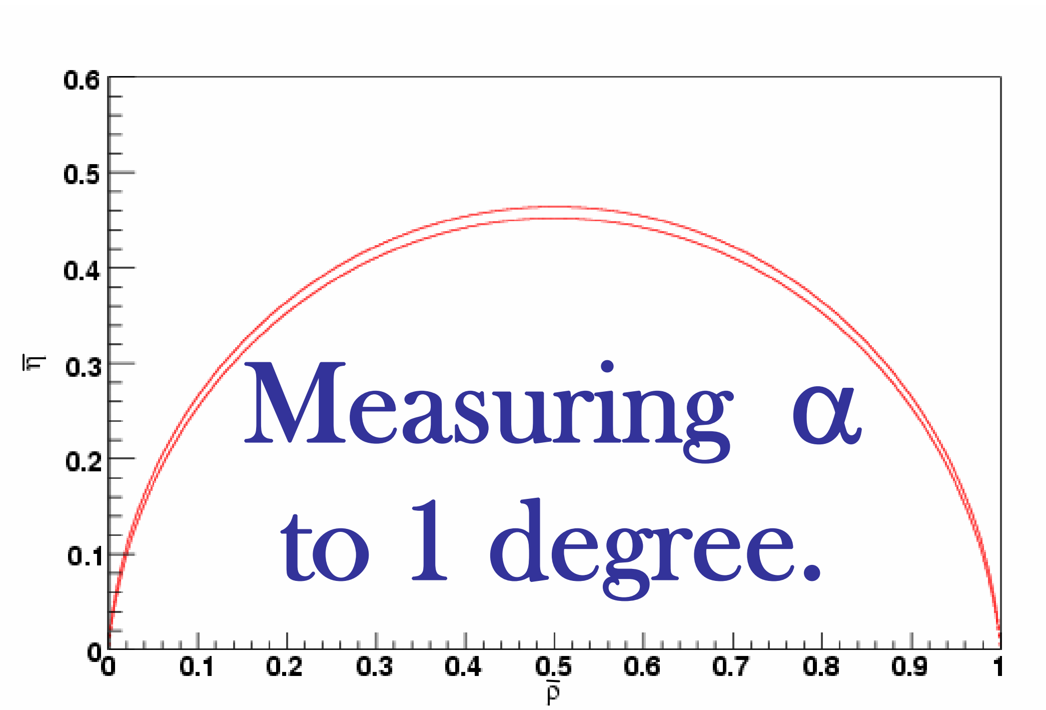

Measuring α to 1 degree.

Is it possible?

Adrian Bevan

Queen Mary
University of London

Overview

- Current status of measurements.
- SU(2) based methods.
  - $\rho\rho$, $\pi\pi$, $\pi\pi\pi$.
- SU(3) based methods.
  - $\rho\rho$, $\pi\pi$, $a_1\pi$.
- Precision with 75 ab^{-1}.
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- Potential of LHCb.
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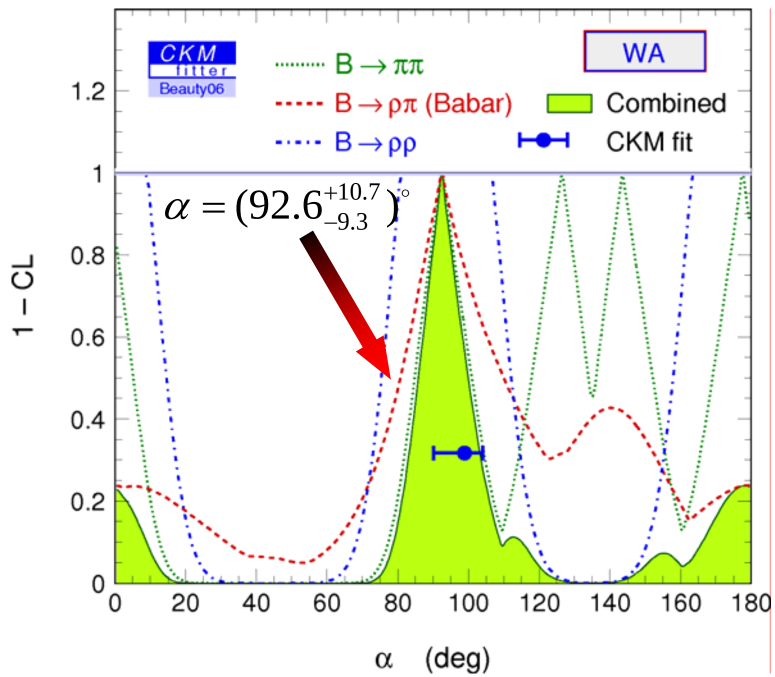

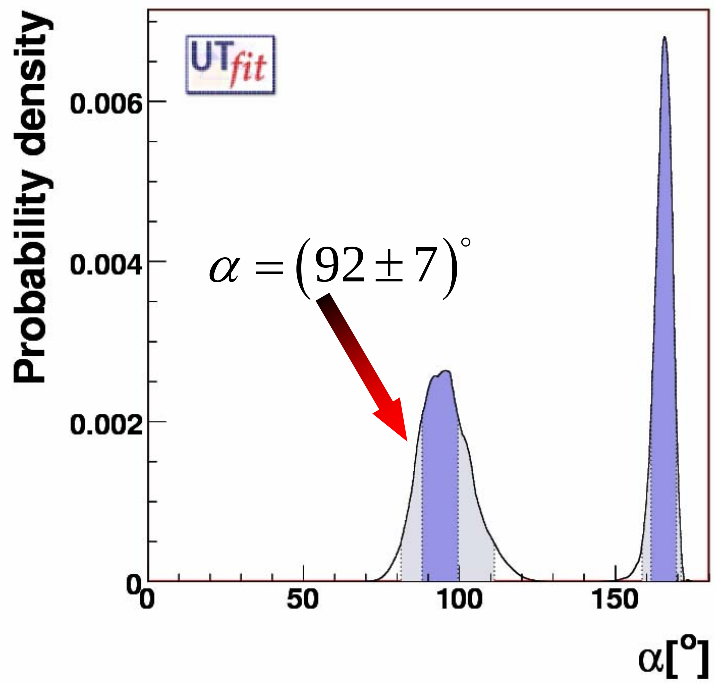

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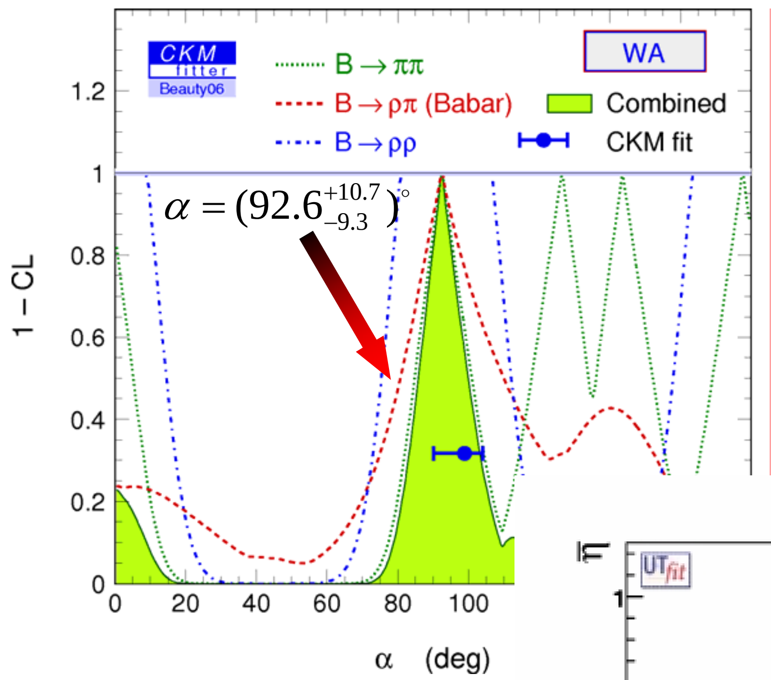

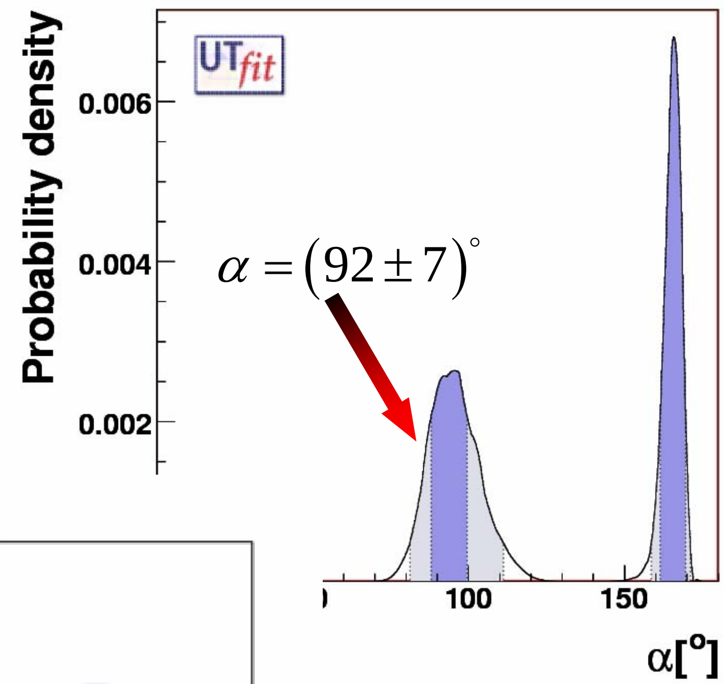

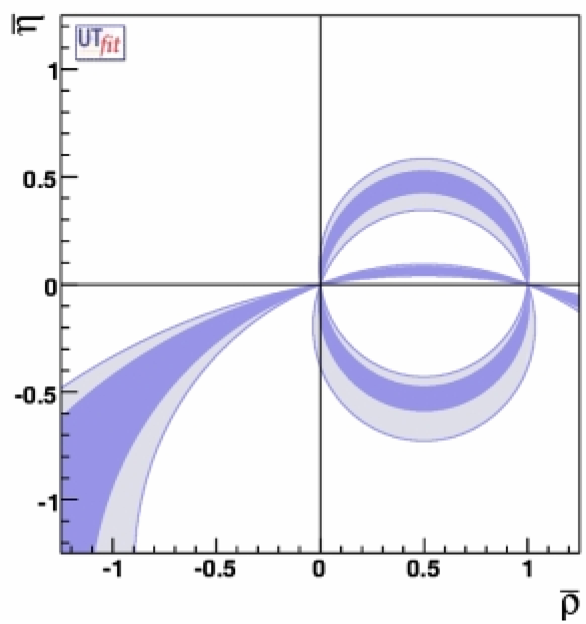

+ results using SU(3) based methods (see later).

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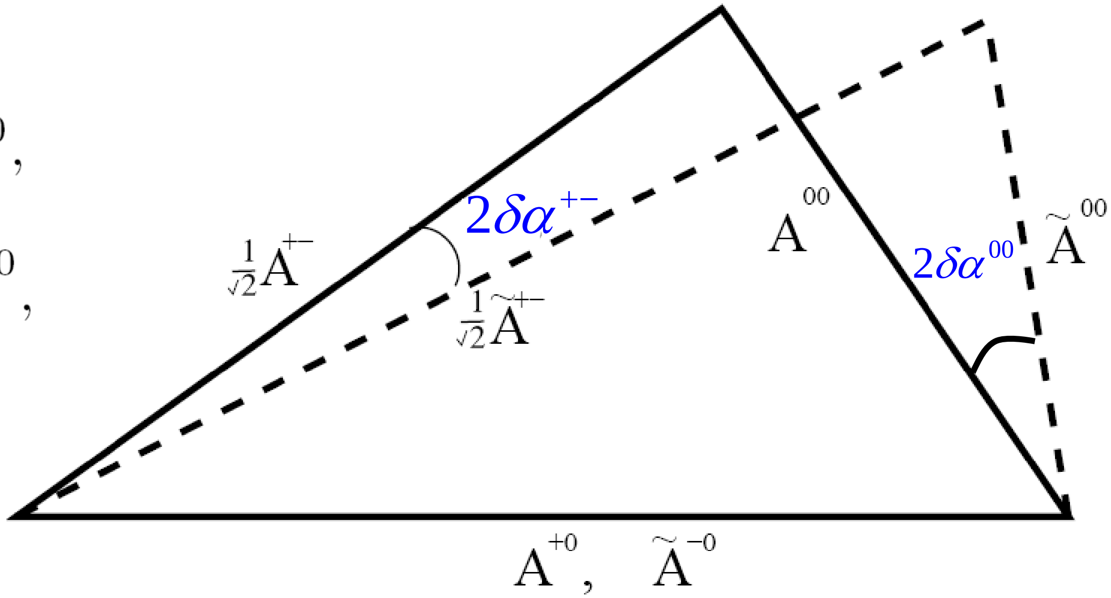
SU(2) based methods.

- SU(2) isospin relates the different B→hh' amplitudes (h, h' = π, ρ): Gronau London (**GL**) method.

$$\frac{1}{\sqrt{2}}A^{+-} = A^{+0} - A^{00},$$
$$\frac{1}{\sqrt{2}}\overline{A}^{+-} = \overline{A}^{+0} - \overline{A}^{00},$$
$$|A^{+0}| = |\overline{A}^{+0}|$$

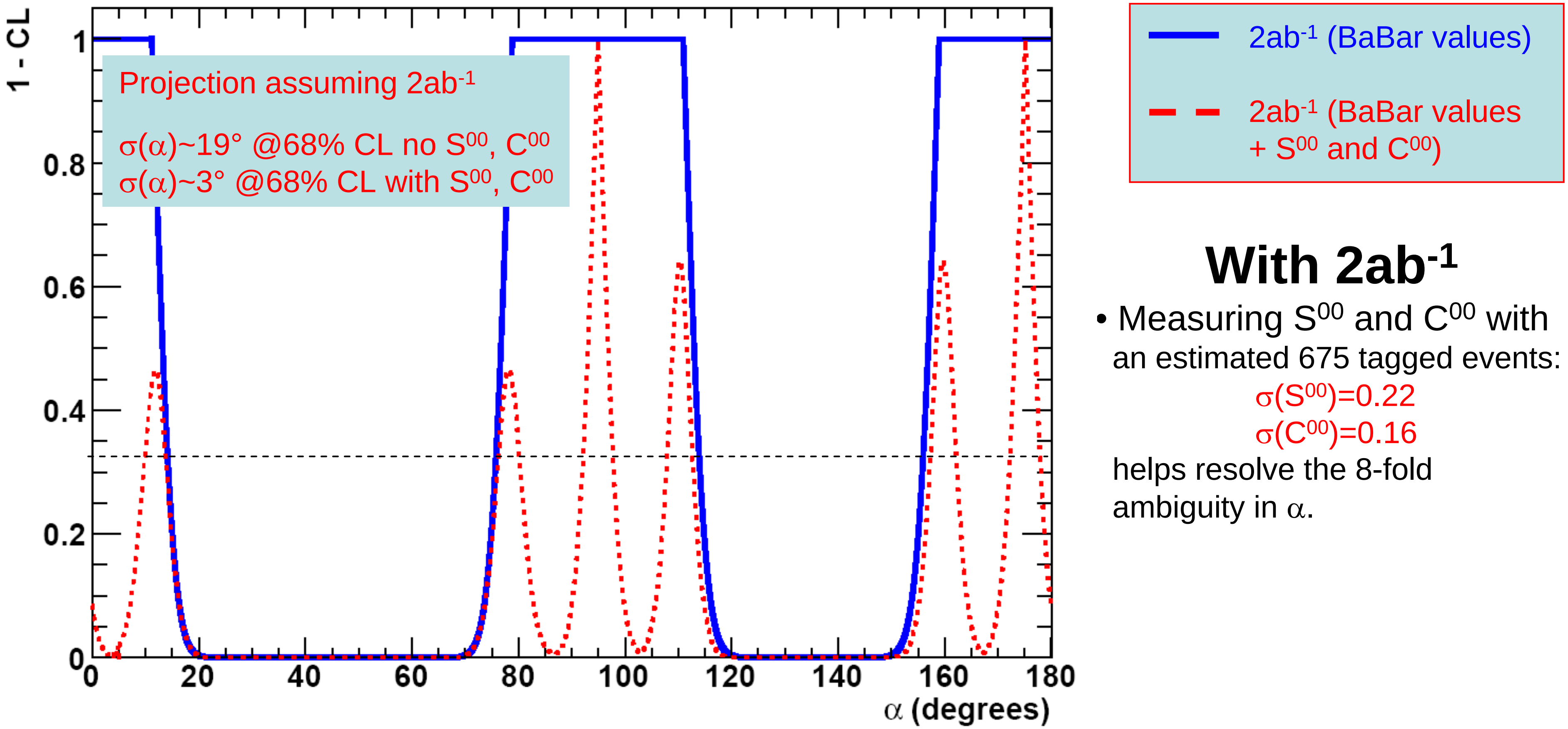


- $\delta\alpha^{ij} = \alpha^{ij}_{eff} - \alpha$ parameterise penguin pollution in +– and 00 charged final states.
- Relationship to S and C:

$$\sin(2\alpha^{+-}_{eff}) = \frac{S^{+-}}{\sqrt{1-(C^{+-})^2}},$$
$$\sin(2\alpha^{00}_{eff}) = \frac{S^{00}}{\sqrt{1-(C^{00})^2}},$$

SU(2) based methods: ρρ

- Projections at 2ab^{-1} #



With 2ab^{-1}

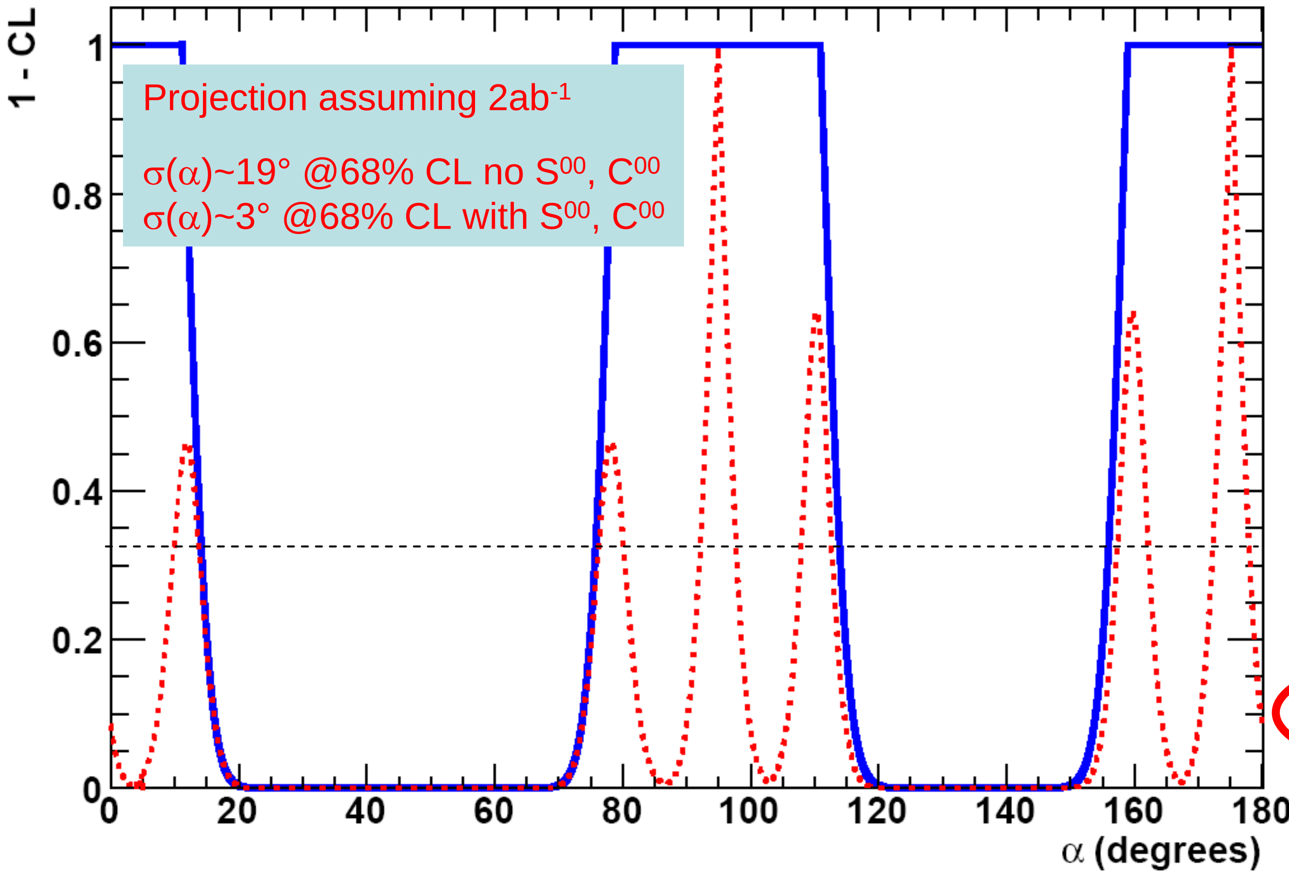
- Measuring S^{00} and C^{00} with an estimated 675 tagged events:
  $\sigma(S^{00})=0.22$
  $\sigma(C^{00})=0.16$
  helps resolve the 8-fold ambiguity in α.

 # assumed to be the final combined B-factory luminosity.

Assume $C^{00} = C^{+-} = 0$ and $\alpha = 95°$ for this study.

SU(2) based methods: ρρ

- Projections at $2ab^{-1}$ #



With $2ab^{-1}$

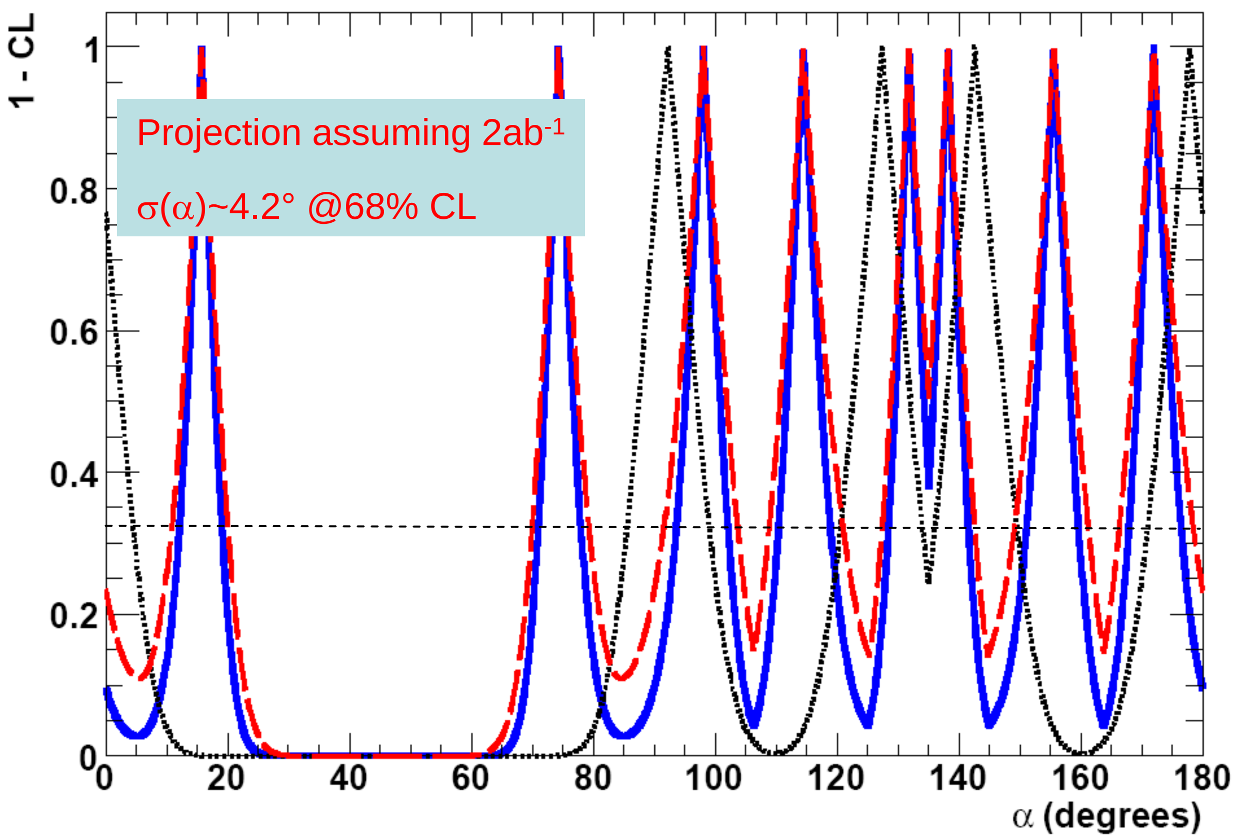
- Measuring S^{00} and C^{00} with an estimated 675 tagged events:
  $\sigma(S^{00})=0.22$
  $\sigma(C^{00})=0.16$
  helps resolve the 8-fold ambiguity in α.
- Provides the next big jump in the measurement of this angle.
- Lets wait and see what the B-factories measure!

assumed to be the final combined B-factory luminosity.

Assume $C^{00} = C^{+-} = 0$ and $\alpha = 95°$ for this study.

SU(2) based methods: $\pi\pi$

- Projections at $2ab^{-1}$ #



$1ab^{-1}$ (BaBar values)

$2ab^{-1}$ (BaBar values)

$2ab^{-1}$ (world average)

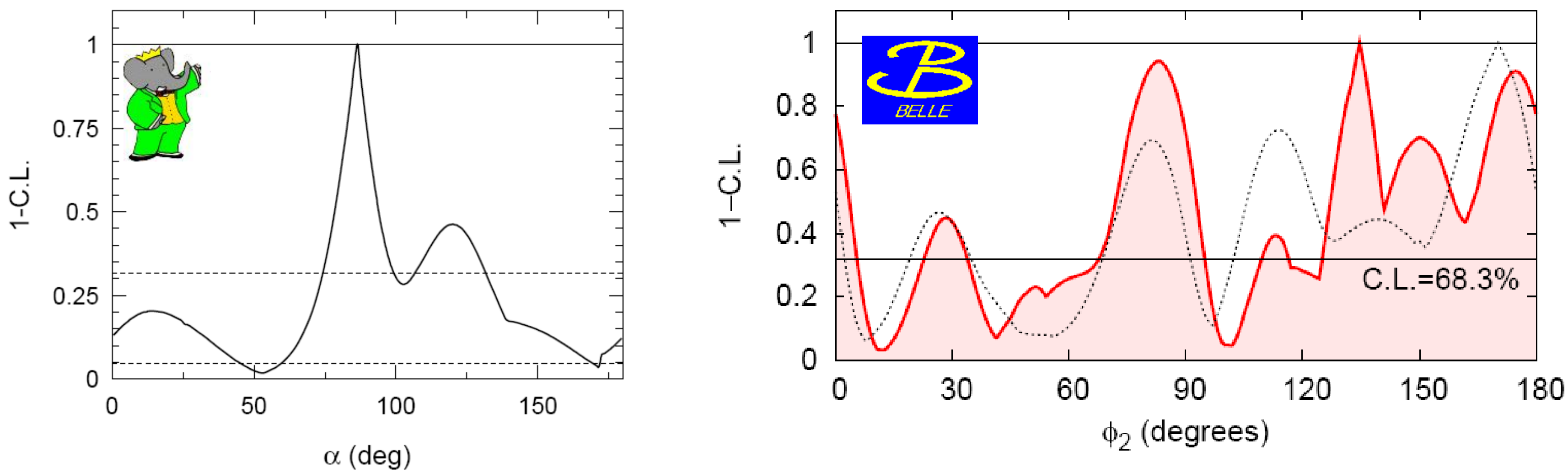
With $2ab^{-1}$

- Solution at 0° excluded using external information:
  Botella & Nebot arXive:0704.0174
  UTfit hep-ph/0701204.
- Region near 40° excluded at 90% CL.
- Start excluding mirror solution space at 90% CL.

assumed to be the final combined B-factory luminosity.

SU(2) based methods: $\pi^+\pi^-\pi^0$

- Theoretically clean, but experimentally challenging TD Dalitz plot analysis: The Snyder Quinn (**SQ**) method.
- Multi-parameter fit that is difficult to sensibly project to higher luminosities.



- No studies available with current statistics to understand systematic uncertainty limits of Dalitz model assumed etc.

hep-ex/0701015
hep-ex/0703008

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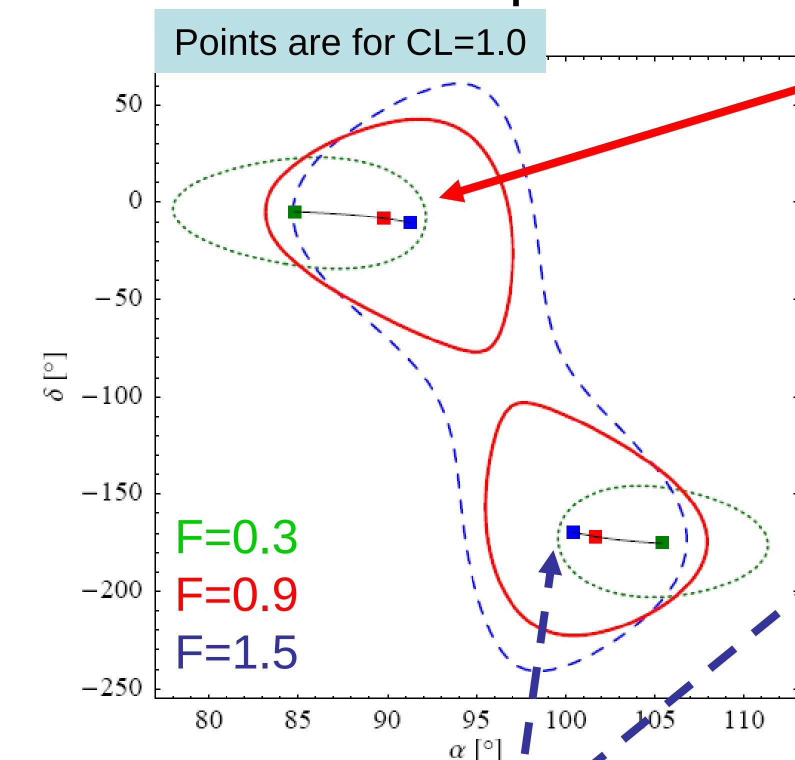
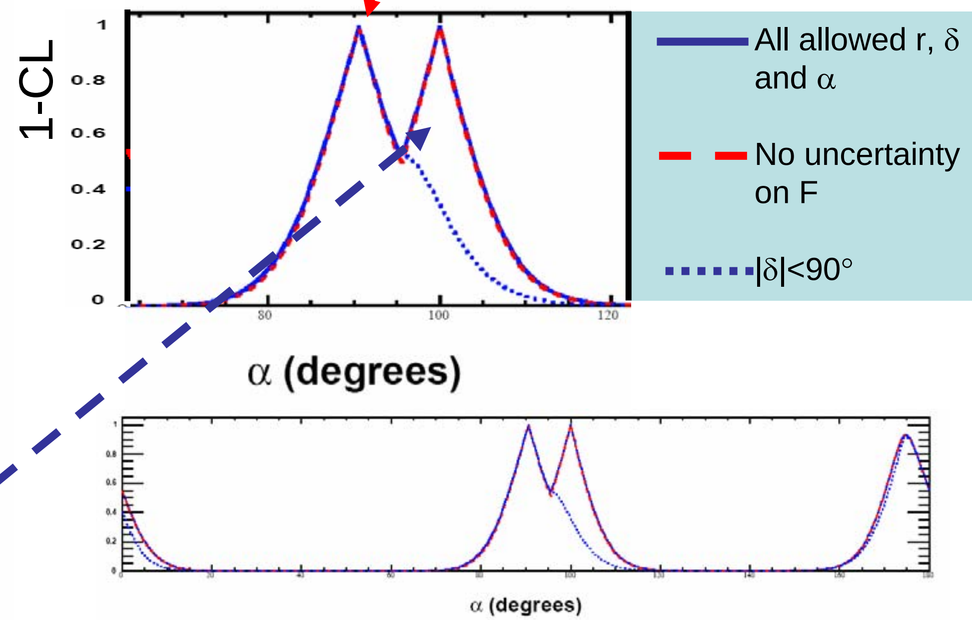
SU(3) based methods: ρρ

- Relate $K^{*0}\rho^{+}$ to the penguin contribution in $\rho^{+}\rho^{-}$ (**BGRS**):
  - Gives most precise single determination of α.

$\alpha \sim 90^\circ$ is preferred for $|\delta|<90^\circ$





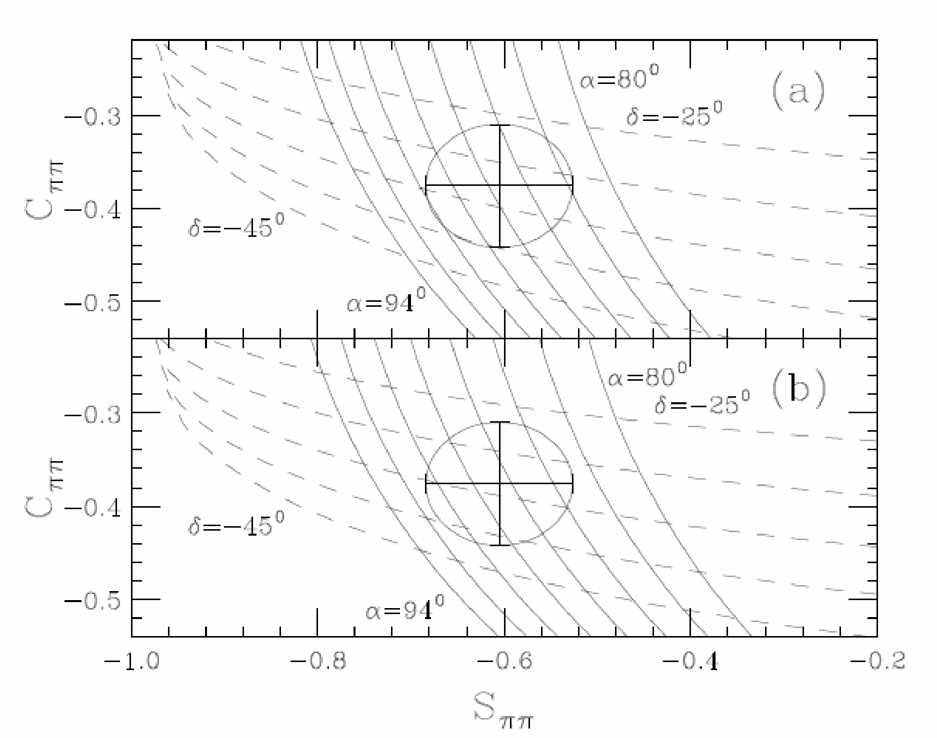
$\alpha \sim 100^\circ$ is preferred for $|\delta|>90^\circ$

$\sigma(\alpha) \sim 7^\circ(\text{expt.}) \pm 1.5\,^\circ(\text{th.})$

Beneke et al., Phys.Lett. B638 (2006) 68-73

SU(3) based methods: $\pi\pi$

- Relate $K\pi$ to the penguin contribution in $\pi^+\pi^-$ (**GR**):
  - Not as precise as **BGRS**.
  - 20% SU(3) breaking error.



Different values of α and δ correspond to different points in the $S_{\pi\pi}$ - $C_{\pi\pi}$ plane.

The measurements of $S_{\pi\pi}$ and $C_{\pi\pi}$ are used to extract constraints on α.

$\sigma(\alpha)\sim 4^\circ(\text{expt.})^{+10}_{-8}\,{}^\circ(\text{th.})$

Gronau and Rosner arXiv:0704.3459 [hep-ph]

SU(3) based methods: $a_1\pi$

- BaBar recently performed TDCPV measurement of $a_1\pi$.
  - α_{eff} =78.6 ±7.3° → as good $\rho\rho/\rho\pi$, but need to control penguin contribution to measure α.
- Proposal from Gronau and Zupan et al. to constrain penguins with SU(3): (**GZ**)
  - Need
    - $B\to K_1(1270)\pi$
    - $B\to K_1(1400)\pi$
    - $B\to a_1 K_{(s)}$

    to determine α
  - To early to make quantitative statements.

PRL **98** 181803 (2007)
PRD **73** 057502 (2006)

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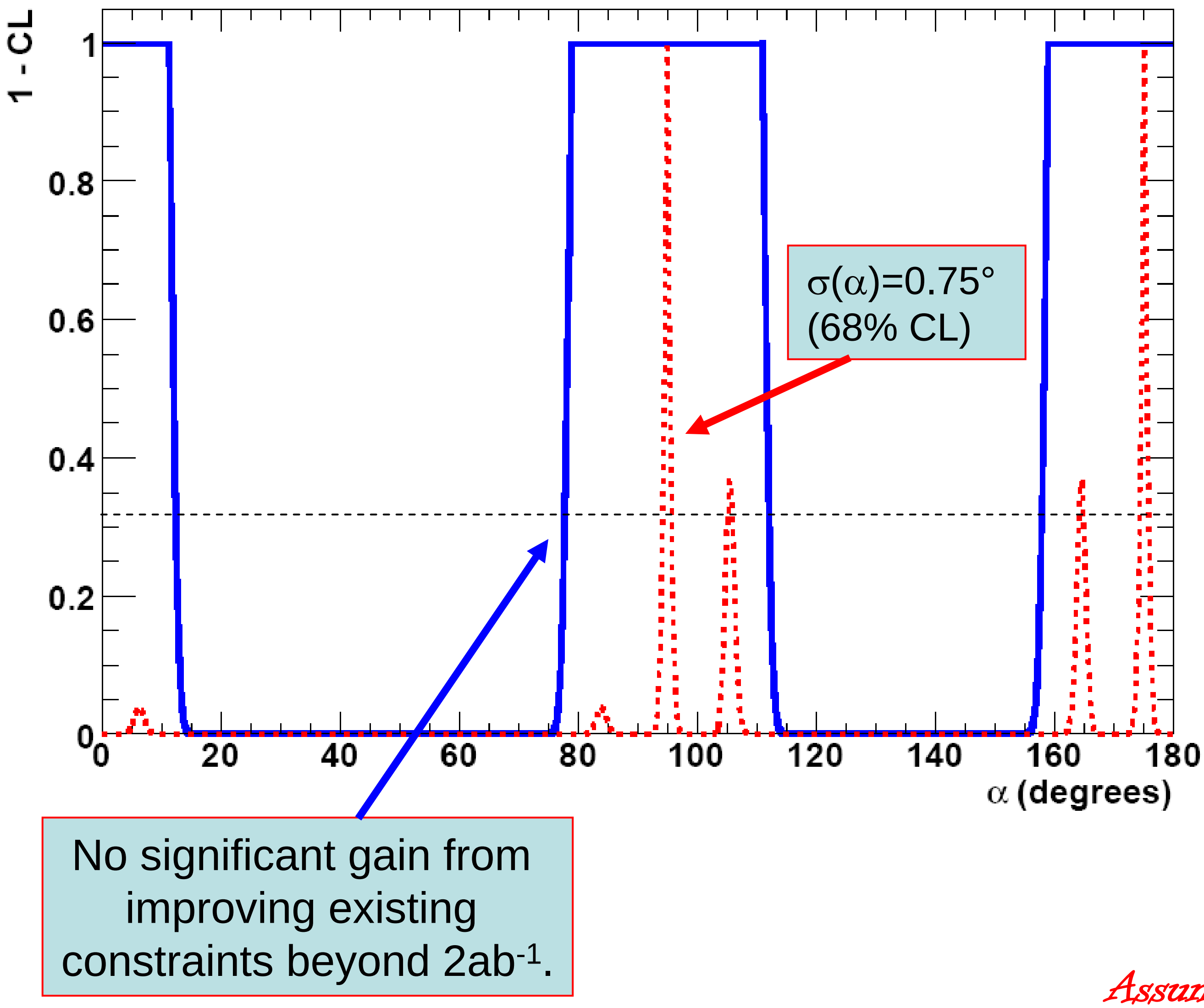
Precision with 75 ab^{-1}: $\rho\rho$



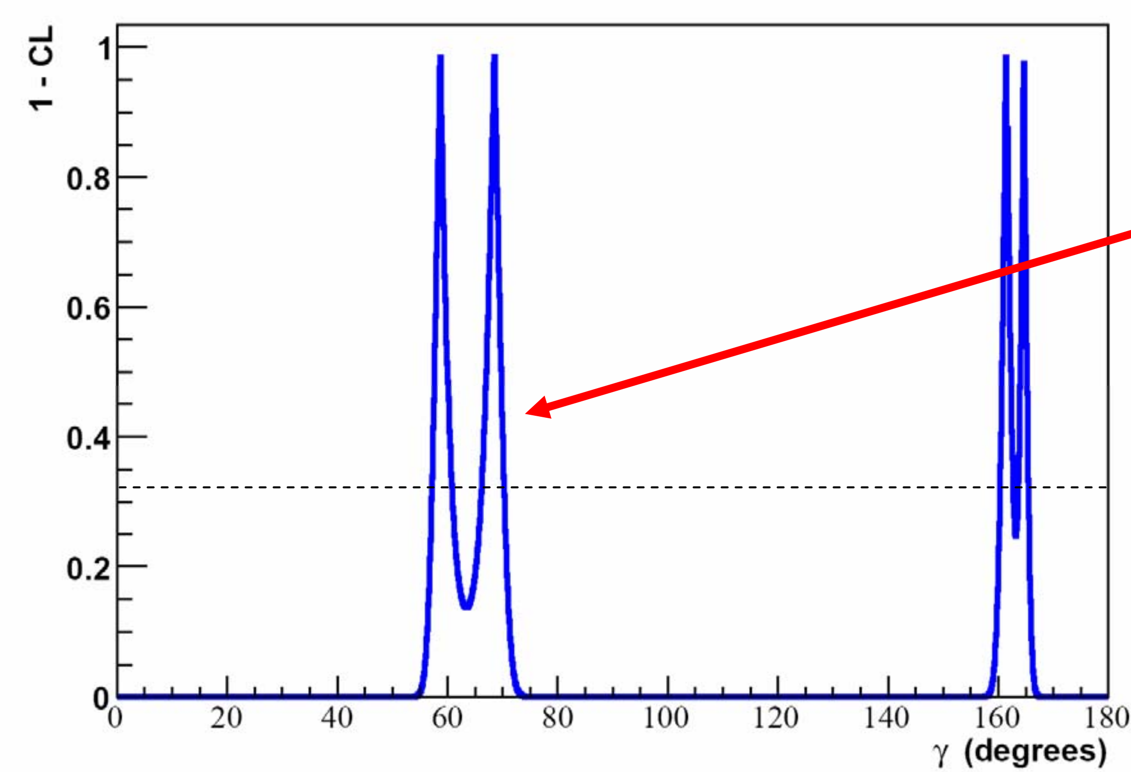
Predictions using the **GL** method.

- Measuring S^{00} and C^{00} means we can achieve a precision of $\sigma(\alpha)=0.75°$ with the **GL** method from $\rho\rho$ decays.
- Constrain penguins using CP violation measurements in $\rho^0\rho^0$ to achieve this.
- This is the most precise measurement of α obtainable at Super-B from the methods studied.

Assume $C^{00} = C^{+-} = 0$ and $\alpha = 95°$ for this study.

Precision with 75 ab^{-1}: $\rho\rho$

- SU(3) based BGRS method
  - Currently most precise single determination: $\sigma(\alpha)$~7°.
  - Error is dominated by SU(3) breaking uncertainties at 75ab^{-1}.

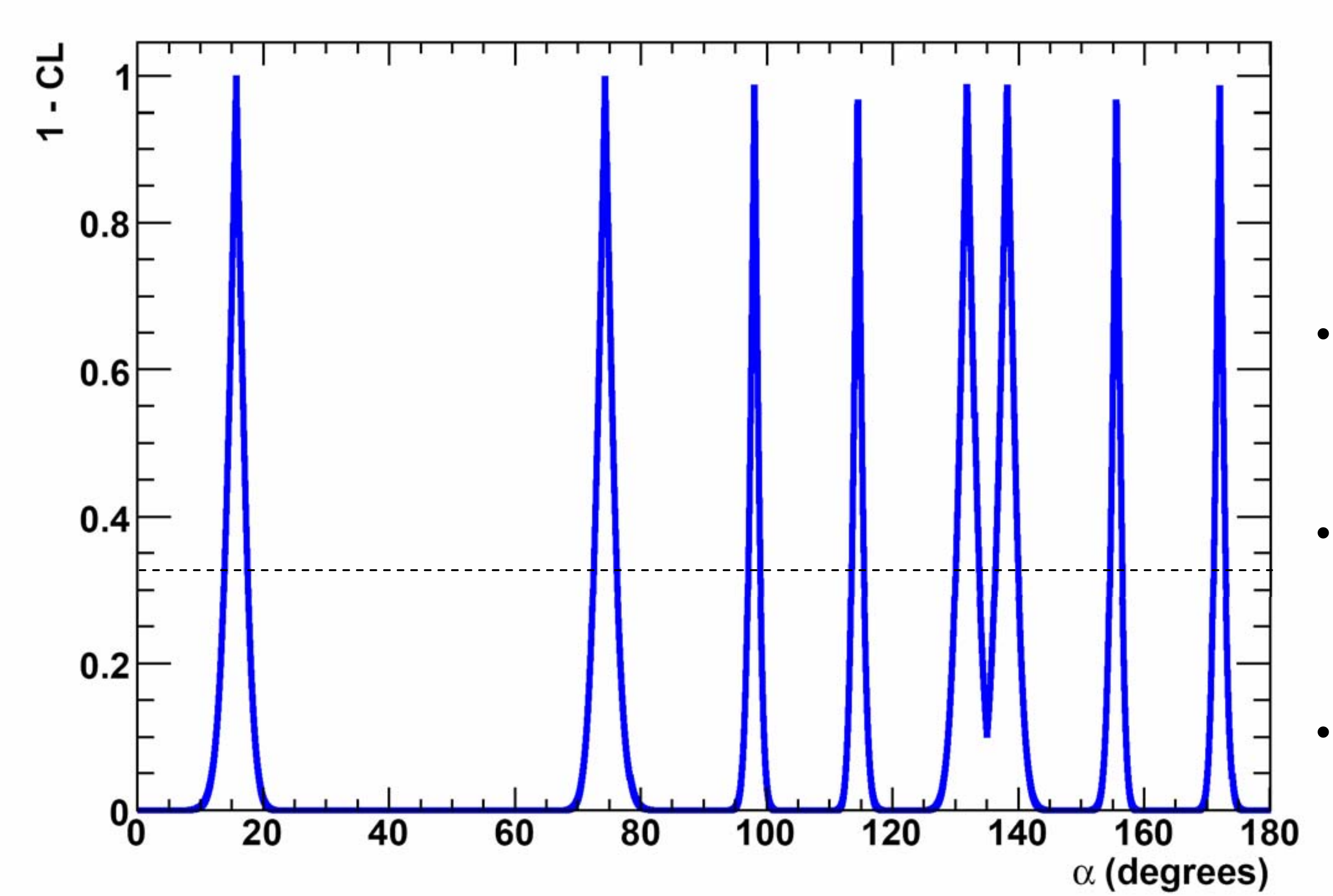


Error on α (or γ) is ~1.9° using the total data set of a Super-B factory.

This is limited by the uncertainties from annihilation/exchange contributions that are neglected in the model.

Assume α= 95° for this study.

Precision with 75 ab^{-1}: $\pi\pi$

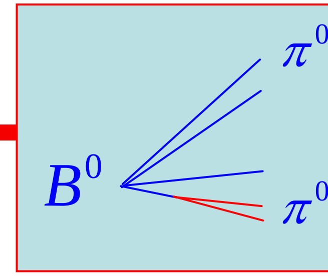


Predictions using the GL method.

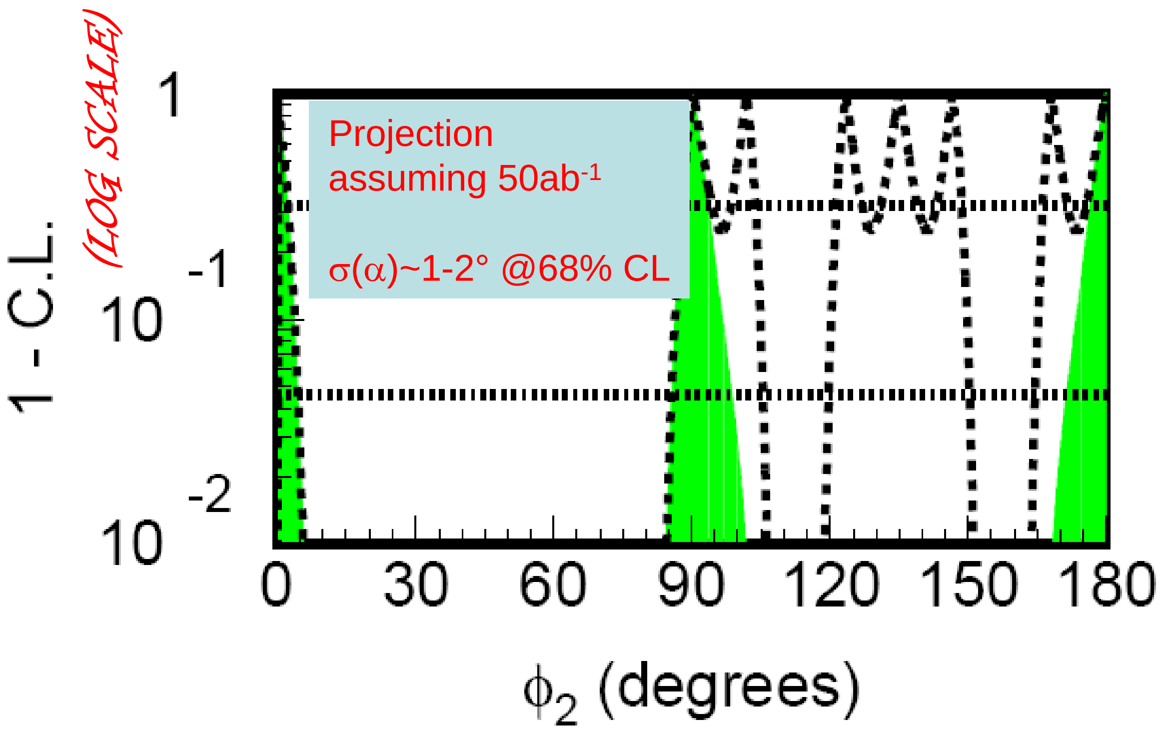
- All ambiguities are distinct solutions at 75ab^{-1} data samples.
- Precision of solutions vary from O(0.9) – O(1.9) degrees.
- Good Precision to combine with results from $B \rightarrow \rho\rho$.

Project current BaBar measurements to higher luminosity.

New tricks for old methods



- The $\pi\pi$ isospin analysis isn't over-constrained like $\rho\rho$: Can't measure S^{00} with a 4 γ final state.
  - But … can use external photon conversion to vertex $B \to \pi^0\pi^0$. So we can measure S^{00}.



Assumes α = 90°

Estimate: $\sigma(S^{00})$~0.23, which Can be used to
- rule out most non SM solutions for α.
- constrain ΔI=5/2 contributions.

Ishino et al. hep-ex/0703039

Limiting uncertainties at Super-B

- ππ $$\sigma_{\rho\rho}(\alpha) = 0.9 \sim 1.9 \text{ (expt)} \pm \text{ (th.)}$$
  - ΔI=5/2 amplitudes to test for.
  - SU(2) breaking in π^0–η–η' mixing.
  - Should be dominated by experimental uncertainty.

See the following Refs. (<u>not an exhaustive list</u>) for more details on sources of theoretical uncertainty: Gronau and Zupan PRD**71** 074017 (2005); Gardner PRD**72** 034015 (2005); hep-ph/9906269; Botella et al. PRD**73** 071501 (2006) …

- ρρ $$\sigma_{\rho\rho}(\alpha) = 0.75 \text{ (expt)} \pm 0.4 \text{ (EWP)}$$
  - I=1 amplitudes to test for.
  - ΔI=5/2 amplitudes to test for.
  - ρ-ω mixing to include in $\rho^+\rho^0$ and $\rho^0\rho^0$ measurements.
  - SU(3) method has a precision of O(2)°: Limited by theory uncertainties.

- ρπ $$\sigma_{\rho\pi}(\alpha) =^{+45}_{-13} \text{ (Currernt BaBar Error)}$$
  - Too complicated to make sensible projections for at the moment.

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See the following Refs. (<u>not an exhaustive list</u>) for more details on sources of theoretical uncertainty: Gronau and Zupan PRD**71** 074017 (2005); Gardner PRD**72** 034015 (2005); hep-ph/9906269; Botella et al. PRD**73** 071501 (2006) …

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Limit is experimental

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  - ΔI=5/2 amplitudes to test for.
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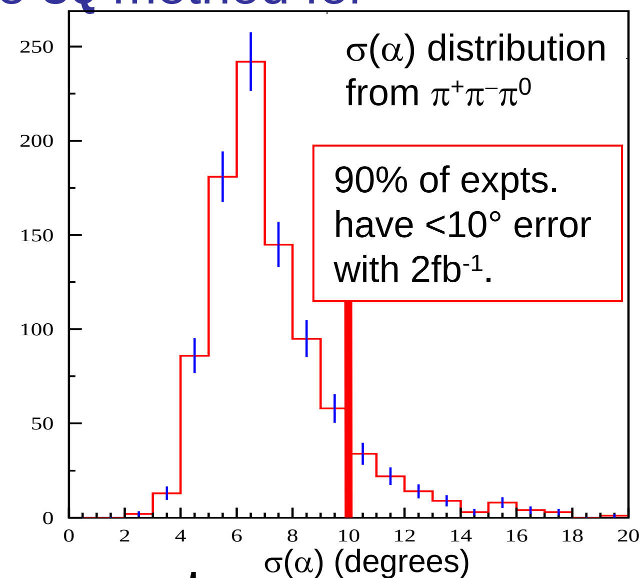
Potential of LHCb

- Most thoroughly studied channel:
  - $B \rightarrow \pi^+\pi^-\pi^0$
    - ~10° precision from $2fb^{-1}$ (1yr) using the **SQ** method for measuring α.
    - ~4.5° with $10fb^{-1}$.
- Other accessible channels:
  - Only list all charged final states
    - $\pi^+\pi^-$: contribute to the **GL** analysis
    - $\rho^0\rho^0$: contribute to the **GL** analysis
    - $a_1\pi$: contribute to the **GZ** analysis



- So we can expect σ~4.5° to be a worst case scenario with $10fb^{-1}$.
- Should also note the upgrade potential of LHCb.

LHCb-2005-024
O. Schneider @ LHCb upgrade WS

Concusion

- SU(2) Methods:
  - **GL** with $\pi\pi$ using S^{00}: $\sigma(\alpha)$ = 0.9-1.9°.
  - **GL** with $\rho\rho$ using S^{00} and C^{00}: $\sigma(\alpha)$ = 0.75°.
  - **SQ** with $\rho\pi$ … wait and see.

- SU(3) Methods:
  - The **BGRS** method for $\rho\rho$ currently gives the most stringent constraints than the **GL** result. Expect $\sigma(\alpha)$~2° from a Super-B factory.

- Sub 1°
  - The measurement of α will be a 3-step process: $\pi\pi+\rho\pi+\rho\rho$.

Overview

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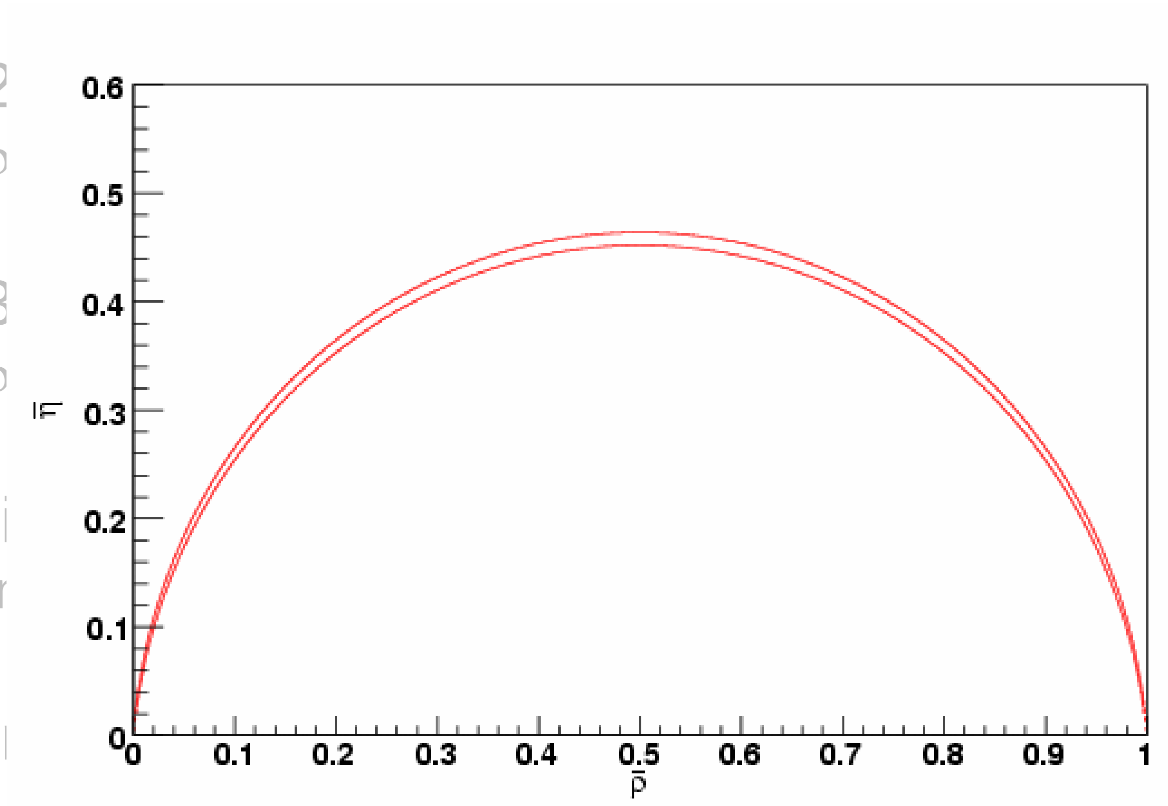
- SU(2
  - ρρ
- SU(3
  - ρρ
- Preci
  - Lir
- Pote



- Conclusion.
  - A sub 1° measurement of α is possible for $B\to\rho\rho$ and $B\to\pi\pi$ decays individually!

Scaling of Errors

- For the projections summarised here:
  - The statistical uncertainties have been scaled by $\sqrt{N}$.
  - The systematic uncertainties have been split into contributions that:
    - do not scale (e.g. detector performance: B counting, π^0, tracking, PID uncertainties etc.,
    - and those that do scale by $\sqrt{N}$.