preliminary study of process $e^+e^- \to \gamma\Lambda\bar{\Lambda}$ with full datasets

September 14, 2024

Contents

Datasets

- Datasets with relatively large luminosity around or above open charm energy region.

Table: Detail information of the possible datasets.

$\sqrt{s}$ (GeV)	$\mathcal{L}$ (pb^{-1})	runNo.	BOSS	$\sqrt{s}$ (GeV)	$\mathcal{L}$ (pb^{-1})	runNo.	BOSS	$\sqrt{s}$ (GeV)	$\mathcal{L}$ (pb^{-1})	runNo.	BOSS
3.650	445.5	9613-9779, 69612-70132	709	3.682	395.5	70133-70505	709	3.686	3877.1	8093-9025, 25338-27090, 66257-69292	709
3.768	415.8	81389-81631	7xx	3.773	20274.8	11414-13988, 14395-14604, 20448-23454, 70522-81094	712	3.780	410.0	81095-81272	7xx
4.009	482.0	23463-24141	703	4.129	398.0	59163-59573	705	4.158	411.3	59574-59896	705
4.178	3189.0	43716-47066	703	4.189	526.7	47543-48170	703	4.199	526.6	48172-48713	703
4.209	517.1	48714-49239	703	4.219	514.6	49270-49787	703	4.230	1056.4	32239-33484	703
4.236	530.3	49788-50254	703	4.244	538.1	50255-50793	703	4.258	828.4	29677-30367, 31561-31981	703
4.267	531.1	50796-51302	703	4.288	501.2	59902-60363	705	4.313	502.1	60364-60805	705
4.338	513.8	60808-61242	705	4.358	544.0	30616-31279	703	4.378	534.1	61249-61762	705
4.397	517.8	61763-62285	705	4.416	1043.9	36773–38140	703	4.437	585.1	62286-62823	705
4.600	586.9	35227-36213	703	4.628	521.5	63075-63515	706	4.641	551.7	63516-63715	706
4.661	529.4	63718-63852	706	4.682	1667.4	63867-64015, 64365-65092	706	4.699	535.5	64028-64313	706
4.750	366.6	65322-65494	707	4.781	511.5	65495-65645	707	4.843	525.2	65647-65864	707

- 36 energy points with Lum. 46.31 fb (33 energy points with Lum. 41.59 fb) in total.
- Involve BOSS version 703 (XYZ data before 2019), 705 (XYZ data in 2019), 706 (XYZ data in 2020), 707 (XYZ data in 2021), 709 (psip data), and 712 (psipp data).

Display of Lum.

- The data sets are divides in five groups as shown below.

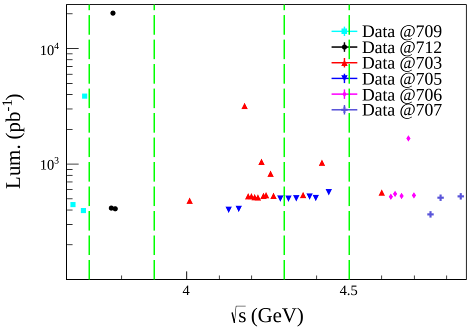
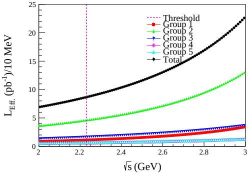


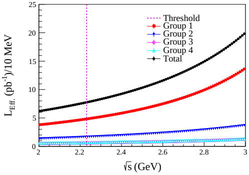
Figure: Display of the luminosity of data sets and the division method.

- group 1: (3.650, 3.682, 3.686) GeV, with Lum. 4.718 fb^{-1}; group 2: (3.768, 3.773, 3.780), with Lum. 21.101 fb^{-1}; group 3: (4.009, 4.129, 4.160, 4.178, 4.189, 4.199, 4.209, 4.219, 4.23, 4.236, 4.244, 4.258, 4.267, 4.288) GeV, with Lum. 10.541 fb^{-1}; group 4: (4.313, 4.337, 4.358, 4.378, 4.397, 4.416, 4.437) GeV, with Lum. 4.175 fb^{-1}; group 5: (4.600, 4.628, 4.641, 4.661, 4.682, 4.699, 4.750, 4.781, 4.843) GeV, with Lum. 5.776 fb^{-1}.

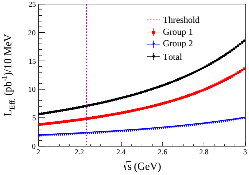
- The efficiency luminosity for ISR return of each data group with bin width of 10 MeV.



(a) 5 group



(b) 4 group



(c) 2 group

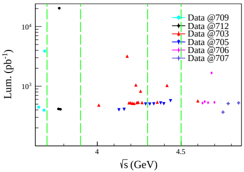


Figure: Display of the Eff. luminosity of data groups with different division method.

- The efficiency luminosity for ISR return of data sets with bin width of 20 MeV.

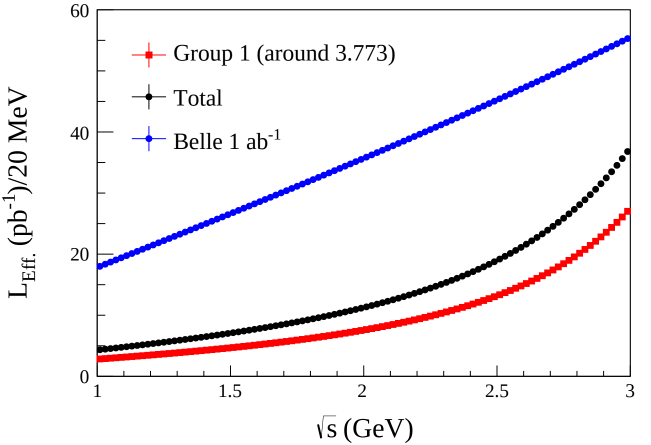


Figure: Display of the Eff. luminosity of data groups compared with Belle.

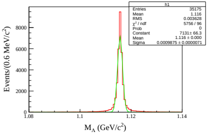
Pre. event selection (Same as previous)

The physics process is $e^+e^- \to \gamma\Lambda\bar{\Lambda} \to \gamma p\pi^-\bar{p}\pi^+$.

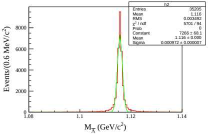
- Good charged track: $V_r < 10$ cm and $|V_z| < 30$ cm; $|\cos\theta| < 0.93$; nGood$\geq$3.
- Good photon: $|\cos\theta_\gamma| < 0.8$ for barrel and $0.86 < |\cos\theta_\gamma| < 0.92$ for endcaps; $E_\gamma \geq$ 0.025 GeV barrel and 0.050 GeV endcaps; $0 \leq T \leq 700$ ns; $\theta(\gamma, \pi^\pm\&p) \geq 10°$ ($\theta(\gamma, \bar{p}) \geq 20°$); among them at least one photon with $E_\gamma \geq 0.4$.
- PID: information of dE/dx and TOF used, Prob(p) > Prob(π&K) for p($\bar{p}$). Prob(π) > Prob(K&p) for π:
    - Full reco.: $n_p \geq 1$, $n_{\bar{p}} \geq 1$, $n_{\pi^-} \geq 1$, $n_{\pi^+} \geq 1$;
    - Missing π^-: $n_p \geq 1$, $n_{\bar{p}} \geq 1$, $n_{\pi^-} = 0$, $n_{\pi^+} \geq 1$; (similar for Missing π^+)
- (Secondary) Vertex fit:
    - Full reco.: Fit to all $p\pi^-$ and $\bar{p}\pi^+$ pairs, the combination with minimum $\chi^2_{\text{Total}} = \chi^2_{\text{Pri}} + \chi^2_{\text{Sec}}$ chosen as Λ and $\bar{\Lambda}$ candidates, respectively;
    - Missing π^-: Fit to all $\bar{p}\pi^+$ pairs, the combination with minimum $\chi^2_{\text{Total}} = \chi^2_{\text{Pri}} + \chi^2_{\text{Sec}}$ chosen as $\bar{\Lambda}$ candidate (similar for Missing π^+)
- kinematic fit:
    - Full reco.: loop all γ with $E_\gamma \geq 0.4$ GeV, perform 4C fit to $\gamma\Lambda\bar{\Lambda}$ final state, retain the photon with minimum χ^2_{4C}; $\chi_{4C,\gamma} \leq \chi_{4C,\gamma\gamma}$.
    - Missing π^-: loop all γp pairs ($E_\gamma \geq 0.4$ GeV), perform 1C fit to $\bar{\Lambda}\gamma p\pi^-$ where π^- is missing, choose the γp pair with minimum χ^2_{1C}; 1C means constain $m_{p\pi} = m_\Lambda$. (similar for Missing π^+)

Mass resolution of Λ

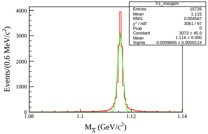
To define the requirement of $\Lambda(\bar{\Lambda})$ mass window, m_Λ of signal MC is fitted with Gaussian roughly.



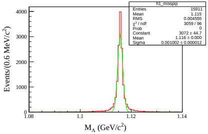
(a) 4C, Λ



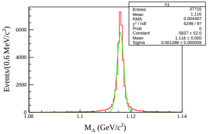
(b) 4C, $\bar{\Lambda}$



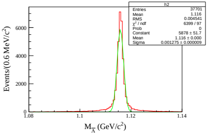
(c) miss π^-, $\bar{\Lambda}$



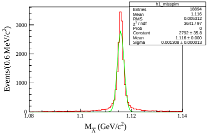
(d) miss π^+, Λ



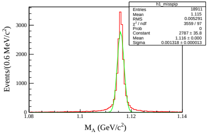
(e) 4C, Λ



(f) 4C, $\bar{\Lambda}$



(g) miss π^-, $\bar{\Lambda}$



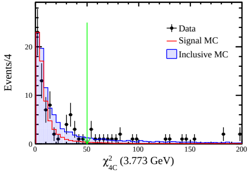
(h) miss π^+, Λ

Figure: Comparison of the m_Λ resolution. First row with VtxfitUpdate, second row with origianl vtxfit package.

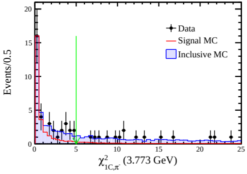
The resonlusion is reduced from about 1.3 MeV to 1 MeV.

requirement on $\chi^2_{4C(1C)}$

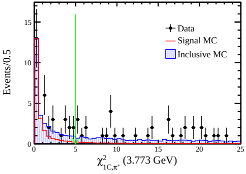
The $\chi^2_{4C(1C)}$ cut is opptimized by FOM $= \frac{S}{\sqrt{S+B}}$, wherer S is obtained from signal MC normalized to data Lum., S+B is determined from data.



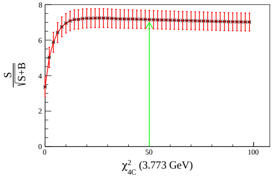
(a) χ^2_{4C}



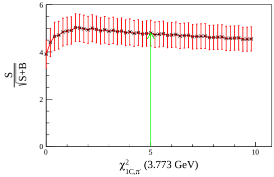
(b) χ^2_{1C}, miss π^-



(c) χ^2_{1C}, miss π^+



(d) FOM χ^2_{4C}

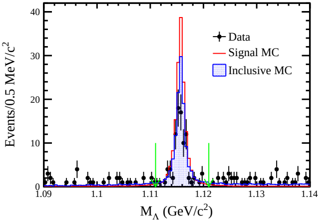


(e) FOM χ^2_{1C}

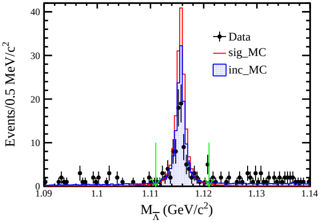
Figure:

requirement on $\Lambda(\bar{\Lambda})$

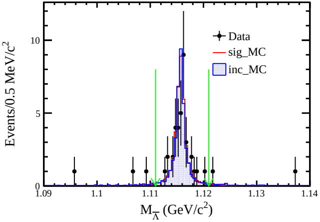
According to the fit of m_Λ, we get the requirement on $\Lambda(\bar{\Lambda})$: $|m_\Lambda| \leq 5$ MeV.



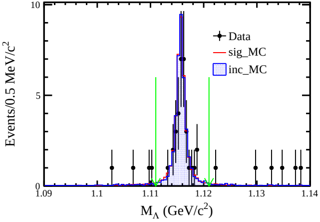
(a) 4C, m_Λ



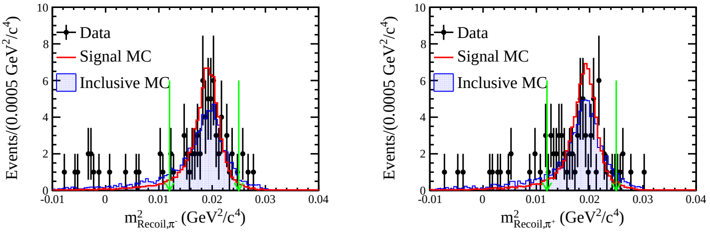
(b) 4C, $m_{\bar{\Lambda}}$



(c) miss π^+, m_Λ



(d) miss π^-, $m_{\bar{\Lambda}}$



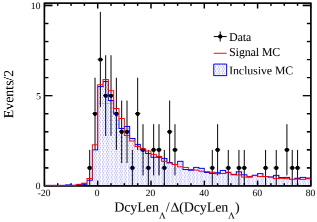
(a) $m^2_{\pi^-}$ (b) $m^2_{\pi^+}$

Figure:

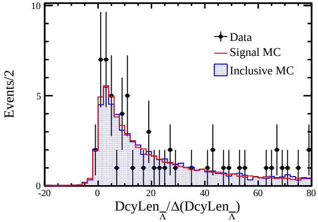
- $0.012 \le m^2_{\pi^\pm} \le 0.025$ GeV^2

Decay length over its error

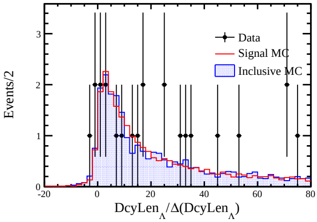
After above selections, decay length over its error shown below.



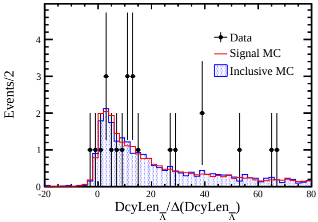
(a) 4C, L_{Λ}



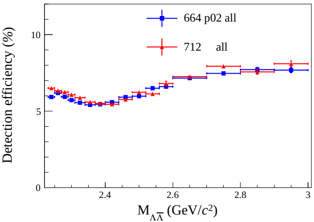
(b) 4C, $L_{\bar{\Lambda}}$



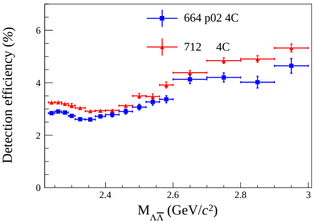
(c) miss π^{+}, L_{Λ}



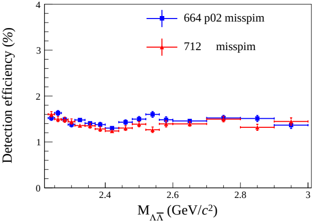
(d) miss π^{-}, $L_{\bar{\Lambda}}$



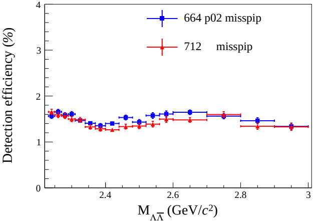
(a) Total



(b) 4C



(c) miss π^-



(d) miss π^+

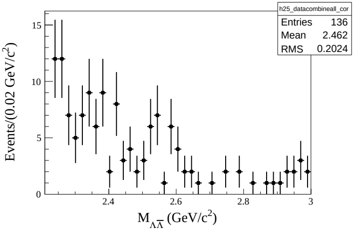
Table: Cut flow of signal MC (ConExc) at $\sqrt{s} = 3.773$ GeV.

Selection criteria	Events number			Efficiency (%)			
	4C	Missing π^-	Missing π^+	4C	Missing π^-	Missing π^+	Total
Generated	1000000			100			100
Good charged track	722177			72.22			72.22
Good photon	134287			13.43			13.43
PID	51640	24001	23741	5.16	2.40	2.37	9.94
Vertex fit	48590	23250	22935	4.86	2.33	2.29	9.48
Kinematic fit ($m_{\Lambda\bar{\Lambda}} \leq 3$ GeV)	34473	18166	18264	4.12	2.17	2.18	8.48
$\chi^2_{4C(1C)}$	31178	16018	16087	3.73	1.92	1.92	7.57
$M_{\Lambda(\bar{\Lambda})}$	26746	14067	14205	3.20	1.68	1.70	6.58
$m^2_{\pi^-(\pi^+)}$	-	12229	12670	-	1.46	1.51	6.17

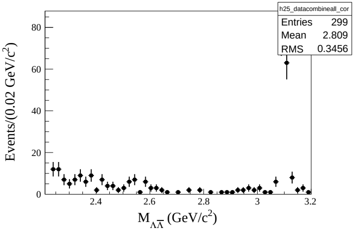
Selection criteria	Events number			Efficiency (%)			
	4C	Missing π^-	Missing π^+	4C	Missing π^-	Missing π^+	Total
Generated	1000000			100			100
Good charged track	739963			74.00			74.00
Good photon	141335			14.13			14.13
PID	55946	22931	22308	5.59	2.29	2.23	10.11
Vertex fit	52475	22181	21455	5.25	2.22	2.15	9.62
Kinematic fit ($m_{\Lambda\bar{\Lambda}} \leq 3$ GeV)	32009	14989	15047	4.34	2.03	2.04	8.42
$\chi^2_{4C(1C)}$	29157	13261	13270	3.96	1.80	1.80	7.56
$M_{\Lambda(\bar{\Lambda})}$	25865	11808	11845	3.51	1.60	1.61	6.72
$m^2_{\pi^-(\pi^+)}$	-	10240	10614	-	1.39	1.44	6.34

Number of events in truth level with $m_{\Lambda\bar{\Lambda}} \leq 3$ GeV is 736956 and 836403 for 712 and 664p02.

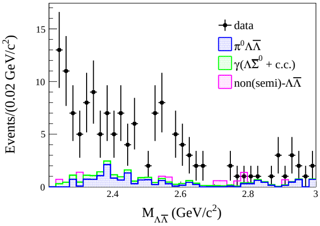
$m_{\Lambda\bar{\Lambda}}$ spectrum



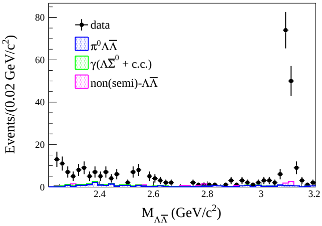
(a) 712



(b) 712



(c) 664p02



(d) 664p02

A new attempt of 1C fit strategy

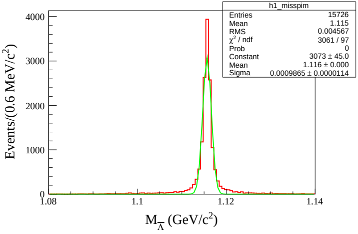
We try a new 1C fit strategy.

- old 1C fit: loop all γp pairs ($E_\gamma \geq 0.4$ GeV), perform 1C fit to $\bar{\Lambda}\gamma p\pi^-$ where π^- is missing, choose the γp pair with minimum χ^2_{1C}; 1C means constain $m_{p\pi} = m_\Lambda$. (similar for Missing π^+)
- new 1C fit: loop all γp pairs ($E_\gamma \geq 0.4$ GeV), perform 1C fit to $\bar{\Lambda}\gamma p\pi^-$ where π^- is missing, choose the γp pair with minimum χ^2_{1C}; 1C means constain the mass of missing particle to π nominal mass. (similar for Missing π^+)

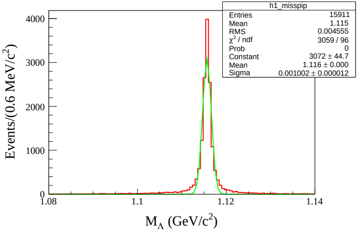
Only change the 1C km fit strategy, others same as before.

Mass resolution of Λ

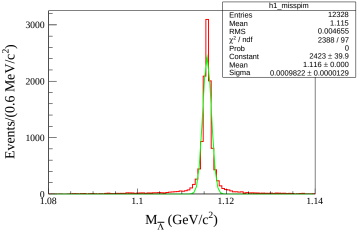
Comparison of the Λ mass resolution for old and new 1C fit.



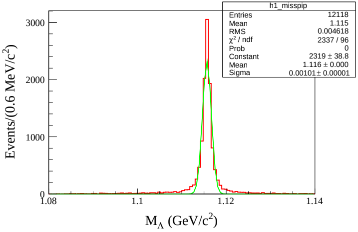
(a) miss π^-, $\bar{\Lambda}$



(b) miss π^+, Λ

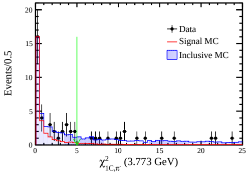


(c) miss π^-, $\bar{\Lambda}$

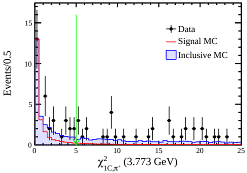


(d) miss π^+, Λ

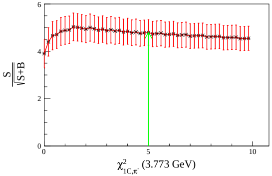
The χ^2_{1C} cut is opptimized by FOM $= \frac{S}{\sqrt{S+B}}$, wherer S is obtained from signal MC normalized to data Lum., S+B is determined from data.



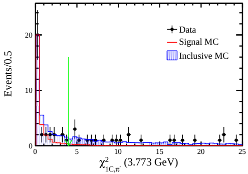
(a) χ^2_{1C}, miss π^-



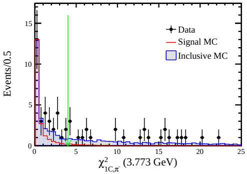
(b) χ^2_{1C}, miss π^+



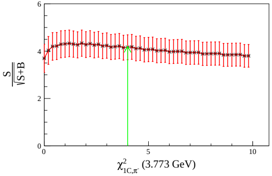
(c) FOM χ^2_{1C}



(d) χ^2_{1C}, miss π^-



(e) χ^2_{1C}, miss π^+

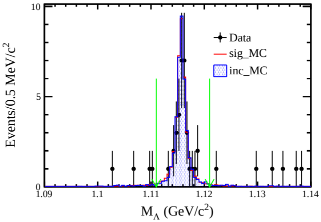


(f) FOM χ^2_{1C}

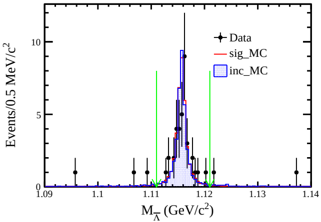
Figure:

requirement on $\Lambda(\bar{\Lambda})$

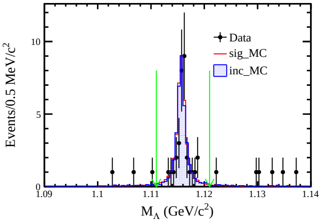
According to the fit of m_Λ, we get the requirement on $\Lambda(\bar{\Lambda})$: $|m_\Lambda| \leq 5$ MeV.



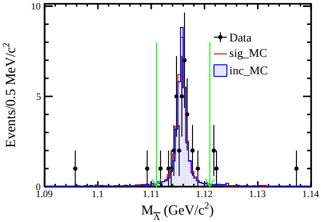
(a) miss π^+, m_Λ



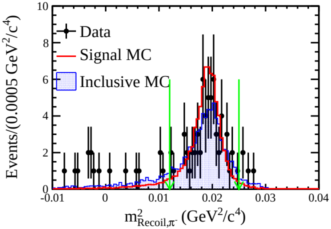
(b) miss π^-, $m_{\bar{\Lambda}}$



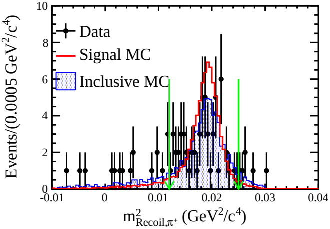
(c) miss π^+, m_Λ



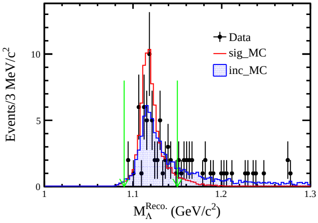
(d) miss π^-, $m_{\bar{\Lambda}}$



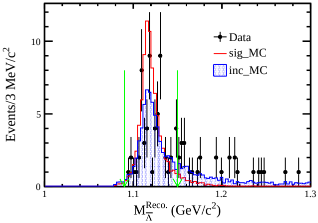
(a) $m_{\pi^-}^2$



(b) $m_{\pi^+}^2$



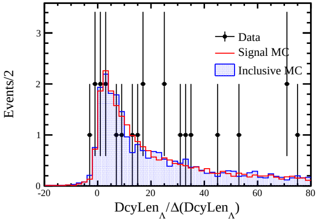
(c) $m_{\pi^-}^2$



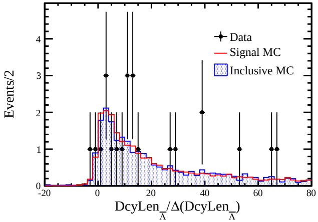
(d) $m_{\pi^+}^2$

Decay length over its error

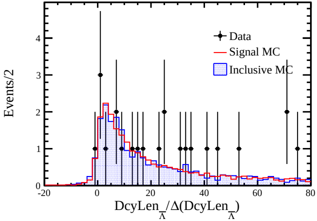
After above selections, decay length over its error shown below.



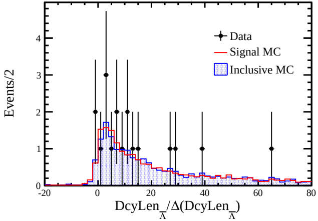
(a) miss π^+, L_Λ



(b) miss π^-, $L_{\bar{\Lambda}}$

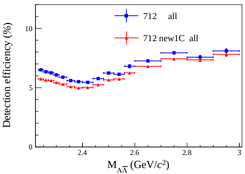


(c) miss π^+, L_Λ

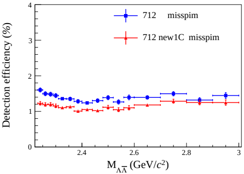


(d) miss π^-, $L_{\bar{\Lambda}}$

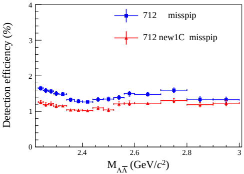
Comparison of eff. curve



(a) Total



(b) miss π^-



(c) miss π^+

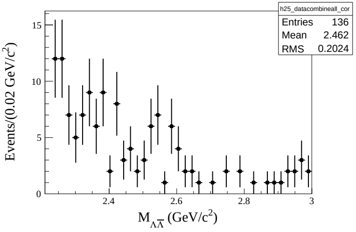
Figure:

Table: Cut flow of signal MC (ConExc) at $\sqrt{s} = 3.773$ GeV.

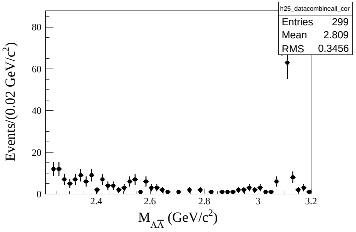
Selection criteria	Events number			Efficiency (%)			
	4C	Missing π^-	Missing π^+	4C	Missing π^-	Missing π^+	Total
Kinematic fit ($m_{\Lambda\bar{\Lambda}} \leq 3$ GeV)	32009	14989	15047	4.34	2.03	2.04	8.42
$\chi^2_{4C(1C)}$	29157	13261	13270	3.96	1.80	1.80	7.56
$M_{\Lambda(\bar{\Lambda})}$	25865	11808	11845	3.51	1.60	1.61	6.72
$m^2_{\pi^-(\pi^+)}$	-	10240	10614	-	1.39	1.44	6.34

Selection criteria	Events number			Efficiency (%)			
	4C	Missing π^-	Missing π^+	4C	Missing π^-	Missing π^+	Total
Kinematic fit ($m_{\Lambda\bar{\Lambda}} \leq 3$ GeV)	32009	11312	11285	4.34	1.54	1.53	7.41
$\chi^2_{4C(1C)}$	29157	10218	10233	3.96	1.39	1.39	6.73
$M_{\Lambda(\bar{\Lambda})}$	25865	9094	9161	3.51	1.23	1.24	5.99
$m^2_{\pi^-(\pi^+)}$	-	8394	8506	-	1.14	1.15	5.80

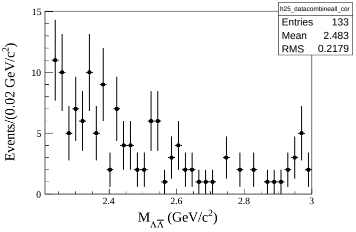
new stratygy with lower eff. by about 20%



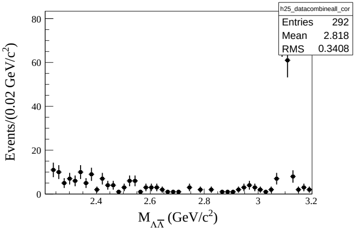
(a) 712



(b) 712



(c) 712



(d) 712