Update on GDA studies with $p\,\bar{p} \rightarrow \pi^0\gamma$ Channel

Faiza Khalid

Justus Liebig University Giessen

October 11, 2022

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

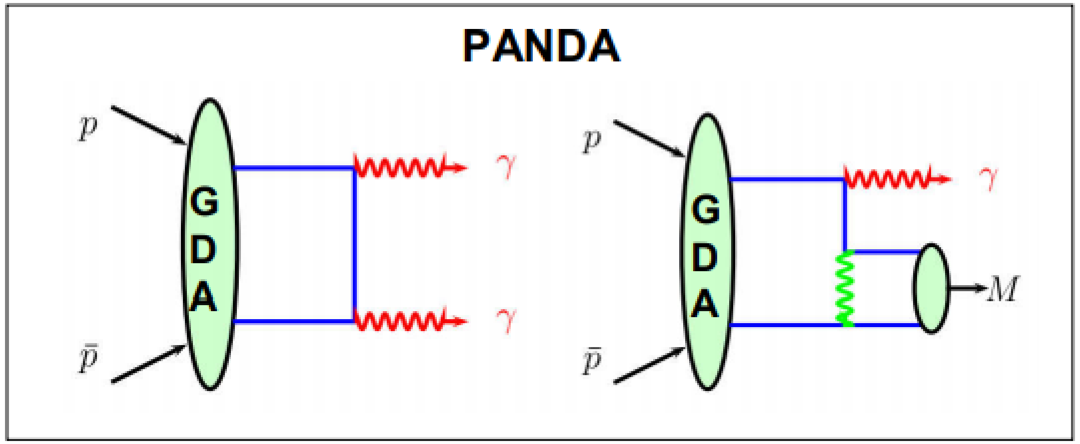
Introduction

$p\bar{p} \rightarrow \gamma\, M$ at large Mandelstam variables

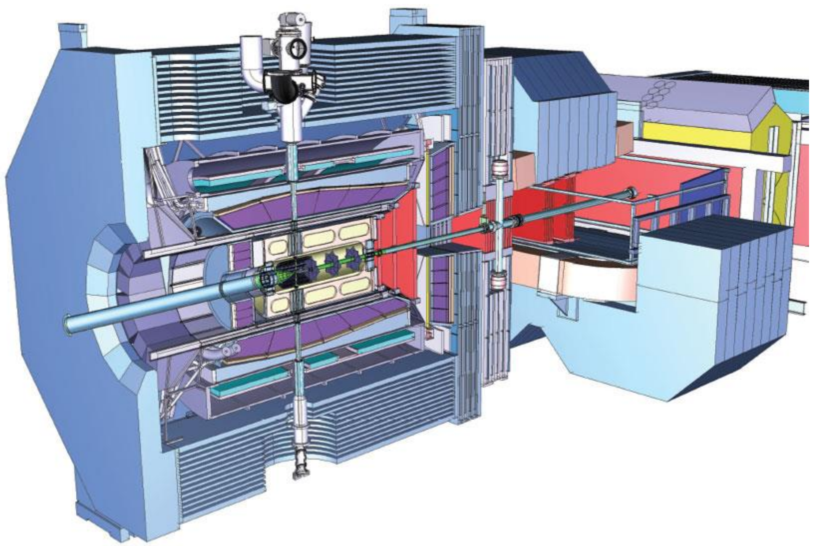
process amplitudes factorizes:

hard partonic subprocesses + annihilation form factors

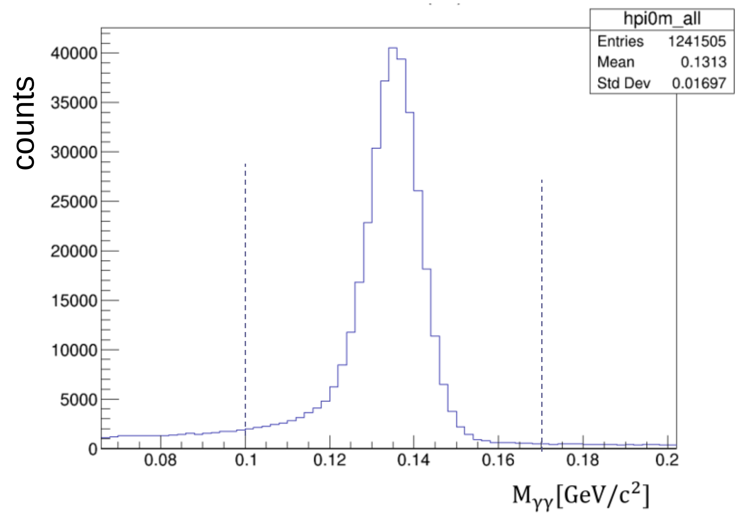
represent moments of baryon-antibaryon **G**eneralized **D**istribution **A**mplitudes (GDAs)



Simulation and Event Selection

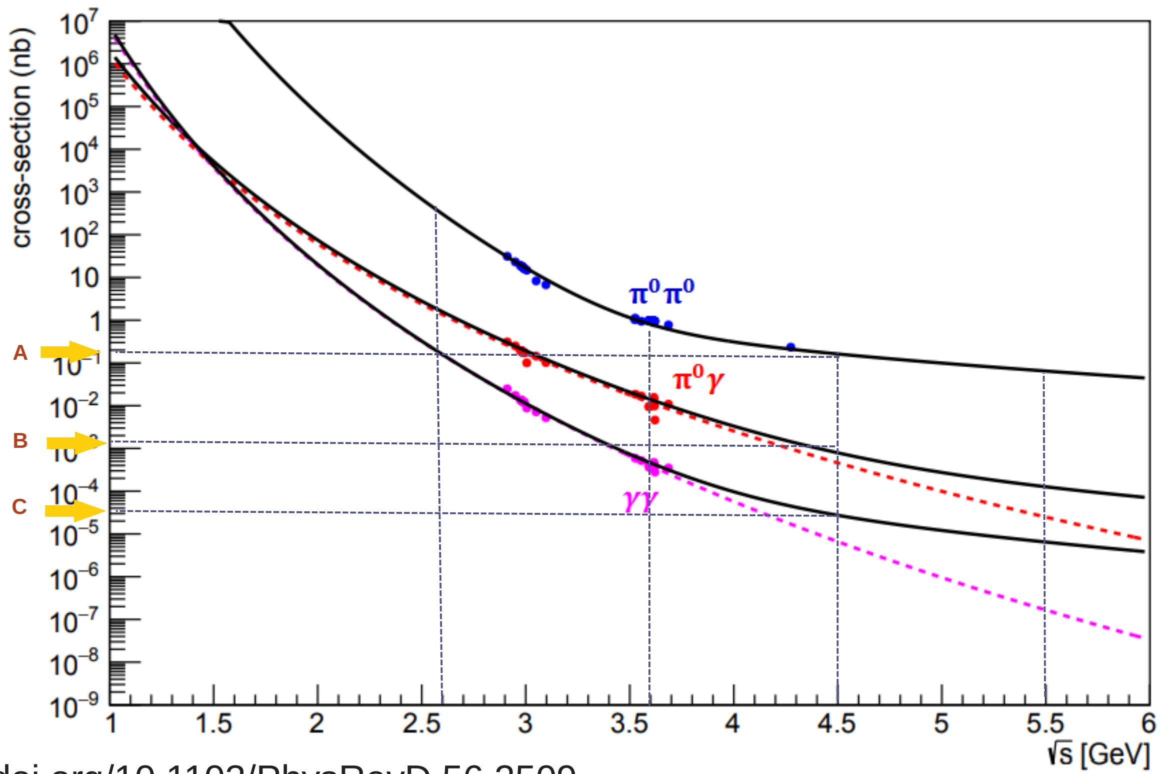


- Full MC simulation with PANDARoot Framework
- Signal $p\bar{p} \rightarrow \pi^0\gamma$ and background $p\bar{p} \rightarrow \pi^0\pi^0$
- 1M signal and 1M background events simulated at beam momenta of 2.5, 5 and 10 GeV
- Events with at least three photons were selected
- Pion mass cut: $0.1 < M_{\pi^0} < 0.17\ (\mathrm{GeV}/c^2)$
- Selected π^0 was combined with one of the remaining gamma to form initial $\bar{p}p$ system
- 4C fit is applied to select exclusive events



Cross-sections from E760 Data

- T. A. Armstrong*, Two-body neutral final states produced in antiproton-proton annihilations at $2.911 \leq \sqrt{s} \leq 3.686\ \text{GeV}$
- Integrated the angular range for a fixed $\sqrt{s}$ to get the partially integrated cross section in the cos(θ) range which is available for all energies.



$\sqrt{s}$	$\frac{\pi^0\pi^0}{\pi^0\gamma}$	$\frac{\pi^0\pi^0}{\gamma\gamma}$
2.6	226	1962
3.36	66	1502
4.5	386	27672
5.5	2485	361374

*https://doi.org/10.1103/PhysRevD.56.2509

Background Suppression with improved pions

- Neutral pions are reconstructed through their two photon decay channel
- Invariant mass spectrum is formed by combining all photons within an event into γγ pairs
- Invariant mass spectra has contribution from combinatorial γγ pairs which can be reduced by relying on the kinematics correlation of pion decay photons that the combinatorial γγ pairs do not display.
- ‘Feasibility study for the measurement of πN TDAs at PANDA in $\bar{p}p \rightarrow J/\Psi\pi^0$’

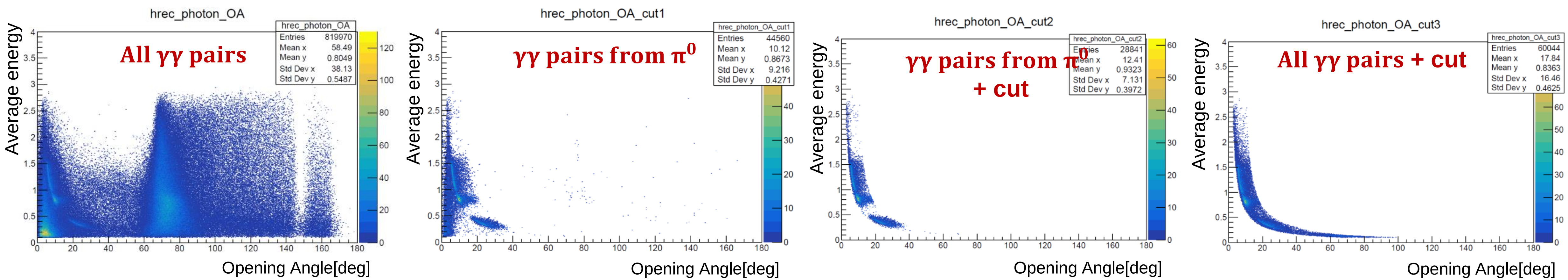
$$f_L(OA) < \frac{E_{\gamma_1} + E_{\gamma_2}}{2} < \begin{cases} \infty, & if\ OA \leq a_2^U \\ f_L(OA), & if\ OA > a_2^U \end{cases}$$

$$f_L(x) = a_0^L + \frac{a_1^L}{x - a_2^L}$$

$$f_U(x) = a_0^U + \frac{a_1^U}{x - a_2^U}$$

BKG: Correlation of the reconstructed average photon energy to the opening angle

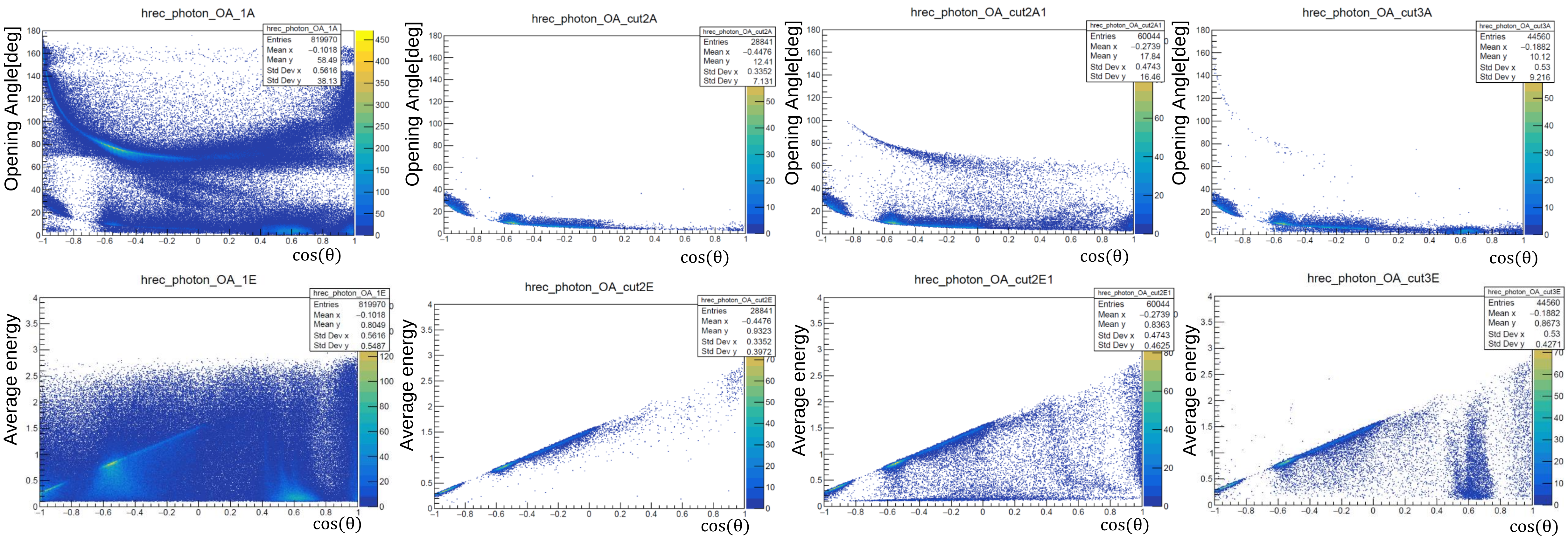
$E_\gamma > 0.1 + Kinfit > 0.01$



Average reconstructed energy of a photon pair versus its opening angle for all γγ pairs within an event (All) compared to γγ pairs stemming from π^0 decay before (MCTM) and after the cut (MCTM+OA), and all γγ pairs after cut (OA), in a simulation of $\bar{p}p \rightarrow \pi^0\gamma$ at beam momentum of 5 GeV/c.

BKG: Opening angle vs costheta and Average reconstructed energy of photon pair vs costheta for background at 5 GeV with $E_\gamma > 0.1$

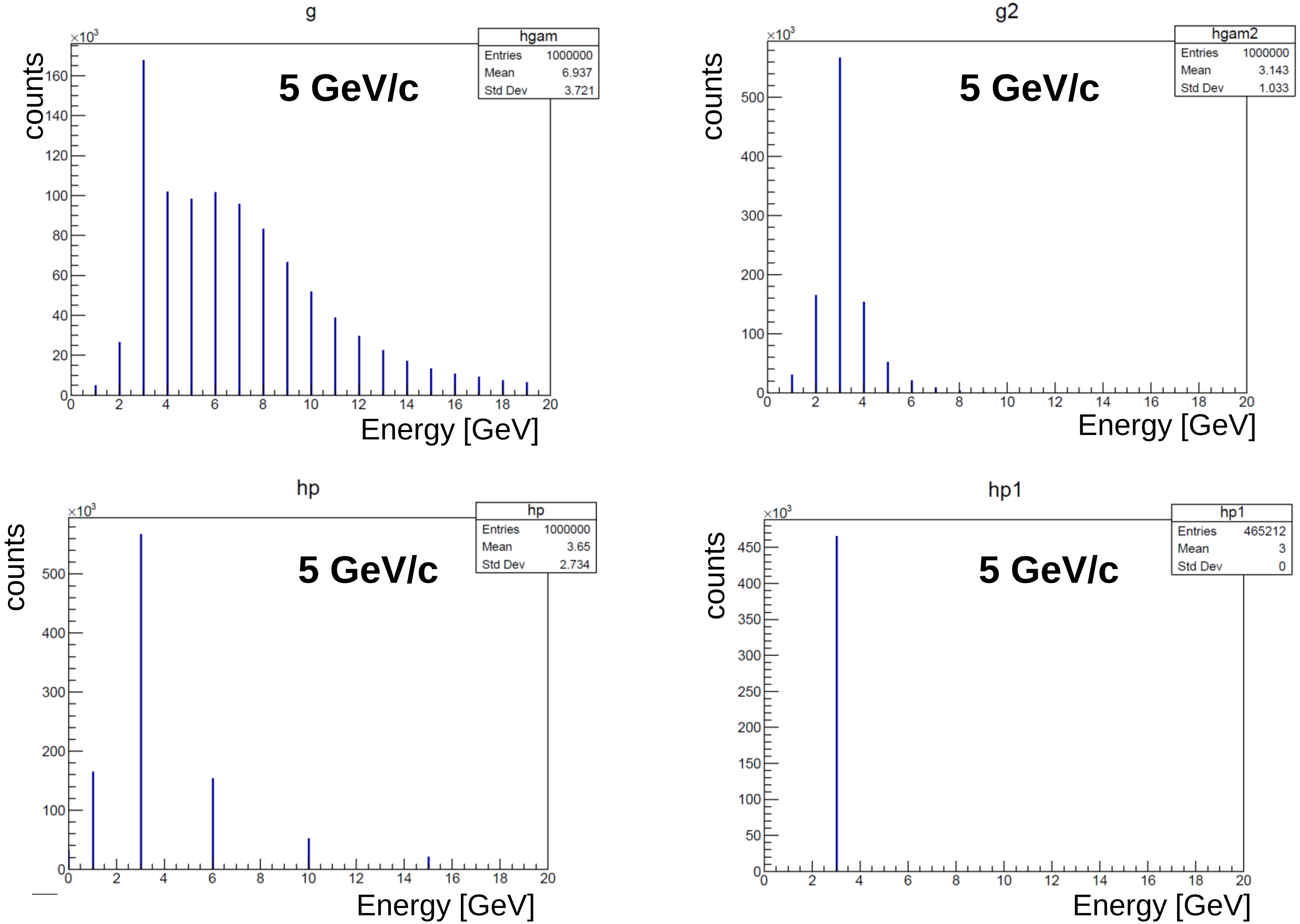
$E_\gamma > 0.1 + Kinfit > 0.01$



Upper row shows opening angle vs costheta and lower row shows the average reconstructed energy of a photon pair versus costheta. Left to right: All, MCTM+OA, MCTM and OA

$E_\gamma > 0.1 + N_{\pi^0} = 1$

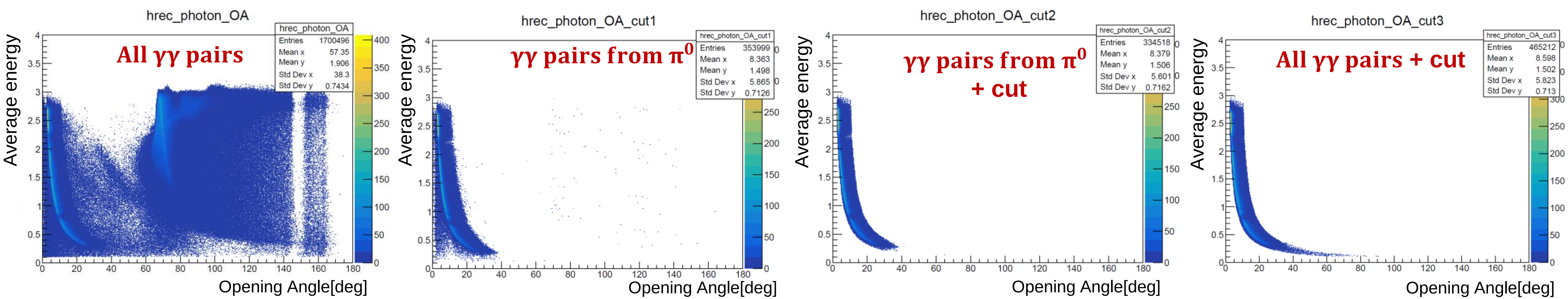
SIGNAL



Gamma distribution before energy threshold and after threshold; Distribution of pions with energy threshold and with additional OA & Energy cuts for energy threshold of 0.1GeV.

SIG: Correlation of the reconstructed average photon energy to the opening angle

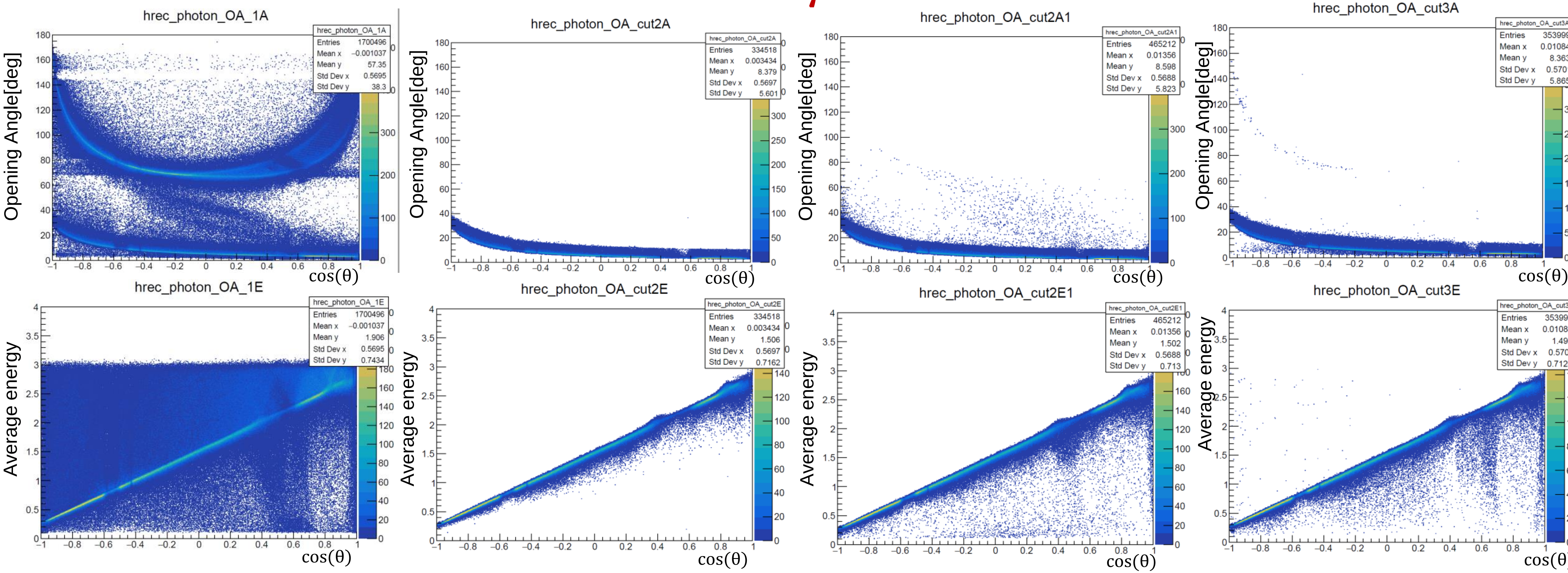
$E_\gamma > 0.1 + N_{\pi^0} = 1$



Average reconstructed energy of a photon pair versus its opening angle for all γγ pairs within an event (All) compared to γγ pairs stemming from π^0 decay before (MCTM) and after the cut (MCTM+OA), and all γγ pairs after cut (OA), in a simulation of $\bar{p}p \rightarrow \pi^0\gamma$ at beam momentum of 5 GeV/c.

SIG: Opening angle vs costheta and Average reconstructed energy of photon pair vs costheta for background at 5 GeV with $E_{\gamma} > 0.1$

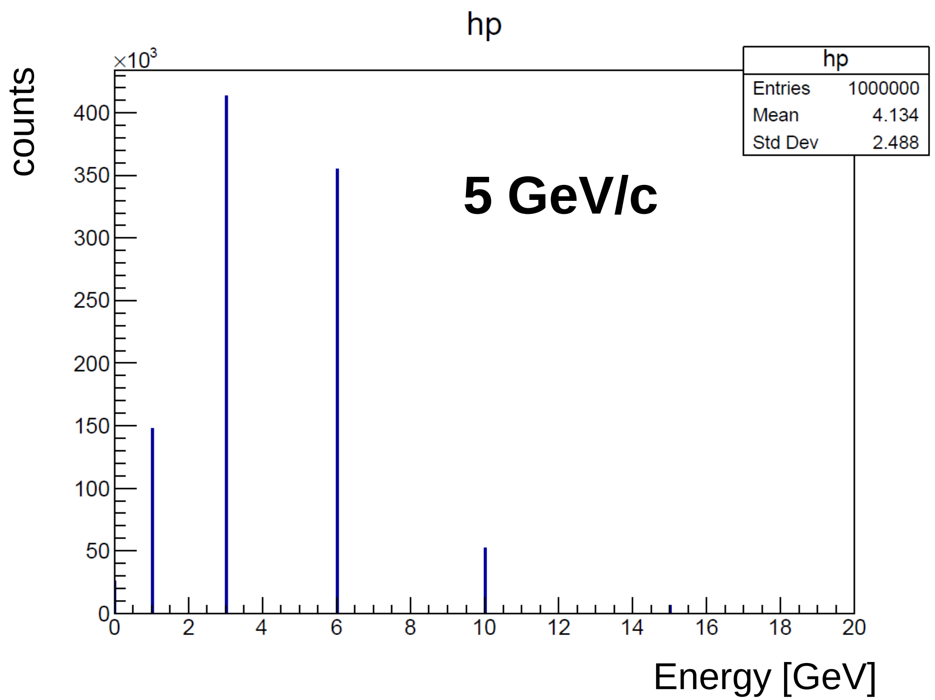
$E_{\gamma} > 0.1 + N_{\pi^0} = 1$

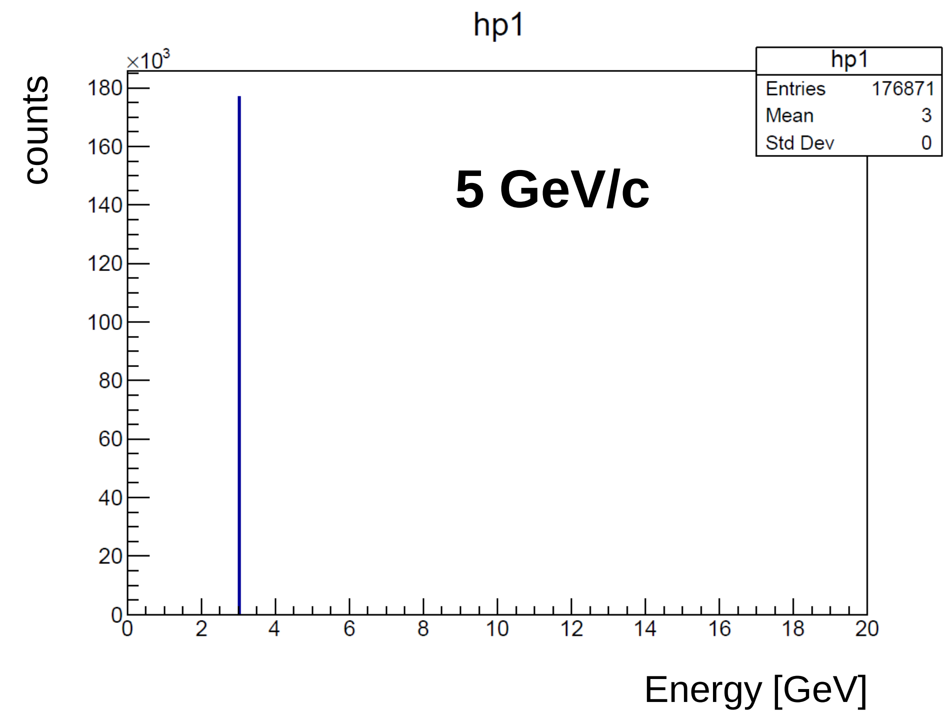


Upper row shows opening angle vs costheta and lower row shows the average reconstructed energy of a photon pair versus costheta. Left to right: All, MCTM+OA, MCTM and OA

$E_\gamma > 0.1 + N_{\pi^0} = 1$

BACKGROUND

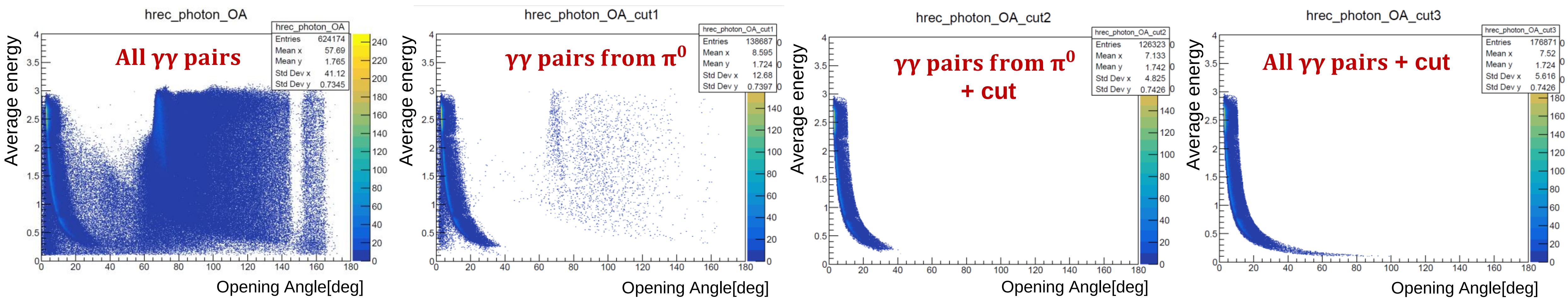




Distribution of pions with energy threshold and with additional OA & Energy cuts for energy threshold of 0.1GeV.

BKG: Correlation of the reconstructed average photon energy to the opening angle

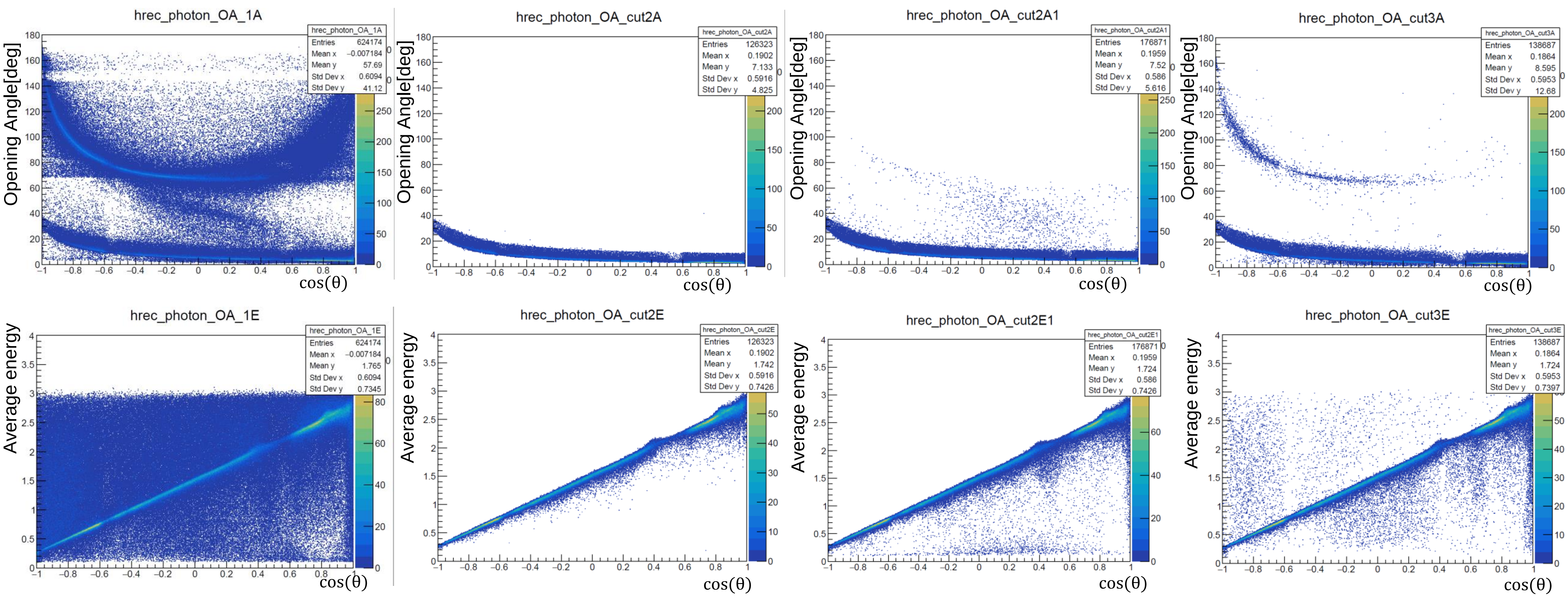
$E_\gamma > 0.1 + N_{\pi^0} = 1$



Average reconstructed energy of a photon pair versus its opening angle for all γγ pairs within an event (All) compared to γγ pairs stemming from π^0 decay before (MCTM) and after the cut (MCTM+OA), and all γγ pairs after cut (OA), in a simulation of $\bar{p}p \rightarrow \pi^0\gamma$ at beam momentum of 5 GeV/c.

BKG: Opening angle vs costheta and Average reconstructed energy of photon pair vs costheta for background at 5 GeV with $E_\gamma > 0.1$

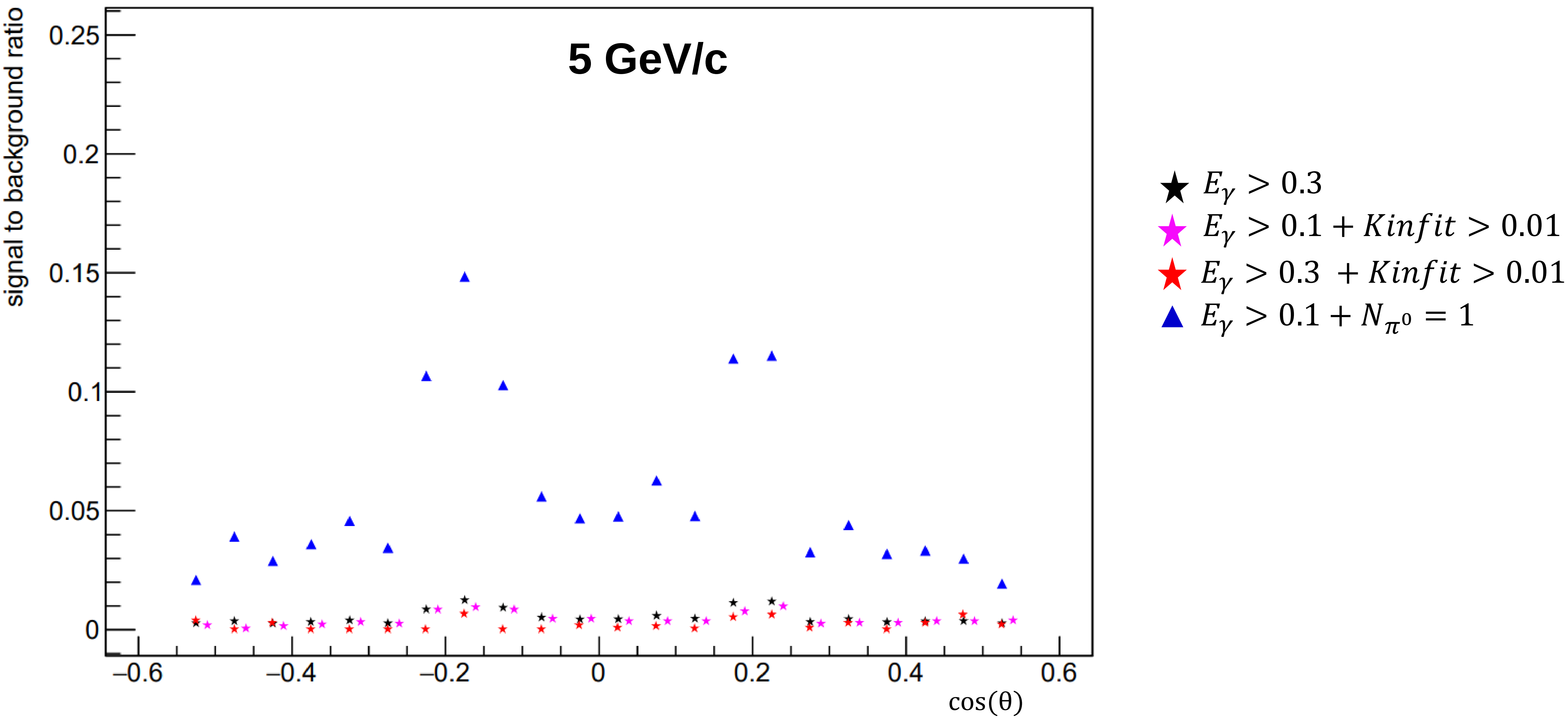
$E_\gamma > 0.1 + N_{\pi^0} = 1$



Upper row shows opening angle vs costheta and lower row shows the average reconstructed energy of a photon pair versus costheta. Left to right: All, MCTM+OA, MCTM and OA

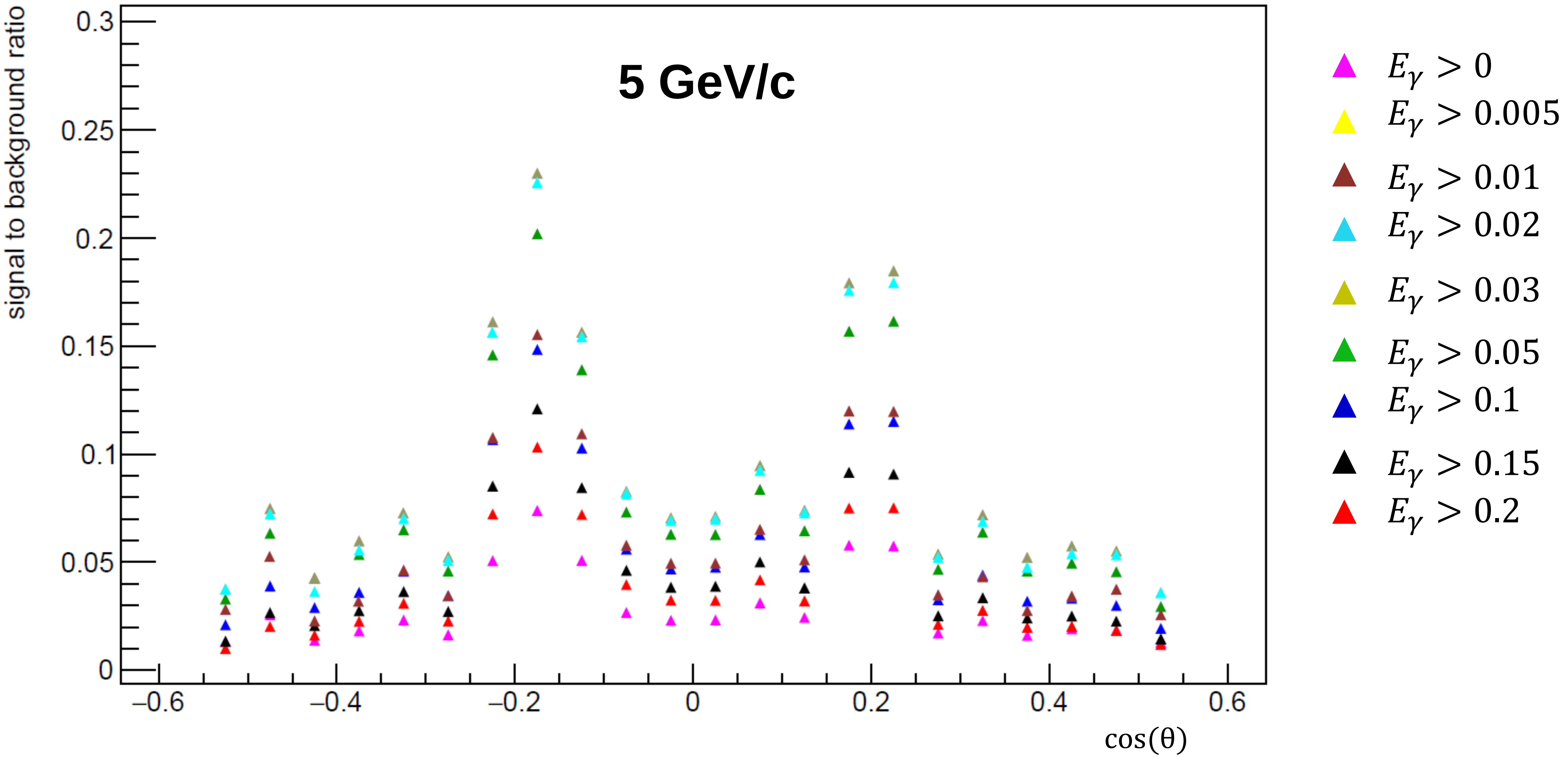
Signal to Background Ratio

*OA & Av. Energy Cut

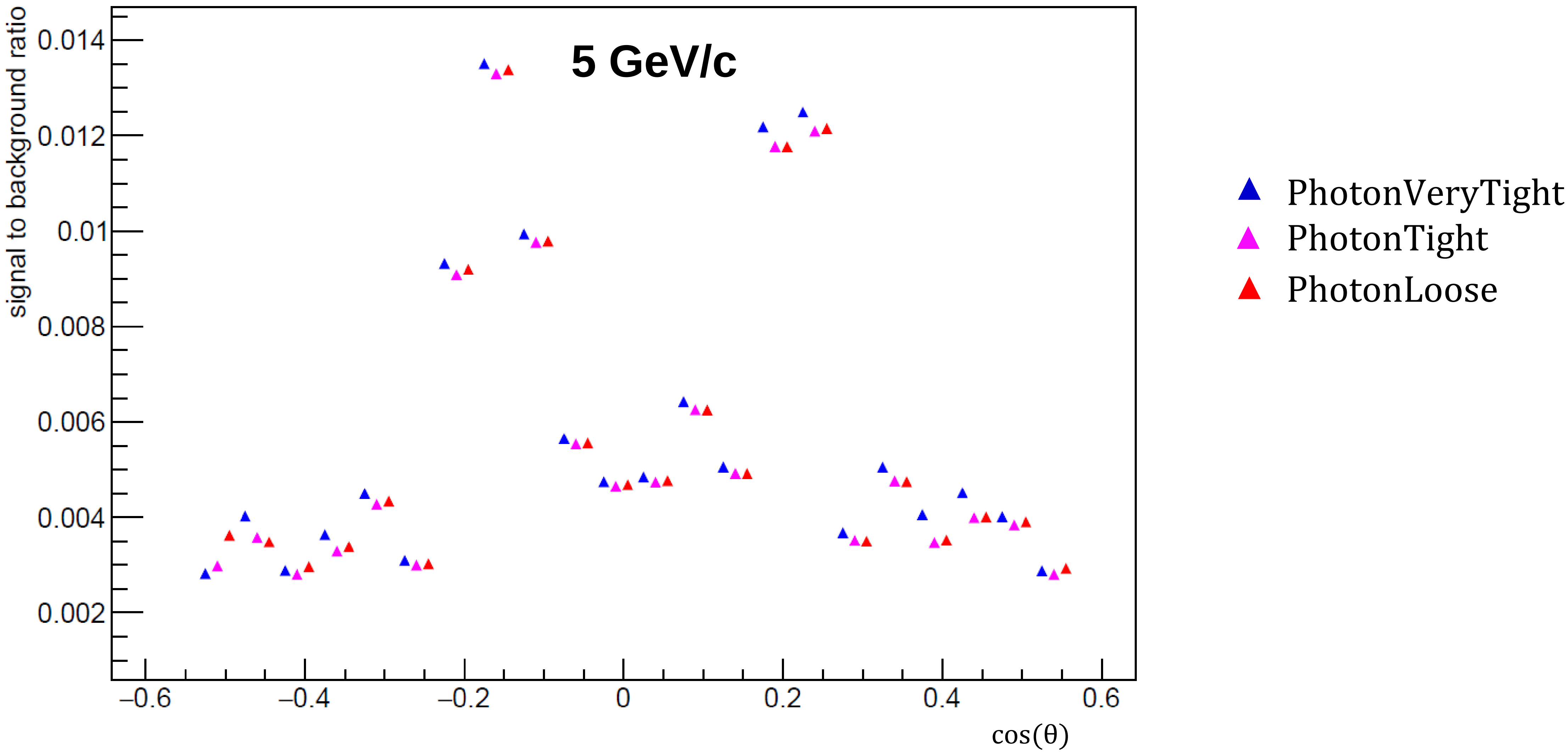


Signal to Background Ratio

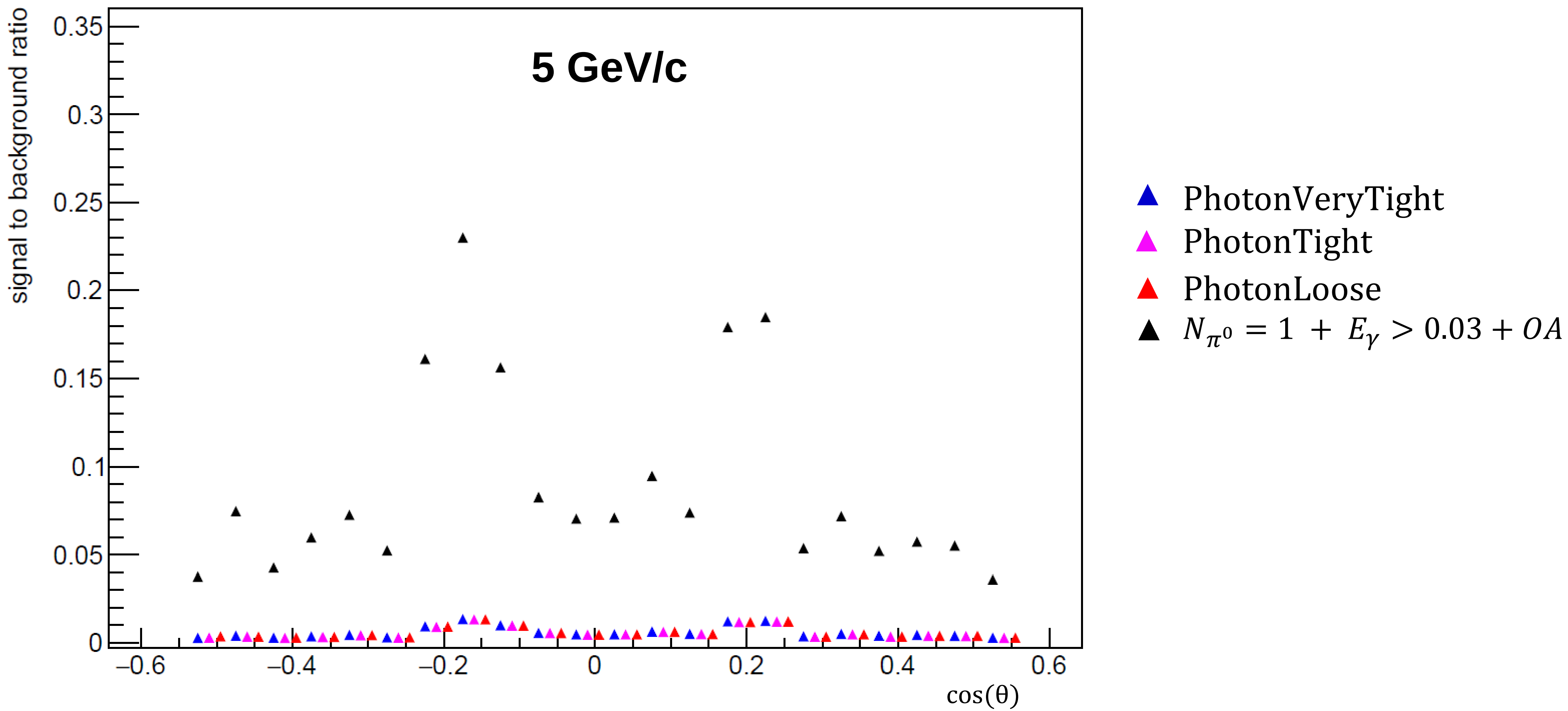
$^{*}N_{\pi^0} = 1 + OA\ \&\ Av.Energy$



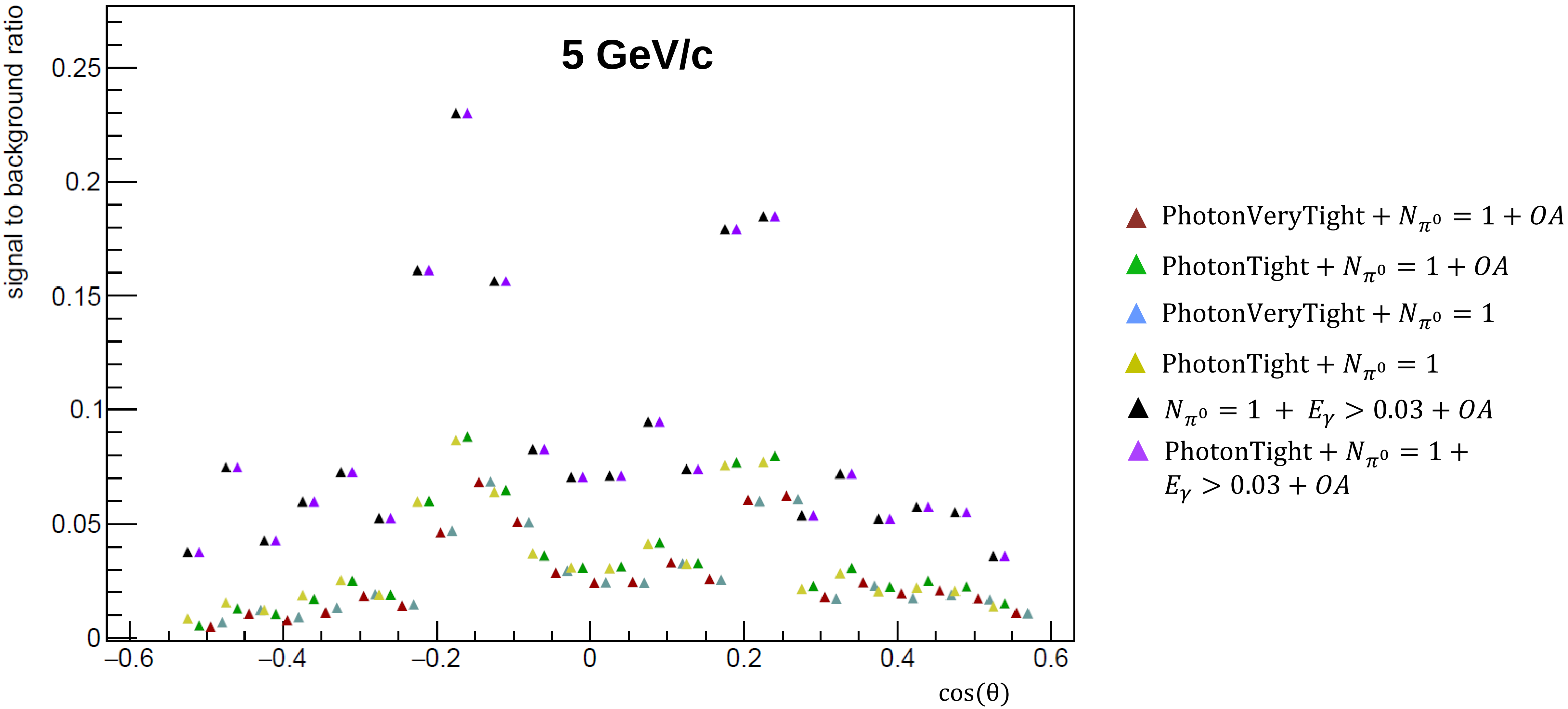
Signal to Background Ratio Using RhoGoodPhotonSelector



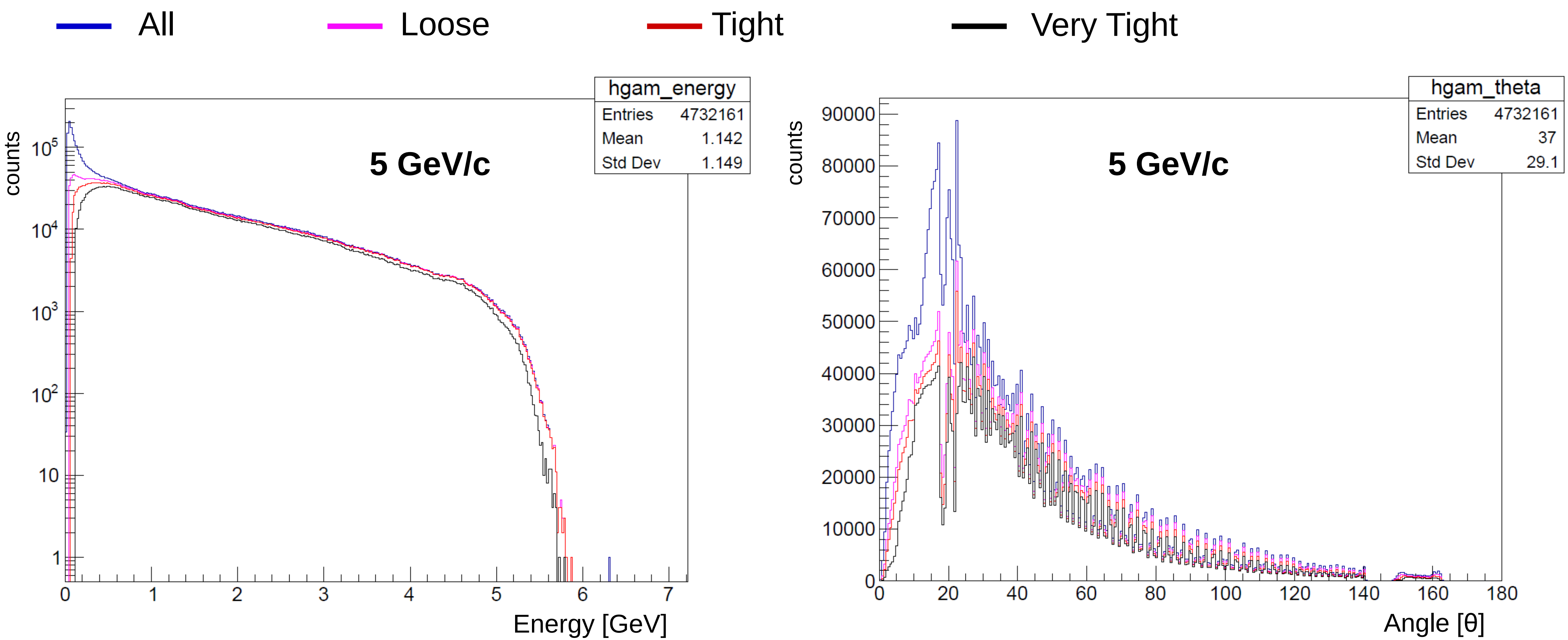
Signal to Background Ratio



Signal to Background Ratio



Energy and theta distribution of gammas

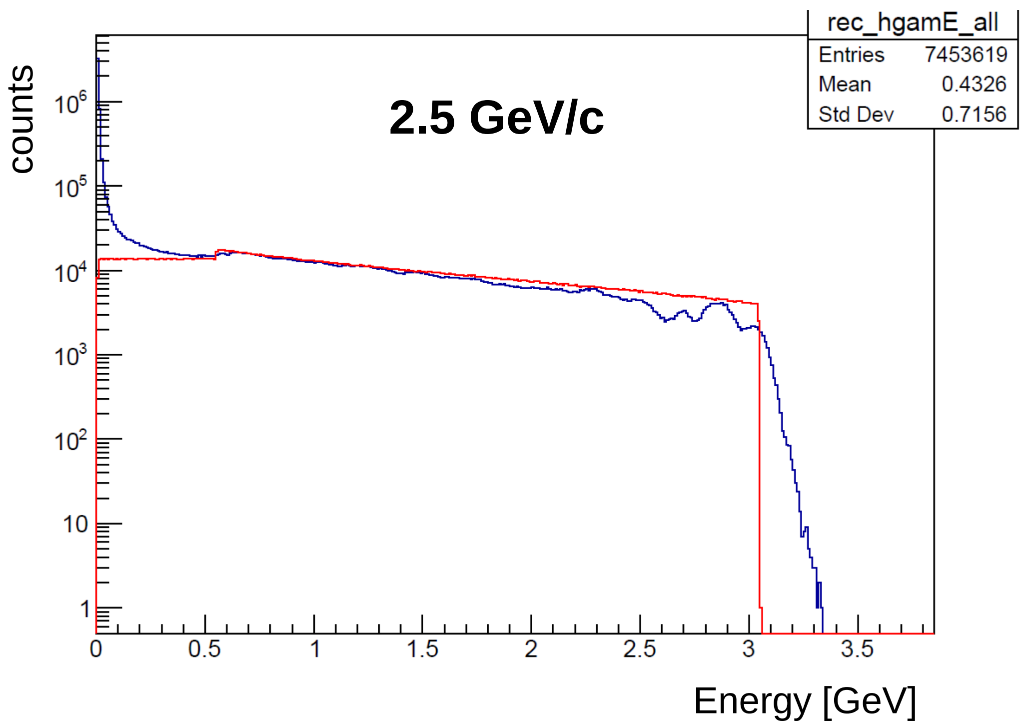


Energy and theta distribution of gammas at 5 GeV for different photon selection criteria

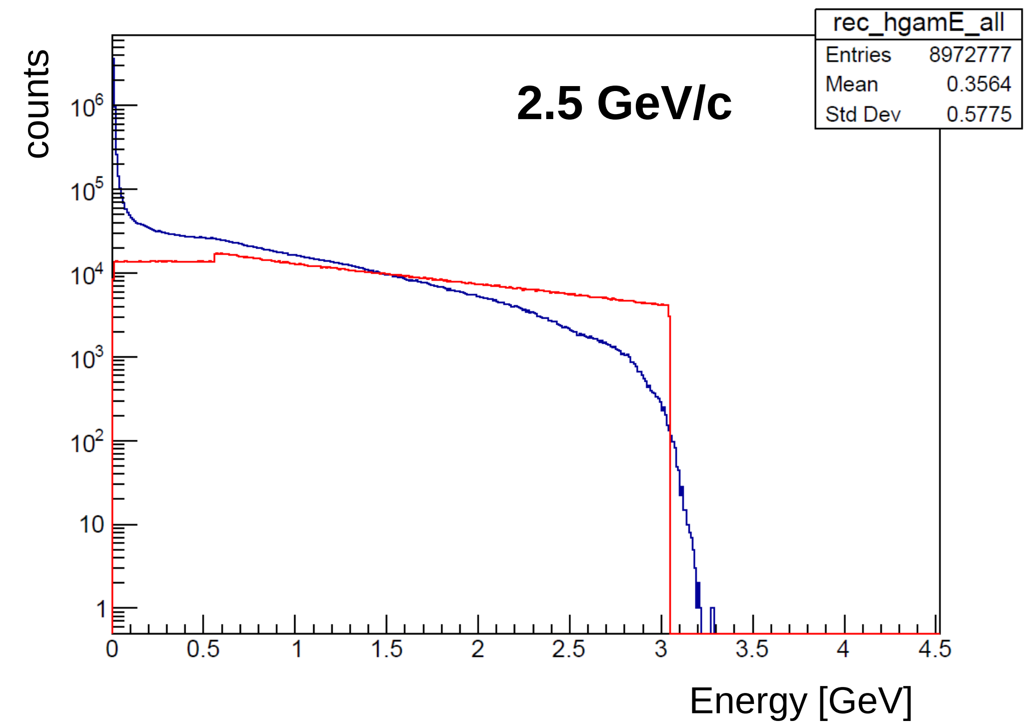
Energy of generated and reconstructed gammas at 2.5 GeV

Reconstructed
Generated

signal



background

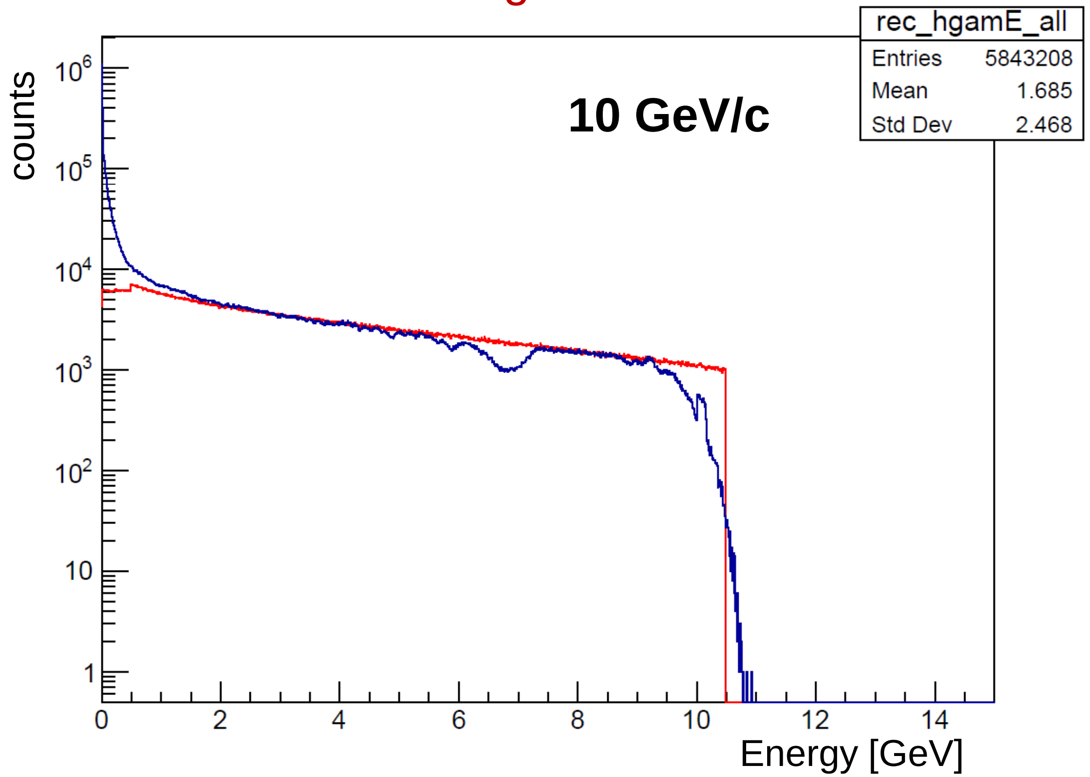


$E_{\gamma} > 0.015$

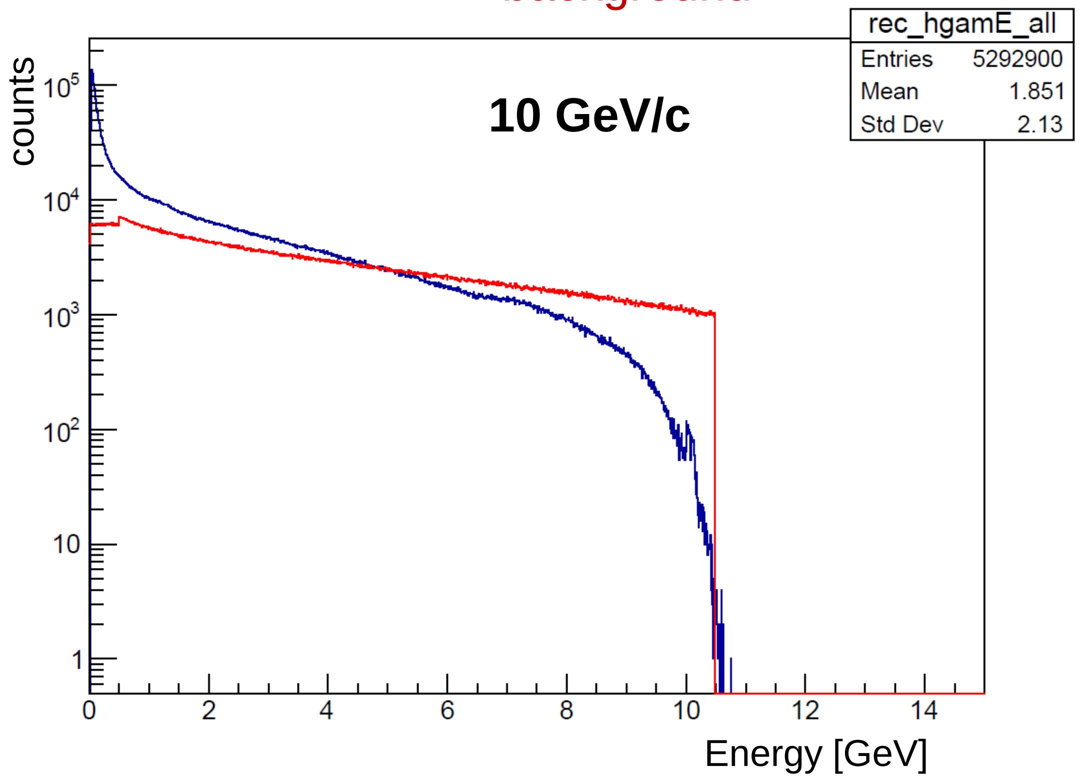
Energy of generated and reconstructed gammas at 10 GeV

Reconstructed
Generated

signal



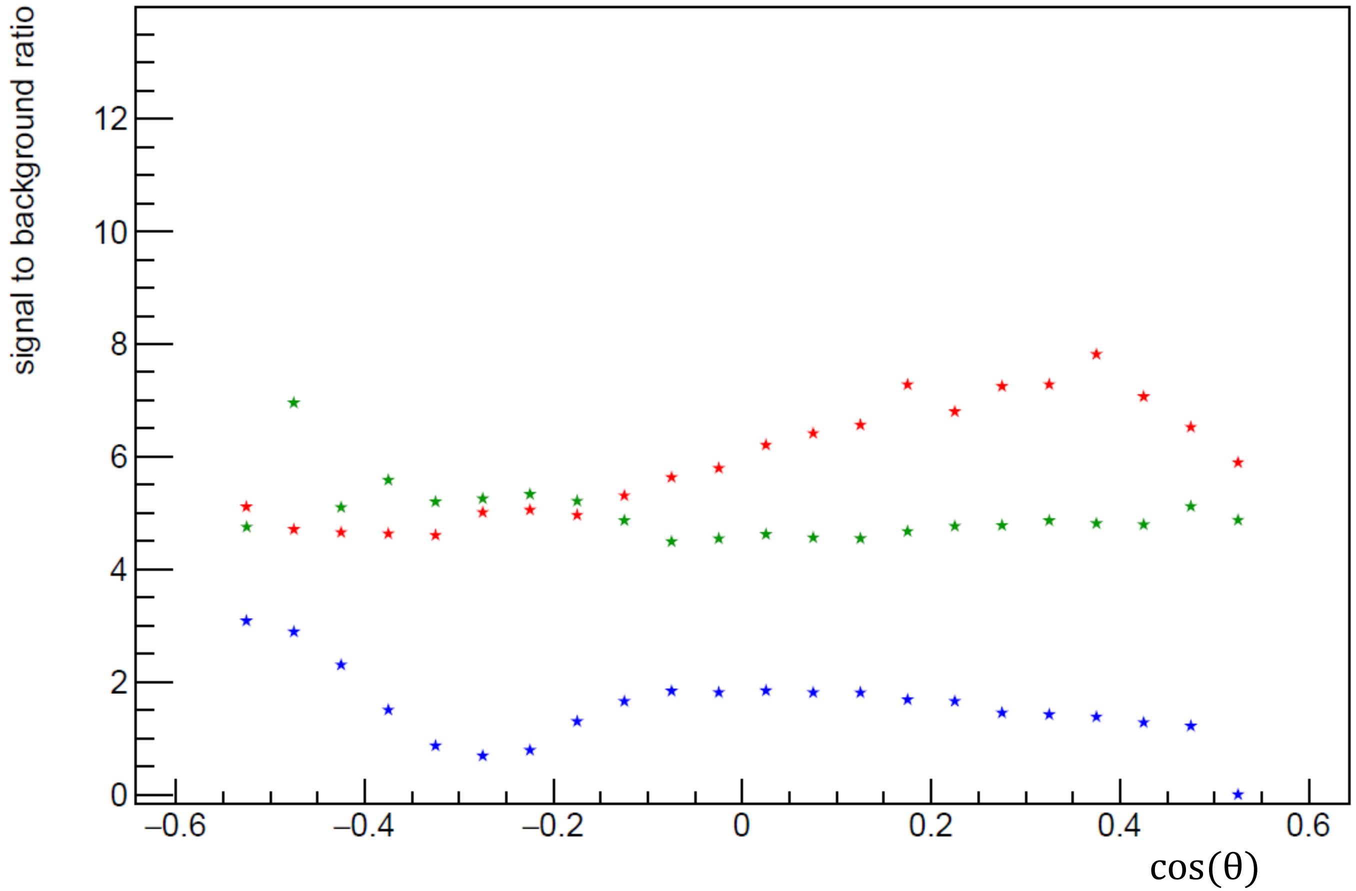
background



$E_\gamma > 0.5$

Signal to background ratio at different beam momenta

$$N_{\pi^0} = 1 + E_\gamma > X + OA$$



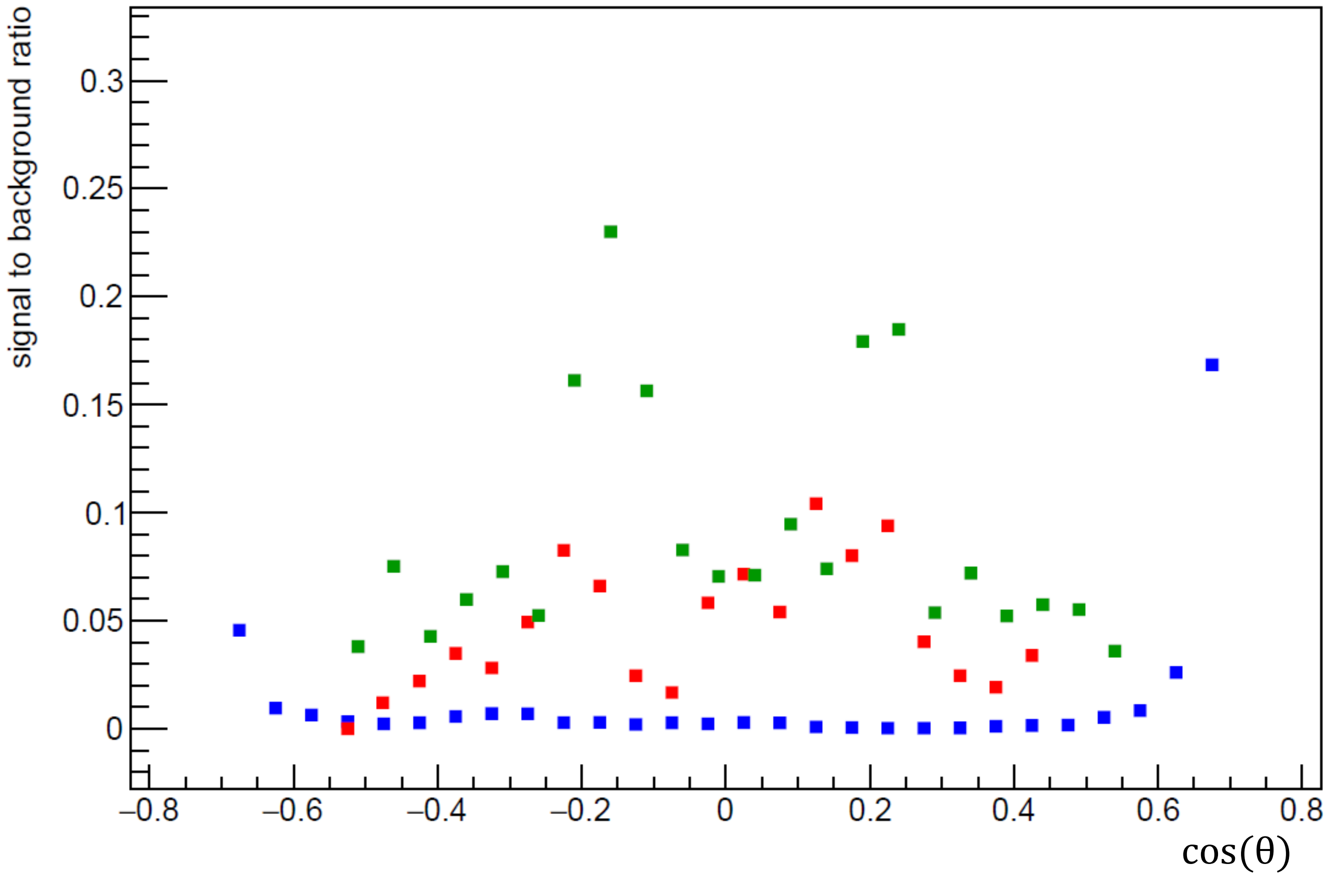
Ratio of the acceptances

$\mathbf{p_{beam} = 2.5\ GeV/c}$
$\mathbf{p_{beam} = 5\ GeV/c}$
$\mathbf{p_{beam} = 10\ GeV/c}$

plot assumes equal cross-sections to see the rejection power of the applied cuts.

Signal to background ratio at different beam momenta

$N_{\pi^0} = 1 \; + \; E_\gamma > X + OA$



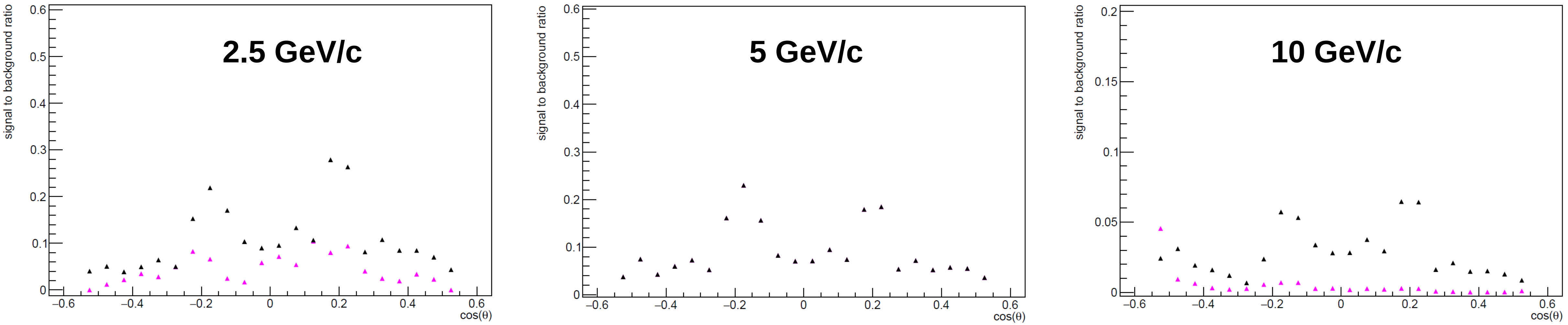
$p_{beam} = 2.5\ GeV/c$
$p_{beam} = 5\ GeV/c$
$p_{beam} = 10\ GeV/c$

Signal to background ratio at 2.5 *GeV*, 5 *GeV* and 10 *GeV*

Signal to background ratio

▲ (black) $\frac{Acceptance_{sig}}{Acceptance_{bkg}} *$ cross-section ratio from 5GeV

▲ (magenta) $\frac{Acceptance_{sig}}{Acceptance_{bkg}} *$ cross-section ratio at respective energies



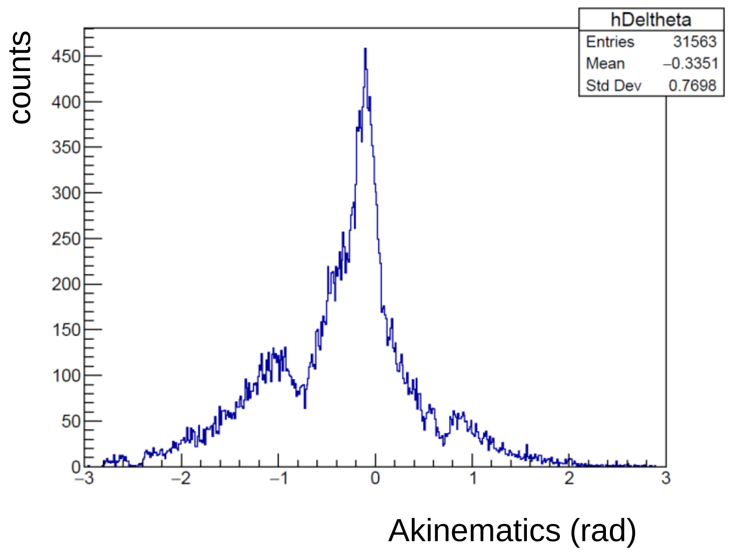
Signal to background ratio at different beam momenta. Black markers show ratio of acceptances with the ratio of cross-sections from 5GeV. Magenta markers correspond to ratio of cross-sections at their corresponding energies.

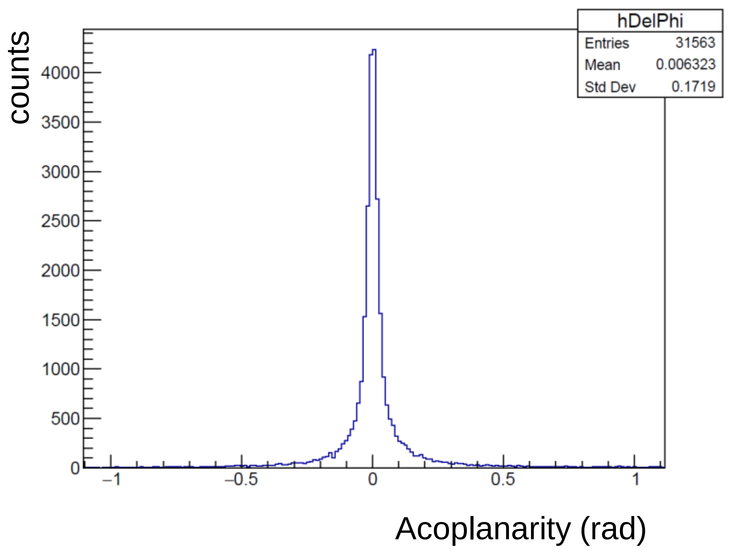
Outlook: Background Suppression

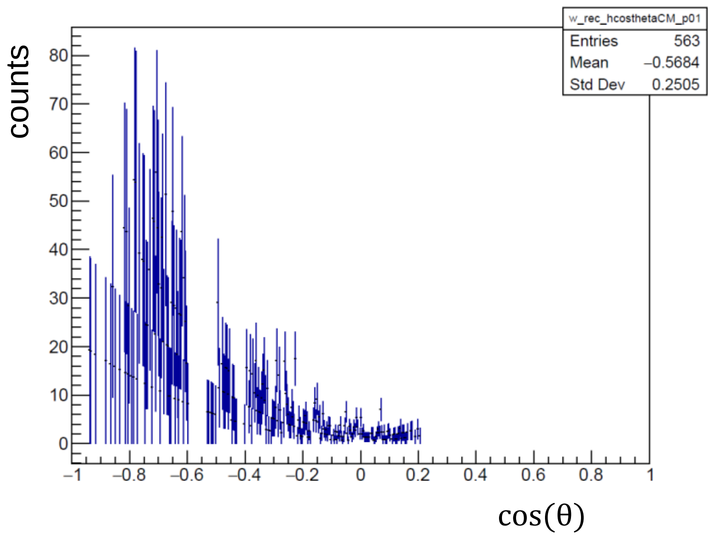
T. A. Armstrong, Two-body neutral final states produced in antiproton-proton annihilations at $2.911 \leq \sqrt{s} \leq 3.686$ GeV

- Exactly 3 calorimeter clusters each with threshold > 50MeV.
- Combine all photons within an event into $\pi^0\gamma$
- Combination associated with lowest $\sqrt{(\Delta\theta)^2 + (\Delta\phi)^2}$ is taken as event topology
- Mass cut is applied
- 4C kinematic fit is applied and events with confidence level less than 10% are rejected.

Weighted reconstructed







$$\Delta\theta\ (akinematics) = \theta_1 - \theta_2$$

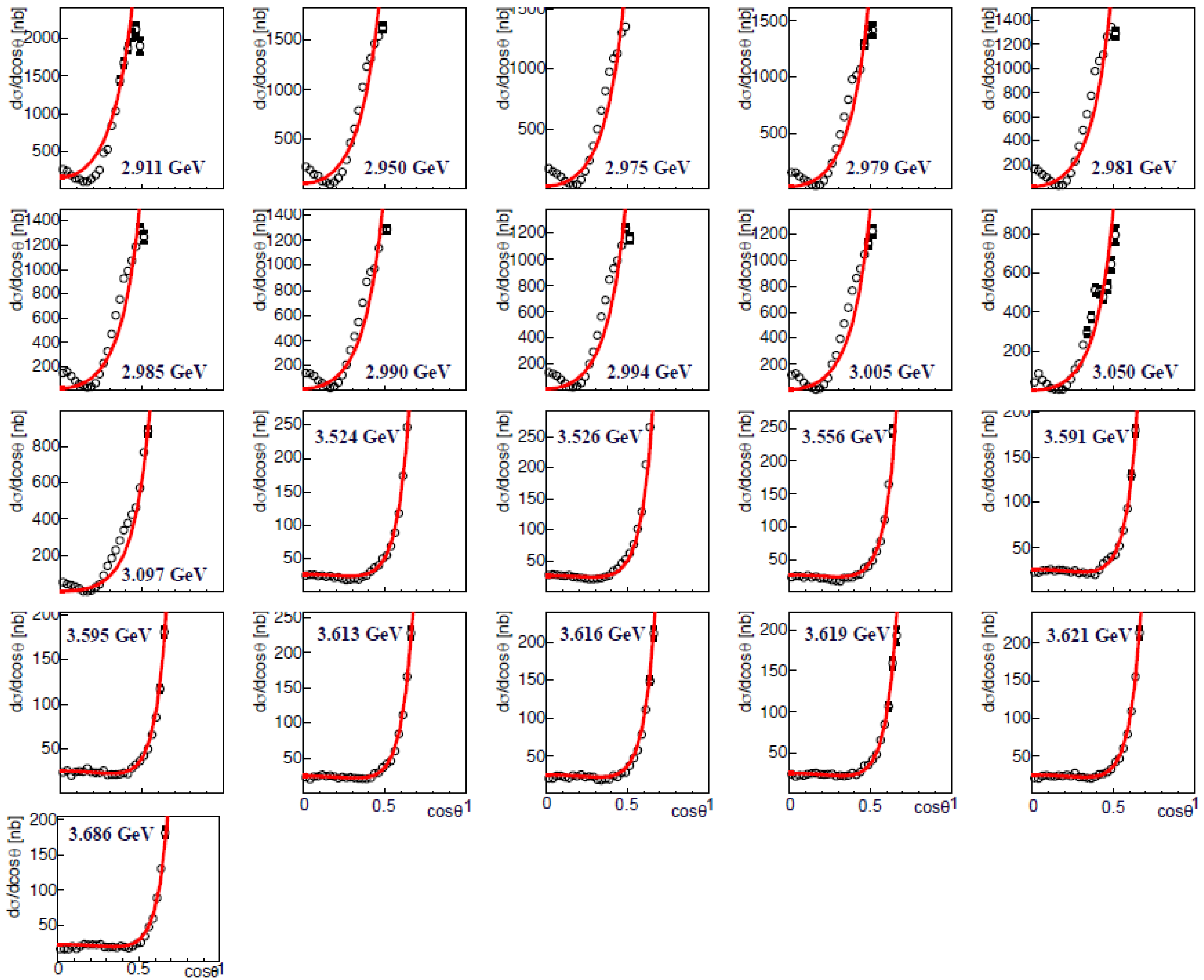
$$\Delta\phi\ (acoplanarity) = \pi - |\phi_1 - \phi_2|$$

Summary

- The cos(θ) dependence of the cross-section has been implemented and a reconstruction study has been performed at $\sqrt{s} = 2.6\ GeV$, $\sqrt{s} = 3.4\ GeV$ and $\sqrt{s} = 4.5\ GeV$
- Differential cross-sections from E760 data were plotted and fitted to provide an estimate at different beam momenta.
- Signal to background ratio was determined.
- Different selection cuts were investigated to optimize the signal to background ratio while keeping a reasonable reconstruction efficiency.
- More detailed studies, including count rate estimates and signal to background are in progress
- Continuation of the study at 15 GeV/c beam momentum

Thank You For Your Attention!

Backup Slides



O E760 data.

— calculation from model

Angular distribution for the reaction $p\,\bar{p} \to \pi^0\gamma$ in CMS in the energy range 2.911 GeV ≤ $\sqrt{s}$ ≤ 3.686 GeV.

-Ying Wang arXiv:1706.00205v1