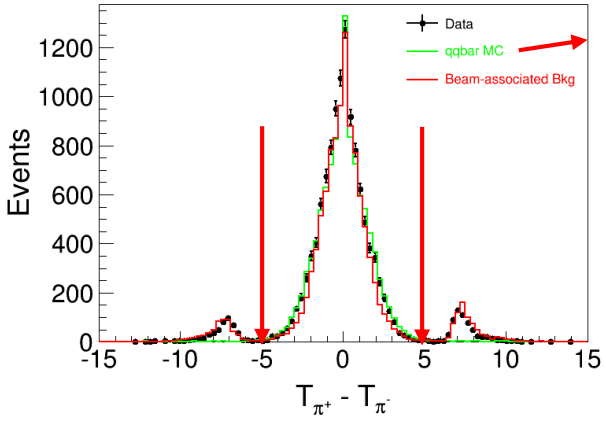
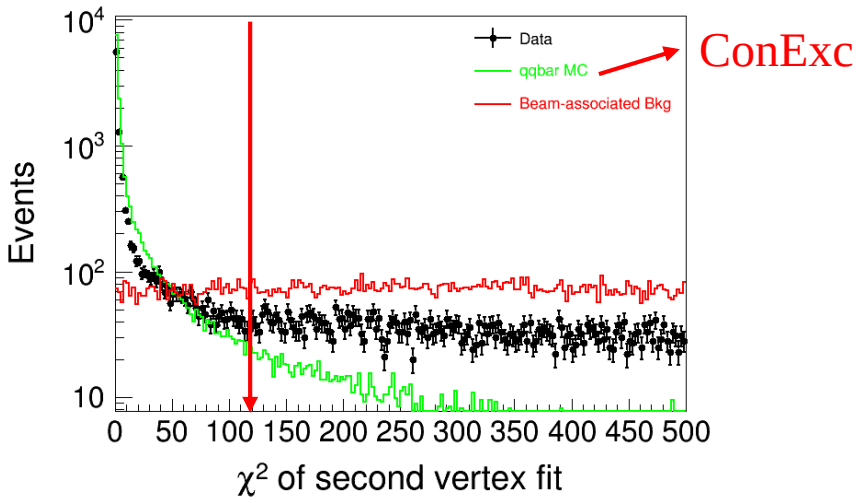
Ks cut criteria

- ✓ Track selection
  - ➢ |Vr|< 10cm, |Vz|<30cm
- ✓ PID: Prob π > Prob K and Prob π > Prob P

  $N_{\pi+}$ >=1 and $N_{\pi-}$ >=1
- ✓ Second vertex fitting: $L/\sigma_L > 2.0$



- ✓ Remove the cosmic rays: $|T(\pi^+) - T(\pi^-)| < 5$



- ✓ Remove the beam-associated backgrounds: χ^2(second vertex fit) < 120

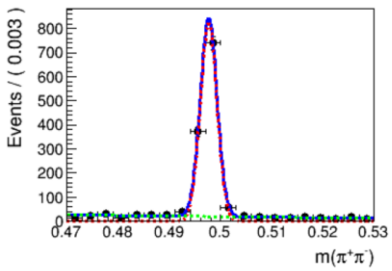
1, Ks efficiency differences

Here, MSTJ(21) = 0

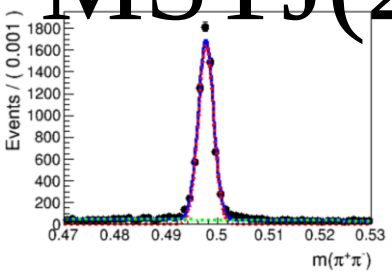
Table 18: K_S^0 efficiencies (%) vary with momentum in different MC models.

p(GeV)	$\varepsilon(K_S^0)$ from ConExc	$\varepsilon(K_S^0)$ from Lundalw(0)	Uncertainty
0.0-0.1	30.3	33.0	-9.1
0.1-0.2	39.8	40.8	-2.4
0.2-0.3	44.3	44.6	-0.6
0.3-0.4	45.3	46.1	-1.9
0.4-0.5	48.2	47.7	0.9
0.5-0.6	45.3	50.6	-11.8
0.6-0.7	43.4	51.7	-19.1
0.7-0.8	44.3	53.9	-21.6
0.8-0.9	49.6	55.6	-12.1
0.9-1.0	55.8	54.3	2.6
1.0-1.1	52.8	54.5	-3.3
1.1-1.2	47.8	49.1	-2.7
1.2-1.3	62.6	52.3	16.4

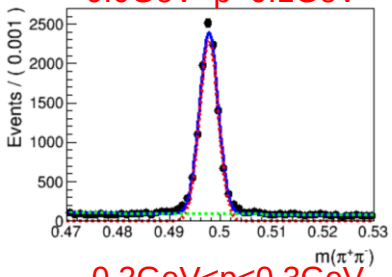
Ks mass distribution with MSTJ(21) = 0



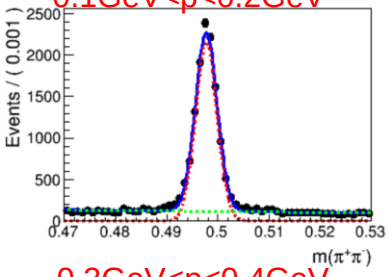
0.0GeV<p<0.1GeV



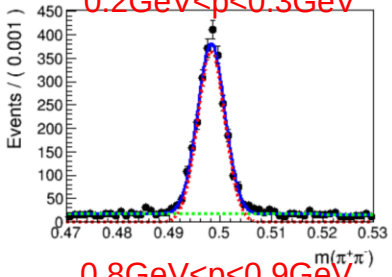
0.1GeV<p<0.2GeV



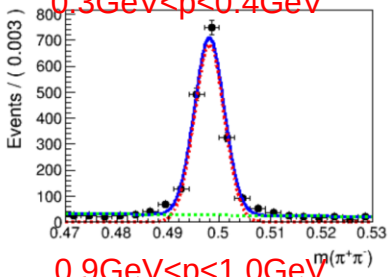
0.2GeV<p<0.3GeV



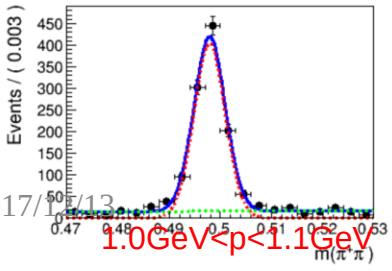
0.3GeV<p<0.4GeV



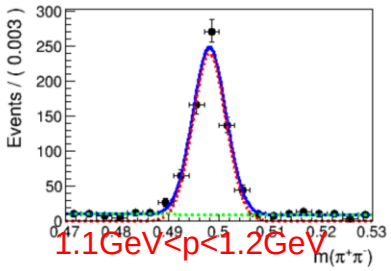
0.8GeV<p<0.9GeV



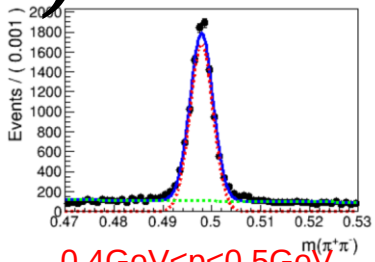
0.9GeV<p<1.0GeV



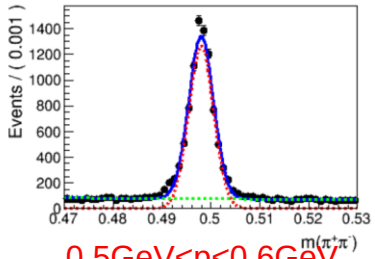
1.0GeV<p<1.1GeV



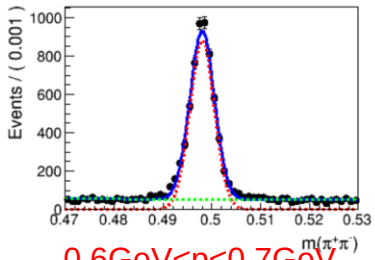
1.1GeV<p<1.2GeV



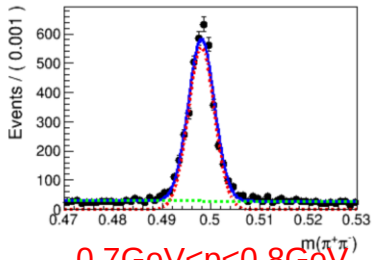
0.4GeV<p<0.5GeV



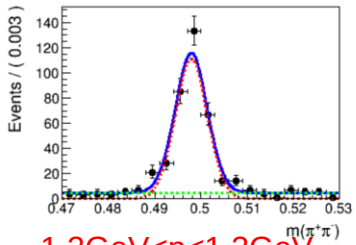
0.5GeV<p<0.6GeV



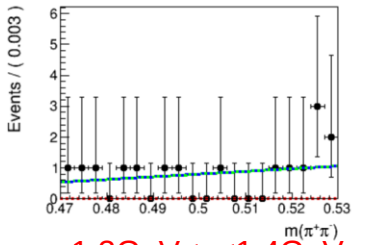
0.6GeV<p<0.7GeV



0.7GeV<p<0.8GeV

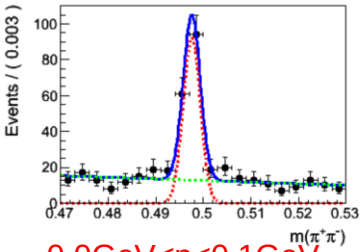


1.2GeV<p<1.3GeV

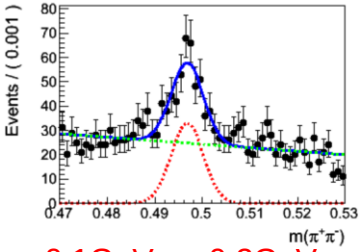


1.3GeV<p<1.4GeV

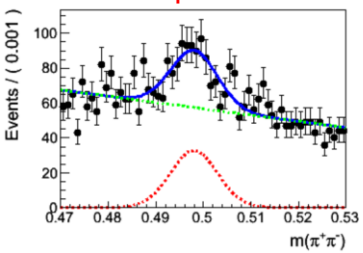
Ks mass distribution with MSTJ(21) = 2



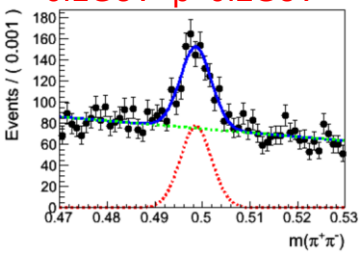
0.0GeV<p<0.1GeV



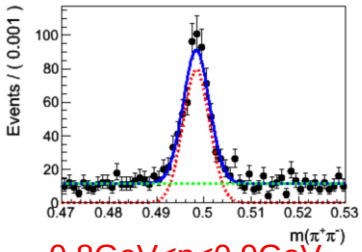
0.1GeV<p<0.2GeV



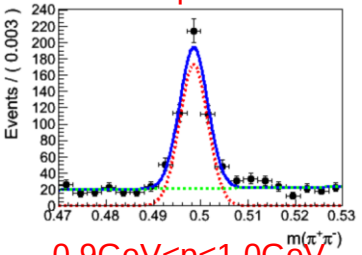
0.2GeV<p<0.3GeV



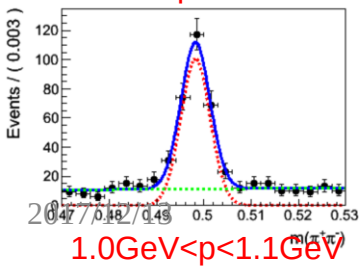
0.3GeV<p<0.4GeV



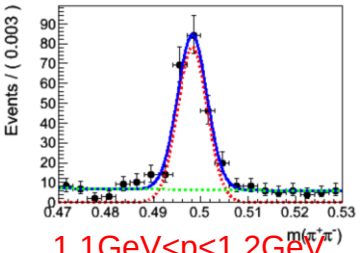
0.8GeV<p<0.9GeV



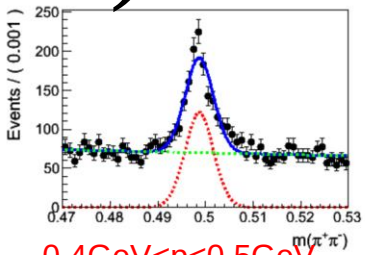
0.9GeV<p<1.0GeV



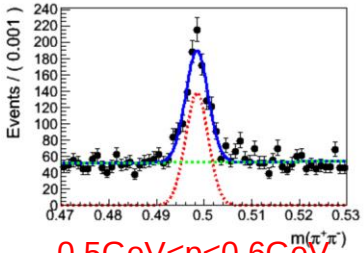
1.0GeV<p<1.1GeV



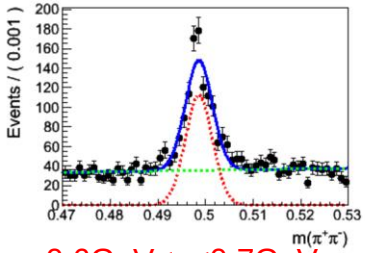
1.1GeV<p<1.2GeV



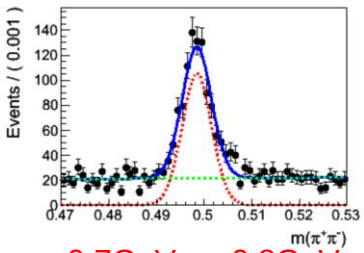
0.4GeV<p<0.5GeV



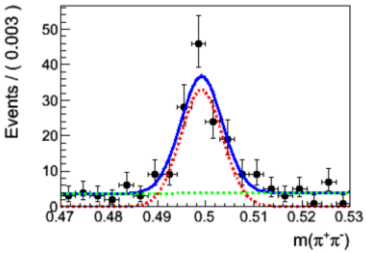
0.5GeV<p<0.6GeV



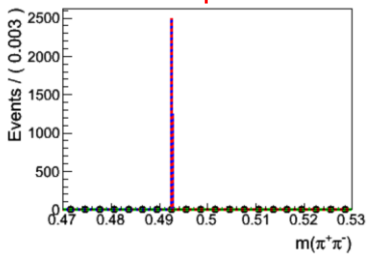
0.6GeV<p<0.7GeV



0.7GeV<p<0.8GeV



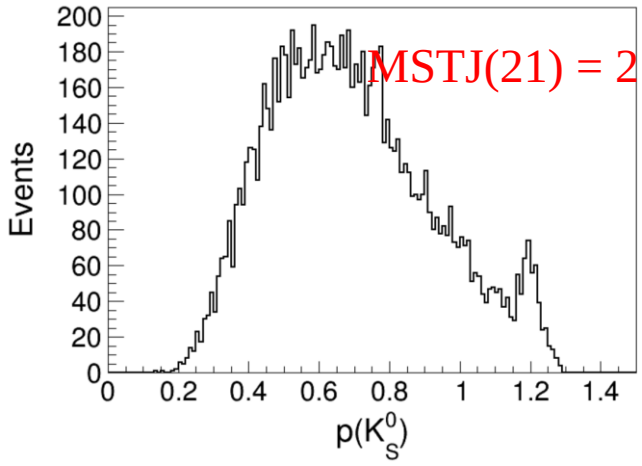
1.2GeV<p<1.3GeV

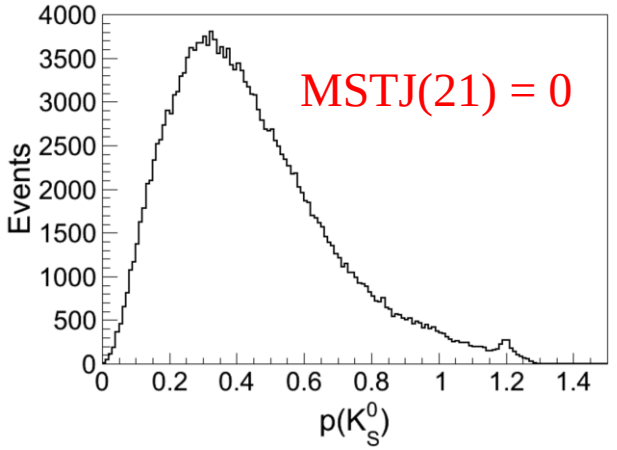


1.3GeV<p<1.4GeV

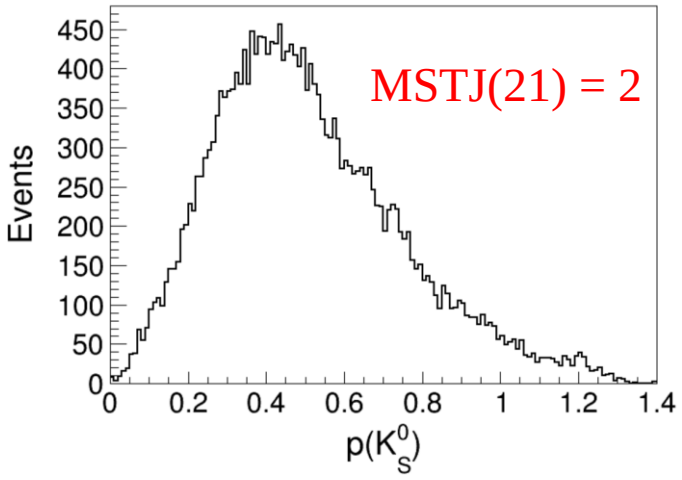
Ks momentum in truth level and detect level

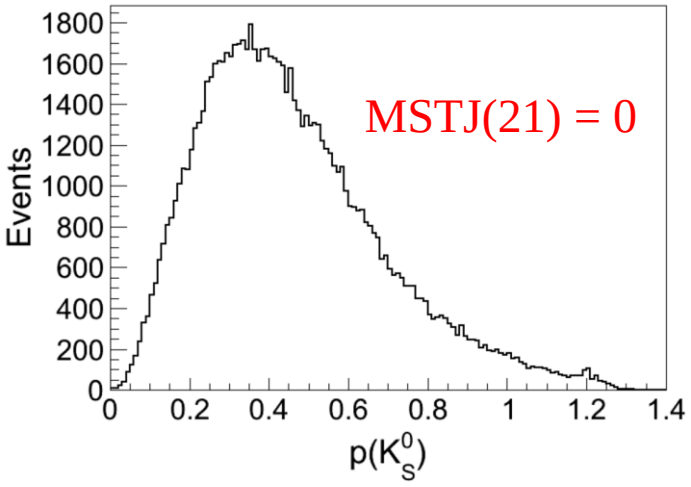
Ks momentum in truth level:





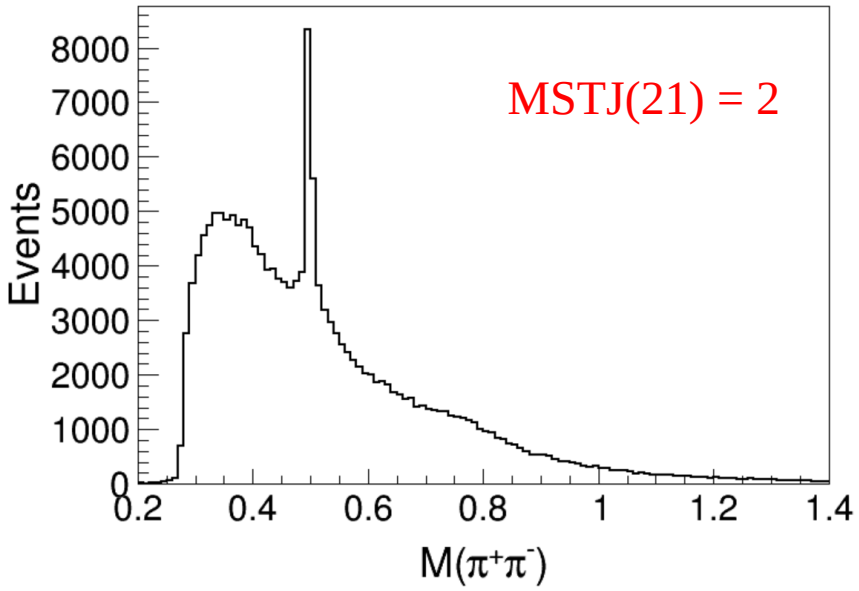
Ks momentum in detect level:

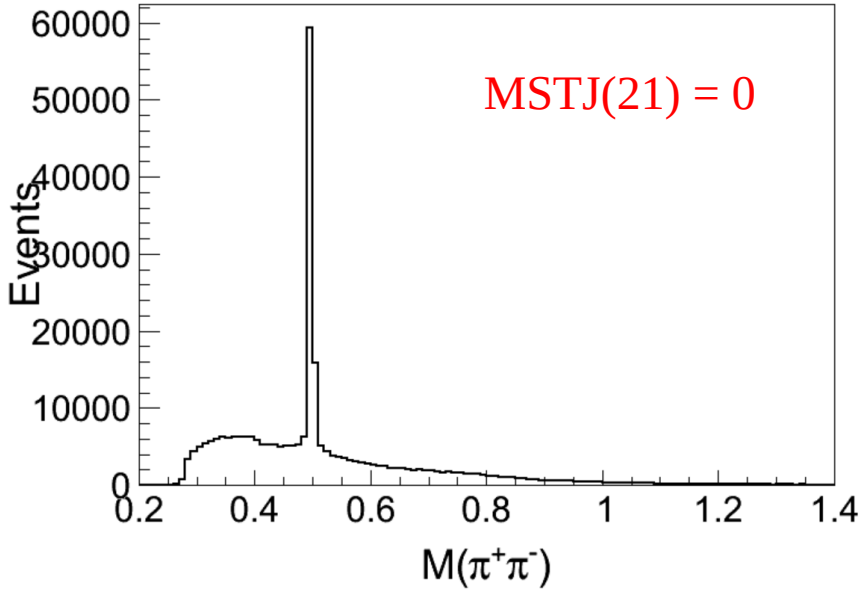


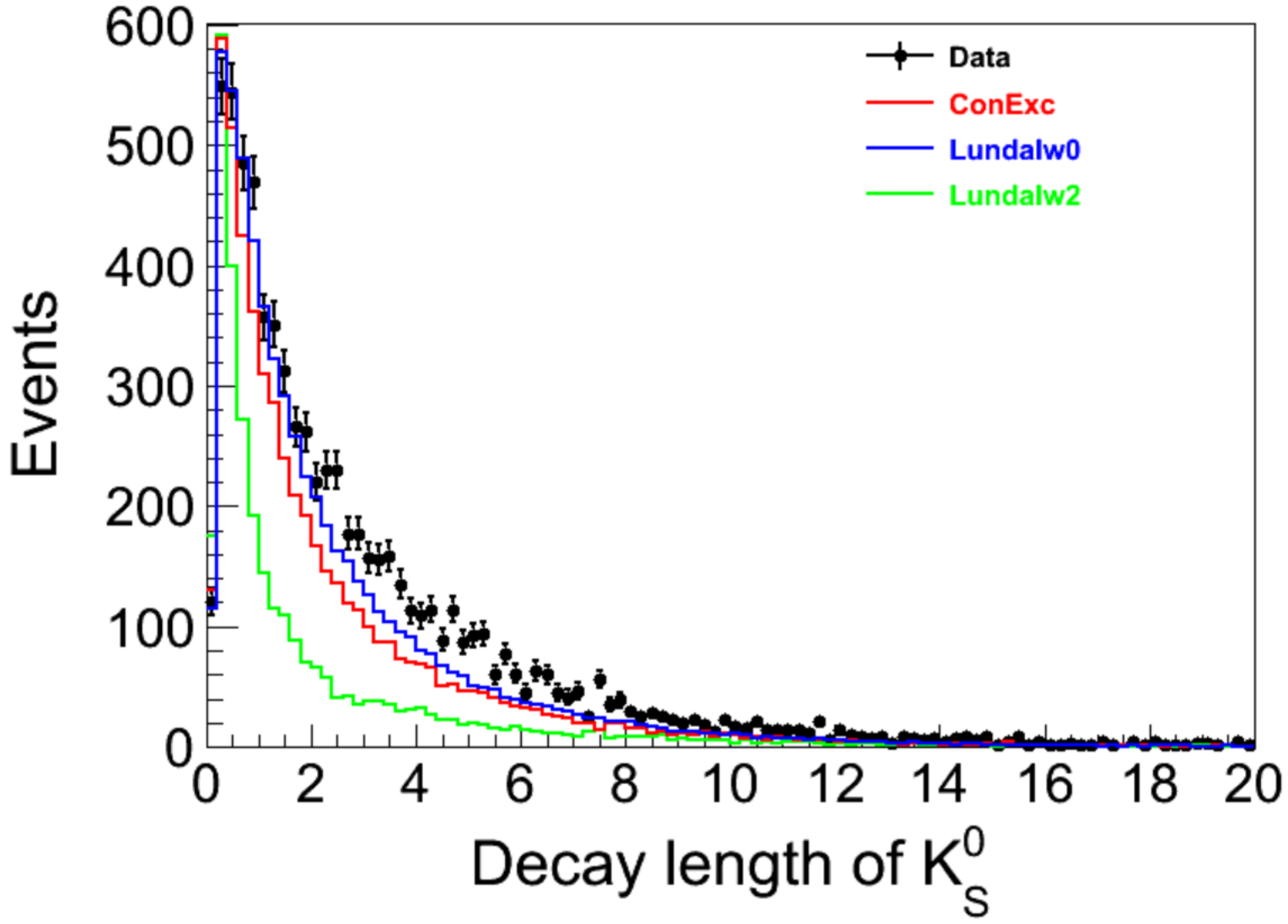


Ks mass in detect level

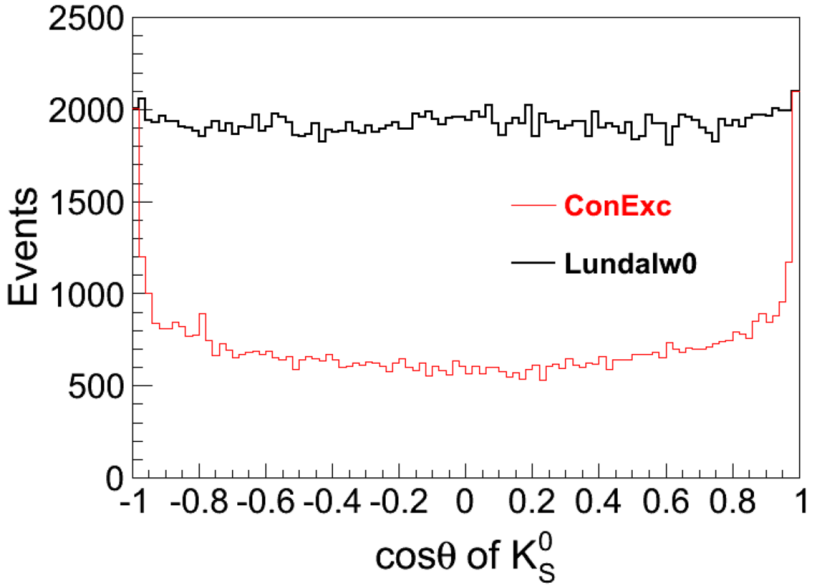
Ks mass in detect level:

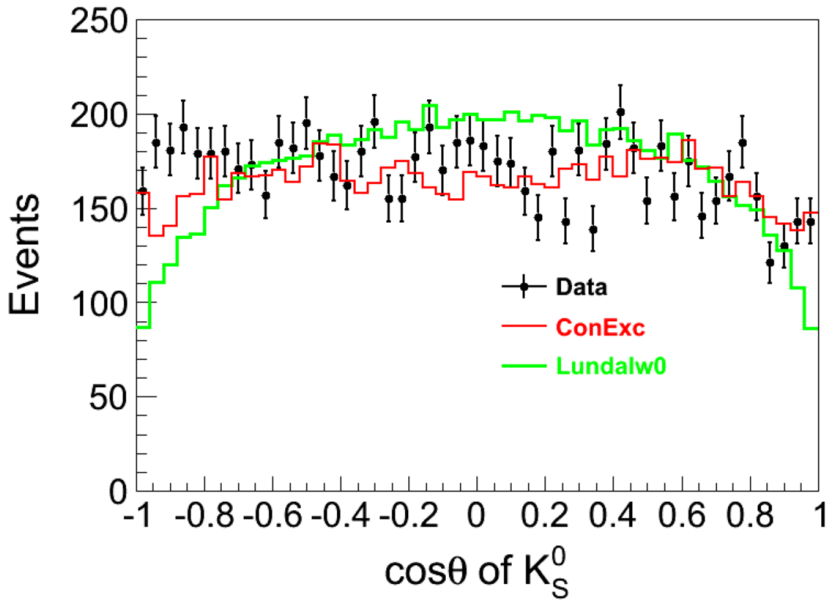




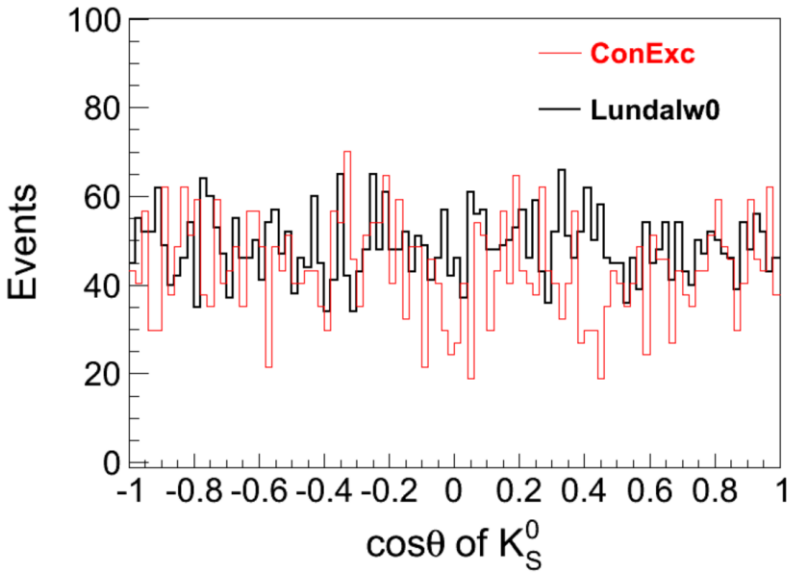

Data
ConExc
Lundalw0
Lundalw2
Events
Decay length of K^0_S
0
100
200
300
400
500
600
0
2
4
6
8
10
12
14
16
18
20

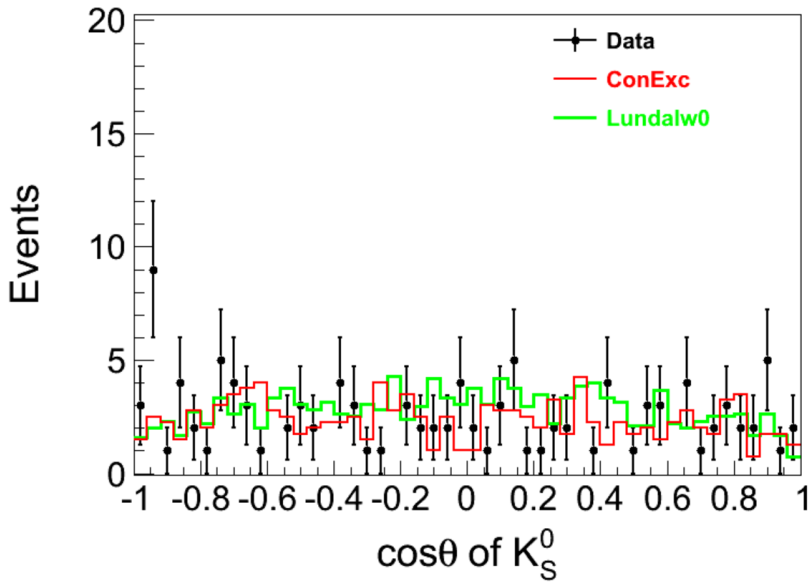
Costheta distribution



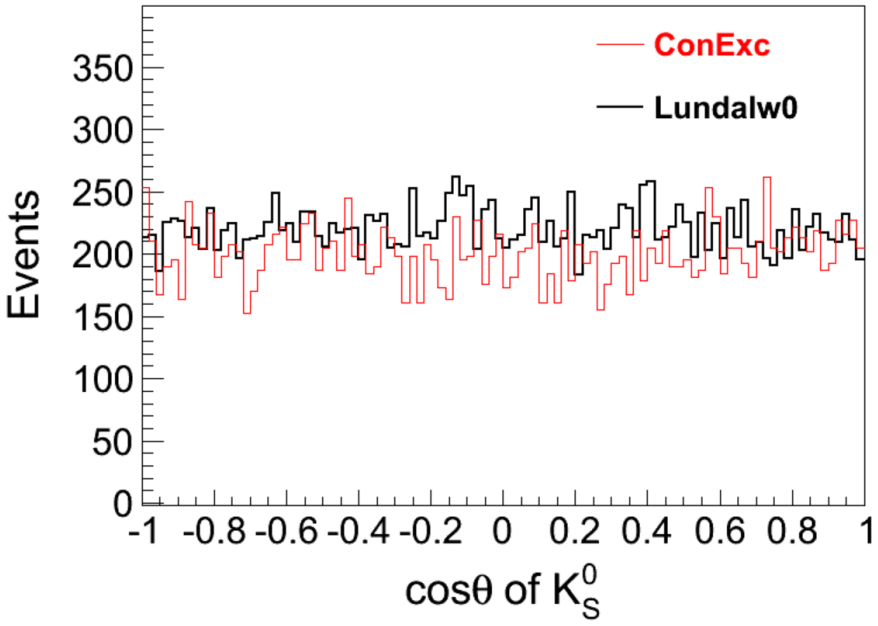


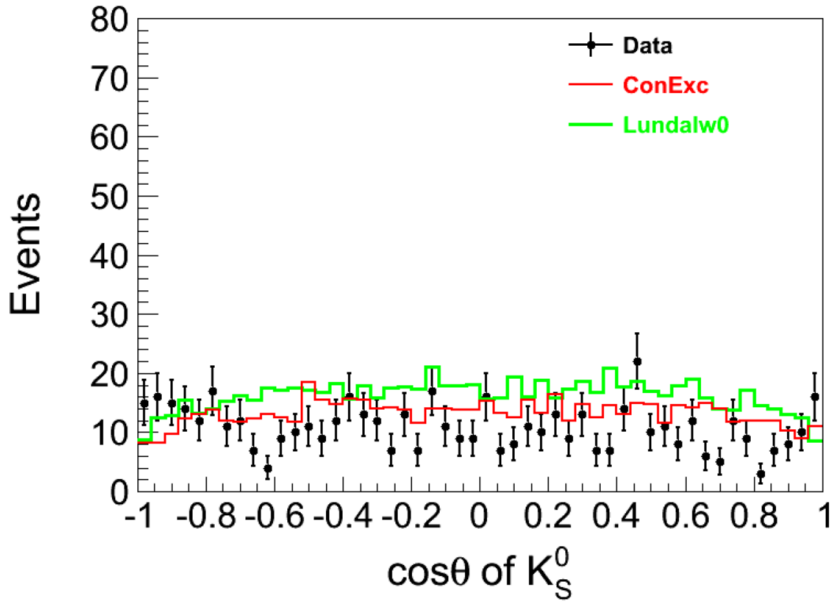
0.0-0.1


ConExc
Lundalw0
Events
cosθ of K^0_S

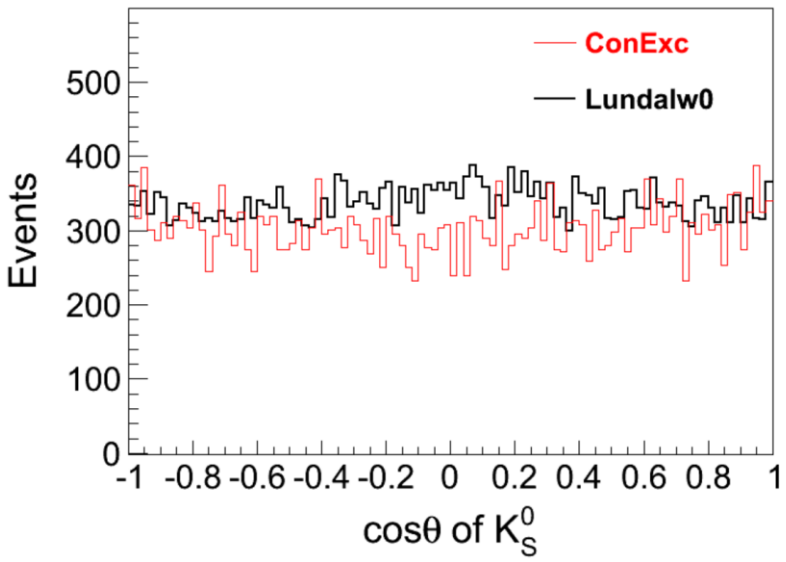

Data
ConExc
Lundalw0
Events
cosθ of K^0_S

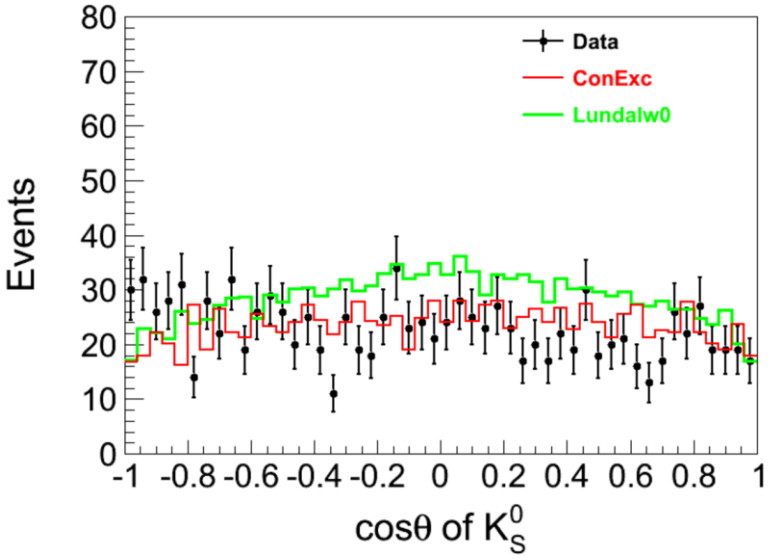
0.1-0.2


ConExc
Lundalw0
Events
cosθ of K^0_S

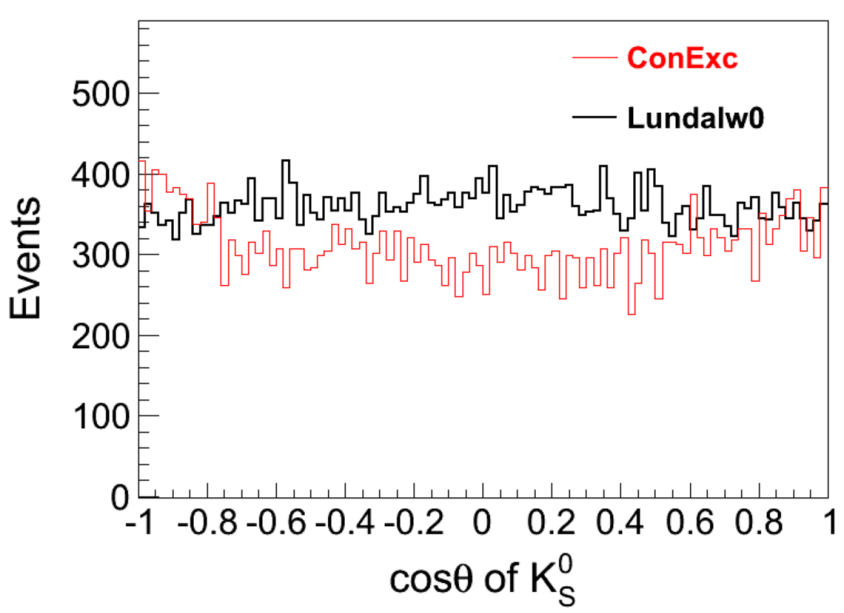

Data
ConExc
Lundalw0
Events
cosθ of K^0_S

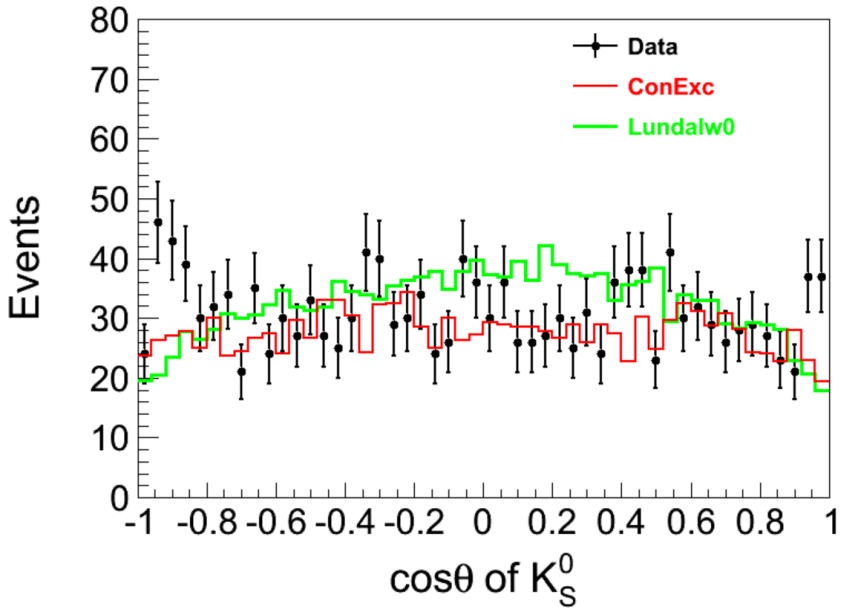
0.2-0.3


ConExc
Lundalw0
Events
500
400
300
200
100
0
-1 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1
cosθ of K^0_S

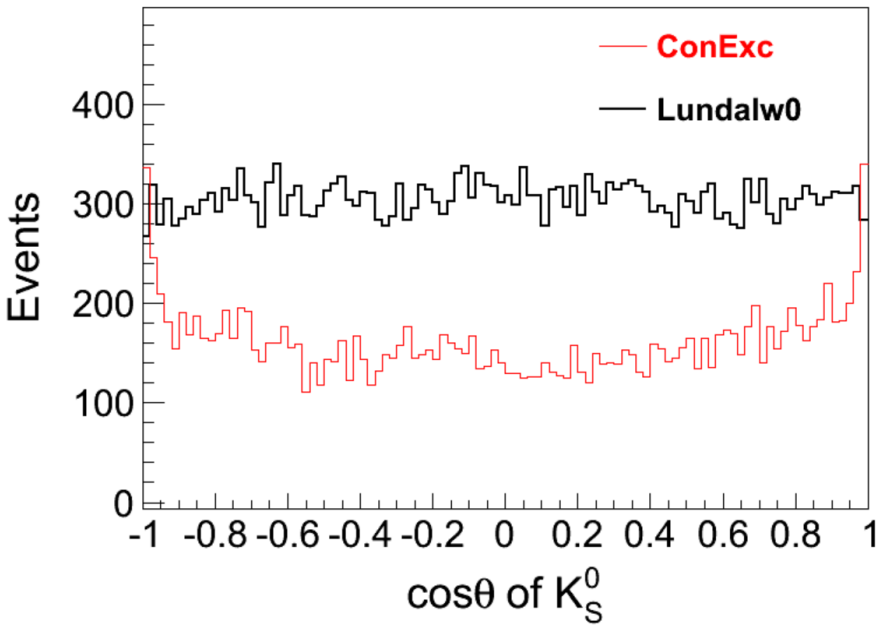

Data
ConExc
Lundalw0
Events
80
70
60
50
40
30
20
10
0
-1 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1
cosθ of K^0_S

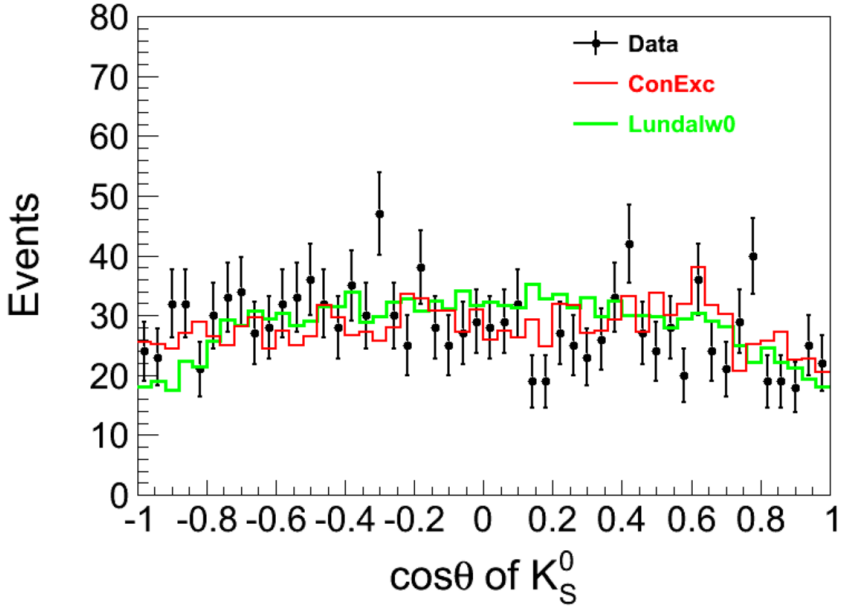
0.3-0.4


ConExc
Lundalw0
Events
500
400
300
200
100
0
-1 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1
cosθ of K^0_S

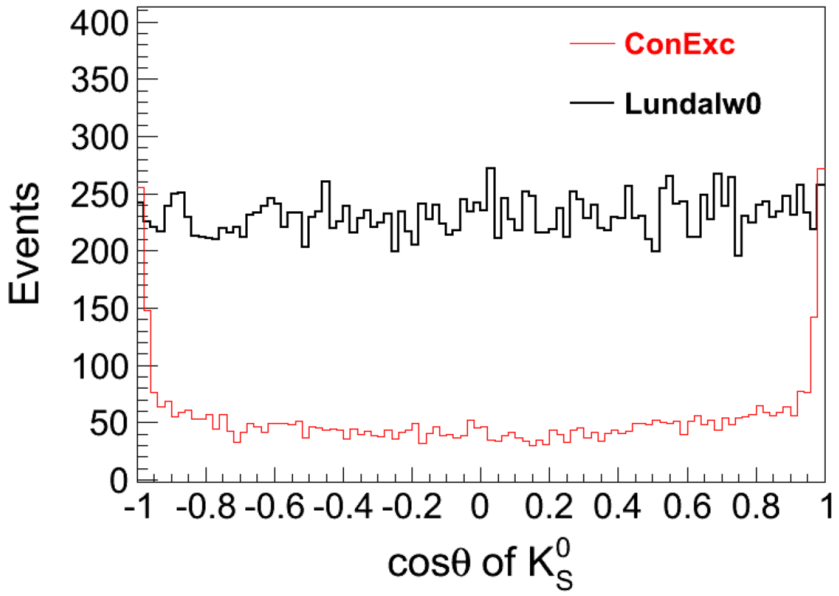

Data
ConExc
Lundalw0
Events
80
70
60
50
40
30
20
10
0
-1 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1
cosθ of K^0_S

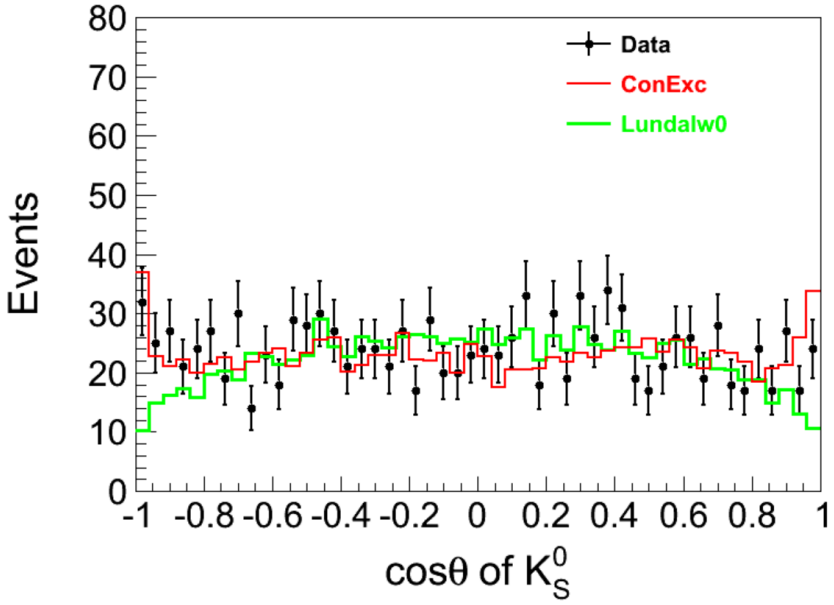
0.4-0.5


ConExc
Lundalw0
Events
400
300
200
100
0
-1 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1
cosθ of K^0_S

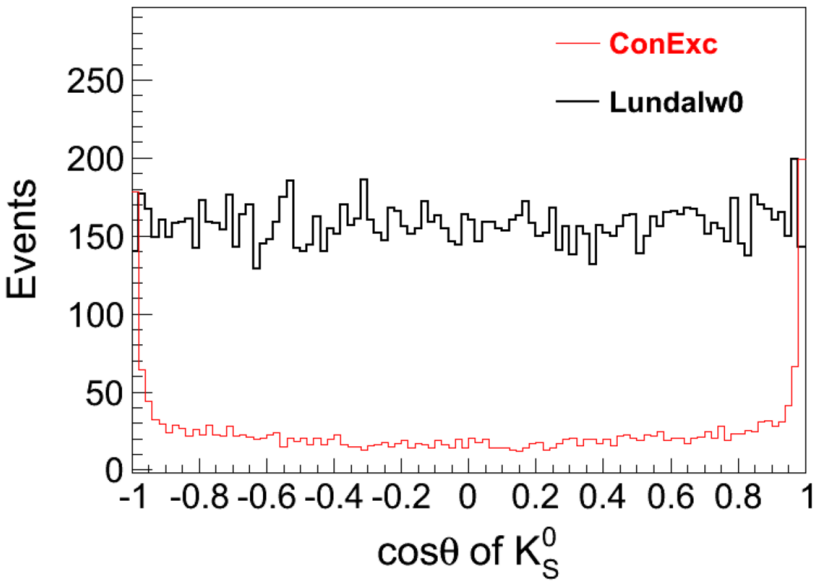

Data
ConExc
Lundalw0
Events
80
70
60
50
40
30
20
10
0
-1 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1
cosθ of K^0_S

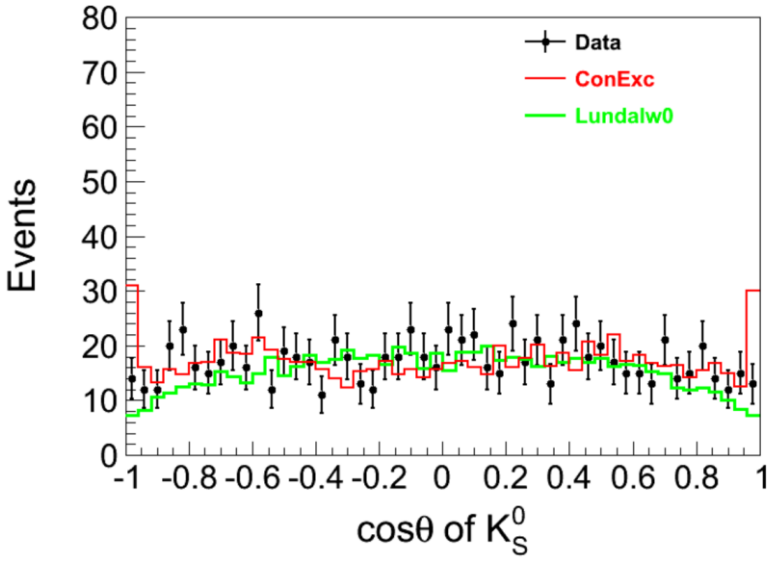
0.5-0.6


ConExc
Lundalw0
Events
cosθ of K^0_S


Data
ConExc
Lundalw0
Events
cosθ of K^0_S

0.6-0.7

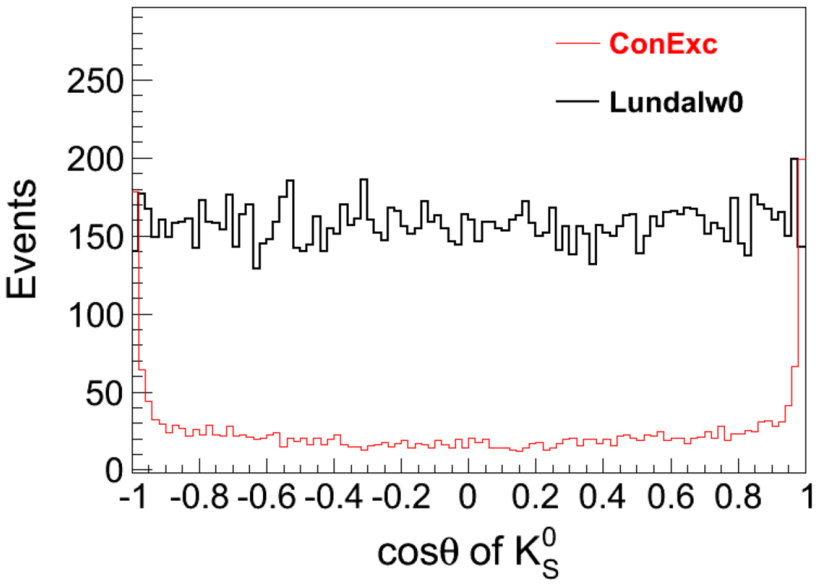


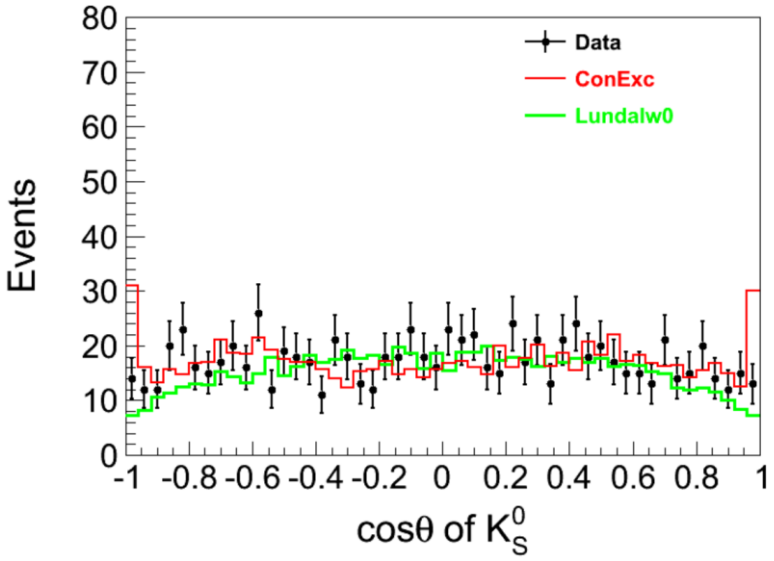


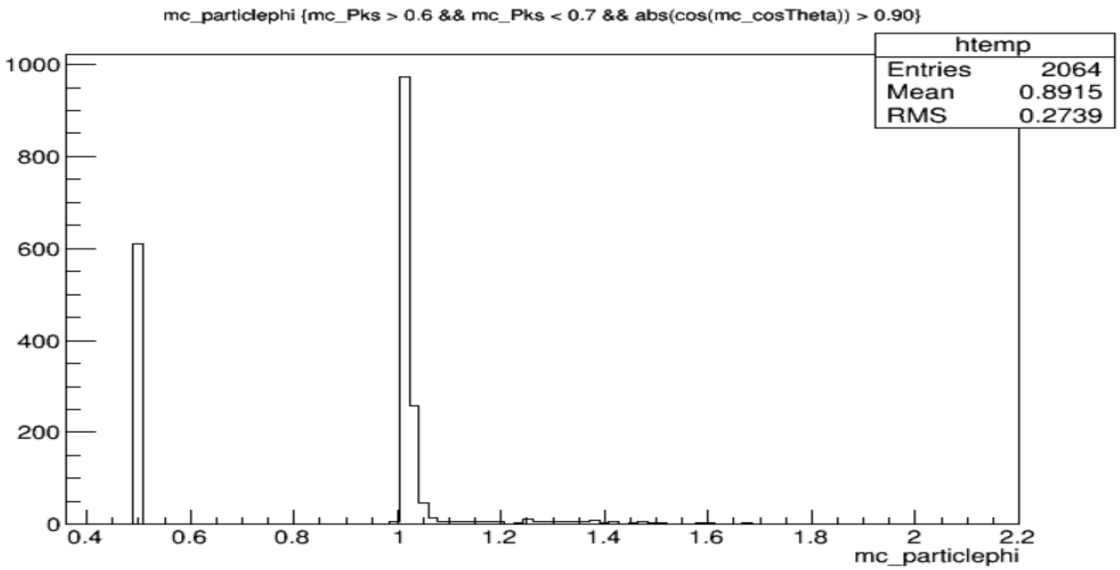
No.	decay chain	final states	iTopo	nEvt	nTot
0	$e^+e^- \to \gamma K_L K_S,\ K_S \to \pi^-\pi^+$	$e^+e^- \to \gamma\pi^+K_L\pi^-$	5	179	179
1	$e^+e^- \to \gamma\gamma^*,\ \gamma^* \to \pi^-\pi^-\pi^0\pi^0\pi^+\pi^+$	$e^+e^- \to \gamma\pi^+\pi^+\pi^0\pi^0\pi^-\pi^-$	17	66	245
2	$e^+e^- \to \pi^-\pi^-\pi^0\pi^0\pi^+\pi^+$	$e^+e^- \to \pi^+\pi^+\pi^0\pi^0\pi^-\pi^-$	13	61	306
3	$e^+e^- \to \gamma\gamma^*,\ \gamma^* \to \pi^-\pi^-\pi^-\pi^+\pi^+\pi^+$	$e^+e^- \to \gamma\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-$	3	44	350
4	$e^+e^- \to \gamma\gamma K_L K_S,\ K_S \to \pi^-\pi^+$	$e^+e^- \to \gamma\gamma\pi^+K_L\pi^-$	41	40	390
5	$e^+e^- \to \pi^-\pi^-\pi^-\pi^+\pi^+\pi^+$	$e^+e^- \to \pi^+\pi^+\pi^+\pi^-\pi^-\pi^-$	0	30	420
6	$e^+e^- \to \pi^-\pi^-\gamma\pi^+\pi^+$	$e^+e^- \to \gamma\pi^+\pi^+\pi^-\pi^-$	54	21	441
7	$e^+e^- \to \pi^-\gamma\pi^0\pi^+$	$e^+e^- \to \gamma\pi^+\pi^0\pi^-$	38	16	457
8	$e^+e^- \to \pi^-\gamma\pi^0\pi^0\pi^+$	$e^+e^- \to \gamma\pi^+\pi^0\pi^0\pi^-$	29	11	468
9	$e^+e^- \to a_1^-\pi^+a_1^0,\ a_1^- \to \pi^-\rho^0,\ a_1^0 \to \pi^-\rho^+,\ \rho^+ \to \pi^0\pi^+,\ \rho^0 \to \pi^-\pi^+$	$e^+e^- \to \pi^+\pi^+\pi^+\pi^0\pi^-\pi^-\pi^-$	16	8	476
10	$e^+e^- \to K^-\pi^-\pi^0\pi^+K^+$	$e^+e^- \to K^+\pi^+\pi^0\pi^-K^-$	60	8	484
11	$e^+e^- \to \gamma\gamma^*,\ \gamma^* \to \pi^-K_SK^+,\ K_S \to \pi^-\pi^+$	$e^+e^- \to \gamma K^+\pi^+\pi^-\pi^-$	117	7	491
12	$e^+e^- \to a_1^-K_SK^+,\ a_1^- \to \pi^-\rho^0,\ K_S \to \pi^-\pi^+,\ \rho^0 \to \pi^-\pi^+$	$e^+e^- \to K^+\pi^+\pi^+\pi^-\pi^-\pi^-$	55	6	497
13	$e^+e^- \to \gamma\gamma^*,\ \gamma^* \to \pi^-\pi^-\pi^0\pi^+\pi^+$	$e^+e^- \to \gamma\pi^+\pi^+\pi^0\pi^-\pi^-$	140	6	503
14	$e^+e^- \to \pi^-\pi^-\pi^+\pi^+\eta,\ \eta \to \gamma\gamma$	$e^+e^- \to \gamma\gamma\pi^+\pi^+\pi^-\pi^-$	209	6	509
15	$e^+e^- \to \pi^-\pi^-\pi^0\pi^+\pi^+$	$e^+e^- \to \pi^+\pi^+\pi^0\pi^-\pi^-$	63	5	514
16	$e^+e^- \to K^-K_Sa_1^+,\ K_S \to \pi^-\pi^+,\ a_1^+ \to \rho^0\pi^+,\ \rho^0 \to \pi^-\pi^+$	$e^+e^- \to \pi^+\pi^+\pi^+\pi^-\pi^-K^-$	76	5	519
17	$e^+e^- \to \gamma\gamma^*,\ \gamma^* \to \pi^-\pi^-\pi^+\pi^+\eta,\ \eta \to \pi^-\pi^0\pi^+$	$e^+e^- \to \gamma\pi^+\pi^+\pi^+\pi^0\pi^-\pi^-\pi^-$	23	5	524
18	$e^+e^- \to K_LK_Sa_1^0,\ K_S \to \pi^-\pi^+,\ a_1^0 \to \pi^-\rho^+,\ \rho^+ \to \pi^0\pi^+$	$e^+e^- \to \pi^+\pi^+K_L\pi^0\pi^-\pi^-$	36	5	529
19	$e^+e^- \to \pi^-\pi^-\pi^+\pi^+\eta,\ \eta \to \pi^-\pi^0\pi^+$	$e^+e^- \to \pi^+\pi^+\pi^+\pi^0\pi^-\pi^-\pi^-$	42	5	534

Table 1: The possible background channels extracted from Inclusive MC sample

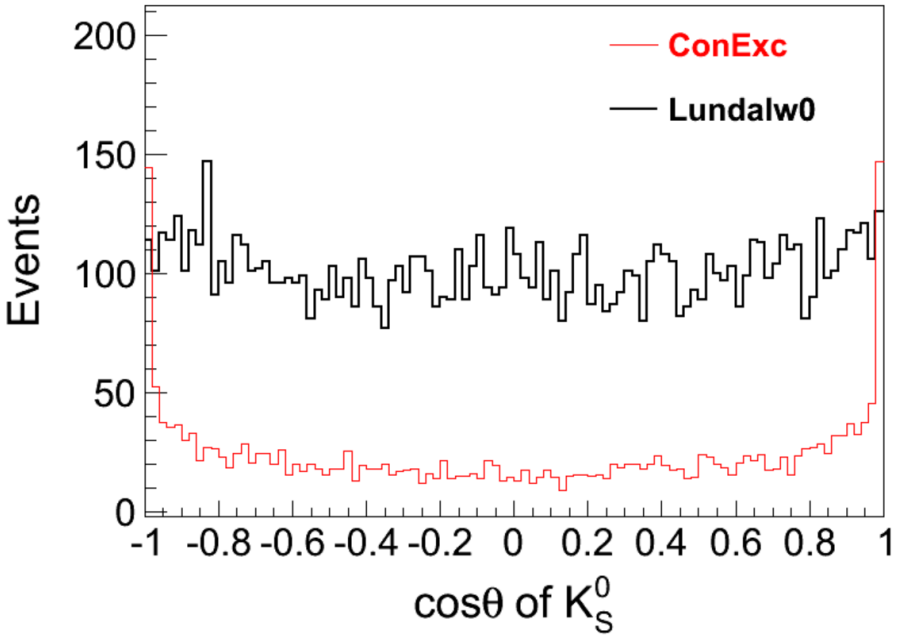
0.6-0.7

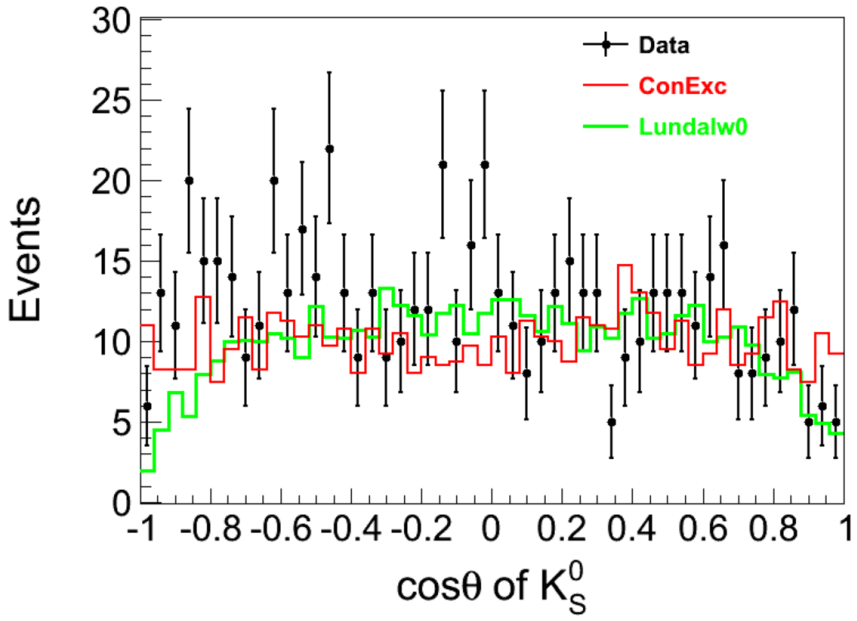

ConExc
Lundalw0
Events
cosθ of K^0_S


Data
ConExc
Lundalw0
Events
cosθ of K^0_S

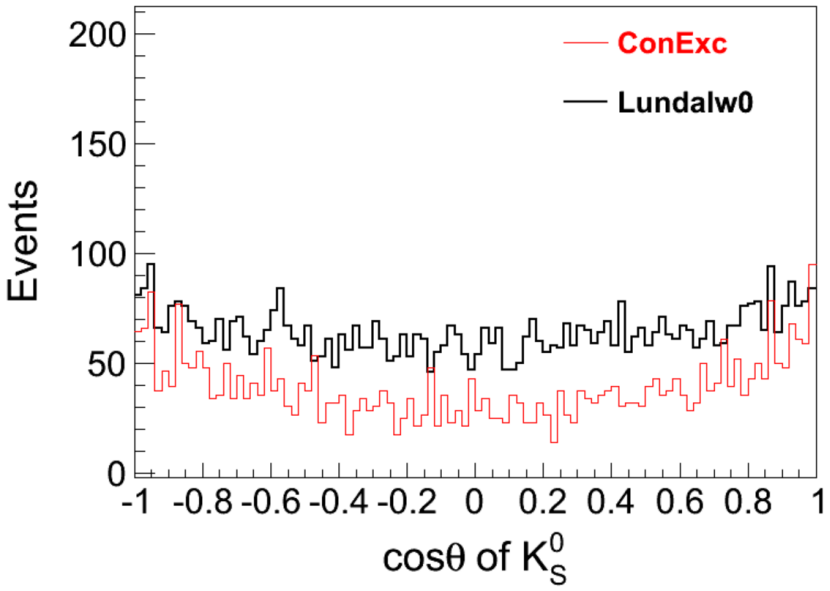

mc_particlephi {mc_Pks > 0.6 && mc_Pks < 0.7 && abs(cos(mc_cosTheta)) > 0.90}
htemp
Entries 2064
Mean 0.8915
RMS 0.2739
mc_particlephi

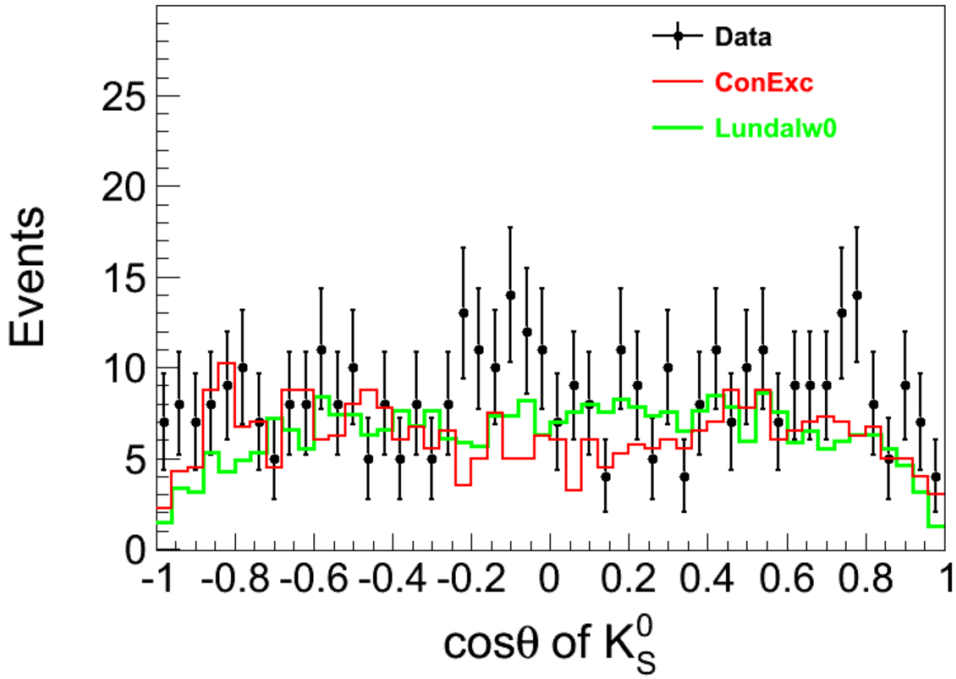
0.7-0.8


ConExc
Lundalw0
Events
200
150
100
50
0
-1 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1
cosθ of K^0_S

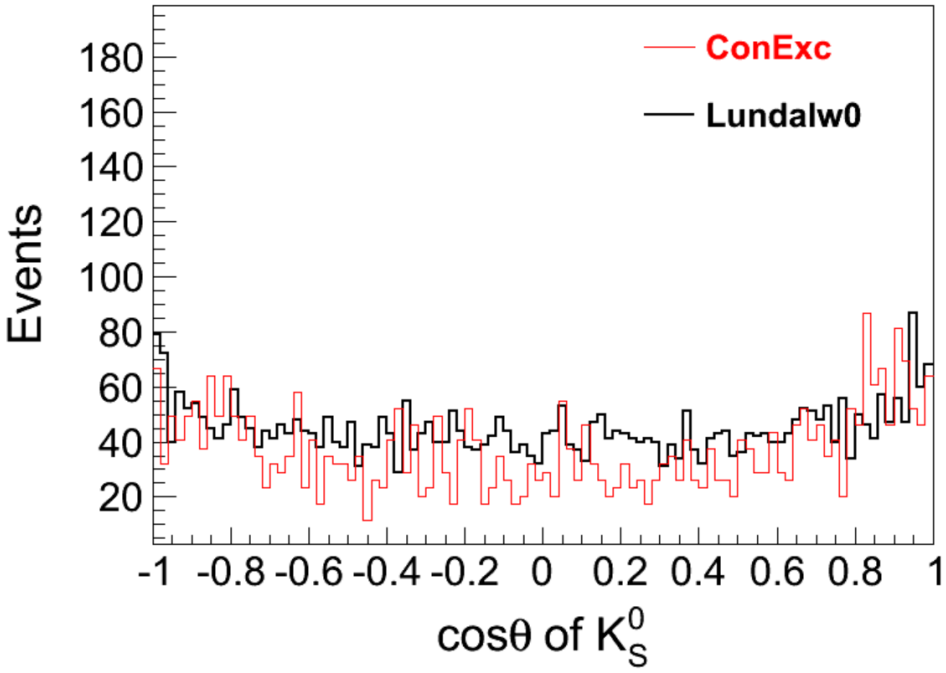

Data
ConExc
Lundalw0
Events
30
25
20
15
10
5
0
-1 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1
cosθ of K^0_S

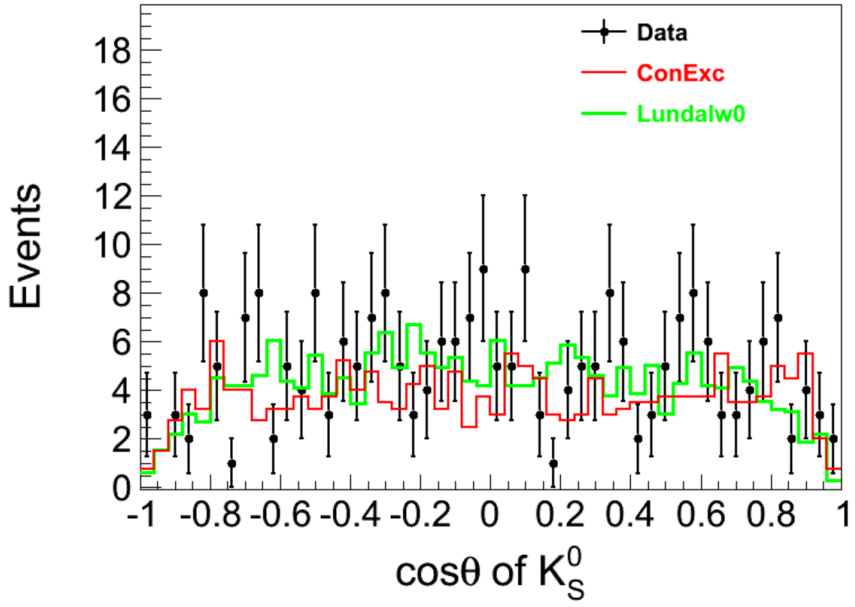
0.8-0.9


ConExc
Lundalw0
Events
200
150
100
50
0
-1 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1
cosθ of K^0_S

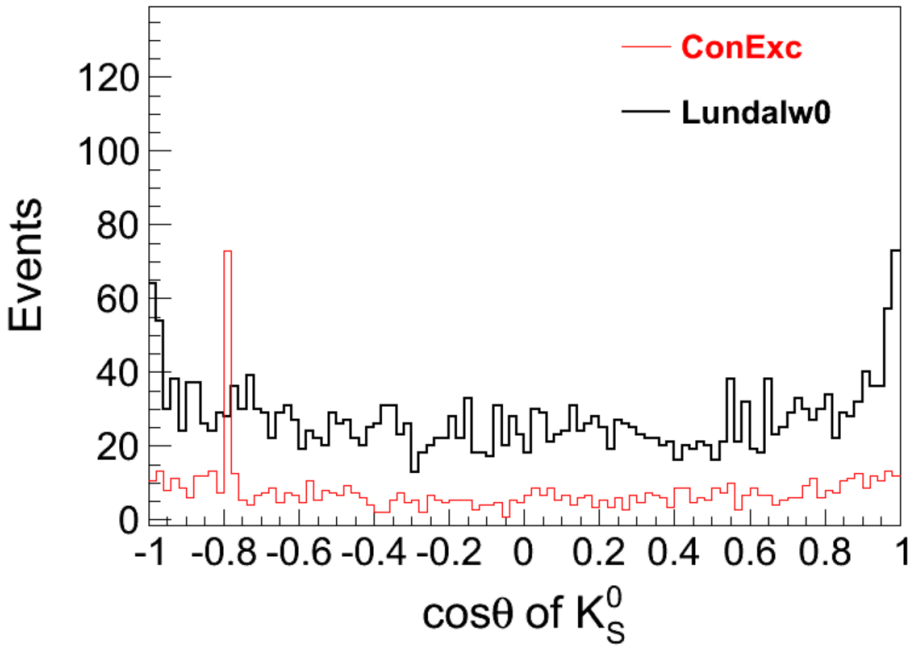

Data
ConExc
Lundalw0
Events
25
20
15
10
5
0
-1 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1
cosθ of K^0_S

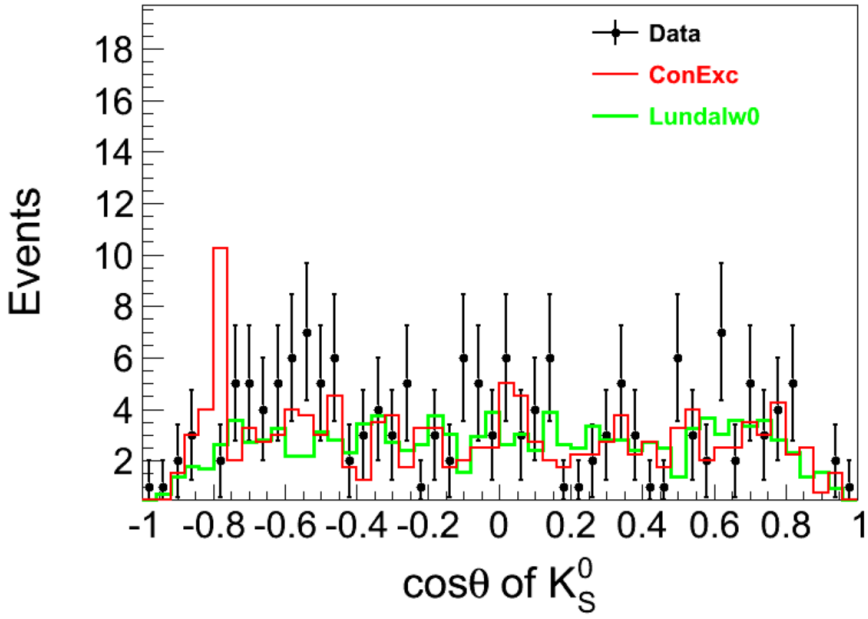
0.9-1.0


ConExc
Lundalw0
Events
cosθ of K^0_S

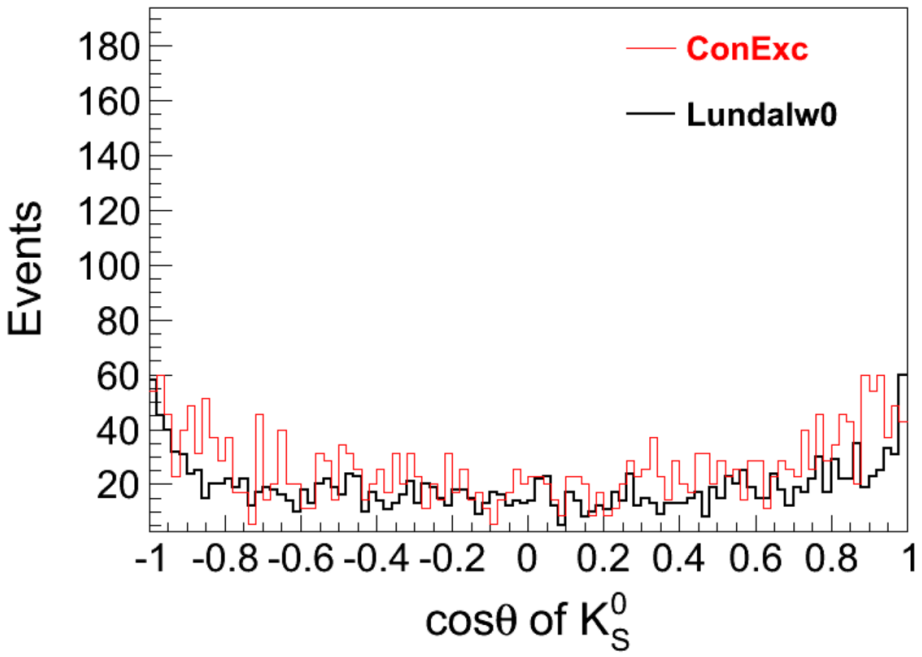

Data
ConExc
Lundalw0
Events
cosθ of K^0_S

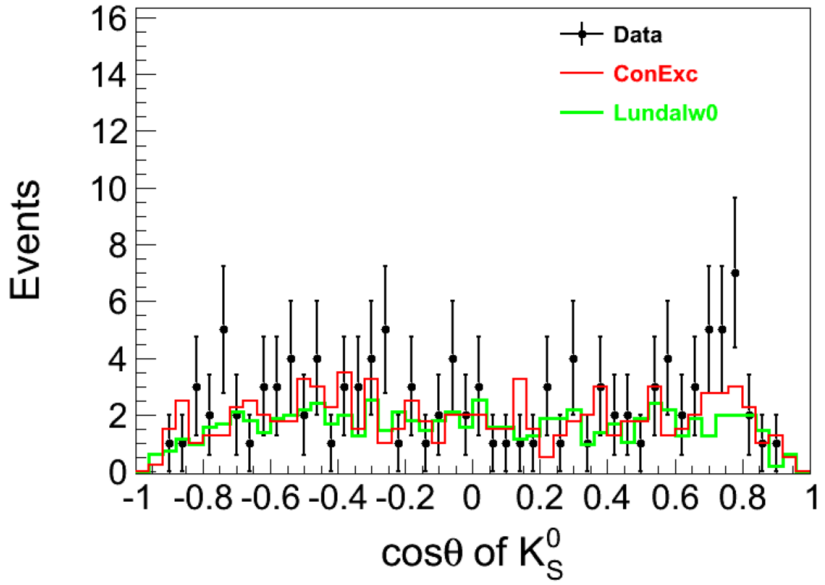
1.0-1.1


ConExc
Lundalw0
Events
cosθ of K^0_S

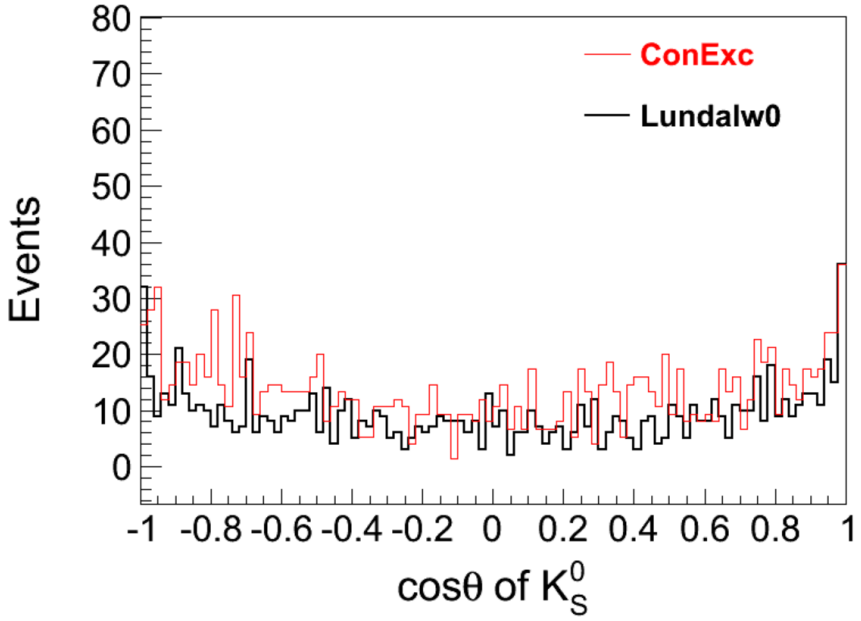

Data
ConExc
Lundalw0
Events
cosθ of K^0_S

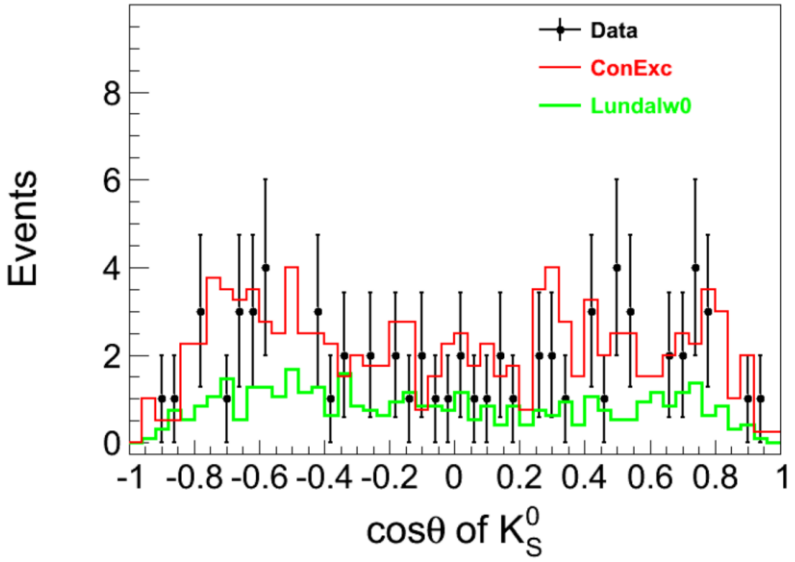
1.1-1.2


ConExc
Lundalw0
Events
cosθ of K^0_S

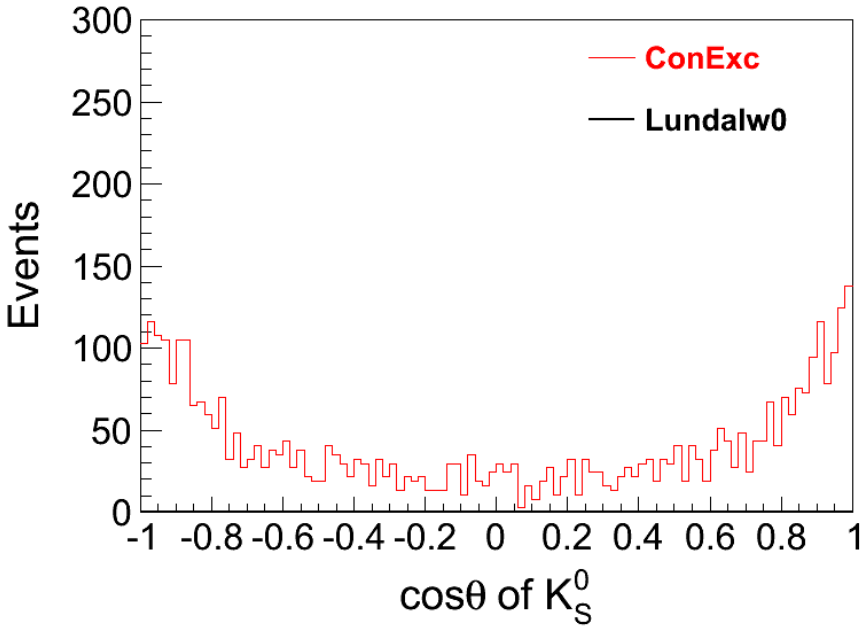

Data
ConExc
Lundalw0
Events
cosθ of K^0_S

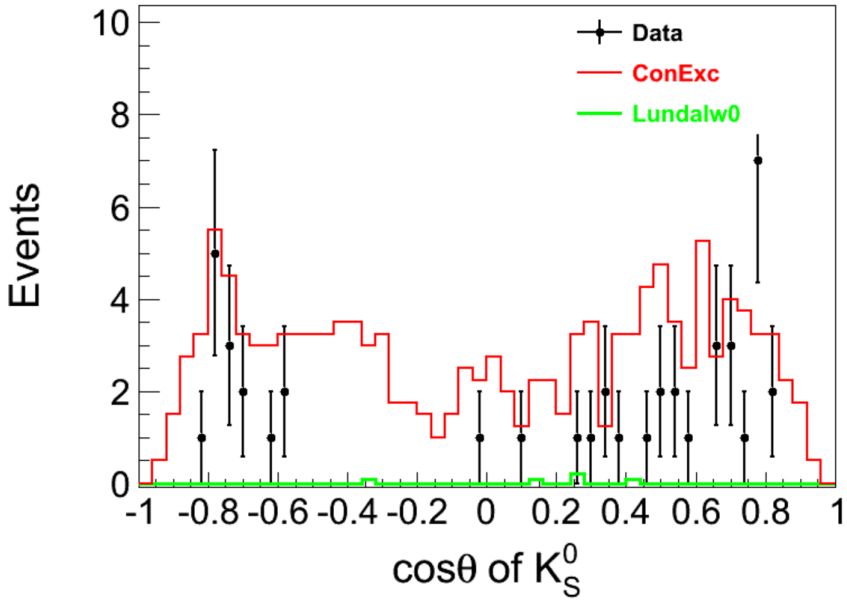
1.2-1.3


ConExc
Lundalw0
Events
cosθ of K^0_S


Data
ConExc
Lundalw0
Events
cosθ of K^0_S

1.3-1.4


ConExc
Lundalw0
Events
300
250
200
150
100
50
0
-1 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1
cosθ of K^0_S


Data
ConExc
Lundalw0
Events
10
8
6
4
2
0
-1 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1
cosθ of K^0_S

2, Hadron efficiency differences

- Hadronic event selection efficiency:

  74.2% (Here, the generator is Lundalw, and MSTJ(21) = 2, Gao zhen's efficiency is 72.7%)

  82.9% (Here, the generator is Lundalw, and MSTJ(21) = 0)

  72.8% (Here, the generator is ConExc, and Gao Zhen's efficiency is 72.7%)

Cut flow for hadronic event selection:

MSTJ(21) = 0

MSTJ(21) = 2

Table 19: Hadron efficiencies (%) using different Lundalw parameters.

Cut criteria	ConExc		Lundalw(0)		Lundalw(2)		ε diff
	Events	$\varepsilon(hadron)$	Events	$\varepsilon(hadron)$	Events	$\varepsilon(hadron)$	
Total events	200000	-	200000	-	200000	-	-
N_{good} >= 1(No cut)	190099	95.05	195206	97.60	185006	92.50	5.5
$\lvert\theta_1 + \theta_2 - 180°\rvert < 10°$ and $E > 0.65 * E_{beam}$	199937	99.97	199983	99.99	199960	99.98	0.01
N_{good} >= 2	164894	82.47	180048	90.03	162542	81.29	10.8
$N_{good} = 2$	54850	-	44676	-	40356	-	-
$\lvert\theta_1 + \theta_2 - 180°\rvert < 15°$ and $\lvert\lvert\phi_1 - \phi_2\rvert - 180°\rvert < 10°$	52805	96.27	43032	96.32	39061	97.15	-0.9
$N_{Isolated}$ >= 2	38316	72.56	33792	78.53	28955	71.75	9.4
	148360	89.97	169164	93.95	151141	92.75	1.3
$N_{good} = 3$	38313	-	46034	-	39084	-	-
$\lvert\theta_1 + \theta_2 - 180°\rvert < 15°$ and $\lvert\lvert\phi_1 - \phi_2\rvert - 180°\rvert < 10°$	36892	96.29	44232	96.09	37548	96.03	-0.1
$N_{eop} > 1$	35959	97.45	43096	97.43	36610	93.67	4.0
$N_{ProbE} > 1$	35526	98.80	42710	99.10	36259	99.04	0.1
	145573	98.12	165840	98.04	148316	98.13	-0.1
Finally Efficiency	145573	72.79	165840	82.92	148316	74.16	11.8

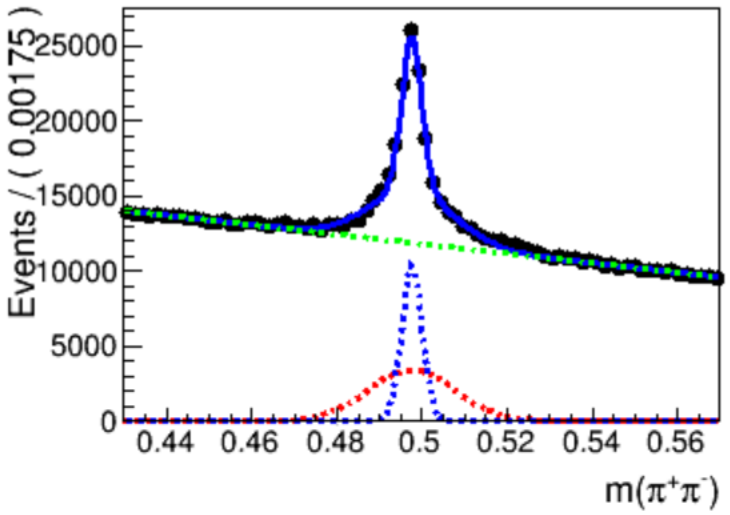
Table 22: K_S^0 efficiencies (%) vary with momentum in different MC models.

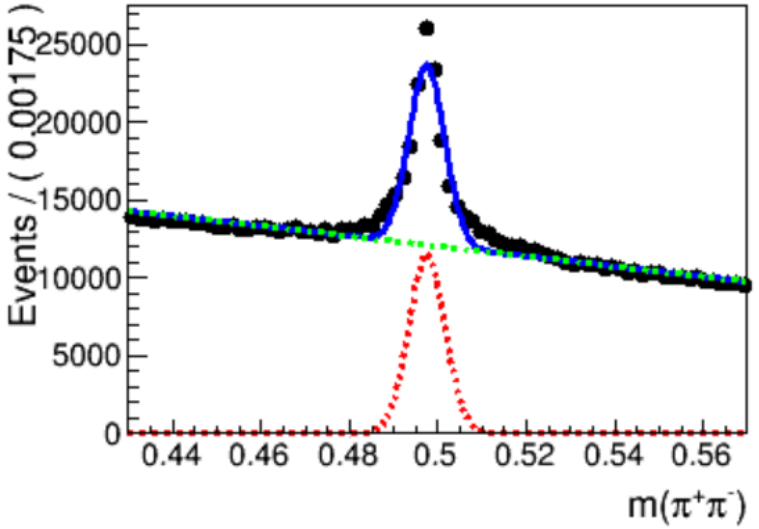
p(GeV)	$\varepsilon(K_S^0)$ ConExc	$\varepsilon(K_S^0)$ Lundalw(0)	$\varepsilon(K_S^0)$ Lundalw(2)S	Lundalw(2)D
0.0-0.1	64.2±3.3	68.6±1.8	46.4±2.0	72.8±21.9
0.1-0.2	62.8±1.8	61.3±0.9	48.3±1.1	75.2±3.3
0.2-0.3	55.9±1.7	56.9±0.8	43.5±1.0	53.9±2.3
0.3-0.4	55.2±2.3	51.4±0.9	46.6±1.1	67.0±2.5
0.4-0.5	56.5±3.0	52.1±1.2	57.4±1.1	73.6±3.3
0.5-0.6	46.8±3.5	47.7±1.6	53.5±1.3	88.1±6.9
0.6-0.7	45.8±3.3	45.5±2.4	53.4±1.6	79.0±18.3
0.7-0.8	34.8±15.1	43.9±3.0	66.5±1.9	109.1±25.4
0.8-0.9	38.5±5.9	45.9±4.3	51.8±2.5	71.1±6.3
0.9-1.0	24.7±6.5	41.2±5.2	51.3±2.7	68.8±6.9
1.0-1.1	22.0±6.1	35.1±7.8	44.7±2.9	67.9±13.5
1.1-1.2	22.6±5.7	22.9±4.3	48.2±3.1	69.2±10.7
1.2-1.3	30.2±4.6	25.1±7.2	50.3±4.9	84.7±18.4

Lundalw(0)s = 61209+/- 500 Lundalw(2)s = 67316.3 +/- 558

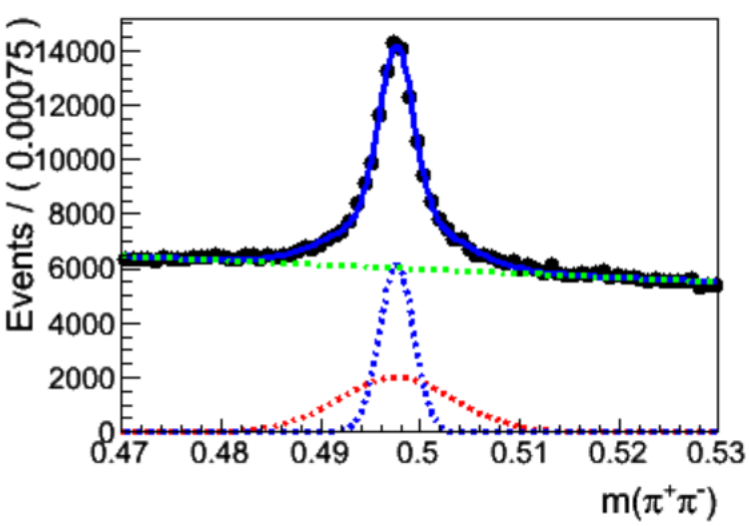
Lundalw(0)d = 74132+/-1789 Lundalw(2)d = 85500 +/- 1408

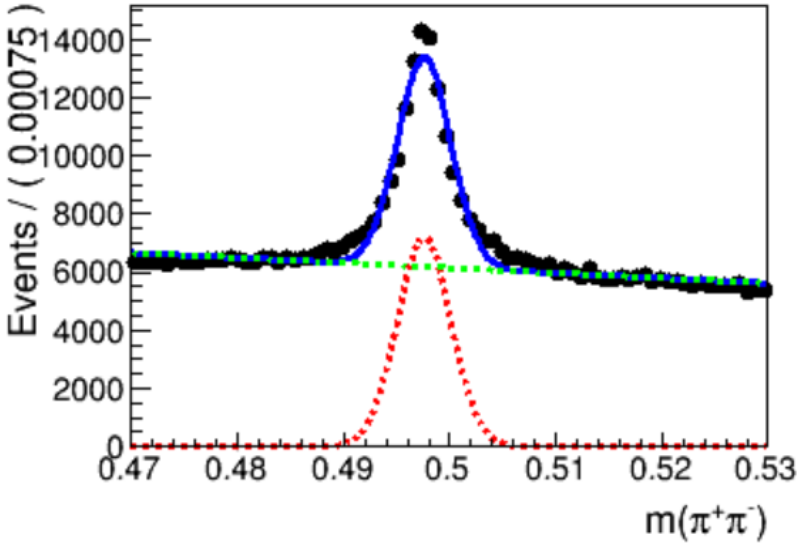
Lundalw2 (Total fit)



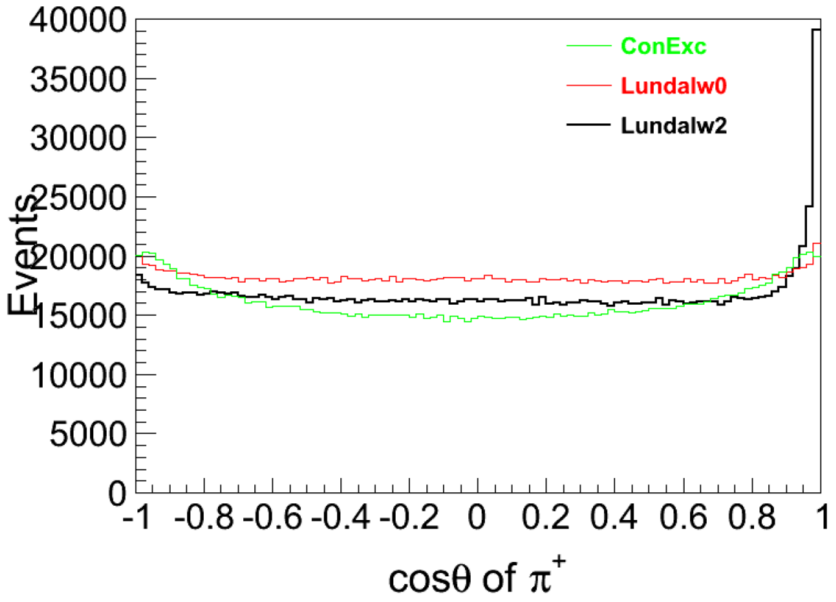


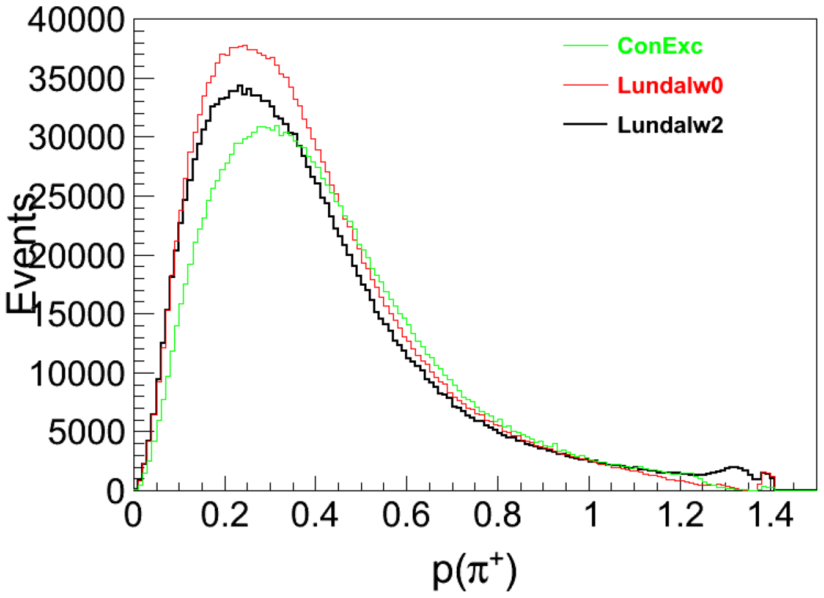
Lundalw0 (Total fit)



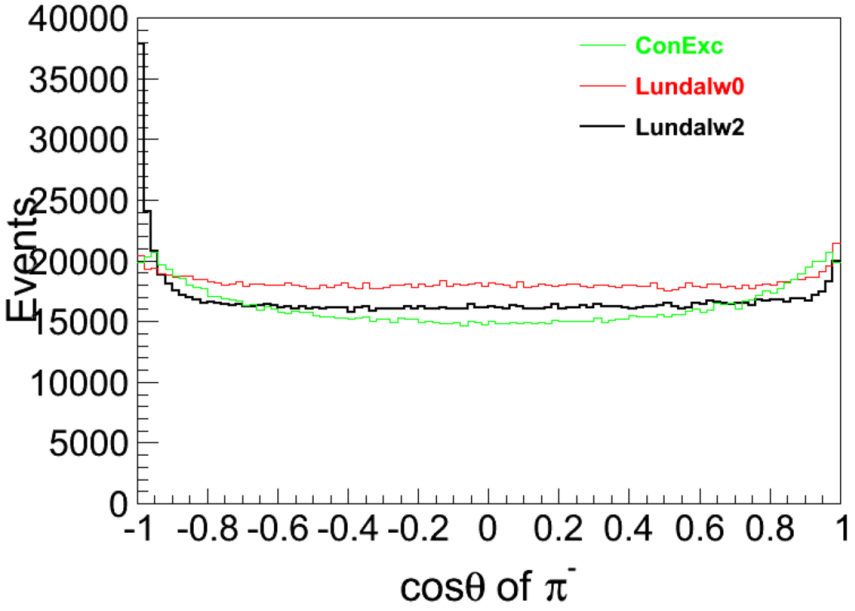


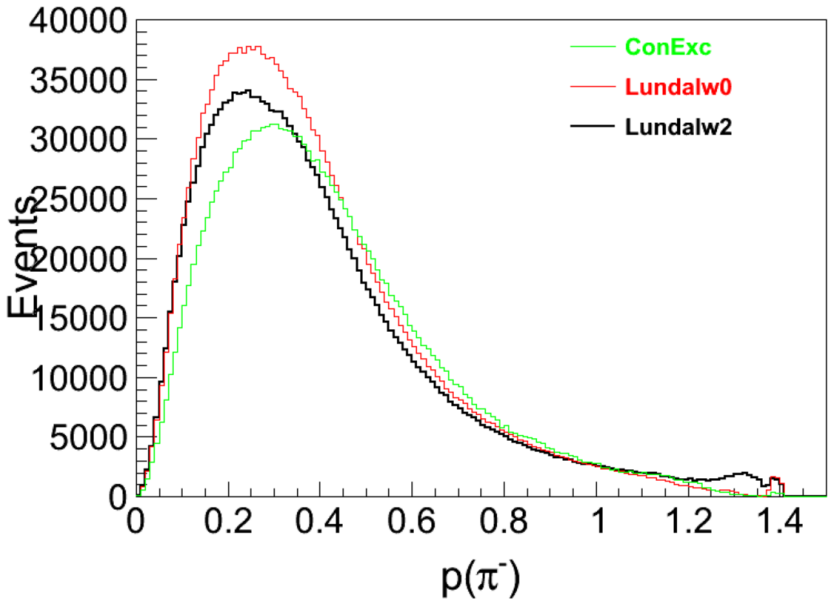
MC truth of π^+



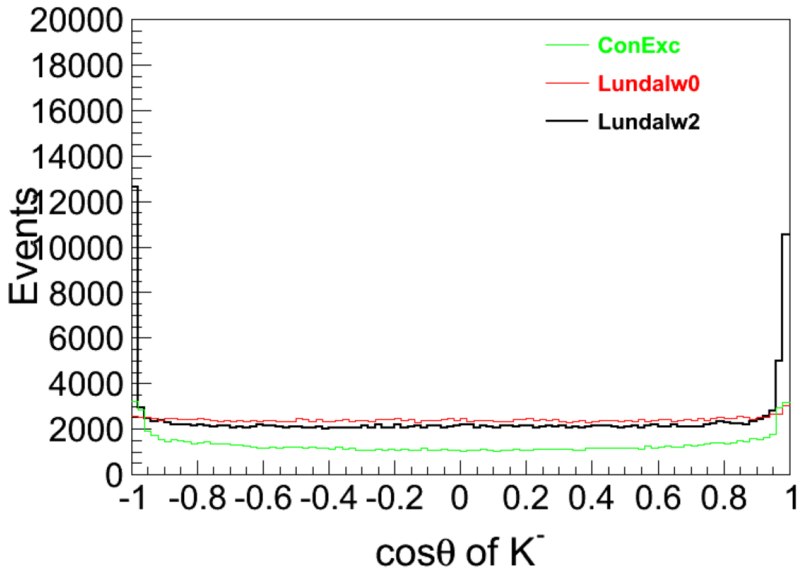


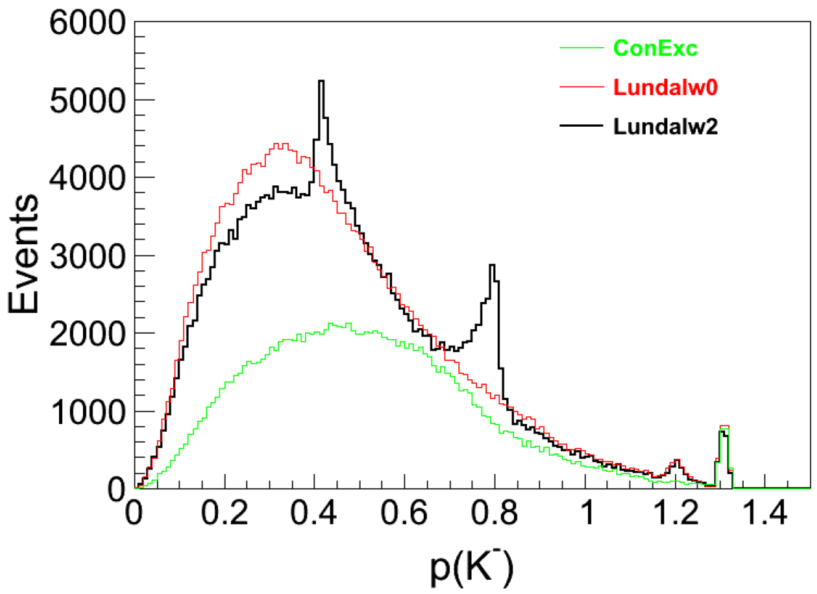
MC truth of π^-



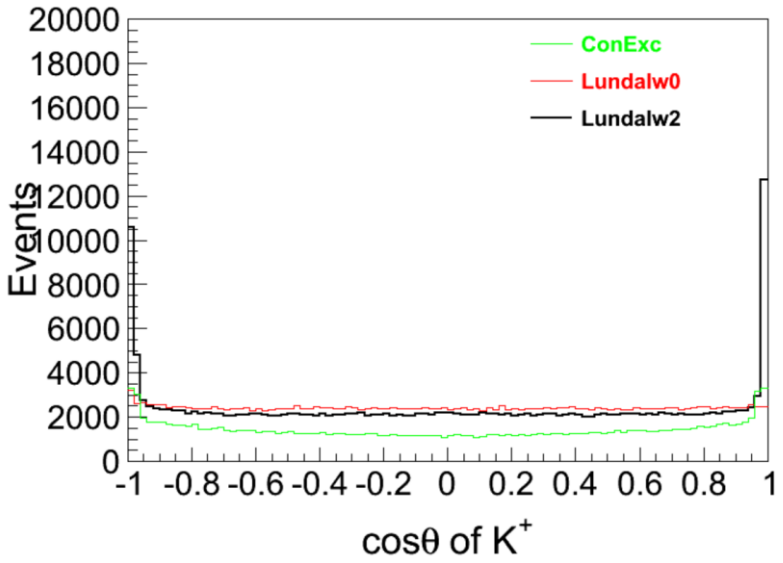


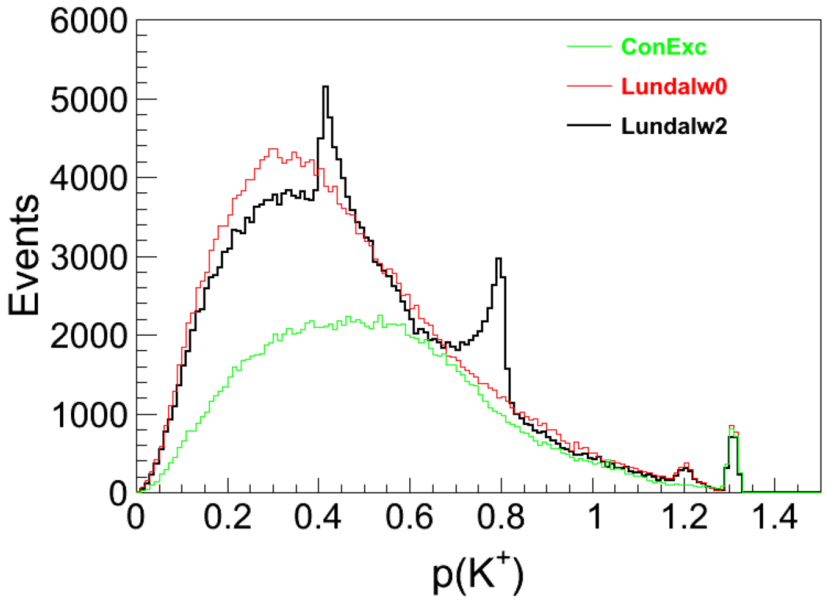
MC truth of K^-


ConExc
Lundalw0
Lundalw2
Events
cosθ of K-

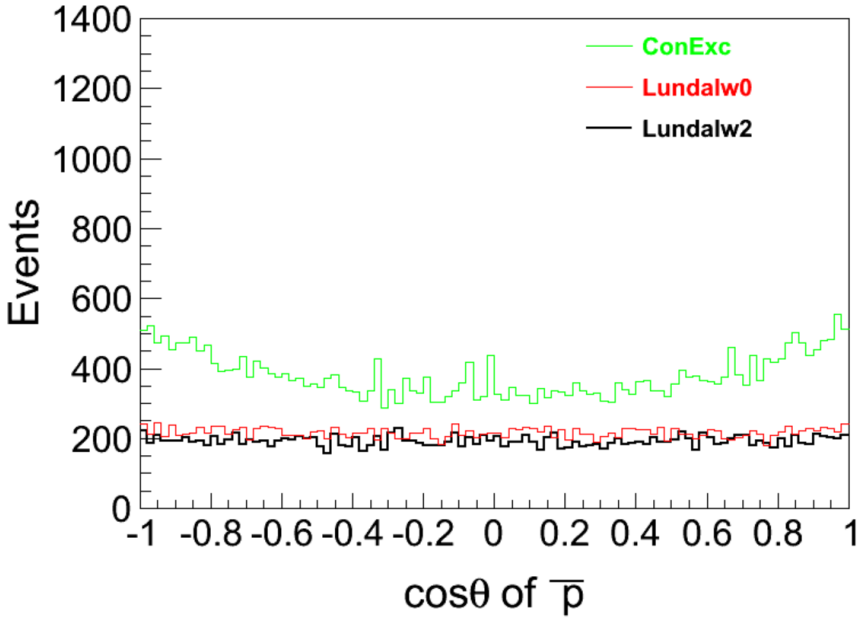

ConExc
Lundalw0
Lundalw2
Events
p(K-)

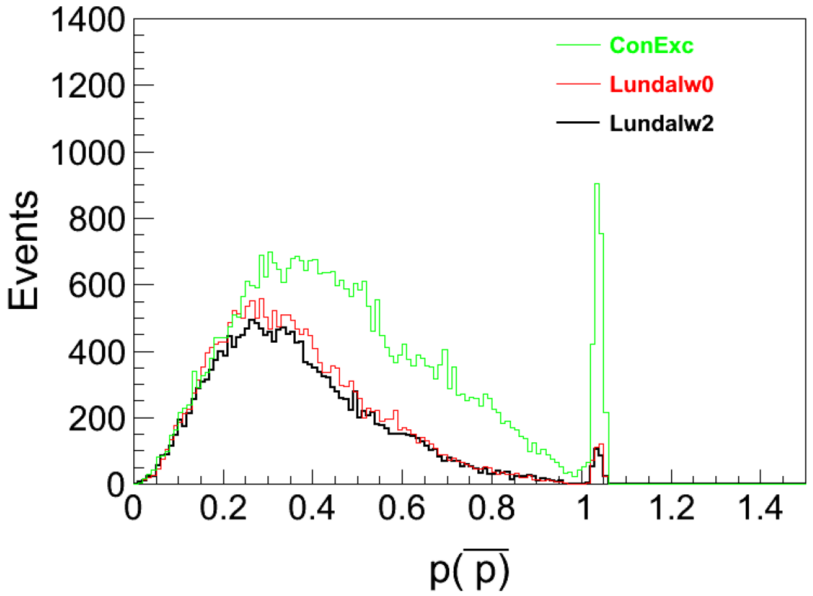
MC truth of K^+


ConExc
Lundalw0
Lundalw2
Events
cosθ of K+

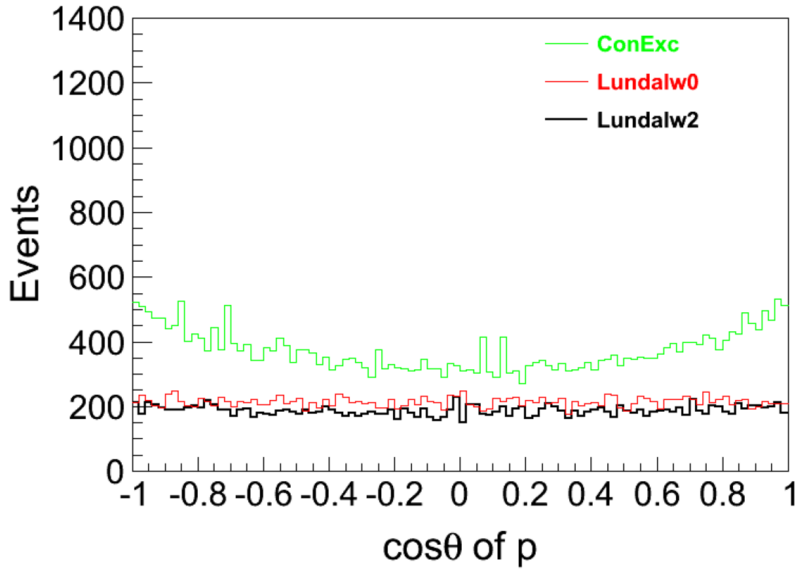

ConExc
Lundalw0
Lundalw2
Events
p(K+)

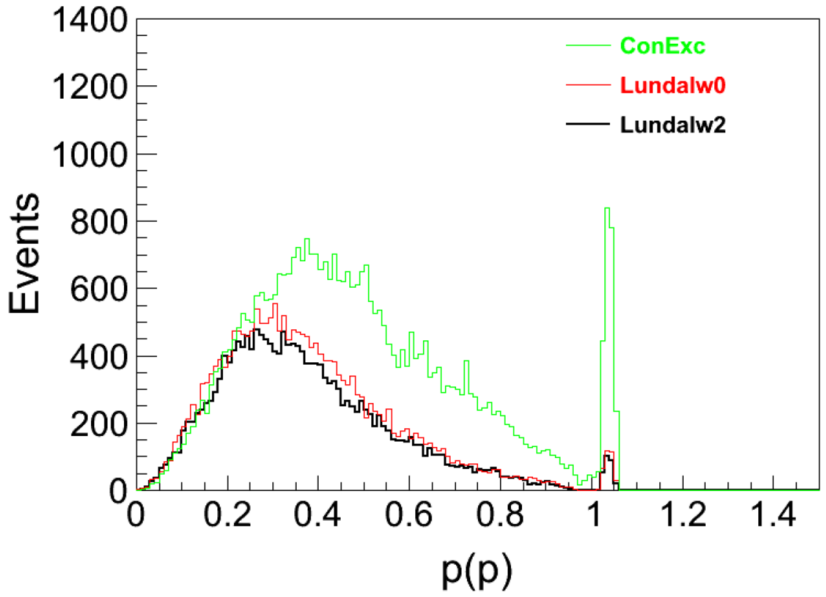
MC truth of anti-proton



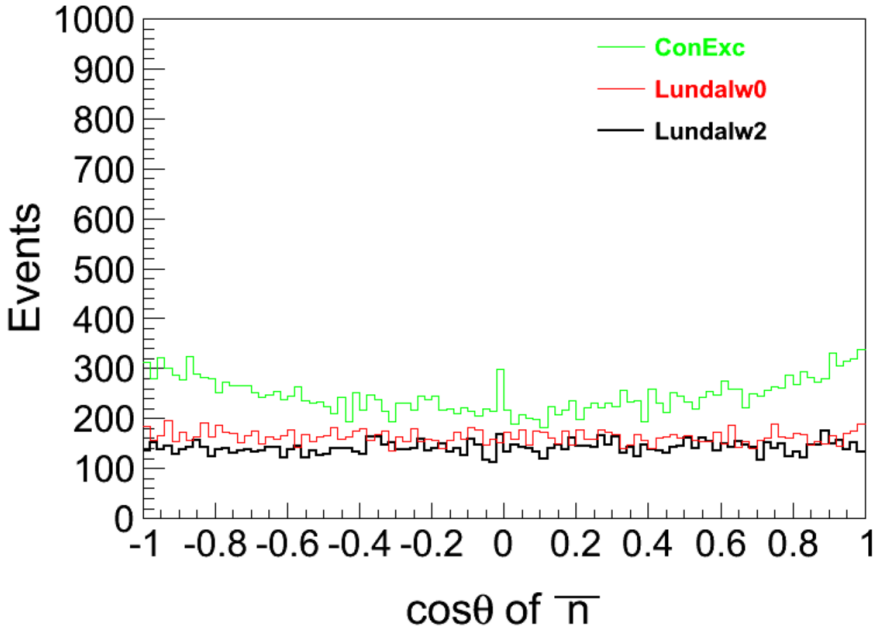


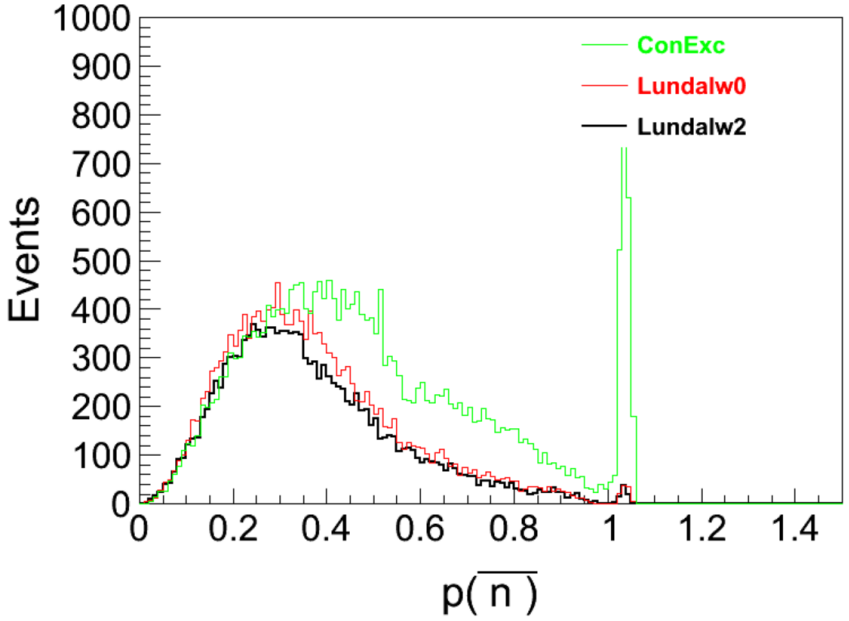
MC truth of proton



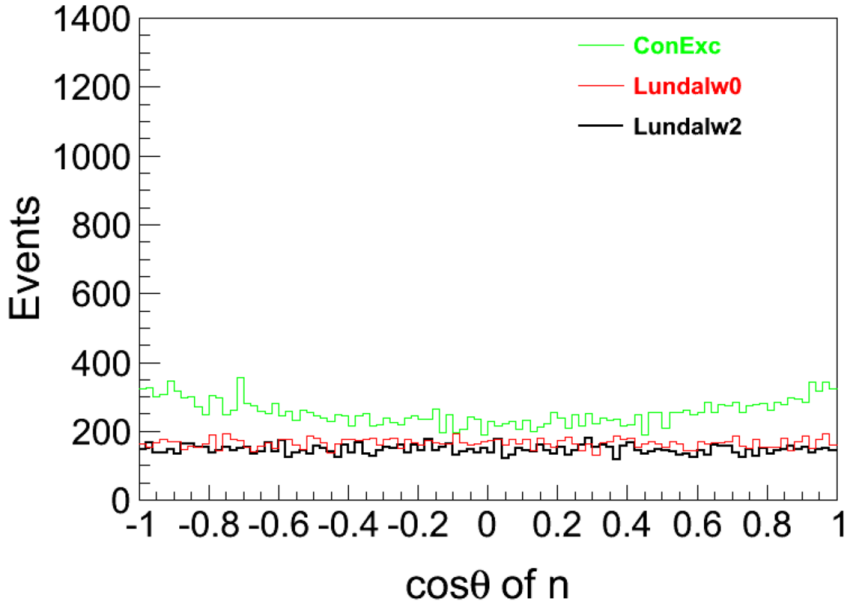


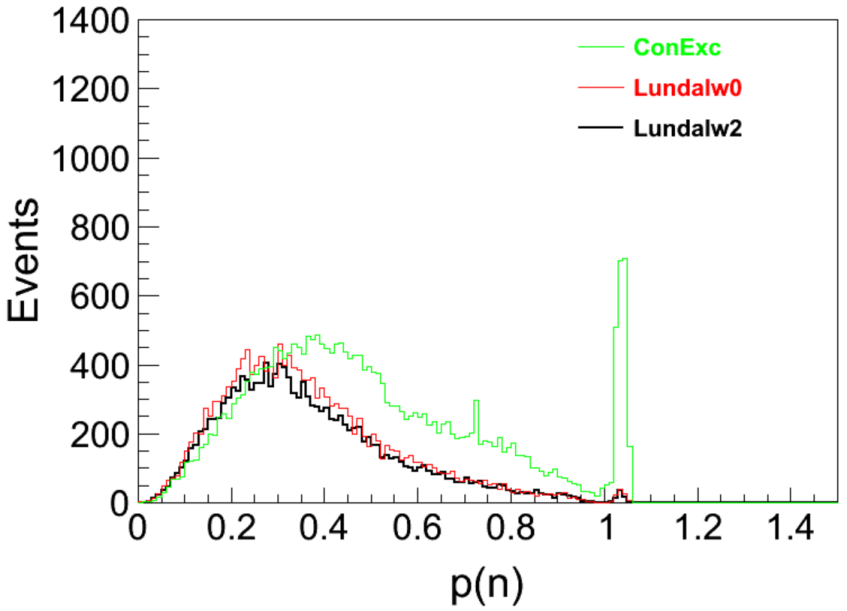
MC truth of anti-neutron



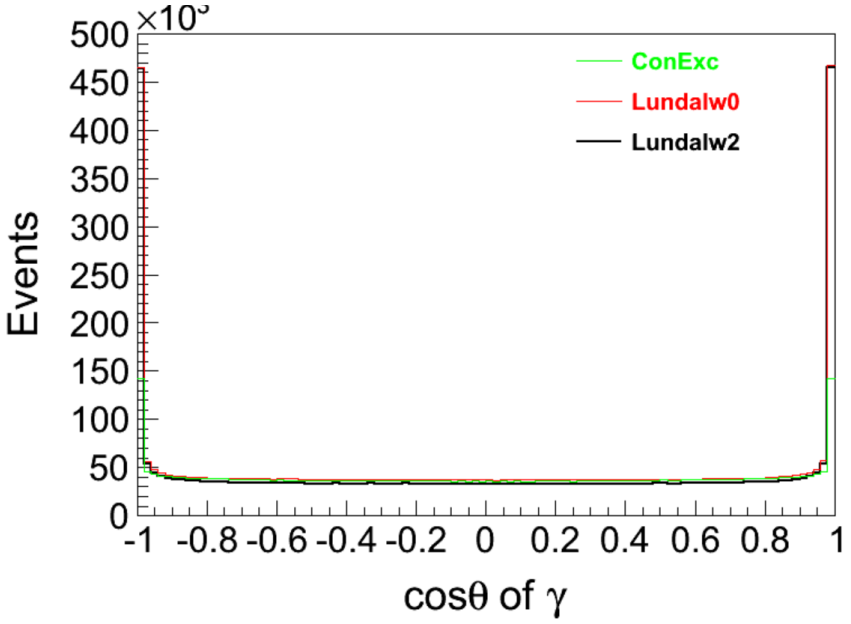


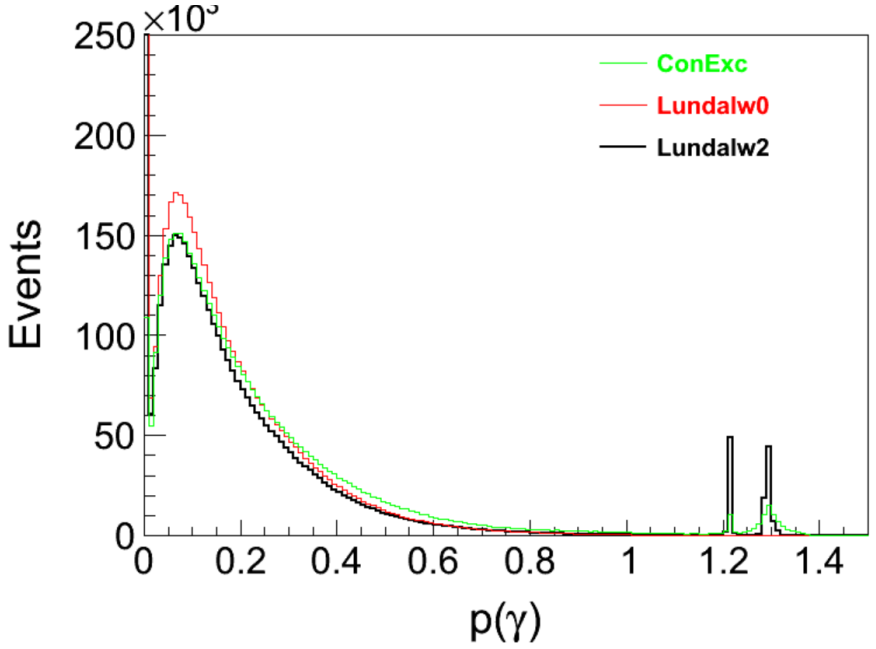
MC truth of neutron

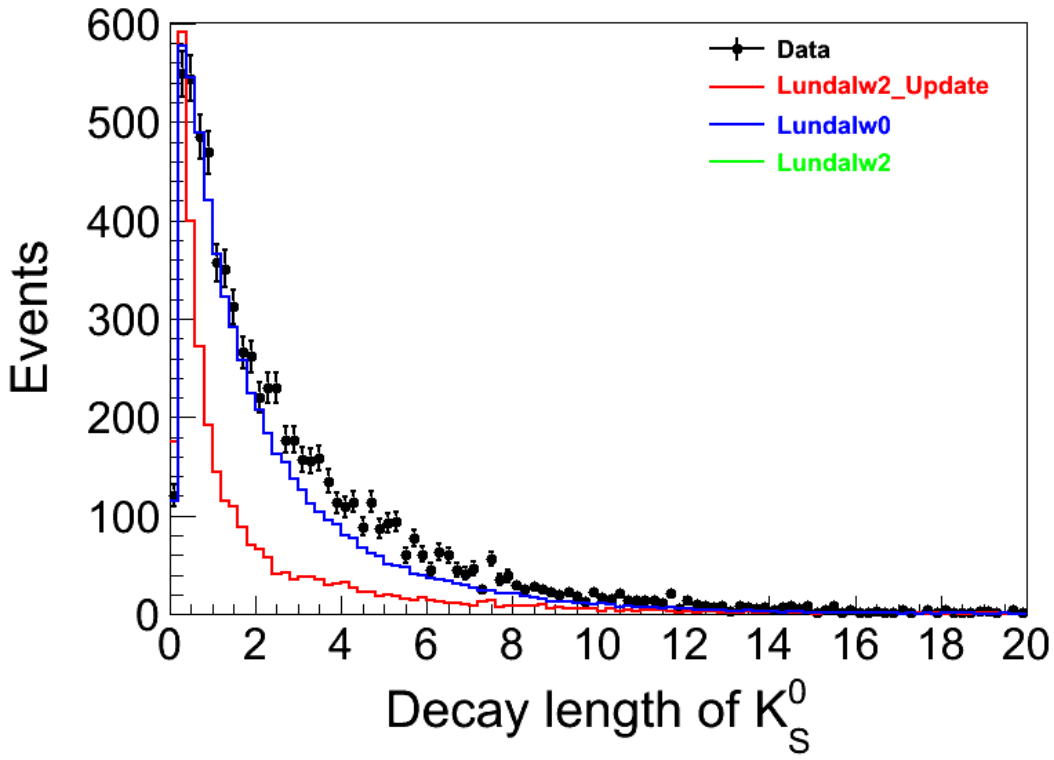


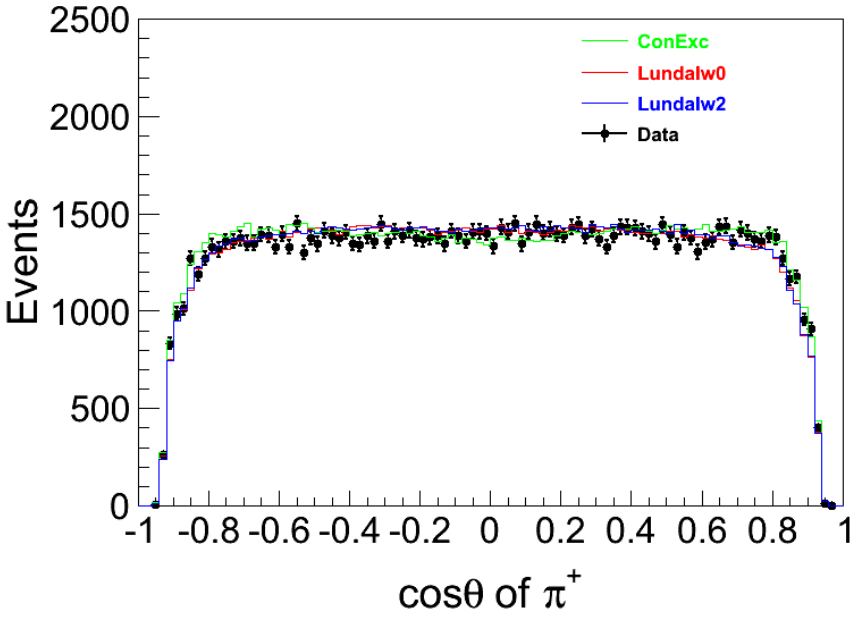


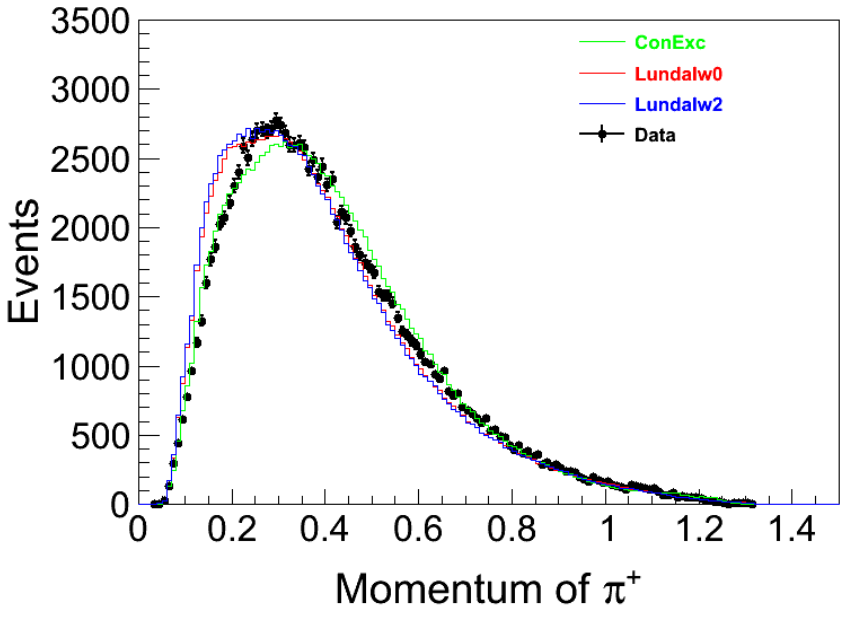
MC truth of gamma

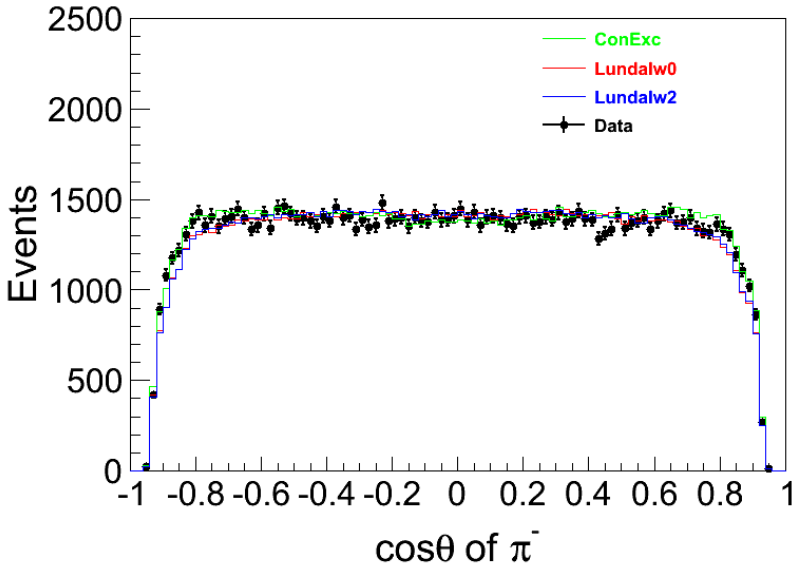


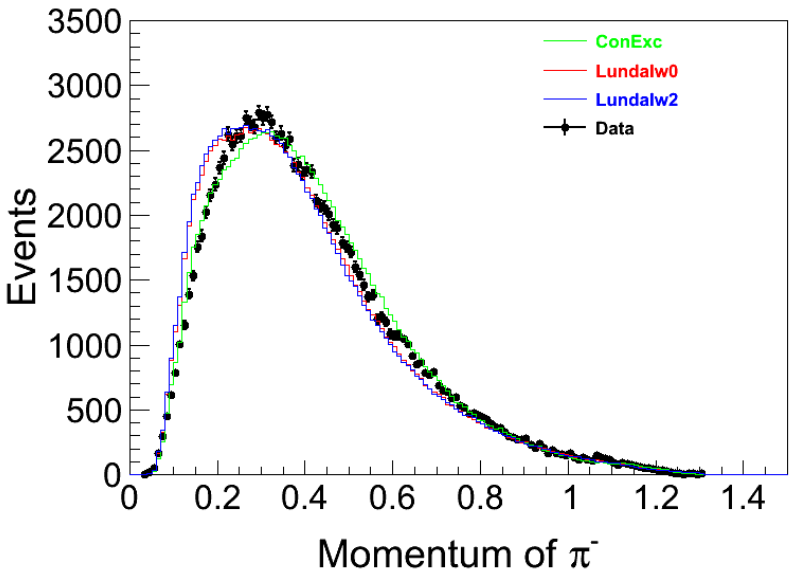


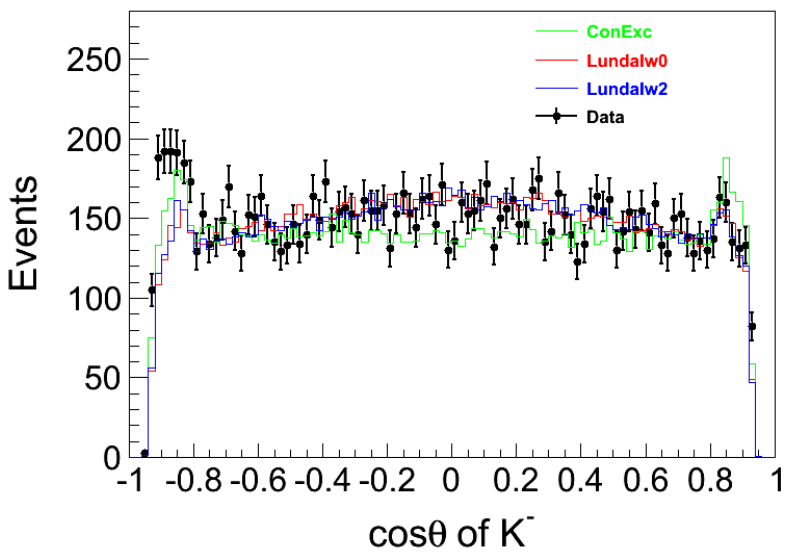

Data
Lundalw2_Update
Lundalw0
Lundalw2
Events
Decay length of K^0_S
0
100
200
300
400
500
600
0
2
4
6
8
10
12
14
16
18
20

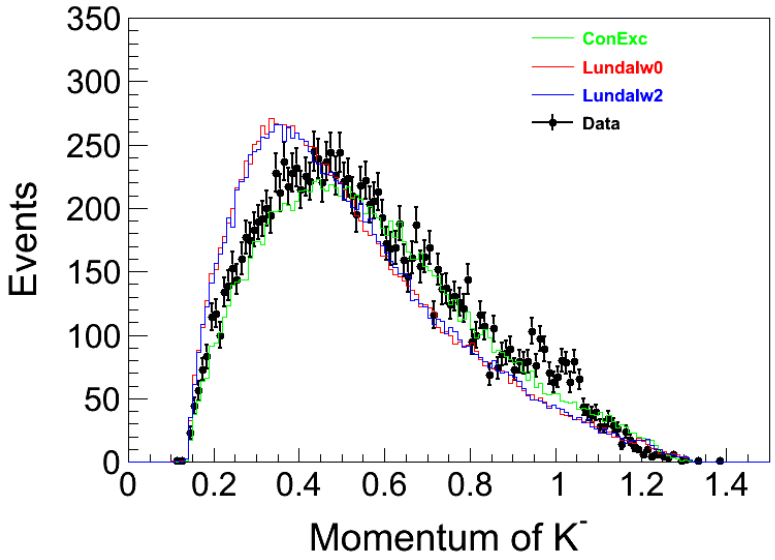

ConExc
Lundalw0
Lundalw2
Data
Events
cosθ of π+
2500
2000
1500
1000
500
0
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1

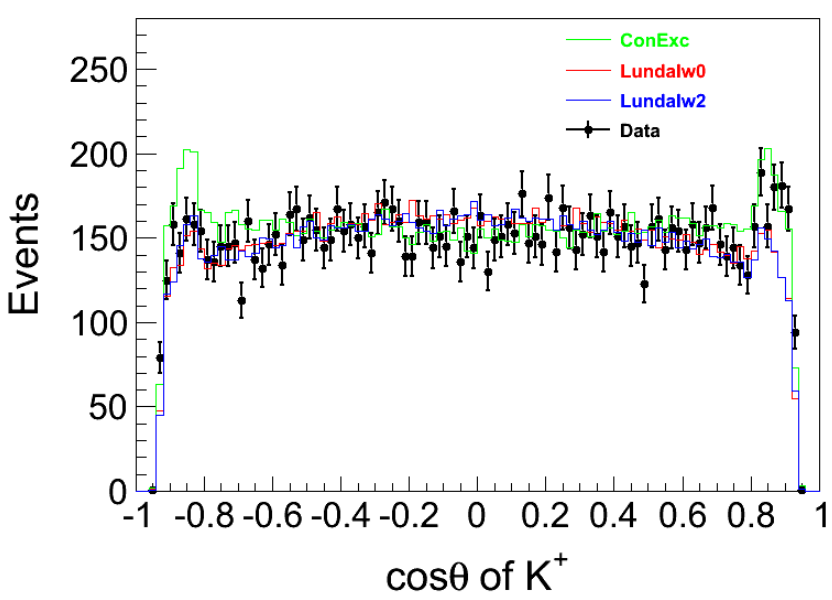

ConExc
Lundalw0
Lundalw2
Data
Events
Momentum of π+
3500
3000
2500
2000
1500
1000
500
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4

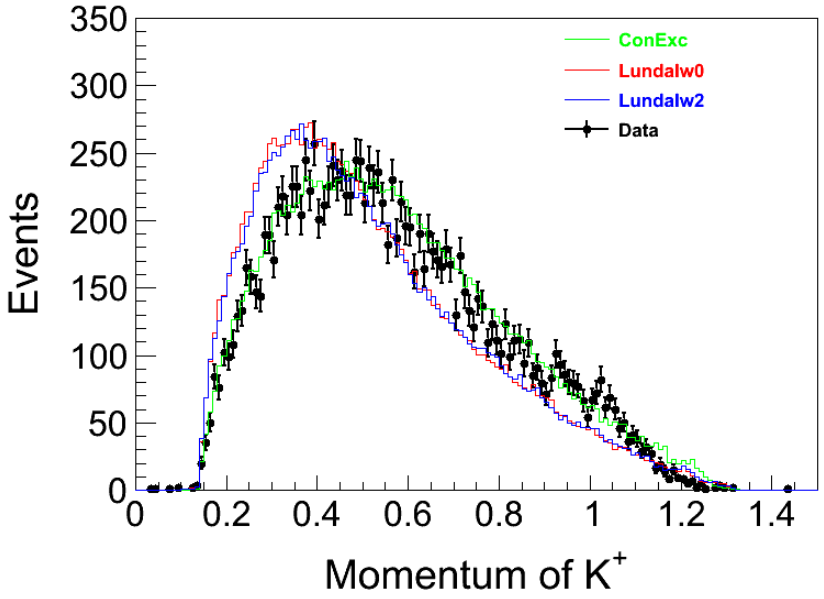

ConExc
Lundalw0
Lundalw2
Data
Events
cosθ of π-
2500
2000
1500
1000
500
0
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1


ConExc
Lundalw0
Lundalw2
Data
Events
Momentum of π-
3500
3000
2500
2000
1500
1000
500
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4


ConExc
Lundalw0
Lundalw2
Data
Events
250
200
150
100
50
0
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
cosθ of K-


ConExc
Lundalw0
Lundalw2
Data
Events
350
300
250
200
150
100
50
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Momentum of K-


ConExc
Lundalw0
Lundalw2
Data
Events
cosθ of K+
0
50
100
150
200
250
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1


ConExc
Lundalw0
Lundalw2
Data
Events
Momentum of K+
0
50
100
150
200
250
300
350
0
0.2
0.4
0.6
0.8
1
1.2
1.4

4.2 Bhabha suppression

QED processes like Bhabha and di-mu have large cross section and can pollute interest signal. The tracks of Bhabha events are mainly in the forward directions of $e^{\pm}$ beams and hit the endcap of the detector, as shown in Fig. 3 and 4. Thus polar angle can be used to veto them with requirement: $\cos\theta_{+} < 0.8$ for positive tracks and $\cos\theta_{-} > -0.8$ for negative tracks.

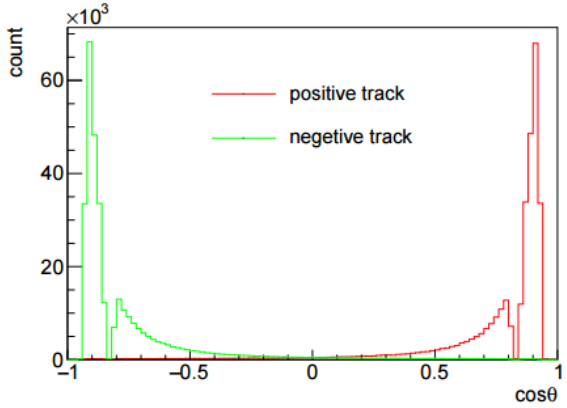
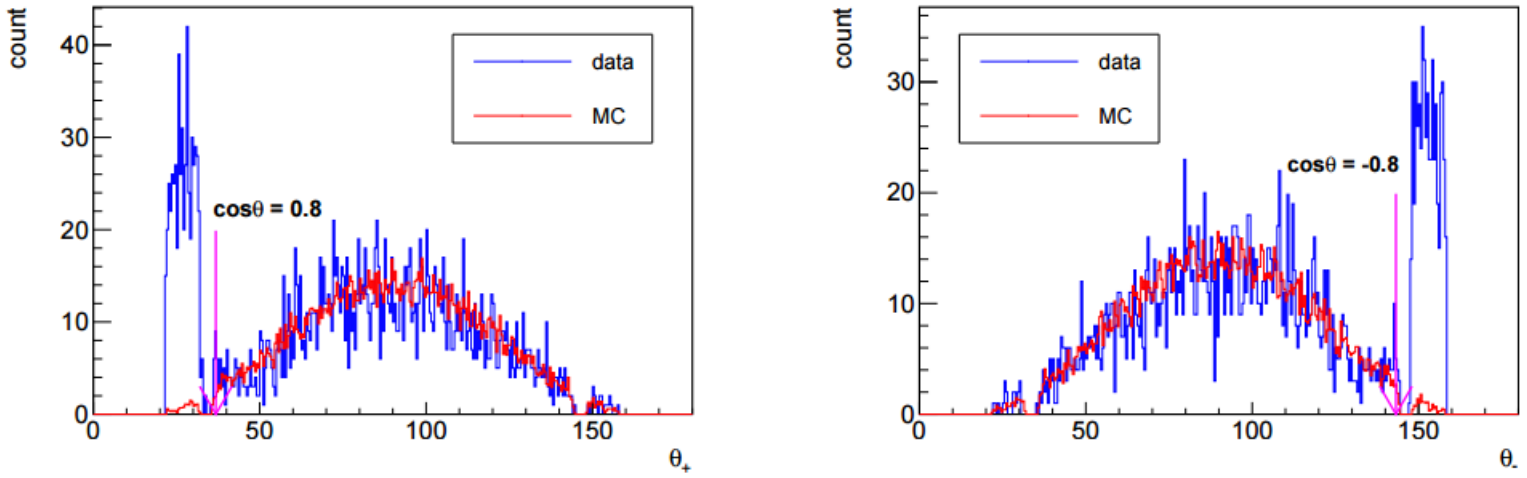


Figure 3: Polar angle distribution of tracking from Bhabha MC at 2.0 GeV. Red line is positive tracks. Green line is negetive tracks.

After rejecting forward tracks, there are still lots of Bhabha events. Further study shows the ratio of energy deposit in EMC to the momentum of the track (E/p) can be used to separate $K^{\pm}$ and $e^{\pm}$. Plots in Fig. 5 are the E/p spectra of $e^{\pm}$ and $K^{\pm}$ showing that most E/p of $e^{\pm}$ accumulate at 1, while the E/p of $K^{\pm}$ are far away from 1, indicating E/p can be used to veto Bhabha events. The cut value is optimized via maximizing signal to noise ratio.



a) polar angle of positive charged track

b) polar angle of negative charged track

Figure 4: Polar angle distribution of tracks at 2.0 GeV. Red line is from K^+K^- MC. Blue line is from data. For data, the events are after all events selection criteria except rejecting forward tracks.