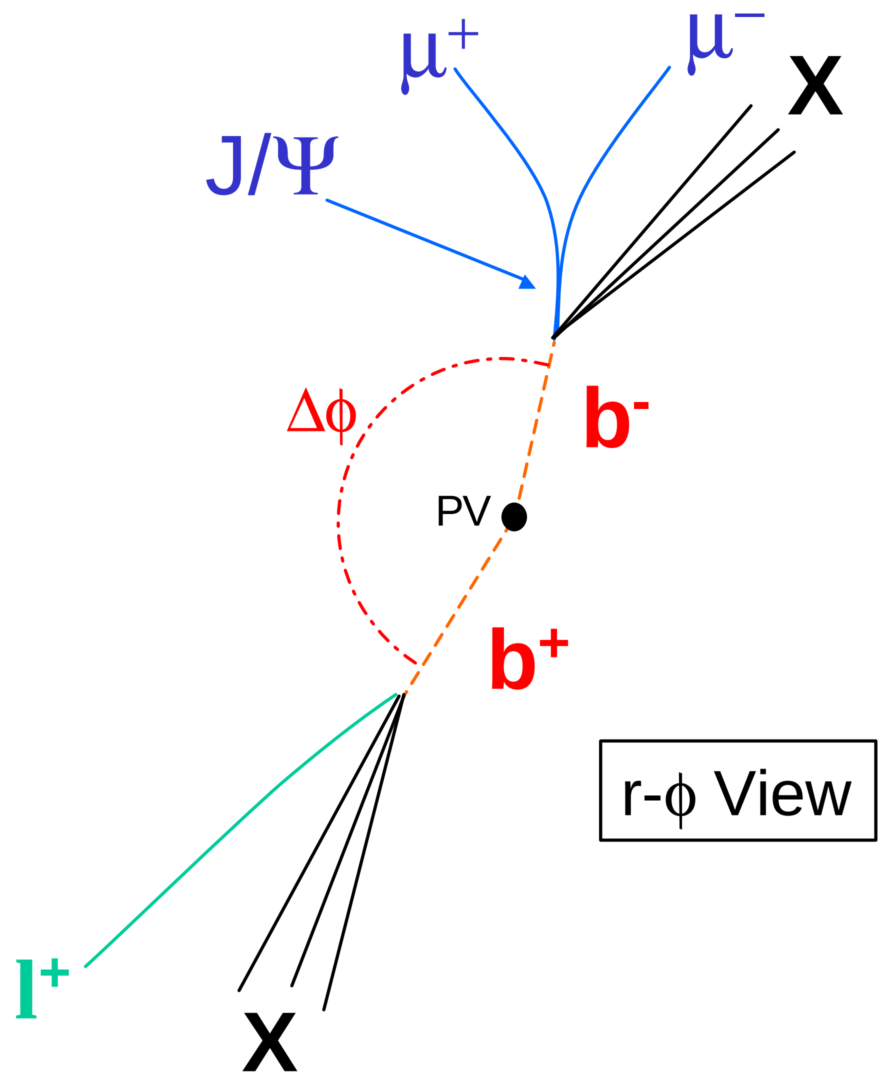
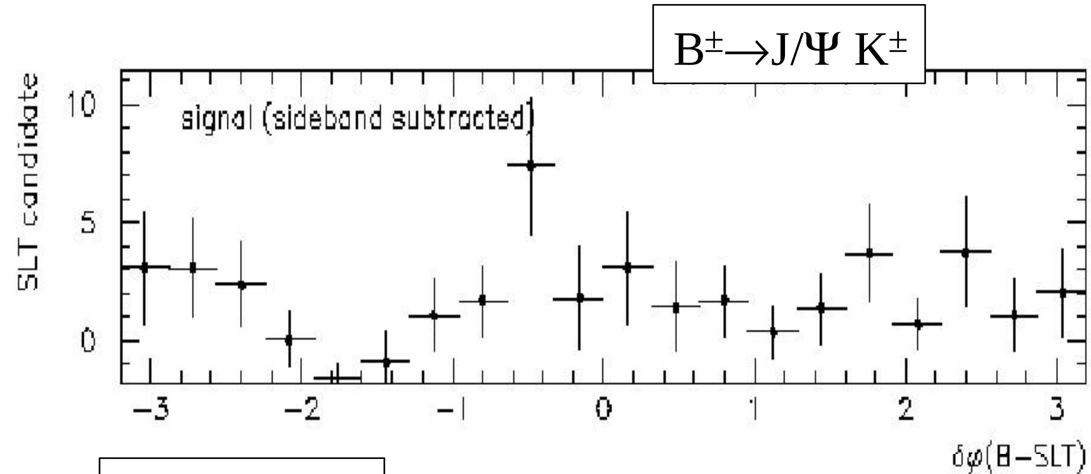
Introduction

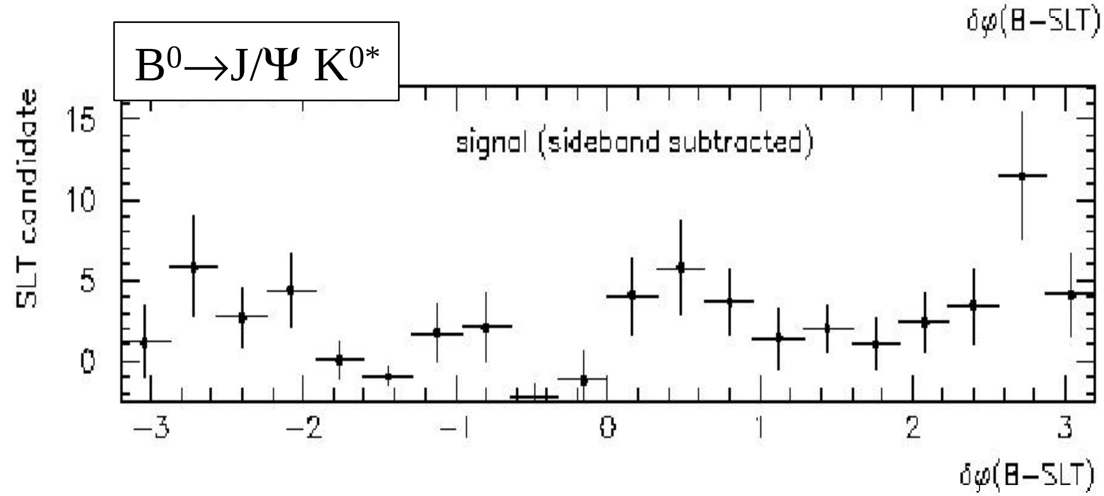
- Measurement of fraction of bottom quark pairs produced in the same hemisphere in ϕ
  - $\rightarrow f_{towards}$
- Study uses sample where one bottom decays into a J/Ψ and the other bottom decays into a SLT electron or CMUP muon
  - $\rightarrow$ Measures number of bottom quark pairs by fitting $c\tau$ of the J/Ψ and d_0 of the additional lepton simultaneously using an unbinned log-likelihood
- Try to study relative rates of the different bottom quark production mechanisms using angular correlations ($\Delta\phi$) between bottom quarks



Motivation (1)

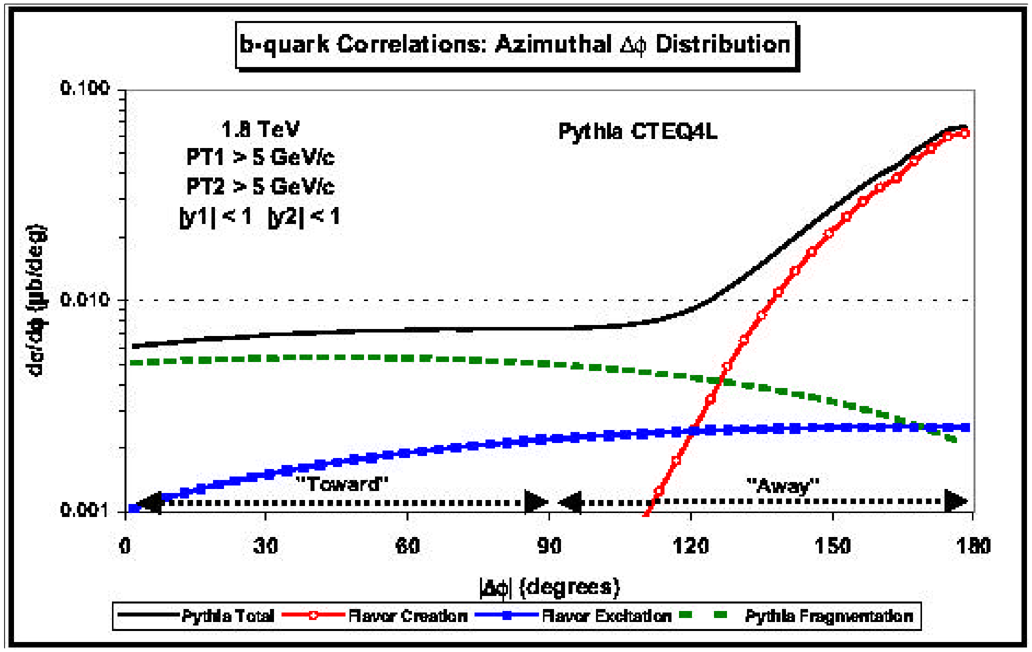
- Sin(2β) studies had large fraction of lepton flavor tags in same hemisphere as fully reconstructed bottom decays in the azimuthal angle.
  - → Δϕ not consistent with simulation
- This study was undertaken to better understand location of flavor tags for Run II measurements





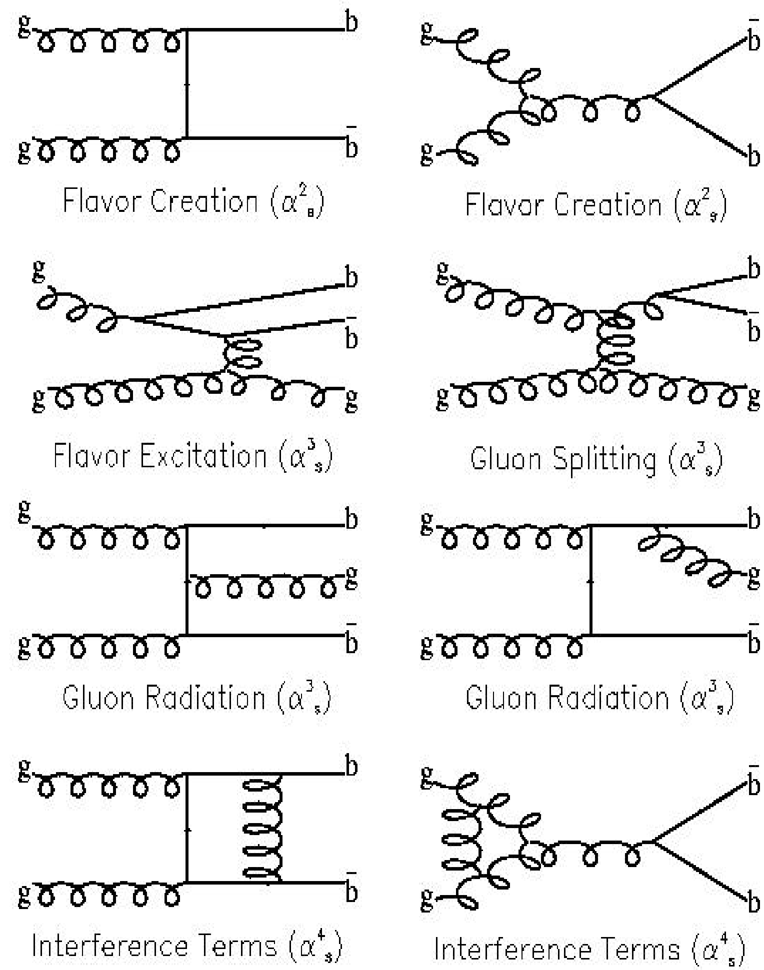
Motivation (2)

- At low ΔΦ between the bottom quarks, gluon splitting and flavor excitation separate from flavor creation
  - → No ΔΦ cut between J/Ψ and lepton necessary
    - – Only $B_c \rightarrow J/\Psi\ l\ X$ and $b \rightarrow J/\Psi\ l_{fake}\ X$ produce candidates from same bottom decay
- Measurement of angular correlations can be used to tune leading-log generators
  - → Pythia, Herwig, Isajet, …



Production Mechanisms

- Bottom production proceeds through three categories of diagrams in perturbative calculations
  - → Flavor creation
    - – 2 bottom quarks final state in hard scatter (showering MC)
  - → Flavor excitation
    - – 1 bottom quark in initial and final state in hard scatter (showering MC)
  - → Gluon splitting
    - – No bottom quarks in initial or final state in hard scatter (showering MC)
    - – Also known as shower/fragmentation
- In showering Monte Carlos, mechanisms generated separately and added

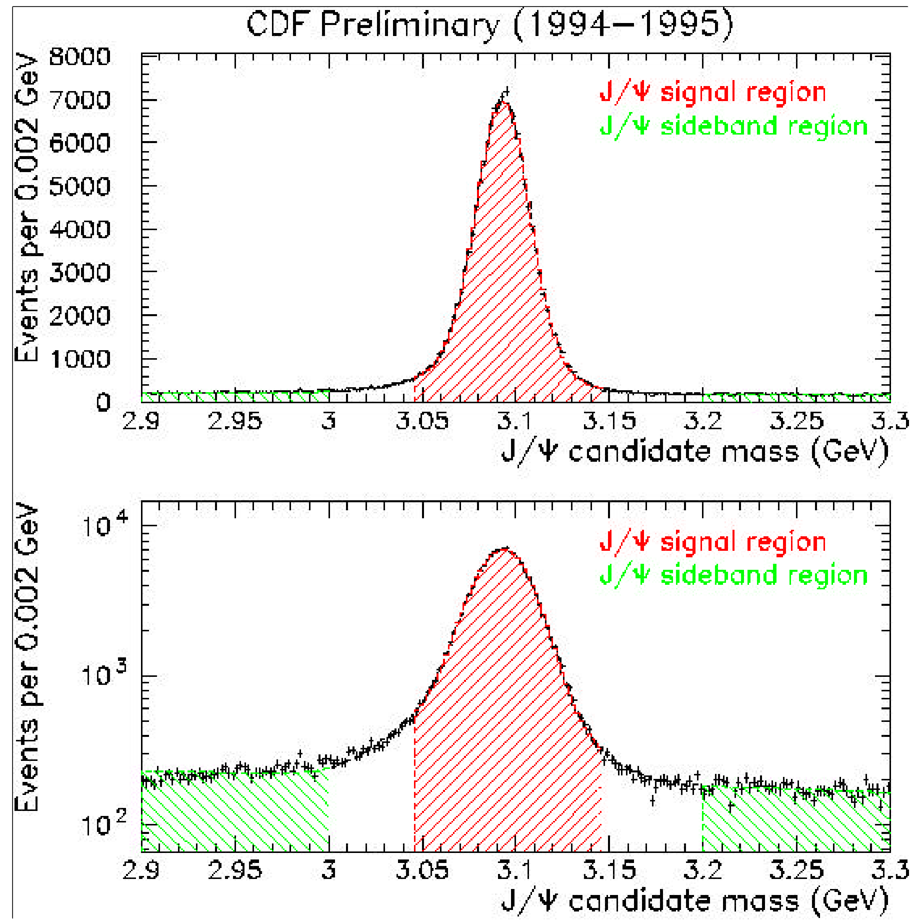


J/Ψ Selection

- Search for J/Ψ in low p_T di-muon triggers
- Muons pass a trigger
- Muons pass p_T requirement
  - → Varies with trigger
- Vertex χ^2 probability>1%
- Good χ^2 match of tracks to muon chambers
  - → $\chi^2 < 9$ (r-ϕ)
  - → $\chi^2 < 12$ (r-z)
- Tight track quality
  - → Both stereo, axial hits in drift chamber (CTC)
  - → At least 3 of 4 silicon layers (SVX') with hits
- $2.9 < M_{J/\Psi} < 3.2$
  - → Signal region
    - – $|M_{PDG} - M_{J/\Psi}| < 50$ MeV
  - → Sidebands
    - – $2.9 < M_{J/\Psi} < 3.0$
    - – $3.1 < M_{J/\Psi} < 3.2$

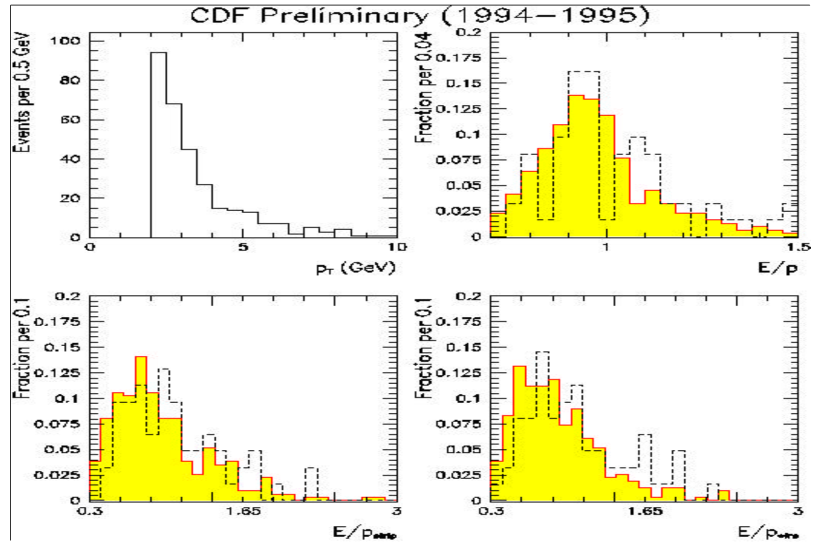
J/Ψ Candidates

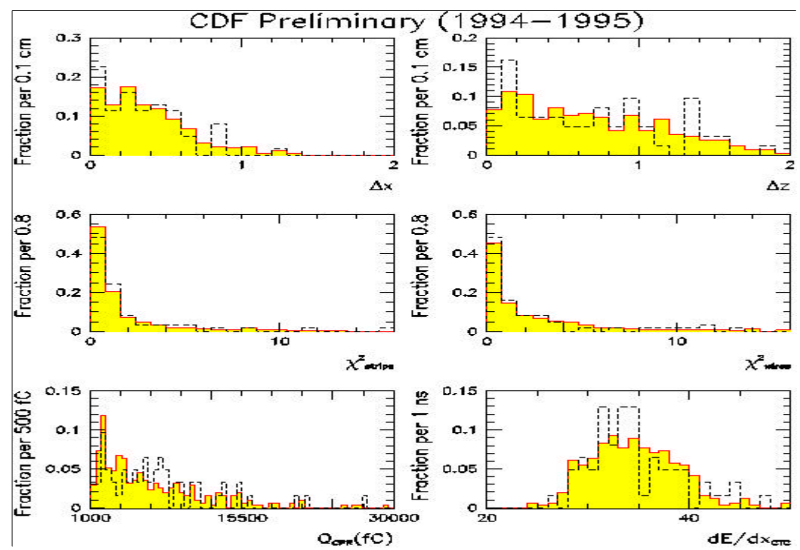
- 177650 pass selection
- Fit with signal + sideband
  - → Signal 2 G(x,σ)
  - → Sideband 1st order polynomial
    - – 2nd order polynomial used as a systematic check of shape assumption
- R_{side}=0.501 ± 0.000043 (stat) ±0.044 (syst)
  - → Ratio of random track combinations in J/Ψ mass signal vs sideband region



SLT Electron Selection

- Standard SLT electron selection except:
  - → Sliding dE/dx cuts
    - – Same as B_c discovery
  - → Quality Track
    - – Both stereo, axial hits in CTC
    - – 3+ SVX hits
- $p_T > 2$ GeV/c
- Conversion removal
  - → 15 candidates vetoed in J/Ψ mass signal region
- 312 candidates found in J/Ψ mass signal region
  - → 107 Towards ($\Delta\phi<\pi/2$)
  - → 205 Away ($\Delta\phi>\pi/2$)
- 92 candidates found in J/Ψ mass sideband region
  - → 45 Towards ($\Delta\phi<\pi/2$)
  - → 47 Away ($\Delta\phi>\pi/2$)



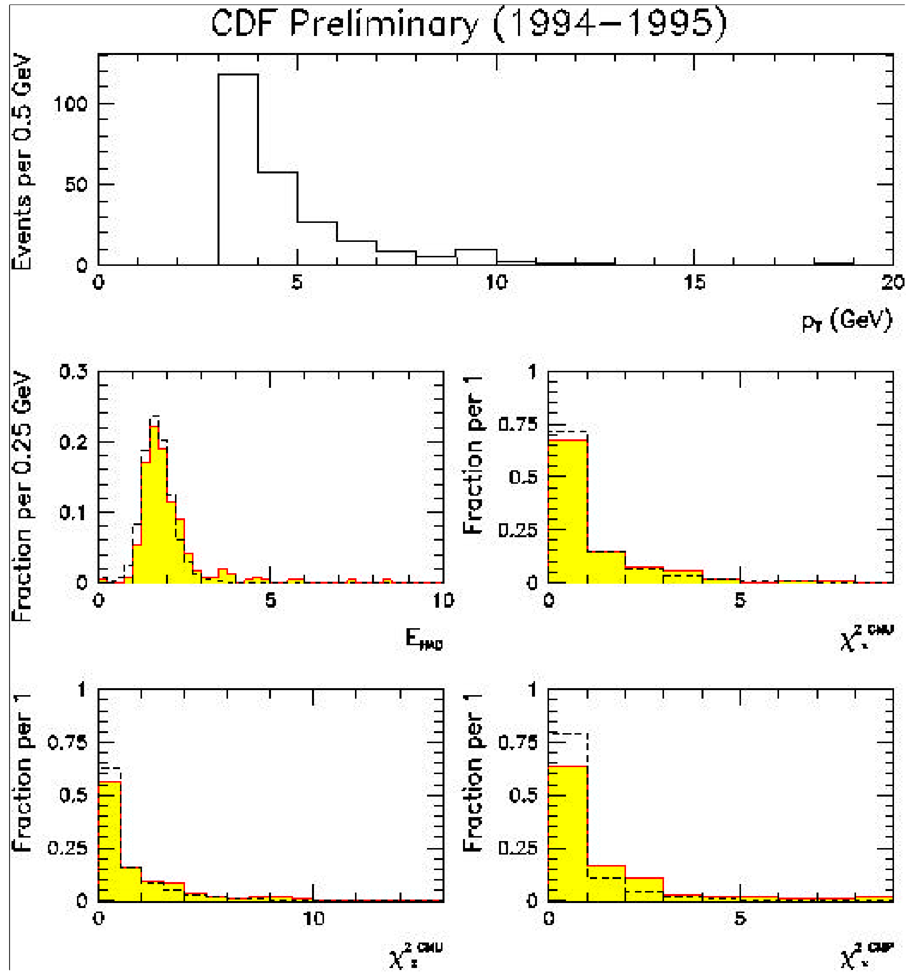


Black histograms-SLT electron candidates

Yellow histograms-Conversion electrons

SLT Muon Selection

- CMUP muon
  - → Same χ^2 requirements as J/Ψ muon
- Quality Track
  - → Both stereo, axial hits in CTC
  - → 3+ SVX hits
- $p_T > 3$ GeV/c
- 142 candidates found in J/Ψ mass signal region
  - → 64 Towards ($\Delta\phi<\pi/2$)
  - → 78 Away ($\Delta\phi>\pi/2$)
- 51 candidates found in J/Ψ mass sideband region
  - → 34 Towards ($\Delta\phi<\pi/2$)
  - → 17 Away ($\Delta\phi>\pi/2$)



Black histograms-SLT CMUP muon candidates

Yellow histograms-J/Ψ CMUP muons

Fit Description

- Binned unbinned extended log-likelihood
- Bin data in J/Ψ mass(signal/sideband) and $\Delta\phi$ (towards/away)
- Inputs to the fit are the measured impact parameter of SLT lepton and $c\tau$ of J/Ψ
- Fit uses impact parameter and lifetime templates in order to determine number of events from each source
- Fit includes external constraints
  - → Number of found conversion, estimated number of B_c events, etc.
  - → Constraints are in all capital letters, fit values in all in lower case
- Similar of B_c Discovery Fits
  - → CDF Note #3991
- Fit described in CDF Note #6263

Fit Description(2)

- Fit Breaks Up Into 3 Components
  - → Global Constraints
    - – Ratios of residual/found conversions, sideband/signal region for J/Ψ background
  - → Bin Constraints
    - – Number of sideband, signal, conversion events measured
    - – Estimated number of B_c, b→J/Ψ l_{fake} X events
  - → Shape
    - – Impact parameter and cτ distributions for each of the event sources

$$L = (\text{Global Constraints}) \prod_{i}^{\text{towards,away}} \left[(\text{Bin Constraints})_i \prod_{j}^{Nj} (\text{shape}_i(d_{0j}, ct_j)) \right]$$

Event Sources

Impact parameter and pseudo-cτ uncorrelated

- J/Ψ
  - → Bottom Decay
  - → Direct J/Ψ
  - → Sideband
- Additional Lepton
  - → Direct Fake Lepton
  - → Bottom Decay
    - – Includes sequential charm
  - → Candidate with J/Ψ candidate in mass sideband
  - → Conversions (electrons)

Impact parameter and pseudo-cτ correlated

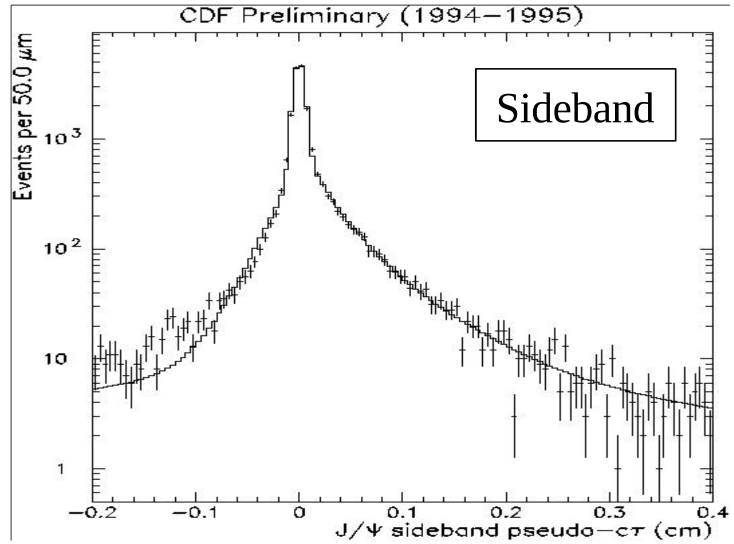
- Occurs when J/Ψ and leptons originate from the same displaced vertex
  - → $B_c \rightarrow J/\Psi\ l\ X$
  - → $b \rightarrow J/\Psi\ l_{fake}\ X$

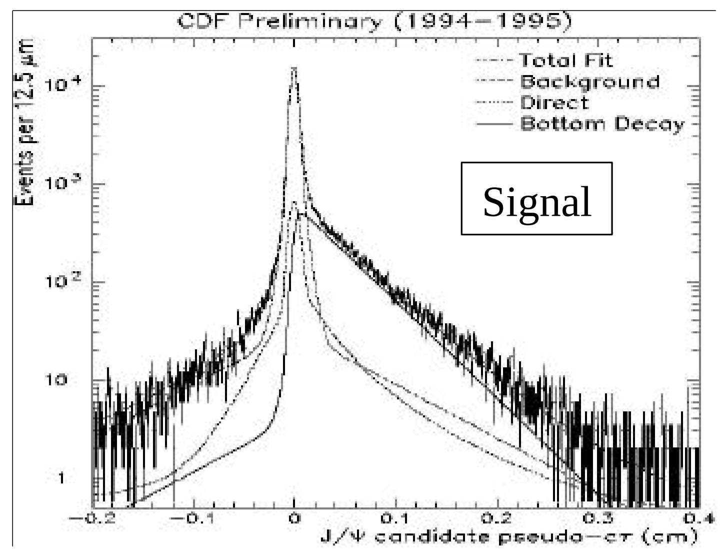
Event Sources (2)

- Uncorrelated
  - → J/Ψ from bottom decay- Lepton from bottom decay (n_{bb})
  - → J/Ψ from bottom decay- Direct lepton (n_{bd})
  - → J/Ψ from bottom decay- Conversion electron
  - → Direct J/Ψ- Direct lepton (n_{dd})
  - → Direct J/Ψ- Conversion electron
  - → Events with J/Ψ candidate in mass sideband (n_{side})
    - – Direct J/Ψ- Lepton from bottom decay (n_{db}) is assumed to be small and set equal to zero.
- Correlated
  - → $B_c \to J/\Psi\ l\ X$ (n_{Bc})
  - → $b \to J/\Psi\ l_{fake}\ X$ (n_{Bfake})

J/Ψ cτ Fit

- Uncorrelated bottom and direct J/Ψ shapes determined by fit to entire Run 1B sample
  - → CDF Note #5029 (R. Cropp)
- Fit results
  - → 22150±270 Bottom
  - → $c\tau_B$=442±5 μm
  - → 16.6±0.2% Bottom
  - → CDF Note #3460 (H. Wenzel, D. Benjamin)
    - – 16.69±0.16% Bottom
    - – $c\tau_B$=452.4±4.6 μm
  - → CDF Note #5029 (R. Cropp)
    - – 17.62±0.16% Bottom
    - – $c\tau_B$=445.0±4.8 μm





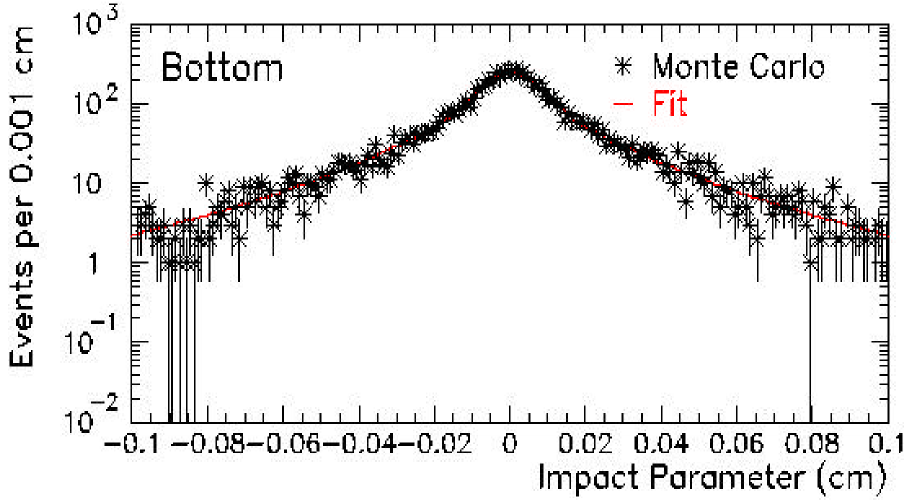
Bottom Impact Parameter Template

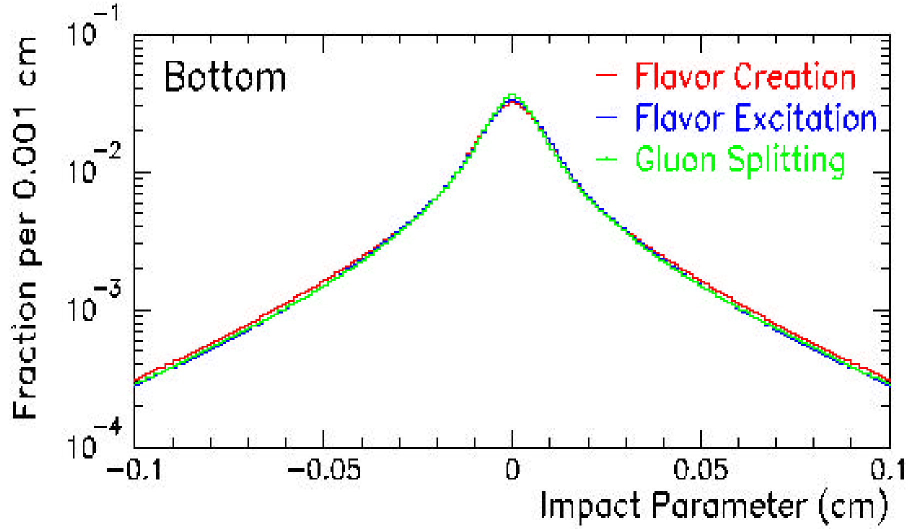
- Template fit to Monte Carlos
- Pythia 5.6 using CTEQ3L PDF
  - → Generate flavor creation, flavor excitation, and gluon splitting separately.
  - → Combined in Monte Carlos predicted ratio.
- b or $\overline{b}$ forced to decay to J/Ψ

- Event selection
  - → J/Ψ
    - DIMUTG
    - p_T same as data
    - Quality tracks
    - Vertex Probability >1%
    - J/Ψ mass signal region
  - → Additional lepton requirements are same as data except:
    - χ^2 requirement not applied to muons
    - CPR, CES, CTC dE/dx efficiencies applied using measured efficiencies

Bottom Impact Parameter Template

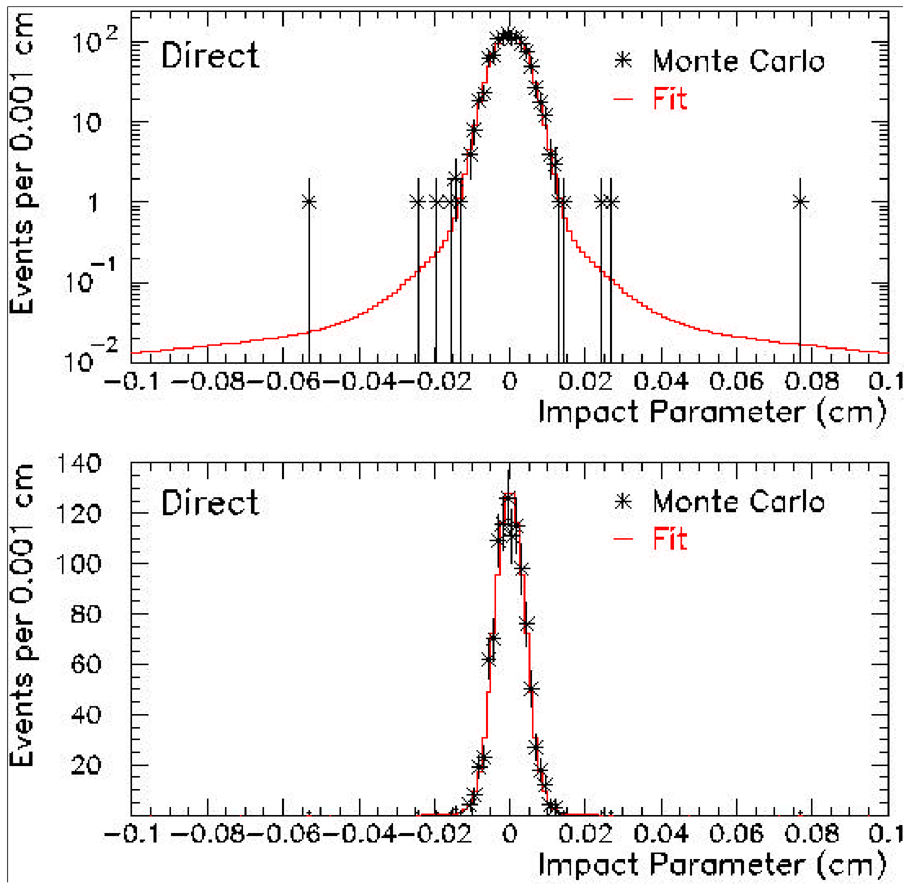
- The combined sample is fit to a function to include in unbinned likelihood fit
- Fits to individual mechanisms are very similar





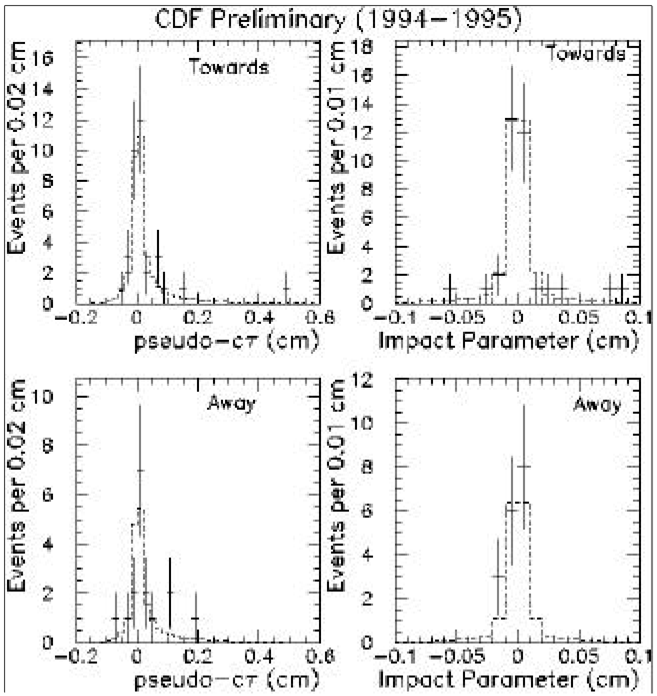
Direct Impact Parameter Template

- Direct template determined by Monte Carlos
  - → Heavy flavor background in jet samples has similar size/shape to tail in impact parameter resolution function
  - → Pythia 6.129+QFL'
    - – Lepton Fiducials
    - – p_T>3 GeV/c (muon)
    - – p_T>2 GeV/c (electron)
    - – Quality Track
- Monte Carlos fit to smooth function to include in unbinned log-likelihood fit

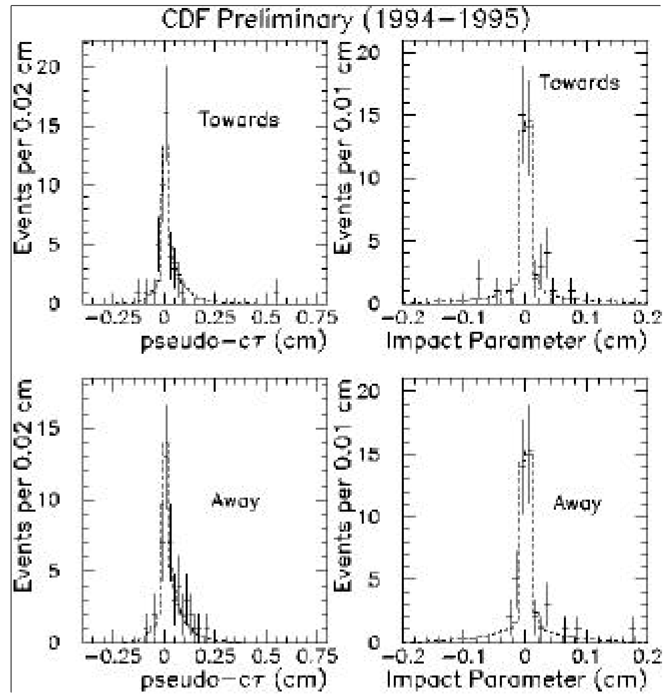


J/Ψ Sideband Templates

Muon



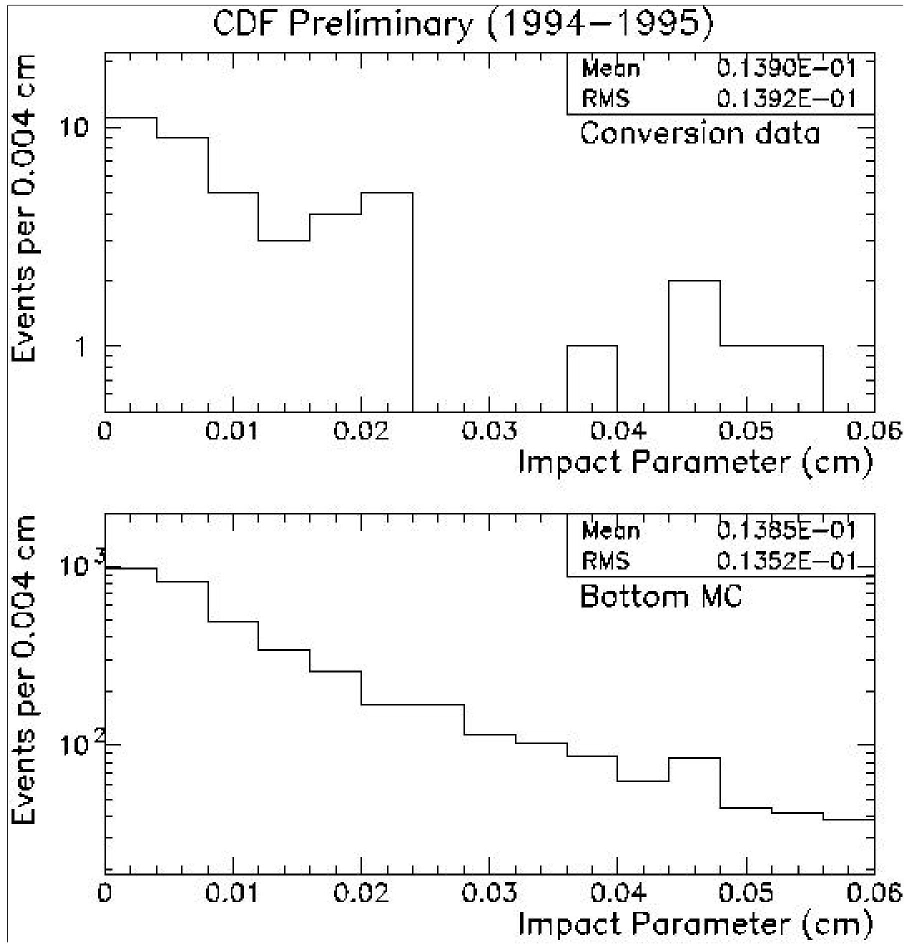
Electron



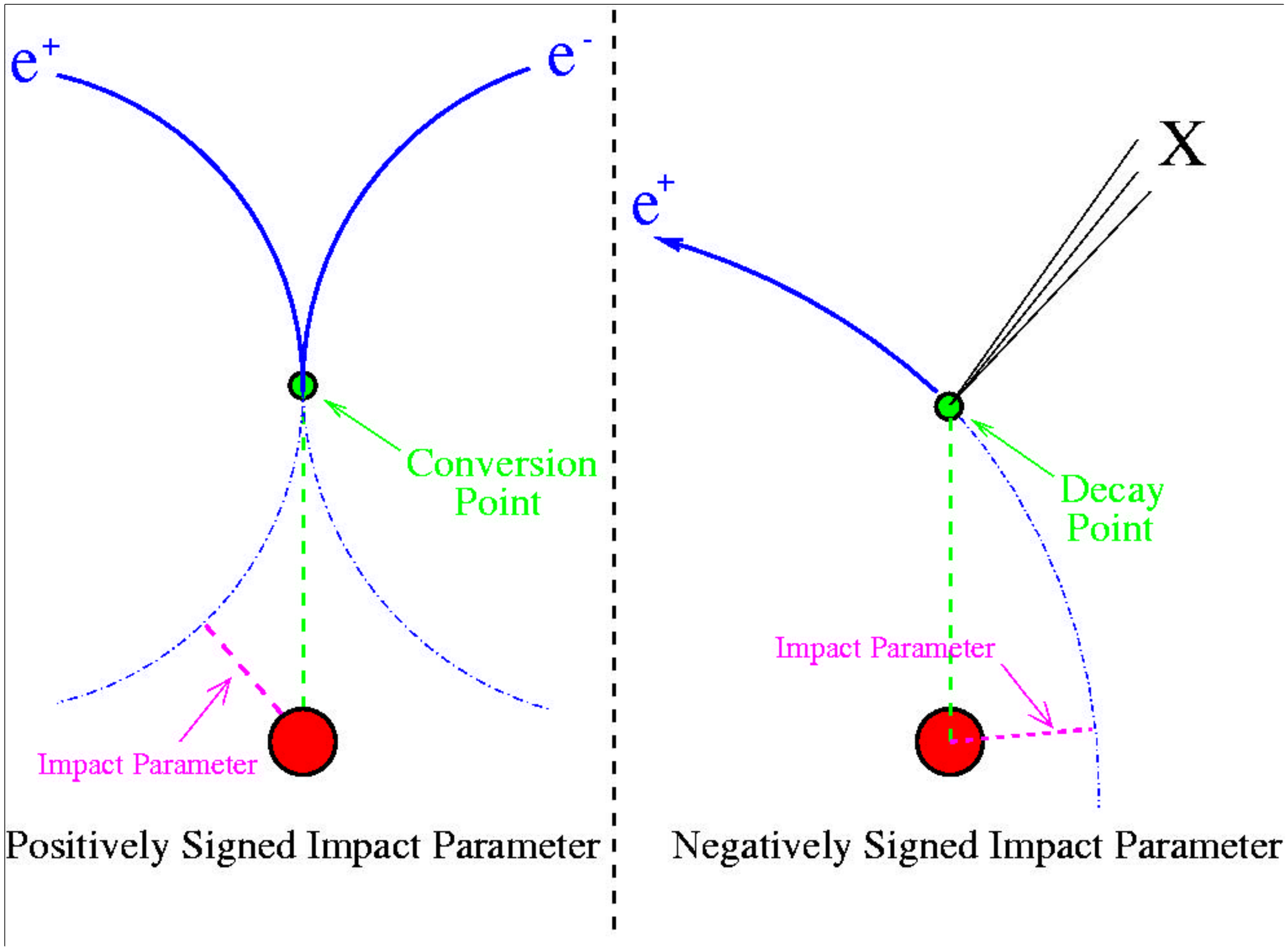
- The impact parameter-cτ shape used to describe events with J/Ψ in mass sidebands fit for using sideband data
  - → cτ and impact parameter fit independently
  - → In electron sample, conversion component added to fit

Conversions vs. Bottom

- Conversion candidates (with SVX hits) and electrons from bottom MC have very similar absolute impact parameter shapes
- Signed impact parameter such that majority of conversion have positive impact parameter (see next slide)
  - → Sign(C) d_0

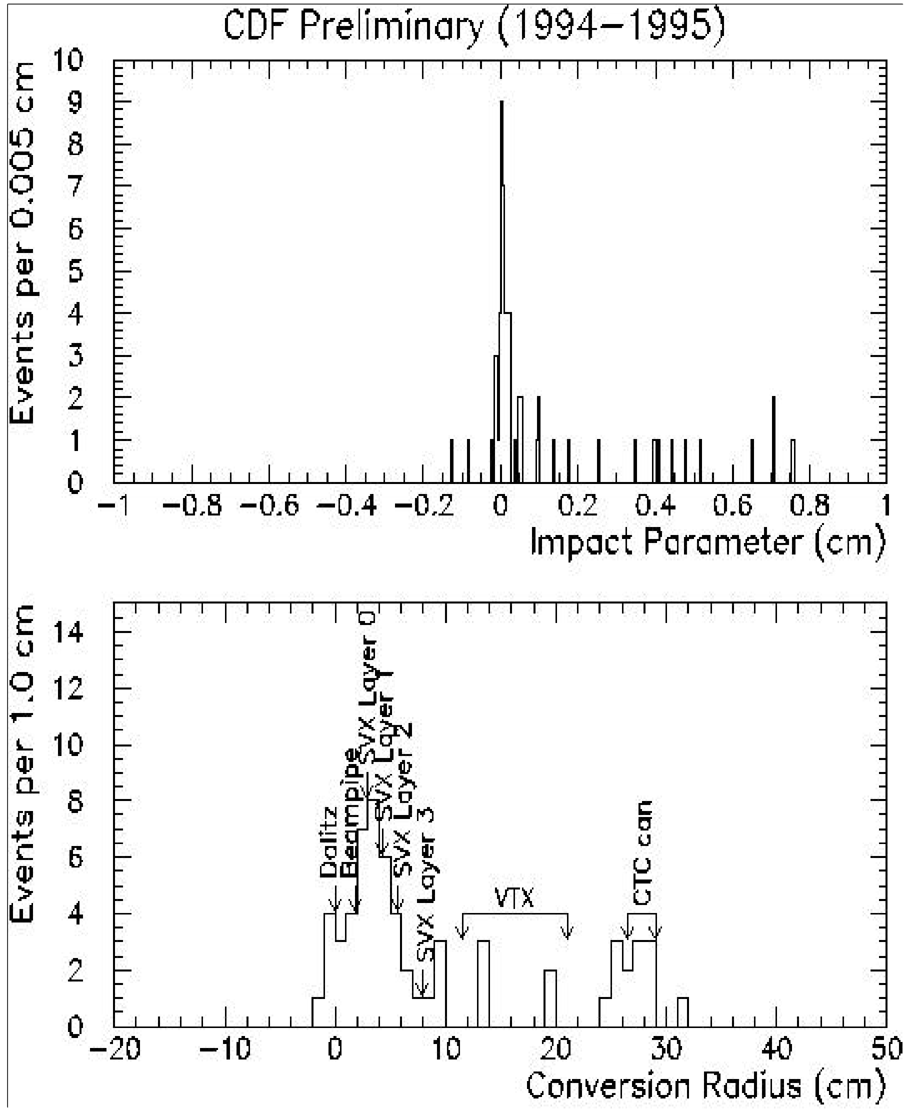


Impact Parameter Signing



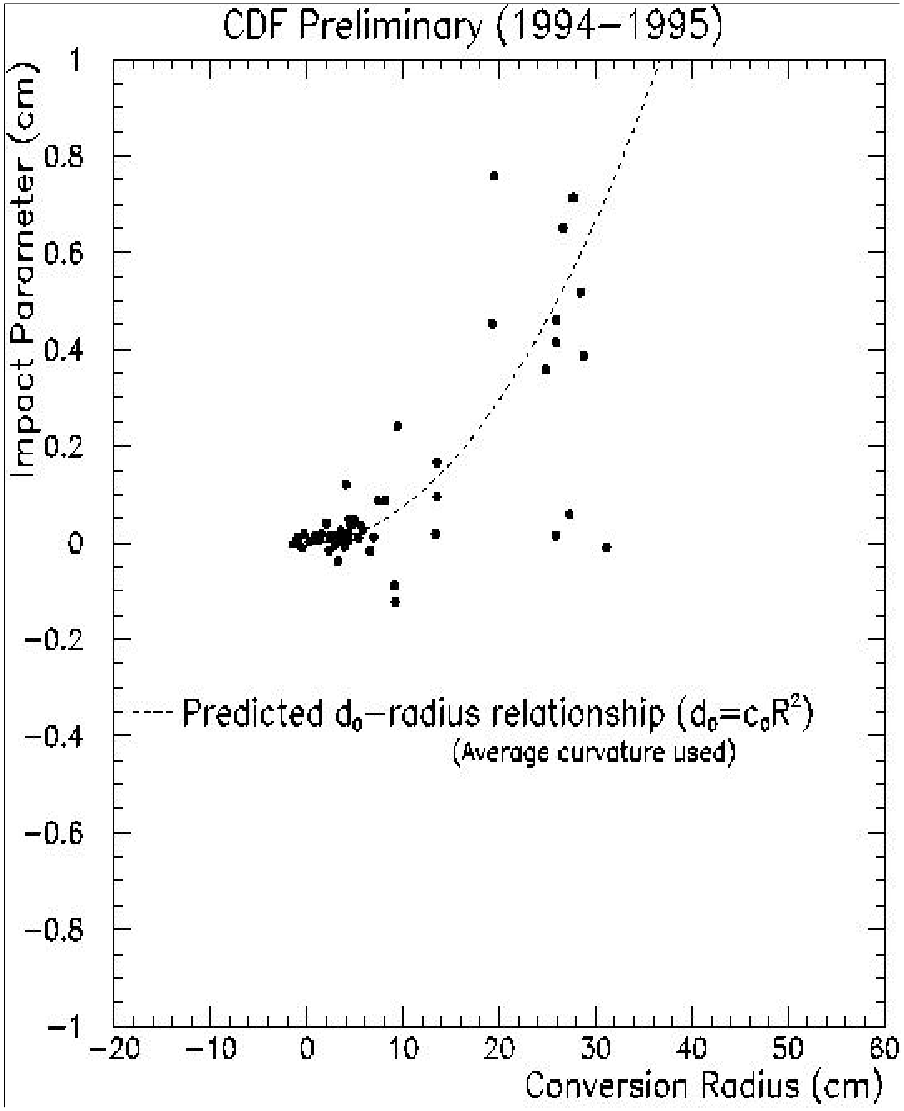
Conversion Sample (1)

- Conversion found in J/Ψ sample are mostly positively signed
  - → But large impact parameter tail and conversion radii outside of SVX layer 2
- How can 3 SVX hits be attached to theses tracks?
  - → Large impact parameter yields a higher SVX search road
  - → Higher false SVX hit attachment



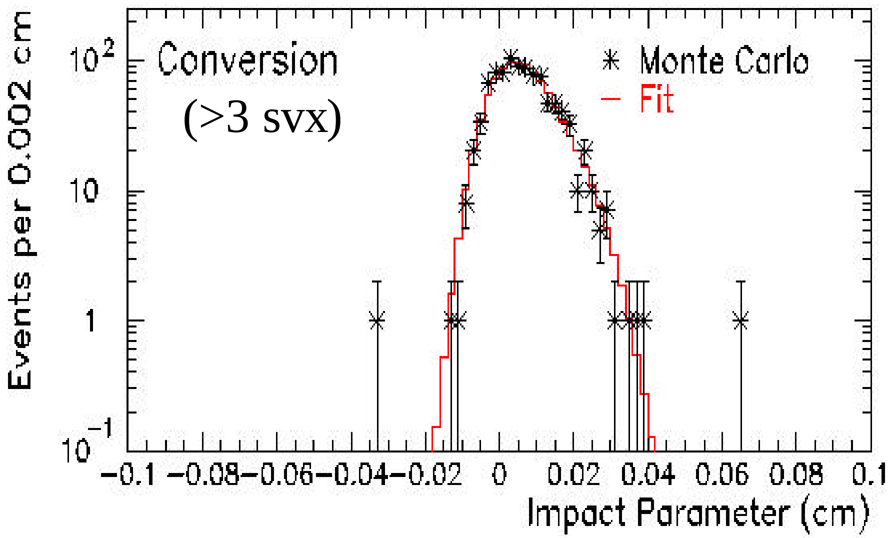
Conversion Sample (2)

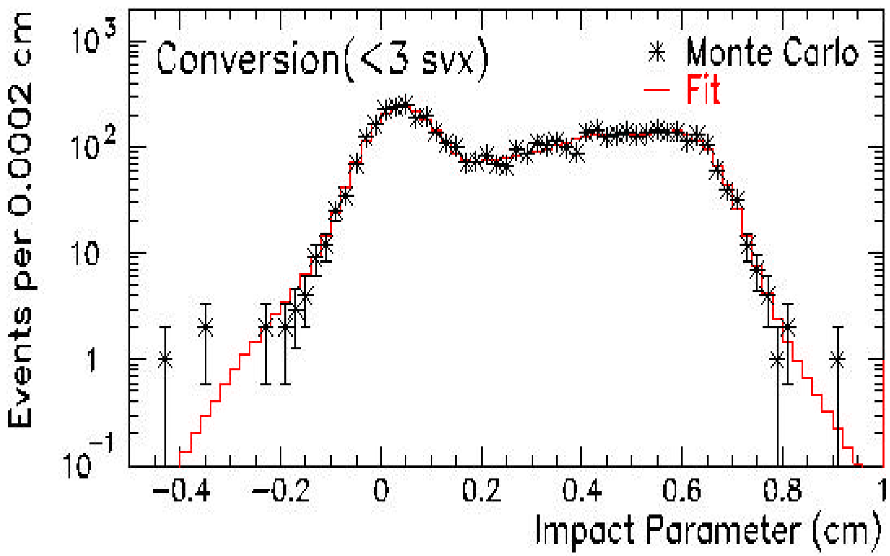
- Effect can be seen in conversion radius vs. impact parameter plot
  - → Conversion candidates have expected impact parameter-conversion radius relationship
  - → Larger scatter at high conversion radius because at least one SVX hit mis-attached
    - – Resolution closer to CTC only tracks



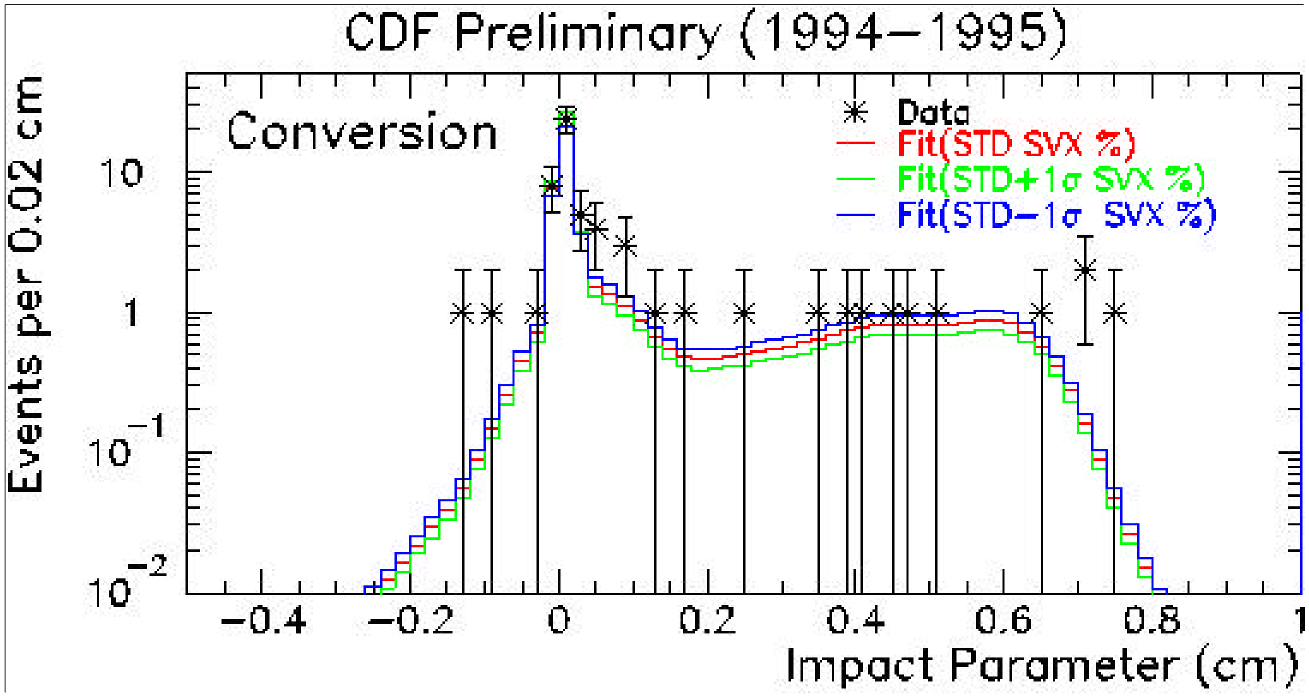
Conversion Impact Parameter Template

- Construct conversion impact parameter template from Monte Carlos
  - → Sample not large enough to measure from data directly
  - → Candidates with at least 3 SVX Hits
  - → Candidates with less than 3 SVX hits
- Relative amount of each component set by distribution of conversion radius seen in data
  - → Fraction of conversion candidates inside 6 cm in Monte Carlos matched to what is seen in data
    - – Fraction of two components varied within statistical errors in data to estimate systematic uncertainty due to low number of found conversion found in J/Ψ dataset





Conversion Impact Parameter Template



Constructed shape describes conversion impact parameter shape remarkably well

Residual Conversion Estimates

- Residual conversions assumed to be caused by inefficiency of tracking at low p_T and of conversion finding algorithm
  - →$\varepsilon_{cnv}(p_T)$ is tracking efficiency of softer conversion leg
  - →$\varepsilon_{cnv}(cut)$ is the efficiency of conversion selection criteria
- Ratio of residual/found conversions (R_{conv}) is:

$$R_{conv} = P_{cnv} \bullet (1/\ \varepsilon_{cnv}(p_T)/\ \varepsilon_{cnv}(cut) -1)$$

  - →P_{cnv} is the purity of the conversions removed
    - – Assumed to be 1.0
  - →R_{conv}=1.00±0.38
    - – Approximately 15 of 312 SLT electrons are conversions

B_c measurement had a R_{conv} of 1.06 ±0.36

$b \rightarrow J/\Psi\ l_{Fake}$ Background (1)

- Number of events with a bottom hadron decaying into a J/Ψ and a "fake" lepton
  - → Punch-thorough/decay-in-flight (Muons)
- Estimated using B_c analysis' fake lepton rates and techniques
  - → Bgenerator(NDE)+QFL'
  - → Details in CDF #5879 and #6263

- Decay-in-flight
  - → 9.9±2.4
    - – Using B_c Signal Cuts

      6.0±1.3 Predicted

      5.5±1.4 B_c Analysis
- Punch-through
  - → 1.76±0.88
    - – Using B_c Signal Cuts

      0.83 ±0.33 Predicted

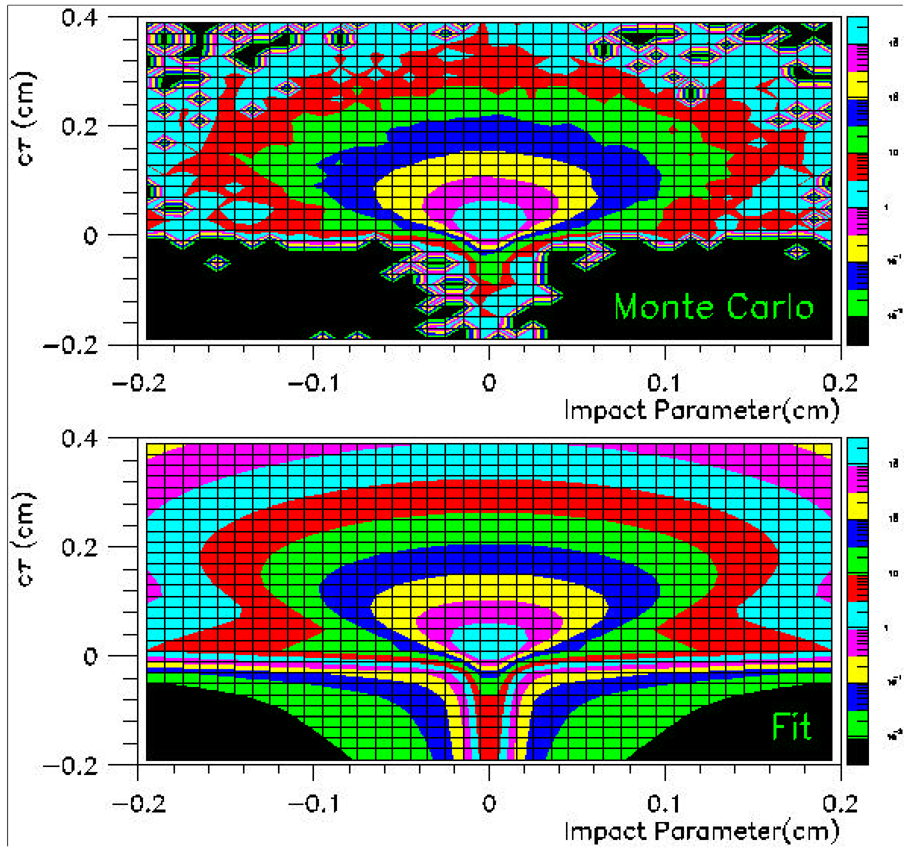
      0.88±0.35 B_c Analysis
- Fake electrons
  - → 2.85±0.75
    - – Using B_c Signal Cuts

      1.8 ±0.6 Predicted

      2.6±0.3 B_c Analysis

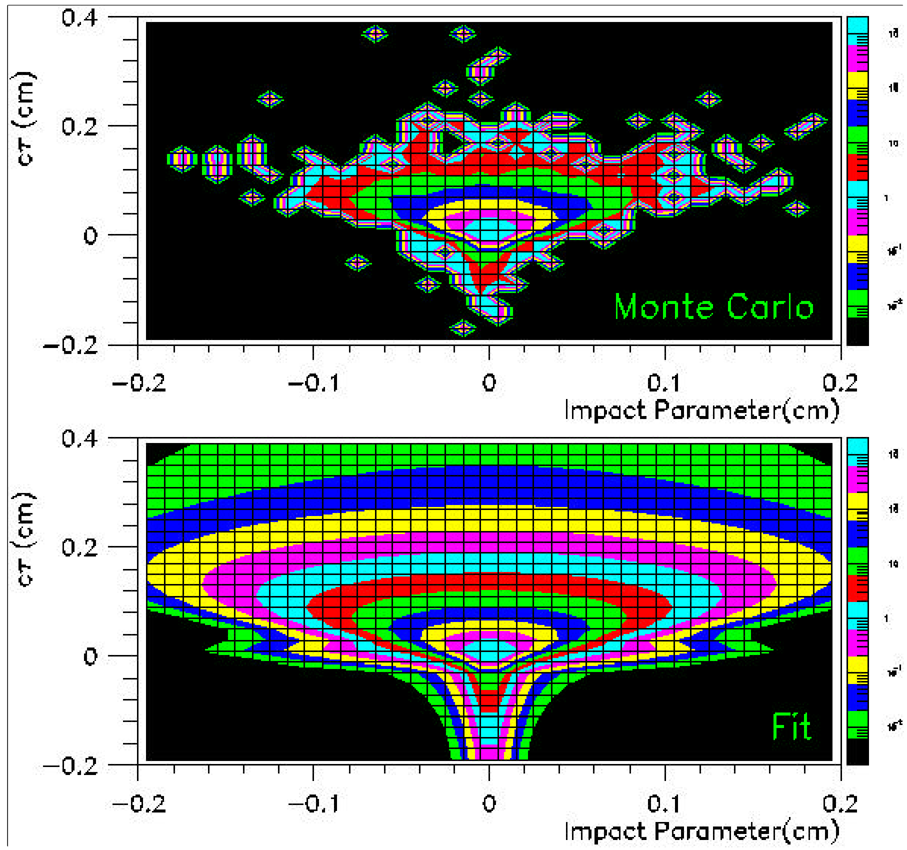
$b \to J/\Psi\ l_{Fake}$ Background

- Impact parameter-$c\tau$ shape determined by fit to NDE Monte Carlo
- Muons required to:
  - $\to p_T > 3$ GeV
  - $\to$ CMUP fiducial
    - – CWUSWM
  - $\to$ Quality Track
- Electrons required to:
  - $\to p_T > 2$ GeV
  - $\to$ Electron fiducial
  - $\to$ Quality Track

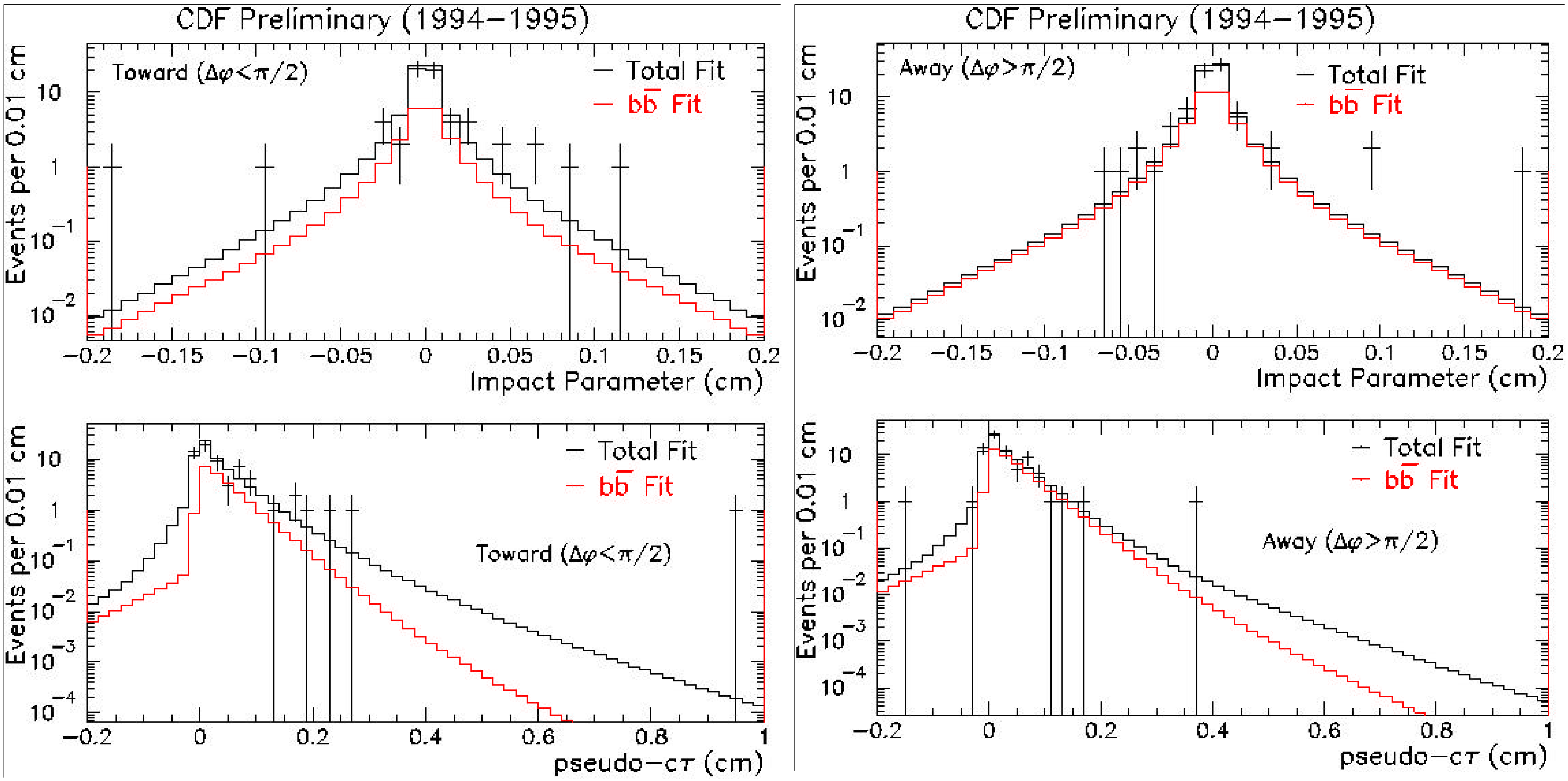


B_C $c\tau$-Impact Parameter Template

- Number of $B_c \rightarrow J/\Psi\ l\ X$ background (N_{Bc}) determined using published B_c cross section ratio and efficiencies and fit number of $B^+ \rightarrow J/\Psi\ K^+$
  - → See CDF #5879 & # 6263
  - → $N^{\mu}_{Bc}=7.2^{+2.6}_{-2.4}$
  - → $N^{e}_{Bc}=10.0^{+3.5}_{-3.3}$
- All B_c in towards bin
- Impact parameter-$c\tau$ shape determined using B_c fragmention Monte Carlos + QFL'.
  - → E. Braaten, et. al.



Fit Results (Muons)



$$f^{\mu}_{towards} = .345^{+0.092}_{-0.082}$$

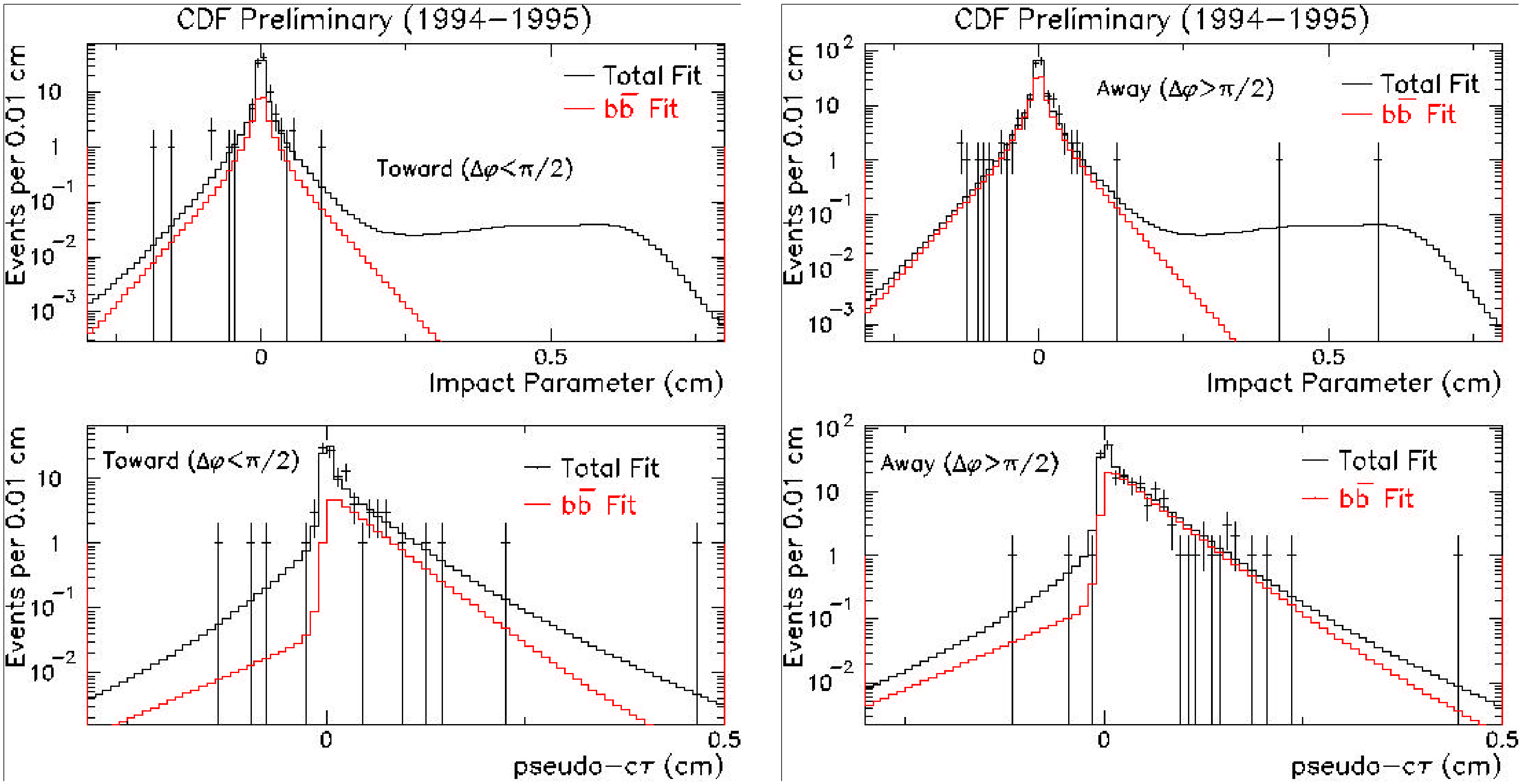
Fit Results (Muons)

CDF Preliminary (1994-1995)

Parameter	Fit Result
n_{bb}^{t}	$23.0^{+7.6}_{-6.9}$
n_{bd}^{t}	$1.6^{+4.6}_{-2.9}$
n_{dd}^{t}	$11.3^{+5.1}_{-4.5}$
n_{bb}^{a}	$43.6^{+10.2}_{-9.0}$
n_{bd}^{a}	$8.1^{+8.0}_{-7.5}$
n_{dd}^{a}	$16.0^{+5.5}_{-5.2}$

Parameter	Fit Result	Constraint
r_{side}	$0.501^{+0.04}_{-0.04}$	0.501 ± 0.044
n_{Bfake}	$10.7^{+2.5}_{-2.5}$	11.7 ± 2.6
n_{Bc}	$5.1^{+2.5}_{-2.5}$	$7.2^{+2.6}_{-2.4}$
n_{side}^{t}	$32.9^{+5.7}_{-5.1}$	34
n_{side}^{a}	$18.2^{+4.5}_{-3.9}$	17

Fit Results (Electrons)



$$f^{e}_{towards} = .192^{+0.065}_{-0.059}$$

Fit Results (Electrons)

CDF Preliminary (1994-1995)

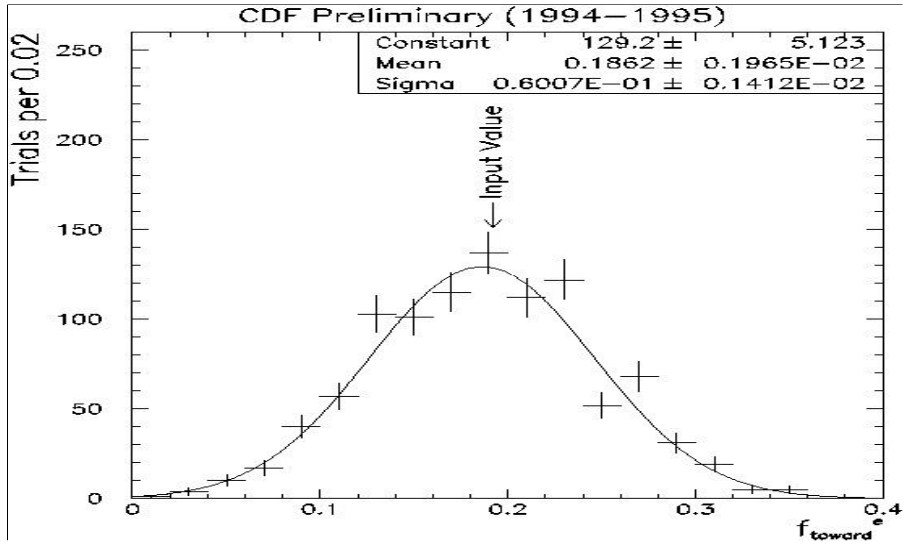
Parameter	Fit Result
n_{bb}^{t}	$29.6^{+11.7}_{-10.4}$
n_{bd}^{t}	$1.5^{+8.5}_{-8.1}$
n_{bconv}^{t}	0.6 (Constrained)
n_{dd}^{t}	$37.0^{+8.0}_{-7.3}$
n_{dconv}^{t}	$2.8^{+2.1}_{-1.7}$
n_{bb}^{a}	$124.7^{+17.9}_{-16.7}$
n_{bd}^{a}	$-1.4^{+12.5}_{-12.2}$
n_{bconv}^{a}	1.2 (Constrained)
n_{dd}^{a}	$49.5^{+9.2}_{-8.5}$
n_{dconv}^{a}	$6.0^{+2.6}_{-2.2}$

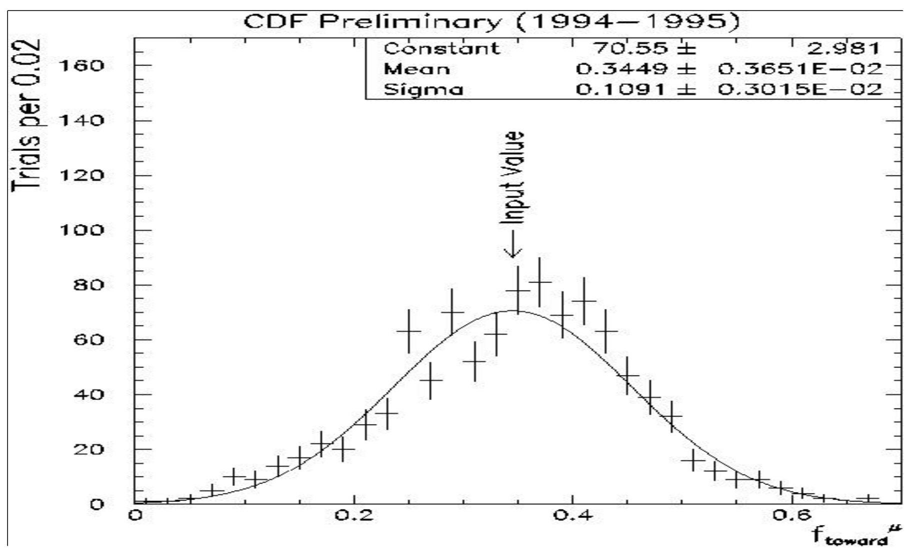
Parameter	Fit Result	Constraint
r_{side}	$0.504^{+0.04}_{-0.04}$	0.501 ± 0.044
r_{conv}	$0.99^{+0.31}_{-0.28}$	1.00 ± 0.38
n_{Bfake}	$2.8^{+0.7}_{-0.7}$	2.85 ± 0.75
n_{Bc}	$10.0^{+3.2}_{-3.3}$	$10.0^{+3.5}_{-3.3}$
$n_{convside}$	$8.9^{+2.9}_{-2.04}$	9
n_{side}^{t}	$45.4^{+6.9}_{-6.2}$	45
n_{side}^{a}	$47.6^{+7.1}_{-6.5}$	47

Constrained $n_{bconv}=0.20\ n_{dconv}$
(Ratio of J/Ψ from bottom/direct)

Toy Monte Carlos Studies (1)

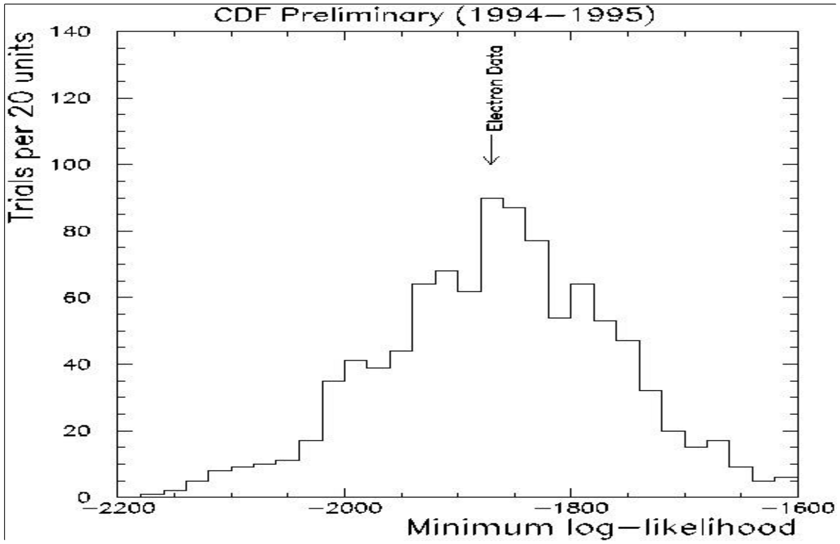
- 1000 Toy Monte Carlos samples made using assumed cτ-impact parameter shapes and with similar numbers as data
  - → Fitted results for all components has less than 0.1 (0.1) event bias and pulls of .95-1.08 (.94-1.05) for electrons (muons).
  - → The fitted f_{toward} consistent with input value and width of distribution consistent with the error returned from the fit of data

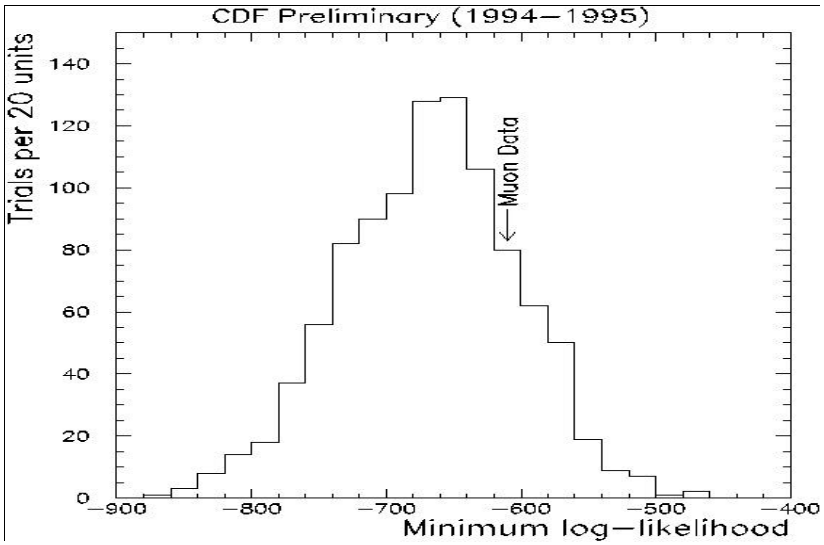




Toy Monte Carlos Studies (2)

- The fitted minimum of log-likelihood in data is also consistent with the distribution for the toy Monte Carlos assembles
  - → Electron: 50% of trials have a larger likelihood than data
  - → Muon: 20% of trials have a larger likelihood than data





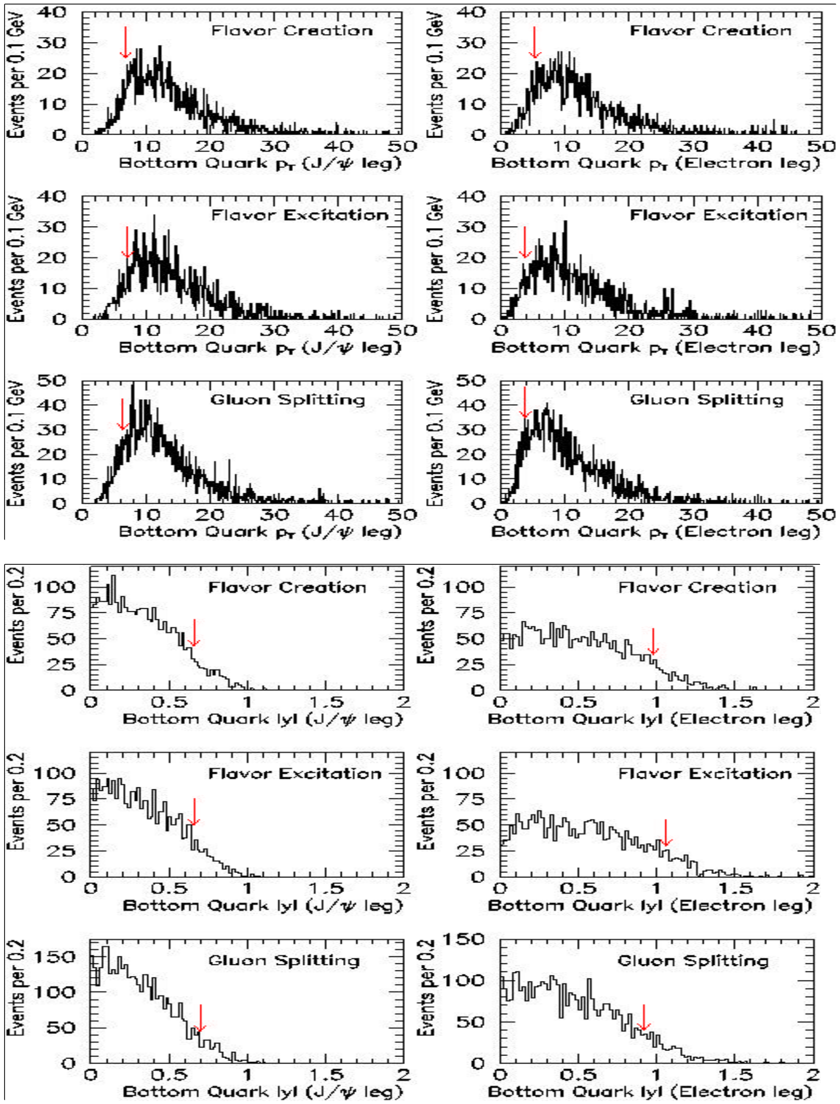
Fit Systematics

- Sequential fraction varied by ±19%
  - → As in μ–μ and μ-jet correlations papers
- Bottom lifetimes varied by ±1σ
- Λ_B fragmentation fraction varied by ±1σ
- Conversion shape varied
- f_{back} varied by ±1σ and J/Ψ shapes refit
- Fit re-done with $N_{db} \neq 0$
- $N_{dconv}=0$ or $N_{bconv}=0$ and refit
- Direct d_0 shape parameter varied by ±1σ and re-fit
  - → As in B_c lifetime analysis

	Electrons	Muons
Sequential Fraction	±0.001	±0.003
Bottom Lifetimes	±0.003	±0.022
Frag. Functions	±0.001	±0.002
Conversion d_0 Shape	±0.002	
f_{back} (J/Ψ shapes)	±0.0002	±0.0001
N_{db}	±0.001	±0.02
N_{dconv}/ N_{bconv}	±0.001	
Direct d_0 Shape	$^{+0.003}_{-0.004}$	$^{+0.074}_{-0.010}$
Total Fit Systematic	$^{+0.005}_{-0.006}$	$^{+0.080}_{-0.031}$

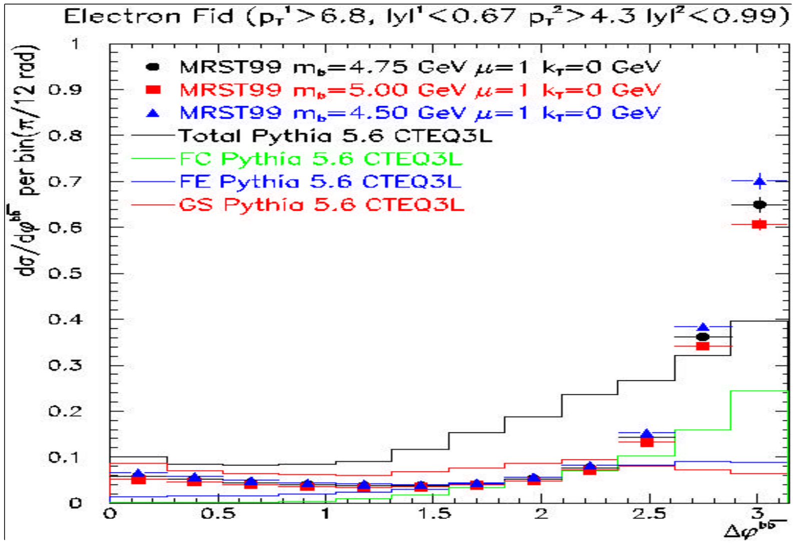
Correction of Data to Quark Level

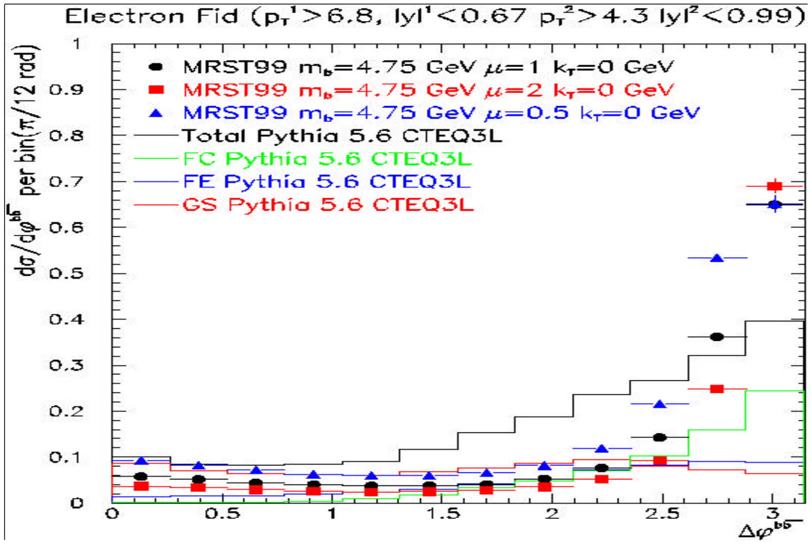
- To compare to theory predictions, the experimental measurement is corrected to the quark level
  - → The p_T and |y| in which 90% of Monte Carlos passing the selection criteria that have a smaller p_T (higher |y|) is found
  - → $f_{towards}$ of the Monte Carlos is measured with/without the addition requirements
  - → Ratio with/without cuts is the correction factor for B hadrons to partons
    - – As in B rapidity correlations & μ–μ correlation measurements
- The correction factor given by Monte Carlos combination of FC, FE, and GS is central value of correction used
  - → Maximum difference for one production mechanism from the average is used to estimate the systematic uncertainty in correction
- $C^{e}_{B\to b}$=0.967±0.019(stat)±0.088(syst)
- $C^{\mu}_{B\to b}$=0.968±0.026(stat)±0.061(syst)



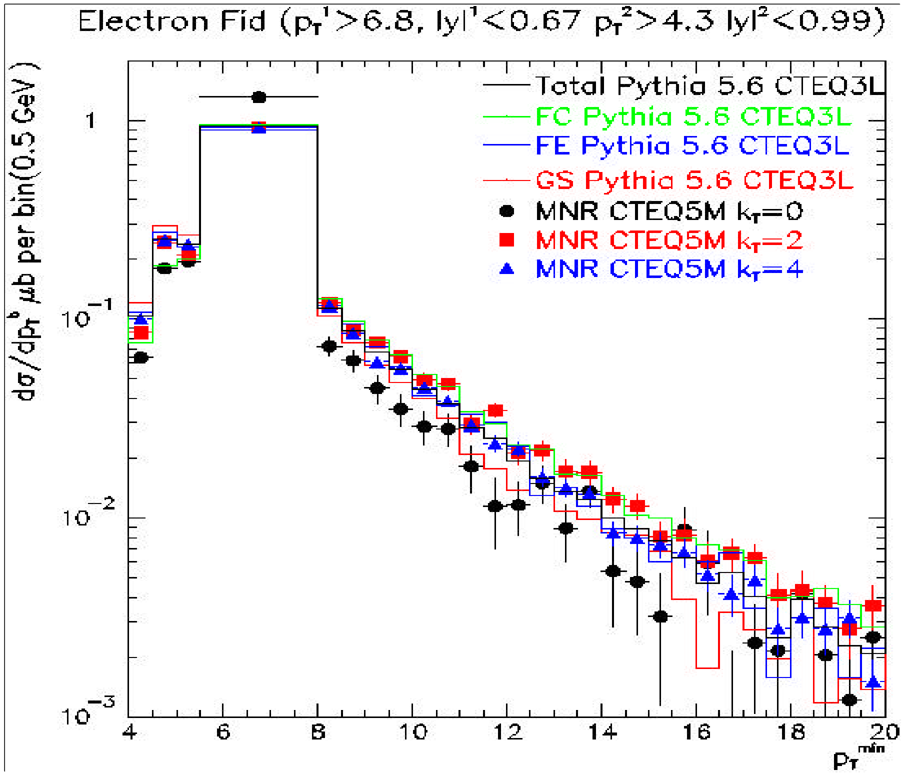
Theory Prediction

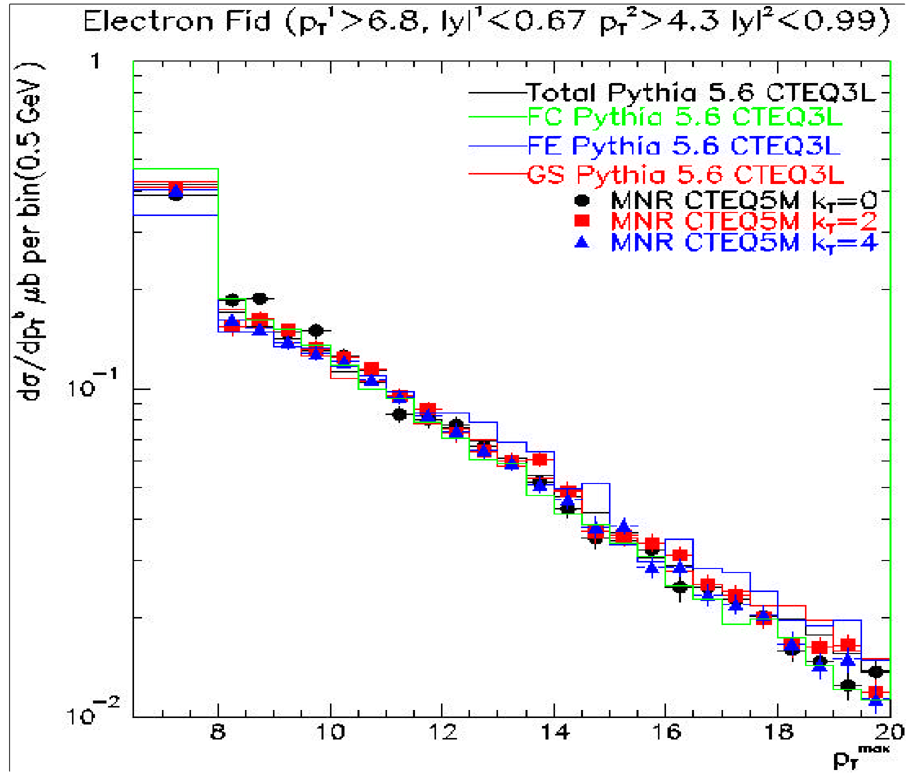
- NLO QCD predictions is made with MNR
  - → CTEQ5M and MRST99 used
  - → m_b is varied from 4.5-5.0 GeV
  - → Renormalization scale is varied between 0.5-2.0
- Effects of large initial state transverse momenta made by varying $\langle k_T \rangle$ between 0-4 GeV
  - → Implied is the same method as diphoton (CDF #4726), μ-b (CDF #3165), and μ–μ (CDF #3374)





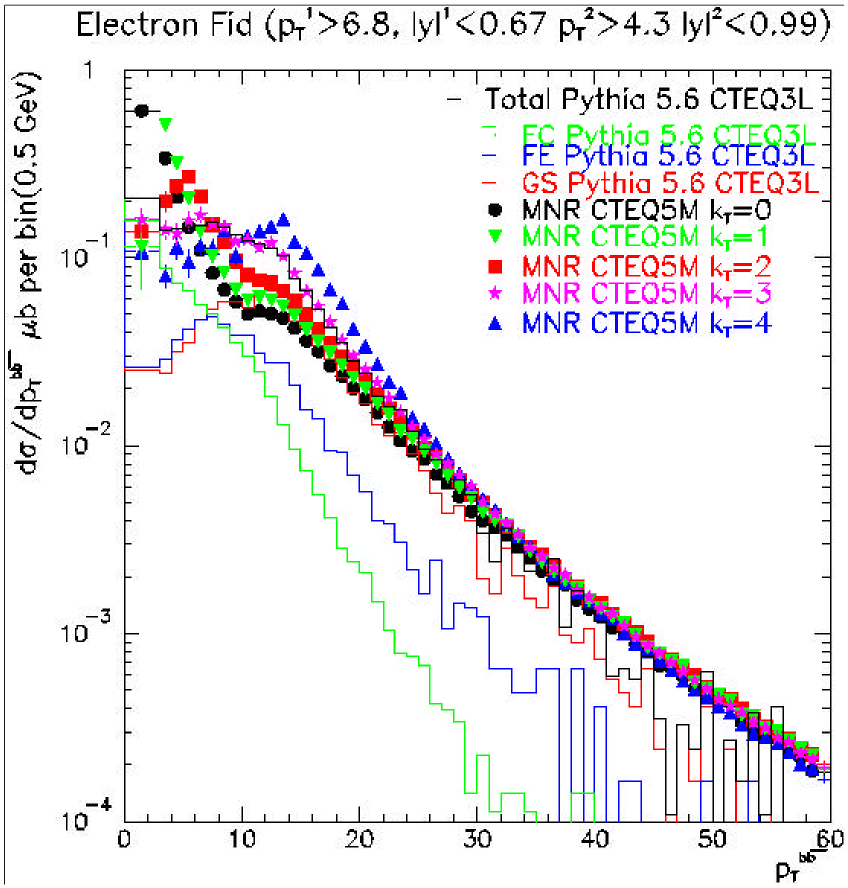
Comparisons between PYTHIA/MNR (1)

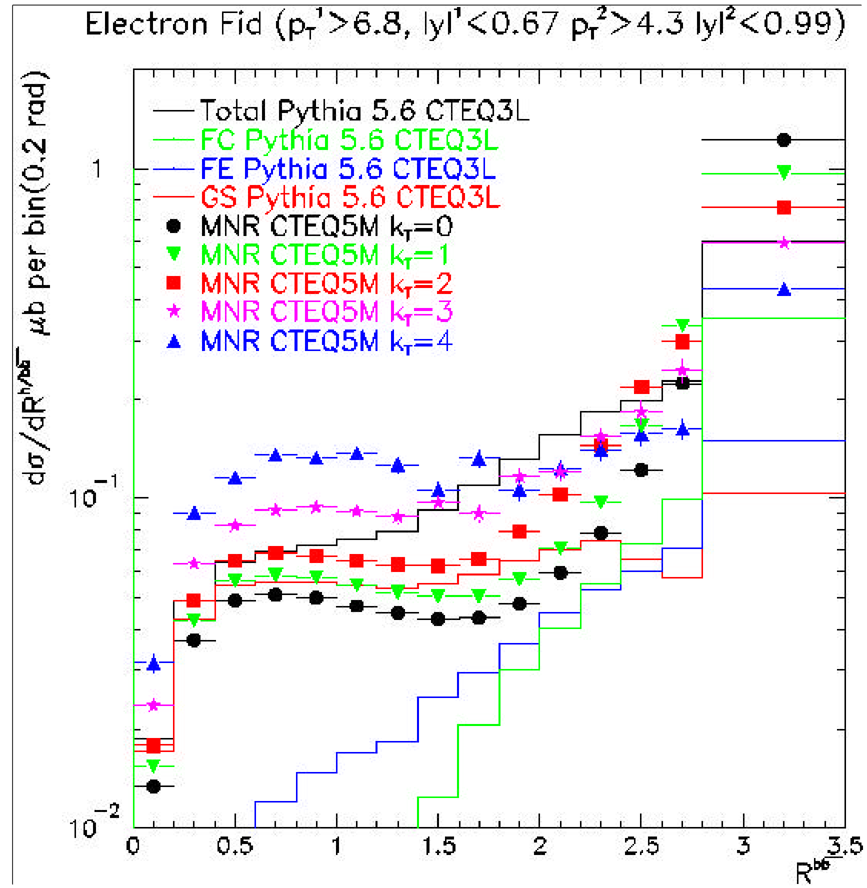




- Bottom quark p_T and y (not shown) very similar in PYTHIA and NLO (MNR)
  - → Three production mechanisms in PYTHIA also have very similar distributions

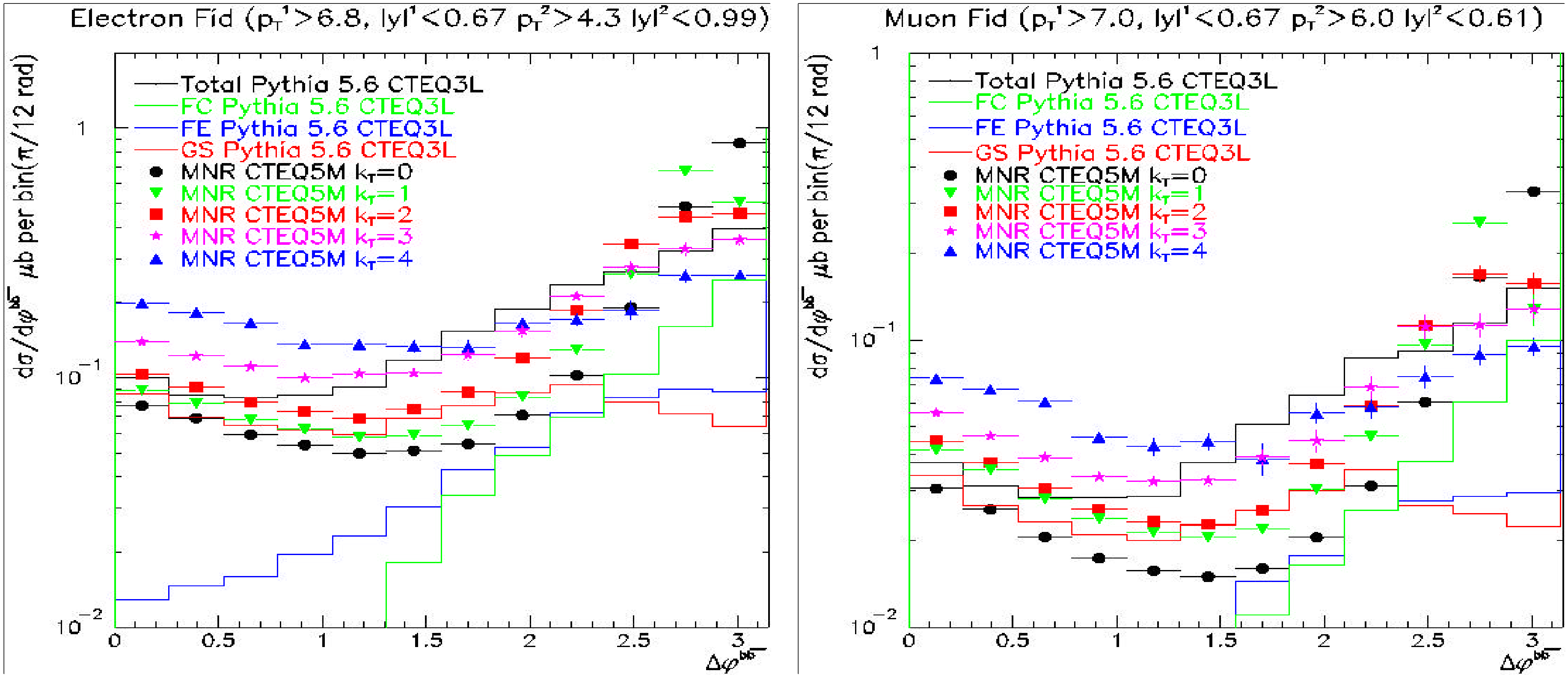
Comparisons between PYTHIA/MNR (2)





- Bottom correlations in PYTHIA and NLO (MNR) look similar once a k_T between 2-3 GeV is applied to NLO theory

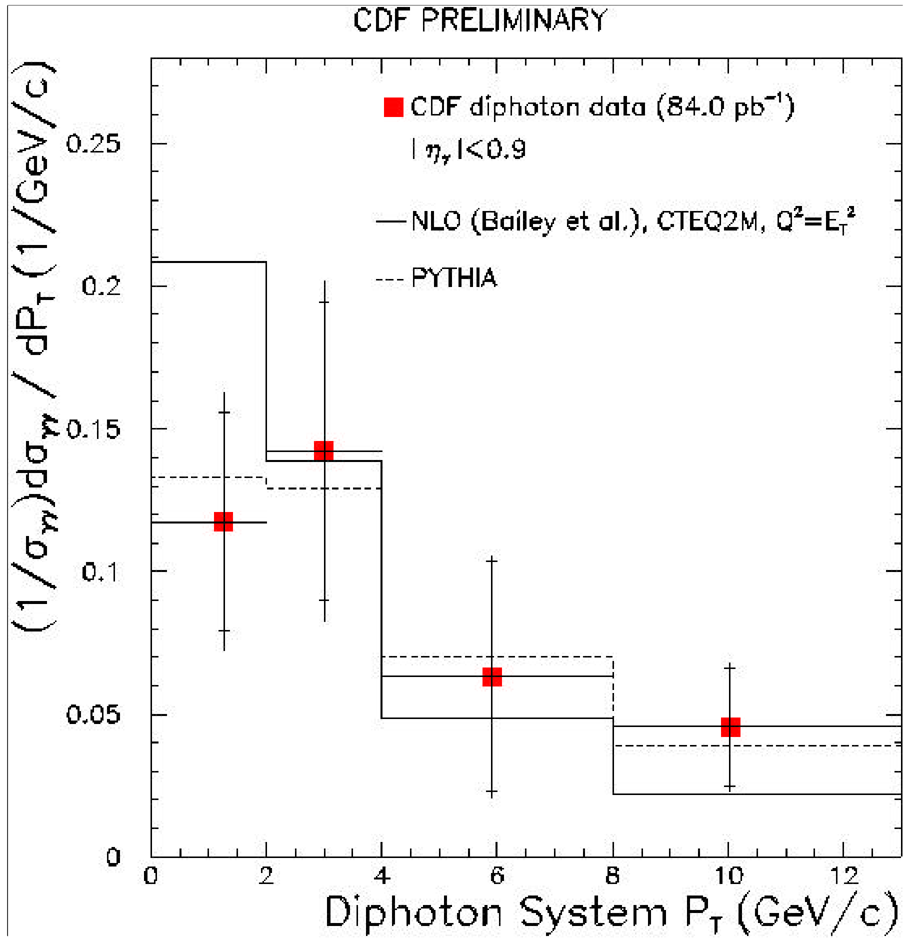
Comparisons between PYTHIA/MNR (3)



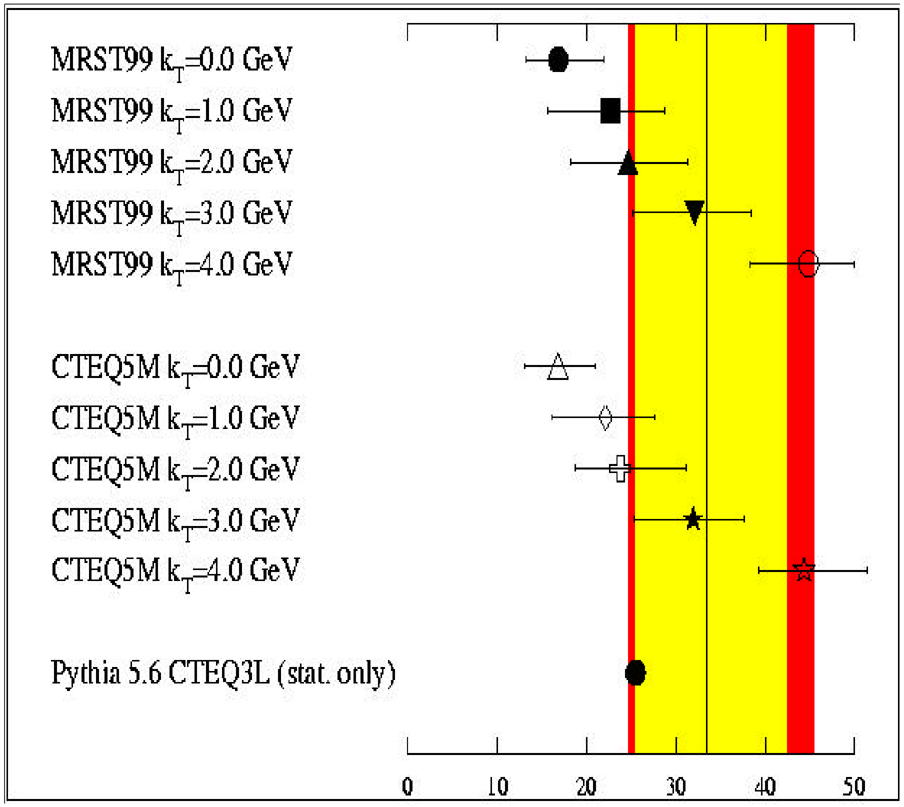
- $\Delta\Phi$ also matches between NLO and PYTHIA with a k_T between 2-3 GeV

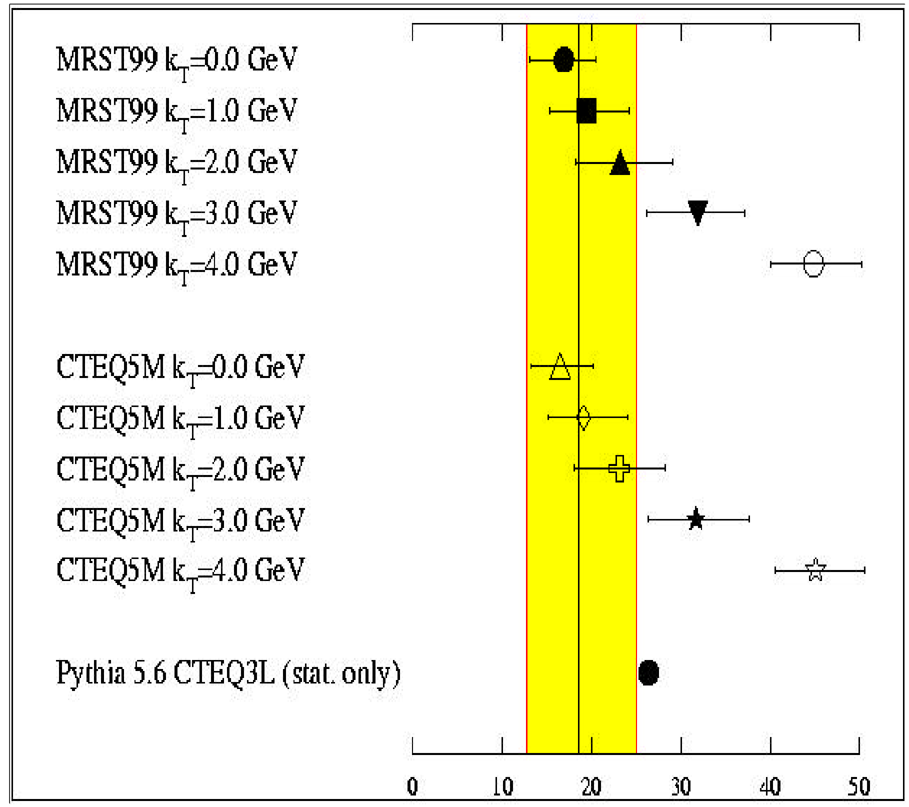
CDF Diphoton k_T

- Measured diphoton system p_T is NOT consistent with NLO theory
  - → Average system p_T in range of 2-4 GeV.
- Measurement is consistent with PYTHIA
  - → Includes initial and final state radiation beyond NLO calculations



Final Results

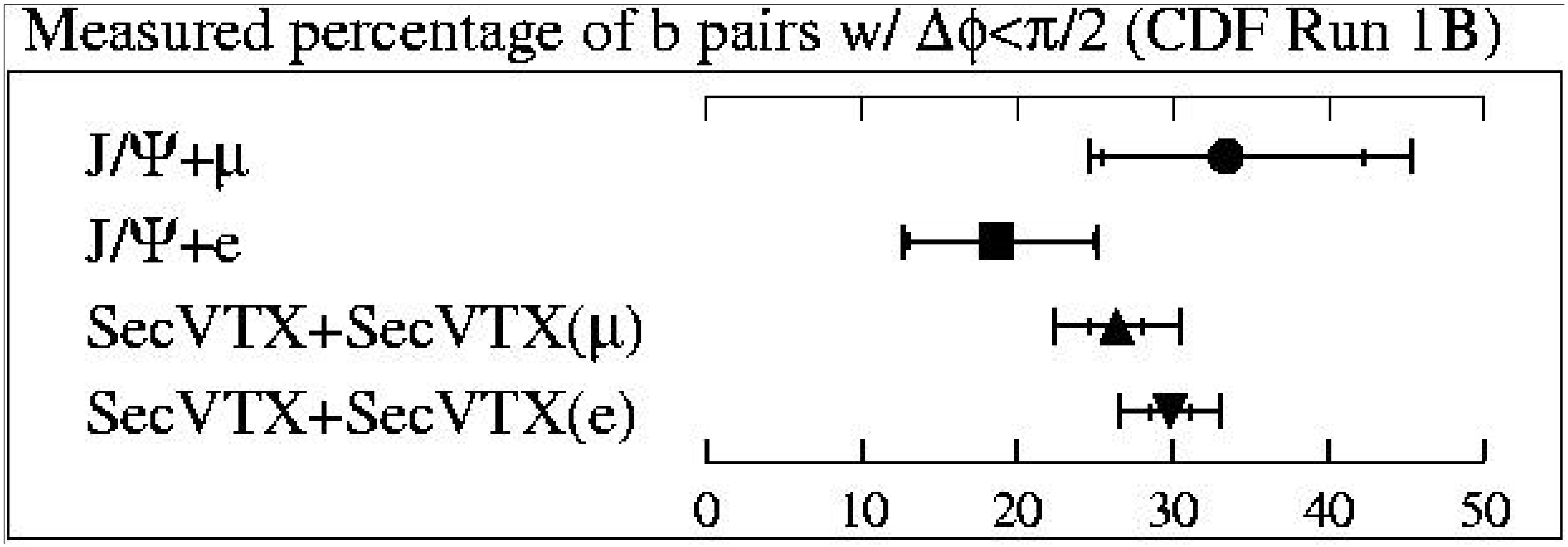




$$f^{corr,\mu}_{towards} = 0.334\,^{+0.089}_{-0.079}\,^{+0.077}_{-0.030} \pm 0.023$$

$$f^{corr,e}_{towards} = 0.186\,^{+0.063}_{-0.057}\,^{+0.005}_{-0.006} \pm 0.017$$

Comparison to SECVTX-SECVTX



$f^{corr,\mu}_{towards} = 0.334\,^{+0.089}_{-0.079}\,^{+0.077}_{-0.030} \pm 0.023$

$f^{corr,e}_{towards} = 0.186\,^{+0.063}_{-0.057}\,^{+0.005}_{-0.006} \pm 0.017$

This Analysis

$f^{corr,\mu}_{towards} = 0.264 \pm 0.017 \pm 0.037$

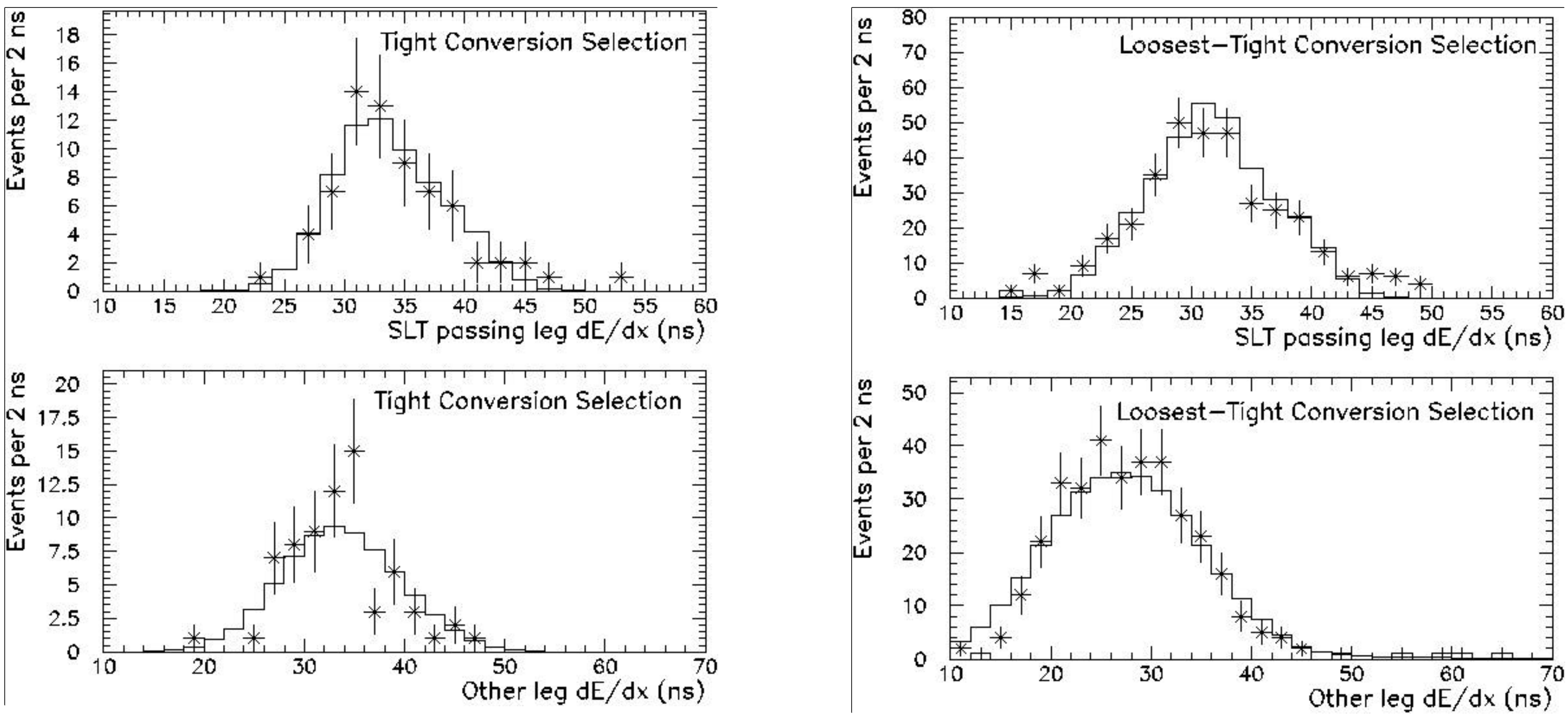
$f^{corr,e}_{towards} = 0.298 \pm 0.013 \pm 0.029$

K. Lannon's Analysis

Conclusions

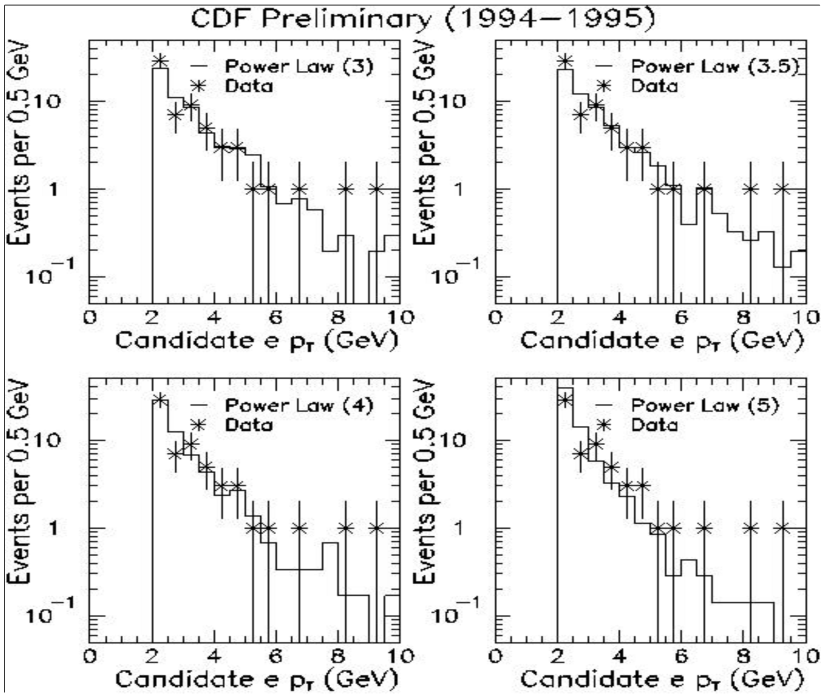
- $f_{towards}$ measured is consistent with the NLO prediction (MNR) with a $<k_T>$ with a range between 0-3 GeV
  - → Most consistent with 2 GeV
  - → MNR with $<k_T>$=4 GeV disagrees with the $f^{e}_{towards}$ measurement at the 3 σ level
- The measured value of $f_{towards}$ agrees with PYTHIA when combining all three bottom production mechanisms
  - → PYTHIA flavor creation only disagrees with measurements by 3.4 σ and 2.1 σ for the muon and electron samples, respectively
- Measured $f_{towards}$ completely consistent with $\Delta\Phi$ measured in $B^{\pm} \rightarrow J/\Psi\, K^{\pm}$ and $B^{0} \rightarrow J/\Psi\, K^{0*}$
- PYTHIA and NLO kinematics agree once a $<k_T>$ =2-3 applied to the NLO prediction

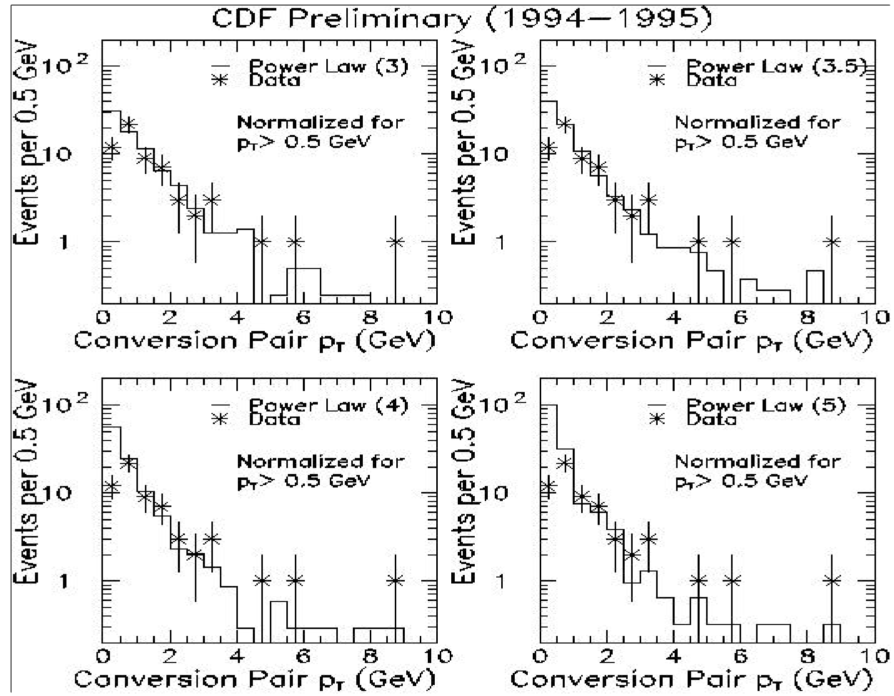
ε_{cnv}(cut) Calculation



- ε_{cnv}(cut) measured by loosening the conversion selection criteria and fitting the dE/dx of the additional conversion pair candidates
- ε_{cnv}(cut)=72.3±6.5%

$\varepsilon_{cnv}(p_T)$ Calculation

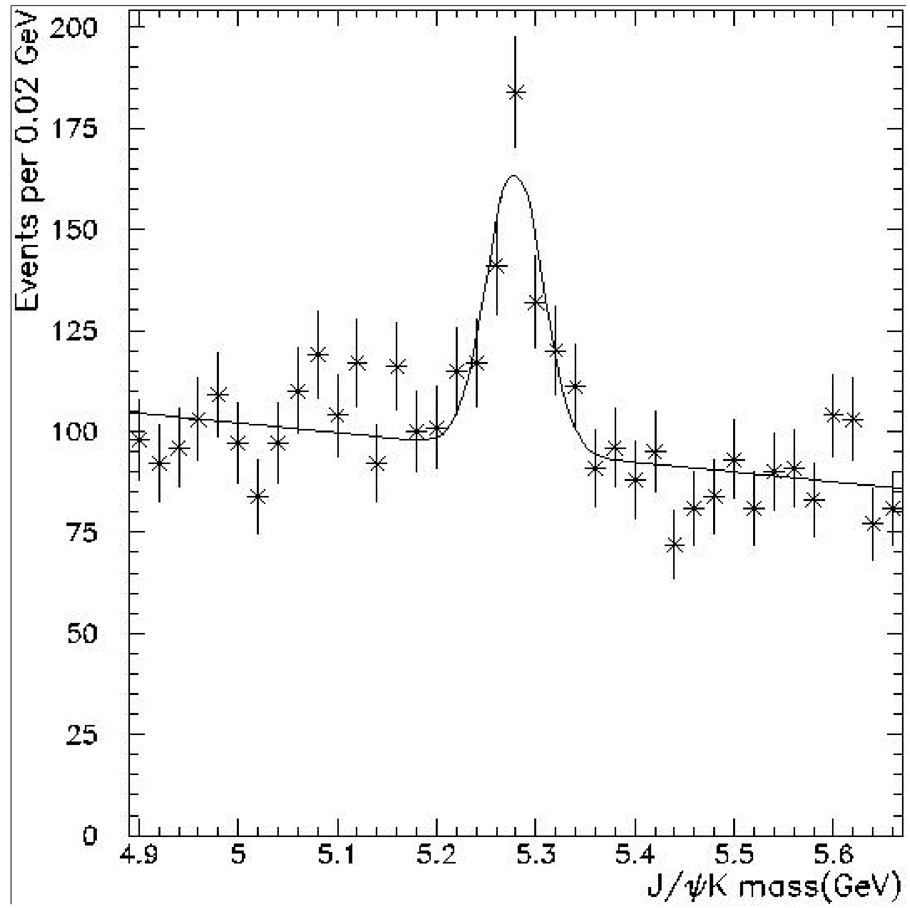




- $\varepsilon_{cnv}(p_T)$ calculated in manner similar to B_c analysis
  - → Monte Carlos π^0 matched to measured conversion pairs' p_T above 0.5 GeV where tracking is assumed to be fully efficient
  - → $\varepsilon_{cnv}(p_T)$=# of found conversion (data)/ # of conversions in MC (full p_T range)
- $\varepsilon_{cnv}(p_T)$=69±5(stat)±9(syst)%

Normalization of B_C Background

- To normalize the B_c background, the number of $B^+ \rightarrow J/Y\ K^+$ candidates in sample are fit
- The kaon is required to:
  - → Be in SLT electron fiducial region
  - → p_T > 2 GeV
- 245±39 $B^+ \rightarrow J/Y\ K^+$ candidates fit



Direct vs. Sequential Leptons