Andrei Sakharov and Cosmological Baryogengesis

A critical view after more than half century of the seminal paper

COSMOS & CONTEXTO

· SAKHAROV: FÍSICO TEÓRICO OU INVENTOR? ·

Ignacio Alfonso de Bediaga e Hickman / 26 de abril de 2019

Ignacio Bediaga: Centro Brasileiro de Pesquisas Físicas.

Mário Novello's 80th Anniversary Symposium

September 12 Centro Brasileiro de Pesquisas Físicas.

Sakharov conditions

It is traditional to start any discussion of baryogengesis with the list of three necessary ingredients needed to create a baryon asymmetry :

1- Baryonic number violation.

2- Loss of thermal equilibrium

3- C and CP violation.

Although these principles have come to be attributed to Sakharov, he did not enunciate them as clearly in his three-page paper as one might have been led to think, especially the second point.

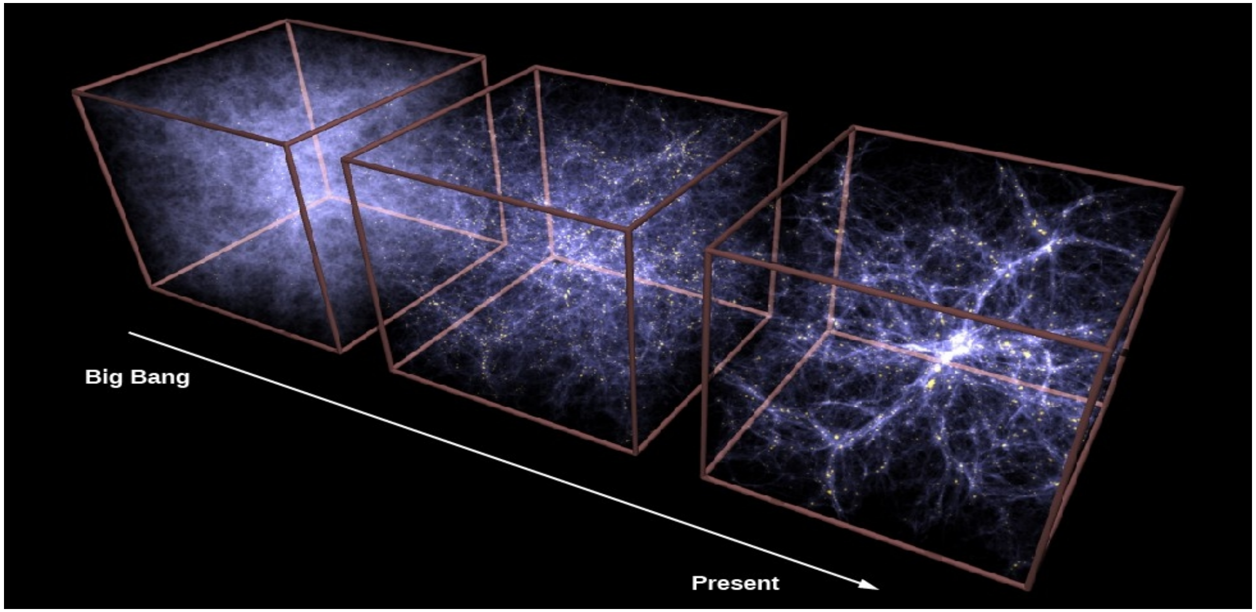
James M. Cline

Cold Universe Expansion

Based in the Zeldovich Cold Universe:

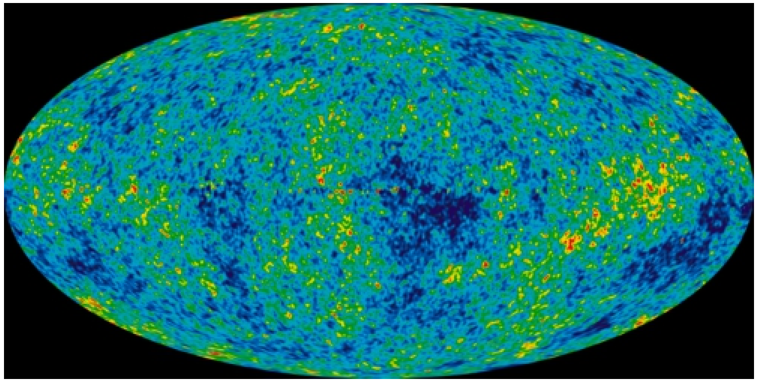
‘The initial stage of an expanding Universe and the appearance of a nonuniform distribution of matter"   Soviet Physics JETP, Vol. 22, p.241.

Initial state super-dense matter at -273 ^{0}C with a non uniform matter distribution, with a state equations arrive to a non-uniform mass distribution.



Cosmic Radiation Background

Arno Penzias and Robert Wilson



Uniform distribution of the radiation
2.7248 to 2.7252 Kelvin variation of 0.01%

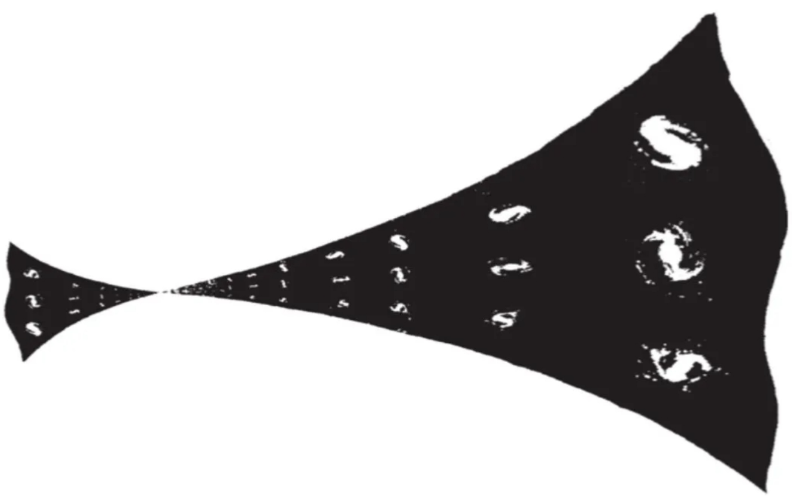
Hot Universe Expansion

Based in the Gamow/Zeldovich Hot Universe:

'Violation of CP invariance, C asymmetry, and baryon asymmetry of the Universe',
Pisma Zh. Eksp. Teor. Fiz. 5, 32-35, 1967)

Sakharov describes a scenario where a universe which was initially contracting and with equal and opposite baryon asymmetry to that existing today goes through a bounce at the singularity and reverses the magnitude of its baryon asymmetry

This scenario kept the CPT Invariance



The world of Andrei Sakharov:
a Russian physicist's path to
freedom, de Gennady Gorelik.
Oxford University Press (2005).

T<0 anti-matter Universe

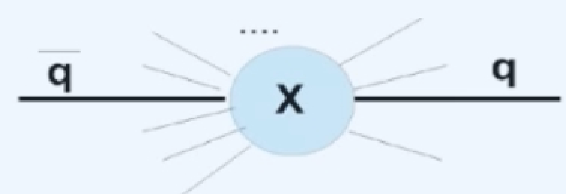
T=0 Bounce with "Maximum" particles X

Massa 2 x10^{-5}g or 10^{19} proton mass

Possible only out of the thermodynamical equilibrium

Maximum: Double baryon number violation

T>0 matter Universe

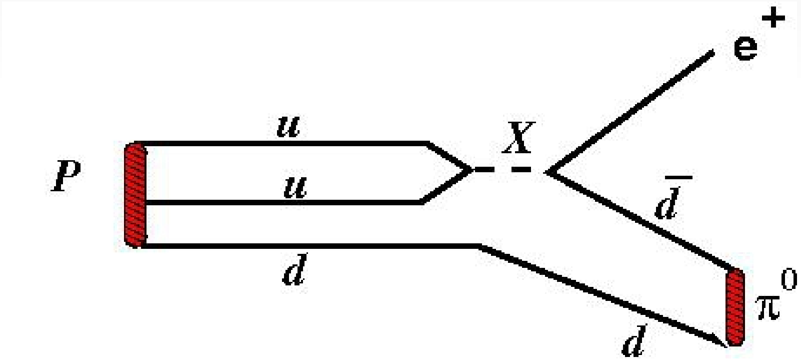


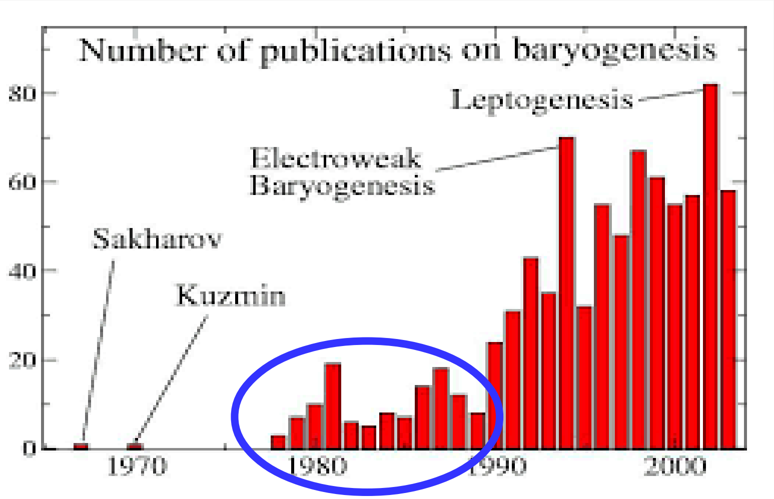
Baryonic violation problem

In 1955, Lee and Yang discussed a new massless gauge field based on the established conservation of baryon number.

They predicted the existence of a repulsive force between baryonic matter.

Grand Unify Theory
SU(5)

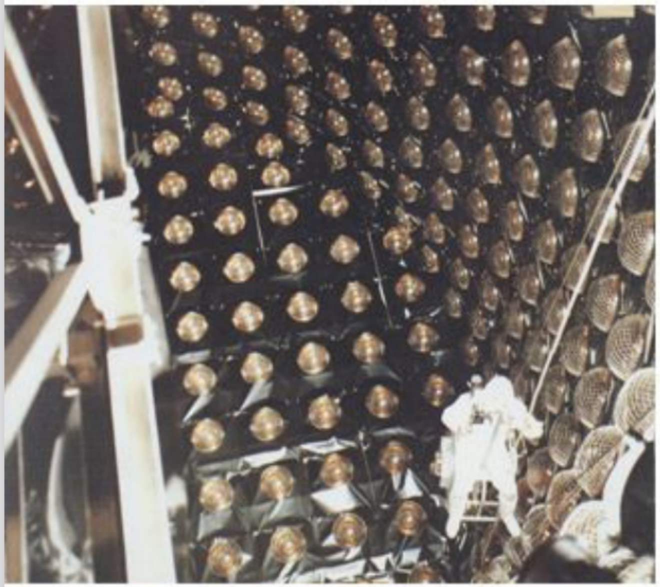




Big experimental effort to looking for protons decays

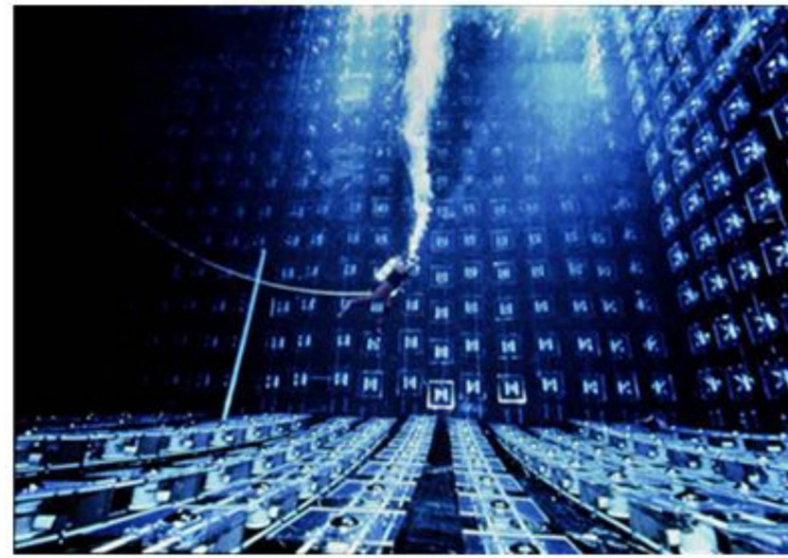
Proton decay experiments

Grand Unified Theories (in the late 1970's) ➔ $\tau_p = 10^{30 \pm 2}$ years



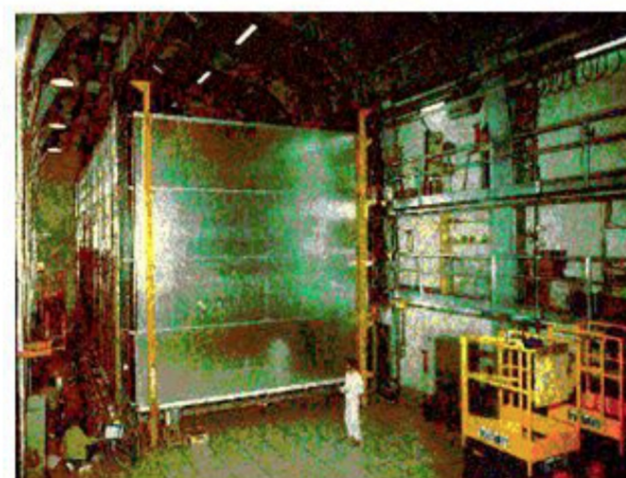
Kamiokande
(1000ton)

IMB
(3300ton)



NUSEX
(130ton)

Frejus
(700ton)

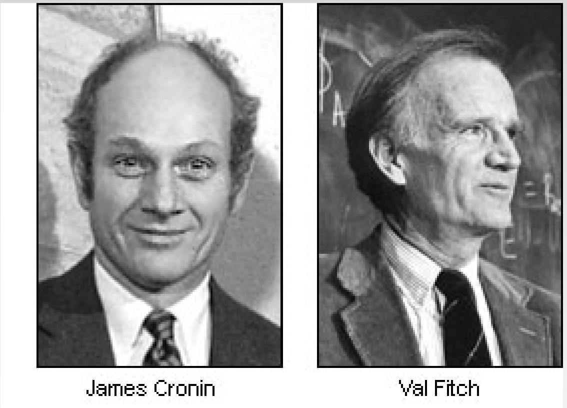


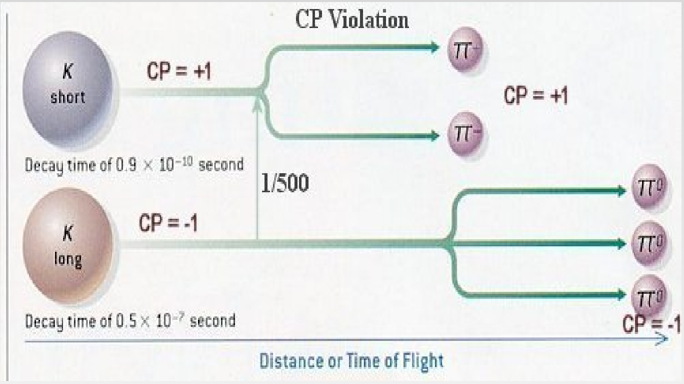
These experiments observed many contained atmospheric neutrino events (background for proton decay).

Negative experimental results: Particle Data Group

p DECAY MODES	Partial mean life (10^{30} years)	C
Antilepton + meson		
$N \to e^+ \pi$	> 158 (n), > 1600 (p)	
$N \to \mu^+ \pi$	> 100 (n), > 473 (p)	
$N \to \nu \pi$	> 112 (n), > 25 (p)	
$p \to e^+ \eta$	> 313	
$p \to \mu^+ \eta$	> 126	
$n \to \nu \eta$	> 158	
$N \to e^+ \rho$	> 217 (n), > 75 (p)	
$N \to \mu^+ \rho$	> 228 (n), > 110 (p)	
$N \to \nu \rho$	> 19 (n), > 162 (p)	
$p \to e^+ \omega$	> 107	
$p \to \mu^+ \omega$	> 117	
$n \to \nu \omega$	> 108	
$N \to e^+ K$	> 17 (n),	
$p \to e^+ K^0_S$	> 120	
$p \to e^+ K^0_L$	> 51	
$N \to \mu^+ K$	> 26 (n),	
$p \to \mu^+ K^0_S$	> 150	
$p \to \mu^+ K^0_L$	> 83	
$N \to \nu K$	> 86 (n),	
$n \to \nu K^0_S$	> 51	
$p \to e^+ K^*(892)^0$	> 84	
$N \to \nu K^*(892)$	> 78 (n),	
Antilepton + mesons		
$p \to e^+ \pi^+ \pi^-$	> 82	
$p \to e^+ \pi^0 \pi^0$	> 147	
$n \to e^+ \pi^- \pi^0$	> 52	
$p \to \mu^+ \pi^+ \pi^-$	> 133	
$p \to \mu^+ \pi^0 \pi^0$	> 101	
$n \to \mu^+ \pi^- \pi^0$	> 74	
$n \to e^+ K^0 \pi^-$	> 18	
Lepton + meson		
$n \to e^- \pi^+$	> 65	
$n \to \mu^- \pi^+$	> 49	
$n \to e^- \rho^+$	> 62	
$n \to \mu^- \rho^+$	> 7	
$n \to e^- K^+$	> 32	
$n \to \mu^- K^+$	> 57	
Lepton + mesons		
$p \to e^- \pi^+ \pi^+$	> 30	
$n \to e^- \pi^+ \pi^0$	> 29	
$p \to \mu^- \pi^+ \pi^+$	> 17	
$n \to \mu^- \pi^+ \pi^0$	> 34	
$p \to e^- \pi^+ K^+$	> 75	
$p \to \mu^- \pi^+ K^+$	> 245	
Antilepton + photon(s)		
$p \to e^+ \gamma$	> 670	
$p \to \mu^+ \gamma$	> 478	
$n \to \nu \gamma$	> 28	
$p \to e^+ \gamma\gamma$	> 100	
$n \to \nu \gamma\gamma$	> 219	

1964 CP violation observed





Epigraph in a copy of his paper to his friend Evgeny Feinberg

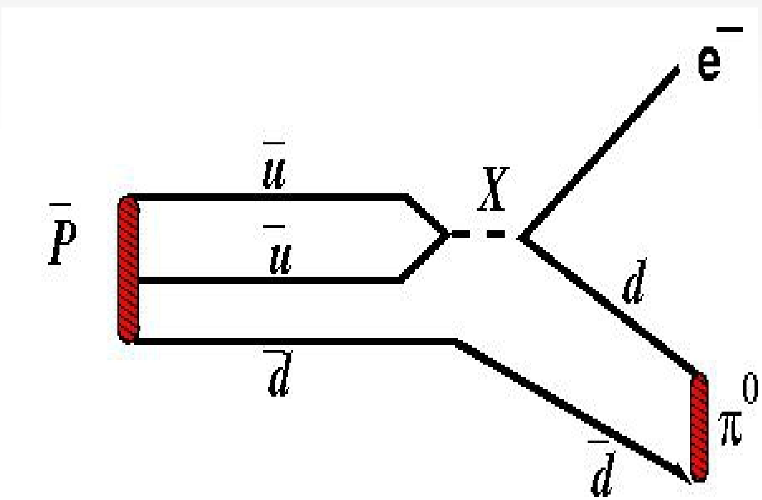
> *"Making use of the effect*
>
> *1. Okubo has proposed,*
>
> *While the temperature is high*
>
> *The universe is richly clothed*
>
> *In a coat made to fit*
>
> *Its crooked figure-head to foot."*

In 1957 Okubo proposed that CP violation imply in a different rate between particles and anti-particles decays

Direct CP violation

Direct CP violation

Anti-proton decay rate bigger than proton decay.



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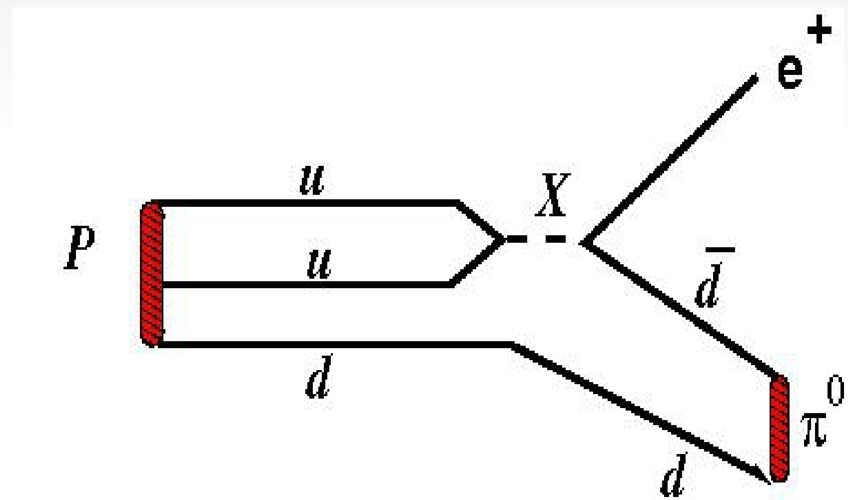


Real life: directly C̸P violation:

Phases ϕ_i *change signal with charge conjugate operation: weak phase.*

Phases δ_i *no change signal with charge conjugate operation: strong phase.*

$$\langle f|T|i\rangle = A_1 e^{i(\delta_1+\phi_1)} + A_2 e^{i(\delta_2+\phi_2)},$$
$$\langle \bar{f}|T|\bar{i}\rangle = A_1 e^{i(\delta_1-\phi_1+\theta)} + A_2 e^{i(\delta_2-\phi_2 \ldots}$$

CP Violation
Branco, Lavoura and Silva
Oxford U. Press

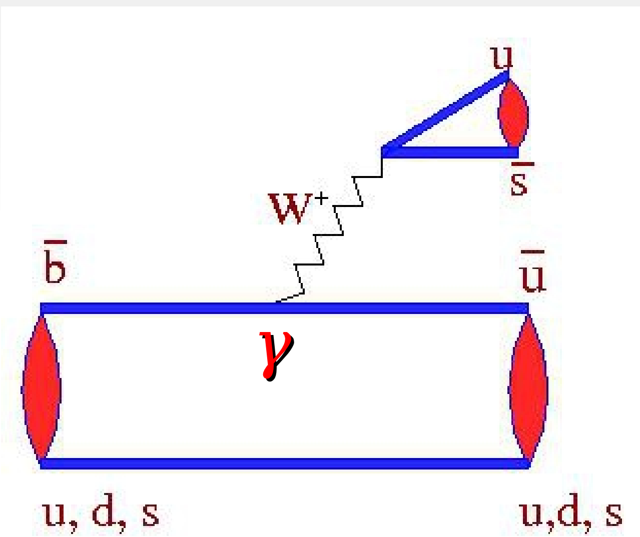
$$|\langle f|T|i\rangle|^2 - |\langle \bar{f}|T|\bar{i}\rangle|^2 = -4A_1A_2 \sin(\delta_1-\delta_2)\sin(\phi_1-\phi_2).$$

Directly CP violation: two amplitudes with different strong and weak phase.

$\not{C}P$ in charge meson decays: quark graphics contributions to the charmless B decays

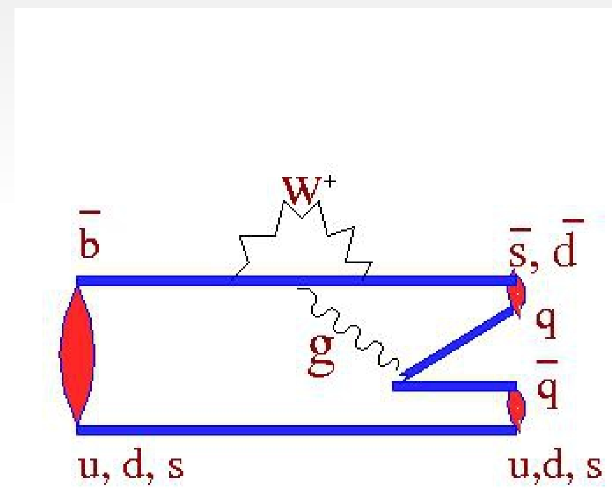
Myron Bander, D. Silverman, A. Soni : Phys.Rev.Lett. 43 (1979) 242

Tree



Interference=>$\not{C}P$

Penguin



Weak CKM phase γ change signal with charge conjugate operation

Strong phase coming from the loop in the Penguin contribution.

CP in charge meson decays: hadronic FSI contributions to the charmless B decays

Wolfenstein (**Phys.Rev. D43 (1991) 151-156)**

Simplified formulation: P particle decay in a family of only two final states **α** e **β**

Weak CKM phase γ change signal with charge conjugate operation

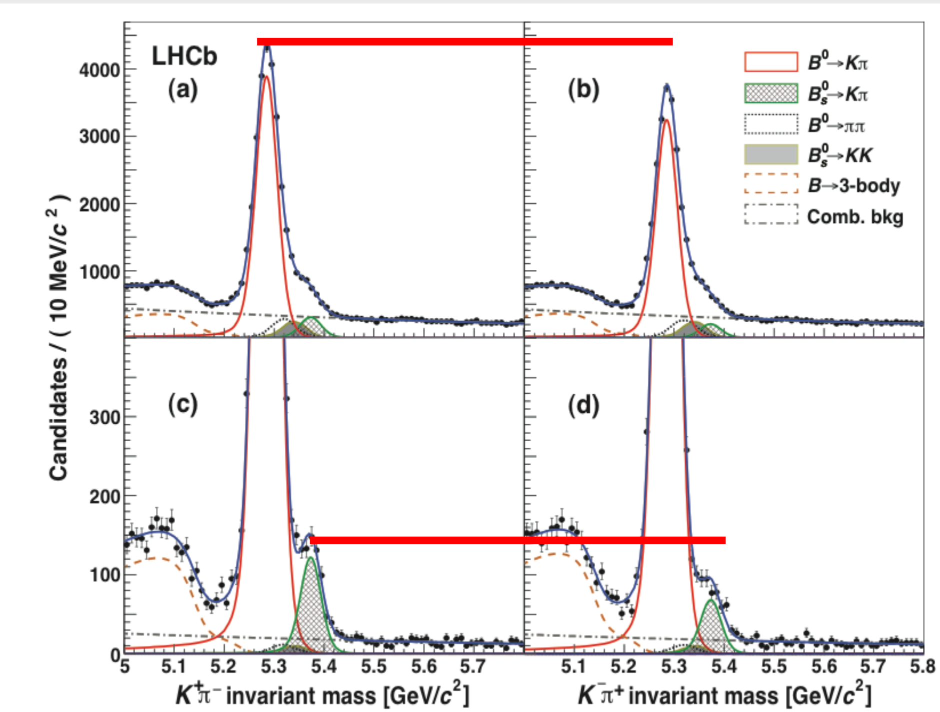
Strong phase coming from hadronic final state interaction.

Directly CP violation for :
$B^0 \rightarrow K^+\pi^-$ e $B^0_s \rightarrow K^+\pi^-$

LHCb: *Phys. Rev. Lett. 110, 221601 (2013)*

Directly CP violation:

simple counting of events between charge conjugates final states.



$$A_{CP}(B^0 \rightarrow K^+\pi^-) = \frac{N(B^0 \rightarrow K^+\pi^-) - N(\bar{B}^0 \rightarrow K^-\pi^+)}{N(B^0 \rightarrow K^+\pi^-) + N(\bar{B}^0 \rightarrow K^-\pi^+)}$$

$$A_{CP}(B^0 \rightarrow K^+\pi^-) = -0.080 \pm 0.007\,(\text{stat}) \pm 0.003\,(\text{syst}),$$

$$A_{CP}(B^0_s \rightarrow K^-\pi^+) = 0.27 \pm 0.04\,(\text{stat}) \pm 0.01\,(\text{syst}).$$

CP violation
in heavy meson three body decay

Search of C$\not{P}$ violation in three body Beauty decays.

- *General questions about CP Violation.*
- *CP Violation in heavy meson three body decays.*
- *Experimental evidence of CP Violation in $B^{\pm} \to K^{\pm} \pi^{+} \pi^{-}$, $B^{\pm} \to K^{\pm} K^{+} K^{-}$ decays.*
- *CPT constraint for direct CP asymmetry.*
- *Perspectives*

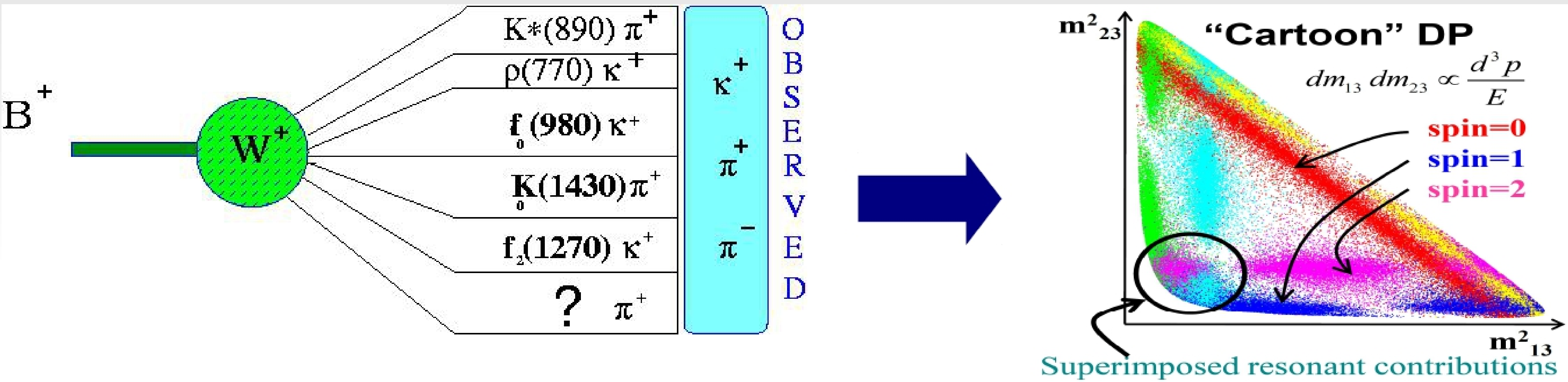
Ignacio Bediaga: Centro Brasileiro de Pesquisas Físicas.

Mário Novello's 70th Anniversary Symposium

August 15 to 17 Centro Brasileiro de Pesquisas Físicas

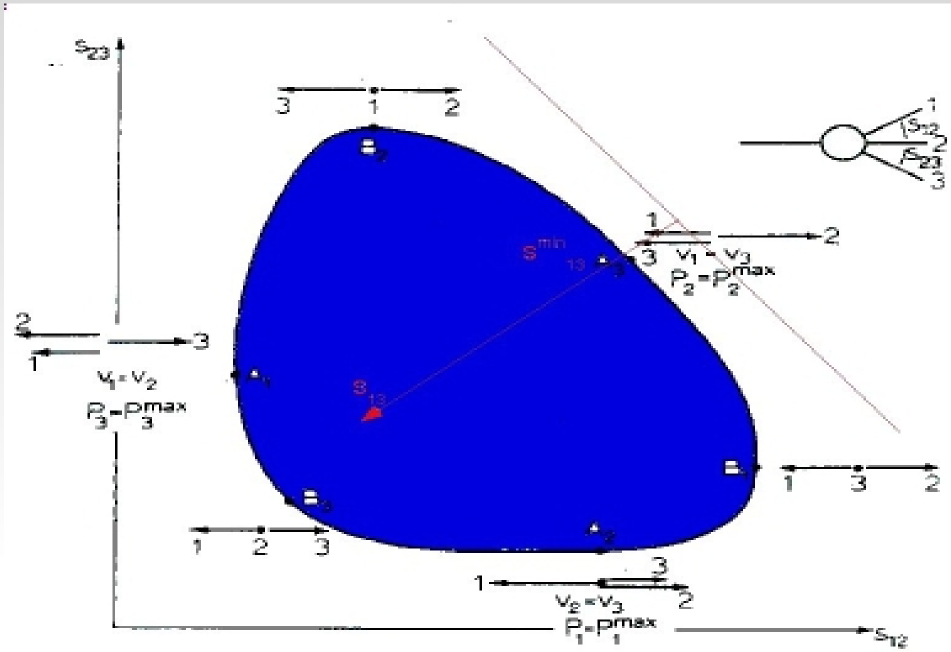
Charmless three body B charge decays

- *Study the B decays and their intermediary states:*



- $B^{\pm}$ –>$K^{\pm}\ \pi^{+}\ \pi^{-}$
- $B^{\pm}$ –>$\pi^{\pm}\ \pi^{+}\ \pi^{---}$
- $B^{\pm}$ –>$\pi^{\pm}\ K^{+}\ K^{-}$
- $B^{\pm}$ –>$K^{\pm}\ K^{+}\ K^{-}$

Dalitz Plot-



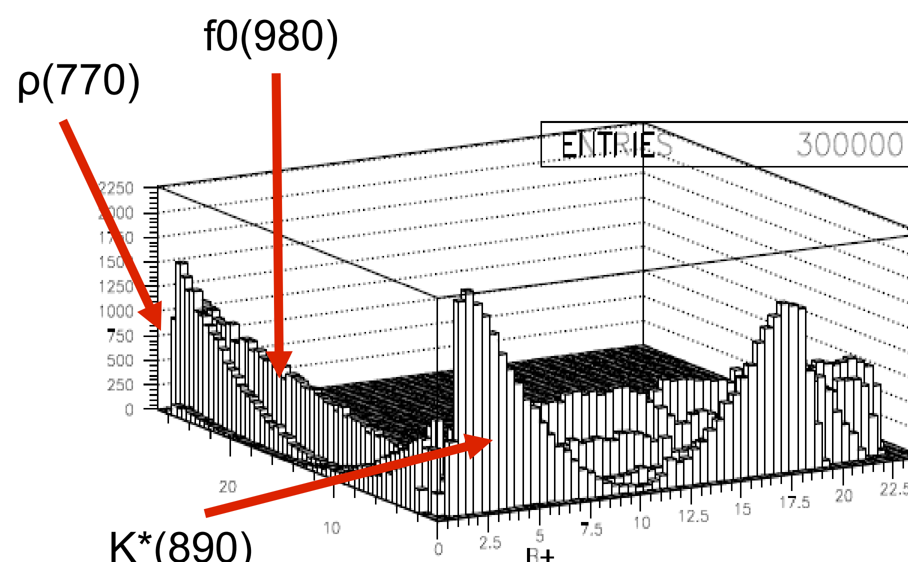
$$s_{12} = M_{12}^2 = (p_1^\nu + p_2^\nu)^2$$
$$s_{13} = M_{13}^2 = (p_1^\nu + p_3^\nu)^2$$
$$s_{23} = M_{23}^2 = (p_2^\nu + p_3^\nu)^2$$

With one constraint

Flat phase space where it is write the dynamics.

$$d\Gamma(s_{12}, s_{23}) = \frac{1}{(2\pi)^3 32 M_B^3} |\mathcal{M}|^2 \, ds_{12} ds_{23}$$

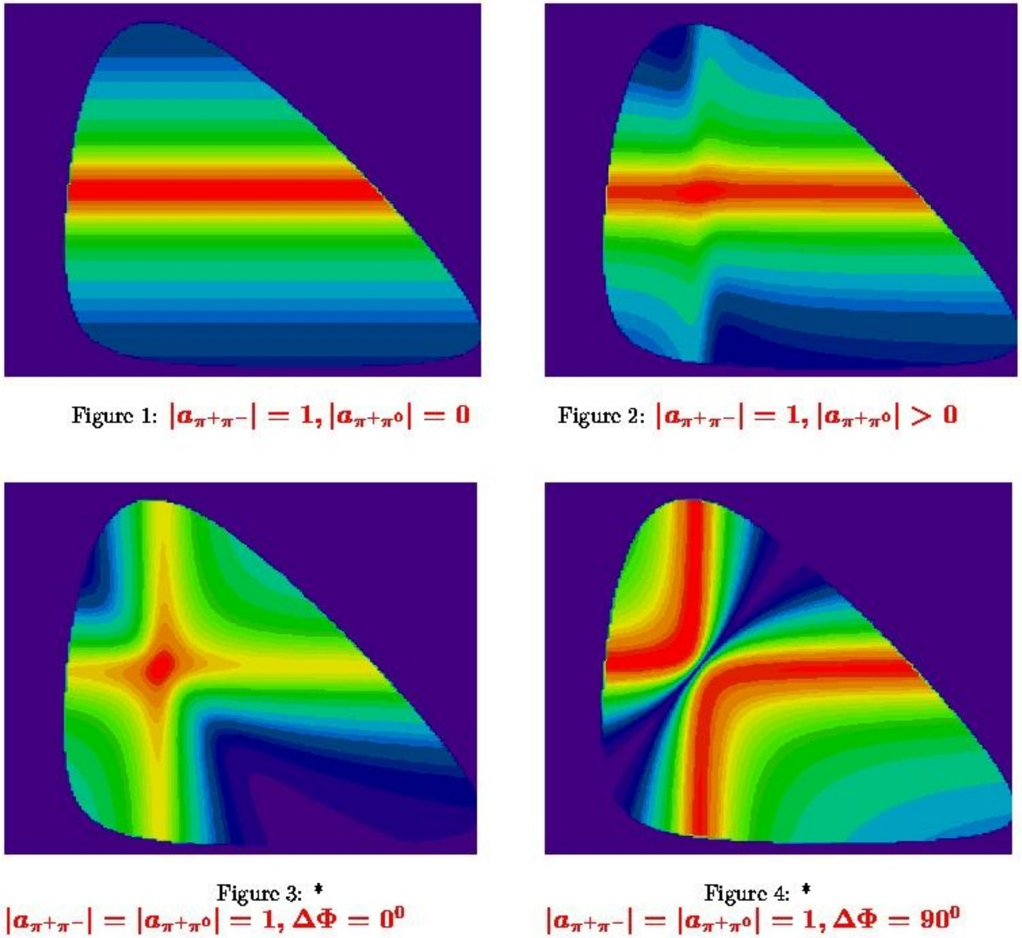
$$| M |^2 \Rightarrow \textbf{resonances}$$



Phases in amplitude analysis

Signature of the phase difference
between two interfering resonances

$$|\mathcal{M}|^2 = |a_{\pi^+\pi^-}|^2 + |a_{\pi^+\pi^0}|^2 + 2|a_{\pi^+\pi^-}\ a_{\pi^+\pi^0}|$$



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-EP-2022-100
LHCb-PAPER-2021-049
June 16, 2022

Direct *CP* violation in charmless three-body decays of $B^{\pm}$ mesons

LHCb collaboration

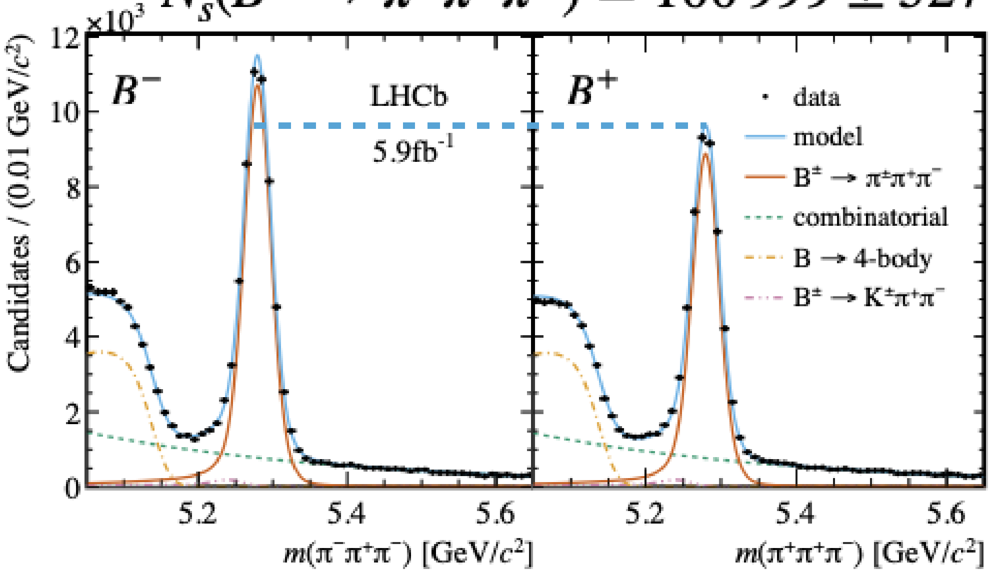
Abstract

Measurements of *CP* asymmetries in charmless three-body decays of $B^{\pm}$ mesons are reported using proton-proton collision data collected by the LHCb detector, corresponding to an integrated luminosity of $5.9\,\mathrm{fb}^{-1}$. The previously observed *CP* asymmetry in $B^{\pm} \to \pi^{\pm}K^{+}K^{-}$ decays is confirmed, and *CP* asymmetries are observed with a significance of more than five standard deviations in the $B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ and $B^{\pm} \to K^{\pm}K^{+}K^{-}$ decays, while the *CP* asymmetry of $B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}$ decays is confirmed to be compatible with zero. The distributions of these asymmetries are also studied as a function of the three-body phase space and suggest contributions from rescattering and resonance interference processes. An indication of the presence of the decays $B^{\pm} \to \pi^{\pm}\chi_{c0}(1P)$ in both $B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ and $B^{\pm} \to \pi^{\pm}K^{+}K^{-}$ decays is observed, as is *CP* violation involving these amplitudes.

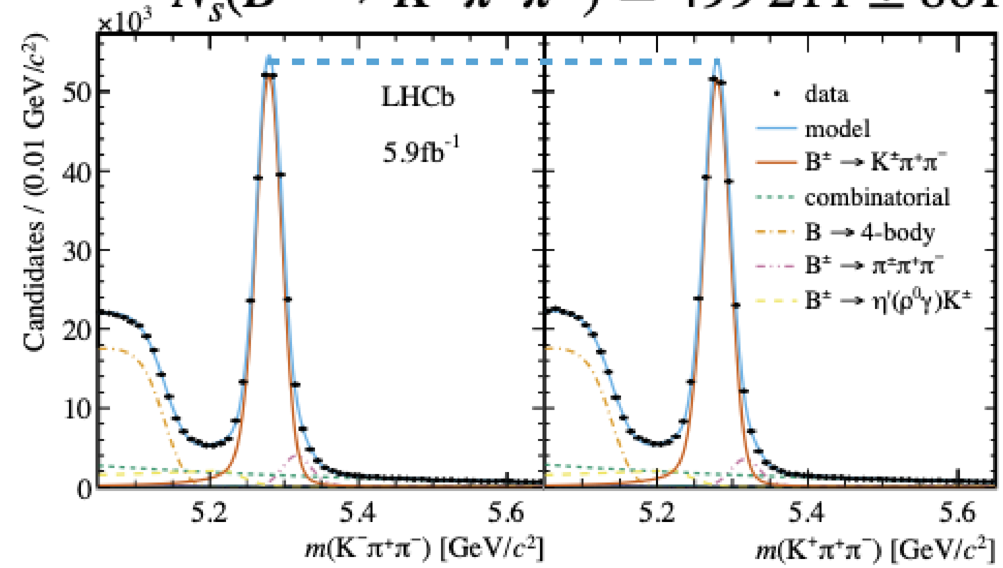
Submitted to Phys. Rev. D

Fit results

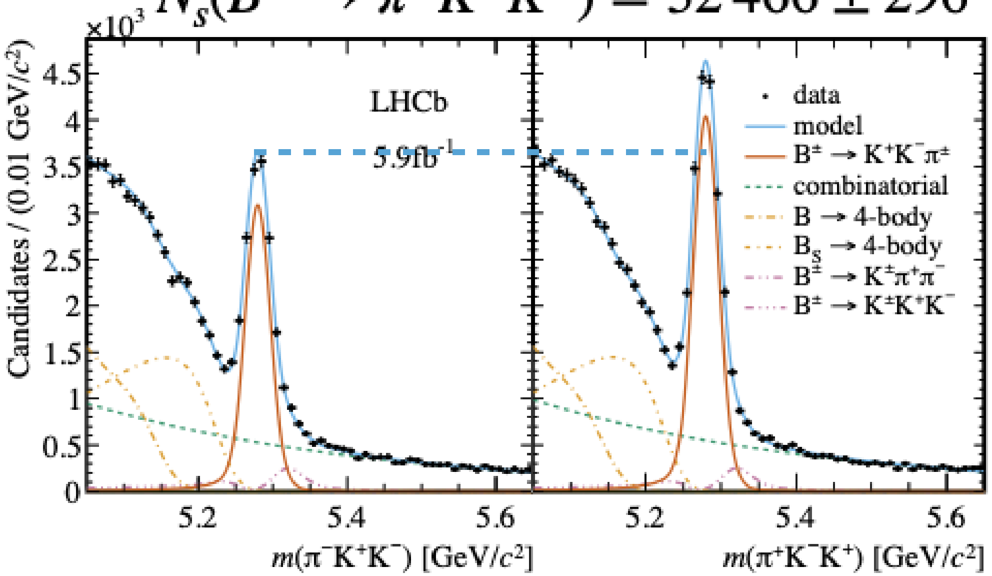
$N_s(B^\pm \to \pi^\pm\pi^+\pi^-) = 100\,999 \pm 527$



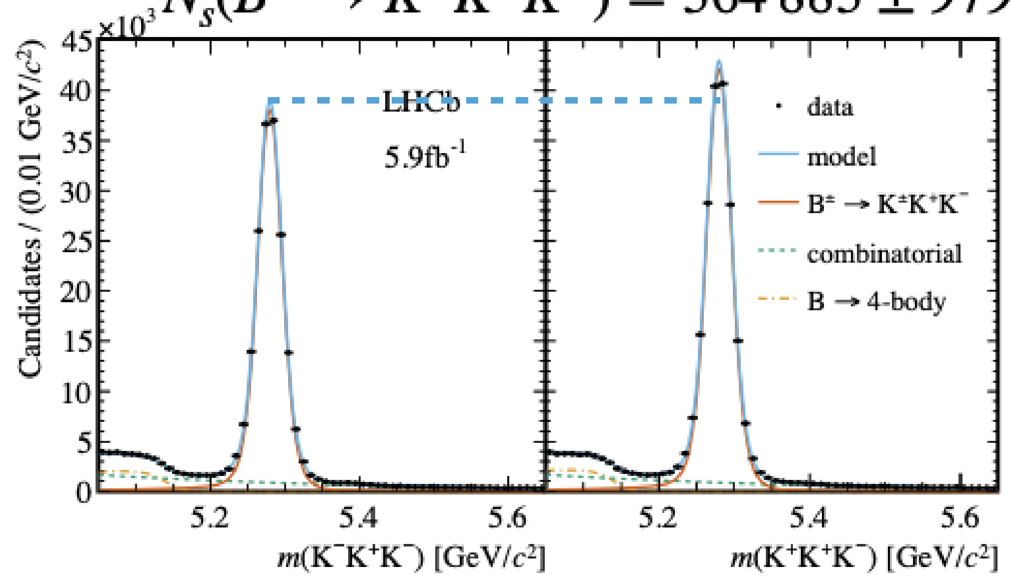
$N_s(B^\pm \to K^\pm\pi^+\pi^-) = 499\,211 \pm 861$



$N_s(B^\pm \to \pi^\pm K^+K^-) = 32\,466 \pm 296$

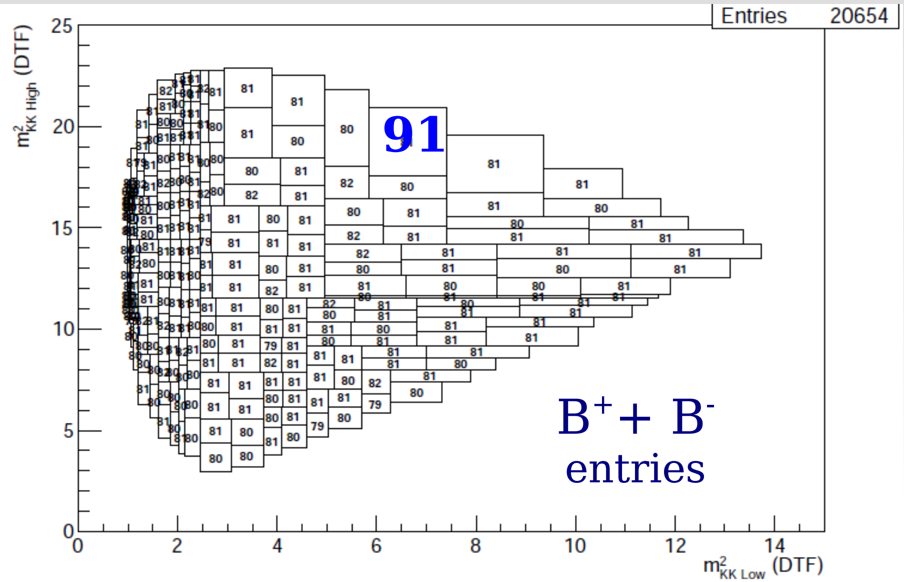


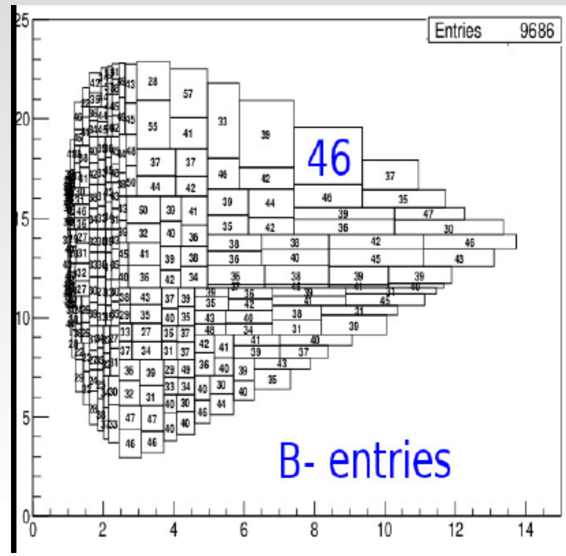
$N_s(B^\pm \to K^\pm K^+K^-) = 364\,883 \pm 979$

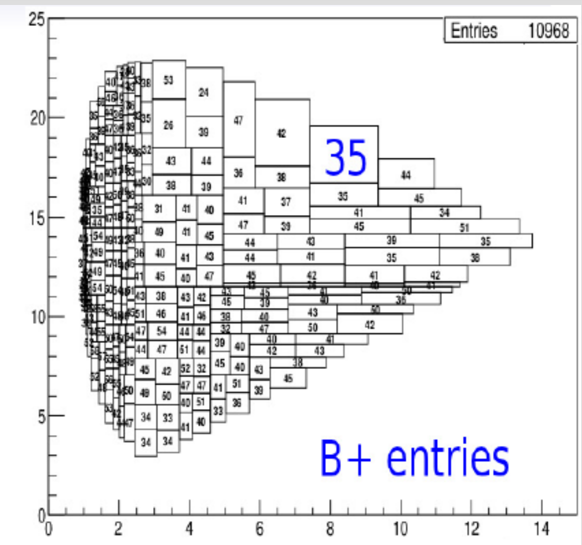


$B^+ - B^-$ Dalitz differences

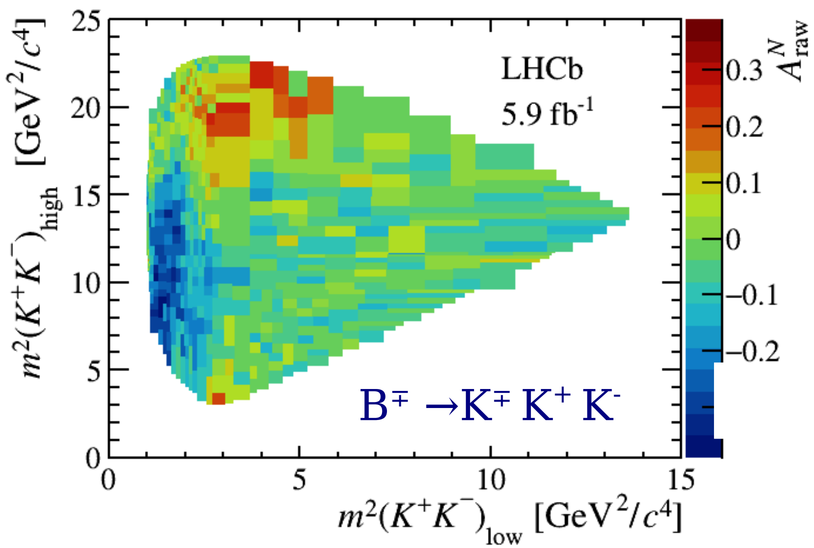
M^2_{K+K-} Vs M^2_{K+K-} phase space distribution







Dalitz Map of the CP violation



Simetrical Dalitz

If $M^2_{K+K1-} > M^2_{K+K2-}$

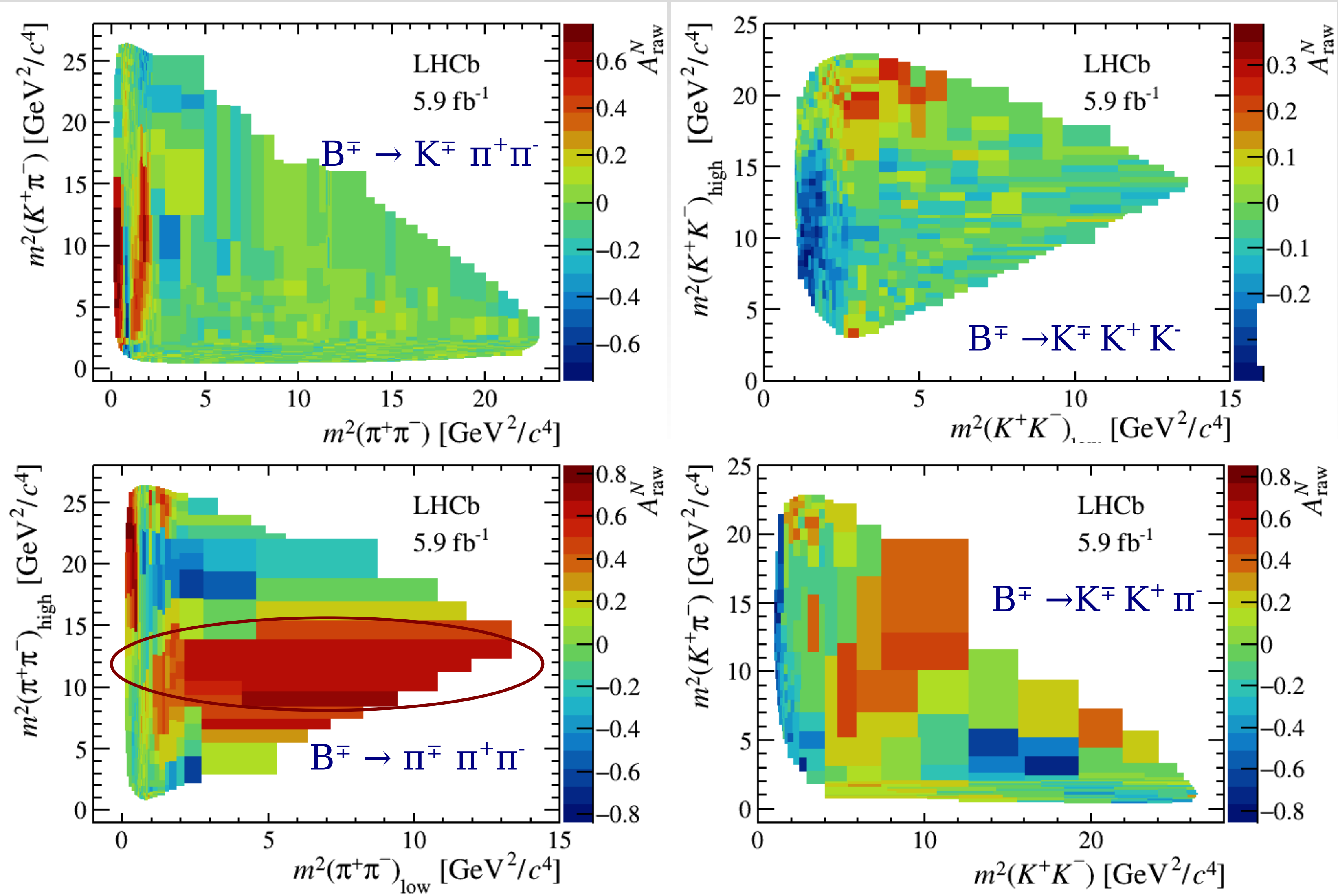
$M^2_{K+K1-} = M^2_{K+K\,-high}$

and

$M^2_{K+K1-} = M^2_{K+K\,-low}$

Otherwise ....

CP Dalitz distribution for the four $B^{\mp} \to h^{\mp} h^{+} h^{-}$ channels



The CKM weak phase γ is a constant

Hadronic final state interaction phase changing in the phase

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Review

Direct *CP* violation in beauty and charm hadron decays

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ABSTRACT

Since the discovery of *CP* violation more than 5 decades ago, this phenomenon is still attracting a lot of interest. Among the many fascinating aspects of this subject, this review is dedicated to direct *CP* violation in non-leptonic decays. The advances within the last decade have been enormous, driven by the increasingly large samples of *b*- and *c*-hadron decays, and have led to very interesting results such as large *CP* asymmetries in charmless B decays and the observation of direct *CP* violation in the charm sector. We address the quest for understanding the origin of strong phases, the importance of final state interactions and the relation with *CPT* symmetry, and different approaches to measure direct *CP* violation in these decays. The main experimental results and their implications are then discussed.

Contents

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0146-6410/

C̸P in charge meson decays: hadronic FSI contributions to the charmless B decays

Wolfenstein (Phys.Rev. D43 (1991) 151-156)

Simplified formulation: P particle decay in a family of only two final states **α** e **β**

Weak CKM phase γ change signal with charge conjugate operation

Strong phase coming from hadronic final state interaction.

Sakharov model keep the CPT Invariance

- *CPT invariance ⇒ Same lifetime and same mass to particle and anti-particle.*

$$\text{Lifetime} \quad \tau = 1 / \Gamma_{total} = 1 / \overline{\Gamma}_{total}$$

$$\Gamma_{total} = \Gamma_1 + \Gamma_2 + \Gamma_3 + \Gamma_4 + \Gamma_5 + \Gamma_6 + \ldots\ldots\ldots\ldots\ldots\ldots$$

$$\overline{\Gamma}_{total} = \overline{\Gamma}_1 + \overline{\Gamma}_2 + \overline{\Gamma}_3 + \overline{\Gamma}_4 + \overline{\Gamma}_5 + \overline{\Gamma}_6 + \ldots\ldots\ldots\ldots\ldots\ldots$$

- CP violation $\Rightarrow \Gamma_1 > \overline{\Gamma}_1$.
- CPT conservation:

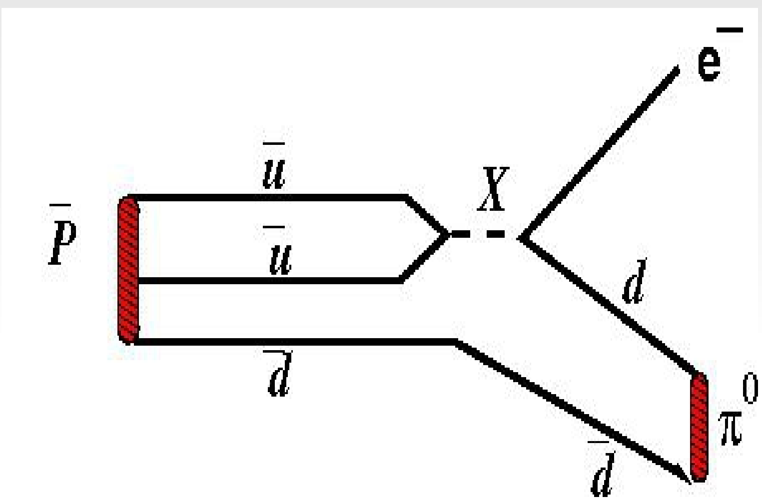
$$\Gamma_2 + \Gamma_3 + \Gamma_4 + \Gamma_5 + \Gamma_6 + \ldots\ldots\ldots\ldots < \overline{\Gamma}_2 + \overline{\Gamma}_3 + \overline{\Gamma}_4 + \overline{\Gamma}_5 + \overline{\Gamma}_6 + \ldots\ldots\ldots\ldots\ldots$$

In a exact proportion.

- **This imply a necessary communication between CP violation channels.**
- **In strong interaction it can be produced by re-scattering.**

Direct CP violation

Anti-proton decay rate bigger than proton decay.



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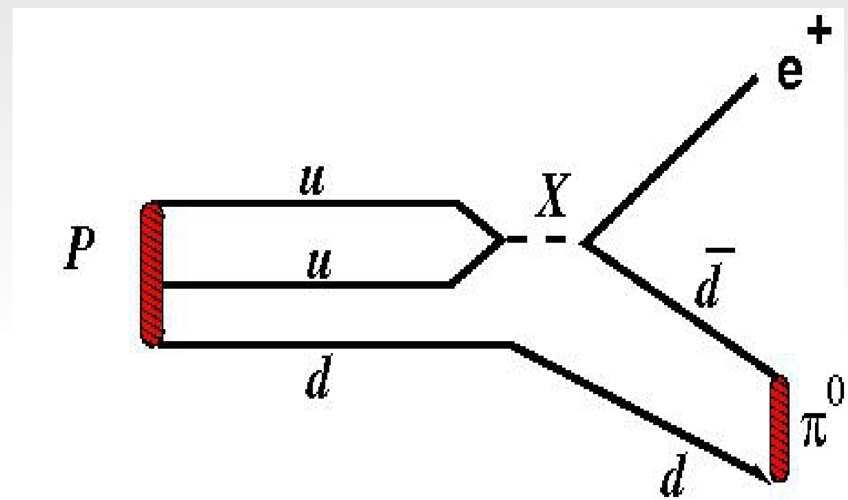
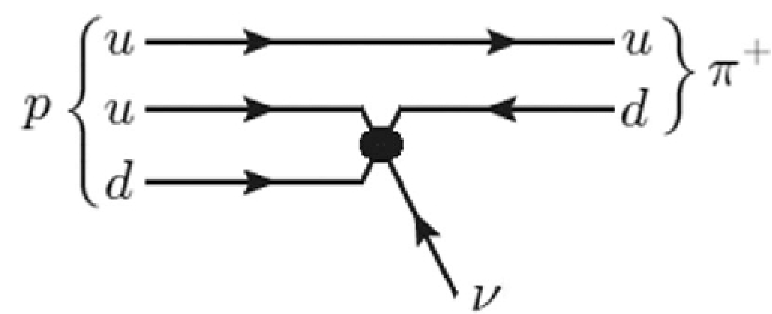


It is necessary another proton decay channel, where the CP violation of the anti-proton is bigger than the proton



The Sakharov proposed apparently is non-feasible if one keep CPT

Apparent solution

James Claine lectures at Les Houches Summer School

arXiv:hep-ph/0609145

Channel with direct CP violation

$$\Gamma(X \rightarrow qq) \neq \Gamma(\bar{X} \rightarrow \bar{q}\bar{q})$$

Channel with direct CP violation

$$\Gamma(X \rightarrow Y) \neq \Gamma(\bar{X} \rightarrow \bar{Y})$$

Y with a different baryon number than qq

$$\Gamma(X \rightarrow qq) + \Gamma(X \rightarrow Y) = \Gamma(\bar{X} \rightarrow \bar{q}\bar{q}) + \Gamma(\bar{X} \rightarrow \bar{Y})$$

In a exact proportion.

This imply a necessary communication between CP violation channels.

So, Y must couple with qq

Marshak et al, Theory of Weak interactions in particles physics: Wiley & Sons, 1969.

CPT Invariance

If *CPT* invariance holds, we have for any final state $|\lambda\rangle$ into which K can decay

$$\langle\lambda^{\text{out}}|\, H_w^h\, |\bar{K}\rangle = \langle\lambda^{\text{out}}|\, (CPT)^{-1}H_w^h CPT\, |\bar{K}\rangle$$

Now we can choose the phase factors of the state vectors $|K\rangle$ and $|\bar{K}\rangle$ such that

$$CPT\, |\bar{K}\rangle = -\langle K| \qquad (6.76a)$$

and

$$CPT\, |\lambda^{\text{out}}\rangle = \eta_\lambda \langle\hat{\lambda}^{\text{in}}| \qquad (6.76b)$$

where $|\eta_\lambda|^2 = 1$ and $\hat{\lambda}$ denotes the *CPT* conjugate state to λ (particles replaced by antiparticles with the same momenta but with all spins

reversed). Then

$$\begin{aligned}\langle\lambda^{\text{out}}|\, H_w^h\, |\bar{K}\rangle &= -\eta_\lambda \langle K|\, H_w^h\, |\hat{\lambda}^{\text{in}}\rangle \\ &= -\eta_\lambda \sum_{\hat{\lambda}''} \langle K|\, H_w^h\, |\hat{\lambda}''^{\text{out}}\rangle\langle\hat{\lambda}''^{\text{out}}\mid \hat{\lambda}^{\text{in}}\rangle \\ &= -\eta_\lambda \sum_{\hat{\lambda}''} S_{\hat{\lambda}''\hat{\lambda}}\langle K|\, H_w^h\, |\hat{\lambda}''^{\text{out}}\rangle\end{aligned}$$

where $S_{\hat{\lambda}\hat{\lambda}''} = e^{2i\delta}{}_{\hat{\lambda}\hat{\lambda}''}$ is the S matrix element for the final states. Thus

$$\langle\lambda^{\text{out}}|\, H_w^h\, |\bar{K}\rangle = -\eta_\lambda \sum_{\hat{\lambda}''} S_{\hat{\lambda}\hat{\lambda}''}\langle\hat{\lambda}''^{\text{out}}|\, H_w^h\, |K\rangle^* \qquad (6.77)$$

If λ denotes many-particle final states, as is the case here, the application of the above result is complicated by the difficulty of classifying the final states in such a way that each has a single phase shift. Nevertheless, if we sum absolute squares on both sides of (6.77) over all final states, we obtain [33]

$$\begin{aligned}\Gamma_{\bar{K}} &= \sum_{\lambda} |\langle\lambda^{\text{out}}|\, H_w^h |\bar{K}\rangle|^2 \\ &= \sum_{\hat{\lambda}}\sum_{\hat{\lambda}''}\sum_{\hat{\lambda}'''} S_{\hat{\lambda}''\hat{\lambda}} S_{\hat{\lambda}'''\hat{\lambda}} \langle\hat{\lambda}''^{\text{out}}|\, H_w^h\, |K\rangle^* \langle\hat{\lambda}'''^{\text{out}}|\, H_w^h\, |K\rangle \\ &= \sum_{\hat{\lambda}''}\sum_{\hat{\lambda}'''} \delta_{\hat{\lambda}''\hat{\lambda}'''} \langle\hat{\lambda}''^{\text{out}}|\, H_w^h\, |K\rangle^* \langle\hat{\lambda}'''^{\text{out}}|\, H_w^h\, |K\rangle \\ &= \sum_{\hat{\lambda}''} |\langle\hat{\lambda}''^{\text{out}}|\, H_w^h\, |K\rangle|^2 = \Gamma_K\end{aligned} \qquad (6.78)$$

It is not necessary [34] to sum over all final states. Summation is necessary over only such states as would be mixed together in forming S matrix eigenstates. Now for $K \rightarrow 3\pi$ decay, parity conservation forbids any strong or electromagnetic transitions between a total $J = 0$ three-pion state and a $J = 0$ two-pion state; nor is either connected to leptonic final states except by the weak interaction. Thus, neglecting electromagnetism, two-pionic, three-pionic, and leptonic rates of K should be separately equal [34, 35] to the corresponding rates of $\bar{K}$.

(i) 3π *modes of charged kaons.* The above considerations show that *CPT* invariance implies [33, 34] (neglecting the electromagnetic interaction)

$$\begin{aligned}\Gamma(K^+ \rightarrow 3\pi) &\equiv \Gamma(K^+ \rightarrow \pi^+\pi^+\pi^-) + \Gamma(K^+ \rightarrow \pi^0\pi^0\pi^+) \\ &= \Gamma(K^- \rightarrow \pi^-\pi^-\pi^+) + \Gamma(K^- \rightarrow \pi^0\pi^0\pi^-) \equiv \Gamma(K^- \rightarrow 3\pi)\end{aligned} \qquad (6.79)$$

Simplified version of the Marshak et al, demonstration

I.B., T. Frederico and O. Lourenço PRD 89, 094013 (2014)

III. *CPT* INVARIANCE IN A DECAY

To define our notation and the framework for implementing the *CPT* constraint in *B* meson decays, we follow closely Refs. [22,23]. A hadron state $|h\rangle$ transforms under *CPT* as $\mathcal{CPT}|h\rangle = \chi\langle\bar{h}|$, where $\bar{h}$ is the charge conjugate state and χ a phase. The weak and strong Hamiltonians conserve *CPT* , therefore $(\mathcal{CPT})^{-1}H_w\mathcal{CPT} = H_w$ and $(\mathcal{CPT})^{-1}H_s\mathcal{CPT} = H_s$.The weak matrix element for the hadron decay is $\langle\lambda_{\rm out}|H_w|h\rangle$, where $\lambda_{\rm out}$ includes the distortion from the strong force due to the final state interaction. The requirement of $\mathcal{CPT}$ invariance is fulfilled for the matrix element when

$$\langle\lambda_{\rm out}|H_w|h\rangle = \chi_h\chi_\lambda\langle\bar{\lambda}_{\rm in}|H_w|\bar{h}\rangle^*. \qquad (1)$$

Inserting the completeness of the strongly interacting states, eigenstates of H_s, and using hermiticity of H_w, one gets

$$\langle\lambda_{\rm out}|H_w|h\rangle = \chi_h\chi_\lambda\sum_{\bar{\lambda}'}S_{\bar{\lambda}',\bar{\lambda}}\langle\bar{\lambda}'_{\rm out}|H_w|\bar{h}\rangle^*, \qquad (2)$$

where the S-matrix element is $S_{\bar{\lambda}',\bar{\lambda}} = \langle\bar{\lambda}'_{\rm out}|\bar{\lambda}_{\rm in}\rangle$.

The sum of partial decays width of the hadron decay and the correspondent sum for the charge conjugate should be identical, which follows from Eq. (2)

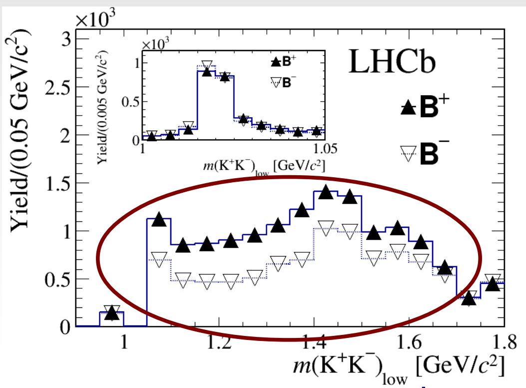
$$\sum_\lambda|\langle\lambda_{\rm out}|H_w|h\rangle|^2 = \sum_{\bar{\lambda}}\left|\sum\nolimits_{\bar{\lambda}'}S^*_{\bar{\lambda}',\bar{\lambda}}\langle\bar{\lambda}'_{\rm out}|H_w|\bar{h}\rangle\right|^2 = \sum_{\bar{\lambda}}|\langle\bar{\lambda}_{\rm out}|H_w|\bar{h}\rangle|^2, \qquad (3)$$

and note that besides the *CPT* constraint we have also used the hermiticity of the weak Hamiltonian.

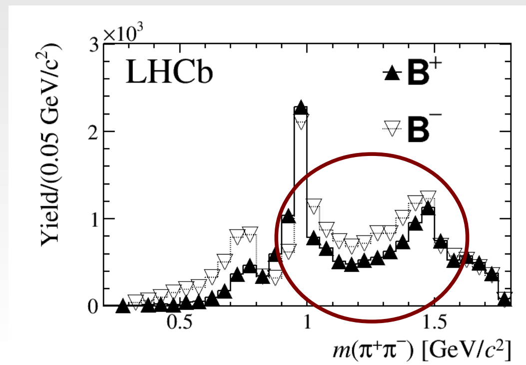
Thanks Mario!!!!

CP violation from re-scattering : *final state interaction $\pi^+ \pi^- \rightarrow K^+ K^-$*

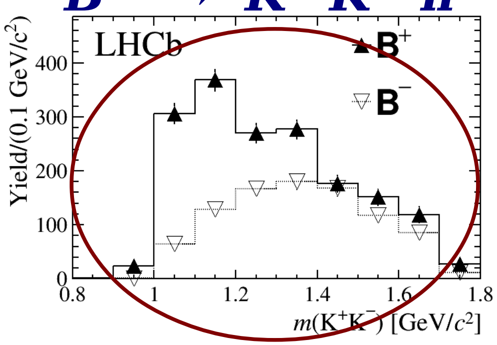
$B^{\mp} \rightarrow K^{\mp} K^+ K$



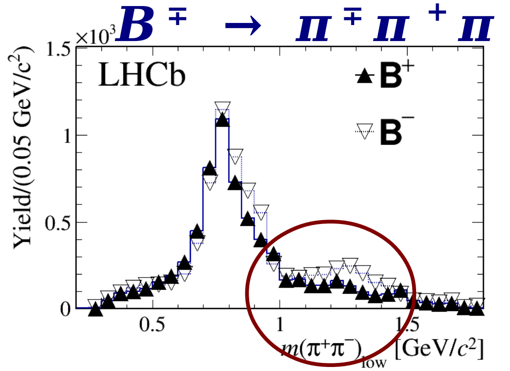
$B^{\mp} \rightarrow K^{\mp} \pi^+ \pi^-$



$B^{\mp} \rightarrow K^{\mp} K^+ \pi$



$B^{\mp} \rightarrow \pi^{\mp} \pi^+ \pi^-$



- positive ~~CP~~ in $B^{\mp} \rightarrow K^{\mp} \pi^+ \pi^-$ and $B^{\mp} \rightarrow \pi^{\mp} \pi^+ \pi^-$
- negative in $B^{\mp} \rightarrow \pi^{\mp} K^+ K^-$ and $B^{\mp} \rightarrow K^{\mp} K^+ K^-$.
- Same invariant mass: between 1 to 1.6GeV

Cohen, D et al PRD 22 (1980) 2595

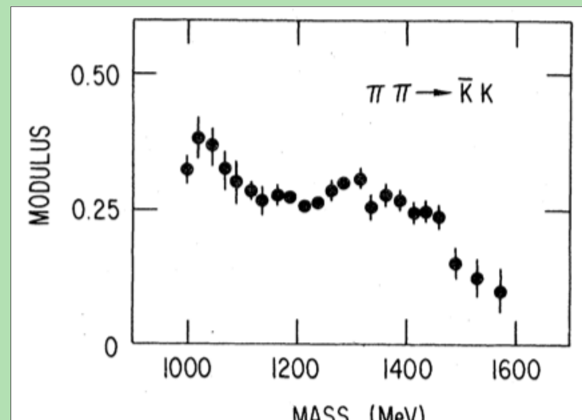


FIG. 27. Modulus of the $\pi\pi \rightarrow \overline{K}K$ scattering amplitude $|T(\pi\pi \quad \overline{K}K)|$ from solution I(b).