Phenomena related to CP violation at CDF

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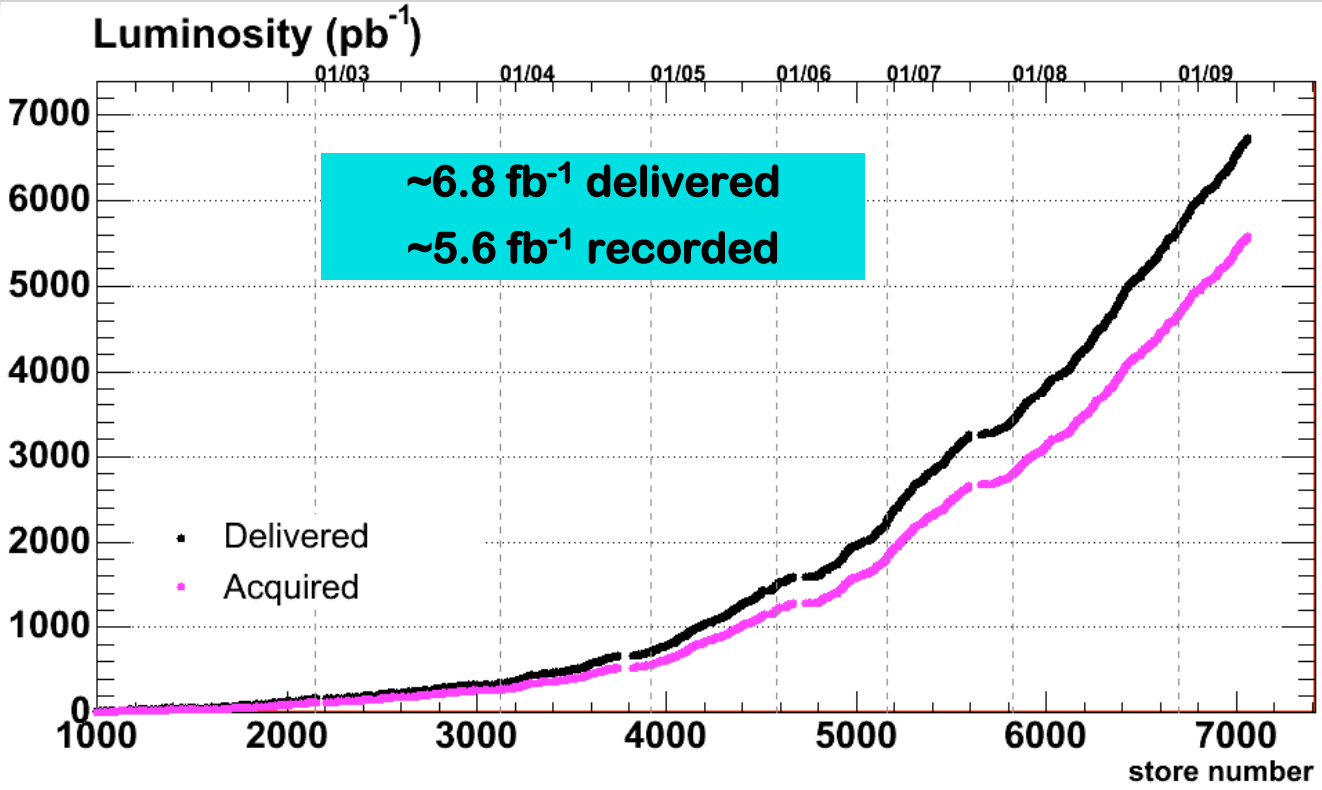
Topics:

- Direct CPV:
  - $B_s \to K\pi$
  - $\Lambda_b \to pK^-$ and $\Lambda_b \to p\pi^-$
  - $B^- \to DK^-$
  - $D \to h^+h^-$

The Tevatron



- ppbar collisions at 1.96 TeV
- Excellent performance of Tevatron accelerator
- Peak Initial Luminosity recent record: 3.7 x 10^{32} cm^{-2}s^{-1}
- Expect 8 fb^{-1} by 2010
- Analysis presented today use 1 to 3 fb^{-1} of data

The CDF II detector

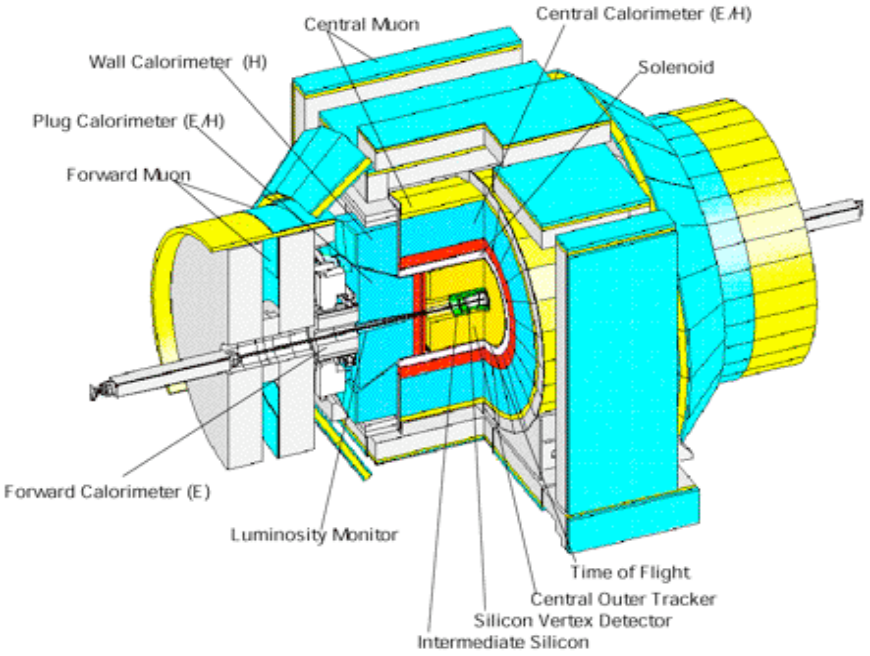
TRACKING system:

- **DRIFT CHAMBER**
96 layers ($|\eta|<1$)

  → particle ID with dE/dx

- **SILICON TRACKER**
(L00+SVX+ISL, up to $|\eta|\sim2$)

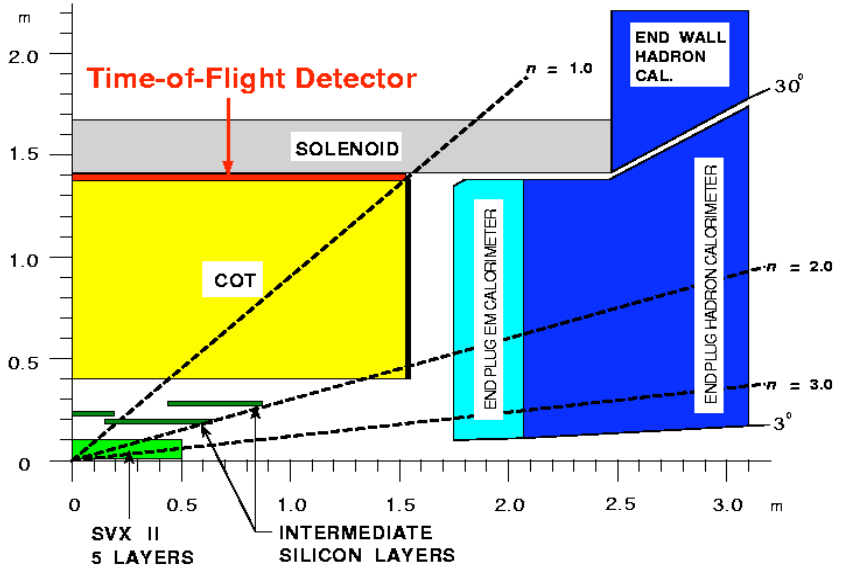
I.P. resolution 35 μm at 2 GeV



TRACKING TRIGGER system:

- **XFT** at L1, 2D tracks in COT, $p_T>1.5$ GeV

- **SVT** at L2, 2D tracks $p_T > 2$ GeV, Impact Parameter measurement (trigger on events containing long lived particles)



Paola Squillacioti

Charmless two-body decay modes

$B^0_{(s)} \rightarrow h^+ h^-$

Direct CP violaton in $B_{d,s} \to K\pi$

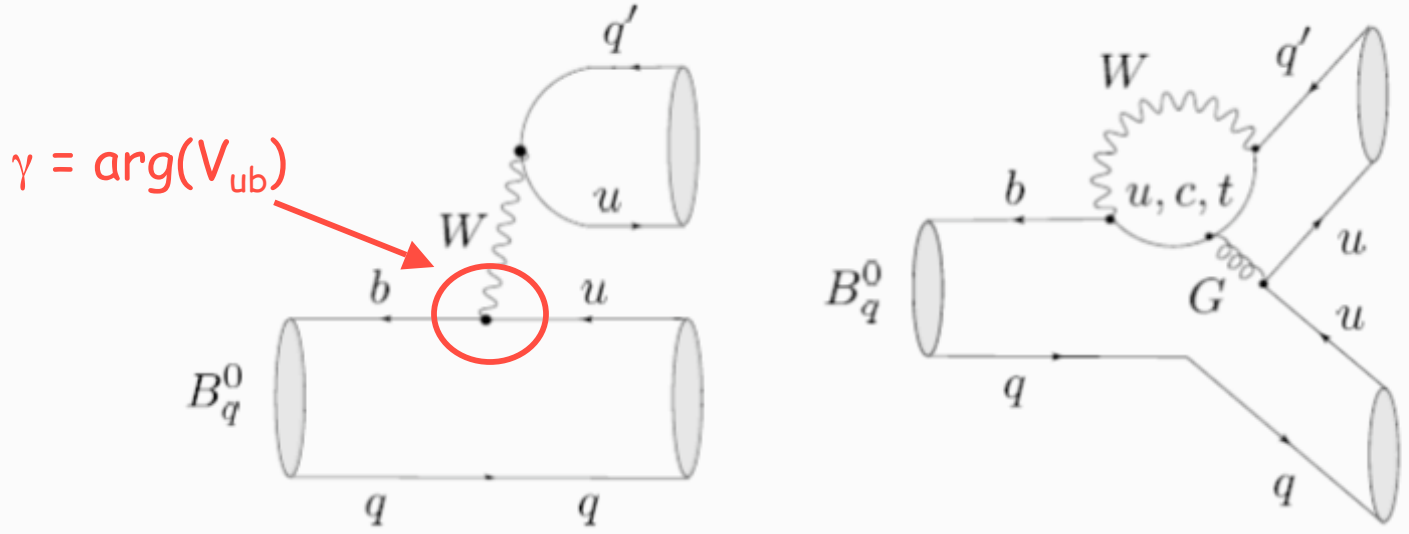


Figure 1: Tree and penguin topologies contributing to the U-spin-related $B_d^0 \to \pi^+\pi^-$, $B_s^0 \to K^+K^-$ and $B_d^0 \to \pi^-K^+$, $B_s^0 \to \pi^+K^-$ decays $(q, q' \in \{d, s\})$.

- Interference between Tree and Penguin amplitudes may generate sizeable direct CP violation
- Still many things to understands on CP violation. Simultaneous access to B_d, B_s and Λ_b decays (New physics?)
- Sensitive to the CKM angle γ
- Useful combining B_d and B_s to test/use flavor symmetries (U-spin, SU(3), etc.)

$B_{d,s} \rightarrow hh'$ signal

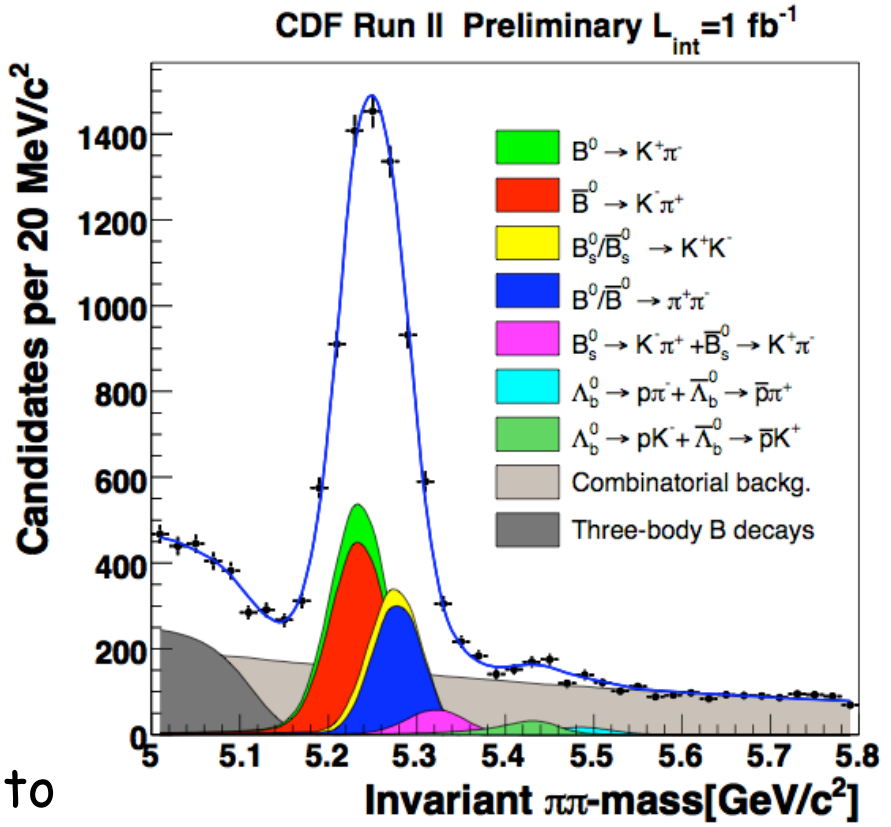
- Large signal selected through the displaced track trigger

- Superposition of $B_d \rightarrow K\pi$, $B_d \rightarrow \pi\pi$, $B_s \rightarrow KK$, $B_s \rightarrow K\pi + \Lambda_b$ ($p\pi/K$)

- Need multidimensional unbinned likelihood fit to kinematics + dE/dx information to disentangle various components

- Signal yield and resolution comparable to B-factories (with 1 fb^{-1} of Tevatron data)

- High precision CPV measurement:
  CPV in $B_d \rightarrow K\pi$ (4045 ± 84 events)
  A_{CP} = -0.086 ± 0.023(stat) ± 0.09(syst)



Compare to:

Babar $A_{CP} = -0.107 \pm 0.018^{+0.007}_{-0.004}$
(PRL 99 (2007) 021603)

Belle $A_{CP} = -0.094 \pm 0.018 \pm 0.08$
(Nature 452 (2008) 332)

http://www-cdf.fnal.gov/physics/new/bottom/060921.blessed-bhh_1fb/

Direct CP violation in $B_s \to K\pi$

$B_s \to K\pi$ mode with 1 fb^{-1} [arXiv:0812.4271v1]

$$N(B_s^0 \to K^-\pi^+) = 230 \pm 34(stat) \pm 16(syst) \quad [8\sigma \text{ significance}]$$

Measurement of direct CP Violation:

http://www-cdf.fnal.gov/physics/new/bottom/060921.blessed-bhh_1fb/

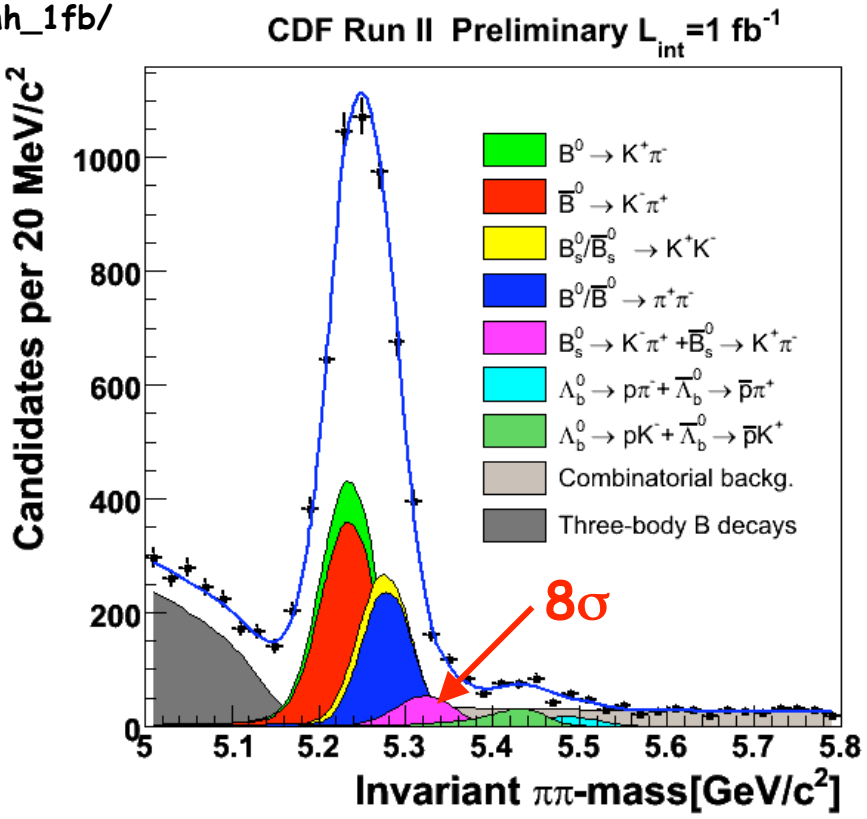
$$A_{CP} = \frac{N(\bar{B}_s^0 \to K^+\pi^-) - N(B_s^0 \to K^-\pi^+)}{N(\bar{B}_s^0 \to K^+\pi^-) + N(B_s^0 \to K^-\pi^+)}$$

$$A_{CP}(B_s^0 \to K^-\pi^+) = 0.39 \pm 0.15(stat) \pm 0.08(syst)$$

- A_{CP} is 2.5σ different from 0

- Compatible with SM expectations of a large asymmetries: $A_{CP} \approx 0.37$

[Gronau, Phys. Lett B 492, 497 (2000); Lipkin, Phys. Lett B 621, 126 (2005)]



Direct CP violation in $\Lambda_b \to ph$

Charmless Λ_b decays:

$$BR(\Lambda_b^0 \to pK) = (5.6 \pm 0.8(stat) \pm 1.5(syst)) \times 10^{-6}$$
$$BR(\Lambda_b^0 \to p\pi) = (3.5 \pm 0.6(stat) \pm 0.9(syst)) \times 10^{-6}$$

(Assuming PDG value $f_{baryon}/f_d = 0.230 \pm 0.052$)

Predicted:

$$BR(\Lambda_b^0 \to pK) = 2 \times 10^{-6}$$
$$BR(\Lambda_b^0 \to p\pi) = 1 \times 10^{-6}$$

Exclusion of BR ≈ O(10^{-4}) values indicated for R-parity violating Minimal Supersymmetric extension of the SM model [PRD 63 056006 (2001)]

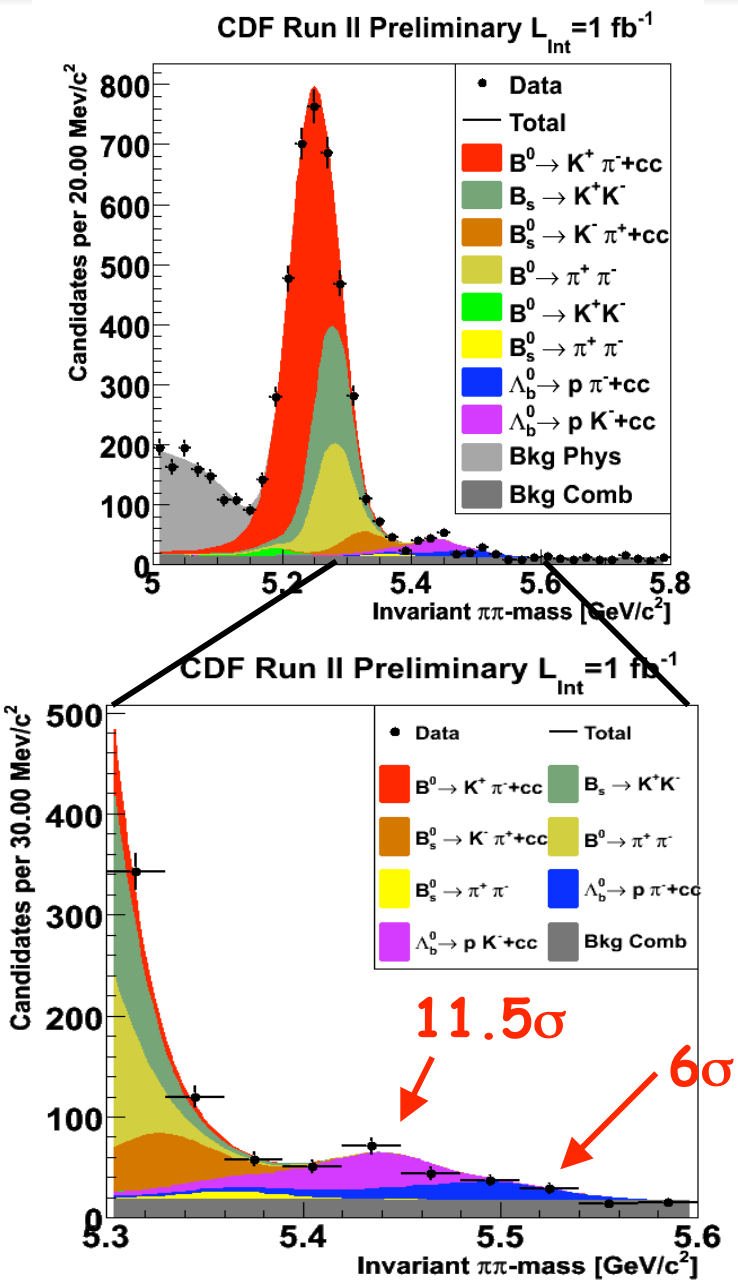
First hint of DCPV in baryon decays:

2.1 σ

$$A_{CP}(\Lambda_b^0 \to pK^-) = 0.37 \pm 0.17(stat) \pm 0.03(syst)$$
$$A_{CP}(\Lambda_b^0 \to p\pi^-) = 0.03 \pm 0.17(stat) \pm 0.05(syst)$$

Statistical uncertainty dominates.
Very interesting to update with data available on tape (5 fb^{-1}).

[arXiv:0812.4271v1] and http://www-cdf.fnal.gov/physics/new/bottom/071018.blessed-ACP_Lambdab_ph/

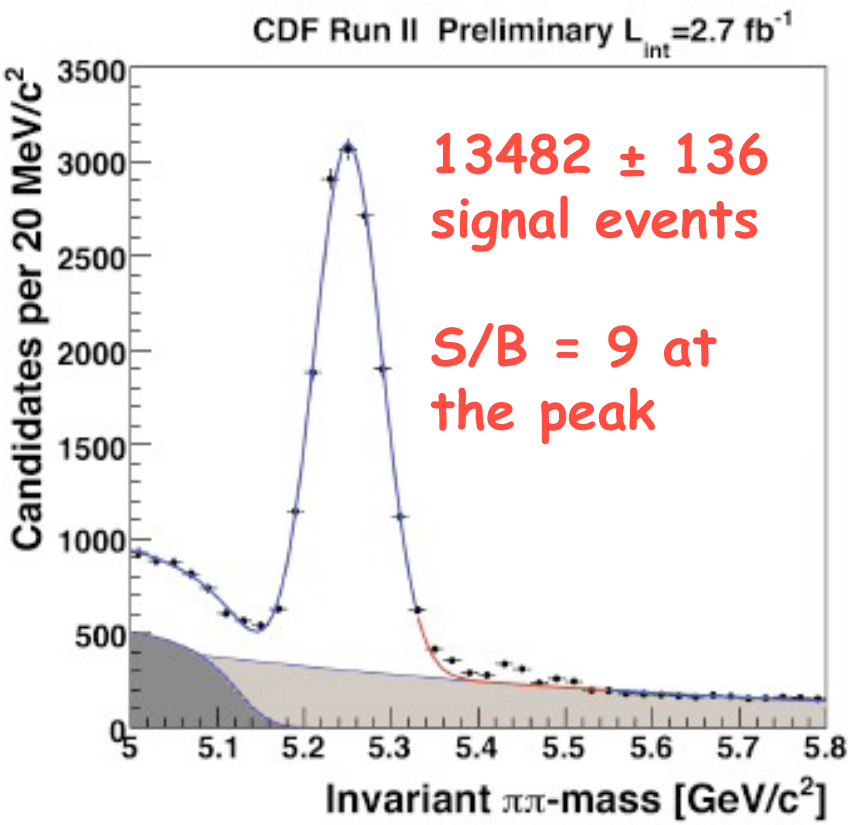


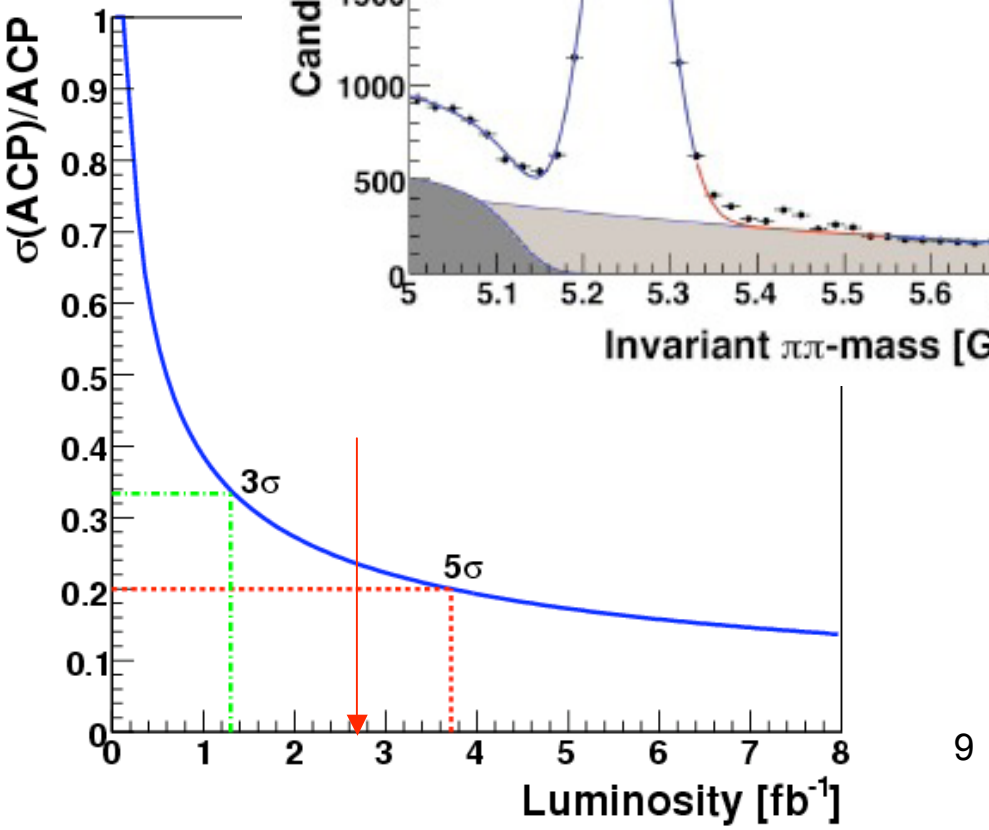
B → hh' prospects

- Measurement update on 2.7 fb^{-1} on going
  - Precision dE/dx calibration performed
  - Data validation almost completed

- Yield improved of a factor 2.1 (Next update on $B_d \to K\pi$ is suppose to be the world best)

- Bs->Kpi expected to show 5 sigma asymmetries Assuming SM hypothesis (Gronau-Lipkin relation true)





$B \rightarrow DK$ modes

Measurement of the CKM angle γ

- GLW (Gronau-London-Wyler) method *([PLB253,483 PLB265,172])*

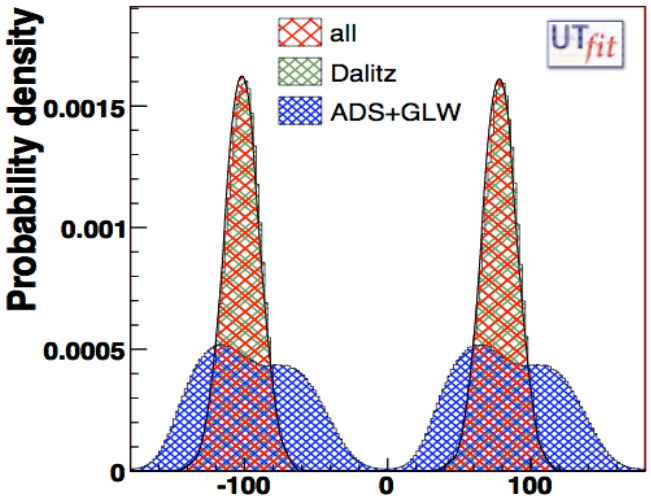
that uses the $B^{\pm} \to D K^{\pm}$ decays with D_{CP} decay modes.
$D_{CP+} \to \pi^+ \pi^-$, $K^+ K^-$ and $D_{CP-} \to K^0_s \pi^0$, $K^0_s \omega$, $K^0_s \phi$.

- ADS (Atwood-Dunietz-Soni) method *([PRL78,3257;PRD63,036005])*

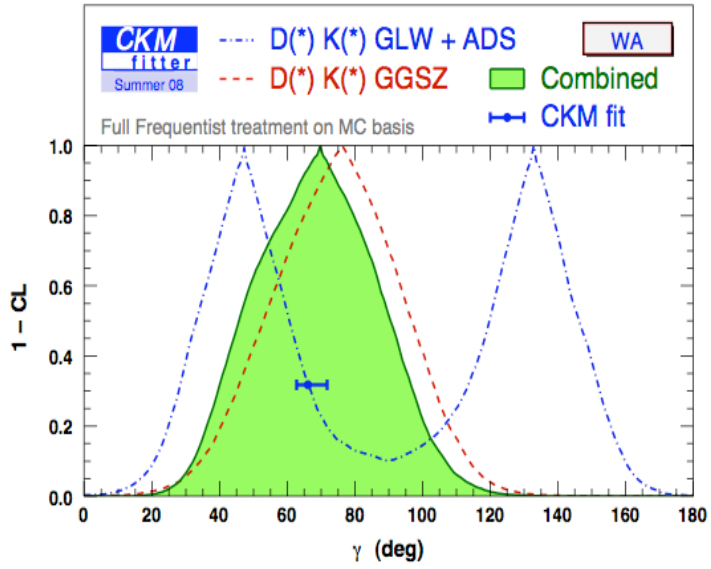
that uses the $B^{\pm} \to D K^{\pm}$ decays with D reconstructed in the doubly cabibbo suppressed $D^0_{DCS} \to K^+ \pi^-$

- GGSZ (Giri-Grossmann-Soffer-Zupan) method *([PRL78,3257, PRD68,054018])*

that uses the $B^{\pm} \to D K^{\pm}$ decays with the D^0 and $\bar{D}^0$ reconstructed into three-body final state. For example the $D^0 \to K^0_s \pi^+ \pi^-$



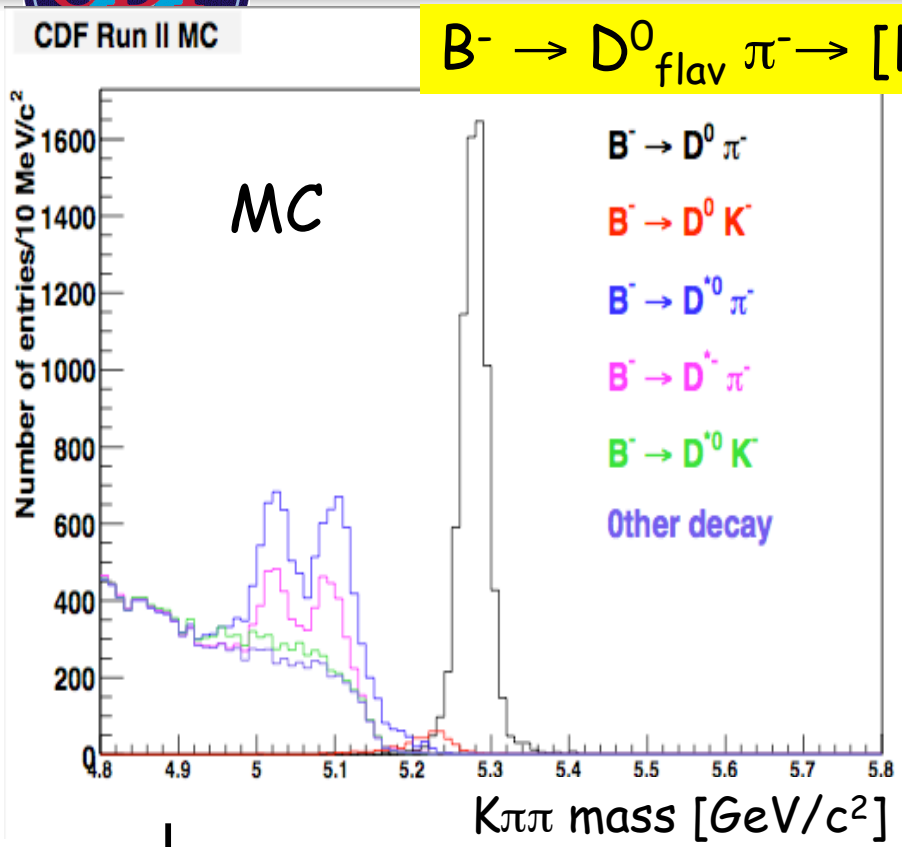
γ (deg) = 78 ± 12 ([54,102] @ 95% Prob.)
γ (deg)= -102 ± 16 ([-126,-78] @ 95% Prob.)

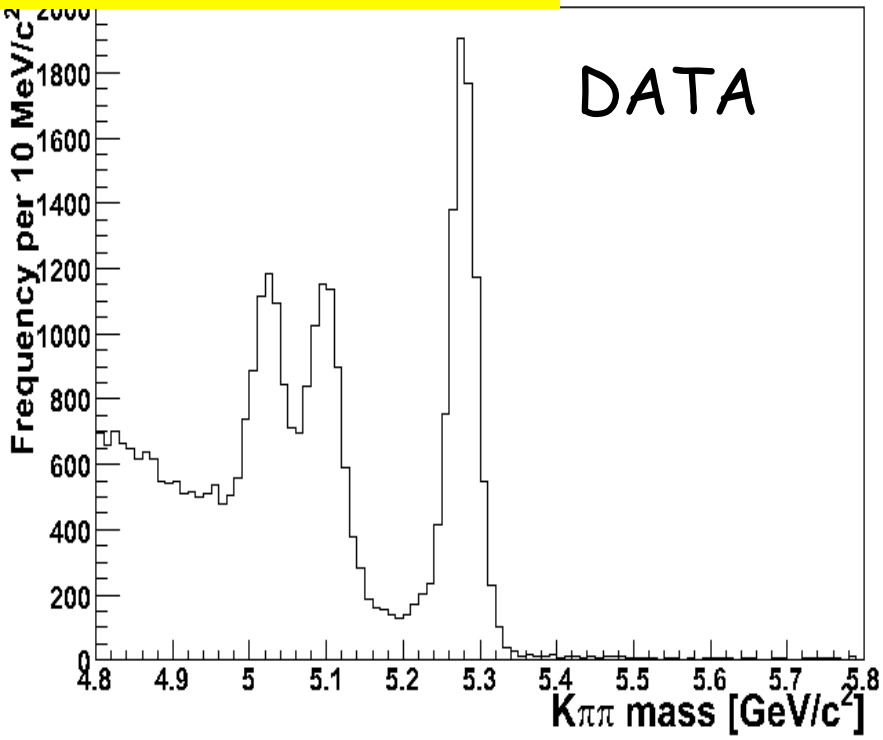


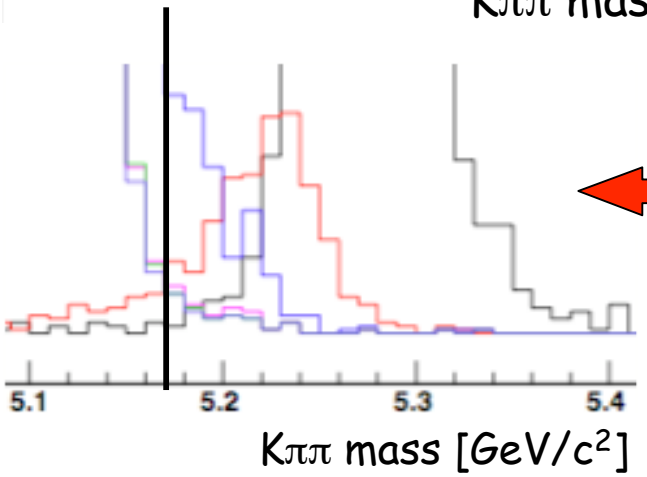
γ (deg) = 70 [+27 -29]

B → DK signal

$B^- \to D^0_{flav}\,\pi^- \to [K^-\,\pi^+]\,\pi^-$ $\quad L = 1fb^{-1}$







To reject most of the physical backgrounds, narrow fit windows [5.17,5.6] GeV/c^2

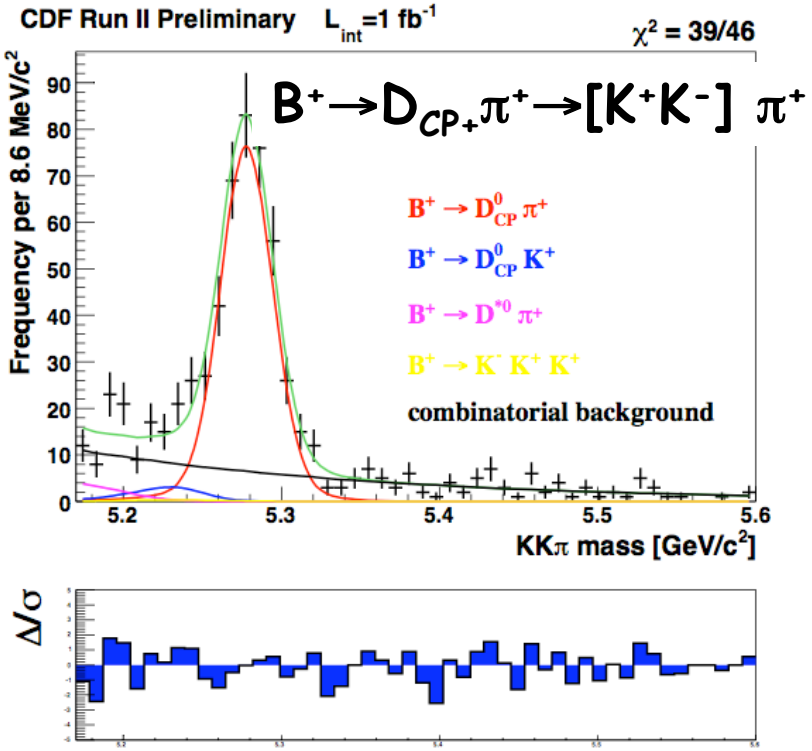
The only significant physics backgrounds are $B^- \to D^0\pi^-$ and $B^- \to D^{0*}\pi^-$

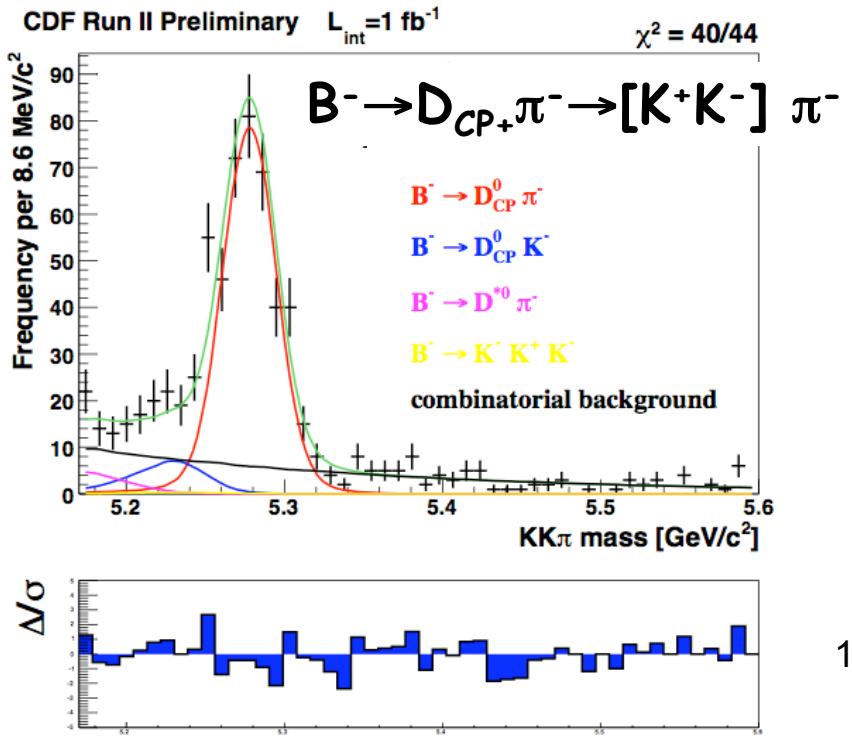
Direct CP violation in $B \to D_{CP+}K$

Implementation of a Likelihood FIT using kinematics (masses and momenta) and particle identification (dE/dx) information to determine the signal composition

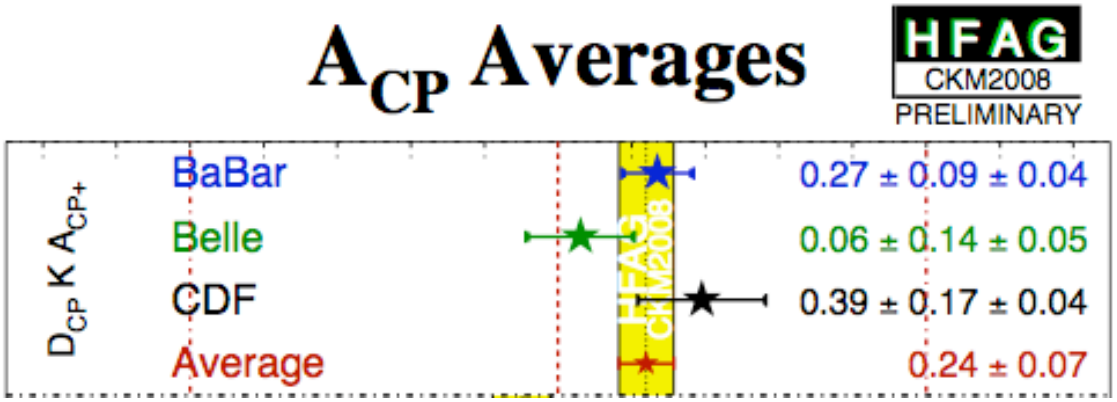
Cut optimization by minimizing the expected statistical uncertainty on A_{CP+} (Yield ($B \to D_{CP+}K$) ~ 90)

$$A_{CP+} = 0.39 \pm 0.17(stat) \pm 0.04(syst)$$





A_{CP} Averages



Agrees with previous measurements from other experiments. Resolution is also comparable

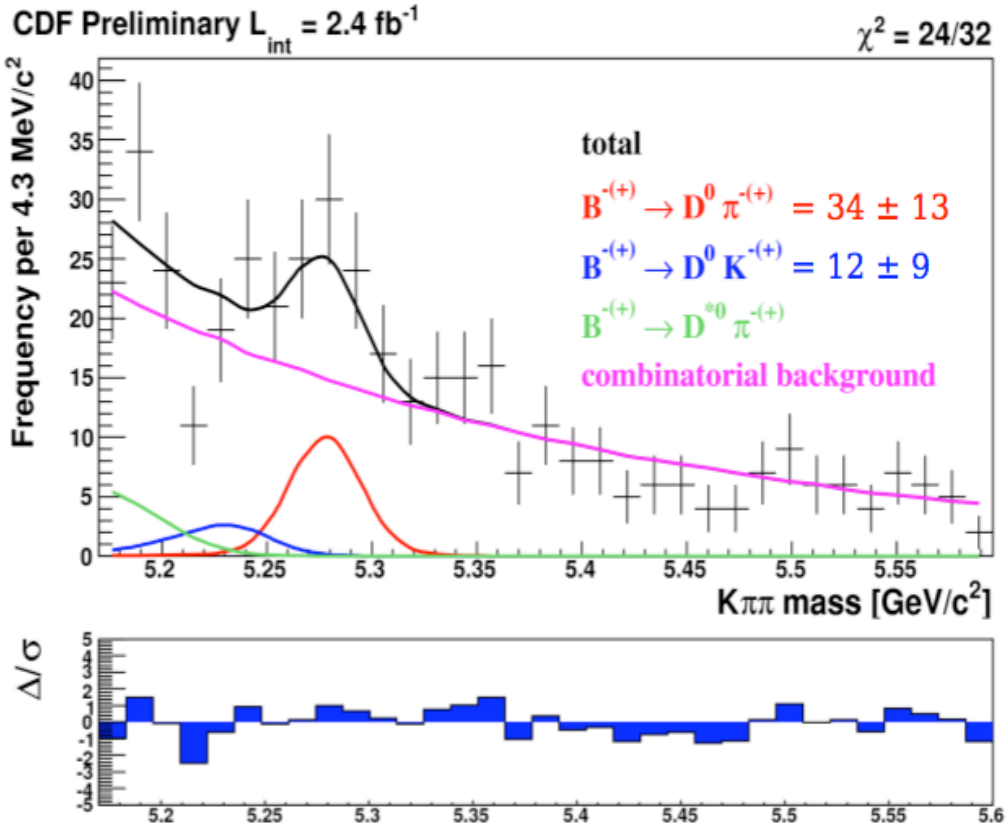
B mode	D mode	Meth.	CDF Yield $1fb^{-1}$	CDF Yield $5\ fb^{-1}$
$B \rightarrow DK$	KK, $\pi\pi$	GLW	90	450

CDF contributing to CKM γ angle via GLW method, now looking also for double Cabibbo suppressed D0 modes for ADS method

Reconstruction of $B \to D_{DCS}\,\pi$ mode

$L = 2.4\ fb^{-1}$

This is the first step towards the ADS method



$B \to D_{DCS}\pi$ Significance

$\sqrt{-2\Delta \log L} = 3.8\sigma$

Expected ~ 30% Asymmetry resolution

Belle:

$A_{ADS}(\pi) = -0.023 \pm 0.218(stat) \pm 0.071(syst)$

B mode	D mode	Meth.	CDF Yield 2.4 fb^{-1}	CDF Yield 5 fb^{-1}
$B \to D\pi$	$K\pi$ DCS	ADS	34	70

$D^0 \rightarrow hh$ modes

Motivations

• Recent experimental advancements in D^0 mixing and CP violation renewed interest in charm physics as a window to new physics [arXiv:0902.3048]

• CDF has world's largest charm sample (e.g. 40M inclusive $D^0 \rightarrow K\pi$): rich program that include access to direct CPV asymmetries, branching fractions, mixing, mixing-induced CPV

• Working on updating CDF published results on direct CP asymmetries in Cabibbo suppressed D^0 decays [Phys. Rev. Lett 94 (2005) 122001]

$$A_{CP}(\pi\pi) = (2.0 \pm 1.2(stat) \pm 0.6(syst))\%$$
$$A_{CP}(KK) = (1.0 \pm 1.3(stat) \pm 0.6(syst))\%$$

Performed using 0.12 fb^{-1}

Now more than 5 fb^{-1}

$D^0 \to h^+h'^-$ signals L = 2.9 fb^{-1}

Use D*-tagged D^0 decays

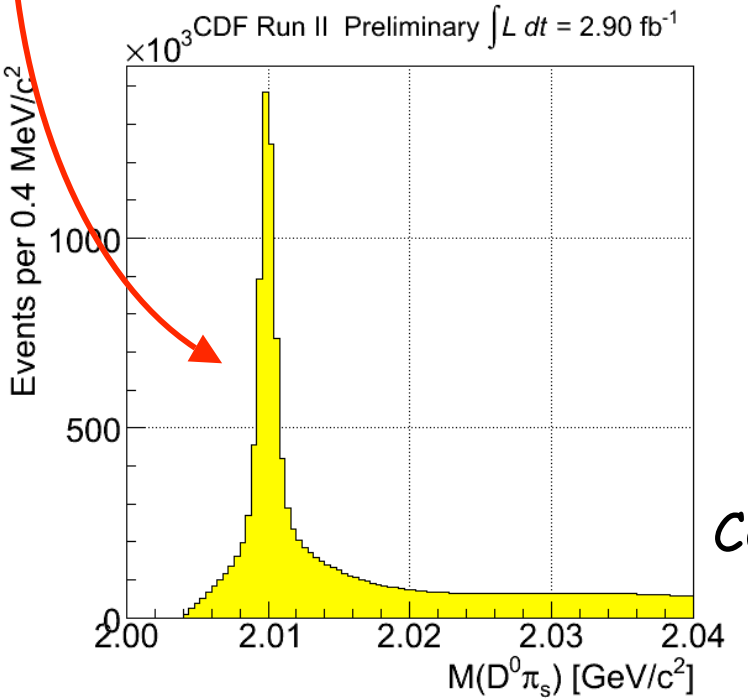
$$\begin{cases} D^{*+} \to D^0\pi_s^+ \to [h^+h'^-]\pi_s^+ \\ D^{*-} \to \overline{D}^0\pi_s^- \to [h^+h'^-]\pi_s^+ \end{cases}$$

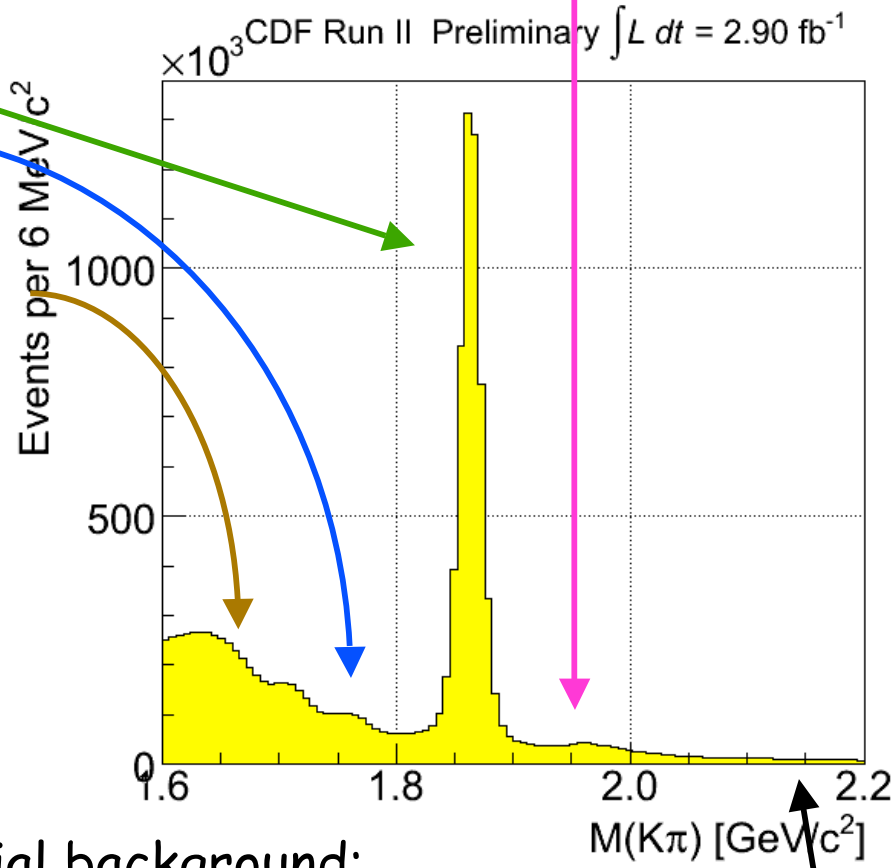
$D^{*+} \to D^0\pi^+_s$+C.C.

- $\pi^+\pi^- \approx 17 \cdot 10^4$ events
- $K^-\pi^+ \approx 4 \cdot 10^6$ events
- $K^+K^- \approx 36 \cdot 10^4$ events

Physics backgrounds:

Partially reconstructed $D^{0/\pm} \to$ 3Bodies



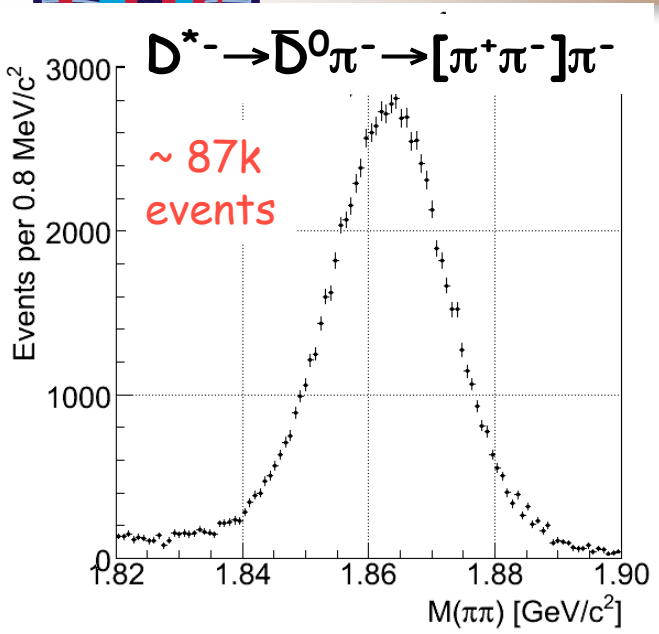


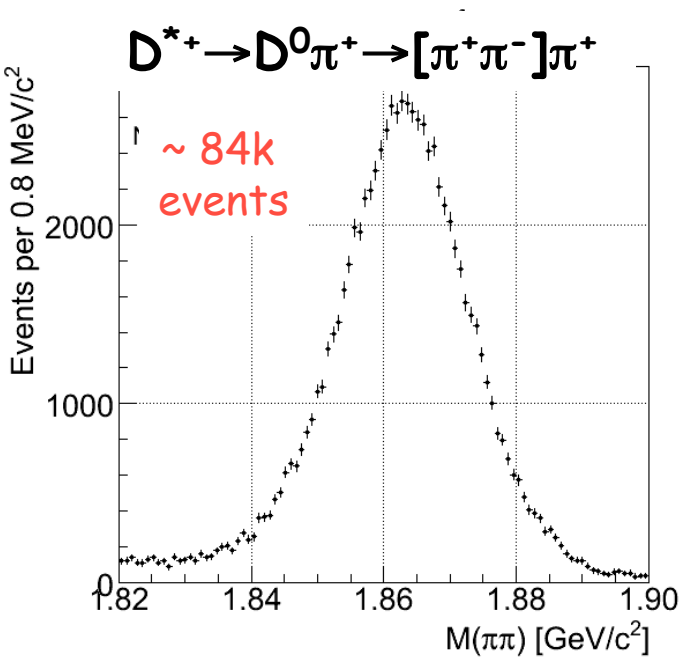
Combinatorial background:

Fake D* = true D^0 + random π_s

Fake D^0 = three random tracks

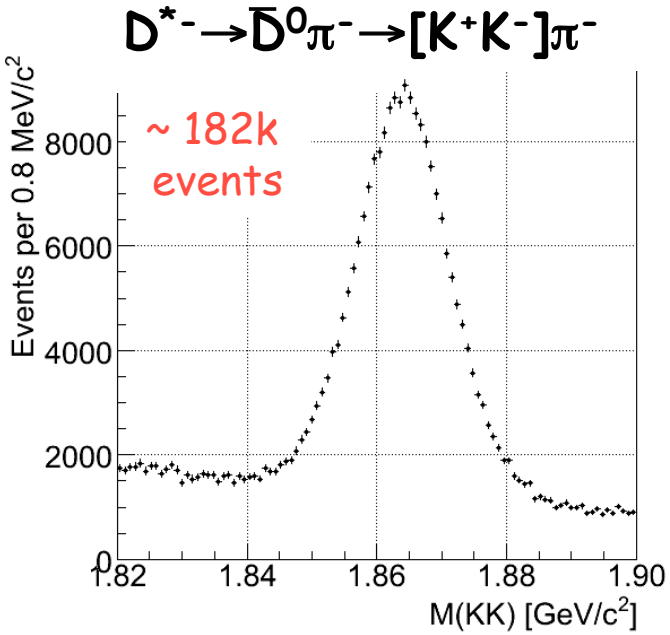
Signals: data sideband subtracted

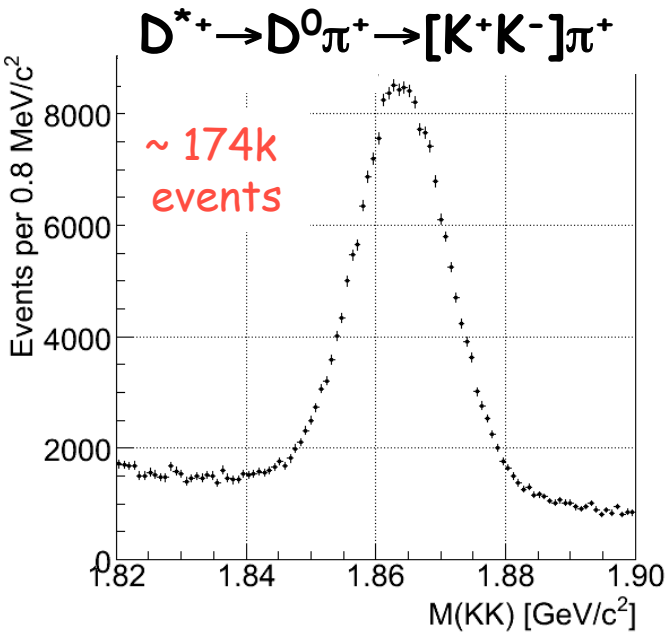




$L = 2.9\ fb^{-1}$

$\pi^+ \pi^-$ peak
Very clean





$K^+ K^-$ peak over 3 body decays
We subtract only combinatorial background

Statistical resolution on $A_{CP}(D^0 \to \pi^+\pi^-)$

Estimate statistical uncertainty on the $D^0 \to \pi^-\pi^+$ CP violating asymmetry assuming:

- Negligible contamination from $K^-\pi^+$ final states
- Uncertainty on counting $\sigma_N \sim \sqrt{N}$

Experiment	$A_{CP}(\pi^+\pi^-)$ (%)
Our estimate on 2.9/fb	$\mathrm{XXX} \pm 0.24\ (stat.)$
CDF on 0.123/fb *Phys. Rev. Lett.* **94** (2005) 122001	$+2.00 \pm 1.20\ (stat.) \pm 0.60\ (syst.)$
BaBar on 386/fb *Phys. Rev. Lett.* **100** (2008) 061803	$-0.24 \pm 0.52\ (stat.) \pm 0.22\ (syst.)$
Belle on 540/fb *Phys. Lett.* **B 670** (2008) 190	$-0.43 \pm 0.52\ (stat.) \pm 0.12\ (syst.)$

Low systematic uncertainty:
The detector has charge asymmetry, the calibration is based on large control sample of D^0 and D^* (40M of events)

Summary

- $B \to h^+h'^-$
  - Observation of $B_s \to K^-\pi^+$, $\Lambda^0_b \to p\pi^-$, $\Lambda^0_b \to pK^-$
  - Measurement of DCPV in B_s: $A_{CP}(B_s \to K^-\pi^+)$ appears to be large in agreement with expectation
  - First hint of DCPV in baryon decays
- $B \to DK$
  - Measurement of DCPV in $B \to D_{CP}K$ decays (performed for the first time in hadron collisions)
  - Observation of $B \to D_{DCS}\,\pi$
- $D^0 \to h^+h'^-$
  - First steps through the DCPV measurements in $D^0 \to KK$ and $D^0 \to \pi\pi$

- Now, over 5 fb^{-1} on tape: more significantly improved results coming soon

BACKUP

$\Lambda_b \rightarrow ph$

Observation of charmless Λ_b decays:

$$\frac{f_\Lambda}{f_d} \times \frac{BR(\Lambda_b^0 \rightarrow p\pi^-)}{BR(B^0 \rightarrow K^+\pi^-)} = 0.042 \pm 0.007(stat) \pm 0.006(syst)$$

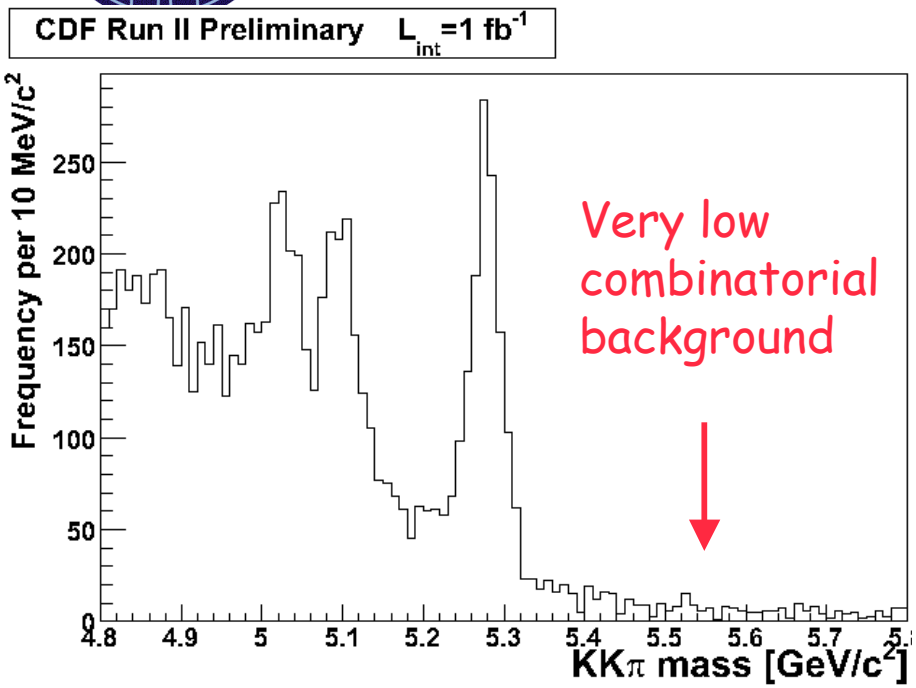
$$\frac{f_\Lambda}{f_d} \times \frac{BR(\Lambda_b^0 \rightarrow pK^-)}{BR(B^0 \rightarrow K^+\pi^-)} = 0.066 \pm 0.009(stat) \pm 0.008(syst)$$

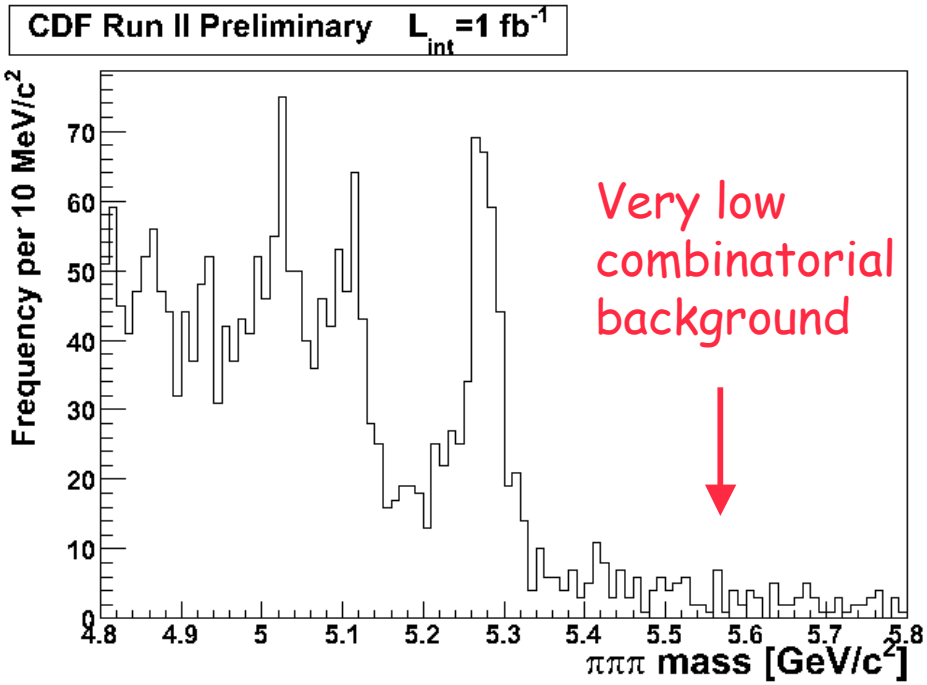
BRs are in agreement with SM predictions and exclude BR≈O(10^{-4}) values indicated for R-parity violating Minimal Supersymmetric extensions of the SM model. *[PRD63,056006(2001)]*

DATA sample 1 fb^{-1}

$B^- \to D^0_{CP+}\,\pi^- \to [K\,K]\,\pi^-$

$B^- \to D^0_{CP+}\,\pi^- \to [\pi\,\pi]\,\pi^-$





We optimized the cuts by minimizing the expected statistical uncertainty on A_{CP}

- Isol > 0.65
- chi3D < 13
- |d0_B| < 0.007 cm
- Sig_LxyB > 12
- LxyD_B > -0.01 cm
- LxyD > 0.04 cm
- $\Delta R = (\Delta\phi^2 + \Delta\eta^2)^{1/2} < 2$

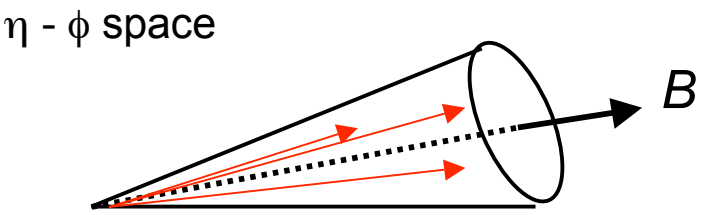
Select the sub-sample where the B-pion is a trigger track (kinematics differ according to which tracks trigger, need a separate fit for the rest)

Isolation(B) and 3D-vertex quality χ^2_{3D}(B)

Off-line selection

The cuts on the isolation and on the tridimensional χ^2 permit to suppress the combinatorial background

1) $$I_{R=1}(B) = \frac{p_T(B)}{p_T(B) + \sum_i p_T(i)}$$



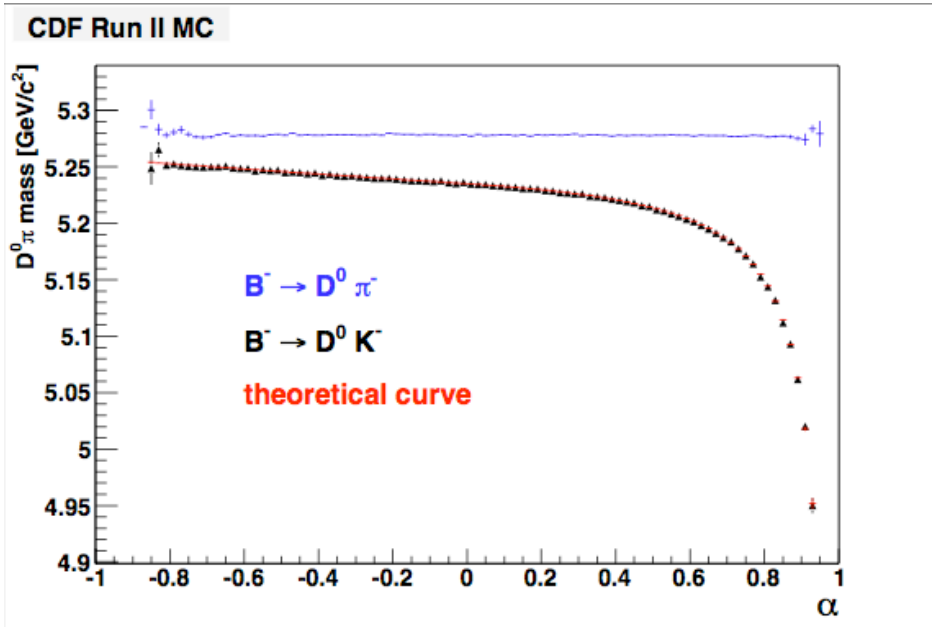
Fraction of p_T carried by the B candidate after fragmentation in a cone (η - ϕ space) with radius 1. High discrimination power signal vs backg.

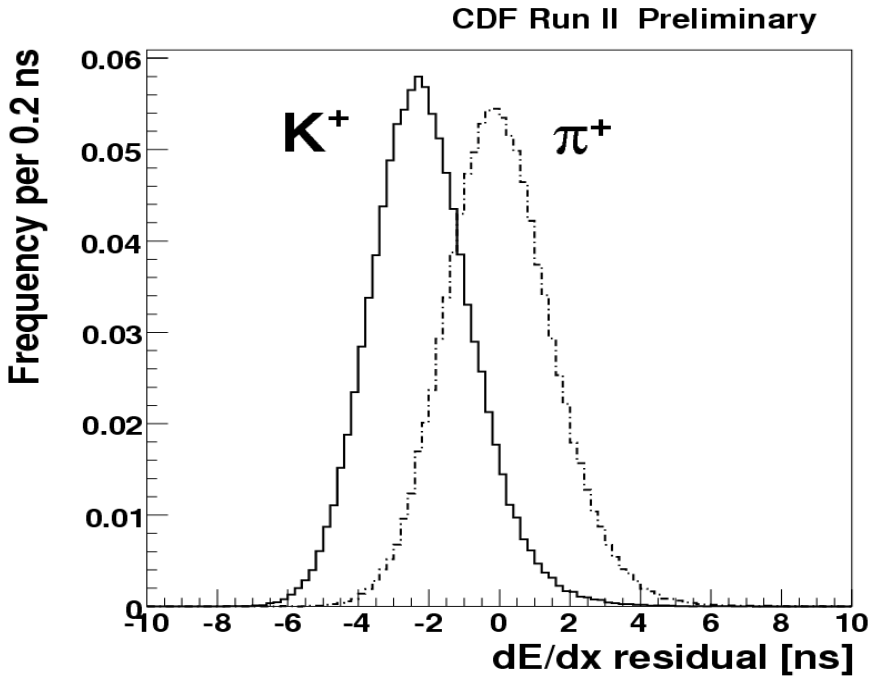
2) Exploit the powerful 3D silicon-tracking to resolve multiple vertices along the beam direction and to reject fake tracks. Backg. reduces x2, small inefficiency on signal (<10%).

Likelihood Fit

Implementation of a Likelihood FIT using kinematics (masses and momenta) and particle identification (dE/dx) information to determine the signal composition

$D^0\pi$ mass *vs* momentum imbalance α





If $P_t < P_{D0}$ $\quad \alpha = 1 - P_t/P_{D0} > 0$

If $P_t >= P_{D0}$ $\quad \alpha = -(1 - P_{D0}/P_t) <= 0$

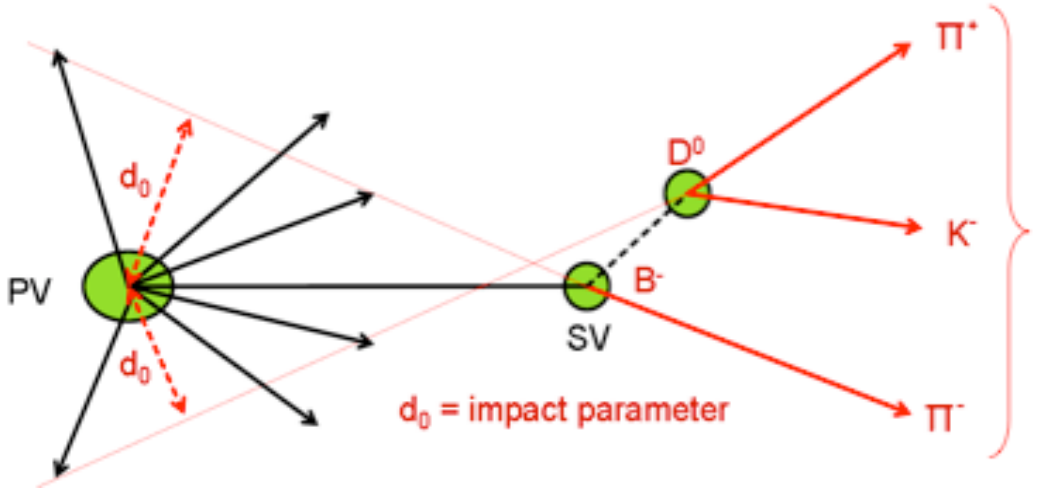
K - π separation: 1.5 σ for p > 2 GeV/c

SVT Trigger

SVT permits to trigger directly on B hadron decay vertices

SVT provides a precise online measurement of the impact parameter (d) of charged particle tracks ($\delta d \sim 30\ \mu m$) allowing triggering on events containing long lived particles.

At least two tracks with
$p_T > 2$ GeV
$120\ \mu m < d_0 < 1$ mm
$\Delta\phi < 90°$



Any pair of tracks can trigger. This makes for different kinematics

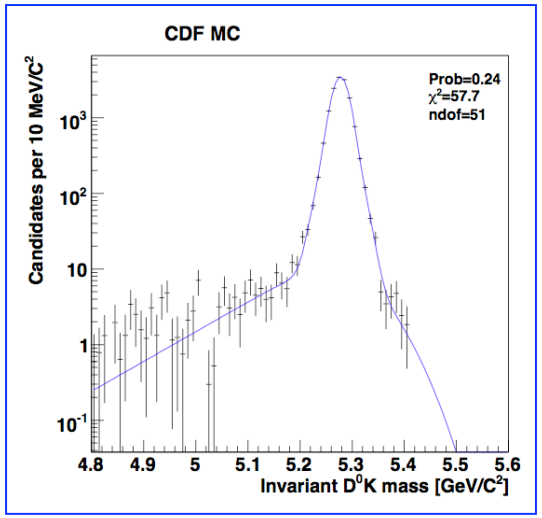
Putting it all together

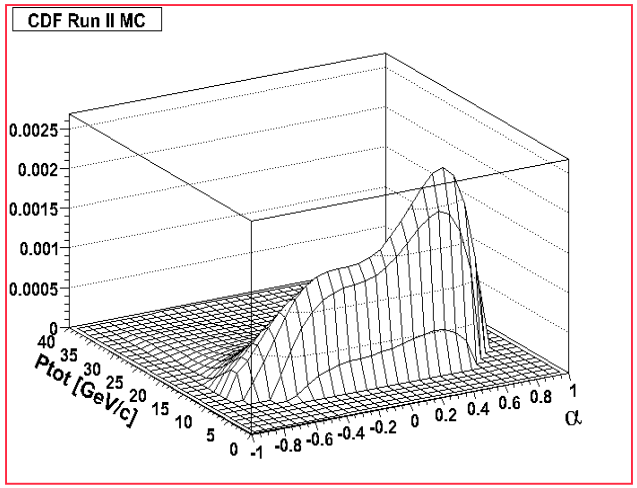
$F_i(\alpha, Ptot, M_{D0\pi}, ID) = pdf(M_{D0\pi}|\alpha, Ptot)\, pdf(\alpha, Ptot)\, pdf(dE/dx|\alpha, Ptot)$

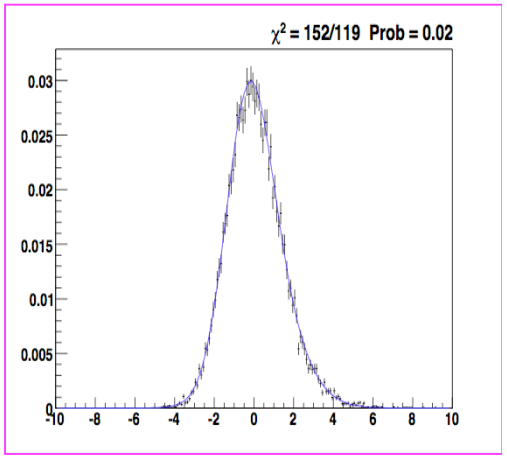
Mass term
- Signal shape from MC (including FSR)
- Background shape: exponential function free in the fit

Momentum term
- Signal shape from MC
- Background shape from data sideband

PID term
Signal and background shapes from $D^0 \rightarrow K^-\pi^+$







Fit Results on 1 fb^{-1}

Parameter	fraction	yield
$B^+ \to \overline{D}^0\pi^+$ (f_π^{flav+})	0.902 ± 0.006	3769 ± 68
$B^- \to D^0\pi^-$ (f_π^{flav-})	0.902 ± 0.006	3763 ± 68
$B^+ \to \overline{D}^0 K^+$ (f_K^{flav+})	0.060 ± 0.005	250 ± 26
$B^- \to D^0 K^-$ (f_K^{flav-})	0.064 ± 0.005	266 ± 27
$B^+ \to D^0_{CP+}\pi^+ \to [K^+K^-]\pi^+$ (f_π^{dcp+})	0.910 ± 0.018	381 ± 25
$B^- \to D^0_{CP+}\pi^- \to [K^+K^-]\pi^-$ (f_π^{dcp-})	0.854 ± 0.018	399 ± 26
$B^+ \to D^0_{CP+}K^+ \to [K^+K^-]K^+$ (f_K^{dcp+})	0.052 ± 0.018	22 ± 8
$B^- \to D^0_{CP+}K^- \to [K^+K^-]K^-$ (f_K^{dcp-})	0.105 ± 0.018	49 ± 11
$B^+ \to D^0_{CP+}\pi^+ \to [\pi^+\pi^-]\pi^+$ (f_π^{dcp+})	0.910 ± 0.018	101 ± 13
$B^- \to D^0_{CP+}\pi^- \to [\pi^+\pi^-]\pi^-$ (f_π^{dcp-})	0.854 ± 0.018	117 ± 14
$B^+ \to D^0_{CP+}K^+ \to [\pi^+\pi^-]K^+$ (f_K^{dcp+})	0.052 ± 0.018	6 ± 6
$B^- \to D^0_{CP+}K^- \to [\pi^+\pi^-]K^-$ (f_K^{dcp-})	0.105 ± 0.018	14 ± 6

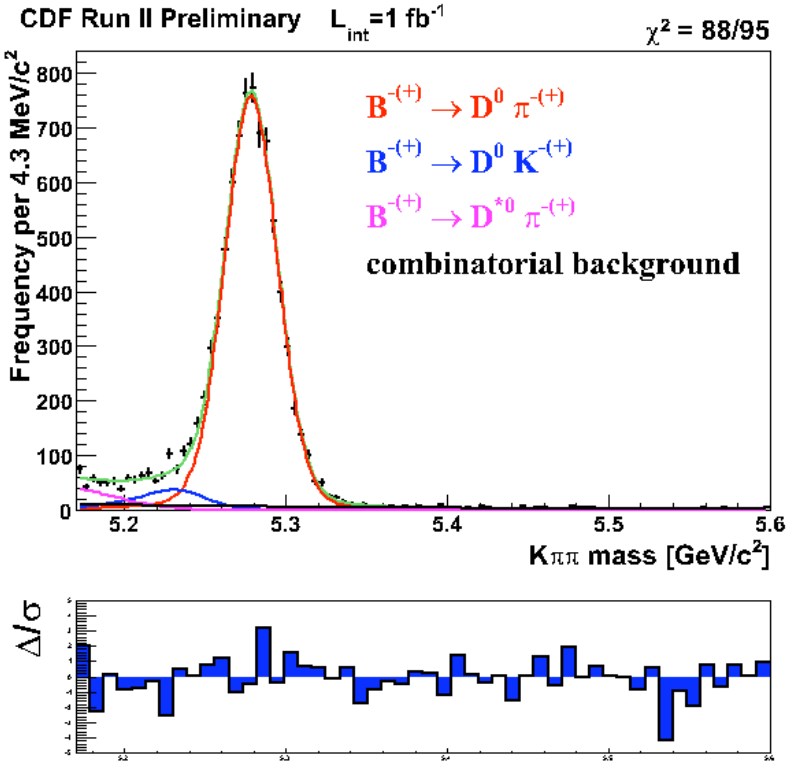
~ 7500 $D^0_{flav}\,\pi$
~ 520 D^0_{flav} K

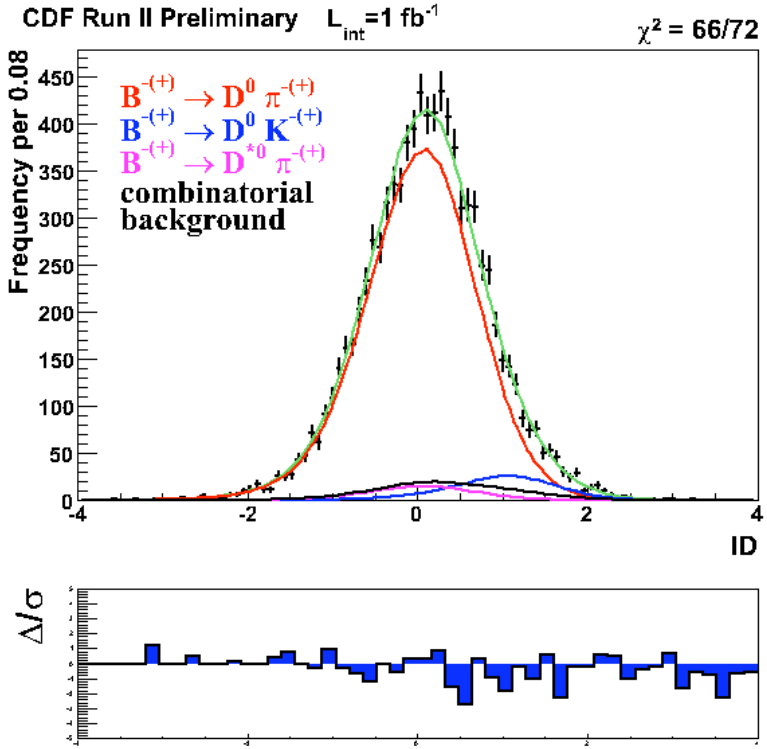
~ 1000 $D^0_{CP}\,\pi$
~ 90 D^0_{CP} K

Fit Results on 1 fb^{-1} Flavor mode

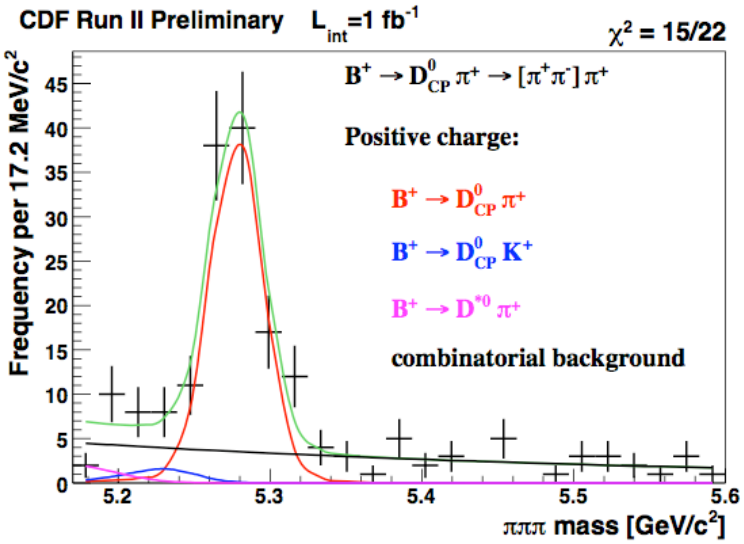
$$R = 0.0745 \pm 0.0043(stat) \pm 0.0045(syst)$$

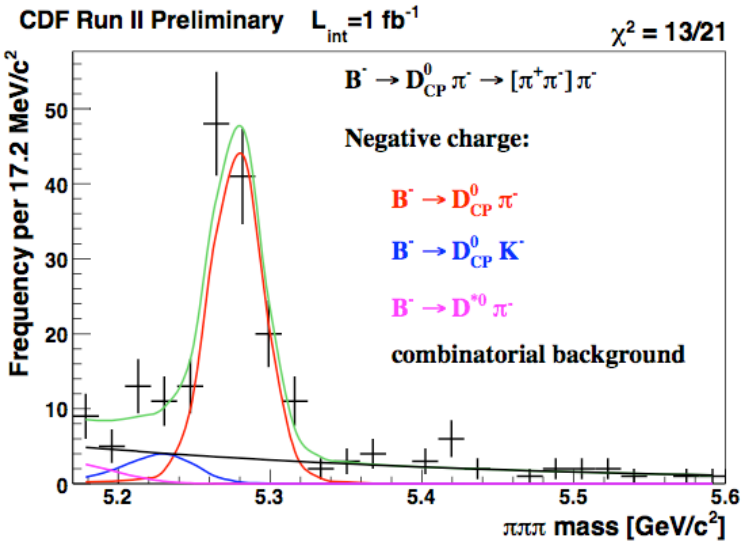
Babar: R = 0.0831 ± 0.0035 ± 0.002
Belle: R = 0.077 ± 0.005 ± 0.006





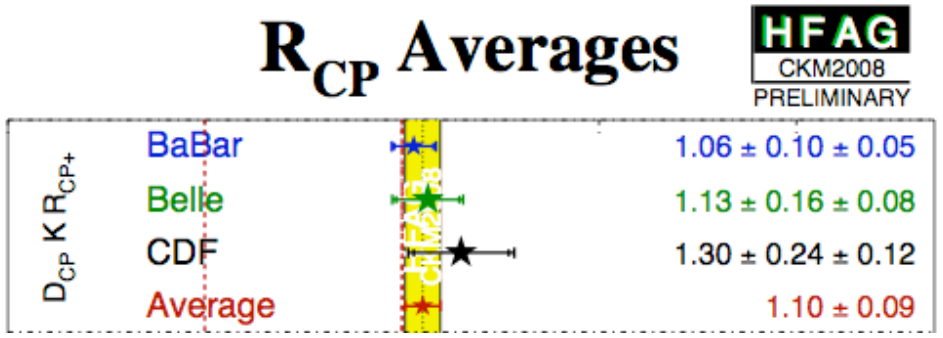
Fit Results on 1 fb^{-1} DCP modes

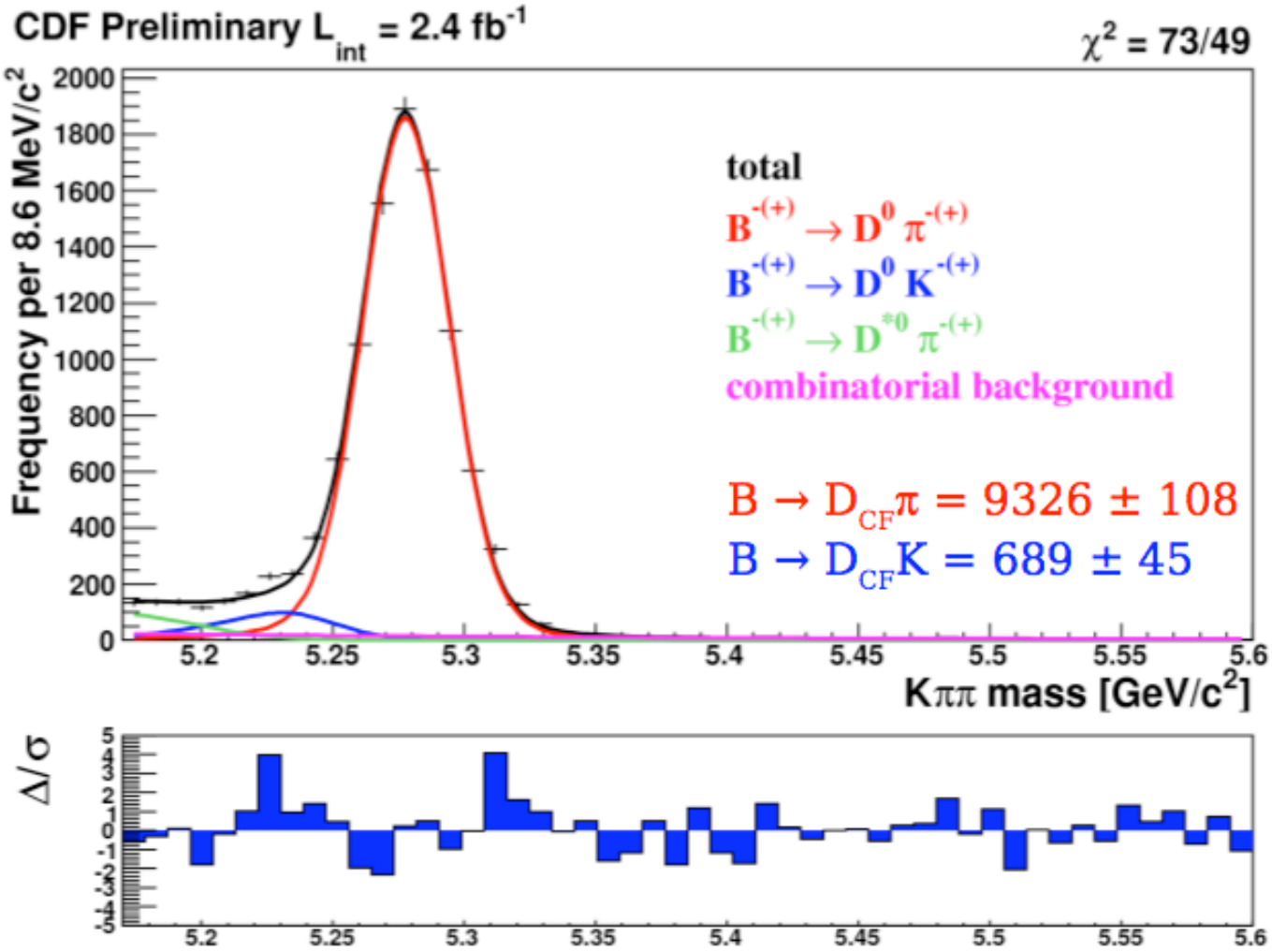




$$R_{CP+} = 1.30 \pm 0.24(stat) \pm 0.12(syst)$$
$$A_{CP+} = 0.39 \pm 0.17(stat) \pm 0.04(syst)$$

R_{CP} Averages



Reconstruction of $B \to D_{CF}\,\pi$ mode

$L = 2.4\ fb^{-1}$