Polarization Puzzles in Quasi-2-Body Penguin Decays at BaBar

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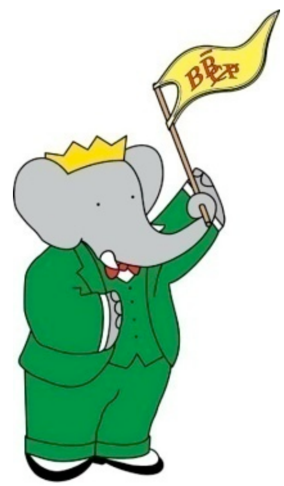
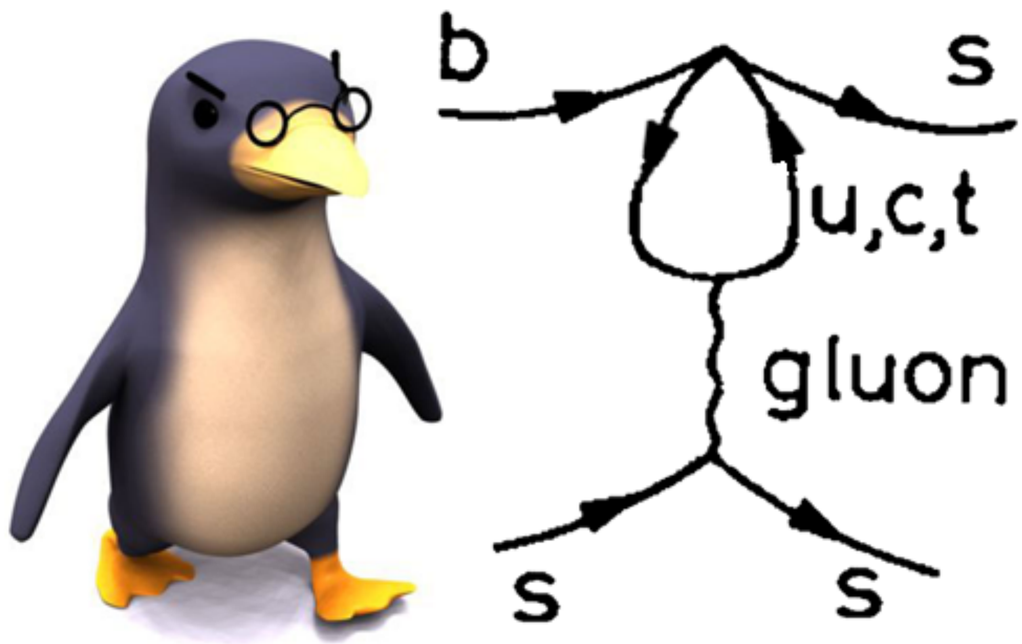


Motivation



- FCNC: Indirect way to search for new physics
- Polarization puzzle in $B \to \phi K^*$

Polarization in B Decays to Two Vectors

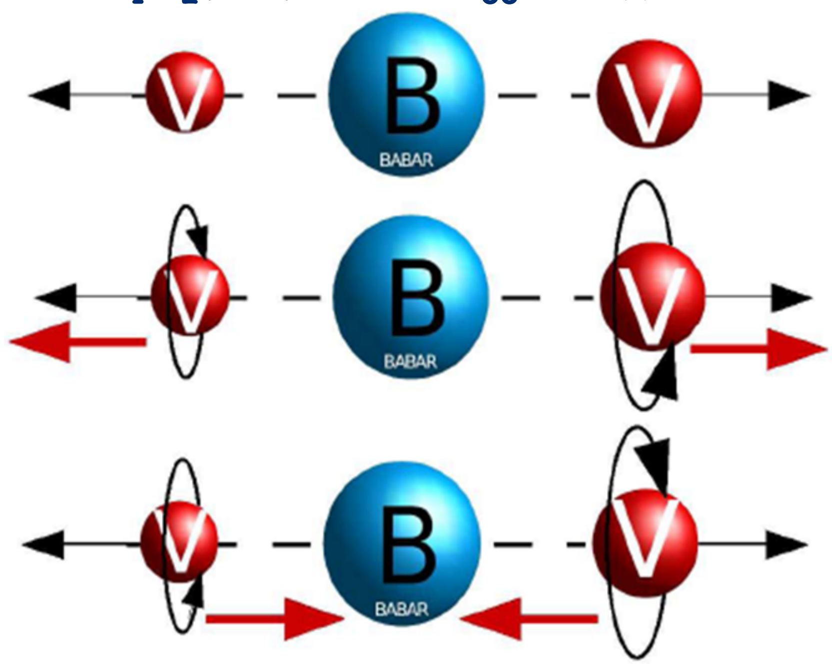
- From Quantum Mechanics

At helicity basis: $A = \langle V_1 V_2 | H | B \rangle = A_{00} + A_{++} + A_{--}$

$A_{00}(A_0)$

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

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



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

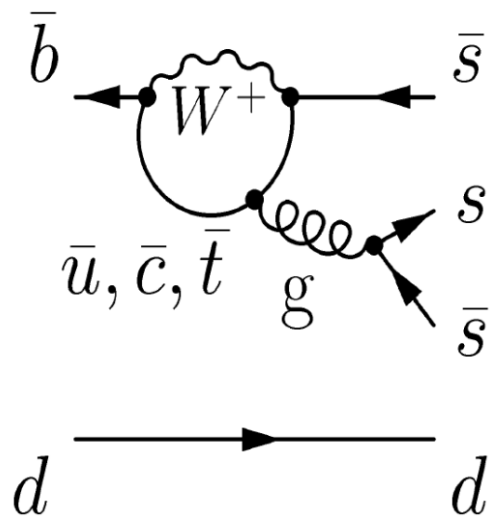
Longitudinal Polarization $f_L = |A_0|^2 / \sum |A_\lambda|^2$

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

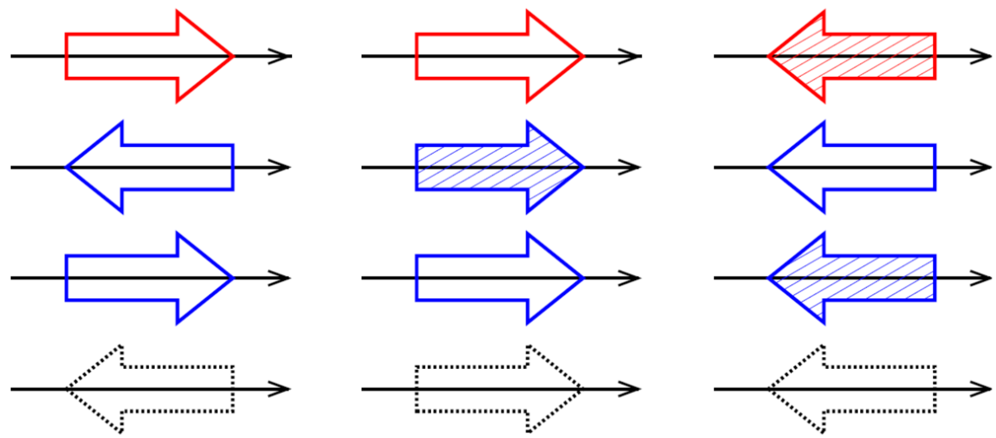
Spin Flip Suppression and Amplitude Hierarchy

- Spin Flip Suppression => Amplitude Hierarchy

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



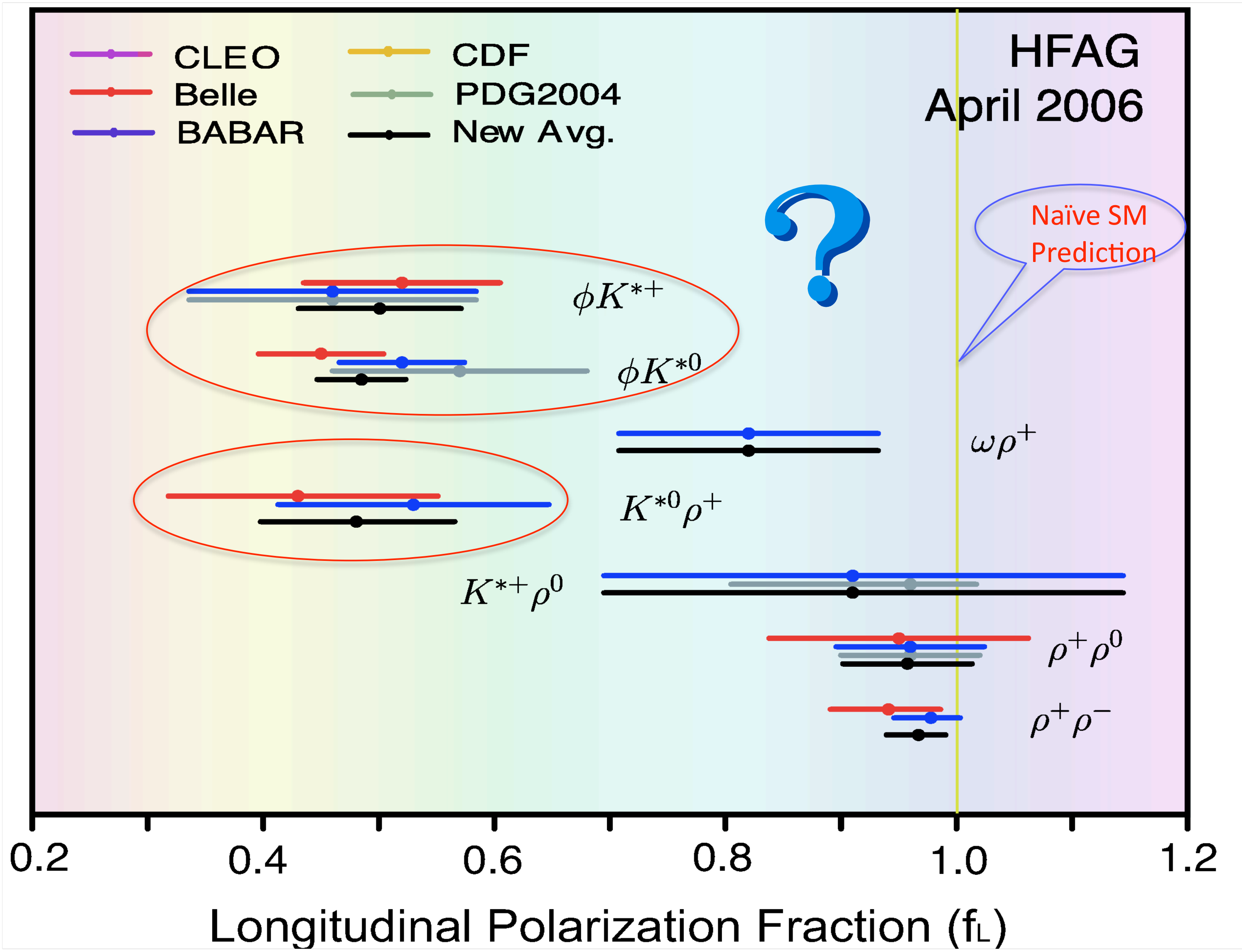
$A_0 \sim 1 \quad \gg \quad A_+ \sim \frac{m_V}{m_B} \quad \gg \quad A_- \sim \frac{m_V^2}{m_B^2}$



Naïve SM => $f_L \approx 1$

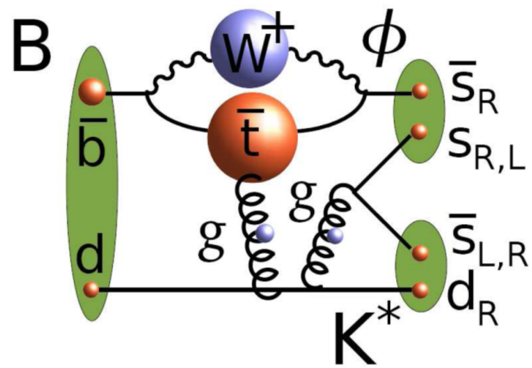
Polarization Puzzle

HFAG: Rare B Decay Parameters: http://www.slac.stanford.edu/xorg/hfag/rare/index.html

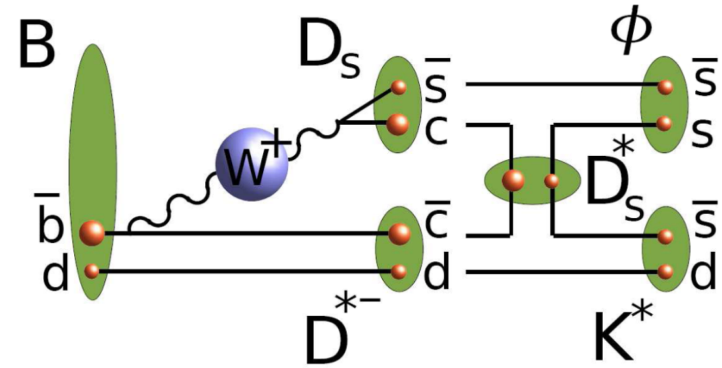


Selected Theoretical Efforts Beyond Naïve SM

- Within SM: new look at the previously neglected contributions



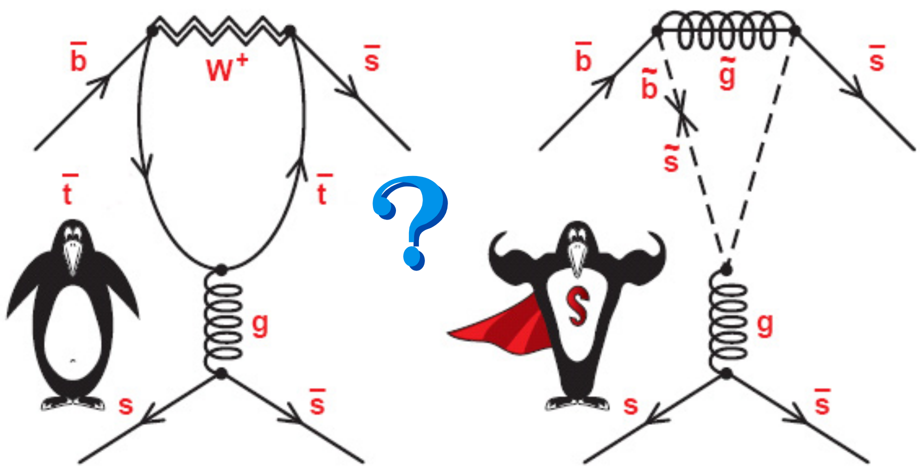
Penguin Annihilation(PA)



Rescattering(FSI)

Calculations suffer large QCD Uncertainties, essentially no prediction power

- New Physics : Ad Hoc NP-induced contributions

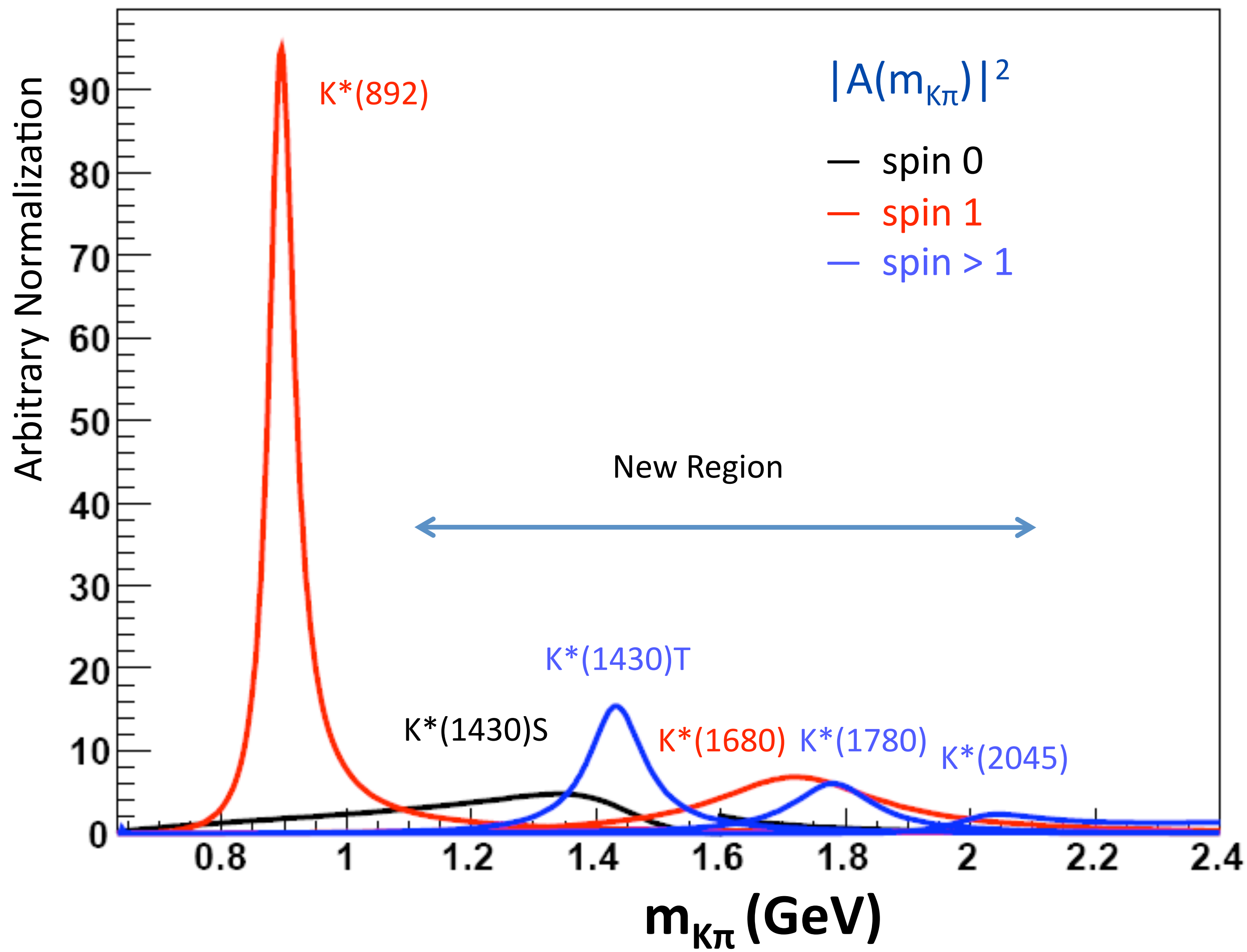


NP physics not clear;
Suffer similar QCD uncertainties;

Nothing conclusive yet!

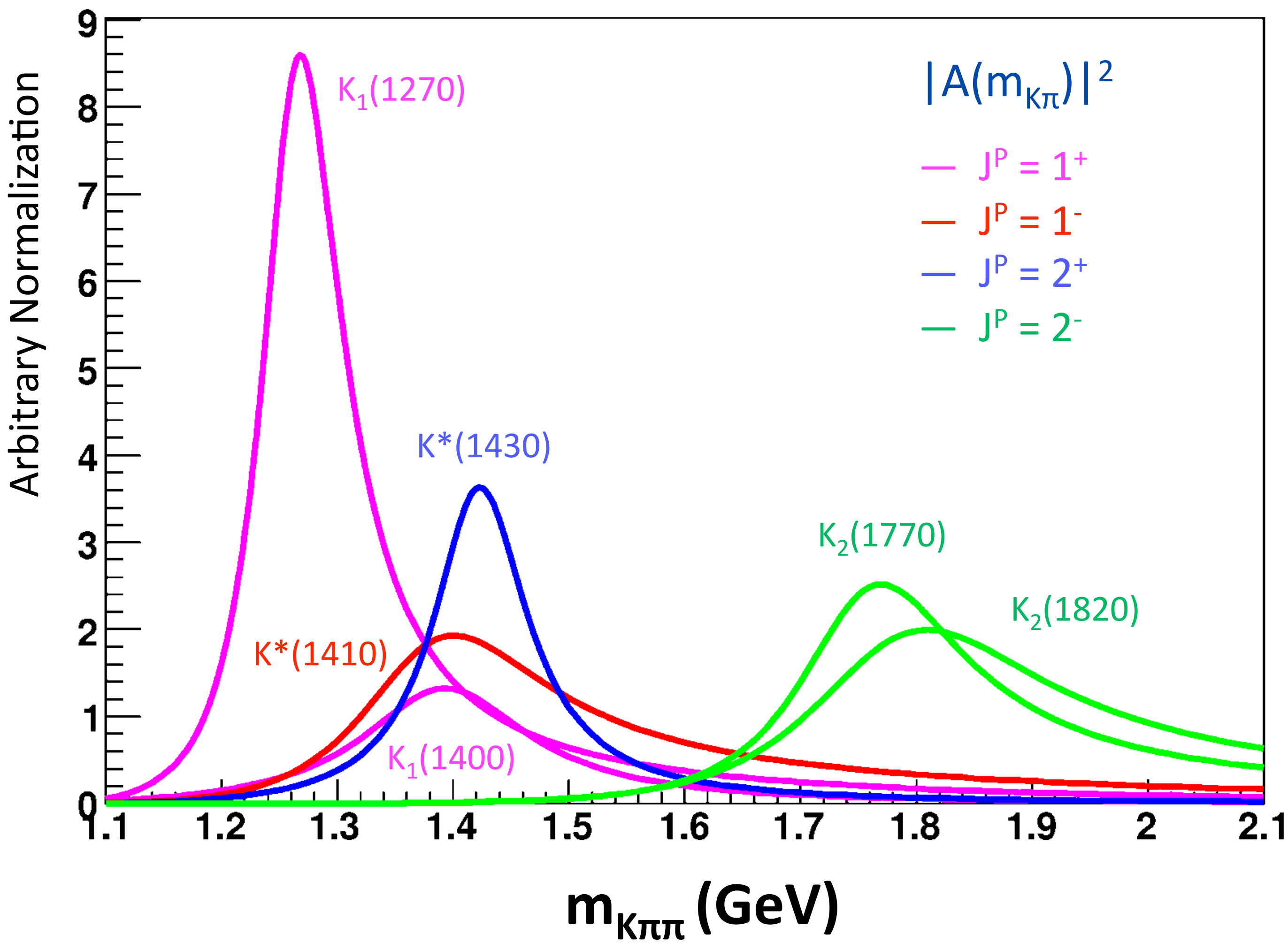
Four-body Final State Decays Search Window

- 4-body Final State (FS) K*→Kπ ϕ→KK



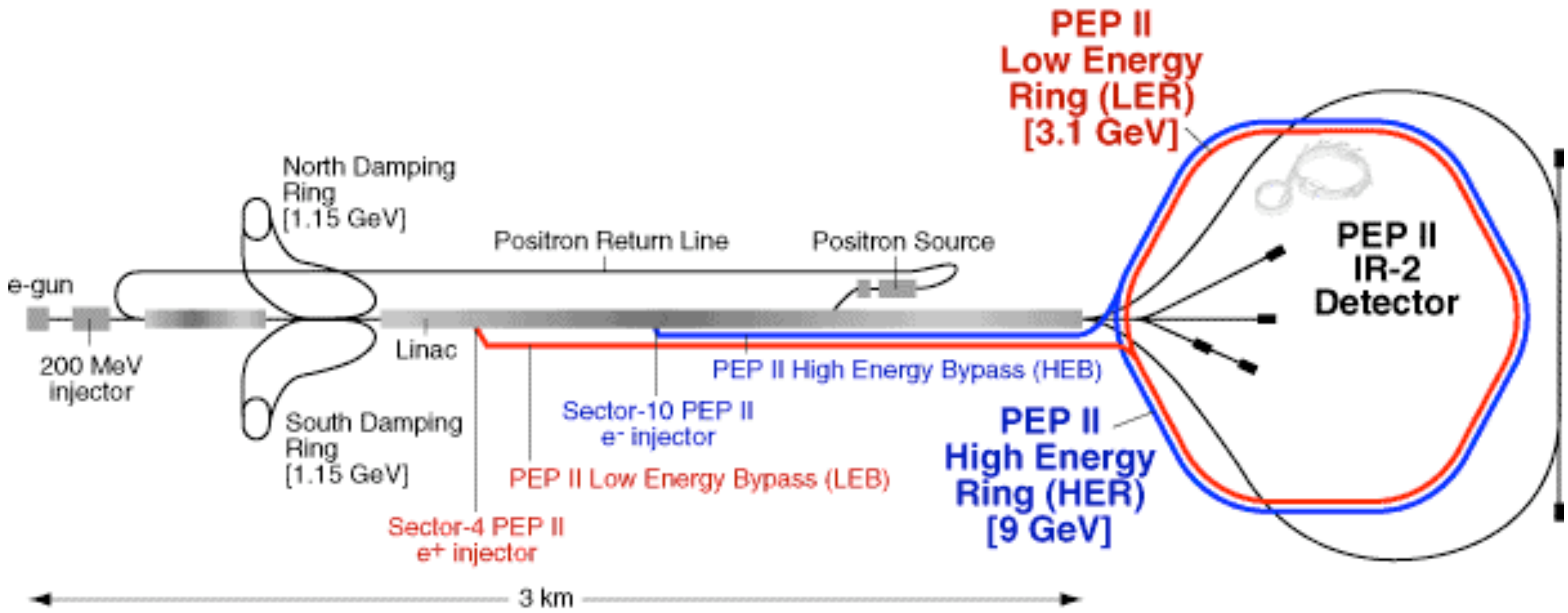
Five-body Final State Decays Search Window

- 5-body Final State (FS) K*→Kππ ϕ→KK

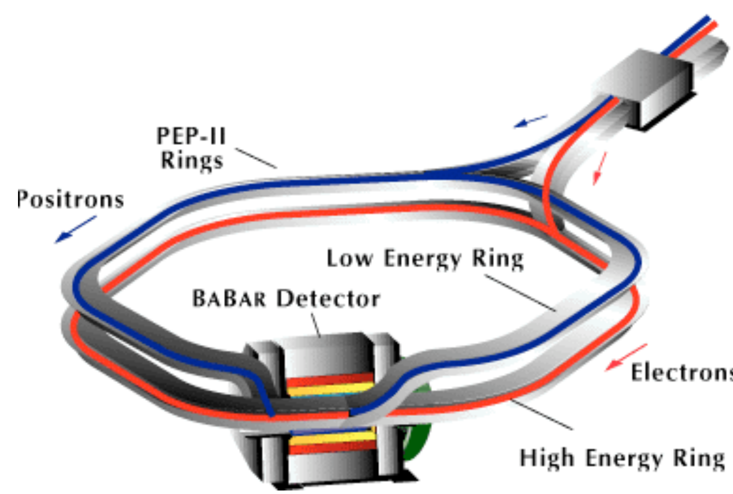


The BaBar Experiment at SLAC

The PEP-II Asymmetric B Factory



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



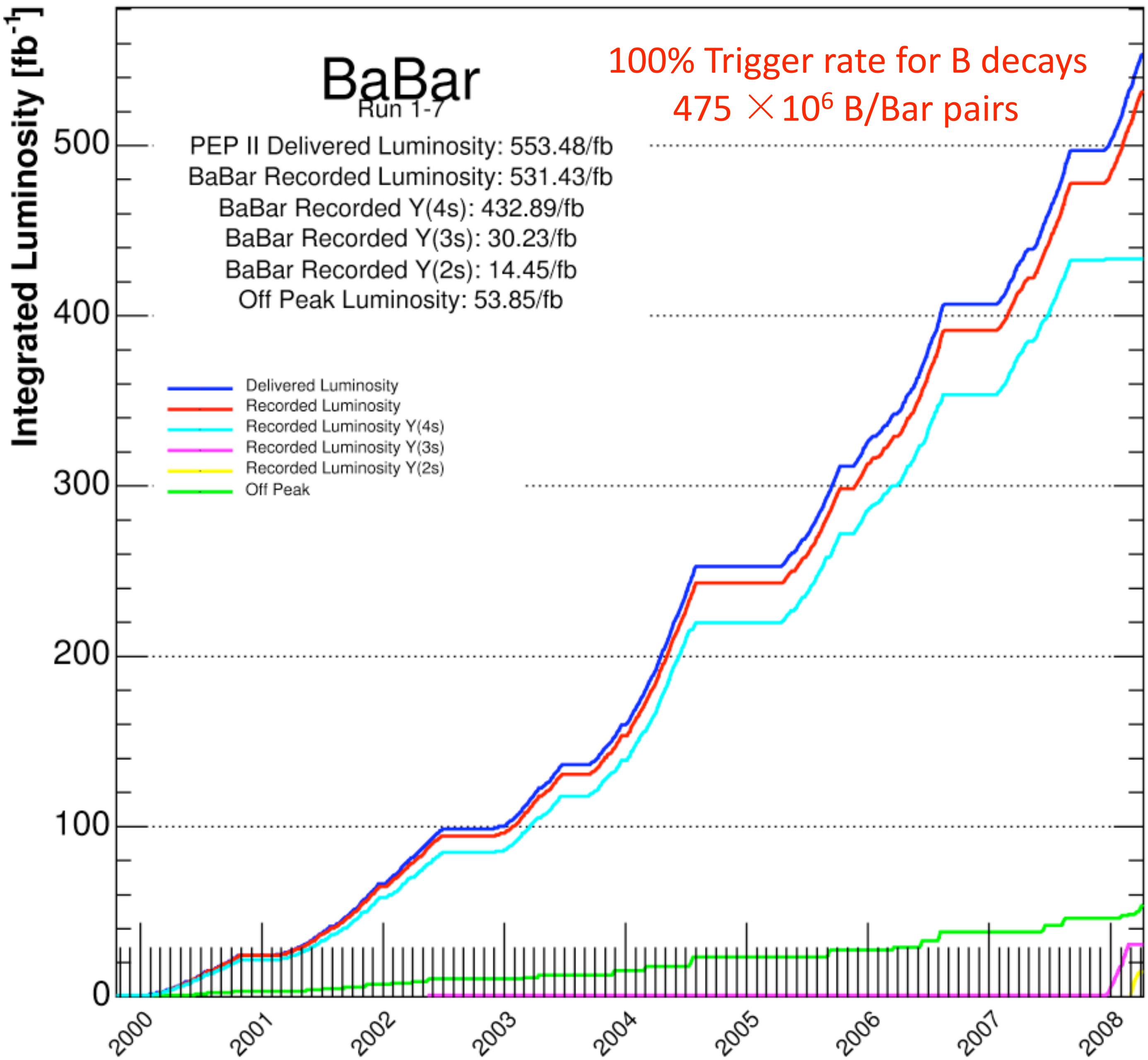
- Center of Mass Energy = 10.58 GeV
- Asymmetric machine at Lorentz Boost

  $E(e^-) = 9.0$ GeV $E(e^+) = 3.1$ GeV

  => $\beta\gamma = 0.56$ $\Delta Z \approx 250\ \mu m$ between the two B

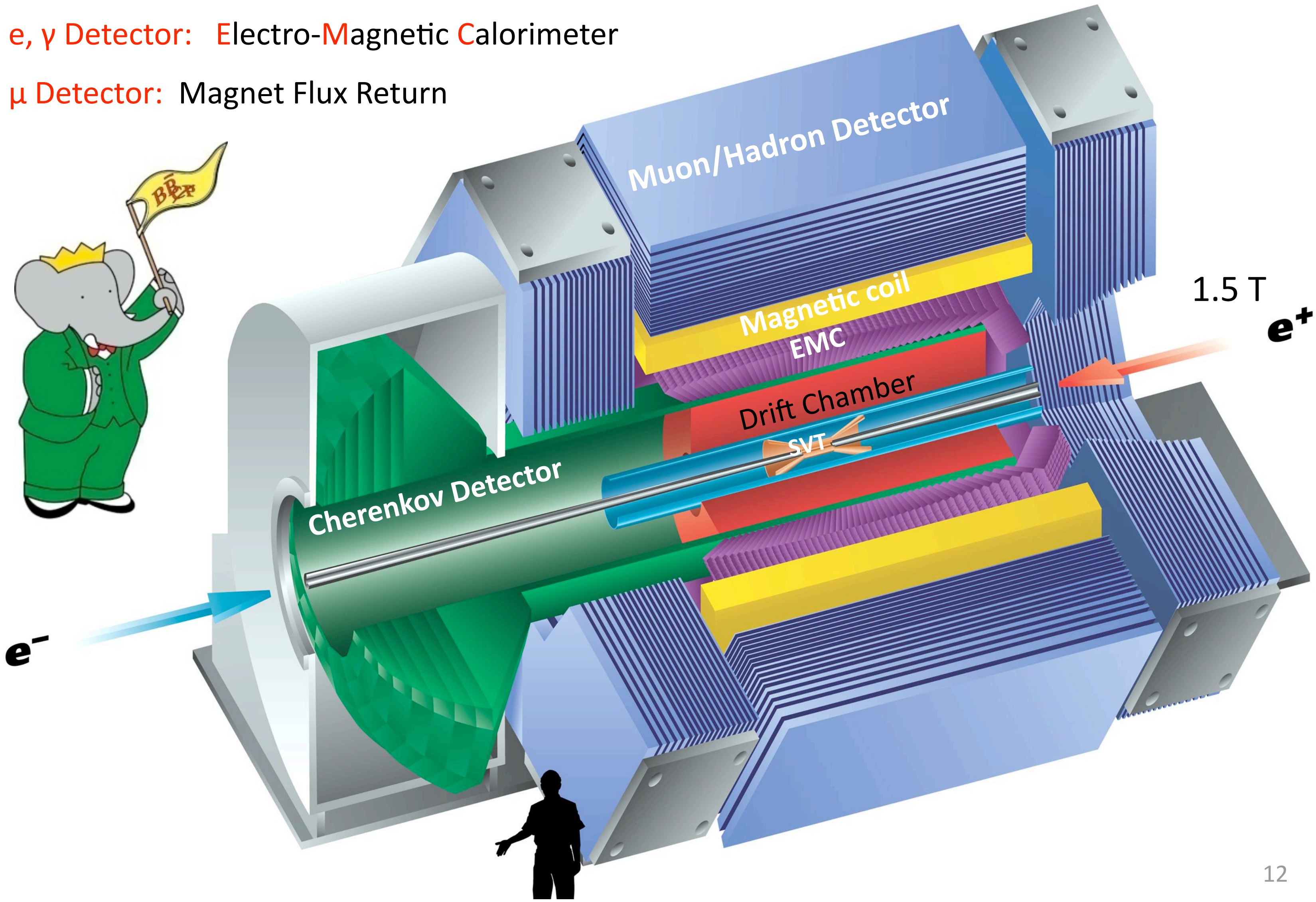
Integrated Luminosity

As of 2008/04/11 00:00



The BaBar Detector

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



Charged Tracks (e, μ, π, K, p)

- Central Tracking

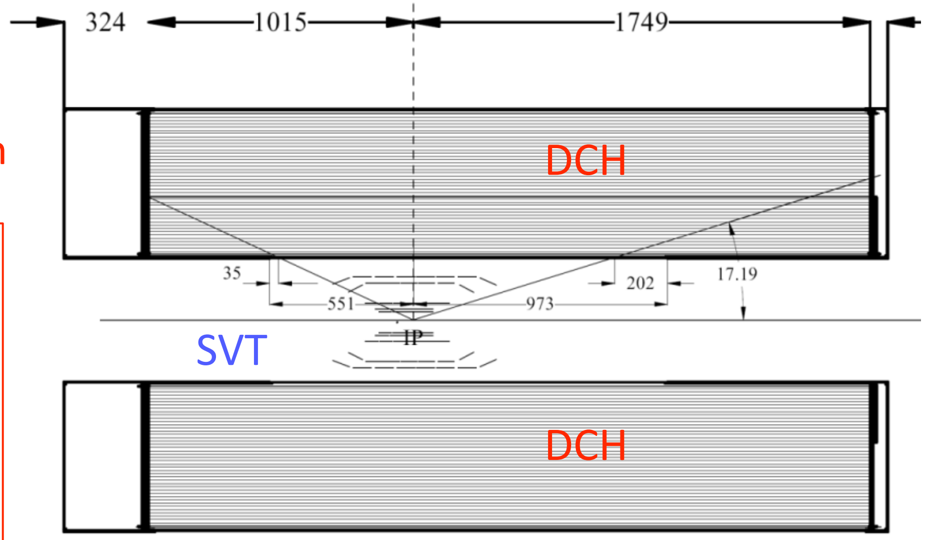
SVT: vertex position + DCH: momentum

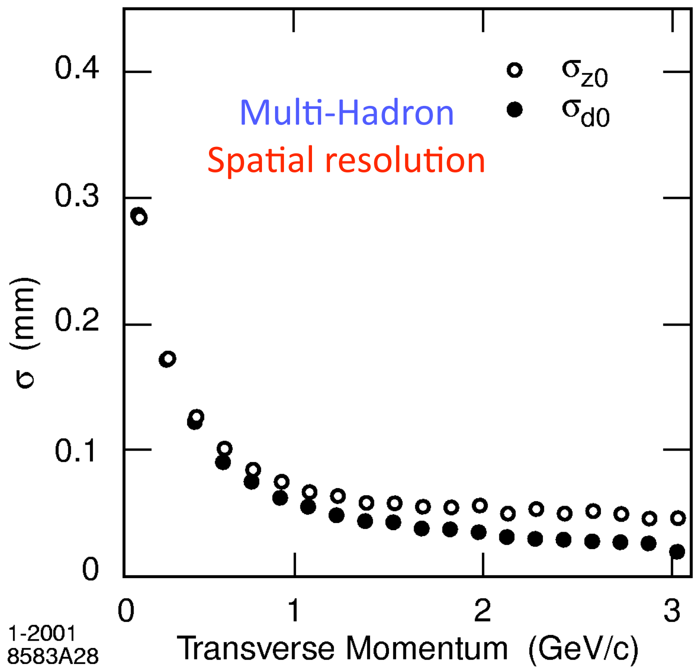
1. A track with p_T = 3 GeV/c

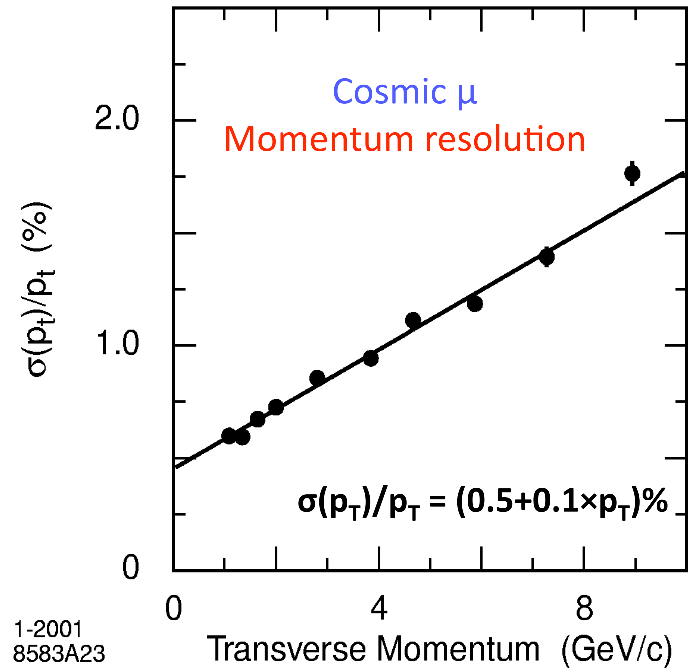
   $\sigma(d_0)$ = 25 μm $\sigma(z_0)$ = 40 μm

2. A typical B track with

   $p_T \approx$1.5 GeV/c $\sigma(p_T) \approx$10 MeV/c



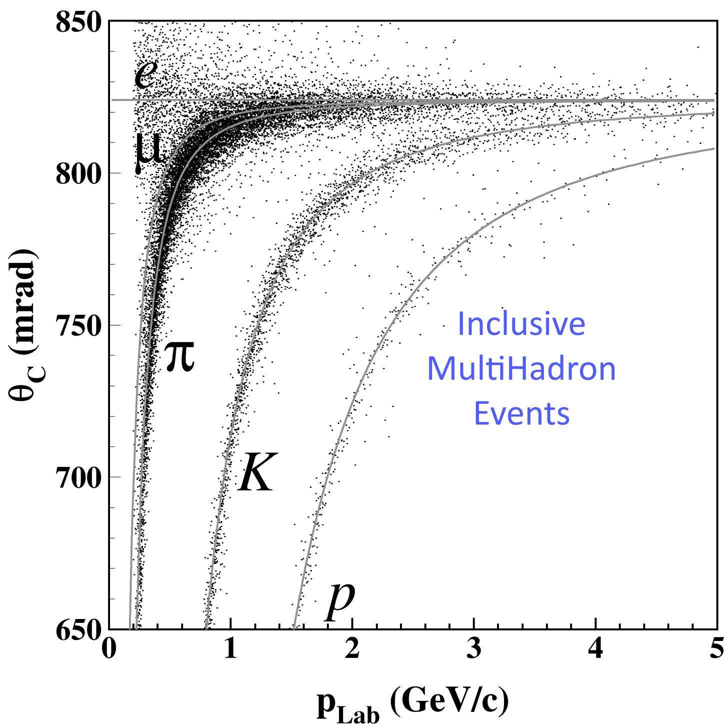


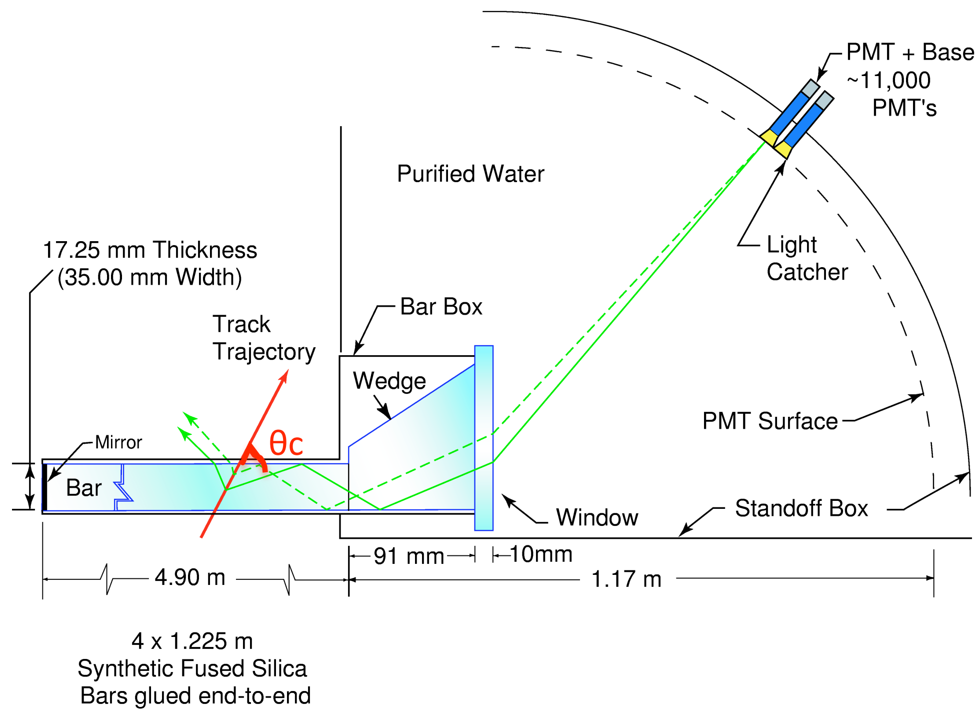


PID (Particle Identification)

- SVT/DCH dE/dX, especially for tracks with $p_T < 700$ MeV/c
- For pt> 150 MeV/c DIRC measures Cerenkov Radiation Angle θc

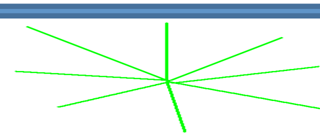
$$\cos \theta_c = 1/(\beta n) \rightarrow \theta_c = f(P, m)$$





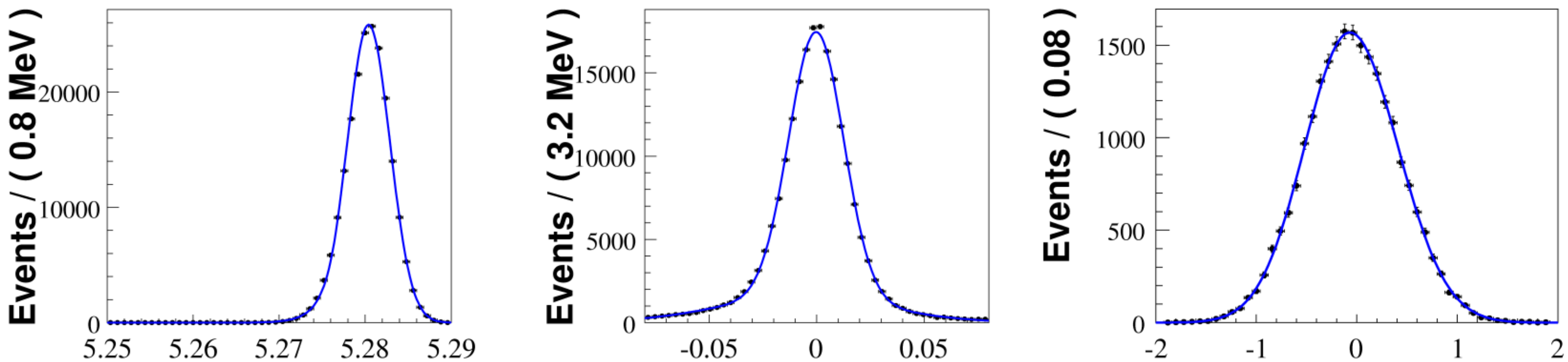
- DIRC Provides the primary π/K separation from 2.5 to 10 σ

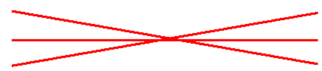
Identify the B mesons

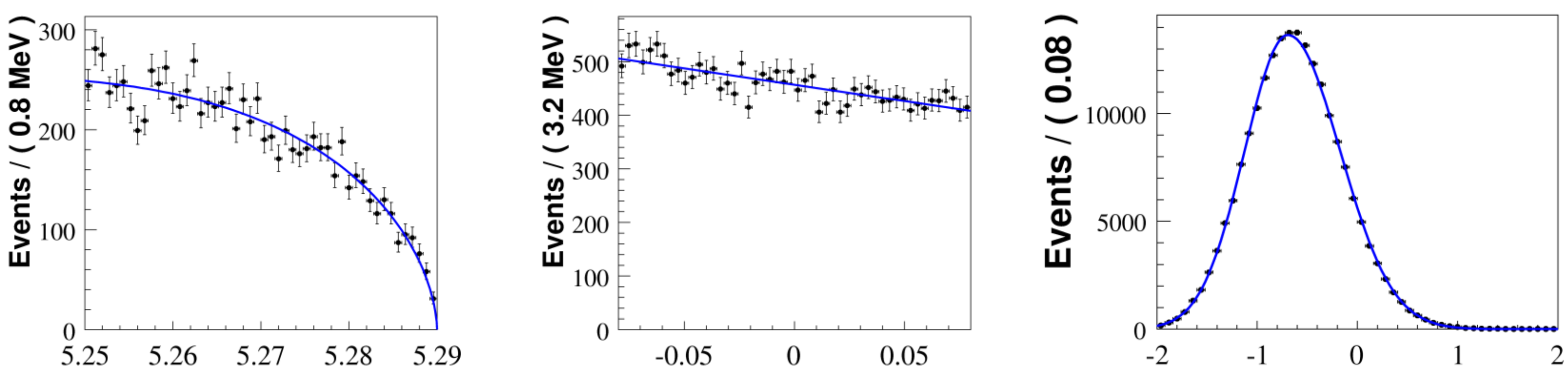
- B signals $e^+e^- \to B\bar{B}$  with ϕ(K⁺K⁻)K₁(1270)(K⁺π⁺π⁻) FS

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

Event Shape (Fisher)

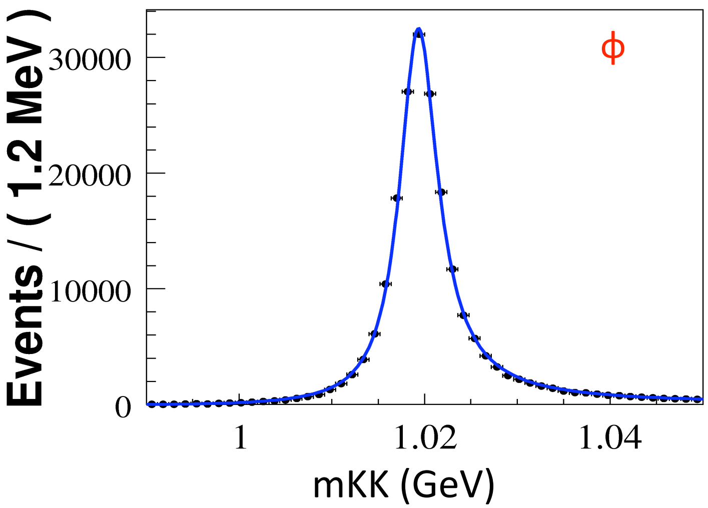


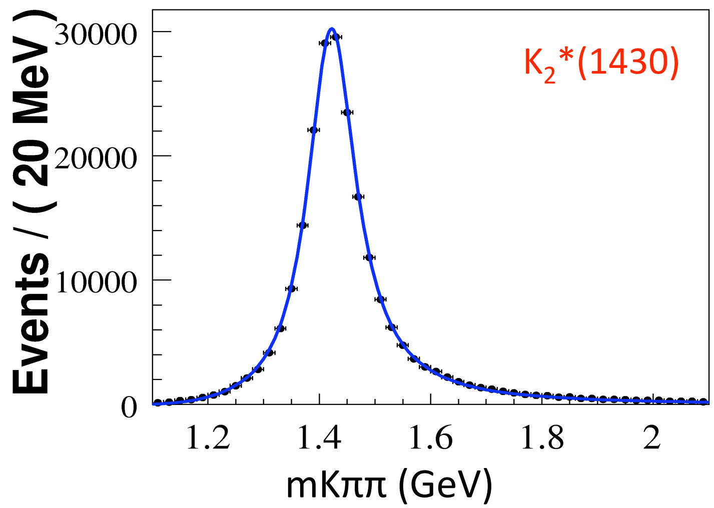
- "Jetty" background $e^+e^- \to q\bar{q}$  with (K⁺K⁻K⁺π⁺π⁻) FS



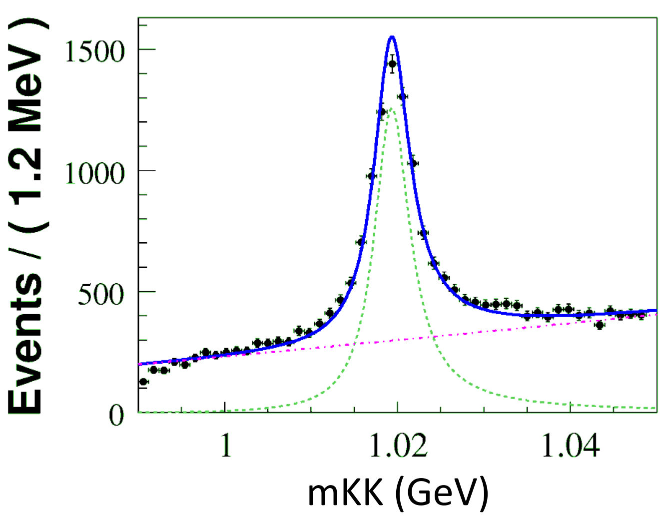
Reconstruct the ϕ and K*

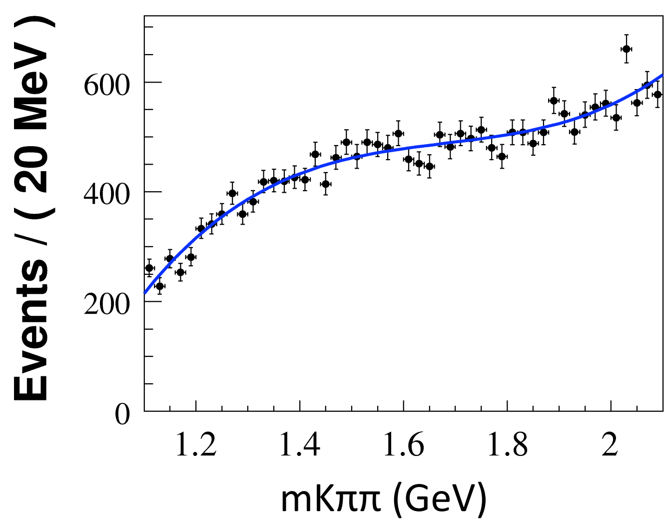
- Monte Carlo

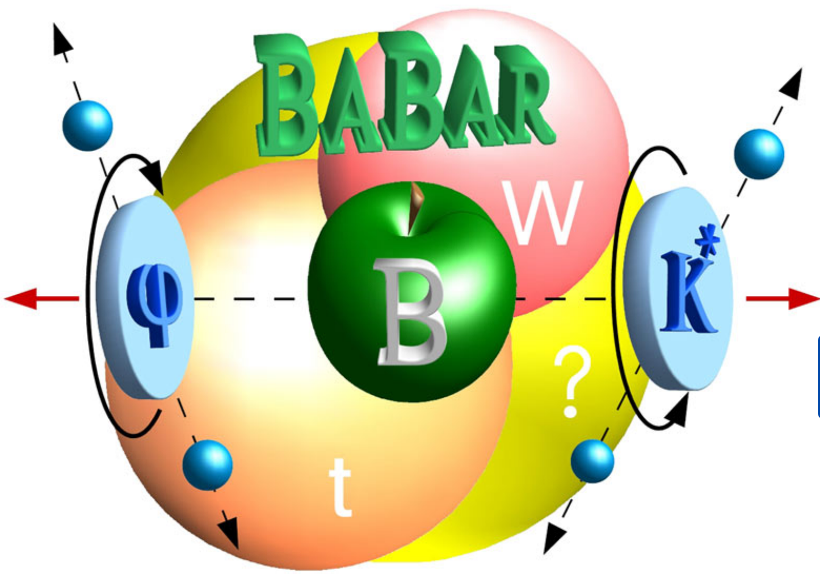




- OffPeak Data with center of mass energy 40 MeV below Y(4S) Resonance





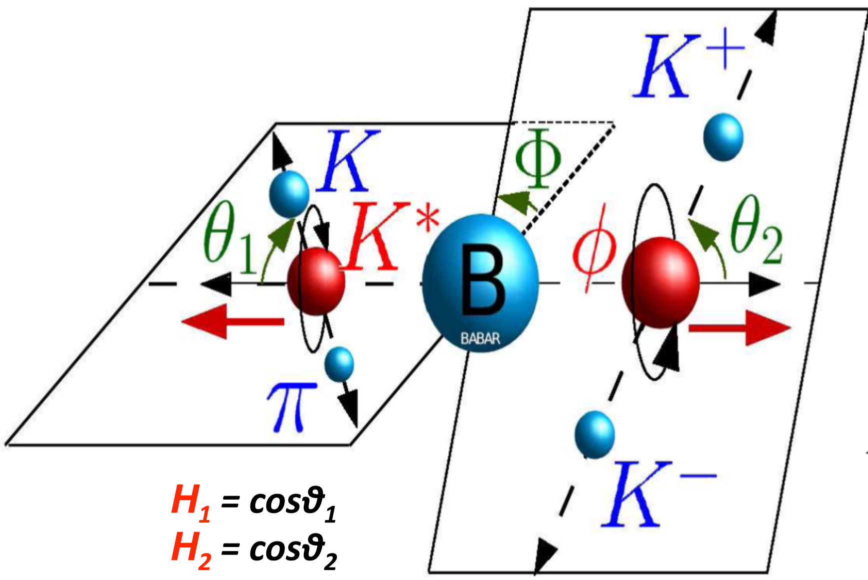


Angular Distributions

The Angles and Angular Distributions (4body FS)

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

$B^0 \to \phi\ K^*(892)^0,\ K^*(1430)^0(T, S),\ K^*(1680)^0,\ K_3^*(1780)^0,\ K_4^*(2045)^0$



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

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

XAxis

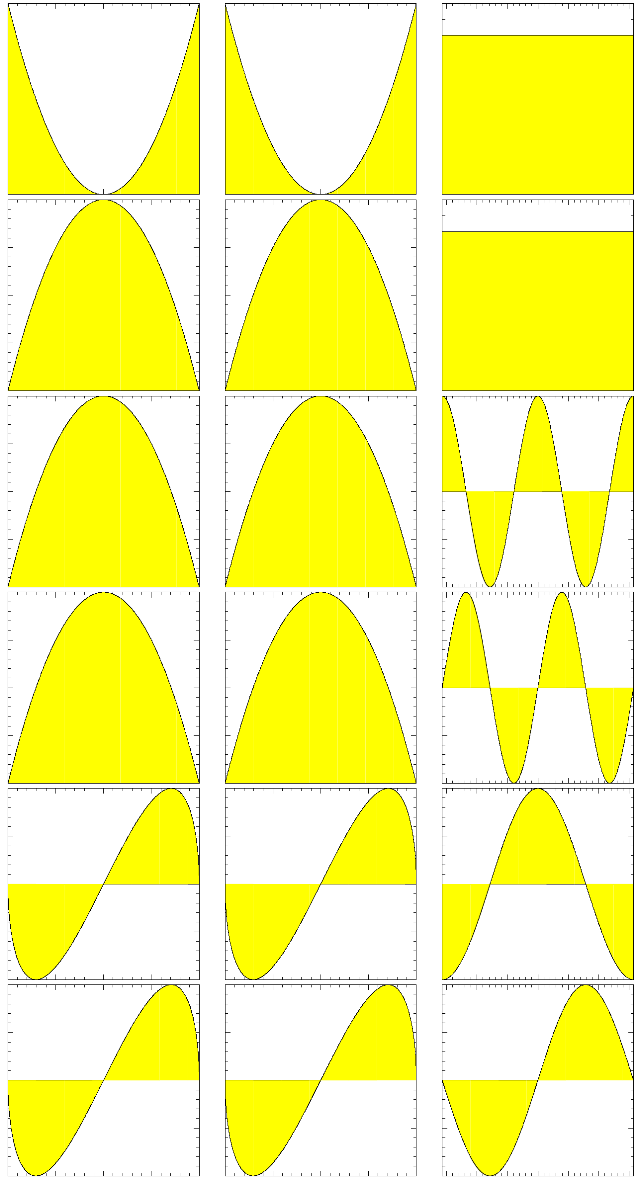
$\alpha_2(f_L)\times$ $\Rightarrow |A_\parallel|^2+|A_\perp|^2$

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

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

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

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

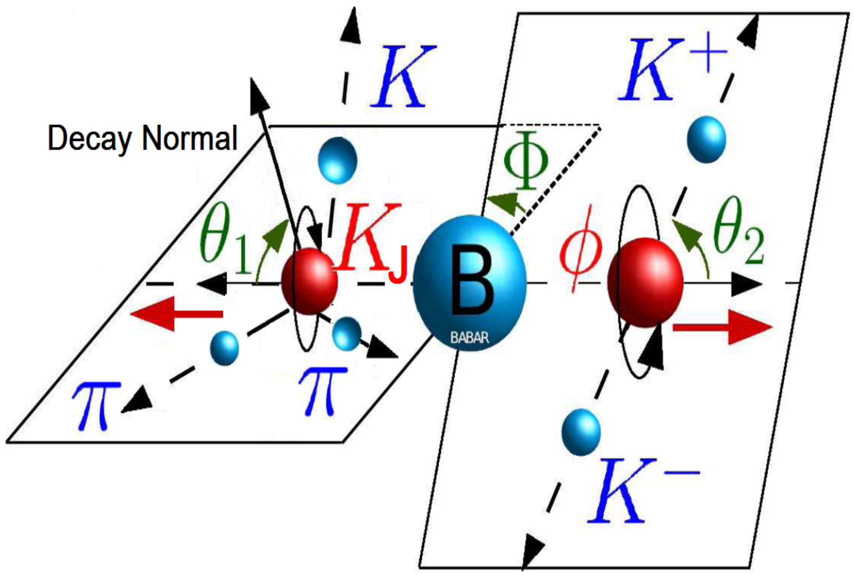


$\cos\theta_1(H_1)$ $\cos\theta_2(H_2)$ Φ

The Angles and Angular Distributions (5body FS)

- Five-body Final States (KK)(Kππ)

  $B^{\pm} \to \phi\ K_1(1270/1400)^{\pm}$, $K_2(1770/1820)^{\pm}$ 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)

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

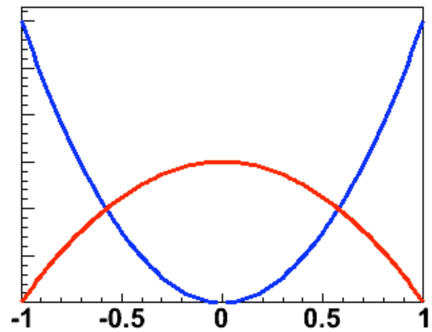
R_m: kinematic parameters depending on the $K_J \to (K\pi\pi)$ spin eigenstates, no on λ

Ideal Angular Distributions

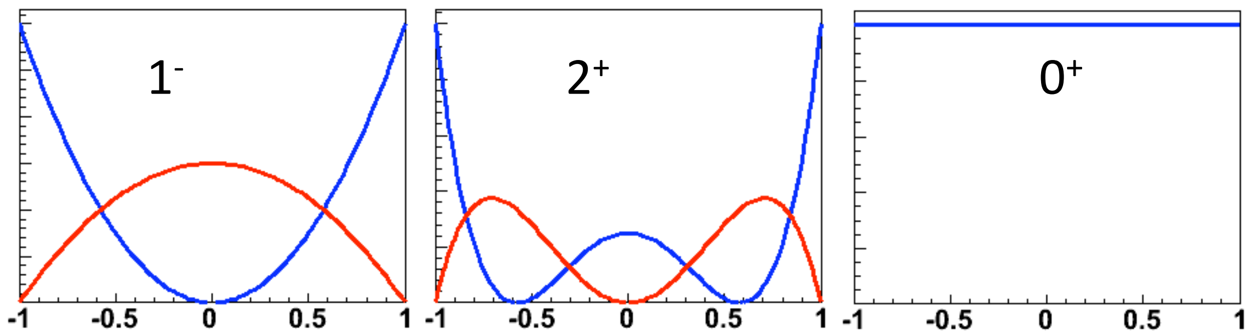
- $\cos\theta_2$ distributions (with the vector ϕ meson)

  Blue : longitudinal mode $f_L = 1$

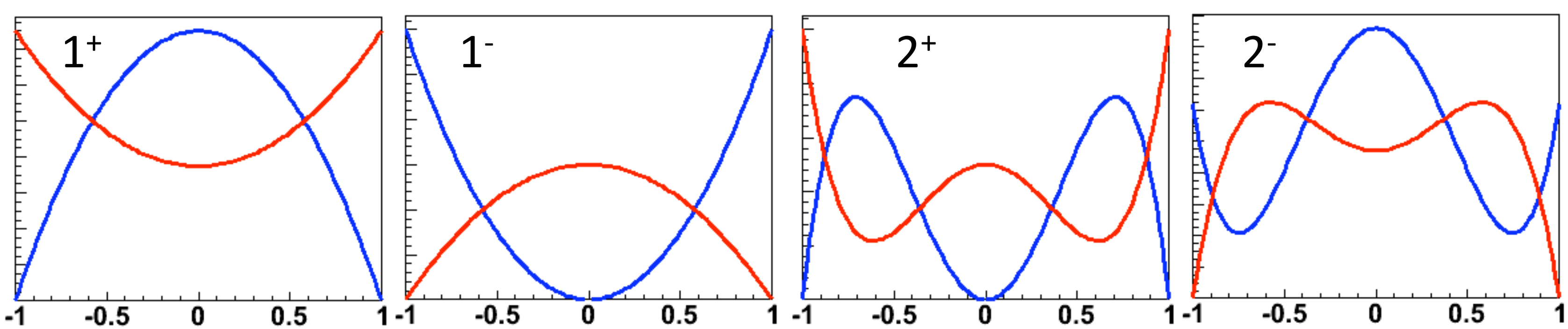
  Red : transverse mode $f_L = 0$



- 4body FS ($K^* \rightarrow K\pi$) $\cos\theta_1$ distributions with J^P of ($K\pi$)



- 5body FS ($K^* \rightarrow K\pi\pi$) $\cos\theta_1$ distributions with J^P of ($K\pi\pi$)



No Detector acceptance

CP Asymmetries in B→ϕK*

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

  Q_B = + 1 for b-quark Q_B = -1 for bar-quark

- Direct CP-Asymmetries

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

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

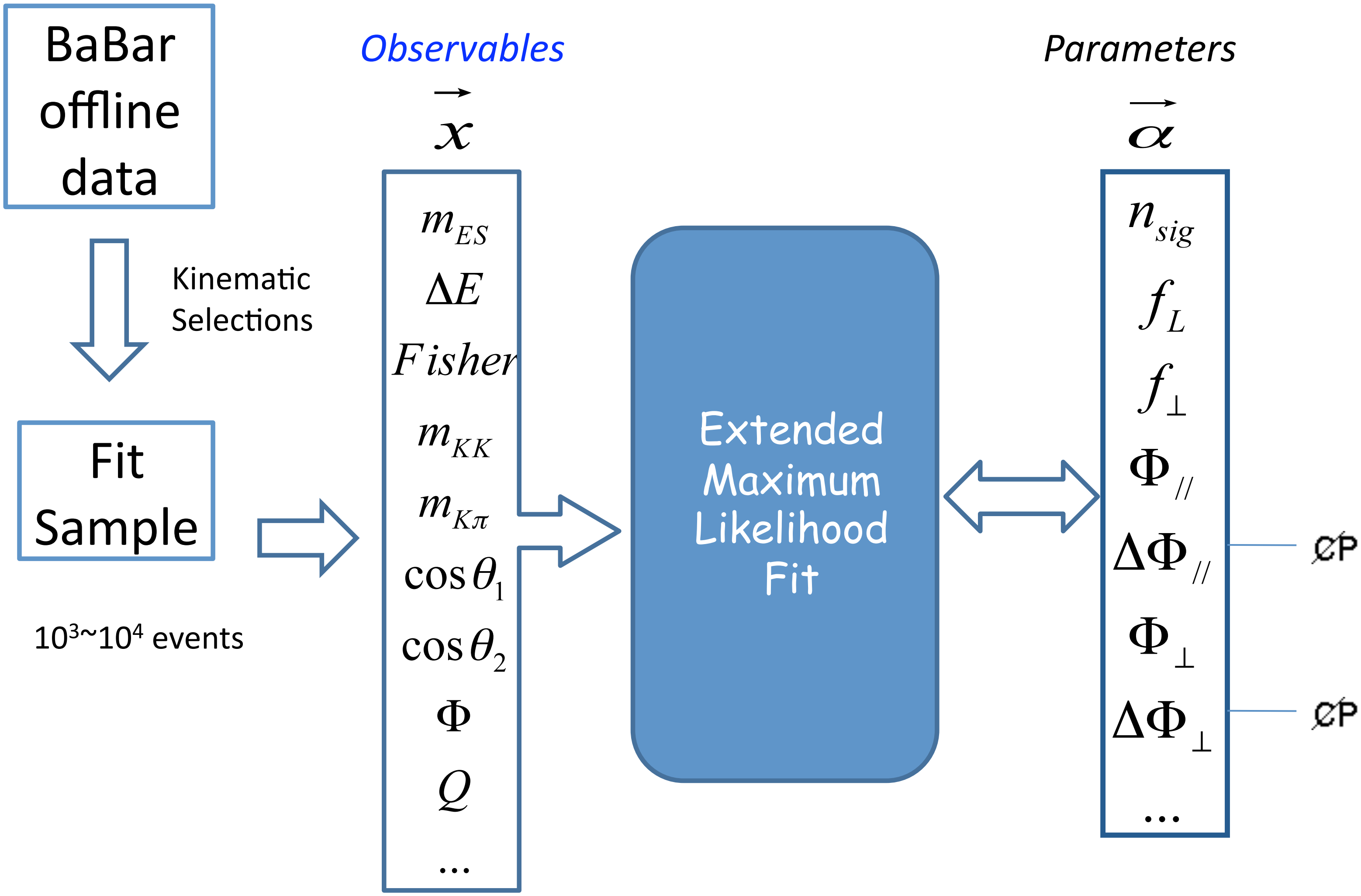
CP-Even transverse phase A_{CP}
$$\Delta\phi_\parallel = \tfrac{1}{2}\arg(\bar{A}_\parallel A_0/A_\parallel \bar{A}_0)$$

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

Statistical Method

Estimate a set of parameters in a likelihood fit

Extended Maximum Likelihood Fit



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

Extended Maximum Likelihood Fit

- For each candidate in the final data sample

  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 event 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. If B→ϕK* appear in different final states, *physics quantities are forced to be the same*.
  5. Interference between resonances are ignored except for the two K*(1430)

- The combined Likelihood

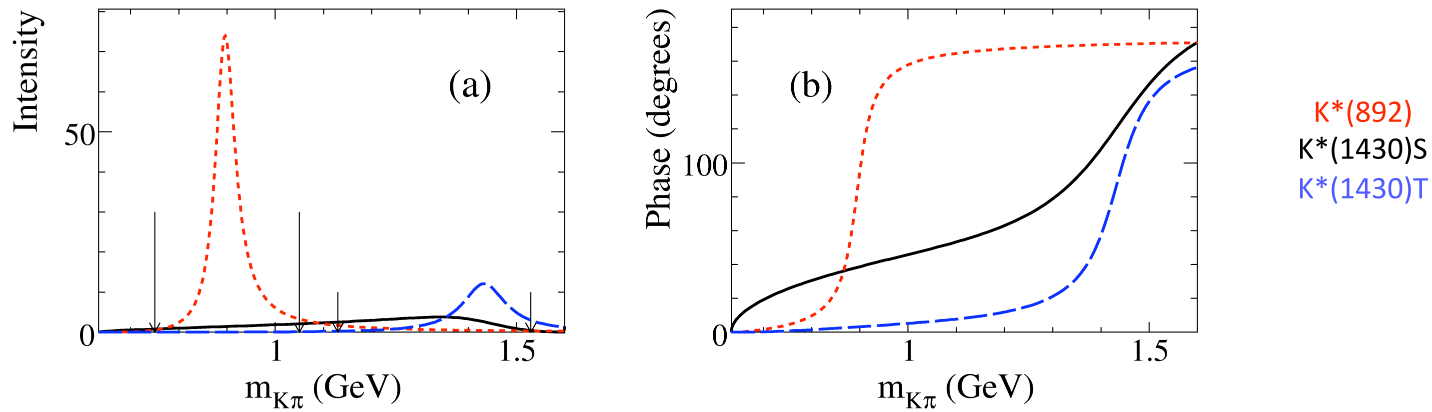
$$\mathcal{L} = \exp\left(-\sum_{i,k} n_{ik}\right) \prod_{j=1}^{N} \left(\sum_{i,k} n_{ik}\, \mathcal{P}_{ik}(\vec{x}_j; \vec{\alpha})\right)$$

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

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-Tensor (A) and Vector-Scalar (B)

$$A = \sqrt{\frac{15}{32\pi}}[A_0(3\cos^2\theta_1 - 1)\cos\theta_2 + \frac{\sqrt{3}}{2}\sin 2\theta_1 \sin\theta_2 (A_{+1} e^{i\Phi} + A_{-1} e^{-i\Phi})] A_{\rm BW}(m_{K\pi})$$

$$B = \sqrt{\frac{3}{8\pi}} B_0 \cos\theta_2 B_{\rm LASS}(m_{K\pi})$$

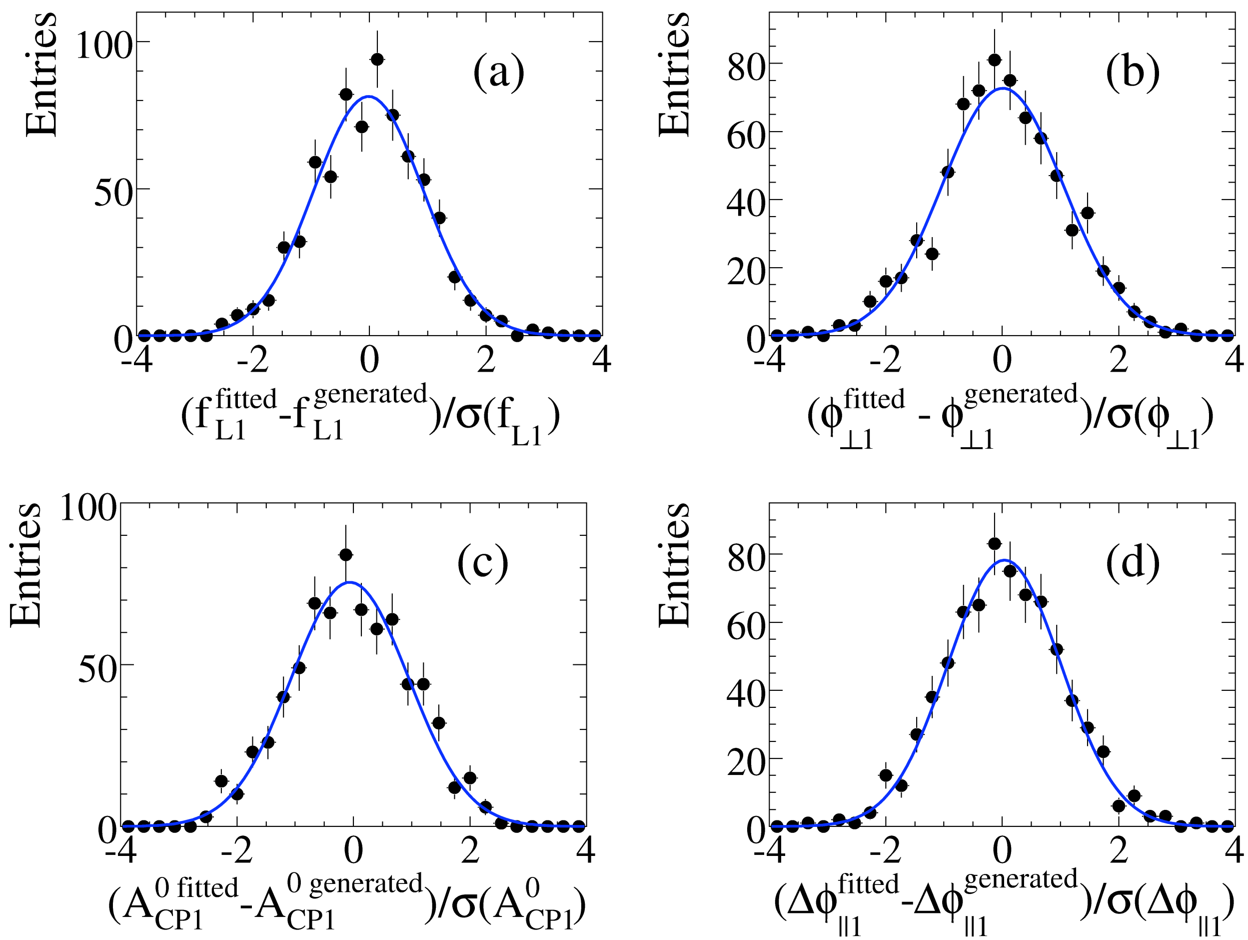
Total amplitude $|A+B|^2$ =>

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

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

Fit Validation

- Blind Analysis
  - ✓ Validate the fit in ~ 1000 *individual pesudo-MC experiments*
  - ✓ Inconsistency between fitted results and the generated value → *systematic uncertainties*



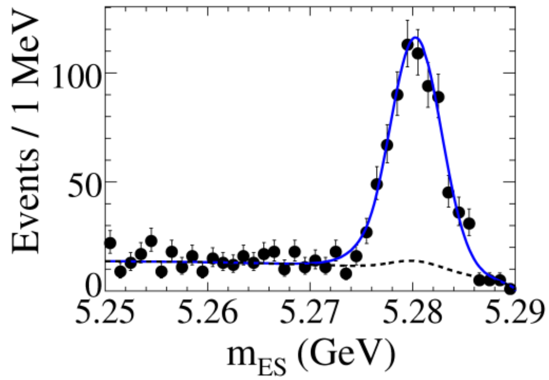
Measurements

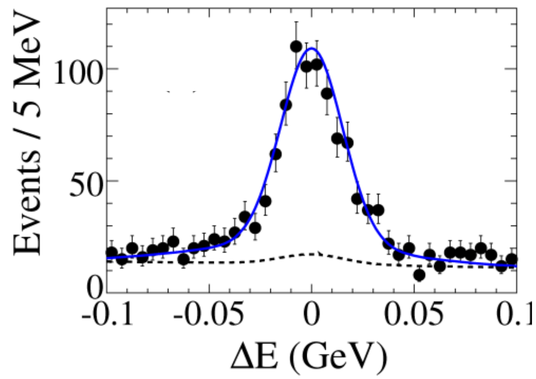
Phys. Rev. Lett. 98, 051801(2007)
Phys. Rev. D 76, 051103(2007)
Phys. Rev. Lett. 99, 201802(2007)
Phys. Rev. Lett. 101, 161801 (2008)
Phys. Rev. D 78, 092008 (2008)

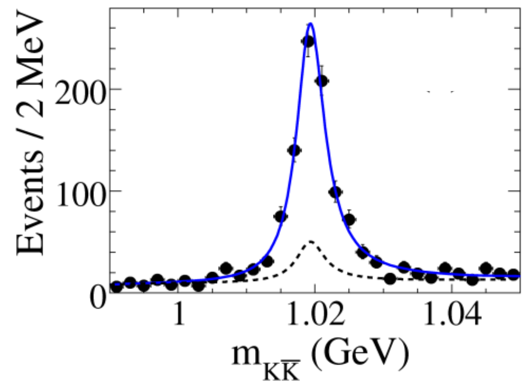
4body FS

B^0 -> ϕ ($K^+\pi^-$)

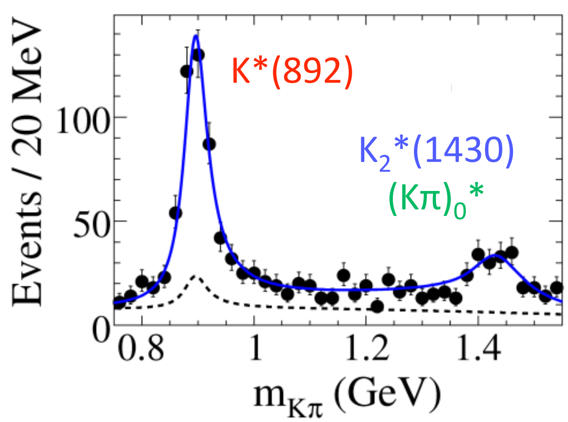
$B^0 \to \phi\ (K^+\pi^-)$ Branching Fractions

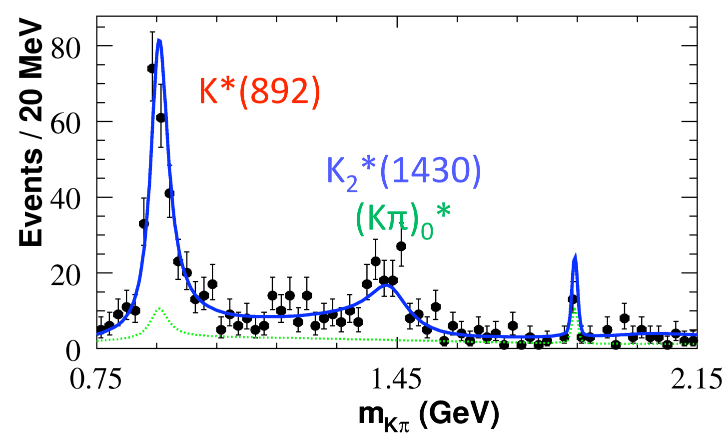






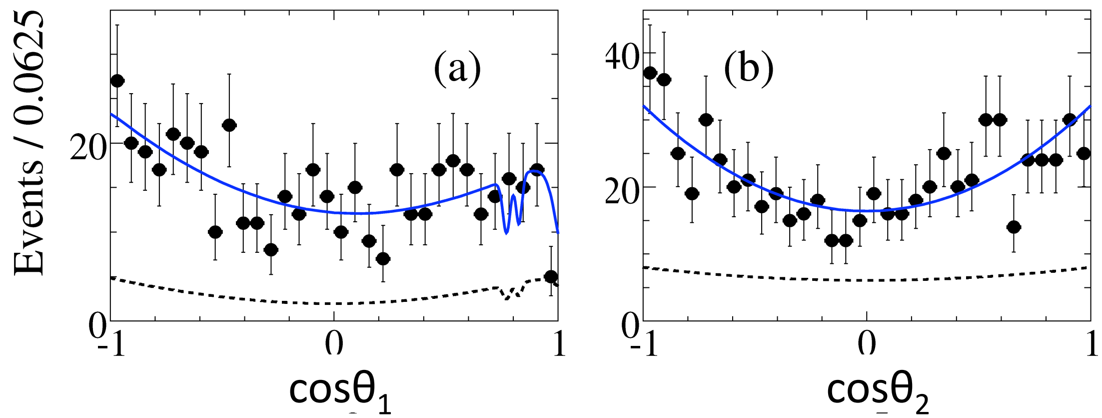
Mode	Yields	B.F. (10^{-6})	A_{CP}
$\phi(K\pi)_0{}^*$	158 ± 22 ± 13	4.3 ± 0.6 ± 0.4	+0.20 ± 0.14 ± 0.06
$\phi K^*(892)^0$	500 ± 28 ± 19	9.7 ± 0.5 ± 0.5	+0.01 ± 0.06 ± 0.03
$\phi K^*(1680)^0$	-	<3.5	Fixed to 0
$\phi K_2{}^*(1430)^0$	158 ± 20 ± 7	7.5 ± 0.9 ± 0.5	-0.08 ± 0.12 ± 0.05
$\phi K_3{}^*(1780)^0$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





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

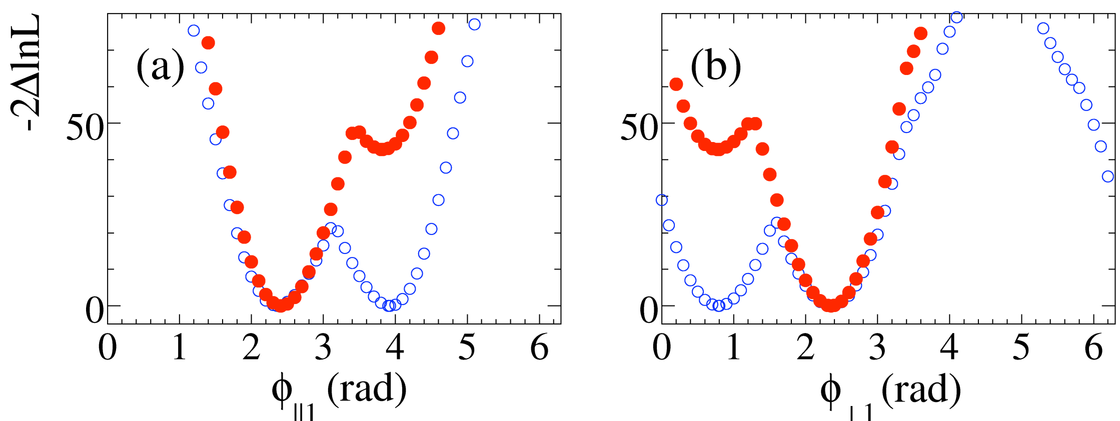
f_L	0.494 ± 0.034 ± 0.013
$f_\perp$	0.212 ± 0.032 ± 0.013
$\phi_{\|\|}$(rad)	2.40 ± 0.13 ± 0.08
$\phi_\perp$(rad)	2.35 ± 0.13 ± 0.09
δ_0(rad)	2.82 ± 0.15 ± 0.09
$\mathcal{A}_{CP}$	+0.01 ± 0.06 ± 0.03
$\mathcal{A}_{CP}^0$	+0.01 ± 0.07 ± 0.02
$\mathcal{A}_{CP}^\perp$	-0.04 ± 0.15 ± 0.06
$\Delta\phi_{\|\|}$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

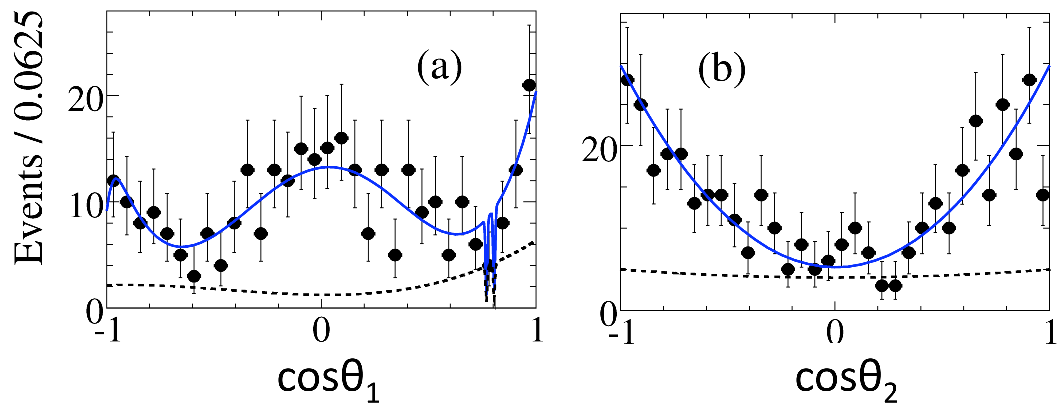
without interf. $(\Phi_{||},\Phi_\perp) \Leftrightarrow (2\pi-\Phi_{||}, \pi-\Phi_\perp)$: (A_{+1}? A_{-1})

with interf. $A_{+1} \gg A_{-1}$



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

f_L	$0.901(^{+0.046}_{-0.058}) \pm 0.037$
$f_\perp$	$0.002(^{+0.018}_{-0.002}) \pm 0.031$
$\phi_{\|\|}$(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
$\mathcal{A}^0_{CP}$	-0.05 ± 0.06 ± 0.01
$\mathcal{A}^\perp_{CP}$	----
$\Delta\phi_{\|\|}$	-1.00 ± 0.38 ± 0.09
$\Delta\phi_\perp$	----
$\Delta\delta_0$	+0.27 ± 0.14 ± 0.08



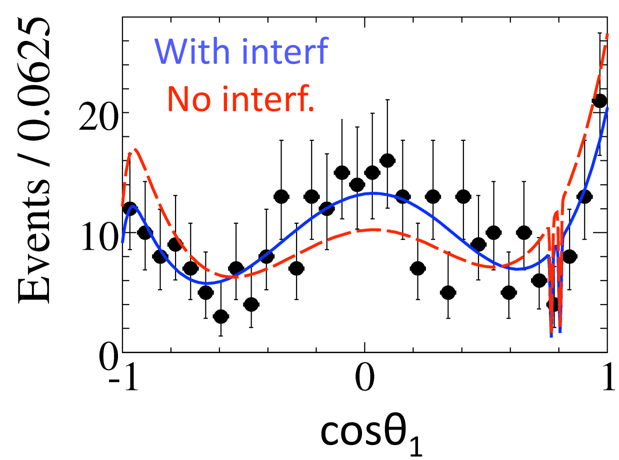
- Vector-Tensor Puzzle

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

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

SM's favor!

- Interference parameter $\delta_0 \approx \pi$ consistent with K*(892)/K*(1430) interference.

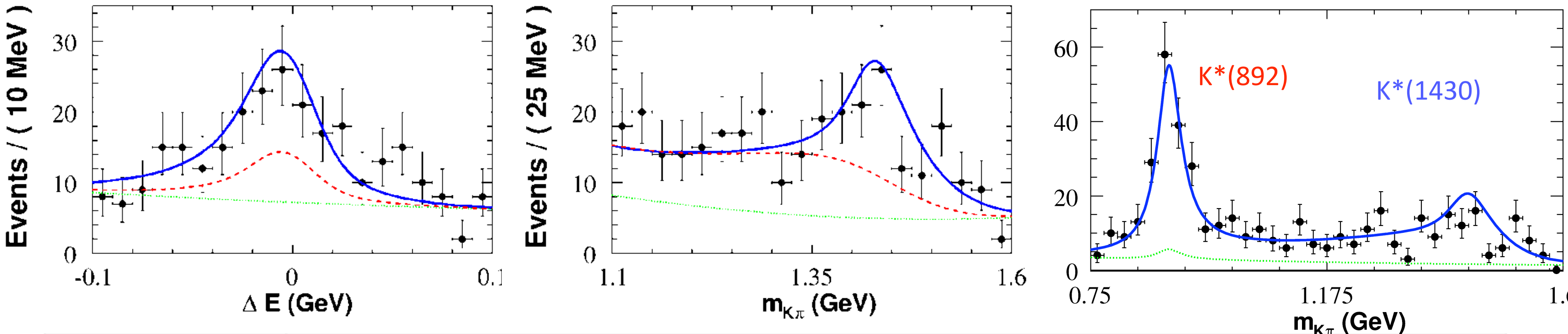


4body and 5body FS

$B^{\pm}$ -> ϕ ($K^{\pm}\pi^{0}$/$K\pi^{\pm}$/$K^{\pm}\pi^{+}\pi^{-}$)

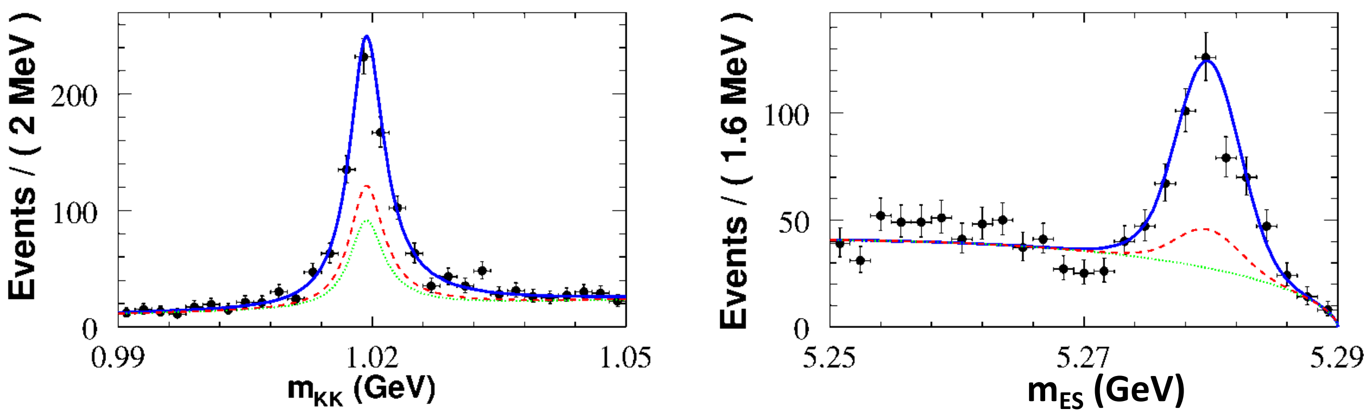
$B^{\pm} \to \phi(K_S\pi^{\pm})/(K^{\pm}\pi^0)$ Branching Fractions

- Consistent results with B^0 decay modes



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
$\phi K_2^*(1430)$	27±6±3	38±9±4	8.4±1.8±1.0	-0.23±0.19±0.06

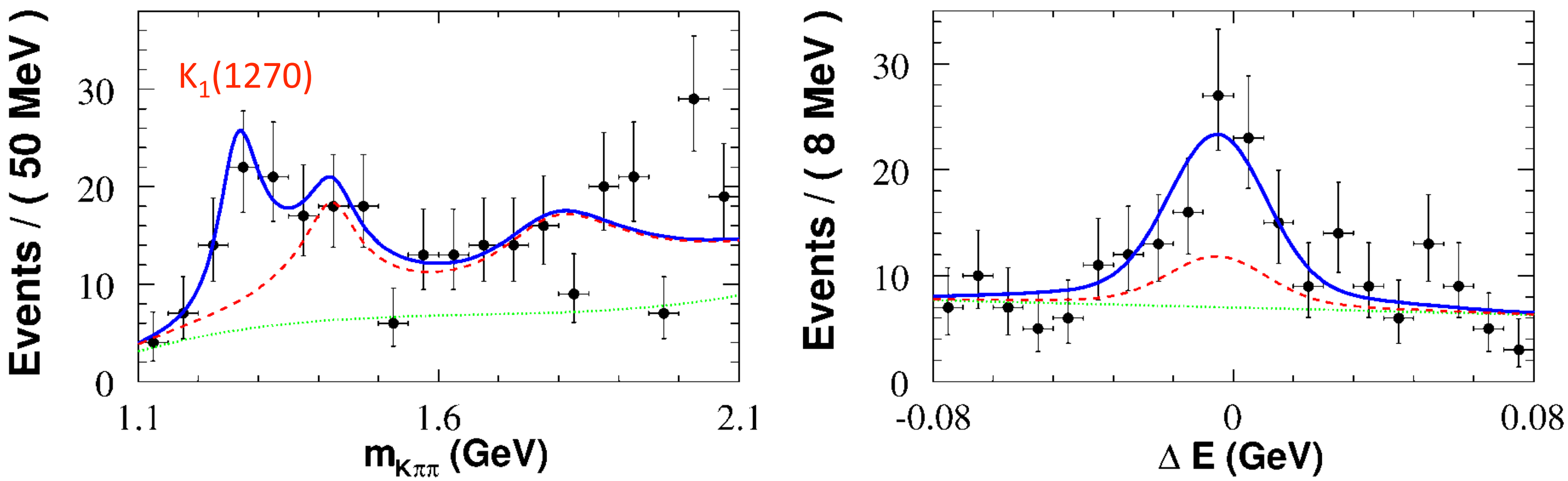
- Combining all 3 B^+ decay channels $K_S\pi^{\pm}/K^{\pm}\pi^0/K^{\pm}\pi^+\pi^-$



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

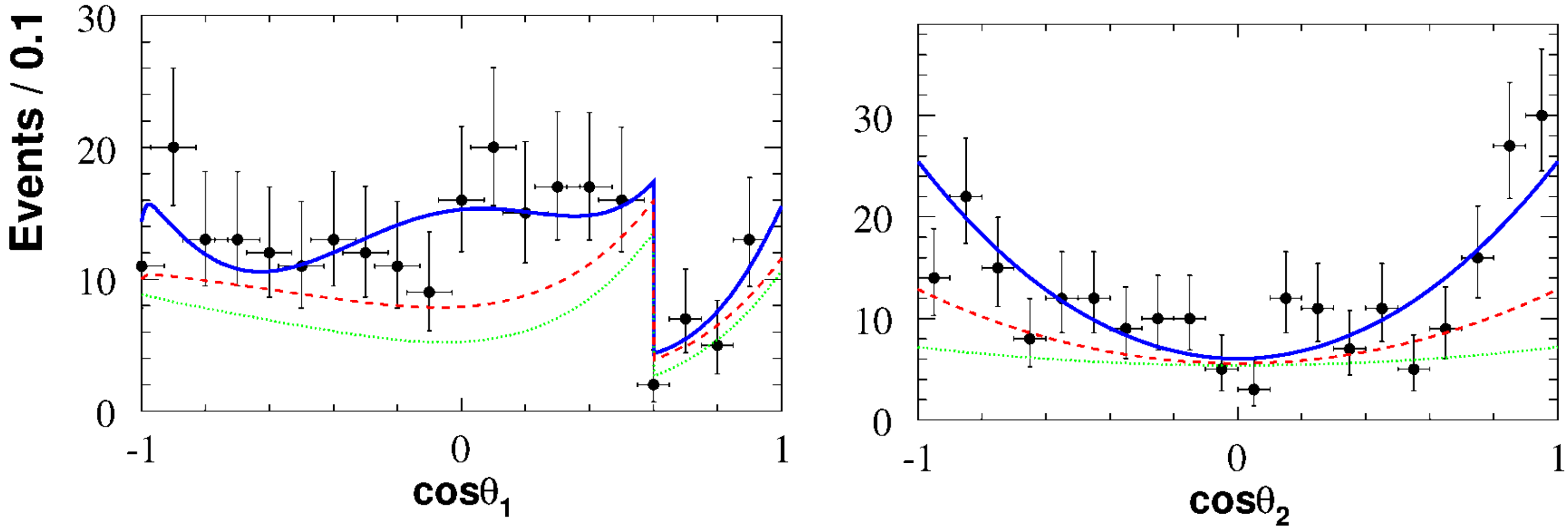
- Vector—Axial-Vector decay observed

5.0 σ significance including systematic uncertainty)



Mode	Yields	B.F. (10^{-6})	A_{CP}
$\phi K_1(1270)$	$116 \pm 26\ ^{+15}_{-14}$	6.1 ± 1.6 ± 1.1	-0.23 ± 0.19 ± 0.06
$\phi K_1(1400)$	7 ± 39 ± 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 ± 14 ± 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

$B^{\pm} \to \phi(K_S\pi^{\pm})/(K^{\pm}\pi^0)$ Polarizations



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

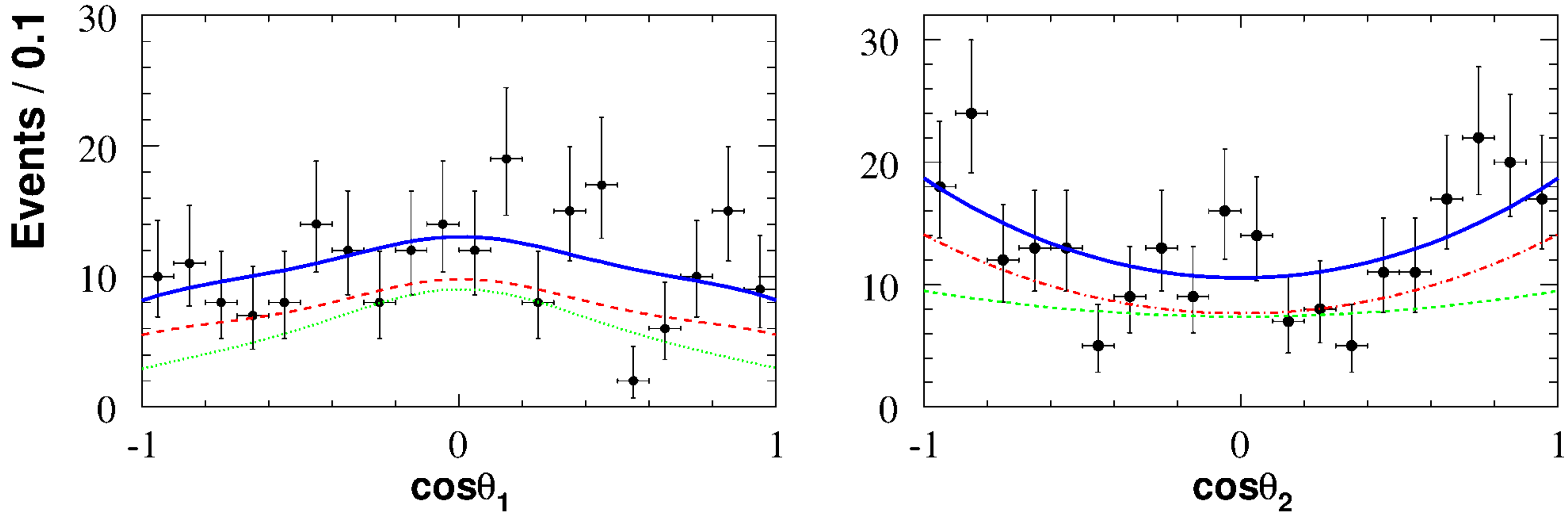
Confirms the Vector-Tensor Polarization Puzzle

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

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

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

Polarization in $B^{\pm} \to \phi(K^{\pm}\pi^{+}\pi^{-})$



- 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

- For all other modes, we don't observe enough events .

  f_L=0.8 is chosen as best estimate from SM.

  The polarization is varied from (0.5-0.93) to account for systematic uncertainties.

Summary

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

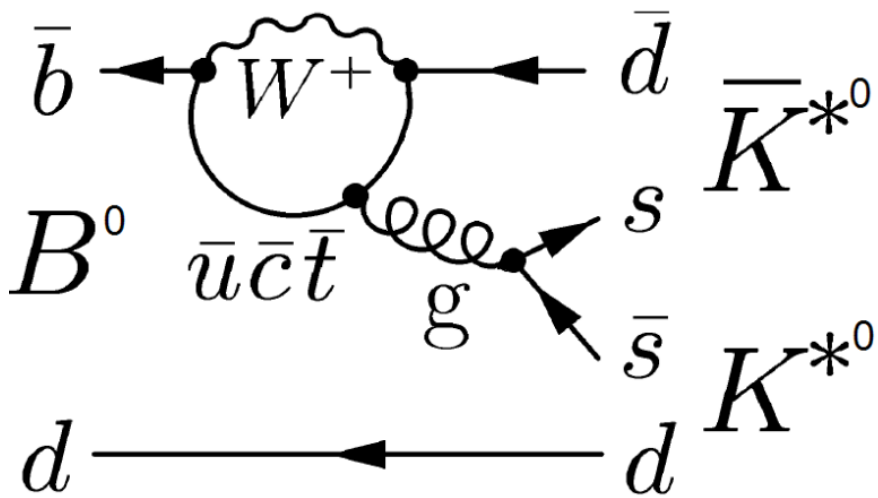
J^P	Mode B ->ϕ	B.F. (10^{-6})	f_L
0^+	$K_0^*(1430)^0$	4.6 ± 0.7 ±0.6	
0^+	$K_0^*(1430)^+$	7.0 ± 1.3 ±0.9	
1^-	$K^*(892)^0$	9.2 ± 0.7 ±0.6	0.51 ± 0.04 ± 0.02
1^-	$K^*(892)^\pm$	11.2 ± 1.0 ±0.9	0.49 ± 0.05 ± 0.03
1^-	$K^*(1410)^\pm$	<4.8	
1^-	$K^*(1680)^\pm$	<3.5	
1^+	$K_1(1270)^\pm$	6.1 ± 1.6 ± 1.1	$0.46(^{+0.12}_{-0.13})(^{+0.06}_{-0.07})$
1^+	$K_1(1400)^\pm$	<3.2	
2^+	$K_2^*(1430)^0$	7.8 ± 1.1 ±0.6	$0.901(^{+0.046}_{-0.058})\pm 0.037$
2^+	$K_2^*(1430)^\pm$	8.4 ± 1.8 ±0.9	$0.80(^{+0.09}_{-0.10}) \pm 0.03$
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	

- Observed several polarization puzzles that can not be explained in naïve SM.

- $|A_0| \approx |A_+| >> |A_-|$ 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)

b->d Penguin Dominated Process

$$B.F = (1.28^{+0.35}_{-0.30} \pm 0.11) \times 10^{-6}$$

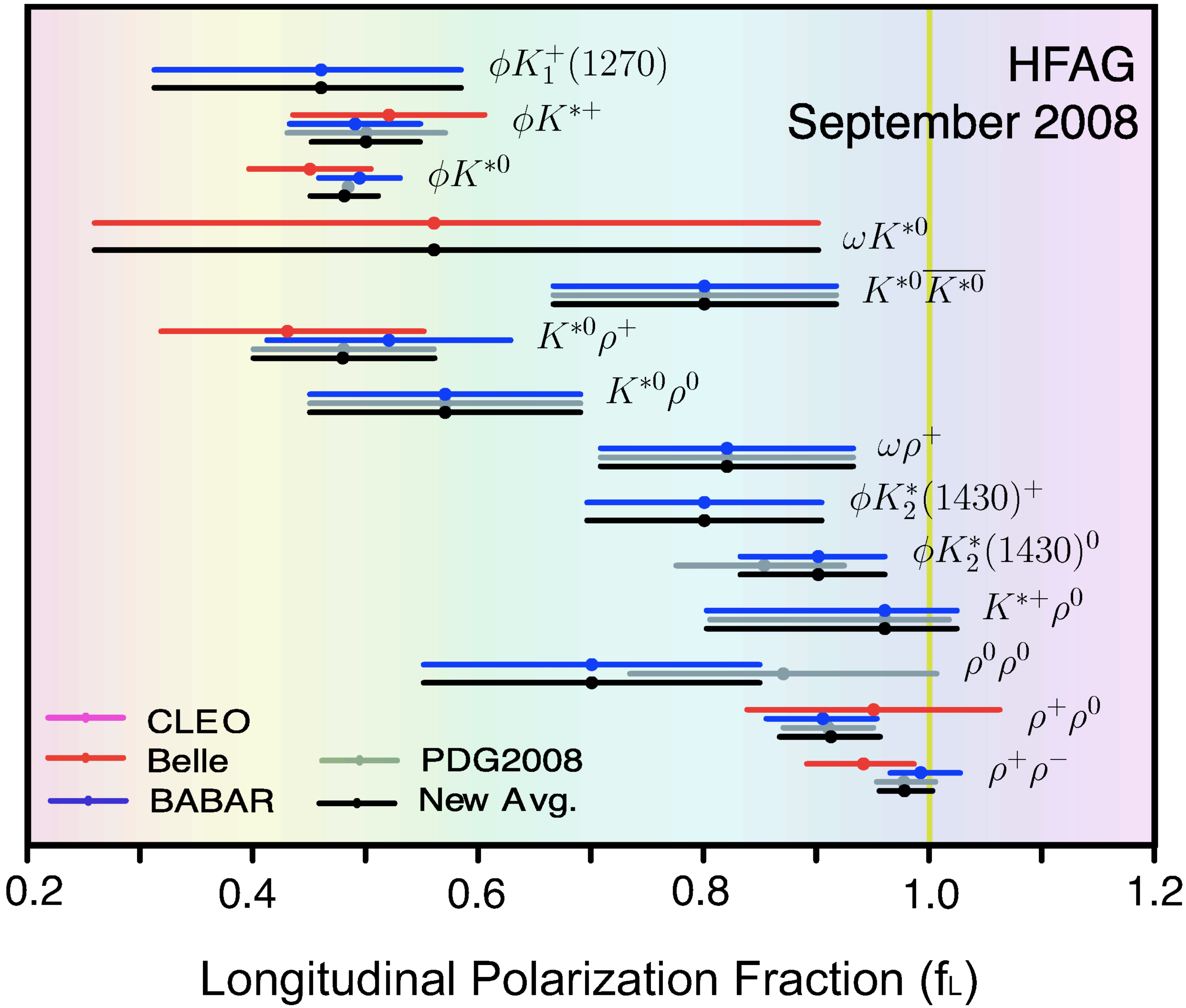


$$f_L = 0.80^{+0.10}_{-0.12} \pm 0.06$$

f_L (b->d penguin) ≠ f_L (b->s penguin)

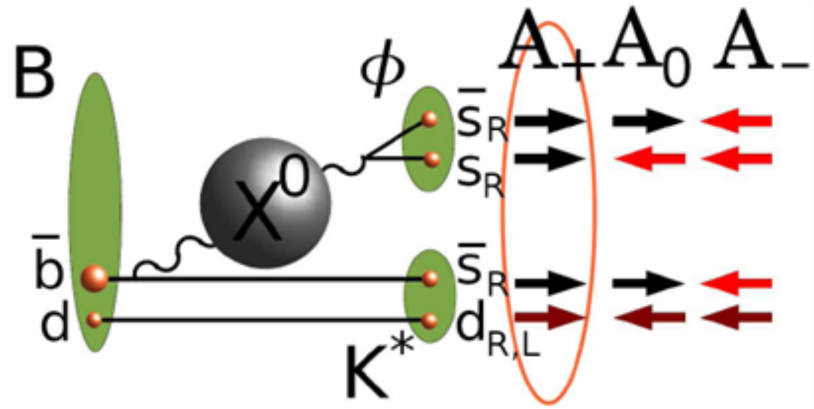
Charmless B Decay Polarizations

HFAG: Rare B Decay Parameters: http://www.slac.stanford.edu/xorg/hfag/rare/index.html

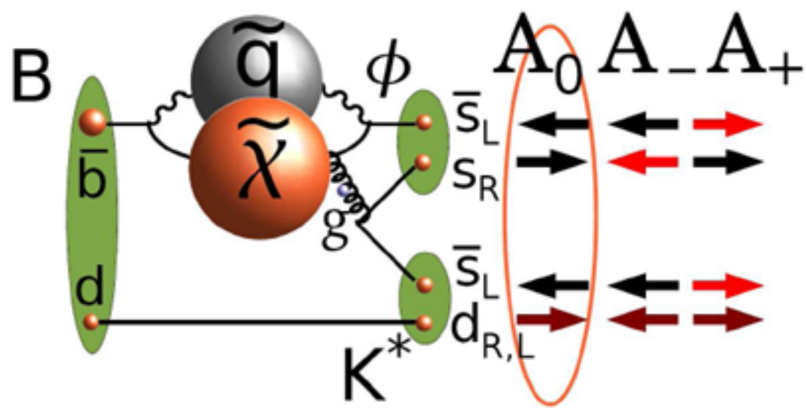


New Physics in the Penguin Loop?

- Scalar Interactions



- SUSY

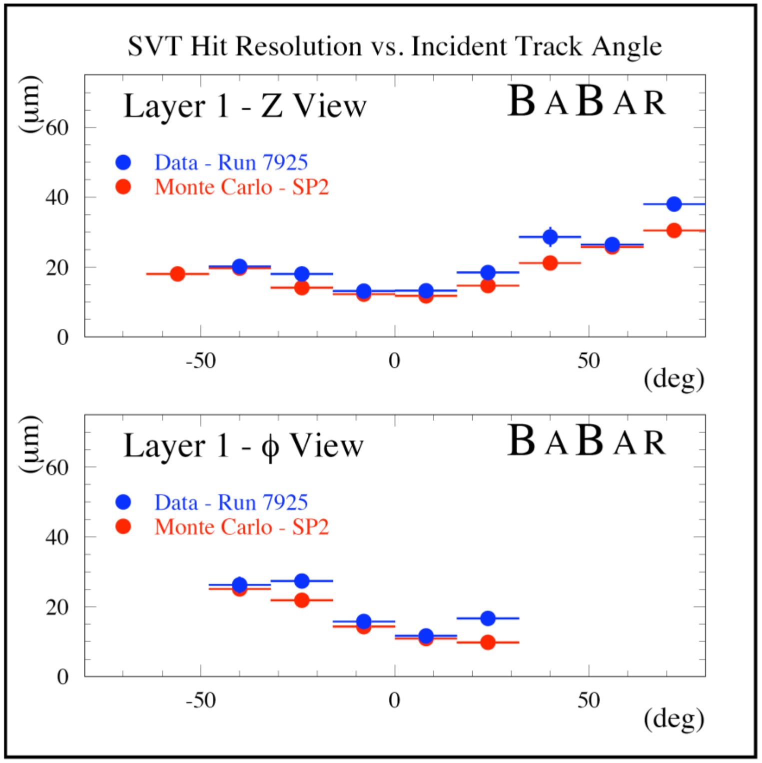


New physics models cannot explain the puzzle or predict anything until we understand better the nature of the NP and reduce the QCD uncertainties significantly.

BACKUP SLIDES

Silicon Vertex Tracker Performance

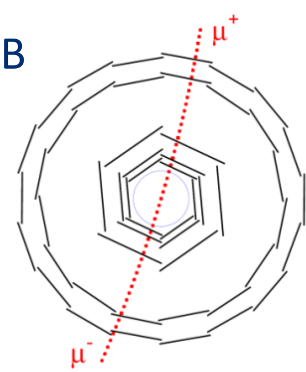
- Spatial Resolutions



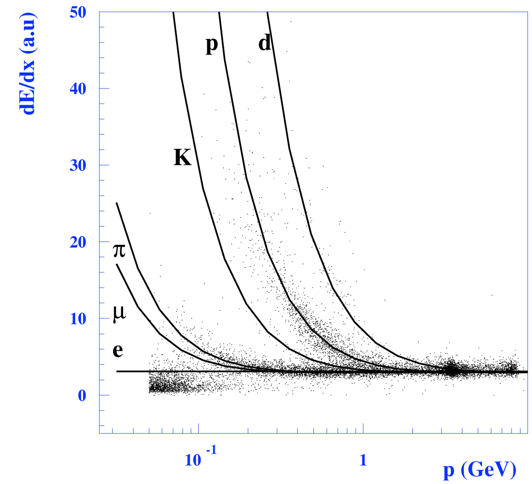
z-distance of the two B

$\sigma(\Delta Z_B) \sim$ 180 μm

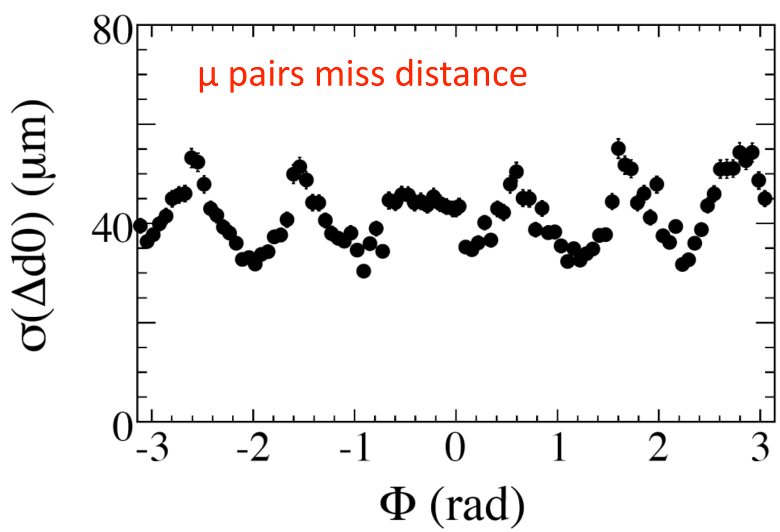
$\beta\gamma c\tau_B \sim$ 250 μm



- Low p track particle identification



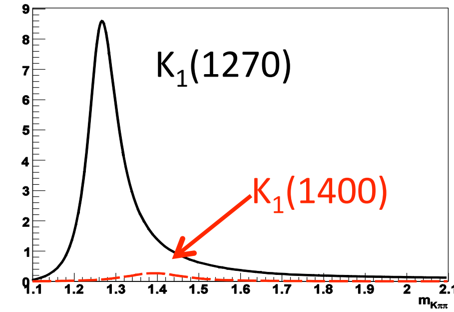
- μμ + cosmic rays for alignment



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

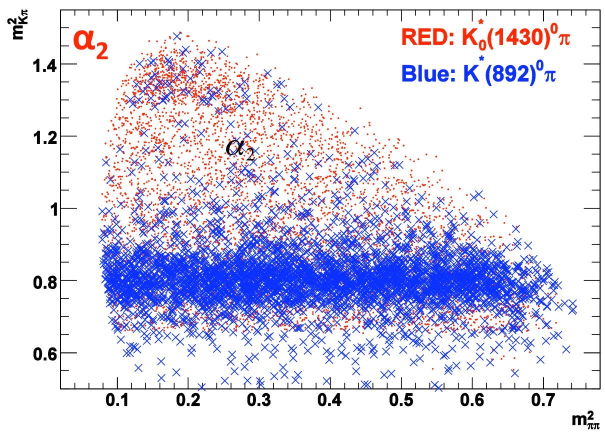
$$f|A_1|^2 + (1-f)|A_2|^2 + 2\alpha\sqrt{f(1-f)}\,\mathrm{Re}(A_1 A_2^* e^{i\delta})$$

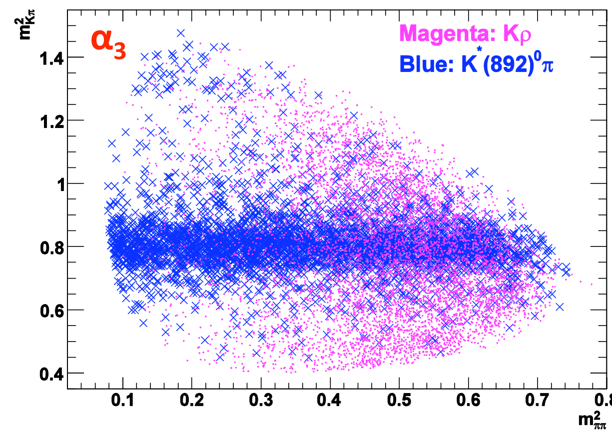


- Interference between 3 different channels

Channel	K*π	K_0*(1430) π	Kρ
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.)

$B^\pm \to \phi K^*(1430)(K_S\pi^\pm/K^\pm\pi^0/K^\pm\pi^+\pi^-)$ 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 combining likelihood in all channels

- Yields in different FS can be related by the relative efficiencies

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

- Directly fit two parameters:

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

"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

Statistical significance due to nuisance parameter

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

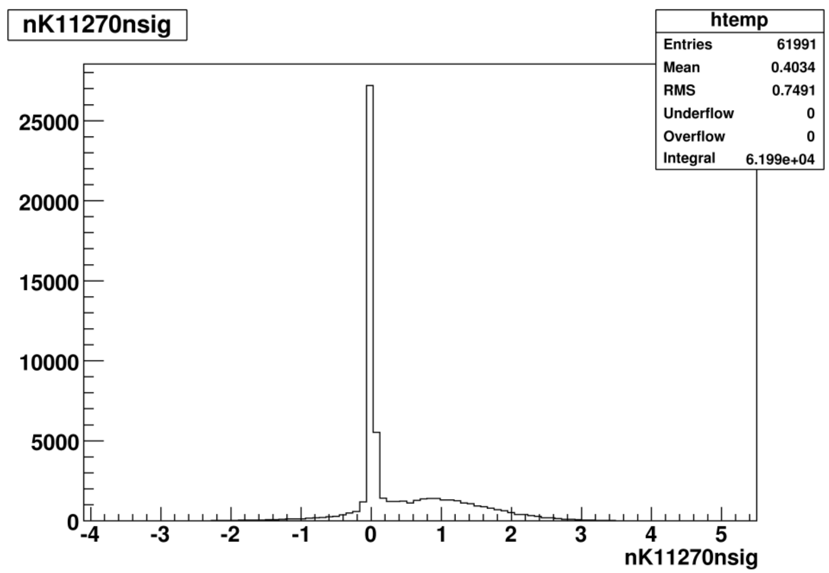
  With 1(2) dof change assumption

  $\phi K_1(1270)$: 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->$\phi K^*(892)$ show a similar trend till 5σ

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