Charmless B-decays
& the scalar sector of QCD

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CONTENTS

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INTRODUCTORY REMARKS

- $B \longrightarrow \sigma\pi$ is an important "hadronic pollution" for the extraction of α from $B \longrightarrow \rho\pi$

A. Deandrea and A. D. Polosa, Phys. Rev. Lett. **86** (2001) 216 [arXiv:hep-ph/0008084]

S. Gardner and UGM, Phys. Rev. D **65** (2002) 094004 [arXiv:hep-ph/0112281]

J. Tandean and S. Gardner, Phys. Rev. D **66** (2002) 034019 [arXiv:hep-ph/0204147]

- Long distance effects in $B \longrightarrow 3P$ are linked to the scalar sector of QCD

A. Furman, R. Kaminski, L. Lesniak and B. Loiseau, Phys. Lett. B **622** (2005) 207 [arXiv:hep-ph/0504116]

H. Y. Cheng, C. K. Chua and K. C. Yang, Phys. Rev. D **73** (2006) 014017 [arXiv:hep-ph/0508104]

- $B^0(\bar{B}^0) \longrightarrow f_0(980)K_S$ enters the determination of $\sin 2\beta$ from $b \longrightarrow s s \bar{s}$

Y. Grossman, Z. Ligeti, Y. Nir and H. Quinn, Phys. Rev. D **68** (2003) 015004 [arXiv:hep-ph/0303171]

M. Beneke, Phys. Lett. B **620** (2005) 143 [arXiv:hep-ph/0505075]

S. Gardner and R. Dutta, in preparation.

What is our present knowledge of these issues
and how can it be improved ?

SCALAR SECTOR of QCD

- Highly interesting: quark mass terms, σ–terms, vacuum quantum numbers, OZI
- Very strong Final State Interactions (for isospin zero)
  - ⋆ rapidly rising phase shift $\delta_0^0(s) \longrightarrow$ scalar mesons as PP composites
  - ⋆ scalar pion radius $\langle r_S^2 \rangle_\pi \simeq 0.6\,\mathrm{fm}^2 \gg$ vector radius $\langle r_V^2 \rangle_\pi \simeq 0.4\,\mathrm{fm}^2$
  - ⋆ . . .

Theoretical investigations using different tools (scalar ffs)

- ○ Chiral Perturbation Theory (CHPT) — Gasser, Leutwyler, UGM, Bijnens, Descotes, . . .
- ○ Chiral Unitary Approach — Oller, Oset, UGM, . . .
  resummation scheme consistent with CHPT, unitarity, analyticity, . . .
- ○ Dispersion relations (w/ or w/o low-energy constraints) — Au, Morgan, Pennington, Donoghue, Gasser, Leutwyler, Moussallam
- ○ Unitary Coupled Channel Model — Kaminski, Lesniak, Loiseau

$\Rightarrow$ Light scalar mesons dynamically generated

$\Rightarrow$ Consistent picture of the scalar (pion and kaon) form factors ?

SCALAR FORM FACTORS

- Definitions

$$\langle 0|n\bar{n}|\pi\pi\rangle = \sqrt{2}B_0\,\Gamma_1^n(s) \qquad \langle 0|n\bar{n}|\bar{K}K\rangle = \sqrt{2}B_0\,\Gamma_2^n(s)$$

$$\langle 0|s\bar{s}|\pi\pi\rangle = \sqrt{2}B_0\,\Gamma_1^s(s) \qquad \langle 0|s\bar{s}|\bar{K}K\rangle = \sqrt{2}B_0\,\Gamma_2^s(s)$$

with

$\star$ $B_0 = -\langle 0|\bar{q}q|0\rangle/F_\pi^2$

$\star$ $\bar{n}n = (\bar{u}u + \bar{d}d)/\sqrt{2}$

$\star$ index 1, 2 = pions, kaons

$\star$ $\sqrt{s}$ = cms energy

- Scalar form factors in the chiral unitary approach (suppress flavor index)

$$\boxed{\Gamma(s)_i = [I + K(s)\cdot g(s)]^{-1}_{ij}\cdot R(s)_j} \qquad (i,j = 1,2)$$

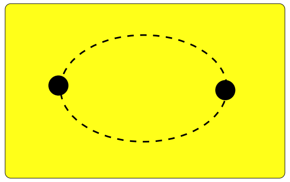
scattering amplitude from CHPT ↗

scalar loop integral ↑

vector of functions free of singularities ↖

coupled $\pi\pi/\bar{K}K$ channels

data well described $\surd$



$\rightarrow$ matching to CHPT very important!

SCALAR FORM FACTORS: RESULTS I

UGM and J. A. Oller, Nucl. Phys. A **679** (2001) 671 [arXiv:hep-ph/0005253]

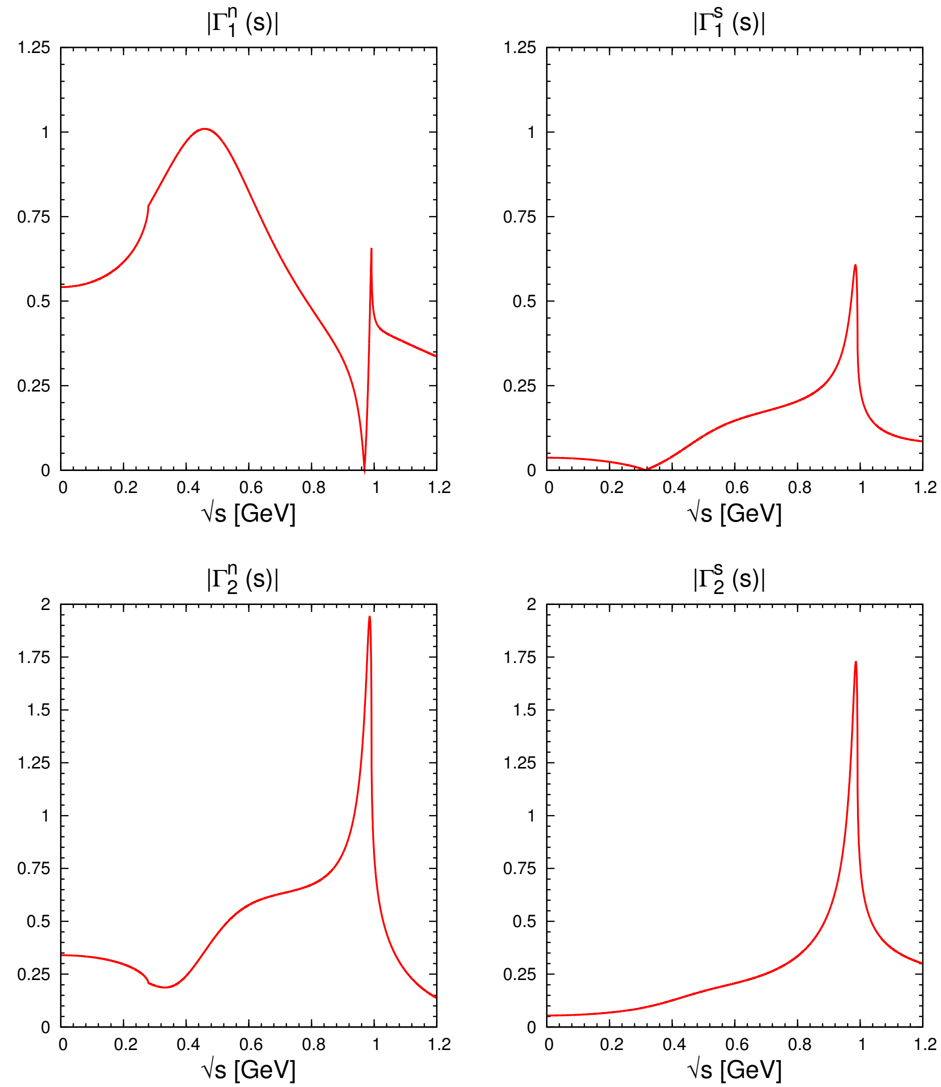
- cusp at the two-pion threshold in $\mathbf{\Gamma^n_{1,2}}$
- Broad structure reminiscent of the $\boldsymbol{\sigma}$ in $\mathbf{\Gamma^n_1}$ $\to$ archetype of a dynamically generated resonance

UGM, Comments Nucl. Part. Phys. **20** (1991) 119

I. Caprini, G. Colangelo and H. Leutwyler, arXiv:hep-ph/0512364

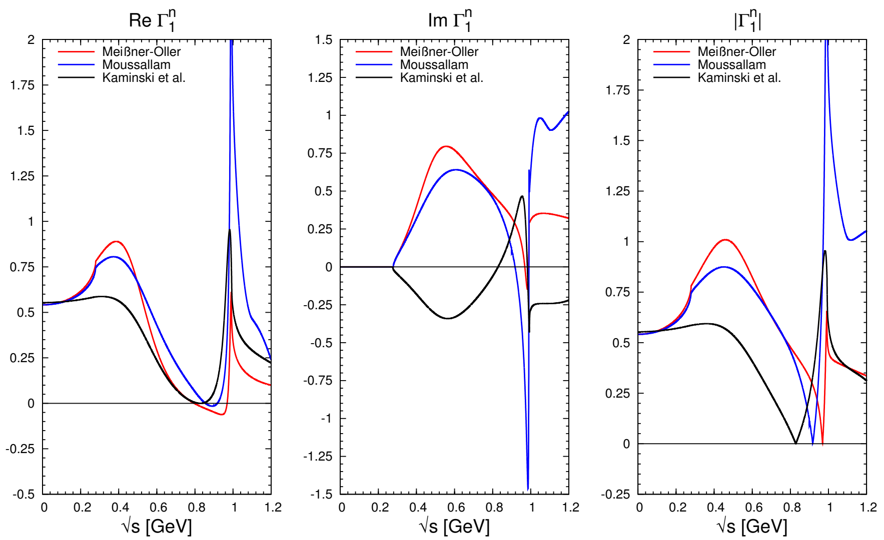
- $\boldsymbol{f_0(980)}$ clearly visible in all ffs $\to$ dominates all scalar ffs except $\mathbf{\Gamma^n_1}$
- can be matched to pQCD behaviour

$$\mathrm{Re}\,\Gamma^n_1(s) \to a/s, \quad s \to \infty$$
$$\mathrm{Im}\,\Gamma^n_1(s) \to b/s^2, \quad s \to \infty$$

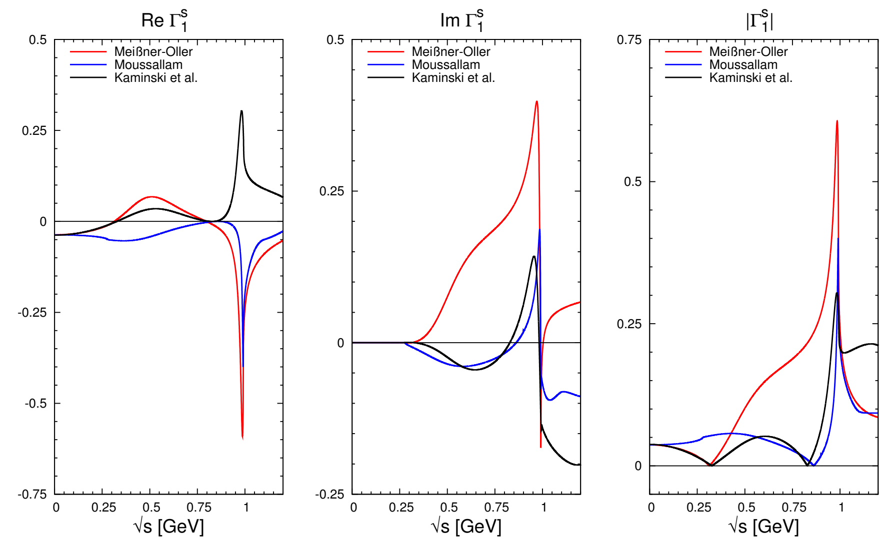


SCALAR FORM FACTORS: RESULTS II

- pion non-strange ff $\Gamma_1^n(s)$



- pion strange ff $\Gamma_1^s(s)$



$\longrightarrow$ similar, but diff. strength

$\longrightarrow$ MO very diff. from the others

NB: Normalization enforced to all ffs at $s \simeq 0 \longrightarrow$ CHPT

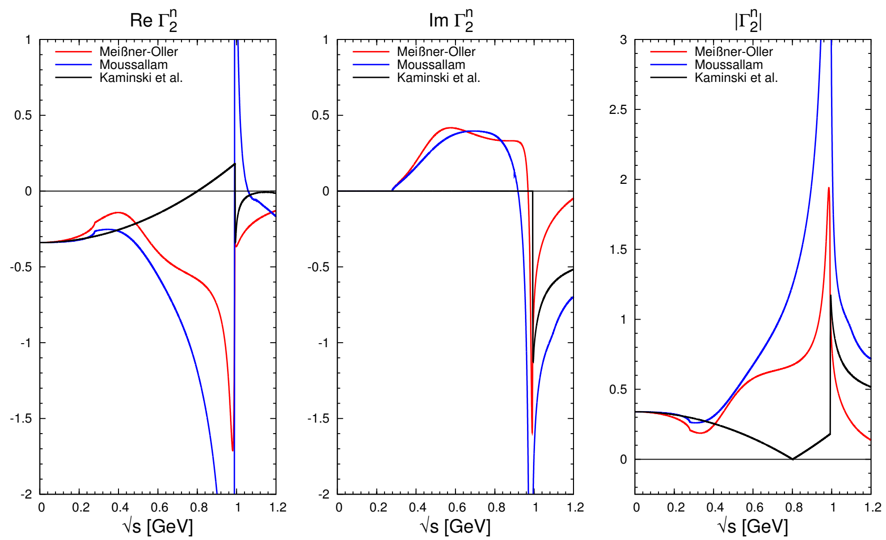
— M & Oller
— Moussallam
— Kaminski, Lesniak & Loiseau

B. Moussallam, Eur. Phys. J. C **14** (2000) 111 [arXiv:hep-ph/9909292]

R. Kaminski et al., Phys. Lett. B **413** (1997) 130 [arXiv:hep-ph/9707377]

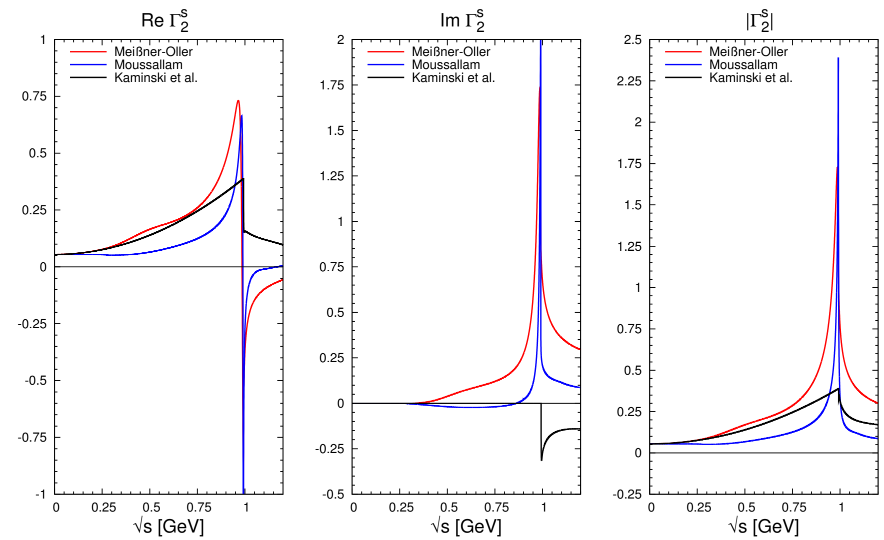
SCALAR FORM FACTORS: RESULTS III

- kaon non-strange ff $\Gamma_2^n(s)$



→ very diff. esp. around f_0

- kaon strange ff $\Gamma_2^s(s)$



→ MO ff most pronounced

NB: Normalization enforced to all ffs at $s \simeq 0 \rightarrow$ CHPT

— M & Oller
— Moussallam
— Kaminski, Lesniak & Loiseau

B. Moussallam, Eur. Phys. J. C **14** (2000) 111 [arXiv:hep-ph/9909292]

R. Kaminski et al., Phys. Lett. B **413** (1997) 130 [arXiv:hep-ph/9707377]

A FIRST TEST: $J/\psi \to \phi\pi\pi/\bar{K}K$

D. Morgan and M.R. Pennington, Phys. Rev. D **3** (1993) 1185; UGM and J. A. Oller, Nucl. Phys. A **679** (2001) 671 [arXiv:hep-ph/0005253]

- OZI and doubly OZI suppressed
  $\rightarrow$ very sensitive to the scalar sector of QCD

- data from DM2, MARK-III and BES-II

$\rightarrow$ exp. facts: ϕ is a spectator, S-wave dominant

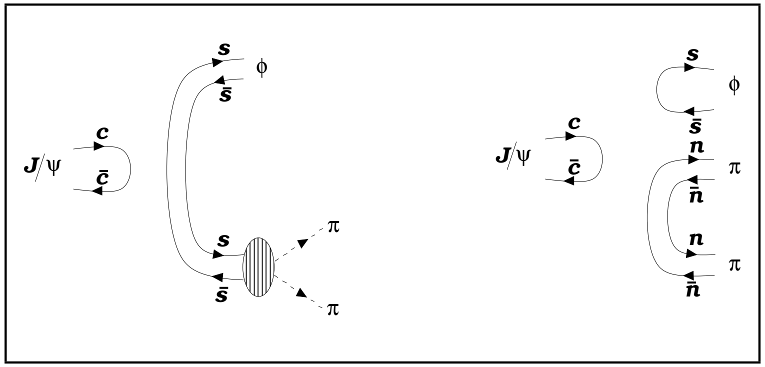
- effective Lagrangian and T-matrix:

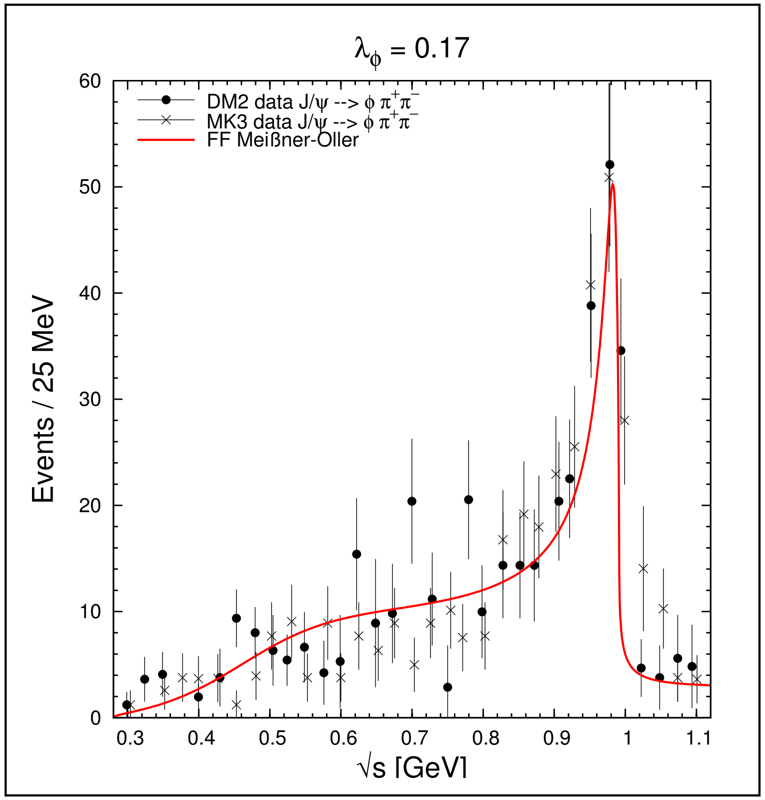
$$\mathcal{L} = g\,\bar{\psi}_\mu\,\phi^\mu\,S$$
$$S = \bar{s}s + \lambda_\phi\,\bar{n}n$$
$$T = \varepsilon(\psi,\rho)_\mu\varepsilon(\phi,\rho')^\mu\;\underbrace{\langle 0|\bar{s}s + \lambda_\phi\,\bar{n}n|\bar{P}P\rangle}_{\text{scalar ffs}}$$

- good description of $J/\psi \to V\pi\pi/\bar{K}K$ with

$$\lambda_\phi = 0.17 \pm 0.06$$

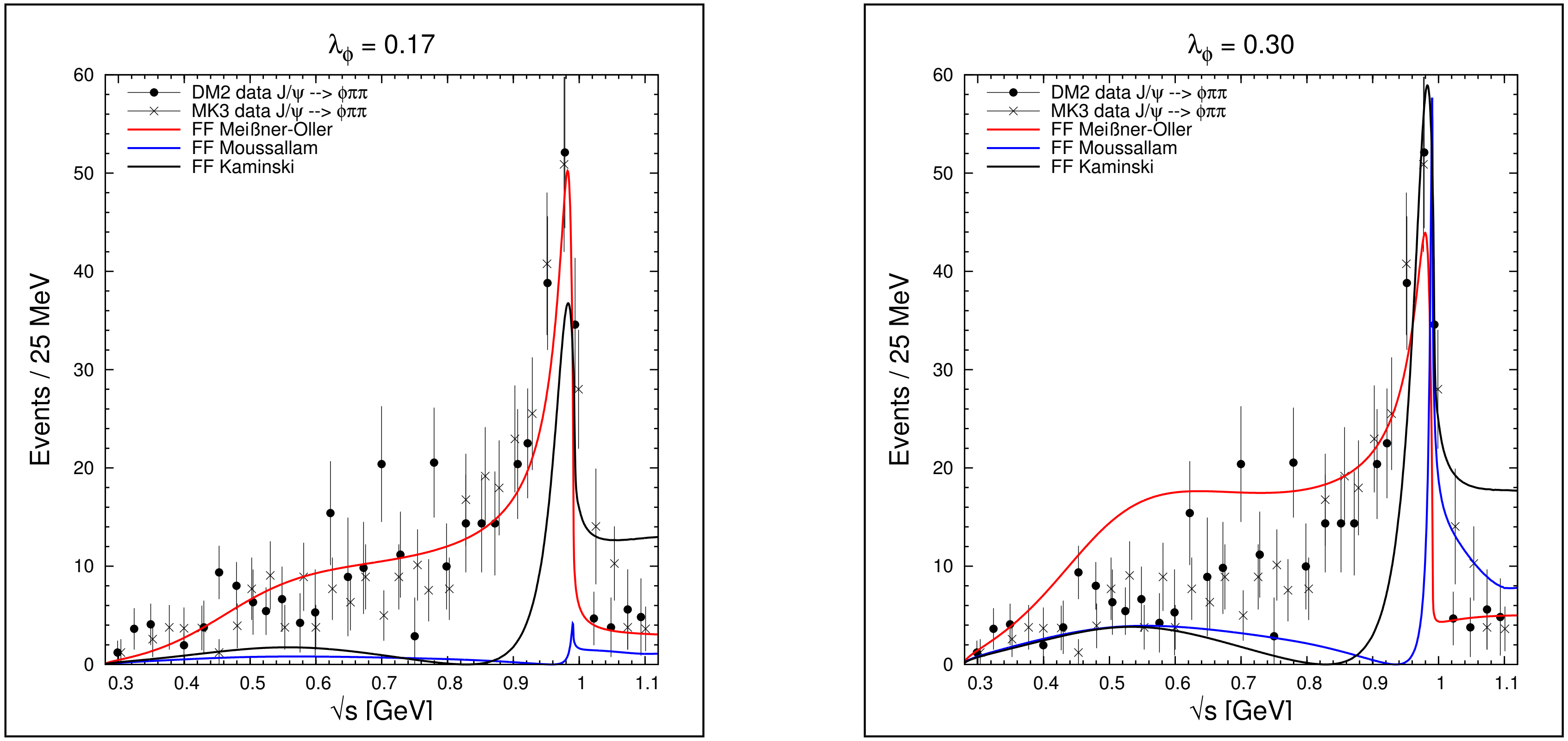
& $L_4^r = 0.44\cdot 10^{-3}$, $L_6^r = -0.38\cdot 10^{-3}$ $\quad(\mu = 1.1\,\mathrm{GeV})$





MORE on $J/\psi \to \phi\pi\pi/\bar{K}K$

- How do these results depend on the choice of scalar ffs?

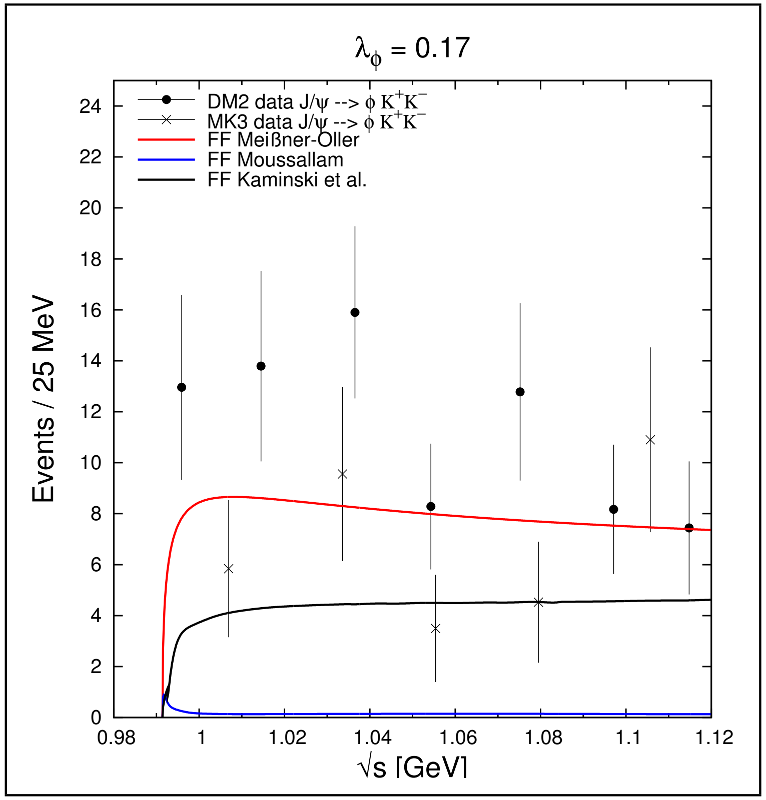


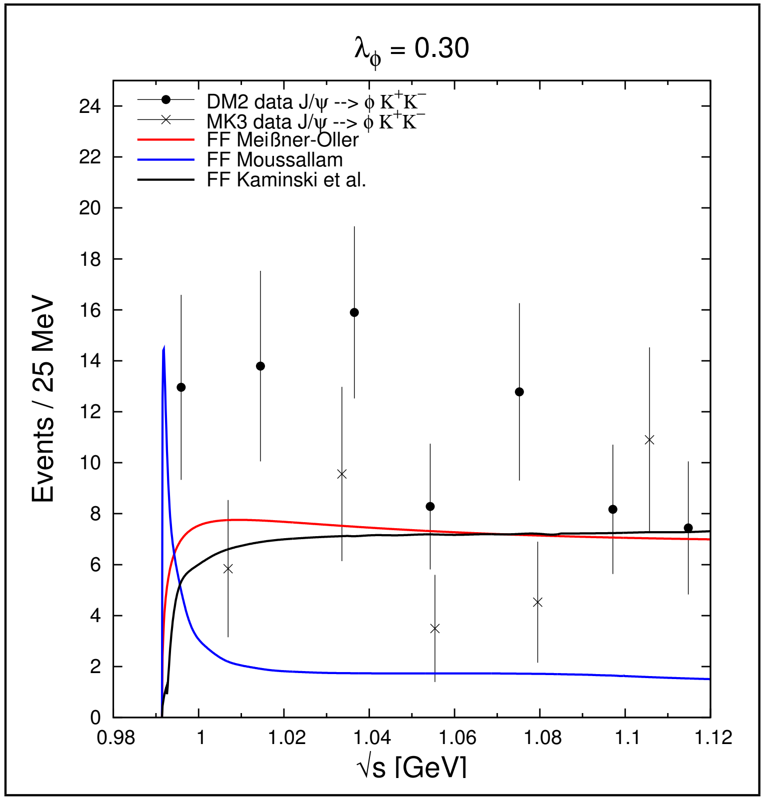
$\Rightarrow$ M and KLL ffs require larger coupling to the strangeness channel

$\Rightarrow$ M and KLL ffs exhibit too few strength on the left wing of the f_0

MORE on $J/\psi \to \phi\pi\pi/\bar{K}K$

- Consider now $J/\psi \to \phi K\bar{K}$

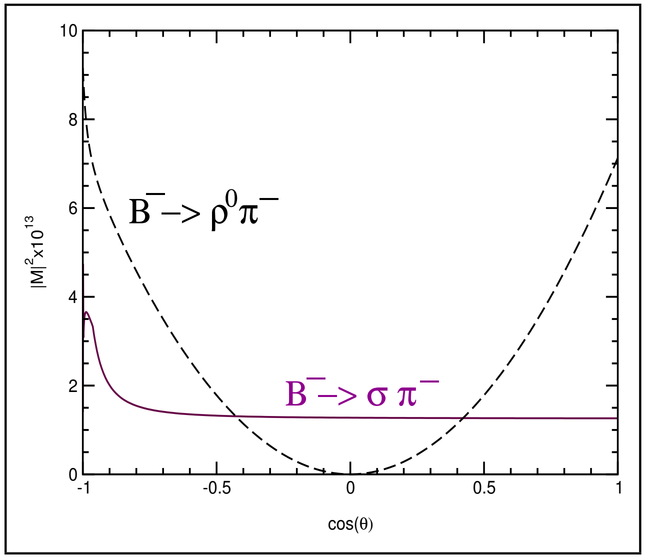




$\Rightarrow$ M and KLL ffs require larger coupling to the strangeness channel

$\Rightarrow$ M ffs show strong destructive interference on the right wing of the f_0

REMARKS on $B \to \sigma\pi$



- $B \to \sigma\pi$ is sensitive to $\Gamma_1^n(s)$

  $\to$ can not be approximated by a BW form !

- $B \to \sigma\pi$ has a large influence on

$$\mathcal{R} = \frac{\mathrm{Br}(\bar{B}^0 \to \rho^\mp \pi^\pm)}{\mathrm{Br}(B^- \to \rho^0 \pi^-)} = 2.8 \pm 0.9$$

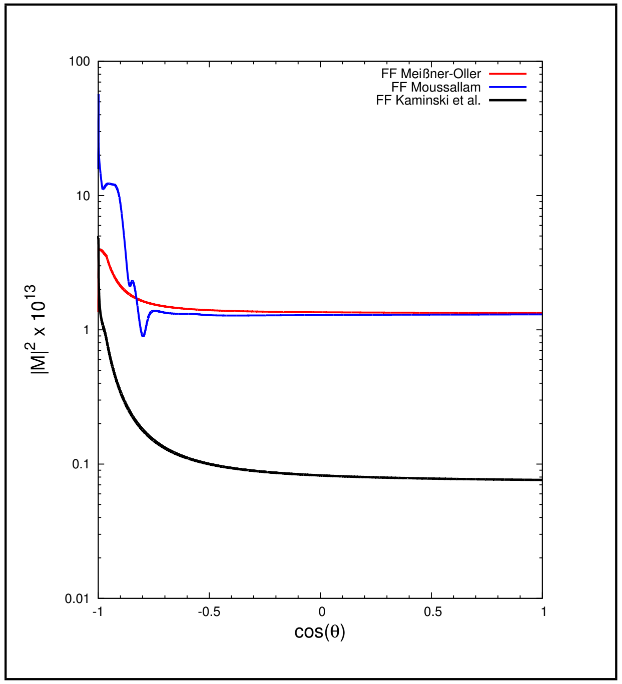
prediction by Gardner & M: $\mathcal{R} = 2.0 \ldots 2.6$

& influences the Dalitz-plot of $B \to \rho\pi$

$\to$ most pronounced in $B^- \to \rho^0\pi^- / \sigma\pi^-$

$\to$ cut for $\cos(\theta) \le -0.8$

Gardner and UGM, Phys. Rev. D **65** (2002) 094004



- dependence on the form of $\Gamma_1^n(s)$:

  $\star$ MO and M form factor lead to similar result

  $\star$ KLL form factor has too few strength

  [ff zero close to $s = M_\rho^2$]

$\Rightarrow$ FSI in this channel under control

$B \to K\pi\pi$: FORMALISM

- Employ the slightly modified formalism of Furman et al. (FKLL):

  QCD factorization + long-distance effects (scalar ffs) [+ charming penguins]

A. Furman, R. Kaminski, L. Lesniak and B. Loiseau, Phys. Lett. B **622** (2005) 207 [arXiv:hep-ph/0504116]

(see also recent work by Dutta and Gardner)

$$\langle(\pi^+\pi^-)_S K_S^0|\mathcal{H}_{\rm eff}|B^0\rangle = \frac{G_F}{\sqrt{2}}\sqrt{\frac{2}{3}}\,\chi\left\{\Big[P(M_{\pi\pi})U + C(M_{\pi\pi})\Big]\,\Gamma_1^{n*}(M_{\pi\pi}) + \Big[Q(M_{f_0})V + C(M_K)\Big]\,\Gamma_1^{s*}(M_{\pi\pi})\right\}$$

with $Q = \frac{2\tilde{f}M_{f_0}}{m_b - m_s}(M_B^2 - M_K^2)F_0^{B\to K}(M_{f_0}^2)$

since $\underbrace{B_0}_{\rm FKLL} \to \underbrace{\chi\langle f_0|\bar{s}s|0\rangle = \chi\tilde{f}M_{f_0}}_{\rm LM}$ w/ $\tilde{f} = 0.33$ GeV

⋆ U, V, P, C as in FKLL — U, V contain the short-distance coeffs & $V_{\rm CKM}$

N. de Groot, W.N. Cottingham and I.B. Whittigham, Phys. Rev. D **68** (2003) 113005

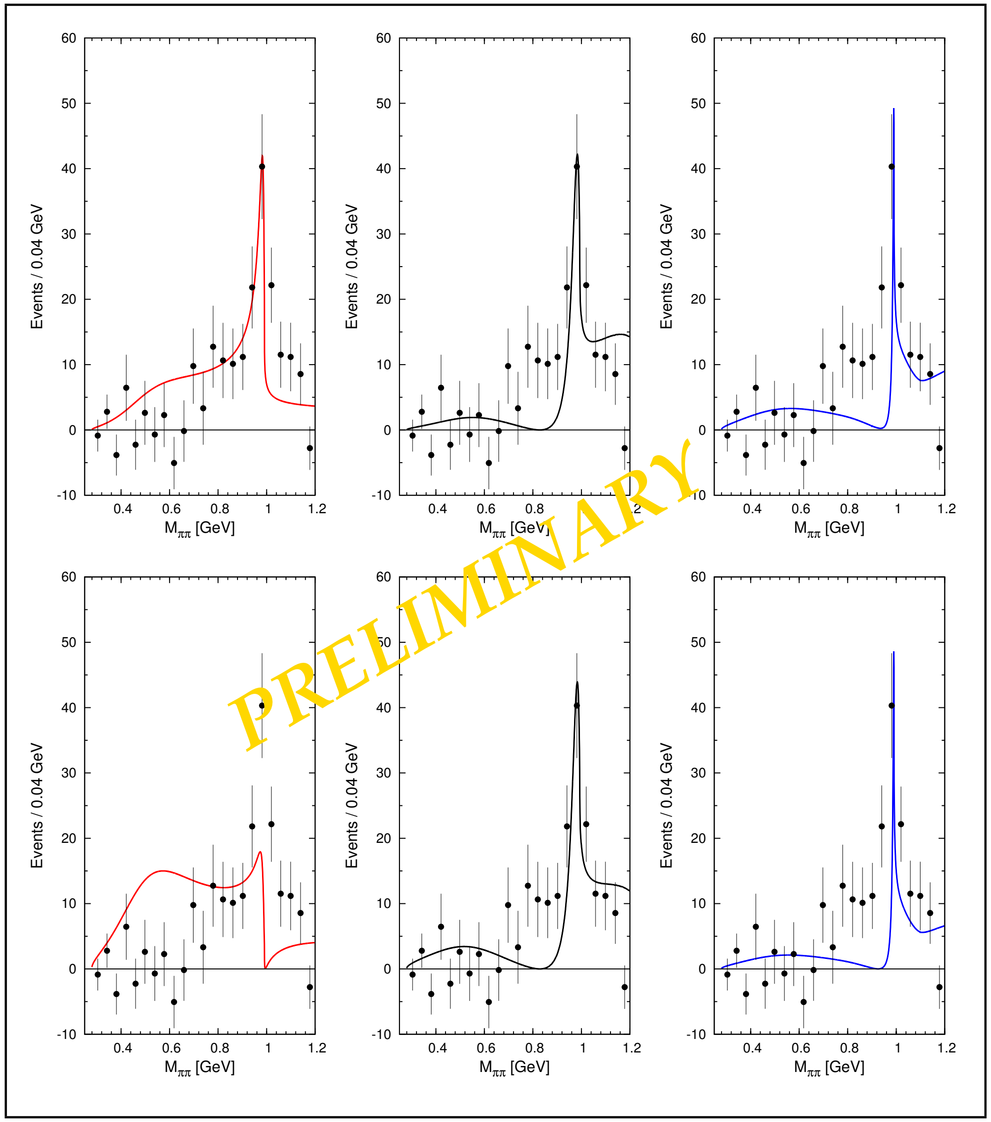
⋆ charming penguins C subject to discussion

⋆ overall normalization χ - coupling of the scalar source process–dependent (see G. & M.)

RESULTS for $B^0 \to K^0_S \pi^+ \pi^-$

- Compare to the BELLE data

K.-F. Chen et al. (Belle Coll.), Phys. Rev. D **72** (2005) 012004



⋆ w/o charming penguins

– MO ffs generate strength on the left wing from pronounced Γ_1^s

– KLL and M ffs lead to similar results less strength on the left wing

⋆ w/ charming penguins: trouble

– MO ffs show too much strength on the left wing: too much Γ_1^s contr.

– KLL and M ffs lead to similar results

Note: Normalization adjusted!

RESULTS for $B^0 \to K_S^0 \pi^+ \pi^-$

- Compare to the BaBar data

  ⋆ w/o charming penguins

  – f_0 peak described by all ffs

  – FKLL ffs look best

  ⋆ w/ charming penguins: trouble

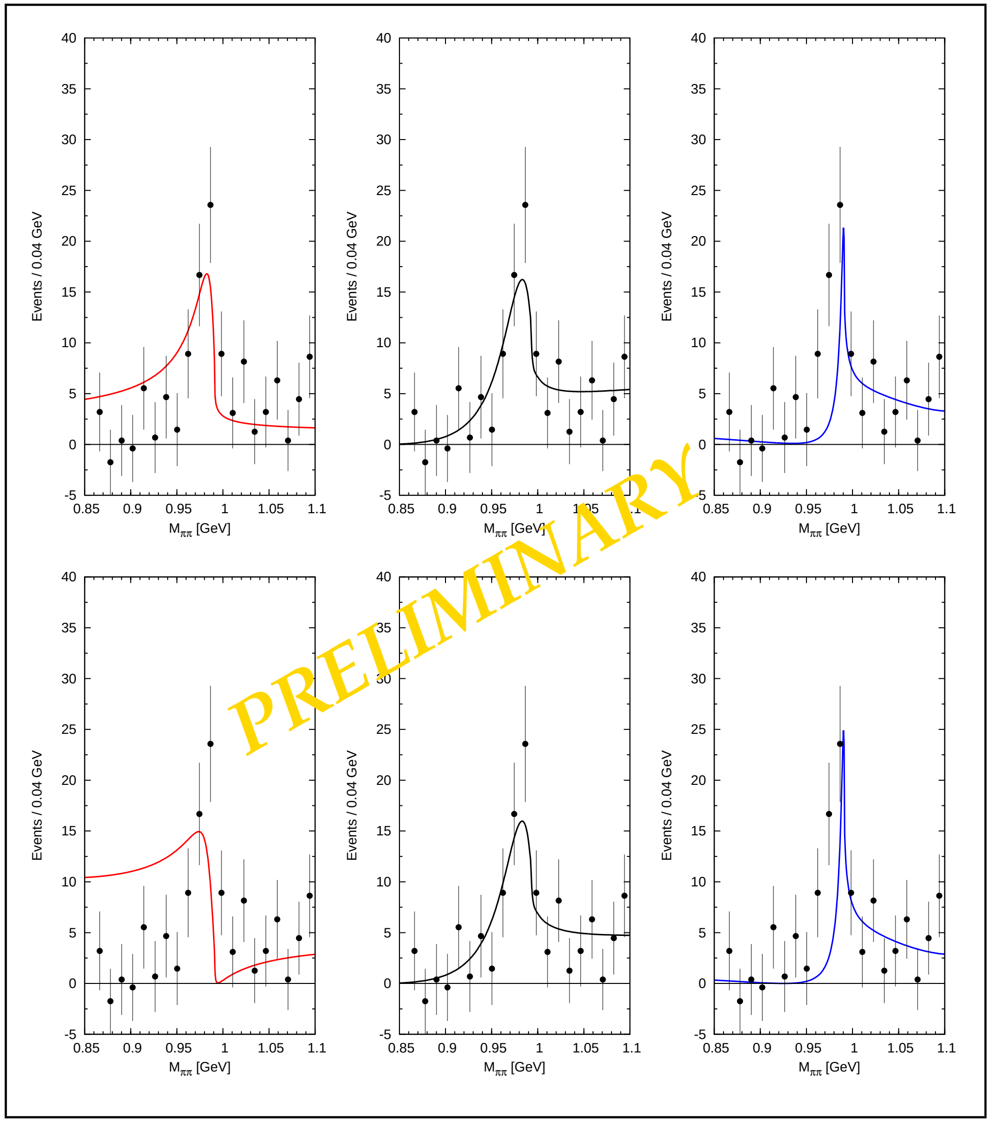
  – MO ffs: too much strength from Γ_1^s below the f_0 peak

  – FKLL/M ffs good/fine, but . . .

  Note 1: Background subtracted

  Note 2: Normalization adjusted!

B. Aubert et al. (BaBar Coll.), Phys. Rev. Lett. **94** (2005) 041802



SUMMARY & OUTLOOK

- Scalar sector of QCD leaves its imprints in heavy quark physics, e.g. charmless B-decays
- Scalar form factors play a crucial role - many reactions must be considered
- Specific examples
  - $J/\psi \longrightarrow \phi\,(\omega)\;\pi\pi/\bar{K}K$ decays and OZI violation
  - Hadronic "pollution" from $B \longrightarrow \sigma\pi$ to $B \longrightarrow \rho\pi$ is under control
  - $B \longrightarrow K\pi\pi$ sensitive to the precise form of scalar ffs
  - $B \longrightarrow K\pi\pi$ sensitive to charming penguins → at odds with scalar ffs à la MO
- To be done:
  - better determination of $\Gamma_1^s(s)$?
  - scalar ffs beyond the $f_0(980)$ peak
  - parameter scans in $B \longrightarrow K\pi\pi$, $B \longrightarrow K\bar{K}K$, etc.