On the New Enhanced Promise of ~~CP~~ in Charm!

Ikaros Bigi (Notre Dame du Lac)

Executive Summary

- Relative `dullness' of SM on FCNC & ~~CP~~ for charm - unique low (yet $\neq 0$) background search for NP

$$\left[\frac{\text{NP signal}}{\text{theor.SM noise}}\right]_{\text{up-type}} > \left[\frac{\text{NP signal}}{\text{theor.SM noise}}\right]_{\text{down-type}}$$

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- Discovery of D^0 oscillations has widened stage for ~~CP~~ and added impetus to such searches
- Complementarity with B & connection with K studies
- The new lab -- ~~CP~~ in final state distributions

The Menu

I Uniqueness of Charm

II New Physics Scenarios & their Footprints

III $\not{CP}$ in Final State Distributions

IV Outlook

Epilogos: Bismarck's Rule

I Uniqueness of Charm

- New Physics in general induces FCNC
  - their couplings could be substantially stronger for Up-type than for Down-type quarks (although not true in SM)
- SM `background' much smaller for FCNC of *Up*-type quarks
  - ➥ cleaner (not larger) signal:

$$\left[\frac{\text{NP signal}}{\text{theor.SM noise}}\right]_{\text{up-type}} > \left[\frac{\text{NP signal}}{\text{theor.SM noise}}\right]_{\text{down-type}}$$

Up-type quarks: u c t

only Up-type quark allowing full range of probes for New Phys.

- top quarks do not hadronize $\Longrightarrow$ no T^0 - $\overline{T}^0$ oscillations

  hadronization while hard to force under theor. control

  enhances observability of ~~CP~~

- up quarks: no π^0-π^0 oscillations possible

  CP asymmetries in partial widths basically ruled out by CPT

basic contention:
charm transitions are a unique portal for obtaining a novel access to flavour dynamics with the experimental situation being a priori favourable (apart from absence of Cabibbo suppression)!

II New Physics Scenarios & their Footprints

Discovery of D^0 oscillations

-- $x_D = (1.00 \pm 0.26)\%$, $y_D = (0.76 \pm 0.18)\%$ --

a great and essential experimental achievement;

in its theoretical interpretation it resembles the Cannonade of Valmy:

Tactically a draw in our battle against the SM --
yet it promises a strategic victory
in the fields of ~~CP~~

Analogy with another topical case: B_s oscillations

The observed value of $\Delta M(B_s)$ is fully consistent with SM expectations -- within sizable uncertainties. Yet a subdominant NP contribution to $\Delta M(B_s)$ could still provide the dominant source of time dependent ~~CP~~ in $B_s \to \psi\phi$!

[$3\%|_{SM} \to 30\%|_{NP}$!]

(2.1) Generalities

- ☺ baryon # of Universe implies/requires NP in ~~CP~~ dynamics
- ☺ existence of three-level Cabibbo hierarchy

  SM rate CF : CS : DCS ~ 1 : 1/20 : 1/400
- ☺ within SM:
  - ☞ tiny weak phase in 1x Cabibbo supp. modes: $V(cs) = 1 \ldots + i\lambda^4$
  - ☞ no weak phase in Cab. favoured & 2 x Cab. supp. modes (except for $D^{\pm} \to K_S h^{\pm}$)
- ☺ CP asymmetry linear in NP amplitude
- ☺ final state interactions large
- ☺ ...
- ☺ many $H_c \to \geq 3$ P, VV... with sizeable BR's
  - ➥ CP observables also in final state distributions
- ☺ D^0 oscillations adds a second coherent amplitude needed to make a complex phase observable

CP asymmetries in partial rates

Well suited channels:

D^0 (t) $\to K^+K^-, \pi^+\pi^-, K^+\pi^-, K_S K^+K^-, K_S\pi^+\pi^-$

$D^\pm \to K_S\pi^\pm$

~~CP~~ in $L(\Delta C=2) \to \phi_{NP}$ & $\varepsilon_{NP} = 1 - |q/p|$

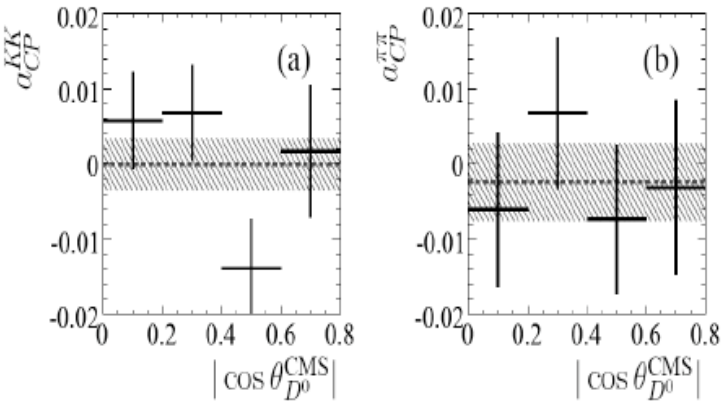
- CFD: $D^0 \to K_S\phi$ $A_{CP}(t) = (x_D \sin\phi_{NP} - y_D \varepsilon_{NP} \cos\phi_{NP})(t/\tau)$
- SCSD: $D^0 \to K^+K^-, \pi^+\pi^-$ $A_{CP}(t) = (x_D \sin\phi'_{NP} - y_D \varepsilon_{NP} \cos\phi'_{NP})(t/\tau)$
- DCSD: $D^0 \to K^+\pi^-$ -- the SM amplitude suppress. by $tg^2\theta_C$

➥ need to measure x_D & y_D accurately & independently

oscillations can generate time *dependent* CP asymmetries that survive integrating over time (unless $e^+ e^- \to D^0\bar{D}^0$)

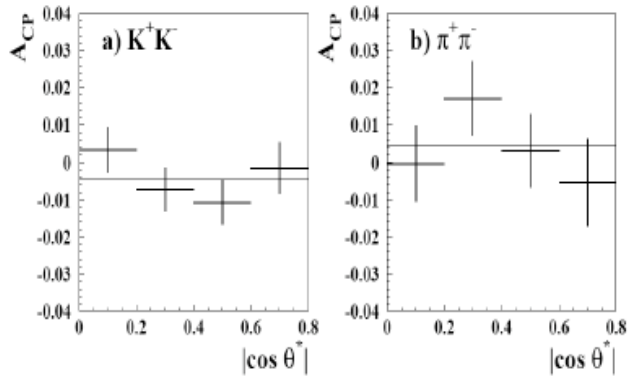
$D^0 \to K^+K^-$ and $\pi^+\pi^-$

Phys.Rev.Lett.100:061803 (2008)



$$A_{CP}^{KK} = [\ 0.00 \pm 0.34(\text{stat.}) \pm 0.13(\text{syst.})]\%$$
$$A_{CP}^{\pi\pi} = [-0.24 \pm 0.52(\text{stat.}) \pm 0.22(\text{syst.})]\%$$

Arxiv:0807.0148v1 (2008) **NEW**



$$A_{CP}^{KK} = [\ 0.43 \pm 0.30(\text{stat.}) \pm 0.11(\text{syst.})]\%$$
$$A_{CP}^{\pi\pi} = [0.43 \pm 0.52(\text{stat.}) \pm 0.12(\text{syst.})]\%$$

- none seen so far down to the 1% ($1\%/tg^2\,\theta_C$) level --
- they are ~ (x_D or y_D) (t/τ_D)sin ϕ_{weak};
  - with x_D, $y_D \leq 0.01$ a signal would hardly have been credible
  - yet now it is getting interesting!

The `Dark Horse'

SL: $D^0 \to l^- \nu K^+$ vs. $D^0 \to l^+ \nu K^-$

$a_{SL} \sim \text{Min}[\Delta\Gamma/\Delta M, \Delta M/\Delta\Gamma] \sin\phi_{NP}$, $\Delta\Gamma/\Delta M \sim O(1)$

- $a_{SL} \sim 0.1$ conceivable (even few x 0.1)

i.e. relatively few wrong-sign leptons, yet with a large asymmetry!

vs.

- $a_{SL}(K_L) = 3.3 \times 10^{-3}$ with $\Delta\Gamma/\Delta M \sim O(1)$ & $\sin\phi_{CKM,eff} << 1$
- $a_{SL}(B_d) \sim 4 \times 10^{-4}$ with $\Delta\Gamma/\Delta M \sim O(\text{few} \times 10^{-3})$
- $a_{SL}(B_s) \sim 2 \times 10^{-5}$ with $\Delta\Gamma/\Delta M \sim O(\text{few} \times 10^{-3})$ & $\sin\phi_{CKM,eff} \sim O(\text{few} \times 10^{-2})$

$a_{SL}(D^0)$ probably cannot be measured by LHCb, yet

$|p/q| \sim |1 - a_{SL}/2|$ affects NL ~~CP~~ observables

IV A New Physics Scenario -- LHT

- Baryogenesis requires New Physics with ~~CP~~ !
- do *not* need SUSY without R parity to generate observable ~~CP~~ in D decays

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☞ Baryogenesis requires New Physics with ~~CP~~ !

☞ do *not* need SUSY without R parity to generate observable ~~CP~~ in D decays

["SUSY without R parity can do anything -- except make coffee!"]

(2.2) A New Physics Scenario -- LHT

☞ Baryogenesis requires New Physics with ~~CP~~ !

☞ do *not* need SUSY without R parity to generate observable ~~CP~~ in D decays

["SUSY without R parity can do anything -- except make coffee!"]

can invoke natural scenarios like Littlest Higgs models with T parity

- LHT designed to `delay the day of reckoning' --

i.e. reconcile SM electroweak quantum corrections with NP to emerge directly at the LHC

- quadratic mass divergence cancelled on 1-loop level with bosons unlike SUSY
  - SM + $(W,Z,A)_H$ + T_H + $\Phi_{I=1}$
- non-SM particles <1 TeV
  - need T parity: T+: SM, T_H^+

    T-: $(W,Z,A)_H^-$, T_H^-, $\Phi_{I=1}^-$ + mirror fermions' q_H

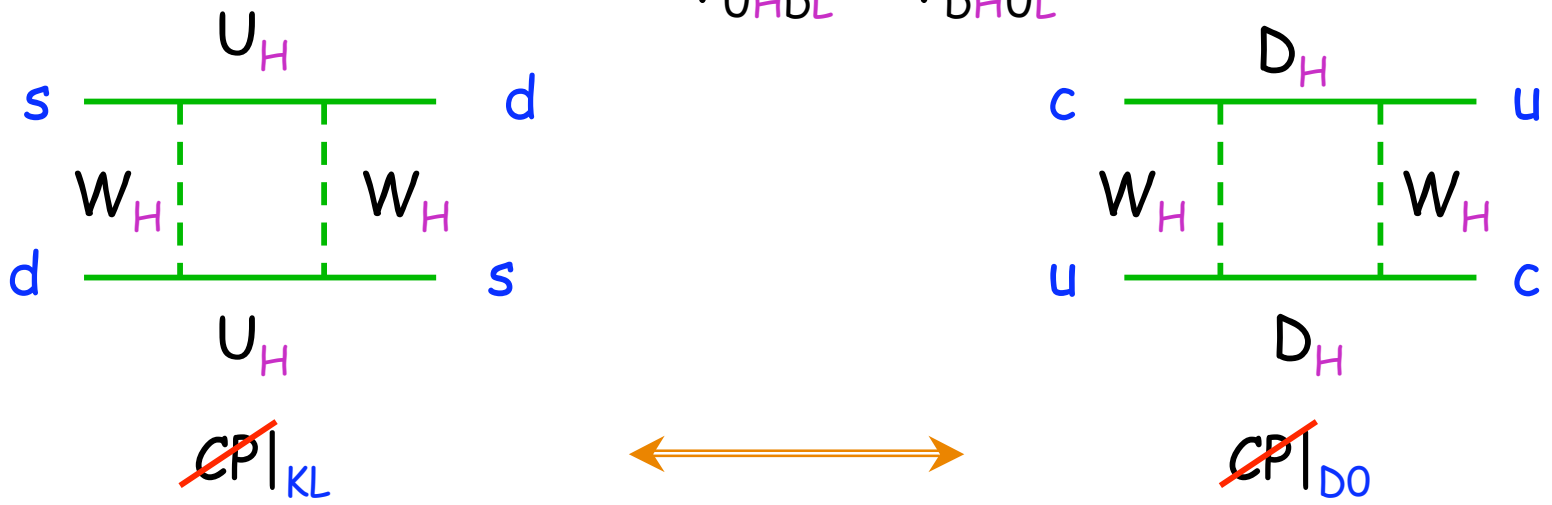
flavour dynamics not part of the motivation!

✍ even so: LHT ≠ MFV

2 new 3x3 mixing matrices for coupling U_H to D_L & D_H to U_L

$$U_H\, V_{UHDL} = V_{DHUL}\, V_{CKM}^*$$

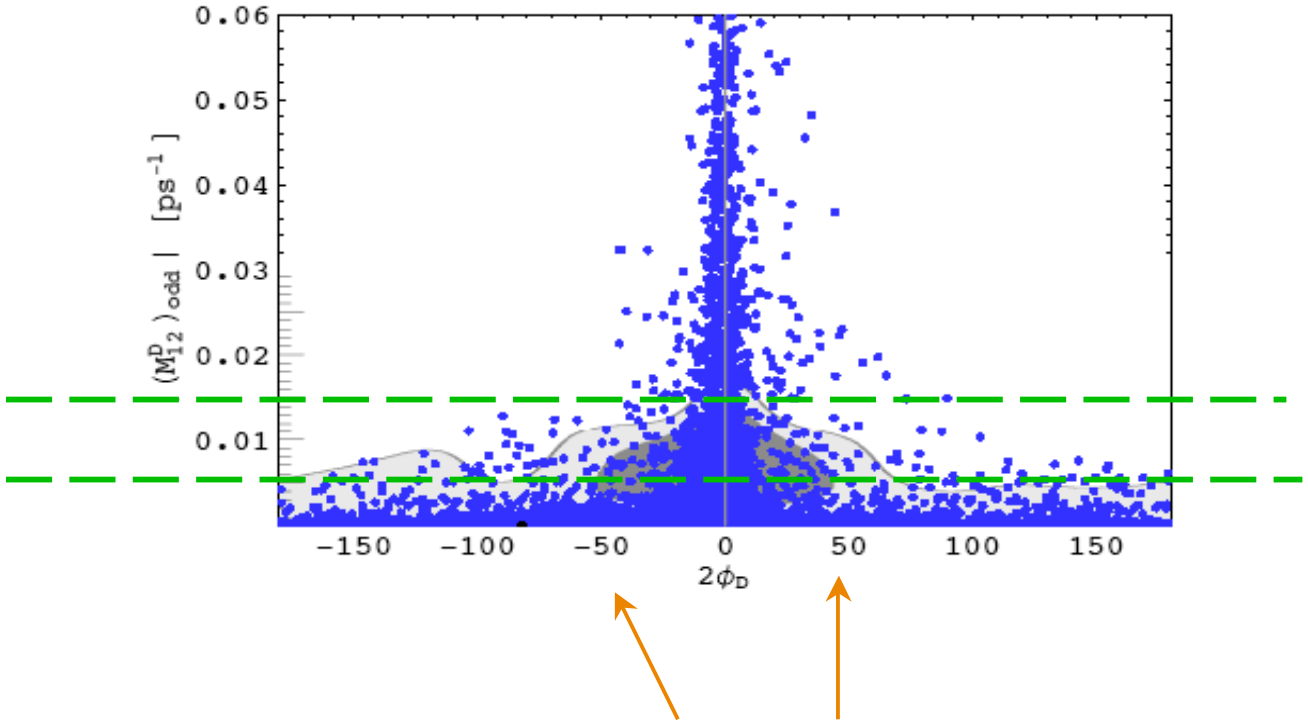
➥ $V_{UHDL} \sim V_{DHUL}$



➥ LHT could

- generate observed value of x_D without violating other bounds
- exhibit a weak phase only moderately constrained!

Monika Blanke[a,b], Andrzej J. Buras[a], Stefan Recksiegel[a],
Cecilia Tarantino[a] and Selma Uhlig[a]



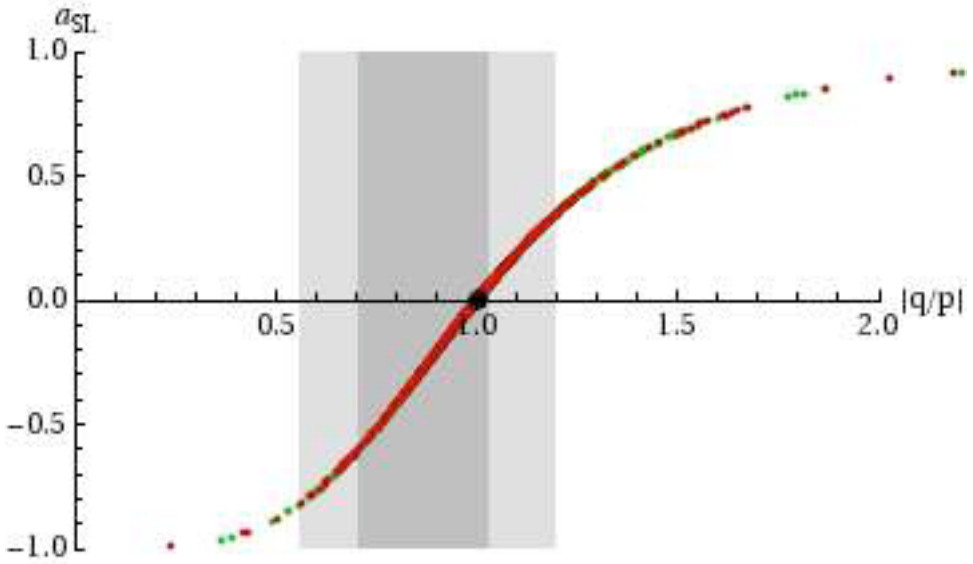
oscillation phase $2\phi_D$ = [-50°,+50°]

➥ sizable time dependent ~~CP~~ conceivable!

➥ presumably also a general feature for *direct* ~~CP~~
(to be worked out soon)

$D^0 \to l^- \nu K^+$ vs. $D^0 \to l^+ \nu K^-$

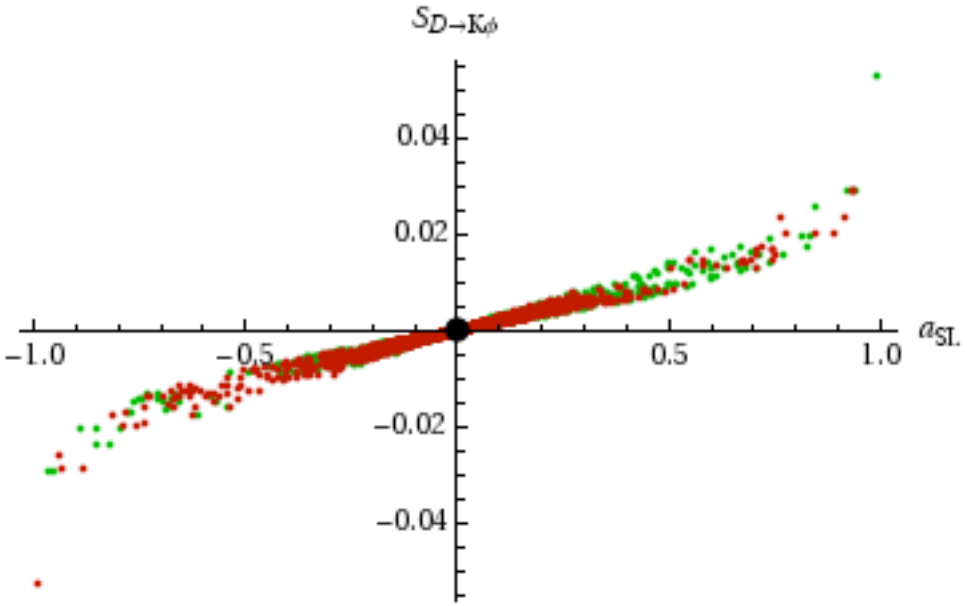
$a_{SL} = [1-|q/p|^4]/[1+|q/p|^4]$



BBBR= IB, M. Blanke, A. Buras, S. Recksiegel: arXiv:0904.1545

$D^0 \to K_S\phi$

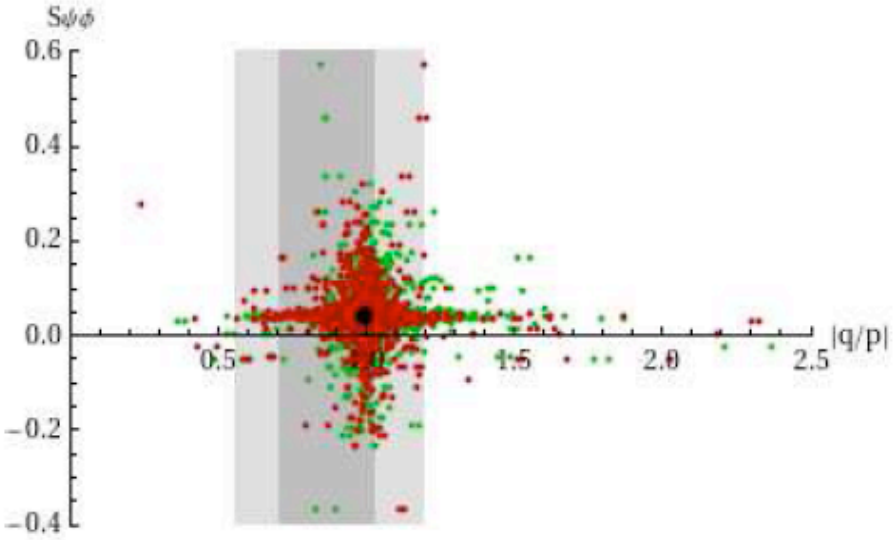
$$\frac{\Gamma(D^0(t) \to K_S\phi) - \Gamma(\bar{D}^0(t) \to K_S\phi)}{\Gamma(D^0(t) \to K_S\phi) + \Gamma(\bar{D}^0(t) \to K_S\phi)} \equiv S_{D\to K_S\phi}\frac{t}{2\tau_D}$$



Andrzej Buras has authorized me to make the following statement:

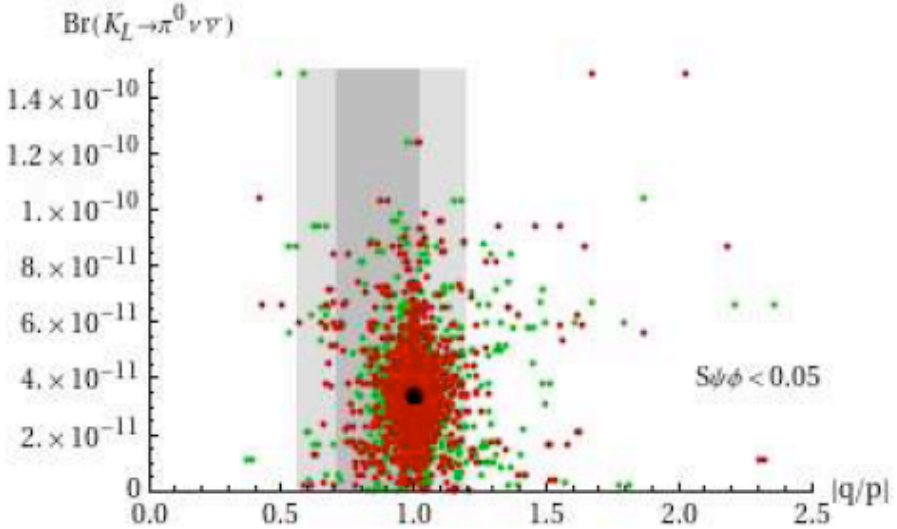
He is willing to bet his beard that LHT models would lead to

observable ~~CP~~ in D decays!



large CP-violating effects in both $B_s - \bar{B}_s$ and $D^0 - \bar{D}^0$ unlikely

simultaneous large CP-violating effects in both $D^0 - \bar{D}^0$ and rare K_L decays possible



III $\not{CP}$ in Final State Distributions

Four reasons for going beyond 2-body modes

1. in 2-body modes one probably has to aim for
   10^{-3} sensitivity levels -- systematics?

amplitude for D → 2P, VP merely a number

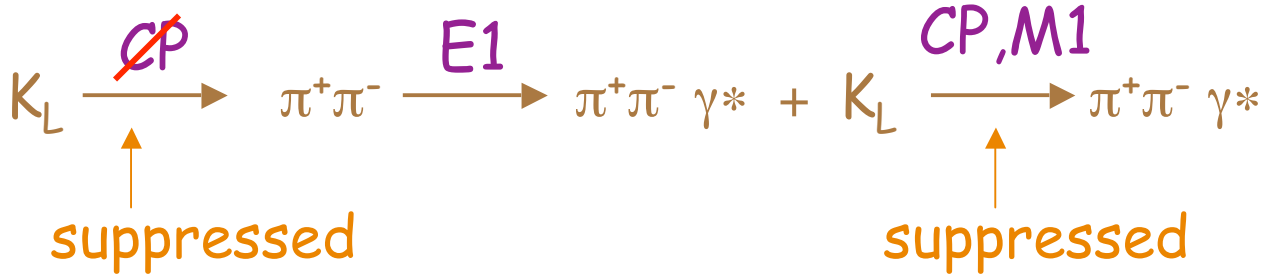
   ➥ direct $\not{CP}$ can be faked by detector biases, production asymmetries etc.

2. In D → 3P, 4P, … $\not{CP}$ can arise in final state distributions --
   - local asymmetries will be larger than integrated ones.
   - can rely on relative rather than absolute calibration
3. Such asymmetries subject to more internal constraints
4. can give us more info on the NP operator generating them.

   ➥ ultimate tool for CP studies

So far all observed ~~CP~~ in partial widths -- except for one:

$K_L \to \pi^+\pi^- e^+ e^-$



ϕ = angle between $\pi^+\pi^-$ & e^+e^- planes analyzes γ^* polarization

interference between CP E1 & CP M1 amplitude

➥ Forw-Backw asymmetry A in ϕ (Sehgal et al.)

A= 14 % driven by ε=0.002

price: BR ~ 3×10^{-7}

} trade BR for size of asymm.!

D → PPP

A Catholic Scenario:

single path to heaven: asymmetries in the Dalitz plot

The challenge: search for

- presumably small asymmetries -- ~ 1 % … 0.1 % --
- in subdomains of the Dalitz plot
- shaped by non-perturb. dynamics
  - ➥ statistical fluctuations !?

How to deal with them?

need

- lots of statistics
- final states with (multi)neutrals
- robust pattern recognition
- some theoretical guidance!

robust pattern recognition

Can learn a lot from astronomers -- typically they have little
a priori knowledge of
where to look for
what kind of sources!

$\Longrightarrow$ `significance' $\sigma = (N_{on} - N_{off})/(N_{on} + N_{off})^{1/2}$

CP signal both in amplitudes and phases!

Intriguing suggestion by J.Miranda, I.Bediaga from CBPF(Rio):

- adopt this procedure for CP asymmetries in Dalitz plot
  (also adopted by P. Auger Collab.!)

bin-by-bin `significance' $\sigma(i) = (N(i) - \overline{N}(i))/(N(i) + \overline{N}(i))^{1/2}$

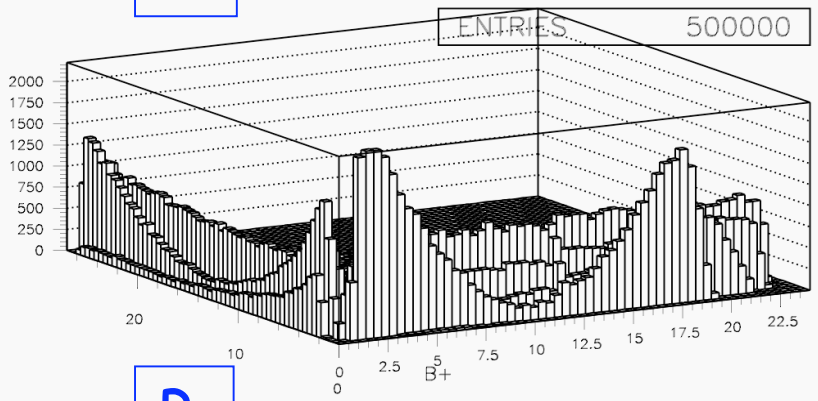
A New `Miranda' Procedure for Dalitz CP Studies

I. Bediaga, ibi, A. Gomes, G. Guerrer, J. Miranda, A. Reis

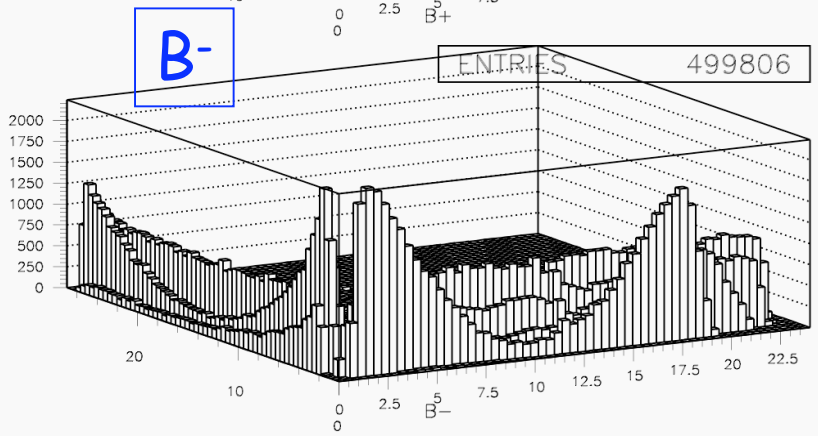
$B^{\pm} \rightarrow K^{\pm}\pi^{+}\pi^{-}$

$\Delta\delta = 20^{o}$

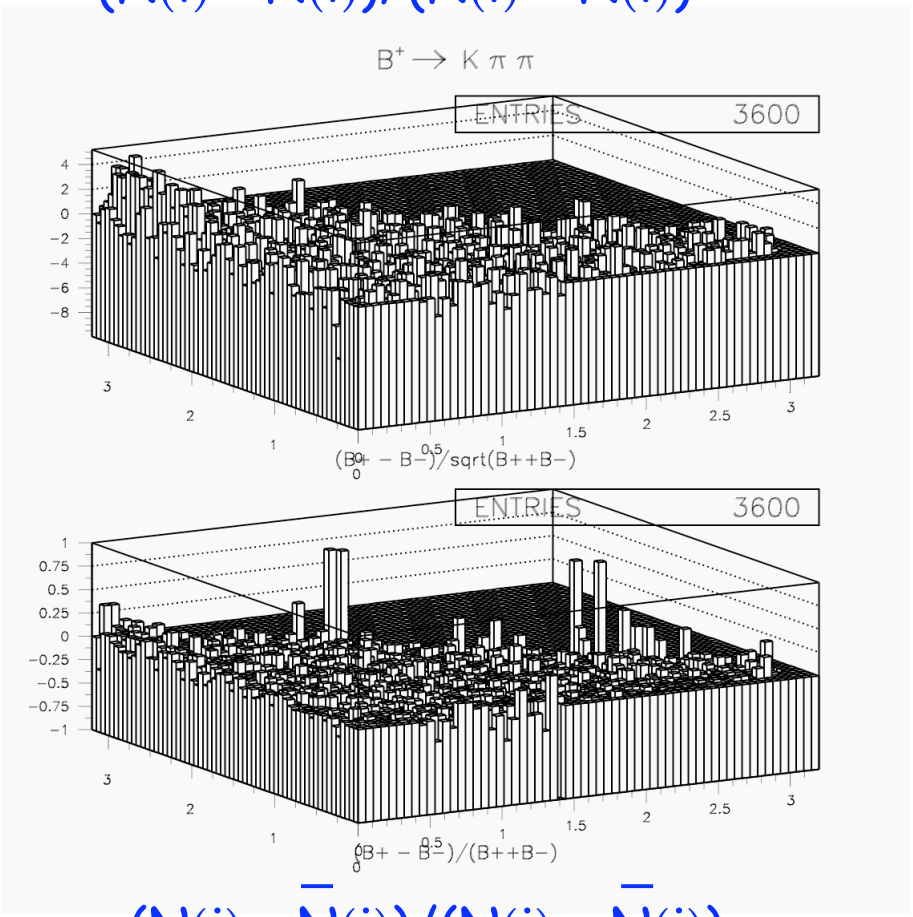
B^{+}



B^{-}



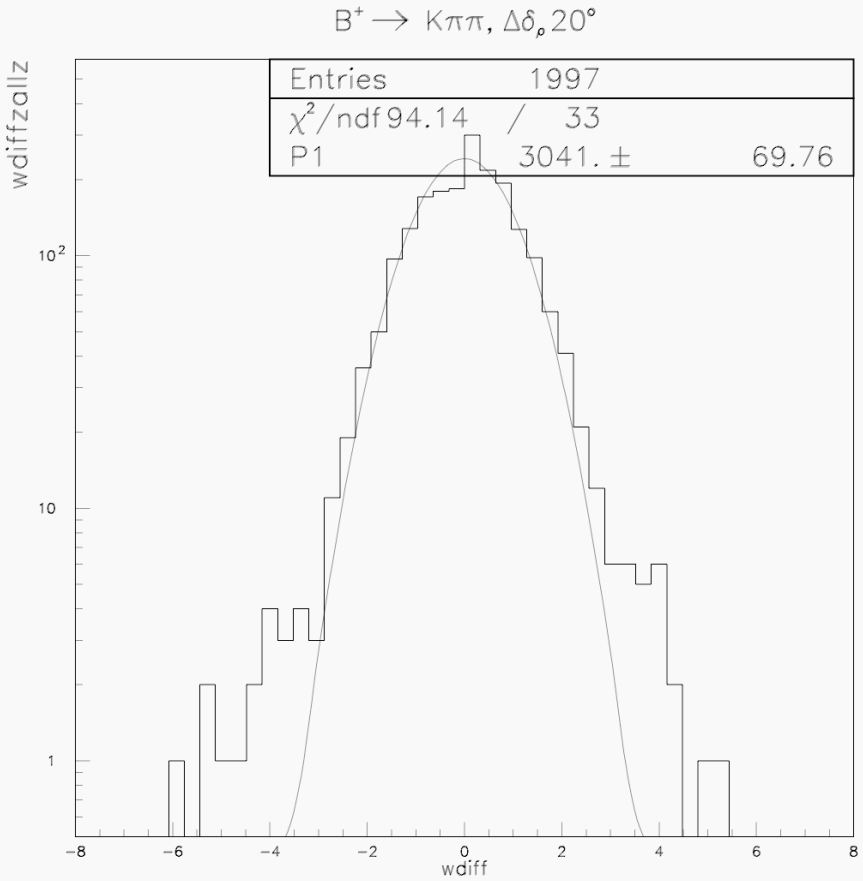
$(N(i) - \bar{N}(i))/(N(i) + \bar{N}(i))^{1/2}$



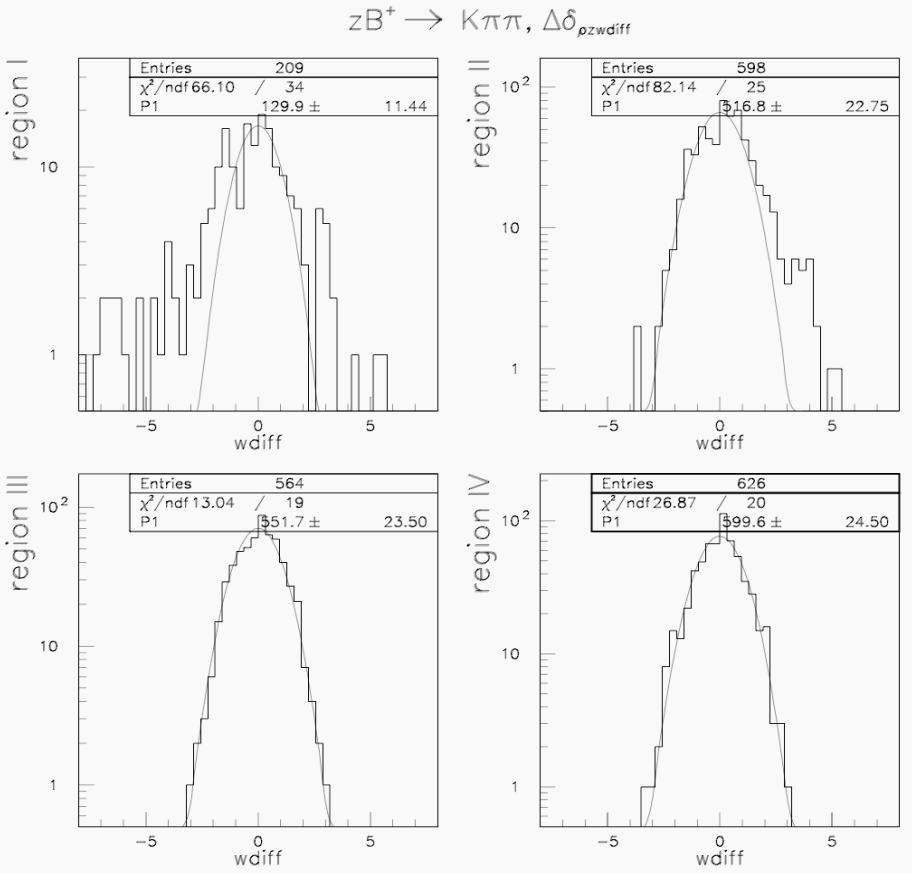
$(N(i) - \bar{N}(i))/(N(i) + \bar{N}(i))$

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

σ(i) distribution for whole DP



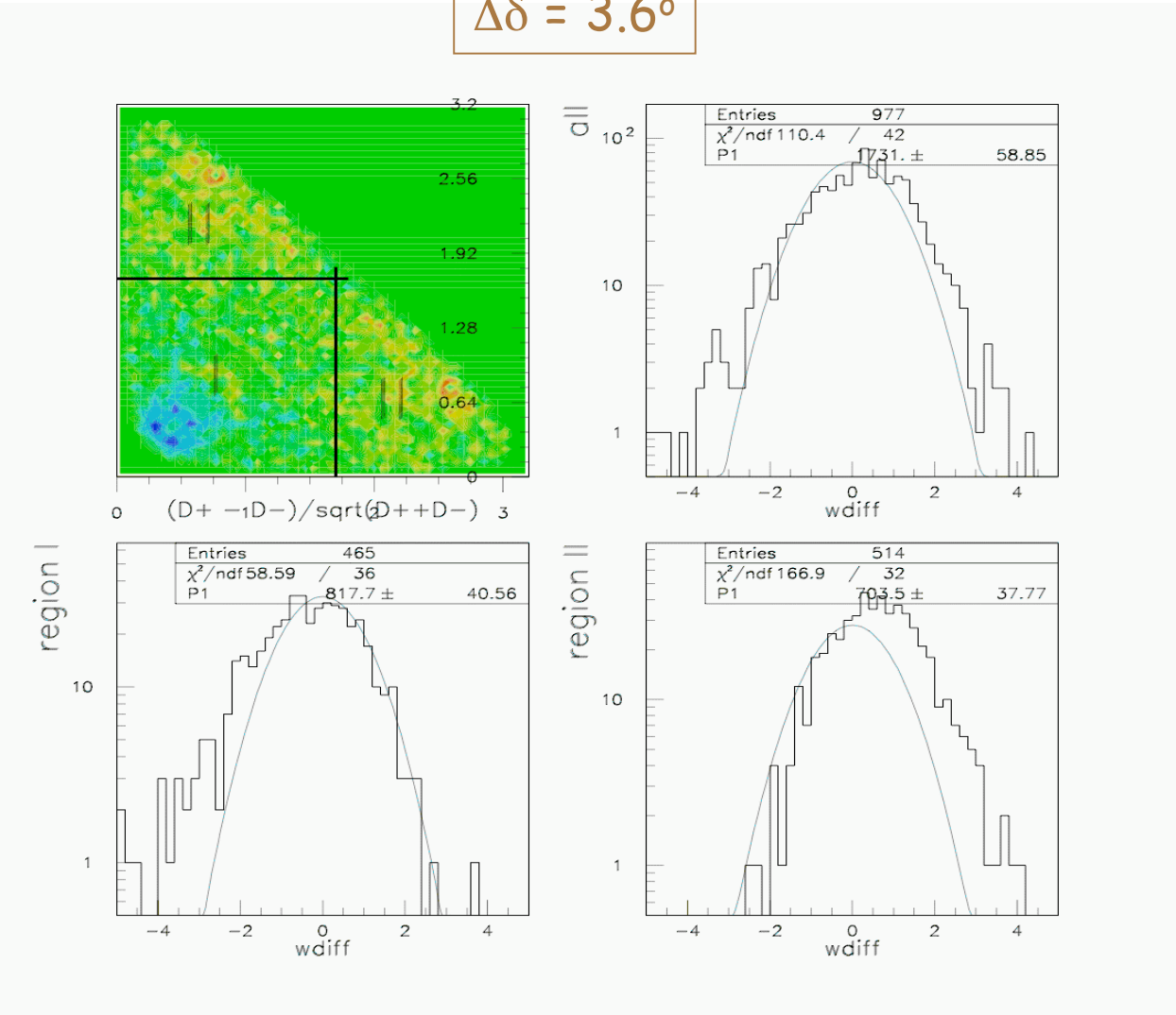
σ(i) distributions for subregions



$D^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$

$\sigma(i)$ distribution for whole DP $\sigma(i)$ distributions for subregions

$\Delta\delta = 3.6^{o}$



- probably more lessons to be learnt from astronomers

"Copying is highest form of flattery!"

$D \to PPPP$

A Calvinist Scenario

many paths to heaven -- success reveals Heaven's blessing

$D \to K \bar{K} \pi^+\pi^-$

ϕ= angle between $\pi^+\pi^-$ & $K \bar{K}$ planes

$d\Gamma/d\phi\ (D \to K \bar{K} \pi^+\pi^-) = \Gamma_1 \cos^2\phi + \Gamma_2 \sin^2\phi + \Gamma_3 \cos\phi \sin\phi$

$d\Gamma/d\phi\ (\bar{D} \to K \bar{K} \pi^+\pi^-) = \bar{\Gamma}_1 \cos^2\phi + \bar{\Gamma}_2 \sin^2\phi - \bar{\Gamma}_3 \cos\phi \sin\phi$

- Γ_3 drops out after integrating over ϕ
  - Γ_1 vs. $\bar{\Gamma}_1$ & Γ_2 vs. $\bar{\Gamma}_2$: ~~CP~~ in partial widths
- T odd moments $\Gamma_3, \bar{\Gamma}_3 \neq 0$ can be faked by FSI

  yet $\Gamma_3 \neq \bar{\Gamma}_3 \Longrightarrow$ ~~CP~~!

$D \to K \bar{K} \mu^+\mu^-$ likewise

yet many other ~~CP~~ observables

-- `optimal' one depends on underlying dynamics

V Summary

- Discovery of D^0 oscillations greatly enhances chances for
  - observing ~~CP~~ in charm decays,
  - establishing it as manifestations of NP
  - differentiating direct vs. indirect ~~CP~~
- present absence of ~~CP~~ signal not telling
- `realistically' can `expect' small effects only

$$O(10^{-2}) - O(10^{-3}) - O(10^{-4})$$

- NP signal/SM backgr. probably larger than in B decays
- no `compelling' models, yet viable = *non*-ad-hoc models exist
- Electroweak dynamics: CP studies in charm sector

`hypothesis-generating' rather than `hypothesis-probing' research

-- yet LHT scenarios could provide high p_t-low p_t connection

- excellent news for LHCb -- host of promising modes for ~~CP~~
  - ✍ $D^{\pm} \to K_S\pi^{\pm}$, $\pi^+\pi^-\pi^{\pm}$, $K^+K^-\pi^{\pm}$,...
  - ✍ $D^0(\bar{t}) \to K_S K^+K^-, K_S\pi^+\pi^-, K^+K^-, \pi^+\pi^-$, $K^+\pi^-$, $K^+K^-\pi^+\pi^-$, $K^+K^-\mu^+\mu^-$,...
- do not count on miracles from theorists, but can expect a

positive learning curve -- *if* faced by accurate data

✍ a great deal of expertise exists in the hadronic community that can be applied in CP studies of Dalitz plots etc. with great profit!

- not `merely' a "Ceterum censeo fascinum esse studiandum"

  increased `maturity' $\Longrightarrow$ `phase transition'!

  - experimental observation of D^0 oscillations
  - theoretical `awakening' concerning NP touching on charm

BBBR arXiv:0904.1545[hep-ph];
Grossman et al., arXiv:0904.0305, 0903.2118
Golowich et al., arXiv:0903.2830.

Epilogos: Bismarck's Rule

Bismarck:

"… role of the statesman is to grab the mantle of history when he feels it passing by…"

Likewise:

It is the task of the physicist to make the greatest use of a special gift from Nature

D^0 oscillations are such a gift

➥ it is our duty --

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Likewise:

It is the task of the physicist to make the greatest use of a special gift from Nature

D^0 oscillations are such a gift

➥ it is our duty -- & there is fame within your grasp!