Inclusive π^0 & K_S^0 Production at 2.800GeV

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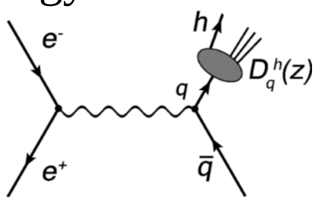
2017/11/6

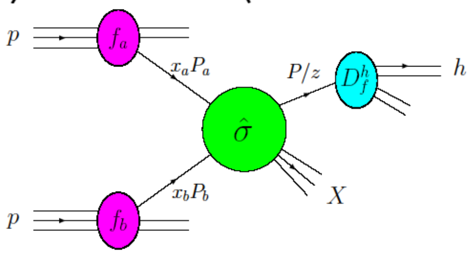
Fragmentation function

●Fragmentation function (FF) $D_q^h(z)$: probability that hadron h is found in the debris of a parton carrying a fraction z of parton's energy



LO

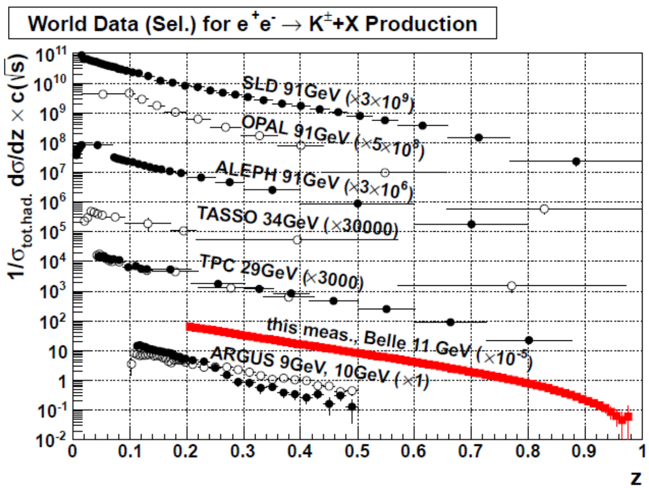
$$\frac{d\sigma}{dz}(e^- e^+ \to hX) = \sum_q \sigma(e^- e^+ \to q\bar{q})\left[D_q^h(z) + D_{\bar{q}}^h(z)\right]$$



$$\sigma = \sum_{a,b,c} f_a(x_a, Q^2) \otimes f_b(x_b, Q^2) \otimes \hat{\sigma}(ab \to cX) \otimes D_c^{\pi}(z, Q^2)$$

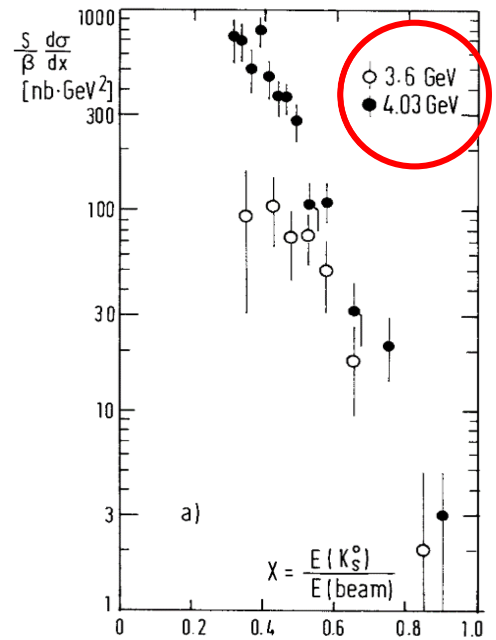
- FF: QCD first principle (NOT YET);
  - ➢ FF evolution function: DGLAP (similar to that of PDF)
  - ➢ Fitting: parametrization & experimental data (e^+e^-, SIDIS, pp and p $\bar{p}$)

$e^+e^-\to K + X$



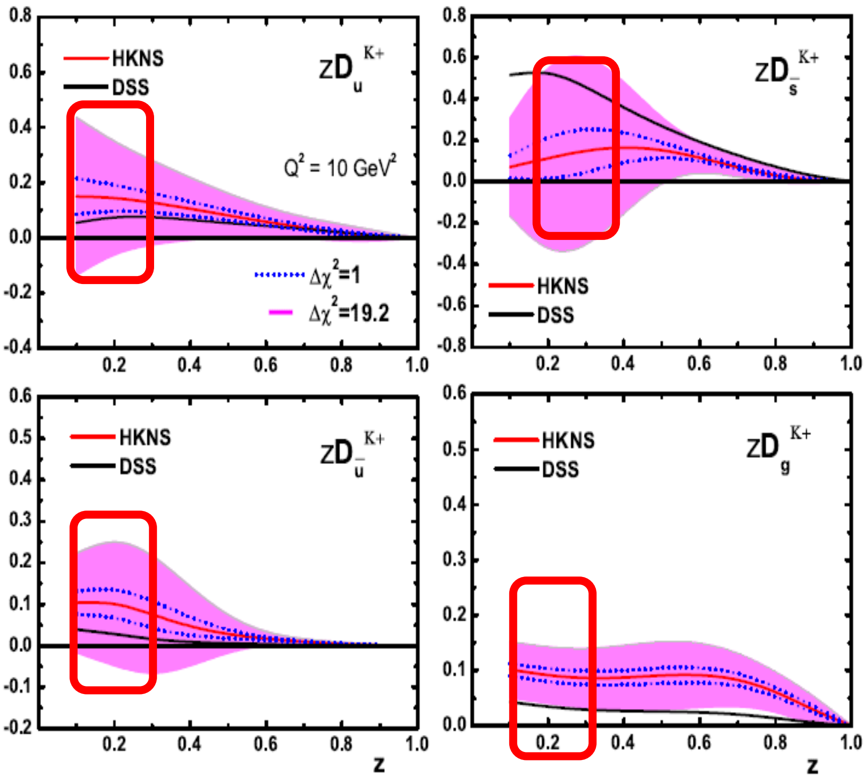
PRL 111 062002 (2013)

- Lack of data at **low energy scale**
- PLUTO: about 35 years ago
  - Stat. uncertainty: 18-41%

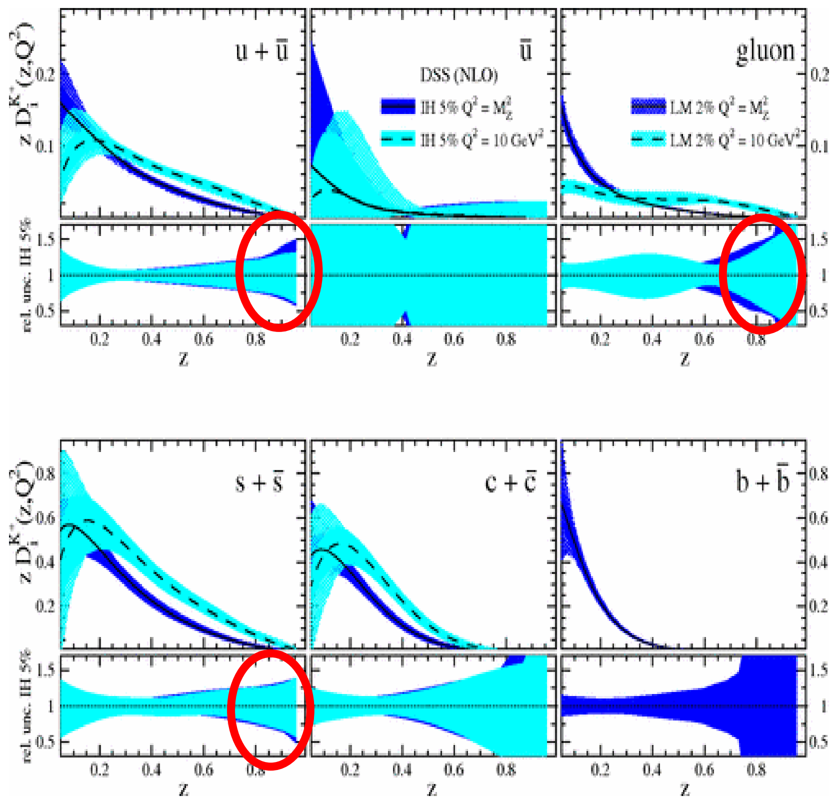


PLB 67 367 (1977)

Kaon Fragmentation function



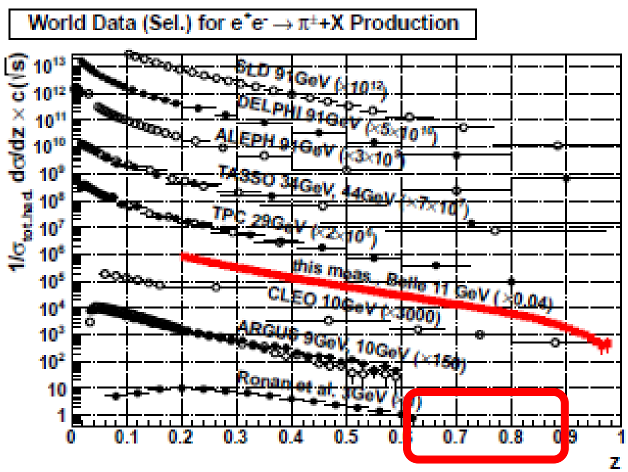
PRD 84 014002 (2011)



PRD 86 074028 (2012)

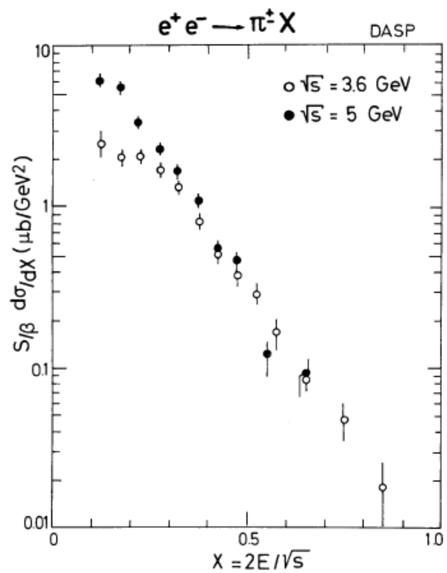
Large uncertainty!

$e^+e^-\to\pi + X$



PRL 111 062002 (2013)

- Lack of data at **low energy scale**
  - BESIII energy: [2, 4.6]GeV
  - Poor precision
- Lack data **at high $z=2E_{hadron}/\sqrt{s}$**

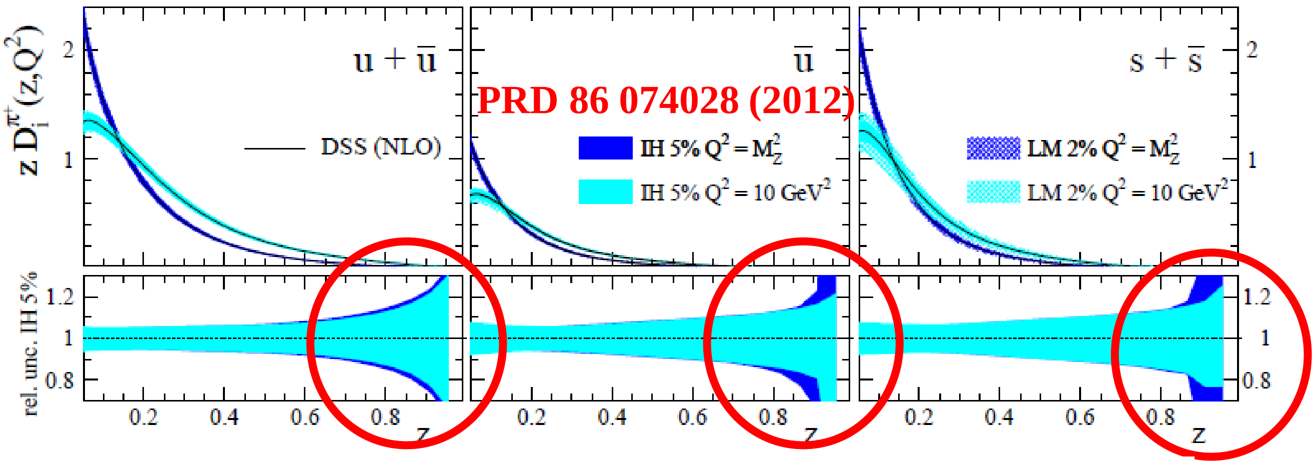


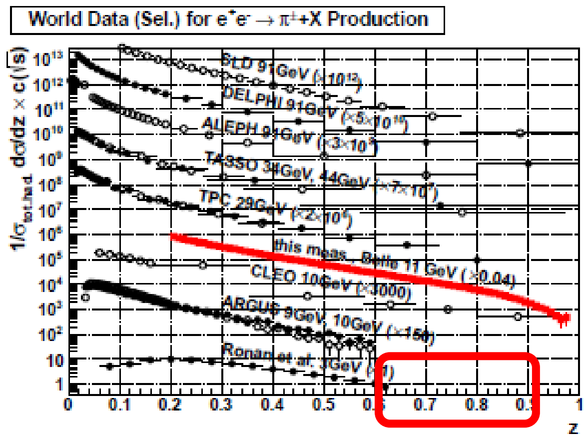
NPB 148 189 (1979)

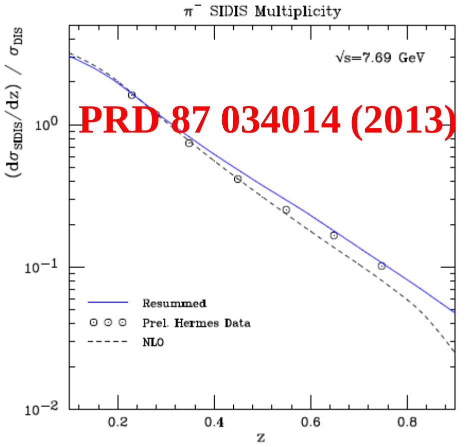
- DASP: about 35 years ago
- Stat. uncertainty: 18%

Pion Fragmentation function

- Theory predictions at **high z: with lage unceraintY**







Data Samples

- BOSS 664p01
- Data sets
  - ✓ Collision data at **2.800GeV (**3.753 pb^{-1}**)**
  - ✓ Hadronic event: **1 M** via generator ConExc
- Physics QED background: Monte Carlo data sets
  - ✓ Bhabha: **6M** via generator **Babayaga**
  - ✓ $(\gamma)\mu^+\mu^-$: **6M** via generator **Babayaga**
  - ✓ $(\gamma)\gamma\gamma$: 6**M** via generator **Babayaga**
  - ✓ $e^+e^- \to e^+e^- + X$: 6**M** via generator **BESTWOGAM**
- Non-physics background
  - ✓ Beam-gas, beam-wall, cosmic, and so on
  - ✓ Use sideband method

Hadronic event selection

Hadronic event selection, π^0 and K_S^0 production

① Select hadronic event ② π^0 and K_S^0 reconstruction

- Remove Bhabha and (γ) γ γ events with EMC information
  - ✓ Two showers with $1^{st}/2^{nd}$ energy deposition $|\theta_1+\theta_2-180^\circ| < 10^\circ$ and $E > 0.65*E_{beam}$
- Good track selection
  - ✓ $|Vr| < 0.5$, $|Vz| < 1$, $|\cos\theta| < 0.93$
  - ✓ Momentum $< 0.94*E_{beam}$
  - ✓ $(dE/dx_{mea} - dE/dx_{proton})/\sigma_{proton} < 10$
  - ✓ Veto election with Momentum $> 0.65*E_{beam}$ && $e/p > 0.8$
  - ✓ Veto gamma conversion with $M(e,e) < 100$MeV && Open angle$<15^\circ$
  - ✓ $Prob(E) / (Prob(E) + Prob(\pi) + Prob(K) + Prob(P)) < 0.25$
- good photon selection
  - ✓ $E_{barrel} > 25$MeV; $E_{endcap} > 50$MeV
  - ✓ $0 <= TDC <= 14(\times 50ns)$;
- Isolated photon selection
  - ✓ $E_{barrel} > 25$MeV; $E_{endcap} > 50$MeV
  - ✓ $0 <= TDC <= 14(\times 50ns)$;
  - ✓ Angle $> 20^\circ$ && $E_{deposited} > 100$MeV

Hadronic event selection

- Event level selection
  - ✓ Number of good track N_{good}>=2

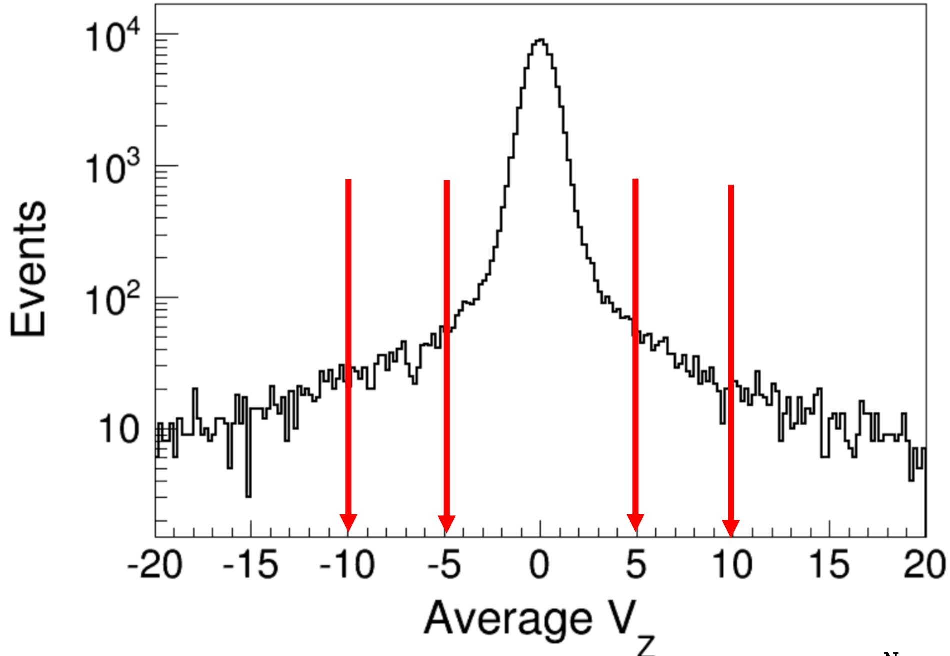
  1. Event with N_{good}=2
  - ✓ veto $|\theta_1+\theta_2-180^\circ|<15^\circ$ && $||\varphi_1-\varphi_2|-180^\circ|<10^\circ$

    number of Isolated photon N >= 2

  2. Event with N_{good}=3
  - ✓ Veto, angle between 1st/2nd energy track

    $|\theta_1+\theta_2-180^\circ|<15^\circ$ and $||\varphi_1-\varphi_2|-180^\circ|<10^\circ$

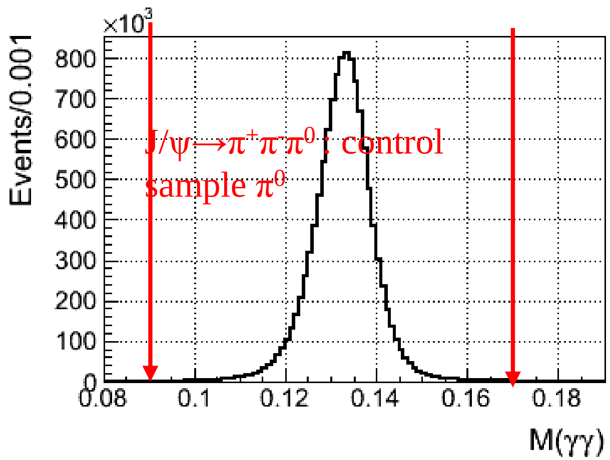
Non-physics background

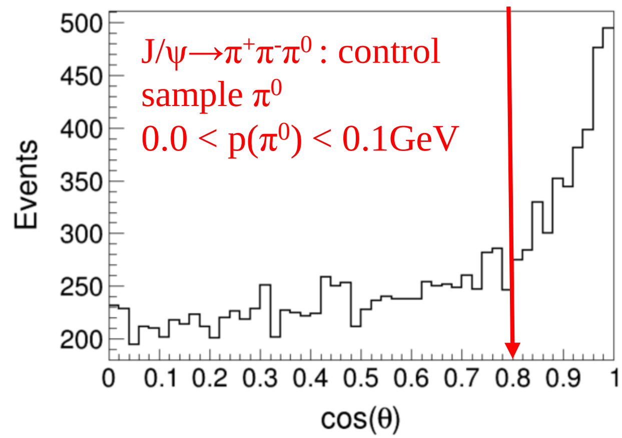


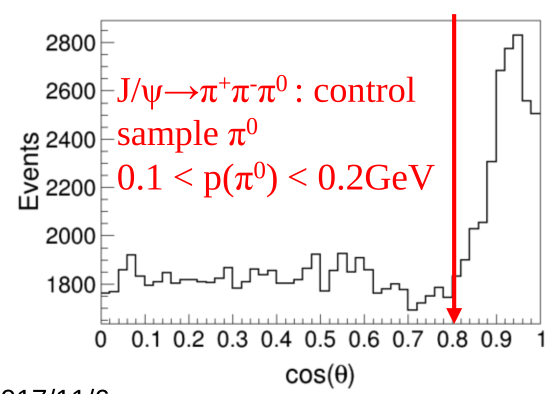
- Average Z-direction vertex for a event $V_z = \sum_{i=1}^{N_{good}} V_z^i \Big/ N_{good}$
  - Non-physics background: $5.0 < |V_z| < 10.0$cm

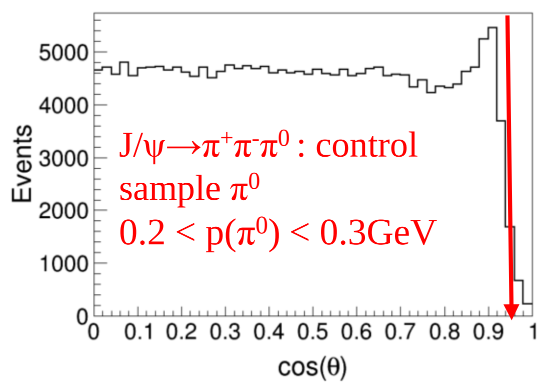
π^0 reconstruction

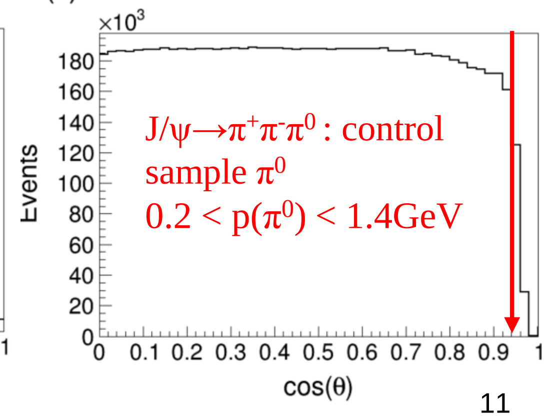
- π^0 selection: loop all the neutral tracks from hadronic selection
  - ✓ $0.09\text{GeV} < M(\gamma\gamma) < 0.17\text{GeV}$
  - ✓ $|\cos\theta_{\gamma\pi}| < 0.95$ (for $0.2 < p(\pi^0) < 1.4\text{GeV}$)
  - ✓ $|\cos\theta_{\gamma\pi}| < 0.8$ (for $0.0 < p(\pi^0) < 0.2\text{GeV}$)



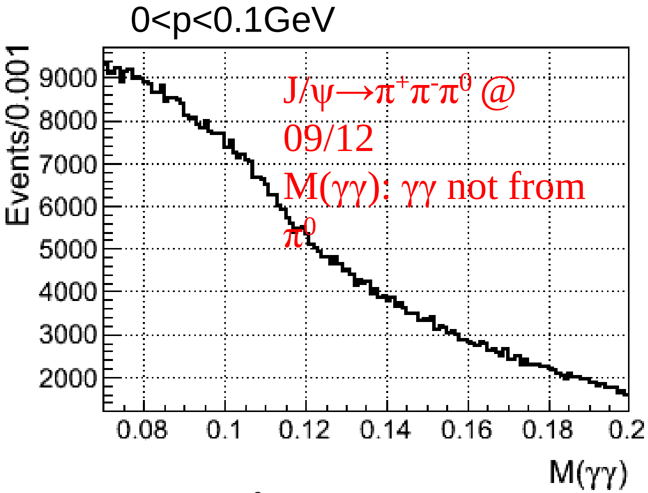




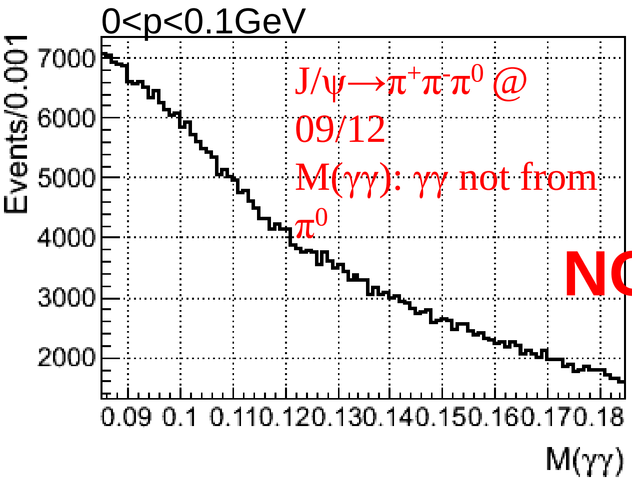




Miscombine of π^0



Before the π^0 selection criteria



NO BIAS!

After the π^0 selection criteria

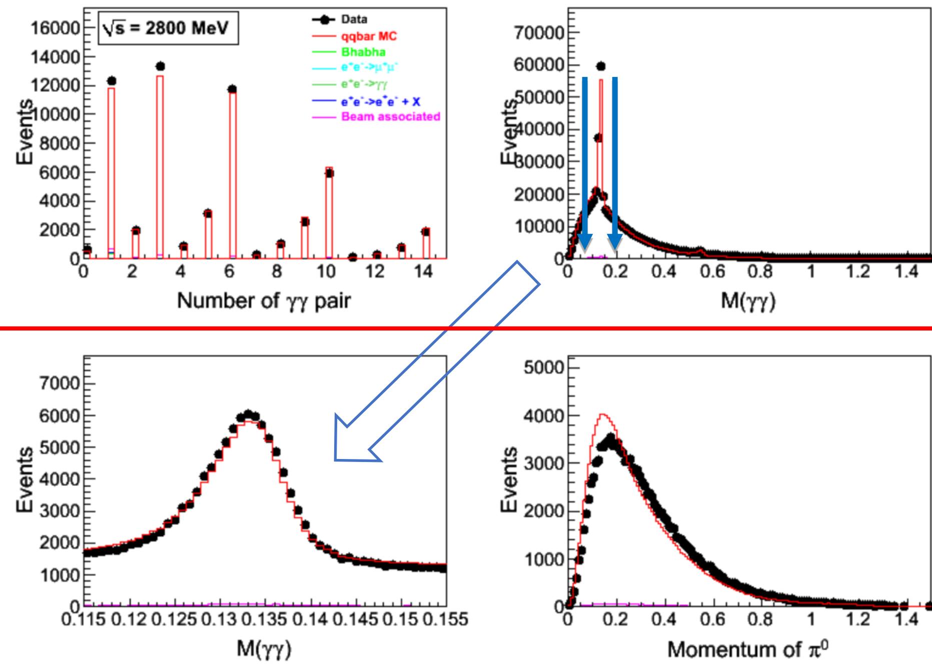
π^0 selection criteria:

- ✓ 0.09GeV < M(γγ) < 0.17GeV
- ✓ $|\cos\theta_{\gamma\pi}|$< 0.95 (for 0.2 < p(π^0) < 1.4GeV)
- ✓ $|\cos\theta_{\gamma\pi}|$< 0.8 (for 0.0 < p(π^0) < 0.2GeV)

Distribution about π^0 candidates

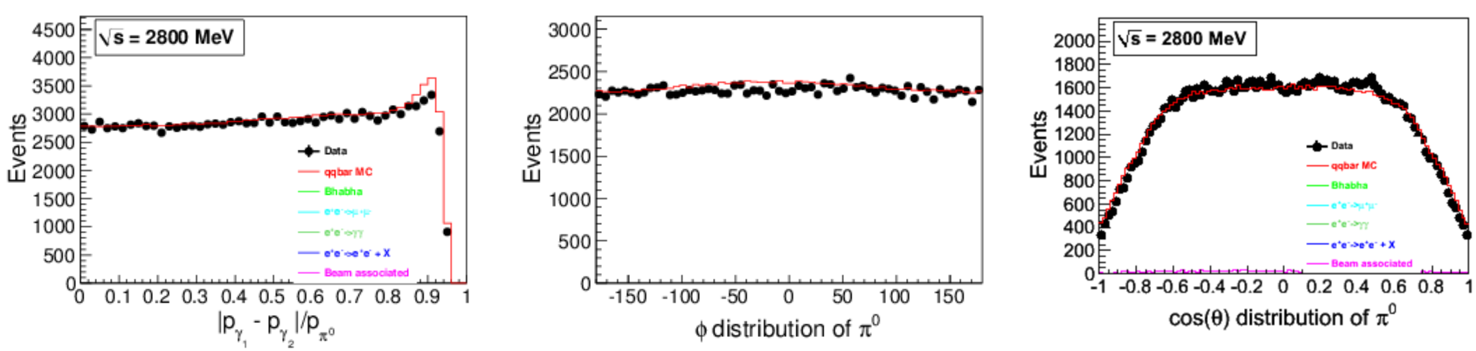
selection criteria :

- ✓ $|\cos\theta_{\gamma\pi}| < 0.95$



selection criteria :

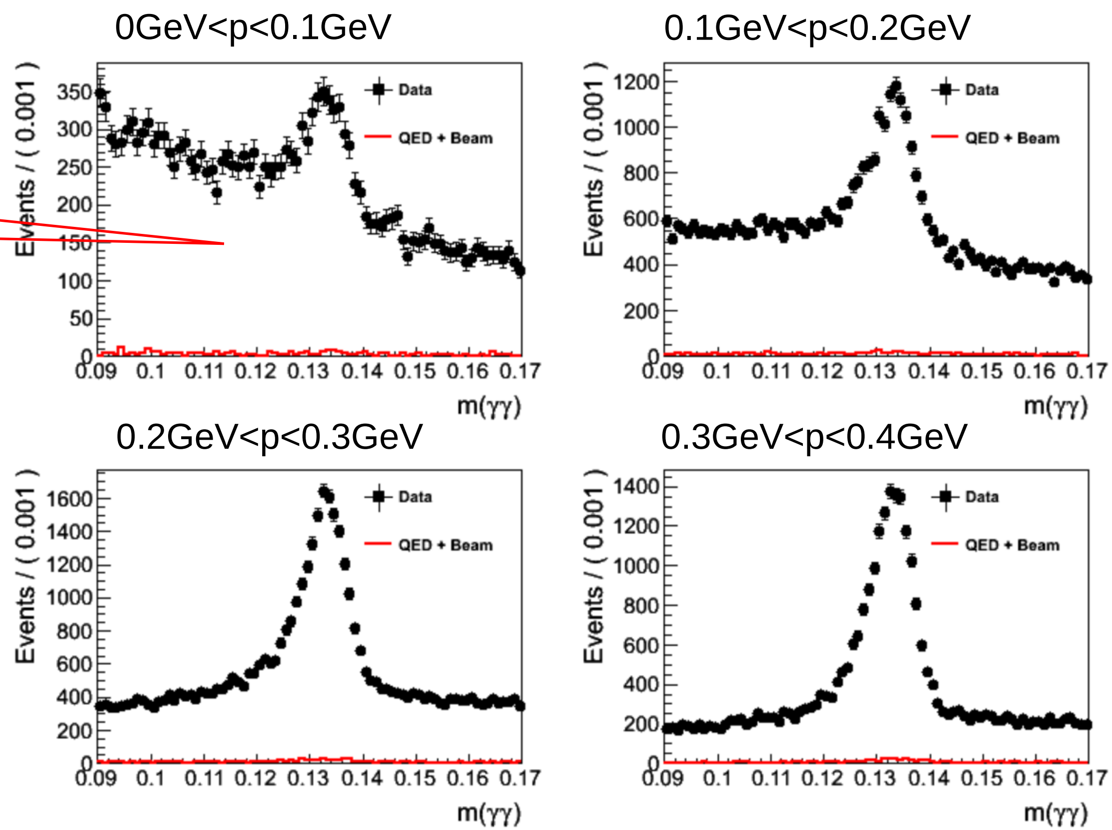
- ✓ $0.115\text{GeV} < M(\gamma\gamma) < 0.155\text{GeV}$
- ✓ $|\cos\theta_{\gamma\pi}| < 0.95$



MC and Exp.Data can consist each other

Backgrounds and π^0 candidates

Miss combination



QED and beam associated background are flat

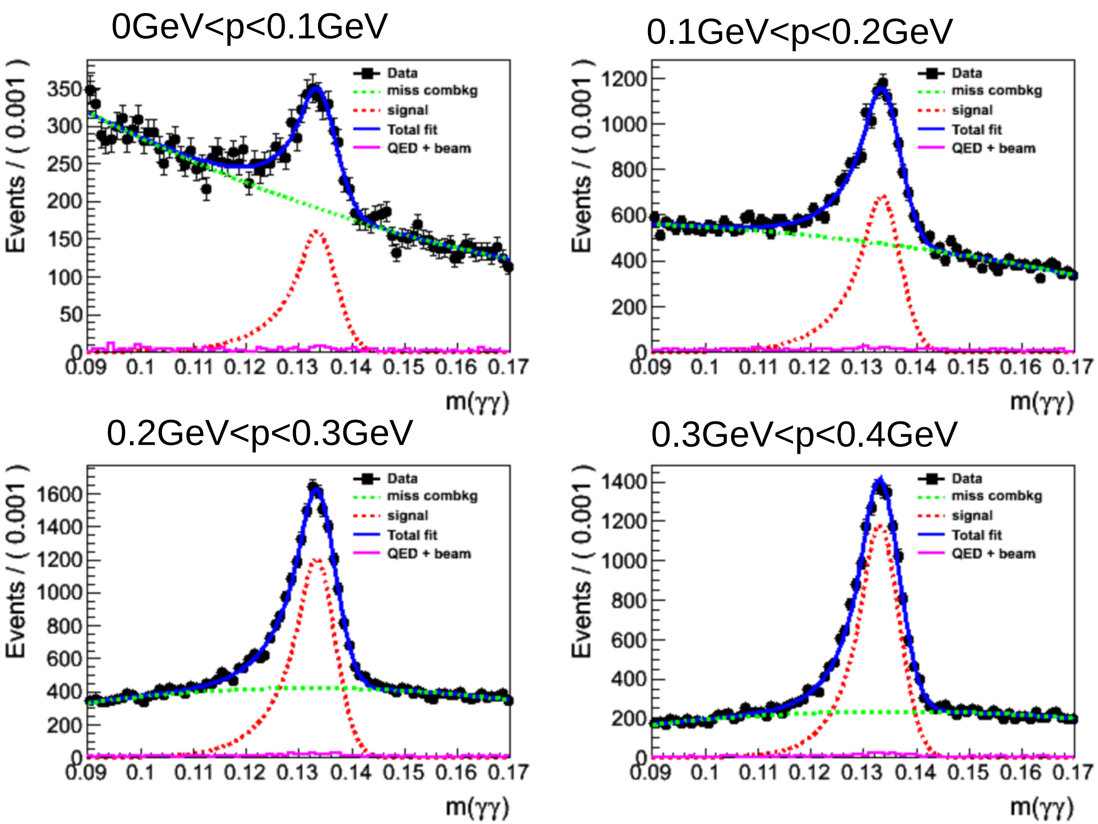
Backgrounds and π^0 candidates

Table 4: Background events of π^0 candidates

Source	π^0 candidate events (including miss combination) @[0.09,0.17] GeV mass region
$e^+e^- \to (\gamma)e^+e^-$	60.6 (0.032%)
$e^+e^- \to (\gamma)\mu^+\mu^-$	8.2 (0.004%)
$e^+e^- \to (\gamma)\gamma\gamma$	3.1 (0.002%)
$e^+e^- \to (\gamma)e^+e^- + X$	24.2 (0.013%)
Beam associated	2755 (1.472%)
Experiment data	187179

Most contribution come from beam associated background and the branching ratio is smaller than 2%

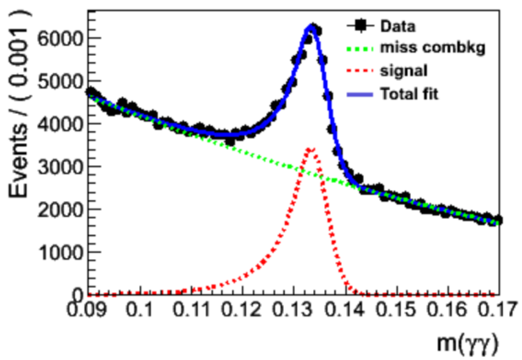
Data: π^0 fitting at 2.800GeV



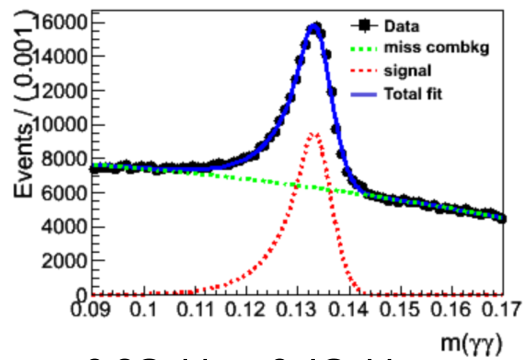
Fitting function: Crystal ball + 2 order of Chebychev

MC: π^0 fitting at 2.800GeV

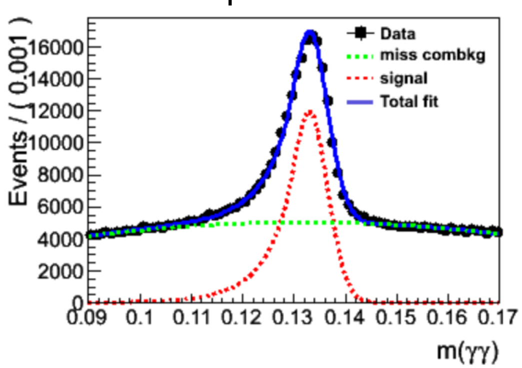
0GeV<p<0.1GeV



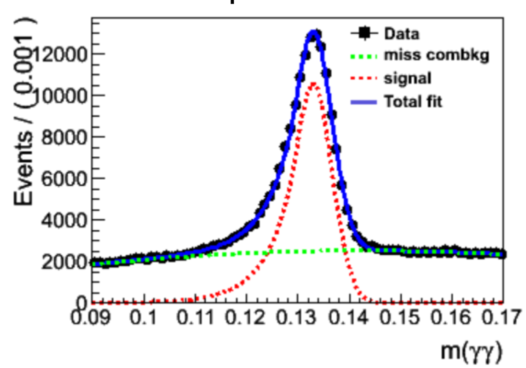
0.1GeV<p<0.2GeV



0.2GeV<p<0.3GeV



0.3GeV<p<0.4GeV



Fitting function: Crystal ball + 2 order of Chebychev

Inclusive π^0 production

$$\frac{1}{\sigma_{had}} \cdot \frac{d\sigma_{\pi^0}}{dp} = C \cdot \frac{1}{Br(\pi^0 \to \gamma\gamma)} \cdot \frac{1}{N_{had}^{exp}} \cdot \frac{N_{\pi^0}^{exp}(p)}{\Delta p}$$

N_{had}^{exp} : Observed hadronic event number

$N_{\pi^0}^{exp}(p)$: Fitted π^0 number in a momentum bin

Δp : Bin width in a momentum bin (100 MeV)

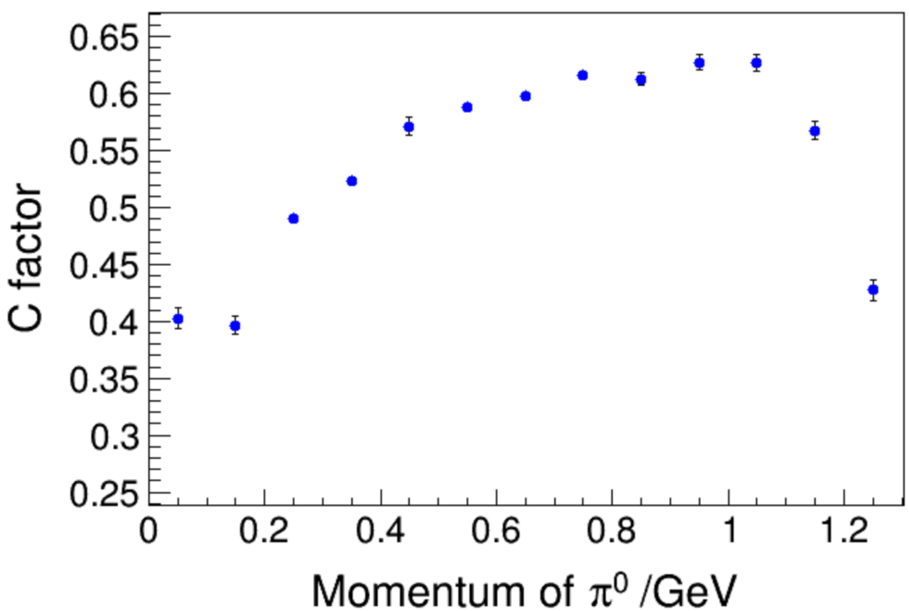
C : Correction factor in a momentum bin

π^0 : bin-to-bin correction

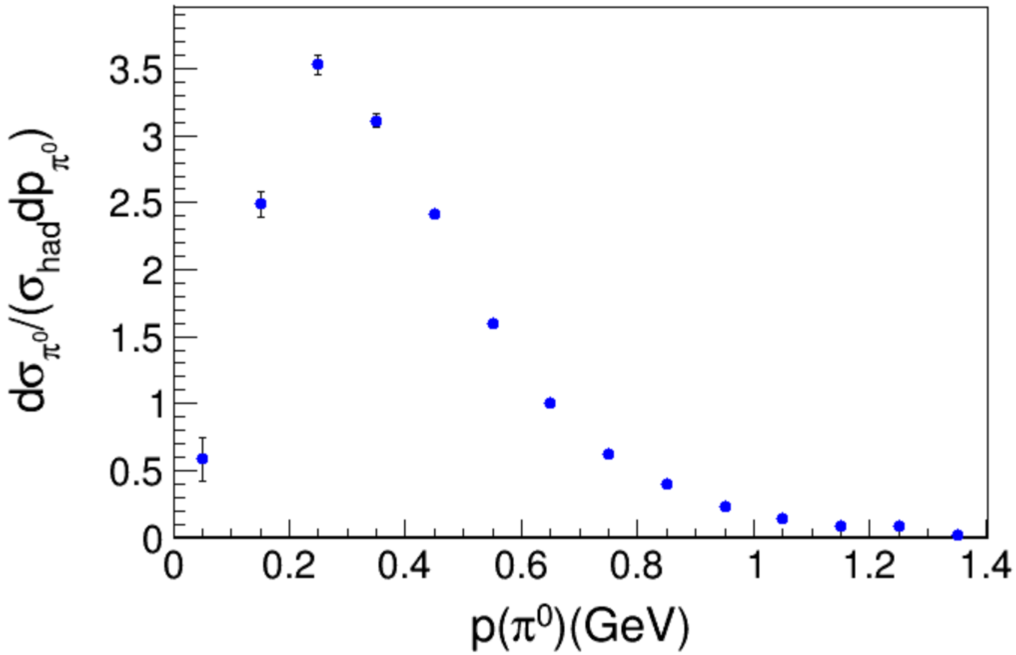
$$C = \frac{N_{\pi^0}^{truth} / N_{had}^{truth} \ @ \ MC \ without \ ISR}{N_{\pi^0}^{det} / N_{had}^{det} \ @ \ MC \ with \ ISR}$$

$N_{\pi^0}^{truth}$ π^0 from MC Truth

C corrects for event selection, π^0 reconstruction, ISR and so on.



Inclusive π^0 production



$$\frac{1}{\sigma_{had}} \cdot \frac{d\sigma_{\pi^0}}{dp} = C \cdot \frac{1}{Br(\pi^0 \to \gamma\gamma)} \cdot \frac{1}{N_{had}^{exp}} \cdot \frac{N_{\pi^0}^{exp}(p)}{\Delta p}$$

π^0 systematic study

hadron event selection

Source	Cut	Default	Alternative
veto Bhabha and $\gamma\gamma$	E_{ratio}	$0.65 \cdot E_{beam}$	$0.6 \sim 0.7 \cdot E_{beam}$
	$\Delta\theta$	$10°$	$5° \sim 15°$
good hadronic tracks determination	Vr	0.5 cm	1.0 cm
	$p(track)$	$0.94 \cdot p_{beam}$	$0.92 \sim 0.96 \cdot p_{beam}$
	dE/dx cut	10	15
	E/p ratio	0.8	$0.75 \sim 0.85$
	Bhabha momentum limit	$0.65 \cdot p_{beam}$	$0.6 \sim 0.7 \cdot p_{beam}$
	isolated photon angle	$20°$	$15° \sim 25°$
	isolated photon energy	100 MeV	$75 \sim 125$ MeV
	gamma conversion angle	$15°$	$10° \sim 20°$
	gamma conversion mass	100 MeV	$80 \sim 120$ MeV
	PID ratio value	0.25	$0.1 \sim 0.4$
2 prong events	$\Delta\theta$	$15°$	$10° \sim 20°$
	$\Delta\phi$	$10°$	$5° \sim 15°$
3 prong events	$\Delta\theta$	$15°$	$10° \sim 20°$
	$\Delta\phi$	$10°$	$5° \sim 15°$

π^0 systematic study

Fitting uncertainty and model dependent

1, Fitting range

Default fitting range [0.09, 0.17] GeV

Tight fitting range: [0.095, 0.165] GeV

Loose fitting range: [0.085, 0.175] GeV

Pick up the one which have large differences with default result as the fitting range uncertainty

2, Fitting function

Default fitting function: Crystal ball + 2 order of Chebychev

Change to: Crystal ball + 3 order of Chebychev

Take the difference as fitting function uncertainty

3, Model dependent (On going)

Use the qqbar MC generated by Luarlw tuned by Prof. Hu and take the difference with ConExc as model uncertainty.

π^0 systematic study

π^0 cut criteria uncertainty

π^0 default cut criteria:

✓$|\cos\theta_{\gamma\pi}| < 0.95$ (for $0.2 < p(\pi^0) < 1.4$GeV)
✓$|\cos\theta_{\gamma\pi}| < 0.8$ (for $0.0 < p(\pi^0) < 0.2$GeV)

Up the cut criteria:

✓$|\cos\theta_{\gamma\pi}| < 0.97$ (for $0.2 < p(\pi^0) < 1.4$GeV)
✓$|\cos\theta_{\gamma\pi}| < 0.82$ (for $0.0 < p(\pi^0) < 0.2$GeV)

Down cut criteria:

✓$|\cos\theta_{\gamma\pi}| < 0.93$ (for $0.2 < p(\pi^0) < 1.4$GeV)
✓$|\cos\theta_{\gamma\pi}| < 0.78$ (for $0.0 < p(\pi^0) < 0.2$GeV)

Take the differences of MC and experiment data as the π^0 reconstruction uncertainty

π^0 systematic study

Table 3: Summary of systematic uncertainties (%) for inclusive π^0 production varying with momentum.

p(GeV)	Hadron event	Hadron track	$\cos\theta$	Fit range	Bkg shape	Sig shape	Photon	Total
0.0-0.1	8.5	6.4	2.4	1.2	4.1	8.8	2.0	14.8
0.1-0.2	10.9	10.1	4.7	3.8	2.6	8.0	2.0	18.2
0.2-0.3	5.1	6.1	0.2	3.5	1.4	2.3	2.0	9.3
0.3-0.4	2.5	4.6	0.8	1.4	1.2	2.6	2.0	6.5
0.4-0.5	1.8	2.1	0.1	0.3	2.0	1.8	2.0	4.3
0.5-0.6	0.4	2.1	0.0	0.4	1.3	3.4	2.0	4.7
0.6-0.7	1.1	2.1	0.4	0.4	0.9	2.8	2.0	4.3
0.7-0.8	1.9	1.7	0.4	0.7	2.1	0.6	2.0	4.0
0.8-0.9	0.9	2.6	2.2	1.9	0.3	3.4	2.0	5.6
0.9-1.0	0.8	2.6	0.9	1.2	1.6	0.9	2.0	4.1
1.0-1.1	1.6	1.0	0.4	0.4	1.2	2.3	2.0	3.8
1.1-1.2	3.0	2.4	0.7	0.4	1.1	2.6	2.0	5.2
1.2-1.3	2.3	1.8	1.4	1.3	2.0	1.1	2.0	4.6
1.3-1.4	26.1	10.0	5.6	2.1	7.4	2.0	2.0	29.7

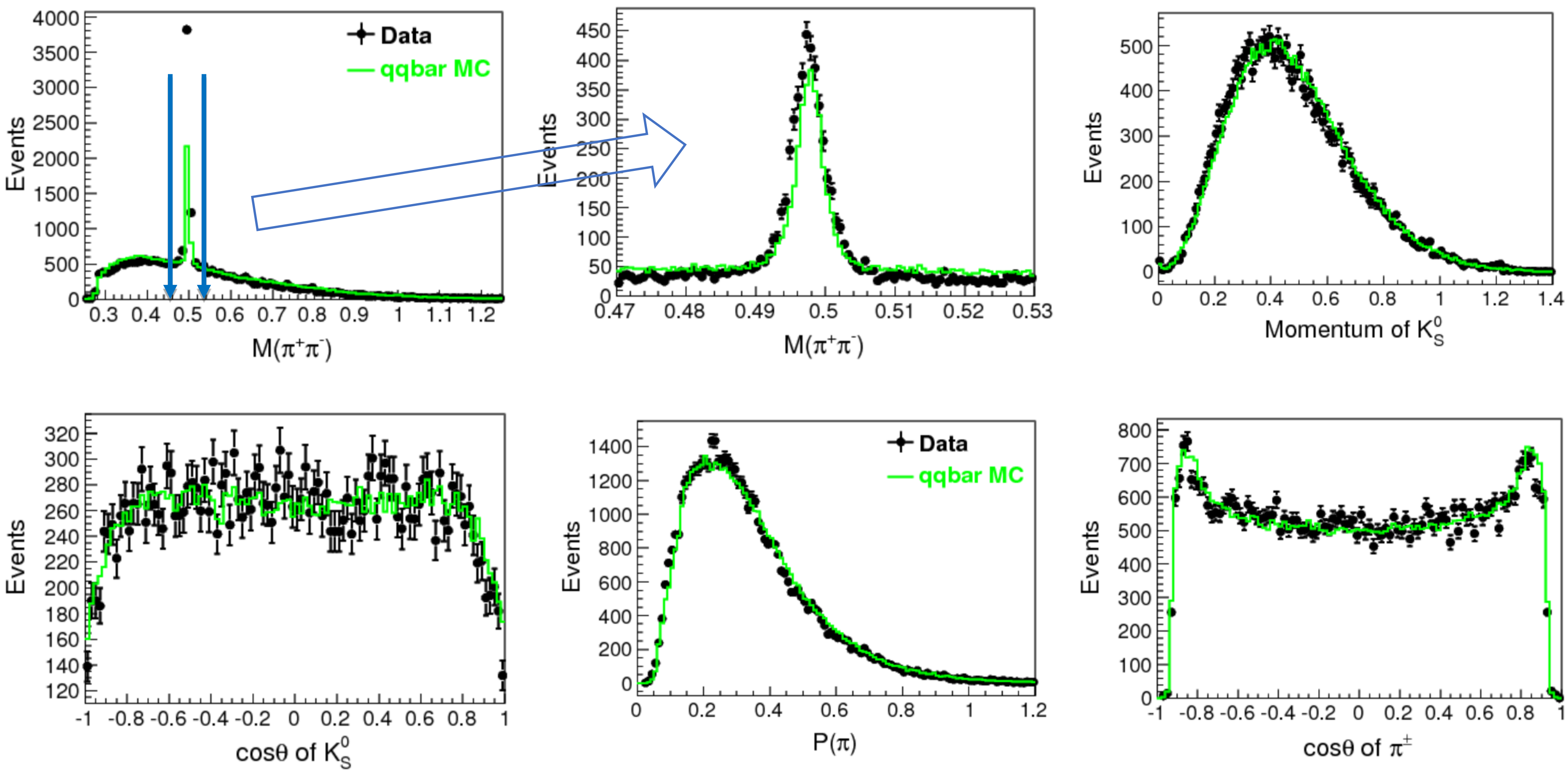
2^{nd} K_s reconstruction

K_s selection: charged track after hadronic events selection

- ✓ Re-do track selection
  - ➢ $|Vr|< 10cm$, $|Vz|<30cm$
  - ➢ Other selection criteria: same
- ✓ PID: Prob π > Prob K and Prob π > Prob P

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

K_s candidates distribution

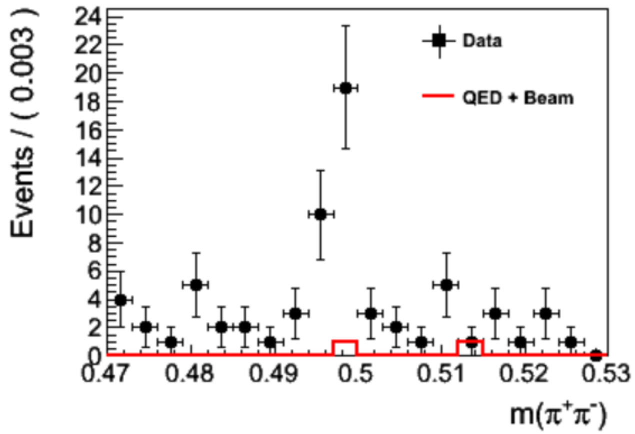


The contribution from background events are substracted.

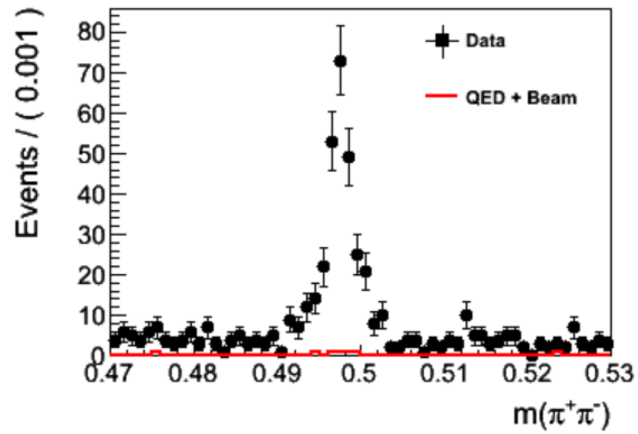
Experiment data and qqbar MC are consistent with each other

Data: K_s signal and background @2.8 GeV

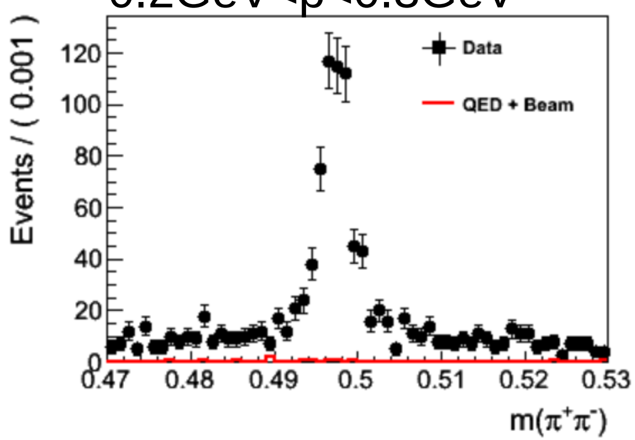
0GeV<p<0.1GeV



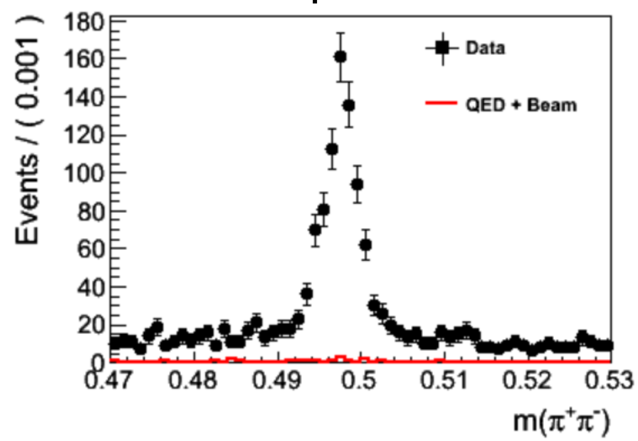
0.1GeV<p<0.2GeV



0.2GeV<p<0.3GeV



0.3GeV<p<0.4GeV



The bkg include $e^+e^-\to(\gamma)e^+e^-$, $(\gamma)\mu^+\mu^-$, $(\gamma)\gamma\gamma$, $(\gamma)\tau^+\tau^-$, e^+e^-+X and non-physics background

Backgrounds and K_S^0 candidates

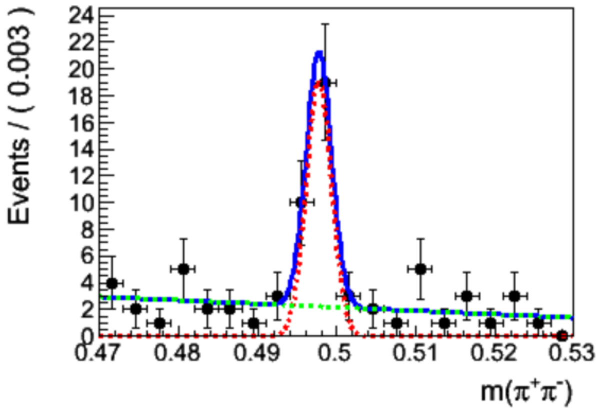
Table 5: Background events of K_S^0 candidates

Source	K_S^0 candidate events (including miss combination) @[0.47,0.53] GeV mass region
$e^+e^- \rightarrow (\gamma)e^+e^-$	27.0 (0.10%)
$e^+e^- \rightarrow (\gamma)\mu^+\mu^-$	3.6 (0.01%)
$e^+e^- \rightarrow (\gamma)\gamma\gamma$	6.7 (0.03%)
$e^+e^- \rightarrow (\gamma)e^+e^- + X$	1.5 (0.01%)
Beam associated	427 (1.63%)
Experiment data	26276

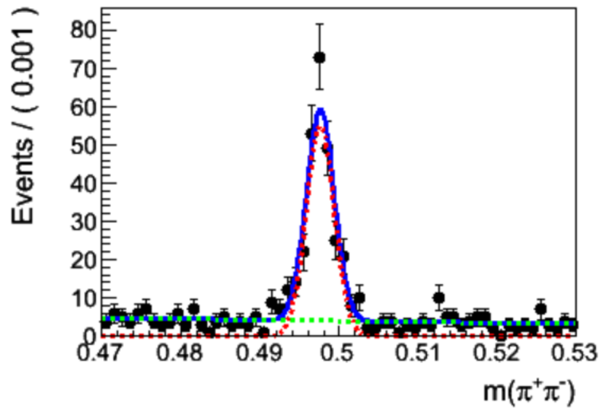
Most contribution come from beam associated background and the uncertainty is smaller than 2%

Data: Ks fitting @ 2.8 GeV

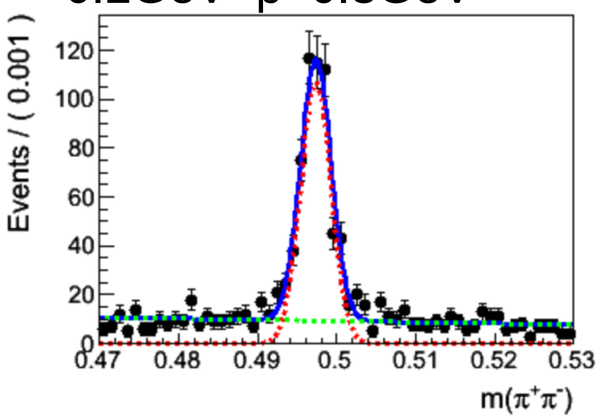
0GeV<p<0.1GeV



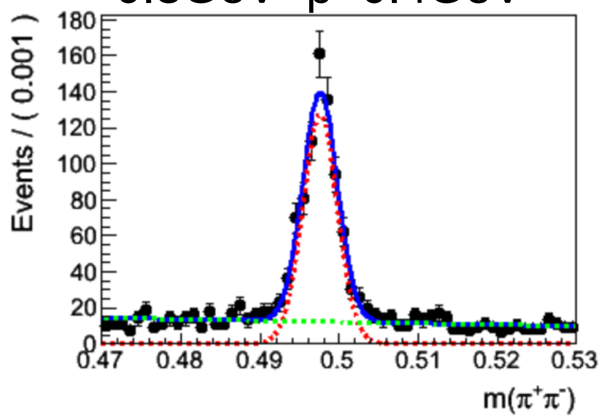
0.1GeV<p<0.2GeV



0.2GeV<p<0.3GeV



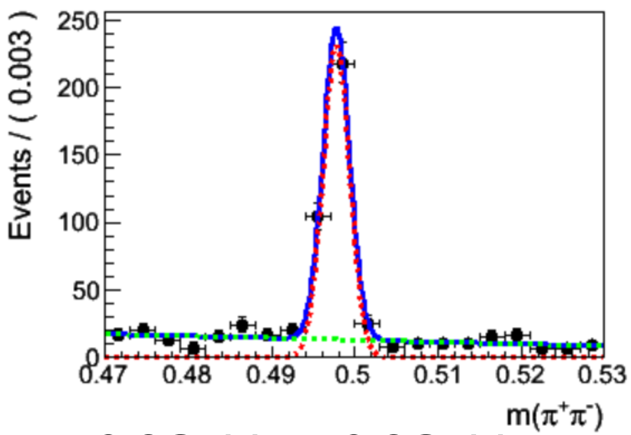
0.3GeV<p<0.4GeV



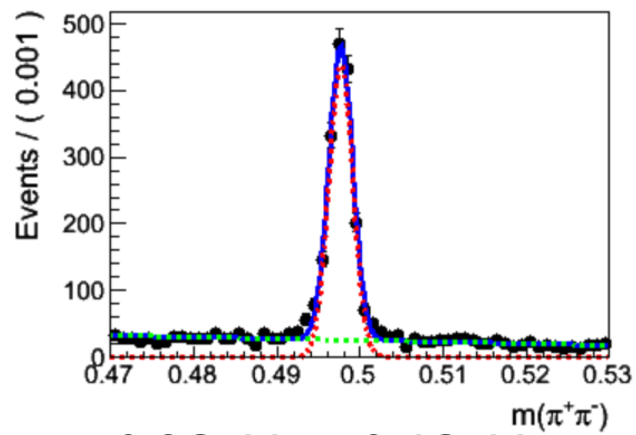
Fitting function: Gaussian function + one order of Chebychev

MC: K_s fitting @ 2.8 GeV

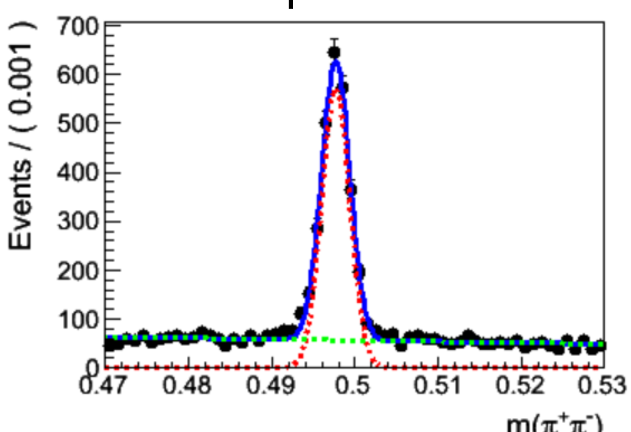
0GeV<p<0.1GeV



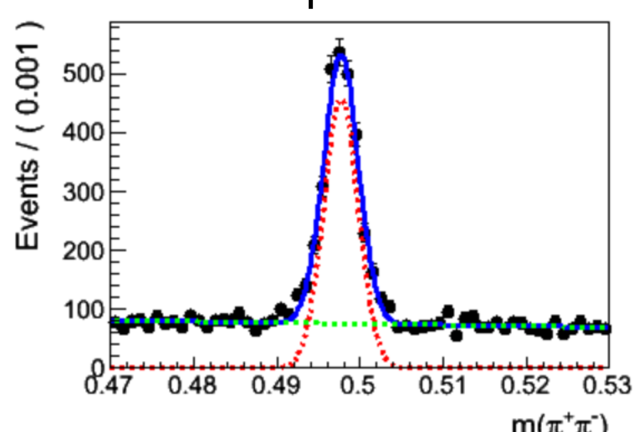
0.1GeV<p<0.2GeV



0.2GeV<p<0.3GeV



0.3GeV<p<0.4GeV



Fitting function: Gaussian function + one order of Chebychev

Inclusive K_S^0 production

$$\frac{1}{\sigma_{had}} \cdot \frac{d\sigma_{K_S^0}}{dp} = C \cdot \frac{1}{Br(K_S^0 \rightarrow \pi^+\pi^-)} \cdot \frac{1}{N_{had}^{exp}} \cdot \frac{N_{K_S^0}^{exp}(p)}{\Delta p}$$

N_{had}^{exp} Observed hadronic event number

$N_{K_S^0}^{exp}(p)$ Fitted K_S^0 number in a momentum bin

Δp Bin width in a momentum bin

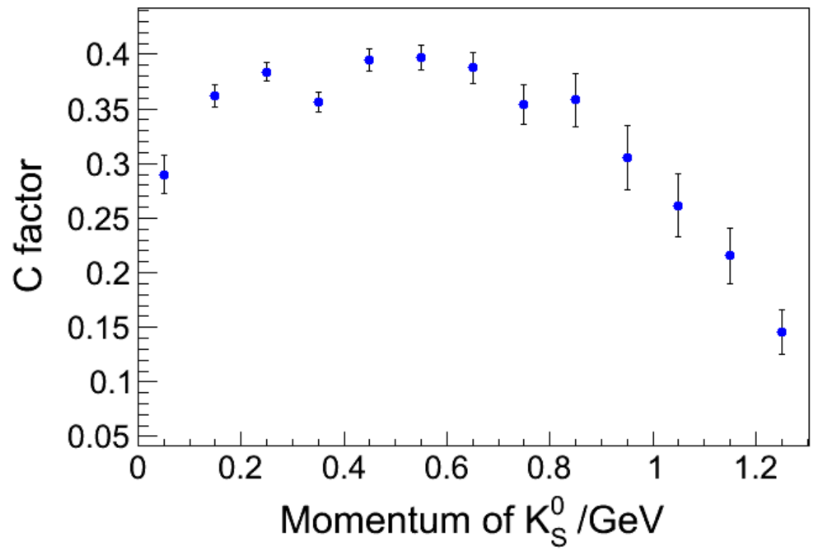
C Correction factor in a momentum bin

K_S^0 : bin-to-bin correction

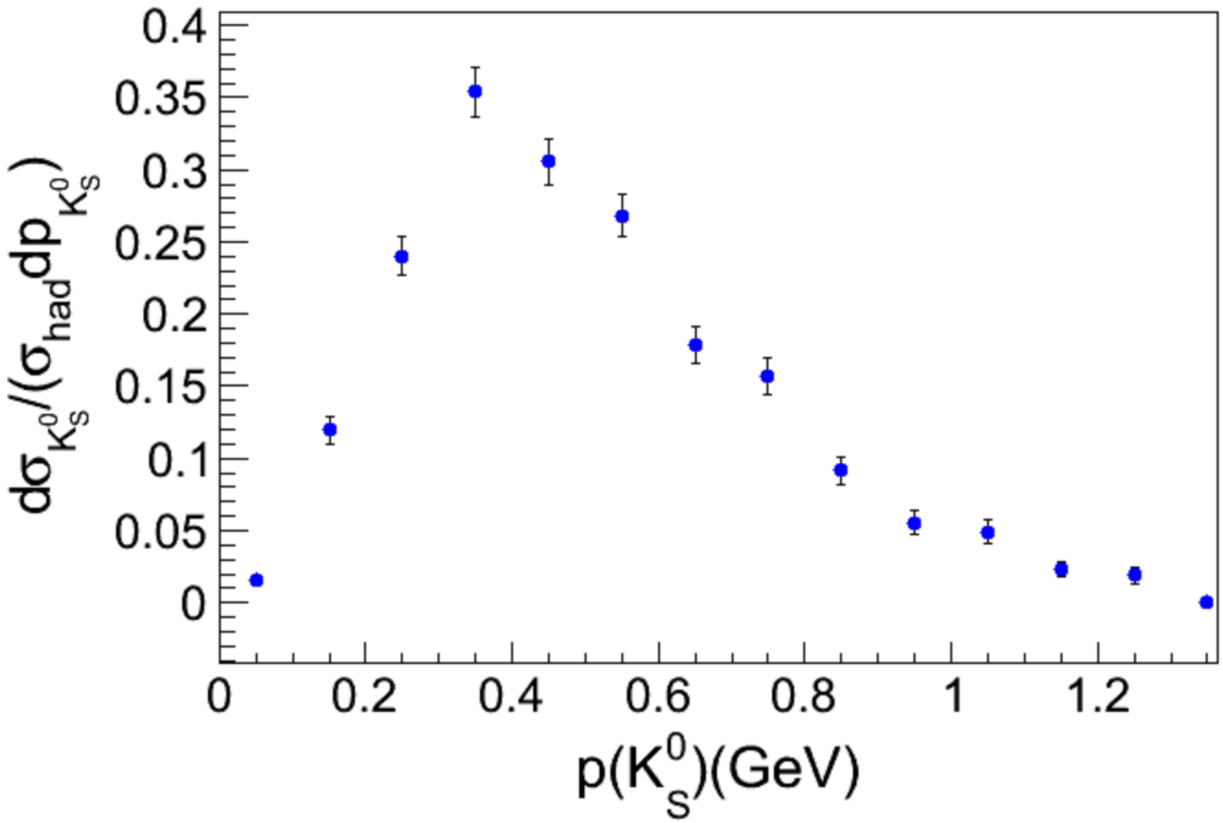
$$C = \frac{N_{K_S^0}^{truth} / N_{had}^{truth} \ @\ MC\ without\ ISR}{N_{K_S^0}^{det} / N_{had}^{det} \ @\ MC\ with\ ISR}$$

$N_{K_S^0}^{truth}$ K_S^0 from MC Truth

C corrects for event selection, K_S^0 reconstruction, ISR and so on.



K_S^0 : bin-to-bin correction



$$\frac{1}{\sigma_{had}} \cdot \frac{d\sigma_{K_S^0}}{dp} = C \cdot \frac{1}{Br(K_S^0 \to \pi^+\pi^-)} \cdot \frac{1}{N_{had}^{exp}} \cdot \frac{N_{K_S^0}^{exp}(p)}{\Delta p}$$

Hadronic event selection

Hadronic event selection, π^0 and K_S^0 production

① Select hadronic event ② π^0 and K_S^0 reconstruction

- Remove Bhabha and (γ) γ γ events with EMC information
  - ✓ Two showers with 1st/2nd energy deposition $|\theta_1+\theta_2-180^\circ| < 10^\circ$ and $E > 0.65*E_{beam}$
- Good track selection
  - ✓ $|Vr| < 0.5$, $|Vz| < 1$, $|\cos\theta| < 0.93$
  - ✓ Momentum $<0.94*E_{beam}$
  - ✓ $(dE/dx_{mea}-dE/dx_{proton})/\sigma_{proton}<10$
  - ✓ Veto election with Momentum $> 0.65*E_{beam}$ && $e/p > 0.8$
  - ✓ Veto gamma conversion with $M(e,e) < 100$MeV && Open angle$<15^\circ$
  - ✓ $Prob(E) / (Prob(E) + Prob(\pi) + Prob(K) + Prob(P)) < 0.25$
- good photon selection
  - ✓ $E_{barrel} > 25$MeV; $E_{endcap} > 50$MeV
  - ✓ 0<= TDC <= 14(×50ns);
- Isolated photon selection
  - ✓ $E_{barrel} > 25$MeV; $E_{endcap} > 50$MeV
  - ✓ 0<= TDC <= 14(×50ns);
  - ✓ Angle $> 20^\circ$ && $E_{deposited} > 100$MeV

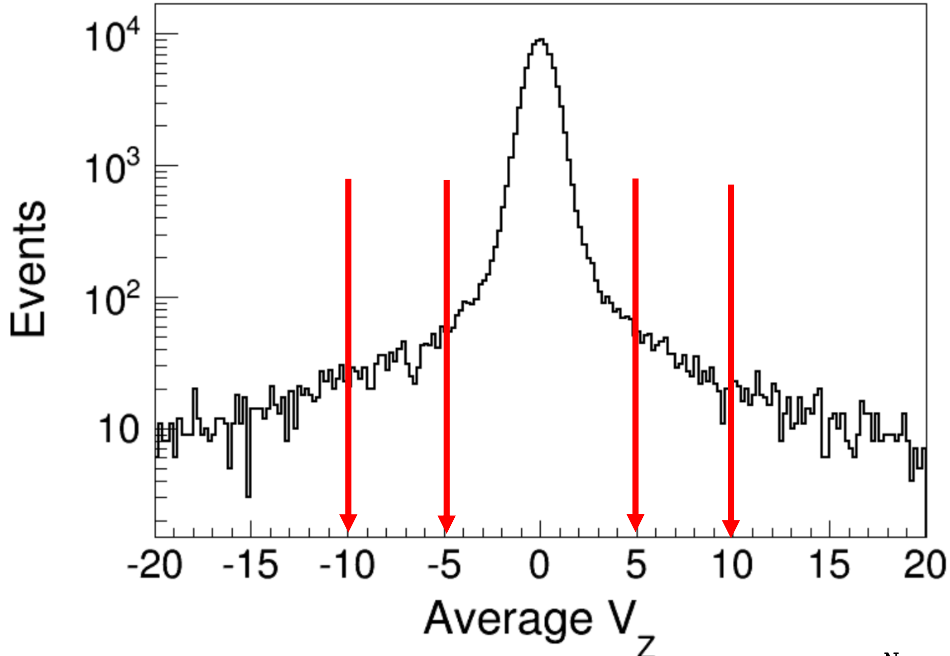
Hadronic event selection

- Event level selection
  - ✓ Number of good track N_{good}>=2

  1. Event with $N_{good}=2$
  - ✓ veto $|\theta_1+\theta_2-180^\circ| < 15^\circ$ && $||\varphi_1-\varphi_2|-180^\circ| < 10^\circ$
    number of Isolated photon N >= 2

  2. Event with $N_{good}=3$
  - ✓ Veto, angle between 1st/2nd energy track
    $|\theta_1+\theta_2-180^\circ| < 15^\circ$ and $||\varphi_1-\varphi_2|-180^\circ| < 10^\circ$

Non-physics background



- Average Z-direction vertex for a event $V_z = \sum_{i=1}^{N_{good}} V_z^i \Big/ N_{good}$
    - Non-physics background: $5.0 < |V_z| < 10.0$cm

2^{nd} K_s reconstruction

K_s selection: charged track after hadronic events selection

- ✓ Re-do track selection
  - ➢ $|Vr| < 10cm$, $|Vz| < 30cm$
  - ➢ Other selection criteria: same
- ✓ PID: Prob π > Prob K and Prob π > Prob P
  $N_{\pi+} >= 1$ and $N_{\pi-} >= 1$
- ✓ Second vertex fitting: $L/\sigma_L > 2.0$

K_S^0 systematic study
hadron event selection

Source	Cut	Default	Alternative
veto Bhabha and $\gamma\gamma$	E_{ratio} $\Delta\theta$	$0.65 \cdot E_{beam}$ $10°$	$0.6 \sim 0.7 \cdot E_{beam}$ $5° \sim 15°$
good hadronic	Vr	0.5 cm	1.0 cm
tracks determination	$p(track)$ dE/dx cut E/p ratio Bhabha momentum limit isolated photon angle isolated photon energy gamma conversion angle gamma conversion mass PID ratio value	$0.94 \cdot p_{beam}$ 10 0.8 $0.65 \cdot p_{beam}$ $20°$ 100 MeV $15°$ 100 MeV 0.25	$0.92 \sim 0.96 \cdot p_{beam}$ 15 $0.75 \sim 0.85$ $0.6 \sim 0.7 \cdot p_{beam}$ $15° \sim 25°$ $75 \sim 125$ MeV $10° \sim 20°$ $80 \sim 120$ MeV $0.1 \sim 0.4$
2 prong events	$\Delta\theta$ $\Delta\phi$	$15°$ $10°$	$10° \sim 20°$ $5° \sim 15°$
3 prong events	$\Delta\theta$ $\Delta\phi$	$15°$ $10°$	$10° \sim 20°$ $5° \sim 15°$

K_S^0 systematic study

hadron event selection

Table 7: Summary of systematic uncertainties for inclusive K_S^0

p(GeV)	Hadron event	Hadron track	Vr cut
0.0-0.1	2.0	2.8	1.0
0.1-0.2	1.3	1.7	0.6
0.2-0.3	0.7	1.8	1.9
0.3-0.4	0.6	0.9	1.3
0.4-0.5	0.7	1.7	0.5
0.5-0.6	1.0	1.7	1.8
0.6-0.7	0.9	2.7	3.3
0.7-0.8	1.2	3.8	7.0
0.8-0.9	2.0	2.4	0.4
0.9-1.0	1.9	3.4	9.3
1.0-1.1	3.8	5.1	15.4
1.1-1.2	7.2	4.9	5.0

Nominal cut: Vr = 0.5cm

Alternative cut: Vr = 1.0cm

Large uncertainty!

K_S^0 systematic study

hadron event selection

Table 8: Comparison of K_S^0 events using different Vr cut

Momentum	MC			Exp.Data		
p(GeV)	0.5(cm)	1.0(cm)	Difference(%)	0.5(cm)	1.0(cm)	Difference(%)
0.0-0.1	310	323	4.2	25	26	4.0
0.1-0.2	1584	1744	10.1	243	269	10.7
0.2-0.3	2424	2733	12.3	518	594	14.7
0.3-0.4	2406	2801	16.4	707	811	14.7
0.4-0.5	2423	2813	16.1	679	783	15.3
0.5-0.6	1827	2124	16.3	598	682	14.0
0.6-0.7	1282	1570	22.5	388	458	18.0
0.7-0.8	662	827	24.9	311	361	16.1
0.8-0.9	410	521	27.1	184	234	27.2
0.9-1.0	188	275	46.3	95	126	32.6
1.0-1.1	140	206	47.1	72	89	23.6
1.1-1.2	105	148	41.0	27	41	51.9

Considering 2.7cm decay length, the Ks events production increase dramatically when the Vr cut vary from 0.5cm to 1.0cm.
Large differences present between MC and experiment data.

New method

First: K_S^0 selection
Second: Hadron selection

First: K_S^0 selection: Method A, Method B, Method C, Method D

Method A: $\mathbf{K_S^0}$ selection
- ✓ Track selection
  - ➢ |Vr|< 10cm, |Vz|<30cm
  - ➢ Other selection criteria: the same with hadron selection
- ✓ PID: Prob π > Prob K and Prob π > Prob P
  $N_{\pi+}$ >=1 and $N_{\pi-}$ >=1
- ✓ Second vertex fitting: $L/\sigma_L > 2.0$

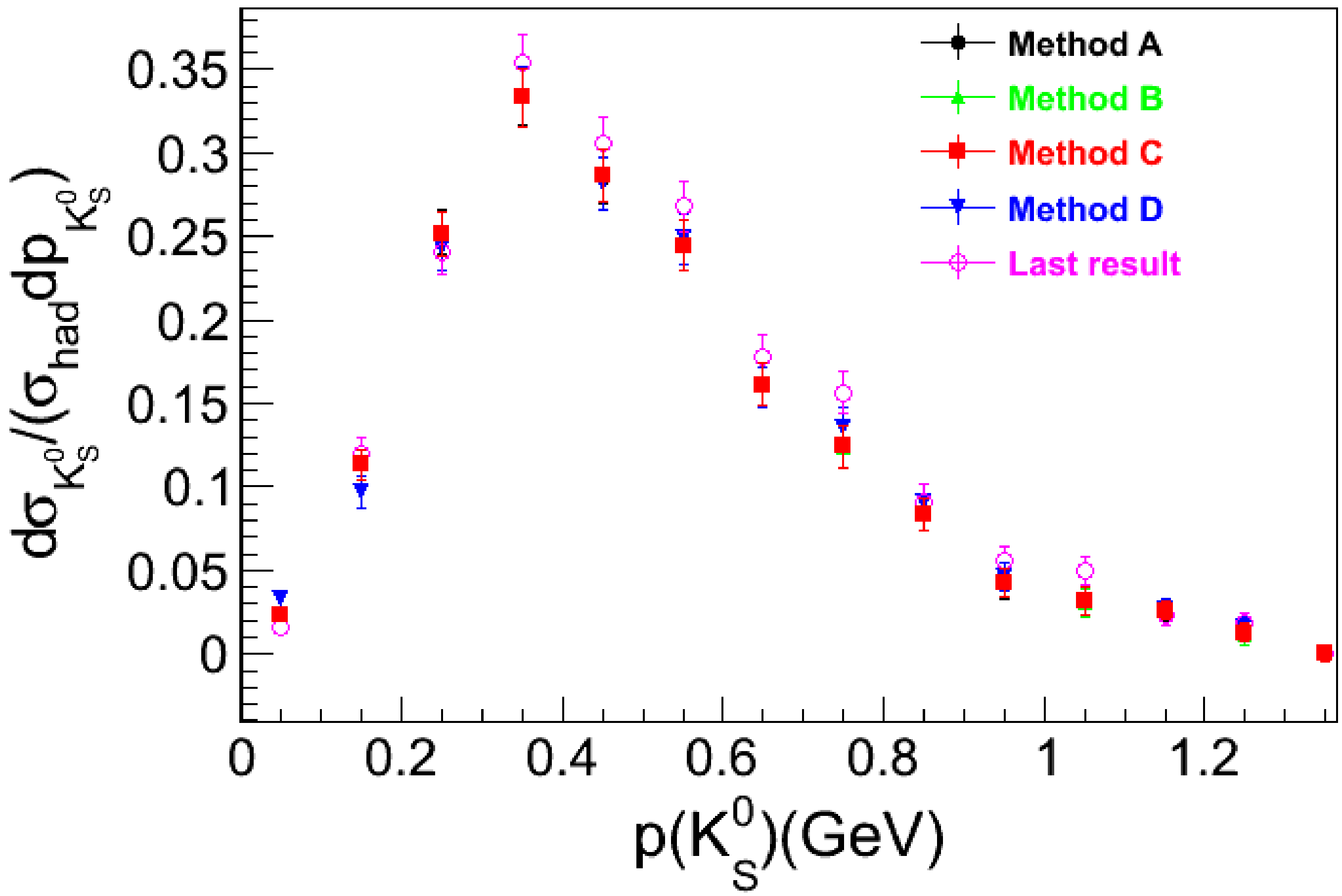
Method B: $\mathbf{K_S^0}$ selection
- ✓ Track selection
  - ➢ |Vr|< 10cm, |Vz|<30cm
  - ➢ Other selection criteria: Only include Bhabha remove
- ✓ PID: Prob π > Prob K and Prob π > Prob P
  $N_{\pi+}$ >=1 and $N_{\pi-}$ >=1
- ✓ Second vertex fitting: $L/\sigma_L > 2.0$

Method C: $\mathbf{K_S^0}$ selection
- ✓ Track selection
  - ➢ |Vr|< 10cm, |Vz|<30cm
  - ➢ No other selection criteria
- ✓ PID: Prob π > Prob K and Prob π > Prob P
  $N_{\pi+}$ >=1 and $N_{\pi-}$ >=1
- ✓ Second vertex fitting: $L/\sigma_L > 2.0$

Method D: $\mathbf{K_S^0}$ selection
- ✓ Track selection
  - ➢ |Vr|< 10cm, |Vz|<30cm
  - ➢ No other selection criteria
- ✓ No PID: assuming charged tracks are $\pi^{\pm}$,
  $N_{\pi+}$ >=1 and $N_{\pi-}$ >=1, loop all the pion pairs
- ✓ Second vertex fitting: $L/\sigma_L > 2.0$

Second: Re-do events selection for Hadronic events

Comparisons of different methods



Comparisons of different methods

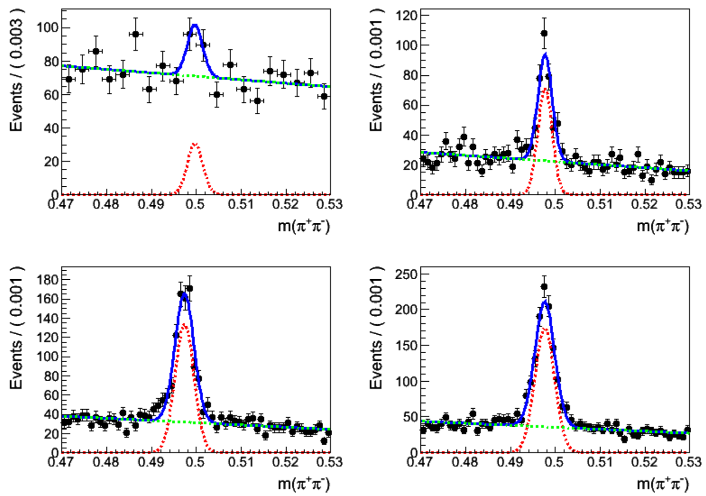
Table 9: Extracted K_S^0 events and of K_S^0 efficiency varying with momenta

p(GeV)	Method A		Method B		Method C		Method D	
	Exp.data	$\varepsilon(K_S^0)$	Exp.data	$\varepsilon(K_S^0)$	Exp.data	$\varepsilon(K_S^0)$	Exp.data	$\varepsilon(K_S^0)$
0.0-0.1	45.0±15.2	31.2	44.3±15.2	31.2	44.7±15.2	31.2	61.5±22.3	31.0
0.1-0.2	285.2±24.2	41.2	285.7±24.3	41.3	285.6±24.3	41.3	245.1±29.1	41.6
0.2-0.3	711.5±36.5	46.2	711.9±36.4	46.3	711.0±36.4	46.3	695.1±46.1	46.8
0.3-0.4	972.4±40.5	47.7	972.4±40.5	47.9	972.7±40.6	47.9	988.1±50.7	48.6
0.4-0.5	935.3±39.8	53.6	935.8±39.8	53.6	937.3±39.8	53.6	946.5±50.4	55.1
0.5-0.6	856.0±37.0	57.2	855.0±36.9	57.3	854.8±37.0	57.3	886.9±48.4	58.5
0.6-0.7	602.3±31.1	61.3	603.0±31.1	61.4	602.7±31.1	61.4	600.6±43.3	61.7
0.7-0.8	457.0±25.9	60.5	456.9±25.9	60.4	458.1±26.0	60.4	495.7±35.5	60.1
0.8-0.9	311.7±21.2	60.9	311.3±21.1	61.0	312.6±21.2	61.0	354.9±29.8	63.8
0.9-1.0	190.3±16.3	74.8	191.9±16.3	74.8	193.6±16.5	74.8	216.3±23.7	77.1
1.0-1.1	136.7±13.1	74.2	137.6±13.1	74.4	140.7±13.3	74.4	147.5±18.4	76.8
1.1-1.2	87.5±10.2	56.2	88.9±10.3	56.9	89.2±10.5	56.9	102.5±15.4	61.8
1.2-1.3	51.1±7.5	57.7	50.6±0.0	57.9	56.2±9.2	57.9	80.2±19.1	62.6
1.3-1.4	1.3±1.8	47.8	0.9±1.6	48.6	0.0±3.4	48.6	0.0±13.3	54.2

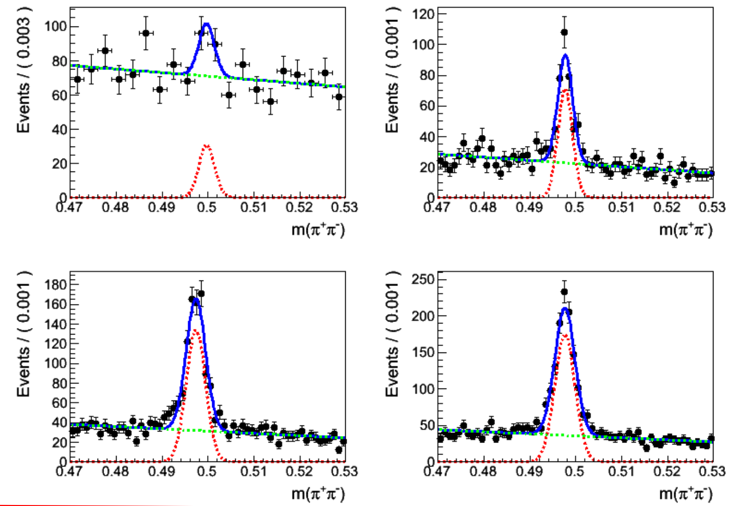
Methods A, B, C almost have the same efficiencies.
Method D have slight higher efficiencies.

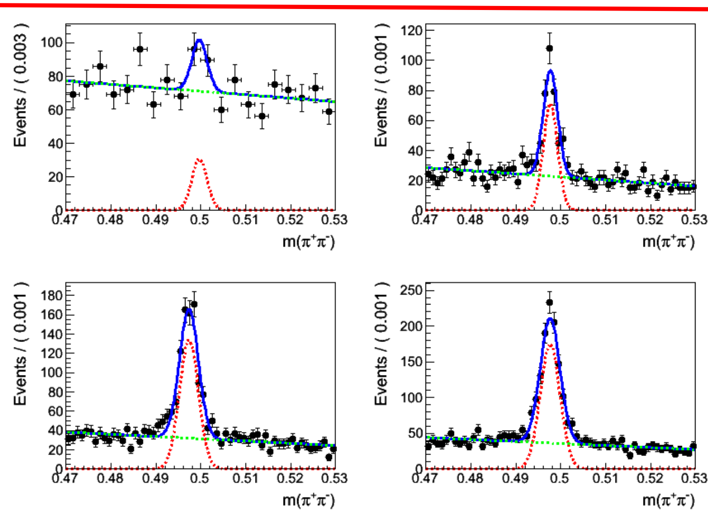
Comparisons of different methods: Data

Method A

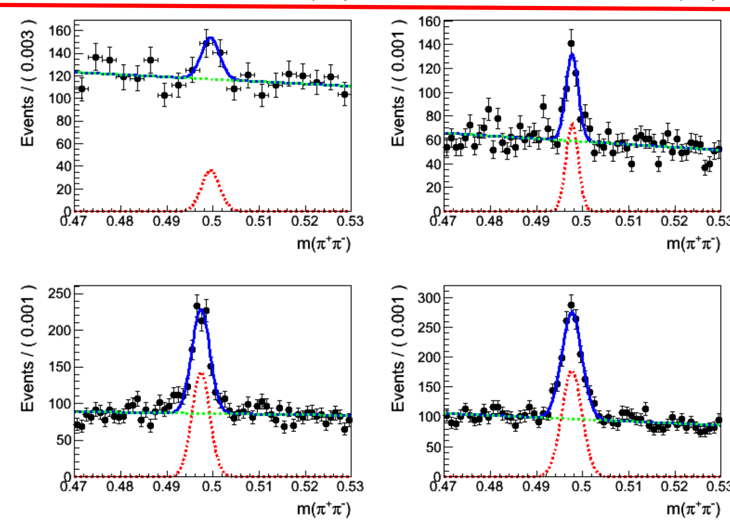


Method B





Method C

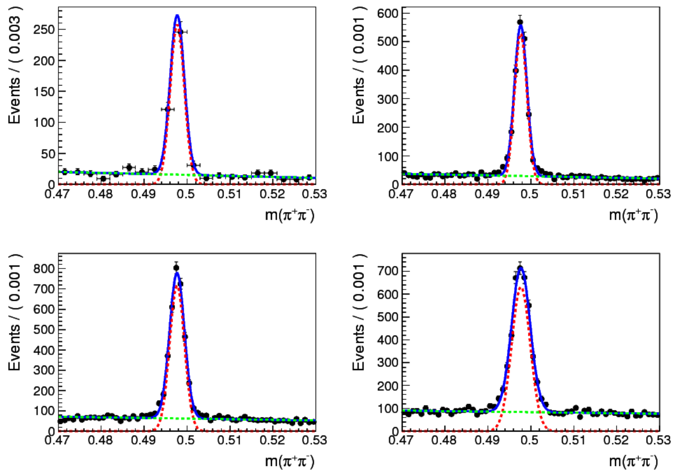


Method D

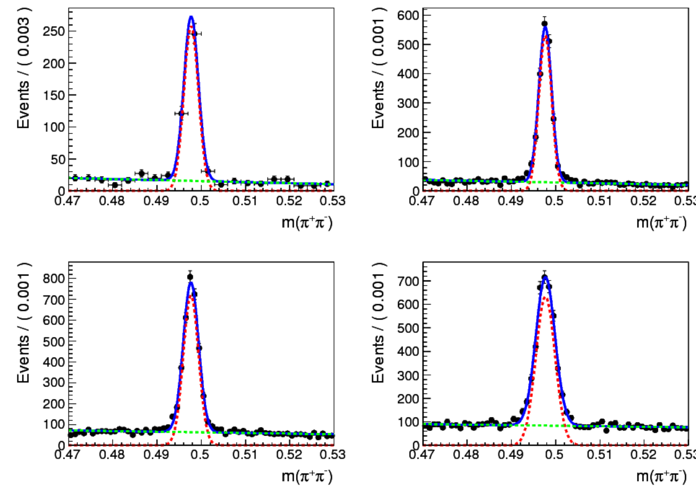
Thicker backgrounds

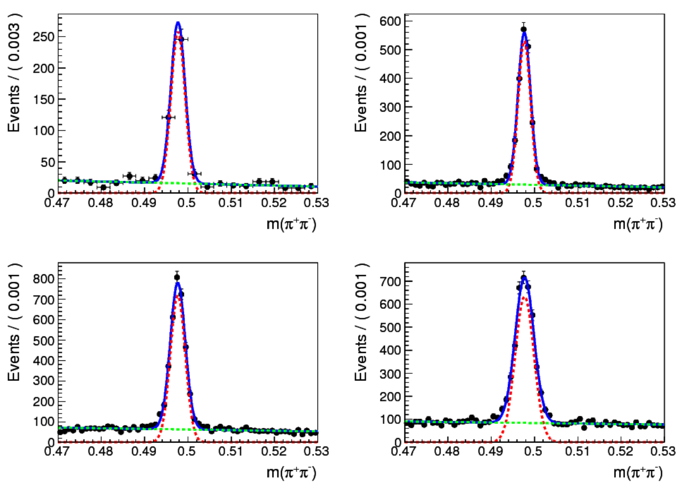
Comparisons of different methods: MC

Method A

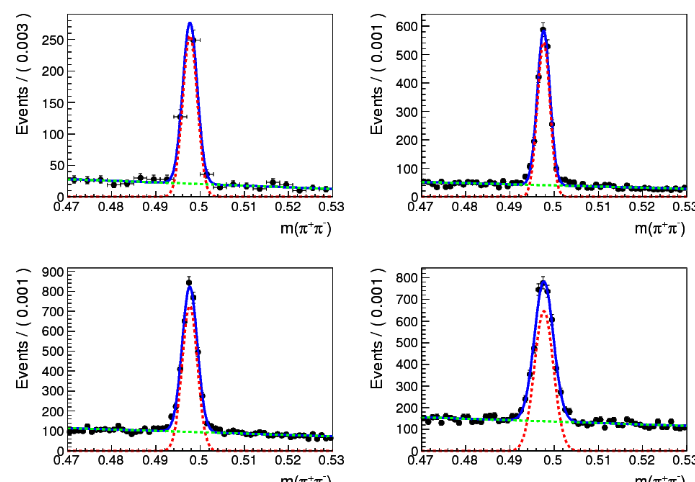


Method B





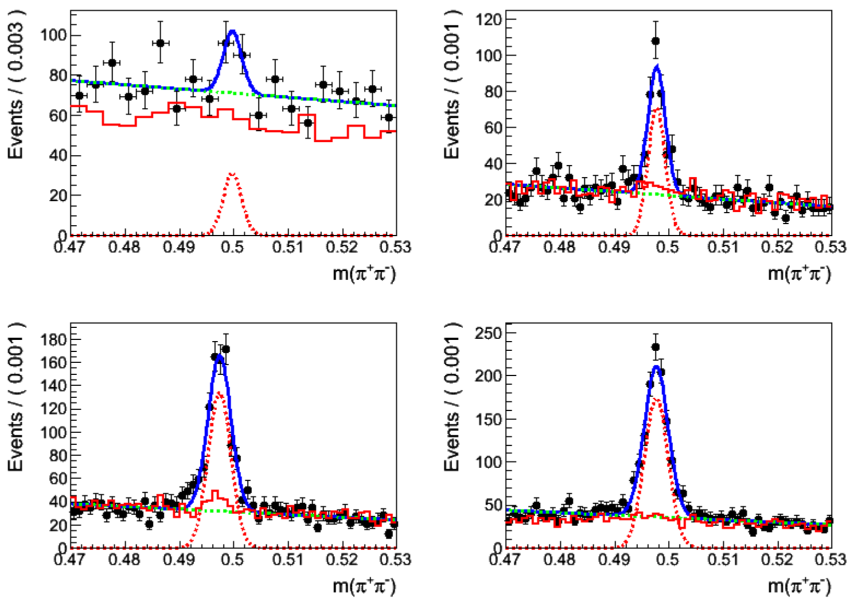
Method C



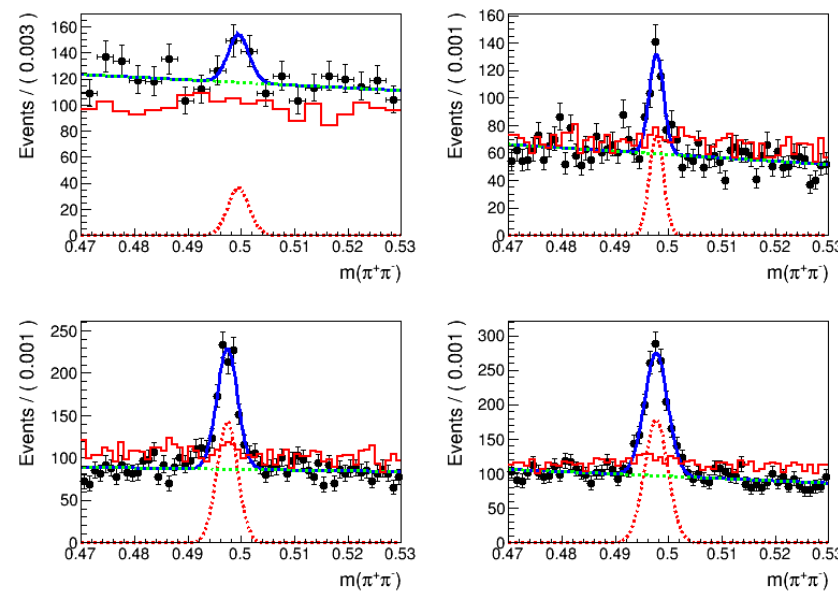
Method D

Slight higher backgrounds

Contribution from the beam-associated backgrounds



Method C



Method D

Most backgrounds come from beam-associated background and mis-combination

Possible cut to remove the beam-associated backgrounds:
1. angle of $\pi^+\pi^-$

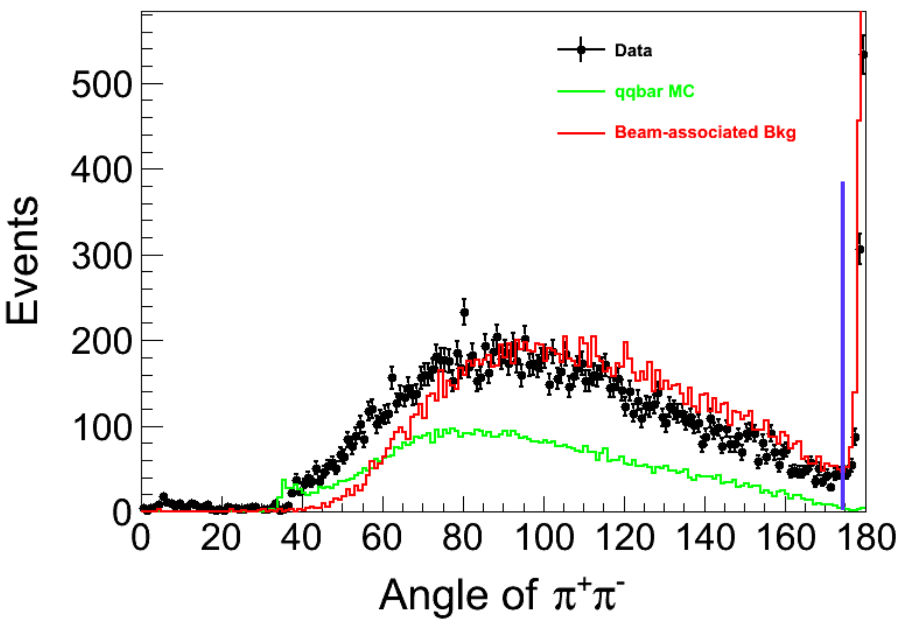
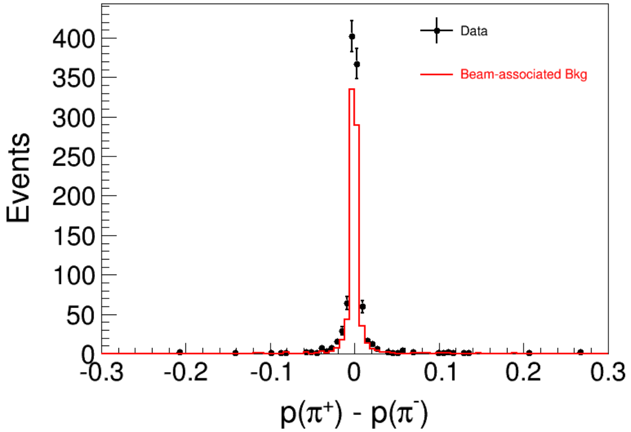


Table 11: Extracted K_S^0 events and of K_S^0 efficiency varying with momenta

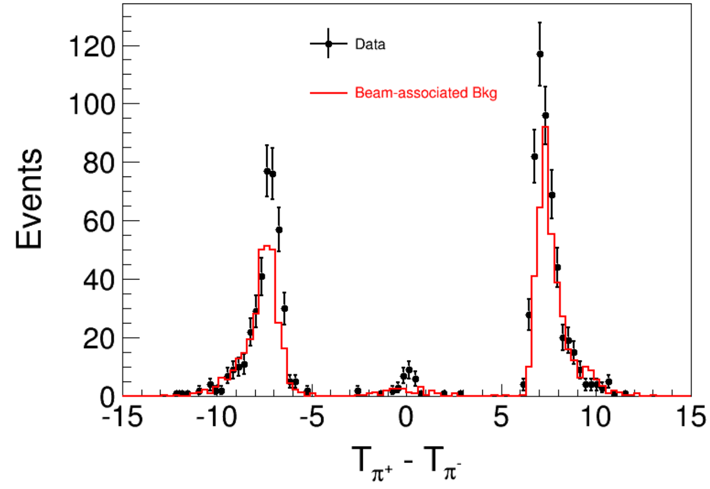
p(GeV)	With angle cut		Without angle cut (method C)	
	Exp.data	$\varepsilon(K_S^0)$	Exp.data	$\varepsilon(K_S^0)$
0.0-0.1	50.3±19.8	30.3	44.7±15.2	31.2
0.1-0.2	283.8±24.3	41.3	285.6±24.3	41.3
0.2-0.3	711.2±36.5	46.3	711.0±36.4	46.3
0.3-0.4	972.9±40.5	47.9	972.7±40.6	47.9
0.4-0.5	935.4±39.8	53.6	937.3±39.8	53.6
0.5-0.6	854.6±36.9	57.3	854.8±37.0	57.3
0.6-0.7	602.5±31.1	61.4	602.7±31.1	61.4
0.7-0.8	457.8±25.9	60.4	458.1±26.0	60.4
0.8-0.9	311.3±21.1	61.0	312.6±21.2	61.0
0.9-1.0	193.1±16.5	74.8	193.6±16.5	74.8
1.0-1.1	141.1±13.4	74.4	140.7±13.3	74.4
1.1-1.2	89.9±10.5	56.9	89.2±10.5	56.9
1.2-1.3	57.6±9.1	57.9	56.2±9.2	57.9
1.3-1.4	0.0±3.5	48.6	0.0±3.4	48.6

The angle of $\pi^+\pi^-$ from K_S candidate is required to satisfy:

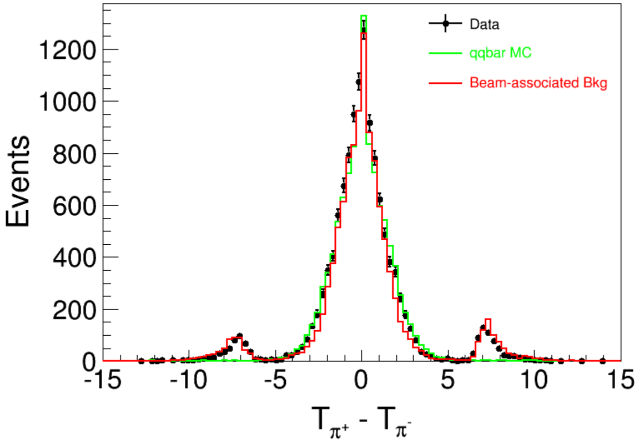
$\theta(\pi^+\pi^-) < 175^\circ$



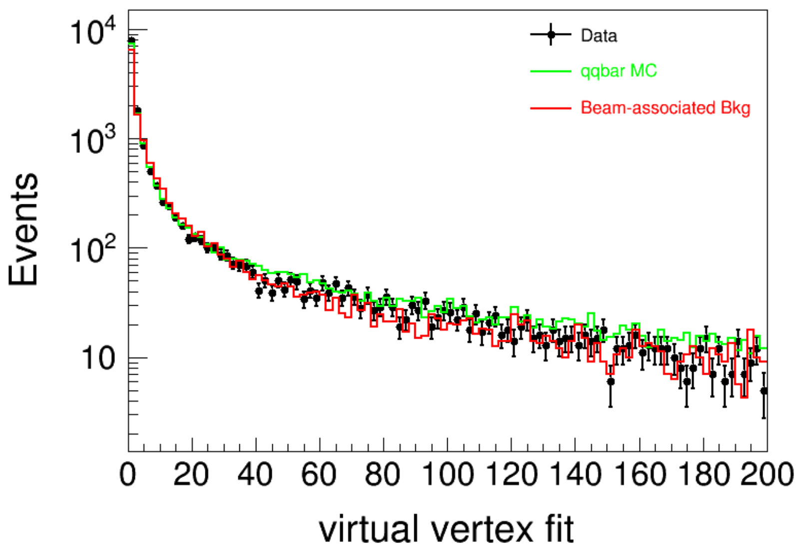
Data
Beam-associated Bkg
Events
$p(\pi^+) - p(\pi^-)$

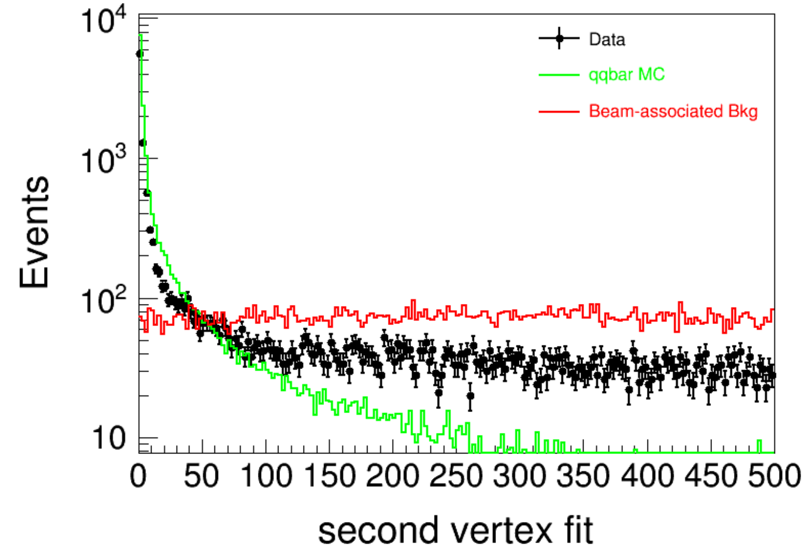


Data
Beam-associated Bkg
Events
$T_{\pi^+} - T_{\pi^-}$

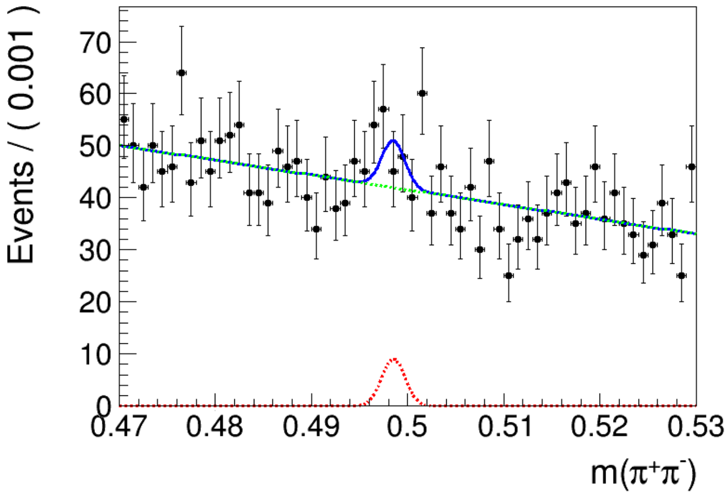


Data
qqbar MC
Beam-associated Bkg
Events
$T_{\pi^+} - T_{\pi^-}$


Data
qqbar MC
Beam-associated Bkg
Events
virtual vertex fit
0 20 40 60 80 100 120 140 160 180 200
10
10^2
10^3
10^4


Data
qqbar MC
Beam-associated Bkg
Events
second vertex fit
0 50 100 150 200 250 300 350 400 450 500
10
10^2
10^3
10^4

2.2324

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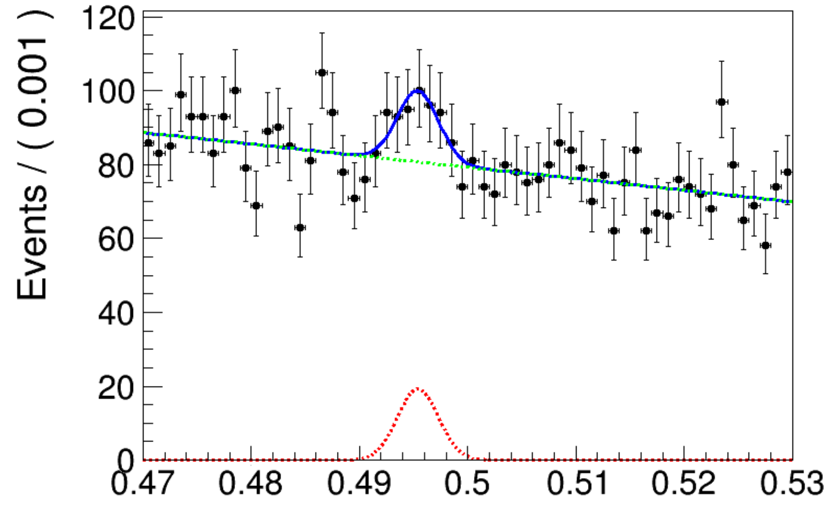
 ERR MATRIX NOT POS-DEF
[#1] INFO:Minization -- RooMinuit::optimizeConst: deactivating const optimization
[#1] INFO:Plotting -- RooAbsPdf::plotOn(sum) directly selected PDF components: (Gaussian)
[#1] INFO:Plotting -- RooAbsPdf::plotOn(sum) indirectly selected PDF components: ()
[#1] INFO:Plotting -- RooAbsPdf::plotOn(sum) directly selected PDF components: (bkg)
[#1] INFO:Plotting -- RooAbsPdf::plotOn(sum) indirectly selected PDF components: ()
check 27.5326 43.2826
check if successfully: 0
check 27.5326 43.2826
RooRealVar::mean1 = 0.498531 +/- 0.0122359  L(0.49 - 0.51)
RooRealVar::nsignal = 27.5326 +/- 43.2826  L(0 - 500)
RooRealVar::nbkg = 2521.78 +/- 19.9322  L(0 - 20000)
root [1]
```

2.6444

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[#1] INFO:Minization -- RooMinuit::optimizeConst: deactivating const optimization
[#1] INFO:Plotting -- RooAbsPdf::plotOn(sum) directly selected PDF components: (Gaussian)
[#1] INFO:Plotting -- RooAbsPdf::plotOn(sum) indirectly selected PDF components: ()
[#1] INFO:Plotting -- RooAbsPdf::plotOn(sum) directly selected PDF components: (bkg)
[#1] INFO:Plotting -- RooAbsPdf::plotOn(sum) indirectly selected PDF components: ()
check 91.3246 30.187
check if successfully: 0
check 91.3246 30.187
RooRealVar::mean1 = 0.495406 +/- 0.000722966  L(0.49 - 0.51)
RooRealVar::nsignal = 91.3246 +/- 30.187  L(0 - 2000)
RooRealVar::nbkg = 4757.65 +/- 74.6916  L(0 - 40000)
root [1]
```
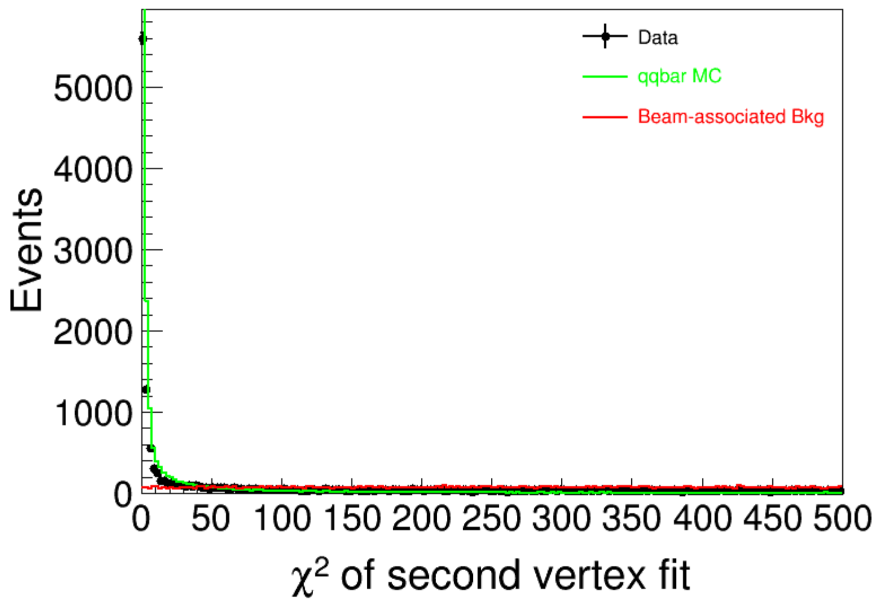

3.1 K_S^0 selection

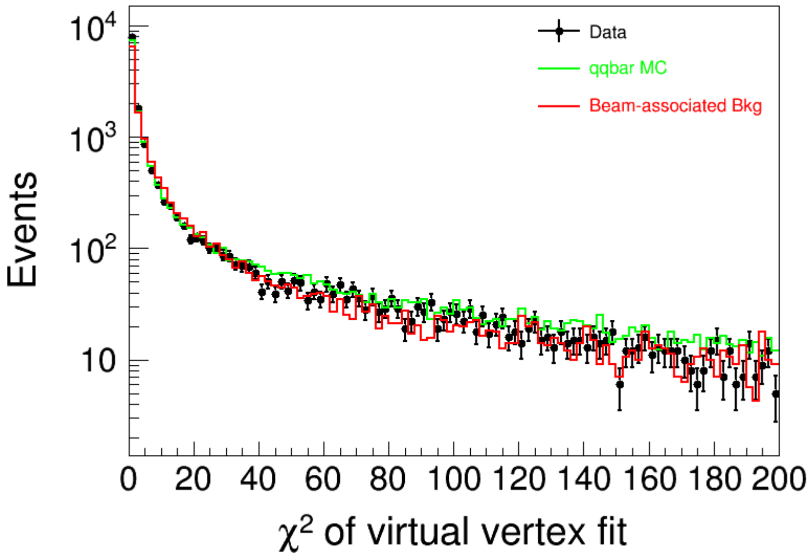
To reconstruct the K_S^0, the common vertex fit is performed for π^+, π^- pairs by looping all charged tracks. The charged particles are all assumed as pions when tagging the K_S^0. The decay point of the K_S^0 is determined by the common vertex fit. It should be located in the reasonable region where could be calculated by the K_S^0 flight direction from IP considering the error of IP. The IP is determined by averaging the event vertices in each run, where event vertices are obtained from the vertex fit on the events with at least 3 charged tracks. The above constraint between the decay point and the IP is called second vertex fit. The χ^2 of second vertex fit should be less than 20 to veto the backgrounds. Fig. 1 shows the distribution of χ^2 of second vertex fit for the signal, and this cut is safe for signal selection. Actually, the second vertex fit is the decay length fit. To reconstruct K_S^0, the K_S^0 decay point is found by the common vertex fit first. Then we require that the common vertex fit and the IP(interaction point) should be in the straight line along the K_S^0 flight direction in the decay length fit. The equations are shown blow:

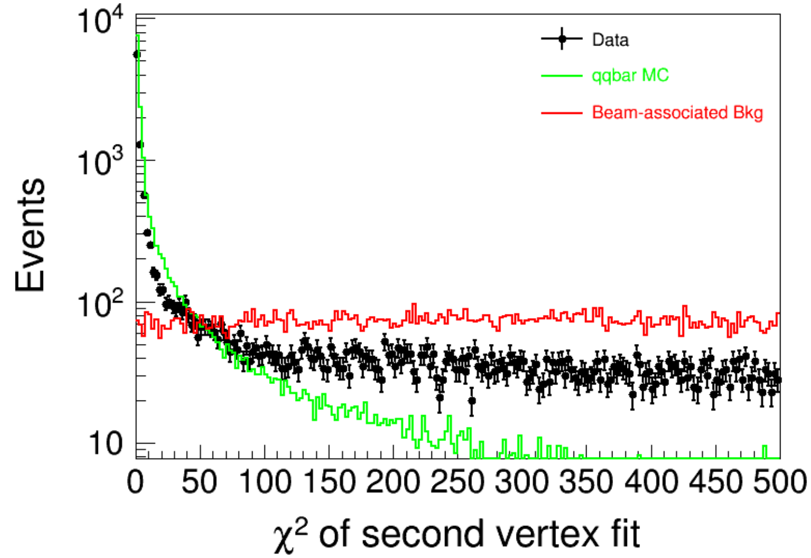
$$x_p - x_d + \frac{p_x}{m} c\tau = 0,$$
$$y_p - y_d + \frac{p_y}{m} c\tau = 0,$$
$$z_p - z_d + \frac{p_z}{m} c\tau = 0.$$

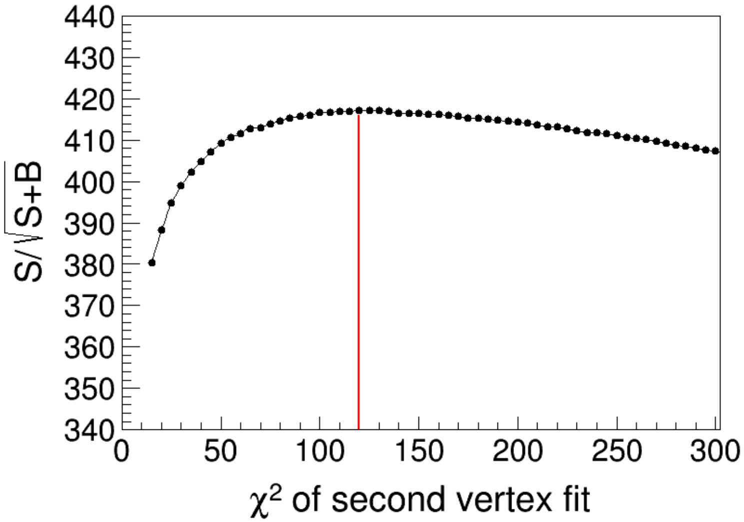
where $(x_p,\, y_p,\, z_p)$ is the IP, $(x_d,\, y_d,\, z_d)$ is the K_S^0 decay point, $(p_x,\, p_y,\, p_z)$ is the momentum of K_S^0, m is the mass of K_S^0, c is the speed of light and τ is the life time of K_S^0. It is called


Data
qqbar MC
Beam-associated Bkg
Events
0
1000
2000
3000
4000
5000
0 50 100 150 200 250 300 350 400 450 500
χ^2 of second vertex fit

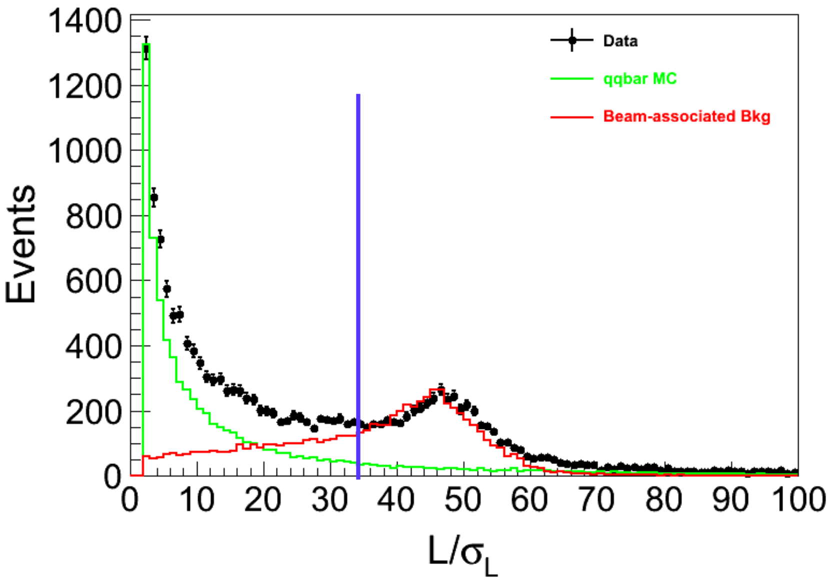
Possible cut to remove the beam-associated backgrounds:
3. Second vertex fit

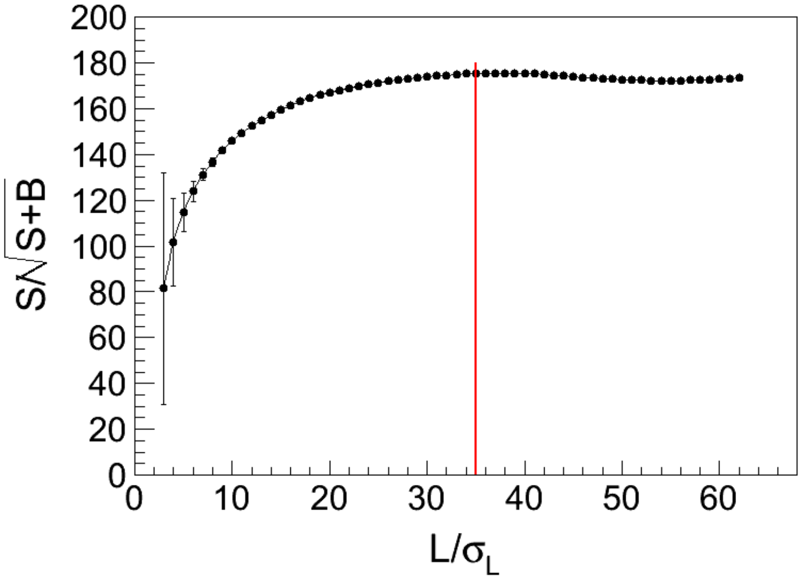






Possible cut to remove the beam-associated backgrounds:
2. Ratio of decay length and decay length error





The ratio of decay length and decay length error from K_S candidate is required to satisfy:

$L/\sigma_L < 35$

Possible cut to remove the beam-associated backgrounds:

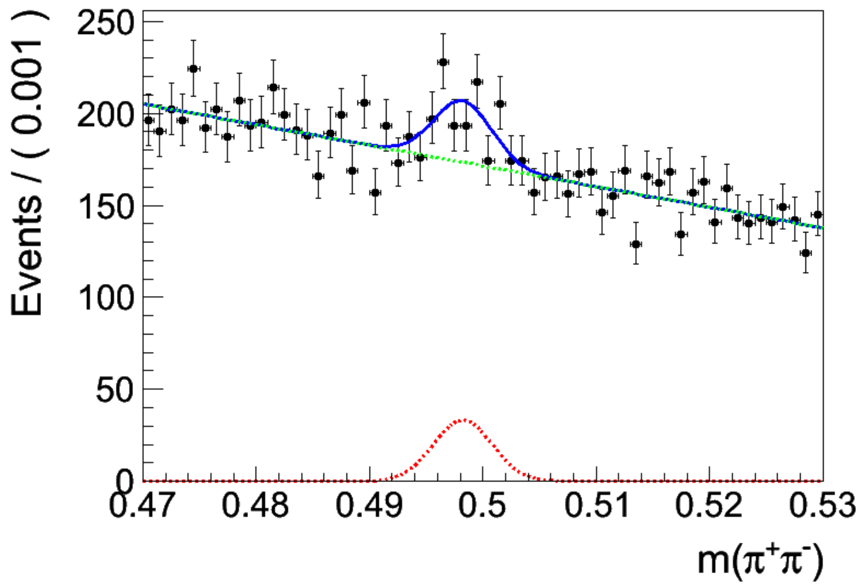
2. Ratio of decay length and decay length error

Table 10: Extracted K_S^0 events and of K_S^0 efficiency varying with momenta

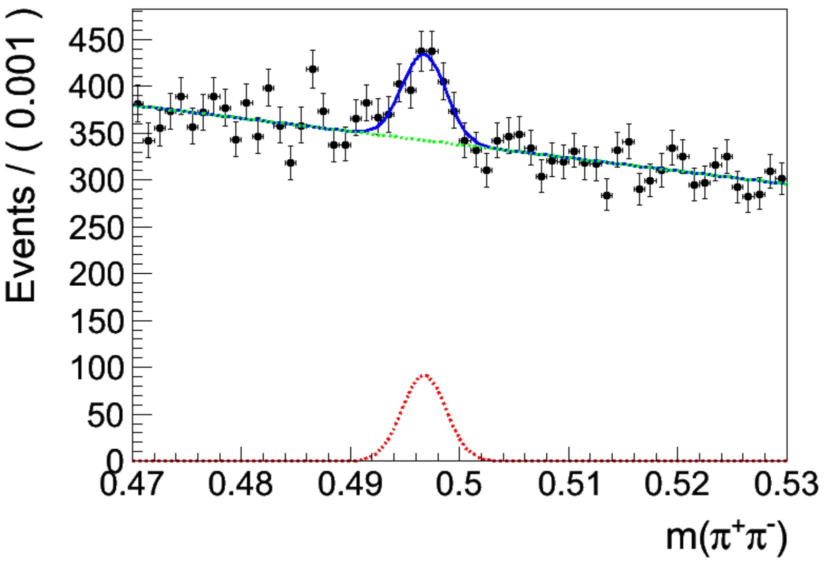
p(GeV)	Without L/σ_L cut		With L/σ_L cut	
	Exp.data	$\varepsilon(K_S^0)$	Exp.data	$\varepsilon(K_S^0)$
0.0-0.1	50.3±19.8	30.3	53.2±14.2	28.1
0.1-0.2	283.8±24.3	41.3	283.4±22.4	39.6
0.2-0.3	711.2±36.5	46.3	622.7±31.6	41.7
0.3-0.4	972.9±40.5	47.9	759.8±34.5	39.0
0.4-0.5	935.4±39.8	53.6	663.1±32.3	39.1
0.5-0.6	854.6±36.9	57.3	560.8±30.4	38.5
0.6-0.7	602.5±31.1	61.4	335.4±25.0	38.2
0.7-0.8	457.8±25.9	60.4	242.8±19.2	33.0
0.8-0.9	311.3±21.1	61.0	134.7±14.6	30.2
0.9-1.0	193.1±16.5	74.8	90.3±12.0	34.5
1.0-1.1	141.1±13.4	74.4	62.7±9.3	32.4
1.1-1.2	89.9±10.5	56.9	36.7±6.7	24.6
1.2-1.3	57.6±9.1	57.9	26.5±6.0	26.2
1.3-1.4	0.0±3.5	48.6	0.0±586.2	20.2

Efficiencies are largely decreased, and this cut is not appropriate.

Beam-associated Backgrounds



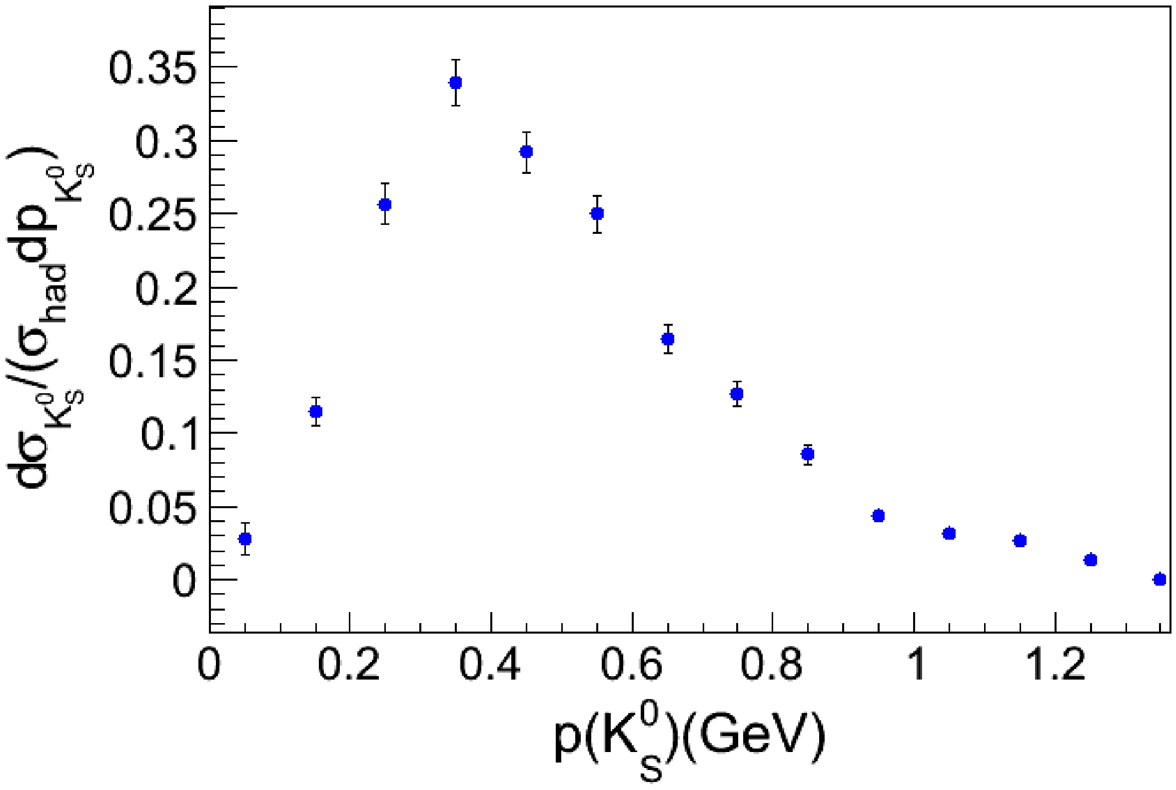
Non-collision data @ 2.2324 GeV:
(215±54)*0.452 = 97.2±24.4



Non-collision data @ 2.6444:
(458±74)*0.442 = 202.4±32.7

Total fitted Ks number at 2.8000 GeV:
5661.6
For Non-collision data @ 2.6444, the uncertainty is :
202.4/5661.6 = 3.6%
For Non-collision data @ 2.6444, the uncertainty is :
97.2/5661.6 = 1.7%

This result



0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.2
0.4
0.6
0.8
1
1.2
$d\sigma_{K_S^0}/(\sigma_{had} dp_{K_S^0})$
$p(K_S^0)$(GeV)

Comparison with last result

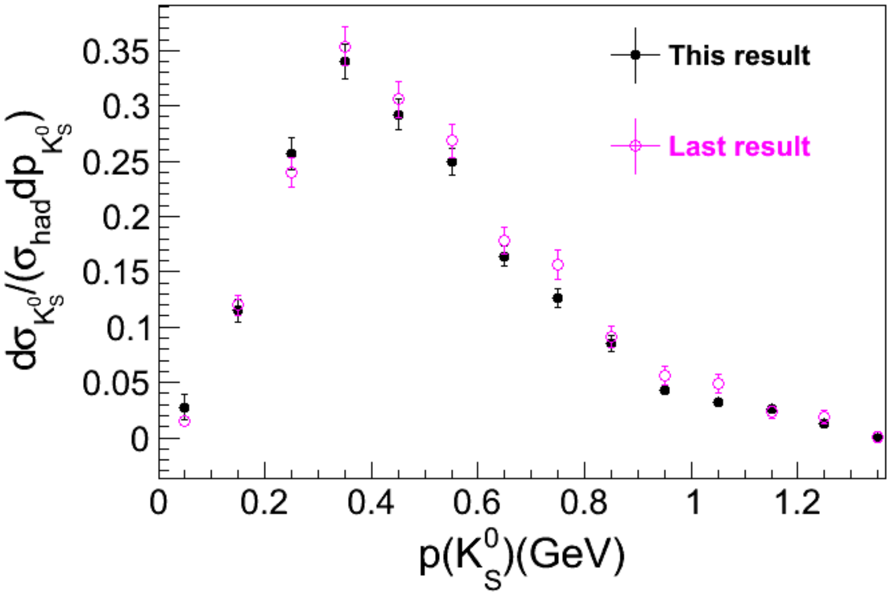


Table 12: Extracted K_S^0 events and of K_S^0 efficiency varying with momenta

p(GeV)	This result		Last result	
	Exp.data	$\varepsilon(K_S^0)$	Exp.data	$\varepsilon(K_S^0)$
0.0-0.1	50.3±19.8	30.3	25.3±5.7	27.3
0.1-0.2	283.8±24.3	41.3	243.4±17.7	34.0
0.2-0.3	711.2±36.5	46.3	518.7±26.2	36.1
0.3-0.4	972.9±40.5	47.9	708.0±30.6	33.5
0.4-0.5	935.4±39.8	53.6	679.4±30.8	37.2
0.5-0.6	854.6±36.9	57.3	599.0±28.3	37.4
0.6-0.7	602.5±31.1	61.4	388.3±23.3	36.5
0.7-0.8	457.8±25.9	60.4	311.8±20.0	33.3
0.8-0.9	311.3±21.1	61.0	184.2±15.8	33.7
0.9-1.0	193.1±16.5	74.8	95.8±11.4	28.8
1.0-1.1	141.1±13.4	74.4	72.6±9.5	24.6
1.1-1.2	89.9±10.5	56.9	27.9±5.7	20.3
1.2-1.3	57.6±9.1	57.9	15.4±4.1	10.6
1.3-1.4	0.0±3.5	48.6	0.3±2.5	4.2

Efficiencies are improved

Summary and outlook

- For the inclusive K_S^0 and π^0 production @BESIII, we could provide
  ✓relative cross section of pion @ 2.800 GeV.
  ✓Preliminary systematic uncertainty.
- To do list

  Model dependent uncertainty

  Similar study for other energy points (2.396GeV, 2.6444GeV, 2.90GeV, 3.08GeV, 3.40GeV, 3.65GeV) taken for R value in 2012 and 2015.

Backup

Fragmentation Function:

$$
\begin{aligned}
\frac{1}{\sigma_{had}} \cdot \frac{d\sigma_{\pi^0}}{dp} &= \frac{1}{N_{had}/(L \cdot \varepsilon_{had} \cdot (1+\delta)_{had})} \cdot \frac{\sigma_{\pi^0}(p_i)}{\triangle p} \\
&= \frac{1}{N_{had}/(L \cdot \varepsilon_{had} \cdot (1+\delta)_{had})} \cdot \frac{N_{\pi^0}(p_i)/(L \cdot \varepsilon_{\pi^0}(p_i) \cdot (1+\delta)_{\pi^0}(p_i))}{\triangle p} \\
&= \frac{N_{\pi^0}(p_i)}{N_{had} \cdot \triangle p} \cdot \frac{\varepsilon_{had}}{\varepsilon_{\pi^0}(p_i)} \cdot \frac{(1+\delta)_{had}}{(1+\delta)_{\pi^0}(p_i)}
\end{aligned}
$$

$$
\varepsilon_{had} = \frac{N^{MC\ det}_{had\ with\ ISR}}{N^{MC\ truth}_{had\ with\ ISR}}, \varepsilon_{\pi^0} = \frac{N^{MC\ det}_{\pi^0\ with\ ISR}(p_i)}{N^{MC\ truth}_{\pi^0\ with\ ISR}(p_i)}, \boxed{1+\delta = \frac{N^{MC\ truth}_{with\ ISR}}{N^{MC\ truth}_{without\ ISR}}}
$$

Backup

Fragmentation Function:

$$
\begin{aligned}
\frac{1}{\sigma_{had}} \cdot \frac{d\sigma_{\pi^0}}{dp} &= \frac{N_{\pi^0}(p_i)}{N_{had} \cdot \triangle p} \cdot \frac{\varepsilon_{had}}{\varepsilon_{\pi^0}(p_i)} \cdot \frac{(1+\delta)_{had}}{(1+\delta)_{\pi^0}(p_i)} \\
&= \frac{N_{\pi^0}(p_i)}{N_{had} \cdot \triangle p} \cdot \frac{N^{MC\ det}_{had\ with\ ISR}}{N^{MC\ truth}_{had\ without\ ISR}} \cdot \frac{N^{MC\ truth}_{\pi^0\ without\ ISR}(p_i)}{N^{MC\ det}_{\pi^0\ with\ ISR}(p_i)} \\
&= \frac{N_{\pi^0}(p_i)}{N_{had} \cdot \triangle p} \cdot \boxed{\frac{N^{MC\ det}_{had\ with\ ISR}}{N^{MC\ det}_{\pi^0\ with\ ISR}(p_i)} \cdot \frac{N^{MC\ truth}_{had\ without\ ISR}}{N^{MC\ truth}_{\pi^0\ without\ ISR}(p_i)}} \\
&= \frac{N_{\pi^0}(p_i)}{N_{had} \cdot \triangle p} \cdot C
\end{aligned}
$$

Two methods

Typical example:
OPAL collaboration in LEP

Typical example:
Belle collaboration

Backup

OPAL collaboration :

$$\frac{1}{\sigma_{had}} \cdot \frac{d\sigma_{\pi^0}}{dp} = \frac{N_{\pi^0}(p_i)}{N_{had} \cdot \triangle p} \cdot \frac{\varepsilon_{had}}{\varepsilon_{\pi^0}(p_i)} \cdot \frac{(1+\delta)_{had}}{(1+\delta)_{\pi^0}(p_i)}$$

$$= \frac{N_{\pi^0}(p_i)}{N_{had} \cdot \triangle p} \cdot \frac{N^{MC\ det}_{had\ with\ ISR}}{N^{MC\ truth}_{had\ without\ ISR}} \cdot \frac{N^{MC\ truth}_{\pi^0\ without\ ISR}(p_i)}{N^{MC\ det}_{\pi^0\ with\ ISR}(p_i)}$$

$$= \frac{N_{\pi^0}(p_i)}{N_{had} \cdot \triangle p} \cdot \boxed{\frac{N^{MC\ det}_{had\ with\ ISR}}{N^{MC\ det}_{\pi^0\ with\ ISR}(p_i)} \cdot \frac{N^{MC\ truth}_{had\ without\ ISR}}{N^{MC\ truth}_{\pi^0\ without\ ISR}(p_i)}}$$

$$= \frac{N_{\pi^0}(p_i)}{N_{had} \cdot \triangle p} \cdot C$$

Two inclusive MC samples:
One with the ISR open and another with the ISR off

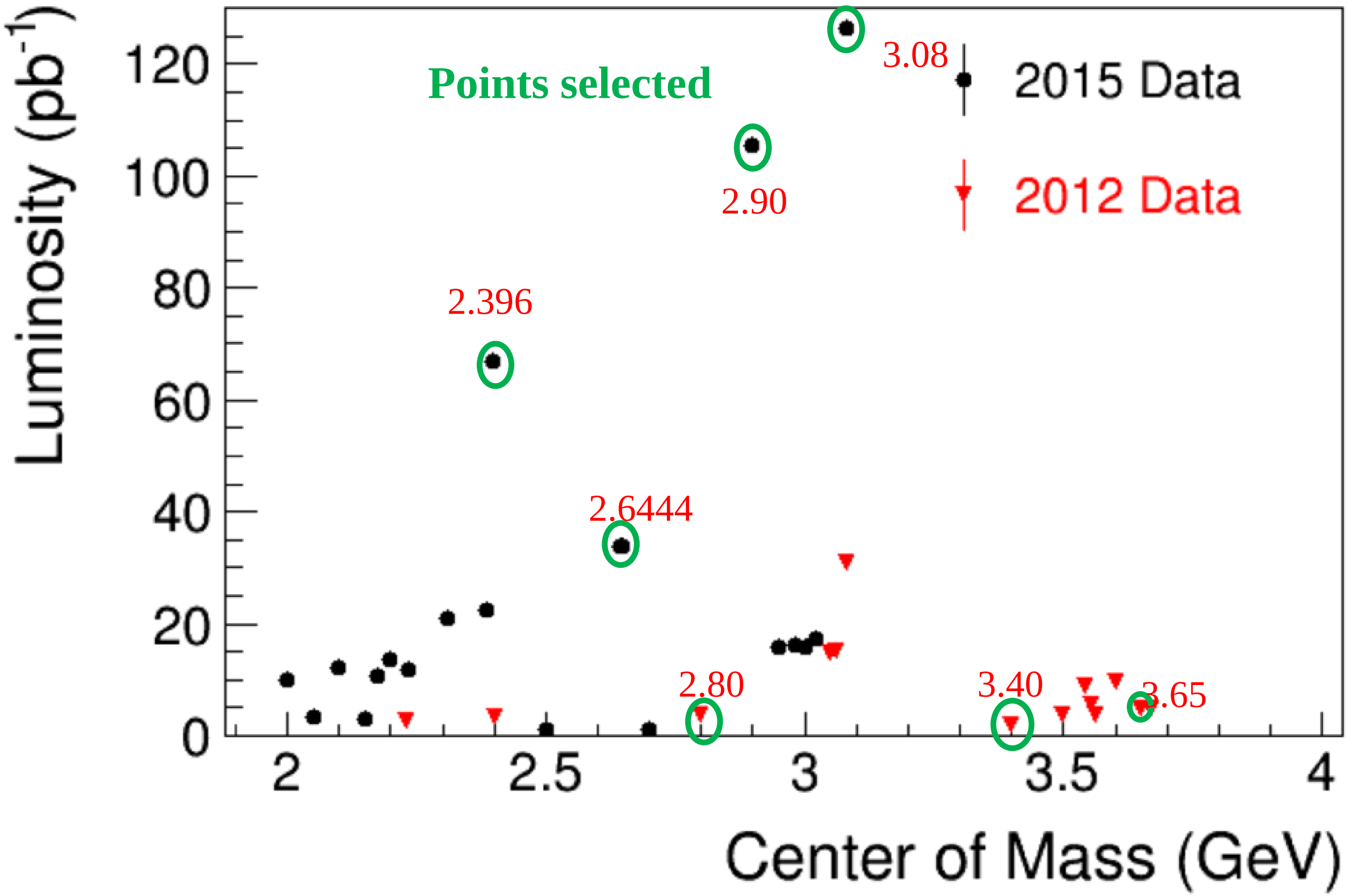
Backup

Belle collaboration:

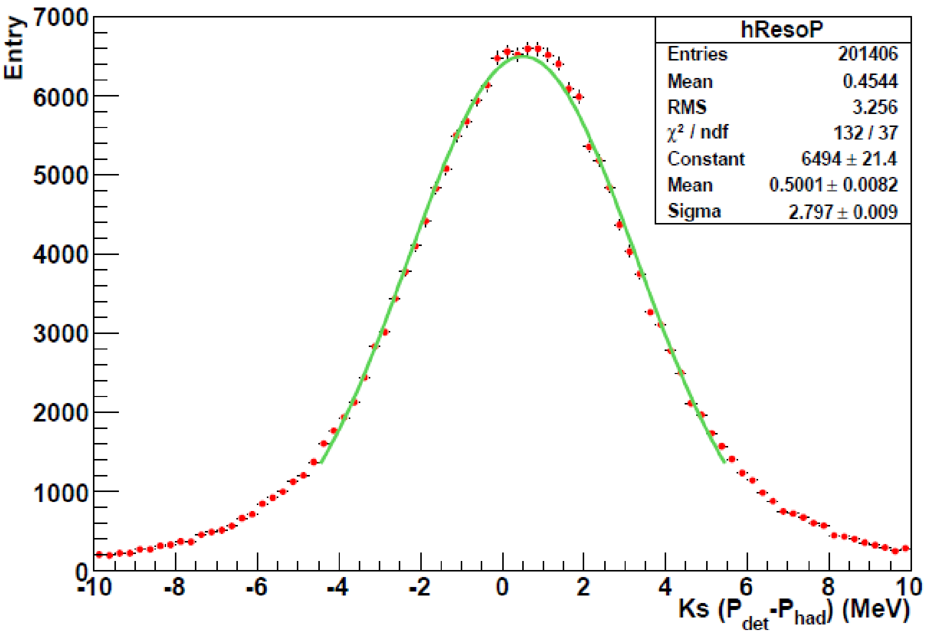
$$
\begin{aligned}
\frac{1}{\sigma_{had}}\cdot\frac{d\sigma_{\pi^0}}{dp} &= \frac{N_{\pi^0}(p_i)}{N_{had}\cdot\triangle p}\cdot\frac{\varepsilon_{had}}{\varepsilon_{\pi^0}(p_i)}\cdot\frac{(1+\delta)_{had}}{(1+\delta)_{\pi^0}(p_i)}\\
&= \frac{N_{\pi^0}(p_i)}{N_{had}\cdot\triangle p}\cdot\frac{N^{MC\ det}_{had\ with\ ISR}}{N^{MC\ truth}_{had\ without\ ISR}}\cdot\frac{N^{MC\ truth}_{\pi^0\ without\ ISR}(p_i)}{N^{MC\ det}_{\pi^0\ with\ ISR}(p_i)}\\
&= \frac{N_{\pi^0}(p_i)}{N_{had}\cdot\triangle p}\cdot\boxed{\frac{N^{MC\ det}_{had\ with\ ISR}}{N^{MC\ det}_{\pi^0\ with\ ISR}(p_i)}\cdot\frac{N^{MC\ truth}_{had\ without\ ISR}}{N^{MC\ truth}_{\pi^0\ without\ ISR}(p_i)}}\\
&= \frac{N_{\pi^0}(p_i)}{N_{had}\cdot\triangle p}\cdot C
\end{aligned}
$$

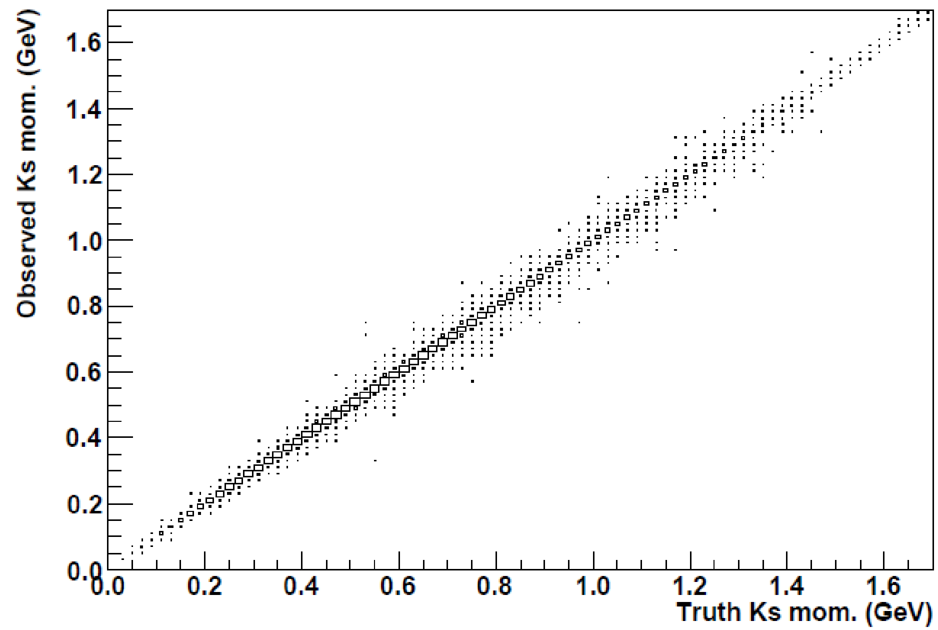
Only one inclusive MC samples:
Total isr photon with energy < 0.5%×√s / 2 : No ISR events

Luminosity of Data in 2012 and 2015



K_s: momentum resolution & binning





- Ks: momentum resolution **2.8MeV**
- Ks: momentum bin width **100MeV**

Possible cut to remove the beam-associated backgrounds:
1. angle of $\pi^+\pi^-$

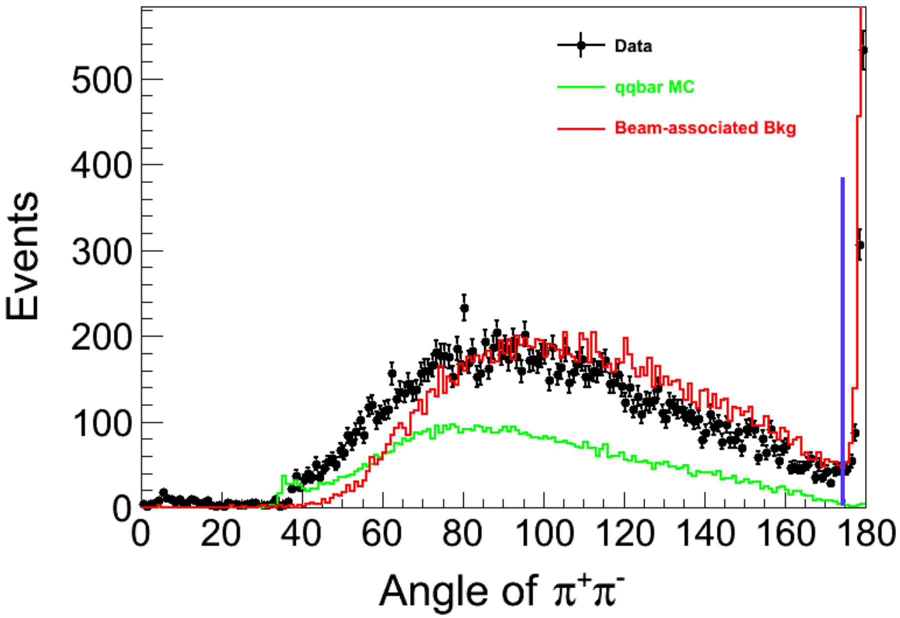
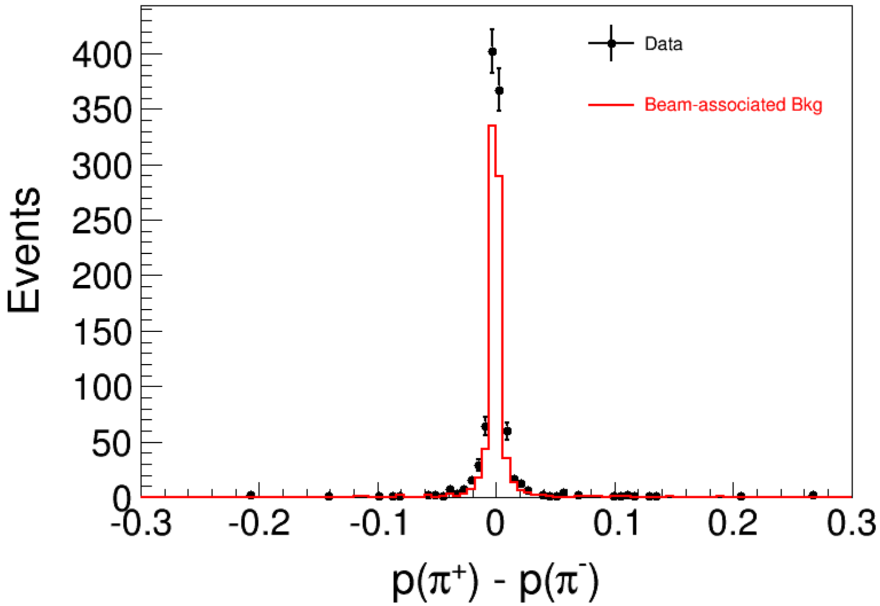


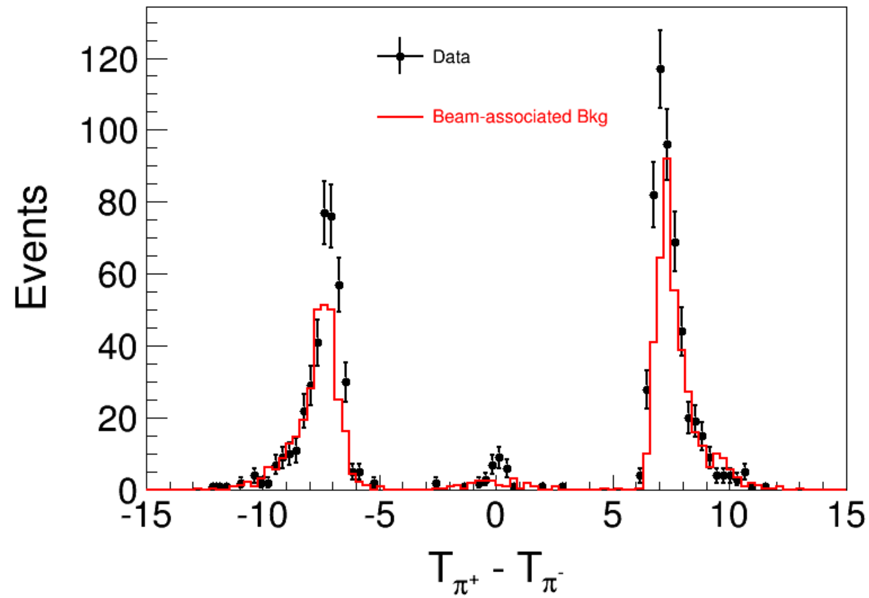
Table 11: Extracted K_S^0 events and of K_S^0 efficiency varying with momenta

p(GeV)	With angle cut		Without angle cut (method C)	
	Exp.data	$\varepsilon(K_S^0)$	Exp.data	$\varepsilon(K_S^0)$
0.0-0.1	50.3±19.8	30.3	44.7±15.2	31.2
0.1-0.2	283.8±24.3	41.3	285.6±24.3	41.3
0.2-0.3	711.2±36.5	46.3	711.0±36.4	46.3
0.3-0.4	972.9±40.5	47.9	972.7±40.6	47.9
0.4-0.5	935.4±39.8	53.6	937.3±39.8	53.6
0.5-0.6	854.6±36.9	57.3	854.8±37.0	57.3
0.6-0.7	602.5±31.1	61.4	602.7±31.1	61.4
0.7-0.8	457.8±25.9	60.4	458.1±26.0	60.4
0.8-0.9	311.3±21.1	61.0	312.6±21.2	61.0
0.9-1.0	193.1±16.5	74.8	193.6±16.5	74.8
1.0-1.1	141.1±13.4	74.4	140.7±13.3	74.4
1.1-1.2	89.9±10.5	56.9	89.2±10.5	56.9
1.2-1.3	57.6±9.1	57.9	56.2±9.2	57.9
1.3-1.4	0.0±3.5	48.6	0.0±3.4	48.6

The angle of $\pi^+\pi^-$ from K_S candidate is required to satisfy:
$\theta(\pi^+\pi^-) < 175^\circ$

Possible cut to remove the beam-associated backgrounds:



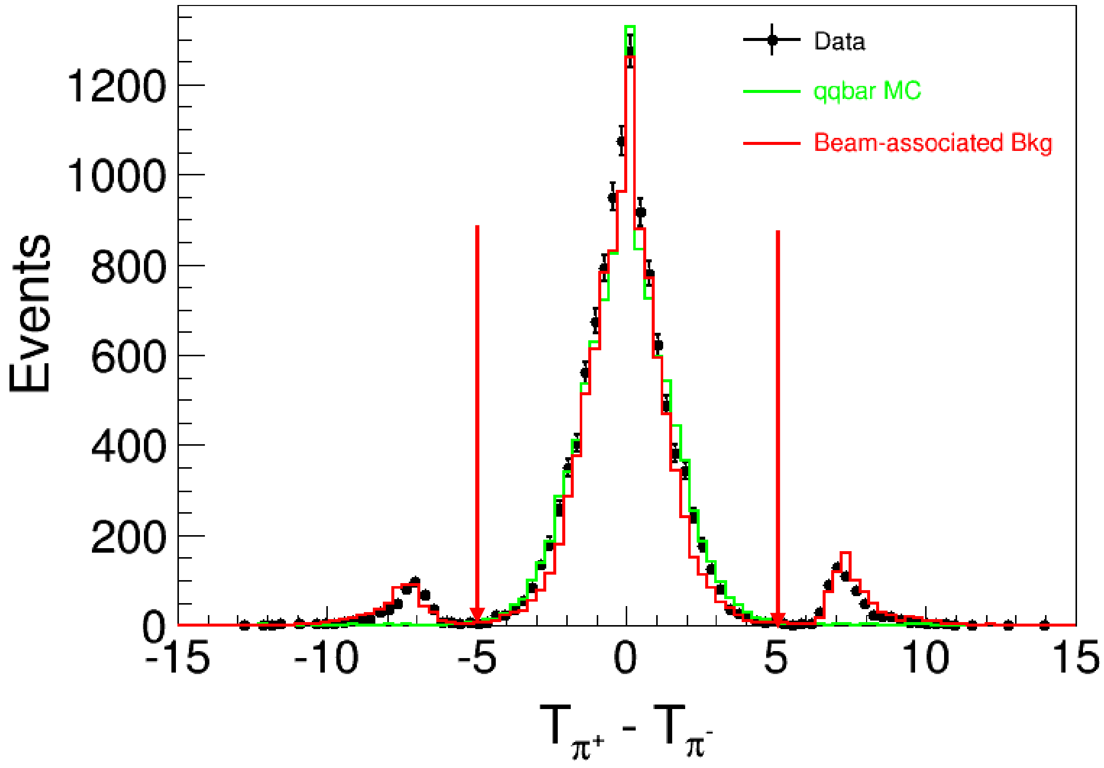


The events with angle of $\pi^+\pi^-$ smaller than 175° come from cosmic rays.

Cosmic rays (at the sea level):

Due to the cascade shower, most components are muon (~75%) and proton(~2%). And the average momentum of muon is about 4 GeV.

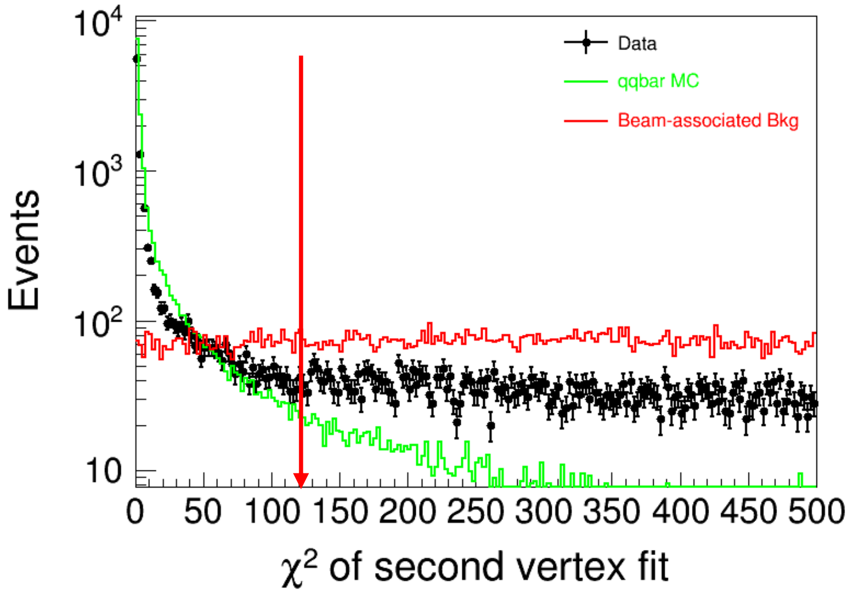
Remove the cosmic ray evets

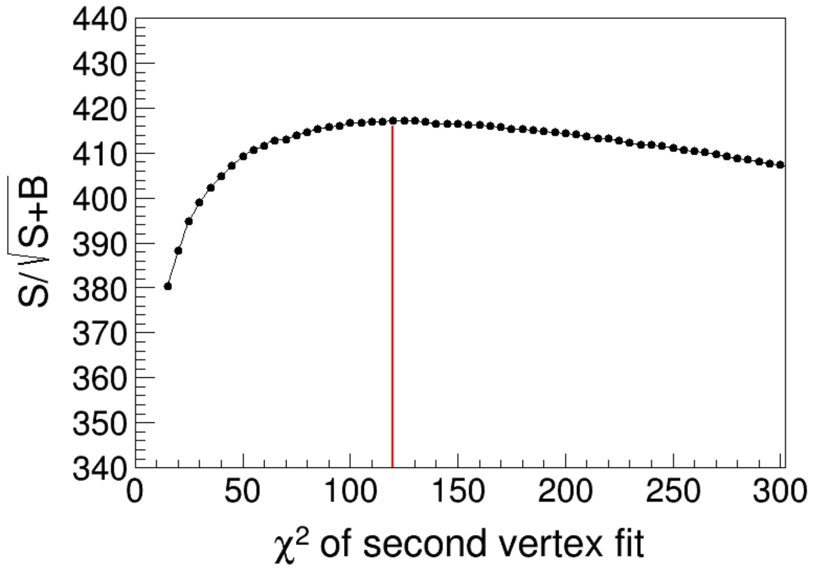


Remove the cosmic rays: $|T(\pi^+) - T(\pi^-)| < 5$

Possible cut to remove the beam-associated backgrounds:
3. Second vertex fit

After the cosmic rays cut applied:



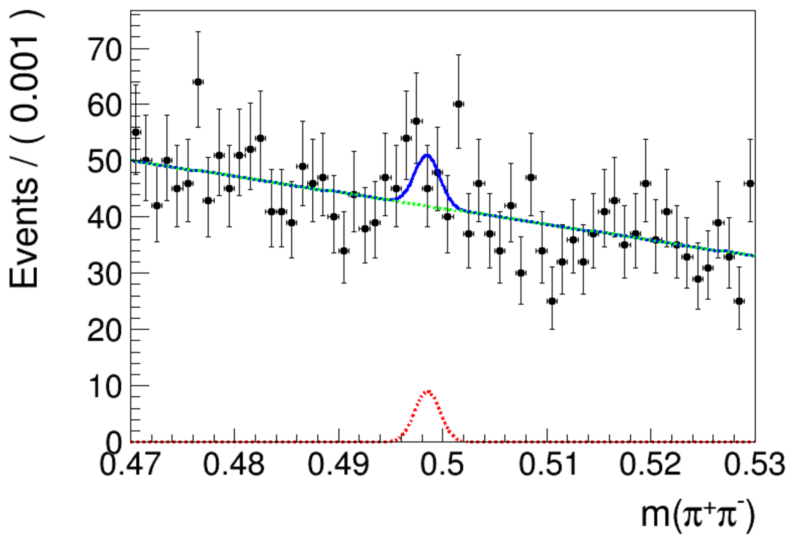


S are the qqbar MC and (S+B) are experiment data

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

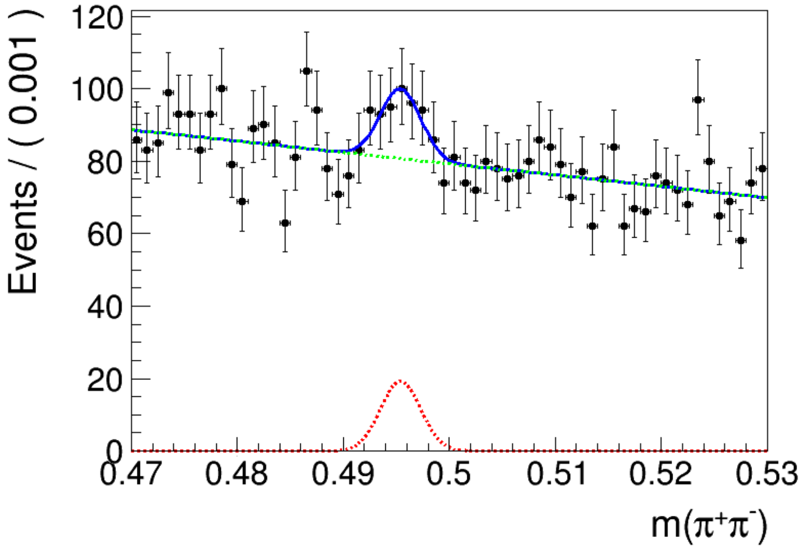
Possible cut to remove the beam-associated backgrounds: 3. Second vertex fit

After χ^2(second vertex fit) < 120 cut applied:



Non-collider data at 2.2324 GeV
Extracted Ks events: 27.5±43.3

(27.5±43.3)*0.452/5582.9
=(12.1±19.1)/5582.9
=0.2%



Non-collider data at 2.6444 GeV
Extracted Ks events: 91.3±30.2

(91.3±30.2)*0.442/5582.9
=(40.4±13.3)/5582.9
=0.7%

Explanation for the cut of second vertex fit

3.1 K_S^0 selection BAM-69m Yan Liang

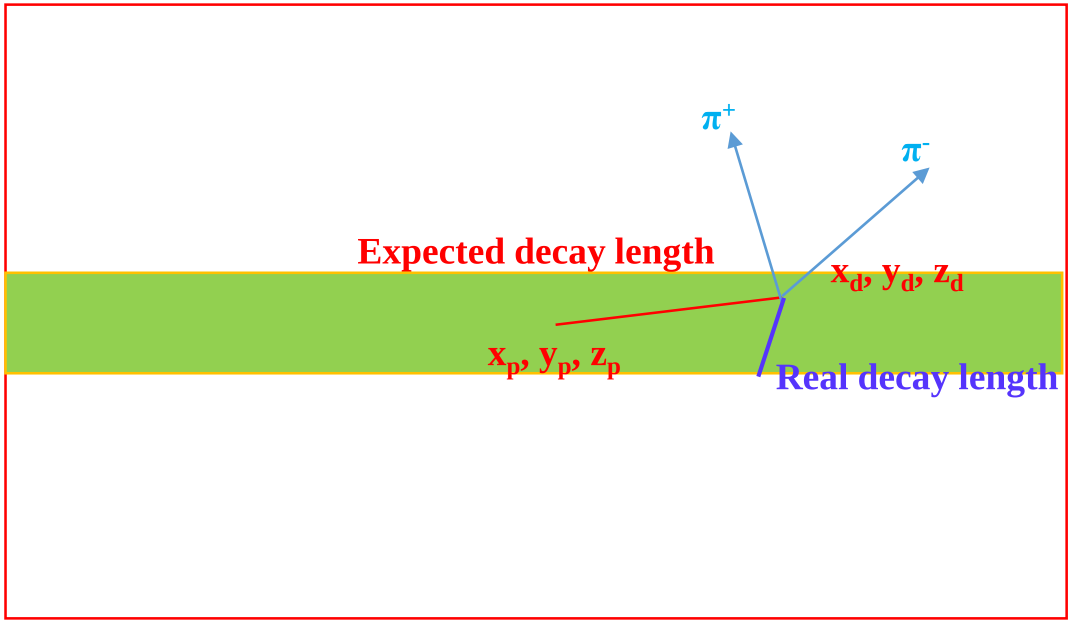
To reconstruct the K_S^0, the common vertex fit is performed for π^+, π^- pairs by looping all charged tracks. The charged particles are all assumed as pions when tagging the K_S^0. The decay point of the K_S^0 is determined by the common vertex fit. It should be located in the reasonable region where could be calculated by the K_S^0 flight direction from IP considering the error of IP. The IP is determined by averaging the event vertices in each run, where event vertices are obtained from the vertex fit on the events with at least 3 charged tracks. The above constraint between the decay point and the IP is called second vertex fit. The χ^2 of second vertex fit should be less than 20 to veto the backgrounds. Fig. 1 shows the distribution of χ^2 of second vertex fit for the signal, and this cut is safe for signal selection. Actually, the second vertex fit is the decay length fit. To reconstruct K_S^0, the K_S^0 decay point is found by the common vertex fit first. Then we require that the common vertex fit and the IP(interaction point) should be in the straight line along the K_S^0 flight direction in the decay length fit. The equations are shown blow:

$$x_p - x_d + \frac{p_x}{m} c\tau = 0,$$
$$y_p - y_d + \frac{p_y}{m} c\tau = 0,$$
$$z_p - z_d + \frac{p_z}{m} c\tau = 0.$$

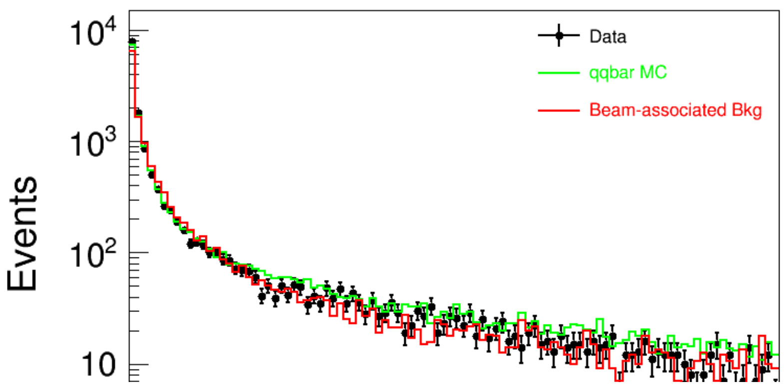
where $(x_p,\ y_p,\ z_p)$ is the IP, $(x_d,\ y_d,\ z_d)$ is the K_S^0 decay point, $(p_x,\ p_y,\ p_z)$ is the momentum of K_S^0, m is the mass of K_S^0, c is the speed of light and τ is the life time of K_S^0. It is called

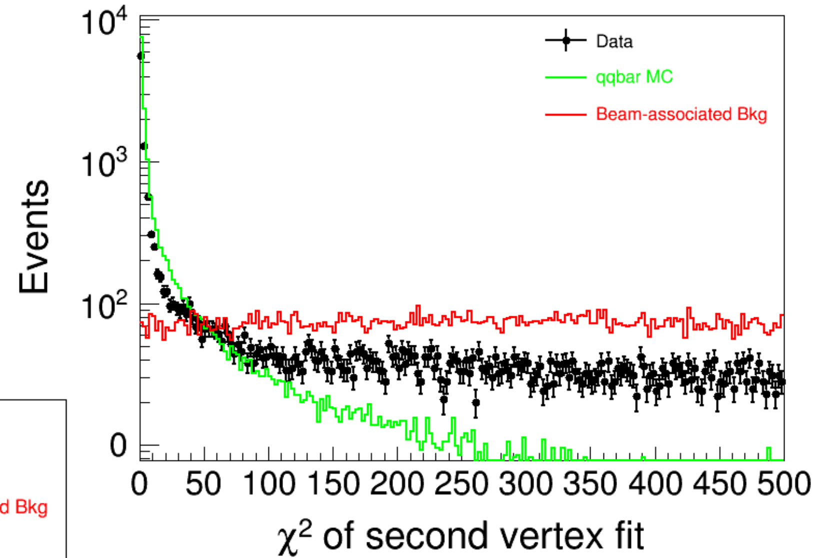
Explanation for the cut of second vertex fit

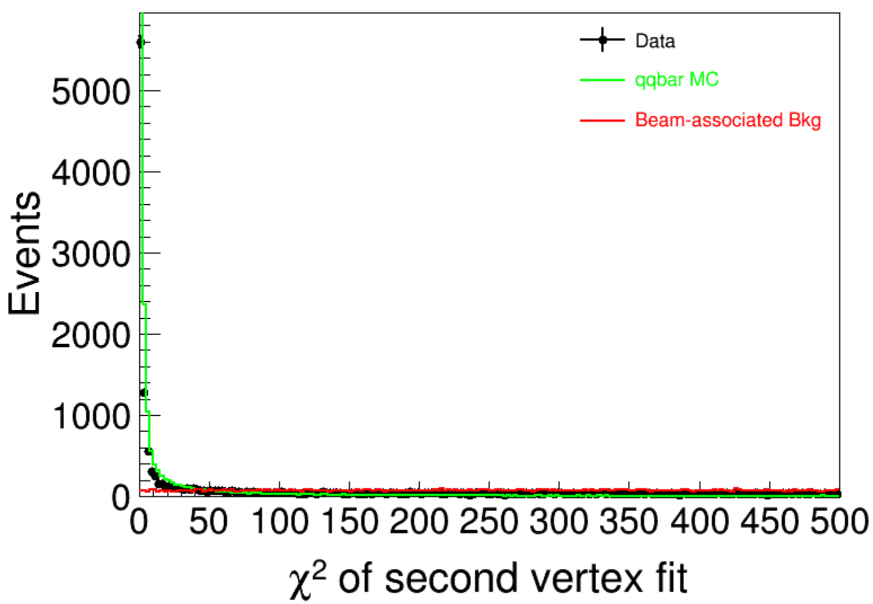
$$x_p - x_d + \frac{p_x}{m} c\tau = 0,$$
$$y_p - y_d + \frac{p_y}{m} c\tau = 0,$$
$$z_p - z_d + \frac{p_z}{m} c\tau = 0.$$



Possible cut to remove the beam-associated backgrounds:
3. Second vertex fit







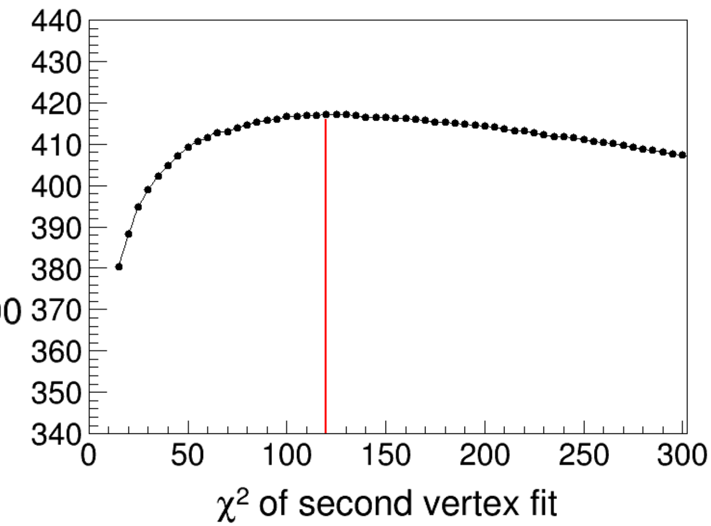
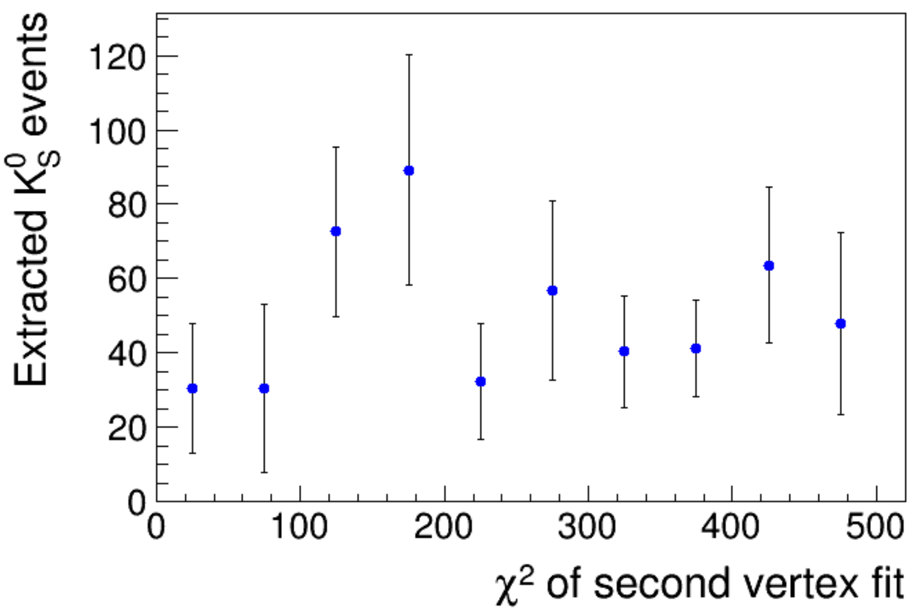


Table 13: Extracted K_S^0 events varying with momenta

p(GeV)	Before χ^2(second vertex fit)	After χ^2(second vertex fit)	Differences
0.0-0.1	50.3±19.8	26.1±8.8	-24.2
0.1-0.2	279.9±24.3	272.6±19.8	-7.3
0.2-0.3	702.6±36.2	668.4±30.3	-34.2
0.3-0.4	969.3±40.5	941.1±36.0	-28.2
0.4-0.5	934.7±39.8	939.3±35.7	4.6
0.5-0.6	853.8±36.9	861.1±34.3	7.2
0.6-0.7	601.4±31.0	609.8±29.1	8.4
0.7-0.8	456.5±25.9	463.0±24.5	6.5
0.8-0.9	310.6±21.1	319.3±20.5	8.7
0.9-1.0	193.5±16.5	191.1±15.9	-2.5
1.0-1.1	140.8±13.4	141.9±13.2	1.1
1.1-1.2	90.5±10.5	90.9±10.5	0.4
1.2-1.3	58.3±9.1	58.4±9.1	0.0
Total events	5642.3	5582.9	−59.4
Beam at 2.2324	97.2 ± 24.4	12.1±19.1	−85.1
Beam at 2.6444	202.4± 32.7	40.4±13.3	−162.0

Table 14: Extracted K_S^0 efficiency varying with momenta (%)

p(GeV)	ε before χ^2 cut	ε after χ^2 cut	Differences
0.0-0.1	30.9	30.7	-0.1
0.1-0.2	41.1	41.0	-0.2
0.2-0.3	46.0	45.9	-0.1
0.3-0.4	47.5	47.7	0.2
0.4-0.5	53.0	53.0	-0.0
0.5-0.6	56.9	57.1	0.2
0.6-0.7	61.1	60.7	-0.4
0.7-0.8	59.8	59.8	-0.0
0.8-0.9	60.7	60.4	-0.4
0.9-1.0	74.6	74.5	-0.1
1.0-1.1	73.9	74.4	0.4
1.1-1.2	56.7	57.1	0.4
1.2-1.3	57.6	57.6	-0.0



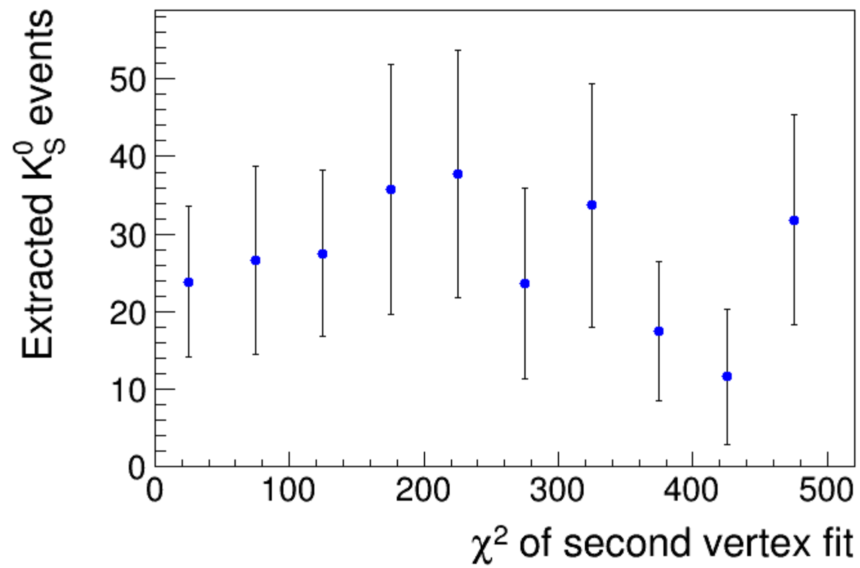


Table 14: Extracted K_S^0 efficiency varying with momenta (%)

Momentum (GeV)	$\chi^2(Beam) > 120$	$\chi^2(Beam) < 120$	ratio ratio	$\chi^2(Data) > 120$	Estimated $\chi^2(Data) < 120$	uncertainty
0.0-0.1	26.6	15.4	0.6	9.1	5.2	20.1
0.1-0.2	66.2	50.7	0.8	16.5	12.6	4.6
0.2-0.3	124.6	39.9	0.3	32.3	10.4	1.5
0.3-0.4	182.2	52.6	0.3	38.6	11.2	1.2
0.4-0.5	55.6	25.1	0.5	14.1	6.4	0.7
0.5-0.6	84.3	12.5	0.1	11.1	1.6	0.2
0.6-0.7	15.6	7.1	0.5	4.4	2.0	0.3

Beam associated background

Momentum (GeV)	$\chi^2(Beam)$ > 120	$\chi^2(Beam)$ < 120	ratio ratio	$\chi^2(Data)$ > 120	Estimated $\chi^2(Data)$ < 120	uncertainty
0.0-0.1	26.6	15.4	0.6	9.1	5.2	20.1
0.1-0.2	66.2	50.7	0.8	16.5	12.6	4.6
0.2-0.3	124.6	39.9	0.3	32.3	10.4	1.5
0.3-0.4	182.2	52.6	0.3	38.6	11.2	1.2
0.4-0.5	55.6	25.1	0.5	14.1	6.4	0.7
0.5-0.6	84.3	12.5	0.1	11.1	1.6	0.2
0.6-0.7	15.6	7.1	0.5	4.4	2.0	0.3

Ks uncertainty

p(GeV)	Hadron event	Hadron track	Beam associated	χ^2 < 120	$\lvert T_{\pi^+} - T_{\pi^-}\rvert$ < 5	K_S^0 Reconst	2^{nd} Poly	Double Gaussians	PID	Total
0.0-0.1	0.1	2.2	20.1	5.3	7.8	6.7	11.5	24.1	2.0	35.5
0.1-0.2	0.1	2.2	4.6	1.6	0.6	5.0	2.8	0.0	2.0	8.2
0.2-0.3	0.1	2.2	1.5	1.3	0.3	3.4	4.8	0.0	2.0	6.9
0.3-0.4	0.1	2.2	1.2	0.6	0.4	1.7	3.8	0.0	2.0	5.3
0.4-0.5	0.1	2.2	0.7	0.6	0.3	0.9	2.7	0.0	2.0	4.3
0.5-0.6	0.1	2.2	0.2	0.8	0.3	0.9	3.0	0.0	2.0	4.4
0.6-0.7	0.1	2.2	0.3	0.3	0.2	0.9	3.5	0.0	2.0	4.7
0.7-0.8	0.1	2.2	0.0	0.3	0.7	0.9	2.0	0.0	2.0	3.8
0.8-0.9	0.1	2.2	0.0	0.0	0.9	0.9	2.1	0.0	2.0	3.9
0.9-1.0	0.1	2.2	0.0	0.7	0.5	0.9	4.3	0.7	2.0	5.5
1.0-1.1	0.1	2.2	0.0	0.2	0.1	0.9	3.0	0.0	2.0	4.3
1.1-1.2	0.1	2.2	0.0	0.8	0.8	0.9	2.3	0.0	2.0	4.1
1.2-1.3	0.1	2.2	0.0	0.2	0.6	0.9	3.3	0.0	2.0	4.6