Review of $B \to VV$ decays

Branching fractions, CP asymmetries and polarisation measurements

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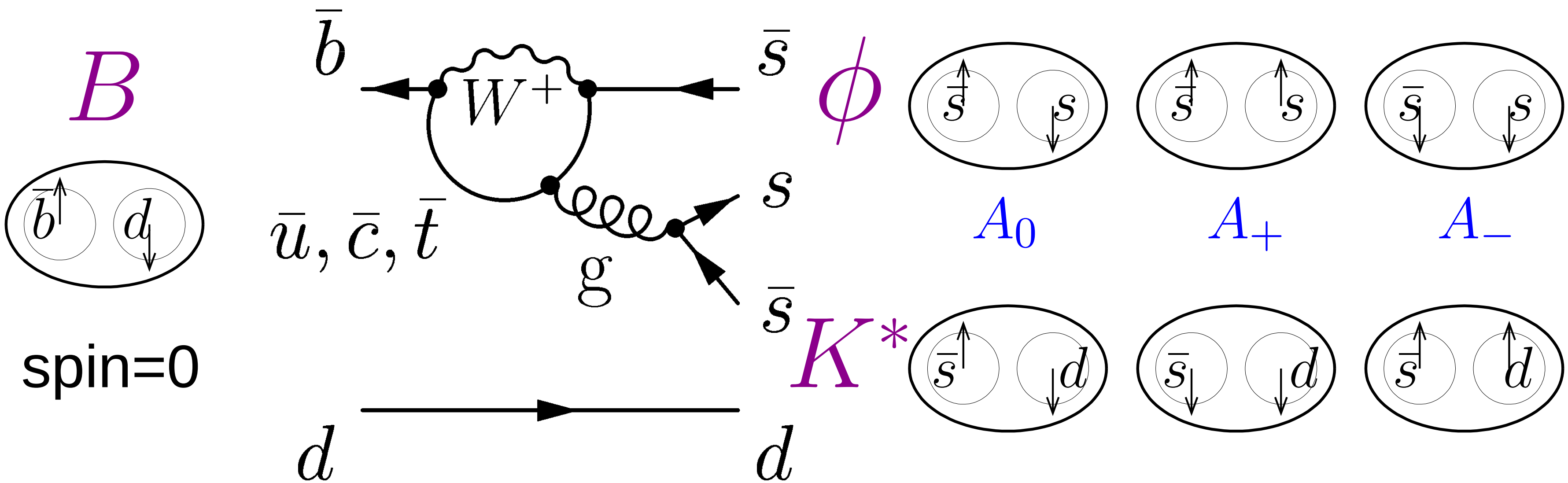
Talk Overview

- Introduction to $B \rightarrow VV$ decays
  - Decay dynamics, CP violation & polarisation
- Experimental techniques used
  - (Mainly BaBar)
- Results
  - $B \rightarrow VV$ tree dominated decays
  - $B \rightarrow VV$ penguin dominated decays
  - Polarisation
  - CP asymmetries
- Conclusions

Thanks to: A. Gritsan (LBL) and J. Zhang (KEK)

B meson decays to two vector mesons

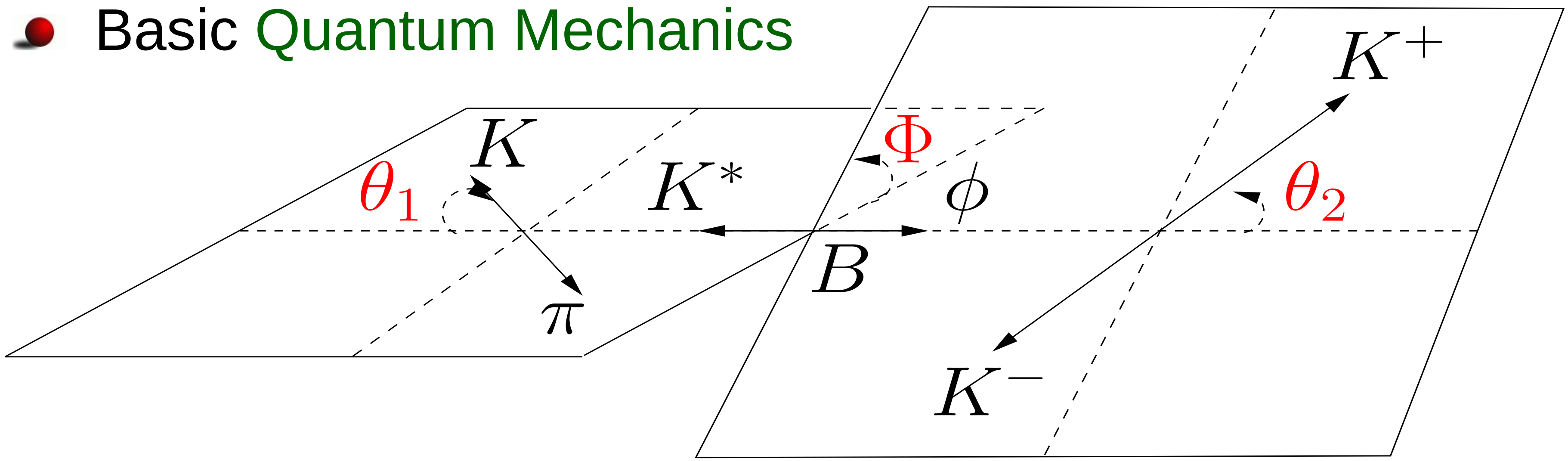
- Can reveal underlying spin structure (e.g. $B \to \phi K^*$):



- Helicity amplitudes: A_0 A_+ A_-
- 11 observables (B and $\bar{B}$): 6 $|A_i|$, 5 arg(A_i/A_j)
- Compare to: $\phi K^\pm$ 2 observables: $|A|$, $|\bar{A}|$
  ϕK^0_S 3 observables: $|A|$, $|\bar{A}|$, arg($A/\bar{A}$)

Angular Distributions

- Basic Quantum Mechanics



$$\frac{d^3\Gamma}{d\cos\theta_1 d\cos\theta_2 d\Phi} \propto \left| \sum_{m=-1,0,1} A_m \times Y_{1,m}(\theta_1, \Phi_1) \times Y_{1,-m}(\theta_2, \Phi_2) \right|^2$$

$$\propto \Bigg\{ \boxed{\frac{1}{4} \sin^2\theta_1 \sin^2\theta_2 \left(|A_+|^2 + |A_-|^2\right)} + \boxed{\cos^2\theta_1 \cos^2\theta_2 |A_0|^2}$$

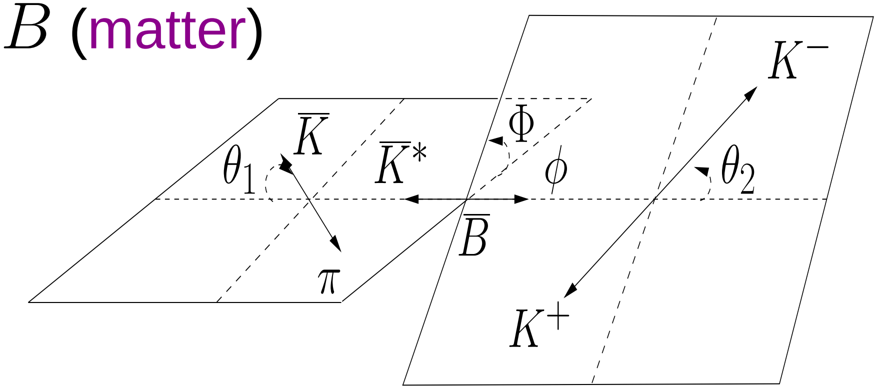
transverse — longitudinal

$$+\frac{1}{2}\sin^2\theta_1 \sin^2\theta_2 \left[\cos 2\Phi \, \mathrm{Re}(A_+ A_-^*) - \sin 2\Phi \, \mathrm{Im}(A_+ A_-^*)\right]$$

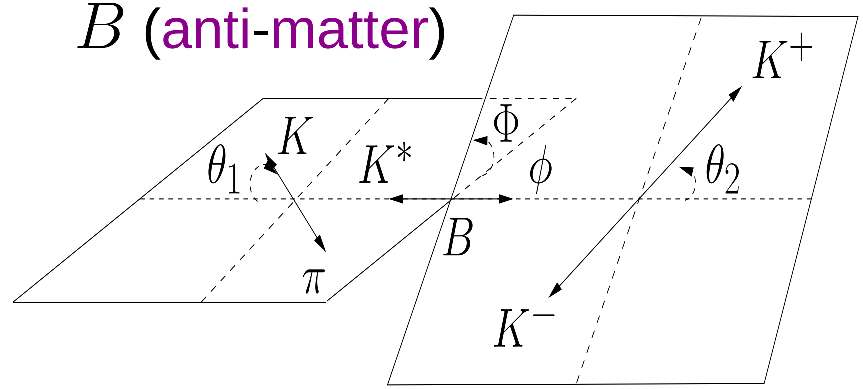
$$+\frac{1}{4}\sin 2\theta_1 \sin 2\theta_2 \left[\cos\Phi \, \mathrm{Re}\left(A_+ A_0^* + A_- A_0^*\right) - \sin\Phi \, \mathrm{Im}\left(A_+ A_0^* - A_- A_0^*\right)\right] \Bigg\}$$

CP violation in $B \to VV$

$\bar{B}$ (matter)



B (anti-matter)



- Direct asymmetries (rate):

$\propto \sin \Delta\delta_{\rm EW} \ \sin \Delta\delta_{\rm strong}$

$$|A_0|^2 \neq |\bar{A}_0|^2$$
$$|A_\parallel|^2 \neq |\bar{A}_\parallel|^2 \quad A_\parallel = \frac{A_+ + A_-}{\sqrt{2}}$$
$$|A_\perp|^2 \neq |\bar{A}_\perp|^2 \quad A_\perp = \frac{A_+ - A_-}{\sqrt{2}}$$

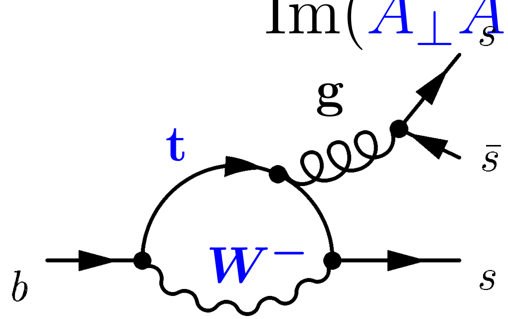
- “Triple-product” asymm. $(\epsilon_1 \times \epsilon_2 \cdot p)$

$\propto \sin \Delta\delta_{\rm EW} \ \cos \Delta\delta_{\rm strong}$

G. Valencia, Phys. Rev. D **39**, 3339 (1989)
A. Datta, D. London, Int. J. Mod. Phys. A **19**, 2505 (2004)

$$\mathrm{Im}(A_\perp A_0^*) \neq -\mathrm{Im}(\bar{A}_\perp \bar{A}_0^*)$$
$$\mathrm{Im}(A_\perp A_\parallel^*) \neq -\mathrm{Im}(\bar{A}_\perp \bar{A}_\parallel^*)$$

$\Delta\delta_{\rm EW} \neq 0 \quad \Leftrightarrow$



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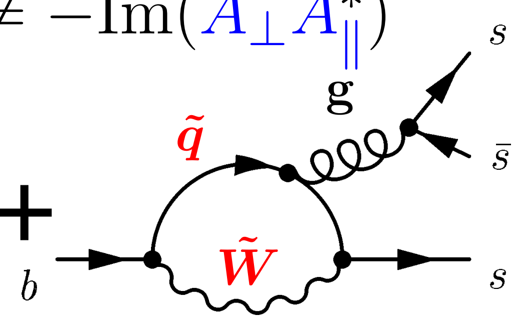
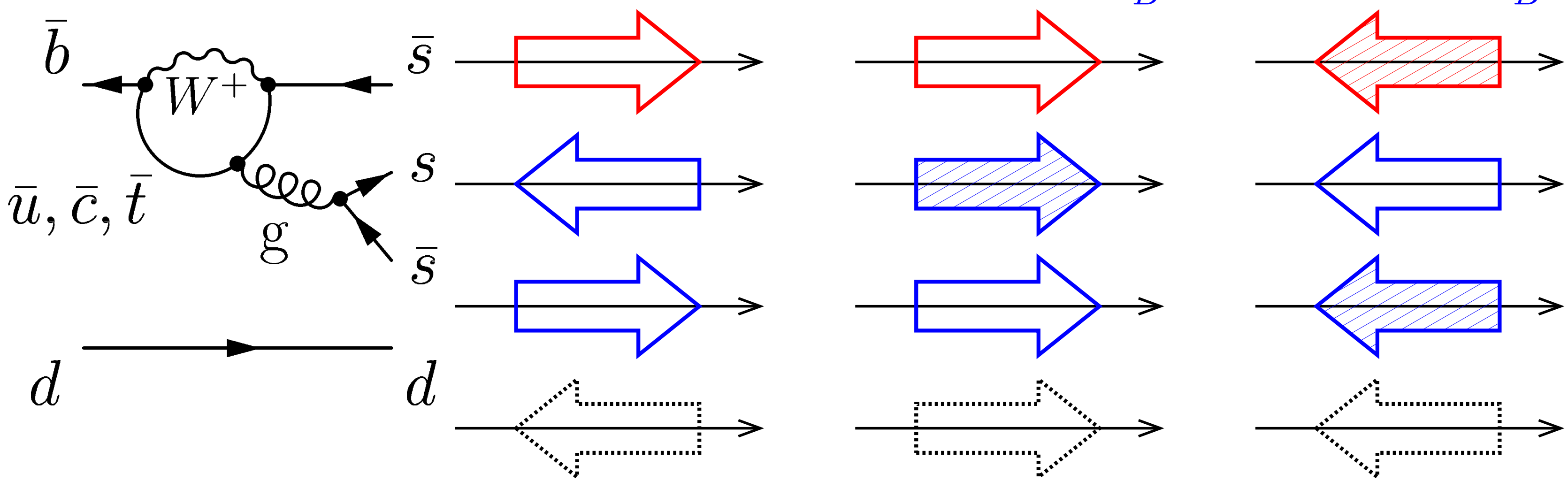


Polarisation puzzle

- SM: $\bar{q}W^+ \to \bar{s} \Rightarrow \lambda_{\bar{s}} = +\frac{1}{2}$ $\quad$ $g \to s\bar{s} \Rightarrow \lambda_s = \pm\frac{1}{2}, \lambda_{\bar{s}} = \mp\frac{1}{2}$

  A. Ali (1979), M. Suzuki (2002) $A_0 \sim 1, \gg A_+ \sim \frac{m_V}{m_B} \gg A_- \sim \frac{m_V{}^2}{m_B{}^2}$



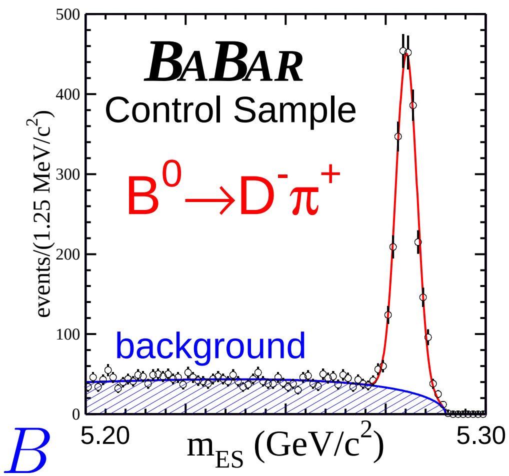
- Surprise ϕK^{*+} and ϕK^{*0}: A_0 ~0.5 Phys. Rev. Lett. **91**, 171802 (2003)
- New Physics? new SM amplitude? Re-scattering?

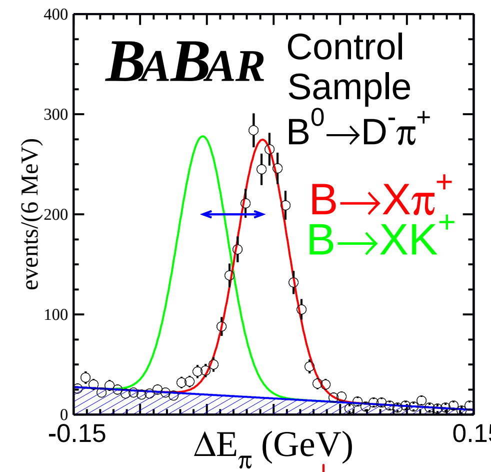
  Y. Grossman, hep-ph/0310229 $\quad$ A. Kagan, hep-ph/0405134

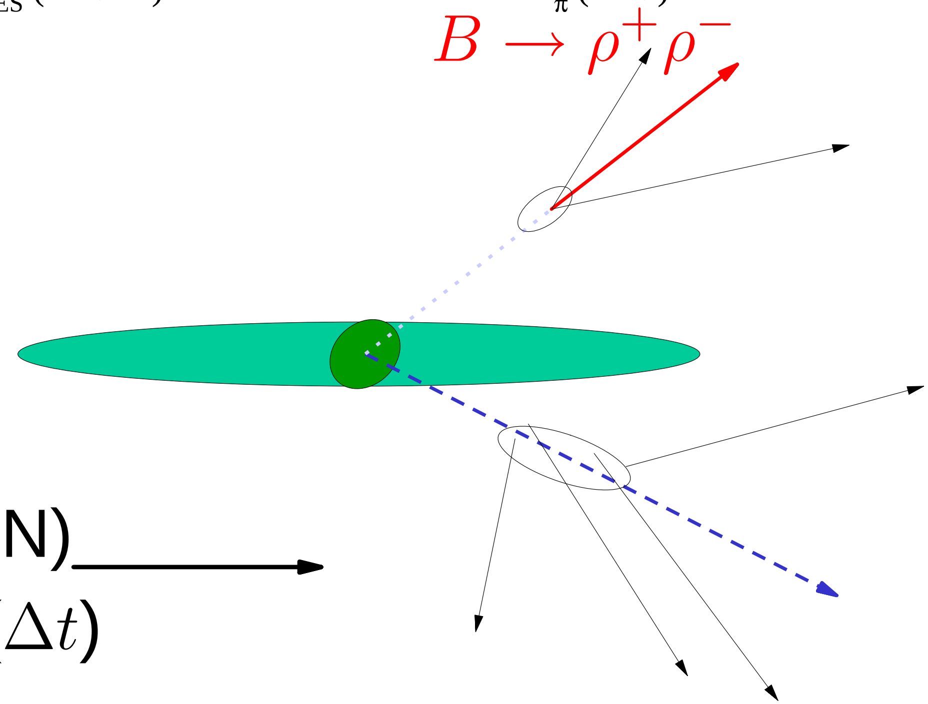
  W.-S. Hou *et al.*,hep-ph/0408007 $\quad$ P. Colangelo *et al.*, hep-ph/0406162
- Broad $B \to VV$ programme required

B-decay Analysis at $\Upsilon(4S)$

- B reconstruction
  - Mass
  - Energy
  - Particle ID
  - Vertexing
- Constrain $\Upsilon(4S) \rightarrow BB$
  - Beam momenta
  - Beam spot
- Using other B
  - Event shape
    - Thrust
    - Multivariate $\mathcal{E}$ (Fisher/NN)
  - B flavour tagging, vertex (Δt)







Maximum Likelihood Method

- Estimate parameters (e.g. $n_{\rm sig}$) with $B \to V_1 V_2$:

$$\vec{x}_j = (m_{\rm ES},\, \Delta E,\, \mathcal{E},\, m_{V_1},\, m_{V_2},\, \theta_1,\, \theta_2,\, \Phi,\, Q_B, \{\Delta t, Q_{\rm tag}\}).$$

$$\mathcal{L} = \exp\left(-\sum_{i,k} n_{ik}\right) \prod_{j=1}^{N_{\rm comb}} \exp\left(w_j \ln\left(\sum_{i,k} n_{ik}\, \mathcal{P}_{ik}(\vec{x}_j;\vec{\alpha})\right)\right)$$

- PDF:

$$\mathcal{P}_{i,k}(\vec{x}_j) = \mathcal{P}_{i1}(m_{\rm ES})\cdot\mathcal{P}_{i2}(\Delta E)\cdot\mathcal{P}_{i3}(\mathcal{E})\cdot\mathcal{P}_{i4}(m_{V_1})\cdot\mathcal{P}_{i5}(m_{V_2})\cdot\delta_{kQ}$$

and angular part with acceptance $\mathcal{G}$

$$\times\, \mathcal{P}^{\rm hel}_{i,k}(\theta_1, \theta_2, \{\Phi\}, {f_L}^k, \{{f_\perp}^k, {\phi_\perp}^k, {\phi_\parallel}^k\}) \times \mathcal{G}(\theta_1, \theta_2, \Phi)$$

- Measure:

$${f_L}^\pm = \frac{|{A_0}^\pm|^2}{\Sigma|{A_\lambda}^\pm|^2} \qquad {f_\perp}^\pm = \frac{|{A_\perp}^\pm|^2}{\Sigma|{A_\lambda}^\pm|^2}$$

$${\phi_\parallel}^\pm = \arg\left(\frac{{A_\parallel}^\pm}{{A_0}^\pm}\right) \qquad {\phi_\perp}^\pm = \arg\left(\frac{{A_\perp}^\pm}{{A_0}^\pm}\right)$$

construct asymmetries $\mathcal{A}^i_{CP}$

Angular Observables

$\alpha_1(f_L)\times$ $\Rightarrow |A_0|^2$

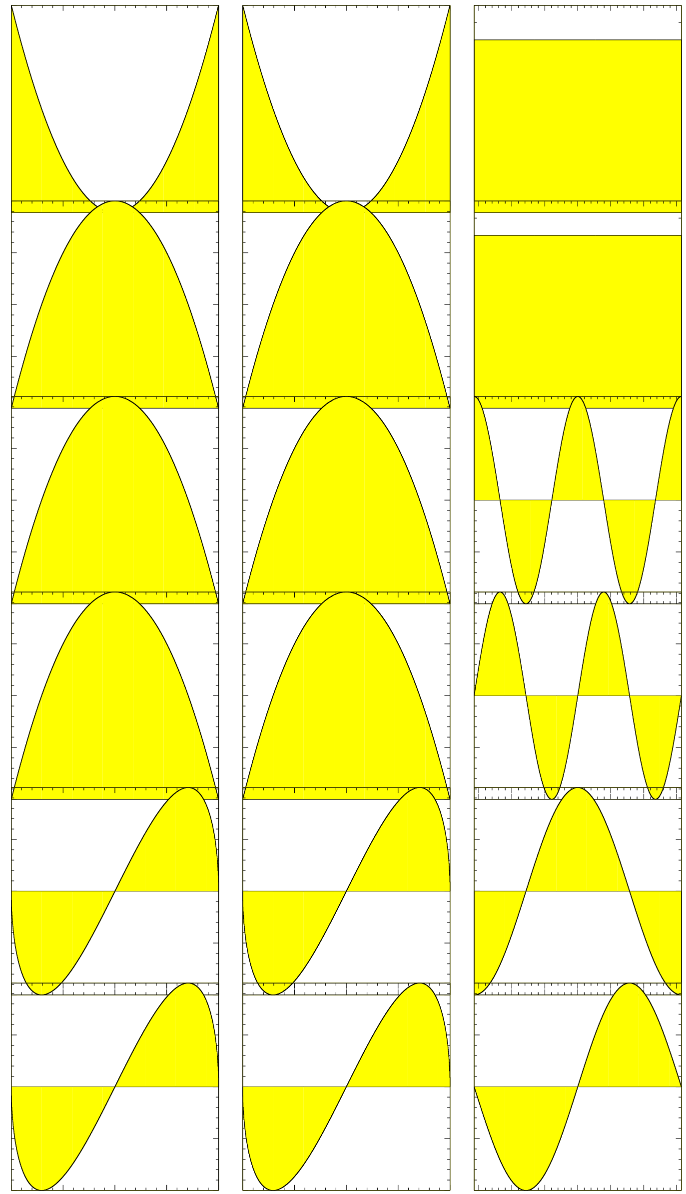
$\alpha_2(f_L)\times$ $|A_\parallel|^2+|A_\perp|^2$

$\alpha_3(f_L, f_\perp)\times$ $|A_\parallel|^2-|A_\perp|^2$

$\alpha_4(f_L, f_\perp, \phi_\perp, \phi_\parallel)\times$ $\Rightarrow \mathrm{Im}(A_\perp A_\parallel^*)$

$\alpha_5(f_L, f_\perp, \phi_\parallel)\times$ $\Rightarrow \mathrm{Re}(A_\parallel A_0^*)$

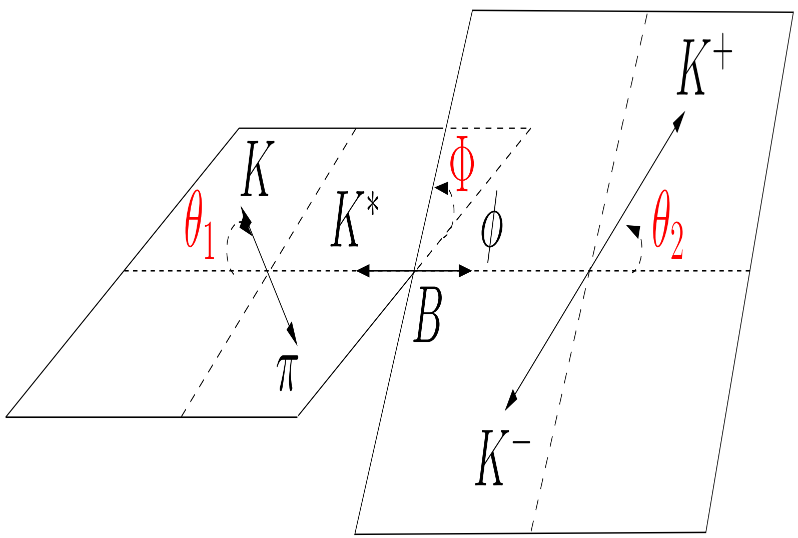
$\alpha_6(f_L, f_\perp, \phi_\perp)\times$ $\Rightarrow \mathrm{Im}(A_\perp A_0^*)$

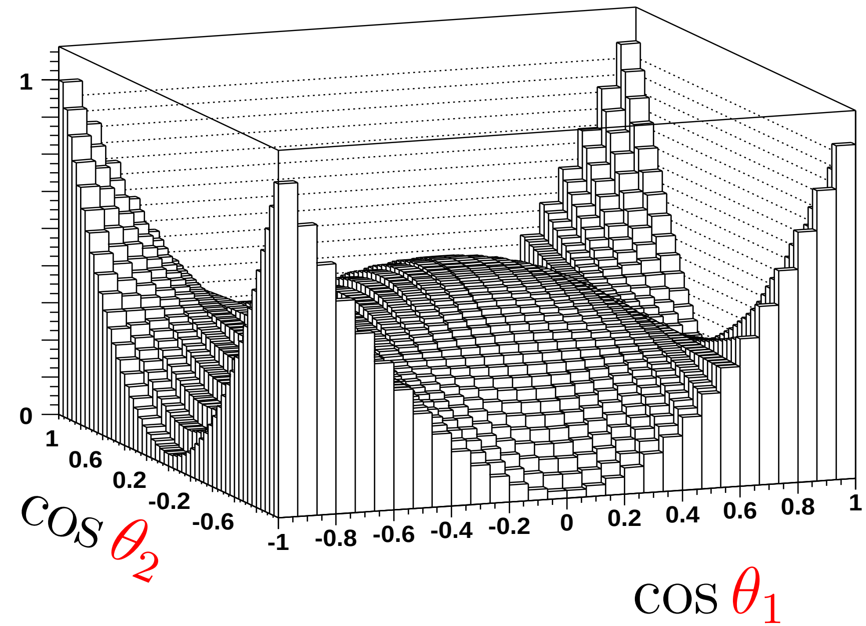


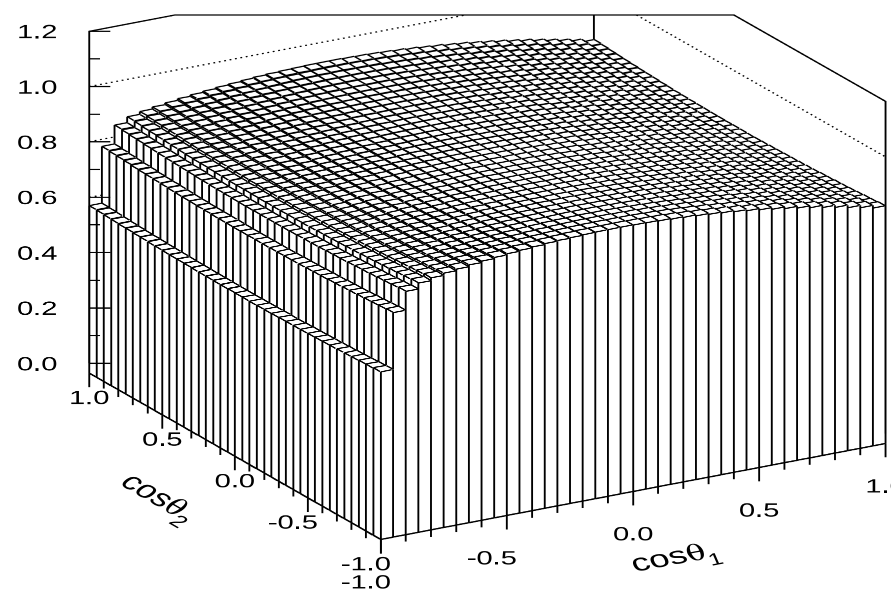
$\cos\theta_1$ $\cos\theta_2$ Φ $\times$ acceptance

Some angular distributions

- Example of ideal PDF:
  - Integrated over Φ





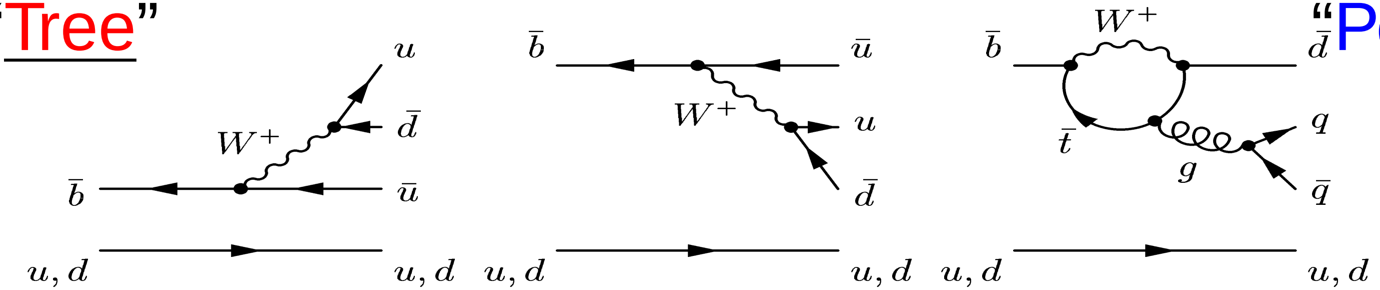


- Almost uniform acceptance with particle momenta

$B \to VV$ “Tree” Decays

$$\alpha_T \cdot T \quad + \quad \alpha_C \cdot C \quad + \quad \alpha_P \cdot P$$

“Tree” “Penguin”



B decay	α_T	α_C	α_P	$\mathcal{B}\ (10^{-6})$	f_L	$N_{B\bar{B}}\,(10^6)$
$\rho^-\rho^+$(BaBar)	$\sqrt{2}$	0	$\sqrt{2}$	$30 \pm 4\ \pm 5$	$0.99 \pm 0.03^{+0.04}_{-0.03}$	89
$\rho^0\rho^+$(BaBar)	1	1	0	$22.5\ ^{+5.7}_{-5.4}\ \pm 5.8$	$0.97^{+0.03}_{-0.07} \pm 0.04$	89
$\rho^0\rho^+$(Belle)	1	1	0	$31.7 \pm 7.1\ ^{+3.8}_{-6.7}$	$0.95 \pm 0.11 \pm 0.02$	85
$\rho^0\rho^0$(BaBar)	0	1	-1	< 1.1 (90%)	–	227 (new)
$\omega\rho^+$(BaBar)	-1	-1	2	$12.6\ ^{+3.7}_{-3.3}\ \pm 1.8$	$0.88^{+0.12}_{-0.15} \pm 0.03$	89 (new)
$\omega\rho^0$(BaBar)	0	0	-$\sqrt{2}$	< 3.3 (90%)	–	89 (new)
$\phi\phi$(BaBar)	0	0	0	< 1.5 (90%)	–	89 (new)

(new) = Preliminary Summer 2004

- $\rho^-\rho^+$, $\rho^0\rho^+$, $\omega\rho^+$: large decay rate with “tree” (compared to $\pi\pi$)
- Confirm $f_L \sim 1 \Rightarrow CP$-even eigenstate $\rho^-\rho^+$
- $\rho^0\rho^0$, $\omega\rho^0$: small “penguin” $\Rightarrow$ good news for $\sin 2(\alpha/\phi_2)$

New Results for $B^0 \to \rho^0\rho^0$ and $\omega\rho^0$

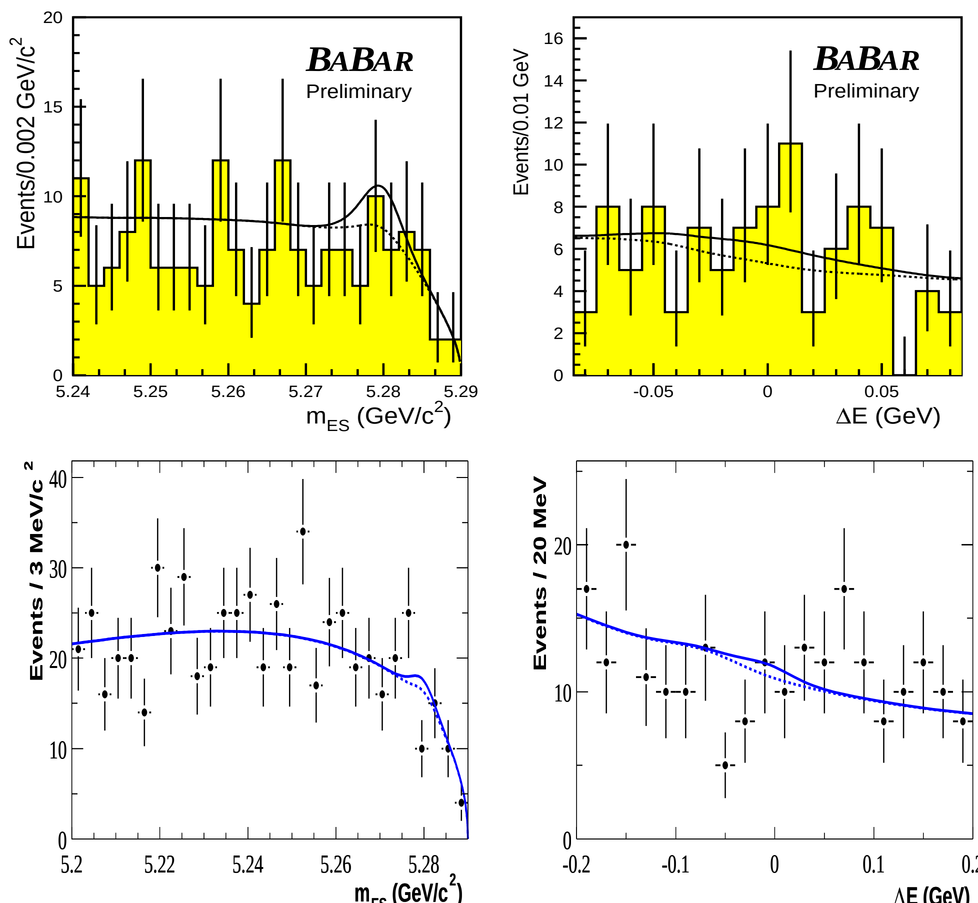
- BaBar $B \to \rho\rho$ Phys.Rev.Lett 91,171802(2003), Phys.Rev.D69,031102(2004)
- New improved $\rho^0\rho^0$ technique, sensitivity, statistics

Preliminary

$n_{\text{sig}}(\rho^0\rho^0)$	33^{+22}_{-20}
UL (90% CL)	$< 1.1 \times 10^{-6}$
$\mathcal{B}\ (\times 10^{-6})$	$0.54^{+0.36}_{-0.32} \pm 0.19$
$\mathcal{E}ff$	27%
$N_{B\bar{B}}$	227×10^6

Preliminary

$n_{\text{sig}}(\omega\rho^0)$	$4.3^{+11.0}_{-9.1}$
UL (90% CL)	$< 3.3 \times 10^{-6}$
$\mathcal{B}\ (\times 10^{-6})$	$0.6^{+1.3}_{-1.1} \pm 0.4$
$\mathcal{E}ff$	9.3%
$N_{B\bar{B}}$	89×10^6

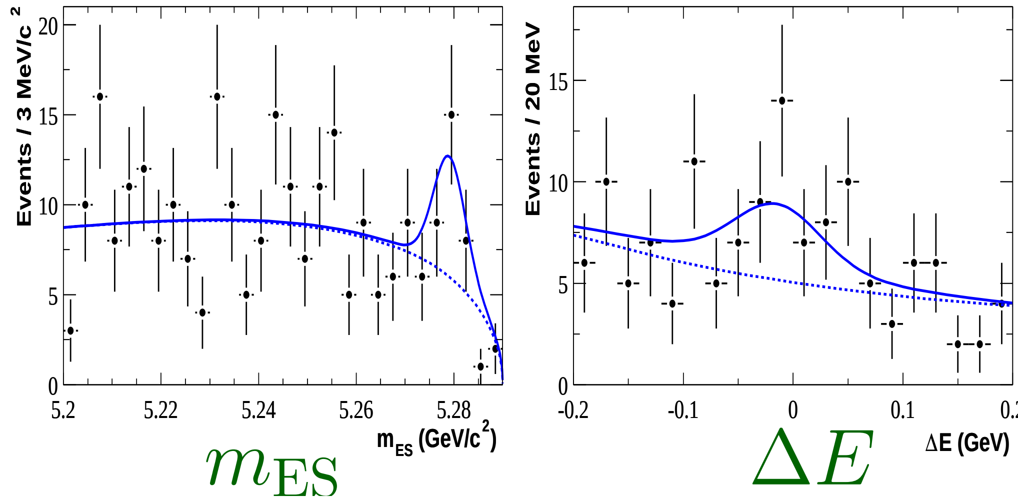


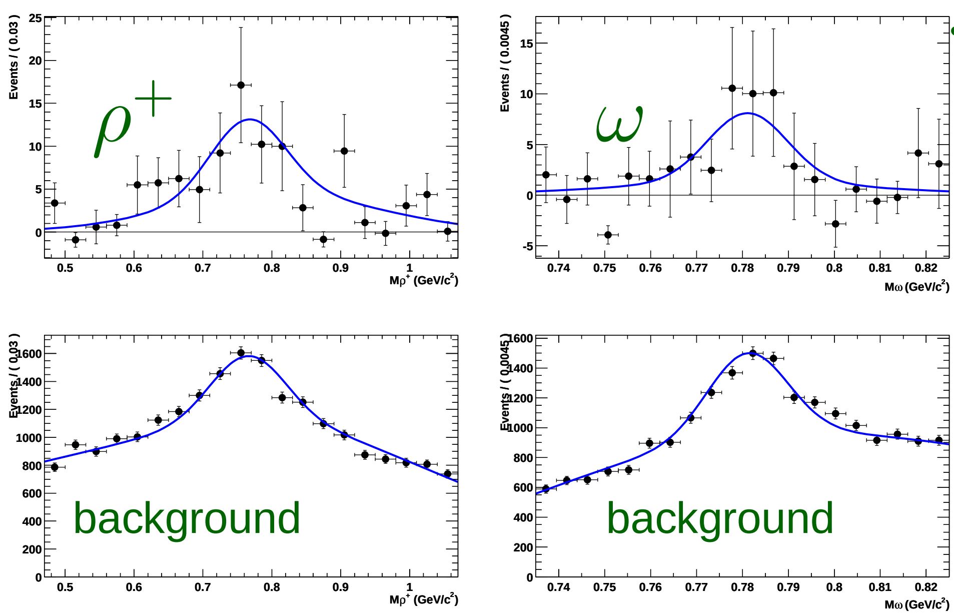
- Both $\rho^0\rho^0$ and $\omega\rho^0$ set tight constraints on "penguin pollution"
  - conservative $\mathcal{B}$ limit f_L=1.0 (0.9 $\omega\rho^0$);

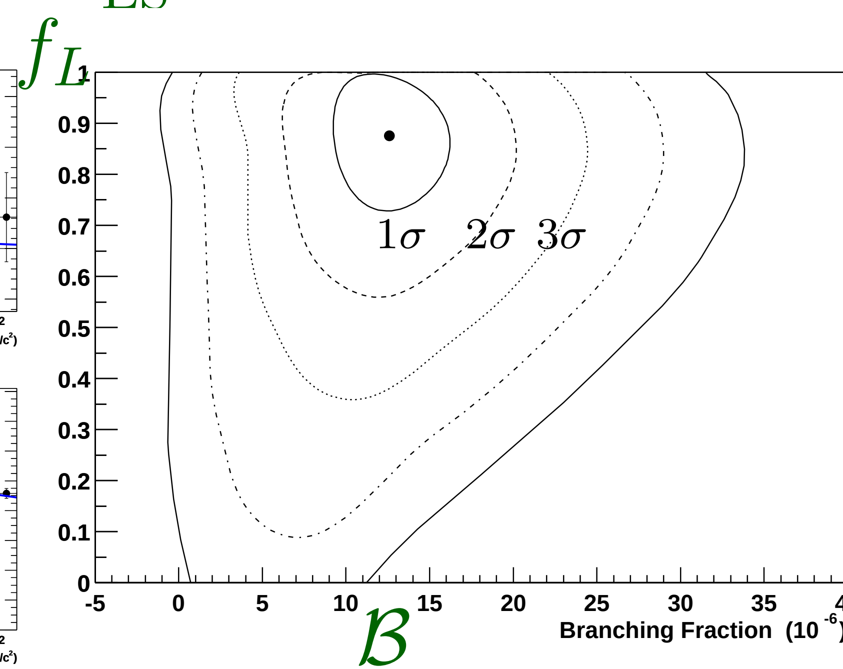
BaBar observation of $B^+ \to \omega\rho^+$

- $B \to \omega\rho^+$ complements $\rho^0\rho^+$ and $\rho^-\rho^+$, large $\mathcal{B}$ and f_L

$n_{\rm sig}(\omega\rho^+)$	$57.7^{+18.5}_{-16.5}$
f_L	$0.88^{+0.12}_{-0.15} \pm 0.03$
signif.	4.7σ
$\mathcal{B}(\times 10^{-6})$	$12.6^{+3.7}_{-3.3} \pm 1.8$
$\mathcal{A}_{CP}$	$0.05 \pm 0.26 \pm 0.02$
$\mathcal{E}ff$	4.8%
$N_{B\bar{B}}$	89×10^6



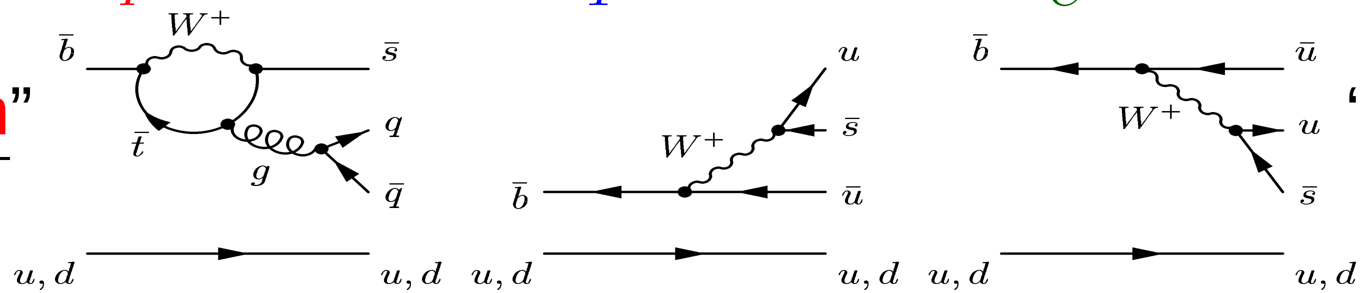




$B \rightarrow VV$ "Penguin" Decays

$$\alpha_P \cdot P' + \alpha_T \cdot T' + \alpha_C \cdot C'$$

"Penguin"



"Tree"

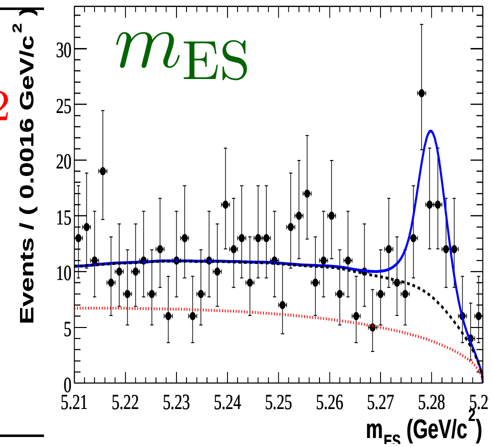
B decay	α_P	α_T	α_C	$\mathcal{B}(10^{-6})$	f_L	$N_{B\bar{B}}(10^6)$
ϕK^{*0}BaBar	$\sqrt{2}$	0	0	$9.2 \pm 0.9 \pm 0.5$	$0.52 \pm 0.05 \pm 0.02$	227 (new)
ϕK^{*0}Belle	$\sqrt{2}$	0	0	$10.0\ ^{+1.6}_{-1.5}\ ^{+0.7}_{-0.8}$	$0.52 \pm 0.07 \pm 0.05$	152 (new)
ϕK^{*+}BaBar	$\sqrt{2}$	0	0	$12.7\ ^{+2.2}_{-2.0} \pm 1.1$	$0.46 \pm 0.12 \pm 0.03$	89
ϕK^{*+}Belle	$\sqrt{2}$	0	0	$6.7\ ^{+1.1}_{-0.9} \pm 0.3$	$0.49 \pm 0.13 \pm 0.05$	152 (new)
$\rho^0 K^{*0}$Belle	1	0	-1	$< 2.6 \times 10^{-6}$	–	–
$\rho^0 K^{*+}$BaBar	-1	-1	-1	$10.6\ ^{+3.0}_{-2.6} \pm 2.4$	$0.96^{+0.04}_{-0.15} \pm 0.04$	89
$\rho^- K^{*0}$BaBar	$\sqrt{2}$	0	0	$17.0{\pm}2.9{\pm}2.0^{+0.0}_{-1.9}$	$0.79{\pm}0.08{\pm}0.04{\pm}0.02$	89 (new)
$\rho^- K^{*0}$Belle	$\sqrt{2}$	0	0	$6.6{\pm}2.2{\pm}0.8$	$0.50{\pm}0.19\ ^{+0.05}_{-0.07}$	152 (new)
$\rho^- K^{*+}$BaBar	-$\sqrt{2}$	-$\sqrt{2}$	0	< 24 (90%)	–	123 (new)
ωK^{*0}BaBar	1	0	1	< 6.1 (90%)	–	89 (new)
ωK^{*+}BaBar	1	1	1	< 7.4 (90%)	–	89 (new)

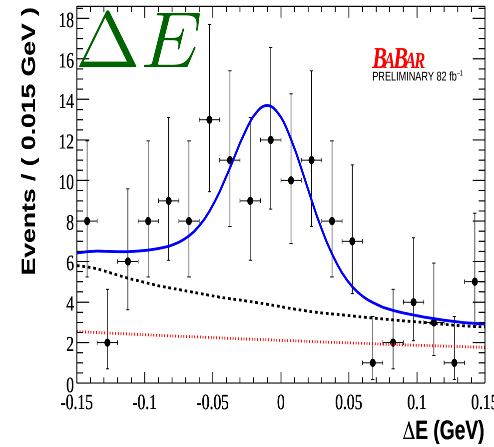
(new) = Preliminary Summer 2004

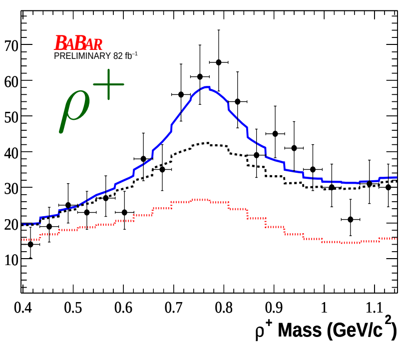
BaBar Observation of $B^+ \rightarrow \rho^+ K^{*0}$

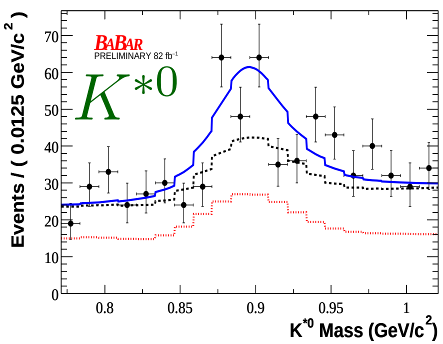
- $B \rightarrow \rho^+ K^{*0}$ is a “pure” penguin like ϕK^*

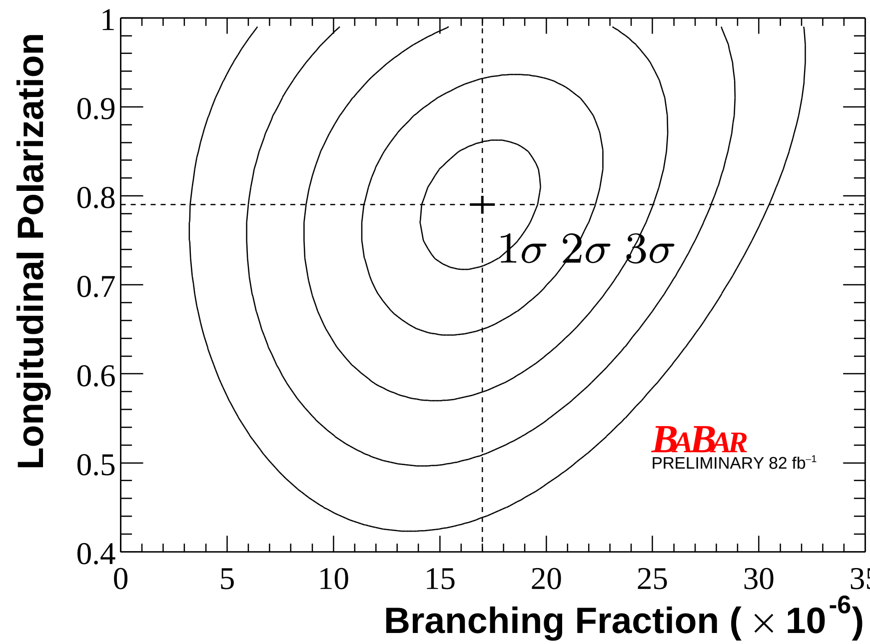
$n_{\text{sig}}(\rho^+ K^{*0})$	$141.0^{+23.4}_{-22.3}$
f_L	$0.79 \pm 0.08 \pm 0.04 \pm 0.02$
signif.	$>5\sigma$
$\mathcal{B}(\times 10^{-6})$	$17.0 \pm 2.9 \pm 2.0^{+0.0}_{-1.9}$
$\mathcal{A}_{CP}$	$-0.14 \pm 0.17 \pm 0.04$
$\mathcal{E}ff$	9.4%
$N_{B\bar{B}}$	89×10^6

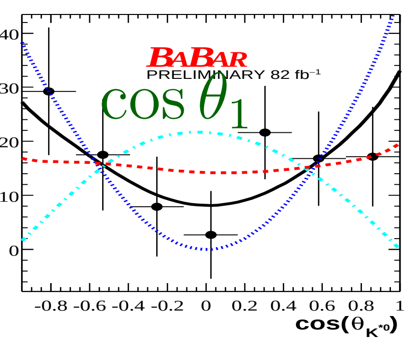


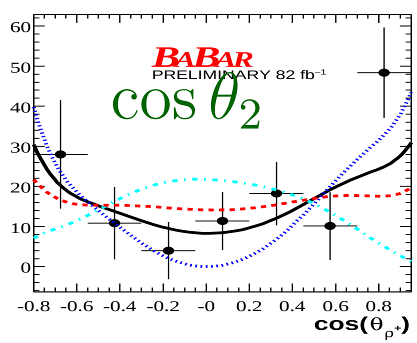












BELLE Observation of $B^+ \rightarrow \rho^+ K^{*0}$

- 140 fb^{-1}
- Unbinned ML fit

  dE and mB only

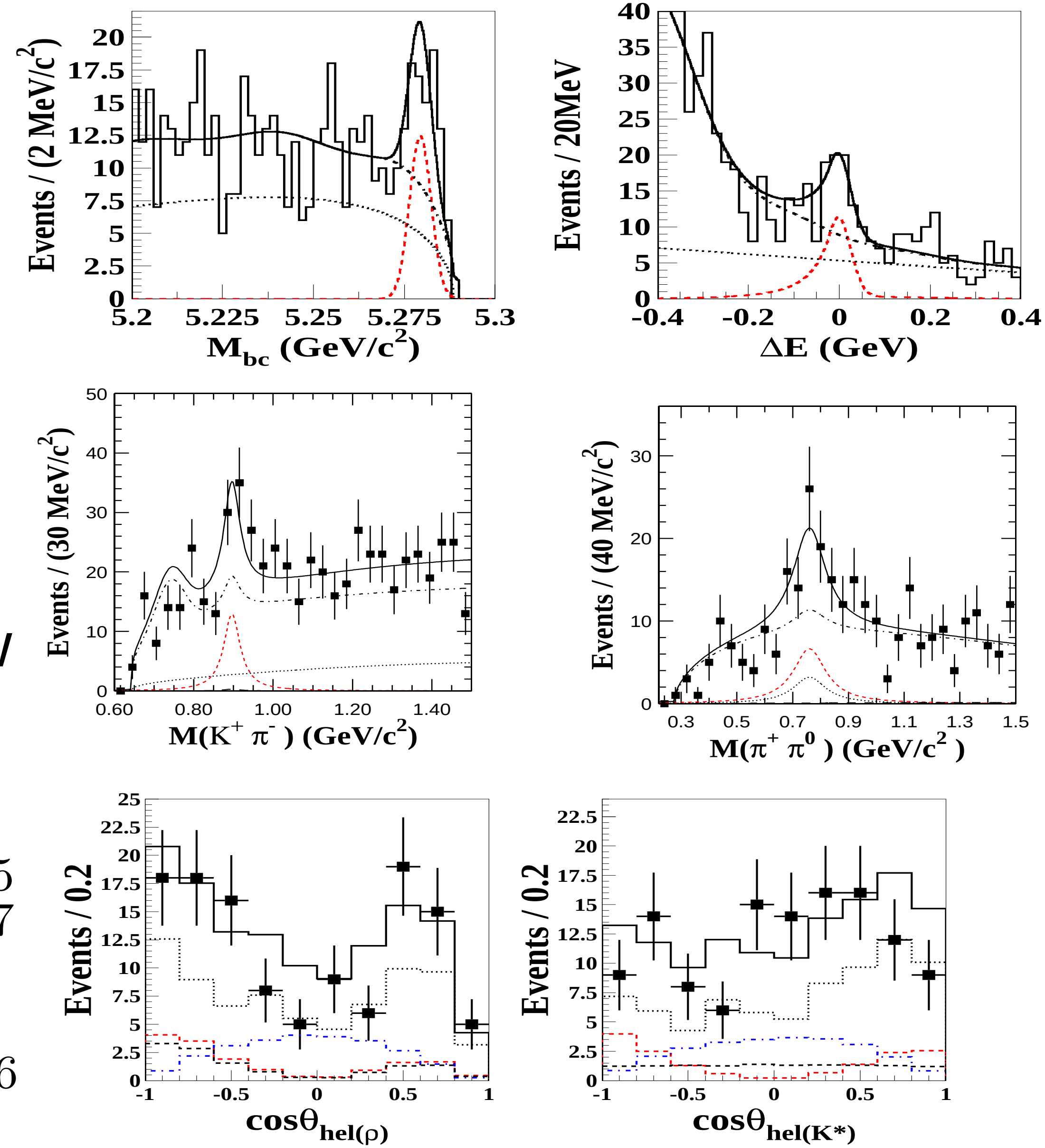
- $B \rightarrow K^+\pi^-\pi^+\pi^0$
  - n_{sig} 56.5 ± 11.6
- Significance$= 6.3\sigma$
- ρ & K^* mass window

  $\rho^+ K^{*0}$ n_{sig} 26.6 ± 8.7

  $S = 3.2\sigma$

- $f_L = 0.50 \pm 0.19 \; ^{+0.05}_{-0.07}$
- $\mathcal{B}(B^+ \rightarrow \rho^+ K^{*0})$

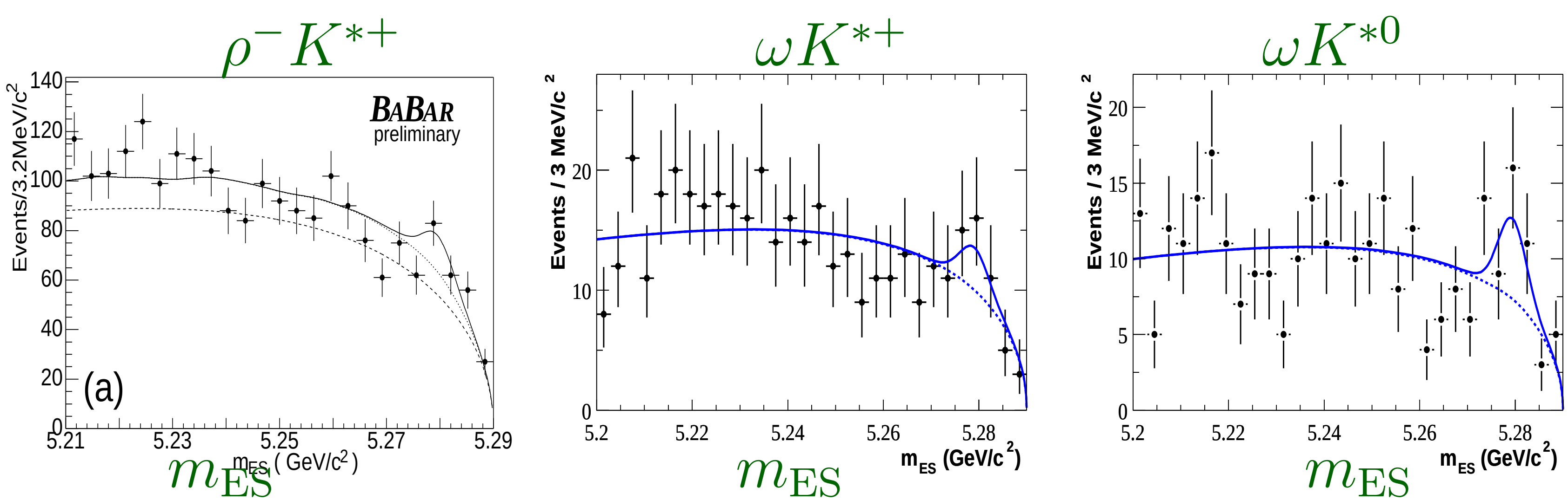
  $6.6 \pm 2.2 \pm 0.8 \times 10^{-6}$



- Efficiency needs to be understood.

BaBar Search for $B \to \rho^- K^{*+}$ & ωK^*

B decay	$\rho^- K^{*+}{}_{K^+\pi^0}$	$\omega K^{*+}{}_{K^+\pi^0 \;\&\; K^0\pi^+}$	ωK^{*0}
$n_{\rm sig}$	58 ± 19	$5.4^{+6.0}_{-4.2}$ & $11.6^{+8.7}_{-7.2}$	$26.1^{+12.1}_{-10.8}$
UL (90% CL)	$< 24 \times 10^{-6}$	$< 7.4 \times 10^{-6}$	$< 6.1 \times 10^{-6}$
$\mathcal{B}(\times 10^{-6})$	$16.3 \pm 5.4 \pm 2.3^{+0.0}_{-6.3}$	$3.5^{+2.5}_{-2.0} \pm 0.7$	$3.4^{+1.7}_{-1.6} \pm 0.4$
$\mathcal{E}ff$	2.9%	4.7%	7.8%
UL with $f_L =$	0.7	0.9	0.9
$N_{B\bar{B}}$	123×10^6	89×10^6	89×10^6



- Upper limits and hints of a signal

BELLE search for $B^0 \to \rho^0 K^{*0}$

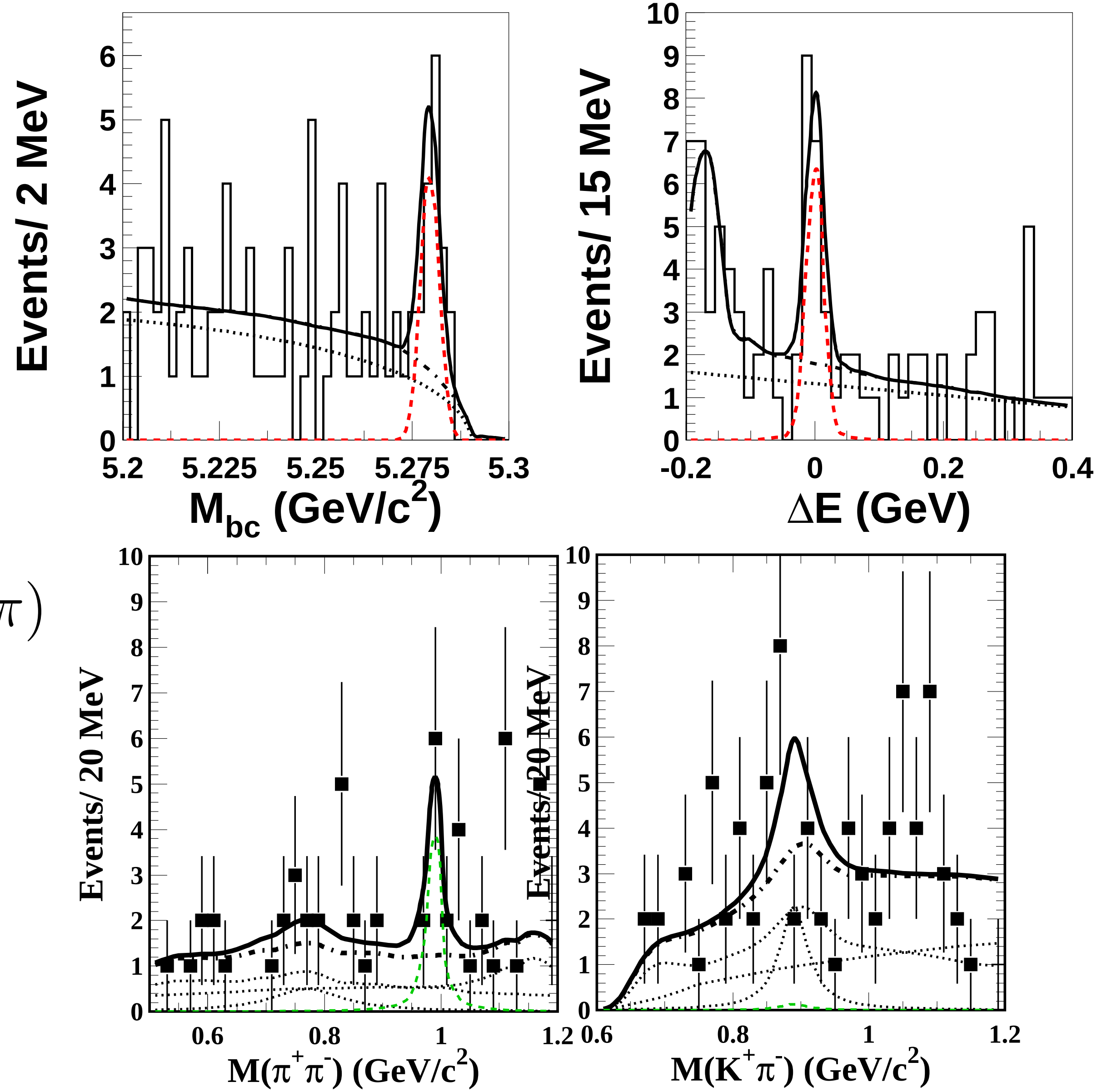
- 140 fb^{-1}
- Unbinned ML fit

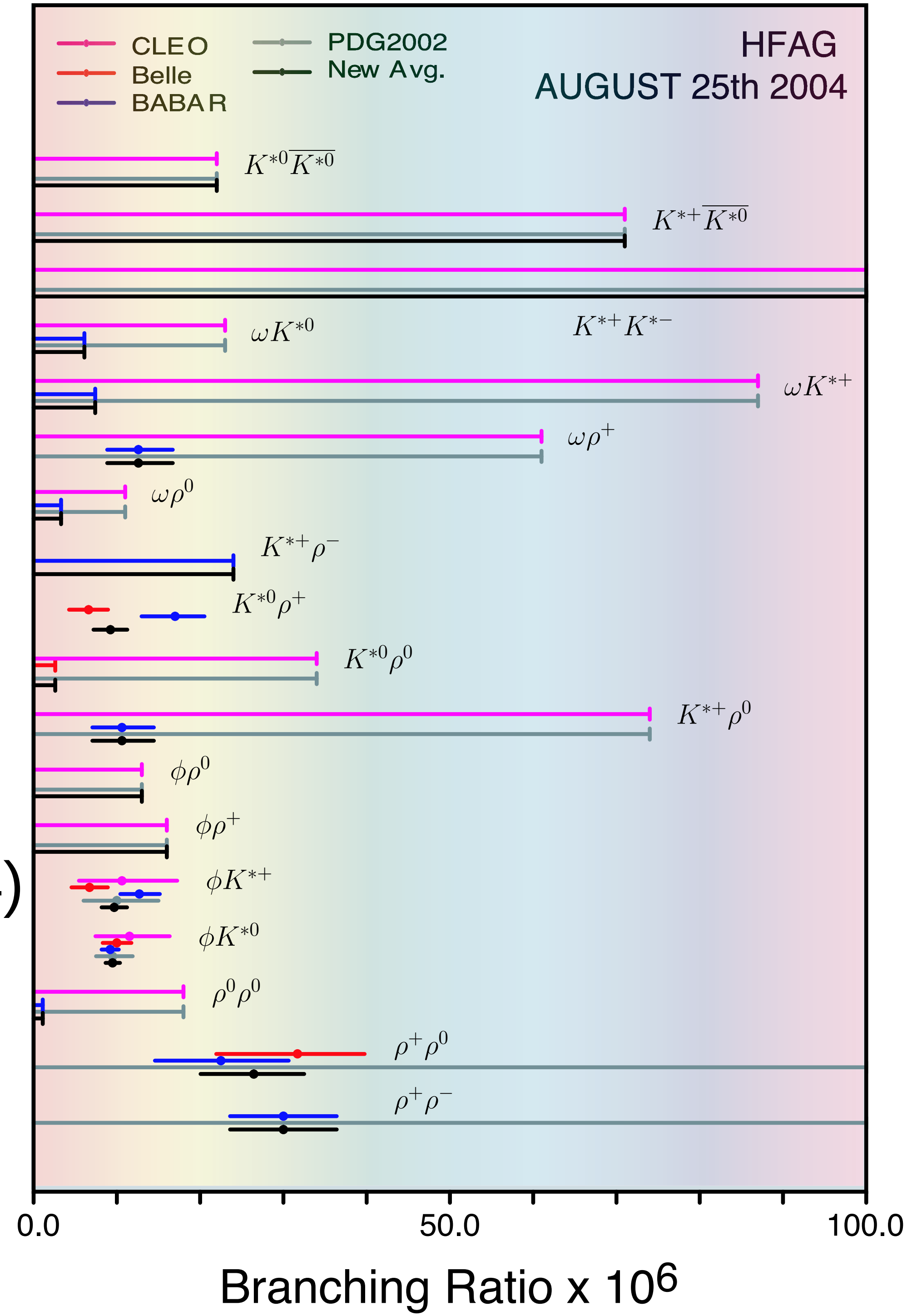
  dE and mB only
- $B \to K^+\pi^-\pi^+\pi^-$
  - $n_{sig}\ 14.5\ ^{+4.9}_{-4.2}$
- Significance$= 5\sigma$
- $M(\pi\pi)$ and $M(K\pi)$

  $\rho^0 K^{*0}$ $n_{sig}\ 0 \pm 5.2$

  $< 2.6 \times 10^{-6}$

  $f_0 K^{*0}$ $n_{sig}\ 10.2\ ^{+5.3}_{-4.4}$
- Ass. $f_L = 1.0$





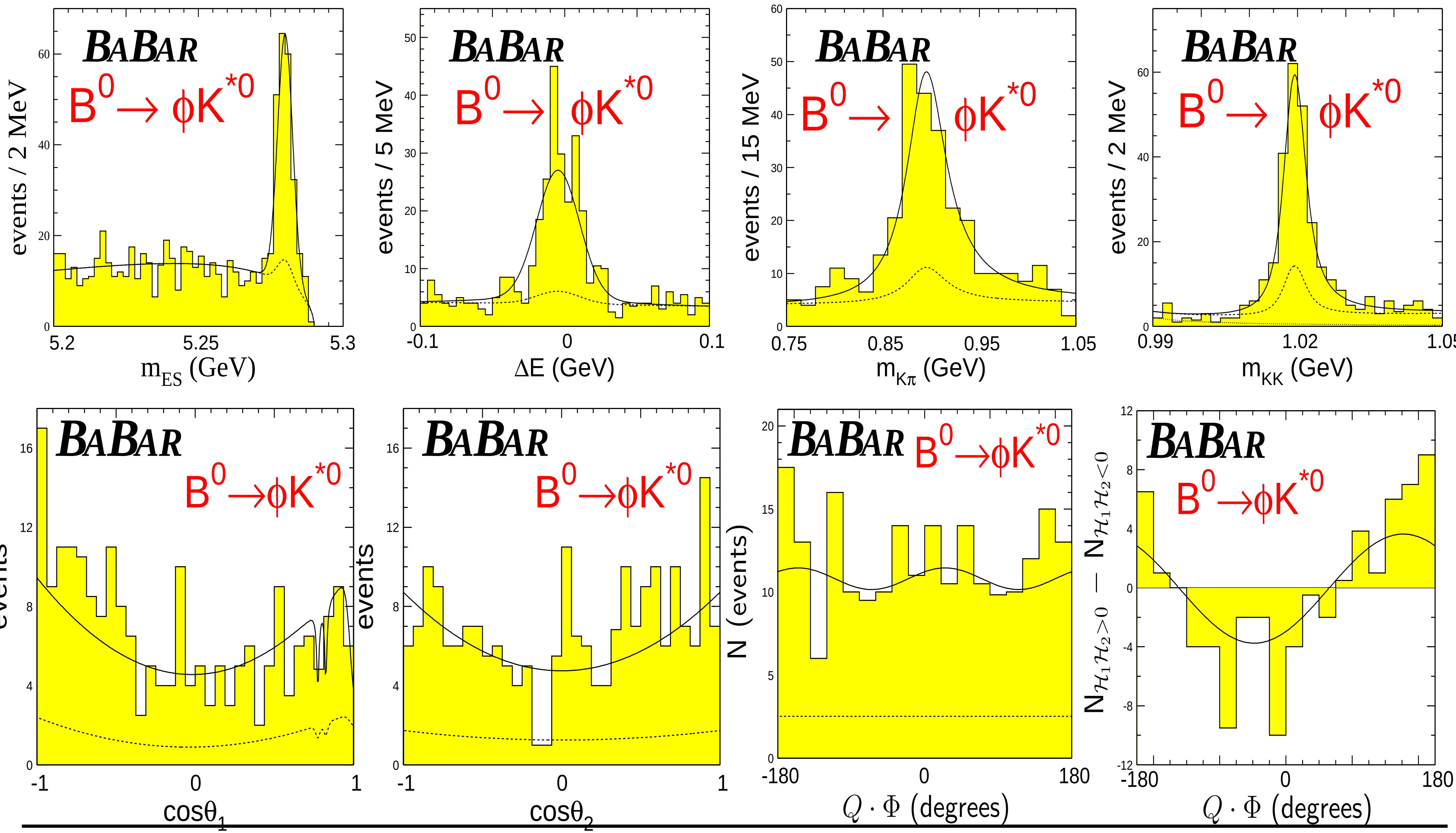
HFAG
(ICHEP 2004)

BaBar – $B^0 \to \phi K^{*0}$

- 10 measurements (BaBar Winter 2004):
  - $n_{\text{sig}}^{\pm} = n_{\text{sig}} \cdot (1 \pm \mathcal{A}_{CP})/2$
  - $f_L^{\pm} = f_L \cdot (1 \pm \mathcal{A}_{CP}^0)$
  - $f_\perp^{\pm} = f_\perp \cdot (1 \pm \mathcal{A}_{CP}^\perp)$
  - $\phi_\parallel^{\pm} = \phi_\parallel \pm \Delta\phi_\parallel$
  - $\phi_\perp^{\pm} = \phi_\perp \pm \Delta\phi_\perp + \frac{\pi}{2} \pm \frac{\pi}{2}$
- With 227 million $B\bar{B}$ (Summer 2004):
  - $n_{\text{sig}} = 201 \pm 20 \pm 6$
- Float S-wave $K\bar{K}$ (f_0) and $K\pi$
- Derived Triple-Product Asymmetries:
  - $\mathcal{A}_T^{\parallel,0} = \frac{1}{2}\left(\frac{\text{Im}(A_\perp^+ A_{\parallel,0}^{+*})}{\Sigma|A_m^+|^2} + \frac{\text{Im}(A_\perp^- A_{\parallel,0}^{-*})}{\Sigma|A_m^-|^2}\right)$

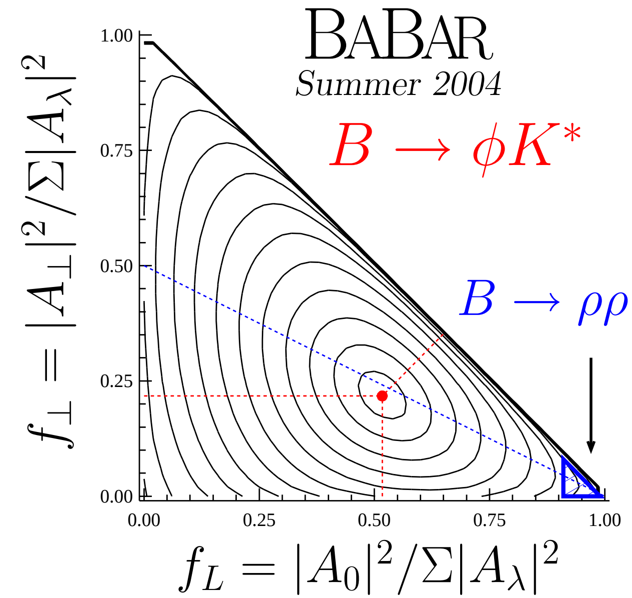
BaBar $B^0 \to \phi K^{*0}$ Projections

- Projections with $\mathcal{P}_{\text{sig}}/\mathcal{P}_{\text{bkg}} > \mathcal{C}$ $(K^{*0} \to K^+\pi^-, \phi \to K^+K^-)$

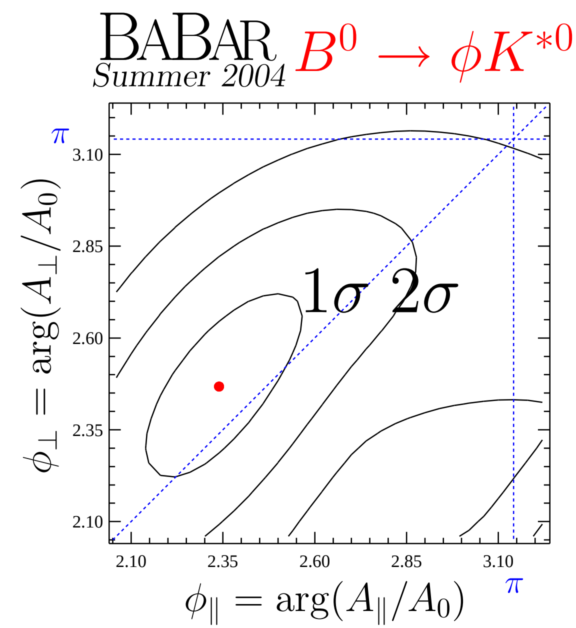


Polarisation in $B^0 \to \phi K^{*0}$

- Observation: $|A_0|$, $|A_\perp|$, $|A_\parallel|$ $>5\sigma$ each
  - $f_L = 0.52 \pm 0.05 \pm 0.02$
  - $f_\perp = 0.22 \pm 0.05 \pm 0.02$



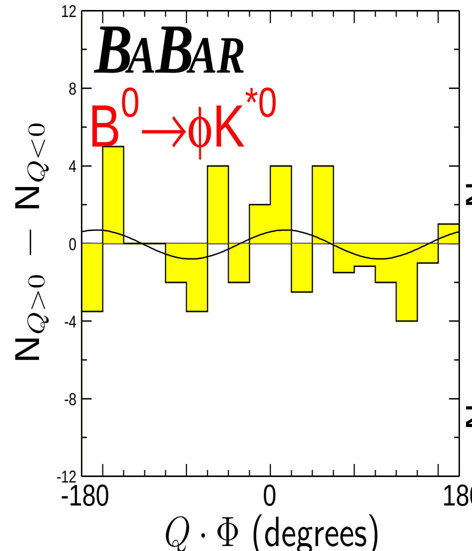
- Observation of phases $>3\sigma$
  - $\phi_\parallel = 2.34\,^{+0.23}_{-0.20} \pm 0.05$ (rad)
  - $\phi_\perp = 2.47 \pm 0.25 \pm 0.05$ (rad)

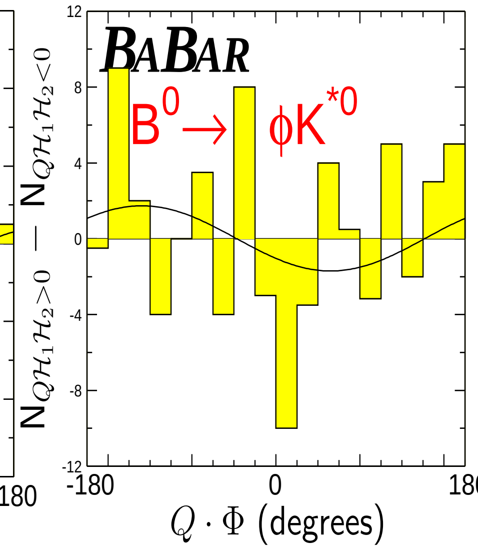


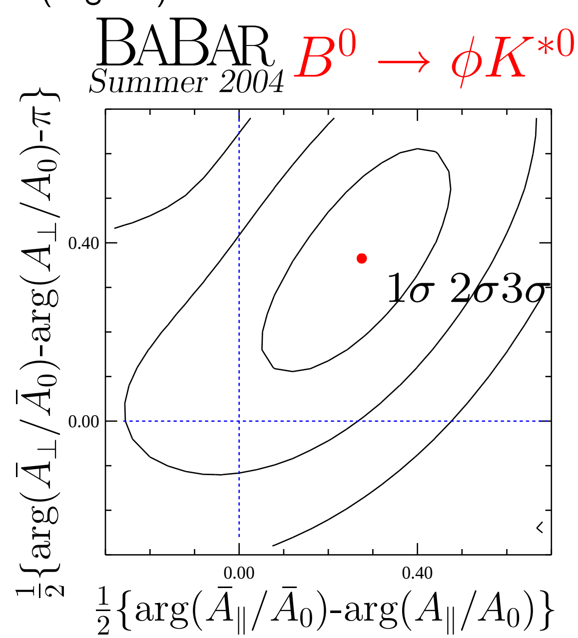
- $|A_0| \gg |A_\pm|$ strongly violated
  - $|A_\pm| \gg |A_\mp|$ consistent

BaBar CP Asymmetries in $B^0 \to \phi K^{*0}$

- Direct-CP measurements
  - $\mathcal{A}_{CP} = -0.01 \pm 0.09 \pm 0.02$
  - $\mathcal{A}^0_{CP} = -0.06 \pm 0.10 \pm 0.01$
  - $\mathcal{A}^{\perp}_{CP} = -0.10 \pm 0.24 \pm 0.05$
- Weak-phase difference
  - $\Delta\phi_{\parallel} = 0.27^{+0.20}_{-0.23} \pm 0.05$ (rad)
  - $\Delta\phi_{\perp} = 0.36 \pm 0.25 \pm 0.05$ (rad)
- Derived triple-product asymmetries
  - $\mathcal{A}^{\parallel}_{T} = -0.02 \pm 0.04 \pm 0.01$
  - $\mathcal{A}^{0}_{T} = +0.11 \pm 0.05 \pm 0.01$
- New Physics if $\mathcal{A}_i \neq 0$

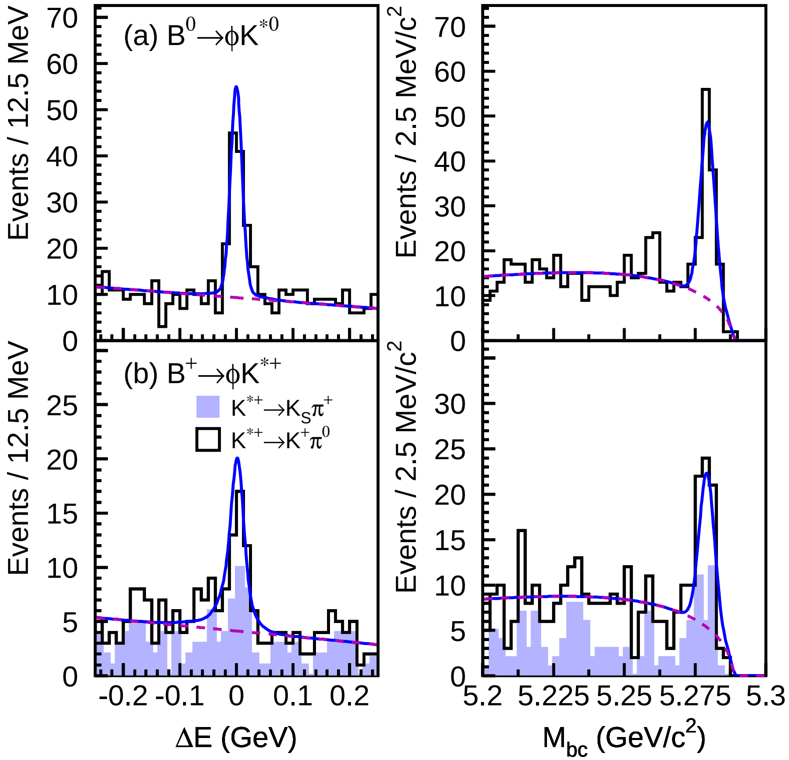


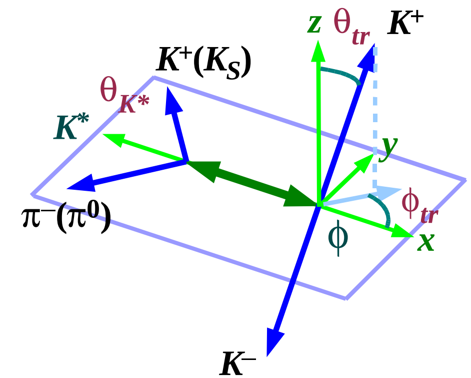


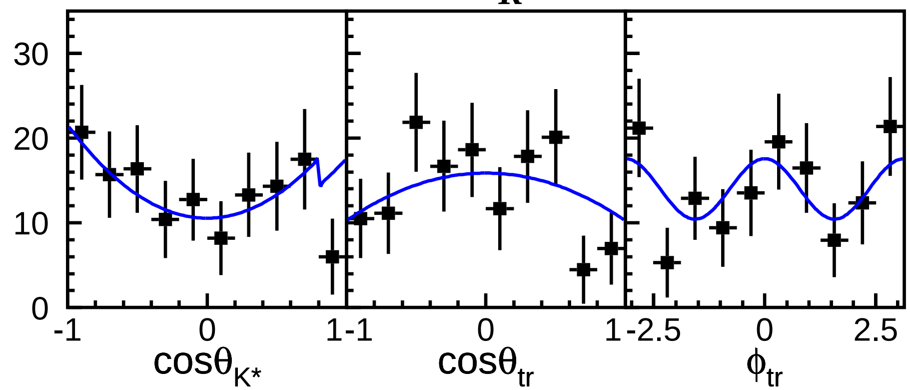


BELLE $B^0 \to \phi K^{*0}$ Results

Analysis method uses “transversity”







	ϕK^{*0}	ϕK^{*+}	Combined
$\lvert A_0\rvert^2$	$0.52 \pm 0.07 \pm 0.05$	$0.49 \pm 0.13 \pm 0.05$	$0.51 \pm 0.06 \pm 0.04$
$\lvert A_\perp\rvert^2$	$0.30 \pm 0.07 \pm 0.03$	$0.12\ ^{+0.11}_{-0.08} \pm 0.03$	$0.24 \pm 0.06 \pm 0.03$
$arg(A_\parallel)$	$-2.30 \pm 0.28 \pm 0.04$	$-2.07 \pm 0.34 \pm 0.07$	$-2.21 \pm 0.22 \pm 0.05$
$arg(A_\perp)$	$0.64 \pm 0.26 \pm 0.05$	$0.93\ ^{+0.55}_{-0.39}$	$0.72 \pm 0.21 \pm 0.06$

BELLE CP Asymmetries – $B^0 \to \phi K^{*0}$

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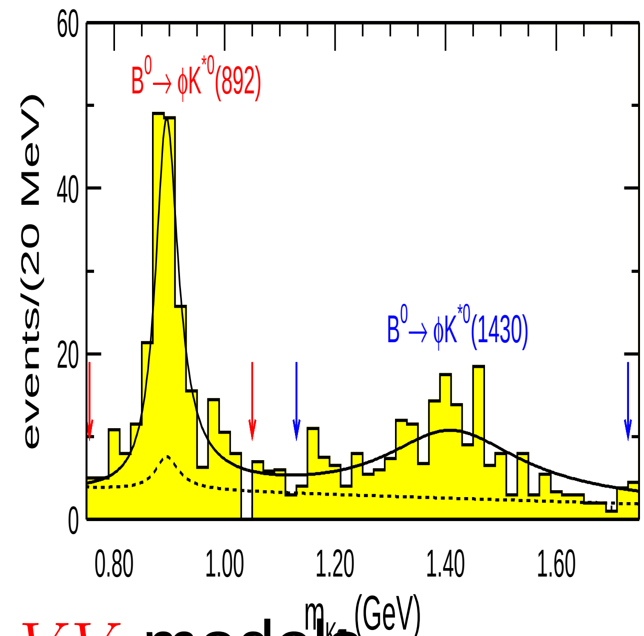
$$\Lambda_{\perp i} = -\mathrm{Im}(A_\perp A_i^* - \bar{A}_\perp \bar{A}_i^*)$$
$$\Sigma_{\lambda\lambda} = \frac{1}{2}(|A_\lambda|^2 - |\bar{A}_\lambda|^2)$$
$$\Sigma_{\parallel 0} = \mathrm{Re}(A_\parallel A_0^* - \bar{A}_\parallel \bar{A}_0^*)$$

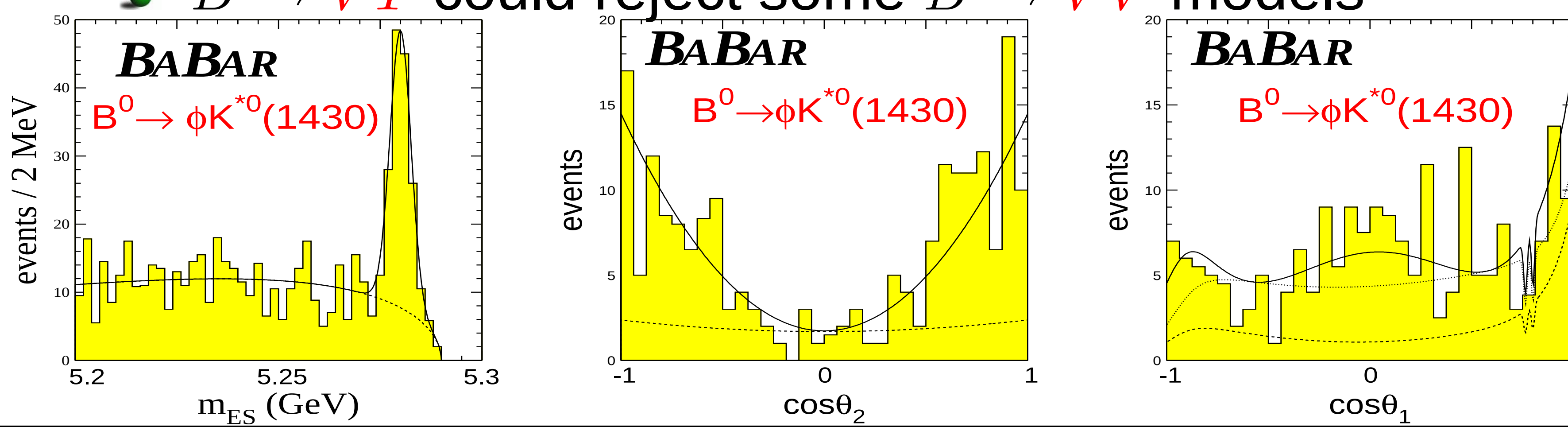
- CP measurements
  - $\Sigma_{00} = -0.09 \pm 0.06 \pm 0.02$
  - $\Sigma_{\parallel\parallel} = -0.10 \pm 0.06 \pm 0.012$
  - $\Sigma_{\perp\perp} = -0.01 \pm 0.06 \pm 0.02$
  - $\Sigma_{\parallel 0} = -0.11 \pm 0.13 \pm 0.04$
- Derived triple-product asymmetries
  - $\Lambda_{\perp 0} = \mathcal{A}_T^{\parallel} = -0.07 \pm 0.11 \pm 0.04$
  - $\Lambda_{\perp\parallel} = \mathcal{A}_T^{0} = +0.02 \pm 0.10 \pm 0.03$

BaBar Observation of $B \to \phi K^*(1430)$

- Observed 181 ± 17 $B \to \phi K_J^{*0}(1430)$ events (>10σ)
- Tensor (J=2) or Scalar (J=0)
  - Observation:
    $\phi K_0^{*0}(1430)$ (>10σ)
  - angular distribution evidence for
    $\phi K_2^{*0}(1430)$ (>3σ)



- Polarization longitudinal (ϕ helicity)
  - obvious for $B \to VS$
  - $B \to VT$ could reject some $B \to VV$ models



Conclusions

- Broad physics with $B \to VV$ decays
  - large $\mathcal{B}$ and f_L with "tree" $\rho\rho$, $\omega\rho$
  - small "penguin pollution" from $\rho^0\rho^0$, $\omega\rho^0$
  - f_L in between for $\rho^+ K^{*0}$, $\rho^0 K^{*+}$
  - approach other "penguins" ρK^*, ωK^*
- Many results with $B \to \phi K^*$:
  - $f_L \sim 0.5$ (puzzle since 2002); $A_{0,\perp,\parallel} > 5\sigma$
  - $\phi_\parallel$ and $\phi_\perp$: 3σ possible FSI
  - $\mathcal{A}_{CP}$, $\mathcal{A}^0_{CP}$, $\mathcal{A}^\perp_{CP}$: search direct-CP
  - $\mathcal{A}^\parallel_T$ and $\mathcal{A}^0_T$: measure triple-products
  - Analyse $B \to$ Vector-Tensor, polarisation
- Nature is showing something interesting