Charm Physics in CDF

Ivan K. Furić, M.I.T.

for the CDF collaboration

- Tevatron & CDF
- Why can CDF do charm?
- Charmed results
- Prospects

XVII Rencontres de Physique

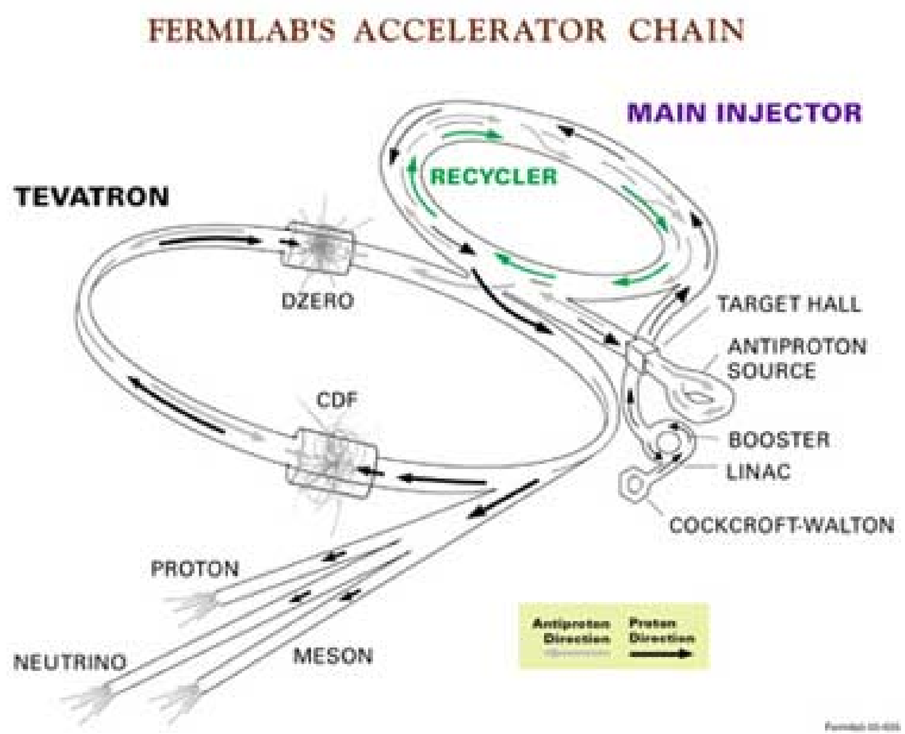
de la Vallee d'Aoste

March 9-15, 2003

Tevatron Upgrade

Main Injector

- New injection stage for Tevatron
- Ability to accelerate and deliver higher intensity of protons
- More efficient $\overline{\mathrm{p}}$ transfer
- $\overline{\mathrm{p}}$ recycler (in progress)

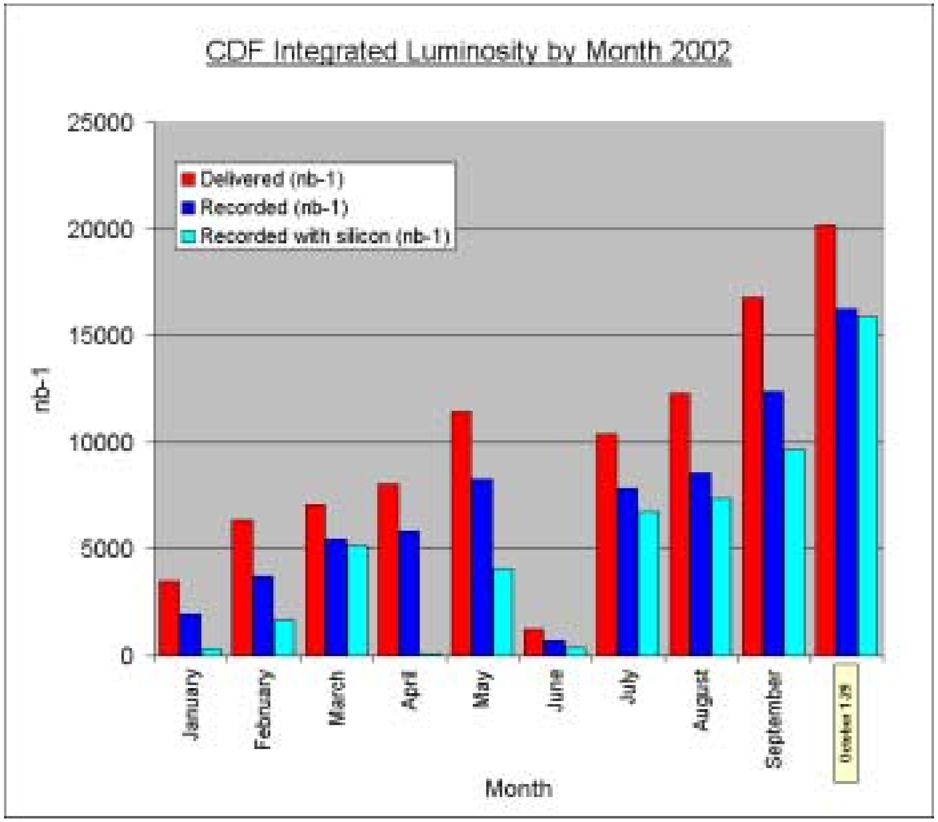


- Higher Collision rate: 396ns (36x36 bunches)
  $\Rightarrow$ 5-10 Higher Luminosity than run 1
- Higher C.M. Energy: $1.8 \Rightarrow 1.96$ TeV

Luminosity

Tevatron Performance

- Below expectation but improving
  - Record luminosity: $3.6 \times 10^{31} \mathrm{cm}^{-2}\mathrm{s}^{-1}$
  - Now consistently $4 - 7\ \mathrm{pb}^{-1}$ per week



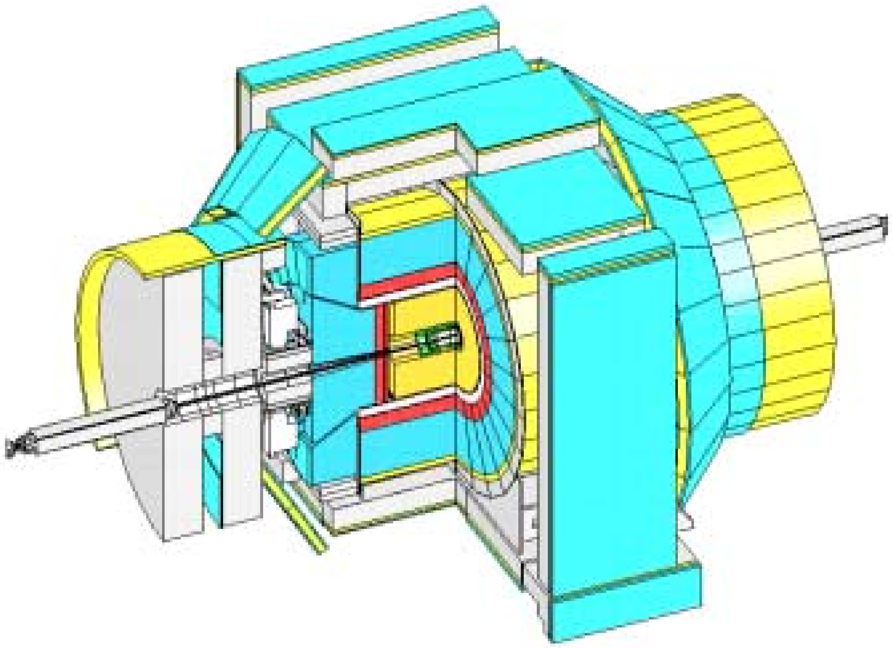
At CDF:

- Expect $\sim 10\% - 20\%$ improvement due to work performed in January shutdown
- $180\ \mathrm{pb}^{-1}$ delivered, $130\ \mathrm{pb}^{-1}$ recorded
- $65\ \mathrm{pb}^{-1}$ all critical systems on, after commissioning period

The CDF II Detector

Integrated tracking system:

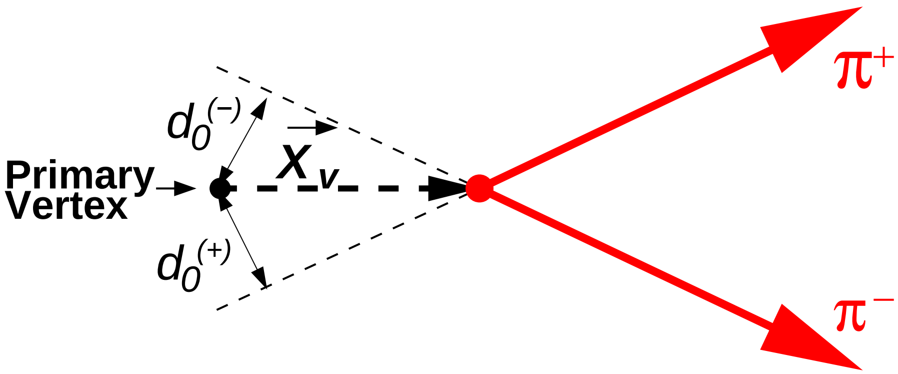
- **1.4 T solenoidal B field**
- **drift chamber (COT)**
- **silicon vertex detector (see M. Herndon's talk)**



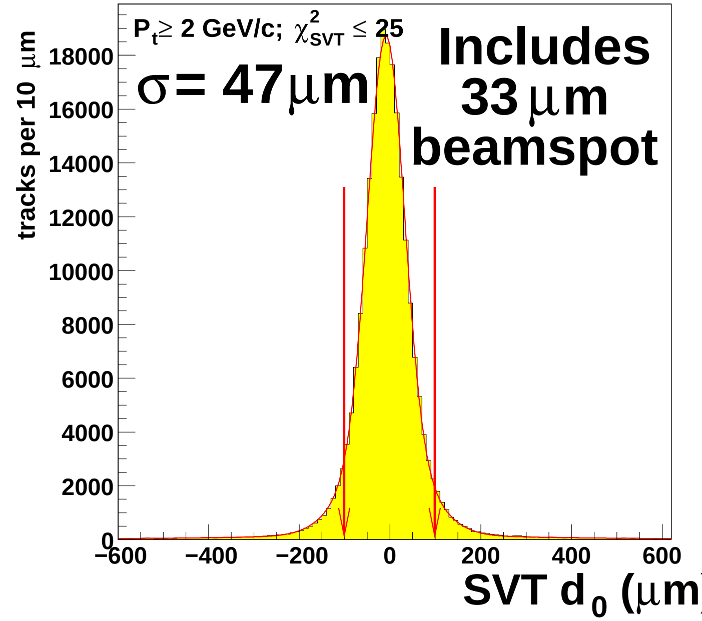
- **Extended muon coverage, EM/HAD Calorimetry**
- **Improved particle identification**
- **Upgraded 3-level trigger system**

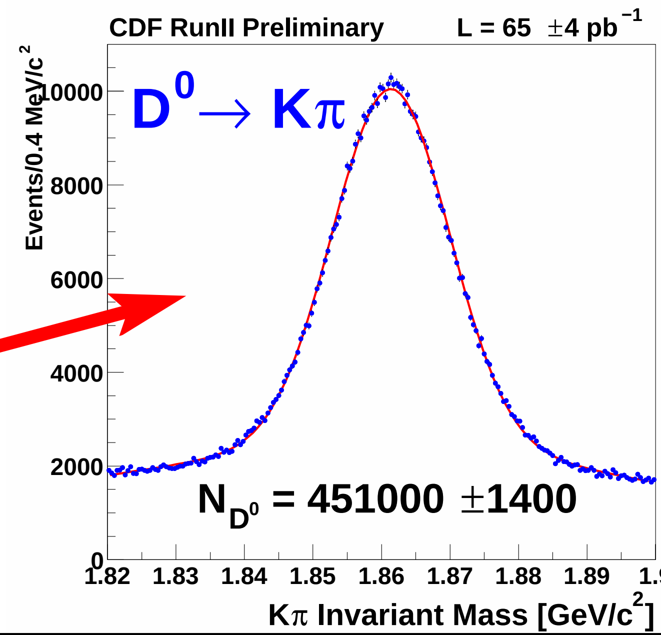
Triggering on displaced tracks

- trigger $B \to \pi\pi, B_s \to D_s\pi$
- challenge: read out SVX and track at 10's of kHz $\to$ SVT



- trigger on 2 displaced tracks
  ($p_T > 2$ GeV/c, 120 μm $< |d_0| <$ 1 mm)
- huge charm samples gathered
- the SVT is why CDF can do charm physics

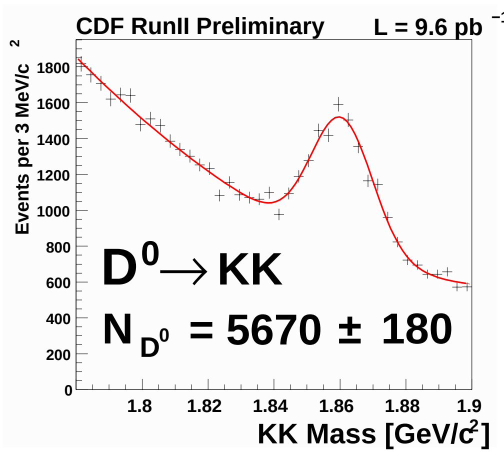


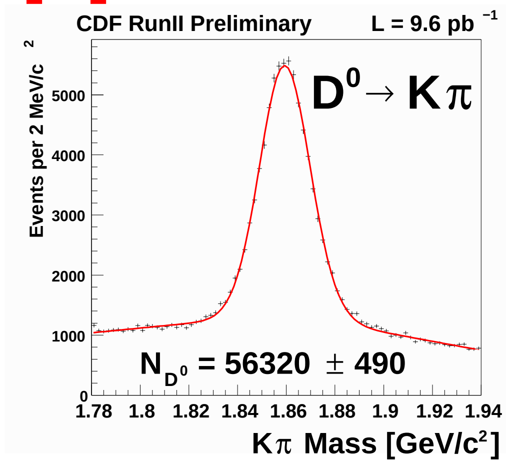


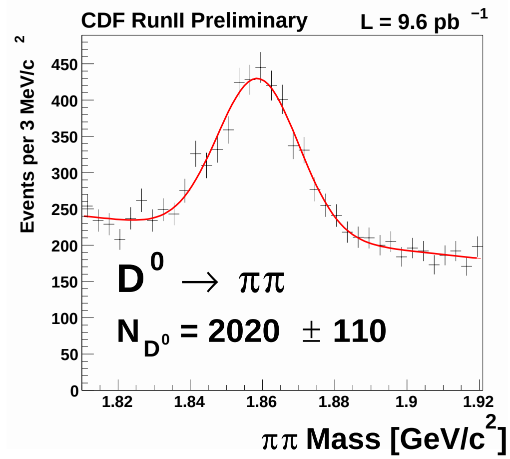
Charm Physics Subjects

- **branching ratios:** $D^0 \to \pi^+\pi^-, K^+K^-$
- **cross-section:** $\frac{d\sigma}{dp_T}(J/\psi, D^0, D^{*+}, D^+, D_s^+)$
- **spectroscopy and properties:**
  $D_1^0, D_2^{*0} \to D^{*+}\pi^-$
- **D^0 mixing:** $\Gamma(D^0 \to CP)$ vs $\Gamma(D^0 \to K^-\pi^+)$
  wrong sign decays ($D^0 \to K^+\pi^-$)
- **direct CP violation:**
  D^0 vs $\overline{D^0} \to \pi^+\pi^-, K^+K^-$
  D^+ vs $D^- \to \pi\pi\pi, KK\pi$
- **rare decays:**
  $D^0 \to \mu^+\mu^-, \mu^+e^-$
  $D^+ \to \mu^+\mu^-\pi^+$

Cabibbo suppressed D^0 decays







- correct for relative trigger and reconstruction efficiency:

$$\frac{\Gamma(D^0 \to K^+K^-)}{\Gamma(D^0 \to K^-\pi^+)} = (11.17 \pm 0.48 \pm 0.98)\%$$

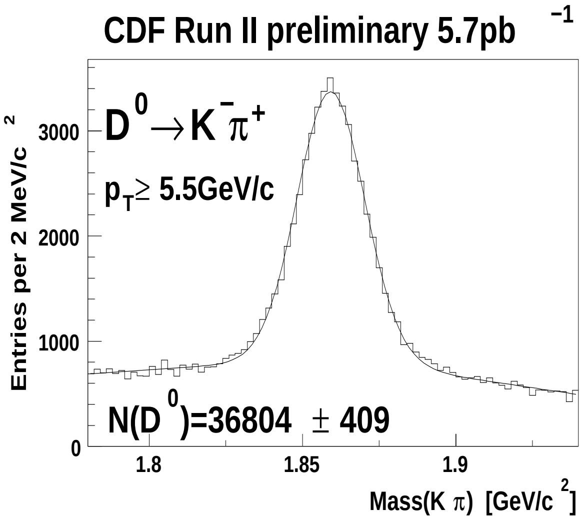
$$\frac{\Gamma(D^0 \to \pi^+\pi^-)}{\Gamma(D^0 \to K^-\pi^+)} = (3.37 \pm 0.20 \pm 0.16)\%$$

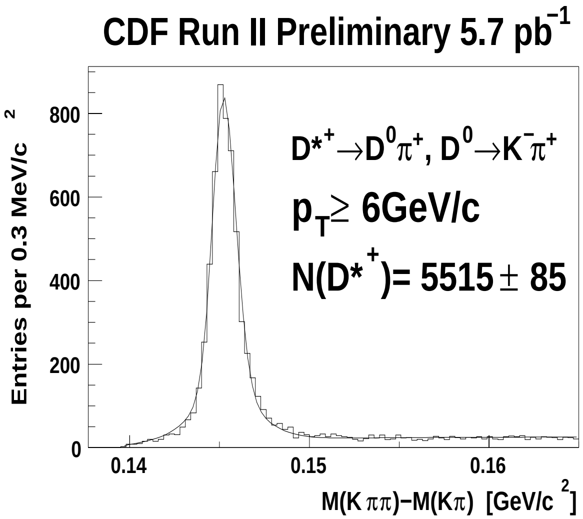
- comparable to 2002 PDG: (used only 9.6 pb^{-1})

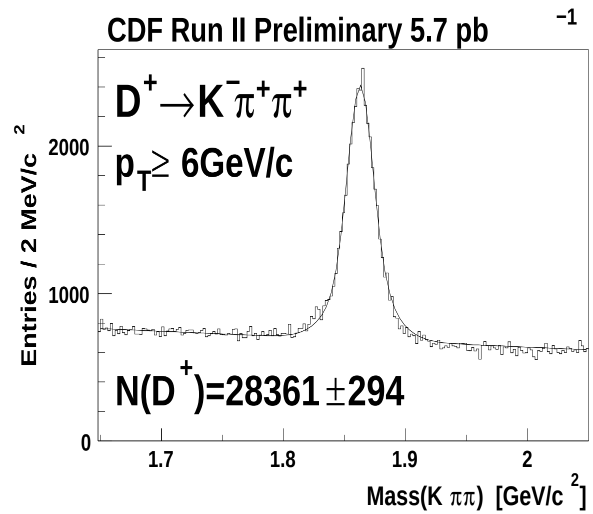
$$\frac{\Gamma(D^0 \to K^+K^-)}{\Gamma(D^0 \to K^-\pi^+)} = (10.40 \pm 0.33 \pm 0.27)\%$$

$$\frac{\Gamma(D^0 \to \pi^+\pi^-)}{\Gamma(D^0 \to K^-\pi^+)} = (3.51 \pm 0.16 \pm 0.17)\%$$

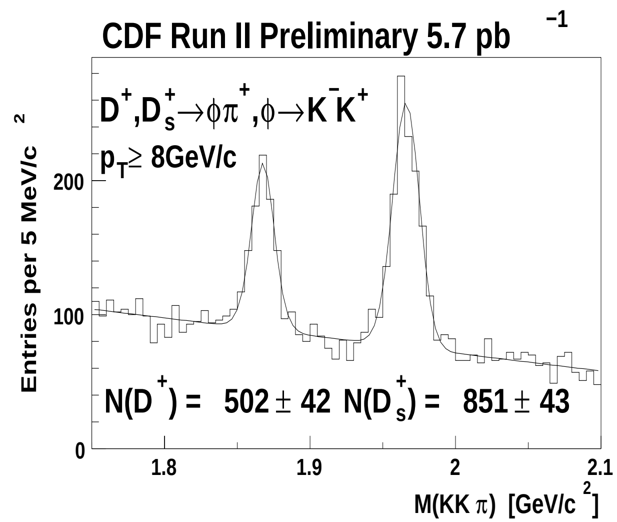
Charm Meson Cross-Section:







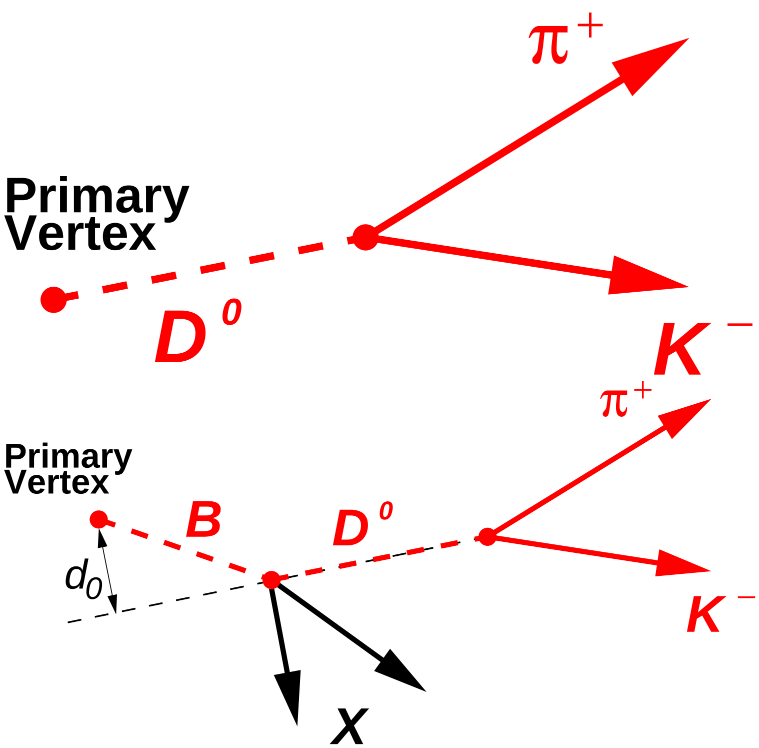
- $d\sigma/dp_T$ of D^0, D^{*+}, D^+, D_s^+
- challenges:
  - direct vs secondary charm
  - detailed trigger study
  - correlations with offline

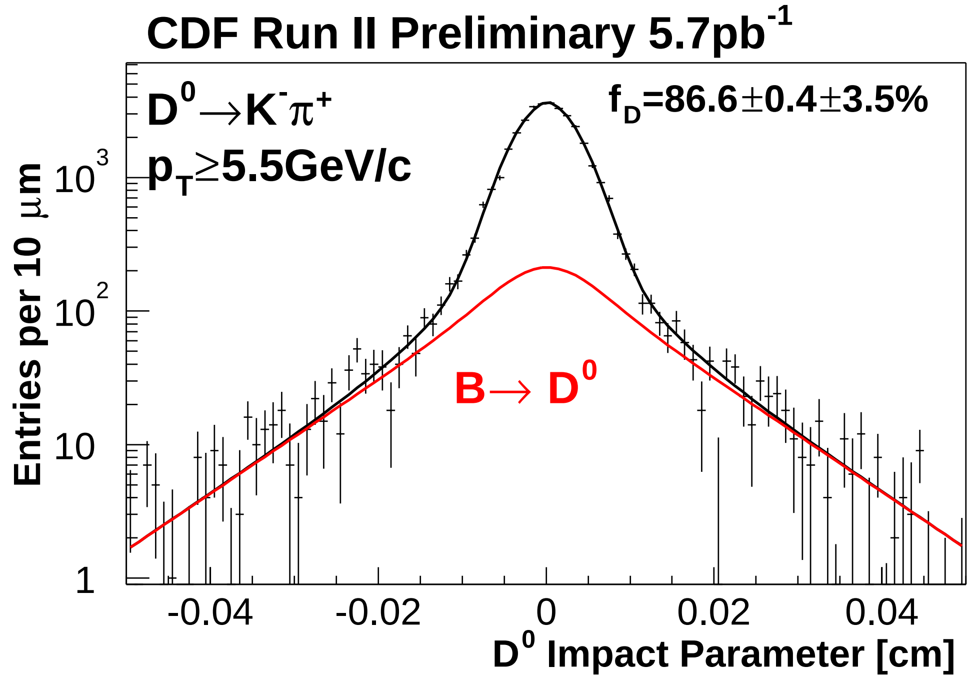


Prompt Vs Secondary Charm:

- discriminating variable:

  meson impact parameter





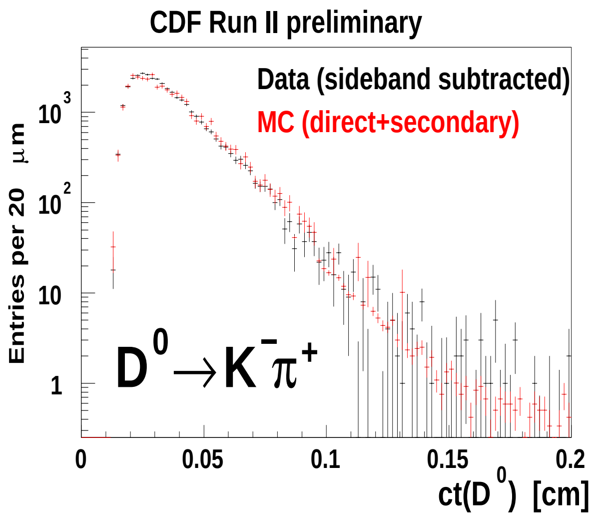
- d_0 resolution function:

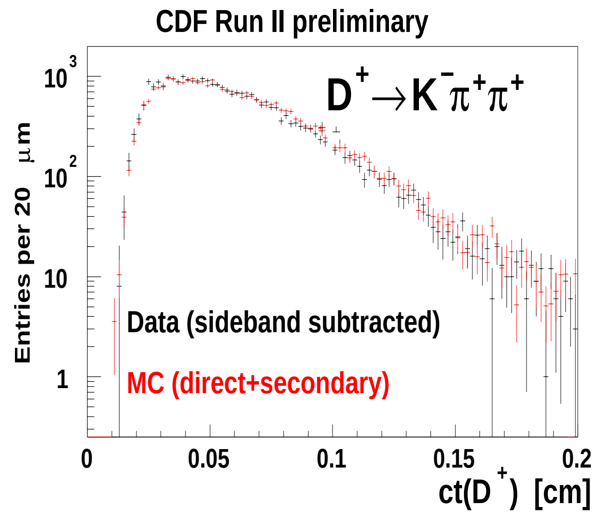
  from $K^0_S \to \pi^+\pi^-$ decays

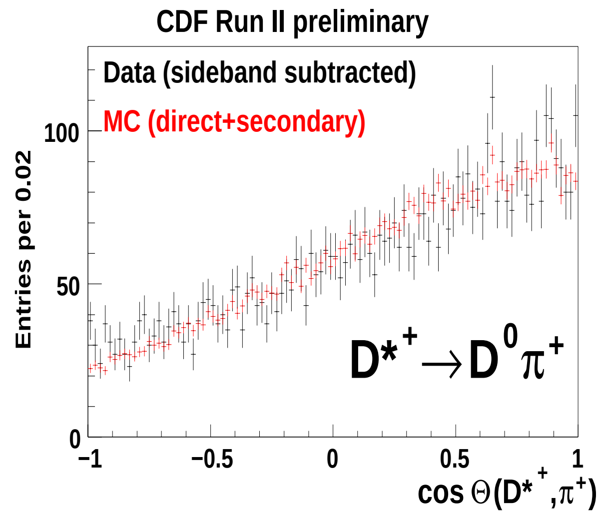
most charm is prompt:

$$f_D(D^0) = 86.6 \pm 0.4 \pm 3.5\%$$
$$f_D(D^{*+}) = 88.1 \pm 1.1 \pm 3.9\%$$
$$f_D(D^+) = 89.1 \pm 0.4 \pm 2.8\%$$
$$f_D(D_s^+) = 77.3 \pm 3.8 \pm 2.1\%$$

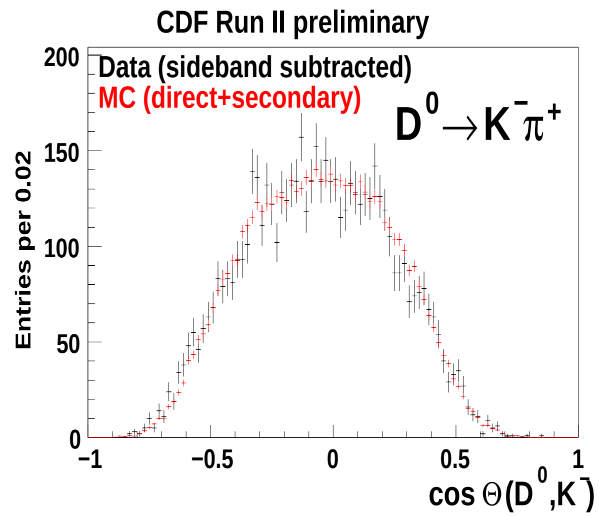
Trigger And Offline Simulation:



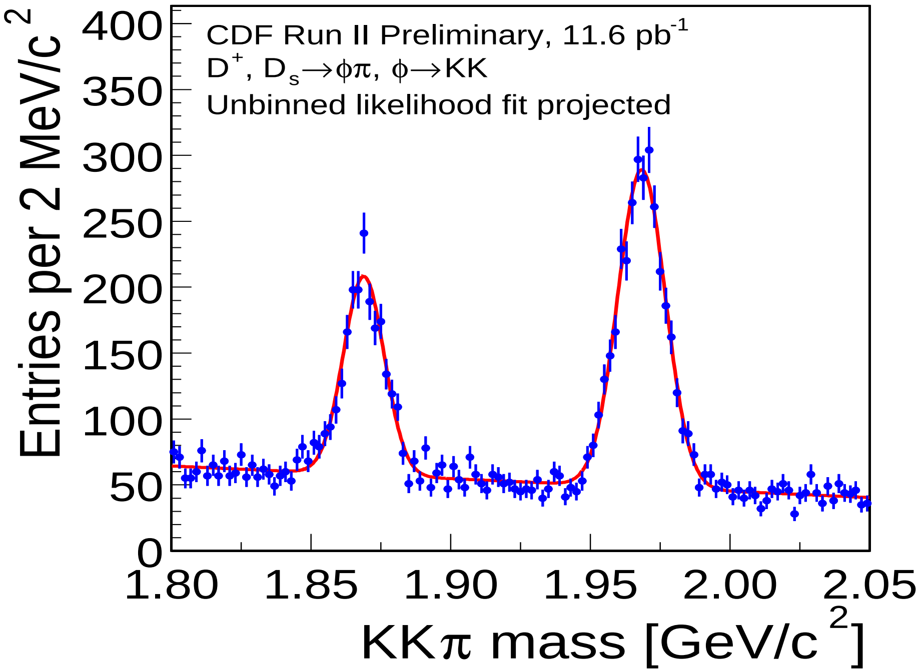


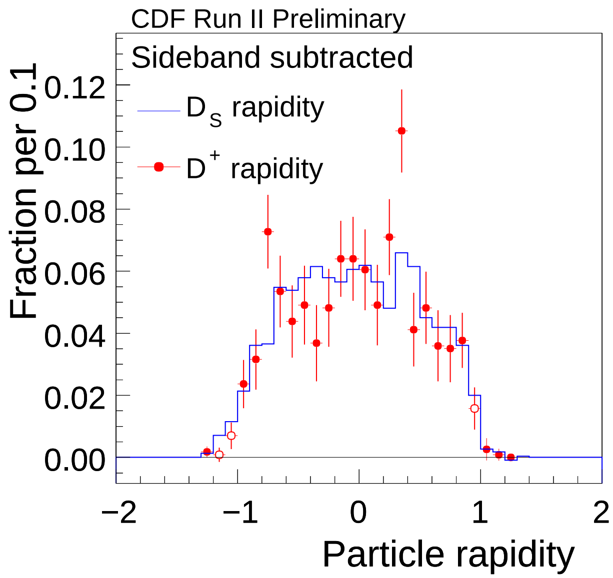


- **succesfully simulated:**
  - **track triggers**
  - **two-track correlations**
  - **correlations with offline**
- **properly reproduce data**
- **final result coming soon..**

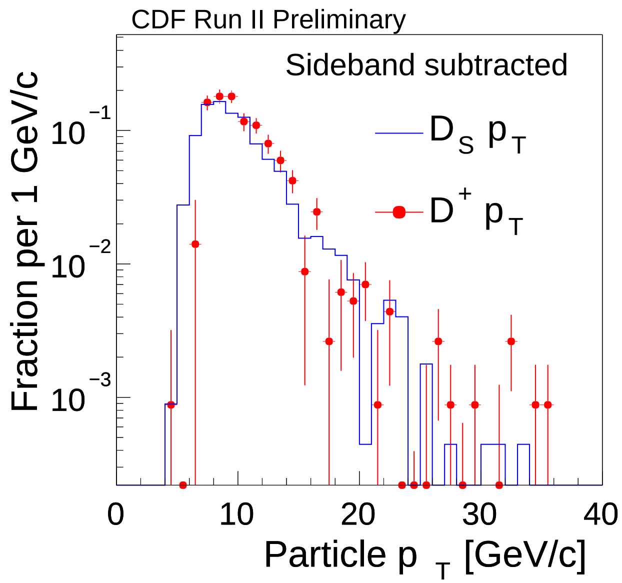


$m_{D_s^+} - m_{D^+}$ Mass Difference



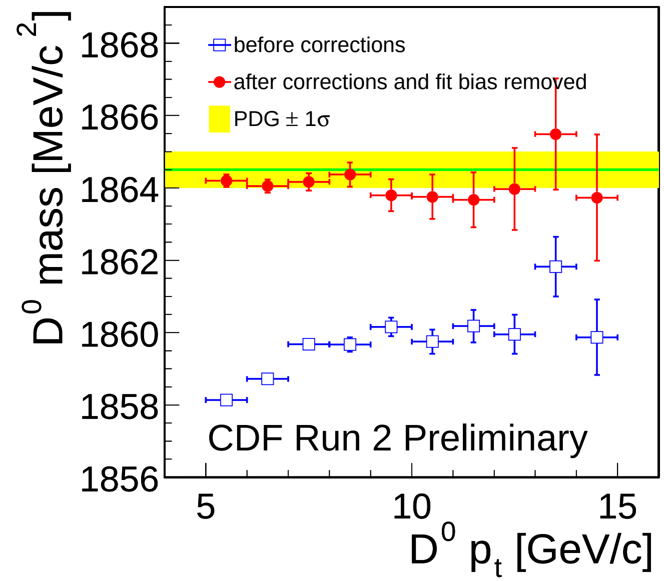


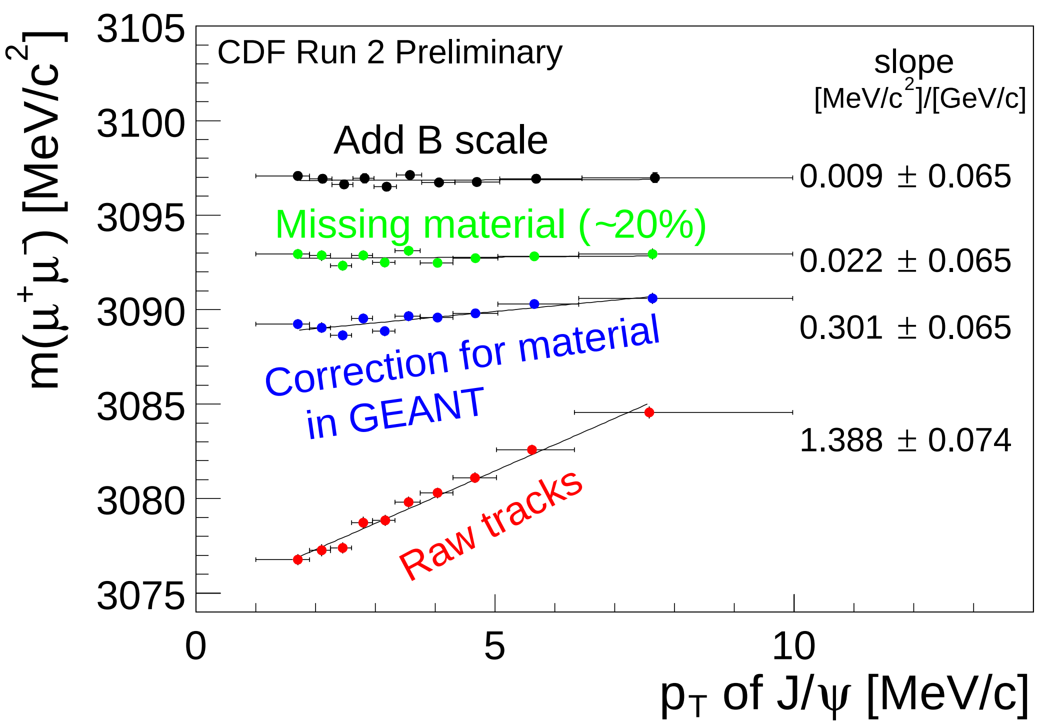
- $1.4\text{k } D^+, 2.4\text{k } D_S^+ \to \phi\pi^+$
- **mass resolution** $\sim 8\,\text{MeV}/c^2$
- **similar kinematics**
- **expect small syst. errors**

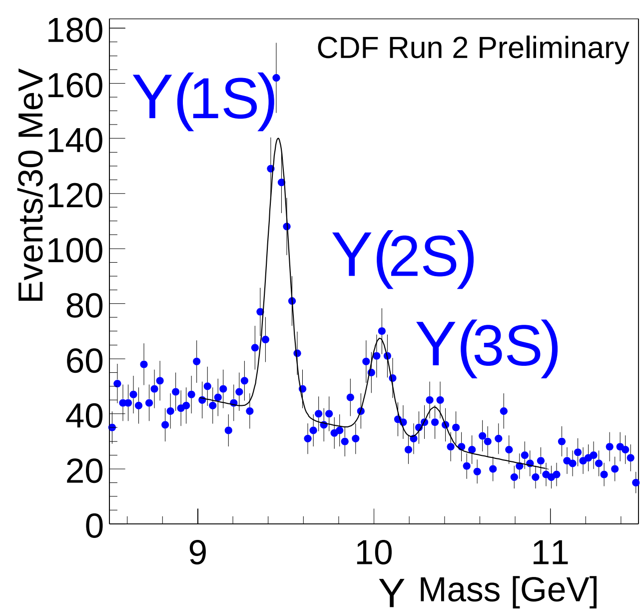


Momentum Scale Calibration

- study J/ψ's to calibrate:
  - energy loss in detector
  - magnetic field value
- crosscheck with other decays







Mass Difference Result:

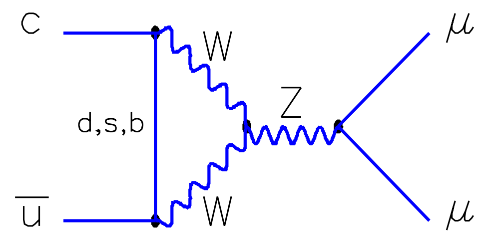
$$m(D_s^+) - m(D^+) = 99.41 \pm 0.38(stat) \pm 0.21(syst)\ \mathrm{MeV}/c^2$$

- **systematics small, dominated by bkg model:**

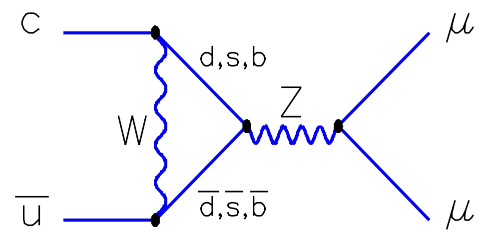
Effect	Syst. $[\mathrm{MeV}/c^2]$
fitting	0.14
event selection	0.11
momentum scale	0.10
tracker effects	0.06
calibration procedure	0.03
Total	0.21

- **PDG '02:** $99.2 \pm 0.5\ \mathrm{MeV}/c^2$
- **CLEO2 (1998):** $99.5 \pm 0.6 \pm 0.3\ \mathrm{MeV}/c^2$
- **BaBar (2002):** $98.4 \pm 0.1 \pm 0.3\ \mathrm{MeV}/c^2$
- **submitted to PRD**

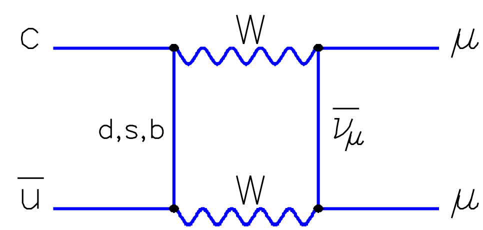
Search for $D^0 \to \mu^+\mu^-$

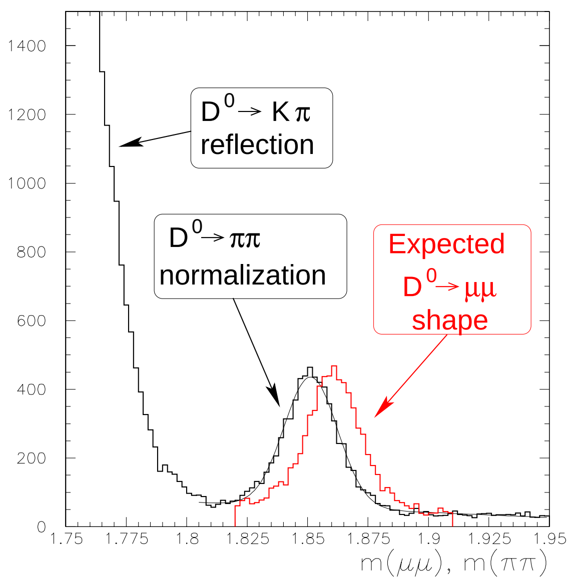


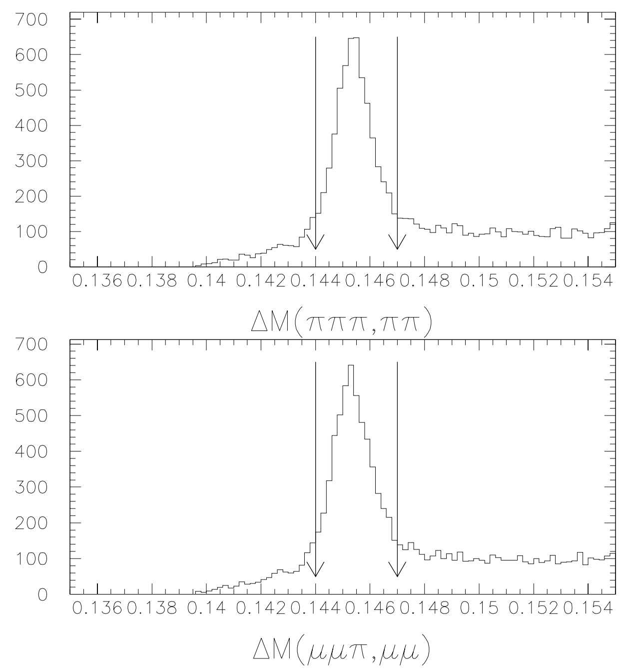
- estimated $BR_{SM} \approx 3 \times 10^{-13}$

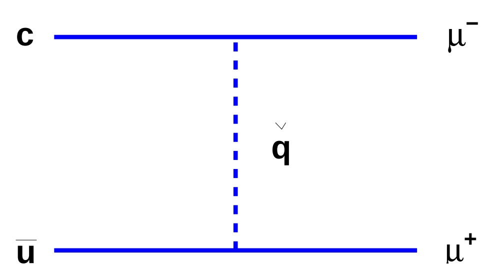


- $\not{R}$ SUSY: $BR \sim 3.5 \times 10^{-6}$
- $D^0 \to \mu\mu$ looks like $D^0 \to \pi\pi$ (with two muon tags)







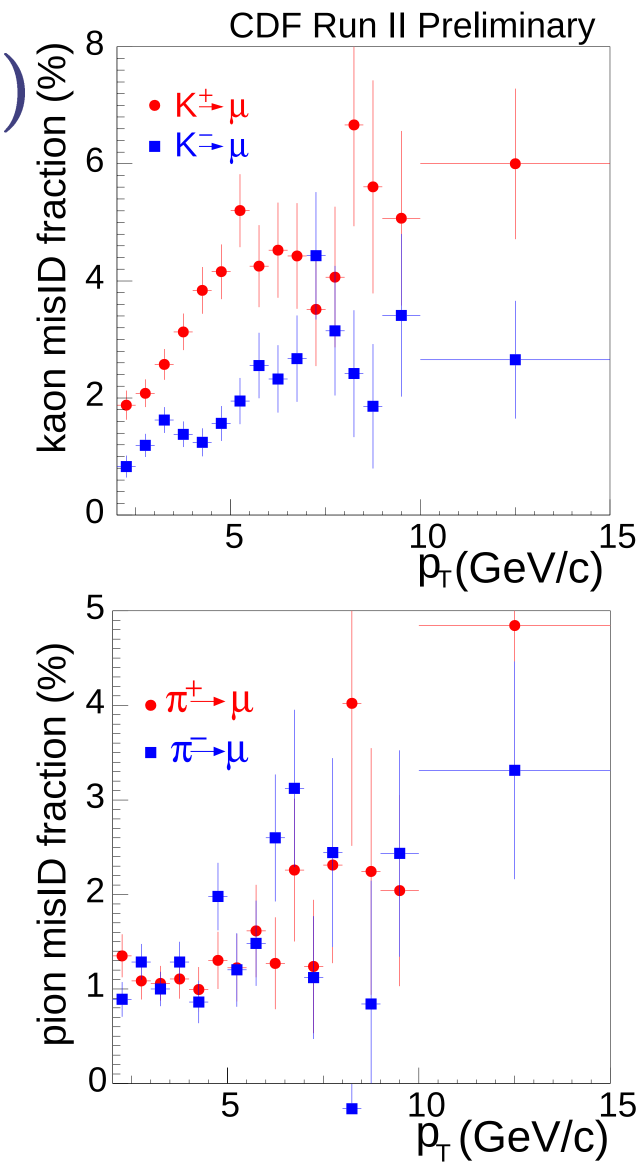


FCNC Search Cont'd

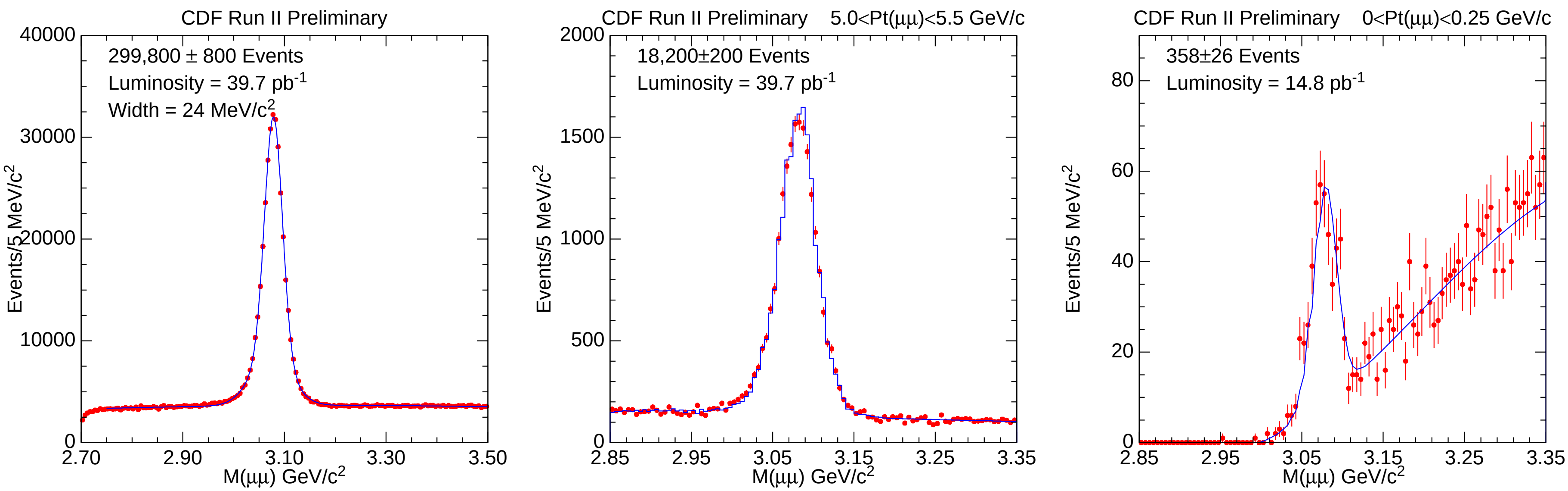
- normalize to $BR(D^0 \to \pi\pi)$

$\Rightarrow$ need only rel. efficiency

- understand backgrounds:
  - $2\times$ mistagged $D^0 \to \pi\pi$
  - combinatorics
- study in high sideband of $D^{*+} \to D^0\pi^+, D^0 \to \pi\pi$
- muon fake rates $\sim 1\%$
- blind analysis
- "box" opens tomorrow



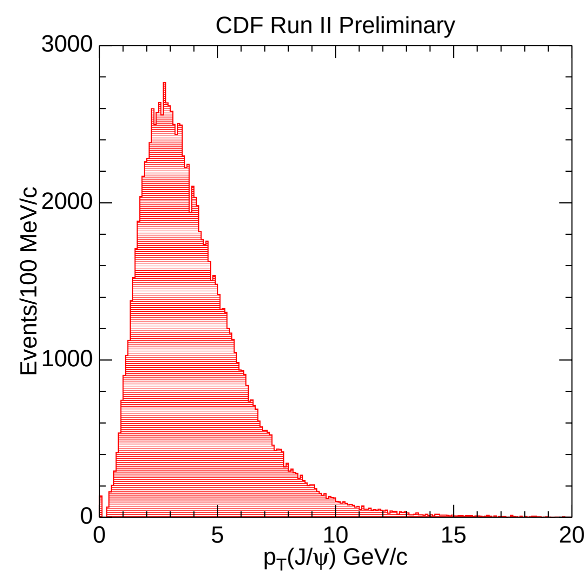
J/ψ Cross-Section



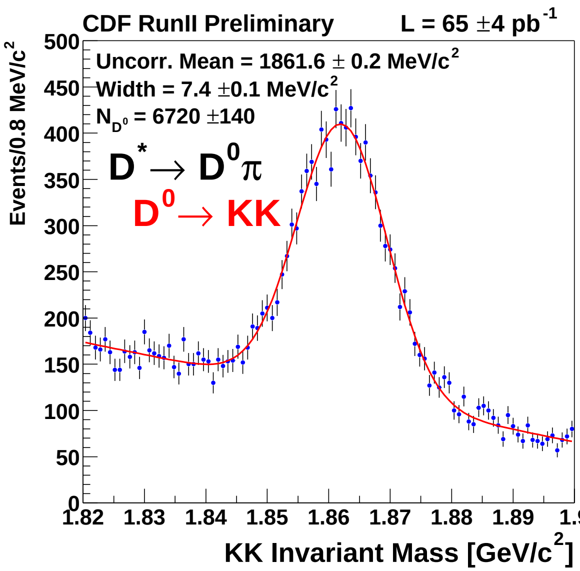
- $J/\psi \to \mu^+\mu^-$, **dimuon trigger**
- **Feb - Oct '02** $\longrightarrow$ **300K** J/ψ
- **like Run I,** $|y(J/\psi)| < 0.6$, **but**
- $p_T(\mu^\pm) \geq 1.5$ GeV$/c$ **(new!)**

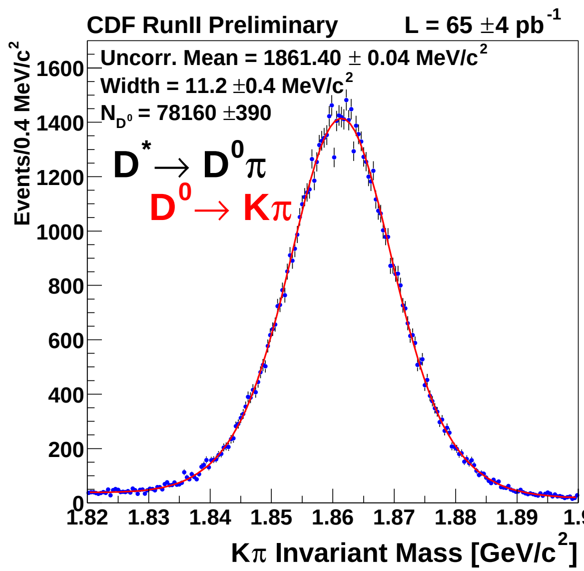
$\Rightarrow p_T(J/\psi) \geq 0$ GeV$/c$

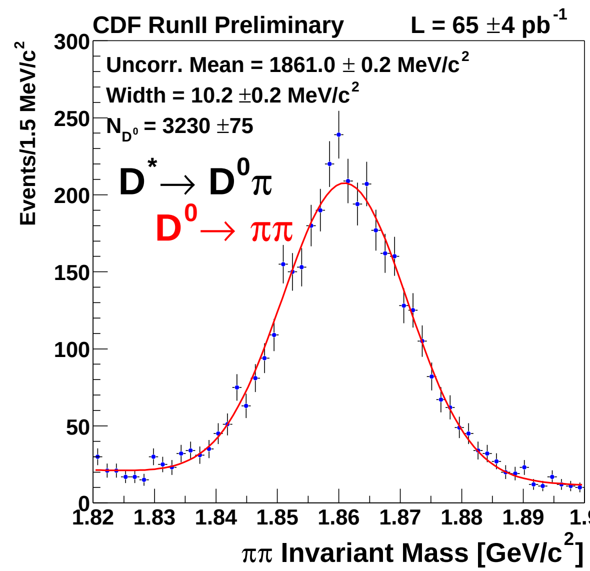
- **final result coming soon...**



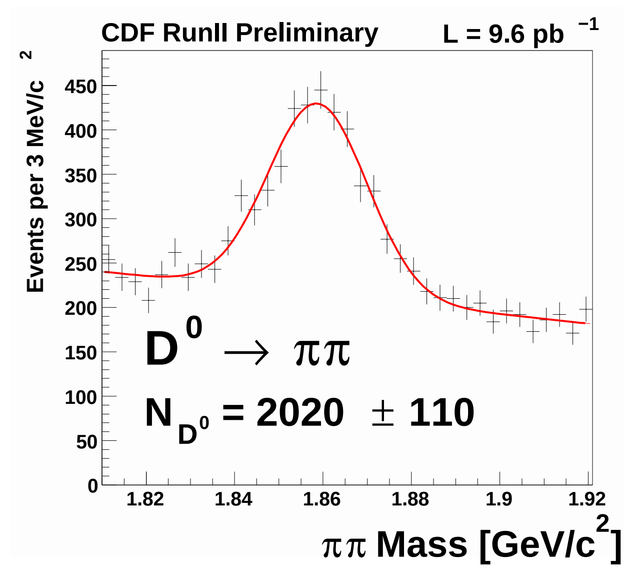
Data Are Rolling In:



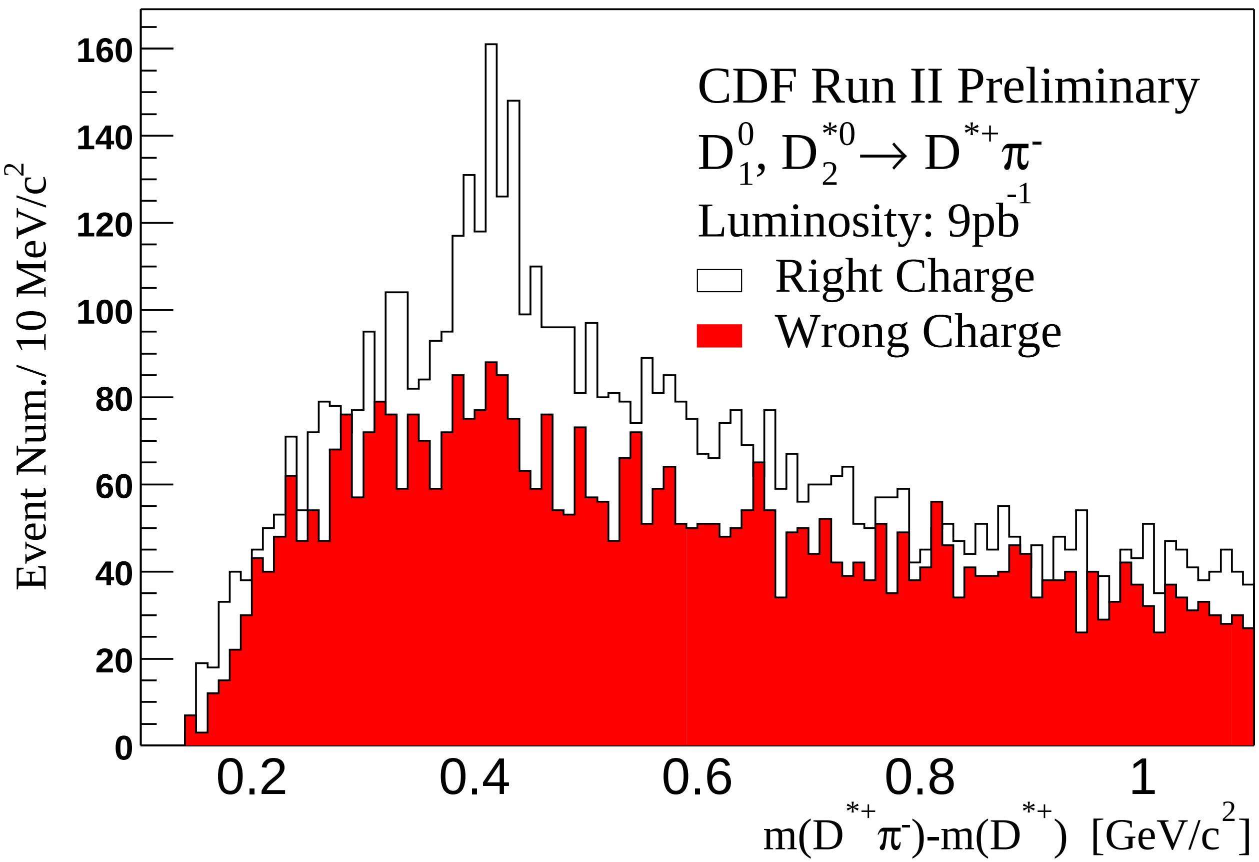




- use 65 pb^{-1} of data
- clean up with $D^* \to D^0\pi$
- more signal, much better S/B
- improve BR measurement (largest syst. from bkg model)
- measure lifetimes



Work In Progress (Summer):



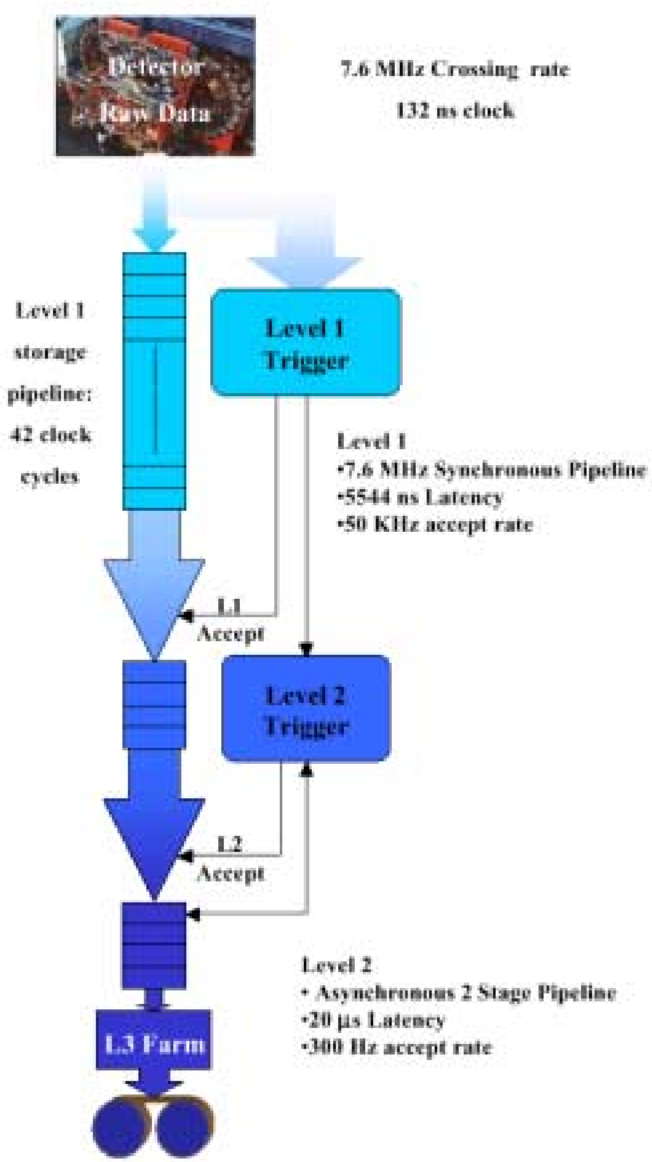
- $D^{**} \rightarrow D^{*+}\pi^-, D^{*+} \rightarrow D^0\pi^+$ **studies**
- **more rare decays:** $D^0 \rightarrow \mu e$, $D^0 \rightarrow \mu\mu\pi$

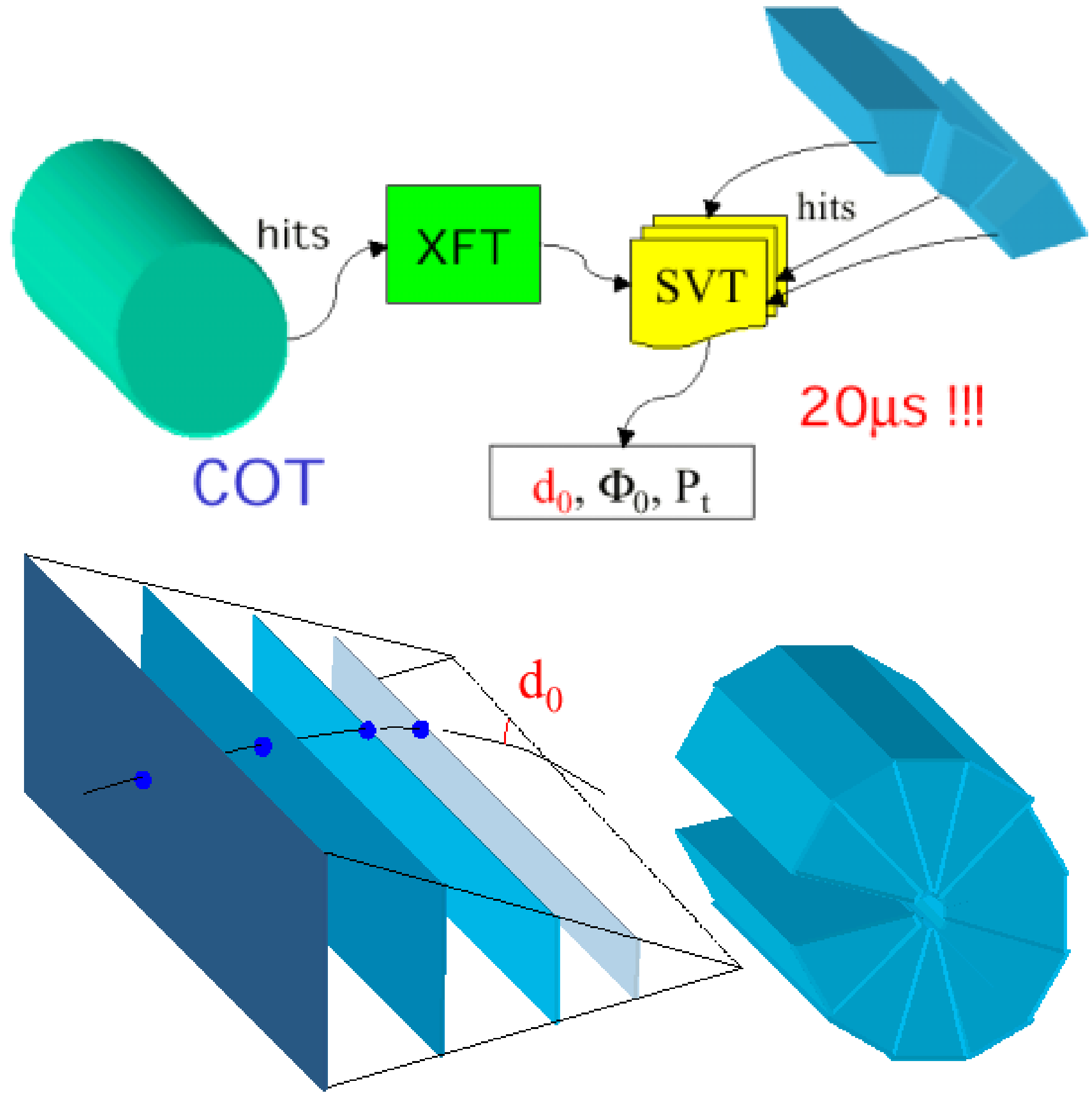
Summary

- **SVT made charm analyses possible**
- **first results with small samples comparable to world averages**
- **results to come soon: rare decays, cross sections**
- **after that: D^{**}, more rare decays, lifetimes, CP**
- **data gathering continues ..**
- **estimated $\mathcal{O}(10^7)$ $D^0 \to K^-\pi^+$ decays in 2 fb $^{-1}$**
- **trigger, detector understanding constantly improving**
- **beginning of a diverse and competitive charm program**

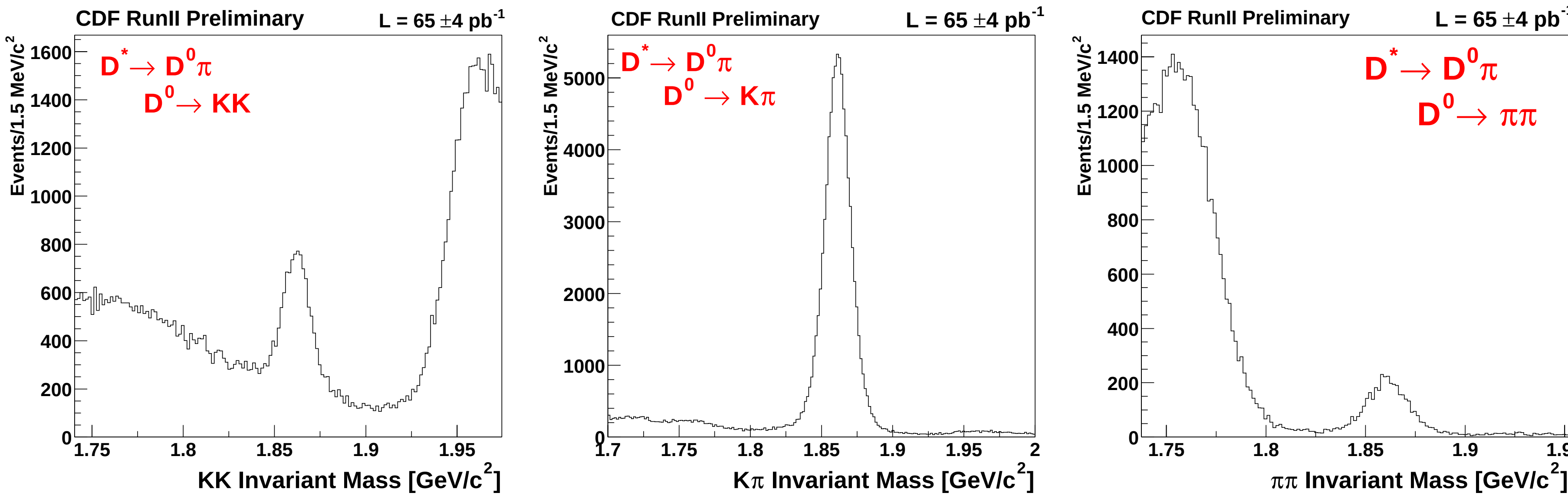
Backup Slides

What Does SVT Do?





D^0 Decays, Extended View



- **reflection peaks are well separated from the signal peaks**

- **bump on the low end of the K^+K^- plot from partially reconstructed charm**