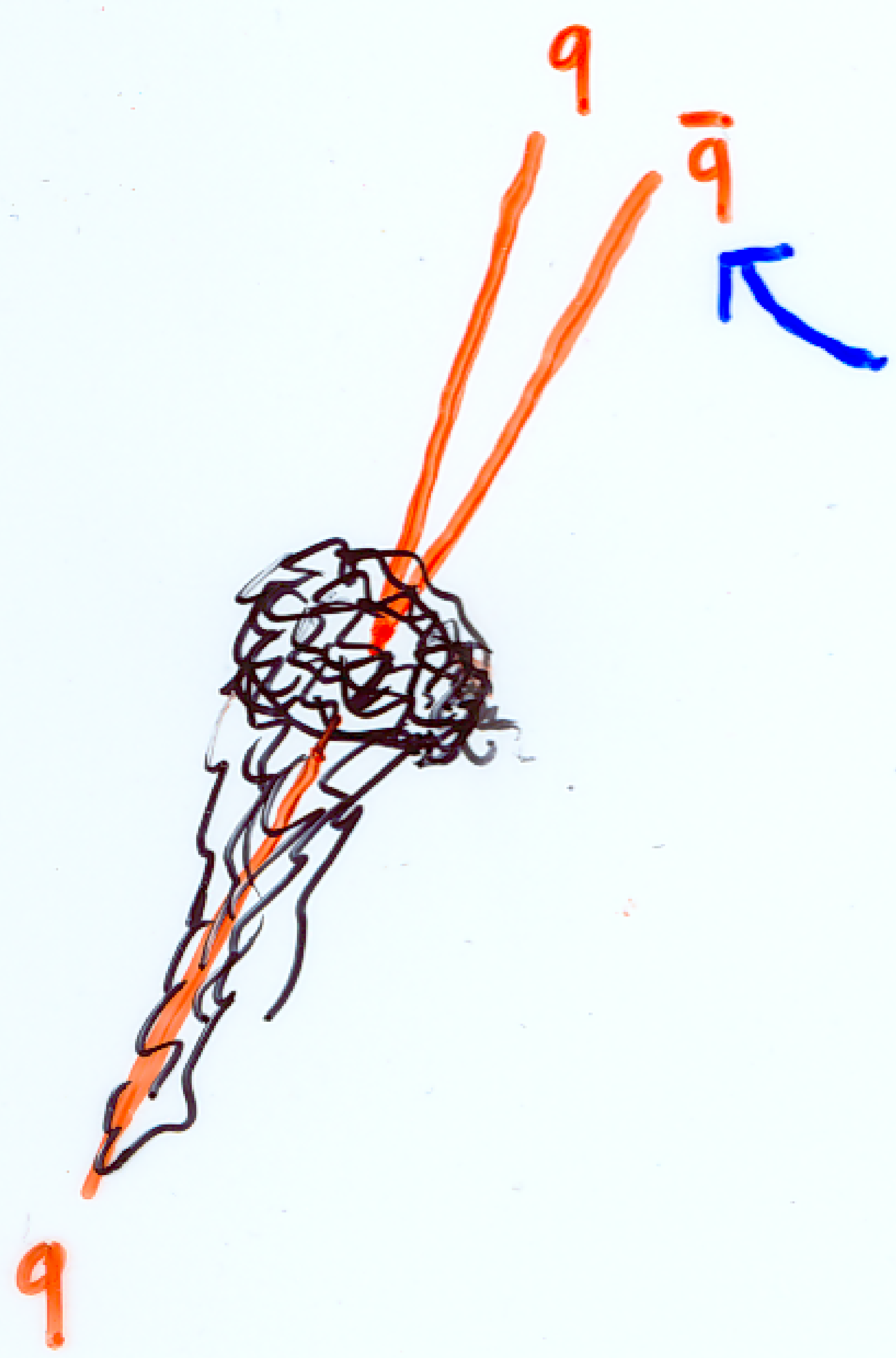
Quasi-Two-Body and Three-Body B Decays in the Heavy Quark Expansion / Factorization / Effective Theory

M. Beneke
3-Body Charmless Workshop
Paris, 2 Feb 2006

1) Factorization
2) $B \to PV$ status
3) What do we learn from $B \to PV$ (VV)?
4) Remarks on $B \to PPP$ in factorization / effective theory

Factorization works at leading order in Λ/m_b
(and to all orders in α_s , probably), because:

$\bar{B}$ 



energetic, low-invariant mass, colour-singlet
($\rightarrow$ compact)
escapes soft $\bar{B}$ remnant and hadronizes far away due to time-dilatation factor $\gamma \sim E/\Lambda \sim m_B/\Lambda$

independent of what $(q\bar{q})$ and q+ remnant hadronize into

Factorization formula (MB, Buchalla, Neubert, Sachrajda)

$$A(\bar{B} \to M_1 M_2) = F^{BM_1}_{(0)} \cdot \int_0^1 du\, \phi_{M_2(u)}\, T^{I}_{(u)}$$

$$+ \int_0^1 dz \int_0^1 du\, \phi_{M_2(u)}\, H^{II}_{(u,z)} \underbrace{\int_0^\infty d\omega \int_0^1 dv\, J(z;\omega,v)\, \phi_B(\omega)\, \phi_{M_1}(v)}_{\equiv\ \varrho_J(z) \text{ in BPRS}}$$

(Bauer, Pirjol, Rothstein, Stewart)

- long-distance
- short-distance

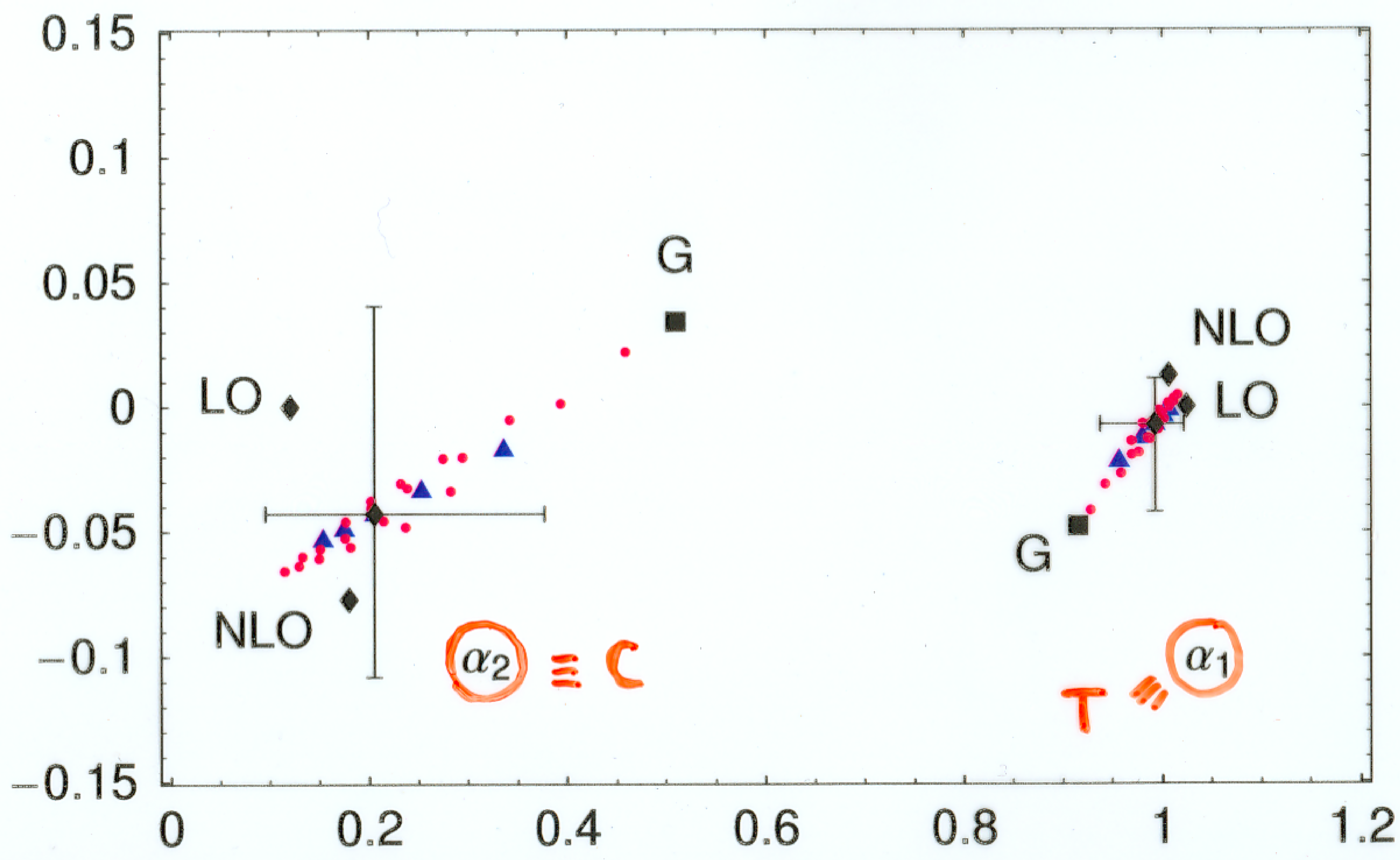
Note: QCD factorization $\equiv$ SCET (there is only one heavy quark expansion)

but BBNS $\neq$ BPRS

- BPRS claim perturbative expansion of J fails and use $\varrho_J(z)$.
  H^{II}, J now known to NLO (Becher et al.; MB, Yang; MB, Jäger)
  convergence ok (→ Fig.)
- BPRS treat penguin amplitudes as non-perturbative (→ 3))
- BPRS use tree-level T^I, H^{II} (→ naive factorization for T^I) vs. NLO in BBNS

Partial NNLO tree amplitudes (NLO spectator scattering)

(MB, S. Jäger, hep-ph/0512351)



Perturbative expansion under control.

Parameter uncertainties dominate

The tree amplitudes $\alpha_1(\pi\pi)$ and $\alpha_2(\pi\pi)$ represented in the complex plane. The black diamonds show the LO, NLO, and partial NNLO approximations. The dark square represents the parameter set 'G', which provides a good description of the experimental data on branching fractions. The blue triangles show the variation of the tree amplitudes, when λ_B takes the values 0.2 GeV to 0.5 GeV in steps of 75 MeV, such that the triangles in the direction of the point 'G' correspond to smaller values of λ_B. From each triangle emanates a set of red points that correspond to varying a_2^π from -0.1 to 0.3 in steps of 0.1 for the given value of λ_B. Here points lying towards 'G' correspond to larger a_2^π.

$B \to PV$ status

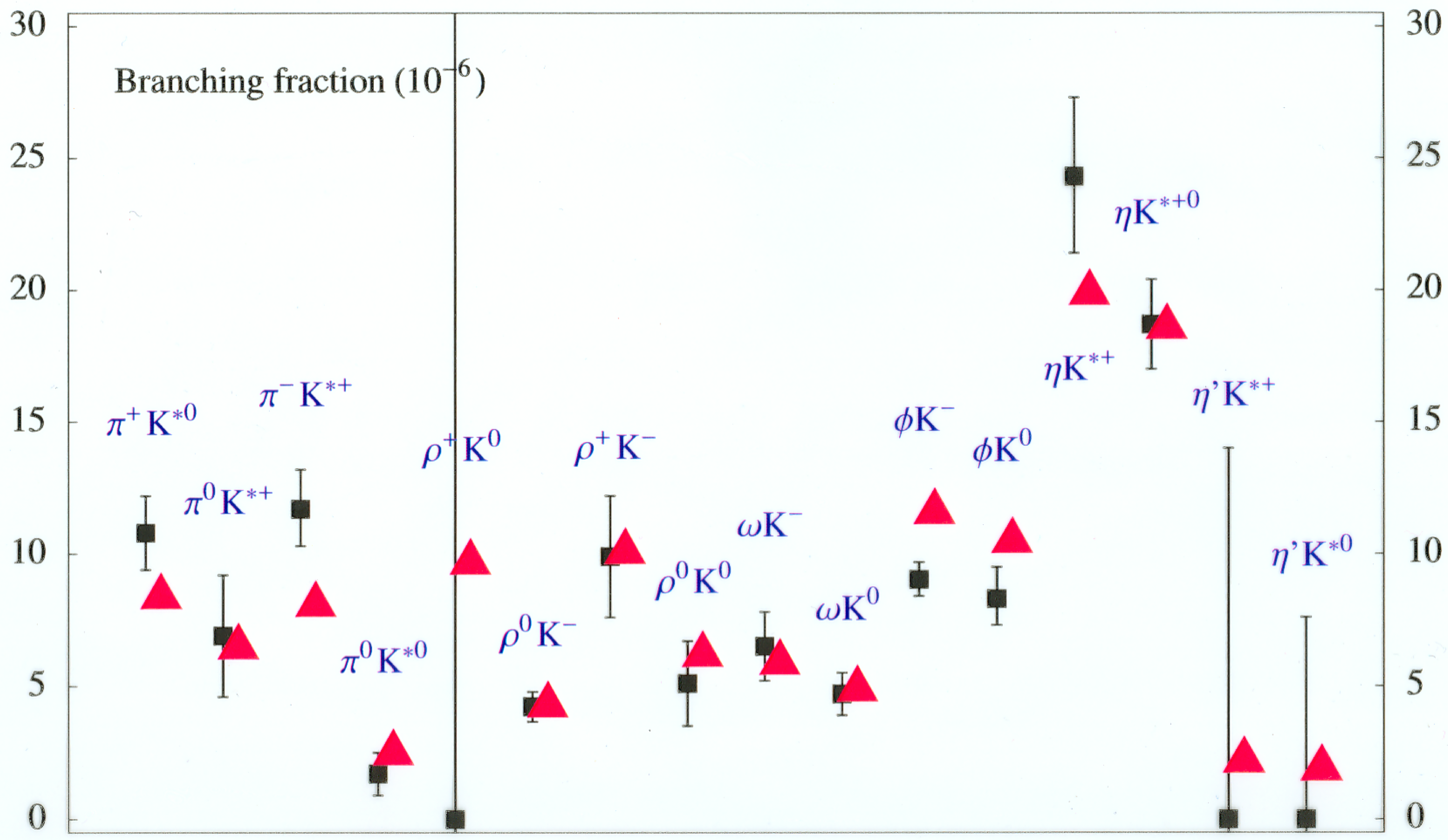
- Br, A_{CP}, some S calculated at NLO for all
  16 $\Delta S = 1$ and 23 $\Delta S = 0$ $B \to PV$ decays
  (P,V from ground state nonet)

  MB, Neubert
  NPB 675 (2003) 333

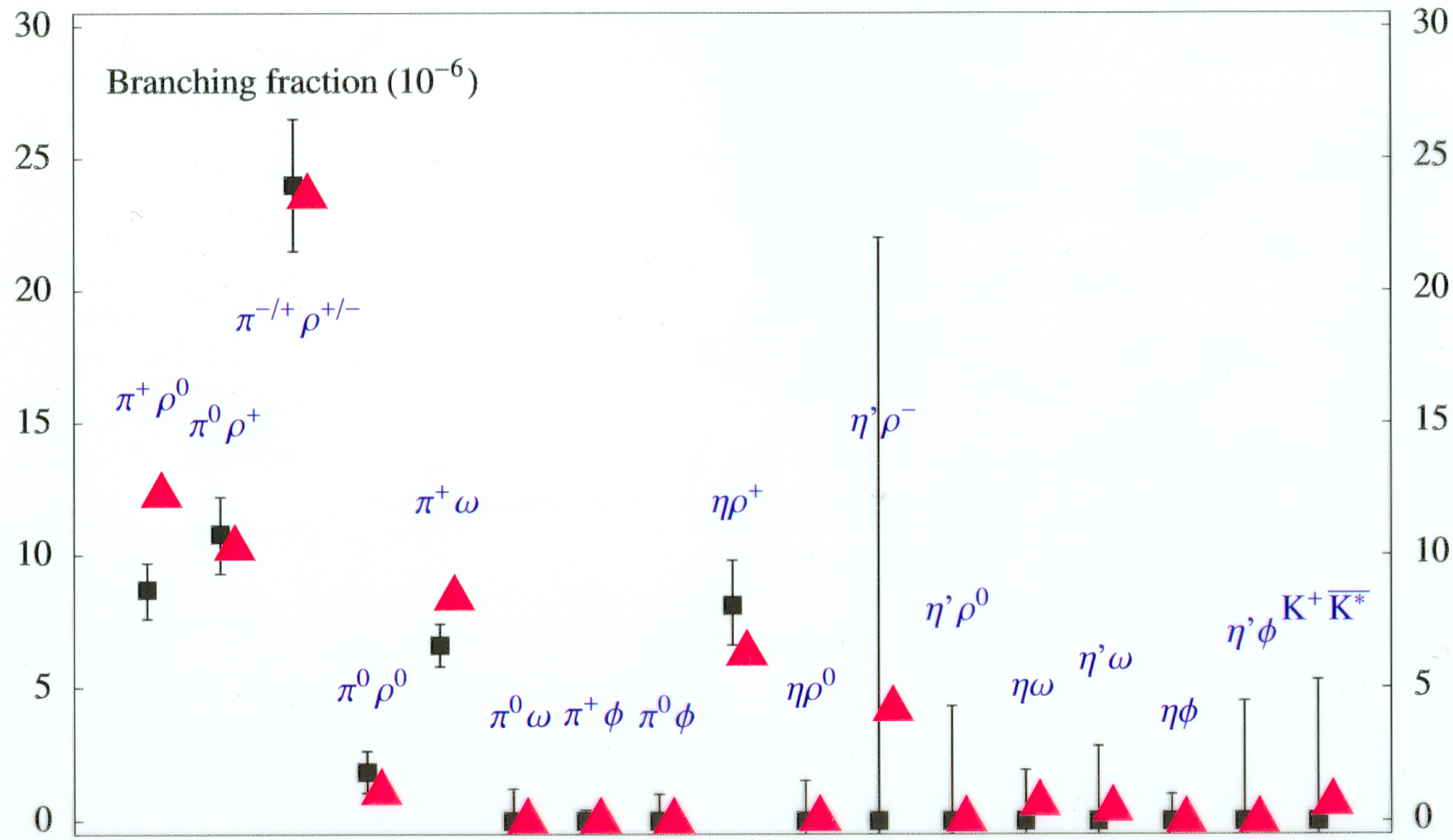
- no update performed since 2003
  [maybe in the future with NLO spectator scattering]

- In 2003 chose some parameter set (S4) to obtain better description for $\pi\pi$, πK.
  Without further modification this gives a very good description of PV - many modes not measured 2003

- Calculation treats V as stable

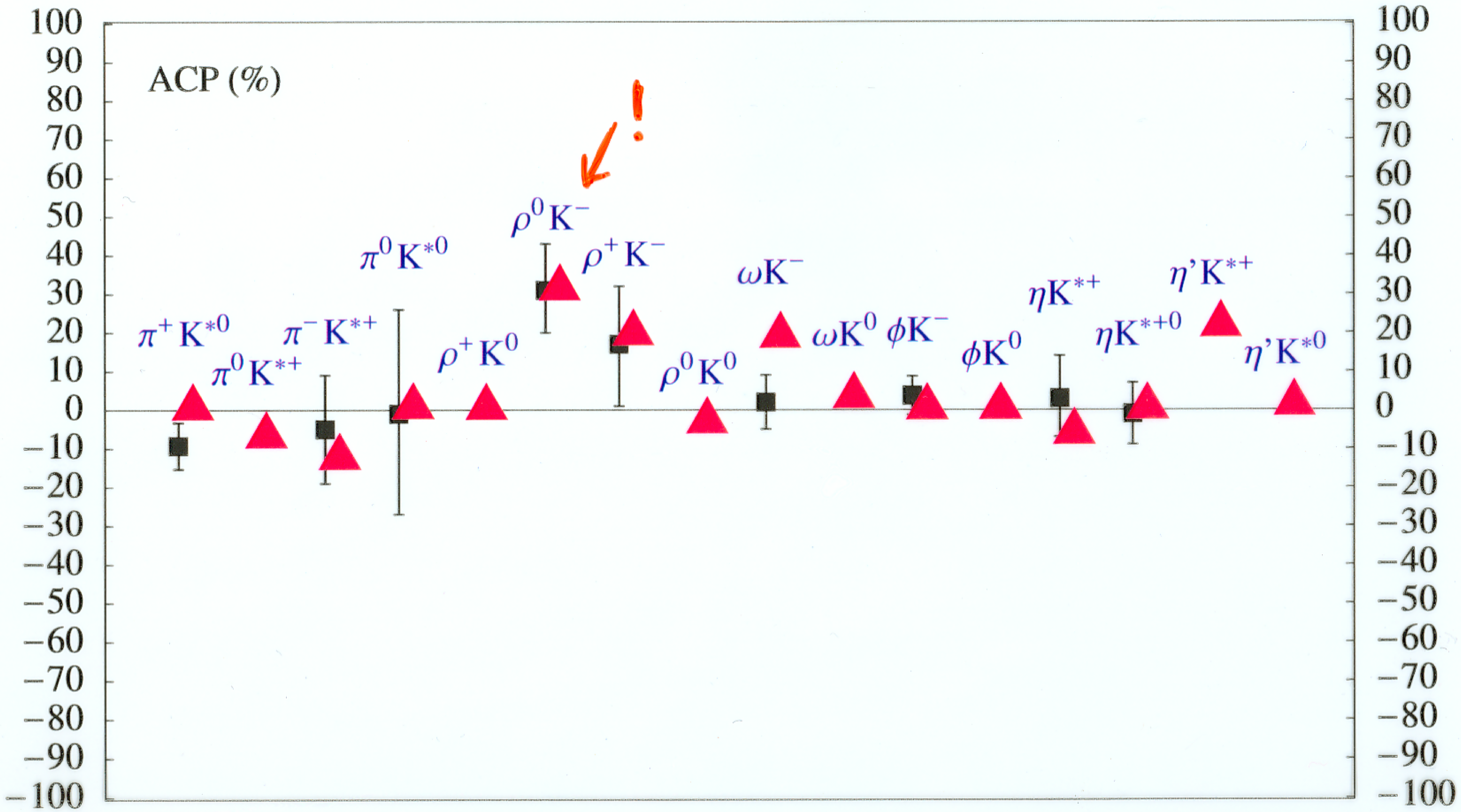


CP-averaged $\Delta S = 1$ branching fraction $B \to PV$ data. Red triangles from MB, M. Neubert, Nucl. Phys. B675 (2003) 333.

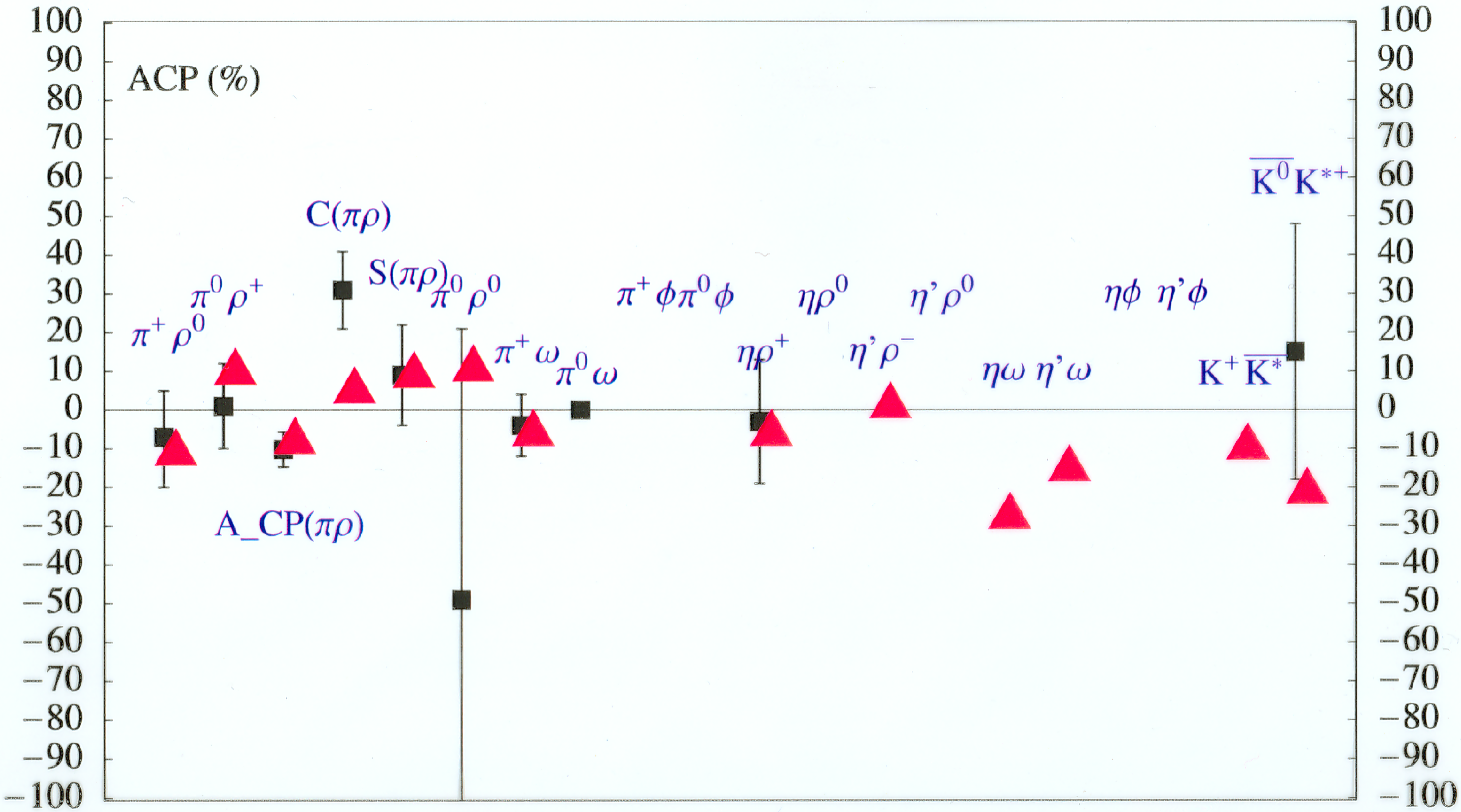


CP-averaged $\Delta S = 0$ branching fraction $B \to PV$ data. Red triangles from MB, M. Neubert, Nucl. Phys. B675 (2003) 333.

-C-



$\Delta S = 1$ $B \to PV$ CP asymmetries. Red triangles from MB, M. Neubert, Nucl. Phys. B675 (2003) 333.



$\Delta S = 0\ B \to PV$ CP asymmetries. Red triangles from MB, M. Neubert, Nucl. Phys. B675 (2003) 333.

What do we learn from PV?

- No helicity information ($\to$ VV)

- Penguin amplitudes are smaller ($\to$ Fig)
  Interference of $V \mp A$ and $S+P$ as predicted in factorization

  $\hookrightarrow$ no doubt that penguin amplitudes factorize (experimentally and theoretically)

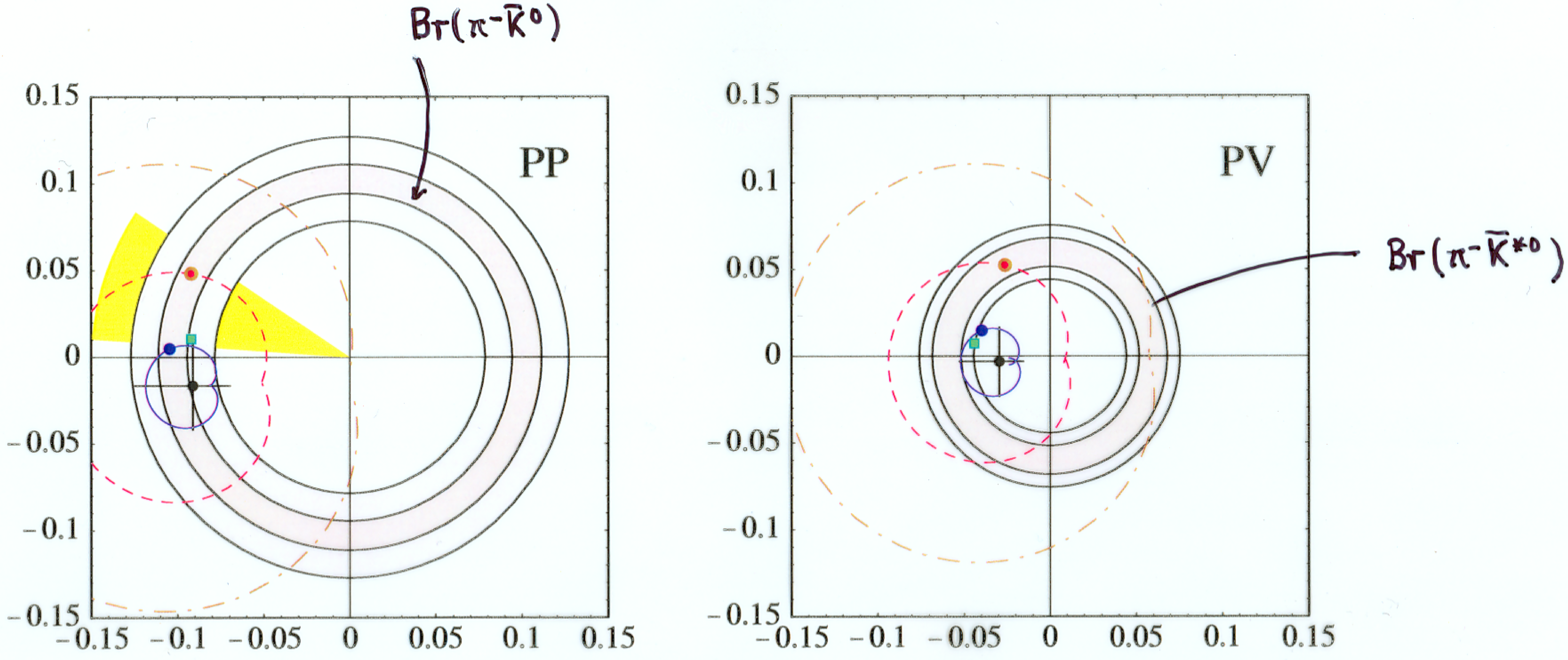
  [but the calculation may not be very precise]

- Penguin-dominated decays more sensitive to electro-weak penguins (test the πK puzzle!) and New Physics

- Smaller corrections from P to tree-dominated decays.
  Good for α: $S_{\pi\rho} = \sin 2\alpha +$ small
  ($\to$ Fig)

Penguin amplitudes

P/T in the complex plane



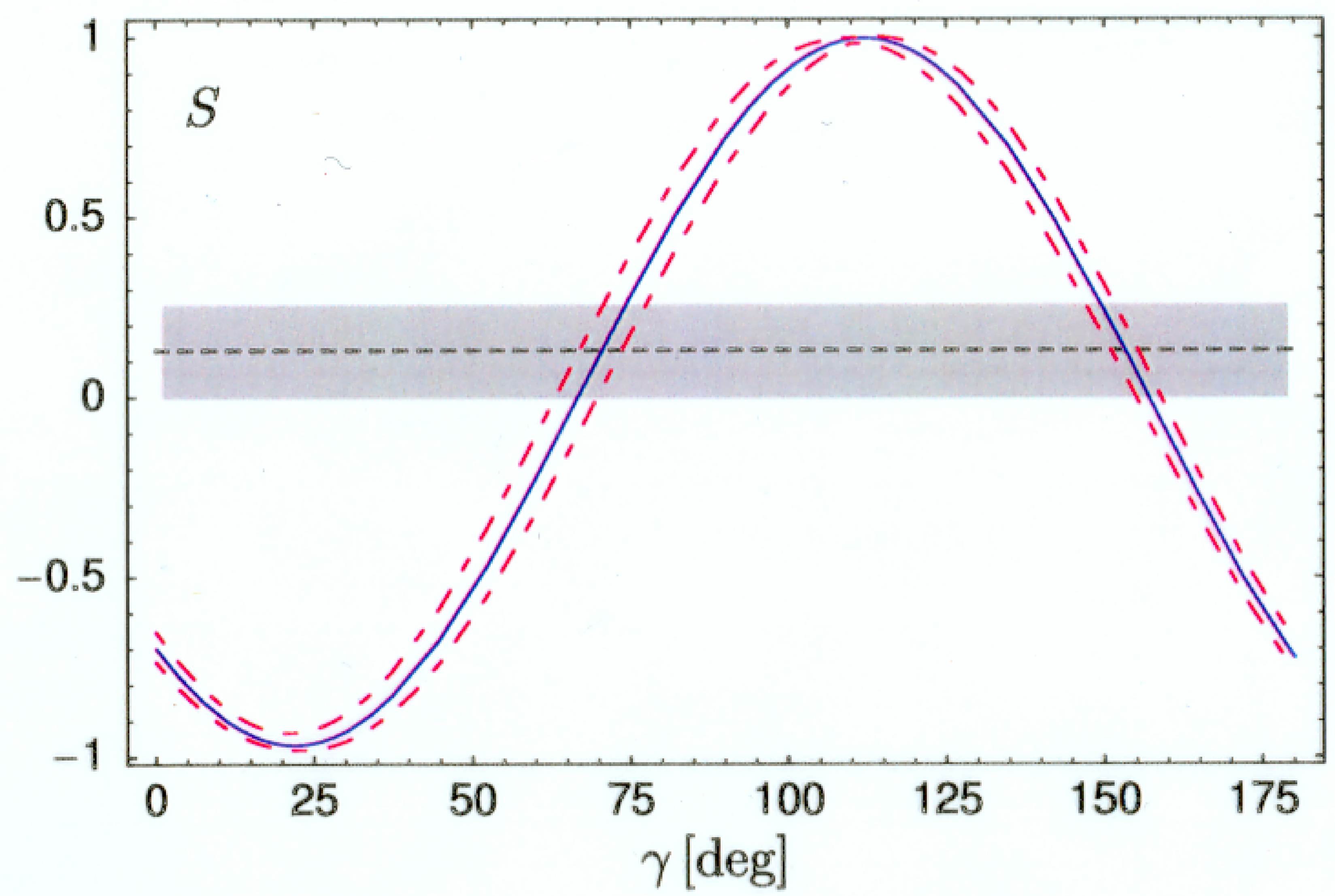
(from MB, M. Neubert, Nucl. Phys. B675 (2003) 333)

$$\mathrm{PP} \sim \underbrace{a_4}_{\mathrm{V\mp A}} + \underbrace{r_\chi a_6}_{\mathrm{S+P}} \qquad \mathrm{PV} \sim a_4 \approx \frac{\mathrm{PP}}{3} \qquad \mathrm{VP} \sim a_4 - r_\chi a_6 \sim -\mathrm{PV}$$

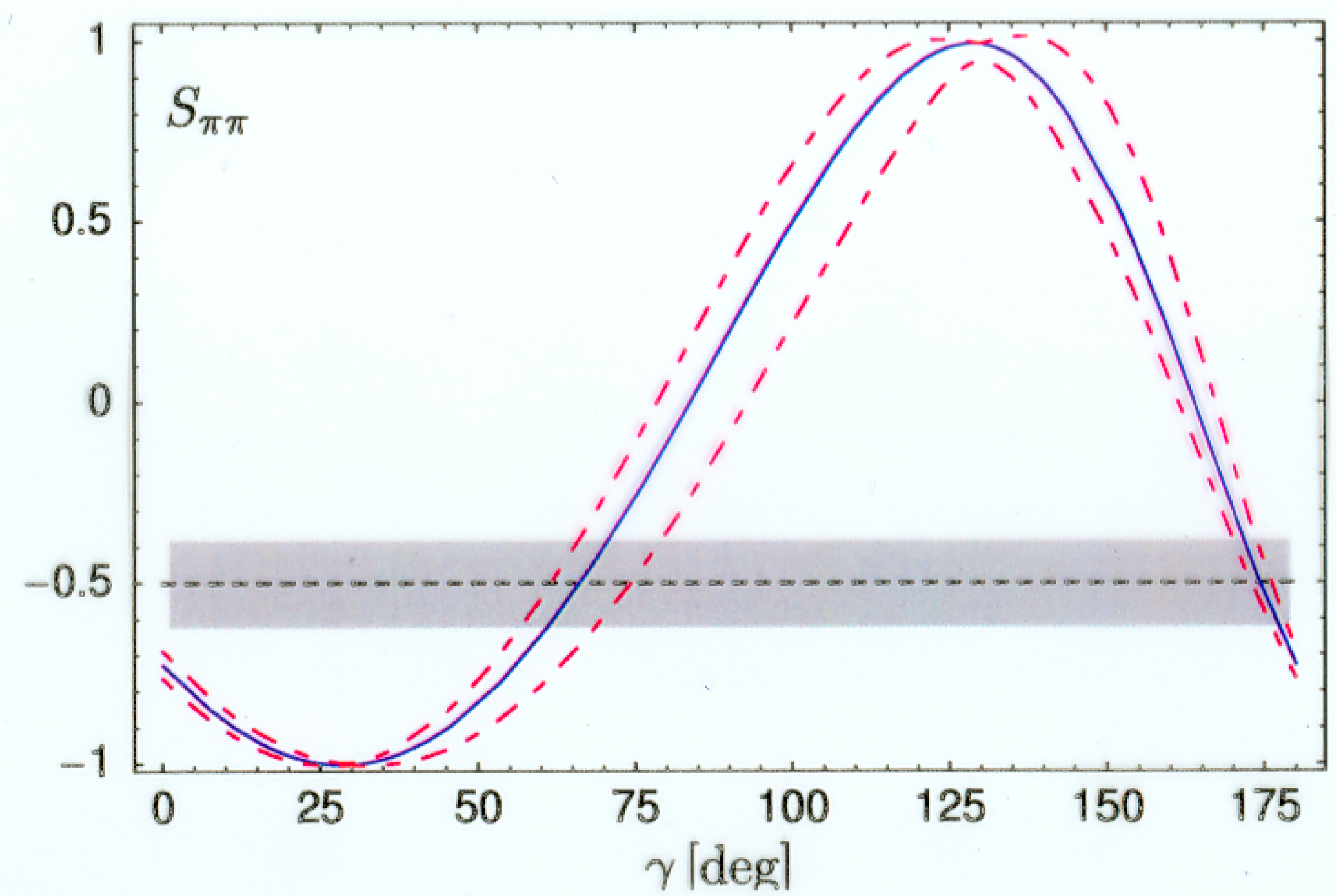
calculable (!?) power correction,
$a_6 > a_4$!!

γ (α) from $S_{\pi\rho}$ (and $S_{\pi\pi}$) (update from MB, M. Neubert, Nucl. Phys. B675 (2003) 333)

$\pi\rho$



$\pi\pi$



$S \equiv (S_{\pi^+\rho^-} + S_{\pi^-\rho^+})/2.$
Without subdominant (penguin) amplitude:

$$S = S_{\pi\pi} = -\sin 2(\beta + \gamma)$$

Result

from $S = 0.13 \pm 0.13$:

$\gamma = (70\,^{+8}_{-8})^\circ$ or $\gamma = (153\,^{+6}_{-6})^\circ$

from $S_{\pi\pi} = -0.50 \pm 0.12$:

$\gamma = (66\,^{+13}_{-12})^\circ$ or $\gamma = (174\,^{+5}_{-5})^\circ$

The first ranges are mutually consistent and consistent as well with the global fit to the BR's and the standard mixing-based fit.

$\bar{B} \to VV$

$$A_+ \ll A_- \ll A_0$$ for V-A weak interactions

Λ^2/m_b^2 — Λ/m_b — 1

[exception]

does not factorize

factorize, but in practice

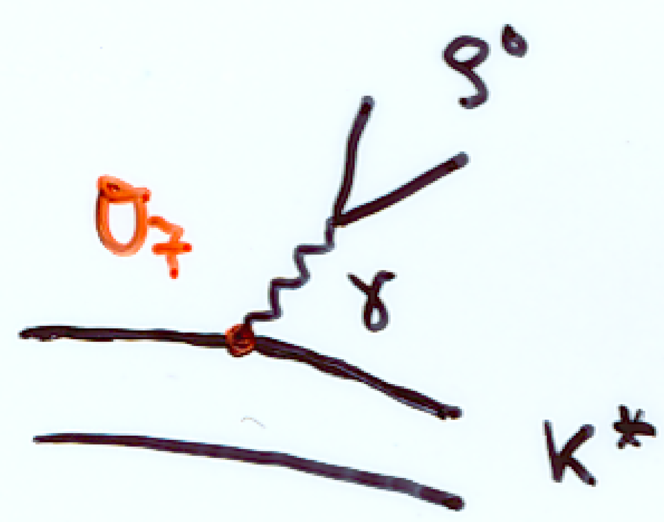
$P_- \sim P_0$ (almost)

[Kagan; MB, Rohrer, Yang]

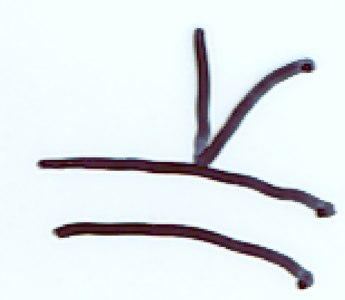
have to take penguin amplitude P_- from data

Formally A_- is leading due to

Electromagnetic dipole operators have a large effect on the transverse electroweak penguin amplitude
(MB, Rohrer, Yang, hep-ph/0512258)



$$\approx \frac{m_B^2}{m_{\rho^0}^2}$$



include O_7

$$\frac{\Gamma_-(\rho^0 \bar{K}^{*0})}{\Gamma_-(\rho^- \bar{K}^{*0})} \sim \left| \frac{1-p^{EW}}{1+p^{EW}} \right|^2 + \Delta \approx 0.7 \longrightarrow 3$$

↪ find this effect

↪ high sensitivity to C_7' (opposite chirality) if A_+, A_- are measured separately

Remarks on 3-body decays in factorization / effective theory

Standard Dalitz analysis assumes

[Snyder, Quinn]

- no non-resonant background (or a model for it)
- Breit-Wigner line shape

note: there is no universal line-shape
distributions are process-dependent

Can one go beyond this?

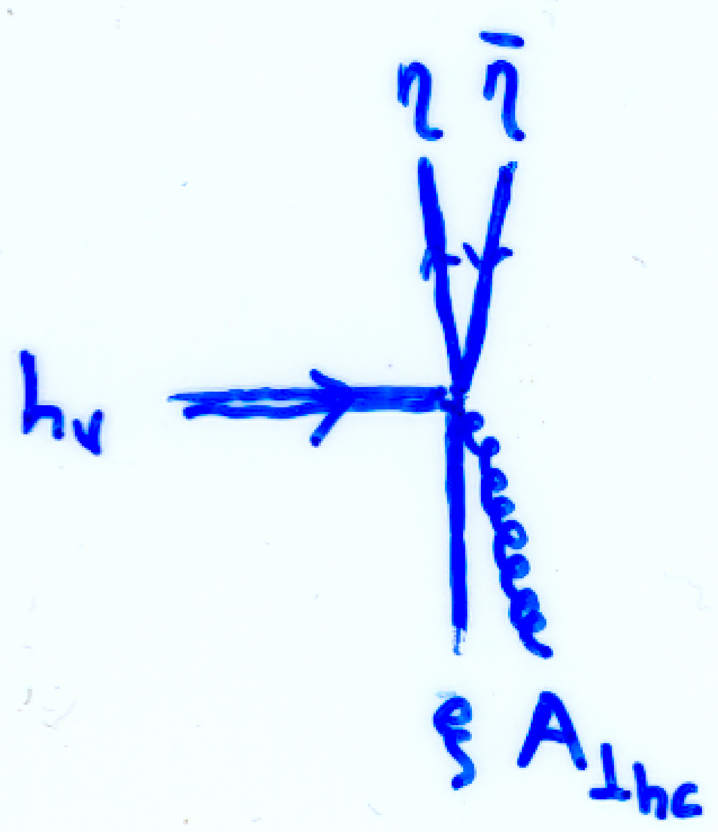
note: no factorization / SCET results on 3-body published -

Factorization at scale m_b :

$$\mathcal{O} \longrightarrow [\bar{\eta}\eta]\,[\bar{\xi}(A_{\perp hc})h_v]$$

SCET$_{I}$ ops at leading power

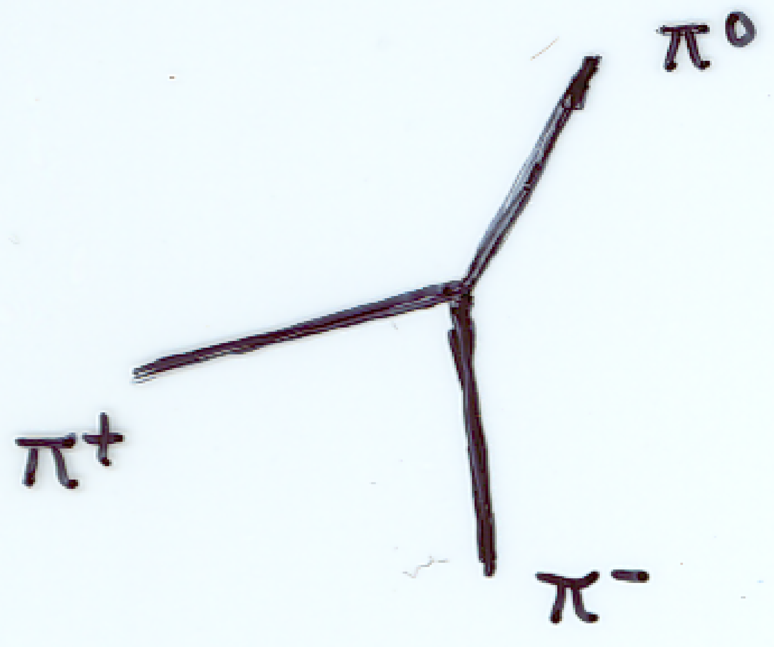
independent of final state



$\bar{B} \to \pi^+\pi^-\pi^0$

$s_\pm = (p_\pm + p_0)^2$

$s_0 = (p_+ + p_-)^2$

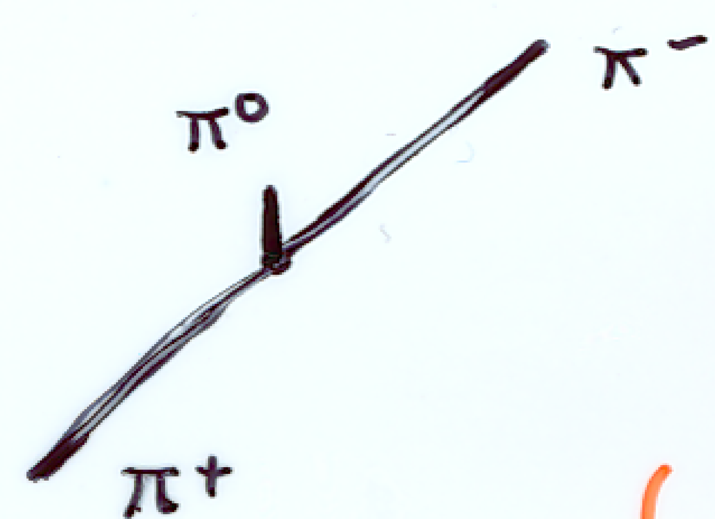


$s_{+,-,0} \sim m_B^2$

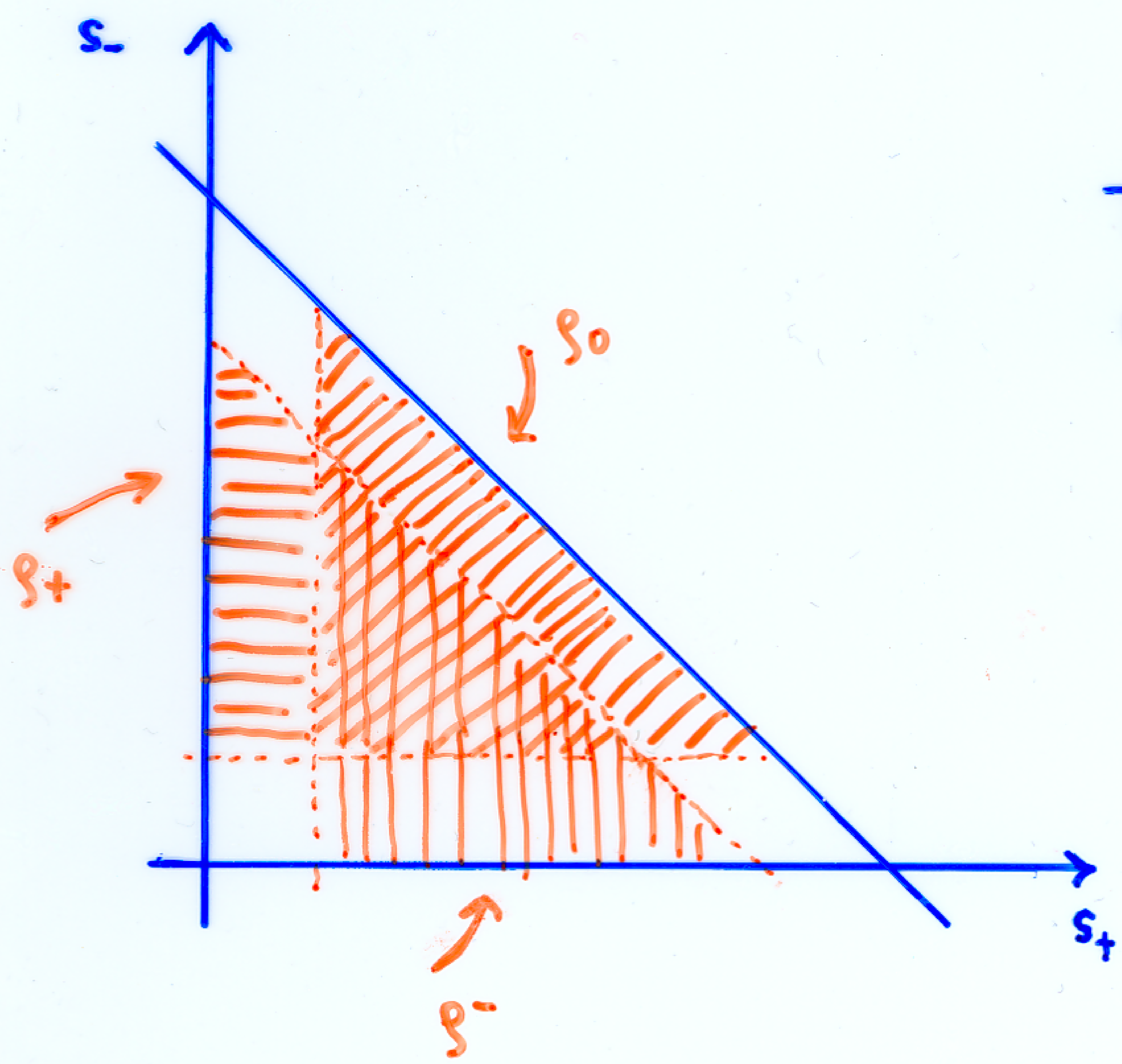
Factorization applies
power-suppressed relative to
2-body
Probably unrealistic for
$m_b \approx 5$ GeV

+ perms.

Factorization applies
with generalized two-
meson distribution
amplitudes & form
factors – see below



does not
factorize
(χPT + SCET)



Two out of $s_{+,-,0}$
must be $\mathcal{O}(m_B^2)$

Structure of factorization formula in the ρ bands

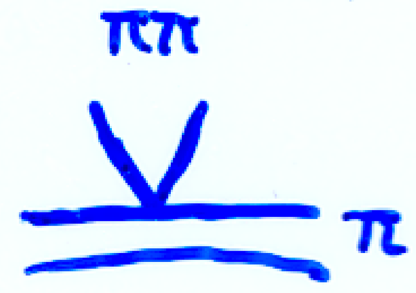
$$\langle \pi\pi\pi | \mathcal{O} | \bar{B} \rangle \longrightarrow$$

standard $F^{B\pi}$

or $\xi_J = J * \phi_B * \phi_\pi$

$$C \, \langle \pi\pi | \bar{\eta}\eta | 0 \rangle \langle \pi | \bar{\xi}(A_{\perp c}) h_v | \bar{B} \rangle$$

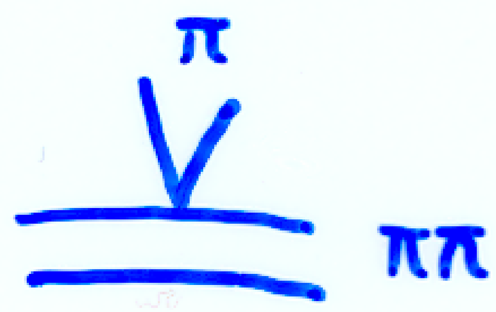
1



$$+ \; D \, \langle \pi | \bar{\eta}\eta | 0 \rangle \langle \pi\pi | [\bar{\xi}(A_{\perp hc}) h_v] | \bar{B} \rangle$$

2

Standard LCDA ϕ_π



1 → two-pion distribution amplitude $\phi_{\pi\pi}(z, \zeta, s)$ [Mueller et al; Diehl et al; Polyakov]

At tree-level only need

$$\int_0^1 dz \, \phi_{\pi\pi}(z,\zeta,s) = (2\zeta - 1) F_\pi(s)$$

Time-like pion form factor

known in the ρ region including phase

2 → generalized $B \to (\pi\pi)$ form factor(s)

Magnitude (not phase) could be obtained from semi-leptonic $B \to (\pi\pi) \ell \nu$ in ρ region for $q^2 \to 0$

↪ Model-independent approach in principle (leading order $1/m_b$, but no assumption on non-resonant background, Breit-Wigner)

In practice ?