HADRONIC UNCERTAINTIES IN ΔA_{CP}

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Introduction

Isospin amplitudes from BR's

Unitarity constraints & CP asymmetries

How large can penguins be?

Conclusions

European Research Council
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INTRODUCTION

- Some basic facts known for a long time:
- To obtain a good description of SCS D BR's need:
  - final state interactions and corrections to factorization
  - sizable SU(3) breaking
- The SM expectation for direct CPV is $\lesssim 10^{-3}$

See for example Buccella et al. '95

INTRODUCTION II

- Can we envisage a mechanism to enhance the SM prediction for CPV by one order of magnitude to reproduce the exp result $\Delta a_{CP}^{dir} = a_{CP}^{dir}(K^+K^-) - a_{CP}^{dir}(\pi^+\pi^-) = (-6.6 \pm 1.6)\ 10^{-3}$?
- Can anything analogous to the $\Delta I=1/2$ rule take place in SCS charm decays?

Golden & Grinstein, '89; Brod, Kagan & Zupan '11; Pirtskhalava & Uttayarat '11; Bhattacharya, Gronau & Rosner '12; Cheng & Chiang '12; Brod, Grossman, Kagan & Zupan '12

ISOSPIN & UNITARITY

- Let us start from the basic knowledge:
  - SU(3) breaking is large $\Rightarrow$ use only isospin
  - corrections to factorization are large $\Rightarrow$ use a general parameterization
  - final state interactions are important $\Rightarrow$ implement unitarity & external info on rescattering

Franco, Mishima & LS '12

ISOSPIN AMPLITUDES

r_{CKM}=6.4 10^{-4}

A CP-even

B CP-odd

$$A(D^+ \to \pi^+\pi^0) = \frac{\sqrt{3}}{2}\mathcal{A}_2^\pi\,,$$

$$A(D^0 \to \pi^+\pi^-) = \frac{\mathcal{A}_2^\pi - \sqrt{2}(\mathcal{A}_0^\pi + i r_{\rm CKM}\mathcal{B}_0^\pi)}{\sqrt{6}}\,,$$

$$A(D^0 \to \pi^0\pi^0) = \frac{\sqrt{2}\mathcal{A}_2^\pi + \mathcal{A}_0^\pi + i r_{\rm CKM}\mathcal{B}_0^\pi}{\sqrt{3}}\,,$$

$$A(D^+ \to K^+\bar{K}^0) = \frac{\mathcal{A}_{13}^K}{2} + \mathcal{A}_{11}^K + i r_{\rm CKM}\mathcal{B}_{11}^K\,,$$

$$A(D^0 \to K^+K^-) = \frac{-\mathcal{A}_{13}^K + \mathcal{A}_{11}^K - \mathcal{A}_0^K + i r_{\rm CKM}\mathcal{B}_{11}^K - i r_{\rm CKM}\mathcal{B}_0^K}{2}\,,$$

$$A(D^0 \to K^0\bar{K}^0) = \frac{-\mathcal{A}_{13}^K + \mathcal{A}_{11}^K + \mathcal{A}_0^K + i r_{\rm CKM}\mathcal{B}_{11}^K + i r_{\rm CKM}\mathcal{B}_0^K}{2}\,.$$

NUMERICAL RESULTS FROM BR's

$$|\mathcal{A}_2^\pi| = (3.08 \pm 0.08) \times 10^{-7}\ \mathrm{GeV}\,,$$
$$|\mathcal{A}_0^\pi| = (7.6 \pm 0.1) \times 10^{-7}\ \mathrm{GeV}\,,$$
$$\arg(\mathcal{A}_2^\pi/\mathcal{A}_0^\pi) = (\pm 93 \pm 3)^\circ\,.$$

No ΔI=1/2 rule for D decays, large strong phases

$$|\mathcal{A}_{13}^K - \mathcal{A}_{11}^K - \mathcal{A}_0^K| = (5.0 \pm 0.4) \times 10^{-7}\ \mathrm{GeV}$$

Should vanish in the SU(3) limit, but is O(1)!!

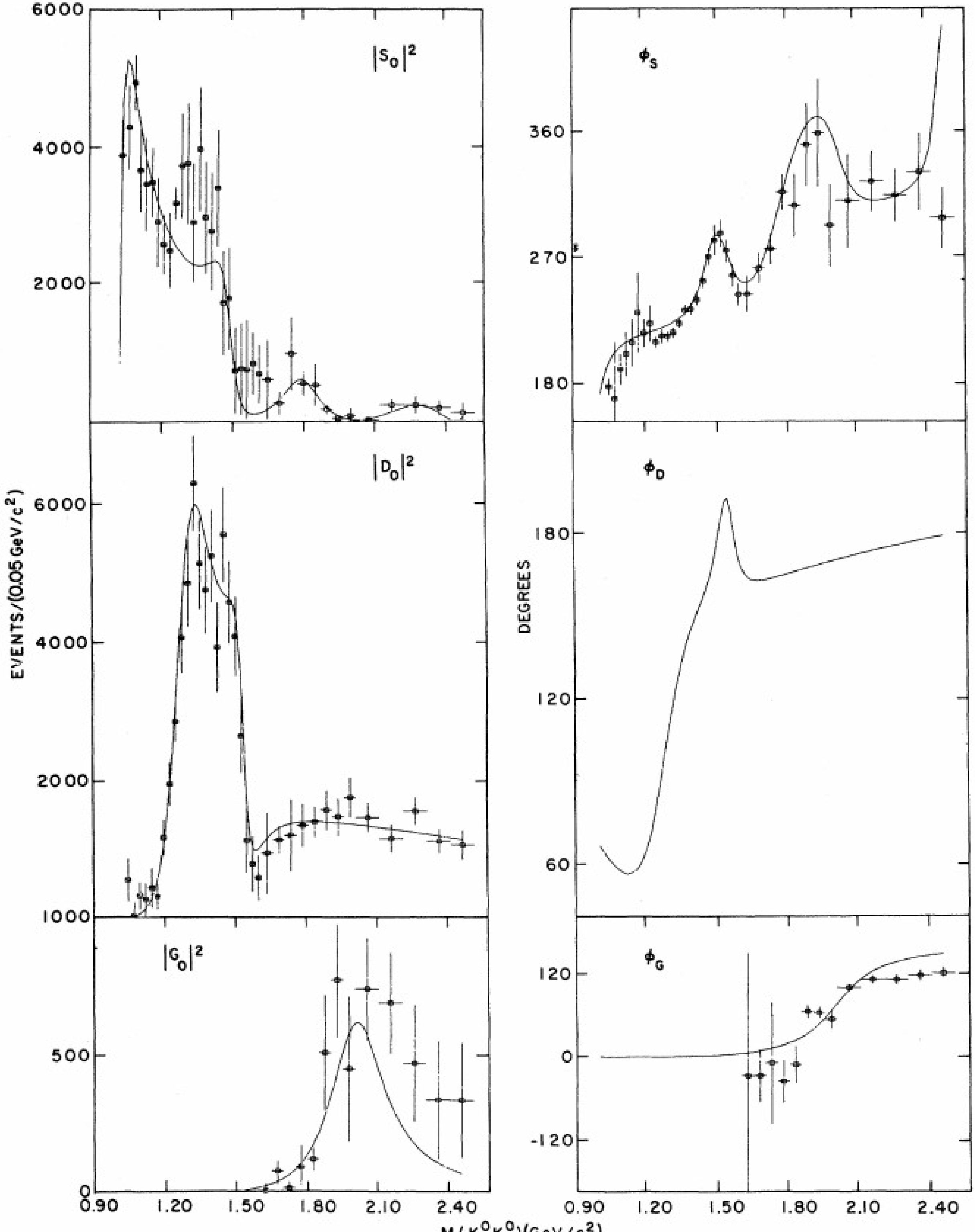
UNITARITY CONSTRAINTS

$$S = \left(\begin{array}{c|cccc} D \to D & D \to \pi\pi & D \to KK & \cdots \\ \hline \pi\pi \to D & \pi\pi \to \pi\pi & \pi\pi \to KK & \cdots \\ KK \to D & KK \to \pi\pi & KK \to KK & \cdots \\ \vdots & \vdots & \vdots & \ddots \end{array}\right) \equiv \begin{pmatrix} 1 & -i(T)^T \\ -i\,\mathrm{CP}(T) & S_S \end{pmatrix}$$

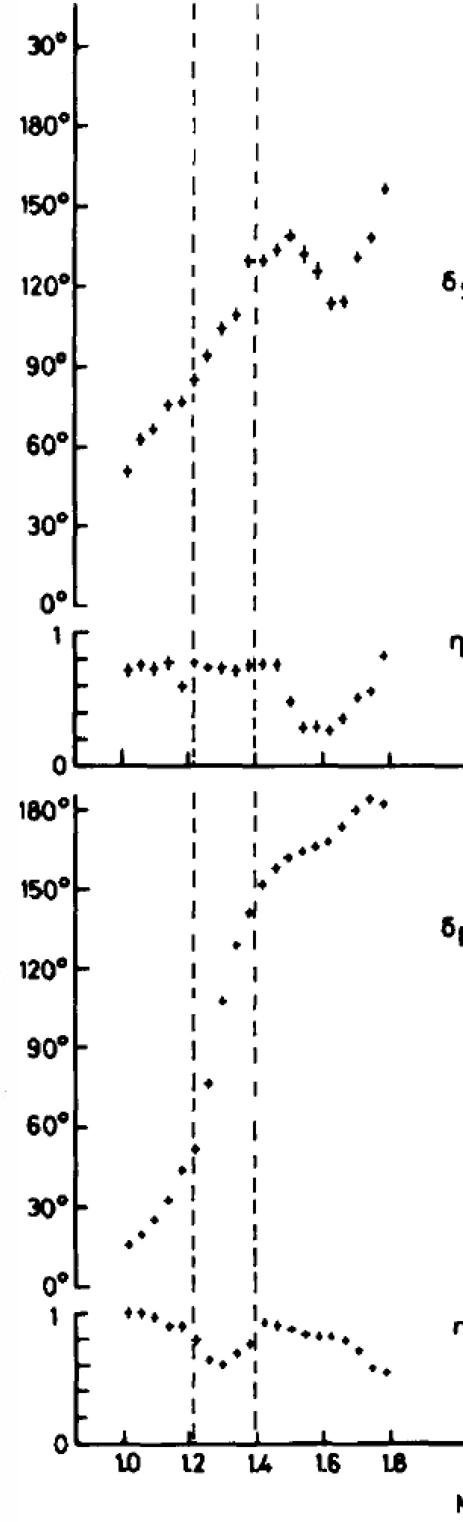
implies

$$T^R = S_S (T^R)^*, \qquad T^I = S_S (T^I)^*$$

Unfortunately, exp data at the D mass are ambiguous. If unitarity is saturated by the ππ and KK channels alone, then constraints on Δa_{CP}^{dir} can be derived, otherwise not.

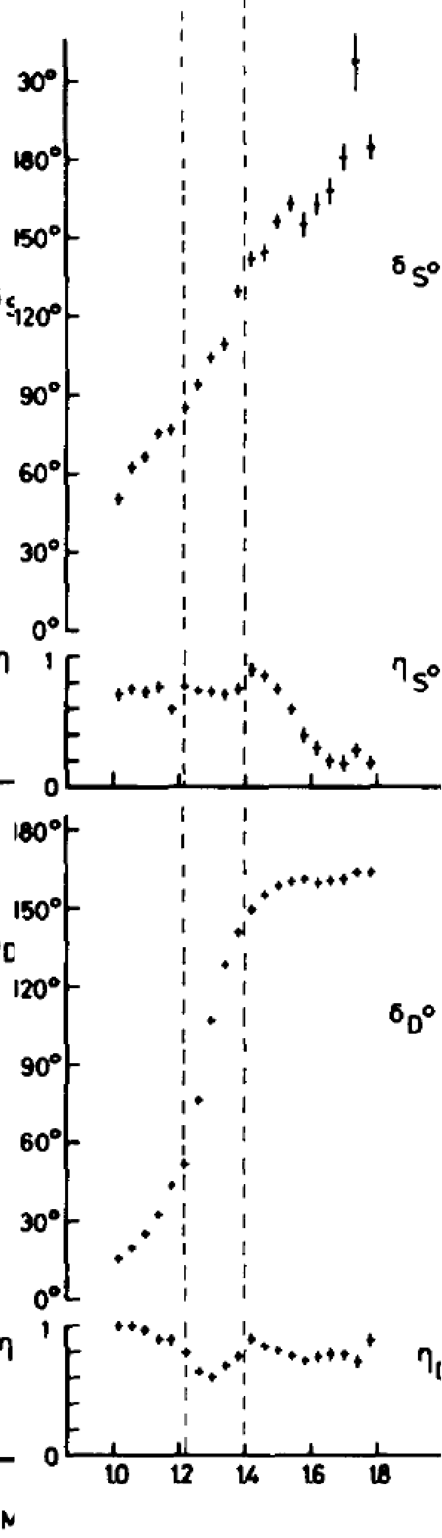


$|S_0|^2$
$|D_0|^2$
$|G_0|^2$
ϕ_S
ϕ_D
ϕ_G
EVENTS/(0.05 GeV/c^2)
DEGREES
M($K^0_S K^0_S$)(GeV/c^2)



δ_S
η
δ_D
η

Fig. 4. S



$\delta_S°$
$\eta_S°$
$\delta_D°$

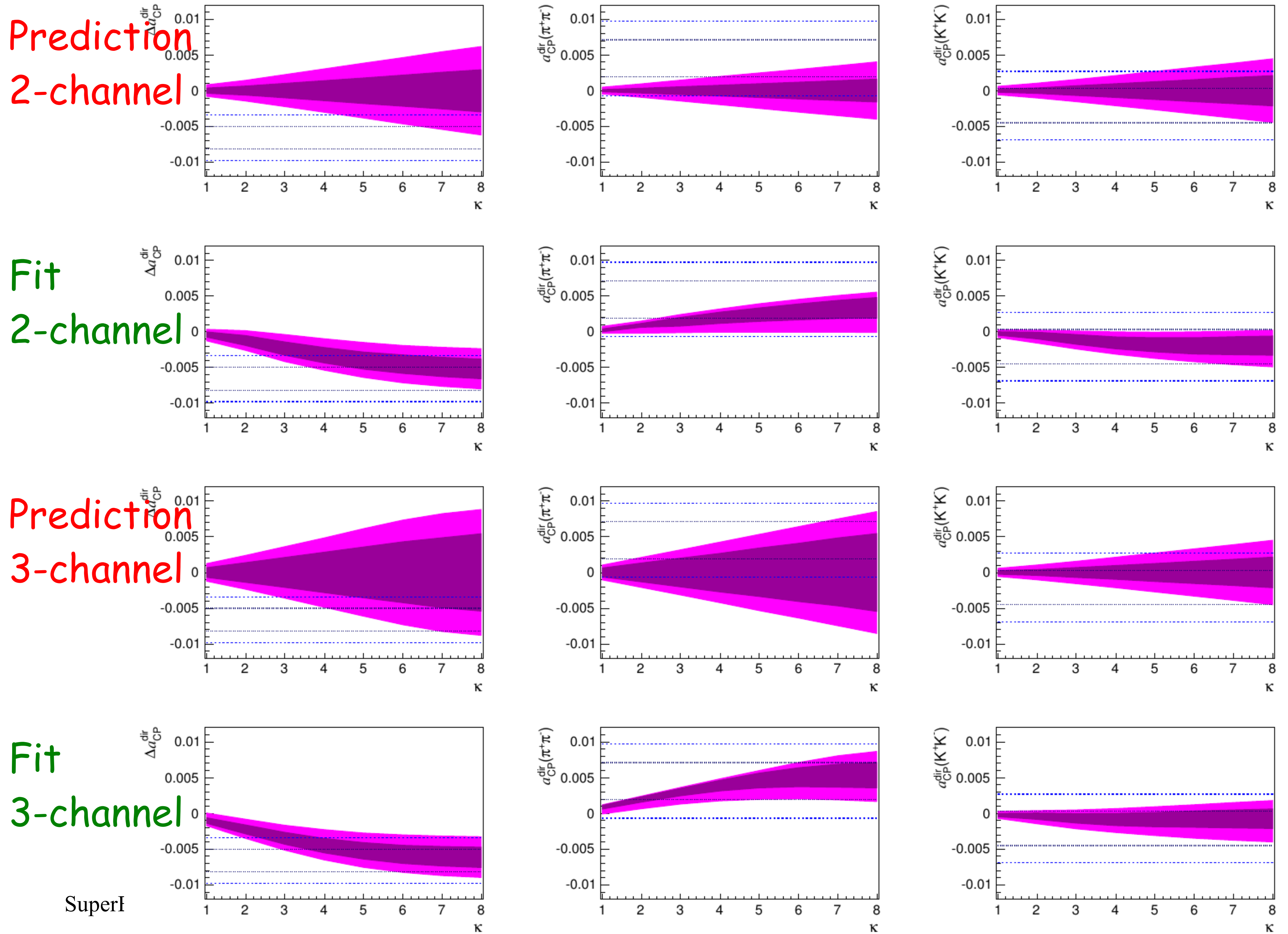
Fig. 3.

CP ASYMMETRIES

- One can study the CP asymmetries as a function of the upper bound on the size of CPV contributions in the two- and three-channel scenarios. We write

$$|\mathcal{B}_0^\pi| < \kappa |\mathcal{A}_0^\pi| \,,$$
$$|\mathcal{B}_0^K - \mathcal{A}_0^K| < \kappa |\mathcal{A}_0^K| \,,$$
$$|\mathcal{B}_{11}^K - (\mathcal{A}_{11}^K - \mathcal{A}_{13}^K)| < \kappa |\mathcal{A}_{11}^K - \mathcal{A}_{13}^K| \,,$$

  and consider predictions and fit results for CP asymmetries



Prediction
2-channel
Fit
2-channel
Prediction
3-channel
Fit
3-channel
Δa_{CP}^{dir}
$a_{CP}^{dir}(\pi^+\pi^-)$
$a_{CP}^{dir}(K^+K^-)$
0.01
0.005
0
-0.005
-0.01
1 2 3 4 5 6 7 8
κ
SuperI

CONCLUSIONS FROM UNITARITY

- The prediction does not reach the exp value within 2σ even for κ=8 in the 2-channel case
- Without unitarity constraints, the prediction reaches the exp value at the 2σ level for κ>5, but even for κ=8 it is still 1σ below
- How large can κ be?
  - translate fit results into RGI parameters
  - compare with K and B

FROM ISOSPIN AMPLITUDES TO RGI PARAMETERS

- The BR fit results can be translated into results for RGI parameters (aka topologies). Neglecting for simplicity $O(1/N_c^2)$ terms:

$$E_1(\pi) + E_2(\pi) = (1.72 \pm 0.04) \times 10^{-6}\, e^{i\delta}\ \mathrm{GeV}\,,$$

$$E_1(\pi) + A_2(\pi) - P_1^{\mathrm{GIM}}(\pi) = (2.10 \pm 0.02) \times 10^{-6}\, e^{i(\delta \pm (71 \pm 3)^\circ)}\ \mathrm{GeV}\,,$$

$$E_2(\pi) - A_2(\pi) + P_1^{\mathrm{GIM}}(\pi) = (2.25 \pm 0.07) \times 10^{-6}\, e^{i(\delta \mp (62 \pm 2)^\circ)}\ \mathrm{GeV}$$

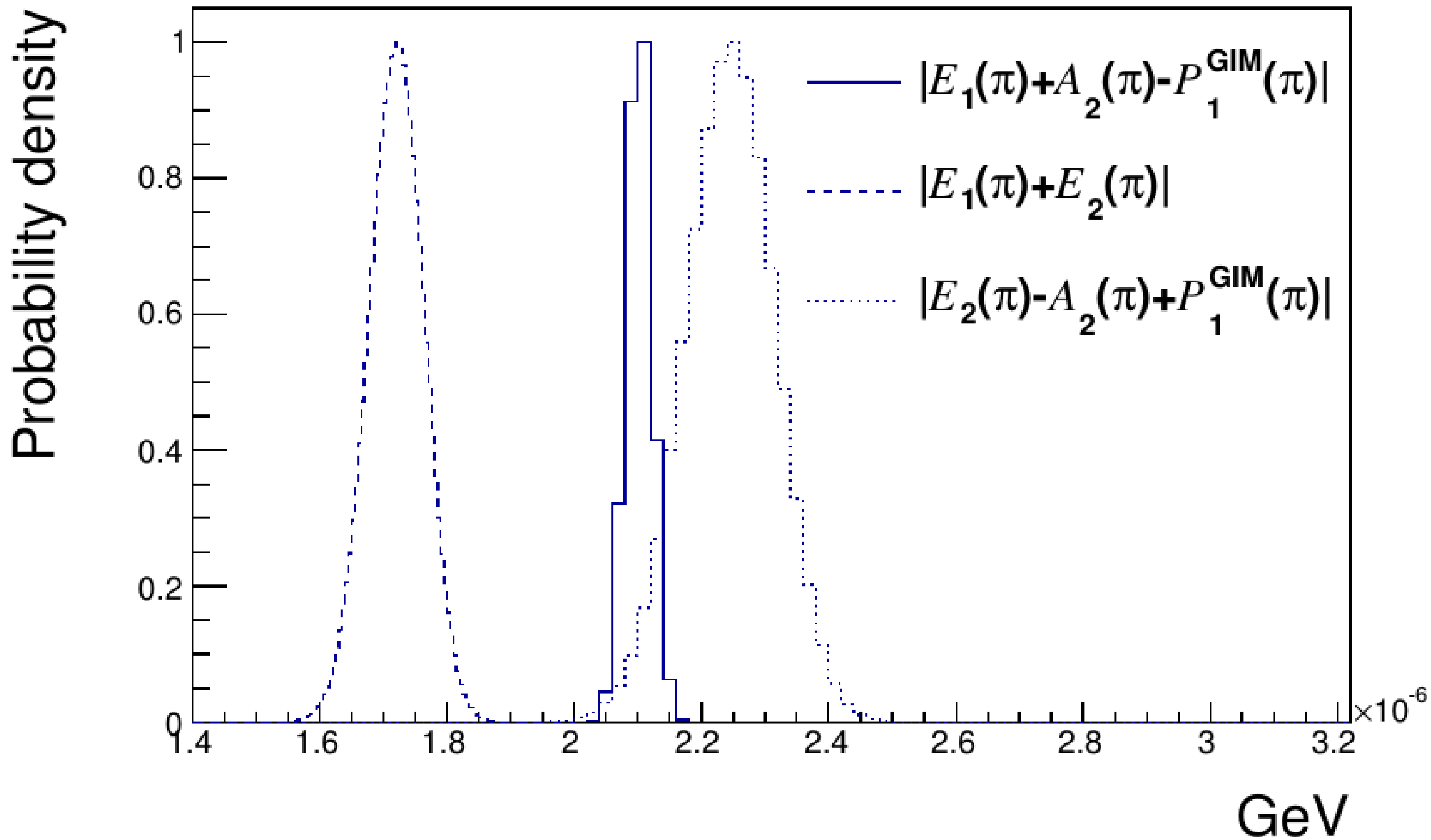
- E_1 does not dominate the amplitudes $\Rightarrow$ we are away from the infinite mass limit
- All amplitudes of same size, w. large phases

THE MEANING OF κ

- The condition $|\mathcal{B}_0^\pi| < \kappa |\mathcal{A}_0^\pi|$, means

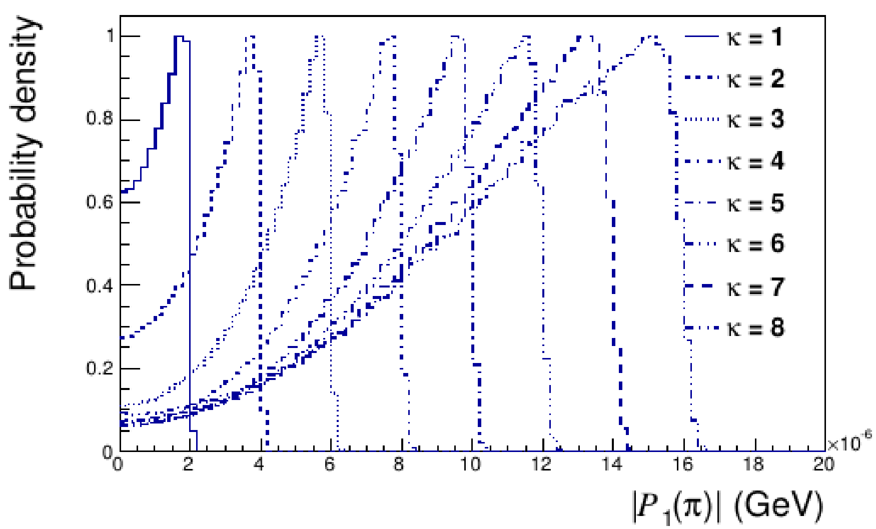
$$|P_1(\pi)| \le \kappa \left| \frac{2}{3} E_1(\pi) - \frac{1}{3} E_2(\pi) + A_2(\pi) - P_1^{\rm GIM}(\pi) \right|$$

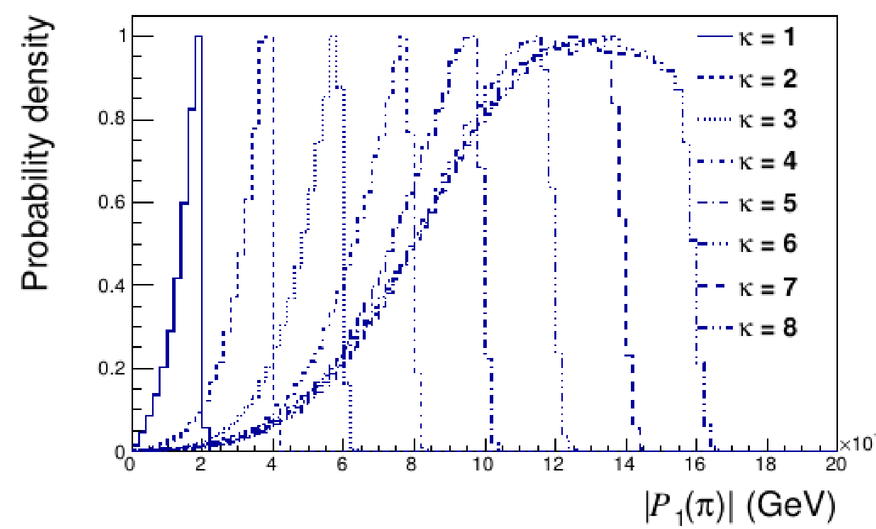
- κ is the ratio of $|P_1|$ over all other topologies
- Notice that $P_1 \sim P_b - P_s$ while $P_1^{GIM} \sim P_d - P_s$
- How large should $|P_1|$ be to reproduce Δa_{CP}^{dir}?



2-channel

3-channel





Su

DYNAMICAL ARGUMENTS

- The amplitudes for K, D and B $\rightarrow \pi\pi$ are formally the same, with the obvious flavour and CKM replacements.
- In the Kaon system, one has

$$(P_u-P_c) \sim 3\ (P_t-P_c) \sim 25\ (E_1 + E_2)$$

- No enhancement expected for P_u (will be checked on the lattice soon), while P_c and P_t generate local operators with chirally enhanced matrix elements (SVZ)

DYNAMICAL ARGUMENTS II

- In charm decays, no chiral enhancement is present, so that one expects

$$|P_1| = |P_b - P_s| \leq |E_1|, |E_2|, |A_1|, |A_2|, |P_1^{GIM}|$$

i.e. $\kappa \leq 1$.

- In B decays one is much closer to the infinite mass limit so that $|E_1|$ and $|E_2|$ dominate, with all other contractions power suppressed.

CONCLUSIONS

- We have performed a phenomenological analysis of Δa_{CP}^{dir} with minimal assumptions as a function of κ ~ relative size of $|P_1|$
- From the BR we confirm large nonfactorizable contributions, large strong phases and large SU(3) breaking
- Unfortunately, data on $\pi\pi$ scattering at the D mass are not able to fully determine the relevant FSI

CONCLUSIONS II

- In the most conservative scenario (no constraints from unitarity), values of $\kappa > 5$ are needed to reach at 2σ the experimental result
- We cannot find any reasonable dynamical origin for such a large value of $|P_1|$
- If the central value stays with improved errors, we have strong indications of NP