Summary of systematic uncertainty

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Outline

- PID Efficiency of $K^{\pm}$
- Tracking Efficiency of $K^{\pm}$
- Photon Efficiency
- Kinematic Fit

PID Efficiency: Data set and MC samples

Control sample: $J/\psi \to K_s^0 K^\mp \pi^\pm \to \pi^+ \pi^- K^\mp \pi^\pm$

Data sets:

- 2018, 2019 J/ψ data.

Boss Version:

- 708

MC samples:

- 2019 inclusive MC
- 2018, 2019 DIY signal MC

PID Efficiency: Event selection

Good charged tracks:

- $|cos\theta| < 0.93$
- N_{Good} =4, $\sum Q_{track} = 0$

Vertex Fit:

- Using the second vertex fit to reconstruct K_s^0
- Retain the combination with the mass closest to K_s^0.
- $L/\sigma_L > 2$
- $|M_{\pi^+\pi^-} - K_s^0| < 10$ MeV

PID:

- Tracks from K_s^0 and the π from J/ψ: $\mathcal{P}_\pi > \mathcal{P}_K \&\& \mathcal{P}_\pi > \mathcal{P}_K$

Kinematic Fit:

- K_s^0, $\pi^\pm$ and $K^\mp$ are used to do the 4c kinematic fit: $\chi^2_{4c} < 40$.
- Exchanging K and π and getting χ^2_{Exc}. $\chi^2_{4c} < \chi^2_{Exc}$.

PID Efficiency: Event selection

Further Selection:

- $|V_z| < 20$ cm, $V_r < 5$ cm for the tracks from K_s^0
- $|V_z| < 10$ cm, $V_r < 1$ cm for the tracks from J/ψ

Then identify Kaon as the nominal $e^+e^- \to K^+K^-\gamma_{\text{ISR}}$ selection:

PID strategy:

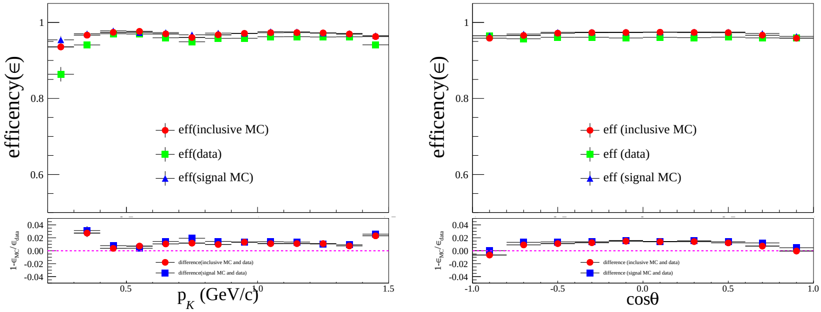
- $\mathcal{P}_p > \mathcal{P}_K \&\& \mathcal{P}_K > 0.0001$

The event number got without identifying the Kaon is N_1 and that passing the Kaon identification is N_2. The PID efficiency is:

$$\epsilon = N_2/N_1, \text{ and the error is } \sigma_\epsilon = \sqrt{\frac{\epsilon(1-\epsilon)}{N_1}}$$

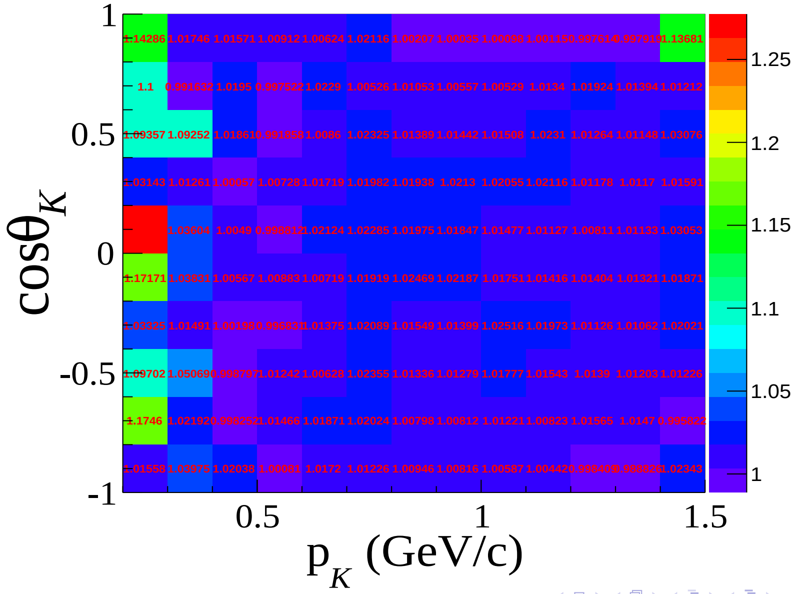
The signal purity is more than 99%, nearly background free.

PID Efficiency: 1D efficiency

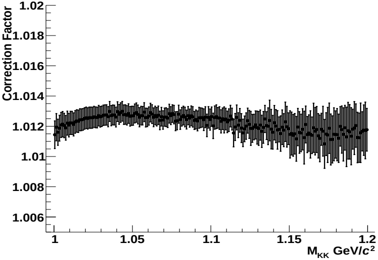


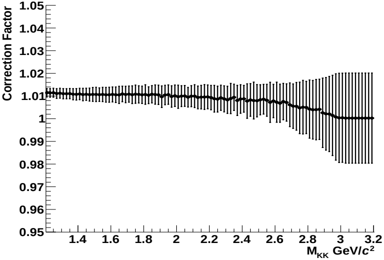
- Good agreement between data and MC except the region at the low energy which doesn't matter in this work.

PID Efficiency: Correction factor (2D)



PID Efficiency: Correction factor varies with M_{KK}

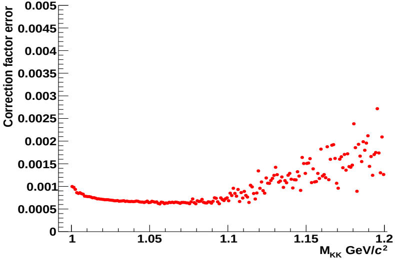


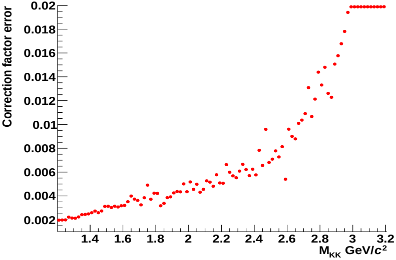


How to get the Correction factor varying with M_{KK}:

- For each event, get the correction factor of it in the corresponding bin in the $cos\theta_{K^+}$ and p_{K^+} 2D distribution and fill the histogram weighted by the correction factor.
- Then calculate the ratio of each M_{KK} between the corrected one and the original one and get this bin's correction factor.
- Varying the 2D correction factor by a gauss distribution with mean=correction factor and uncertainty=bin error. Using the new correction factors to do the same thing. Repeating this for 10000 times.
- Using a gauss function to fit the weight factor in each M_{KK} bin and get the uncertainty of it.

PID Efficiency: Systematic uncertainties of PID efficiency





- We take the uncertainty of the weight factor as the systematic uncertainties. Below the 1.2 GeV/c^2 the systematic uncertainty is taken as 0.08% for one track. From 1.2 to 2.6 GeV/c^2, the systematic uncertainty is taken as 0.6% for one track. Above 2.6 GeV/c^2, the systematic uncertainty is taken as 1%

Tracking Efficiency: Event selection

Good charged tracks:

- $|cos\theta| < 0.93$
- N_{Good} =3, $\sum Q_{track} = \pm 1$ for tagging $K^{\pm}$. N_{Good} =4, $\sum Q_{track} = 0$

Vertex Fit:

- Using the second vertex fit to reconstruct K_s^0
- Retain the combination with the mass closest to K_s^0.
- $L/\sigma_L > 2$
- $|M_{\pi^+\pi^-} - K_s^0| < 10$ MeV

PID:

- Tracks from K_s^0 and the π from J/ψ: $\mathcal{P}_\pi > \mathcal{P}_K \&\& \mathcal{P}_\pi > \mathcal{P}_K$

Kinematic Fit:

- Missing K and doing 1c kinematic fit: $\chi^2_{1c} < 5$.
- $|cos\theta_{fit}| < 0.93$
- Exchanging K and π and getting χ^2_{Exc}. $\chi^2_{1c} < \chi^2_{Exc}$.

Tracking Efficiency: Event selection

Further Selection:

- For the events with $N_{Good} = 4$, **the angle between the reconstructed Kaon track and the recoiled track should be smaller than** 2°.
- $|V_z| < 20$ cm, $V_r < 5$ cm for the tracks from K_s^0
- $|V_z| < 10$ cm, $V_r < 1$ cm for the tracks from J/ψ

Then tracking the Kaon as the nominal $e^+e^- \to K^+K^-\gamma_{\text{ISR}}$ selection:

Tracking method:

- $|cos\theta| < 0.93$
- $|V_z| < 10$ cm, $V_r < 1$ cm
- E/p< 0.8, here E is the deposited energy in EMC.

The event number got without tracking the Kaon is N_1 and that after tracking Kaon is N_2. The tracking efficiency is:

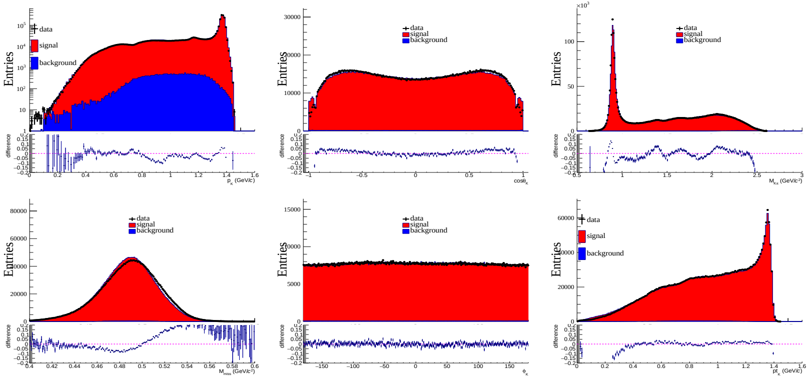
$$\epsilon = N_2/N_1, \text{ and the error is } \sigma_\epsilon = \sqrt{\frac{\epsilon(1-\epsilon)}{N_1}}$$

Tracking Efficiency: Comparison of different selections

Selection criteria	background ratio	Signal lost	N_{signal}
Original selection	5.5%		4212687
$\chi^2_{1c} < \chi^2_{Exc}$	4.5%	7.4%	3979619
$\chi^2_{1c} < \chi^2_{Exc} \&\& matchangle < 2$	2.5%	16.9%	3855789
$\chi^2_{1c} < \chi^2_{Exc} \&\& matchangle < 2 \&\& N_\gamma < 2$	1.0%	41.0%	2742770

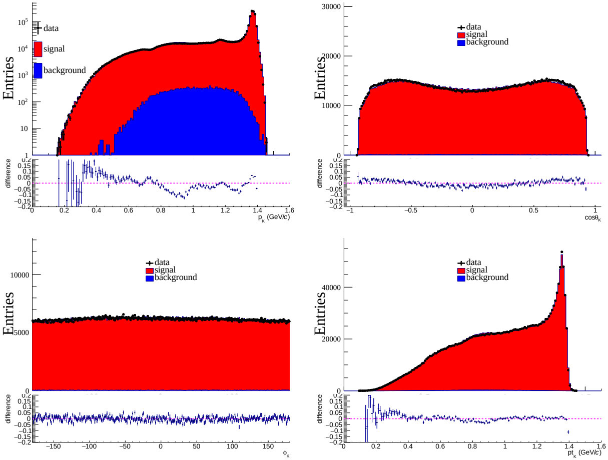
- More cuts to suppress the background. The photon is tagged by the nominal good photon selection except that the open angle should be smaller than 10.
- The last cut is chosen for now, since we need to minimize the impact of background description as much as possible.

Tracking Efficiency: Comparison between MC and data (missing)



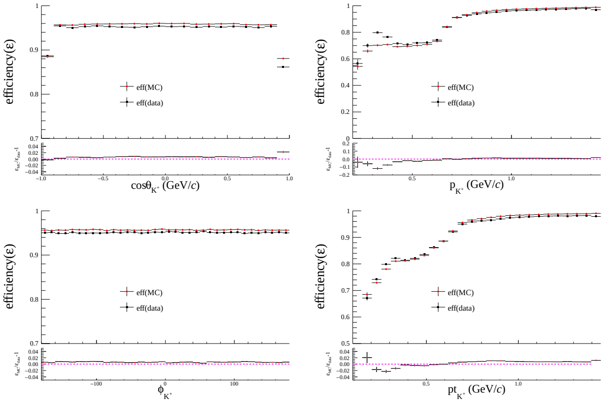
- The signal MC is the DIYMC and the background is got by the inclusive MC. The total event of MC is scaled to data. And the background MC is scaled by the statistics of data.
- The combined MC can described the data well.

Tracking Efficiency: Comparison between MC and data (reconstructed)



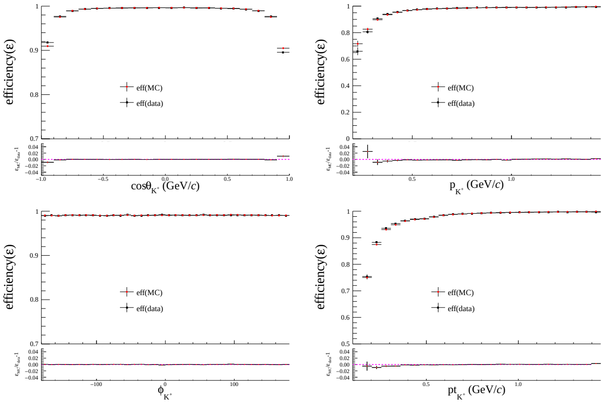
- Situation is similar to the missing.

Tracking Efficiency: 1D efficiency



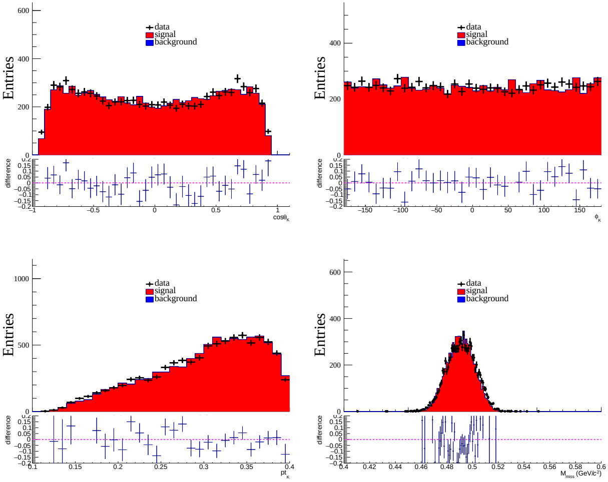
- Great agreement between data and MC near 1 GeV. However the efficiency of data jumps near $p_{K^+} = 0.3$ GeV/c.
- There is an enhancement from $p_{K^+} = 0.6$ GeV/c to $p_{K^+} = 0.8$ GeV/c
- The background has been subtracted from data .

Tracking Efficiency: 1D efficiency



- This is the tracking efficiency without the E/p requirement.
- The "stair" structure is caused by the E/p cut which is caused by the improvement of transverse momentum.

Tracking Efficiency: Check for some distributions near $p_{K^+} = 0.3\text{GeV}/c$.



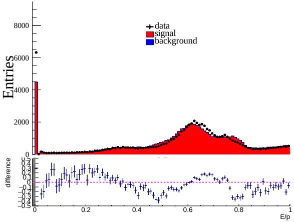
- The MC matches the data well in this momentum bin.

Tracking Efficiency: Check for the efficiency near $p_{K^+} = 0.3\text{GeV}/c$.

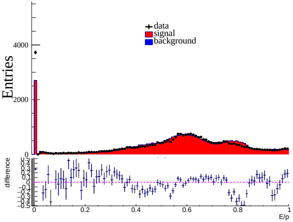
region	type	eff(no E/p)	eff(with E/p)	eff(E/p not 0)
$0.3\,\text{GeV}/c < p < 0.4\,\text{GeV}/c$	Signal MC	95.76%	68.54%	53.10%
$0.3\,\text{GeV}/c < p < 0.4\,\text{GeV}/c$	Data	95.59%	76.62%	55.14%
$0.4\,\text{GeV}/c < p < 0.5\,\text{GeV}/c$	Signal MC	96.40%	72.12%	63.13%
$0.4\,\text{GeV}/c < p < 0.5\,\text{GeV}/c$	Data	96.47%	73.69%	61.68%
$0.5\,\text{GeV}/c < p < 0.6\,\text{GeV}/c$	Signal MC	96.02%	76.98%	65.79%
$0.5\,\text{GeV}/c < p < 0.6\,\text{GeV}/c$	Data	96.54%	78.02%	64.82%
$0.6\,\text{GeV}/c < p < 0.7\,\text{GeV}/c$	Signal MC	95.50%	85.09%	72.57%
$0.6\,\text{GeV}/c < p < 0.7\,\text{GeV}/c$	Data	95.03%	84.14%	69.62%

- efficiency(no E/p): the tracking efficiency without E/p requirement
- efficiency(with E/p): nominal tracking efficiency
- efficiency(E/p not 0): the tracking efficiency requiring $0 <$E/p < 0.8
- The jump of data is mainly caused by the E/p ratio cut and in fact caused by the E/p=0 tracks.

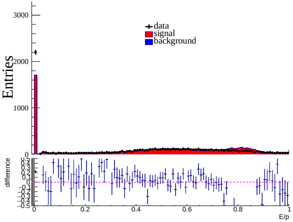
Tracking Efficiency: Check for E/p distributions.



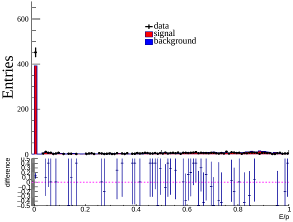
$0.5\,\mathrm{GeV}/c < p < 0.6\,\mathrm{GeV}/c$



$0.4\,\mathrm{GeV}/c < p < 0.5\,\mathrm{GeV}/c$



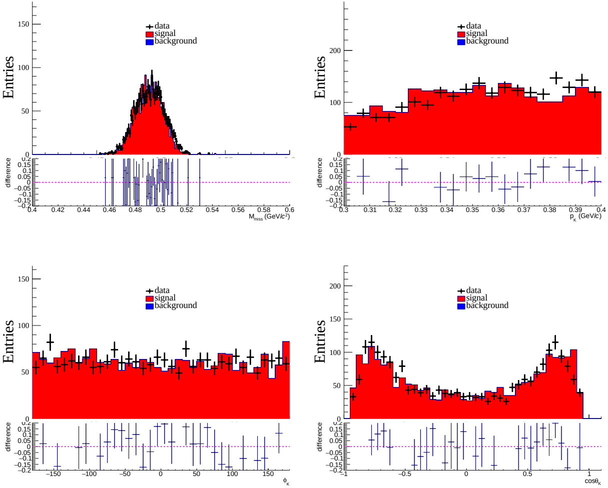
$0.3\,\mathrm{GeV}/c < p < 0.4\,\mathrm{GeV}/c$



$0.2\,\mathrm{GeV}/c < p < 0.3\,\mathrm{GeV}/c$

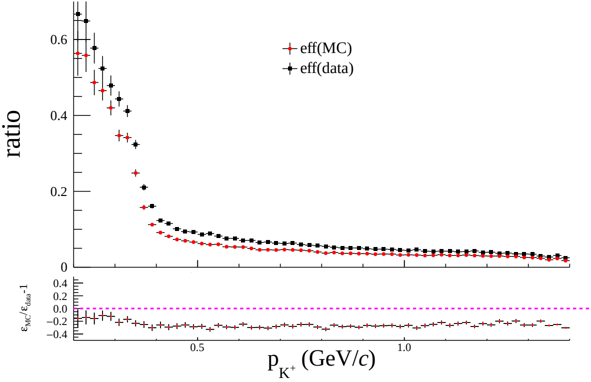
- Distributions of E/p events of different momentum bins.

Tracking Efficiency: Check for E/p=0 events.



- Some distributions of E/p=0 events at the region $0.3\mathrm{GeV}/c < p < 0.4\mathrm{GeV}/c$.

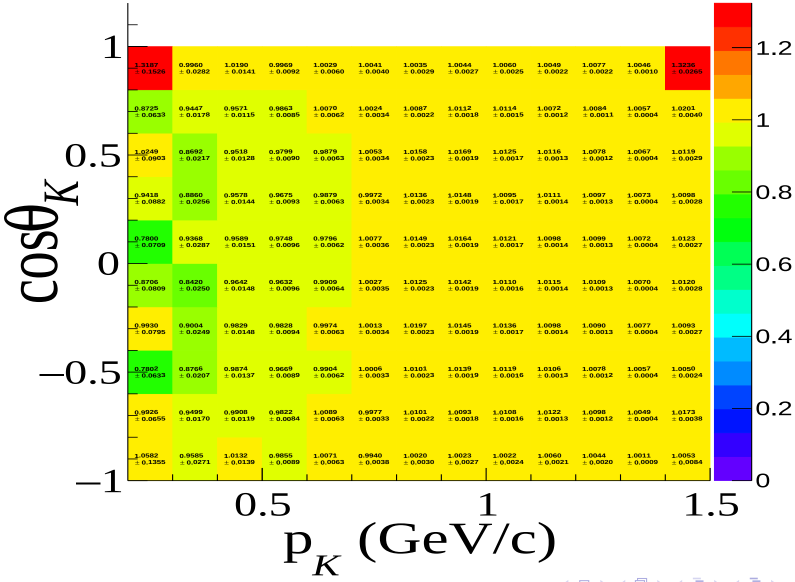
Tracking Efficiency: Check for E/p=0 events.



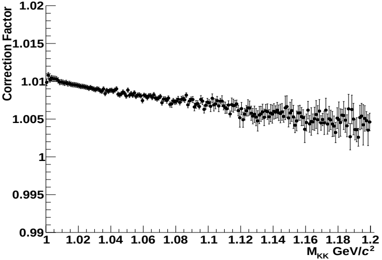
ratio of E/p=0 events varies with momentum

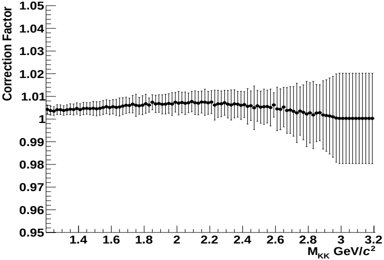
- It seems that the absolute difference of the ratio is larger near 0.3 GeV/c.

Tracking Efficiency: weight factor (2D)



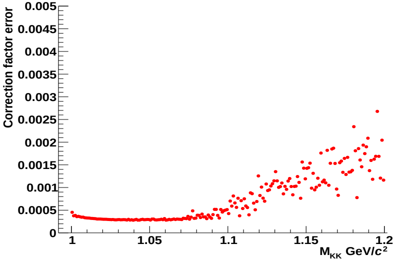
weight factor varies with M_{KK}

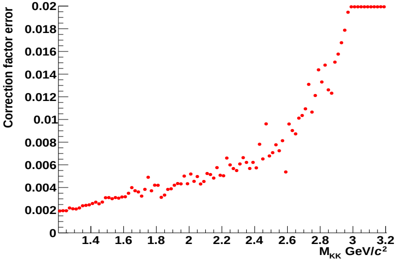




- The method is same as before.

Tracking Efficiency: Systematic uncertainties of tracking efficiency





- Below the 1.2 GeV/c^2 the systematic uncertainty is taken as 0.1%. From 1.2 to 2.6 GeV/c^2, the systematic uncertainty is taken as 0.6%. Above 2.6 GeV/c^2, the systematic uncertainty is taken as 1%

Photon Efficiency: Data set and MC samples

Data sets:

- 4180 data at BOSS 703 for now.

MC samples:

- $e^+e^- \to (\gamma_{\text{ISR}})\mu^+\mu^-$ with PHOKHARA(ISR,FSR, J/ψopen), 10M$\sim$1.119X.
- $e^+e^- \to (\gamma_{\text{ISR}})\pi^+\pi^-$ with PHOKHARA, 10M$\sim$3.125X.
- $e^+e^- \to$ hadrons with HYBRID, 80M$\sim$1X.
- $e^+e^- \to (\gamma_{\text{ISR}})e^+e^-$ with BABAYAGA NLO, 541M$\sim$0.4X.
- $e^+e^- \to (\gamma_{\text{ISR}})\tau^+\tau^-$ with KKMC, 11M$\sim$1X.
- $e^+e^- \to e^+e^-X$ with BESTWOGAM, 5.4M$\sim$1X.

Photon Efficiency: Event selection

Good charged tracks:

- $|V_z| < 10$ cm, $V_r < 1$ cm and $|cos\theta| < 0.93$
- $E_{deposited}/p$ <0.5, $E_{deposited}$ is the deposited energy of charge track
- $p/E_{beam} < 0.95$, E_{beam} is the beam energy
- The depth of at least one track should be larger than 35 cm
- N_{Good} =2, $\sum Q_{track} = 0$

Vertex Fit:

- Successful vertex fit for the two charge tracks

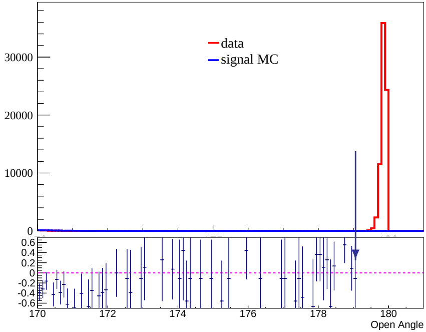
Kinematic Fit:

- Successful 1c kinematic fit, χ^2_{1c} <10
- $|cos\theta_\gamma| < 0.93$

Photon Efficiency: Event selection

Further Selection:

- From figure, it can be seen the open angle between the two charge tracks of the cosmic ray background is nearly π. A cut of open angle should be smaller than 179 degree can also be used to select the control sample.



The openangle distribution of data and signalMC

Photon Efficiency: Event selection

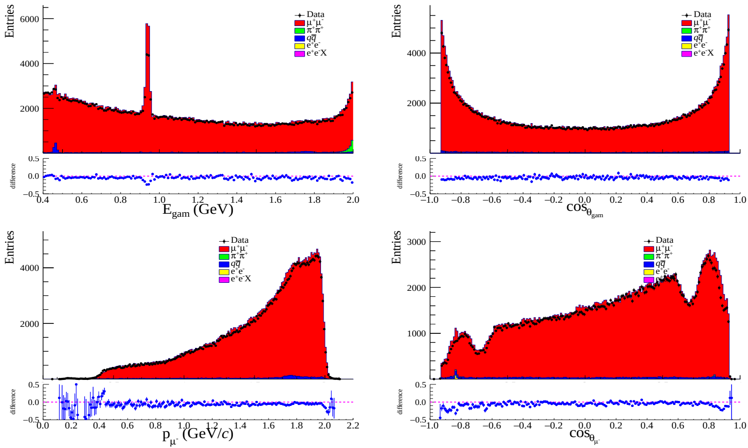
Tag ISR photon:

- EMC time:$0 < t < 700$ ns, $|cos\theta_\gamma| < 0.8$ for the barrel and $0.86 < |cos\theta_\gamma| < 0.92$ for the endcap
- Angle from the nearest charge should be larger than 20 degree.
- The photon with the largest energy is regarded as the nominal ISR photon, and its energy should be larger than 0.4 GeV.
- Using the nominal ISR photon and two charge tracks selected before to do the 4C kinematic and the require $\chi^2 < 50$ same as ISRKK's selection.

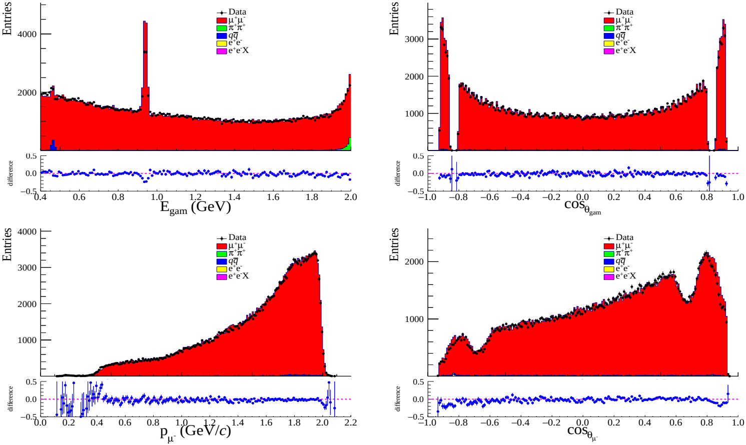
The event number got without tagging the ISR photon is N1 and the event number after tagging ISR photon is N2. The photon efficiency (also including the kinematic fit) is:

$$\epsilon = N2/N1, \text{ and the error is } err_\epsilon = \sqrt{\frac{\epsilon(1-\epsilon)}{N_1}}$$

Photon Efficiency: Comparisons without tagging photon



Photon Efficiency: Comparisons after tagging photon

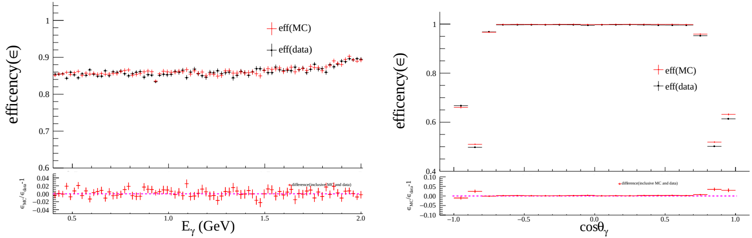


Selection Result

Data/MC sample	N_{gen}	N_{sur}	L_{int}	σ_{obv}	scale factor	N_{sur_scale}
Data		275972	3194500	1	1	275972
$\mu^+\mu^-$	1000000	317913	3194500	2.7974	0.8936	284087
$\pi^+\pi^-$	1000000	4675	3194500	1.00	0.32	1496
hadron	8000000	4303	3194500	24.08	1.01	4346
eeX	5431500	8	3194500	1.70	1.00	8
e^+e^-	271000000	37	3194500	424	4.99	185

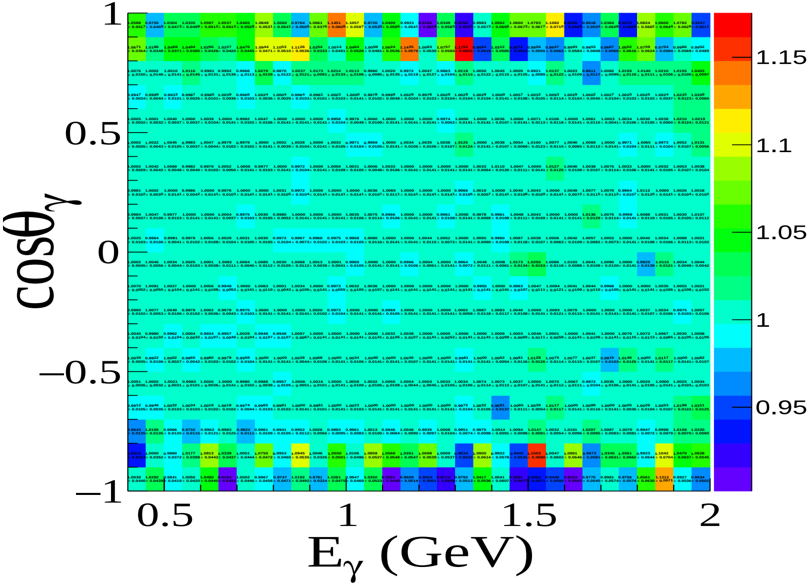
- Signal fraction is about 97.92%.

Photon Efficiency: 1D efficiency

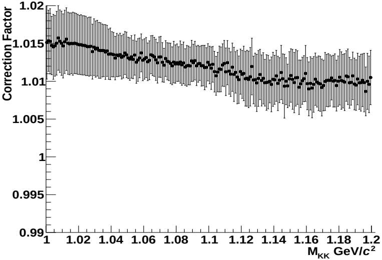


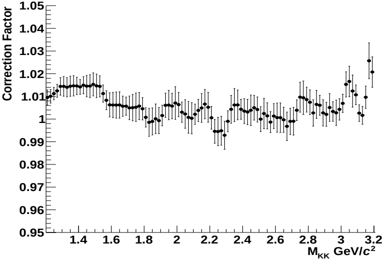
- The two efficiencies of data and MC are nearly same.
- Here the $\pi^+\pi^-\gamma_{\rm ISR}$ is treated as signal since the behavior of $\gamma_{\rm ISR}$ of these two samples are nearly same.

Photon Efficiency: weight factor(2D)



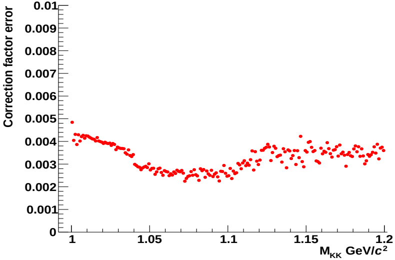
Photon Efficiency: weight factor varies with M_{KK}

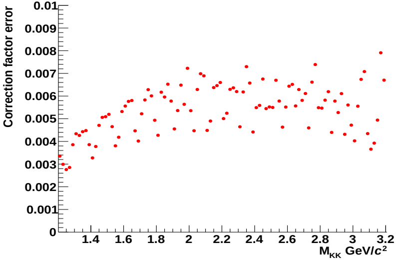




- The method is same as before.

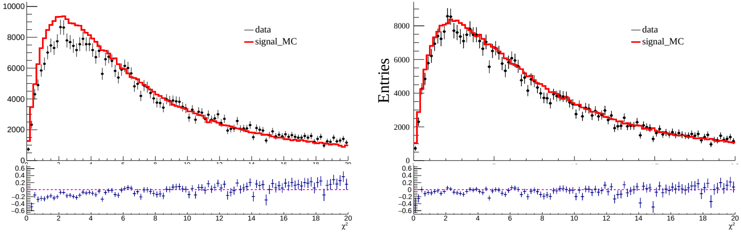
Photon Efficiency: Systematic uncertainties of photon efficiency





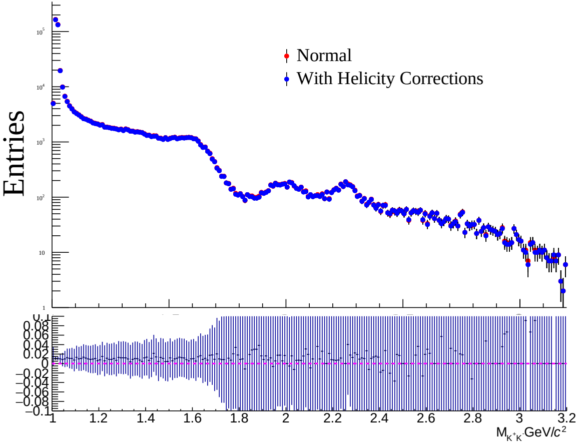
- Below the 1.2 GeV/c^2 the systematic uncertainty is taken as 0.4%. Above 1.2 GeV/c^2, the systematic uncertainty is taken as 0.8%.

Kinematic Fit: Comparison of χ^2_{4C}



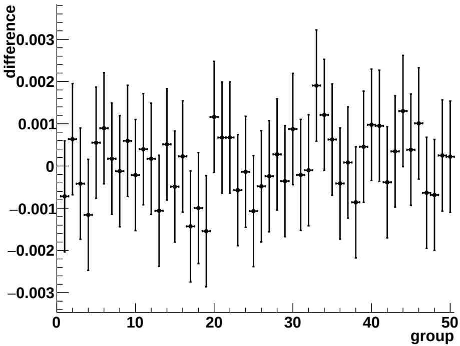
- The correction factor is given by the XYZ data group using the control sample $e^+e^- \to K^+K^-\pi^+\pi^-$ in 4.26 GeV.
- The distributions of χ^2_{4C} of data and MC become much closer to each other after corrections.

Kinematic Fit: Systematic uncertainties



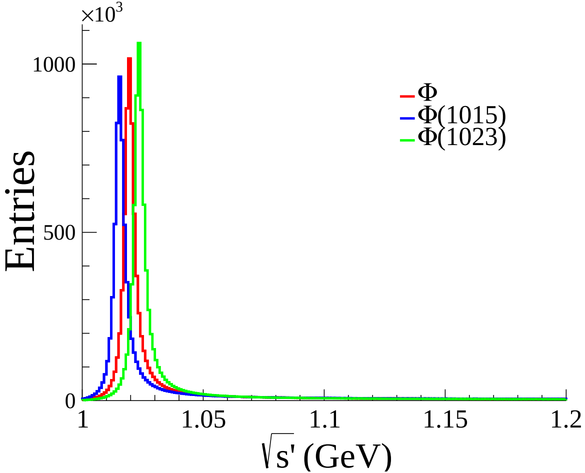
- Taking half of the difference between the signal MC as the systematic uncertainty.
- Systematic uncertainty is estimated to about 0.5% by taking the overall difference

Unfolding: Systematic uncertainties



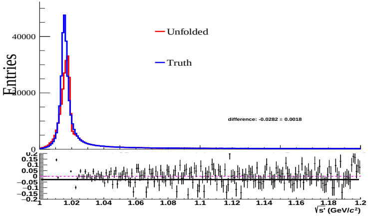
- Changing the event number of each bin into a Gauss random number with mean=event number and error=bin error. Unfolding the new pseudo-data with the original response matrix. Repeating this 50 times.
- Fitting the difference by a constant. The largest difference is about 0.2% so the systematic uncertainty is estimated by 0.2%.

Unfolding: Systematic uncertainties

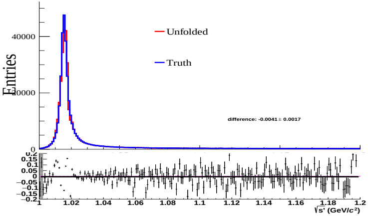


- Changing the position of ϕ peak by 1 width and unfolding by the original response matrix.

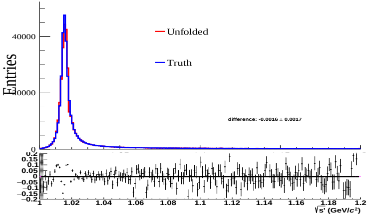
Unfolding: Systematic uncertainties



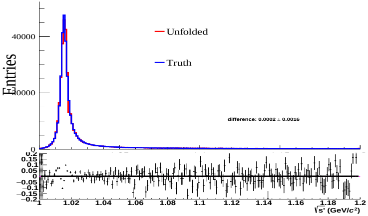
k_{reg}=20



k_{reg}=40



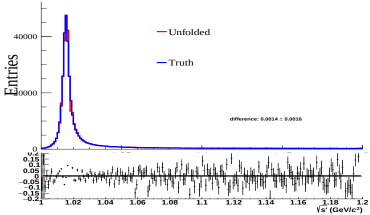
k_{reg}=45



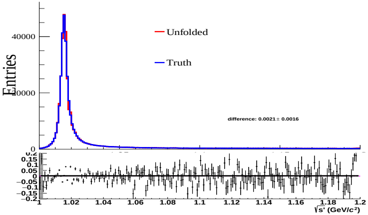
k_{reg}=50

- Test different k_{reg} (M_ϕ=1.015 GeV/c^2).

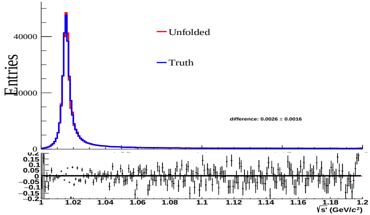
Unfolding: Systematic uncertainties



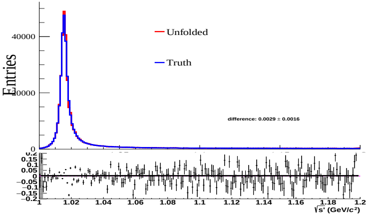
k_{reg}=55



k_{reg}=60



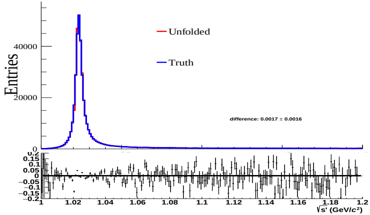
k_{reg}=65



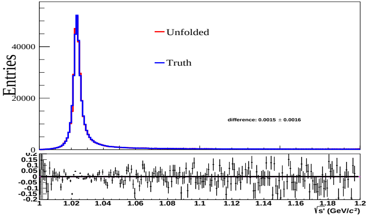
k_{reg}=70

- Test different k_{reg}.

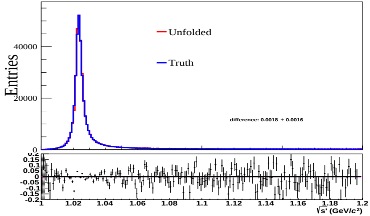
Unfolding: Systematic uncertainties



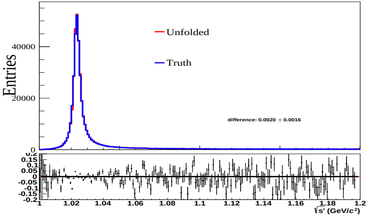
k_{reg}=20



k_{reg}=40



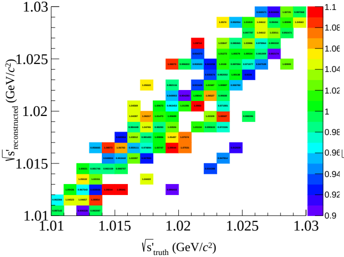
k_{reg}=45



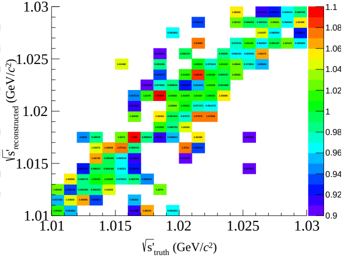
k_{reg}=50

- Test different k_{reg} (M_{ϕ}=1.023 GeV/c^2).

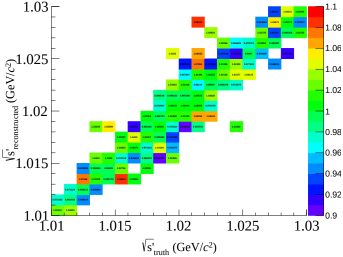
2D efficiency



(a)Compare response matrix 1023

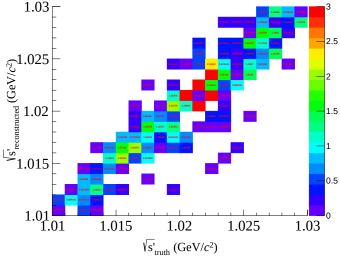


(b)Compare response matrix 1015

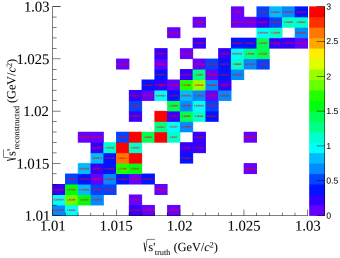


(c)Compare response matrix signal

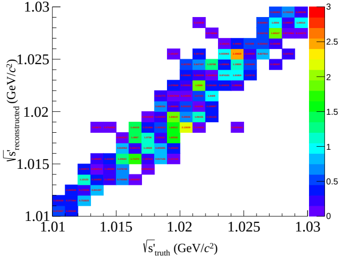
2D efficiency (ratio of uncertainty)



(a)Compare response matrix 1023



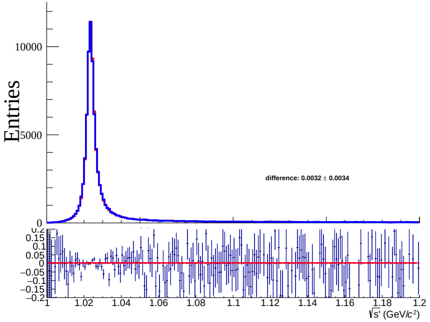
(b)Compare response matrix 1015



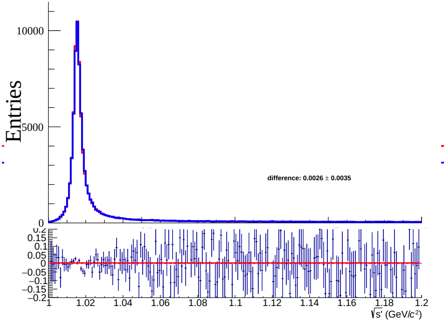
(c)Compare response matrix signal

- The response matrix of different samples have

Unfolding result after the correction of response matrix



M_{ϕ}=1.023 GeV/c^2



M_{ϕ}=1.015 GeV/c^2

- The response matrix is from the 1015/1023 MC but the resolution of the response matrix is corrected to the signal MC.
- The unfolding works much better, so the main reason causing the bad unfolding is the shape of the input sample not the resolution effect.

Summary

- **Systematic uncertainties finished:**
  - ☐ PID Efficiency of $K^{\pm}$
  - ☐ Tracking Efficiency of $K^{\pm}$
  - ☐ Photon Efficiency
  - ☐ Kinematic Fit
- **Systematic uncertainties waiting to be finished:**

☐ Unfolding: Varying the position of ϕ peak and generating the new MC. Using the previous response matrix to do the unfolding the difference of the unfolded result and the truth is taken as systematic uncertainty.

  - ☐ Background
  - ☐ MC model: Changing the from factor.