An update on charming penguins in charmless B decays

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paper in preparation

Current Experimental Situation

- The establishment of CP violation in $K^+\pi^-$ and the observed discrepancy with respect to $K^+\pi^0$ called for a "puzzle" in $K\pi$ decays. For us, this is just the indication that charming and GIM penguins are not the end of the story

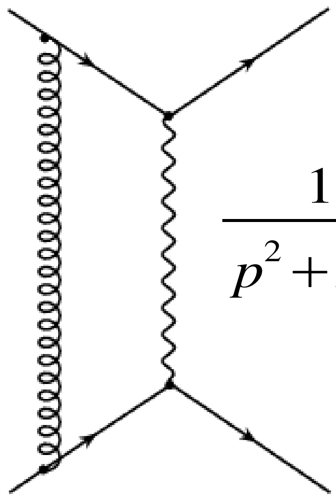
- the enhancement with time of $BR(K^0\pi^0)$ introduced some tension in the commonly accepted models, interpreted as a possible hint of SU(2) breaking

- The large set of measurements (including S and C) from BaBar and Belle allows to study not only $K\pi$ but also PV modes

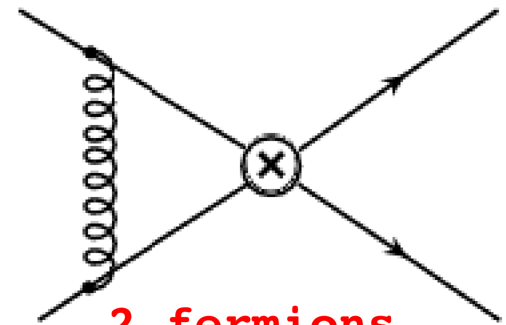
The OPE and decay amplitudes

Since m_b~4GeV and m_W~80GeV, weak interaction can be replaced by an effective local theory, contracting the W propagator to a point (similar approach with t quark)

2 fermions 2 bosons in the loop



$$\frac{1}{p^2+m_W^2} \rightarrow \left(1+O\left(\frac{p^2}{m_W^2}\right)\right)$$



2 fermions 1 boson in the loop

This operation breaks the ultraviolet behavior of the theory.

$$\int \frac{d^4p}{p^6} \approx \int \frac{dp}{p^3} \rightarrow 0 \quad \Rightarrow \quad \int \frac{d^4p}{p^4} \approx \int \frac{dp}{p} \rightarrow \infty$$

To remove the ∞ after integrating out the heavy degrees of freedom we need to renormalize the theory. New operators couplings are generated

The effective Hamiltonian

After the renormalization of the effective theory we get

$$\mathcal{H}_{\rm eff} = \frac{G_F}{\sqrt{2}} \sum_{p=u,c} \lambda_p \Big(C_1\, Q_1^p + C_2\, Q_2^p + \sum_{i=3,\dots,10} C_i\, Q_i + C_{11}\, Q_{12} + C_{12}\, Q_{12} \Big) + \text{h.c.}$$

Tree level operators

$$Q_1^p = (\bar p b)_{V-A} (\bar s p)_{V-A}\,, \qquad Q_2^p = (\bar p_i b_j)_{V-A} (\bar s_j p_i)_{V-A}\,,$$

Penguin operators

$$Q_3 = (\bar s b)_{V-A} \sum\nolimits_q (\bar q q)_{V-A}\,, \qquad Q_4 = (\bar s_i b_j)_{V-A} \sum\nolimits_q (\bar q_j q_i)_{V-A}\,,$$

$$Q_5 = (\bar s b)_{V-A} \sum\nolimits_q (\bar q q)_{V+A}\,, \qquad Q_6 = (\bar s_i b_j)_{V-A} \sum\nolimits_q (\bar q_j q_i)_{V+A}\,,$$

EW Penguin operators

$$Q_7 = (\bar s b)_{V-A} \sum\nolimits_q \tfrac{3}{2} e_q (\bar q q)_{V+A}\,, \qquad Q_8 = (\bar s_i b_j)_{V-A} \sum\nolimits_q \tfrac{3}{2} e_q (\bar q_j q_i)_{V+A}\,,$$

$$Q_9 = (\bar s b)_{V-A} \sum\nolimits_q \tfrac{3}{2} e_q (\bar q q)_{V-A}\,, \qquad Q_{10} = (\bar s_i b_j)_{V-A} \sum\nolimits_q \tfrac{3}{2} e_q (\bar q_j q_i)_{V-A}\,,$$

$$Q_{7\gamma} = \frac{-e}{8\pi^2} m_b\, \bar s \sigma_{\mu\nu} (1+\gamma_5) F^{\mu\nu} b\,, \qquad Q_{8g} = \frac{-g_s}{8\pi^2} m_b\, \bar s \sigma_{\mu\nu} (1+\gamma_5) G^{\mu\nu} b\,,$$

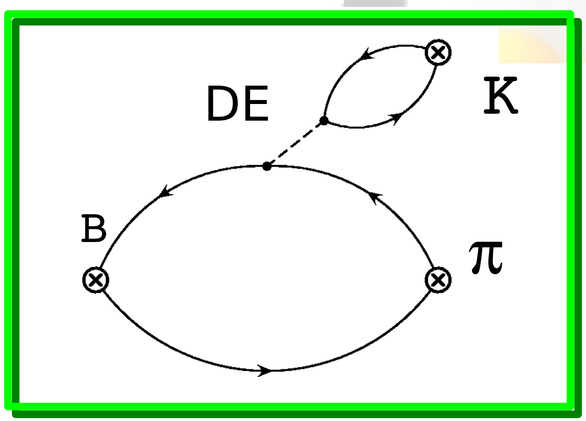
(cromo)magnetic operators

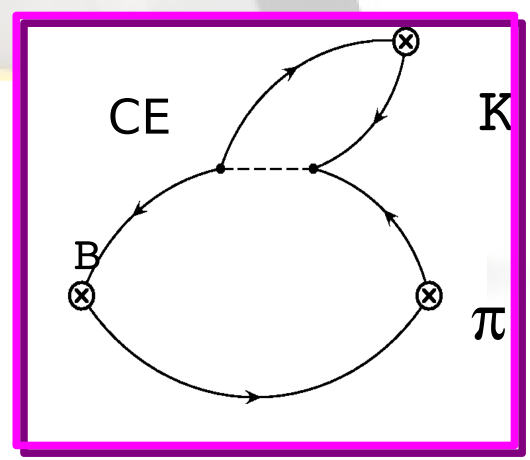
Contractions of the H_{eff}

Contracting (Wick theorem) H_{eff} on initial and final states

$$A(B^0 \to K^+\pi^-) = \langle K^+\pi^- | H_{eff} | B^0 \rangle = \sum_{i=1,10} C_i(\mu) \langle K^+\pi^- | Q_i(\mu) | B^0 \rangle$$

All the perturbative physics (scale > μ) in the Wilson coeff. $C_i(\mu)$. All the non-perturbative physics (scale < μ) in the matrix elements. The unphysical dependence on μ has to cancel out. One operator can produce several diagram topologies. Example: tree level operators generate $\langle Q \rangle_{DE}(\mu)$ and $\langle Q \rangle_{CE}(\mu)$





The RGI combinations

One can rearrange contractions into Renormalization Group Invariant combinations, corresponding to physical quantities (**Buras & Silvestrini, hep-ph/9812392**). Example: T and T_C (trees) correspond to the RGI's E_1 and E_2

$$E_1 = C_1 \langle Q_1 \rangle_{DE} + C_2 \langle Q_2 \rangle_{CE} \qquad E_2 = C_1 \langle Q_1 \rangle_{CE} + C_2 \langle Q_2 \rangle_{DE}$$

Penguins are more complicated

$$P_1 = C_1 \langle Q_1 \rangle^c_{CP} + C_2 \langle Q_2 \rangle^c_{DP} + \sum_{i=2}^{5} \left(C_{2i-1} \langle Q_{2i-1} \rangle_{CE} + C_{2i} \langle Q_{2i} \rangle_{DE} \right)$$
$$+ \sum_{i=3}^{10} \left(C_i \langle Q_i \rangle_{CP} + C_i \langle Q_i \rangle_{DP} \right) + \sum_{i=2}^{5} \left(C_{2i-1} \langle Q_{2i-1} \rangle_{CA} + C_{2i} \langle Q_{2i} \rangle_{DA} \right)$$

$$P_1^{\mathrm{GIM}} = C_1 \left(\langle Q_1 \rangle^c_{CP} - \langle Q_1 \rangle^u_{CP} \right) + C_2 \left(\langle Q_2 \rangle^c_{DP} - \langle Q_2 \rangle^u_{DP} \right)$$

Every RGI correponds to a contraction of the $J_\mu J^\mu$ interaction term of the Standard Model (i.e. RGIs are the physical quantities)

The Decay Amplitude

The final formula is simplified and the dependence on μ is formally canceled out

$$A(B^0 \to K^+ \pi^-) = V_{ts} V_{tb}^* \times P_1 - V_{us} V_{ub}^* \times \{E_1 - P_1^{GIM}\}$$

$$A(B^+ \to K^0 \pi^+) = -V_{ts} V_{tb}^* \times P_1 + V_{us} V_{ub}^* \times \{A_1 - P_1^{GIM}\}$$

$$\sqrt{2} \cdot A(B^+ \to K^+ \pi^0) = V_{ts} V_{tb}^* \times P_1 - V_{us} V_{ub}^* \times \{E_1 + E_2 + A_1 - P_1^{GIM}\}$$

$$\sqrt{2} \cdot A(B^0 \to K^0 \pi^0) = -V_{ts} V_{tb}^* \times P_1 - V_{us} V_{ub}^* \times \{E_2 + P_1^{GIM}\}$$

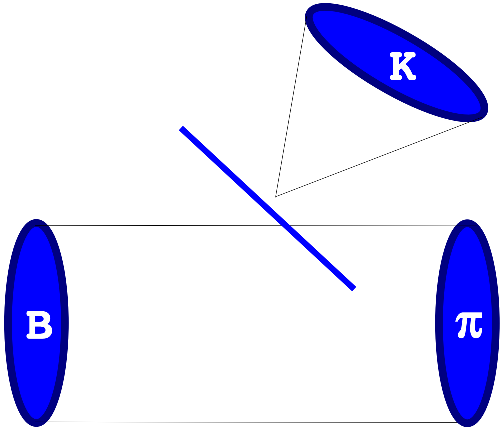
- We know **C(μ)** from perturbative calculations
- We still **miss** a technique to calculate **matrix elements** to obtain the values of the RGI

Perturbative Approaches

Perturbative calculations are possible in $m_b \to \infty$ limit

- pQCD by Keum, Li & Sanda hep-ph/0004004
- QCD Factorization by BBNS hep-ph/0006124
- SCET by BPRS hep-ph/0401188

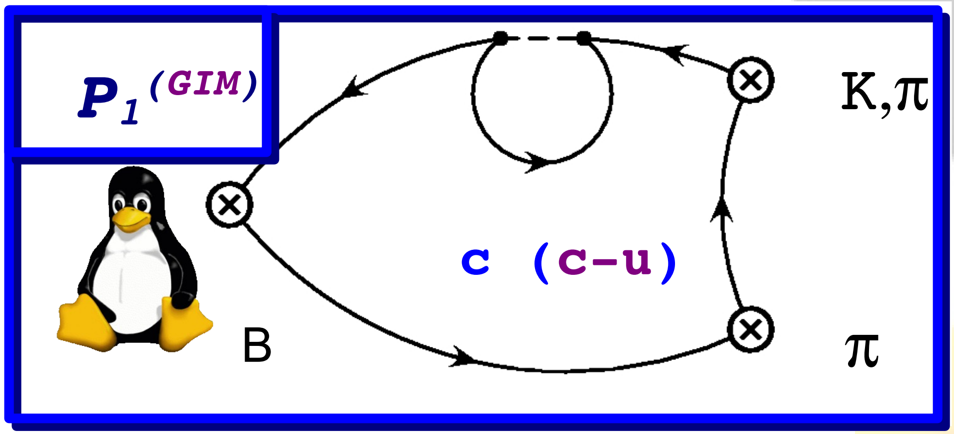
$$\langle B^0 | J_\mu J^\mu | K\pi \rangle = \langle B^0 | J_\mu | \pi \rangle \langle 0 | J^\mu | K \rangle (1 + O(\alpha_s)) + O\left(\frac{\Lambda_{QCD}}{m_b}\right)$$



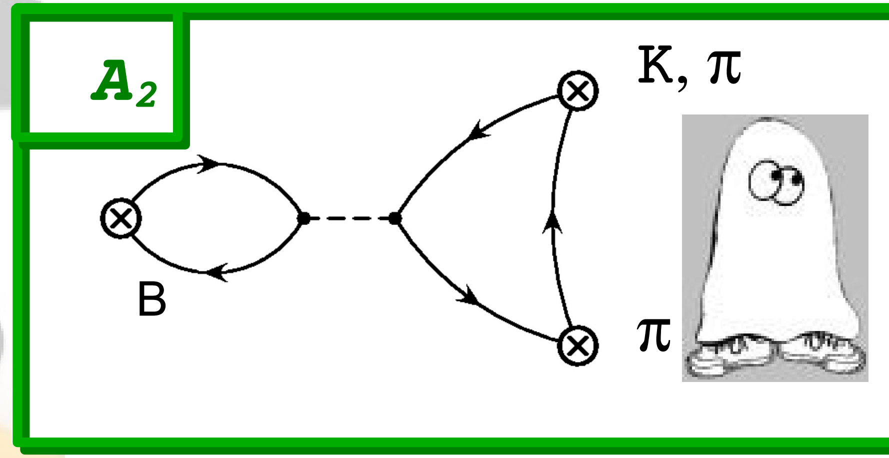
- A clear demonstration that penguins do factorize is still missing (Bauer et al. hep-ph/0401188 vs Beneke et al. hep-ph/0411171)
- As previously pointed out (Ciuchini et al. hep-ph/9703353) Λ_{QCD}/m_b contributions may play a relevant role in phenomenology ($m_b \not\to \infty$)

RGI~Λ_{QCD}/m_b in b→s decays

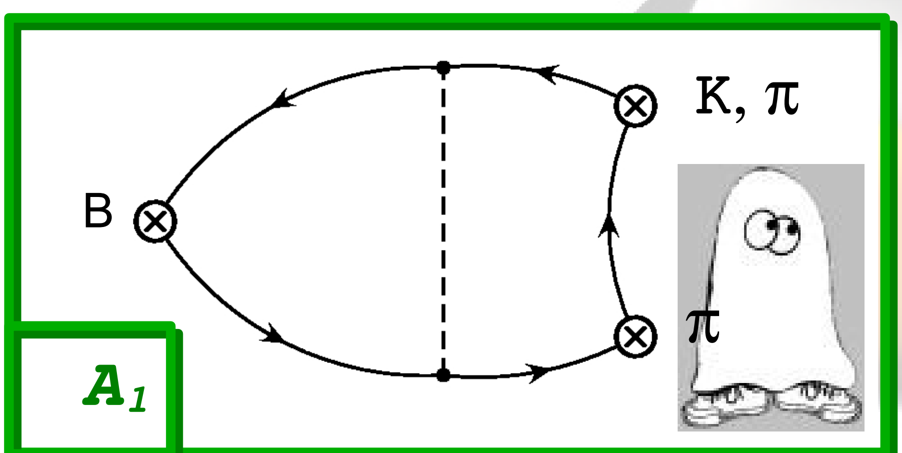
Charming and GIM penguins(c−u)



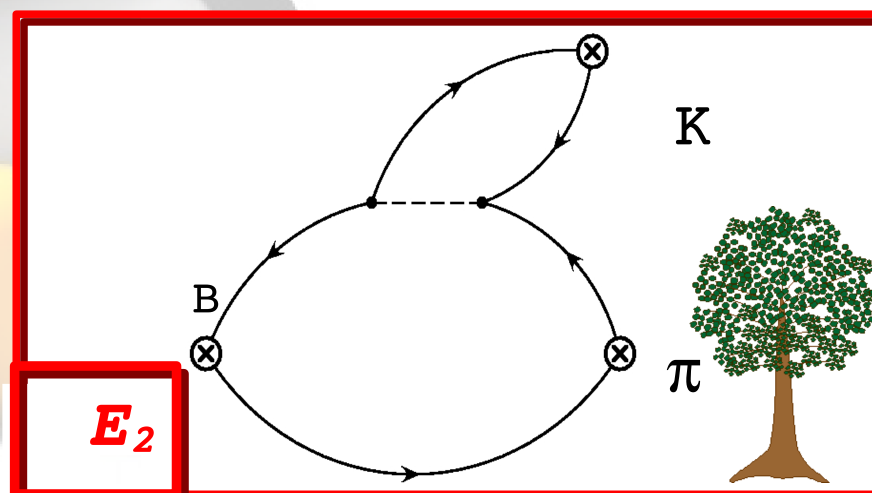
Disconnected Annihilation



Connected Annihilation



Connected emission



A Few Comments

One can move from the exact calculation to some model dependent approach, but all Λ_{QCD}/m_b terms have to be considered

- P_1 is doubly Cabibbo enhanced, so it plays the major role
- Nevertheless, the others are important

In principle: we have enough observables to determine all the parameters (4 complex RGI) and keep some predictive power

In practice: we are not precisely sensitive to the doubly Cabibbo suppressed Λ_{QCD}/m_b terms (which are ~% corrections to BR's)

What we can do:

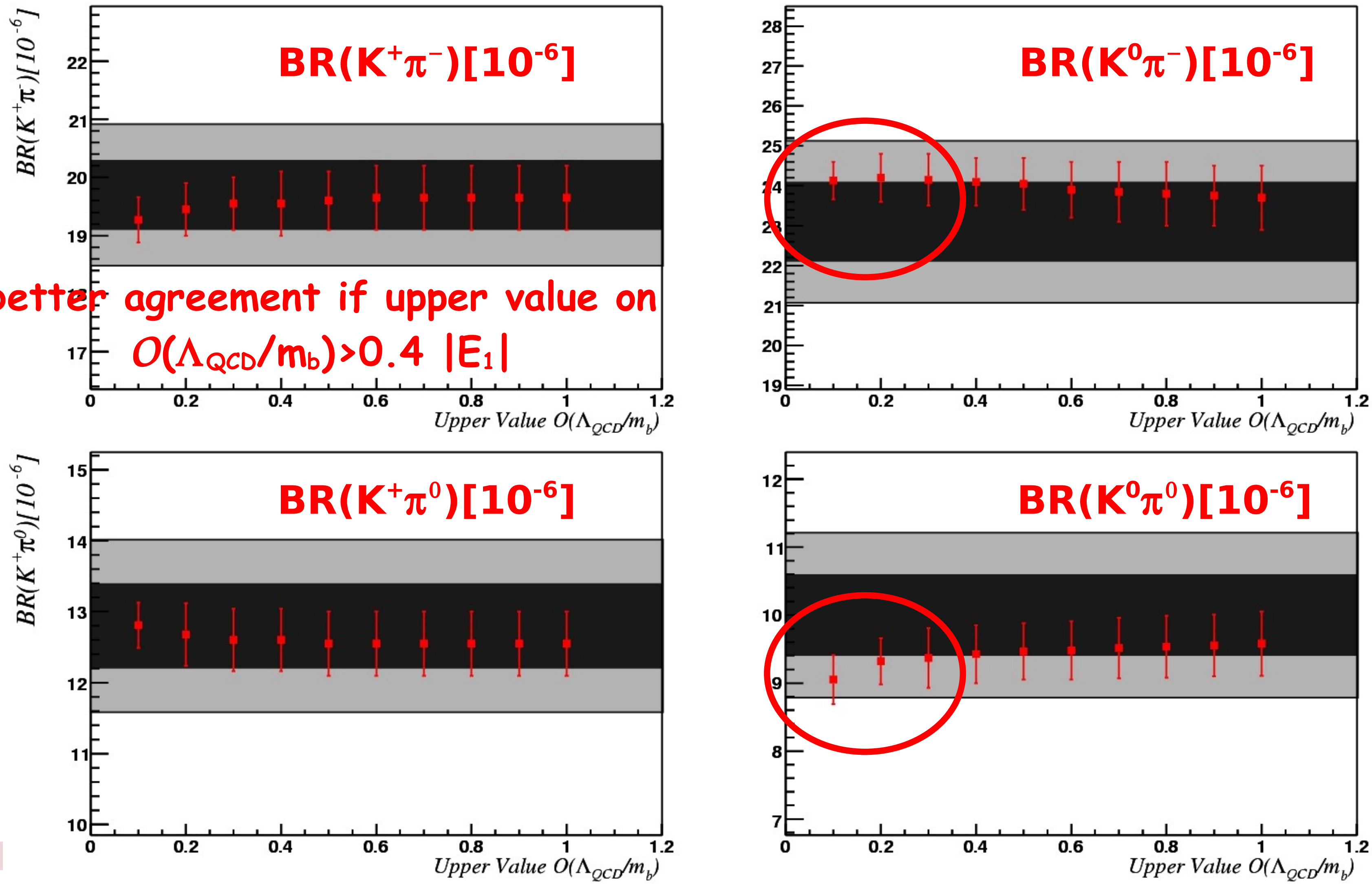
- Describe E_1 in factorization
- Fit for the leading term P_1
- Vary the other in some *a-priori fixed range*
- Use BR and direct CP asymmetries to obtain information on $S(K^0\pi^0)$

We can still obtain a prediction on S within the Standard Model, but the error on it will depend on the chosen range. **So, we scan the upper bound on the range**

Result on B→Kπ (I)

- 1σ exp range
- 2σ exp range

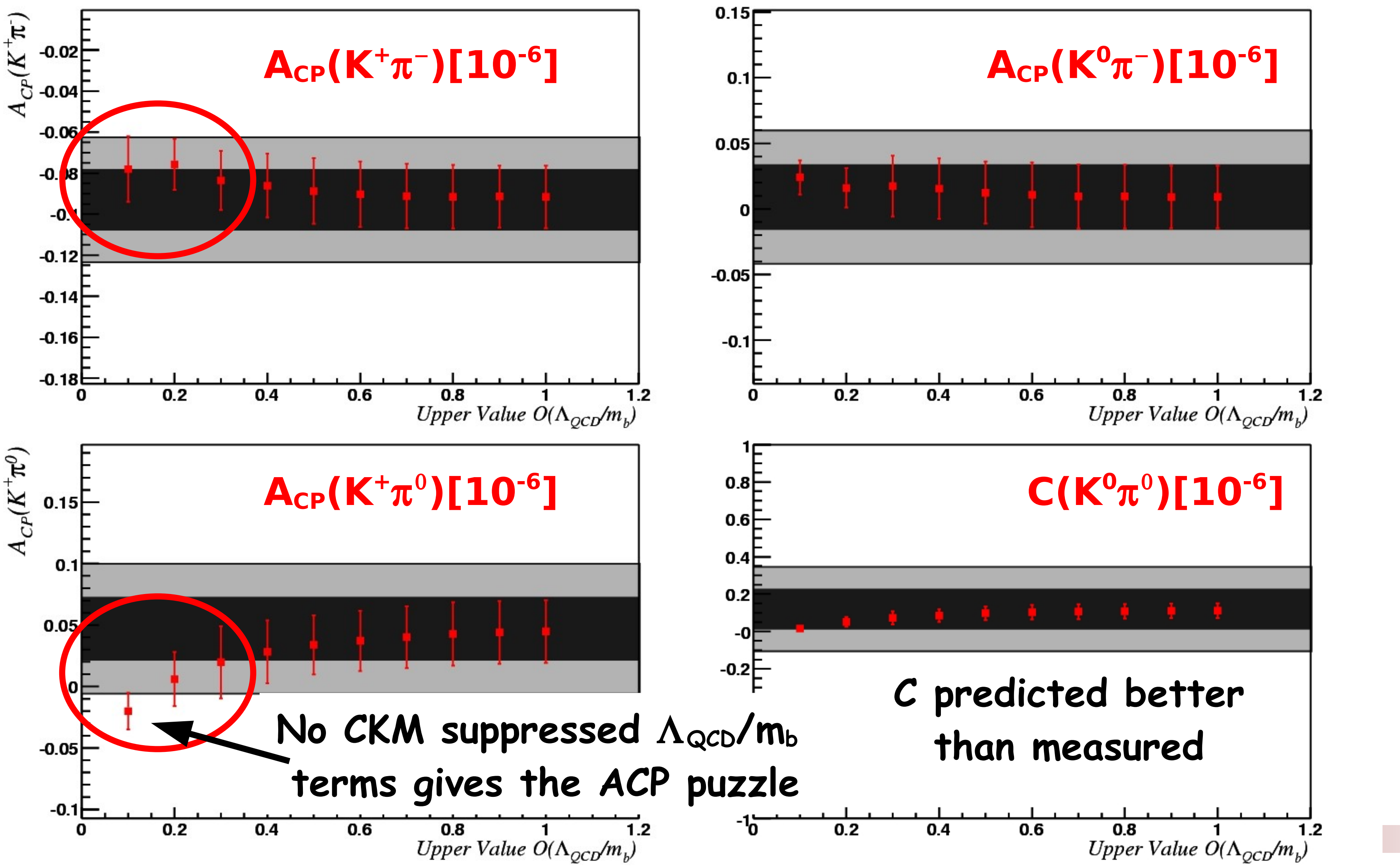
With all Λ_{QCD}/m_b corrections no BR Kπ puzzle!!!



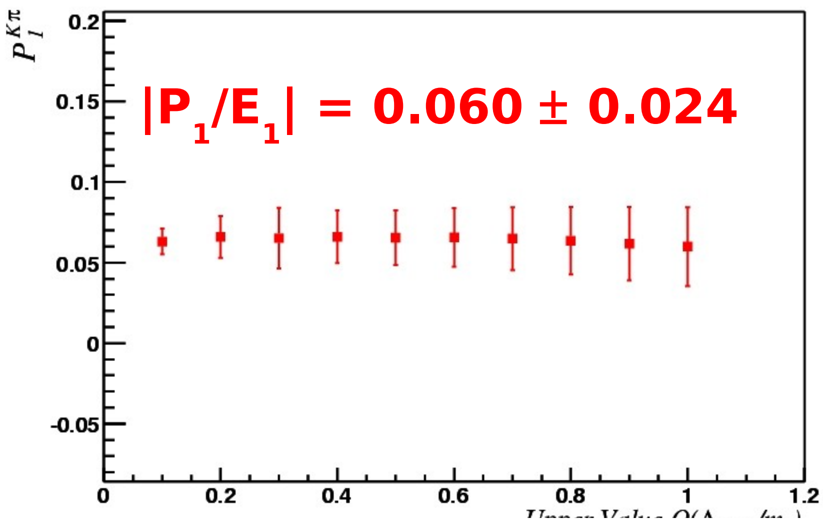
Result on B→Kπ (II)

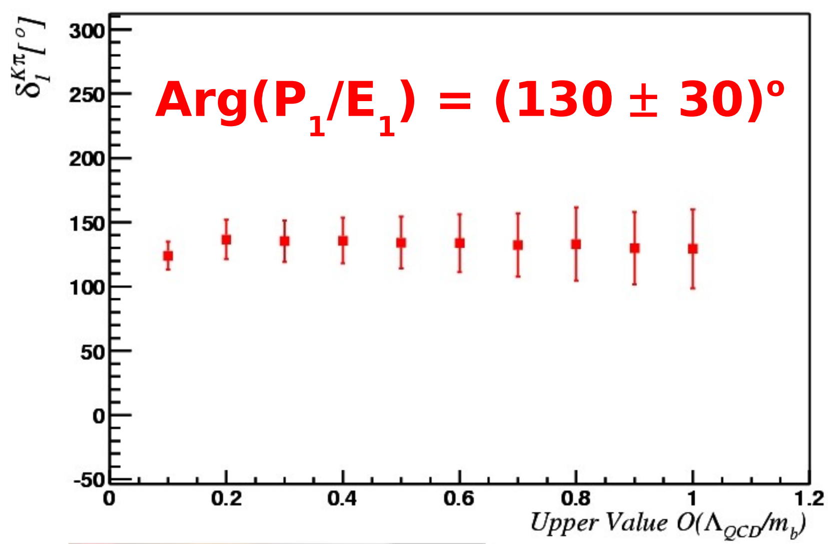
1σ exp range
2σ exp range

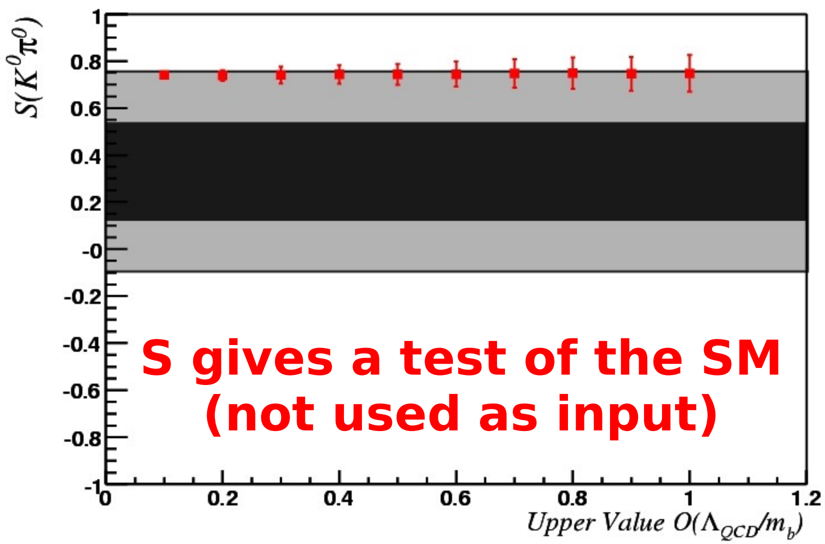
With all Λ_{QCD}/m_b corrections no A_{CP} Kπ puzzle!!!



Result on B→Kπ (III)







- The prediction on $S(K^0\pi^0)$ is stable
- The error depends on the upper value of the range
- In a very conservative situation ($O(\Lambda_{QCD}/m_b)/E_1 \in [0,1]$) we can still test the SM
- Limiting factor is still the exp. precision

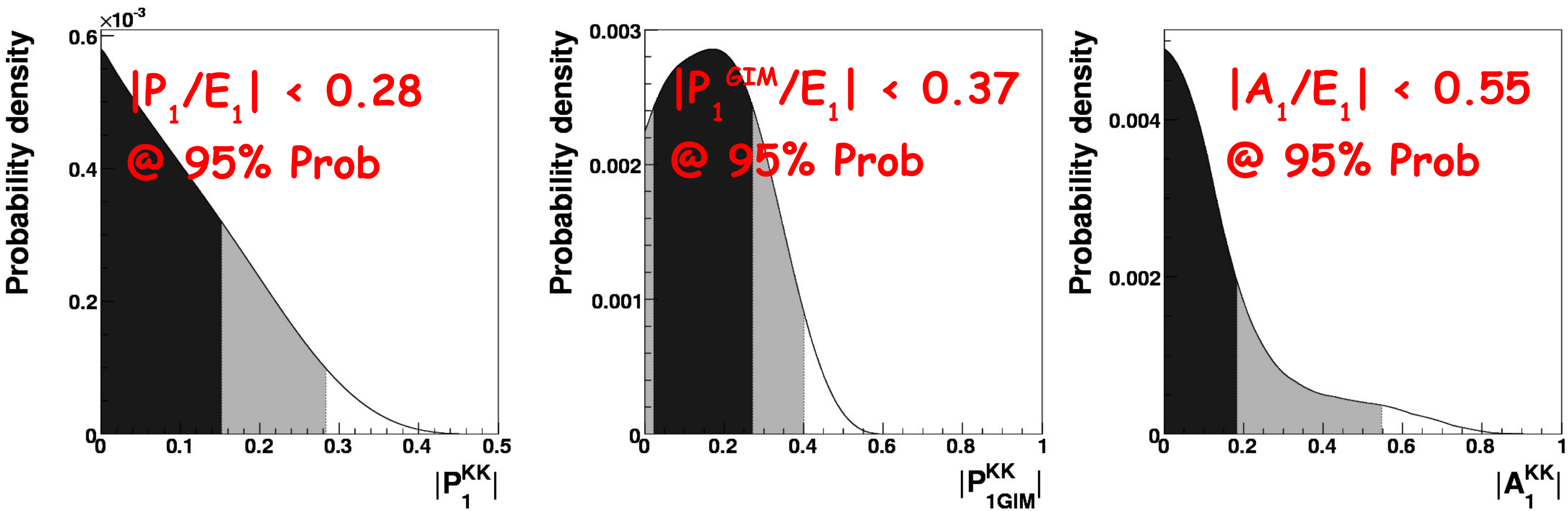
B→KK and the magnitude of $O(\Lambda_{QCD}/m_b)$

3 RGI (i.e. 5 real parameters to fit)
2BR, 2 direct CP asymmetry and S(K+K-)

$$A(B^+ \to K^+K^0) = -V_{td}V_{tb}^* \times P_1 + V_{ud}V_{ub}^* \times \{A_1 - P_1^{GIM}\}$$

$$A(B^+ \to K^0K^0) = -V_{td}V_{tb}^* \times P_1 - V_{ud}V_{ub}^* \times \{P_1^{GIM}\}$$

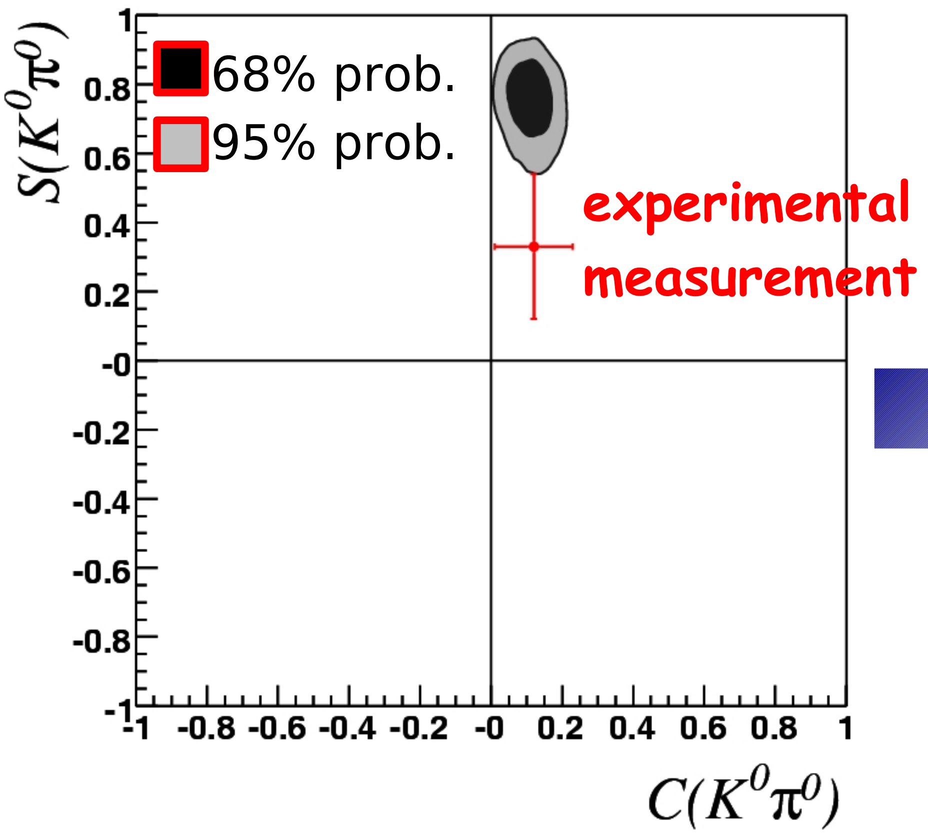
Large values of the parameters are suppressed.
Even with SU(3) broken @100% we do not expect large enhancements



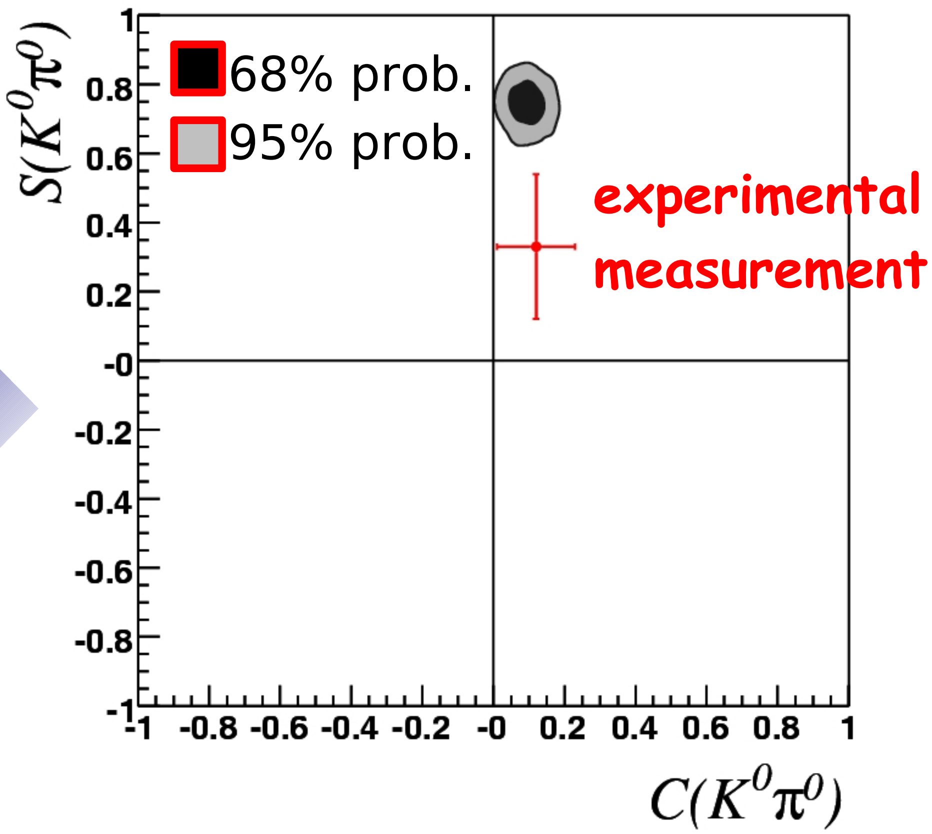
Test of SM: $S_{K\pi}$ vs $C_{K\pi}$

Since C is better determined by the fit than by the experiment, we have information on it from the other variables + SU(2) relations (all possible sum rules you can imagine are implemented). We can remove also C from the set of inputs and look at the agreement in the S vs C plane

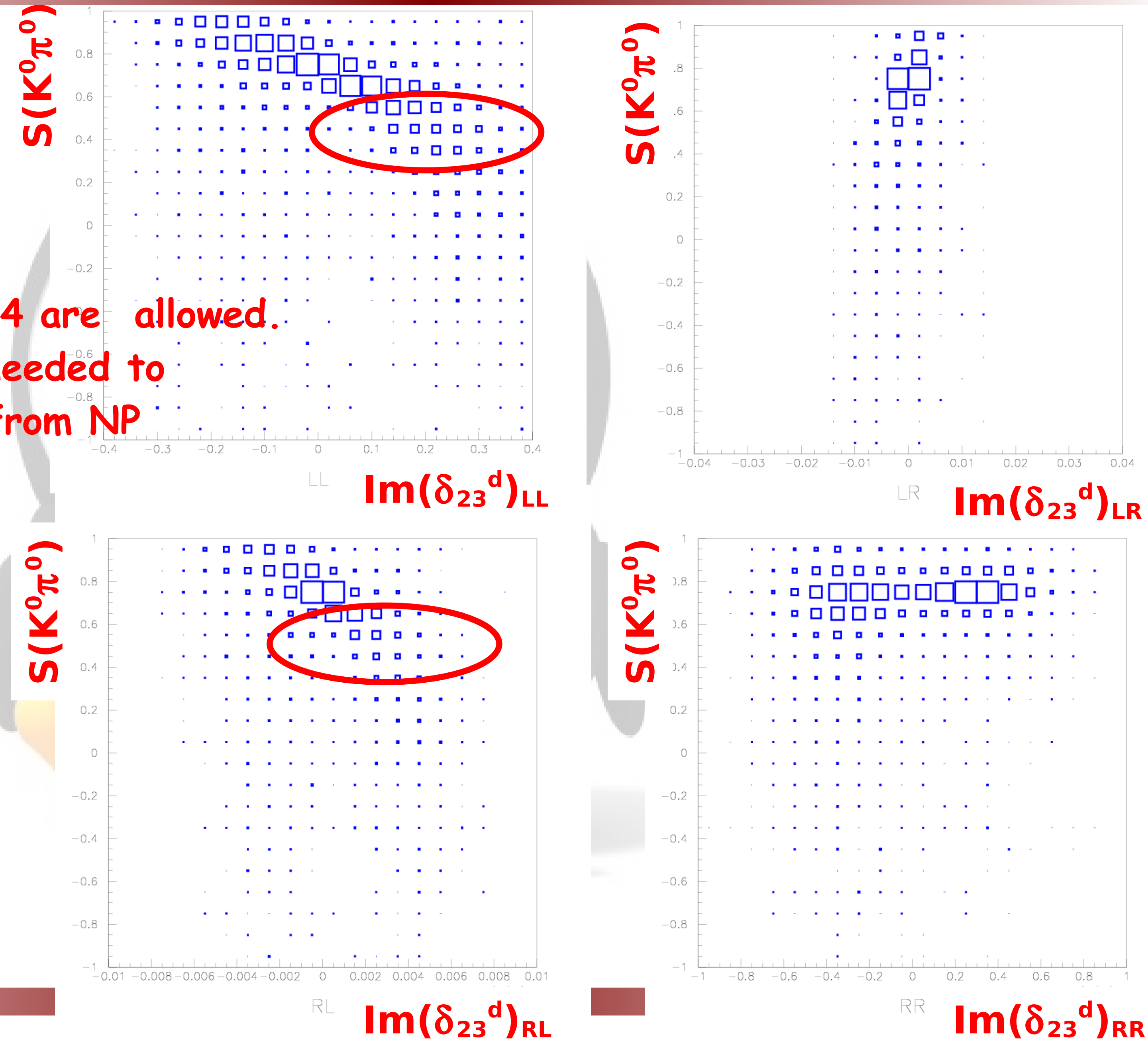
$O(\Lambda_{QCD}/m_b)/E_1 \in [0,1]$



$O(\Lambda_{QCD}/m_b)/E_1 \in [0,0.5]$

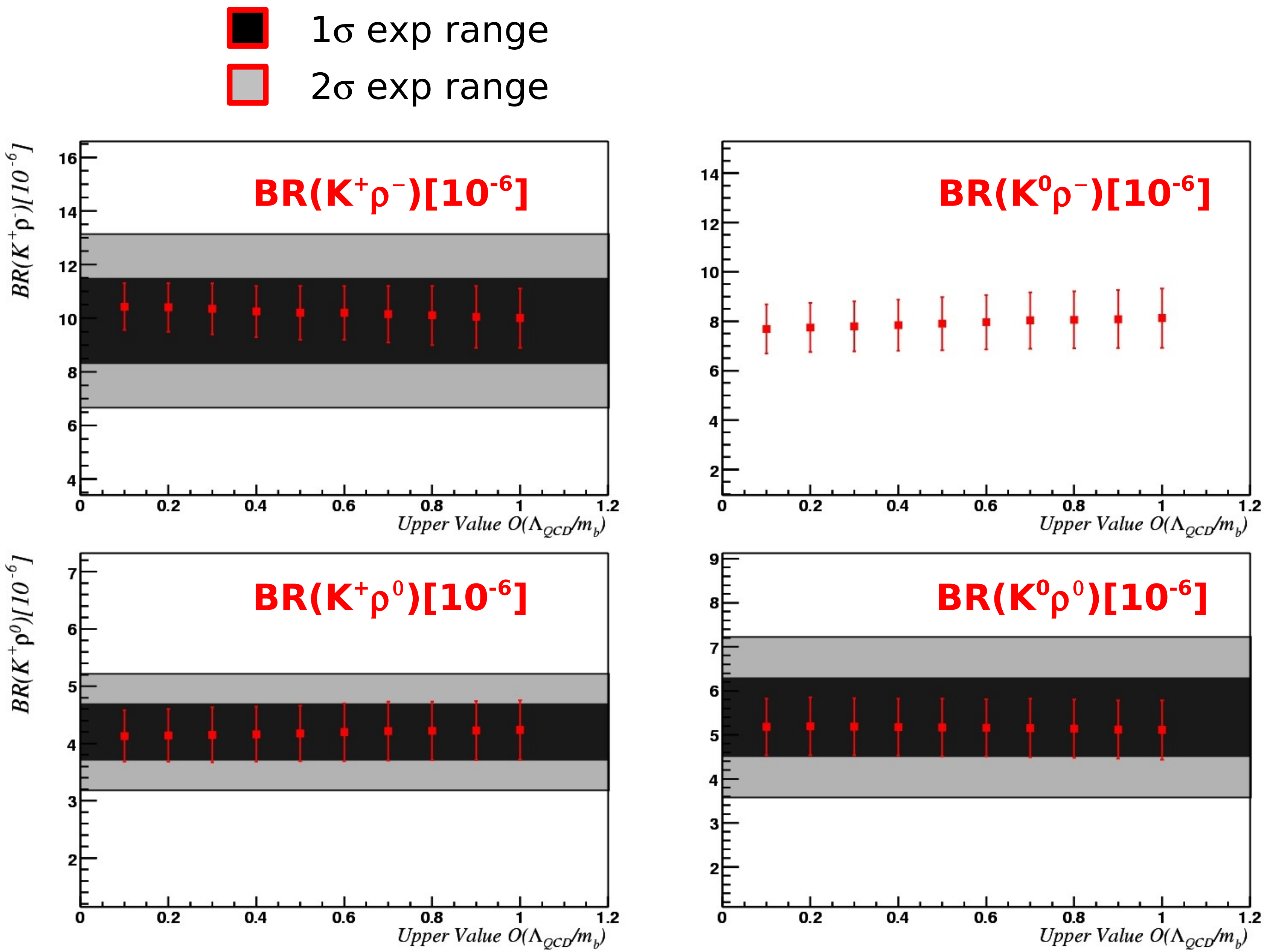


What SUSY can do



Typical values of 0.3-0.4 are allowed.
SuperB statistics needed to
disentangle SM from NP

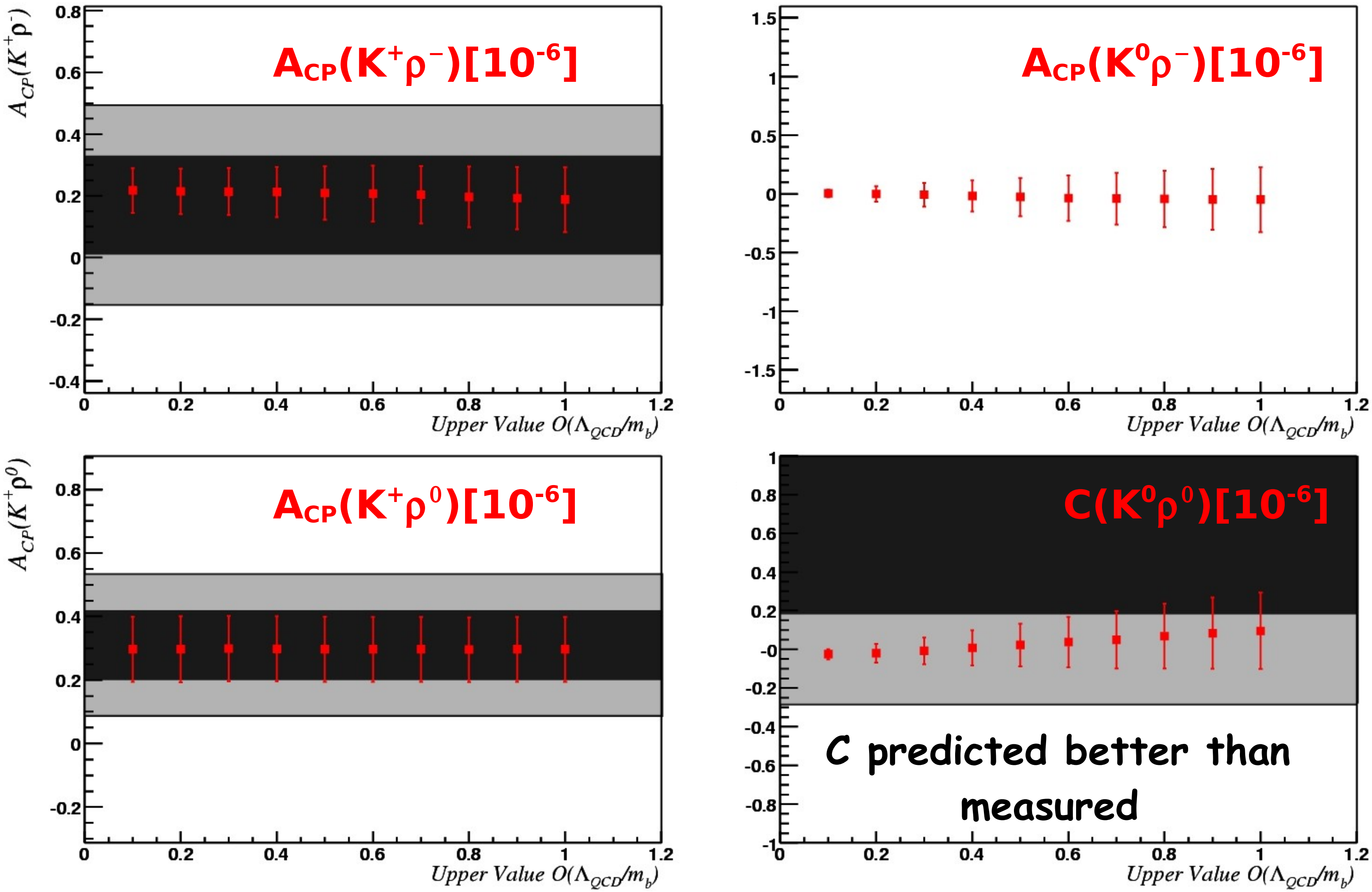
Result on B→Kρ (I)



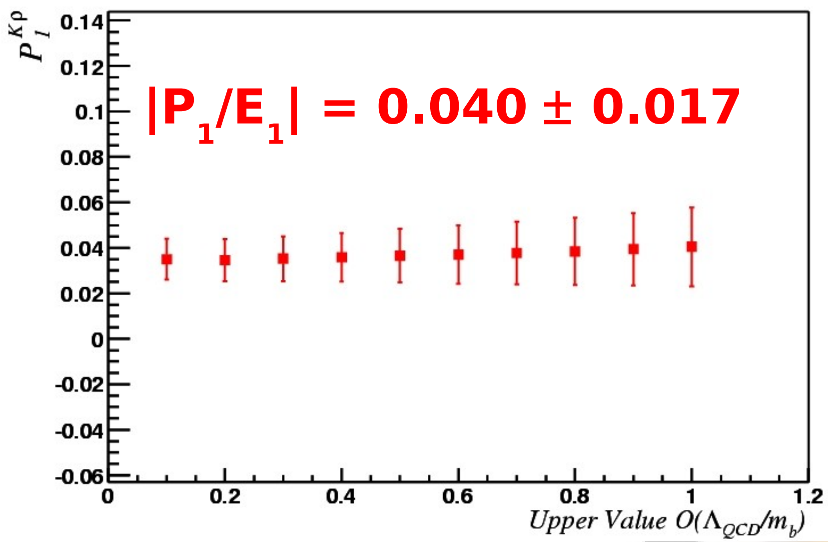
Result on B→Kρ (II)

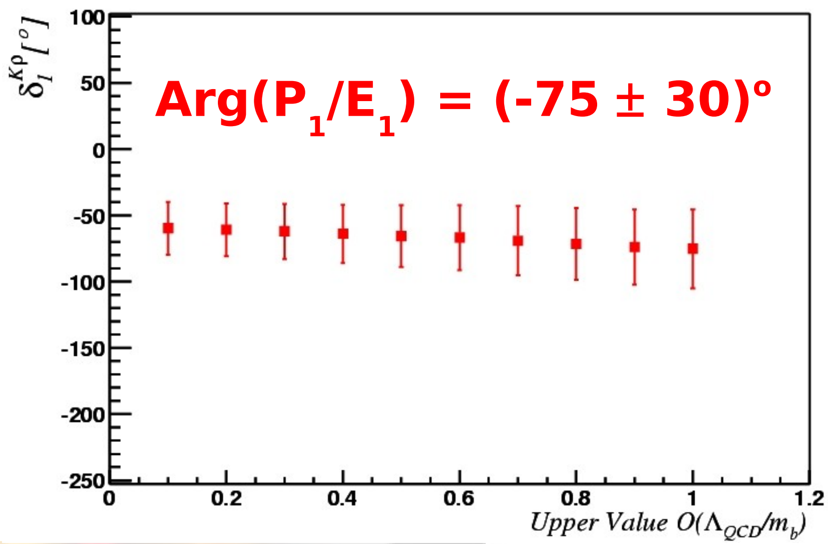
■ 1σ exp range

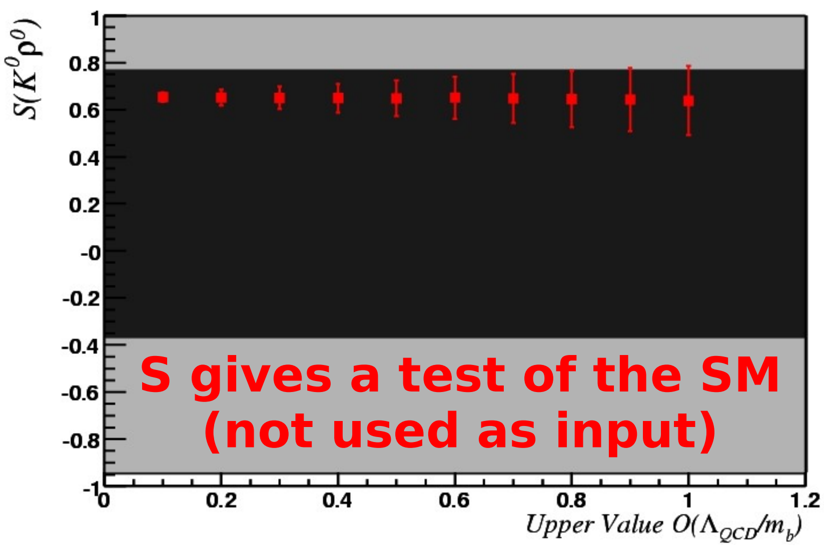
□ 2σ exp range



Result on B→Kρ (III)







- The prediction on $S(K^0\rho^0)$ is stable
- The error depends on the upper value of the range
- In a very conservative situation ($O(\Lambda_{QCD}/m_b)/E_1 \in [0,1]$) we can still test the SM
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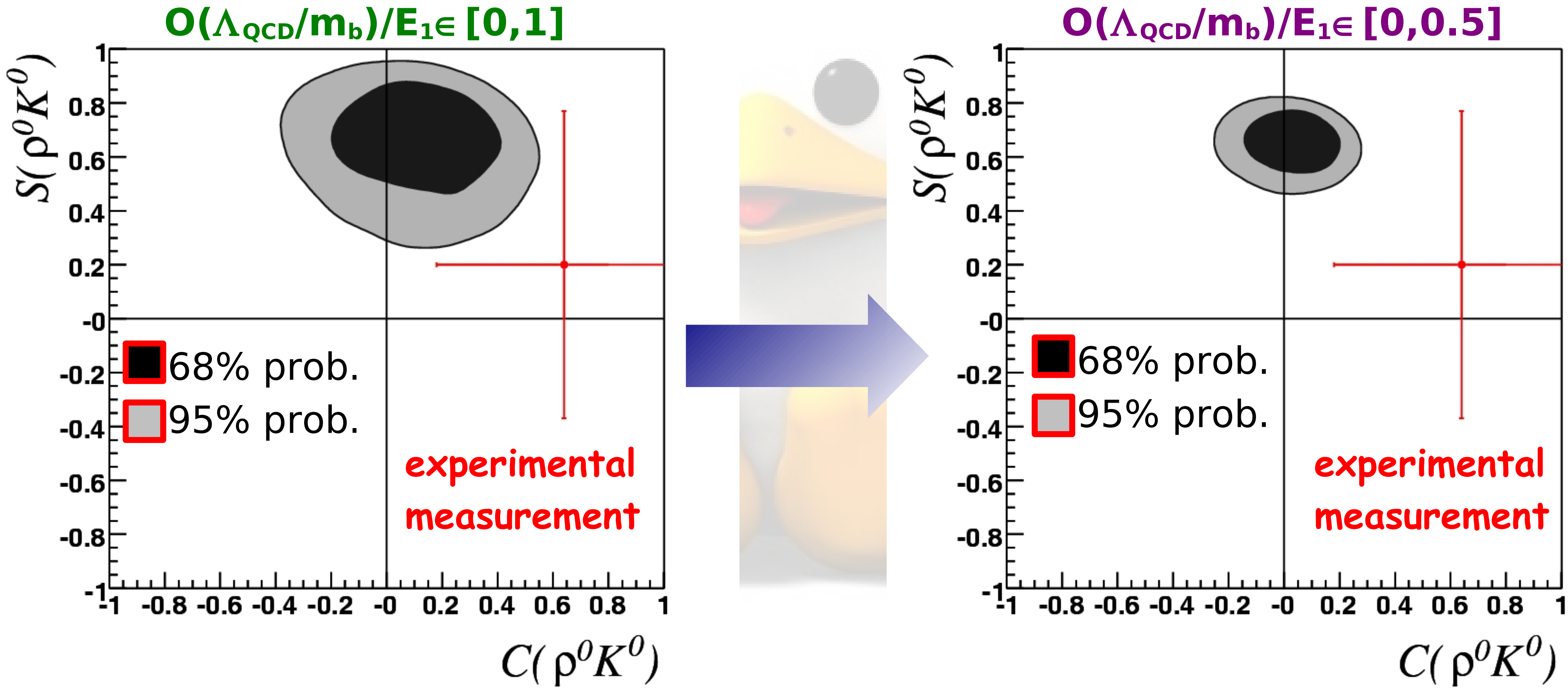
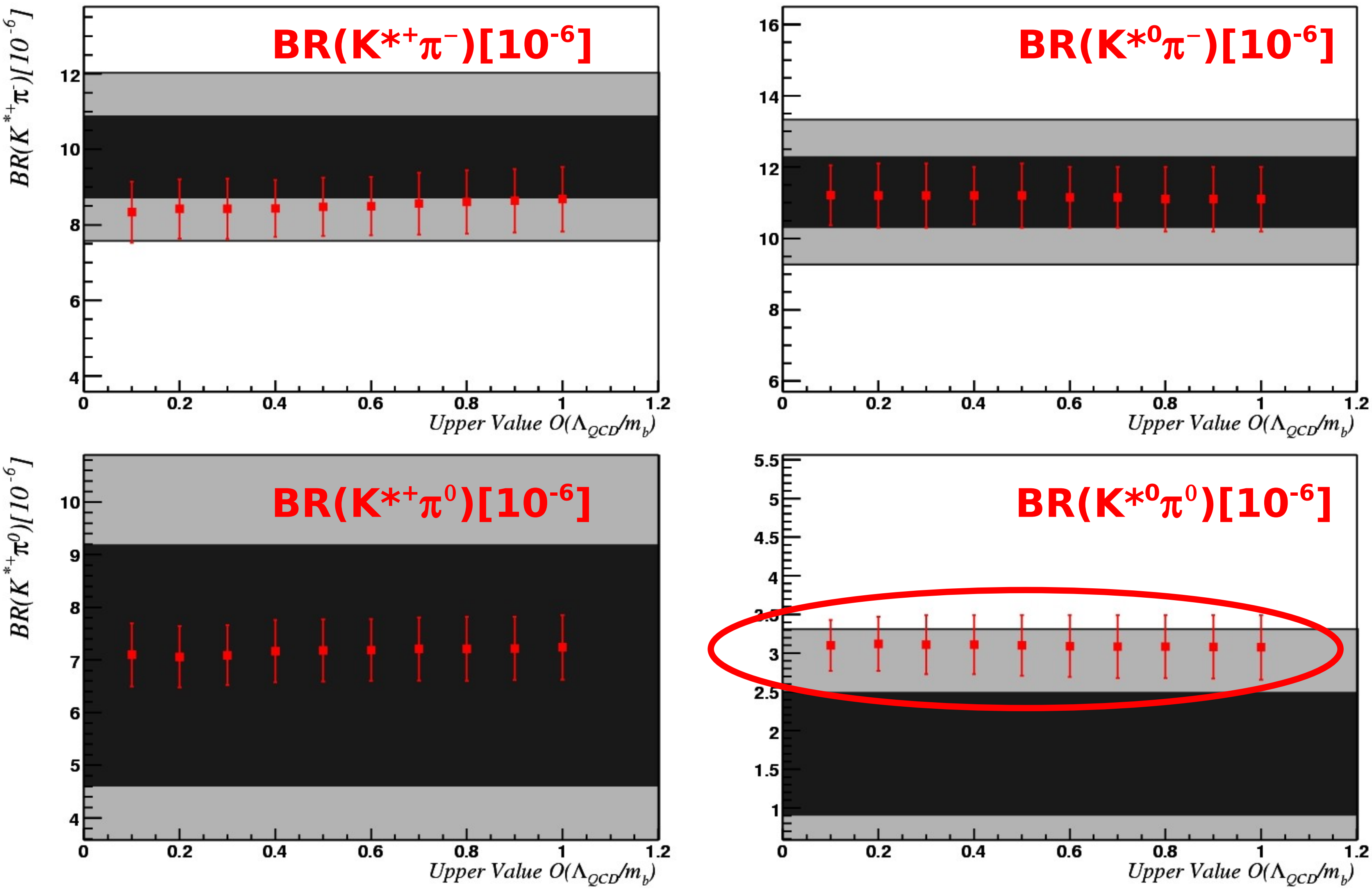
Test of SM: $S_{K\rho}$ vs $C_{K\rho}$

Since C is better determined by the fit than by the experiment, we have information on it from the other variables + SU(2) relations (all possible sum rules you can imagine are implemented). We can remove also C from the set of inputs and look at the agreement in the S vs C plane



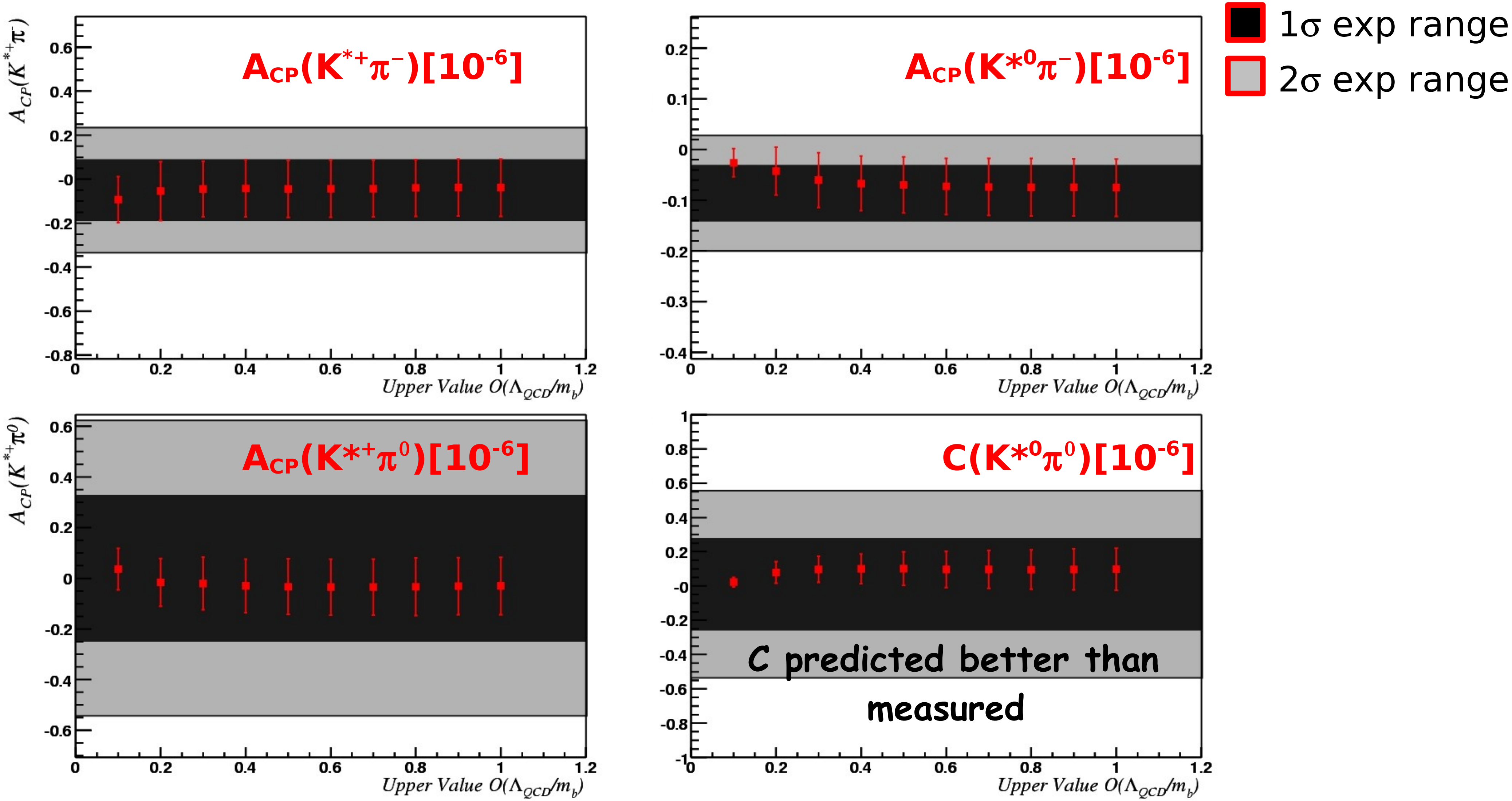
Result on B→K*π (I)

■ 1σ exp range
■ 2σ exp range

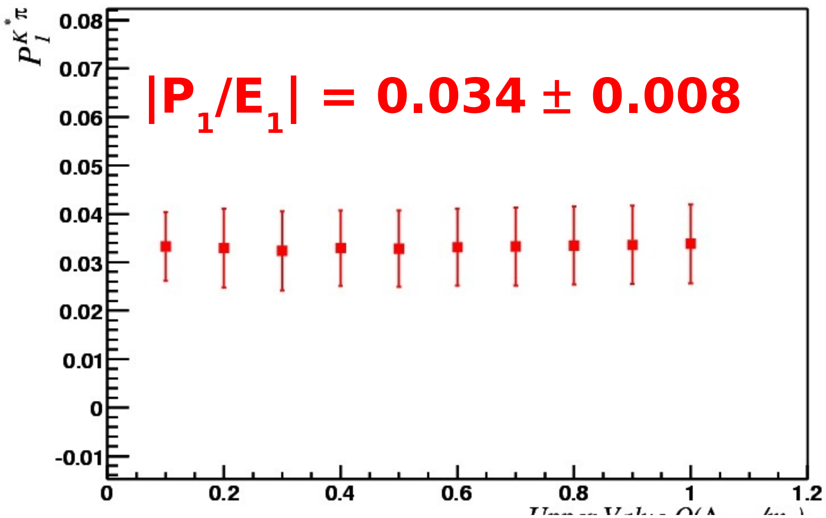


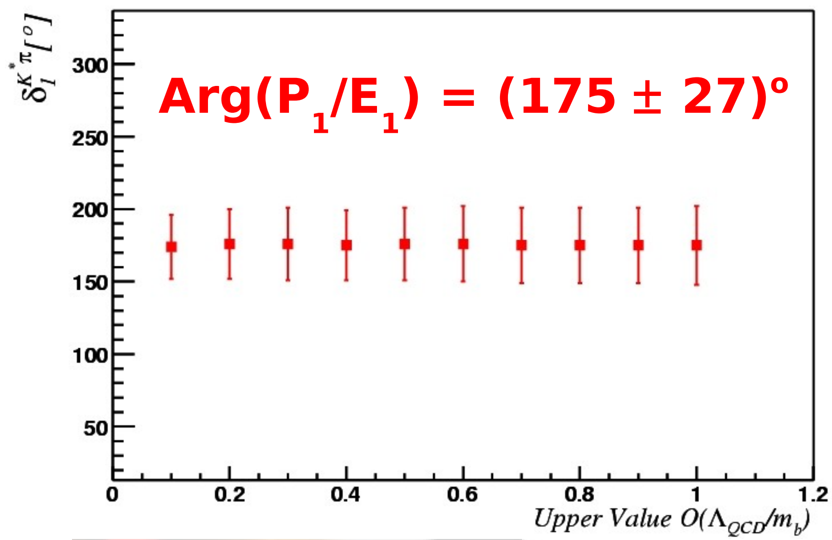
Exp average
of ~3 from BaBar
and ~0 from Belle

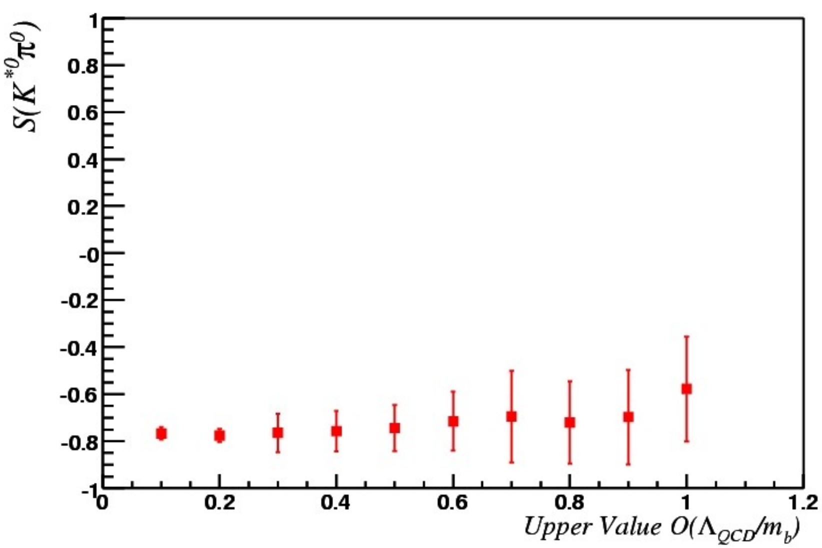
Result on B→K*π (II)



Result on B→K*π (III)







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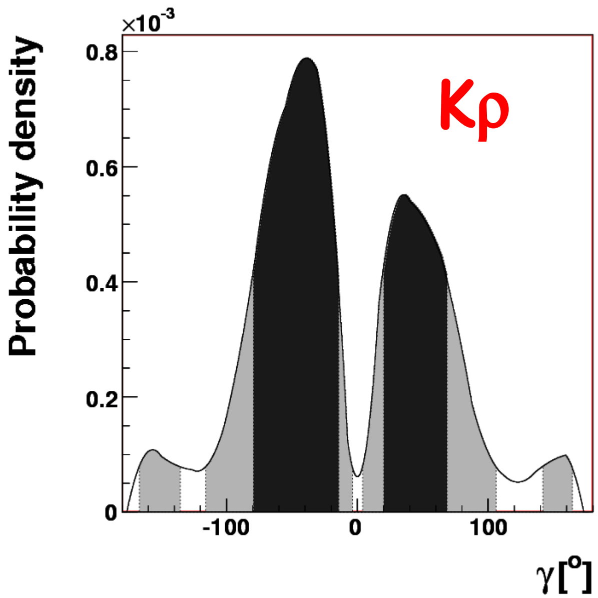
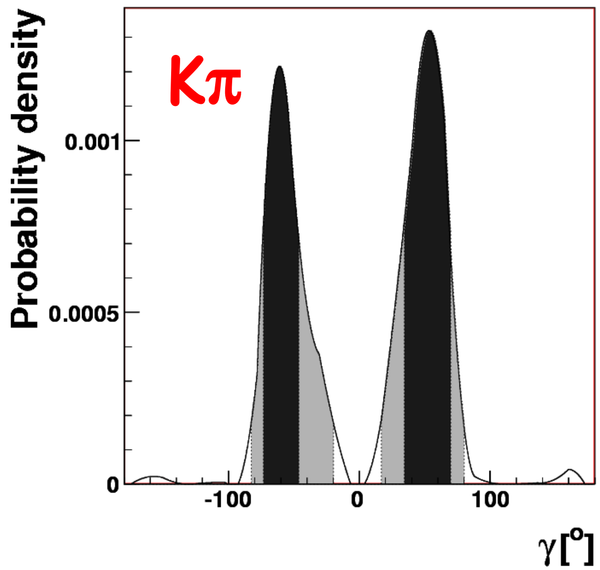
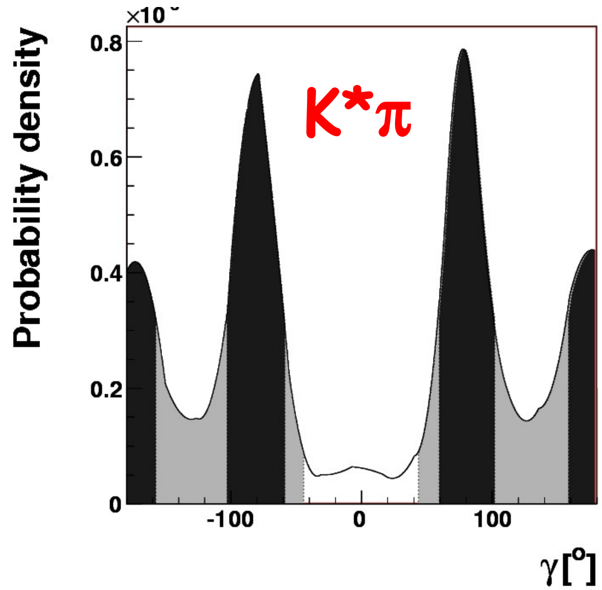
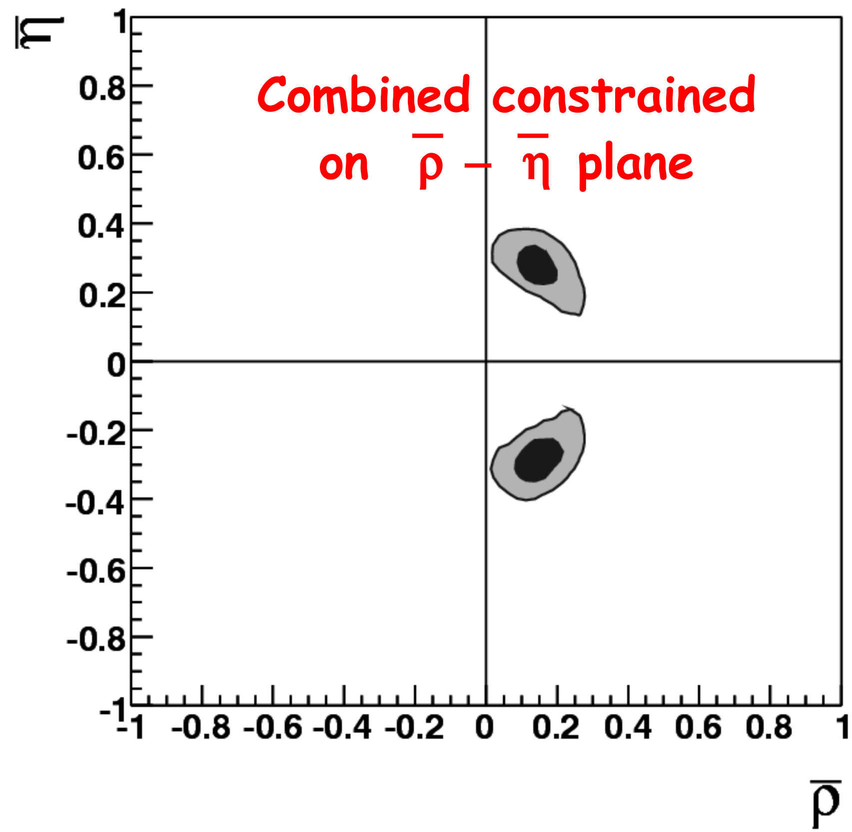
Determination of γ with UL@1.0

Remove the input information on $\bar{\rho}$ and $\bar{\eta}$ and fit for them using all BR and direct A_{CP}

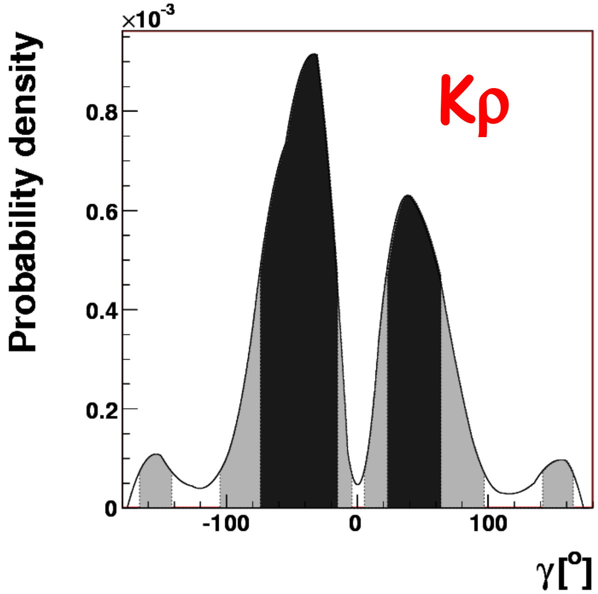


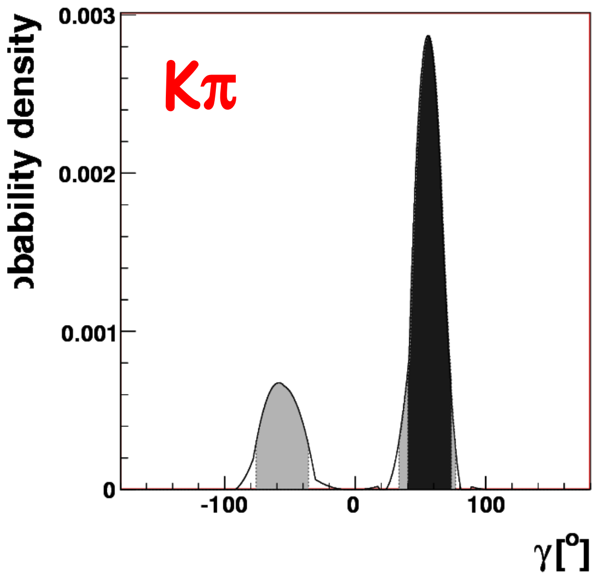


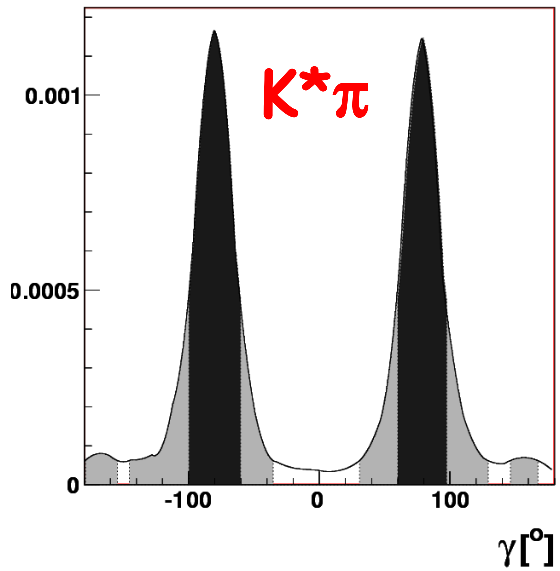


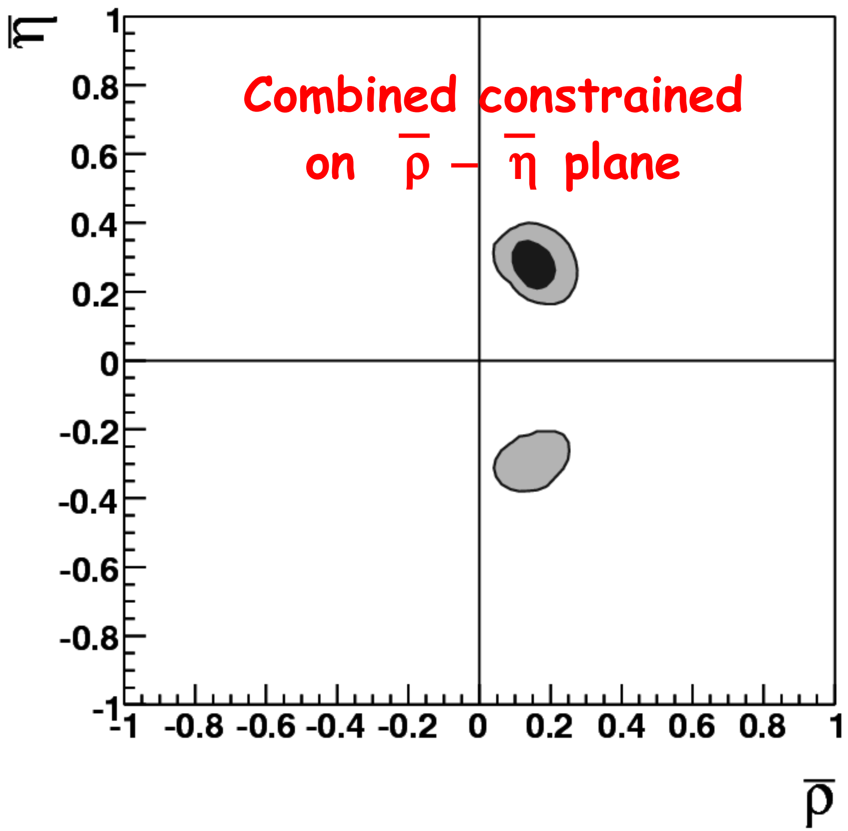


Determination of γ with UL@0.5

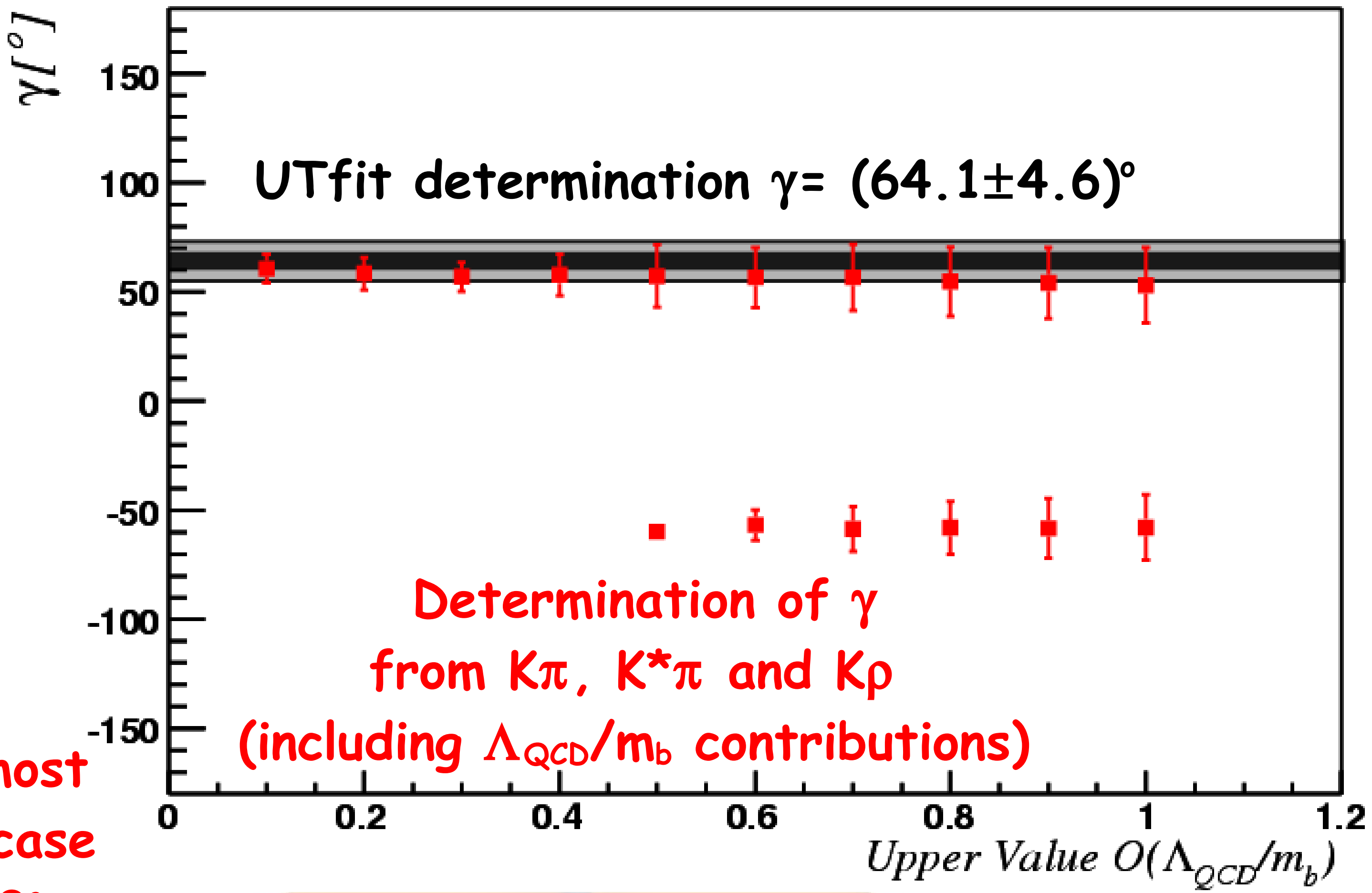








γ as a function of the UL



Even in the most conservative case we have a 10° determination of γ from charmless B decays

$\gamma = (-65 \pm 12)^o \cup (63 \pm 9)^o$ for UL@1.0

$\gamma = (-61 \pm 3)^o \cup (60 \pm 10)^o$ for UL@0.5

Conclusions

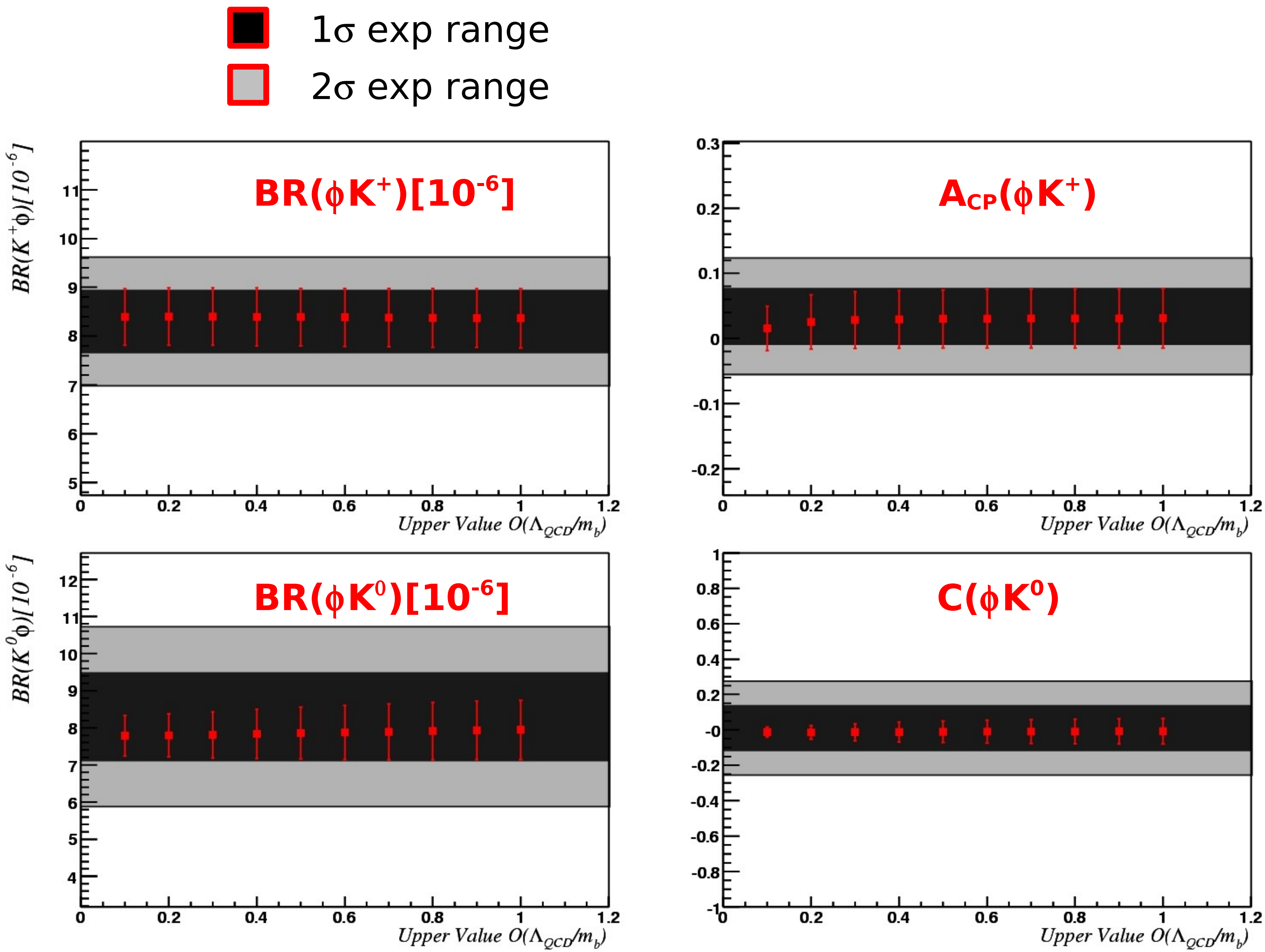
- The zoology of $b \to s$ transitions looks more rich that a land full of trees and charming penguins
- The perturbative calculations can describe the main features of the decays but additional effort is needed to match the experimental precision
- We are not sensitive yet to Λ_{QCD}/m_b CKM suppressed corrections, which have impact on the prediction of S in NP sensitive modes
- We can still obtain some information from data, but the upper value of the allowed range is needed as external input
  - too low values produce deviation from data ($A_{CP}(K^+\pi^0)$)
  - UV~1 (ignoring Λ_{QCD}/m_b hierarchy) reduces predictive power
- Still, experimental measurements of S are the limiting factor of a meaningful SM test
- With Λ_{QCD}/m_b in [0.0,0.5]E_1
  - Good agreement with data
  - Confirmed by $B \to KK$ data (no CKM suppression)

See backup slides (or ask)for ϕK, ηK, ωK and $B_s \to KK$

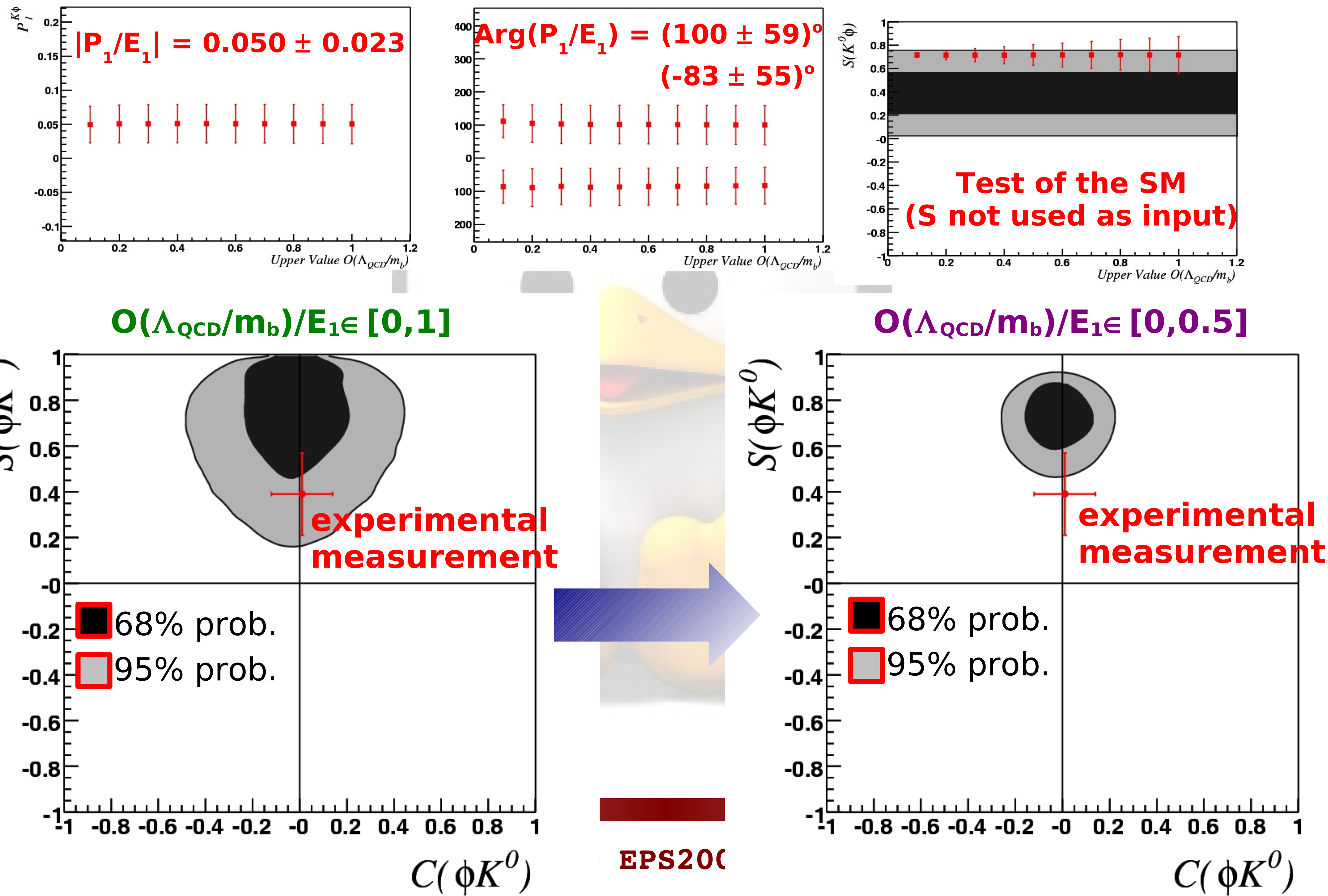
In this picture, $S(K^0\pi^0)$ emerges as the most predictive test of the SM

Backup Slides

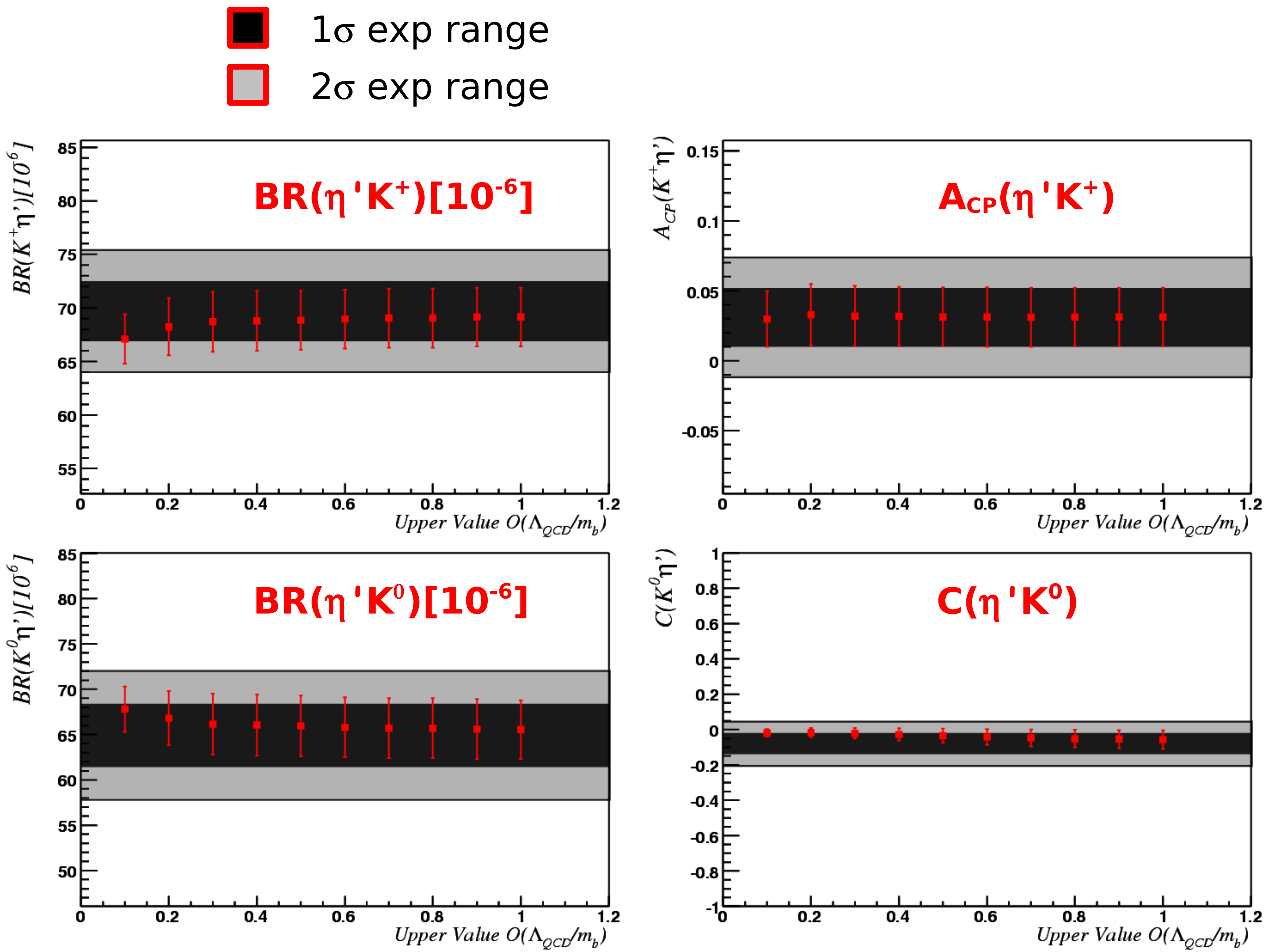
Result on $B \to \phi K$ (I)



Result on B→φK (II)



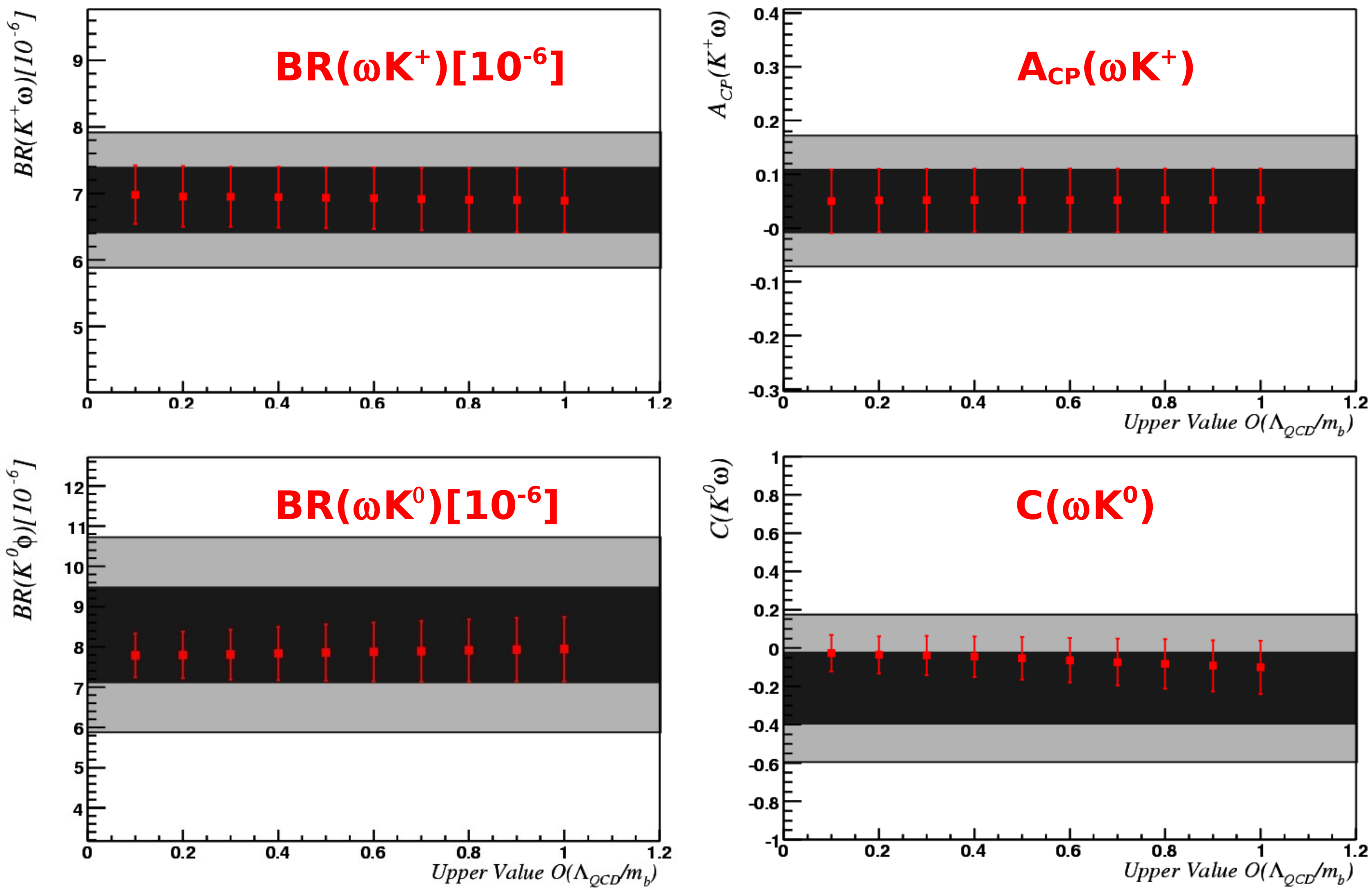
Result on B→η'K and B→ωK (I)



Result on B→η'K and B→ωK (II)

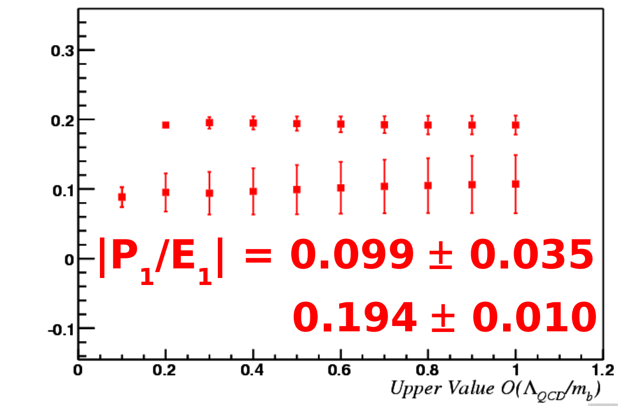
1σ exp range

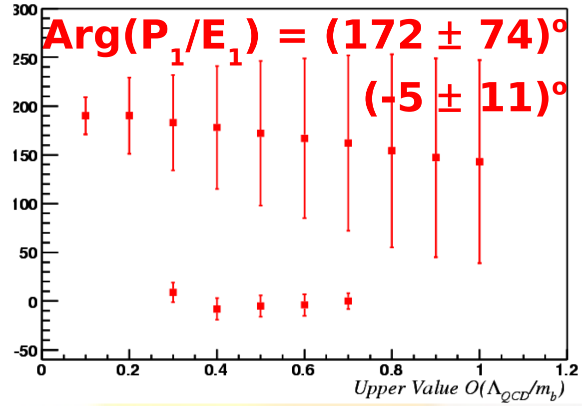
2σ exp range

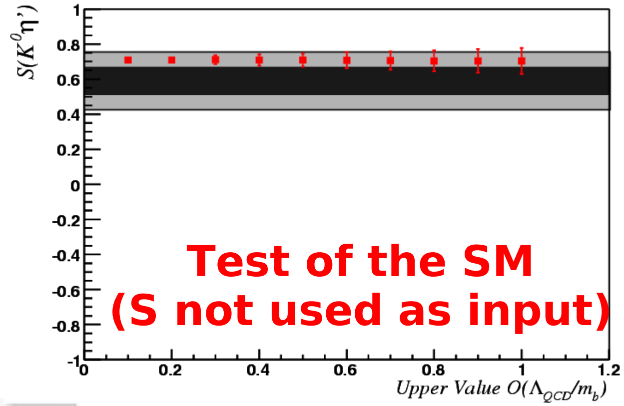


Result on B→η'K and B→ωK (III)

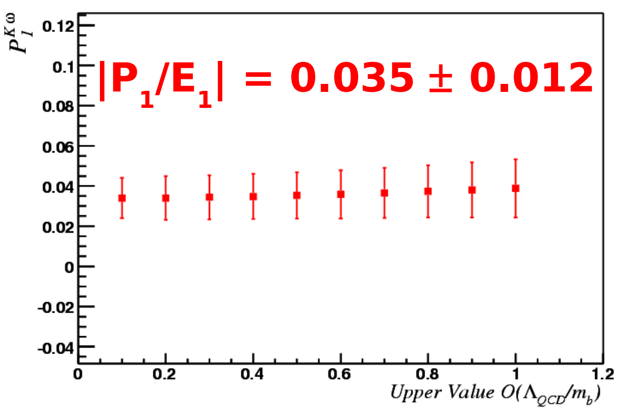
B→η'K

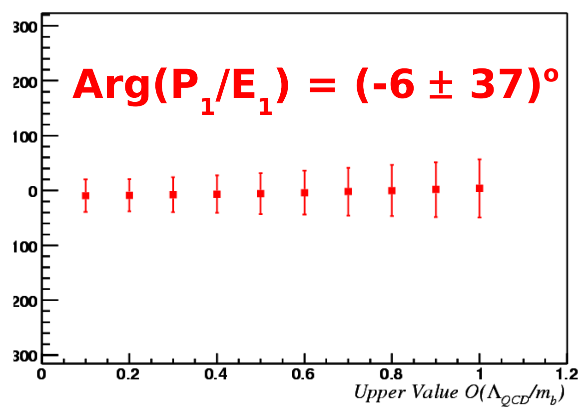


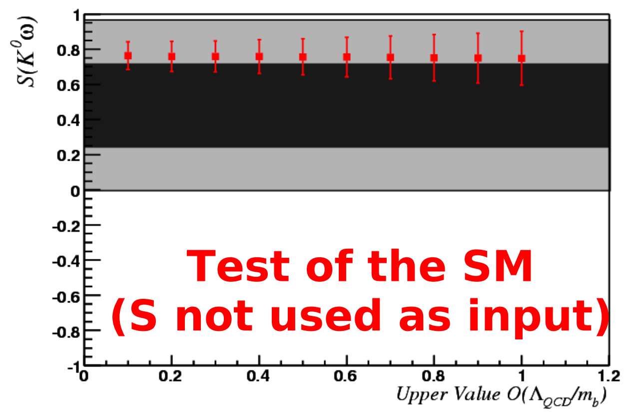




B→ω'K

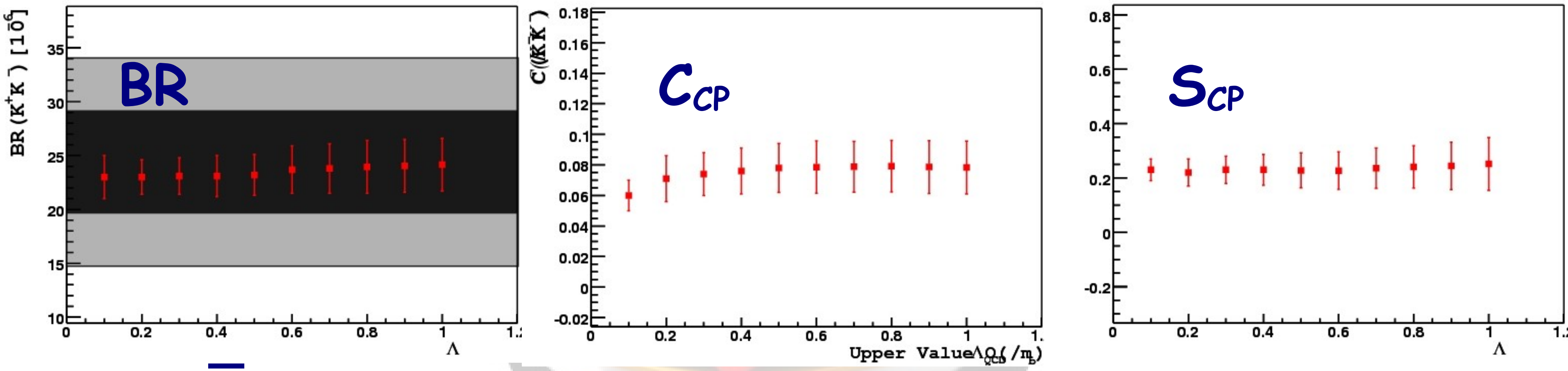






SU(3) Predictions on $B_s \to KK$

$B_s \to K^+K^-$



$B_s \to K^0\overline{K}^0$