Study of Initial state radiation photon Efficiency

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

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

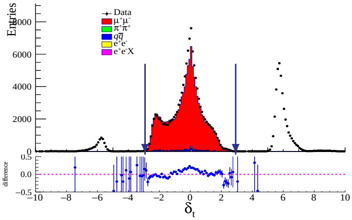
Kinematic Fit:

- Successful 1c kinematic fit, χ^2_{1c} <10
- 0.4 GeV $< E_\gamma$ <2.0 GeV
- $|cos\theta_\gamma| < 0.93$

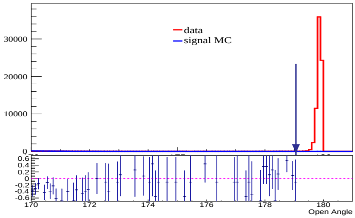
Event selection

Further Selection:

- From figure(a), it can be seen that the main unmatched part between data and MC is the region where the absolute difference of flight time between μ^+ and μ^- (δ_t)is larger than 3 ns. This is caused by the cosmic ray events. So $|\delta_t| < 3ns$ is required.
- From figure(b), it can be seen the open angle between the two charge tracks of the cosmic ray background is nearly π. Therefore the net recoiled momentum should be close to 0, which may be the reason why these events can pass 1c Kmfit. A cut of open angle should be smaller than 179 degree can also be used to select the control sample.



(a)$\delta_t$distribution of data and MC samples



(b)The openangle distribution of data and signalMC

Event selection

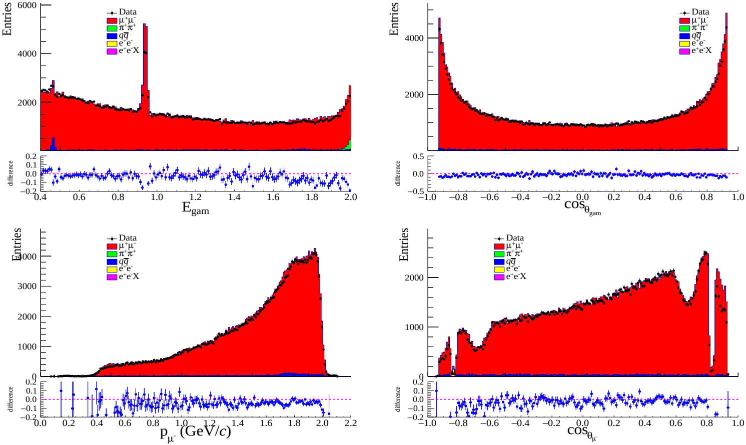
Tag ISR photon:

- 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:

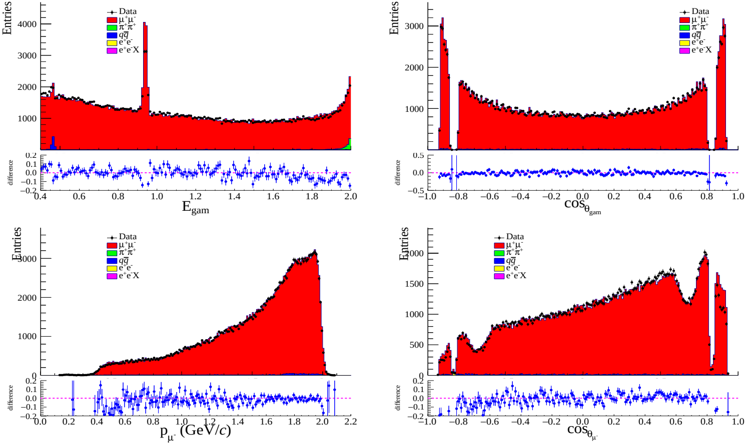
$$\epsilon = N2/N1, \text{ and the error is } err_\epsilon = \sqrt{\frac{\epsilon(1-\epsilon)}{N_1}}$$

Comparisons betweens data and MC without tagging ISR photon



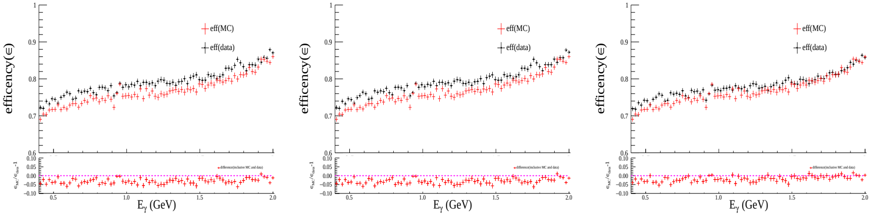
- The MC and data match well with each other except for the region near the j/ψ
- The asymmetry of the $cos\theta_{\mu-}$ is caused by the FSR effect

Comparisons betweens data and MC after tagging ISR photon



- Situation is very similar before tagging an ISR photon

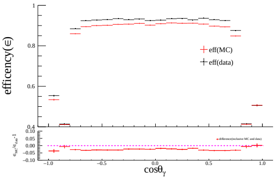
efficiency varies with momentum

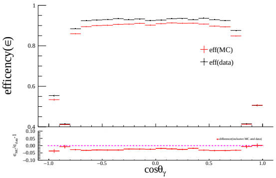


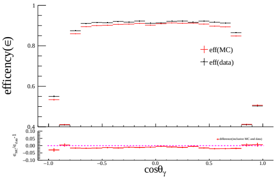
(a) (b) (c)

- Figure(a) is the photon efficiency varying with the momentum of photon. Here the $\pi^+\pi^-\gamma_{\text{ISR}}$ is treated as the background which is subtracted from the data. It can be seen that the efficiency of data is systematically higher than MC especially near the 2 GeV.
- Figure(b) is the efficiency without subtracting the $\pi^+\pi^-\gamma_{\text{ISR}}$. No large difference from before.
- Figure (c) is the efficiency without subtracting any background. It can be found that the two efficiencies become much closer.

efficiency varies with cosθ







- All cases mentioned before show the consistencies that the efficiencies in nearly all bins of data are higher than MC except for the bins near the boundary.

Cutflow of signal and data

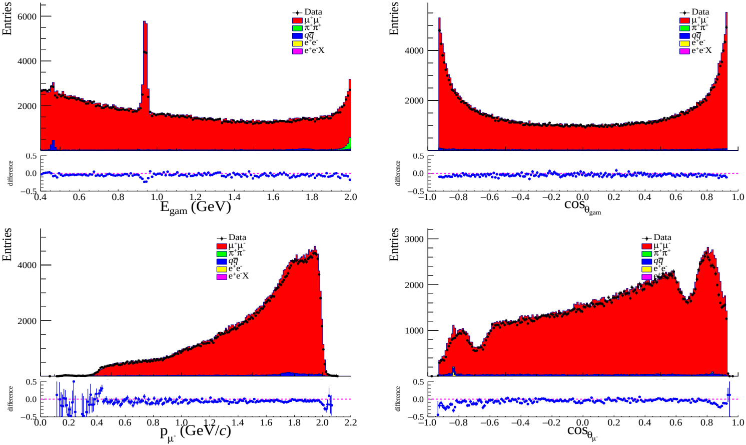
	N_{data}	eff_{re}	N_{sig}	eff_{re}
Original selection	597968167		2194873	21.94%
EP ratio	17053456		2094886	95.44%
PE ratio	1155635		674510	32.20%
$\mu^{\pm}$ distance	659500		535647	79.41%
0.4 GeV$<E_{\gamma}<$2 GeV	500821		379212	70.80%
$\chi^2_{1c} < 10$	358929		317929	83.84%
$\|\delta_{tof}\| < 3$	248927		280076	88.09%
$N_{\gamma} > 1$	214657	**86.23%**	241438	**86.20%**
$\chi^2_{4c} < 50$	192995	**89.91%**	213196	**88.30%**

Selection Result

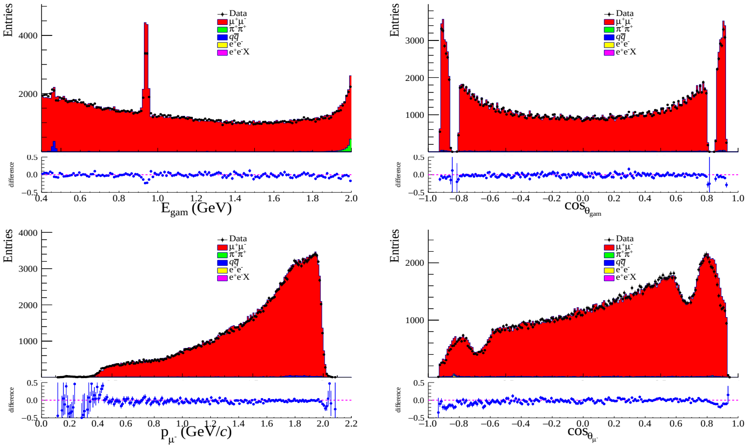
Data/MC sample	N_{gen}	N_{sur}	L_{int}	σ_{obv}	scale factor	N_{sur_scale}
Data		248927	3194500	1	1	248927
$\mu^+\mu^-$	1000000	280076	3194500	2.7974	0.8936	250276
$\pi^+\pi^-$	1000000	3400	3194500	1.00	0.32	1088
hadron	8000000	3381	3194500	24.08	1.01	3415
eeX	5431500	6	3194500	1.70	1.00	6
e^+e^-	271000000	37	3194500	424	4.99	185

- Signal-background ratio is about 98.16%.

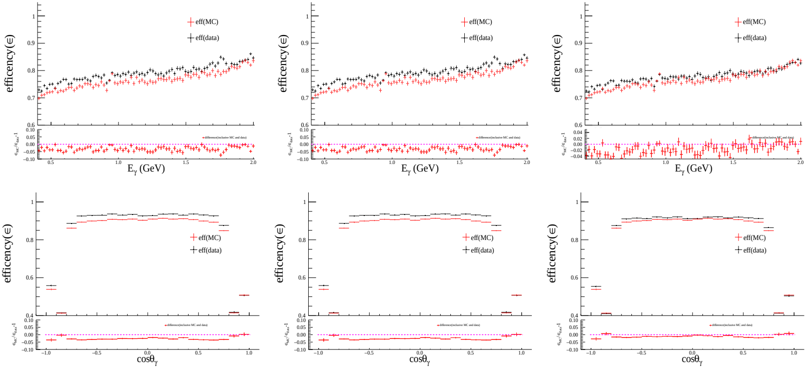
Comparisons betweens data and MC without tagging ISR photon (openangle)



Comparisons betweens data and MC after tagging ISR photon (openangle)



efficiency (openangle)



(a)no bkg (b)with $\pi^+\pi^-$ (c)with all bkg

- Things are similar to before.

Cutflow of signal and data

	N_{data}	eff_{re}	N_{sig}	eff_{re}
Original selection	597968167		2194873	21.94%
EP ratio	17053456		2094886	95.44%
PE ratio	1155635		674510	32.20%
$\mu^{\pm}$ distance	659500		535647	79.41%
0.4 GeV$<E_{\gamma}<$2 GeV	500821		379212	70.80%
$\chi^2_{1c}<10$	358929		317929	83.84%
open angle<179	275972		317929	100%
$N_{\gamma}>1$	237662	**86.12%**	273944	**86.17%**
$\chi^2_{4c}<50$	213662	**89.90%**	241967	**88.33%**

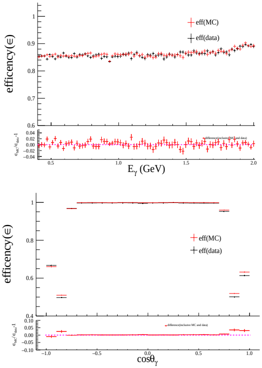
- From the cutflow of the two cases, it is found that the difference is mainly caused by the 4c kinematic fit, so maybe we should separate this two systematic uncertainties. For now, we consider the openangle cut as our nominal cut.

Selection Result

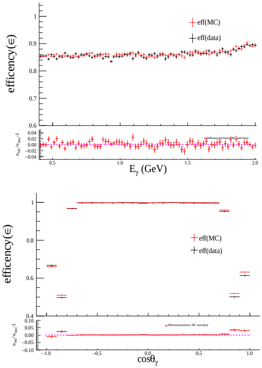
Data/MC sample	N_{gen}	N_{sur}	L_{int}	σ_{obv}	scale factor	N_{sur_scale}
Data		275972	3194500	1	1	275972
$\mu^+\mu^-$	1000000	317913	3194500	2.7974	0.8936	284087
$\pi^+\pi^-$	1000000	4675	3194500	1.00	0.32	1496
hadron	8000000	4303	3194500	24.08	1.01	4346
eeX	5431500	8	3194500	1.70	1.00	8
e^+e^-	271000000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

- Signal-background ratio is about 97.92%.

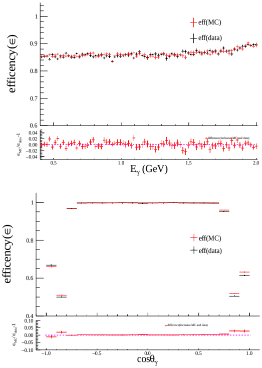
efficiency (no χ^2 cut)



(a)no bkg



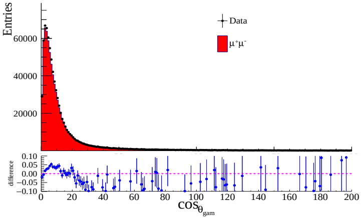
(b)with $\pi^+\pi^-$



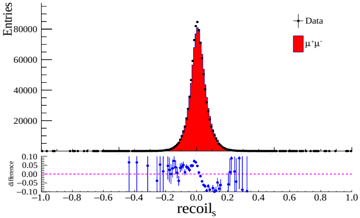
(c)with all bkg

- The two efficiencies get much closer than before and become nearly same for the last case.
- So we decide to separate the systematic uncertainties form the photon reconstruction and the kinematic fit.

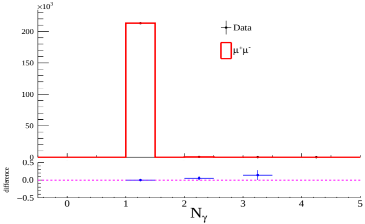
check for χ^2_{4c}



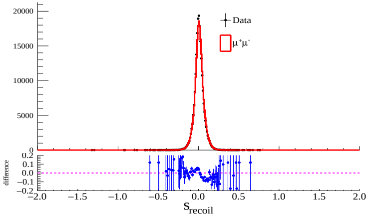
(a)χ^2_4c



(b)s_{recoil} before tagging the photon



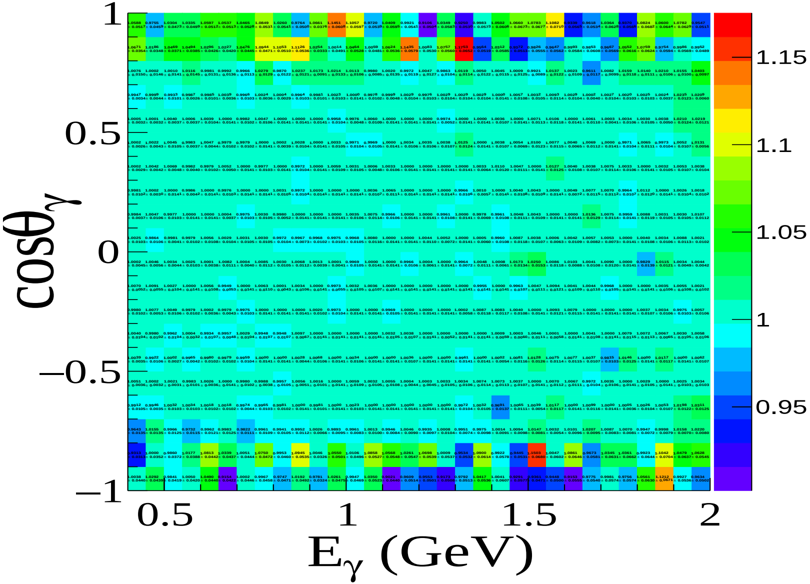
(c)N_γ



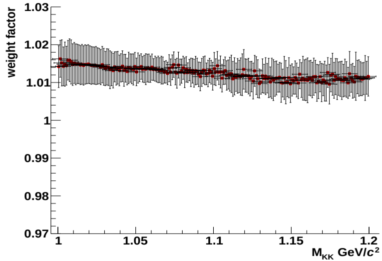
(d)s_{recoil} after tagging the photon

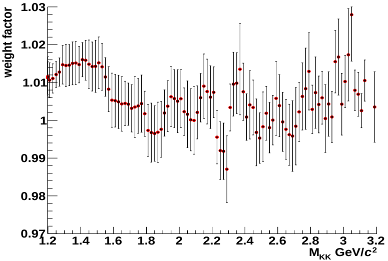
- There are more events of data than MC at the region of low χ^2_{4c}. But the ratio of data with just one good photon is not higher than data.
- But in Figure (b) and (d), we can find that there are more data near the recoil$_s$ =0, which indicates that there maybe more leading order events in data.

efficiency (2D)



weight factor varies with M_{KK}

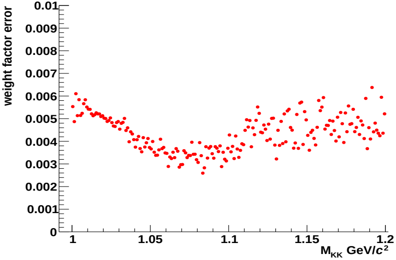


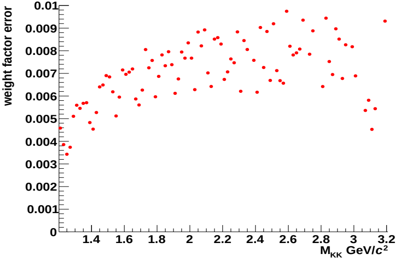


How to get the weight factor varying with M_{KK}:

- Get the $cos\theta_\gamma$ and E_γ 2D distribution of different M_{KK} bins.
- Then calculate the ratio of each 2D bin to the total event number of the M_{KK} bin and get the corresponding weight factor.
- Sum over the product of the weight factor and the ratio, then we can get the weight factor of the MKK bin. The error of it is calculated as: $err = \sqrt{\sum(ratio * err_{weight})^2}$

Systematic uncertainties of photon efficiency





- For now, we take the error of the weight factor as the systematic uncertainties. Below the 1.2 GeV/c^2 the systematic uncertainty is taken as 0.5%. Above 1.2 GeV/c^2, the systematic uncertainty is taken as 0.9%.