CP violation and CKM measurements in Bottom and Charm decays at CDF

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On behalf of the CDF collaboration

6th Int. Conf. on Hyperons, Charm and Beauty Hadrons

Chicago, July 1st 2004

Contents:

- Introduction: b-Physics at the hadron collider
- Charm-less b-decays
  - $B_u \rightarrow \varphi K^{\pm}$
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  - $B_{d,s} \rightarrow h^{\pm} h^{\mp}$ ($h = K, \pi$)
- CP violation in charm decays
  - $D_0 \rightarrow \pi \pi$, $K K$
- Conclusions and perspective

Moment analysis: see separate talk by R. Miquel,
Mixing & detector issues have been covered by J. Piedra.

Introduction

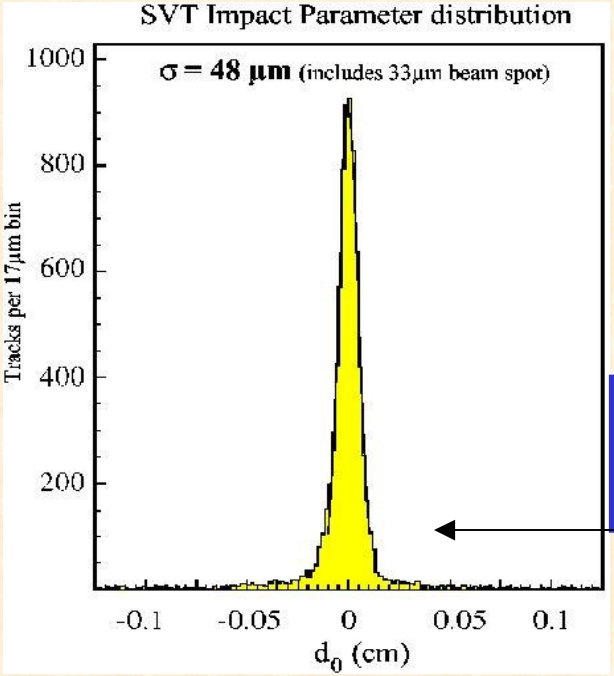
3 sources of A_{CP}:

- A_{CP} from mixing: neutral meson oscillate with different phase, mass eigenstates not CP eigenstates.
- **A_{CP} direct: $A_f \neq A_{\bar{f}}$ in SM from interference of weak and strong phases in decay.**
- A_{CP} from the interference of mixing and direct A_{CP}

Tevatron excellent source of b-hadrons, $\sigma_b = 29.4 \pm 0.6 \pm 6.2$ μb ($|y| < 1$) (CDF)
New hadronic trigger, based on tracking→ new channels available.

- Charm-less b-decays
  - $B_u \rightarrow \varphi K^{\pm}$ Direct A_{CP}
  - $B_s \rightarrow \varphi \varphi$ mixing & direct A_{CP} (presently $\mathcal{BR}$ only)
  - $B_{d,s} \rightarrow h^{\pm} h^{\mp}$ ($h = K, \pi$) Direct only or mixing & direct
- CP violation in CKM-suppressed charm decays
  - $D_0 \rightarrow \pi \pi$, K K Search for direct Asymmetry

Introduction: trigger strategies



Select b-events: 1 in 10^3

Hadronic trigger (2-track-trigger)

In addition to

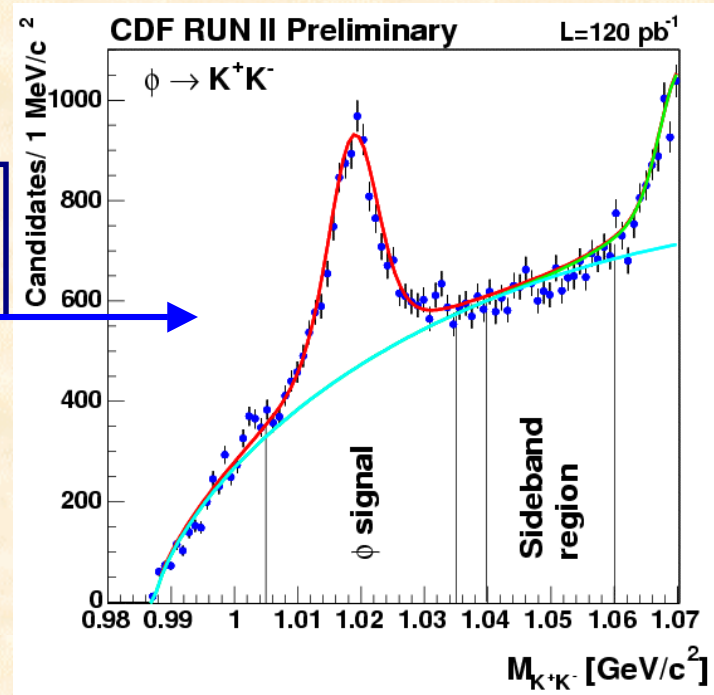
- soft-lepton trigger (updated!)
- J/Ψ trigger

On-line resolution:
33 μm beam ⊕ 35μm intrinsic

Trigger requires:

- 2 opposite charge tracks,
- each $P_t \geq 2$ GeV/c,
- impact parameter (d_0) > 120 μm
- Scalar pt sum > 5.5 GeV/c
- Projected decay L_{xy} > 200 μm
- Polar angle difference $2° < \Delta\phi < 90°$

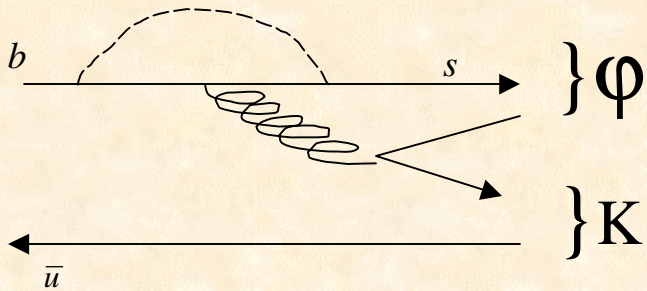
ϕ signal from hadronic trigger

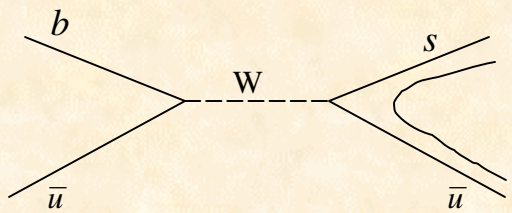


First case: $B^{\pm} \rightarrow \varphi K^{\pm}$

B→ VP

Almost pure penguin (annihilation at tree level)





EW penguin contribution expected ~10%.
Expect very little asymmetry, probe for new Physics.

Already measured by Belle and BaBar, proof of principle, bench test and measurement with comparable errors (< 2×).

$B^{\pm} \rightarrow \varphi K^{\pm}$: the method

Control sample:

$B_u \rightarrow J/\Psi K^{\pm}$ same event topology, same trigger, different angular distribution.

Un-binned maximum likelihood fit

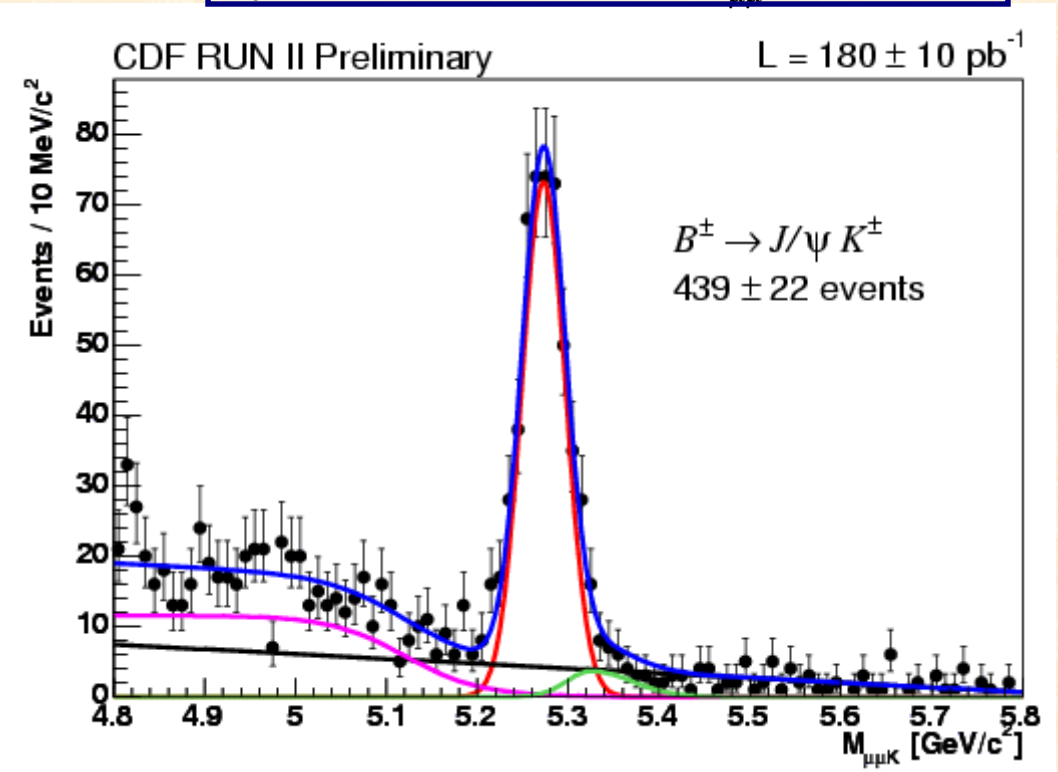
- 3-track invariant mass
- Two-track invariant mass
- Helicity angle
  (φ or J/Ψ polarization)
- Specific ionization (dE/dx)

Use templates for physical background, based on MC

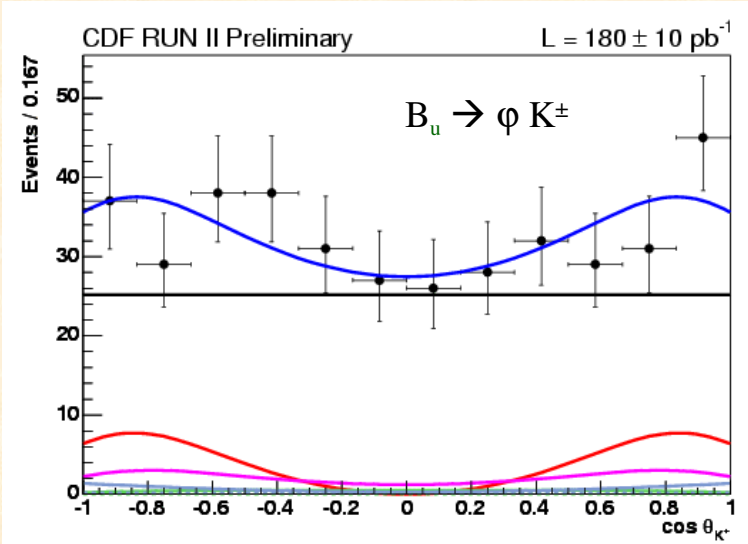
Fit at the same time for CP asymmetry, yield, mass, (Background)

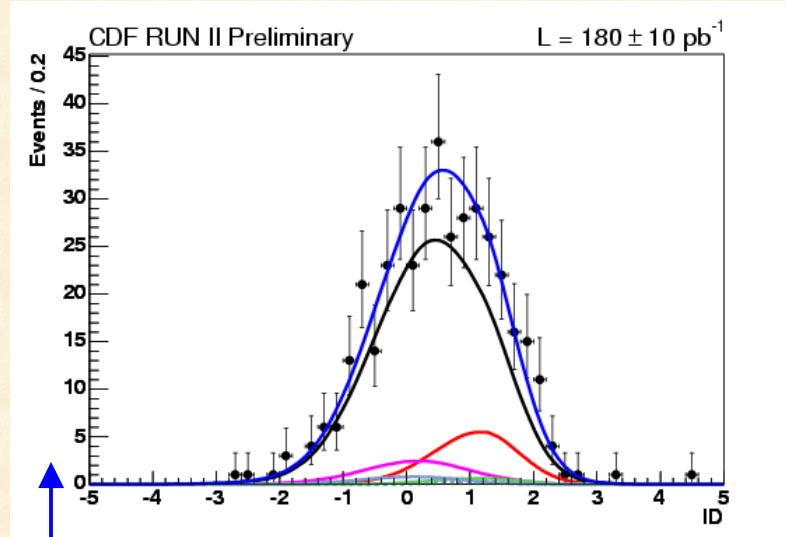
Analysis cuts:

$L_{xy} > 350\mu m$	Isolation$_{(R<1.0)} > 0.5$
Vertex $\chi^2 < 8$	$1 < M_{KK} < 1.06 GeV/c^2$
$P_t^{soft} > 1.3 GeV/c$	$5 < M_{KKK} < 5.6\ GeV/c^2$
$d_0(B) < 100\ \mu m$	$\Delta M_{\mu\mu} < 100 MeV/c^2$



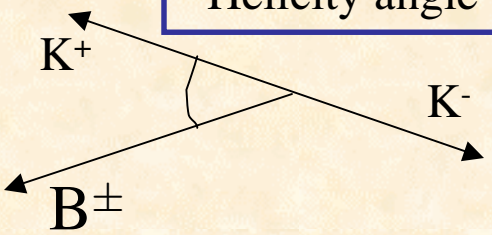
Signal in $B^{\pm} \rightarrow \varphi K^{\pm}$





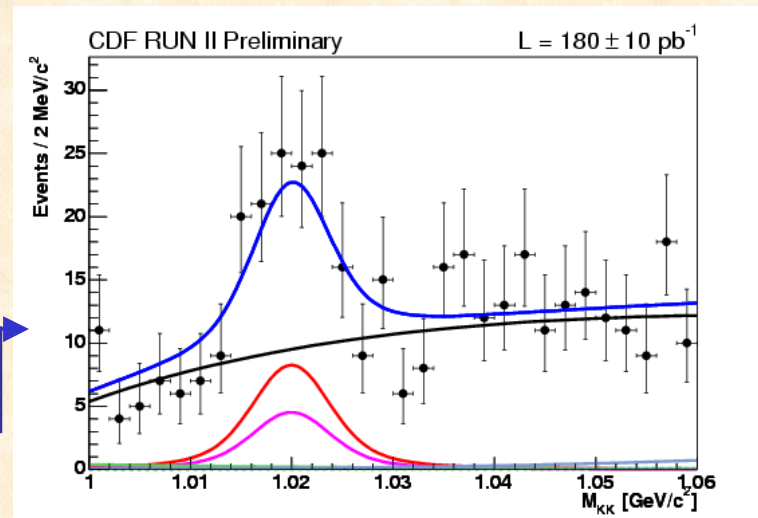
"Helicity angle"

χ^2/d.o.f = 17.5/14; P=23%



Particle ID: dE/dx in central tracking chamber

φ mass



Signal in $B^{\pm} \rightarrow \varphi K^{\pm}$

Red: signal template

Black: combinatorial background

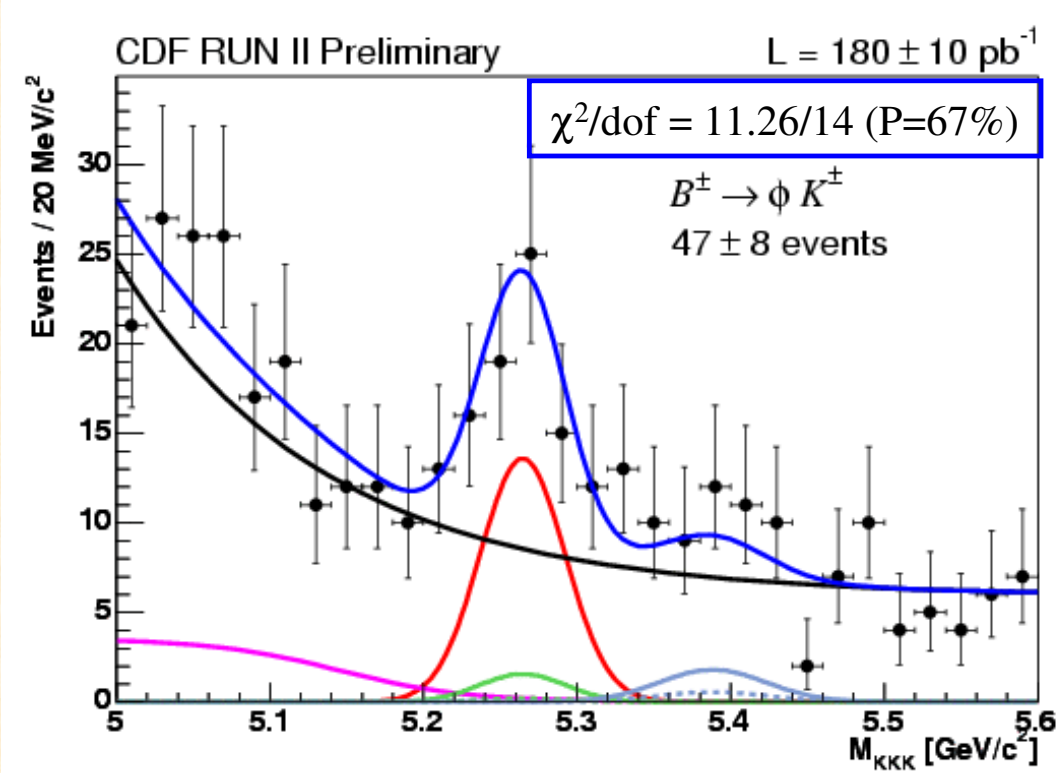
Physical backgrounds:

Partially reconstructed B's

$B^{\pm} \rightarrow f_0 K^{\pm}$

$B^{\pm} \rightarrow K^{\pm} K^{\mp} K^{\pm}$

$B^{\pm} \rightarrow K^{0*} \pi$



Direct A_{CP} in $B_u \rightarrow \varphi K^{\pm}$

Fit results

Parameter	$B_u \rightarrow J/\Psi K^{\pm}$	$B_u \rightarrow \varphi K^{\pm}$
Signal (evts)	439 ± 22	47.0 ± 8.4
A_{CP}	**0.046 ± 0.050**	**-0.07 ± 0.17**

Systematic errors:

Detector asymmetry: 5% in this analysis from $J/\Psi K^{\pm}$; Can be factor 10 better

Fit templates and method give 2.5%

$$A_{CP} = \frac{\Gamma_{B^- \rightarrow \phi k^-} - \Gamma_{B^+ \rightarrow \phi k^+}}{\Gamma_{B^+ \rightarrow \phi k^+} + \Gamma_{B^- \rightarrow \phi k^-}} = -0.07 \pm 0.17^{+0.06}_{-0.05}$$

Branching fraction measured w.r.t control channel,
Cancellation of most systematic errors: ε(abs) → ε(rel),
ε trigger and reconstruction from MC.

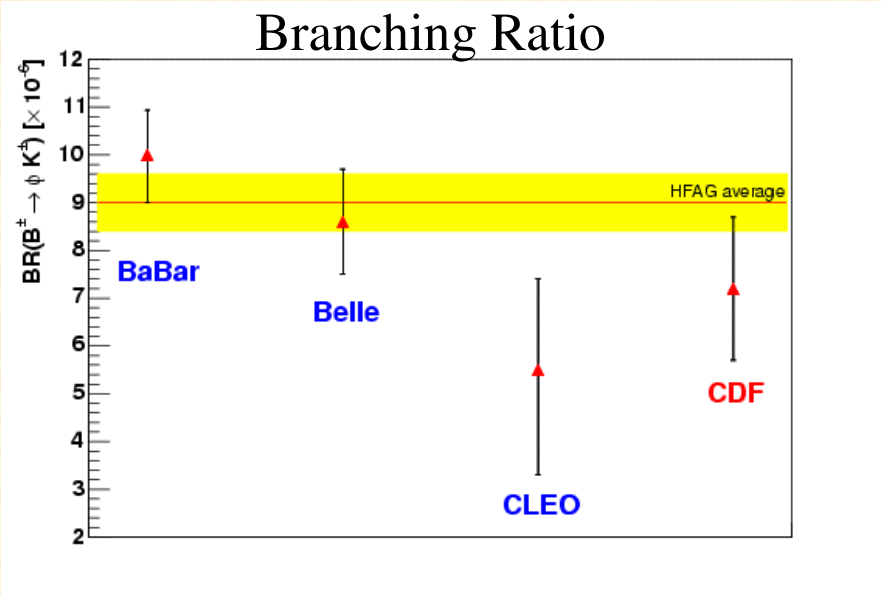
$$\mathcal{BR}(B^{\pm} \rightarrow \phi K^{\pm}) / \mathcal{BR}(B^{\pm} \rightarrow J/\Psi K^{\pm}) = (7.2 \pm 1.3 \pm 0.7) \times 10^{-3}$$

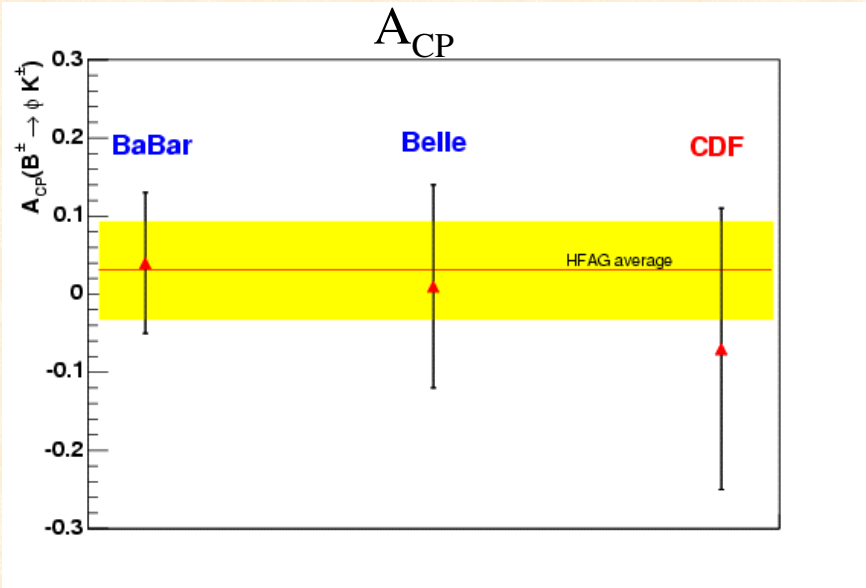
Using PDG value: $\mathcal{BR}(B^{\pm} \rightarrow \phi K^{\pm}) = (7.2 \pm 1.3 \pm 0.7) \times 10^{-6}$

Main systematic on BR is
Particle-dependant trigger efficiency

Measurement limited by statistics:
with $2fb^{-1}$ σ_{stat} / 3 and σ_{sys} / 10 on A_{CP}

A_{CP} (HFAG) = 0.03 ± 0.07



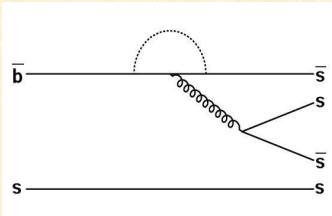


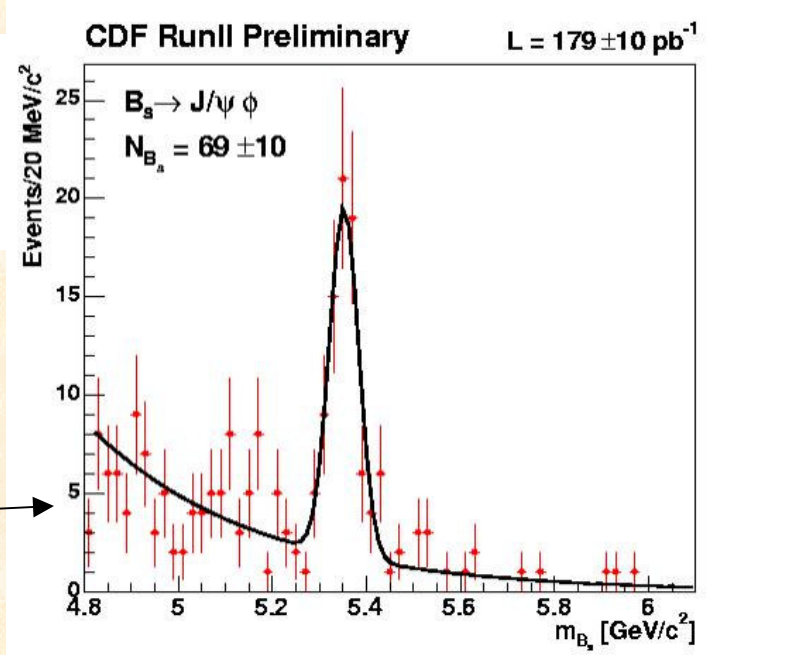
Second case: $B_s \rightarrow \varphi\,\varphi$

Motivations:

- Penguin diagram decay, never observed before.
- Decay to vector-vector, not CP eigenstate, but angular analysis possible in future, other method for $\Delta\Gamma_s$.
- Same final state accessible by both initial states.
- No or very little direct asymmetry expected in this channel by SM.

  Rare penguin→ Probe for new physics





Method:

- Cut-based blind analysis:
  - Optimize cuts on MC + data background
- Establish signal, then fit analysis.
- Reference channel:

  $B_s \rightarrow J/\Psi\ \phi$

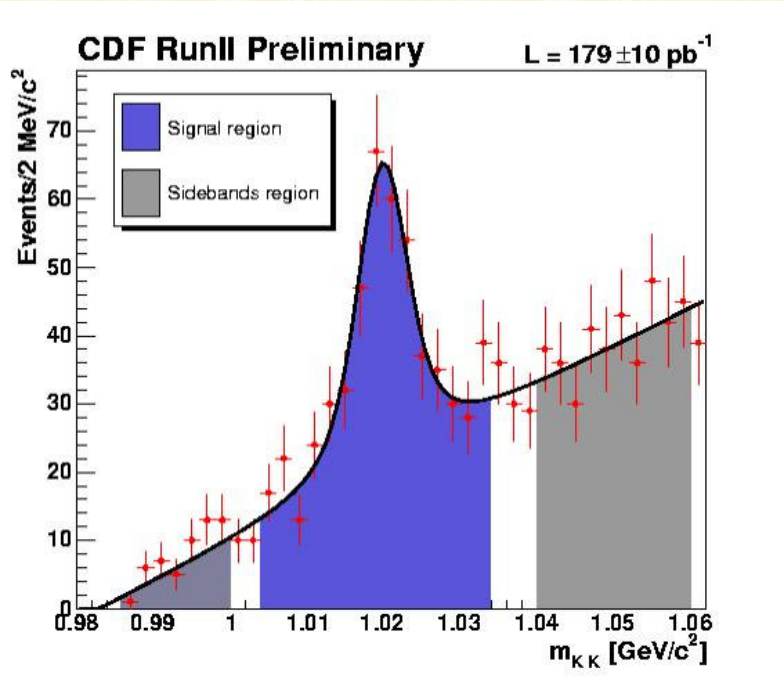
$B_s \rightarrow \varphi\,\varphi$ Analysis highlights:

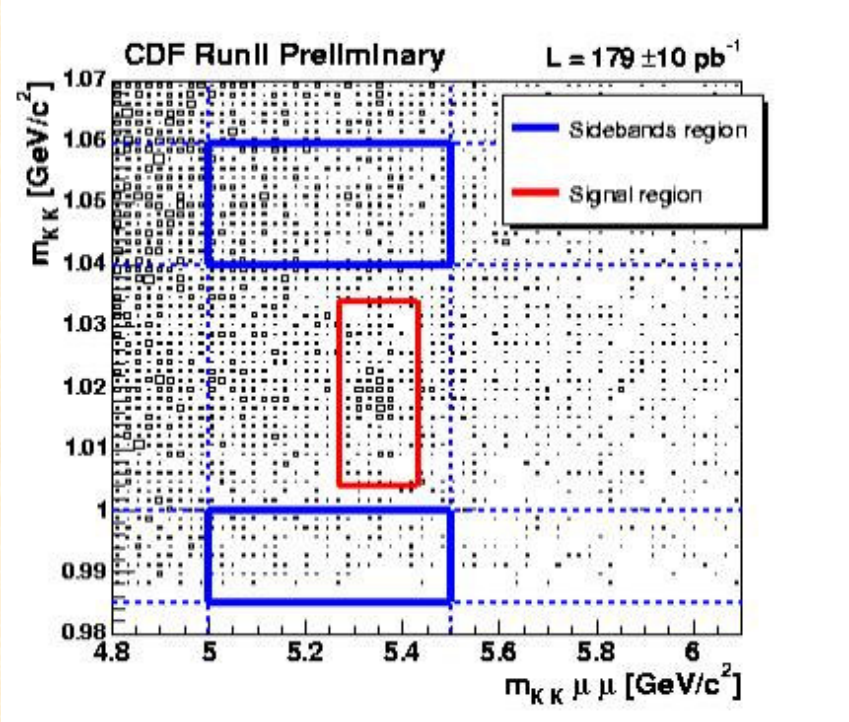
Optimize cuts based on MC
Projection of decay length L_{xy},
$P_t(\phi_1)$, $P_t(\phi_2)$, χ^2
pointing constraint $d_0(B_s)$,
impact parameter of reconstructed ϕ,

Maximize the score function

$$\Sigma = \frac{S}{1.5+\sqrt{B}}$$

optimization independent on MC sample size. Optimized for 3σ significance.

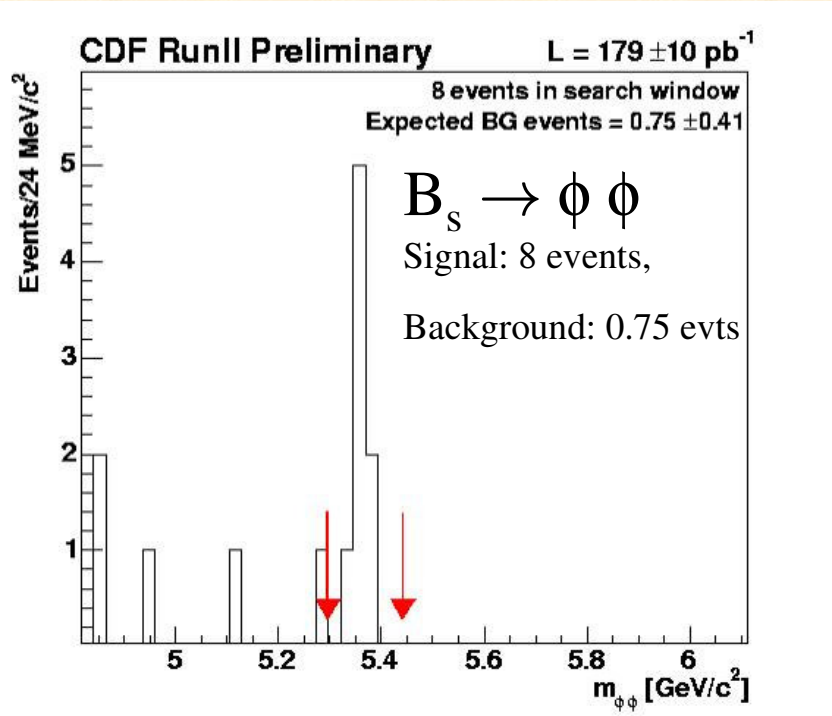




$B_s \rightarrow \varphi\,\varphi$ results

Analysis cuts:

- $d_0(B_s) < 80\ \mu m$
- $P_t(\varphi) > 2.5$ GeV/c
- $L_{xy} > 350\ \mu m$
- $\chi^2_{xy} < 10$
- Cuts slightly depending on trigger topology



$$BR(B_s \rightarrow \varphi\varphi) = \frac{N(B_s \rightarrow \varphi\varphi)}{N(B_s \rightarrow \psi\varphi)^{corr}} \frac{\varepsilon(\psi\varphi)}{\varepsilon(\varphi\varphi)} \cdot \frac{BR(B_s \rightarrow \psi\varphi).BR(J/\psi \rightarrow \mu^+\mu^-)}{BR(\varphi \rightarrow K^+K^-)}$$

From MC

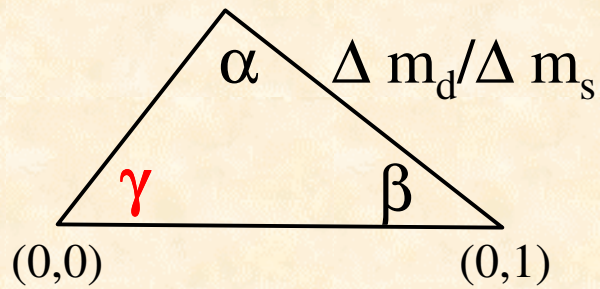
From PDG

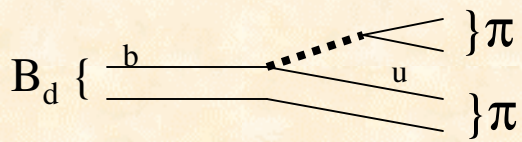
$$\mathcal{BR} = (1.4 \pm 0.6 \pm 0.2 \pm 0.5\ (BR)) \times 10^{-5}$$

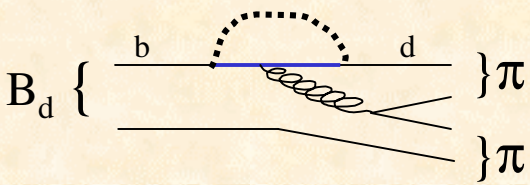
QCD Factorization: $\mathcal{BR} = 3.68 \times 10^{-5}$ (Li-Lu-Yang hep-ph/0309136)

B to 2-body final states

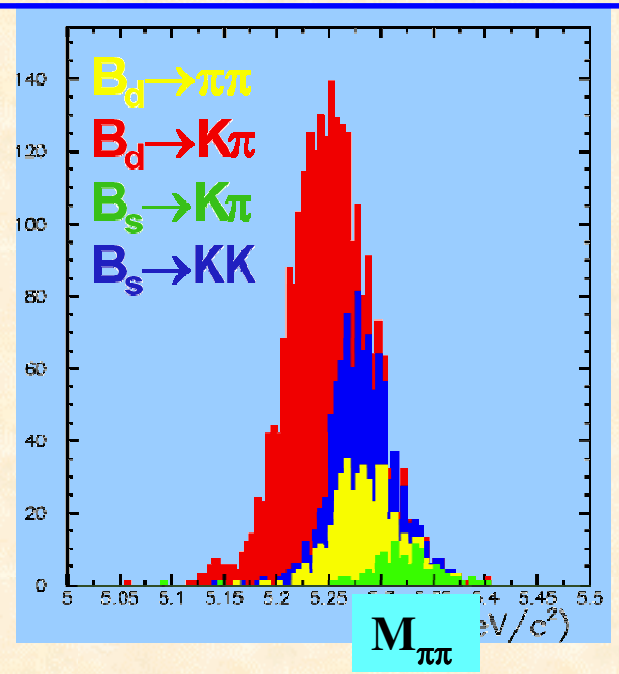
$B_d \to \pi^\pm \pi^\mp$ Tree and penguin amplitudes
$B_d \to K^\pm \pi^\mp$ Weak and strong phases,
$B_s \to \pi^\pm K^\mp$ Direct A_{CP}
$B_s \to K^\pm K^\mp$





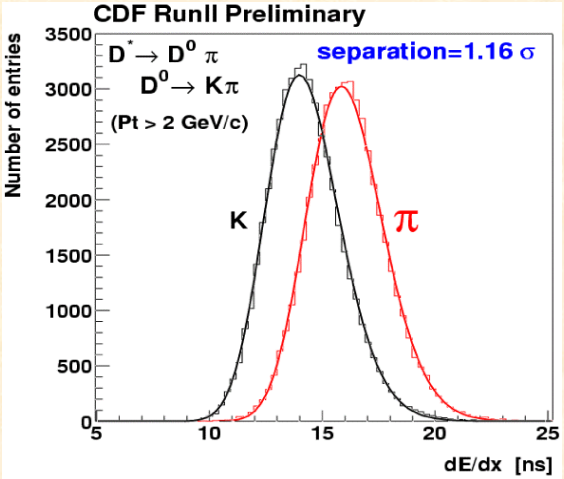


Experimental challenge:
Disentangle the various decays

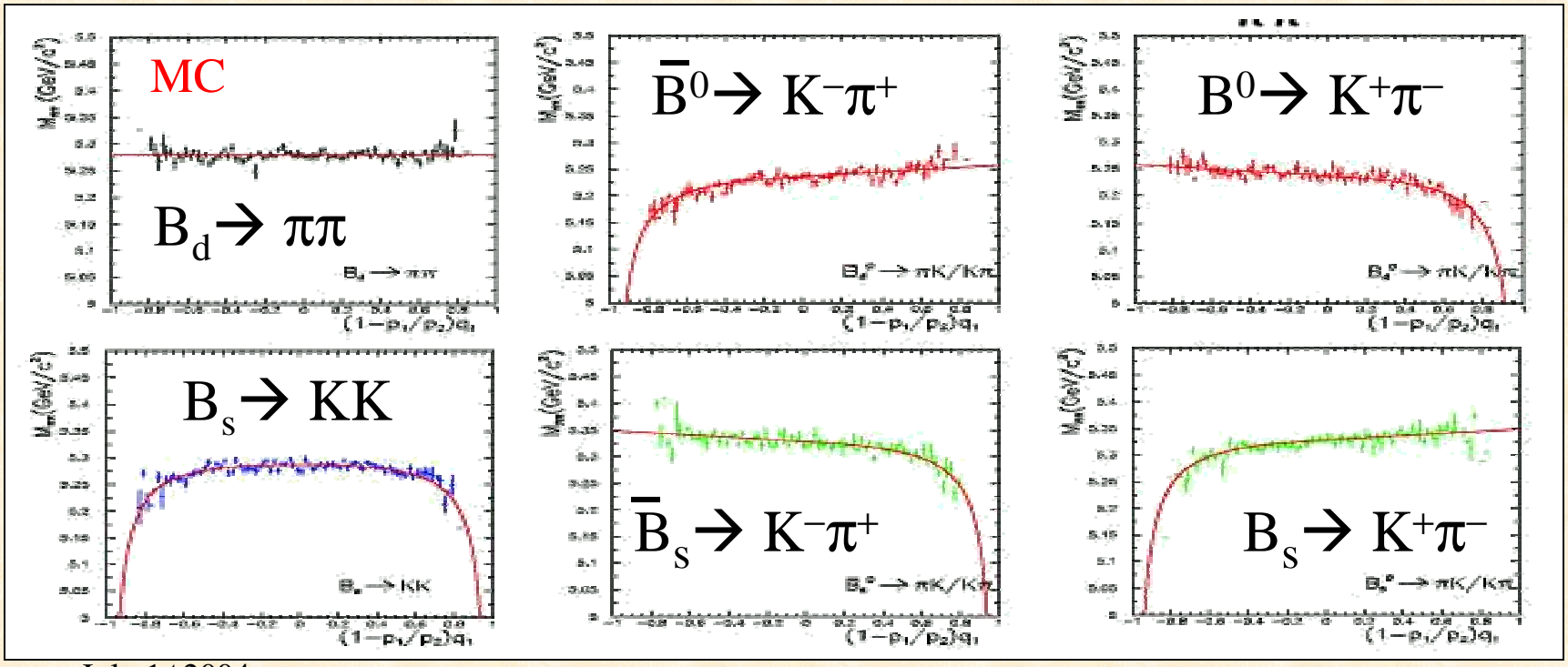


Fleischer method: assume U-spin symmetry
Measure the 4 asymmetries
Fit the 4 A_{CP} as function of
β, γ and Penguin / Tree amplitude ratio

Specific energy loss: K/π separation →
Recently improved to 1.4 σ
Kinematic variables:
mass, charge and momentum unbalance



$M_{\pi\pi}$ vs. $(1 - p_{min} / p_{max})\, Q_{min}$



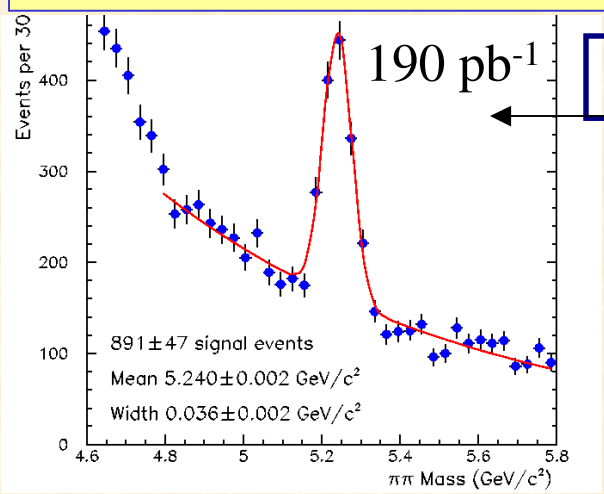
B→ h h Results

All these results using the first 65 pb^{-1}, update to 190 pb^{-1} very soon

$$\frac{BR(B^0{}_d \to \pi\pi)}{BR(B^0{}_d \to K\pi)} = 0.26 \pm 0.11(stat) \ \pm 0.055(syst)$$

$$A_{CP}(K\pi) = \frac{\bar{B}^0 \to K^-\pi^+ - B^0 \to K^+\pi^-}{\bar{B}^0 \to K^-\pi^+ + B^0 \to K^+\pi^-} = 0.02 \pm 0.15 \pm 0.017$$

$$\frac{f_s}{f_d}\frac{BR(B_s \to KK)}{BR(B_d \to K\pi)} = 0.74 \pm 0.20 \pm 0.22$$



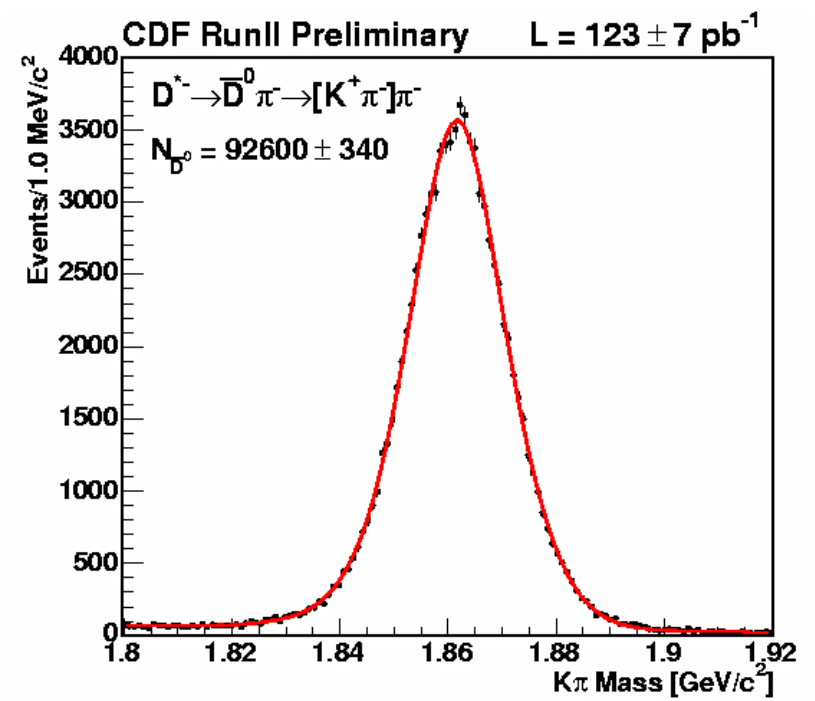
891±47 evts

Relative yields 65 pb^{-1} :

$B^0 \to \pi\pi$	39± 14	14%
$B^0 \to K\pi$	148± 17	53%
$B_s \to KK$	**90± 17**	**32%**
$B_s \to K\pi$	3± 11	1%

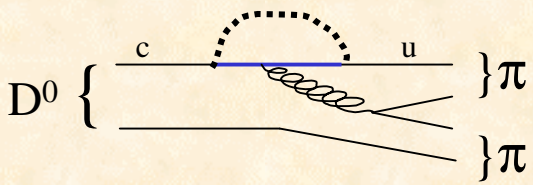
CP Asymmetry in charm decays

- Effect small in standard model (0.1 to 1%) due to small contribution of box diagrams.
- Check direct A_{CP} in Cabibbo-suppressed decays as a test for new physics.
- Large production of charm.
- Very large charm sample collected to date
- Method:
  - Use $D^0\overline{D}^0$ from $D^{*\pm} \rightarrow D^0\,\pi$ and tag flavour from soft π charge
  - Measure relative branching ratios
  - final products CP eigenstates
  - Take into account slight detector asymmetry



$D^0 \to K^+K^-$, $D^0 \to \pi^+\pi^-$

High statistics of reconstructed and tagged D^0: 2×10^5 candidates
We measure the relative branching ratio and A_{CP} for the suppressed modes



Relative branching fraction:

$$\frac{\Gamma_{D^0\to KK(\pi\pi)}}{\Gamma_{D^0\to K\pi}} = \frac{N(KK)}{N(K\pi)}\frac{\varepsilon(K\pi)}{\varepsilon(KK)}$$

From MC including trigger, Detector config., nuclear interactions

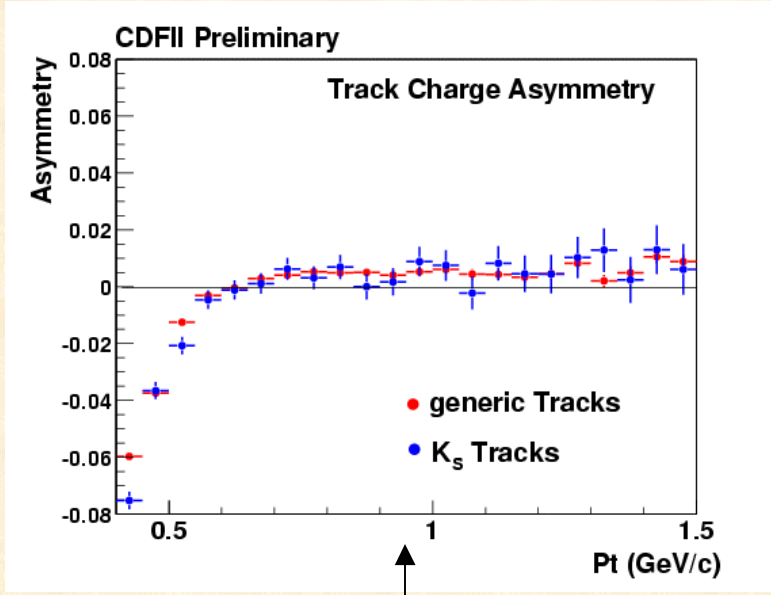
$$A_{CP} = \frac{\Gamma(D^0\to f)-\Gamma(\overline{D}^0\to f)}{\Gamma(D^0\to f)+\Gamma(\overline{D}^0\to f)};\ f=(\pi\pi, KK)$$

$D^0 \to K^+K^-$, $D^0 \to \pi^+\pi^-$

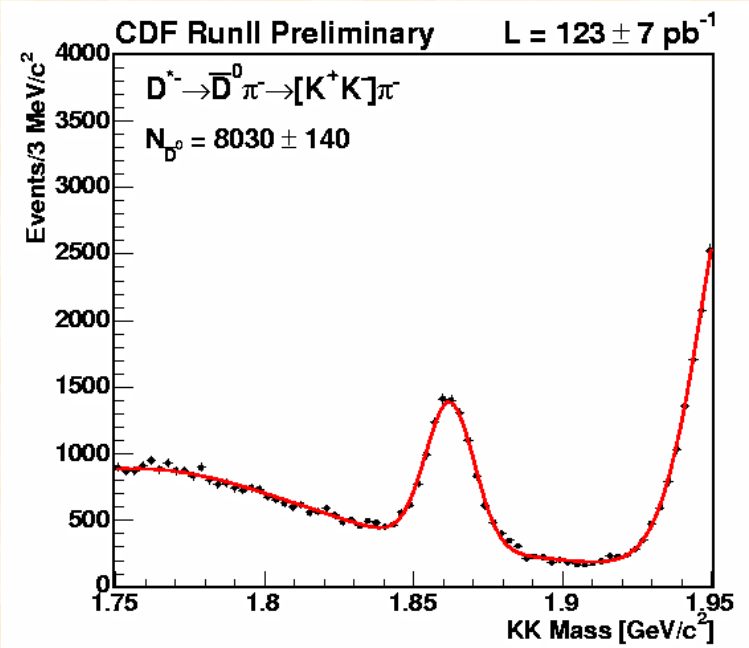
$L_{xy} > 350\ \mu\ m$
$\Delta M_D = (M_{D^*} - M_{D^o}) < 3\sigma \approx 1.8 MeV/c^2$
$d_0(1)\ d_0(2) < 0$

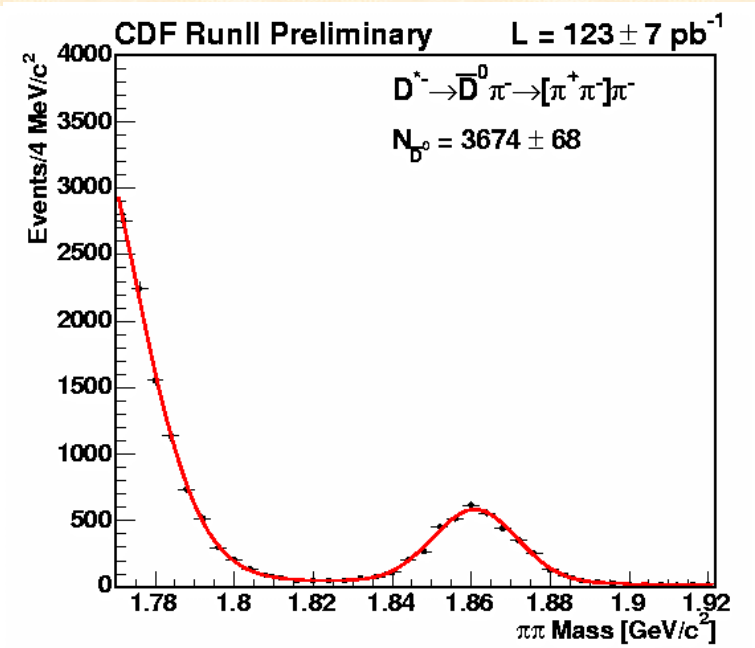
Signal peaks are very well separated from background.

$D^0 \to K^{\mp}\pi^{\pm}\pi^0$ Physical background for KK



Asymmetry corrections at 1% level
High statistics, precise measurement





$D^0 \to K^+K^-$, $D^0 \to \pi^+\pi^-$

Results:

Branching ratios:

$$\frac{\Gamma(D^0 \to KK)}{\Gamma(D^0 \to K\pi)} = 9.96 \pm 0.11(stat) \pm 0.12(sys)\%$$

$$\frac{\Gamma(D^0 \to \pi^+\pi^-)}{\Gamma(D^0 \to K\pi)} = 3.608 \pm 0.054(stat.) \pm 0.040(sys.)\%$$

$$\frac{\Gamma(D^0 \to K^+K^-)}{\Gamma(D^0 \to \pi^+\pi^-)} = 2.762 \pm 0.040(stat.) \pm 0.034(sys.)\%$$

Asymmetries:

$$A_{CP}(D^0 \to K^+K^-) = 2.0 \pm 1.2(stat.) \pm 0.6(sys.)\%$$

PDG (0.5 ± 1.6) %

$$A_{CP}(D^0 \to \pi^+\pi^-) = 1.0 \pm 1.3(stat.) \pm 0.6(sys.)\%$$

PDG (2.1 ± 2.6) %

Conclusions

- CP Asymmetry in hadronic charmless decays measured at CDF , agreement with HFAG, consistent with zero
- New pure penguin decay mode observed for B_s, additional mode for $\Delta\Gamma_s$
- Measurement of γ possible with $\pi\pi$, $K\pi$,KK decays to charged particles. Measurement update soon.
- Asymmetry in charm decays consistent with zero, in future measurement will be possible at < 0.2 % level
- Looking forward for $2fb^{-1}$ (Run-IIa)
- Looking for more channels and developing tag algorithms
- B_s mixing….!