$B^{\pm} \to D^{(*)}K^{\pm}$ Dalitz γ Analysis

Fernando Martinez-Vidal
IFIC-Valencia & INFN-Pisa

for the D0K-dalitz group
BaBar Collaboration Meeting, December 2004

BAD#899 and BAD#1086

PRL draft under way

Outline

- Method of measurement
- The Dalitz model
- Data sample and event selection
- Background parameterization
- CP fit
- Frequentist interpretation and significance of CP violation
- Summary and plans

Method of measurement

$$B+: \quad pdf_+ = | f(s_{12},s_{13}) + r_b\, e^{i(\gamma+\delta)} f(s_{13},s_{12}) |^2$$

$$B-: \quad pdf_- = | f(s_{13},s_{12}) + r_b\, e^{i(-\gamma+\delta)} f(s_{12},s_{13}) |^2$$

γ changes sign in the two different B charge samples

V_{cb} amplitude

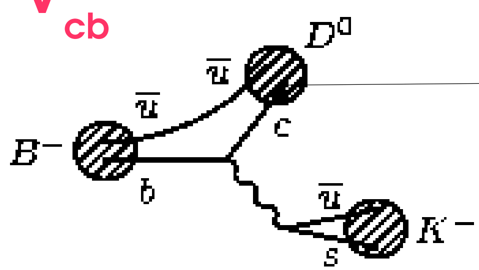
V_{ub} amplitude

$s_{12}=m^2(Ks\pi^-)$

$s_{13}=m^2(Ks\pi^+)$

$V_{ub} = |V_{ub}| e^{-i\gamma}$

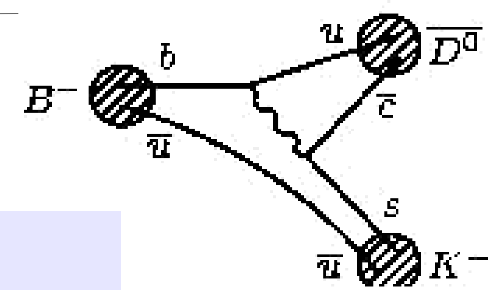
V_{cb}



Same final state

$B^- \to D(*)K^-$, $D \to Ks\pi^+\pi^-$

Interference



The Dalitz model gives $f(s_{12},s_{13})$

The CP Dalitz analysis extracts $r(*)_B$, γ, $\delta(*)$

Only two-fold ambiguity in γ extraction ($\gamma \to \gamma+\pi$, $\delta \to \delta+\pi$)

Method of measurement

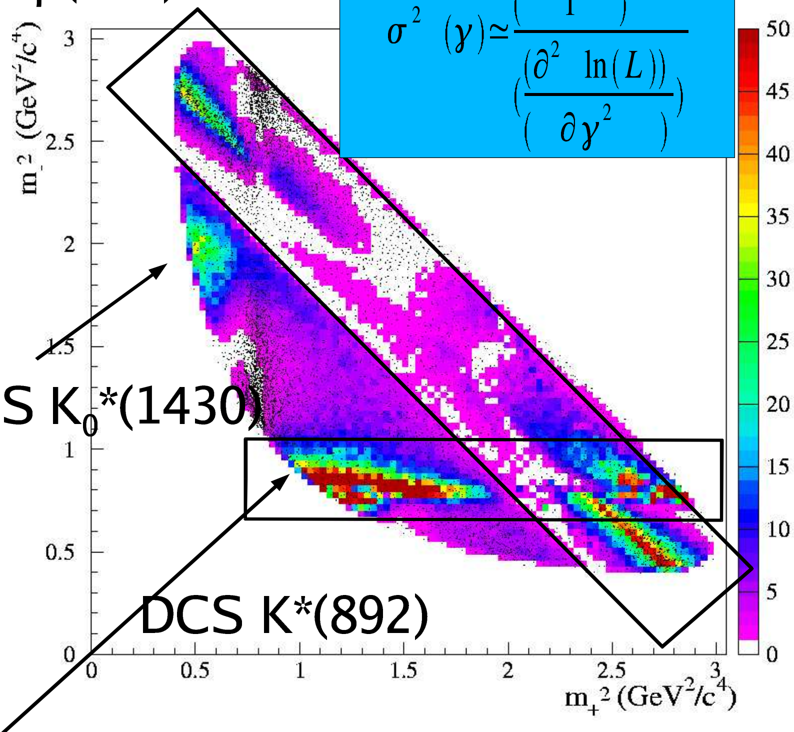
Advantages:

- Interference is proportional to r_B~0.1 and to $A(s_{12},s_{13})A^*(s_{13},s_{12})$ which is large in several regions of the Dalitz plot, i.e. K*(892) DCS, ρ(770), K^{*0}(1430) DCS
- Combination of GLW and ADS methods
- Need to reconstruct only one decay channel which has relatively high statistics

Disadvantages:

- Dalitz plot analysis imposes a model dependency which may limit asymptotically the reach of the method
- Model independent approach exists but not convenient with the present statistics **A.Giri et al., Phys. Rev. D68, 054018 (2003)**

Sensitivity to γ



γ=75, δ=180, r_B=0.12

Not all the events in the Dalitz are sensitive to γ.
Need regions where interference term is large

E.g. K*(892) regions, maximal interference

B decay	•	D decay	interfere	B decay	•	D decay
Vub	•	A_D(CA)	⇔	Vcb	•	A_D(DCS)
small	•	large	⇔	large	•	small

$r_B A_D(s_{12},s_{13})$ = from Vub $A_D(s_{12},s_{13})$ CA region D^0 Decay
$A^*_D(s_{13},s_{12})$ = from Vcb $A^*_D(s_{13},s_{12})$ DCS region D^0 Decay

$$d\hat{\Gamma}(B^- \to (K_S\pi^-\pi^+)_D K^-) = \Big(A^2_{12,13} + r_B^2 A^2_{13,12}$$
$$+ 2 r_B\, Re\Big[A_D(s_{12},s_{13})\, A^*_D(s_{13},s_{12})\, e^{-i(\delta_B - \gamma)}\Big]\Big) dp$$

Interference term

D* relative effective strong phase

In B→D*K decays:

$$\tilde{D}^* = \frac{D_+^* + D_-^*}{\sqrt{2}} + r_B e^{i(\delta_B - \phi_3)} \frac{D_+^* - D_-^*}{\sqrt{2}}.$$

$D^*_\pm$ decaying into CP eigenstates $D^0\pi^0$, $D^0\gamma$

$\eta_{D^*} = \eta_{\pi,\gamma}\eta_D(-1)^{l=1}$ l=1 for parity/ang momentum conservation

$\eta_\gamma = -1 \cdot \eta_\pi$

$D^*_\pm \to D^0_\pm \pi^0$, $D^*_\pm \to D^0_\mp \gamma$

Effective strong phase shift of π between $D^0\pi^0$ and $D^0\gamma$

Same arguments for ADS analysis.

A.Bondar,T.Gershon, hep-ph/0409281

The Dalitz model

Dalitz model uses 17 components (13 resonances + 1 Non Resonant term)
Removed DCS K*(1680), and added K*(1410), ρ(1450) respect to Belle Model
All single Breit-Wigners, except for ρ's (Gounaris-Sakurai)

From ~80K D* →D0π, D0→Ksπ+π− events provided by Antimo Palano

Nothing changed after Summer !

Resonance	Amplitude	phase (degrees)	fit fraction (%)
$K^*(892)$	1.781 ± 0.018	131.0 ± 0.79	58.60
$\rho^0(770)$	1 (fixed)	0(fixed)	22.36
$K^*(892)$ DCS	0.1796 ± 0.0079	-44.1 ± 2.4	0.60
$\omega(782)$	0.0391 ± 0.0016	115.3 ± 2.5	0.56
$f_0(980)$	0.4817 ± 0.011	218.2 ± 2.2	6.09
$f_0(1370)$	2.25 ± 0.28	113.2 ± 4.4	3.20
$f_2(1270)$	0.922 ± 0.040	-21.3 ± 2.8	3.00
$K_0^*(1430)$	2.447 ± 0.073	-8.3 ± 2.0	8.32
$K_0^*(1430)$ DCS	0.368 ± 0.067	-342.2 ± 9.8	0.19
$K_2^*(1430)$	1.054 ± 0.045	-54.3 ± 2.5	2.74
$K_2^*(1430)$ DCS	0.075 ± 0.036	-104 ± 30	0.01
$K^*(1410)$	0.515 ± 0.071	154 ± 10	0.37
$K^*(1680)$	0.89 ± 0.29	-139 ± 19	0.28
$\rho(1450)$	0.515 ± 0.092	38 ± 13	0.24
σ_1	1.358 ± 0.040	-177.9 ± 2.4	9.27
σ_2	0.340 ± 0.024	-207.0 ± 3.8	1.34
Non resonant	3.53 ± 0.44	-232.4 ± 4.7	7.30

Added → K*(1410)

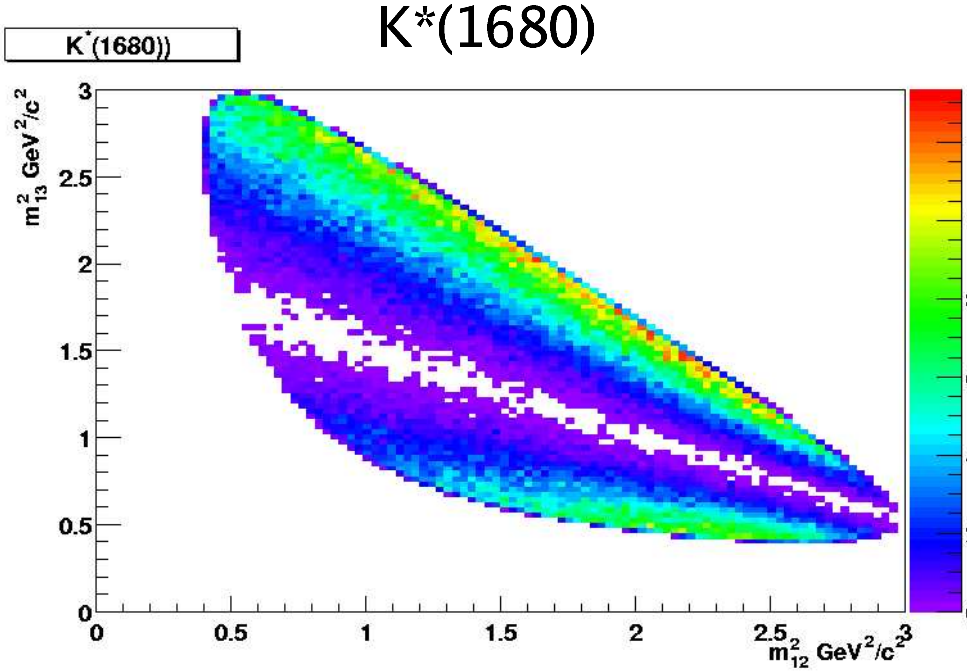
Added → ρ(1450)

Mass and widths are fixed to the PDG 2004 values, except for σ1, σ2 for which we directly fit

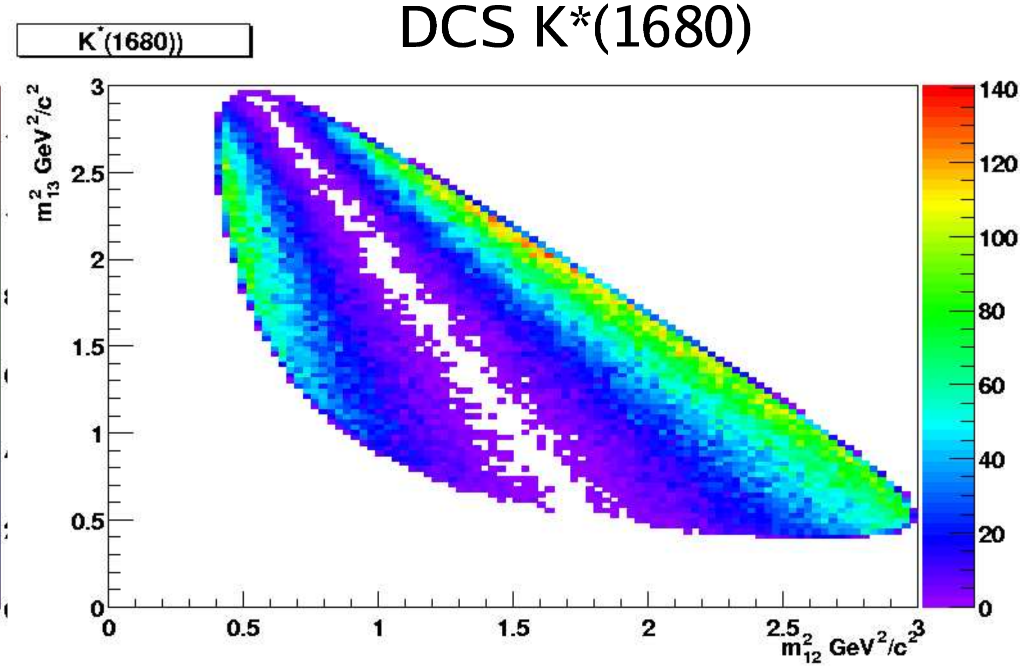
The Dalitz model

DCS K*(1680) and DCS K*(1410) excluded because:
- the number of events expected is very small
- the K*(1680) and the DCS K*(1680) overlap in the same Dalitz region: the fit returns ≈ the same amplitude for CA and DCS !

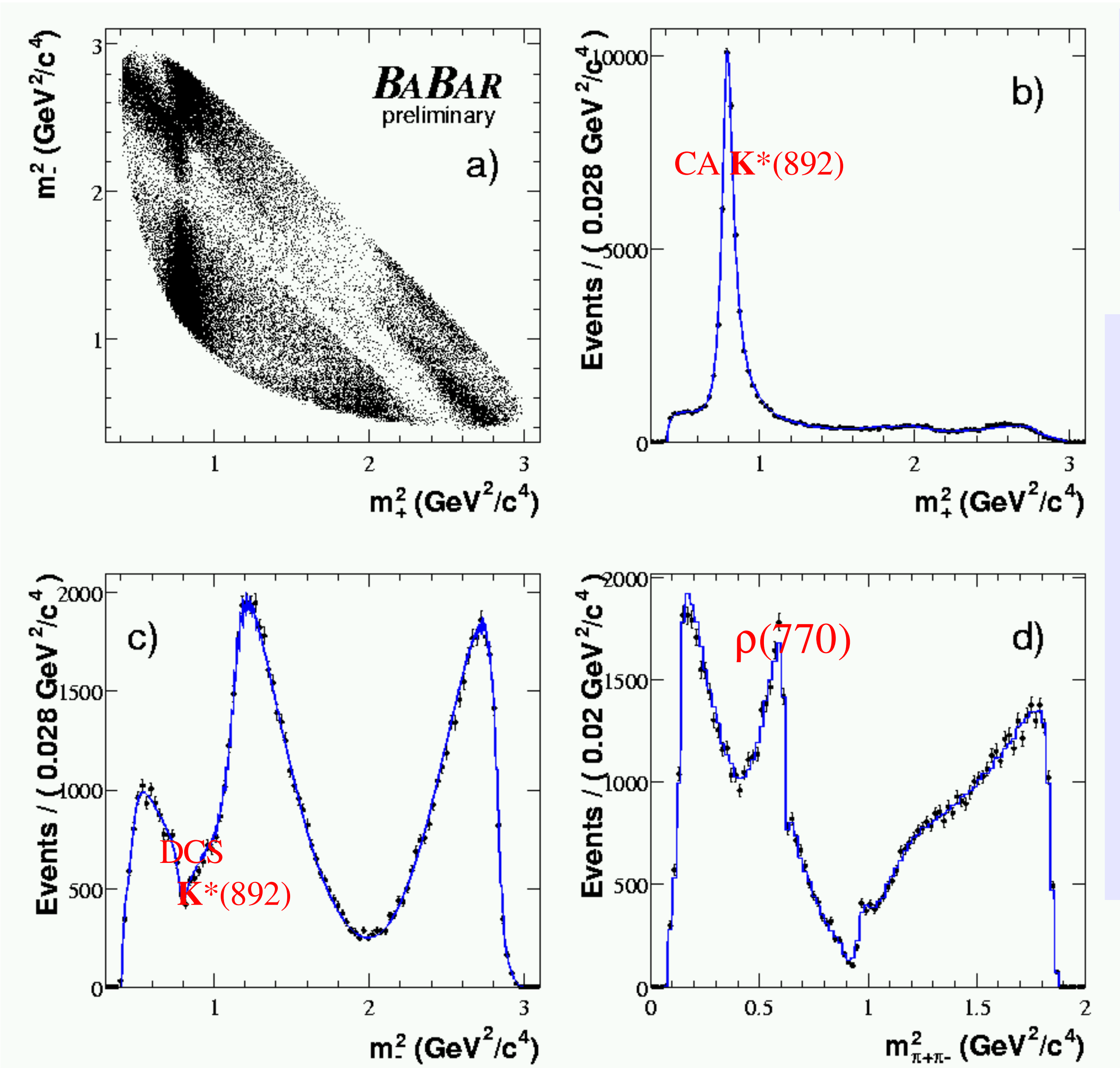
K*(1680)



DCS K*(1680)



The Dalitz model



BaBar Data with Dalitz model fit overlayed

χ^2 fit evaluation of goodness of fit:

BaBar model: 1.27/dof(3054)

CLEO model: 2.2/dof(3054)

Belle model: 1.88/dof(1130)

Total fit fraction:

BaBar model: 125.0%

CLEO model: 120%

Belle model: 137%

Data samples

- MC sample :
  - B+ 501 fb-1
  - B0 394 fb-1
  - ccbar 140 fb-1
  - uds 135 fb-1
  - D*0K, D0→Ks$\pi\pi$ MC signal 300K events
- DATA sample :
  - **BlackDiamond**
    - DATA ON 215 fb-1
    - DATA OFF 10 fb-1

Event selection

	D^0K	$D^{*0}K$ ($D^0\pi^0$)	$D^{*0}K$ ($D^0\gamma$)
$\lvert\cos(\theta_T)\rvert$	<0.8	<0.8	<0.8
$\lvert$ mass(D^0)-PDG $\rvert$	<12MeV	<12MeV	<12MeV
$\lvert$ mass(Ks)-PDG $\rvert$	<9MeV	<9MeV	<9MeV
Kaon Tight Selector	Yes	Yes	Yes
$\lvert \Delta M$-PDG $\rvert$	-----	<2.5MeV	<10.0MeV
$\cos\alpha_{Ks}$	>0.99	>0.99	>0.99
$\lvert \Delta E \rvert$	<30MeV	<30MeV	<30MeV

$\lvert\cos(\alpha_{Ks})\rvert$ suppress fake Ks

$\lvert\cos(\theta_T)\rvert$ suppress jet-like events

Kaon Tight Selector suppress D(*)π events

Bkg parametrization

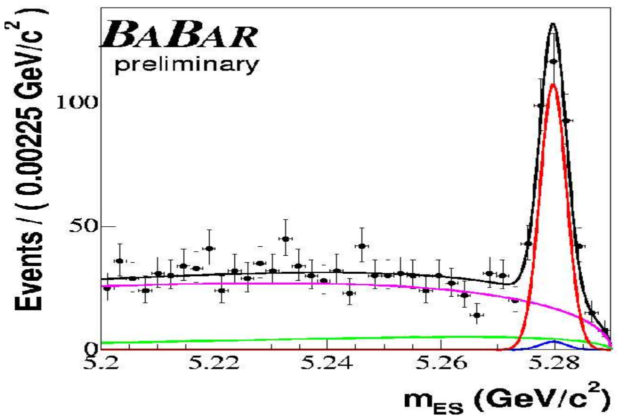
- Continuum events are the largest bkg
  - Fisher PDF for the continuum bkg suppression

  $Fisher = \mathscr{F}$ [LegendreP0,LegendreP2,$|\cos(\theta_T)|$,$\cos(\theta_B{}^*)$]

  - allows evaluation of the relative fraction of BB and continuum events from data
- Very small $D\pi$ bkg due to tight ΔE cut
  - Momentum dependent ΔE PDF
- True D^0 fraction evaluated directly on data using the mES<5.272 GeV sidebands and fitting for the D^0 mass (assuming no BB contribution, check on MC)
- Fake D^0 Dalitz shape parameterized as 2D symmetric 2nd order polynomial function and taken from
  - off-resonance data for qqbar combinatorics (continuum)
  - MC for BB

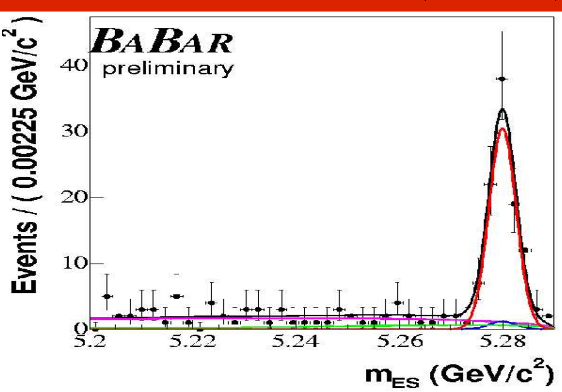
Selection yields: m_{ES}

$B^- \to DK^-$ $D^0 \to (K_s\pi\pi)$

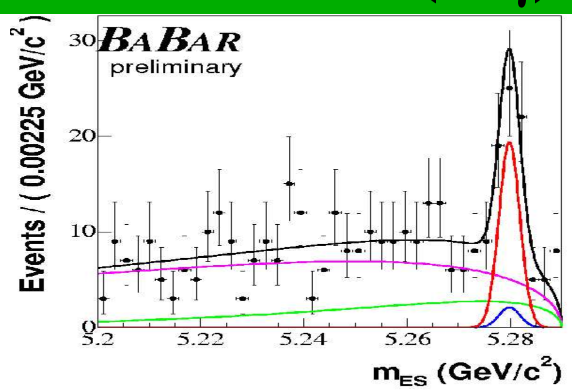


DK	282±20 Sig Evt
D*K ($D^0\pi^0$)	89±11 Sig Evt
D*K ($D^0\gamma$)	44±8 Sig Evt
red	signal
magenta	qqbar
green	bbar
blu	Dπ

$B^- \to D^*K^-$ $D^{*0} \to (D^0\pi^0)$



$B^- \to D^*K^-$ $D^{*0} \to (D^0\gamma)$

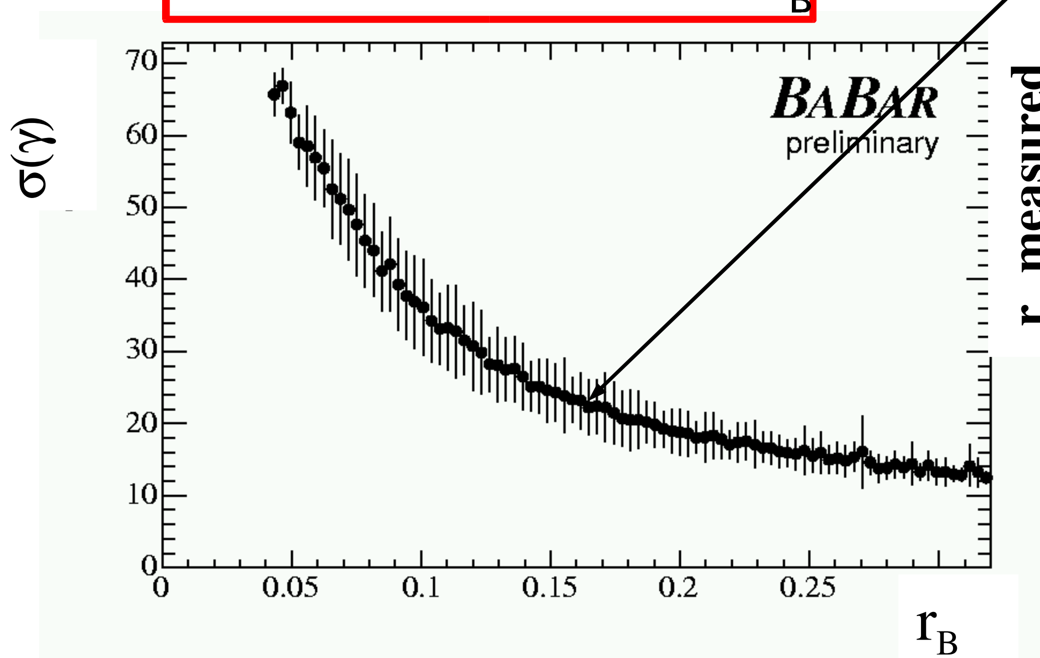


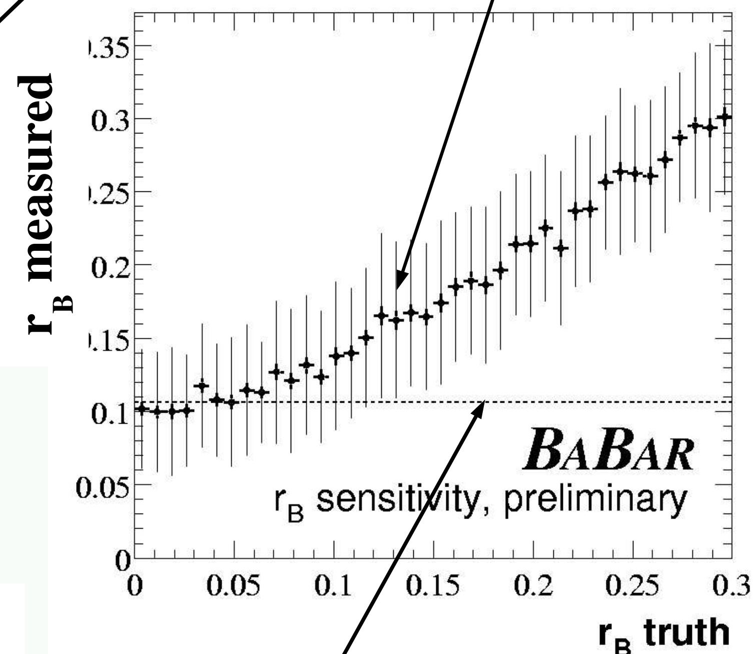
Best Candidate choice applied for DK $\chi^2=\chi^2(m_{D^0})$ D*K $\chi^2=\chi^2(\Delta m,(m_{\pi^0}))$

CP fit to r_B,γ,δ: Non-Gaussian effects

Strong dependency of σ(γ) on the value of r_B

Error is the RMS of the fitted value





r_B = 0.106 unblinded DK r_B value

With current statistics, no r_B sensitivity for $r_B<0.10$

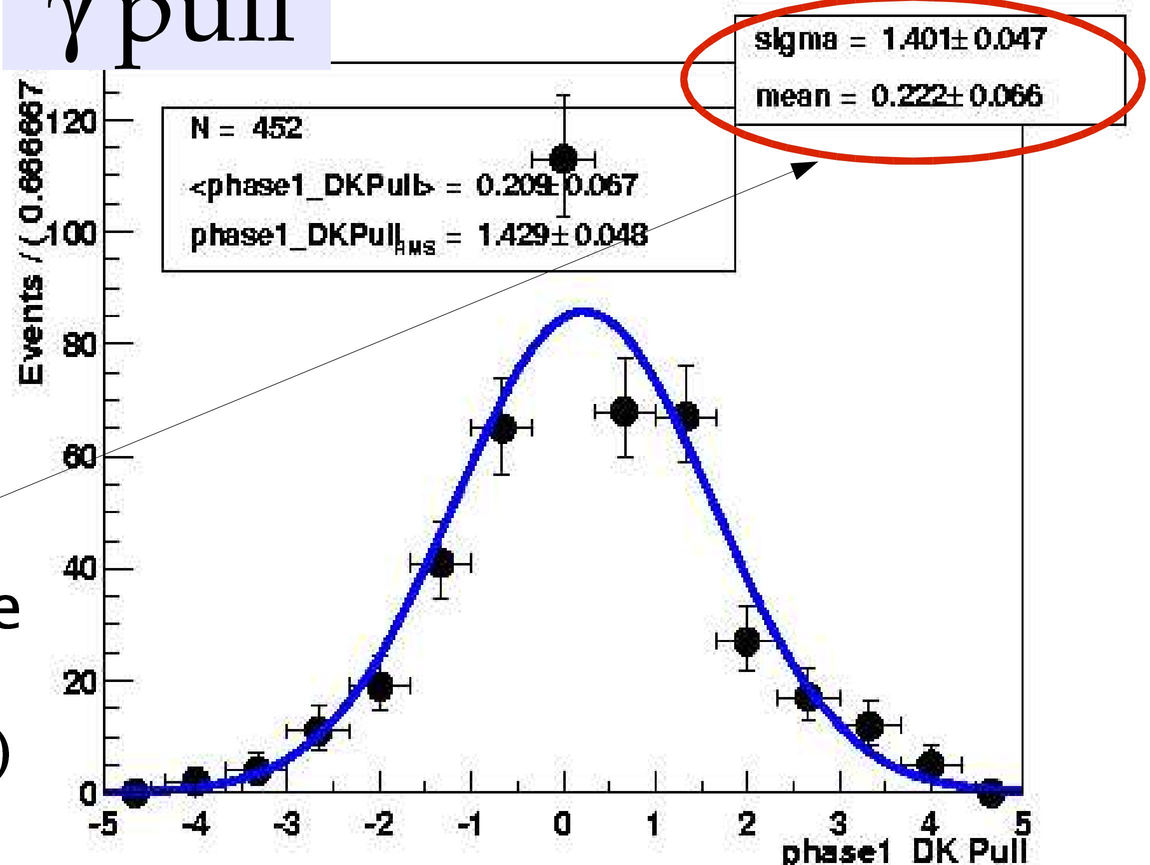
Large non-Gaussian effects: low statistics & physical bound ($r_B \geq 0$)

Requires sophisticated statistical treatment to extract constraints on r_B and γ

CP fit to r_B,γ,δ: Non-Gaussian effects

γ pull

r_B=0.106



- r_B estimation biased ($r_B \geq 0$)
- γ and δ are unbiased but the statistical error is underestimated (pulls~1.4)

Cannot trust fit results (central values and errors)

CP fit to cartesian coord (CC)

$x_\pm = \mathrm{Re}[r_{B\pm}\exp^{i(\delta\pm\gamma)}] = r_{B\pm}\cos(\delta\pm\gamma)$, $y_\pm = \mathrm{Im}[r_{B\pm}\exp^{i(\delta\pm\gamma)}] = r_{B\pm}\sin(\delta\pm\gamma)$

Nominal Dalitz fit to BlackDiamond data set

Observable	D^0K	$D^{*0}K$
x_-	$0.0772^{+0.0688}_{-0.0708}$ [±0.0692]	$-0.1306^{+0.0940}_{-0.0935}$ [±0.0934]
y_-	$0.0635^{+0.0953}_{-0.0888}$ [±0.0919]	$-0.1433^{+0.1064}_{-0.1059}$ [±0.1049]
x_+	$-0.1287^{+0.0701}_{-0.0704}$ [±0.0703]	$0.1397^{+0.0941}_{-0.0943}$ [±0.0926]
y_+	$0.0186^{+0.0762}_{-0.0814}$ [±0.0787]	$0.0131^{+0.1183}_{-0.1201}$ [±0.1195]

Correlations D0K

Observable	x_-	y_-	x_+	y_+
x_-	1	2.5×10^{-2}	9.4×10^{-5}	-3.0×10^{-5}
y_-		1	-1.8×10^{-4}	-2.3×10^{-4}
x_+			1	6.0×10^{-2}

Correlations D*0K

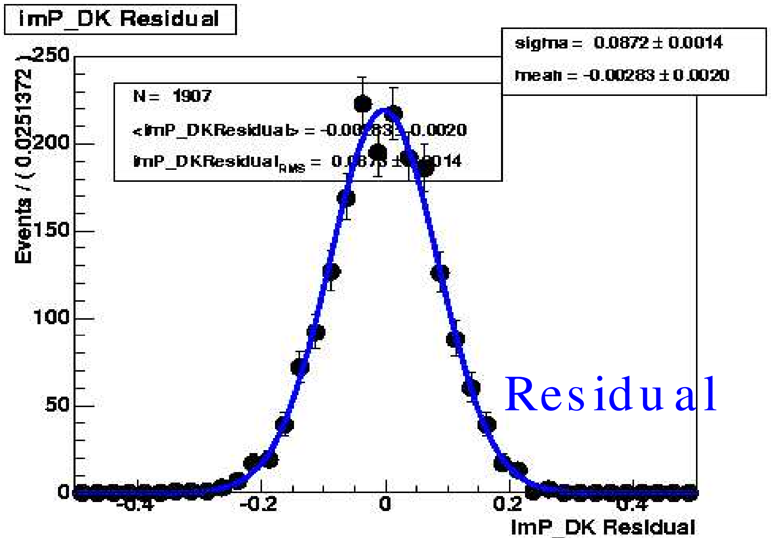
Observable	x_-	y_-	x_+	y_+
x_-	1	-1.7×10^{-1}	-6.3×10^{-3}	3.6×10^{-3}
y_-		1	-5.7×10^{-3}	2.6×10^{-3}
x_+			1	-2.7×10^{-1}

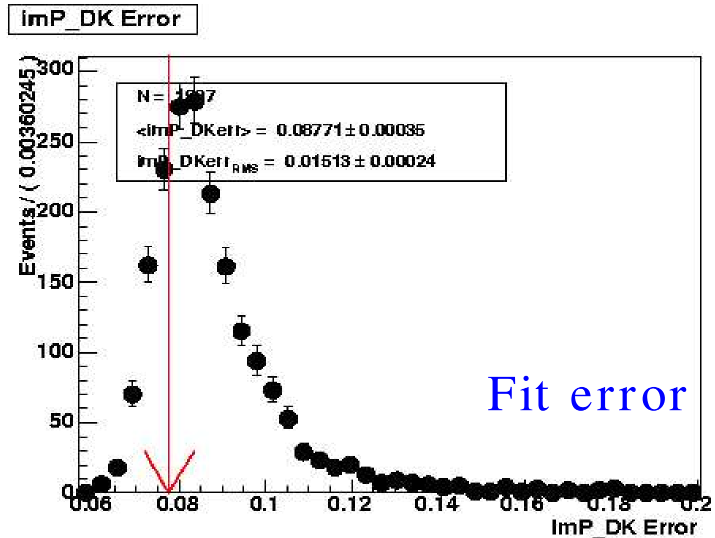
Are these results statistically meaningful?

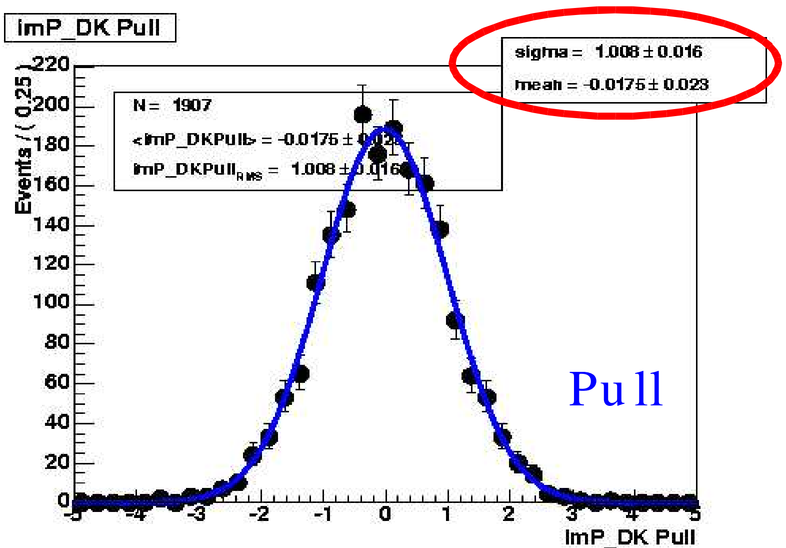
Cartesian coordinates: toy MC

y-

D0K







Excellent Gaussian behavior!

Correlations among coordinates all zero, except pairs

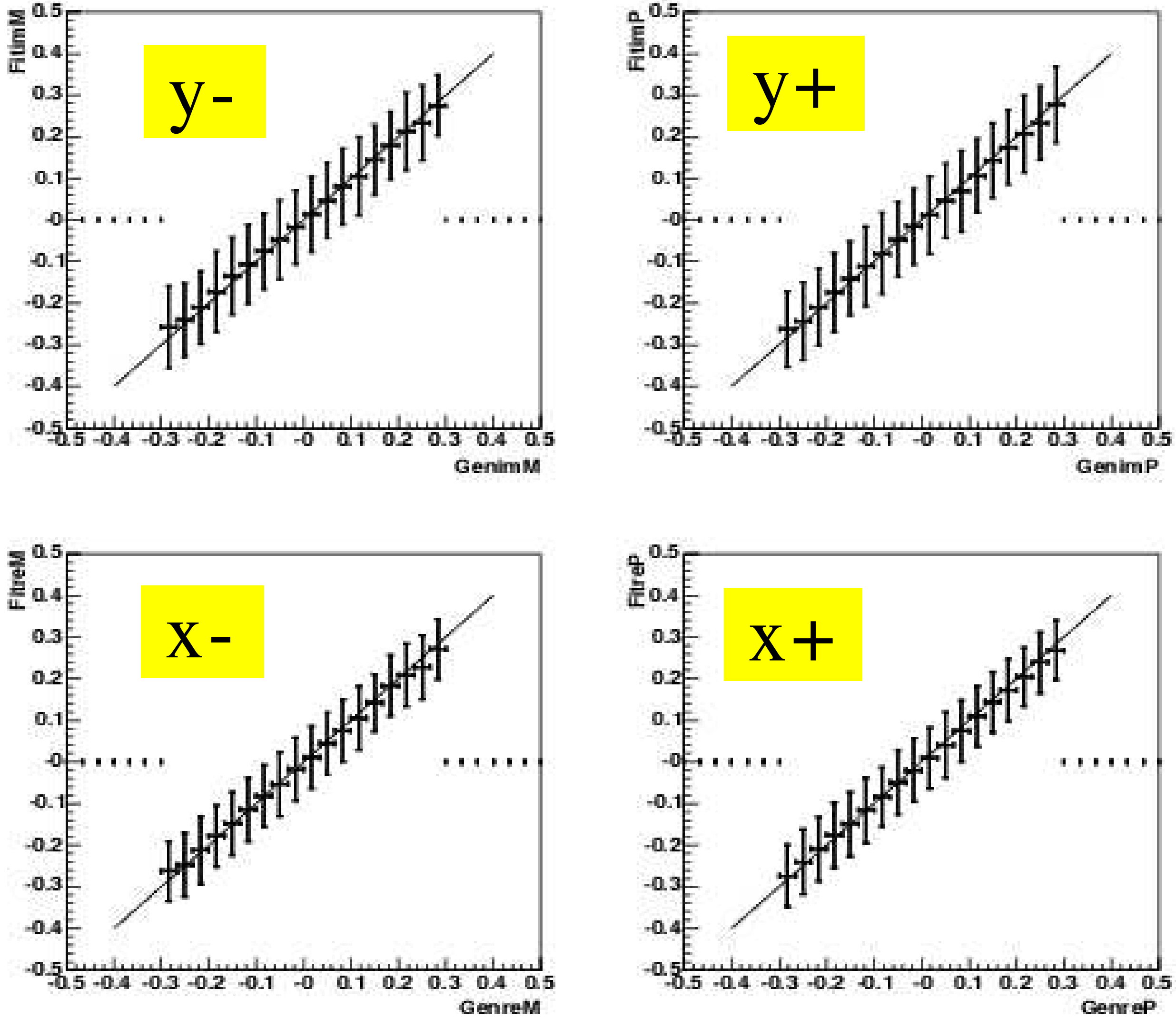
(x-,y-) D0K

(x+,y+) D0K

(x-,y-) D*0K

(x+,y+) D*0K

Cartesian coordinates: toy MC



Excellent linearity and rms stability !

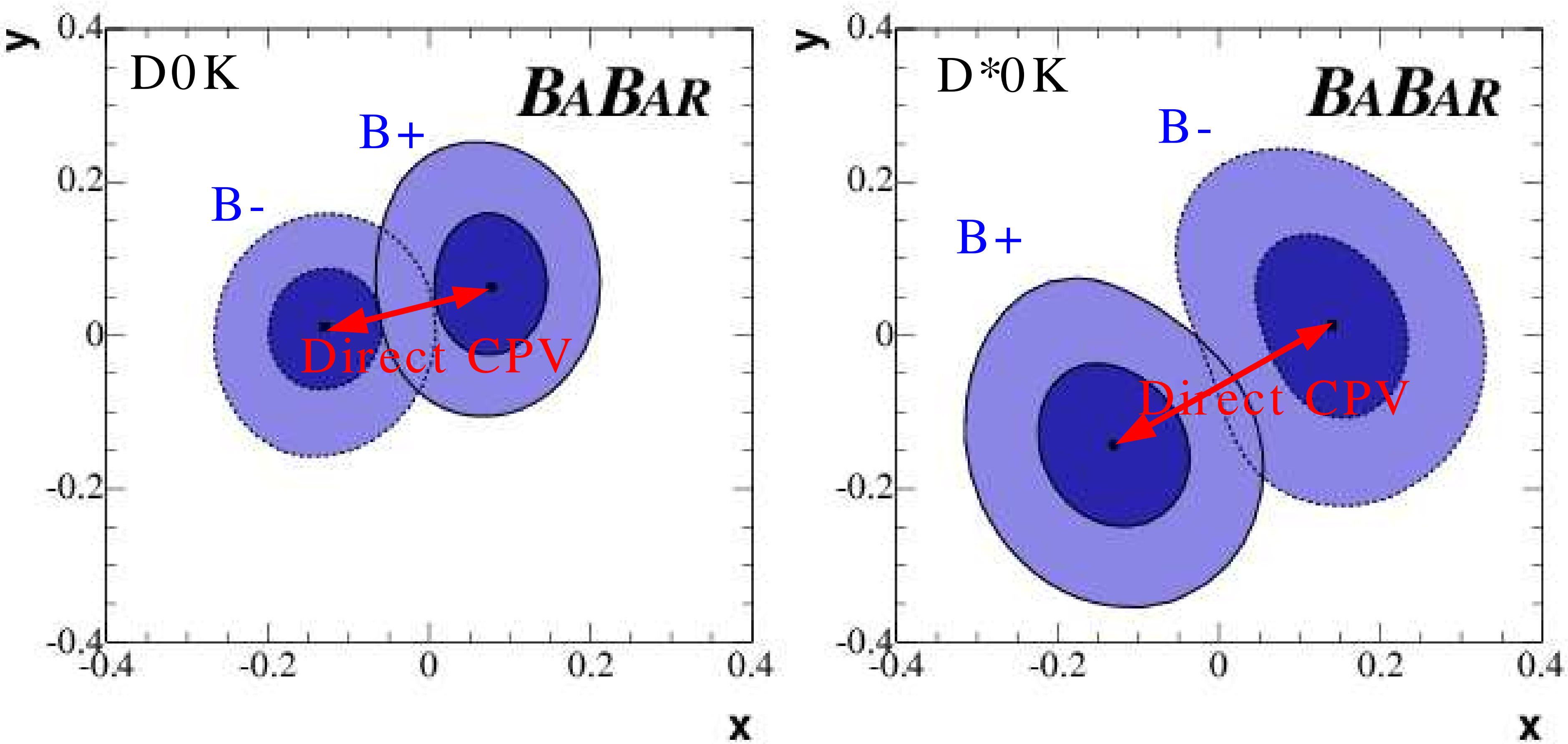
Stability of fit error and
residual width (σ_{xy})
studied in bins of
truth r_B
in range [0,0.3]

Good <10%
(deviations
only at large,
unrealistic r_B values)

Same behavior for
normalized residual

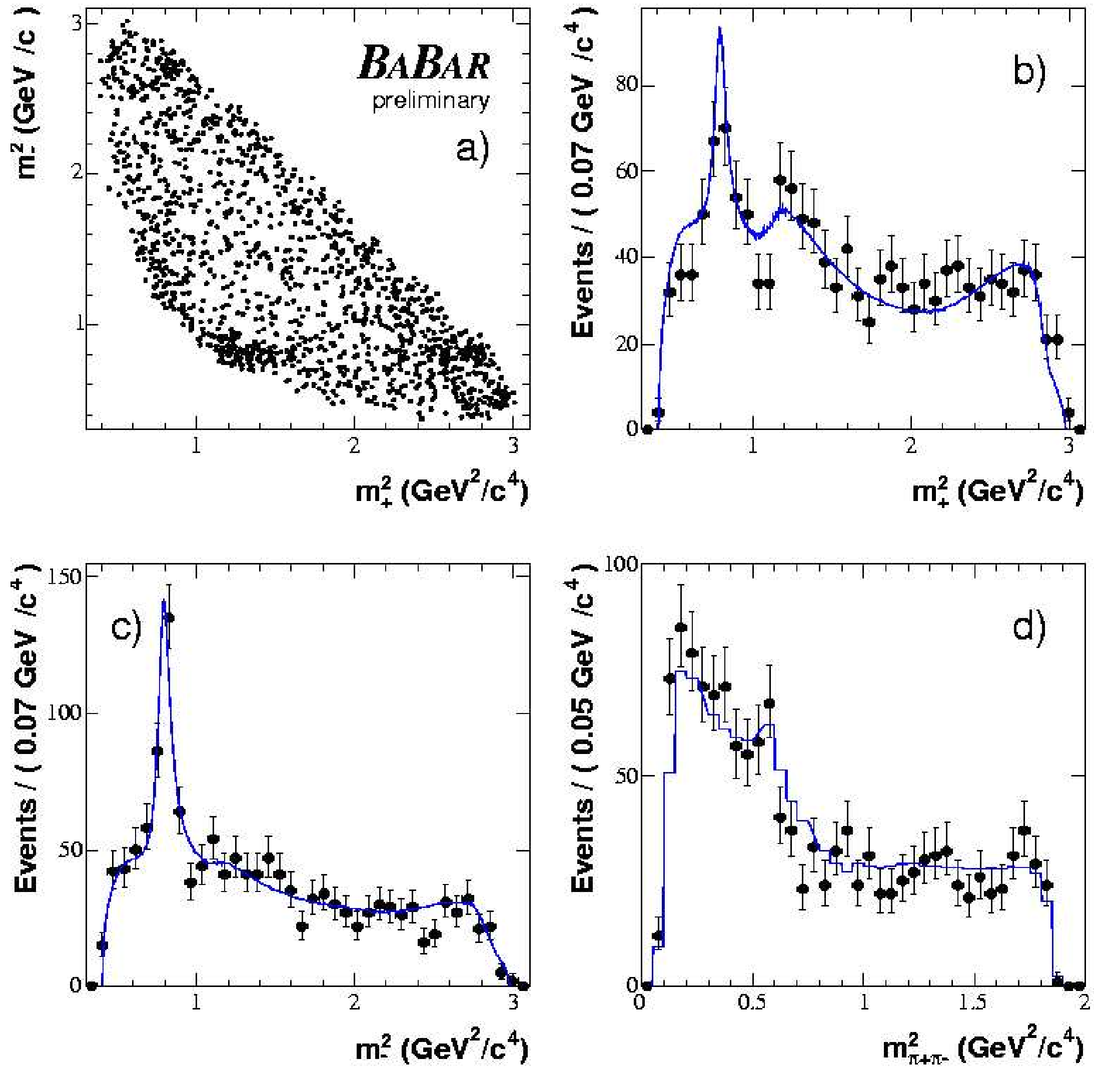
CP fit to CC: likehood contours

Likelihood contours from $\Delta\ln L = 0.5, 1.921$ (68.3%, 95% CL)



CP fit to CC: Dalitz distributions

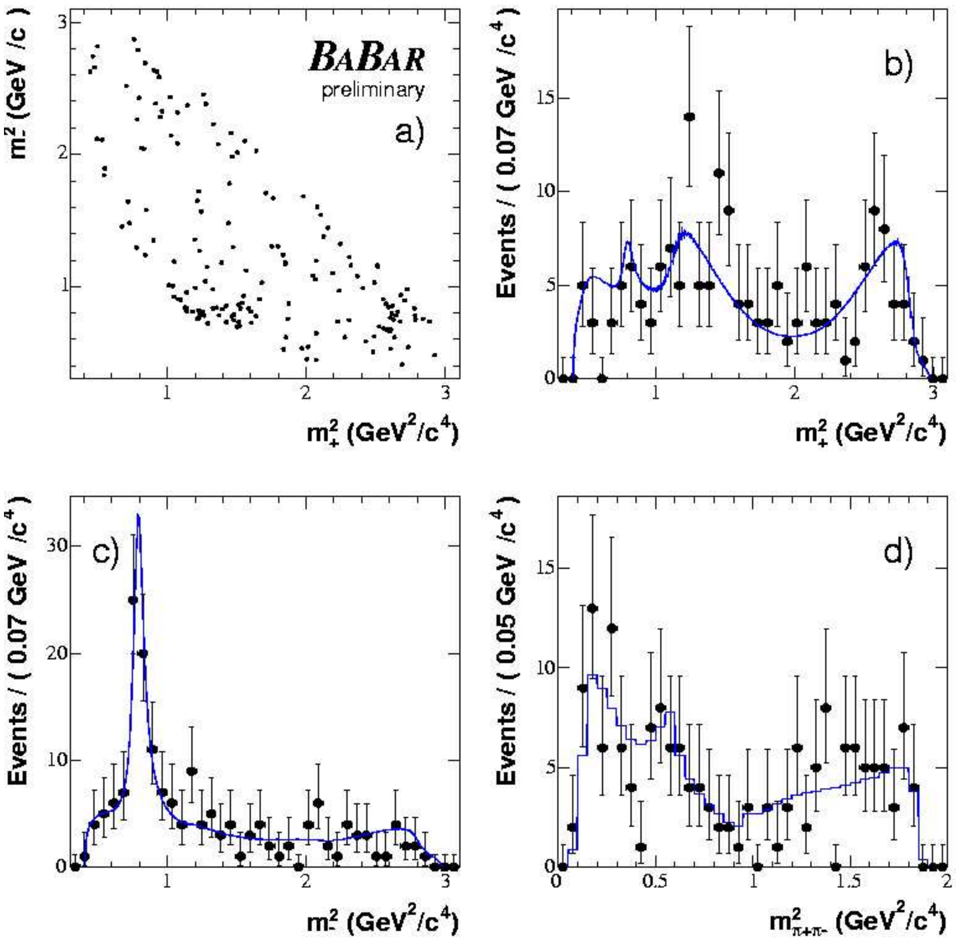
D0K



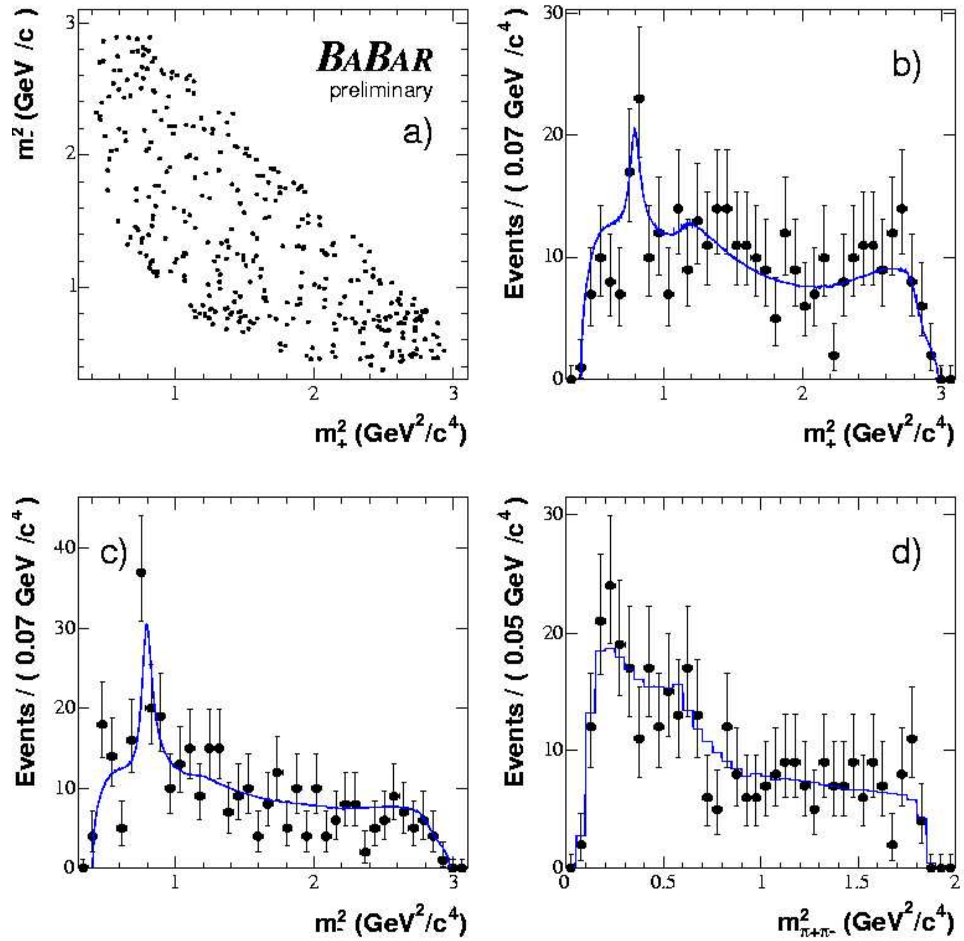
B candidates with m_{ES}>5.272 GeV/c^2

CP fit to CC: Dalitz distributions

(D0π0)K



(D0γ)K



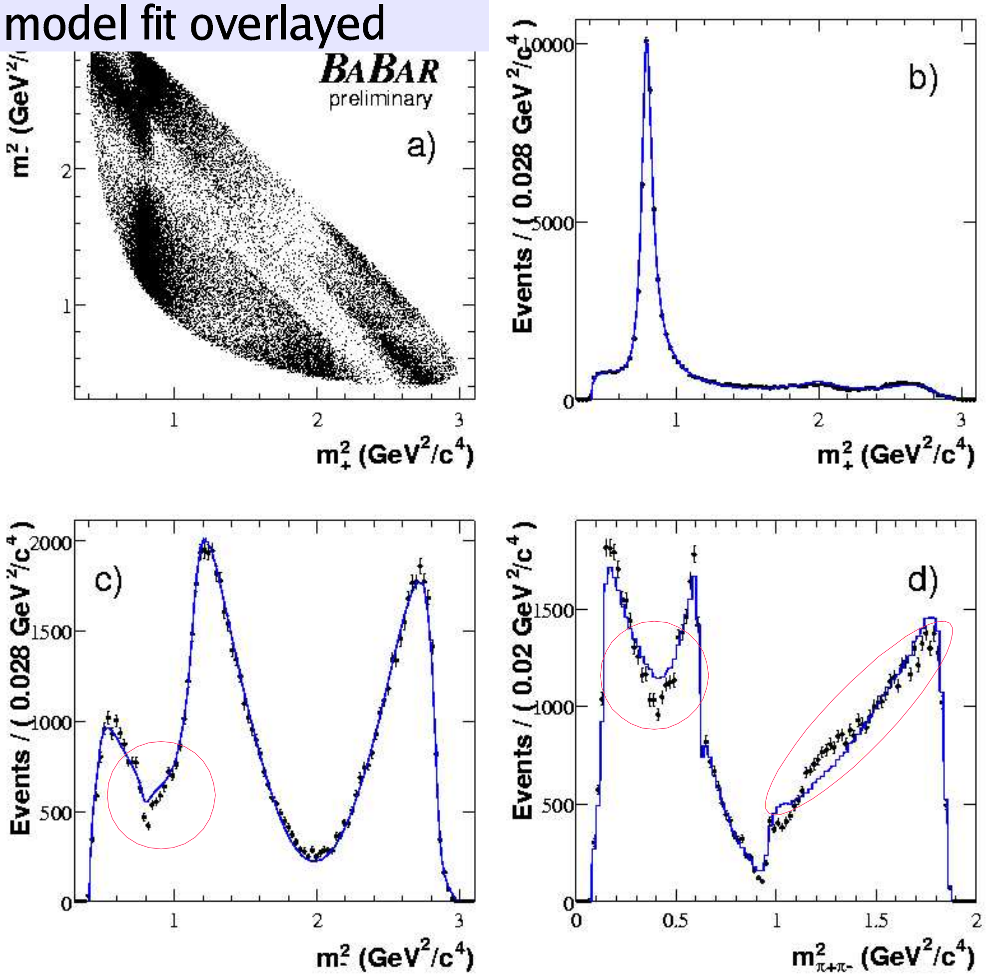
B candidates with m_{ES}>5.272 GeV/c^2

CP fit to CC: systematic errors

Source	x_+	y_+	x_-	y_-	x_+^*	y_+^*	x_-^*	y_-^*
$m_{ES}, \Delta E, \mathcal{F}$ shapes	0.0105	0.0086	0.0088	0.0141	0.0196	0.0218	0.0218	0.0146
Real D^0 fraction	0.0050	0.0047	0.0061	0.0036	0.0035	0.0049	0.0028	0.0032
Right sign D^0's	0.0157	0.0090	0.0070	0.0211	0.0065	0.0163	0.0108	0.0103
Eff. in the Dalitz plot	0.0078	0.0085	0.0089	0.0119	0.0067	0.0119	0.0040	0.0079
Tracking efficiency	0.0082	0.0080	0.0095	0.0123	0.0058	0.0109	0.0051	0.0046
Cont bkg. Dalitz shape	0.0195	0.0096	0.0160	0.0149	0.0133	0.0084	0.0083	0.0046
BB bkg. Dalitz shape	0.0026	0.0072	0.0069	0.0130	0.0061	0.0098	0.0029	0.0003
Invariant mass resolution	0.0031	0.0023	0.0022	0.0016	0.0031	0.0023	0.0022	0.0016
Dalitz amplitude and phases	0.0012	0.0069	0.0050	0.0033	0.0043	0.0138	0.0079	0.0079
SubTotal	0.0301	0.0226	0.0258	0.0368	0.0275	0.0373	0.0280	0.0223
Dalitz model	0.0068	0.0057	0.0414	0.0109	0.0084	0.0058	0.0346	0.0320
Total	0.0309	0.0232	0.0488	0.0384	0.0288	0.0377	0.0445	0.0390

Dalitz model systematics

BaBar data with CLEO model fit overlayed



Change Blatt-Weisskopf penetration factors (negligible)

Take into account the fit uncertainty of the phases and amplitudes of the resonances

Use different models for the Ks$\pi\pi$ Dalitz decay

CLEO model is the worse tried model (χ2 and total fit fraction)

Remove

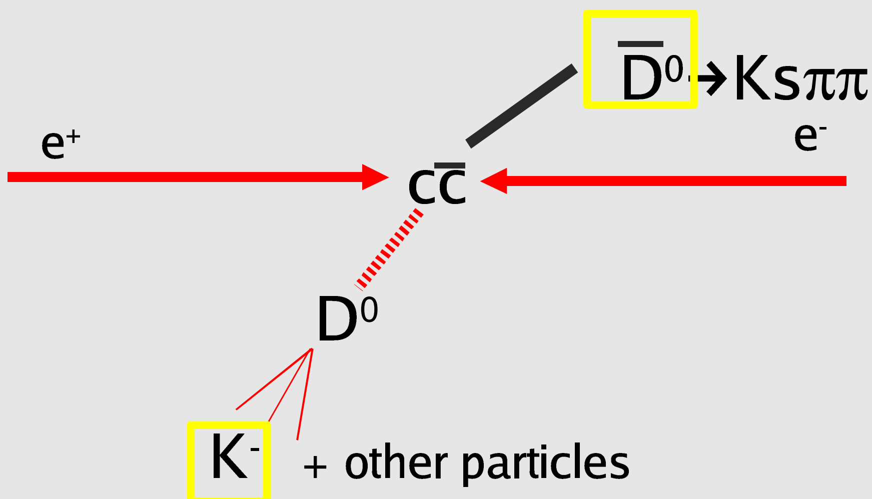
- K*0(1430) DCS,
- K*2(1430) DCS,
- K*(1410),
- ρ(1450),
- σ1,
- σ2

All single Breit-Wigners

Dalitz model uncertainty on γ: 10 degree

Right sign D^0 systematics

D^0 charge correlation in $c\bar{c}$ events



It is more probable to reconstruct a $B^- \to \bar{D}^0 K^-$

Estimate parameter $R = B^- \to \bar{D}^0 K^- / (B^- \to D^0 K^- + B^+ \to \bar{D}^0 K^-)$ on MC

Vary between the nominal value and 0.5 (quite conservative)

Frequentist interpretation

- Use a frequentist (classical) approach to determine CL regions in $r_B^{(*)}$, γ, $\delta^{(*)}$
- Determines α CL regions so that the probability that the region will contain the true point is α
- Basic problem: find PDF of fitted parameters as a function of the true parameters
  - In principle, fitted-true parameter mapping requires multi-dimensional scan of the experimental (full) likelihood
    - prohibitive amount of CPU and limited precision (steps in the scan)
  - Make optimal choice of fit parameters space and try analytical construction
    - **Cartesian coordinates**

The frequentist PDF

Single channel (D0K or D*0K)

Measured parameters (4D): z+≡(x+, y+), z-≡(x-, y-)

Truth parameters (3D): r_B, γ, δ

$$\frac{d^4P}{d^2\mathbf{z}_+ d^2\mathbf{z}_-}(\mathbf{z}_+,\mathbf{z}_-|\mathbf{p}^t) = G_2\left(\mathbf{z}_+; r_B^t\cos(\delta^t+\gamma^t), r_B^t\sin(\delta^t+\gamma^t), \sigma_{x_+}, \sigma_{y_+}, \rho_+\right) \times G_2\left(\mathbf{z}_-; r_B^t\cos(\delta^t-\gamma^t), r_B^t\sin(\delta^t-\gamma^t), \sigma_{x_-}, \sigma_{y_-}, \rho_-\right)$$

where

$$G_2(\mathbf{z};\mu_x,\mu_y,\sigma_x,\sigma_y,\rho) = \frac{1}{2\pi\sigma_x\sigma_y\sqrt{1-\rho^2}} e^{-\frac{1}{2(1-\rho^2)}\left[\frac{(x-\mu_x)^2}{\sigma_x^2}+\frac{(y-\mu_y)^2}{\sigma_y^2}-\frac{2\rho(x-\mu_x)(y-\mu_y)}{\sigma_x\sigma_y}\right]}$$

D0K-D*0K combination

Measured parameters (8D): z+, z-, z*+, z*-

Truth parameters (5D): r_B, γ, δ, r^*_B, δ*

$$\frac{d^8P}{d^2\mathbf{z}_+ d^2\mathbf{z}_- d^2\mathbf{z}^*_+ d^2\mathbf{z}^*_-}(\mathbf{z}_+,\mathbf{z}_-,\mathbf{z}^*_+,\mathbf{z}^*_-|\mathbf{p}^t) = \frac{d^4P}{d^2\mathbf{z}_+ d^2\mathbf{z}_-}(\mathbf{z}_+,\mathbf{z}_-|r_B^t,\gamma^t,\delta^t) \times \frac{d^4P}{d^2\mathbf{z}^*_+ d^2\mathbf{z}^*_-}(\mathbf{z}^*_+,\mathbf{z}^*_-|r_B^{*t},\gamma^t,\delta^{*t})$$

Confidence Regions (CR): D0K-D*0K combination

$$\alpha(\mathbf{p}^t) = \int_D \frac{d^8 P}{d^2\mathbf{z}_+ d^2\mathbf{z}_- d^2\mathbf{z}^*_+ d^2\mathbf{z}^*_-}(\mathbf{z}_+, \mathbf{z}_-, \mathbf{z}^*_+, \mathbf{z}^*_- | \mathbf{p}^t) d^2\mathbf{z}_+ d^2\mathbf{z}_- d^2\mathbf{z}^*_+ d^2\mathbf{z}^*_-$$

CL=1 - α(**pt**)

$$\frac{d^8 P}{d^2\mathbf{z}_+ d^2\mathbf{z}_- d^2\mathbf{z}^*_+ d^2\mathbf{z}^*_-}(\mathbf{z}_+, \mathbf{z}_-, \mathbf{z}^*_+, \mathbf{z}^*_- | \mathbf{p}^t) \geq \frac{d^8 P}{d^2\mathbf{z}_+ d^2\mathbf{z}_- d^2\mathbf{z}^*_+ d^2\mathbf{z}^*_-}(\mathbf{z}_+^{\text{data}}, \mathbf{z}_-^{\text{data}}, \mathbf{z}_+^{*\,\text{data}}, \mathbf{z}_-^{*\,\text{data}} | \mathbf{p}^t)$$

Integration domain D (CR)
Likelihood ordering

Generate ≈200M **pt** points

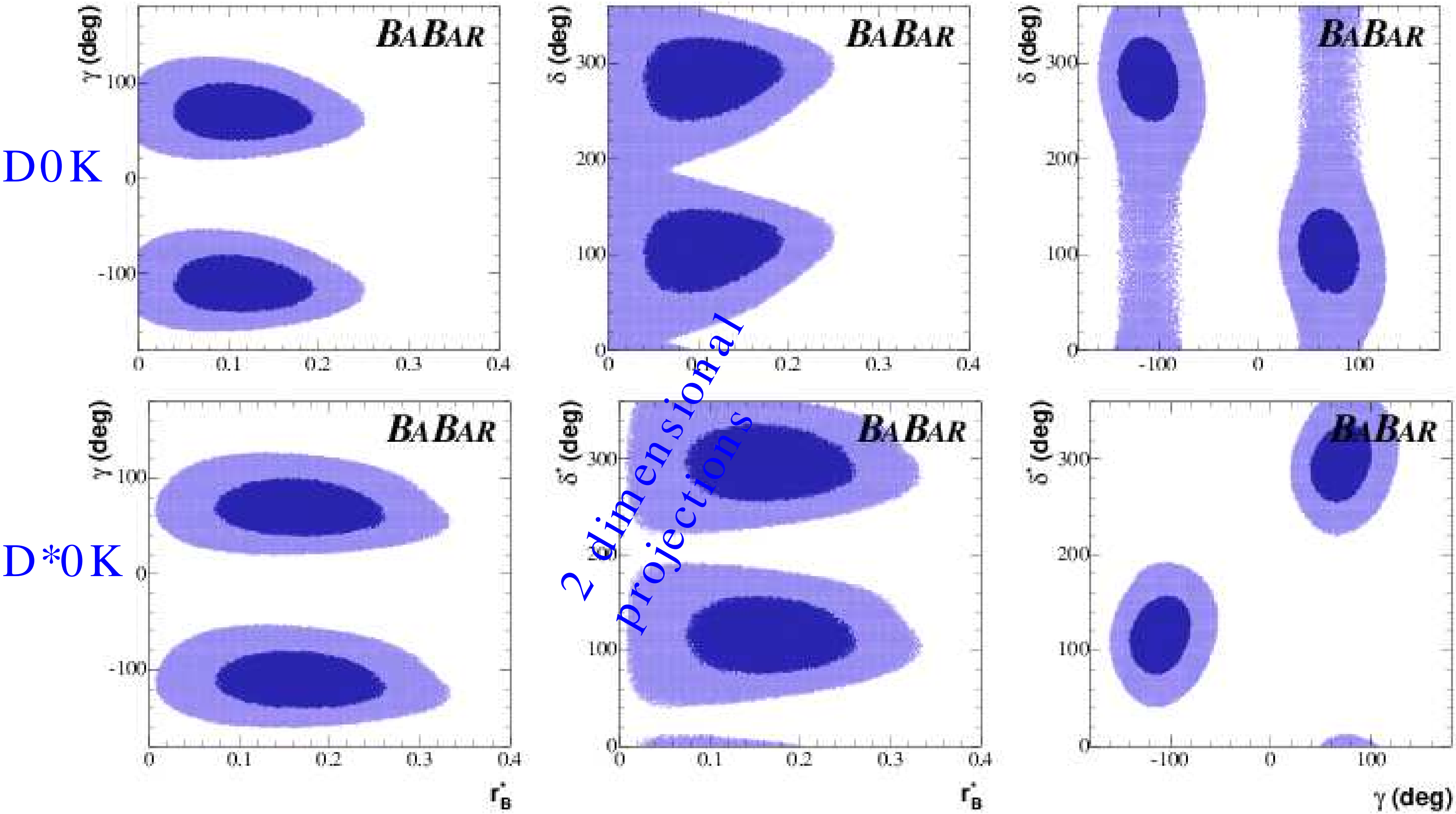
Calculate α(**pt**): Calculated analytically (hyperspheric coordinates)

Select points α(**pt**)≤α_0

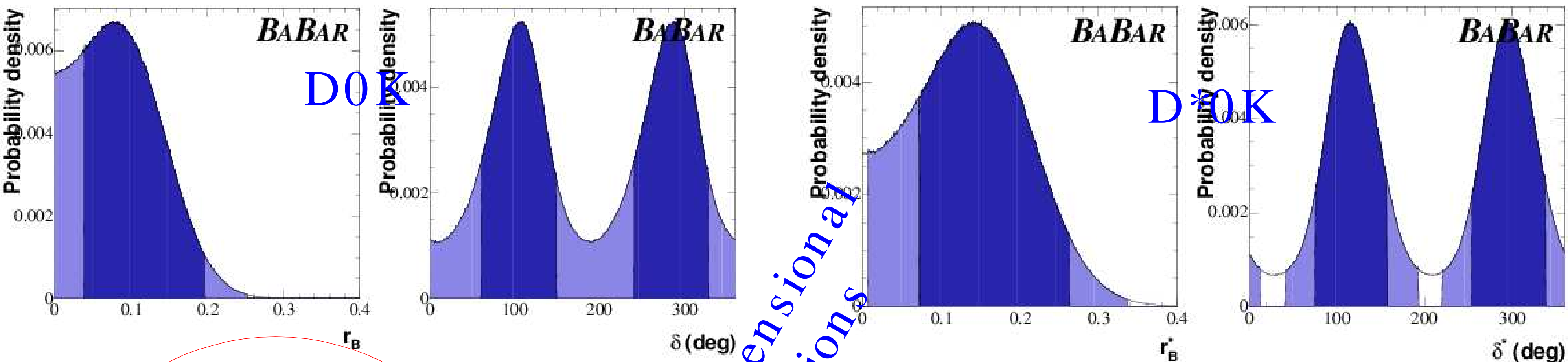
Chose α_0=0.037, 0.428

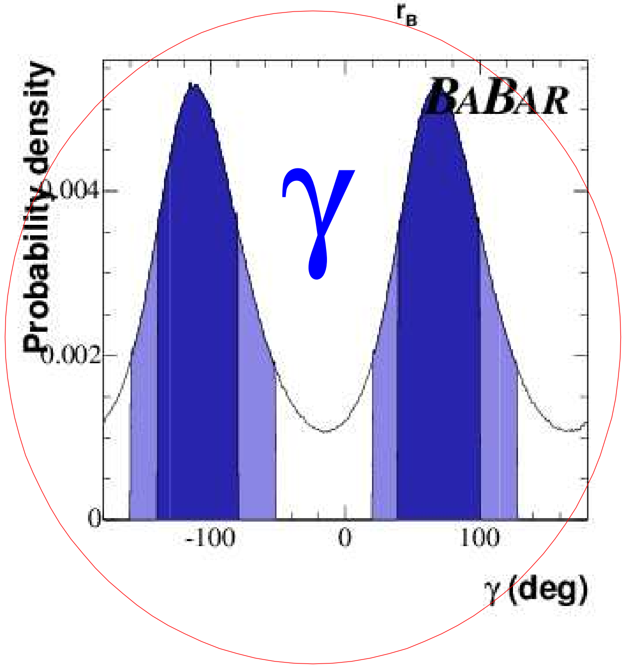
- 5D joint probability (cumulative χ^2 integral for ν=5)
- Correspond to 1σ and 1.96σ elipsoides
- Make 1D projections to quote 1σ and 1.96σ regions

D0K-D*0K combined CR I



D0K-D*0K combined CR II





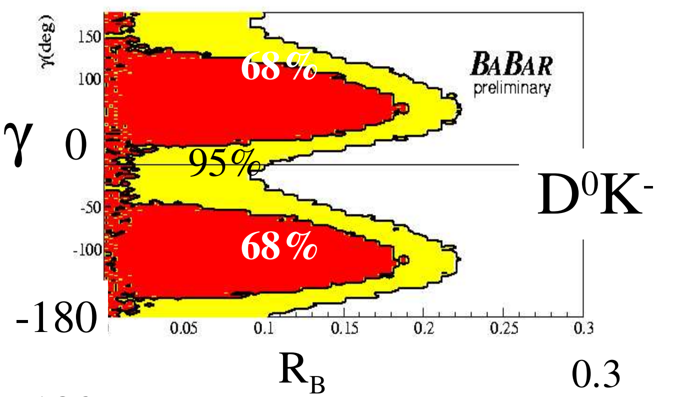
Parameter	1σ	1.96σ	Central value with error (1σ)
γ	[39,101] [220,280]	[20,129] [200,309]	70 ± 31
r_B	[0.039,0.198]	[0,0.253]	0.119 ± 0.079
r_B^*	[0.072],0.264]	[0.007,0.337]	0.168 ± 0.096
δ	[60,150] [240,329]	–	105 ± 45
δ^*	[254,339] [75,158]	[221,374] [41,194]	296 ± 43

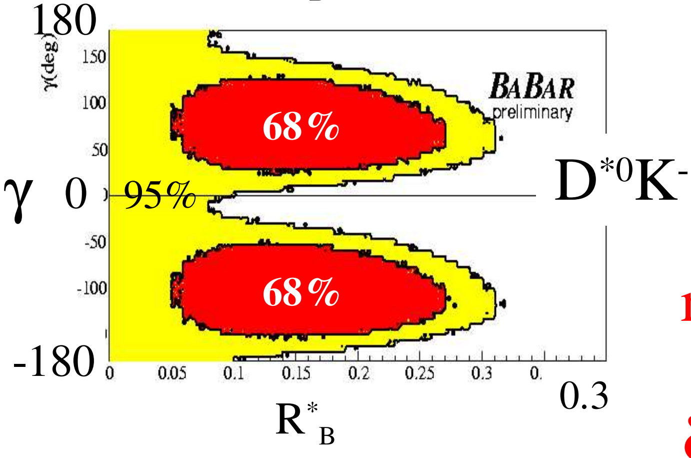
Statistical uncertainties only

Central values are the mean of the confidence intervals

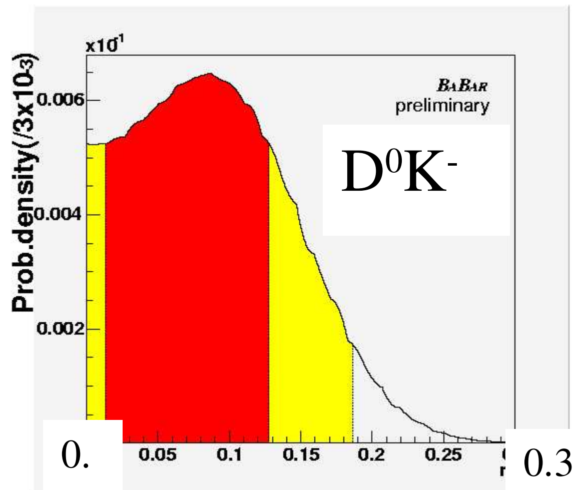
Bayesian approach (check)

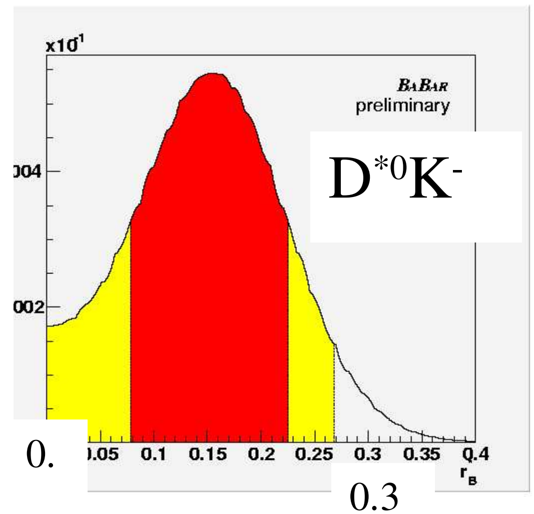
Updated ICHEP result





A posteriori $r_B(r_B^*)$ with uniform a priori





$r_B < 0.19$ (90% CL) *stat+syst*

$r^*_B = 0.16^{+0.07}_{-0.08} \pm 0.04 \pm 0.02$ *stat+syst*

$\delta_B = 114° \pm 41° \pm 8° \pm 10°$

$\delta_B^* = 303° \pm 34° \pm 14° \pm 10°$

$\gamma = 70 \pm 26° \pm 10° \pm 10°$

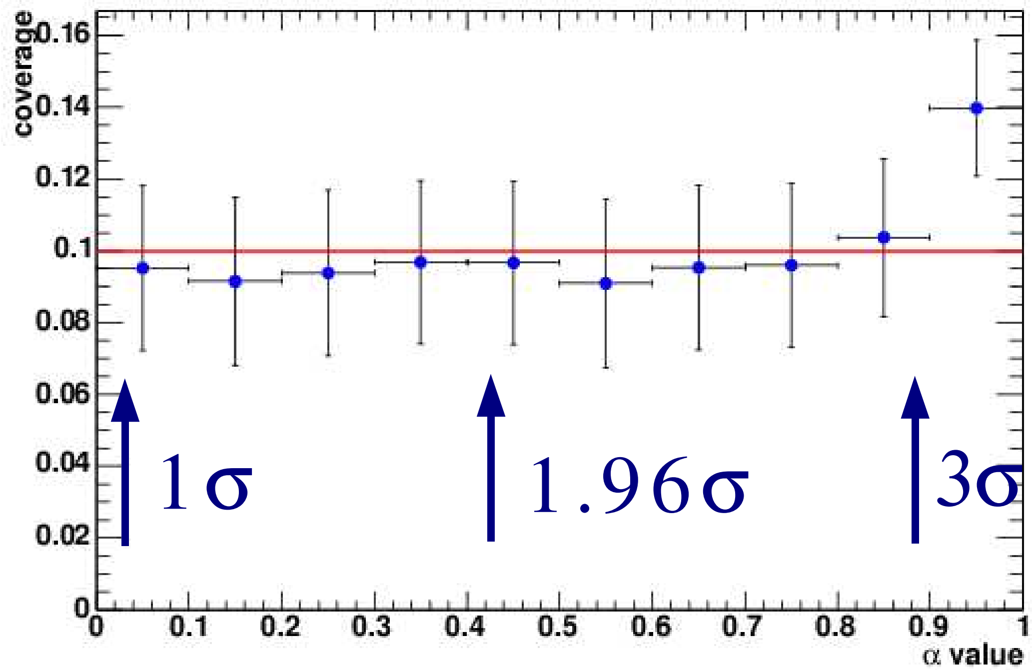
Dalitz model syst

Bayesian confidence regions

Good agreement with frequentist method !

Frequentist coverage

- Check coverage using experimental (full) likelihood
  - Verify perfect Gaussian behavior, fit error and correlation stability
- Generate 20K toy MC experiments tunned to data using as truth point **pt**=(r_B, r_B*, γ, δ, δ*) the fr
- For each experiment:
  - Perform fit in cartesian parameter space
  - Calculate α(**pt**)
  - Count number of experim for which $\alpha(\mathbf{pt}) \leq \alpha_0$



Significance of CP Violation

- Significance of CP Violation determined by evaluating the CL of the most probable CP conserving **pt** point
  - CL most probable CP conserving point = 1-α_{min}
  - Significance of CP violation or CL of CP violation = α_{min}

$$\mathbf{p}^t_{CP} = \{\mathbf{p}^t | \mathbf{p}^t = (r^t_B = 0, r^{*t}_B = 0, \gamma^t, \delta^t, \delta^{*t}) \text{ or } \mathbf{p}^t = (r^t_B, r^{*t}_B, \gamma^t = 0, \delta^t, \delta^{*t})\}$$

- D0K only (statistical): α_{min} = 65.5% (1.82σ)
- D*0K only (statistical): α_{min} = 82.8% (2.24σ)
- D0K+D*0K (statistical): α_{min} = **79.1% (2.68σ)**

Systematic uncertainties

Systematic uncertainties easily included by replacing the statistical errors in frequentist PDF (σ_{x+},σ_{y+},...) by the total

Parameter	1σ	1.96σ	Central value with error (1σ)
γ	[37,104] [217,284]	[13,134] [191,314]	70 ± 34
r_B	[0.029,0.206]	[0,0.268]	0.118 ± 0.089
r_B^*	[0.066],0.271]	[0.000,0.348]	0.169 ± 0.103
δ	[54,156] [233,335]	–	105 ± 51
δ^*	[253,342] [72,163]	–	298 ± 45

Significance of CP violation D0K+D*0K (statistical+systematic)

α_{min} = **72.1% (2.51σ)**

Summary and plans

- We have measured the CP violating parameters:

$x_+ = r_{B+}\cos(\delta+\gamma) = -0.129 \pm 0.070 \pm 0.031$

$y_+ = r_{B+}\sin(\delta+\gamma) = 0.019 \pm 0.079 \pm 0.023$

$x_- = r_{B-}\cos(\delta-\gamma) = 0.077 \pm 0.069 \pm 0.049$

$y_- = r_{B-}\sin(\delta-\gamma) = 0.064 \pm 0.092 \pm 0.038$

$x^*_+ = r^*_{B+}\cos(\delta^*+\gamma) = 0.140 \pm 0.093 \pm 0.029$

$y^*_+ = r^*_{B+}\sin(\delta^*+\gamma) = 0.013 \pm 0.120 \pm 0.038$

$x^*_- = r^*_{B-}\cos(\delta^*-\gamma) = -0.131 \pm 0.093 \pm 0.045$

$y^*_- = r^*_{B-}\sin(\delta^*-\gamma) = -0.143 \pm 0.105 \pm 0.039$

- A frequentist analysis of these results yields:

$$\gamma = (70 \pm 34)^{\circ}$$

- Significance of direct CP violation 2.5σ
- Good agreement with Bayesian analysis with flat prior
- Planning to have PRL draft ready for CWR by the end of the month