

Étude de la violation de la symmétrie CP dans l'expérience *BABAR* à l'aide du canal de désintégration $B^0 \rightarrow \rho^0 \rho^0$

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- 1 Motivations
 - Angle α de la matrice CKM
 - Analyse d'isospin
- 2 Analyse
 - Description générale
 - Validation
- 3 Résultats (LP 2007)

1 Motivations

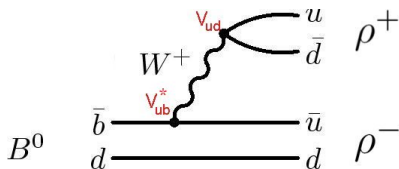
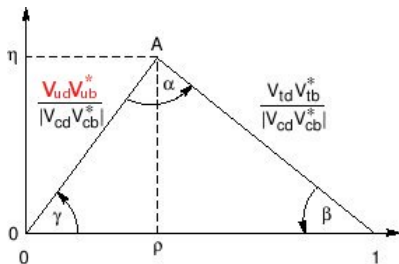
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Mesure de α : diagramme en arbre

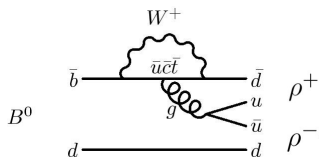


$$\lambda = \frac{p \bar{A}}{q A} = e^{-2i\beta} e^{-2i\gamma} = e^{2i\alpha}$$

$$C = \frac{1 - |\lambda|^2}{1 + |\lambda|^2} = 0 \quad S = \frac{2 \text{Im} \lambda}{1 + |\lambda|^2} = \sin 2\alpha$$

$$A_{CP}(\Delta t) = -C \cos(\Delta m \Delta t) + S \sin(\Delta m \Delta t) \Rightarrow \sin(2\alpha)$$

Mesure de α : diagrammes pingouins



$$\lambda = e^{-2i\beta} \frac{T e^{-i\gamma} e^{i\delta_T} + P e^{-i\phi_P} e^{i\delta_P}}{T e^{i\gamma} e^{i\delta_T} + P e^{i\phi_P} e^{i\delta_P}}$$

$$S = \sin 2\alpha_{\text{eff}} \neq \sin 2\alpha$$

dans $\pi^+\pi^-$, $|P/T| \sim 30\%$

Séparer amplitude arbre et amplitude pingouin ?

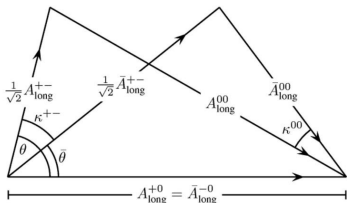
- pingouin pur $\Delta I = 1/2$
- arbre 2 composantes : $\Delta I = 1/2$ and $\Delta I = 3/2$

M. Gronau and D. London, Phys. Rev. Lett., 65, 3381 (1990)

Triangle d'isospin

$$A_L(B^+ \rightarrow \rho^+ \rho^0) = 1/\sqrt{2} A_L(B^0 \rightarrow \rho^+ \rho^-) + A_L(B^0 \rightarrow \rho^0 \rho^0)$$

$$|A_L(B^+ \rightarrow \rho^+ \rho^0)| = |A_L(B^- \rightarrow \rho^- \rho^0)| \quad (\text{pur diag. en arbre})$$



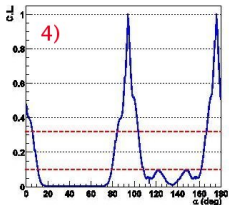
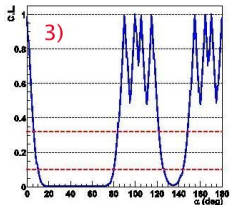
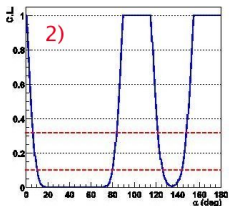
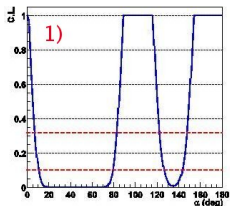
$\kappa^{+-} = 2(\alpha - \alpha_{eff})$ différence de phase induite par le diag. pingouin

expérimentalement :

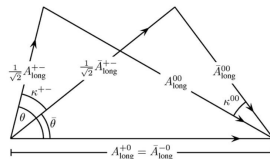
- $BR = |A|^2 + |\bar{A}|^2$
- $C : |A|^2 / |\bar{A}|^2$
- $S : \text{phase de } \bar{A}/A$

$$B(B \rightarrow \rho^+ \rho^-) / B(B \rightarrow \pi^+ \pi^-) \sim 5 \Rightarrow |\alpha - \alpha_{eff}| \text{ mieux contraint dans } \rho\rho$$

Exemple illustratif



- 1 C_L^{+-} , C_L^{00} , S_L^{00} non mesurés
- 2 + info sur C_L^{+-}
- 3 + info sur C_L^{00}
- 4 + info sur S_L^{00}



paramètres utilisés pour $\rho^0 \rho^0$:

$$B(B^0 \rightarrow \rho^0 \rho^0) = 2 \pm 0.24 \cdot 10^{-6}, S_L^{00} = 0.5 \pm 0.3, C_L^{00} = 0.5 \pm 0.2$$

analyse dépendante du temps possible dans $\rho^0 \rho^0 \neq \pi^0 \pi^0$: en principe levée complète des ambiguïtés quadruples

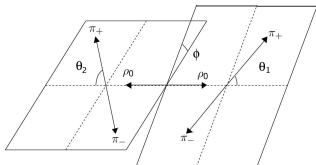
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désintégration vecteur-vecteur + intégration sur ϕ

$$\frac{1}{\Gamma} \frac{d^2\Gamma}{\cos\theta_1 \cos\theta_2} = \frac{9}{4} \left[\cos^2\theta_1 \cos^2\theta_2 f_L + \frac{1}{4} \sin^2\theta_1 \sin^2\theta_2 (1 - f_L) \right]$$

Var discriminantes : m_{ES} , ΔE , NN , Δt , m_1 , m_2 , $\cos\theta_1$, $\cos\theta_2$

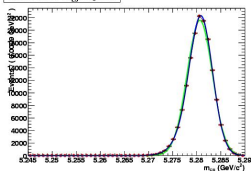
Bruits de fond :

- $q\bar{q} \sim 62000$ év.
- $B\bar{B} \sim 3000$ év.
- $a_1\pi \sim 300$ év.
- $\rho^0 f_0$
- $f_0 f_0$
- charmless

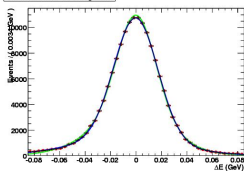
On veut mesurer : $\mathcal{B}(B^0 \rightarrow \rho^0 \rho^0) \sim 10^{-6}$, f_L , C_L , S_L

Modélisation basée sur des simulations Monte-Carlo.

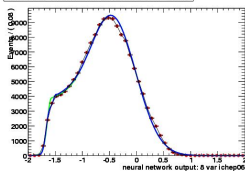
A RooPlot of "m_{B⁰}" SigTrue



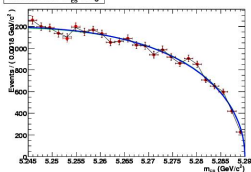
A RooPlot of "ΔE" SigTrue



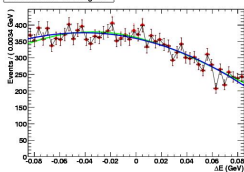
A RooPlot of "neural network output: 8 var ichep08" SigTrue



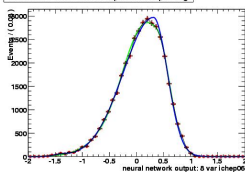
A RooPlot of "m_{B⁰}" Bkg



A RooPlot of "ΔE" SigSXF



A RooPlot of "neural network output: 8 var ichep08" Bkg



données $\vec{x}_i = \{\text{var disc}\}$

paramètres $\vec{\theta}$ que l'on veut ajuster

total pdf : $f(\vec{x}; \theta)$

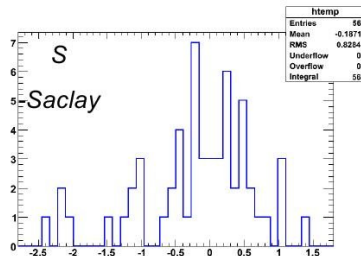
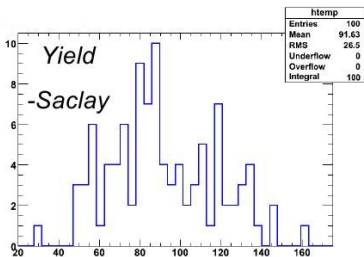
vraisemblance : $L = \prod_{i=1}^N f(\vec{x}_i; \vec{\theta})$

Paramètres laissés libres dans l'ajustement :

- $N_{\rho^0 \rho^0}, f_L, C_L, S_L!$
- certains paramètres du $q\bar{q}$
- le nombre de $q\bar{q}, B\bar{B}, a_1\pi$
- le nombre de $\rho^0 f_0$ et $f_0 f_0$ (BR pas mesurés)

Validation de la méthode

- Création de pseudo-données en utilisant des événements du MC pour toutes les catégories sauf $q\bar{q}$ et $B\bar{B}$
- ajustement par maximum de vraisemblance pour estimer des biais éventuels \Rightarrow systématique



	Injecté	Ajusté	RMS
$N_{\rho^0\rho^0}$	85	91.6 ± 2.65	26.5
f_L	0.705	0.726 ± 0.012	0.12
C_L	0	-0.08 ± 0.14	1.21
S_L	-0.4	-0.37 ± 0.14	1.18
pull $N_{\rho^0\rho^0}$	0	0.19 ± 0.1	1.00
pull C_L	0	-0.031 ± 0.11	0.91
pull S_L	0	0.054 ± 0.12	1.04
convergence	72/100		

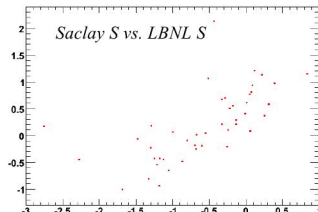
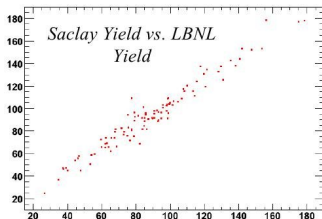
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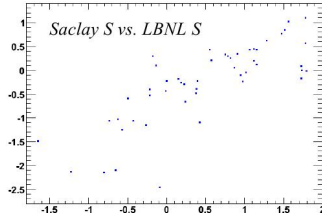
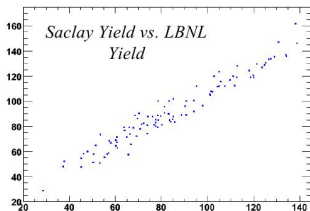
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LBL datasets



Saclay datasets



corrélations utilisées pour dans la procédure de moyennage
des deux fitters (erreurs statistiques)

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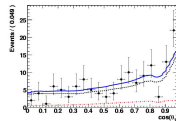
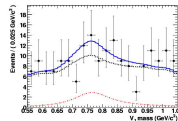
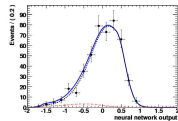
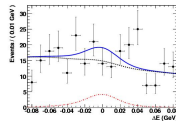
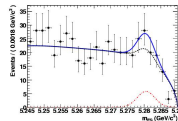
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Résultats de l'ajustement

Quantity	Value
$n(B^0 \rightarrow \rho^0 \rho^0)$	$85 \pm 28 \pm 17$
f_L	$0.70 \pm 0.14 \pm 0.05$
Eff (%)	23.8 ± 1.0
$\mathcal{B}_{\text{sig}} (\times 10^{-6})$	$0.84 \pm 0.29 \pm 0.17$
Significance, stat. only (σ)	4.0
Significance, syst. included (σ)	3.6
C_L^{00}	$0.4 \pm 0.9 \pm 0.2$
S_L^{00}	$0.5 \pm 0.9 \pm 0.2$
$n(B^0 \rightarrow \rho^0 f_0(980))$	-11 ± 16
$n(B^0 \rightarrow f_0(980) f_0(980))$	6 ± 6
$n(B^0 \rightarrow a_1^\pm \pi^\mp)$	296 ± 42
$n(\text{charmless})$	348 ± 64
$n(B\bar{B})$	2614 ± 134
$n(q\bar{q})$	62298 ± 268



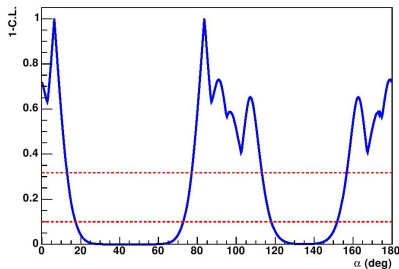
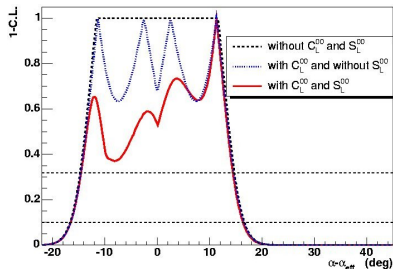
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Contraintes sur α



$|\alpha - \alpha_{\text{eff}}| < 14.5^\circ (16.5^\circ)$ at 68%(90%) CL

$\alpha - \alpha_{\text{eff}} = 11.3$ favorisé

$$\alpha = \left(83.6^{+30}_{-6.5} \right)^\circ$$

première analyse dépendante du temps dans $B^0 \rightarrow \rho^0 \rho^0$

$$\mathcal{B}(B \rightarrow \rho^0 \rho^0) = 0.84 \pm 0.29 \pm 0.17 (\times 10^{-6})$$

$$f_L = 0.70 \pm 0.14 \pm 0.05$$

$$C_L^{00} = 0.4 \pm 0.9 \pm 0.2$$

$$S_L^{00} = 0.5 \pm 0.9 \pm 0.2$$

$$|\alpha - \alpha_{\text{eff}}| < 14.5^\circ (16.5^\circ) \text{ at } 68\% (90\%) \text{ CL}$$

- ajout de la fin du Run 6 très prochainement + systématiques
- conférences d'hiver visées

Backup

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$$5.245 < m_{\text{ES}}^{\text{corr}} < 5.29 \text{ GeV}/c^2$$

$$|\Delta E| < 0.085 \text{ GeV}$$

$$0.55 < m_1 m_2 < 1.05 \text{ GeV}/c^2$$

$$|\mathcal{E}\text{-shape}| < 10$$

$$|\cos \theta_1|, |\cos \theta_2| < 0.98$$

$$\chi_{\text{vtx}}^2 < 15$$

$$|\Delta t| < 15 \text{ ps}$$

$$0.1 < \sigma(\Delta t) < 2.5 \text{ ps}$$

PID not kaon, not electron LH tight

D-veto

~66000 events after selection

Source	$n(B \rightarrow \rho^0 \rho^0)$		f_L	S_L^{00}	C_L^{00}
	fraction	events			
Multiplicative					
Number of B mesons	1.1%	–	–	–	–
Event selection	2.4%	–	–	–	–
PID selection	2.0%	–	–	–	–
Track finding	1.4%	–	–	–	–
MC statistics	<1%	–	< 0.01	< 0.01	< 0.01
Additive					
$a_1\pi$ interference	–	14	0.025	0.07	0.07
PDF variation	–	6	0.035	0.07	0.11
Fit bias	–	4	0.014	0.11	0.09
B background BR& CP	–	5	0.010	0.14	0.18
B background model	–	3	0.005	0.11	0.02
Total	3.6%	17	0.047	0.23	0.24

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$$\chi^2 = \sum_{\rho^+\rho^-, \rho^0\rho^0} \left(\frac{(\tilde{S}_L^{ij} - \sqrt{1 - C_L^{ij}} \sin(2\alpha + \kappa^{ij}))^2}{\sigma^2(\tilde{S}_L^{ij})} + \frac{(\tilde{C}_L^{ij} - C_L^{ij})^2}{\sigma^2(\tilde{C}_L^{ij})} \right) \\ + \sum_{\rho^+\rho^-, \rho^0\rho^0, \rho^\pm\rho^0} \left(\frac{(\tilde{B}^{ij} - B^{ij})^2}{\sigma^2(\tilde{B}^{ij})} + \frac{(\tilde{f}_L^{ij} - f_L^{ij})^2}{\sigma^2(\tilde{f}_L^{ij})} \right) \\ + \text{correlation terms}$$

(1) Capria

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$$F_{Q_{tag}}^{\rho^0 \rho^0}(\Delta t) \sim \frac{e^{-|\Delta t|/\tau}}{4\tau} \times \left\{ 1 - Q_{tag}\Delta w + Q_{tag}\mu(1 - 2w) \right. \\ \left. + (Q_{tag}(1 - 2w) + \mu(1 - Q_{tag}\Delta w)) [S \sin(\Delta m_d \Delta t) - C \cos(\Delta m_d \Delta t)] \right\} \quad (2)$$

where $Q_{tag} = 1(-1)$ when the tagging meson B_{tag}^0 is a $B^0(\bar{B}^0)$, τ is the mean B^0 lifetime, Δm_d is the mass difference between the two B^0 mass eigenstates, and the mistag parameters w and Δw are the average and difference, respectively, of the probabilities that a true B^0 is incorrectly tagged as a \bar{B}^0 or vice versa. μ is the tag efficiency difference between B^0 and \bar{B}^0 . The Δt resolution R function is the sum of three gaussian, weighted by the Δt error for two of them :

$$R(\Delta t, \sigma_{\Delta t}) = f_{core}G(\Delta t, \mu_{core}\sigma_{\Delta t}, \sigma_{core}\sigma_{\Delta t}) + f_{tail}G(\Delta t, \mu_{tail}\sigma_{\Delta t}, \sigma_{tail}\sigma_{\Delta t}) + f_{out}G(\Delta t, \mu_{out}, \sigma_{tail}) \quad (3)$$

where $\Delta t = t' - t$ and $G(\mu, \sigma)$ is a gaussian distribution with bias μ and standard deviation σ .