

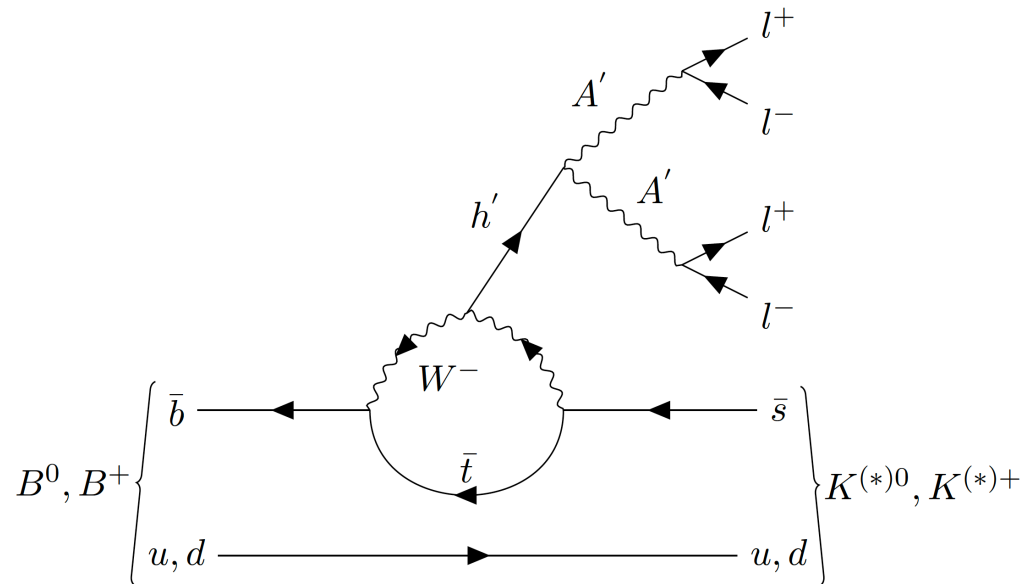
$$B \rightarrow KA'A'$$

Yongkyu Kim

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Introduction



In previous research, theorists expected this decay to connect real matter world and dark world. (Multilepton signature of a hidden sector in rare B decays)

Final States

$B^+ \rightarrow K^+ e^+ e^- e^+ e^-$	$B^0 \rightarrow K^0 e^+ e^- e^+ e^-$	$B^+ \rightarrow K^{*+} e^+ e^- e^+ e^-$	$B^0 \rightarrow K^{*0} e^+ e^- e^+ e^-$
$B^+ \rightarrow K^+ e^+ e^- \mu^+ \mu^-$	$B^0 \rightarrow K^0 e^+ e^- \mu^+ \mu^-$	$B^+ \rightarrow K^{*+} e^+ e^- \mu^+ \mu^-$	$B^0 \rightarrow K^{*0} e^+ e^- \mu^+ \mu^-$
$B^+ \rightarrow K^+ \mu^+ \mu^- \mu^+ \mu^-$	$B^0 \rightarrow K^0 \mu^+ \mu^- \mu^+ \mu^-$	$B^+ \rightarrow K^{*+} \mu^+ \mu^- \mu^+ \mu^-$	$B^0 \rightarrow K^{*0} \mu^+ \mu^- \mu^+ \mu^-$

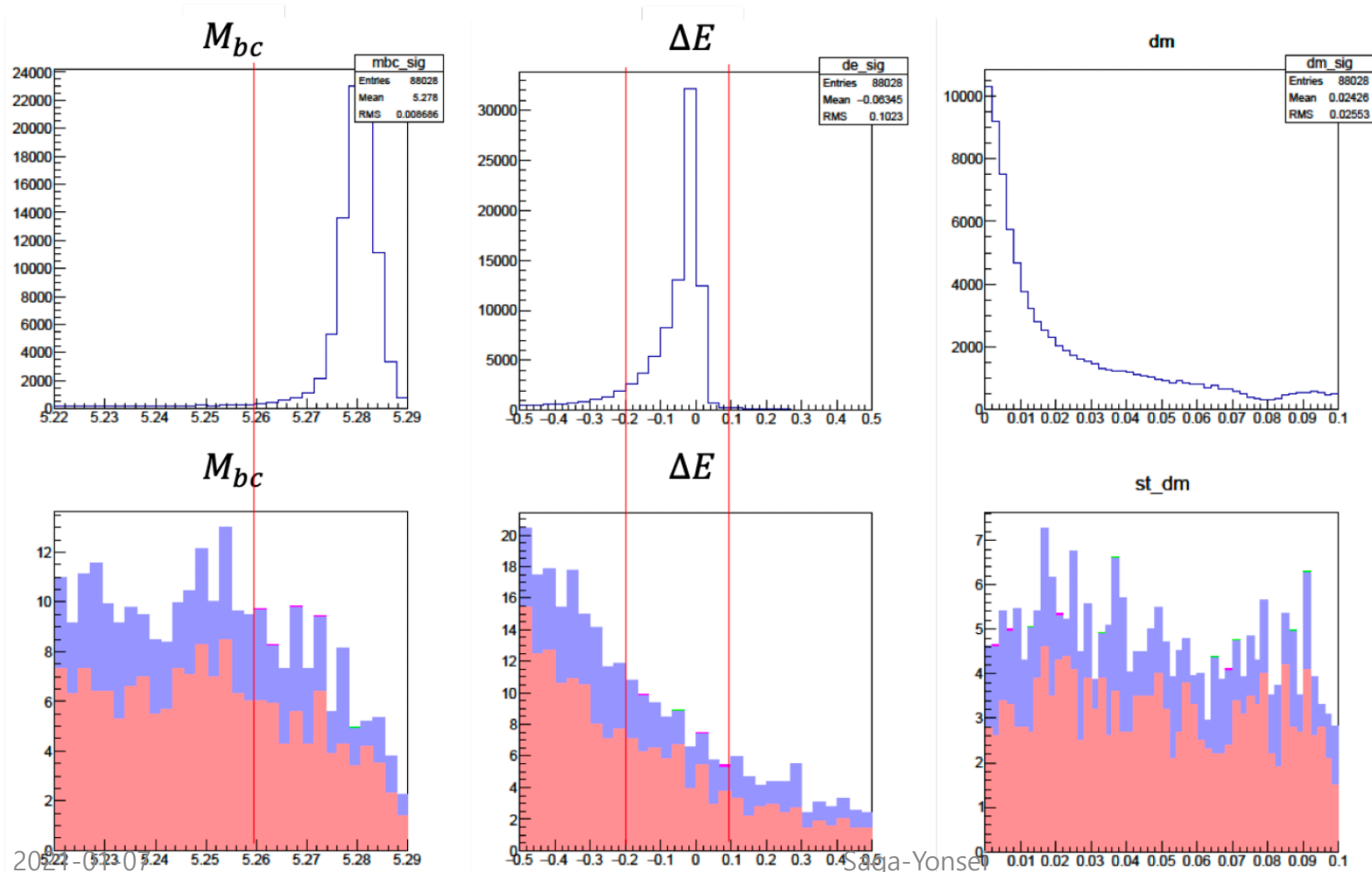
Particle Selection

- Charged track selection : $dr < 2$ cm, $dz < 5$ cm.
- e^\pm selection : $\mathcal{L}_e > 0.9$, $\mathcal{L}_e > \mathcal{L}_{\mu'}$,
Bremsstrahlung reconstructed ($\angle < 0.05$)
- μ^\pm selection : $\mathcal{L}_\mu > 0.9$, $\mathcal{L}_\mu > \mathcal{L}_e$
- K^\pm selection : $\mathcal{L}_{K/\pi} > 0.6$, $\mathcal{L}_{P/K} > 0.4$
- π^\pm selection : $\mathcal{L}_{K/\pi} < 0.4$, $\mathcal{L}_{P/\pi} < 0.4$
- K_S^0 selection : From *Mdst_vee2* table, *niskfinder* standard cut applied.
- γ selection : Endcap : $E_\gamma > 0.15$ GeV
Barrel : $E_\gamma > 0.05$ GeV good gamma selection applied.
- π^0 selection : From *Mdst_pi0*, $0.1 < m_{\pi^0} < 0.14$ (GeV), $p_{\pi^0} > 0.1$ (GeV)
- Kaon Reconstruction
 - K^{*0} : From $K^{*0} \rightarrow K^+\pi^-$ and $K^{*0} \rightarrow K_S^0\pi^0$, $0.8 < M_{K^{*0}} < 1.0$ (GeV)
 - K^{*+} : From $K^{*+} \rightarrow K_S^0\pi^+$ and $K^{*+} \rightarrow K^+\pi^0$, $0.8 < M_{K^{*+}} < 1.0$ (GeV)
- Dark photon reconstruction
 - We chose the $\Delta m_{A'}$ neutral lepton pairs as our dark photon. To reduce effect of $c\bar{c}$ background, we used $m_{A'W}$ (Wrong paired dark photon mass)
 - Low mass veto : there was many backgrounds by arbitrary low mass leptons.
 - $c\bar{c}$ veto : we vetoed $2.8 < m_{A'W} < 3.15$, $3.55 < m_{A'W} < 3.7$ (GeV).
 - $\phi(1020)$ veto : Didn't observed anything on MC. We only vetoed 10MeV region centered at 1.02 GeV.
- Best B selection : Least $|\Delta E|$

Used Variables

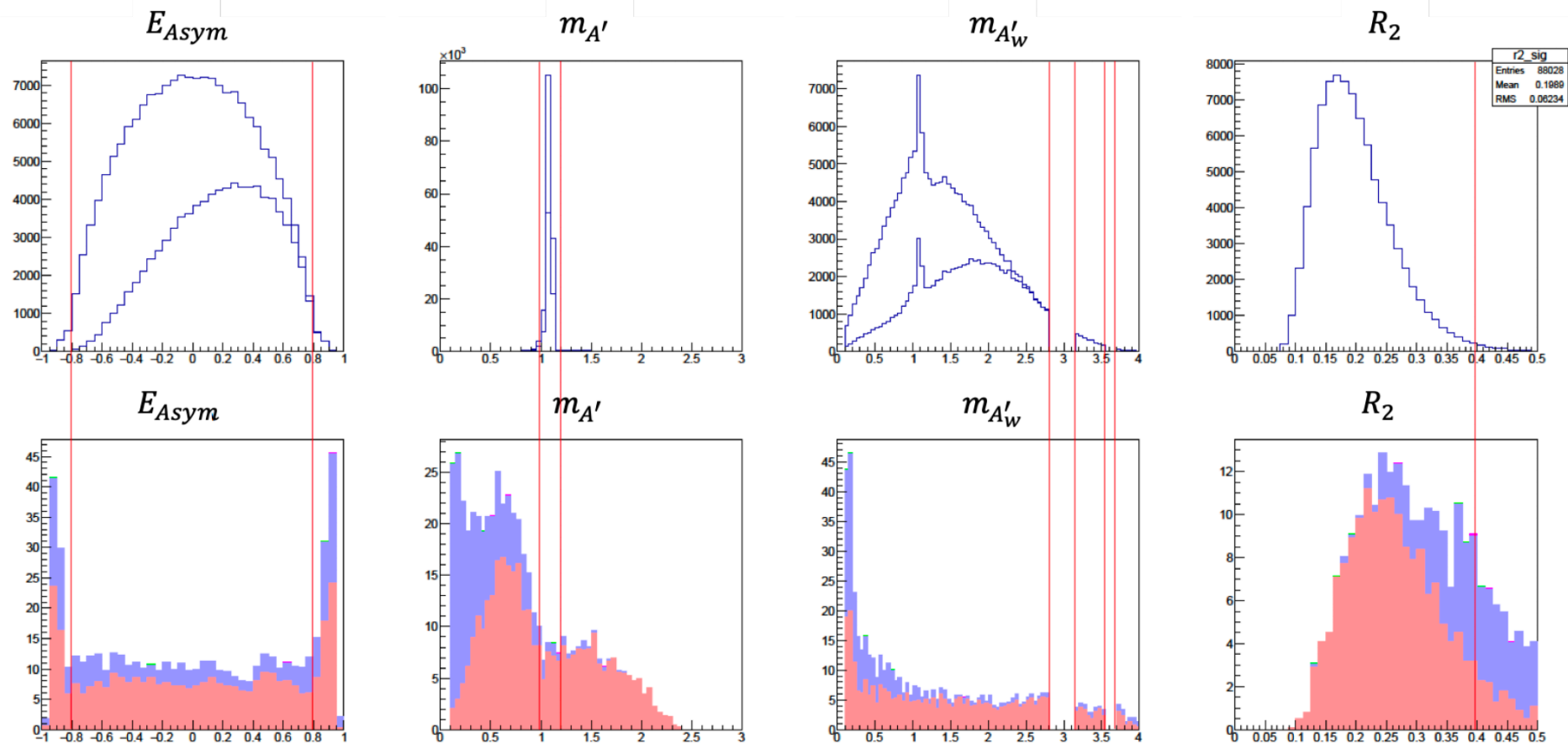
- M_{BC} : Beam constrained Mass
- ΔE : Energy difference
- $\Delta m_{A'}$: difference between two dark photon masses
- E_{Asym} : Energy Asymmetry between dark photon's daughter
- $m_{A'}$: mass of dark photon
- $m_{A'_W}$: mass of wrong paired dark-photon
- R_2 : Ratio of 2nd Fox-Wolfram Moment

Signal Extraction



$M_{BC} > 5.26$
 $-0.2 < \Delta E < 0.1$
 $\Delta m_{A'} < 0.1$
 More cut applied later

Signal Extraction



$$|E_{Asym}| < 0.8$$

$$|m_{A'} - \bar{m}_{A'}| < 0.1$$

Low mass veto

$$m_{A'} > 0.1$$

$$m_{A'W} > 0.1$$

$c\bar{c}$ veto

$$2.8 < m_{A'W} < 3.15$$

$$3.55 < m_{A'W} < 3.7$$

Continuum suppression

$$R_2 < 0.4$$

$\Delta m_{A'}$ 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
$K^0 e^+ e^- e^+ e^-$	0.062	0.068	0.078	$K^+ e^+ e^- e^+ e^-$	0.060	0.068	0.080
$K^0 e^+ e^- \mu^+ \mu^-$	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

Signal Efficiency

$B \rightarrow K^{(*)} A' A'$							
Final state	$m_{A'}$	N_{sig}	ϵ_{sig} (%)	Final state	$m_{A'}$	N_{sig}	ϵ_{sig} (%)
$K^0 e^+ e^- e^+ e^-$	0.6	19105	1.91 %	$K^{*0} e^+ e^- e^+ e^-$	0.6	30223	3.02 %
	1.1	26294	2.63 %		1.1	43106	4.31 %
	1.6	31092	3.11 %		1.6	59251	5.93 %
$K^0 e^+ e^- \mu^+ \mu^-$	0.6	8276	0.83 %	$K^{*0} e^+ e^- \mu^+ \mu^-$	0.6	12155	1.22 %
	1.1	10849	1.08 %		1.1	16424	1.64 %
	1.6	19767	1.98 %		1.6	35476	3.55 %
$K^0 \mu^+ \mu^- \mu^+ \mu^-$	0.6	2570	0.25 %	$K^{*0} \mu^+ \mu^- \mu^+ \mu^-$	0.6	3492	0.35 %
	1.1	3675	0.37 %		1.1	4916	0.49 %
	1.6	11243	1.24 %		1.6	19547	1.95 %
$K^+ e^+ e^- e^+ e^-$	0.6	48357	4.84 %	$K^{*+} e^+ e^- e^+ e^-$	0.6	23297	2.33 %
	1.1	69404	6.94 %		1.1	33910	3.39 %
	1.6	92550	9.25 %		1.6	47480	4.75 %
$K^+ e^+ e^- \mu^+ \mu^-$	0.6	22829	2.28 %	$K^{*+} e^+ e^- \mu^+ \mu^-$	0.6	9446	0.94 %
	1.1	31023	3.10 %		1.1	12875	1.29 %
	1.6	60488	6.05 %		1.6	28393	2.84 %
$K^+ \mu^+ \mu^- \mu^+ \mu^-$	0.6	8010	0.80 %	$K^{*+} \mu^+ \mu^- \mu^+ \mu^-$	0.6	2742	0.27 %
	1.1	11281	1.13 %		1.1	4020	0.40 %
	1.6	34310	3.43 %		1.6	15530	1.55 %

Expected Upper limit of Branching Fraction

Mode	N_{bkg}	σ_{bkg}	ϵ_{sig}	U.L of \mathcal{B}
$K^0 e^+ e^- e^+ e^-$	0.32	0.19	2.62%	2.13×10^{-7}
$K^0 e^+ e^- \mu^+ \mu^-$	0.10	0.10	1.08%	5.57×10^{-7}
$K^0 \mu^+ \mu^- \mu^+ \mu^-$	0.00	0.00	0.36%	1.67×10^{-6}
$K^{*0} e^+ e^- e^+ e^-$	2.19	0.63	4.12%	1.78×10^{-7}
$K^{*0} e^+ e^- \mu^+ \mu^-$	2.73	0.73	1.54%	4.03×10^{-7}
$K^{*0} \mu^+ \mu^- \mu^+ \mu^-$	0.60	0.24	0.46%	1.11×10^{-6}
$K^+ e^+ e^- e^+ e^-$	0.30	0.17	6.94%	7.70×10^{-8}
$K^+ e^+ e^- \mu^+ \mu^-$	1.20	0.35	3.10%	2.02×10^{-7}
$K^+ \mu^+ \mu^- \mu^+ \mu^-$	0.30	0.17	1.13%	4.73×10^{-7}
$K^{*+} e^+ e^- e^+ e^-$	1.43	0.57	1.40%	4.29×10^{-7}
$K^{*+} e^+ e^- \mu^+ \mu^-$	1.00	0.32	0.51%	1.28×10^{-6}
$K^{*+} \mu^+ \mu^- \mu^+ \mu^-$	0.10	0.10	0.14%	4.12×10^{-6}

Most N_{BKG} is in $O(1)$.

Expected upper limit of branching fraction is calculated using polelim.

We set N_{obs} as least same or bigger integer.

Most Expected upper limit of branching fraction is less than $10^{-7} \sim 10^{-6}$

Control sample study. $B^+ \rightarrow D^0 \overline{D}^0 K^+$

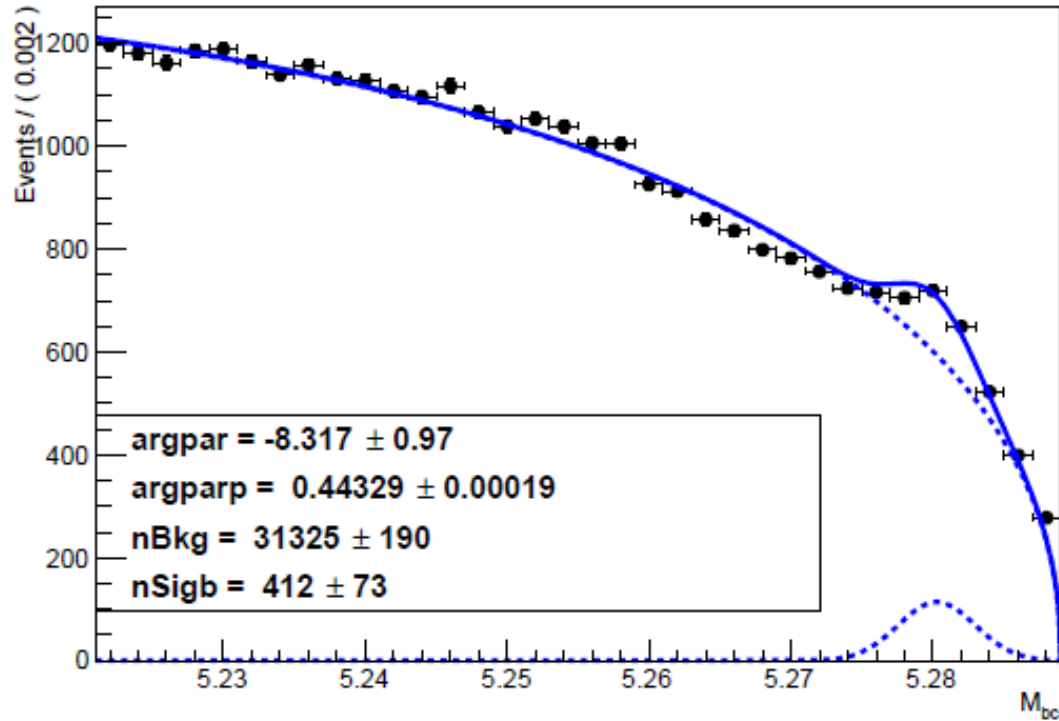
- $M_{bc} > 5.22$ ($M_{bc} > 5.27$) Inside () : cut of $B \rightarrow KA'A'$, if cut is different
- $|\Delta E| < 0.05$ ($|\Delta E| < 0.1$), Best B selection using Least $|\Delta E|$.
- $|\Delta M_{A'}| < 0.0698$ Best A' selection., (Mass dependent value.)
- $R_2 < 0.4$
- $E_{Asym} < 0.8$
- $|M_{A'} - 1.865| < 0.02$. (0.1 with mass dependent value.)
- Ands vetos.

Many decay in our control sample.

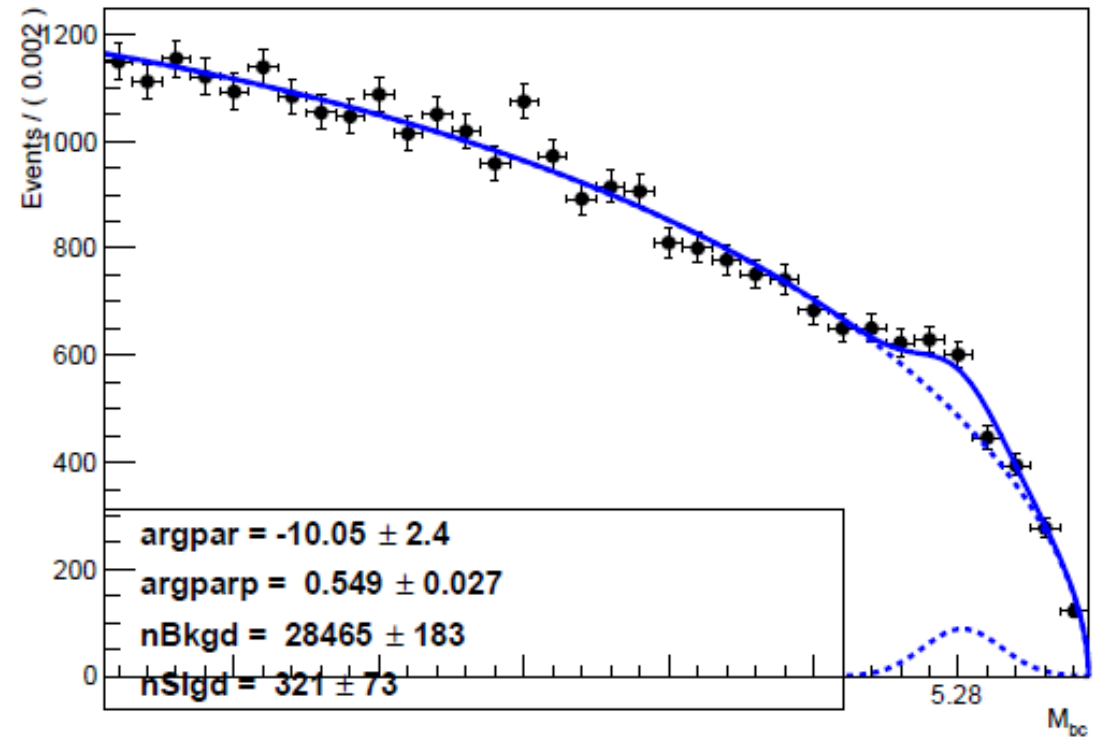
N_{obs}	PDG	ϵ	\overline{N}_{MC}	B.F(Ds->DK)
$B^+ \rightarrow D^0 \overline{D^0} K^+$	278.29	0.155	238.97	Control sample
$B^+ \rightarrow D_{s2}^{*+} (2573) \overline{D^0}$	1.34	0.136	26.65	$(8 \pm 15) \times 10^{-6}$
$B^+ \rightarrow D_{s1}^{*+} (2700) \overline{D^0}$	104.70	0.151	49.40	$(5.6 \pm 1.8) \times 10^{-4}$
$B^+ \rightarrow K^+ \psi(3770)$	31.20	0.168	53.39	$(1.5 \pm 0.5) \times 10^{-4}$
$B^+ \rightarrow K^+ \psi(4040)$			0.16	$< 1.3 \times 10^{-4*}$)
$B^+ \rightarrow K^+ \psi(4160)$	16.25	0.164	36.46	$(8 \pm 5) \times 10^{-5}$
$B^+ \rightarrow K^+ X(3872)$			1.98	$< 6.0 \times 10^{-5}$
Sum	431.80		407.00	

Shape difference between MC and DATA

A RooPlot of " M_{bc} "



A RooPlot of " M_{bc} "



With free argus parameter.

So...

- Shape difference is quite big.
- Background is huge.
- N_{sig} difference $\sim 1.5\sigma$ between data and MC

- Changed our control sample decay mode.
- $B^+ \rightarrow J/\psi\phi K^+$ where $J/\psi \rightarrow l^+l^-$, $\phi \rightarrow K^+K^-$

Selections

- $M_{BC} > 5.22$ As we use fit, M_{BC} are loosen
- $-0.2 < \Delta E < 0.1$
- $|\Delta M_{J/\psi\phi} - (3.1 - 1.020)| < 0.0701$
- $E_{Asym} < 0.8$ Energy asymmetry of leptons and Kaons
- $|M_{J/\psi} - 3.1| < 0.03$ These masses are narrower due to BG
- $|M_{\phi} - 1.020| < 0.03$ < 0.1 for $B \rightarrow KA'A'$
- $R_2 < 0.4$
- Best $J/\psi\phi$ pair selection : Least $|\Delta M_{J/\psi\phi} - (3.1 - 1.020)|$
- Best B selection : Least $|\Delta E|$

Fitting result using MC

SigMC : CB
GenMC : CB+Argus

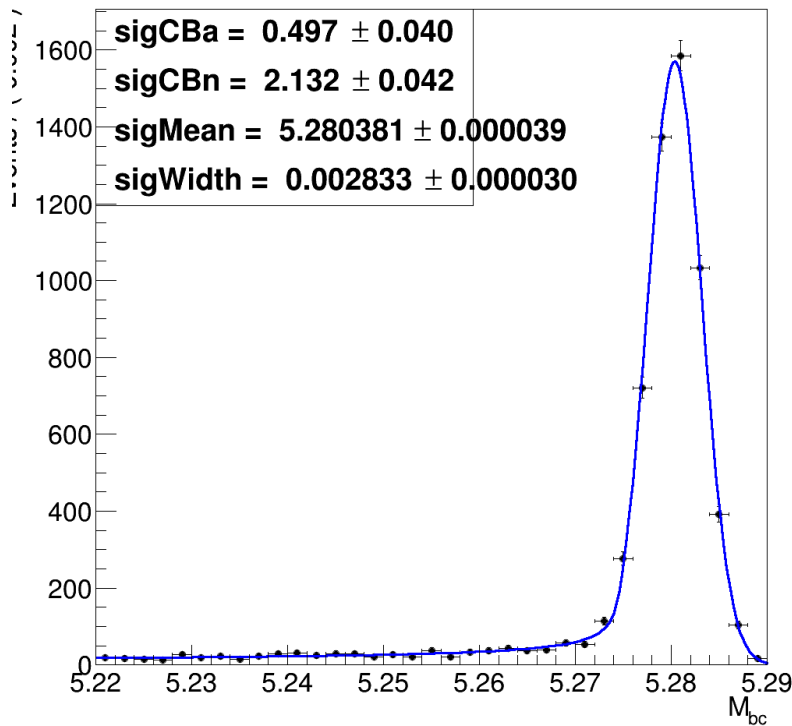
Expected $N_{sig} \sim 254.9$
using DECA.Y.DEC

Expected $N_{sig} \sim 251.9$
using PDG value.

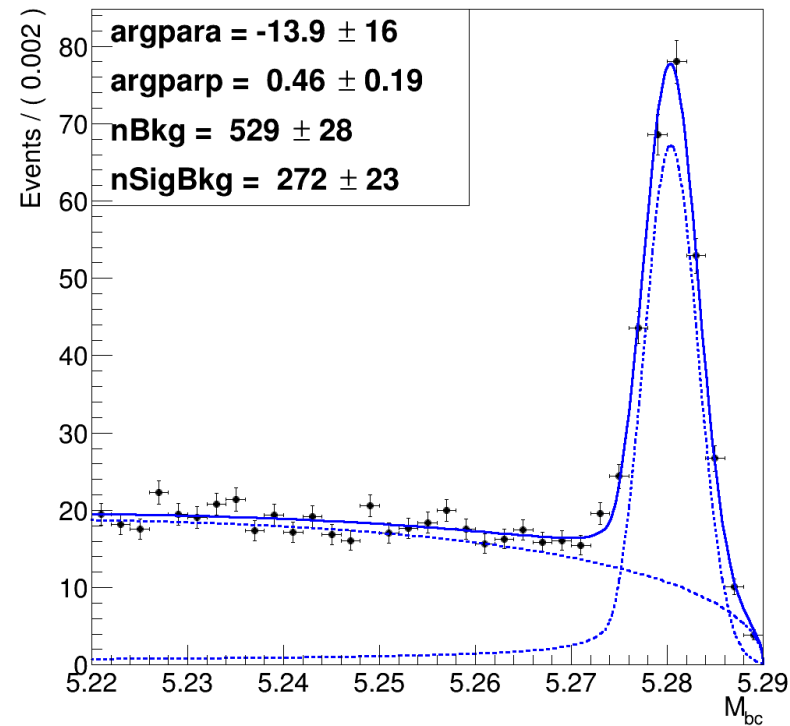
Although I did not
applied systematics,
 $R = \frac{N_{Data}}{N_{MC}} \sim 0.9$ expected,
deduced from experience.
(2% for each track)

Consistent with our
expected values.

A RooPlot of "M_{bc}"

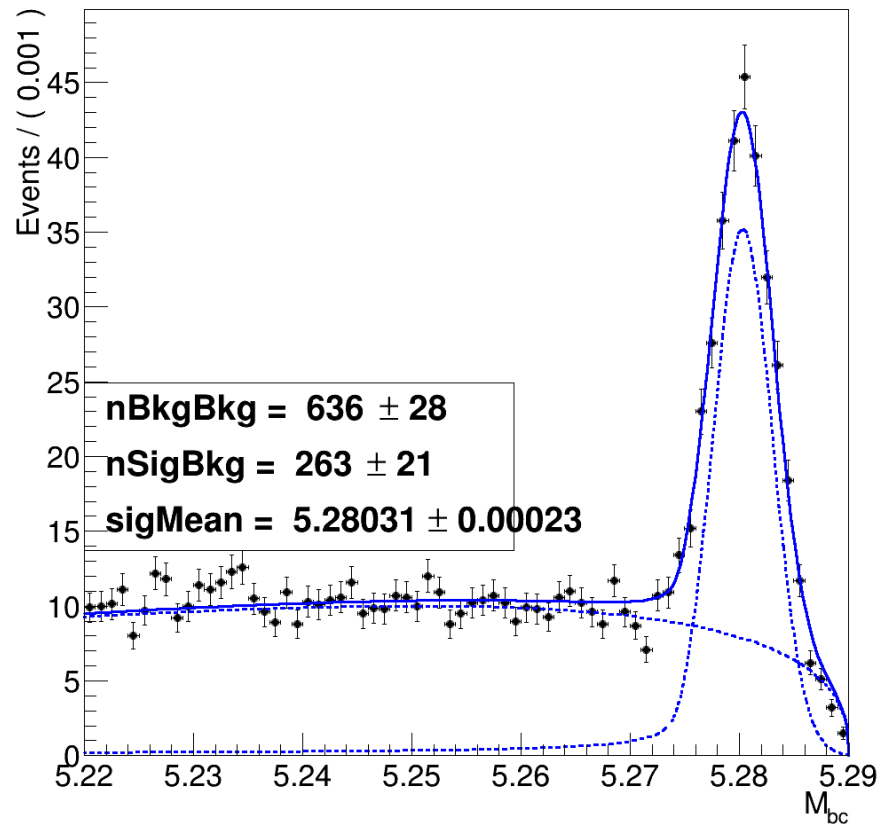


A RooPlot of "M_{bc}"

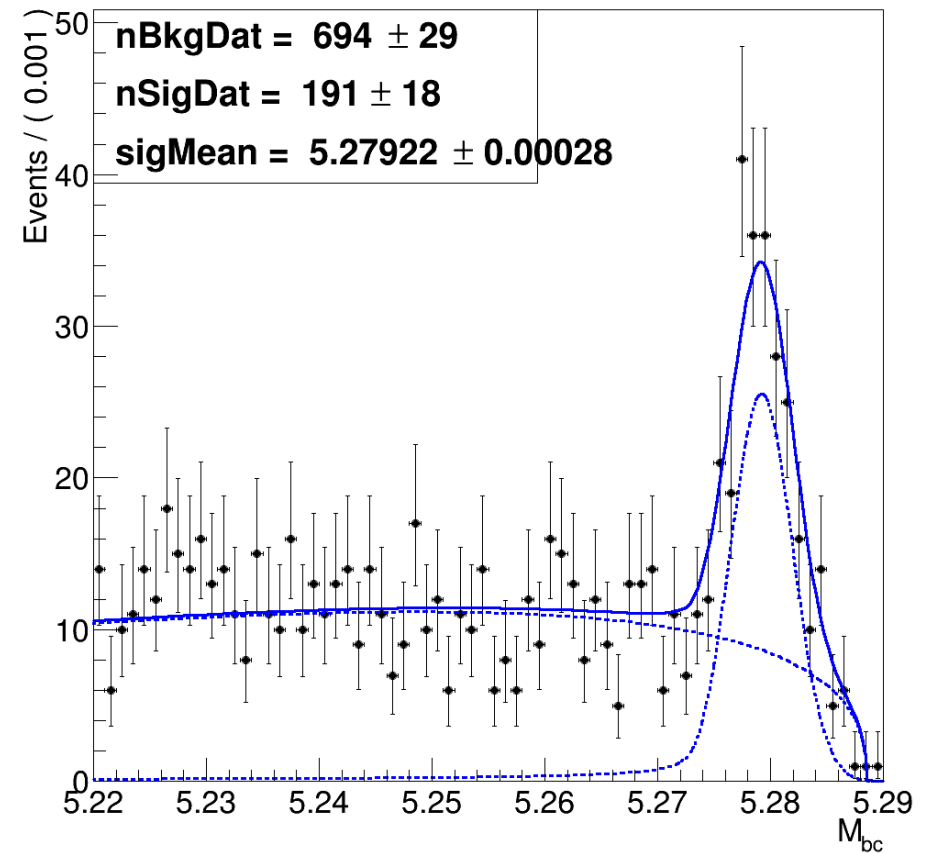


MC vs DATA

A RooPlot of " M_{bc} "



A RooPlot of " M_{bc} "



But we still have problems

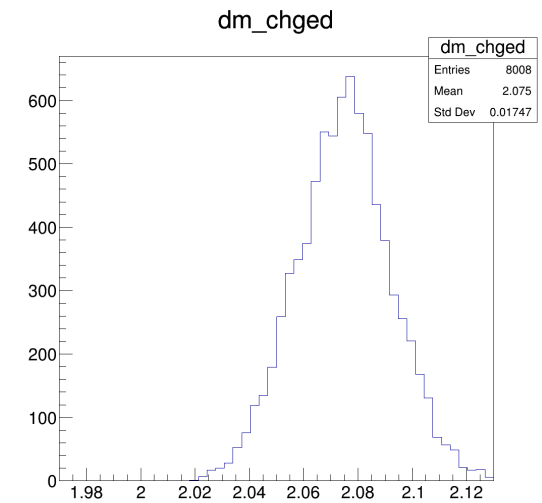
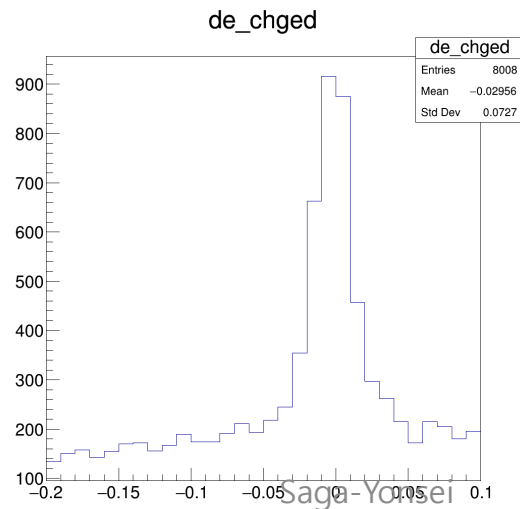
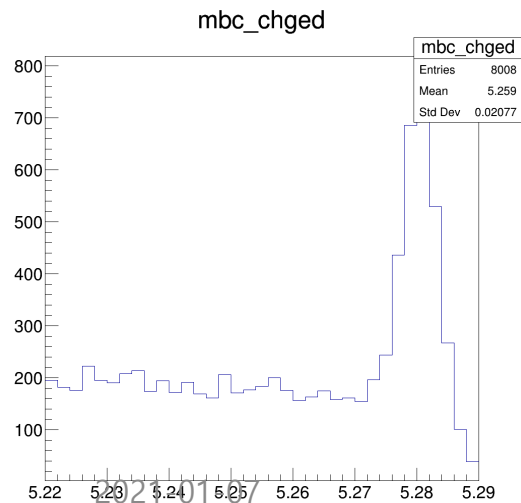
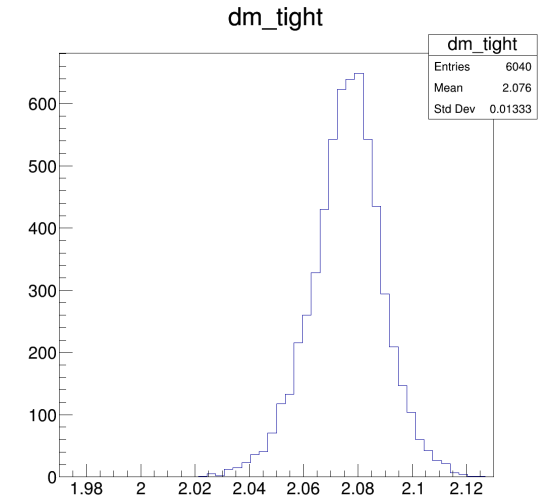
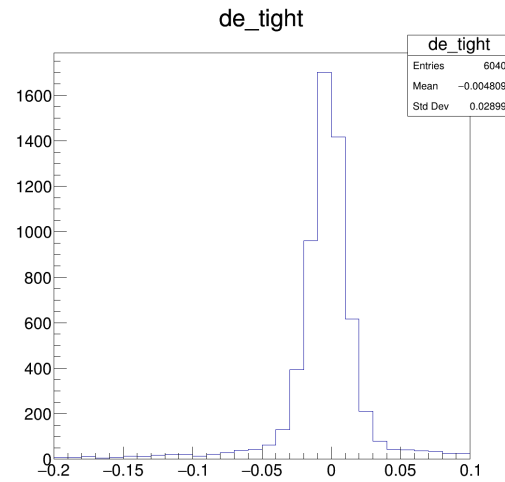
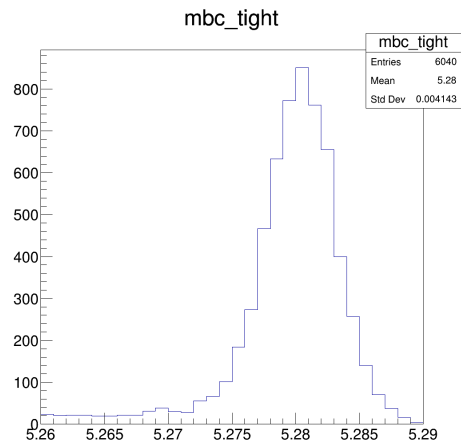
- Slight shift on M_{BC} peak.
- Slight shift of Argus endpoint

Plan & Summary

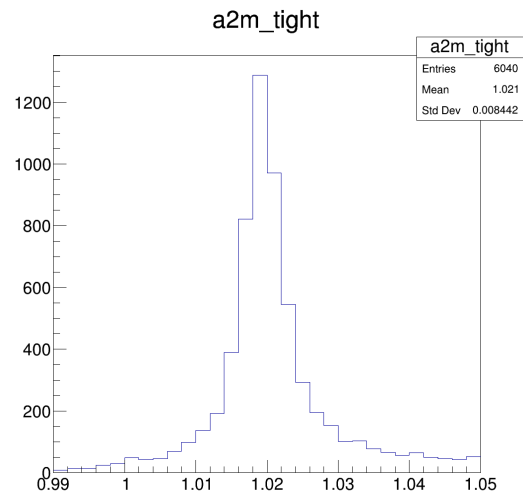
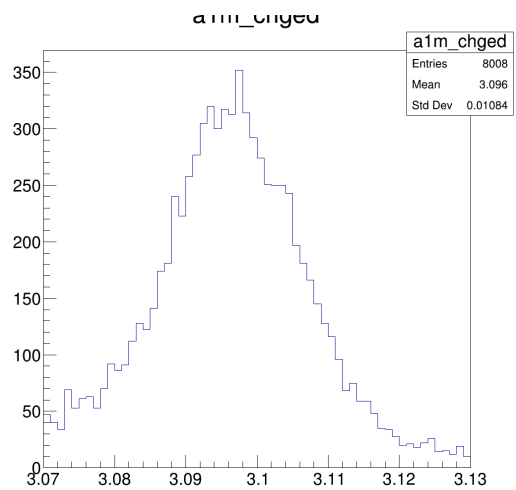
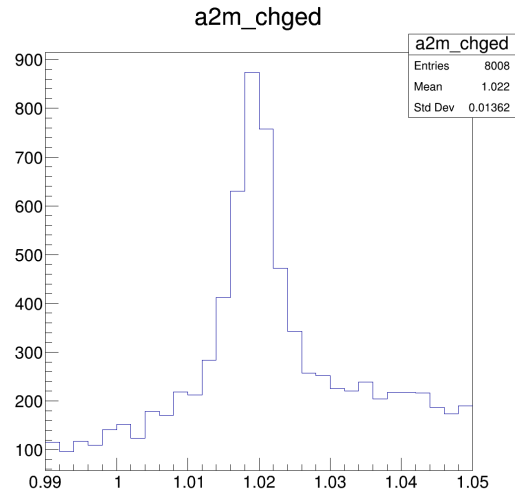
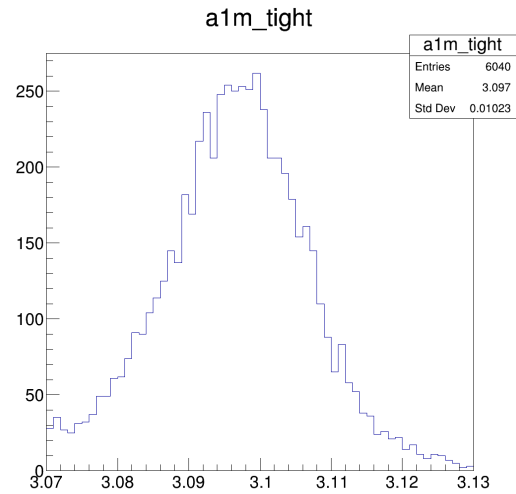
- Control sample study is ongoing using $B^+ \rightarrow J/\psi\phi K^+$.
- Try to find the reason why I have difference between MC and DATA

Backup

Major Variables Distribution on SigBox



cont'd



M_{bc} fitting

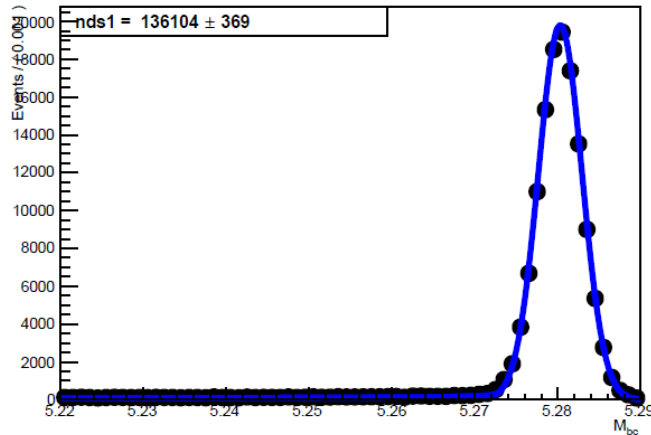
$$B^+ \rightarrow D_{s2}^{*+}(2573)\overline{D}^0$$

$$B^+ \rightarrow D_{s1}^{*+}(2700)\overline{D}^0$$

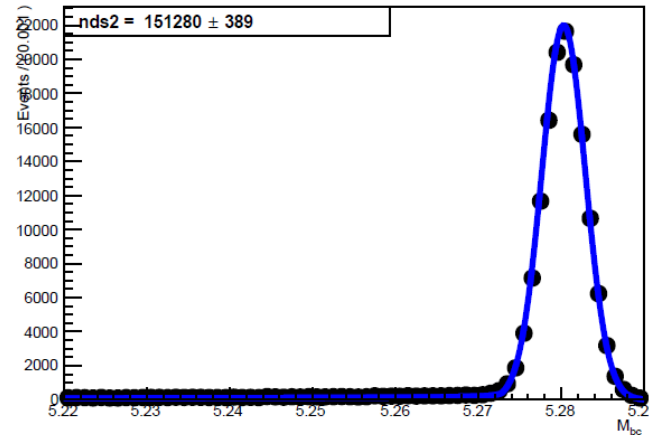
$$B^+ \rightarrow K^+\psi(3770)$$

$$B^+ \rightarrow K^+\psi(4160)$$

A RooPlot of " M_{bc} "



A RooPlot of " M_{bc} "

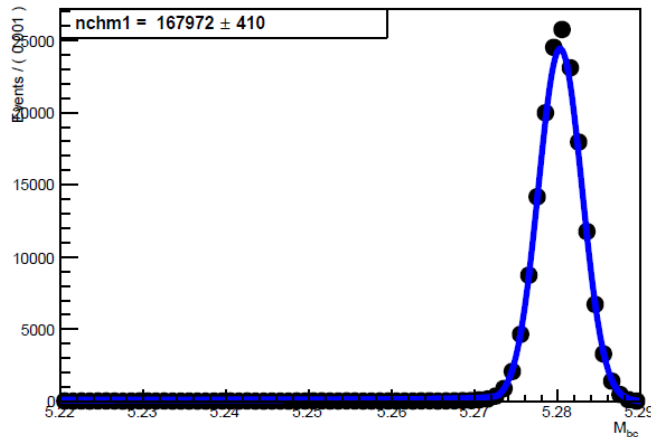


1M signal MC for each decay.
Same constant used.

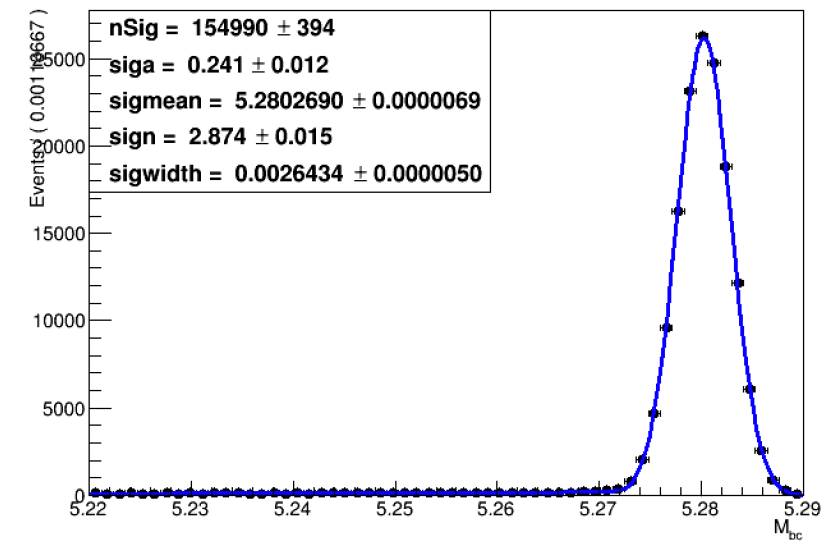
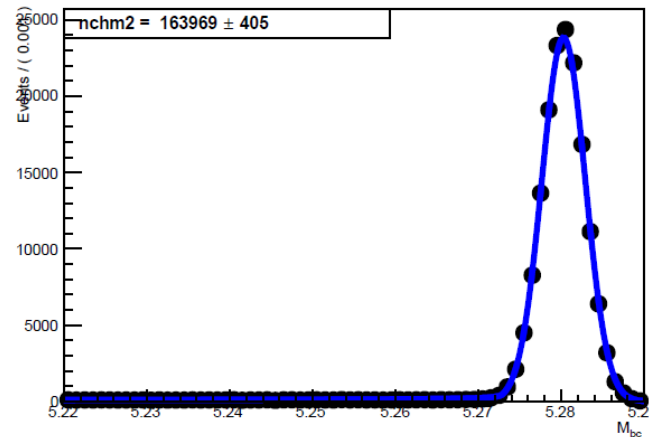
$$B^+ \rightarrow D^0\overline{D}^0K^+$$

A RooPlot of " M_{bc} "

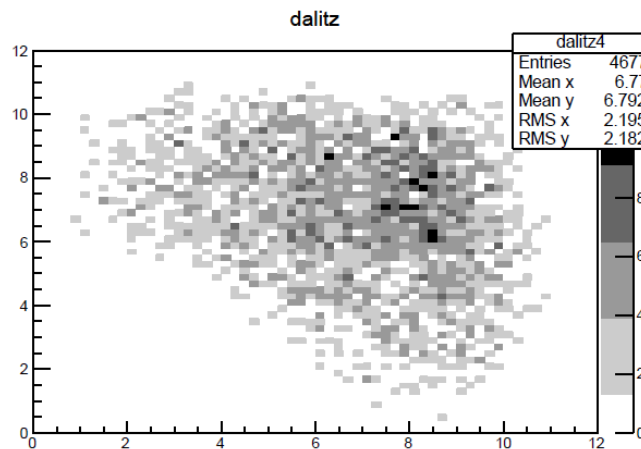
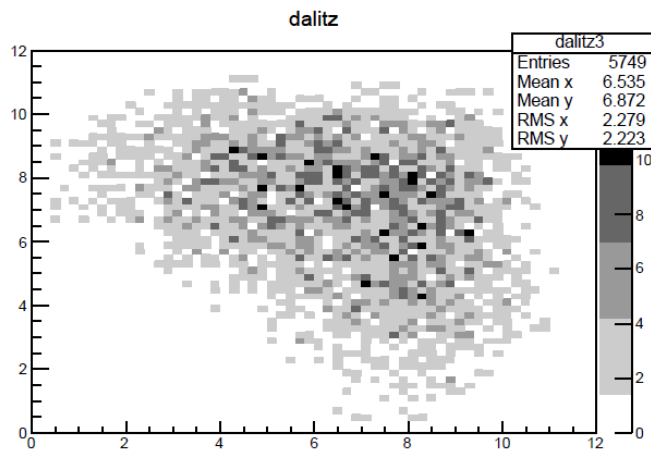
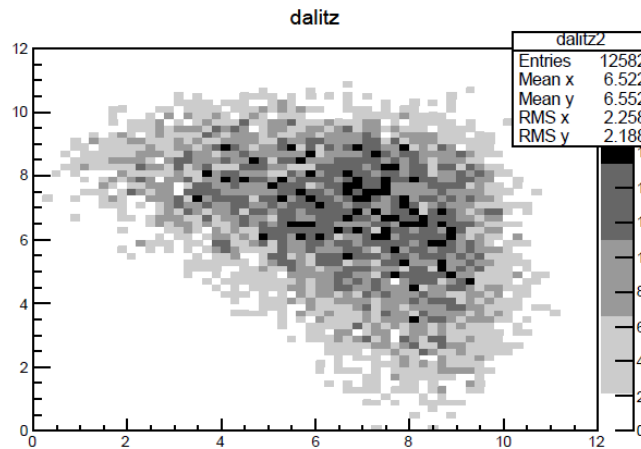
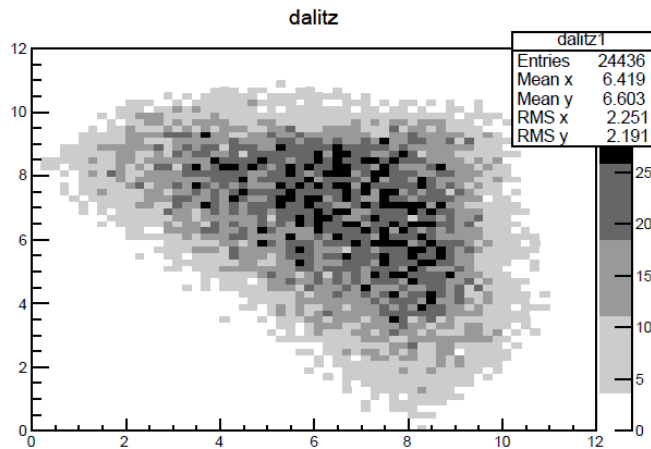
A RooPlot of " M_{bc} "



A RooPlot of " M_{bc} "



Background Dalitz Plot



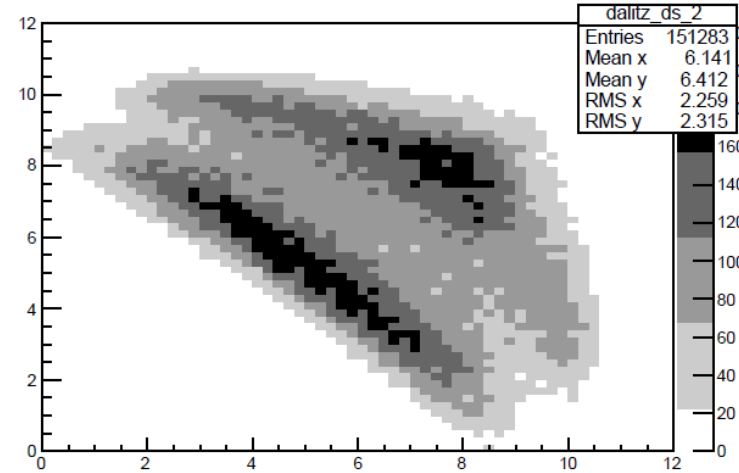
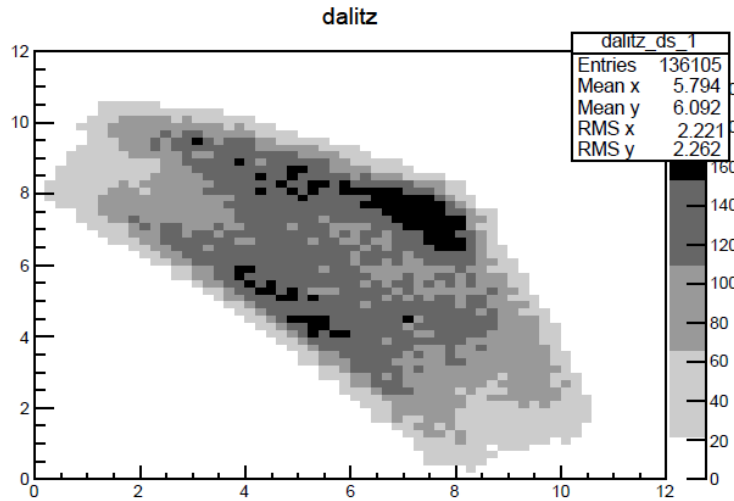
Dalitz plot have each axis for each D meson.

$$M_{KD}^2$$

charged 10 stream	mixed 10 stream
charm 6 stream	uds 6 stream

D_s resonance

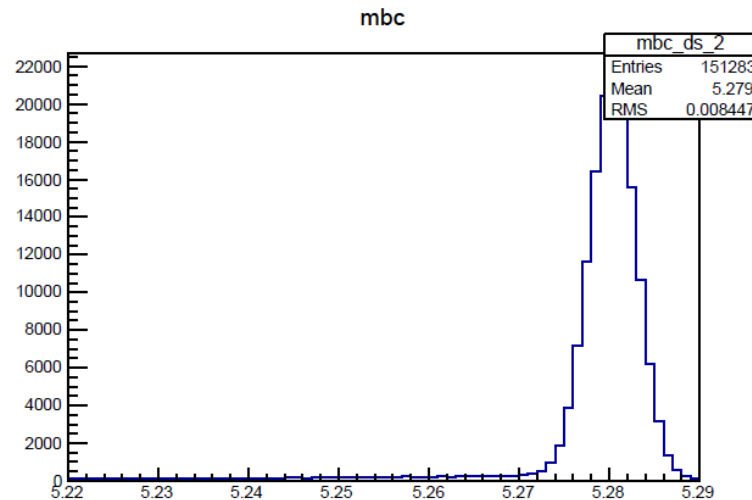
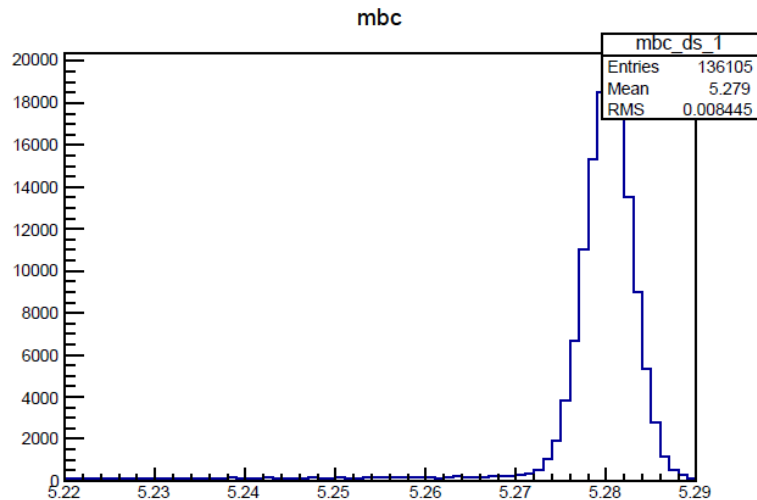
Decay	ϵ	B.F($D_s \rightarrow DK$)
$B^+ \rightarrow D_{s2}^{*+} (2573) \bar{D}^0$	0.136	$(8 \pm 15) \times 10^{-6}$
$B^+ \rightarrow D_{s1}^{*+} (2700) \bar{D}^0$	0.151	$(5.6 \pm 1.8) \times 10^{-4}$



1M signal.

Dalitz plot have each axis for each D meson.

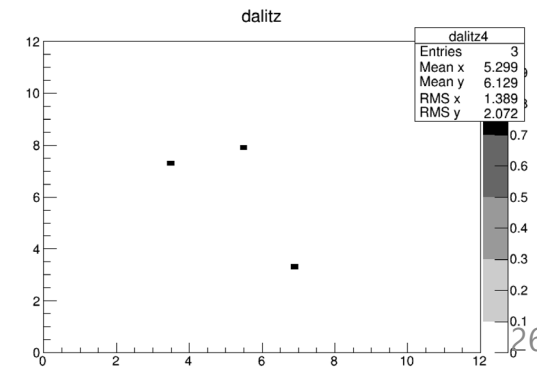
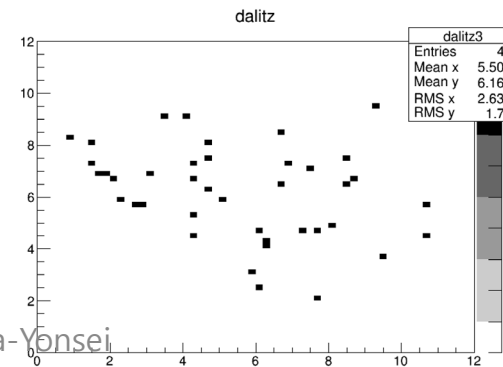
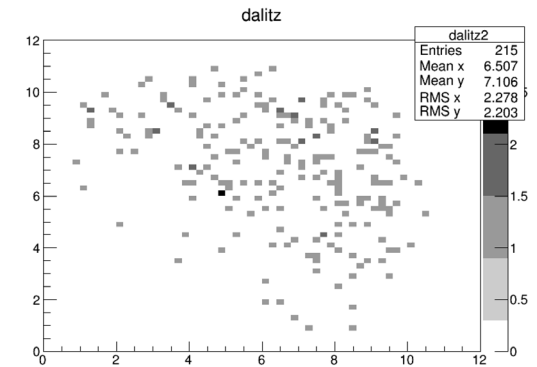
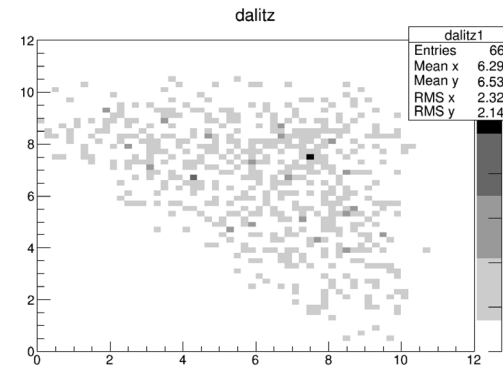
$$M_{KD}^2$$



D_s resonance

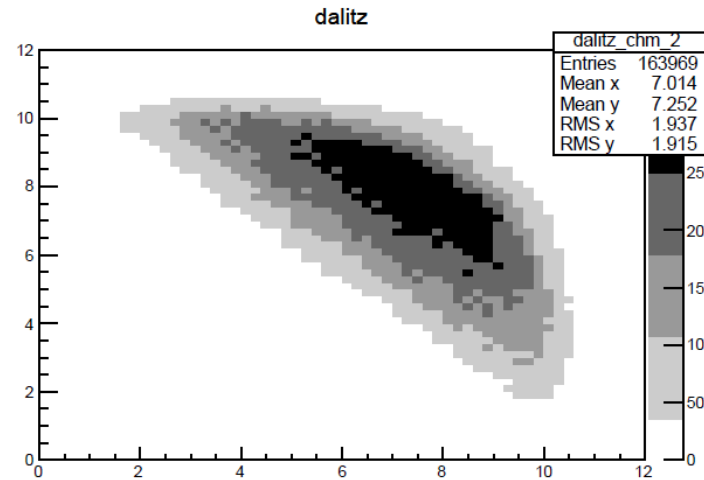
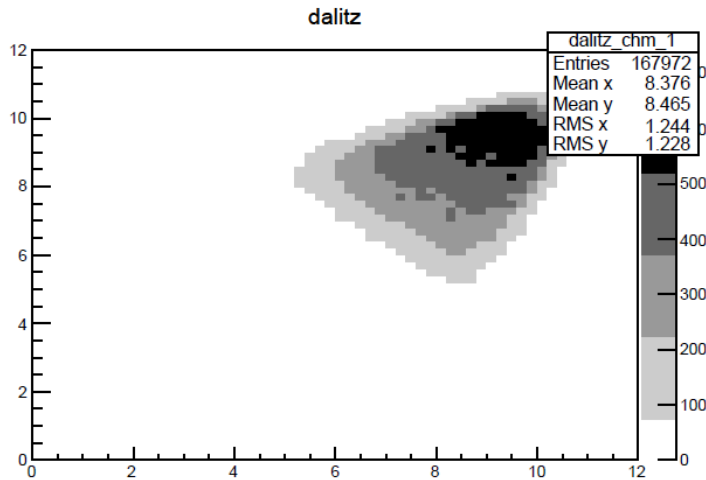
N_{obs}	PDG	DECAY.DEC	B.F($D_s \rightarrow DK$)
$B^+ \rightarrow D_{s2}^{*+}(2573)\overline{D}^0$	1.34	26.65	$(8 \pm 15) \times 10^{-6}$
$B^+ \rightarrow D_{s1}^{*+}(2700)\overline{D}^0$	104.70	49.40	$(5.6 \pm 1.8) \times 10^{-4}$

- $D_{s2}^{*+}(2.5724) = D_{s2}^*(2573)$
- $D_{sj}^+(2700) = D_{s1}^*(2700)^+$
- Each number from 1 corresponds to charged, mixed, charm, uds
- Used 10 stream of BB, 6 stream of qq.
- Not scaled.
- loose gen_hep matched



Charmonium Resonance

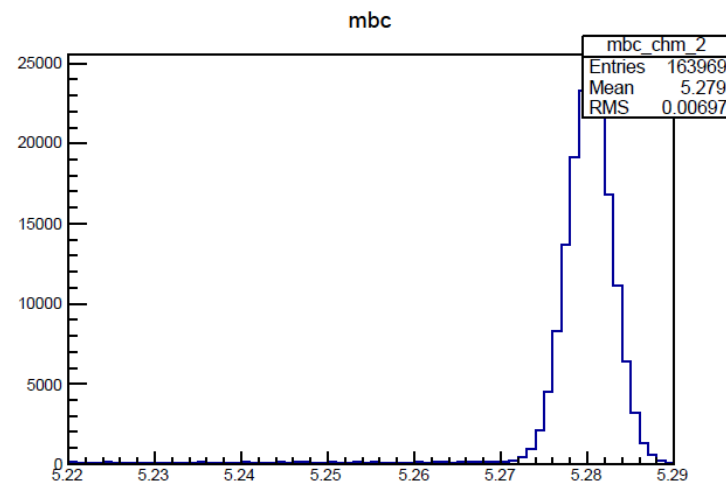
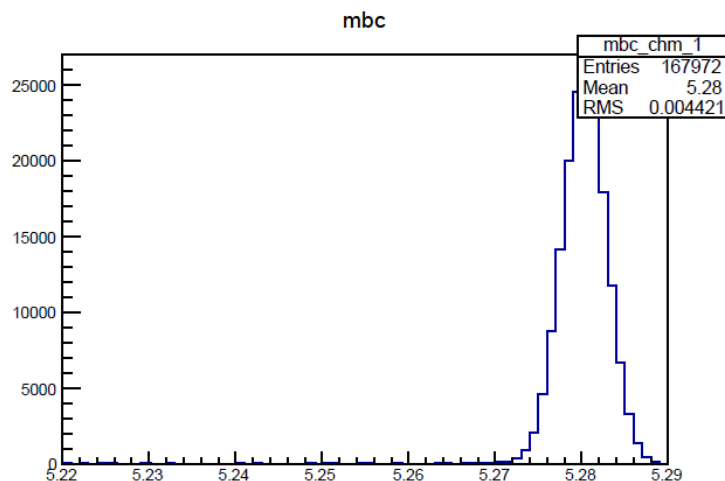
Decay	ϵ	B.F (B- \rightarrow cc- \rightarrow DD)
$B^+ \rightarrow K^+ \psi(3770)$	0.168	$(1.5 \pm 0.5) \times 10^{-4}$
$B^+ \rightarrow K^+ \psi(4160)$	0.164	$(8 \pm 5) \times 10^{-5}$



1M signal.

Dalitz plot have each axis for each D meson.

$$M_{KD}^2$$



Charmonium Resonance

N_{obs}	PDG	DECAY.DEC	B.F ($B \rightarrow cc \rightarrow DD$)
$B^+ \rightarrow K^+ \psi(3770)$	31.20	53.39	$(1.5 \pm 0.5) \times 10^{-4}$
$B^+ \rightarrow K^+ \psi(4040)$		0.16	$< 1.3 \times 10^{-4}$ *)
$B^+ \rightarrow K^+ \psi(4160)$	16.25	36.46	$(8 \pm 5) \times 10^{-5}$
$B^+ \rightarrow K^+ X(3872)$		1.98	$< 6.0 \times 10^{-5}$

- Each number from 1 corresponds to charged, mixed, charm, uds
- Used 10 stream of BB, 6 stream of qq.
- Not scaled.
- loose gen_hep matched

• * cc->DD is not included

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