Search for ALP through $B \to K a'$ $(a' \to \gamma\gamma)$ Decay

Sungjin Cho

sjcho93@yonsei.ac.kr

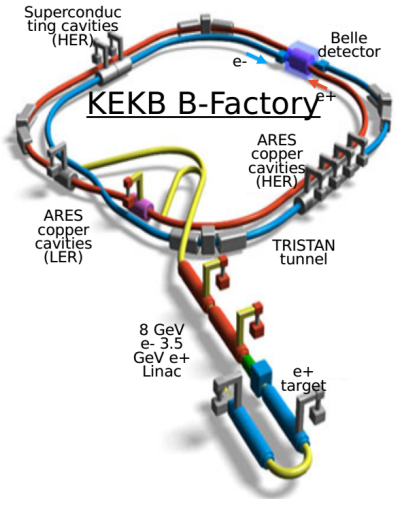
Yonsei University

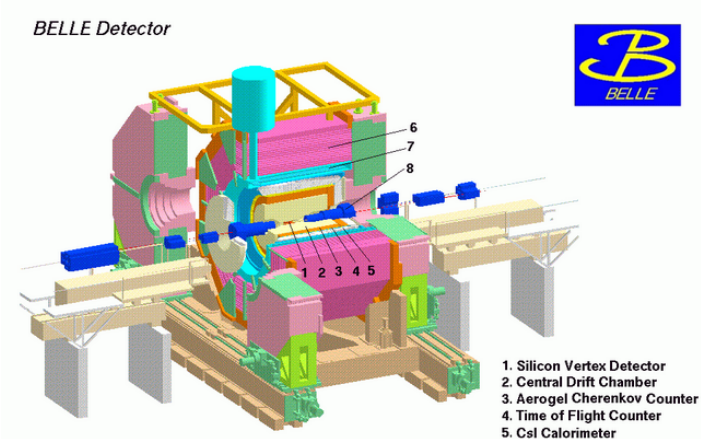
Jan 7th, 2021

Contents

- KEKB and Belle Experiment
- Event Generation
- Skimming Strategy
- mva with FBDT
- Koppenberg $\pi^0\eta$ Probability
- Peaking background veto
- Setting analysis region
- Optimizing FBDT
- $B \to X_s\gamma$ veto
- Signal extraction with PDF Fitting
- Calculate expected UL of BF
- Result
- Conclusion and Plan

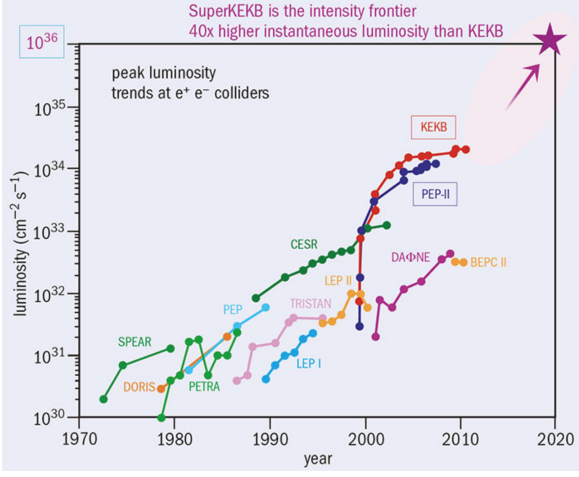
KEKB and Belle Experiment



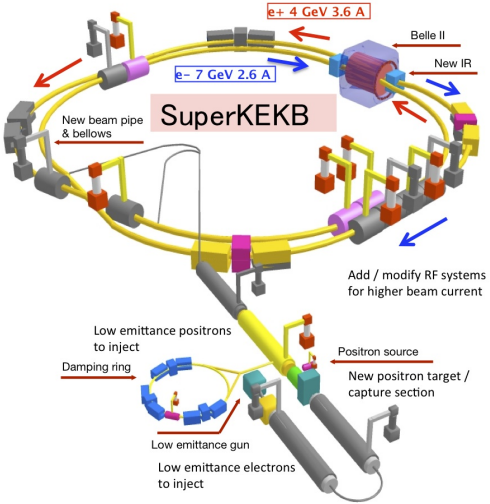


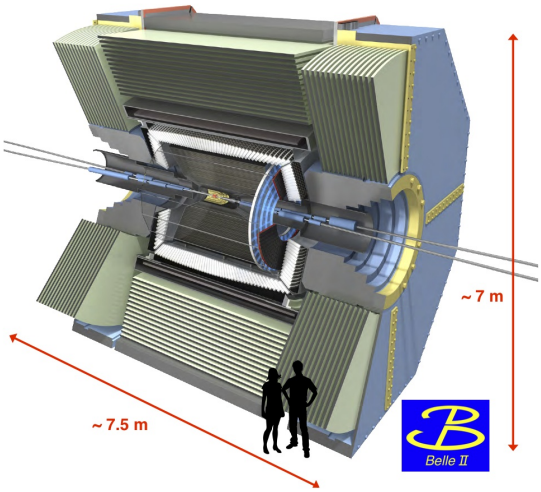
KEKB and Belle Experiment

- Belle Experiment :
- 8 GeV HER, 3.5 GeV LER head-on colliding
- Energy set to generate $\Upsilon(4S)$ (10.58 GeV)
- $\Upsilon(4S)$ decays into $B\bar{B}$ pair (5.28 GeV)
- from 1999 to 2010, 710 fb^{-1} integrated luminocity collected, corresponding to 772 million $B\bar{B}$ pair
- Have several layers of detectors
- SVD, CDC, TOF, ACC, CsI, KLM
- Now upgraded Belle II experiment with SuperKEKB is under operation



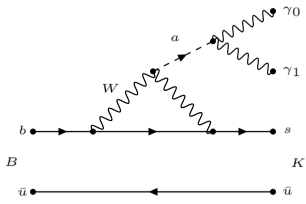
SuperKEKB and Belle II Experiment





Event generation

- a' stands for Axion-Like-Particle (ALP)
- $B^0 \to K^0 a'$ $(a' \to \gamma\gamma)$
- $B^+ \to K^+ a'$ $(a' \to \gamma\gamma)$ (What we show in this talk)
- $B^0 \to K^0 a'$ $(a' \to \gamma\gamma)$
- $B^+ \to K^+ a'$ $(a' \to \gamma\gamma)$
- a' : Spin-less pseudoscarlar particle
- a' : Decay into $\gamma\gamma$ 100%
- $M_{a'}$: $0.1 \sim 1.0$ GeV (0.05 GeV interval)
- $M_{a'}$: $1.0 \sim 3.0$ GeV (0.1 GeV interval)
- Each signal MC sample contains 100K events,



Skim

- Background data skimemd to include all K mode
- B2BII applied : allow using Belle I data in Belle 2 Analysis Framework (BASF2)
- B2BII conditions : BELLE2_RELEASE = release-05-01-06

Partilce List	Selection Criteria
Charged track	$\|d0\| < 3.0$ cm
	$\|z0\| < 4.0$ 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	$E_\gamma > 50$ MeV
	$0.5 < goodBelleGamma < 1.5$
π^0	pi0:mdst
K_S^0	goodBelleKShort
	vertex kFit
	ksnbStandard = 1 (nisKs)

Partilce List	Selection Criteria
K^*	$0.7 < m_{K^*} < 1.1$ GeV
	$K^0 \to K^0 pi^0$
	$K^0 \to K^+ pi^-$
	$K^+ \to K^0 pi^+$
	$K^+ \to K^+ pi^0$
ALP	$0.102 > M_{a'} \| M_{a'} > 0.166$ GeV (π^0 mass regi
	$0.480 > M_{a'} \| M_{a'} > 0.584$ GeV (η mass regio
	$0.866 > M_{a'} \| M_{a'} > 0.997$ GeV (η' mass regi
B	$M_{bc} > 5{,}26$GeV
	$-0.6 < \Delta E < 0.3$ GeV
	$B^0 \to K^0 a'$
	$B^+ \to K^+ a'$
	$B^0 \to K^0 a'$
	$B^+ \to K^+ a'$

Variables

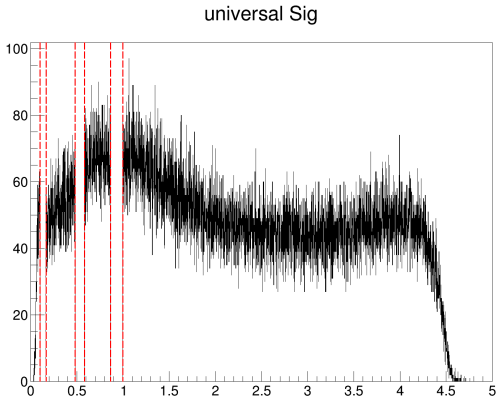
Selection Criteria	Description
$\|d0\|$	Signed distance to the point of closest approach (POCA) in the $r-\phi$ plane
$\|z0\|$	z coordinate of the POCA
eIDBelle	Belle electron likelihood
muIDBelle	Belle muon likelihood
$muIDBelleQuality$	muIDBelle quaility flag
$\mathscr{L}(ij)$	Belle atcPID $\mathscr{L}_i/(\mathscr{L}_i+\mathscr{L}_j)$
$goodBelleGamma$	dependent energy selection for Belle data and MC (50/100/150 MeV)
goodBelleKShort	$0.468 < M < 0.528$ GeV,Vertex fit not failed
$M_{a'}$ cut	$3 \times RMS$ of π^0, η, η' mass distribution
M_{bc}	$\sqrt{(E_{\mathrm{beam}}/2)^2 - \vec{\mathrm{p}}_B^{\,2}}$, Beam constraint mass for signal side B
ΔE	$(E_{\mathrm{beam}}/2) - E_B$

FBDT

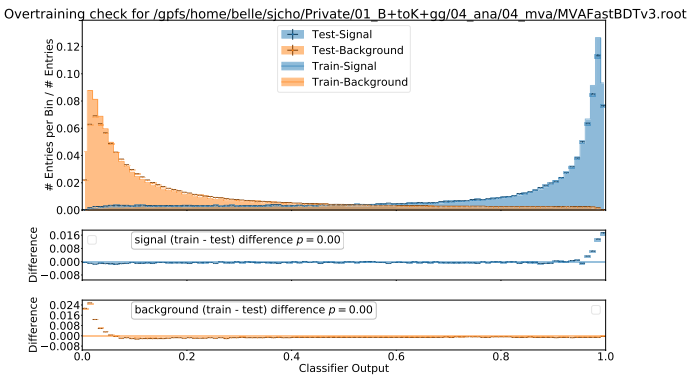
- TMVA not works well with B2BII dataset
- -> apply BASF2 mva
- training for each sigMC data leads MVA to select signal-like mass region :
- so generate SigMC with various a' mass (0.01~4.5 GeV, 10MeV interval) to use as MVA training sample.
- peaking background mass region has removed.
- 100,000 evts from uniSig MC sample used as Sig training sample
- 50,000 evts from each CHM and UDS stream 01 used as Bkg training sample
- Pre-MVA Cuts :

Precut	Conditions
Mbc	5.2~
deltaE	-0.6~0.3
Easy	~0.9
kopp Prob	~0.8

- $Easy = \frac{|E_{\gamma 0} - E_{\gamma 1}|}{E_{\gamma 0} + E_{\gamma 1}}$



FBDT



input variables :

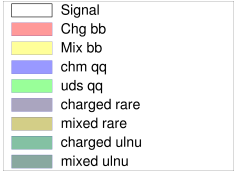
- thrustOm
- cosTBTO
- cosTBz
- et
- mm2
- R2
- KSFW (14)
- CleoCone (9)
- E_{asy}

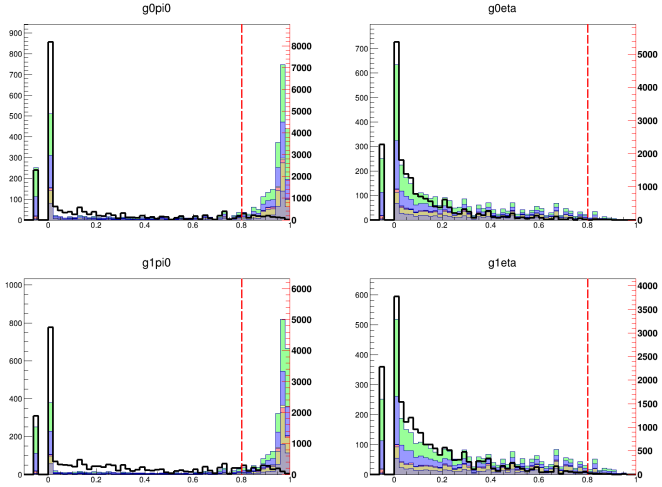
Continuum Suppersion Variables

Variable	Description
thrustOm	Magnitude of the ROE thrust axis
cosTBTO	Cosine of angle between thrust axis of the signal B and thrust axis of ROE
cosTBz	Cosine of angle between thrust axis of the signal B and z-axis
et	Transverse energy
mm2	Missing mass squeared
R2	Reduced Fox-Wolfram moment R2
KSFW (14)	Kakuno-Super-Fox-Wolfram
CleoCone (9)	variables based on the sum of the absolute values of the momenta of all particles within thrust axis 9 concentric cones

Koppenberg $\pi^0\eta$ Probability

- Use Koppenberg method to exculde π^0, η dauther candidates.
- Calculate the photon's probability for being daugther of π^0 or η
- $\mathscr{P}_{\pi/\eta}(\gamma_i) = \max(P_{\pi/\eta}(\gamma_i, \gamma_j))$
- γ_j: every γ from mdst_gamma table
- if ($E_i < 1.5$ and $E_j < 1.5$ GeV) then $\mathscr{P} = -0.1$
- veto γ which has $\mathscr{P}_{\pi/\eta} > 0.8$

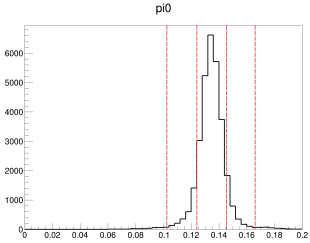


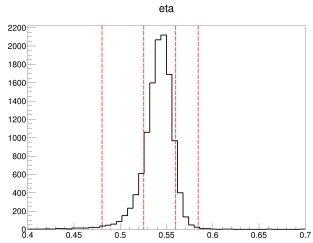


A1600 gamma π^0/η Probability

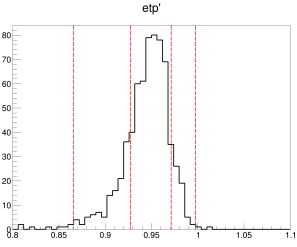
Peaking background veto

- π^0, η, η' are 3 major gamma pair generating SM background.
- to reject designated mass region, each MC samples are generated
- and upper/lower rms for each sample's A0_M($M_{a'}$) value are calculated.
- peaking background veto region is from $3 \times rms^L$ to $3 \times rms^R$
- $rms^L_{\pi^0} = \sqrt{\frac{\sum (M_{a'} - M_{\pi^0})^2}{N_{evt}}}$ when $M_{a'} > M_{\pi^0}$
- $rms^R_{\pi^0} = \sqrt{\frac{\sum (M_{a'} - M_{\pi^0})^2}{N_{evt}}}$ when $M_{a'} < M_{\pi^0}$

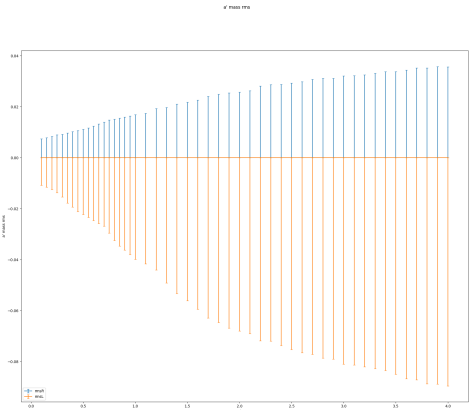




type	veto region (GeV)
π^0	0.102 ~ 0.166
η	0.480 ~ 0.584
η'	0.866 ~ 0.997



Analysis Region

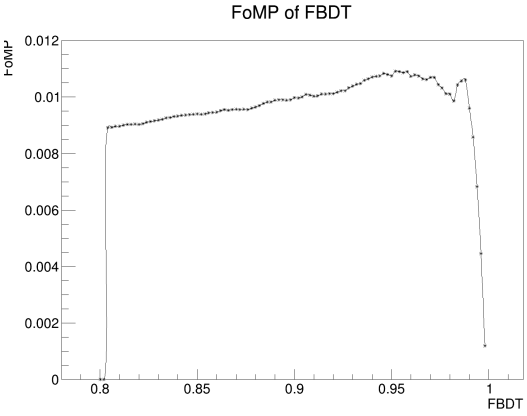


- 0.7 ~ 1.2 window is not very effective with low a' mass
- also not very logical selection
- calculate σ for each a' mass sig MC

precut	Condition
a' mcPDG	matched
Mbc	5.27~ (GeV)
ΔE	-0.2 ~ 0.1 (GeV)
$M_{a'}$	0.5 ~ 1.2

- $rms^L = \sqrt{\frac{\sum(M_{a'} - ref\_Mass)^2}{N_{evt}}}$ when $M_{a'}$ > ref_Mass
- $rms^R = \sqrt{\frac{\sum(M_{a'} - ref\_Mass)^2}{N_{evt}}}$ when $M_{a'}$ < ref_Mass
- Main Band : 2.5 rms^L to 2.5 rms^R
- Side Band : main band width

Optimizing Punzi FoM



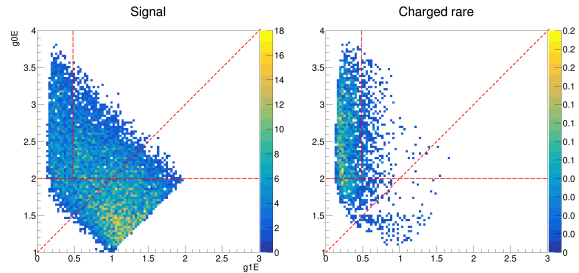
- Punzi FoM maximized around 0.95
- unify Punzi FoM cut 0.95 for all mass region
- Fom calc :

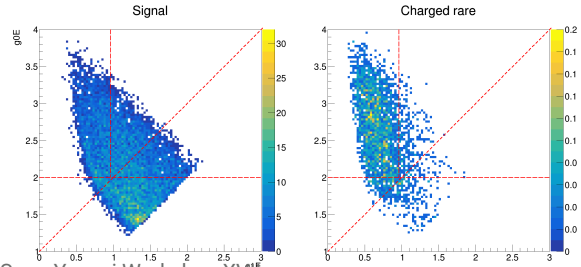
Precut	Conditions
Mbc	> 5.27 (GeV)
ΔE	-0.2 ~ 0.1 (GeV)
kopp Prob	< 0.8
Easy	< 0.9

Punzi FoM = $\frac{\epsilon_{sig}}{\sigma/2+\sqrt{N_{bkg}}}(\sigma : 3)$

$M_{a'}$ 1600 MeV representive.

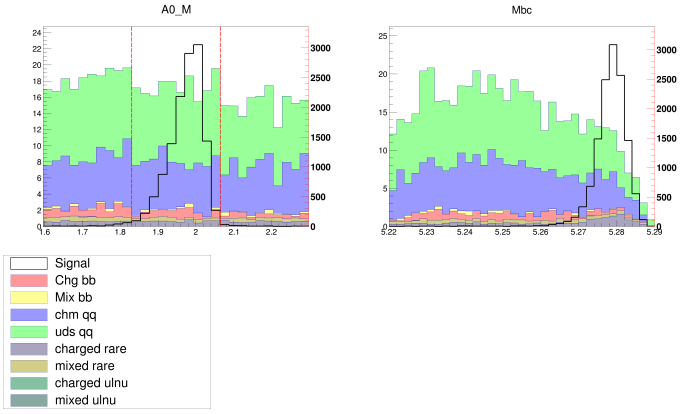
$B \to X_s\gamma$ veto





- major of rare B Background
- from $E_{\gamma_0} : E_{\gamma_1}$ distribution
  - $E_{\gamma_0} < 2.0$ || $E_{\gamma_1} > (mass/2.5)$ GeV
- Not carefully optimized cut value
- But Extremely powerfull to veto $B \to X_s\gamma$
- 1.2 GeV, 2.4 GeV representive

Background Distibution

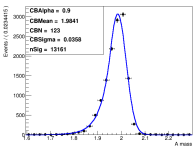


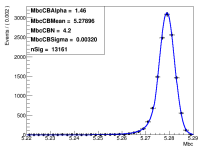
- continuum is major source of bkg.
- $B\bar{B}$ and ulv events are almost suppressed.

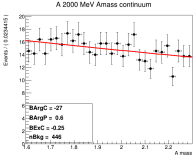
bkg	remaining
chg	23.2
mix	6.2
chm	179.8
uds	266.6
charged rare	18.66
mixed rare	13.74
charged ulnu	0.1
mixed ulnu	0

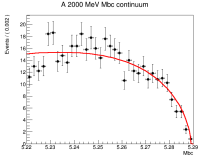
$M_{a'}$ 2000 MeV representive.

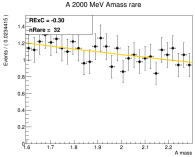
Fitting and applying PDF

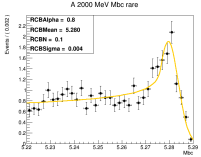


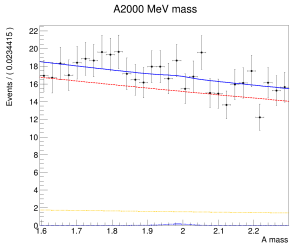


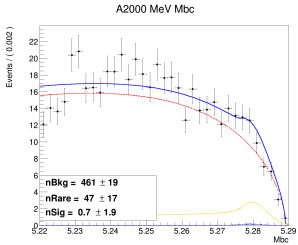








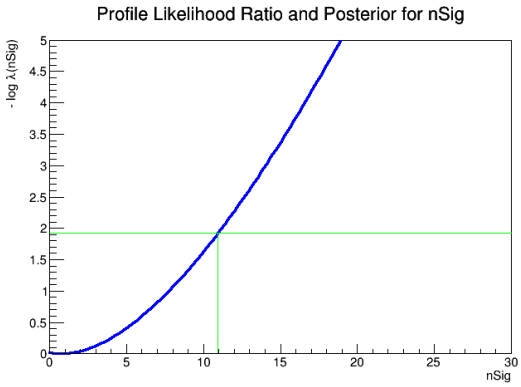




type	A0_M	Mbc
Signal	CB	CB
Generic	exponential	BGArgus
Special	exponential	CB

- fitting for each a' mass region are performed.

Profile Likelihood



- Profile Likelihood Calculator
- 95 C.L
- Expected U.L. = $\frac{N_{Sig}^{95yield}}{\epsilon_{sig} \times N_{BB}}$
- $N_{Sig}^{95yield} = N_{PLC\_output}$
- $\epsilon_{sig} = \frac{N_{pass\_cuts}^{sig}}{N_{gen}^{sig}}$
- $N_{BB} = 772 \times 10^6$

$M_{a'}$ 2000 MeV representive.

Expected U.L of BF with 95 CL

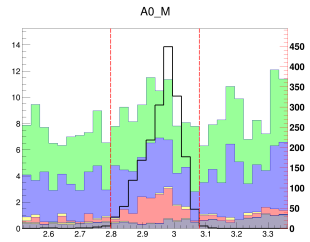
$M_{a'}$(GeV)	ϵ_{sig}(%)	N_{bkg}	N_{sig}	N_{sig}/σ	95CL	Expected B.F	Expected U.L
1.5	12.6	437.31 ± 48.4	1.72 ± 4.48	0.38	12.2	1.75E-08	1.23E-07
2.0	13.2	507.87 ± 39.6	0.73 ± 4.34	0.17	10.9	0.72E-08	1.07E-07
2.5	9.0	358.53 ± 20.5	-2.28 ± 3.43	0.66	6.35	-3.26E-08	0.91E-07
3.0	1.9	245.52 ± 14.3	10.0 ± 5.20	1.92	21.7	6.78E-07	1.47E-06

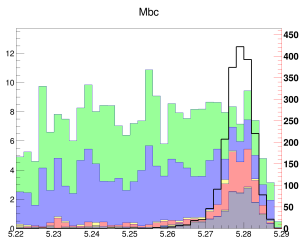
conclusion and plan

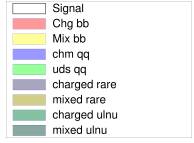
- conclusion
  - koppenberg π^0/η applied.
  - FBDT trained and applied
  - Analysis region decided.
  - SigMC generated, full bkg stream skimmed.
  - FBDT optimized with Punzi FoM
  - Fitting done on remaining bkg/sig MC
  - Sig Yield value and expected U.L calculated
- plan
  - Try 3D fit
  - new π^0, η veto

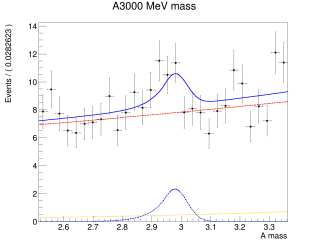
Back UP

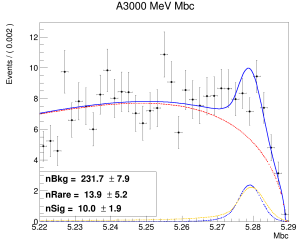
$B^+ \to K^+ \eta_c$











SM BF	Value
$BF(B^+ \to K^+ \eta_c)$	0.001030
$BF(\eta_c \to \gamma\gamma)$	0.0003
$BF(B^+ \to K^+ \eta_c(\eta_c \to \gamma\gamma))$	3.09E-7
$BF(B^+ \to K^+ \eta_c(\eta_c \to \gamma\gamma))$	$2.2^{+0.09}_{-0.07}$E-7

- $B^+ \to K^+ \eta_c(\eta_c \to \gamma\gamma)$ from Decay.dec
- last BF from 2008 J.Wicht Belle paper