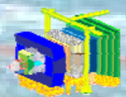
PHYSICS AT LHC
3-8 July 2006
CRACOW POLAND

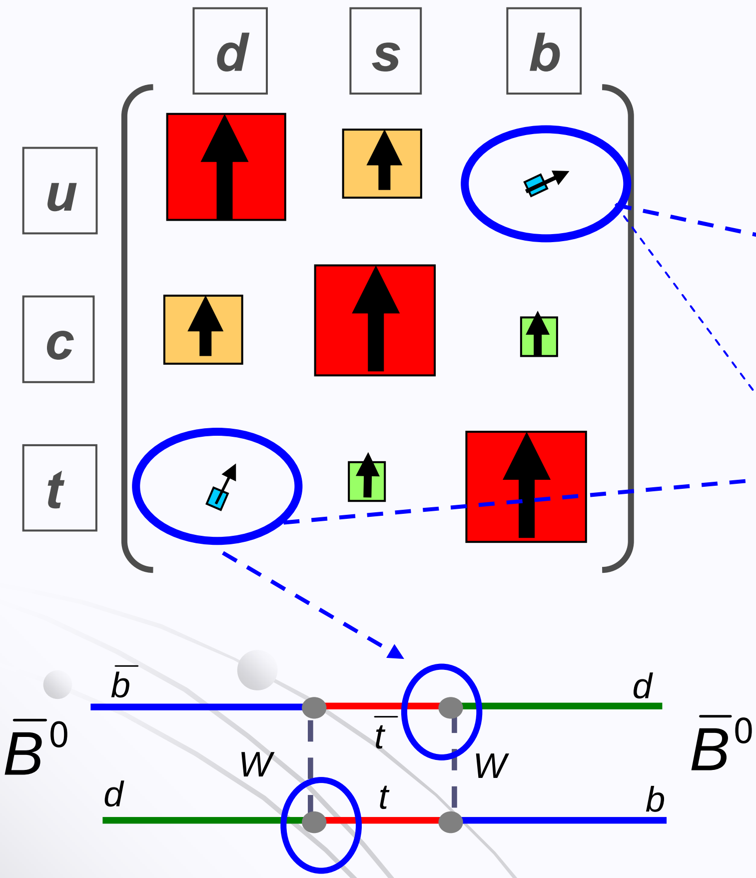
Angle α at LHCb

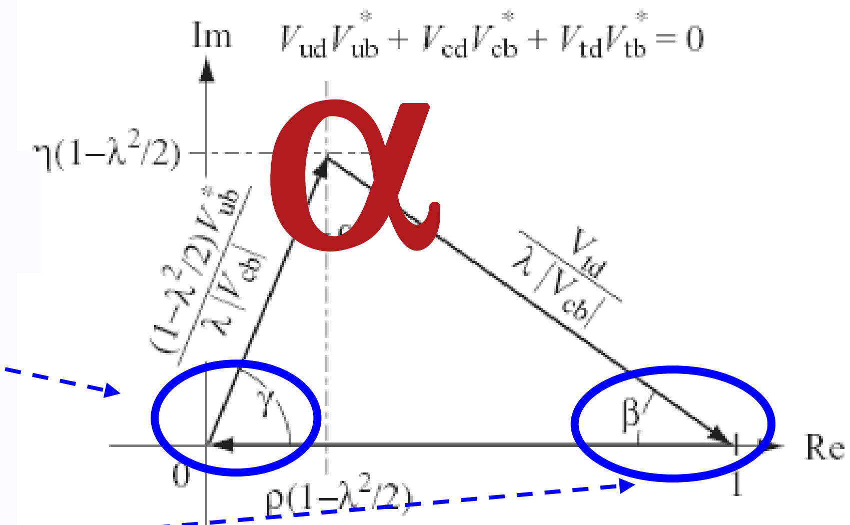


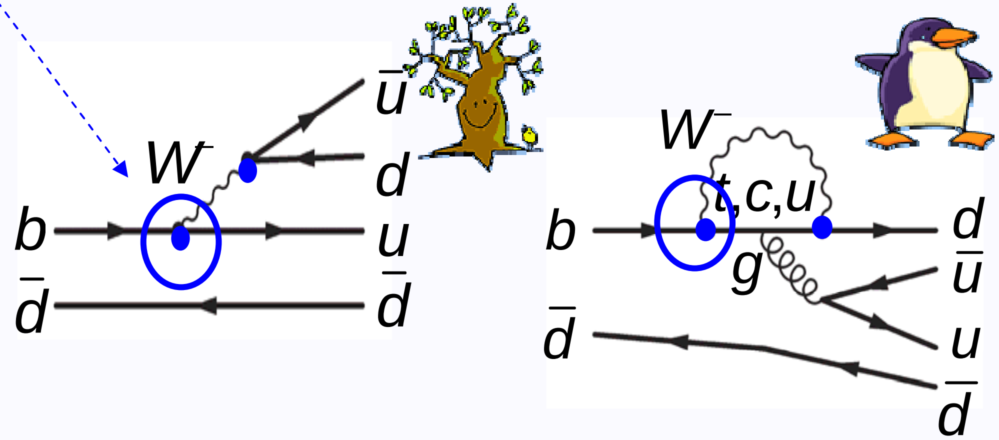
O. Deschamps
LPC Clermont-Ferrand
On behalf of the LHCb collaboration

The angle α in SM

CKM unitary matrix :







charmless B_d decays as B→ ππ/ρρ/ρπ are sensitive to $\beta + \gamma = \pi - \alpha$

Current status of α

- Direct measurements at B factories :

B➛ππ $\alpha^{\pi\pi} > 71°$

B➛ρρ $\alpha^{\rho\rho} = (96.5 \pm 16.5)°$

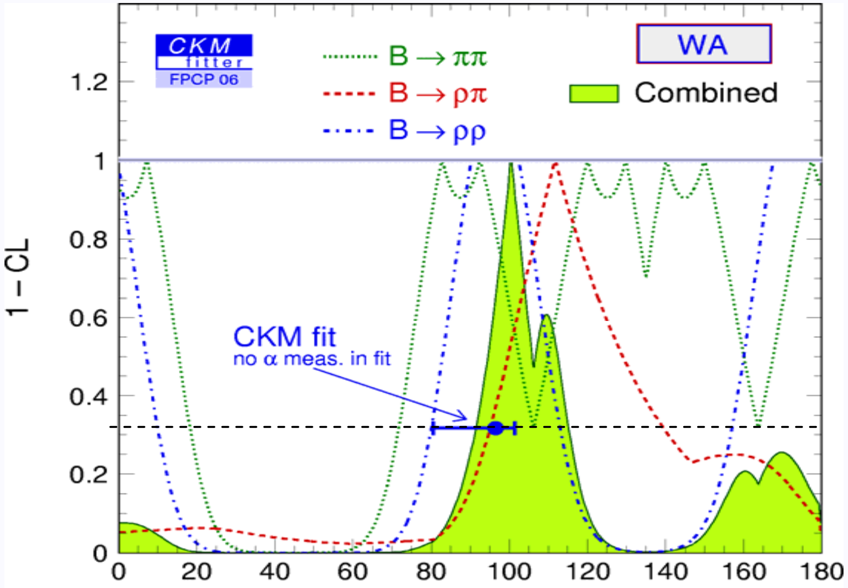
B➛ρπ $\alpha^{\rho\pi} = (111.8\ ^{+27.7}_{-16.6})°$

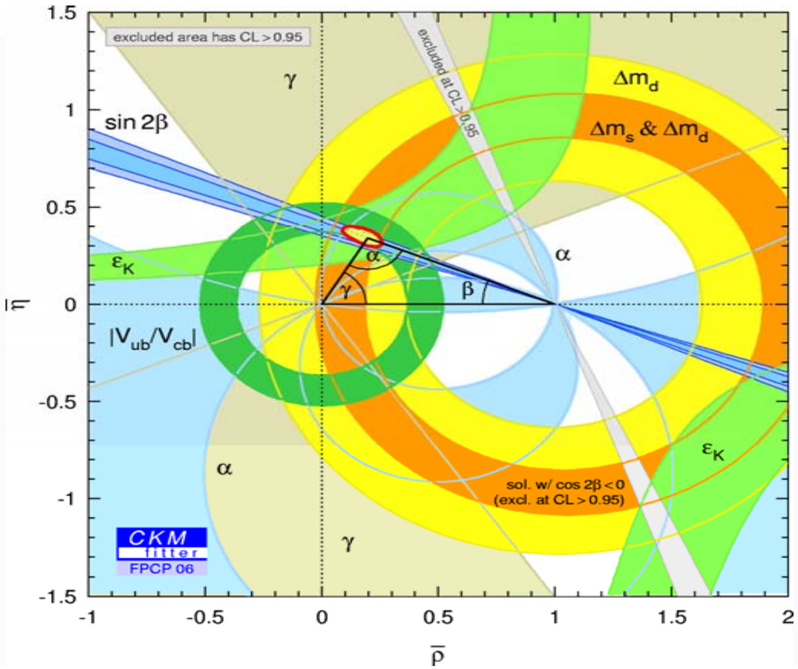
- Combined :

$$\alpha = (100.2\ ^{+4.9}_{-16.0})°$$

- Indirect :

$$\alpha = (96.5\ ^{+15.0}_{-8.8})°$$



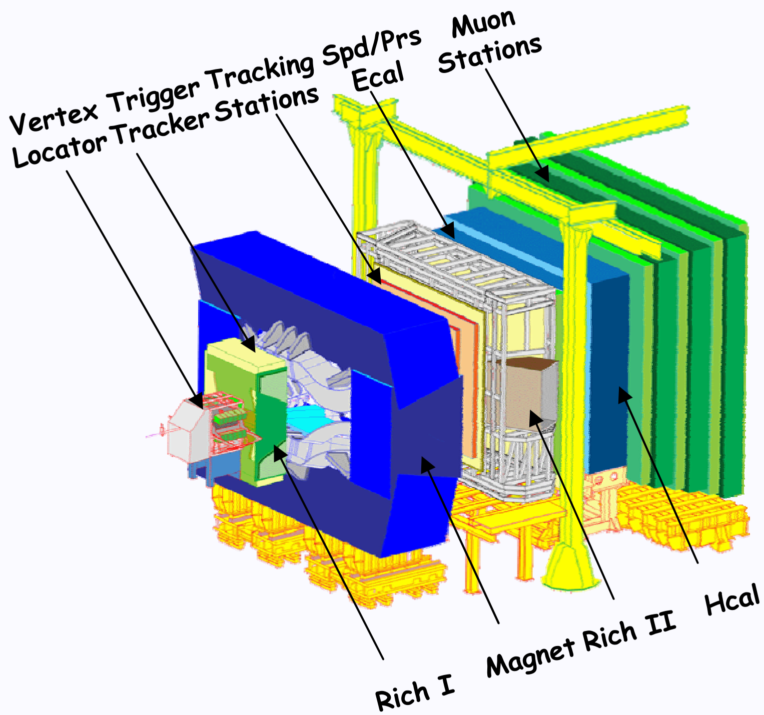


The angle α in LHCb context

- α extraction with LHCb

I - Time dependent Dalitz analysis of $B_d \to (\rho\pi)^0$

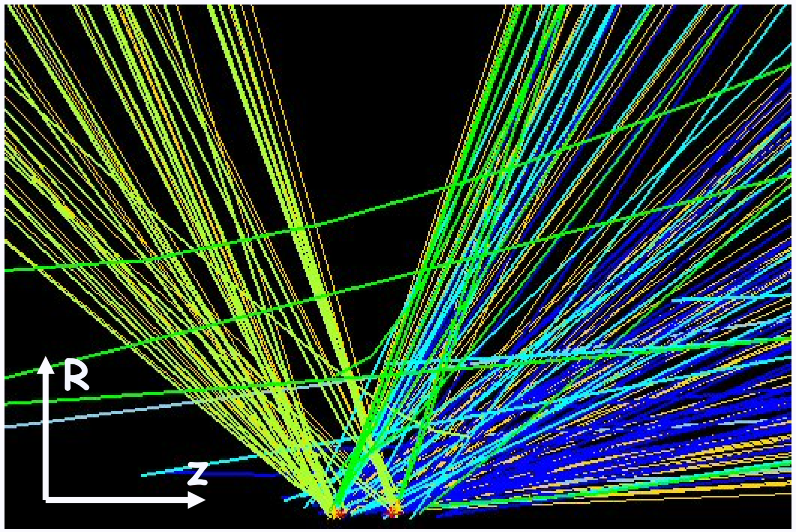
II - SU(2) analysis of $B \to \rho\rho$ modes



- Experimental challenge :

• Reconstruct $B \to 3\pi$ & 4π final states in a high multiplicity environment

• Neutral π^0 in $\rho^+\rho^-$, $\rho^+\rho^0$, $(\rho\pi)^0$ decays



Neutral pions reconstruction with LHCb

❑ Resolved π^0 :

neutral pion reconstructed from a pair of isolated photons

mass resolution ~ 10 MeV/c^2

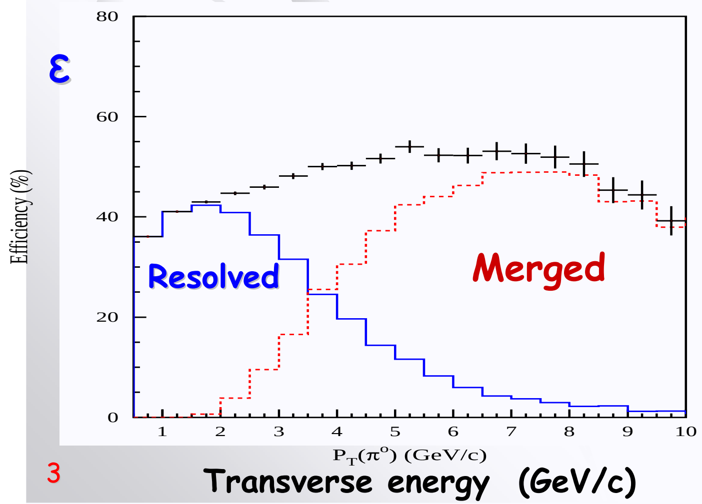
❑ «Merged» π^0 :

High energy π^0s form a single Ecal cluster with merged photon showers.

The photons pair are reconstructed thanks to a dedicated algorithm based on the expected shower shape.

mass resolution ~ 15 MeV/c^2

❑ π^0 reconstruction efficiency

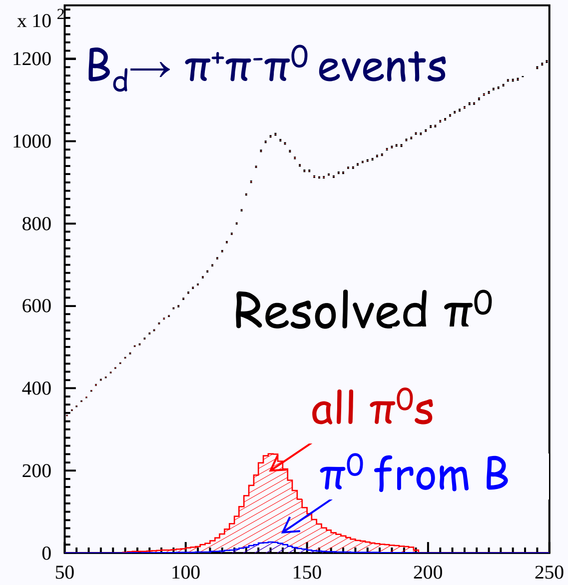


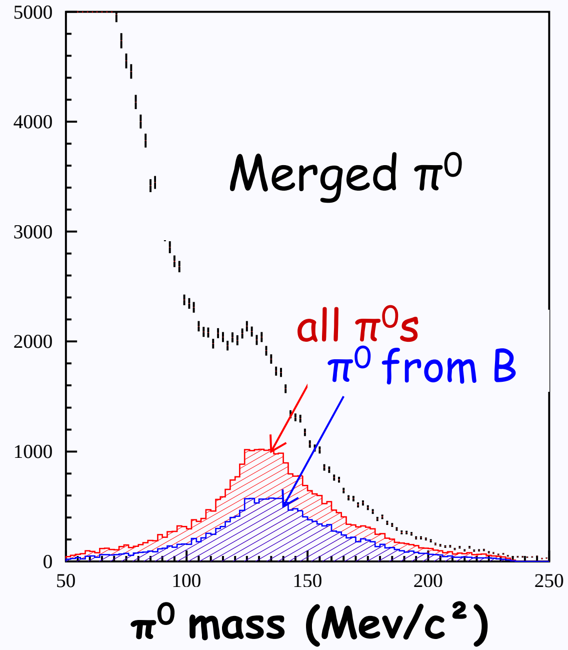
$B_d \to \pi^+\pi^-\pi^0$ events

$\langle\varepsilon\rangle = 53\%$

33% from resolved

+ 20% from merged





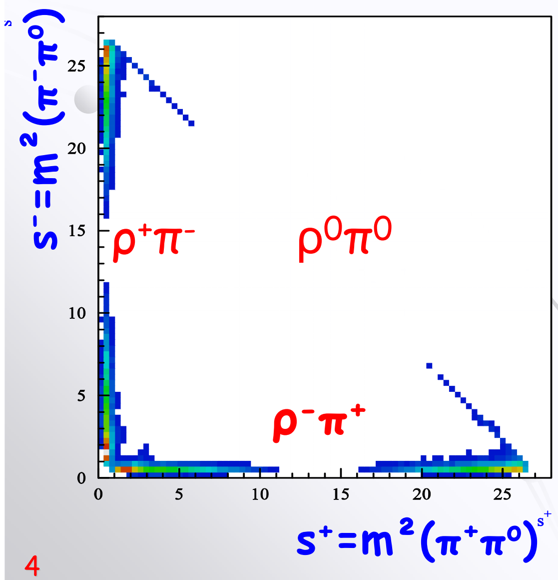
I - α from $B \to (\rho\pi)^0$

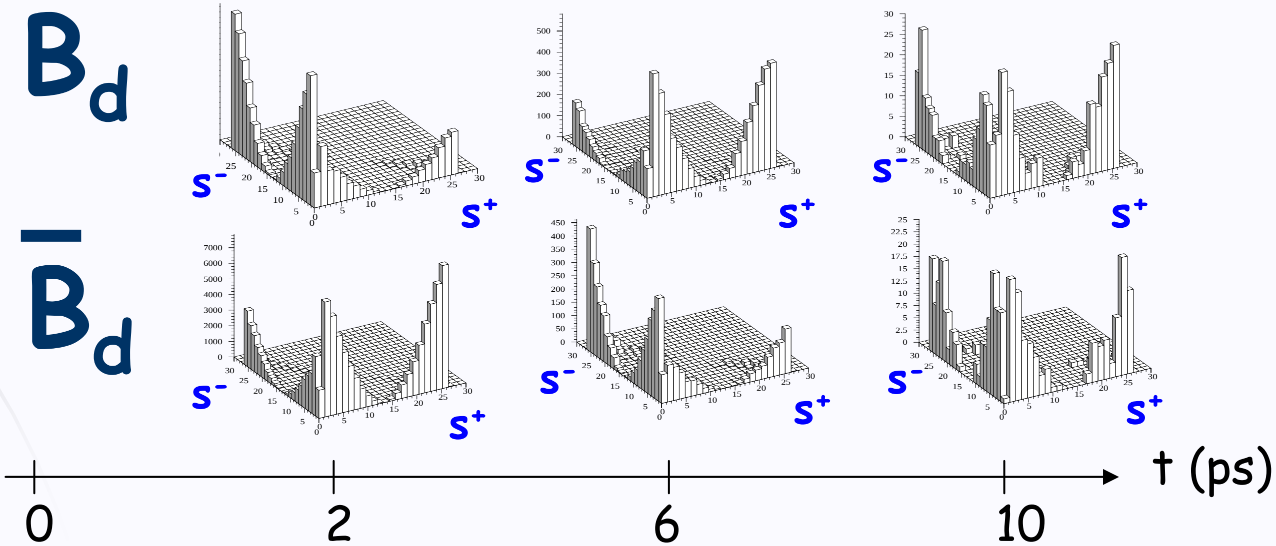
Thanks to the interferences between the $\bar{B}$ / B → $\rho^+\pi^-$, $\rho^0\pi^0$, $\rho^-\pi^+$ → $\pi^-\pi^0\pi^+$ transitions

we can simultaneously extract α with amplitudes and strong phases. [Snyder, Quinn, 1993]

The time dependence of the tagged Dalitz plot distributions provides all the required information : $f(s^+, s^-, t, B_{tag})$

$$M^{\pm}(s^+,s^-,t) = e^{-\frac{\Gamma t}{2}} \left\{ \cos\left(\frac{\Delta m}{2} t\right) A^{\pm}(s^+,s^-) + i \left(\frac{q}{p}\right)^{\pm 1} \sin\left(\frac{\Delta m}{2} t\right) A^{\mp}(s^+,s^-) \right\}$$





Extracting α : the method

Maximize a Likelihood with 9 parameters $\vec{\alpha}$ (+ background fractions $\vec{r}$)

Theoretical ingredients

$$A_{3\pi} = f^{+}A^{+-} + f^{-}A^{-+} + f^{0}A^{00}$$

with $A^{ij} = e^{-i\alpha}T^{ij} + P^{ij}$

and Isospin: $\left(P^{+-} + P^{-+}\right) = -2P^{00}$

$$\vec{\alpha} = (\alpha, T^{-+}, \phi^{-+}, T^{00}, \phi^{00}, P^{-+}, \delta^{-+}, P^{+-}, \delta^{+-})$$

Phenomenological ingredients

The ρ line-shape

$$f^{\pm 0} \propto \left(f^{\pm 0}_{\rho 770} + \beta f^{\pm 0}_{\rho 1450} + \gamma f^{\pm 0}_{\rho 1700} \right) \times Y^{01}\left(\cos\theta^{\pm 0}(s^{+}, s^{-})\right)$$

$$\mathcal{L}(\vec{\alpha}, \vec{r}) = \prod_{k}^{N_{evt}} \left[(1-r)\,\xi^{3\pi}(s_k^{+}, s_k^{-}, t_k) \sum_{b=B,\bar{B}} \omega_b^{tag} \left| M_b^{3\pi}(s_k^{+}, s_k^{-}, t_k, \vec{\alpha}) \right|^2 + \sum_{bkg}^{N_{bkg}} r^{bkg} \mathcal{L}_k^{bkg} \right] \otimes G(\sigma_{s^+}, \sigma_{s^-}, \sigma_t)$$

Event Yield

Experimental acceptances

Experimental (mis)tagging tag = +1/0/-1

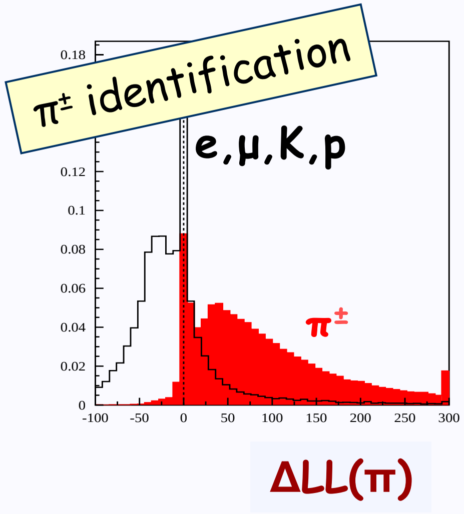
Background contamination

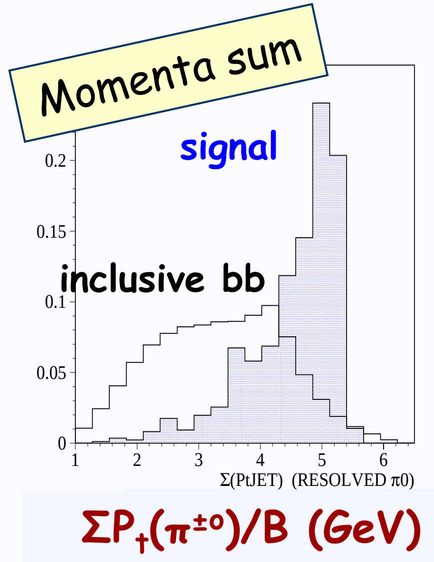
Experimental resolutions

Experimental ingredients

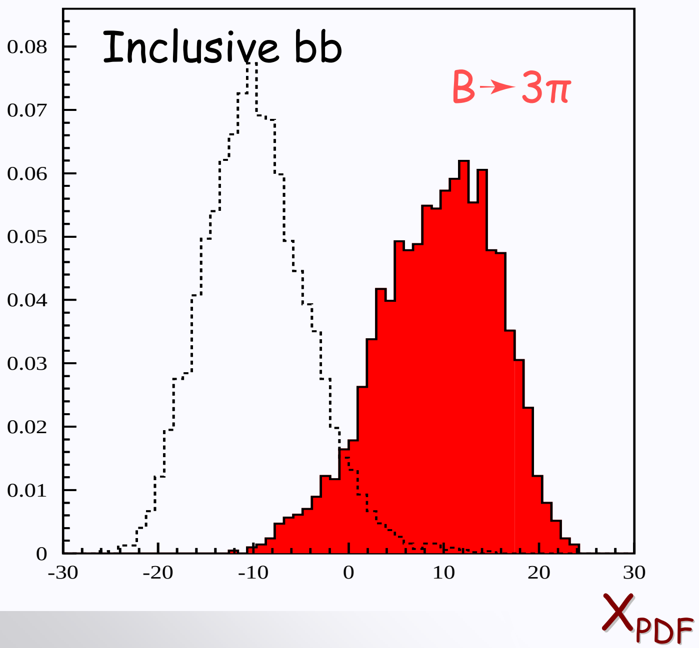
The B→3π selection

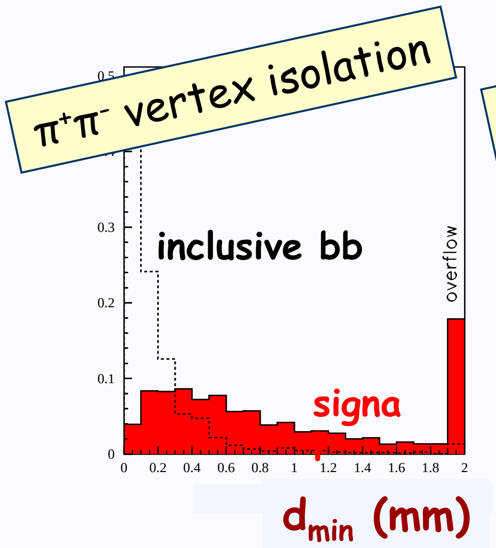
- Multivariate selection based on :
  - • Particle identification
    Charged pion Id, neutral π^0 clusters, …
  - • Kinematical criteria
    Transverse momenta, …
  - • Vertexing criteria
    Impact parameters, vertex isolation, …

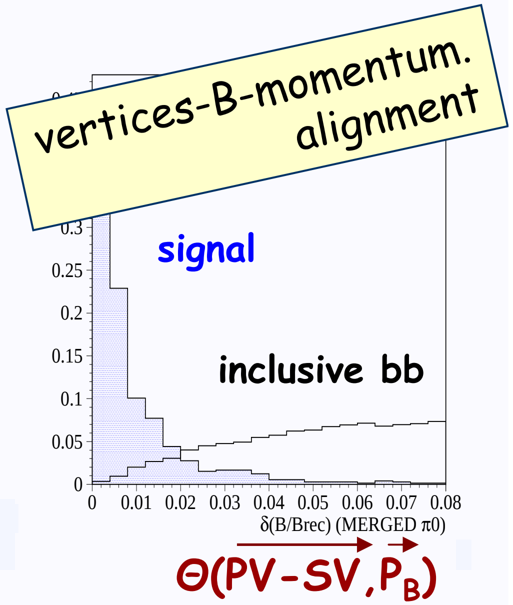




- Combined PDF







Signal yield and background contamination

- 1 million of fully simulated B→ρπ events
  - → ~10 days of LHCb @ 2.10^{32} $cm^{-2}s^{-1}$
  - → 1300 evts selected ≈ Babar ρπ statistics (up to 2004)
  - → 50% with merged π^{o}s

$\varepsilon_{det+rec}$	ε_{sel}	ε_{trig}	ε_{tot}
4%	3.5%	50%	7×10^{-4}

$N_{3\pi} = 14\times10^{3}$ $evt/2fb^{-1}$

- 33 millions of inclusive BB events
  - → 15 mn of LHCb @ 2.10^{32} $cm^{-2}s^{-1}$

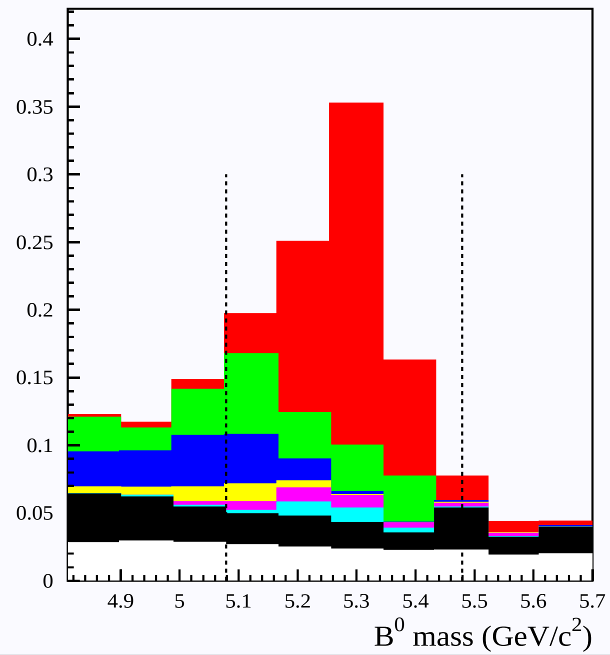
    3 signal events selected & passing the trigger

    5 background events in side-bands ($D_{(s)}\pi$, $D_{(s)}\rho$) & rejected by the trigger

Consistent with : B/S~ 20% (B/S < 80% @ 90% CL)

- Few millions of specific charmless B decays

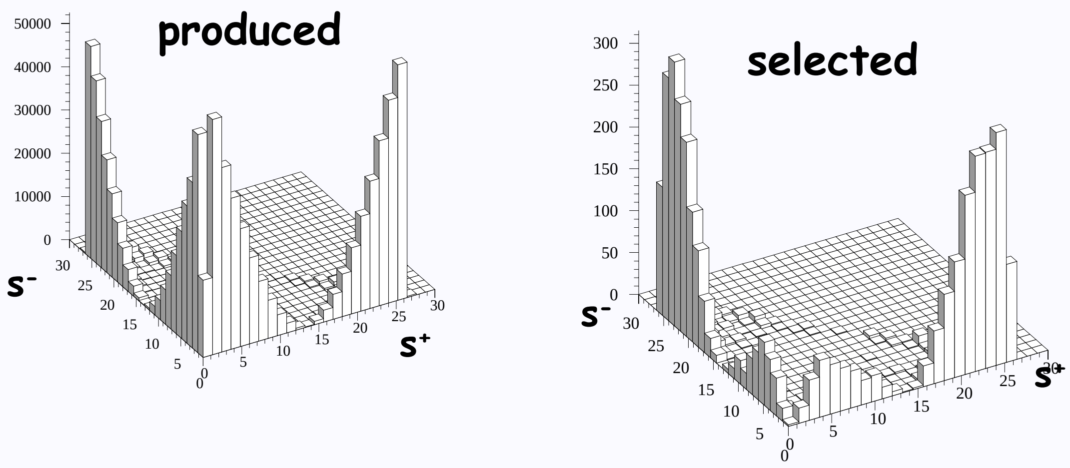
	Eq. LHCb time	N_{sel}	B/S
$B_d \to \rho^+\rho^-$	4 days	40	9%
$B_d \to K^*\gamma$	1.3 days	10	6%
$B_d \to K\pi\pi^0$	12 days	90	5%
Other $B_d \to$ charmless	1.5h	5	29%
$B_u \to \rho^+\rho^0$	5 days	16	3%
Other $B_u \to$ charmless	1.5 h	3	17%

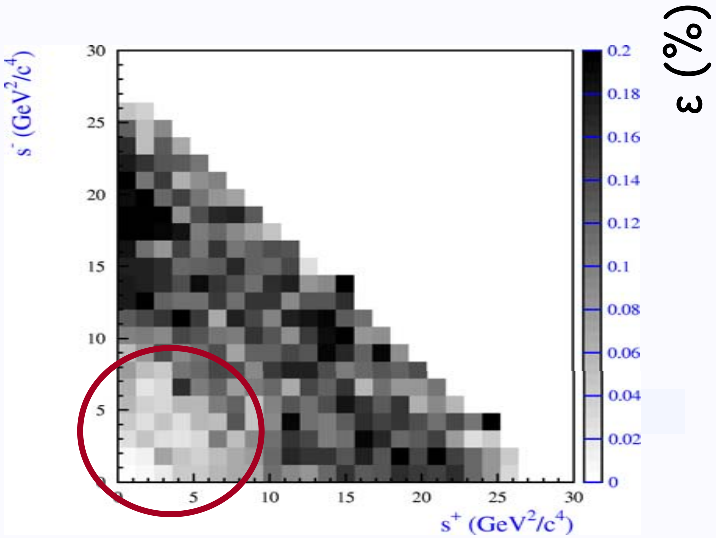


Assume B/S =1 in the following

Experimental inputs in the fit : signal acceptance

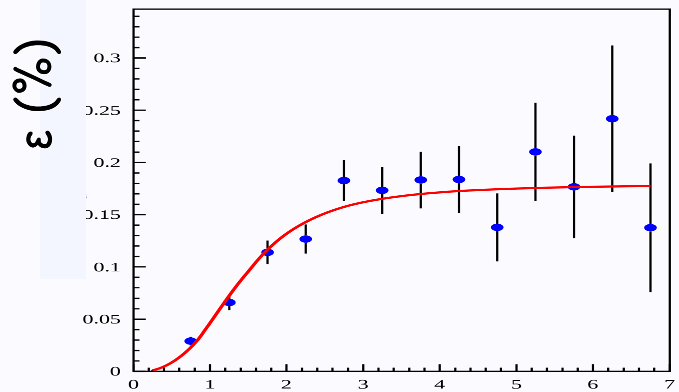
- Acceptance in Dalitz plane →





➛ The lower corner of the Dalitz plot is highly depopulated due to the cut on the π^0 energy. However, the upper region of the Dalitz figure contains enough interference to allow the α extraction.

- Proper time acceptance →

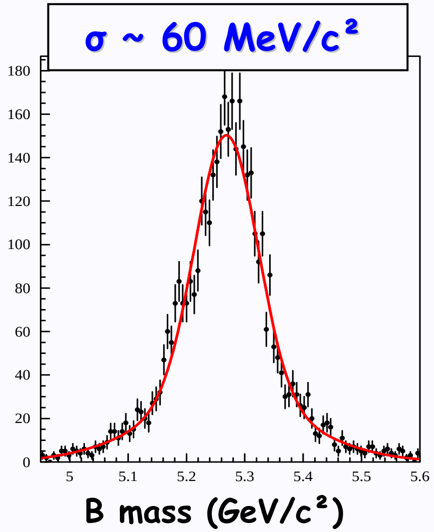


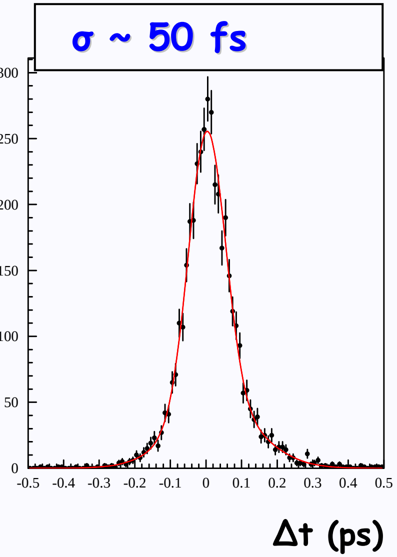
➛ region of low lifetime depopulated due to the large impact parameters required in the selection

Experimental input in the fit : resolution & tagging

❑ Expected resolutions :

Resolutions are
dominated by
calorimeter energy resolution





❑ Flavour tagging

• Performance estimated from full MC simulation:

→ Tagging efficiency $\varepsilon = 40 \pm 2$ %
→ Wrong tag fraction $\omega = 31 \pm 2$ %

➛ $\varepsilon_{eff} = \varepsilon\,(1-2\omega)^2 = 6 \pm 2$ %

• The tagging performance actually depends on the position in Dalitz plane.
• On real experiment, the wrong tag fraction will be extracted from data (e.g. using the auto-tagged $K^+\pi^-\pi^0$ decay)

• NB : the untagged sample also enters in the global fit :

$$\{\omega_b^{tag}\} = \begin{pmatrix} 1-\omega & 1/2 & \omega \\ \omega & 1/2 & 1-\omega \end{pmatrix}$$

Assessing the LHCb sensitivity on α : the method

- Assume a set of theoretical parameters $\vec{\alpha}^{gen}$

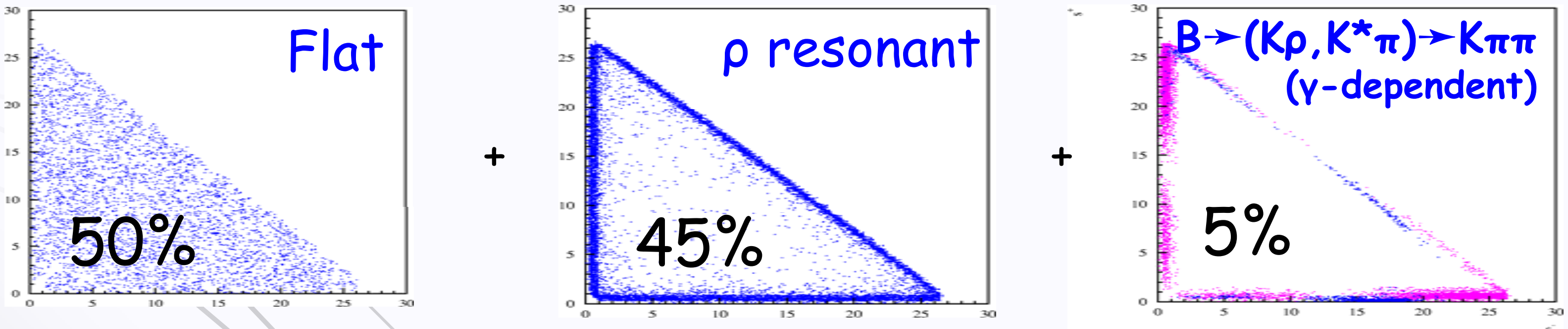
α	T^{-+}	Φ^{-+}	T^{00}	Φ^{00}	P^{+-}	δ^{+-}	P^{-+}	δ^{-+}
96.5°	0.47	0.00	0.14	0.00	-0.2	-0.5	0.15	2.0

- Simulate a set of toy experiments accordingly

Yield = 10^4 signal events ~ 1 year of LHCb data taking

- Simulate backgrounds according to $\vec{r}^{gen}$ ratios

Bkg structure poorly known. Assume B/S = 1 and use a mixture made of :

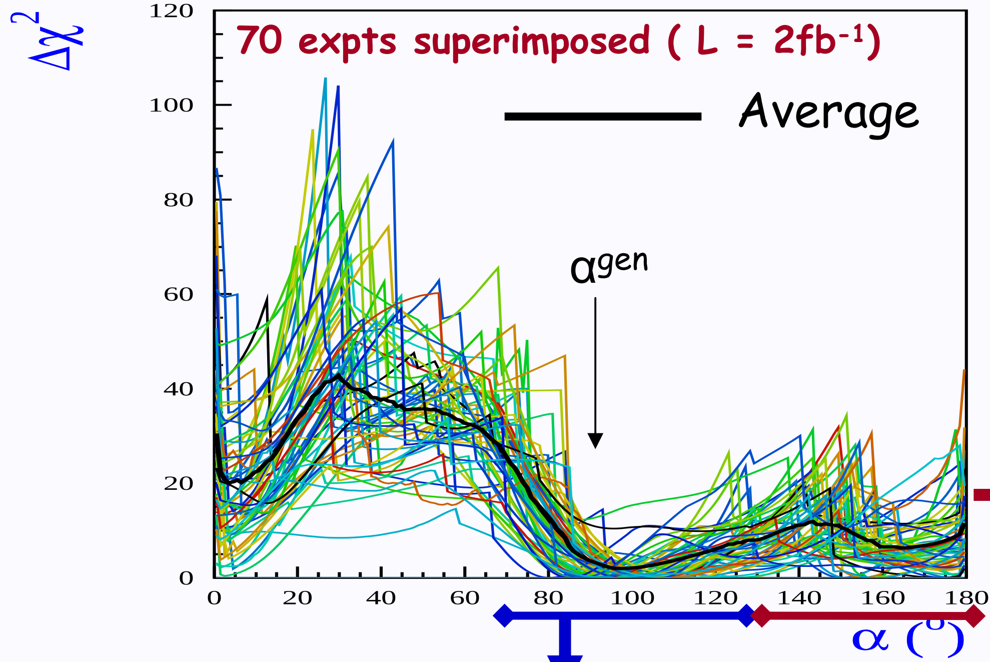


The same proper time distribution, resolutions and tagging dilution as signal are assumed
On real data informations on background will be extracted from the side-bands

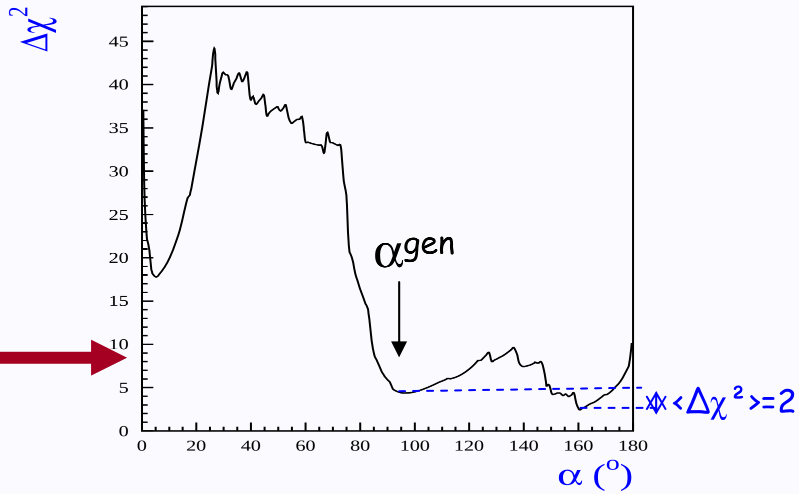
- Simulate the experimental effects (resolution, acceptance, wrong tag, ...)

- Maximize the likelihood wrt $\vec{\alpha}^{fit}$ and the background ratios $\vec{r}^{fit}$ (12D fit)

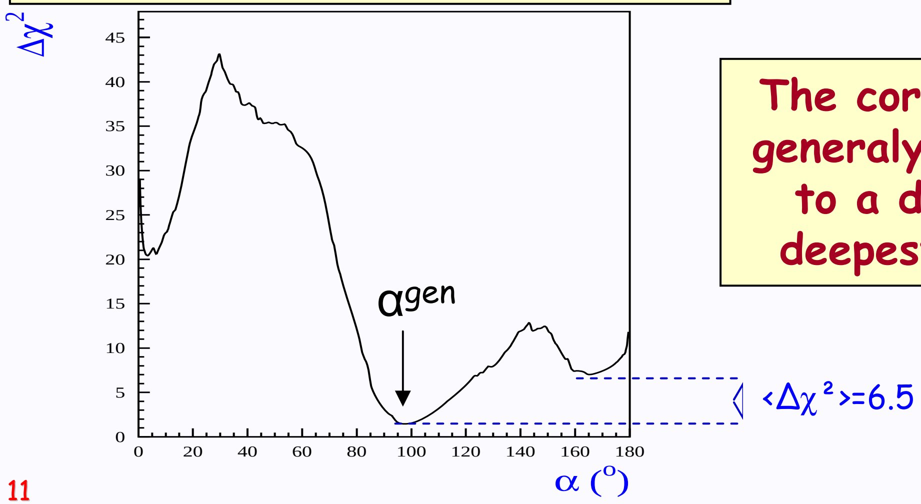
LHCb sensitivity to α : the results with 2 fb^{-1}



15% converge to a pseudo-mirror solution.
Fraction decreases with luminosity (<1% @ $10fb^{-1}$)

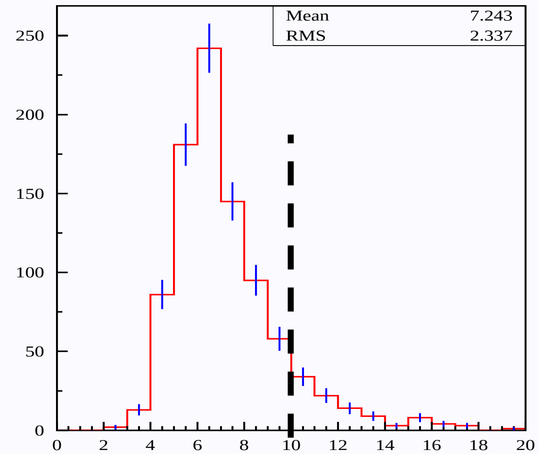


85% converge to the correct solution



The correct solution generaly corresponds to a deep (if not deepest) minimum.

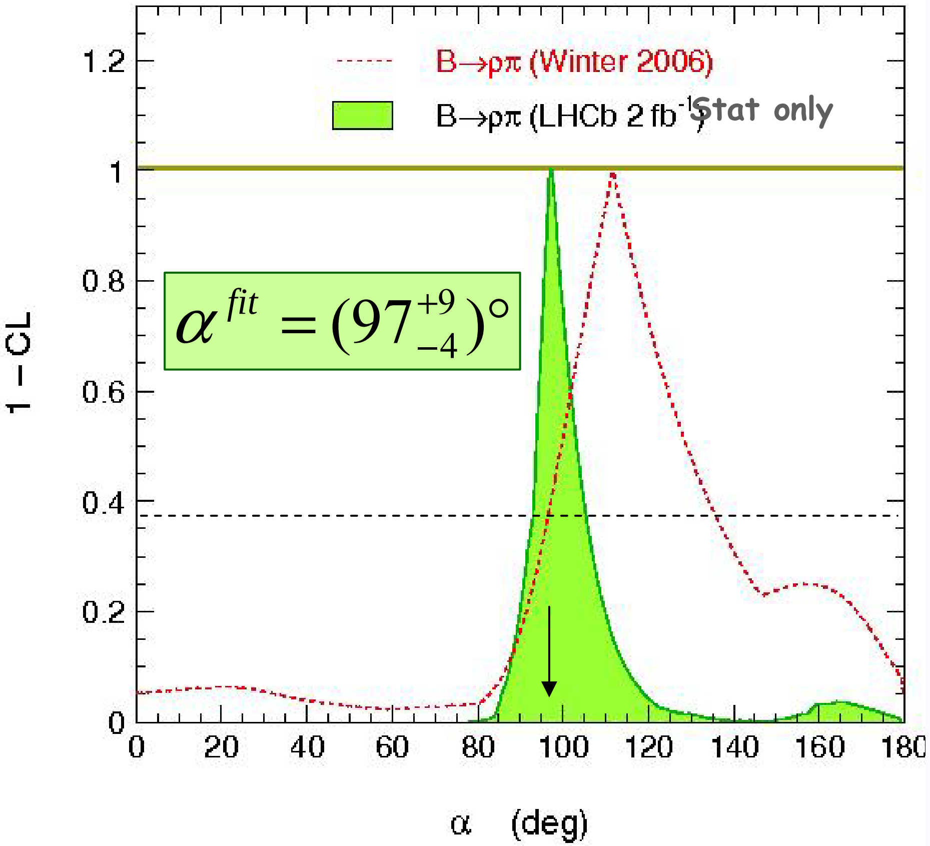
Distribution of fit error

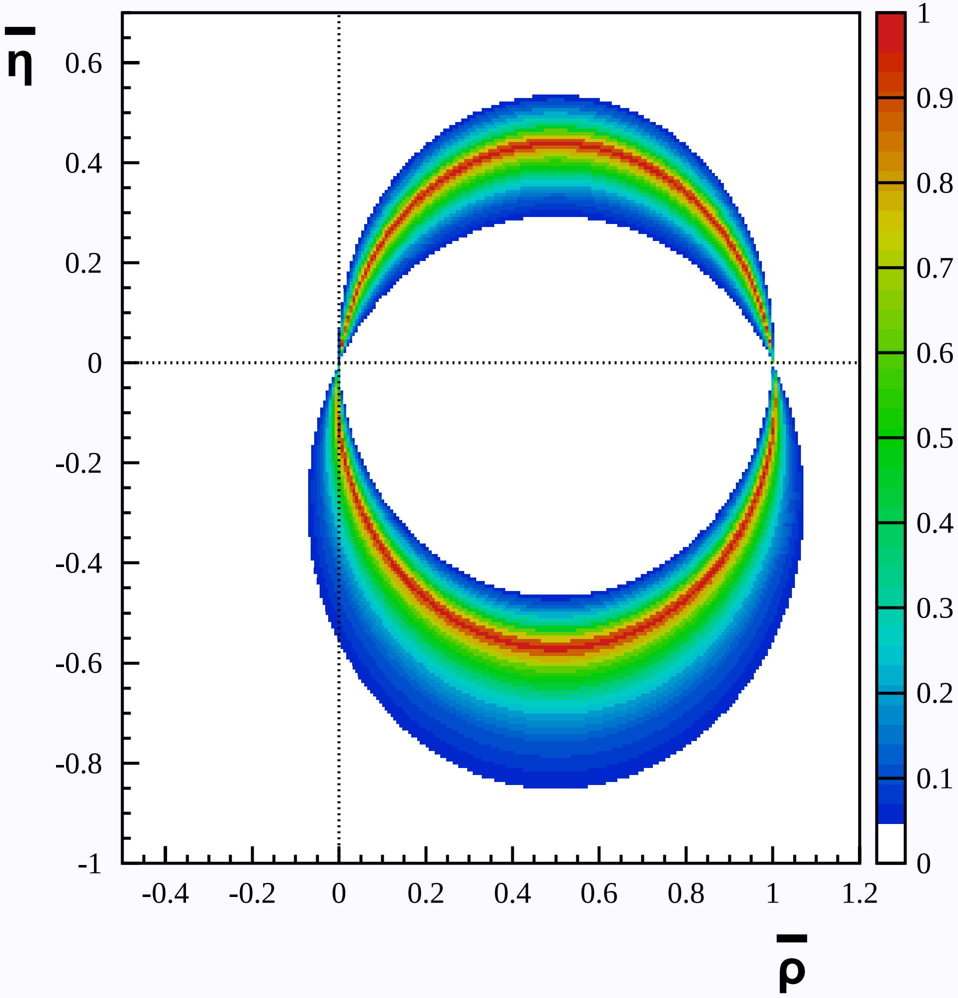


90% of experiments w/ σ_α < 10°

LHCb sensitivity to α

- A typical LHCb toy experiment (2fb^{-1})





Current Babar measurement :

$$\alpha^{\rho\pi} = (111.8\ ^{+27.7}_{-16.6})^\circ$$

Systematics

❑ Impact of an imperfect knowledge of the experimental or phenomenological ingredients feeding the likelihood

Non-uniform wrong-tag - averaged in the likelihood	$\Delta\alpha \sim 1°$
Proper time acceptance not accounted in the likelihood	$\Delta\alpha \sim 0°$
Dalitz acceptance not accounted in the likelihood	$\Delta\alpha \sim 5°$
ρ/ω mixing in signal not accounted in the likelihood	$\Delta\alpha \sim 0°$
ρ' and ρ'' contribution in signal not accounted in the likelihood	$\Delta\alpha \sim 7°$
Large ρ^3 contribution (weight 20%) in signal not accounted in the likelihood	$\Delta\alpha \sim 12°$

Extracting α via the 3π Dalitz analysis requires an accurate control of the inputs.

The final analysis will be much more difficult than this prospective study
Babar achieved the analysis in 2004.
First results from Belle expected for summer 2006

→ Not likely to be a 'first year' analysis for LHCb but very promising results.

II - α from B ➛ ρρ

❑ The method

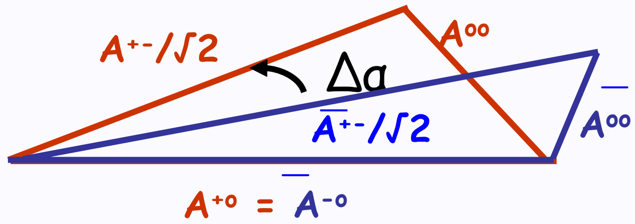
B ➛ $\rho^+\rho^-$ decay has been measured to be an almost pure CP-eigenstates

⇒ Measuring the time dependent asymetry of B ➛ $\rho^+\rho^-$ provide $\alpha_{eff} = \alpha + \Delta\alpha$

$$A^{+-}_{\rho\rho}(t) = S^{+-}_{\rho\rho}\sin(\Delta m_d t) - C^{+-}_{\rho\rho}\sin(\Delta m_d t) \quad \text{with} \quad S^{+-}_{\rho\rho} = \sqrt{1 - C^{+-2}_{\rho\rho}}\,\sin(2\alpha_{eff})$$

⇒ Measuring SU(2)-related modes, $\rho^+\rho^0$, $\rho^0\rho^0$ allows to put constraint on Δα

⇒ Resolving the full (ρρ) system gives access to α (modulo 8-fold ambiguities)

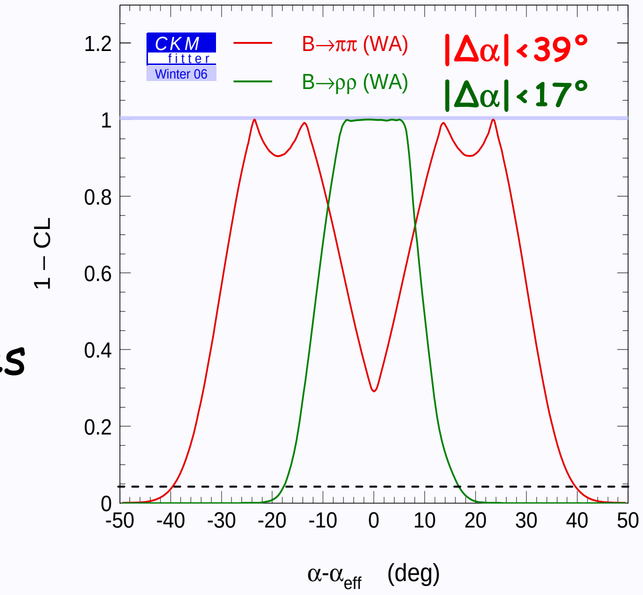


❑ Many advantages of the (ρρ) system over (ππ)

- B^{+-}, B^{+0} 5 times larger
- B^{00} is small (HFAG 2006 : $B^{00} < 1.1\times10^{-6}$)

↳ the Isospin triangles is squashed in (ρρ) system

- The time dependent asymmetry for B ➛ $\rho^0\rho^0$ provides additional information, in principle experimentally accessible



LHCb performance for $B \to \rho^+\rho^-$ & $B^\pm \to \rho^\pm\rho^0$

- Selection for $B \to \rho^+\rho^-$ & $B^\pm \to \rho^\pm\rho^0$
  - Multivariate selection as forB→ρπ
  - 2 & 1 neutral pion(s) in the final state, respectively
  - Overall efficiency : 0.01% & 0.045%
  - B mass resolution dominated by Ecal resolution : 80 MeV/c^2 and 52 MeV/c^2
  - Proper time resolution : 85 fs & 47 fs

- Expected annual yield (2fb^{-1}) :

  - $B^\pm \to \rho^\pm\rho^0$: 9000 — B/S ~ 1
  - $B \to \rho^+\rho^-$: 2000 — B/S < 5 @ 90%CL

One year of LHCb probably not competitive with current B factory performance.
Will need several years to provide a sizeable contribution to C^{+-}, S^{+-} measurement

The main contribution of LHCb to the B→ ρρ analysis could be the measurement of the $B \to \rho^0\rho^0$ mode

LHCb performance on $B \to \rho^0\rho^0$ selection

- **Selection**
  - ➛ multivariate selection
  - ➛ overall efficiency : 0.16%

- **Expected annual yield ($2fb^{-1}$/year) :**

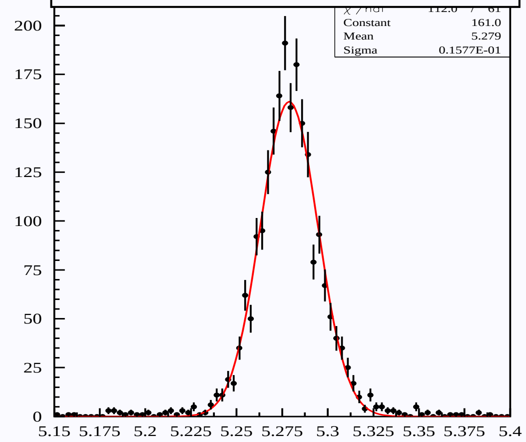
HFAG 2006 : BR < 1.1×10^{-6} @ 90% CL	< 1000

- **Background contamination**

	Eq. LHCb time	Nsel	B
BB inclusive	15 mn	0	< 4000
$B_d \to \pi^+\pi^-\pi^+\pi^-$ (NR)	2.5 days	7	300
$B_d \to K^+\pi^-\pi^+\pi^-$ (NR)	1 days	0	< 600

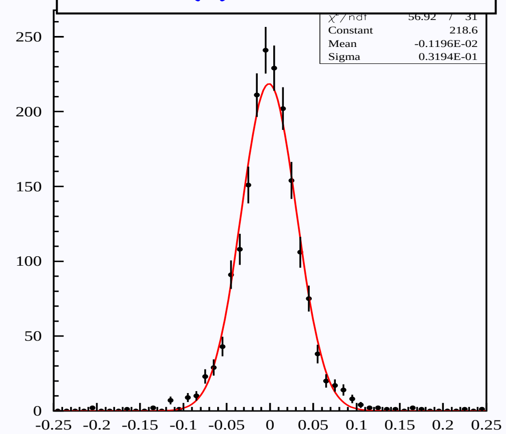
B mass resolution

$\sigma(m_B)$ ~ 16 MeV/c^2



Proper time resolution

$\sigma(t)$ ~ 32 fs

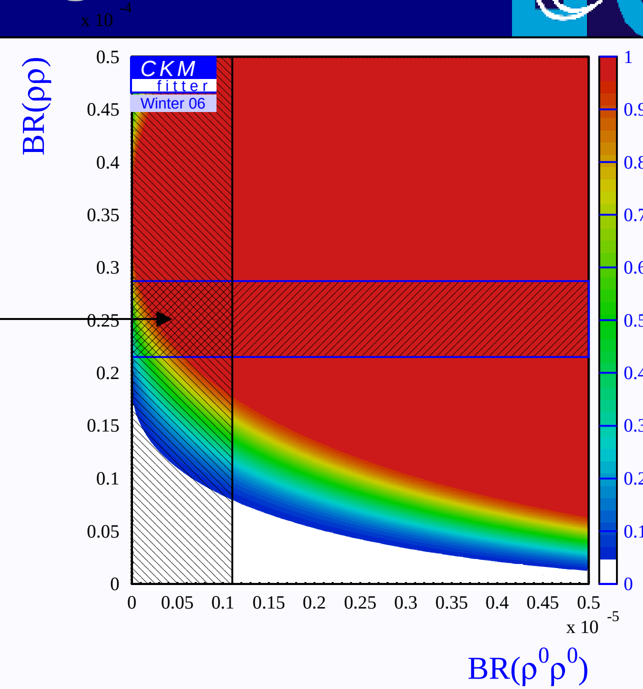


Prospective for $2fb^{-1}$ @ LHCb : setting a scenario

❑ Assumptions

- Branching ratio : $B^{00} = 0.5\ 10^{-6}$

Babar : $B^{00} = (0.54^{+0.36}_{-0.32} \pm 0.19)10^{-6}$



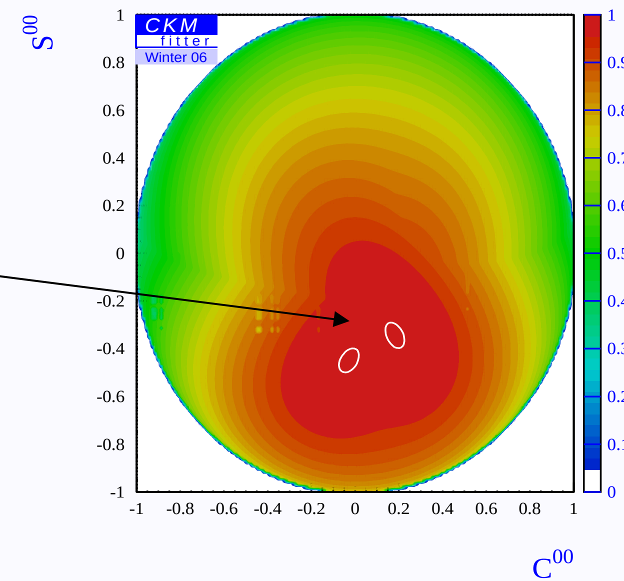
- LHCb will achieve σ_{B00}/B^{00} = 20%

Current B Factories error on B^{+-}, B^{+0} meas. : ~ 15%

- Scenario for C^{00} & S^{00}

The prefered value from CKM fit (weak constraint)

(C^{00},S^{00}) = (0.195,-0.35) or (-0.035,-0.44)



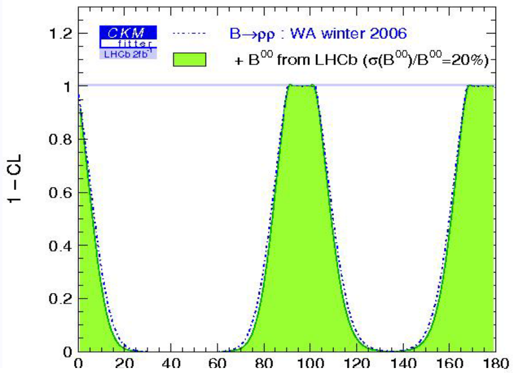
- Resolution on C^{00} & S^{00} : $\sigma_{C/S00}$ = 0.4

Rescaling the expected LHCb performance for $B\rightarrow\pi\pi$

Prospective for 2fb^{-1} @ LHCb : the results for ρρ

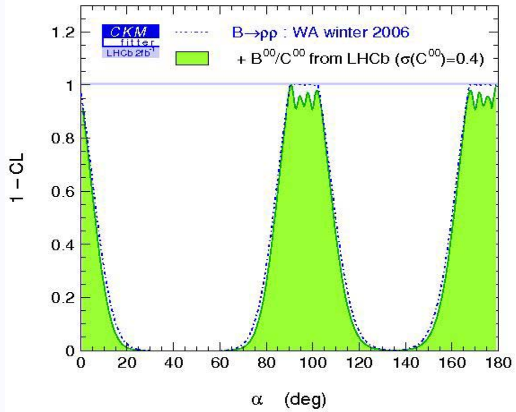
- measuring B^{00}

$B^{00} = 0.5\times10^{-6}$
$\sigma_{B^{00}}/B^{00} = 20\%$



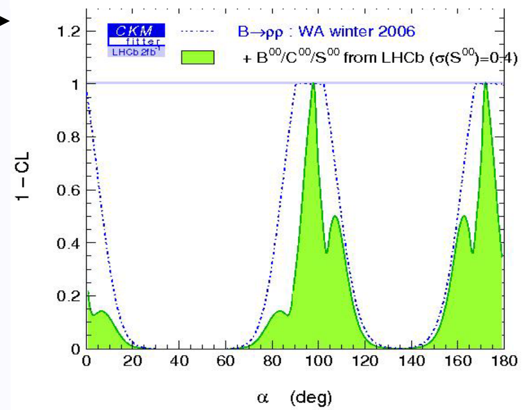
- & measuring C^{00}

$\sigma_{C^{00}}= 0.4$



- & measuring S^{00}

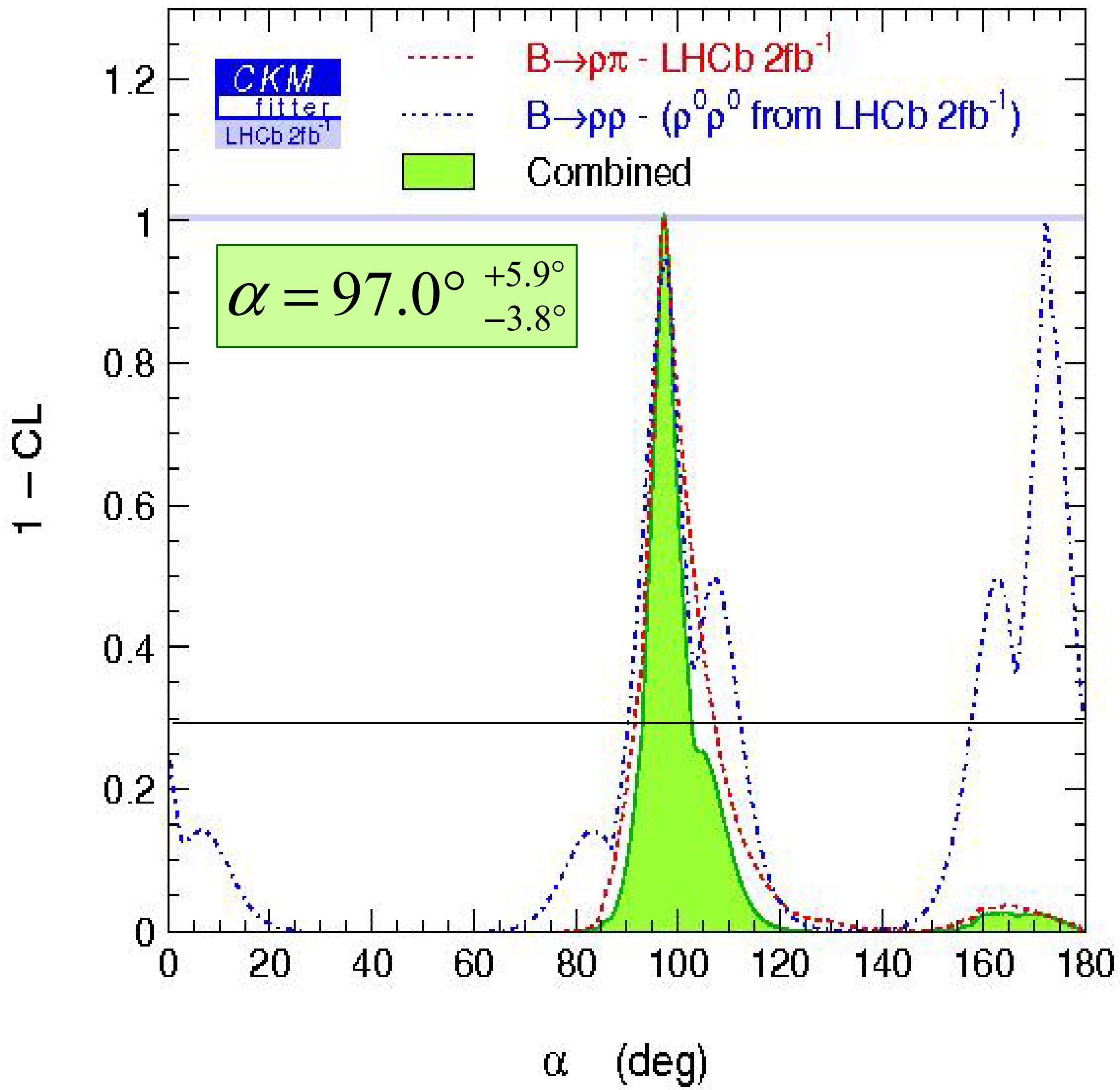
$\sigma_{S^{00}}= 0.4$

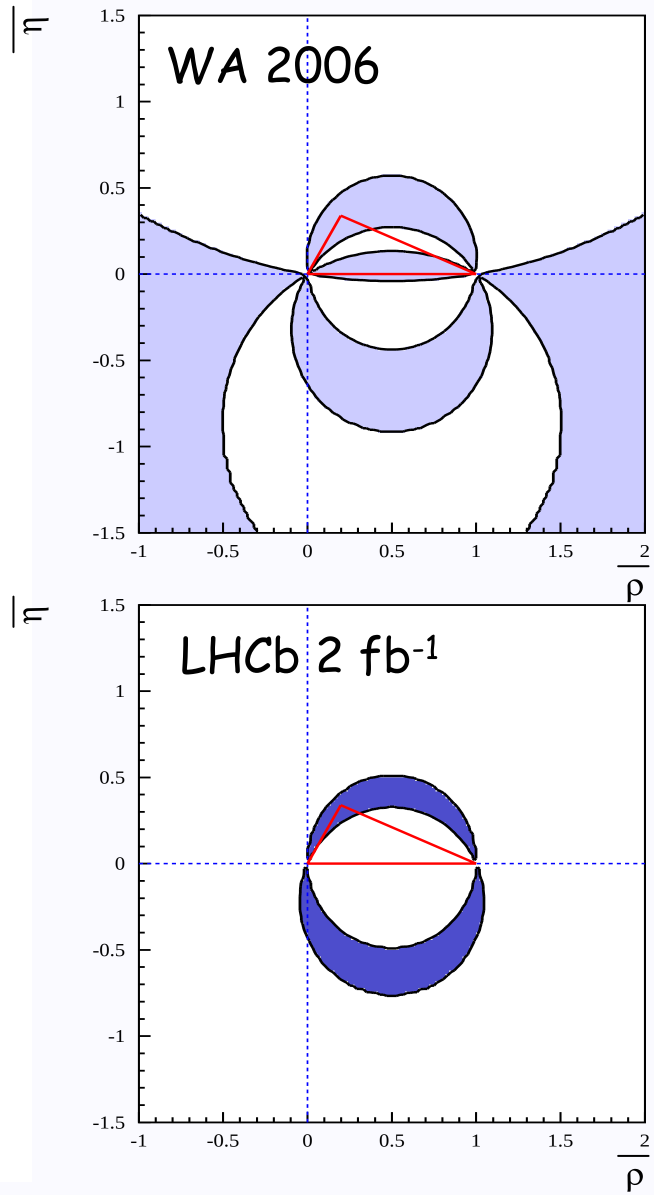


$$\alpha = 98.1^{\circ}{}^{+14^{\circ}}_{-8^{\circ}}$$

2006 WA : $\alpha^{\rho\rho} = (96.6 \pm 16.5)^{\circ}$

Prospective for $2fb^{-1}$ @ LHCb : ρρ/ρπ combination





Conclusions

Measuring α with LHCb : two complementary approaches

- The time-dependent $B_d \to (\rho\pi)^0$ Dalitz plot

o No ambiguity on α in $[0,\pi]$ but pseudo-mirror solutions.
o With 2 fb^{-1} LHCb may achieve $\sigma^{stat} < 10°$ on α
o Require an accurate control of the ρ-lineshapes and the experimental distortions.
o Ambitious but promising.
o Probably several years to setup the analysis

- The time-dependent $B_d \to \rho^+\rho^-$ asymmetry + SU(2) analysis

o 8-fold ambiguity on α in $[0,\pi]$
o Several years of LHCb needed to improve the current $B_d \to \rho^+\rho^-$ measurements
o With 2 fb^{-1} the main LHCb contribution could be the measurement of $B_d \to \rho^0\rho^0$.
o Accessing the $\rho^0\rho^0$ time-dependent asymmetry will reduce the degeneracy of mirror-solutions and improve the current α determination.
o Performance strongly depends of the actual values of C^{00} and S^{00}.

- During LHCb era the stat. error on α could reach the few degrees level

SU(2) breaking effects, electroweak penguin contributions could be an issue

SPARE SLIDES

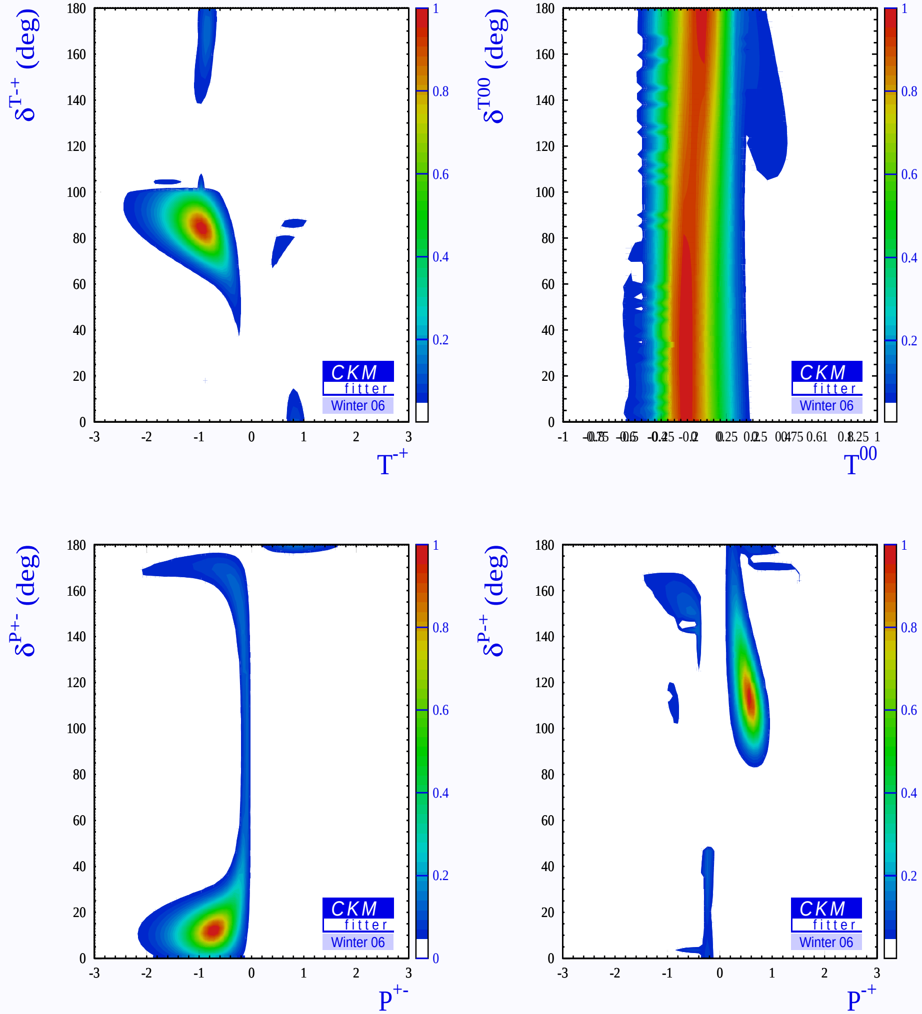
Another scenario for T & P

- prefered values from data

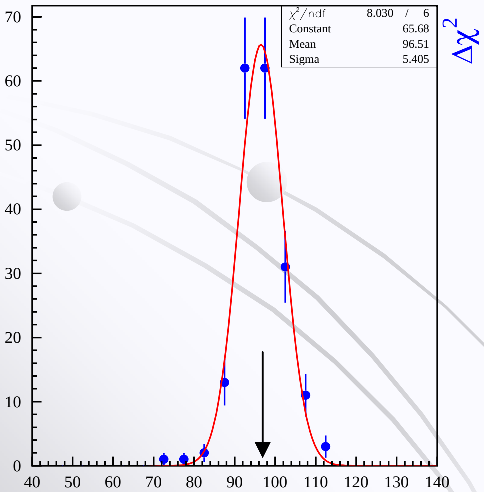
T^{-+}	Φ^{-+}	T^{00}	Φ^{00}	P^{+-}	δ^{+-}	P^{-+}	δ^{-+}
-0.93	83.7°	0.07	27.9°	-0.75	33.3°	0.57	112.5°

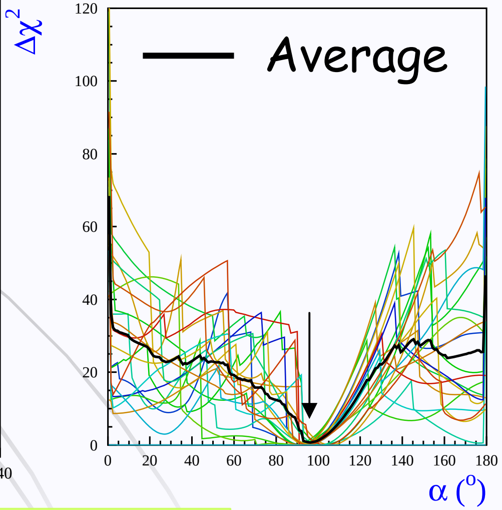
Using CKMFitter© package
α value obtained from the standard CKM fit (meas. not in fit) used as a constraint

Large P/T favored : $|P/T|^{-+} = 0.61 \pm 0.27$



- LHCb performance w/ this scenario





$$\sigma_\alpha^{stat.} = 5°$$

B→ρπ : sensitivity to the other parameters

- Penguin strong phases

  $\sigma(\delta^{-+}) \sim (^{+20}_{-50})^\circ$

  $\sigma(\delta^{+-}) \sim (^{+4}_{-25})^\circ$

- Tree strong phases

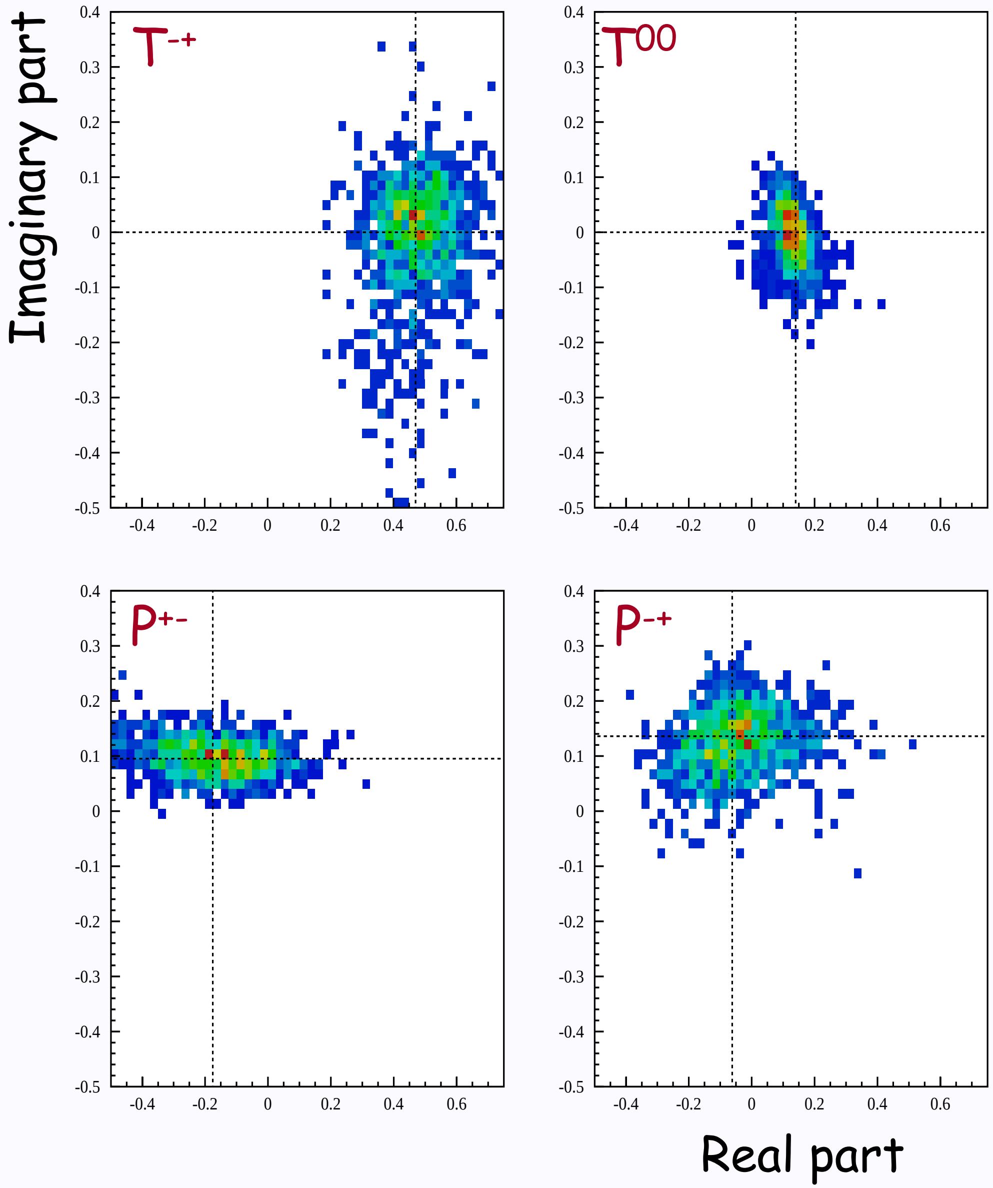
  $\sigma(\Phi^{-+}) \sim (^{+6}_{-10})^\circ$

  $\sigma(\Phi^{00}) \sim (^{+26}_{-17})^\circ$

- R=|P/T| ratios

  $\sigma_{R^{-+}}/R^{-+} \sim (^{+50}_{-30})\%$

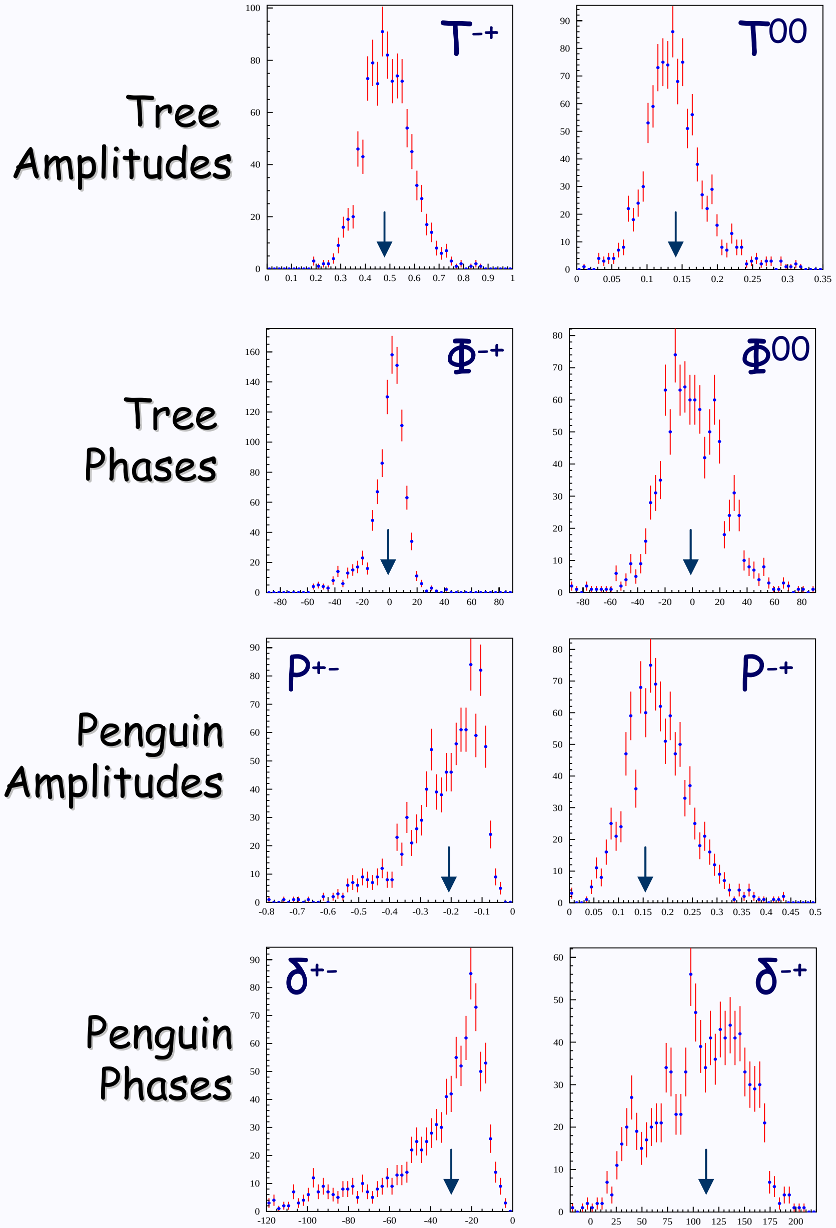
  $\sigma_{R^{+-}}/R^{+-} \sim (^{+70}_{-10})\%$



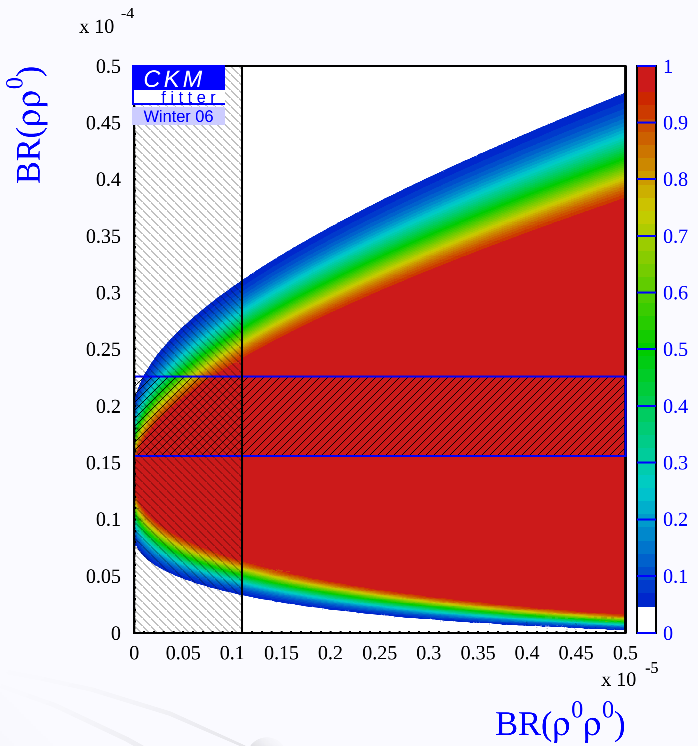
Sensitivity to other parameters

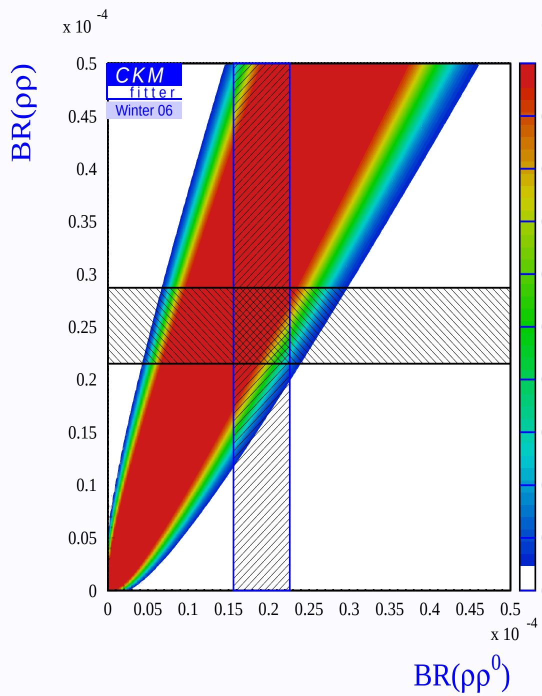
- α^{gen}=106°
- Flat:Resonant ratio = 40:60

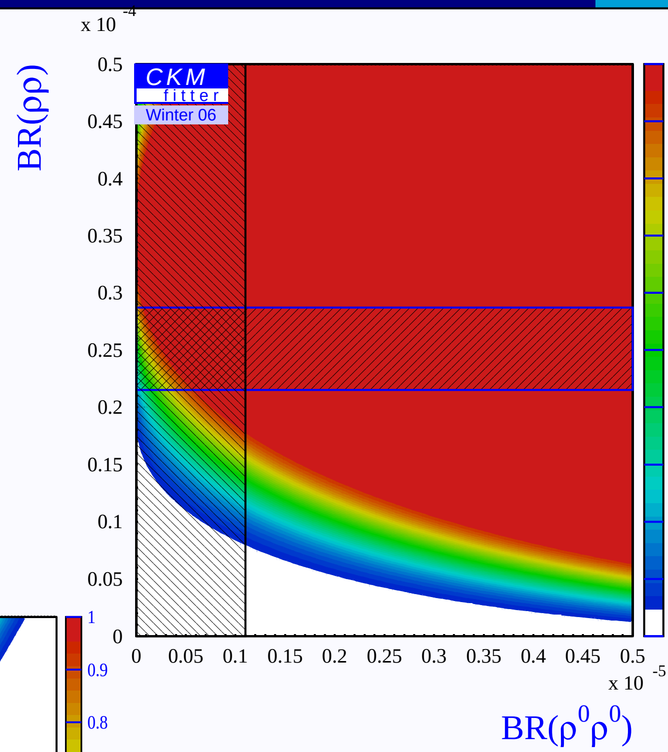
	Toy	<fit>	σ
T^{-+}	47%	(49±3)%	9%
Φ^{-+}	0°	(1.5±0.5)°	+6° -10°
T^{00}	14%	(14±1)%	4%
Φ^{00}	0°	(-1±1)°	+26° -17°
P^{+-}	-20%	(-11±6)%	+20% -2%
δ^{+-}	-28.6°	(15±1)°	+4° -25°
P^{-+}	40%	(18±1)%	±6%
δ^{-+}	114.6°	(135±5)°	+20° -50°



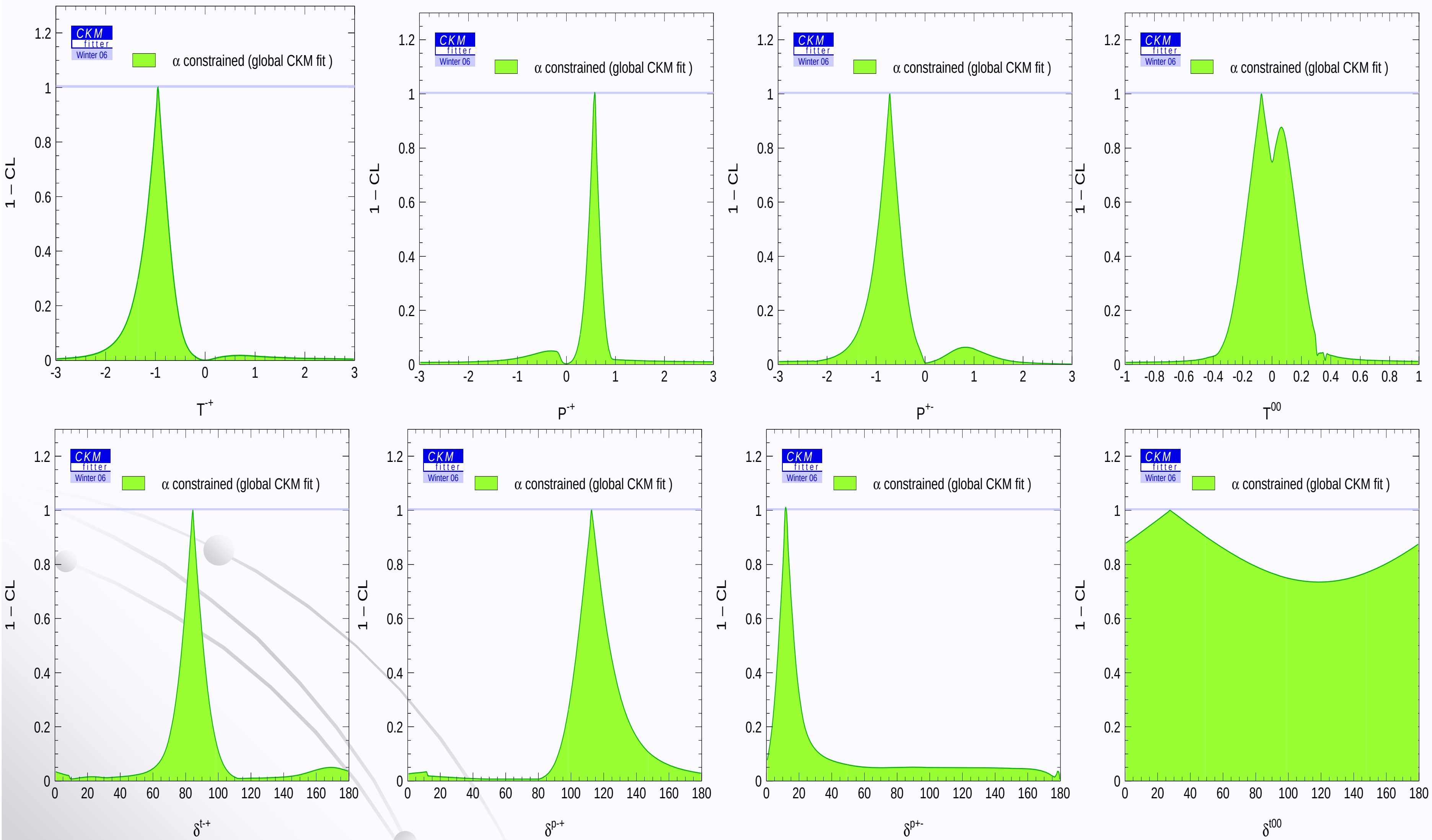
B→ρρ branching ratios





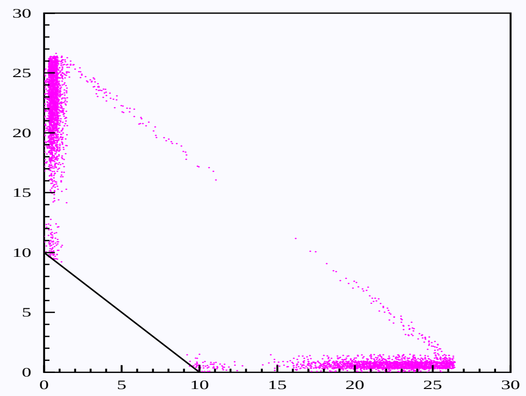


$B \to (\rho\pi)^0$: another scenario for T & P



Sensitivity to α : lower Dalitz corner

- The lower corner of the Dalitz plot is highly depopulated due to selection
- Can we fully remove this region of interference between rho-bands ?

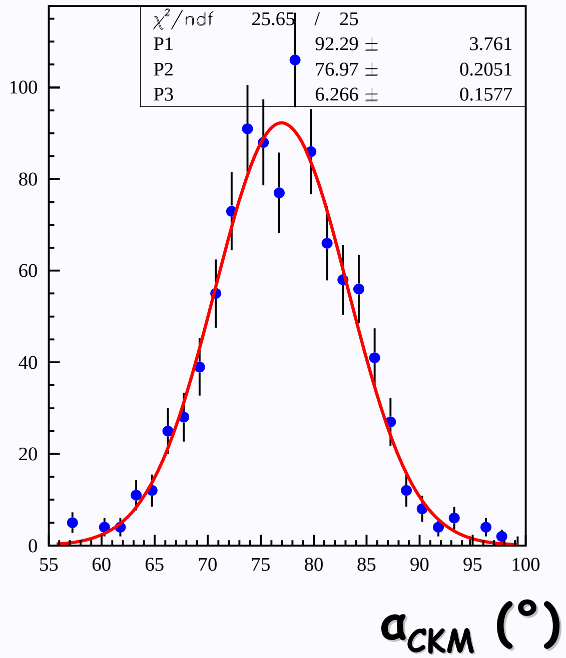


• Depopulated lower corner (no background)

$< \alpha_{CKM} >= (77.2 \pm 4.4)^\circ$

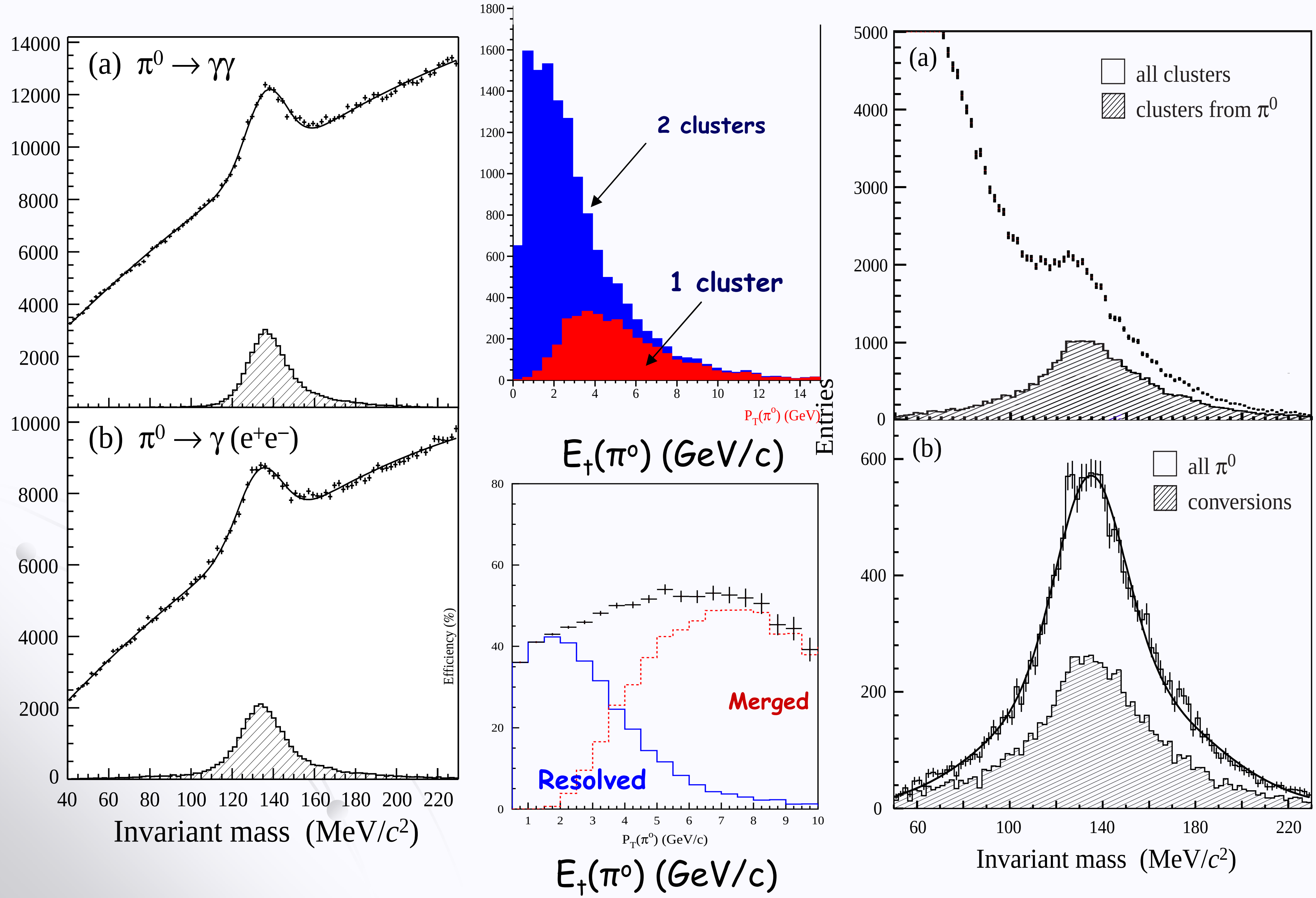
• Fully removing the lower corner (no background)

$< \alpha_{CKM} >= (77.0 \pm 6.2)^\circ$



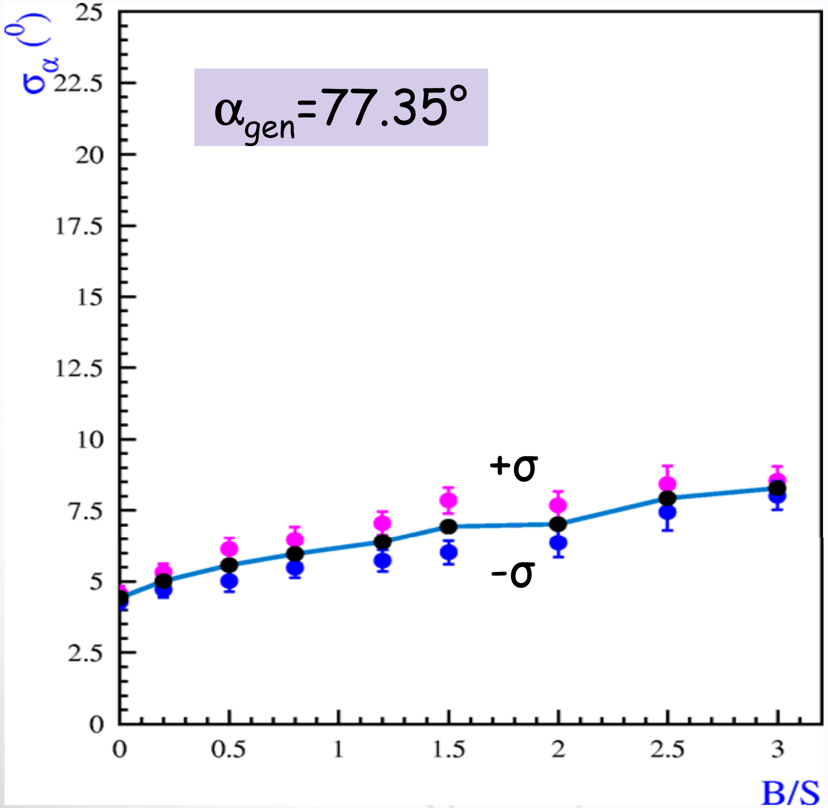
→ The lower Dalitz corner carries useful but not essential information.

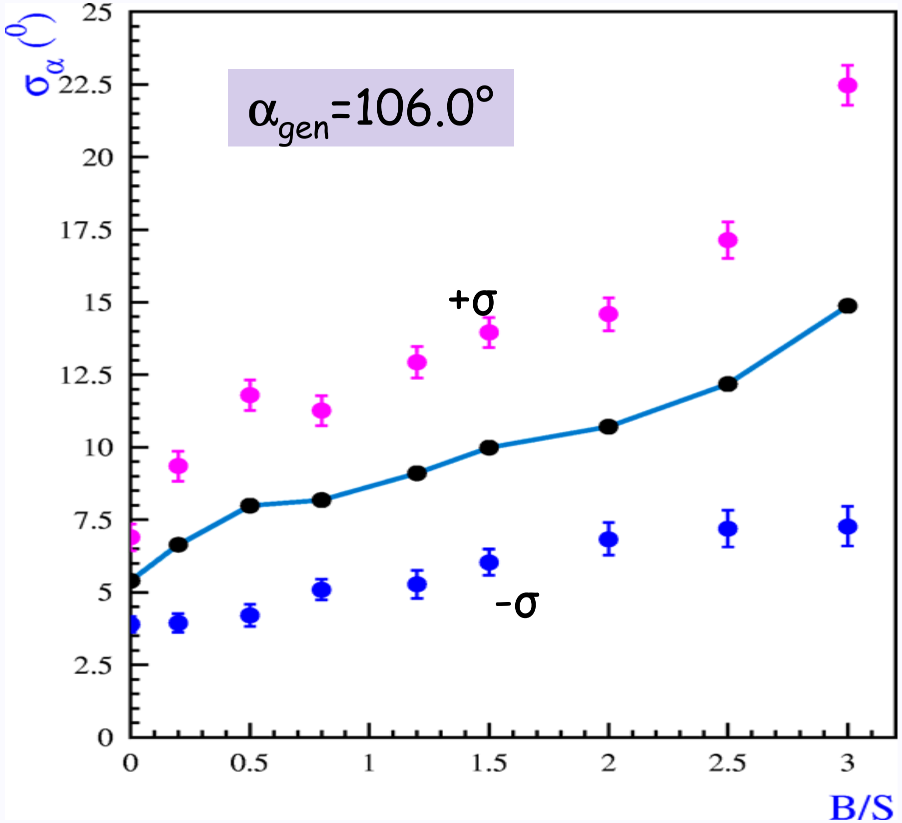
Neutral pion reconstruction



B→(ρπ)° : impact of B/S on alpha error

- 2 background classes: {0.5(res), 0.5(flat)}





Prospective for $2 fb^{-1}$ @ LHCb : another scenario

- Very low $B \rightarrow \rho^0\rho^0$ branching ratio : the decay is not observed with LHCb

→ Stronger limit on B^{00}

- Assume the background contamination is as high as the currently estimated upper limit (i.e. 4000 evts / 2 fb^{-1})

→ $B^{00} < 1.3\ 10^{-7}$ @ 90% CL could be achieved

$$\alpha = (96.6 \pm 12)^\circ$$