$K^{(*)}\pi$ revisited

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Three messages from this talk:

i) typical predictions of factorization in the infinite mass limit for Kπ amplitudes are off by ~-30-40% (Luca was almost right!)

ii) Kπ decays are not puzzling once subleading terms are included. Measured CP asymmetries are compatible with the Standard Model

iii) K*π decays are a perfect playground for QCD challenges

MC, Franco, Martinelli, Pierini, Silvestrini, in preparation

new physics in Kπ CP asymmetries?

$$\mathcal{A}_{K^\pm\pi^\mp} \equiv \frac{N(\bar{B}^0 \to K^-\pi^+) - N(B^0 - K^+\pi^-)}{N(\bar{B}^0 \to K^-\pi^+) + N(B^0 \to K^+\pi^-)} = -0.094 \pm 0.018 \pm 0.008$$

$$\mathcal{A}_{K^\pm\pi^0} = +0.07 \pm 0.03 \pm 0.01$$

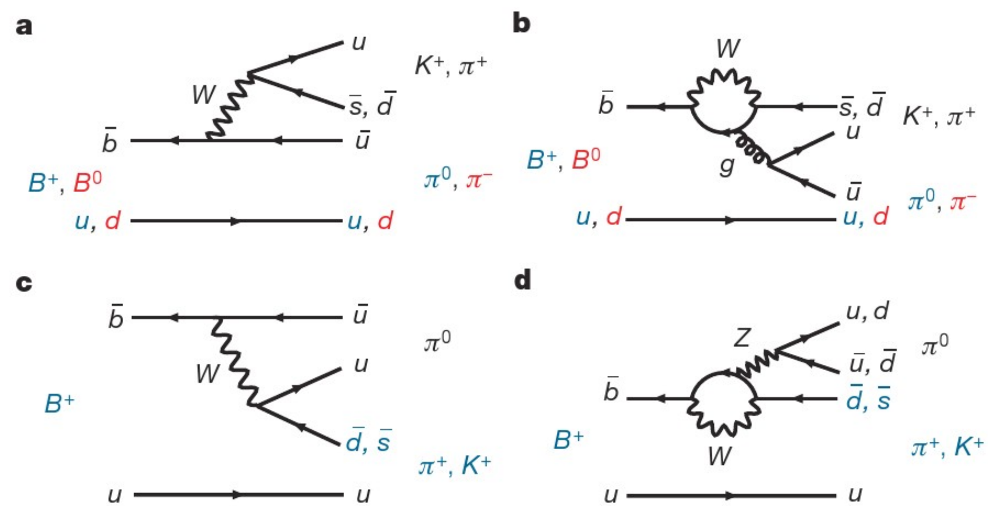
Belle collaboration
Nature 452,2008

$$\Delta\mathcal{A} \equiv \mathcal{A}_{K^\pm\pi^0} - \mathcal{A}_{K^\pm\pi^\mp} = +0.164 \pm 0.037$$

4.4σ away from 0

Is this new physics?

It could be but SM predictions depend on hadronic models



Silvestrini
arXiv:0705.1624

%	QCDF [50]	PQCD [54, 55]	SCET [58]	GP [92]
$\mathcal{A}_{CP}(\pi^0 K^-)$	$7.1\,{}^{+1.7\,+2.0\,+0.8\,+9.0}_{-1.8\,-2.0\,-0.6\,-9.7}$	-1^{+3}_{-5}	$-11 \pm 9 \pm 11 \pm 2$	3.4 ± 2.4
$\mathcal{A}_{CP}(\pi^+ K^-)$	$4.5\,{}^{+1.1\,+2.2\,+0.5\,+8.7}_{-1.1\,-2.5\,-0.6\,-9.5}$	-9^{+6}_{-8}	$-6 \pm 5 \pm 6 \pm 2$	-8.9 ± 1.6

Amplitude Parametrization

general parametrization

*one simplification only: isospin breaking in the hadronic ME neglected

can be reintroduced if need be

$$
\begin{aligned}
A(B^+ \to K^0\pi^+) &= -V_{ts}V_{tb}^* P + V_{us}V_{ub}^* A\,, \\
A(B^+ \to K^+\pi^0) &= \frac{1}{\sqrt{2}}\big(V_{ts}V_{tb}^*(P + \Delta P_1 + \Delta P_2) \cdot \\
&\qquad V_{us}V_{ub}^*(E_1 + E_2 + A)\big)\,, \\
A(B^0 \to K^+\pi^-) &= V_{ts}V_{tb}^*(P + \Delta P_1) - V_{us}V_{ub}^* E_1 \\
A(B^0 \to K^0\pi^0) &= -\frac{1}{\sqrt{2}}\big(V_{ts}V_{tb}^*(P - \Delta P_2) + V_{us}V_{ub}^* E_2\big)
\end{aligned}
$$

$$
\begin{aligned}
E_1 &= E_1^{\rm F} + F\left(r(E_1)e^{i\delta(E_1)} - r(P_1^{\rm GIM})e^{i\delta(P_1^{\rm GIM})}\right) \\
&= E_1^{\rm F} + F\,R(E_1)e^{i\Delta(E_1)}\,, \\
E_2 &= E_2^{\rm F} + F\left(r(E_2)e^{i\delta(E_2)} + r(P_1^{\rm GIM})e^{i\delta(P_1^{\rm GIM})}\right) \\
&= E_2^{\rm F} + F\,R(E_2)e^{i\Delta(E_2)}\,, \\
A &= A^{\rm F} + F\left(r(A)e^{i\delta(A)} - r(P_1^{\rm GIM})e^{i\delta(P_1^{\rm GIM})}\right)\,, \\
&= A^{\rm F} + F\,R(A)e^{i\Delta(A)}\,, \\
P &= P^{\rm F} + F\,r(P)e^{i\delta(P)}\,, \\
\Delta P_1 &= \Delta P_1^{\rm F} + F\,\alpha_{\rm em}\,r(\Delta P_1)e^{i\delta(\Delta P_1)}\,, \\
\Delta P_2 &= \Delta P_2^{\rm F} + F\,\alpha_{\rm em}\,r(\Delta P_2)e^{i\delta(\Delta P_2)}\,,
\end{aligned}
$$

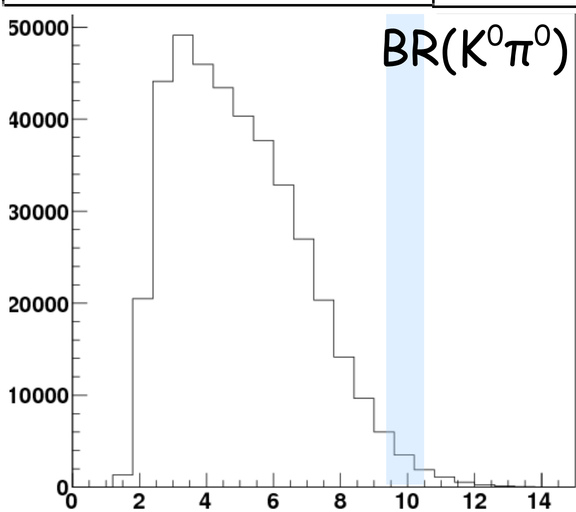
deviations from factorization: R(X) exp[iΔ(X)] in units of $F=\bar{A}_{K\pi}$

related to Buras, Silvestrini, hep-ph/9806278

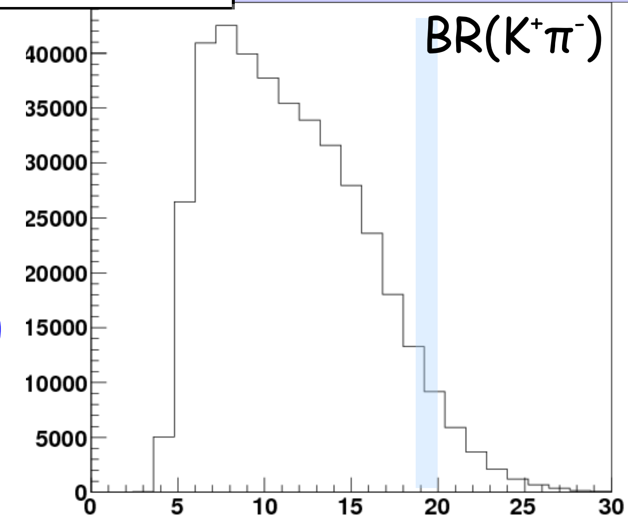
$$
\begin{aligned}
E_1 &= E_1(s,q,q;B,K,\pi) - P_1^{\rm GIM}(s,q;B,K,\pi) \\
E_2 &= E_2(q,q,s;B,\pi,K) + P_1^{\rm GIM}(s,q;B,K,\pi) \\
A &= A_1(s,q,q;B,K,\pi) - P_1^{\rm GIM}(s,q;B,K,\pi) \\
P &= P_1(s,d;B,K,\pi)\,, \\
\Delta P_1 &= P_1(s,u;B,K,\pi) - P_1(s,d;B,K,\pi)\,, \\
\Delta P_2 &= P_2(s,u;B,\pi,K) - P_2(s,d;B,\pi,K)\,.
\end{aligned}
$$

Step #0: try throwing away all these ugly parameters

Decay Mode	$BR^{exp} \times 10^6$		$\mathcal{A}_{CP}^{exp} = -C$	
$K^+\pi^-$	19.4 ± 0.6	11.6 ± 4.4	-0.097 ± 0.012	0.065 ± 0.016
$K^+\pi^0$	12.9 ± 0.6	8.4 ± 3.2	0.050 ± 0.025	0.086 ± 0.014
$K^0\pi^+$	23.1 ± 1.0	14.8 ± 5.7	0.009 ± 0.025	0.008 ± 0.001
$K^0\pi^0$	9.9 ± 0.6	5.0 ± 2.0	-0.14 ± 0.11	-0.03 ± 0.01
S			0.38 ± 0.19	0.73 ± 0.01



QCD factorization predictions for $m_b \to \infty$ (including χ-enhanced terms)



Two non-contradictory statements:

- typical factorized Kπ amplitudes are off by ~ -30-40%
- factorized amplitudes can reproduce the Kπ data

Old method, new perspective

* old idea: use data to determine the subleading terms, but

  11 real unknowns

  9 measurements

too many parameters! One can:

- reduce the parameter set (like in the good old charming-penguin days)
- vary all the parameters in theoretically sensible ranges (we take $r \in [0,0.5]$, $\delta \in [-\pi,\pi]$)

Final goal: find "upper bounds" to the theoretical errors compatible with data and the $1/m_b$ expansion

Quick facts on charming penguins

- first appearance
  Colangelo, Nardulli, Paver, Riazuddin
  Z. Phys. C45 (1990) 575
- christening
  MC, Franco, Martinelli, Silvestrini
  hep-ph/9703353
- revisited (I)
  MC, Franco, Martinelli, Pierini, Silvestrini, hep-ph/0104126
- revisited (II)
  Bauer, Pirjol, Rothstein, Stewart
  hep-ph/0401188

Results of the fit to the Kπ data

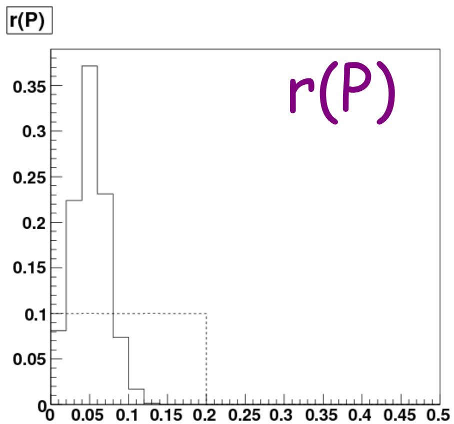
"global fit":
results obtained fitting the whole data set

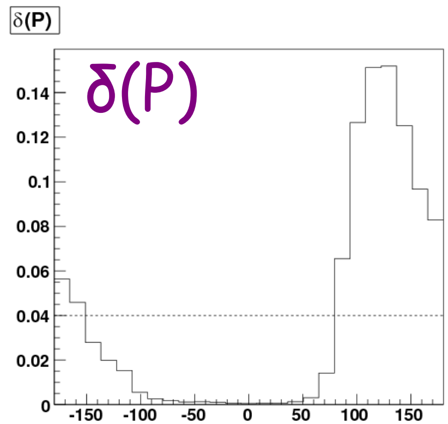
"fit predictions":
results obtained fitting the whole data set but the "prediction"

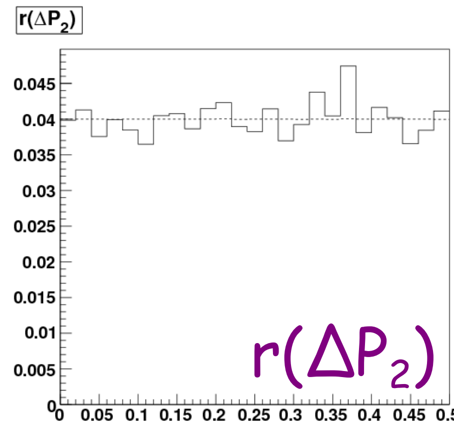
	global fit	fit prediction
$BR(K^+\pi^-)\times 10^6$	19.6 ± 0.5	20.1 ± 1.0
$BR(K^+\pi^0)\times 10^6$	12.7 ± 0.5	12.4 ± 0.7
$BR(K^0\pi^+)\times 10^6$	23.7 ± 0.8	24.6 ± 1.2
$BR(K^0\pi^0)\times 10^6$	9.2 ± 0.4	8.6 ± 0.6
$\mathcal{A}_{CP}(K^+\pi^-)$	-0.095 ± 0.012	-0.01 ± 0.08
$\mathcal{A}_{CP}(K^+\pi^0)$	0.043 ± 0.024	-0.02 ± 0.07
$\mathcal{A}_{CP}(K^0\pi^+)$	0.010 ± 0.023	0.02 ± 0.06
$C(K_S\pi^0)$	0.12 ± 0.04	0.12 ± 0.04
$S(K_S\pi^0)$	0.702 ± 0.067	0.74 ± 0.06

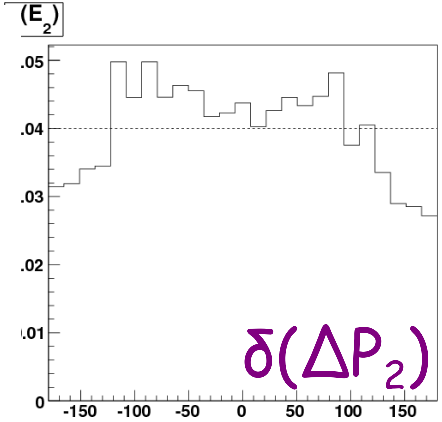
Decay Mode	$BR^{exp}\times 10^6$	$\mathcal{A}_{CP}^{exp} = -C$	S
$K^+\pi^-$	19.4 ± 0.6	-0.097 ± 0.012	–
$K^+\pi^0$	12.9 ± 0.6	0.050 ± 0.025	–
$K^0\pi^+$	23.1 ± 1.0	0.009 ± 0.025	–
$K^0\pi^0$	9.9 ± 0.6	-0.14 ± 0.11	0.38 ± 0.19

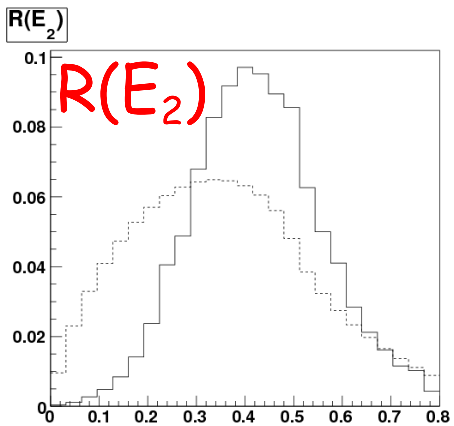
- BR's OK and fairly insensitive to the "Λ/m_b noise"
- A_{CP} can be reproduced thanks to the "Λ/m_b noise"
- $S(K_S\pi^0)$ cannot be "satisfactorily" reproduced

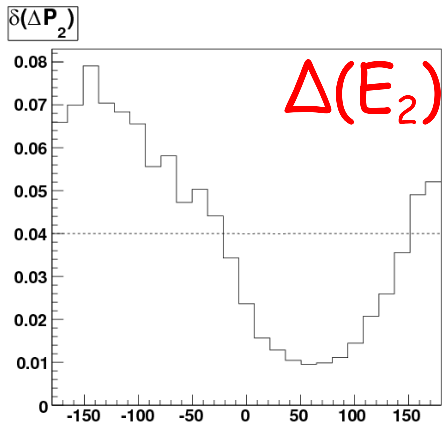


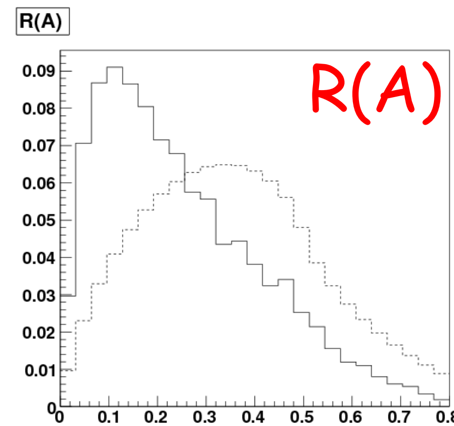


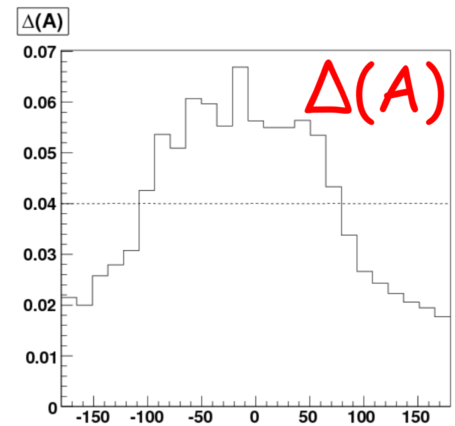


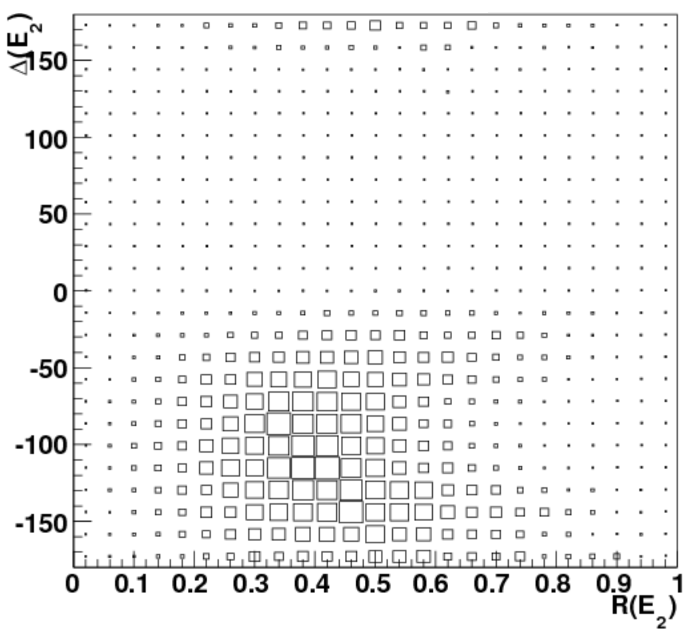




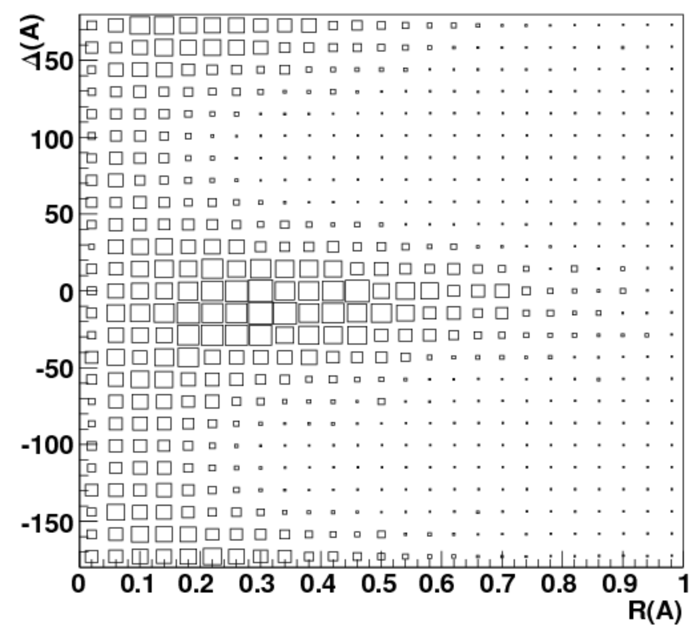




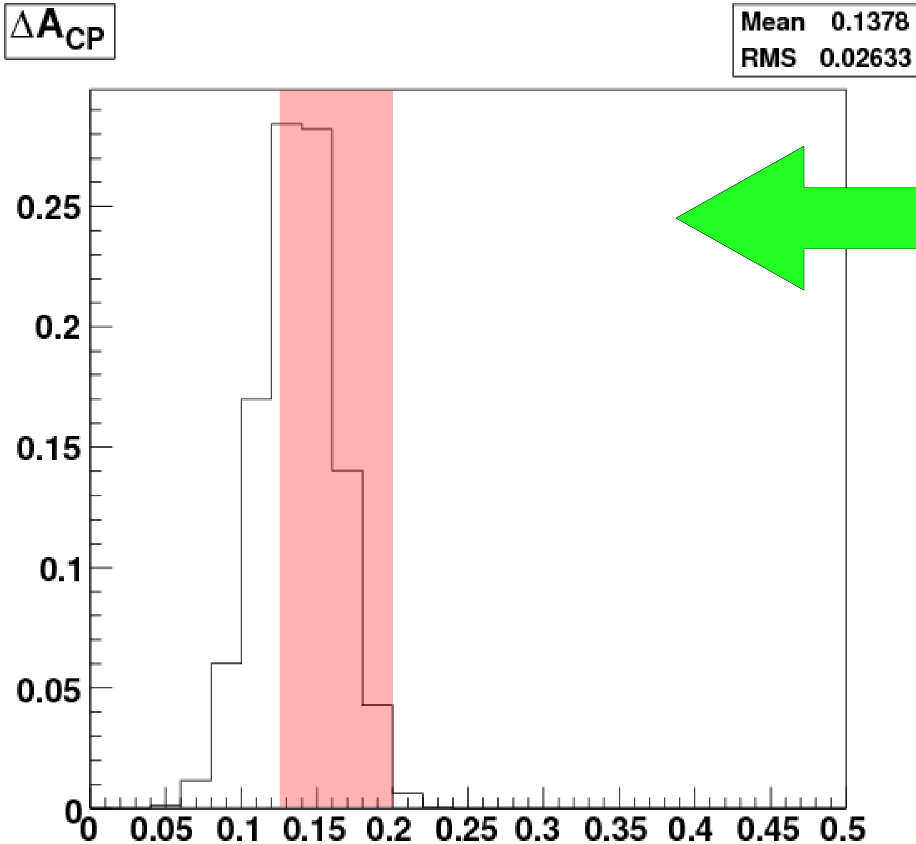




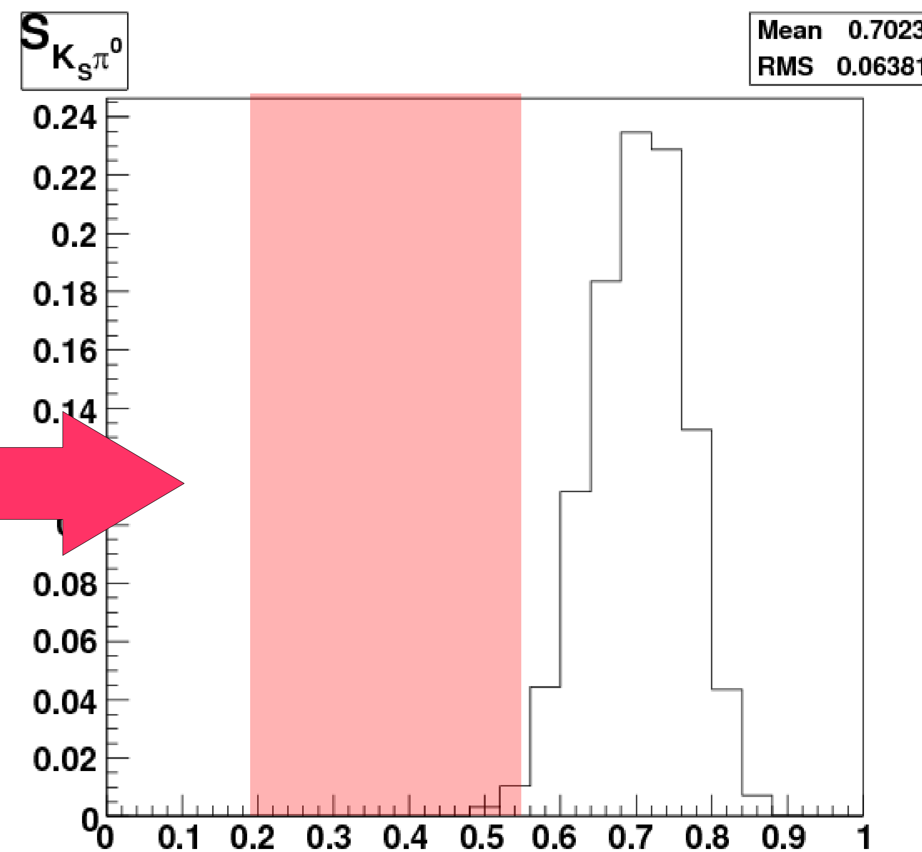
* charming penguins $r(P)$ are well determined
* Λ/m_b corrections $R(A)$ ~0.1-0.2 and $R(E_2)$ ~0.3-0.4 are selected
* data do not fix values for the other terms



preliminary



No clash with the Belle measurement of the CP asymmetries



However...

$$S(K_S\pi^0)_{exp} = 0.38 \pm 0.19$$

The $K^*\pi$ playground for QCD challenges

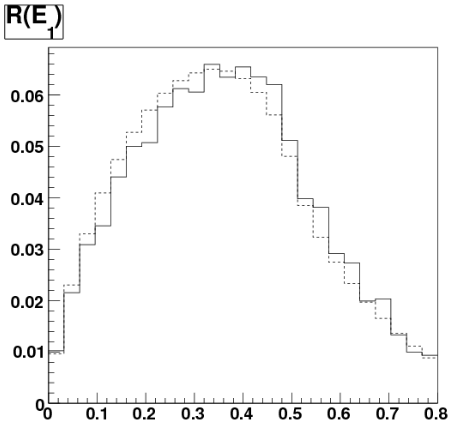
* 11 real hadronic parameters as in the $K\pi$ case

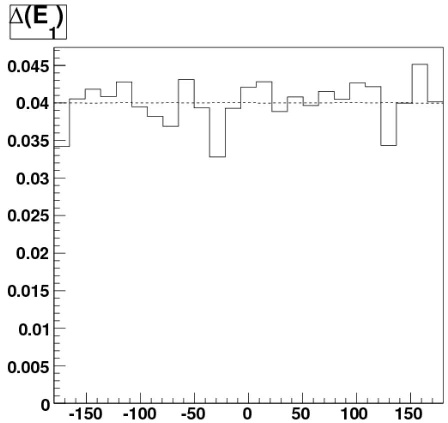
* 11 observables ⇒ **fully determined in the SM**

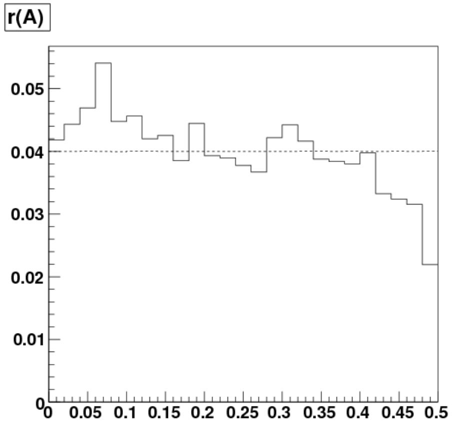
1. $K^+\pi^-\pi^0$ Dalitz plot: (3)
   $|A(K^{*+}\pi^-)|$, $|A(K^{*0}\pi^0)|$,
   $\arg A(K^{*+}\pi^-) - \arg A(K^{*0}\pi^0)$
2. $K^-\pi^+\pi^0$ Dalitz plot: (3)
   $|A(K^{*-}\pi^+)|$, $|A(\overline{K}^{*0}\pi^0)|$,
   $\arg A(K^{*-}\pi^+) - \arg A(\overline{K}^{*0}\pi^0)$
3. $K_S\pi^-\pi^+$ Dalitz plot: (1)
   $|A(K^{*+}\pi^-)|$, $|A(K^{*-}\pi^+)|$,
   $\arg A(K^{*+}\pi^-) - \arg A(K^{*-}\pi^+)$
4. $K_S\pi^0\pi^0$ Dalitz plot: (0)
   $|A(K^{*0}\pi^0)|$, $|A(\overline{K}^{*0}\pi^0)|$,
   $\arg A(K^{*0}\pi^0) - \arg A(\overline{K}^{*0}\pi^0)$
5. $K_S\pi^+\pi^0$ Dalitz plot: (3)
   $|A(K^{*+}\pi^0)|$, $|A(K^{*0}\pi^+)|$,
   $\arg A(K^{*+}\pi^0) - \arg A(K^{*0}\pi^+)$
6. $K_S\pi^-\pi^0$ Dalitz plot: (3)
   $|A(K^{*-}\pi^0)|$, $|A(K^{*0}\pi^-)|$,
   $\arg A(K^{*-}\pi^0) - \arg A(K^{*0}\pi^-)$

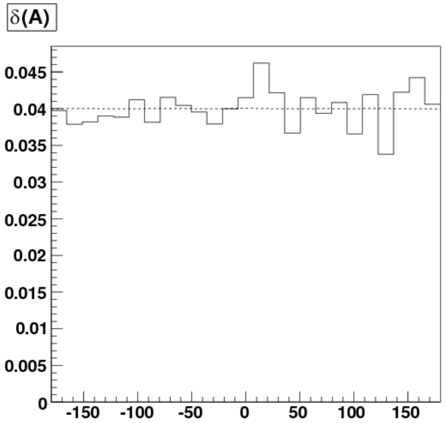
amplitudes satisfy 2 isospin quadrangular relations (-2)

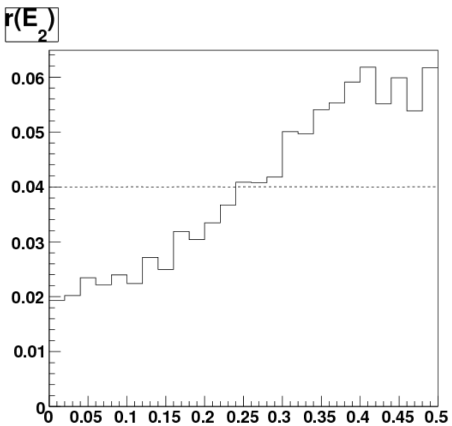
Spare Slides

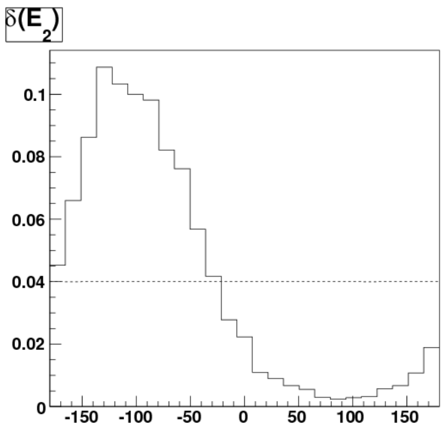

$R(E_1)$

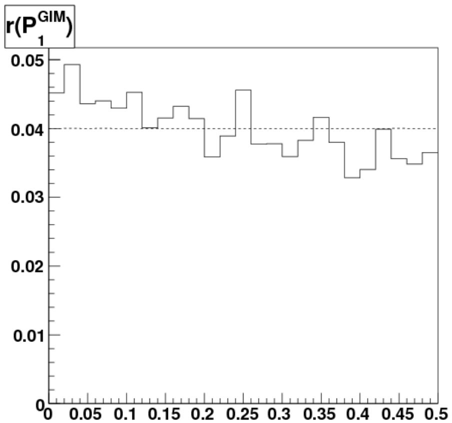

$\Delta(E_1)$

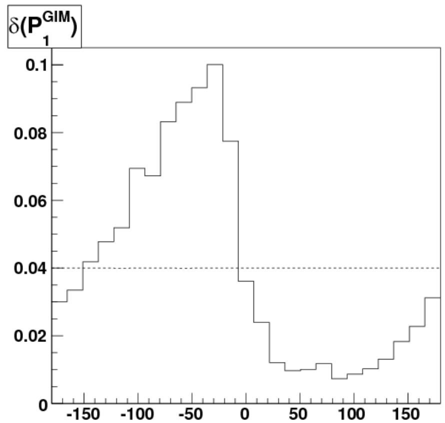

$r(A)$

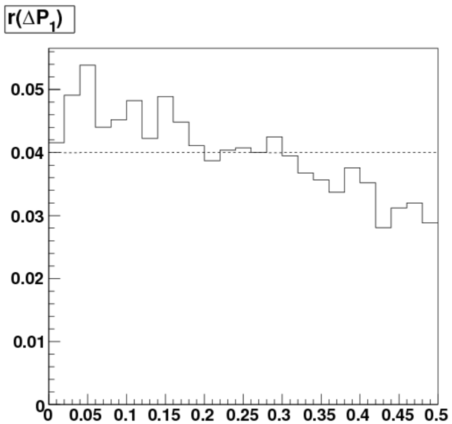

$\delta(A)$

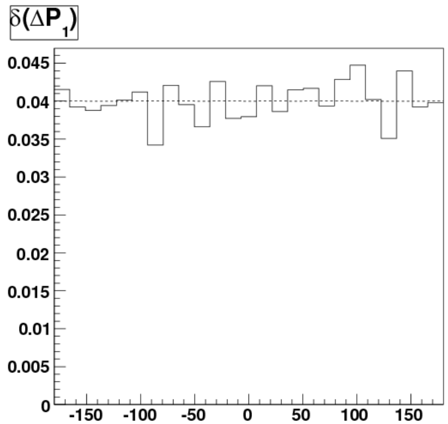

$r(E_2)$


$\delta(E_2)$


$r(P_1^{GIM})$


$\delta(P_1^{GIM})$


$r(\Delta P_1)$


$\delta(\Delta P_1)$

$$E_1^{\rm F} = A_{\pi K}\left(-\alpha_1 - \alpha_4^u + \alpha_4^c - \alpha_{4,EW}^u + \alpha_{4,EW}^c\right)$$

$$E_2^{\rm F} = A_{K\pi}\left(-\alpha_2 - \frac{3}{2}(\alpha_{3,EW}^u - \alpha_{3,EW}^c)\right) + A_{\pi K}\left(\alpha_4^u - \alpha_4^c - \frac{1}{2}(\alpha_{4,EW}^u - \alpha_{4,EW}^c)\right),$$

$$A^{\rm F} = A_{\pi K}\left(-\alpha_4^u + \alpha_4^c + \frac{1}{2}(\alpha_{4,EW}^u - \alpha_{4,EW}^c)\right),$$

$$P^{\rm F} = A_{\pi K}\left(-\alpha_4^c + \frac{1}{2}\alpha_{4,EW}^c\right),$$

$$\Delta P_1^{\rm F} = -A_{\pi K}\frac{3}{2}\alpha_{4,EW}^c,$$

$$\Delta P_2^{\rm F} = -A_{K\pi}\frac{3}{2}\alpha_{3,EW}^c,$$

+ m_s=(98±6±12) MeV

$$A_{\pi K} = G_F/\sqrt{2} m_B^2 f_k F_\pi(0)$$
$$A_{K\pi} = G_F/\sqrt{2} m_B^2 f_\pi F_k(0)$$

f_π	0.1307 GeV	f_K	0.1598 GeV
$F^{B\to\pi}$	0.27 ± 0.08	$F^{B\to K}/F^{B\to\pi}$	1.20 ± 0.10
τ_{B^0}	$1.546 \cdot 10^{-12}$ ps	τ_{B+}	$1.674 \cdot 10^{-12}$ ps
m_B	5.2794 GeV/c^2	f_B	0.189 ± 0.027 GeV
m_π	0.14 GeV/c^2	m_K	0.493677 GeV/c^2

Conclusions

Flavour physics is a unique tool for searching and studying NP complementary to the LHC

There is a first evidence for NP in b<->s transitions. Confirmation in Summer

From $\Delta F=2$ transitions, a pattern of flavour violation in NP emerges:
2<->3: O(1), 1<->3: < O(0.1), 1<->2 strong suppr.

The next 15 years of flavour physics are well motivated and clearly planned: exciting times ahead