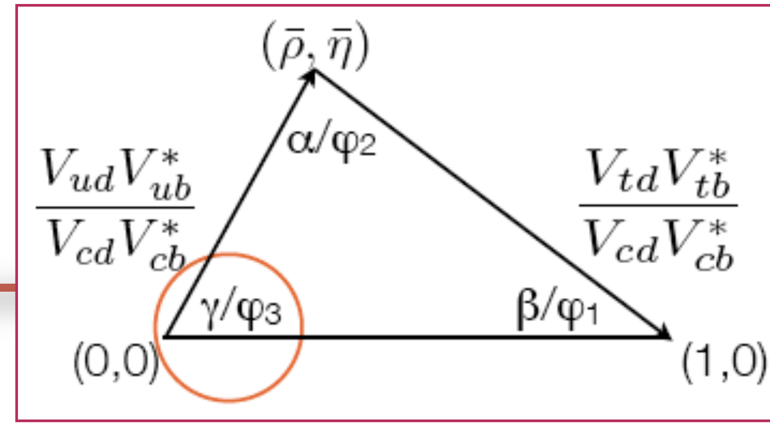
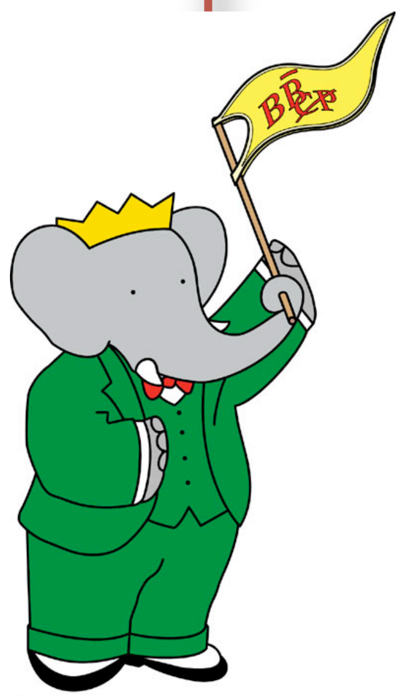


Hadronic b→c decays related to γ at BABAR



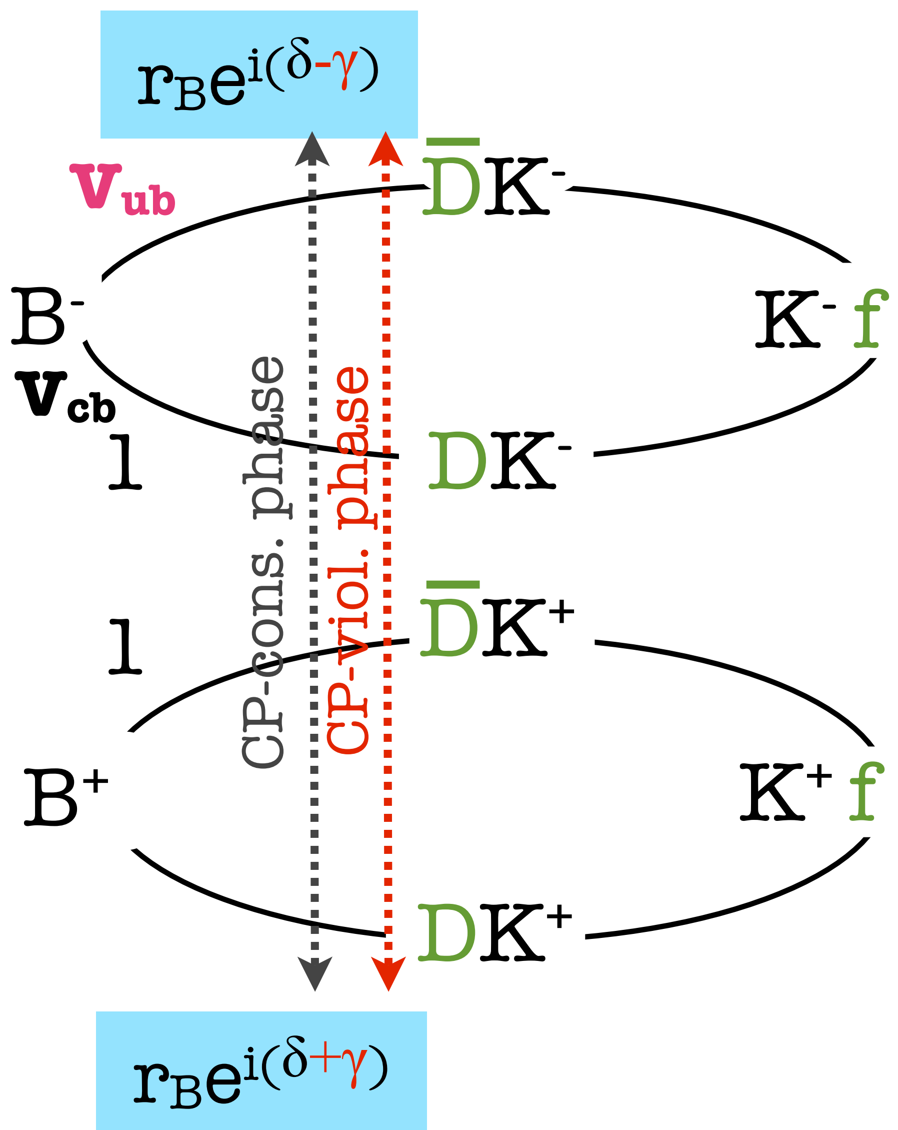
Neus López March
on behalf of the BABAR collaboration

IFIC (Universitat de València -CSIC)

IFIC
INSTITUT DE FÍSICA CORPUSCULAR

EPS09, Krakovia, July 16th 2009

γ from B→DK decays



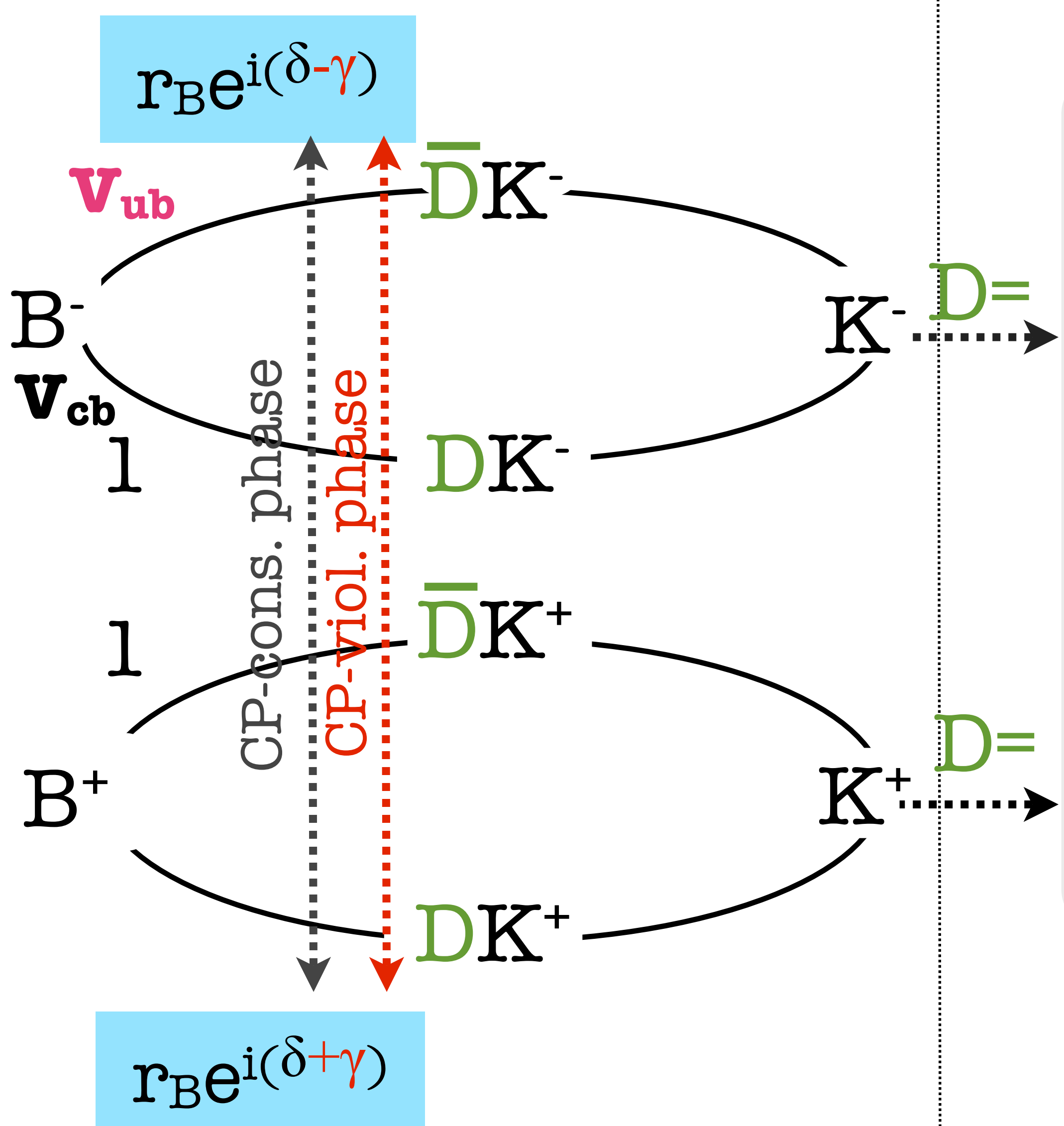
δ: strong phase

$D=D^0$
$D=D^{*0}\to D^0\pi^0$, $D^0\gamma$
K^- or K^*

- Exploit interference between tree diagrams amplitudes b→c (V_{cb},real) and b→u (V_{ub},∝ $e^{-i\gamma}$)
- Interference for B^- is $\propto\cos(\delta-\gamma)$ and for B^+ is $\propto\cos(\delta+\gamma)$
- Largely unaffected by New Physics
- Clear theoretical interpretation of observables in terms of γ
- The sensitivity is driven by the ratio: $r_B=|A_{ub}|/|A_{cb}|$
  - ~ *0.1* in charged $B\to D^{(*)0}K^{(*)}$ decays
  - ~*0.3* in neutral $B^0\to D^{(*)0}K^{*0}$ decays
- The branching ratios for $B\to[f]_D$ K decays are very low (10^{-5}-10^{-7}) due to CKM suppression
- All measurements are statistitics limited.

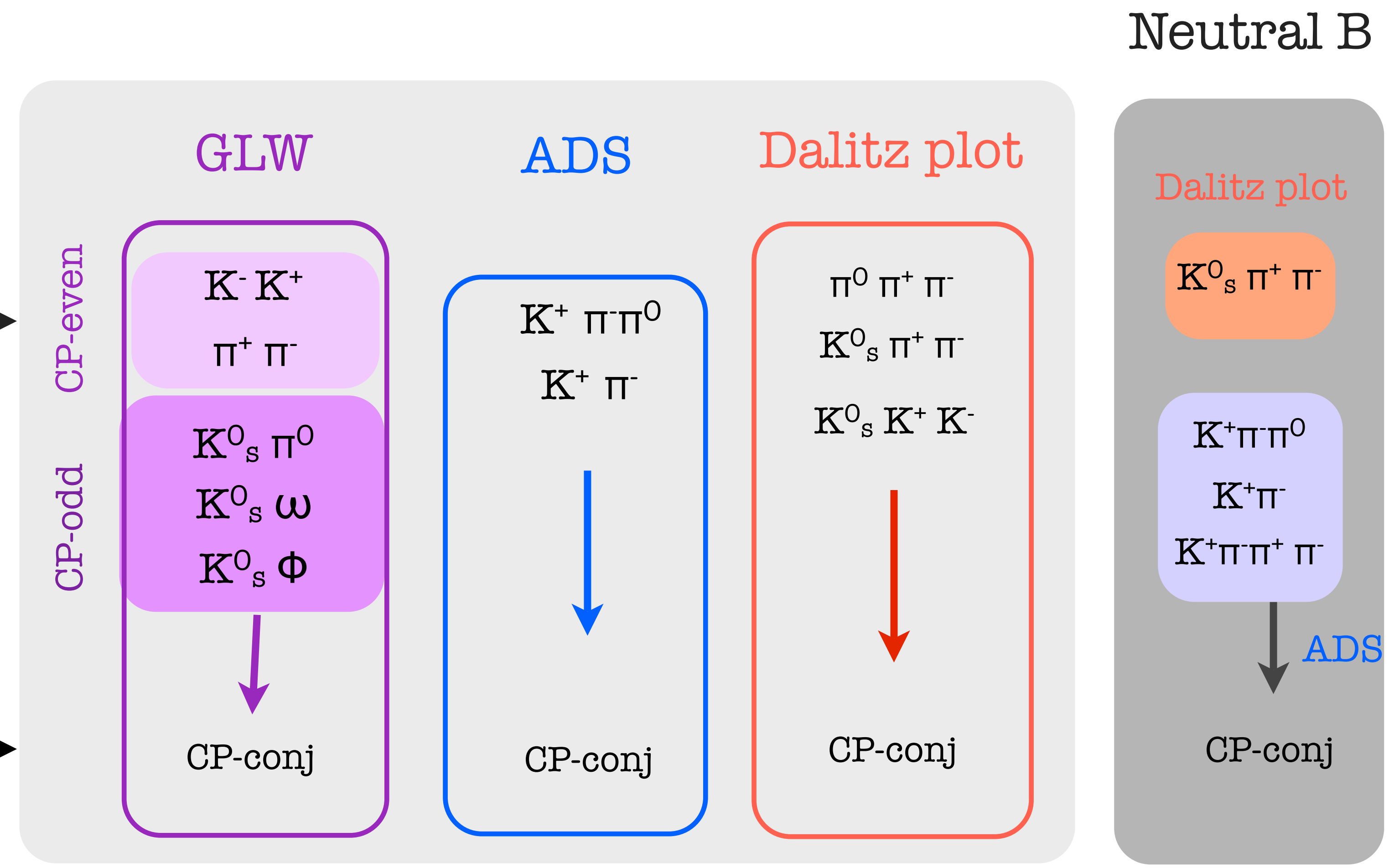
γ from B→DK decays

Charged B



δ: strong phase

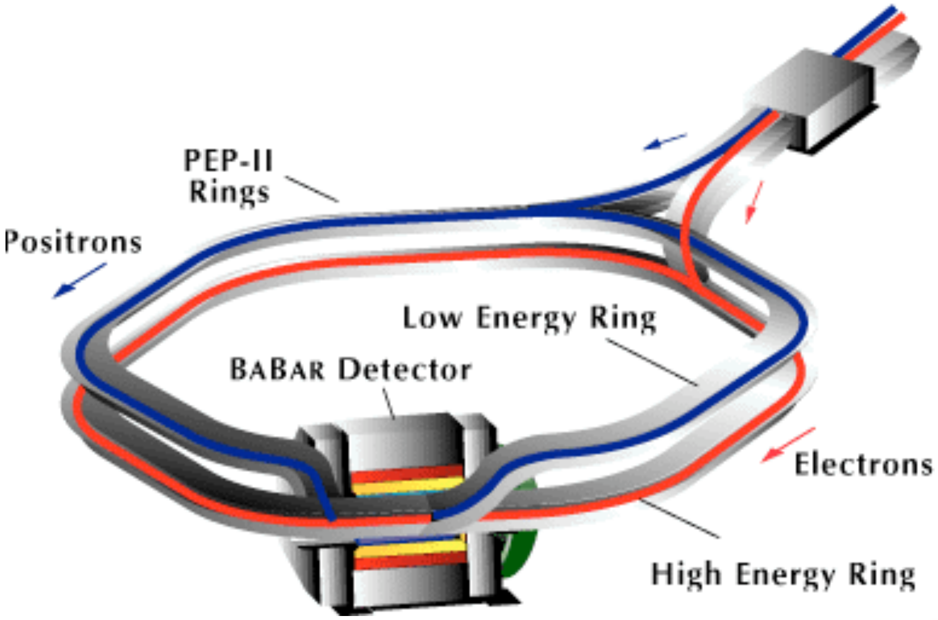
$D=D^0$
$D=D^{*0}\to D^0\pi^0$, $D^0\gamma$
K^- or K^*

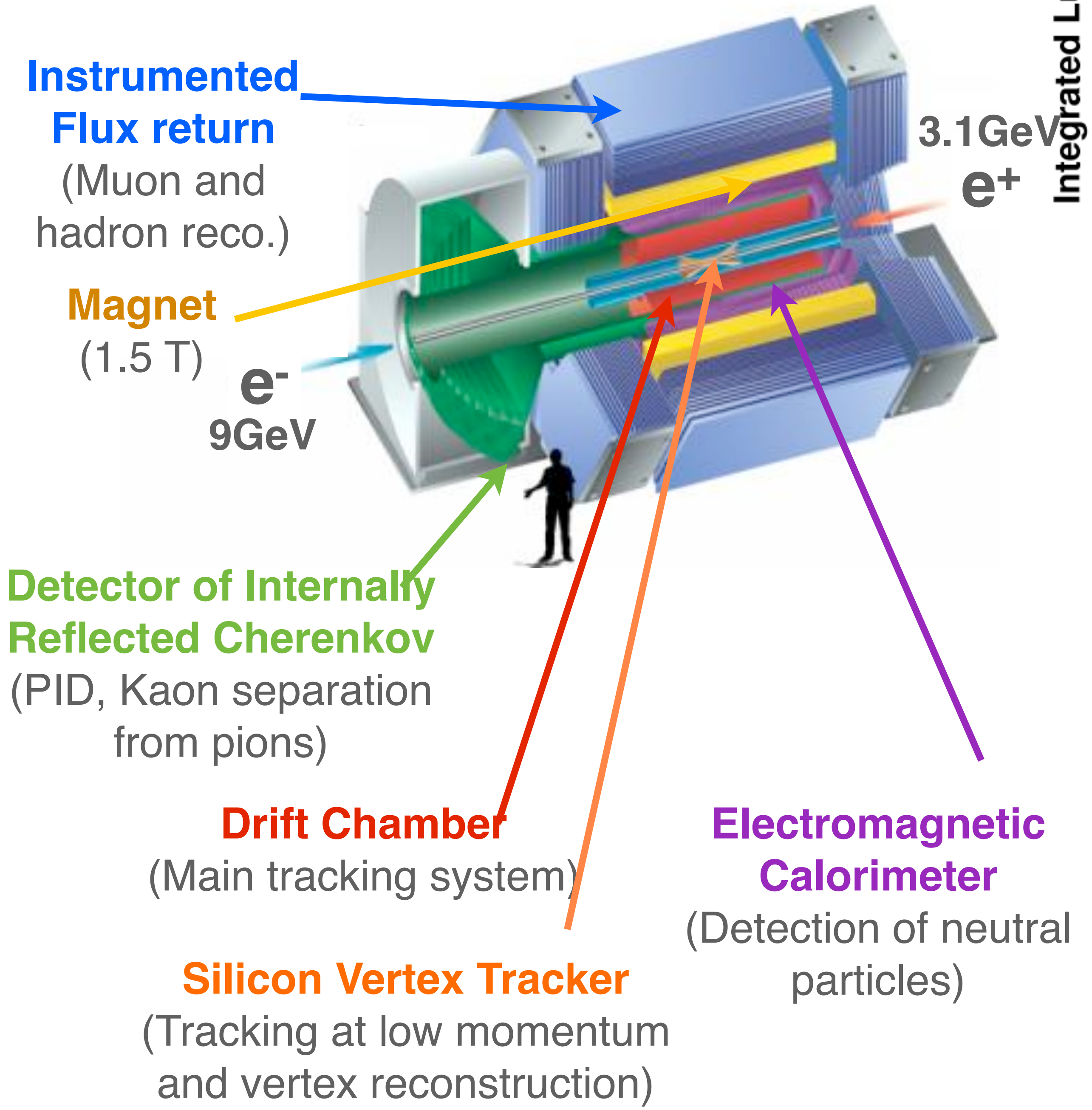


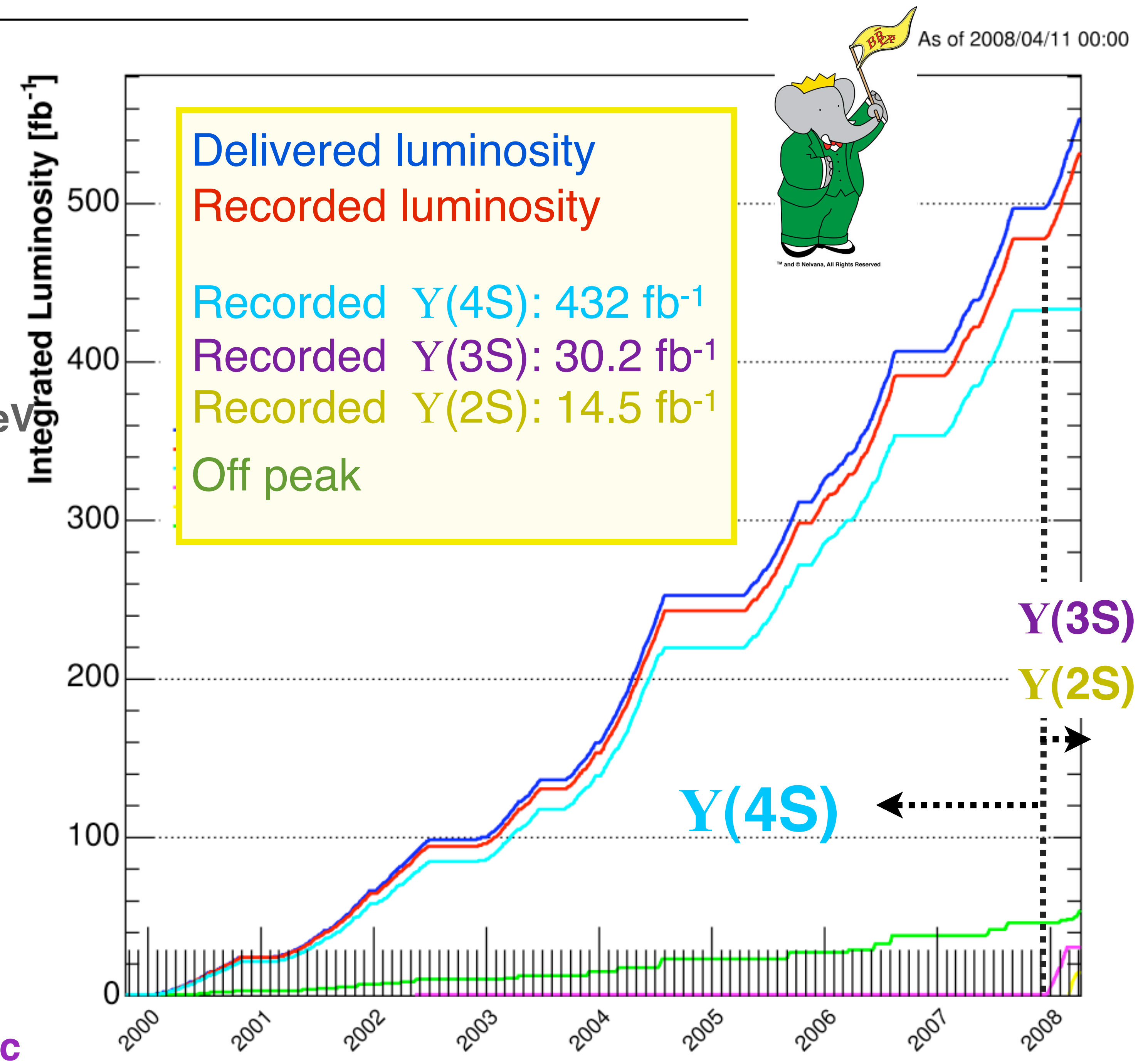
- Many decay chains are analyzed and then combined to improve the overall sensitivity to γ

- *In this talk* we present the most recent results and a **new result** using the ADS method with the decays $B^-\to D^{(*)0}K^-$, $D^0\to K^+\pi^-$

BaBar detector







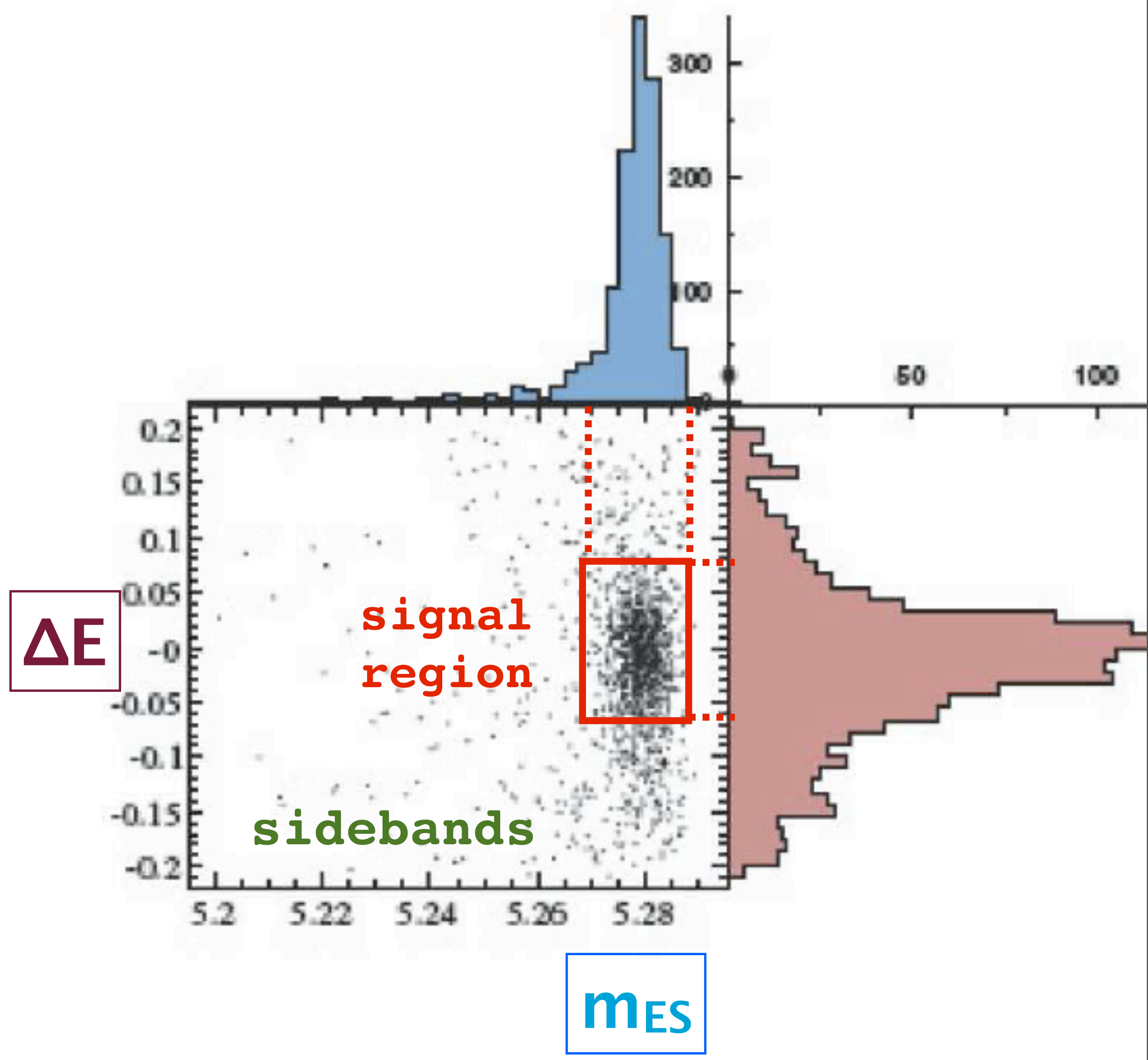
- BaBar data taking ended on 7th April 2008
- BaBar recorded ***470M $B\bar{B}$*** at $\Upsilon(4S)$

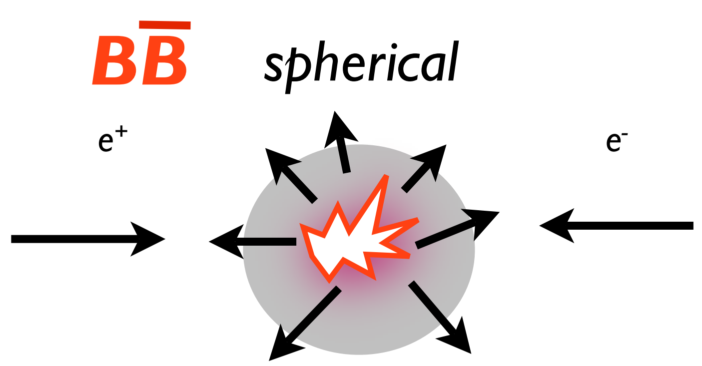
Experimental technique

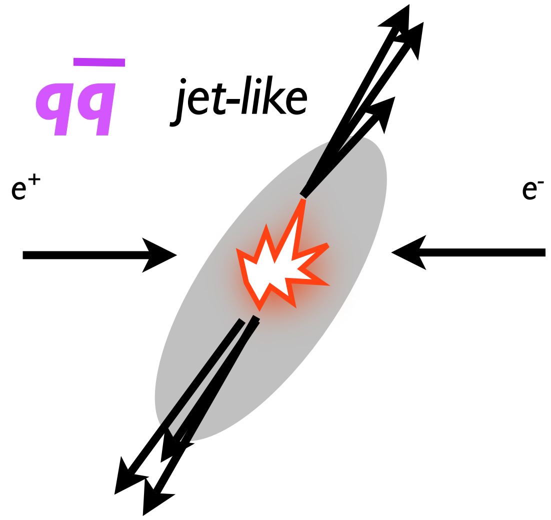
- Exclusive reconstruction of B decays
- Exploit kinematic constraints from beam energies.

$m_{ES} = \sqrt{E^{*2}_{beam} - |p_B^*|^2}$ $\Delta E = E_B^* - E^*_{beam}$

- The main source of background : $e^+e^- \rightarrow q\bar{q}$, with q=u,d,s,c
- Event shape variables combined into a linear *(Fisher)* or non linear *(Neural Network)* combination







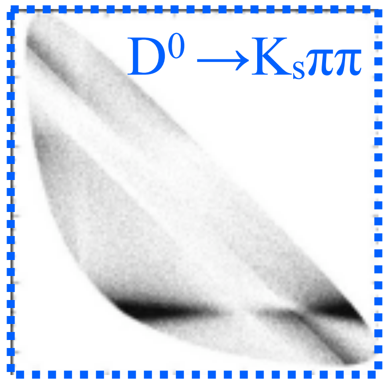
Giri, Grossman, Soffer, Zupan PRD68,054018 (2003)

Dalitz plot or "GGSZ" method

- Reconstruct $D^{(*)0} K^{(*)-}$ final states with $D \to K_s\pi\pi$, K_sKK (many intermediate states)
- Simultaneous fit to the Dalitz plot density of B^+/B^- data
- Input: D^0 amplitude from an independent sample tagging the D^0 flavour yields ($D^{*+} \to D^0\pi^+$)

A_{D-}

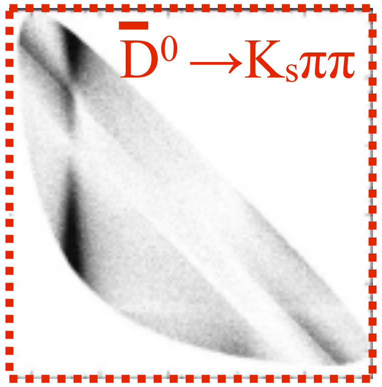
$A(B^-) = |A(D^0K^-)| \times$



$+ |A(D^0K^-)| r_B\, e^{i(\delta_B - \gamma)} \times$

Sensitivity varies over Dalitz plane

A_{D+}

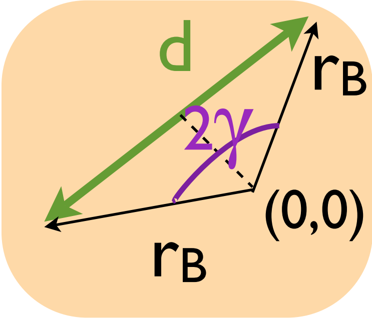


Results: 383M $B\bar{B}$

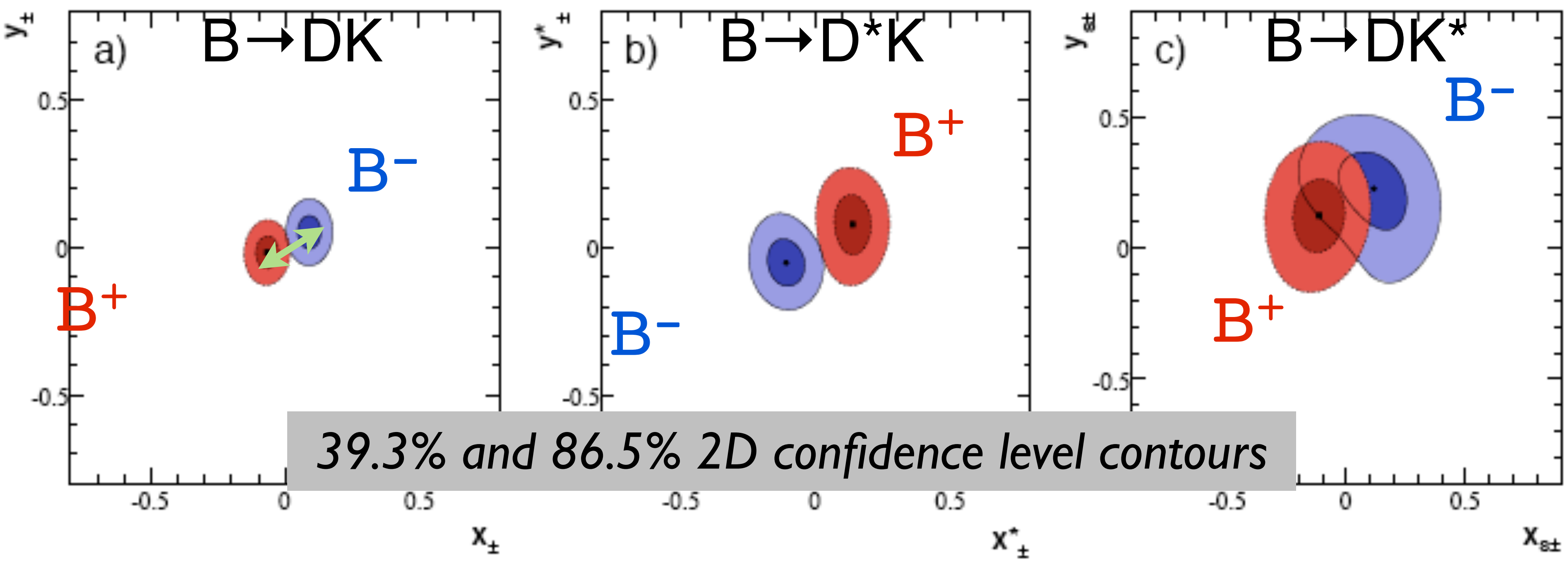
PRD 78:034023(2008)

$$R^{\mp} = \frac{\mathcal{A}(B^{\mp} \to \bar{D}K^{\mp})}{\mathcal{A}(B^{\mp} \to DK^{\mp})} \qquad R = |r_B|$$

$$x_{\mp} = \mathcal{Re}\{R^{\mp}\} = r_B\cos(\delta_B \mp \gamma)$$
$$y_{\mp} = \mathcal{Im}\{R^{\mp}\} = r_B\sin(\delta_B \mp \gamma)$$



$d = 2r_B|\sin\gamma| \neq 0 \Rightarrow$ direct CPV



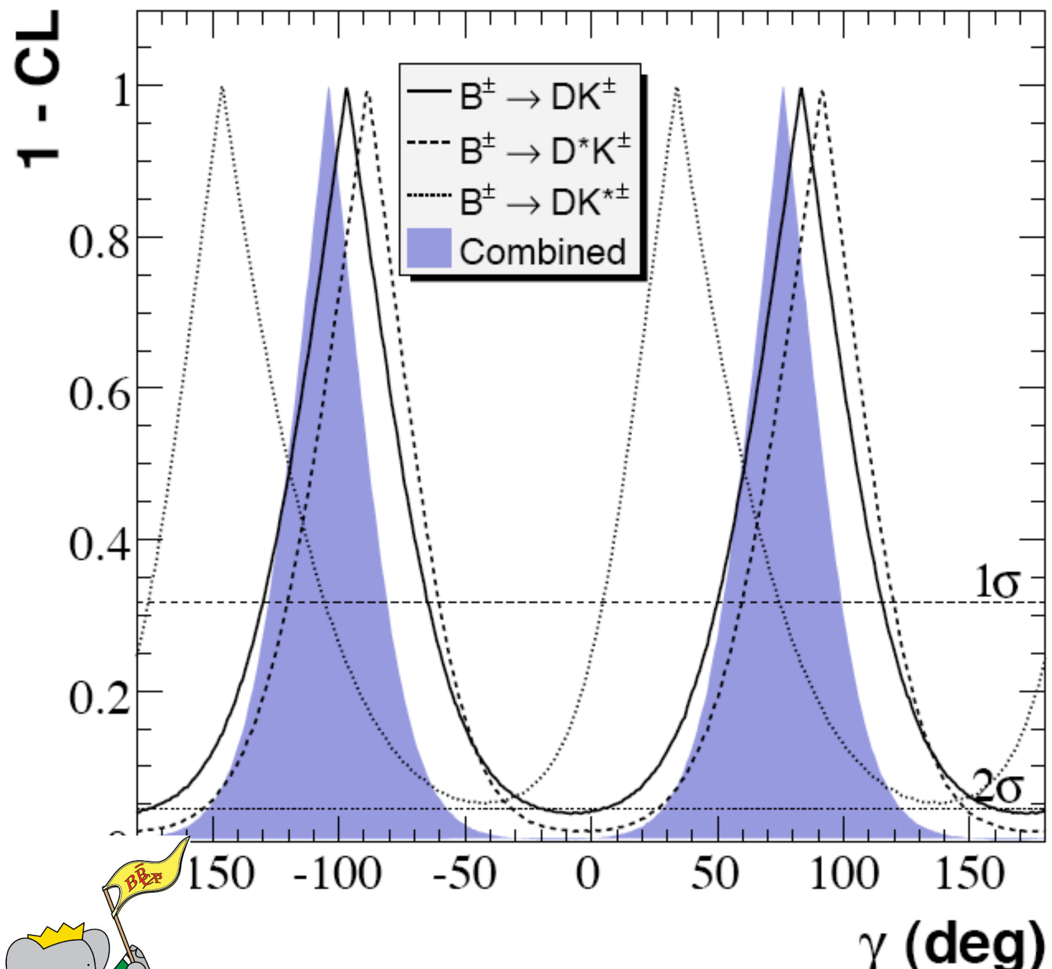
39.3% and 86.5% 2D confidence level contours

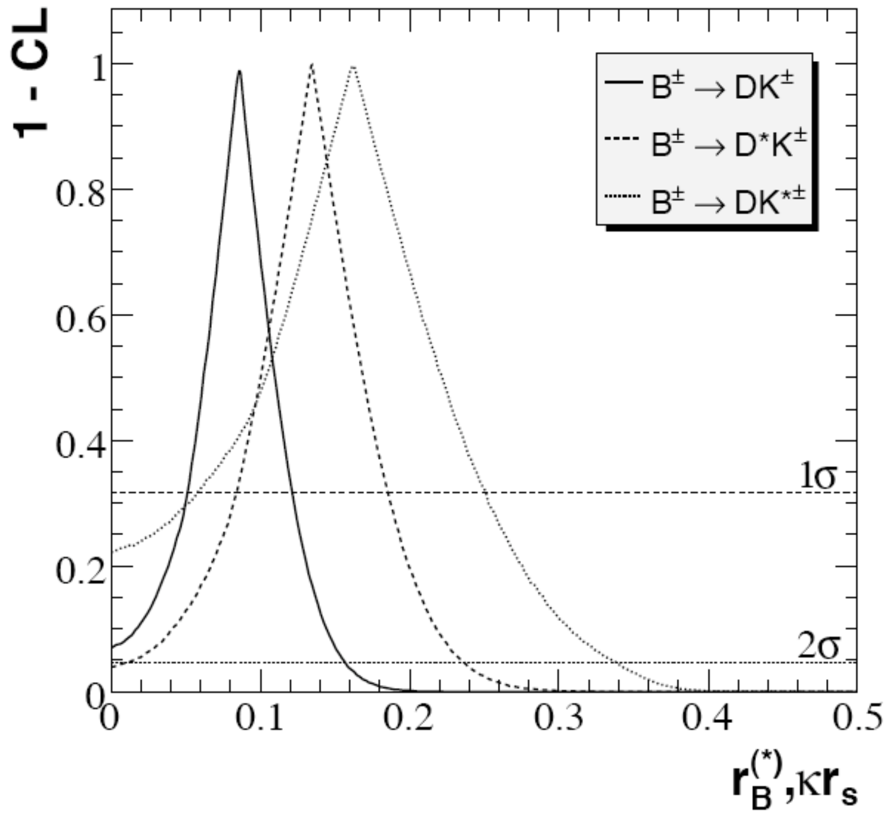
383M $B\bar{B}$

PRD 78:034023(2008)

γ, r_B and δ from x,y

- Used a frequentist method to obtain the physical parameters γ, r_B, δ_B from $(x_\pm, y_\pm)$





Direct CPV significance:
$B \to DK$: 2.2σ
$B \to D^*K$: 2.5σ
$B \to DK^*$: 1.5σ

combined: 3.0σ

γ (mod 180°) = $(76 \pm 22 \pm 5 \pm 5)^\circ$

$r_B = 0.086 \pm 0.035$
$r^*_B = 0.135 \pm 0.051$
$r_S = 0.163\,^{+0.008}_{-0.105}$

δ_B (mod 180°) = $(109^{+28}_{-31})^\circ$
δ^*_B (mod 180°) = $(-63^{+28}_{-30})^\circ$
δ_S (mod 180°) = $(104^{+28}_{-30})^\circ$

BELLE (657M $B\bar{B}$): γ (mod 180°) = $(76\,^{+12}_{-13} \pm 4 \pm 9)^\circ$ $r_B = (0.161\,^{+0.04}_{-0.038} \pm 0.011 \pm 0.049)$

Belle errors on x,y are comparable to BaBar. But r_B is bigger ⇒ different sensitivity to γ

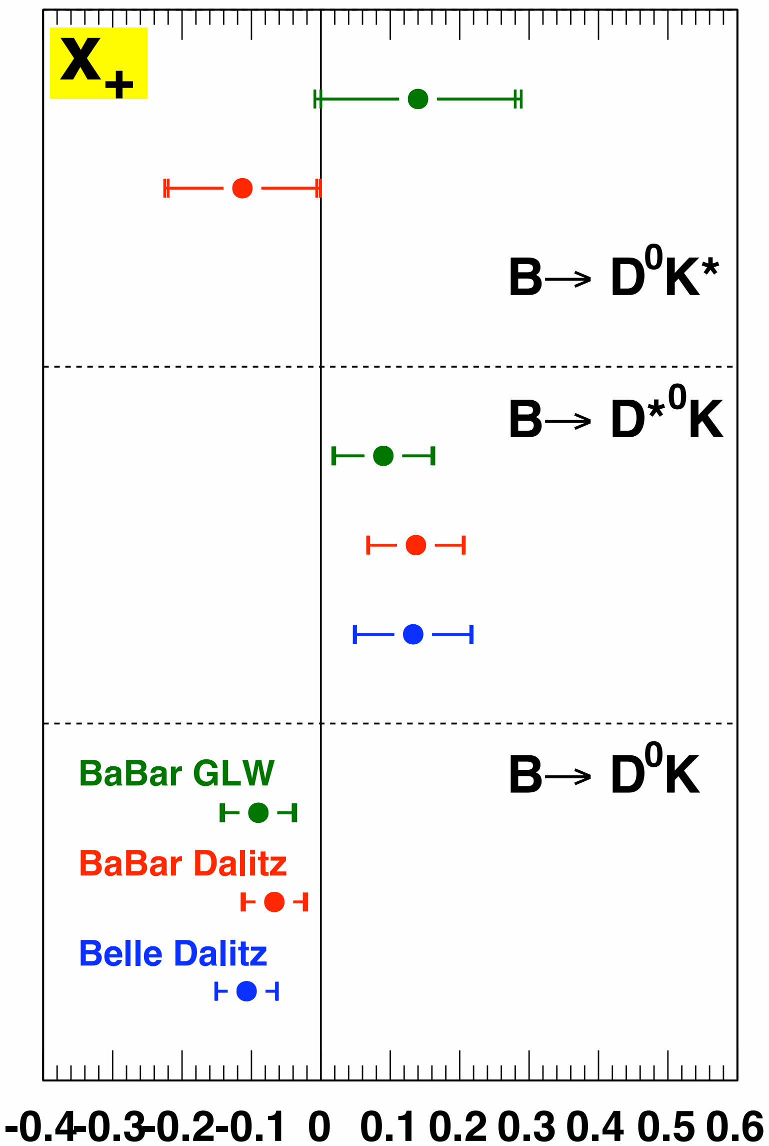
Dalitz plot-GLW X,Y

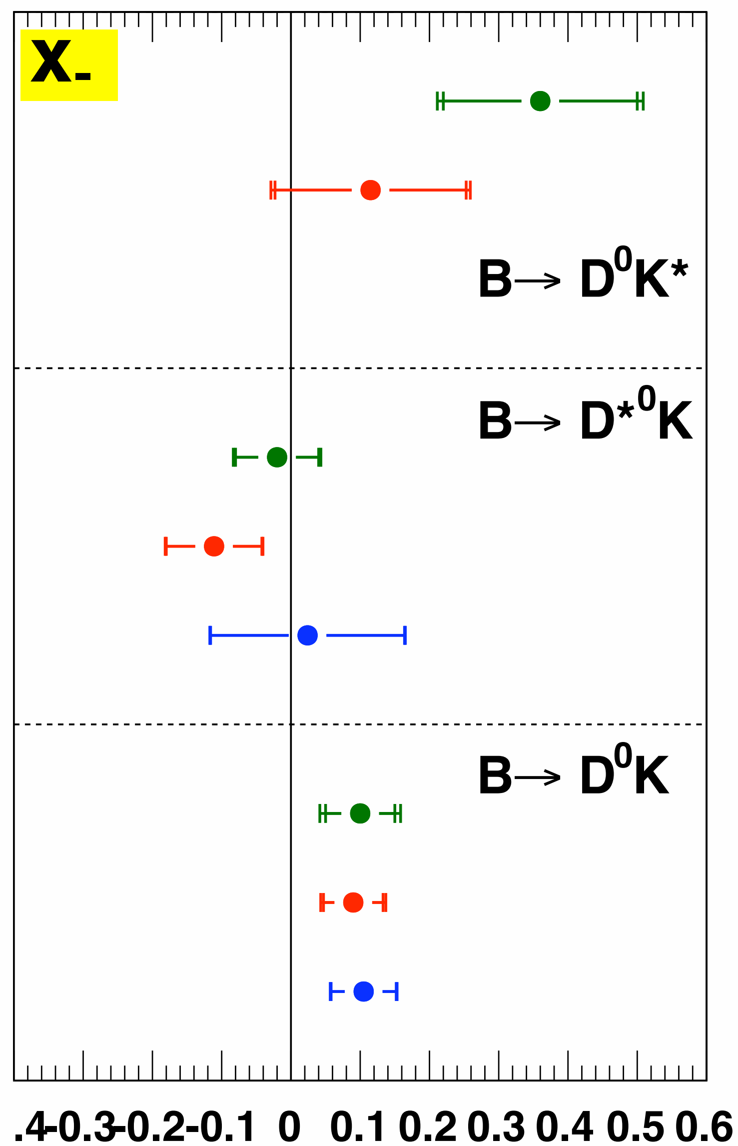
DK: PRD 77, 111102(2008)
D*K: PRD 78, 092002(2008)
DK*: preliminary CKM08

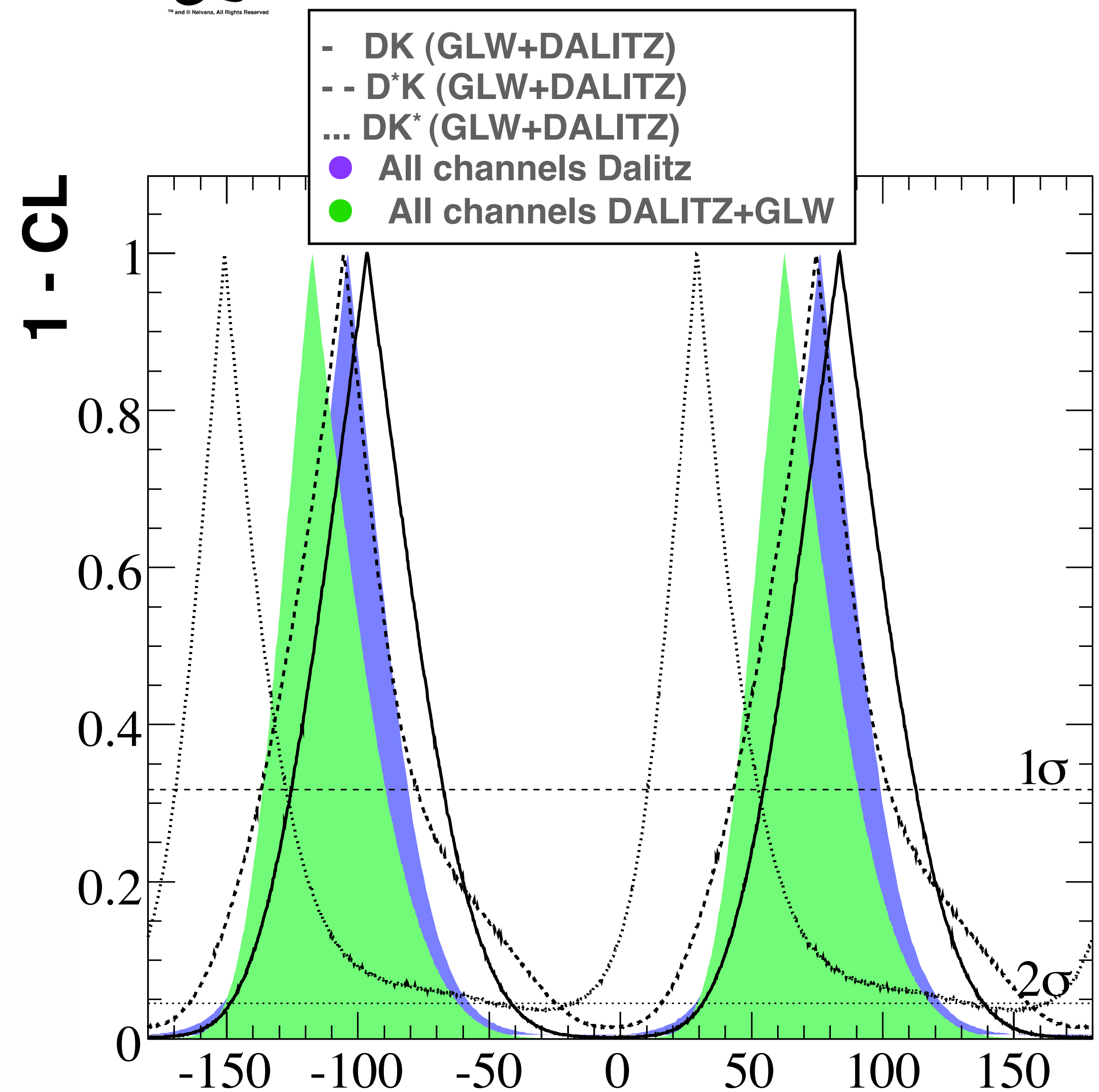
- **Dalitz plot - GLW relation:**

$$x_{\pm} = \frac{R_{CP+}\,(1 \mp A_{CP+}) - R_{CP-}(1 \mp A_{CP-})}{4}$$

$$r_B^2 = x_{\pm}^2 + y_{\pm}^2 = \frac{R_{CP+} + R_{CP-} - 2}{2}$$







γ (deg)

Dalitz + GLW combination:

$\gamma = 61.5^{+29.0}_{-19.2}$

$r_B(D^0K) = 0.092^{+0.028}_{-0.028}$

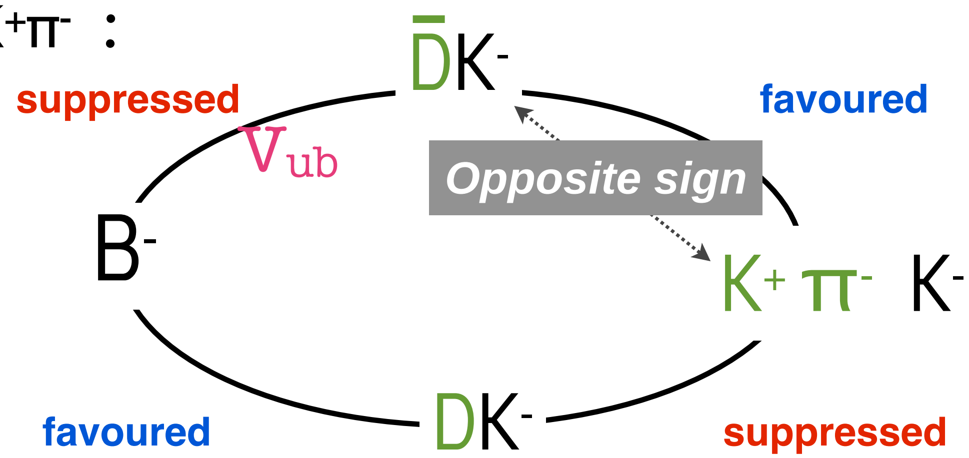
$r^*_B(D^{*0}K) = 0.108^{+0.054}_{-0.041}$

$r_S(D^0K^*) = 0.179^{+0.087}_{-0.098}$

Atwood, Dunietz, Soni PRL 78,3257(1997)

ADS method

- Reconstruct D^0 into $K^+\pi^-$:



$\longrightarrow$ Large interference ~ O(1)

Ratio of BFs:

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

CP violating charge asymmetry:

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

Inputs:

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

$$\delta_D = \arg\left[\frac{A(\bar{D}^0 \to K^+\pi^-)}{A(D^0 \to K^+\pi^-)}\right]$$ (CLEO-C)

- 2 eq. and 3 unknowns + r_D and δ_D
  - no γ determination by itself
  - improved sensitivity to γ when combined with other methods

ADS analysis strategy

NEW!!

467M $B\bar{B}$

Preliminary

- Previous analysis: *PRD 72,032004(2005)* (232M $B\bar{B}$ pairs)
- Decays:

$B^- \to D^{(*)0} K^-$ with $D^0 \to K^+\pi^-$ suppressed (ADS)

$B^- \to D^{(*)0} K^-$ with $D^0 \to K^-\pi^+$ favoured (CAB)

$D^{*0} \to D^0\pi^0$ and $D^{*0} \to D^0\gamma$

DCS $D^{(*)0}\pi$ both suppressed and favoured NEW

- Characterize B candidates using m_{ES} and ΔE ($|\Delta E| < 40$ MeV)

Main background:

$e^+e^- \to c\bar{c}$, with $\bar{c} \to \bar{D}^0X$, $\bar{D}^0 \to K^+\pi^-$ and $c \to DX_1, D \to K^-X_2$

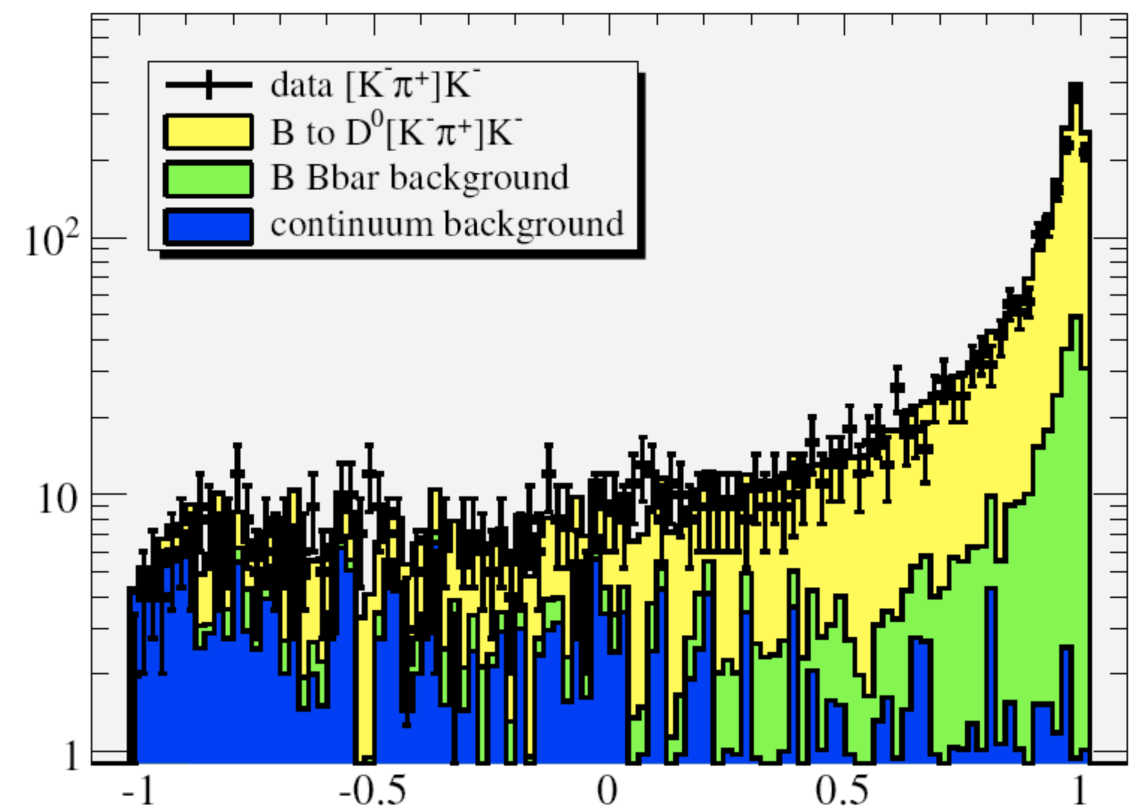
- reduced by using **NN techniques**

Peaking $B\bar{B}$ background:

For DK: $B \to K^+K^-\pi^-$, $B \to [K^+K^-]_D\pi^-$

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

D^0K CAB $5.2725 < m_{ES} < 5.2875$



NN inputs

- Event shape variables
- Tagging variables:
  - hemisphere charge
  - kaon charge sum in the ROE
  - lepton kaon mass
  - time difference between the reconstructed B and the other B

R_{ADS} and A_{ADS} are obtained by performing an unbinned maximum likelihood fit to **m_{ES} and NN**, separately for $D^{(*)}K$ and $D^{(*)}\pi$ NEW

ADS: Dπ results

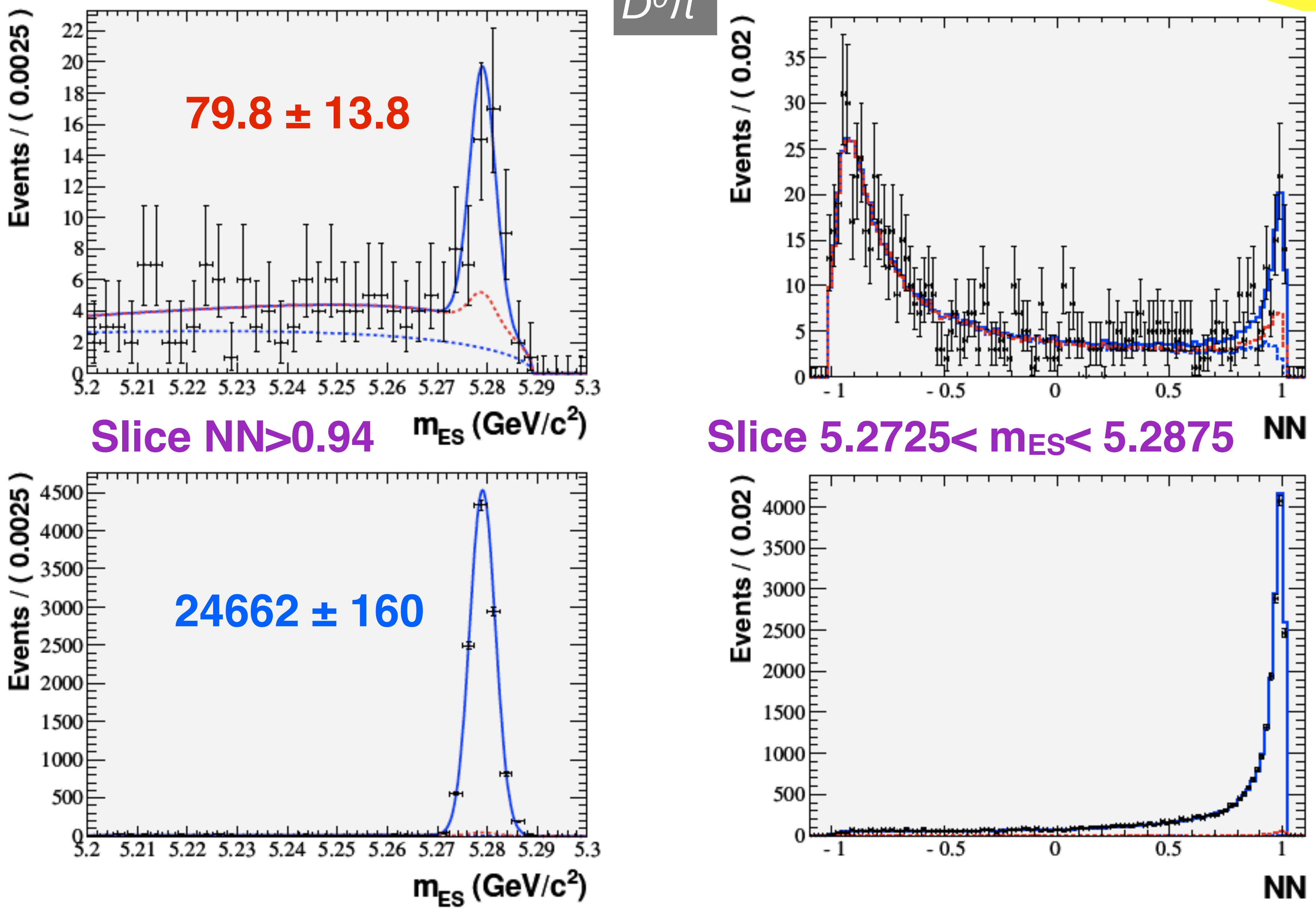
NEW!!

Preliminary

$D^0\pi$

ADS

CAB



R_{ADS} (Dπ) = $(3.30 \pm 0.57 \pm 0.35)10^{-3}$

R_{ADS}([Dπ^0]π)=$(3.17 \pm 0.86 \pm 0.86)10^{-3}$

R_{ADS} ([Dγ]π) = $(2.7 \pm 1.4_{stat} \pm 2.2_{syst})10^{-3}$

World average: $r_D^2 = (3.36 \pm 0.08)10^{-3}$

A_{ADS} (Dπ) = $+0.03 \pm 0.17_{stat}$

ADS Ratio of BF's: DK results

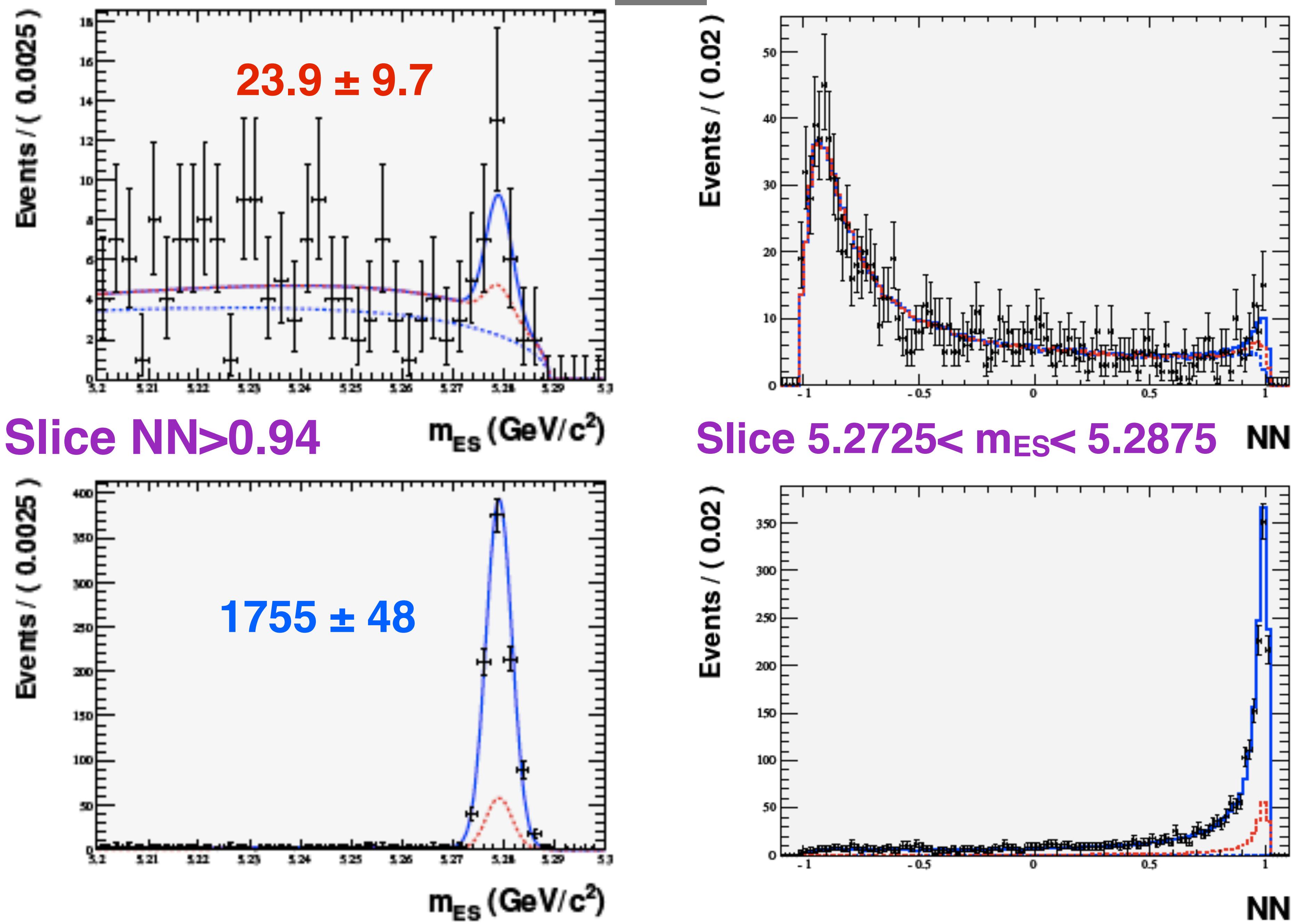
NEW!!

Preliminary

D^0K

ADS

CAB



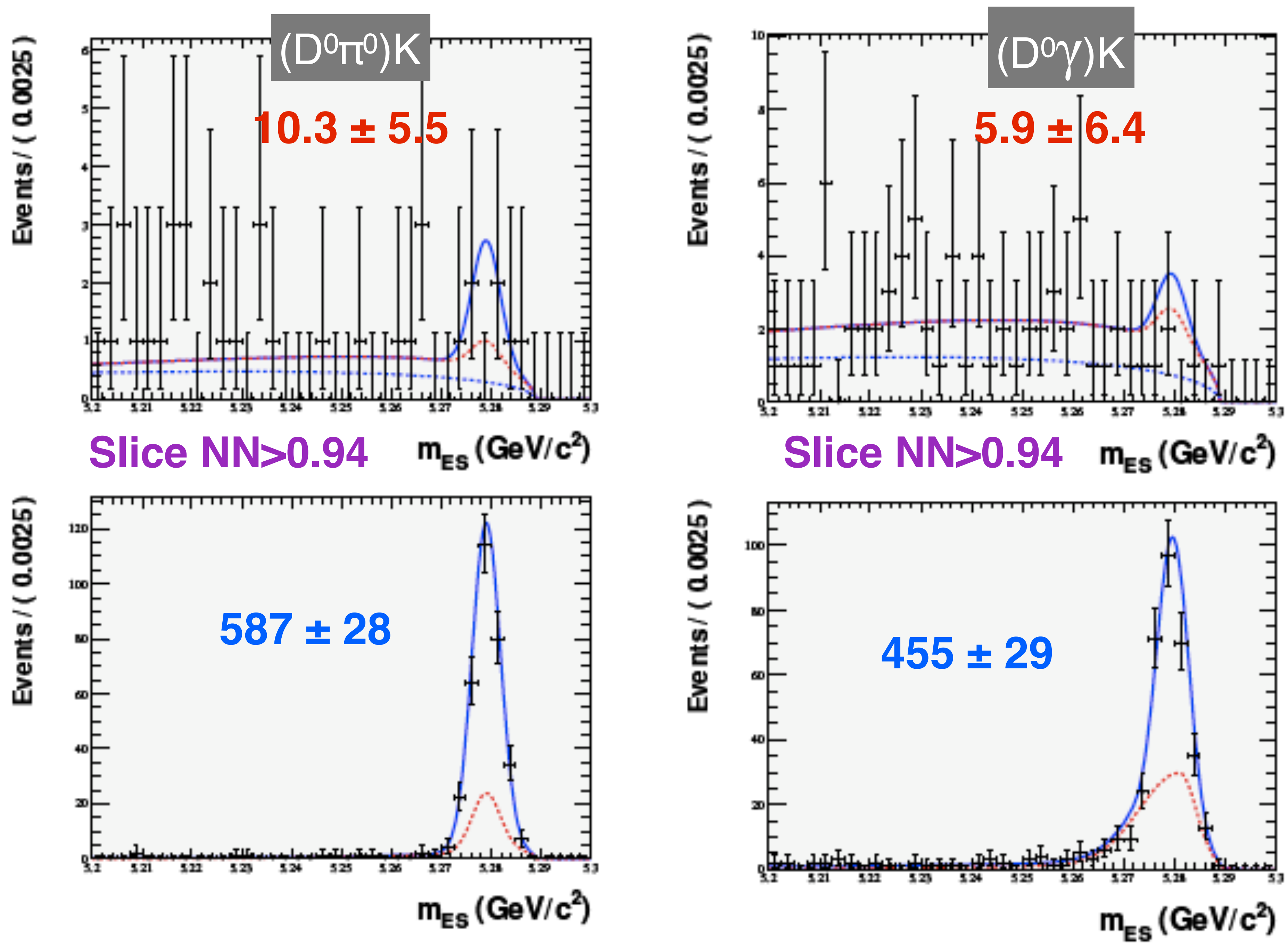
$$R_{ADS}(DK) = 0.0136 \pm 0.0055_{stat} \pm 0.0027_{syst}$$

ADS Ratio of BF's: D*K results

NEW!!
Preliminary

ADS

CAB



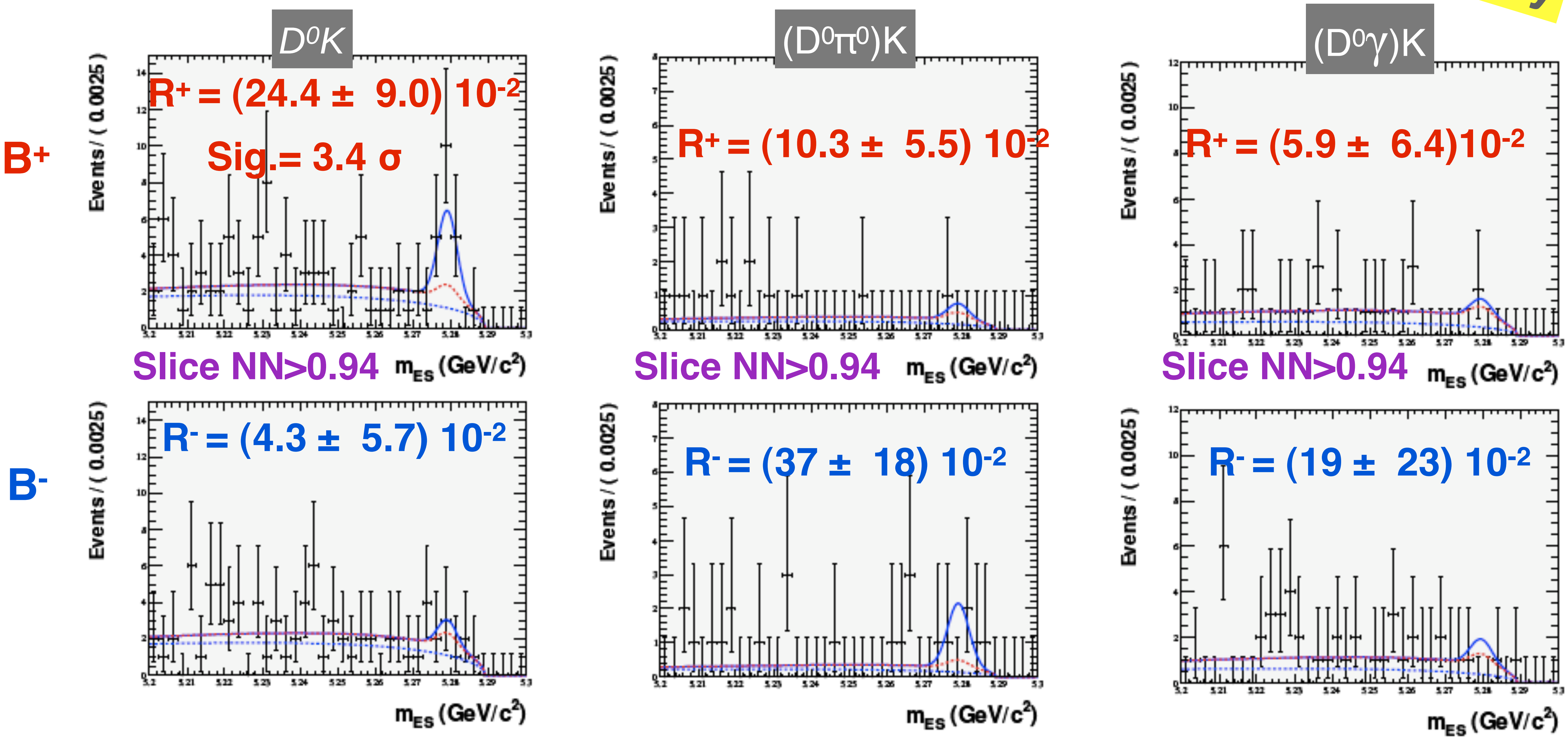
No evidence of $(D^0\gamma)K$ events

$R_{ADS}([D\pi^0]K) = 0.0176 \pm 0.0093 \pm 0.0042$

$R_{ADS}([D\gamma]K) = 0.013 \pm 0.014_{stat} \pm 0.007_{syst}$

ADS Charge asymetry: $D^{(*)}K$ results

NEW!! Preliminary



$A_{ADS}(DK) = -0.70 \pm 0.35\ ^{+0.09}_{-0.14}$

$A_{ADS}([D\pi^0]K) = 0.77 \pm 0.35 \pm 0.12$

$A_{ADS}([D\gamma]K) = 0.36 \pm 0.94\ ^{+0.25}_{-0.41}$

stat syst

r_B from ADS results

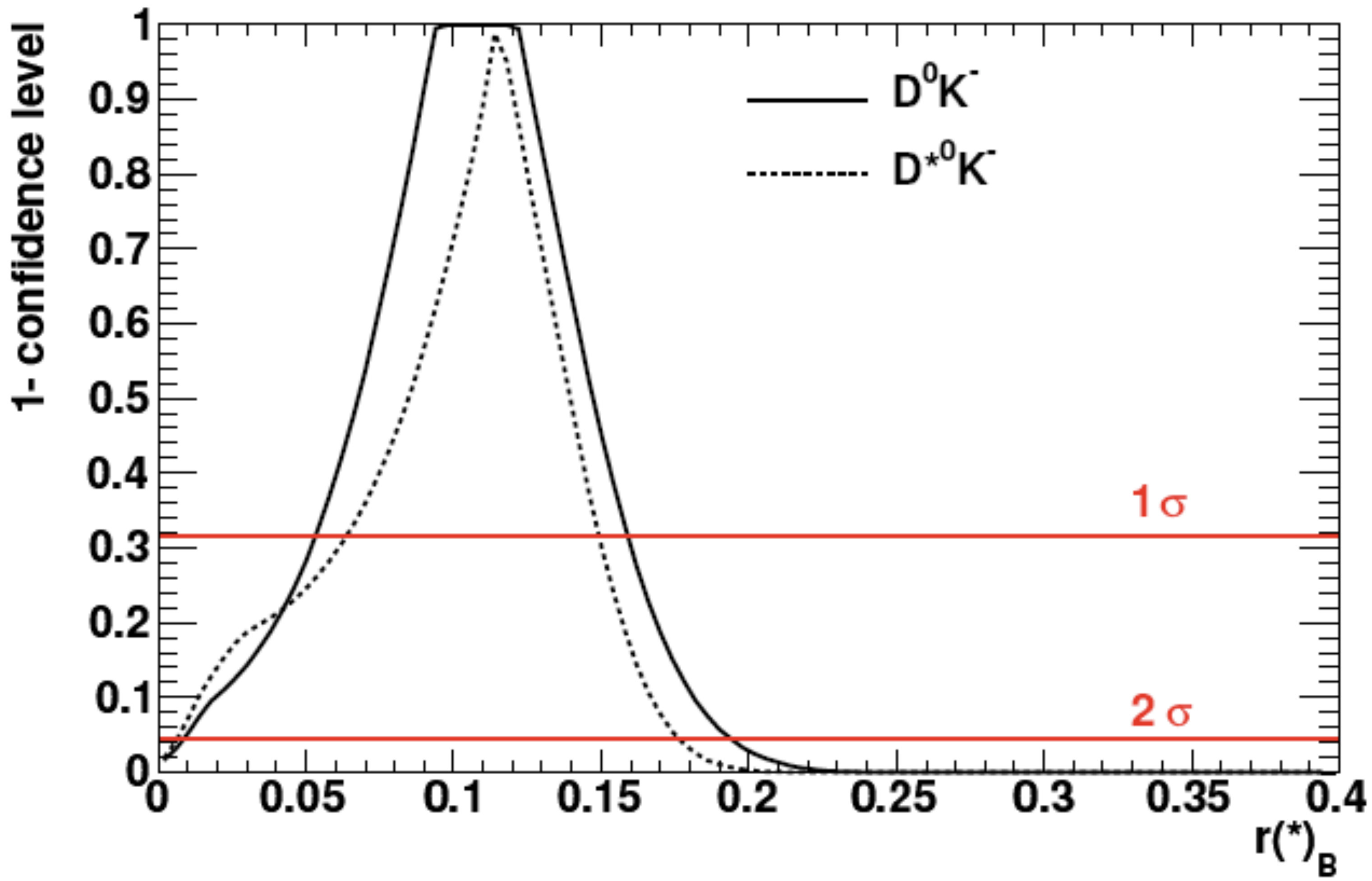
NEW!!

Preliminary

- Using a frequentist approach from the ADS observables $R_{K\pi}$, $A_{K\pi}$ we can obtain constraints on the physical parameters r_B and δ_B

inputs

$r_D = (5.78 \pm 0.08)\%$ (HFAG) $\delta_D = (22.7^{+11.4}_{-12.3})^o$ (CLEO-C)



$r_B(D^0K) = 0.109^{+0.049}_{-0.056}$

$r_B(D^{*0}K) = 0.116^{+0.033}_{-0.051}$

$r_B < 0.18$ at 90% C.L
467M $B\bar{B}$

$r_B < 0.19$ at 90% C.L
657M $B\bar{B}$

Dalitz plot + GLW combination:

$r_B(D^0K) = 0.092^{+0.027}_{-0.028}$

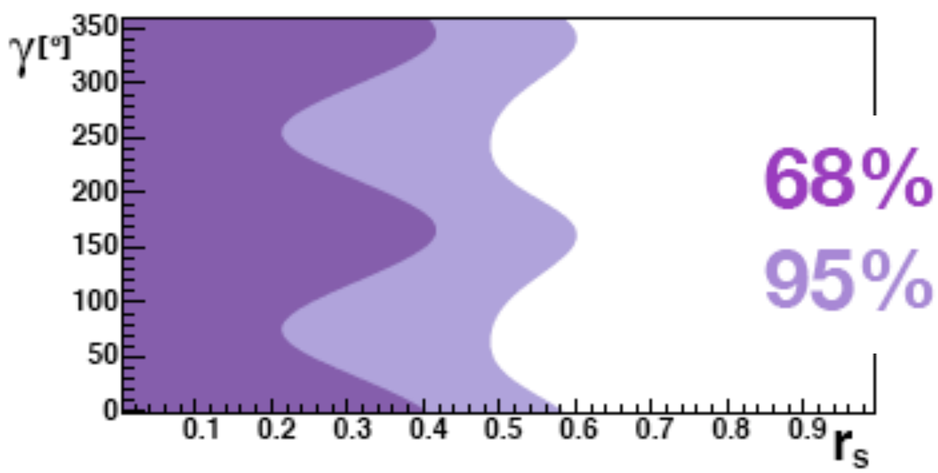
$r_B(D^{*0}K) = 0.108^{+0.052}_{-0.041}$

Neutral B (Dalitz and "ADS")

- Tag B flavour using $K^* \to K^+\pi^-$
- $r_B \sim 0.4$

Dalitz

- $B^0 \to D^0 K^{*0}$, $D^0 \to K_s\pi\pi$ (D^0 model as B^-)
- N_{sig} = 39 ± 9 events



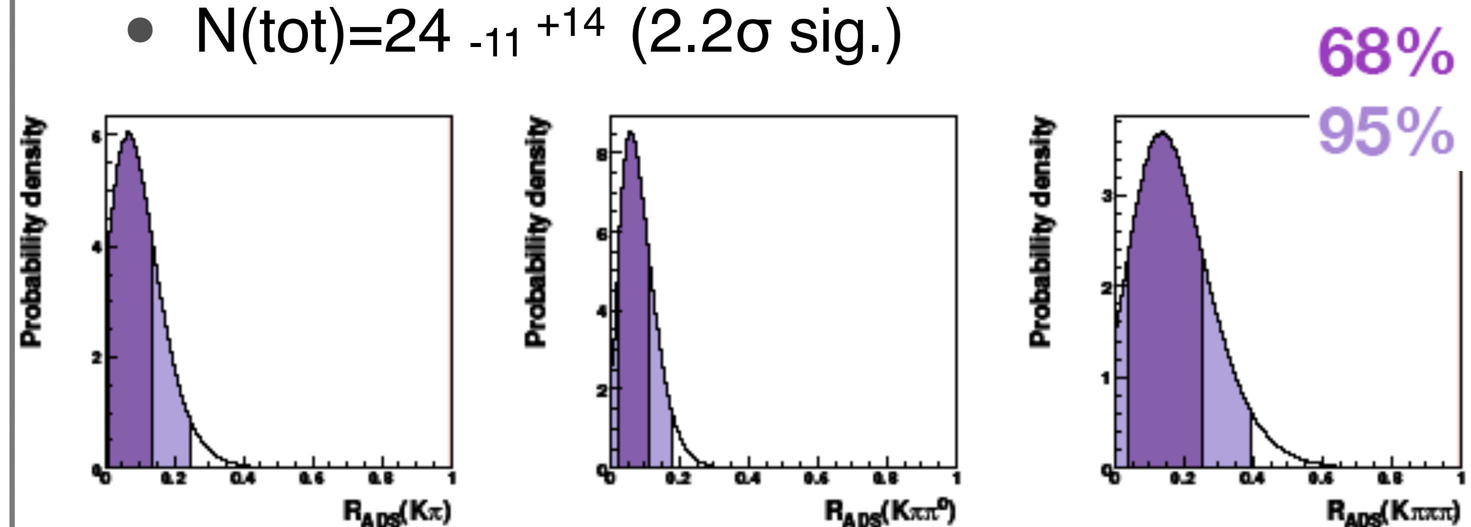
$$\gamma = (162 \pm 56)^\circ \text{ or } (342 \pm 56)^\circ$$
$$r_S < 0.55 \text{ at } 95\% \text{ probability}$$

input: r_S from PRD74,031101(2006):

371M $B\bar{B}$ PRD79,072003(2009)

ADS

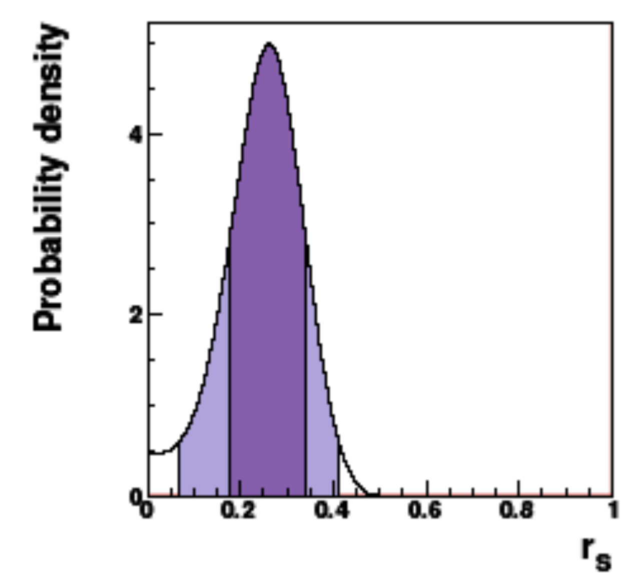
- $B^0 \to D^0 K^{*0}$, $D^0 \to K^+\pi^-$, $K^+\pi^-\pi^0$, $K^+\pi^-\pi^+\pi^-$
- N(tot)=24 $_{-11}^{+14}$ (2.2σ sig.)



R_{ADS} (Kπ)<0.244 R_{ADS} (Kπ)<0.181 R_{ADS} (Kπ)<0.391

All modes + inputs for r_D (PDG) and δ_D (CLEO-c):

r_B in [0.18,0.34] @68% CL



465M $B\bar{B}$ *arxiv: 0904.2112 accepted by PRD*

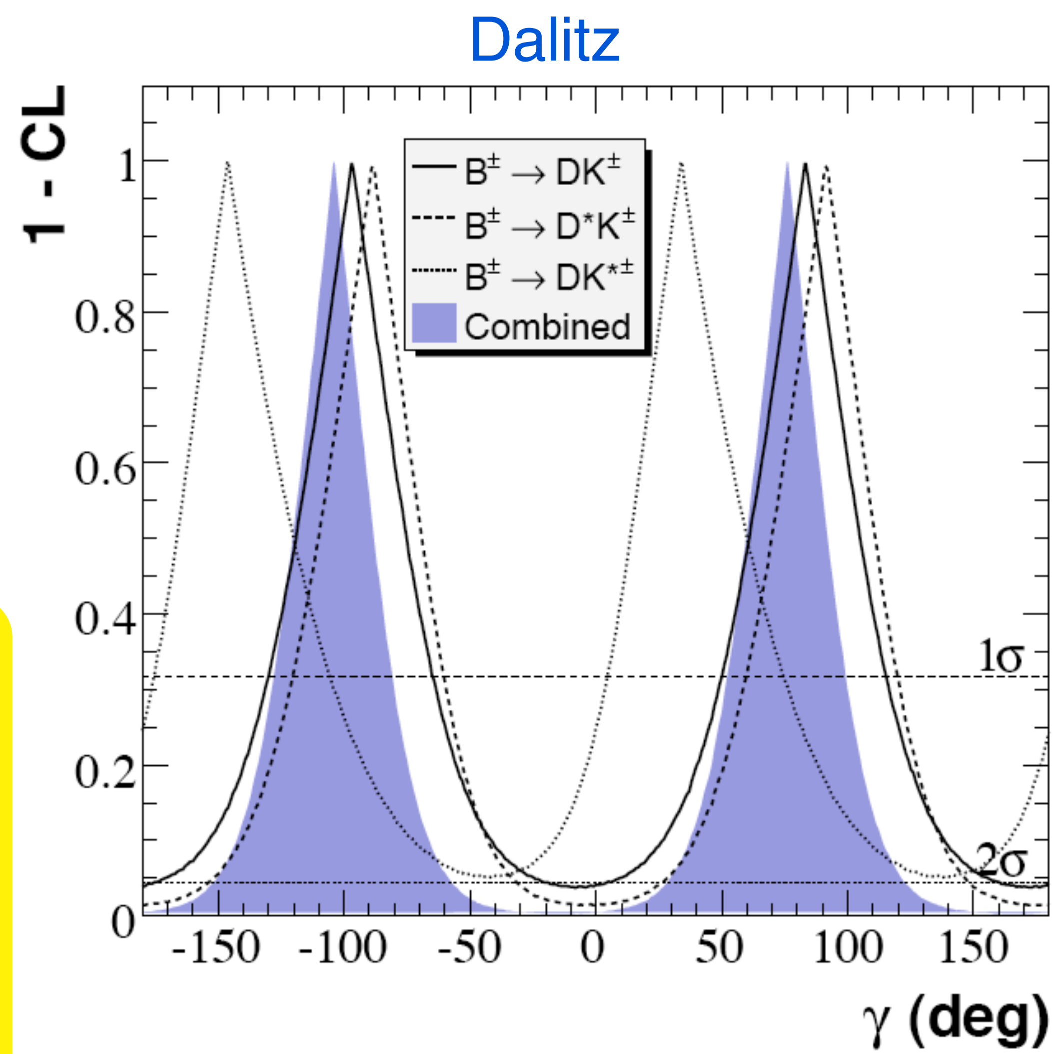
Summary

✓ Many measurements have been performed in BaBar to improve the overall precision on γ

✓ **Dalitz plot** method in $B^{\pm} \rightarrow DK^{\pm}$ is currently the **most sensitive** method $\sigma(\gamma)$~20˚

✓ **NEW** preliminary ADS result:

- evidence of D^0K ADS signal (3σ) and 2.4σ for D^{*0} $(D^0\pi^0)K$
- confirmed the small value of r_B
- the CP asymmetries in DK may be potentially very large

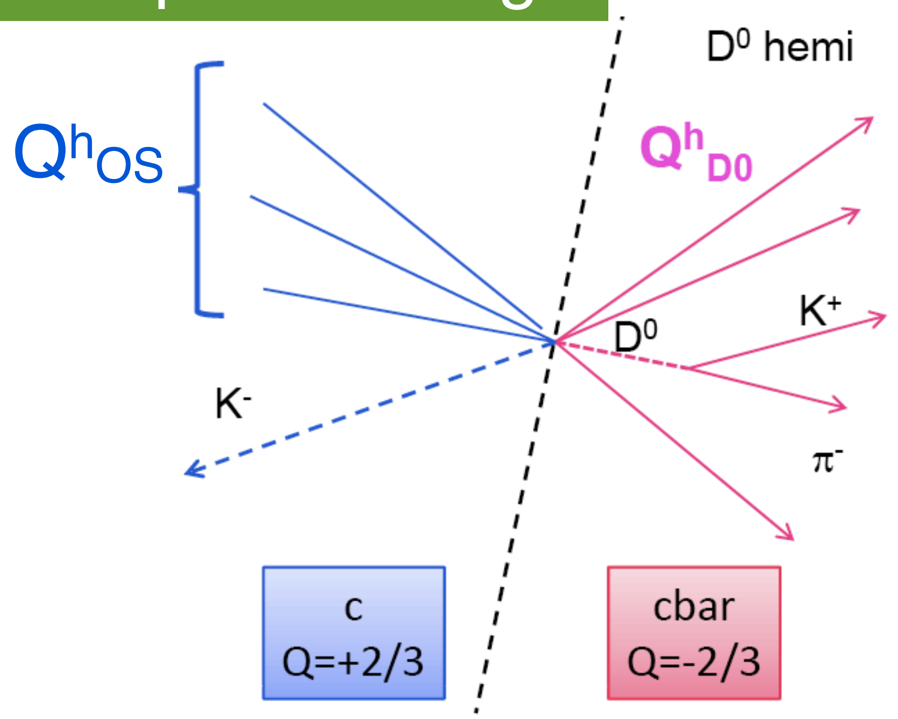


✓ Still potential improvements from new results using the full BaBar dataset (coming soon)

Backup

ADS NN input variables

hemisphere charge



For fake B- from ccbar:
$(Q^h_{D0} - Q^h_{OS}) = -2/3 - 2/3 - 1 = -7/3$

Kaon charge

B^+ from ccbar background:
true D^0 from c & K^+ from the cbar ⇒ all the kaons of the event have been used .
$\langle Q_K^{ROE} \rangle = 0$

True B^+ from ads signal ⇒
excess of K- from b →c → s cascade in the ROE
$\langle Q_K^{ROE} \rangle \times Q_B < 0$

Lepton Kaon mass

Look for leptons with charge opposite to the bachelor kaon and build lepton-kaon mass

- ccbar: less leptons and mass peaked at low mass [m(lK)<m(D^0)]
- BBbar: more leptons, peaked at larger mass [lepton from the other B]

Time difference

Δt between the reconstructed B and the other B: more peaked for continuum (|Δt|<2)

Gronau, London , WylerPRL B265, 172(1991)

GLW method

- Neutral D meson reconstructed in CP-eigenstate final states (CP-even: $K^+ K^-$, $\pi^+\pi^-$ and CP-odd: $K_s\pi^0$, $K_s\omega$, $K_s\Phi$) and in Cabibbo favored $K\pi$ final state
- Limited by statistics (BF ~ 10^{-6})
- 8-fold γ ambiguity
- Use measured B yields to determine GLW observables:

3eq. for 3 unknowns
$R_{CP+} A_{CP+} = -R_{CP-} A_{CP-}$

Ratio of BFs(CP eigenstates/flavour specific):

weak sensitivity to r_B

$$R_{CP\pm} = \frac{2[\Gamma(B^- \to D^0_{CP\pm}K^-) + \Gamma(B^+ \to D^0_{CP\pm}K^+)]}{\Gamma(B^- \to D^0 K^-) + \Gamma(B^+ \to D^0 K^+)} = 1 + r_B^2 \pm 2r_B \cos\delta_B \cos\gamma$$

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

CP violating charge asym.:

$$A_{CP\pm} = \frac{\Gamma(B^- \to D^0_{CP\pm}K^-) - \Gamma(B^+ \to D^0_{CP\pm}K^+)}{\Gamma(B^- \to D^0_{CP\pm}K^-) + \Gamma(B^+ \to D^0_{CP\pm}K^+)} = \frac{\pm 2r_B \sin\delta_B \sin\gamma}{R_{CP\pm}}$$

- Dalitz-GLW relation:

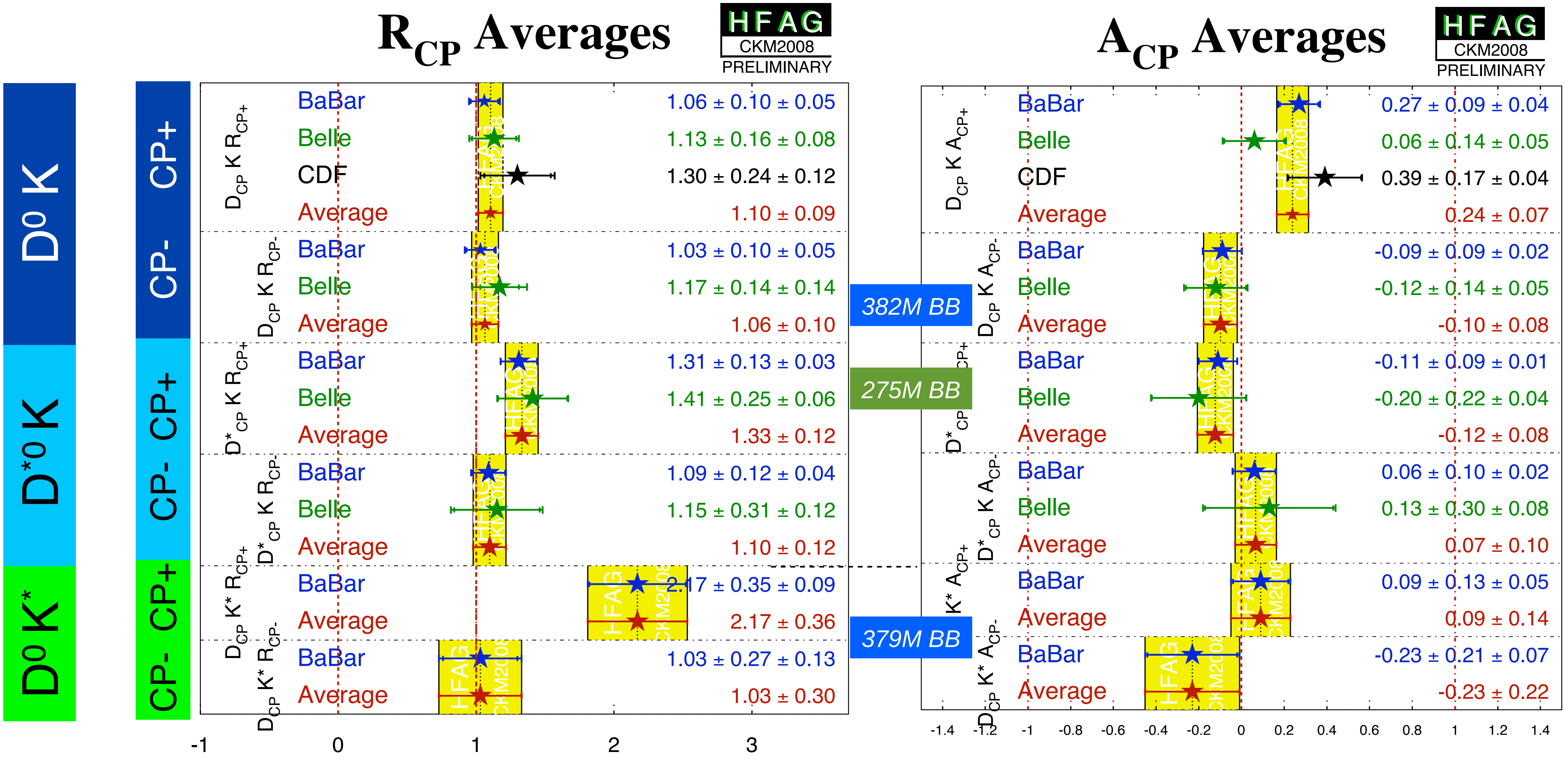
$$\frac{R_{CP+}(1 - A_{CP+}) - R_{CP-}(1 - A_{CP-})}{4} = r_B \cos(\delta_B + \gamma) = x_+$$

$$\frac{R_{CP+}(1 + A_{CP+}) - R_{CP-}(1 + A_{CP-})}{4} = r_B \cos(\delta_B - \gamma) = x_-$$

$$\frac{R_{CP+} + R_{CP-} - 2}{2} = r_B^2$$

- *Status of the analysis*:
  - Recent (2008) publications on the channels $B \to D^0K$ ***(PRD 77,111102)*** and $B \to D^{*0}K$ ***(PRD 78, 092002)*** and $B \to D^0K^*$ using ~ 380M BB. Being updated!

GLW results



R_{CP} Averages
HFAG
CKM2008
PRELIMINARY
$D^0 K$
$D^{*0} K$
$D^0 K^*$
CP+
CP-
CP+
CP-
CP+
CP-
BaBar 1.06 ± 0.10 ± 0.05
Belle 1.13 ± 0.16 ± 0.08
CDF 1.30 ± 0.24 ± 0.12
Average 1.10 ± 0.09
BaBar 1.03 ± 0.10 ± 0.05
Belle 1.17 ± 0.14 ± 0.14
Average 1.06 ± 0.10
BaBar 1.31 ± 0.13 ± 0.03
Belle 1.41 ± 0.25 ± 0.06
Average 1.33 ± 0.12
BaBar 1.09 ± 0.12 ± 0.04
Belle 1.15 ± 0.31 ± 0.12
Average 1.10 ± 0.12
BaBar 2.17 ± 0.35 ± 0.09
Average 2.17 ± 0.36
BaBar 1.03 ± 0.27 ± 0.13
Average 1.03 ± 0.30
-1 0 1 2 3
382M BB
275M BB
379M BB
A_{CP} Averages
HFAG
CKM2008
PRELIMINARY
BaBar 0.27 ± 0.09 ± 0.04
Belle 0.06 ± 0.14 ± 0.05
CDF 0.39 ± 0.17 ± 0.04
Average 0.24 ± 0.07
BaBar -0.09 ± 0.09 ± 0.02
Belle -0.12 ± 0.14 ± 0.05
Average -0.10 ± 0.08
BaBar -0.11 ± 0.09 ± 0.01
Belle -0.20 ± 0.22 ± 0.04
Average -0.12 ± 0.08
BaBar 0.06 ± 0.10 ± 0.02
Belle 0.13 ± 0.30 ± 0.08
Average 0.07 ± 0.10
BaBar 0.09 ± 0.13 ± 0.05
Average 0.09 ± 0.14
BaBar -0.23 ± 0.21 ± 0.07
Average -0.23 ± 0.22
-1.4 -1.2 -1 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1 1.2 1.4

Neutral B $2\beta+\gamma$

PRD77,071102 (2008)

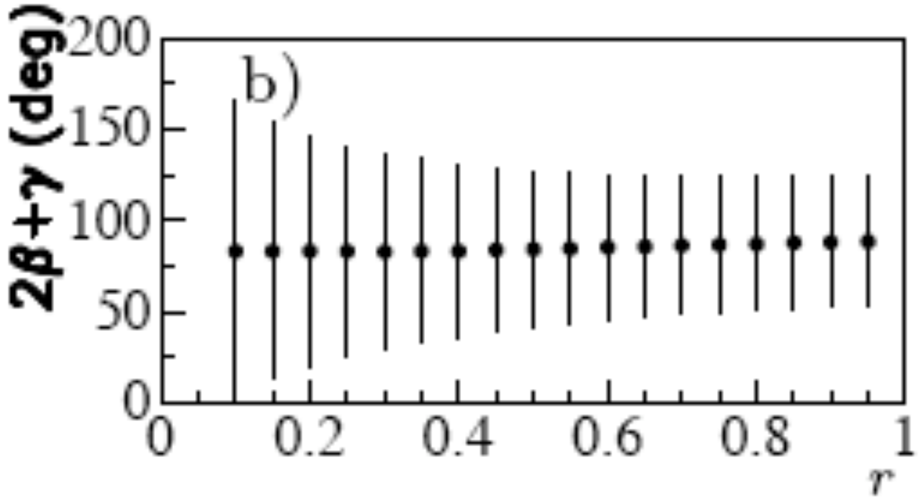
347M BB

. Interference of the direct ($B^0 \rightarrow f$) and indirect ($B^0 \rightarrow \bar{B}^0 \rightarrow f$) decay $\rightarrow$ Sensitivity to $2\beta+\gamma$

.. Time Dependent Dalitz plot analysis of $B^0 \rightarrow D^{\mp} K^0 \pi^{\pm}$.

... Sensitivity from the interference r~0.4 some regions of the Dalitz plot (for previous analysis $D\pi/\rho$ r~0.02)

....Assumed $r_B = 0.3$ as the V_{ub} amplitude cannot be determined with the present statistics



$$2\beta+\gamma = (83 \pm 53 \pm 20)^\circ$$