Anomalies in Heavy Flavor Jets at CDF

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For the CDF Collaboration

Les Rencontres de Physique de la Vallée d’Aoste
LaThuile
March 5th, 2004
Anomaly in W+2,3 jet Events at CDF
PRD 65, 052007(2002)

- **CDF Data sample used in top quark measurements**
  \[ p\bar{p} \rightarrow \bar{t}t + X \rightarrow Wb\bar{W} \rightarrow l\nu + 3,4 \text{ jets} \]
- **Heavy Flavor Ident. (tagging) methods**
  \[ b \quad c \]
  - **SECVTX**
    - 43% 9%
  - **JPB**
    - 43% 30%
  - **Soft Lepton Tagging**
    - 6.4% 4.6%
  - **Supertag (or superjet): jet containing both a SECVTX and an SLT tag.**

![Diagram of jet relations]

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● The kinematic of the anomalous W+2,3 jets events has a $10^{-6}$ probability of being consistent with the SM simulation - *PRD 64, 032004 (2002)*

● Superjets modeled by postulating a low mass, strong interacting object which decays with a semileptonic branching ratio of $\sim 1$ and a lifetime of $\sim 1$ ps - *hep-ph/0109020*

● No limit on the existence of a charge $-1/3$ scalar quark with mass smaller than 7 GeV/c$^2$ (the supersymmetric partner of the bottom quark, $b_s$, is a potential candidate) - *PRL 86, 4463 (2001).*

● This analysis is intended to search for evidence either supporting or disfavoring this hypothesis.

● *hep-ph/0007318* and *hep-ph/0401034* use it to resolve the discrepancy between the measured and predicted values of $R$ for $5 < \sqrt{s} < 10$ GeV and for $20 < \sqrt{s} < 209$ GeV at $e^+ e^-$ colliders

● *If light $b_s$ existed, Run I has produced $10^9$ pairs; why didn’t we see them?*
- **PRL 86, 4231 (2001)** uses it in conjunction with a light gluino which decays to $b\bar{b}_s$ to explain the difference of a factor of 2 between the measured single-$b$ production cross section and the NLO prediction.

- **Necessary but not sufficient condition**
  - NLO not robust
However….  

- Some interesting CDF & DØ disagreements between Data and Simulation:  
  - \( b+\mu \) Production Cross-Section:  \( \sigma_{bb} \cdot BR \)  
    - Data are 1.5 times larger than NLO calculation, LO and NLO calculations are comparable  
    - PRD 53, 1051 (1996)  
  - \( bb \to \mu^+\mu^- \) Correlations:  \( \sigma_{b\bar{b}} \cdot BR^2 \)  
    - Data are 2.2 times larger than NLO calculation, LO and NLO calculations are within a few percent  
    - PRD 55, 2547 (1997)  

- Hint: Data-Simulation discrepancy could increase with the number of leptons in the final state  
- Other necessary but not sufficient condition
**Situation**

- The NLO calculation of $p \bar{p} \rightarrow b_s \bar{b}_s$ predicts $\sigma_{bs} = 19.2 \mu b$ for a squark mass of 3.6 GeV/c$^2$ (Prospino MC generator program).
  - $\sigma_{bb} = 48.1 \mu b$ (NLO)
  - $\sigma_{cc} = 2748.5 \mu b$ (NLO)
- We have used a generic jets data sample with $E_T > 15$ GeV and $|\eta| < 1.5$ (corresponding to partons with $E_T$ larger than 18 GeV) to calibrate the simulation by using measured rates of SECVTX and JPB.
- Can easily “bend” any Heavy Flavor generator or NLO calculation to explain in terms of SM processes an additional 10% production of scalar quarks

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### PRD 64, 032002 (2001)

- $\sigma_{bs} = 84 \text{ nb (Prospino MC)}$
- $\sigma_{bb} = 298 \text{ nb (NLO)}$
- $\sigma_{cc} = 487 \text{ nb (NLO)}$

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### Strategy

<table>
<thead>
<tr>
<th></th>
<th>$\sigma$ (nb)</th>
<th>$b_s$ (%)</th>
<th>tuned QCD</th>
<th>$\sigma/\sigma_{QCD}$</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>$b$</td>
<td>$c$</td>
<td>$b_s$</td>
<td>total</td>
</tr>
<tr>
<td>generic jets tuned</td>
<td>298</td>
<td>487</td>
<td>84</td>
<td>869</td>
</tr>
<tr>
<td>g. j. t. x BR</td>
<td>110</td>
<td>102</td>
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<td>296</td>
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</tbody>
</table>

The Control Sample is used to calibrate the SLT efficiency in the simulation and a comparison between the S.S. and the C.S. could have a discrepancy of ~30%.
Models to predict Heavy Flavor Production
HERWIG vs Exact NLO Calculation

LO – Born term

NLO – Virtual Emission

Scattering with 2 b-partons in the final state

Gluon splitting

Parton shower

Flavor Excitation

Structure function

Scattering produces a gluon recoiling against 1 or 2 b-hadrons in the final state
**HERWIG vs Exact NLO Calculation**

NLO/LO terms can be different for different models (NLO/LO~4 for HERWIG, NLO/LO~2 for NLO Calc.).

Fraction of away h.f. jets in detector acceptance is different for LO vs. NLO terms

Use tools to disentangle bb from cc production
Generic Jet Control Sample

- The simulation of the SLT algorithm uses efficiencies derived from the data (conversions, Z's and $\psi$ mesons decays).
- Use generic-jet data to calibrate and cross-check the efficiency for finding SLT tags and supertags.
- Efficiency for finding supertags empirically corrected by 15%

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Signal Sample

- **Use sample enriched in Heavy Flavor content**
  - Events with 2 or more jets with $E_T > 15$ GeV and at least two SVX tracks (taggable, $|\eta| < 1.5$)
  - one electron with $E_T > 8$ GeV or one muon with $p_T > 8$ GeV/c contained in one of the jets
- **Counting Experiment:**
  - Determine the b- and c-quark composition of the data by counting the number of SECVTX, and JPB tags on both the lepton- and away-jets
  - Check the semileptonic branching ratio of Heavy Flavor hadrons by counting the number of a-jets with a SLT and in the data and in the simulation
**Tuning the Simulation to the data**

- "Kitchen Dirty Work":
  - Mistags evaluated with parameterization (10%)
  - SECVTX-JPB tagging efficiencies measured in data (6%)
  - SLT Efficiency uncertainty (10%)
  - Simulated supertag efficiency (SECVTX+SLT or JPB+SLT) is corrected for the data-to-simulation scale factor measured in the generic-jet sample ($85\pm5\%$).
  - Take care of tagging rates in the fraction of lepton-trigger events with no h.f. using a parameterized probability of finding a tag due to heavy flavor in generic-jet data.
### Tuned HERWIG

**NLO Calculation**

- $F_{hf} = (45.3 \pm 1.9)\%$ for $e$
- $F_{hf} = (59.7 \pm 3.6)\%$ for $\mu$

**Addressed Issues**

- $b$-quark fragmentation
- $k_T$ factorization (CASCADE)
- Berger's model (gluinos)
- Single $b$ cross sections derived from 2 $b$ cross sections using NLO prediction

### Table

<table>
<thead>
<tr>
<th></th>
<th>$T_{SEC}$ 1-jet</th>
<th>$T_{JPB}$ 1-jet</th>
<th>$T_{SEC}$ a-jet</th>
<th>$T_{JPB}$ a-jet</th>
<th>DT$^{SEC}$</th>
<th>DT$^{JPB}$</th>
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</thead>
<tbody>
<tr>
<td>Tuned QCD</td>
<td>110</td>
<td>102</td>
<td>84</td>
<td>296</td>
<td>28%</td>
<td>194</td>
</tr>
<tr>
<td>$\sigma / \sigma_{QCD}$</td>
<td>41</td>
<td>22</td>
<td>84</td>
<td>147</td>
<td>57%</td>
<td>72</td>
</tr>
</tbody>
</table>

### Graph

- **Tuned HERWIG**
- **Number of Jets**
- **Data**
- **c-gsp**
- **c-f.exc**
- **c-dir**
- **b-gsp**
- **b-f.exc**
- **b-dir**

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Kinematic Variables Data-Simulation Comparison

(a) electron sample

(b) a-jet

(c) a-jet with SECVTX tags

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Comparison of $a$-jets with SLT tags in the data and the tuned simulation

**SEEN 1137±140.0 (±51.0 STAT.)**
**EXPECTED 746.9±75.0 (SYST)**

**SEEN 453±29.4 (±25 STAT.)**
**EXPECTED 316.5±25.4 (SYST)**

~3 $\sigma$ discrepancy, with errors dominated by systematic effects

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<tbody>
<tr>
<td>g .j. x BR tuned (or lep-trig. evts)</td>
<td>110 102 84 296 28%</td>
<td>194 102 296 1</td>
<td></td>
</tr>
<tr>
<td>lep-trig. evts. x BR</td>
<td>41 22 84 147 57%</td>
<td>72 21 93 1.5 SS</td>
<td></td>
</tr>
</tbody>
</table>

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Supertags

- Data-Simulation comparison for the yield of $R$ ($R'$), the ratio of number of jets with a SECVTX (JPB) and SLT tag - supertags - to that with a SECVTX (JPB) tag in the generic jet sample and in the Lepton-trigger sample.
  - The tuned QCD Simulation predicts the same yield of supertags in generic jet and lepton-trigger jets.
  - Data show a ~30% discrepancy between supertags in generic jets and lepton-trigger jets.
    - Systematic uncertainties in the SLT simulated efficiency would shift in the same direction the yield $R$ in the generic jets sample and lepton-trigger sample.
Uncertainty on Mistags and SLT Tagging Efficiency on Heavy Flavors

- SLT mistags and tagging efficiency have been determined historically on data (PRD - 64, 032002) with conservative errors of 10%.
- The availability of a tuned simulation can be used to reduce the previous estimate of the SLT mistags and tagging efficiency systematic errors.
- Fit observed rates of SLT tags in generic jets with $P_f \times \text{fakes } + P_{hf} \times \text{h.f.}$
- The fit returns $P_f = 1.017 \pm 0.013$ and $P_{hf} = 0.981 \pm 0.045$, $\rho = -0.77$
- Using this result the SLT expectation in in the SS away-jets is $1362 \pm 28$ whereas $1757 \pm 104$ are observed ($3.8 \sigma$)
- This discrepancy cannot come from obvious prediction deficiencies

<table>
<thead>
<tr>
<th></th>
<th>observed</th>
<th>pred. fakes.</th>
<th>pred. h.f.</th>
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</thead>
<tbody>
<tr>
<td>SLT’s in g. jets</td>
<td>18885</td>
<td>15570±1557</td>
<td>3102±403</td>
</tr>
<tr>
<td>SLT’s in g. jets with</td>
<td>1451</td>
<td>999 ±60</td>
<td>508 ±51</td>
</tr>
<tr>
<td>SECVTX</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SLT’s in g. jets with</td>
<td>2023</td>
<td>856 ±86</td>
<td>1175 ±71</td>
</tr>
<tr>
<td>JPB</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SLT’s in a-jets (lep-trig.)</td>
<td>1757</td>
<td>619 ±62</td>
<td>747 ± 75</td>
</tr>
</tbody>
</table>
Conclusions

• We have measured the heavy flavor content of the inclusive lepton sample by comparing rates of SECVTX and JPB tags in the data and the simulation.

• We find good agreement between the data and the simulation tuned within the experimental and theoretical uncertainties.

• We find a 50% excess of a-jets with SLT tags due to heavy flavor with respect to the simulation; the discrepancy is a $3\sigma$ systematic effect due to the uncertainty of the SLT efficiency and background subtraction. However, comparisons of analogous tagging rates in generic-jet data and their simulation do not support any increase of the efficiency or background subtraction beyond the quoted systematic uncertainties.
Conclusions

- A discrepancy of this kind and size is expected, and was the motivation for this study, if pairs of light scalar quarks with a 100% semileptonic branching ratio were produced at the Tevatron.

- The data cannot exclude alternate explanations for this discrepancy.

- Previously published measurements support the possibility, born out of the present work, that approximately 30% of the presumed semileptonic decays of heavy flavor hadrons produced at the Tevatron are due to unconventional sources.
Tuning the Simulation to the data

<table>
<thead>
<tr>
<th>Fit parameters</th>
<th>Constraints</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>c dir norm</td>
<td>b dir/c dir ≈ 1</td>
<td>14%</td>
</tr>
<tr>
<td>b flav exc norm</td>
<td>b/c ≈ 0.5</td>
<td>28%</td>
</tr>
<tr>
<td>c flav exc norm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b gluon split norm</td>
<td>1.40</td>
<td>0.19</td>
</tr>
<tr>
<td>c gluon split norm</td>
<td>1.35</td>
<td>0.36</td>
</tr>
<tr>
<td>Ke norm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K_µ norm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SECVTX scale factor, b</td>
<td>1.0</td>
<td>6%</td>
</tr>
<tr>
<td>SECVTX scale factor, c</td>
<td>1.0</td>
<td>28%</td>
</tr>
<tr>
<td>JPB scale factor</td>
<td>1.0</td>
<td>6%</td>
</tr>
</tbody>
</table>

- **Use 6 fit parameters** corresponding to the direct, flavor excitation and gluon splitting production cross sections evaluated by Herwig for b- and c-quarks.
- **K_e** and **K_µ** account for the luminosity and b-direct production.
- **The parameters** bf, bg, c, cf, cg **account** for the remaining production cross sections, relative to the b-direct production.
## Fit results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>( f_{SECVTX} )</td>
<td>( SF_b )</td>
</tr>
<tr>
<td>( f_{SECVTX} )</td>
<td>( SF_c )</td>
</tr>
<tr>
<td>( f_{scaleactor} )</td>
<td>( SF_{JP} )</td>
</tr>
<tr>
<td>( e ) norm.</td>
<td>( K_e )</td>
</tr>
<tr>
<td>( \mu ) norm.</td>
<td>( K_\mu )</td>
</tr>
<tr>
<td>( c ) dir., prod.</td>
<td>( c )</td>
</tr>
<tr>
<td>( b ) flav. exc.</td>
<td>( bf )</td>
</tr>
<tr>
<td>( c ) flav. exc.</td>
<td>( cf )</td>
</tr>
<tr>
<td>( g \rightarrow b\bar{b} )</td>
<td>( bg )</td>
</tr>
<tr>
<td>( g \rightarrow c\bar{c} )</td>
<td>( cg )</td>
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\( \chi^2/\text{DOF}=4.6/9 \)

<table>
<thead>
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<th>g ( j ). x BR tuned</th>
<th>110</th>
<th>102</th>
<th>84</th>
<th>296</th>
<th>28%</th>
<th>194</th>
<th>102</th>
<th>296</th>
<th>1</th>
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<tbody>
<tr>
<td>(or lep-trig. evts)</td>
<td></td>
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<td>57%</td>
<td>72</td>
<td>21</td>
<td>93</td>
<td>1.5</td>
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**b-purity (cross-check)**

- **$l^{-}D^{0}$**: $126.0 \pm 15.5$ in the data and $139.9 \pm 15.0$ in the simulation.
- **$l^{-}D^{\pm}$**: $73.7 \pm 17.8$ (data) and $68.5 \pm 14.1$ (simulation).
- **$J/\psi$**: $90.8 \pm 10.1$ (data) and $101.9 \pm 11.4$ (simulation).
- **Ratio of the $b$-purity in the simulation to that in the data is $1.09 \pm 0.11$**
  - Discrepancy between observed and predicted number of $a$-jets with SLT tags due to heavy flavor is not due to an underestimate of the $bb$ contribution.

\[
D^{0} \rightarrow K^{-}\pi^{+}
\]

\[
D^{-} \rightarrow K^{+}\pi^{-}\pi^{-}
\]
**b-purity (cross-check)**

- $2.6 < m_{ee} < 3.6 \text{ GeV/c}^2$
- $2.9 < m_{\mu\mu} < 3.3 \text{ GeV/c}^2$
- SS dileptons (with 10% error) used to estimate and remove bkg. to OS dileptons due to misidentified leptons.
- $259 \pm 17.2$ and $209.2 \pm 23.7$ (before tagging)
- $89.7 \pm 10.5$ and $100.5 \pm 12.4$ (SECVTX)
- $90.8 \pm 10.1$ and $101.9 \pm 11.4$ (JPB)
\textbf{J/\psi mesons from B-decays}

- In generic-jet data we do not have any excess of jets with SLT tags or supertags.
- We do observe an excess after enriching the \( b \)-purity of the QCD data by requiring a lepton-jet.
- We study a sample of jets recoiling \( J/\psi \) mesons from \( B \)-decays. We use the same \( J/\psi \rightarrow \mu\mu \) data set and selection used for the measurement of the \( J/\psi \) lifetime and fraction from \( B \)-decays.
- 1163 \( J/\psi \) over a background of 1179 events estimated from the side-bands (SB)
**J/ψ lifetime**

- The number of J/ψ mesons from B-decays is $N_\psi = (\psi^+ - \psi^-) - (SB^+ - SB^-) = 561$, which is 48% of the initial sample.
- In the 572 away-jets we find $48.0 \pm 15.1$ SECVTX, $61.7 \pm 17.3$ JPB tags, and $-9.4 \pm 14.4$ SLT tags.
- In the simulation we expect $8.1 \pm 1.1$ SLT tags.
- The observed number of SLT tags is 1.2 $\sigma$ lower than the prediction rather than 50% larger as in the inclusive lepton sample.
# Data

## electron data

<p>| | | | | | | | | | |</p>
<table>
<thead>
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<tbody>
<tr>
<td><strong>tag</strong></td>
<td><strong>e</strong></td>
<td><strong>p</strong></td>
<td><strong>$P_{\text{SEC}}$</strong></td>
<td><strong>$P_{\text{BJP}}$</strong></td>
<td><strong>$I_{\text{SEC}}^{l\rightarrow f_e}$</strong></td>
<td><strong>$I_{\text{BJP}}^{l\rightarrow f_e}$</strong></td>
<td><strong>$T_{\text{SEC}}^{l\rightarrow f_e}$</strong></td>
<td><strong>$T_{\text{BJP}}^{l\rightarrow f_e}$</strong></td>
<td><strong>$I_{\text{SEC}}^{a\rightarrow f_e}$</strong></td>
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<td><strong>$N_{l\rightarrow f_e}$</strong></td>
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<td><strong>$N_{a\rightarrow f_e}$</strong></td>
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</tr>
<tr>
<td><strong>$T_{l\rightarrow f_e}^{SEC}$</strong></td>
<td>$10115.3 \pm 101.7$</td>
<td>$(10221/105.7)$</td>
<td>0</td>
<td></td>
<td>$3657 \pm 60.8$</td>
<td>$(3689/31.7)$</td>
<td>0</td>
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</tr>
<tr>
<td><strong>$T_{l\rightarrow f_e}^{BJP}$</strong></td>
<td>$11165.4 \pm 115.8$</td>
<td>$(11591/425.6)$</td>
<td>0</td>
<td></td>
<td>$4068.6 \pm 66.2$</td>
<td>$(4204/135.4)$</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>$T_{a\rightarrow f_e}^{SEC}$</strong></td>
<td>$4353.3 \pm 68.5$</td>
<td>$(4494/140.7)$</td>
<td>1.56%</td>
<td></td>
<td>$1054.6 \pm 33.3$</td>
<td>$(1094/39.4)$</td>
<td>1.67%</td>
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<tr>
<td><strong>$T_{a\rightarrow f_e}^{BJP}$</strong></td>
<td>$5018.9 \pm 98.9$</td>
<td>$(5661/642.1)$</td>
<td>2.45%</td>
<td></td>
<td>$1265.2 \pm 41.1$</td>
<td>$(1427/161.8)$</td>
<td>2.63%</td>
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<td><strong>$DT_{SEC}^{SEC}$</strong></td>
<td>$1375.2 \pm 37.6$</td>
<td>$(1405/29.8)$</td>
<td>0</td>
<td></td>
<td>$452.6 \pm 21.6$</td>
<td>$(465/12.4)$</td>
<td>0</td>
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<tr>
<td><strong>$DT_{BJP}^{SEC}$</strong></td>
<td>$1627.8 \pm 43.7$</td>
<td>$(1754/126.2)$</td>
<td>0</td>
<td></td>
<td>$546.4 \pm 25.1$</td>
<td>$(600/53.6)$</td>
<td>0</td>
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</table>
Heavy flavors in the simulation are identified at generator level

electron simulation

<table>
<thead>
<tr>
<th></th>
<th>t tag eγp</th>
<th>b-dir</th>
<th>c-dir</th>
<th>b-f.exc</th>
<th>c-f.exc</th>
<th>b-gsp</th>
<th>c-gsp</th>
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<tbody>
<tr>
<td>HF_1→qe</td>
<td>5671</td>
<td>947</td>
<td>10779</td>
<td>2786</td>
<td>5263</td>
<td>1690</td>
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<tr>
<td>HF_α→qe</td>
<td>5848</td>
<td>977</td>
<td>11280</td>
<td>2913</td>
<td>6025</td>
<td>1877</td>
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<tr>
<td>h.f./light</td>
<td>5407/441</td>
<td>899/78</td>
<td>1605/9675</td>
<td>367/2546</td>
<td>707/5318</td>
<td>145/1732</td>
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</table>

**muon simulation**

<table>
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<tr>
<th></th>
<th>t tag eγp</th>
<th>b-dir</th>
<th>c-dir</th>
<th>b-f.exc</th>
<th>c-f.exc</th>
<th>b-gsp</th>
<th>c-gsp</th>
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<tbody>
<tr>
<td>HF_1→qe</td>
<td>1285</td>
<td>298</td>
<td>2539</td>
<td>942</td>
<td>1455</td>
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<tr>
<td>HF_α→qe</td>
<td>1358</td>
<td>313</td>
<td>2705</td>
<td>994</td>
<td>1708</td>
<td>816</td>
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<tr>
<td>h.f./prompt</td>
<td>1206/152</td>
<td>278/35</td>
<td>422/2283</td>
<td>124/870</td>
<td>171/1537</td>
<td>48/768</td>
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</tr>
</tbody>
</table>
Fit of the simulation to the data

- Use 6 fit parameters corresponding to the direct, flavor excitation and gluon splitting production cross sections evaluated by Herwig for b and c-quarks
- $K_e$ and $K_\mu$ account for the luminosity and b-direct production
- The parameters $b_f$, $b_g$, $c$, $c_f$, $c_g$ account for the remaining production cross sections, relative to the $b$-direct production
- The ratio of $b$ to $c$ direct production constrained to the default value (about 1) within 14%
- the ratio of $b$ to $c$ flavor excitation constrained to the default value (about 0.5) with a 28% uncertainty
- $b_g$ constrained to $(1.4 \pm 0.19)$
- $c_g$ constrained to $(1.35 \pm 0.36)$
- The tagging efficiencies are also fit parameters, and are constrained to their measured values within their uncertainties (6% for $b$-quarks, 28% for $c$-quarks)
## Fit result-parameter corr. coeff.

<table>
<thead>
<tr>
<th></th>
<th>$SF_c$</th>
<th>$SF_{JPB}$</th>
<th>$K_e$</th>
<th>$c$</th>
<th>$bf$</th>
<th>$cf$</th>
<th>$bg$</th>
<th>$cg$</th>
<th>$K_\mu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$SF_b$</td>
<td>-0.073</td>
<td>0.718</td>
<td>-0.747</td>
<td>0.054</td>
<td>0.346</td>
<td>0.297</td>
<td>-0.062</td>
<td>0.066</td>
<td>-0.715</td>
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<tr>
<td>$SF_c$</td>
<td>0.358</td>
<td>-0.238</td>
<td>-0.002</td>
<td>0.038</td>
<td>0.147</td>
<td>-0.071</td>
<td>0.086</td>
<td>-0.306</td>
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<tr>
<td>$SF_{JPB}$</td>
<td>-0.810</td>
<td>0.010</td>
<td>0.363</td>
<td>0.127</td>
<td>-0.009</td>
<td>-0.049</td>
<td>-0.802</td>
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<tr>
<td>$K_e$</td>
<td></td>
<td></td>
<td>-0.092</td>
<td>-0.641</td>
<td>-0.302</td>
<td>0.071</td>
<td>0.077</td>
<td>0.933</td>
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<tr>
<td>$c$</td>
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<td>0.053</td>
<td>0.020</td>
<td>0.008</td>
<td>0.002</td>
<td>-0.098</td>
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<tr>
<td>$bf$</td>
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<td>$cf$</td>
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<td>-0.321</td>
<td>-0.164</td>
<td>-0.274</td>
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<tr>
<td>$bg$</td>
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<td></td>
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<td></td>
<td>-0.029</td>
<td>-0.019</td>
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<tr>
<td>$cg$</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.018</td>
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</tr>
</tbody>
</table>
**NLO and Herwig calculations**

- However, in this specific analysis we are interested in comparing rates of a-jet with heavy flavor (signaled by SLT or SECVTX tags) in events in which the l-jet has also heavy flavor.

- These jet have $|\eta|<1$ and corresponds to partons with $E_T > 18$ GeV.

- In this case Herwig evaluates that the gluon splitting+flavor excitation contribution are 40% of the Born contribution and not a factor of 3 higher.

- For this type of kinematics, the ratio of the NLO to Born calculations is also of the order of 1.1-1.3. In addition, for this topology, the NLO calculation depends little on the choice of $\mu$, and it appears to meet general criteria of robustness.
NLO and Herwig calculations

- Herwig ignores interference terms between the Born approximation and the NLO diagrams, and evaluates a gluon splitting+flavor excitation contribution which is a factor of 3 larger than the Born approximation.

- In the NLO calculation the contribution of the Born cross section and of the gluon splitting+flavor excitation are approximately equal using the renormalization scale $\mu$; when using the scale the scale $\mu/2$, the NLO calculation gets closer to Herwig.

- The fact that the ratio between NLO and Born is about two and is not stable as a function of the renormalization scale is taken by the experts as an indication that NNLO corrections are important.

- The relevance of the Herwig result, which models the data, is the indication that the effect of NNLO correction should be that of canceling the interference terms.
away-jets with SLT tags

<table>
<thead>
<tr>
<th>Tag</th>
<th>Electron Data</th>
<th>Muon Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{a-\bar{\nu}_e}^{S_L}$</td>
<td>1063.8 ± 47.0 (2097/1033.2) 0.49%</td>
<td>308.6 ± 34.7 (562/253.4) 0.54%</td>
</tr>
<tr>
<td>$T_{a-\bar{\nu}_e}^{S_L} \cdot SEC$</td>
<td>356.3 ± 22.8 (444/87.7) 0.08%</td>
<td>69.3 ± 9.9 (92/22.7) 0.09%</td>
</tr>
<tr>
<td>$T_{a-\bar{\nu}_e}^{S_L} \cdot JP B$</td>
<td>401.3 ± 25.3 (513/111.7) 0.13%</td>
<td>112.3 ± 12.3 (143/30.7) 0.14%</td>
</tr>
</tbody>
</table>

Electrons  Muons

<table>
<thead>
<tr>
<th>Tag</th>
<th>Data</th>
<th>Simulation</th>
<th>Data</th>
<th>Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T H F_{a-jet}^{S_L}$</td>
<td>865.1 ± 114.8</td>
<td>597.6 ± 69.3</td>
<td>272.7 ± 34.9</td>
<td>149.3 ± 21.0</td>
</tr>
<tr>
<td>$T H F_{a-jet}^{S_L} \cdot SEC$</td>
<td>322.6 ± 23.3</td>
<td>242.4 ± 22.5</td>
<td>63.3 ± 9.9</td>
<td>53.8 ± 8.7</td>
</tr>
<tr>
<td>$T H F_{a-jet}^{S_L} \cdot JP B$</td>
<td>350.2 ± 26.3</td>
<td>251.5 ± 21.7</td>
<td>103.2 ± 12.4</td>
<td>65.0 ± 8.9</td>
</tr>
</tbody>
</table>