Z+jets, Z+b, W+c

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for the D0 collaboration

Special thanks to
Mahsana Ahsan, Amnon Harel and Gavin Hesketh

Matched MC - Introduction

Good at generating hard, large-angle processes (calculates interference)

Partons are matched to parton-shower jets to avoid double counting of equivalent phase space configurations.

Good at generating the details within a jet

Multijet events don't describe data well (and are hard to generate)

Matrix element generator

Alpgen / Sherpa

LO calculations for 2→N hard processes

Hard scatter partons

Parton shower generator

Pythia / Herwig

Only 2→2 hard processes

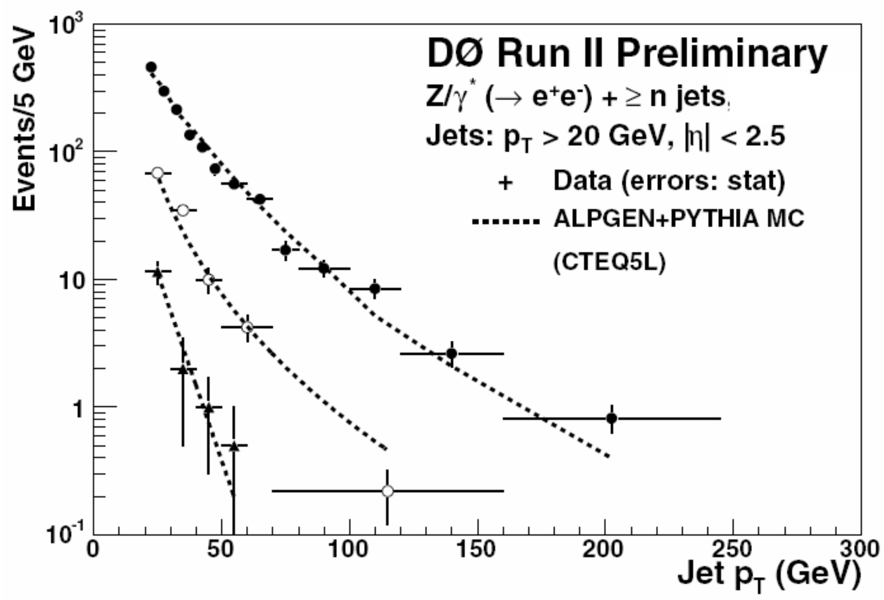
Resummed soft, collinear radiation.

Particles

Detector simulation

Z+Jets at D0 (0.4 fb^{-1}, "old")

- Cross section ratio measurement at particle level
  - 0.4 fb^{-1}
  - electron channel
- Selection
  - Vertex $|z|<60$ cm
  - Electron
    - $p_T>20$ GeV, $|\eta|<1.1$
    - Shower development
    - Isolation
    - Two with at least one track matched
    - $75<M_{ee}<105$
  - Jets
    - RunII cone R=0.5, $p_T>20$ GeV, $|\eta|<2.5$
    - JES corrected
  - Electron-jet separation $\Delta R>0.4$
- 13,893 inclusive Z candidate events



- Comparison with ALPGEN LO with Pythia showering
  - Generator cuts: parton $p_T>8$ GeV, $\Delta R>0.4$
  - No matching
  - Full simulation

Corrections in Z/γ*+jets

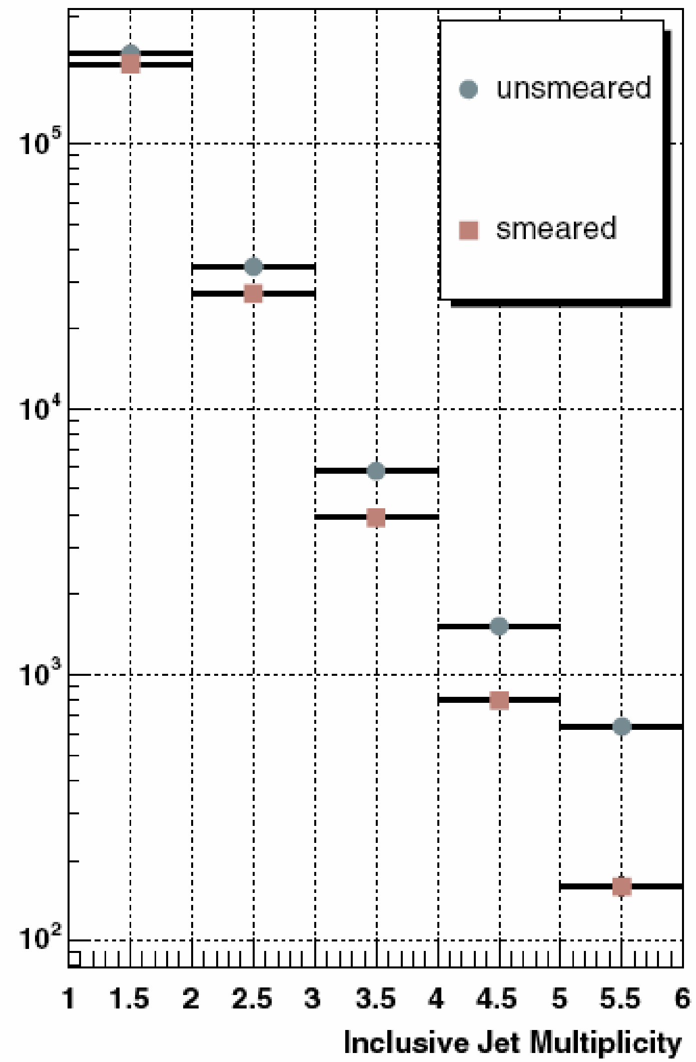
- Electron trigger, reconstruction*id efficiency
- Jet reconstruction-id efficiency
  - In data, look for jets balancing Z, measure eff as a function of Z p_T
  - Do the same in MC and scale factor derived
  - Reconstruction efficiency measured in MC * scale factor
  - Mapping to go from Z p_T to particle jet p_T
  - Closure test done
  - This will be used in unsmearing

Acceptance

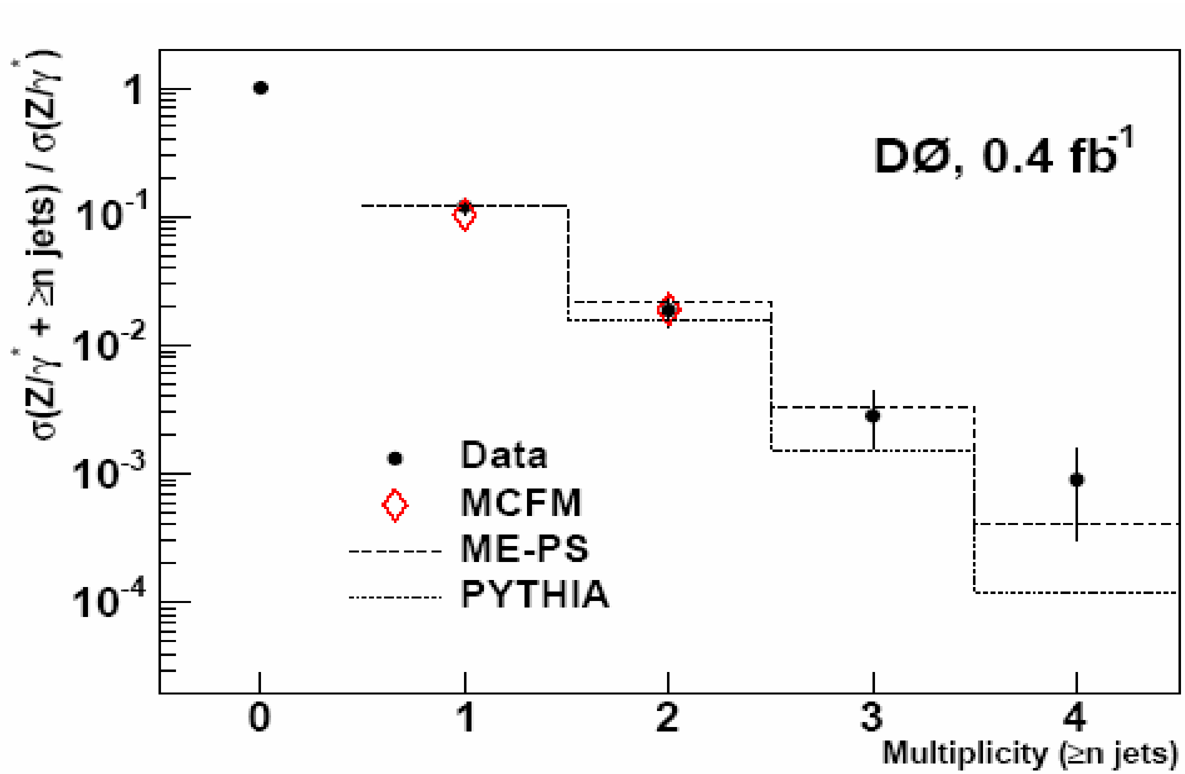
- **Use MC**
  - **Z/γ^* + ≥ 0j**
    - **Pythia reweighted to reproduce Z p_T in data**
      - **Deno: Z/γ^* ($75<M_{ee}<105$)**
      - **Num: Events with two electrons $p_T>25$, $|\eta|<1.1$, $|pvz|<60$cm**
  - **Z/γ^*+ ≥ nj**
    - **Alpgen Z+n jets sample.**
      - **Deno: Z/γ^* ($75<M_{ee}<105$) + ≥n particle jet ($p_T>25$, $|\eta|<1.1$)**
      - **Num: Events with two electrons $p_T>25$, $|\eta|<1.1$, $|pvz|<60$cm**

Unsmearing Corrections

- **Unsmearing to correct for bin migration to due to**
  - Jet energy resolution
  - Jet reconstruction efficiency
- **Unsmearing correction factor derived using particle level PYTHIA MC**
  - First reweight pythia events such that smeared MC distribution agrees with the data
- **Electron-Jet overlap correction**
  - Accidental overlap between Jet and electron must be accounted for
  - See how many partons fall within cone of 0.4~0.7
  - (6±3)% correction at ≥1 jet, (10±8)% at >4 jet



σ(Z/γ*+≥n jets)/σ(Z/γ*)



ME-PS =smpr

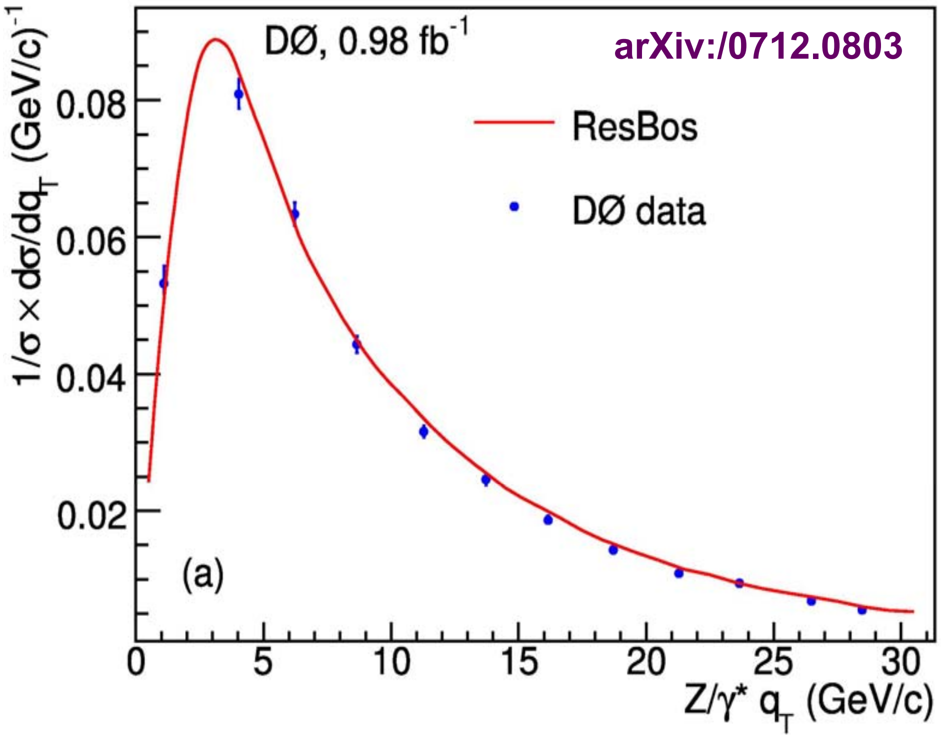
i.e. magraph (up to 3 partons)+ pythia for showering)

JES and jet reco efficiency uncertainty dominates

Multiplicity (≥n jets)	$R_n = \frac{\sigma_n}{\sigma_0}$ [$\times 10^{-3}$]	Statistical Uncertainty [$\times 10^{-3}$]	Systematic Uncertainty [$\times 10^{-3}$]
1	119.1	±3.3	+17.2 / -16.2
2	18.1	±1.3	+4.5 / -4.3
3	2.6	±0.52	+0.90 / -0.89
4	0.61	±0.28	+0.29 / -0.27
5	0.42	±0.30	+0.42 / -0.24

New results (1 fb^{-1}) in collaboration review, to appear soon

Z+jets Shape Corrections (1 fb^{-1})



Measured p_T spectrum of Z (inclusive)

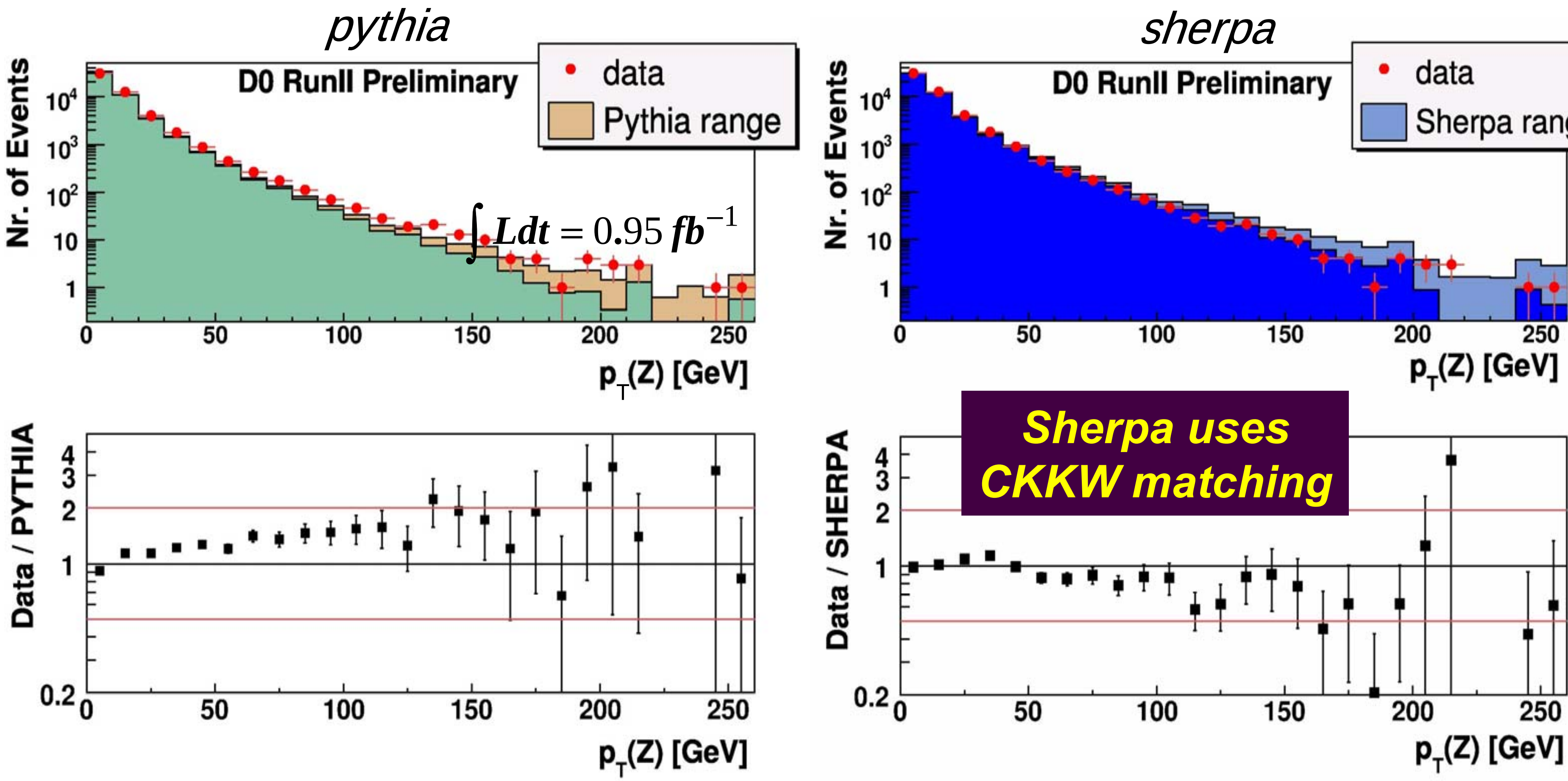
→ Starting to use ResBos as a surrogate to our data

- Reweighting Alpgen+Pythia MC to fit the ResBos spectrum
- Applying the lesson from *Z*+jets to *W*+jets...

Other approaches

Reweight basic distributions directly to data, after background subtraction (as a function of N_{jet})

Z+jets Shape Comparison (1 fb^{-1})



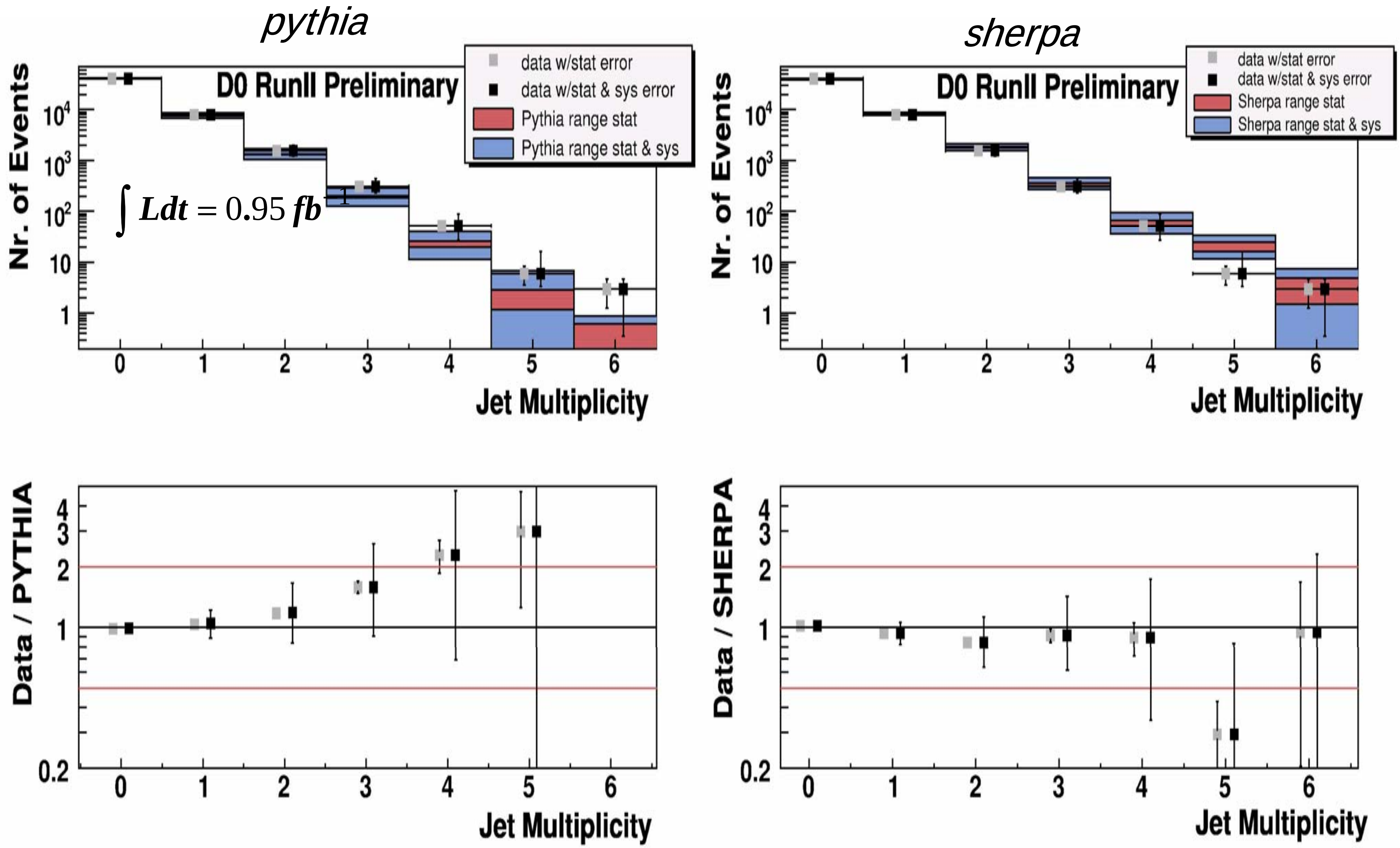
Normalized to data without parametrizing in N_{jet}

JES uncertainties dominate systematics (and are a bit conservative)

As expected, the Pythia spectrum is too soft (not enough radiation), so let's see this more directly…

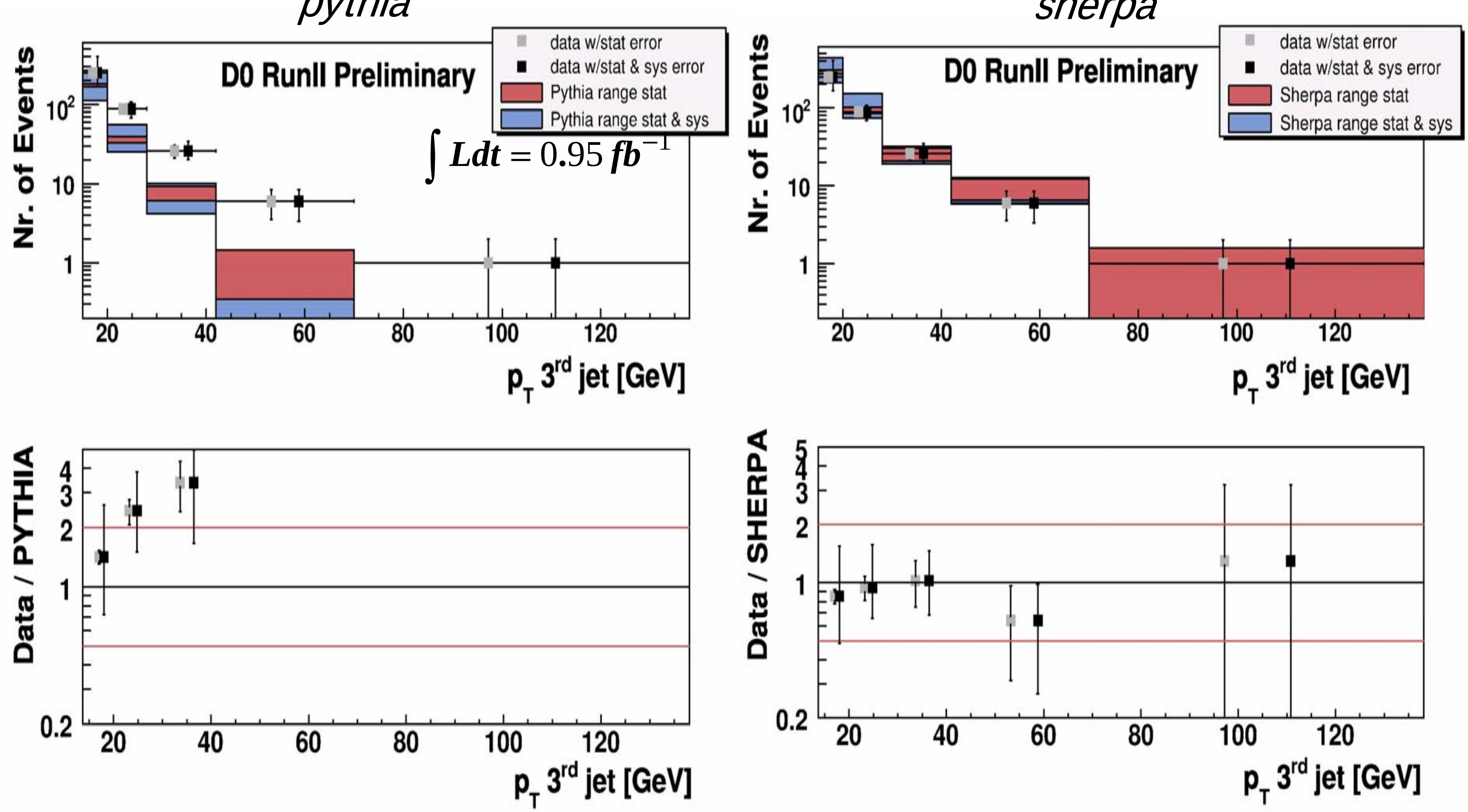
Z+jets Shape Comparison / jet multiplicity

Cone jets, p_T > 15 GeV, η< 2.5

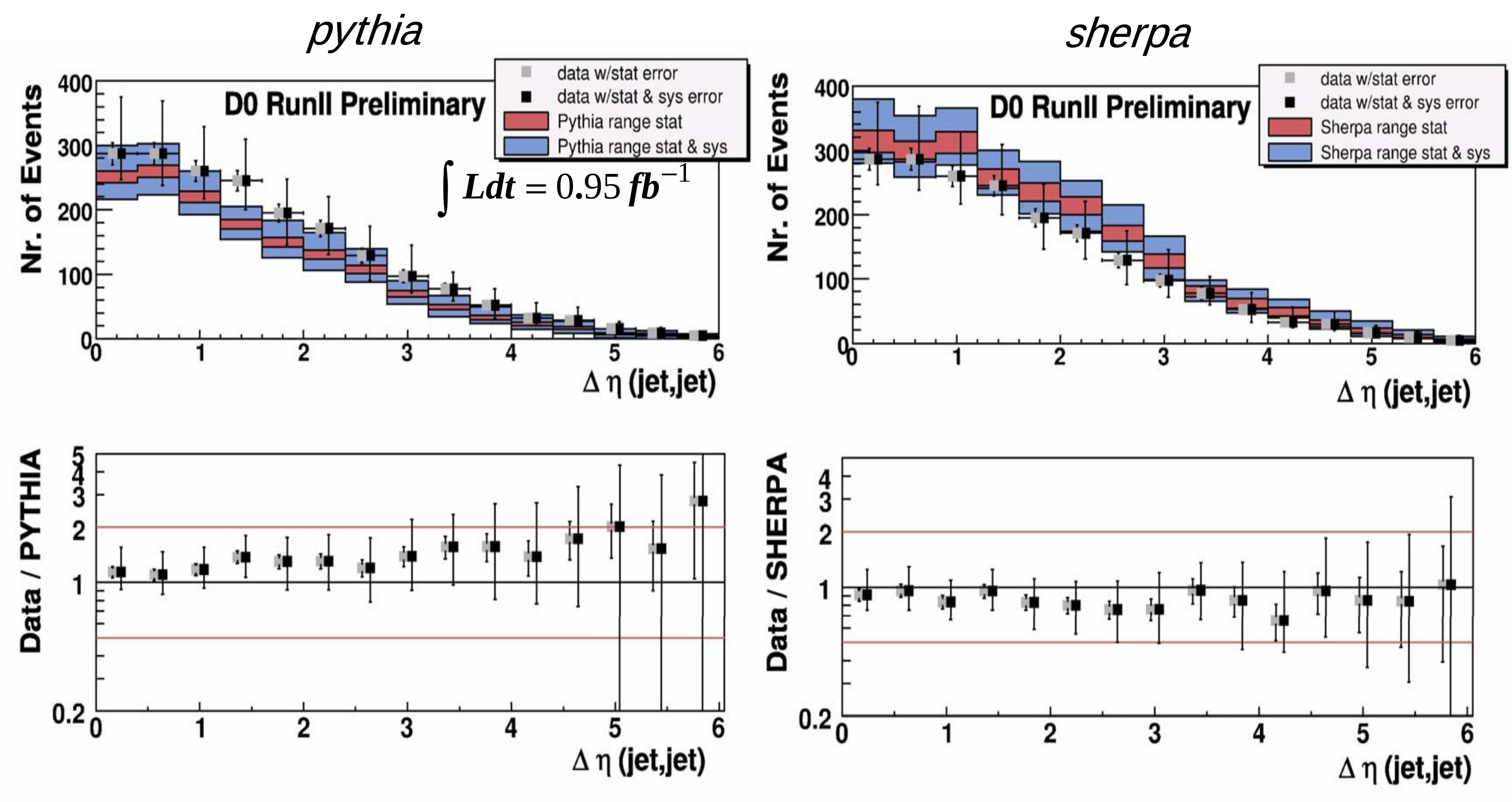


Z+jets Shape Comparison / p_T 3rd jet

pythia *sherpa*



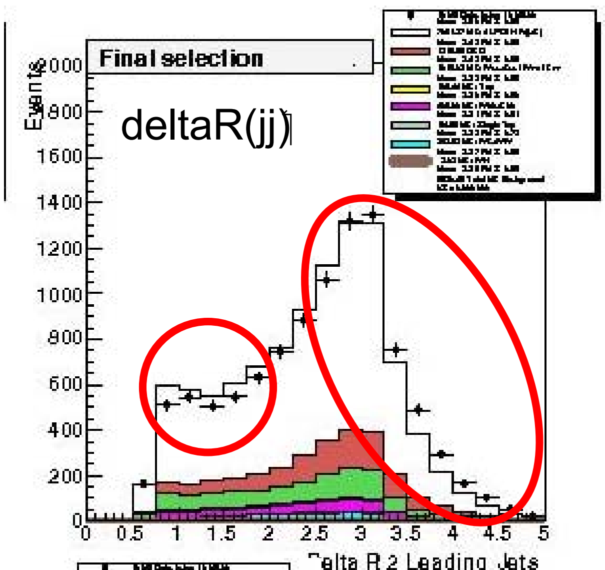
Z+jets Shape Comparison / Δη

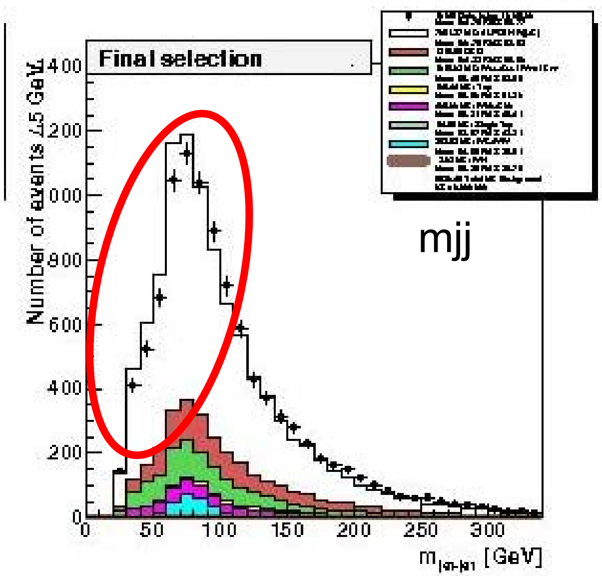


Reweighting ΔEta(jj), ΔPhi(jj) in WH analysis (MC to data)

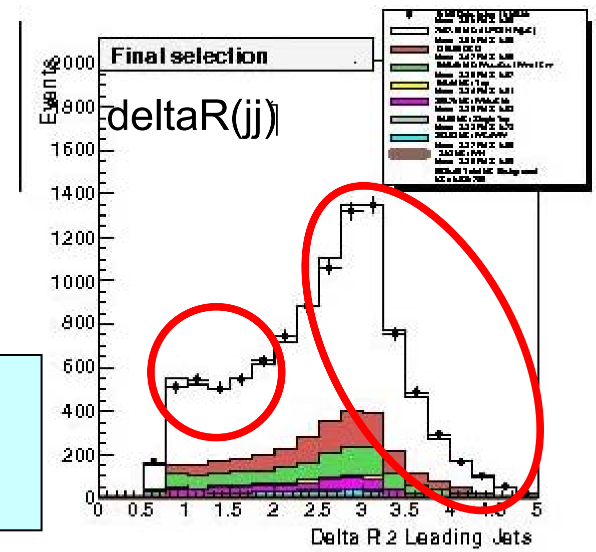
Reweight both deltaEta(jj) and deltaPhi(jj), *no other reweightings*

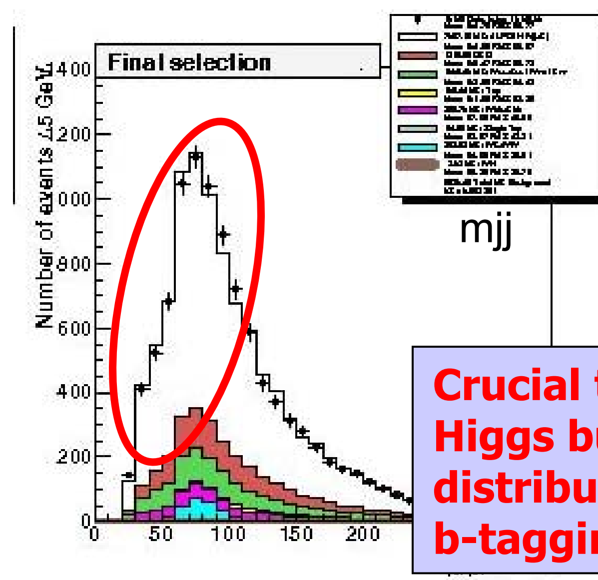
No reweighting at all





After reweighting (dEta, dPhi)

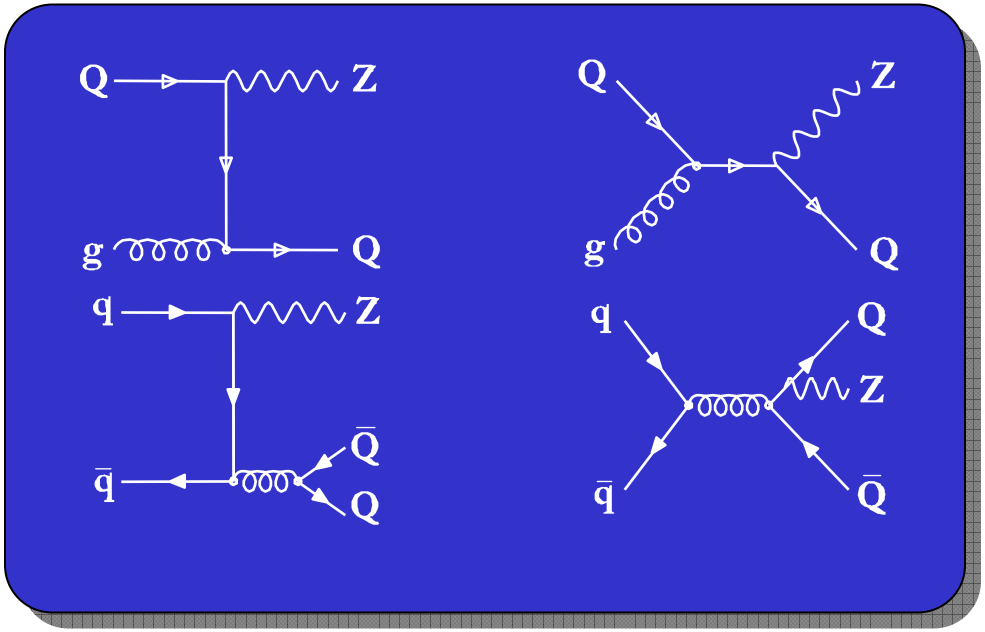




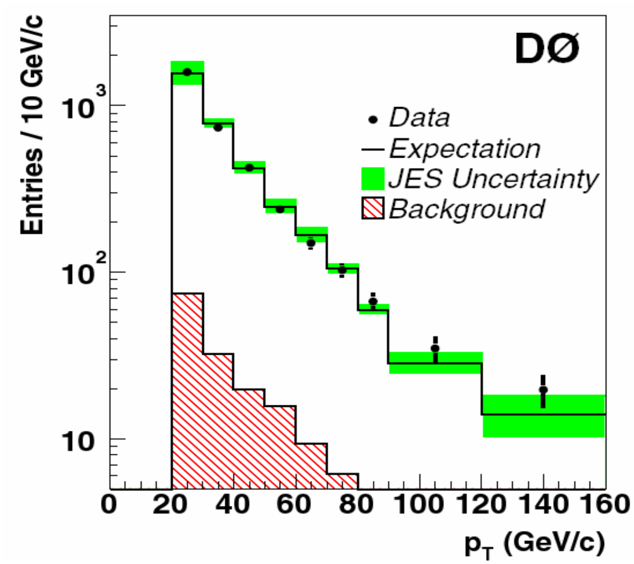
Work in progress not for outside this workshop

Crucial to see a small Higgs bump in this distribution (after b-tagging)

Z+Heavy Flavor (0.3 fb^{-1}, “old”)



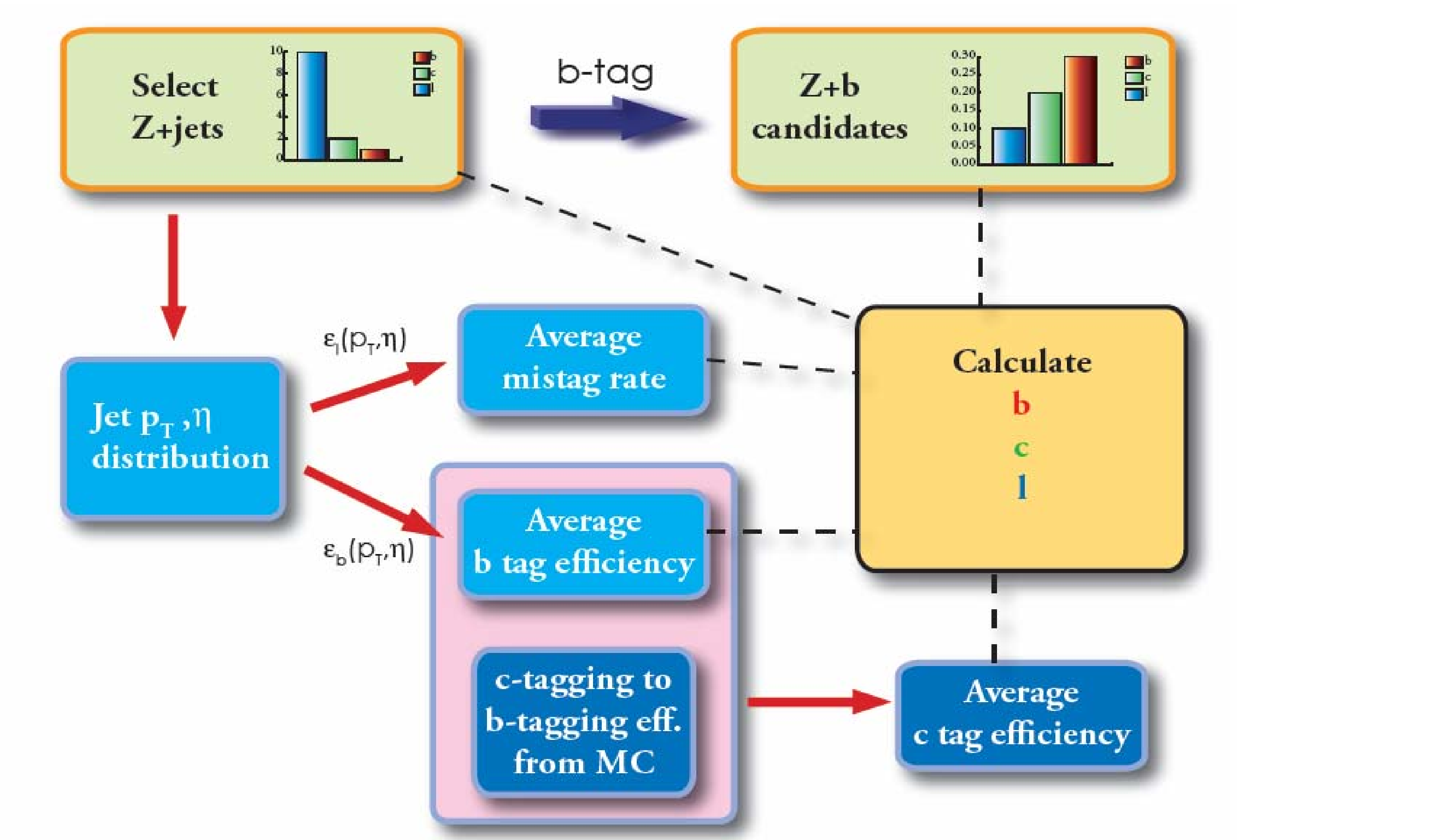
- **Selection**
  - **Z in ee and $\mu\mu$ channels (cut on mass window)**
  - **≥1 Jet p_T>20 GeV, $|\eta|$<2.5**
  - **3458 Z+jet events**



- **Z + single b-tag**
  - **Probe of b-quark PDF**
  - **b PDF is important for *hb* and *single-top* production**
- **Measure inclusive $\sigma(Z+b)/\sigma(Z+j)$**
  - **Many systematics cancel**

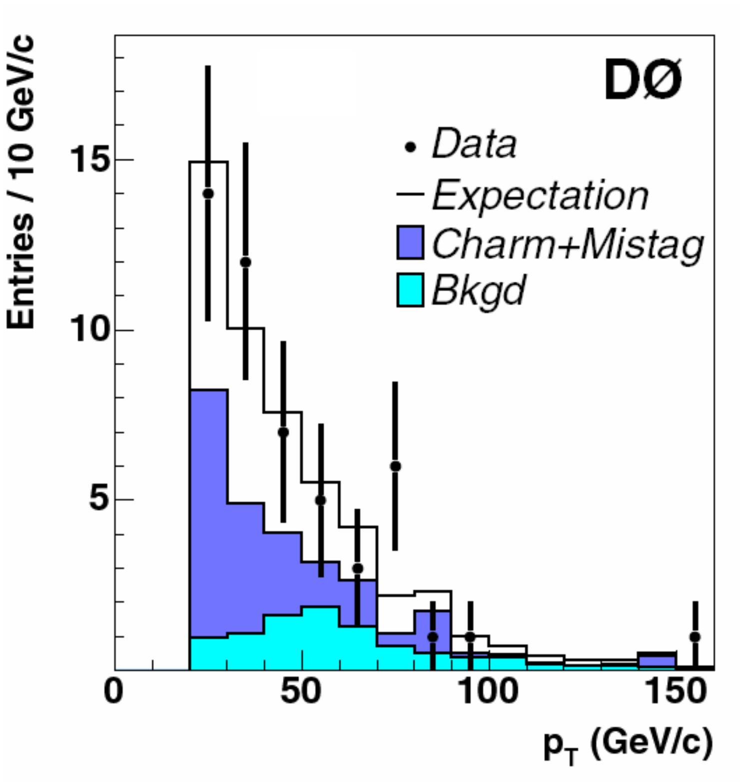
Method

$$N_{\mathrm{before\ b-tag}} = t'_b N_b + t'_c N_c + t'_\ell N_\ell \qquad N_{\mathrm{b-tagged}} = \bar{\epsilon}_b t'_b N_b + \bar{\epsilon}_c t'_c N_c + \bar{\epsilon}_\ell t'_\ell N_\ell$$



$\sigma(Z+b)/\sigma(Z+j)$

- **Apply sec. vertex b-tag**
  42 events with ≥1 tag
  8.3 from QCD background (sideband)



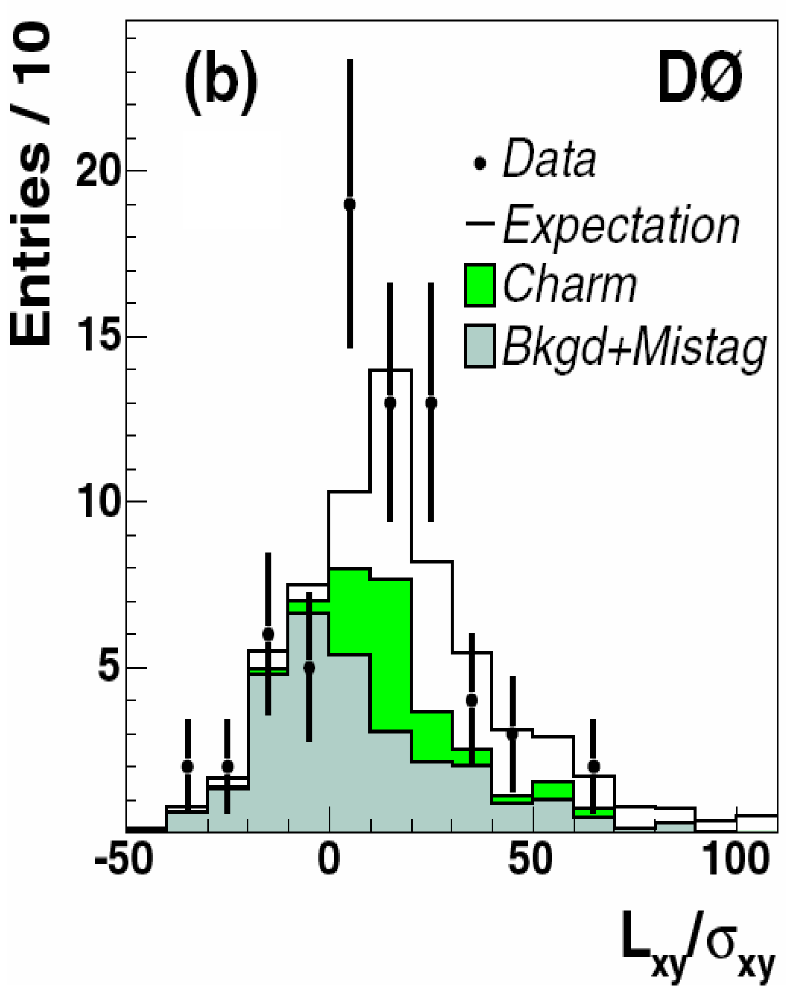
- **Disentangle light, c, b contributions**
  - Use light and b-tagging efficiency from data
  - c-tagging efficiency from MC and scaled for data/MC difference in b-tagging
  - $N_c=1.69N_b$ from theory

- **Cross checks with**
  - Soft lepton tagging
  - Impact parameter tagging

$\sigma(Z+b)/\sigma(Z+j)$ hep-ex/0410078

- **$0.021\pm0.004(stat)\pm0.002(syst)$**
  - **Theory predicts 0.018**
  - **Large part of systematic error from tagging efficiency and background estimation**

- **Disentangling scale from b-PDF needs more measurements**
  - **W+(bb), W+bb**
  - **Z+c, W+c**



Measurement of W+c-jet / W+jet

W + c-jet production

σ(*W + c*-jet) / σ(*W +* jets) ratio method

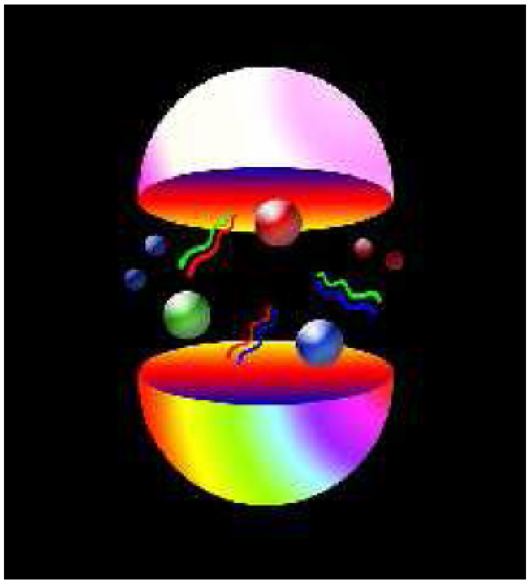
Background processes

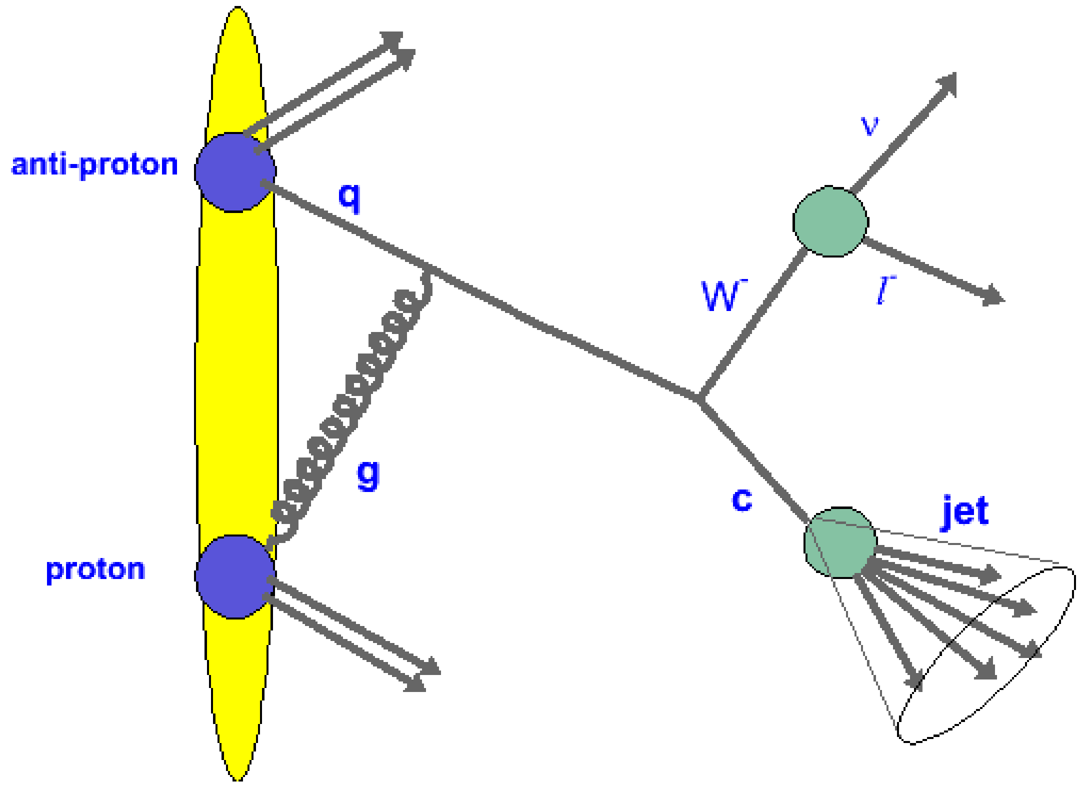
c-jet tagging

Result

Summary & Outlook

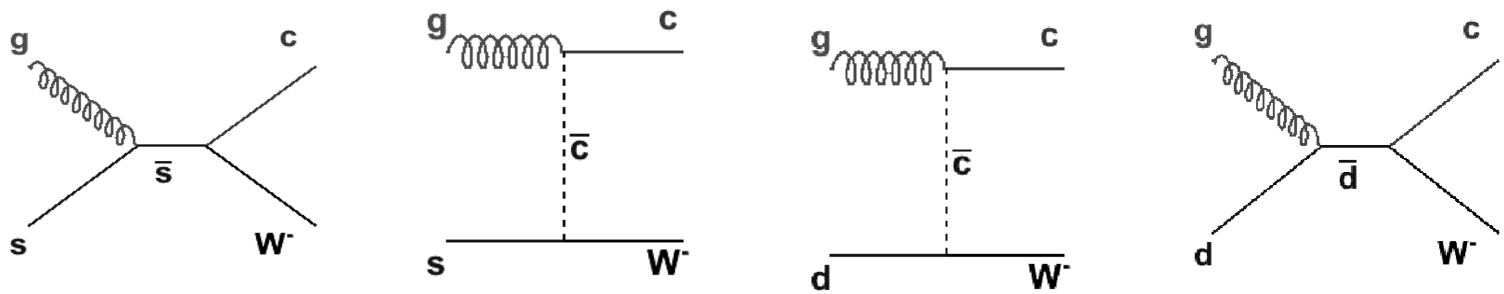
Introduction





- insight into the *s* quark content of the proton
  - important for reliable calculation of SM and new physics processes
- *W*+*c*-jet is a signature of many SM and new physics processes
  - Higgs boson production, top quark production, SUSY scalar top quark production, SUSY charged Higgs production etc…
- test of Quantum chromodynamics and electroweak physics

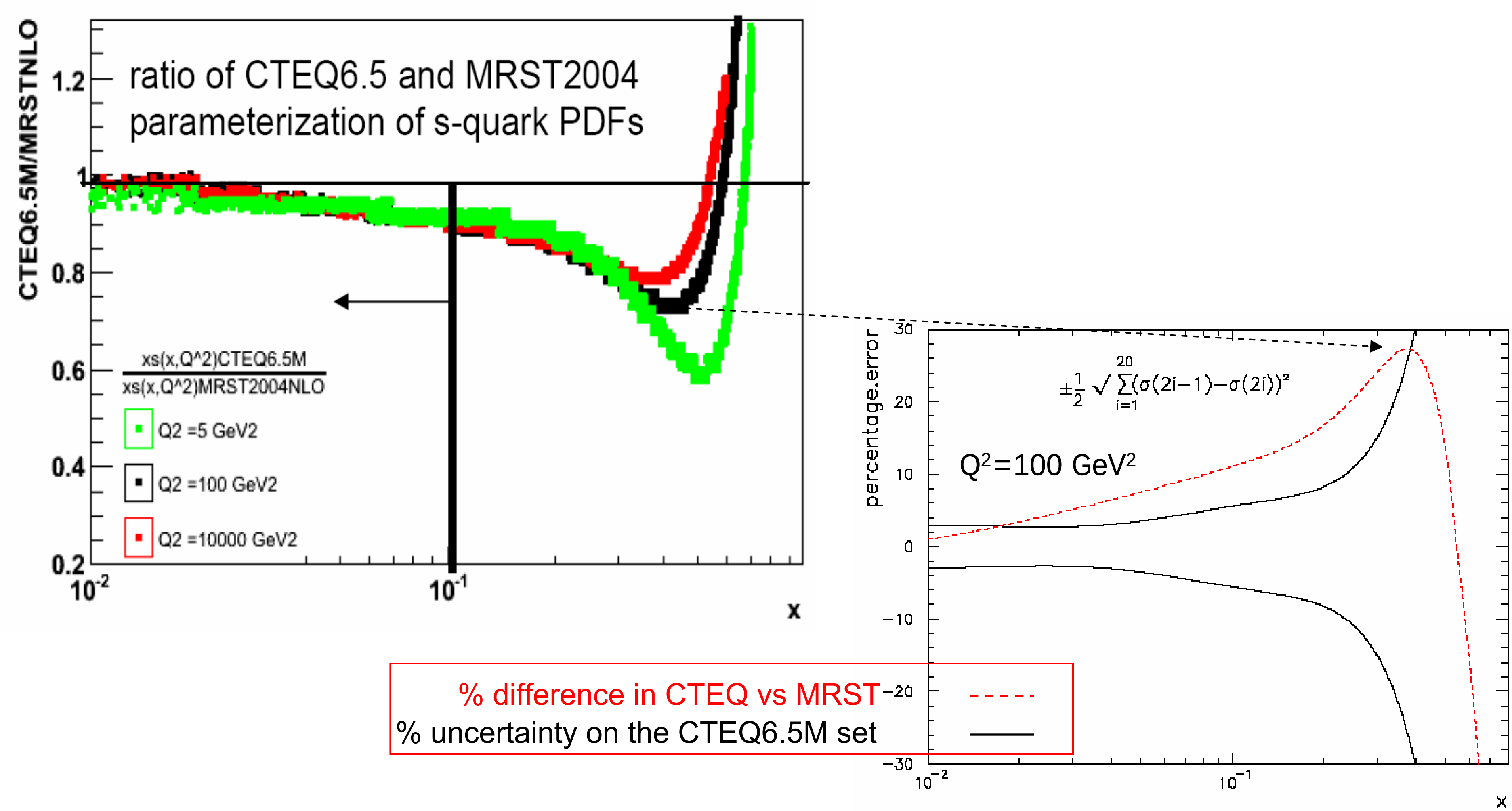
W+c-jet production at leading order



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

- **d(x,Q^2) > s(x,Q^2)**
- **$V_{cs} > V_{cd}$ → σ(sg →Wc) > σ(dg →Wc)**
- **Contribution to W+c production from s-quark ~85%, from d-quark ~15%**

Comparison of CTEQ6.5M and MRSTNLO2004 parameterizations of the strange quark PDFs

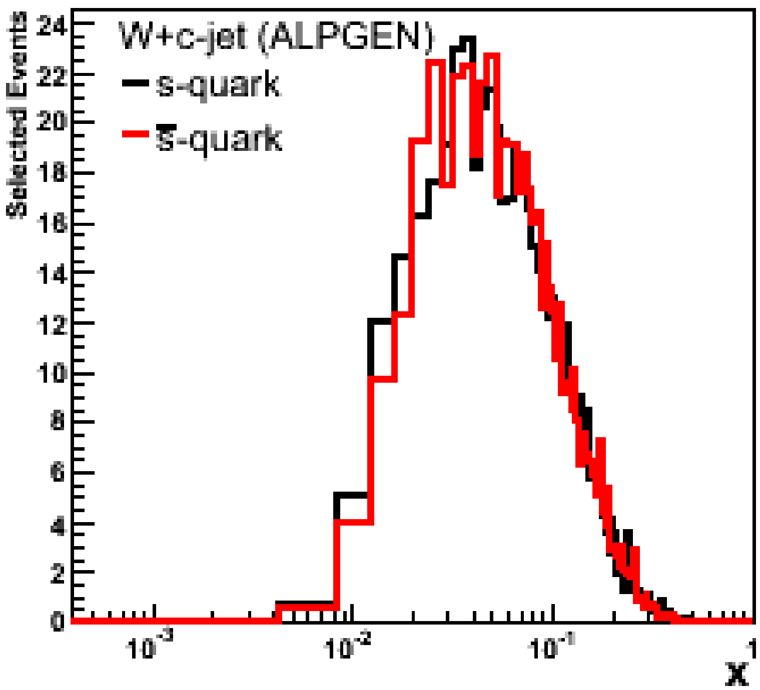


- **not well constrained in the *x* region [0.01,1]**
- **still does not reflect a true uncertainty**
- **no direct measurement at the hadron collider until this year**

Constraining the *s*-quark at the Tevatron

- **fixed target (ν-N) experiments have measured the s-quark PDFs at low momentum scales**
  - **most recent publication:** Phys. Rev. Lett. 99, 192001 (2007)

- **constraining region at the Tevatron**
  - $x \in [0.01, 0.1]$
  - Q **scale of the order of** M_W

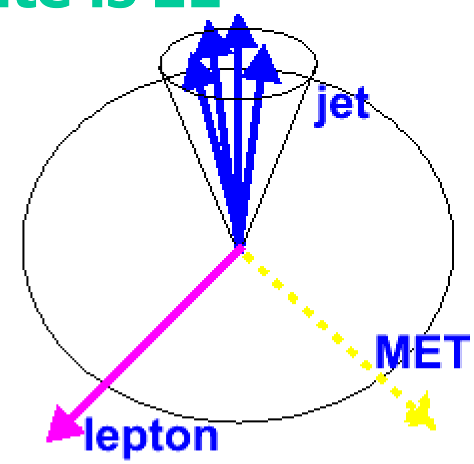


$$x_s x_g \geq \frac{M_W^2}{s} \approx 0.0017$$

$\sigma(W+c\text{-jet})/\sigma(W+\text{jets})$ ratio

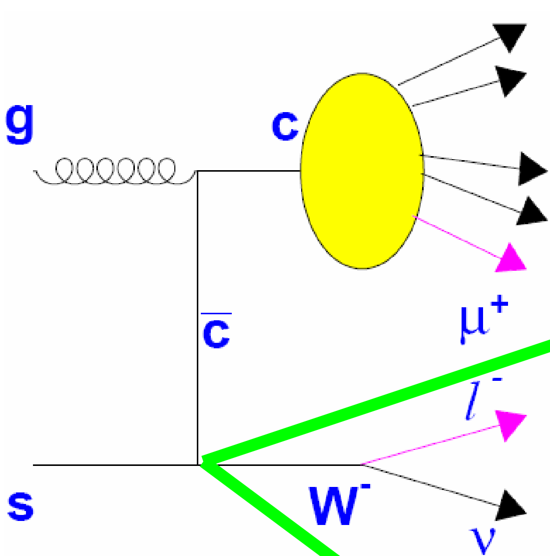
- **event signature for an inclusive *W*+jets selection**
  - **isolated lepton + ETmiss + jet**
  - **W→e ν and W→μ ν modes**
- ***W*+*c*-jet signature:**
  - **isolated lepton + ETmiss + *c*-tagged jet**
  - **net charm quantum number in the final state is ±1**

$$R = \frac{\sigma(W(\rightarrow l\nu) + c\text{ - jet})}{\sigma(W(\rightarrow l\nu) + \text{jets})} = \frac{N(W(\rightarrow l\nu) + c\text{ - jet})}{N(W(\rightarrow l\nu) + \text{jets})}$$



- **many experimental (e.g. jet energy scale, efficiencies and luminosity) and theoretical uncertainties (PDF and scale uncertainties) cancel in ratio**

Event selection



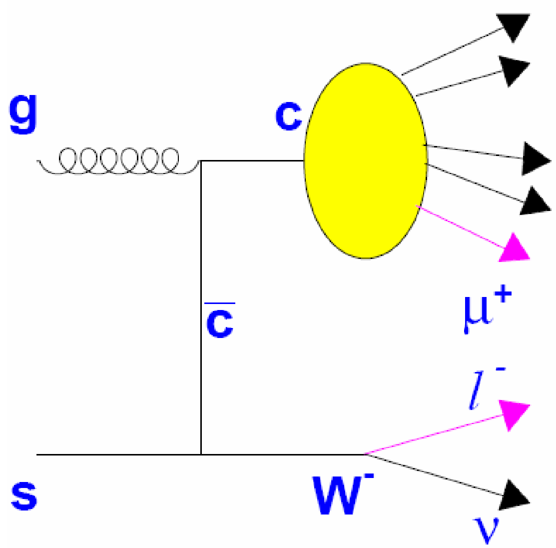
- at least one jet Pt > 20 GeV, others with Pt > 15 GeV
  - jet p_T is calibrated for the jet energy scale (JES)
- Jet pseudorapidity $|\eta| < 2.5$
- muon-tagged jet contains a muon with $p_T > 4$ GeV
  - □ ΔR(jet, muon) < 0.5

- pass single muon trigger
- One isolated muon $p_T > 20$ GeV

- pass single electron trigger
- One isolated electron $p_T > 20$ GeV

- ETmiss > 20 GeV
- W boson transverse mass [40, 120] GeV
- $|\Delta\varphi$(lepton, ETmiss)$| > 0.4$

$\sigma(W+c\text{-jet}) / \sigma(W+\text{jets})$ ratio measurement strategy



***W* charge is opposite to the muon charge from recoiling charm**

A simple counting measurement

$$R = \frac{N(W(\to l\nu) + c\text{ - jet})}{N(W(\to l\nu + \text{jets})} = \frac{N^l_{OS} - f^l_c(N^l_{SS} - N^{l,nonWj}_{SS}) - N^{l,nonWj}_{OS}}{(1 - f^l_Z - f^l_{QCD}) \times N^l_{Wj} \times \varepsilon_c}$$

N^l_{OS} = number of OS events

N^l_{SS} = number of SS events

N^l_{Wj} = number of observed W + jets candidates

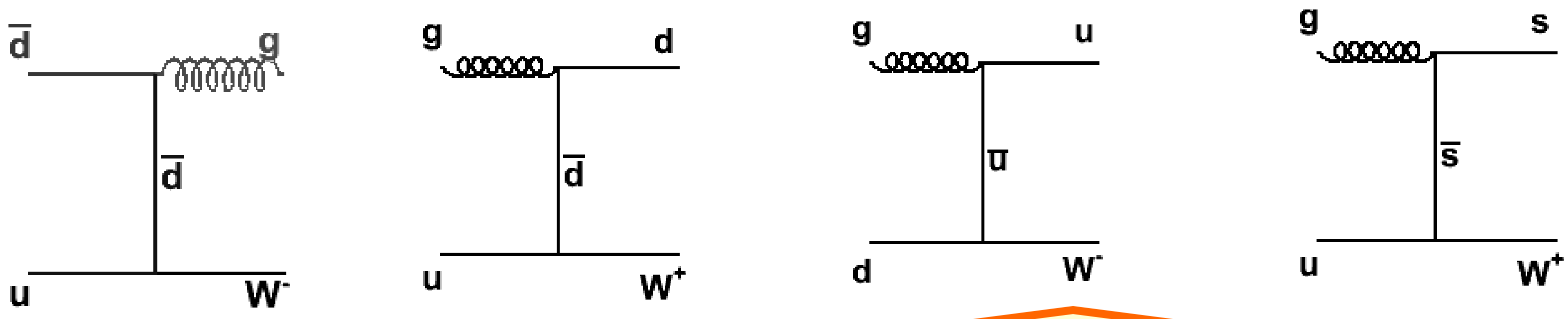
f^l_c = correction to the BKD to W + c

f^l_Z, f^l_{QCD} = fractions of Z + jets and multi - jet background to W + jets

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

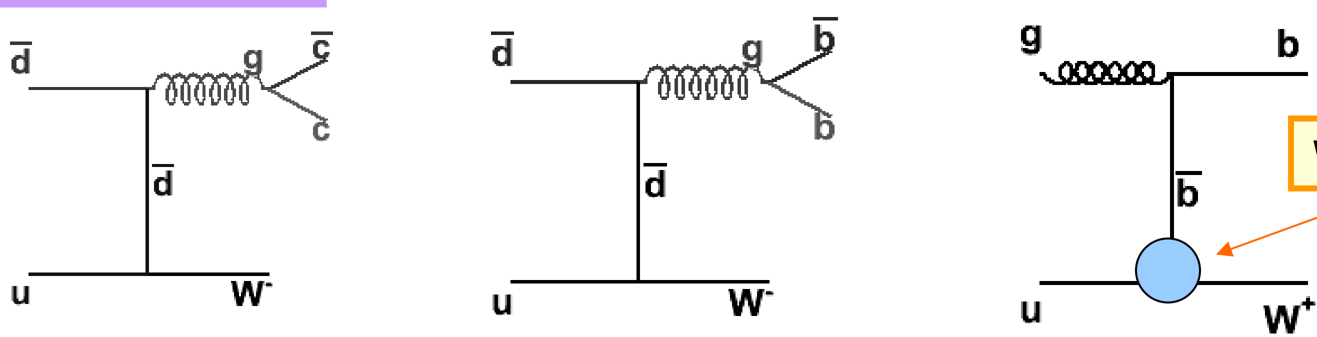
Major physics backgrounds to *W*+*c*-jet process

W+light jets



Contribute to signal due to "leading particle effect"
e.g. described in Phys. Rev. Lett. 78, 3442 (1997)

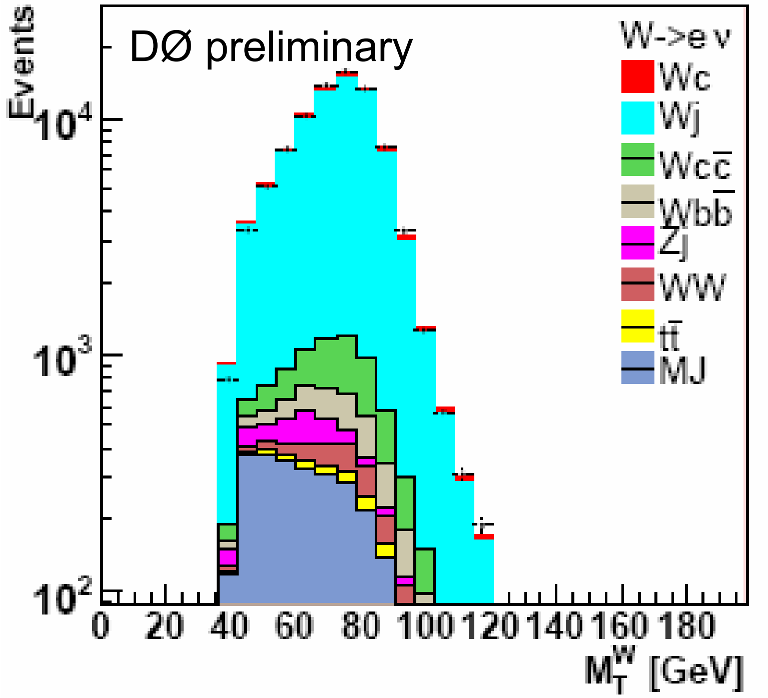
W+heavy flavor jets

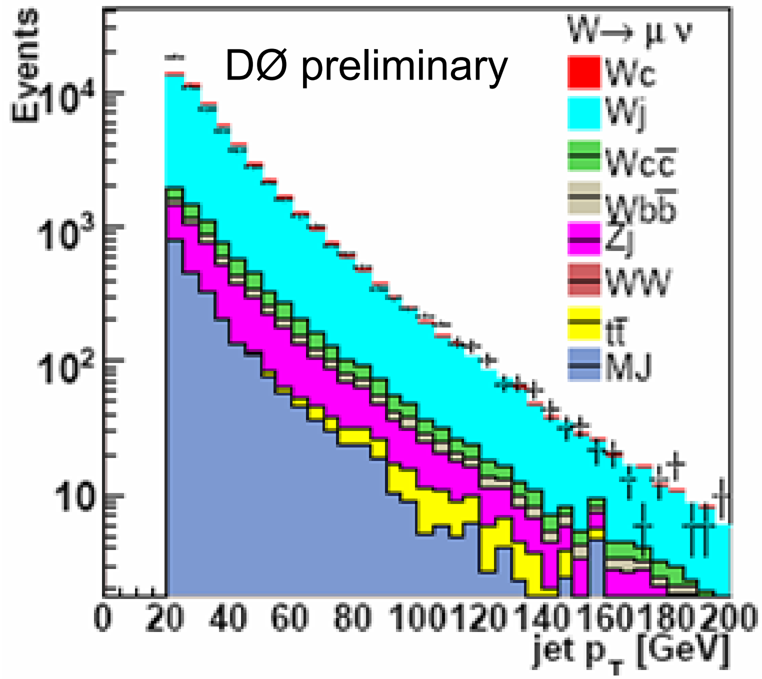


W+b is CKM suppressed

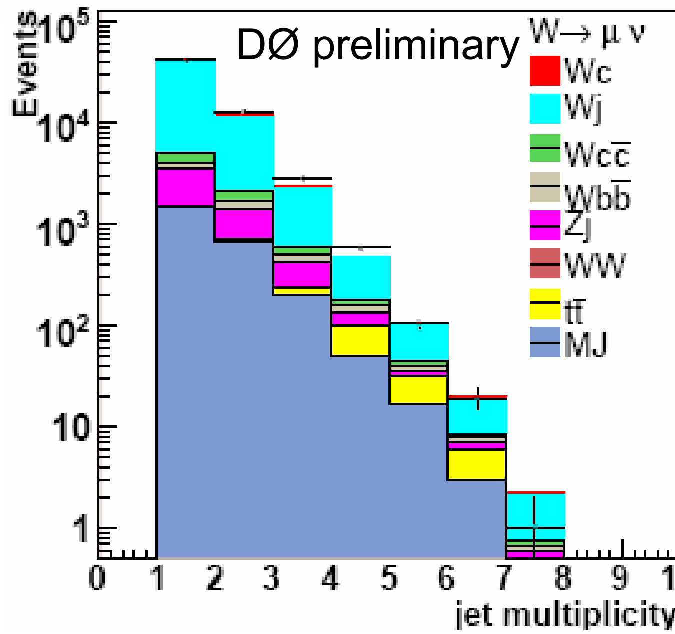
Other relatively small background processes are di-boson and top quark productions

Control plots





- **sample composition: Wc, Wcc, Wbb, Wj, WW, Zj, ttbar, multijets**
- **Data in agreement with the theoretical prediction**
- **theory: ALPGEN + PYTHIA**
  - **ALPGEN: tree level matrix element generator**
  - **PYTHIA: leading order + parton shower generator**



Muon-tagged jet p_T spectra

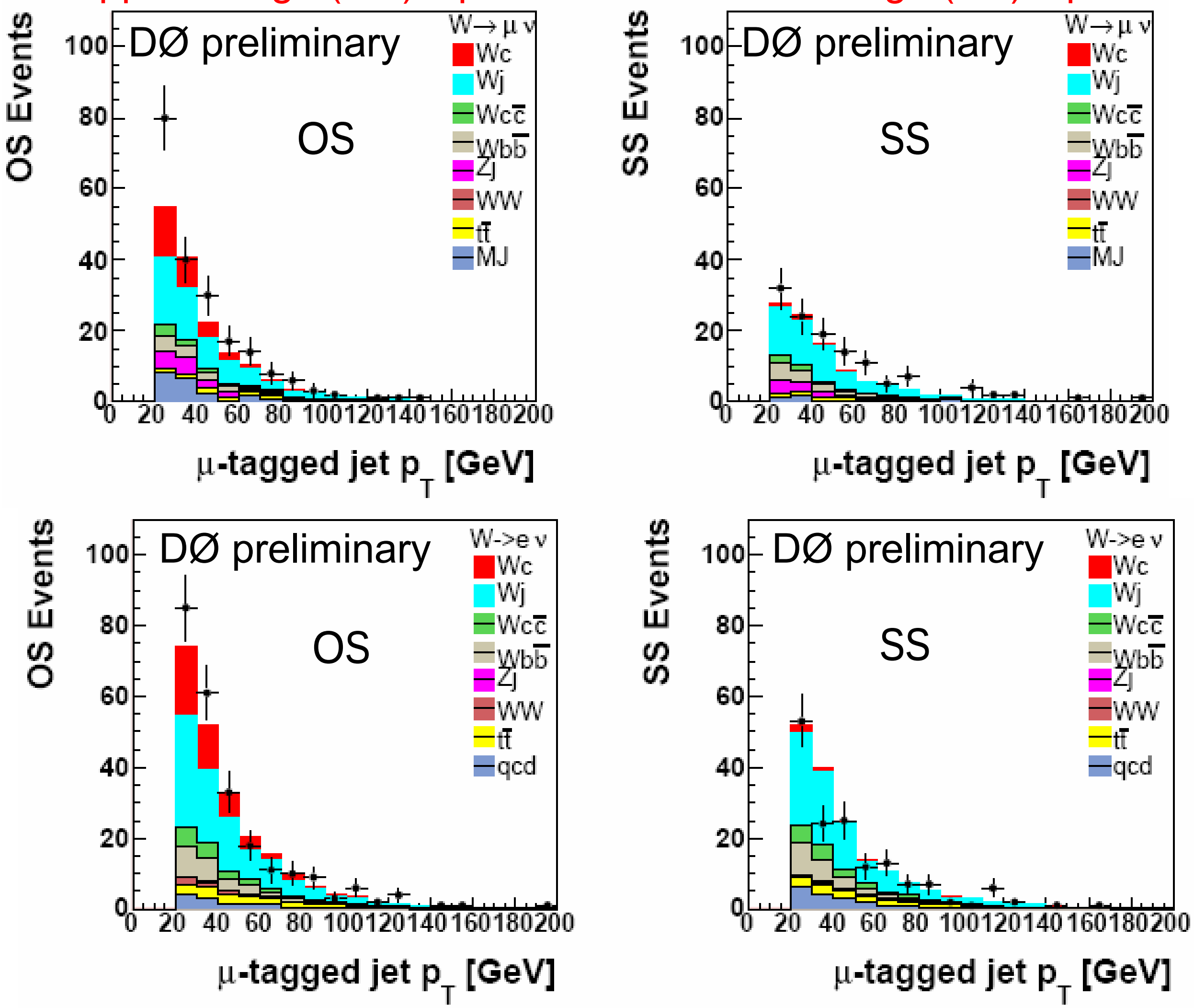
muon p_T > 4 GeV

Opposite sign (OS) leptons

Same Sign (SS) leptons

Electron Channel

Muon Channel



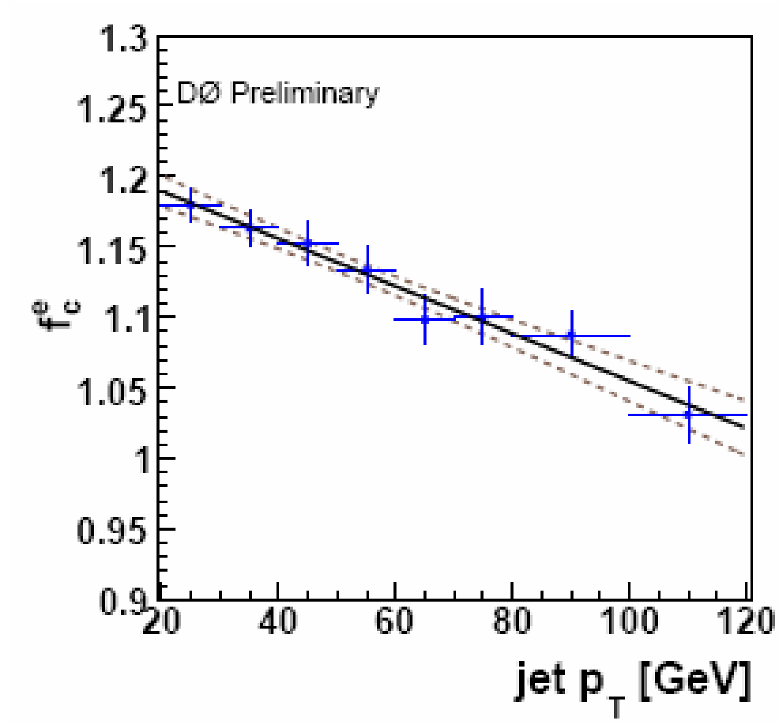
excess of OS events is the signature of W+c !

Background estimations

events containing a soft muon-tagged jet enrich a sample with b/c or pion/kaon semileptonic decays

- irreducible Wbb, Wcc backgrounds are SS events observed in data
- W+light quark jet background estimation needs a weak model dependent small correction to SS events
- multijet background is estimated from data
- other relatively small background estimated from MC simulation

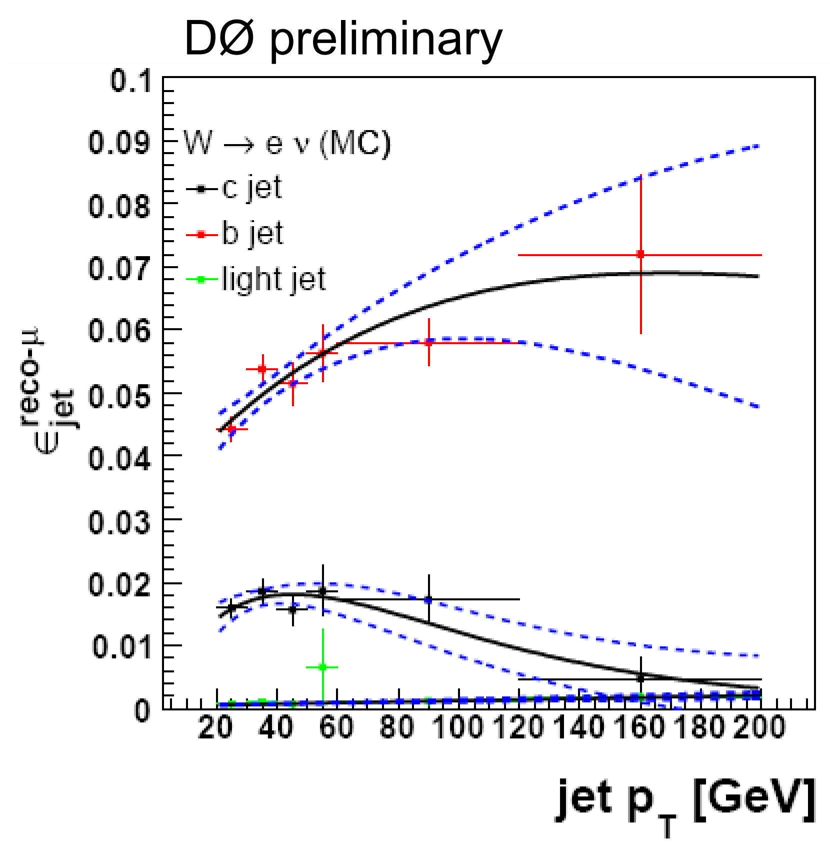
W+g dominates over W+q at high p_T

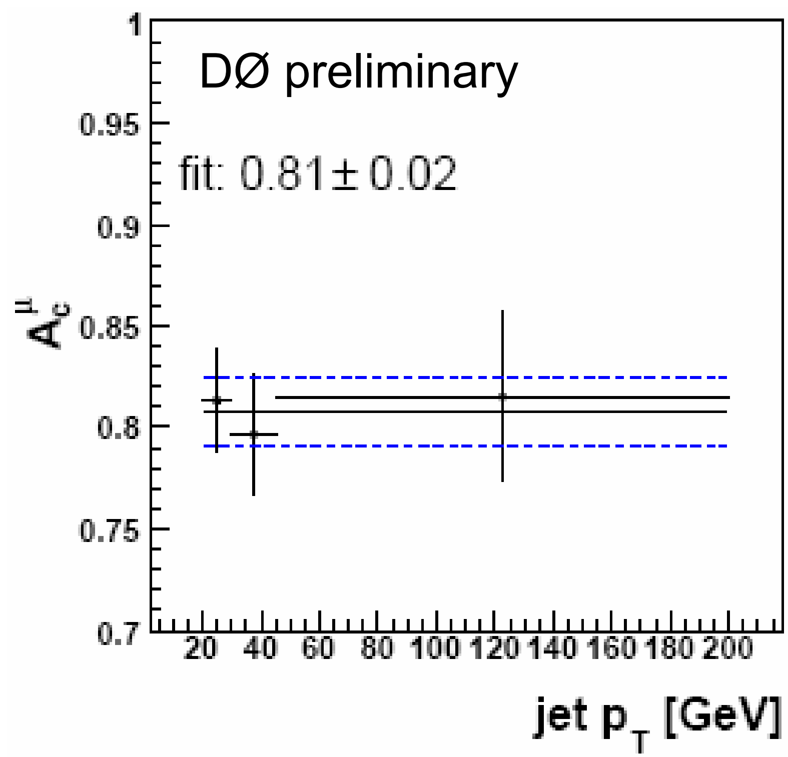


$$f_c^\ell = \frac{\int w_\pi(p_T) N_\pi^{\mathrm{OS}}(p_T) dp_T + \int w_K(p_T) N_K^{\mathrm{OS}}(p_T) dp_T}{\int w_\pi(p_T) N_\pi^{\mathrm{SS}}(p_T) dp_T + \int w_K(p_T) N_K^{\mathrm{SS}}(p_T) dp_T}$$

Relative efficiency of W + c-jet selection

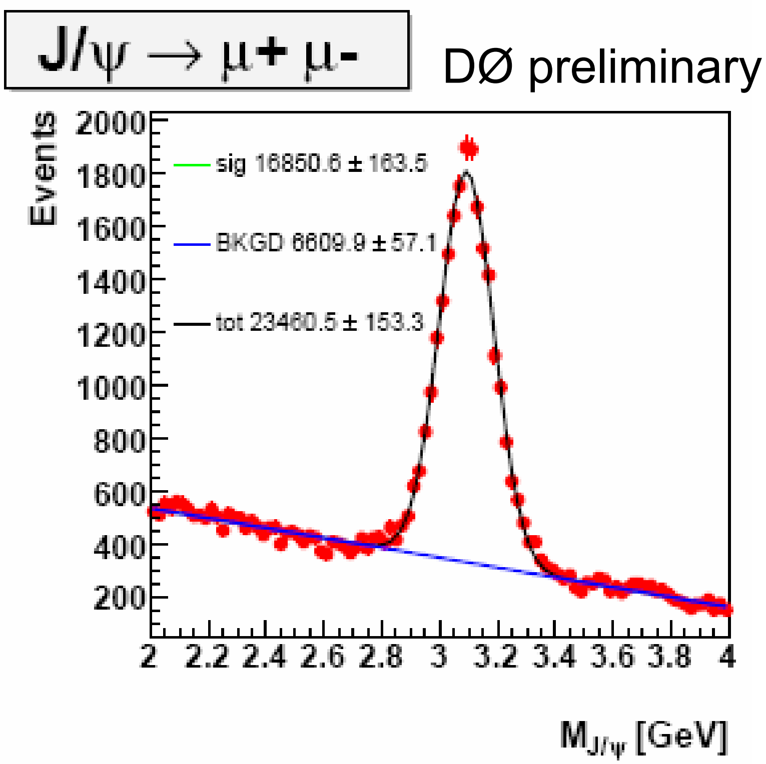
- **includes BF($c \rightarrow \mu$), muon identification and reconstruction, kinematical selection, jet momentum corrections for muon and neutrino energy losses in the jet, and efficiency for charge correlation**
  - **presence of muon from pion/kaon decays in c-jet in the *W*+*c*-jet sample degrades the correlation in final state leptons from 100% → 80%**

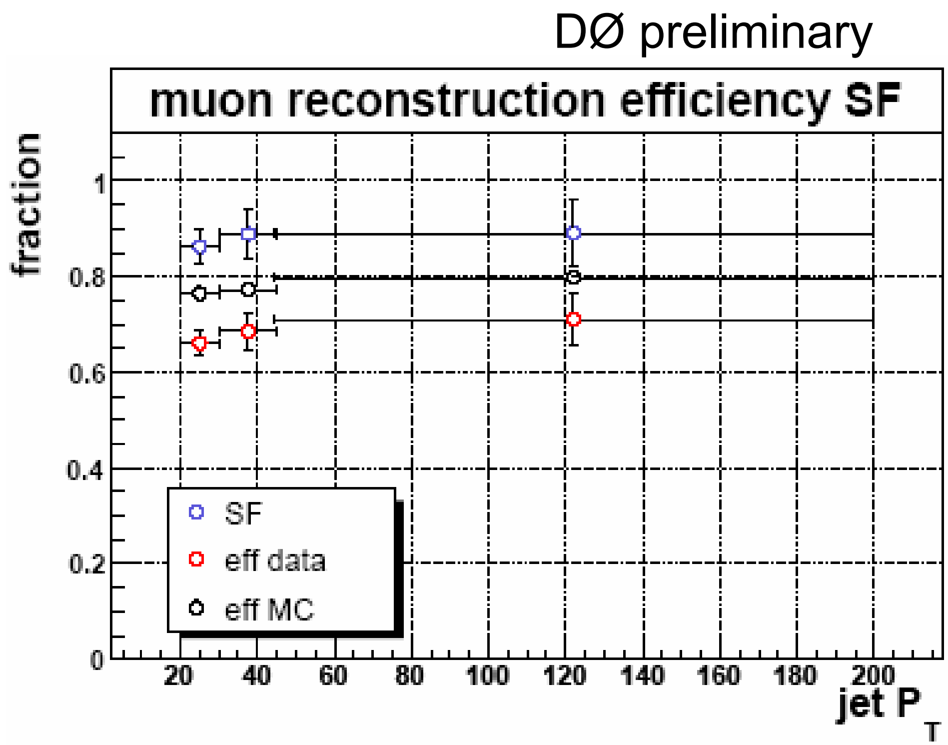




Scale factor for efficiency correction

- muon tagging efficiency estimated from models needs corrections to account for the residual detector effects
- use a large data sample of $J/\psi \rightarrow \mu^+\mu^-$ to estimate the muon reconstruction efficiencies at low p_T
  - use tag and probe method to determine the efficiencies
  - ~10% correction is required to recover the data-MC discrepancies



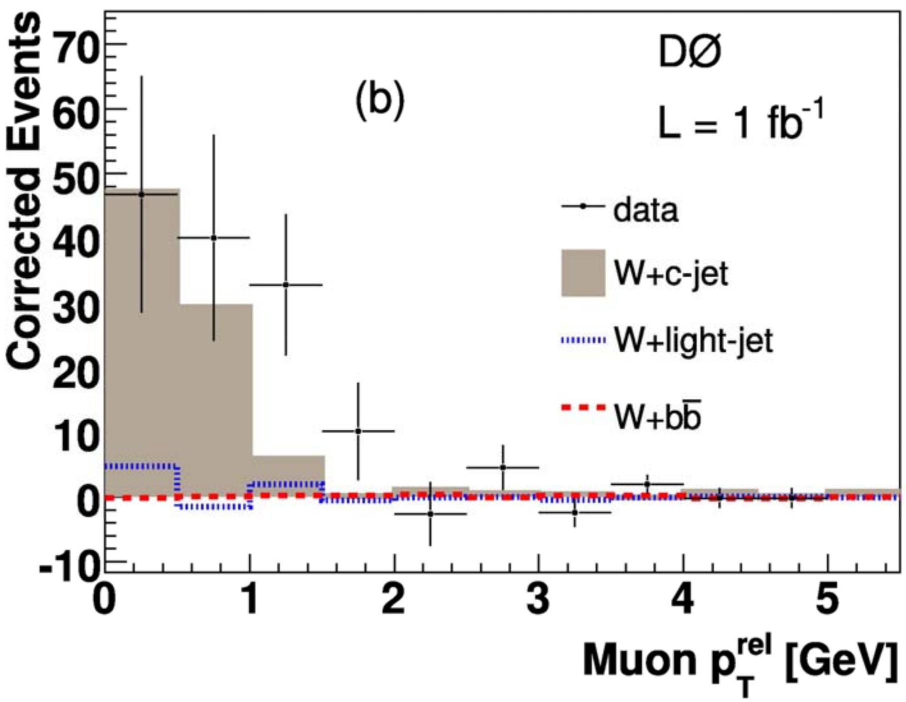


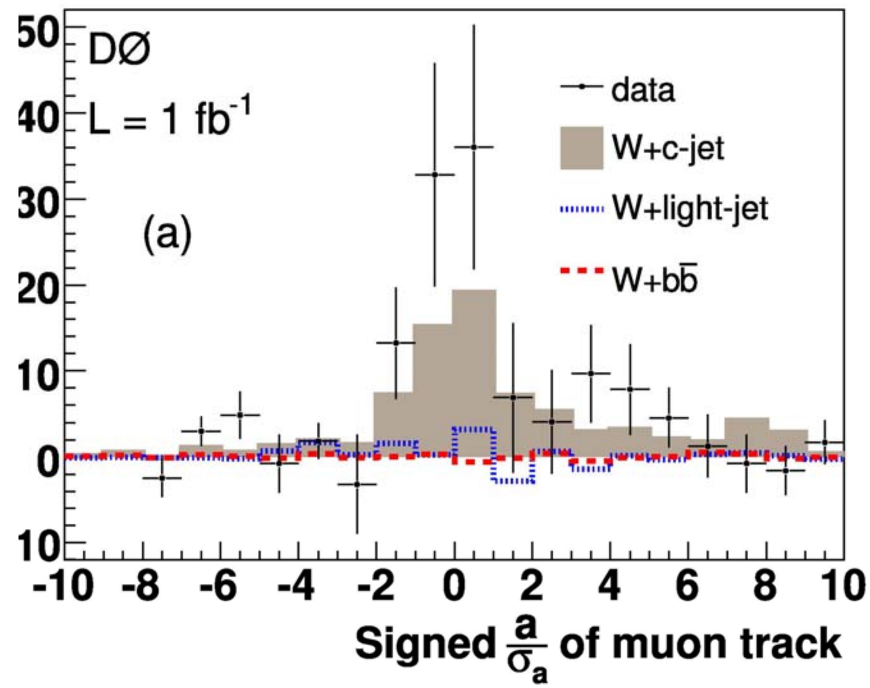
Event yields

	W→eν +jets			W→μν +jets		
Samples	before μ tag	OS	SS	before μ tag	OS	SS
W+c	4301.4 ± 27.3	58.7 ± 3.2	5.6 ± 0.9	2576.1 ± 18.9	32.3 ± 2.2	4.6 ± 0.8
W+cc	**2683.6 ± 13.4**	**15.8 ± 1.1**	**14.6 ± 1.1**	**1623.4 ± 9.3**	**8.2 ± 0.7**	**6.2 ± 0.6**
W+bb	**1229.5 ± 5.7**	**24.5 ± 0.8**	**23.6 ± 0.8**	**728.2 ± 3.9**	**12.3 ± 0.5**	**12.6 ± 0.5**
W+j(udsg)	**71561.6 ± 112.2**	**97.4 ± 3.8**	**84.4 ± 3.4**	**45204.7 ± 79.8**	**60.8 ± 2.7**	**51.2 ± 2.5**
Z+j	**711.7 ± 12.1**	**0.9 ± 0.3**	**1.6 ± 0.5**	**2649.1 ± 21.1**	**12.2 ± 1.4**	**9.3 ± 1.2**
WW	**539.0 ± 3.7**	**6.2 ± 0.4**	**1.9 ± 0.2**	**417.7 ± 3.3**	**4.1 ± 0.3**	**1.2 ± 0.2**
ttbar	**213.5 ± 1.0**	**18.3 ± 0.3**	**15.9 ± 0.3**	**119.7 ± 0.7**	**9.2 ± 0.2**	**8.1 ± 0.2**
single-top	**111.9 ± 0.3**	**6.3 ± 0.1**	**4.6 ± 0.1**	**75.7 ± 0.3**	**4.2 ± 0.1**	**3.0 ± 0.1**
Multi-jet	**2650 ± 64**	**13.3 ± 2.3**	**19.3 ± 2.9**	**2360 ± 178**	**12.2 ± 4.6**	**8.8 ± 5.4**
Background	79588.9 ± 130.6	176.3 ± 5.2	161.4 ± 4.7	53102.8 ± 196.5	118.9 ± 5.6	97.4 ± 6.1
Sig+BKD	**83890.3 ± 124.7**	**235.0 ± 6.1**	**167.0 ± 4.8**	**55678.9 ± 197.4**	**198.5 ± 6.0**	**102.0 ± 6.2**
Data	**82747**	**245**	**154**	**57944**	**203**	**122**

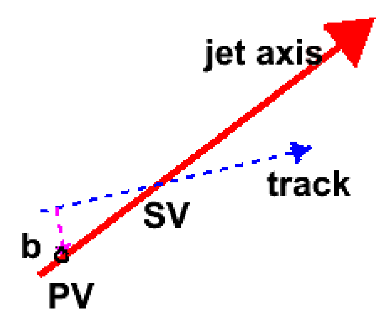
Consistency for the *c*-jet

arXiv:0803.2259v1 [hep-ex]

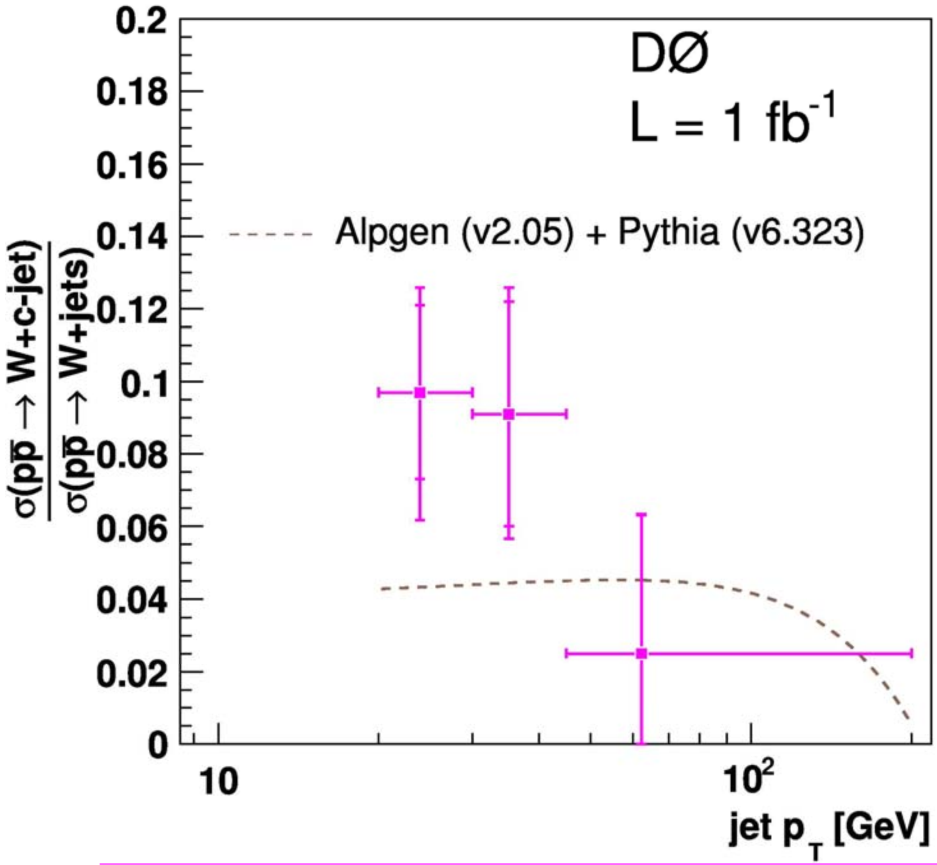




- **background-subtracted data favors the shape for the charm jet variables**
- **b-jet contamination is small**
- **light-jet contribution is indeed subtracted out**



Results



- jet pT is corrected to the particle level
- measurement compared with the theory
  - ALPGEN: for tree level matrix element calculation
  - PYTHIA: for parton shower
  - uncertainty due to CTEQ 6.5M PDFs is 6.6%

integrated over all p_T /all bins with $|\eta| < 2.5$

0.074 ± 0.019 (stat.) + 0.012 -0.014 (syst.)

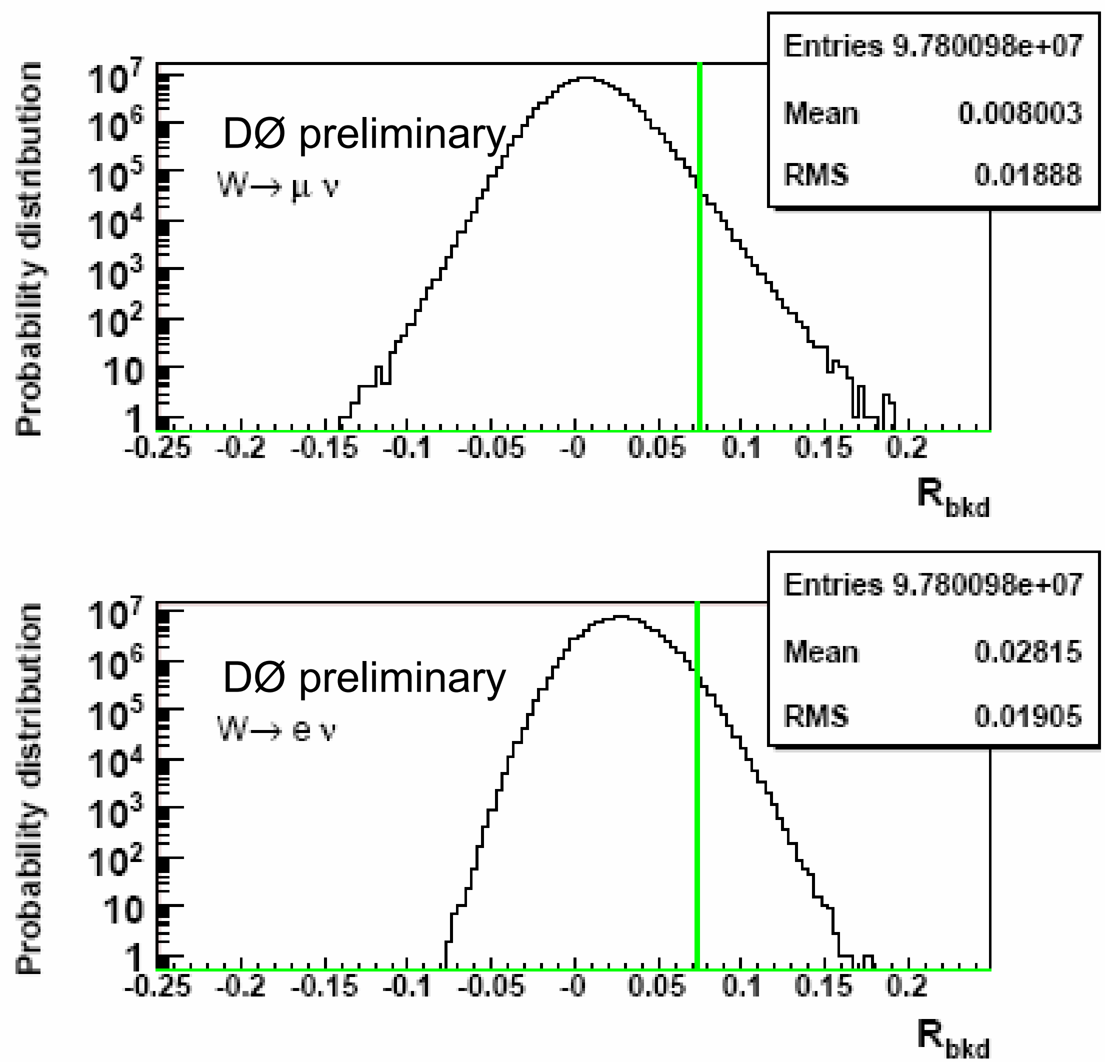
no significant deviation from the LO theoretical prediction

Ratio of data to MC prediction (LO)
- "K"=1.68+/- 0.54

- recently submitted to
  - Physics Letters B
  - arXiv:0803.2259v1 [hep-ex]
  - Fermilab-Pub-08/062-E
- CDF's recently published result:
  - Phys. Rev. Lett. 100, 091803, 2008

Significance of the result

- **follow Bayesian approach**
- **include all systematic uncertainties and their correlations**
- **ensemble test for null hypothesis**
  - **probability that background fluctuations could produce equal to greater than the observed signal rate**
- **$2.5 \times 10^{-4} \rightarrow 3.5\sigma$ significance**



Summary & Outlook

- Measurements of Z+jets and W+jets are being updated, from the first low statistics measurements.
- The measurement of $\sigma(W+c\text{-jet})/\sigma(W+\text{jets})$ ratio provides a probe of the strange quark inside proton and is a test of perturbative QCD and electroweak predictions
- We find agreement within uncertainties with
  - the LO perturbative QCD predictions
  - the s quark evolved from the Q^2 scale that is two orders of magnitude below that of this measurement
- Direct evidence for the quark-gluon interactions that will be more important at the CERN LHC collider
- The DØ detector is operating well, already have ~3 fb^{-1} of data on tape, expected to reach 6 – 9 fb^{-1} by the end of 2009.
- The precision of the measurement can be improved to less than 10% with 6 fb^{-1} of data