$B \rightarrow DK$ measurements:

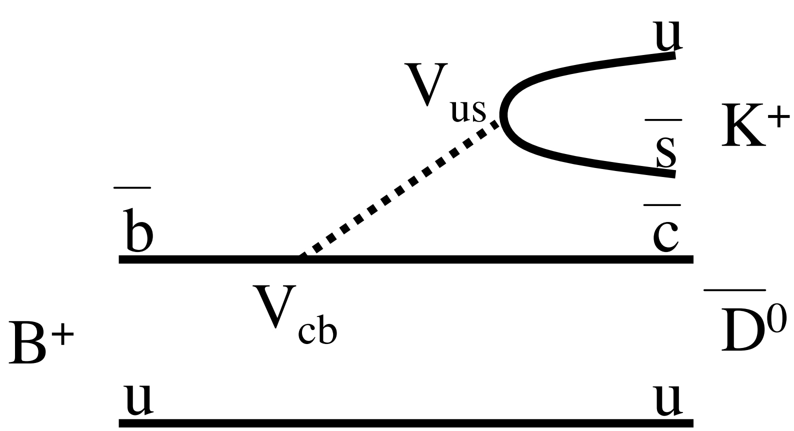
- $B^- \rightarrow D_{CP} K^-$ (M.A. Ciocci, G. Punzi, P. Squillacioti)
- $B^- \rightarrow D_{DCS} K^-$ (P. Garosi, G. Punzi, P. Squillacioti)

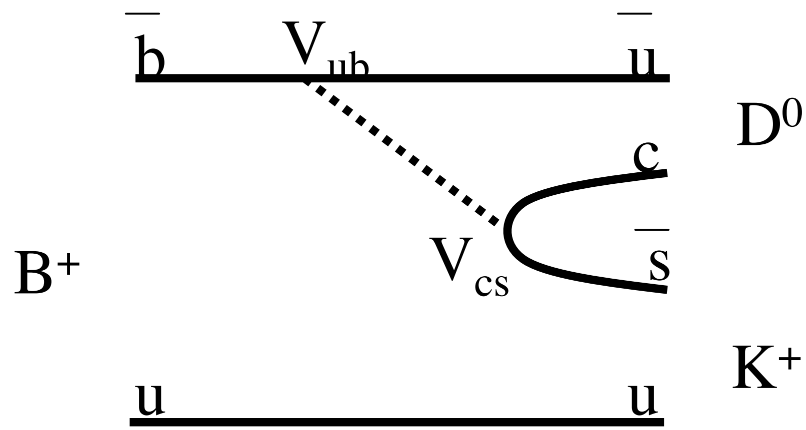
Paola Squillacioti
INFN Pisa & Universita` di Siena

CDF-Italia 2009
2-3 Aprile Trieste

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

γ appears in the relative weak phase 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

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

Interference between these two diagrams into the *same final state* leads to measurable CP-asymmetries, from which γ can be extracted

Tree diagrams $\to$ small theoretical uncertainty (~ 1%)

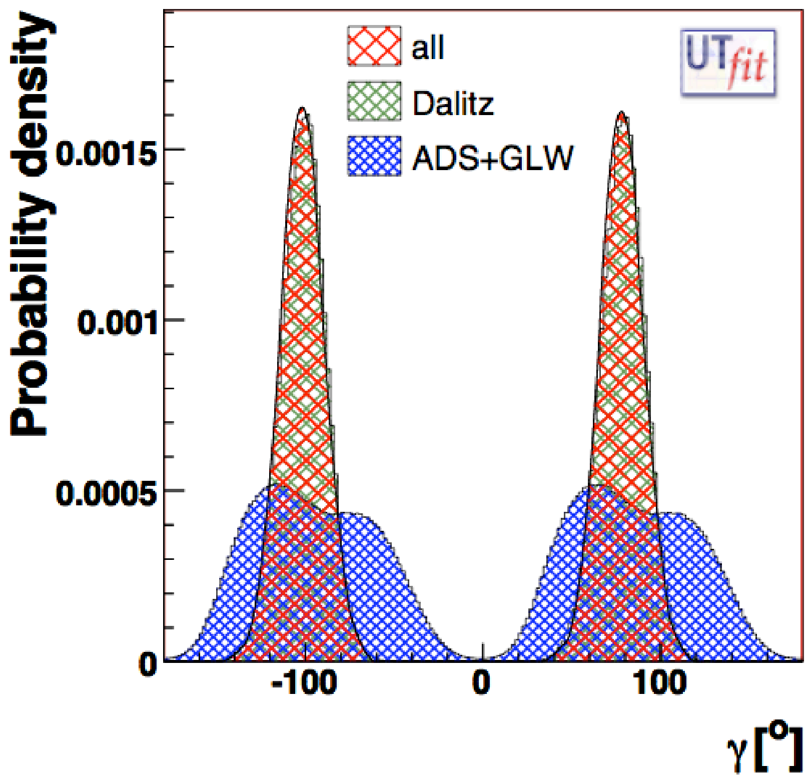
Methods for the γ angle measurement using $B^+ \to \bar{D}^0 K^+$

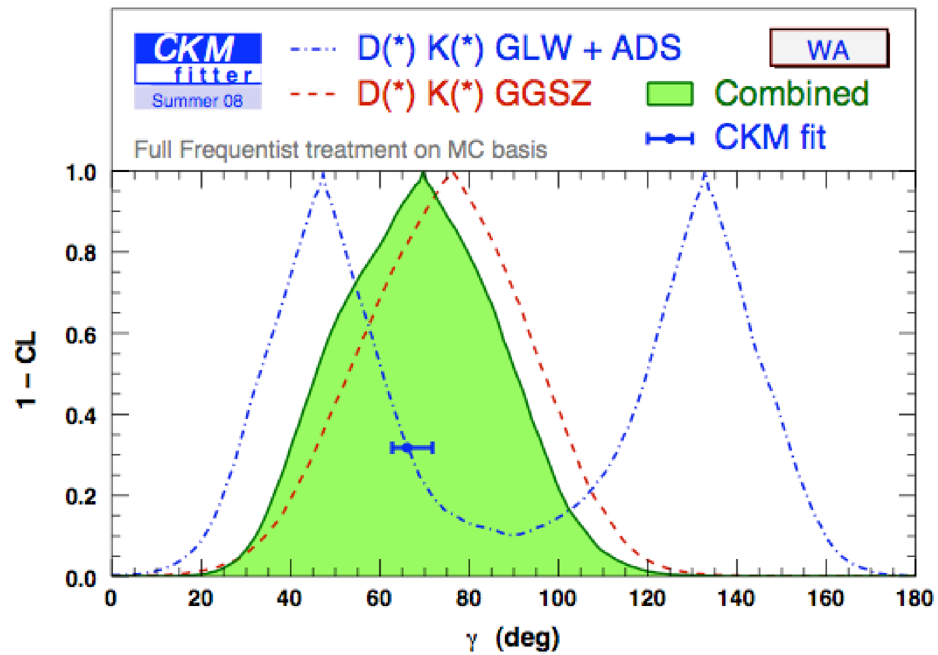
• GLW (Gronau-London-Wyler) method *([PLB253,483 PLB265,172])* that uses the $B^\pm \to D K^\pm$ decays with D_{CP} decay modes.
$D_{CP+} \to \pi^+ \pi^-$, $K^+ K^-$ and $D_{CP-} \to K^0_s \pi^0$, $K^0_s \omega$, $K^0_s \phi$.

• 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 $D^0 \to K^0_s \pi^+ \pi^-$

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





γ = 78 ± 12 ([54,102] @ 95% Prob.)

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

γ (deg) = 70 [+27 -29]

GLW Observables

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

4 observables

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

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

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)

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

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

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

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

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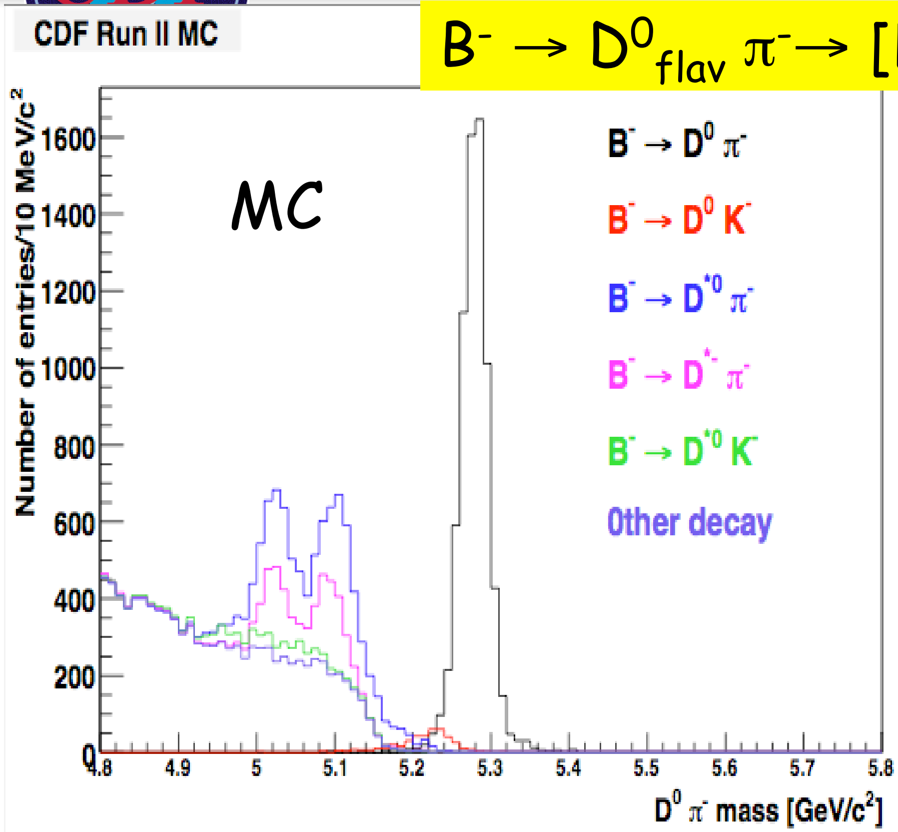
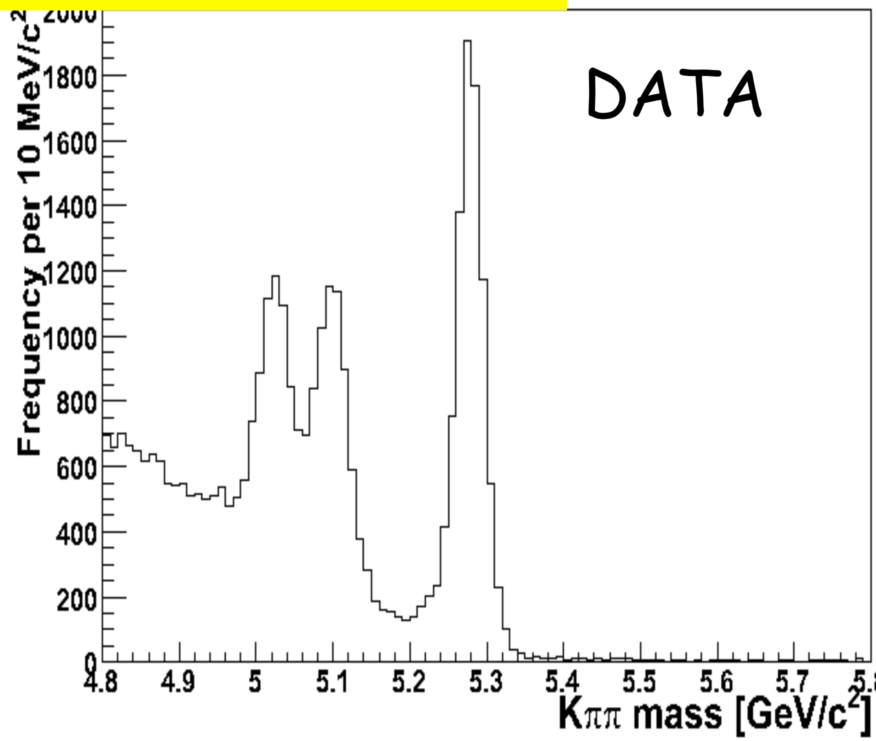
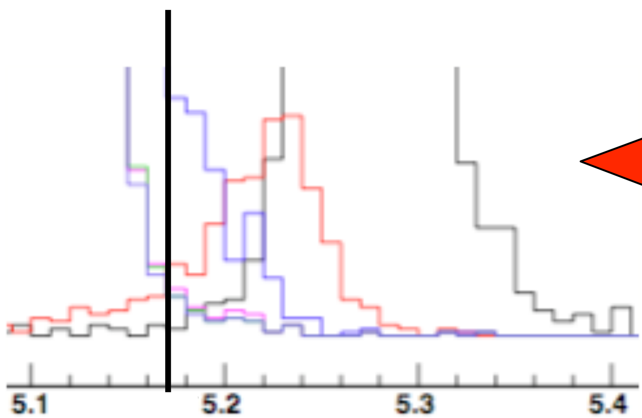
Separating DK from other modes

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





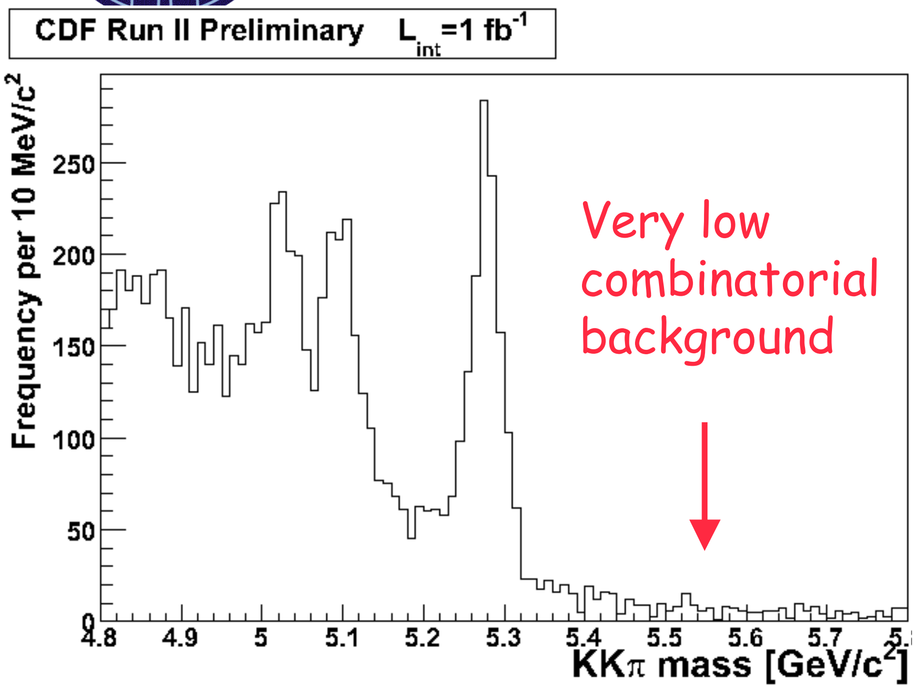


To reject most of the physical backgrounds, narrow fit windows [5.17,5.6]

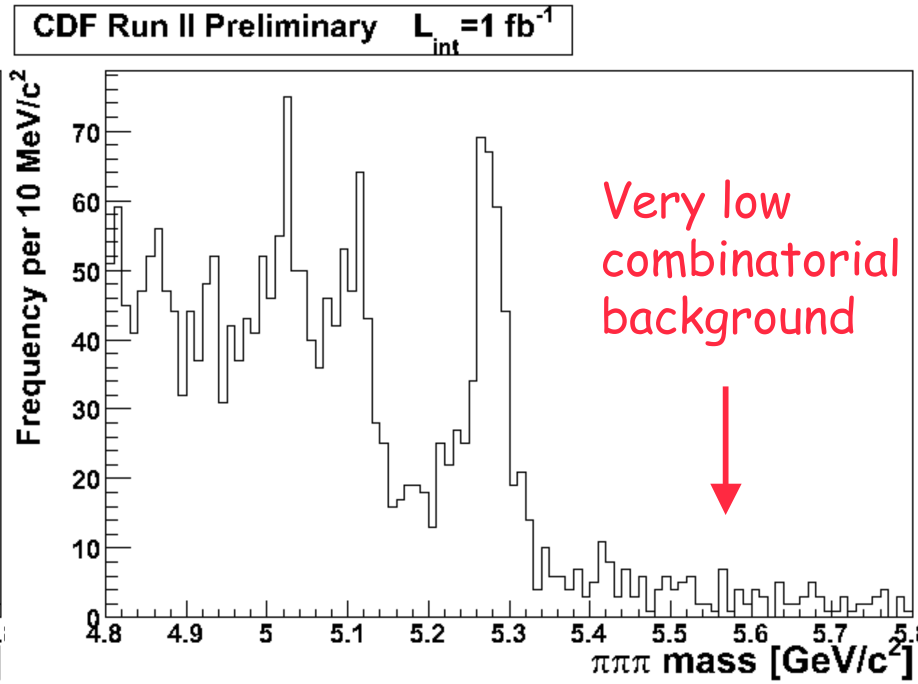
The only significant physics backgrounds are $B^- \rightarrow D^0 \pi^-$ and $B^- \rightarrow D^{0*} \pi^-$

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}

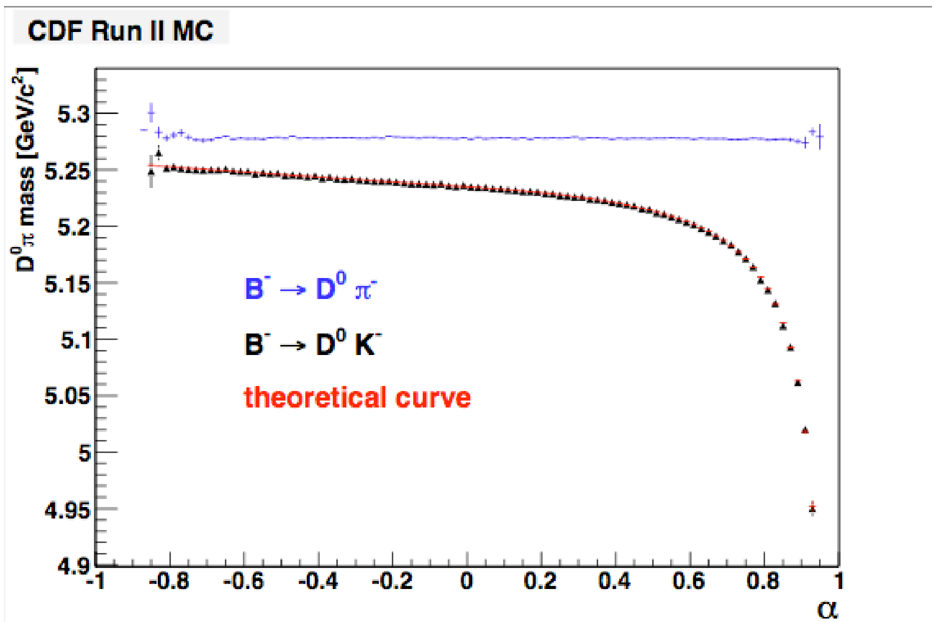
- Isol > 0.65
- chi3D < 13
- |d0_B| < 0.007 cm
- Sig_LxyB > 12
- LxyD_B > -0.01 cm
- LxyD > 0.04 cm
- $\Delta R = (\Delta\phi^2 + \Delta\eta^2)^{1/2} < 2$

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)

Likelihood Fit

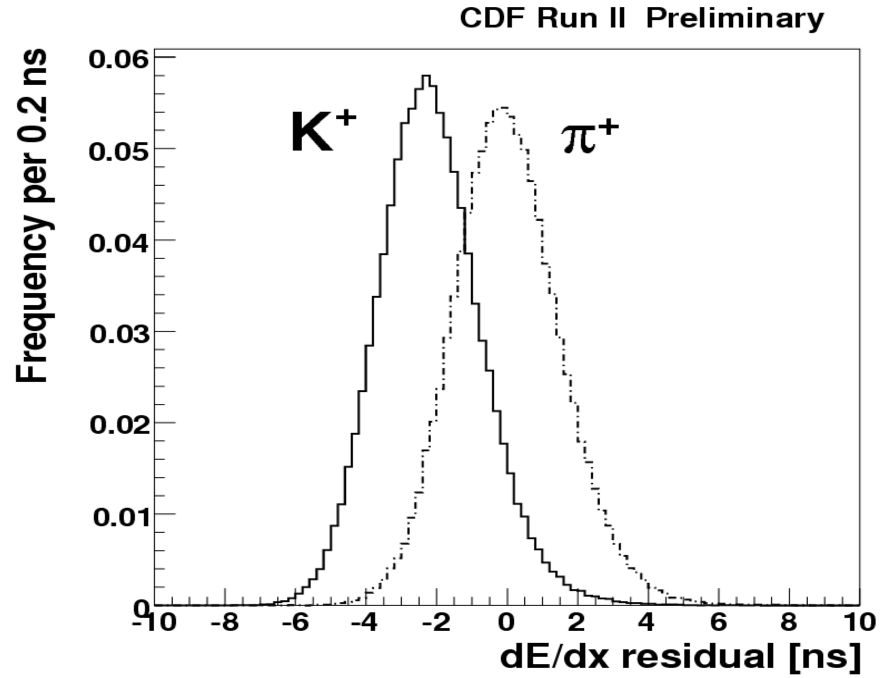
Implementation of a Likelihood FIT using kinematics (masses and momenta) and particle identification (dE/dx) information to determine the signal composition

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



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

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



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

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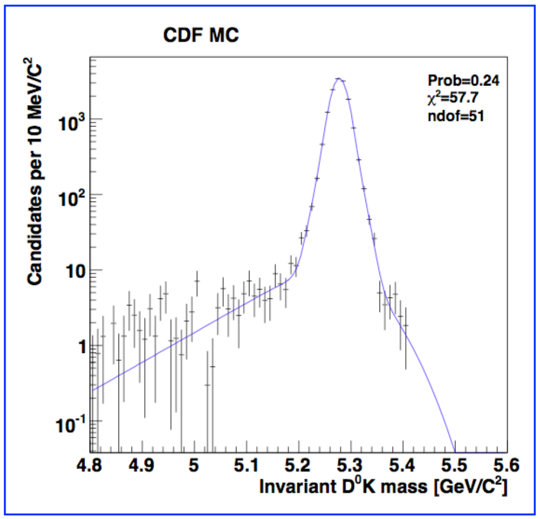
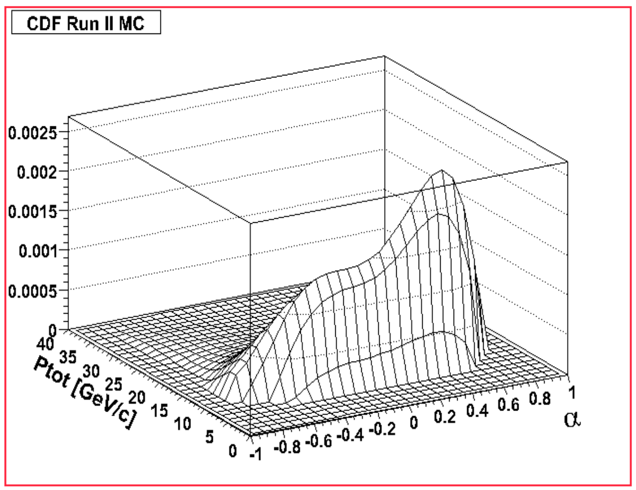
Putting it all together

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

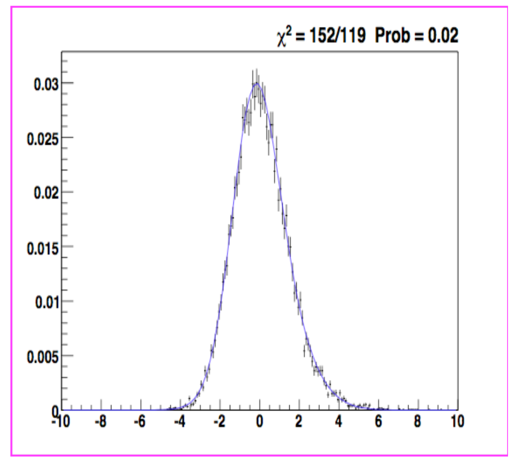
Mass term
- Signal shape from MC (including FSR)
- Background shape: exponential function free in the fit



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



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



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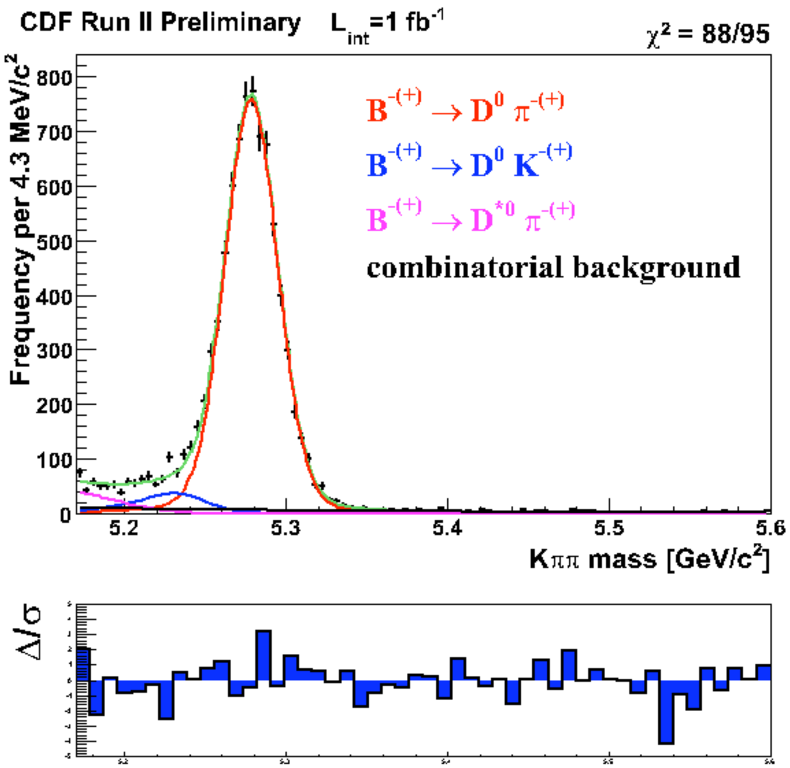
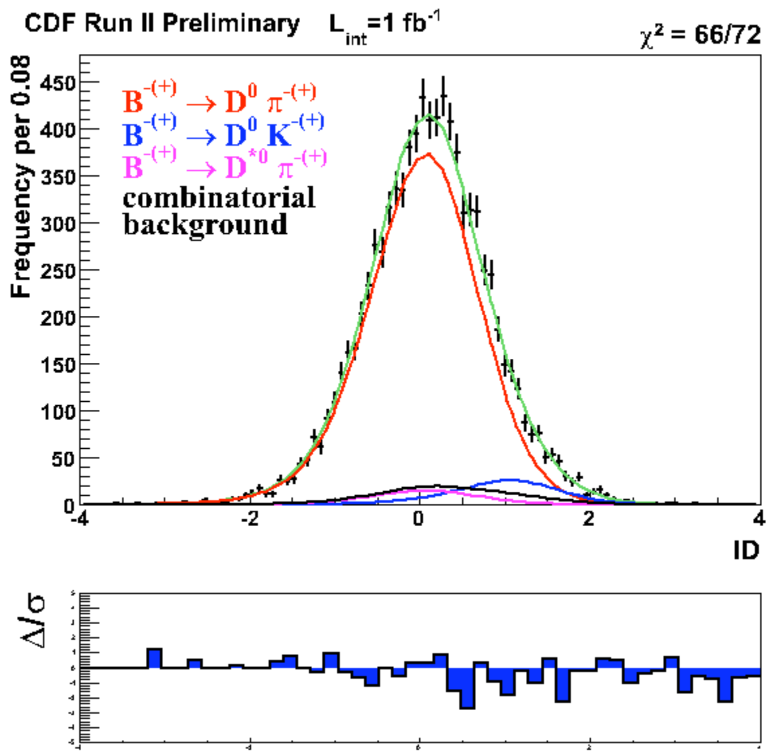
Fit Results on 1 fb^{-1} Flavor mode

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

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





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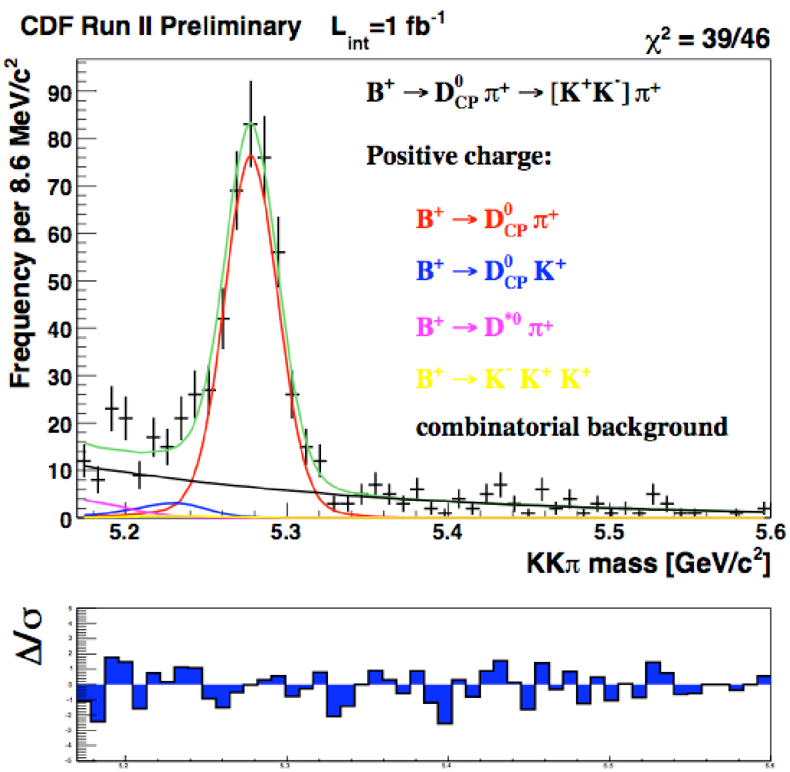
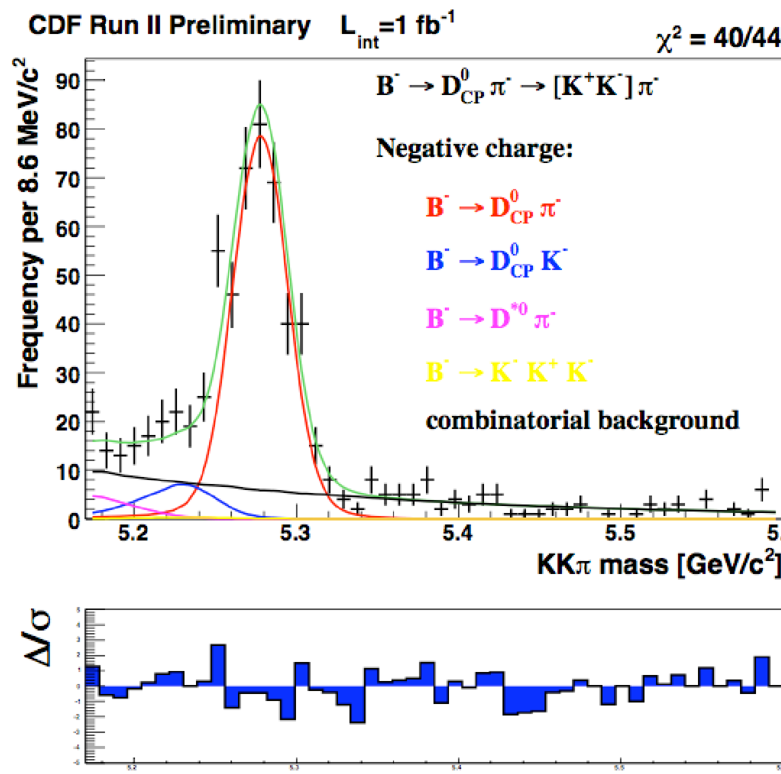
Fit Results on 1 fb^{-1} DCP modes

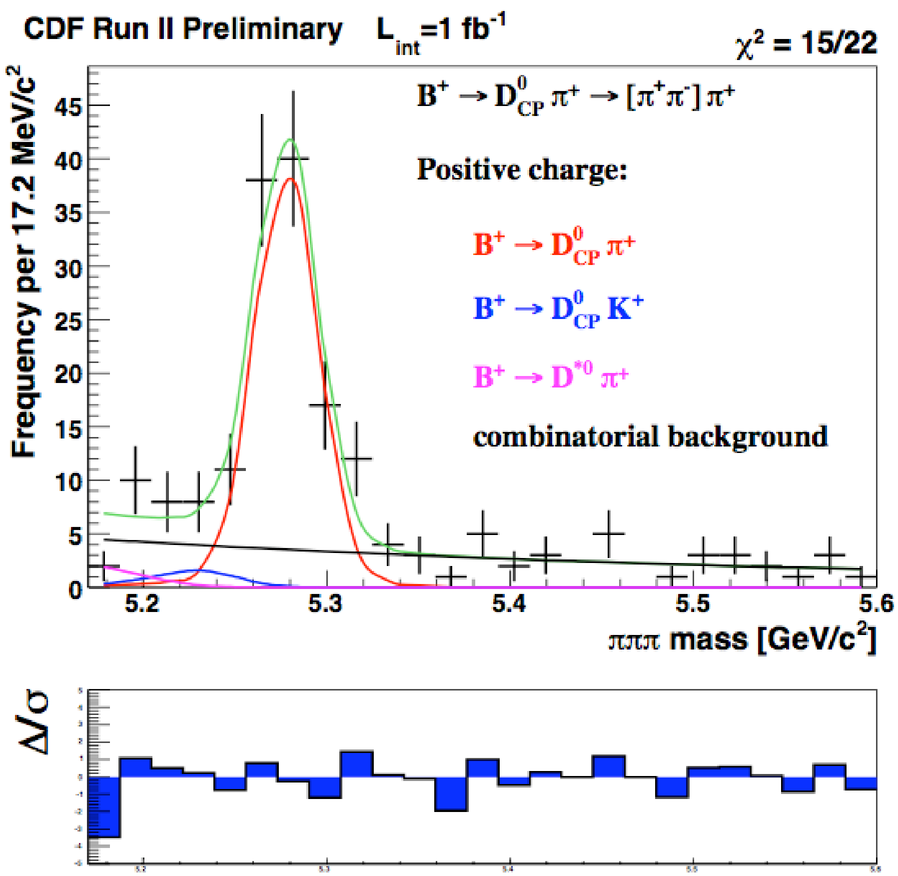
$$R_{CP+} = 1.30 \pm 0.24(stat) \pm 0.12(syst)$$

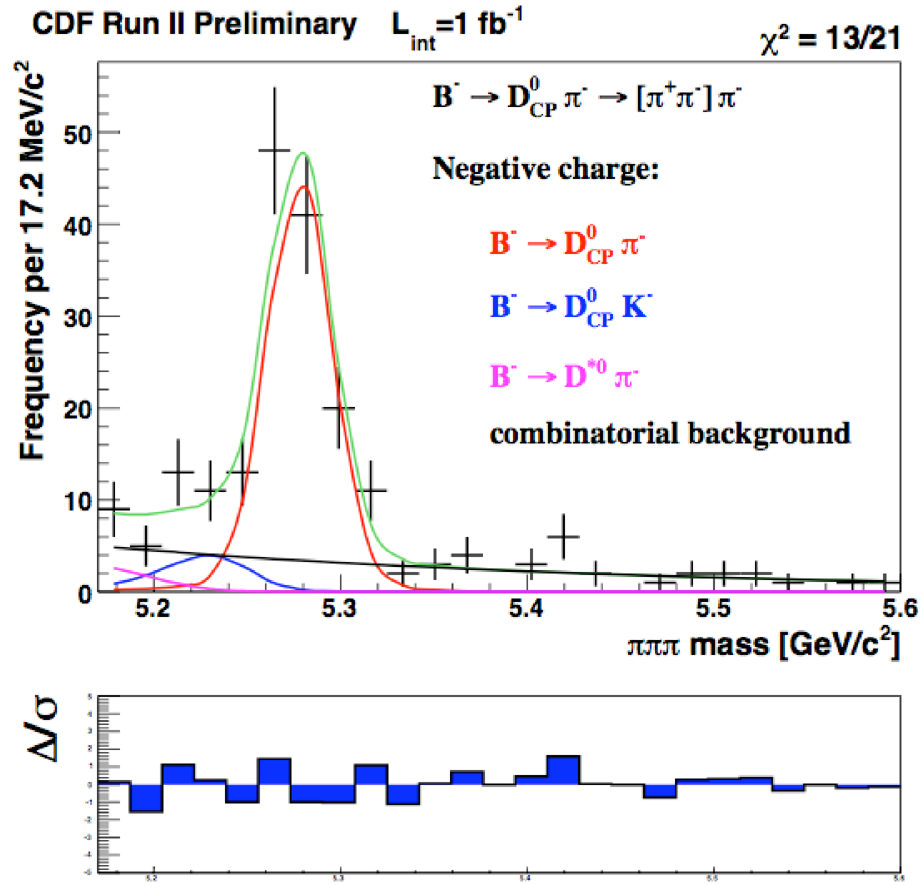
$$A_{CP+} = 0.39 \pm 0.17(stat) \pm 0.04(syst)$$





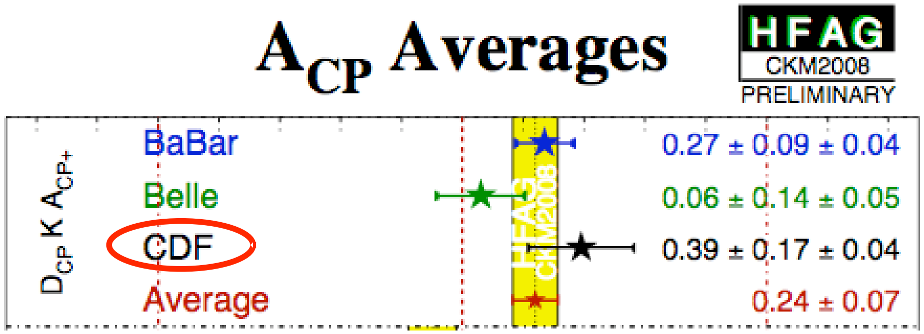
Fit Results on 1 fb^{-1} DCP modes

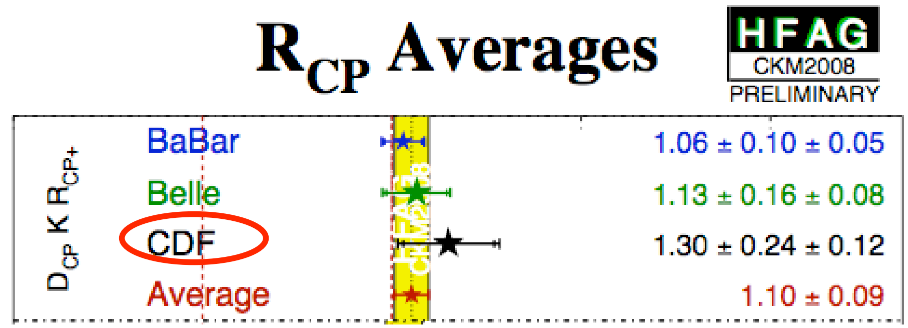




Summary

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





The second paper draft will come out soon

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

ADS method

Interference between:

$B^- \to D^0 K^-$ Color Allowed $b \to c$ transition

$D^0 \to K^+ \pi^-$ Doubly Cabibbo suppressed (DCS) D^0 decay

$B^- \to \overline{D}^0 K^-$, Color Suppressed $b \to u$ transition

$\overline{D}^0 \to K^+ \pi^-$ Cabibbo Favored (CF) D^0 decay

$$\frac{|A(B^- \to \overline{D}^0 K^-, \overline{D}^0 \to K^+\pi^-)|}{|A(B^- \to D^0 K^-, D^0 \to K^+\pi^-)|} \approx r_B \lambda^{-2} \approx 2$$

The CP asymmetry is potentially large, but we need more statistics than the GLW method due to the DCS D^0 decay which is suppressed by a factor of about 3.5×10^{-3}

$$R_{ADS} = \frac{BR(B^- \to [K^+\pi^-]_{D^0} K^-) + BR(B^+ \to [K^-\pi^+]_{D^0} K^+)}{BR(B^- \to [K^-\pi^+]_{D^0} K^-) + BR(B^+ \to [K^+\pi^-]_{D^0} K^+)} = r_D^2 + r_B^2 + 2 r_D r_B \cos\gamma \cos(\delta_B + \delta_D)$$

$$A_{ADS} = \frac{BR(B^- \to [K^+\pi^-]_{D^0} K^-) - BR(B^+ \to [K^-\pi^+]_{D^0} K^+)}{BR(B^- \to [K^-\pi^+]_{D^0} K^-) + BR(B^+ \to [K^+\pi^-]_{D^0} K^+)} = \frac{2 r_B r_D \sin\gamma \sin(\delta_B + \delta_D)}{r_B^2 + r_D^2 + 2 r_B r_D \cos\gamma \cos(\delta_B + \delta_D)}$$

Asymmetry also for $B \rightarrow D_{DCS}\pi$

Asymmetry maximum value

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

$$r_D = \sqrt{\frac{BR(D_{DCS} \rightarrow K^+\pi^-)}{BR(D_{CF} \rightarrow K^-\pi^+)}} = 0.0613 \pm 0.0010$$

$$r_B(K) = \left| \frac{A(B^- \rightarrow \overline{D}^0 K^-)}{A(B^- \rightarrow D^0 K^-)} \right| \approx 0.1$$

→ $A_{ADS}(\max) = 0.9$

CKMfitter Group (J. Charles et al.), Eur. Phys. J. C41, 1-131 (2005), [hep-ph/0406184], updated results and plots available at: http://ckmfitter.in2p3.fr

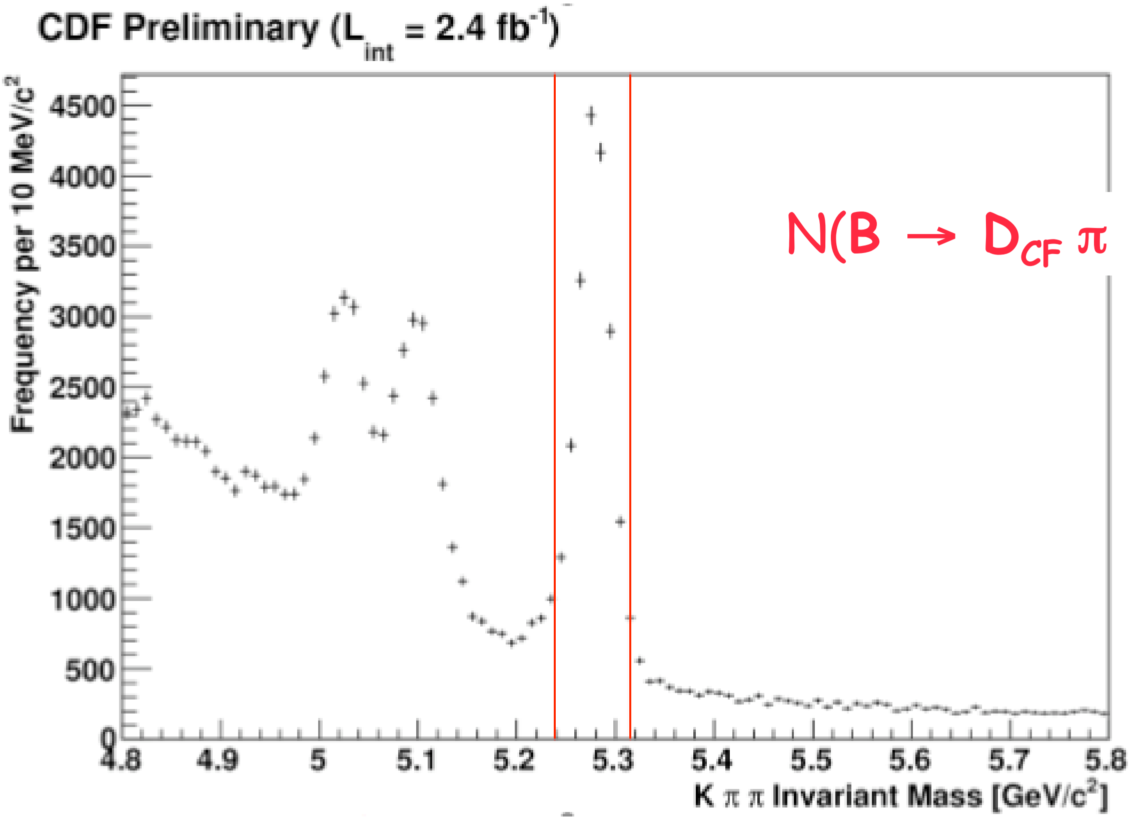
$$r_B(\pi) = \left| \frac{A(B^- \rightarrow \overline{D}^0 \pi^-)}{A(B^- \rightarrow D^0 \pi^-)} \right| \approx 0.01$$

→ $A_{ADS}(\max) = 0.3$

E. Barberio et al., "Averages of b-hadron and c-hadron Properties at the End of 2007," arXiv:0808.1297 Online update at http://www.slac.stanford.edu/xorg/hfag

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

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



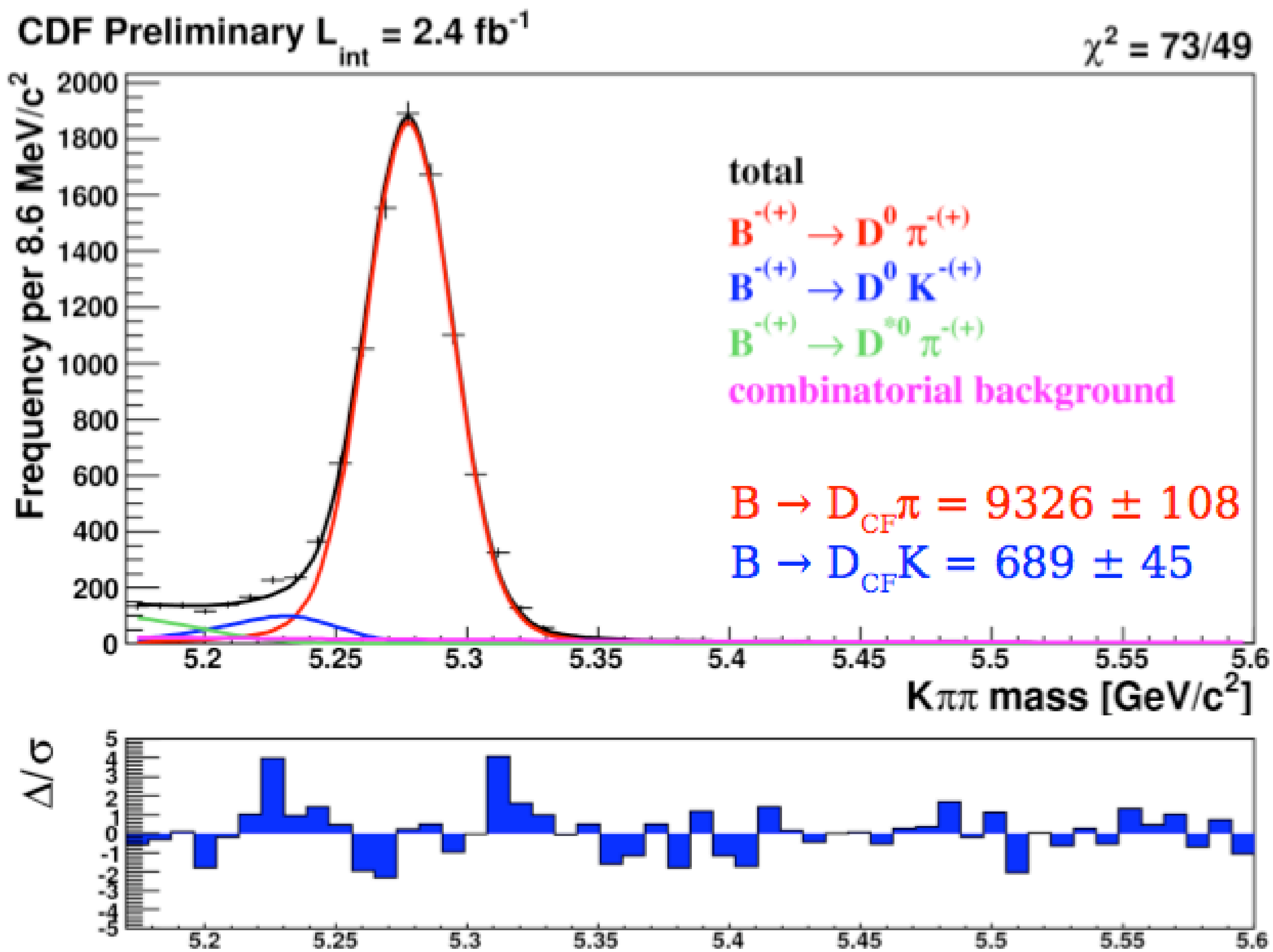
$N(B \to D_{CF}\,\pi) \sim 18500$

Expected $N(B \to D_{DCS}\,\pi) \sim 60$, less than combinatorial background

$\Rightarrow$ need an optimized cut selection to reduce the background

Maximize the quantity $\dfrac{S}{1.5+\sqrt{B}}$ on CF sample

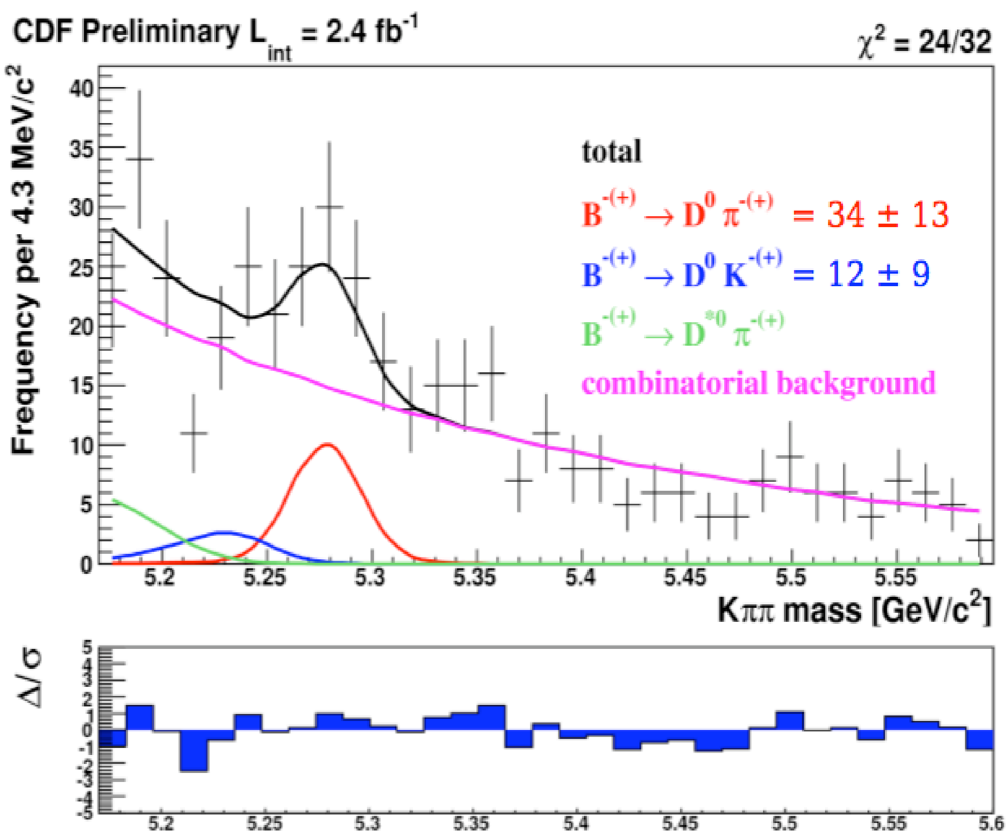
$B \to D_{CF}\,\pi$ mode after optimized selection



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

L = 2.4 fb^{-1}

This is the first step towards the ADS method



$B \rightarrow D_{DCS}\pi$ 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}
$B \rightarrow D\pi$	$K\pi$ DCS	ADS	34	70

Conclusions

$B^- \rightarrow D_{CP} K^-$:

- We measured A_{CP+} and R_{CP+} for the first time at a hadron collider using 1 fb^{-1} of data. The second paper draft will come out soon (We're waiting for the GP approval)

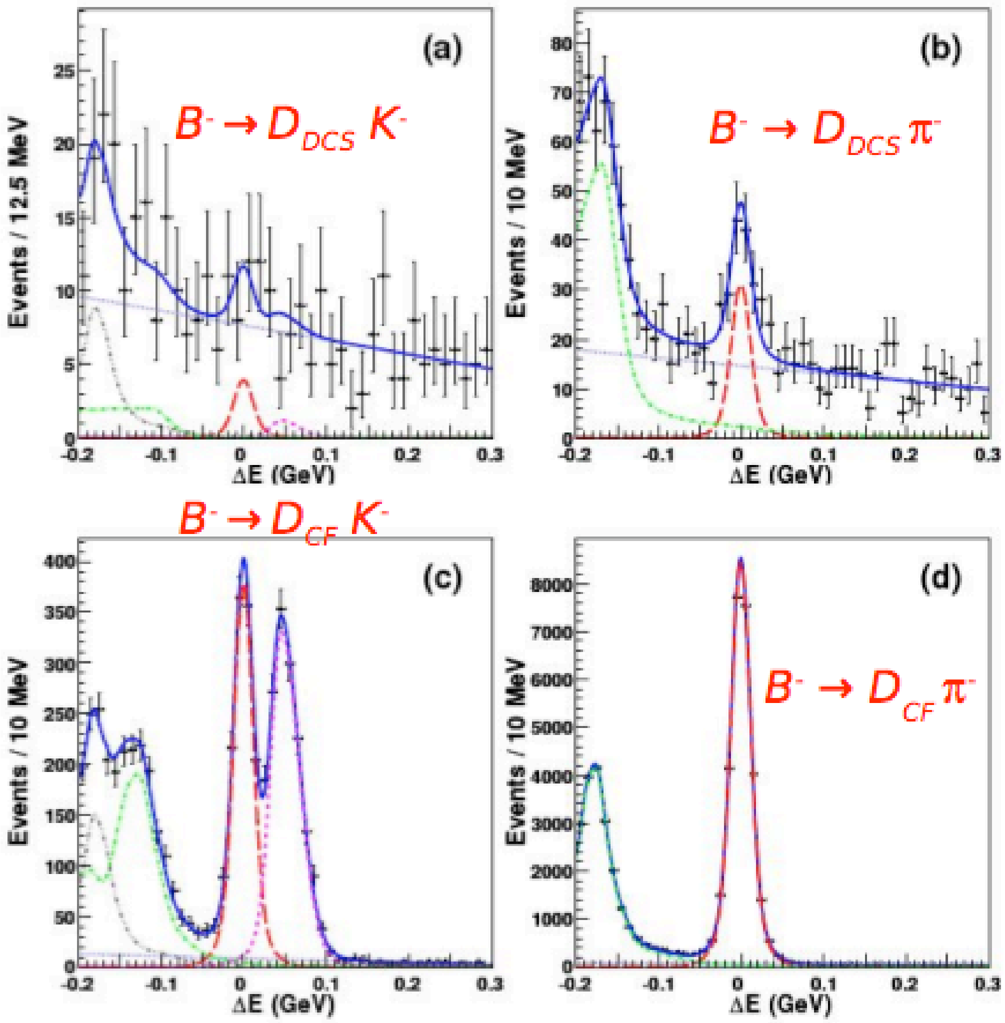
$B^- \rightarrow D_{DCS} K^-$:

- We reconstructed the $B^- \rightarrow D_{DCS}\, \pi^-$ using 2.4 fb^{-1} of data with a significance of 3.8 σ.
- Plan: Perform the ADS measurement using all the statistics available (PhD thesis of Paola Garosi).

BACKUP

ADS results from Belle

[PRD 78:071901,2008]



Belle: *657M $B\bar{B}$ sample*

$B^- \to D_{DCS} K^-$ not yet seen

Mode	Signal yield	Statistical significance
$B^- \to D_{sup} K^-$	$9.7^{+7.7}_{-7.0}$	1.5σ
$B^- \to D_{sup} \pi^-$	$93.8^{+15.3}_{-14.8}$	8.4σ
$B^- \to D_{fav} K^-$	1220^{+41}_{-40}	$\cdots$
$B^- \to D_{fav} \pi^-$	27202^{+177}_{-176}	$\cdots$

$$R_{ADS}(K) = \left(8.0^{+6.3}_{-5.6}(\text{stat})^{+2.0}_{-2.8}(\text{syst})\right) \cdot 10^{-3}$$

$$R_{ADS}(\pi) = \left(3.40^{+0.56}_{-0.54}(\text{stat})^{+0.13}_{-0.21}(\text{syst})\right) \cdot 10^{-3}$$

$$A_{ADS}(K) = -0.13^{+0.97}_{-0.88}(\text{stat}) \pm 0.26(\text{syst})$$

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

$$BR(B^- \to D_{sup}\pi^-) = 6.29^{+1.04+0.24}_{-1.00-0.39} \pm 0.24 \cdot 10^{-7}$$

$$BR(B^- \to D_{sup}K^-) < 2.8 \cdot 10^{-7} \text{ (90\%CL)}$$

GLW Method

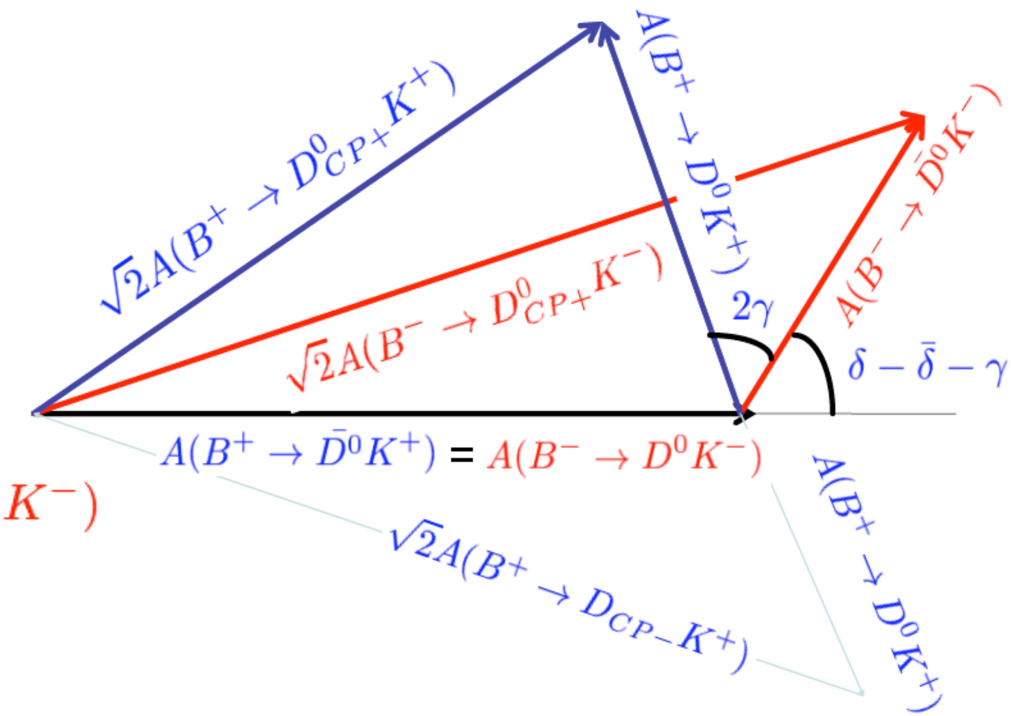
Theoretically very clean to determine γ (but 8 fold-ambiguites)

$B^{\pm} \to D^0_{CP\pm} K^{\pm}$ where $D^0_{CP\pm} = (D^0 \pm \bar{D}^0)/\sqrt{2}$

$$\sqrt{2}A(B^- \to D^0_{CP+}K^-) = A(B^- \to \bar{D}^0 K^-) + A(B^- \to D^0 K^-) = |A|e^{-i\gamma}e^{i\delta} + |\bar{A}|e^{i\bar{\delta}}$$

$$\sqrt{2}A(B^+ \to D^0_{CP+}K^+) = A(B^+ \to D^0 K^+) + A(B^+ \to \bar{D}^0 K^+) = |A|e^{i\gamma}e^{i\delta} + |\bar{A}|e^{i\bar{\delta}}$$

Construct two triangles from above six processes which give one of the solutions for γ



Note:

$A(B^+ \to \bar{D}^0 K^+) = A(B^- \to D^0 K^-)$

› No CP violation

$A(B^+ \to D^0_{CP+} K^+) \neq A(B^- \to D^0_{CP+} K^-)$

› CP violated

Fit Results on 1 fb^{-1}

Parameter	fraction	yield
$B^+ \to \overline{D}^0 \pi^+ \ (f_\pi^{flav+})$	0.902 ± 0.006	3769 ± 68
$B^- \to D^0 \pi^- \ (f_\pi^{flav-})$	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
$B^+ \to D^0_{CP+} \pi^+ \to [K^+K^-]\pi^+ \ (f_\pi^{dcp+})$	0.910 ± 0.018	381 ± 25
$B^- \to D^0_{CP+} \pi^- \to [K^+K^-]\pi^- \ (f_\pi^{dcp-})$	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
$B^+ \to D^0_{CP+} \pi^+ \to [\pi^+\pi^-]\pi^+ \ (f_\pi^{dcp+})$	0.910 ± 0.018	101 ± 13
$B^- \to D^0_{CP+} \pi^- \to [\pi^+\pi^-]\pi^- \ (f_\pi^{dcp-})$	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 $D^0_{CP}\,K$

Systematics

	R	Rcp	Acp
dE/dx model	0.0028	0.056	0.030
$D^{0*}\pi$ mass model	0.0028	0.025	0.006
Input mass to the fit (Bu mass)	0.0002	0.004	0.002
Combinatorial background mass model	0.0002	0.020	0.001
(alpha,ptot) combinatorial background	0.0002	0.100	0.020
(alpha,ptot) $D\pi$	0.0001	0.002	0.001
(alpha,ptot) DK	0.0006	0.002	0.004
(alpha,ptot) $D^{*0}\pi$	0.0007	0.004	0.002
MC and XFT	0.0020	-	-
total	0.0045	0.12	0.04

Statistical errors	0.0043	0.24	0.17

dE/dx systematics

The dE/dx parameters of the likelihood function are randomly varied in a 1σ-radius multidimensional sphere in the space of the parameters of dE/dx calibration.

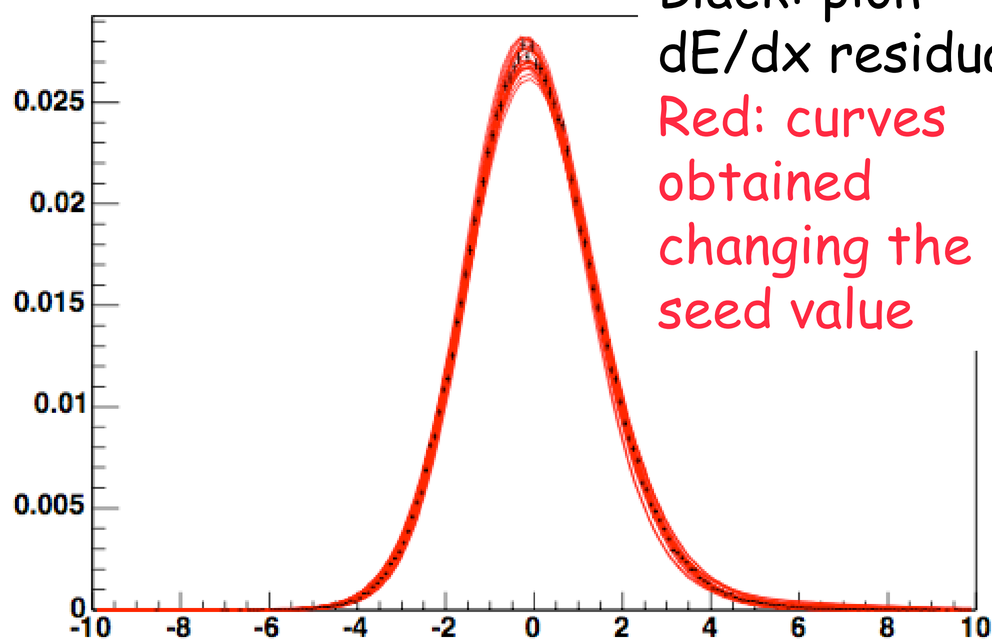
$$X[i+1] = (a \cdot X[i] + c) \bmod m$$

$$S[i+1] = \frac{\sqrt{npar} \cdot X[i+1] \cdot n\sigma}{\sqrt{\mathrm{mod}_X}}$$

$$P_i = P_i + err_i \cdot S[i+1]$$

The base uncertainties (err_i) on each parameter are determined:

- by the statistical error obtained from the parametrization fits
- by systematic shifts between alternative parametrizations



Black: pion dE/dx residual

Red: curves obtained changing the seed value

We generated pseudo-experiments with the modified functions, we fitted these TOY MC obtaining the effect of systematics on the measurement.

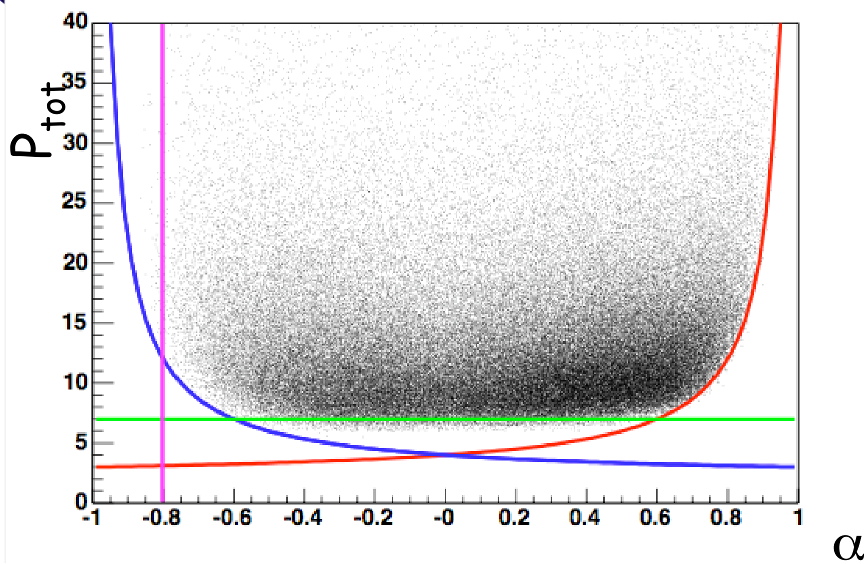
Cuts Optimization

We optimized the cuts by minimizing the expected statistical uncertainty on A_{CP}. Its expression $\sigma(S,B)$ is determined from actual uncertainties observed in analysis of TOY-MC samples.

For any combination of cuts we evaluated the above score function and the optimal cuts are found when the function reach the minimum.

Signal yield S(cuts) is derived from flavor data (from the knowledge of the ratio DCP/Dflav) and background B(cuts) is estimated from DCP mass sideband.

Kinematical domain P(α, Ptot)



$$P_{tot} > 2 \cdot \frac{2-\alpha}{1-\alpha}$$

$$P_{tot} > 2 \cdot \frac{2+\alpha}{1+\alpha}$$

$$P_{tot} > 7$$

$$\alpha > -0.8$$

The bidimensional function describing P(α, Ptot) is

$$\Sigma_{i=0}^{6} a_i U_i(P_{tot}) \cdot \exp(a_7 P_{tot}) \cdot \Sigma_{j=0}^{6} b_j(P_{tot}) \alpha^j$$

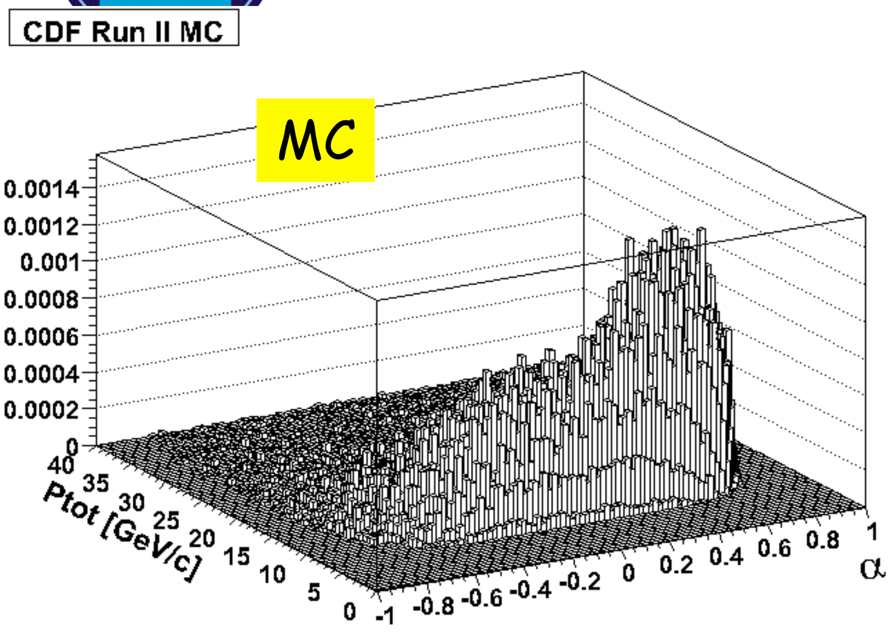
Interpolation technique

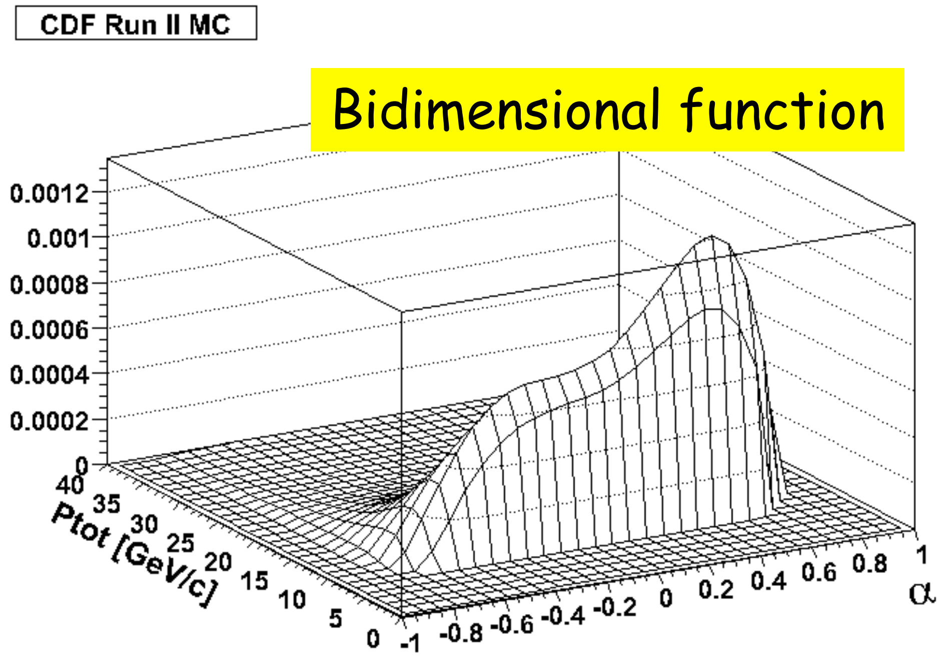
polynomials used to fit the plots parameter value vs Ptot

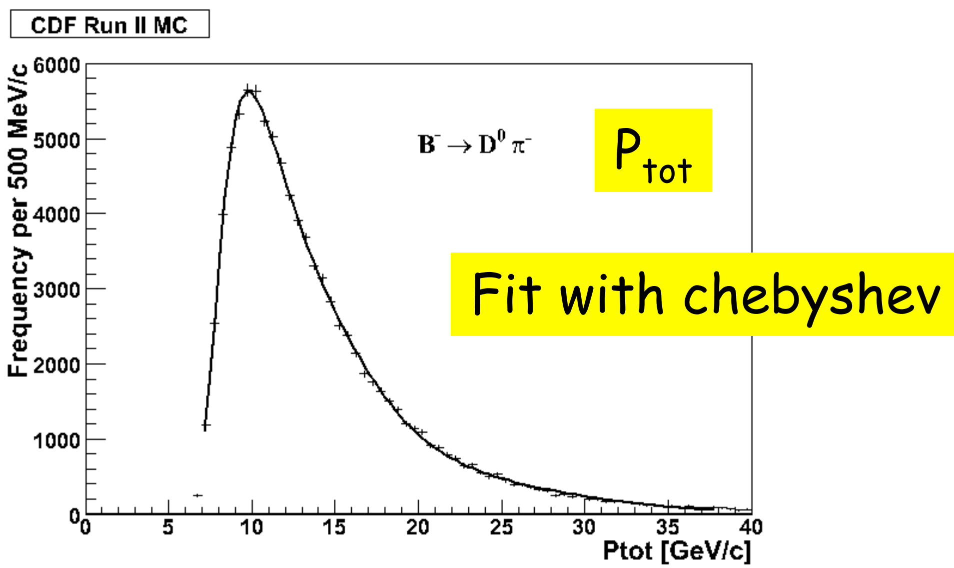
Fit Ptot distribution with Chebyshev polynomial of 2nd kind*exponential

sixth degree polynomial used to fit the α distribution in slices of Ptot

Parameterization: P(α, Ptot) B → D^0 K





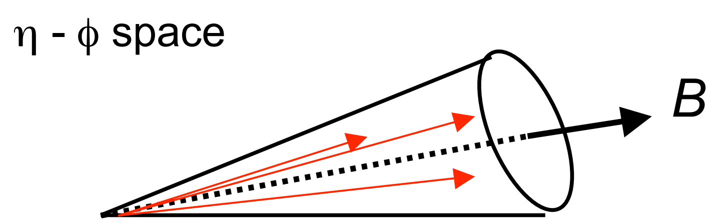


Isolation(B) and 3D-vertex quality $\chi^2_{3D}(B)$

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%).

Paola Squillacioti

Likelihood Fit

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

Invariant mass shape

Method:

- Accurate parameterization of individual track parameters resolution functions from full MC (including resolution non-gaussian tails)
- Add calculated QED radiation to include tails due to FSR [Baracchini,Isidori Phys.Lett B633:309-313,2006]
- Generate mass line shapes with a custom kinematic MC
- Compare results with a huge sample of $D^{*+} \to D^0 \pi^+ \to [K^- \pi^+] \pi^+$
  $\Rightarrow$ good match, no tuning necessary $\Rightarrow$ small systematics
- Generate $B^- \to D^0 K^-/\pi^-$ templates and use them in the Likelihood fit.