W+c production at the Tevatron

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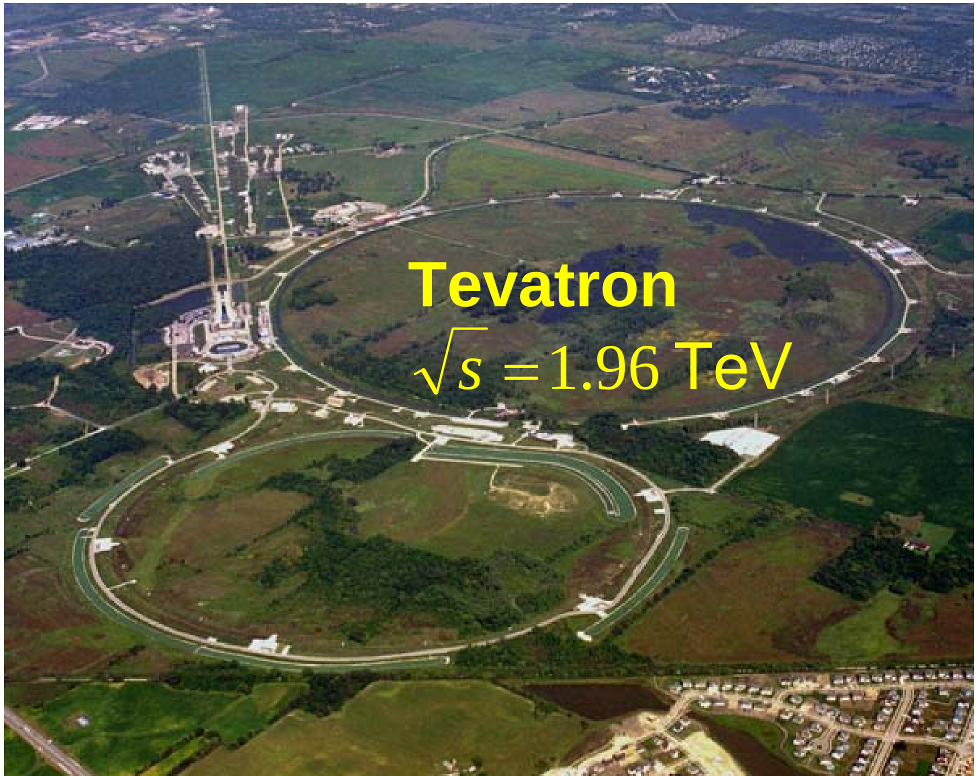
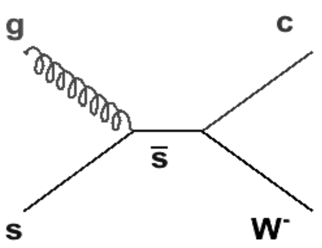
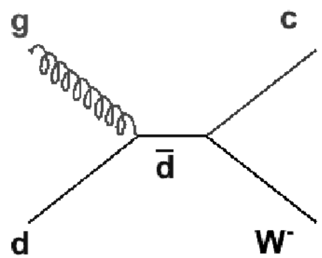
On behalf of the DØ collaboration

The 2007 Europhysics Conference on High Energy Physics
Manchester, England, July 20th, 2007



W+c production in p-pbar collisions



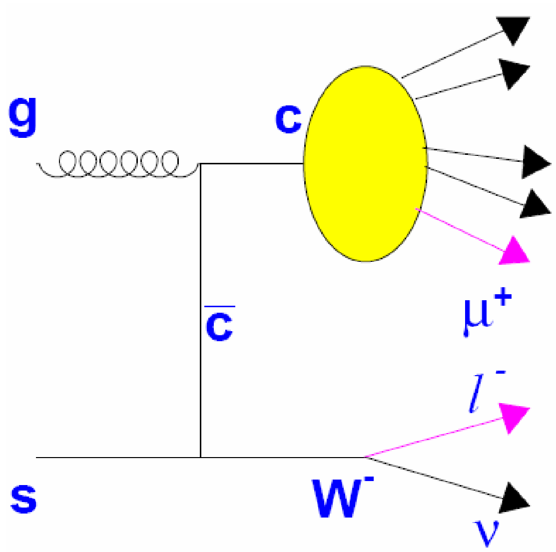


$$\sigma(p\bar{p} \to W^- c) = \iint dx_p \, dx_{\bar{p}} \, s(x_p, Q^2) g(x_{\bar{p}}, Q^2) \hat{\sigma}(sg \to W^- c) + s(x_{\bar{p}}, Q^2) g(x_p, Q^2) \hat{\sigma}(gs \to W^- c) + s \leftrightarrow d$$

- First measurement of W+c production at high $Q^2 \sim M_W^2$
- Direct access to quark-gluon process
- Provides a direct probe of strange sea in proton
  - SUSY H^- (H^+) production in hadron-hadron collisions is also sensitive to s-quark (anti s-quark)
  - At Tevatron, $x_s \in [0.01 - 1]$ range
  - s-quark PDF has been directly measured at the fixed target experiments at low Q^2 scale (two orders of magnitude below the Tevatron scale)
- W/Z +b or c is the signature of many new physics processes at hadron colliders
  - W+c can be a significant background, for example, to top quark and SM Higgs production, to SUSY top production
- Test of pQCD and electroweak predictions

W+c-jet / W+jets ratio

- Fraction of W+jets produced with a net charm quantum number of ±1
- The ratio benefits from:
  - lots of cancellation in efficiencies, systematic uncertainties and luminosity at the first order
  - minimum dependence to the theoretical models



W charge is opposite to the muon charge from recoiling charm

$$R = \frac{N(W + c\text{-jet})}{N(W + \text{jets})} = \frac{N^{OS} - f\ N^{SS}}{N_{Wj}^{obs}(1 - B) \times \varepsilon_c}$$

N^{OS} = Number of OS events

N^{SS} = Number of SS events

N_{Wj}^{obs} = Number of observed W + jets candidates

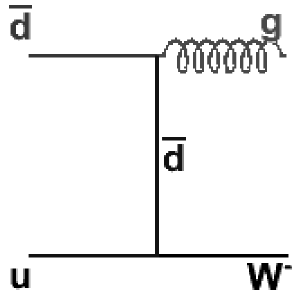
f = Correction to the BKD to W + c

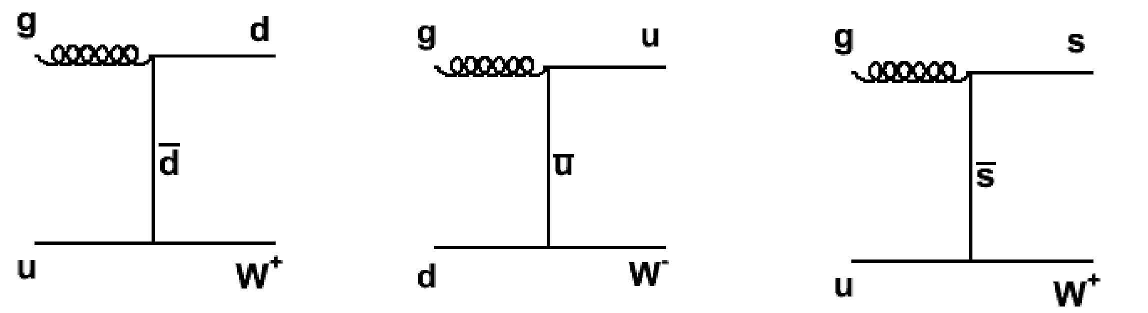
B = fraction of background to W + jets

ε_c = acceptance × efficiency of W + c relative to W + jets

Background W+jets processes to W+c-jet

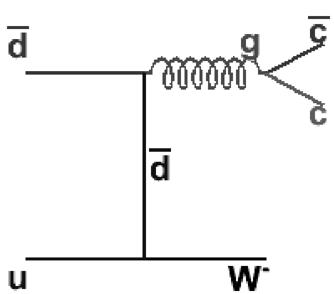
W+light jets

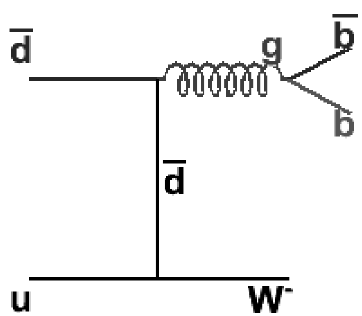


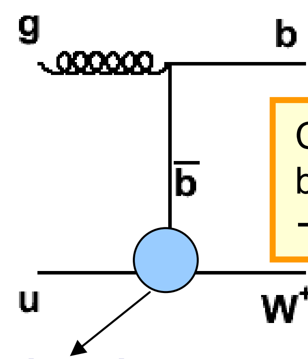


W charge is loosely correlated with the muon charge from hadron decays due to "leading particle effect (the enhanced probability of high pT pion or kaon in jets to contain LO quarks)".

W+heavy flavor jets



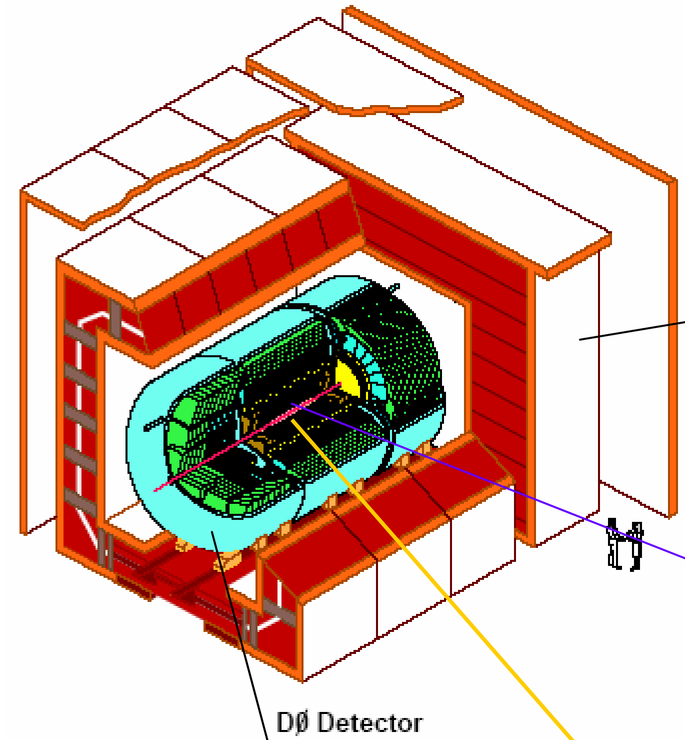




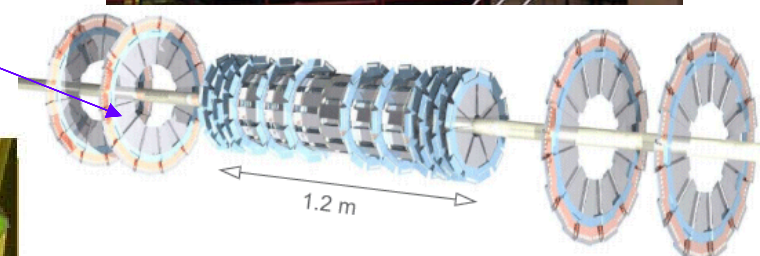
Charge correlation is large but V_{ub} is small
→ tiny background

$|V_{ub}|$ = (3.64 ± 0.22 ± 0.25 +0.39-0.56) x 10^{-3}
BABAR-PUB-02/15, SLAC-PUB-9618

The DØ detector

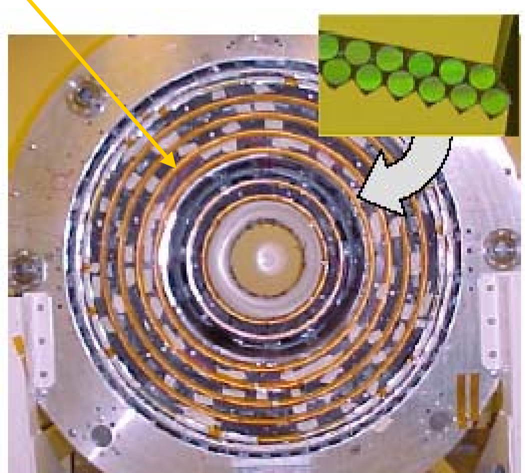


Muon spectrometer



Silicon microstrip detector for tracking

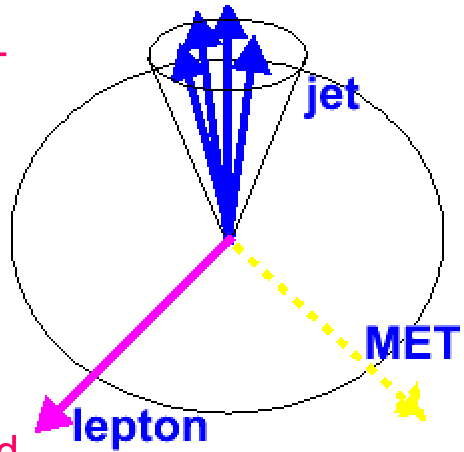
LAr / Uranium calorimeter



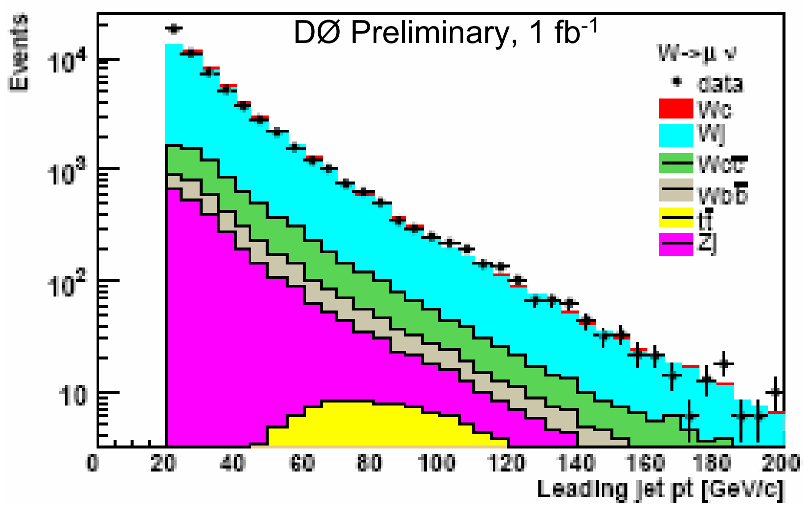
Central fiber tracker

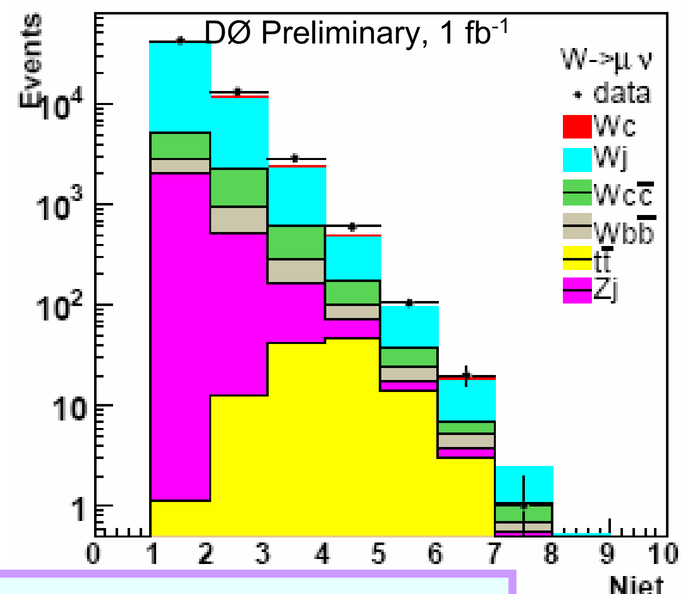
W+jets selection

- W→ lν decay modes, where l = e, μ, τ, with leptonic decays of τ
  - Isolated electron cluster in the EM part of calorimeter with a high pT matched track in the tracking system
  - Isolated muon reconstructed in the muon spectrometer with a high pT matched central track
  - Lepton pT > 20 GeV/c,
  - Missing E_T (MET) > 20 GeV



- W+jets sample is selected inclusively
  - Jets recoiling against the W boson are reconstructed with Run II mid point cone algorithm with cone radius 0.5
  - Minimum Pt of leading jet is 20 GeV/c and pseudo rapidity |η|< 2.5

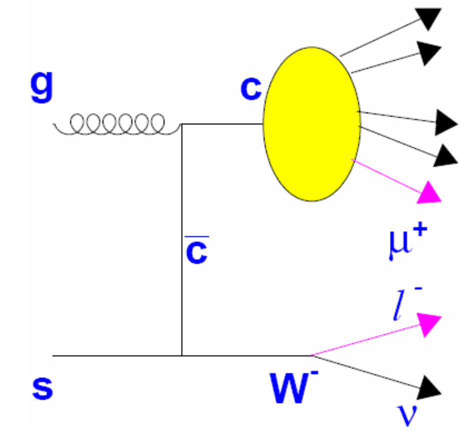




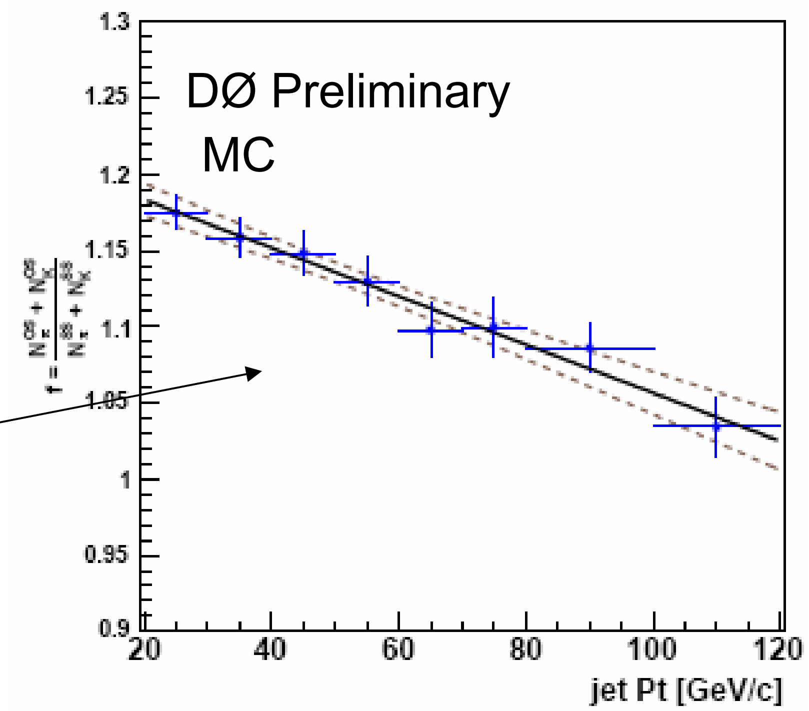
Properties of jets in the W+inclusive jets sample

Method to determine W+c-jet & Background

- A jet containing a soft muon is tagged to enhance the heavy flavor jets in data sample
  - BF(c→μ) ~ 10 %



- Establish a correlation between the charge of muon contained in jet with that of the lepton from W decay
  - Signal comprises of dominantly events containing opposite charge leptons (Nos >> Nss)
  - We estimate the background, *in situ*, from SS data sample
    - Apply only a weakly model dependent small correction "f" to take into account the "leading particle effect" from W+light-jet sample

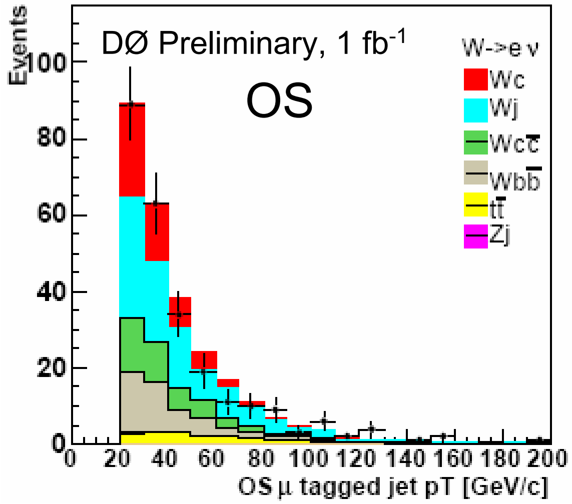


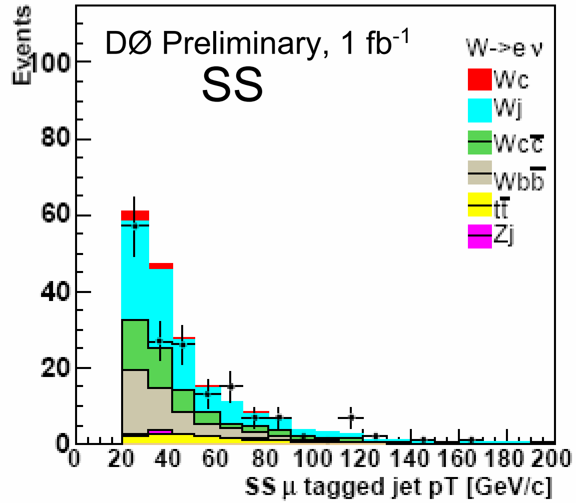
$$R = \frac{N^{OS} - f\,N^{SS}}{N_{Wj}^{obs}(1-B)\times\varepsilon_c}$$

Muon-tagged jets Pt spectrum

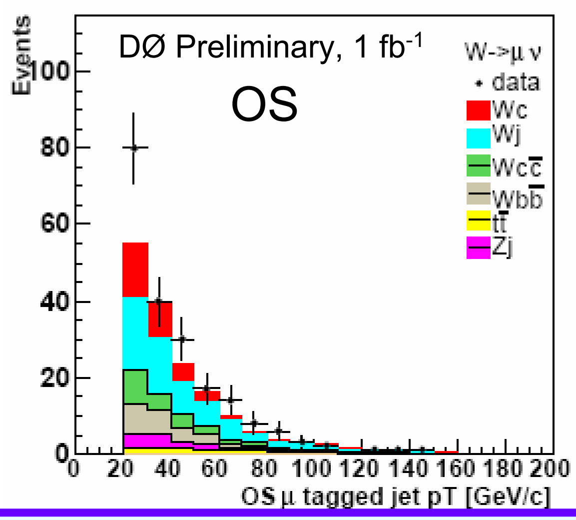
- Minimum Pt muon in jet is 4 GeV/c, and the pseudo rapidity $|\eta| < 2.0$

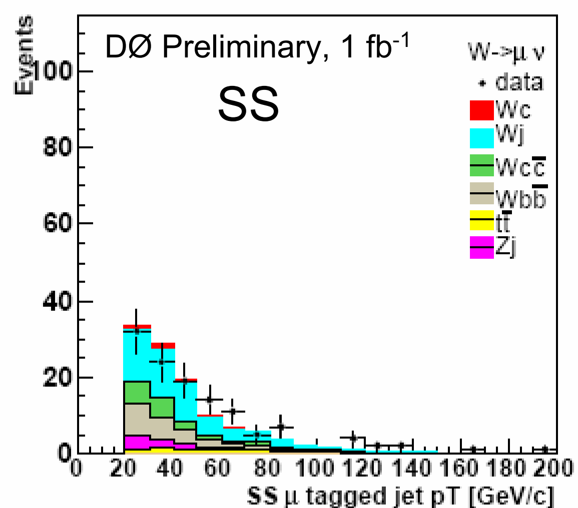
Electron Channel





Muon Channel

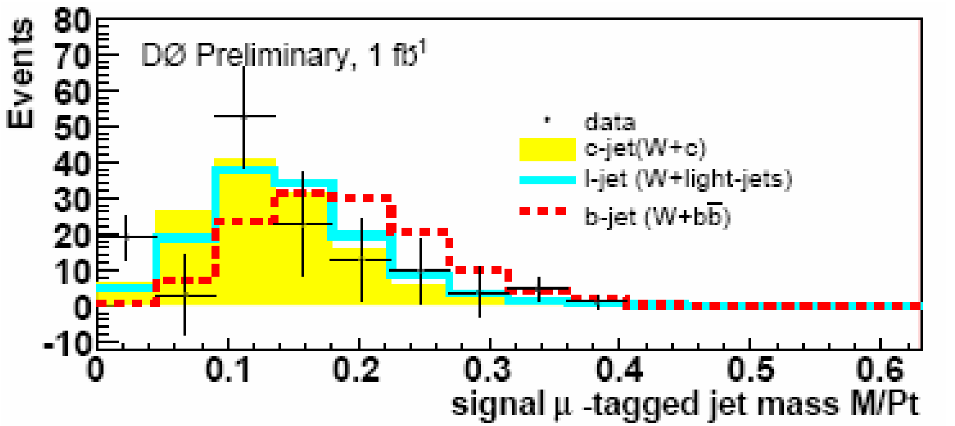




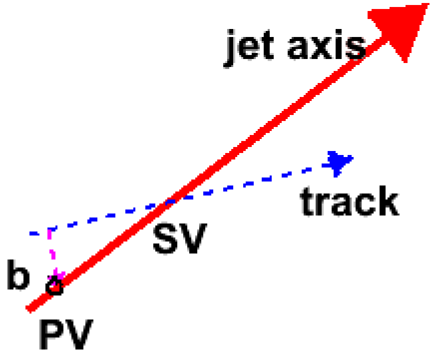
Excess of OS events is the signature of W+c!!

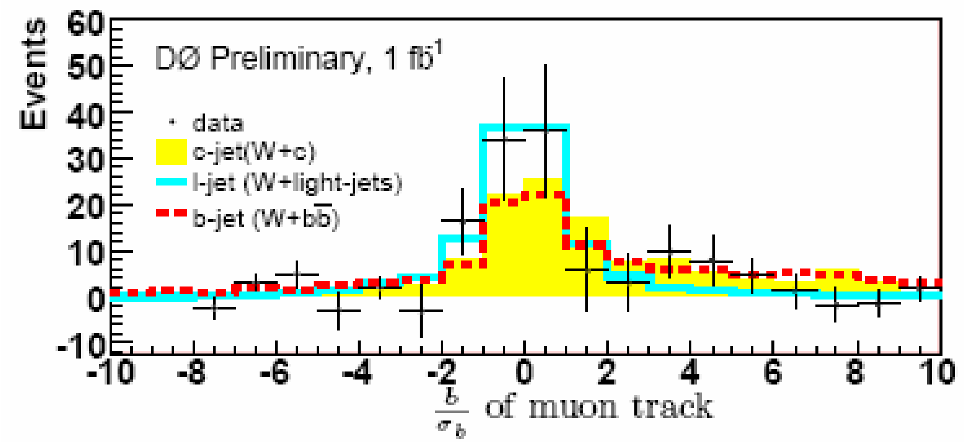
Consistency for W+c-jet signal

- Data sample compared to b, c and light jet templates, after subtracting the background
  - Data favors the c-jet shape
  - Negligible W+b contribution



Discriminates b-jet from c-jet

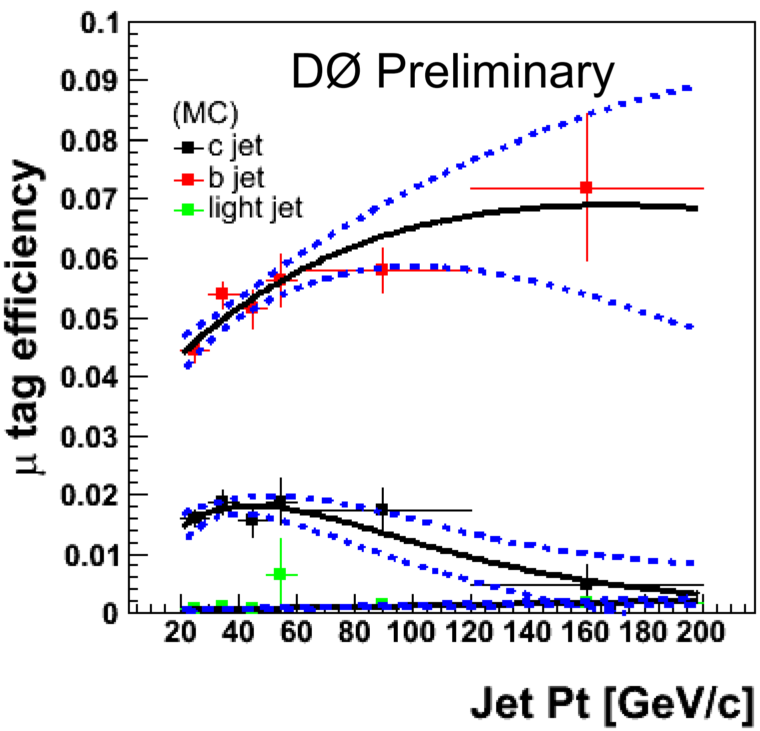


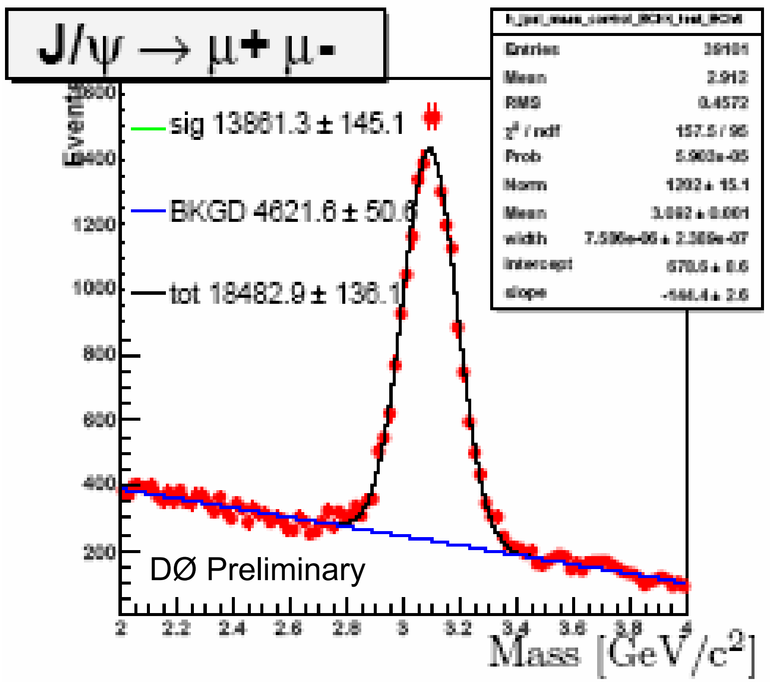


Discriminates c-jet from light-jet

Efficiency for W+c-jet signal

- Many efficiencies cancel in ratio
- Determine the efficiency of finding the muon in jet from signal simulation
  - Correct for ~10% difference due to detector effects
    - Use a large data sample of J/Ψ → $\mu^+\mu^-$ to estimate the correction

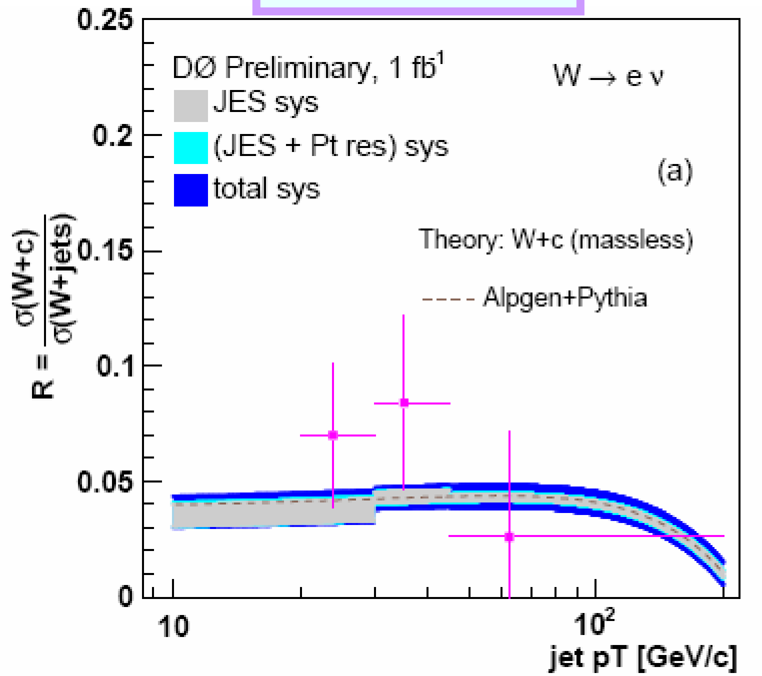




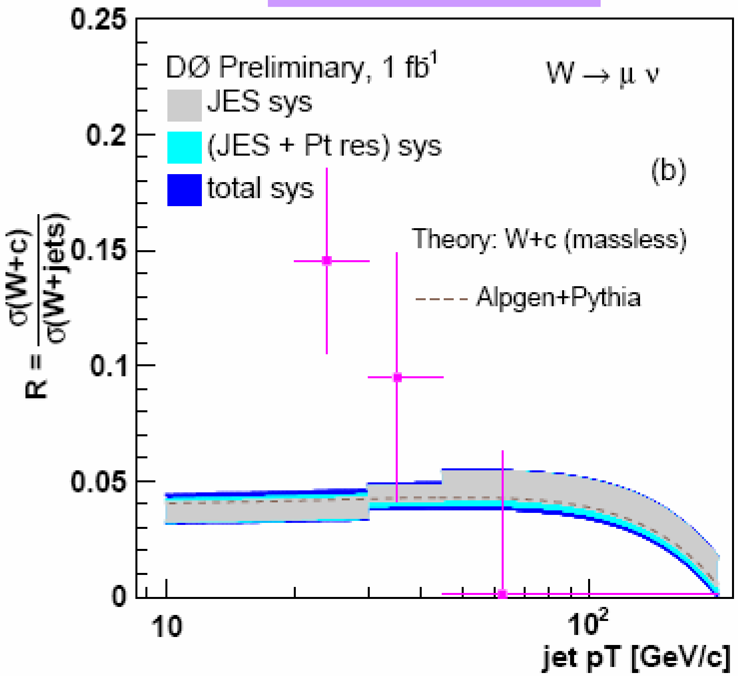
Differential W+c-jet fraction in W+inclusive jet sample

- Comparing with the LO Alpgen + Pythia prediction
  - Alpgen: LO matrix element generation
  - Pythia: Parton shower

W→eν mode



W→μν mode



PDF uncertainty (not shown) on the theoretical prediction is +7.3%, -6.9%

Preliminary Result

- W+c-jet fraction integrated over Pt above 20 GeV/c and $|\eta| < 2.5$

- Muon Channel : 0.093 ± 0.029 (stat) ± 0.005 (syst)
- Electron Channel : 0.060 ± 0.021 (stat) + 0.005 -0.006 (syst)
- Combined: 0.071 ± 0.017 (stat + syst)
  - We observe a significant excess of OS events that is signature of W+c production

- LO Alpgen+Pythia prediction:
  - 0.040 ± 0.003 (PDF uncertainty)

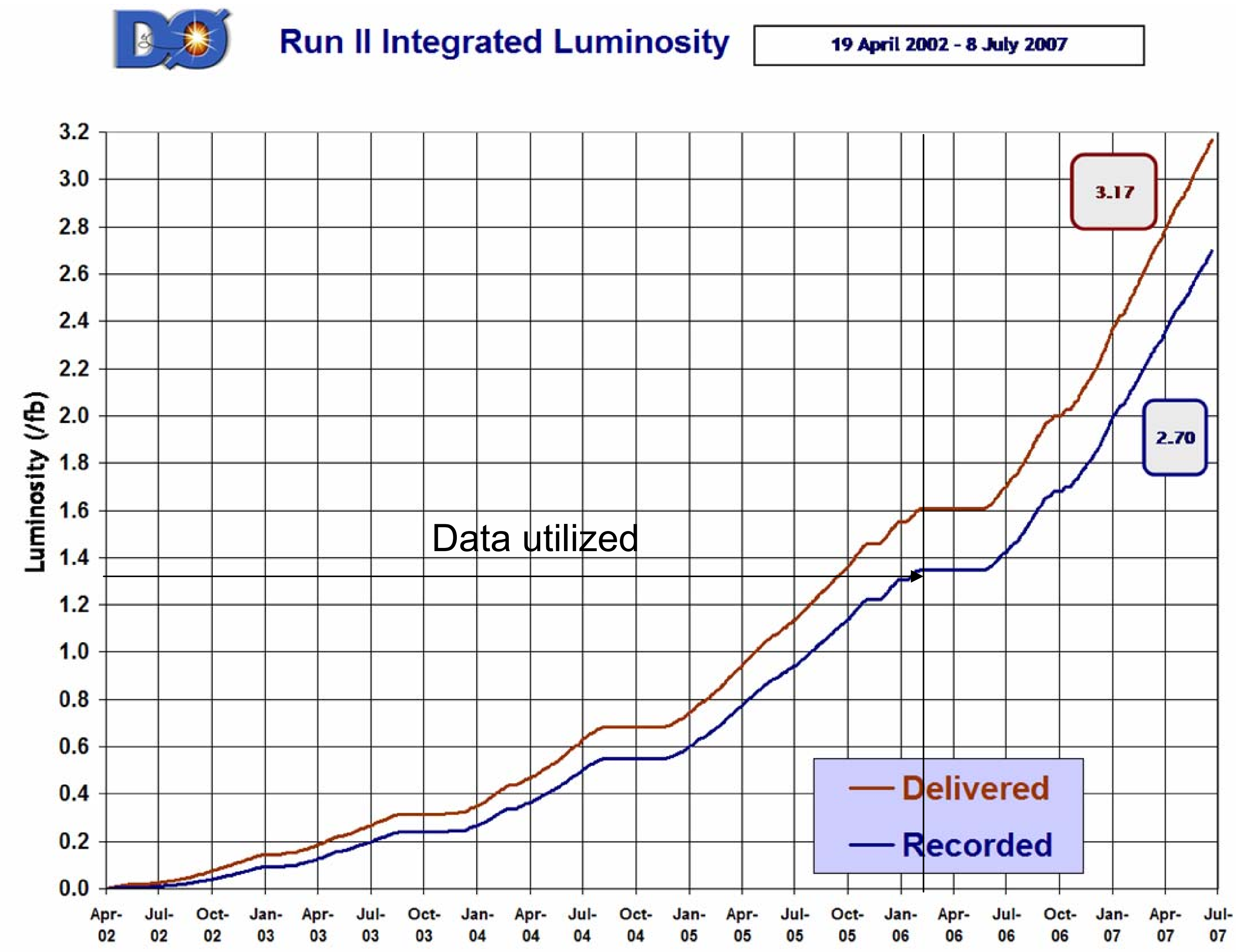
- Ratio of data to MC prediction:
  - **"K"** =1.78 ± 0.44

Conclusion

- The DØ experiment at the Tevatron has made the first measurement of W+c production with 1 fb^{-1}
- The measured W+c production rate is consistent with
  - LO pQCD predictions of Alpgen and Pythia
  - s-quark PDF evolved from low Q^2 scale (two orders of magnitude below that of the Tevatron scale)
- This measurement provides a direct evidence of quark-gluon interaction – more important at LHC

BACKUP SLIDES

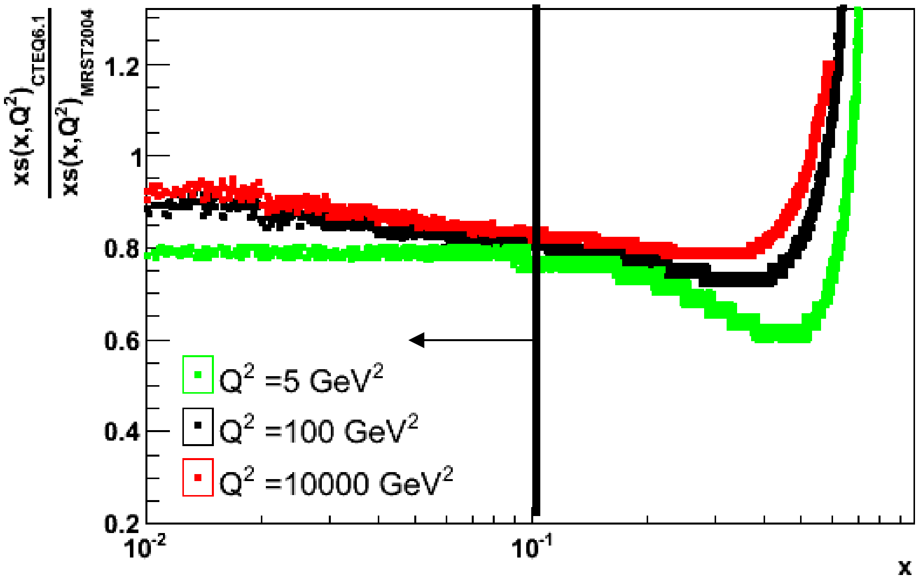
The DØ Luminosity

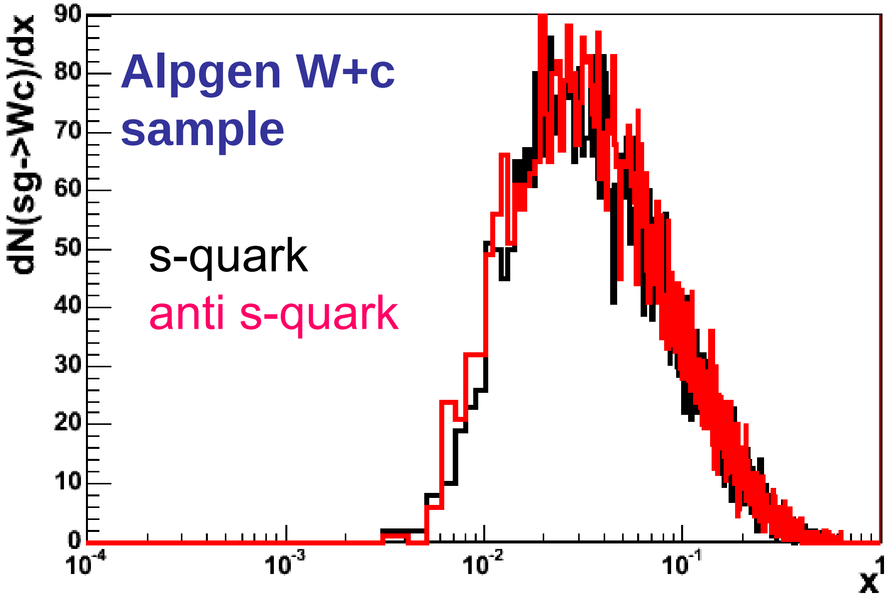


Sensitivity of W+c production on s-quark PDF at Tevatron

- Ratio of CTEQ6.1 and MRST2004 parametrization of s-quark PDFs
- The x ∈ [0.01 - 1] range can be constrained at Tevatron
  - Q scale of the order of M_W

PDFs HEP data
http://durpdg.dur.ac.uk/hepdata/pdf3.h





W+c Measurement Summary

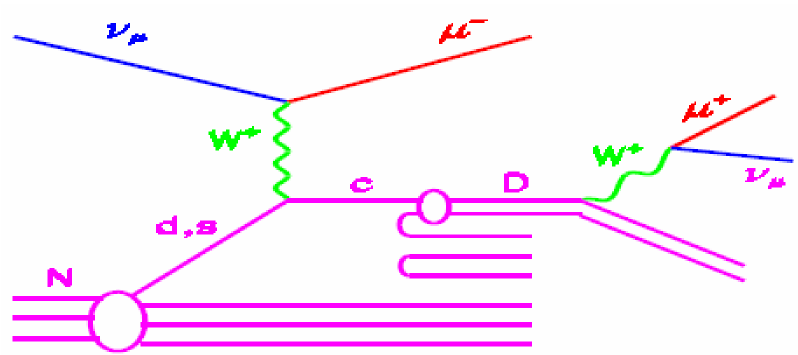
jet P_T[GeV/c]	20-30	30-45	45-200	20-200
$< P_T >$[GeV/c]	23.9	35.1	62.3	34.6
N^e_{Wj}	38556	26347	24539	89442
N^e_{OS}	87	79	88	254
N^e_{SS}	49	45	72	166
f^e_c	1.177±0.013	1.159±0.015	1.117±0.028	1.145±0.007
ϵ^e_c	0.0113±0.0015	0.0125±0.0011	0.0125±0.0020	0.0124±0.0012
$\frac{\sigma[W(\to e\nu)+c]}{\sigma[W(\to e\nu)+jets]}$	0.070±0.031	0.084±0.038	0.026±0.046	0.060±0.021
N^μ_{Wj}	27828	17594	13446	58868
N^μ_{OS}	76	64	63	203
N^μ_{SS}	28	38	56	122
f^μ_c	1.195±0.025	1.174±0.015	1.121±0.035	1.143±0.007
ϵ^μ_c	0.0110±0.0011	0.0122±0.0013	0.0148±0.0018	0.0122±0.0012
$\frac{\sigma[W(\to \mu\nu)+c]}{\sigma[W(\to \mu\nu)+jets]}$	0.145±0.040	0.095±0.054	0.001±0.062	0.093±0.029

Systematics uncertainties:

	e-channel			μ-channel			common
P_T	JES	JER	f^e_c	JES	JER	f^μ_c	ϵ^l_c
20-30	$\pm^{0}_{0.009}$	$\pm^{0.002}_{0.003}$	±0.002	$\pm^{0}_{0.007}$	$\pm^{0.002}_{0.003}$	±0.001	±0.004
30-45	$\pm^{0.003}_{0.002}$	$\pm^{0.002}_{0.003}$	±0.002	$\pm^{0.005}_{0.001}$	$\pm^{0.002}_{0.003}$	±0.001	±0.004
45-200	$\pm^{0.001}_{0.001}$	$\pm^{0.002}_{0.003}$	±0.003	$\pm^{0.011}_{0}$	$\pm^{0.002}_{0.003}$	±0.001	±0.003
20-200	$\pm^{0}_{0.004}$	$\pm^{0.002}_{0.003}$	±0.002	$\pm^{0.002}_{0.001}$	$\pm^{0.002}_{0.003}$	±0.001	±0.004

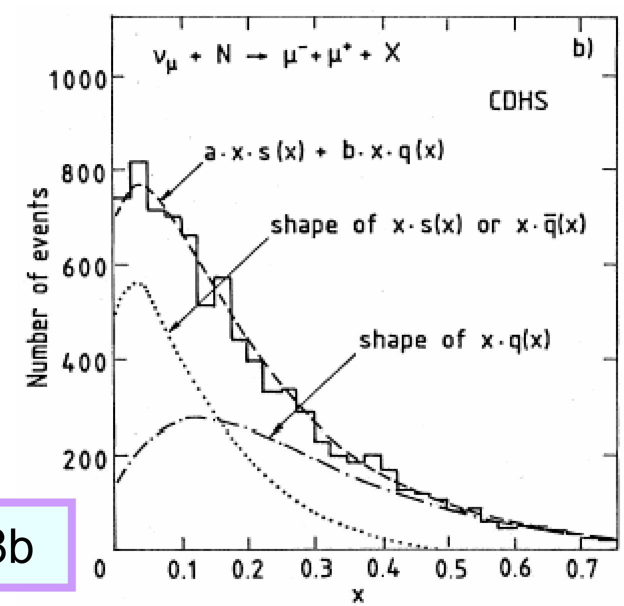
Previous measurements

- The charm production with an isolated muon has been measured at fixed target experiments that directly measure the strange quark PDF at low Q^2 scale



  - FERMILAB-THESIS-2006-01
  - NuTeV collaboration, Phys.Rev. D 64 (2001) 112006
  - Charm II collaboration, Eur. Phys. J. C11: 19-34 (1999)
  - CCFR collaboration, Phys. Rev. Lett. 70 (1993) 134
  - CCFR collaboration, Z. Phys. C 65 (1995) 189
  - CDHS collaboration, Z. Phys. C 15, 19, 1982b
  - CDHS collaboration, Phys. Lett. B 69, 377 1977a

- These experiments determined
  - the size of strange sea in the nucleon
  - asymmetry in strange / anti-strange momentum distribution
  - dynamics of the charm quark

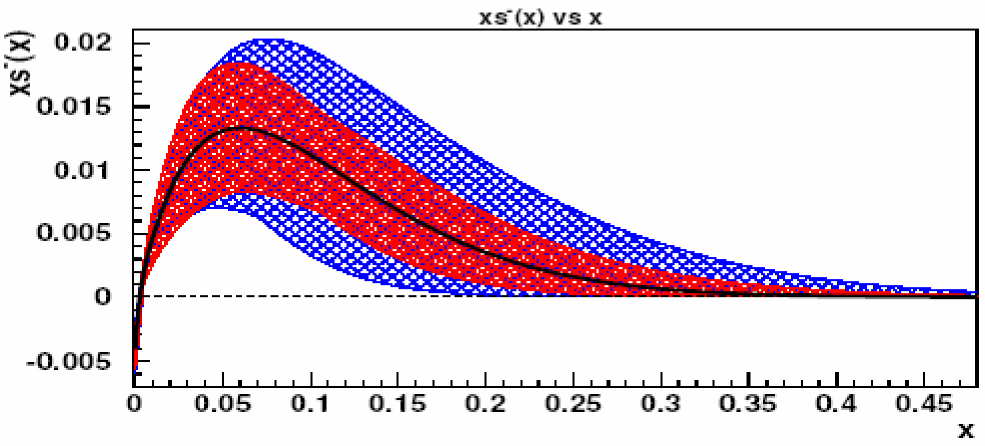


Holder et al. 1977a, Abramowicz et al., 1988b

Strange/Anti-strange Asymmetry

D. Mason, DIS 2006 Proceedings: “Final strange asymmetry Results from NuTeV”

$$S^- = \int [xs(x) - x\bar{s}(x)]dx \sim +0.007$$



0.00196 ± 0.00046 (stat) ± 0.00045 (sys) + 0.00148 – 0.00107 (external)

Xo= 0,01, 0.05, 0.15

As x_o goes up, the asymmetry S^- disappears