Study of the Heavy Flavor content of Jets produced in Run I W events

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For the CDF Collaboration

Les Rencontres de Physique de la Vallee d'Aoste

LaThuile

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Introduction

"Yesterday Discovery is Today Background"

HEP Community Common Wisdom

- *The top quark has been discovered at FNAL by CDF and D0 in 1995 by the observation of the pair production process*

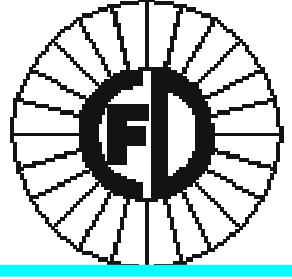
$$p\bar{p} \rightarrow t\bar{t} + X$$

and the subsequent decay of the top quarks into W bosons in association with jets.

- *Previously, all the excesses over non-$t\bar{t}$ backgrounds of tagged* W + ≥3 jets events have been attributed to top quark pair production and used to measure $\sigma_{t\bar{t}}$*

- *Alternative approach: assume the correctness of the Standard Model, use the theoretical predicted value of $\sigma_{t\bar{t}}$ and test if the Standard Model prediction is compatible with the observed yield of W produced in association with heavy flavors.*

** to be defined later*



Plan of the Talk

- *(Quick) Review of the tools used for the selection of $t\bar{t}$ events and the measurement of $\sigma_{t\bar{t}}$*

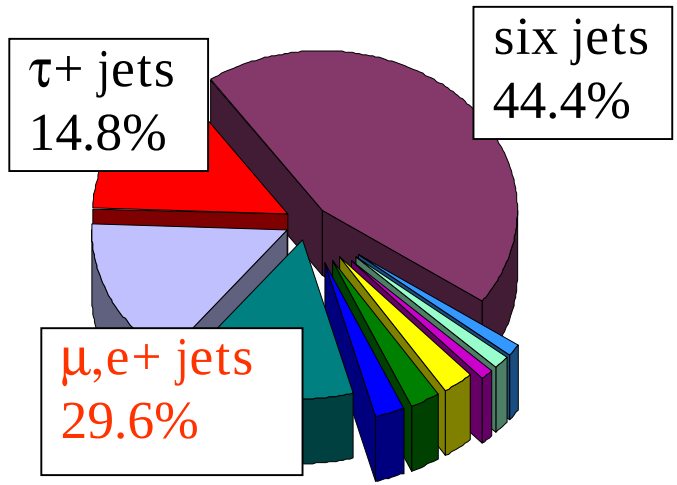
  Summary of Phys. Rev. D64:032002, 2001

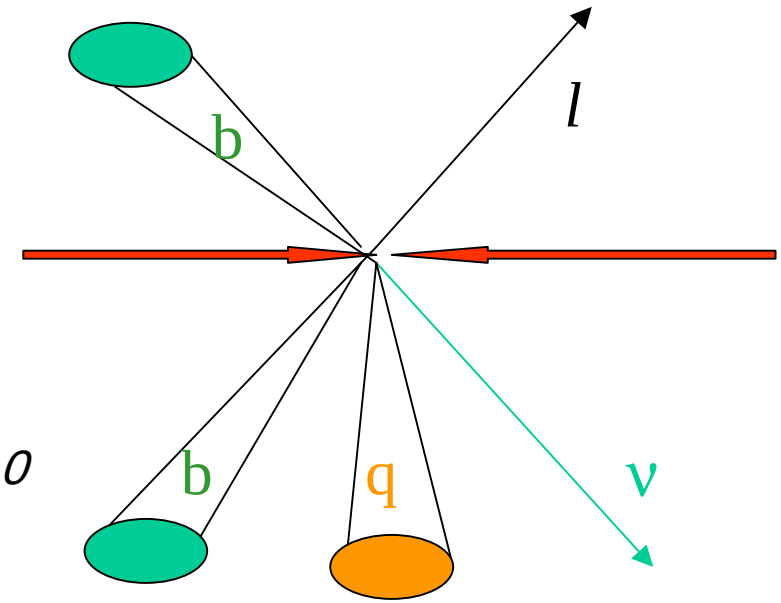
- *Counting Experiment*
  - *Discrepancy between SM expectations and count of Anomalous (Superjet) Events*
- *Kinematics Characteristics of the Anomalous Events*
- *Cross-Checks and Other Properties of the Anomalous Events*
- *Conclusions*

  Phys. Rev. D65, 052007 (2002)

$t\bar{t}$ Physics at CDF

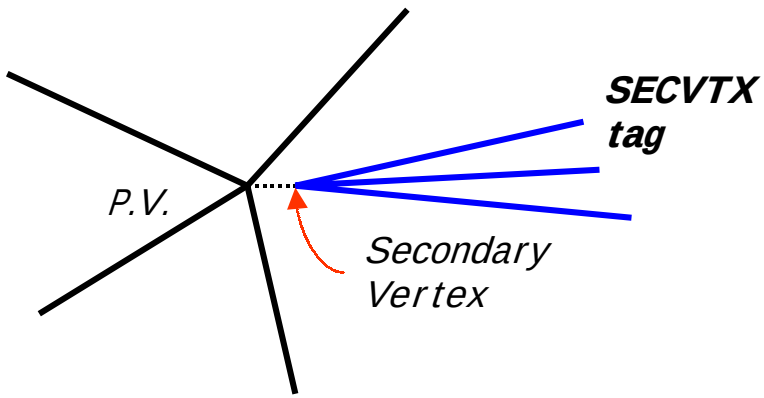
- *In the SM, the top quark completes the third quark family and t→Wb. The leptonic decay of the W characterizes a final state with:*
  - *High transverse momentum e or μ*
  - *Multiple jets, some of which with heavy flavor content*
  - *Missing E_T (undetected ν)*
- *Data Sample:*
  - *One high E_T lepton (e , **μ**)*
    - *E_T>20 GeV*
    - *Central ($|\eta|$ <1.1)*
    - *Isolated*
  - *$\not{E}_T$ > 20 GeV*
  - *at least 1 jet with E_T>15 GeV and $|\eta|$ <2.0*



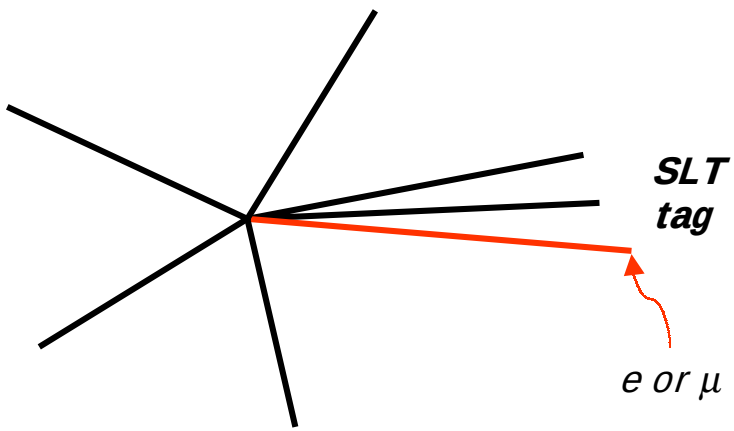


$t\bar{t}$ Physics at CDF (cont.)

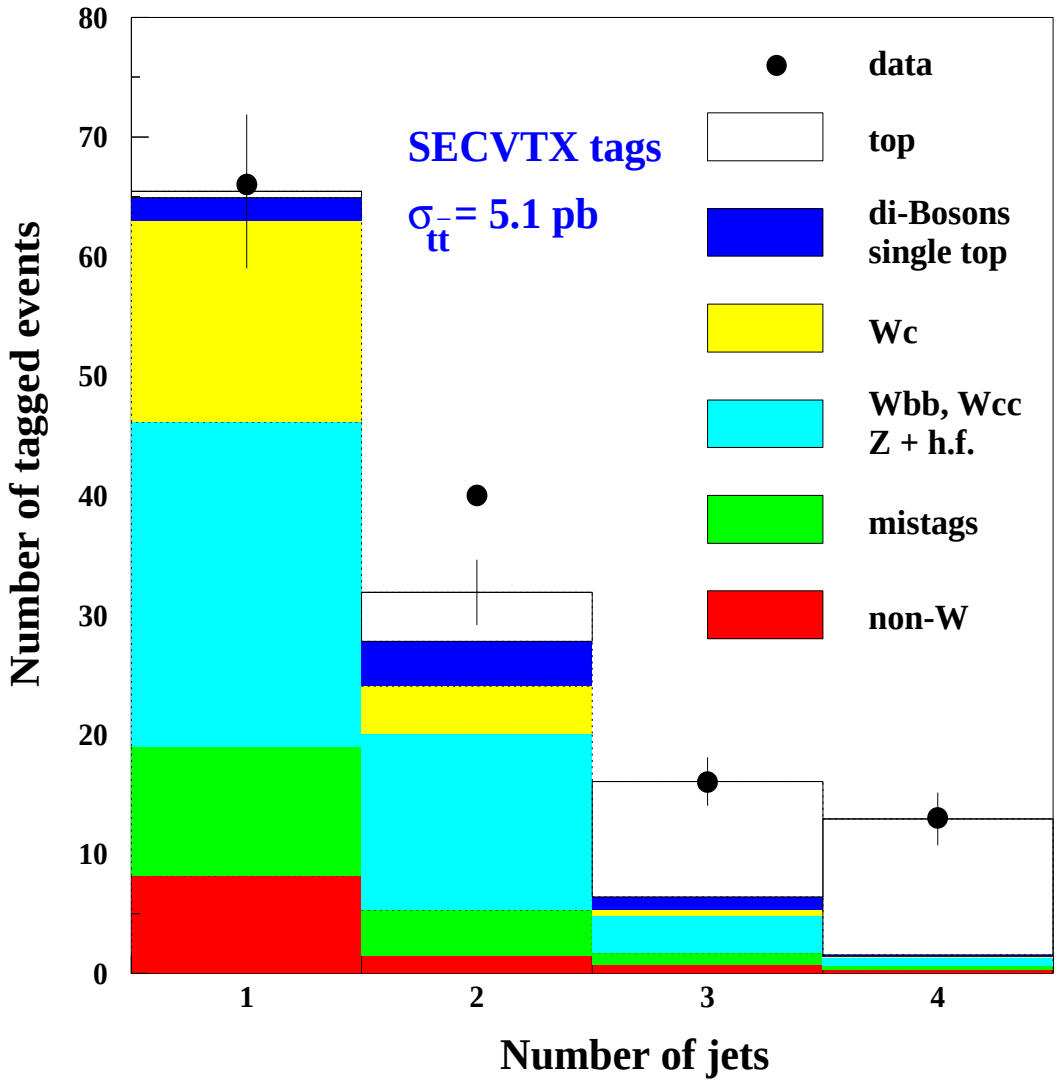
- *Selection strategy*
  - *heavy flavor identification in the jets of the final system*
- *Heavy quark (b&c) identification:*
  - *SECondary VerTeX (SECVTX)*
  - *Jet-ProBability (JPB)*
  - *semileptonic decay ($S_{oft}L_{epton}T_{agging}$)*



- *Backgrounds*
  - *Mistags: tags in jets without heavy flavor content.*
  - *W+h.f.: events where a radiated gluon splits into a pair of heavy flavor quarks.*

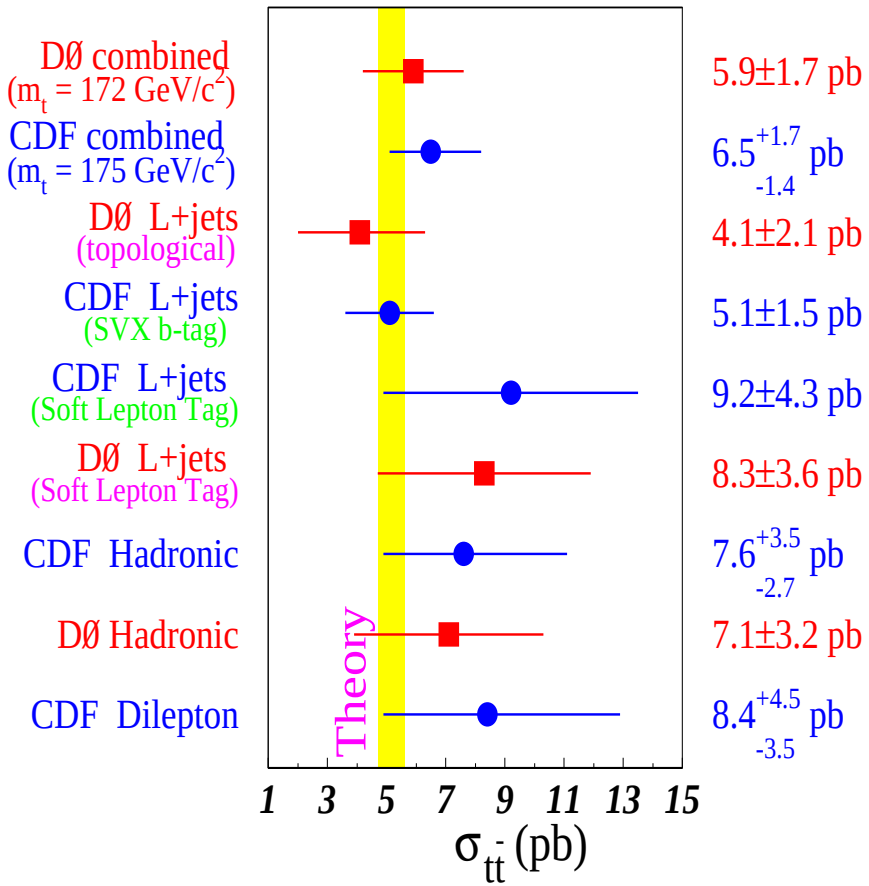


W + jets after tagging (SECVTX)



Measurement of $\sigma_{t\bar{t}}$

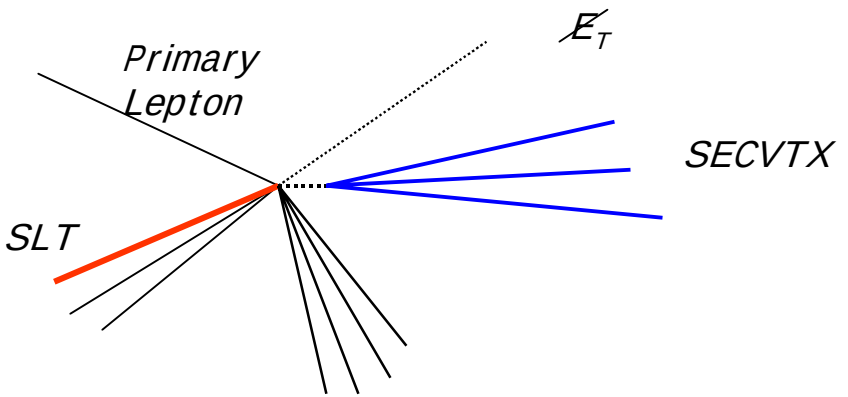
Top Cross Sections



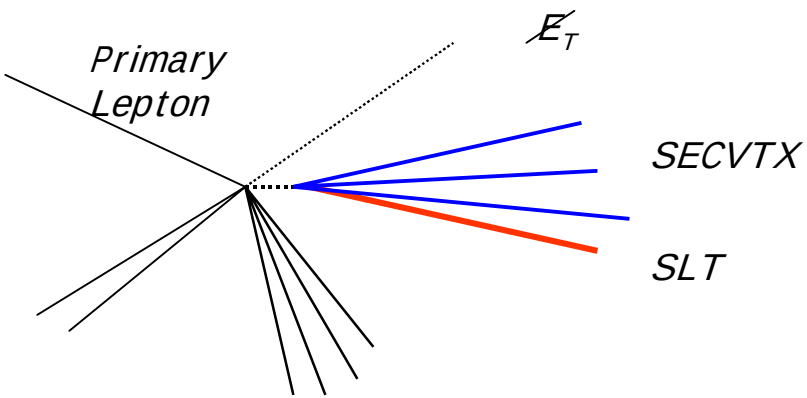
$$\sigma_{t\bar{t}}(Theory) = 5.1 \pm 0.8\, pb$$

Definitions

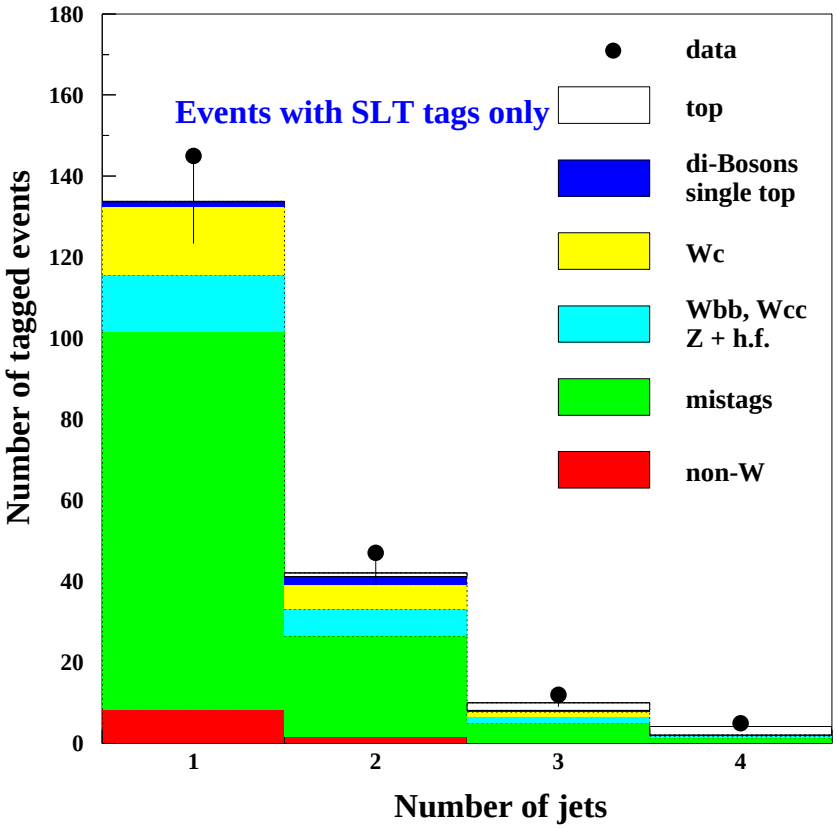
- *Multitag: An event containing both an SLT and a SECVTX tag (not necessarily on the same jet)*

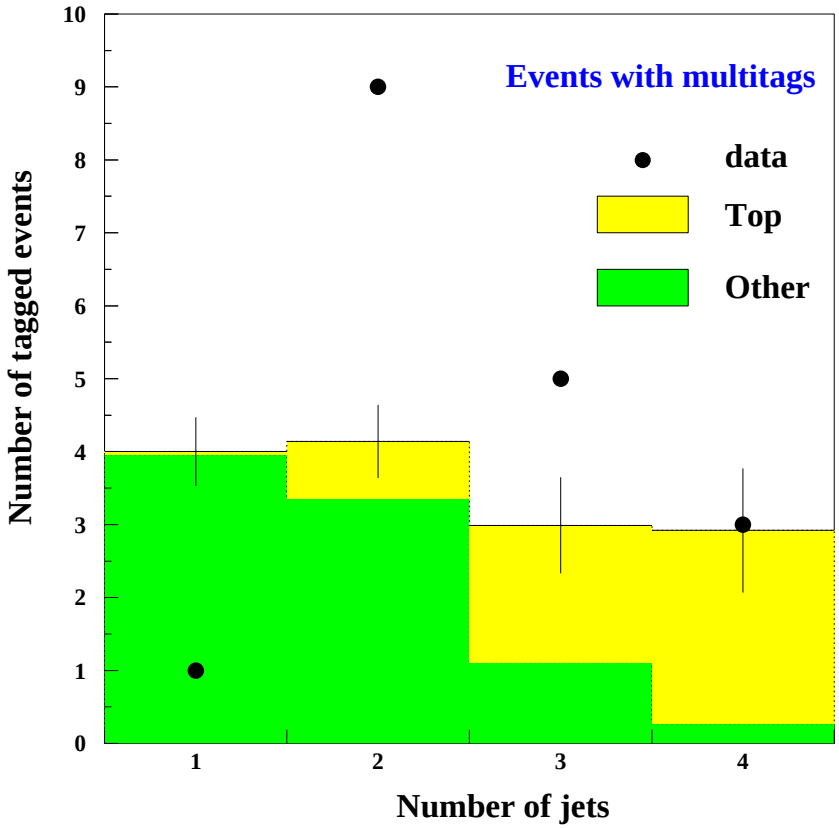


- *Supertag: An event containing an SLT and a SECVTX tag in the same jet.*
- *Superjet: the jet in a Supertag event containing the SLT and SECVTX tags*
  - *We use the prefix "super" as a generalized term of high quality. Not meant as a reference to any particular physics model.*



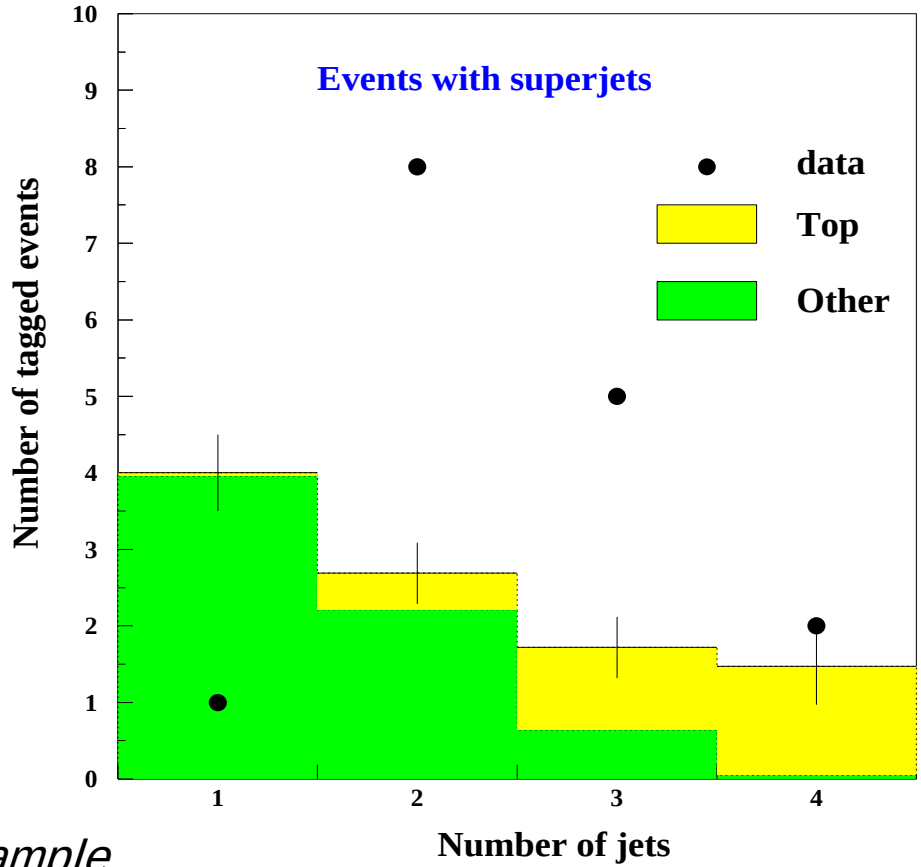
Multitag Events





- *Begin study W+jet events selected with both SECVTX and SLT tags*
- *Split sample in "Events with SLT tags only" and "Events with Multitags"*

Supertag Events



- *Superjet sample*
  - *0.4% probability of consistency with the SM in the 4 jet bins.*
- *13 events observed, 4.4 ± 0.6 expected in the W+2,3 jets bin*
  - *the* "a posteriori" *probability of consistency is* P=10^{-3}

Complementary Sample Cross-Check

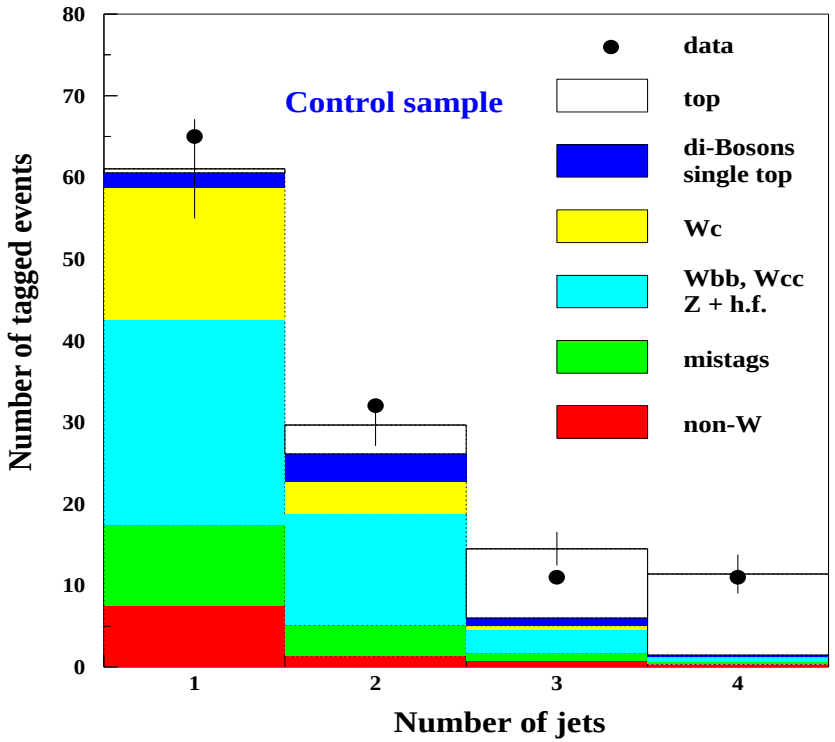
Events with:
SECVTX tag
SLT "taggable" track

→ SECVTX & SLT tags
Superjet sample

→ SECVTX, no SLT tags
Complementary sample

Similar Sample Compositions

- *Complementary Sample:*
  - *42 events observed*
  - *41.2 ± 3.1 events expected*



Study of Kinematics

- If the 13 events are a statistical fluctuation, the kinematics of this sample will be consistent with the SM simulation and the Complementary Sample
- We chose two sets of 9 variables to look for differences

First set

- Study p_T (E_T) and η for every different object in the final state.
- Add the angle between the lepton and W (check if leptons are consistent with the decay of W bosons)
- This set of 9 variables fully describes the kinematics of the final state with modest correlations.

Second Set

- "Physics-related" quantities
  - M_W, M^{b+suj}, etc.

First set

- E_T^{pl} and η^{pl}
- E_T^{suj} and η^{suj}
- E_T^{b} and η^{b}
- $E_T^{l+b+suj}$ and $\eta^{l+b+suj}$
- $\delta\phi^{l,b+suj}$

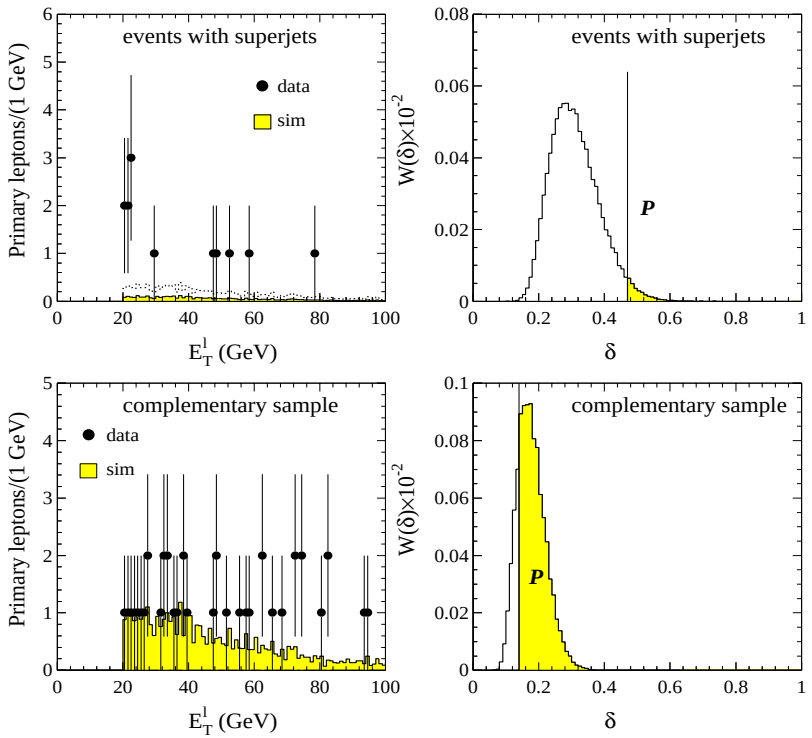
Second Set

- ~~E_T~~ and M_T^{W}
- M^{b+suj}, E_T^{b+suj}, η^{b+suj}
- $\delta\theta^{b,suj}$ and $\delta\phi^{b,suj}$
- $\delta\theta^{l,\ l+b+suj}$
- $M^{l+b+suj}$

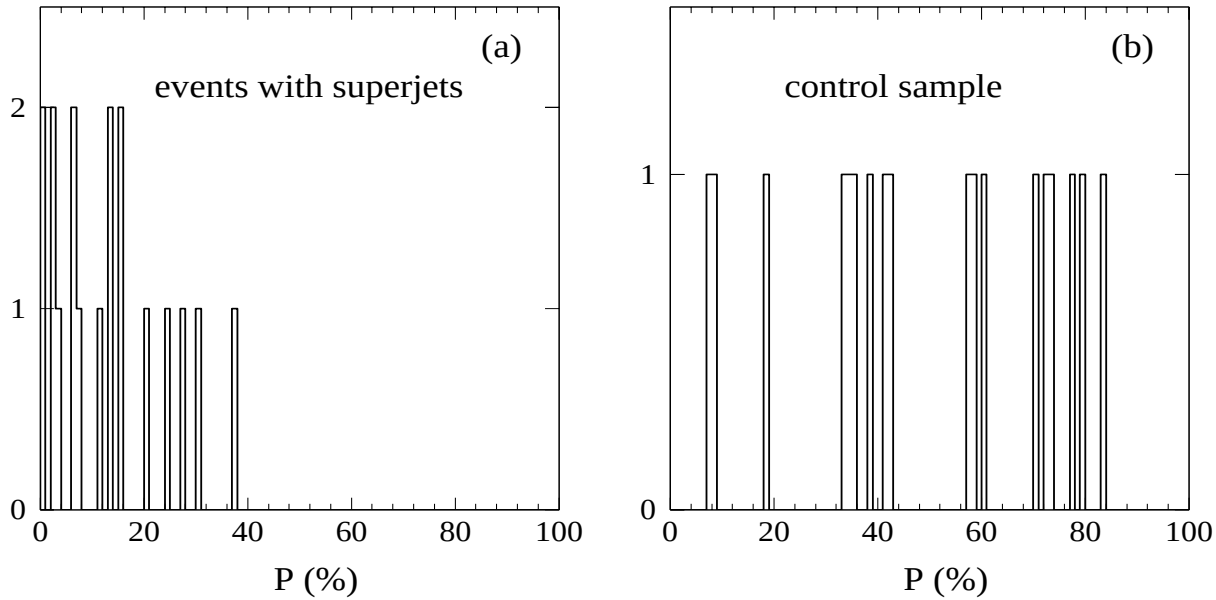
Study of Kinematics (cont.)

Primary lepton E_T

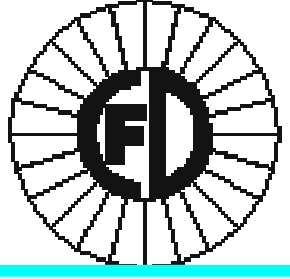
- *Compare distributions in the data and SM simulation using a Kolmogorov-Smirnov (K-S) test.*
- *The probability distribution of the K-S distance δ is determined with pseudo-experiments.*



Kinematics Probabilities Summary



- *Our SM simulation is not adequate to describe events containing a "W" and a jet on which we require the two prominent features of the heavy flavor decays: long lifetime (SECVTX) and semileptonic decay (SLT).*
- *The same simulation describes well the characteristics of other data samples (Complementary Sample -QCD).*

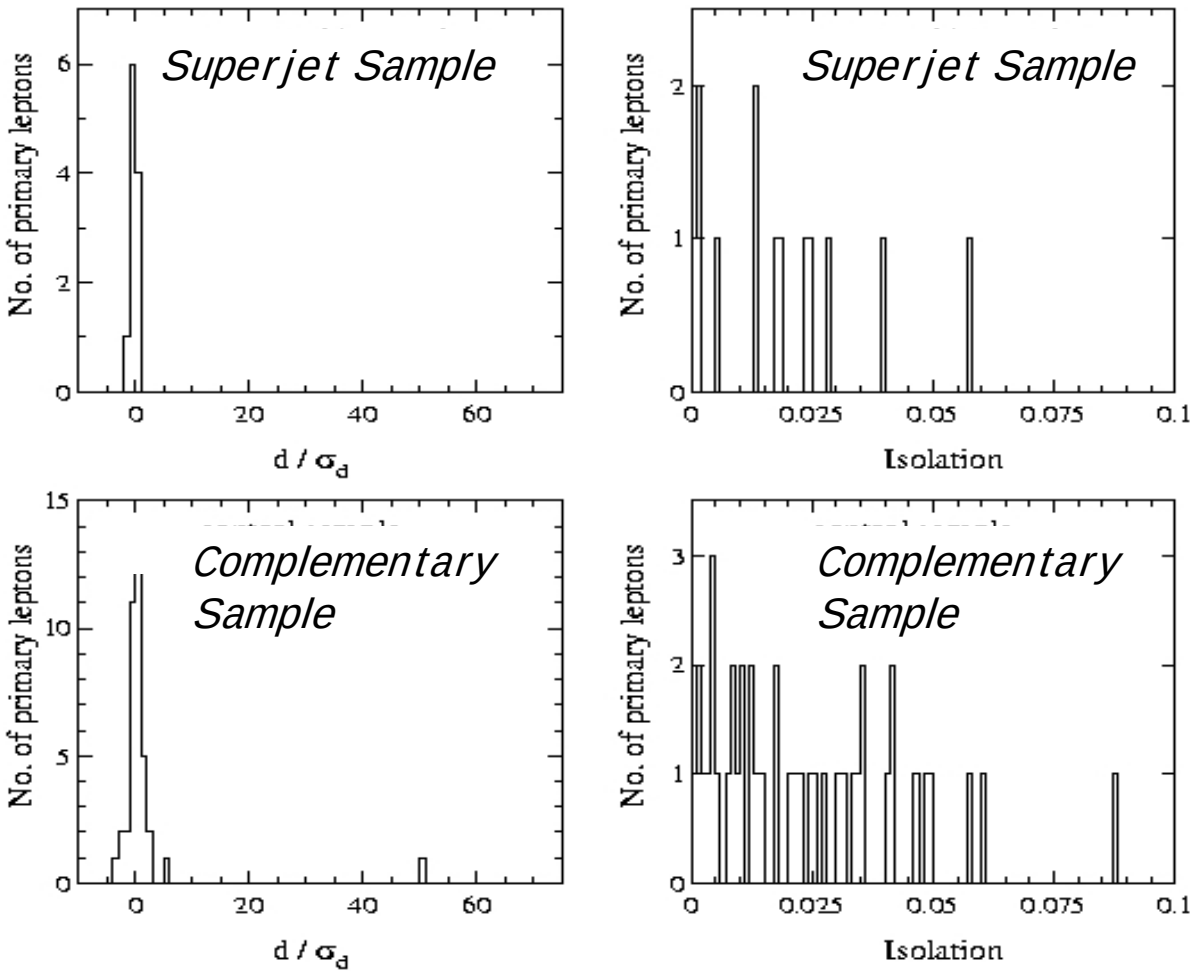


Roadmap of the Talk

- ✔ $\sigma_{t\bar{t}}$ Measurement
- ✔ Supertag Events Counting Experiment
  - Discrepancy between SM expectations and count of Superjet Events
- ✔ Supertag Events Kinematics Variables
  - Hard to reconcile with SM expectations
- Properties of the Superjets and/or Supertag Events
  - Soft Lepton P_T and Other Properties
  - Superjet Fragmentation Properties
  - Superjet Lifetime
  - Primary Lepton Properties
- Backgrounds / Acceptance Studies and Cross-checks
  - Non-W Events & Low P_T lepton Sample
  - Primary Lepton Trigger Studies
  - Extended Acceptance (Plug Electrons)
  - Superjet Tagging Efficiency in inclusive QCD Data
- Conclusions

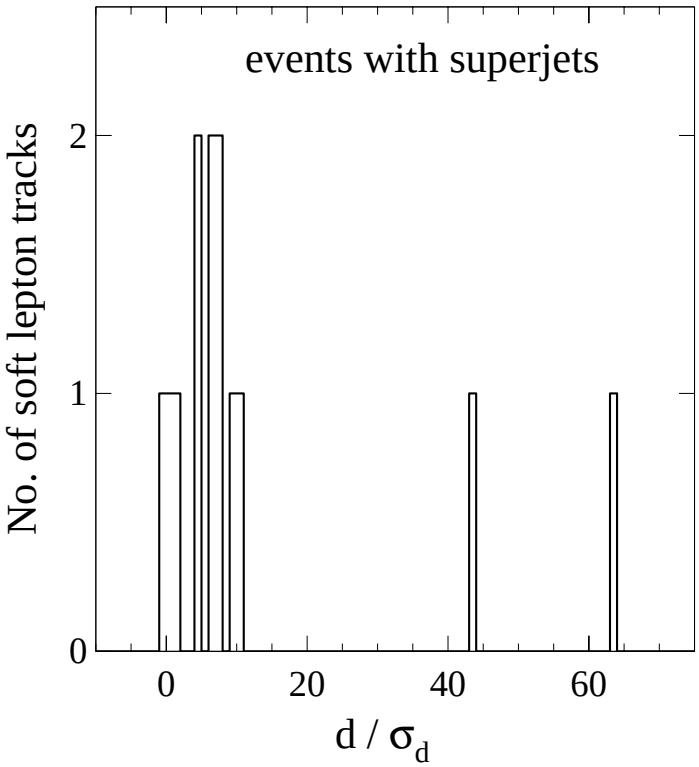
Handpicked for this presentation

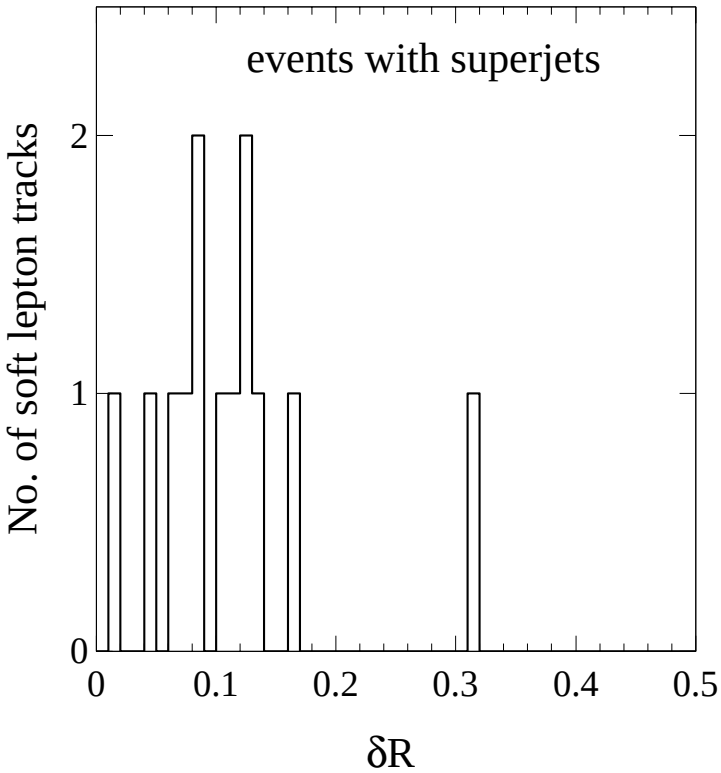
Primary Lepton Properties



- *Primary Lepton is "Primary"* ➡ *Supertags do not select background*

Superjet properties: Soft Lepton distributions

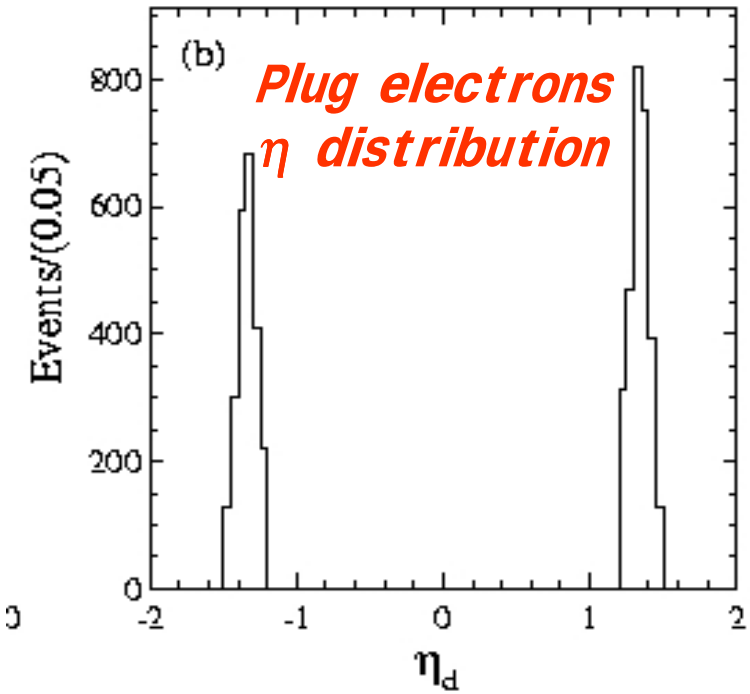




- *Soft leptons*
  - *not prompt*
    - *in 8 cases are part of the SECVTX tag*
  - *emitted along the superjet axis*

→ *Consistent with a long-lived decay inside a jet*

Plug electrons



Acceptance increases by ~20%.

- *Observe 2 additional supertag events.*
  - *Consistent with expectations scaled from the central region observation*
- *SM prediction (scaled from the central region) are low (0.34 ± 0.04 expected) relative to observations.*

Additional Studies

- *Release CDF L2 trigger requirements*
  - *0.10 ± 0.04 expected from SM*
  - *~ 2 events expected (scaling from data)*
  - *Observe 2 additional superjet events*

- *In 13 out of 17 events with a superjet the charges of the primary lepton and soft lepton are opposite*
  - *The probability of an equal or larger fluctuation is 2.4%.*

- *We find no unexpected superjet event by releasing the event selection cuts:*
  - *primary lepton P_T* — p_T>20 GeV → P_T>18 GeV
  - *primary lepton isolation* — $I < 0.1$ → $0.1 < I < 0.2$
  - $\not\!\!E_T$ — $\not\!\!E_T$> 20 GeV → $\not\!\!E_T$<20 GeV

Conclusion

- *We have studied the heavy flavor content of jets produced in association with W bosons at CDF*
- *We generally find good agreement between observed and predicted rates of SECVTX (displaced vertex) and SLT (soft lepton) tags*
- *An exception is the number of events with a superjet (13 events while 4.4 ± 0.6 are expected)*
- *A detailed examination of the kinematical properties of these events shows that they are statistically difficult to reconcile with a simulation of SM processes. The same simulation models well a complementary sample of W+jet events and larger samples of generic-jet data*

Conclusion (cont.)

- *Obscure detector effects can never be ruled out, but extensive studies of these events and investigation of larger statistical data sets have not revealed any effects which might indicate detector problems or simulation deficiencies*
- *We are not aware of any model for new physics which incorporates the production and decay properties necessary to explain all the features of these events.*