Heavy Quark Production at CDF

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Top Production

- ☞ gluon radiation

Bottom Production

- ☞ single inclusive σ
- ☞ double inclusive σ
- ☞ quarkonia: quick update
- ☞ B mesons in Run II

Charm Production

- ☞ two track trigger
- ☞ b fraction in direct charm

Top Production - Gluon Radiation

Measurement

- hard gluon radiation in $t\bar{t}$ events

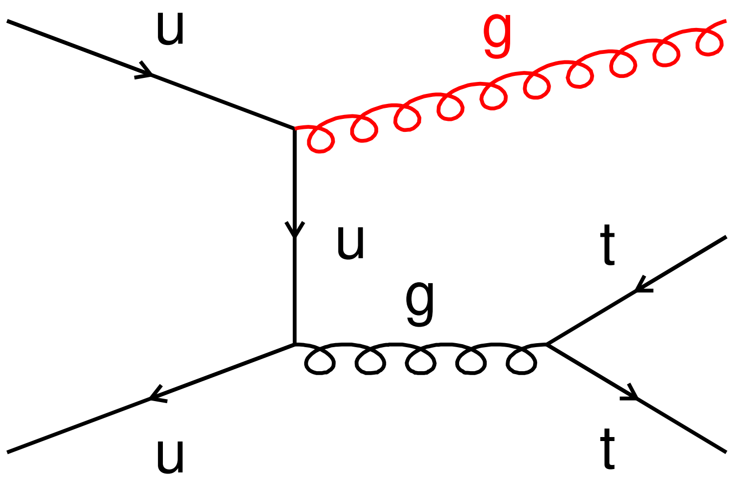
Motivation

- important systematic for top mass:
  $\Delta m_t \approx 5$ GeV; this: $1.8 - 3.1$ GeV
- constrain renormalization scale
- tt + jets: background to new physics

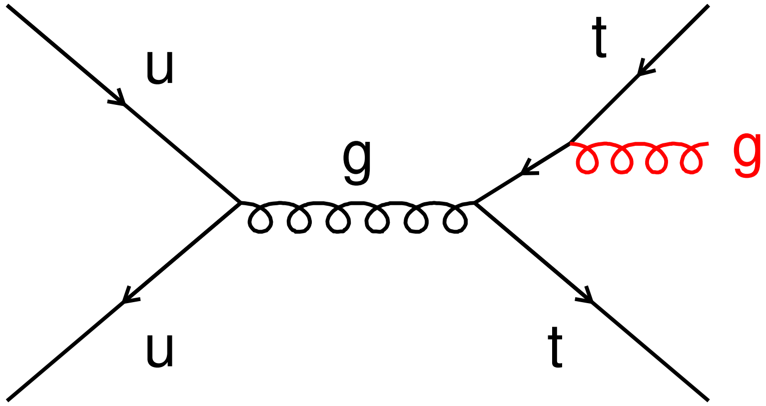
Analysis sketch

- sample: lepton+MET+2 jets+Btag
  $tt + X = tt + ttj + ttjj + ..$
- generate MC templates for tt, ttj, $ttjj$
- likelihood fit: MC templates to data
- convert fractions into cross section ratios

ex. initial state $qq \rightarrow ttg$



ex. final state $qq \rightarrow ttg$



Top Production - Gluon Radiation

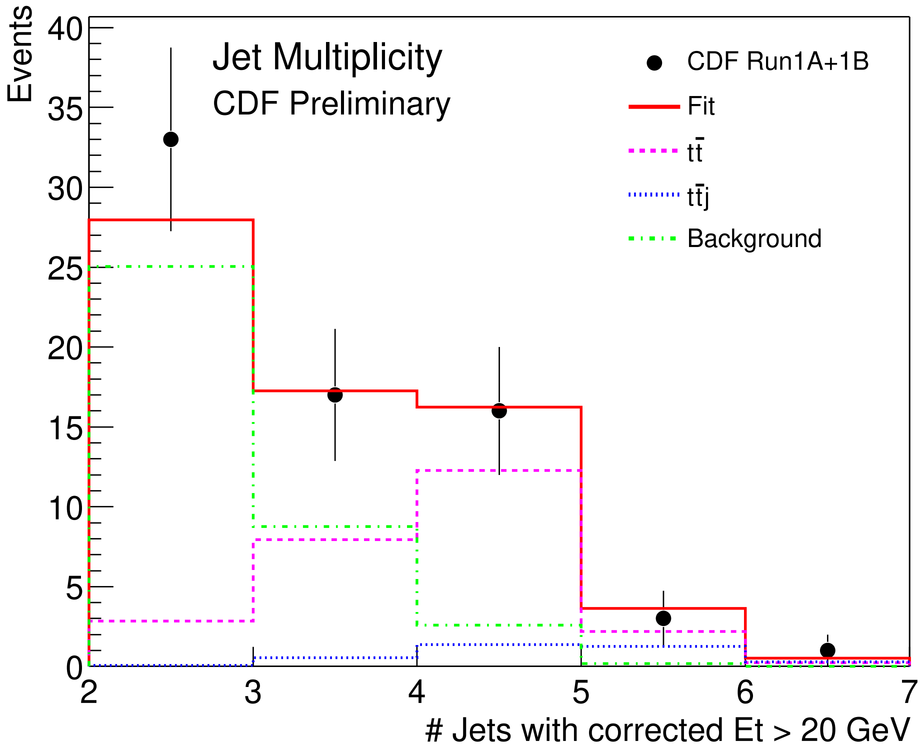
Background

- general top background MC: mistags, $W/Z + b\bar{b}(c\bar{c})$, Wc, diboson+Non-W, single top
- use only multiplicity shape

Model gluon radiation

- gluons from production use MADGRAPH
- gluons from decay use Pythia 6.115 (ISR turned off)

Rainwater



Fit jet multiplicities

- templates: *bg*, *tt*, *ttj*, *ttjj*
- obtain fractions for each category
- perform fit for $E_T > 20, 25$ GeV

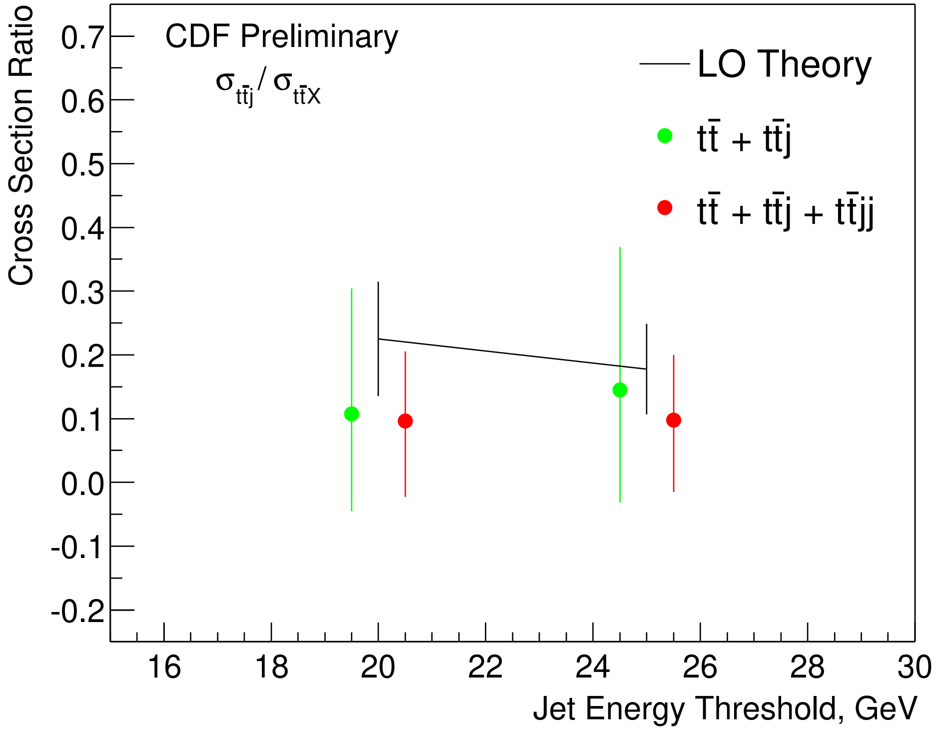
Contribution	Fit ($E_T > 20$ GeV)
f_{tt}	$0.36^{+0.13}_{-0.12}$
f_{ttj}	$0.051^{+0.084}_{-0.059}$
f_{bg}	$0.523^{+0.057}_{-0.056}$

Top Production - Gluon Radiation

Data versus theory

$$\sigma_{ttj}^{theory}/\sigma_{ttX}^{theory} \quad \leftrightarrow \quad f_{ttj}/(1-f_{bg})$$

- f_{ttj}, f_{bg}: from fit to data
- σ_{ttj}^{theory}: MADGRAPH, CTEQ4L
  and m_t renorm. scale
- σ_{ttX}^{theory}: NNLO cross section
  Kidonakis



Method established ✔

Poor statistics: set limits

- $\sigma_{ttj}^{theory}/\sigma_{ttX}^{theory}(E_T = 20\text{ GeV}) < 0.48$ at 90% CL
- $\sigma_{ttj}^{theory}/\sigma_{ttX}^{theory}(E_T = 25\text{ GeV}) < 0.55$ at 90% CL

Bottom Production - Overview

Compare $\sigma(b\bar{b})$:

$\Upsilon(4S)$	$\approx$ 1 nb (only B^0, B^+)
Z^0	$\approx$ 7 nb
$p\bar{p}$	$\approx$ 100 μb

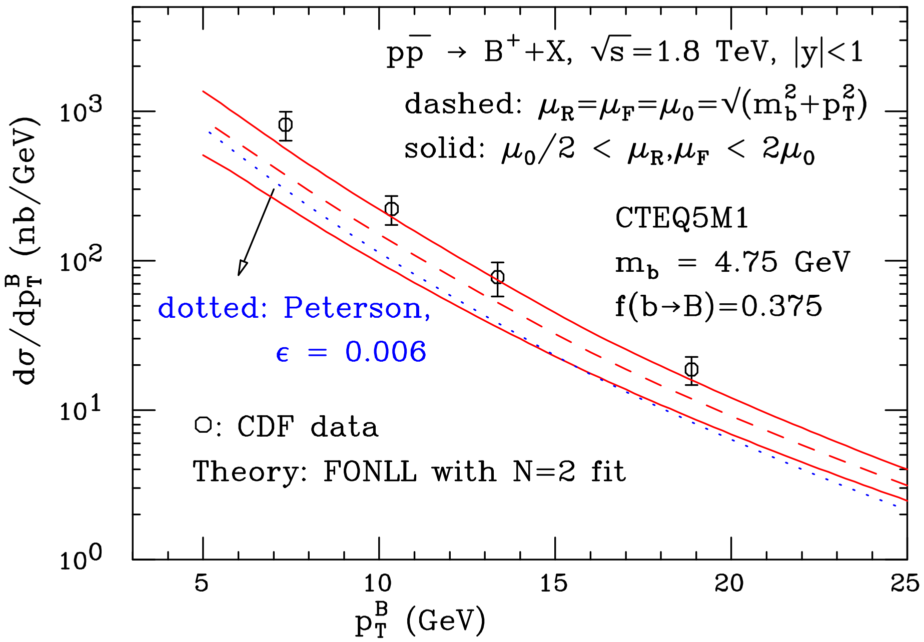
Light quark σ(inelastic) 10^3 larger

b-hadron triggers required

- Run I: based on leptons ($\mu^\pm$, $e^\pm$)
- Run II: also displaced tracks
- hadronic modes available

CDF Run I analysis: $B^+ \to J/\psi K^+$

- single inclusive *B* cross section
- Peterson fragmentation:
  $\varepsilon_b = 0.006 \pm 0.002$
- $\sigma_{data}/\sigma_{theory} = 2.9$



Updated theory

- Peterson fragm. tuned for LL
- different parameter: $\varepsilon_b = 0.002$
- better even different fragm.
- theory update FONLL Cacciari, Nason
- $\sigma_{data}/\sigma_{theory} = 1.7$
- data do not contradict theory

Bottom Production - Double Differential

Production mechanisms

- lowest order
- flavor excitation
- gluon spitting

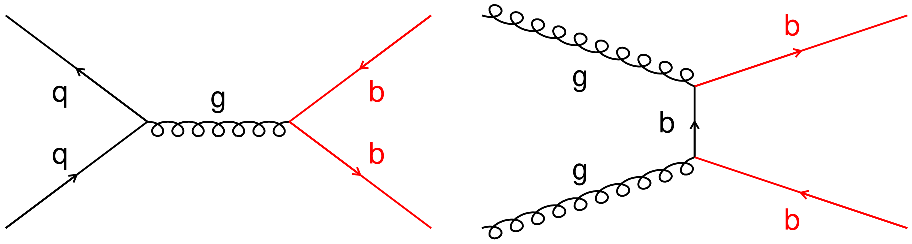
Analysis idea

- events with two *b* quarks
- study angular difference
- tune production contributions
- opposite side flavor tagging

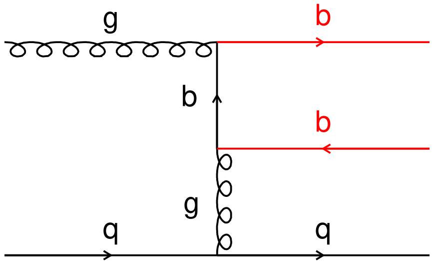
Two analyses under way

- high statistics B tagged sample
- trigger J/ψ and high p_T lepton

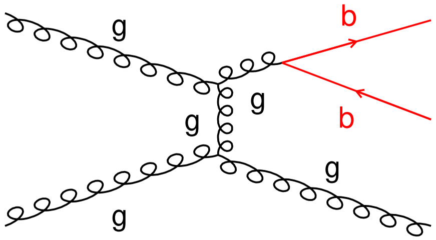
Lowest order



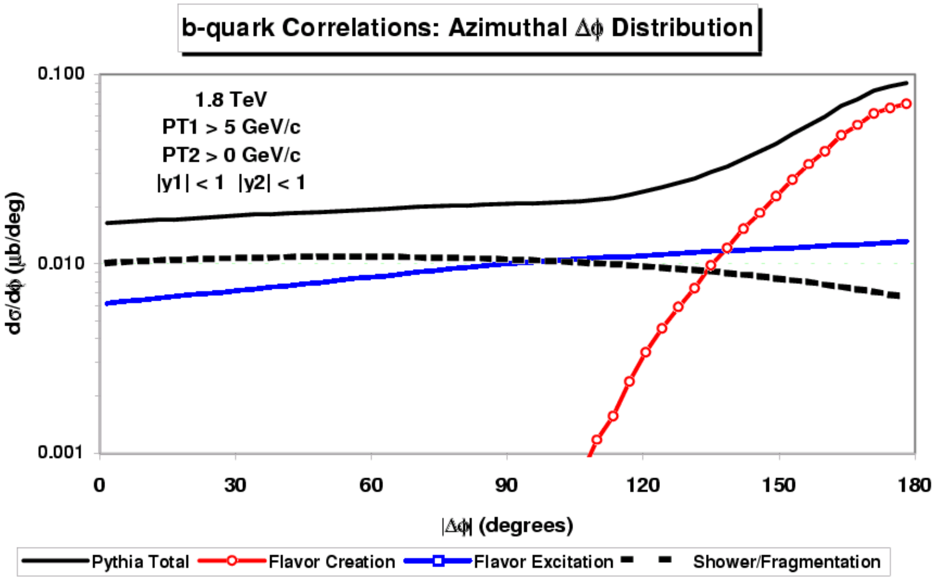
Flavor excitation

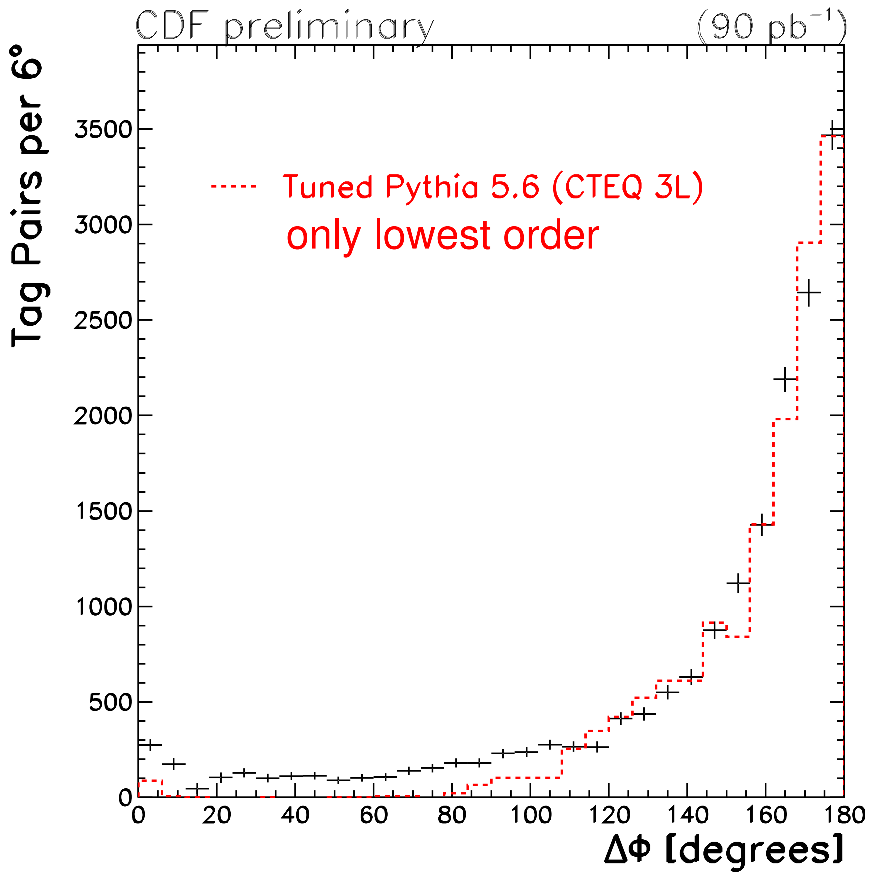


Gluon splitting



Bottom Production - Double Differential





Analysis: $J/\psi \to \mu^+\mu^-$ + lepton

$R(toward/away) = 0.52 \pm 0.20(stat + sys)$

- small statistics
- lowest order not enough

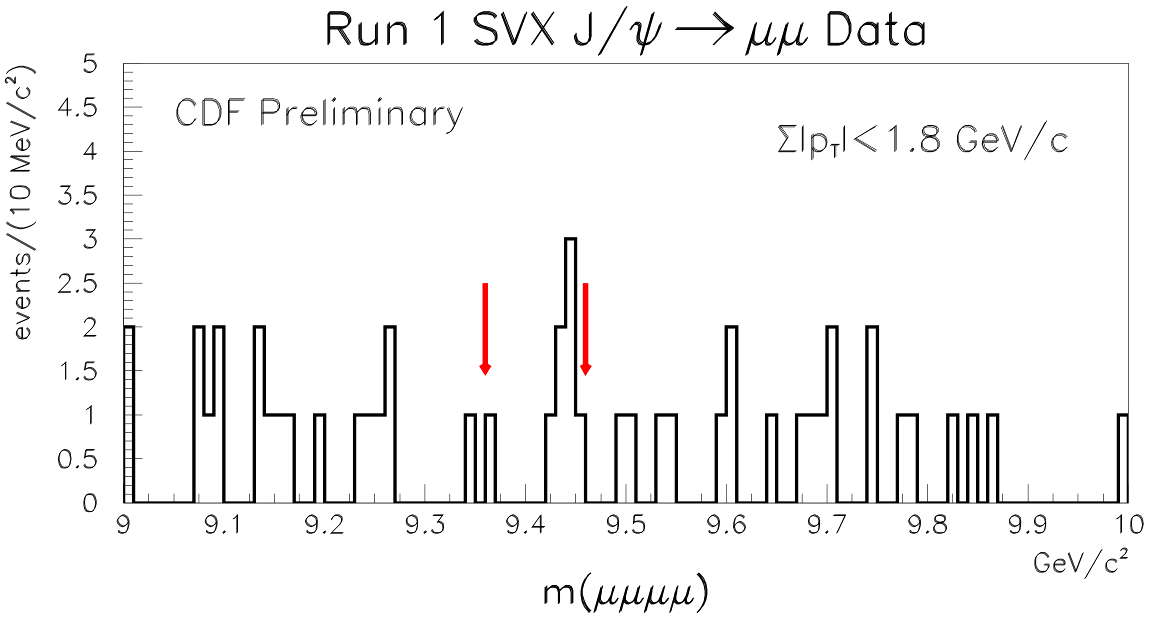
Attention:

results detector/selection dependent

Secondary vertices in Jets

- high statistics
- lowest order not sufficient
- other contributions still missing

Quick Update: Quarkonia



Search η_b in Run I data

- decay: $\eta_b \to J/\psi J/\psi$
- with $J/\psi \to \mu^+\mu^-$
- expected mass:
  9.36 GeV – 9.46 GeV
- ≈ 80 pb^{-1}

- 7 evts in window (bg: 1.8 evts) $\to$ 1.5% probability (2.2σ)
- mass of potential signal: $m_{\eta_b} = 9446 \pm 6(\text{stat})$ MeV

Excellent Quarkonia prospects for Run II

- soon sufficient data for further η_b study
- differential J/ψ cross sections/polarization:
  lower trigger threshold $\to$ study lower p_T

B Mesons in Run II - Momentum Scale

Major J/ψ modes seen

- $B^+ \to J/\psi K^+$
- $B^0 \to J/\psi K^{*0}$
- $B_s^0 \to J/\psi \phi$

B meson masses in MeV$/c^2$

$m(B^+) = 5280.6 \pm 1.7\,\text{(stat)} \pm 1.1\,\text{(sys)}$

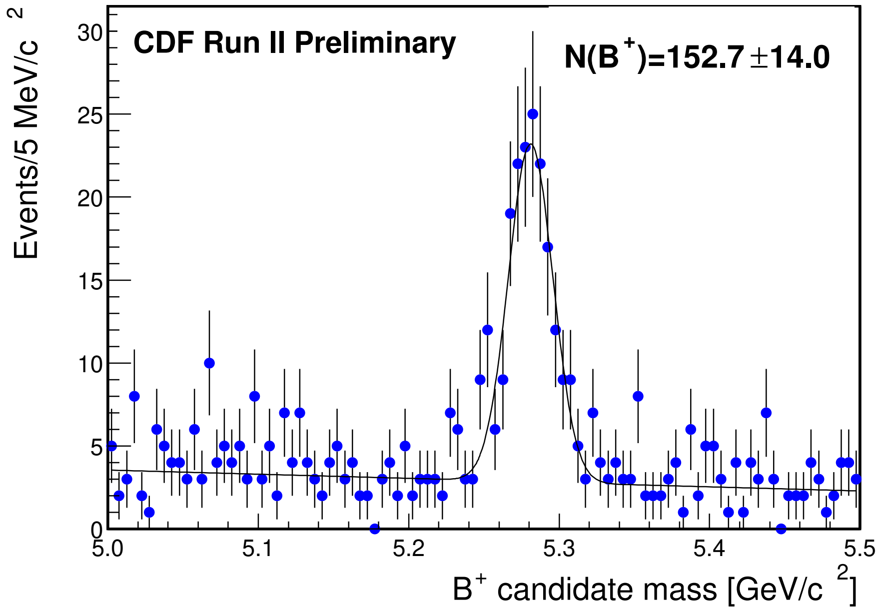
$m(B^0) = 5279.8 \pm 1.9\,\text{(stat)} \pm 1.4\,\text{(sys)}$

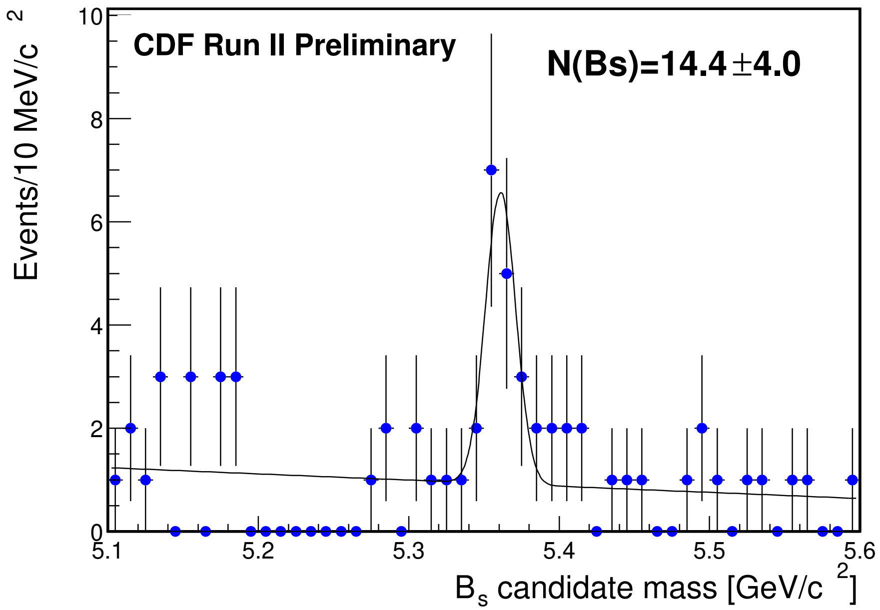
$m(B_s^0) = 5360.3 \pm 3.8\,\text{(stat)}\ ^{+2.1}_{-2.9}\,\text{(sys)}$

Momentum scale well understood

- energy loss in material calibrated
- systematics at the level of Run 1

Soon new cross sections at lower p_T





B Mesons in Run II - Silicon Tracking

Large sample of $J/\psi \to \mu^+\mu^-$ events

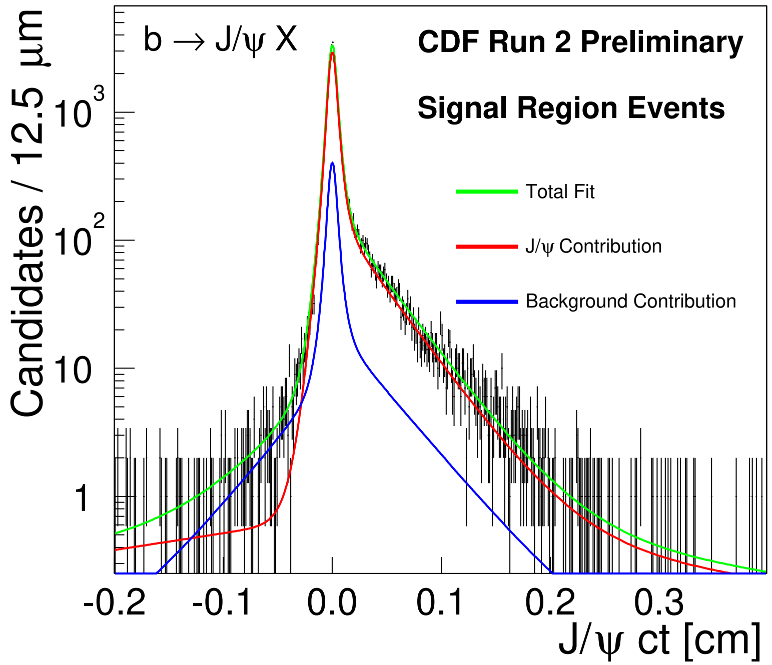
- calibrate resolution
- understand alignment
- measure inclusive B lifetime
- so far only r-ϕ silicon used

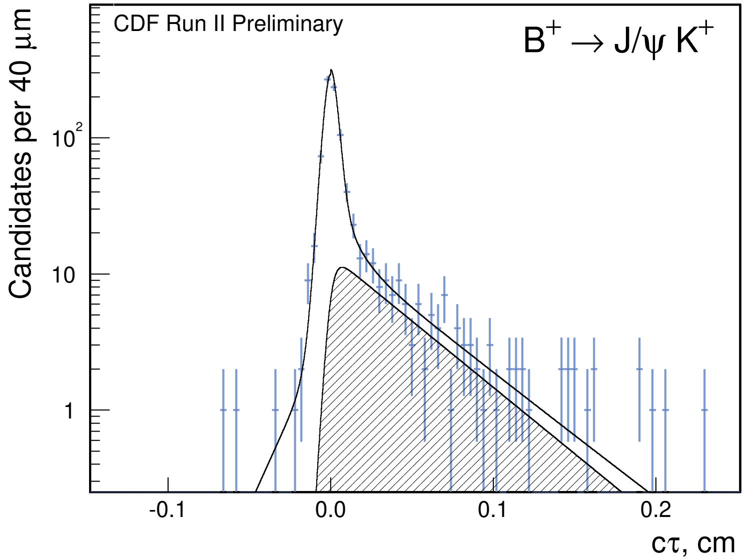
Lifetime measurements

$$c\tau_{incl} = 458 \pm 10\ \text{(stat)} \pm 11\ \text{(sys)}\ \mu\text{m}$$
$$c\tau_{B^+} = 446 \pm 43\ \text{(stat)} \pm 13\ \text{(sys)}\ \mu\text{m}$$

About results

- silicon already well understood
- consistent with Run 1, world average
- incl. systematics as Run 1
- major improvements expected:
  Layer 00, 3D tracking, alignments





Charm Production - Overview

Single inclusive σ_{NLO} for b, c

- $\sigma_b(p_T > 0; |y| < 1) \approx 20\ \mu\text{b}$
- $\sigma_c(p_T > 0; |y| < 1) \approx 400\ \mu\text{b}$

CDF Trigger Strategy for b, c Physics

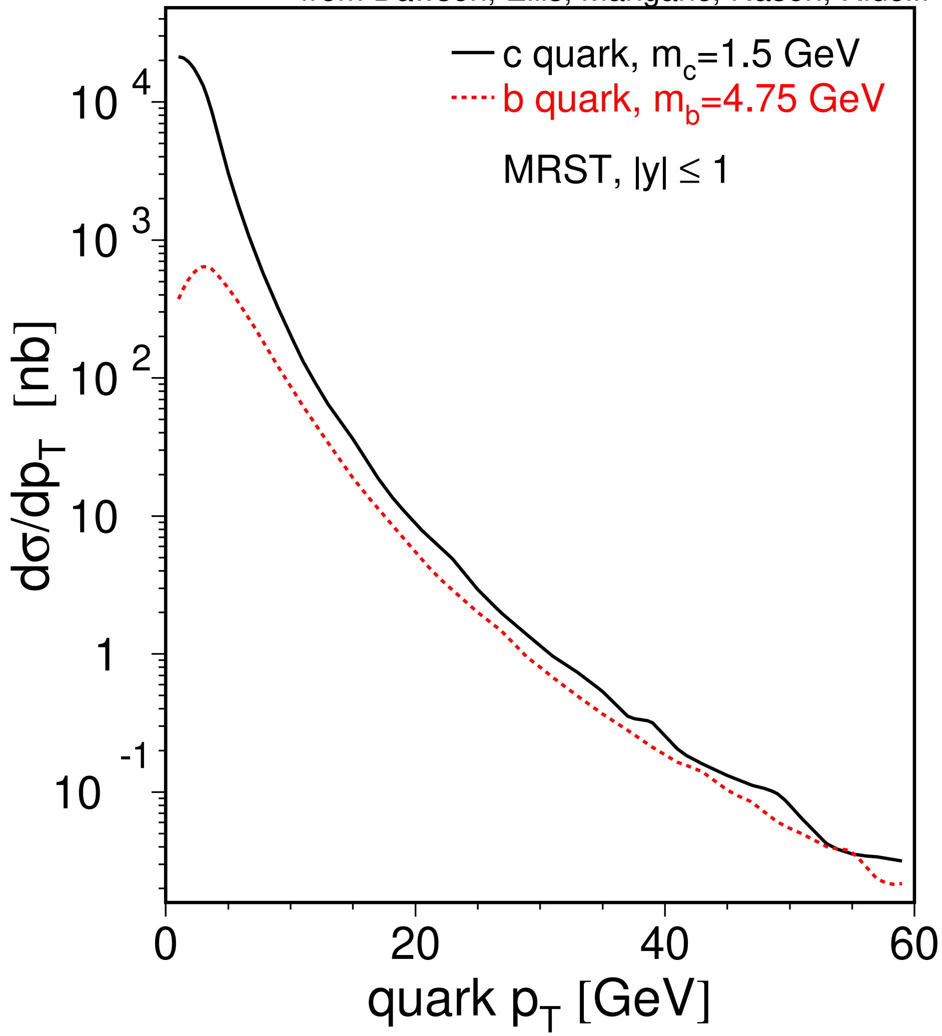
- Run I: based on leptons ($\mu^\pm$, $e^\pm$)
- Run II: also displaced tracks
- hadronic modes available

Displaced track trigger scheme

see talk by A.Cerri

- 2 tracks $p_T > 2.0$ GeV
- opposite charge
- $p_{T,1} + p_{T,2} > 5.5$ GeV
- $2^o < |\Delta\phi| < 90^o$
- impact par. $120\ \mu\text{m} < |d_0| < 1$ mm
- $L_{xy} > 200\ \mu\text{m}$
- lots of charm passes the trigger

from Dawson, Ellis, Mangano, Nason, Ridolfi



An order of magn. difference at low p_T

Charm Production

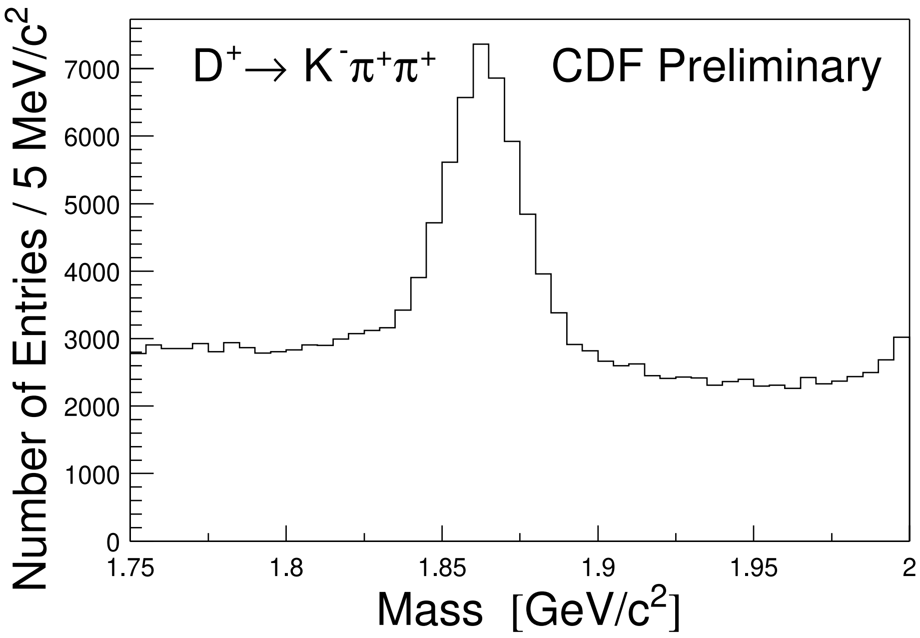
Charm cross section

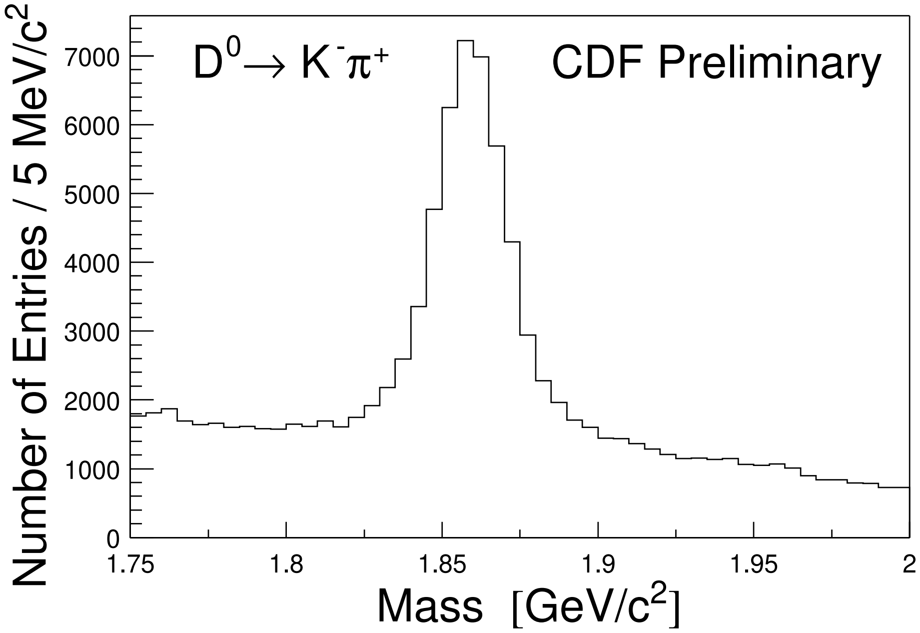
done:

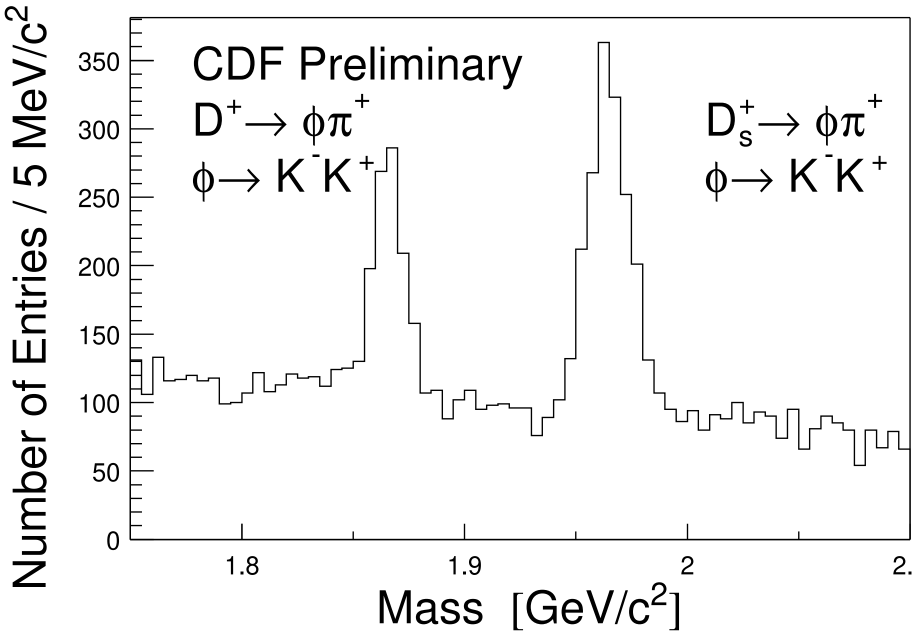
- ☞ reconstruct D mesons
- ☞ separate direct D from $B \to D$

future:

- ☞ acceptance, efficiency
- ☞ compare σ_D to theory







Charm Production: Direct D versus $B \to D$

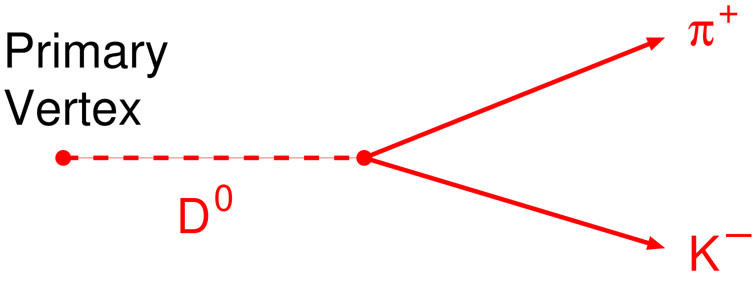
Direct charm versus $B \to D$

- B decays preferentially to D
- $\sigma_D \gg \sigma_{B\to D}$ at low p_T
- trigger prefers $B \to D$: d_0 cut
- use kinematics to separate

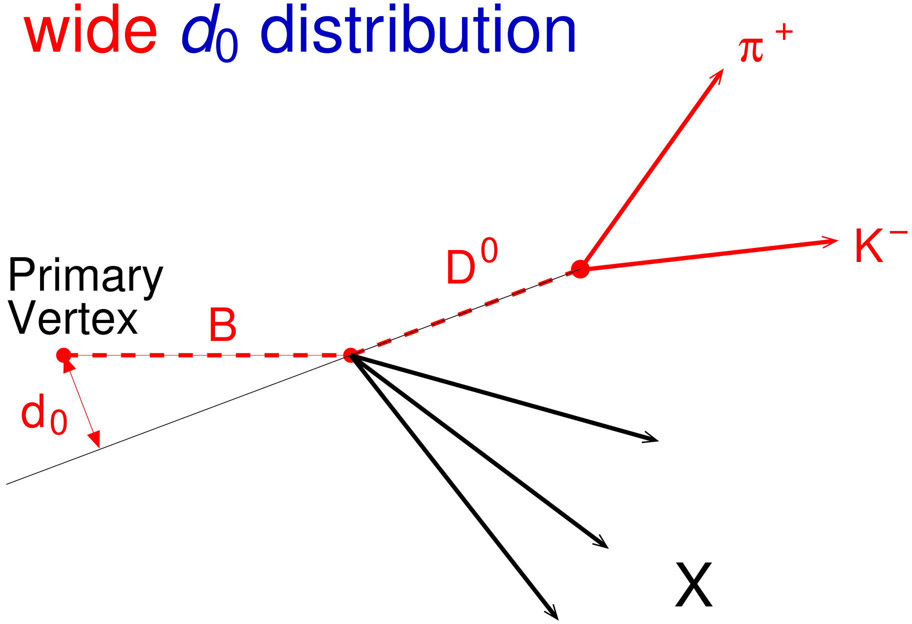
Methods

- D meson impact parameter
  direct D points to primary vertex
  secondary D does not
- D meson proper time
  not yet done
  difficult, trigger bias
  combine with impact parameter

Direct D:
narrow d_0 resolution



Secondary D:
wide d_0 distribution

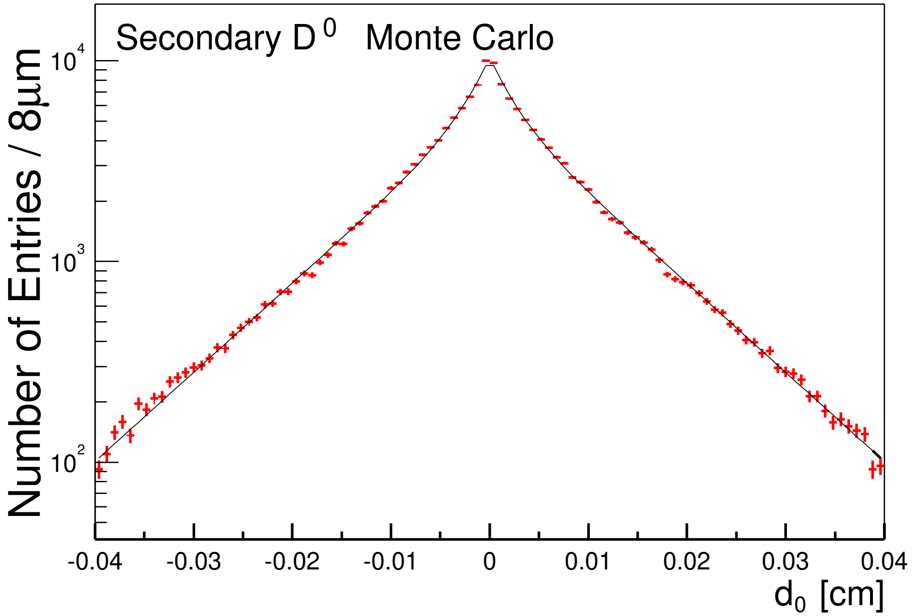


Charm Production: Direct D versus $B \to D$

Fit inclusive d_0 distribution

$$F(d_0) = f_B \int F_B(x) F_D(d_0 - x)\,dx + (1 - f_B) F_D(d_0)$$

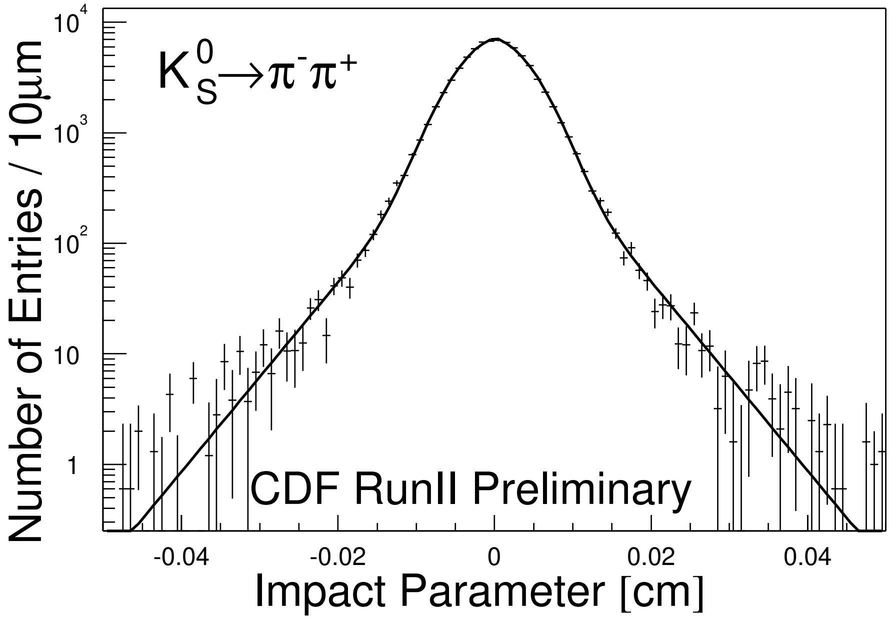
- f_B: fraction of $B \to D$
- F_B: B d_0 distribution from MC
- F_D: detector d_0 resolution
  simple: use single Gaussian
  more realistic: from $K_S \to \pi^+\pi^-$



Event samples ($\mathcal{L} \approx 5$ pb^{-1})

$n_{D^0} \approx 30k$ $\quad n_{D^{*+}} \approx 6k$

$n_{D^+} \approx 27k$ $\quad n_{D_s} \approx 1k$

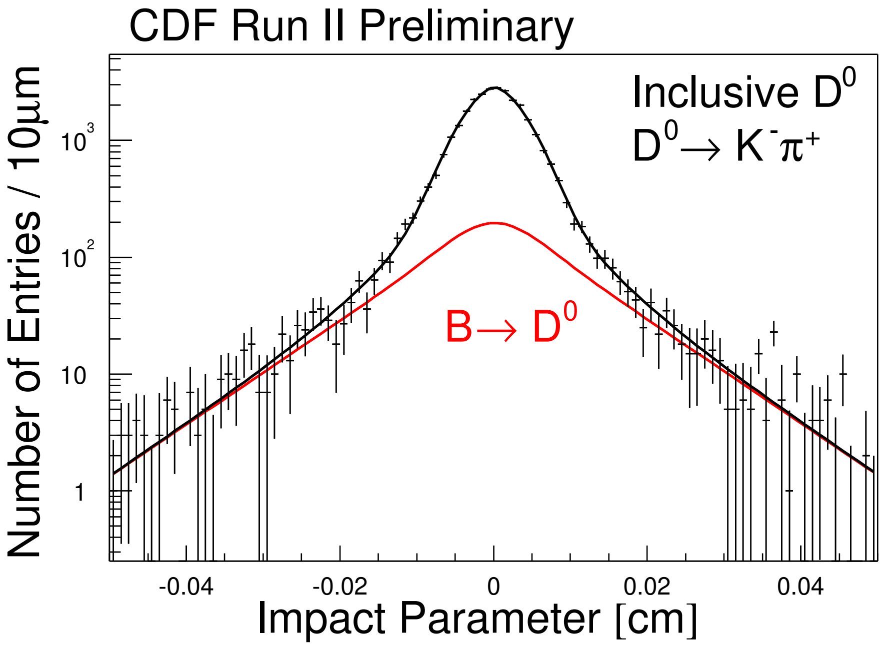


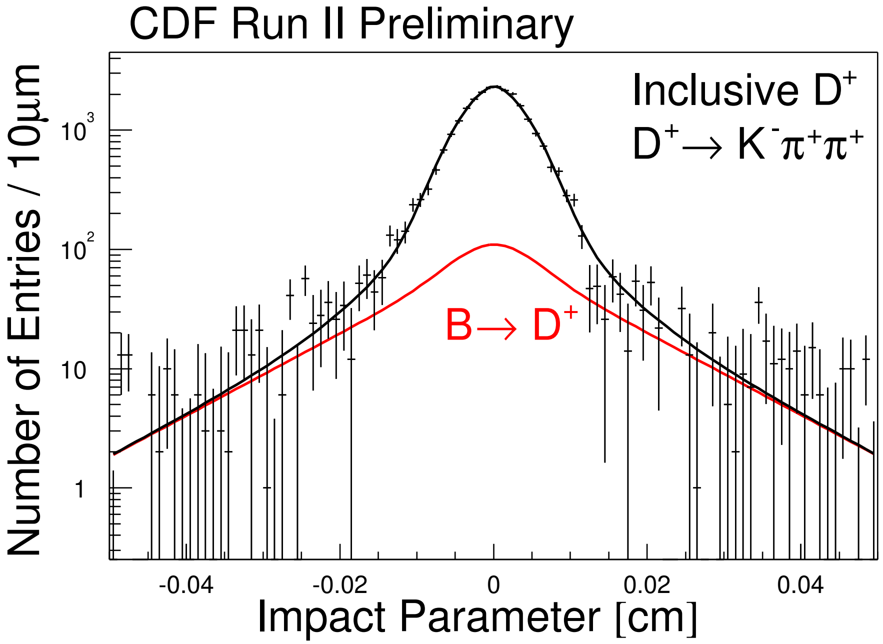
Charm Production: Fit Results

Fraction of $B \to D$:

meson	Gaussian	from K_S
D^0	23.14±0.59	16.43±0.65
D^{*+}	20.00±1.19	11.41±1.37
D^+	17.29±0.53	11.26±0.53
D_s	37.84±2.60	34.80±2.75

still needs trigger/detector corrections





Conclusion

- direct charm dominates
- non Gaussian tails important
- careful modeling necessary
- opportunities for charm physics
- calibration for bottom physics

Summary and Conclusions

Heavy Quark Results from Run I

- top gluon radiation
- updated $b\bar{b}$ correlations
- first hint of $\eta_b \to J/\psi J/\psi$

First Heavy Quark Results from Run II

- only 5 – 18 pb^{-1} used for analyses
- detector already very well understood
- momentum/vertex resolution good $\to$ will further improve
- two track trigger allows for charm physics
- large number of reconstructed D mesons
- direct D versus $B \to D$ in two track data

Tune in for Exciting Results Winter 2003