# Search for the dark scalar, $S$, in rare $\eta$-meson decay

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**for the GlueX Collaboration**

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# Table of contents

# Introduction

Boosted $\eta^{(')}$-mesons can be produced through $\gamma p \to \eta^{(')} p$ process and measured at photon-beam facilities.

- Here, we are searching for the dark scalar, $S$, produced in $\eta \to \pi^0 S$ with $S \to \gamma\gamma$
  => Simulated with genEtaRegge, 20M events for 12 different masses, between few MeV/$c^2$ and $\sim$ 410 MeV/$c^2$
- Expected background sources:
  - $\eta \to \pi^0 \gamma\gamma$ with Branching Ratio (BR), BR = 0.00027 ("irreducible" and main background)
    => Simulated with genEtaRegge
  - $\eta \to \pi^0 \pi^0 \pi^0$ with BR = 0.3257 (reducible and non-negligible background)
    => Simulated with genEtaRegge and evtgen using the Belle (II) eta decay card (in a future iteration we will used Jon opetimized and up-to-date card)
  - Other hadronic decays, (reducible and negligible(?) background)
    => Not yet taken into account but expecting to use bggn

Reaction filter and DSelector are used with standard PID selection criteria

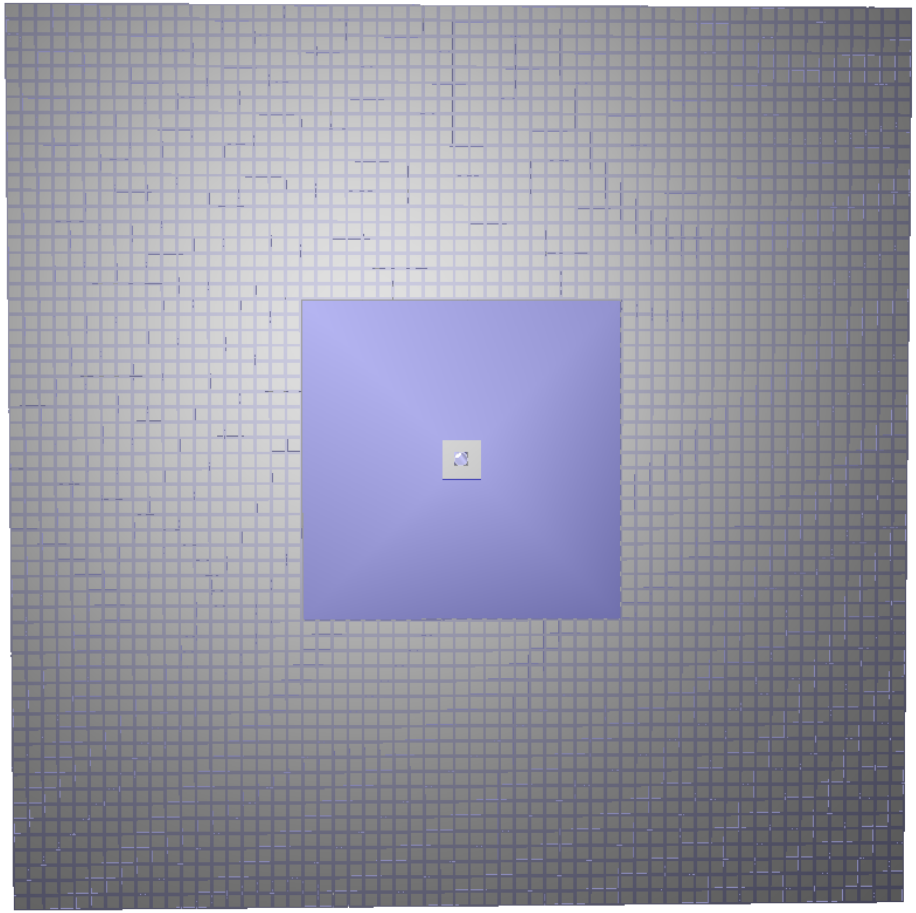
- Reaction: 1_14__17_14, and Decay: 17__7_1_1
- In the simulation results presented today, individual $PbW0_2$ energy threshold set to the default unrealistic value of 50 MeV, we are expecting to run with 5 MeV energy threshold

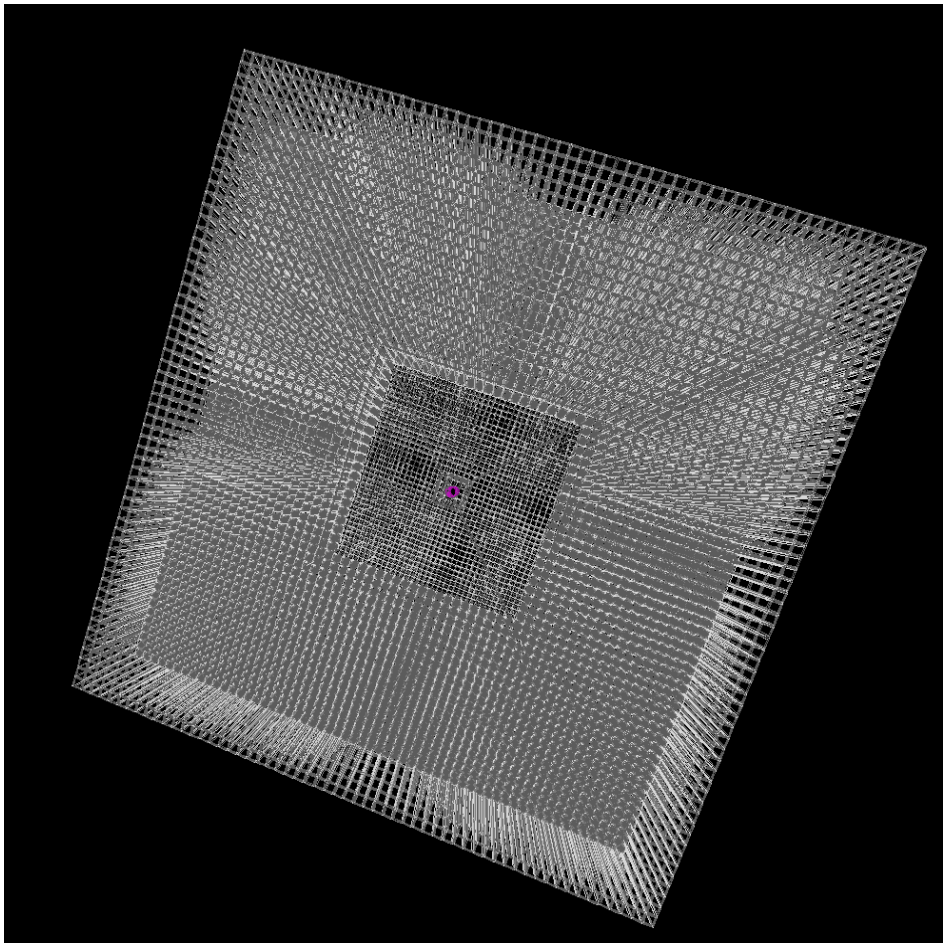
All simulation are done for FCAL and FCAL2

# FCAL2

JEF "software" is on the master branch thanks to Simon

- VARIATION=mc_JEF must be used with run number not yet allocated
  - ROOT-OpenGL
  - ROOT-x3d

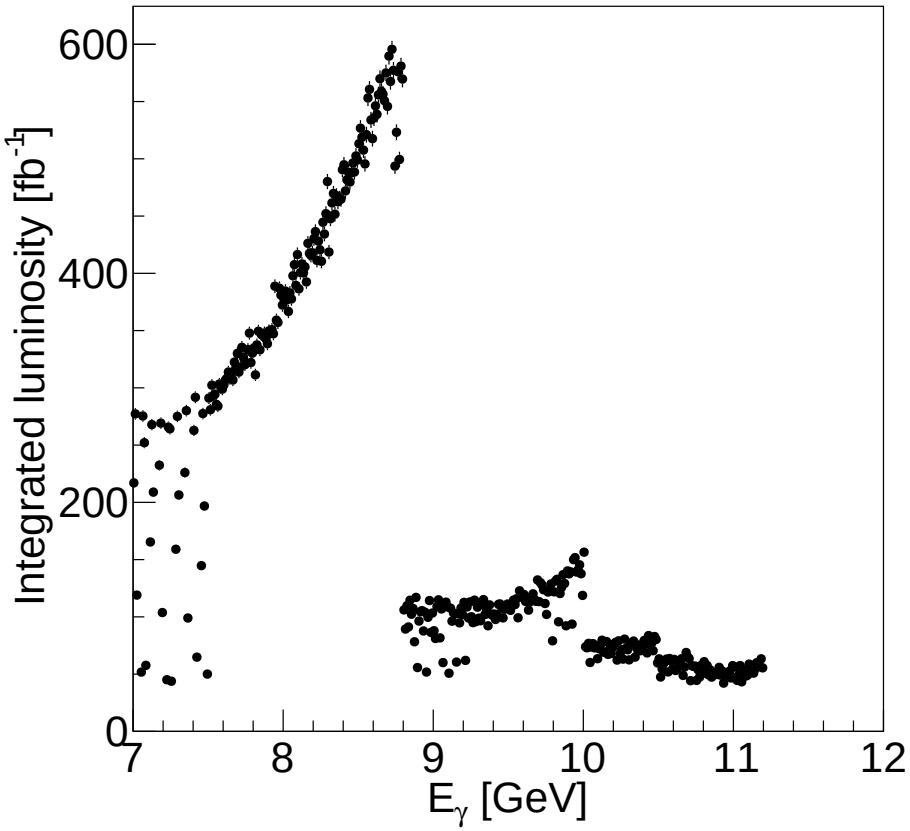


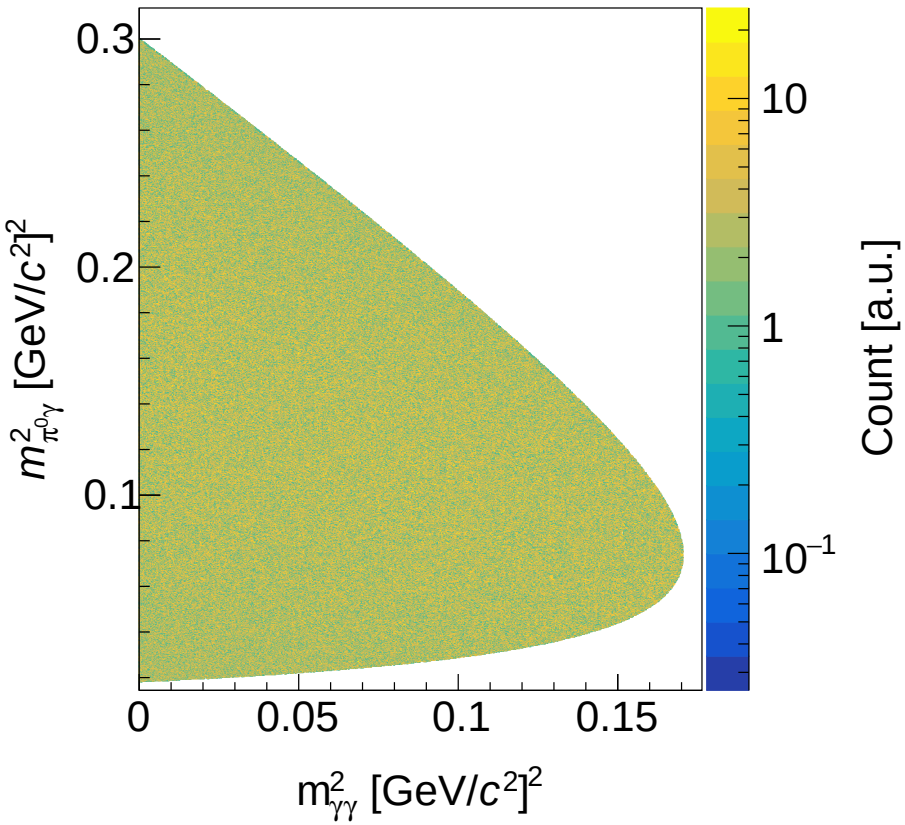


Preliminary coarse geometry is implemented

# $\gamma p \to \eta(\to \pi^0\gamma\gamma)p$

- Simulate 1M events with MCwrapper and genEtaRegge
- $N_{\mathrm{thrown}}(\mathrm{E}_\gamma) = \sigma(\mathrm{E}_\gamma) \cdot \mathrm{BR}(\eta \to \pi^0\gamma\gamma) \cdot \mathcal{L}(\mathrm{E}_\gamma)$
  - Luminosity simulated
  - Phase-space $\eta$ decay



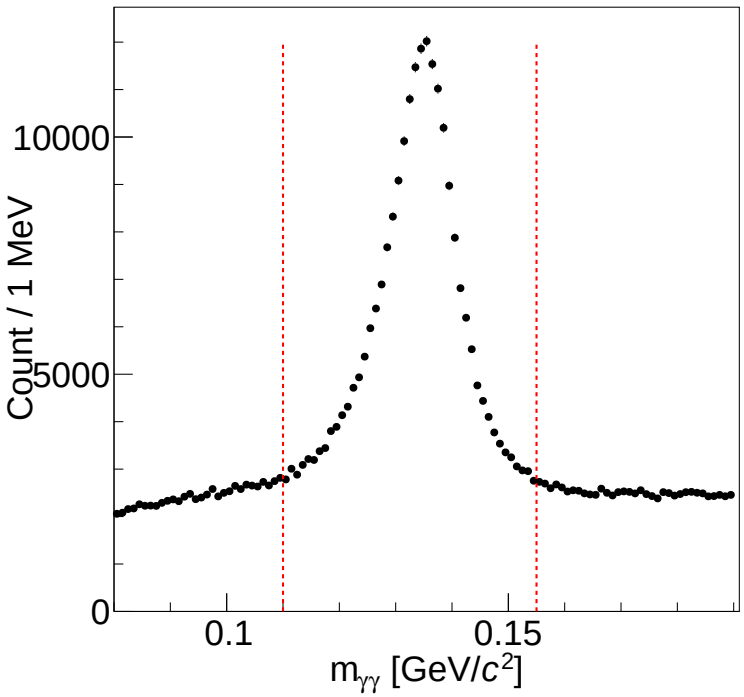




- Also, 1M events with MCwrapper and genEtaRegge w/ $3\pi^0$ and evtgen each

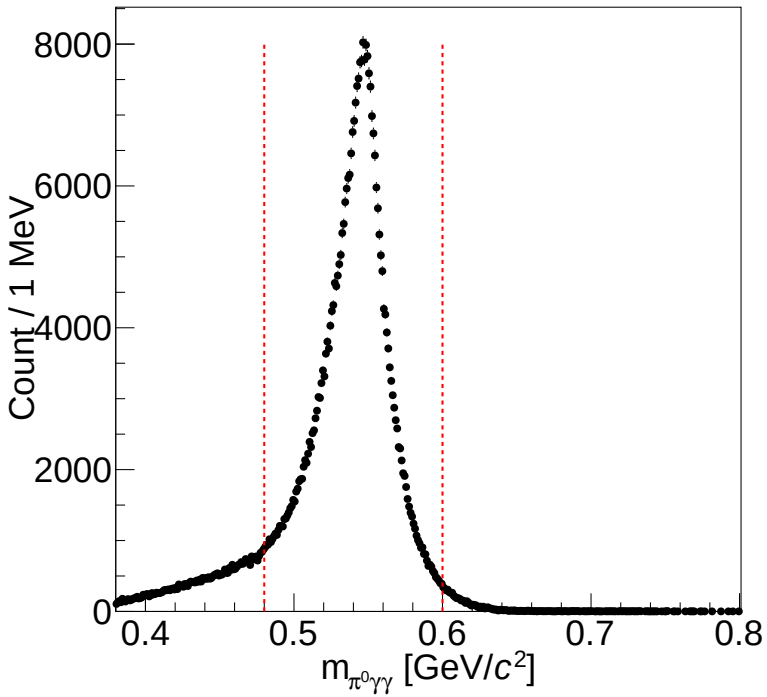
# $\eta \to \pi^0\gamma\gamma$

- Decay channel $\eta \to \pi^0\gamma\gamma$
- Select events with 4 "good" neutral hits in BCAL/FCAL2/CAL
  - BCAL & FCAL2 default GlueX cluster energy threshold
  - CCAL default PRIMEX-D cluster energy threshold
- Invariant mass of photon pair cut on $\pi^0$ mass
- Select best combination of $4\gamma$ to $\pi^0\gamma\gamma$
- Use $\pi^0$ mass as constrain, construct $\pi^0\gamma\gamma$ invariant mass
- No fiducial cuts

- $\pi^0$ candidates




- $\eta$ candidates



# Selection critiria

10 possible variables identified (so far)

- $\chi^2$
- Coplanarity between $\eta$ and $p$
- Mass conservation
- Extra energy
- Unused tracks
- $\pi^0\gamma\gamma$ invariant mass
- Cluster number below $4.5^o$
- Vertex z and r
- Proton momentum

Optimized by the Figure-Of-Merit (FOM), $\mathrm{N_{sig}}(m)/\sqrt{\mathrm{N_{sig}}(m)+\mathrm{N_{nkg}}(m)}$

- Signal, sig: $\eta \to \pi^0\gamma\gamma$, BR $= 0.00027$
  - genEtaRegge, 1M events thrown
  - $\mathrm{N_{sig}}(m) = \mathrm{N_{rec}}(m) \times BR(\eta \to \pi^0\gamma\gamma)/BR(\eta \to \pi^0\pi^0\pi^0)$
- Background, bkg: $\eta \to \pi^0\pi^0\pi^0$, BR $= 0.3257$
  - genEtaRegge, 1M events thrown
  - $\mathrm{N_{sig}}(m) = \mathrm{N'_{rec}}(m)$
- FOM for each $m_{\gamma\gamma}$
- $\mathrm{N}_{rec}(m) = integral(m - 3\sigma(m), m + 3\sigma(m))$

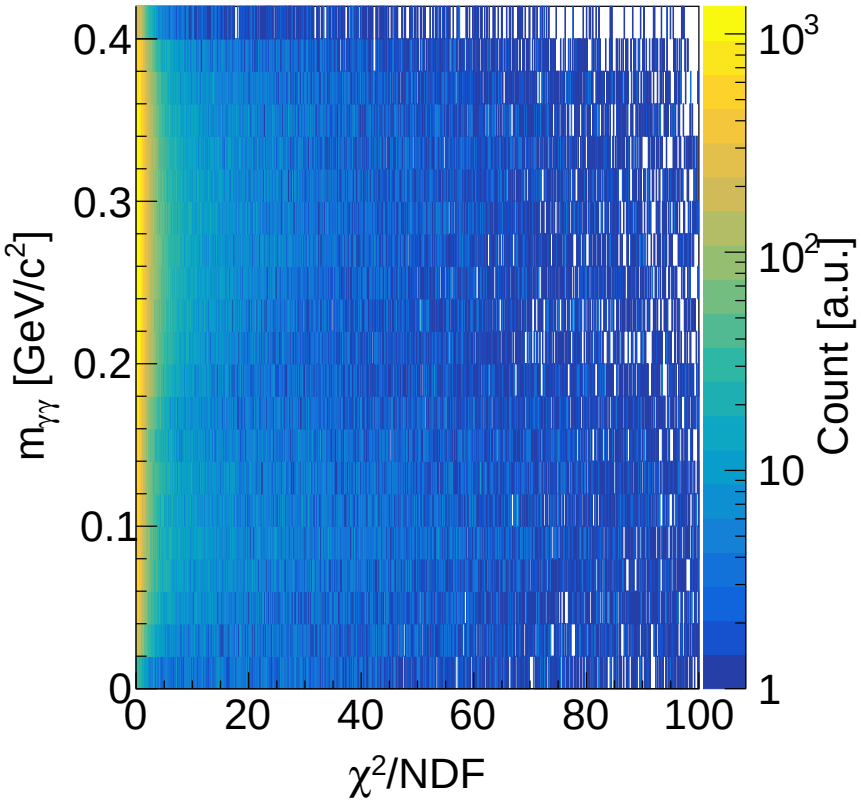
  where m is the mass and $\sigma$ is the dark scalar weighted width ($\sigma(m) = \sqrt{A \cdot w_1^2(m) + (A-1) \cdot w_2^2(m)}$)
- $\mathrm{N'_{rec}}(m) = integral(m - 3\sigma(m), m + 3\sigma(m))$

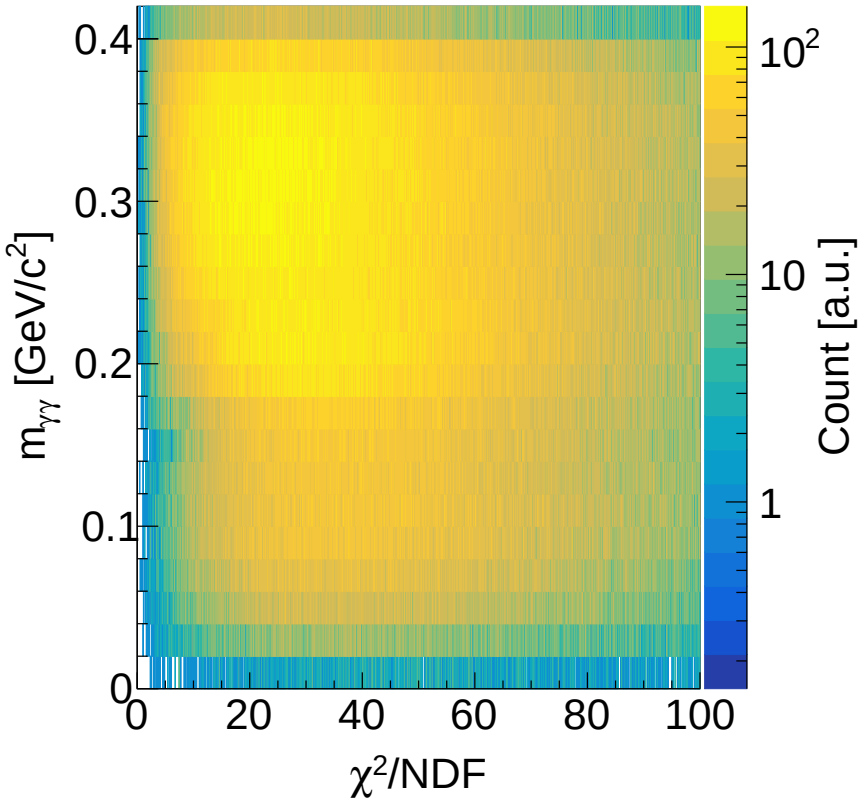
The optimization is very preliminary

# FCAL2, Kinfit $\chi^2$

$m_{\gamma\gamma}$ vs. vs. kinfit $\chi^2$ for:

- Signal
- Background

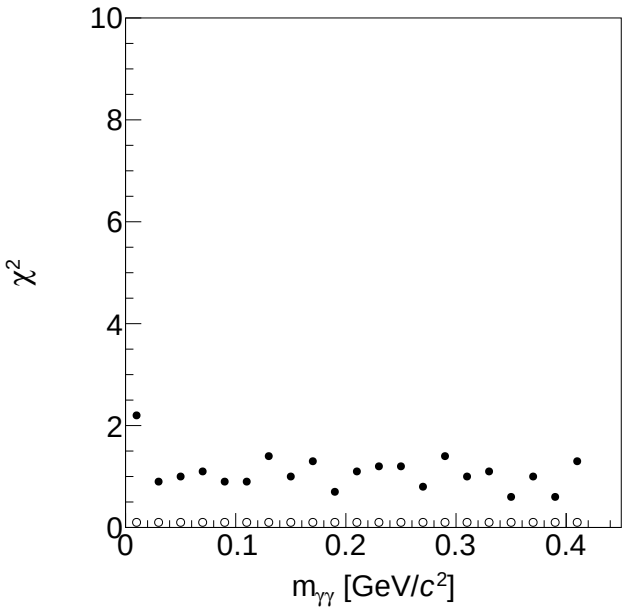


# FCAL2, Kinfit $\chi^2$

FOM vs. kinfit $\chi^2$:

- $m_{\gamma\gamma} = 110$ MeV/$c^2$
- $m_{\gamma\gamma} = 310$ MeV/$c^2$
- Selection critiria vs. $m_{\gamma\gamma}$

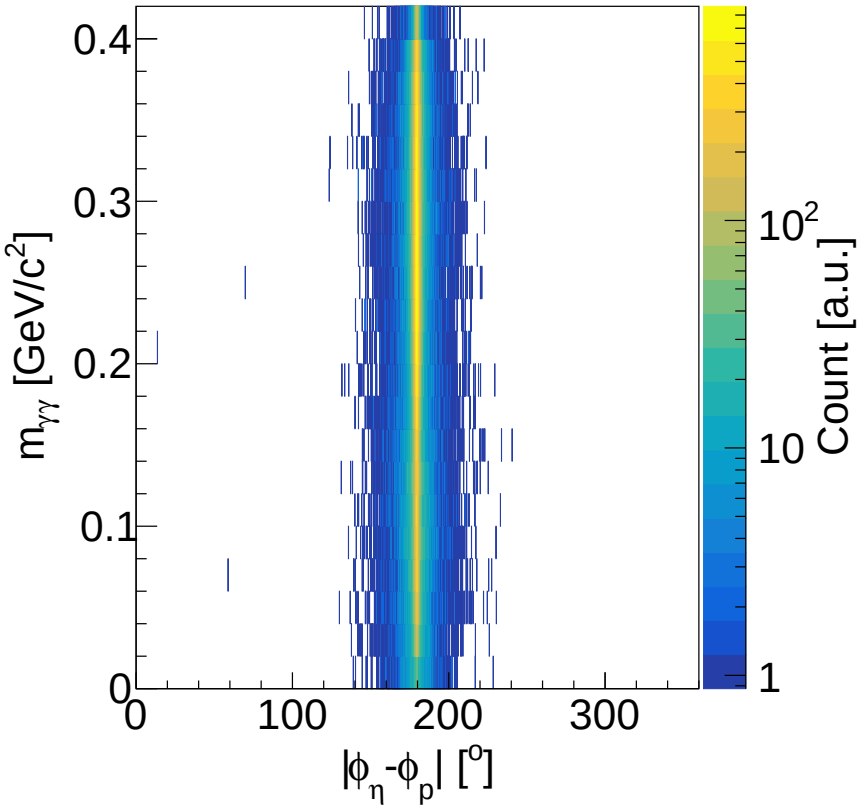


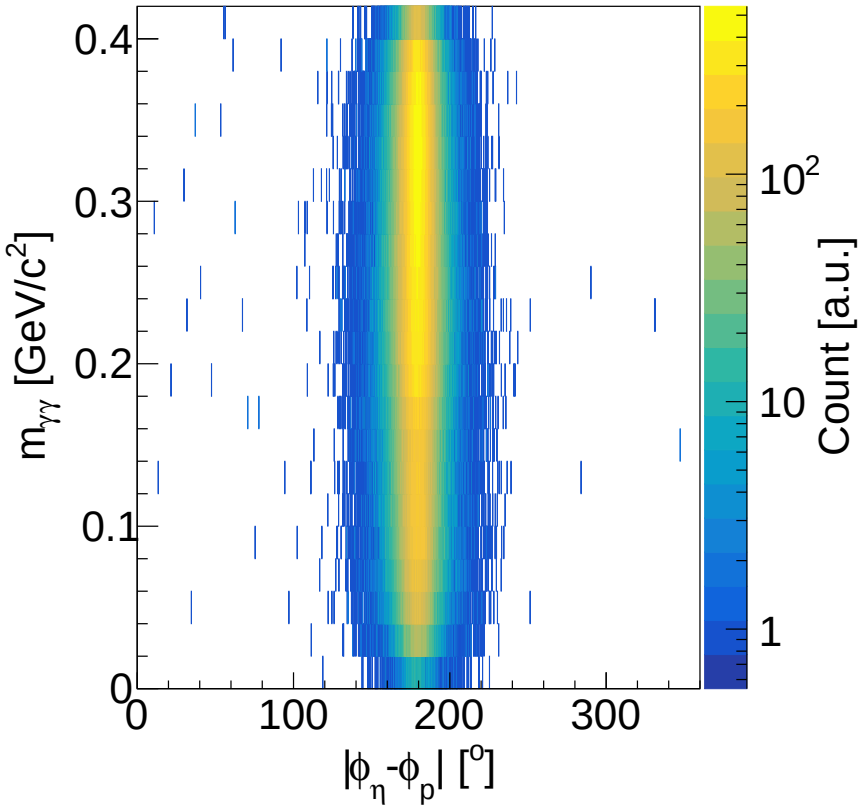

- Find lower value
- Find upper value

# FCAL2, coplanarity between $\eta$ and $p$

$m_{\gamma\gamma}$ vs. coplanarity between $\eta$-candidate and $p$ for:

- Signal
- Background



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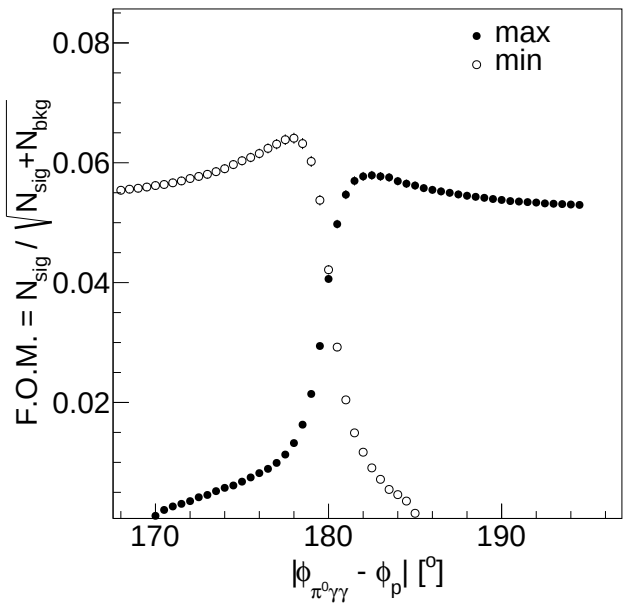
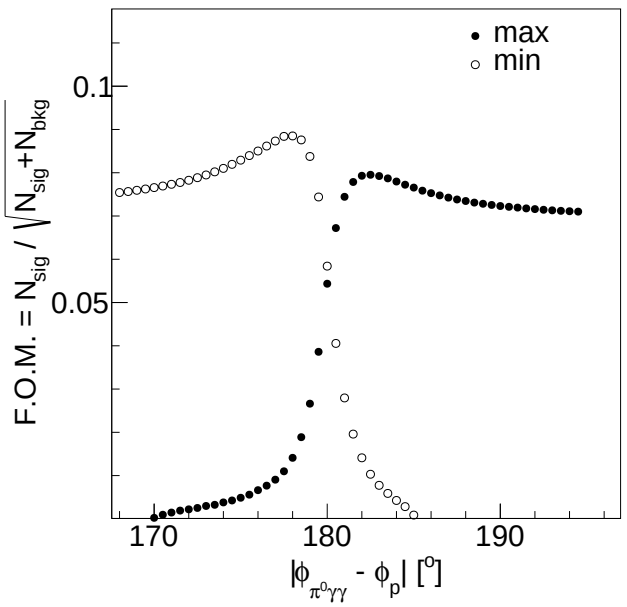
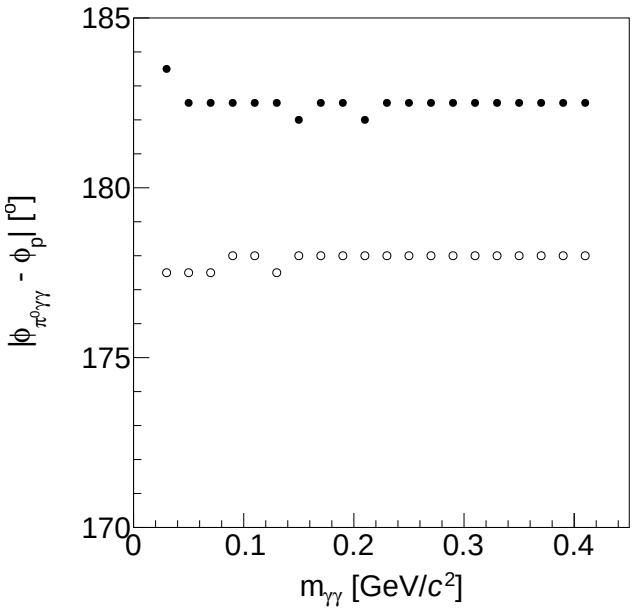


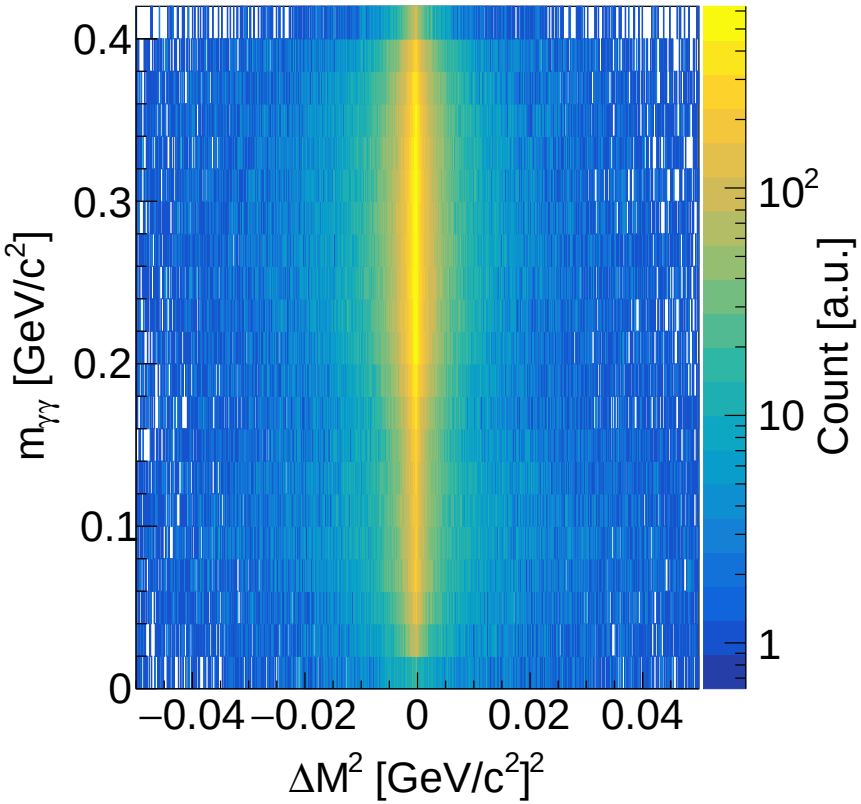



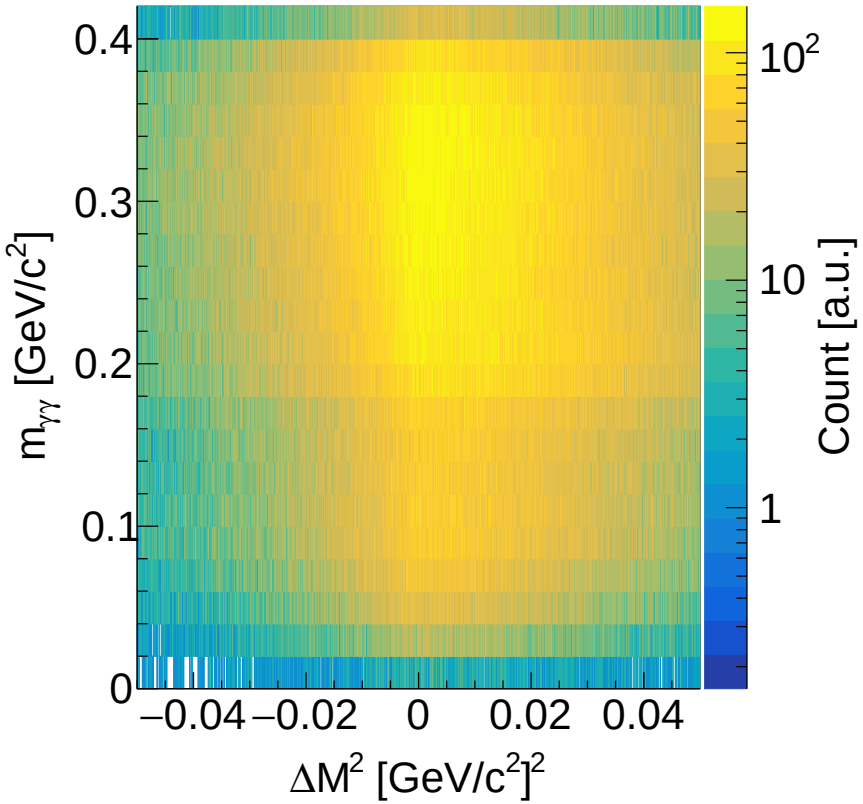

- Find lower value
- Find upper value

# FCAL2, mass conservation

$m_{\gamma\gamma}$ vs. mass conservation, $\Delta M^2$, for:

- Signal
- Background



# FCAL2, mass conservation

FOM vs. mass conservation for:

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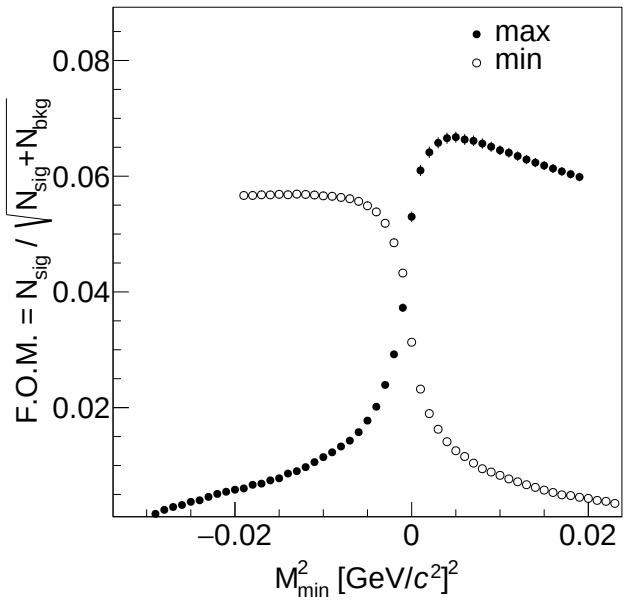
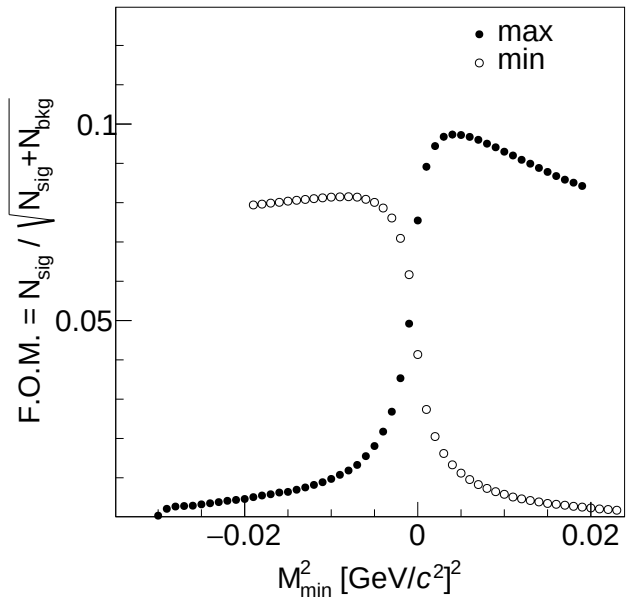
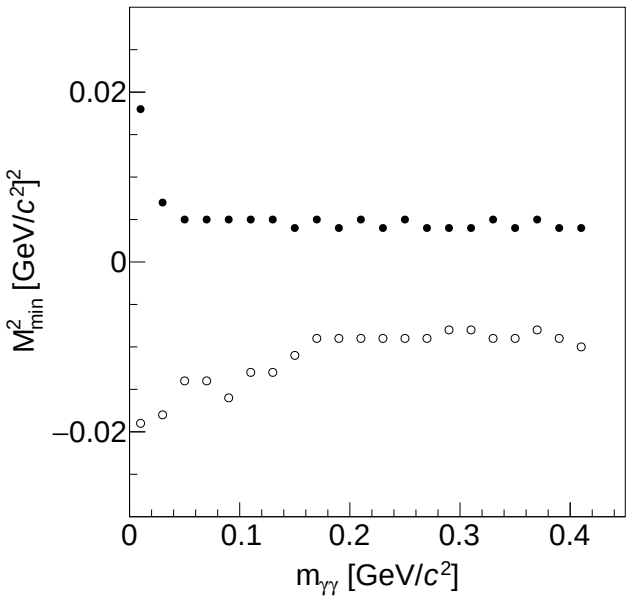
- $m_{\gamma\gamma} = 310$ MeV/$c^2$
- Selection critiria vs. $m_{\gamma\gamma}$



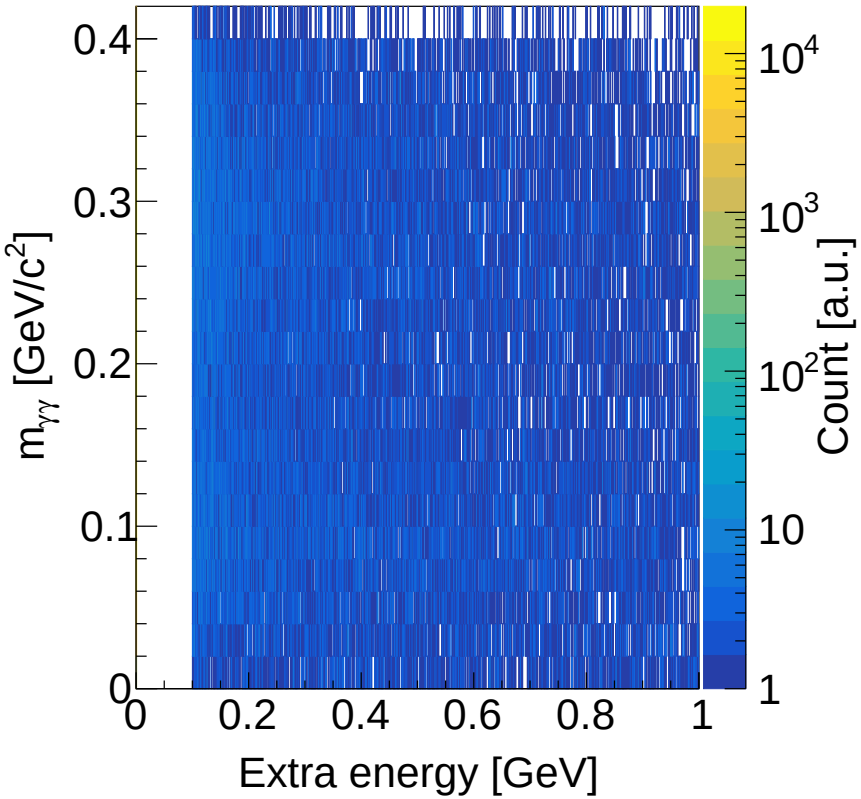



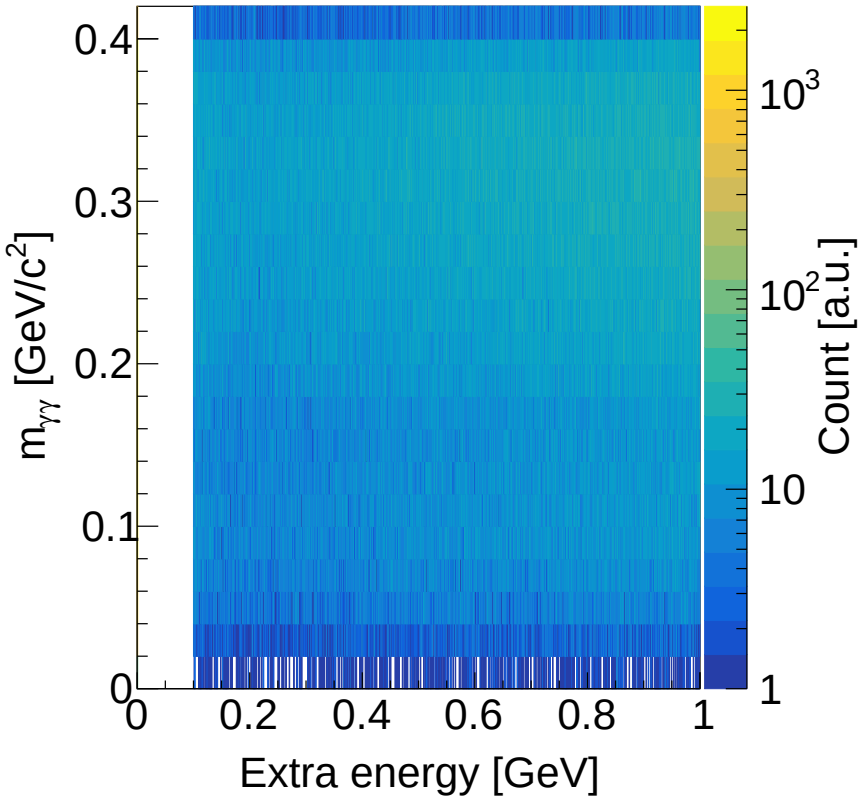

- Find lower value
- Find upper value

# FCAL2, extra energy

$m_{\gamma\gamma}$ vs. extra energy for:

- Signal
- Background



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FOM vs. extra energy for:

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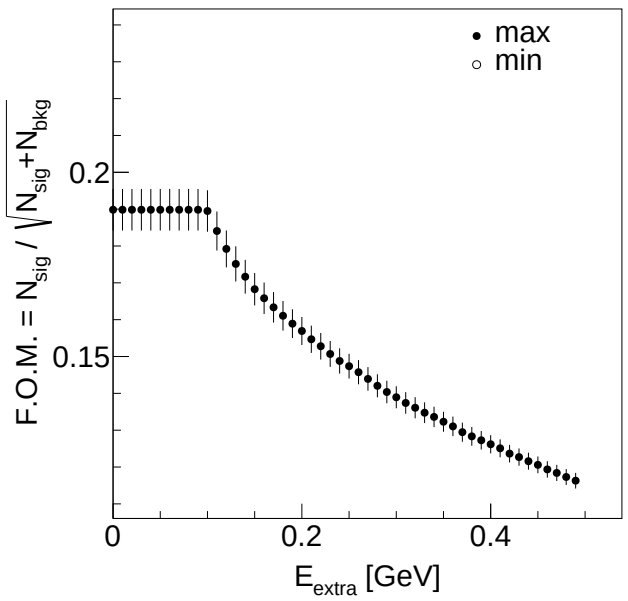
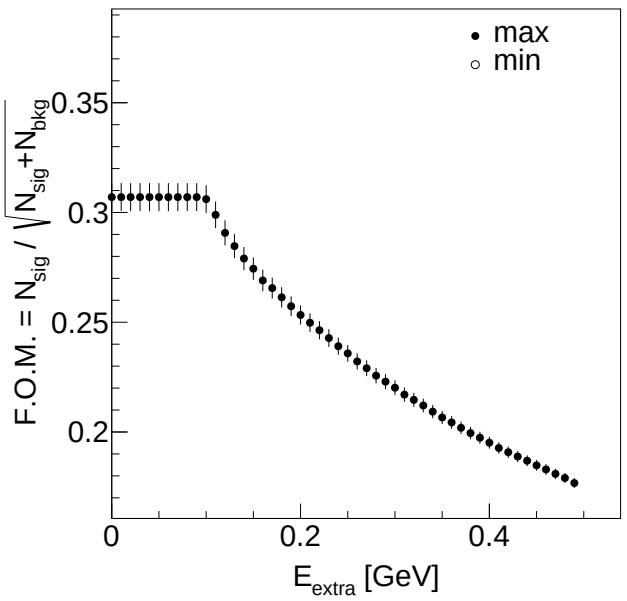
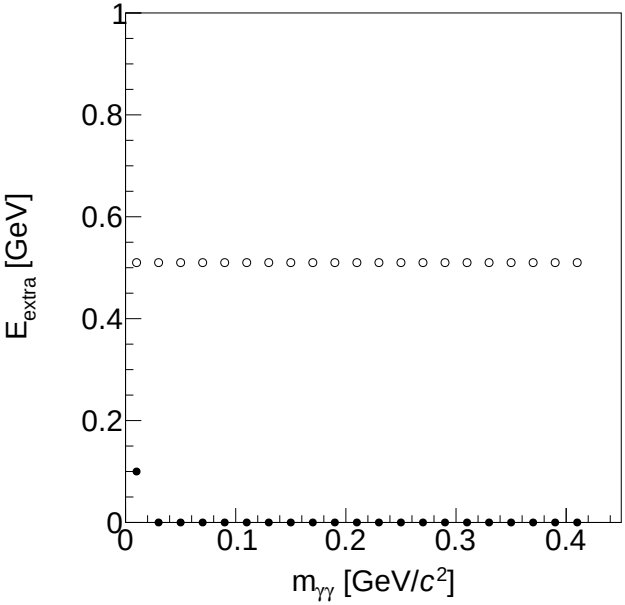


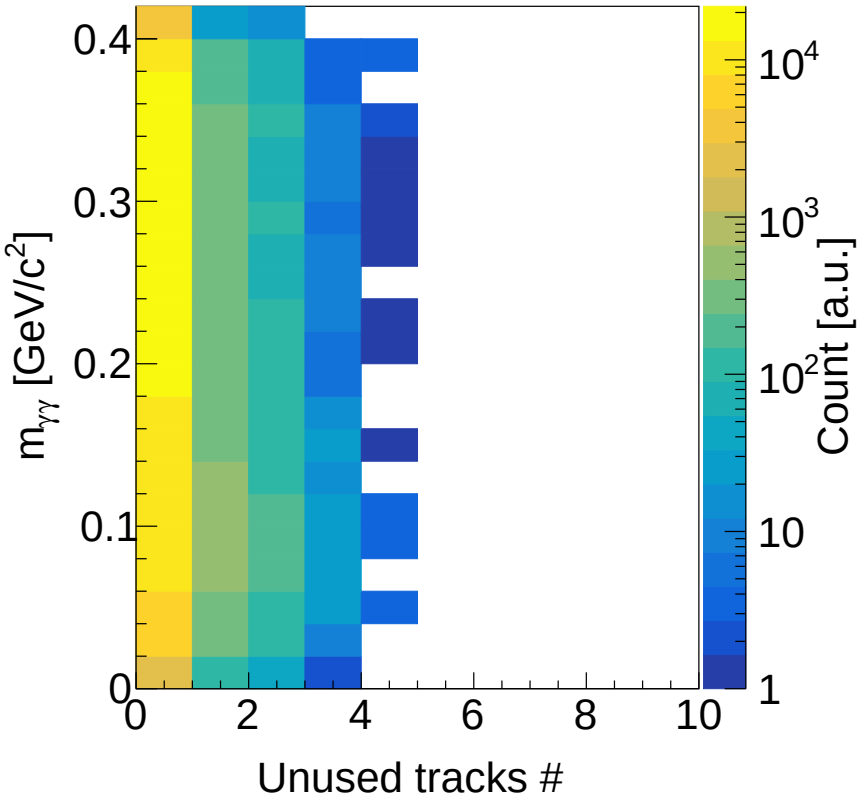



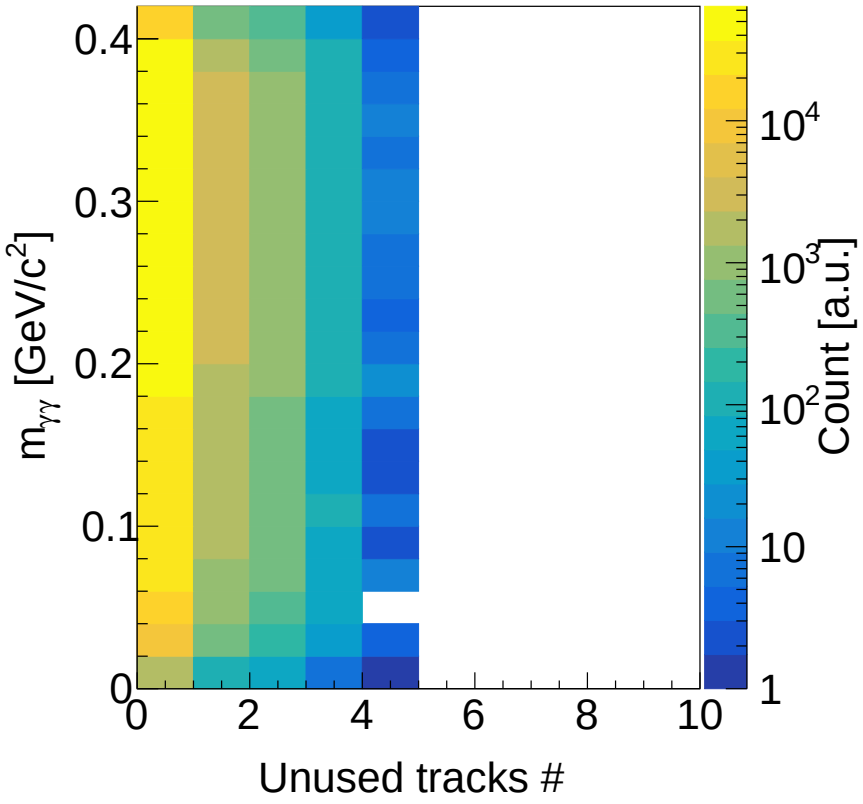

- Find value

# FCAL2, unused track number

$m_{\gamma\gamma}$ vs. unused track number for:

- Signal
- Background



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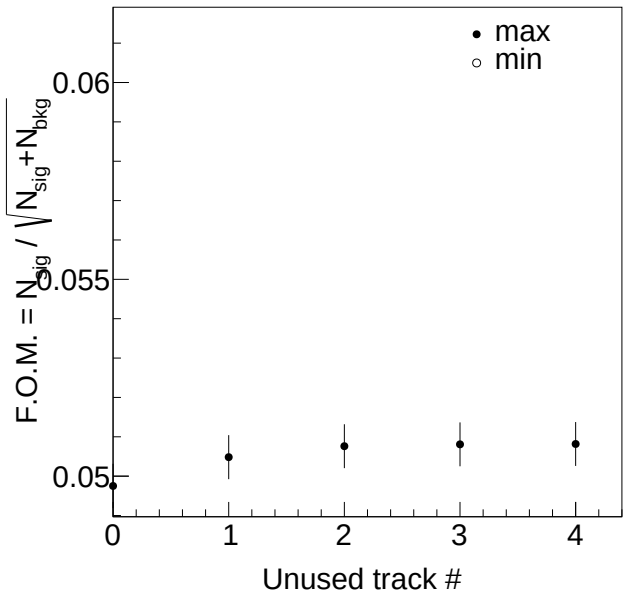
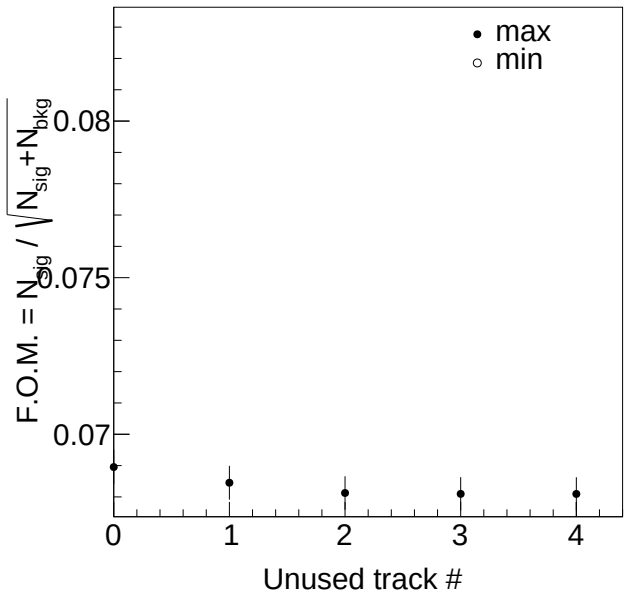
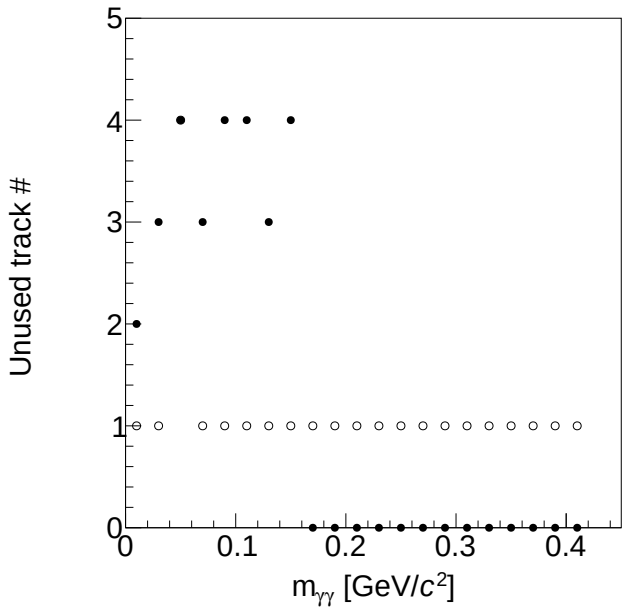


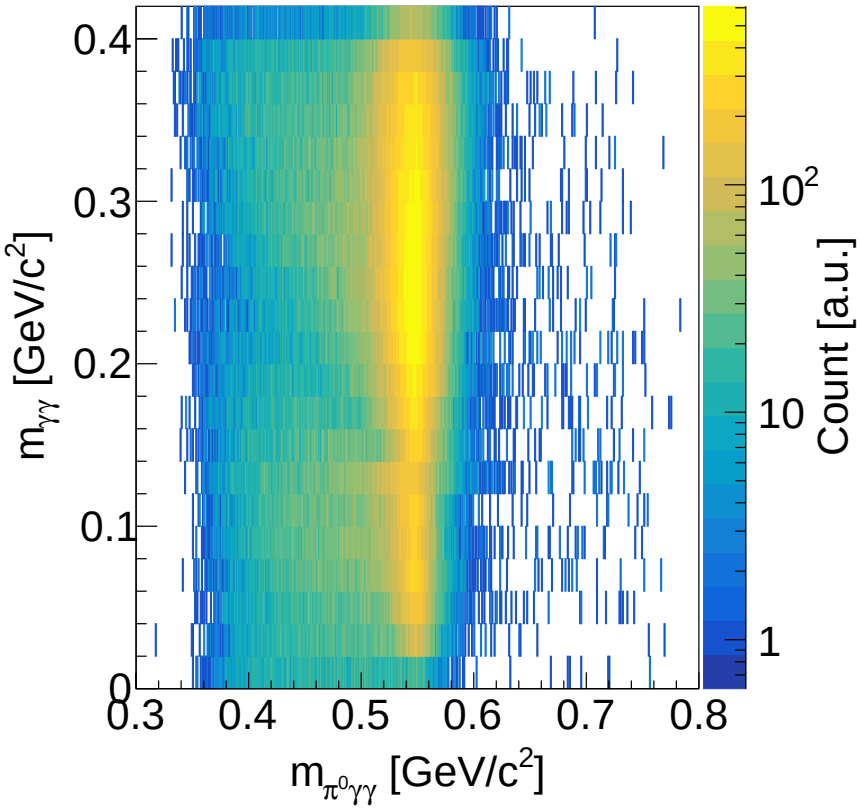



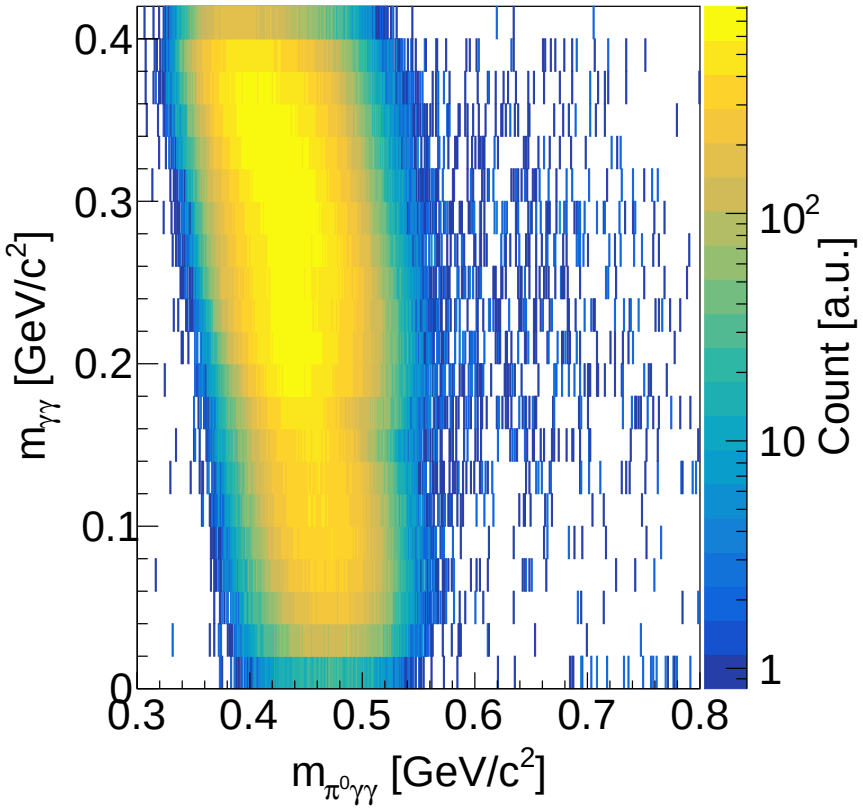

- Find value

# FCAL2, $\pi^0\gamma\gamma$ invariant mass

$m_{\gamma\gamma}$ vs. $\pi^0\gamma\gamma$ invariant mass for:

- Signal
- Background



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FOM vs. $\pi^0\gamma\gamma$ invariant mass for:

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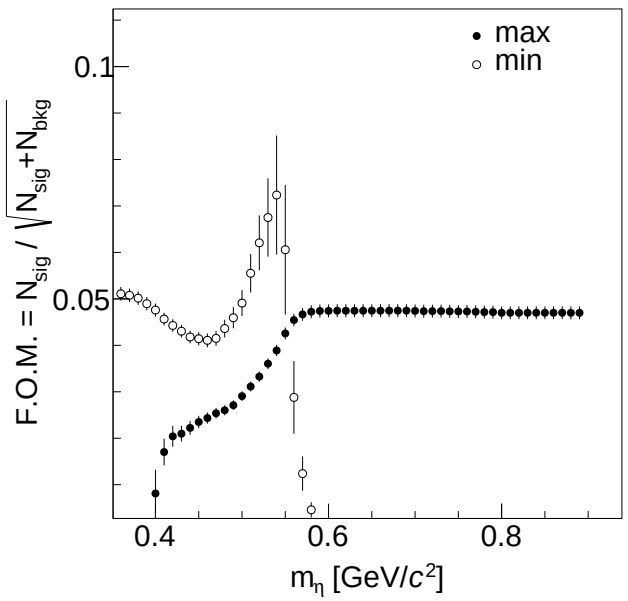
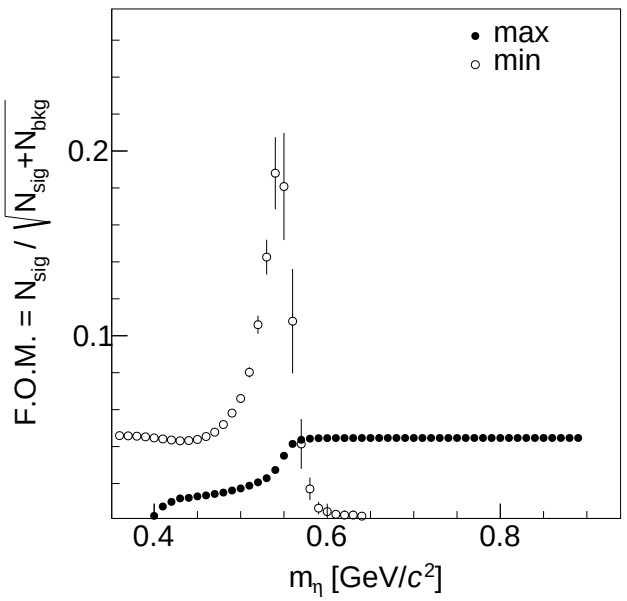
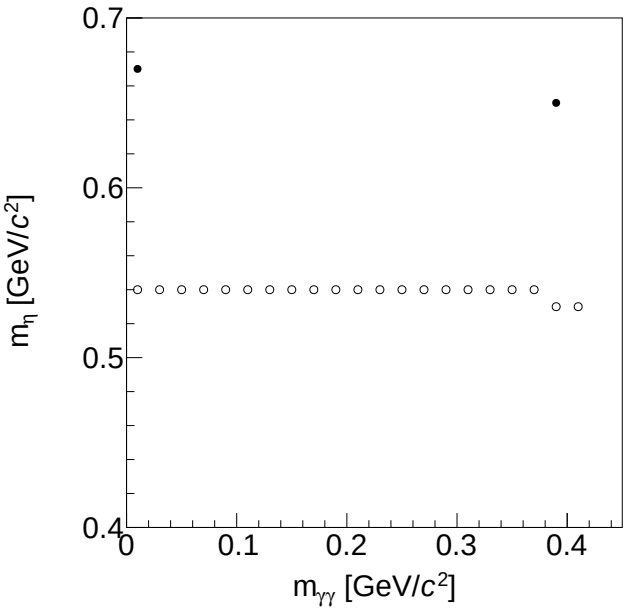


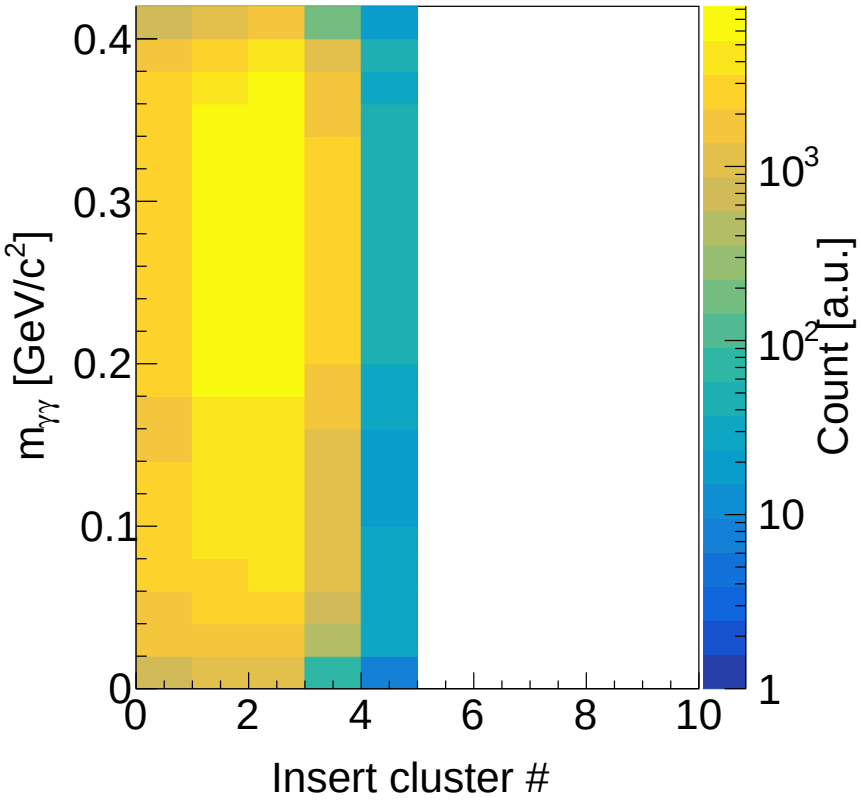



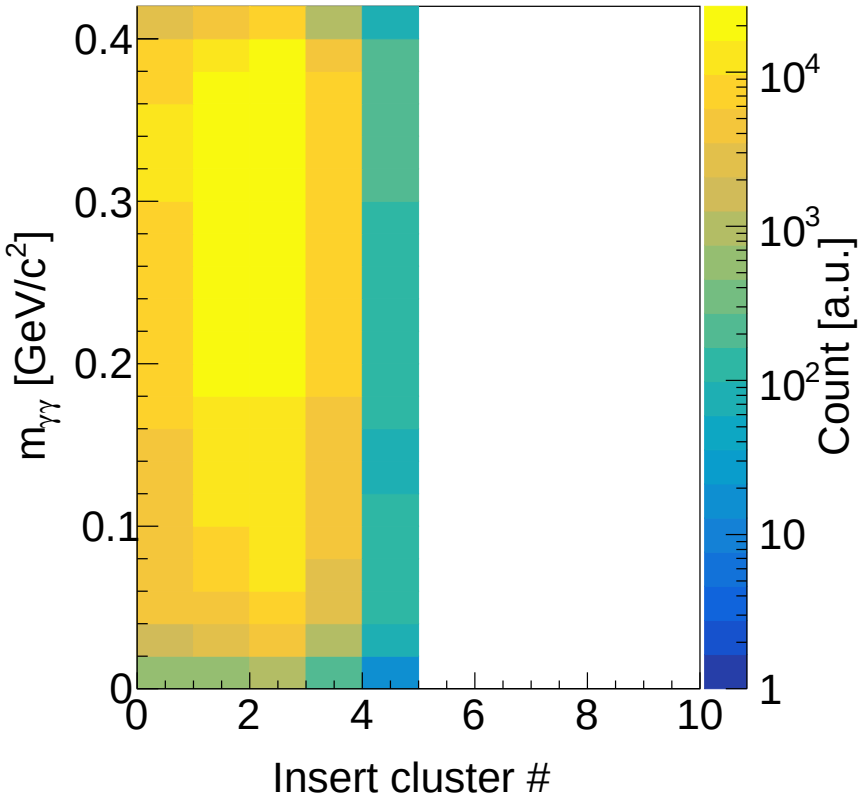

- Find lower value
- Find upper value

# FCAL2, cluster number below 4.5$^o$

$m_{\gamma\gamma}$ vs. cluster number below 4.5$^o$ for:

- Signal
- Background



# FCAL2, cluster number below 4.5$^o$

FOM vs. cluster number below 4.5$^o$ for:

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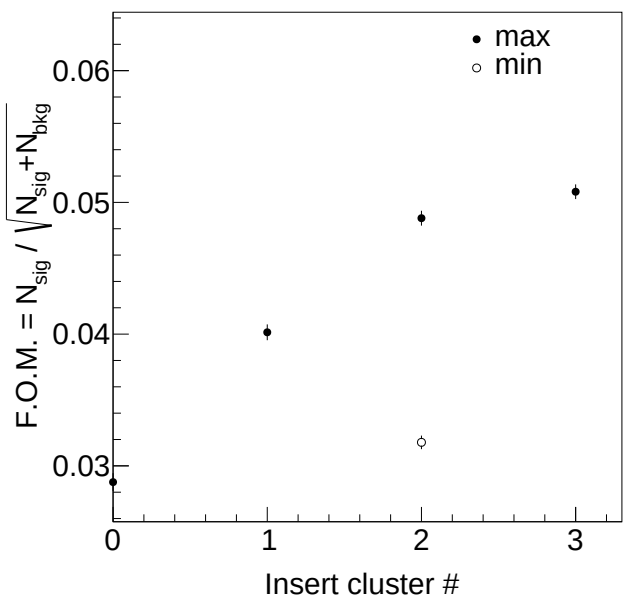
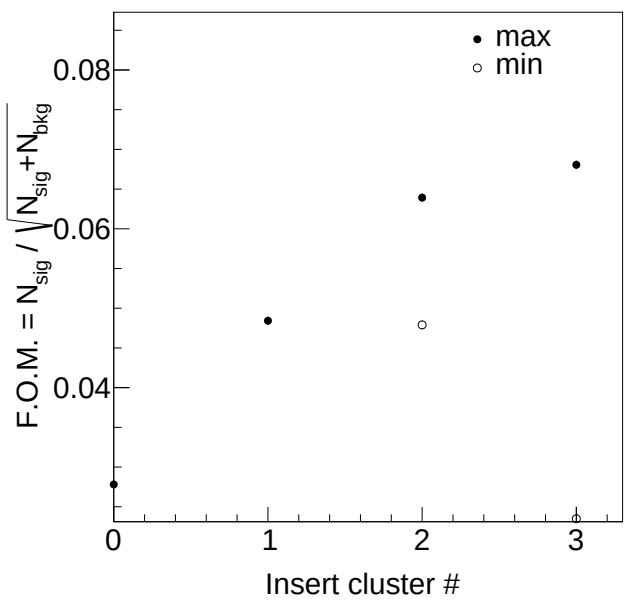
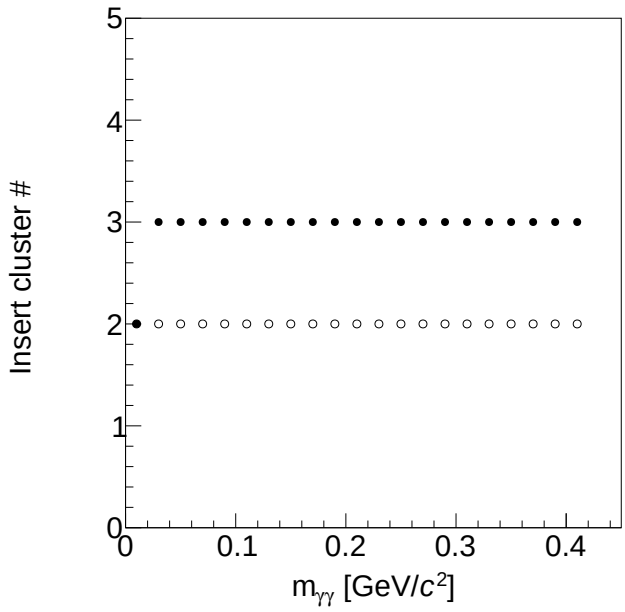


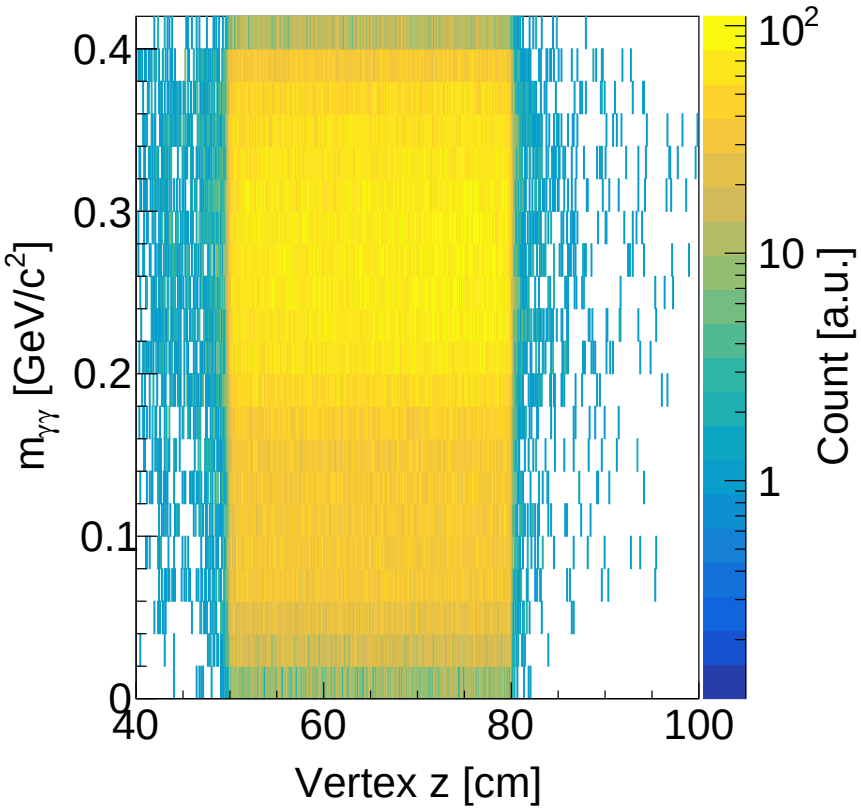



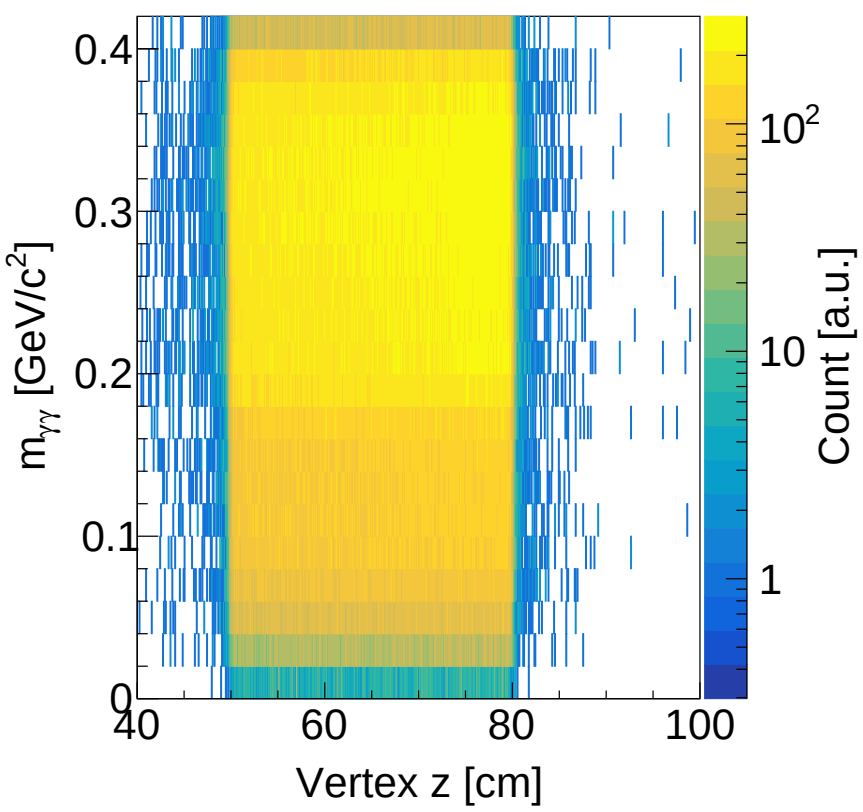

- Find lower value
- Find upper value

# FCAL2, vertex production z

$m_{\gamma\gamma}$ vs. vertex production z for:

- Signal
- Background



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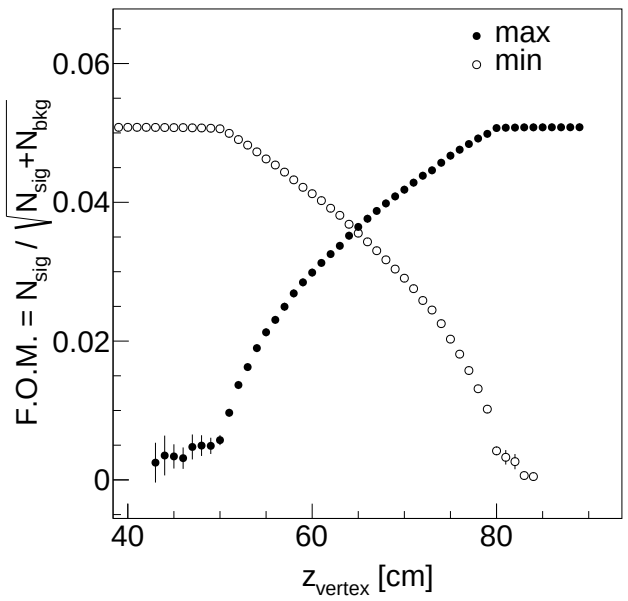
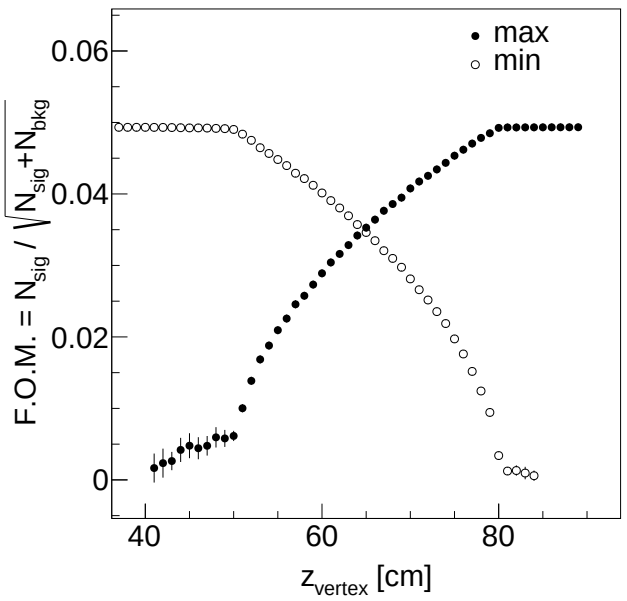
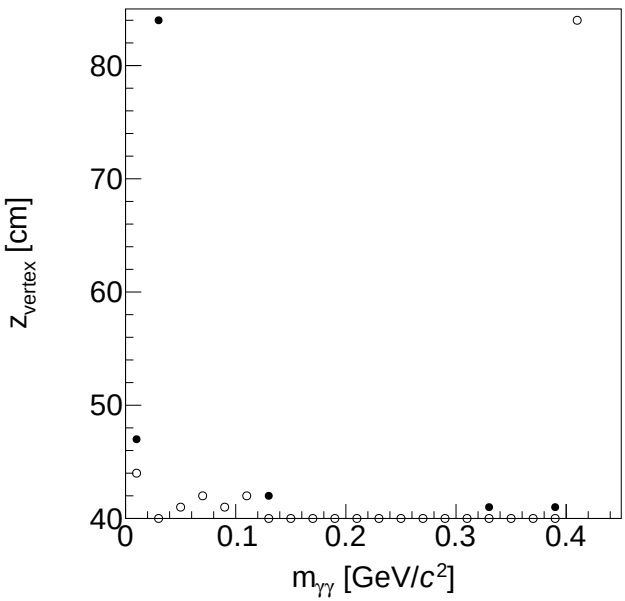


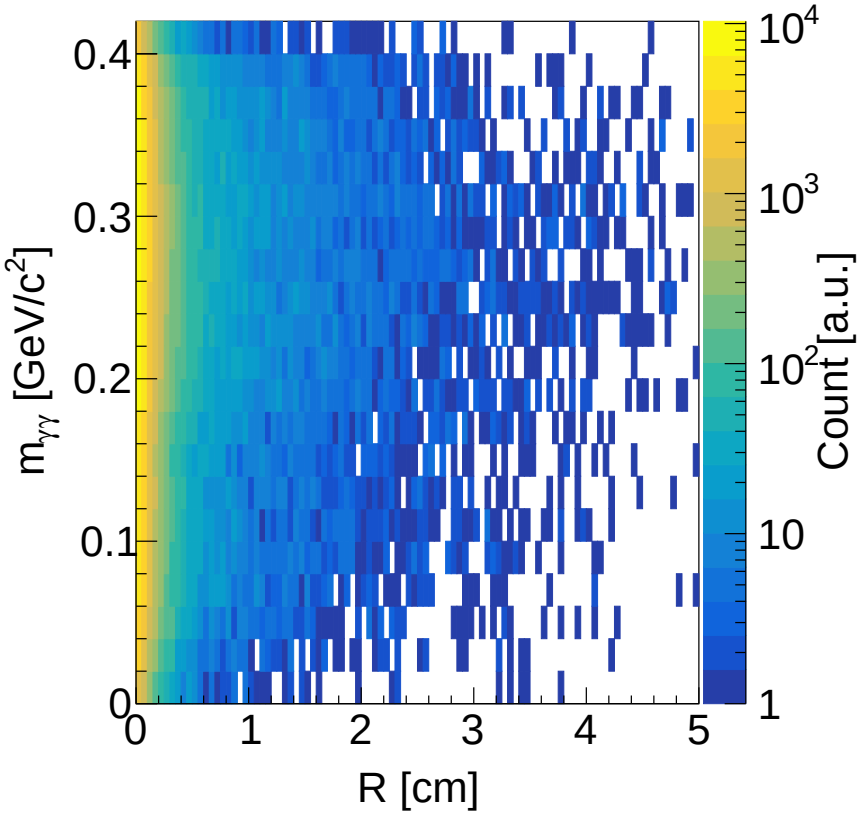



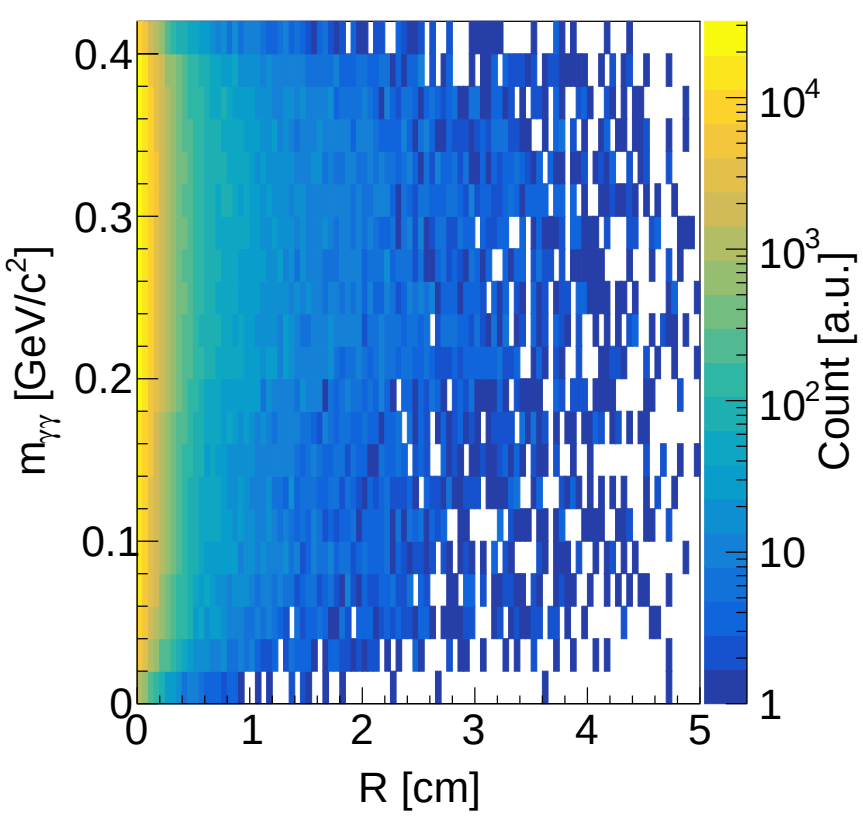

- Find lower value
- Find upper value

# FCAL2, vertex production r

$m_{\gamma\gamma}$ vs. vertex production r for:

- Signal
- Background

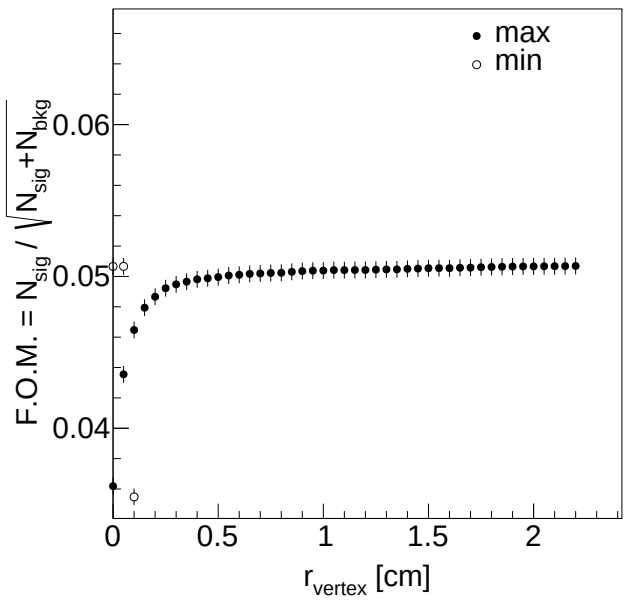


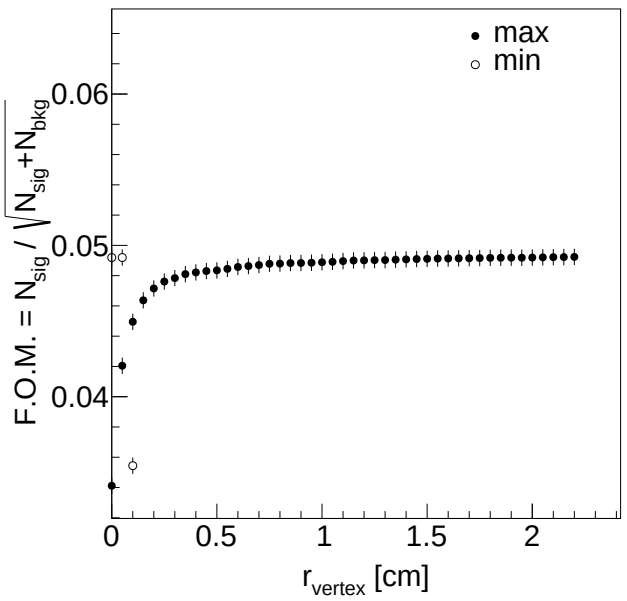



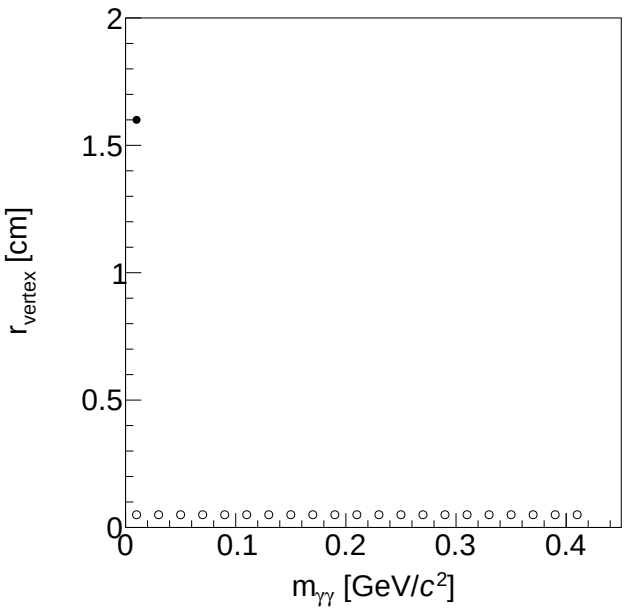
# FCAL2, vertex production r

FOM vs. vertex production r for:

- $m_{\gamma\gamma} = 110$ MeV/$c^2$
- $m_{\gamma\gamma} = 310$ MeV/$c^2$
- Selection critiria vs. $m_{\gamma\gamma}$



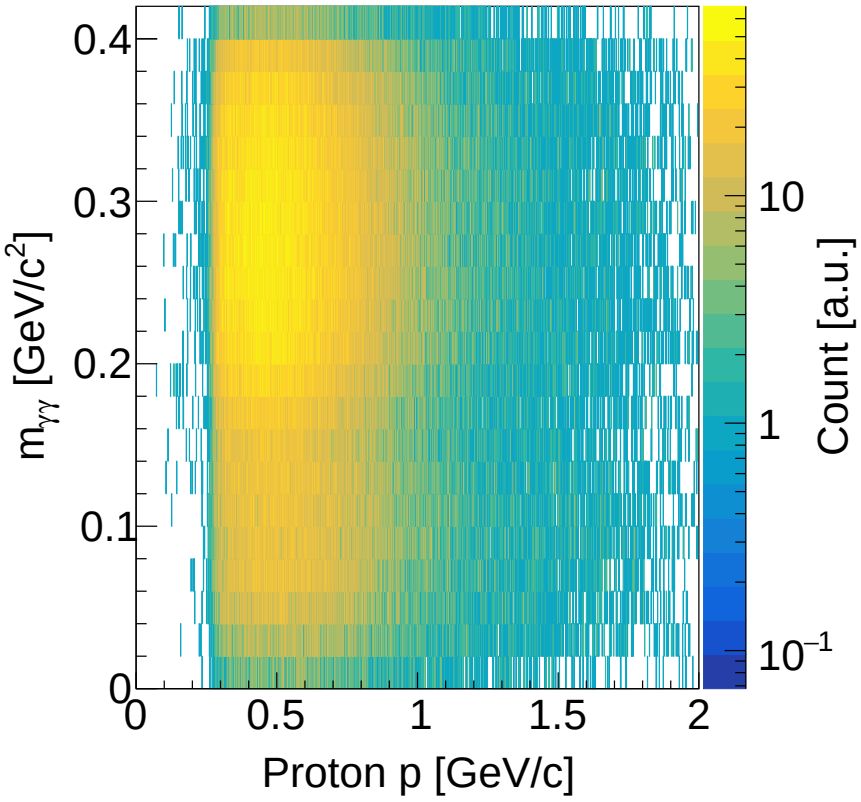



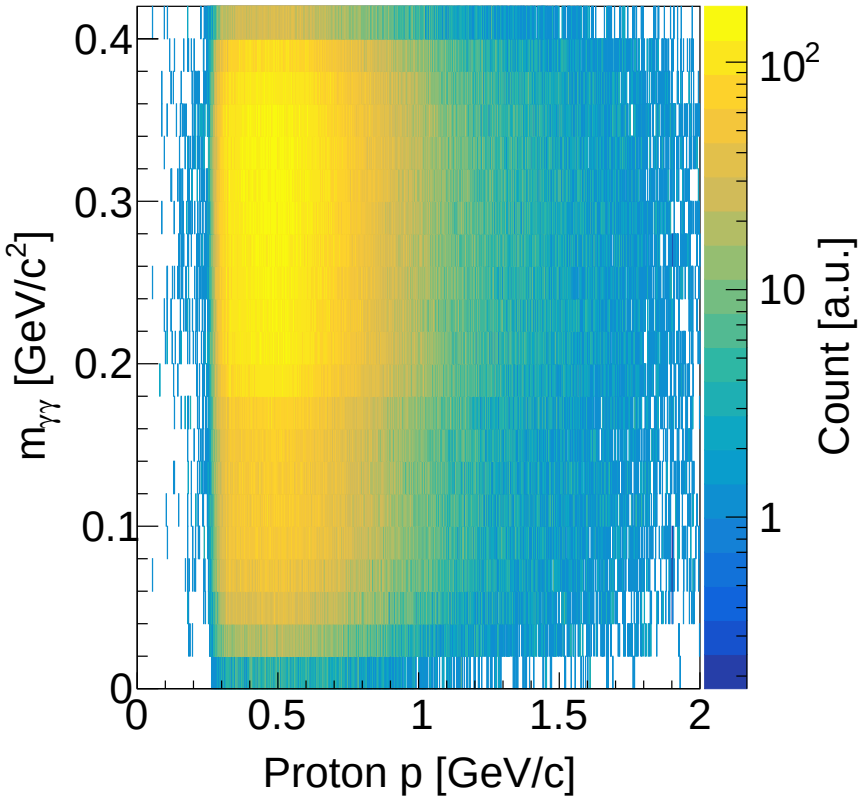

- Find lower value
- Find upper value

# FCAL2, proton momentum

$m_{\gamma\gamma}$ vs. proton momentum for:

- Signal
- Background

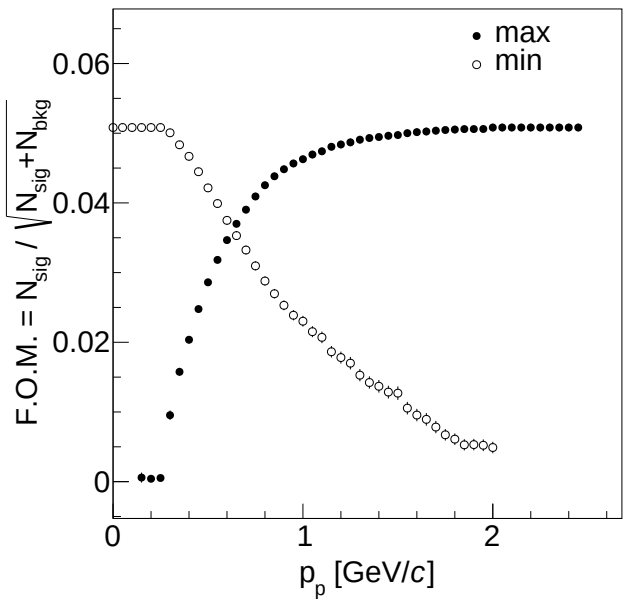


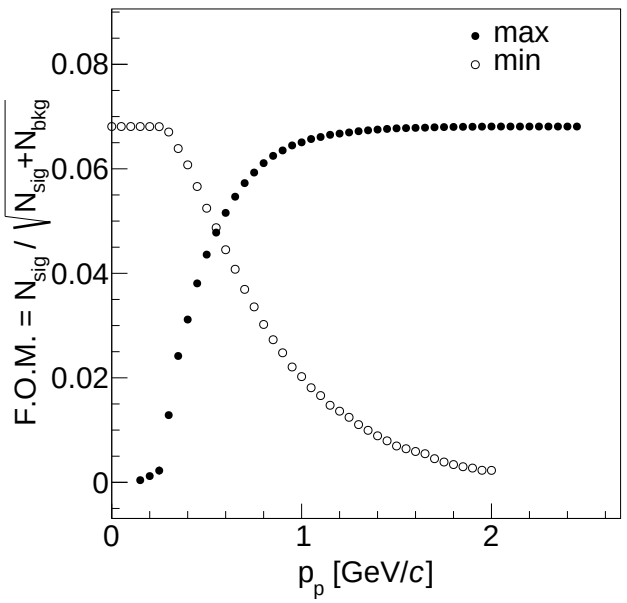



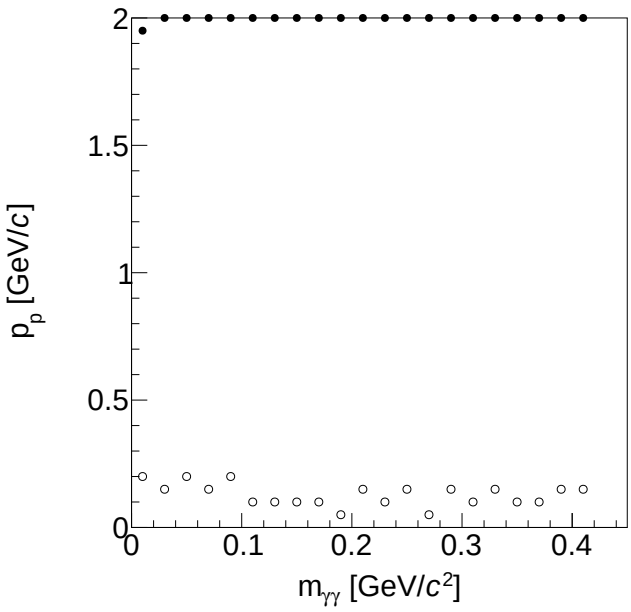
# FCAL2, proton momentum

FOM vs. proton momentum for:

- $m_{\gamma\gamma} = 110$ MeV/$c^2$
- $m_{\gamma\gamma} = 310$ MeV/$c^2$
- Selection critiria vs. $m_{\gamma\gamma}$



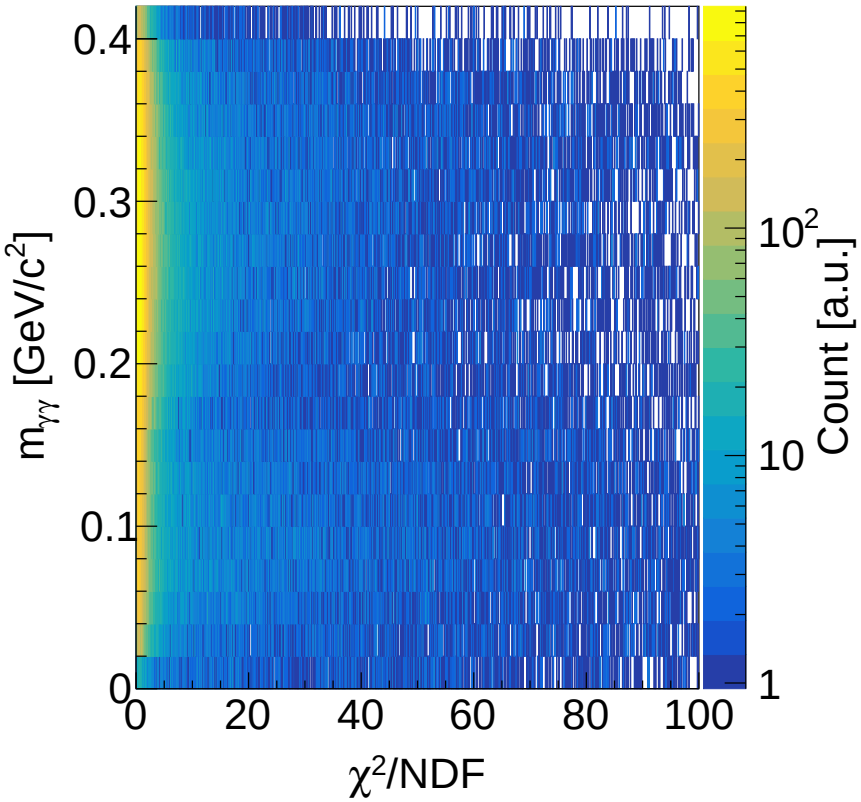



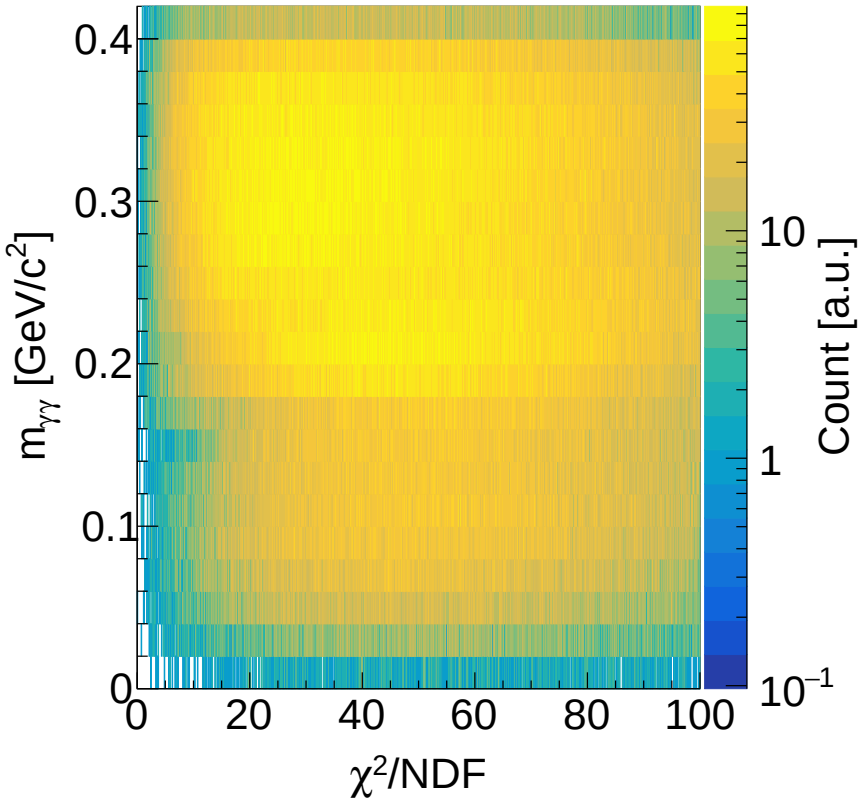

- Find lower value
- Find upper value

# FCAL, Kinfit $\chi^2$

$m_{\gamma\gamma}$ vs. vs. kinfit $\chi^2$ for:

- Signal
- Background

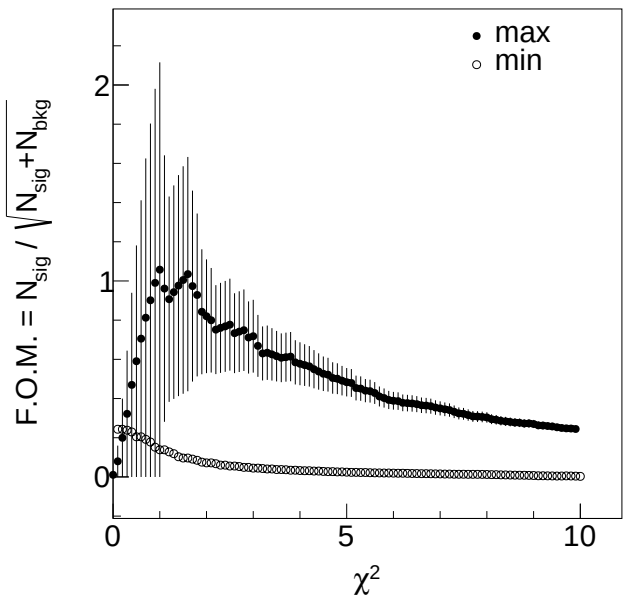


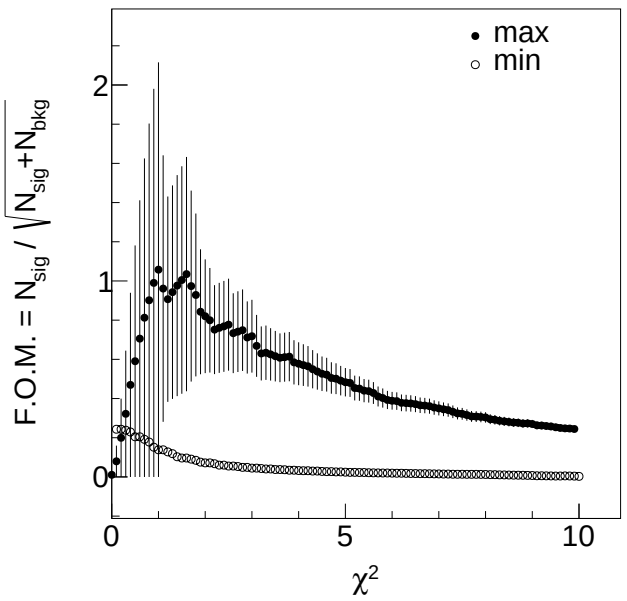



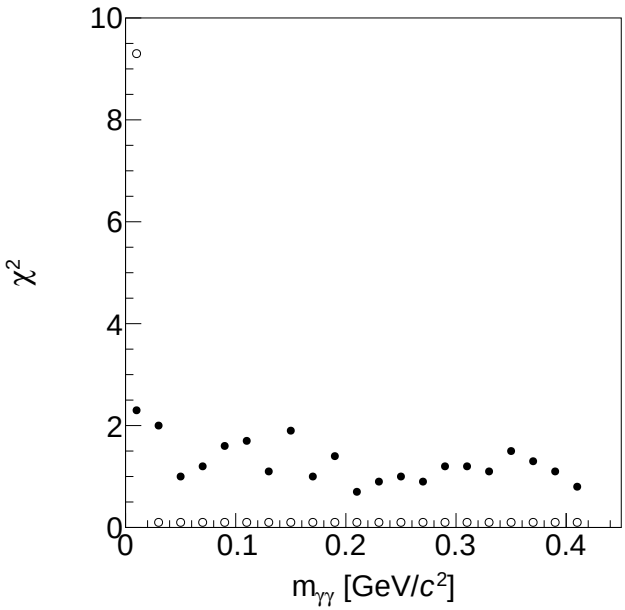
# FCAL, Kinfit $\chi^2$

FOM vs. kinfit $\chi^2$:

- $m_{\gamma\gamma} = 110$ MeV/$c^2$
- $m_{\gamma\gamma} = 310$ MeV/$c^2$
- Selection critiria vs. $m_{\gamma\gamma}$



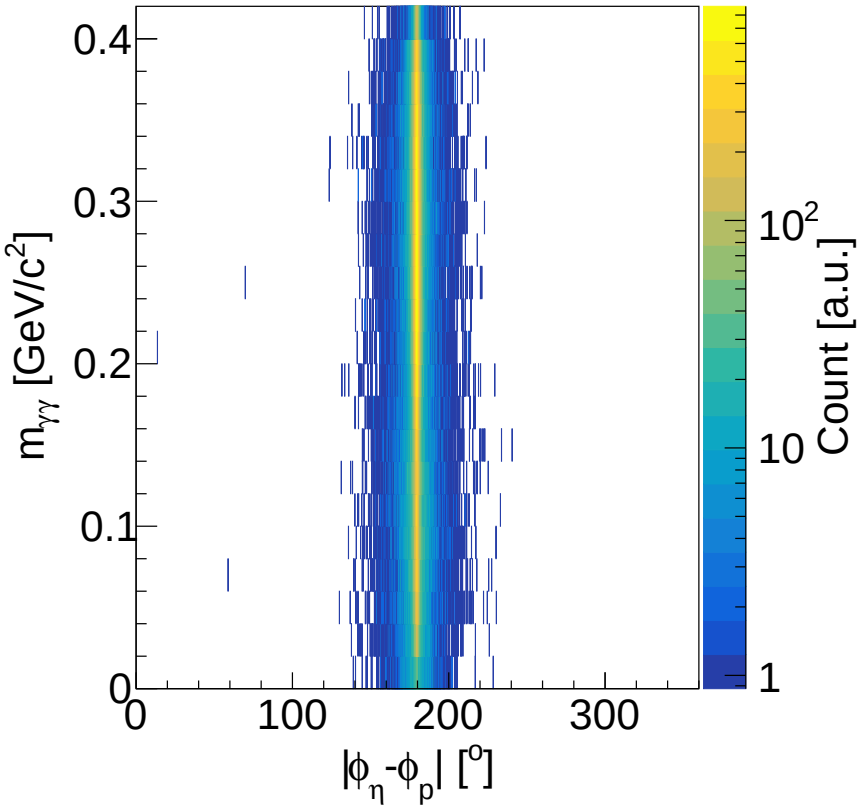



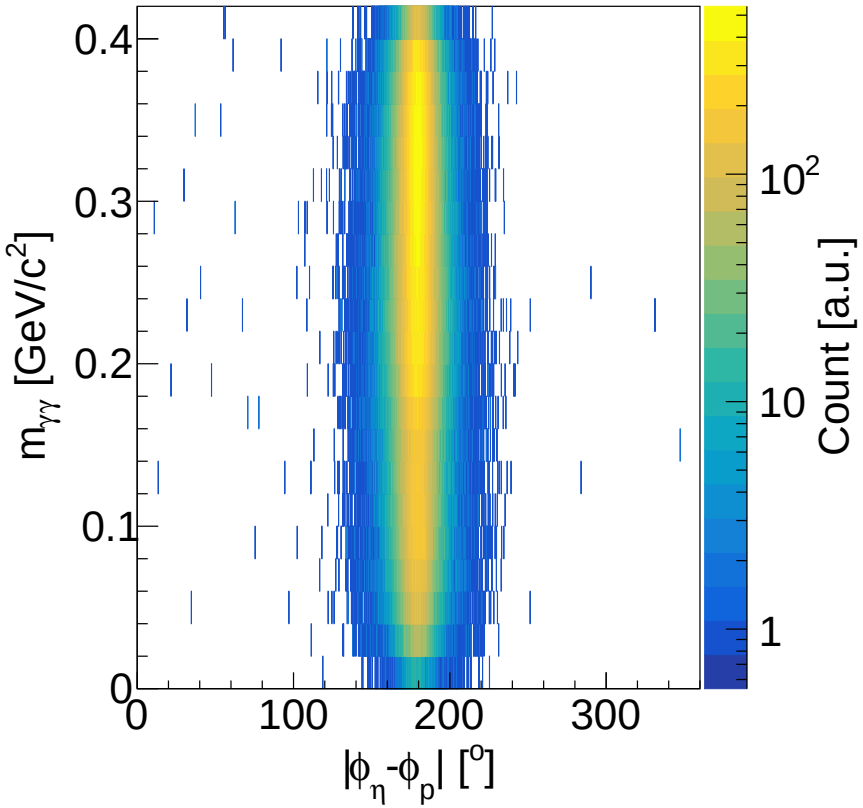

- Find lower value
- Find upper value

# FCAL, Coplanarity between $\eta$ and $p$

$m_{\gamma\gamma}$ vs. coplanarity between $\eta$-candidate and $p$ for:

- Signal
- Background

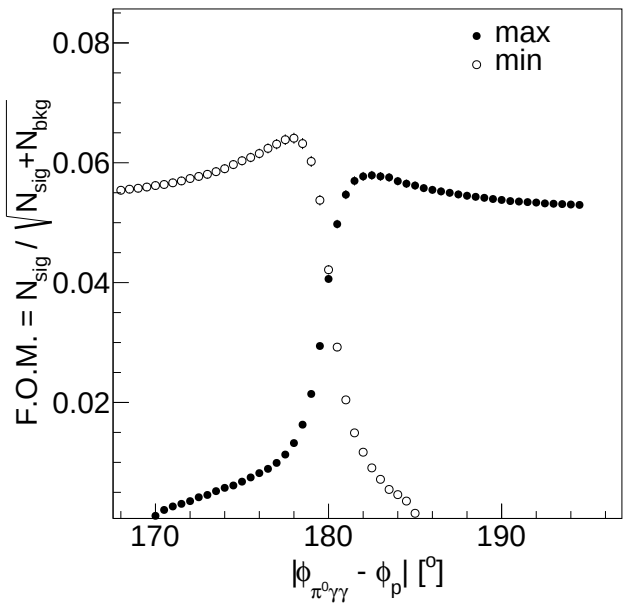


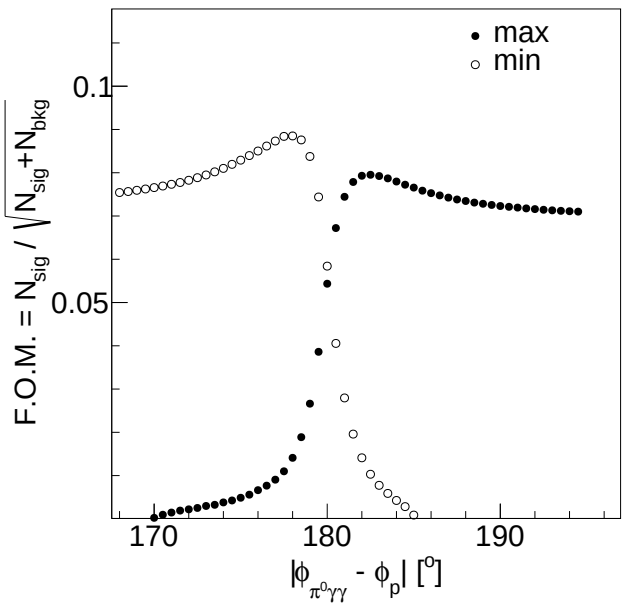



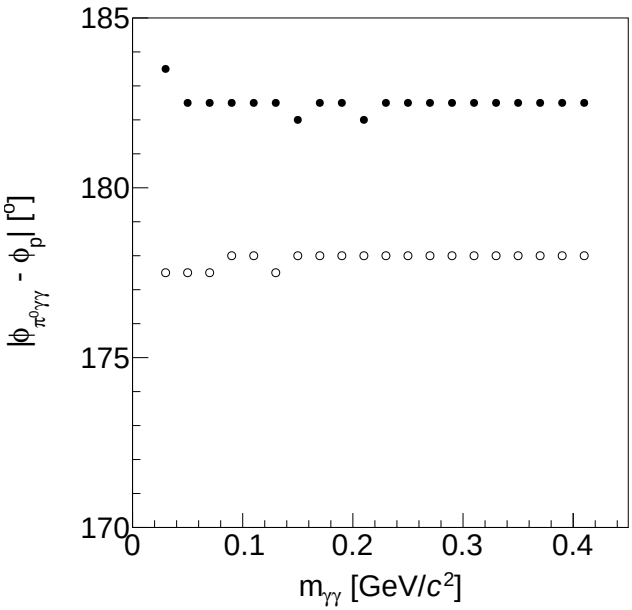
# FCAL, coplanarity between $\eta$ and $p$

FOM vs. coplanarity between $\eta$-candidate and $p$ for:

- $m_{\gamma\gamma} = 110$ MeV/$c^2$
- $m_{\gamma\gamma} = 310$ MeV/$c^2$
- Selection critiria vs. $m_{\gamma\gamma}$



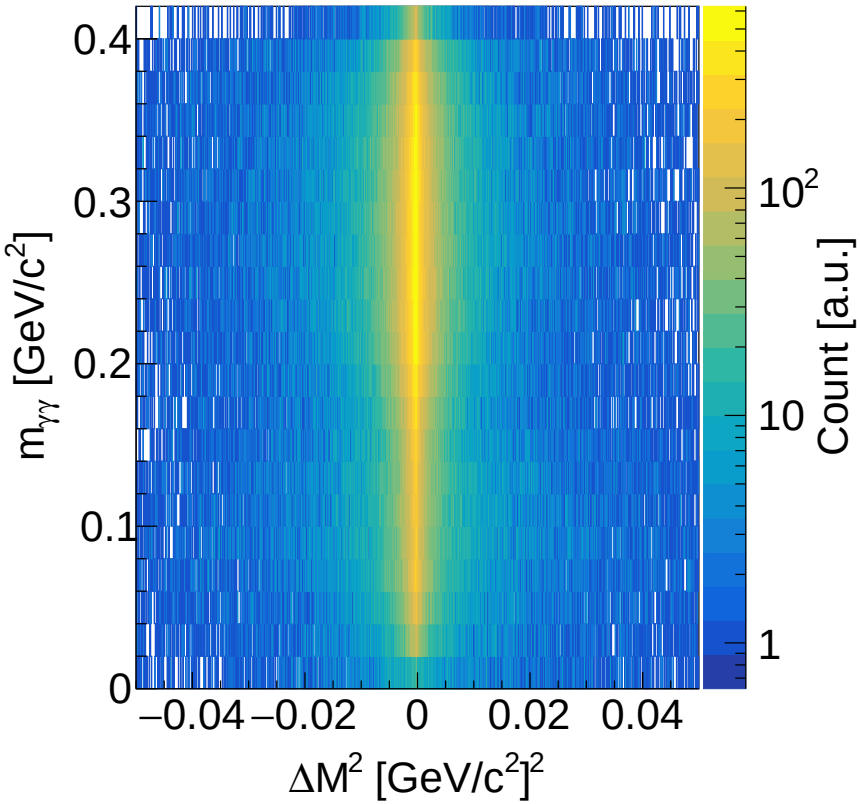



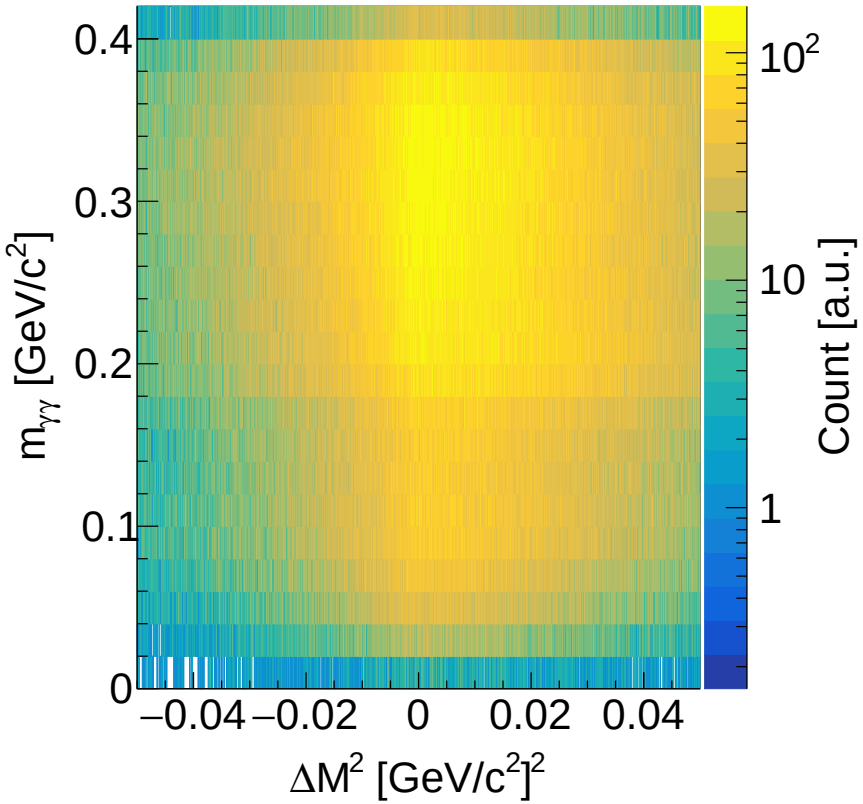

- Find lower value
- Find upper value

# FCAL, mass conservation

$m_{\gamma\gamma}$ vs. mass conservation, $\Delta M^2$, for:

- Signal
- Background

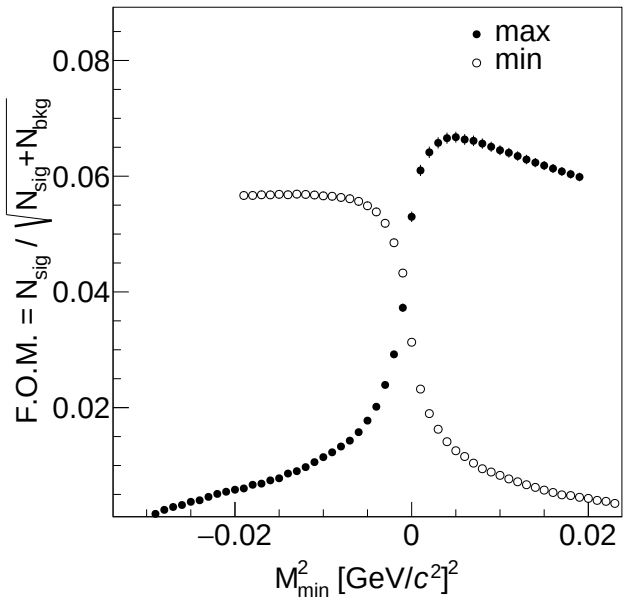


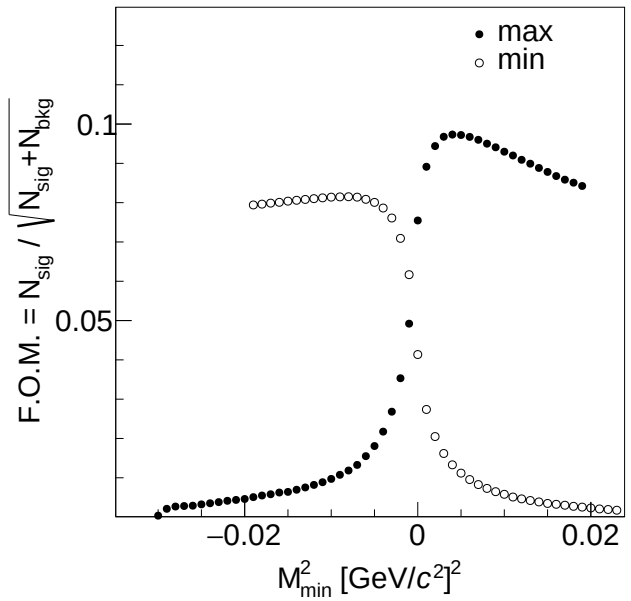



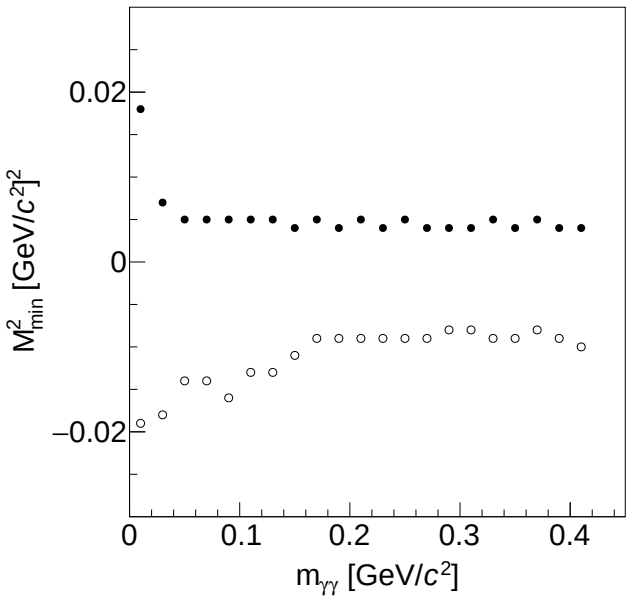
# FCAL, mass conservation

FOM vs. mass conservation for:

- $m_{\gamma\gamma} = 110$ MeV/$c^2$
- $m_{\gamma\gamma} = 310$ MeV/$c^2$
- Selection critiria vs. $m_{\gamma\gamma}$



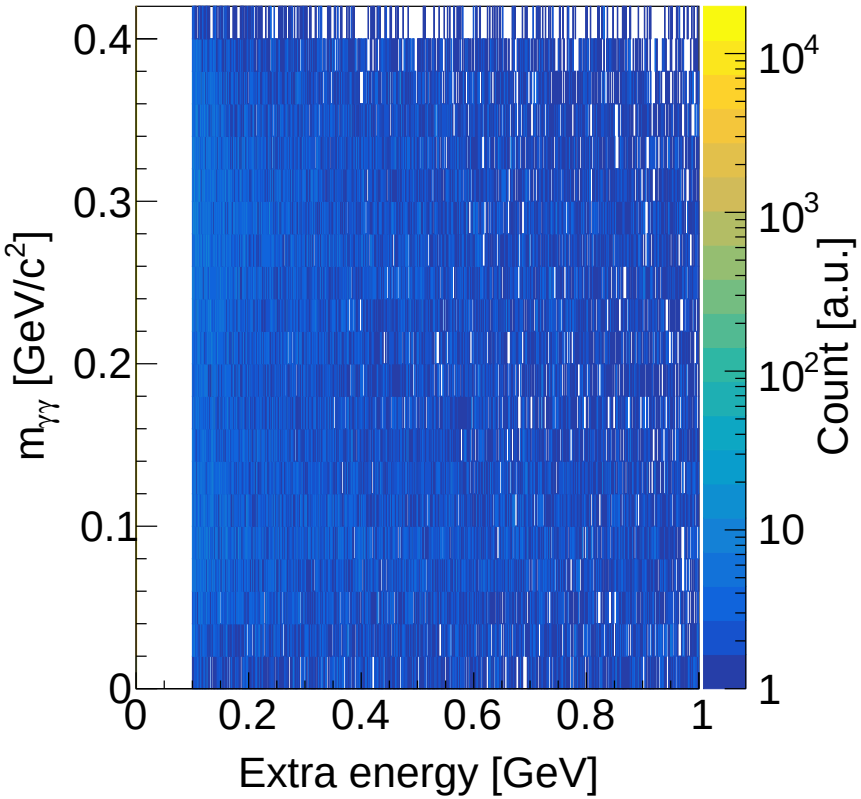



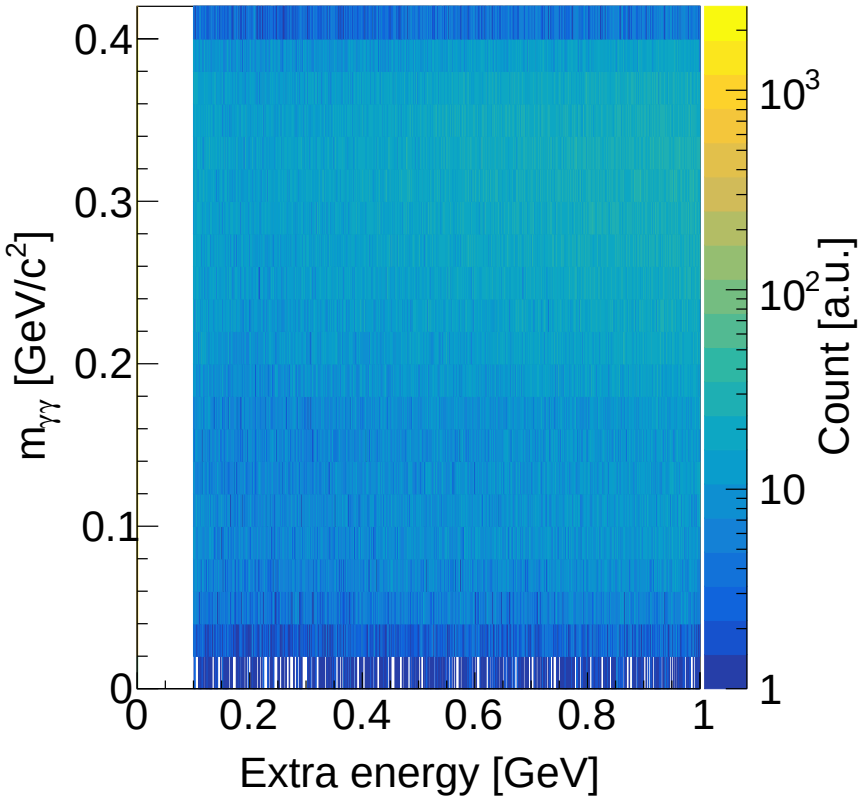

- Find lower value
- Find upper value

# FCAL, extra energy

$m_{\gamma\gamma}$ vs. extra energy for:

- Signal
- Background

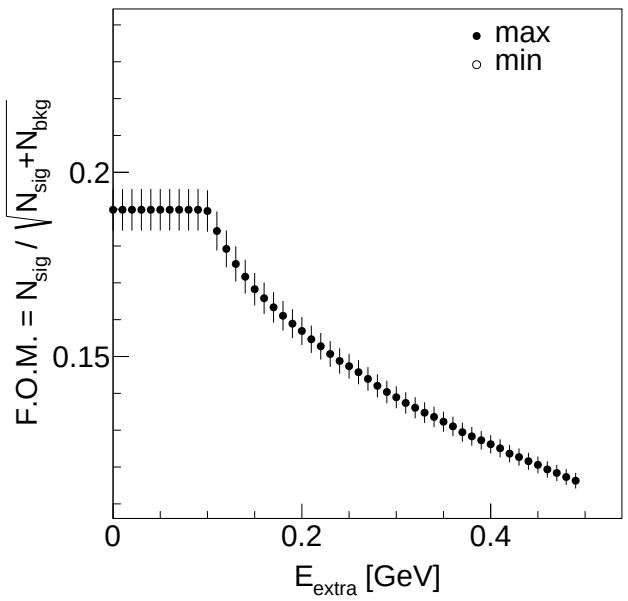


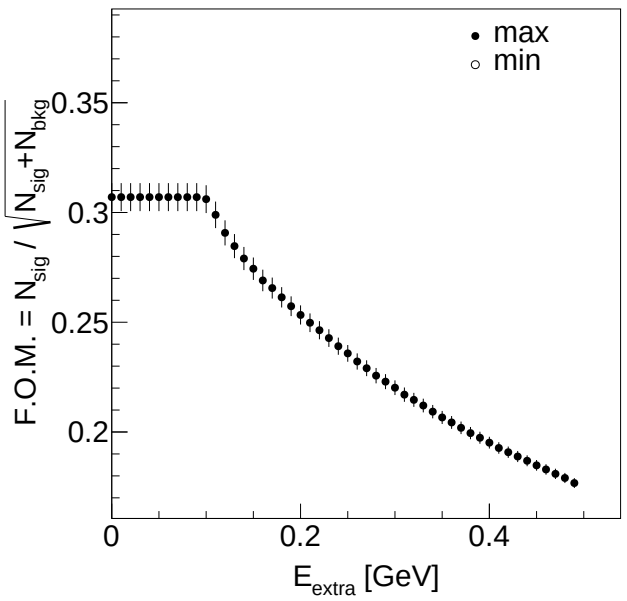



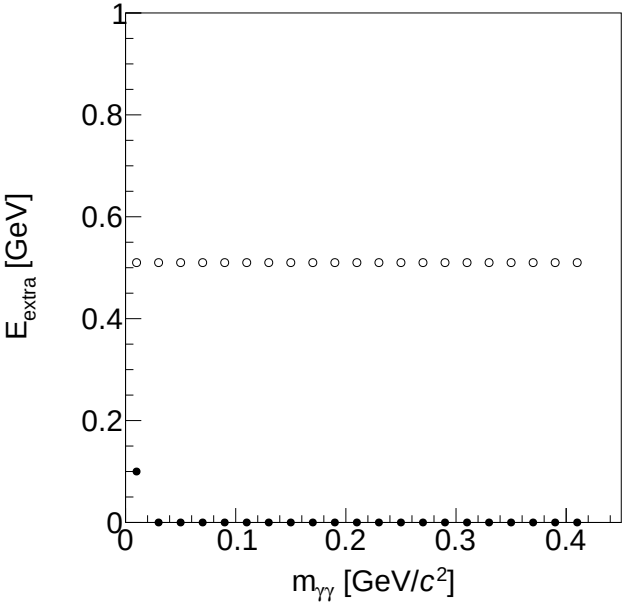
# FCAL, extra energy

FOM vs. extra energy for:

- $m_{\gamma\gamma} = 110$ MeV/$c^2$
- $m_{\gamma\gamma} = 310$ MeV/$c^2$
- Selection critiria vs. $m_{\gamma\gamma}$



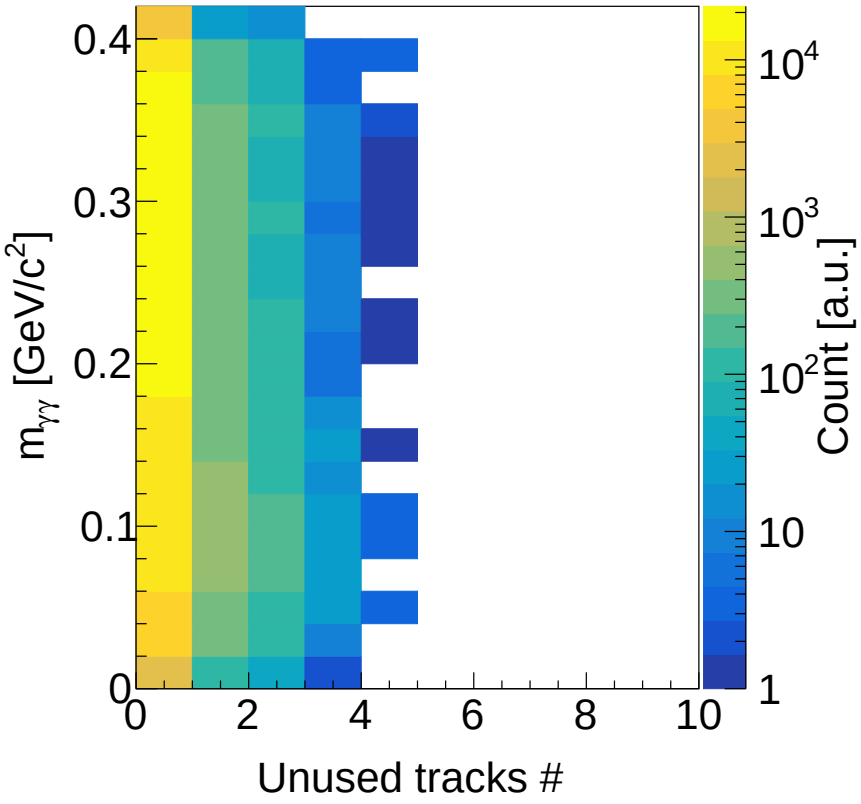



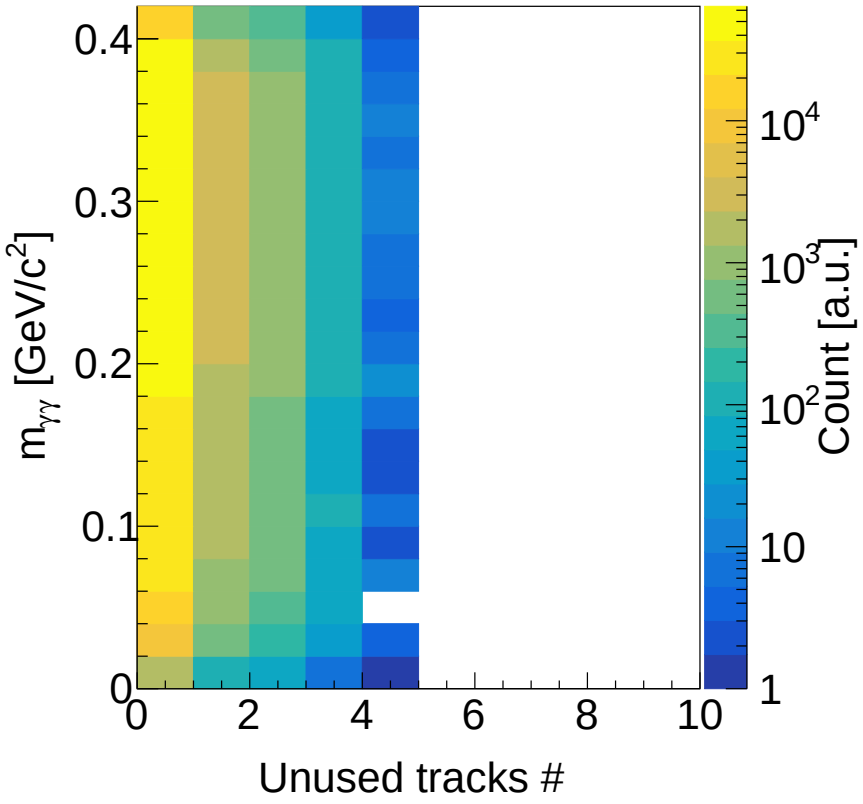

- Find value

# FCAL, unused track number

$m_{\gamma\gamma}$ vs. unused track number for:

- Signal
- Background

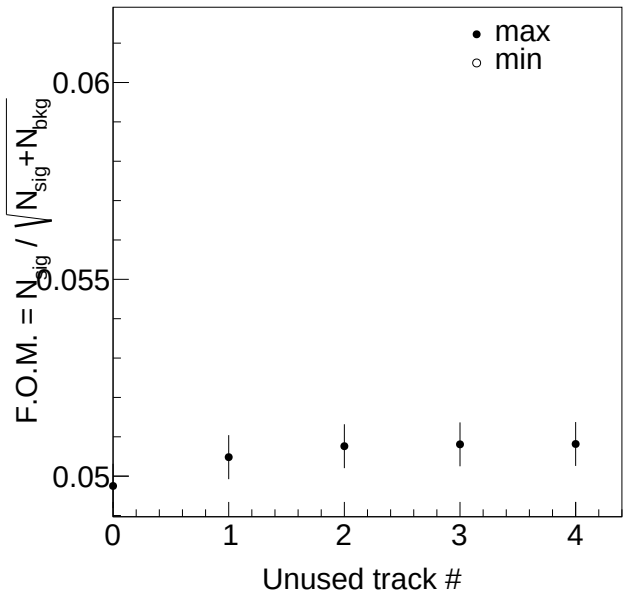


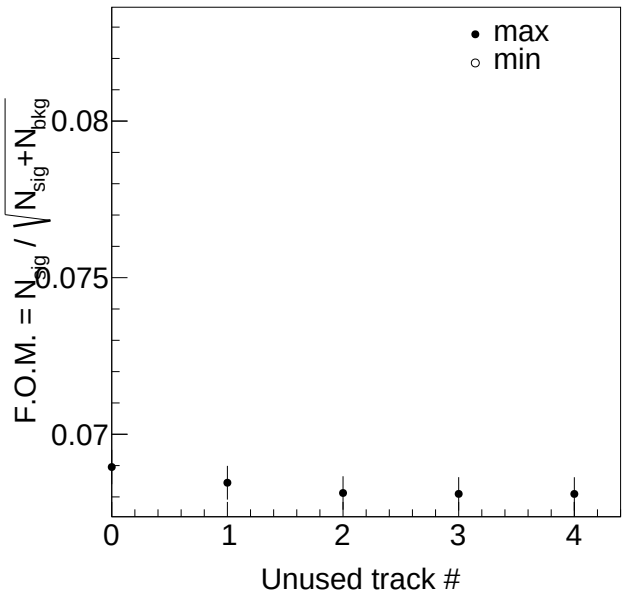



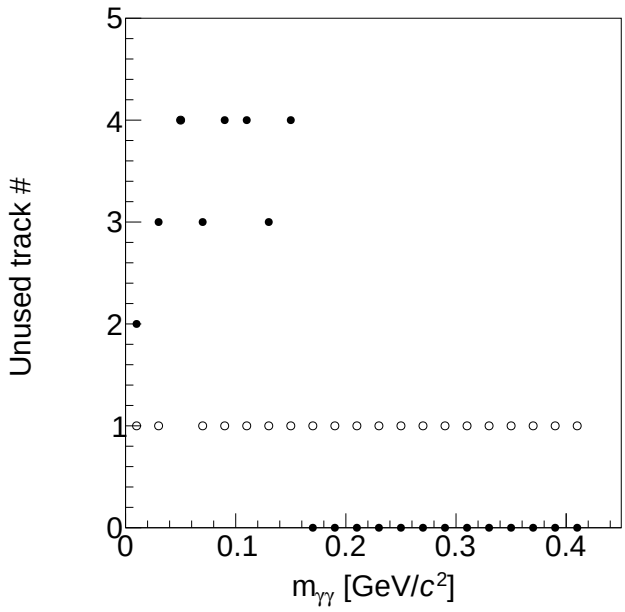
# FCAL, unused track number

FOM vs. unused track number for:

- $m_{\gamma\gamma} = 110$ MeV/$c^2$
- $m_{\gamma\gamma} = 310$ MeV/$c^2$
- Selection critiria vs. $m_{\gamma\gamma}$



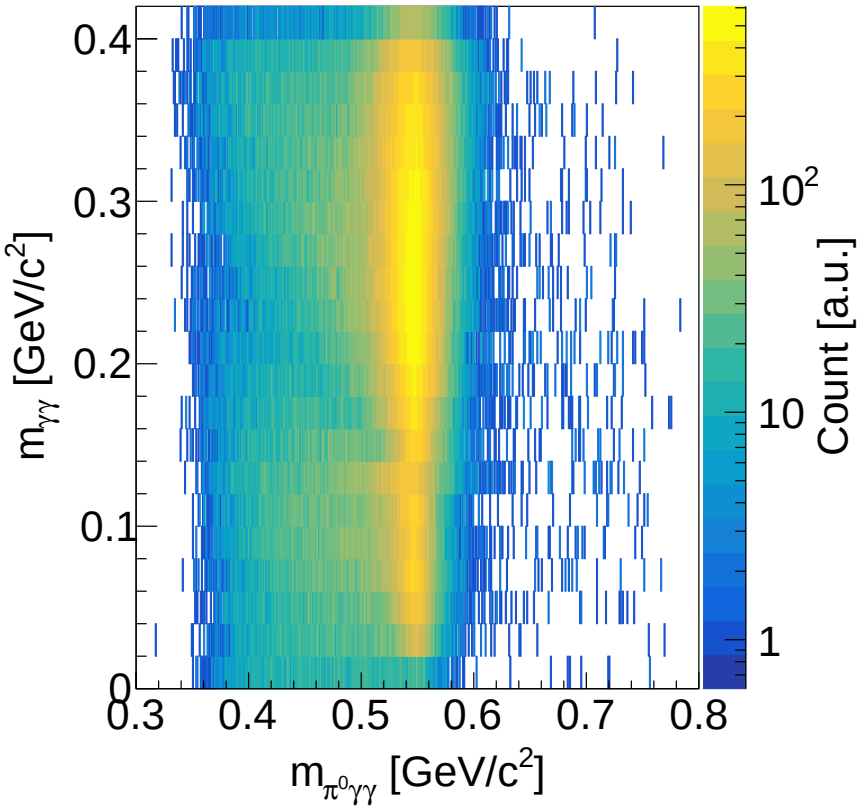



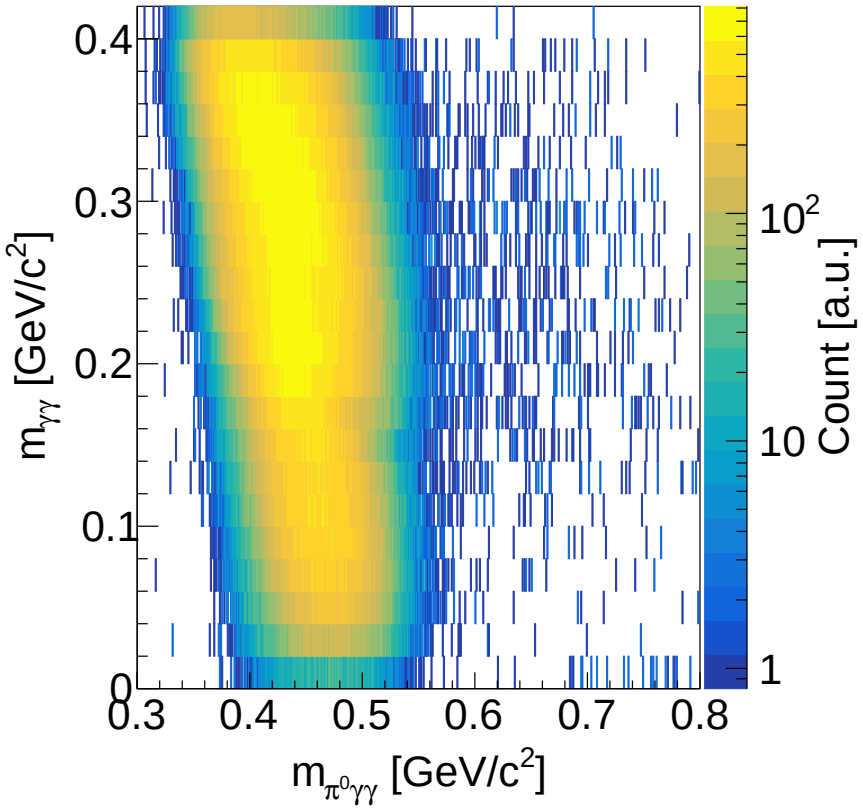

- Find value

# FCAL, $\pi^0\gamma\gamma$ invariant mass

$m_{\gamma\gamma}$ vs. $\pi^0\gamma\gamma$ invariant mass for:

- Signal
- Background

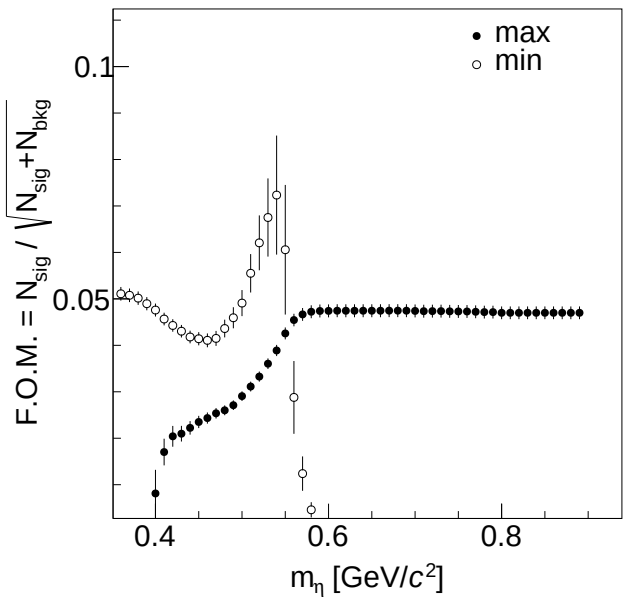


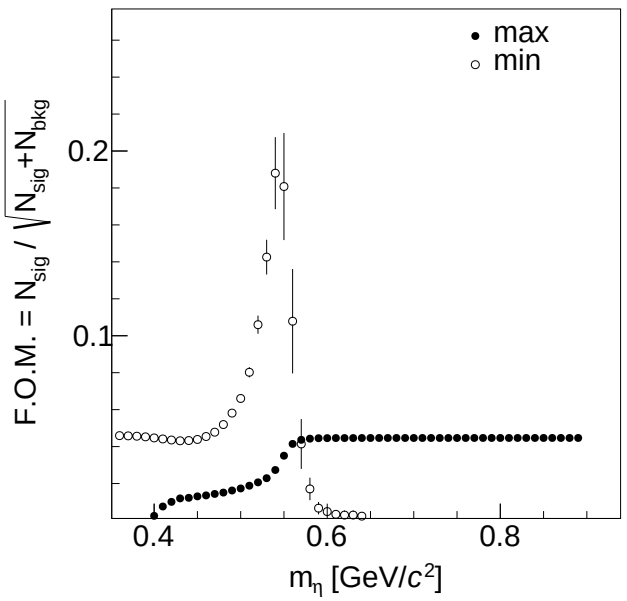



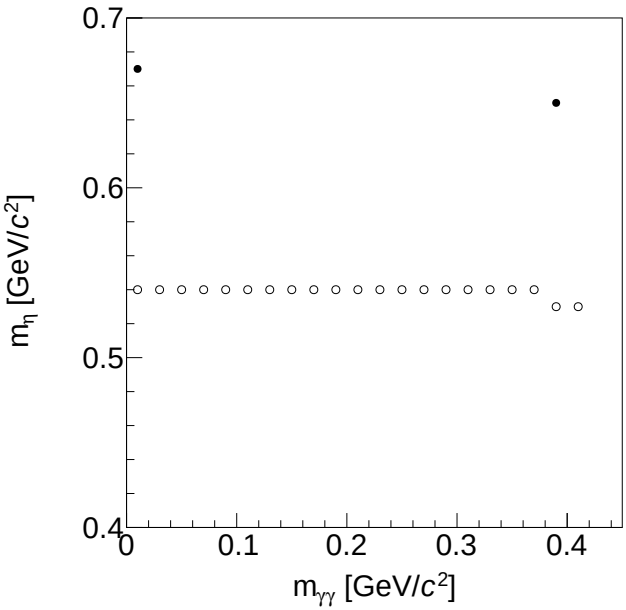
# FCAL, $\pi^0\gamma\gamma$ invariant mass

FOM vs. $\pi^0\gamma\gamma$ invariant mass for:

- $m_{\gamma\gamma} = 110$ MeV/$c^2$
- $m_{\gamma\gamma} = 310$ MeV/$c^2$
- Selection critiria vs. $m_{\gamma\gamma}$



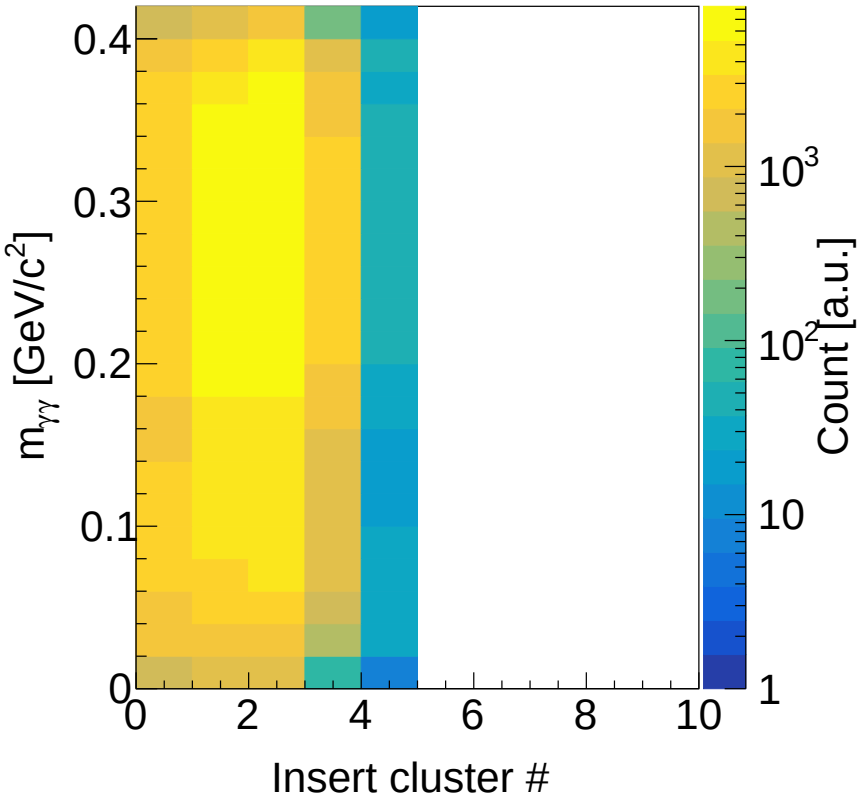



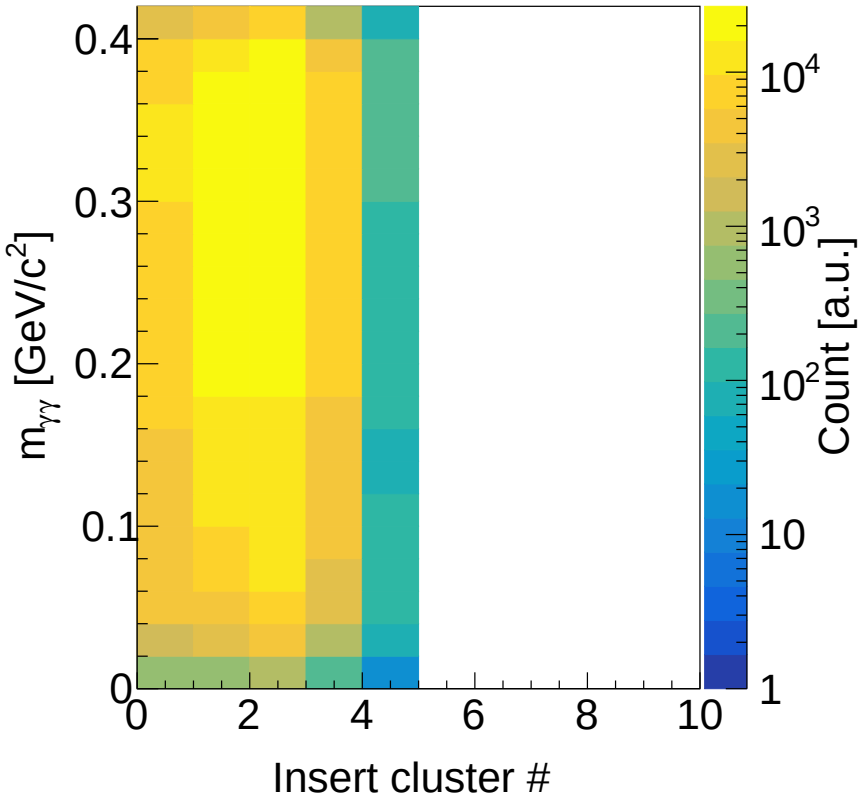

- Find lower value
- Find upper value

# FCAL, cluster number below 4.5$^o$

$m_{\gamma\gamma}$ vs. cluster number below 4.5$^o$ for:

- Signal
- Background

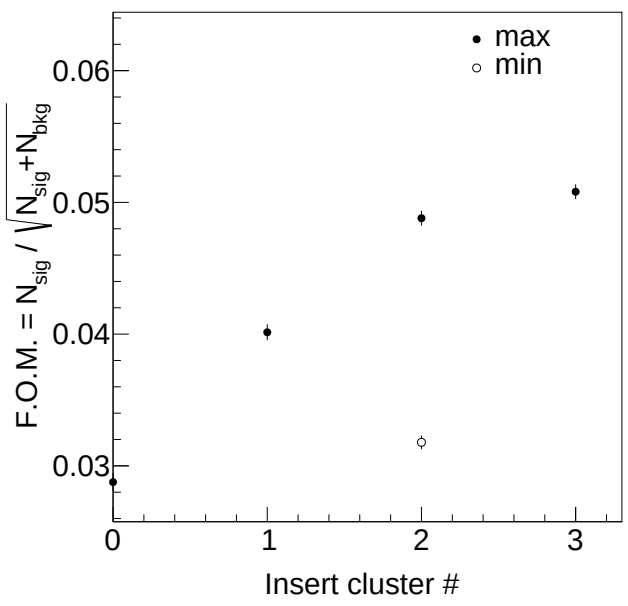


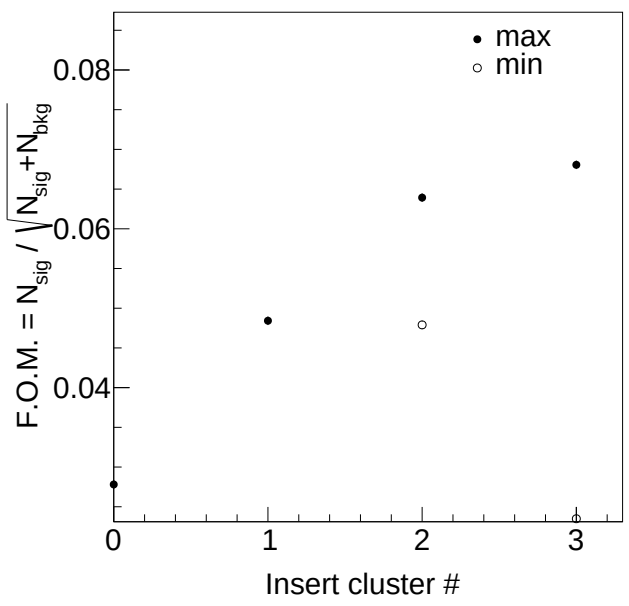



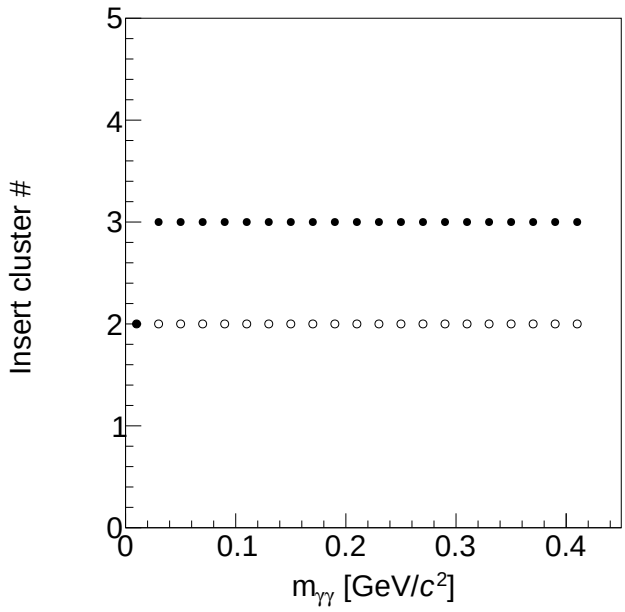
# FCAL, cluster number below 4.5$^o$

FOM vs. cluster number below 4.5$^o$ for:

- $m_{\gamma\gamma} = 110$ MeV/$c^2$
- $m_{\gamma\gamma} = 310$ MeV/$c^2$
- Selection critiria vs. $m_{\gamma\gamma}$



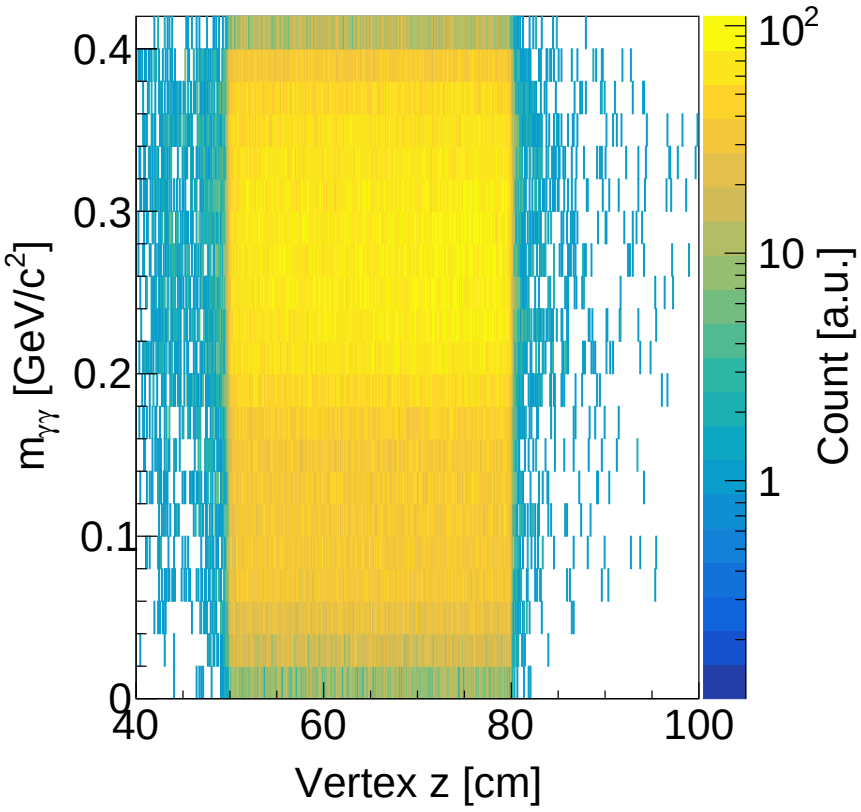



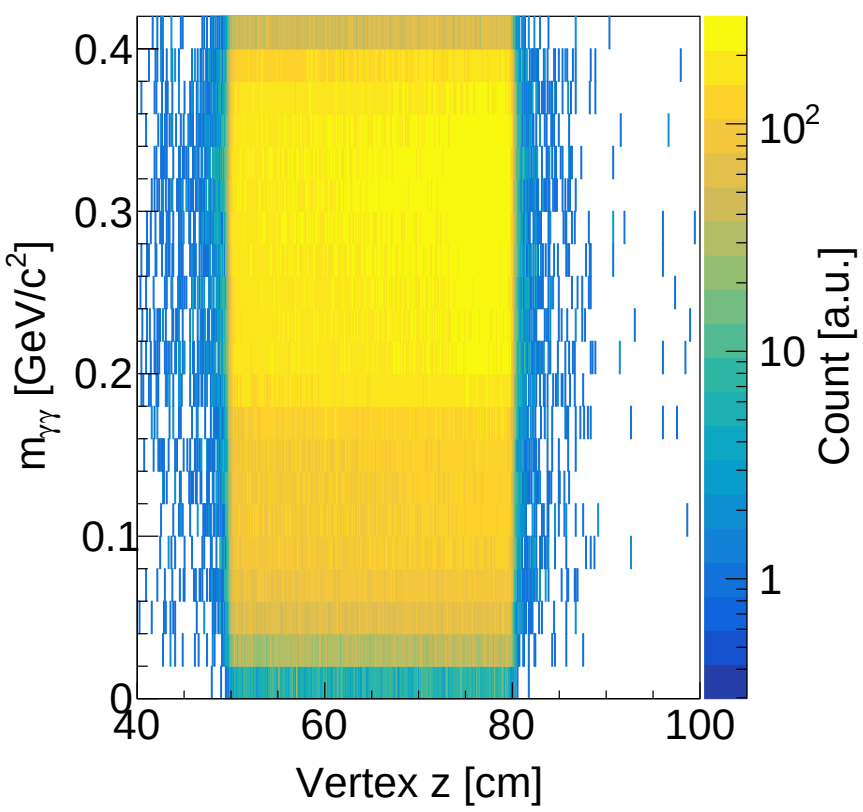

- Find lower value
- Find upper value

# FCAL, vertex production z

$m_{\gamma\gamma}$ vs. vertex production z for:

- Signal
- Background

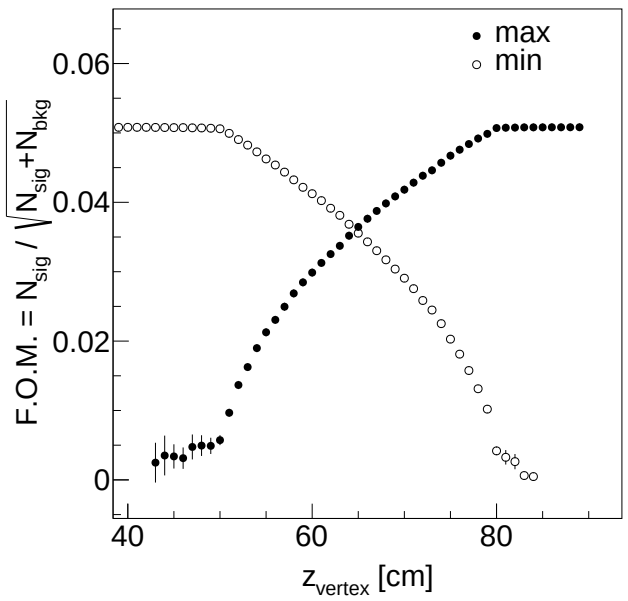


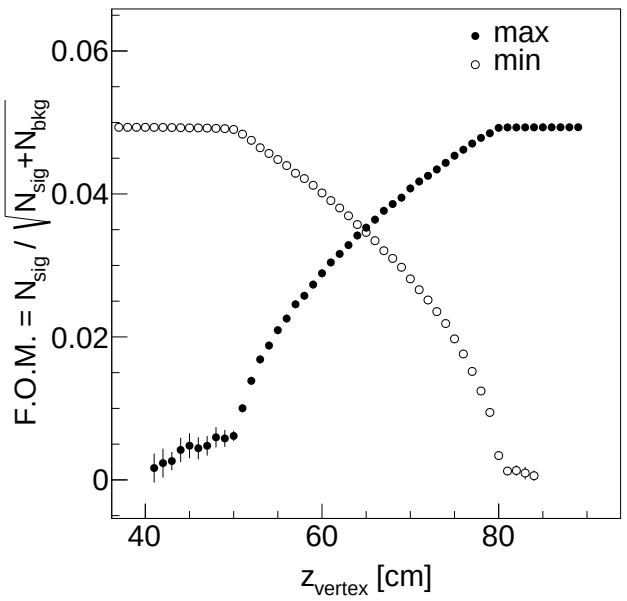



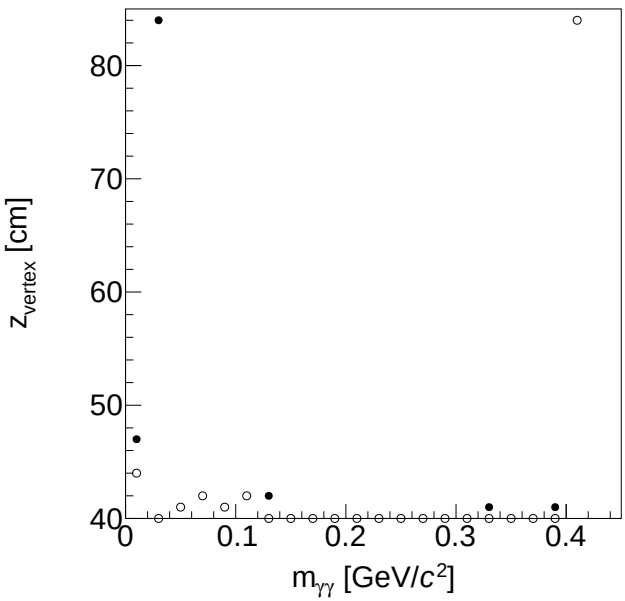
# FCAL, vertex production z

FOM vs. vertex production z for:

- $m_{\gamma\gamma} = 110$ MeV/$c^2$
- $m_{\gamma\gamma} = 310$ MeV/$c^2$
- Selection critiria vs. $m_{\gamma\gamma}$



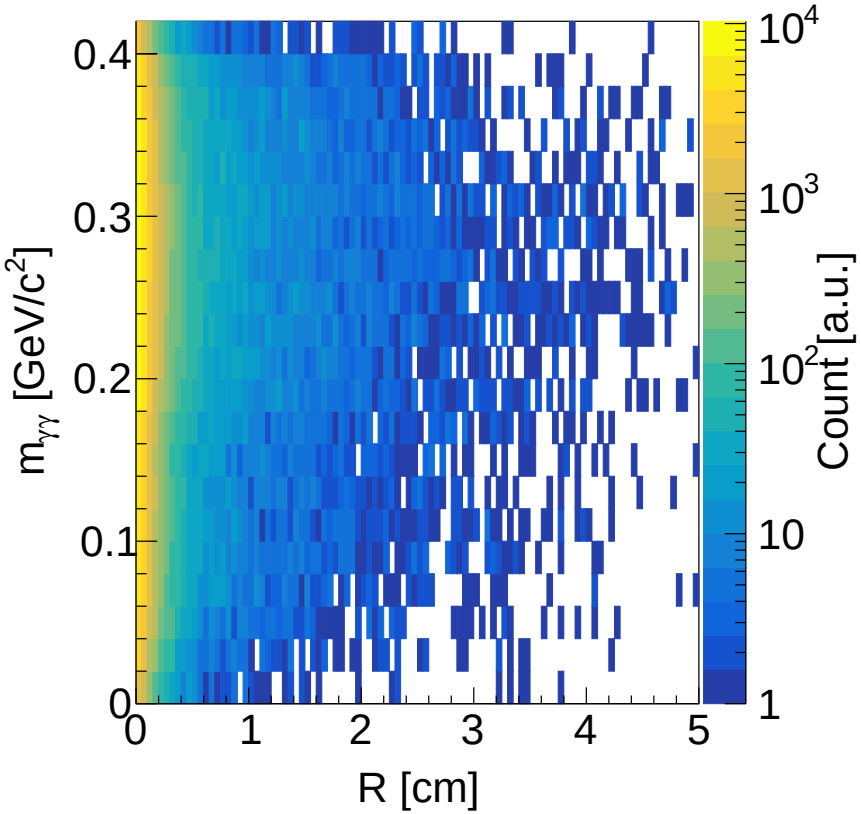



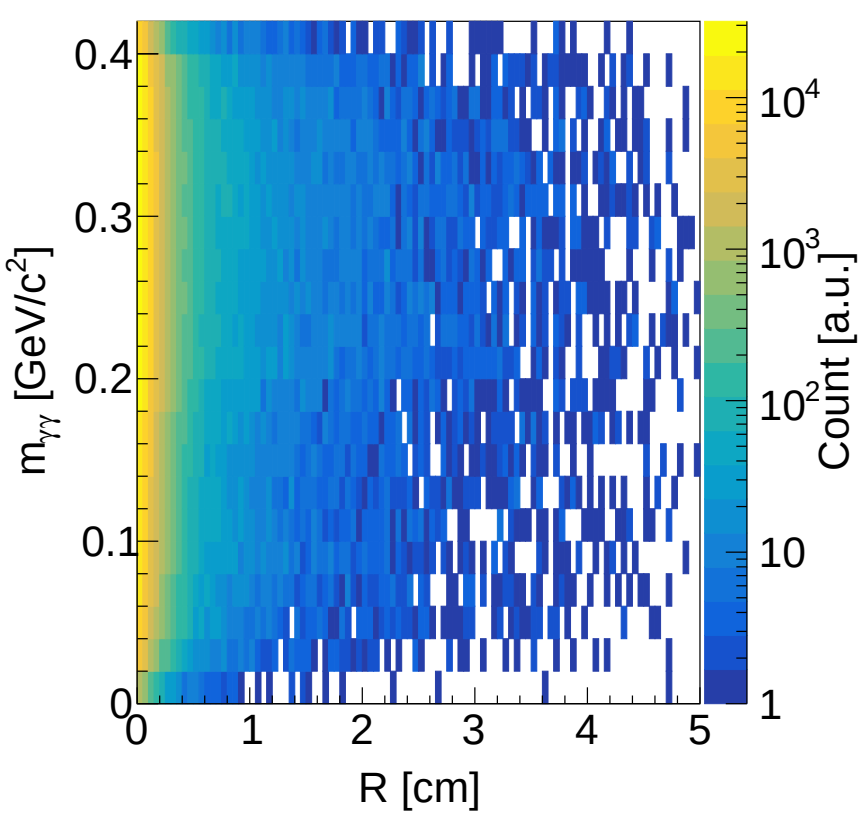

- Find lower value
- Find upper value

# FCAL, vertex production r

$m_{\gamma\gamma}$ vs. vertex production r for:

- Signal
- Background

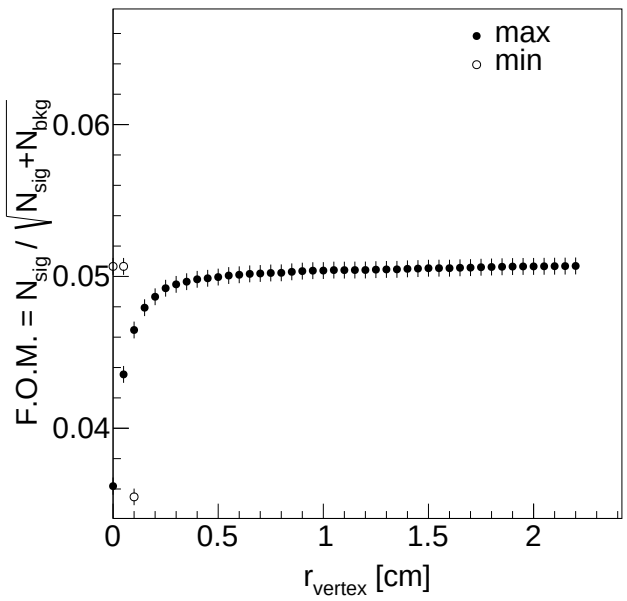


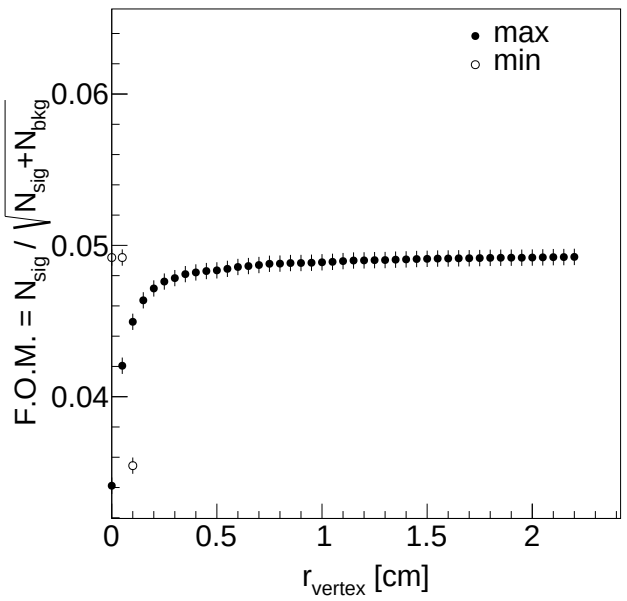



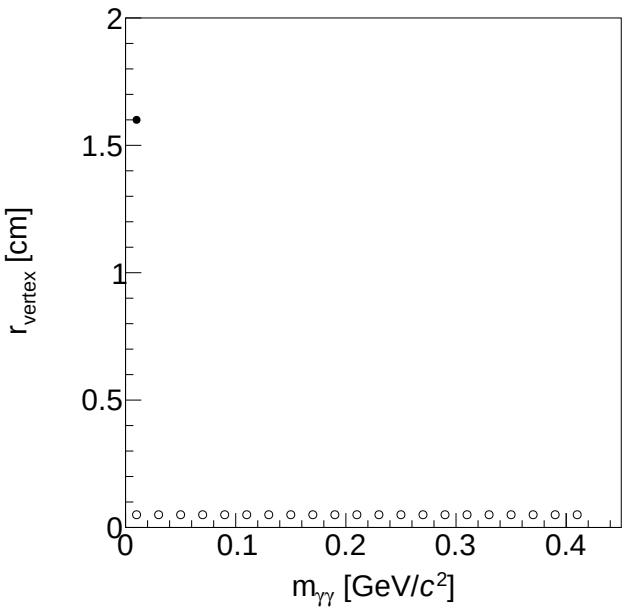
# FCAL, vertex production r

FOM vs. vertex production r for:

- $m_{\gamma\gamma} = 110$ MeV/$c^2$
- $m_{\gamma\gamma} = 310$ MeV/$c^2$
- Selection critiria vs. $m_{\gamma\gamma}$



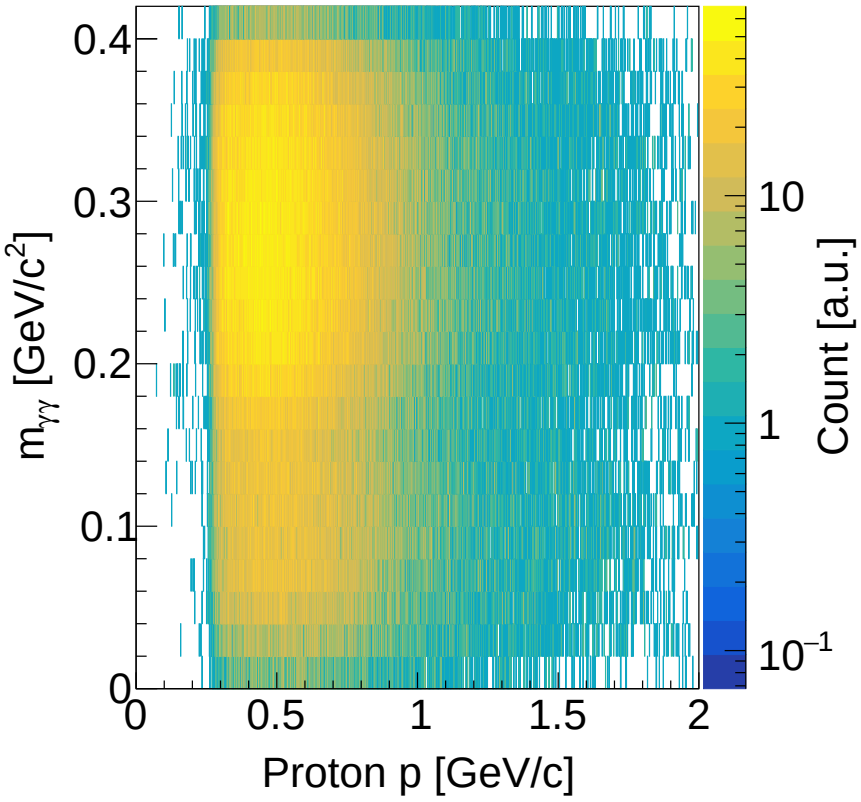



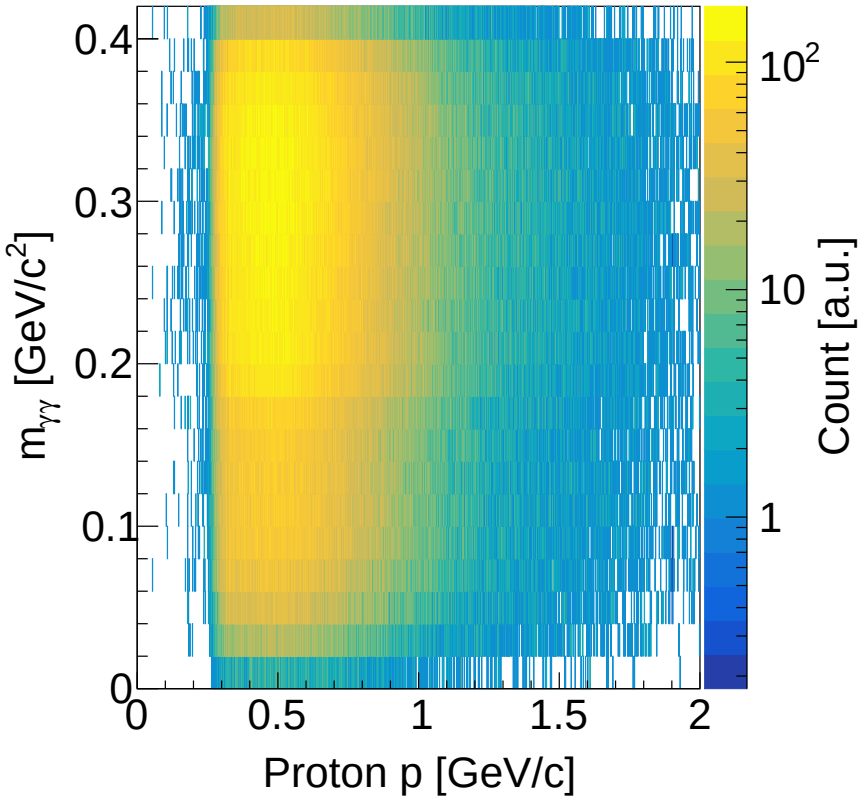

- Find lower value
- Find upper value

# FCAL, proton momentum

$m_{\gamma\gamma}$ vs. proton momentum for:

- Signal
- Background

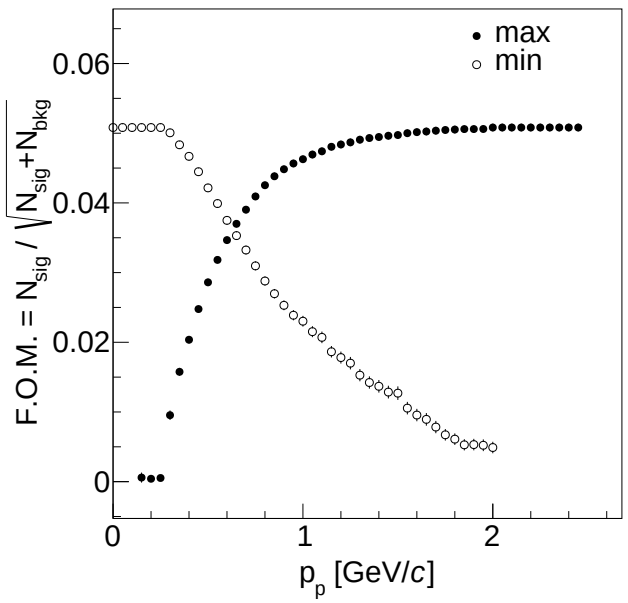


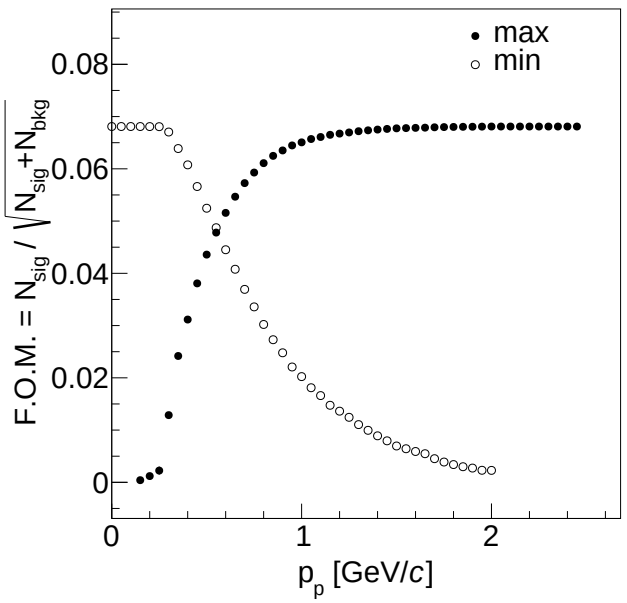



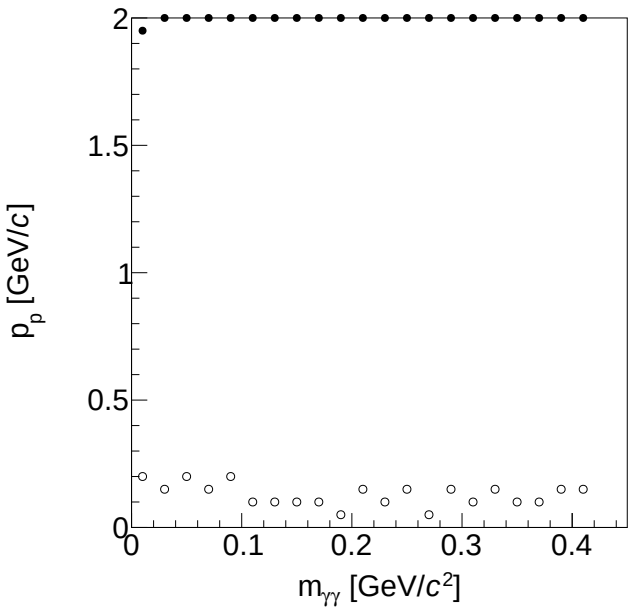
# FCAL, proton momentum

FOM vs. proton momentum for:

- $m_{\gamma\gamma} = 110$ MeV/$c^2$
- $m_{\gamma\gamma} = 310$ MeV/$c^2$
- Selection critiria vs. $m_{\gamma\gamma}$




- Find lower value
- Find upper value

# Selection criteria individual effect

Each selection is applied individually

- Percentage of surviving events relative to the number of events passing the PID selection critiria i.e. $4\gamma$'s + proton
- FCAL ("GlueX")

| Selection criteria | $\pi^0\gamma\gamma$ | $\pi^0\pi^0\pi^0$ | 0.01 | 0.05 | 0.1 | 0.2 | 0.3 | 0.4 |
|---|---|---|---|---|---|---|---|---|
| $\chi^2$ | 43.672 | 0.0112184 | 37.2339 | 40.8227 | 38.847 | 41.2701 | 36.9526 | 31.8757 |
| $\eta$ mass | 52.823 | 0.225907 | 59.969 | 65.3512 | 56.3317 | 59.335 | 58.5022 | 60.3857 |
| Extra energy | 84.7308 | 3.78774 | 86.5824 | 89.2825 | 85.5537 | 87.7503 | 87.9114 | 87.6146 |
| Insert Cluster # | 10.9807 | 12.0343 | 9.03417 | 12.6199 | 12.0863 | 13.7393 | 14.2095 | 8.9927 |
| Coplanarity | 76.832 | 27.6318 | 76.4711 | 81.2351 | 77.5681 | 78.5437 | 76.8432 | 76.5972 |
| Unused tracks | 97.1863 | 93.9026 | 94.4392 | 97.6277 | 97.0667 | 97.5946 | 97.4696 | 97.5548 |
| Vertex z | 98.4894 | 98.9763 | 99.0886 | 98.9905 | 99.0046 | 98.9819 | 98.9754 | 98.9266 |
| Vertex R | 98.6571 | 99.3196 | 98.5727 | 98.5609 | 98.4881 | 98.4807 | 98.4593 | 98.3794 |

- FCAL2 ("JEF")

| Selection criteria | $\pi^0\gamma\gamma$ | $\pi^0\pi^0\pi^0$ | 0.01 | 0.05 | 0.1 | 0.2 | 0.3 | 0.4 |
|---|---|---|---|---|---|---|---|---|
| $\chi^2$ | 37.2939 | 0.0125739 | 42.912 | 49.6509 | 46.5465 | 49.3675 | 45.0621 | 40.9101 |
| $\eta$ mass | 57.7636 | 0.29415 | 54.3901 | 61.6631 | 53.247 | 56.3289 | 54.349 | 57.0939 |
| Extra energy | 87.0665 | 3.50772 | 81.4739 | 87.2083 | 83.636 | 86.3082 | 86.2306 | 85.8524 |
| Insert cluster # | 13.4118 | 13.0171 | 7.26749 | 10.6096 | 10.319 | 12.7841 | 13.0609 | 7.22132 |
| Coplanarity | 77.079 | 27.290 | 73.8225 | 81.1225 | 77.2915 | 78.6463 | 76.7438 | 76.89078 |
| Unused tracks | 97.3437 | 94.1531 | 94.8914 | 97.6763 | 97.1152 | 97.5583 | 97.5463 | 97.6232 |
| Vertex R | 98.4515 | 99.1361 | 98.5727 | 98.5609 | 98.4881 | 98.4807 | 98.4593 | 98.3794 |
| Vertex z | 98.985 | 99.4657 | 99.0886 | 98.9905 | 99.0046 | 98.9819 | 98.9754 | 98.9266 |

Kinfit $\chi^2$ and $\eta$ mass are the most selective critiria

# Selection criteria breakdown effect

- FCAL ("GlueX") - $S$: $\gamma p \to \eta(\to \pi^0\gamma\gamma)p$ and $B$: $\gamma p \to \eta(\to \pi^0\pi^0\pi^0)p$

| Selection criteria | Surviving background % | $S/\sqrt{B}$ | $S/\sqrt{B}$ for $m_{\gamma\gamma\gamma\gamma} \geq 500$ MeV/$c^2$ |
|---|---|---|---|
| $\chi^2$ | 0.0122 | 7.18344 | 7.28472 |
| $\eta$ mass | 0.1884 | 2.44417 | 3.32048 |
| Extra energy | 2.6202 | 1.01711 | 5.07379 |
| Insert cluster # | 9.7274 | 0.081368 | 0.804007 |
| Missing mass squared | 18.751 | 0.343467 | 2.36959 |
| Coplanarity | 21.477 | 0.320764 | 2.28333 |
| Unused tracks | 70.3186 | 0.21952 | 2.06865 |
| Vertex R | 74.0405 | 0.21637 | 2.02067 |
| Vertex z | 74.2868 | 0.217182 | 2.02803 |
| PID | 74.6858 | 0.21882 | 2.03977 |

- After all selection critiria applied: $S/\sqrt{B} = 3.9988$ or 10.2 if insert cluster # not used
- FCAL2 ("JEF") - $S$: $\gamma p \to \eta(\to \pi^0\gamma\gamma)p$ and $B$: $\gamma p \to \eta(\to \pi^0\pi^0\pi^0)p$

| Selection criteria | Surviving background % | $S/\sqrt{B}$ | $S/\sqrt{B}$ for $m_{\gamma\gamma\gamma\gamma} \geq 500$ MeV/$c^2$ |
|---|---|---|---|
| $\chi^2$ | 0.0102 | 10.7212 | 10.9194 |
| $\eta$ mass | 0.2054 | 2.88945 | 4.70812 |
| Extra energy | 3.4405 | 1.13246 | 7.16187 |
| Insert cluster # | 10.9375 | 0.0823647 | 1.12712 |
| Missing mass squared | 20.1207 | 0.427684 | 3.61593 |
| Coplanarity | 25.0955 | 0.380222 | 3.30907 |
| Unused tracks | 85.2883 | 0.260893 | 2.97222 |
| Vertex z | 89.8986 | 0.257527 | 2.88503 |
| Vertex R | 90.2104 | 0.257519 | 2.88929 |
| PID | 90.8282 | 0.260134 | 2.91293 |

- After all selection critiria applied: $S/\sqrt{B} = 6.12$ or 17.34 if insert cluster # not used

35 % improvements w/ insert cluster # selection & 75 % w/o it

# Selection criteria individual effect

Each selection is applied individually on dark scalar signal ($\gamma p \to \eta(\to S(\to \gamma\gamma)\pi^0)p$)

- FCAL ("GlueX")

| Selection criteria | 0.01 | 0.05 | 0.1 | 0.2 | 0.3 | 0.4 |
|---|---|---|---|---|---|---|
| $\chi^2$ | 3.0628 | 11.554 | 7.0183 | 8.5832 | 7.4493 | 5.9863 |
| $\eta$ mass | 2.5427 | 9.2897 | 6.0656 | 10.0223 | 9.7627 | 7.475 |
| Extra energy | 4.1021 | 15.4207 | 9.9815 | 13.6671 | 13.6685 | 10.9226 |
| Insert cluster # | 0.3399 | 2.1238 | 1.3065 | 2.0027 | 2.1108 | 1.0062 |
| Missing mass squared | 3.7296 | 14.1002 | 9.038 | 12.1182 | 11.9533 | 9.5998 |
| Coplanarity | 3.7962 | 14.5189 | 9.2224 | 12.2912 | 12.0757 | 9.6887 |
| Unused tracks | 4.2364 | 16.0069 | 10.436 | 14.0007 | 14.0759 | 11.322 |
| Vertex R | 4.2178 | 15.929 | 10.3742 | 13.8677 | 13.9342 | 11.1929 |
| Vertex z | 4.2414 | 15.9835 | 10.419 | 13.9164 | 13.9903 | 11.2549 |
| PID | 4.2811 | 16.1406 | 10.5187 | 14.0505 | 14.1359 | 11.3872 |

- FCAL2 ("JEF")

| Selection criteria | 0.01 | 0.05 | 0.1 | 0.2 | 0.3 | 0.4 |
|---|---|---|---|---|---|---|
| $\chi^2$ | 3.2284 | 11.5059 | 7.9237 | 11.3275 | 10.4511 | 7.5408 |
| $\eta$ mass | 3.7579 | 13.5346 | 8.2126 | 11.3775 | 11.054 | 9.5762 |
| Extra energy | 5.0411 | 17.6229 | 11.8129 | 16.0275 | 16.104 | 12.9436 |
| Insert cluster # | 0.4237 | 2.1725 | 1.472 | 2.4045 | 2.4781 | 1.0273 |
| Missing mass squared | 4.8081 | 16.6969 | 11.0107 | 14.5512 | 14.2749 | 11.527 |
| Coplanarity | 4.6018 | 16.5187 | 10.9236 | 14.5874 | 14.1898 | 11.1114 |
| Unused tracks | 5.3708 | 18.3849 | 12.4094 | 16.4492 | 16.6364 | 13.4645 |
| Vertex R | 5.3695 | 18.3007 | 12.3571 | 16.3304 | 16.5131 | 13.331 |
| Vertex z | 5.3548 | 18.259 | 12.3152 | 16.2516 | 16.4442 | 13.2979 |
| PID | 5.4347 | 18.5405 | 12.5146 | 16.5095 | 16.7119 | 13.5431 |

Insert cluster # selection seems again counter-productive

# Selection criteria gradual effect

Consecutively the most to least effective on dark scalar signal ($\gamma p \to \eta(\to S(\to \gamma\gamma)\pi^0)p$)

- FCAL ("GlueX")

| Selection criteria | 0.01 | 0.05 | 0.1 | 0.2 | 0.3 | 0.4 |
|---|---|---|---|---|---|---|
| PID | 4.242 | 16.104 | 10.4818 | 13.9418 | 14.0414 | 11.385 |
| $\chi 2$ | 3.0423 | 11.5426 | 7.0066 | 8.5392 | 7.4219 | 5.986 |
| Insert cluster # 6 | 0.2358 | 1.4454 | 0.8237 | 1.1716 | 1.076 | 0.5046 |
| $\eta$ mass | 0.1622 | 0.9316 | 0.5484 | 0.8989 | 0.8451 | 0.3901 |
| Extra energy | 0.1614 | 0.9268 | 0.5455 | 0.8951 | 0.8422 | 0.3883 |
| Coplanarity | 0.1537 | 0.8626 | 0.5057 | 0.8278 | 0.7769 | 0.3493 |
| Unused tracks | 0.1537 | 0.8624 | 0.5057 | 0.8278 | 0.7768 | 0.3492 |
| Missing mass squared | 0.1452 | 0.8157 | 0.4818 | 0.801 | 0.7515 | 0.3353 |
| Vertex x | 0.1532 | 0.8579 | 0.5033 | 0.8254 | 0.7737 | 0.3482 |
| Vertex Z | 0.153 | 0.8604 | 0.5048 | 0.8266 | 0.7757 | 0.3486 |
| All applied | 0.1442 | 0.8098 | 0.4787 | 0.7978 | 0.7473 | 0.3335 |

- FCAL2 ("JEF")

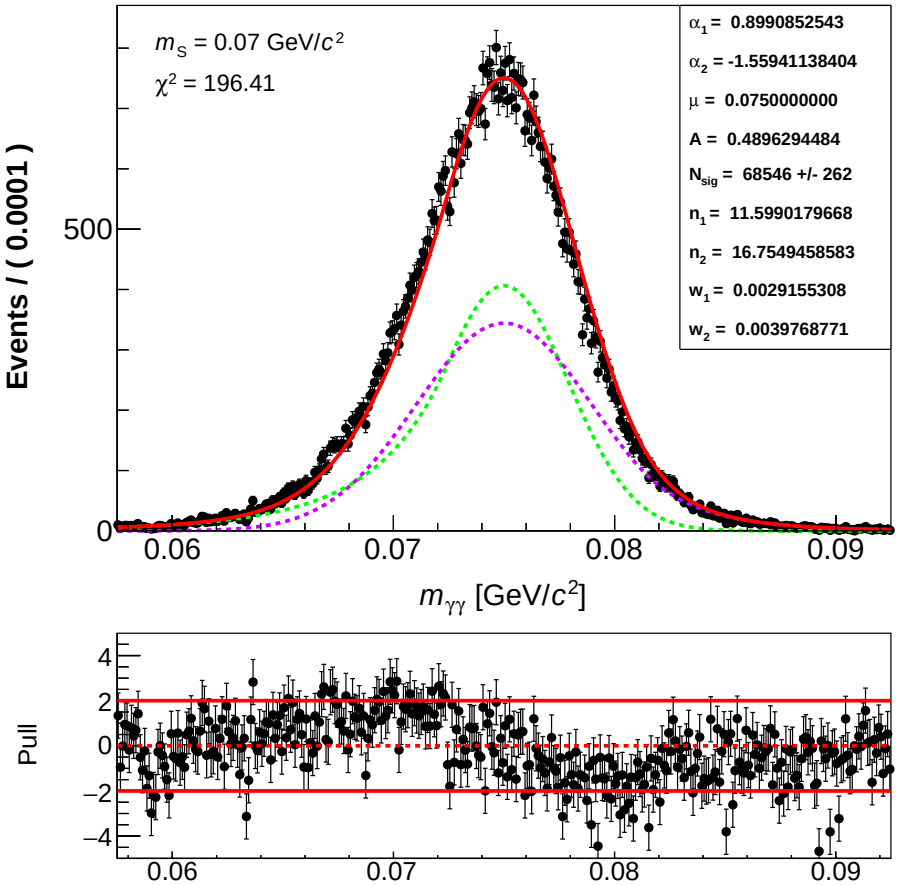
| Selection criteria | 0.01 | 0.05 | 0.1 | 0.2 | 0.3 | 0.4 |
|---|---|---|---|---|---|---|
| PID | 5.3978 | 18.5006 | 12.4716 | 16.4093 | 16.6082 | 13.5397 |
| $\chi^2$ | 3.2194 | 11.5003 | 7.9146 | 11.2922 | 10.419 | 7.5408 |
| Insert cluster # | 0.2969 | 1.4764 | 1.0171 | 1.81 | 1.7292 | 0.6664 |
| $\eta$ mass | 0.278 | 1.3325 | 0.8277 | 1.3749 | 1.3154 | 0.5836 |
| Extra energy | 0.277 | 1.3297 | 0.8256 | 1.3721 | 1.3123 | 0.5811 |
| Coplanarity | 0.2717 | 1.2941 | 0.7917 | 1.284 | 1.219 | 0.5279 |
| Unused tracks | 0.2717 | 1.2937 | 0.7915 | 1.2839 | 1.2186 | 0.5278 |
| Missing mass squared | 0.2645 | 1.2756 | 0.7758 | 1.2459 | 1.1774 | 0.5113 |
| Vertex z | 0.2693 | 1.2808 | 0.7828 | 1.2711 | 1.2075 | 0.5194 |
| Vertex R | 0.2716 | 1.2938 | 0.7915 | 1.2839 | 1.219 | 0.5279 |
| All applied | 0.262 | 1.2624 | 0.7669 | 1.2341 | 1.1662 | 0.5035 |

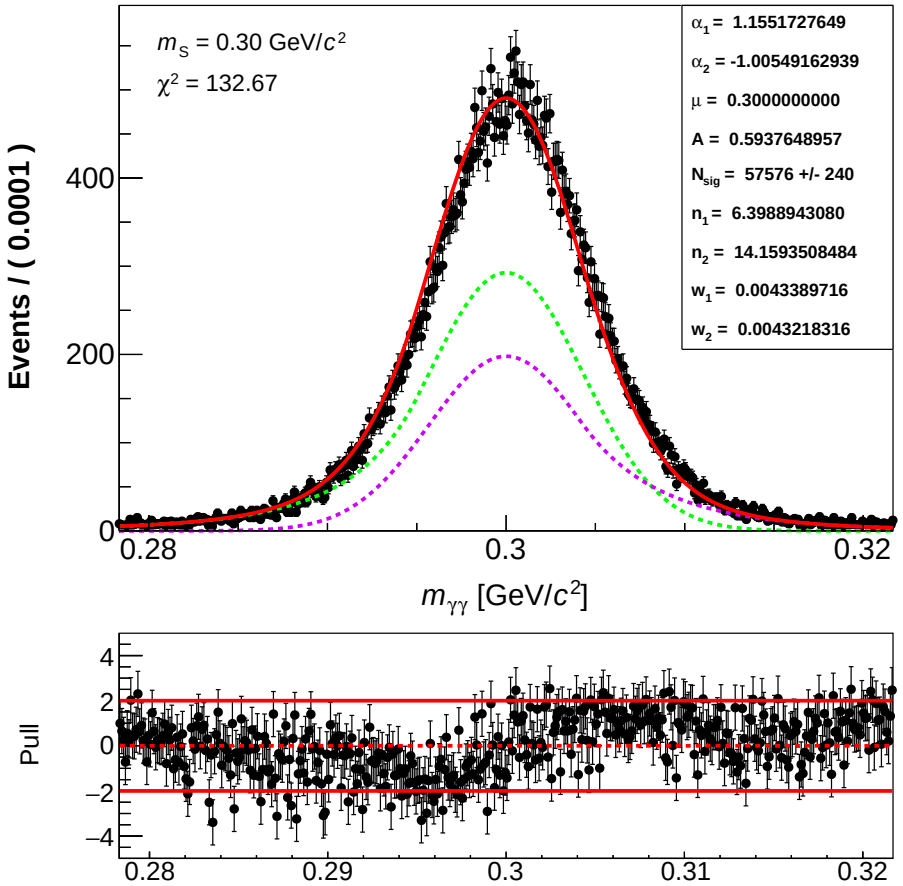
Insert cluster # selection decreases the detection efficiency by an order of magnitude

# Signal PDF

Determined by Jared `https://halldweb.jlab.org/wiki/images/c/c9/Jared1.pdf`

- 2 Crystal Balls with common mean and two different widths
- Set of python macros that iterate until each parameter has a smooth behavior vs. mass



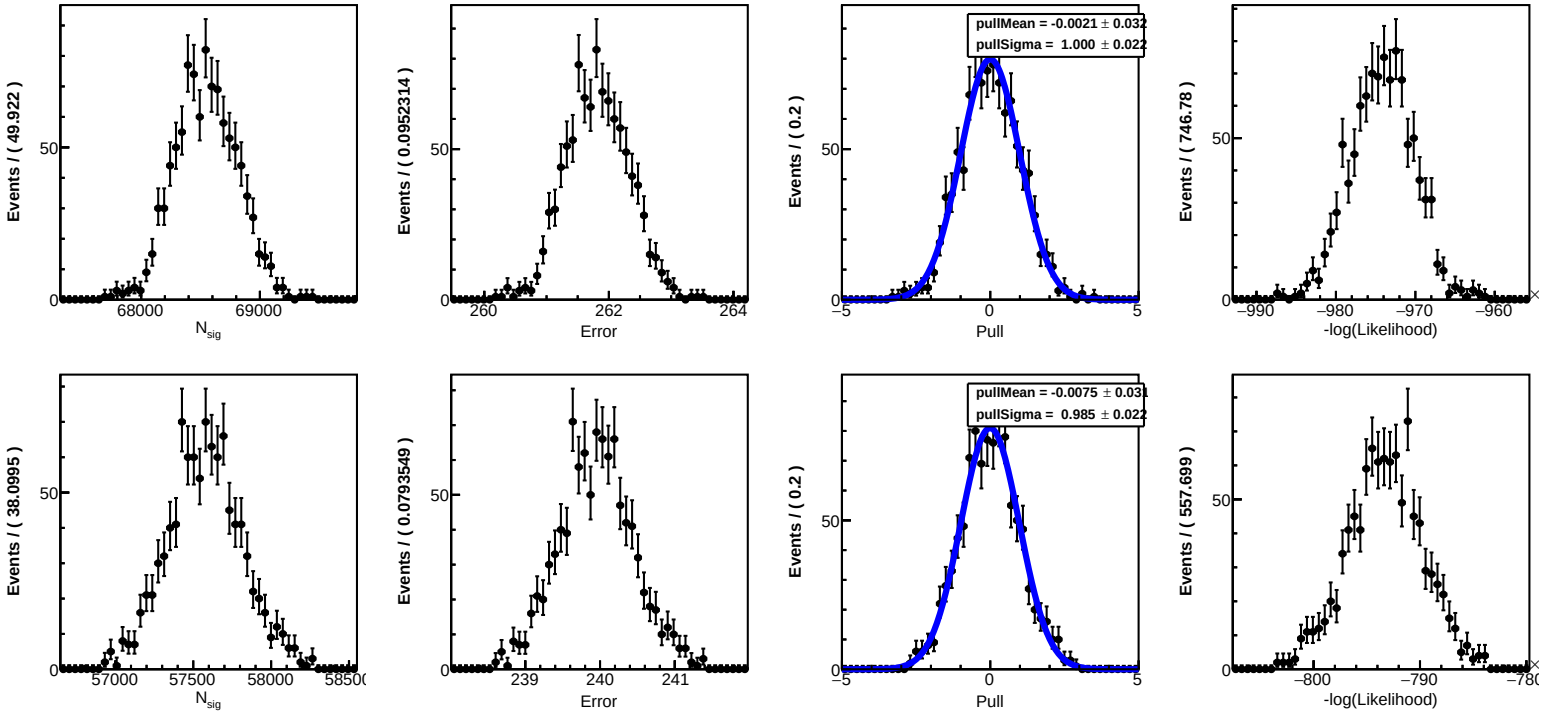




After 6th iteration, the behavior starts to be smooth

# Signal PDF, quality check

Determined by Jared `https://halldweb.jlab.org/wiki/images/c/c9/Jared1.pdf`

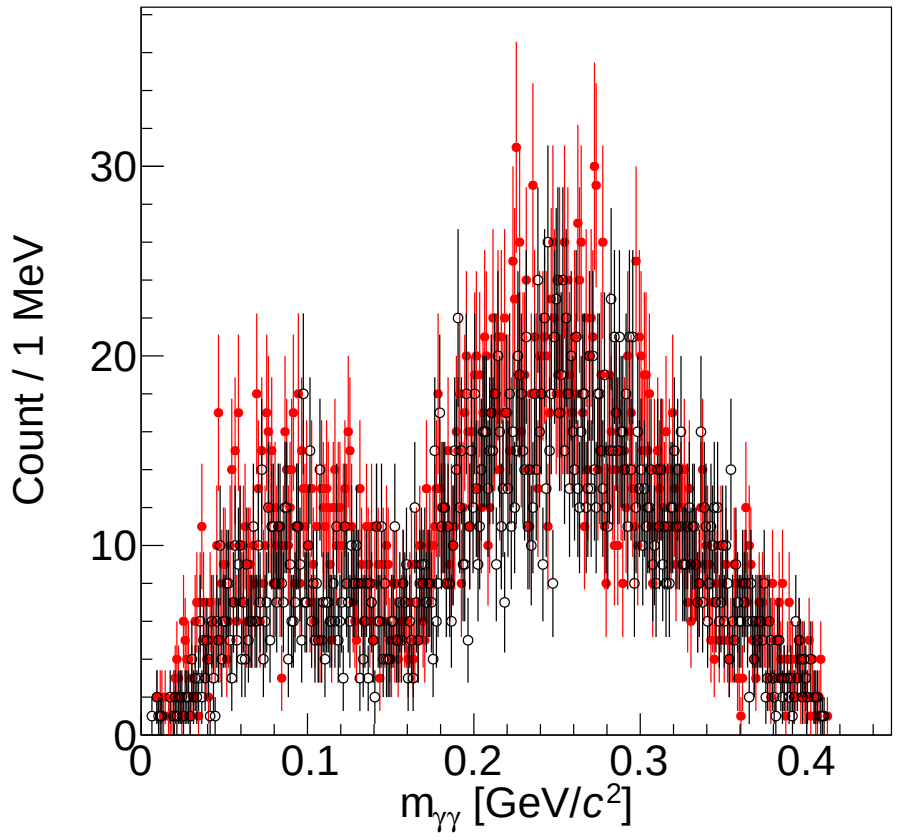
- RooFit build-in toy mc study to check fit quality
- Parametrization is working well between 75 and 350 MeV/$2^2$
- At each edges, the PDF not yet determined

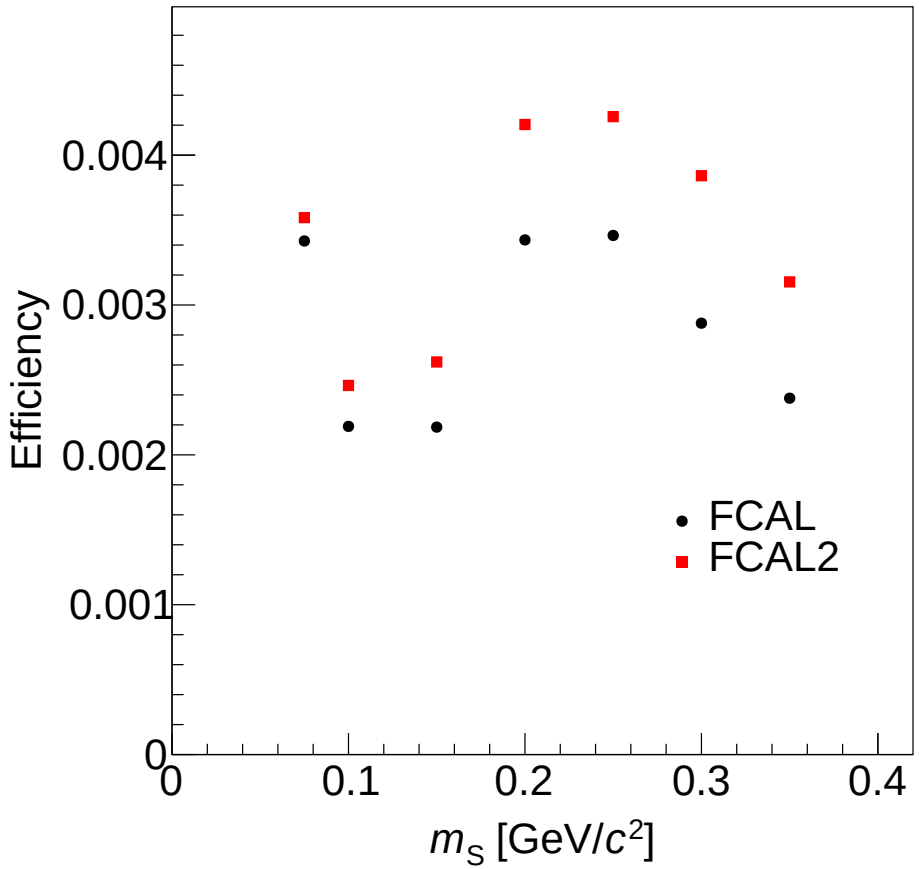



Good PDF, but Jared will also find a more simple PDF: Gauss + Crystal Ball or 2/3 Gauss

# Detection efficiency and irreducible background

After all selection criteria are applied:



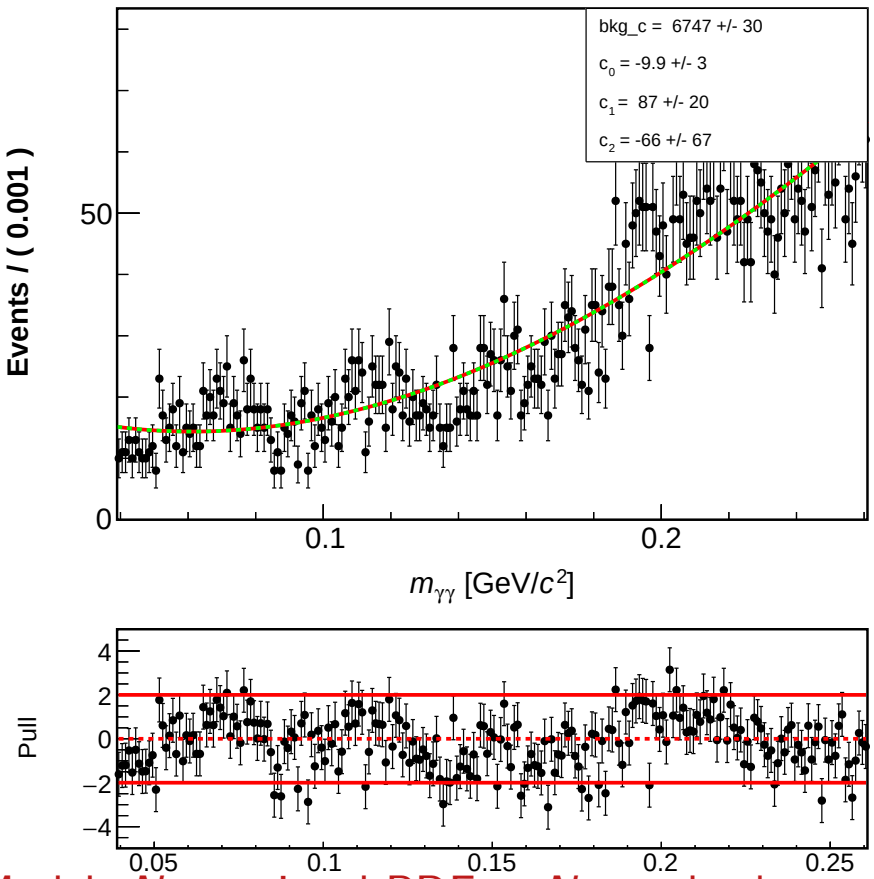



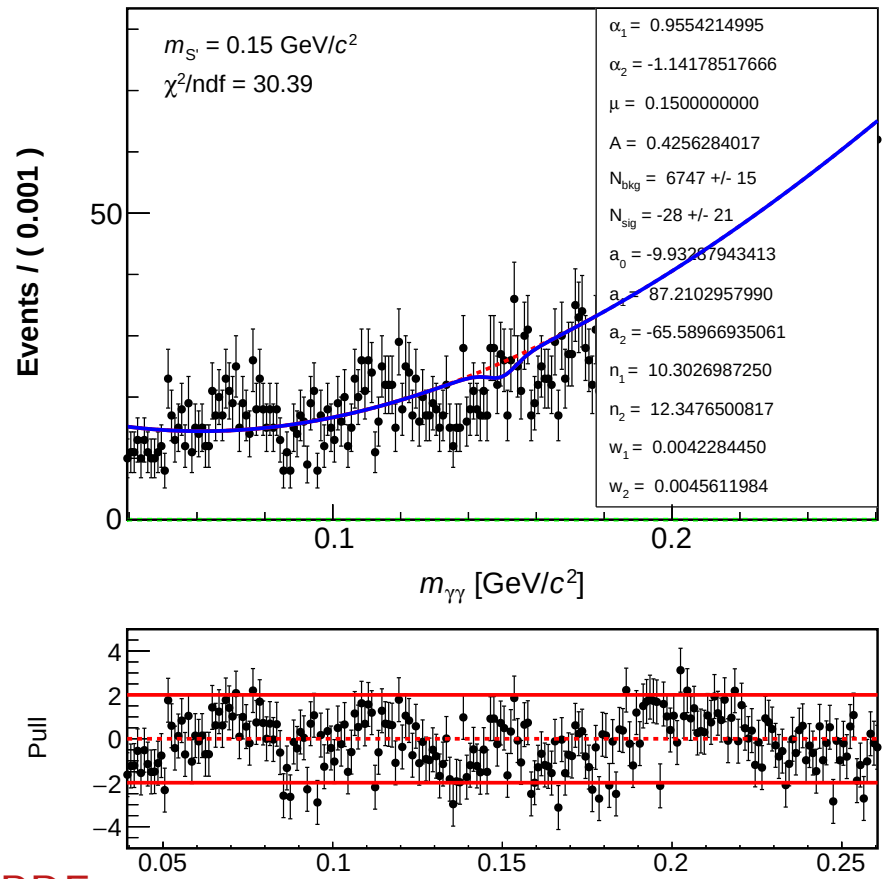

Background un-smooth behavior is still not understood

# Limit calculation

With ROOFIT and ROOSTAT build-in calculator

- Background PDF, 3rd polynomial
- 25 MeV/$c^2$ step scan
- Fit range $\pm 25 \cdot \sigma_{\text{weighted}}$ around the mass scanned

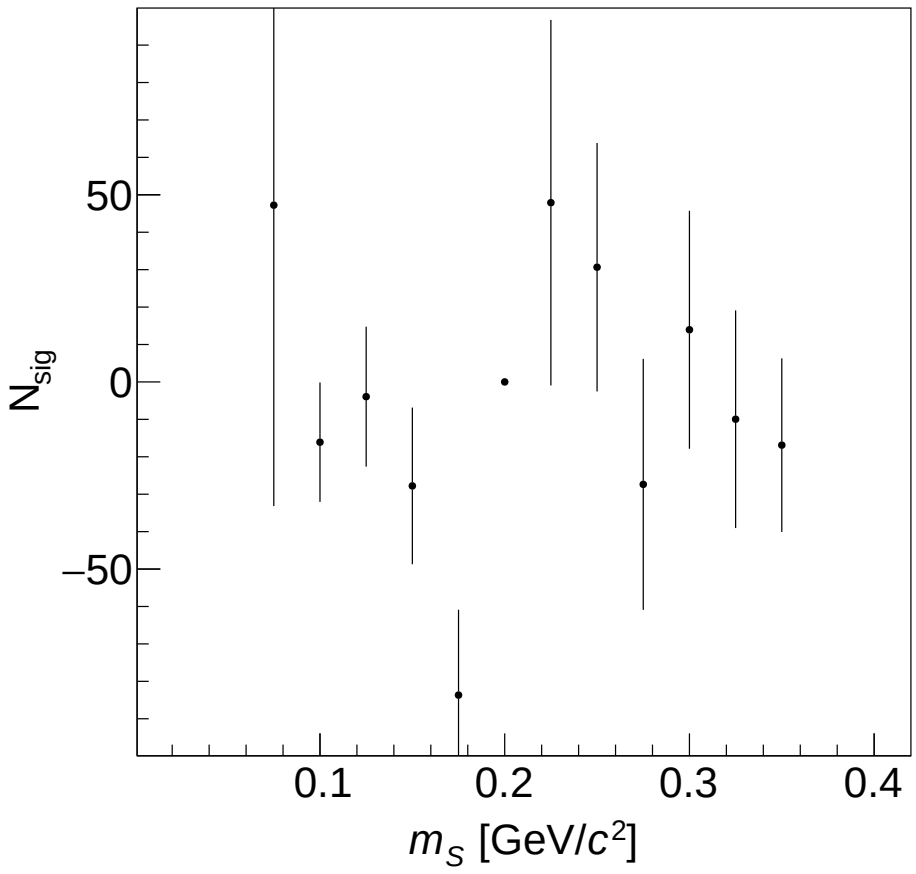


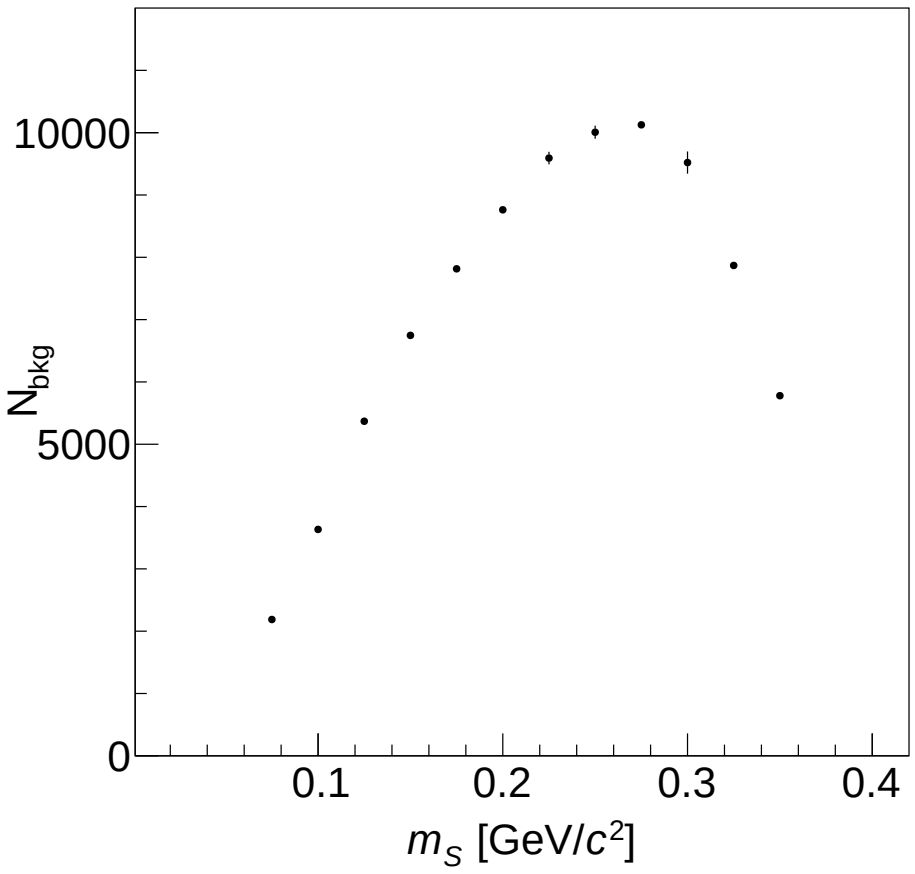




Model: $N_{sig} \times$ signal PDF $+$ $N_{bkg} \times$ background PDF

# Limit calculation

Measured $N_{sig}$ and $N_{bkg}$ vs mass



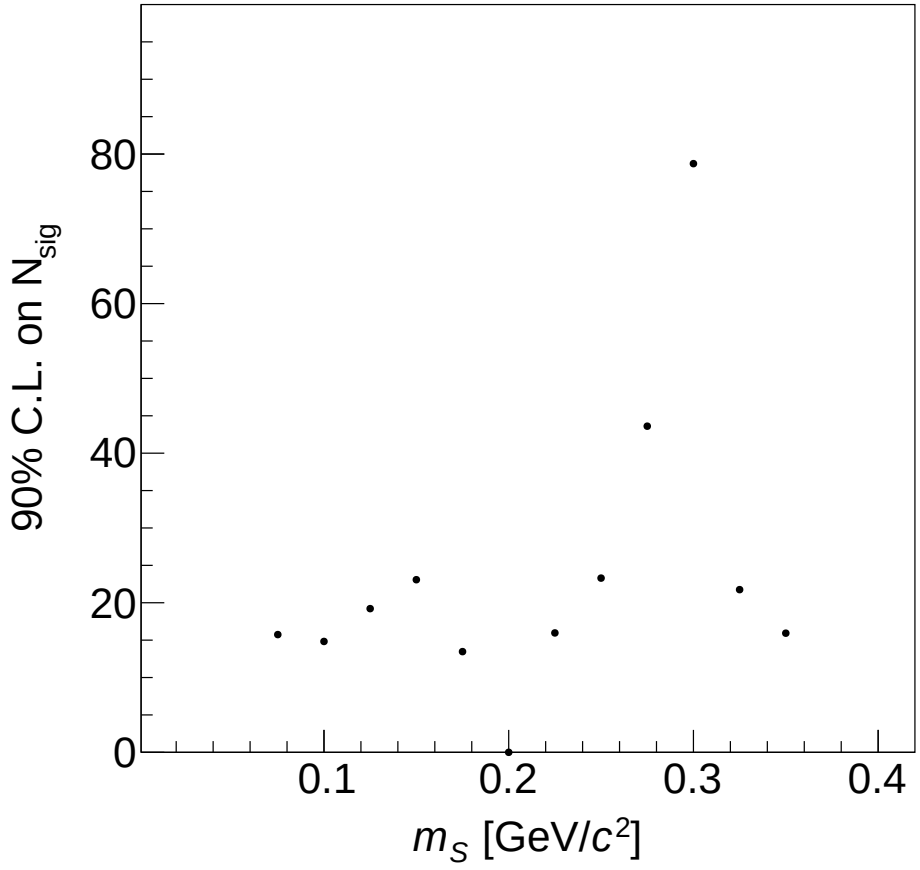



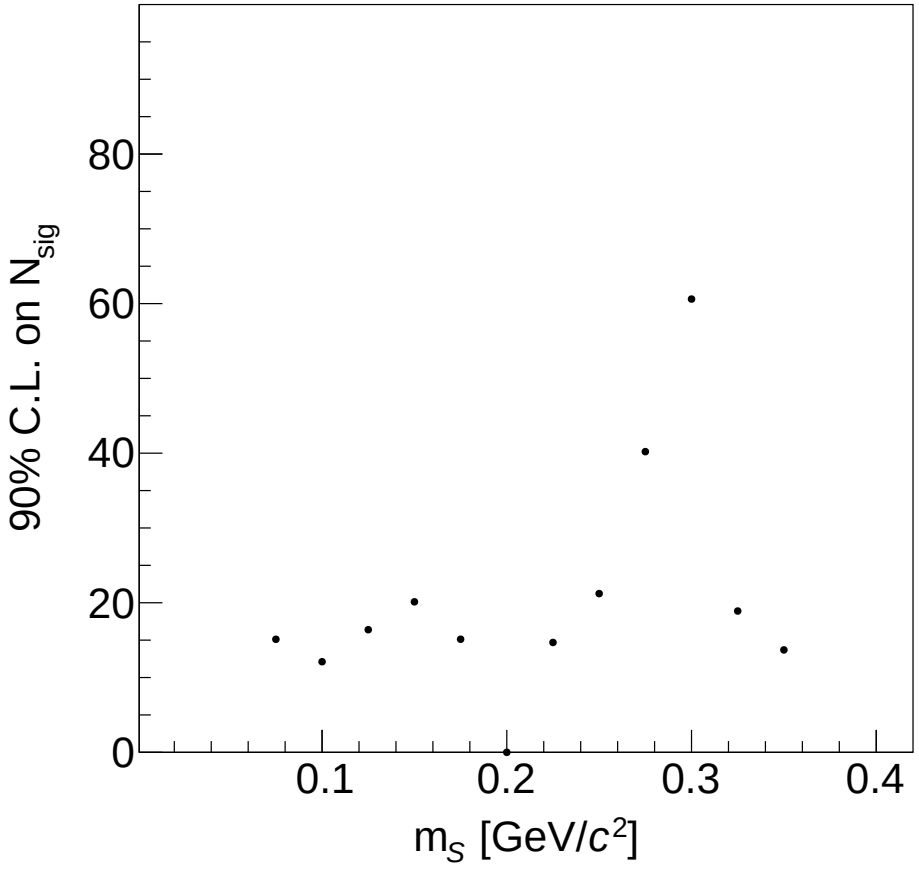

Shape and $N_{sig}$ are transferred to the limit calculator

# Limit calculation

Two calculators used:

- ProfileLikelihoodCalculator
- BayesianCalculator

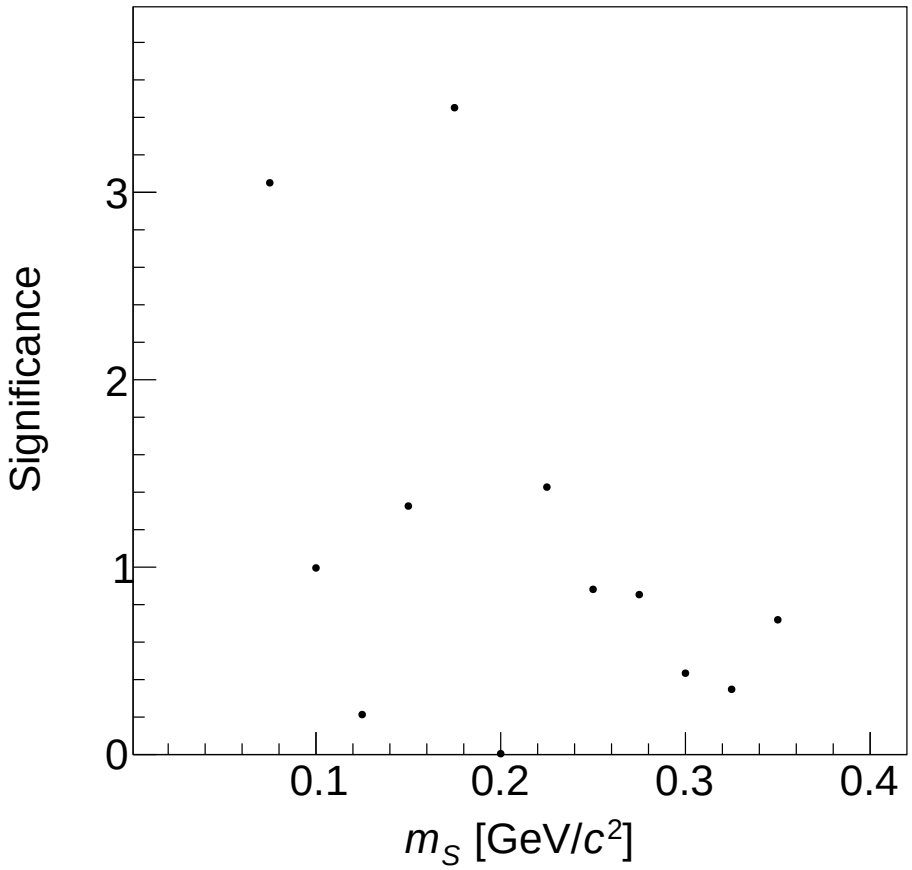


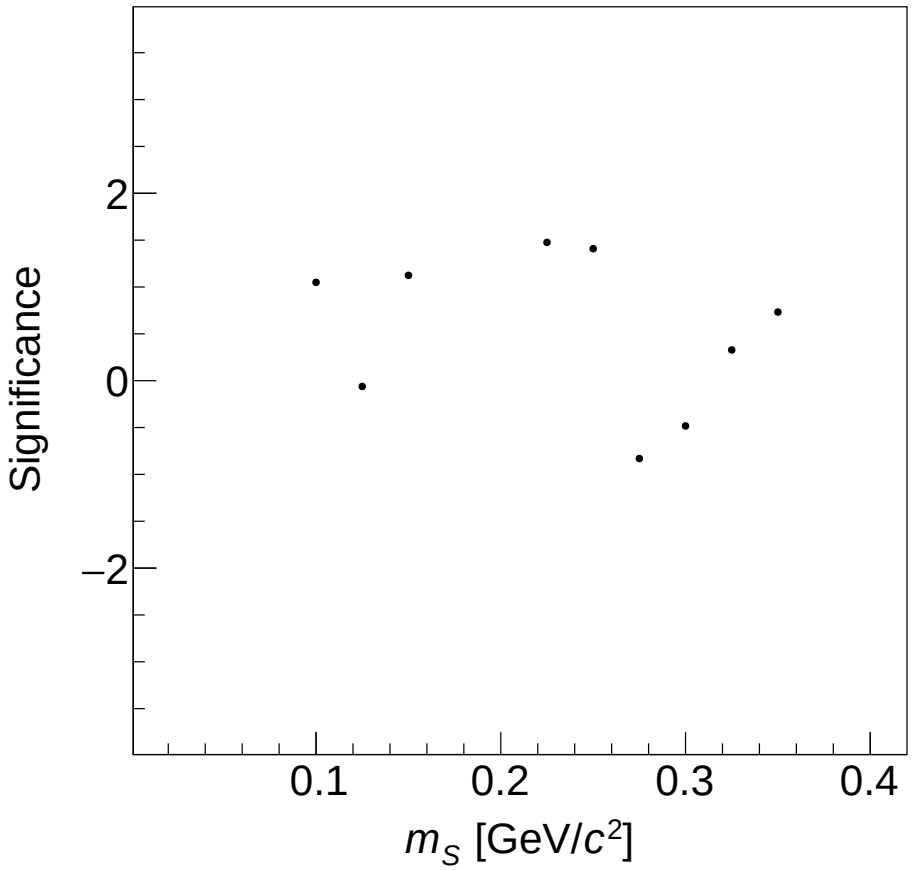




90% upper limit on the number of signal measured

# Limit calculation

Significance




As expected the background simulation as no signal but only large local fluctuations

# Baryonic fine structure constant

$\alpha_S$ using the equation for the partial width ratio $\Gamma(\eta \to S\pi^0)/\Gamma(\eta \to \gamma\gamma)$ from B case and S. Tulin, PRD **89**, 114008 (2014) as:

$$\begin{aligned}\alpha_S &= \left[\frac{\alpha}{2}\left(1-\frac{m_S^2}{m_\eta^2}\right)^{-3}\left|\mathcal{F}(m_S^2)\right|^{-2}\frac{1}{\mathcal{B}(S\to\gamma\gamma)}\right] \\ &\times \left[\frac{\Gamma(\eta\to\gamma\pi^0\gamma)}{\Gamma(\eta\to\gamma\gamma)}\right] \\ &\times \left[\frac{\Gamma(\eta\to S\pi^0\to\gamma\pi^0\gamma)}{\Gamma(\eta\to\pi^0\gamma\gamma)}\right], \end{aligned} \tag{1}$$

where $\alpha$ is the electromagnetic fine structure constant. The first factor in Eq. (1), which is purely theoretical, contains the phase space, the form factor $\mathcal{F}(m_S^2)$, and the branching fraction of $S \to \gamma\gamma$ decay. The branching fraction provided in arXiv:1812.05103v1. The second factor is obtained from the latest measurements PDG. The third factor is determined from the $\eta$ and $S$ yields and reconstruction efficiencies $(N_S/\varepsilon(\eta \to S\pi^0 \to \pi^0\gamma\gamma))/\alpha_S/(N_\eta/\varepsilon(\eta \to \pi^0\gamma\gamma))$. Not sure if $\mathcal{F}(m_S^2)$ should be the same than for B case

# Conclusion

Preliminary selection critiria:

- Hand-made guided by FOM
- MVA (to do list)

Preliminay PDF for:

- Signal
- (Background, we will start once the non-smooth distribution is understood)
  => Considered at the moment as a crude 3rd order Polynomial

Preliminary expected 90% upper limit on the number of signal measured