First ADS analysis of $B^- \rightarrow D^0 K^-$ decays in hadron collisions

Paola Garosi
(University of Siena & INFN Pisa)
for the CDF collaboration

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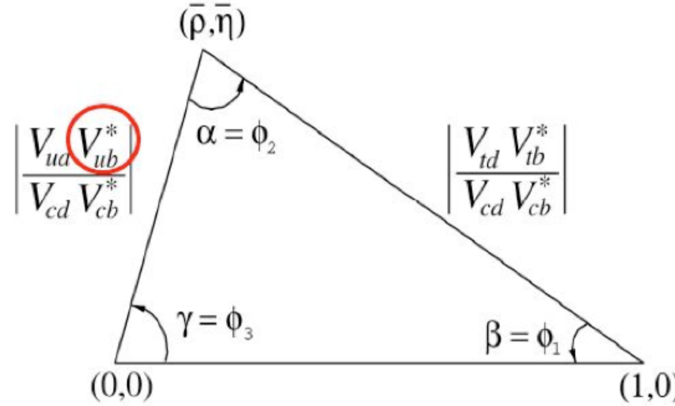
Motivation: CKM γ angle measurement

CKM matrix

CP violation if $\eta \neq 0$

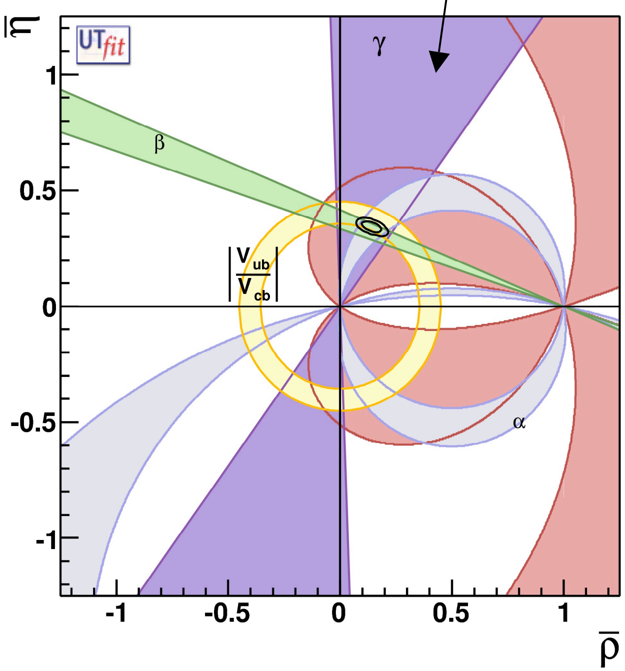
$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

b → u transition
B meson system

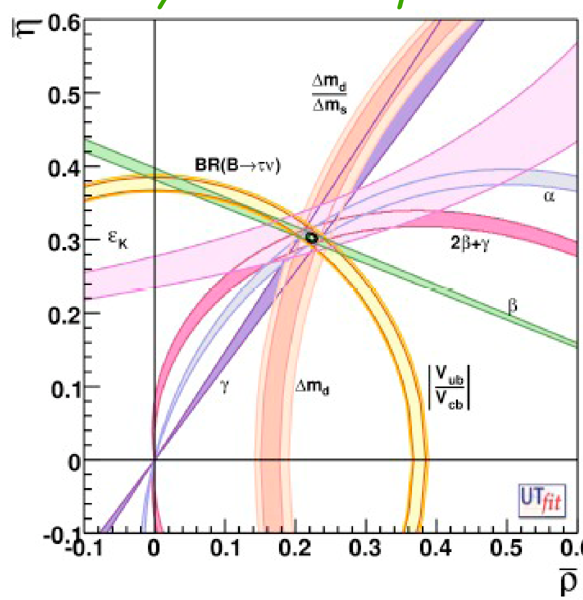


γ is the least well-known angle of the CKM triangle nowadays

Can probe New Physics
(select ρ−η values valid in most of the NP extensions)



Improving the resolution can lead to:
- *consistency with SM prediction*



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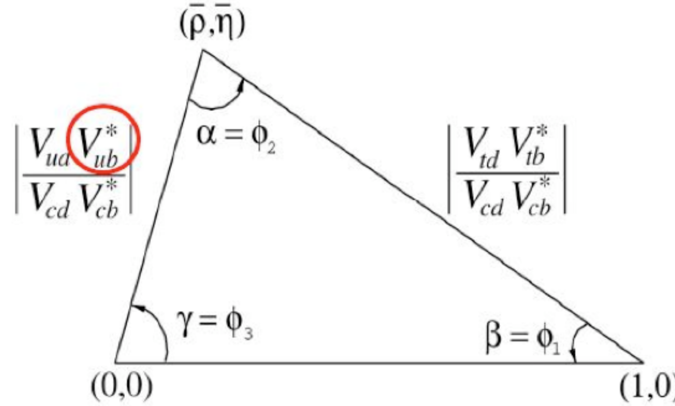

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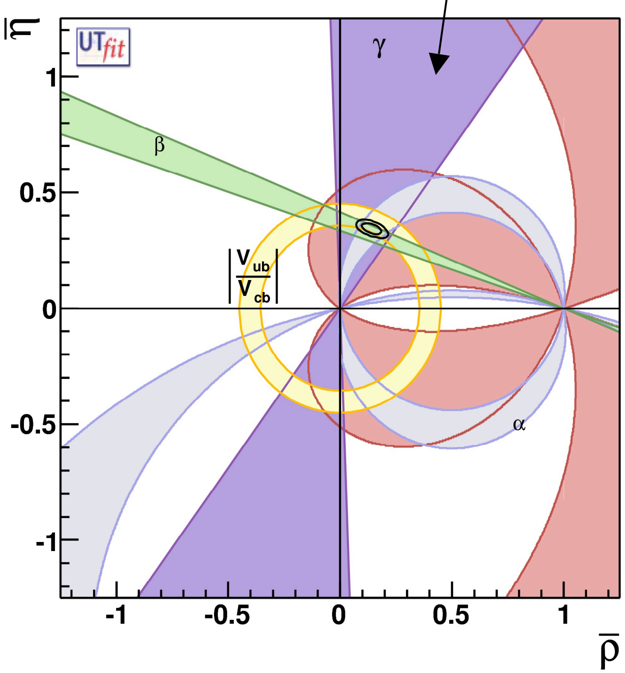
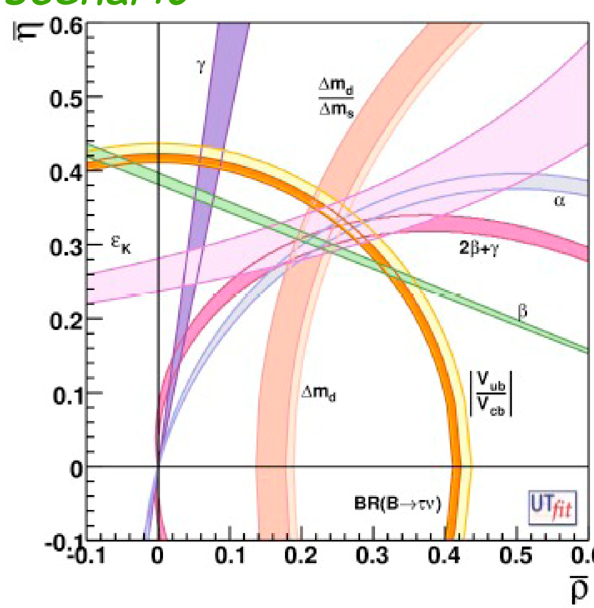


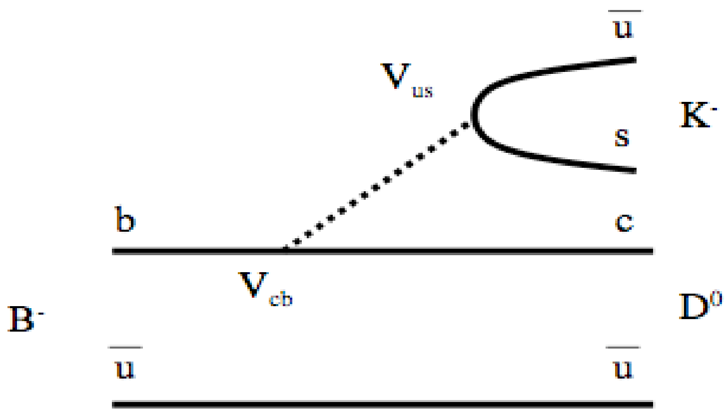
Improving the resolution can lead to:
- *NP scenario*

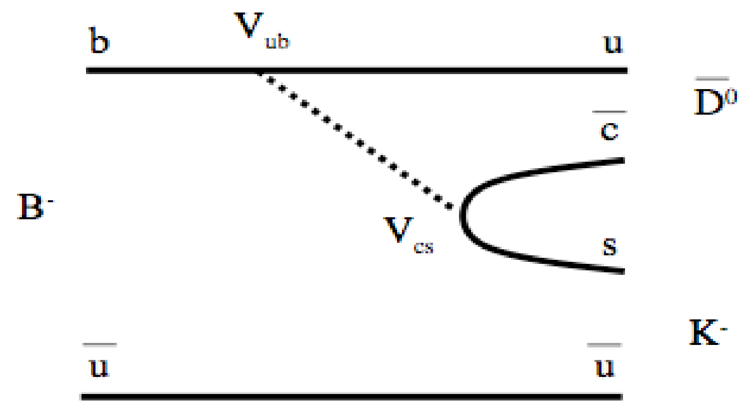


CKM γ angle through B→DK decays

Use of B→DK decays is the cleanest way to measure γ:
- tree-level amplitude only
- tiny theoretical uncertanties

γ can be extracted exploiting the interference between the processes $b \to c\bar{u}s$ ($B^- \to D^0 K^-$) and $b \to u\bar{c}s$ ($B^- \to \bar{D}^0 K^-$), when D^0 and $\bar{D}^0$ decay to the same final state





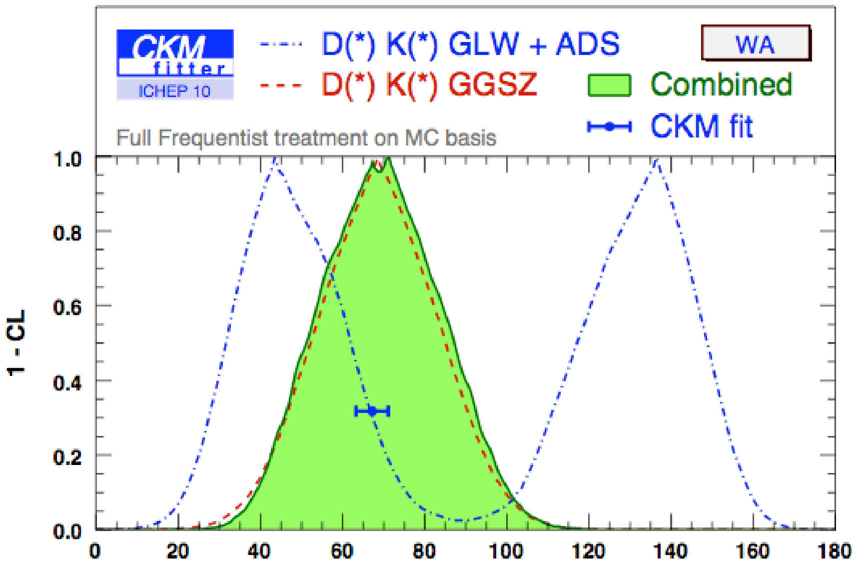
Favored $b \to c$ transition

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

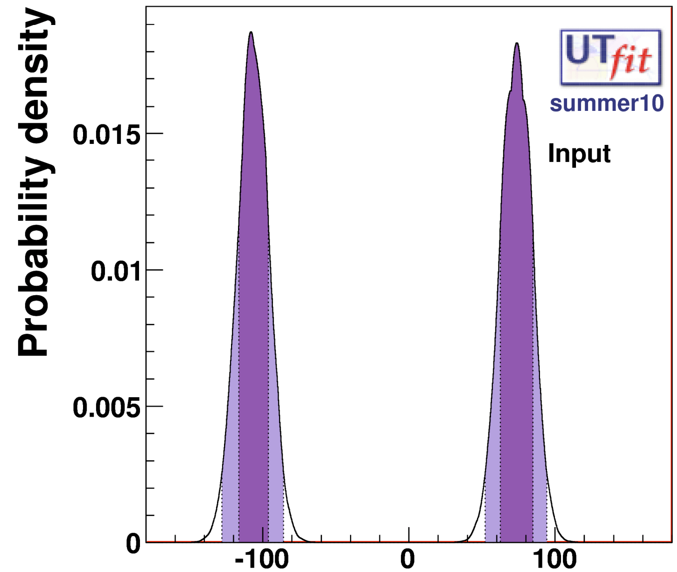
Color suppressed $b \to u$ transition

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

Current situation for the γ angle measurement using $B^- \rightarrow D^0 K^-$



γ(deg) = 71 [+21 -25]



γ(deg) = -106±11 and 74 ± 11

Still large statistical uncertanty

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

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

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

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

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

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

ADS method

ADS Observables

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

- expected large CP asymmetry
- decay suppressed by a factor of $\sim 10^{-3}$ wrt favored
- results have to be combined with other methods to obtain γ measurement

ADS Observables

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

- expected large CP asymmetry
- decay suppressed by a factor of ~10^{-3} wrt favored
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Observables

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

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

$D^0_{CF} \rightarrow K^-\pi^+$, $D^0_{DCS} \rightarrow K^+\pi^-$

From theory:

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

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

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

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

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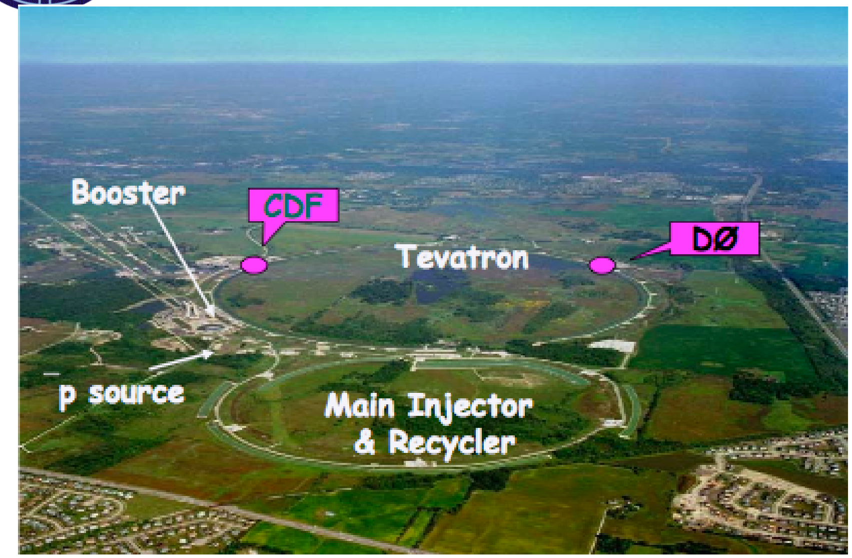
Sizeable asymmetries may be found also for $B \to D_{DCS}\,\pi$

ADS method at CDF

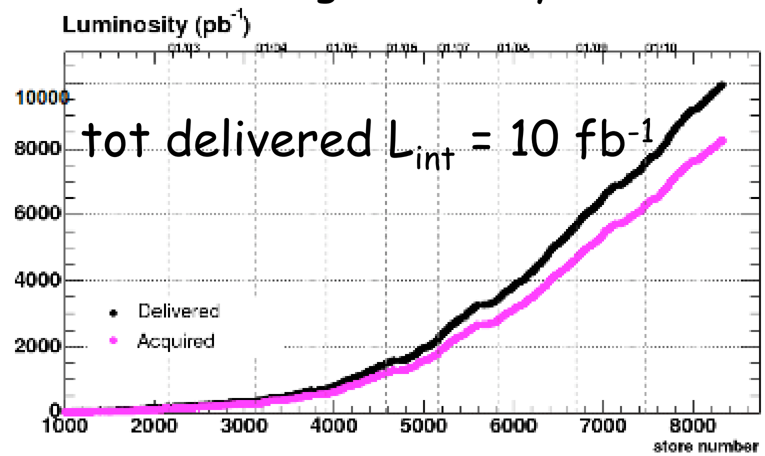
First measurement of A_{ADS} and R_{ADS} at a hadron collider

The Tevatron



Good performances on Run II:

- peak L_{inst} = 3.5-4 $10^{32} cm^{-2} s^{-1}$
- delivering 2.5 fb^{-1}/year



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...)

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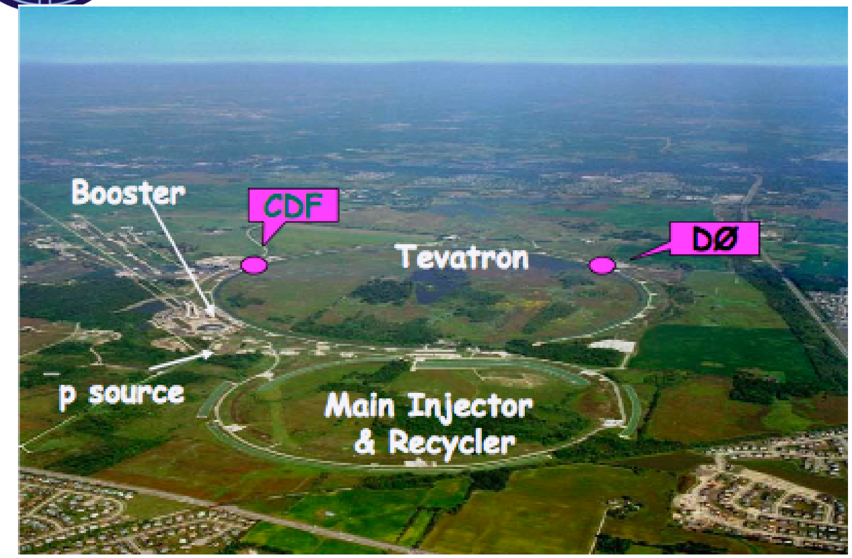

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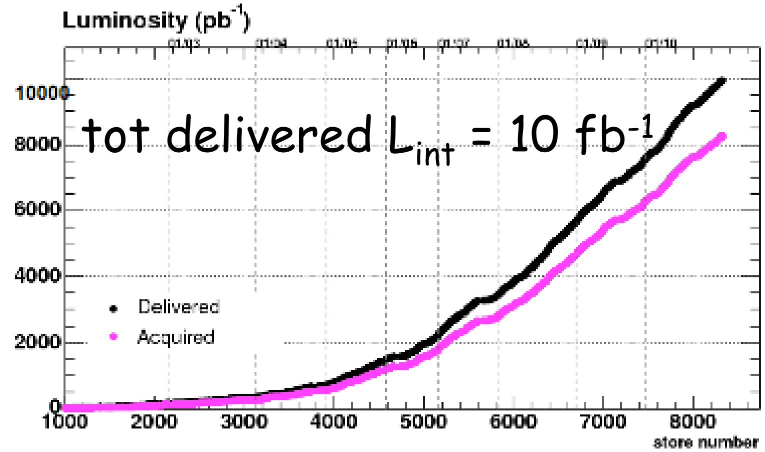

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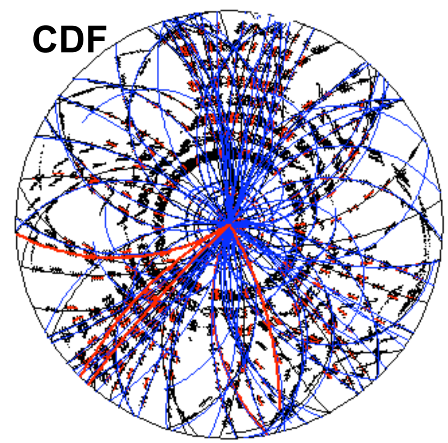
- ***All* B species** are produced (B^0, B^+, B_s, Λ_b…)

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

Interesting events must be extracted from a high track multiplicity environment



Detectors need to have:

- Very **good tracking** and vertex resolution and **highly selective trigger**

The CDF II detector

TRACKING system:

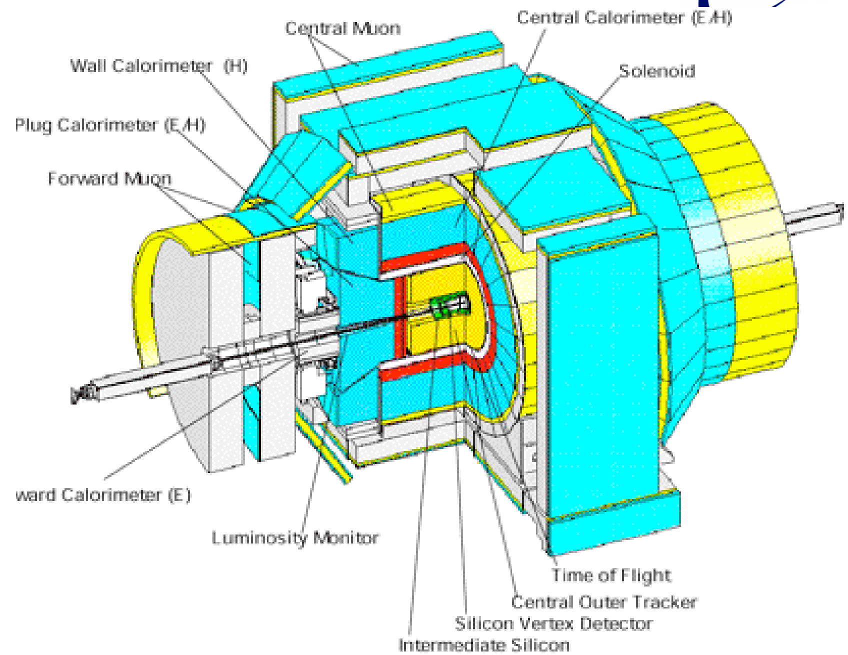
• **DRIFT CHAMBER**
96 layers ($|\eta|<1$)

→ 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

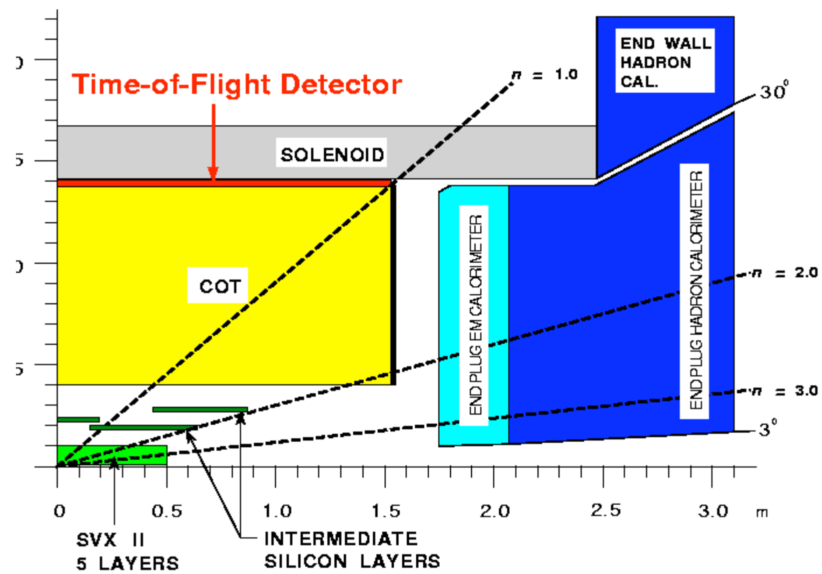
→ $\sigma(p_T)/p_T^2$ ~ 0.015% (c/GeV)



TRACKING TRIGGER system:

• ***Chamber track processor*** at L1,
2D tracks in COT, p_T > 1.5 GeV

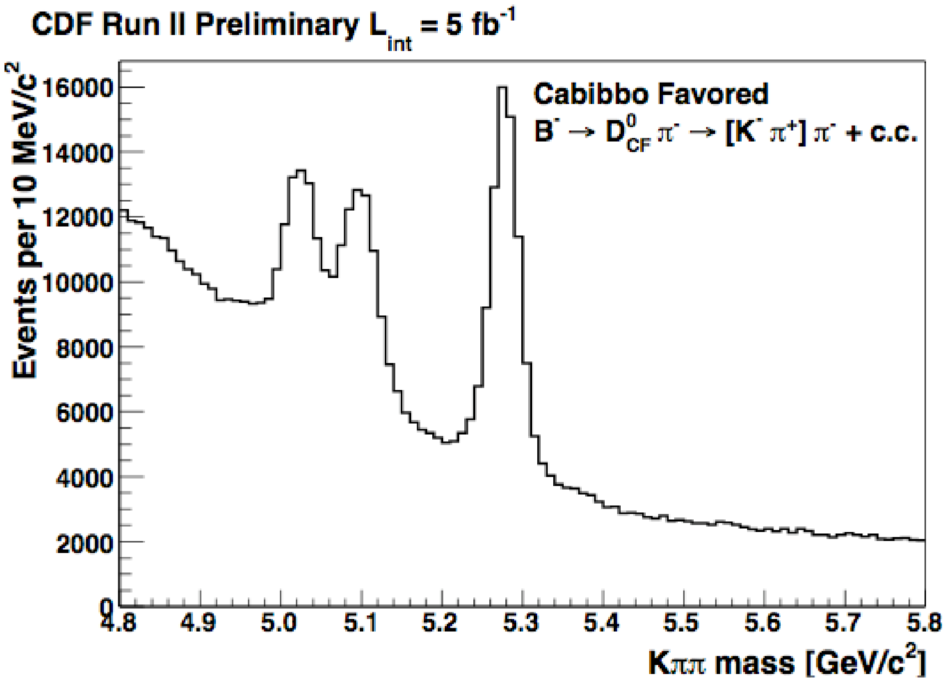
• ***Silicon Vertex Trigger*** at L2,
2D tracks p_T > 2 GeV,
Impact Parameter measurement (trigger on events containing long lived particles)

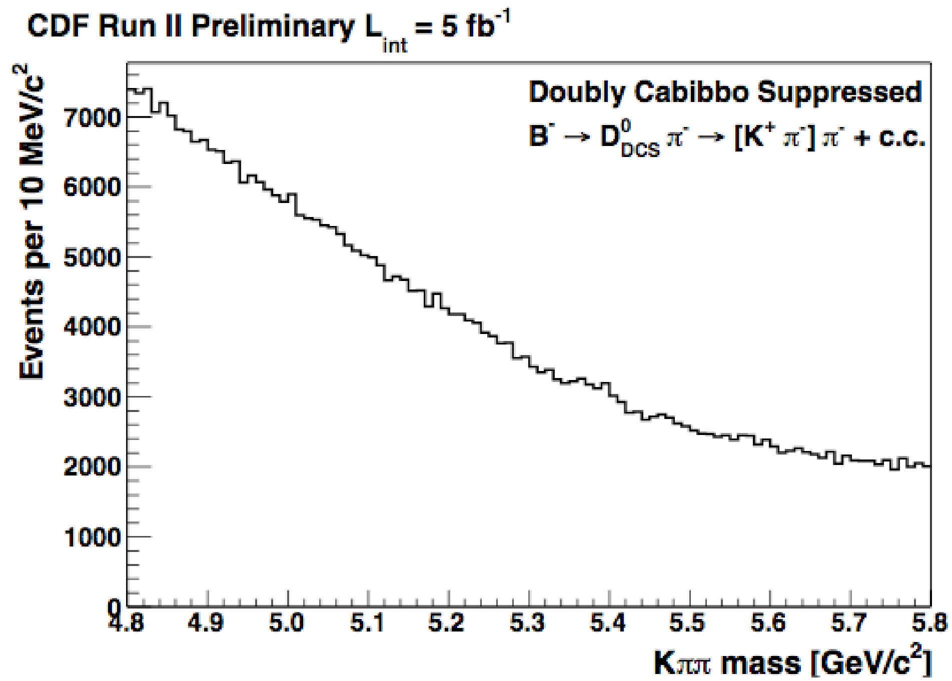


CF and DCS samples (L = 5fb^{-1})

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

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





Cuts optimization → Crucial step toward the DCS modes

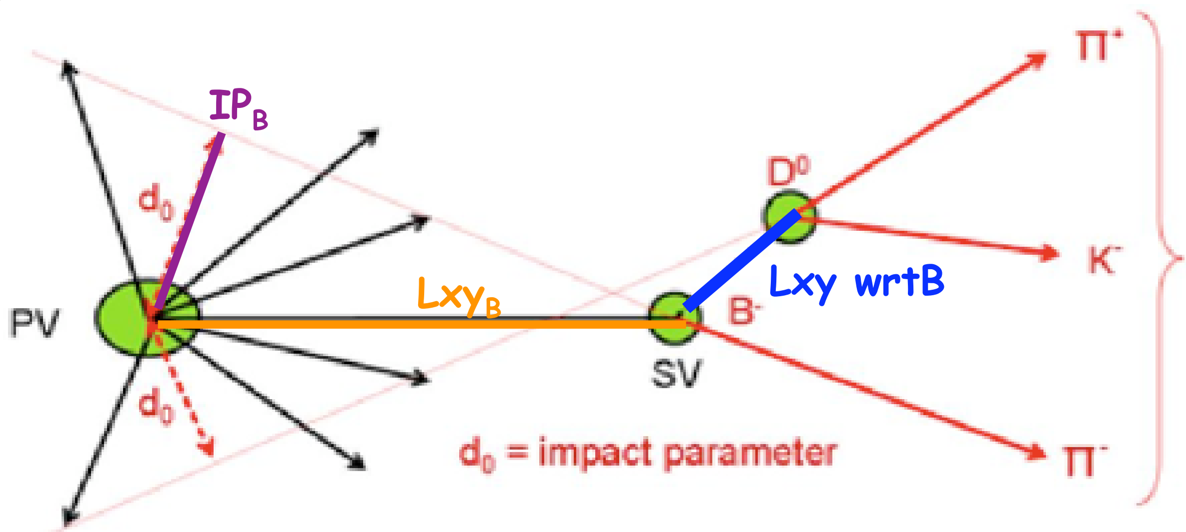
- Maximize the quantity $\dfrac{S}{1.5+\sqrt{B}}$ on CF sample. (arXiv:0808063v2)

Optimized selection

D^0 candidate

Cuts on:

- the invariant mass
- angular distribution
- the decay length wrt B to remove $B \rightarrow 3$ body decays
- particle identification of tracks from D^0 to remove $D^0 \rightarrow \pi\pi$ events

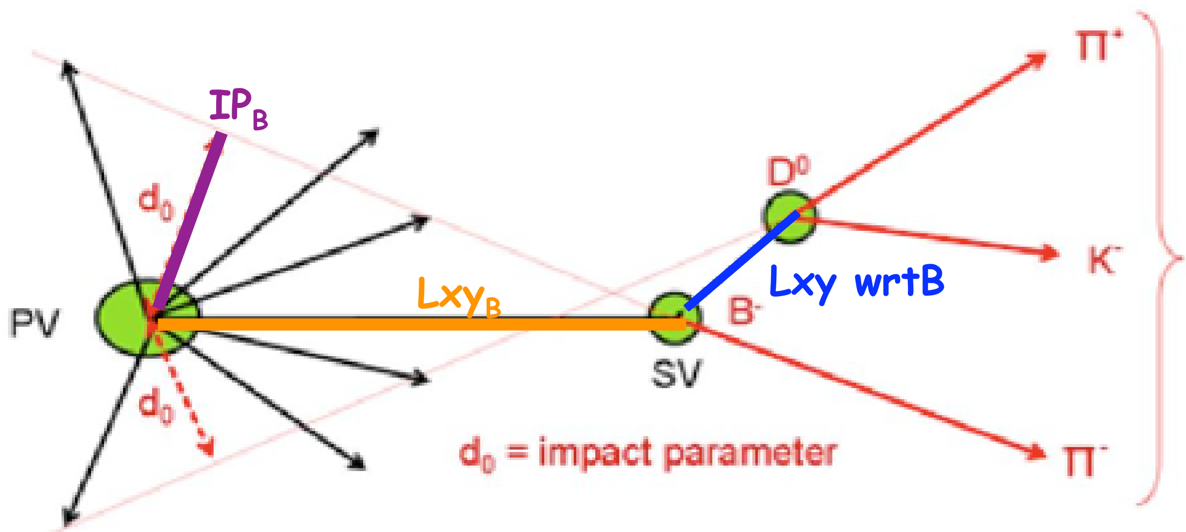


Optimized selection

B candidate

Cuts on:

- decay length wrt primary vertex
- impact parameter
- angle between momentum and decay length



Optimized selection

B candidate

Cuts on:

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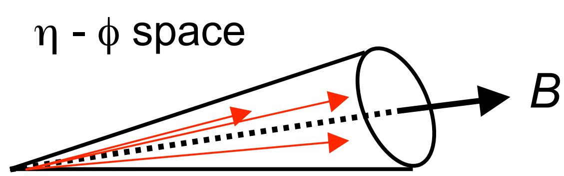
- isolation $$I(B) = \frac{p_T(B)}{p_T(B) + \sum_i p_T(i)}$$

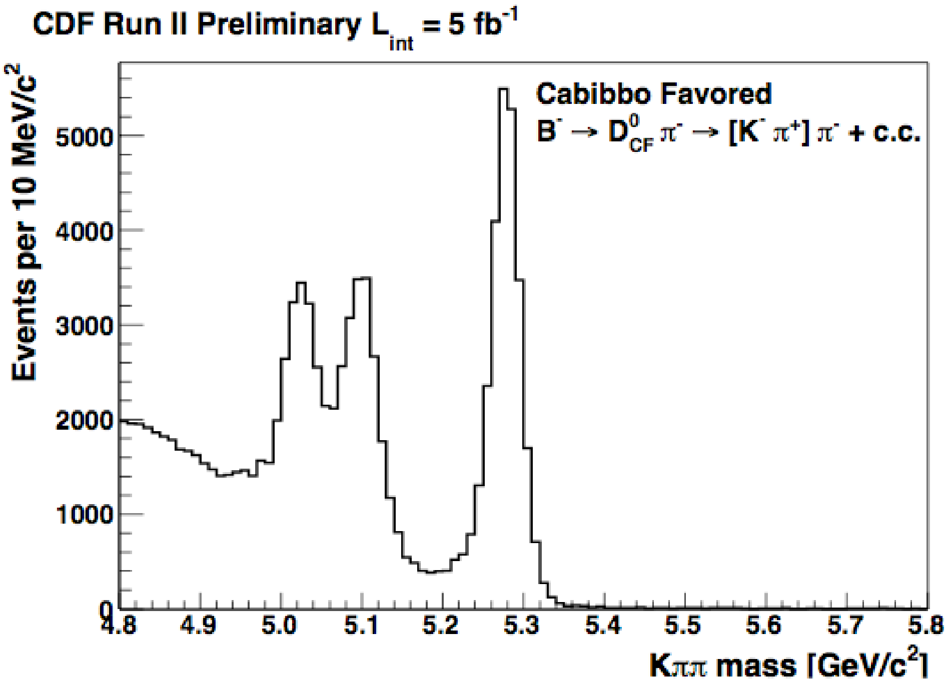


- 3D vertex quality, obtained with the 3D silicon-tracking, to:
  - resolve multiple vertices along the beam direction
  - reject fake tracks.

Backg. reduces x2, small inefficiency on signal (<10%).

CF and DCS after cut optimization

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



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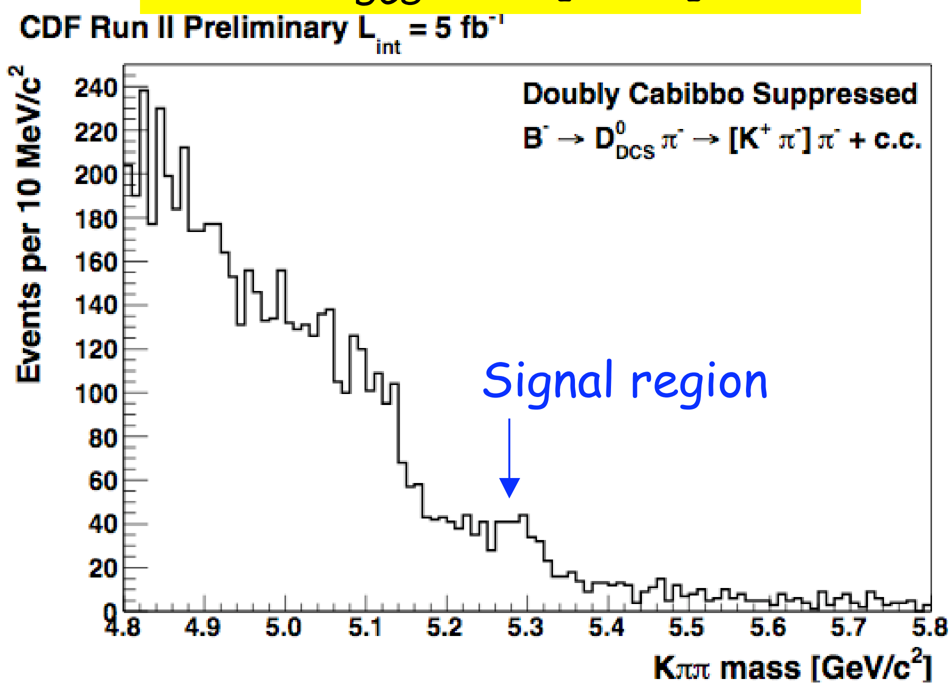

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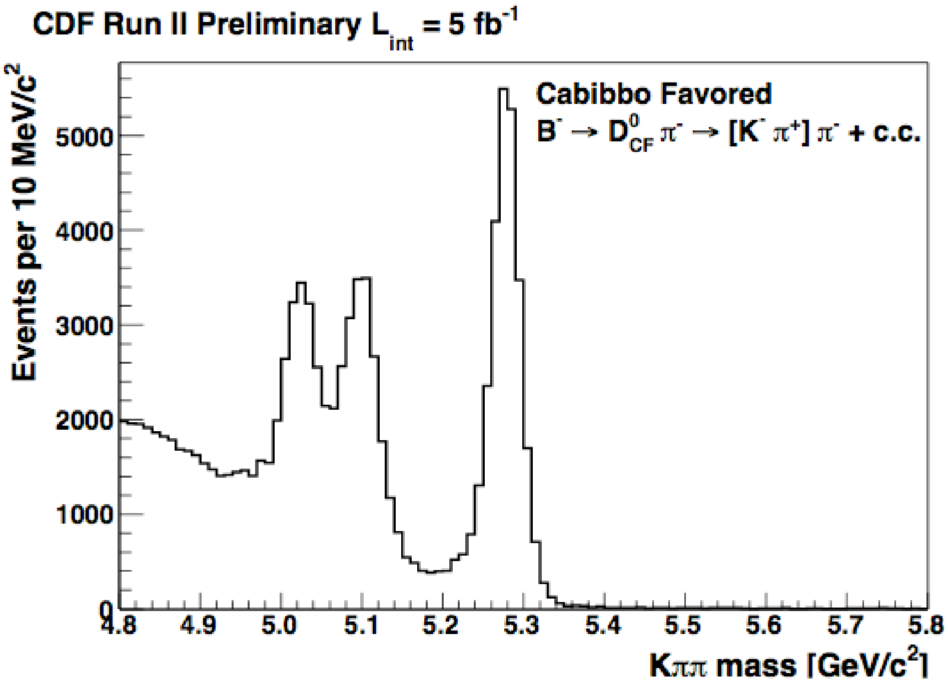

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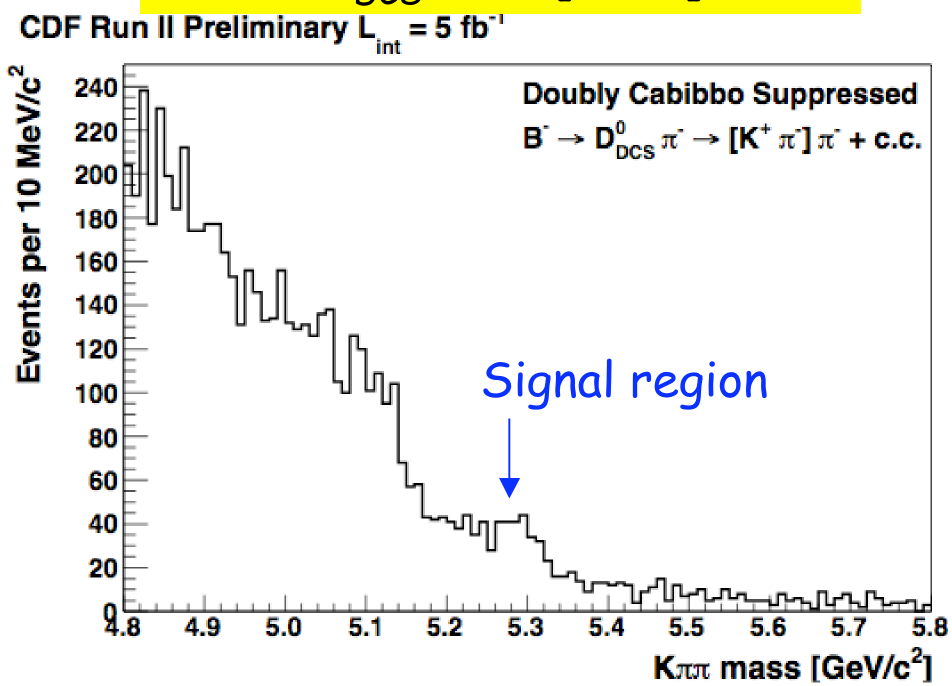


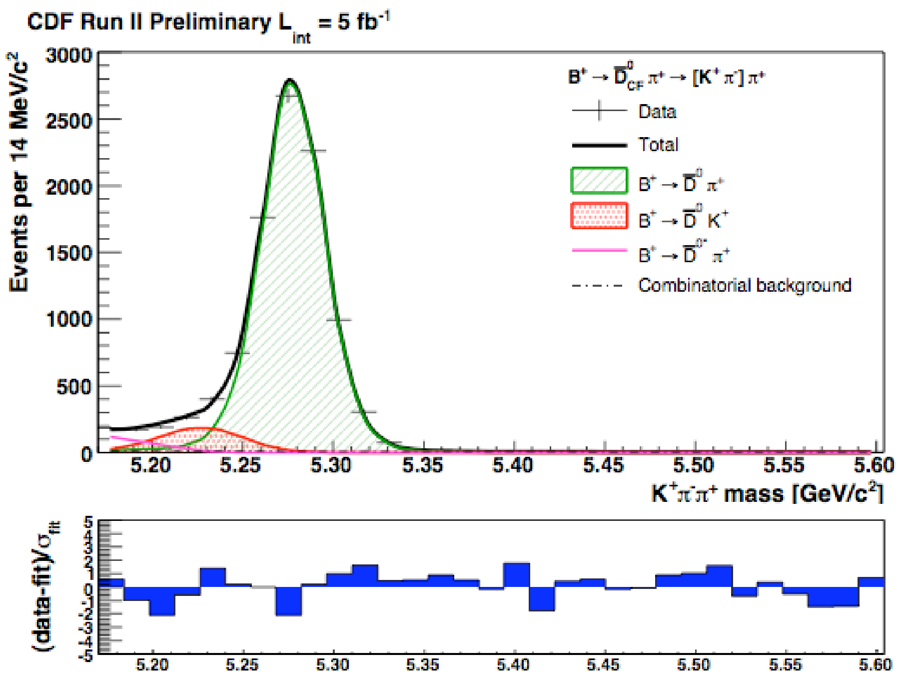
Fit procedure

Use of an *unbinned maximum likelihood fit* (combined on CF and DCS modes) to separate signals contribution using:

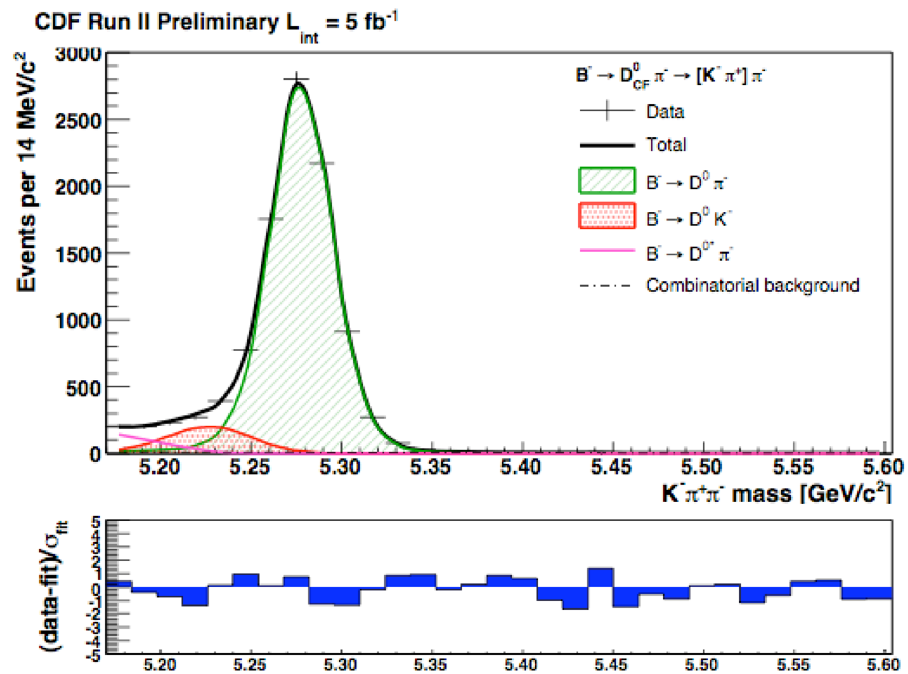
- mass information
- particle identification (dE/dx with K-π separation: 1.5 σ for p > 2 GeV/c)

Results: CF reconstruction

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



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

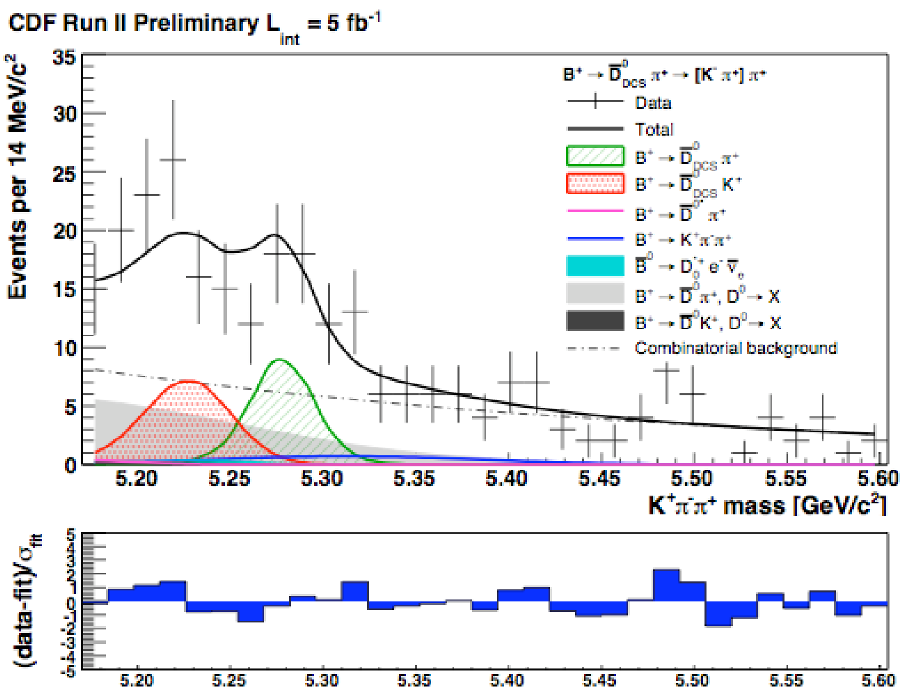


Yield ($B \rightarrow D_{CF}K$) = 1513 ± 68 (5 fb^{-1})
Yield ($B \rightarrow D_{CF}\pi$) = 17677 ± 146 (5 fb^{-1})

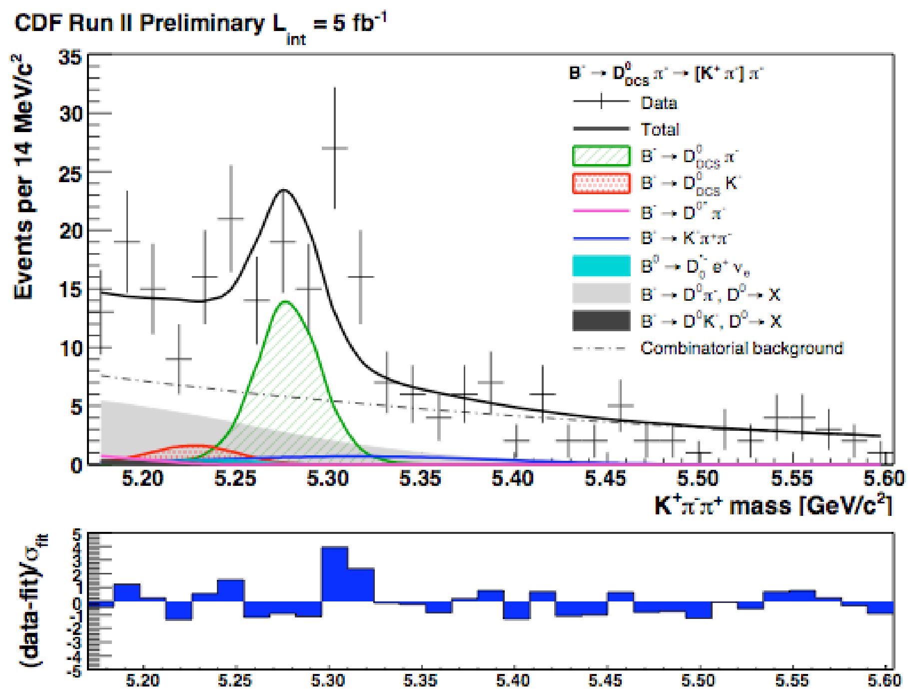
Results: DCS reconstruction

First reconstruction of DCS signals at a hadron collider.

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



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



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

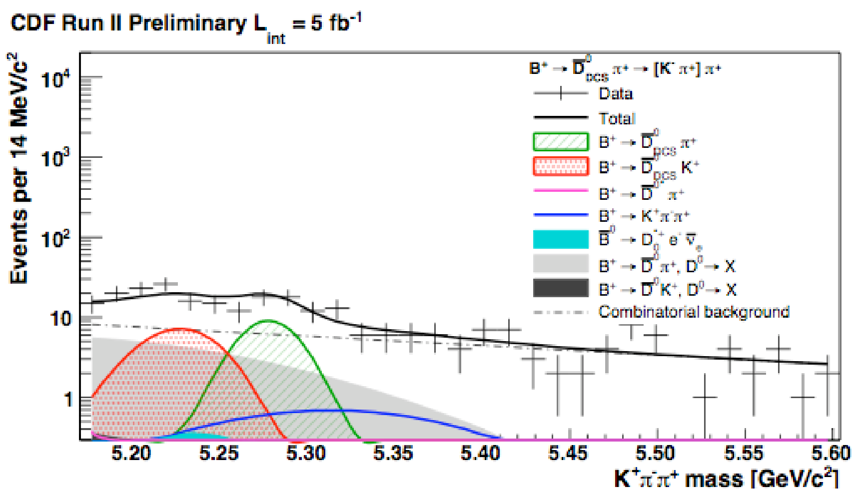
Significance for all DCS signals ($D_{DCS}\pi$ + $D_{DCS}K$) > 5 σ

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

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



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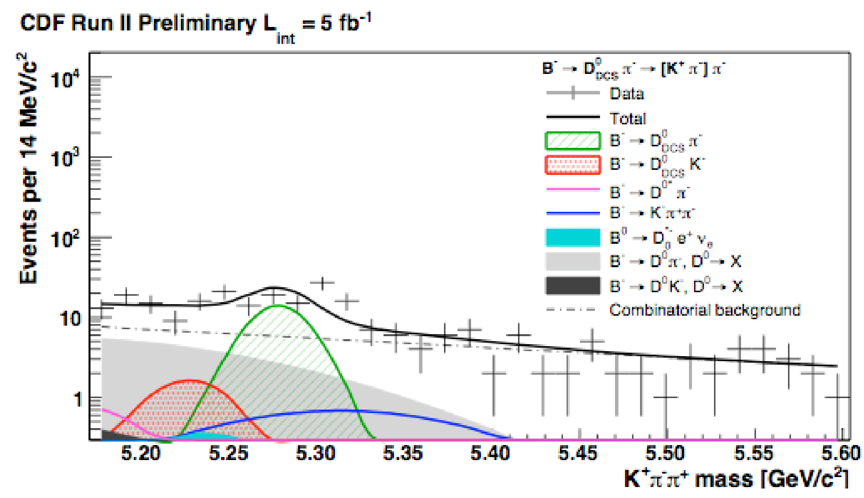


Results: the observables

First measurement of A_{ADS} and R_{ADS}
at a hadron collider.

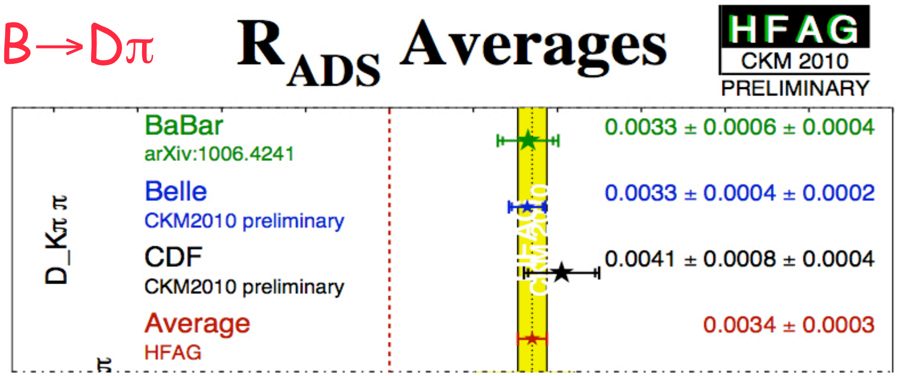
$$R_{ADS}(\pi) = 0.0041 \pm 0.0008(stat) \pm 0.0004(syst)$$
$$A_{ADS}(\pi) = 0.22 \pm 0.18(stat) \pm 0.06(syst)$$
$$R_{ADS}(K) = 0.0225 \pm 0.0084(stat) \pm 0.0079(syst)$$
$$A_{ADS}(K) = -0.63 \pm 0.40(stat) \pm 0.23(syst)$$

(CDF public note 10309)

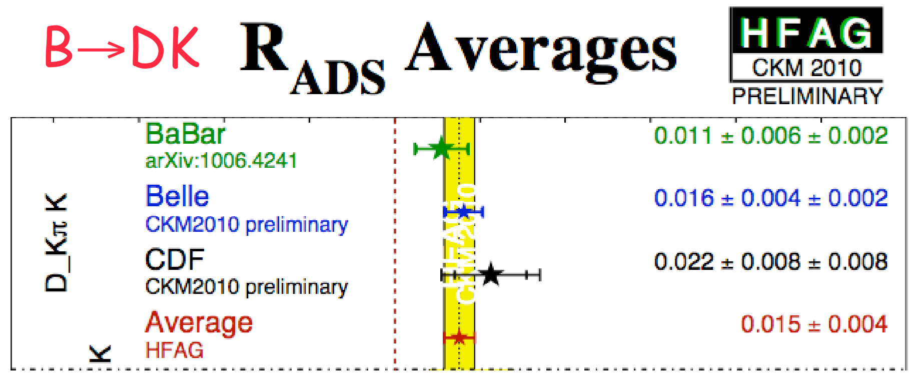
Summary of results

The results are in agreement and compatible with B-factories

B→Dπ



B→DK



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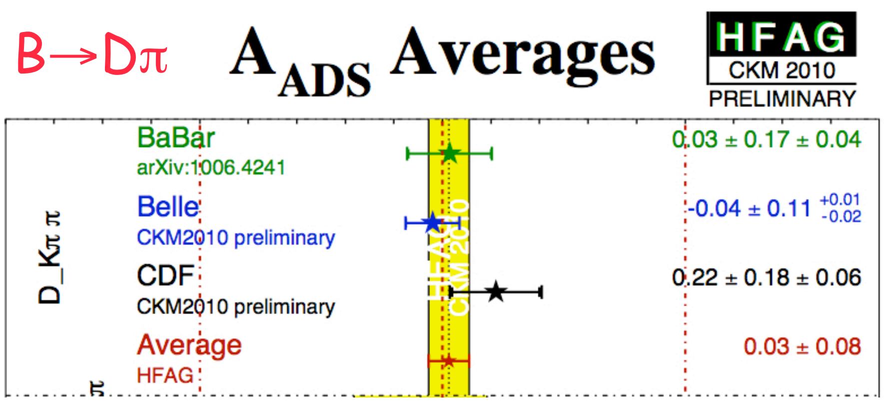

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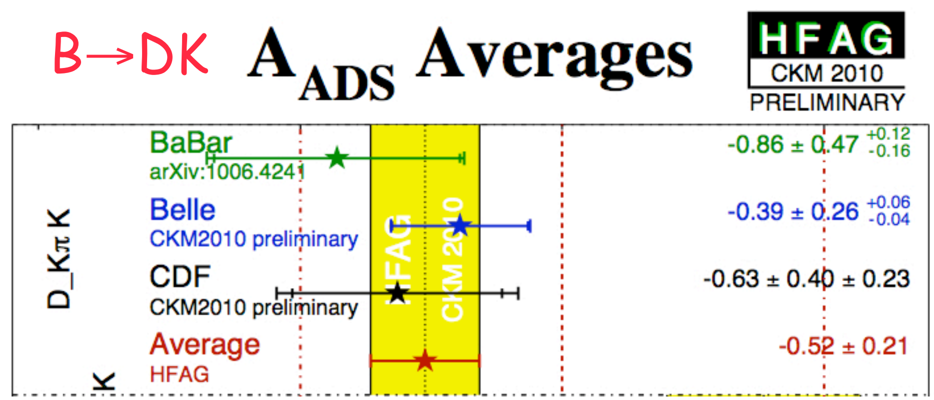


CDF program on γ

The ADS measurement belongs to a *broader program of CDF for measuring γ from trees.*

Recently published the **GLW measurement** using 1 fb^{-1} of data *(Phys.Rev.D81:031105,2010)*

The GLW method

- Direct CP violation in $B \to D_{CP}K$ modes ($D_{CP+} \to \pi^+ \pi^-$, $K^+ K^-$ and $D_{CP-} \to K^0_s \pi^0$, $K^0_s \omega$, $K^0_s \phi$.)
- very clean method
- small asymmetry, sensitivity to γ proportional to r_B

The 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:

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

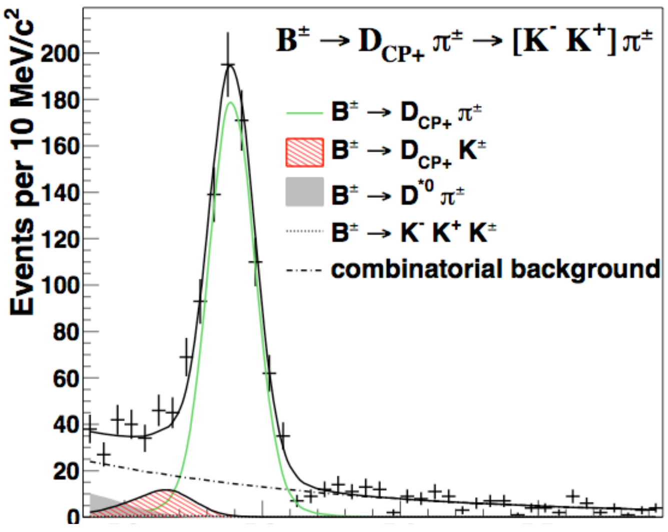
$A_{CP\pm} = 2r_B \sin\delta_B \sin\gamma / R_{CP\pm}$

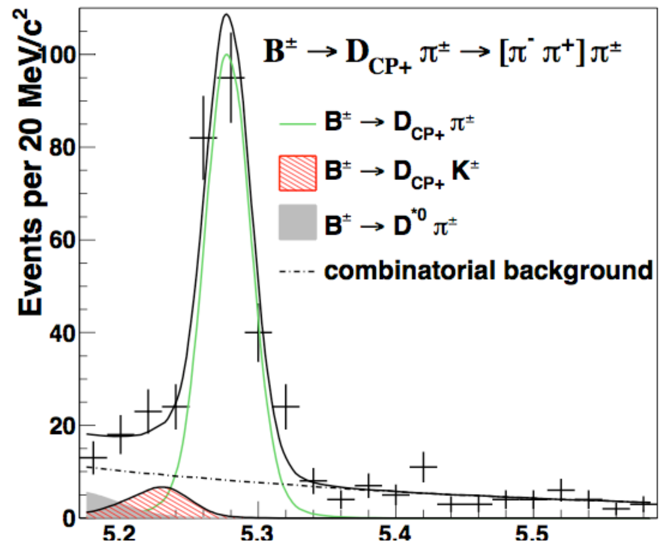
3 independent equations ($A_{CP+}R_{CP+} = -A_{CP-}R_{CP-}$)
and 3 unknowns (r_B, γ, δ_B)

Results

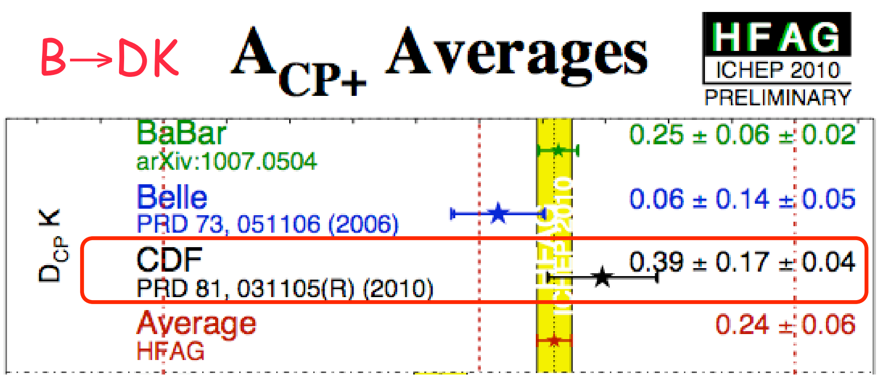
D mode	$B^+ \to D\pi^+$	$B^- \to D\pi^-$	$B^+ \to DK^+$	$B^- \to DK^-$
$K^-\pi^+$	3769 ± 68	3763 ± 68	250 ± 26	266 ± 27
K^+K^-	381 ± 25	399 ± 26	22 ± 8	49 ± 11
$\pi^+\pi^-$	101 ± 13	117 ± 14	6 ± 6	14 ± 6

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

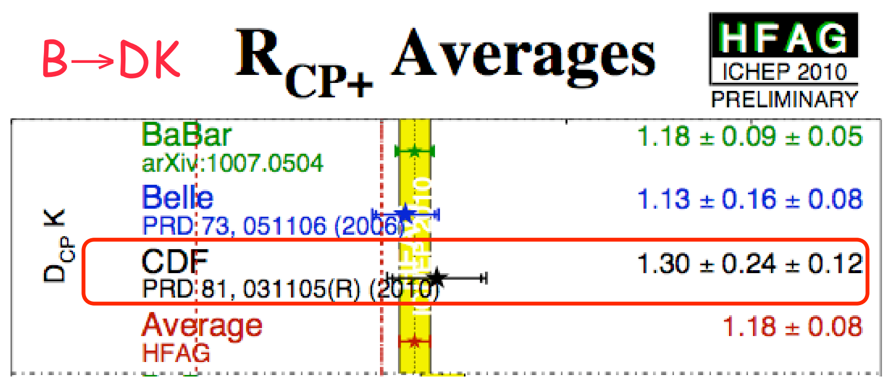




B→DK



B→DK



Conclusions

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

- Demostrated **capability** of hadron collider with **B to charm decays**. The results are competitive with B-factories

- While B-factories updated the measurement to all dataset available, CDF expect to **double the data-set** by 2011 and give significant updates soon.

BACK-UP

From an LHCb study: resolution on γ (assuming $2fb^{-1}$)

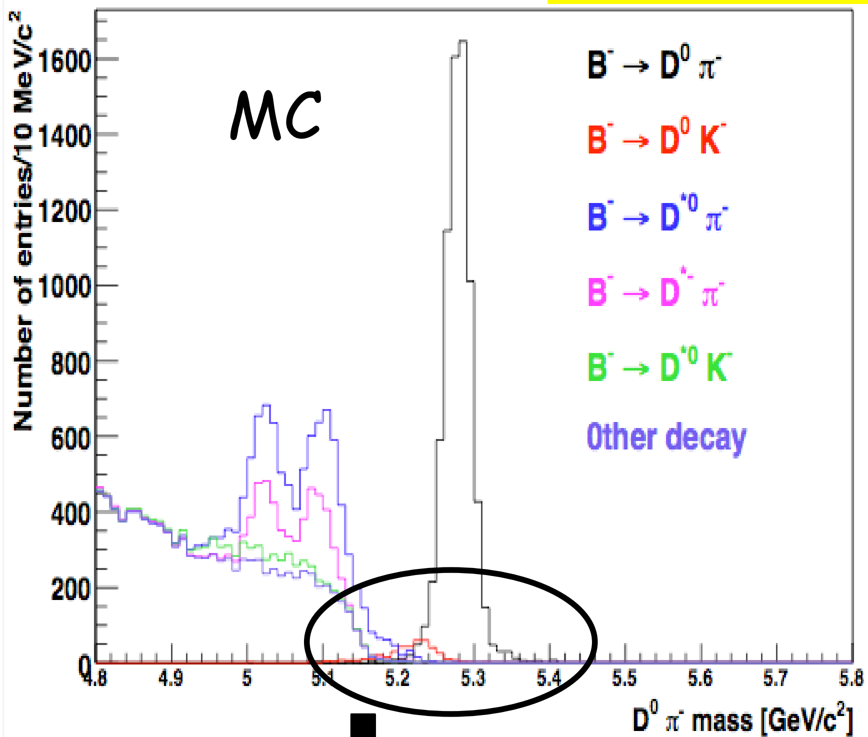
B mode	D mode	Method	$\sigma(\gamma)$
$B^+ \to DK^+$	$K\pi + KK/\pi\pi + K\pi\pi\pi$	ADS+GLW	5°-15°
$B^+ \to D^*K^+$	$K\pi$	ADS+GLW	under study
$B^+ \to DK^+$	$K_S\pi\pi$	Dalitz	15°
$B^+ \to DK^+$	$KK\pi\pi$	4-body “Dalitz”	15°
$B^+ \to DK^+$	$K\pi\pi\pi$	4-body “Dalitz”	under study
$B^0 \to DK^{*0}$	$K\pi + KK + \pi\pi$	ADS+GLW	7°-10°
$B^0 \to DK^{*0}$	$K_S\pi\pi$	Dalitz	under study
$B_S \to D_S K$	$KK\pi$	tagged, A(t)	13°
$B \to \pi\pi, KK$			4°-10°

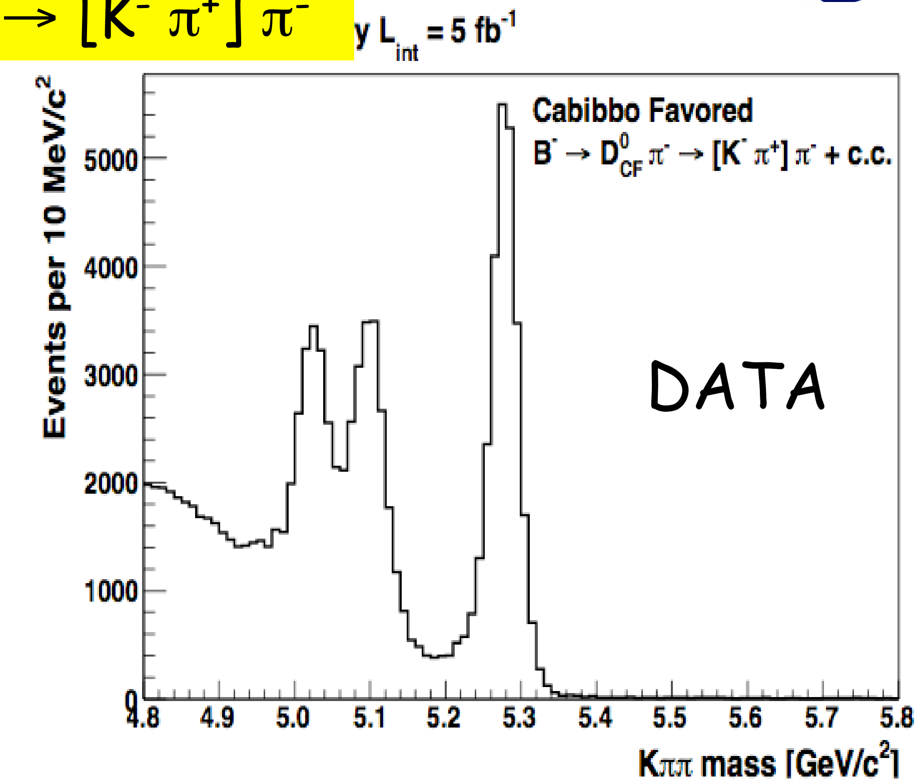
Signal only, no accept. effect

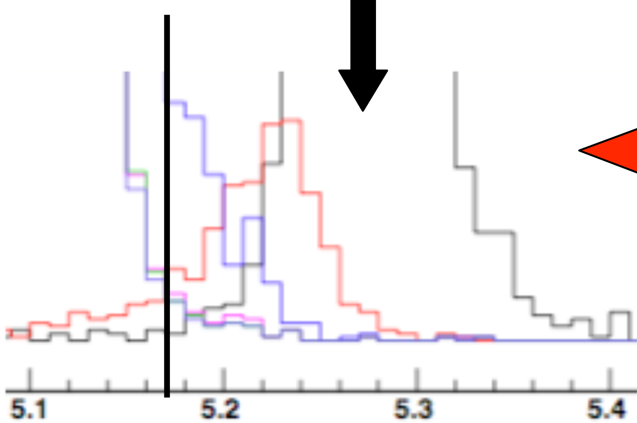
When statistics becomes sufficiently large to actually **see** the **B->DK DCS** decay, the most sensitive method for measuring gamma becomes **ADS** (+GLW), not Dalitz.

Separating DK from other modes

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





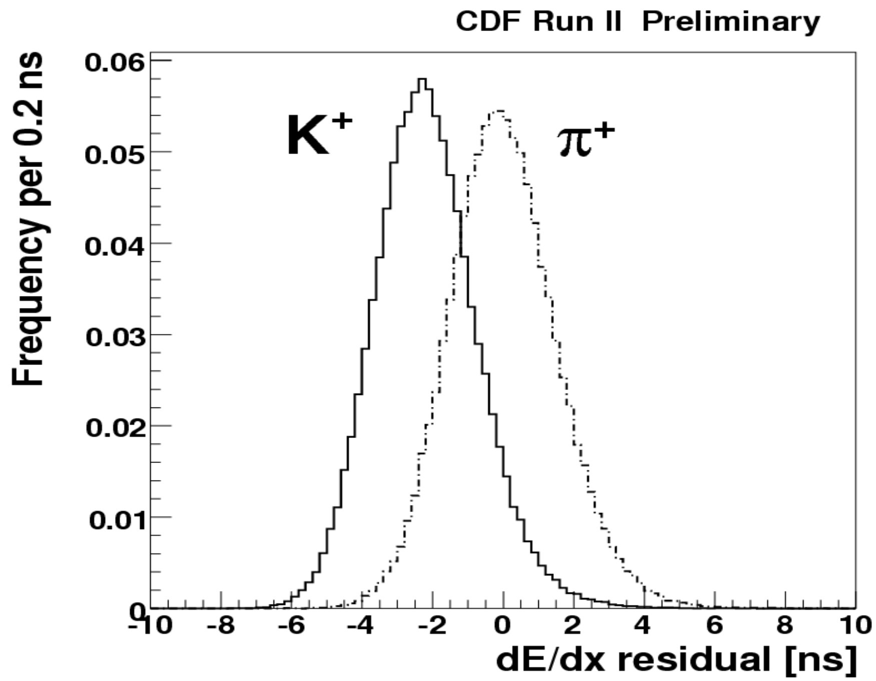


To reject most of the physical backgrounds, narrow fit windows [5.17,6.5]

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

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

$$\mathcal{L} = \mathcal{L}_{CF+} \cdot \mathcal{L}_{CF-} \cdot \mathcal{L}_{DCS+} \cdot \mathcal{L}_{DCS-}$$

$$\begin{aligned}\mathcal{L}_{CF+} = \prod_{i}^{Nevents} \Big[& (1 - b_{CF+}) \cdot \Big(f_\pi^{CF+} \cdot pdf_\pi(M, ID) + \mathbf{c}^+ \cdot f_\pi^{CF+} \cdot pdf_{D*}(M, ID) + \\ & + \Big(1 - f_\pi^{CF+} - \mathbf{c}^+ \cdot f_\pi^{CF+}\Big) \cdot pdf_K(M, ID)\Big) + b_{CF+} \cdot pdf_{comb}(M, ID)\Big]\end{aligned}$$

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

Analogous expressions for negative charges

- **$pdf_i(M,ID) = pdf_i(M) * pdf_i(ID)$**
- **Fitted parameters**
  - **$b_{CF,\ DCS}$ = background fraction for CF and DCS**
  - **$f_{\pi,\ CF,\ DCS}$ = B->D^0 π fraction for CF and DCS signal**
  - **$c = f_{D*} / f_\pi$ (equal for CF and DCS)**
  - **$f_{[X]\pi}$ = fraction of B->D^0 π, D^0->X in DCS reconstruction (constrained from MC)**
  - **$f_{[X]K}$ = fraction of B->D^0K, D^0->X in DCS reconstruction (constrained from MC)**
  - **$f_{K\pi\pi}$ = fraction of B->K- π+ π- in DCS reconstruction (constrained from MC)**
  - **f_{B0} = fraction of B^0->D*- e ν in DCS reconstruction (constrained from MC)**