Simulation study of $B^0 \to \phi K_S$, $\eta' K_S$, $K^+K^-K_S$

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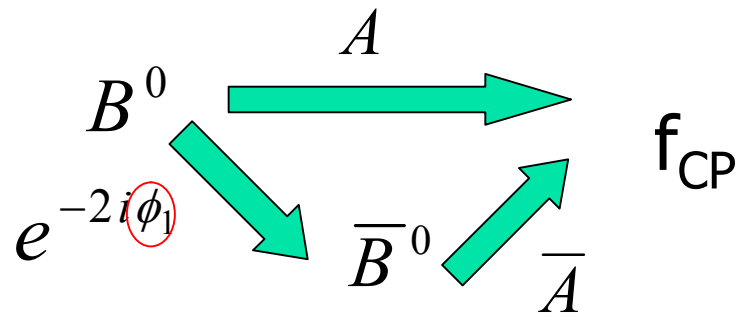
Super B Factory Workshop
in Hawaii

Time-dependent CP Violation in B^0 Decays

- Interference between the decay and the mixing causes time-dependent CP-violation:



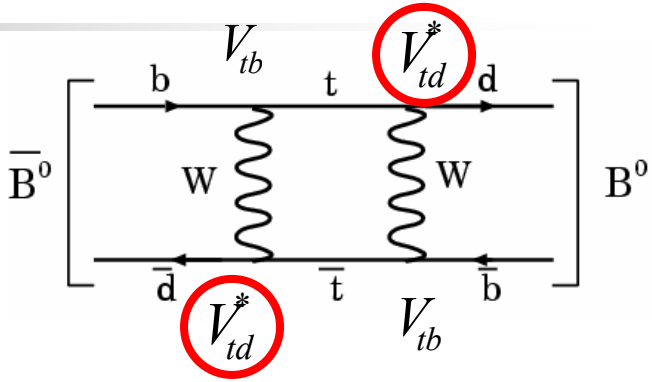


Diagram for B^0-$\overline{B}^0$ mixing including **CKM complex phase**.

$$\mathcal{P}(B^0(t) \to f_{CP}) = \frac{e^{-t/\tau_{B^0}}}{2\tau_{B^0}}(1 - \mathcal{S}\sin\Delta m_d t - \mathcal{A}\cos\Delta m_d t)$$

$$\mathcal{P}(\overline{B}^0(t) \to f_{CP}) = \frac{e^{-t/\tau_{B^0}}}{2\tau_{B^0}}(1 + \mathcal{S}\sin\Delta m_d t + \mathcal{A}\cos\Delta m_d t)$$

$$A_{cp}(t) = \frac{\mathcal{P}(\overline{B}^0(t) \to f_{CP}) - \mathcal{P}(B^0(t) \to f_{CP})}{\mathcal{P}(\overline{B}^0(t) \to f_{CP}) + \mathcal{P}(B^0(t) \to f_{CP})} = \mathcal{S}\sin\Delta m_d t + \mathcal{A}\cos\Delta m_d t$$

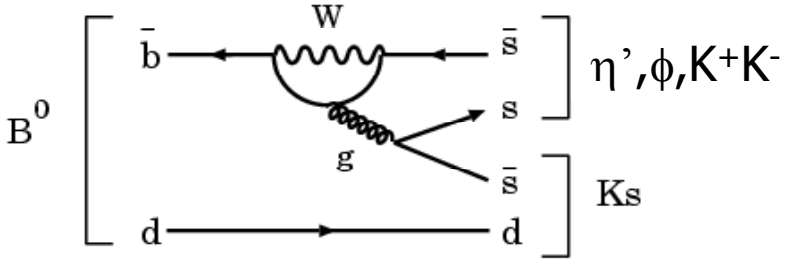
$$\lambda \equiv e^{-2i\phi_1}\frac{\overline{A}}{A}$$

$$\mathcal{A} \equiv \frac{|\lambda|^2 - 1}{|\lambda|^2 + 1}$$

$$\mathcal{S} \equiv \frac{2\,\mathrm{Im}\,\lambda}{|\lambda|^2 + 1}$$

CP Violation in b→sq̄q Decays and New Physics

Standard Model



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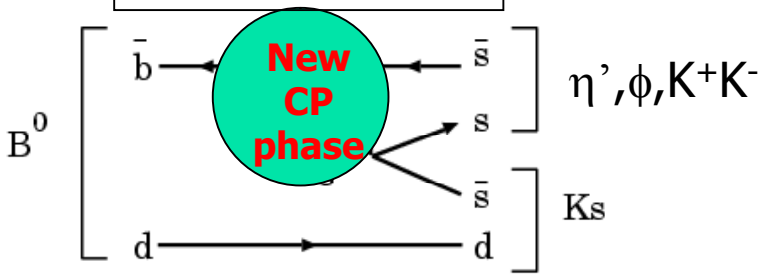
New Physics



$$\mathcal{S} \simeq= -\xi_f \sin 2\phi_1$$

$$\mathcal{A} \simeq= 0$$

ξ_f:CP eigenvalue

$$\sin 2\phi_1 = 0.736 \pm 0.049$$

(b→cc̄s LP2003 WA)

If either

$$\mathcal{S} \neq -\xi_f \sin 2\phi_1$$

or

$$\mathcal{A} \neq 0,$$

Evidence for new physics

New Physics Effect on $\mathcal{A}, \mathcal{S}$

$$A = |A_{SM}|e^{i\phi_{SM}}e^{i\delta_{SM}} + |A_{NP}|e^{i\phi_{NP}}e^{i\delta_{NP}}$$
$$\overline{A} = |A_{SM}|e^{-i\phi_{SM}}e^{i\delta_{SM}} + |A_{NP}|e^{-i\phi_{NP}}e^{i\delta_{NP}}$$

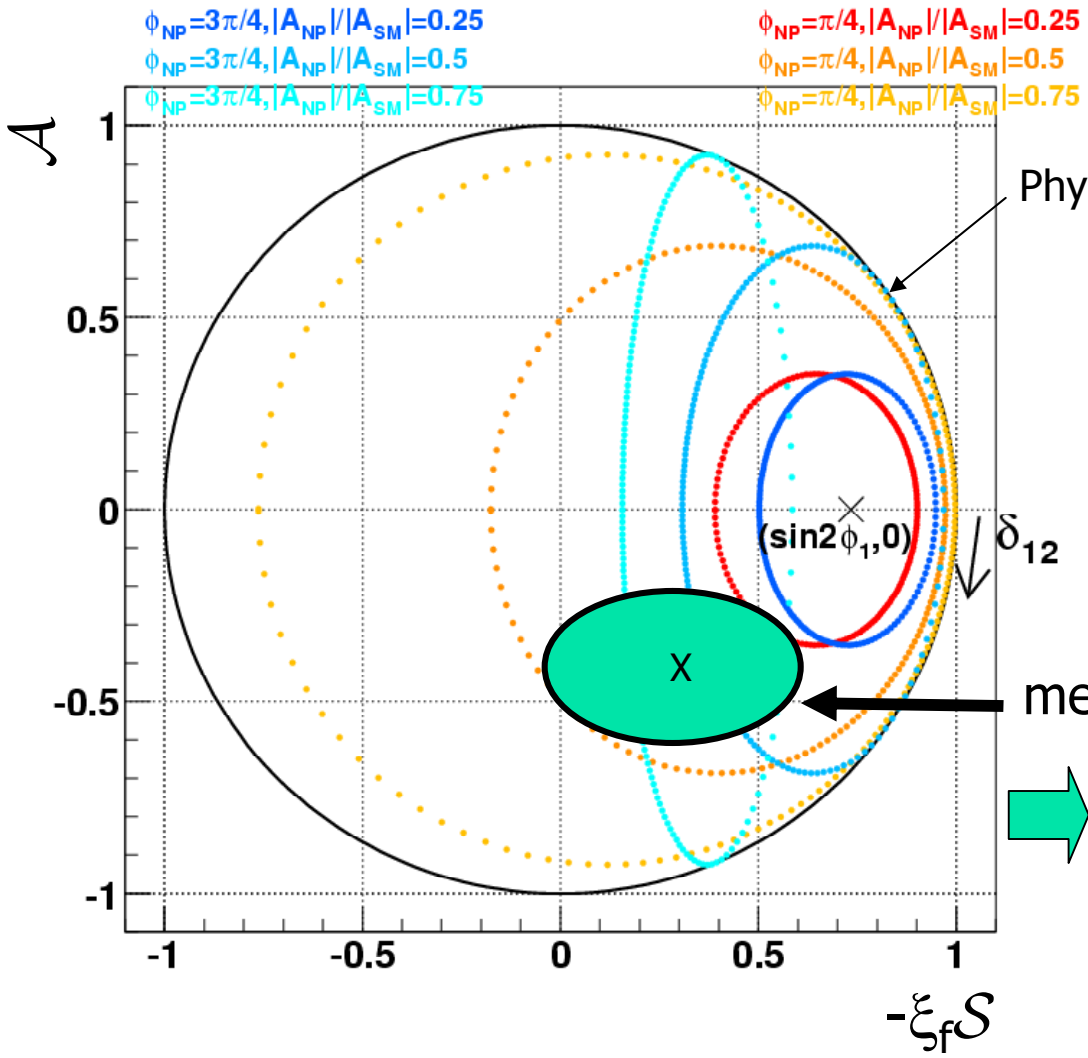
$\phi_{SM,NP}$: CP-violating phase (ϕ_{SM}=0 in b→$\bar{s}$qq)

$\delta_{SM,NP}$: CP-invariant strong phase

$$\mathcal{A} = -\frac{2\frac{|A_{NP}|}{|A_{SM}|}\sin\delta_{12}\sin\phi_{NP}}{1+2\frac{|A_{NP}|}{|A_{SM}|}\cos\delta_{12}\cos\phi_{NP}+\left(\frac{|A_{NP}|}{|A_{SM}|}\right)^2} \qquad (\delta_{12} \equiv \delta_{SM} - \delta_{NP})$$

$$\mathcal{S} = -\xi_f \frac{\sin 2\phi_1 + 2\frac{|A_{NP}|}{|A_{SM}|}\cos\delta_{12}\sin(\phi_{NP}+2\phi_1)+\left(\frac{|A_{NP}|}{|A_{SM}|}\right)^2\sin(2\phi_{NP}+2\phi_1)}{1+2\frac{|A_{NP}|}{|A_{SM}|}\cos\delta_{12}\cos\phi_{NP}+\left(\frac{|A_{NP}|}{|A_{SM}|}\right)^2}$$

$\mathcal{A}, \mathcal{S}$ measurement and constraint on new physics



Physical Boundary $\mathcal{A}^2 + \mathcal{S}^2 \leq 1$

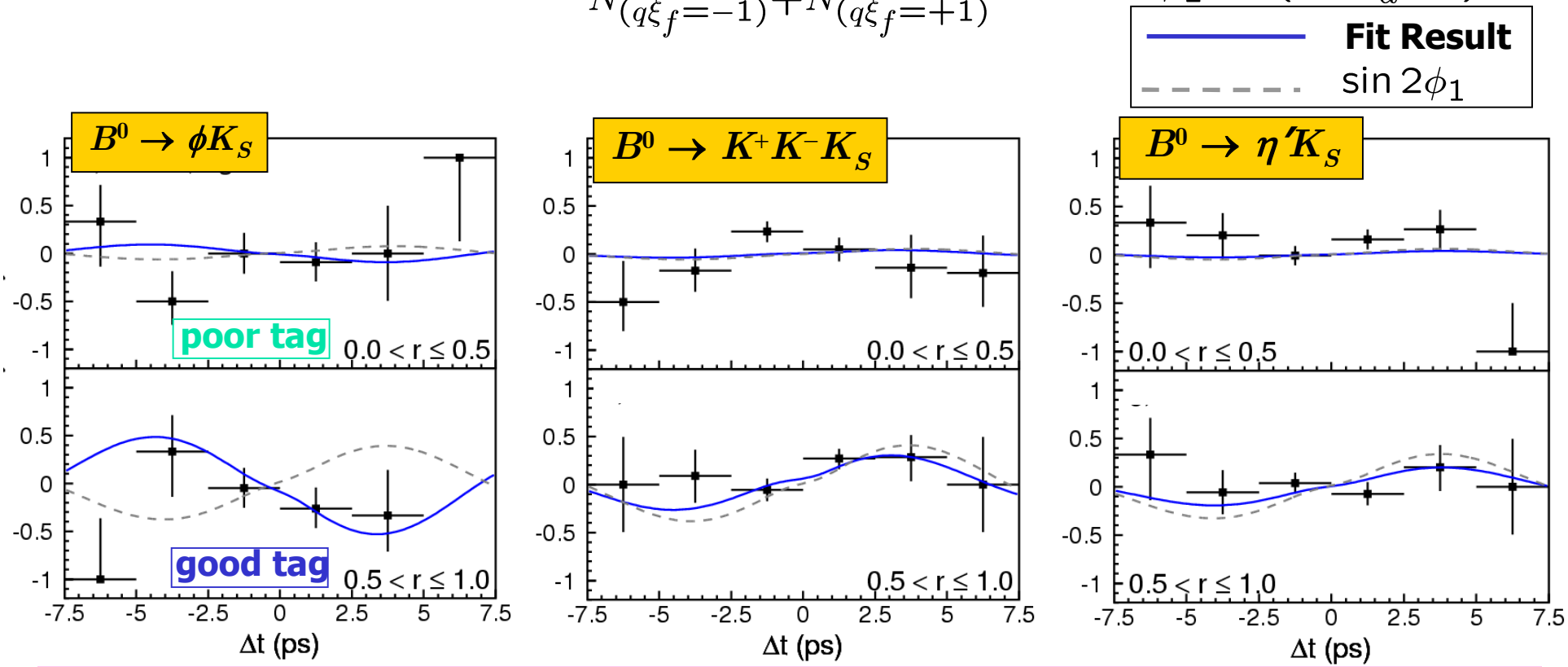
measurement of $\mathcal{A}, \mathcal{S}$ (an example)

Discovery of New physics,

constraint on $\phi_{NP}, \delta_{12}, |A_{NP}|/|A_{SM}|$

140fb-1 Belle Result

- Raw Asymmetry $\equiv \frac{N_{(q\xi_f=-1)} - N_{(q\xi_f=+1)}}{N_{(q\xi_f=-1)} + N_{(q\xi_f=+1)}} = \sin 2\phi_1 \sin(\Delta m_d \Delta t)$ (in the SM)



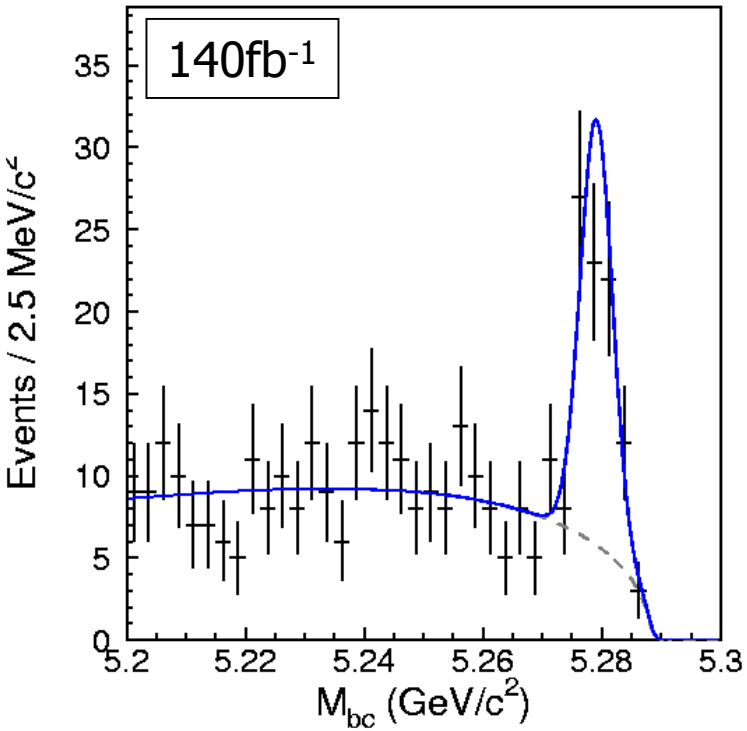
	$B^0 \to \phi K_S$	$B^0 \to K^+K^-K_S$	$B^0 \to \eta' K_S$
$-\xi_f \mathcal{S}$ (=sin2ϕ_1 in the SM)	$-0.96 \pm 0.50^{+0.09}_{-0.11}$	$+0.51 \pm 0.26 \pm 0.05^{+0.18}_{-0.00}$	$+0.43 \pm 0.27 \pm 0.05$
$\mathcal{A}$ (=0 in the SM)	$-0.15 \pm 0.29 \pm 0.07$	$-0.17 \pm 0.16 \pm 0.04$	$-0.01 \pm 0.16 \pm 0.04$

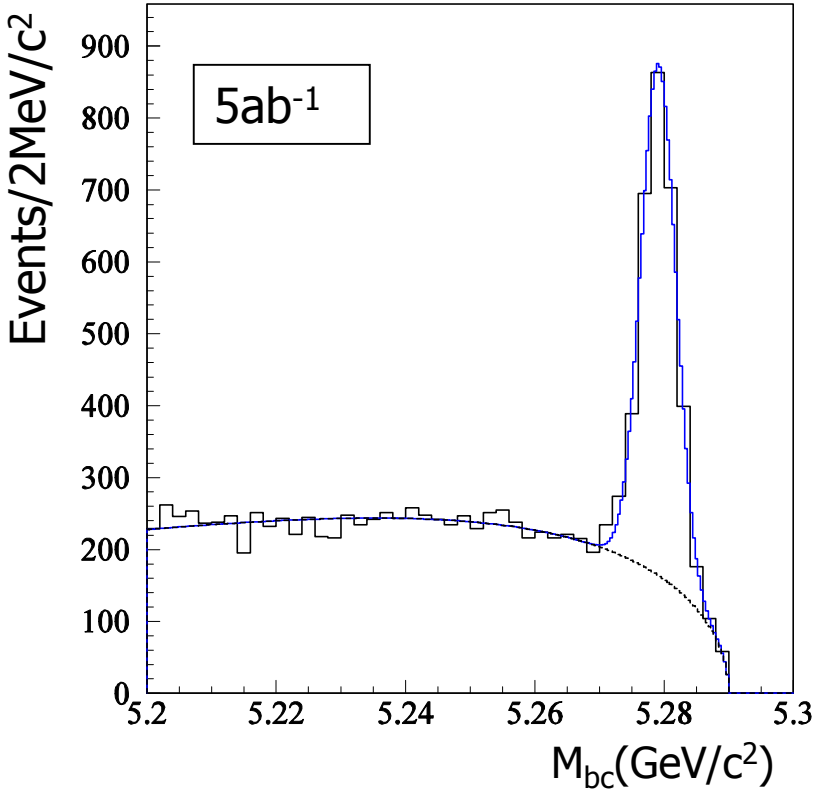
CPV Measurement at Super B

- MC pseudo-experiments
  - Parameters are obtained from 140fb^{-1} Belle data
    - S/N, ΔE and Mbc shape
    - Δt resolution ~1.4ps
    - background Δt shape
    - flavor tagging performance ε_{eff}=(28.7±0.5)%
  - 1000 pseudo experiments at 5ab^{-1}
    - ϕK_S, $\eta' KS$, $K^+K^-K_S$
    - $J/\psi K_S$ (standard model reference)
  - Input parameters: $\mathcal{A} = 0,$

    $-\xi_f \mathcal{S} = 0.736$ (Standard Model expectation)
  - Significance of $\Delta\mathcal{A}$ and $\Delta\mathcal{S}$ between b$\to$s and $J/\psi K_S$

$B^0 \to \phi K_S$





<u>140fb^{-1}</u>

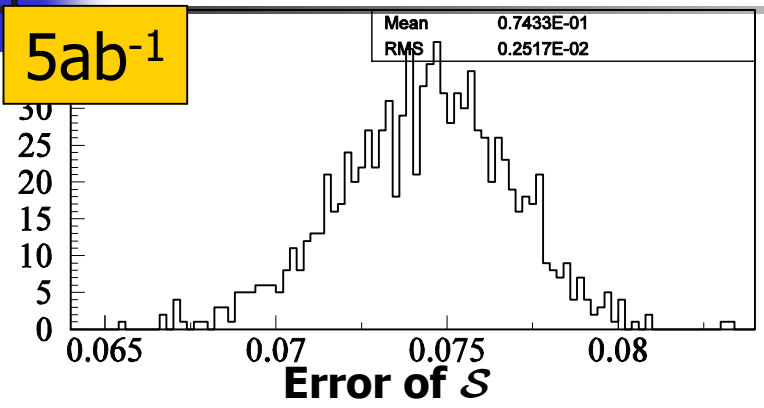
106 candidates
purity = 0.64±0.10

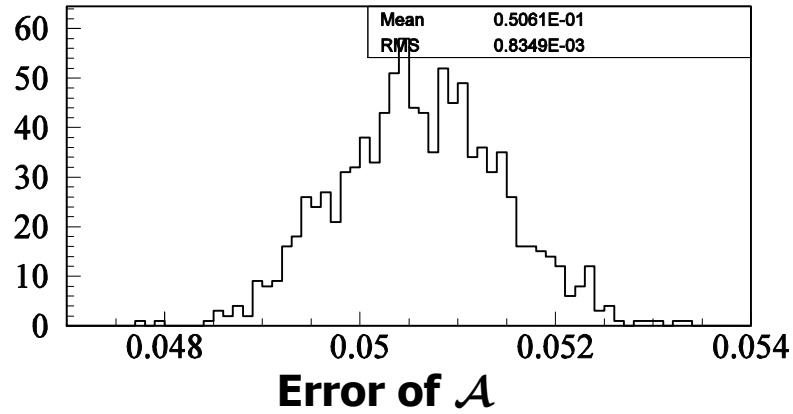
<u>5ab^{-1}</u>

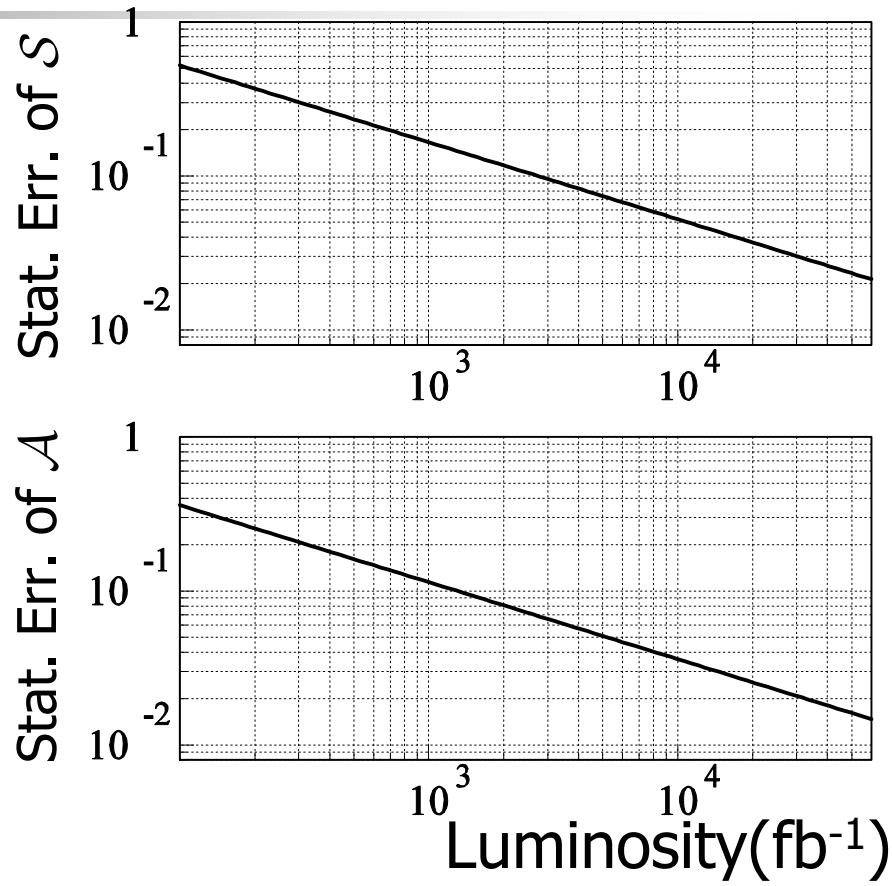
N_{sig} ~2400

Statistical Errors $\mathcal{A}_{\phi K_S}, \mathcal{S}_{\phi K_S}$

5ab^{-1}

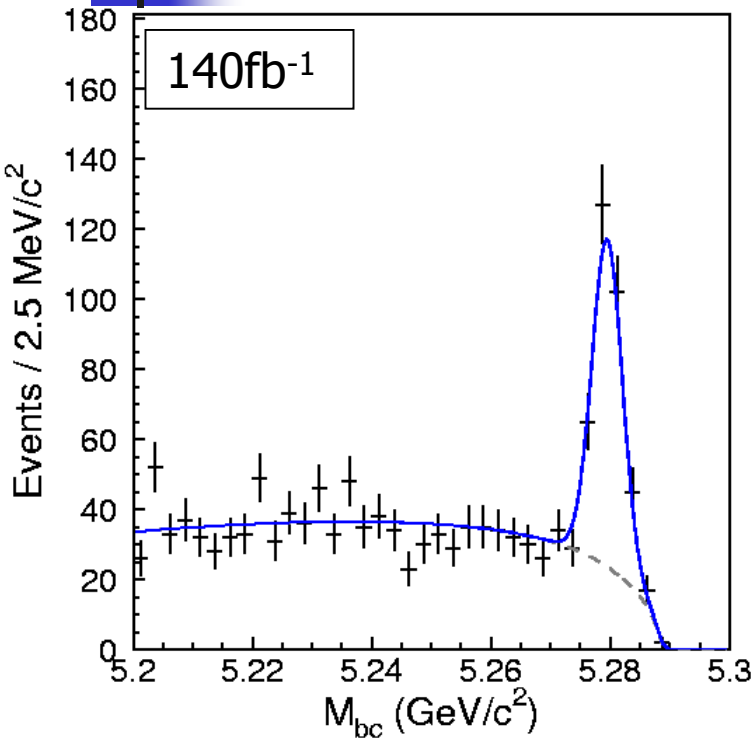


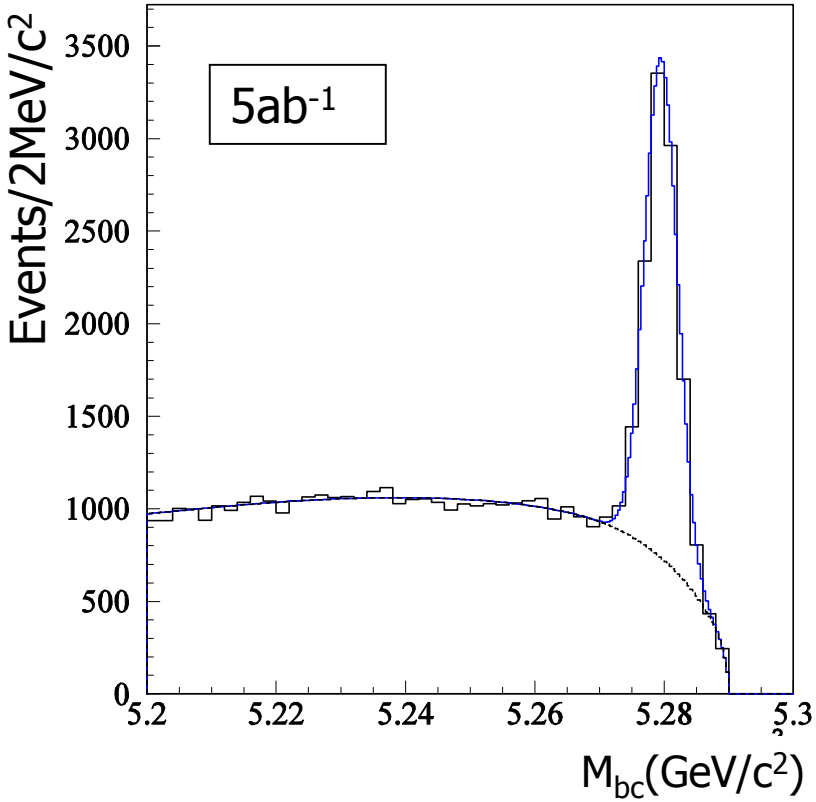




- Mean error 5ab^{-1}
  - $\mathcal{S}$ 0.074
  - $\mathcal{A}$ 0.051

$B^0 \to \eta' K_S$





<u>140fb^{-1}</u>

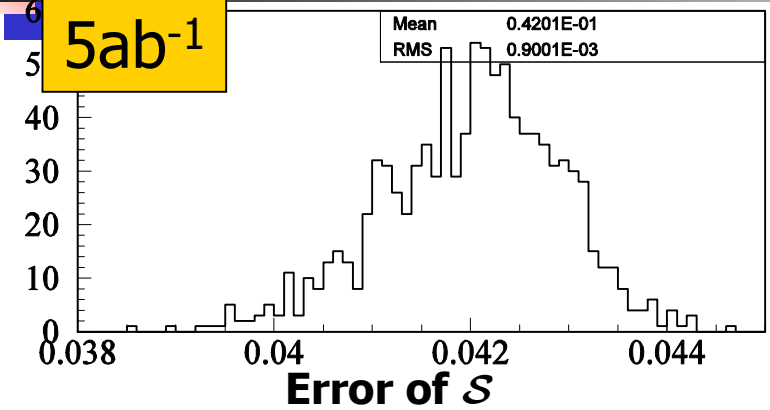
421 candidates
purity = 0.58±0.05

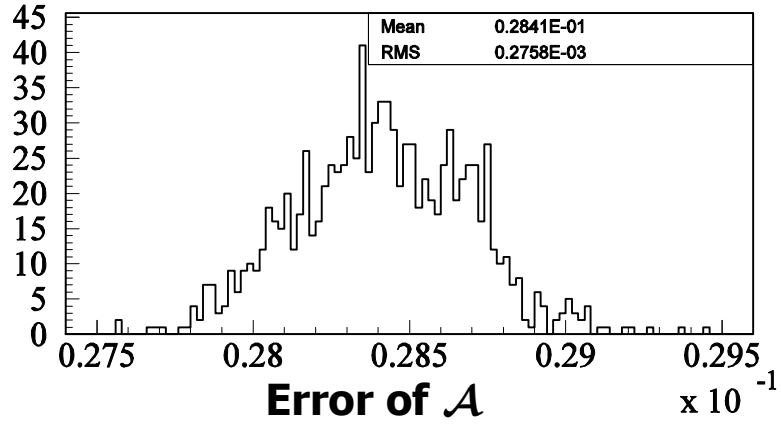
<u>5ab^{-1}</u>

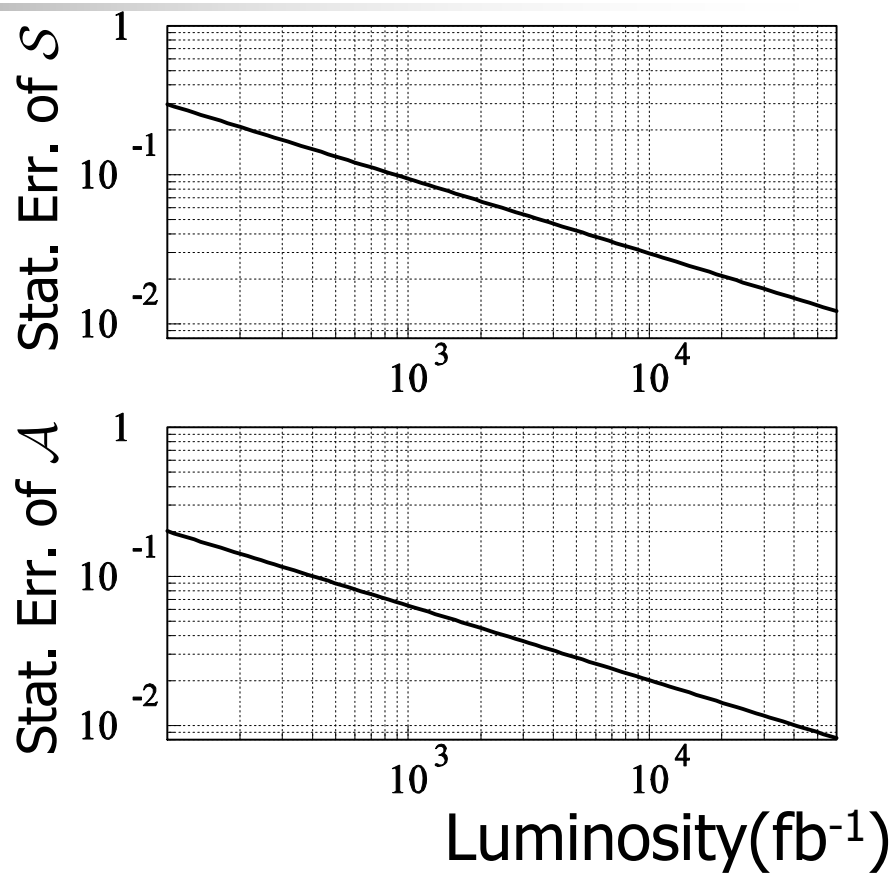
N_{sig} ~ 8700

Statistical Errors of $\mathcal{A}_{\eta' K_S}, \mathcal{S}_{\eta' K_S}$

5ab^{-1}

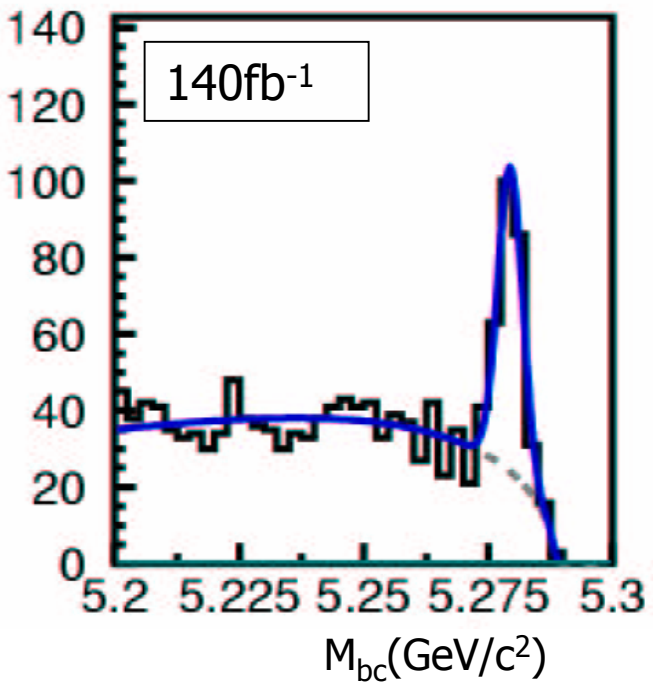


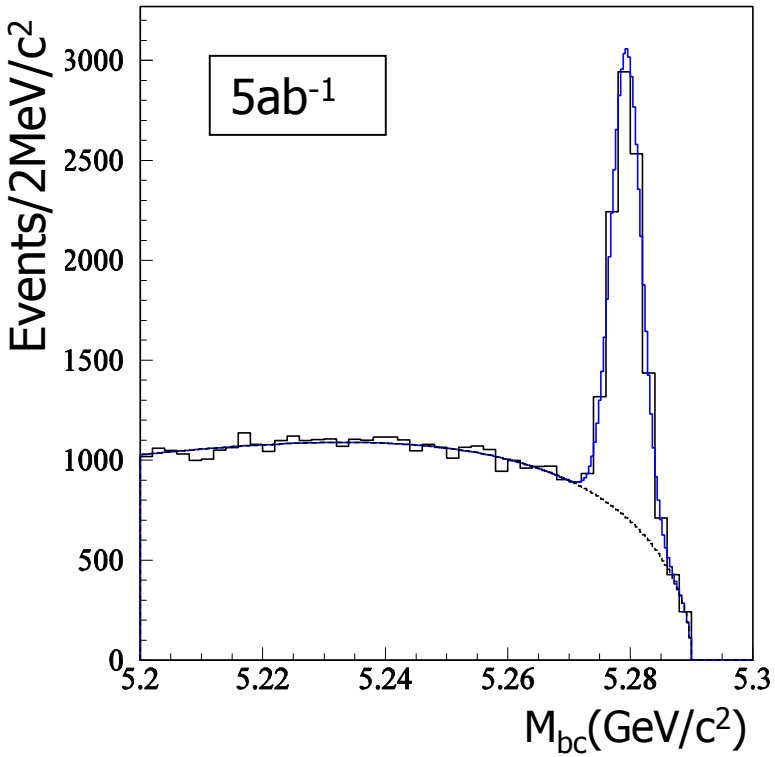




- Mean error 5ab^{-1}
  - $\mathcal{S}$ 0.042
  - $\mathcal{A}$ 0.028

$B^0 \to K^+K^-K_S$





<u>140fb^{-1}</u>

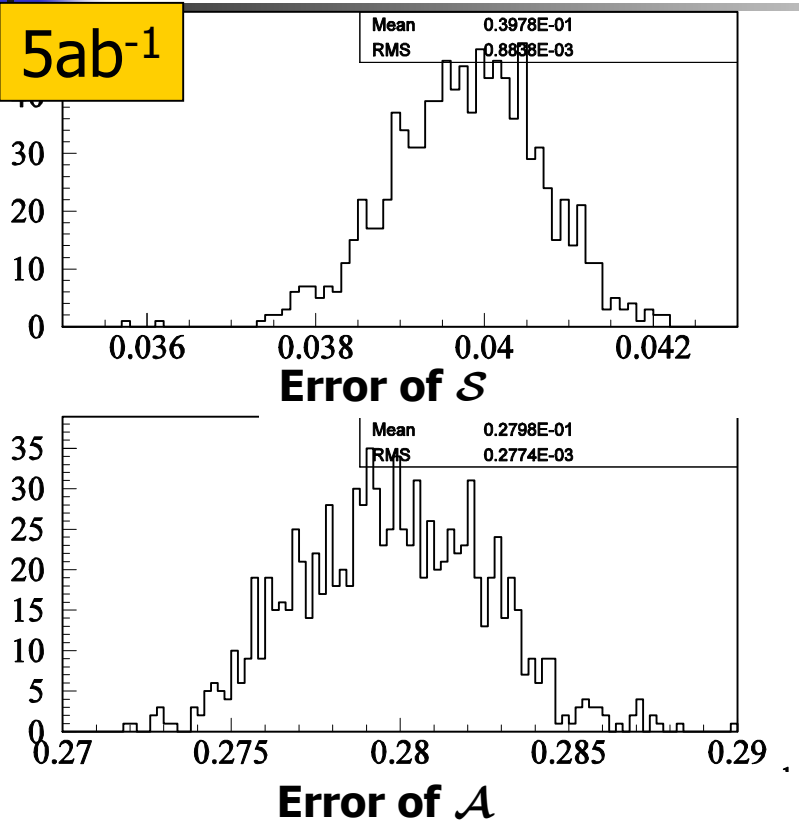
362 candidates
purity = 0.55±0.05
CP even=100^{+0}_{-15}%

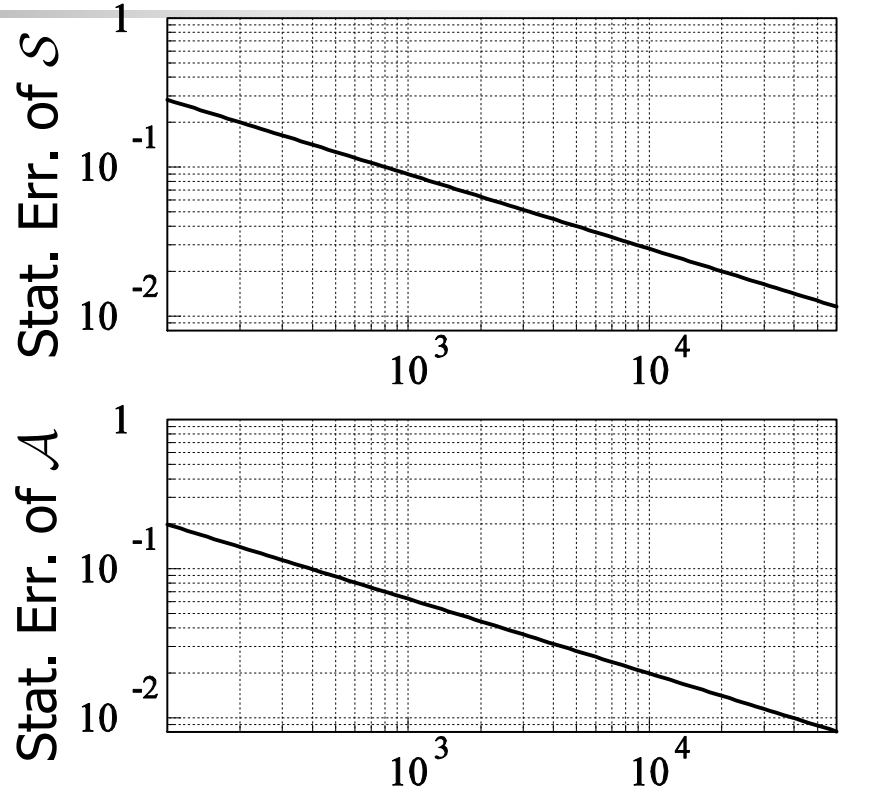
<u>5ab^{-1}</u>

N_{sig} ~7100

Statistical Errors of $\mathcal{A}_{KKK_S}, \mathcal{S}_{KKK_S}$

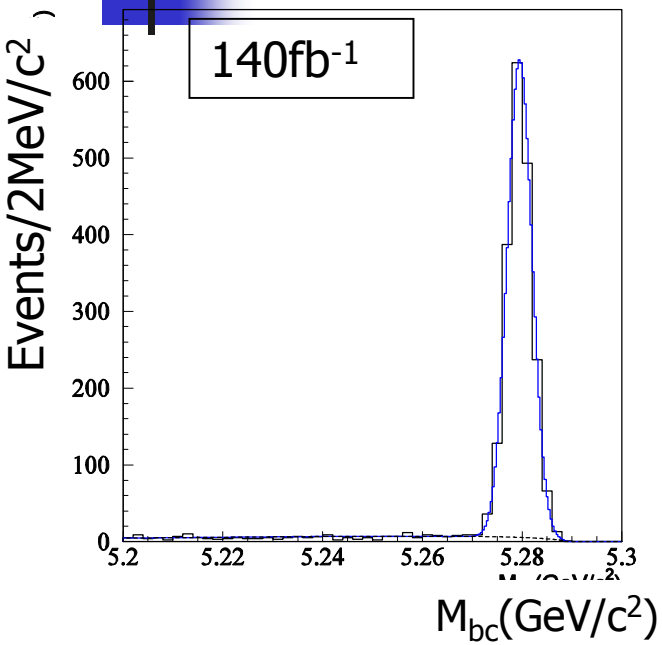
5ab^{-1}

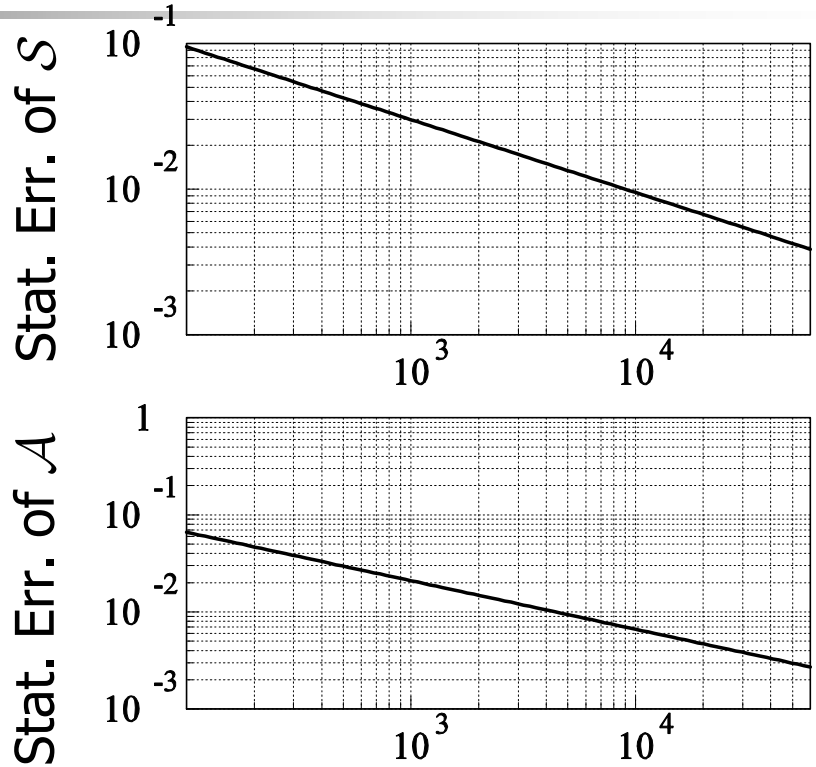




- Mean error 5ab^{-1}
  - $\mathcal{S}$ 0.040
  - $\mathcal{A}$ 0.028

Statistical Errors of $\mathcal{A}_{J/\psi K_S}, \mathcal{S}_{J/\psi K_S}$





- 140fb-1
- 1997 candidates
- purity = 0.976±0.001

5ab-1

N_{sig} ~70000

Mean error	5ab-1
$\mathcal{S}$	0.013
$\mathcal{A}$	0.009

Systematic Errors

- Systematic errors for 140fb-1

	ϕKs		η'Ks		KKK	
	S	**A**	**S**	**A**	**S**	**A**
Wtag fractions	±0.018	±0.007	±0.005	±0.006	±0.005	±0.007
Physics parameters	±0.033	±0.002	±0.006	±0.002	±0.003	±0.003
Vertexing	±0.022	±0.046	±0.016	±0.027	±0.044	±0.024
Background fraction	±0.053	±0.035	±0.045	±0.026	±0.029	±0.036
Background Dt	±0.015	±0.008	±0.003	±0.003	±0.010	±0.006
Resolution function	±0.013	±0.005	±0.004	±0.003	±0.007	±0.004
Boundary bias	+0.06					
KKKs + f_0Ks bkg.	+0.001 -0.084	±0.039				
Sum	**+0.09 -0.11**	**±0.07**	**±0.05**	**±0.04**	**±0.05**	**±0.04**

- How much can we reduce them with high luminosity?
  - Estimate the limit from J/ψK_S systematic errors

Systematic Error limit

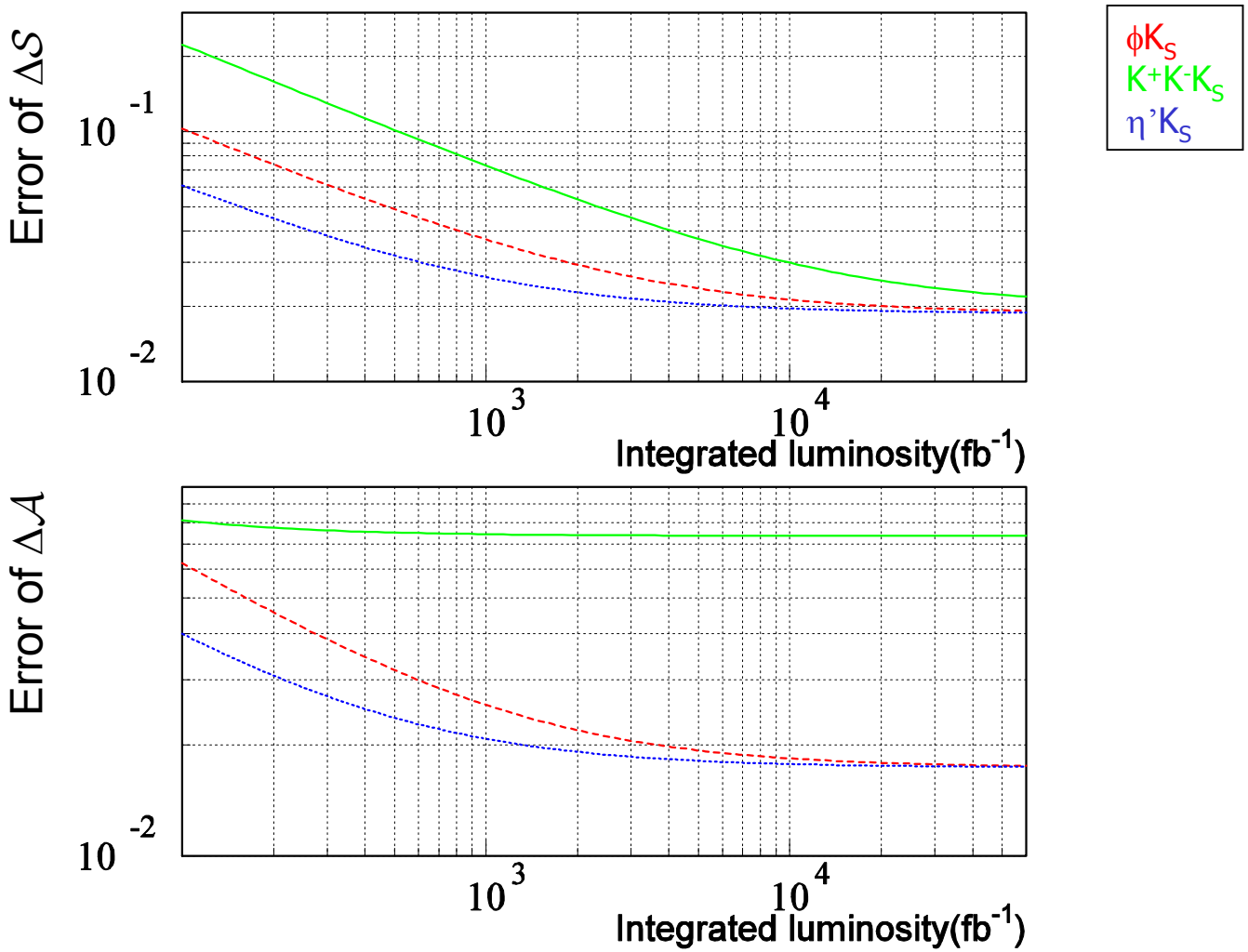
- Estimate irreducible systematic errors with more luminosity from current $J/\psi K_S$

	S	A	
Wtag fractions	0.006	0.006	
Physics parameters	0.002	0.001	
Vertexing	0.012	0.026	
Background fraction	0.006	0.012	
Background Dt	0.001	0.000	**(Preliminary)**
Resolution function	0.008	0.008	
Resolution parameterization	0.007	0.003	
Tag-side interference	0.001	0.027	
Possible fit bias	0.008	0.006	(MC statistics)
Sum	**0.020**	**0.041**	
reducible	0.014	0.017	
Irreducible	0.014	0.038	

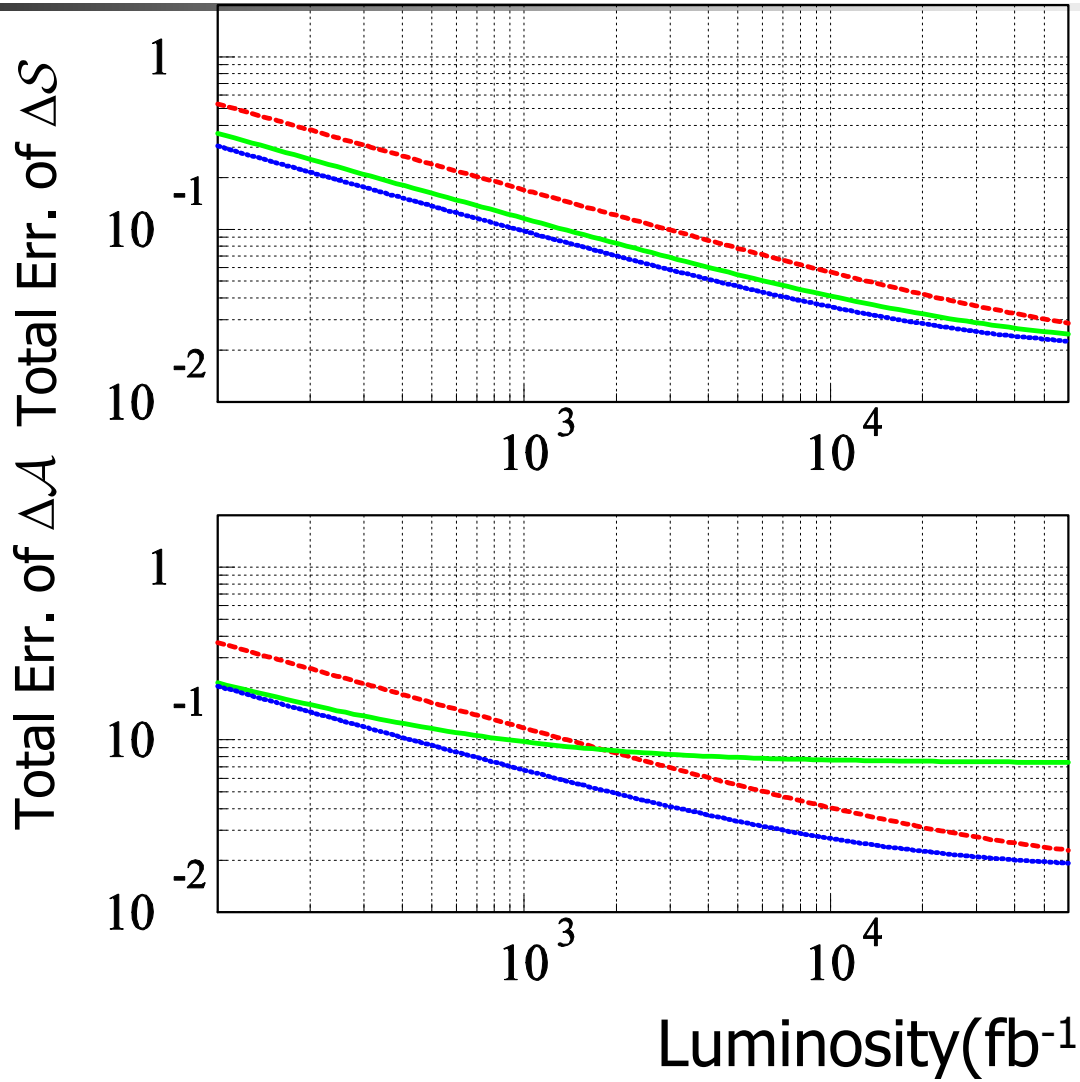
Other systematic sources

- $K^+K^-K_S$ and f^0K_S background in ϕK_S
  - The error can be reducible by including it in the fit.
  - Need K^+K^- mass distribution.
- Boundary bias of $\mathcal{S}_{\phi Ks}$
  - It will be negligible with more data.
- CP even fraction in $K^+K^-K_S$
  - Assumed to be reducible.
  - Amplitude analysis of the Dalitz plot will be done with the high luminosity.
- Some sources cancel by taking difference from $\mathcal{A}/\mathcal{S}$ of $J/\psi K_S$
  - Tag-side interference
  - Tracking charge asymmetry (a part of the vertexing error)
  - As for $K^+K^-K_S$, due to the opposite CP, they do not cancels
    $\rightarrow$Very large errors, need more study.

Systematic Error of $\Delta\mathcal{A}$ and $\Delta\mathcal{S}$

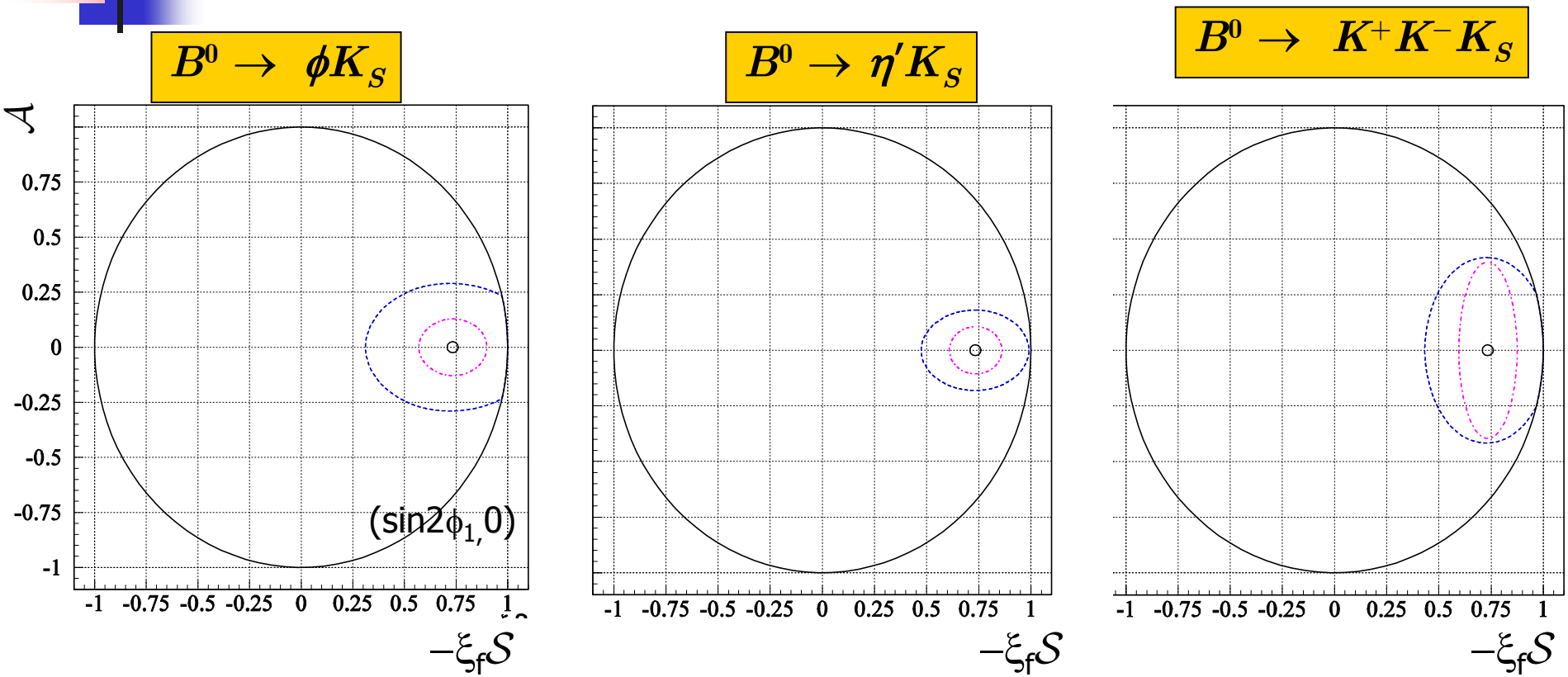


Total Errors

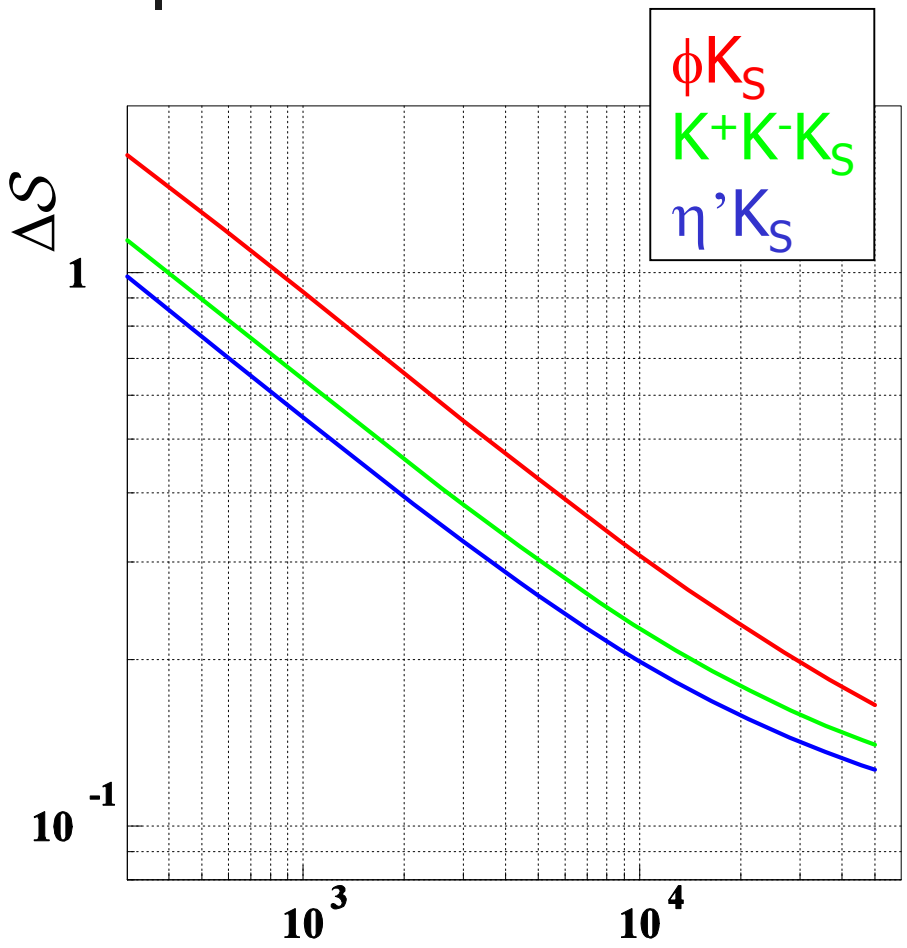


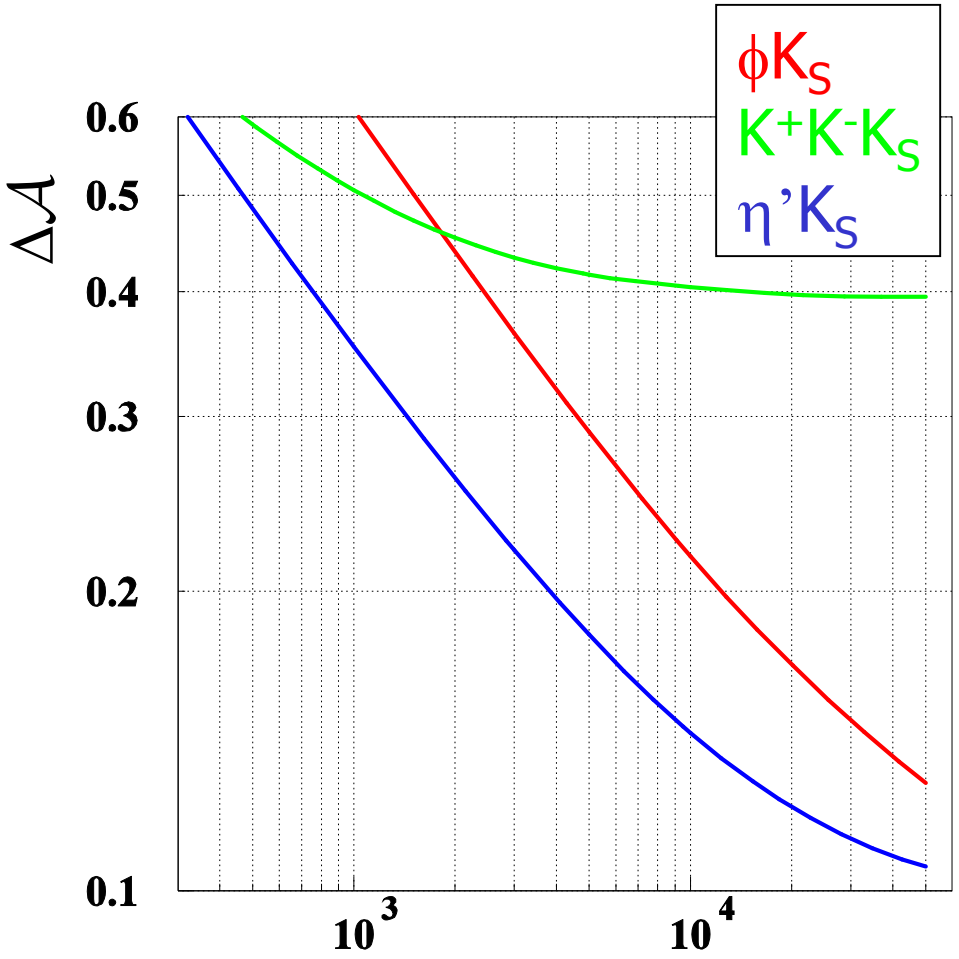
ϕK_S
$K^+K^-K_S$
$\eta' K_S$
$\sin 2\phi_1$($c\bar{c}$ K^0)

Expected 5σ Confidence regions

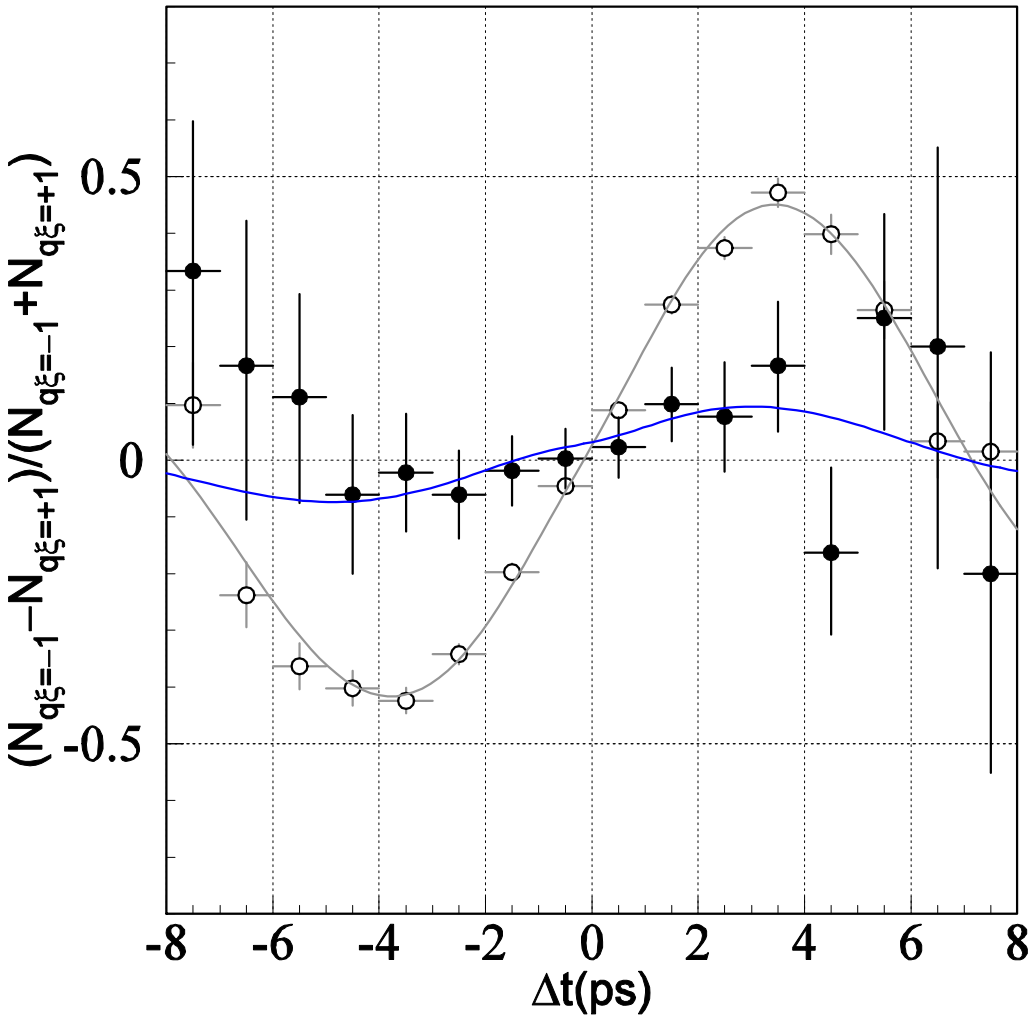


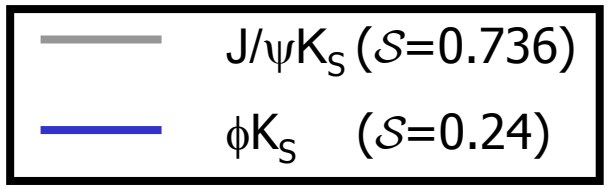
5σ Discovery Regions





5ab^{-1} example





Summary

- CPV parameter $\mathcal{A}$,$\mathcal{S}$ measurement in b→s$\bar{q}$q at Super B factory
  - Large discovery potential for new physics
  - Useful to determine new physics parameter
- 5σ observation regions
  - 5ab^{-1}

	ϕK_S	$\eta' K_S$
$\Delta\mathcal{S}$	>0.42	>0.26
$\Delta\mathcal{A}$	>0.29	>0.18

  - 50ab^{-1}

	ϕK_S	$\eta' K_S$
$\Delta\mathcal{S}$	>0.17	>0.13
$\Delta\mathcal{A}$	>0.13	>0.11

- KKK_S mode suffers from large error due to tag-side interference. → study more. It may be reducible using semileptonic decays and ϕ_3 measurements.
- Other modes under study
  - B→$\phi\phi$K, $\pi^0 K_S$....