b\bar{b} cross section measurement at CDF

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Outline

• b production at the Tevatron
• The CDF detector
• The Silicon Vertex Trigger
• Jet reconstruction
• b-jet identification
• The b$b$ di-jet cross section
• Comparison to Monte Carlo
b quark production

THE STUDY OF b PRODUCTION PROPERTIES IS AN IMPORTANT TEST TO pQCD

Proton structure

\[
\frac{d\sigma(p^- p \rightarrow BX)}{d p_T(B)} = \frac{d\sigma(q^- / g g / qg \rightarrow bX)}{d p_T(b)} \otimes F_{p p} \otimes D_{b \rightarrow B}
\]

NLO QCD

Fragmentation

b-jets as experimental input:
• include most of quark fragmentation remnants
• small dependence on fragmentation
• wide $P_T$ spectrum

CDF HAS ALREADY MEASURED THE INCLUSIVE B-JET CROSS SECTION

RUN II
b quark production

- $b \bar{b}$ CROSS SECTION AND CORRELATION GIVE A HINT ON $b$ PRODUCTION MECHANISM
- GOOD TEST TO NLO VS LO PREDICTIONS

Run I LO Monte Carlo study
CDF

TEVATRON HAS DELIVERED MORE THAN 2 fb⁻¹

CDF FULLY UPGRADED FOR RUN II:
- SI & TRACKING
- EXTENDED CALORIMETERS RANGE
- L2 TRIGGER ON DISPLACED TRACKS
- HIGH RATE TRIGGER/DAQ

CALORIMETER
- CEM LEAD + SCINT 13.4%/√E_T+2%
- CHA STEEL + SCINT 75%/√E_T+3%

TRACKING
- σ(d_0) = 40μm (INCL. 30μm BEAM)
- σ(P_T)/P_T = 0.15 % P_T

~85 % DAQ EFFICIENCY

2.3 fb⁻¹ delivered
2 fb⁻¹ to tape
Silicon Vertex Trigger

$\sigma(\bar{b}b) \sim 50 \, \mu b @ 1.96 \, \text{TeV} \rightarrow $ RATE OF FEW KHz

LONG LIFETIME (~1.5 ps) OF B-HADRON

$\rightarrow$ DEDICATED IMPACT PARAMETER TRIGGER
BASED ON SILICON DETECTOR HITS
AND L1 FAST TRACKER INFO

USE @ HIGH PT:
SEARCH FOR NEW PHYSICS
NEW FOR QCD STUDIES
Jet reconstruction

Final state partons result in collimated flows of hadrons: \textit{jets}

**CONE ALGORITHM:** PARTICLES OR TOWERS CLUSTER WITHIN A \((\eta,\phi)\) CONE

- **Seed towers:** Only iterate over towers above \(E_T > 1\) GeV

Need to correct jet energy:

**Detector effects:**
- resolution and efficiency
- pile-up interactions (up to \(~4\))

**Model dependent:**
- fragmentation/hadronization effects
- mc based \(\rightarrow\) to be tuned on data

Underlying event

In this measurement: specific \(b\)-jet correction
Identifying b-jets

B-TAGGING:
SEARCHING FOR THE B DECAY VERTEX

- Need ≥ two displaced tracks to reconstruct a secondary vertex
- Require secondary vertex to be well separated from primary vertex in r-φ space by cutting on \( L_{xy} \) significance

SVT TRIGGER EFF. FOR B-TAGGED JETS

EFFICIENCY IS ~ 50%

MEASURED ON DATA
Event selection

**ONLINE SELECTION:**
- Level1: 2 L1 TRACKS AND 2 CAL TOWER
- Level2: 2 SVT TRACKS |d_{0}|>100 µm AND 2 CAL CLUSTER E_{T}>15 GeV (Δφ CLUSTER-TRACK MATCHING)
- Level3: 2 TRACKS MATCHED TO 2 JETS

**OFFLINE SELECTION:**
- PRIMARY VERTEX |Z|<60 cm FOR GOOD ENERGY MEASUREMENT AND VERTEXING
- 2 SVT TRACKS |d_{0}|>120 µm
- 2 b-TAGGED JET (CONE 0.4) E_{T}>35, 32 GEV, |η|<1.2
- GEOMETRICAL (ΔR) TRACK - JET MATCHING

**NEED A TIGHT OFFLINE SELECTION TO ACCOUNT FOR EVENT SHAPING BY THE TRIGGER**

**OFFLINE SELECTION EFFICIENCY IS MEASURED IN MC & SCALED TO DATA**

![Graph showing Leading jet E_{T} vs. 2 SVT-tag jets efficiency](image)
b purity of tagged jets

b JET FRACTION IN A TAGGED JET SAMPLE CAN BE EXTRACTED FROM DATA: the invariant mass of the tracks of the secondary vertex is different for b/c/light or gluon jets

In a 2 tagged jet sample:
- SUM SEC. VTX MASS OF 2 JETS
- BUILD bb AND NON-bb TEMPLATES
- FIT DATA

SVT + TAG selection has low efficiency
BUT very high purity ~80%
**bb** di-jet cross section

\[
\frac{d\sigma}{dE_T\Delta\eta} = \frac{N_{2\text{SVT}} \cdot f_{2\text{SVT}}^{2b} \cdot C_i}{\Delta\eta \cdot \Delta E_T \cdot \epsilon_{2\text{SVT}} \cdot \int L}
\]

- **\(N_{2\text{svt}}\):** Number of events including 2 SVT-tagged jets
- **\(f_{2\text{svt}}^{2b}\):** bb-jets fraction
- **\(\epsilon_{2\text{svt}}\):** Efficiency for 2 SVT-tagged jets
  - Leading jet: \(E_T^{\text{corr}}>35\ |\eta|<1.2\)
  - Second jet: \(E_T^{\text{corr}}>32\ |\eta|<1.2\)
- **\(C_i\):** Correction factors from Monte Carlo for acceptance and smearing effects
- **\(\Delta\eta\):** Pseudorapidity range \(|\eta|<1.2\)
- **\(\Delta E_T\):** Transverse energy bin size
- **\(\int L\):** Integrated luminosity

**\(E_T^{\text{corr}}\):** specific correction is applied to account for harder fragmentation and b-hadron decays inside the jet
TOTAL SYSTEMATIC UNCERTAINTIES ARE ~20-30%

- **Jet Energy Scale (15%-20%)**, 
- **Luminosity (6%)**
- **Unfolding Factors (4%)**
  - $E_T$ dependence data/MC
- **Tagging Efficiency (4%)**
  - $b$ quark multiplicity inside the jet
- **B-Purity (~7%) (fraction fit)**
  - Composition of non-$b$ templates ($b/c/light$ ratios)
  - Secondary vertex mass reco (Tracking efficiency in data and MC)
bb di-jet cross section

Data is compared to Monte Carlo prediction:

- **PYTHIA (TUNE A)**
- **HERWIG + JIMMY**
- **NLO MC@NLO + JIMMY**

* tuned on Run I data for underlying event (UE)
° Multi-parton interactions generator links to Herwig (see hep-ph/9601371)
Δφ correlation

**Δφ CORRELATION IS SENSITIVE TO PRODUCTION MECHANISMS**

- **PEAK @ LARGE Δφ**
- **NON NEGLIGIBLE TAIL AT LOW Δφ**

CDF Run II Preliminary

![Graph showingΔφ correlation data and theoretical predictions](image)

- **JetCut R_{core} = 0.4, |η|<1.2**
- **E_T,1 > 35 GeV, E_T,2 > 32 GeV**
- **\( \sqrt{s} = 1.96 \text{ TeV, } L\sim 260 \text{ pb}^{-1} \)**
Δφ correlation

**MC@NLO** agrees with data within the systematic error AND describes low Δφ better than Herwig + Jimmy

Herwig + Jimmy prediction is better than Pythia.

-> In the region $E_T^{\text{jet1}}>35 \text{ GeV}$, $E_T^{\text{jet2}}>32 \text{ GeV}$ $|\eta_{1,2}|<1.2$

LOW Δφ prediction is different at LO and NLO (MC@NLO)
Δφ correlation

Both LO and NLO predictions are enhanced by adding Multi-Parton interaction simulation (Jimmy):

CDF Run II Preliminary

HERWIG

MC@NLO
A preliminary measurement of the $b\bar{b}$ di-jet cross section and angular correlation has been presented.

- The SVT trigger is very helpful in the study of high PT QCD processes and well under control.
- **Comparison to NLO is good**
  - $b\bar{b}$ angular correlation shows events are mainly produced by flavour creation mechanisms.
  - **Low $\Delta\phi$ tail suggests non-negligible contribution from other processes.**
- The simulation of the underlying event is necessary to correctly describe data.
Trigger selection

• **Level 1**
  - Two 5GeV towers
  - Two XFT tracks $p_t > 2$GeV/c

• **Level 2**
  - Two clusters ($E_t > 15$ GeV, $|\eta| < 1.5$)
  - Two SVT tracks $|d_0| > 100 \mu$m
  - Cluster-SVT matching ($|\Delta \phi| < 0.7$)

• **Level 3**
  - Two cone-04 jets $E_t > 20$ GeV
  - Two COT tracks matched to SVT ($|d_0| > 100 \mu$m)
  - Two Si tracks matched to SVT ($|d_0| > 80 \mu$m)
SVT-tag efficiency

**DI-JET INVARIANT MASS**

CDF Run II Preliminary
Scale Factor applied

- b$\bar{b}$ events (stat. err. only)

**DI-JET $\Delta\phi$**

CDF Run II Preliminary
Scale Factor applied

- b$\bar{b}$ events (stat. err. only)
bb purity

**DI-JET IN Variant MASS**

![Graph 1: DI-JET INvariant MASS](image1)

**DI-JET Δφ**

![Graph 2: DI-JET Δφ](image2)
Systematic uncertainties:
MC@NLO vs LO

Select events with 2 b quarks: $p_T^b > 10$ GeV and

$|\eta| < 1$
$|\eta| < 1.5$

ONLY COMPARE SHAPES
NORMALIZATION TO SAME AREA