Anomalies in Heavy Flavor jets in pp interactions at Ös=1.8 TeV

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For the CDF Collaboration

Les Rencontres de Physique de la Vallee d'Aoste

LaThuile

March 1-6th,2004

Anomaly in W+2,3 jet Events at CDF PRD 65, 052007(2002)

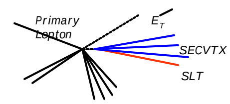
- CDF Data sample used in top quark measurements

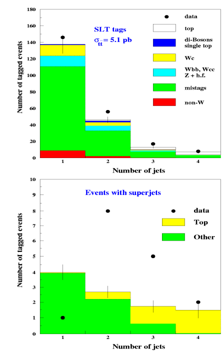
$$p\bar{p} \rightarrow t\bar{t} + X \rightarrow WbW\bar{b} \rightarrow l\nu + 3{,}4\,jets$$

- Heavy Flavor Id. (tagging) methods

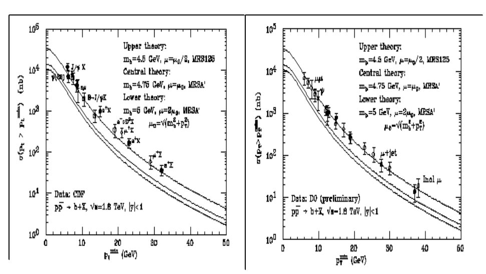
	b	c
SECVTX	43%	9%
JPB	43%	30%
Soft Lepton Tagging	6.4%	4.6%

- Supertag (or superjet): jet containing both a SECVTX and an SLT tag.





- *The kinematic of the anomalous W+2,3 jets events has a 10^{-6} probability of being consistent with the SM simulation - PRD 65, 032004 (2002)*
- *Superjets modeled by postulating a low mass, strong interacting object which decays with a semileptonic branching ratio of ~1 and a lifetime of ~1 ps - hep-ph/0109020*
- *No limit on the existence of a charge –1/3 scalar quark with mass smaller than 7 GeV/c² (the supersymmetric partner of the bottom quark, b_s, is a potential candidate) - PRL 86, 4463 (2001)*
- *hep-ph/0007318 and hep-ph/0401034 use it to resolve the discrepancy between the measured and predicted values of R for 5 < Ös < 10 GeV and for 20 < Ös < 209 GeV at e⁺e⁻ colliders*
- *If light b_s existed, Run I has produced 10⁹ pairs; why we did't see them ?*

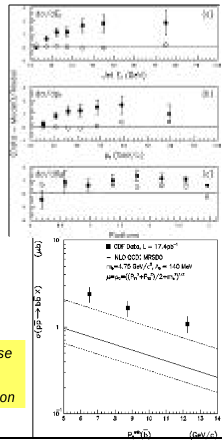


- *PRL 86, 4231 (2001) uses it in conjunction with a light gluino which decays to $b\, b_s$ to explain the difference of a factor of 2 between the measured single-b production cross section and the NLO prediction.*
- *Necessary but not sufficient condition*
  - *NLO not robust*

However ....

- *Some interesting CDF & D0 disagreements between Data and Simulation:*
  - *b+m Production Cross-Section: $s_{bb} \cdot BR$*
    - *Data are 1.5 times larger than NLO calculation, LO and NLO terms are comparable*
    - *PRD 53, 1051 (1996)*
  - *bb® m⁺m⁻ Correlations: $s_{bb} \cdot BR^2$*
    - *Data are 2.2 times larger than NLO calculation, LO and NLO calculations are within a few percent*
    - *PRD 55, 2547 (1997)*
    - *Ph.L. B 487, 264 (2000)*

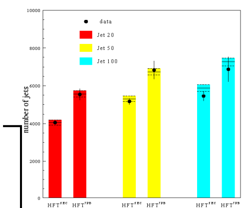
- *Hint: Data-Simulation discrepancy could increase with the number of leptons in the final state*
  - *Other necessary but not sufficient condition*



Situation

- *The NLO calculation of $p\bar{p}$ ® $b_s\bar{b}_s$ predicts s_{bs} = 19.2 mb for a squark mass of 3.6 GeV/c² (Prospino MC generator program).*
  - *s_{bb} = 48.1 mb (NLO)*
  - *s_{cc} = 2748.5 mb (NLO)*
- *We have used a generic jets data sample with E_T>15 GeV and |h|<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*

PRD 64, 032002 (2001)



s_{bs} = 84 nb (Prospino MC)

s_{bb} = 298 nb (NLO)

s_{cc} = 487 nb (NLO)

Strategy

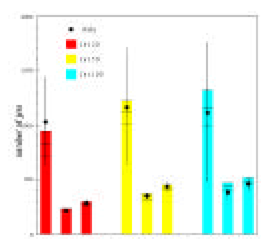
	σ (nb)				b_s(%)	tuned QCD			σ/ $σ_{QCD}$	
	b	c	b_s	total		b	c	total		
generic jets tuned	298	487	84	869	10%	382	487	869	1	
g. j. t. x BR	110	102	84	296	28%	141	102	243	1.2	CS
g. j. t. x BR²	41	22	84	147	57%	52	21	73	2	
g .j. x BR tuned (or lep-trig. evts)	110	102	84	296	28%	194	102	296	1	
lep-trig. evts. x BR	41	22	84	147	57%	72	21	93	1.5	SS

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%.

theoretical uncertainties and uncertainties in the triggering lepton ...

Generic Jet Control Sample

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



	σ (nb)				b_s(%)	tuned QCD			σ/ $σ_{QCD}$	
	b	c	b_s	total		b	c	total		
generic jets tuned	298	487	84	869	10%	382	487	869	1	
g. j. t. x BR	110	102	84	296	28%	141	102	243	1.2	CS
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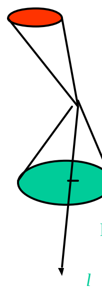
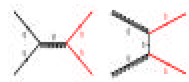
Signal Sample

- 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
- 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

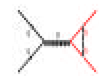


Models to predict Heavy Flavor Production
HERWIG vs Exact NLO Calculation

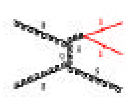
LO – Born term



NLO – Virtual Emission

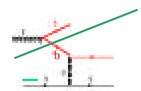


Scattering with 2 b-partons in the final state



Gluon splitting

Parton shower

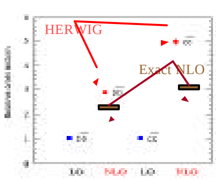


Flavor Excitation

Structure function

Scattering produces a gluon recoiling against 1 or 2 b-hadrons in the final state

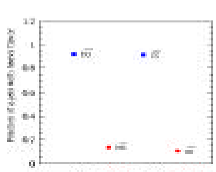
HERWIG vs Exact NLO Calculation

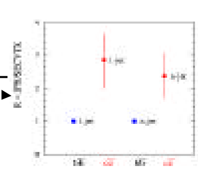


NLO/LO terms can be different for different models (NLO/LO~4 for HERWIG, NLO/LO~2 for NLO Calc.).

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

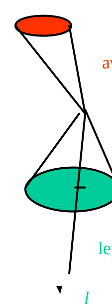
Use tools to disentangle $b\bar{b}$ from $c\bar{c}$ production





Tuning the Simulation to the data

- "Kitchen Dirty Work" :
  - Mistags evaluated with parametrization (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±5%).
  - Take care of tagging rates in the fraction of lepton-trigger events with no h.f. using a parametrized probability of finding a tag due to heavy flavor in generic-jet data.



Tuning the Simulation to the data

SECVTX	lepton side	
	away side	
	Both	
JPB	lepton side	
	away side	
	Both	

Fit parameters	Constraints	Error
c dir norm	b dir/c dir » 1	14%
b flav exc norm	b/c »0.5	28%
c flavexc norm		
b gluon split norm	1.40	0.19
c gluon split norm	1.35	0.36
Ke norm		
Km norm		
SECVTX scale factor, b	1.0	6%
SECVTX scale factor, c	1.0	28%
JPB scale factor	1.0	6%

- 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_m 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

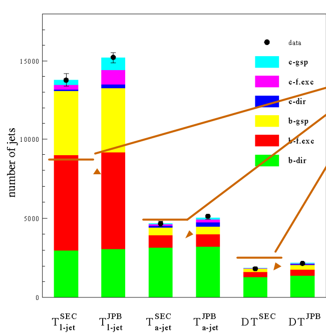
c²/DOF=4.6/9

SECVTX scale factor	SF_b	0.97 ± 0.03
SECVTX scale factor	SF_c	0.94 ± 0.22
JPB scale factor	SF_{JPB}	1.01 ± 0.02
e norm.	K_e	1.02 ± 0.05
μ norm.	K_μ	1.08 ± 0.06
c dir. prod.	c	1.01 ± 0.10
b flav. exc.	bf	1.02 ± 0.12
c flav. exc.	cf	1.10 ± 0.29
$g \to b\bar{b}$	bg	1.40 ± 0.18
$g \to c\bar{c}$	cg	1.40 ± 0.34

	σ (nb)				b_s(%)	tuned QCD			σ/σ_{QCD}	
g.j. x BR tuned (or lep-trig. evts)	110	102	84	296	28%	194	102	296	1	
lep-trig. evts. x BR	41	22	84	147	57%	72	21	93	1.5	SS

Tuned HERWIG

- F_{hf} = (45.3±1.9)% for e
- F_{hf} = (59.7±3.6)% for m



NLO Calculation

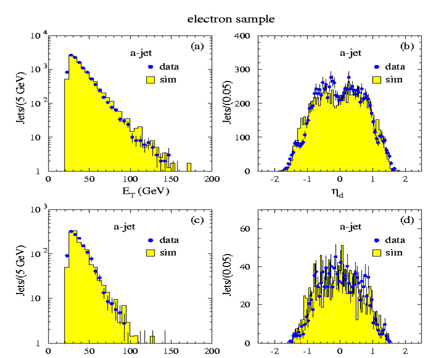
Addressed Issues

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

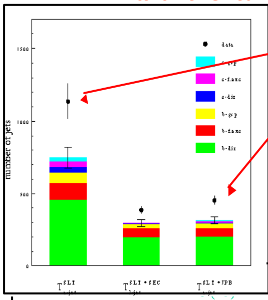
Kinematic Variables Data-Simulation Comparison

A-jet

A-jet with SECVTX tags



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)

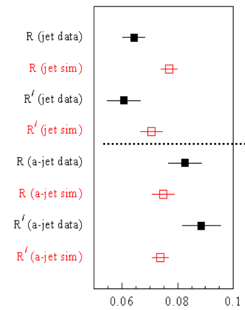
SEEN 453±29.4 (±25 STAT.)
EXPECTED 316.5±25.4 (SYST)

- ~3 s discrepancy, with errors dominated by systematic effects

					b_s(%)	tuned QCD			σ/σ_{QCD}	
g .j. x BR tuned (or lep-trig. evts)	110	102	84	296	28%	194	102	296	1	
lep-trig. evts. x BR	41	22	84	147	57%	72	21	93	1.5	SS

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 D - 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 x fakes $+P_{hf}$ x h.f.
- *The fit returns P_f =1.017±0.013 and P_{hf} =0.981±0.045, r = -0.77*
- *Using this result the SLT expectation in in the SS away-jets is 1362±28 whereas 1757±104 are observed (3.8 s)*
- *This discrepancy cannot come from obvious prediction deficiencies*

	observed	pred. fakes.	pred. h.f.
SLT's in g. jets	18885	15570±1557	3102 ±403
SLT's in g. jets with SECVTX	1451	999 ±60	508 ±51
SLT's in g. jets with JPB	2023	856 ±86	1175 ±71
SLT 's in a-jets (lep -trig.)	1757	619 ±62	747 ± 75

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 s 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 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*