XLIIèmes Rencontres de Moriond:
QCD and Hadronic Interactions
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Measurements of Top Properties at the Tevatron

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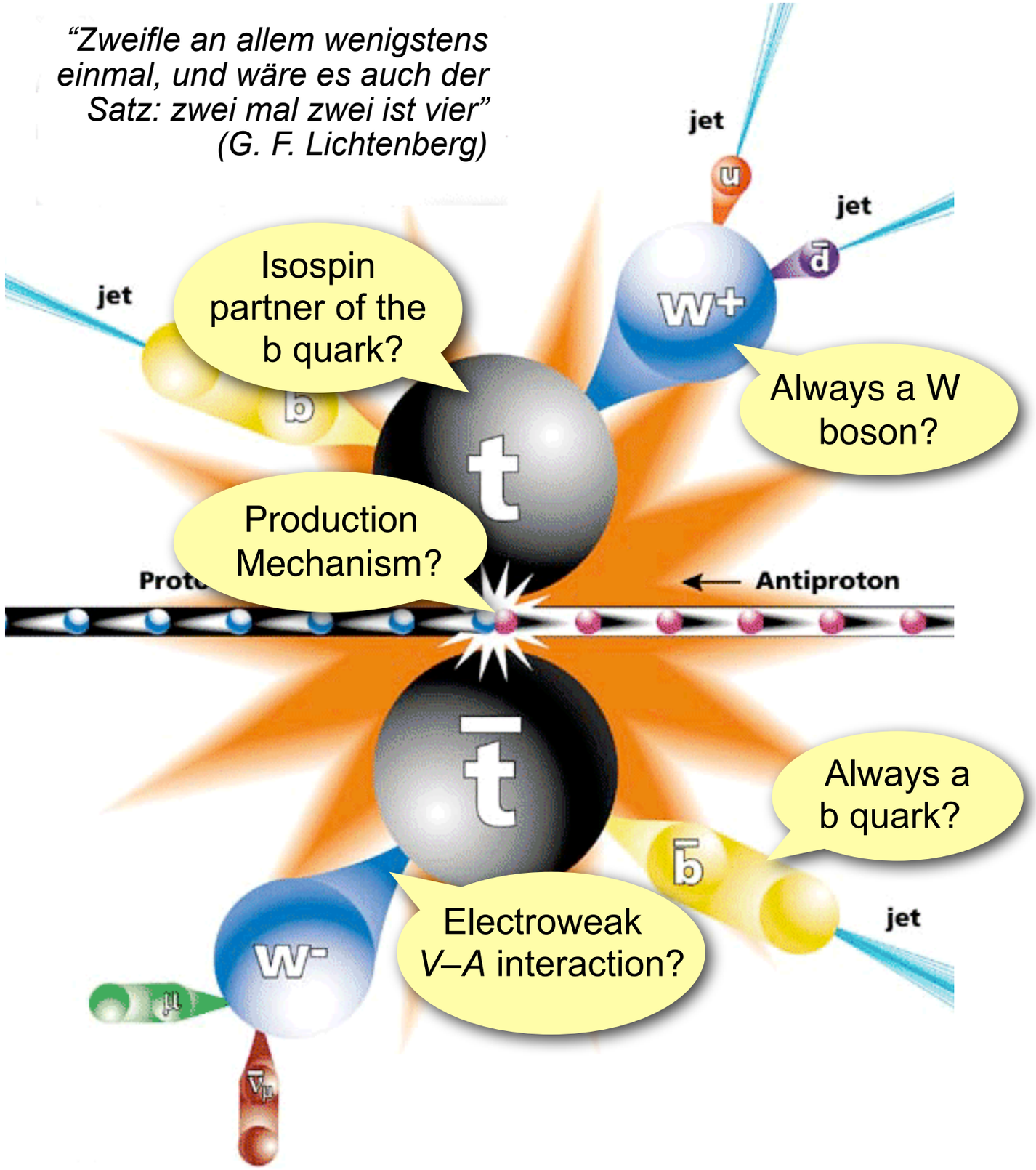
on behalf of the
CDF and DØ Collaborations

Measuring Top Properties

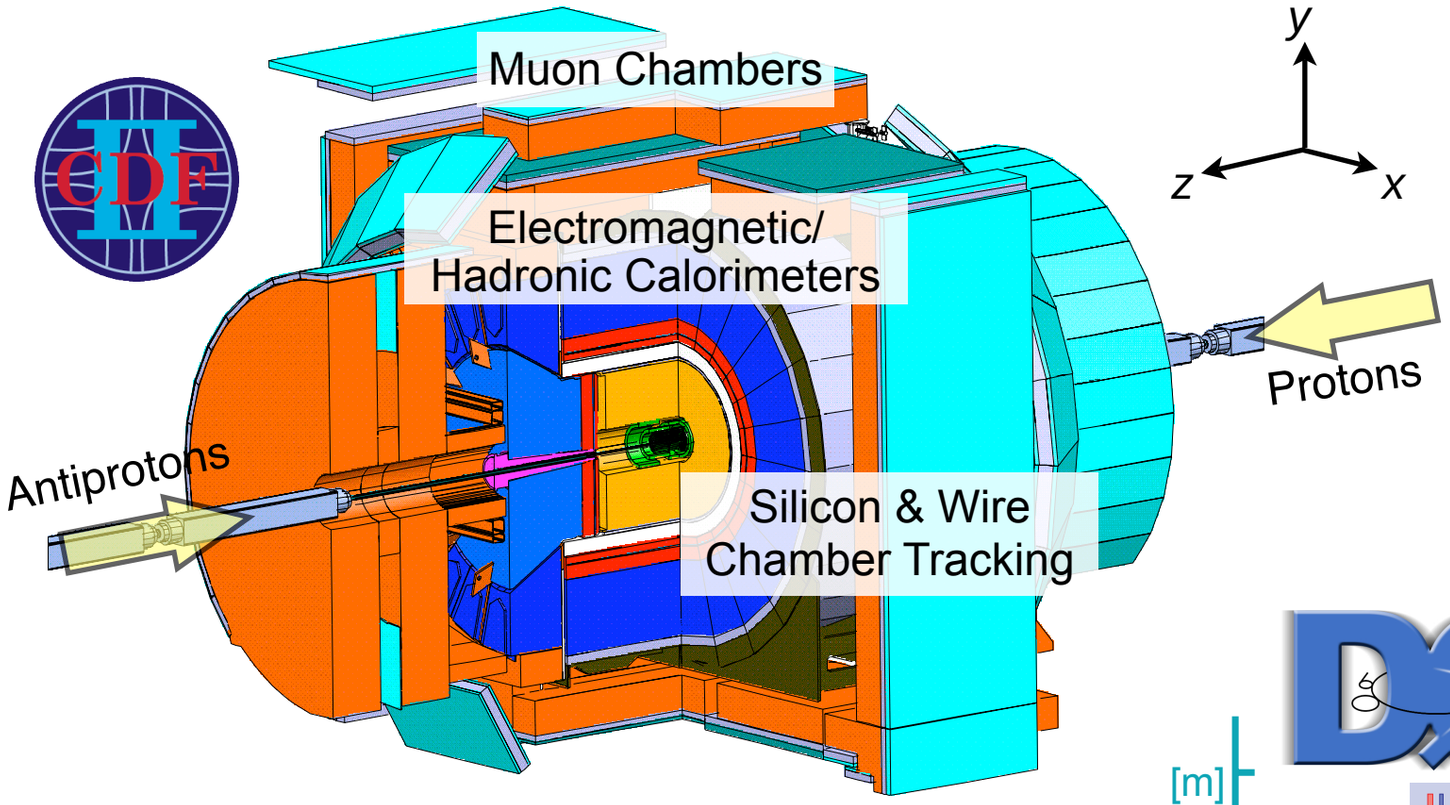
- Top plays a special role in the Standard Model (SM):
  - Mass close to scale of electroweak symmetry breaking
  - Top is the only "free" quark: lifetime < hadronization time
- From Top discovery in 1995 to precision physics in 2007:
  - Datasets: 1000s of Top events
  - Mass & cross section precisely measured
  - Evidence for single Top
- Measurements of Top properties try to answer:

Is the Top really the Standard Model Top?

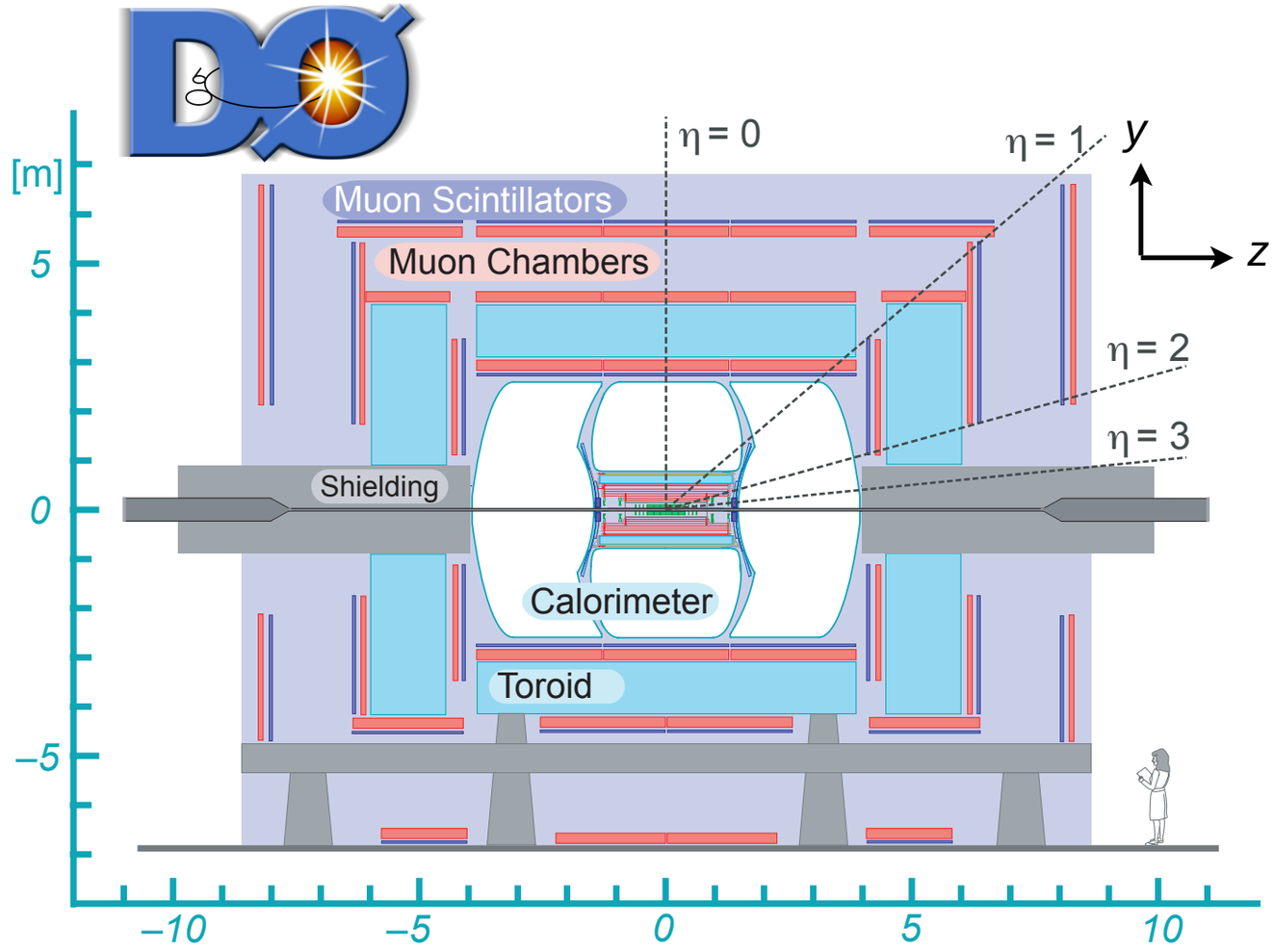
"Zweifle an allem wenigstens einmal, und wäre es auch der Satz: zwei mal zwei ist vier"
(G. F. Lichtenberg)



The Tevatron: CDF & DØ



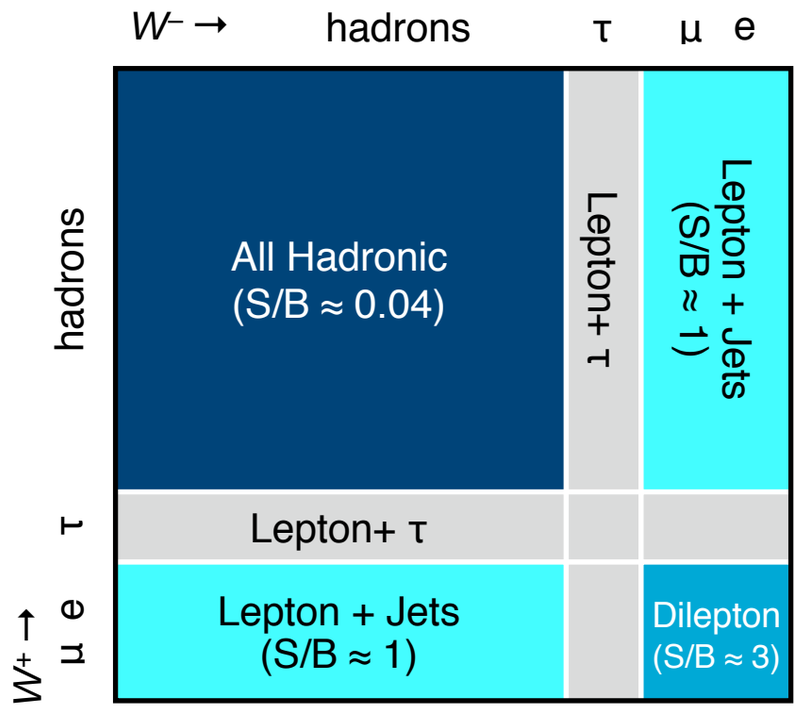
Results presented here use between 230 pb^{-1} and 1.0 fb^{-1} of data (expect 2.0 fb^{-1} results by this summer)



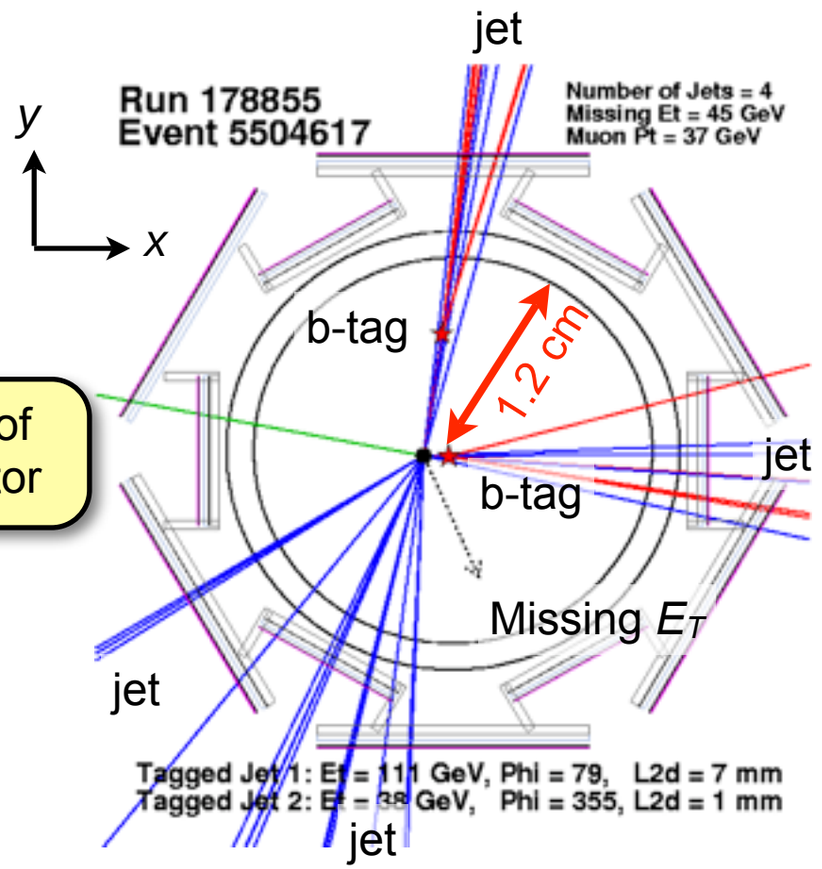
- Tevatron Run II (2001–2009):
  - Proton-antiproton collider: $\sqrt{s}$ = 1.96 TeV
  - Two multi-purpose experiments: CDF & DØ
  - More than 2 fb^{-1} of integrated luminosity recorded per experiment
  - Expect 6–8 fb^{-1} by end of Run II

Top Analysis Basics

- Top decay in the Standard Model: $t \to Wb$ (BR ≈ 100%)
- $t\bar{t}$ decay signatures characterized by W decays, in this talk mainly:
  - Lepton+Jets (30% of all decays)
  - Dilepton (5% of all decays)
- Backgrounds and systematic uncertainties: built on experience gained in Top mass and cross section analyses
  - Main background: W + Jets
  - Main systematic uncertainty: jet energy scale
- Important tool: b-tagging
  - Top events: two jets from b quarks
  - Identify B hadrons by displaced secondary vertex



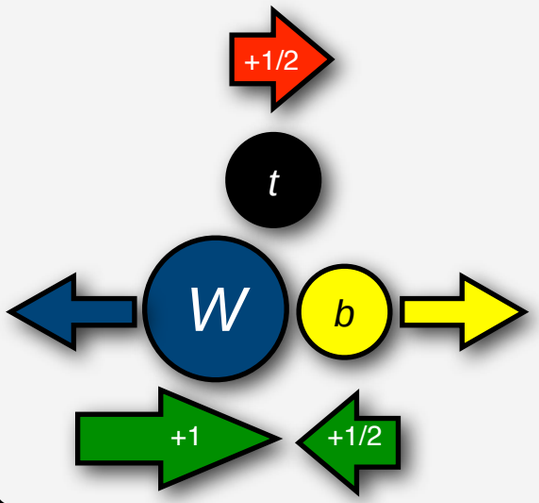
Top Pair Decay Signatures



Event in Layer 00 of CDF Silicon Detector

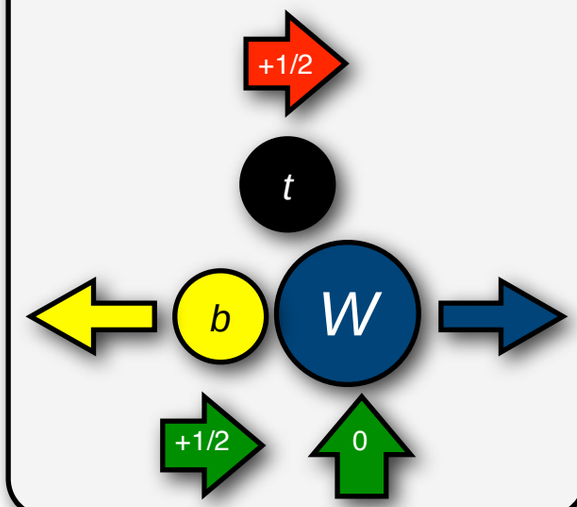
W Helicity in Top Decays

Left-handed Fraction f^-



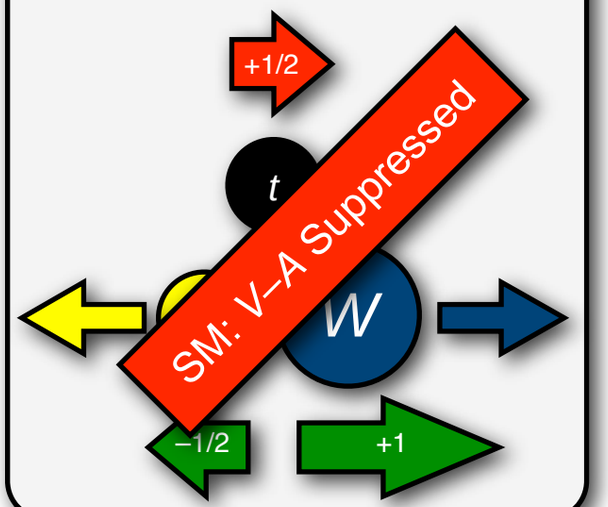
SM Prediction: 0.3

Longitudinal Fraction f^0



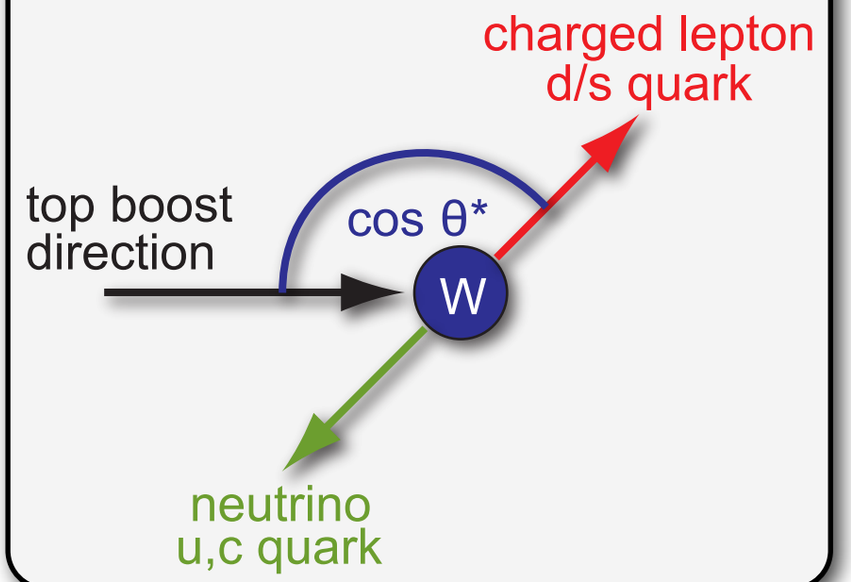
SM Prediction: 0.7

Right-handed Fraction f^+



SM Prediction: 0.0

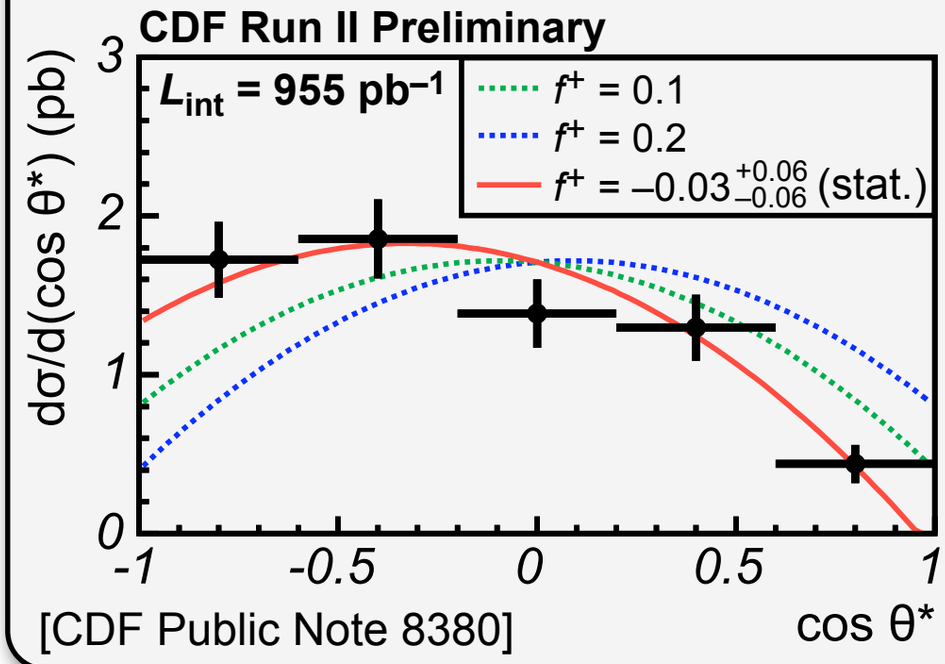
Definition of cos θ*



- Test *V–A* structure of t → Wb decay vertex
  - Close to scale of electroweak symmetry breaking
  - Electroweak interactions couple to left-handed quarks → *V+A* component: New Physics
- Observable "cos θ*":
  - Decay angle of down-type particle from W decay w.r.t. Top boost direction in W rest frame
  - Reconstructed from kinematic fitter or invariant mass of lepton and b-jet ("M_{lb}")

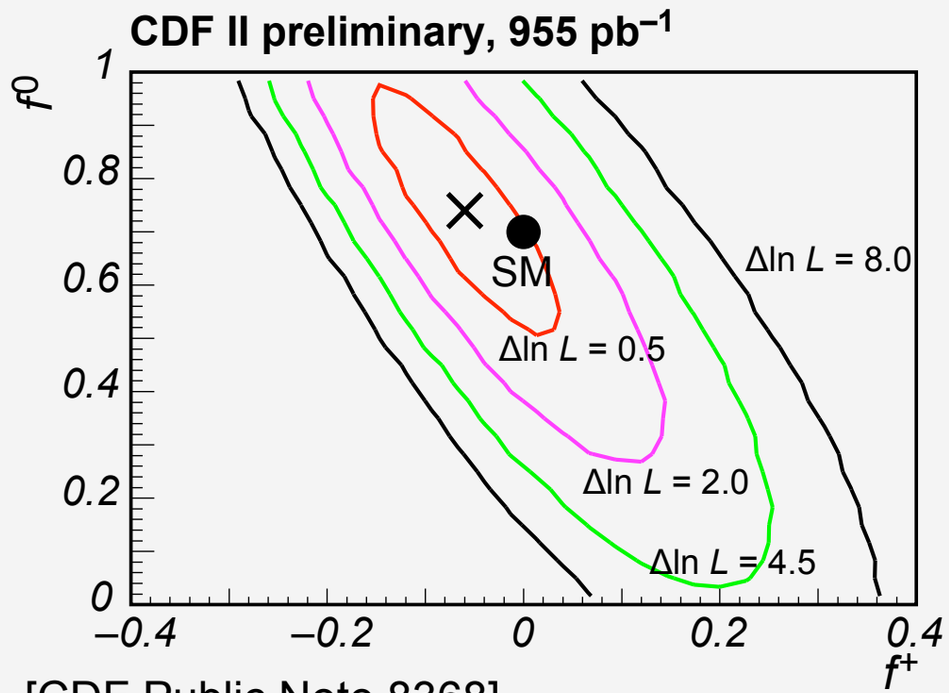
W Helicity: Results

Unfolded Differential Cross Section



[CDF Public Note 8380]

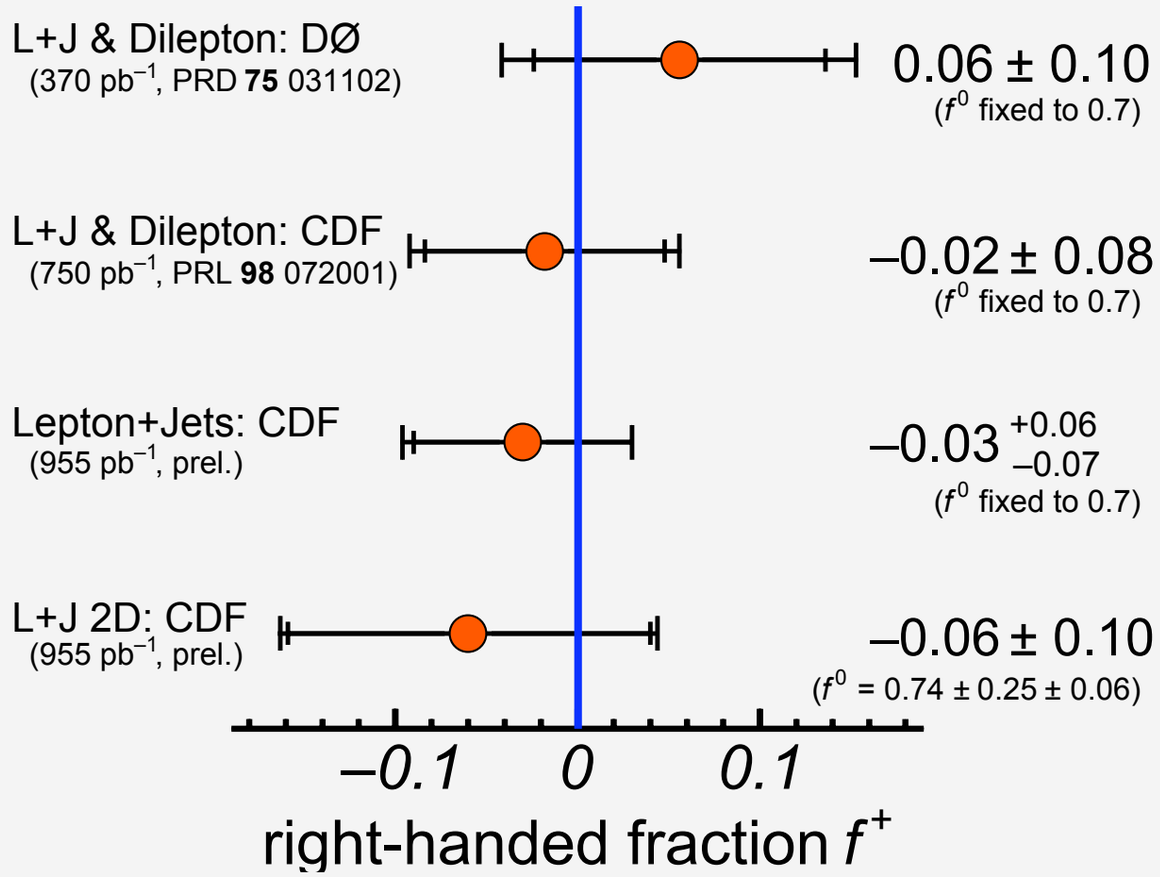
2D Fit to f^0 and f^+: Likelihood Contours



[CDF Public Note 8368]

W Helicity Summary

(Spring 2007)



- 4 independent analyses with Lepton+Jets and Dilepton data samples, up to 1 fb^{-1} of data
- Analyses statistics-limited
- All results consistent with Standard Model

Top Charge: 2/3e or –4/3e?

New

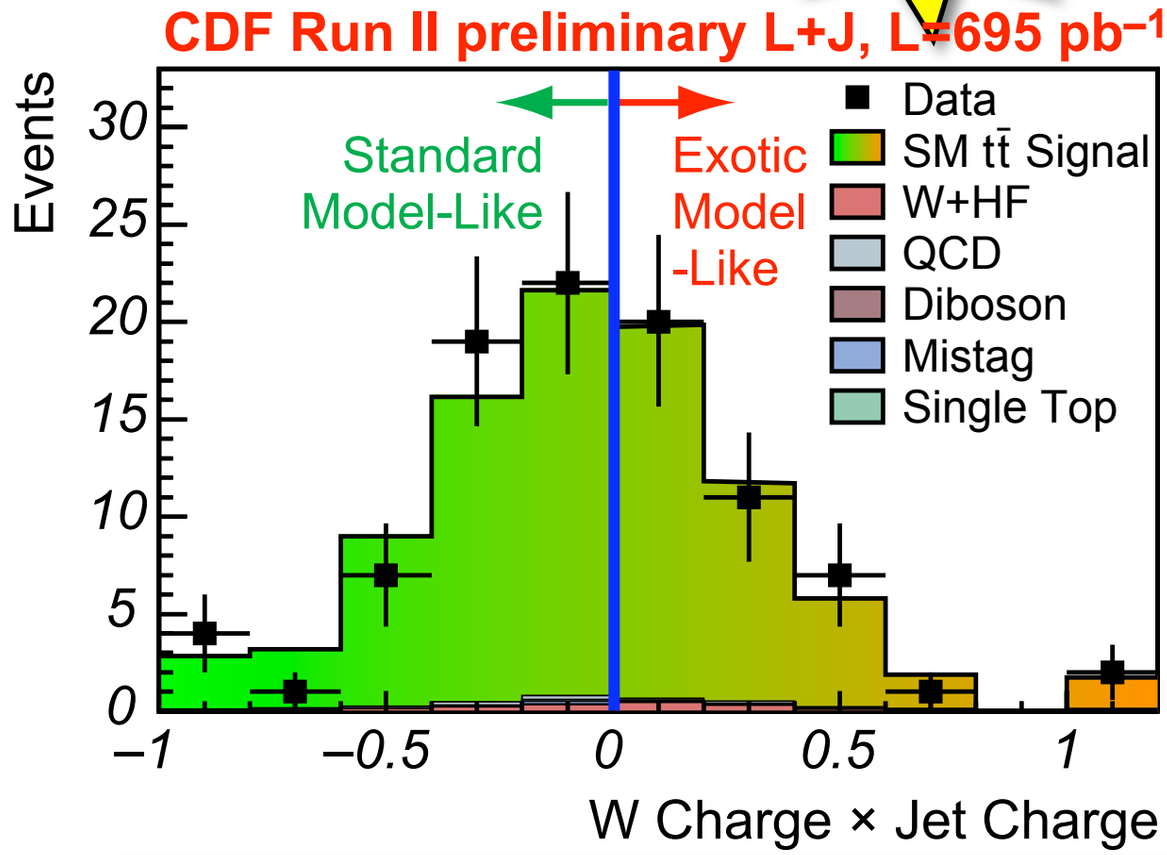
- From fits to electroweak data: observed "Top" could be exotic quark with charge –4/3*e*, true Top mass: 258 GeV/c^2

  [D. Chang *et al.*, Phys. Rev. **D59** (1999) 091503]

- Direct measurement:
  - Measure W charge: lepton charge
  - Correct pairing of W and b jet
  - Flavor of b-quark: "Jet Charge" (calibrated with dijet data)

$$\mathrm{JetQ} = \frac{\sum_{\text{tracks}} \left(\vec{p}_{\text{track}} \cdot \vec{p}_{\text{jet}}\right)^{0.5} \cdot Q_{\text{track}}}{\sum_{\text{tracks}} \left(\vec{p}_{\text{track}} \cdot \vec{p}_{\text{jet}}\right)^{0.5}}$$

- Counting experiment:
  - Lepton+Jets & Dilepton
  - 62 Standard Model-like events
  - 48 exotic model-like events



Statistical Treatment: Hypothesis Test

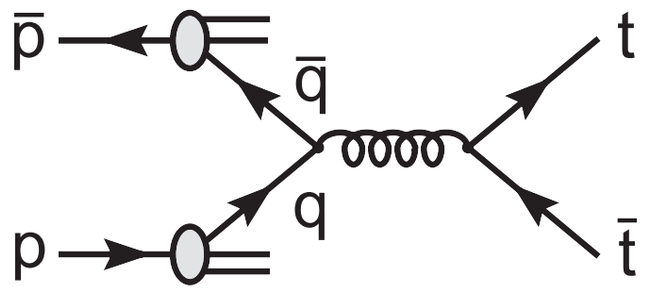
- Null hypothesis: SM is correct
- Decide *a priori*: probability of incorrectly rejecting SM: α = 0.01
- If exotic model is true: 81% of all p-values are below 0.01
- Measured p-value: 0.35, larger than α
  → data consistent with SM
  → exotic model excluded at 81% C.L.

Top Production Mechanism

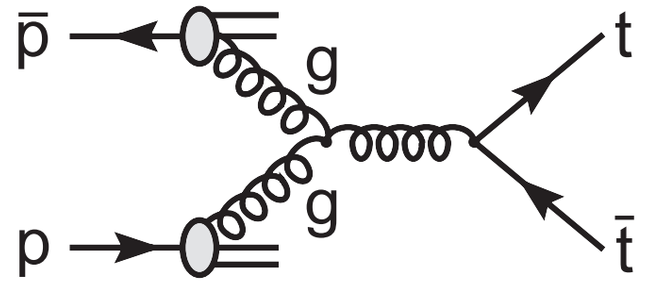
New

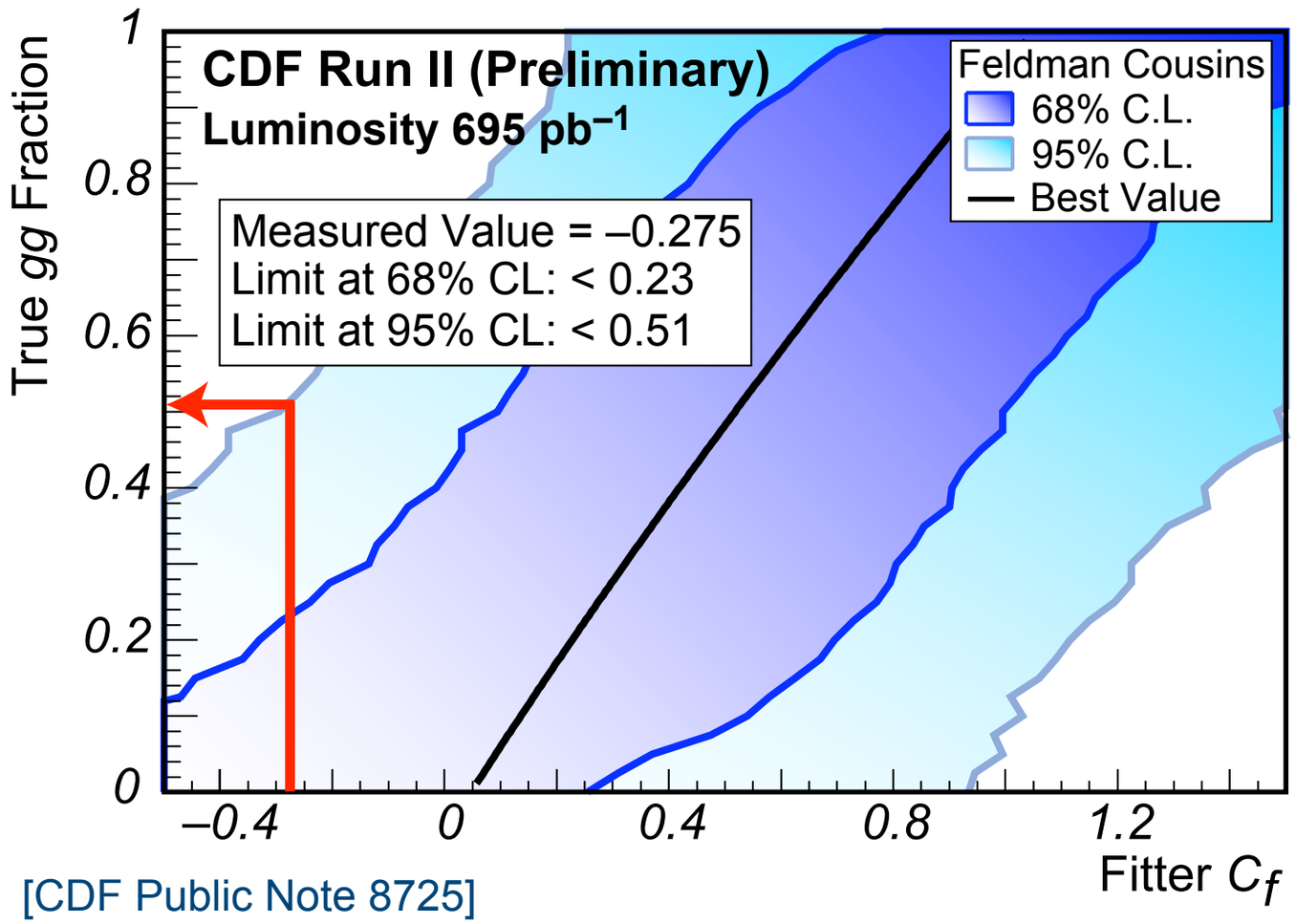
- Top pair production at the Tevatron: rather large theoretical uncertainties
- Measurement of gg fraction in top production: two very promising approaches, both statistics-limited

qq̄: 0.85 ± 0.05



gg: 0.15 ± 0.05





[CDF Public Note 8725]

Approach 1: Neural Network

- Train neural network on production and decay kinematics
- Distinguish $q\bar{q} \to t\bar{t}$, $gg \to t\bar{t}$, and background from W + Jets
- Neural network input: velocity and angle of Top, decay angles
- Derive Feldman-Cousins limit for gg fraction

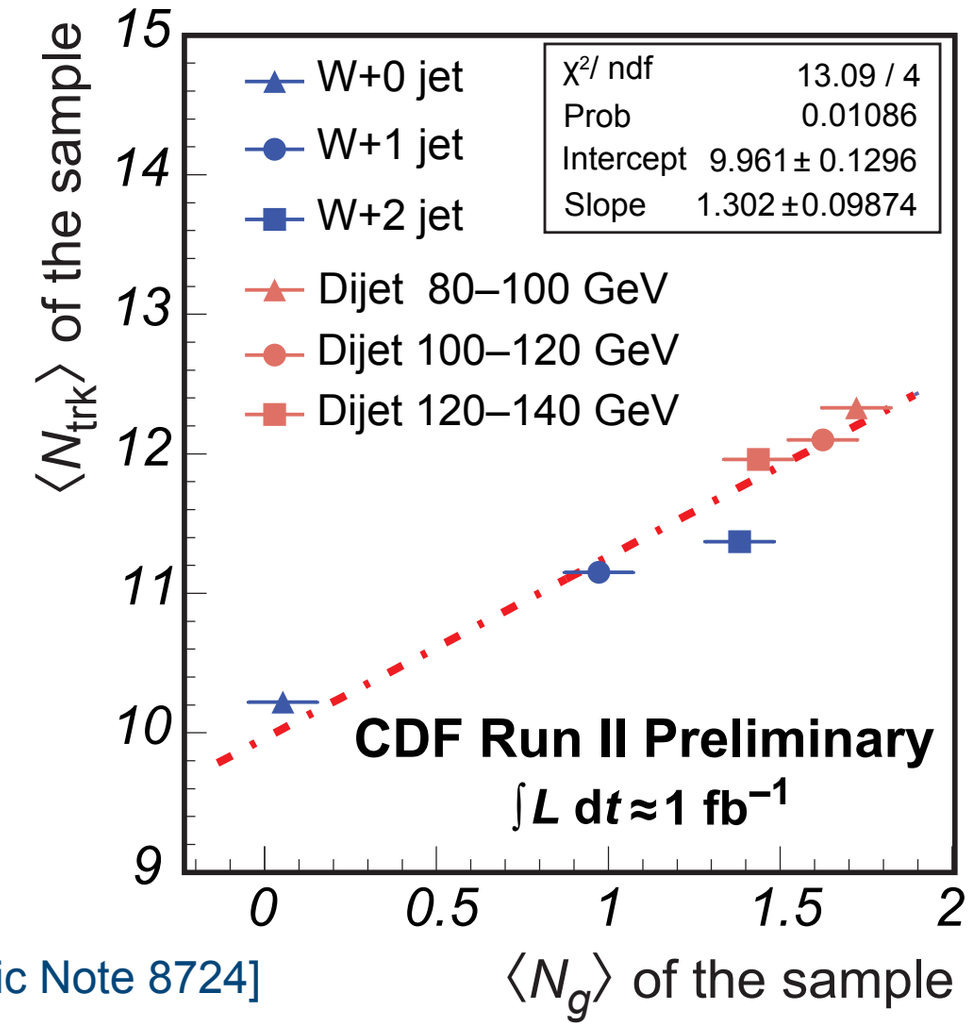
$$\frac{\sigma(gg \to t\bar{t})}{\sigma(p\bar{p} \to t\bar{t})} < 0.51 \quad (95\%\ \text{C.L.})$$

Top Production Mechanism

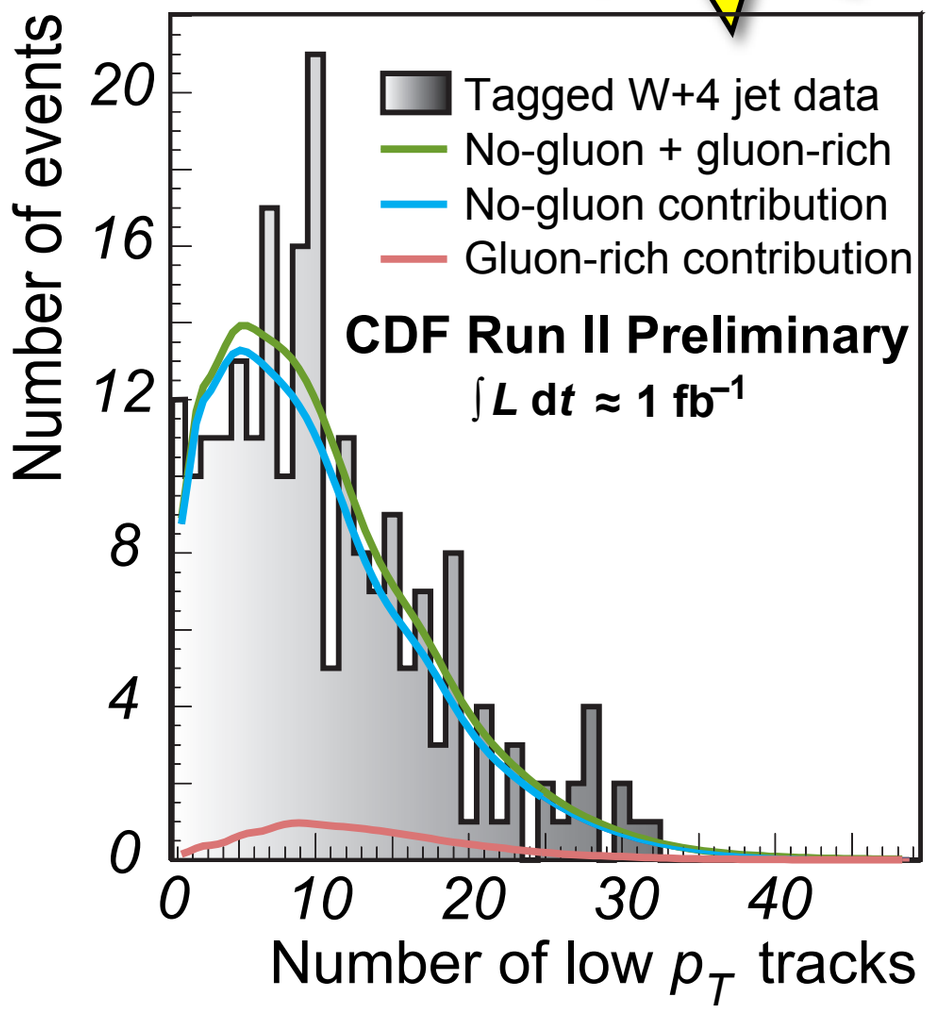
New

Approach 2: Track Multiplicity

- Average multiplicity of low-p_T tracks strongly correlated with average number of gluons
- Calibrate gluon content with data:
  - W + 0 Jets sample: approx. gluon-free
  - Low energy dijet sample: gluon rich



[CDF Public Note 8724]



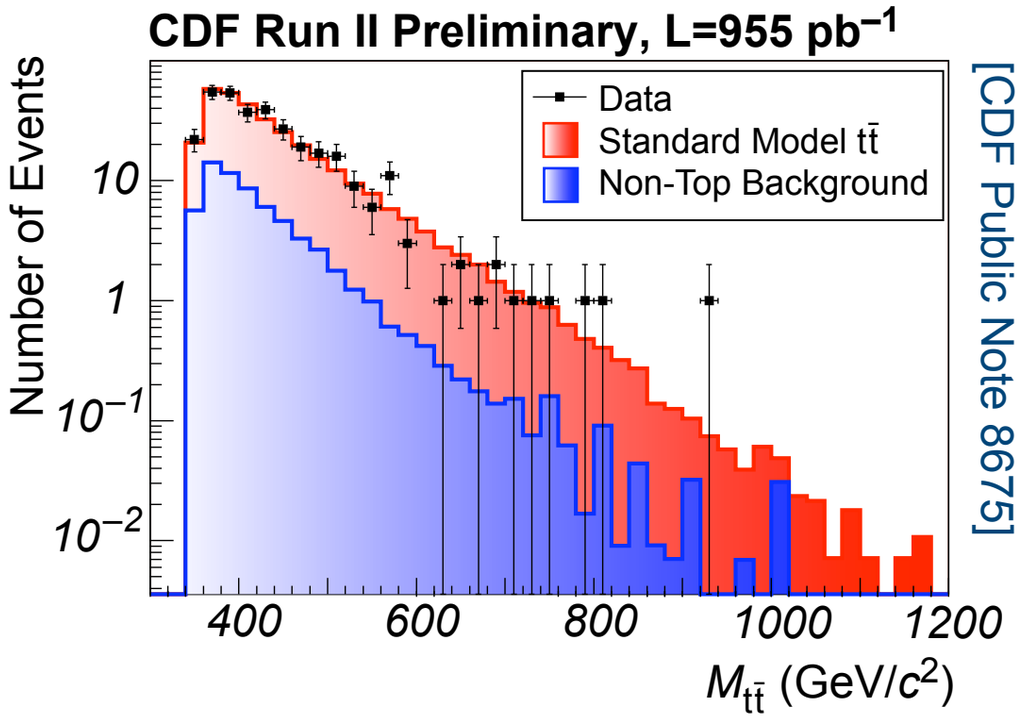
- Extrapolate to Top-rich W + 4 Jets sample, create templates for track multiplicity
- Fit templates to data:

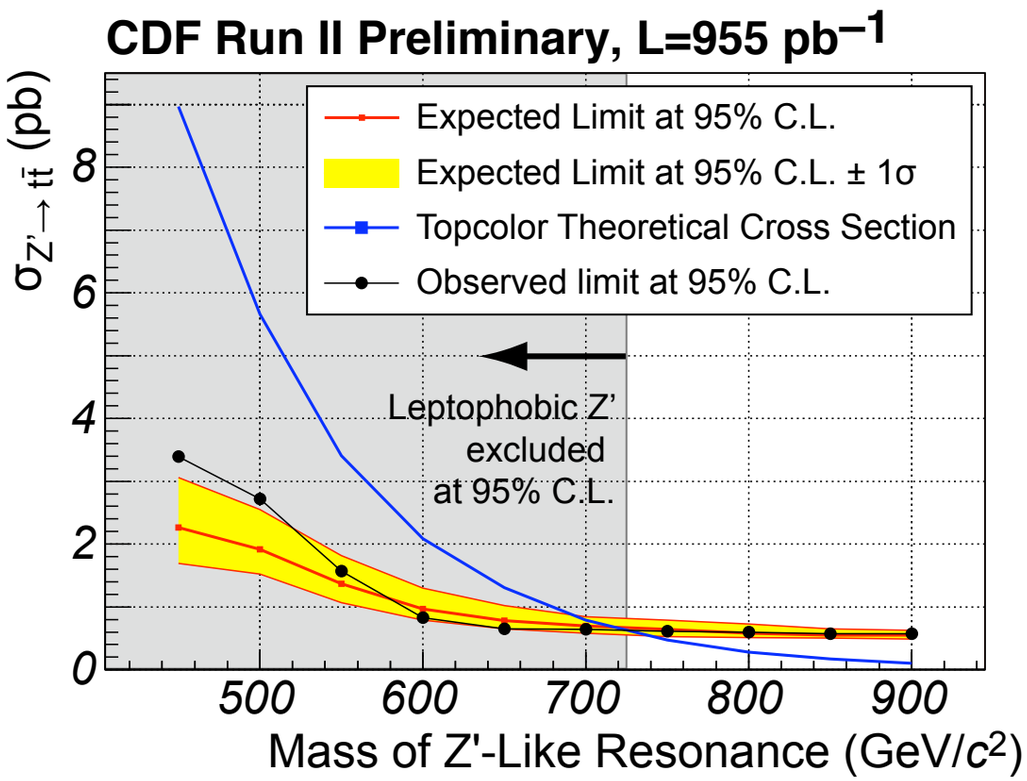
$$\frac{\sigma(gg \to t\bar{t})}{\sigma(p\bar{p} \to t\bar{t})} = 0.01 \pm 0.16\,(\text{stat.}) \pm 0.07\,(\text{syst.})$$

Search for $t\bar{t}$ Resonances

- Top pairs could be produced by heavy particle decays: $X \rightarrow t\bar{t}$
- E.g.: Topcolor-Assisted Technicolor
  - X = Z' couples strongly to 3rd generation, weakly to 1st and 2nd generation
  - Z' does not couple to leptons ("leptophobic")
  - Assume narrow resonance: $\Gamma_Z = 0.012\, M_Z$
- Experimental challenge:
  - Reconstruct invariant $t\bar{t}$ mass with kinematic fitter (or matrix-element methods)
  - Understand background composition and kinematics
- Limit on production of leptophobic Z':

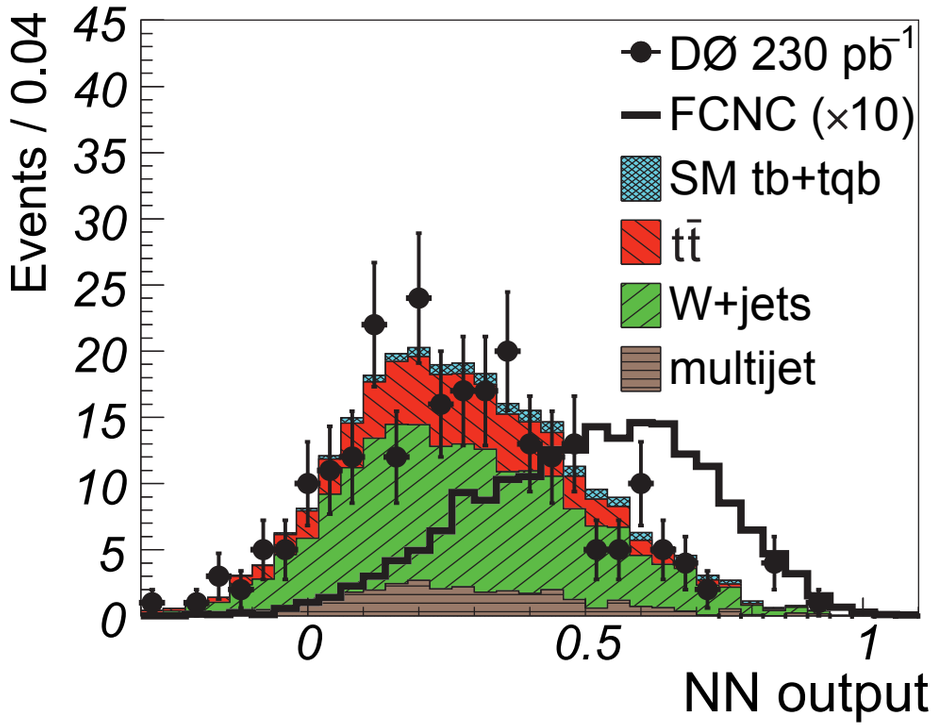
$$M_{Z'} > 725\,\mathrm{GeV}/c^2 \quad (95\%\ \mathrm{C.L.})$$

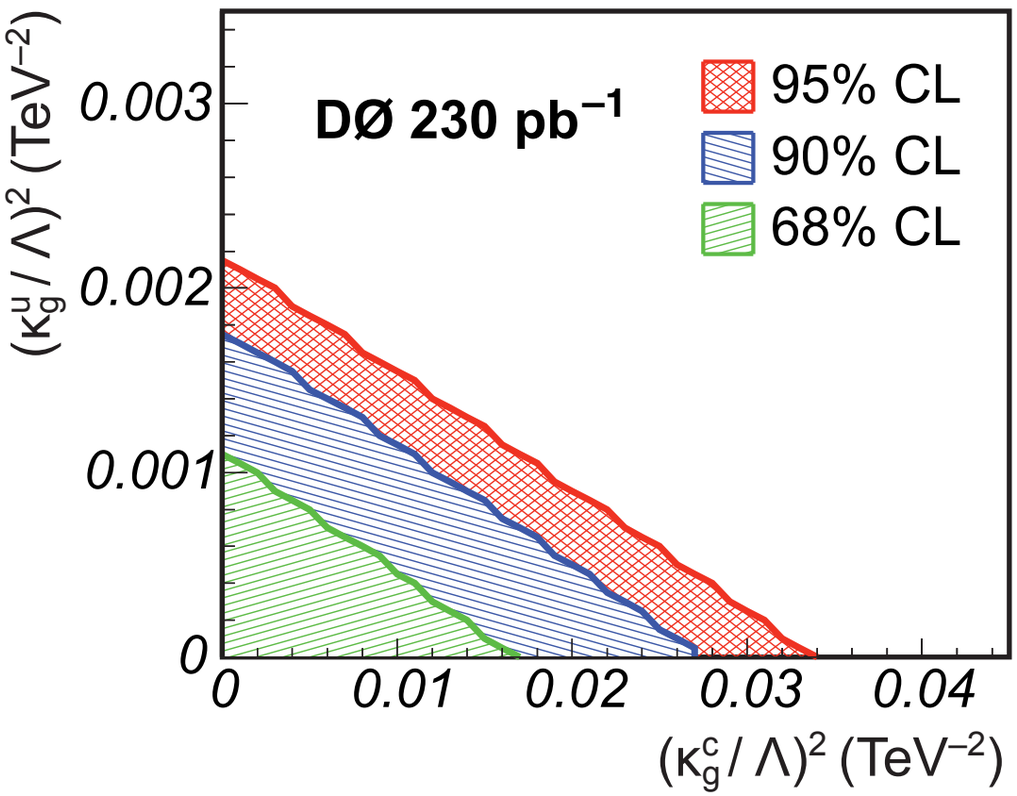




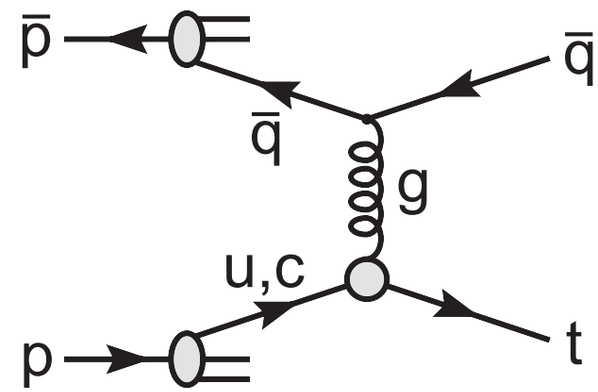
Single Top via FCNC

New





- Flavor changing neutral currents (FCNC) in the Top sector:
  - Heavily suppressed in the Standard Model, e.g. BR($t \to cg$) $\approx 5 \times 10^{-12}$
  - Any signal at the Tevatron: New Physics
- Study single Top production via FCNC:
  - More sensitive than decays
  - Neural network (NN) to discriminate signal/background



- World's new best limit on t-c-g and t-u-g couplings $(\kappa/\Lambda)^2 \to$ previous limits improved by order of magnitude

$$\left(\kappa_g^c/\Lambda\right)^2 < 0.023\,\text{TeV}^{-2} \quad (95\%\ \text{C.L.})$$
$$\left(\kappa_g^u/\Lambda\right)^2 < 0.0014\,\text{TeV}^{-2} \quad (95\%\ \text{C.L.})$$

[V. M. Abazov *et al.*, hep-ex/0702005, submitted to PRL]

Summary & Conclusions

- Tevatron is the only place to study Top quarks until LHC turn-on
- Ideal training ground to test new ideas for Top analysis at the LHC
- Study of Top properties is an exciting and active field at the Tevatron:
  - New or updated results: W helicity, Top charge, Top production mechanism, anomalous couplings
  - Many results statistics-limited
  - And there is more: Top lifetime, search for massive t' quarks, $|V_{tb}|$, …
- Data consistent with Standard Model

Please visit the CDF and DØ public Top web pages for more information:

- CDF: http://www-cdf.fnal.gov/physics/new/top/top.html
- DØ: http://www-d0.fnal.gov/Run2Physics/top/top_public_web_pages/top_public.html