Polarization Puzzle in Gluonic Penguin Decays of B Mesons

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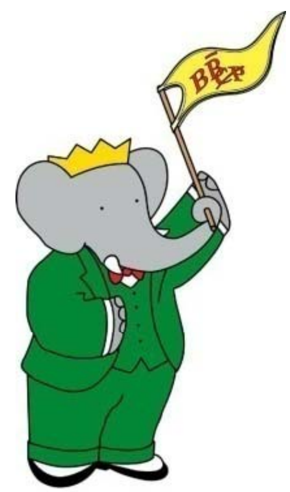
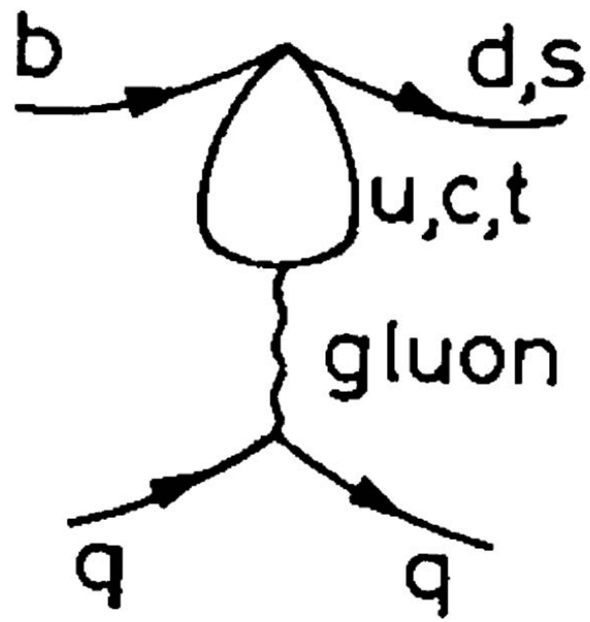


Fermilab Seminar, Sept. 30, 2008

Motivation

Polarization puzzle in penguin decay B→ϕK*



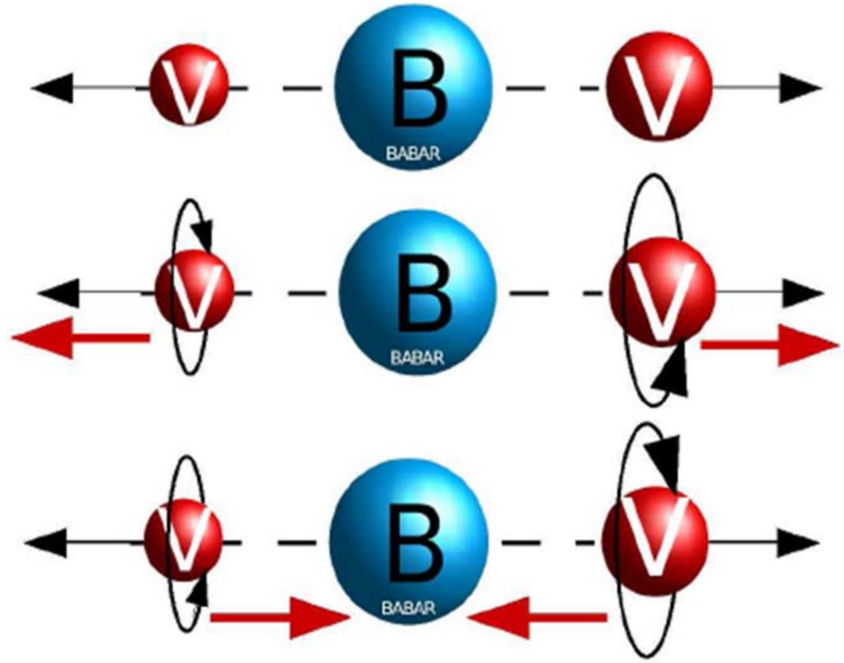
Polarization in B decays to Two Vectors

- Quantum Mechanics => $A = \langle V_1 V_2 | H | B \rangle = A_{00} + A_{++} + A_{--}$

$A_{00}(A_0)$

$A_{++}(A_{+1})$

$A_{--}(A_{-1})$



- CP-Even $A_{//} = \dfrac{A_{+1} + A_{-1}}{\sqrt{2}}$ phase $\phi_{||}$ CP-Odd $A_{\perp} = \dfrac{A_{+1} - A_{-1}}{\sqrt{2}}$ phase $\phi_{\perp}$

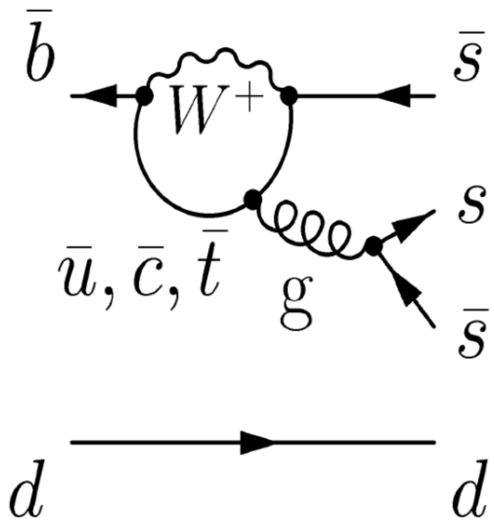
Longitudinal Polarization $f_L = |A_0|^2 / \sum |A_\lambda|^2$

CP-Odd Transverse Polarization $f_\perp = |A_\perp|^2 / \sum |A_\lambda|^2$

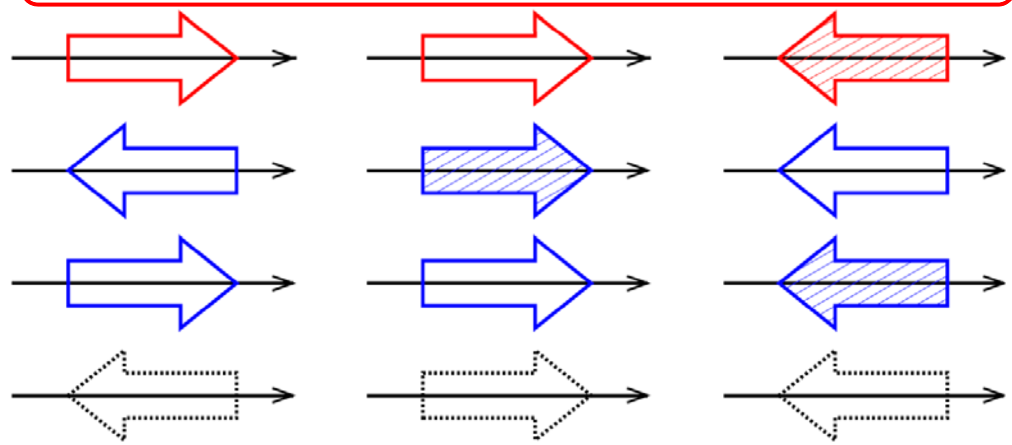
Spin Flip Suppression and Polarization Puzzle

- Spin Flip Suppression => Amplitude Hierarchy

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



$$A_0 \sim 1 \gg A_+ \sim \frac{m_V}{m_B} \gg A_- \sim \frac{{m_V}^2}{{m_B}^2}$$



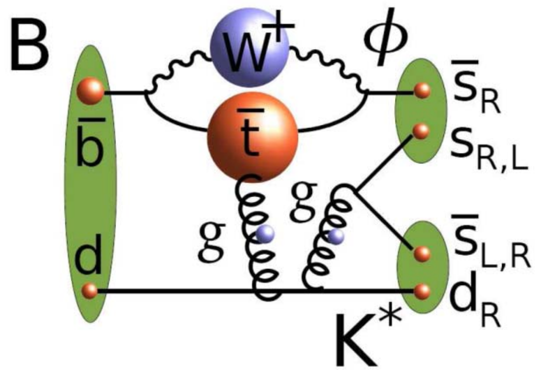
Naïve SM = > $f_L \approx 1$

- Polarization Puzzle

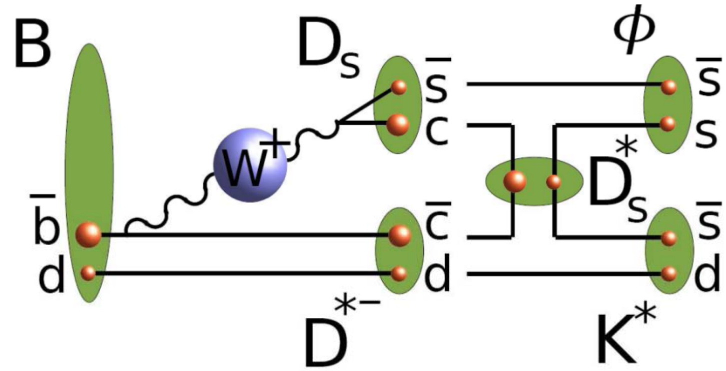
Mode	Branching Fraction (10^{-6})	f_L	$f_\perp$
ϕ K*(892)^0	9.5 ± 0.9	0.49 ± 0.03	0.25± 0.03
ϕ K*(892)$^+$	10.0± 1.1	0.50± 0.05	0.20 ± 0.05
ρ^+ K*(892)^0	9.2 ± 1.5	0.48 ± 0.08	
ρ^0 K*(892)^0	5.6 ± 1.6	0.57 ± 0.08	
ρ^0 K*(892)$^+$	<6.1 @ 90% C.L.	0.9 ± 0.2	

Some Theoretical Efforts Beyond Naïve SM

- Within SM: new look at the previously neglected contributions



Penguin Annihilation(PA)



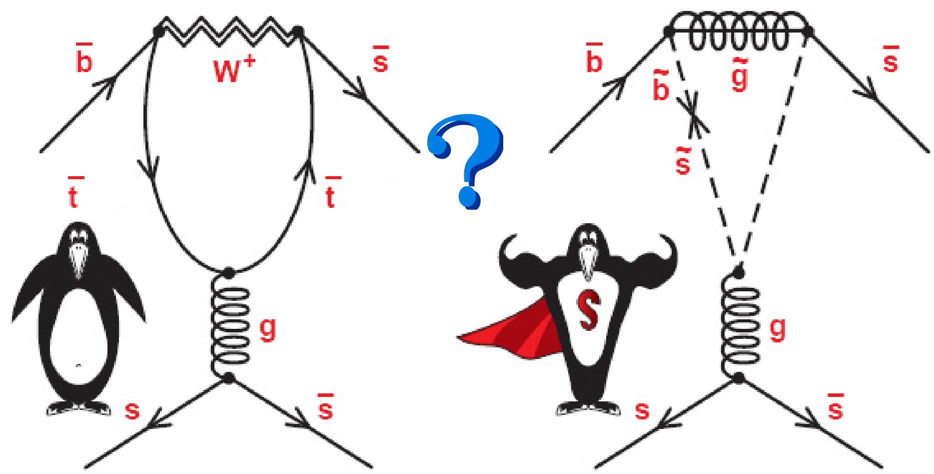
Rescattering(FSI)

<u>Models generally parameters dependent(essential incalculable), no firm prediction power</u>

- New Physics : Ad Hoc NP-induced contributions

<u>Models also parameters dependent.</u>
<u>Tune B->T form factors (hierarchy)</u>

Nothing conclusive yet!



Amplitude and Angular Search Window

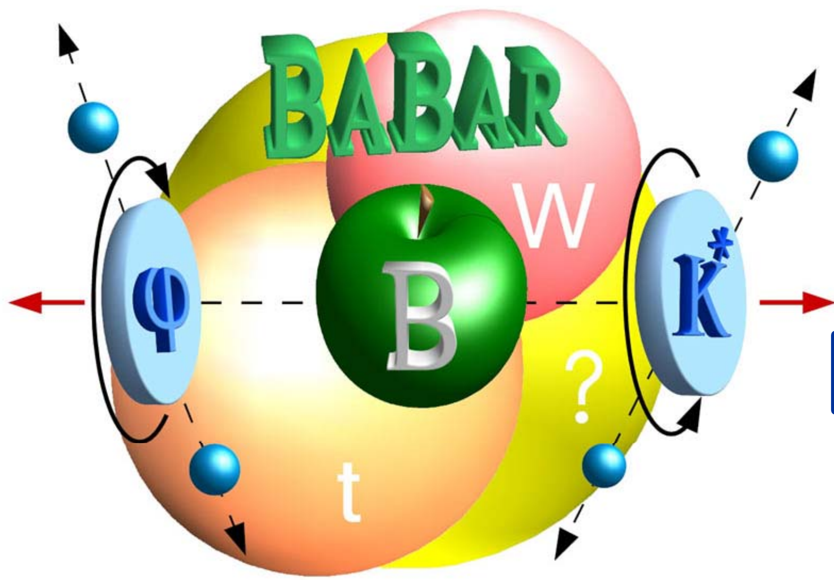
- $B^0 \to \phi\ K^* \to (KK)(K^+\pi^-)$ for all interesting $J^P = (-1)^J$ K^* resonances

  1. Update $B \to \phi\ K^*(892)$
  2. Probe $K_2^*(1430)$, $K_0^*(1430)$, $K^*(1680)$, $K_3^*(1780)$, $K_4^*(2045)$

- Complement the B^0 with decays $B^+ \to \phi K^{*+} \to (KK)(K_S\pi^+/K^+\pi^0)$, with

- Search for new parity K^*, $K_J^{(*)}$ $J^P = (-1)^{J+1}$, through $K_J^{(*)} \to K\pi\pi$

  1. Axial Vector $K_1(1270)$, $K_1(1400)$
  2. Pseudo Tensor $K_2(1770)$, $K_2(1820)$

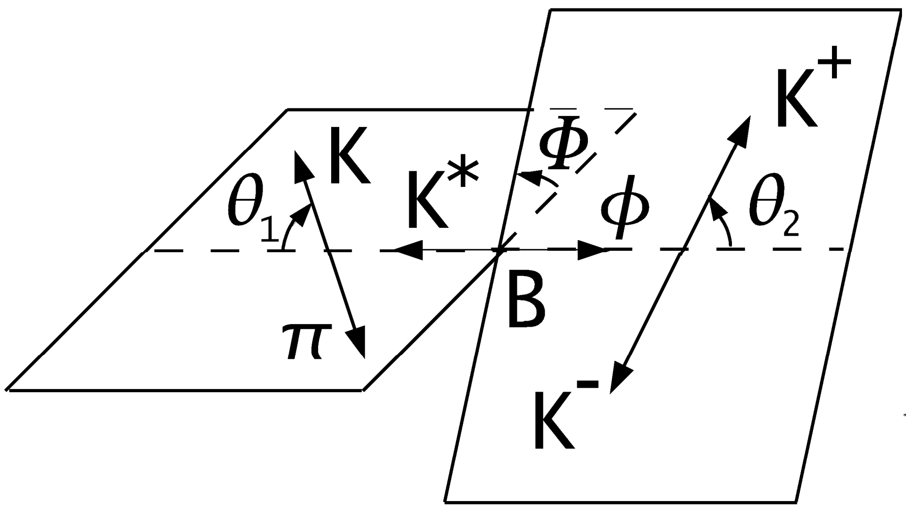


Angular Distributions

The Angles and Angular Distributions (I)

- Four-body Final States (KK)(Kπ) Parity $(-1)^J$ spin-J (Kπ) resonances

B→ϕ K*(892), K*(1430)(T, S), K*(1680), K_3*(1780), K_4*(2045)



Vector Vector

$$\frac{8\pi}{9\Gamma}\frac{d^3\Gamma}{d\mathcal{H}_1 d\mathcal{H}_2 d\Phi} = \alpha_1 \times \mathcal{H}_1^2 \cdot \mathcal{H}_2^2 + \alpha_2 \times (1-\mathcal{H}_1^2)\cdot(1-\mathcal{H}_2^2) + \alpha_3 \times (1-\mathcal{H}_1^2)\cdot(1-\mathcal{H}_2^2)\cdot\cos 2\Phi + \alpha_4 \times (1-\mathcal{H}_1^2)\cdot(1-\mathcal{H}_2^2)\cdot\sin 2\Phi + \alpha_5 \times \sqrt{1-\mathcal{H}_1^2}\cdot\mathcal{H}_1\cdot\sqrt{1-\mathcal{H}_2^2}\cdot\mathcal{H}_2\cdot\cos\Phi + \alpha_6 \times \sqrt{1-\mathcal{H}_1^2}\cdot\mathcal{H}_1\cdot\sqrt{1-\mathcal{H}_2^2}\cdot\mathcal{H}_2\cdot\sin\Phi$$

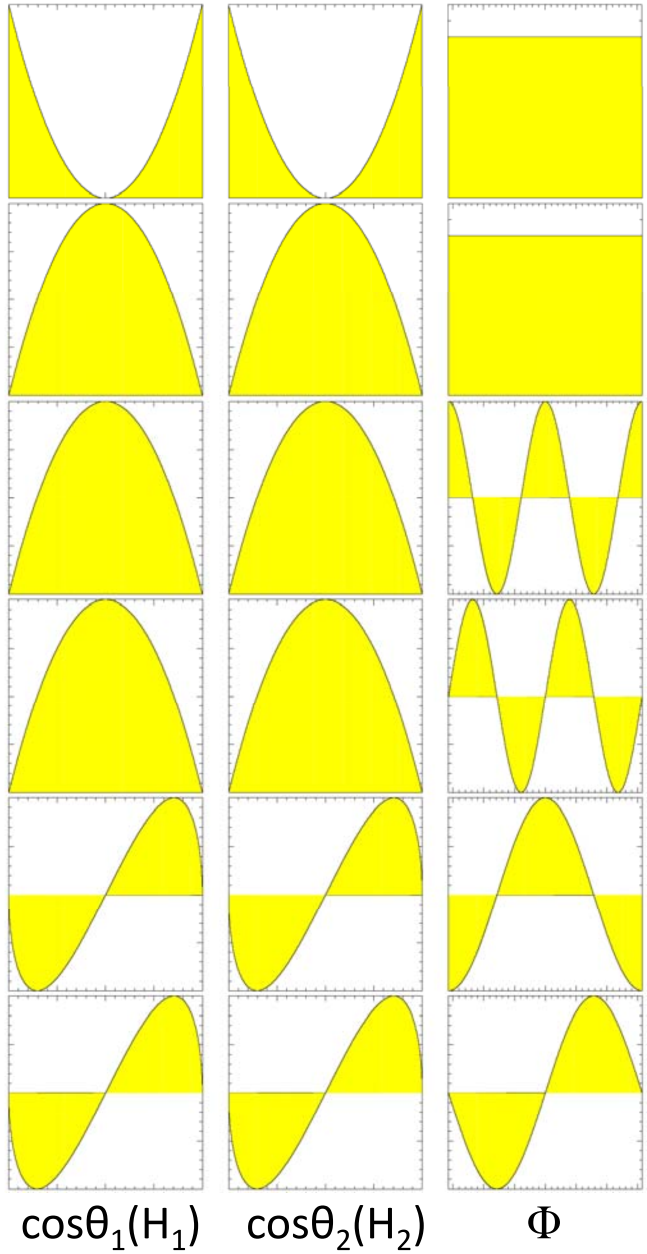
- Scalar → Spin(J_1) + Spin(J_2)

$$\frac{1}{\Gamma}\frac{d^3\Gamma}{d\cos\theta_1\cos\theta_2 d\Phi} = \frac{1}{\sum_\lambda |A_\lambda|^2}\left|\sum_\lambda A_\lambda Y_{J_1}^{-\lambda}(\pi-\theta_1,-\Phi)Y_{J_2}^{\lambda}(\theta_2,0)\right|^2$$

Phenomenology Paper Phys. Rev. D. 77, 114025 (2008),

A. Datta, ***Y. Y. Gao***, A.V. Gritsan, D. London, M. Nagashima, A. Szynkman

Angular Measurements in α for Vector-Vector Decays



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

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

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

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

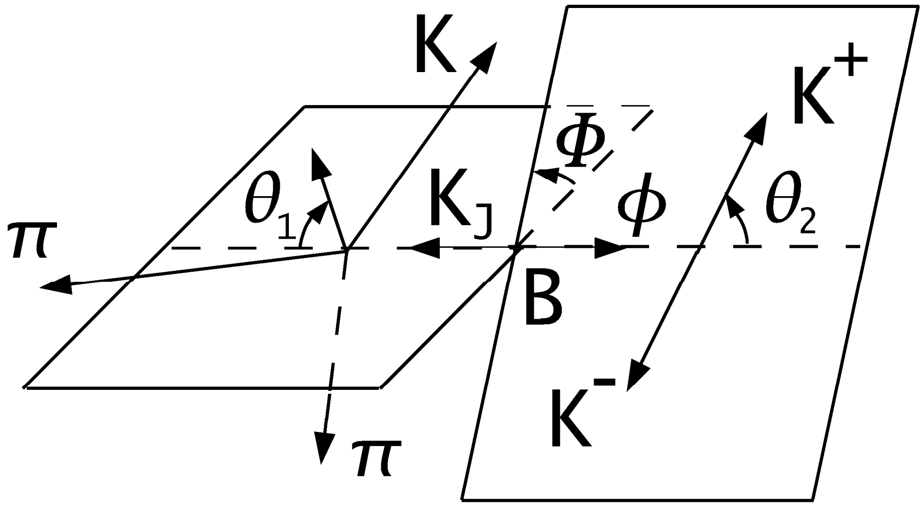
$\alpha_5(f_L, f_\perp, \phi_\parallel)\times \Rightarrow \mathrm{Re}(A_\parallel A_0^*)$

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

The Angles and Angular Distributions (II)

- Five-body Final States (KK)(Kππ)

$B^{\pm}\rightarrow\phi\ K_1(1270/1400)^{\pm}$, $K_2(1770/1820)^{\pm}$ Parity $J^P(-1)^{J+1}$ resonances + $K_2^*(1430)^{\pm}$



Vector Axial-Vector

$$\frac{16\pi}{9\Gamma}\frac{d^3\Gamma}{d\mathcal{H}_1 d\mathcal{H}_2 d\Phi} = \alpha_1\times(1-\mathcal{H}_1^2)\mathcal{H}_2^2$$
$$+\alpha_2\times(1+\mathcal{H}_1^2)(1-\mathcal{H}_2^2)$$
$$-\alpha_3\times(1-\mathcal{H}_1^2)(1-\mathcal{H}_2^2)\cos 2\Phi$$
$$-\alpha_4\times(1-\mathcal{H}_1^2)(1-\mathcal{H}_2^2)\sin 2\Phi$$
$$-\alpha_5\times\mathcal{H}_1\mathcal{H}_2\sqrt{1-\mathcal{H}_1^2}\sqrt{1-\mathcal{H}_2^2}\cos\Phi$$
$$-\alpha_6\times\mathcal{H}_1\mathcal{H}_2\sqrt{1-\mathcal{H}_1^2}\sqrt{1-\mathcal{H}_2^2}\sin\Phi\ \}$$

- Scalar → Spin(J_1) + Spin(J_2)

$$\frac{1}{\Gamma}\frac{d^3\Gamma}{d\cos\theta_1\cos\theta_2 d\Phi} = \frac{1}{\sum_\lambda |A_\lambda|^2}\sum_m |R_m|^2 \left|\sum_\lambda A_\lambda Y_{J_1}^{-\lambda}(\pi-\theta_1,-\Phi)d_{\lambda,m}^{J_2}(\theta_2)\right|^2$$

R_m: kinematic parameters depending on the $K_J\rightarrow(K\pi\pi)$ spin eigenstates, no on λ

CP Asymmetries in B→ϕK*

- Separate $B\bar{B}$ discrete B flavor observable

  $Q_B = +1$ for $\bar{B}^0/B^-$ $\quad$ $Q_B = -1$ for B^0/B^+

- Direct CP-Asymmetries

Overall
$$\mathcal{A}_{CP} = \frac{\Gamma^+ - \Gamma^-}{\Gamma^+ + \Gamma^-} = \frac{n^+_{\text{sig}} - n^-_{\text{sig}}}{n^+_{\text{sig}} + n^-_{\text{sig}}}$$

Longitudinal
$$\mathcal{A}^0_{CP} = \frac{f^+_L - f^-_L}{f^+_L + f^-_L}$$

CP-Odd Transverse
$$\mathcal{A}^\perp_{CP} = \frac{f^+_\perp - f^-_\perp}{f^+_\perp + f^-_\perp}$$

$$|A_0|^2 \neq |\bar{A}_0|^2$$
$$|A_\parallel|^2 \neq |\bar{A}_\parallel|^2$$
$$|A_\perp|^2 \neq |\bar{A}_\perp|^2$$

- Angular (Phases) CP Asymmetries

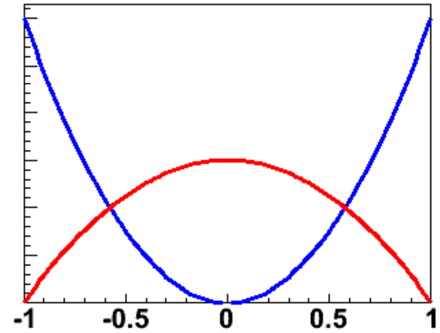
CP-Even transverse phase A_{CP} $\quad$ $\Delta\phi_\parallel = \frac{1}{2}\arg(\bar{A}_\parallel A_0 / A_\parallel \bar{A}_0)$

CP-Odd transverse phase A_{CP} $\quad$ $\Delta\phi_\perp = \frac{1}{2}\arg(\bar{A}_\perp A_0 / A_\perp \bar{A}_0) - \frac{\pi}{2}$

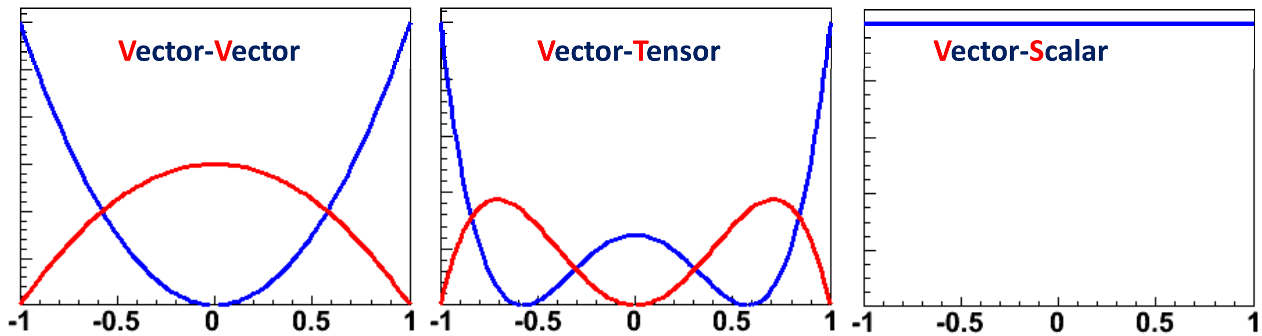
Ideal Angular Distributions

- $\cos\theta_2$ distributions (with the vector ϕ meson)

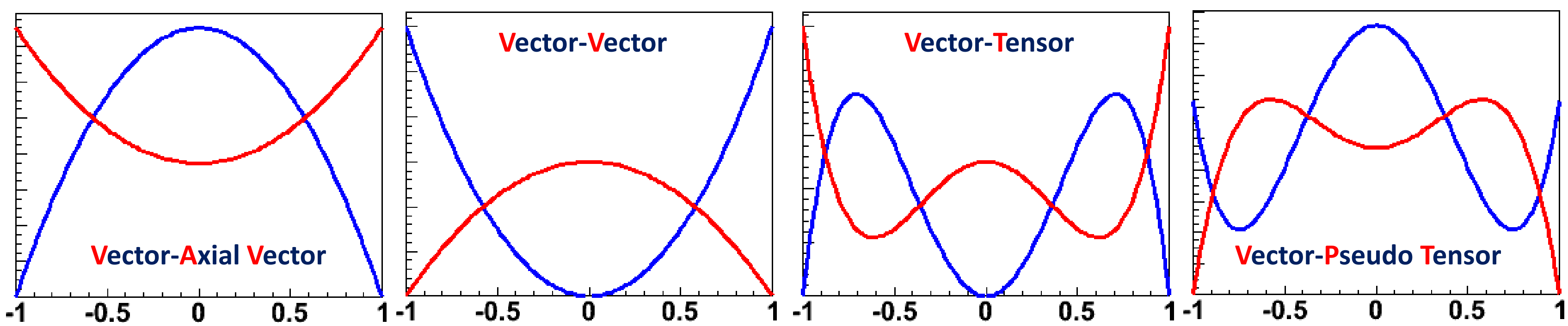
Blue : longitudinal mode
Red : transverse mode



- Four-body FS ($K^* \to K\pi$) $\cos\theta_1$ (with the spin-J K^* meson) distributions



- Five-body FS ($K^* \to K\pi\pi$) $\cos\theta_1$ (with the spin-J K^* meson) distributions

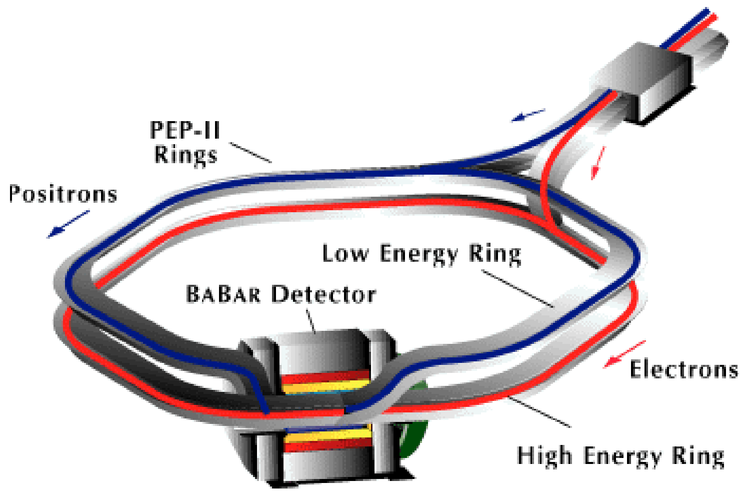


The BaBar Experiment at SLAC

The PEP-II Asymmetric B Factory

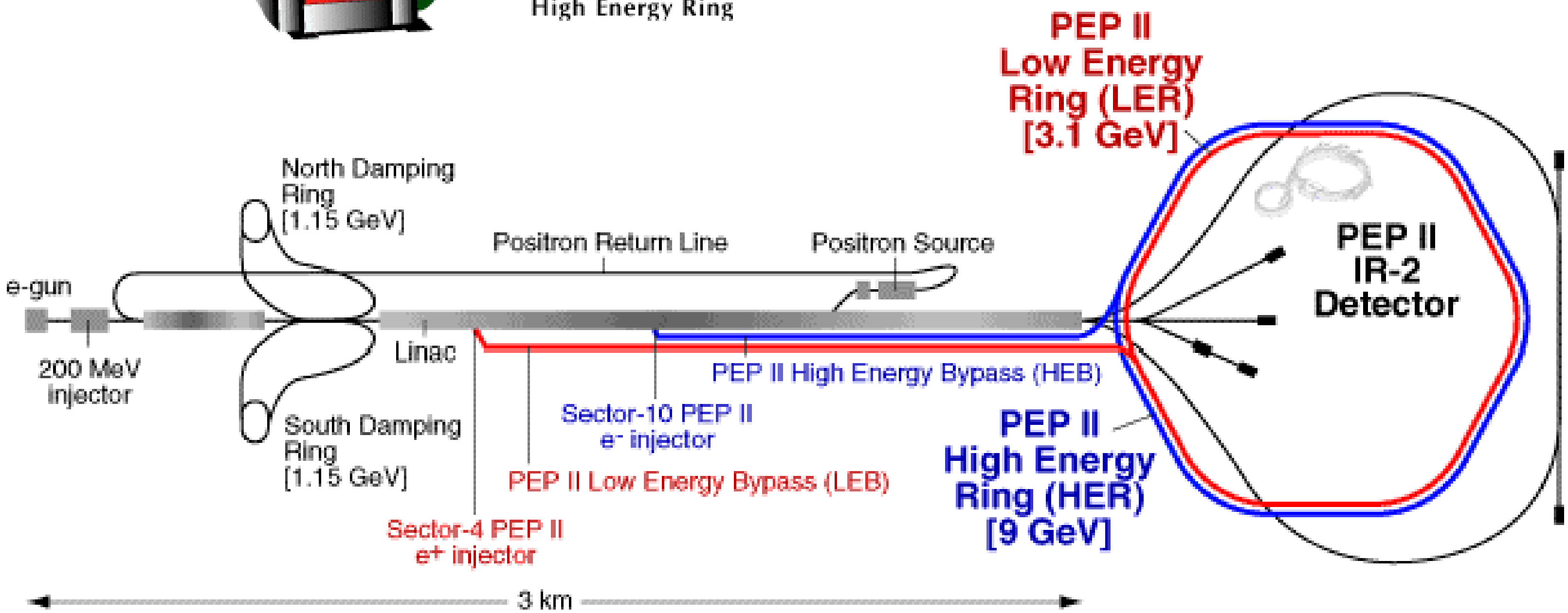
- B production at PEP-II Collider

475 $\times 10^6$ $B\bar{B}$

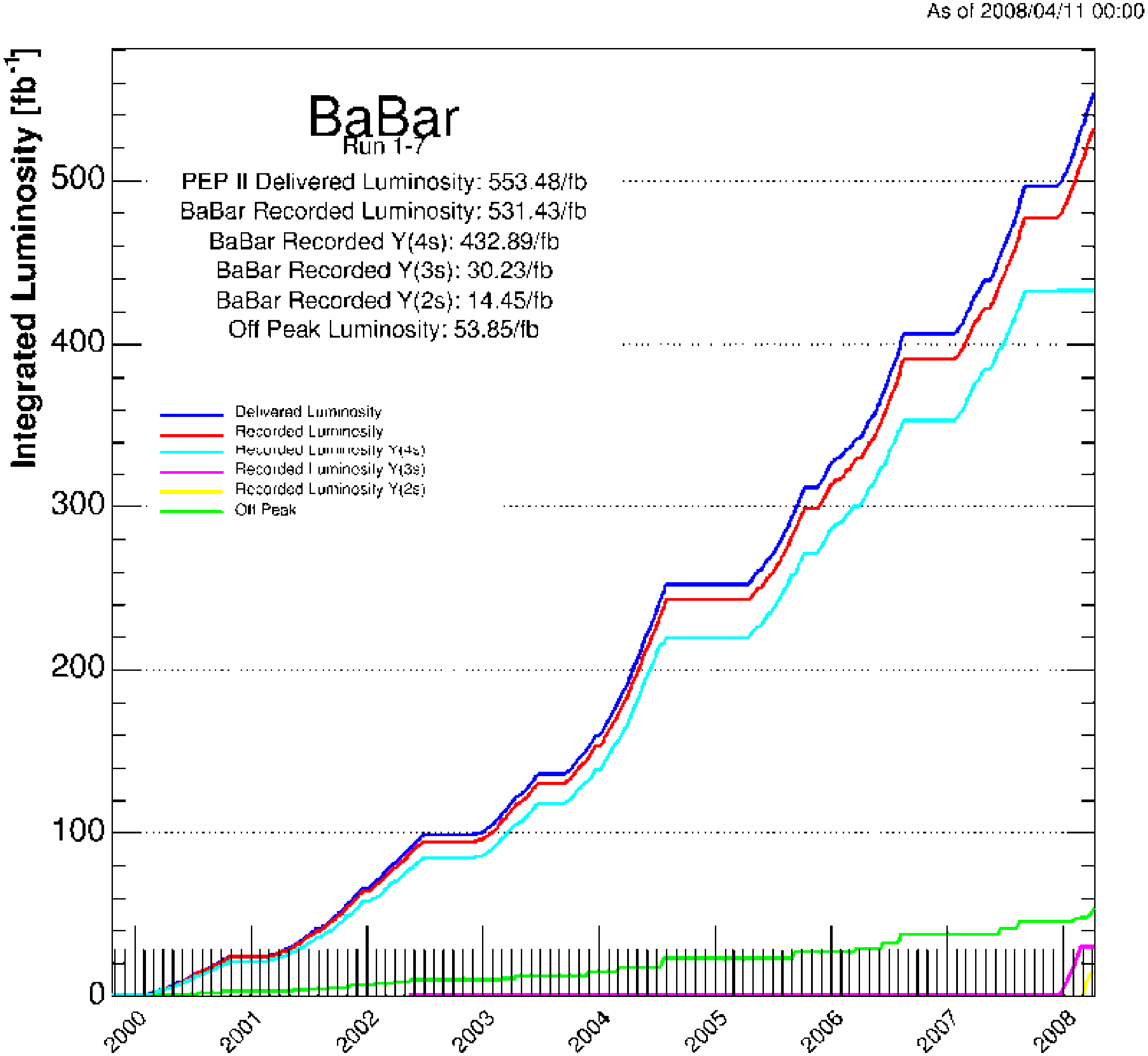


$$e^+e^- \rightarrow \Upsilon(4S)(b\bar{b}) \rightarrow B\bar{B}$$

- **10.58GeV Center of Mass energy**
- **E(e^-)> E(e^+) => β = 0.56**

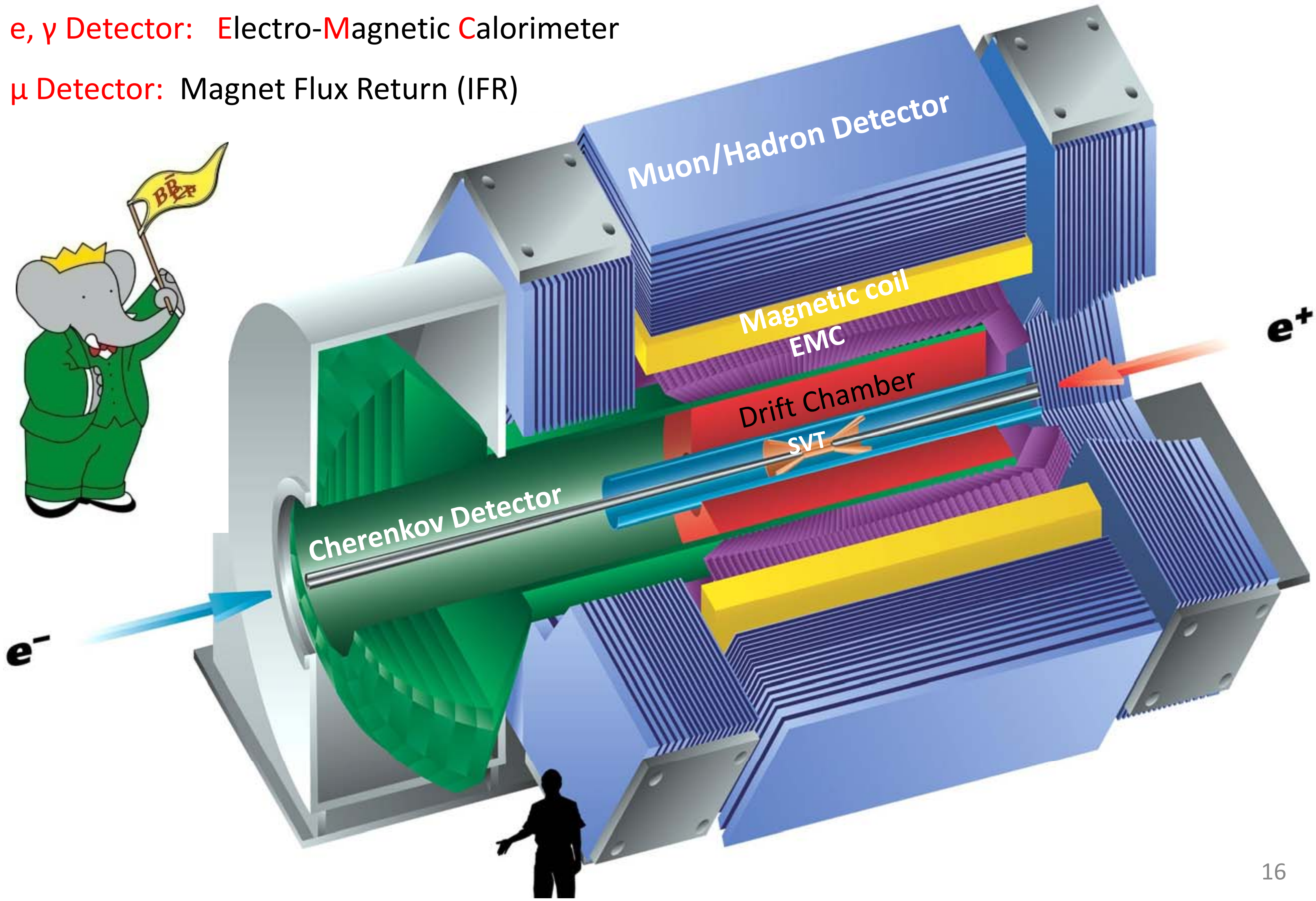


Luminosity Performance



The BaBar Detector

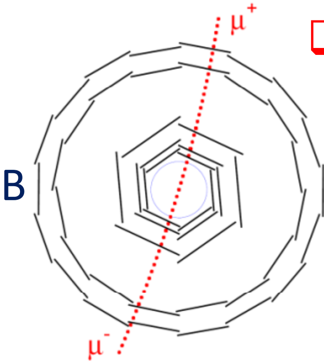
- Central Tracking: Silicon Vertex Tracker(SVT) + Drift Chamber(DCH)
- Particle ID: Cherenkov Detector + dE/dx (SVT+ DCH)
- e, γ Detector: Electro-Magnetic Calorimeter
- μ Detector: Magnet Flux Return (IFR)

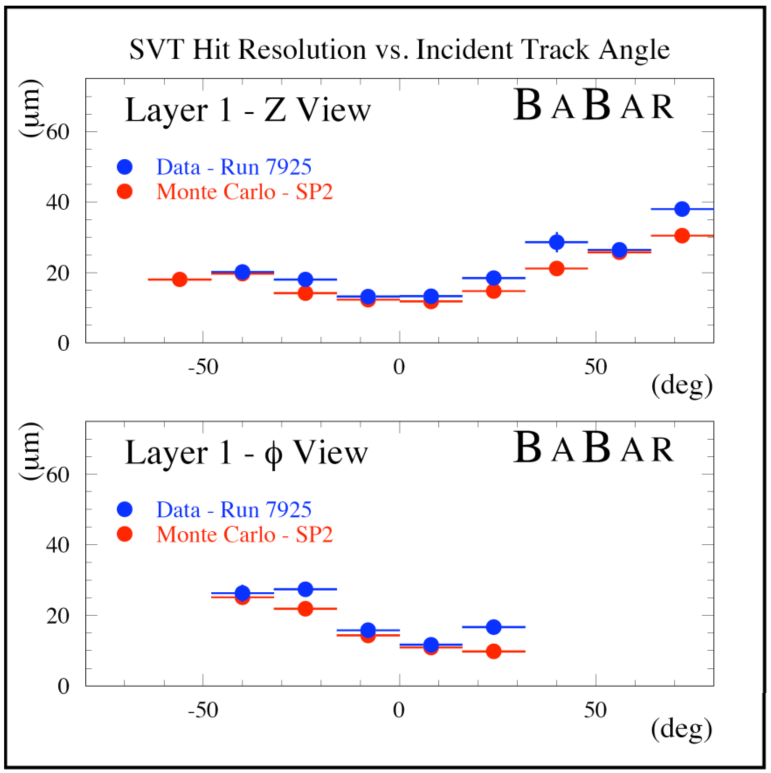


Silicon Vertex Tracker Performance

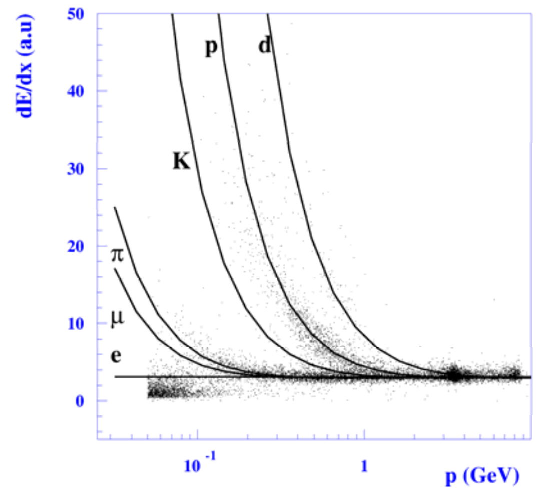
- Spatial Resolutions

z-distance of the two B
$\sigma(\Delta Z_B) \sim$ 180 µm
$\beta\gamma c\tau_B \sim$ 250 µm

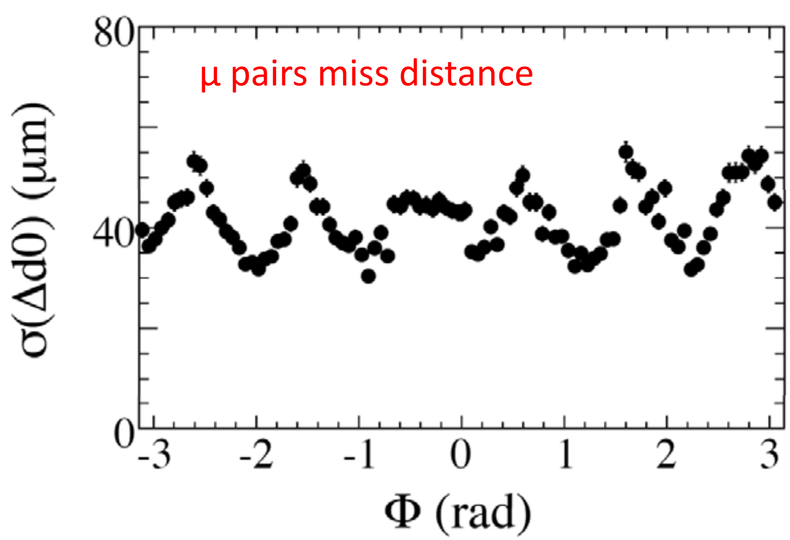




- Low p track particle identification



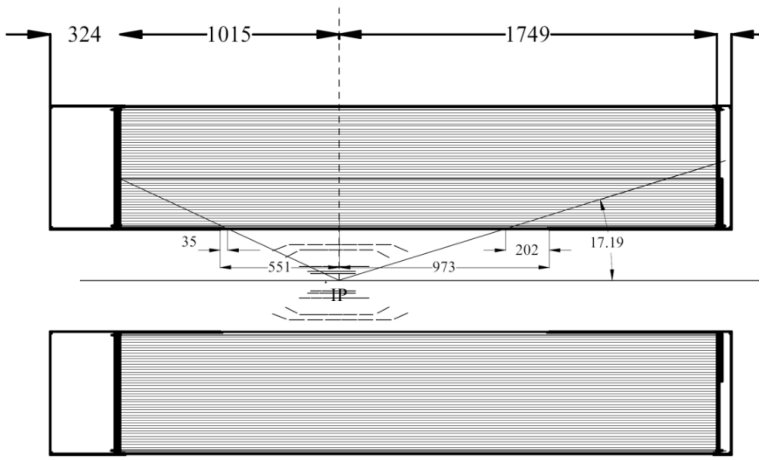
- µµ + cosmic rays for alignment

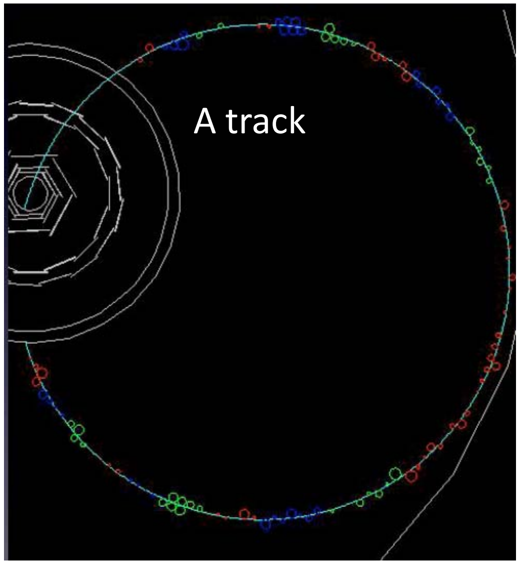


Charged Particle Tracking in BaBar (e, μ, π, K, P)

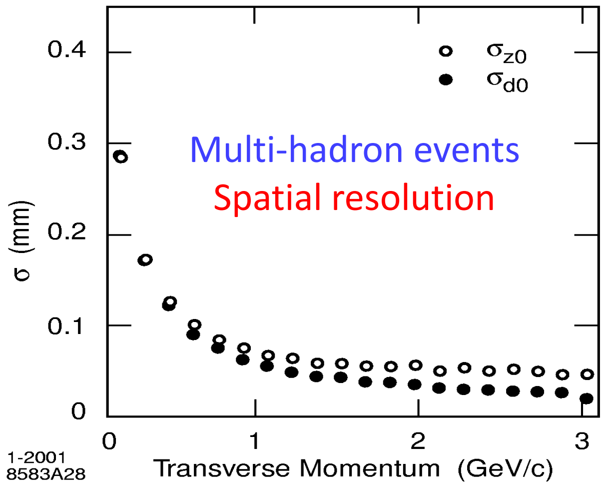
- Central Tracking: SVT+DCH

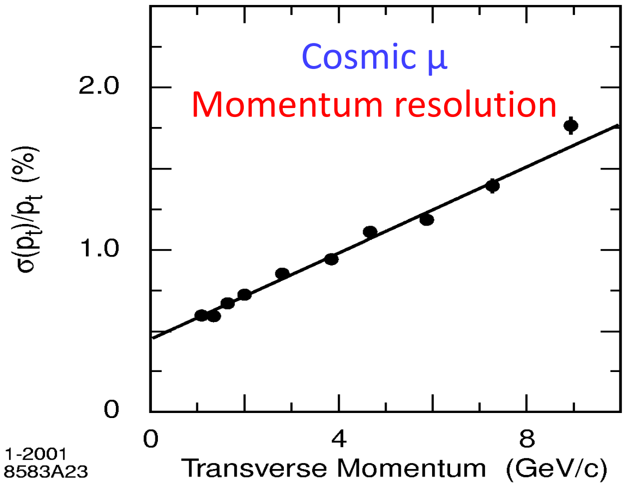
1.5 T B-field





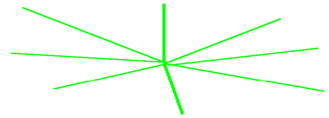
- SVT： vertex position, low p_T momentum near IP
- DCH： momentum and angles (track curvature)





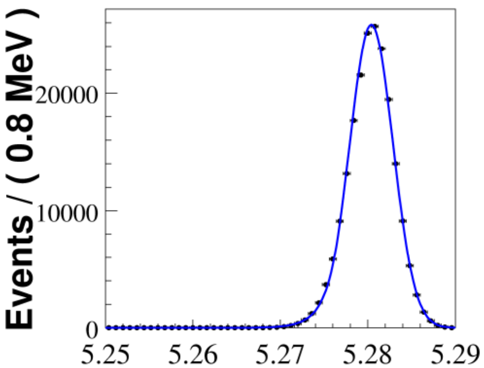
A typical B track, with p_T ~ 1.5 GeV, $\sigma(p_T)$ resolution is 10 MeV

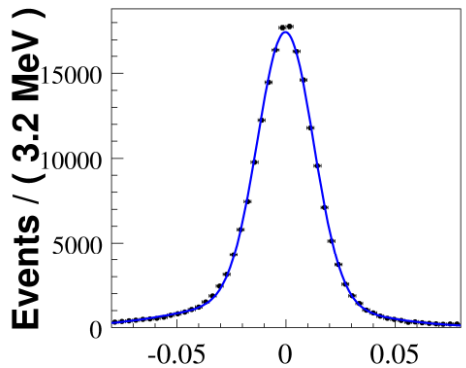
Identify the B mesons

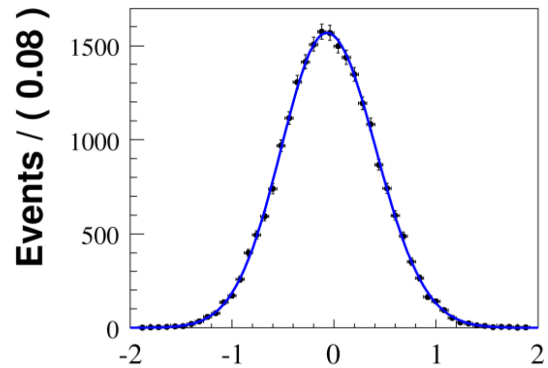
- B signals $e^+e^- \to B\bar{B}$  $\phi(K^+K^-)K_1(1270)(K^+\pi^+\pi^-)$ MC

$$m_{ES} = \sqrt{E_{beam}^2 - \vec{p}_B^{\,2}} \qquad \Delta E = E_B^{cm} - E_{beam}^{cm}$$

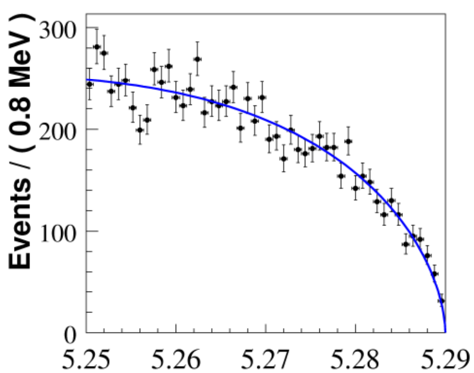
Event Shape (Fisher)

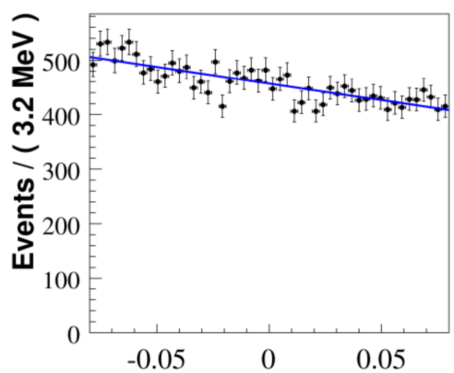


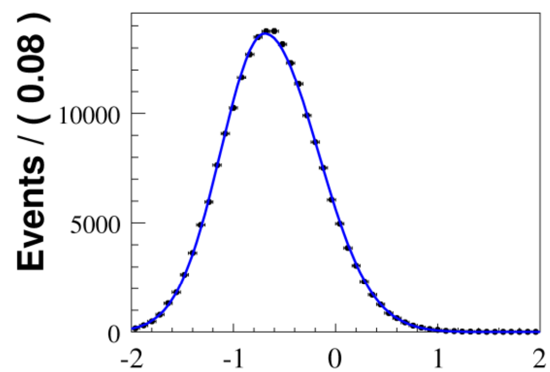




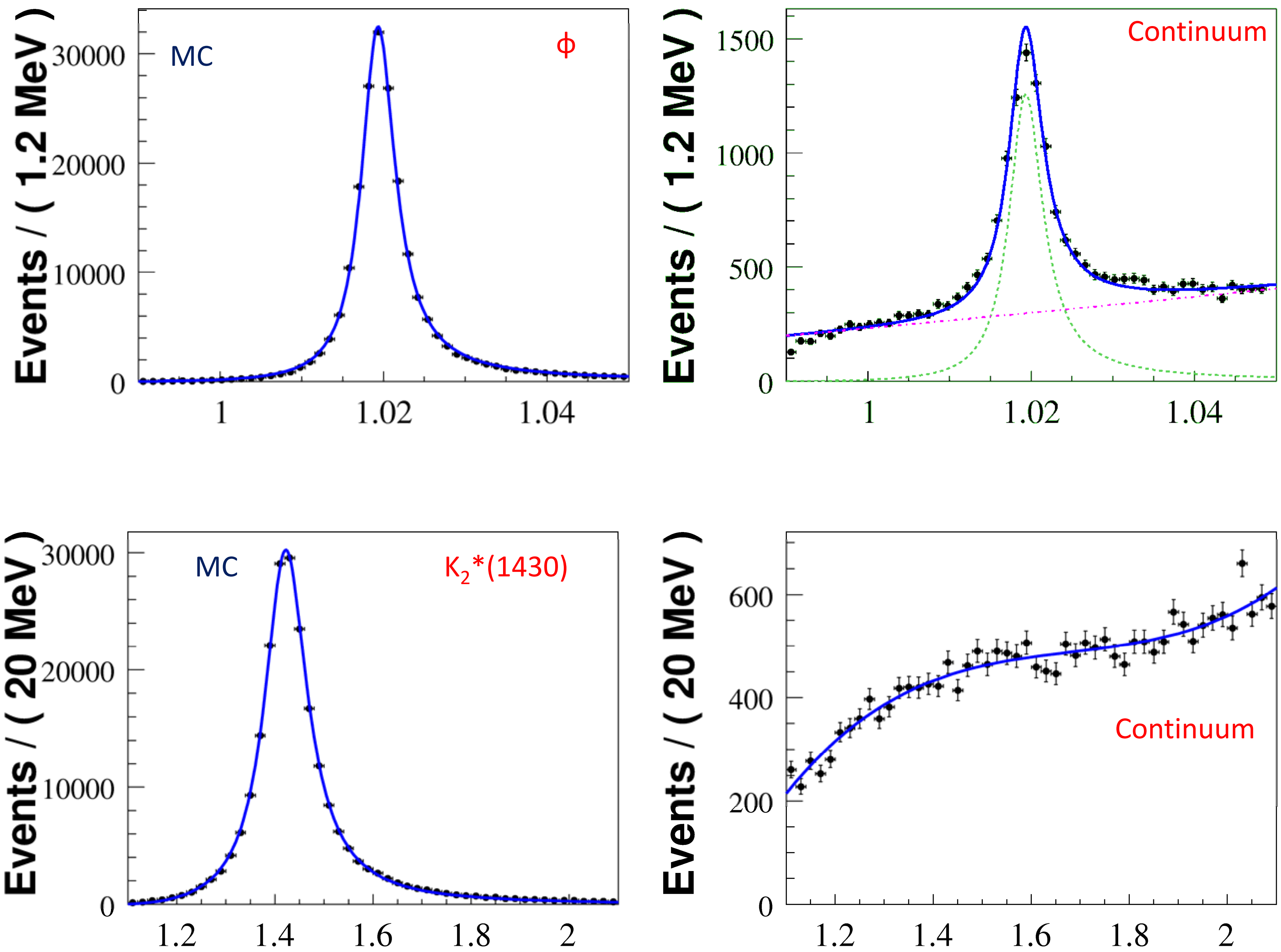
- Jet-like background $e^+e^- \to q\bar{q}$  with $(K^+K^-K^+\pi^+\pi^-)$ FS







Reconstruct the ϕ and K*



Background Study

- Various Backgrounds

1. Dominant $e^+e^- \rightarrow$ qqbar

   suppressed by $\cos(\theta_T) < 0.8$, angle between the B thrust & the rest of the events
   rest are Included in the fit

2. Charm decays $B \rightarrow D_{(S)}{}^*K(\pi)$ vetoed $|m(\phi\pi)-m(D_{(S)})| < 12$ MeV

3. Possible signal-like B-decays $B \rightarrow f_0K^*$, nonresonant $B \rightarrow \phi K\pi(\pi)$, $(KK)K^*$

   included in the fit

4. Random tracks from B mesons

   accounted well by qqbar events(thus in the fit!)

Analysis Method

Estimate a set of parameters in a likelihood fit

Extended Maximum Likelihood Fit

- After the preliminary selection cuts, several (10^3 – 10^4) events left
  1. Observables $\vec{x}_j = \{m_{\rm ES},\ \Delta E,\ \mathcal{F},\ m_{KK},\ m_{K\pi},\ \theta_1,\ \theta_2,\ \Phi,\ Q_B\}$
  2. Event type j Signal {B → φK*..}, Non-Resonant bkg {B→φ(Kπ), f_0K*…}, Continuum
  3. Probability Density Function (PDF)s for each type

$$\mathcal{P}_{i,k}(\vec{x}_j) = \mathcal{P}_{i1}(m_{\rm ES})\cdot\mathcal{P}_{i2}(\Delta E)\cdot\mathcal{P}_{i3}(\mathcal{F})\cdot\mathcal{P}_{i4}(m_{KK})\cdot\delta_{kQ}\times$$
$$\times\ \mathcal{P}^{\rm hel}_{i,k}(m_{K\pi},\theta_1,\theta_2,\Phi,{f_L}^k,{f_\perp}^k,{\phi_\perp}^k,{\phi_\parallel}^k,{\delta_0}^k)\times\mathcal{G}(\theta_1,\theta_2,\Phi)$$

  4. Interferences between different resonances are neglected unless overlap too much

- The combined Likelihood

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

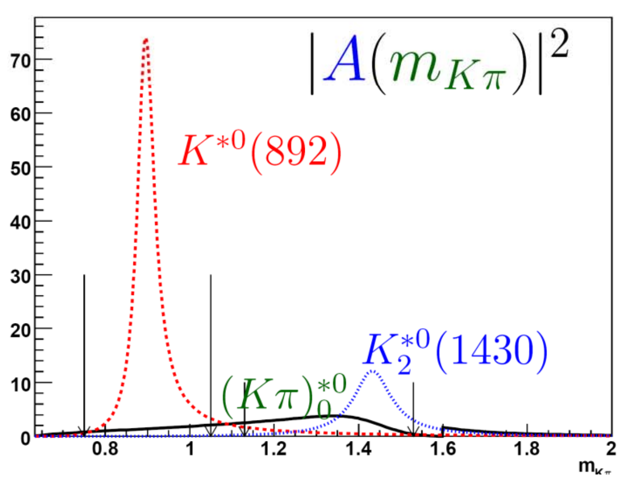
-2ln (L) minimized to obtain yields, angular, CP measurements

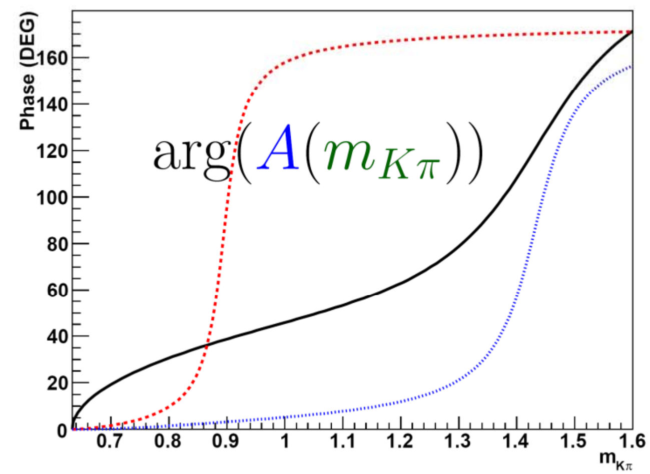
- Blind Analysis
  1. Fit Monte Carlo data samples, perform ~ 1000 individual MC experiments
  2. Inconsistency between fit results and input → systematic error

Interference Between Two Amplitudes

- Broad Scalar $(K\pi)^*$ J^P (0^+) Scattering + resonant

$$A_{\rm LASS}(m) = \frac{m e^{i\delta_0}}{q\cot\Delta B - iq} + e^{2i\Delta B} e^{i\delta_0} \frac{\Gamma_0 m_0^2/q_0}{m_0^2 - m^2 - i\Gamma_0 m_0^2 q/(m q_0)}$$





- Full angular-mass PDF of Vector-Vensor(Tensor) (A) and Vector-Scalar (B)

$$\mathcal{P}(\theta_1, \theta_2, \Phi, m_{K\pi}) = f\cdot|A|^2 + (1-f)\cdot|B|^2 + \boxed{\sqrt{f(1-f)}\cdot 2\mathcal{R}e(AB^*)}$$

- Effects on the $\cos\theta_1$:

  VV/VS: forward-backward asymmetry $\cos\theta_1 \times \cos^2\theta_2$

  VT/VS: middle-edge effect $(3\cos^2\theta_1 - 1)^2 \times \cos^2\theta_2$

- Interference parameter δ_0 measured in $B^0 \to J/\psi\,(K\pi)_0^{*0}$ $\delta_0 \approx \pi$

$B^{\pm} \to \phi K^*(1430)(K_S\pi^{\pm}/K^{\pm}\pi^0/K^{\pm}\pi^+\pi^-)$ Joint Fit

- Different FS decays $K_2^*(1430) \to K_S\pi^{\pm}/K^{\pm}\pi^0/K^{\pm}\pi^+\pi^-$ $(K\pi)_0^* \to K_S\pi^{\pm}/K^{\pm}\pi^0$

  Constrain same b.f. and polarization in all FS by $L = L_1 \cdot L2(\cdot L_3)$

- Constrain yields in different FS by their relative efficiencies

$$r_1 = \frac{\varepsilon_{K_S\pi^{\pm}}}{\varepsilon_{K^{\pm}\pi^0}}(\varphi K_2^*) \quad r_2 = \frac{\varepsilon_{K_S\pi^{\pm}}}{\varepsilon_{K^{\pm}\pi^0}}(\varphi (K\pi)_0^*) r_3 = \frac{\varepsilon_{K\pi\pi}}{\varepsilon_{K\pi^0}}(\varphi K_2^*)$$

- Directly fit two parameters:

$$f_1 = \frac{n_{\mathrm{VT1}}}{n_{\mathrm{VT1}} + n_{\mathrm{VS1}}} \quad n_{\mathrm{tot}} = n_{\mathrm{VT1}} + n_{\mathrm{VS1}} + n_{\mathrm{VT2}} + n_{\mathrm{VS2}}$$

"1,2,3" subscripts are for $K_S\pi^{\pm}$, $K^{\pm}\pi^0$, and $K\pi\pi$ channels respectively

- Calculate the yields in each final state, and propagate the errors accordingly

$\varphi K_2^*(1430)$

$$n_{VT1} = \frac{n_{tot}\ f_1\ r_1\ r_2}{f_1\ (r_2 - r_1) + r_1(r_2 + 1)}$$

$$n_{VT2} = \frac{n_{VT1}}{r_1}$$

$$n_{VT3} = n_{VT2} \times r_3$$

$\varphi(K\pi)_0^*$

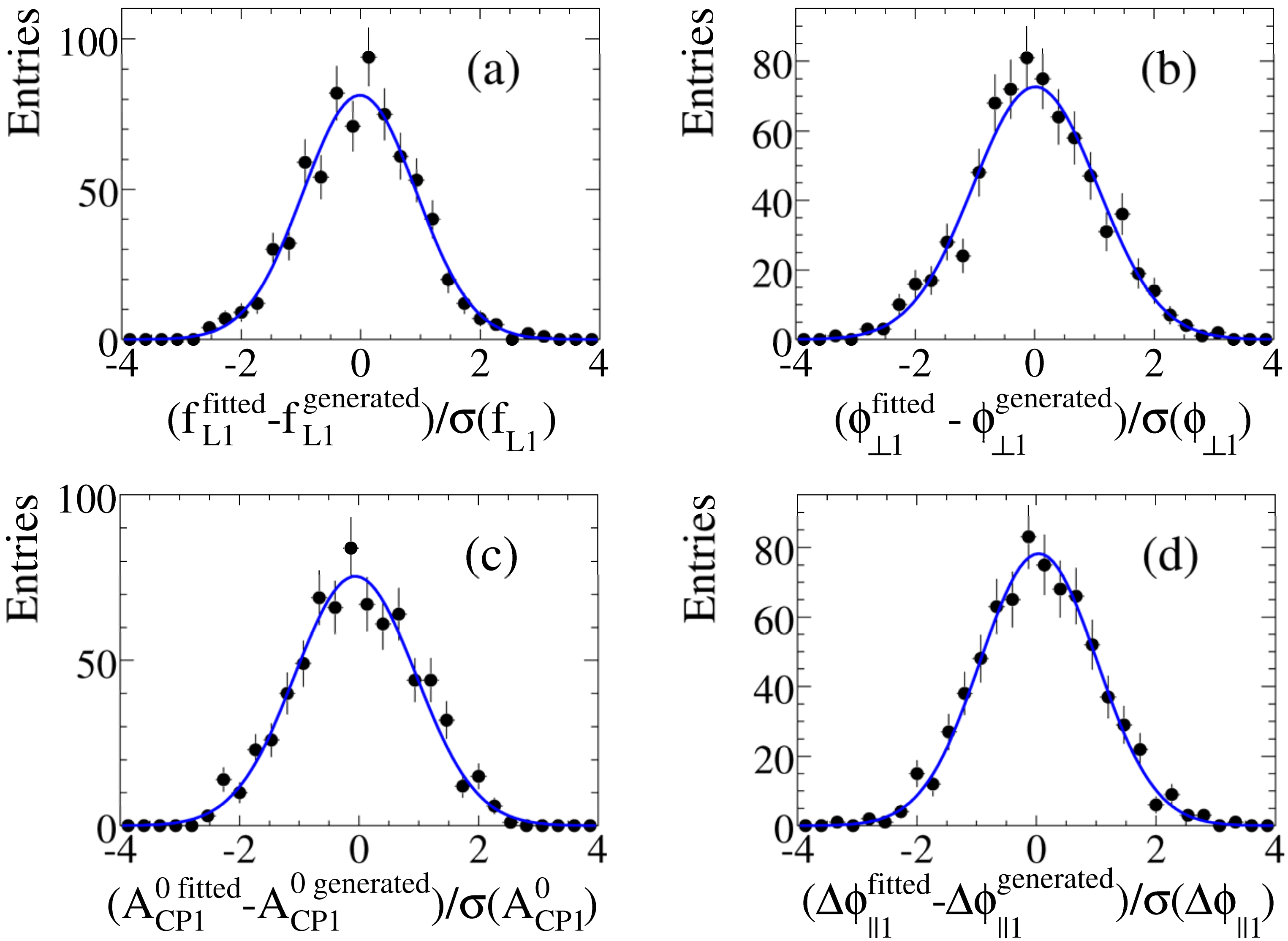
$$n_{VS1} = \frac{n_{VT1}(1 - f_1)}{f_1}$$

$$n_{VS2} = \frac{n_{VS1}}{r_2}$$

Implementation is further complicated due to combination of VT and VS decays

B→ϕK* Angular Parameters Fit Performance

$(X^{generated} - X^{fitted})/\sigma(x)$ Gaussian(0,1)

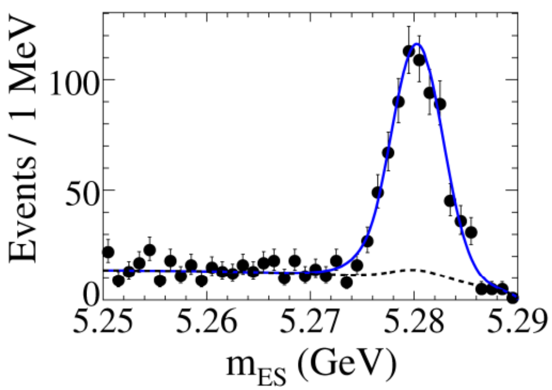


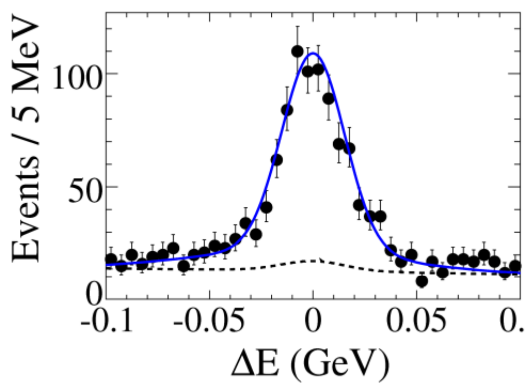
Measurements

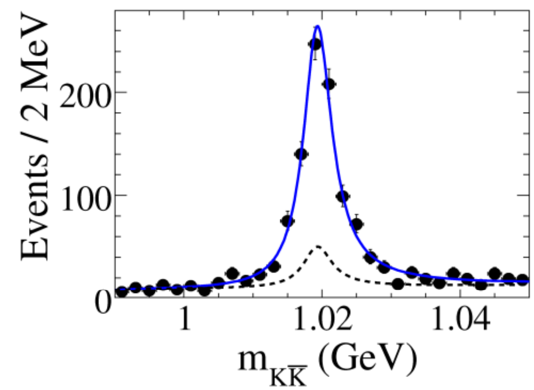
Phys. Rev. Lett. 98, 051801(2007)
Phys. Rev. D 76, 051103(2007)
Phys. Rev. Lett. 99, 201802(2007)
arXiv:0806.4419[hep-ex], Accepted by PRL
arXiv:0803.3586[hep-ex], Accepted to PRD

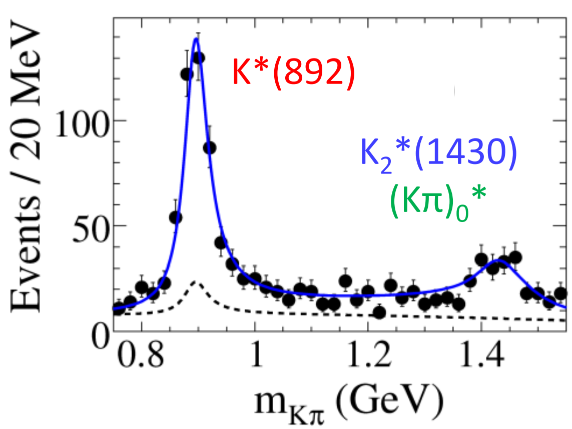
$B^0 \to \phi(K^+\pi^-)$ Branching Fractions

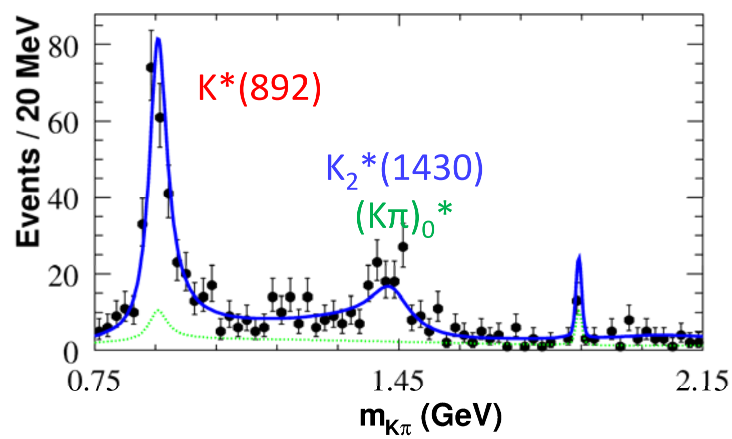
Mode	Yields	B.F. (10^{-6})	A_{CP}
$\phi(K\pi)_0^*$	158 ± 22 ± 13	4.3 ± 0.6 ± 0.4	+0.20 ± 0.14 ± 0.06
$\phi K^*(892)^0$	500 ± 28 ± 19	9.7 ± 0.5 ± 0.5	+0.01 ± 0.06 ± 0.03
$\phi K^*(1680)^0$	8(+10,-7) ± 11	<3.5	0 C
$\phi K_2^*(1430)^0$	158 ± 20 ± 7	7.5 ± 0.9 ± 0.5	-0.08 ± 0.12 ± 0.05
$\phi K_3^*(1780)^0$	-6 ± 10 ± 7	<2.7	0 C
$\phi K_4^*(2045)^0$	18 (+14, -12) ± 12	<1.7	0 C





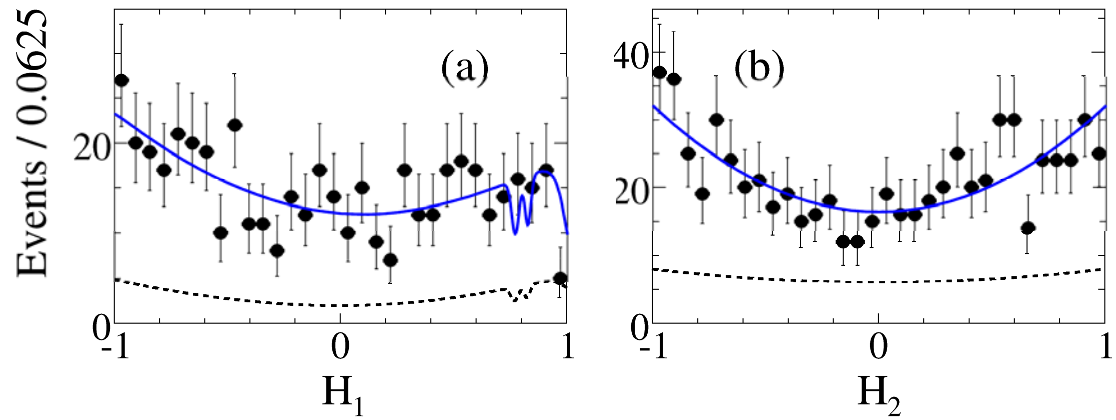






Polarizations and CP: Vector-Vector Decay $B^0 \rightarrow \phi K^*(892)$

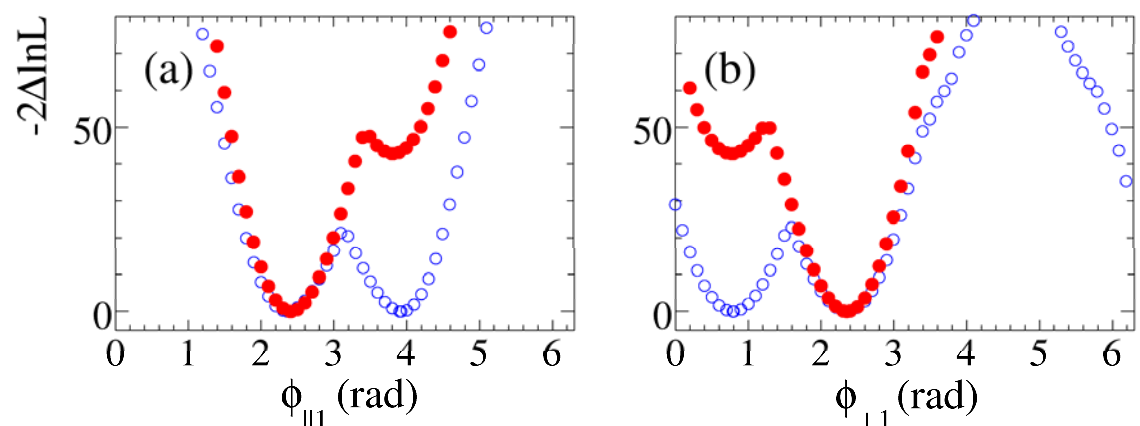
f_L	0.494 ± 0.034 ± 0.013
$f_\perp$	0.212 ± 0.032 ± 0.013
$\phi_{\|\|}$(rad)	2.40 ± 0.13 ± 0.08
$\phi_\perp$(rad)	2.35 ± 0.13 ± 0.09
δ_0(rad)	2.82 ± 0.15 ± 0.09
$\mathcal{A}_{CP}$	+0.01 ± 0.06 ± 0.03
$\mathcal{A}_{CP}^0$	+0.01 ± 0.07 ± 0.02
$\mathcal{A}_{CP}^\perp$	-0.04 ± 0.15 ± 0.06
$\Delta\phi_{\|\|}$	+0.22 ± 0.12 ± 0.08
$\Delta\phi_\perp$	+0.21 ± 0.13 ± 0.08
$\Delta\delta_0$	+0.27 ± 0.14 ± 0.08



- Polarization puzzle confirmed with better precision
- Resolve the phase ambiguity with interference

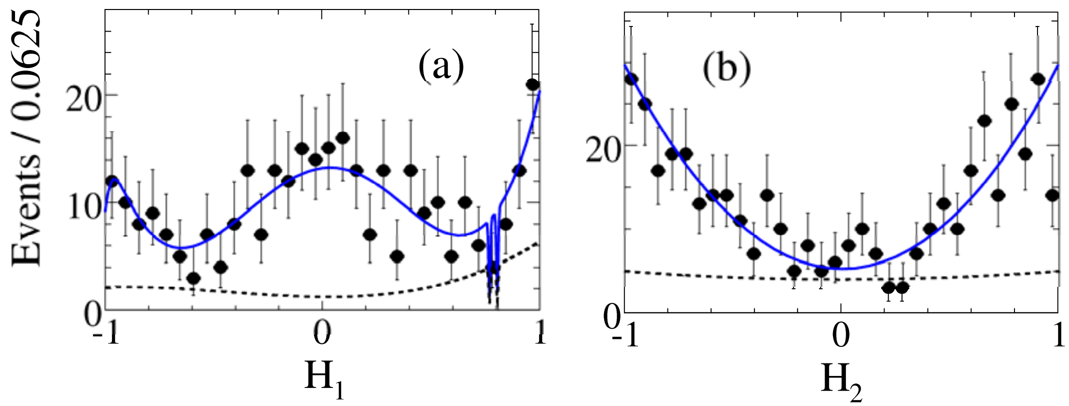
without interf. $(\Phi_{||},\Phi_\perp)$ <=> $(2\pi-\Phi_{||}, \pi-\Phi_\perp)$: (A_{+1}? A_{-1})

with interf. $A_{+1} >> A_{-1}$



Polarizations and CP: Vector-Tensor Decay $B^0 \to \phi K^*(1430)$

f_L	0.901(+0.046, -0.058)± 0.037
$f_\perp$	0.002(+0.018,-0.002) ± 0.031
$\phi_{\parallel}$(rad)	3.96 ± 0.38 ± 0.06
$\phi_\perp$(rad)	----
δ_0(rad)	3.41 ± 0.13 ± 0.13
$\mathcal{A}_{CP}$	-0.08 ± 0.12 ± 0.05
$\mathcal{A}_{CP}^0$	-0.05 ± 0.06 ± 0.01
$\mathcal{A}_{CP}^\perp$	----
$\Delta\phi_{\parallel}$	-1.00 ± 0.38 ± 0.09
$\Delta\phi_\perp$	----
$\Delta\delta_0$	+0.27 ± 0.14 ± 0.08



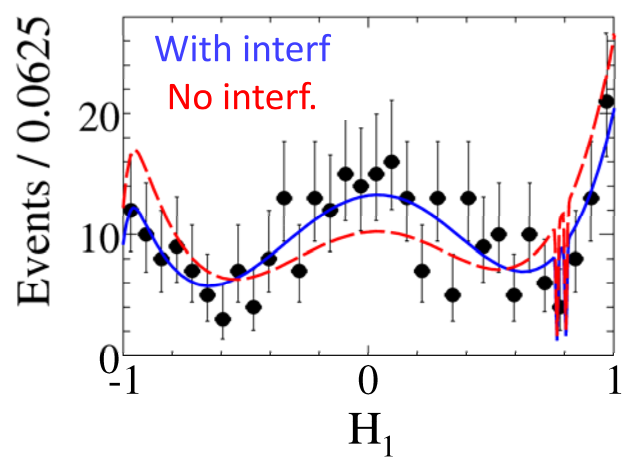
- Vector-Tensor Puzzle

Vector-Vector $|A_0| \cong |A_+| >> |A_-|$

Vector-Tensor $|A_0| >> \sqrt{|A_+|^2 + |A_-|^2}$

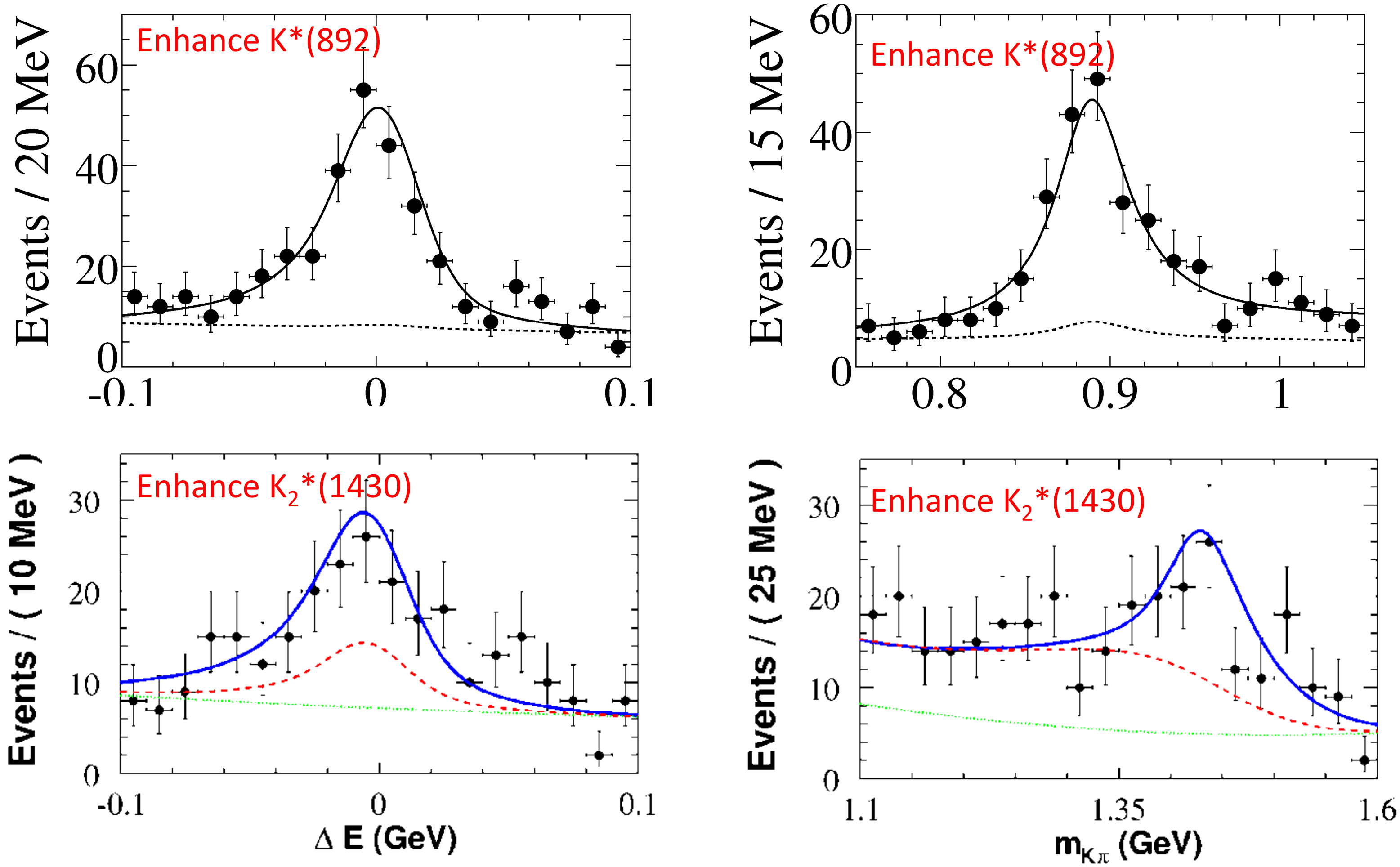
SM's favor!

- $\delta_0 \approx \pi$, consistent with K*(892)/K*(1430) interf.



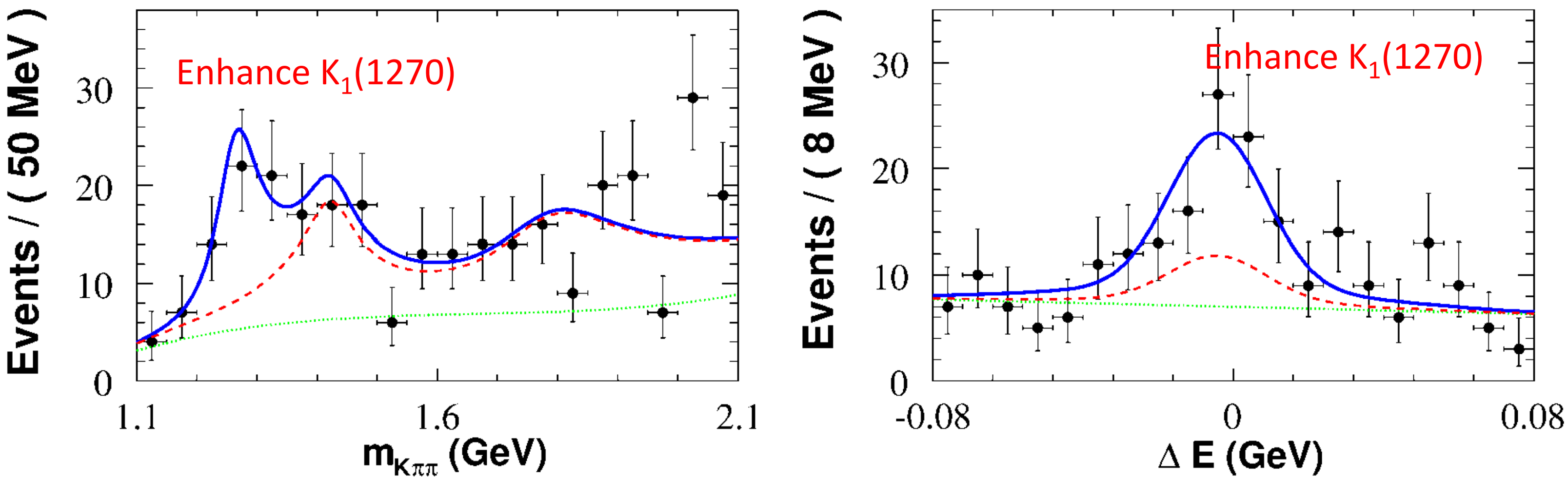
$B^\pm \to \phi(K_S\pi^\pm)/(K^\pm\pi^0)$ Branching Fractions

Mode	Yields ($K_S\pi^\pm$)	Yields ($K^\pm\pi^0$)	B.F. (10^{-6})	A_{CP}
$\phi(K\pi)_0^*$	48 ± 8 ± 4	80 ± 13 ± 8	8.3 ± 1.4 ± 0.8	+0.04±0.15±0.04
$\phi K^*(892)$	102 ± 13 ± 6	117(+15,-16) ± 7	11.2 ± 1.0 ± 0.9	-0.23±0.19±0.06
$\phi K_2^*(1430)$	27 ± 6 ± 3	38 ± 9 ± 4	8.4 ± 1.8 ± 1.0	-0.23±0.19±0.06



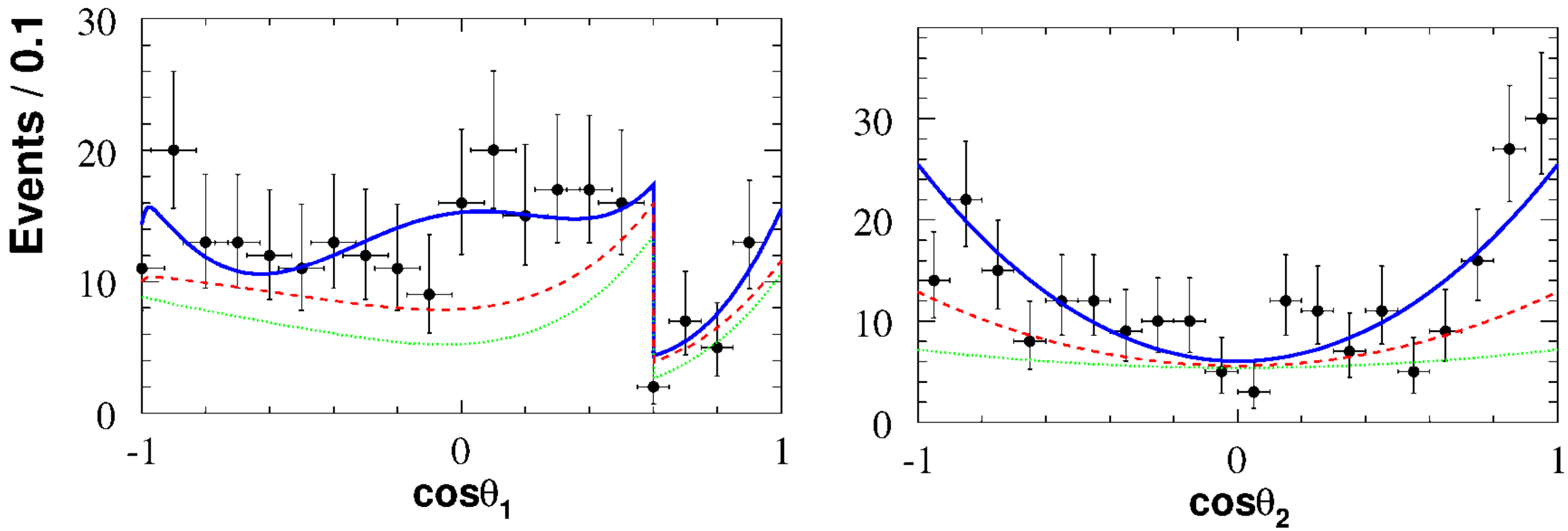
$B^{\pm} \to \phi(K^{\pm}\pi^{+}\pi^{-})$ Branching Fractions

Mode	Yields	B.F. (10^{-6})	A_{CP}
$\phi K_1(1270)$	$116 \pm 26\,^{+15}_{-14}$	$6.1 \pm 1.6 \pm 1.1$	$-0.23 \pm 0.19 \pm 0.06$
$\phi K_1(1400)$	$7 \pm 39 \pm 18$	<3.2 @ 90% C.L.	0 C
$\phi K^*(1410)$	$64 \pm 31^{+20}_{-31}$	< 4.8 @ 90% C.L.	0 C
$\phi K_2^*(1430)$	$64 \pm 14 \pm 7$	8.4±1.8±1.0	-0.23±0.19±0.06
$\phi K_2(1770)$	$90 \pm 32\,^{+36}_{-49}$	<16.0 @ 90% C.L.	0 C
$\phi K_2(1820)$	$122 \pm 40\,^{+26}_{-83}$	<23.4 @ 90% C.L.	0 C



- Vector-Axial Vector observed with 5.0 σ signf (including syst.)
- Only $K_2(1820)$ is included in the nominal fit assuming no $K_2(1770)$
  $\phi K_2(1770)$ B.F. obtained assuming no $K_2(1820)$
- K_2 interference is considered conservatively in syst. study

Polarizations: Vector-Tensor Decay $B^+ \to \phi K^*(1430)^+$



- Vector-Tensor B->ϕ K*(1430) polarization $0.80^{+0.09}_{-0.10} \pm 0.03$

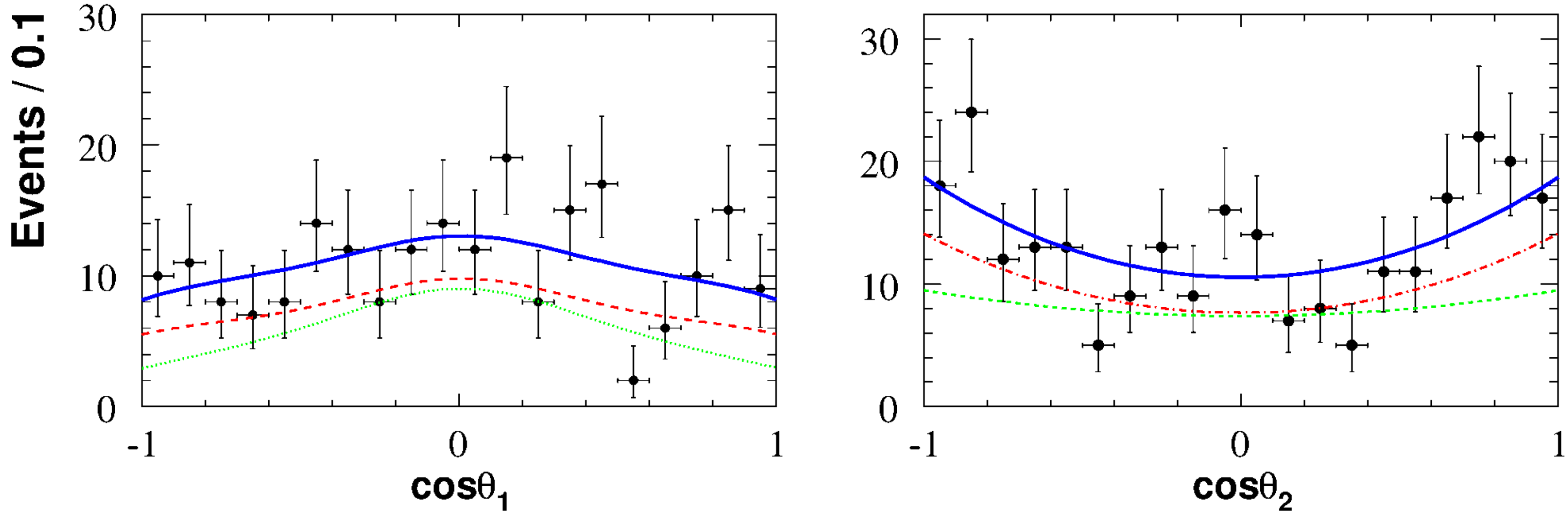
  Confirms the Vector-Tensor Polarization Puzzle

  Vector-Tensor $|A_0| \cong |A_+| >> |A_-|$

  Vector-Vector $|A_0| >> \sqrt{|A_+|^2 + |A_-|^2}$

- Due to limited statistics all angular A_{CP} fixed to 0

Polarizations: Vector-Axial Vector Decay $B^+ \rightarrow \phi K_1(1270/1400)^+$



- Vector—Axial Vector $B\to\phi K_1$, polarization $0.46^{+0.12+0.06}_{-0.13-0.07}$

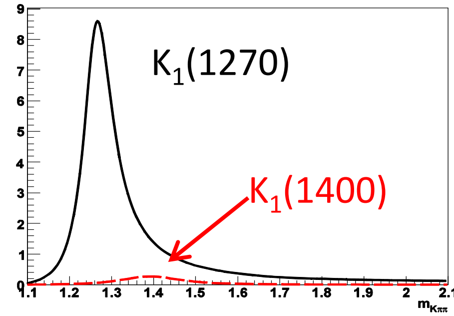
  naïve SM $f_L \approx 1$ => another polarization puzzle!

- Due to limited statistics, all angular A_{CP} fixed to 0

ϕ K_1(1270/1400) Interference Effects

- Combine two K_1 using the fraction f of K_1(1270) taken from nominal results with ±1 σ variation

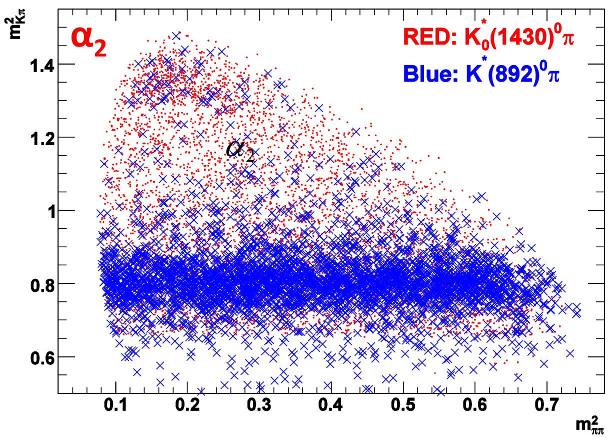
$$f|A_1|^2 + (1-f)|A_2|^2 + 2\alpha\sqrt{f(1-f)}\,\mathrm{Re}(A_1 A_2^* e^{i\delta})$$

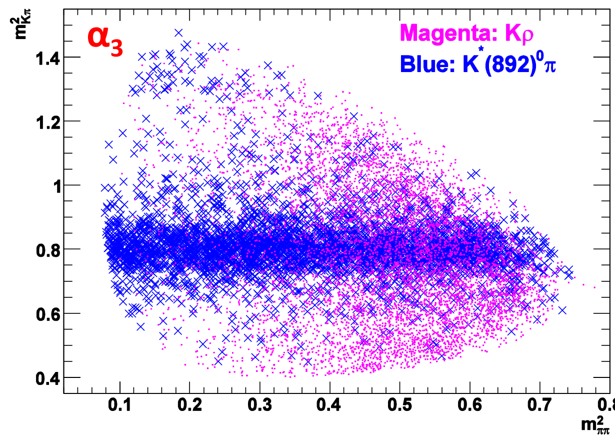


- Interference between 3 different channels

Channel	$K^*\pi$	$K_0^*(1430)\ \pi$	$K\rho$
K_1(1270)	(16±5)%	(28±4)%	(42±6)%
K_1(1400)	(94±6)%	Not Seen	(3±3)%

$$\alpha = \left| f_1 \cdot 1 + f_2 \cdot \alpha_2 e^{i\delta_2} + f_3 \cdot \alpha_3 e^{i\delta_3} \right|$$





- Analytical Integrate the interference term over dalitz-plot **α = 0.357**

- Generate 1000 MC datasets with phase δ(0,π,0.5π), fit with and without interf. The largest fit difference of the yields become the dominant systematic error σN

σN(ϕK_1(1270))=10.3 σN(ϕK_1(1400))=11.0 (no effect on signf.)

Statistical significance due to nuisance parameter

- Nuisance parameter f_L when estimating signf. $\phi K_1(1270)$ / $K_2^*(1430)$

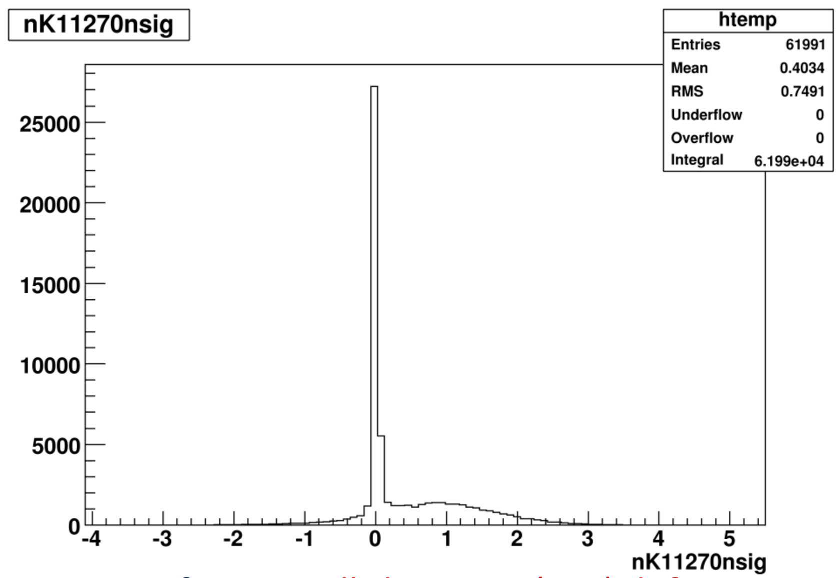
  With 1(2) degree of freedom change assumption

  $\phi K_1(1270)$: 5.5σ (5.1σ) $\phi K_2^*(1430)$: 6.2σ (5.8σ)

- Start with no signal and see how often can we get the observed significance with 62,000 MC datasets, and compare with the statistical expectation

Prob. (signf. > S): TMath::Prob(S*S,n_dof)/2.0

S	1 dof	2 dof.	MC (events)
0	50%	50%	57.7%
1	15.9%	30.3%	24.5%
2	2.27%	6.76%	5.10%
3	0.13%	0.56%	0.39%
3.2	0.07%	0.30%	0.21%(77)
3.4	0.034%	0.15%	0.12%(39)
3.6	0.016%	0.077%	0.063%(39)
3.8	0.007%	0.037%	0.023%(14)
4.0	0.003%	0.017%	0.010%(6)
5.0	2.9e-07	1.9e-05	0 events



Significance Falls between (1, 2) dof

Full test till 5.5σ requires 10 million jobs, ~40 days, B->ϕK*(892) show a similar trend till 5σ

- Best Guess $\phi K_1(1270)$ 5.3σ $\phi K_2^*(1430)$ 6.0σ

Summary

- Studied $B \to \varphi K_J^{(*)}$ with each K* resonance (0.75-2.15) GeV listed at PDG

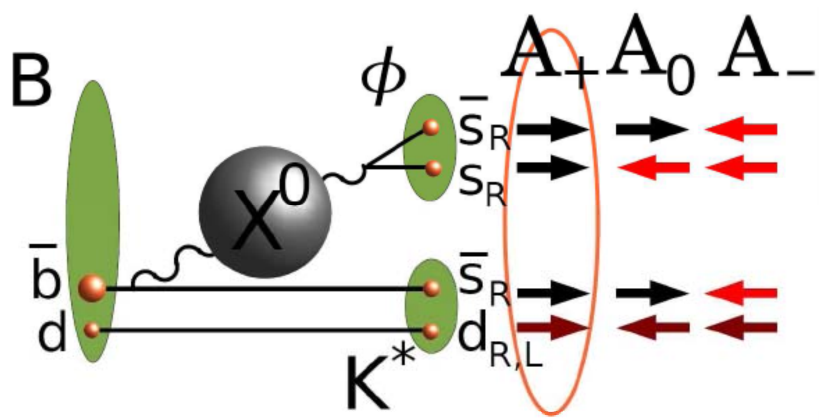
J^P	Mode B ->ϕ	B.F. (10^{-6})	f_L
0^+	$K_0^*(1430)^0$	4.3 ± 0.6 ±0.4	
0^+	$K_0^*(1430)^+$	7.0 ± 1.3 ±0.9	
1^-	$K^*(892)^0$	9.7 ± 0.5 ± 0.5	0.49 ± 0.03 ± 0.01
1^-	$K^*(892)^\pm$	11.2 ± 1.0 ±0.9	0.49 ± 0.05 ± 0.03
1^-	$K^*(1410)^\pm$	<4.8	
1^-	$K^*(1680)^\pm$	<3.5	
1^+	$K_1(1270)^\pm$	6.1 ± 1.6 ± 1.1	$0.46^{+0.12+0.06}_{-0.13-0.07}$
1^+	$K_1(1400)^\pm$	<3.2	
2^+	$K_2^*(1430)^0$	7.5 ± 0.9 ± 0.5	0.901(+0.046, -0.058)± 0.037
2^+	$K_2^*(1430)^\pm$	8.4 ± 1.8 ± 1.0	0.80(+0.09, -0.10)± 0.03
2^-	$K_2(1770)^\pm$	<16.0	
2^-	$K_2(1820)^\pm$	<23.4	
3^-	$K^*(1780)^0$	<2.7	
4^+	$K^*(2045)^0$	<15.3	

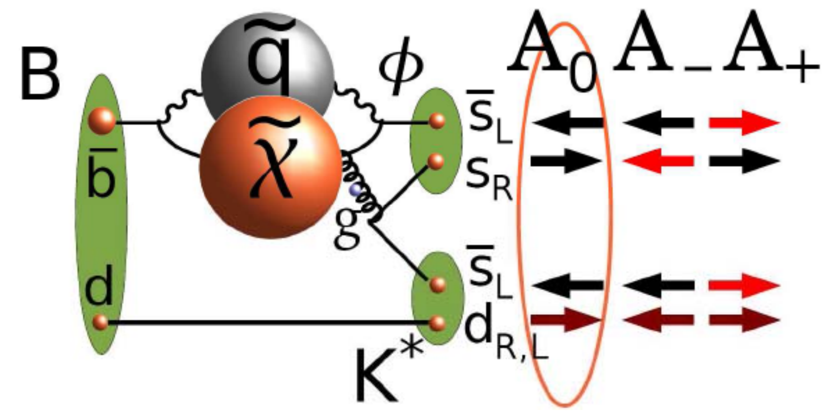
- Confirmed polarization puzzle in Vector-Vector decay with better precision
- Find new Vector-Tensor and Vector-Axial vector polarization puzzles

- $|A_0| \approx |A_+| >> |A_-|$ Vector–Vector B→ ϕK*(892)
- $|A_0| \approx \sqrt{|A_+|^2 + |A_-|^2}$ Vector–Axial Vector B→ ϕK_1
- $|A_0| >> \sqrt{|A_+|^2 + |A_-|^2}$ Vector–Tensor B→ϕK*(1430)

New Physics in the Penguin Loop?

- Scalar Interactions
- SUSY





- Right-Handed Couplings

model	current	A_0	A_+	A_-
SM	$\bar{s}\gamma^\mu(1-\gamma_5)b\bar{s}\gamma_\mu(1\pm\gamma_5)s$	~ 1	$\sim\frac{m_V}{m_B}$	$\sim(\frac{m_V}{m_B})^2$
RH vector	$\bar{s}\gamma^\mu(1+\gamma_5)b\bar{s}\gamma_\mu(1\pm\gamma_5)s$	~ 1	$\sim(\frac{m_V}{m_B})^2$	$\sim\frac{m_V}{m_B}$
Tensor current	$\bar{s}\sigma^{\mu\nu}(1+\gamma_5)b\bar{s}\sigma_{\mu\nu}(1+\gamma_5)s$	$\sim\frac{m_V}{m_B}$	~ 1	$\sim(\frac{m_V}{m_B})^2$
Tensor current	$\bar{s}\sigma^{\mu\nu}(1-\gamma_5)b\bar{s}\sigma_{\mu\nu}(1-\gamma_5)s$	$\sim\frac{m_V}{m_B}$	$\sim(\frac{m_V}{m_B})^2$	~ 1

Not in a good shape to accommodate the results or predict anything.