$B \to K A' A'$, $A' \to l^+ l^-$

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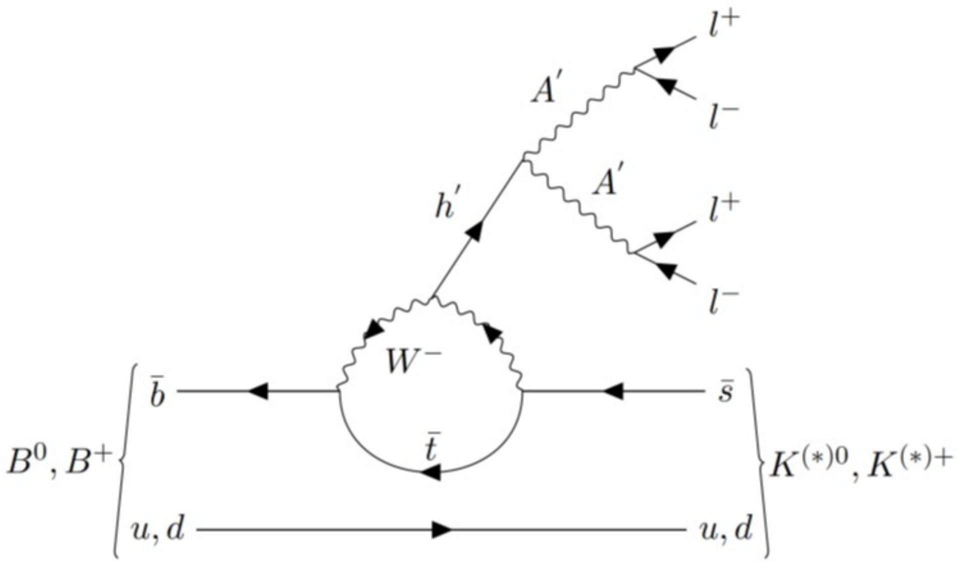
Introduction



Multilepton signature of a hidden sector in rare B decays.
Phys. Rev. D 83,054005, B. Batell et al

Final States			
$B^+ \to K^+e^+e^-e^+e^+$	$B^0 \to K^0e^+e^-e^+e^+$	$B^+ \to K^{*+}e^+e^-e^+e^+$	$B^0 \to K^{*0}e^+e^-e^+e^+$
$B^+ \to K^+e^+e^-\mu^+\mu^+$	$B^0 \to K^0e^+e^-\mu^+\mu^+$	$B^+ \to K^{*+}e^+e^-\mu^+\mu^+$	$B^0 \to K^{*0}e^+e^-\mu^+\mu^+$
$B^+ \to K^+\mu^+\mu^-\mu^+\mu^+$	$B^0 \to K^0\mu^+\mu^-\mu^+\mu^+$	$B^+ \to K^{*+}\mu^+\mu^-\mu^+\mu^+$	$B^0 \to K^{*0}\mu^+\mu^-\mu^+\mu^+$

Particle selection

- $dr < 2\ \text{cm},\ dz < 5\ \text{cm}$
- $e^{\pm}$: $\mathcal{L}_e > 0.9,\ \mathcal{L}_e > \mathcal{L}_\mu$, Bremstrahlung-$\gamma$ recon $\angle_e^{\gamma} < 0.05\ \text{rad}$
- $\mu^{\pm}$: $\mathcal{L}_\mu > 0.9,\ \mathcal{L}_e < \mathcal{L}_\mu$
- $K^{\pm}$: $\mathcal{L}_{K/\pi} > 0.6,\ \mathcal{L}_{P/K} < 0.4$
- $\pi^{\pm}$: $\mathcal{L}_{K/\pi} < 0.4,\ \mathcal{L}_{P/\pi} < 0.4$
- γ : Endcap : 150 MeV Barrel : 50 MeV
- K_S^0 : $nisksfinder$ standard cut.
- π^0 : $0.1 < M_\pi < 0.14\ (\text{GeV}),\ P_\pi > 0.1\ \text{GeV}$

Particle Selection cont'd

- K^{*+} : $K^{*+} \rightarrow K_S^0\pi^+, K^+\pi^0$, $0.8 < M_{K^{*+}} < 1.0$ (GeV)
- K^{*0} : $K^{*0} \rightarrow K_S^0\pi^0, K^+\pi^-$, $0.8 < M_{K^{*0}} < 1.0$ (GeV)
- A' : $A' \rightarrow e^+e^-, \mu^+\mu^-$, $\Delta M_{A'} < 0.1$ GeV
- Best A' pair selection based on least $\Delta M_{A'}$
- When we select $A' \rightarrow l_{1,3}l_{2,4}$, we call $A'_W \rightarrow l_{1,2}l_{4,3}$
- Best B selection based on least $|\Delta E|$.

of B candidates

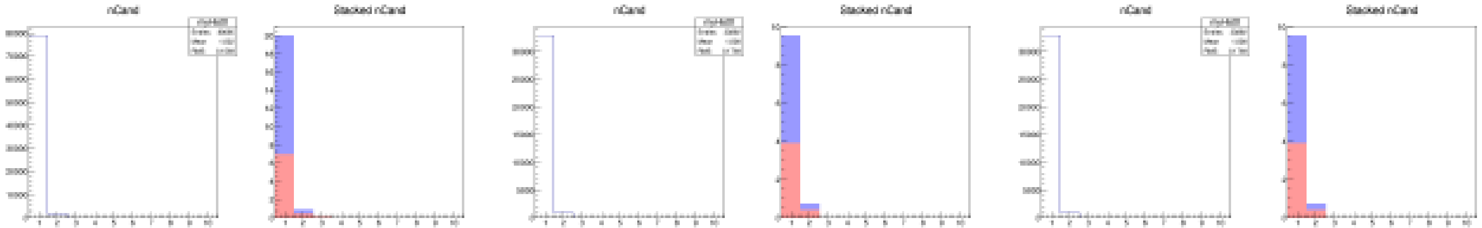


Figure 4: Number of B candidates before best B selection. From left, signalMC(Black Line) and generic backgrounds (Red for $B\bar{B}$ and Blue for $q\bar{q}$) with decay of $B^+ \to K^+e^+e^-e^+e^-$, $B^+ \to K^+e^+e^-\mu^+\mu^-$, $B^+ \to K^+\mu^+\mu^-\mu^+\mu^-$.

nCandidates	Entries	Mean	Max
$B^+ \to K^+e^+e^-e^+e^-$	21.07	1.05	48
$B^+ \to K^+e^+e^-\mu^+\mu^-$	10.30	1.07	25
$B^+ \to K^+\mu^+\mu^-\mu^+\mu^-$	4.83	1.09	10
$B^0 \to K^0e^+e^-e^+e^-$	1.23	1.00	3
$B^0 \to K^0e^+e^-\mu^+\mu^-$	0.63	1.32	2
$B^0 \to K^0\mu^+\mu^-\mu^+\mu^-$	0.10	1	1
$B^+ \to K^{*+}e^+e^-e^+e^-$	92.13	4.13	61
$B^+ \to K^{*+}e^+e^-\mu^+\mu^-$	25.33	3.61	20
$B^+ \to K^{*+}\mu^+\mu^-\mu^+\mu^-$	11.63	5.25	7
$B^0 \to K^{*0}e^+e^-e^+e^-$	35.57	1.43	56
$B^0 \to K^{*0}e^+e^-\mu^+\mu^-$	9.16	1.62	15
$B^0 \to K^{*0}\mu^+\mu^-\mu^+\mu^-$	4.80	2.33	10

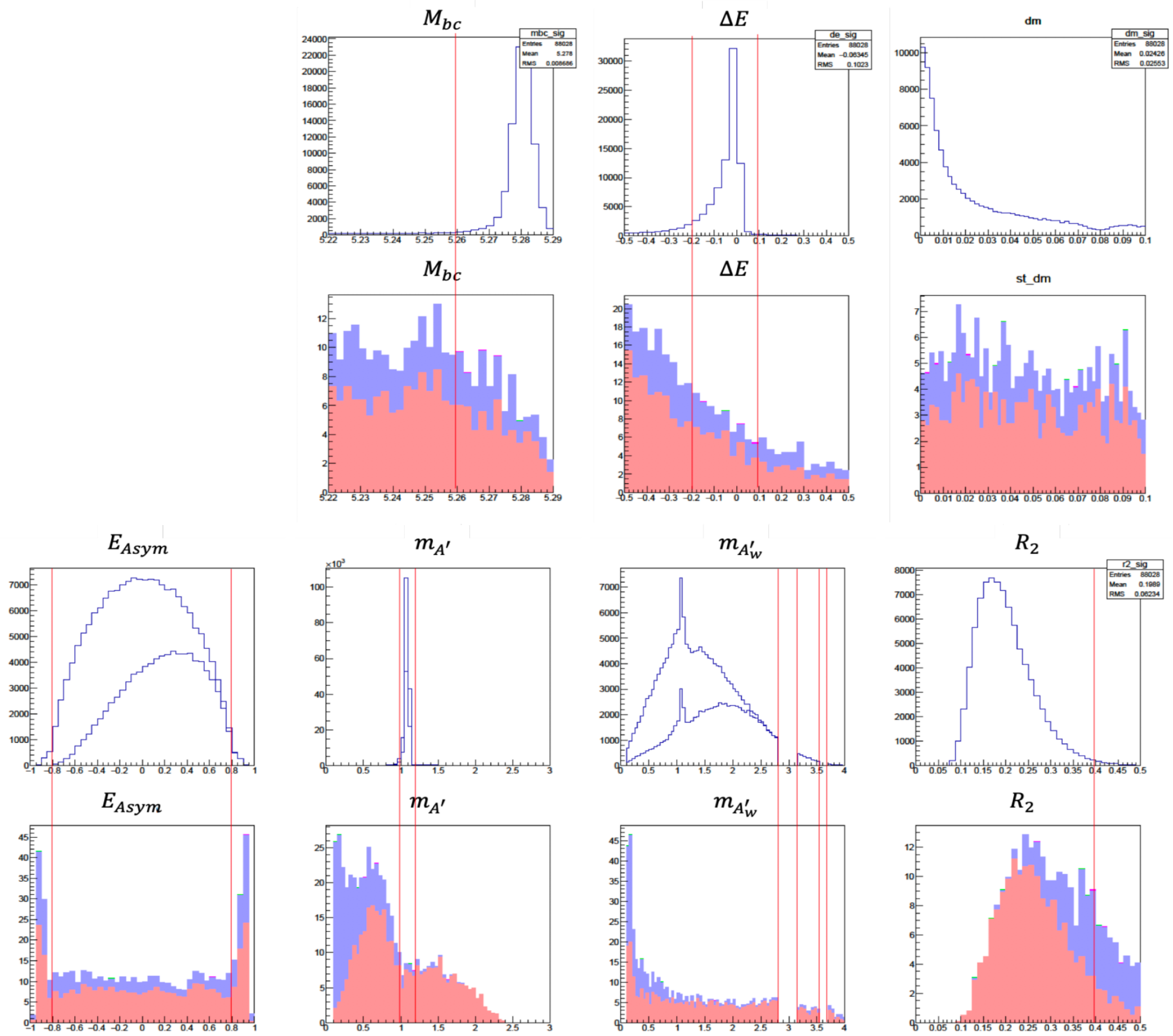
Table 3: Number of B candidates depending on each decay modes. These values are exaggerated as signal selection on these variables are not applied. ($\Delta m_{A'}(< 0.1), m_{A'}$, and E_{Asym}).

Best B select using least $|\Delta E|$.

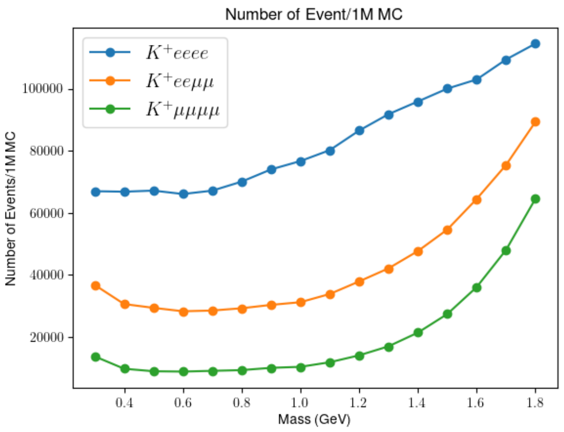
Number of B candidates are not significant on Signal MC and generic MC as shown in figure and Table (Mean ~1).

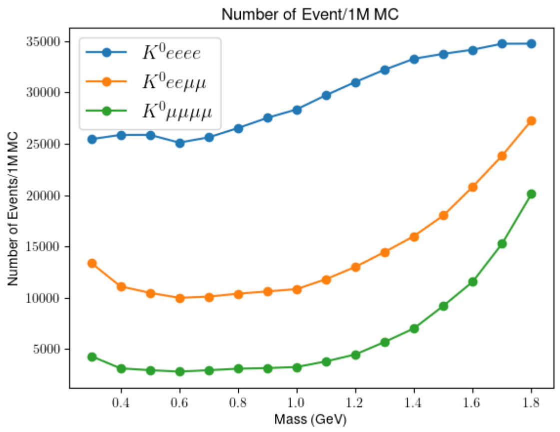
Signal Extraction

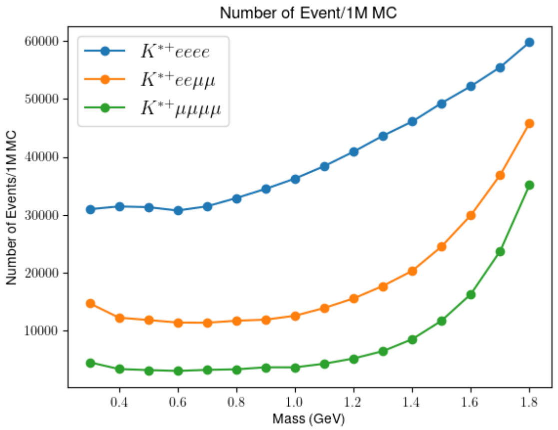
Cuts
$M_{BC} > 5.26$
$-0.2 < \Delta E < 0.1$
$\Delta M_{A'}$: 95% of signal cut
$\lvert E_{Asym} \rvert < 0.8$
$\lvert M_{A'} - \overline{M_{A'}} \rvert < 0.1$ $M_{A'} > 0.1$
$M_{l_{1,2}l_{4,3}} > 0.1$ Veto $J/\psi, \phi$ on $M_{l_{1,2}l_{4,3}}$
$R_2 < 0.4$

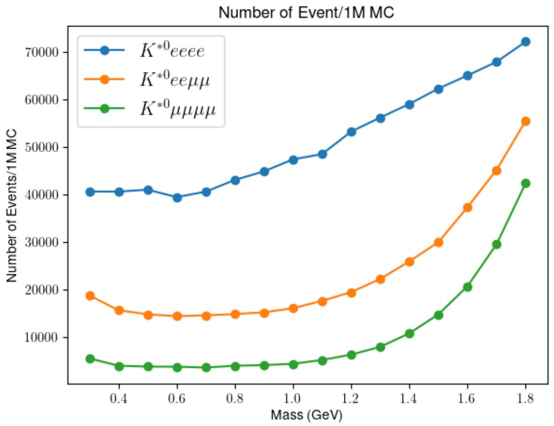


Number of event/1M MC vs Dark photon masses in SignalMC







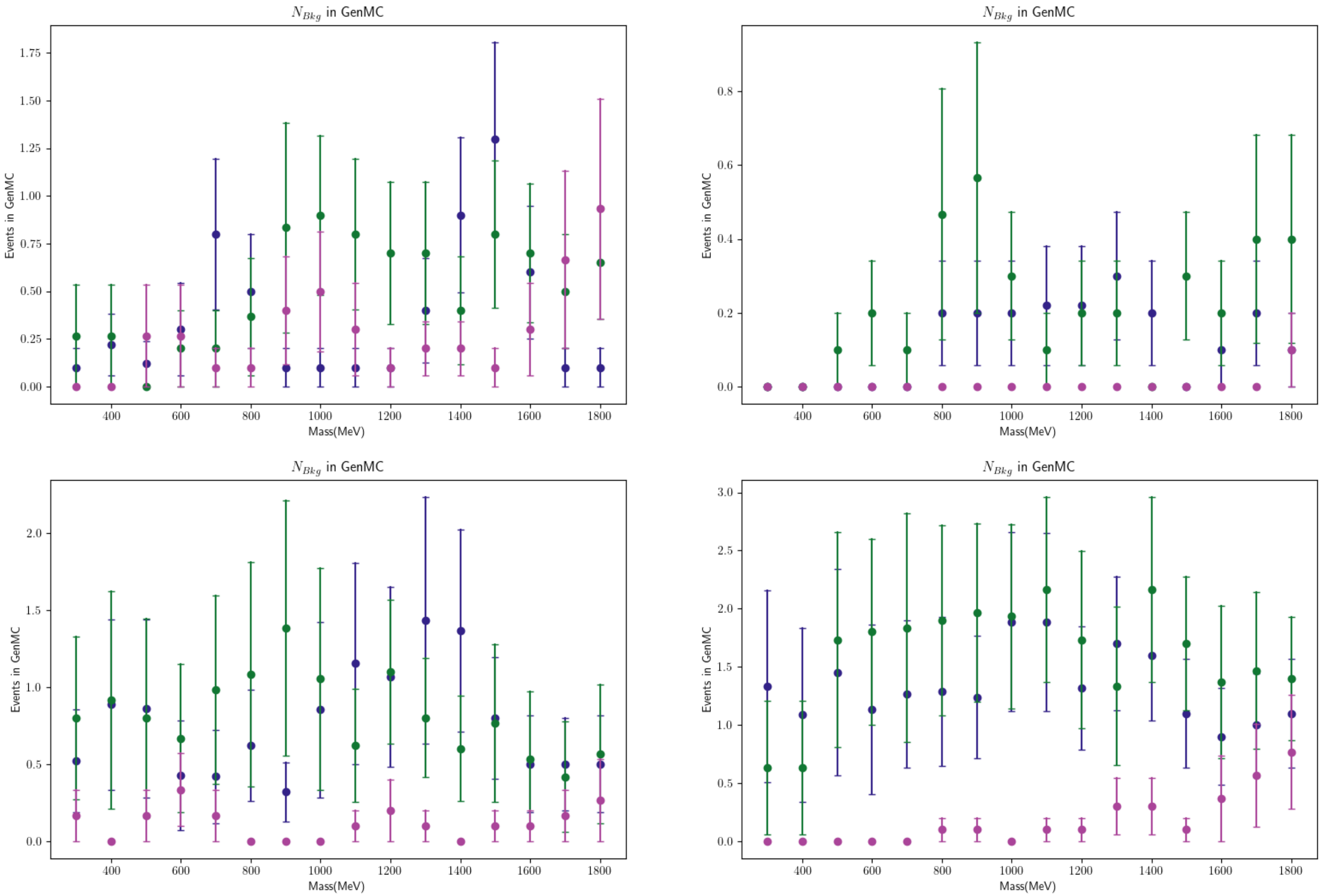


Efficiency tend to increase as M
ass increases.
Minimum around 0.6 GeV

Possible for more higher mass r
egion and 0.2 GeV for 4 electron
subdecay mode.
(Currently 0.3 GeV ~ 1.8 GeV)

K^+ K^0 $eeee$
K^{*+} K^{*0} $ee\mu\mu$
$\mu\mu\mu\mu$

Number of event/1stream vs Dark photon masses in GenMC



This is number of background and its statistical error.

Most of case they are in $O(1)$, 4μ decay have least backgroun ds.

K^+	K^0	$eeee$
		$ee\mu\mu$
K^{*+}	K^{*0}	$\mu\mu\mu\mu$

Expected U.L. of B.F.

Final State	$m_{A'}$	$N_{obs}=0$	$N_{obs}=1$	$N_{obs}=2$	$N_{obs}=3$
$K^0e^+e^-e^+e^-$	0.6	1.32×10^{-7}	2.46×10^{-7}	3.28×10^{-7}	4.28×10^{-7}
	1.1	1.06×10^{-7}	1.96×10^{-7}	2.67×10^{-7}	3.43×10^{-7}
	1.6	9.48×10^{-8}	1.77×10^{-7}	2.37×10^{-7}	3.08×10^{-7}
$K^0e^+e^-\mu^+\mu^-$	0.6	3.16×10^{-7}	5.87×10^{-7}	7.98×10^{-7}	1.02×10^{-6}
	1.1	2.74×10^{-7}	5.11×10^{-7}	6.86×10^{-7}	8.92×10^{-7}
	1.6	1.51×10^{-7}	2.82×10^{-7}	3.83×10^{-7}	4.92×10^{-7}
$K^0\mu^+\mu^-\mu^+\mu^-$	0.6	1.18×10^{-6}	2.20×10^{-6}	2.94×10^{-6}	3.84×10^{-6}
	1.1	8.74×10^{-7}	1.63×10^{-6}	2.17×10^{-6}	2.83×10^{-6}
	1.6	2.87×10^{-6}	5.34×10^{-6}	7.13×10^{-6}	9.31×10^{-6}

Final State	$m_{A'}$	$N_{obs}=0$	$N_{obs}=1$	$N_{obs}=2$	$N_{obs}=3$
$K^{*0}e^+e^-e^+e^-$	0.6	5.07×10^{-7}	1.06×10^{-7}	1.71×10^{-7}	2.71×10^{-7}
	1.1	3.05×10^{-8}	7.01×10^{-8}	1.59×10^{-7}	2.00×10^{-7}
	1.6	3.38×10^{-8}	6.97×10^{-8}	1.08×10^{-7}	1.39×10^{-7}
$K^{*0}e^+e^-\mu^+\mu^-$	0.6	1.07×10^{-7}	2.42×10^{-7}	3.68×10^{-7}	5.44×10^{-7}
	1.1	7.41×10^{-8}	1.78×10^{-7}	2.77×10^{-7}	4.17×10^{-7}
	1.6	4.93×10^{-8}	1.05×10^{-7}	1.72×10^{-7}	2.25×10^{-7}
$K^{*0}\mu^+\mu^-\mu^+\mu^-$	0.6	8.80×10^{-7}	1.64×10^{-6}	2.19×10^{-6}	2.85×10^{-6}
	1.1	6.25×10^{-7}	1.17×10^{-6}	1.56×10^{-6}	2.03×10^{-6}
	1.6	1.47×10^{-7}	2.66×10^{-7}	3.74×10^{-7}	4.75×10^{-7}

Final State	$m_{A'}$	$N_{obs}=0$	$N_{obs}=1$	$N_{obs}=2$	$N_{obs}=3$
$K^+e^+e^-e^+e^-$	0.6	4.43×10^{-8}	8.09×10^{-8}	1.12×10^{-7}	1.43×10^{-7}
	1.1	3.82×10^{-8}	7.12×10^{-8}	9.56×10^{-8}	1.24×10^{-7}
	1.6	2.47×10^{-8}	4.65×10^{-8}	6.83×10^{-8}	8.67×10^{-8}
$K^+e^+e^-\mu^+\mu^-$	0.6	3.33×10^{-8}	6.19×10^{-8}	8.41×10^{-8}	1.08×10^{-7}
	1.1	2.40×10^{-8}	4.80×10^{-8}	7.31×10^{-8}	9.35×10^{-8}
	1.6	2.60×10^{-8}	5.04×10^{-8}	7.53×10^{-8}	9.59×10^{-8}
$K^+\mu^+\mu^-\mu^+\mu^-$	0.6	3.31×10^{-7}	6.07×10^{-7}	8.36×10^{-7}	1.07×10^{-6}
	1.1	2.46×10^{-7}	4.49×10^{-7}	6.22×10^{-7}	7.94×10^{-7}
	1.6	8.10×10^{-8}	1.48×10^{-7}	2.05×10^{-7}	2.62×10^{-7}

Final State	$m_{A'}$	$N_{obs}=1$	$N_{obs}=2$	$N_{obs}=3$	$N_{obs}=4$
$K^{*+}e^+e^-e^+e^-$	0.6	9.19×10^{-8}	1.66×10^{-7}	2.36×10^{-7}	2.99×10^{-7}
	1.1	4.89×10^{-8}	1.03×10^{-7}	1.65×10^{-7}	2.14×10^{-7}
	1.6	5.19×10^{-8}	9.51×10^{-8}	1.37×10^{-7}	1.73×10^{-7}
$K^{*+}e^+e^-\mu^+\mu^-$	0.6	2.16×10^{-7}	4.12×10^{-7}	6.12×10^{-7}	7.79×10^{-7}
	1.1	1.82×10^{-7}	3.43×10^{-7}	5.06×10^{-7}	6.42×10^{-7}
	1.6	8.90×10^{-8}	1.64×10^{-7}	2.38×10^{-7}	3.01×10^{-7}
$K^{*+}\mu^+\mu^-\mu^+\mu^-$	0.6	9.73×10^{-7}	1.77×10^{-6}	2.47×10^{-6}	3.15×10^{-6}
	1.1	7.25×10^{-7}	1.35×10^{-6}	1.81×10^{-6}	2.36×10^{-6}
	1.6	1.88×10^{-7}	3.51×10^{-7}	4.71×10^{-7}	6.13×10^{-7}

Expected upper limit of branching fraction using MC. $O(10^{-8}) \sim O(10^{-6})$

Systematic uncertainty

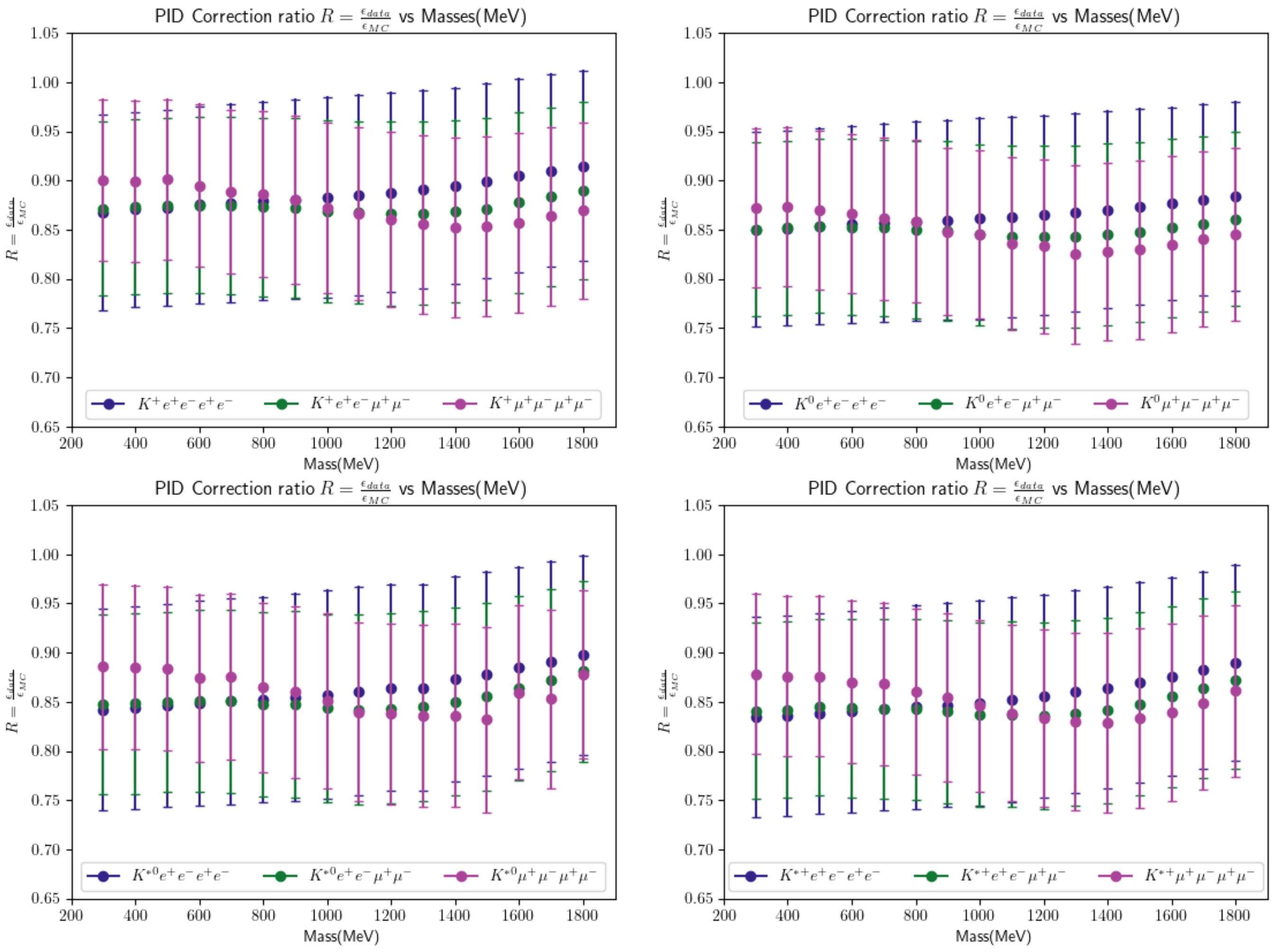
- Major contribution is PID.
- Tracking 0.35%/track
- Increased 0.7%p systematic errors including K^0 particle as I forgot to applied tracking error from $K_S^0 \rightarrow \pi^+\pi^-$

Decay	$K^+e^+e^-e^+e^-$	$K^0e^+e^-e^+e^-$	$K^{*+}e^+e^-e^+e^-$	$K^{*0}e^+e^-e^+e^-$
Mass	1100	1100	1100	1100
Kaon ID	0.0086	0.0001	0.0107	0.0187
Lepton ID 1	0.0207	0.0207	0.0213	0.0214
Lepton ID 2	0.0255	0.0253	0.0259	0.0262
Lepton ID 3	0.0269	0.0270	0.0273	0.0273
Lepton ID 4	0.0287	0.0288	0.0291	0.0294
Tracking	0.0175	0.0210	0.0245	0.0210
NBB	0.0137	0.0137	0.0137	0.0137
Sum	0.1046	0.1037	0.1065	0.1083

Decay	$K^+e^+e^-\mu^+\mu^-$	$K^0e^+e^-\mu^+\mu^-$	$K^{*+}e^+e^-\mu^+\mu^-$	$K^{*0}e^+e^-\mu^+\mu^-$
Mass	1100	1100	1100	1100
Kaon ID	0.0088	0.0001	0.0110	0.0190
Lepton ID 1	0.0196	0.0202	0.0207	0.0207
Lepton ID 2	0.0279	0.0280	0.0278	0.0281
Lepton ID 3	0.0206	0.0205	0.0206	0.0208
Lepton ID 4	0.0242	0.0244	0.0246	0.0249
Tracking	0.0175	0.0210	0.0245	0.0210
NBB	0.0137	0.0137	0.0137	0.0137
Sum	0.0953	0.0951	0.0969	0.0989

Decay	$K^+\mu^+\mu^-\mu^+\mu^-$	$K^0\mu^+\mu^-\mu^+\mu^-$	$K^{*+}\mu^+\mu^-\mu^+\mu^-$	$K^{*0}\mu^+\mu^-\mu^+\mu^-$
Mass	1100	1100	1100	1100
Kaon ID	0.0094	0.0002	0.0114	0.0195
Lepton ID 1	0.0200	0.0201	0.0203	0.0201
Lepton ID 2	0.0224	0.0226	0.0227	0.0227
Lepton ID 3	0.0236	0.0240	0.0241	0.0239
Lepton ID 4	0.0215	0.0215	0.0214	0.0218
Tracking	0.0175	0.0210	0.0245	0.0210
NBB	0.0137	0.0137	0.0137	0.0137
Sum	0.0908	0.0903	0.0920	0.0933

PID Correction ratio R vs Masses



R is around 0.85,
and its error is around 10%.

The more muon event have less error.

K^+	K^0	$eeee$
K^{*0}	K^{*+}	$ee\mu\mu$
		$\mu\mu\mu\mu$

Control sample study

Cuts	notes
$M_{BC} > 5.22GeV$	
$-0.05 < \Delta E < 0.05$	
$3.0 < M_{J\psi} < 3.2$	
$0.97 < M_{\phi} < 1.07$	
$\lvert(M_{J\psi} - M_{\phi}) - (3.1 - 1.020)\rvert < 0.0701$	determined by 95% cut
$M_{(l,K)_i(l,K)_j} > 0.1$	
$R_2 < 0.4$	

Table 19: Signal extraction cut of Control sample $B^+ \to J/\psi\phi K^+$

To validate R_2 cut.

For signal, CB function have used.
For background, Argus function have used.
Comparison between M_{BC} and Modified M_{BC} tested.

Modified $M_{BC} = M_{BC} - E_{beam} + 5.29$

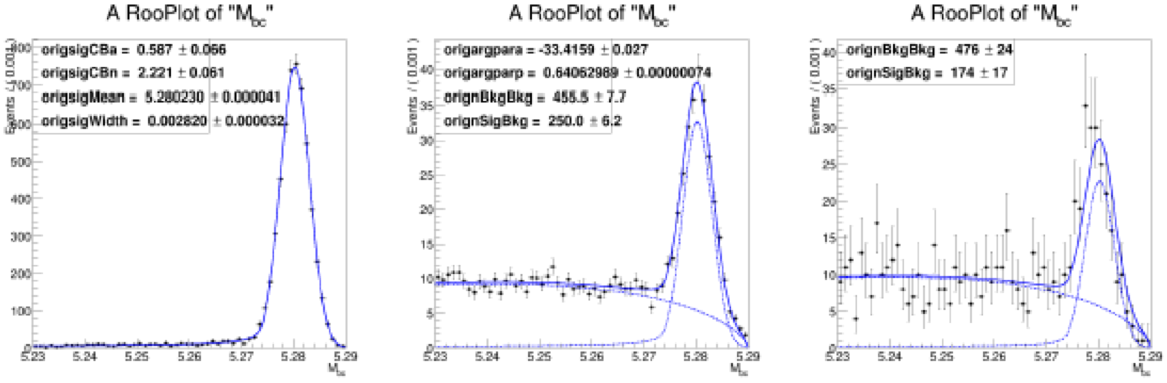


Figure 9: Fitted result of signalMC, genericMC, data from left using M_{BC}

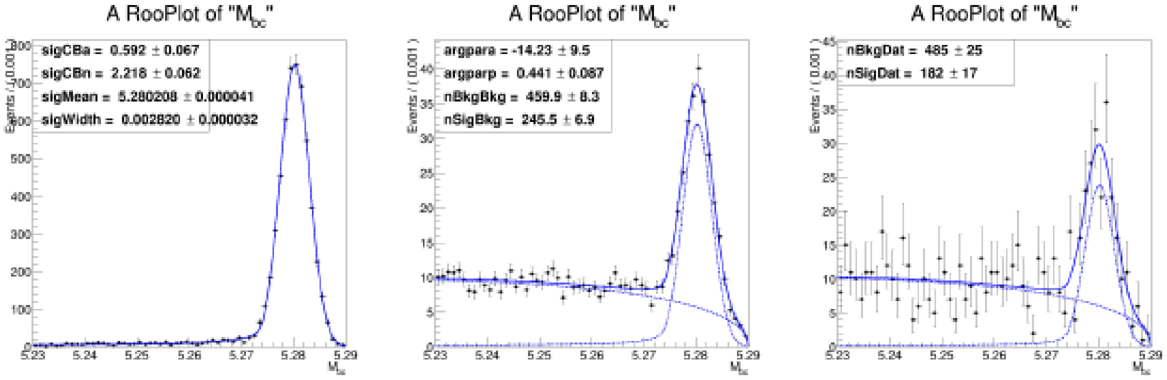


Figure 10: Fitted result of signalMC, genericMC, data from left using modified M_{BC}

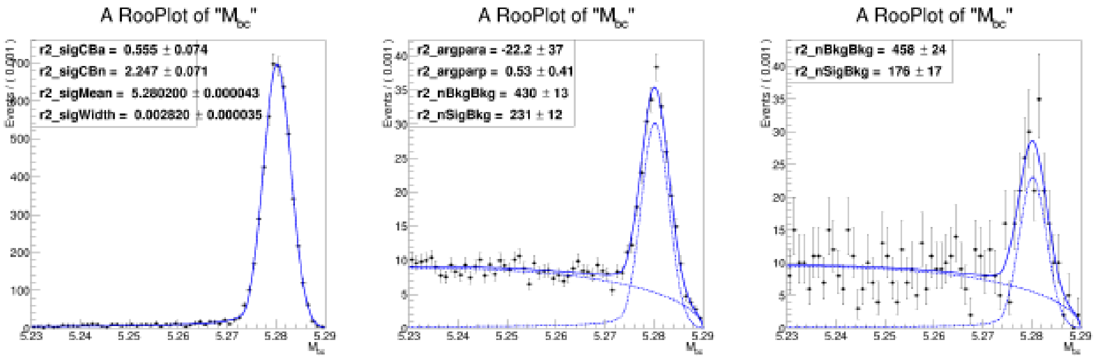


Figure 11: Fitted result of signalMC, genericMC, data from left using modified M_{BC} with R_2

Control sample study cont'd

$R_{trk,/wR_2}$	0.9585 ± 0.0595	$R_{trk,/woR_2}$	0.9578 ± 0.0598
$N_{Sig,MC,/wR_2}$	231 ± 12	$N_{Sig,MC./woR_2}$	245.5 ± 6.9
$N_{Sig,Data,/wR_2}$	176 ± 17	$N_{Sig,Data,/woR_2}$	182 ± 17
$\frac{N_{Sig,MC,/wR_2}}{N_{Sig,MC,/woR_2}}$	$0.9409 \pm 0.052 \pm 0.062$	$\frac{N_{Sig,DATA,/wR_2}}{N_{Sig,DATA,/woR_2}}$	0.9670 ± 0.097
$\frac{N_{Sig,Data,/wR_2} / N_{Sig,Data,/woR_2}}{N_{Sig,MC,/wR_2} / N_{Sig,MC,/woR_2}}$	$1.027 \pm 0.118 \pm 0.068$	$\frac{N_{Sig,Data,/wR_2}}{N_{Sig,MC,/wR_2}}$	0.7619 ± 0.0836

Table 20: Some Values from Control Sample study

Our double ratio comparison on R_2 is well agree between DATA & MC

According to Pull distribution, our fitting works well.

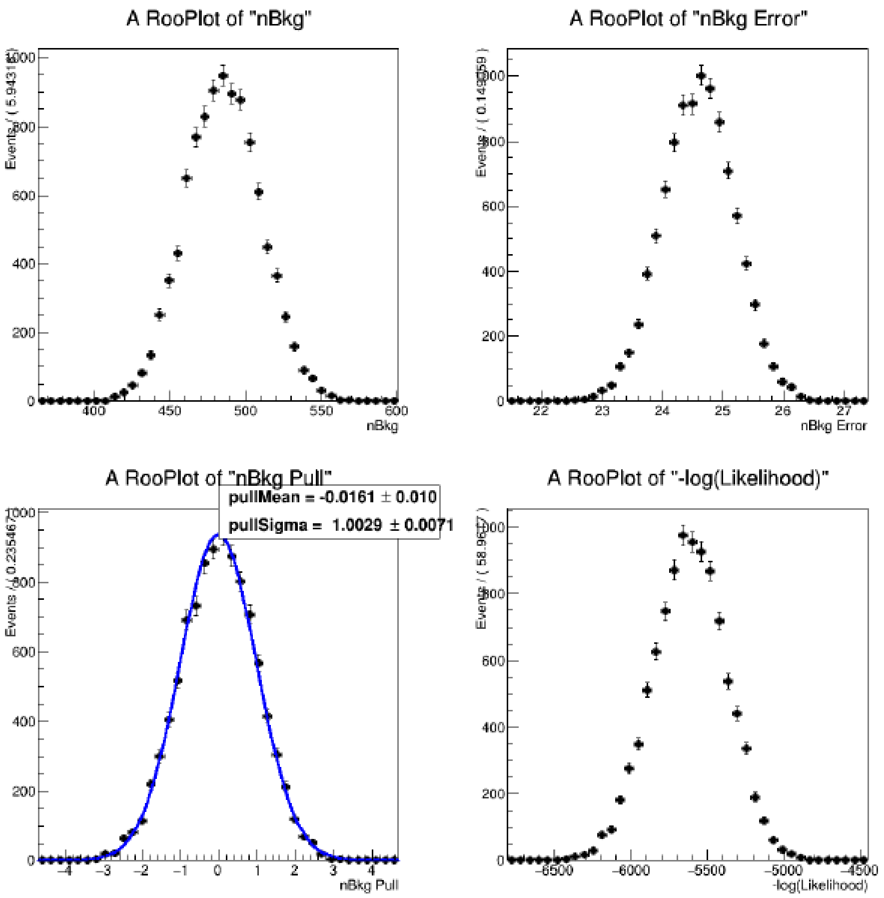


Figure 12: Control sample Toy MC study result

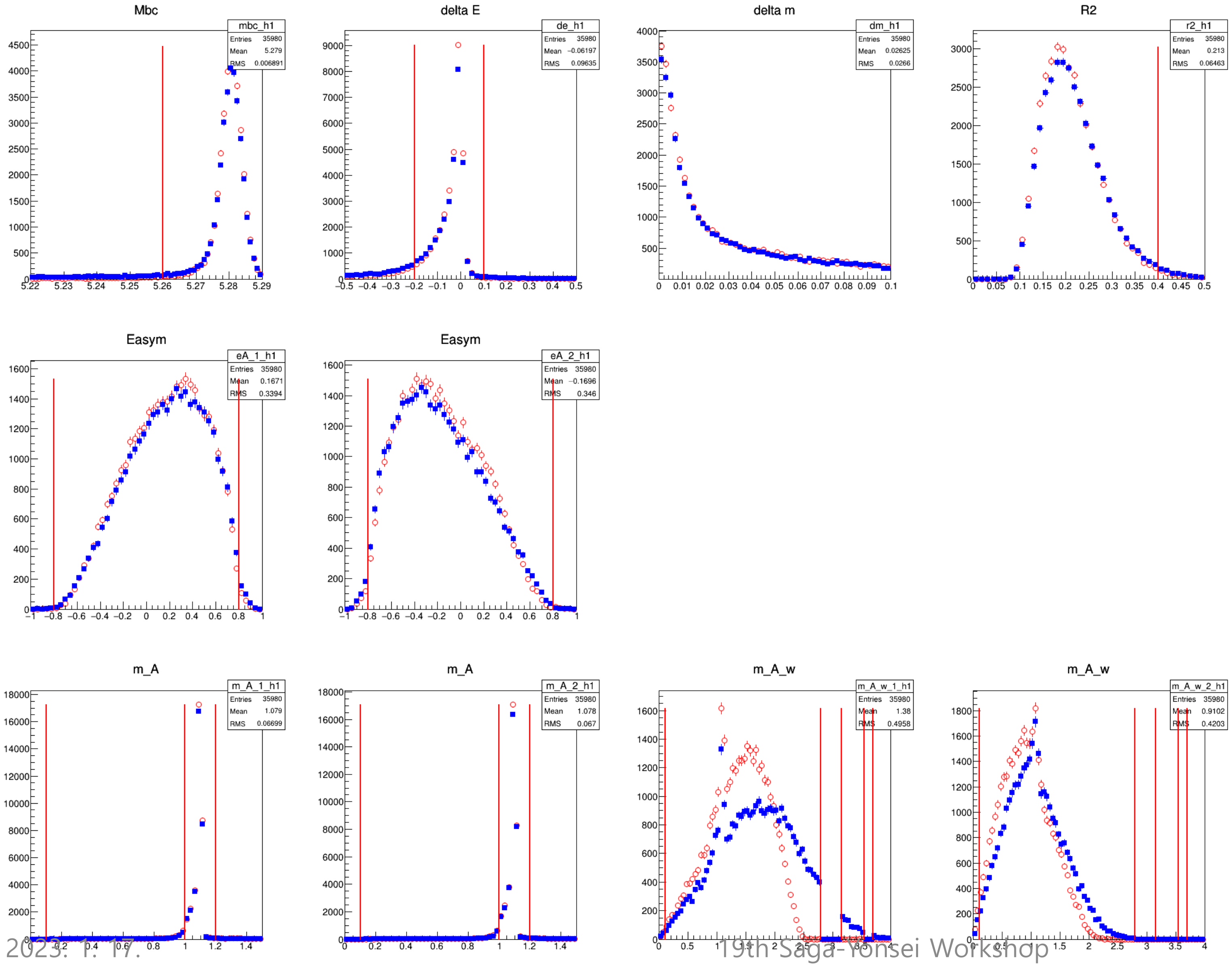
Control sample study cont'd

	BF	Notes
BF_{PDG}	$(5.0 \pm 0.4) \times 10^{-5}$	BABR/CLE2
BF_{MC}	$(5.2) \times 10^{-5}$	DECAY.DEC
BF_{MC}	$(5.41 \pm 0.28 \pm 0.34) \times 10^{-5}$	
BF_{DATA}	$(4.30 \pm 0.41 \pm 0.27) \times 10^{-5}$	
BF_{DATA}^{BN1565}	$(4.35 \pm 0.31 \pm 0.19) \times 10^{-5}$	Belle Note 1565 [5]
$\frac{BF_{DATA}}{BF_{PDG}}$	(0.86 ± 0.12)	slight bigger than 1 σ from 1

Table 21: Branching fraction of $B^+ \to J\psi\phi K^+$ with R_2

- There are some discrepancy between DATA & MC.
- Also have some discrepancy between DATA & PDG
- But our B.F measurement on DATA is consistent with our new study, BN#1565

Intermediate scalar particle effect test



Referees asked to check difference between

$B \to Kh', h' \to A'A', A \to l^+l^-$

And

$B \to KA'A', A \to l^+l^-$

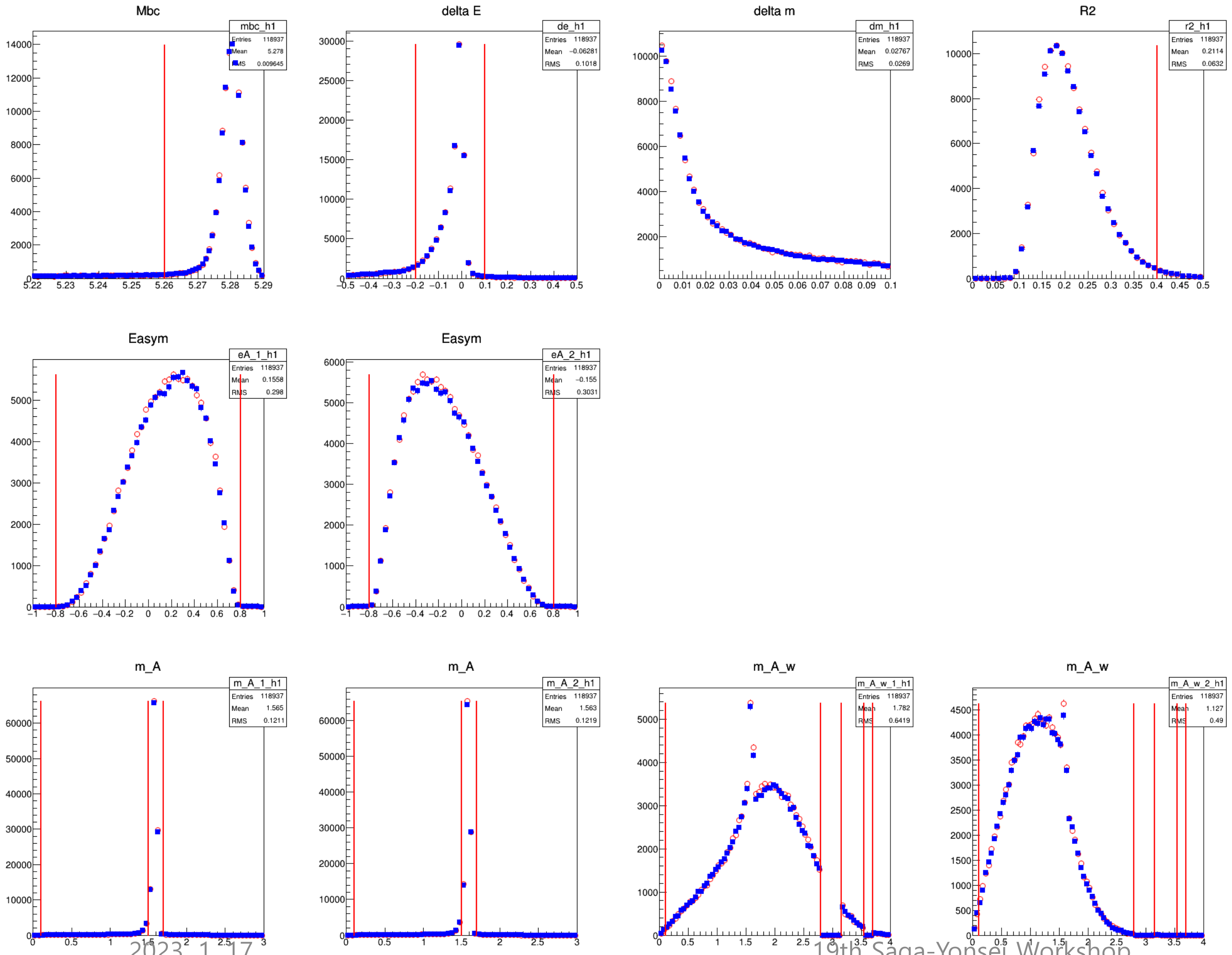
Both are $A'(1100)$ signal MC samples. To see the differences, I draw figure of 2 dark photon separate.

Red empty circle decay via $h'(3000)$

Blue Full square is direct decay

Have almost no difference Except $m_{A_w}(m_{l_{1,2},l_{4,3}})$ as it is limited by h' mass. Also efficiency little bit affected.

PHOTOS effect test



Referees also asked to check difference between

Decay B+
1.0 K+ A(1600) A(1600) PHSP

And

Decay B+
1.0 K+ A(1600) A(1600)
PHOTOS PHSP

Both are $A'(1600)$ signal MC samples. To see the differences, I draw figure of 2 dark photon separate.

Red empty circle decay via $h'(3000)$
Blue Full square is direct decay

Both of signalMC have almost no discrepancy

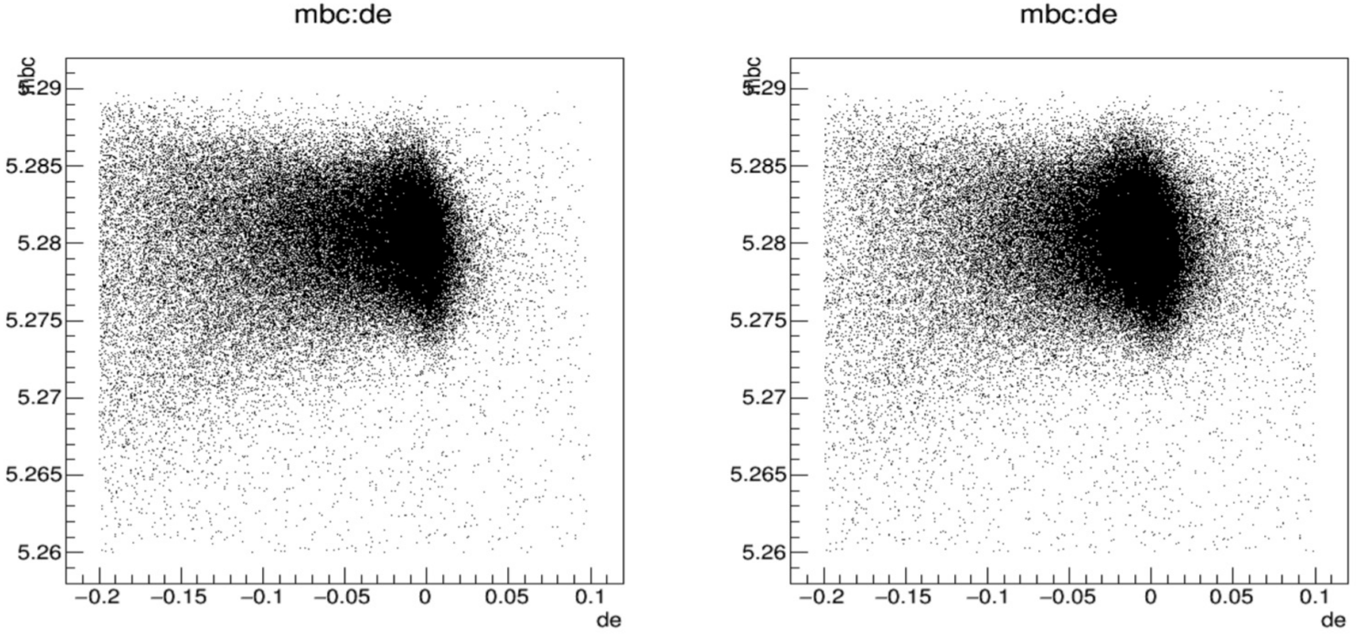
Summary

- Testing several unconsidered/ignored effect according to internal referees' advice
  - Intermediate scalar particle masses.
  - Not using PHOTOS on hadron and dark-photon decay (ex : $B^+ \rightarrow K^+A'A'$).
  - K_S^0 tracking uncertainty

- Updating Belle Note according to test result

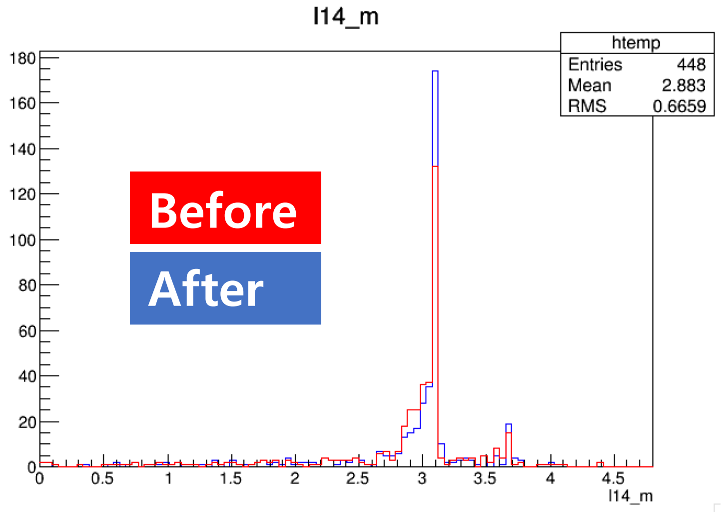
Backup

Bremsstrahlung reconstruction



$M_{bc}\ vs\ \Delta E$ before, after bremsstrahlung reconstruction

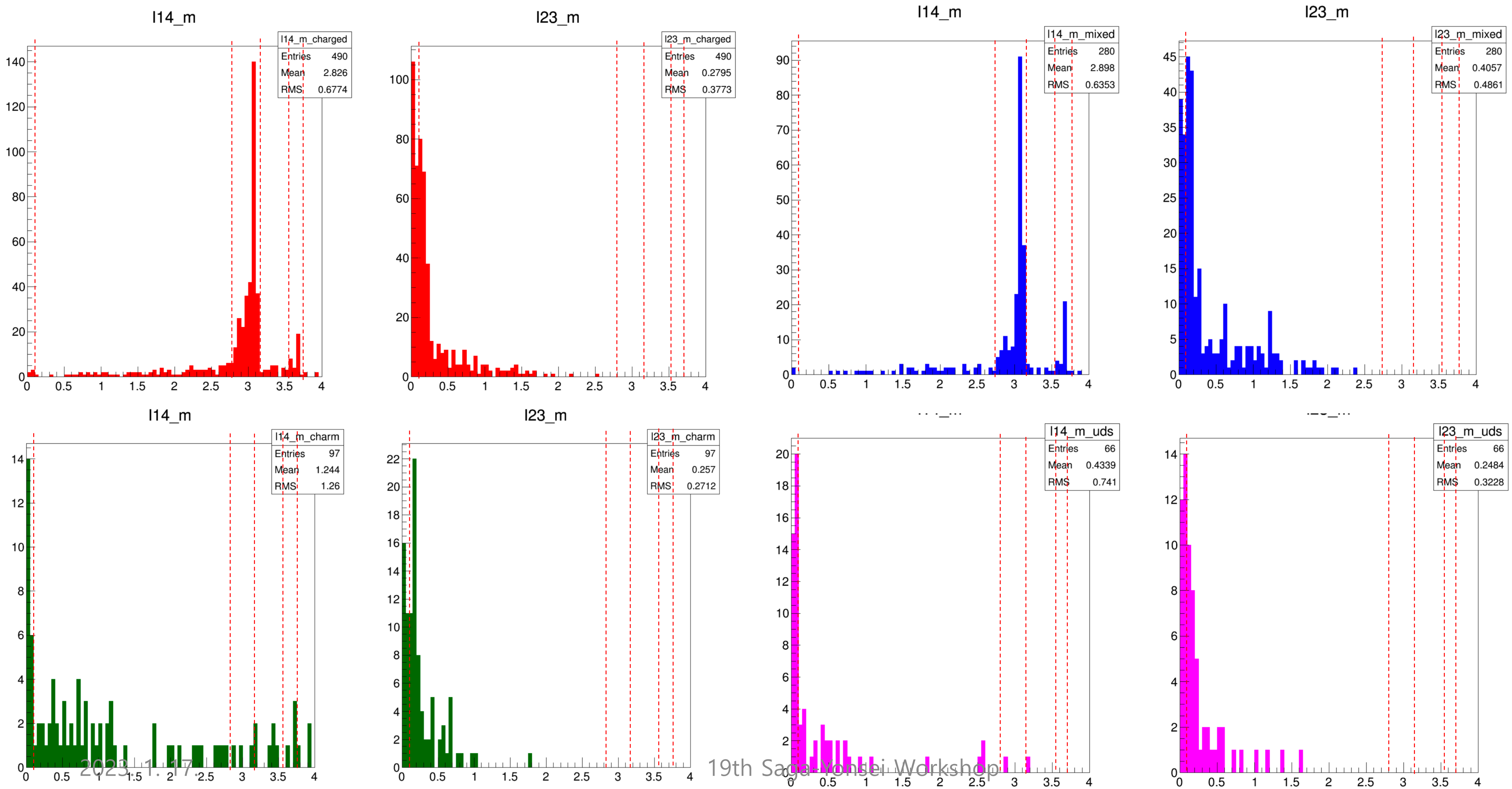
$\angle_e^\gamma < 0.05\, rad$ used bremsstrahlung reconstruction.
Electron containing mode have Bremsstrahlung reconstruction process



Effect on J/ψ, $\psi(2S)$ background veto

Low mass/cc veto

J/ψ veto : $2.8 < m_{A'_w} < 3.15$ GeV
$\psi(2S)$ veto : $3.55 < m_{A'_w} < 3.7$ GeV
Low mass veto
$m_{A'} < 0.1$ GeV, $m_{A'} < 0.1$ GeV



Charged
Mixed
Charm
Uds

$\Delta m_{A'}$ cut determination

Background is almost flat.
Figure of merit punzi fluctuates hard due to lack of background. ($O(1)$)
Signal 95% cut applied to some points,
And interpolated it with dark photon mass

Final States	0.6 GeV	1.1 GeV	1.6 GeV	Final States	0.6 GeV	1.1 GeV	1.6 GeV
$K^0e^+e^-e^+e^-$	0.062	0.068	0.078	$K^+e^+e^-e^+e^-$	0.060	0.068	0.080
$K^0e^+e^-\mu^+\mu^-$	0.056	0.064	0.074	$K^+e^+e^-\mu^+\mu^-$	0.054	0.062	0.074
$K^0\mu^+\mu^-\mu^+\mu^-$	0.016	0.020	0.030	$K^+\mu^+\mu^-\mu^+\mu^-$	0.014	0.020	0.030
$K^{*0}e^+e^-e^+e^-$	0.062	0.068	0.078	$K^{*+}e^+e^-e^+e^-$	0.064	0.068	0.078
$K^{*0}e^+e^-\mu^+\mu^-$	0.058	0.064	0.076	$K^{*+}e^+e^-\mu^+\mu^-$	0.056	0.062	0.072
$K^{*0}\mu^+\mu^-\mu^+\mu^-$	0.016	0.024	0.030	$K^{*+}\mu^+\mu^-\mu^+\mu^-$	0.020	0.028	0.030

PID Correction

	Mass (GeV)	K^+		K^0		K^{*+}		K^{*0}	
		R	σ_R	R	σ_R	R	σ_R	R	σ_R
$e^+e^-e^+e^-$	0.6	0.8751	0.1004	0.8553	0.1004	0.8402	0.1026	0.8483	0.1041
	1.1	0.8849	0.1021	0.8628	0.1018	0.8519	0.1042	0.8609	0.1059
	1.6	0.9049	0.0983	0.8765	0.0978	0.8757	0.1009	0.8844	0.1024
$e^+e^-\mu^+\mu^-$	0.6	0.8750	0.0896	0.8526	0.0895	0.8434	0.0908	0.8509	0.0925
	1.1	0.8673	0.0928	0.8427	0.0931	0.8375	0.0943	0.8422	0.0965
	1.6	0.8777	0.0918	0.8520	0.0906	0.8553	0.0918	0.8637	0.0935
$\mu^+\mu^-\mu^+\mu^-$	0.6	0.8949	0.0825	0.8663	0.0811	0.8699	0.0824	0.8741	0.0848
	1.1	0.8661	0.0881	0.8357	0.0882	0.8385	0.0892	0.8396	0.0906
	1.6	0.8568	0.0912	0.8352	0.0895	0.8395	0.0901	0.8596	0.0881

Table. PID correction ratio($R = \frac{\epsilon_{DATA}}{\epsilon_{MC}}$) and its uncertainty

N_{BKG} and its statistical error

Final State	$m_{A'}$	N_{Bkg}	σ_{Bkg}	Final State	$m_{A'}$	N_{Bkg}	σ_{Bkg}
$B^+ \to K^+e^+e^-e^+e^-$	1.1	0.30	0.17	$B^0 \to K^0e^+e^-e^+e^-$	1.1	0.32	0.19
$B^+ \to K^+e^+e^-\mu^+\mu^-$	1.1	1.20	0.35	$B^0 \to K^0e^+e^-\mu^+\mu^-$	1.1	0.10	0.10
$B^+ \to K^+\mu^+\mu^-\mu^+\mu^-$	1.1	0.30	0.17	$B^0 \to K^0\mu^+\mu^-\mu^+\mu^-$	1.1	0.00	0.00
$B^+ \to K^{*+}e^+e^-e^+e^-$	1.1	2.87	0.80	$B^0 \to K^{*0}e^+e^-e^+e^-$	1.1	2.12	0.71
$B^+ \to K^{*+}e^+e^-\mu^+\mu^-$	1.1	3.67	0.88	$B^0 \to K^{*0}e^+e^-\mu^+\mu^-$	1.1	1.92	0.46
$B^+ \to K^{*+}\mu^+\mu^-\mu^+\mu^-$	1.1	0.87	0.43	$B^0 \to K^{*0}\mu^+\mu^-\mu^+\mu^-$	1.1	0.40	0.20

After cut, in most of mass region, $N_{BKG}{\sim}O(1)$, E.U.L of B.F $O(10^{-8}){\sim}O(10^{-6})$