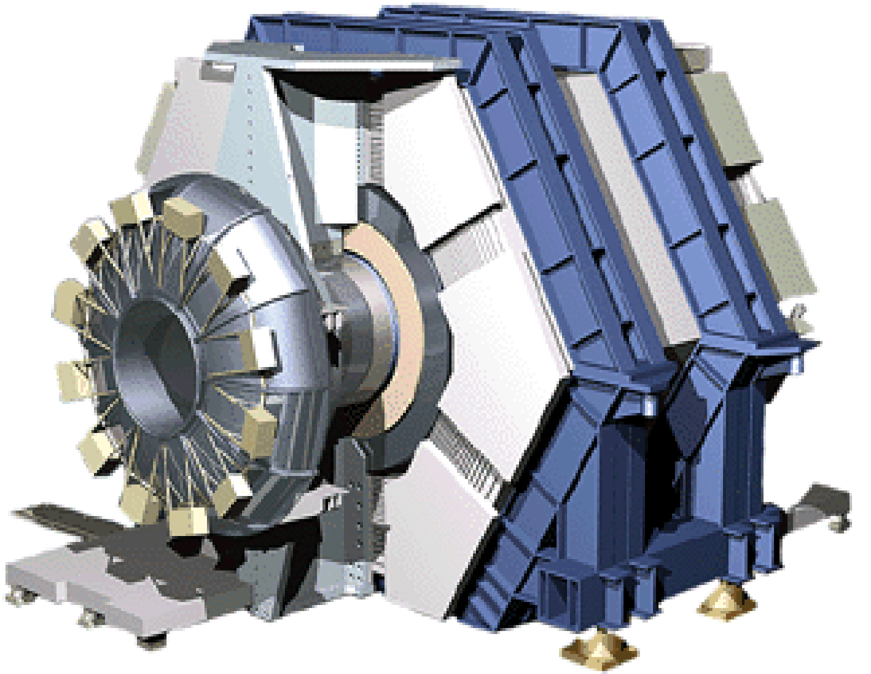
Search for b→u transitions in the decays $B \to D^{(*)}K^-$ using the ADS method at BaBar

Richard Kass for the BaBar Collaboration



Outline of Talk

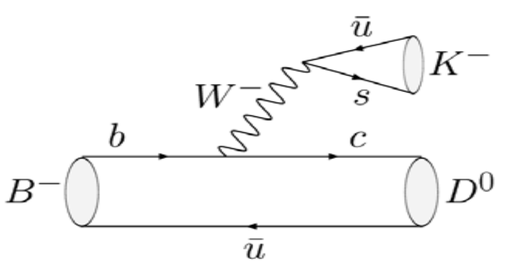
*Introduction/ADS method
*Analysis technique
*Preliminary Results
*Summary & Conclusions

The ADS Method-I

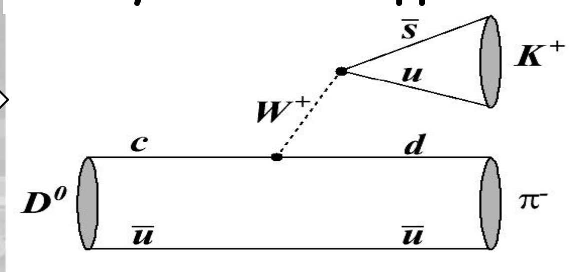
Atwood, Dunietz, Soni, PRL 78, 3257 (1997) & PRD 63, 036005 (2001)

- Use B decays that can reach the same final state via two different decay amplitudes
- Amount of interference depends on CKM angle γ
- ADS idea: use $D^0/\bar{D}^0$ Flavor eigenstates, e.g. $B^- \to DK^- \to [K^+\pi^-]_D K^-$
  - Also can use D^*K^- and $D^{(*)}K^{*-}$

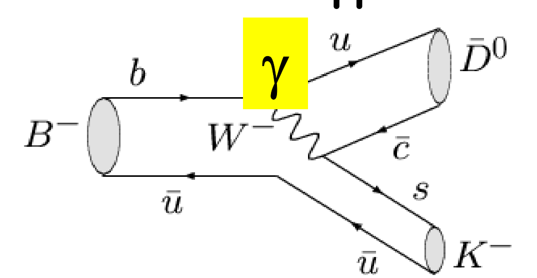
color & CKM favored



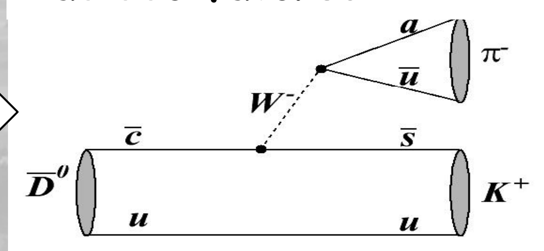
doubly Cabibbo suppressed



color & CKM suppressed



Cabibbo favored



$[K^+\pi^-]_D K^-$

The ADS Method-II

The amplitude for $B^- \to DK^- \to [K^+\pi^-]_D K^-$ can be written as:

$$A(B^- \to [K^+\pi^-]_D K^-) \propto r_B e^{i\delta_B} e^{-i\gamma} + e^{-i\delta_D} r_D$$

$$r_B = \frac{|A(B^- \to \overline{D}^0 K^-)|}{|A(B^- \to D^0 K^-)|} \sim 0.1$$

B strong phase

CKM

D strong phase

$\delta_D = (202^{+11}_{-12})^0$ HFAG

$$r_D = \frac{|A(D^0 \to K^+\pi^-)|}{|A(D^0 \to K^-\pi^+)|}$$

r_D=(5.78±0.08)% HFAG

Can form two observables: R_{ADS} & A_{ADS}

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

$$A_{ADS} = \frac{\Gamma(B^- \to [K^+\pi^-]_D K^-) - \Gamma(B^+ \to [K^-\pi^+]_D K^+)}{\Gamma(B^- \to [K^+\pi^-]_D K^-) + \Gamma(B^+ \to [K^-\pi^+]_D K^+)} = \frac{2 r_B r_D \sin(\delta_B + \delta_D)\sin\gamma}{R_{ADS}}$$

☺news: theoretically clean way to measure γ.
Do not have to measure time dependence & asymmetry expected to be large

😐news: 3 unknowns (r_B, δ_B, γ) but 2 observables (R, A) per decay mode
but add D*K & now have 5 unknowns & 6 observables

☹news: Rates are expected to be small ~10^{-7}

$B(B^- \to D^0 K^-) \times B(D^0 \to K^+\pi^-) \sim (3.7\times10^{-4})(1.3\times10^{-4}) \sim 4.8\times10^{-8}$

PEP-II at SLAC

asymmetric e^+e^- collider: 9 GeV (e^-)/3.1 GeV (e^+)
PEP-II Peak Luminosity $1.2 \times 10^{34}\ cm^{-2}s^{-1}$
BaBar recorded 426 fb^{-1} at $\Upsilon(4S)$

$4.67\times 10^8\ \Upsilon(4S)\rightarrow B\bar{B}$ events

ADS Analysis Strategy

Study the following decays:

$B^- \to DK^-$

$D \to K^+\pi^-$ & $D \to K^-\pi^+$

$B^- \to D^*K^-$

$D^* \to \gamma D$, $D \to K^+\pi^-$ & $D \to K^-\pi^+$

$B^- \to D^*K^-$

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

Notation:

"ADS": suppressed decays,
e.g. K's have opposite sign

"CAB": Cabibbo favored decays,
$D\pi$ and DK decays
e.g. K's have same sign

$B^- \to D\pi^-$

$D \to K^+\pi^-$ & $D \to K^-\pi^+$

$B^- \to D^*\pi^-$

$D^* \to \gamma D$, $D \to K^+\pi^-$ & $D \to K^-\pi^+$

$B^- \to D^*\pi^-$

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

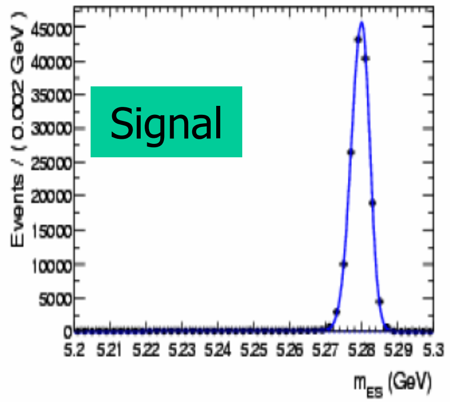
Very useful check of technique due to large rate (>10x DK)

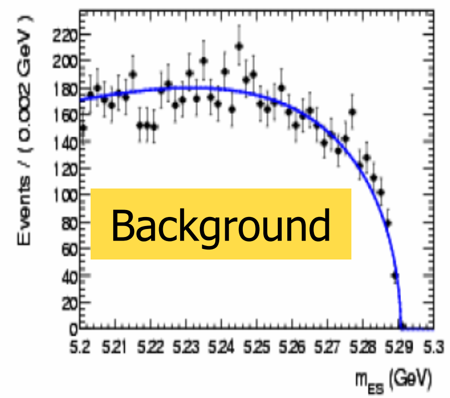
CPV expected to be small in these modes

ADS Analysis Techniques

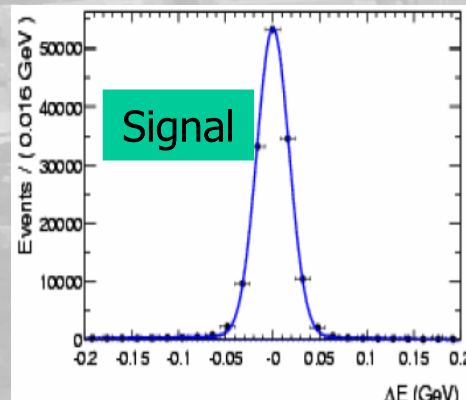
Threshold kinematics: we know the initial energy (E^*_{beam}) of the Υ(4S) system
Therefore we know the energy & magnitude of momentum of each B

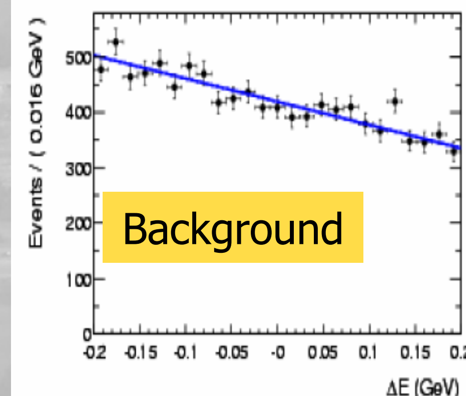
$$m_{ES} = \sqrt{E^{*2}_{beam} - p^{*2}_B}$$



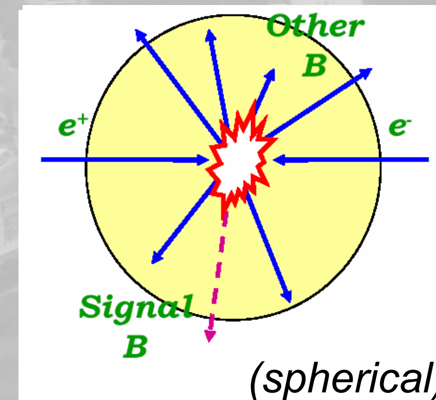


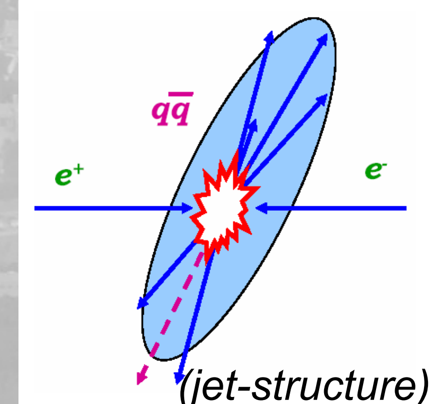
$$\Delta E = E^*_B - E^*_{beam}$$





Event topology





Two main sources of backgrounds: B's & charm from $c\bar{c}$ events

ADS Backgrounds

Continuum Charm Production $e^+e^-\rightarrow c\bar{c}$

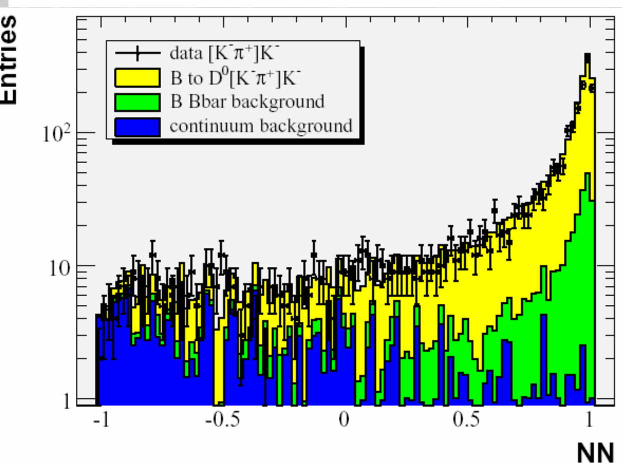
combine a $\bar{D}^0\rightarrow K^+\pi^-$ with a K^- from rest of event

Use a Neural Net to suppress continuum backgrounds

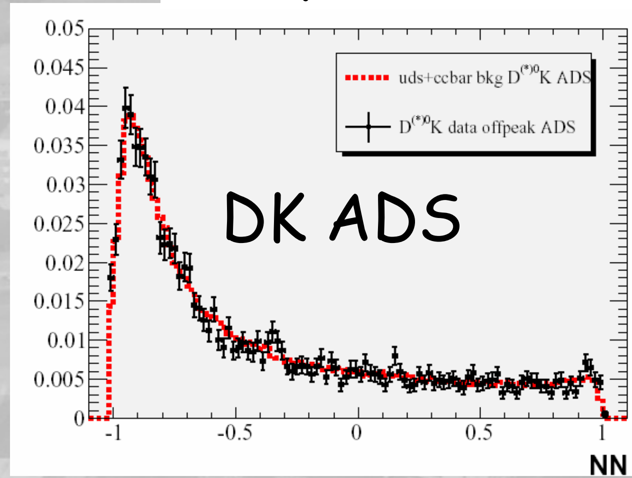
Inputs to NN include:

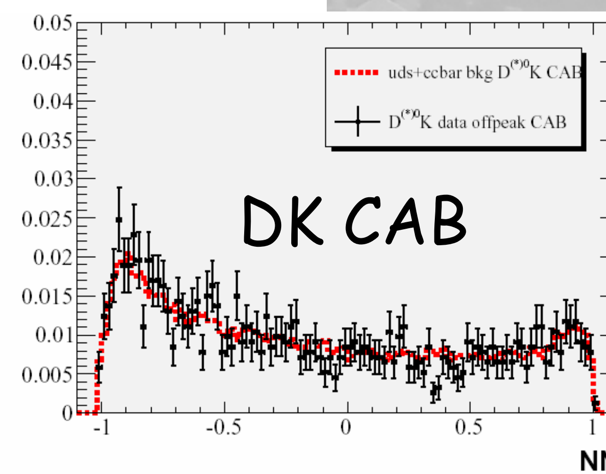
- event shape variables (Legendre moments, Thrust, B meson polar angle in CM)
- B tagging variables (hemisphere charge, kaon charge sum in ROE, kaon-lepton mass, Δt between 2 B's in event)

DK signal enriched CAB
$5.2725<m_{ES}<5.2875$



off peak data vs udsc MC





ADS Backgrounds

B Mesons

Peaking backgrounds from B mesons; for $B^- \to DK^-$:

- $B^- \to D\pi^-$ with π mis-ID as a K ($BR(D\pi^-)/BR(DK^-) \sim 13$)
- $B^- \to DK^-$ with $D \to K^+K^-$ and K mis-ID as a π ($BR(D \to K^+K^-)/BR(D \to K^+\pi^-) \sim 31$)

Charmless B decays

- $B^- \to K^+\pi^- K^+$, $B^- \to K^-\pi^+ K^-$

Eliminate backgrounds from B mesons using:

- tight particle ID
- swap K-π hypotheses & veto if $|m(K^-\pi^+)-m(D)|<40$MeV
- veto K^+K^- if $|m(K^+K^-)-m(D)|<40$MeV

MC estimate of B meson backgrounds (r_B=0.1, $\cos\delta\cos\gamma$=0)

mode	signal	$N_{B\bar{B}}(all)$	$N_{B\bar{B}}$(peaking)	peaking sources
D^0K ADS	26.3	84	8.1 ± 4	$B^+ \to D^0h^+(2)$, $B^+ \to K^-K^+\pi^-(6.1)$
$D^{*0}_{D^0\pi^0}K$ ADS	8.5	20	2.7 ± 1.6	none id. (compatible with 0)
$D^{*0}_{D^0\gamma}K$ ADS	6.8	74	6.0 ± 2.4	none id. (compatible with 0)
DK CAB	1944	354	299 ± 11	$B^+ \to D^0\pi^+$
$D^{*0}_{D^0\pi^0}K$ CAB	618	183	127 ± 8	$B^+ \to D^{*0}_{D^0\pi^0}\pi^+$
$D^{*0}_{D^0\gamma}K$ CAB	503	393	393 ± 35	$B^+ \to D^{*0}_{D^0\gamma}\pi^+$, $B^+ \to D^{*0}_{D^0\pi^0}K^+$, other

ADS Likelihood Fit

Extract parameters of interest using an unbinned extended maximum likelihood fit in m_{ES} and NN distribution.

There are 8 components to the ML fit:

ADS signal: gaussian X NN(B meson)
CAB signal: gaussian X NN(B meson)
ADS background: ARGUS X NN(ADS udsc)
CAB background: ARGUS X NN(CAB udsc)
ADS non-peaking B background: ARGUS X NN(B meson)
ADS peaking B background: gaussian X NN(B meson), FIXED to MC
CAB non-peaking B background: ARGUS X NN(B meson)
CAB peaking B background: gaussian X NN(B meson), FIXED to MC
ALSO fit for the mean & σ of gaussian and the 2 ARGUS parameters

The fit is done individually for six modes:

$D\pi$, $D^*\rightarrow(D\pi^0)\pi$, $D^*\rightarrow(D\gamma)\pi$
DK, $D^*\rightarrow(D\pi^0)K$, $D^*\rightarrow(D\gamma)K$

The fit is done separately for B^-, B^+ & combined charges

ADS Analysis Details

Summary of Selection Efficiencies

Channel	efficiency (%) ϵ_{ADS} $([K^{\pm}\pi^{\mp}]_D h^{\mp})$	ϵ_{CAB} $([\pi^{\pm}K^{\mp}]_D h^{\mp})$	$\epsilon_{ADS}/\epsilon_{CAB}$ $(\times 10^{-2})$
D^0K	26.5±0.1	26.6±0.1	99.5±0.5
$D^{*0}_{D^0\pi^0}K$	13.3±0.1	13.2±0.1	100.0±1.1
$D^{*0}_{D^0\gamma}K$	17.4±0.1	17.5±0.1	99.4±0.8
$D^0\pi$	27.0±0.1	27.5±0.1	98.1±0.5
$D^{*0}_{D^0\pi^0}\pi$	14.3±0.1	14.9±0.1	96.2±0.9
$D^{*0}_{D^0\gamma}\pi$	18.8±0.1	19.6±0.1	96.1±0.7

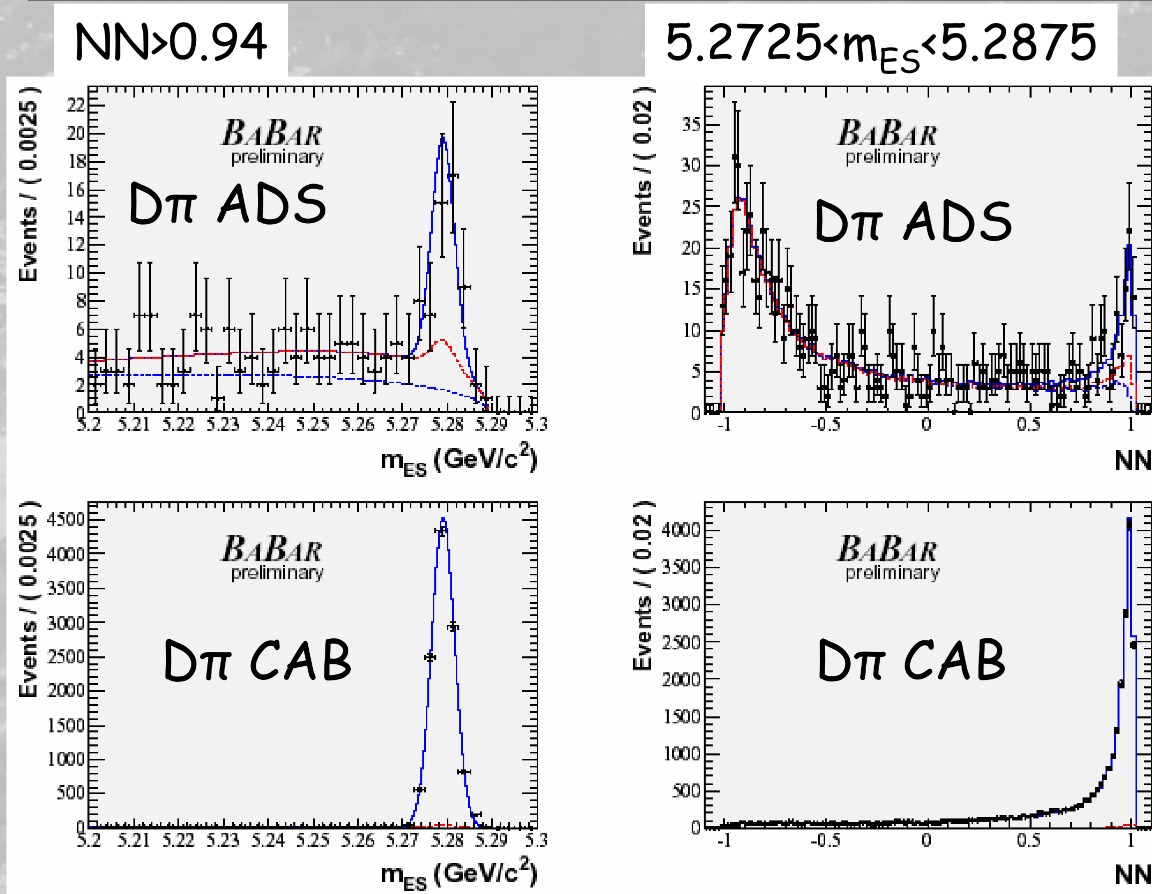
$\varepsilon_{ADS}/\varepsilon_{CAB}\neq 1$ due to slightly different PID cuts at an early stage of analysis

Summary of $D^{(*)}K$ Systematic Errors

error source	$\Delta\mathcal{R}/\mathcal{R}$ D^0K	$\Delta\mathcal{R}/\mathcal{R}$ $D^{*0}_{D^0\pi^0}K$	$\Delta\mathcal{R}/\mathcal{R}$ $D^{*0}_{D^0\gamma}K$
signal NN	+4%	+2%	+8%
$B\bar{B}$ background NN	-7%	+14%	+28%
udsc background NN	-4%	+3%	-5%
$B\bar{B}$ comb. bkg shape (m_{ES})	±4%	±5%	±6%
peaking background ADS	±16%	±15%	±41%
peaking background CAB	±3%	±4%	±9%
float $B\bar{B}$ comb. bkg	-	−10%	0%
Combined	±20%	±24%	±51%

Table for $D^{(*)}\pi$ in "extra slides"

$B^- \to D^{(*)}\pi^-$ Results



$B\bar{B}$ bkgds
continuum bkgds
fit result

$$R = \frac{N_{ADS}}{N_{CAB}}$$

$$A = \frac{N^-_{ADS} - N^+_{ADS}}{N^-_{ADS} + N^+_{ADS}}$$

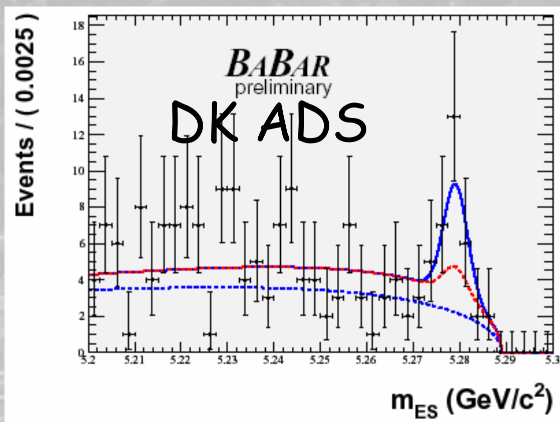
Mode	N_{ADS}	N_{CAB}	$R \times 10^{-3}$	$A \times 10^{-2}$
$D\pi$	79.8±13.8	24662±160	3.3 ± 0.6 ± 0.4	3 ± 17 ± 4
$D^*\pi \to (D\pi^0)\pi$	28.7 ± 7.7	9296 ± 102	3.2 ± 0.9 ± 0.8	-9 ± 27 ± 5
$D^*\pi \to (D\gamma)\pi$	18.7 ± 9.7	7214 ± 105	2.7 ±1.4± 2.2	-65 ± 55± 22

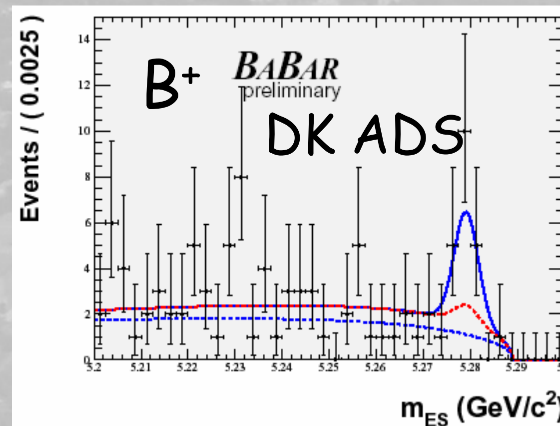
Expect $R \approx r^2_D$ (world average: $r^2_D = (3.36 \pm 0.08) \times 10^{-3}$)

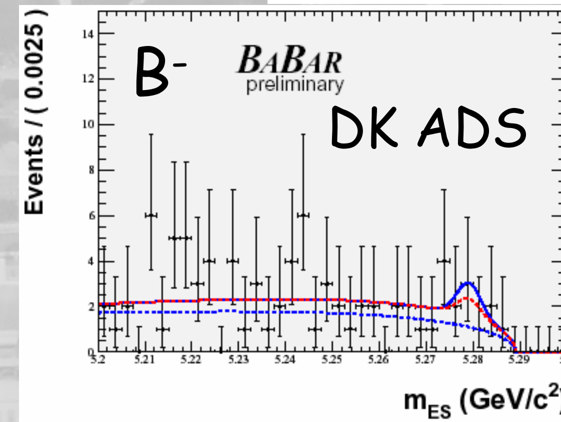
B→DK Results

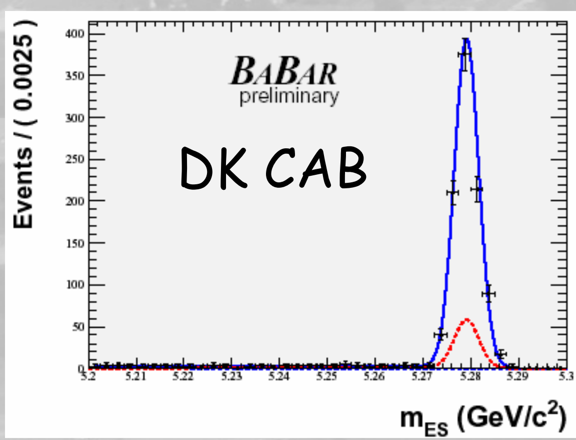
All m_{ES} plots have NN > 0.94

$B\bar{B}$ bkgds (red dotted line)
continuum bkgds (blue dotted line)
fit result (blue solid line)









Significance of R
2.9σ (stat)
2.6σ (stat+syst)

$$R = \frac{N_{ADS}}{N_{CAB}}$$

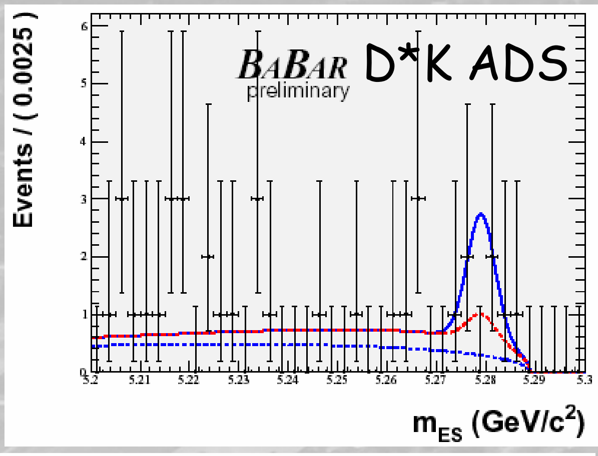
$$A = \frac{N^{-}_{ADS} - N^{+}_{ADS}}{N^{-}_{ADS} + N^{+}_{ADS}}$$

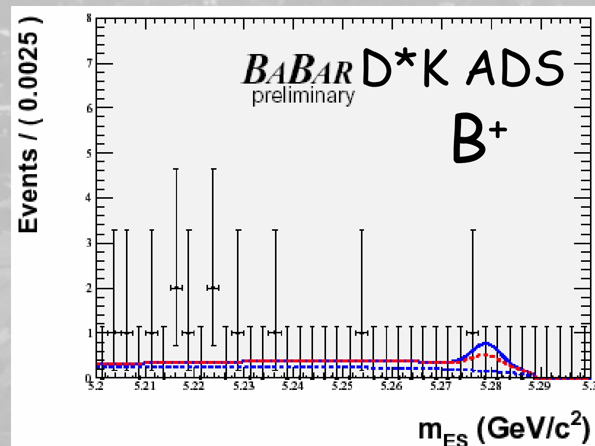
Mode	N_{ADS}	N_{CAB}	$R \times 10^{-2}$	A
DK	23.9 ± 9.7	1755 ±48	1.36 ± 0.55 ± 0.27	$-0.70 \pm 0.35^{+0.09}_{-0.14}$

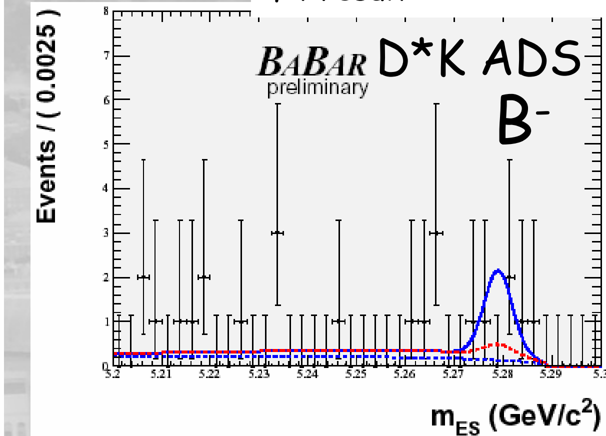
$B \rightarrow D^*(D\pi^0)K$ Results

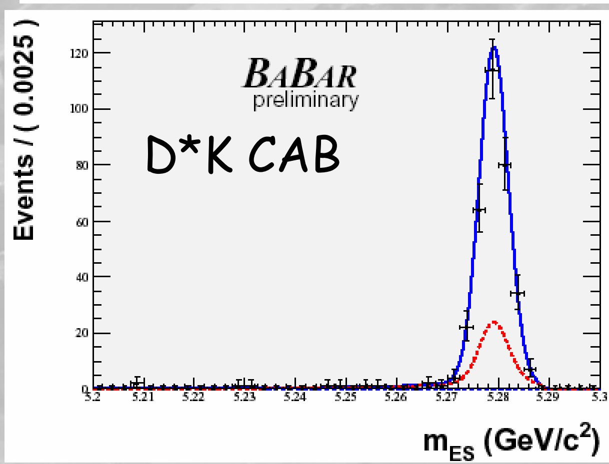
All m_{ES} plots have NN > 0.94

$B\bar{B}$ bkgds
continuum bkgds
fit result









Significance of R
2.4σ (stat)
2.2σ (stat+syst)

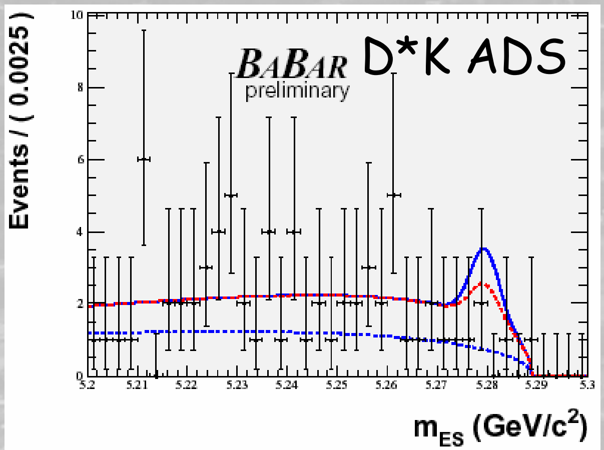
$$R^* = \frac{N_{ADS}}{N_{CAB}}$$

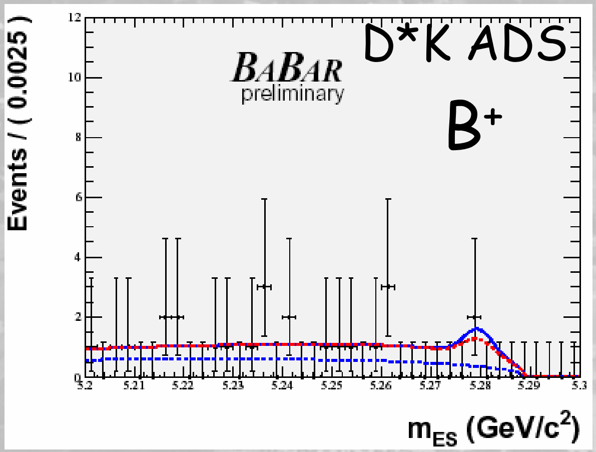
$$A^* = \frac{N^-_{ADS} - N^+_{ADS}}{N^-_{ADS} + N^+_{ADS}}$$

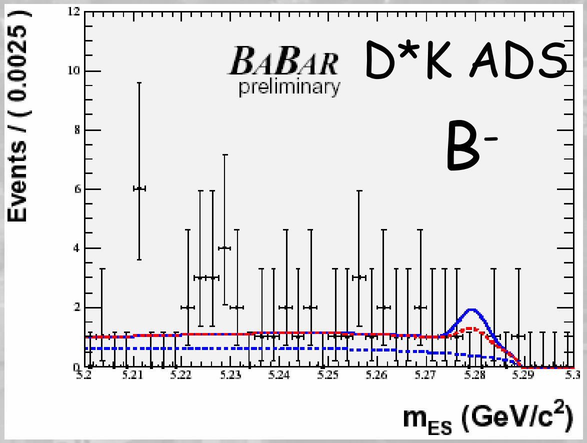
Mode	N_{ADS}	N_{CAB}	$R^*\times10^{-2}$	A^*
$D^*(D\pi^0)K$	10.3 ± 5.5	587 ±28	1.76 ± 0.93 ± 0.42	+0.77 ± 0.35± 0.12

B→D*(Dγ)K Results

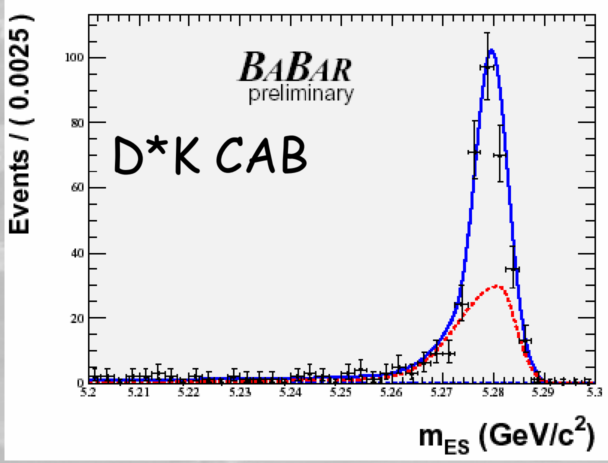
All m_{ES} plots have NN > 0.94







$B\bar{B}$ bkgds
continuum bkgds
fit result



$$R^* = \frac{N_{ADS}}{N_{CAB}}$$

$$A^* = \frac{N^-_{ADS} - N^+_{ADS}}{N^-_{ADS} + N^+_{ADS}}$$

Mode	N_{ADS}	N_{CAB}	$R^* \times 10^{-2}$	A^*
D*(Dγ)K	5.9 ± 6.4	455 ±29	1.3 ± 1.4 ± 0.7	$+0.36 \pm 0.94\,^{+0.25}_{-0.41}$

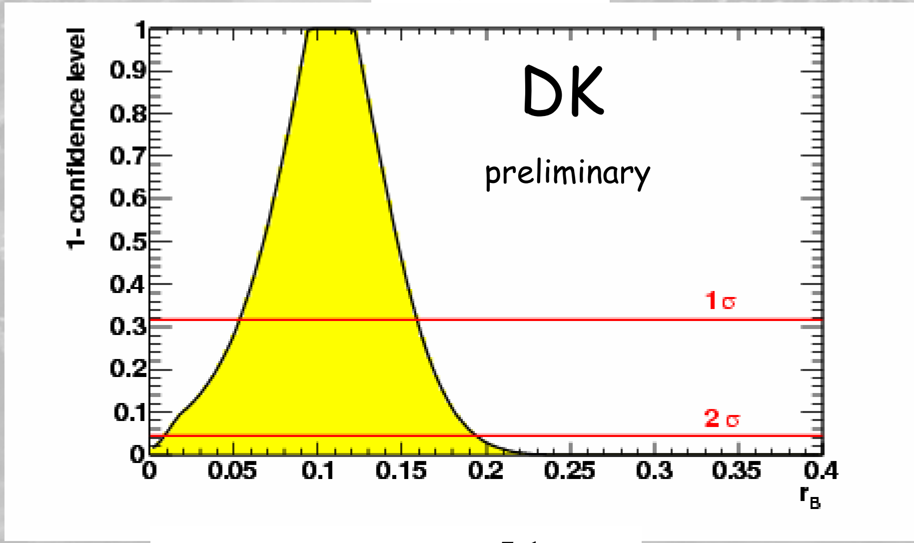
Extraction of $r_{B,DK}$ & r_{B,D^*K}

We use a frequentist ("CKMfitter") approach to determine confidence intervals for the CPV parameters.

r_D and δ are fixed to HFAG values

Very little sensitivity to γ: All values allowed at 1 σ level.

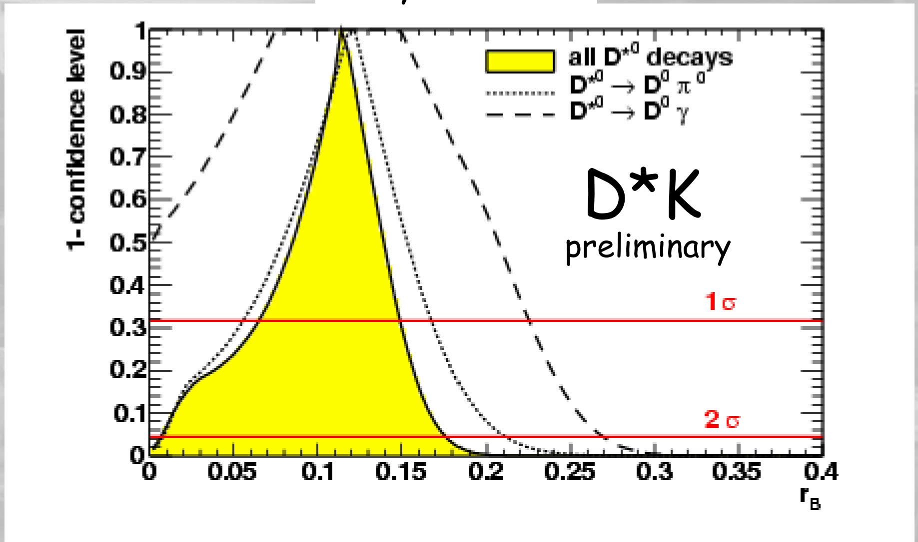
$r_{B,DK}$



$$r_{B,DK} = (10.7^{+5.1}_{-5.4})\%$$

$r_{B,DK} < 18\%$ @ 90% CL

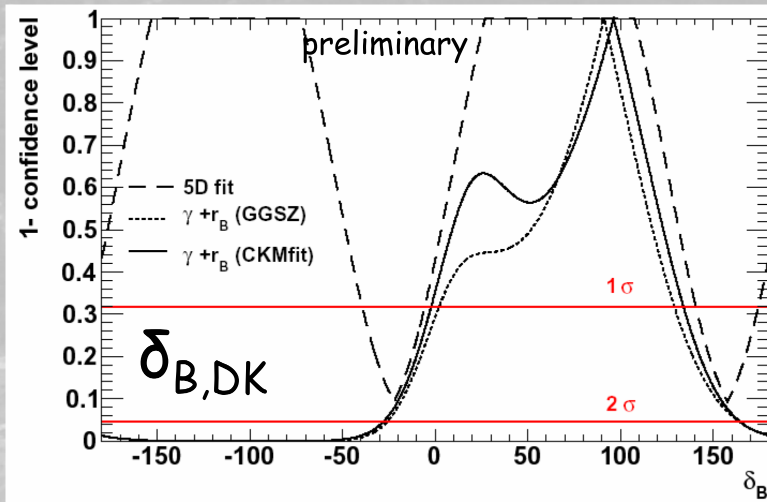
r_{B,D^*K}

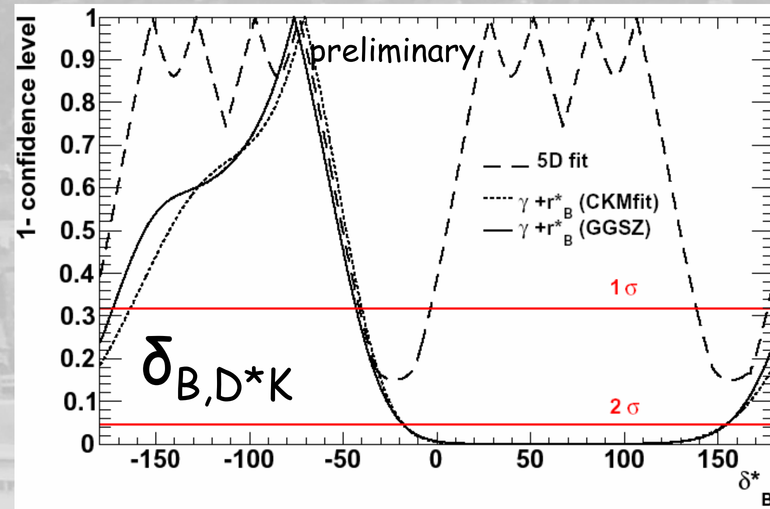


$$r_{B,D^*K} = (11.6^{+3.3}_{-5.1})\%$$ combined

$r_{B,D^*K} < 17\%$ @ 90% CL

Extraction of δ_B

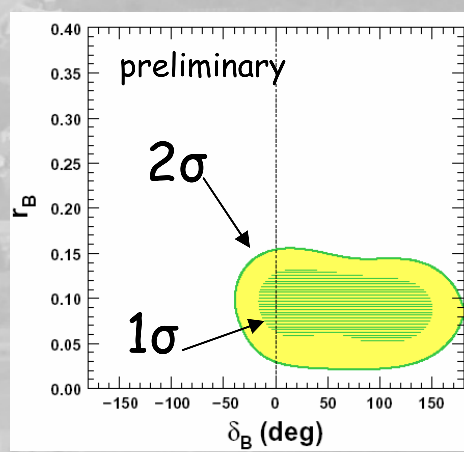


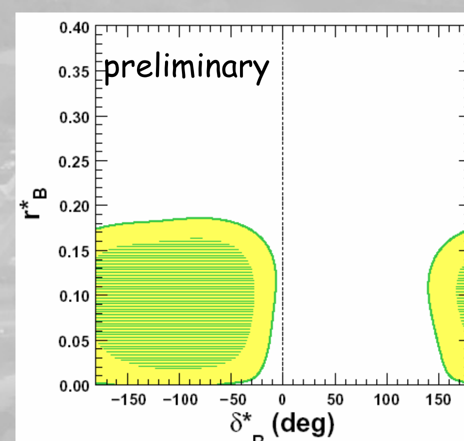


With input from other BaBar analysis (Dalitz*) and/or CKMfitter can resolve ambiguity in δ

*PRD 78 034023 (2008)

Exclude $[-180, -28]^0$ & $[164, 180]^0$ @ 95%CL





Exclude $[-18, 155]^0$ @ 95%CL

2D confidence intervals using $\gamma = 76^0$ from BaBar Dalitz analysis

Summary & Conclusions

- Analysis uses full BaBar data set
  2X data as previous BaBar analysis, PRD 72 032004 (2005)
- Test technique using $D^{(*)}\pi$
- New preliminary measurements of $r_{B,DK}$ & r_{B,D^*K}

$$r_{B,DK} = (10.7^{+5.1}_{-5.4})\%$$
$$r_{B,DK} < 18\% @ 90\% \mathrm{CL}$$

$$r_{B,D^*K} = (11.6^{+3.3}_{-5.1})\%$$
$$r_{B,D^*K} < 17\% @ 90\% \mathrm{CL}$$

Consistent with BaBar's Dalitz analysis (PRD 78 034023 (2008)):
$r_{B,DK}$=(8.6 ± 3.5)% and r_{B,D^*K}=(13.5 ± 5.1)%

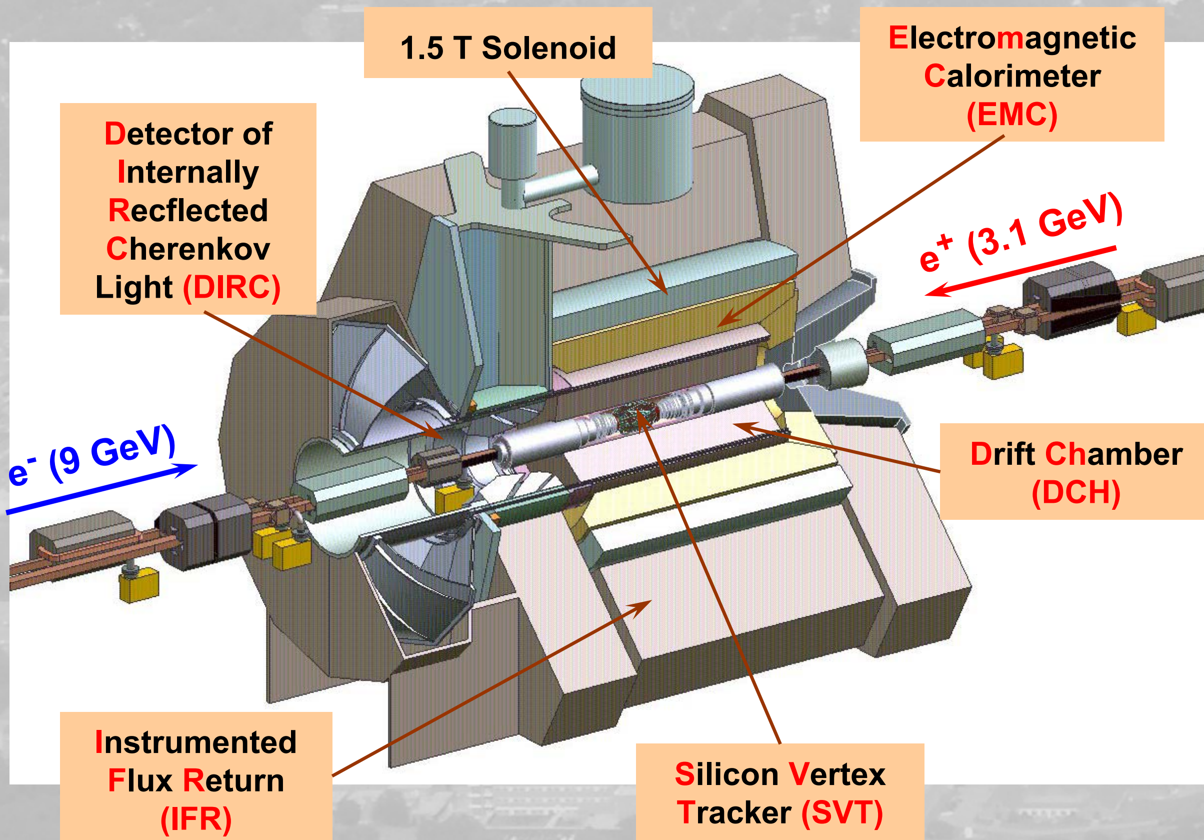
- ADS CP asymmetry for DK & D*K may be very large
  Both DK and D*K have asymmetries ~70% (but with large uncertainties)
- Resolve ambiguity in strong phases, $\delta_{B,DK}$, δ_{B,D^*K}
  good agreement with $\delta_{B,DK}$, δ_{B,D^*K} from BaBar Dalitz analysis

Promising γ analysis for LHCb & Super-B factory

need super-sized data sample to overcome our limited statistics

Extra slides

BaBar Detector



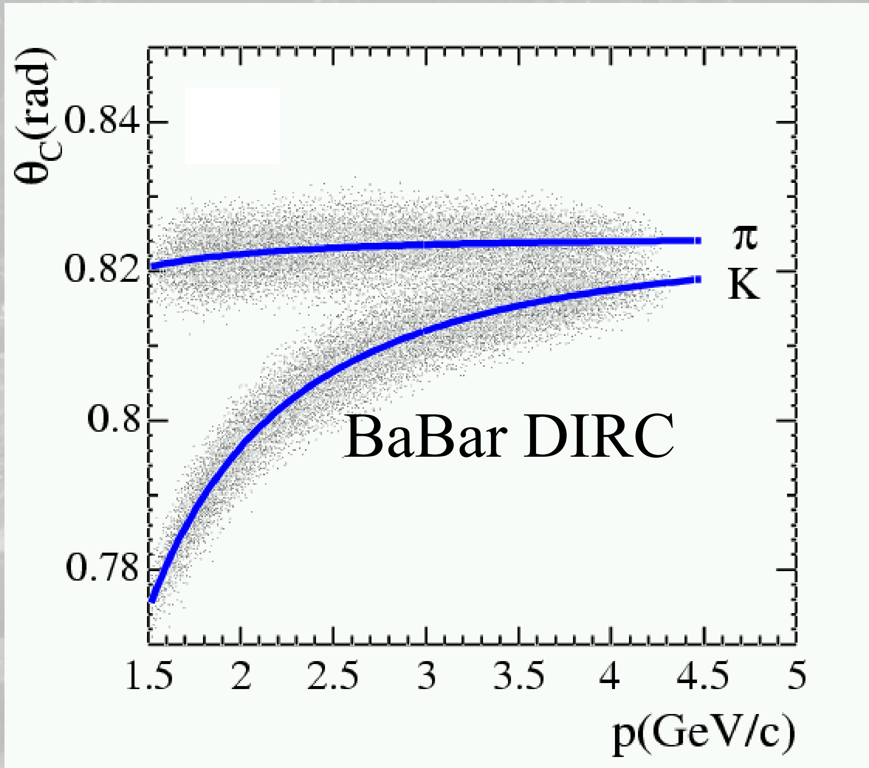
SVT, DCH: charged particle tracking: vertex & mom. resolution, K^0s/Λ

EMC: electromagnetic calorimeter: $\gamma/e/\pi^0/\eta$

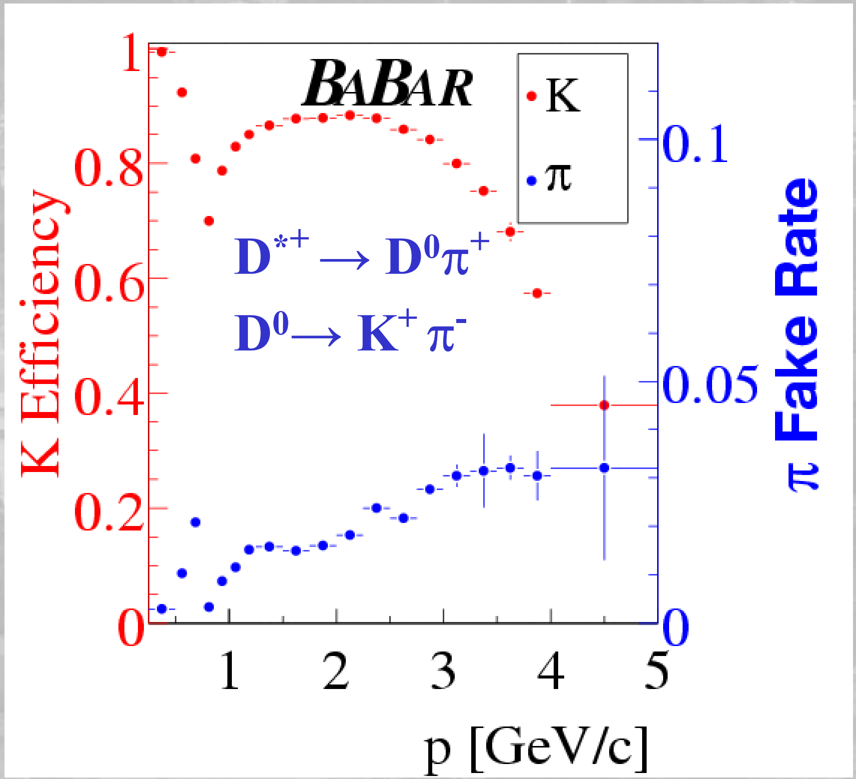
DIRC, IFR, DCH: charged particle ID: $\pi/\mu/K/p$

Highly efficient trigger for B mesons

BaBar K/π ID



θC(rad)
0.84
0.82
0.8
0.78
π
K
BaBar DIRC
1.5
2
2.5
3
3.5
4
4.5
5
p(GeV/c)



BABAR
K
π
$D^{*+} \to D^0\pi^+$
$D^0 \to K^+\pi^-$
K Efficiency
π Fake Rate
1
0.8
0.6
0.4
0.2
0
0.1
0.05
0
1
2
3
4
5
p [GeV/c]

ADS Analysis Details

Summary of $D^{(*)}\pi$ Systematic Errors

error source	$\Delta\mathcal{R}/\mathcal{R}$ $D^0\pi$	$\Delta\mathcal{R}/\mathcal{R}$ $D^{*0}_{D^0\pi^0}\pi$	$\Delta\mathcal{R}/\mathcal{R}$ $D^{*0}_{D^0\gamma}\pi$
signal NN	-3%	-2%	-7%
$B\bar{B}$ background NN	-3%	+3%	+30%
$udsc$ background NN	-3%	-2%	-11%
$B\bar{B}$ comb. bkg shape (m_{ES})	$^{+7}_{-6}$%	$^{+3}_{-5}$%	$^{+7}_{-11}$%
peaking background DCSD	±7%	$^{+23}_{-22}$%	$^{+74}_{-70}$%
peaking background CAB	-	±3%	±4%
float $B\bar{B}$ comb. bkg	-	+2%	-4%
Combined	±11%	≈ ±25%	≈ ±80%

R_{ADS} Significance