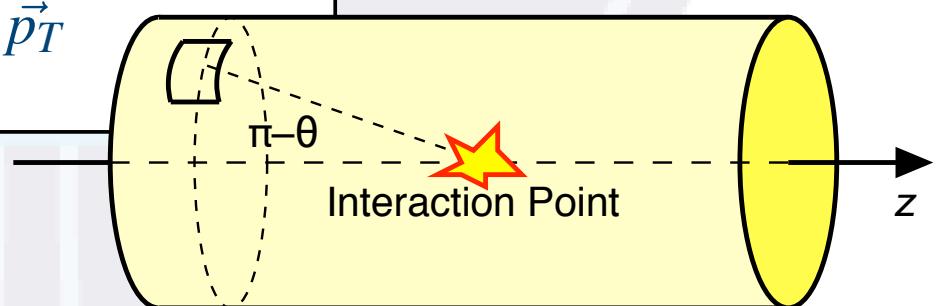
- θ : polar angle w.r.t. to proton direction
- ϕ : azimuthal angle
- Pseudorapidity:

$$\eta = -\ln \tan(\theta/2)$$
- Transverse energy:

$$\vec{E}_T = \sum_{\text{cal towers}} E_i(\sin \theta_i, \phi_i)$$

- Missing transverse energy (“MET”):

$$\vec{E}_T^{\text{miss}} = - \sum_{\text{jets}} \vec{E}_T - \sum_{\text{leptons}} \vec{p}_T$$





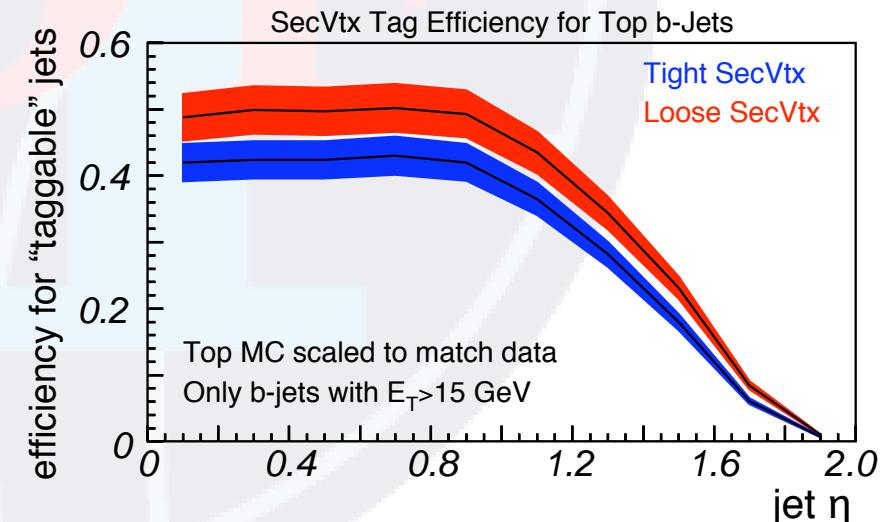
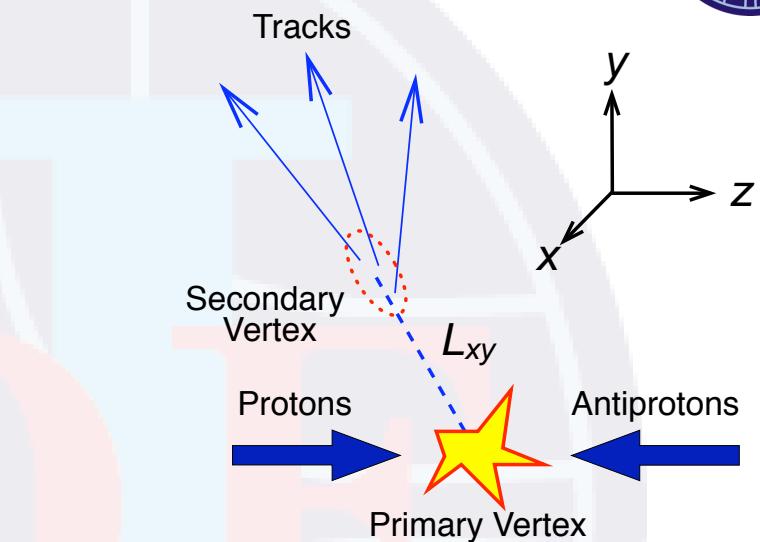
Typical Selection Criteria

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

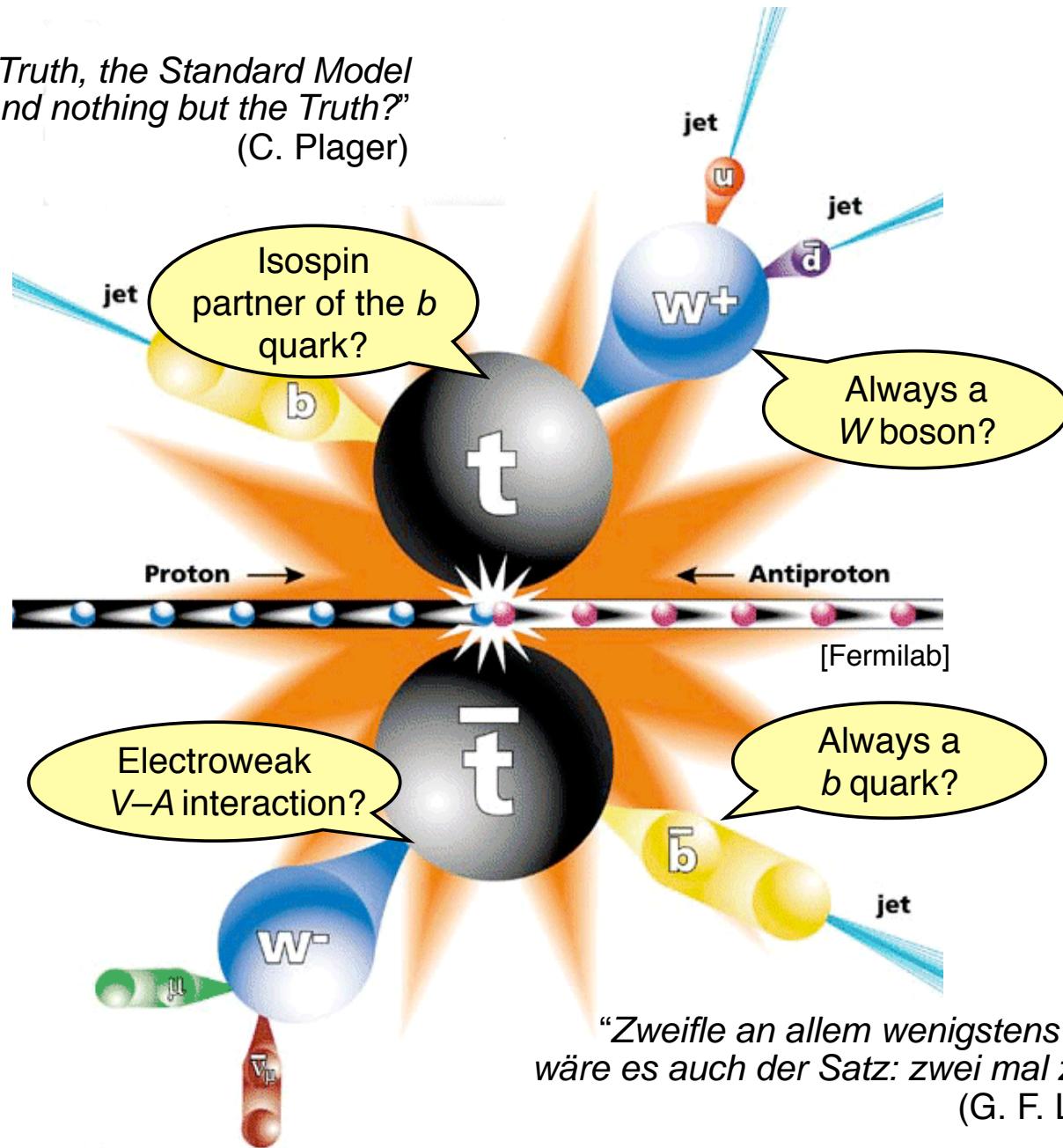
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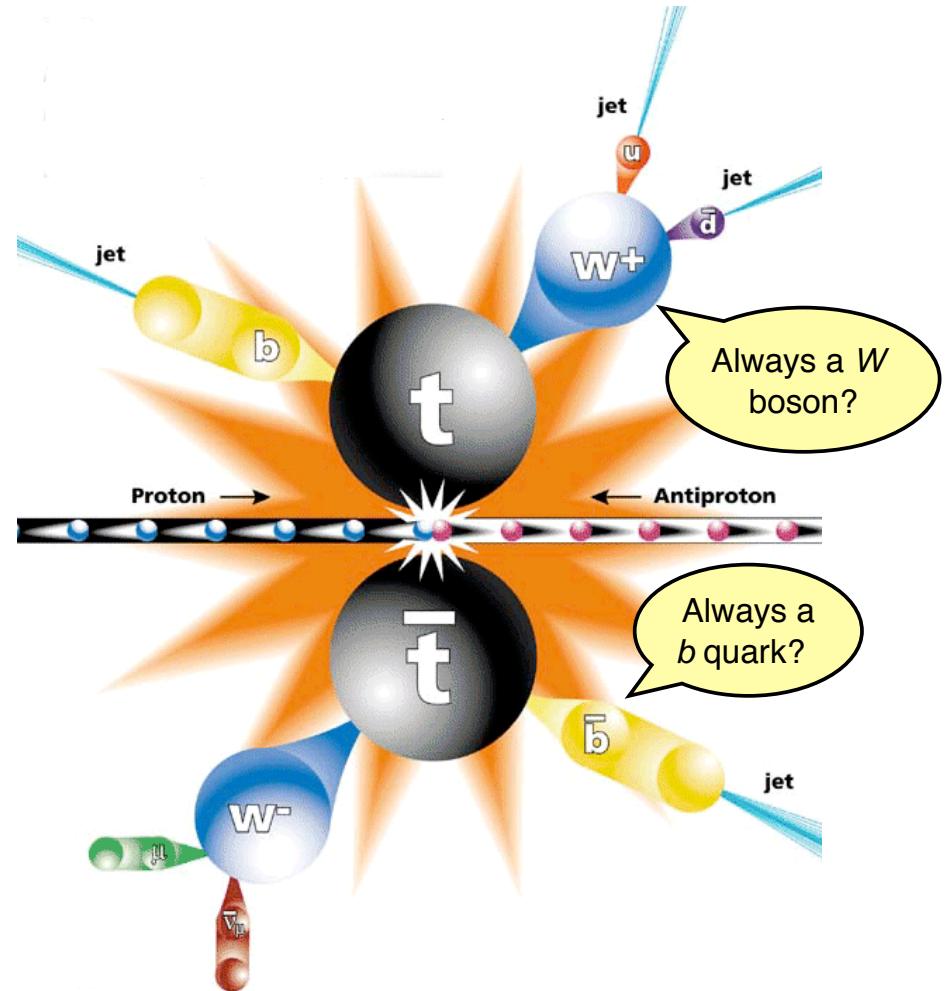


*“Is it the Truth, the Standard Model
Truth, and nothing but the Truth?”
(C. Plager)*



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.)
- ▶ Tevatron: **direct measurement** of $|V_{tb}|$ from top decays:

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

The CKM Matrix

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

Assuming no background:

$$N_0 = N^{t\bar{t}} \epsilon_0 = N^{t\bar{t}} (1 - R\epsilon_b)^2$$

$$N_1 = N^{t\bar{t}} \epsilon_1 = N^{t\bar{t}} (2R\epsilon_b)(1 - R\epsilon_b)$$

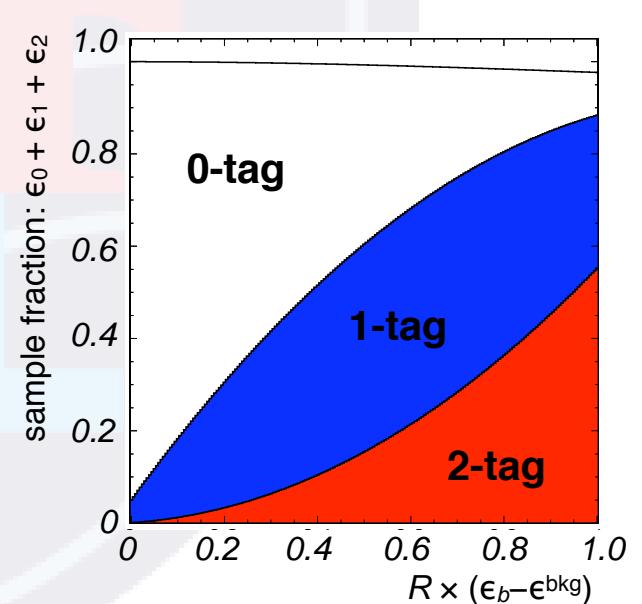
$$N_2 = N^{t\bar{t}} \epsilon_2 = N^{t\bar{t}} (R\epsilon_b)^2$$

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

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

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



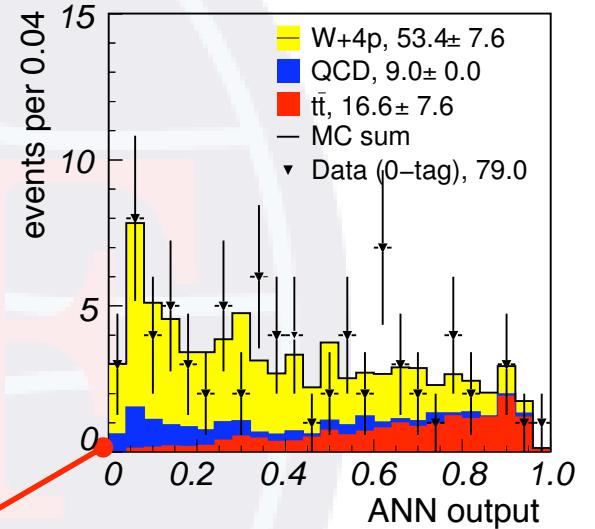
V_{tb} : Background Estimate

- 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)**

Dilepton	0-tag	1-tag	2-tag
$\varepsilon_i(R = 1)$	0.47 ± 0.03	0.43 ± 0.02	0.10 ± 0.02
$N^{\text{bkg}} \text{ (a priori)}$	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

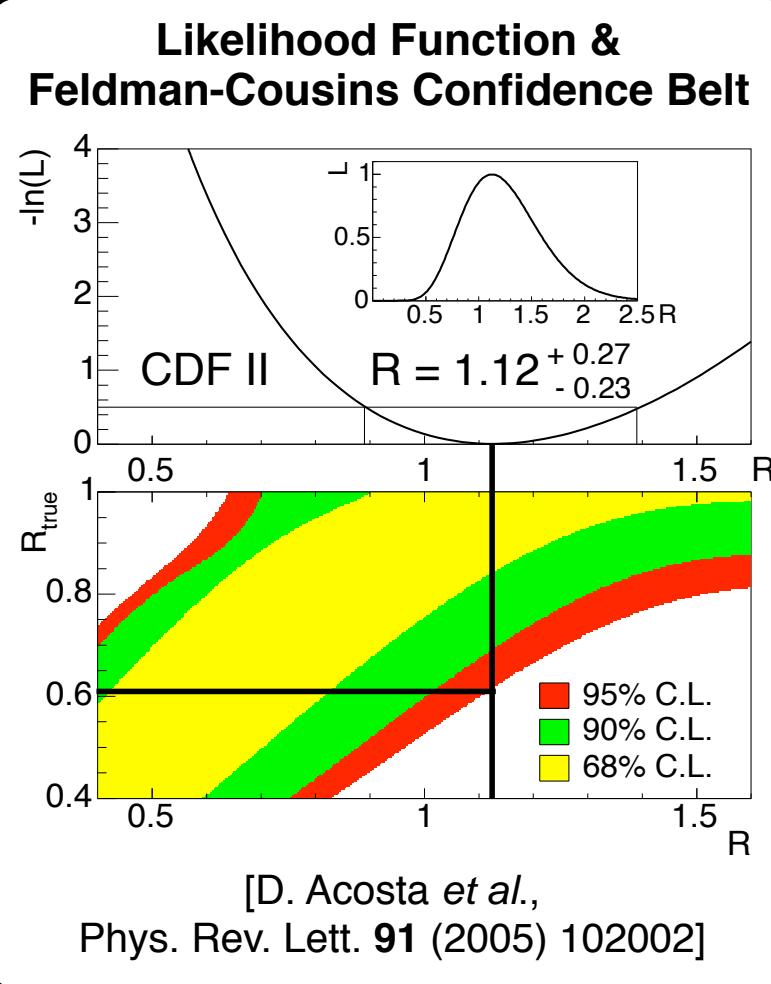
Lepton + Jets	0-tag	1-tag	2-tag
$\varepsilon_i(R = 1)$	0.45 ± 0.03	0.43 ± 0.02	0.12 ± 0.02
$N^{\text{bkg}} \text{ (a priori)}$	N/A	4.2 ± 0.7	0.2 ± 0.1
$N^{\text{bkg}} \text{ (ANN)}$	62.4 ± 9.0	5.8 ± 5.1	$0.1^{+1.0}_{-0.1}$
N^{exp}	80.4 ± 5.2	21.5 ± 4.1	5.0 ± 1.4
N^{obs}	79	23	5

ANN Output for 0-tag L+J



Very good agreement

V_{tb} : Results



- ▶ 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:

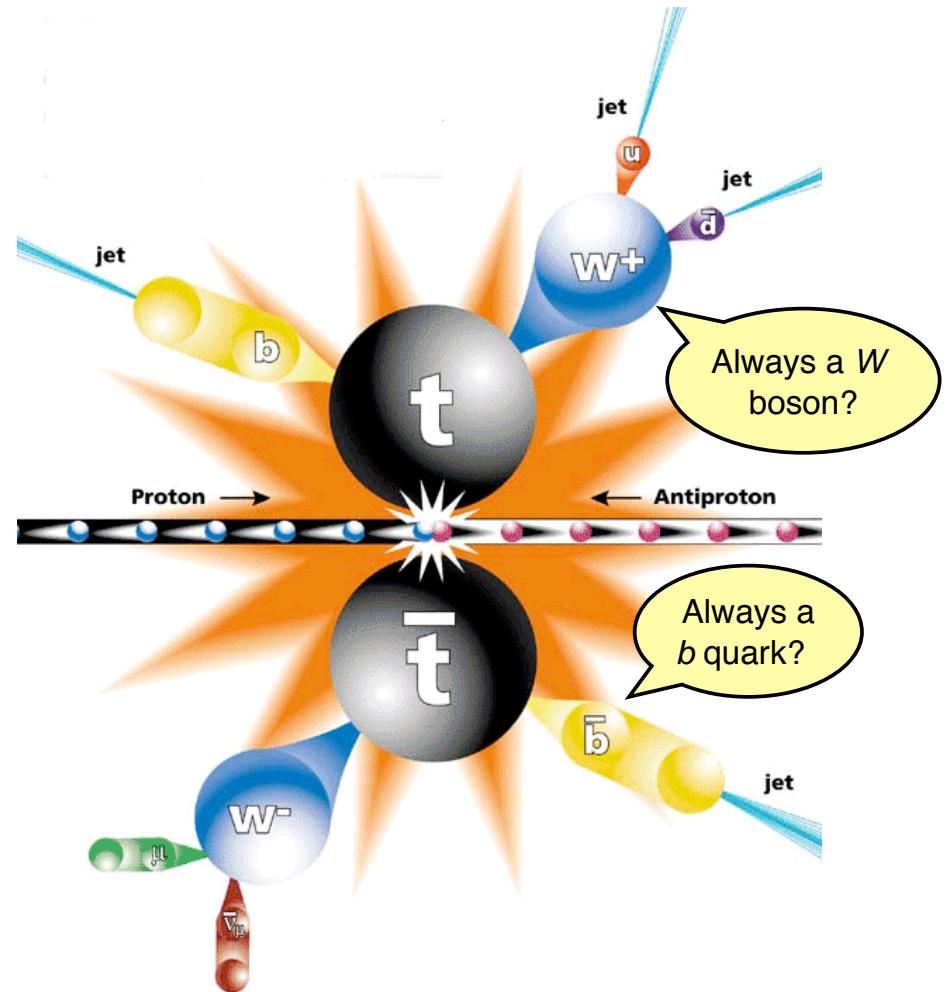
$$R > 0.61 \text{ (95\% C.L.)}$$

- ▶ Assuming three generations of quarks and leptons:

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

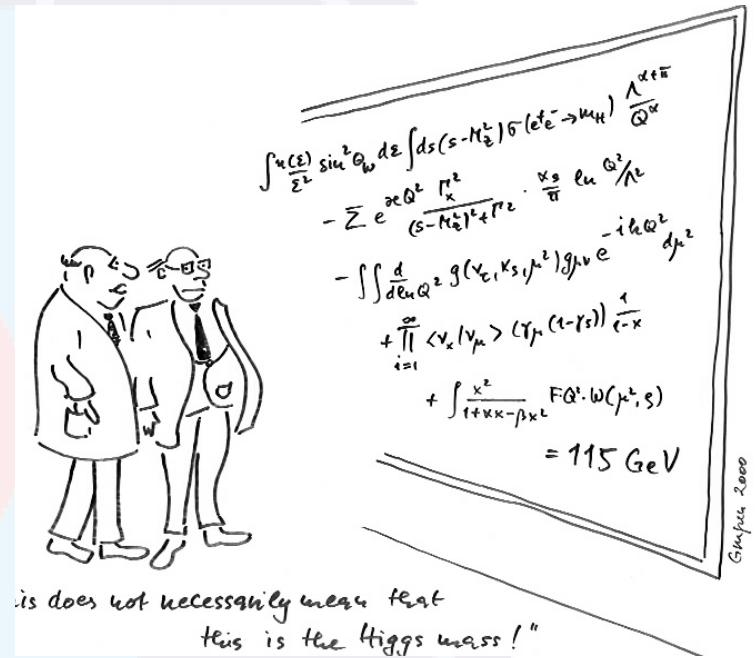
Questions: Part I

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- ▶ 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)



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. $H^+ \rightarrow t^* \bar{b}$, $\tau^+ \nu$, $c \bar{s}$, $W^+ h^0$
- ▶ Presence of H^+ would **change branching fractions** of top decay channels → search for **excesses or deficits**:
 - $H^+ \rightarrow \tau^+ \nu$: enhancement of Lepton + Tau channel
 - $H^+ \rightarrow c \bar{s}$: deficits in Lepton + Jets and Dilepton channels

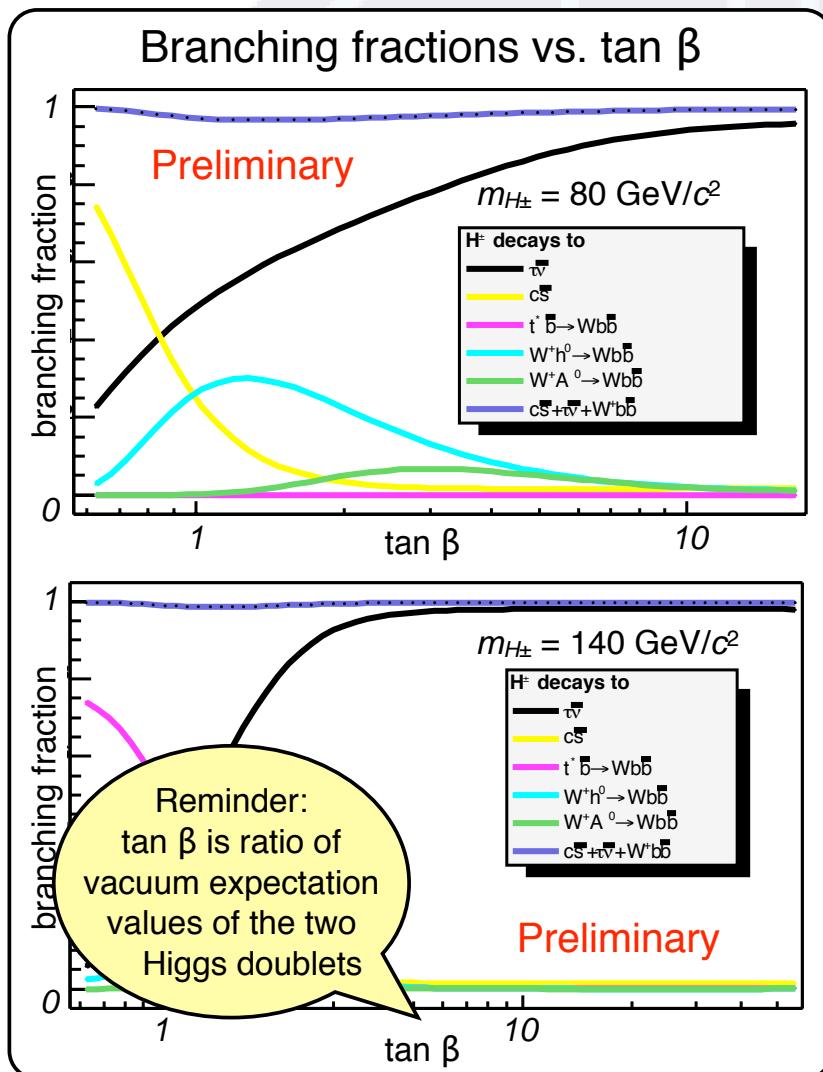


A cartoon illustration shows two scientists in lab coats looking at a large, complex mathematical equation on a board. The equation is related to the calculation of the Higgs mass. Below the equation, a handwritten note says: "is does not necessarily mean that this is the Higgs mass!"

$$\begin{aligned}
 & \int \frac{u(\Sigma)}{\Sigma^2} \sin^2 \theta_W d\Sigma \int ds (s - M_H^2) \Gamma(t\bar{t} \rightarrow W^+ W^-) \frac{\Lambda^{d+t-\bar{n}}}{Q^{2n}} \\
 & - \sum e^{2cQ^2} \frac{T_X^2}{(s - M_H^2)^2 + T^2} \cdot \frac{x_g}{\pi} \ln \frac{Q^2/\Lambda^2}{\mu^2} \\
 & - \iint \frac{d}{dx} Q^2 g(v_\mu, k_S) j_\mu^2 g_{\nu\nu} e^{-i k_\mu Q^2} d\mu^2 \\
 & + \prod_{i=1}^{\infty} \langle v_x / v_\mu \rangle (Y_P (1 - Y_S)) \frac{1}{x - x_i} \\
 & + \int \frac{x^2}{1 + x x_L - \beta x_L} FQ^2 \cdot W(x^2, s) \\
 & = 115 \text{ GeV}
 \end{aligned}$$

Grafik: 2000

Search for Charged Higgs (II)



▶ Assume 5 decay modes:

- $t \rightarrow W^+ b$ (Standard Model)
- $t \rightarrow H^+ b \rightarrow t^* \bar{b} b \rightarrow W^+ b \bar{b} b$
- $t \rightarrow H^+ b \rightarrow \tau^+ v b$
- $t \rightarrow H^+ b \rightarrow c \bar{s} b$
- $t \rightarrow H^+ b \rightarrow W^+ h^0 \bar{b} b \rightarrow W^+ b \bar{b} b$

▶ 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

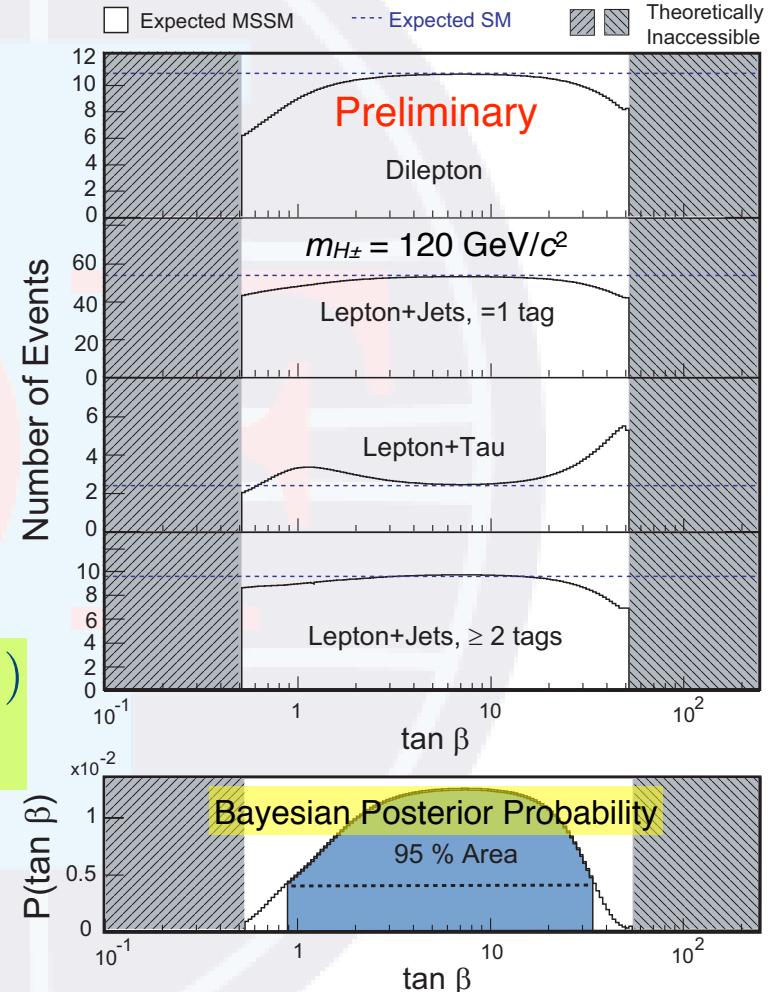
- ▶ Data sample: Dilepton, Lepton + Jets (1 b-tag or ≥ 2 b-tags), Lepton + hadronic Tau
- ▶ Luminosity: $\int L dt = 193 \text{ pb}^{-1}$
- ▶ Calculation of expected number of events per channel:

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

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

- ▶ SUSY scenario chosen:

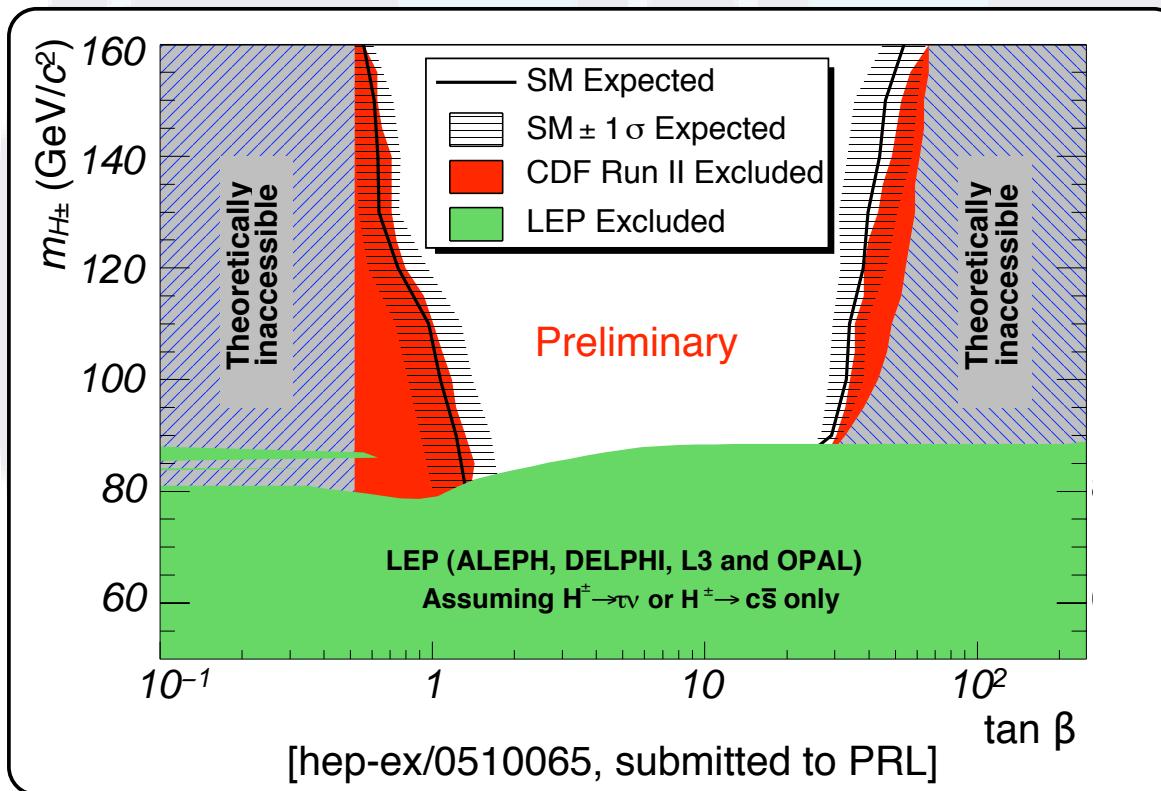
$$\begin{aligned} M_{\text{SUSY}} &= 1000 \text{ GeV}/c^2, \mu = -500 \text{ GeV}/c^2 \\ A_t = A_b &= 2000 \text{ GeV}/c^2, A_\tau = 500 \text{ GeV}/c^2 \\ M_2 = M_3 = M_Q &= M_U = M_D = M_E = M_{\text{SUSY}}, \\ M_1 &= 0.498 M_2 \end{aligned}$$



[hep-ex/0510065, submitted to PRL]

Charged Higgs: Limits

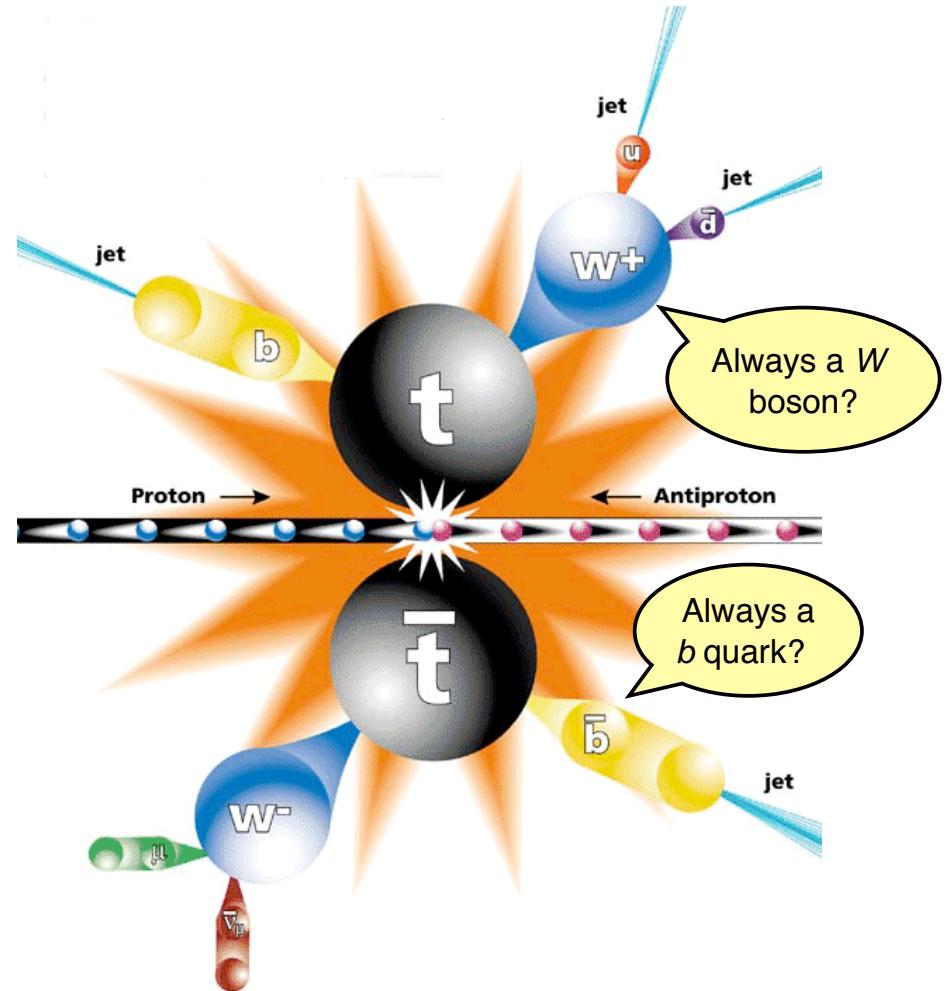
- ▶ No evidence of signal in $80 \text{ GeV}/c^2 < m_{H^\pm} < 160 \text{ GeV}/c^2$
- ▶ Exclusion limits in $(m_{H^\pm}, \tan \beta)$ plane:



- ▶ Low $\tan \beta$ region excluded in all scenarios considered

Questions: Part I

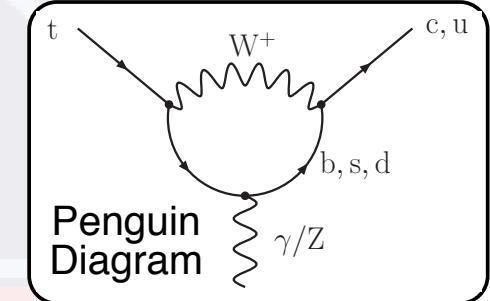
- ▶ Does top decay to Wb most of the time, i.e. the value of the CKM matrix element $|V_{tb}|$ close to unity?
- ▶ Does top sometimes decay into charged Higgs, as predicted in many SUSY models: $t \rightarrow H^+ b$?
- ▶ Are there anomalous couplings, e.g. top **flavor-changing neutral currents (FCNC)**



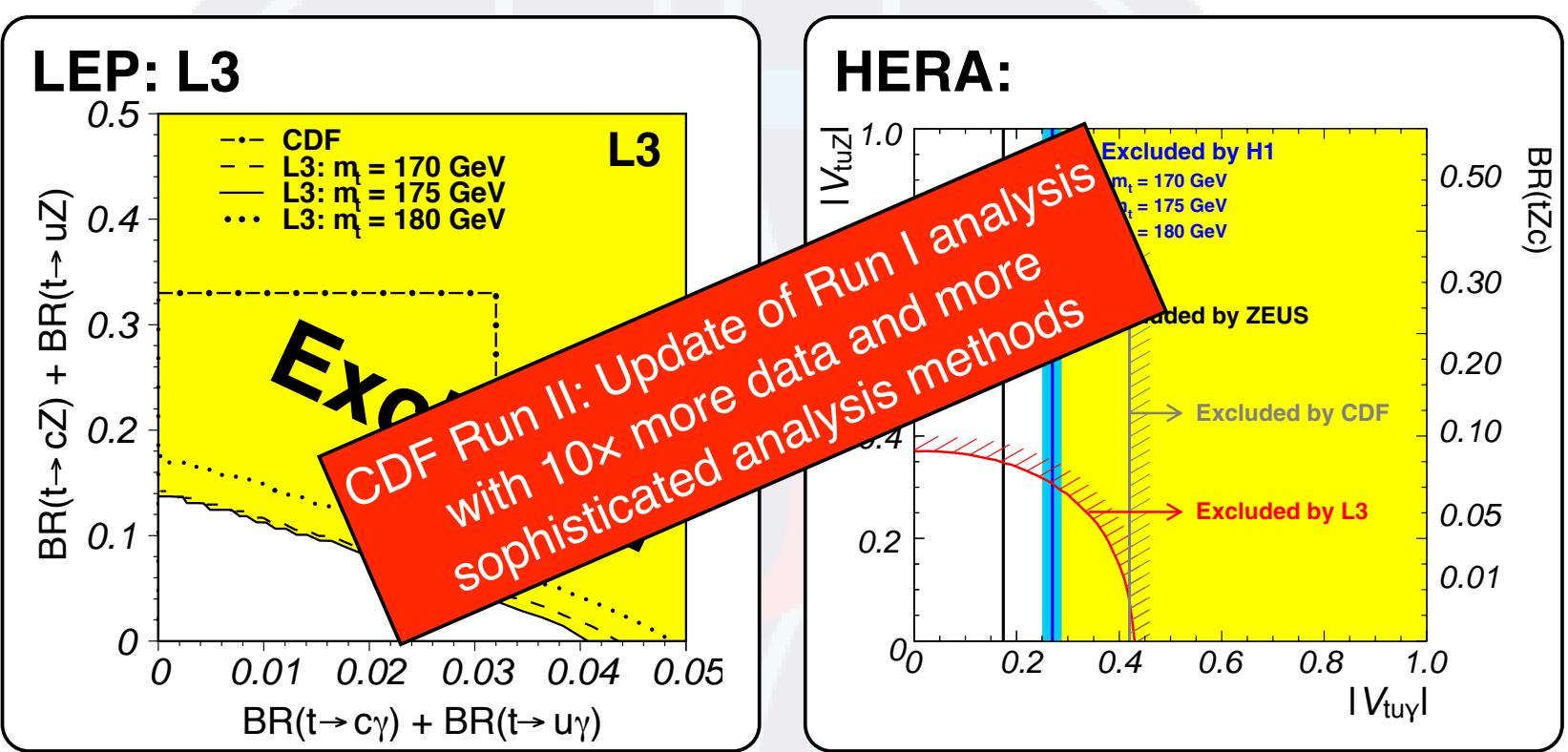


Search for FCNC

- ▶ 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 $t \rightarrow Zc$: as small as 10^{-14}
 - Any signal at the Tevatron: **New Physics**
- ▶ CDF Run I: search for FCNC decays $t \rightarrow Zc$ (and $t \rightarrow \gamma c$):
[F. Abe *et al.*, Phys. Rev. Lett. **80** (1998) 2525]
 - Decay channel: $t\bar{t} \rightarrow Zc$ Wb ; $W \rightarrow qq'$, $Z \rightarrow l^+l^-$
 - Limit: < 6.5 events at 95% C.L. $\rightarrow \text{BR}(t \rightarrow Zc) < 33\%$
- ▶ Meanwhile: better limits from **searches for single top production** at LEP and HERA



FCNC: Current Best Limits

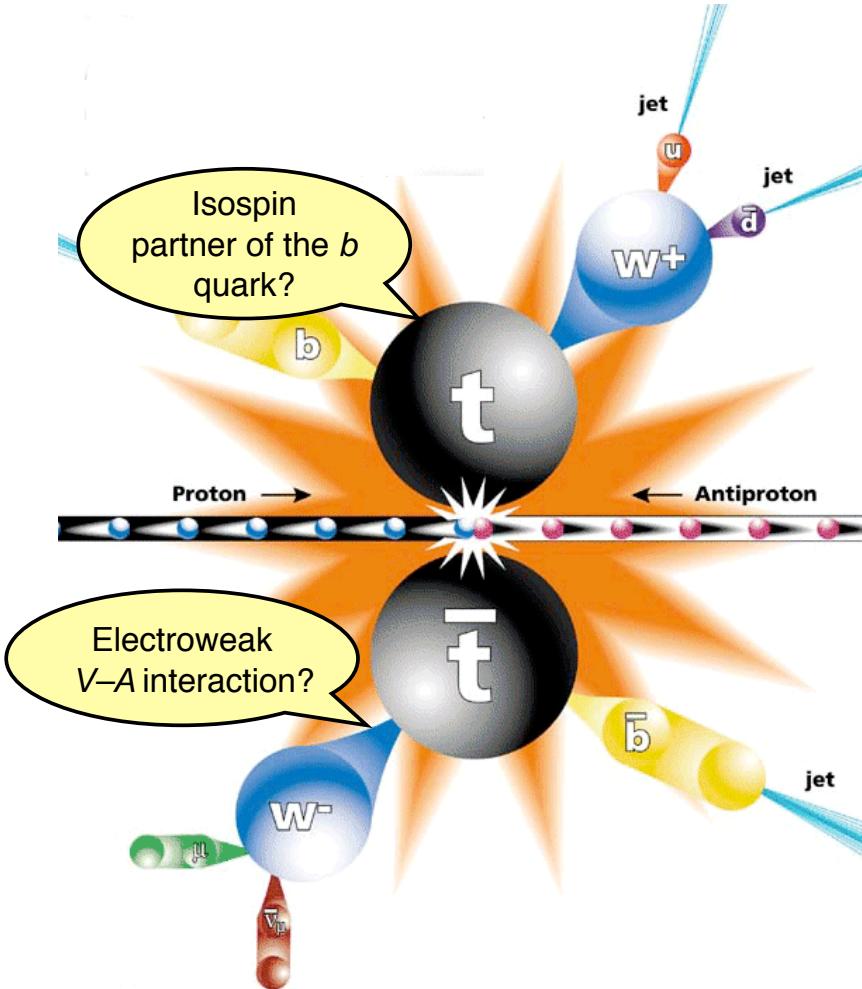


From H1 paper:

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. [...]

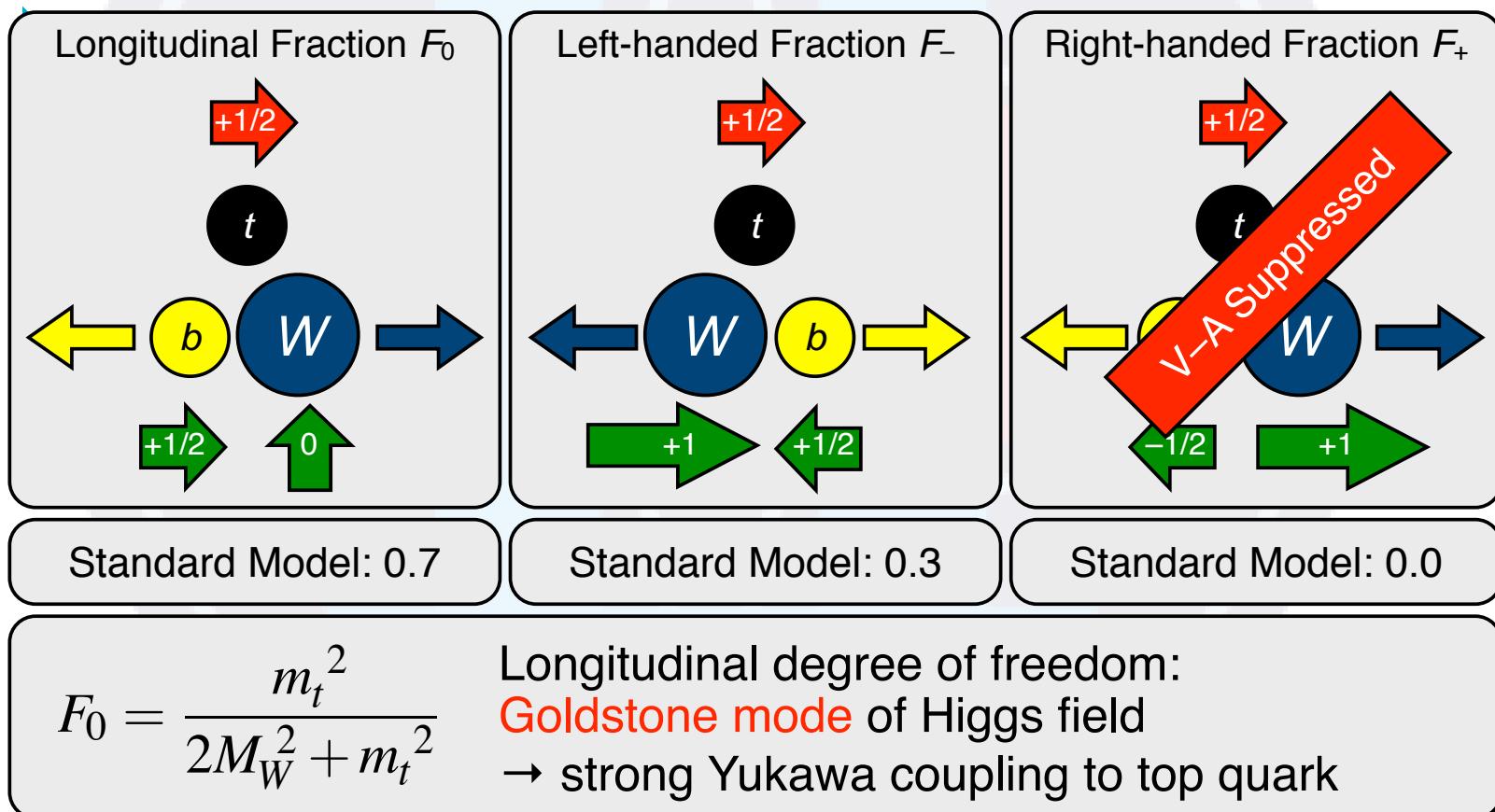
Questions: Part II

- ▶ 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?

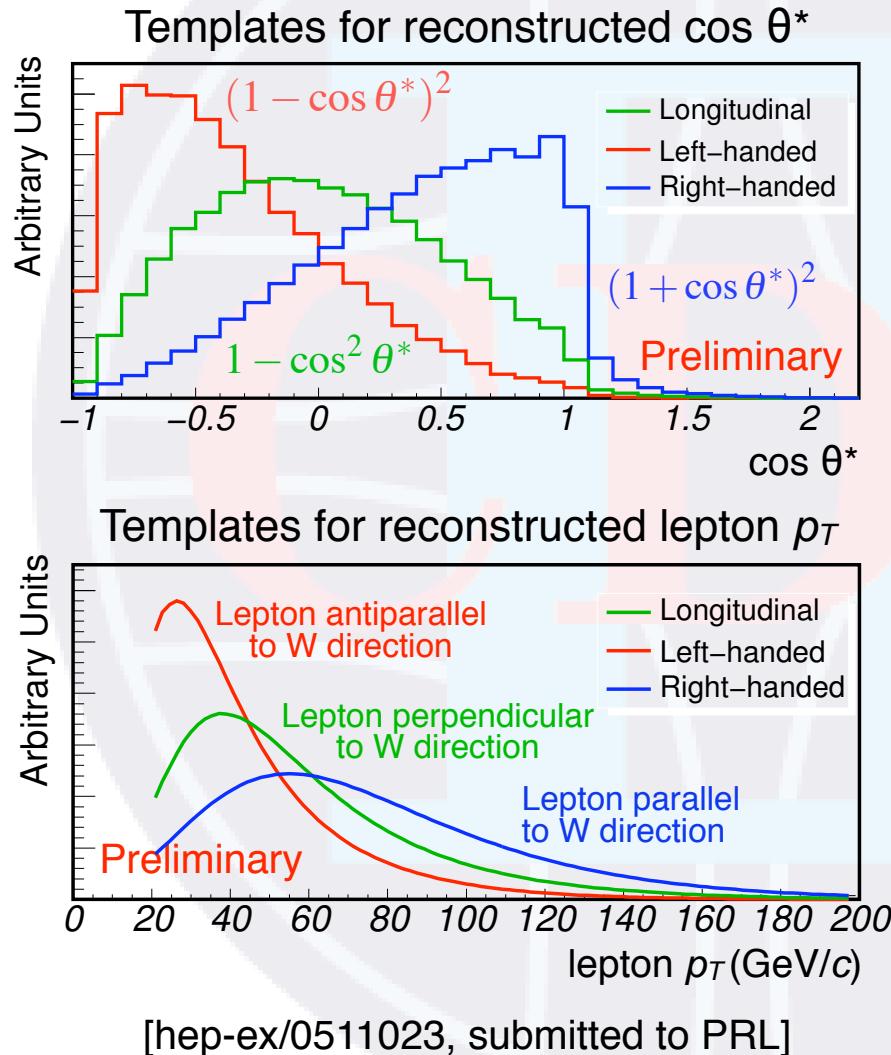


W Helicity in Top Decays

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



How to Measure W Helicity

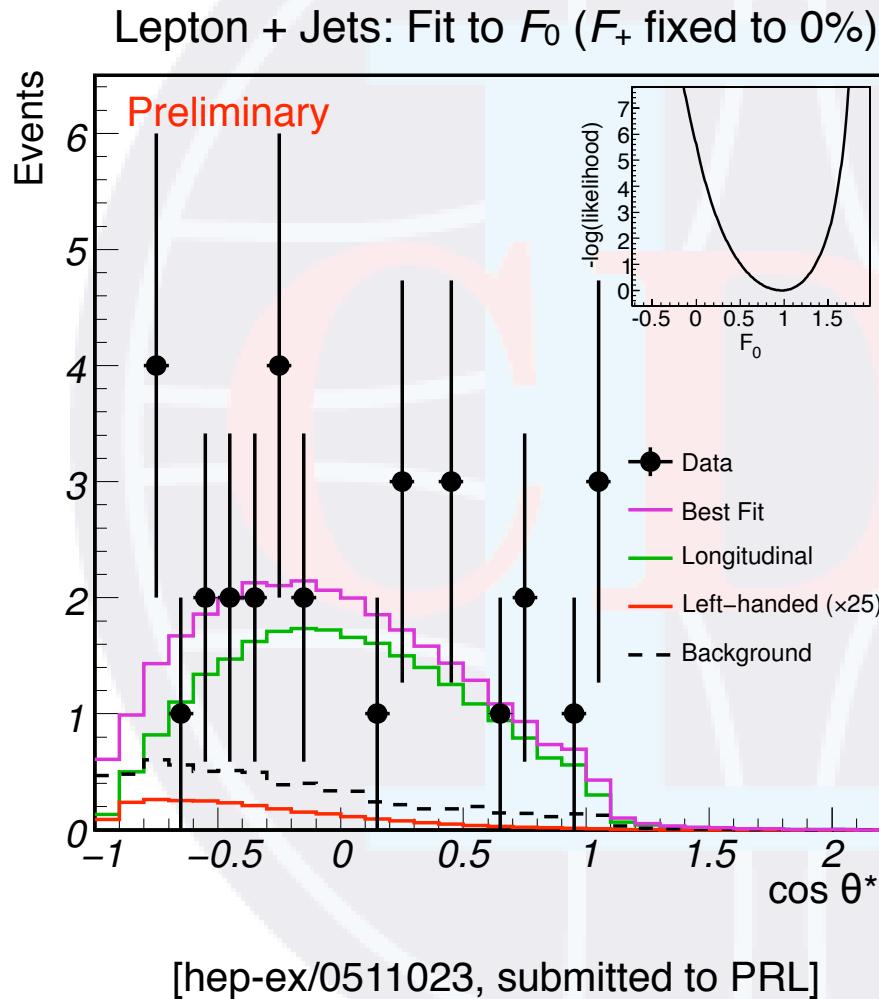


- ▶ Based on charged lepton from $W \rightarrow l\nu$
 - Method 1: distribution of decay angles θ^* of charged lepton w.r.t. top direction in W rest frame, approximated by lepton–b-jet mass:

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

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

W Helicity: $\cos \theta^*$ Results

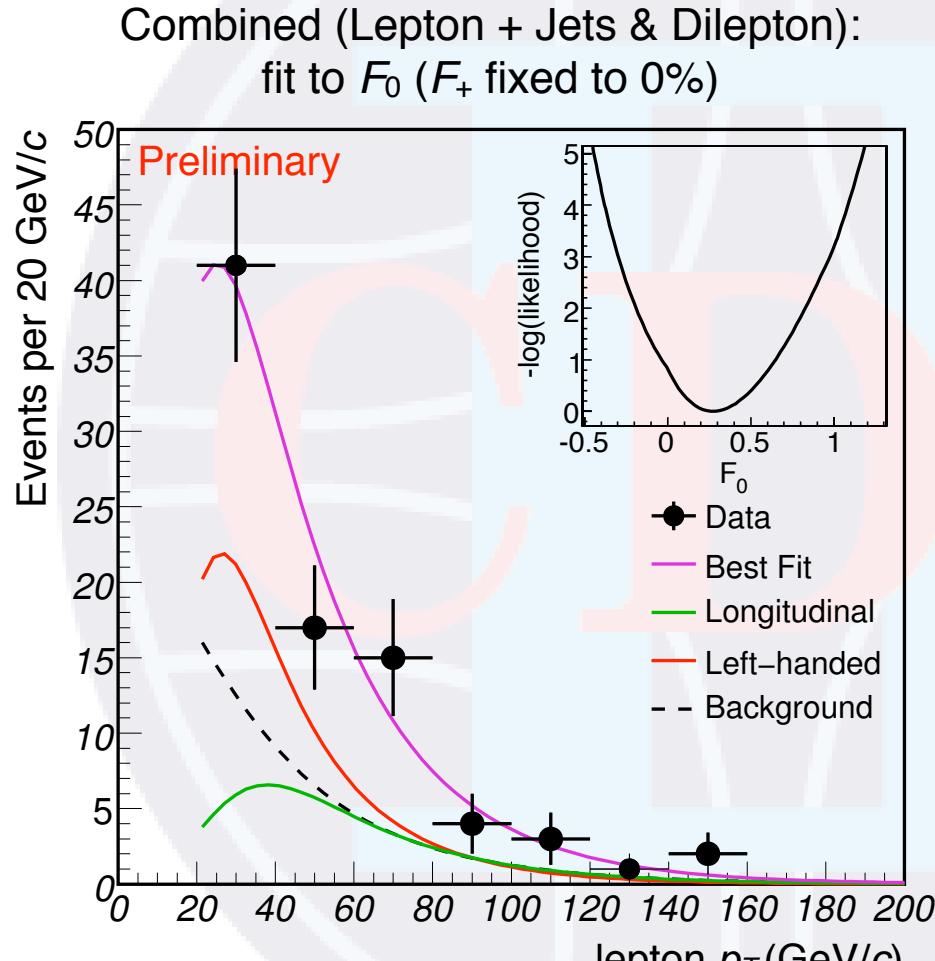


- ▶ $\cos \theta^*$ results based on Lepton + Jets sample ($\int L dt = 200 \text{ pb}^{-1}$, 31 events)
- ▶ Analysis **limited by statistics**: fix one parameter to Standard model value, fit other parameter, results:

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

$$F_+ = 0.23 \pm 0.16 \pm 0.08$$
 (Standard Model: $F_0 = 0.7$, $F_+ = 0.0$)

W Helicity: Lepton p_T Results



[hep-ex/0511023, submitted to PRL]

- ▶ Dilepton and Lepton + Jets, $\int L dt = 200 \text{ pb}^-$: 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 $\cos \theta^*$ and lepton p_T results (including correlations in statistical and systematic uncertainties):

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

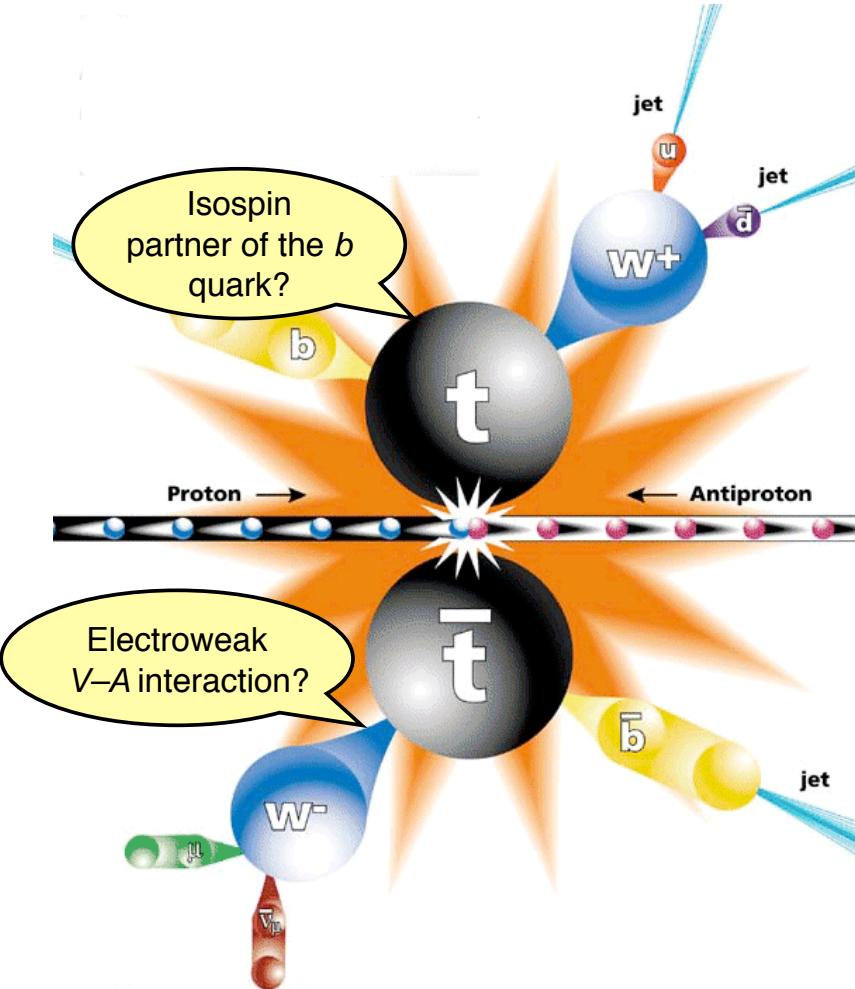
$$F_+ = 0.00^{+0.20}_{-0.19} (\text{stat. \& syst.})$$

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

- ▶ Feldman-Cousins upper limit on F_+ : $F_+ < 0.27$ (95% 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]

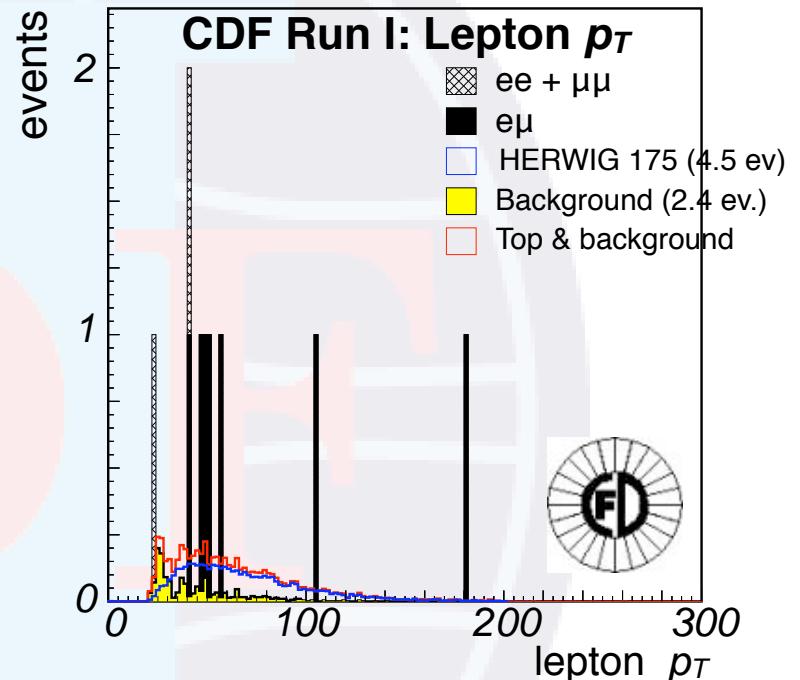
Questions: Part II

- ▶ 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 $e\mu$ combinations
- ▶ Conjecture:
 Data more compatible with 300 GeV/c² squarks
 (SUSY partner of quarks) than with Standard Model
 [R. M. Barnett, L. J. Hall, Phys. Rev. Lett. 77 (1996) 3506]



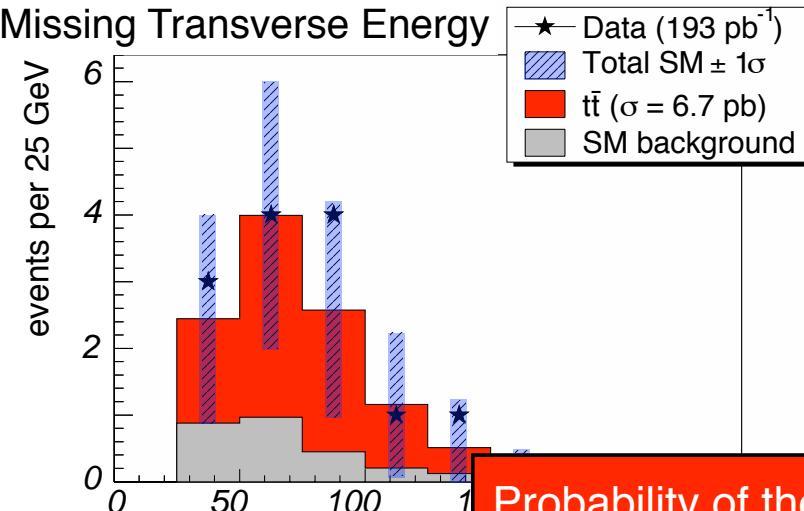


Anomalous Kinematics?

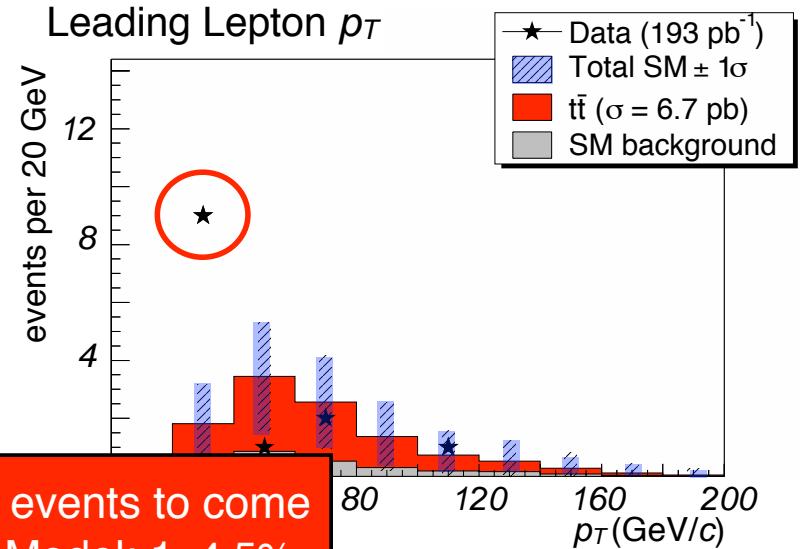
- ▶ Strategy for Run II: **model-independent** search
 - Choose kinematics variables sensitive to New Physics **a priori**:
 - Missing transverse energy
 - Transverse momentum of “leading” (i.e. highest p_T) lepton
 - Angle between MET and p_T ,
 - “Top-ness” (based on MET):
$$T = \int d\vec{E}_T \exp \left[-\frac{(\vec{E}_T^{\text{pred}} - \vec{E}_T^{\text{obs}})^2}{2\sigma_{\vec{E}_T}^2} \right]$$
 - 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?

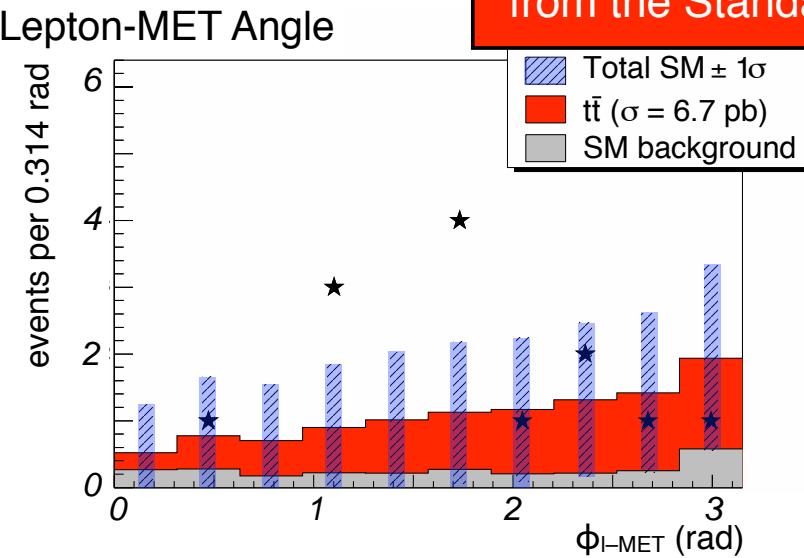
Missing Transverse Energy



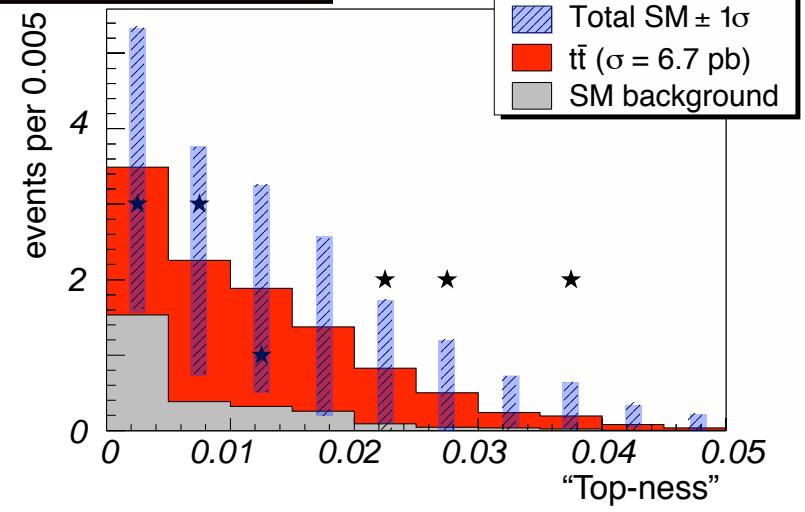
Leading Lepton p_T



Lepton-MET Angle



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 $t \rightarrow W b$
 - 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