Updates on the π/μ analysis for pion formfactor

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Outline

- ✓ Introduction
- ✓ Background subtraction
  - ❑ Bhabha spectrum shape from Experimental Data sample (Background I)
  - ❑ Bhabha spectrum shape from MC Simulation Data sample (Background II)
- ✓ Data/MC comparision in different Q2 slices
- ✓ Simulation crosschecks
- ✓ Conclusion

Introduction

Goal: To measure charged pion formfactor using $N\pi\pi/N\mu\mu$ ratio
Subtask: To perform coparision of DATA/MC for $\mu^+\mu^-\gamma$ events

DATA and MC samples, used in the work:

- ✓Experimental Data Runs 23542 – 27079, Luminosity Integral is 241.38 pb^{-1}
- ✓ $\pi\pi\gamma$ MC Simulation Runs 23587 - 27079, Phokhara Generator, Luminosity Integral is 240.19 pb^{-1}($\times$ 6)
- ✓ $\mu\mu\gamma$ MC Simulation Runs 23546 - 27079, Phokhara Generator, Luminosity Integral is 240.64 pb^{-1}($\times$ 6)
- ✓ $ee\gamma$ MC Simulation Runs 23546 - 27079, Phokhara Generator, Luminosity Integral is 236.57 pb^{-1}($\times$ 6)

Comparision is performed in integral over all Q^2 as well as in different Q^2 bins

Parameters for comparision are trackmass and polar angles of muons

LikelyHood Cut Definition

Legend: "+" – LogRL > 0, "-" – LogRL < 0

LikelyHood Cut	First track	Second Track
OR	+	+
	+	-
	-	+
XOR	+	-
	-	+
NOR	-	-

LikelyHood Cut Definition (Cont.d)

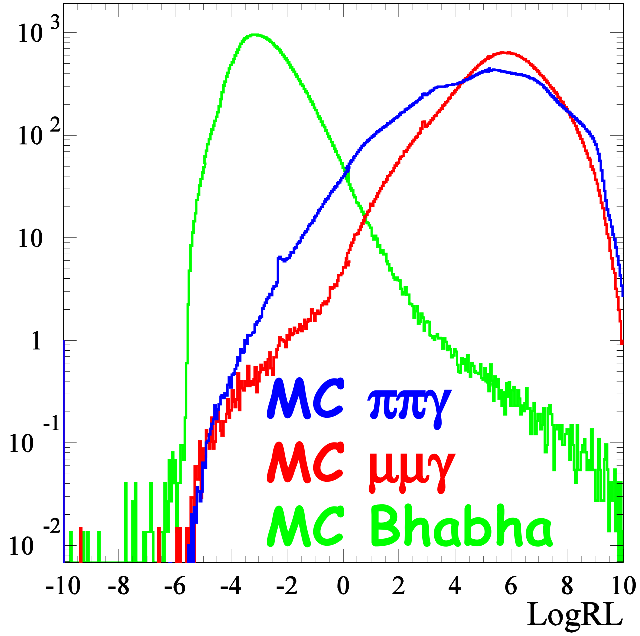
OR LikelyHood is used in DATA analysis
NOR LikelyHood is used to determine Bhabha spectrum shape
XOR LikelyHood is used to determine scale factor for NOR Bhabha spectrum

$$LogRL > 0 \Rightarrow \pi, \mu \quad LogRL < 0 \Rightarrow e$$

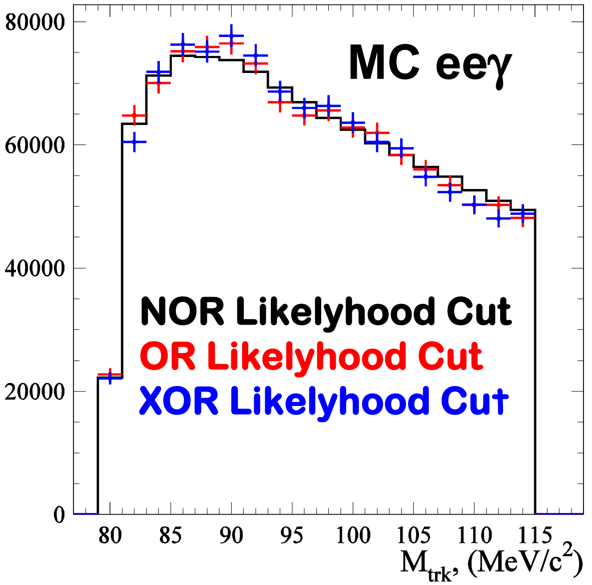
$$I. \varepsilon_e^1 = \varepsilon(LogRL < 0) \approx 98.5\% \Rightarrow \rho = 1 - \varepsilon_e^1 \approx 1.5\% \Rightarrow NOR \Leftrightarrow pure\, e^+ e^-$$

$$II. W_{ee}^{OR} = W_{ee}^{XOR} + W_{ee}^{AND} = W_{ee}^{XOR} \cdot \left(1 + \frac{W_{ee}^{AND}}{W_{ee}^{XOR}}\right) = W_{ee}^{XOR} \cdot \left(1 + \frac{\rho}{2 \cdot \varepsilon_e^1}\right) = W_{ee}^{XOR} \cdot (1 + 0.008)$$

$$W_{ee}^{OR} \cong W_{ee}^{XOR}$$



The shape eeg (NOR) is consistent with eeg (OR)



Trackmass

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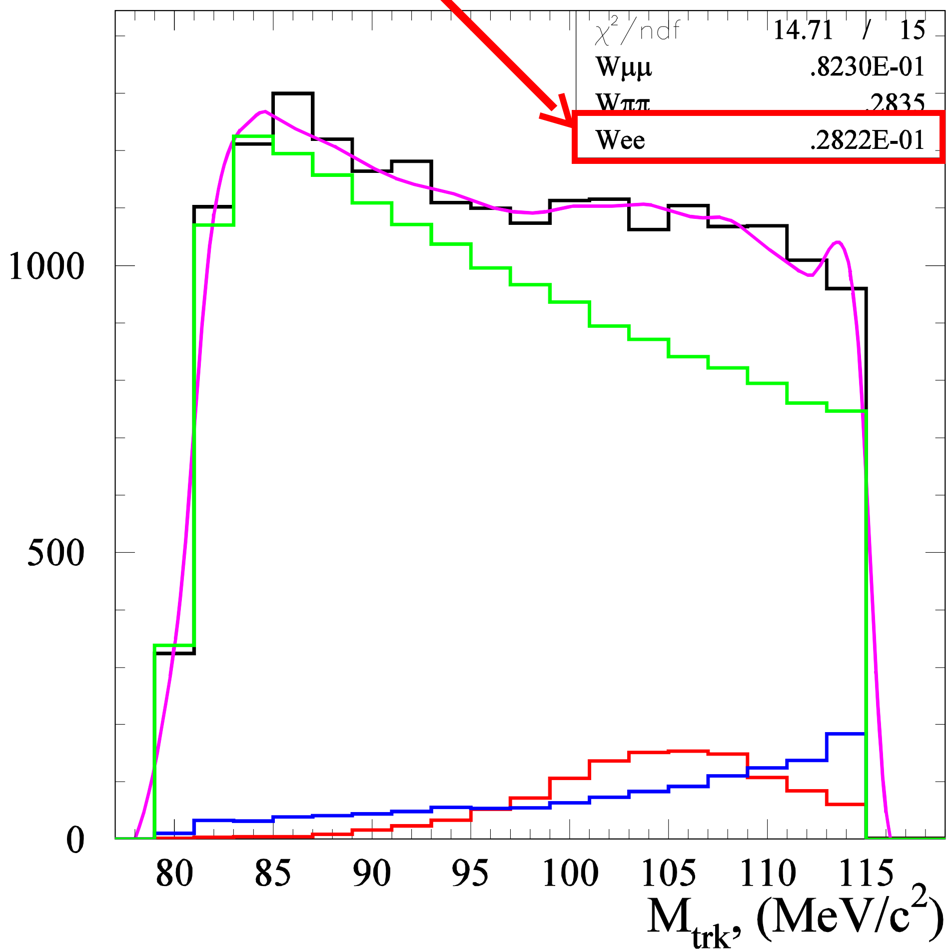
Background subtraction I (scale factor)

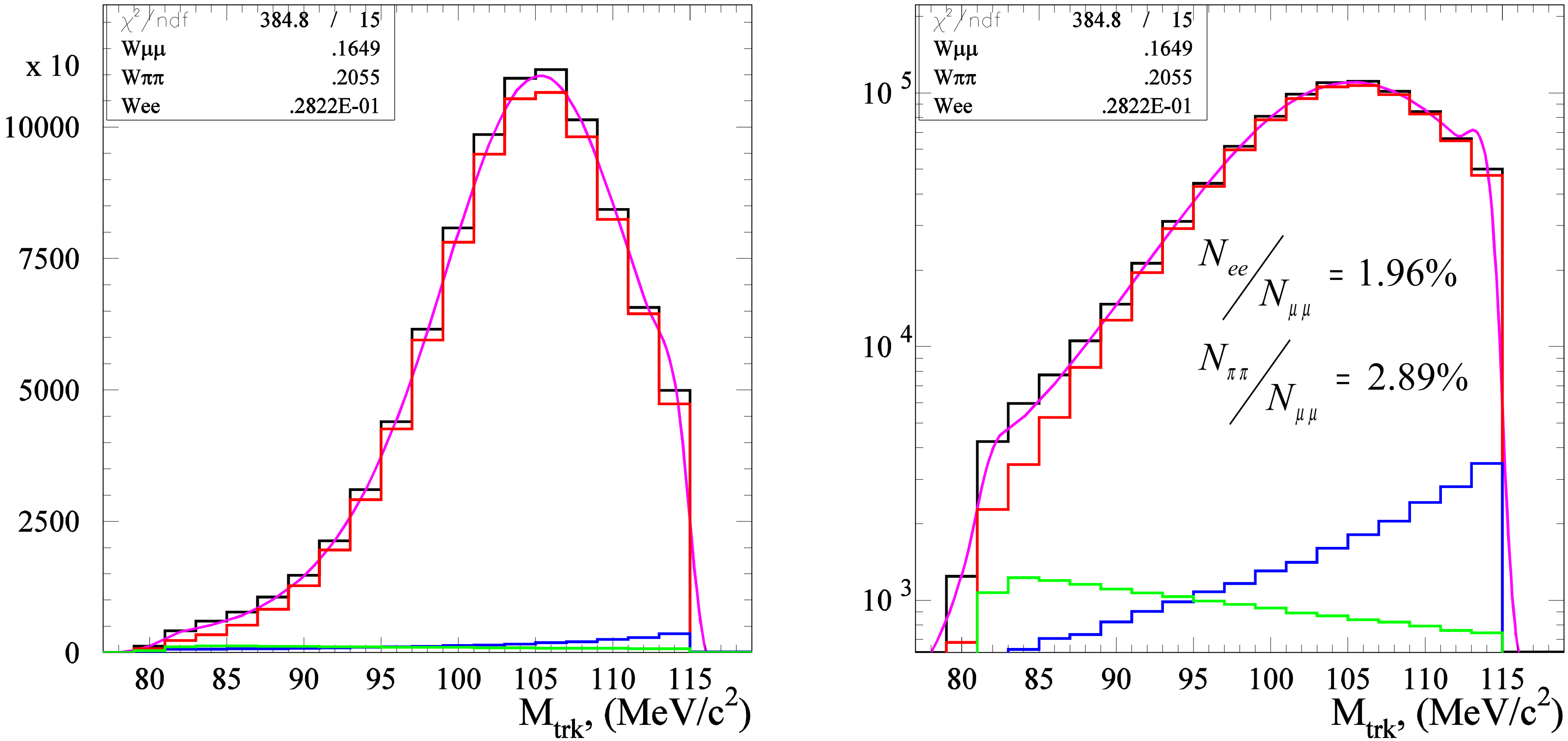
$$F_{DATA}^{XOR}(M) = W_{ee\gamma}^{XOR} \cdot f_{DATA}^{NOR}(M) + W_{\pi\pi\gamma}^{XOR} \cdot f_{MC\,\pi\pi\gamma}^{XOR}(M) + W_{\mu\mu\gamma}^{XOR} \cdot f_{MC\,\mu\mu\gamma}^{XOR}(M)$$



$ee\gamma$ is green
$\pi\pi\gamma$ is blue
$\mu\mu\gamma$ is red
Fitting function is magenta

Background subtraction I (Fit)

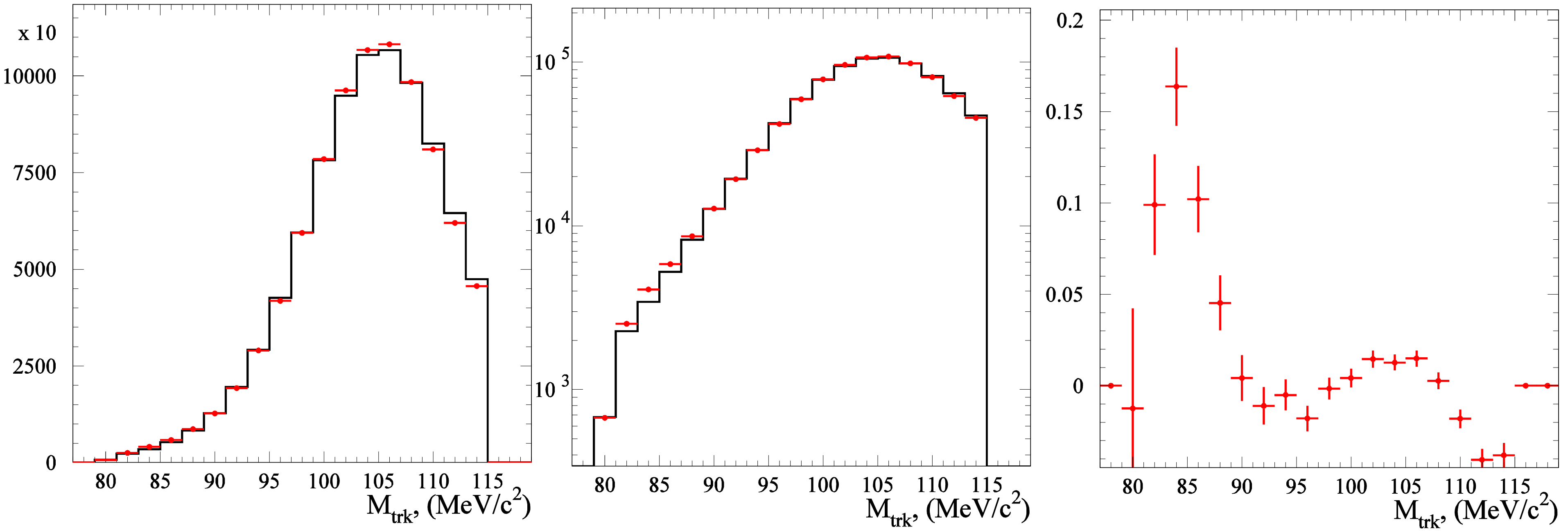
$$F^{OR}_{DATA}(M) = W^{XOR}_{ee\gamma} \cdot f^{NOR}_{DATA}(M) + W^{OR}_{\pi\pi\gamma} \cdot f^{OR}_{MC\pi\pi\gamma}(M) + W^{OR}_{\mu\mu\gamma} \cdot f^{OR}_{MC\mu\mu\gamma}(M)$$



$ee\gamma$ is green, $\pi\pi\gamma$ is blue, $\mu\mu\gamma$ is red, fitting function is magenta

Background subtraction I (Results)

histogram is MC μμγ events, points with errors are EXP DATA,
Normalization is to the number of EXP DATA events after background subtraction

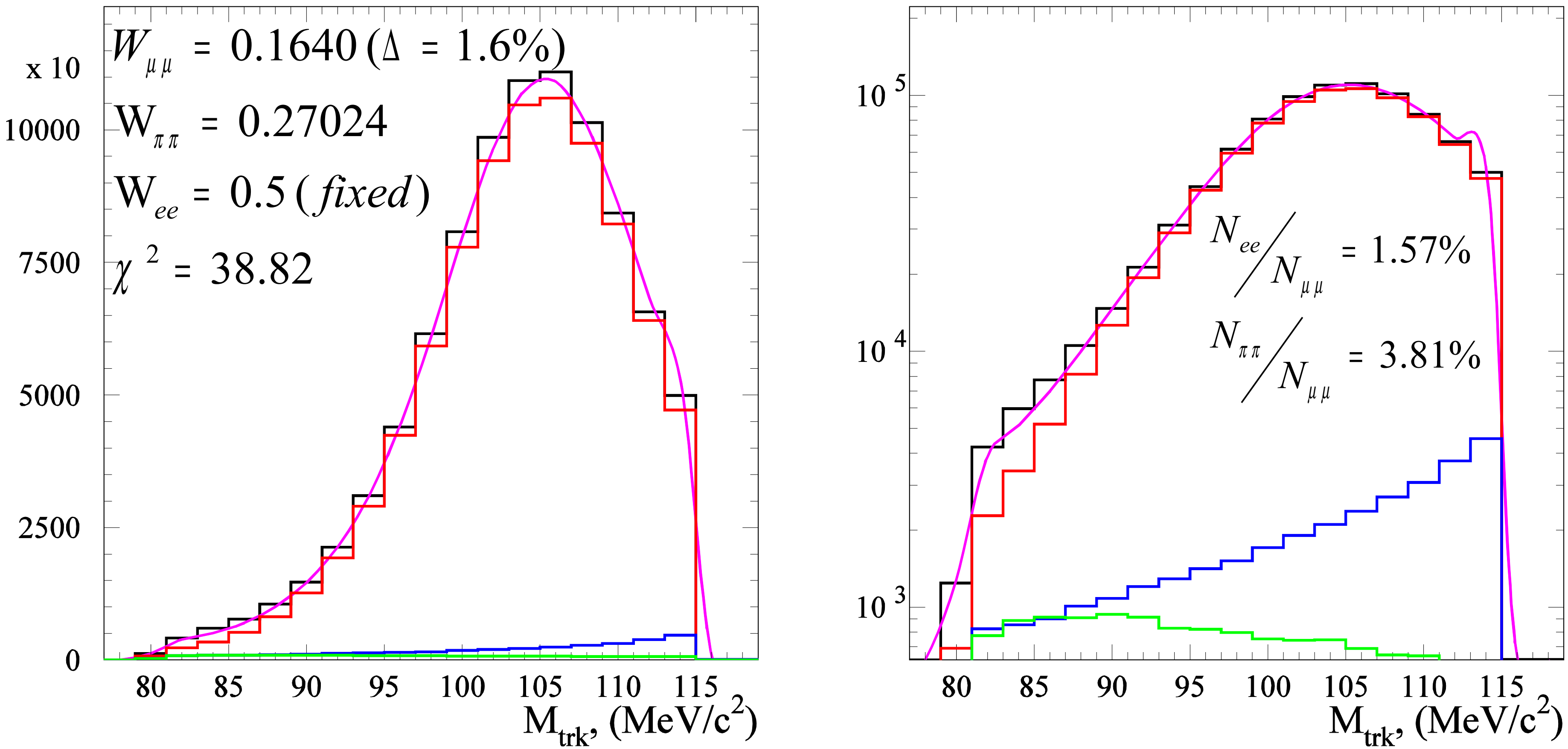


Relative difference = (EXP-MC)/EXP

Background subtraction II (Fit 1)

$$F^{OR}_{DATA}(M) = W^{OR}_{ee\gamma} \cdot f^{OR}_{MC\,ee\gamma}(M) + W^{OR}_{\pi\pi\gamma} \cdot f^{OR}_{MC\,\pi\pi\gamma}(M) + W^{OR}_{\mu\mu\gamma} \cdot f^{OR}_{MC\,\mu\mu\gamma}(M)$$

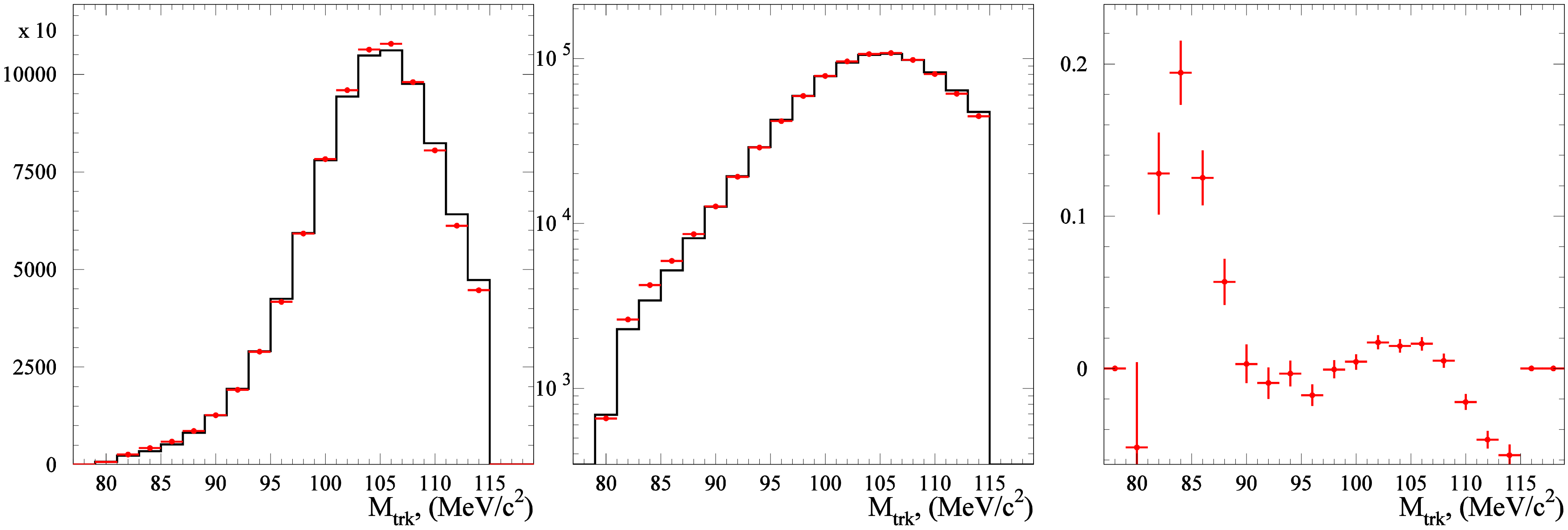
Wee is fixed according to luminosity. Wμμ, Wππ are free



eeγ is green, ππγ is blue, μμγ is red, fitting function is magenta

Background subtraction II (Results Fit 1)

histogram is MC $\mu\mu\gamma$ events, points with errors are EXP DATA,
Normalization is to the number of EXP DATA events after background subtraction

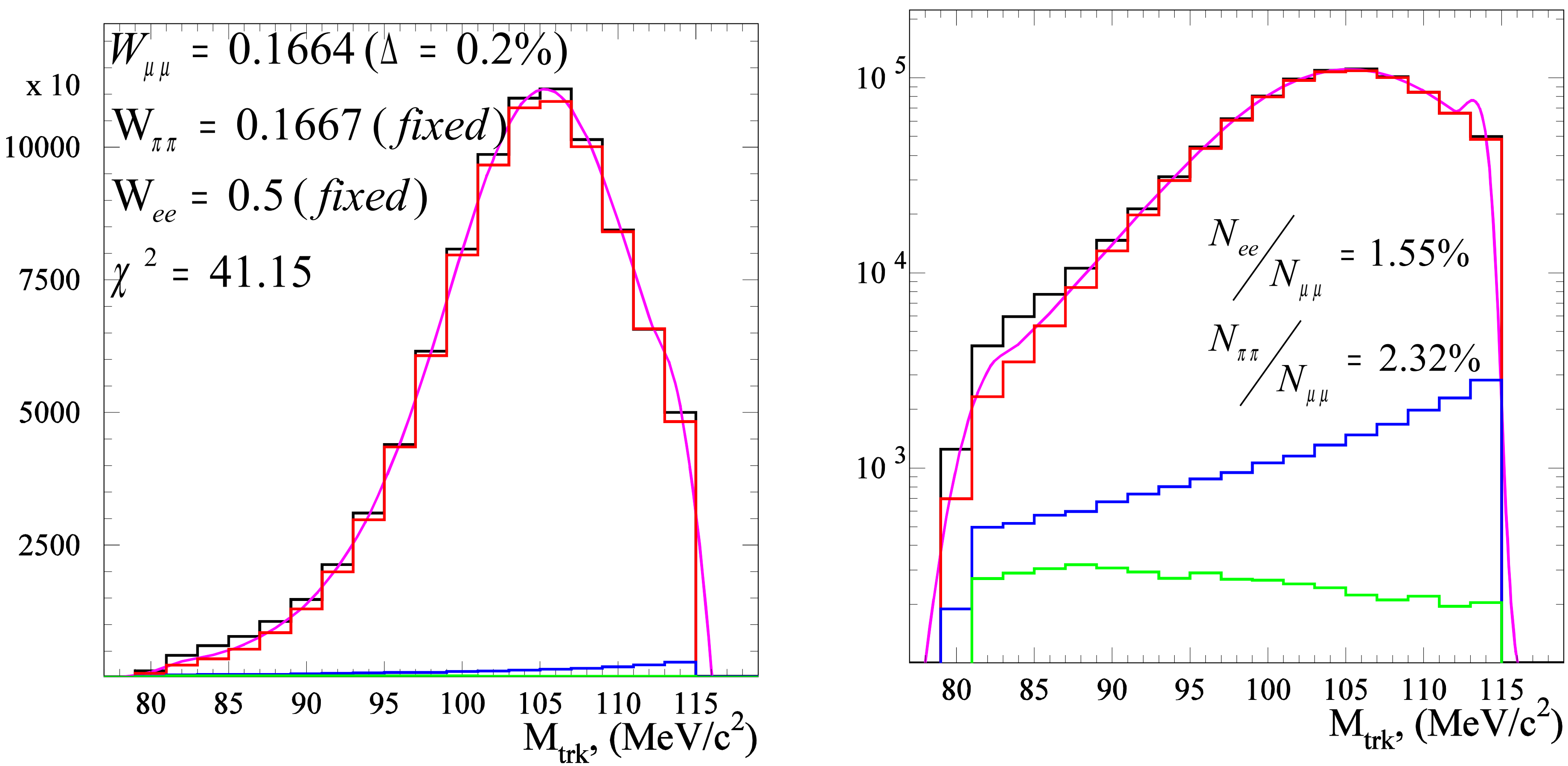


Relative difference = (EXP-MC)/EXP

Background subtraction II (Fit 2)

$$F^{OR}_{DATA}(M) = W^{OR}_{ee\gamma} \cdot f^{OR}_{MC\,ee\gamma}(M) + W^{OR}_{\pi\pi\gamma} \cdot f^{OR}_{MC\,\pi\pi\gamma}(M) + W^{OR}_{\mu\mu\gamma} \cdot f^{OR}_{MC\,\mu\mu\gamma}(M)$$

Wee, Wππ are fixed according to luminosity. Wμμ is free



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Background subtraction II (Results Fit 2)

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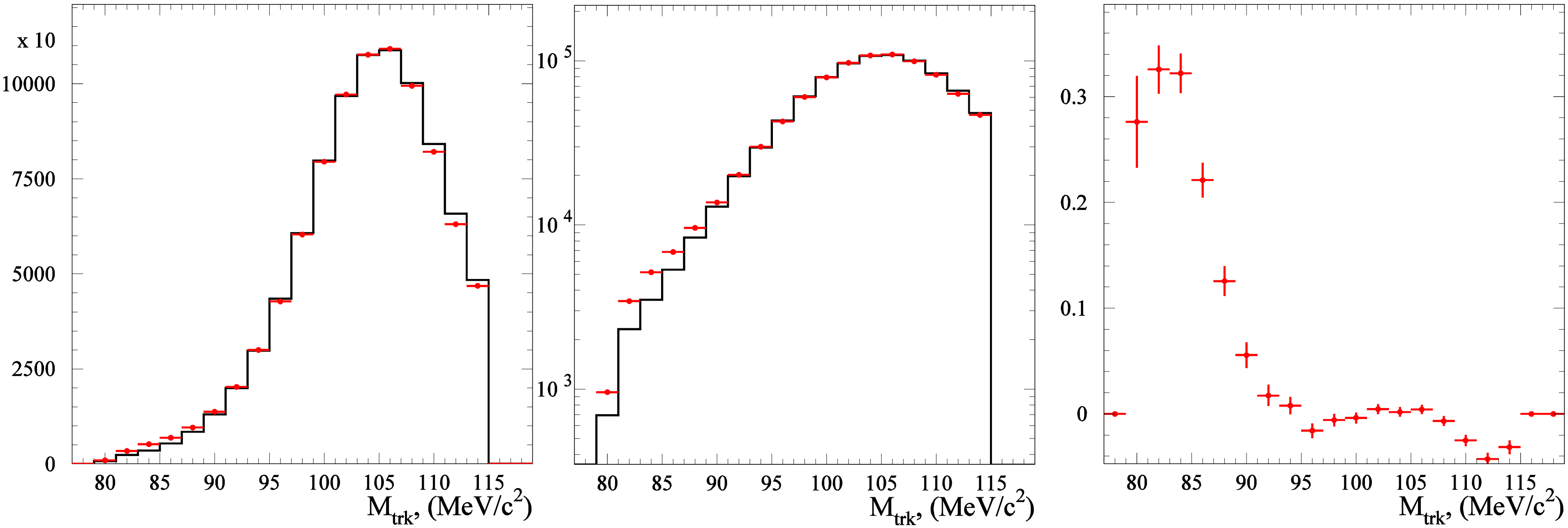
Normalization is to the number of EXP DATA events after background subtraction

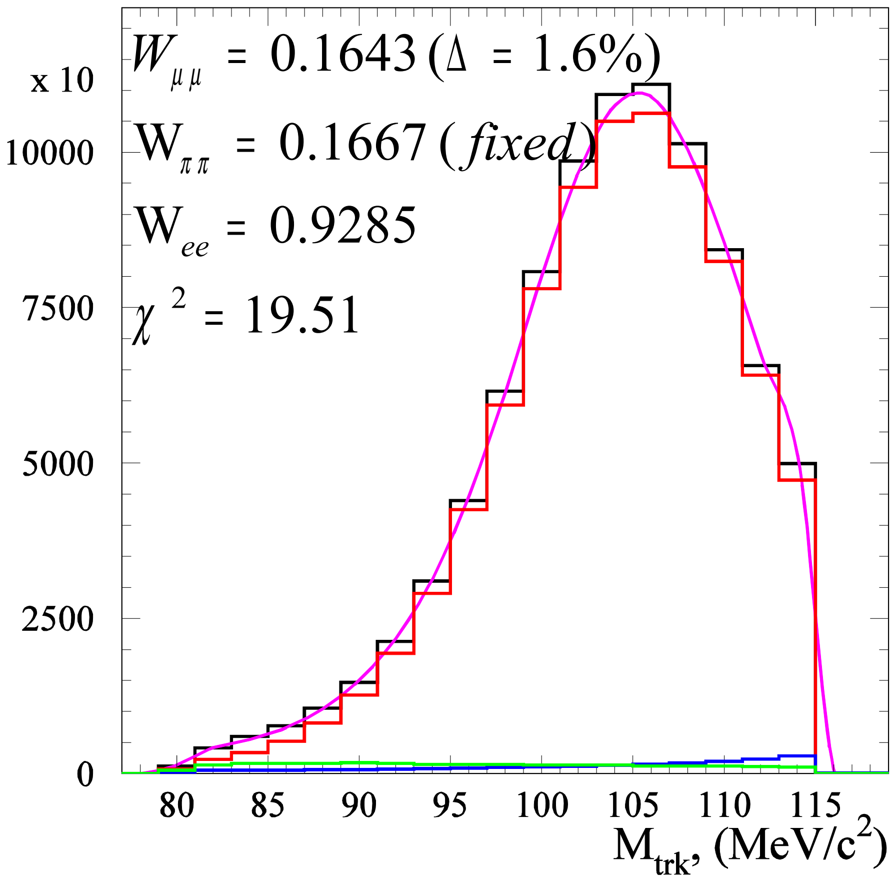


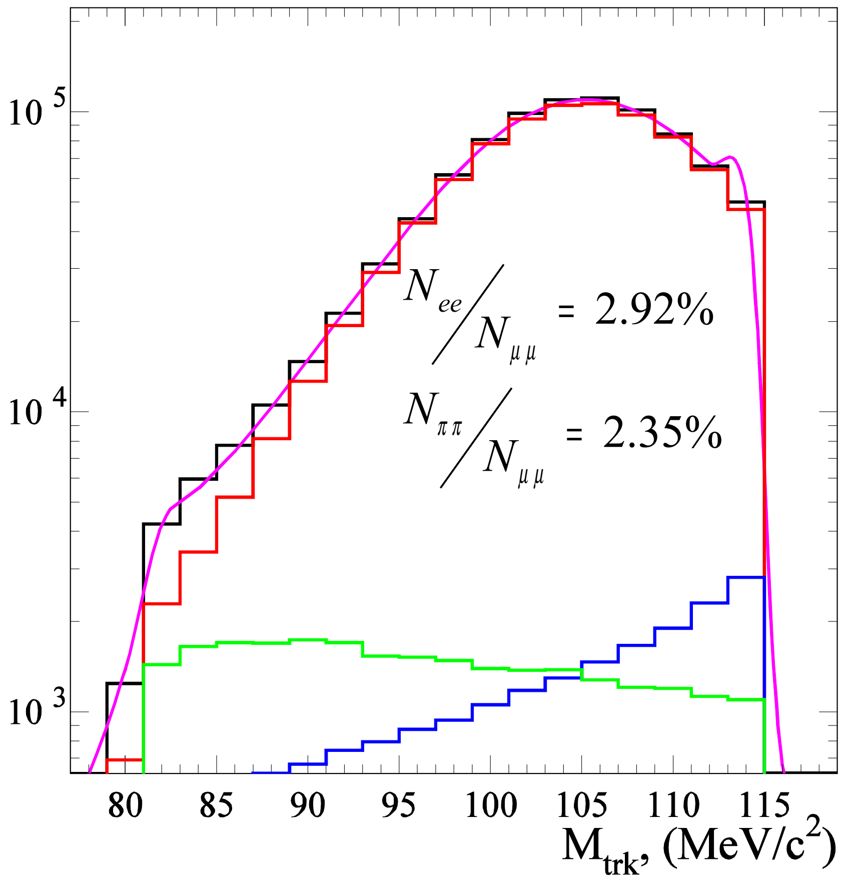
Relative difference = (EXP-MC)/EXP

Background subtraction II (Fit 3)

$$F^{OR}_{DATA}(M) = W^{OR}_{ee\gamma} \cdot f^{OR}_{MC\,ee\gamma}(M) + W^{OR}_{\pi\pi\gamma} \cdot f^{OR}_{MC\,\pi\pi\gamma}(M) + W^{OR}_{\mu\mu\gamma} \cdot f^{OR}_{MC\,\mu\mu\gamma}(M)$$

Wππ is fixed according to luminosity. Wμμ,Wee are free





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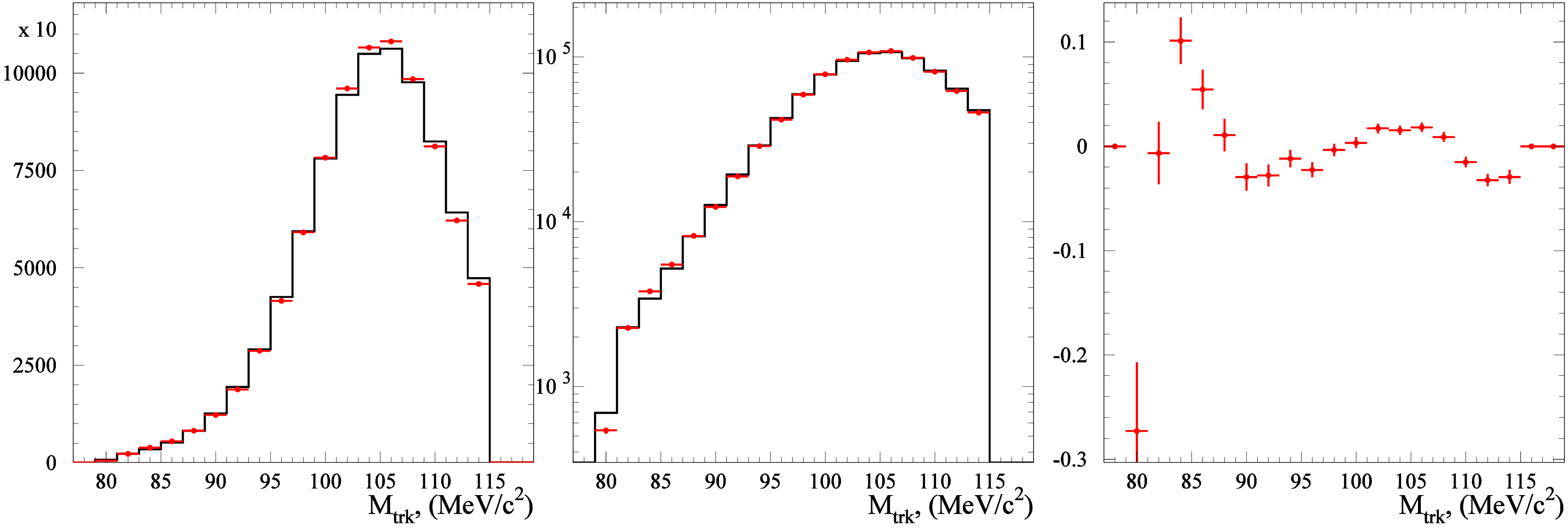
Background subtraction II (Results Fit 3)

histogram is MC $\mu\mu\gamma$ events, points with errors are EXP DATA,
Normalization is to the number of EXP DATA events after background subtraction



Relative difference = (EXP-MC)/EXP

Positive muon polar angle

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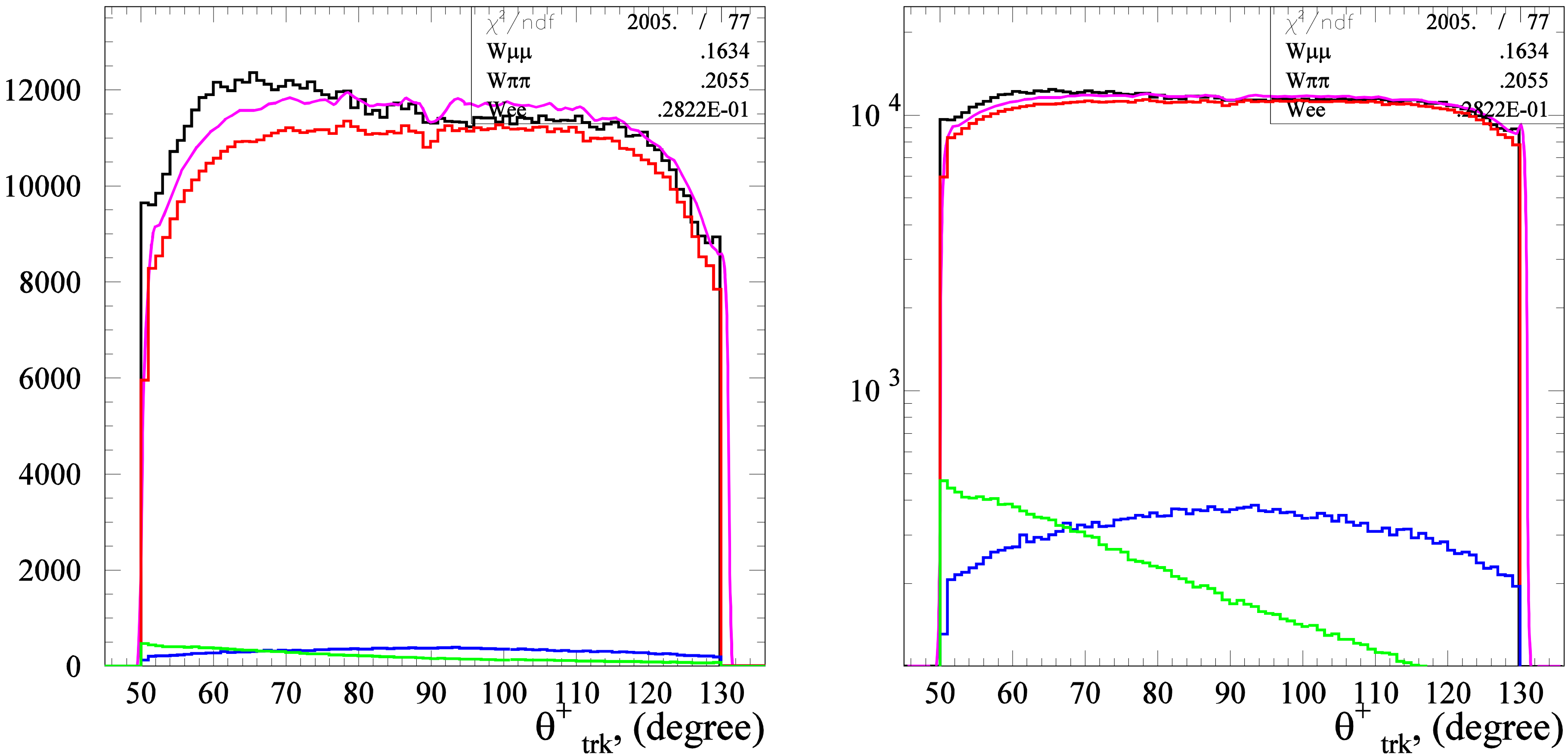
Background subtraction I (Fit)

$$F^{OR}_{DATA}(\theta^{+}) = W^{XOR}_{ee\gamma} \cdot f^{NOR}_{DATA}(\theta^{+}) + W^{OR}_{\pi\pi\gamma} \cdot f^{OR}_{MC\,\pi\pi\gamma}(\theta^{+}) + W^{OR}_{\mu\mu\gamma} \cdot f^{OR}_{MC\,\mu\mu\gamma}(\theta^{+})$$

Wee, Wππ are fixed from trackmass, Wμμ is free



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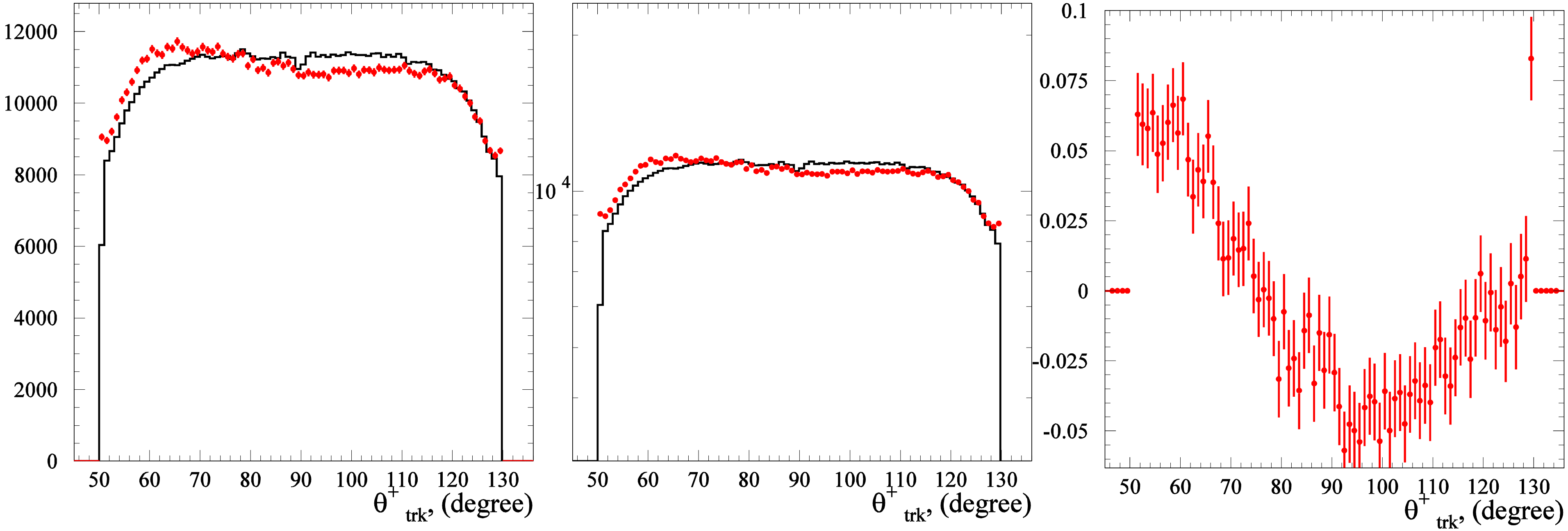
Background subtraction I (Results)

histogram is MC $\mu\mu\gamma$ events, points with errors are EXP DATA,
Normalization is to the number of EXP DATA events after background subtraction

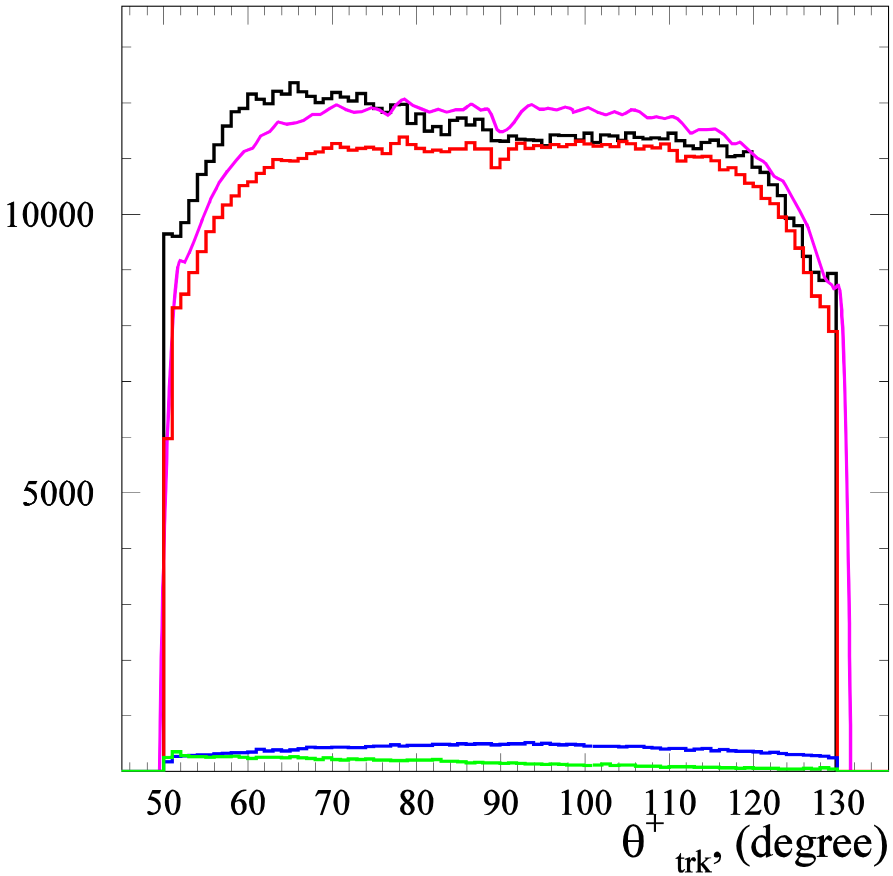


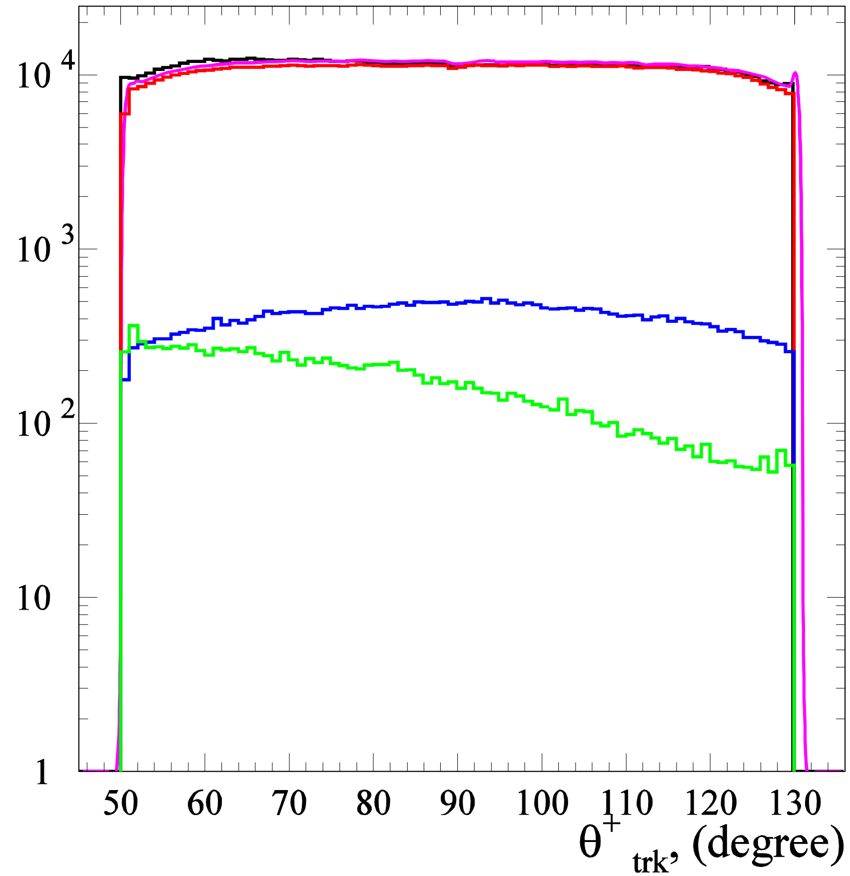
Relative difference = (EXP-MC)/EXP

Background subtraction II (Fit 1)

$$F^{OR}_{DATA}(\theta^+) = W^{OR}_{ee\gamma} \cdot f^{OR}_{MC\,ee\gamma}(\theta^+) + W^{OR}_{\pi\pi\gamma} \cdot f^{OR}_{MC\,\pi\pi\gamma}(\theta^+) + W^{OR}_{\mu\mu\gamma} \cdot f^{OR}_{MC\,\mu\mu\gamma}(\theta^+)$$

Wee is fixed according to luminosity, Wμμ, Wππ are free





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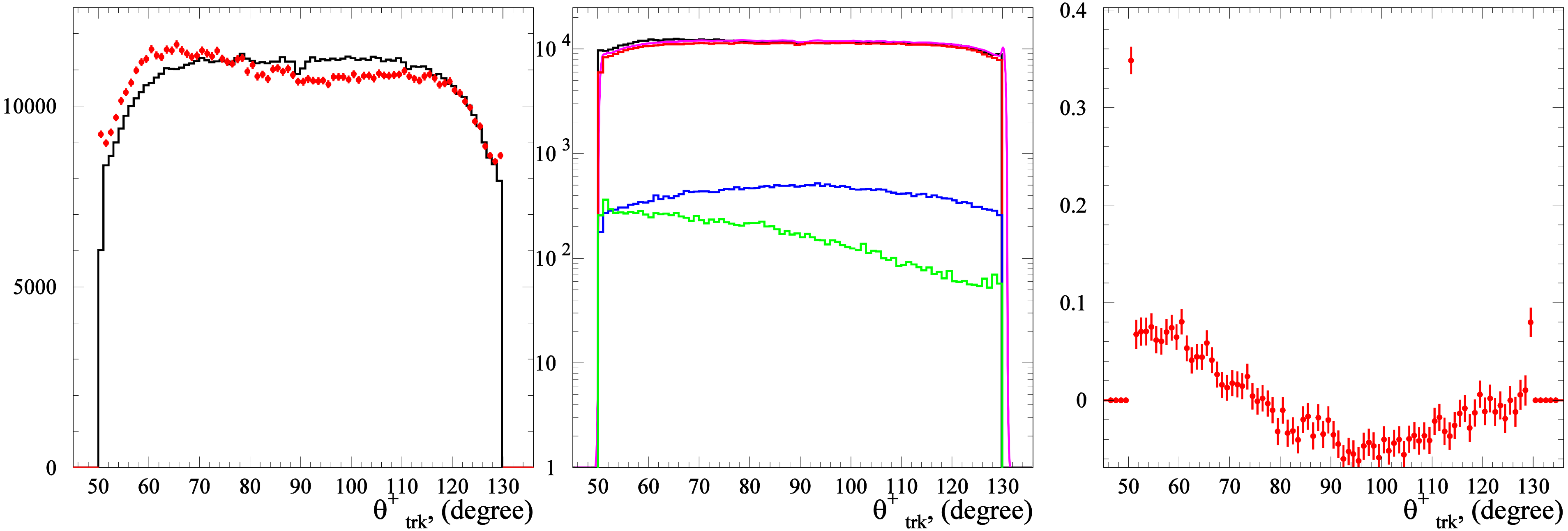
Background subtraction II (Results Fit 1)

histogram is MC $\mu\mu\gamma$ events, points with errors are EXP DATA,
Normalization is to the number of EXP DATA events after background subtraction

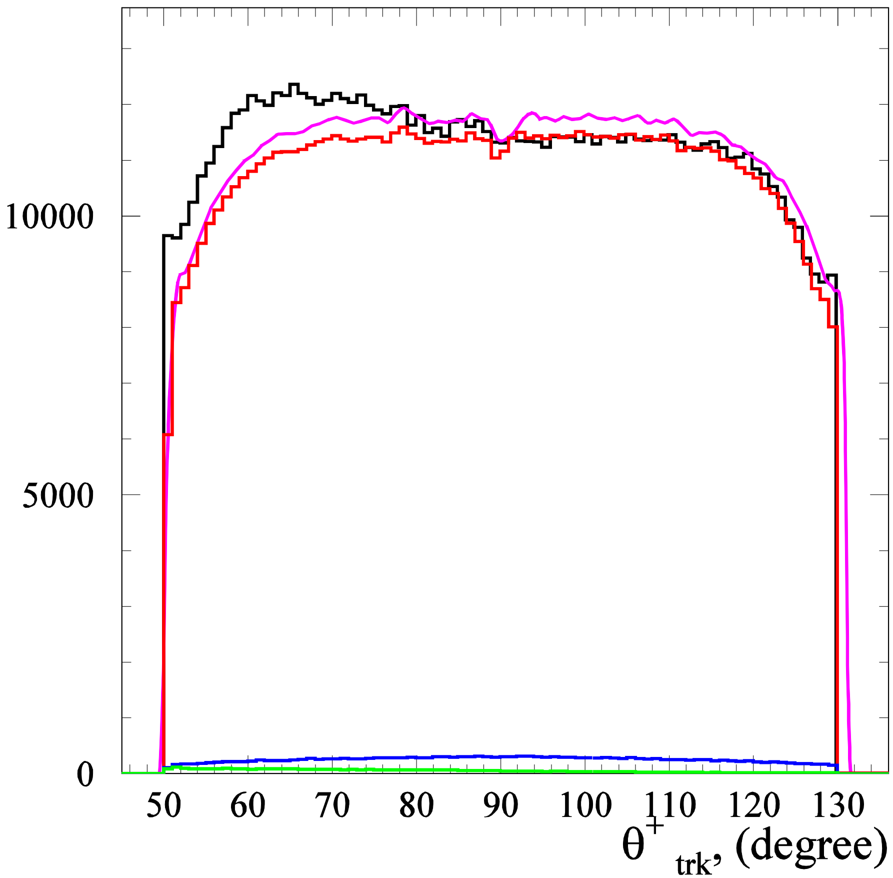


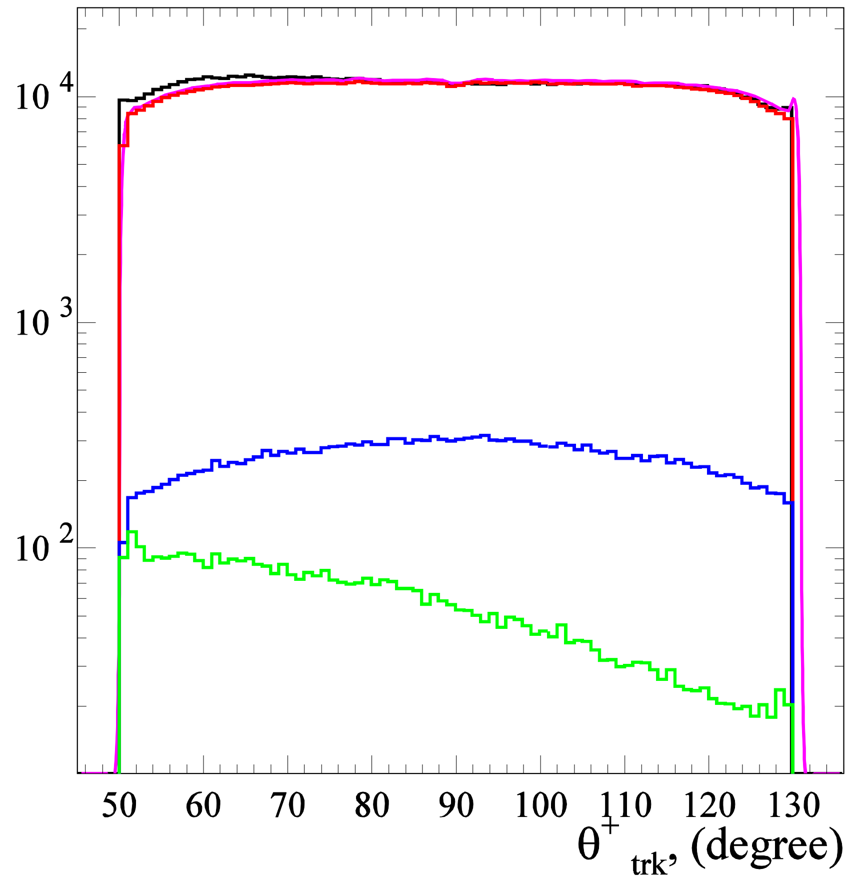
Relative difference = (EXP-MC)/EXP

Background subtraction II (Fit 2)

$$F^{OR}_{DATA}(\theta^+) = W^{OR}_{ee\gamma}\cdot f^{OR}_{MC\,ee\gamma}(\theta^+) + W^{OR}_{\pi\pi\gamma}\cdot f^{OR}_{MC\,\pi\pi\gamma}(\theta^+) + W^{OR}_{\mu\mu\gamma}\cdot f^{OR}_{MC\,\mu\mu\gamma}(\theta^+)$$

Wee,Wππ are fixed according to luminosity, Wμμ is free





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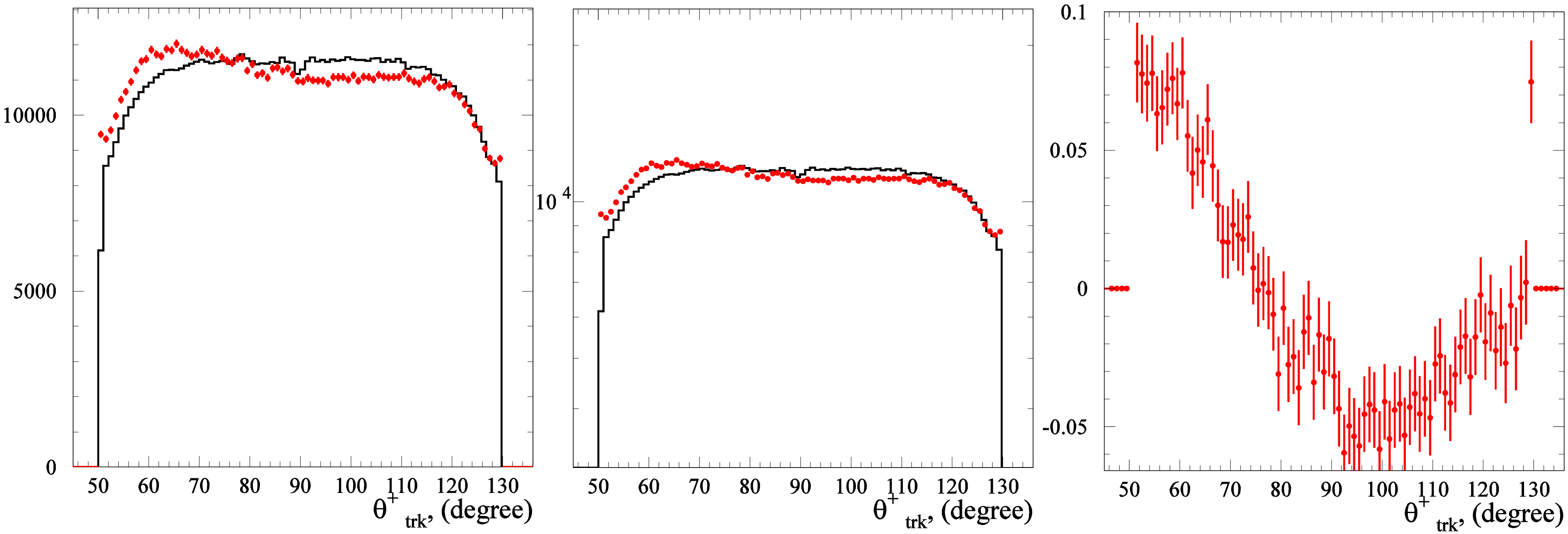
Background subtraction II (Results Fit 2)

histogram is MC $\mu\mu\gamma$ events, points with errors are EXP DATA,
Normalization is to the number of EXP DATA events after background subtraction



Relative difference = (EXP-MC)/EXP

Background subtraction II (Fit 3)

$$F^{OR}_{DATA}\left(\theta^{+}\right) = W^{OR}_{ee\gamma} \cdot f^{OR}_{MC\,ee\gamma}\left(\theta^{+}\right) + W^{OR}_{\pi\pi\gamma} \cdot f^{OR}_{MC\,\pi\pi\gamma}\left(\theta^{+}\right) + W^{OR}_{\mu\mu\gamma} \cdot f^{OR}_{MC\,\mu\mu\gamma}\left(\theta^{+}\right)$$

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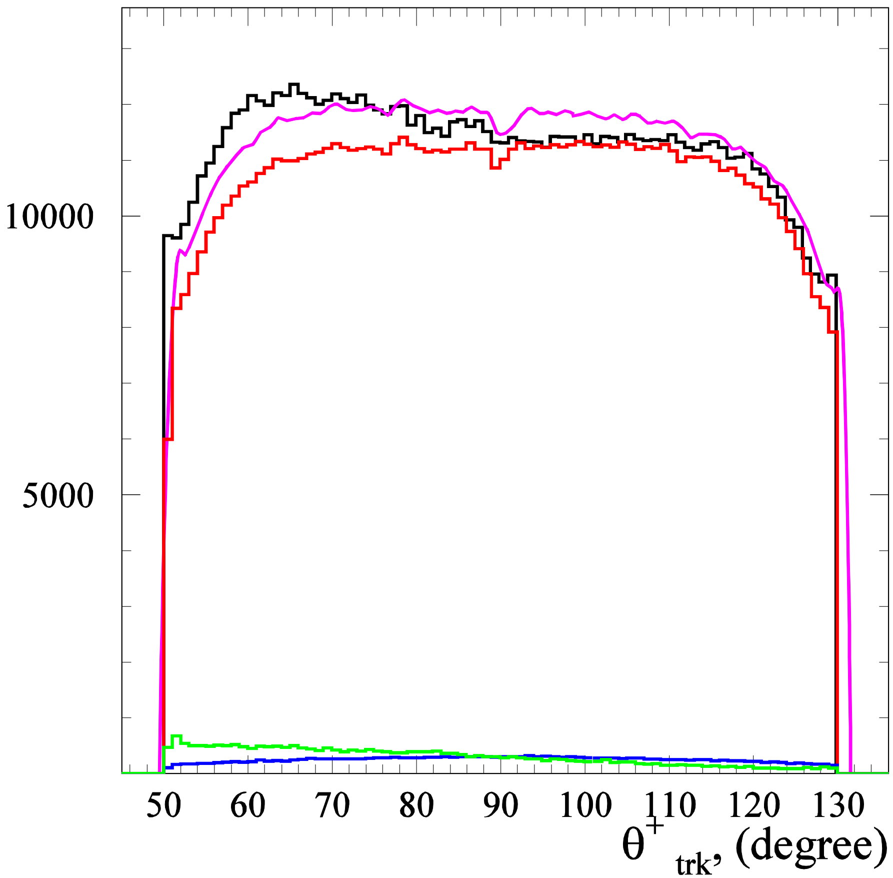

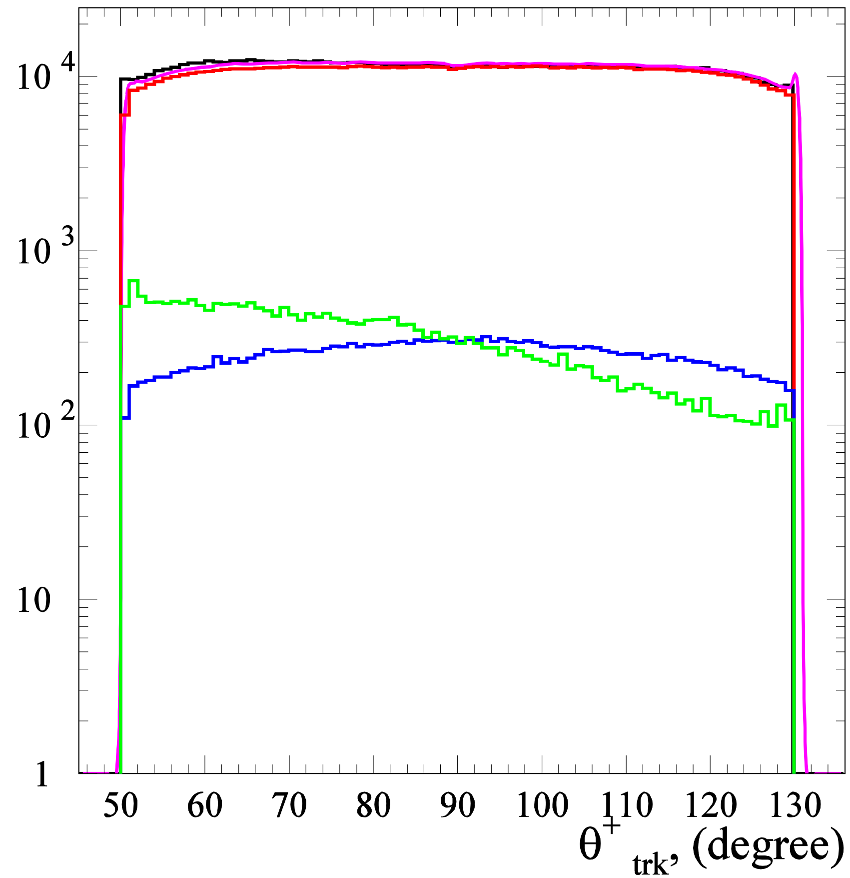

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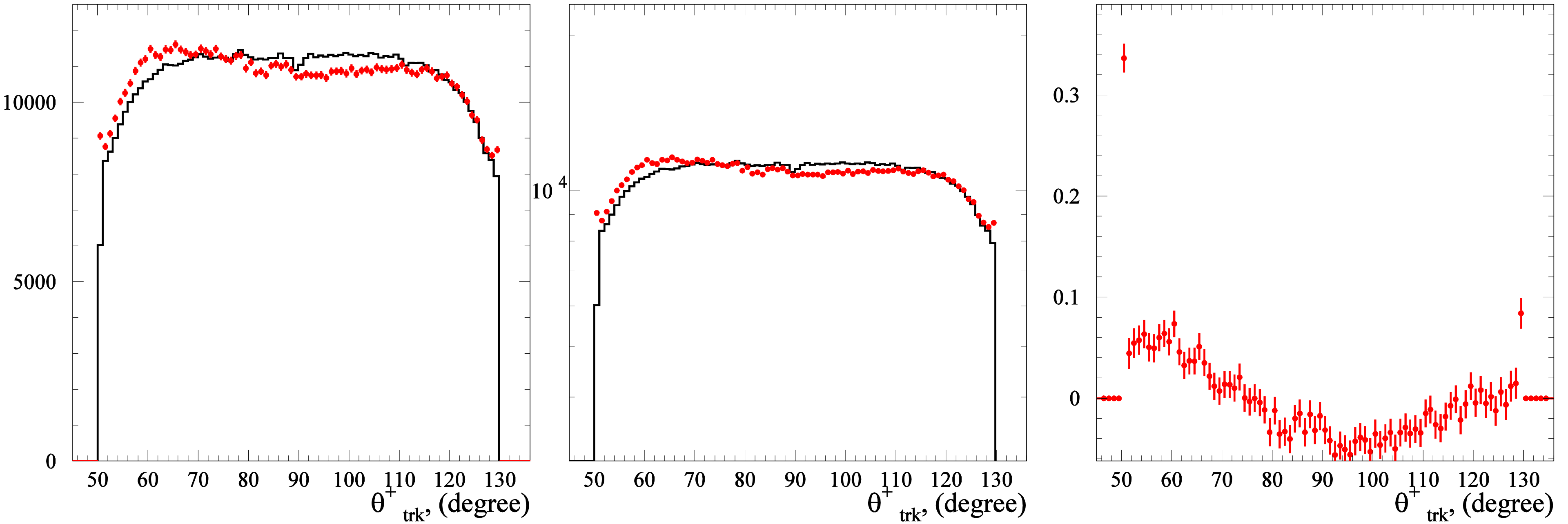
Background subtraction II (Results Fit 3)

histogram is MC $\mu\mu\gamma$ events, points with errors are EXP DATA,
Normalization is to the number of EXP DATA events after background subtraction



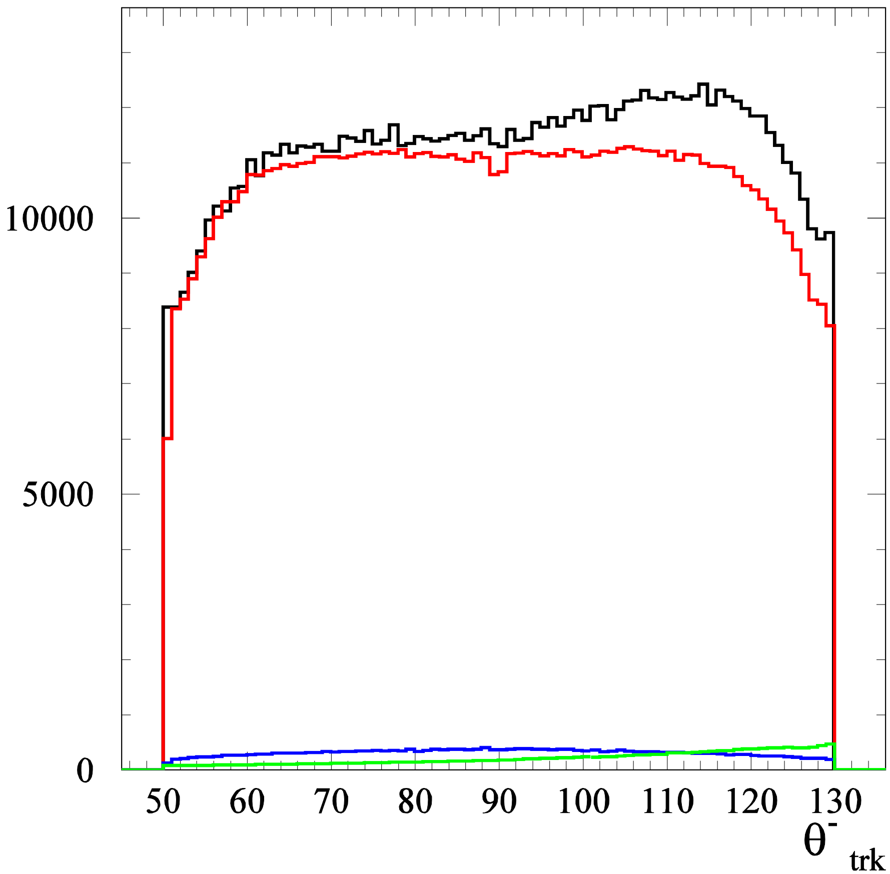
Relative difference = (EXP-MC)/EXP

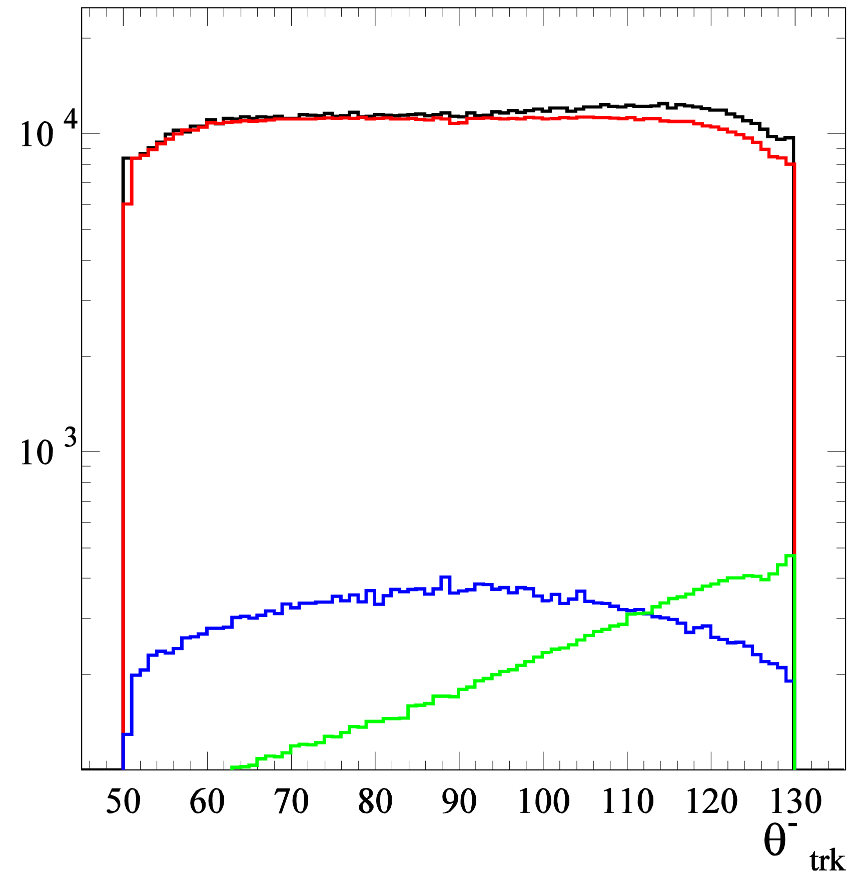
Negative muon polar angle

Background subtraction I (Fit)

$$F_{DATA}^{OR}(\theta^{-}) = W_{ee\gamma}^{XOR} \cdot f_{DATA}^{NOR}(\theta^{-}) + W_{\pi\pi\gamma}^{OR} \cdot f_{MC\,\pi\pi\gamma}^{OR}(\theta^{-}) + W_{\mu\mu\gamma}^{OR} \cdot f_{MC\,\mu\mu\gamma}^{OR}(\theta^{-})$$

Wee, Wππ are fixed from trackmass, Wμμ is free





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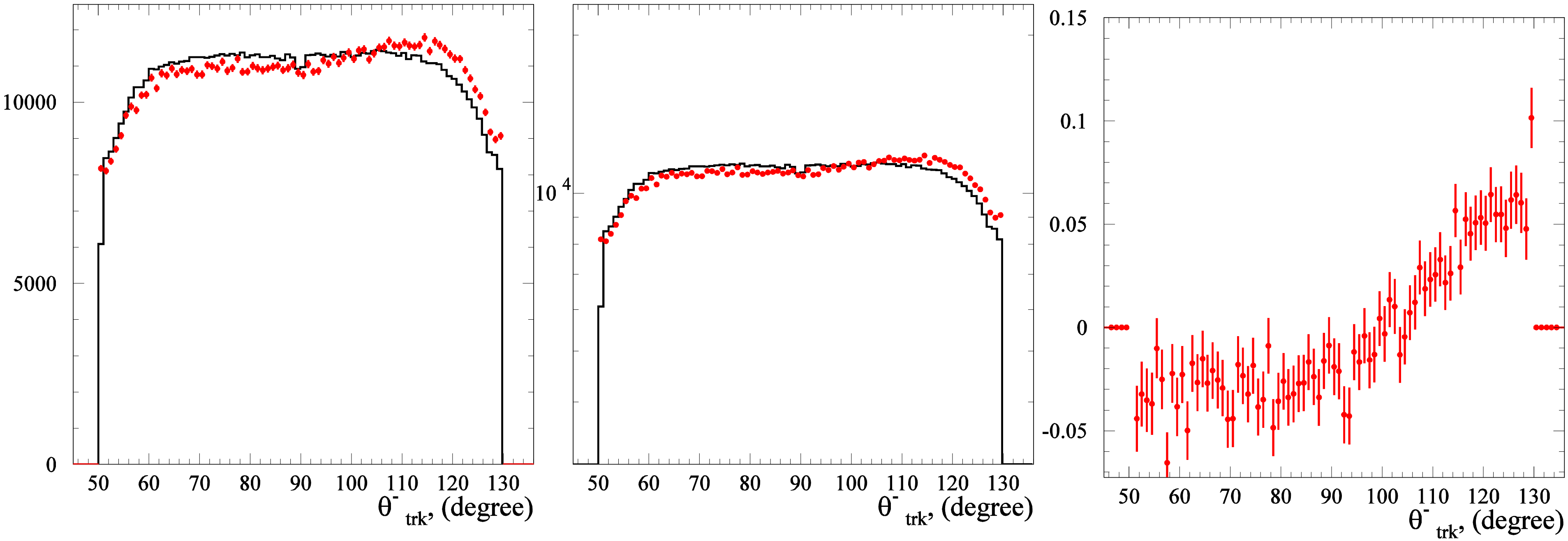
Background subtraction I (Results)

histogram is MC μμγ events, points with errors are EXP DATA,
Normalization is to the number of EXP DATA events after background subtraction

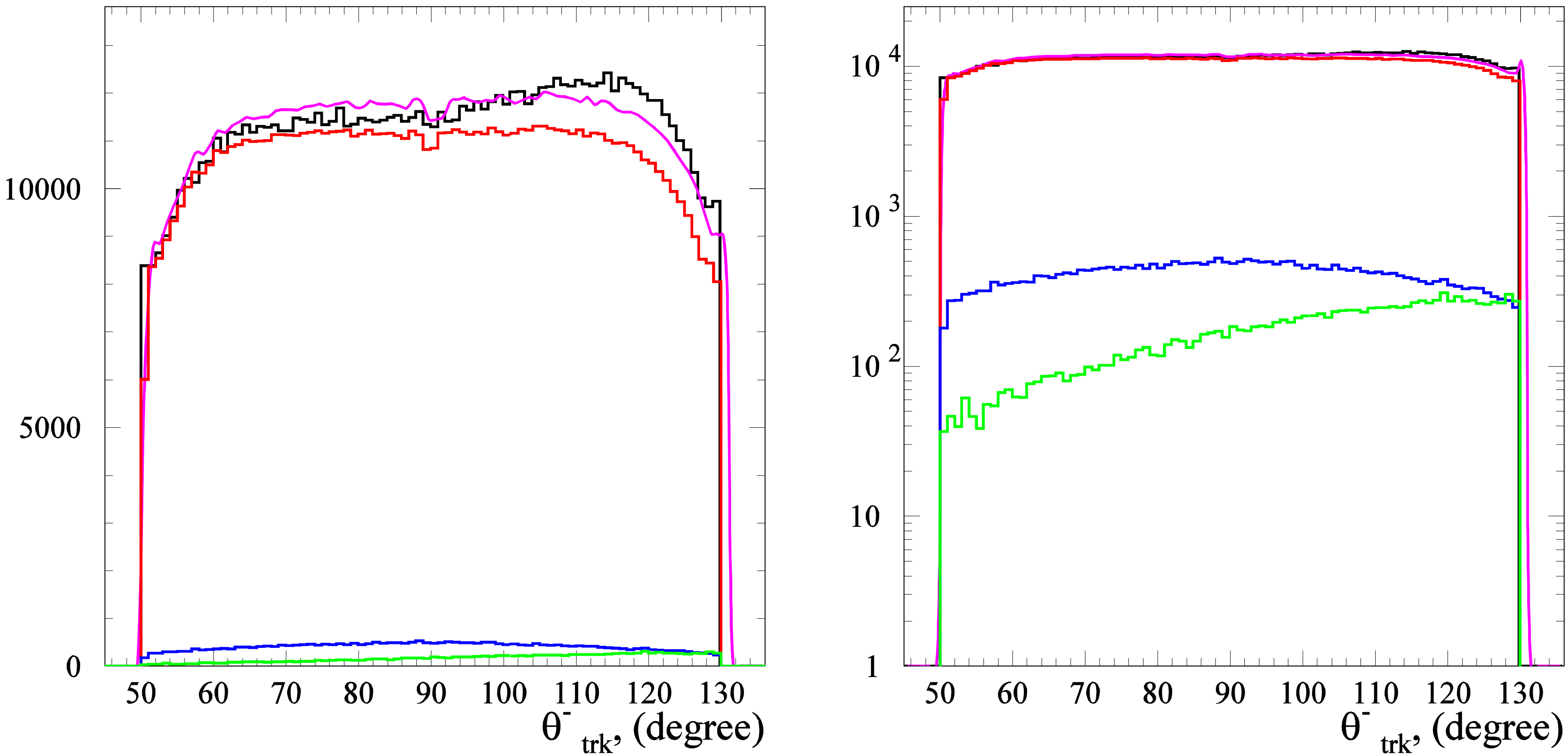


Relative difference = (EXP-MC)/EXP

Background subtraction II (Fit 1)

$$F^{OR}_{DATA}(\theta^-) = W^{OR}_{ee\gamma}\cdot f^{OR}_{MC\,ee\gamma}(\theta^-) + W^{OR}_{\pi\pi\gamma}\cdot f^{OR}_{MC\,\pi\pi\gamma}(\theta^-) + W^{OR}_{\mu\mu\gamma}\cdot f^{OR}_{MC\,\mu\mu\gamma}(\theta^-)$$

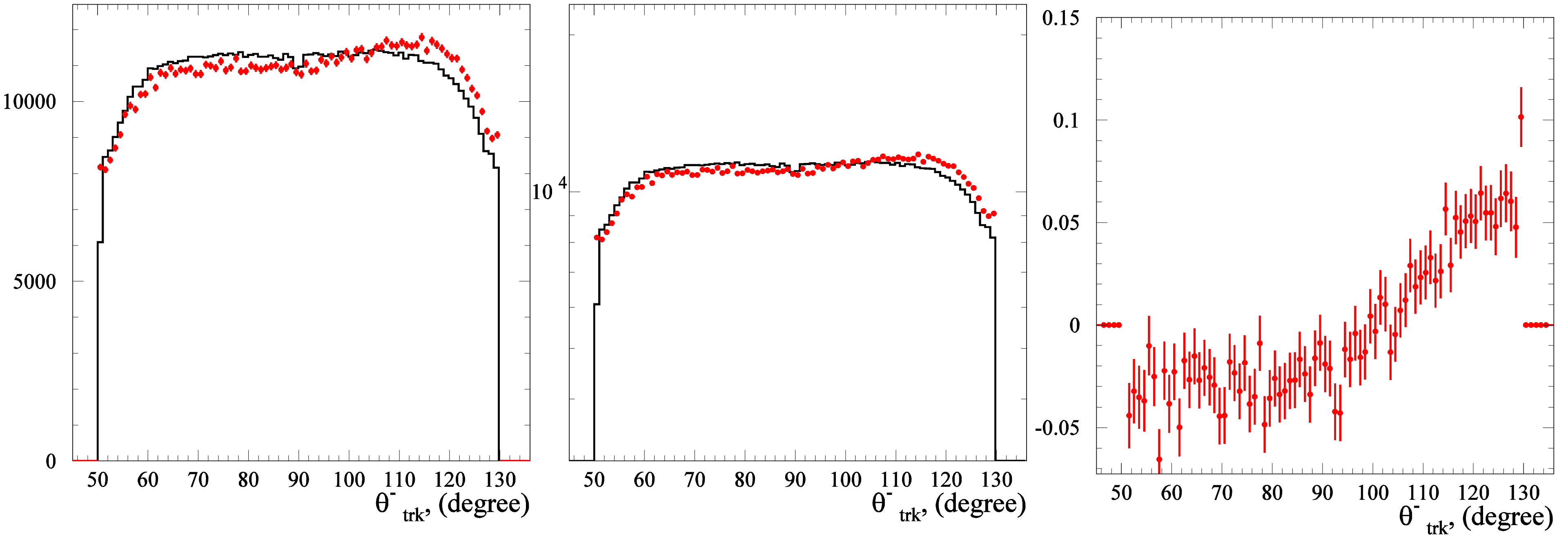
Wee is fixed from trackmass, Wμμ, Wππ are free



eeγ is green, ππγ is blue, μμγ is red, fitting function is magenta

Background subtraction II (Results Fit I)

histogram is MC μμγ events, points with errors are EXP DATA,
Normalization is to the number of EXP DATA events after background subtraction

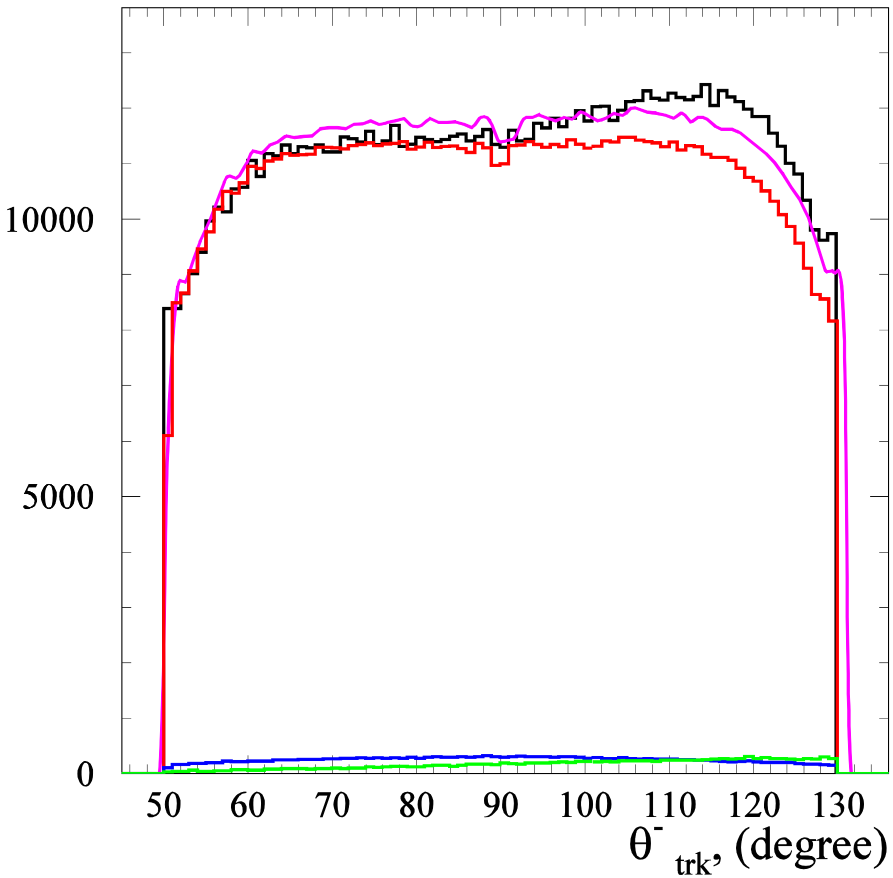


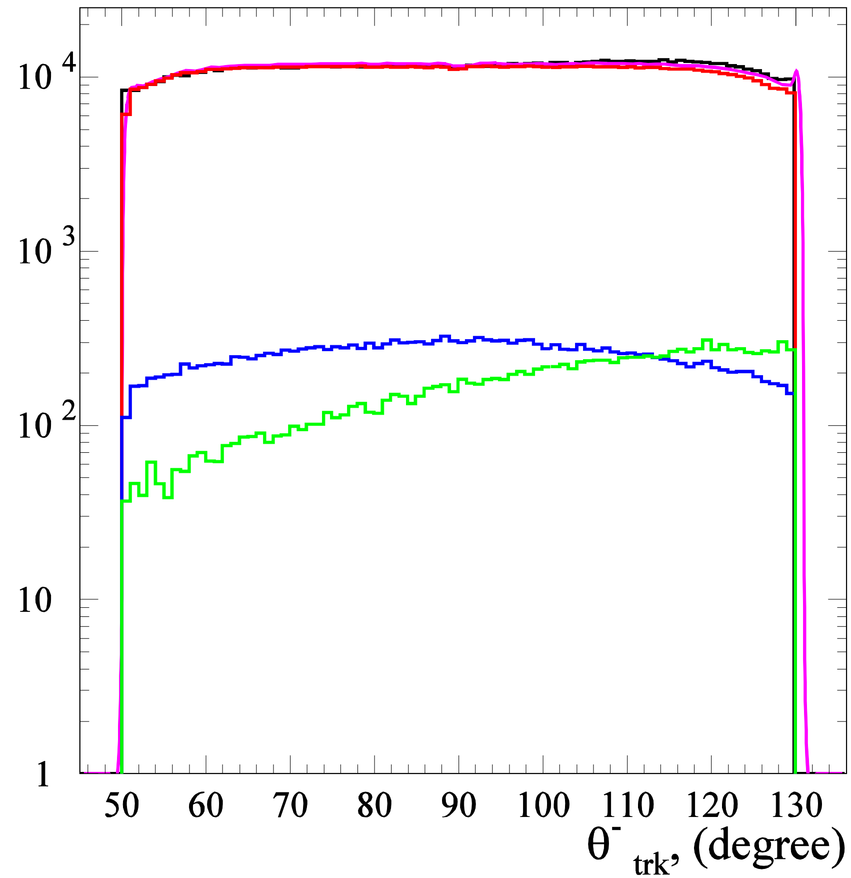
Relative difference = (EXP-MC)/EXP

Background subtraction II (Fit 2)

$$F^{OR}_{DATA}\left(\theta^{-}\right) = W^{OR}_{ee\gamma}\cdot f^{OR}_{MC\,ee\gamma}\left(\theta^{-}\right) + W^{OR}_{\pi\pi\gamma}\cdot f^{OR}_{MC\,\pi\pi\gamma}\left(\theta^{-}\right) + W^{OR}_{\mu\mu\gamma}\cdot f^{OR}_{MC\,\mu\mu\gamma}\left(\theta^{-}\right)$$

Wee, Wππ are fixed from trackmass, Wμμ is free

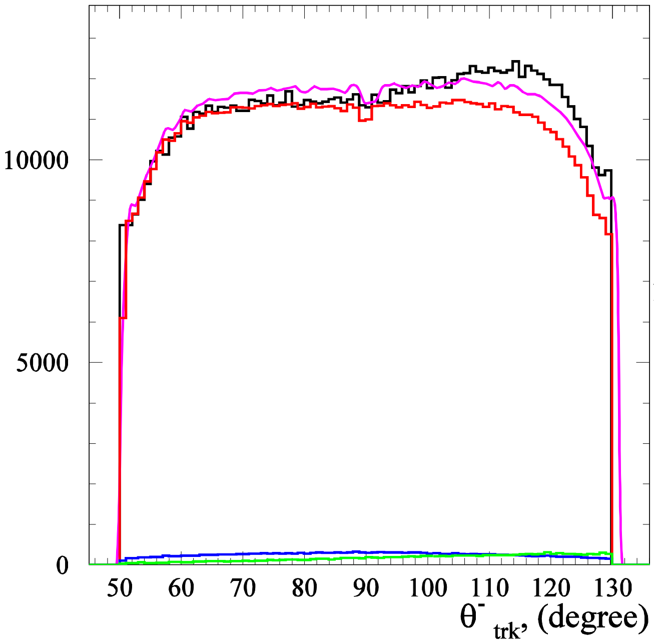


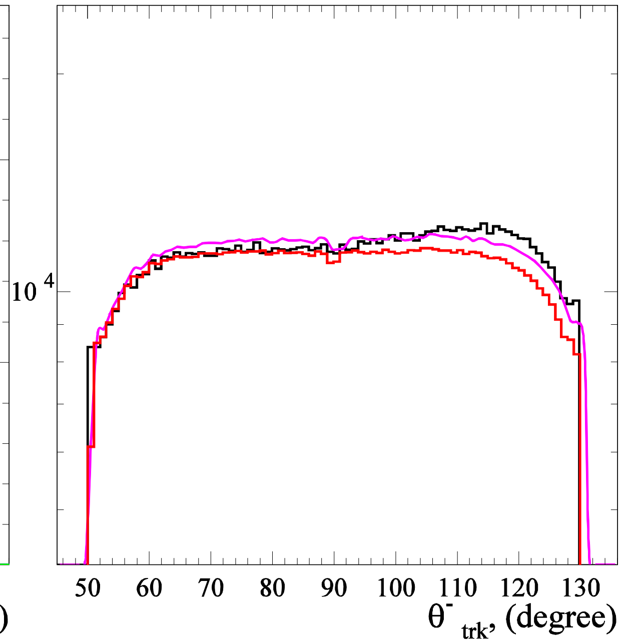


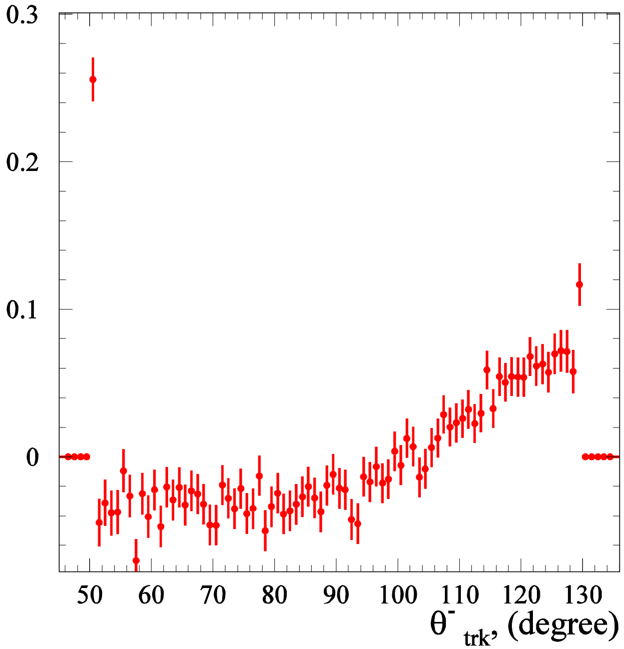
eeγ is green, ππγ is blue, μμγ is red, fitting function is magenta

Background subtraction II (Results Fit 2)

histogram is MC $\mu\mu\gamma$ events, points with errors are EXP DATA,
Normalization is to the number of EXP DATA events after background subtraction





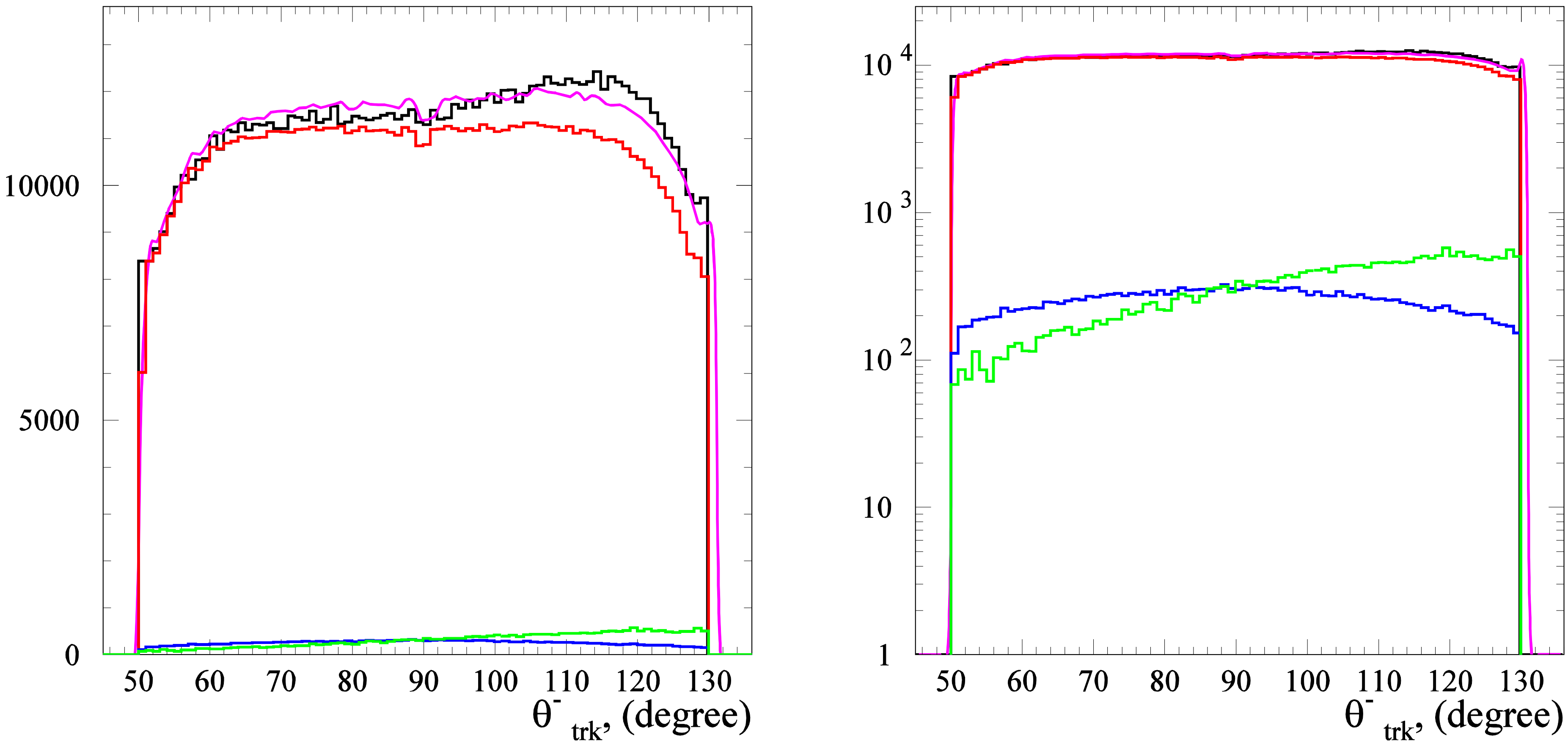


Relative difference = (EXP-MC)/EXP

Background subtraction II (Fit 3)

$$F^{OR}_{DATA}(\theta^-) = W^{OR}_{ee\gamma} \cdot f^{OR}_{MC\,ee\gamma}(\theta^-) + W^{OR}_{\pi\pi\gamma} \cdot f^{OR}_{MC\,\pi\pi\gamma}(\theta^-) + W^{OR}_{\mu\mu\gamma} \cdot f^{OR}_{MC\,\mu\mu\gamma}(\theta^-)$$

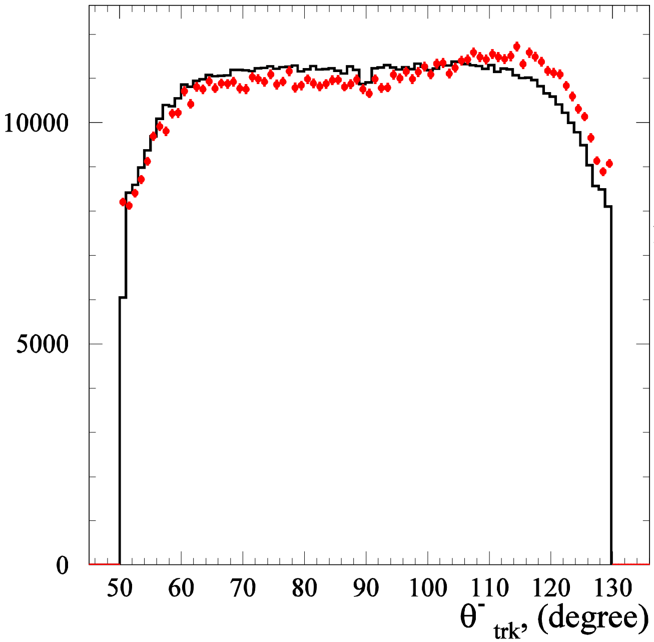
Wππ is fixed from luminosity, Wee,Wμμ are free

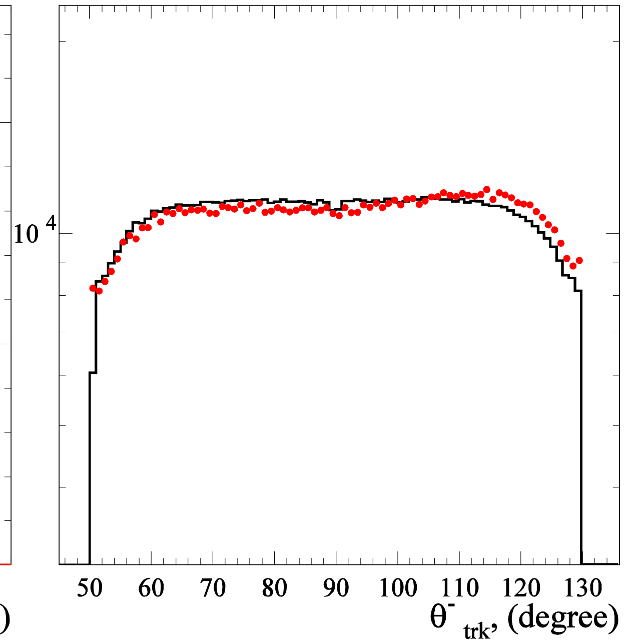


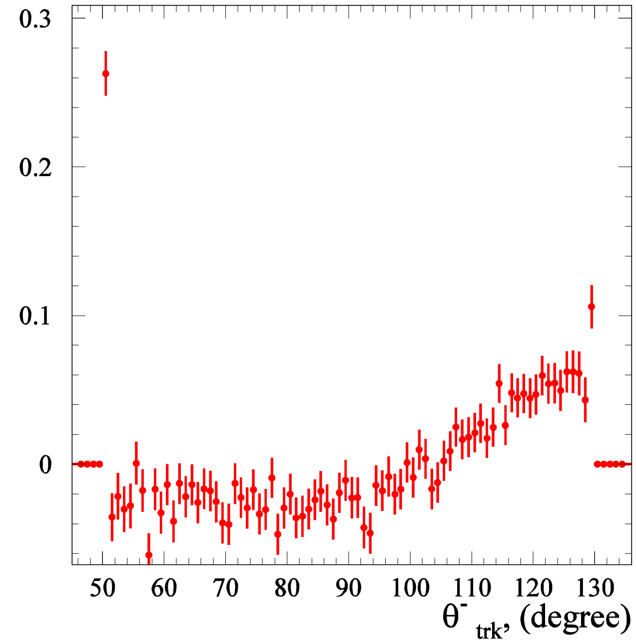
eeγ is green, ππγ is blue, μμγ is red, fitting function is magenta

Background subtraction II (Results Fit 3)

histogram is MC μμγ events, points with errors are EXP DATA,
Normalization is to the number of EXP DATA events after background subtraction



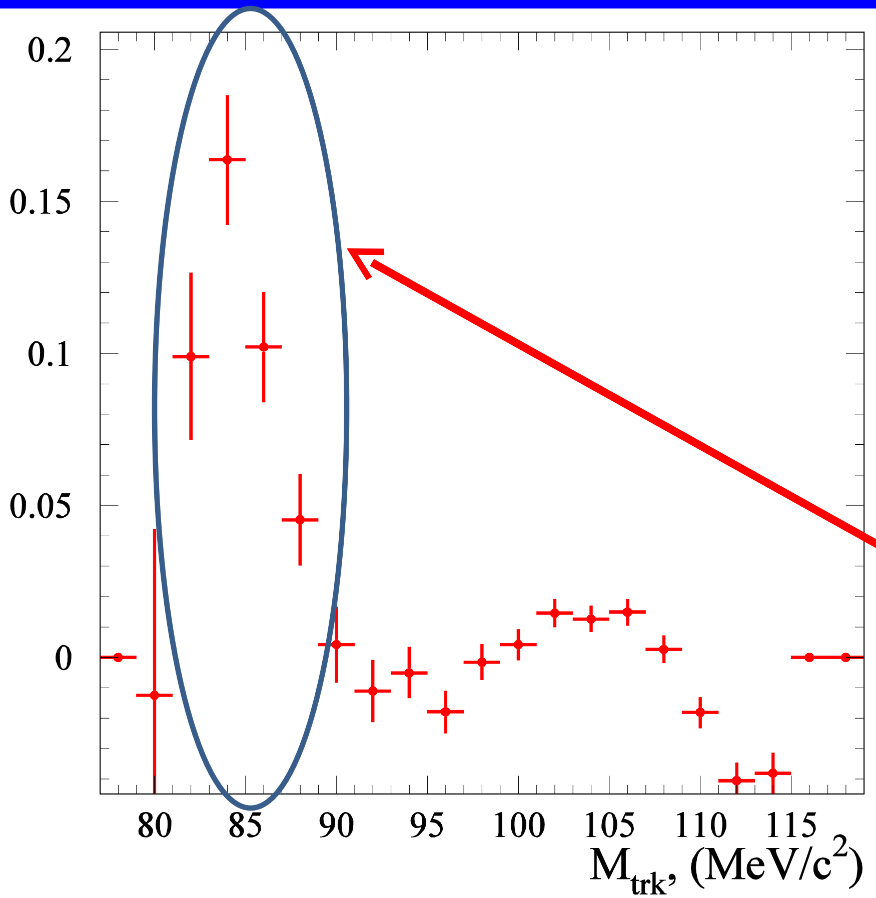


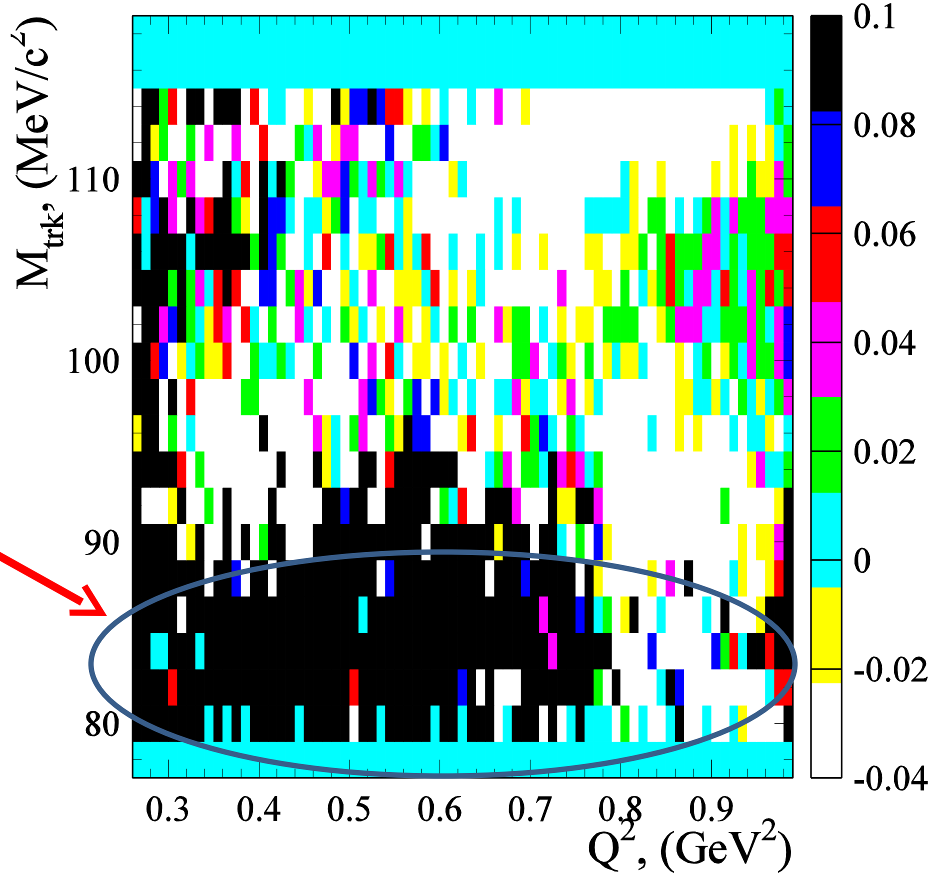


Relative difference = (EXP-MC)/EXP

To the nature of bump at 85 MeV

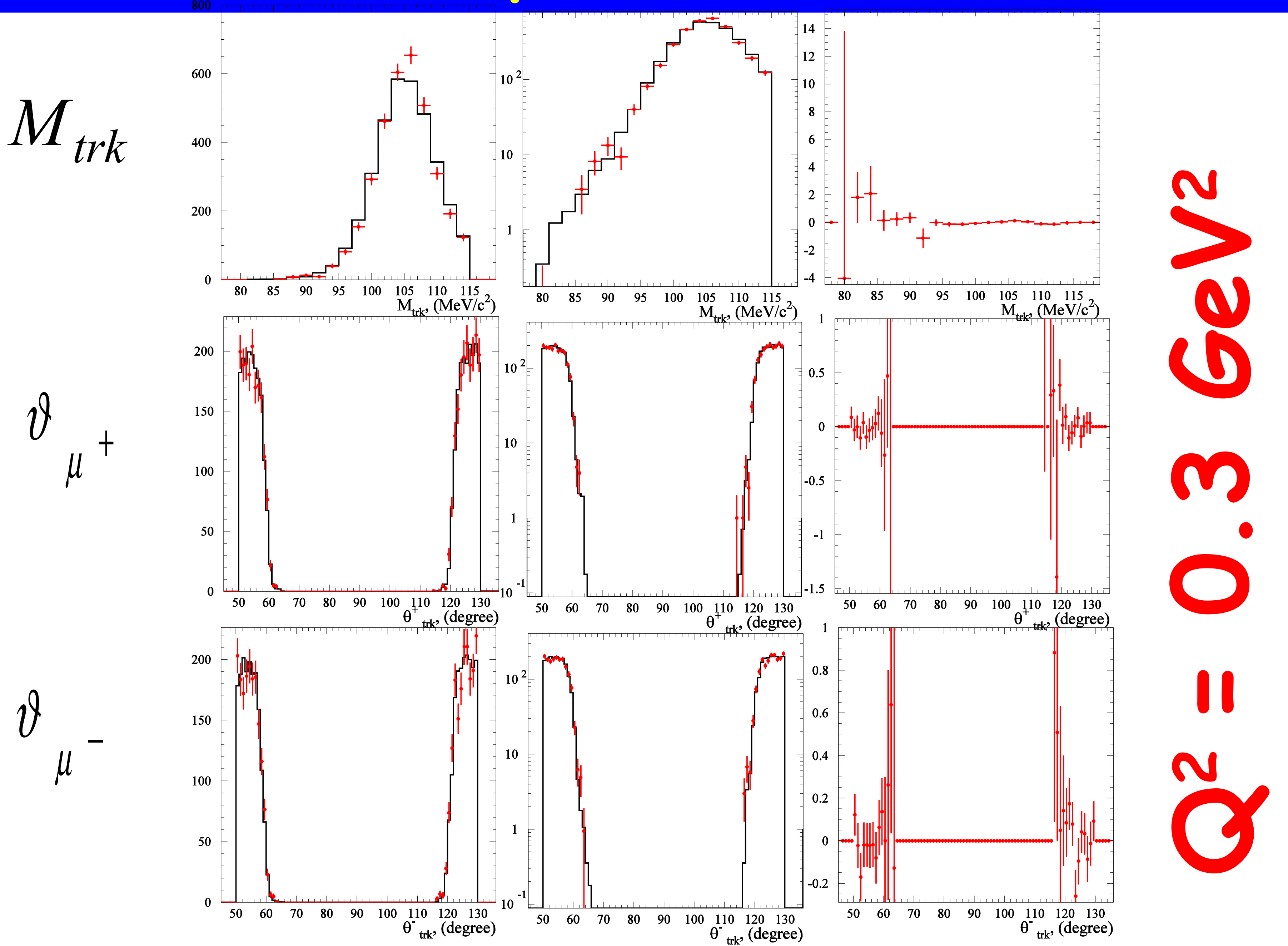
DATA/MC trackmass difference as a function of Q^2





Let's start discussion ?

DATA/MC Comparision in Q^2 slices (I)

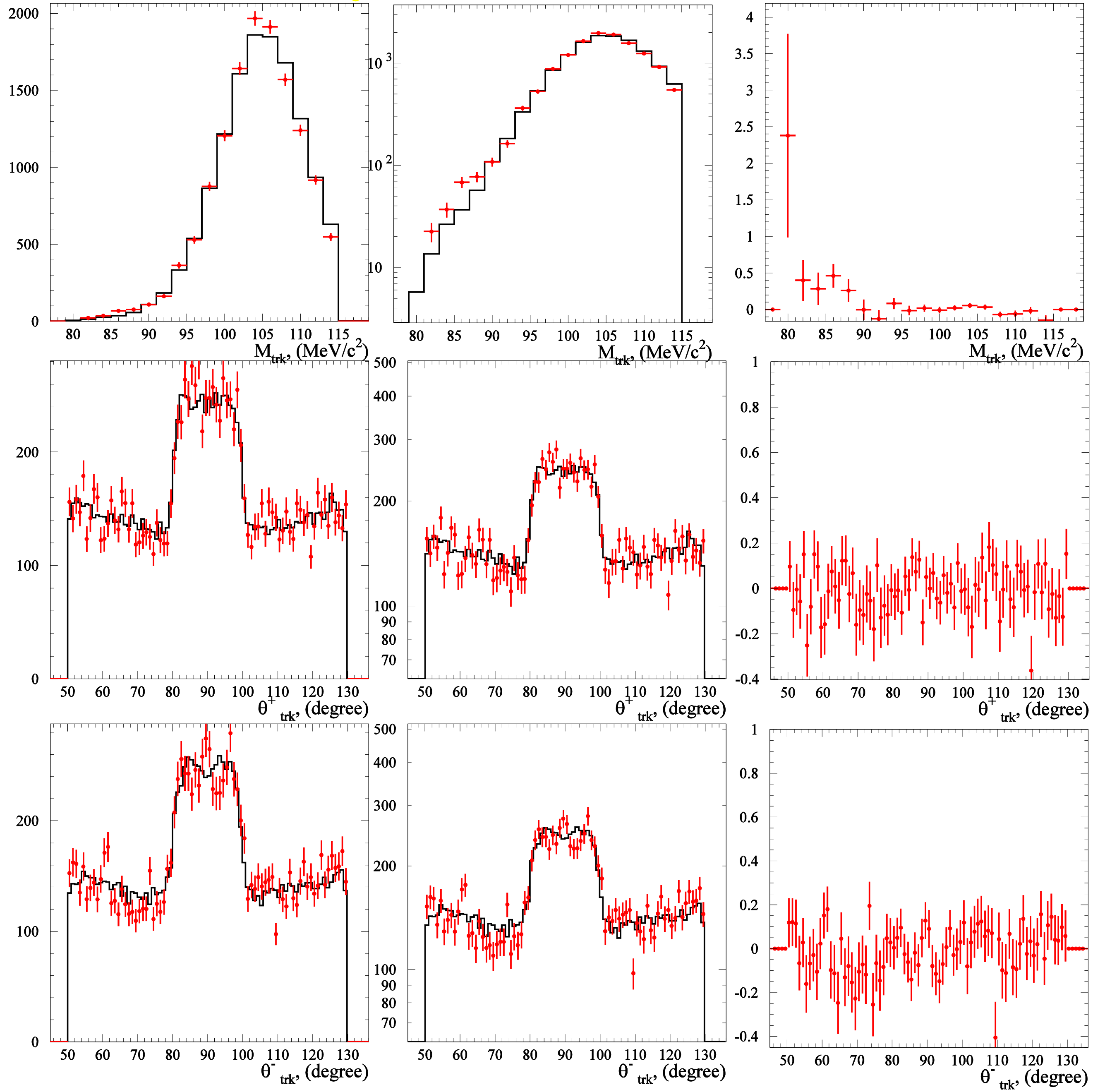


DATA/MC Comparision in Q^2 slices (II)

M_{trk}

ϑ_{μ^+}

ϑ_{μ^-}



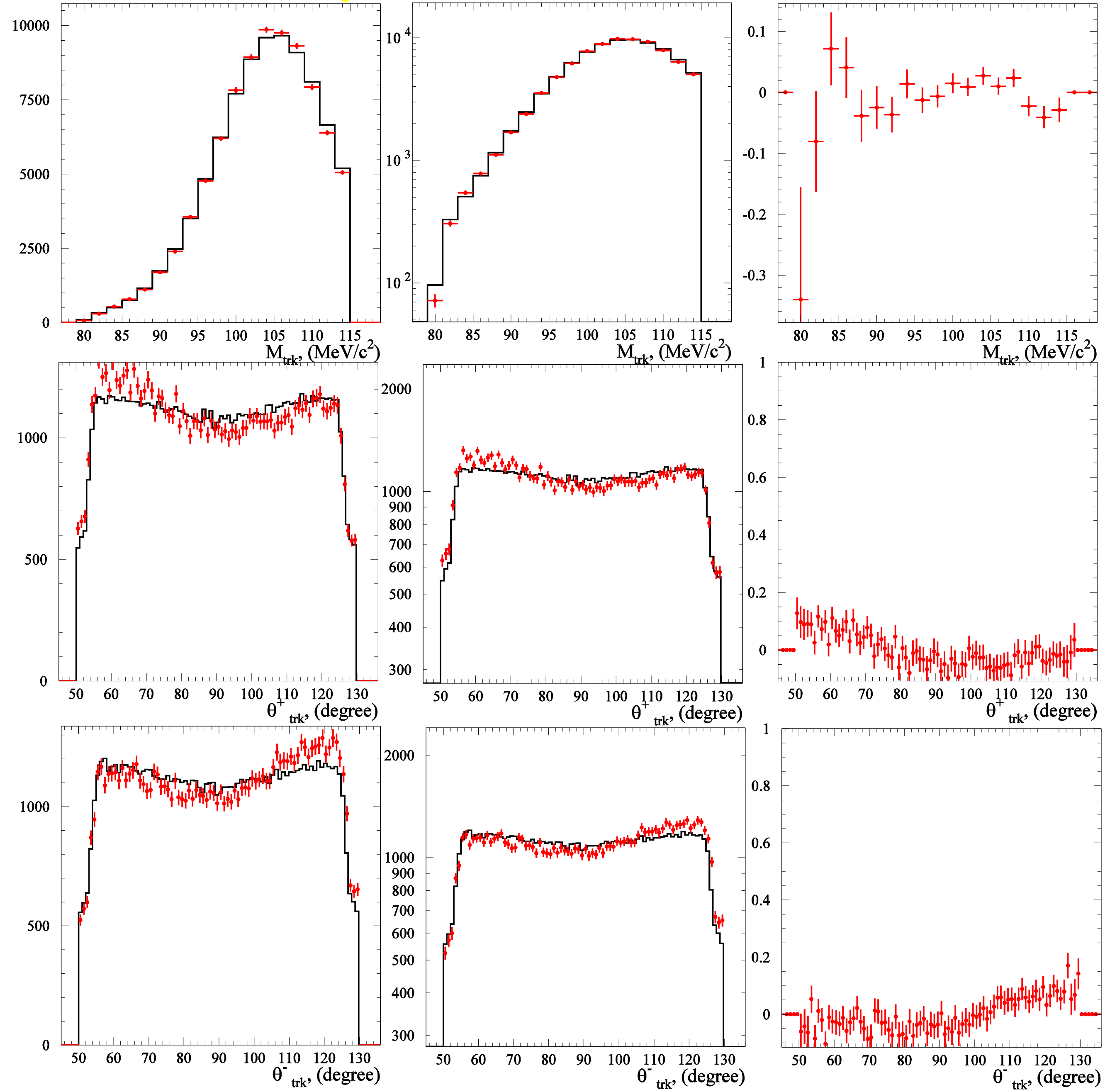
$Q^2 = 0.59$ GeV^2

DATA/MC Comparision in Q^2 slices (III)

M_{trk}

ϑ_{μ^+}

ϑ_{μ^-}



$Q^2 = 0.96$ GeV^2

Crosschecks with pions

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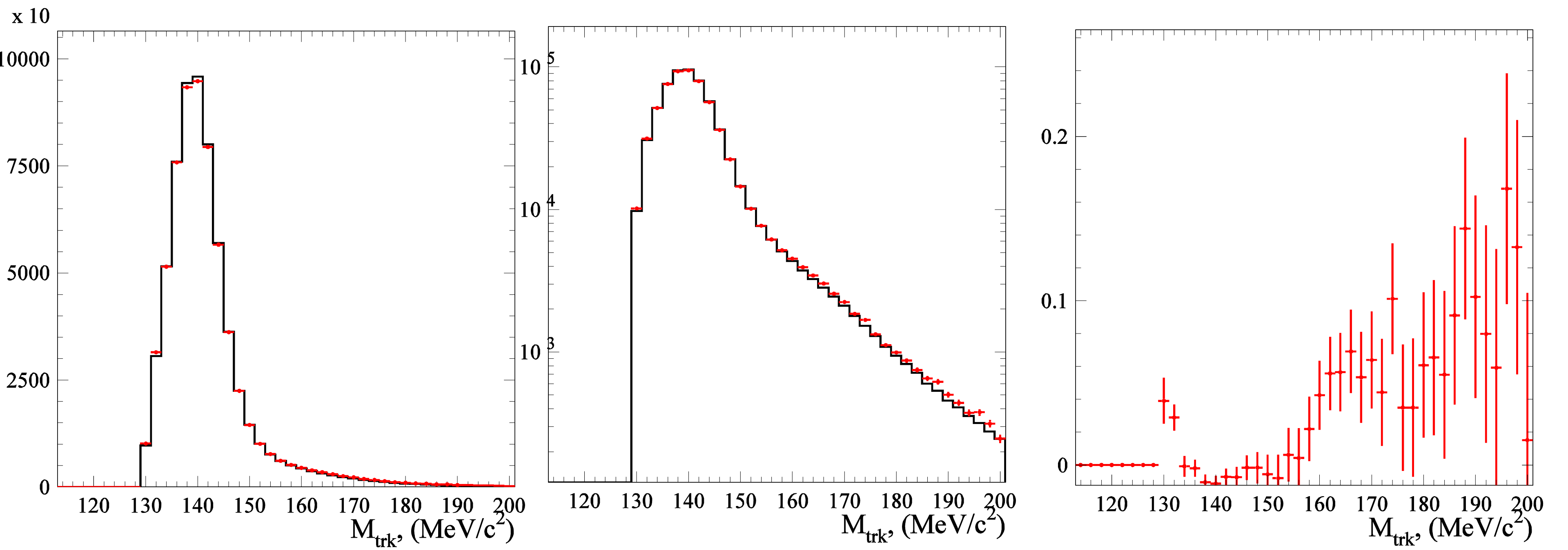
Pions trackmass

histogram is MC μμγ events, points with errors are EXP DATA,
Normalization is to the number of EXP DATA events after background subtraction

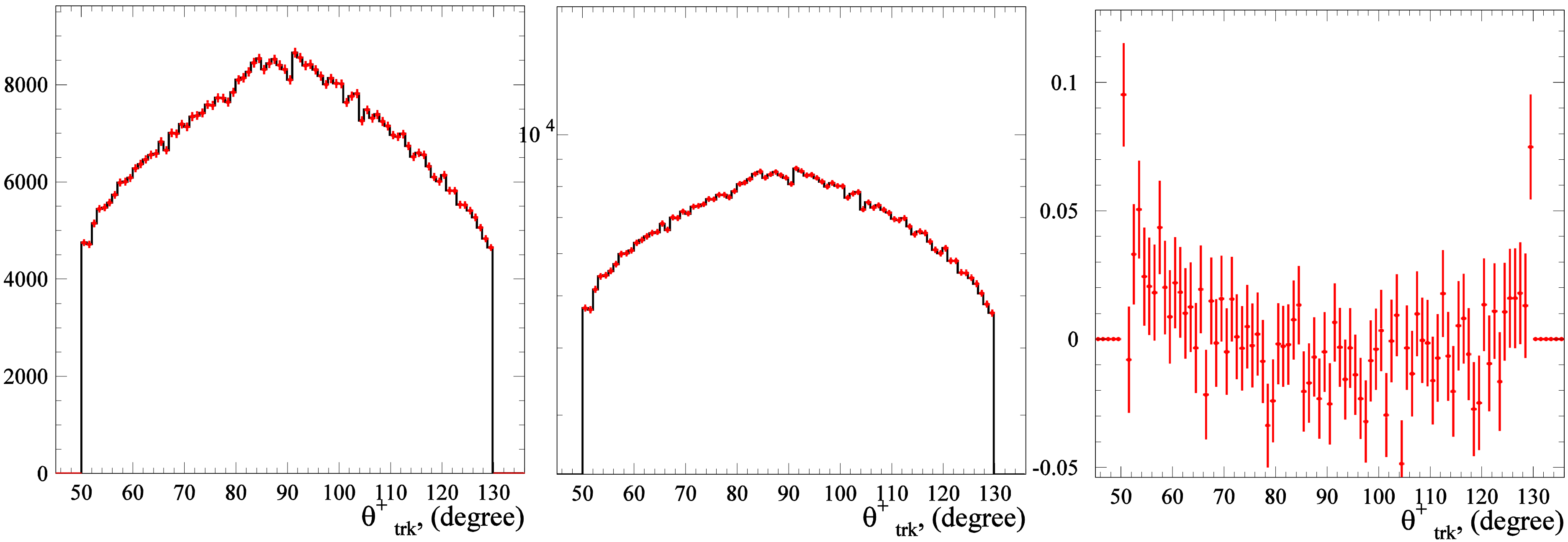


Relative difference = (EXP-MC)/EXP

Difference at higher trackmass is due to 3π background was not subtracted

Positive pion polar angle

histogram is MC μμγ events, points with errors are EXP DATA,
Normalization is to the number of EXP DATA events after background subtraction

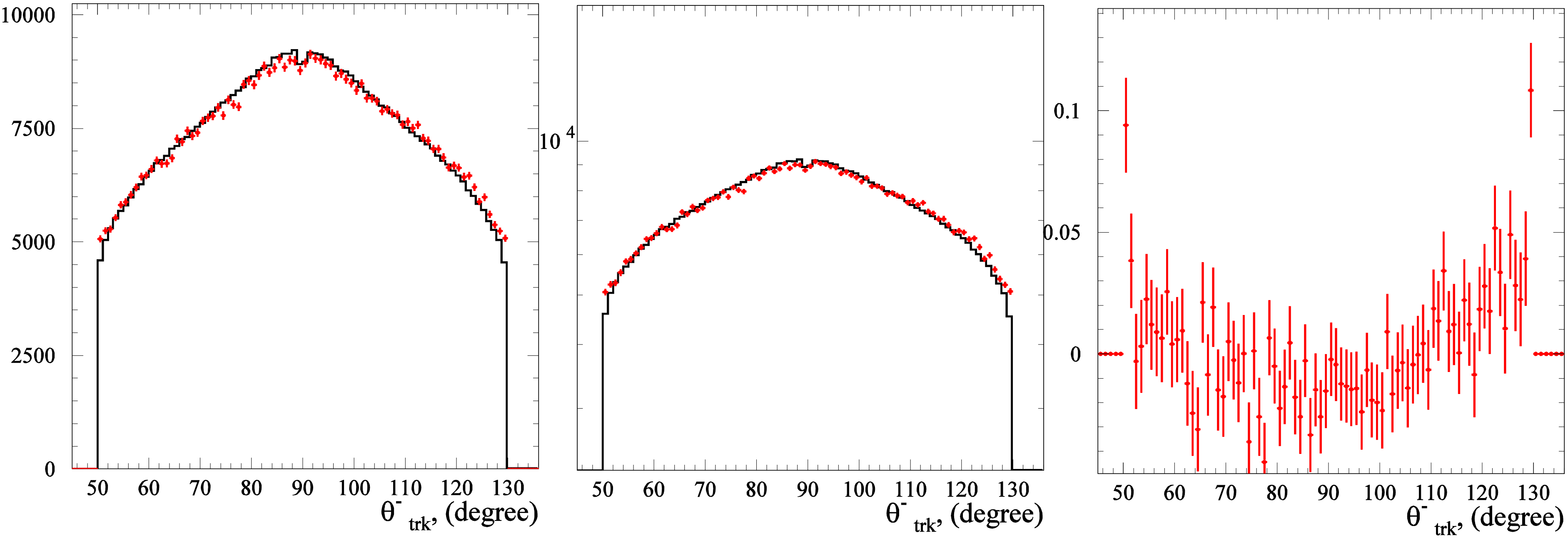


Relative difference = (EXP-MC)/EXP

3π background was not studied

Negative pion polar angle

histogram is MC $\mu\mu\gamma$ events, points with errors are EXP DATA,
Normalization is to the number of EXP DATA events after background subtraction



Relative difference = (EXP-MC)/EXP

3π background was not studied

Cross checks of MC Generators

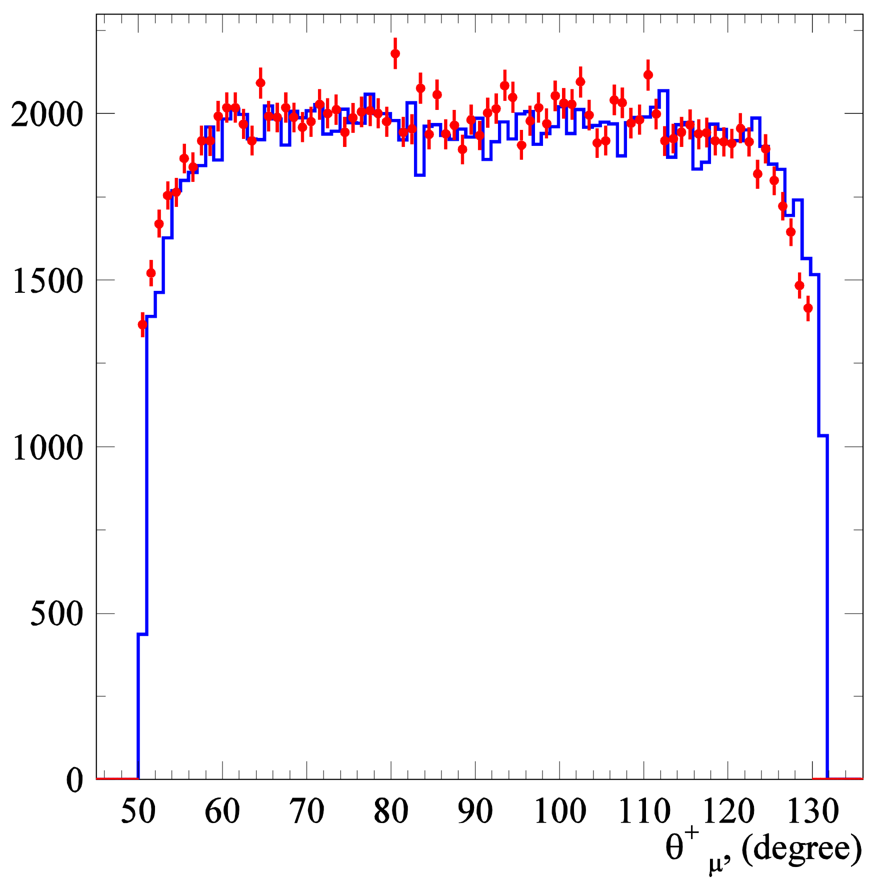
Comparision $\mu^+\mu^-$ MCGPJ & Phokhara 6.0

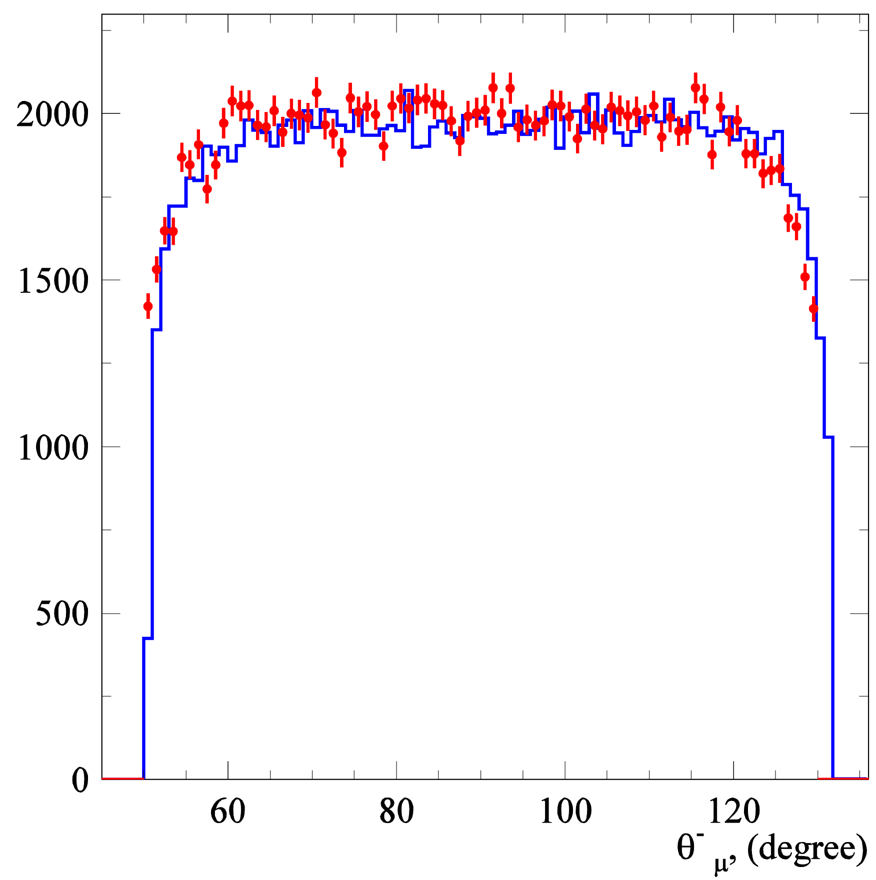
$MCGPJ: 50^\circ < \vartheta_\mu < 130^\circ, |\vartheta_\gamma - 90^\circ| > 75^\circ, \sum E_\gamma > 0.01\,\mathrm{GeV}$

$PHOKHARA: NLO + ISR + FSR + FSNLO$

PHOKHARA is blue histogram

MCGPJ is red points with errors





Quit good agreement in polar angle spectra is observed

Conclusion

- Comparision DATA/MC was performed in both in integral over all Q^2 and in different Q^2 slices.
- The two ways of Bhabha background subtraction were studied, but presence of other background is seen and should be studied yet.
- MC resolution adjustment probably should be performed for muons
- The start of the work is good enough and many things were studied, but a lot of work has to be done for successful completion of whole analysis

Let's continue our fruitful collaboration!

Thank You for Your attention