Tevatron time-integrated γ measurements and prospects

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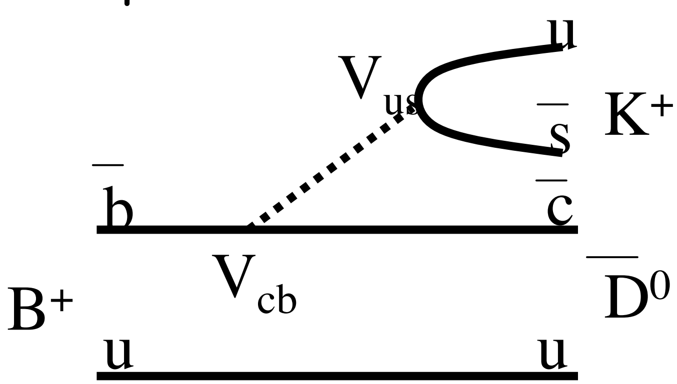
CKM 2010
Warwick, 6-10 September 2010

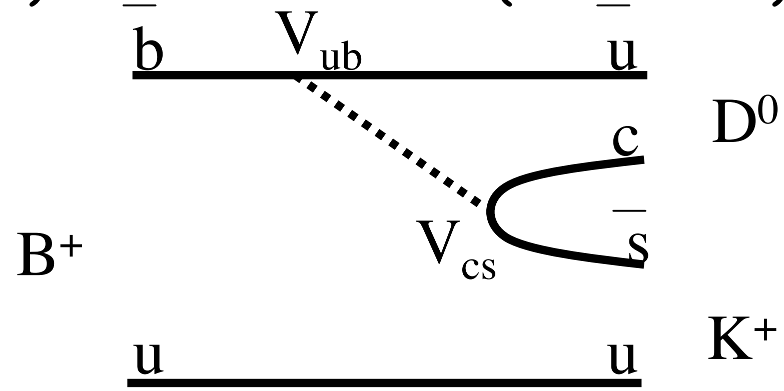
γ angle from $B^+ \to D^0 K^+$

γ could be extracted by exploiting the interference between the processes $\bar{b} \to \bar{c} u \bar{s}$ $(B^+ \to \bar{D}^0 K^+)$ and $\bar{b} \to \bar{u} c \bar{s}$ $(B^+ \to D^0 K^+)$



Favored $\bar{b} \to \bar{c}$ decay

$A_1 \sim V_{cb} V_{us}^* \sim \lambda^3$



Color suppressed $\bar{b} \to \bar{u}$ decay

$A_2 \sim V_{ub} V_{cs}^* \sim \lambda^3 r_B e^{-i\delta B} e^{-i\gamma}$

- **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 $D^0 \to K^0_s \pi^+ \pi^-$

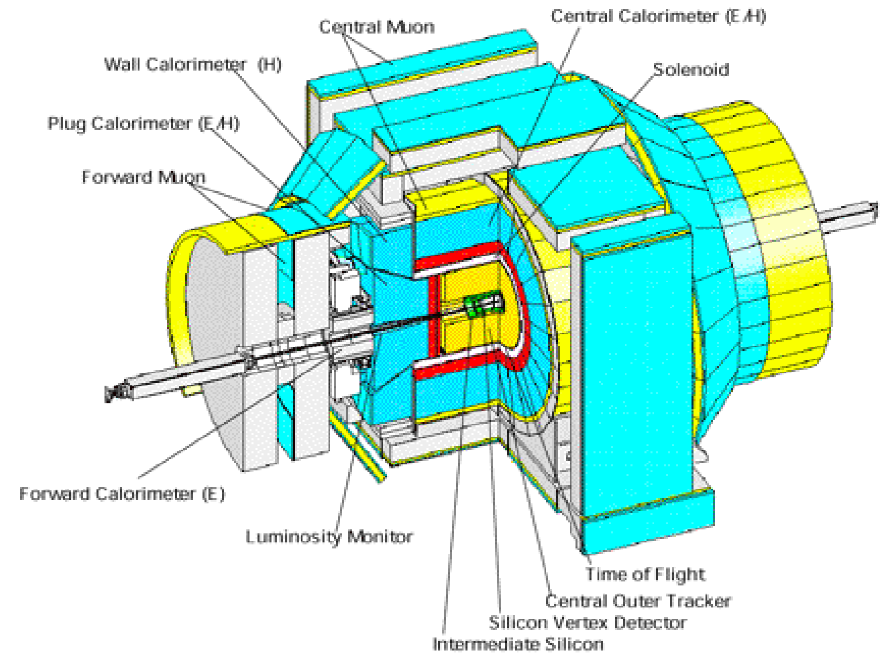
The CDF II detector

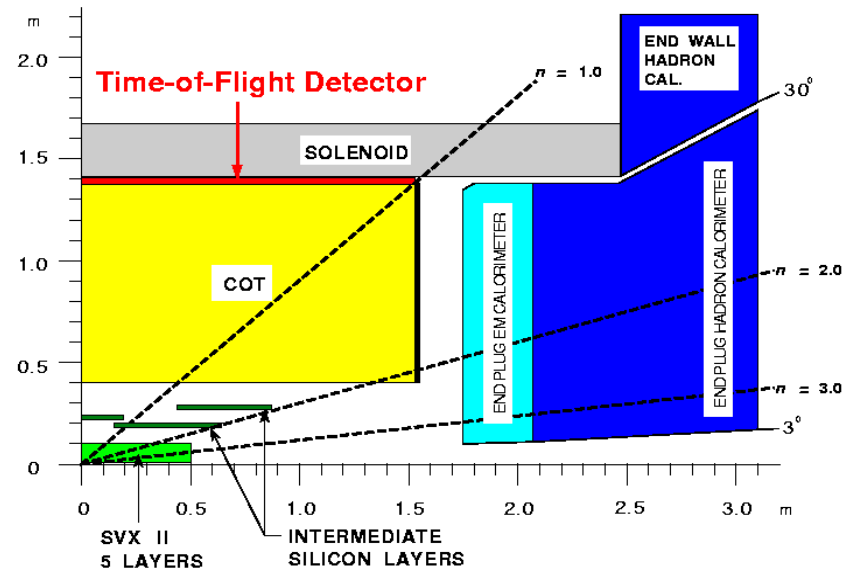
TRACKING system:

- **DRIFT CHAMBER**
96 layers ($|\eta|<1$)
  → 1.5σ π/K separation by dE/dx
- **SILICON TRACKER**
7 layers (1.5-22cm from beam pipe)
→ I.P. resolution 35 μm at 2 GeV
→ $\sigma(p_T)/p_T^2 \sim 0.015\%$ (c/GeV)

TRACKING TRIGGER system:

- **Chamber track processor** at L1,
2D tracks in COT, $p_T > 1.5$ GeV
- **Silicon Vertex Trigger** at L2,
2D tracks $p_T > 2$ GeV, Impact Parameter measurement (trigger on events containing long lived particles)





NEW : ADS method at CDF

First measurement of A_{ADS} and R_{ADS} at a hadron collider using 5 fb^{-1}

ADS Observables

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

Observables

$$R_{ADS}(K) = \frac{N(B^- \to D^0_{DCS}K^-) + N(B^+ \to D^0_{DCS}K^+)}{N(B^- \to D^0_{CF}K^-) + N(B^+ \to D^0_{CF}K^+)}$$

$$\mathcal{A}_{ADS}(K) = \frac{N(B^- \to D^0_{DCS}K^-) - N(B^+ \to D^0_{DCS}K^+)}{N(B^- \to D^0_{DCS}K^-) + N(B^+ \to D^0_{DCS}K^+)}$$

From theory:

$R_{ADS}(K) = r_D^2 + r_B^2 + 2r_Br_D \cos(\delta_B+\delta_D) \cos\gamma$

$A_{ADS}(K) = 2r_Br_D \sin(\delta_B+\delta_D)\sin\gamma/R_{ADS}(K)$

$$A_{ADS}(MAX) = \frac{2r_Br_D}{r_B^2 + r_D^2}$$

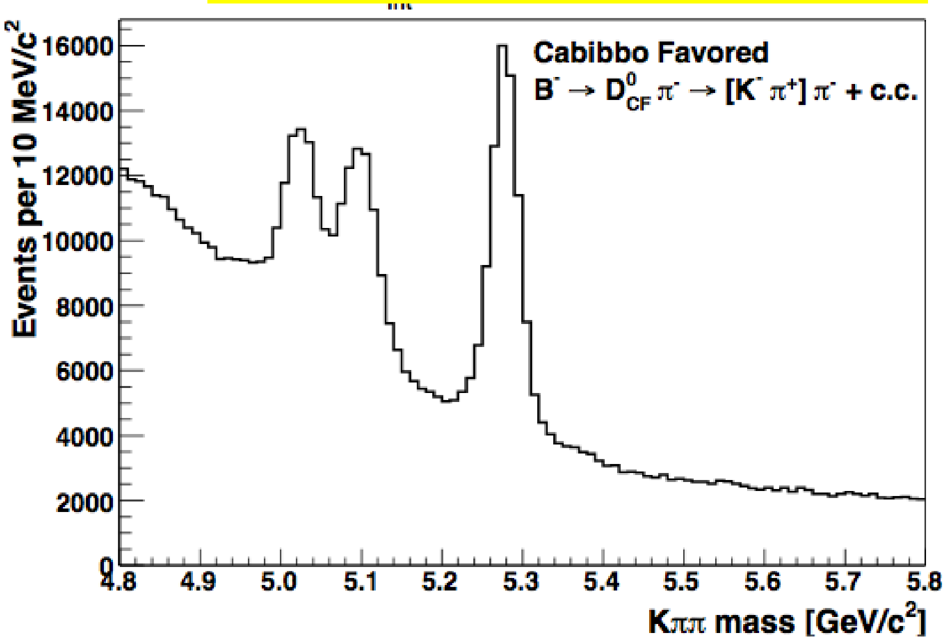
$$\mathcal{A}_{ADS}(\pi) = \frac{N(B^- \to D^0_{DCS}\pi^-) - N(B^+ \to D^0_{DCS}\pi^+)}{N(B^- \to D^0_{DCS}\pi^-) + N(B^+ \to D^0_{DCS}\pi^+)}$$

$$R_{ADS}(\pi) = \frac{N(B^- \to D^0_{DCS}\pi^-) + N(B^+ \to D^0_{DCS}\pi^+)}{N(B^- \to D^0_{CF}\pi^-) + N(B^+ \to D^0_{CF}\pi^+)}$$

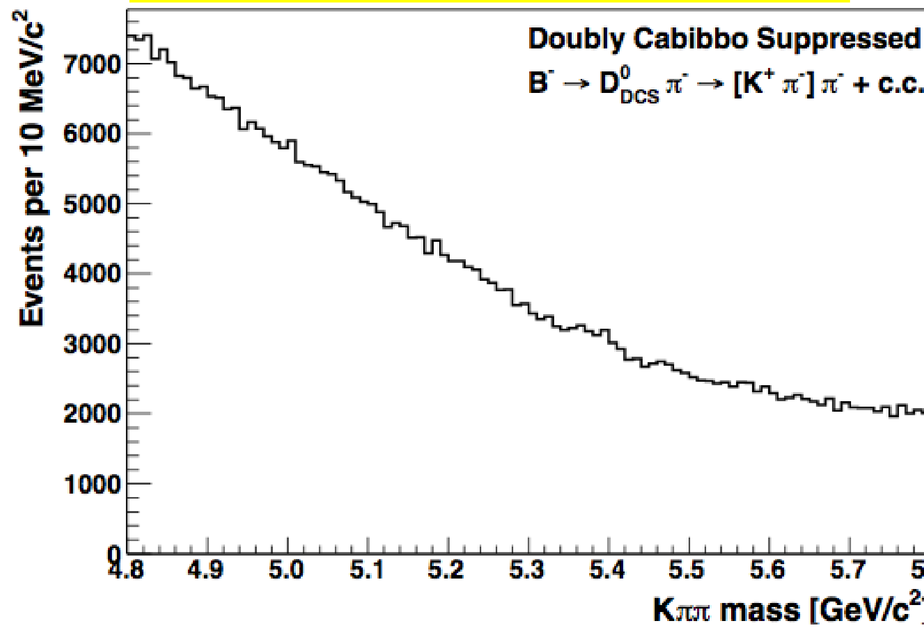
Sizeable asymmetries may be found also for $B \to D_{DCS}\,\pi$

CF and DCS samples ($L = 5fb^{-1}$)

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



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



Cuts optimization → Crucial step toward the DCS modes

- Maximize the quantity $\dfrac{S}{1.5+\sqrt{B}}$ on CF sample. (arXiv:0808063v2)

Optimized cuts

B candidate

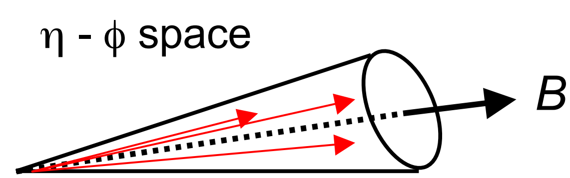
- $Lxy_B/errLxy_B \geq 12$
- $|IP_B| \leq 0.005$ cm
- Pointing angle ≤ 0.15
- Isolation(R=0.4) ≥ 0.7
- Isolation(R=1) ≥ 0.4
- $\chi^2_{3D} \leq 13$

D0 candidate

- Lxy wrtB ≥ 0.01 cm
- ΔR(D-track from B) ≤ 1.5
- ΔID(KfromD-πfromD) $\geq -1.$
- $|\cos(\theta^*)_D| \leq 0.6$
- $1.8495 \leq$ M(HP k-π) ≤ 1.8815
- M(HP π–k) ≥ 1.9045 & M(HP π–k) ≤ 1.8265
- M(HP k-πfromB) ≥ 1.9045 & M(HP k-πfromB) ≤ 1.8265

Reduce contamination from three body decay ($B^+ \to h^+ h^- h^+$)

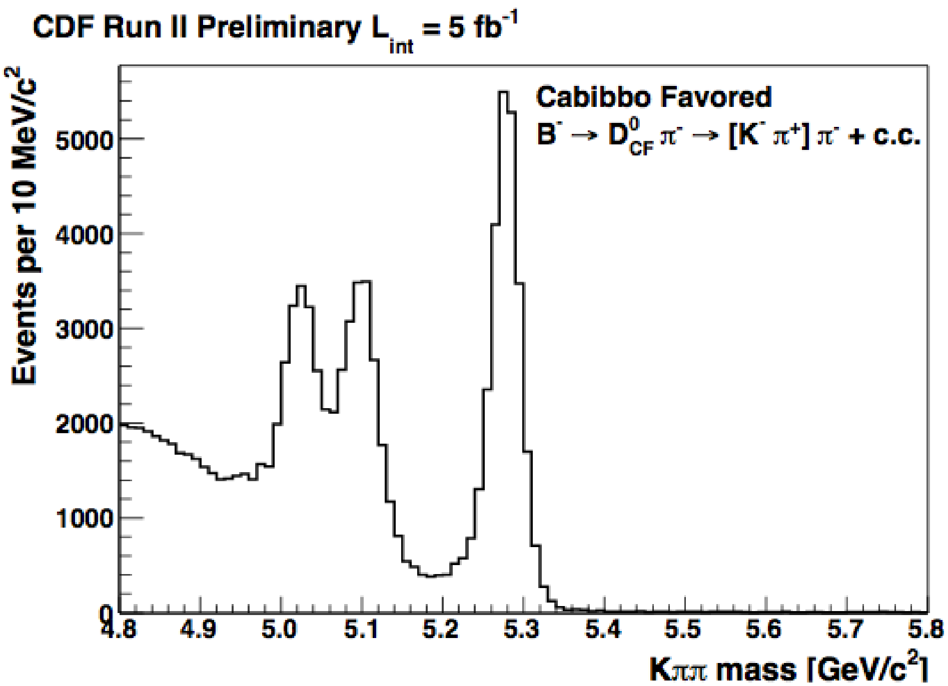
$$I(B) = \frac{p_T(B)}{p_T(B) + \sum_i p_T(i)}$$



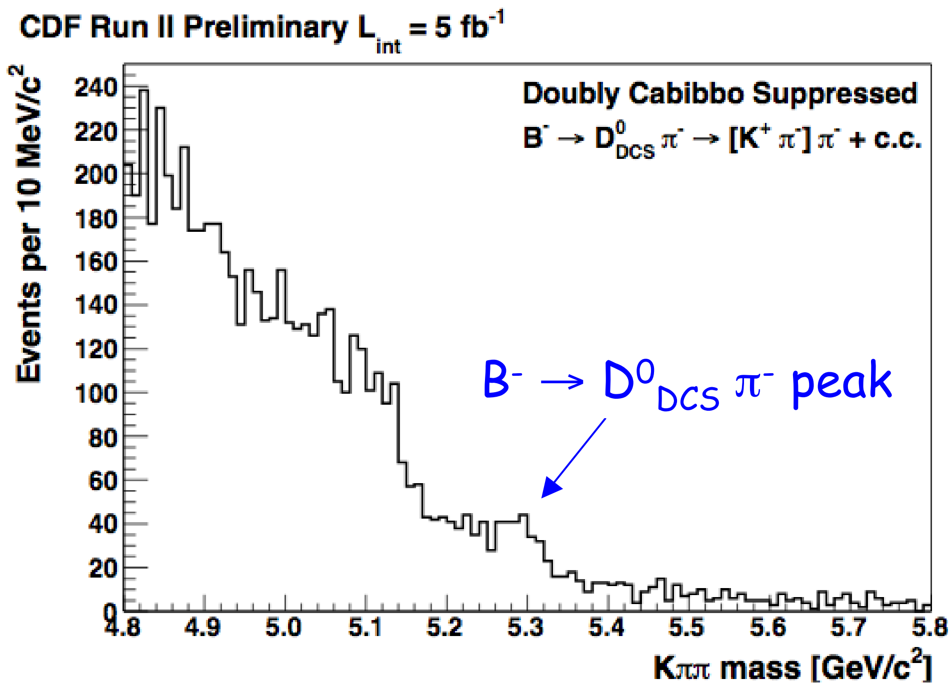
Exploit the powerful 3D silicon-tracking to resolve multiple vertices along the beam direction and to reject fake tracks. Backg. reduces x2, small inefficiency on signal (<10%).

CF and DCS after cut optimization

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

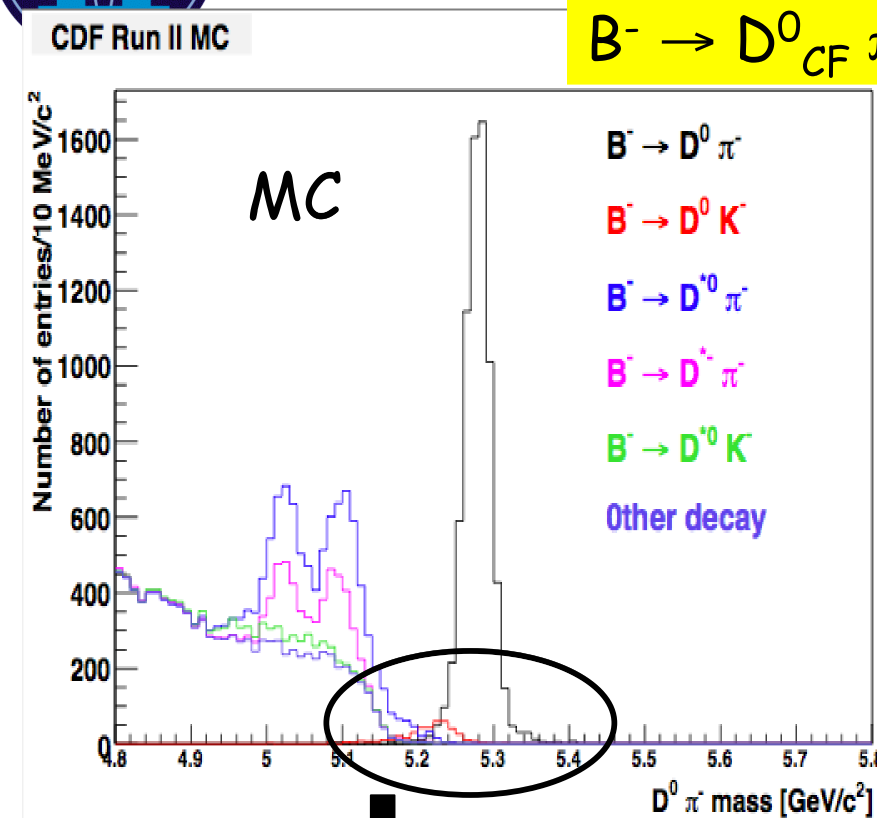


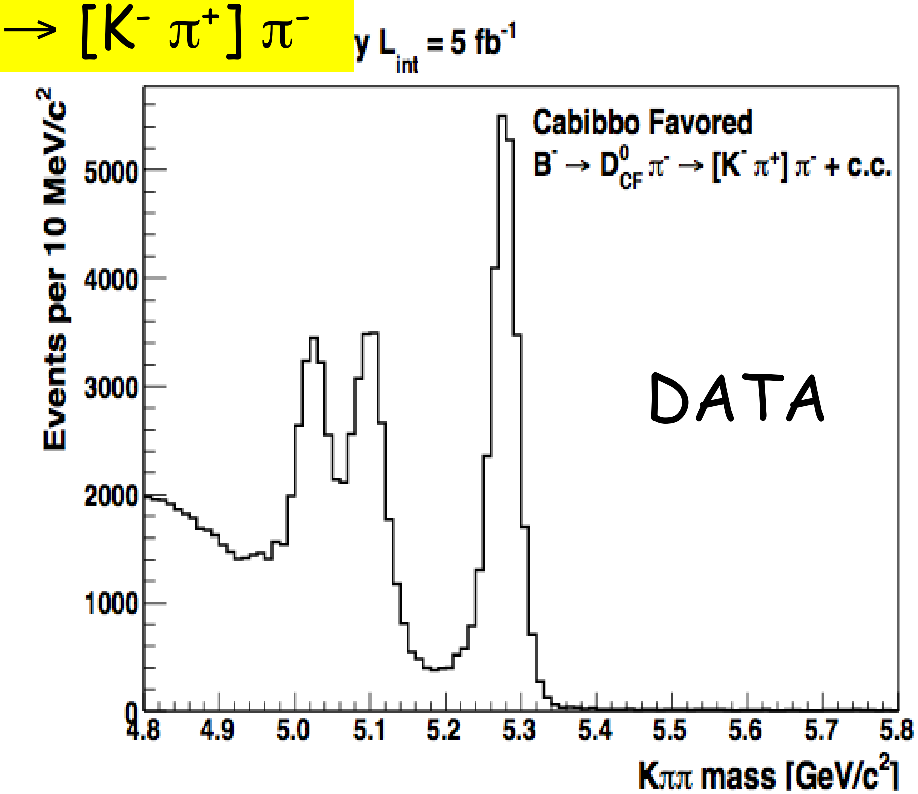
$B^- \to D^0_{DCS}\,\pi^- \to [K^+\,\pi^-]\,\pi^-$

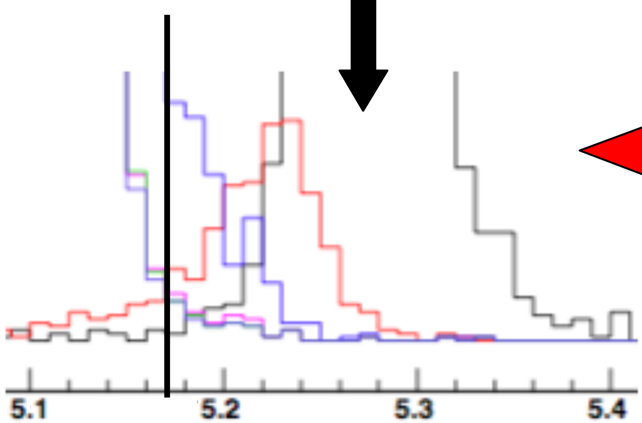


Separating DK from other modes

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





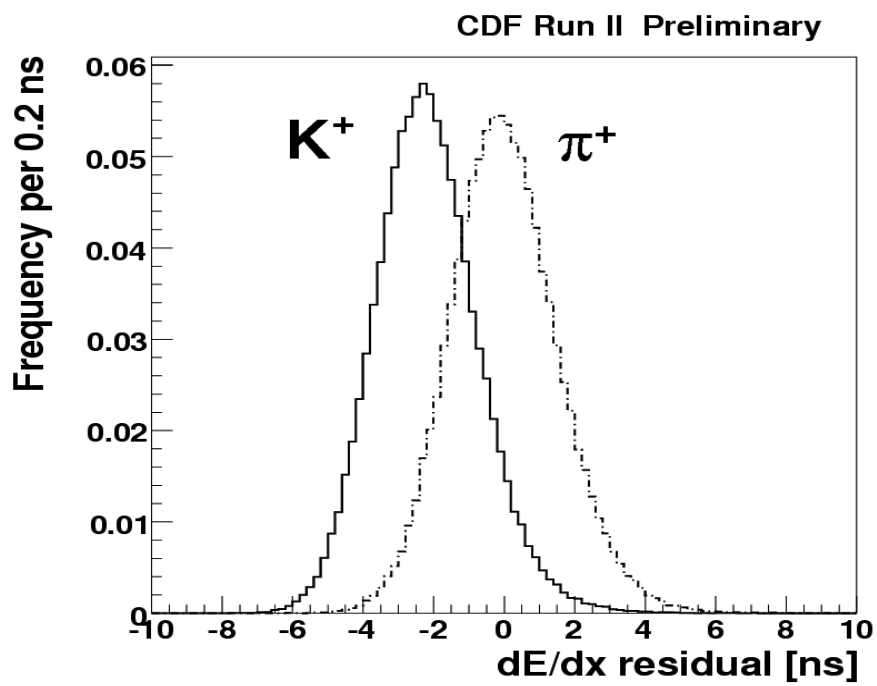


To reject most of the physical backgrounds, narrow fit windows [5.17,6.5]

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

Separation by Particle ID

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



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

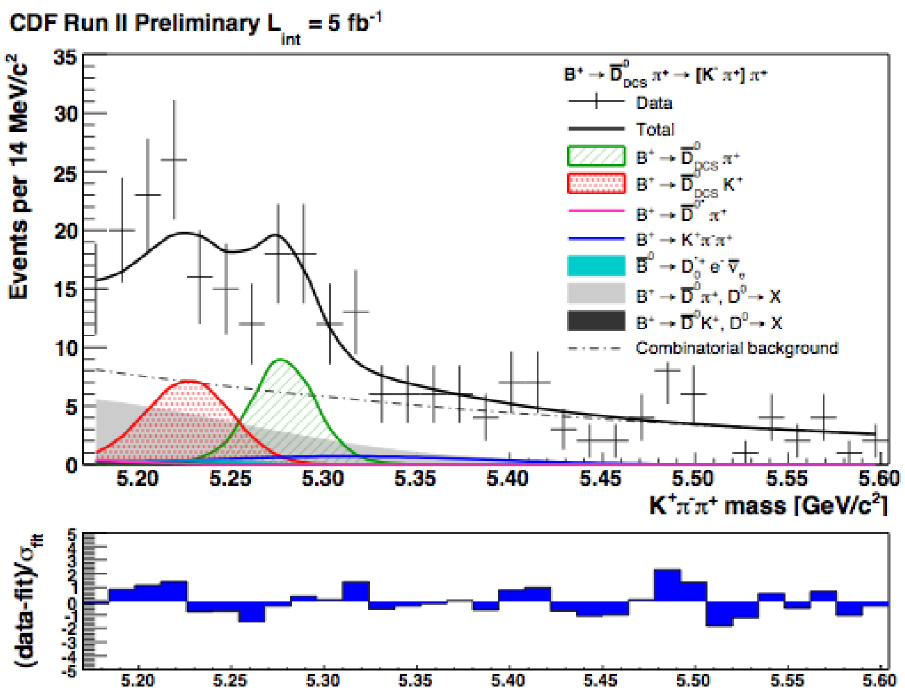
Results

D mode	$B^+ \to D\pi^+$	$B^- \to D\pi^-$	$B^+ \to DK^+$	$B^- \to DK^-$
CF	8873±103	8804±103	727±47	785±49
DCS	29±10	44±12	28±11	6±8

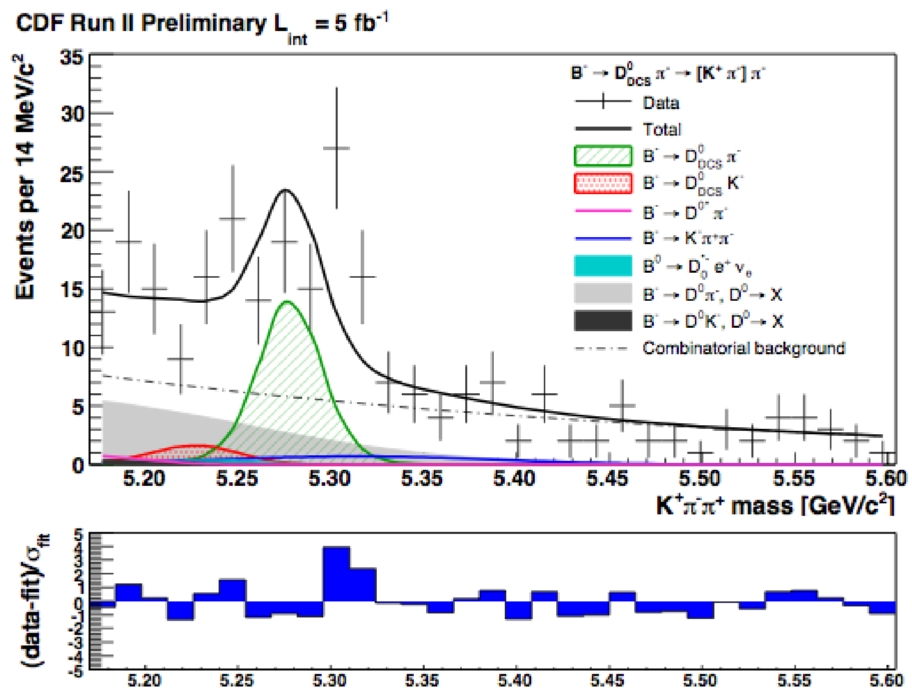
Yield ($B \to D_{DCS}K$) = 34 ± 14 (5 fb^{-1})
Yield ($B \to D_{DCS}\pi$) = 73 ± 16 (5 fb^{-1})

Significance for all DCS signal ($D_{DCS}\pi$ + $D_{DCS}K$) > 5 σ

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



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

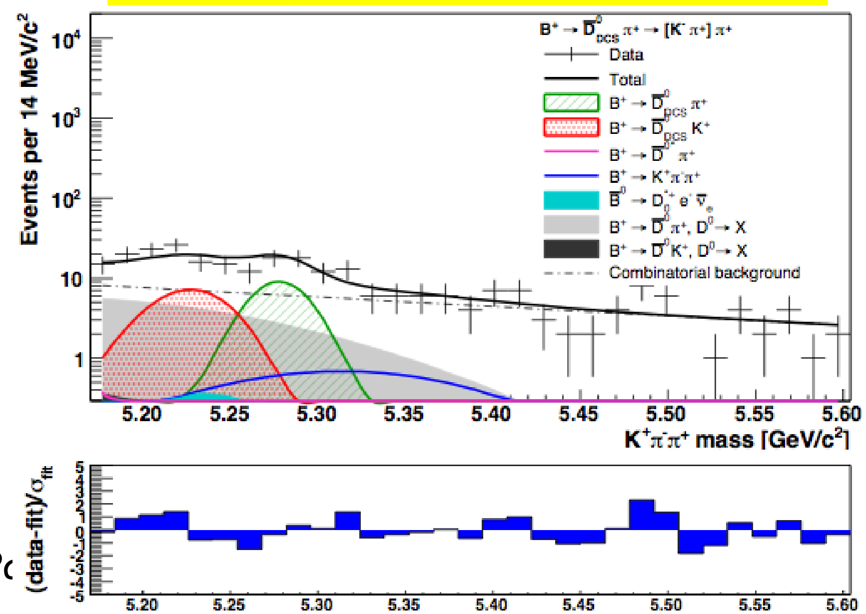


Results: physics background

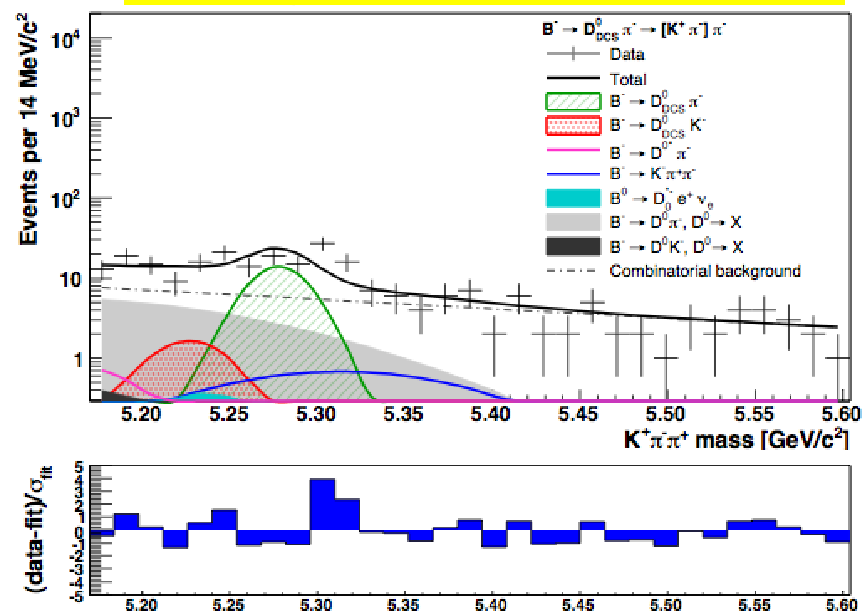
Physics background for DCS:

Decay	Yield
$B^- \to D^{0*} \pi^-$, $D^{0*} \to D^0 \gamma/\pi^0$	3±3
$B^- \to D^0 \pi^-$, $D^0 \to X$	90±13
$B^- \to D^0 K^-$, $D^0 \to X$	4±3
$B^- \to K^- \pi^+ \pi^-$	18±4
$B^0 \to D_0^{*-} e^+ \nu_e$	4±3

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



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

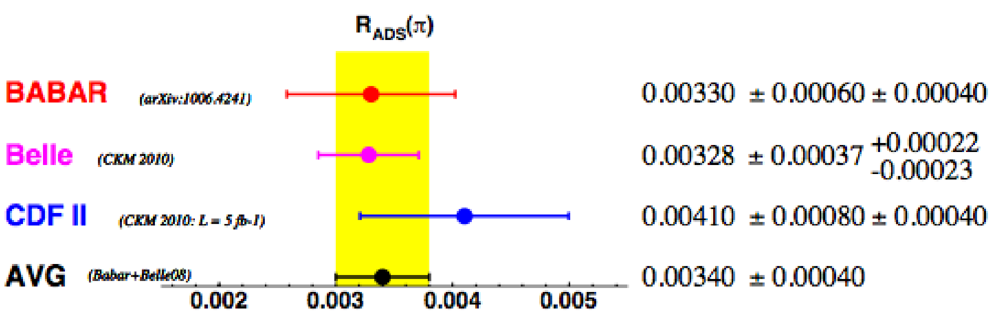


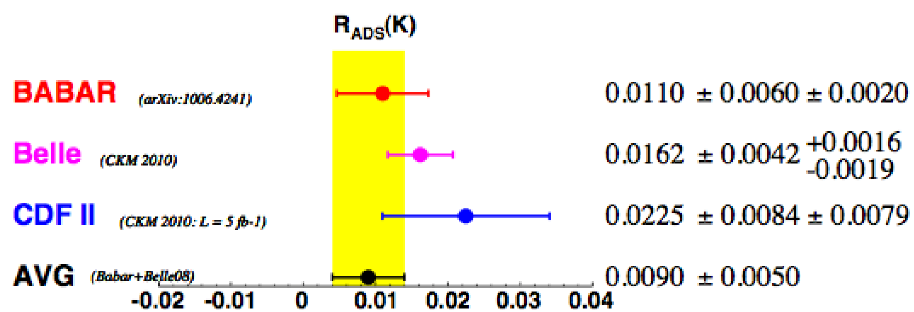
Pc

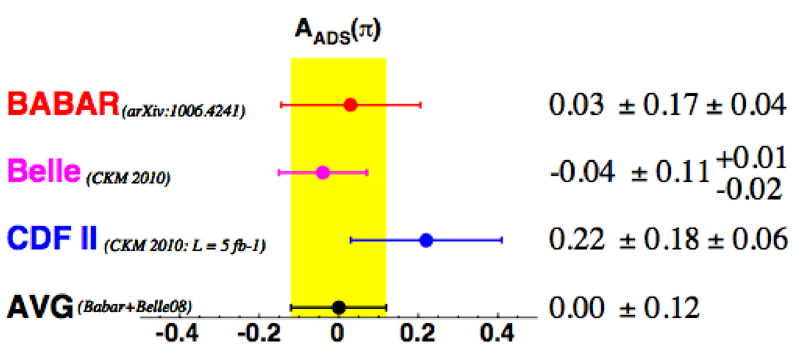
Results

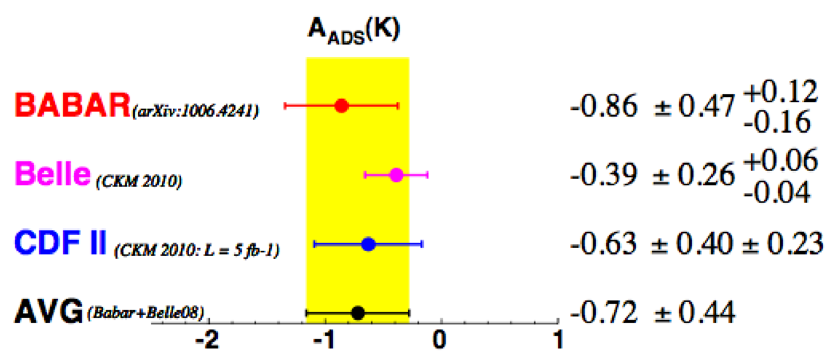
$$R_{ADS}(\pi) = 0.0041 \pm 0.0008(stat) \pm 0.0004(syst)$$
$$A_{ADS}(\pi) = 0.22 \pm 0.18(stat) \pm 0.06(syst)$$
$$R_{ADS}(K) = 0.0225 \pm 0.0084(stat) \pm 0.0079(syst)$$
$$A_{ADS}(K) = -0.63 \pm 0.40(stat) \pm 0.23(syst)$$

- First measurement of A_{ADS} and R_{ADS} at a hadron collider.
- Agrees with previous measurements from other experiments.









GLW method: first measurement of A_{CP+} and R_{CP+} at a hadron collider using 1 fb^{-1}

(Phys.Rev.D81:031105,2010)

GLW Observables

Direct CP violation in $B \rightarrow D_{CP}K$ modes

4 observables

$$R_{CP\pm} = \frac{\Gamma(B^- \rightarrow D^0_{CP\pm}K^-) + \Gamma(B^+ \rightarrow D^0_{CP\pm}K^+)}{[\Gamma(B^- \rightarrow D^0 K^-) + \Gamma(B^+ \rightarrow D^0 K^+)]/2}$$

$$A_{CP\pm} = \frac{\Gamma(B^- \rightarrow D^0_{CP\pm}K^-) - \Gamma(B^+ \rightarrow D^0_{CP\pm}K^+)}{\Gamma(B^- \rightarrow D^0_{CP\pm}K^-) + \Gamma(B^+ \rightarrow D^0_{CP\pm}K^+)}$$

From theory:

$R_{CP\pm} = 1 + r_B^2 \pm 2r_B \cos\delta_B \cos\gamma$

$A_{CP\pm} = 2r_B \sin\delta_B \sin\gamma / R_{CP\pm}$

3 are independent
($A_{CP+}R_{CP+} = -A_{CP-}R_{CP-}$)
and 3 unknowns (r_B, γ, δ_B)

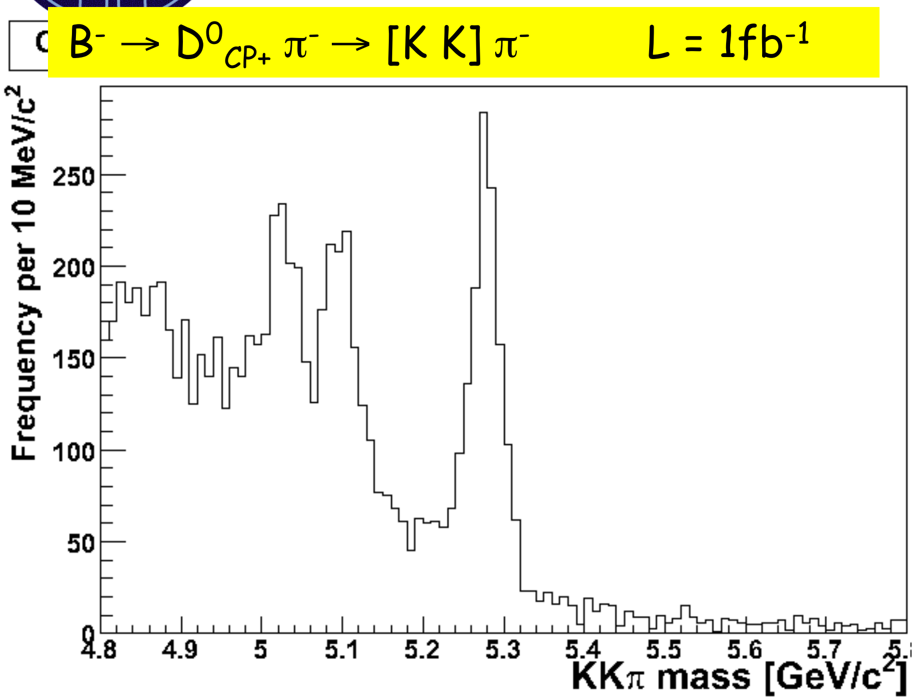
$$R = \frac{B(B^- \rightarrow D^0 K^-) + B(B^+ \rightarrow \overline{D}^0 K^+)}{B(B^- \rightarrow D^0 \pi^-) + B(B^+ \rightarrow \overline{D}^0 \pi^+)}$$

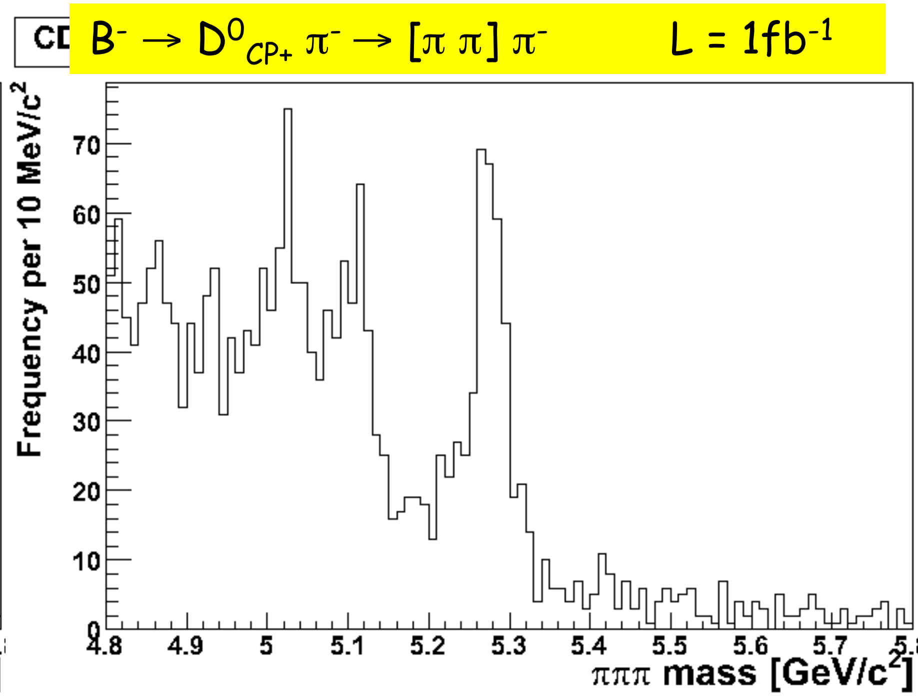
$$R_\pm = \frac{B(B^- \rightarrow D^0_{CP\pm}K^-) + B(B^+ \rightarrow D^0_{CP\pm}K^+)}{B(B^- \rightarrow D^0_{CP\pm}\pi^-) + B(B^+ \rightarrow D^0_{CP\pm}\pi^+)}$$

$R_{CP\pm} \sim R_\pm / R$

We neglect a term $r_B|V_{us}V_{cd}/V_{ud}V_{cs}| \sim 0.01$

Selection of D_{CP} modes





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)

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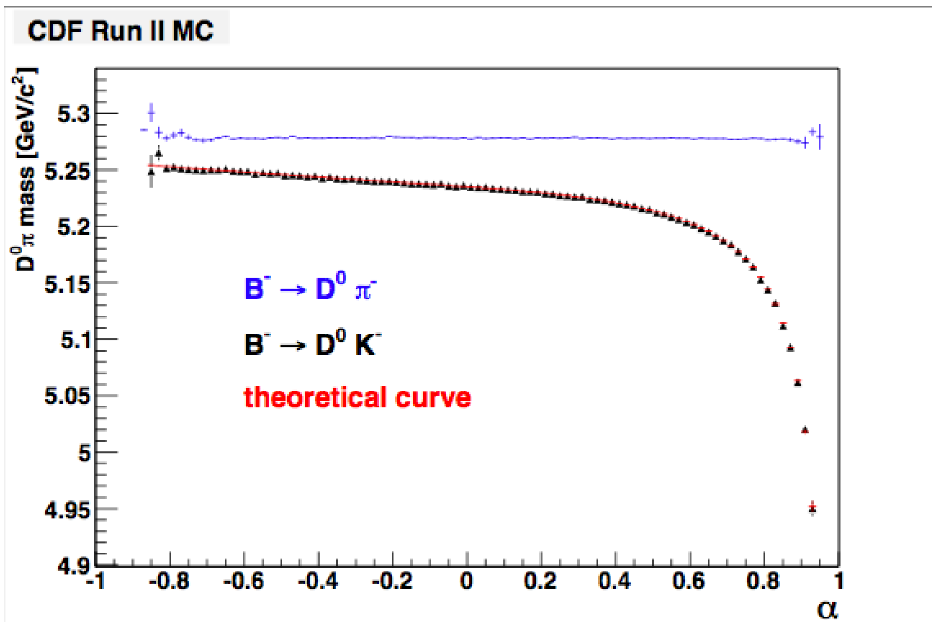
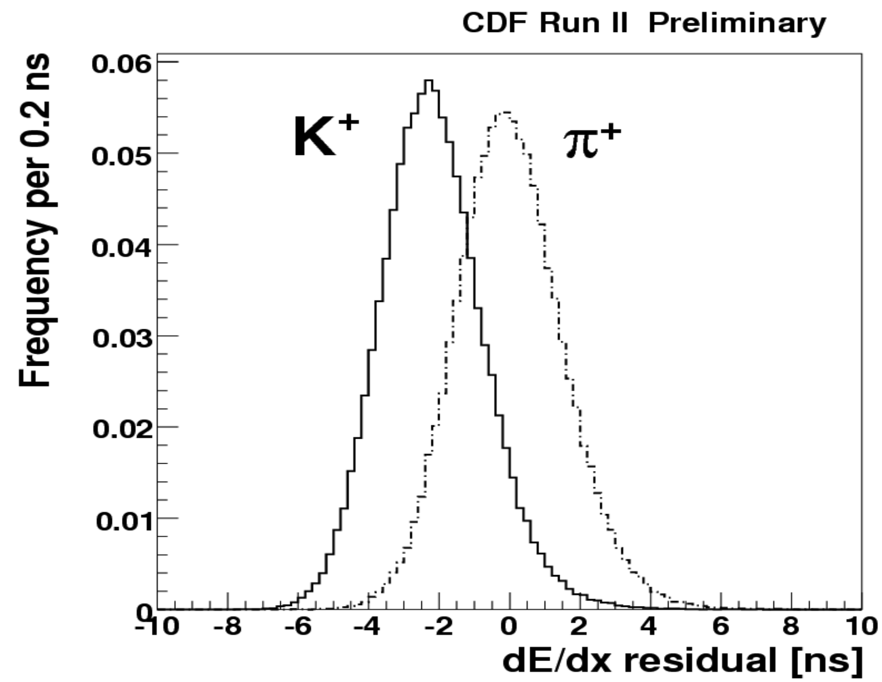
Separation by kinematics and Particle ID

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

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

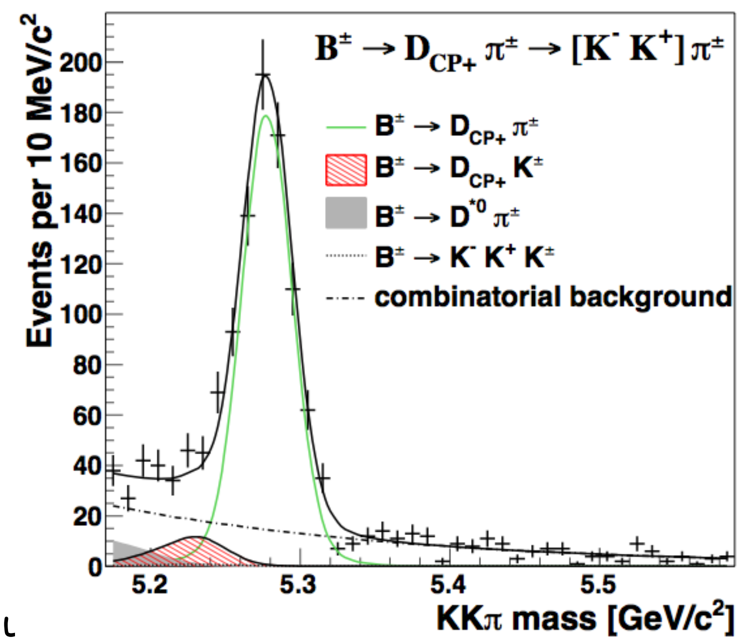
Results

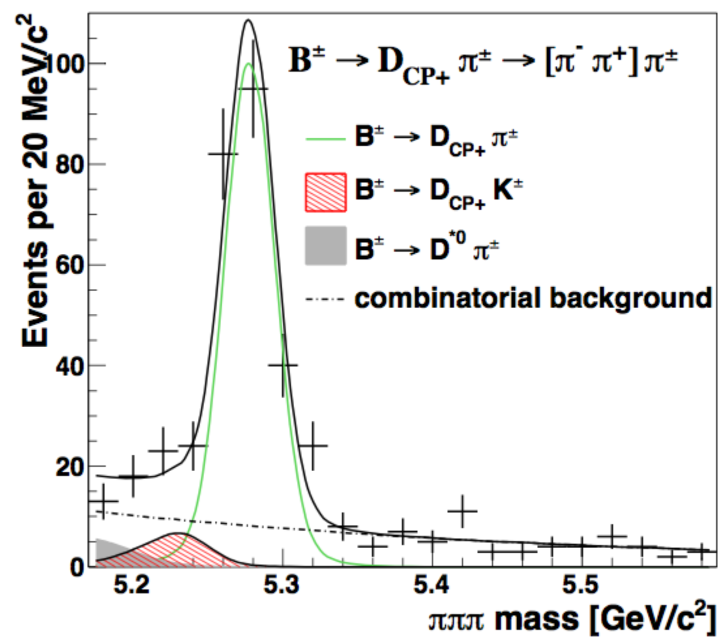
D mode	$B^+ \to D\pi^+$	$B^- \to D\pi^-$	$B^+ \to DK^+$	$B^- \to DK^-$
$K^-\pi^+$	3769 ± 68	3763 ± 68	250 ± 26	266 ± 27
K^+K^-	381 ± 25	399 ± 26	22 ± 8	49 ± 11
$\pi^+\pi^-$	101 ± 13	117 ± 14	6 ± 6	14 ± 6

Yield ($B \to D_{CP+}K$) ~ 90 (1 fb^{-1})

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

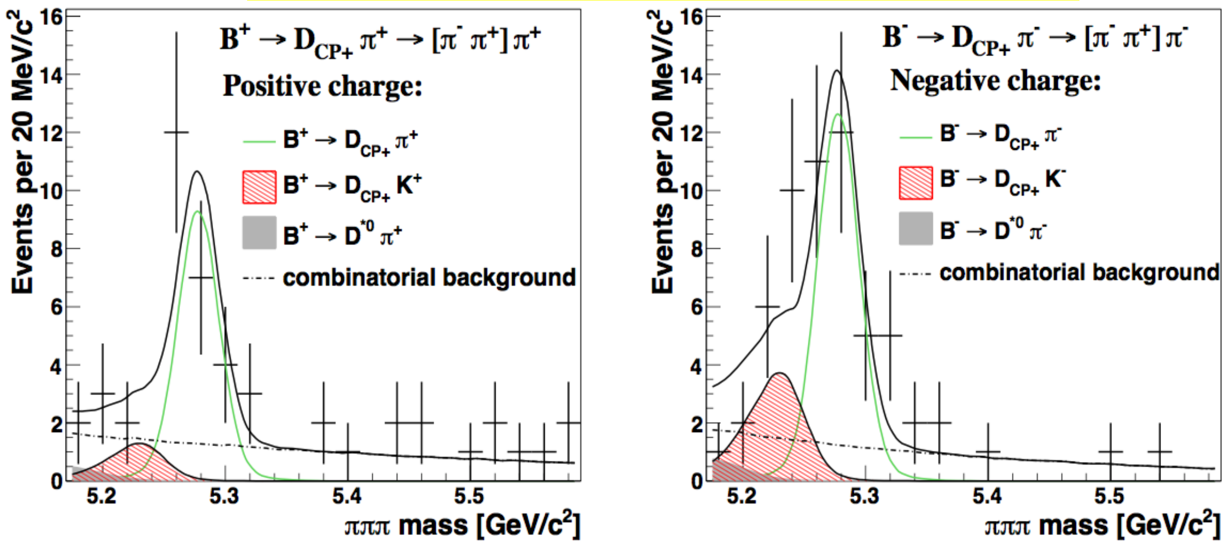
$$A_{CP+} = 0.39 \pm 0.17(stat) \pm 0.04(syst)$$



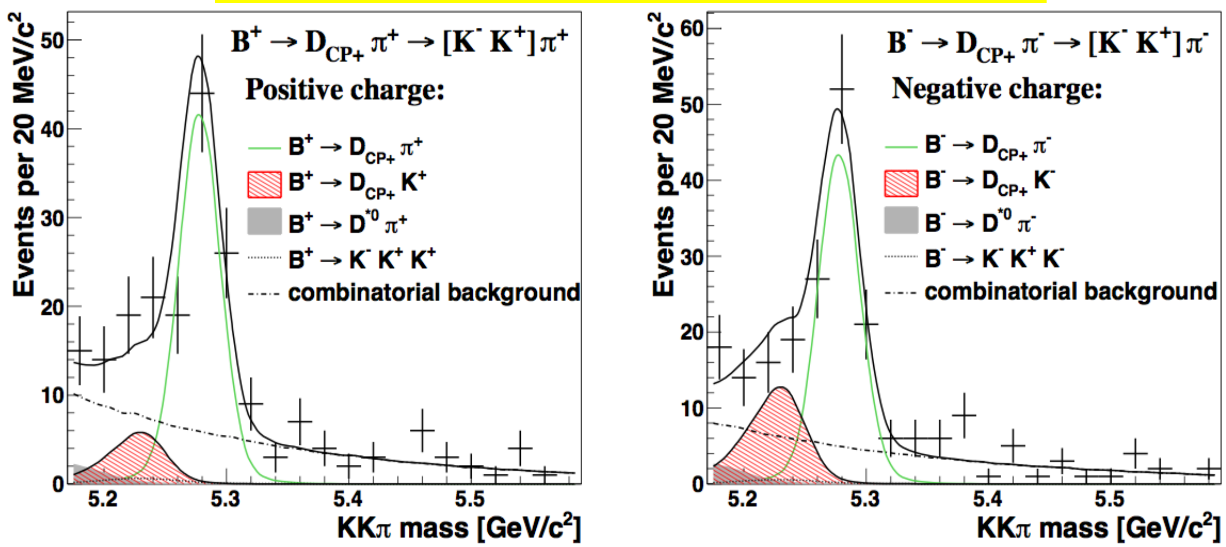


Cross-check: kaon PID selection

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



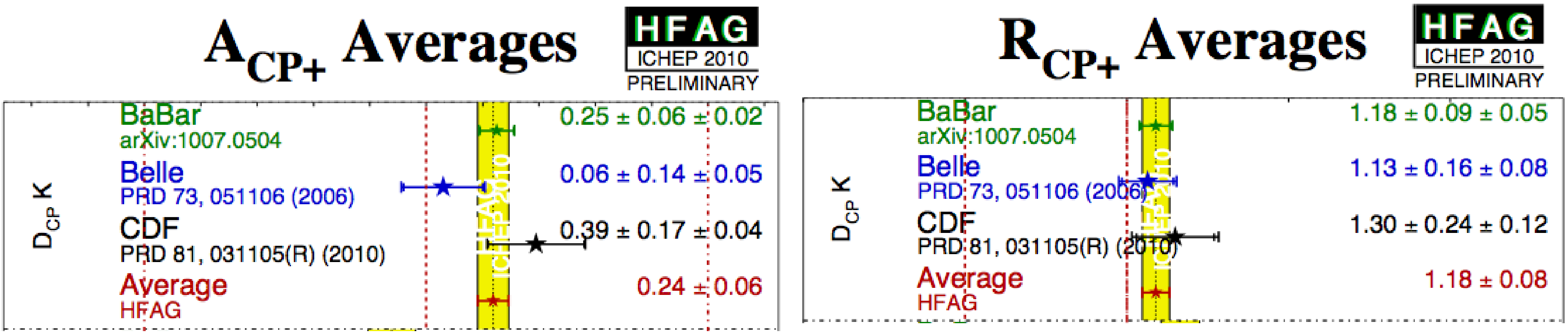
$B \to D^0_{CP+}\, \pi \to [K\, K]\, \pi$ $L = 1fb^{-1}$



A requirement on the PID variable was applied to suppress the $D\pi$ component and favor the DK component.

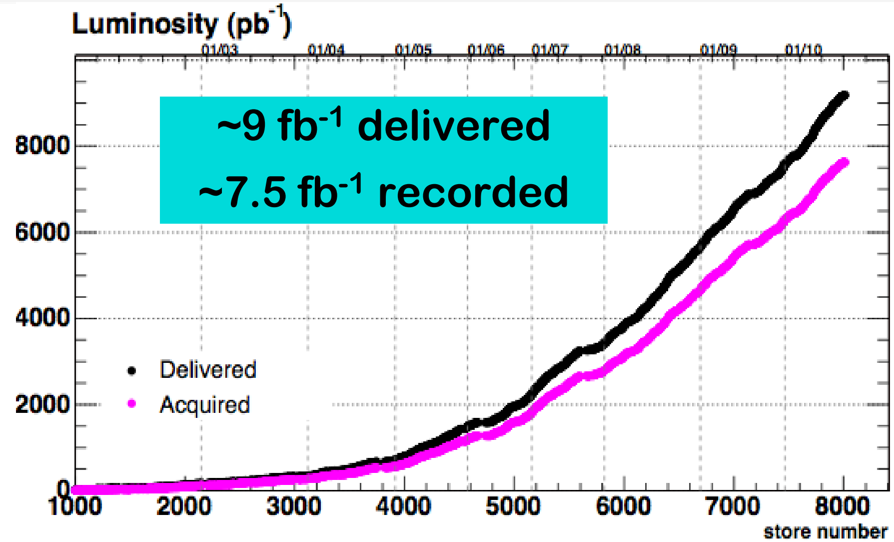
GLW method: Summary

- First measurement of A_{CP+} and R_{CP+} at a hadron collider.
- Agrees with previous measurements from other experiments.



NEXT

- Excellent performance of Tevatron accelerator
- Expect 10-12 fb^{-1} by 2011



B mode	D mode	Meth.	CDF Yield 5fb^{-1}	CDF Yield 10 fb^{-1} (rough extrapolation)
$B \to DK$	KK, $\pi\pi$	GLW	300	550
$B \to D\pi$	$K\pi$ DCS	ADS	70	130
$B \to DK$	$K\pi$ DCS	ADS	35	65

	$\sigma(A_{ADS}(K))$	$\sigma(R_{ADS}(K))$	$\sigma(A_{ADS}(\pi))$	$\sigma(R_{ADS}(\pi))$	$\sigma(A_{CP+})$	$\sigma(R_{CP+})$
Now	0.40	0.0084	0.18	0.0008	0.17	0.24
L=10 fb^{-1}	0.29	0.0062	0.13	0.0006	0.07	0.10

Conclusions

- CDF performed the first measurement of A_{ADS} and R_{ADS} at a hadron collider using 5 fb^{-1}.
  - Significance of DCS signal ($D_{DCS}\,\pi$ + D_{DCS} K) > 5σ

- This supplements recently published first GLW analysis in hadron collisions within a CDF global program to measure angle gamma from trees.

- Now working to expeditely update the GLW analysis to the 5 fb^{-1} sample

BACKUP

ADS: cuts definition

Pointing angle = angle between the momentum 3D of B and the decay axis

$\cos(\theta^*)_D$ = angle between the D^0 in the CM of the B and the flight direction of B

$\Delta ID = ID(K_D) - ID(\pi_D)$ where $ID(h) = \dfrac{dE/dx(h) - dE/dx_{\exp}(\pi)}{dE/dx_{\exp}(K) - dE/dx_{\exp}(\pi)}$

ADS: Systematics

Source	$R_{ADS}(\pi)$	$R_{ADS}(K)$	$A_{ADS}(\pi)$	$A_{ADS}(K)$
dE/dx	0.0001	0.0050	0.0560	0.070
combinatorial background	0.0003	0.0037	0.0073	0.153
$B^- \to [X]_D \pi^-$ shape	0.0002	0.0025	0.0067	0.057
$B^- \to [X]_D K^-$ shape	-	0.0001	0.0003	0.003
$B^- \to K^- \pi^+ \pi^-$ shape	0.0001	0.0004	0.0049	0.009
$B^0 \to D_0^{*-} e^+ \nu_e$ shape	-	0.0003	0.0020	0.007
$B^- \to D^{*0} \pi^-$ shape	-	0.0005	0.0009	0.013
efficiency	-	0.0001	-	0.003
bias	0.0001	0.0042	0.0159	0.148
Total	**0.0004**	**0.0079**	**0.059**	**0.232**

ADS: Likelihood

$$\mathcal{L}_{DCS+} = \prod_i^{Nevents} \Big[(1-b_{DCS+})\cdot\Big(f_\pi^{DCS+}\cdot pdf_\pi(M,ID) + \mathbf{c}^+\cdot f_\pi^{DCS+}\cdot pdf_{D*}(M,ID)+$$
$$+\Big(1-f_\pi^{DCS+}-\mathbf{c}^+\cdot f_\pi^{DCS+}\Big)\cdot pdf_K(M,ID)\Big)+$$
$$+b_{DCS+}\cdot\Big(f^+_{[X]\pi}\cdot pdf_{[X]\pi}(M,ID)+f^+_{[X]K}\cdot pdf_{[X]K}+f^+_{K\pi\pi}\cdot pdf_{K\pi\pi}(M,ID)+$$
$$f^+_{B^0}\cdot pdf_{B^0}(M,ID)+(1-f^+_{[X]\pi}-f^+_{[X]K}-f^+_{K\pi\pi}-f^+_{B^0})\cdot pdf_{comb}(M,ID)\Big)\Big]$$

$$\mathcal{L}_{DCS-} = \prod_i^{Nevents} \Big[(1-b_{DCS-})\cdot\Big(f_\pi^{DCS-}\cdot pdf_\pi(M,ID) + \mathbf{c}^-\cdot f_\pi^{DCS-}\cdot pdf_{D*}(M,ID)+$$
$$+\Big(1-f_\pi^{DCS-}-\mathbf{c}^-\cdot f_\pi^{DCS-}\Big)\cdot pdf_K(M,ID)\Big)+$$
$$+b_{DCS-}\cdot\Big(f^-_{[X]\pi}\cdot pdf_{[X]\pi}(M,ID)+f^-_{[X]K}\cdot pdf_{[X]K}+f^-_{K\pi\pi}\cdot pdf_{K\pi\pi}(M,ID)+$$
$$f^-_{B^0}\cdot pdf_{B^0}(M,ID)+(1-f^-_{[X]\pi}-f^-_{[X]K}-f^-_{K\pi\pi}-f^-_{B^0})\cdot pdf_{comb}(M,ID)\Big)\Big]$$

GLW: Likelihood

Fit for $B^- \to D^0 \pi^-/K^-$ fractions SIMULTANEOUSLY in: D^0_{flav}, $D^0_{CP} \to KK$, $D^0_{CP} \to \pi\pi$ modes.

Likelihood =

$$\Pi_k^{Nevents} [(1-b) * (f_\pi F_\pi (\alpha, Ptot, M_{D0\pi}, dE/dx) + f_D BG_D (\alpha, Ptot, M_{D0\pi}, dE/dx)$$

$$+ (1-f_\pi - f_D) F_K (\alpha, Ptot, M_{D0\pi}, dE/dx)) + b\, BG_{comb} (\alpha, Ptot, M_{D0\pi}, dE/dx)]$$

b = fraction of the background measured with respect to all the events
f_π = fraction of $B \to D^0 \pi$ with respect to the total signal (common to the two DCP modes)
f_D = fraction of $B \to D^{0*} \pi$ with respect to the total signal (common to the flavor and the DCP modes)

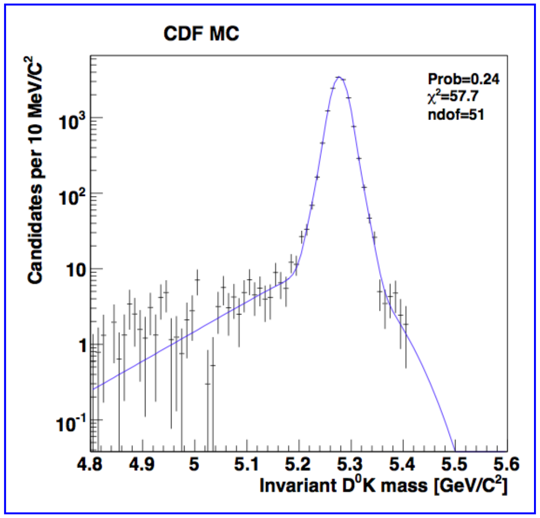
$$F_i (\alpha, Ptot, M_{D0\pi}, ID) = \underbrace{pdf(M_{D0\pi}|\alpha, Ptot)}\ pdf(\alpha,Ptot)\ pdf(dE/dx|\ \alpha, Ptot)$$

Write masses with different particle assignments as functions of a single mass + appropriate kinematics variables α, Ptot

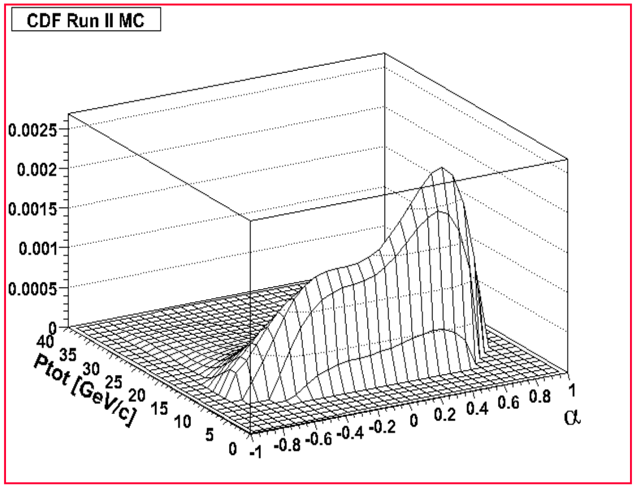
GLW: Likelihood

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

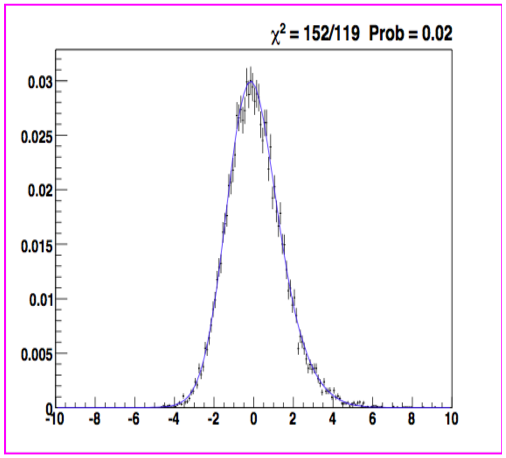
Mass term
- Signal shape from MC (including FSR)
- Background shape: exponential function free in the fit



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



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

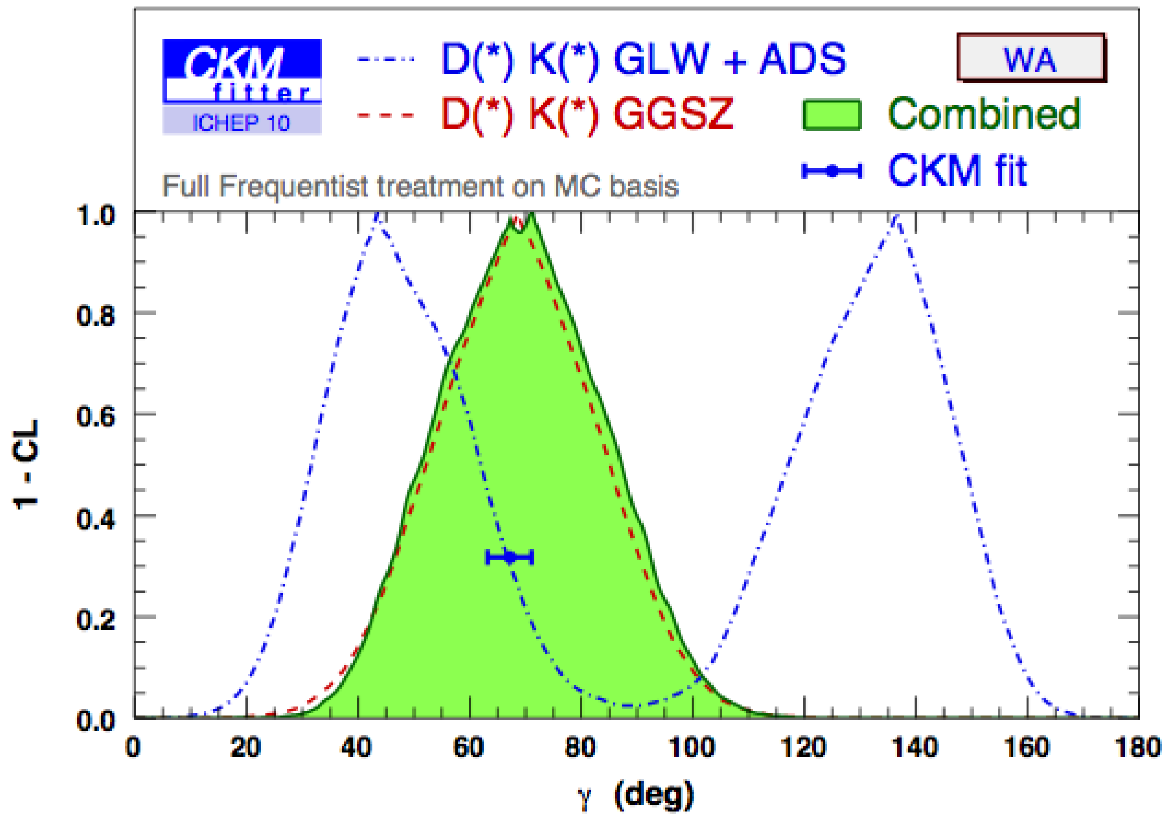


Paola Squillacioti

GLW: Systematics

Source	R_{CP+}	A_{CP+}
dE/dx model	0.056	0.030
$D^{0*}\pi$ mass model	0.025	0.006
Input B^- mass to the fit	0.004	0.002
Combinatorial background mass model	0.020	0.001
Combinatorial background kinematics	0.100	0.020
$D\pi$ kinematics	0.002	0.001
DK kinematics	0.002	0.004
$D^{0*}\pi$ kinematics	0.004	0.002
Fit bias	0.005	0.003
Total (sum in quadrature)	0.12	0.04

Current situation for the γ angle measurement using $B^+ \to \bar{D}^0 K^+$



γ (deg) = 71 [+21 -25]

The Tevatron

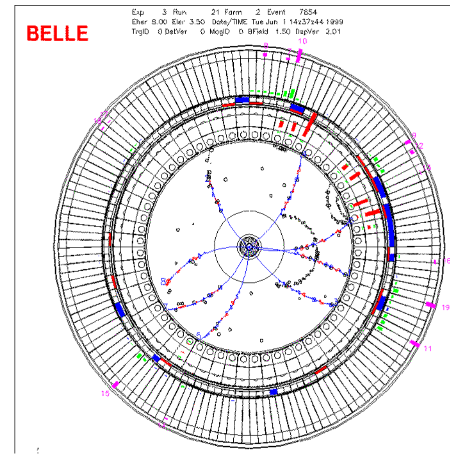
Tevatron is great for rare B decay searches:

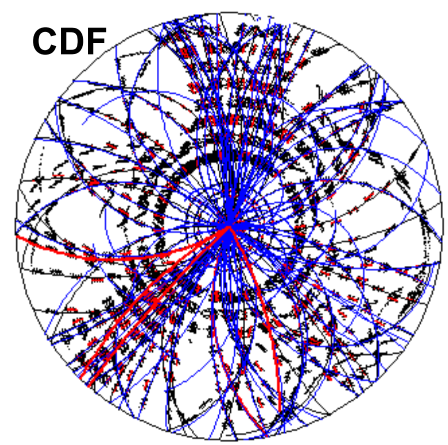
- Enormous *b* production cross section, x1000 times larger than e^+e^- B factories
- All B species are produced (B^0, B^+, B_s, Λ_b…)

But:

- The total inelastic x-section is a factor 10^3 larger than $\sigma(b\ \bar{b})$
- The BRs of rare b-hadron decays are $O(10^{-6})$ or lower

Therefore interesting events must be extracted from a high track multiplicity environment





Detectors need to have:

- Very good tracking and vertex resolution
- Highly selective trigger