CAVEAT

IN 20-25 MINUTES I WILL NOT BE ABLE TO COVER ALL OF THE LATEST DEVELOPMENTS IN THIS WIDESPREAD FIELD.

AS I AM GOING TO DISCUSS CONCEPTUAL AS WELL AS PHENOMENOLOGICAL ASPECTS, THE PHENOMENOLOGICAL PART OF MY TALK WILL NECESSARILY BE SELECTIVE AND SHORT.

I APOLOGIZE FOR NOT COVERING YOUR FAVOURITE TOPIC(S)!
OUTLINE

THEORY

REVIEW OF QCDF / PQCD / SCET

RECENT DEVELOPMENTS: CHARMING PENGUINS

GLAUBER GLUONS IN PQCD

PERTURBATIVE CORRECTIONS IN QCDF

PHENOMENOLOGY

TREE-DOMINATED DECAYS: \( B \rightarrow \pi\pi / \pi\rho / \rho\rho \)

PENGUIN-DOMINATED DECAYS: \( B \rightarrow \pi K \)
THEORY
Charmless hadronic $B$ decays

Particularly rich laboratory to probe the nature of flavour-changing

\[ b \rightarrow u\bar{u}d \ / \ u\bar{u}s \quad b \rightarrow d\bar{q}q \ / \ s\bar{q}q \]

quark transitions and to test the CKM mechanism of CP violation

The challenge: quantitative control over $\langle M_1 M_2 | Q_i | B \rangle$
Charmless hadronic $B$ decays

Particularly rich laboratory to probe the nature of flavour-changing

$$b \rightarrow u\bar{u}d / u\bar{u}s \quad b \rightarrow d\bar{q}q / s\bar{q}q$$

quark transitions and to test the CKM mechanism of CP violation

The challenge: quantitative control over $\langle M_1 M_2 | Q_i | B \rangle$

Two complementary strategies:

- flavour symmetries (isospin, SU(3), . . .) extract hadronic matrix elements from data
  use approximate symmetries of QCD ⇒ relate strong decay amplitudes

- dynamical approaches
  calculate hadronic matrix elements in QCD
  exploit factorization in heavy quark limit $m_b \gg \Lambda_{QCD}$
  some additional insights from light-cone sum rules

[Gronau et al; Fleischer et al; . . . 90+]
[Beneke et al; Li et al; Bauer et al; . . . 99+]
[Khodjamirian et al 00+]
Factorization

Exploit $m_b \gg \Lambda_{QCD}$ to disentangle

- short-distance effects $\sim m_b \Rightarrow$ perturbatively calculable
- long-distance effects $\sim \Lambda_{QCD} \Rightarrow$ universal hadronic parameters

This is not a model, but describes QCD in the well-defined limit $m_b \to \infty$

Why are there three different incarnations of factorization?
Factorization

Exploit $m_b \gg \Lambda_{QCD}$ to disentangle

- short-distance effects $\sim m_b \Rightarrow$ perturbatively calculable
- long-distance effects $\sim \Lambda_{QCD} \Rightarrow$ universal hadronic parameters

This is not a model, but describes QCD in the well-defined limit $m_b \to \infty$

Why are there three different incarnations of factorization?

Factorization of hard exclusive processes pioneered more than 30 years ago for $\pi \gamma^* \to \pi$

$$\langle \pi | J | \pi \rangle \simeq \int du \, dv \, T(u, v) \, \phi_\pi(u) \, \phi_\pi(v)$$

[Brodsky, Lepage 79]

For charmless hadronic $B$ decays expect

$$\langle M_1 M_2 | Q_i | B \rangle \simeq \int d\omega \, du \, dv \, T_i(\omega, u, v) \, \phi_B(\omega) \, \phi_{M_1}(v) \, \phi_{M_2}(u)$$

Problem: convolutions over $\omega$ and $v$ diverge $\Rightarrow$ not dominated by hard gluon exchange!? but still: convolution over $u$ finite $\Rightarrow$ "colour transparency" [Bjorken 89]
QCD factorization

\[ \langle M_1 M_2 | Q_i | B \rangle \sim F^{BM_1} (0) \int du \ T_i^I (u) \ \phi_{M_2} (u) \]
\[ + \int d\omega \ du \ dv \ T_i^{II} (\omega, u, v) \ \phi_B (\omega) \ \phi_{M_1} (v) \ \phi_{M_2} (u) \]

Convolutions are finite, endpoint divergence hidden in \( F^{BM_1} \) which is not factorized.
QCDF / pQCD / SCET

- QCD factorization  
  \[ \langle M_1 M_2 | Q_i | B \rangle \simeq F^{BM_1}(0) \int du \ T^I_i(u) \ \phi_{M_2}(u) \]
  
  \[ + \int d\omega \ du \ dv \ T^{II}_i(\omega, u, v) \ \phi_B(\omega) \ \phi_{M_1}(v) \ \phi_{M_2}(u) \]

  convolutions are finite, endpoint divergence hidden in \( F^{BM_1} \) which is not factorized

- perturbative QCD  
  \[ \langle M_1 M_2 | Q_i | B \rangle \simeq \int d\omega \ du \ dv \ dk_{i\perp} \ T_i(\omega, u, v, k_{i\perp}) \ \phi_B(\omega, k_{1\perp}) \ \phi_{M_1}(v, k_{2\perp}) \ \phi_{M_2}(u, k_{3\perp}) \]

  + Sudakov resummation \( \Rightarrow \) endpoint divergence smeared out by transverse momenta
QCDF / pQCD / SCET

QCD factorization

\[ \langle M_1 M_2 | Q_i | B \rangle \sim F^{BM_1}(0) \int du \ T_i^I(u) \ \phi_{M_2}(u) \]
\[ + \int d\omega \ du \ dv \ T_i^{II}(\omega, u, v) \ \phi_B(\omega) \ \phi_{M_1}(v) \ \phi_{M_2}(u) \]

Convolutions are finite, endpoint divergence hidden in \( F^{BM_1} \) which is not factorized.

perturbative QCD

\[ \langle M_1 M_2 | Q_i | B \rangle \sim \int d\omega \ du \ dv \ dk_{i\perp} \ T_i(\omega, u, v, k_{i\perp}) \ \phi_B(\omega, k_{1\perp}) \ \phi_{M_1}(v, k_{2\perp}) \ \phi_{M_2}(u, k_{3\perp}) \]
\[ + \text{Sudakov resummation} \Rightarrow \text{endpoint divergence smeared out by transverse momenta} \]

Soft-collinear effective theory

SCET = QCDF: simply EFT vs diagrammatical formulation
BPRS ≠ BBNS: phenomenological implementation for \( B \rightarrow M_1 M_2 \) quite different
issues: \( F^{BM_1} \) traded for \( \xi^{BM_1}, \alpha_s(\sqrt{m_b}) \) non-perturbative, ... (minor)
long-distance charm loops, zero-bin subtractions (major)
Long-distance charm loops

Old charming penguin story – two different questions:

- power-suppressed but **numerically** important
  ⇒ not supported by light-cone sum rule estimate

- **leading power** spoiling factorization
  does the threshold region with a non-relativistic $c\bar{c}$ pair require a special treatment?

Recent work addresses second question

- **(a)** $e^+e^- \rightarrow$ hadrons
- **(b)** $B \rightarrow X_s \ell^+\ell^-$
- **(c)** charming penguins

\[ \int dq^2 \ldots \text{Im} \Pi(q^2) \]
\[ \int dq^2 \ldots |\Pi(q^2)|^2 \]
\[ \int dq^2 \ldots \Pi(q^2) \]

⇒ global quark-hadron duality holds in (a) and (c), but breaks down in (b)
⇒ no special treatment required in (c), long-distance charm loops are **power-suppressed**
Glauber gluons in pQCD

It has been realized recently that $k_T$-factorization breaks down in $pp \to h_1h_2X$ at high $p_T$.

- problem related to a peculiar mode: Glauber gluons
- effect is a non-universal long-distance contribution ⇒ ruins $k_T$-factorization
- problem not present in collinear factorization

Important for pQCD approach to non-leptonic $B$ decays

- confirmed that problem exists ⇒ modification of pQCD approach
- claimed that it leads to an universal soft factor $e^{iS}$ ⇒ $k_T$-factorization still holds
- $e^{iS}$ from fit to $\text{Br}(\pi^0\pi^0)$ ⇒ large complex $C$ ⇒ ”solves” $\pi\pi/\pi K$ puzzles

Issues:
- operator definition of soft factor?
- if universal why associated to $\pi$ but not to $\rho$? ⇒ would worsen $\text{Br}(\rho^0\rho^0)$
- at present I consider this rather as a fit than as a dynamical explanation
Perturbative corrections in QCDF

Ongoing effort to compute NNLO corrections in QCDF

\[
\langle M_1 M_2 | Q_i | B \rangle \simeq F^{BM_1} T^I_i \otimes \phi_{M_2} + T^{II}_i \otimes \phi_B \otimes \phi_{M_1} \otimes \phi_{M_2}
\]

strong phases \( \sim \mathcal{O}(\alpha_s) \) \( \Rightarrow \) NNLO is first correction for direct CP asymmetries!

<table>
<thead>
<tr>
<th>Status</th>
<th>2-loop vertex corrections ((T^I_i))</th>
<th>1-loop spectator scattering ((T^{II}_i))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trees</td>
<td>![trees_diagram]</td>
<td>![trees_diagram]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Penguins</td>
<td>![penguins_diagram]</td>
<td>![penguins_diagram]</td>
</tr>
<tr>
<td></td>
<td>in progress</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- factorization found to hold (as expected) at highly non-trivial order
- direct CP asymmetries not yet available at NNLO
- first NNLO results for CP-averaged branching ratios of tree-dominated decays

\[ [GB, Pilipp 09; Beneke, Huber, Li 09] \]
## Summary of theory part

<table>
<thead>
<tr>
<th></th>
<th>BBNS (QCDF)</th>
<th>pQCD</th>
<th>BPRS (SCET)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_s(\sqrt{\Lambda m_b})$</td>
<td>perturbative</td>
<td>perturbative</td>
<td>non-perturbative</td>
</tr>
<tr>
<td>charm loops</td>
<td>perturbative (small phase)</td>
<td>perturbative (small phase)</td>
<td>non-perturbative (large phase from fit to data)</td>
</tr>
<tr>
<td>weak annihilation</td>
<td>non-perturbative (crude model, arbitrary phase)</td>
<td>perturbative (large phase)</td>
<td>perturbative (with zero bins, small phase)</td>
</tr>
<tr>
<td>(power correction)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>strong phases</td>
<td>generically small ($\sim \alpha_s, 1/m_b$)</td>
<td>can be sizeable (annihilation, Glaubers)</td>
<td>can be sizeable (charm loops)</td>
</tr>
<tr>
<td>perturbative</td>
<td>partially NNLO</td>
<td>partially NLO</td>
<td>NLO</td>
</tr>
<tr>
<td>calculation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>hadronic input</td>
<td>from lattice + QCD sum rules</td>
<td>from QCD sum rules + data, model $\phi_B(x, b)$</td>
<td>from QCD sum rules + data, model $\xi^{BM}_B(z)$</td>
</tr>
</tbody>
</table>

- theory predictions for direct CP asymmetries can unfortunately differ a lot!
- measurements (even bounds) of pure annihilation decays highly appreciated:
  
  $B_d \rightarrow K^- K^+$, $B_s \rightarrow \pi\pi/\pi\rho/\rho\rho$
PHENOMENOLOGY
\[ B \rightarrow \pi\pi / \pi\rho / \rho\rho \]

Large \( \text{Br}(\pi^0\pi^0) = (1.55 \pm 0.19) \cdot 10^{-6} \) challenging for dynamical approaches

► seems to indicate large \( C/T \) ⇒ interesting in view of \( \pi K \) puzzle

► Babar: \( (1.83 \pm 0.21 \pm 0.13) \cdot 10^{-6} \) Belle: \( (1.1 \pm 0.3 \pm 0.1) \cdot 10^{-6} \)

⇒ reconsider in the light of NNLO calculation in QCDF and \( \pi\rho / \rho\rho \) data

Tree amplitudes now completely determined to NNLO

\[
T \sim \alpha_1(\pi\pi) = \begin{bmatrix} 1.008 \end{bmatrix} v_0 + \begin{bmatrix} 0.022 + 0.009 \; i \end{bmatrix} v_1 + \begin{bmatrix} 0.024 + 0.026 \; i \end{bmatrix} v_2
\]
\[
- \begin{bmatrix} 0.014 \end{bmatrix} s_1 - \begin{bmatrix} 0.016 + 0.012 \; i \end{bmatrix} s_2 - \begin{bmatrix} 0.008 \end{bmatrix} 1/m_b
\]

\[
= \begin{array}{c}
1.015^{+0.020}_{-0.029} + (0.023^{+0.015}_{-0.015}) \; i \\

C \sim \alpha_2(\pi\pi) = \begin{bmatrix} 0.224 \end{bmatrix} v_0 - \begin{bmatrix} 0.174 + 0.075 \; i \end{bmatrix} v_1 - \begin{bmatrix} 0.029 + 0.046 \; i \end{bmatrix} v_2
\]
\[
+ \begin{bmatrix} 0.084 \end{bmatrix} s_1 + \begin{bmatrix} 0.037 + 0.022 \; i \end{bmatrix} s_2 + \begin{bmatrix} 0.052 \end{bmatrix} 1/m_b
\]

\[
= \begin{array}{c}
0.194^{+0.130}_{-0.095} - (0.099^{+0.057}_{-0.056}) \; i
\end{array}
\]

► individual NNLO corrections quite significant, but substantial cancellations

► \( \text{Re}(\alpha_2) \) still uncertain, mainly due to poor knowledge of \( \lambda_B^{-1} = \int \frac{d\omega}{\omega} \phi_B(\omega) \)
### CP-averaged branching ratios

<table>
<thead>
<tr>
<th>Mode</th>
<th>QCDF</th>
<th>B</th>
<th>Experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^-\pi^0$</td>
<td>$6.22^{+2.37}_{-2.01}$</td>
<td>5.46</td>
<td>$5.59^{+0.41}_{-0.40}$</td>
</tr>
<tr>
<td>$\rho^-\rho^0$</td>
<td>$21.0^{+8.5}_{-7.3}$</td>
<td>21.3</td>
<td>$22.5^{+1.9}_{-1.9}$</td>
</tr>
<tr>
<td>$\pi^-\rho^0$</td>
<td>$9.34^{+4.00}_{-3.23}$</td>
<td>10.4</td>
<td>$8.3^{+1.2}_{-1.3}$</td>
</tr>
<tr>
<td>$\pi^0\rho^-$</td>
<td>$15.1^{+5.7}_{-5.0}$</td>
<td>11.9</td>
<td>$10.9^{+1.4}_{-1.5}$</td>
</tr>
<tr>
<td>$\pi^+\pi^-$</td>
<td>$8.96^{+3.78}_{-3.32}$</td>
<td>5.21</td>
<td>$5.16^{+0.22}_{-0.22}$</td>
</tr>
<tr>
<td>$\pi^0\pi^0$</td>
<td>$0.35^{+0.37}_{-0.21}$</td>
<td>0.63</td>
<td>$1.55^{+0.19}_{-0.19}$</td>
</tr>
<tr>
<td>$\pi^+\rho^-$</td>
<td>$22.8^{+9.1}_{-8.0}$</td>
<td>13.2</td>
<td>$15.7^{+1.8}_{-1.8}$</td>
</tr>
<tr>
<td>$\pi^+\rho^+$</td>
<td>$11.5^{+5.1}_{-4.3}$</td>
<td>8.41</td>
<td>$7.3^{+1.2}_{-1.2}$</td>
</tr>
<tr>
<td>$\pi^0\rho^+$</td>
<td>$34.3^{+11.5}_{-10.0}$</td>
<td>21.6</td>
<td>$23.0^{+2.3}_{-2.3}$</td>
</tr>
<tr>
<td>$\pi^0\rho^0$</td>
<td>$0.52^{+0.76}_{-0.42}$</td>
<td>1.64</td>
<td>$2.0^{+0.5}_{-0.5}$</td>
</tr>
<tr>
<td>$\rho^+_L\rho^-_L$</td>
<td>$30.3^{+12.9}_{-11.2}$</td>
<td>22.3</td>
<td>$23.6^{+3.2}_{-3.2}$</td>
</tr>
<tr>
<td>$\rho^0 L\rho^0 L$</td>
<td>$0.44^{+0.66}_{-0.37}$</td>
<td>1.33</td>
<td>$0.69^{+0.30}_{-0.30}$</td>
</tr>
</tbody>
</table>

**B**: enhanced colour-suppressed amplitude with 
$\lambda_B = 0.2$, $F_B^{\pi} = 0.21$ and $A_B^{\rho} = 0.27$

- Theo. uncertainties highly correlated ($F_{BM1}, |V_{ub}|$)
- Colour-suppressed modes $\pi^0\pi^0 / \rho^0\rho^0$ rather uncertain ($\lambda_B$ and $1/m_b$)
- $\rho^0\rho^0$ and $\pi^0\rho^0$ (with smaller penguins) fit better than $\pi^0\pi^0$
- Preference for enhanced colour-suppressed amplitude

[for a similar analysis cf. Beneke, Huber, Li 09]
Testing factorization

Eliminate dependence on $F^{BM_1}$ and $|V_{ub}|$ via

$$R_{M_3}(M_1 M_2) = \frac{\Gamma(B \rightarrow M_1 M_2)}{d\Gamma(B \rightarrow M_3 \ell \nu)/dq^2|_{q^2=0}}$$

⇒ requires measurement of semileptonic decay spectrum and extrapolation to $q^2 = 0$

$B \rightarrow \pi \ell \nu$

$B \rightarrow \rho \ell \nu$

⇒ $|V_{ub}| F_{+\pi}^{BM}(0) = (9.1 \pm 0.7) \cdot 10^{-4}$

currently insufficient to extract $|V_{ub}| A_0^{BP}(0)$

[Babar 07]

[Babar 05; Belle 07; CLEO 07; figure from Flynn et al 08]
Testing factorization

Eliminate dependence on $F^{BM_1}$ and $|V_{ub}|$ via

$$\mathcal{R}_{M_3}(M_1 M_2) = \frac{\Gamma(B \to M_1 M_2)}{d\Gamma(B \to M_3 \ell\nu)/dq^2|_{q^2=0}}$$

<table>
<thead>
<tr>
<th>Mode</th>
<th>QCDF</th>
<th>B</th>
<th>Experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mathcal{R}_\pi(\pi^-\pi^0)$</td>
<td>$0.70^{+0.12}_{-0.08}$</td>
<td>0.95</td>
<td>$0.81^{+0.14}_{-0.14}$</td>
</tr>
<tr>
<td>$\mathcal{R}_\rho(\rho_L^-\rho_L^0)$</td>
<td>$1.91^{+0.32}_{-0.23}$</td>
<td>2.38</td>
<td>n.a.</td>
</tr>
<tr>
<td>$\mathcal{R}_\rho(\pi^-\rho^0)$</td>
<td>$0.85^{+0.22}_{-0.14}$</td>
<td>1.16</td>
<td>n.a.</td>
</tr>
<tr>
<td>$\mathcal{R}_\pi(\rho^-\rho^-)$</td>
<td>$1.71^{+0.27}_{-0.24}$</td>
<td>2.07</td>
<td>$1.57^{+0.32}_{-0.32}$</td>
</tr>
<tr>
<td>$\mathcal{R}_\pi(\pi^+\pi^-)$</td>
<td>$1.09^{+0.22}_{-0.20}$</td>
<td>0.97</td>
<td>$0.80^{+0.13}_{-0.13}$</td>
</tr>
<tr>
<td>$\mathcal{R}_\pi(\pi^+\rho^-)$</td>
<td>$2.77^{+0.32}_{-0.31}$</td>
<td>2.46</td>
<td>$2.43^{+0.47}_{-0.47}$</td>
</tr>
<tr>
<td>$\mathcal{R}_\rho(\pi^-\rho^+)$</td>
<td>$1.12^{+0.20}_{-0.14}$</td>
<td>1.01</td>
<td>n.a.</td>
</tr>
<tr>
<td>$\mathcal{R}_\rho(\rho^+_L\rho^+_L)$</td>
<td>$2.95^{+0.37}_{-0.35}$</td>
<td>2.68</td>
<td>n.a.</td>
</tr>
<tr>
<td>$R(\rho^-_L\rho^-_L/\rho^+_L\rho^+_L)$</td>
<td>$0.65^{+0.16}_{-0.11}$</td>
<td>0.89</td>
<td>$0.89^{+0.14}_{-0.14}$</td>
</tr>
<tr>
<td>$R(\pi^-\pi^0/\pi^+\pi^-)$</td>
<td>$0.65^{+0.19}_{-0.14}$</td>
<td>0.98</td>
<td>$1.01^{+0.09}_{-0.09}$</td>
</tr>
</tbody>
</table>

B: enhanced colour-suppressed amplitude with

$$\lambda_B = 0.2, \quad F^{B\pi} = 0.21 \quad \text{and} \quad A^{B\rho}_0 = 0.27$$

▶ $\pi^-\pi^0/\rho^-\rho^0$ provide clean access to $|T + C|$

▶ good overall description (in particular for small $\lambda_B$)

▶ only exception $\text{Br}(\pi^0\pi^0)$ which has a substantial penguin contribution and large theo. uncertainties

[GB, Pilipp 09]

[for a similar analysis cf. Beneke, Huber, Li 09]
The $B \to \pi K$ puzzle

Since 2006 branching ratios do no longer look puzzling

<table>
<thead>
<tr>
<th></th>
<th>QCDF</th>
<th>Experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_c$</td>
<td>$1.15^{+0.21}_{-0.18}$</td>
<td>$1.12 \pm 0.07$</td>
</tr>
<tr>
<td>$R_n$</td>
<td>$1.16^{+0.24}_{-0.20}$</td>
<td>$1.02 \pm 0.07$</td>
</tr>
</tbody>
</table>

But direct CP asymmetries look somewhat odd

<table>
<thead>
<tr>
<th>$A_{CP} [%]$</th>
<th>QCDF</th>
<th>Experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^0 K^-$</td>
<td>$9.4^{+12.1}_{-14.6}$</td>
<td>$5.0^{+2.5}_{-2.5}$</td>
</tr>
<tr>
<td>$\pi^+ K^-$</td>
<td>$5.6^{+12.2}_{-15.1}$</td>
<td>$-9.8^{+1.2}_{-1.1}$</td>
</tr>
<tr>
<td>$\Delta A_{CP}$</td>
<td>$3.8^{+2.9}_{-2.7}$</td>
<td>$14.8^{+2.7}_{-2.8}$</td>
</tr>
</tbody>
</table>

$\Delta A_{CP}$ can be predicted quite precisely

⇒ could be NP but also large + complex

$C/T$ beyond factorization

More robust SM test given by isospin sum rule

$A_{CP}(\pi^+ K^-) + A_{CP}(\pi^- \bar{K}^0) \simeq A_{CP}(\pi^0 K^-) + A_{CP}(\pi^0 \bar{K}^0)$

⇒ predicts large $A_{CP}(\pi^0 \bar{K}^0)$, but discrimination of NP requires much more data
Mixing-induced CP asymmetry

Naive expectation neglecting doubly Cabibbo-suppressed terms

\[ S_{\pi^0 K_S} \approx \sin(2\beta) J_{/\psi K_S} = 0.681 \pm 0.025 \]

"tree pollution" estimated to increase \( S_{\pi^0 K_S} \) by 0.04–0.12

Isospin relations reveal some tension with \( \pi K \) data

uses two SU(3) relations \( \Rightarrow R_{T+C} \) and \( R_q \)

SU(3) breaking estimated with QCDF

\[ \Rightarrow S_{\pi^0 K_S} = 0.99^{+0.01}_{-0.08} \exp^{-0.001}_{0.00} \gamma R_{T+C}^{-0.11} R_q^{-0.07} \]

uncertainty reducible by lattice determination of \( F^{BK}/F^{B\pi} \)

Additional information on \( \pi K \) puzzle can be obtained from \( \pi K^*/\rho K \) sector

\( \Rightarrow \) at present data still insufficient, but expect sizeable direct CP asymmetries

[Chiang, London 09; Gronau, Pirjol, Zupan 10]
Conclusion

Factorization is based on a twofold expansion in $\alpha_s(m_b)$ and $1/m_b$

- perturbative calculations are reaching NNLO precision
- unfortunately no similar progress (yet) on power corrections

Satisfactory overall description of $\pi\pi/\pi\rho/\rho\rho$ branching ratios

- large $\text{Br}(\pi^0\pi^0)$ still puzzling, but not necessarily a failure of factorization
- $A_{CP}(\pi^+\pi^-)$ from Belle also somewhat large, but $\sim 2\sigma$ above Babar value

The $B \to \pi K$ puzzle continues to be exciting

- depends crucially on experimental progress on $\pi^0\bar{K}^0$ observables

There are many interesting topics which I could not discuss

- $B_s$ decays, $B \to VV$ polarization puzzle, $B$ decays with scalars, baryons, 3-body, ...