Quantum entanglement at the $\psi(3770)$ and $\Upsilon(4S)$

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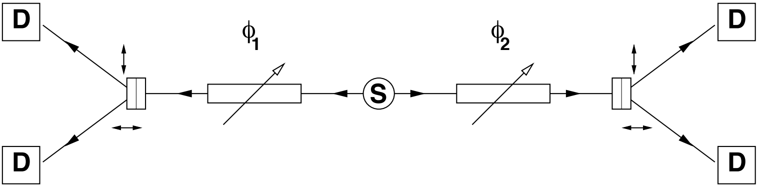
Flavor Physics & CP Violation Conference, NTU, Taipei, 6th May 2008

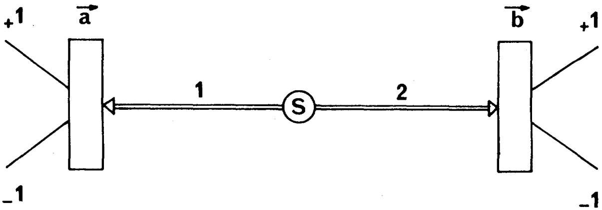


Outline

1. **The flavor singlet state**
   - Spin singlet: Einstein, Podolsky, and Rosen, via Bohm
   - Flavor singlet: $\mathrm{e}^+\mathrm{e}^- \to \Upsilon(4S) \to \frac{1}{\sqrt{2}}\left(|\mathrm{B}^0\rangle|\overline{\mathrm{B}}^0\rangle - |\overline{\mathrm{B}}^0\rangle|\mathrm{B}^0\rangle\right)$
2. **$\Upsilon(4S)$: EPR correlations at Belle**
   - On what can and cannot be measured; Or, conspiracy
   - QM *versus* specific LR models
   - The 2007 Belle result
3. **$\psi(3770)$: CLEO-c rates are tangled up with (x, y), δ, . . .**
   - $\mathrm{D}^0 \to \mathrm{K}^0_{S,L}\pi^0$
   - Charm mixing and $\delta_{\mathrm{K}\pi}$
4. **ϕ_3/Dalitz: $\psi(3770)$ rescues the $\Upsilon(4S)$**
   - Current results (Belle and BaBar)
   - Model-independent analysis
5. **Summary**

Einstein, Podolsky, and Rosen, via Bohm

spin-singlet state of photons or particles: $\frac{1}{\sqrt{2}}\left[|\Uparrow\rangle_1 |\Downarrow\rangle_2 - |\Downarrow\rangle_1 |\Uparrow\rangle_2\right]$



- measurements on 1 (2) indeterminate, but $\Longrightarrow$ full knowledge of 2 (1)
- Bell's Theorem (via Clauser, Horne, Shimony, and Holt):
  - correlation coeff: $E(\vec{a},\vec{b}) = \frac{R_{++}(\vec{a},\vec{b})+R_{--}(\vec{a},\vec{b})-R_{+-}(\vec{a},\vec{b})-R_{-+}(\vec{a},\vec{b})}{R_{++}(\vec{a},\vec{b})+R_{--}(\vec{a},\vec{b})-R_{+-}(\vec{a},\vec{b})+R_{-+}(\vec{a},\vec{b})}$
  - $S = E\left(\vec{a},\vec{b}\right) - E\left(\vec{a},\vec{b}'\right) + E\left(\vec{a}',\vec{b}\right) + E\left(\vec{a}',\vec{b}'\right)$
  - $|S| \leq 2$ for any local realistic model; $S_{QM} = \pm 2\sqrt{2}$ for optimal settings
- QM-like results rule out LR, even if we eventually "get behind" QM

Einstein, Podolsky, and Rosen, via Bohm: Aspect

Aspect et al., Phys. Rev. Lett. 92, 91 (1982)

source: 2-photon cascade decay

ν_1, ν_2 polarizations are correlated

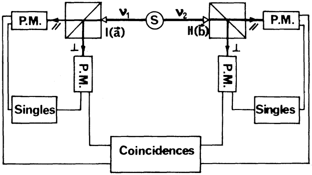


FIG. 2. Experimental setup. Two polarimeters I and II, in orientations $\vec{a}$ and $\vec{b}$, perform true dichotomic measurements of linear polarization on photons ν_1 and ν_2. Each polarimeter is rotatable around the axis of the incident beam. The counting electronics monitors the singles and the coincidences.

[two-channel polarimeters used]

correlation coeffs in data *vs* QM

optimum relative angles 22.5° and 67.5°

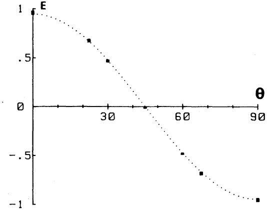


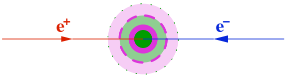
FIG. 3. Correlation of polarizations as a function of the relative angle of the polarimeters. The indicated errors are ±2 standard deviations. The dotted curve is not a fit to the data, but quantum mechanical predictions for the actual experiment. For ideal polarizers, the curve would reach the values ±1.

$$S = 2.697 \pm 0.015;\ cf.\ S_{QM} = 2.70 \pm 0.05$$

$e^+e^- \to \Upsilon(4S) \to$ [flavor singlet state of] $B^0\overline{B}^0$

the B-pair has the same property, substituting flavor for spin/polarization:

- the $\Upsilon(4S)$ is C-odd



Y(4S) resonance

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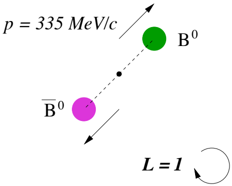

$$|\Psi(t)\rangle = \frac{e^{-t/\tau_{B^0}}}{\sqrt{2}} \left[|B^0(\vec{p})\overline{B}^0(-\vec{p})\rangle - |\overline{B}^0(\vec{p})B^0(-\vec{p})\rangle \right]$$

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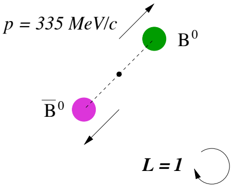

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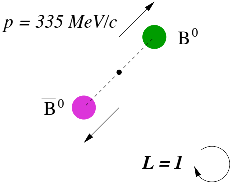

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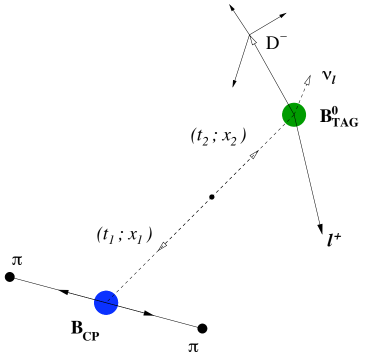
- flagship B-factory measurements:

$$\begin{cases} B^0_{TAG} & \text{definite flavor state} \\ B^0_{CP} & \text{definite CP state} \end{cases}$$



$$\Gamma_{CP}(\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}} \left[1 \pm \{S_{CP} \sin(\Delta m \Delta t) + A_{CP} \cos(\Delta m \Delta t)\}\right]$$

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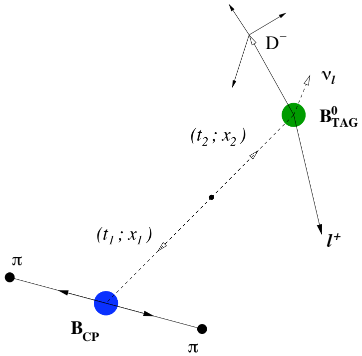

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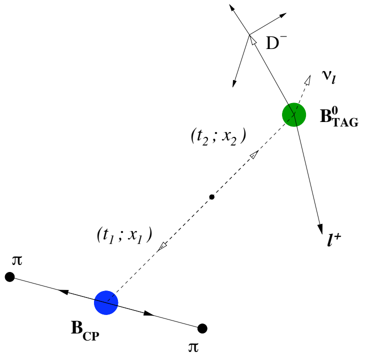

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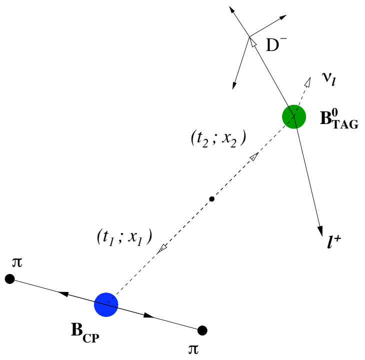
  - and another rate for $\overline{B}^0_{TAG}$: CPV

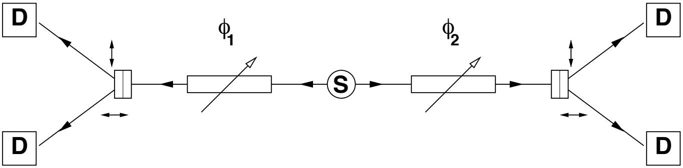


$$\Gamma_{CP}(\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}} \left[1 - \{S_{CP}\sin(\Delta m \Delta t) + A_{CP}\cos(\Delta m \Delta t)\}\right]$$

$\Upsilon(4S)$: On what can and cannot be measured

we can instead assume the B-physics, and study the entanglement:

- quasi-spin: $\begin{cases} |\mathrm{B}^0\rangle & \text{corresponds to spin } |\Uparrow\rangle_z \text{ or polarization } |V\rangle \\ |\overline{\mathrm{B}}^0\rangle & \text{corresponds to spin } |\Downarrow\rangle_z \text{ or polarization } |H\rangle \end{cases}$
- optical measurements can use arbitrary axes $\alpha|\Uparrow\rangle + \beta|\Downarrow\rangle$
- for B-mesons, only $|\Uparrow\rangle$ and $|\Downarrow\rangle$ measurements are practical
- but $|\mathrm{B}^0\rangle \xrightarrow{t} \frac{1}{2}\left[\{1 + \cos(\Delta m_d t)\}|\mathrm{B}^0\rangle + \{1 - \cos(\Delta m_d t)\}|\overline{\mathrm{B}}^0\rangle\right]$
- *time difference* $\Delta m_d \Delta t$ plays the role of angle difference $\Delta\phi$



- unfortunately we can't *choose* the $\phi_{1,2}$, or the decay modes ...

$\Upsilon(4S)$: The Green Baize Table Conspiracy Model

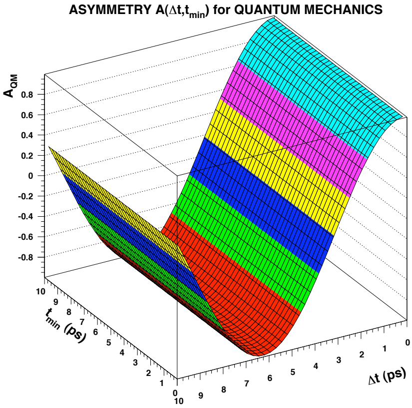
Bramon/Escribano/Garbarino, J. Mod. Opt. 52, 1681 (2005) via Chris Carter

- somewhere, there is a wood-panelled room with a green baize table
- men meet there together, smoke, and make conspiracy . . .
  and decide *everything* that happens *in detail*: including $\Upsilon(4S) \to \mathrm{B}\overline{\mathrm{B}}$
- hidden variables set at $t = 0$:
  - mesons 1 & 2 are given variables (t_1, f_1) & (t_2, f_2)
  - act locally: meson i decays
    - at time $t = t_i$
    - into final state $f = f_i$
- if (t_1, f_1, t_2, f_2) are chosen randomly according to QM . . .
  the phenomena look like QM!
- no $\Delta\phi$ choice: no Bell test

$\Upsilon(4S)$: QM versus specific LR models

QM's entangled flavor oscillations $\Longrightarrow$ distinctive modulation of opposite (OF) & same flavor (SF) decays: $A(t_1, t_2) = (R_{OF} - R_{SF})/(R_{OF} + R_{SF})$

- $A_{QM}(t_1, t_2) = \cos(\Delta m_d \Delta t)$



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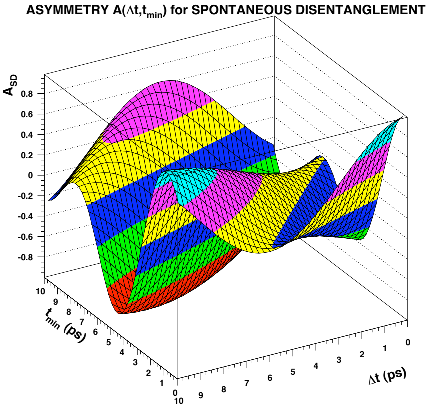

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- Pompili-Selleri class of models:
  $A_{PS}^{min} = 1 - \min(2 + \Psi, 2 - \Psi)$;
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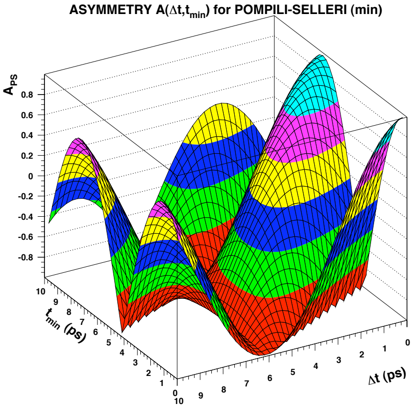

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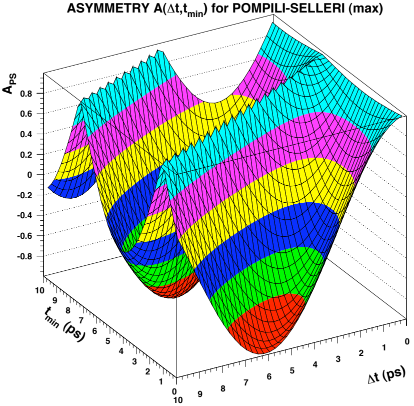
- & upper bound $A_{PS}^{max} = 1 - |\{1 - \cos(\Delta m_d \Delta t)\}\cos(\Delta m_d t_{\min}) + \sin(\Delta m_d \Delta t)\sin(\Delta m_d t_{\min})|$



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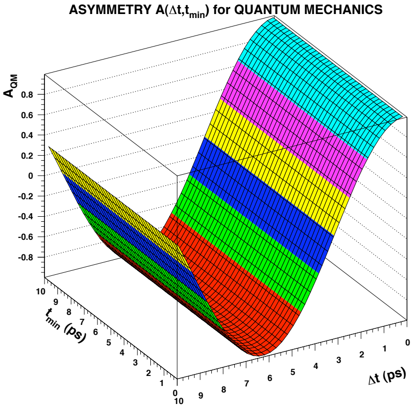
- measure only Δm_d: $\int \mathrm{d}t_{min} A$ ...



$\Upsilon(4S)$: "Measurement of EPR-type Flavor Entanglement ..." (1)

Belle: A. Go, A. Bay et al., Phys. Rev. Lett. 99, 131802 (2007)

- 152×10^6 $\mathrm{B\overline{B}}$ data sample; established Belle tCPV machinery:
  - reconstruct one B in flavor-tagging mode $\mathrm{B}^0 \to \mathrm{D}^{*-}\ell^+\nu$
  - tag other B-flavor using lepton; consistency check to maintain purity
  - 8565 events: 6718 OF, 1847 SF pairs, in 11 bins of Δt
- backgrounds subtracted from OF/SF samples separately, in Δt bins:

$$\begin{cases} \text{fake } \mathrm{D}^*\text{, using sidebands} & 126 \pm 6 \text{ OF}, \quad 54 \pm 4 \text{ SF} \\ \text{bad } \mathrm{D}^* - \ell \text{ combinations, also from data} & 78 \pm 9 \text{ OF}, \quad 236 \pm 15 \text{ SF} \\ \mathrm{B}^+ \to \overline{\mathrm{D}}^{**0}\ell\nu\text{, from } \cos_{\mathrm{B,D}^*\ell} \text{ \& MC} & 254 \quad \text{OF}, \quad 1.5\ (\pm 6\%) \end{cases}$$

  produces a time-structured difference in the asymmetry $\longrightarrow$
- $(1.5 \pm 0.5)\%$ correction for mistagging
- deconvolution (DSVD: SF,OF separately) to remove σ_{vtx}, ϵ effects ...
  [bias among QM/SD/PS subtracted; systematics assigned]
- successful lifetime fit as check: $\tau_{\mathrm{B}^0} = (1.532 \pm 0.017)\,\mathrm{ps}$, *cf.* 1.530

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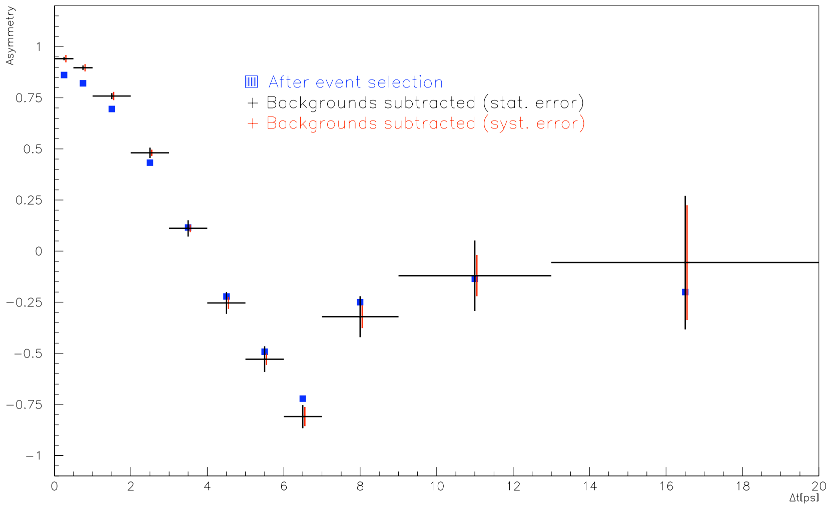

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bad $\mathrm{D^*} - \ell$ combinations, also from data	78 ± 9 OF,	236 ± 15 SF
$\mathrm{B^+ \to \overline{D}^{**0}}\ell\nu$, from $\cos_{\mathrm{B,D^*}\ell}$ & MC	254 OF,	1.5 ($\pm$6%)

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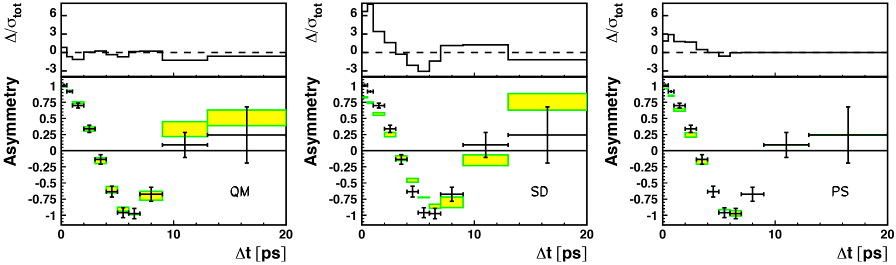
$\Upsilon(4S)$: "Measurement of EPR-type Flavor Entanglement ..." (2)

Belle: A. Go, A. Bay et al., Phys. Rev. Lett. 99, 131802 (2007)

fit: float Δm_d subject to WA-*sans*-(Belle+BaBar): $(0.496 \pm 0.014)\,\mathrm{ps}^{-1}$



QM fits well	SD disfavoured: 13σ	PS disfavoured: 5.1σ
$\chi^2/n_{dof} = 5/11$	$\chi^2/n_{dof} = 174/11$	$\chi^2/n_{dof} = 31/11$

- "SD fraction": $(1 - \zeta_{\mathrm{B^0\overline{B}^0}})A_{QM} + \zeta_{\mathrm{B^0\overline{B}^0}}A_{SD}$, $\zeta_{\mathrm{B^0\overline{B}^0}} = 0.029 \pm 0.057$
- Pompili-Selleri class: QM-like states, stable mass, flavor correlations; QM predictions for *single* B-*mesons* preserved

CPV at the $\Upsilon(4S)$; CP-tagging at the $\psi(3770)$?

Asner and Sun, Phys. Rev. D 73, 034024 (2006); 77, 019902(E) (2008)

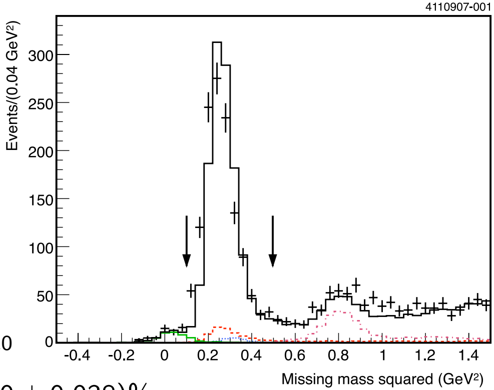
- *formally*, the situation at the $\psi(3770)$ is the same as at the $\Upsilon(4S)$:
  - $\mathrm{e}^+\mathrm{e}^- \to \psi(3770) \to \frac{1}{\sqrt{2}}\left(|\mathrm{D}^0\rangle|\overline{\mathrm{D}}{}^0\rangle - |\overline{\mathrm{D}}{}^0\rangle|\mathrm{D}^0\rangle\right)$ and so on
  - practical difference #1: mixing is a %-level effect in D-amplitudes
  - practical difference #2: CPV is suppressed orders of magnitude further
- *naïvely*, the C-odd state is $\begin{cases}\text{all about CP violation} & \text{at } \Upsilon(4S) \\ \text{all about CP-tagging} & \text{at } \psi(3770)\end{cases}$
  - *e.g.* decays to two CP-even (or two CP-odd) eigenstates don't occur
  - but consider the decay $\psi(3770) \to (\mathrm{K}^-\pi^+)_\mathrm{D}(\mathrm{K}^-\pi^+)_\mathrm{D}$:
    - reduced to the *mixing rate* $R_M = \frac{1}{2}(x^2 + y^2)$
    - *cf.* rate from uncorrelated $\mathrm{D}\overline{\mathrm{D}}$: $R_{WS} \simeq 40 \times R_M$
- there are nontrivial effects due to the coherence of the state
- need an orderly treatment for CLEO-c: Asner & Sun, *op. cit.*, following Gronau/Grossman/Rosner and others

$\psi(3770)$: $\mathrm{D}^0 \to \mathrm{K}^0_{S,L}\pi^0$

CLEO: Q. He et al, Phys. Rev. Lett. 100, 091801 (2008)

simple example: $\mathrm{D}^0 \to \mathrm{K}^0_L\pi^0$ reconstruction in tagged events with M^2_{miss}

- actually three samples:
  - $\overline{\mathrm{D}}^0 \to \mathrm{K}^+\pi^-$ tag
  - $\overline{\mathrm{D}}^0 \to \mathrm{K}^+\pi^-\pi^0$ tag
  - $\overline{\mathrm{D}}^0 \to \mathrm{K}^+\pi^-\pi^-\pi^+$ tag
- rate for tag f gives $\mathcal{B}_{\mathrm{K}^0_L\pi^0}\left(1 + \frac{2r_f\cos\delta_f + y}{1+R_{WS,f}}\right)$
- $r_f e^{-i\delta_f} \equiv \langle f|\overline{\mathrm{D}}^0\rangle / \langle f|\mathrm{D}^0\rangle$ & $R_{WS,f}$ are mode-dependent
- measure product in $\mathrm{D}^0 \to \mathrm{K}^0_S\pi^0$



- $\mathcal{B}_{\mathrm{K}^0_L\pi^0} = (0.998 \pm 0.049 \pm 0.030 \pm 0.038)\%$;

  $(\mathcal{B}_{\mathrm{K}^0_L\pi^0} - \mathcal{B}_{\mathrm{K}^0_L\pi^0})/(\mathcal{B}_{\mathrm{K}^0_L\pi^0} + \mathcal{B}_{\mathrm{K}^0_L\pi^0}) = 0.108 \pm 0.025 \pm 0.024$ (*cf.* $2\tan\theta_C$)

$\psi(3770)$: Charm mixing and $\delta_{K\pi}$ (1)

CLEO: Rosner et al, `arXiv:0802.2264` → PRL; Asner et al, `0802.2268` → PRD

correlations $\Longrightarrow$ interference terms depend on (x, y, δ) in general

use single tag (ST) rates for $\mathcal{B}$'s; double tag (DT) for correlations

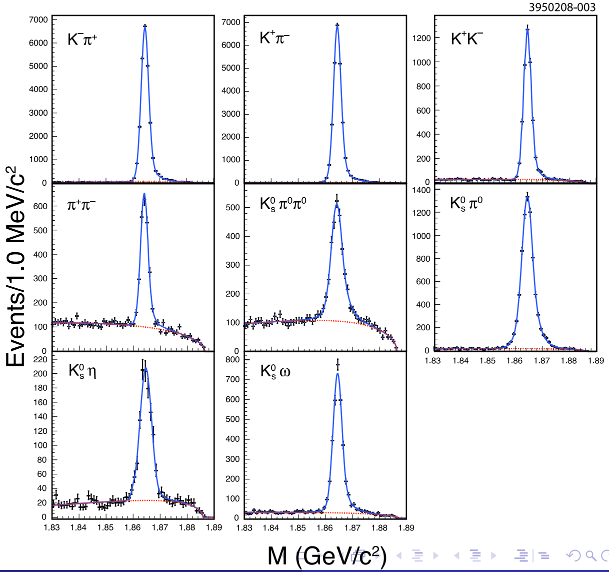
Mode	Correlated	Uncorrelated
$K^-\pi^+$	$1 + R_{\rm WS}$	$1 + R_{\rm WS}$
S_+	2	2
S_-	2	2
$K^-\pi^+, K^-\pi^+$	$R_{\rm M}$	$R_{\rm WS}$
$K^-\pi^+, K^+\pi^-$	$(1 + R_{\rm WS})^2 - 4r\cos\delta(r\cos\delta + y)$	$1 + R_{\rm WS}^2$
$K^-\pi^+, S_+$	$1 + R_{\rm WS} + 2r\cos\delta + y$	$1 + R_{\rm WS}$
$K^-\pi^+, S_-$	$1 + R_{\rm WS} - 2r\cos\delta - y$	$1 + R_{\rm WS}$
$K^-\pi^+, e^-$	$1 - ry\cos\delta - rx\sin\delta$	1
S_+, S_+	0	1
S_-, S_-	0	1
S_+, S_-	4	2
S_+, e^-	$1 + y$	1
S_-, e^-	$1 - y$	1

grand least-squares fit

- 8 ST yields: $\longrightarrow$
- 43 DT yields:
  - 24 full recon
  - 14 semileptonic
  - 5 $K^0_L\pi^0$
- 7 external $\mathcal{B}$ [CP eigenstates, & $K^-\pi^+$ (correlated)]

result: poor $\sigma_y \Longrightarrow$ $x \sin\delta$ unconstrained

- "extended" fit adds external meas^{ts}: y, x, r^2, y', $(x')^2$

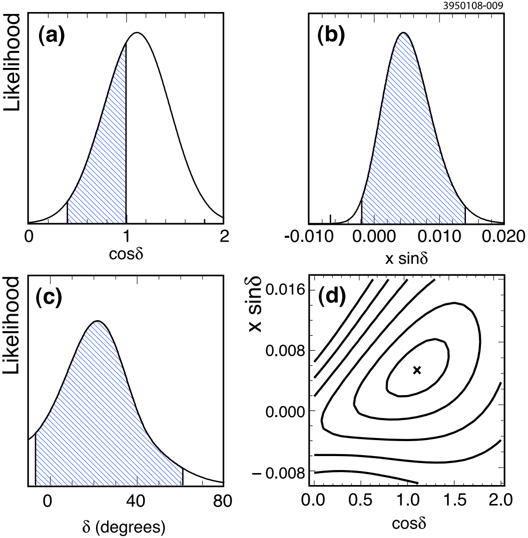


$\psi(3770)$: Charm mixing and $\delta_{K\pi}$ (3)

CLEO: Rosner et al, `arXiv:0802.2264` → PRL; Asner et al, `0802.2268` → PRD

- $\cos\delta = 1.10 \pm 0.35 \pm 0.07$
- $x \sin\delta = (4.4^{+2.7}_{-1.8} \pm 2.9) \times 10^{-3}$
- minimising on physical $(\cos\delta, \sin\delta)$ surface:
  $\delta = (22^{+11+9}_{-12-11})^\circ$
  $\delta \in [-7^\circ, +61^\circ]$ @ 95%
- $\cos\delta$ precision driven by
  - $\{K\pi, S_\pm\}$ DT yields
  - ST yields

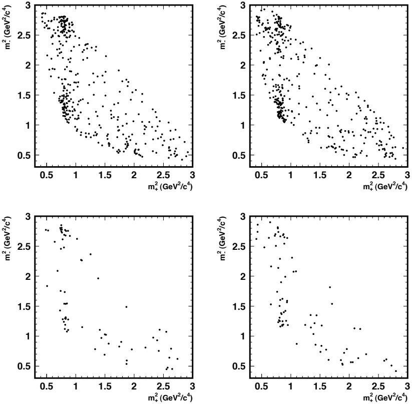
  ("both 100%")
- this is with $281\,\mathrm{pb}^{-1}$



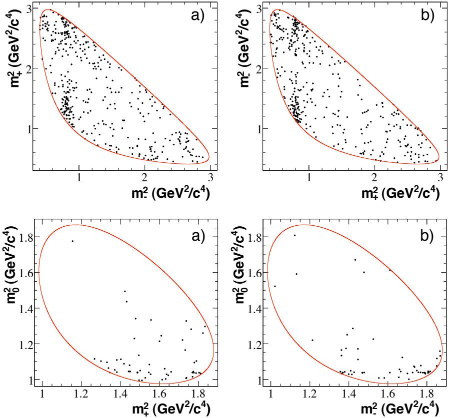
ϕ_3/Dalitz: The state of play

updated Belle `arXiv:0803.3375` prelim AND BaBar `arXiv:0804.2089` → PRD

Belle $\phi_3 = (76^{+12}_{-13} \pm 4 \pm 9)^\circ$



BaBar $\phi_3 = (76 \pm 22 \pm 5 \pm 5)^\circ$



(see Anton Poluektov's talk from Monday); σ_{model} already uncomfortable

ϕ_3/Dalitz: Model-independent analysis

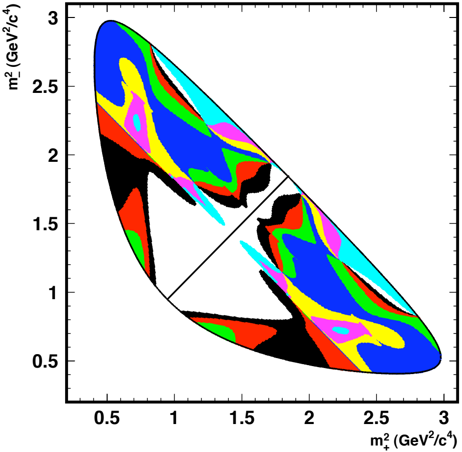
Bondar & Poluektov `arXiv:0801.0840` → EPJC; following EPJC 47, 247 (2006)

extract from $\psi(3770)$ data:

$c = \cos(\delta_D(m_+^2, m_-^2) - \delta_D(m_-^2, m_+^2))$

$s = \sin(\delta_D(m_+^2, m_-^2) - \delta_D(m_-^2, m_+^2))$

1. advance:
   nonobvious binning,
   uniform in $\Delta\delta_D|_{model}$



ϕ_3/Dalitz: Model-independent analysis

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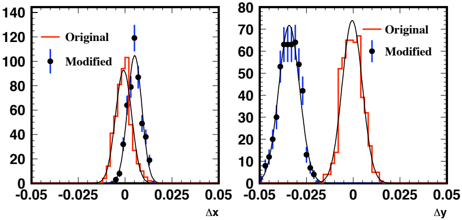
1. advance:
   nonobvious binning,
   uniform in $\Delta\delta_D|_{model}$
2. drawback: bias for finite
   $D_{CP} \to K_S^0\pi^+\pi^-$ sample



generate in one model,
reconstruct with another:
model dependence returns

(only c_i reconstructed; shift in
δ_D region breaks s_i recovery)

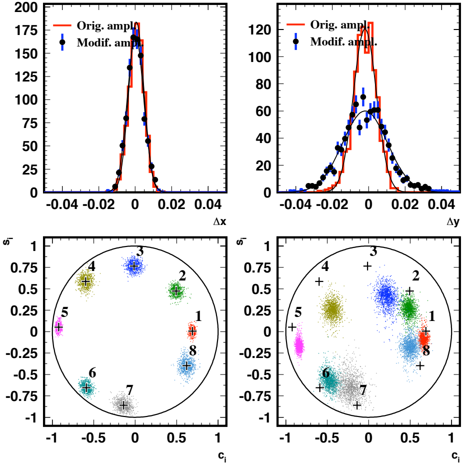
ϕ_3/Dalitz: Model-independent analysis

Bondar & Poluektov `arXiv:0801.0840` → **EPJC; following EPJC 47, 247 (2006)**

extract from $\psi(3770)$ data:

$c = \cos(\delta_D(m_+^2, m_-^2) - \delta_D(m_-^2, m_+^2))$
$s = \sin(\delta_D(m_+^2, m_-^2) - \delta_D(m_-^2, m_+^2))$

1. advance:
   nonobvious binning,
   uniform in $\Delta\delta_D|_{model}$
2. drawback: bias for finite $\mathrm{D}_{CP} \to \mathrm{K}_S^0\pi^+\pi^-$ sample
3. renewed attack:
   $\{c_i, s_i\}$ determined in
   $\psi(3770) \to (\mathrm{K}_S^0\pi\pi)_\mathrm{D}(\mathrm{K}_S^0\pi\pi)_\mathrm{D}$;
   unbiassed at finite stats



Summary

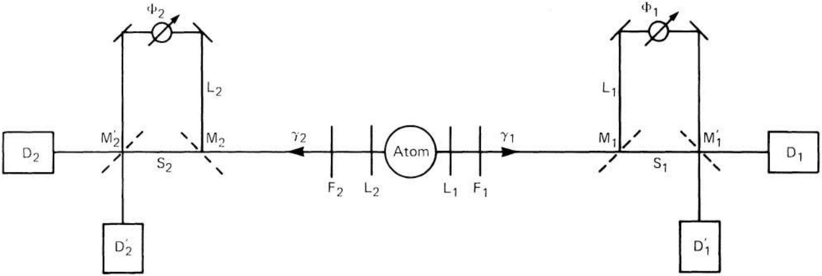
- entangled D-pairs lift model-dependence of ϕ_3/Dalitz analysis
    - CLEO-c will already be necessary for final B-factory results
    - BESIII results will be needed for super-B/flavor analysis
    - opposite-side CP tagged $\mathrm{D}^0 \to \mathrm{K}^0_S\pi^+\pi^-$ help;
      $\psi(3770) \to (\mathrm{K}^0_S\pi^+\pi^-)_\mathrm{D}(\mathrm{K}^0_S\pi^+\pi^-)_\mathrm{D}$ are crucial
- entanglement in $\psi(3770) \to \mathrm{D}^0\overline{\mathrm{D}}^0$ modulates tagged decay rates
    - has to be taken into account for $\mathrm{D}^0 \to \mathrm{K}^0_L\pi^0$ measurement
    - gives mixing- and $\delta_{\mathrm{K}\pi}$-sensitivity for $\{S_+, S_-, \mathrm{K}\pi, \ldots\}$)
    - $\cos\delta_{\mathrm{K}\pi} = (1.10^{+0.31}_{-0.17} \pm 0.06)$; (x,y) constraints $\to \delta_{\mathrm{K}\pi} = (22^{+11}_{-12}{}^{+9}_{-11})^\circ$
- entanglement at $\Upsilon(4S)$, used many times/second, has been tested
    - test of specific models, not a Bell Inequality test ...
    - "decoherent fraction" $\zeta_{\mathrm{B}^0\overline{\mathrm{B}}^0} = 0.029 \pm 0.057$ [modified interf. term]
    - Pompili-Selleri class of LR models is ruled out at 5.1σ
- [many details suppressed: ask me a question!!]

BACKUP SLIDES

EPR-Bohm (backup)

J.D. Franson, Phys. Rev. Lett. 62, 2205–2208 (1989)

some more recent experiments are based on a devious design with alternative paths used to set up a *position-time* correlation:

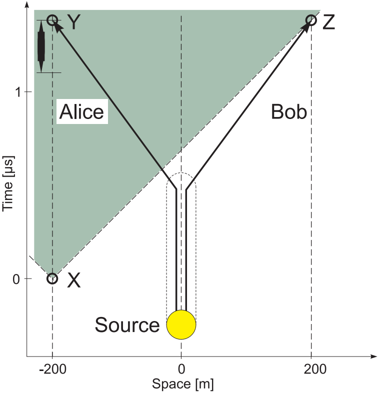


it's the variable phase delays $\Phi_{1,2}$ (*Pockels cells* or similar) which are interesting for our purpose: we shall return ...

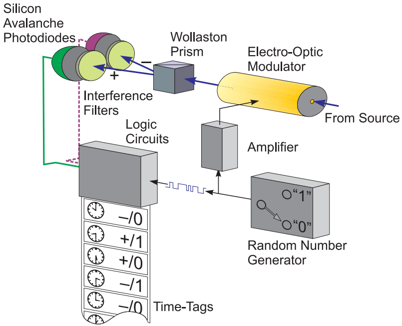
$\Upsilon(4S)$: Green Baize Table Conspiracy (backup)

G. Weihs et al., Phys. Rev. Lett. 81, 5039–5043 (1998): "Aspect++"

changing $\Delta\theta$ *in flight* ...



based on *random numbers*



no conspiracy can fix results according to $\Delta\theta$; but in our experiment, it can

$\Upsilon(4S)$: Bell test in case of active flavor measurement? (backup)

Bertlmann, Bramon, Garbarino, Hiesmayr, Phys. Lett. A 332, 355–360 (2004)

wrong: unfortunately there is another problem with the B-meson case . . .

- B-mesons decay:
  sample decreases rapidly with Δt
- crucial parameter $x_d = \Delta m_d / \Gamma_d$:
  rate of oscillation relative to decay
- Bell test impossible if $x < 2.0$:

system	x
$B^0/\overline{B}^0$	0.77
$K^0/\overline{K}^0$	0.95
$D^0/\overline{D}^0$	< 0.03
$B_s/\overline{B}_s$	~ 26

- so it'd work for B_s mesons . . .

Aspect: free to choose

optimum $\Delta\theta = 22.5°, 67.5°$

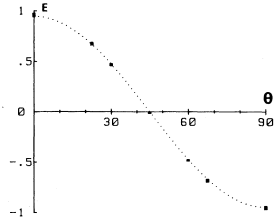


FIG. 3. Correlation of polarizations as a function of the relative angle of the polarimeters. The indicated errors are ±2 standard deviations. The dotted curve is not a fit to the data, but quantum mechanical predictions for the actual experiment. For ideal polarizers, the curve would reach the values ±1.

$\Upsilon(4S)$: "Measurement of EPR-type Flavor Entanglement ..." (b)

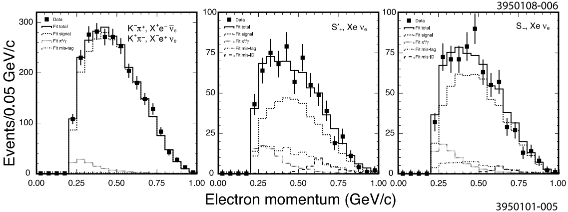
Belle: A. Go, A. Bay et al., Phys. Rev. Lett. 99, 131802 (2007)

			Systematic errors				
window [ps]	A and total error	stat. err.	total	event sel.	bkgd sub.	mistags	deconv.
0.0 – 0.5	1.013 ± 0.028	0.020	0.019	0.005	0.006	0.010	0.014
0.5 – 1.0	0.916 ± 0.022	0.015	0.016	0.006	0.007	0.010	0.009
1.0 – 2.0	0.699 ± 0.038	0.029	0.024	0.013	0.005	0.009	0.017
2.0 – 3.0	0.339 ± 0.056	0.047	0.031	0.008	0.005	0.007	0.029
3.0 – 4.0	-0.136 ± 0.075	0.060	0.045	0.009	0.009	0.007	0.042
4.0 – 5.0	-0.634 ± 0.084	0.062	0.057	0.021	0.014	0.013	0.049
5.0 – 6.0	-0.961 ± 0.077	0.060	0.048	0.020	0.017	0.012	0.038
6.0 – 7.0	-0.974 ± 0.080	0.060	0.053	0.034	0.025	0.020	0.025
7.0 – 9.0	-0.675 ± 0.109	0.092	0.058	0.041	0.027	0.022	0.022
9.0 – 13.0	0.089 ± 0.193	0.161	0.107	0.067	0.063	0.038	0.039
13.0 – 20.0	0.243 ± 0.435	0.240	0.363	0.145	0.226	0.080	0.231

$\psi(3770)$: Charm mixing and $\delta_{K\pi}$ (backup)

CLEO: Rosner et al, `arXiv:0802.2264` → PRL; Asner et al, `0802.2268` → PRD

$Xe^-\nu$ modes (summed):



full recon DT modes (summed):