MEASUREMENT OF CP VIOLATION IN $B \to \phi K$ DECAYS

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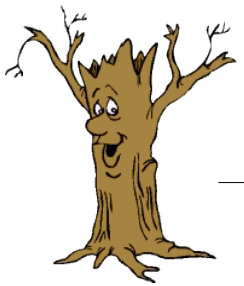
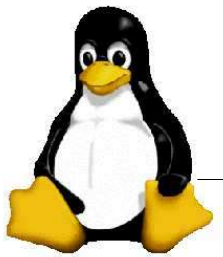
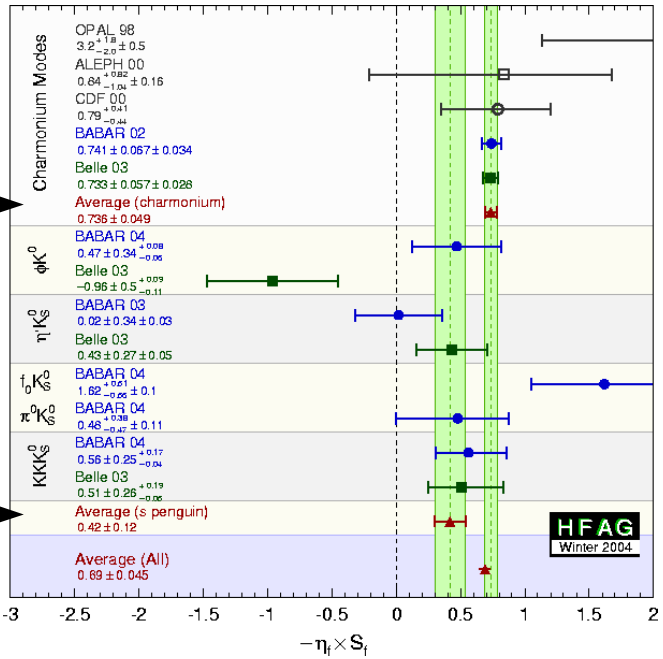
Physics motivations

$B \to \phi K$ is $b \to s$ transition

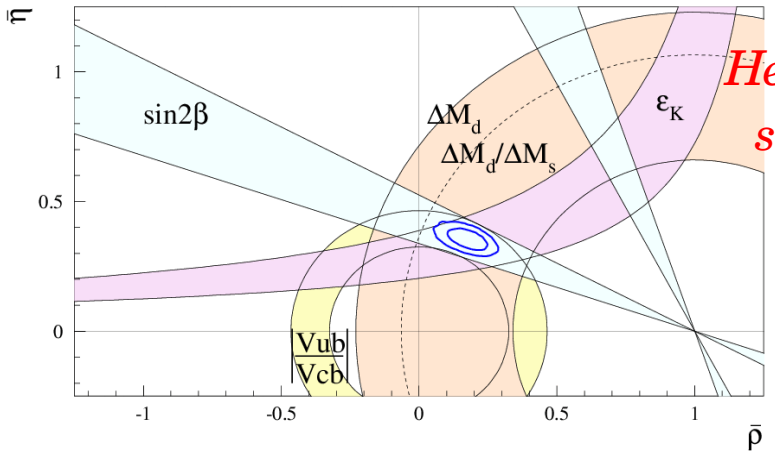
- Tree diagram is FCNC
- Only penguin diagram mediated
- Non SM contributions in the loop can make $\sin(2\beta)$ value different from $J/\psi\, K_S$

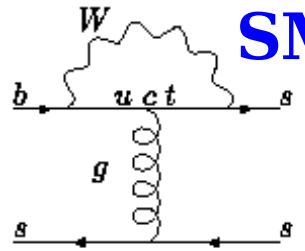






All on a triangle...

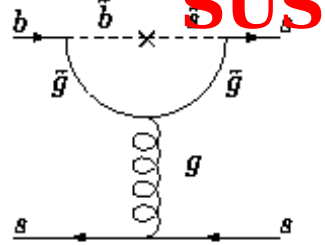




SM

Light masses, weak coupling

SUSY

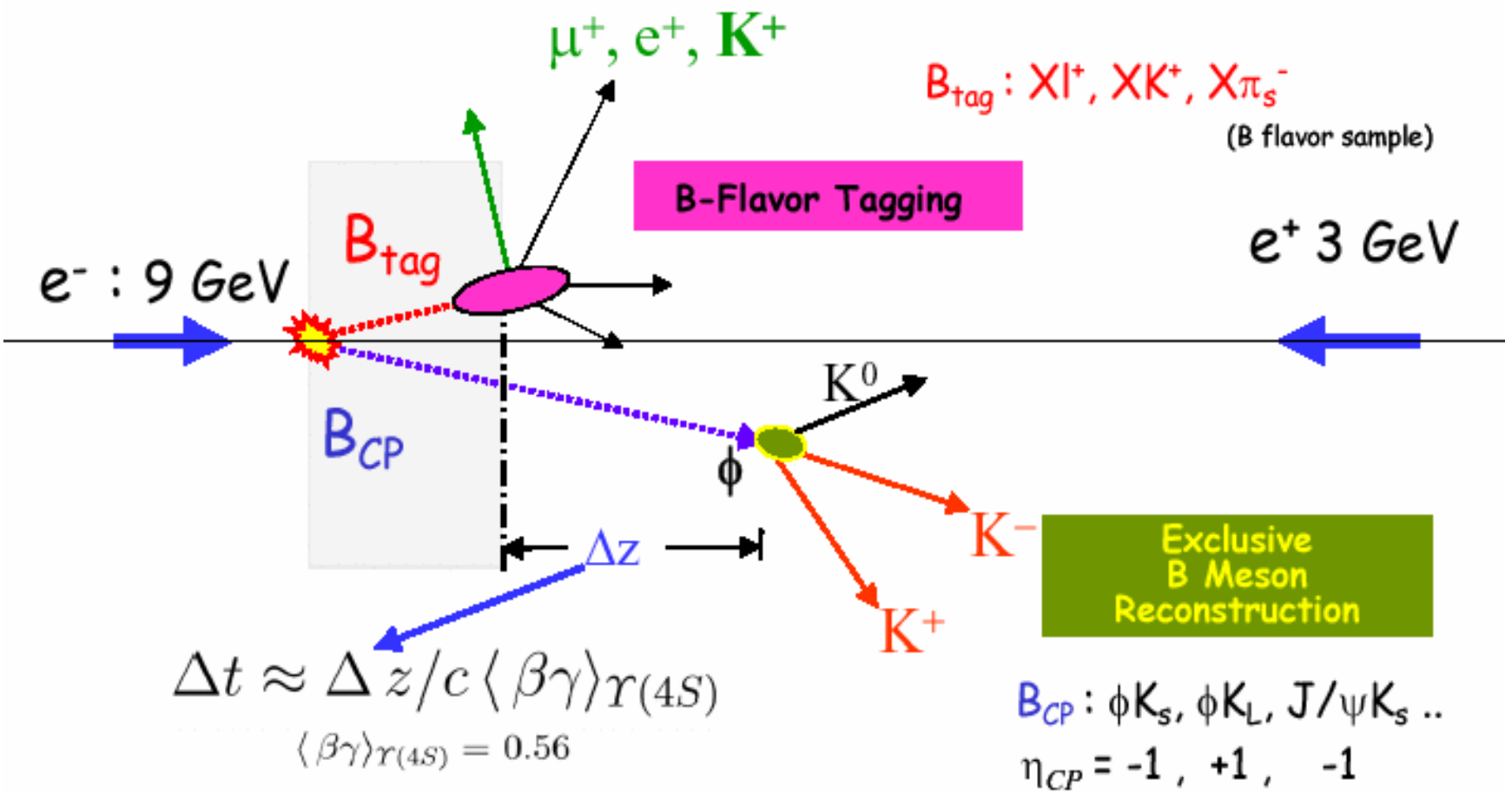


Heavy masses, but strong coupling

We study:

- $\phi(K^+K^-)K_S$, $\phi(K^+K^-)K_L$, $\phi(K_SK_L)K_S$: time tependent study
- $\phi(K_SK_L)K^+$: direct ~~CP~~ measurement

Time measurement @ asymmetric B-Factory

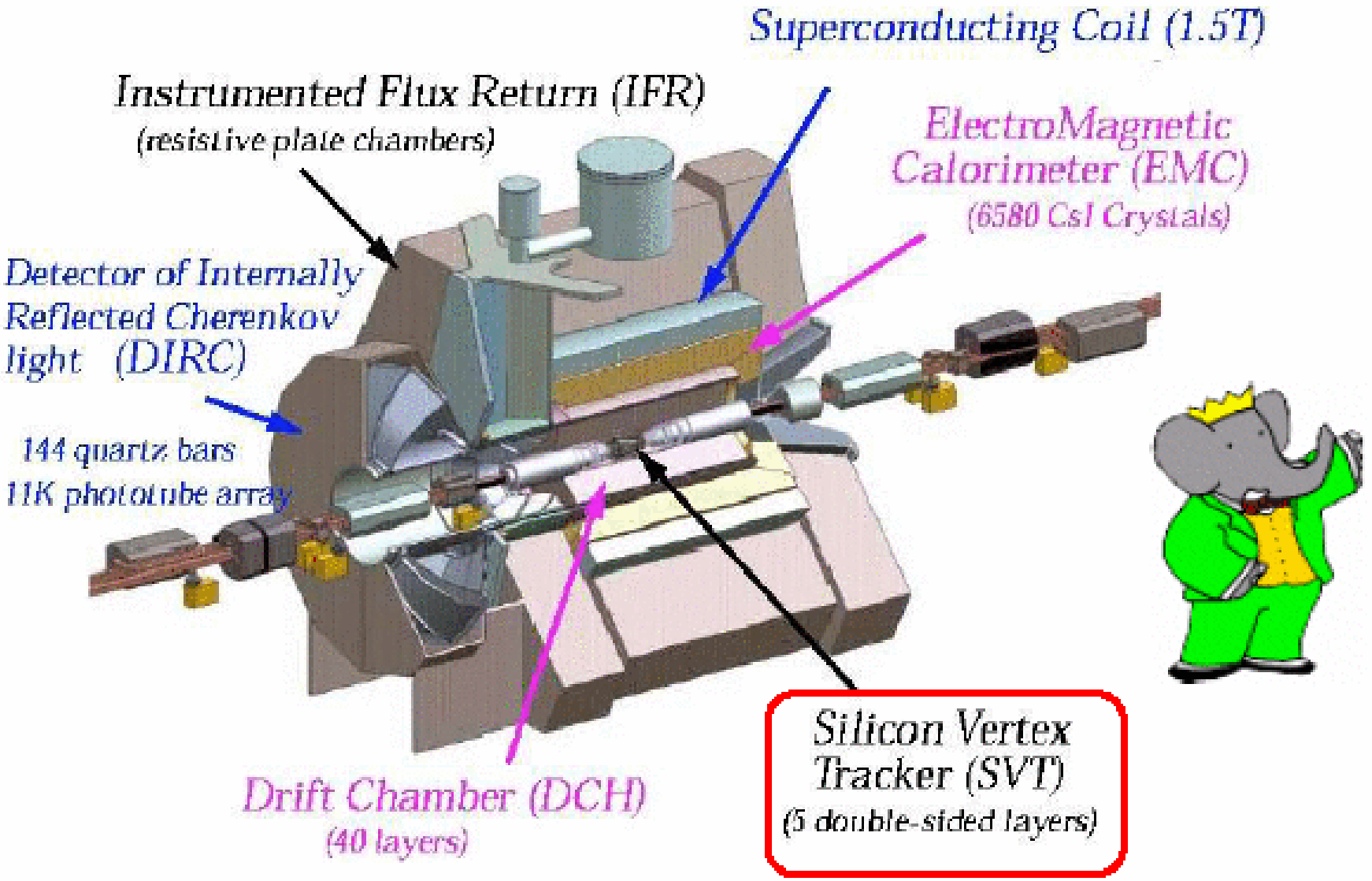


Time dependent asymmetry:

$$a_f(t) = \frac{R - \overline{R}}{R + \overline{R}}(t) = -\boldsymbol{C}\cos(\Delta m_d t) - \eta_{CP} \cdot \boldsymbol{S}\sin(\Delta m_d t)$$

Standard Model: $C = 0$, $S = \sin 2\beta$

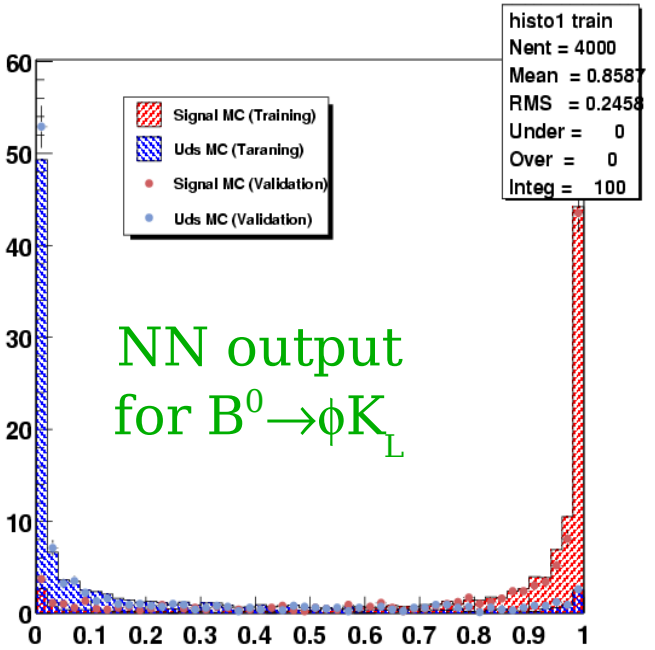
The BaBar detector



K_L reconstruction

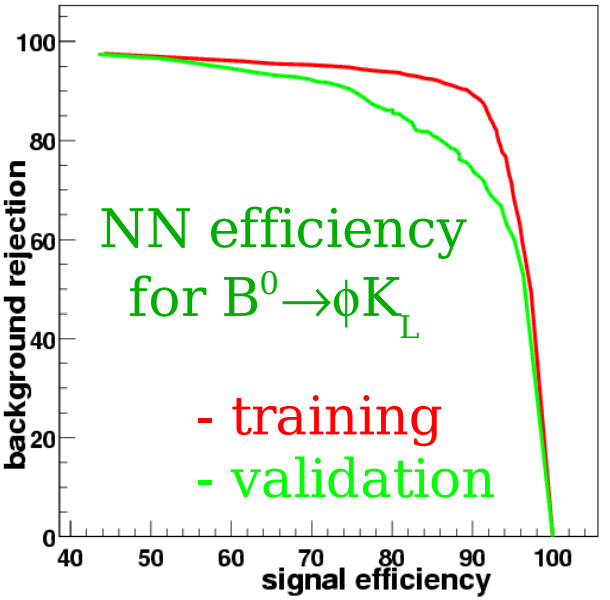
K_L selection in EMC

- Based on π^0 veto
- Background mainly from γ and neutrons
- Cluster shape variables used for discrimination:
  - Lateral moment, second moment
  - Zernike moments Z_{20}, Z_{42}
  - Energy ratios s_1/s_9, s_9/s_{25}
  - number of crystals, number of bumps
- Trained a Neural Network with these inputs



K_L selection in IFR

- Based on track veto
- Residual background from μ
  - Most of K_L are reconstructed in the first layers
  - Best IFR K_L the one with highest number of layers



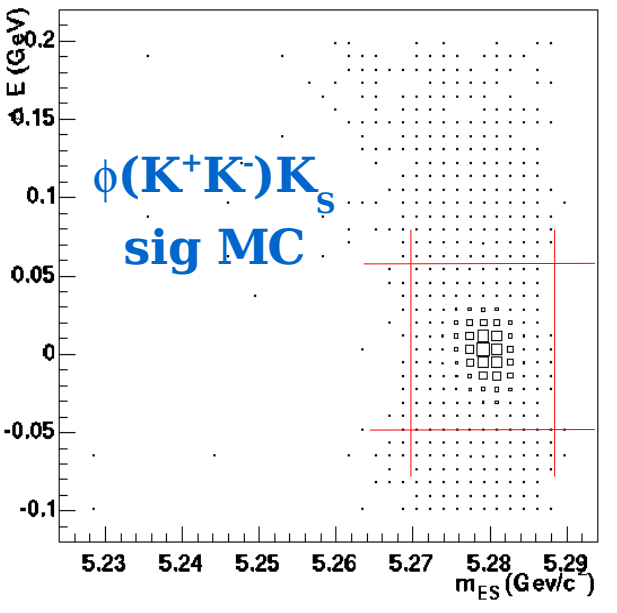
Best K_L :

If both EMC and IFR are present $\Rightarrow$ take the **EMC** (best angular resolution)

Event reconstruction

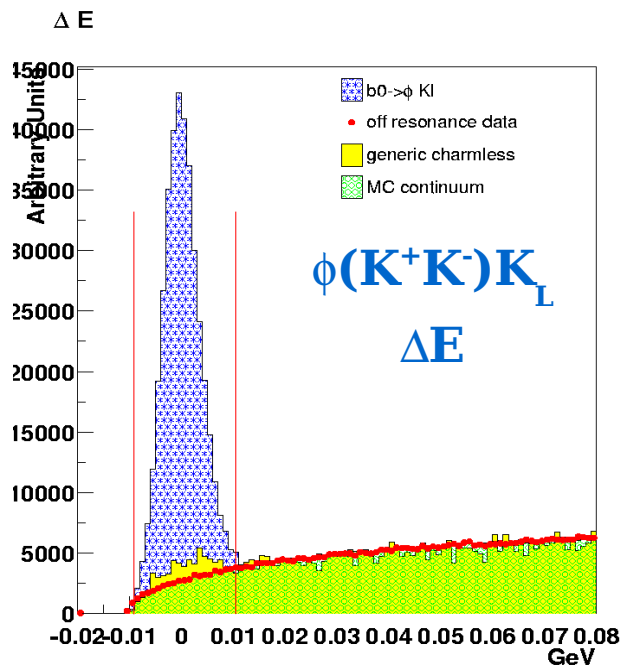
Two low correlated variables:

- $m_{ES} = \sqrt{(\sqrt{s}/2)^2 - p_B^{*2}}$
- $\Delta E = E_B^* - \frac{1}{2}\sqrt{s}$
- m_{ES}= Energy substituted B-mass: resolution on beam energy is higher than reconstructed one
- Define a signal region in m_{ES} - ΔE plane



K_L modes reconstruction:

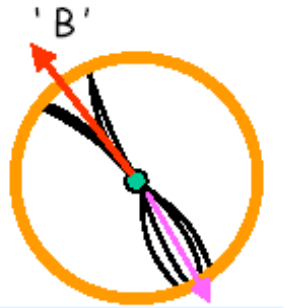
- Can't measure K_L momentum
- Use B mass constraint and calculate it
- Only ΔE variable used for the reconstruction



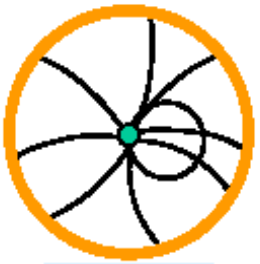
Background fighting

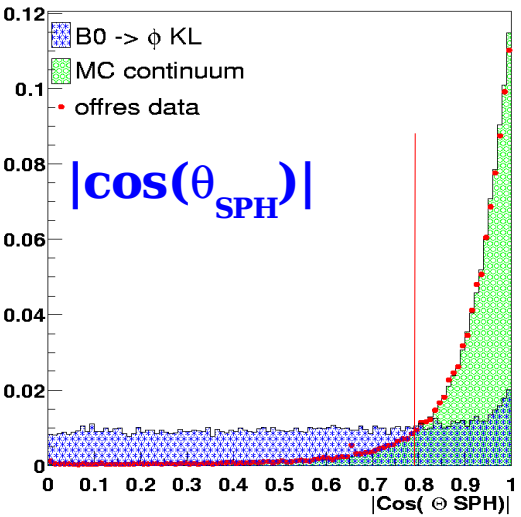
Event topology

- Most of bkg is $q\bar{q}$
- Light quark hadronization produces **jets**
- B events are **spherical**
- **$|\cos(\theta_{SPH})|$**: 10^{-2} bkg rejection
- Legendre polynomials as input of **Fisher discriminant**



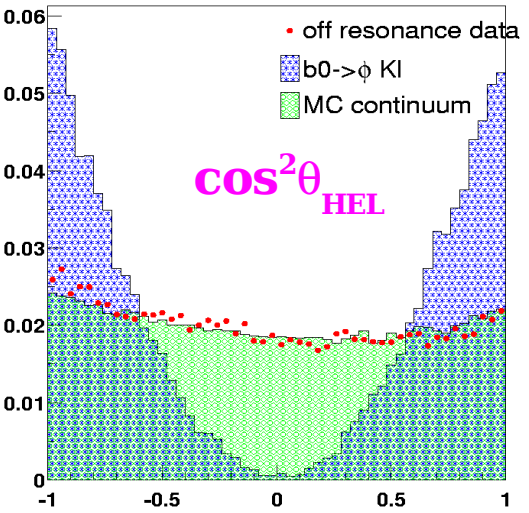
continuum


BB event



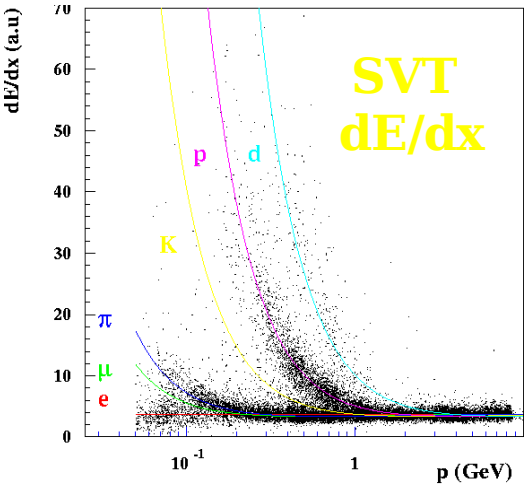
Angular distribution

- B → φ K decay is P-scalar → Vector P-scalar
- In φ frame K^+ direction has **$(\cos^2\theta_{HEL})$** distribution wrt φ flight direction



Kaon Identification for $\phi \to K^+K^-$

- Čerenkov angle in DIRC
- **dE/dx in SVT**, DCH

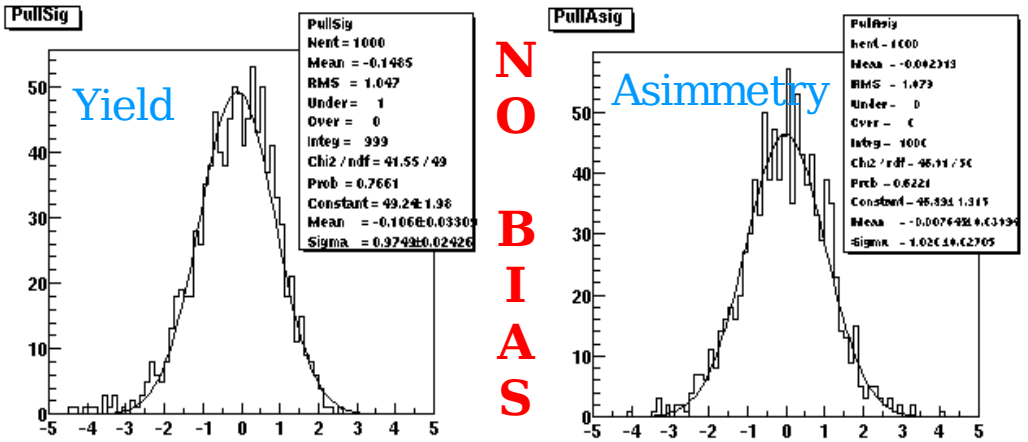


$B^{\pm} \to \phi(K_S K_L) K^{\pm}$: technique

B^+ selection

- $|\cos\theta_{SPH}| < 0.8$
- $NN_{EMC} > 0.6$
- PID on K^+: Very Loose
- $-0.01 < \Delta E < 0.09$ GeV
- $|\cos\theta_{HEL}| < 0.95$
- $-3 < Fisher < +3$
- $1.00 < m(\phi) < 1.07$ GeV/c^2

→ ***Unbinned ML fit***



B^+B^- & $B^0\bar{B}^0$ background

- Other B decays have same topology of the signal
- ... but different **kinematics**, different **angular properties**
- Likelihood power tested on MC cocktails:
  - B^+B^- (47 bkg events): 6.0 ± 6.6 signal events fitted
  - $B^0\bar{B}^0$ (41 bkg events): 3.8 ± 2.8 signal events fitted

$B^{\pm} \to \phi(K_S K_L) K^{\pm}$: results

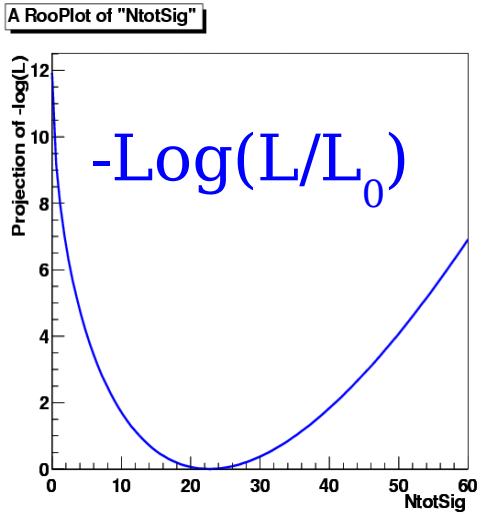
Yields (112 fb^{-1}):

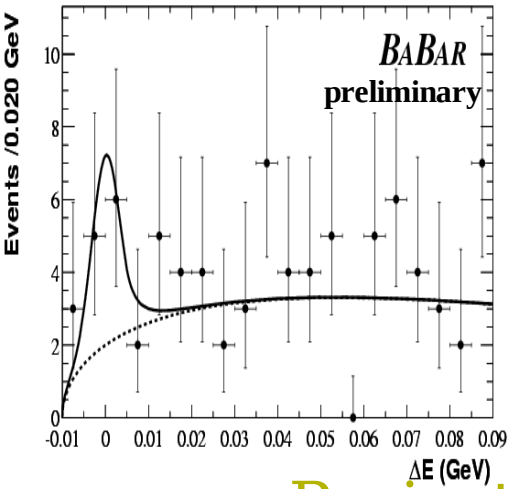
- $N_{SIG} = 22.7\ ^{+8.6}_{-7.6}\ (stat)\ ^{+6.2}_{-5.4}\ (sist)$
- $N_{BKG} = 2126\ ^{+47}_{-46}\ (stat)$

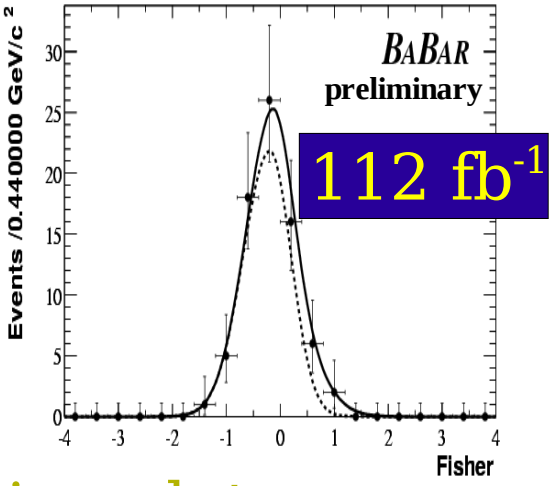
Asimmetry:

- $A_{SIG} = 0.33\ ^{+0.32}_{-0.35}\ (stat)\ ^{+0.04}_{-0.04}\ (sist)$
- $A_{BKG} = 0.008 \pm 0.022$

SM predicts:
A=0 (direct ~~CP~~)







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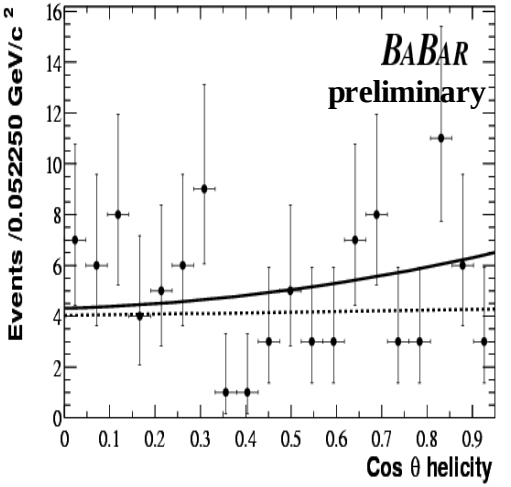
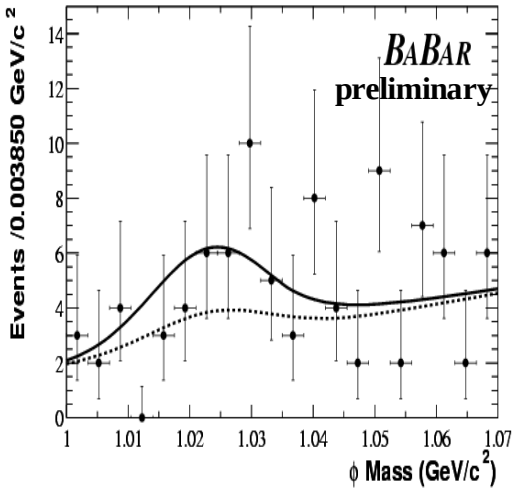
Projection plots





N(σ) = 4.9

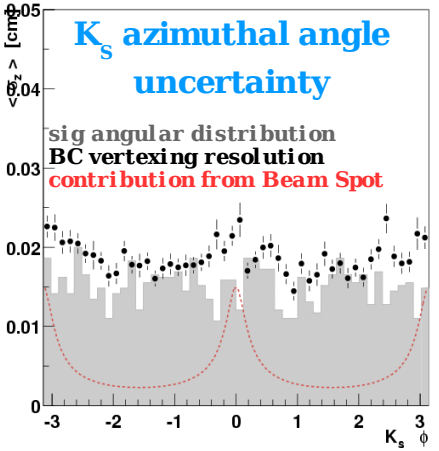
$B^0 \to \phi(K_S K_L) K_S$: technique

B^0 selection:

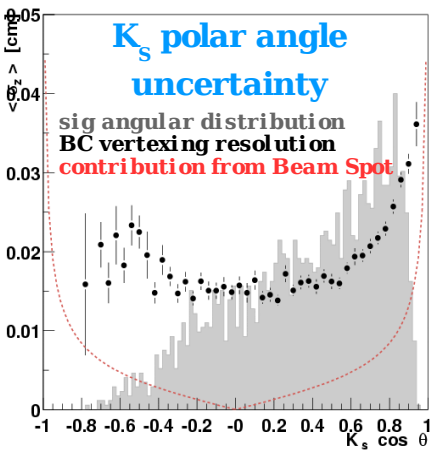
- $|\cos\theta_{SPH}| < 0.8$
- $NN_{EMC} > 0.6$
- $|m(K_S) - m_{PDG}| < 11.2$ MeV/c^2
- $\tau / \sigma_\tau > 5$ (K_S lifetime significance)

- $-0.01 < \Delta E < 0.09$ GeV
- $-3 < \text{Fisher} < +3$
- $|\cos\theta_{HEL}| < 0.98$
- $1.00 < m(\phi) < 1.07$ GeV/c^2

→ ***Unbinned ML fit***

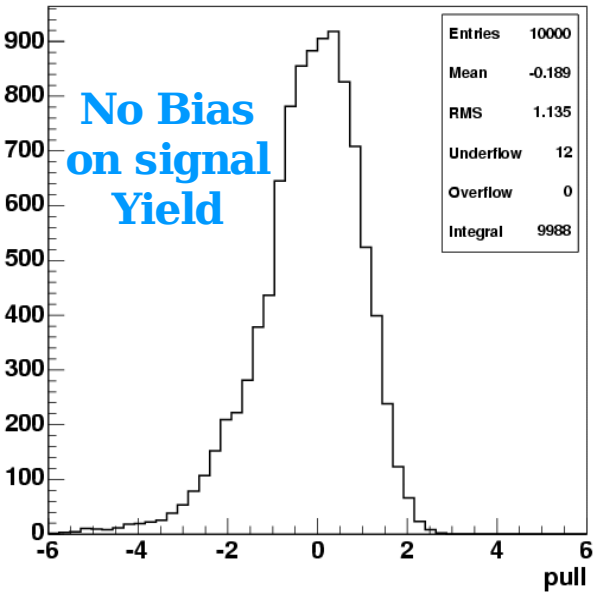


IP VERTEXING



$B^0\bar{B}^0$ background

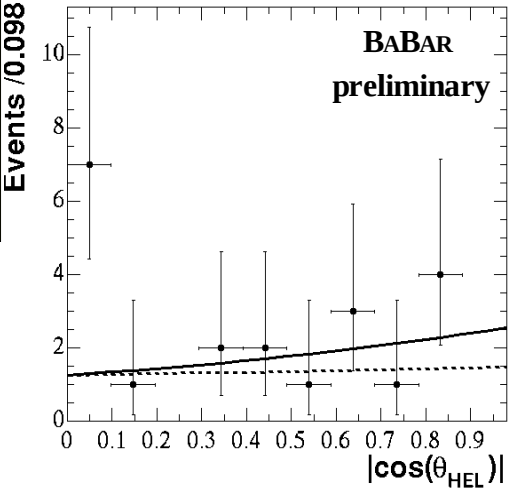
- Likelihood fits on cocktail (13 events)
  - $N_{SIG} = 2.45 \pm 1.80$
  - $N_{BKG} = 10.5 \pm 3.4$

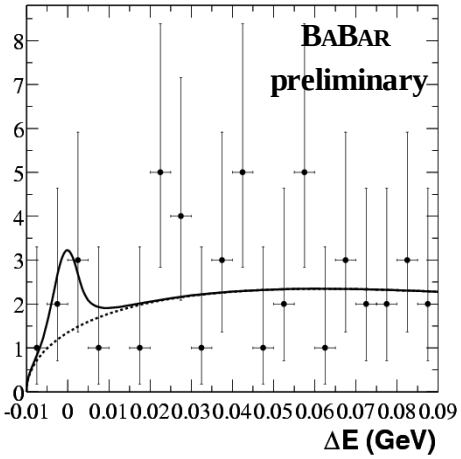


$B^0 \to \phi(K_S K_L) K_S$: results

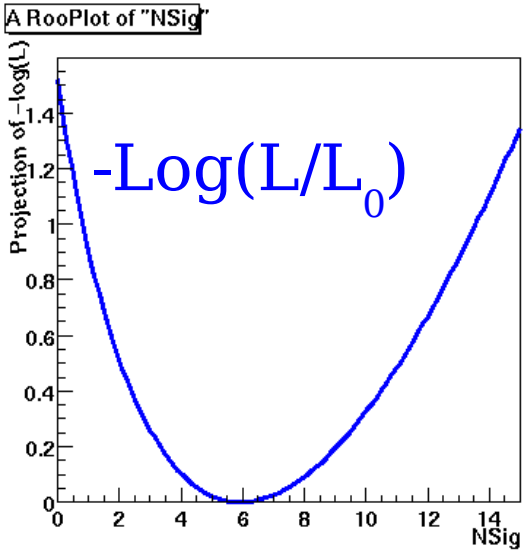
Yields:

- $N_{SIG} = 6.1 \pm 4.6\ (stat)^{+1.86}_{-1.57}\ (sist)$
- $N_{BKG} = 832 \pm 29\ (stat)$

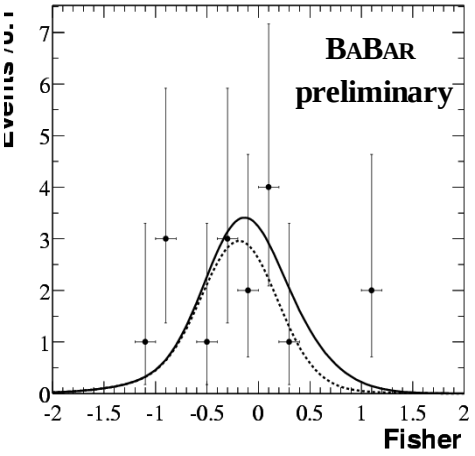


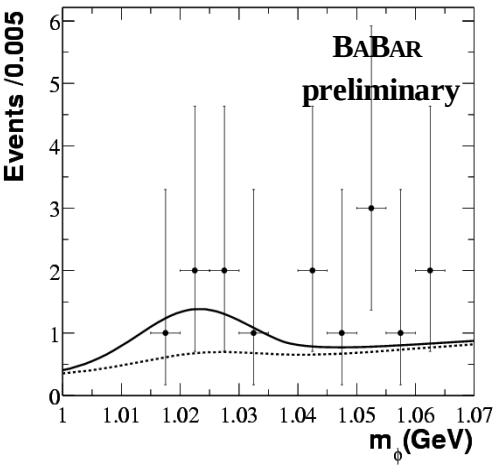


N(σ) = 1.8



Projection plots





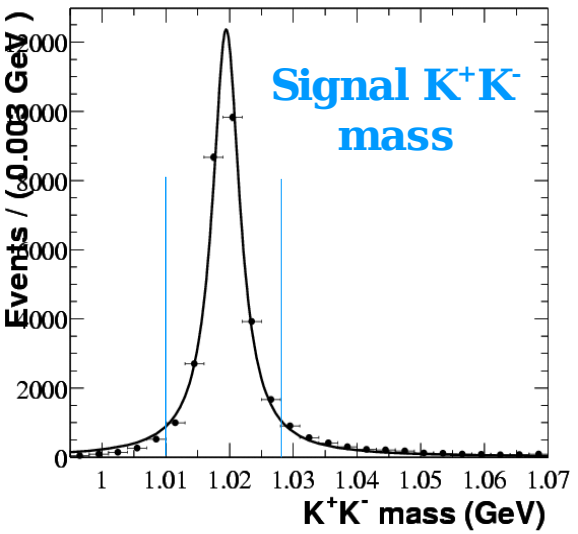
112 fb^{-1}

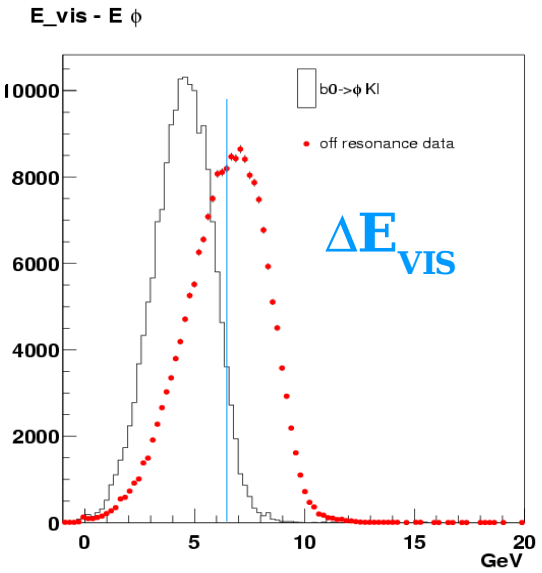
$B^0 \to \phi(K^+K^-)K_L$: technique

B^0 selection:

- $|\cos\theta_{SPH}| < 0.8$
- $|\cos\theta_B| < 0.8$
- $1.008 < m(\phi) < 1.026$ GeV/c^2
- PID: **Not a Pion** × **Tight**
- EMC Neural Network > 0.75
- $\Delta E_{VIS} < 6.5$ GeV

- $-0.01 < \Delta E < 0.08$ GeV
- $-3 < \text{Fisher} < +3$
- $|\cos\theta_{HEL}| < 1$
- $\Delta t < 20$ ps
- $\sigma_{\Delta t} < 2.5$ ps



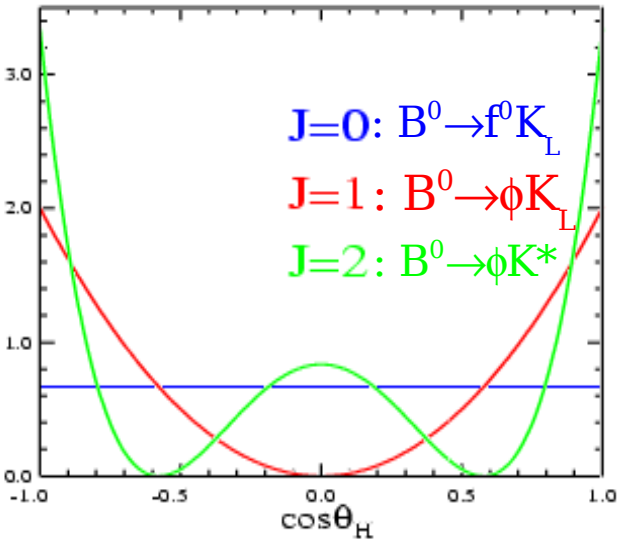


→ ***Unbinned ML fit***

B^+B^- & $B^0\bar{B}^0$ background

- Three peaking modes:
  - $B^0 \to f^0 K_L$: 3 events
  - $B^0 \to \phi K^{*0}(K_L\pi^0)$: 5 events
  - $B^0 \to \phi K^{*+}(K_L\pi^+)$: 10 events

  } $f_L = 0.52$ (meas.)
- They have different angular distribution from ϕK_L
- B bkg component in the Likelihood



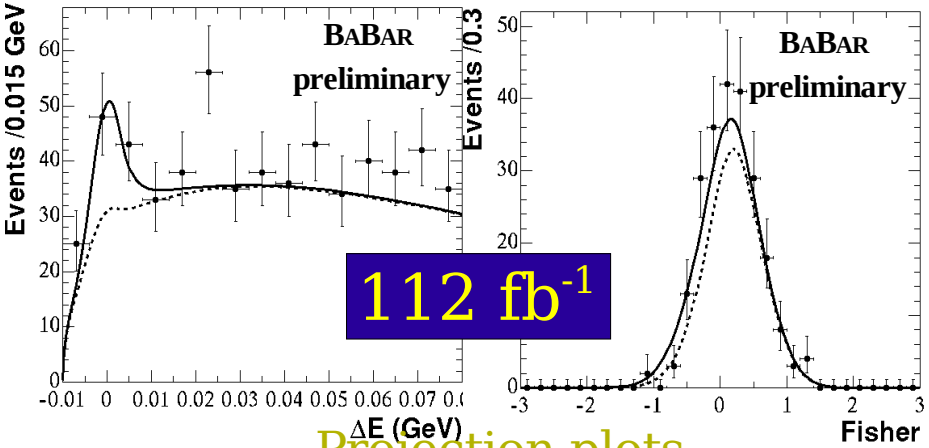
$B^0 \to \phi(K^+K^-)K_L$: (some) results

Yields:

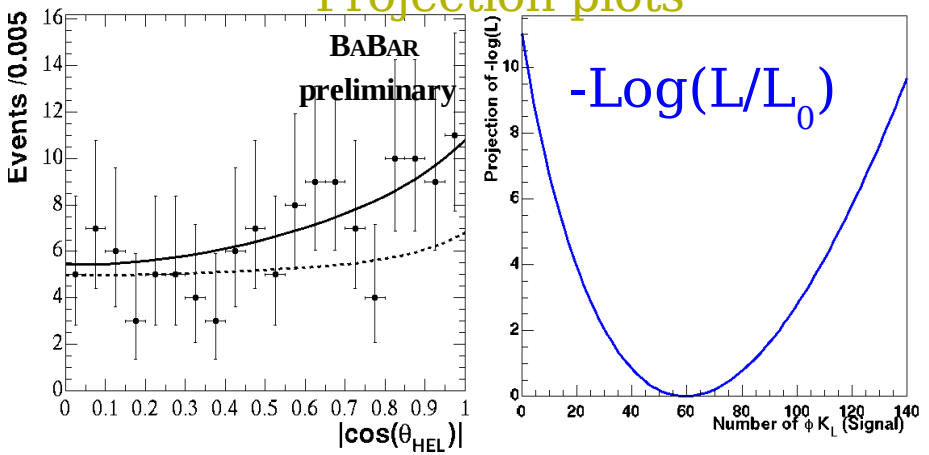
$N_{SIG} = 59.4 \pm 17.6$ (stat)

$N_{BKG} = 5295 \pm 75$ (stat)

$N_{B\,BKG} = 18$ (fixed)



Projection plots



CP:

$S = xxx \pm 1.04$

$C = xxx \pm 0.74$

$N(\sigma) = 4.7$

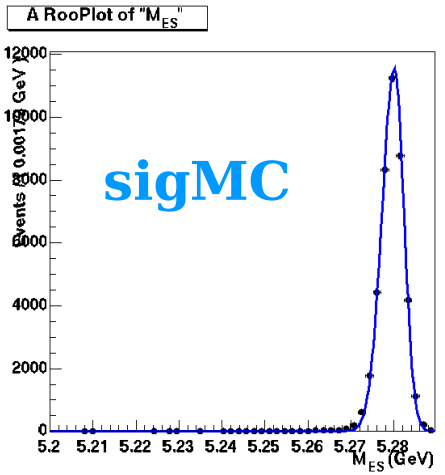
The uncertainties on CP parameters are consistent with expected ones.

$B^0 \to \phi(K^+K^-)K_S$: technique

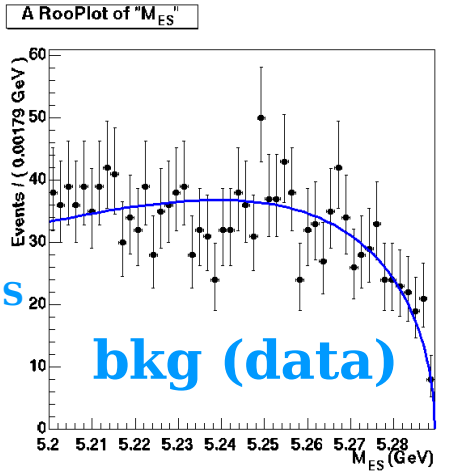
B^0 selection:

- $|\cos\theta_{SPH}| < 0.8$
- $|m(K_S)-m_{PDG}| < 11.2$ MeV/c^2
- $\tau / \sigma_\tau > 5$ (K_S lifetime significance)
- ϕ selection:
  - $0.970 < m(\phi) < 1.050$ GeV/c^2
  - PID: **Not a Pion** × **Loose**
- $5.2 < m_{ES} < 5.2895$ GeV/c^2
- $-0.1 < \Delta E < 0.2$ GeV
- $-3 < \text{Fisher} < 3$
- $|\cos\theta_{HEL}| < 1$
- $\Delta t < 20$ ps
- $\sigma_{\Delta t} < 2.5$ ps

The golden mode in the ϕK family!



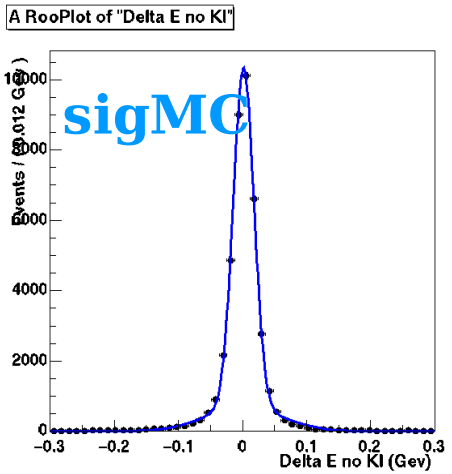
m_{ES}



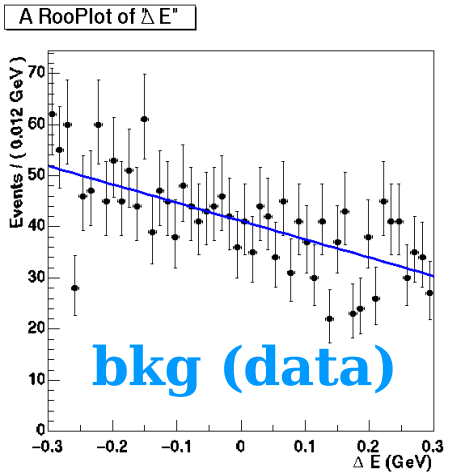
Unbinned ML fit

B^+B^- & B^0B^0 background:

- $B^0 \to \phi K^{*0(+)}$ removed with $\Delta E > -0.1$ GeV
- Two peaking modes:
  - $B^0 \to f^0 K_S$: 3 events
  - $B^0 \to a^0 K_S$: 2 events
- B bkg component in the likelihood



ΔE



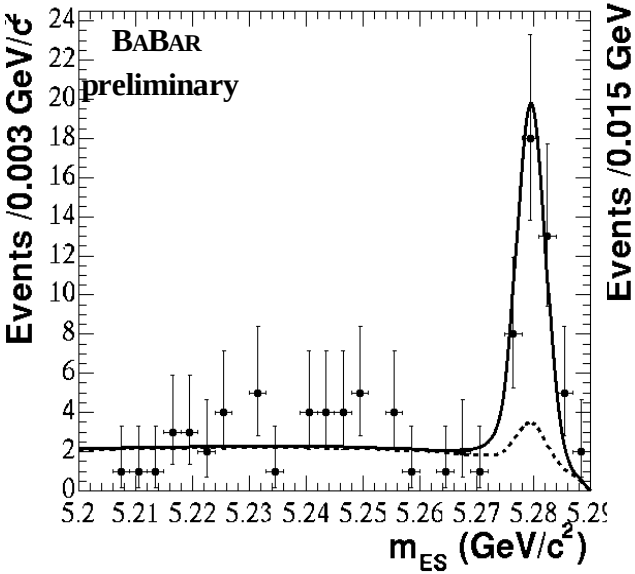
$B^0 \to \phi(K^+K^-)K_S$: (some) results

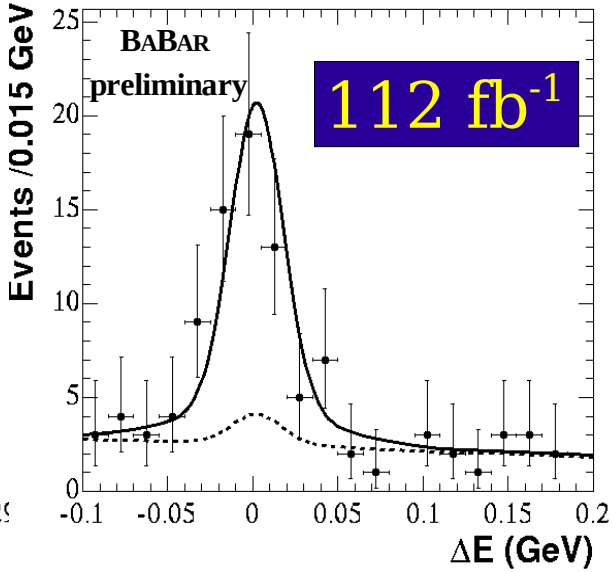
Yields:

$N_{SIG} = 61.6 \pm 9.3(stat)$

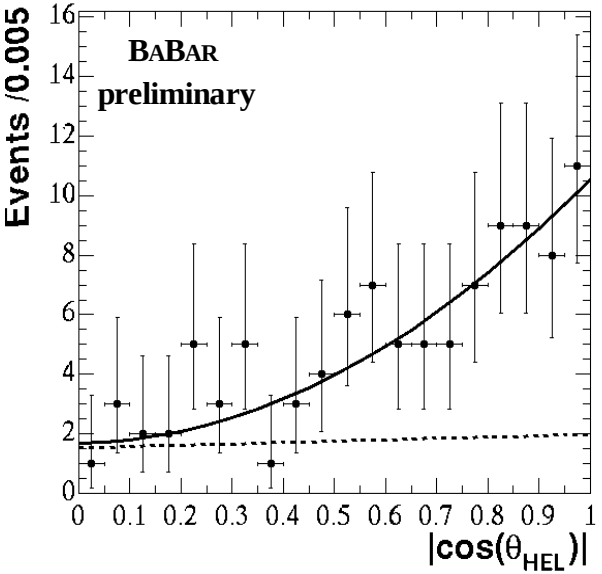
$N_{BKG} = 1127 \pm 34\ (stat)$

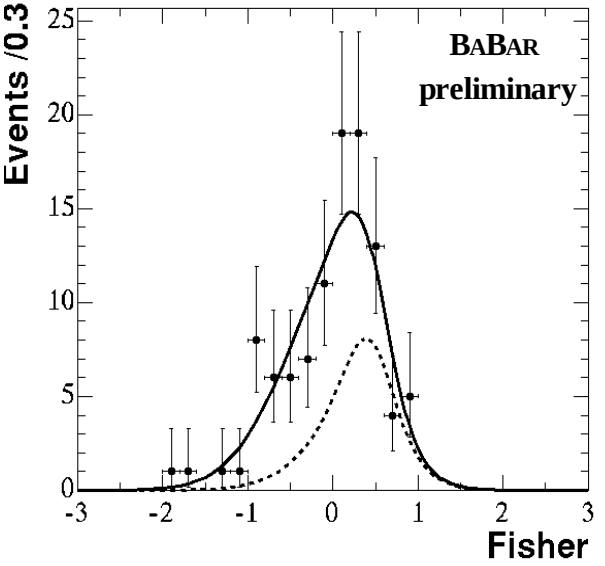
$N_{B\ BKG} = 5\ (fixed)$





Projection plots





~~CP~~:

$S = xxx \pm 0.43$

$C = xxx \pm 0.37$

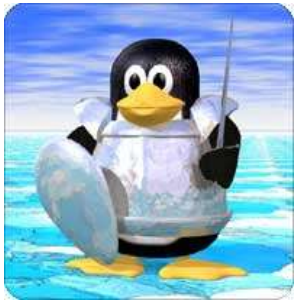
The uncertainties on CP parameters are consistent with expected ones.

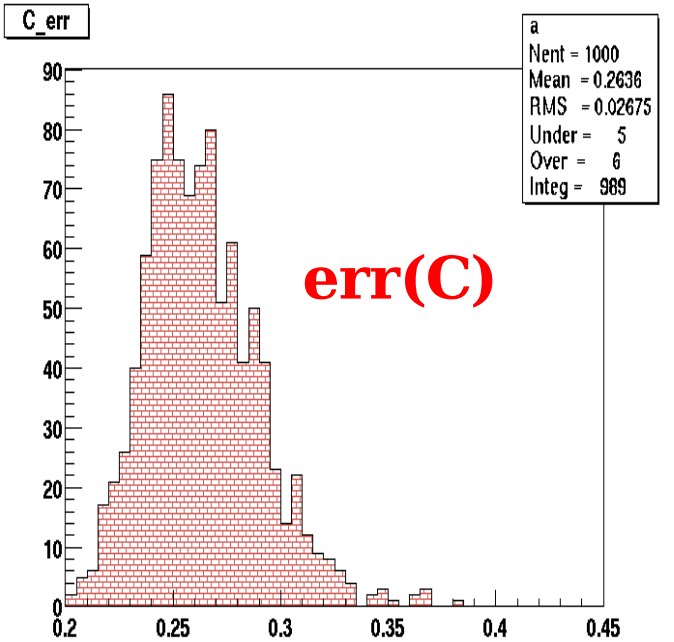
Combined CP fit

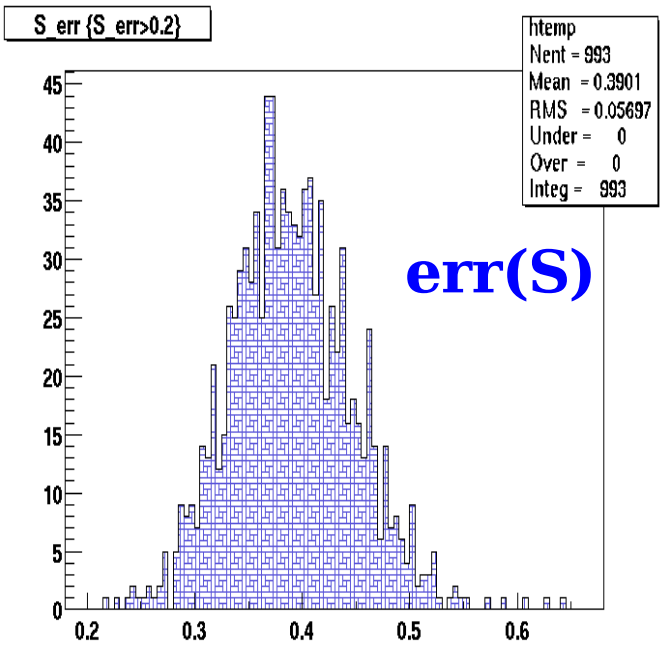
Merge all $B^0 \to \phi K^0$

- Simultaneous extraction of S and C for
  - ϕK_S $(\phi \to K^+K^-)$
  - ϕK_L $(\phi \to K^+K^-)$
  - ϕK_S $(\phi \to K_S K_L)$
- We fit:
  - **C = xxx ± 0.32**
  - **S = xxx ± 0.36**

Hic sunt leones?







Conclusions

2004/05/14 09.20

- $B^0 \to \phi K^0$ is the right place to test the SM
- Some prediction with more luminosity (180 fb^{-1}):
  - $\sigma(S) \sim 0.25$
  - $\sigma(C) \sim 0.20$
- Ready for Run4 dataset inclusion
- The new idea of Beam Spot Constrained Vertexing has made possible the inclusion of ϕK_S ($\phi \to K_S K_L$)
- ***Belle*** measured for ϕK_S: $\mathbf{S = -0.96 \pm 0.50^{+0.09}_{-0.11}}$