# Measuring $\gamma$ with

$$B^0 \to D^0 K^{*0}$$

# decays

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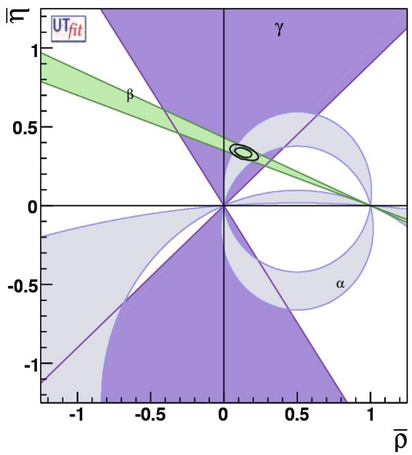
# Outline

- Summary of analysis technique and selection
- Likelihood fit structure
- CP fit and toy-MC tests
  - Cartesian coordinates
  - Polar coordinates
- Measurement strategy
- Unblind results on data

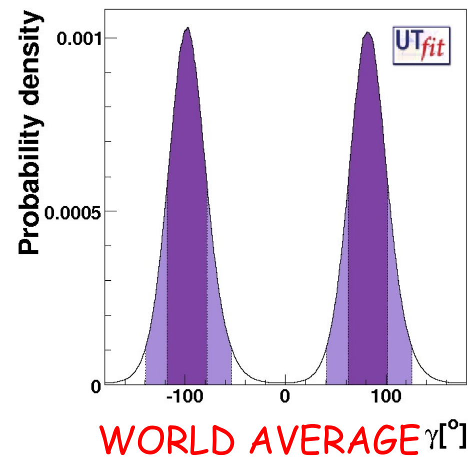
# Measurements of $\gamma$

Relative phase between $V_{cb}$ and $V_{ub}$ ,usually measured in charged channels $B^+ \to D^{(*)0} K^+$



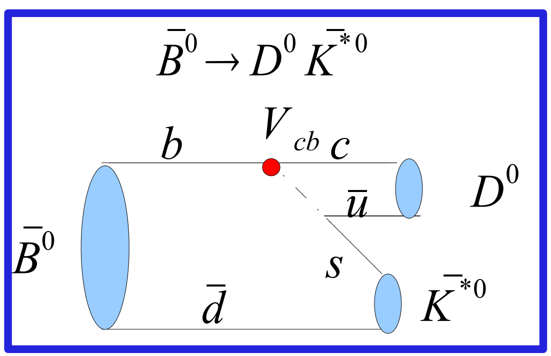

Combination of many methods (GLW, ADS, Dalitz)

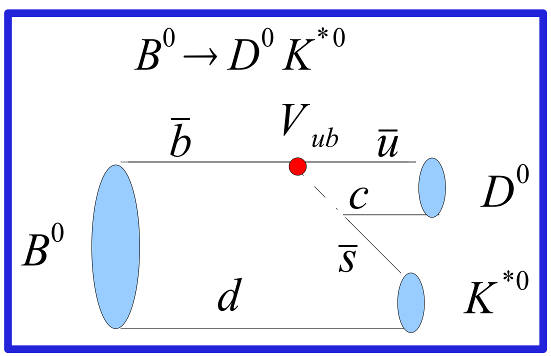
$\gamma = (83 \pm 19)^o$




WORLD AVERAGE

Also in the neutral B decays phases $V_{cb}$ and $V_{ub}$




But $B^0$ – $B^0$bar mixing…$\sin(2\beta+\gamma)$

# The idea

Study the decay:

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

$$K^{*0} \to K^+ \pi^-$$

$$\overline{D}^0 (D^0) \to K_S \pi^+ \pi^-$$

$$K_S \to \pi^- \pi^+$$

with a $D^0$ Dalitz analysis

$$r_B = \left| \frac{A(\bar{B}^0 \to D^0 K^{*0})}{A(B^0 \to D^0 K^{*0})} \right|$$

- Decay is self tagging (no time-dependent measurement)
- The ratio $r_B \sim 0.4$
- The $D^0$ Dalitz plot is well known. In the charged B sector, the Dalitz method gives the best error on $\gamma$ (~40°)

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# Data and MC samples

Moose signal MC production

SP8 MC

| | # events | Cross section [nb]/BR | Luminosity [fb-1] |
|---|---|---|---|
| Signal | 30K | 5.8 10^-7 | ~50ab-1 |
| B0B0bar | 385M | 1.05/2 | 733 |
| B+B- | 394M | 1.05/2 | 751 |
| Ccbar | 267M | 1.3 | 206 |
| Uds | 324M | 2.09 | 155 |

DATA (Vivace dataset)

| | Luminosity [fb-1] |
|---|---|
| Onres | 353 |
| Offres | 37 |

# Selection cuts



STANDARD CUTS

OPTIMIZED CUTS

SELECTION

$\cos\alpha_{K_S} > 0.997$ Angle between the KS flight direction and its momentum

$|M_{D^0} - M_{D^0}^{PDG}| < 0.011\ GeV/c^2$

$|M_{K_S} - M_{K_S}^{PDG}| < 0.007\ GeV/c^2$

$|\Delta E| < 0.025\ GeV$

$P(\chi^2, B^0) > 0.001$ $\quad |\cos\theta_B^{CM}| < 0.9$

$|\cos\theta_{K*}^{HEL}| > 0.3$

$|M_{K*} - M_{K*}^{PDG}| < 0.048\ GeV/c^2$

No dedicated cuts to fight continuum!

K- from K*: PID KTight

$P(\chi^2, B^0) > 0.001$

$P(\chi^2, D^0) > 0$

$P(\chi^2, K^{*0}) > 0$

Best B candidate choice:

$\chi_1^2 = \{(M_{D^0} - M_{D^0}^{PDG})/\sigma_{M_{D^0}}\}^2$

Best (highest) $|\cos\theta_{HEL}^{K*}|$

Efficiency on signal:

$\epsilon_{SELECTION}^{SIG} \sim 11\%$

Peaking background contribution evaluated to be negligible.

See BAD #1467

# Likelihood fit: the structure



Total pdf product of yields and CP pdfs

YIELD PDF:

$$f(x/\theta, N') = \frac{1}{N'}(N_{SIG} f_{SIG}(m_{ES}, Fisher, \Delta t) +$$

$$+ N_{BB} f_{BB}(m_{ES}, Fisher, \Delta t) + N_{CONT} f_{CONT}(m_{ES}, Fisher, \Delta t))$$

variables uncorrelated:

Gaussian (Argus)

$$f(m_{ES}, Fisher, \Delta t) = f(m_{ES}) * f(Fisher) * f(\Delta t)$$

Bifurcated Gaussian

Tail Gaussian

$$(1-\phi_{tail}-\phi_{out}) G(\Delta t, \mu_{core}, s_{core}\sigma_{\Delta t}) + \phi_{tail} G(\Delta t, \mu_{tail}, \sigma_{tail}) +$$

Core Gaussian with sigma dependent from deltat error

$$+\phi_{out} G(\Delta t, \mu_{out}, \sigma_{out})$$

Outlier Gaussian

# Likelihood fit: the structure

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**CP PDF:**

$B^0$ : $PDF^+ = |f(s_{12},s_{13}) + r_s e^{i(\gamma+\delta)} f(s_{13},s_{12})|^2$

$B^0$bar : $PDF^- = |f(s_{13},s_{12}) + r_s e^{i(-\gamma+\delta)} f(s_{12},s_{13})|^2$

$V_{cb}$ amplitude

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

Same $B^0 \to D^0 K^{*0}$ final state : interference

Sum of Breit-Wigner Dalitz model gives $f(s_{12},s_{13})$

CP fit gives the 3 parameters :

$(r_S\ ,\ \gamma\ ,\ \delta_S)$

$$PDF = |f_{\mp.}|^2 + r_S^2 |f_{\pm.}|^2 + 2 k r_S \left( R\{f_{\mp.} f_{\pm.}^*\} \cos(\delta \mp \gamma) - I\{f_{\mp.} f_{\pm.}^*\} \sin(\delta \mp \gamma) \right)$$

parameter k, that takes in account the non-K*(892) contributions, evaluated to be ~0.95.
It will be varied in a reasonable interval and the effect will be a systematic uncertainty.

See:
http://www.slac.stanford.edu/BFROOT/www/Organization/CollabMtgs/2006/detJun06/Wed2a/pruvot.pdf

# New Dalitz parametrization

## CP PDF:

"Classic" Dalitz parametrization: 17 resonances whose amplitudes are parametrized with Breit-Wigner

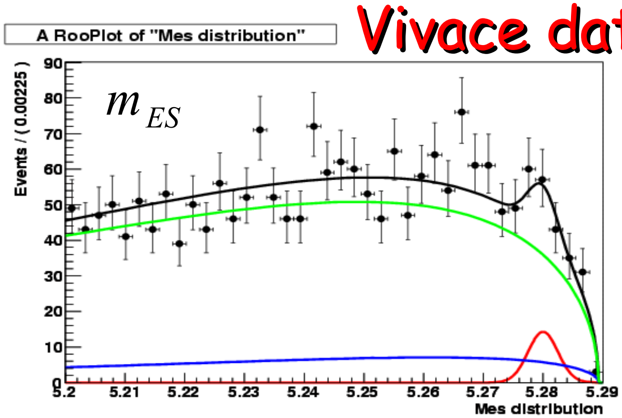
We now use a new Dalitz parametrization:

- K*(892) mass slightly shifted (in Babar is a bit different wrt to PDG)
- Scalar (0+) treated with the K-Matrix formalism
- K*(1-)(1680) parametrized with LASS parameters (no BW)
- no K*(1-)(1410)

No big effect is expected...

# Yield results on data

Fit performed on 353 $fb^{-1}$ on-resonance data (results for CP fit parameters blinded).
Floated parameters: yields, BB background Argus shape, CP parameters ($r_B$ fixed).




**Vivace dataset**

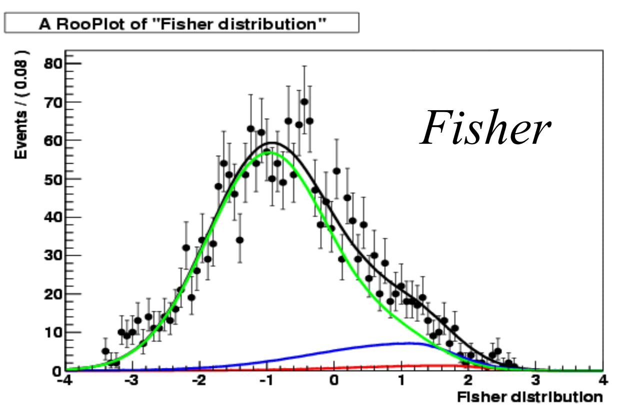
$$N_{SIG} = 39 \pm 9$$

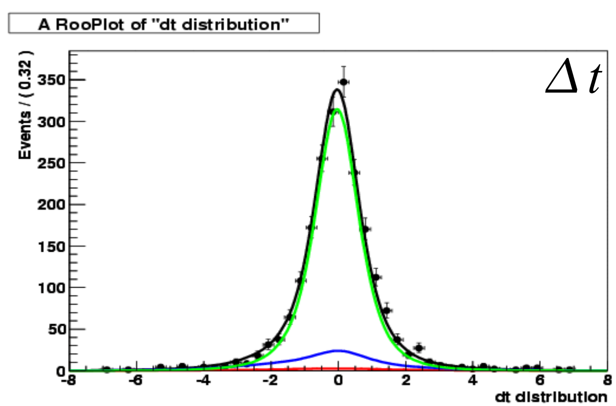
$$N_{B\bar{B}} = 231 \pm 28$$

$$N_{CONT} = 1772 \pm 48$$

$$\frac{N_{SIG}}{\sigma^2_{N_{SIG}}} \sim 0.48$$

**Yield results stable also if $r_B$ floated (and blinded!)**

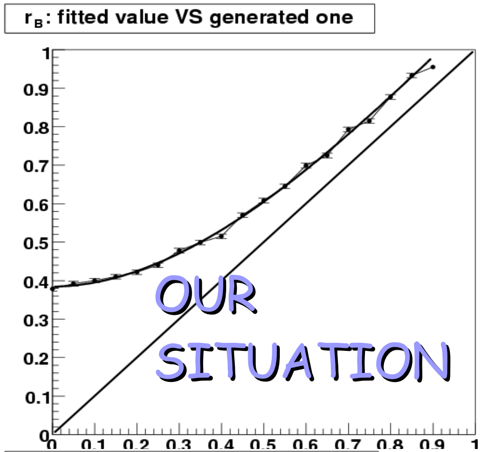


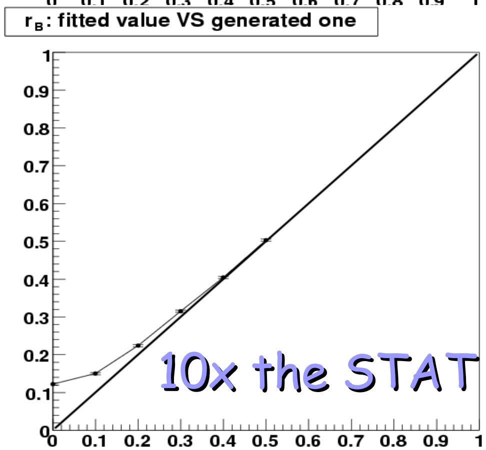



# CP fit: polar coordinates

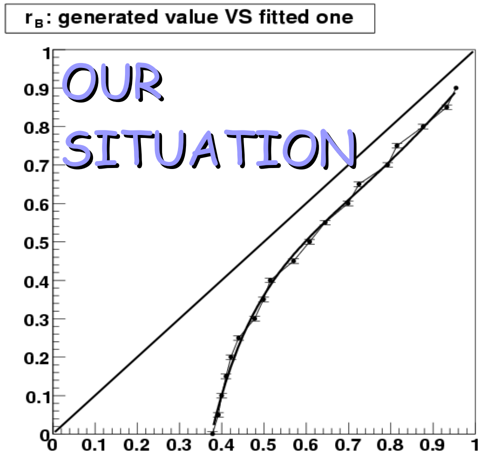
**Linearity problem**: due to the likelihood dependence on $r_B$, one tends to fit a bigger $r_B$ than the “true” one and then to underestimate the error on $\gamma$

**$r_B$ fit vs $r_B$ gen**




**$r_B$ gen vs $r_B$ fit**




0.38 !!!

**Very difficult to convert!!**

# CP fit: cartesian coordinates

$$x_{\pm} = r_B \cos(\delta \pm \gamma)$$

$$y_{\pm} = r_B \sin(\delta \pm \gamma)$$

Cartesian coordintaes, used in the $D^0K^-$ Dalitz analysis, they solve the linearity problem

Problems when performing the fit in cartesian coordinates due to the poor statistics: the variables do not have Gaussian behaviour. Biases.

FROM TOY MC STUDIES..

| | OUR CONFIGURATION | 10x the STAT |
|---|---|---|
| $\mu_{x+}^{PULL}$ | $-0.52 \pm 0.005$ | $-0.04 \pm 0.05$ |
| $\sigma_{x+}^{PULL}$ | $0.82 \pm 0.03$ | $0.97 \pm 0.04$ |
| $\mu_{x-}^{PULL}$ | $-0.07 \pm 0.05$ | $-0.02 \pm 0.05$ |
| $\sigma_{x-}^{PULL}$ | $0.78 \pm 0.04$ | $0.99 \pm 0.04$ |
| $\mu_{y+}^{PULL}$ | $-0.18 \pm 0.05$ | $-0.05 \pm 0.06$ |
| $\sigma_{y+}^{PULL}$ | $0.79 \pm 0.04$ | $1.1 \pm 0.04$ |
| $\mu_{y-}^{PULL}$ | $0.40 \pm 0.05$ | $-0.03 \pm 0.05$ |
| $\sigma_{y-}^{PULL}$ | $0.79 \pm 0.04$ | $1.03 \pm 0.04$ |

And still problems in the case of 45 signal only events...due to the statistics! Bias confirmed by Fernando et al.
We have ~39 events, and background..

See http://www.slac.stanford.edu/cgi-bin/lwgate/DOK-DALITZ/archives/dok-dalitz.200610/date/ for more detail

# Measurement strategy



- The problems we see are due to the low statistics
- The situation will eventually improve when performing a simultaneous fit with a measurement of $r_B$

$N_{SIG} = 39 \pm 9$

$N_{B\bar{B}} = 231 \pm 28$

$N_{CONT} = 1772 \pm 48$

**Strategy:**

for the moment perform the measurement of gamma as a scan in $r_B$ (likelihood scan of gamma for each value of $r_B$).

**TOY-MC with $r_B$ fixed**

Coverage test for $\gamma$ :
(65+-2)% for rB=0.40
(65+-2)% for rB=0.35

% of cases in which:

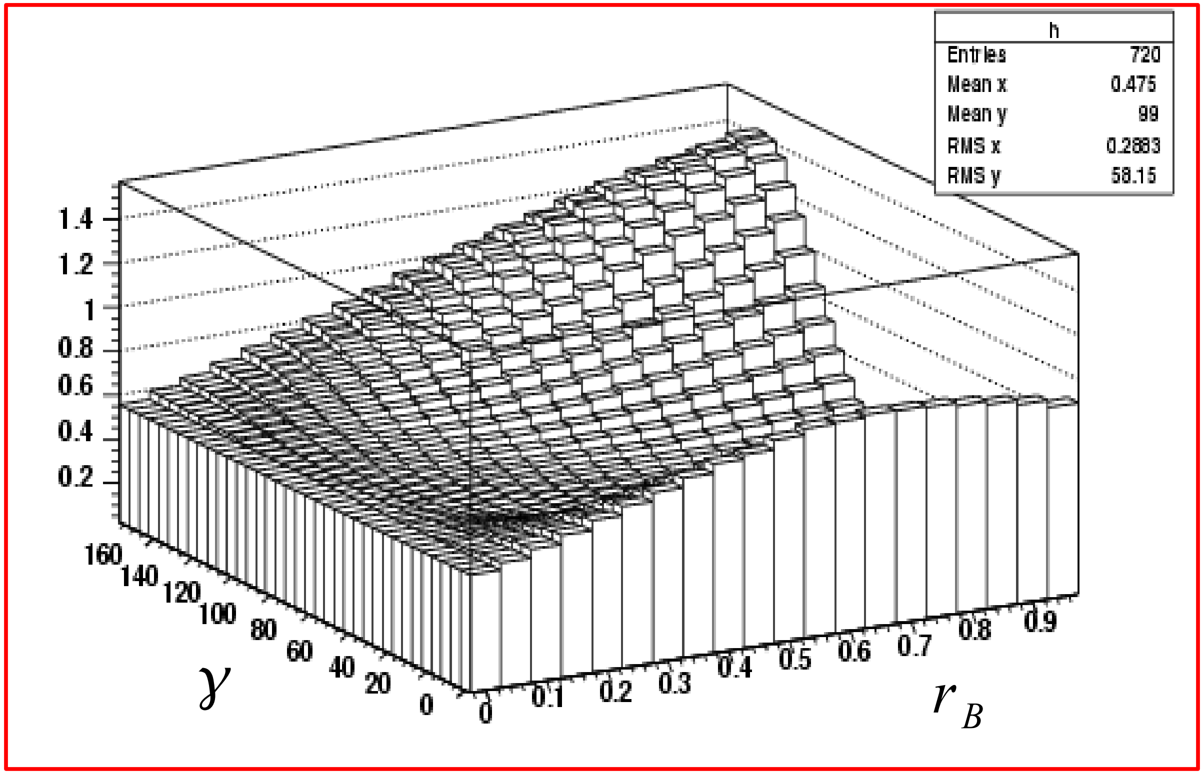
$$|LogL() - LogL(\gamma = \gamma_{GEN})| < 1.$$

Similar to what is done in D(*)pi for $\sin(2\beta+\gamma)$ !!!

# CP results on data

Output of the measurement: scan of gamma wrt rB:

Pdf

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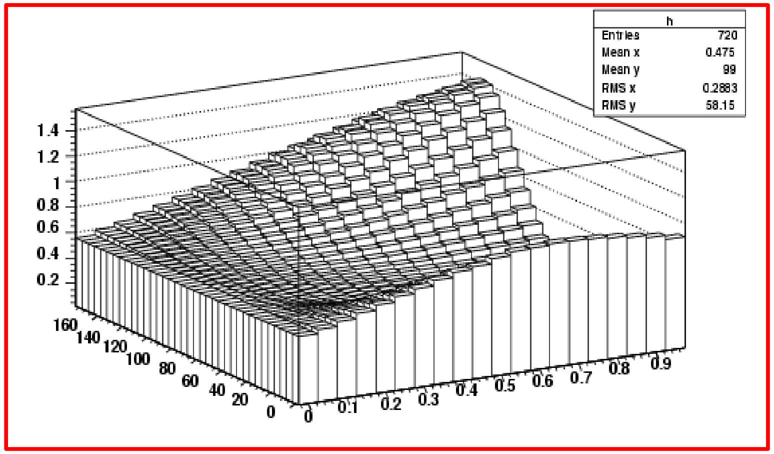
# On data

If we combine the likelihood so obtained with a fake $r_B$ measurement

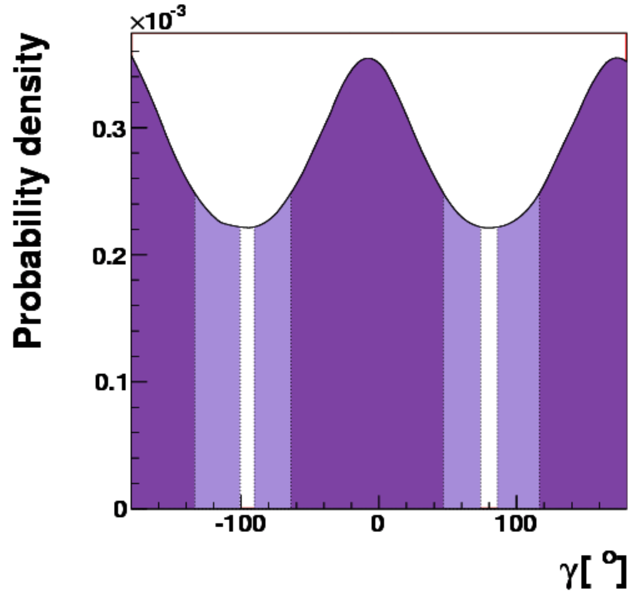



+

$$r_B = r_{D^0 K^{*0}} = 0. \pm 0.27$$

$$(r_B < 0.4 @ 90\% C.L.)$$

=




$$\gamma = -9 \pm 55^o$$

**WITH THE OLD DALITZ:**

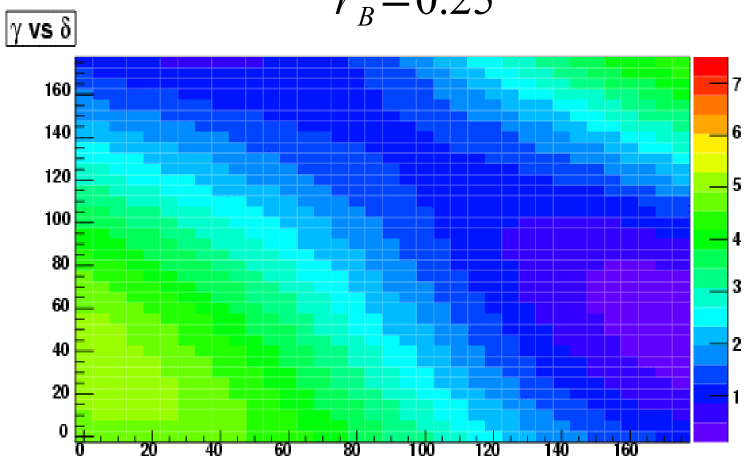
$$\gamma = 2 \pm 53^o$$

# CP results on data

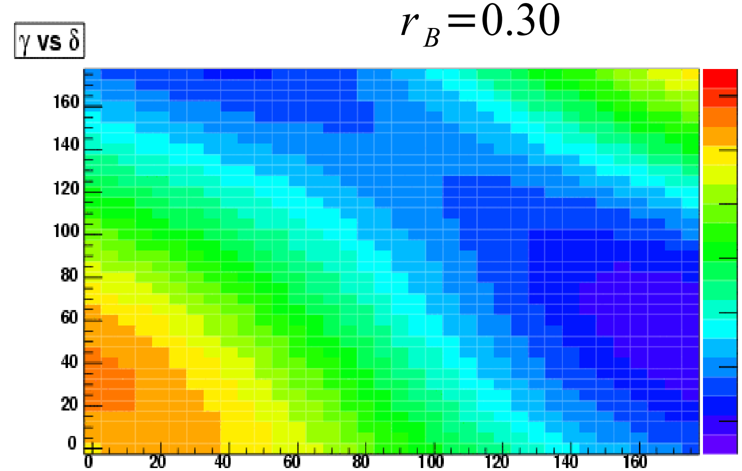
$-\Delta \log L$

Scan $\delta\ VS\ \gamma$ with rB fixed.

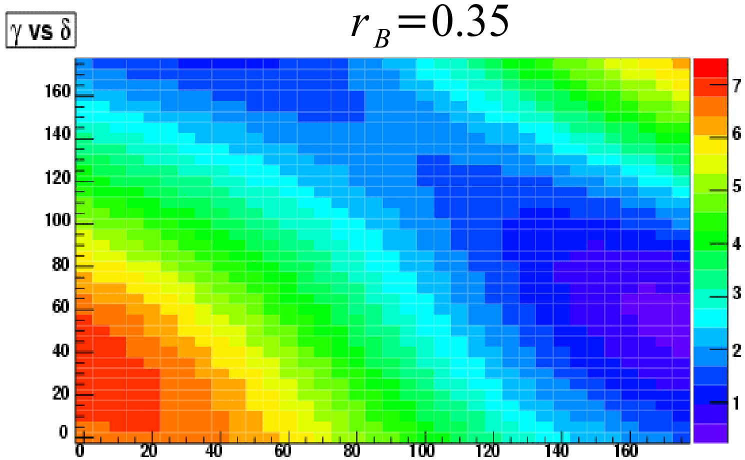
$r_B = 0.25$



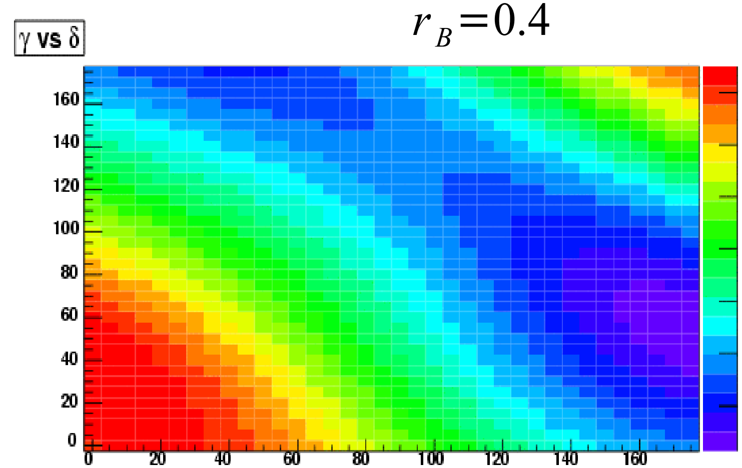

$r_B = 0.30$




$r_B = 0.35$




$r_B = 0.4$

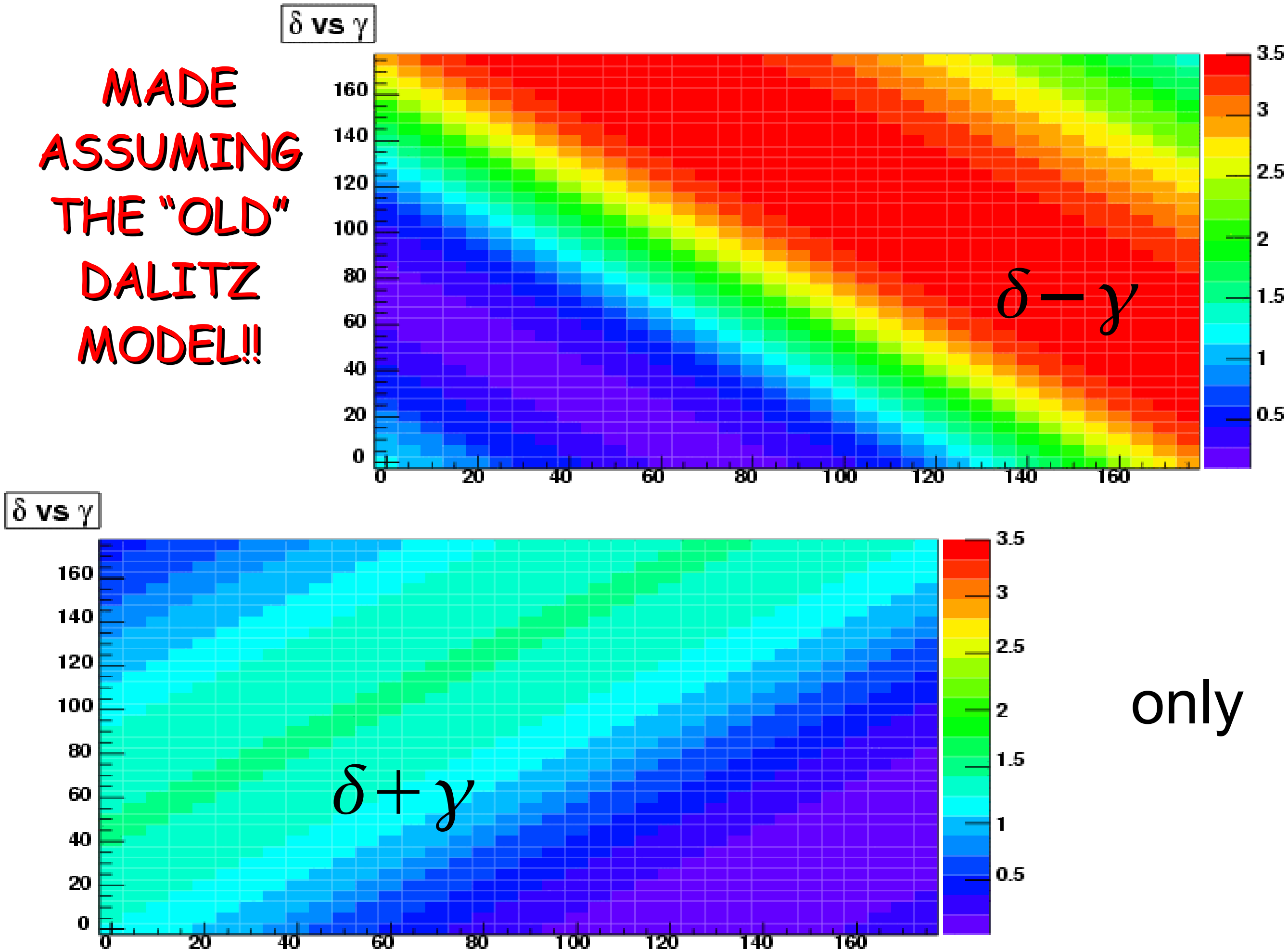



MADE ASSUMING THE "OLD" DALITZ MODEL!!

# CP results on data

$-\Delta \log L$

MADE ASSUMING THE "OLD" DALITZ MODEL!!




only $B^0$

only $\bar{B}^0$

We are more sensitive to gamma in the B0 sample, due to the position of the events in the Dalitz plane

# Conclusions



- 39+-9 signal events found on 353 $fb^{-1}$ onres data (purity~0.48)
- Measure of gamma scanning for $r_B$
- New dalitz model used
- Combining with $r_B$ 0.+-0.27 -> gamma=-9+-55 (~10 deg change with new dalitz)
- BAD #1467 v06 is in RC, plans to go in CWR directly with a PRL-shaped BAD (ready)
- Systematics errors under evaluation

# BACKUP SLIDES

# Reconstruction

**Skim:** B0DKNeut (TagBit B0ToD0KstarDefault)

**Reco:**

- B0 (TreeFitter “Beam” constraint)
  - D0: (prefit 1774<MD0<1.954 TreeFit “Mass” constraint)
    - Ks: KsDefault (TreeFitter “Geo” constraint, post fit: 0.47267<MKs<0.52267)
    - Pions: GoodTracksVeryLoose
  - K*0: (prefit |MK*0 – Mpdg|<0.75 GeV Cascade “Geo” constraint)
    - Kaons and Pions: GoodTracksVeryLoose

# Peaking background evaluation

From MC: three kinds of peaking background:

- Charmless events of the kind: $B^0 \to K^{*0} K_S K_S$
- "Charmed" events of the kind: $B^0 \to \overline{D^0} \rho^0 (D^0 \to K_S \pi^+ \pi^-)$
- "Charmed" events of the kind $B^0 \to \overline{D^0} K^{*0} (D^0 \to 4\pi)$

| SP MC | EVALUATION |
|---|---|
| ~1 event on 730 fb-1 | -2+-8 events. evaluated on data in D0 mass sidebands |
| ~1 event on 730 fb-1 | ~0.9 exp events evaluated on dedicated MC |
| ~1 event on 730 fb-1 | ~0.1exp events,evaluated on dedicated MC |