Search for Axion-Like Particle through $B \to K^{(*)} a' \ (\to \gamma\gamma)$ Decay at Belle

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Feb 22nd, 2025

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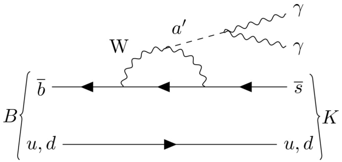
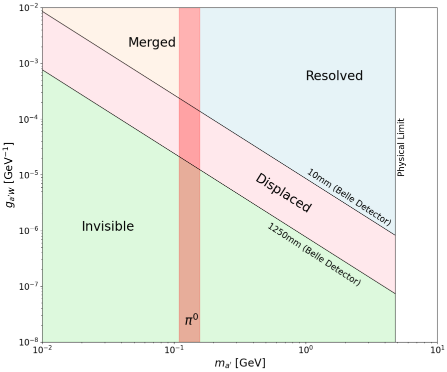
Introduction: $B \to K^{(*)} a' (a' \to \gamma\gamma)$

- Searching for Axion-Like-Particles (ALPs or a')
- ALP (a') :
  - Spin-0 pseudoscarlar particle (pNGB)
  - promptly decays into $\gamma\gamma$ 100%
  - The lifetime is concerned as signal efficeincy constraint: $\Gamma_{a'} = g^2_{a'W} M^3_{a'} \sin^4\theta_W / 64\pi$
- Without significant excess above background, we set the upper on $ALP - W$ coupling ($g_{a'W}$) [1].



[Figure 1]

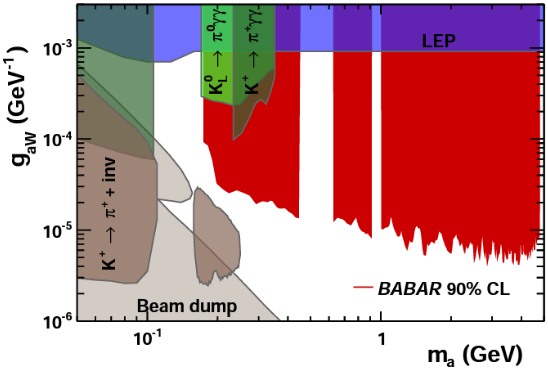


- Mass Scanning : $0.160 \sim 4.50(4.20)\mathrm{GeV/c^2}$
- Mass region is decided by our detector limits and physical limits.
- π^0, η, η' mass region is excluded

[1] Phys. Rev. Lett. 118, 111802 (2017)

Introduction: Advantage over previous studies

- Previous result from $BaBar$, $B^+ \to K^+ a'(a' \to \gamma\gamma)$ with $424\mathrm{fb}^{-1}$ [1] .
- Belle I Full Dataset $(711 fb^{-1})$ is used for analysis
- $B \to K^{(*)} a'(a' \to \gamma\gamma)$
- Four K modes : K_S^0, K^+, K^{*0}, and K^{*+}
- Expand the exclusion region with more total integrated luminocity and combining multiple kaon modes.

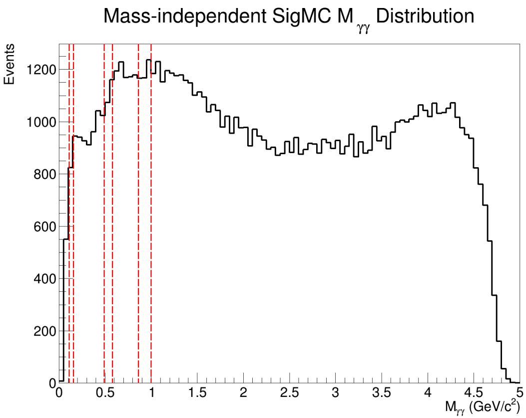


[1] Phys.Rev.Lett. 128, 131802 (2022)

Data Sample: Signal MC

- Generated with EvtGen + gsim
- tested ALP mass hypothesis :
  0.160,[0.200..1.000..0.050],[1.0..4.7..0.1]

Process	Gen. Cond.
Signal $B \to K a'$	PHOTOS PHSP
Signal $B \to K^* a'$	PHOTOS SVS
$a' \to \gamma\gamma$	PHSP
Other B	Free Decay
K	Free Decay

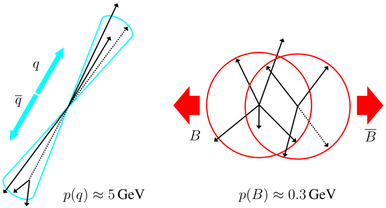


- Mass Independent Signal MC :
  used for FBDT training and optimization.
- include $M_{a'}$ genereated uniformly from 10-4780 MeV with 10 MeV interval.

Data Sample: Background MC

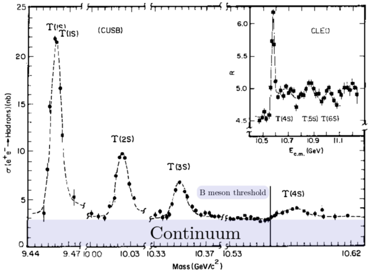
- Every event passes our signal selection criteria
- Any process appears in our signal region.
  - $B\overline{B}$ background
  - $q\overline{q}$ continuum background
  - Peaking Background
  - Combinatorial Background

Tested Bkg Process	MC Streams
$B\overline{B}$	10
$e^+e^- \rightarrow q\overline{q}\,(q = u, d, s, c)$	6
Rare $B\overline{B}$	50
$B \rightarrow X_u l\nu$	20



$p(q) \approx 5\,\mathrm{GeV}$ $p(B) \approx 0.3\,\mathrm{GeV}$

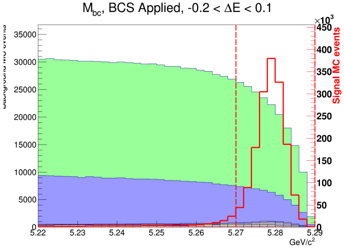
$e^+e^- \rightarrow q\overline{q}\ (q \in \{u, d, s, c\})$ $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\overline{B}$

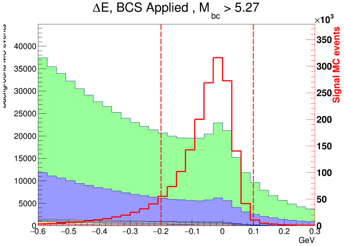


- A ‘stream’ refers to the data amount of $711\mathrm{fb}^{-1}$ data accumulated in $\Upsilon(4S)$ resonance in the Belle experiment.
- A generic background stream 00 is used for FBDT.

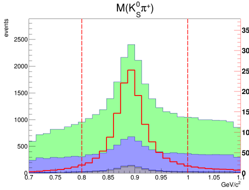
Event Selection and Reconstruction

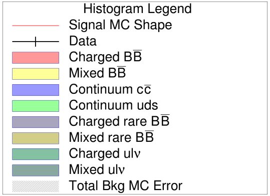
Partilce List	Selection Criteria
Charged track	$\lvert d0 \rvert < 3.0$ cm
	$\lvert z0 \rvert < 4.0$ cm
	eIDBelle < 0.9
	muIDBelle < 0.9 or muIDBelleQuality $= 0$
K^+	$\mathscr{L}(K\pi) > 0.6$ & $\mathscr{L}(Kp) > 0.4$
π^+	$\mathscr{L}(\pi K) > 0.4$ & $\mathscr{L}(\pi p) > 0.7$
γ	$E > 50$ MeV; barrel
	$E > 100$ MeV; forward endcap
	$E > 150$ MeV; backward endcap
K_S^0	ksnbStandard = 1 (nisKs)
	$p > 0.06$ GeV/c
	$\lvert \Delta M \rvert < 20$ MeV/c^2
K^*	$0.8 < M(K\pi) < 1.0$ GeV
	$K^{*0} \to K^{\pm}\pi^{\mp}$
	$K^{*+} \to K_S^0\pi^+$
ALP	π^0, η, η' mass region excluded
B	$M_{bc} > 5.27$ GeV
	$-0.2 < \Delta E < 0.1$ GeV
	Best Candidate Selection min(ΔE)
	Kinematic fit to B meson mass





- K_S^0 reconstructed with charged pion modes.
- π^0 not used in K^* reconstruction.
- The dominant source of background is continuum.

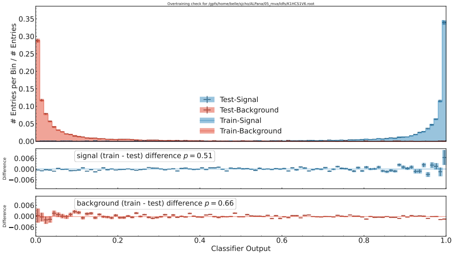


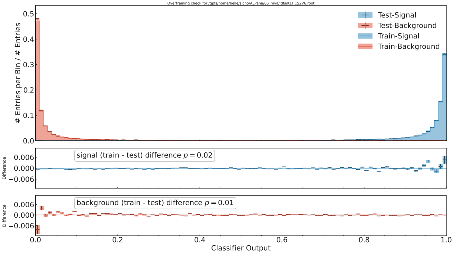


Continuum Suppression

- 2 Fast-BDT (FBDT) for Continuum Suppression
- Generate mass-independent Signal MC (0.01~4.78 GeV, 10 MeV interval).
- Background MC data from CHM/UDS (0th stream)
- CS2 FBDT trained with data pass CS1 loose cut (0.1)

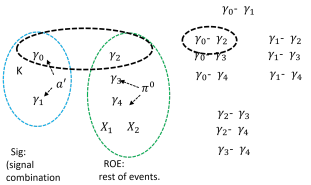
CS1 Variables	CS2 Additional Variables
thrustOm	aplanarity
cosTBz	sphericity
cosTBTO	cosHelicityAngle Beam momentum (K)
R2	CleoCone Thrust
KSFW(6)	Hemisphere Momentum
	FoxWolfram moment and ratio
	cosHelicityAngle (gamma)
	number on ALP candidates
	harmonic Moment Thrust
	$\Delta\theta(a')$
	$Easy$





γ_{π^0} Suppression

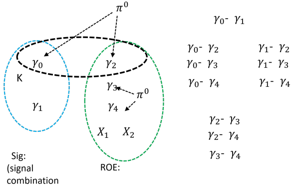
Signal



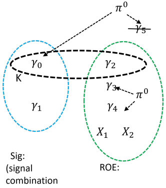
- γ_{π^0} suppression consist of 3 classes of subclassifiers :

Classifier	Training sample for "good" pair	Training sample for "bad" pair
class A	Photon pairs, $(\gamma^{SIG},\gamma^{ROE})$, in Sig MC	Photon pairs from a single π^0 in Bkg MC
class B	Photon pairs, $(\gamma^{SIG},\gamma^{ROE})$, in Sig MC	Photon pairs from a single π^0 in Bkg MC but the photon in ROE is not reconstructed.
class C	Photon pairs from different π^0 or other source of photons in Bkg MC.	Photon pairs form a single particle in Bkg MC

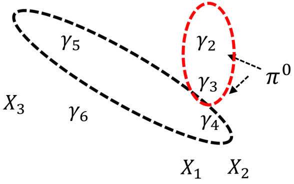
Class A



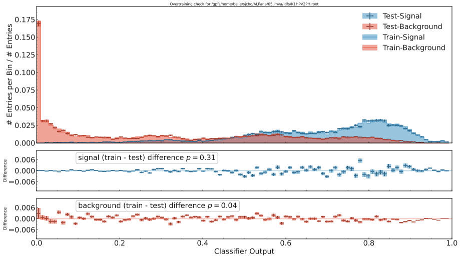
Class B



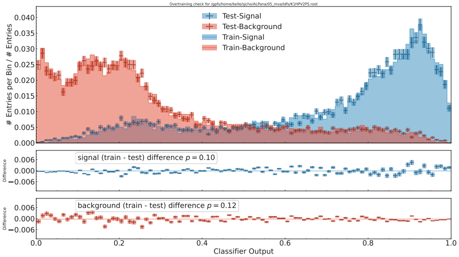
Class C



γ_{π^0} Suppression



Hard Photon π^0 probability (High mass region)

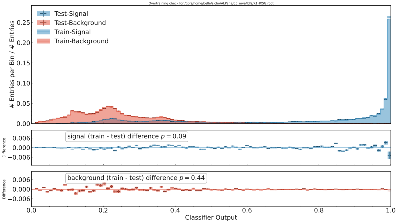


Soft Photon π^0 probability (High mass region)

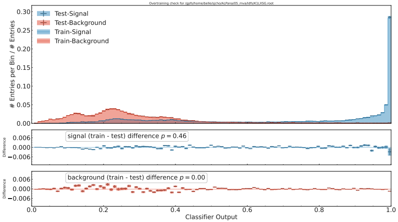
- Trained with FastBDT, mass-independent Signal MC and background MC (stream 00)
- Training for Hard photon (γ_0) and Soft photon (γ_1), ($E_{\gamma_0} > E_{\gamma_1}$) is performed seperately.
- Among the ($\gamma^{SIG}, \gamma^{ROE}$) photon pairs, the pair with lowest subclassifier output value (most π^0-like) is selected for each subclassifiers.
- Phton pair of ($\gamma^{SIG}, \gamma^{ROE}$) is handled seperately when ($E_{\gamma SIG} > E_{\gamma ROE}$) and ($E_{\gamma SIG} < E_{\gamma ROE}$).
- subclassifier output is combined with FastBDT.
- Each subclassifiers and π^0 veto classifiers are trained for signal hard photon and signal soft photon seprately in high/low ALP mass region.

Photon	Photon Pair
E^*	E^*
E9E25	p_t
ErrorPhi	deltaAngle
HighestE	E^*_{asy}
LAT	$M_{\gamma\gamma}$
NHits	

$B \to X_s \gamma$ Veto



High $M_{a'}$

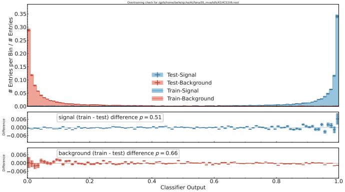


Low $M_{a'}$

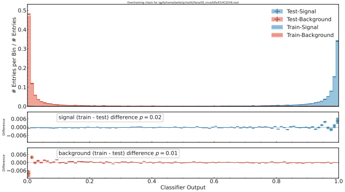
Photon	photon pair
E^*	E^*
E9E25	nALP
HighestE	E^*_{asy}
	deltaAngle
	cosHelicityAngle(a')
	cosHelecityAngleBeamMomentum(K)

- $B \to X_s \gamma$ decay can mimic $B \to K a'$ final state
- X_s : Hadron system involving kaon
- Neutral (or excited state kaon) mesons, their final state particle contains at least one γ with high probability which can be reconstructed to fake ALP with γ from B directly.
- training dataset : [mass-indep $B \to K a'$ vs $B \to X_s \gamma$]
- No Optimization (Not for global background suppression)

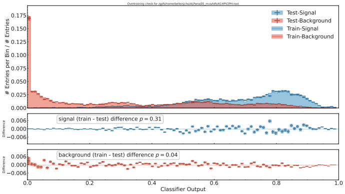
Optimization



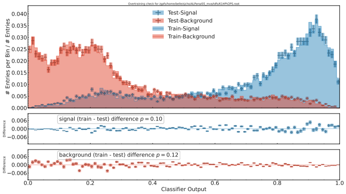
(a) CS1



(b) CS2



(c) $P_{\pi^0}(\gamma_0)$



(d) $P_{\pi^0}(\gamma_1)$

- CS1/CS2/$P_{\pi^0}(\gamma_0)$/$P_{\pi^0}(\gamma_1)$ are 4D Optimized for Low/High mass region with grid-scanning method
- Mass-indep $B \to K a'$ MC samples are used
- All stream BkgMC EXCEPT 00 generic are used
- Punzi Figure of Merit (PFM) is adopted for optimization

$$\mathrm{PFM} = \frac{\epsilon_{sig}}{a/2 + \sqrt{N_{bkg}}},$$

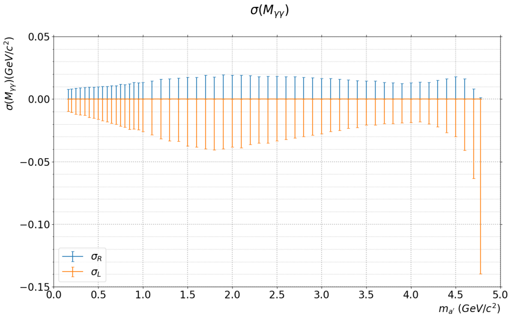
where $a = 3$ is targerting σ value.

K^+ mode optimized values

M(a')	CS1	CS2	$P_{\pi^0}(\gamma_0)$	$P_{\pi^0}(\gamma_1)$
Low	0.929	0.944	0.115	0.130
High	0.914	0.839	0.189	0.150

- Events are accepted in each value is greater than the optimal value.

Analysis Region

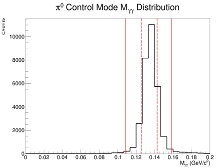


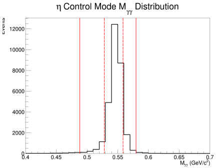
- calculate σ for each a' mass sig MC
- $\sigma = \sqrt{\frac{\sum(M_{\gamma\gamma}-M_{a'})^2}{N_{evt}}}$
- Signal Region : $3\sigma_L$ to $3\sigma_R$. $w = 3(\sigma_L + \sigma_R)$
- Fitting Region : $3\sigma_L + w$ to $3\sigma_R + w$
- Mass Scanning Step Size : σ_R
- $M_{\gamma\gamma}$: diphoton system invariant mass
- $M_{a'}$: ALP mass hypothesis

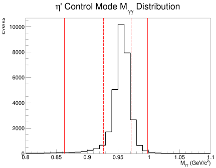
- π^0, η, η' are 3 major gamma pair generating SM background.
- $\sigma^h = \sqrt{\frac{\sum(M_{\gamma\gamma}-m_h)^2}{N_{evt}}}$
- 3 σ of each mass region of peaking background is removed from the analysis and used for Control Mode Validation

h' veto region

Type	3σ $M_{\gamma\gamma}$ region $(\mathrm{GeV/c^2})$
π^0	0.109 ~ 0.158
η	0.497 ~ 0.578
η'	0.882 ~ 0.997



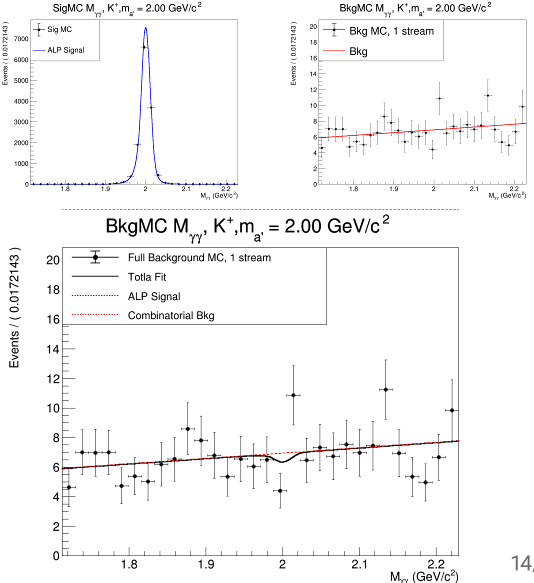




Fitting

Dataset	$M_{\gamma\gamma}$
ALP Signal	2-Side Crystal Ball
Combinatorial Bkg	2nd Chebychev Poly

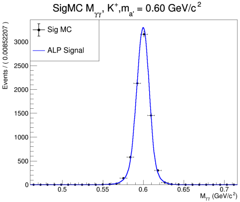
- Unbinned 1D Maximum Likelihood fit is performed to $M_{\gamma\gamma}$ distributions.
- Signal Yield earned with S+B fitting

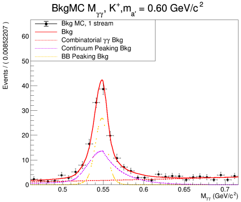


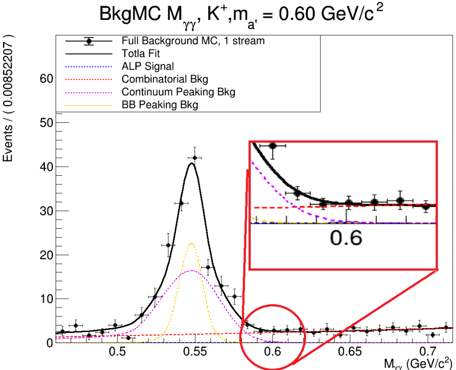
Fitting

Dataset	$M_{\gamma\gamma}$
ALP Signal	2-Side Crystal Ball
Combinatorial Bkg	2nd Chebychev Poly
Continuum Peaking Bkg	2-Side Crystal Ball
BB Peaking Bkg	2-Side Crystal Ball

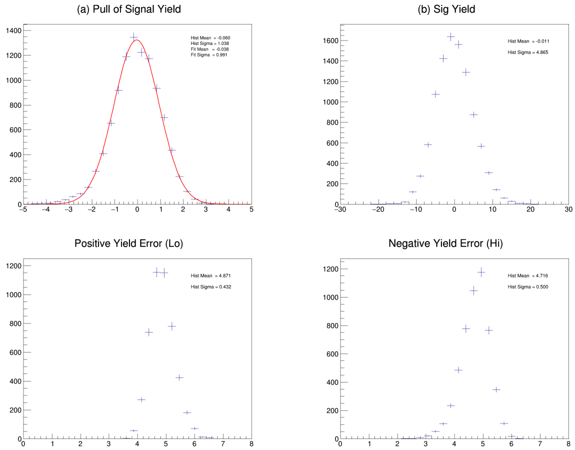
- Unbinned 1D Maximum Likelihood fit is performed to $M_{\gamma\gamma}$ distributions.
- Additional pdf is assigned for control events when peaking background appears in fitting region.
- Signal Yield earned with S+B fitting
- Continuum Peaking backgrounds : $e + e- \rightarrow qq \rightarrow h'X$.
- BB Peaking backgrounds : $B \rightarrow Kh'$





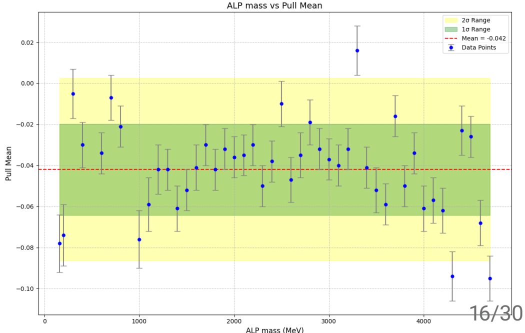


ToyMC

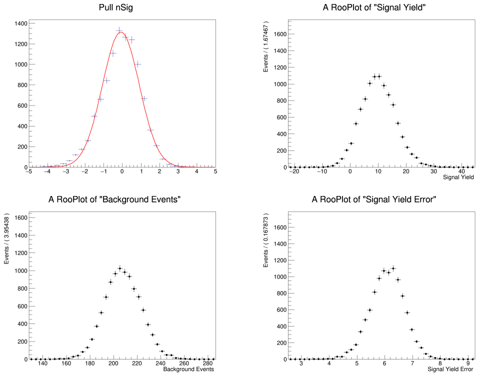


ToyMC Study with $K^+, M_{a'} = 2.0\,\mathrm{GeV/c^2}$ mode. nSig=0.13 and nBkg=241.4

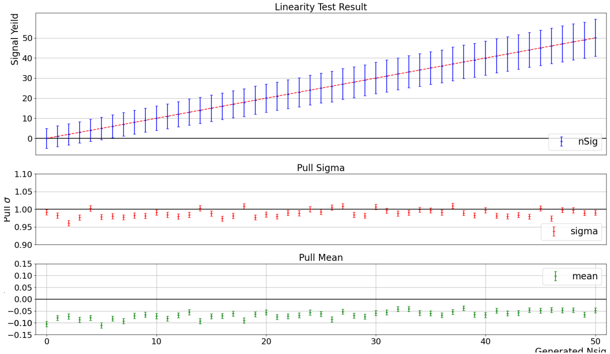
- Signal Extraction Stragety Biasness is tested with pdf based ToyMC study
- 10000 ToyMC datasets are generated / fitted
- nSig/nBkg Toy events are from pdf fit result
- Number of Sig/Bkg events in each ToyMC dataset follows MC result as poisson.
- Fit Bias (4.2%) is applied as calibration factor to B.F and U.L.



Linearity Test

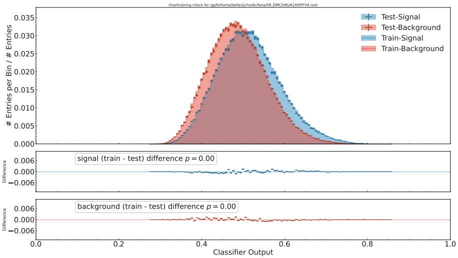


sample output of LT of $B^+ \to K^+ a'(2500)(\to \gamma\gamma)$ (0 Input)



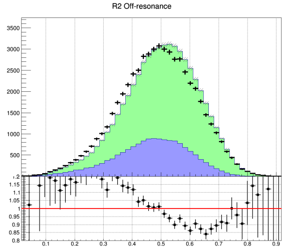
Linearity Test Result. N_{sig}^{in} vs N_{sig}^{out}, red dashed line is expected value(Upper). Pull Mean and Sigma (Middle/Bottom)

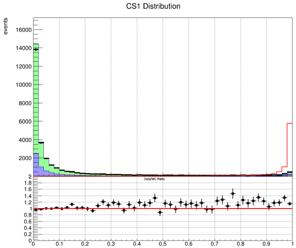
Continuum re-weighting



Re-weighting FBDT score(p) of Data(Signal) and MC(Background)

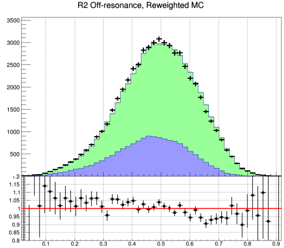
- FBDT Classifier which trained to Data/MC discrepancy.
- The classifier output shows how much the data and MC disagrees
- All variables Used in Continuum Suppression.
- Full skim-passed off-resonance dataset.
- Re-weighting factor $w = \frac{p}{1-p}$

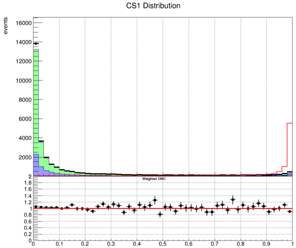




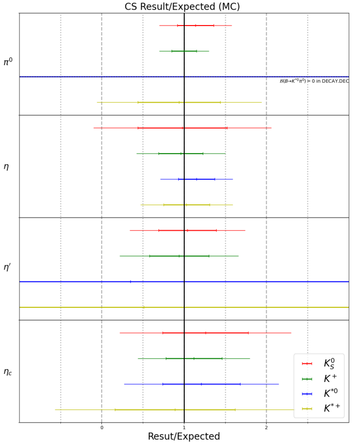
↓ R2

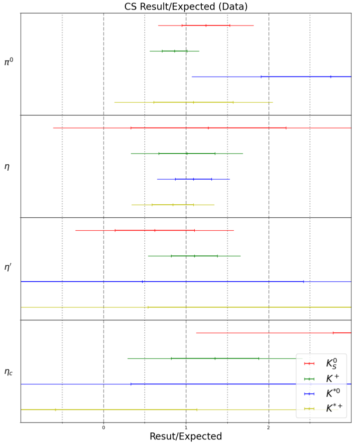
↓ CS1

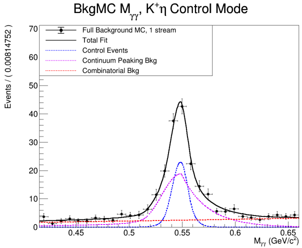




Control Modes : $B \to K\mathfrak{h}'(\to \gamma\gamma)$ Validation







- Control Mode Validation with $B \to K^{(*)}\mathfrak{h}(\mathfrak{h}' \to \gamma\gamma')$ where $\mathfrak{h}' =' \pi^0, \eta, \eta', \eta_c$.
- Generally good agreement except some very low ($\mathcal{O}(10^{-8})$) B.F. modes

Long Lived ALP

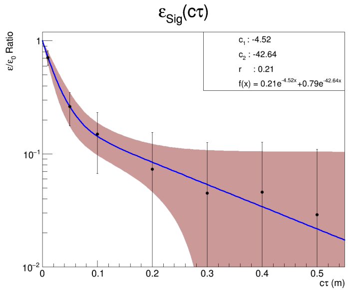
- ALP lifetime is determined by $M_{a'}$ and $g_{a'W}$ (ALP-W coupling).
- Not negligible in low ALP mass hypothesis.
- Long-lived Particle (LLP) signal MC are generated and signal efficiency drop down ratio is calculated.

$$\Gamma_{a'} = g_{a'W}^2 M_{a'}^3 \sin^4\theta_W / 64\pi$$

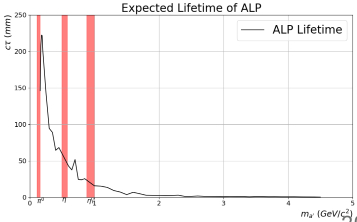
$$c\tau = \frac{c\hbar}{\Gamma_{a'}}$$

$$\varepsilon(x)/\varepsilon_0 = re^{c_1 x} + (1-r)e^{c_2 x}$$

- where x is $c\tau$ in meter(m), c_1,c_2 and r are floating parameters.
- LLP efficiency drop function included into $g_{a'W}$ limit calculation.
- Plots show a sample of LLP signal efficiency drop ratio function and expected lifetime of ALP with 90 C.L. upper limit $g_{a'W}$ value.

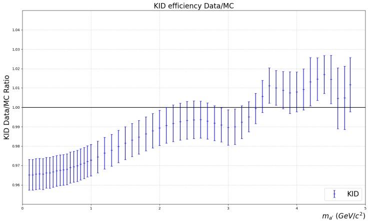


Relative Efficieny vs ALP life time $\epsilon(c\tau)/\epsilon_0$



Systematics

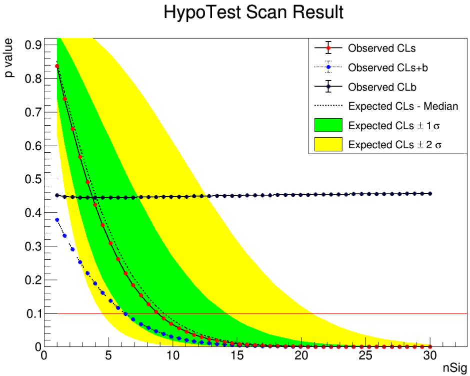
Source	K_S^0 mode	K^+ mode	K^{*0} mode	K^{*+} mode
Selection Efficiency			19.0	
Long lived ALP Efficiency			6.0	
Continuum shape correction			4.1	
Photon Detection efficiency			4.0	
K^+ Identification efficiency	-	3.6	3.6	-
f^{00}/f^{+-}	1.7	2.1	1.7	2.1
K_S^0 reconstruction efficiency	1.6	-	-	1.6
$N_{B\bar{B}}$			1.4	
Tracking efficiency	0.7	0.4	0.7	1.1
Total	20.9	20.9	20.9	21.0



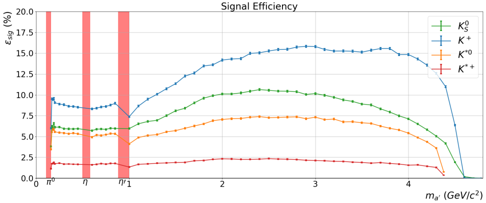
Kaon ID Data/MC

- $\epsilon_{KID} = \frac{\text{number of tracks identified as Kaon}}{\text{number of Kaon tracks}}$
- K_S^0 reconstruction : nisKsFinder recon efficiency

Upper Limit estimation



[90CL Upper Limit N_{Sig} : 9.28]



$$\varepsilon_0 = \frac{N_{Sig}^{remain}}{N_{Sig}^{gen}}$$

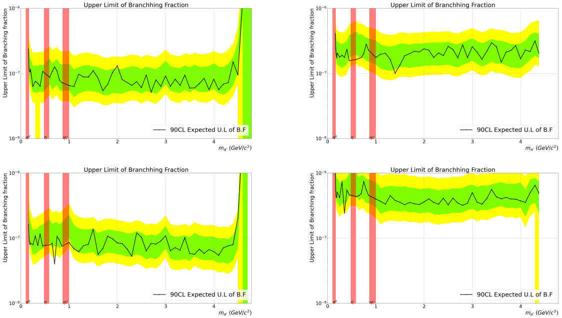
$$\text{Expected } \mathscr{B}(\mathrm{B} \to \mathrm{Ka}'(\mathrm{a}' \to \gamma\gamma)) = \frac{N_{Sig}}{\varepsilon_0 \times N_B}$$

$$\mathscr{L}(\mathscr{B}, \varepsilon) \sim \mathrm{Poisson}(\mathrm{N_{Sig}} + \mathrm{N_{Bkg}}) \times \mathrm{Gauss}(\varepsilon, \varepsilon_0, \sigma_\varepsilon)$$

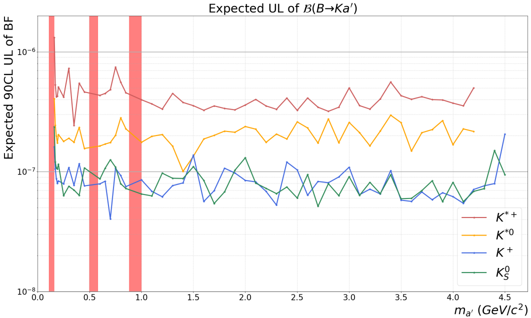
$$\mathrm{Gauss}(\varepsilon, \varepsilon_0, \sigma_\varepsilon) \sim \exp(\frac{(\varepsilon - \varepsilon_0)^2}{2\sigma_\varepsilon^2})$$

- Use CLs frequentist method to estimate upper limit.
- Testing Number of Signal Yields for each Kaon modes.
- 90 C.L. U.L of B.F sett around 1×10^{-7}.

Upper Limit estimation

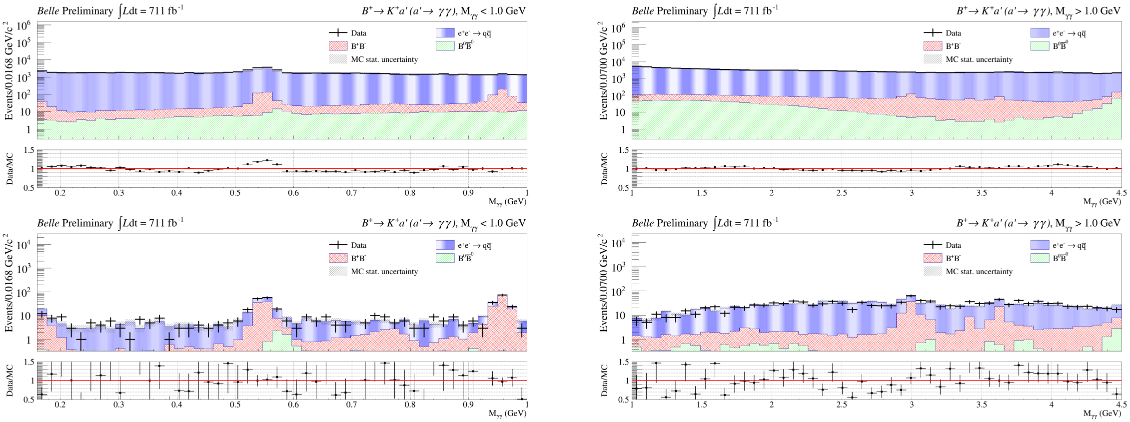


Expected upper limit of braching fraction of K_S^0 mode (Upper left), K^+ mode (Bottom left), K^{*0} mode (Upper right), K^{*+} mode (Bottom right), and it's 1 and 2 sigma range earn by background only model.



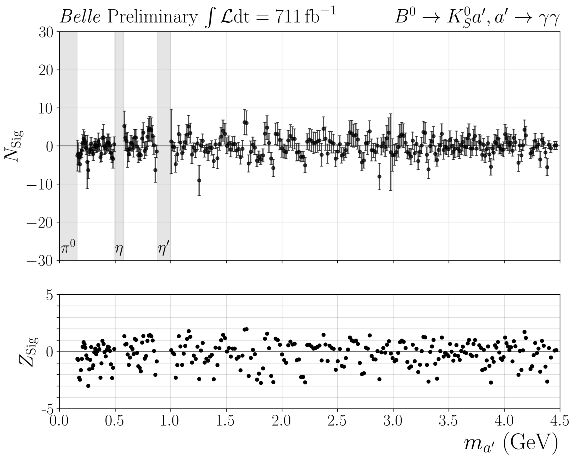
Expected U.L. of $\mathscr{B}(B \to Ka'(a' \to \gamma\gamma))$.

Unblinding Result : Data/MC Comparision

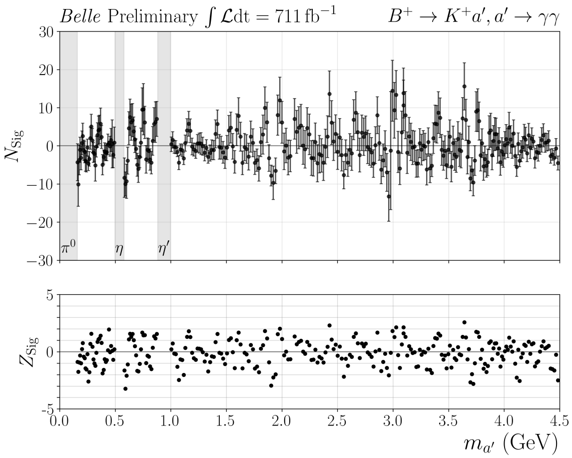


[Figure 2] Before (top) and After(bottom) the MVA cuts

Unbliding Result : Signal Extraction



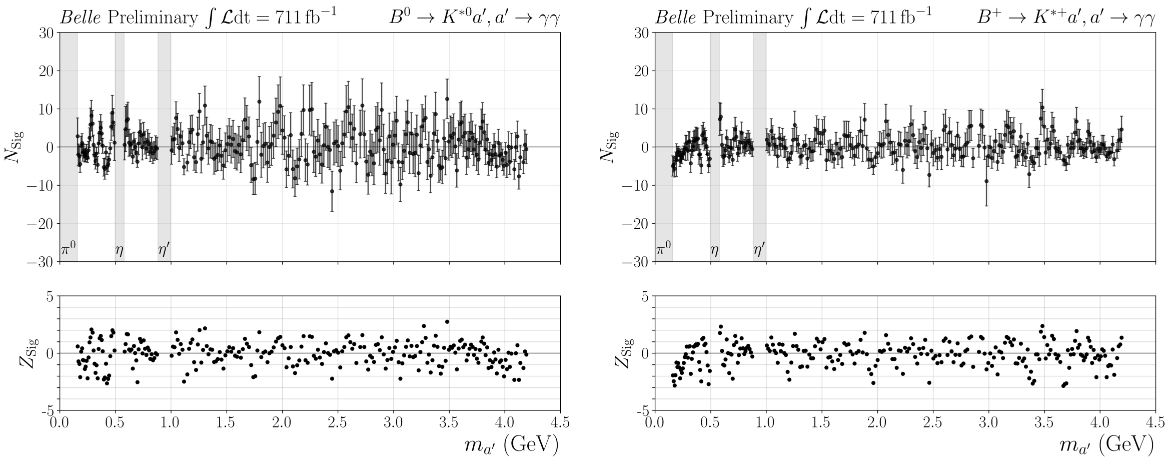
K_S^0 Mode



K^+ Mode

[Figure 3] signal extraction result : K_S^0 and K^+

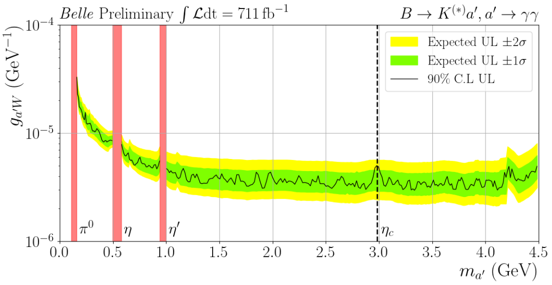
Unbinding Result : Signal Extraction



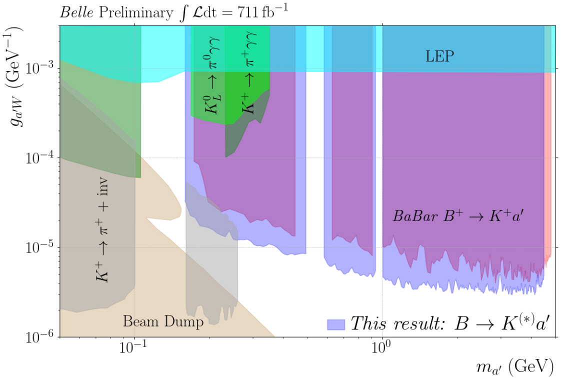
K^{*0} Mode $\qquad$ K^{*+} Mode

[Figure 3] Signal extraction result : K^{*0} and K^{*+}

Unblinding Result : $g_{a'W}$ limitation



[Figure 4]



[Figure 5]

- Simultaneous fit on 4 kaon modes for $g_{a'W}$ limitation.
- Set more stringent limitation than $BaBar$.

Summary and Conclusion

Summary

- Searching for Axion-Like Particle (ALP) through $B \to K^{(*)} a'$ $(a' \to \gamma\gamma)$ Decay at Belle
- Promptly decaying ALP. $a' \to \gamma\gamma$.
  - The lifetime considered as signal efficieny constraint.
- Analysis strategy established with MC:
  - Inlude event selection, background suppression, selection optimization, signal extraction and upper limit calculations
- Result shows more stringent constraint on $g_{a'W}$ than existing limit from $BaBar$.
  - This is one of most powerful limitation on $g_{a'W}$ in the world.
- Long-lived ALP study with more integrated luminosity is expected from Belle II experiment.

Backup

$g_{a'W}$ Calculation

$$\Gamma(B \to K a') = \frac{M_B^3}{64\pi}|g_{a'bs}|^2(1 - \frac{M_K^2}{M_B^2})^2 f_0^2(M_{a'}^2)\lambda_{Ka'}^{1/2}$$

$$\Gamma(B \to K^* a') = \frac{M_B^3}{64\pi}|g_{a'bs}|^2 A_0^2(M_{a'}^2)\lambda_{K^*a'}^{3/2},$$

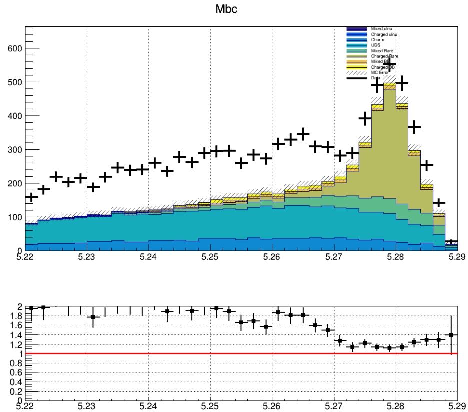
$$g_{a'bs} = -\frac{3\sqrt{2}G_F M_W^2 g_{a'W}}{16\pi^2}\sum_{\alpha=c,t} V_{\alpha b}V_{\alpha s}^* f(\frac{M_\alpha^2}{M_W^2})$$

$$f(x) \equiv \frac{x[1 + x(\log x - 1)]}{(1-x)^2}$$

$$f_0(M_{a'}^2) = \frac{0.330}{1 - M_{a'}^2/37.46}$$

$$A_0(M_{a'}^2) = \frac{1.364}{1 - M_{a'}^2/27.88} - \frac{0.990}{1 - M_{a'}^2/36.78}.$$

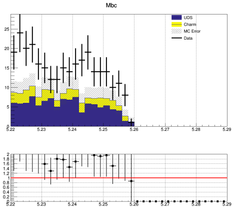
Continuum Data/MC Calibration



- M_{bc} of $B^+ \to K^+ a'(\to \gamma\gamma)$ at π^0 mass window
- π^0 veto is applied in inverted way

- $q\bar{q}$ seems have large Data/MC discrepancy
- continuum correction with Off-resonance data
- Off-resonance data from Exp 31 to Exp 65

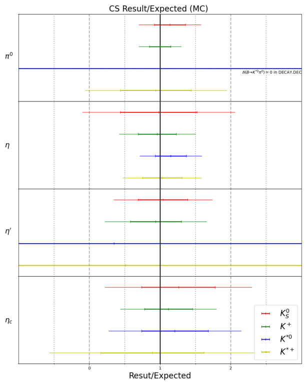
Window	Data/MC Ratio
π^0	1.98
η	2.83
η'	1.49

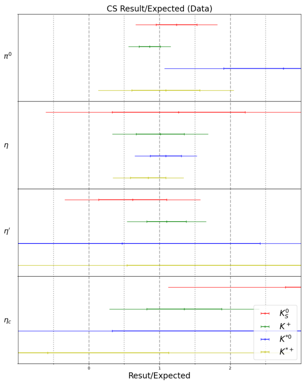


- Apply correction factor to each mass window dataset :

Control Mode : $B \to Kh'(\to \gamma\gamma)$

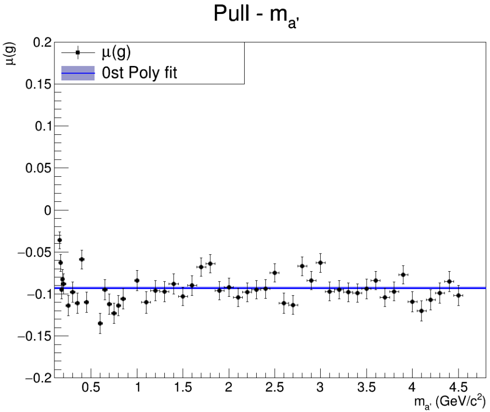
Mode	Result(MC)	$\Gamma_1 \times \Gamma_2$(DECAY.DEC)
$B^0 \to K_S^0 \pi^0$	$4.44 \pm 0.42 \times 10^{-6}$	4.89×10^{-6}
$B^+ \to K^+ \pi^0$	$1.14 \pm 0.05 \times 10^{-5}$	1.27×10^{-5}
$B^0 \to K^{*0} \pi^0$	$-.81 \pm 0.64 \times 10^{-7}$	0.00×10^{-7}
$B^+ \to K^{*+} \pi^0$	$3.72 \pm 1.48 \times 10^{-6}$	6.81×10^{-6}
$B^0 \to K_S^0 \eta$	$6.74 \pm 1.60 \times 10^{-7}$	3.74×10^{-7}
$B^+ \to K^+ \eta$	$0.90 \pm 0.31 \times 10^{-6}$	1.06×10^{-6}
$B^0 \to K^{*0} \eta$	$6.88 \pm 8.42 \times 10^{-6}$	6.26×10^{-6}
$B^+ \to K^{*+} \eta$	$7.51 \pm 1.45 \times 10^{-6}$	7.60×10^{-6}
$B^0 \to K_S^0 \eta'$	$8.02 \pm 1.58 \times 10^{-7}$	6.88×10^{-7}
$B^+ \to K^+ \eta'$	$1.44 \pm 0.19 \times 10^{-6}$	1.49×10^{-6}
$B^0 \to K^{*0} \eta'$	$2.06 \pm 1.92 \times 10^{-7}$	0.81×10^{-7}
$B^+ \to K^{*+} \eta'$	$1.69 \pm 3.57 \times 10^{-7}$	1.04×10^{-7}
$B^0 \to K_S^0 \eta_c$	$2.82 \pm 0.88 \times 10^{-7}$	1.74×10^{-7}
$B^+ \to K^+ \eta_c$	$3.94 \pm 0.92 \times 10^{-7}$	3.09×10^{-7}
$B^0 \to K^{*0} \eta_c$	$7.41 \pm 2.62 \times 10^{-7}$	4.80×10^{-7}
$B^+ \to K^{*+} \eta_c$	$4.13 \pm 5.45 \times 10^{-7}$	5.10×10^{-7}

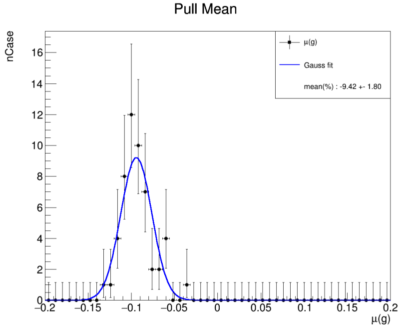




- $\Gamma_1 : \Gamma(B \to Kh')$
- $\Gamma_2 : \Gamma(h' \to \gamma\gamma)$

Fit Bias





- fitting bias
- Average level as systematics

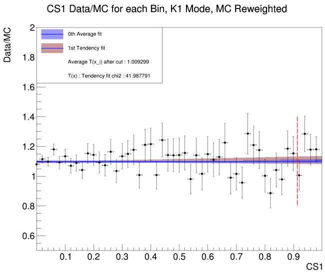
LEE calculation

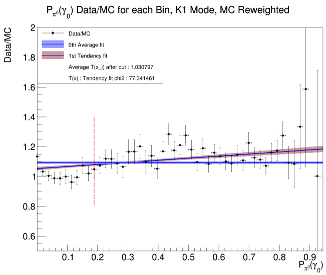
- Scanning points :
- K_S^0, K^+ : 324
- K^{*+}, K^{*0} : 193
- Significance $S = \sqrt{2(NLL_{s+b} - NLL_b)}$
- $p_{global} = p_{local} + \langle N_{up}(Z_0) \rangle e^{\frac{Z_0^2 - Z^2}{2}}$
- Z_0 : 1σ

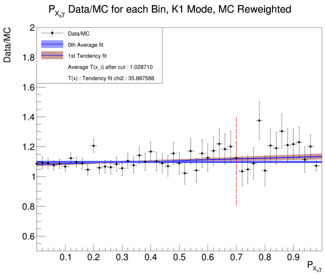
LEE calculation example

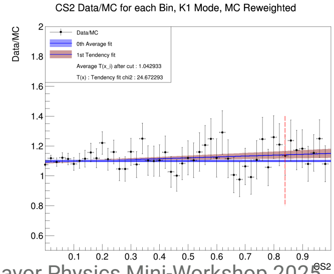
- $B^+ \to K^+ A(3500)$
- $N_{up}(1\sigma)/N_{toy} = 0.1648$
- 3.53σ global significance at 5σ local significance

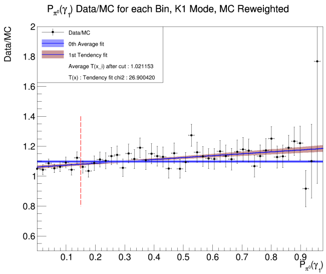
Systematics : FBDT Data/MC









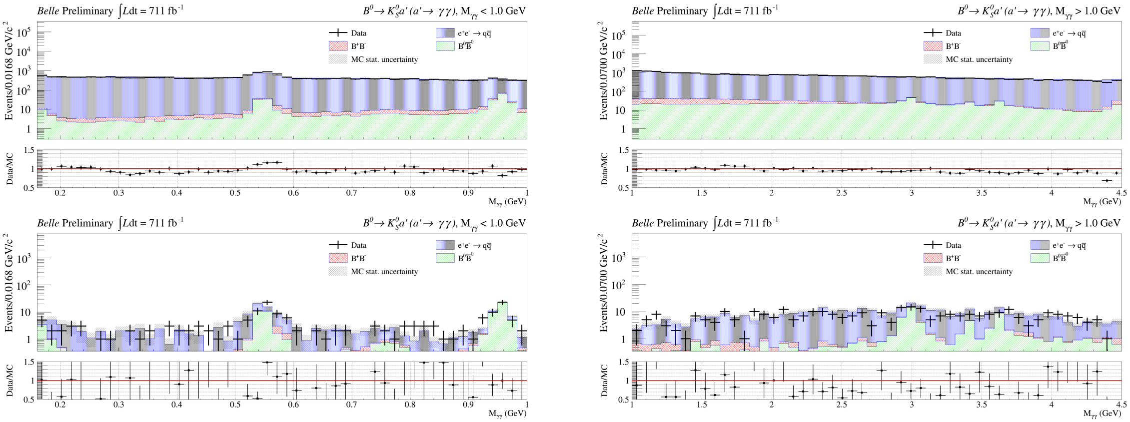


- Use off-resonance data
- Direct comparision easily affected by statistical fluctuation
- 1st order polynomial fit to Data/MC hist for each FBDT result
- Compare poly function average with total average value after cut
- quadratic summation 5 FBDT Data/MC efficiency result.

Systematic Study : reference

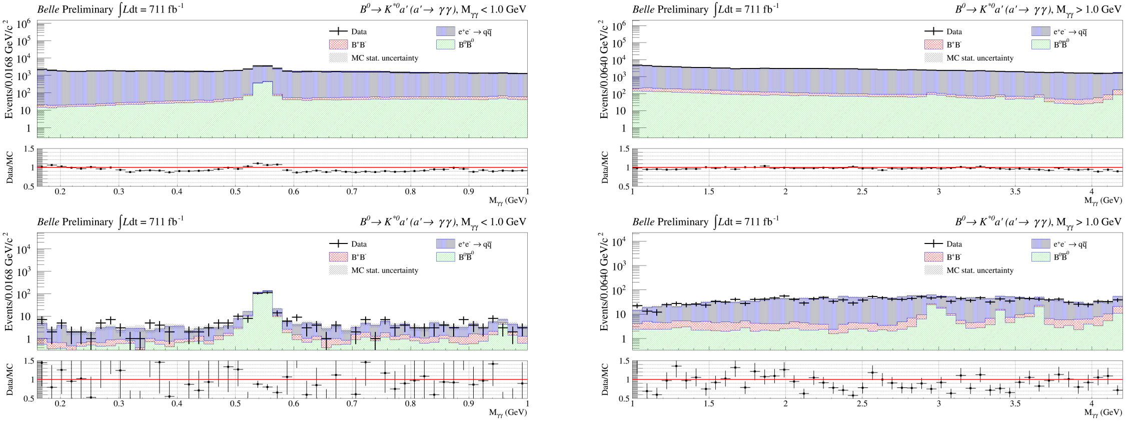
Source	reference
nBB	nBB
$\Upsilon(4S) \to B^+ B^-$	pdg
$\Upsilon(4S) \to B^0 \bar{B}^0$	pdg
Photon Detection	BN499
Tracking efficiency	BN1165
KID	BN779
PID	BN779
K_S^0 recon	BN1472

Unblinding Result : K_S^0 Data/MC Comparision



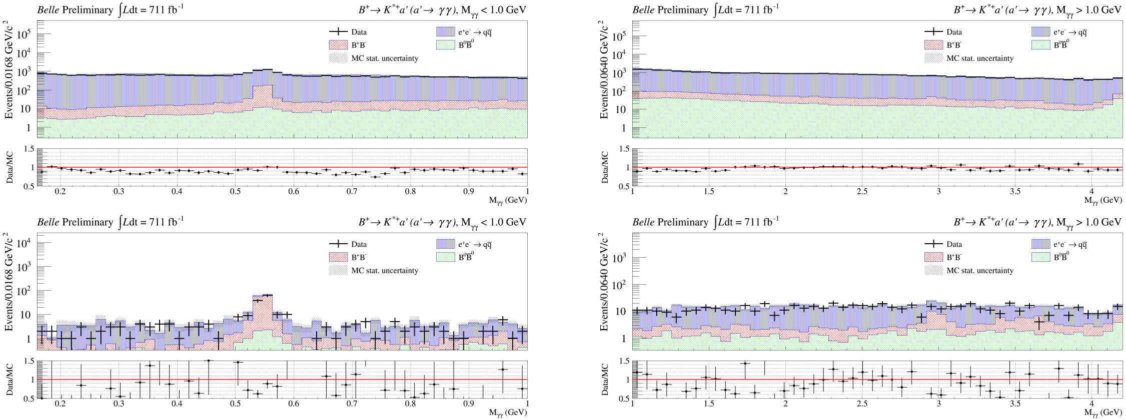
[Figure 6] (Supplemental) Before (top) and After(bottom) the MVA cuts

Unblinding Result : K^{*0} Data/MC Comparision



[Figure 6] (Supplemental) Before (top) and After(bottom) the MVA cuts

Unbinding Result : K^{*+} Data/MC Comparision



[Figure 6] (Supplemental) Before (top) and After(bottom) the MVA cuts