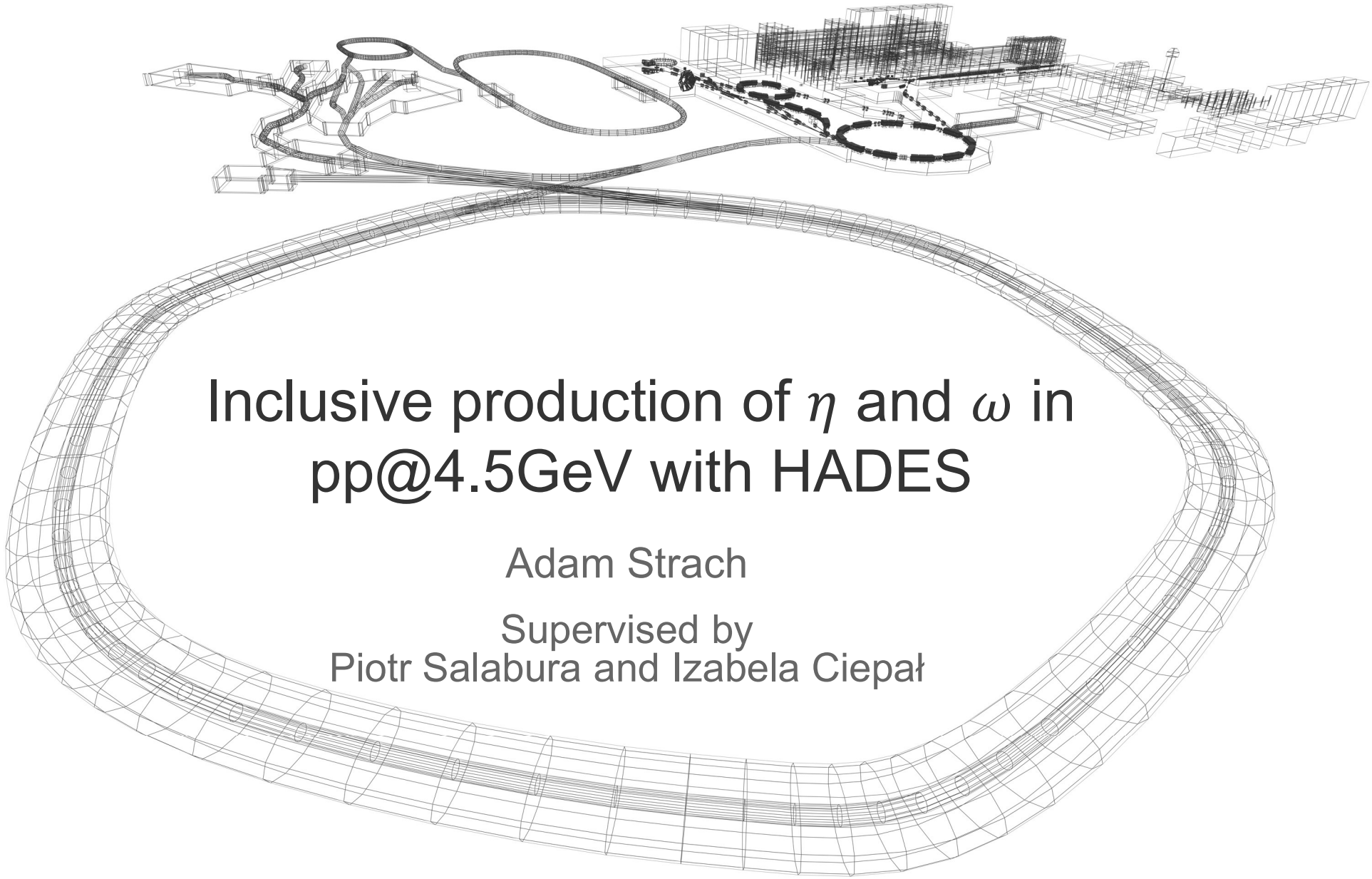


# Inclusive production of $\eta$ and $\omega$ in pp@4.5GeV with HADES

Adam Strach

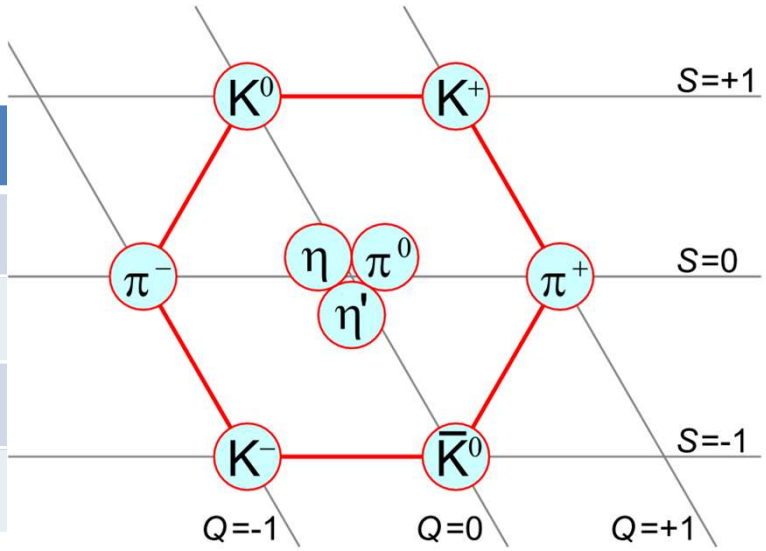
Supervised by
Piotr Salabura and Izabela Ciepał

# $\eta$ meson

- Neutral pseudoscalar meson.
- Mass of (547.862±0.017) MeV [PDG]
- $I^G(J^{PC}) = 0^+(0^{-+})$
- $\eta$ quark content: $\frac{1}{\sqrt{6}}(u\bar{u} + d\bar{d} - 2s\bar{s})$

| Decay channel | Branching ratio |
|---|---|
| $\gamma\gamma$ | $(39.36 \pm 0.18)\%$ |
| $3\pi^0$ | $(32.57 \pm 0.21)\%$ |
| $\pi^+\pi^-\pi^0$ | $(23.02 \pm 0.25)\%$ |
| $\pi^+\pi^-\gamma$ | $(4.28 \pm 0.07)\%$ |

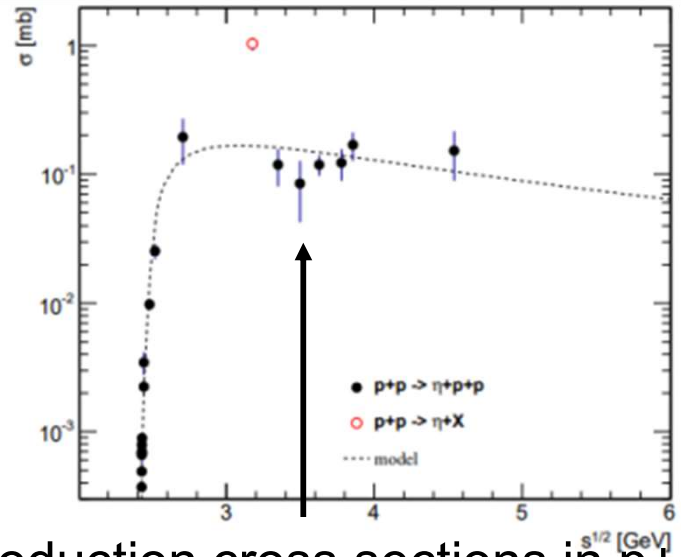
Table of most popular $\eta$ decay channels [PDG]



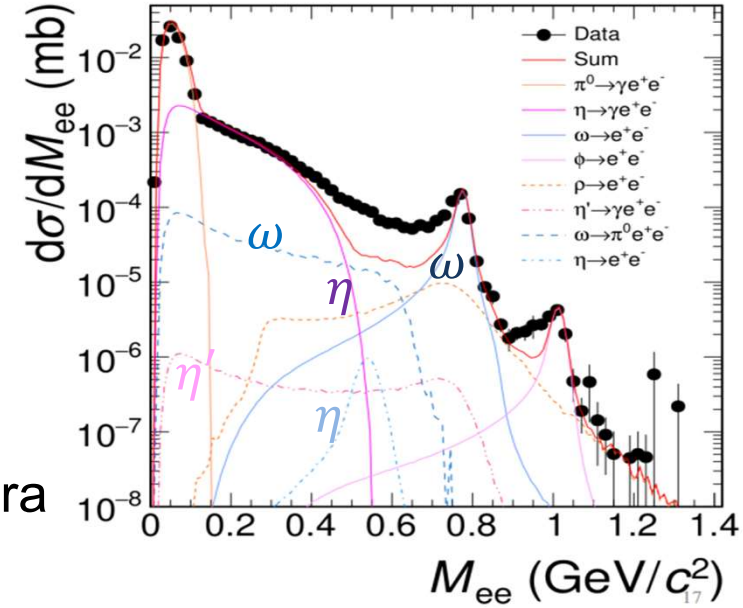

Nonet of pseudoscalar mesons [Wikipedia]

# Importance of $\eta$

- Product of many mesons and baryon resonances decay:
  - $\eta' \rightarrow \eta\pi^+\pi^-$
  - $a_0 \rightarrow \eta\pi$
  - $N^*(1535) \rightarrow N\eta$ and other $N^*$
- Cross section is important input for transport model calculations of p+p, p+A, A+A interactions (Feb 2022 p+p in HADES $\sqrt{s} = 3.46$ GeV)
- Inclusive cross section of $\eta$ and $\eta'$ is important for di-electron invariant mass spectra.
- Production mechanism of $\eta$ and $\eta'$




$\eta$ production cross sections in p+p
Source: HADES Collaboration



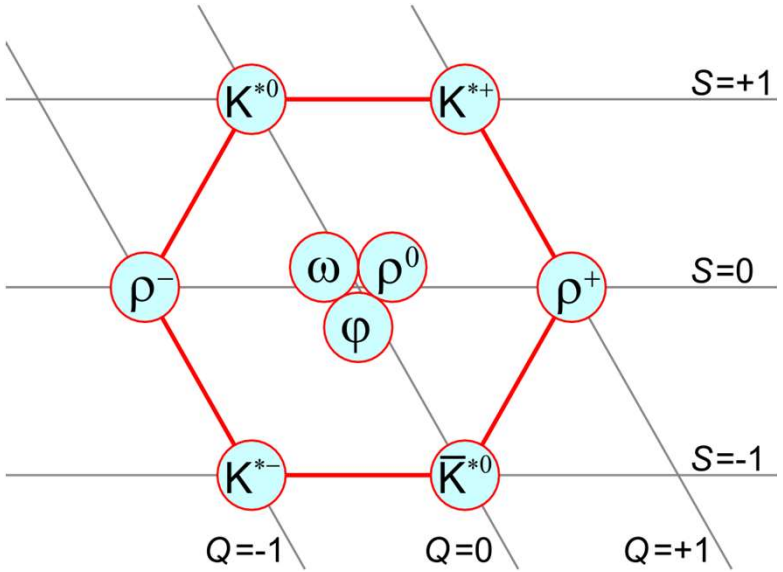

di-electron invariant mass spectra
Rayane Abou Yassine

# $\omega$ meson

- Neutral vector meson
- Mass of (782.65±0.12) MeV [PDG]
- $I^G(J^{PC}) = 0^-(1^{--})$
- $\omega$ quark content: $\frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d})$

| Decay channel | Branching ratio |
|---|---|
| $\pi^+\pi^-\pi^0$ | $(89.2 \pm 0.7)\%$ |
| $\pi^0\gamma$ | $(8.28 \pm 0.28)\%$ |
| $\pi^+\pi^-$ | $(1.53^{+0.11}_{-0.13})\%$ |

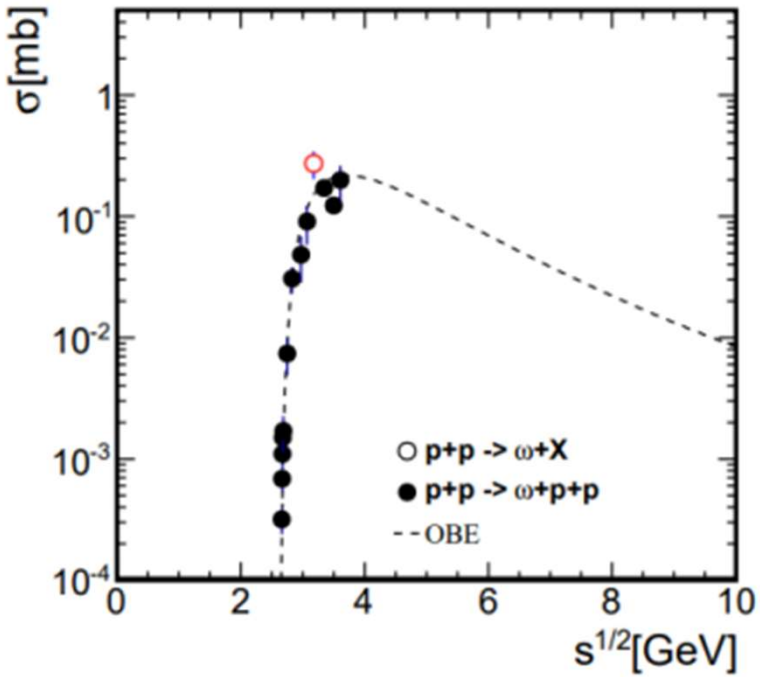
Table of most popular $\omega$ Decay channels [PDG]




Nonet of vector mesons [Wikipedia]

# Importance of $\omega$

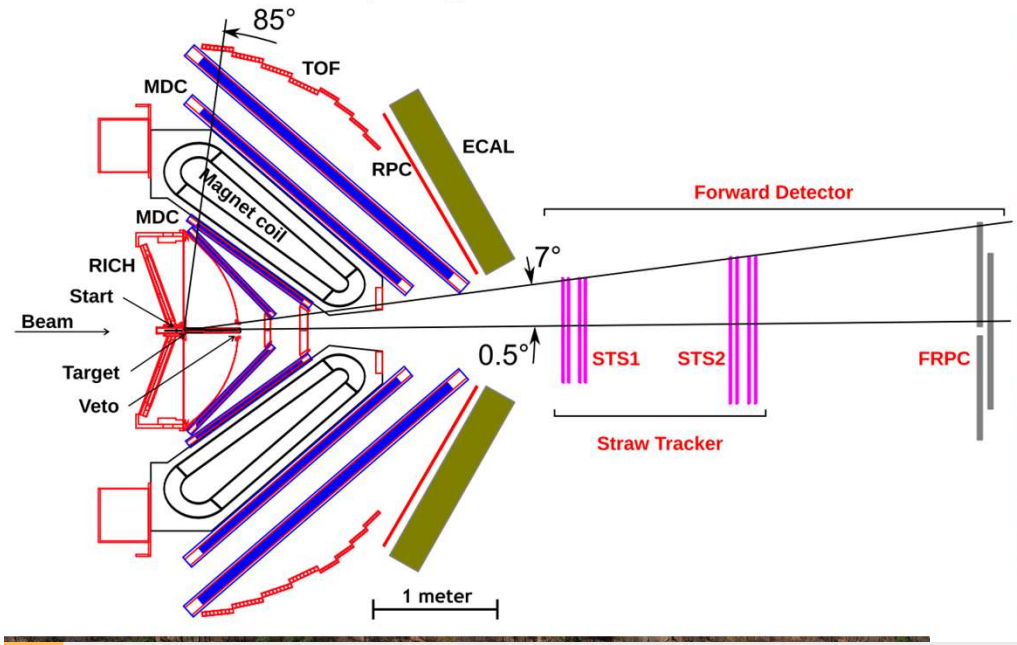
- $\omega$ is a product of many neutral and exotic mesons and some baryon resonances decay:
  - $\eta' \rightarrow \omega\gamma$
  - $b_1 \rightarrow \omega\pi^+$
  - $N^*(1880) \rightarrow N\omega$
- Studies of $\omega$ interactions with nuclear matter
- Both $\eta$ and $\omega$ decay parameters are used in development of chiral effective field theory and lattice QCD

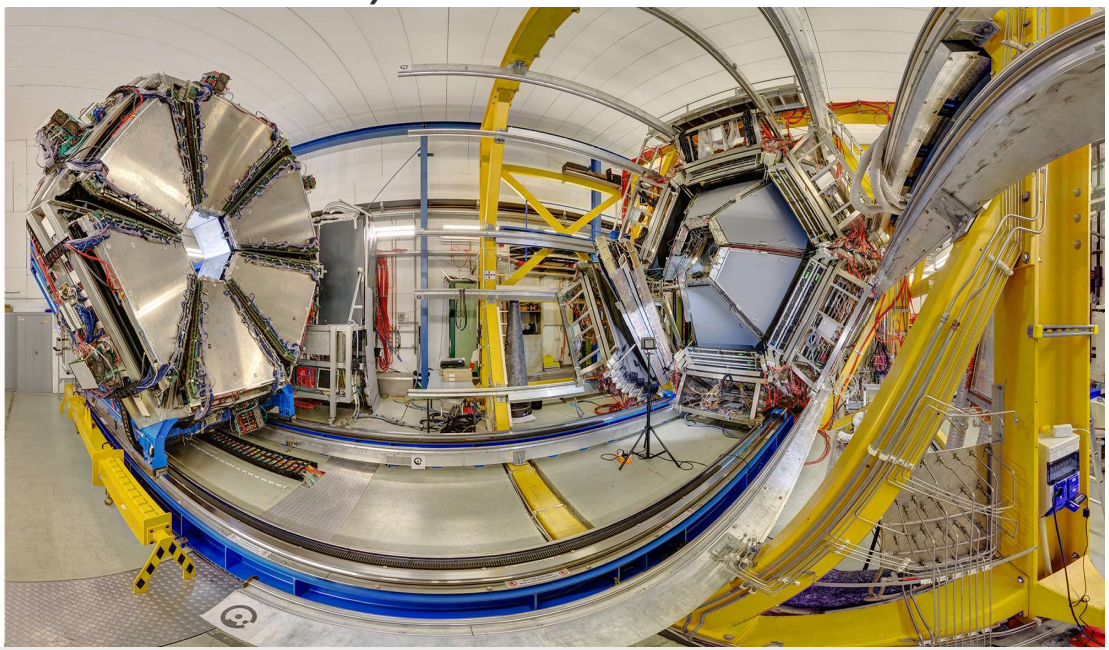



Cross sections of the $\omega$ meson production in p+p collisions. Source: HADES Collaboration

# HADES experiment

- HADES - High Acceptance DiElectron Spectrometer) is a fixed target experiment
- Located at GSI Helmholtzzentrum fur Schwerionenforschung in Darmstadt
- Proton-proton (e.g. pp 4.5 GeV 2022 run) and heavy ions (e.g. Au+Au 1.23 AGeV 2012 run)

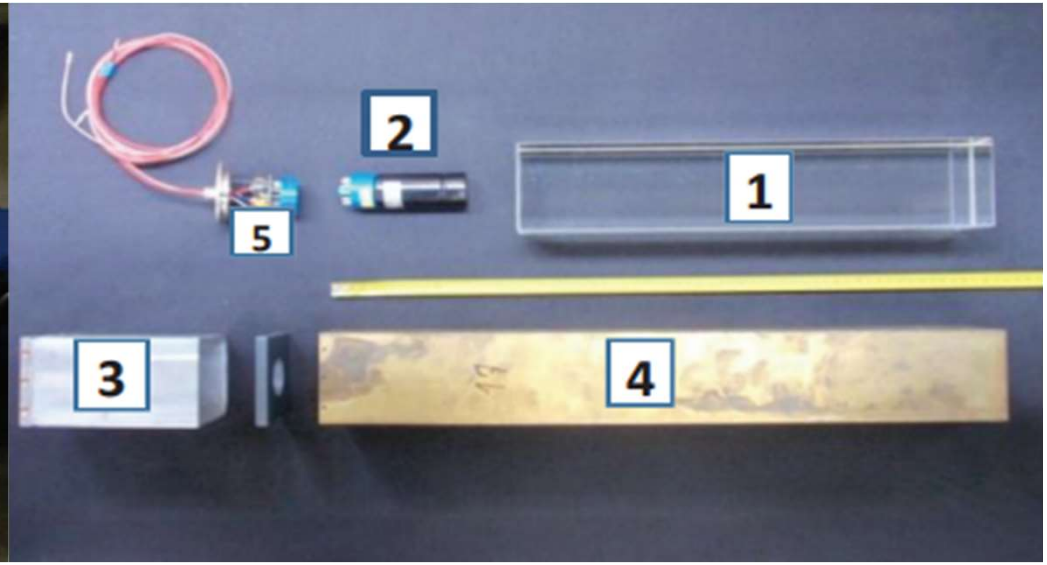


# ECAL

- Polar acceptance $10^{\circ}$ to $45^{\circ}$
- 978 lead glass modules (divided into 6 sectors)
- For February 2022 run only 5 ECAL sectors were present

ECAL sector




ECAL cell

# Analysis scheme

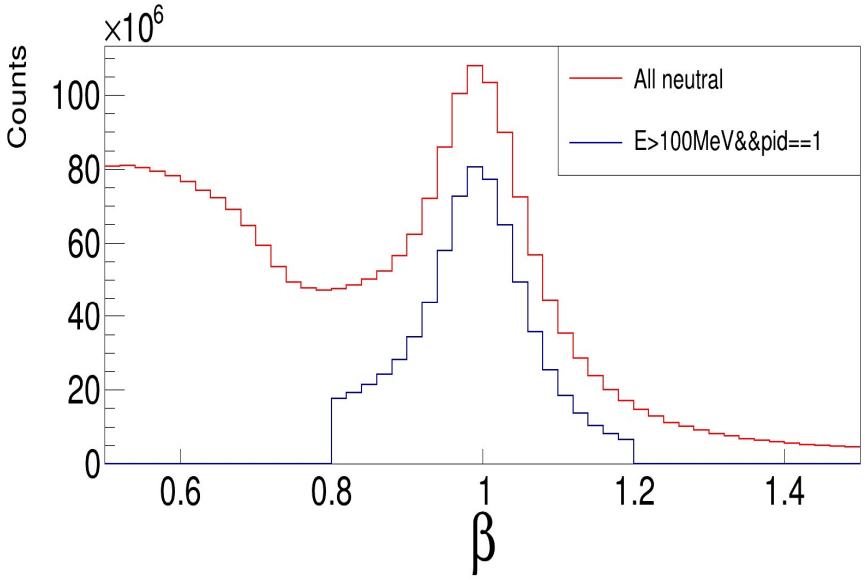
- Particle selection conditions (at least 2 $\gamma$, 1 $\pi^+$, 1 $\pi^-$)
- Resolution parametrization
- $\pi^0 \rightarrow \gamma\gamma$ kinematic refit with $\pi^0$ mass constraint
- $\eta/\omega$ reconstruction
- Estimation of inclusive cross section for $\eta/\omega$ production

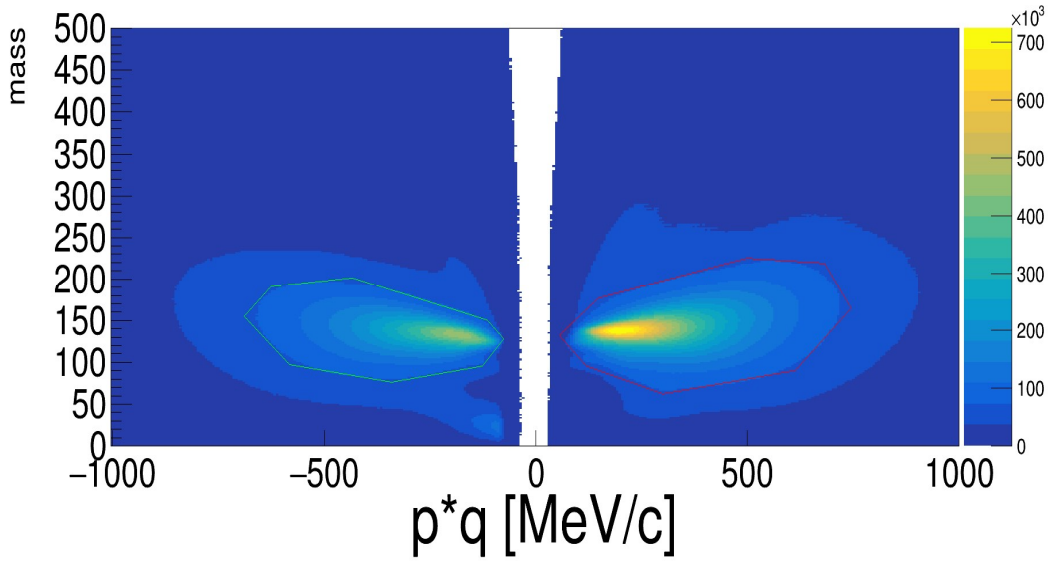
# Particle selection conditions

- Photon selection: $E > 100$ MeV and 0.8<$\beta$<1.2
- $\pi^+, \pi^-$: graphical cuts on mass-charge*momentum spectrum
- Simulations (studies of kinematic refit performance):

$$pp \rightarrow pp\eta(\rightarrow \pi^+\pi^-\pi^0): 10^8 \text{ events}$$

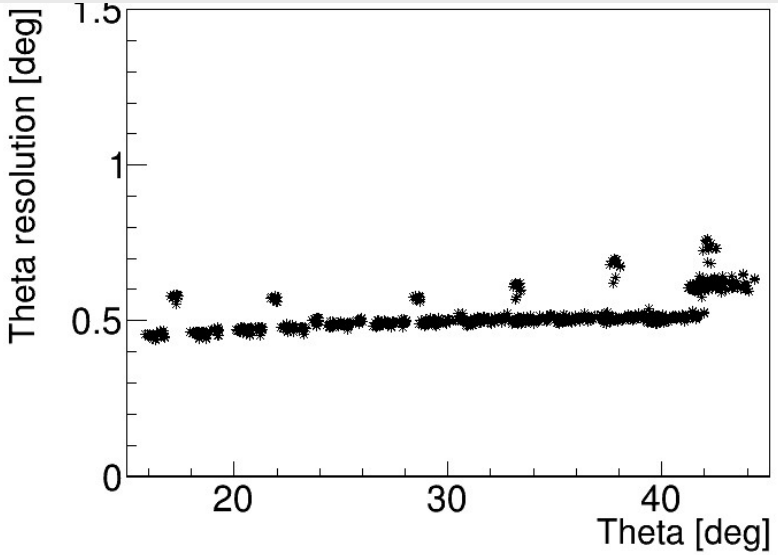
- Statistics corresponds to luminosity of $(6.47 \pm 0.06)\frac{1}{pb}$

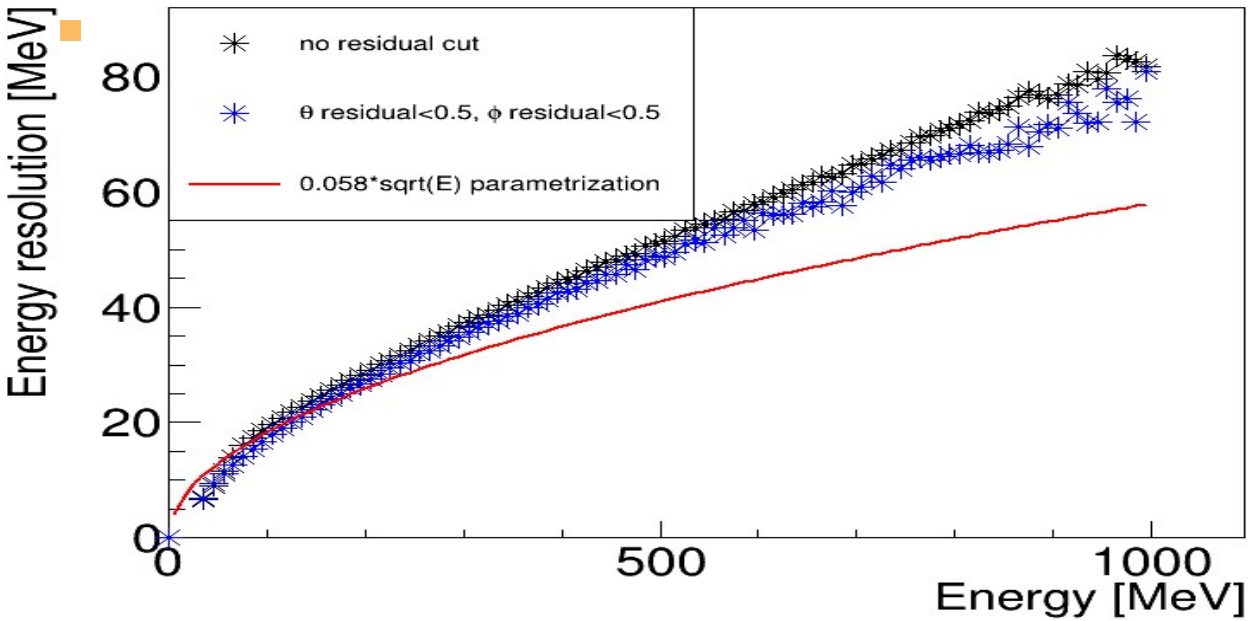


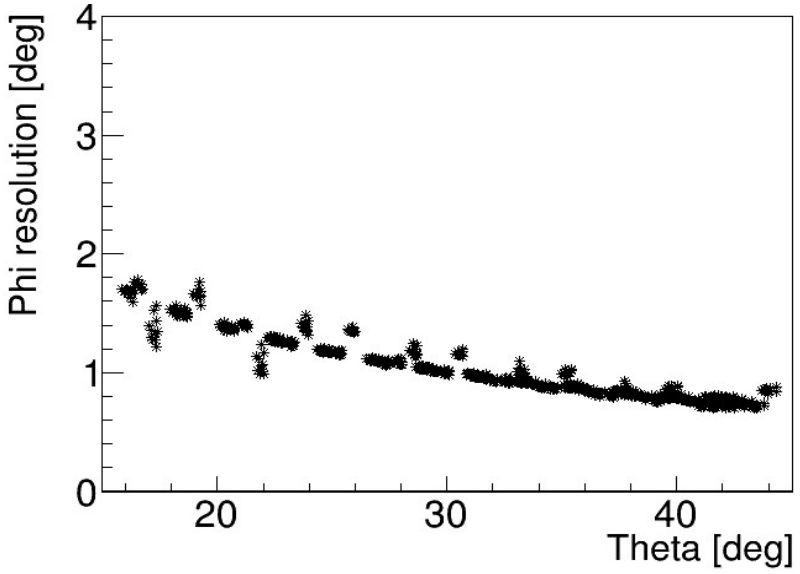



# $\theta$, $\phi$ and energy resolution

- $\theta$, $\phi$: cell-wise Monte Carlo parametrization
- Energy: Monte Carlo parametrization by dependence on energy
- Reference energy resolution:5.8%$\sqrt{E}$ single cell measurement

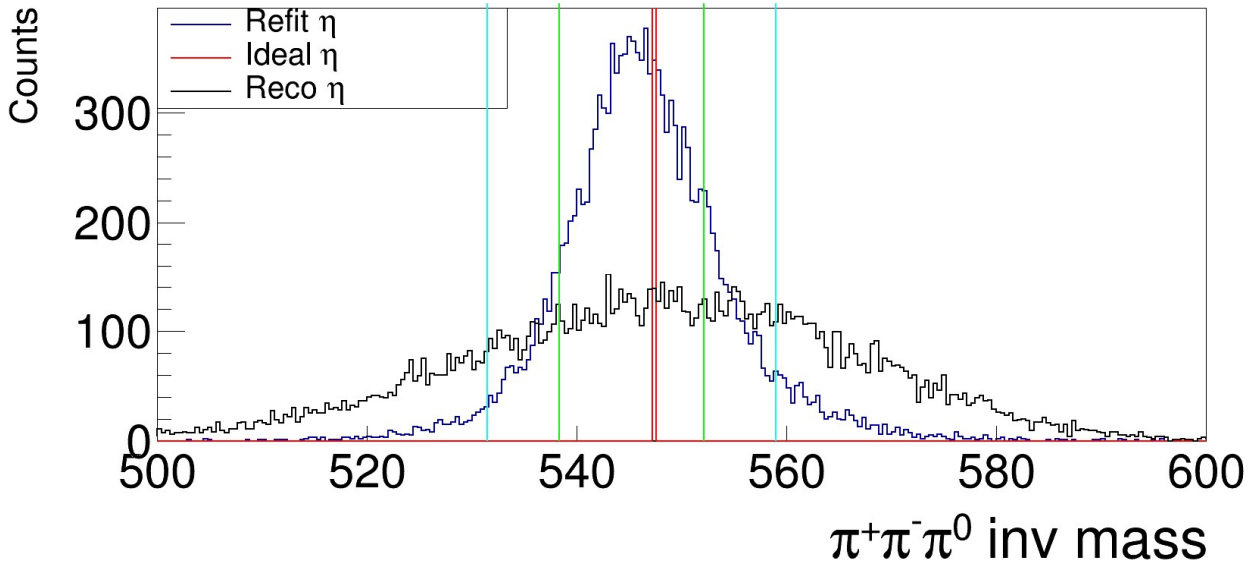


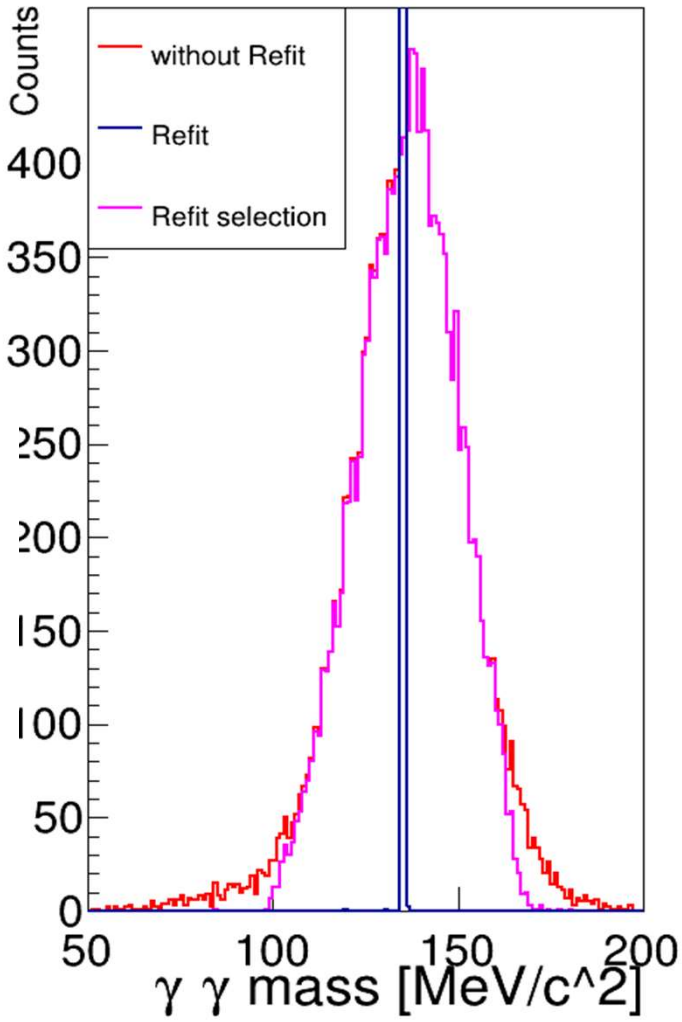



# $\pi^0$ and $\eta$ reconstruction-simulations

- $\pi^0$ mass reconstructed at correct PDG mass.
- Refit selected mass distribution is gaussian.
- Only primary $\gamma$ from $\pi^0$ decay taken into account!

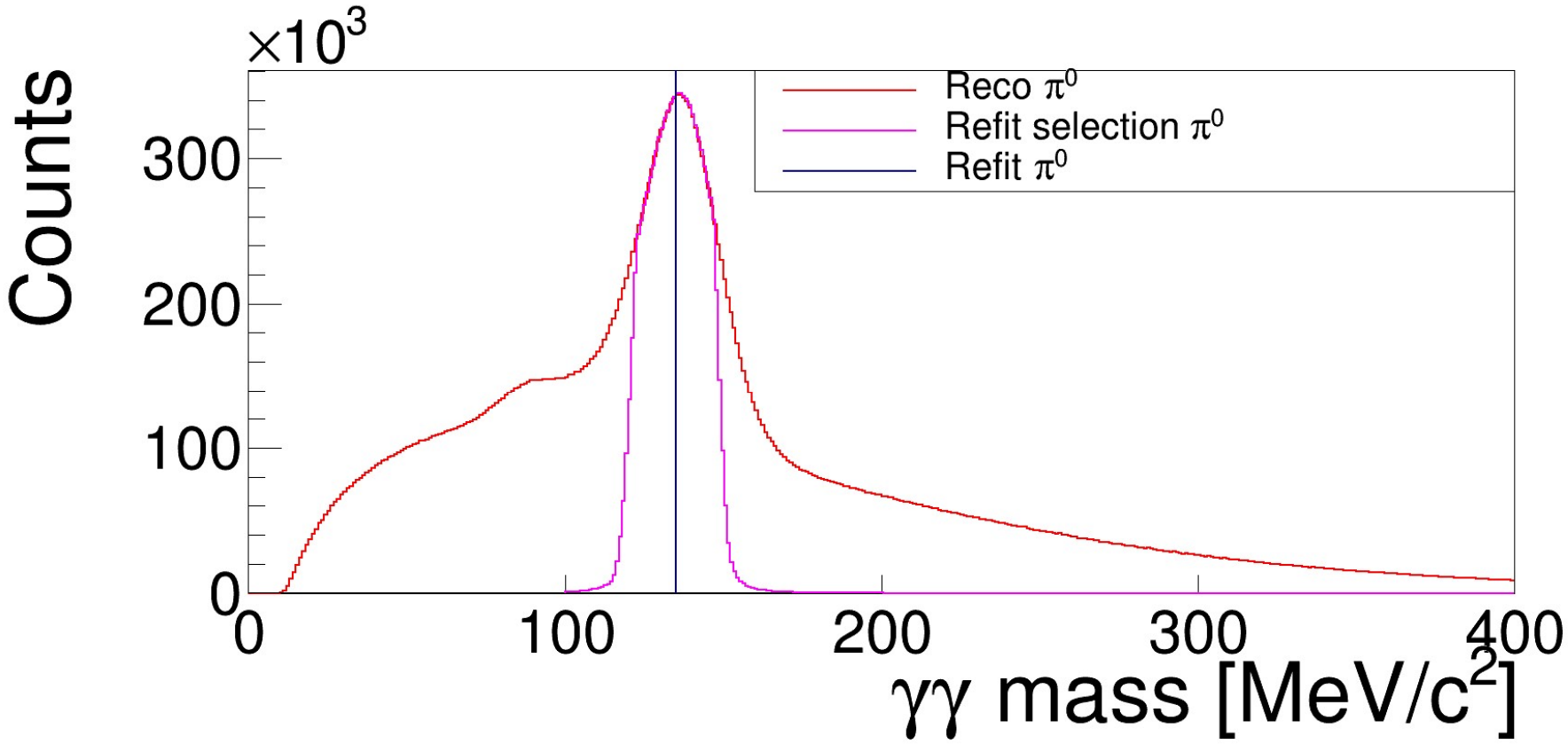



Refited $\eta$ integrated in $\pm 1\sigma$ -10000 $\Rightarrow$ procedure efficiency=0.01%

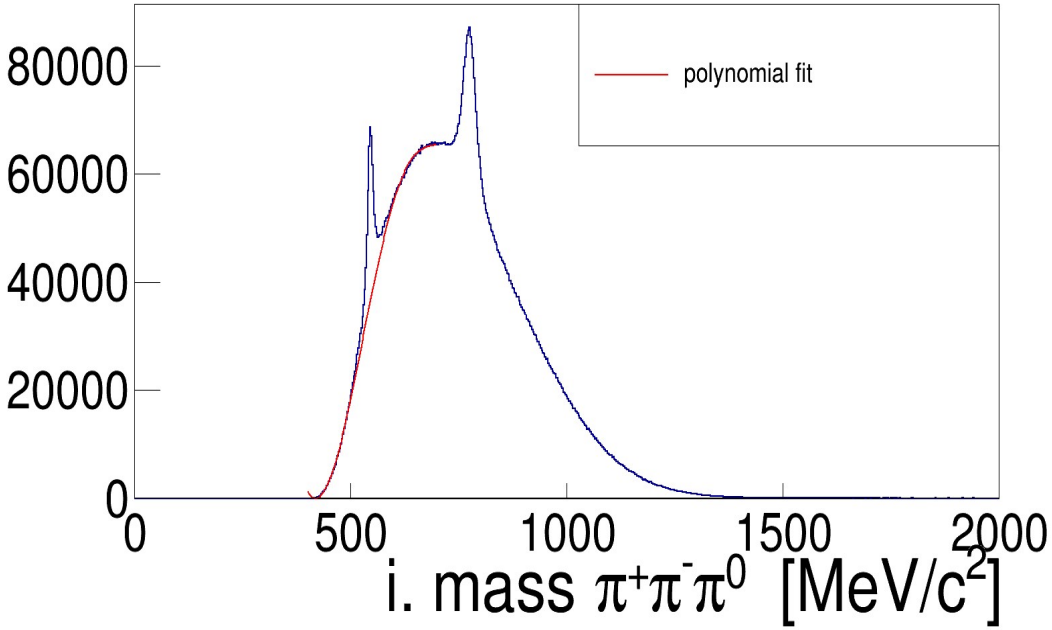
Refited $\eta$ integrated in $\pm 2\sigma$ -14400 $\Rightarrow$ procedure efficiency=0.0144%

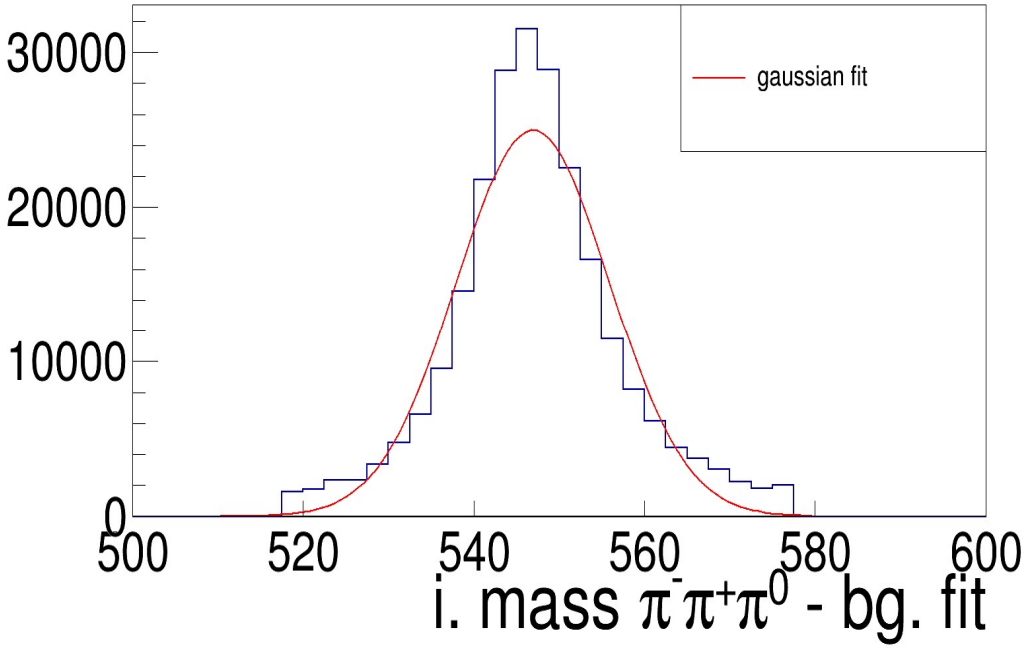
# $\pi^0 \rightarrow \gamma\gamma$ refit results-data




- Large improvement in $\pi_0$ mass resolution.

# $\eta$ reconstruction-data

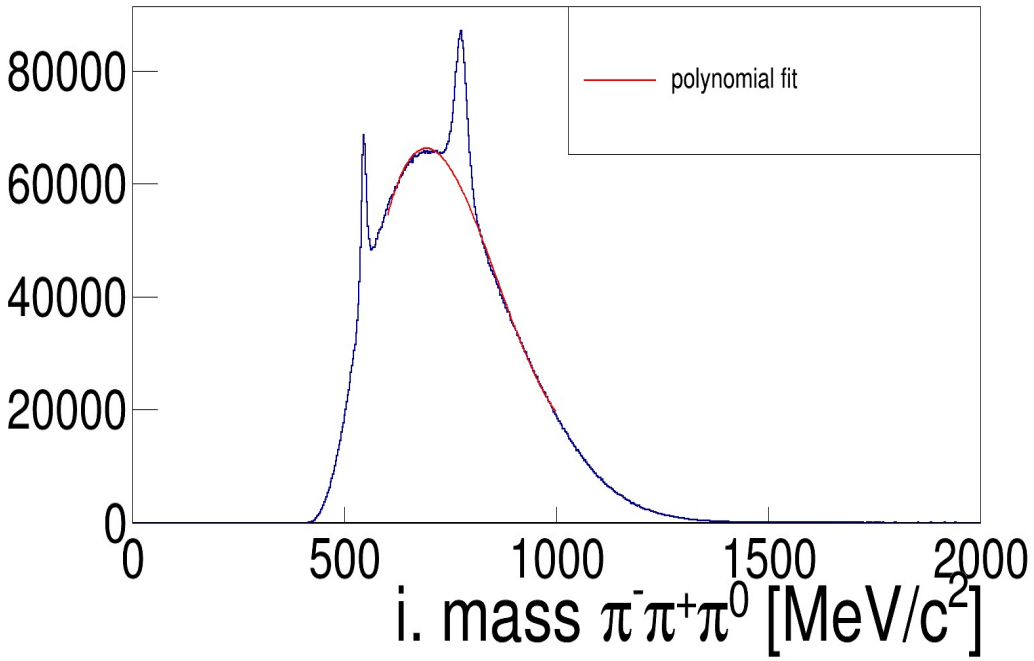


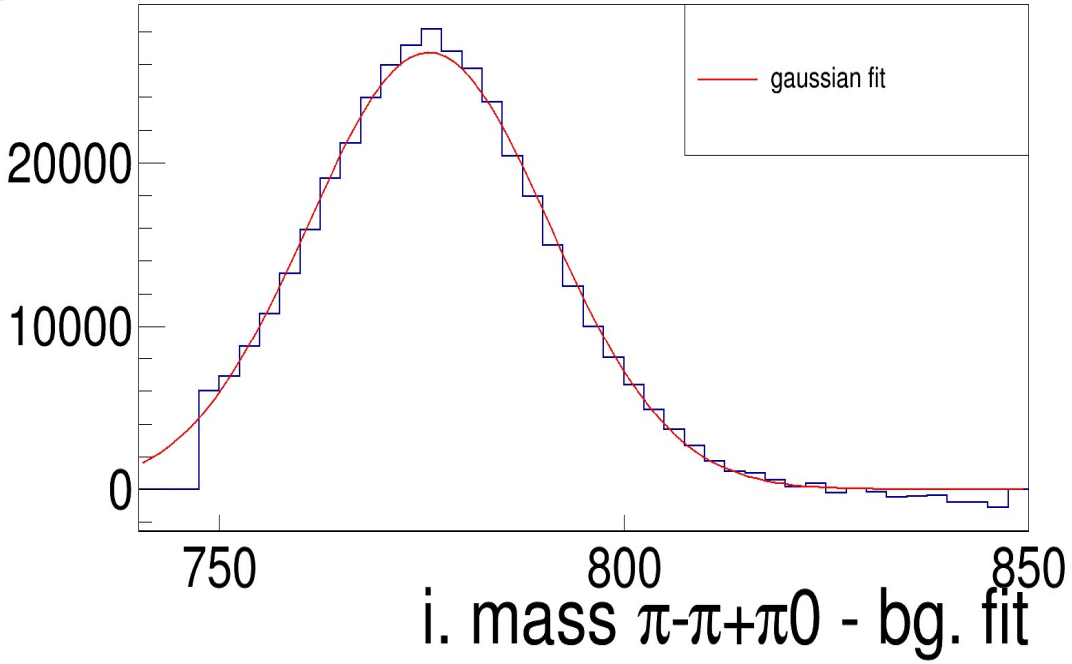




- Background subtraction: fitting 3rd rank polynomial
- Gaussian fit result: $\mu_\eta = 547.26(10)$ $\sigma_\eta = 9.30(10)$
- PDG: $\mu_\eta = 547.862(17)\frac{MeV}{c^2}$

| | $\eta$ | $\sigma_\eta$ |
|---|---|---|
| $\pm 1\sigma$ | 176000 | 1.15 mb |
| $\pm 2\sigma$ | 226000 | 1.72 mb |

# $\omega$ reconstruction

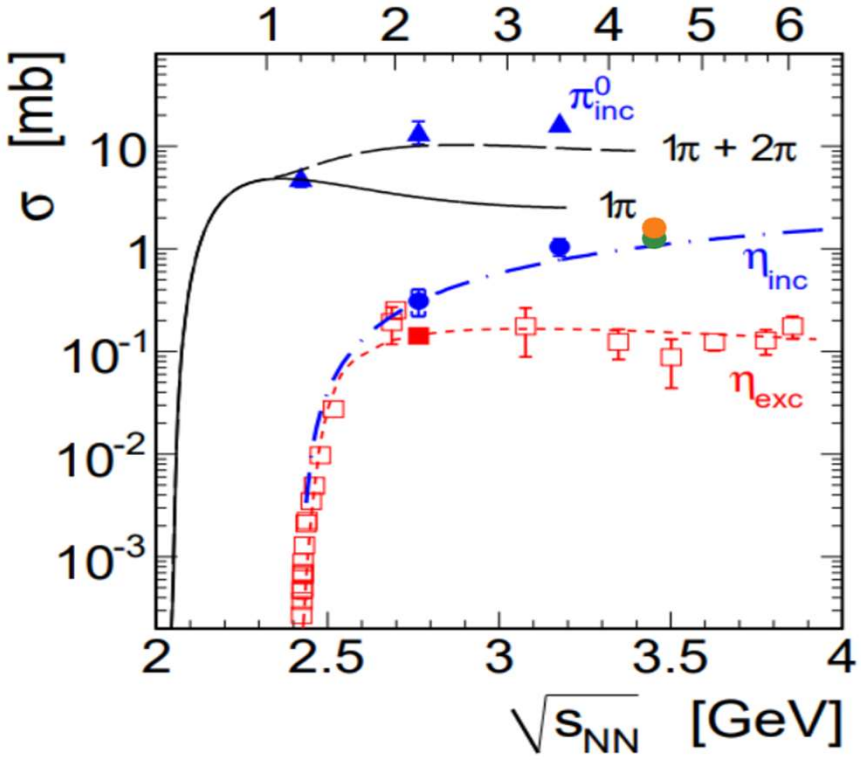



- Background subtraction: fitting 3rd rank polynomial
- Gaussian fit result: $\mu_\omega = 776.77(14)$ $\sigma_\omega = 15.00(12)$
- PDG: $\mu_\omega = 782.65(12) \frac{MeV}{c^2}$

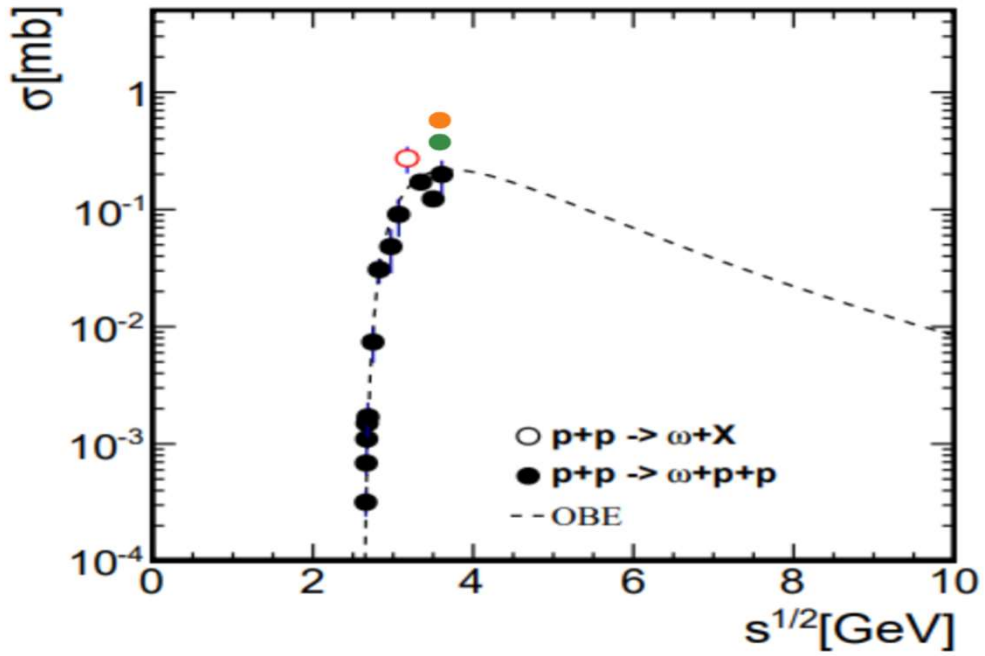
| | $\omega$ | $\sigma_\omega$ |
|---|---|---|
| $\pm 1\sigma$ | 371000 | 0.381 mb |
| $\pm 2\sigma$ | 479000 | 0.573 mb |

# $\eta$ preliminary cross section




- Cross sections for $\pi^0$ and $\eta$ production in p-p collisions at various$\sqrt{s}$.
- Our results for ±1σ and ±2σ presented as green and orange circles respectively
- Other HADES data presented as solid triangles, circles squares.
- The dot-dashed blue curve: parametrization of inclusive η production from [W. Cassing A. Sibirtsev and U. Mosel].
- Figure [G. Agakishiev et al.].

# $\omega$ preliminary cross section



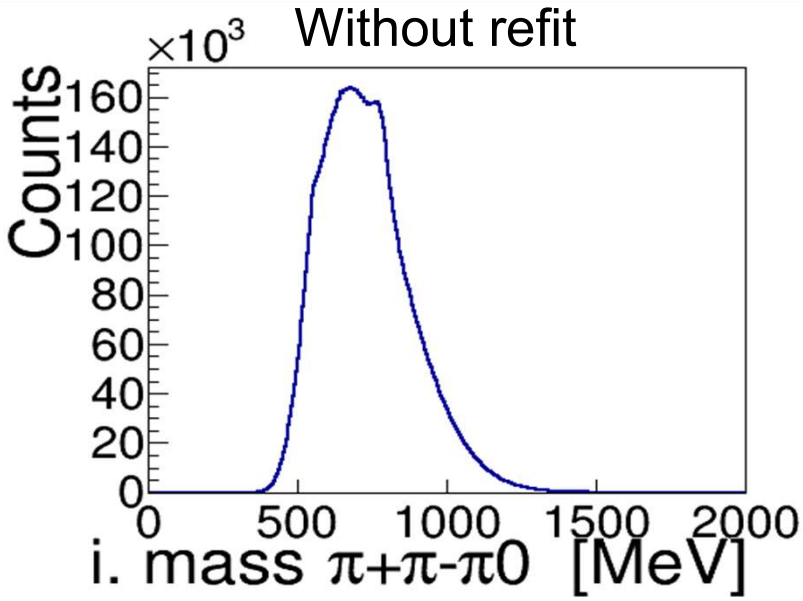

- Cross sections for $\omega$ production production in p-p collisions at various $\sqrt{s}$.
- Our results for ±1σ and ±2σ presented as green and orange circles respectively
- Red empty circle is the HADES result obtained in pp@3.5 GeV.
- The dashed curve refers to the OBE calculations for the exclusive channels [W. Cassing A. Sibirtsev and U. Mosel].
- Figure [HADES Collaboration].

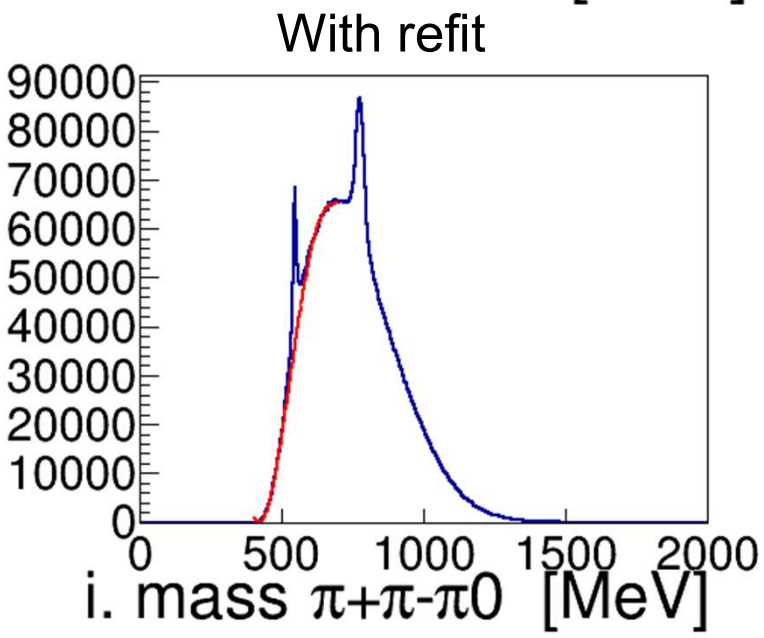
# Summary and outlook

- New resolution parametrization for ECAL developed successfully
- Significantly improved eta/omega resolution
- Preliminary cross section has been obtained, they are consistent with previous measurement

**Outlook**

- Studies of systematic error
- Multi-differential cross sections for η and ω
- $\eta' \to \eta\pi^+\pi^-$ with $\eta \to \pi^+\pi^-\pi^0$ or $\eta \to \gamma\gamma$

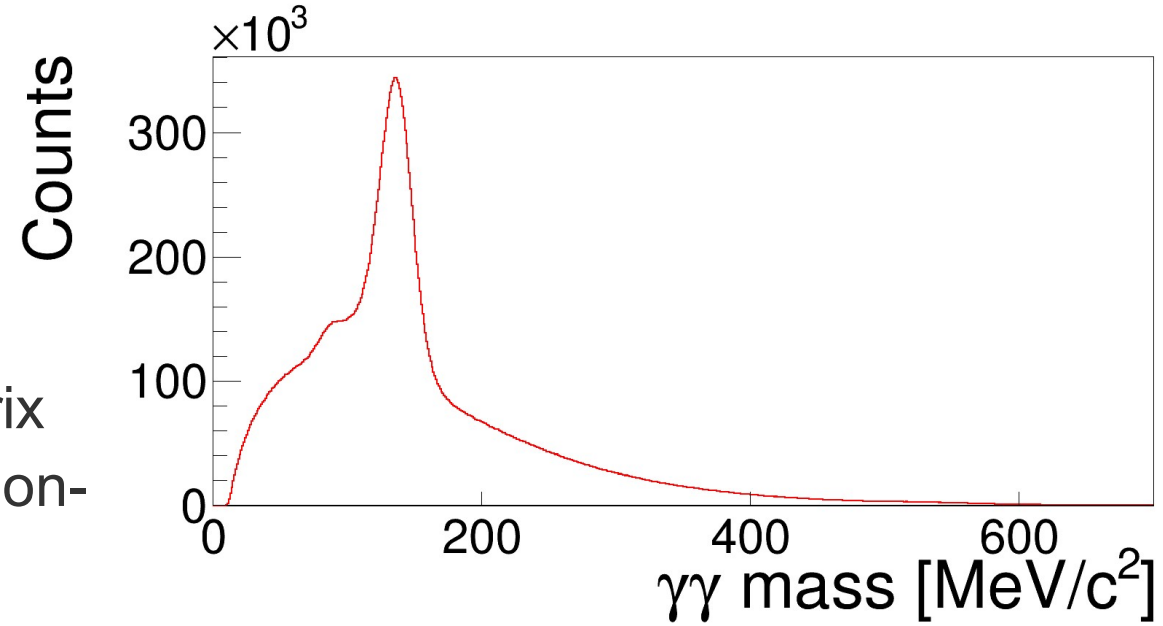


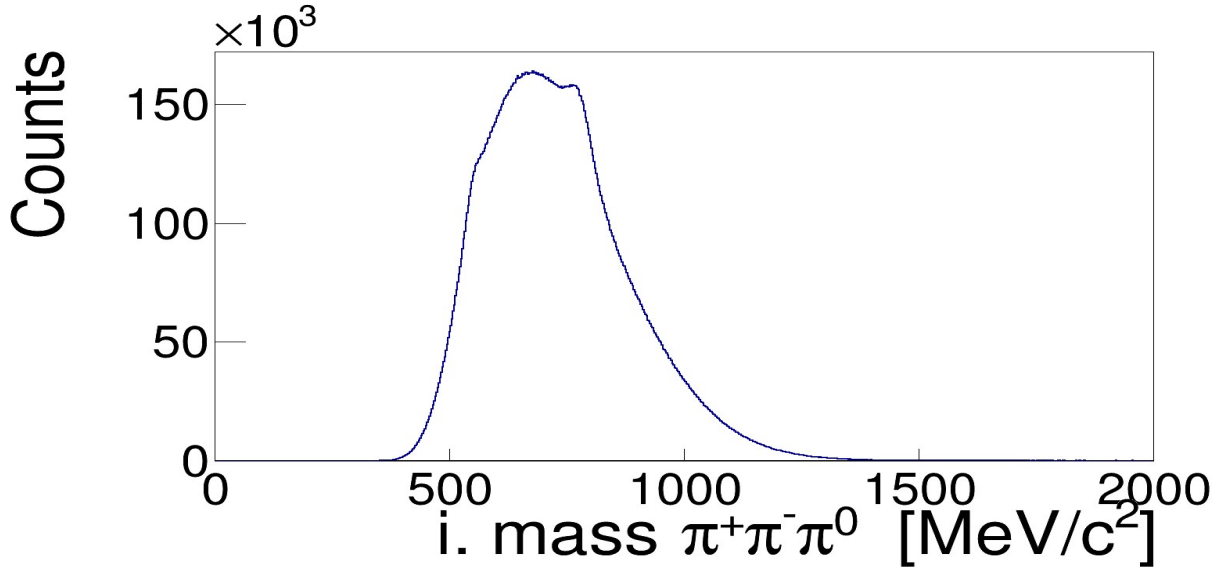



# BACKUP

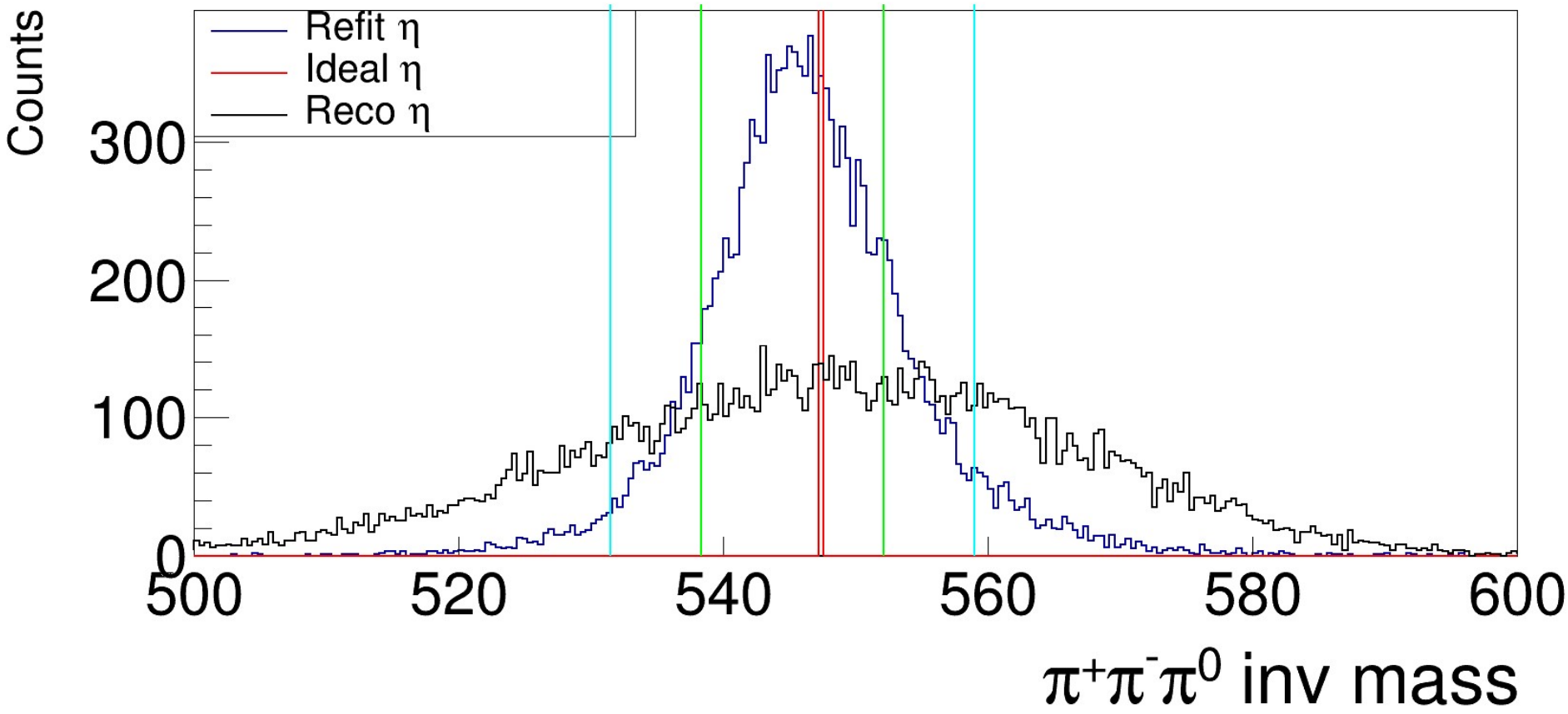
# Motivations of kinematic fit usage

- $\eta/\omega \rightarrow \pi^-\pi^+\pi^0[\rightarrow \gamma\gamma]$ $\pi^0 \rightarrow \gamma\gamma$ lowers $\eta/\omega$ mass resolution
- $\chi^2 = (\vec{y}-\vec{x})^T V^{-1}(\vec{y}-\vec{x})$ $\vec{x}$-measured,$\vec{y}$-estimated quantities, $V$-resolution matrix
- $\vec{g}(y,\eta) = 0$ constraint equation- $|\overline{\gamma_1} + \overline{\gamma_2}| = m_{\pi^0}$
- Kinematic fit procedure: $\chi^2$ minimized with $\vec{g}(y,\eta) = 0$ condition
- Varaibles used:
  - E-enegy
  - $\theta$-polar angle
  - $\Phi$-azimuthal angle



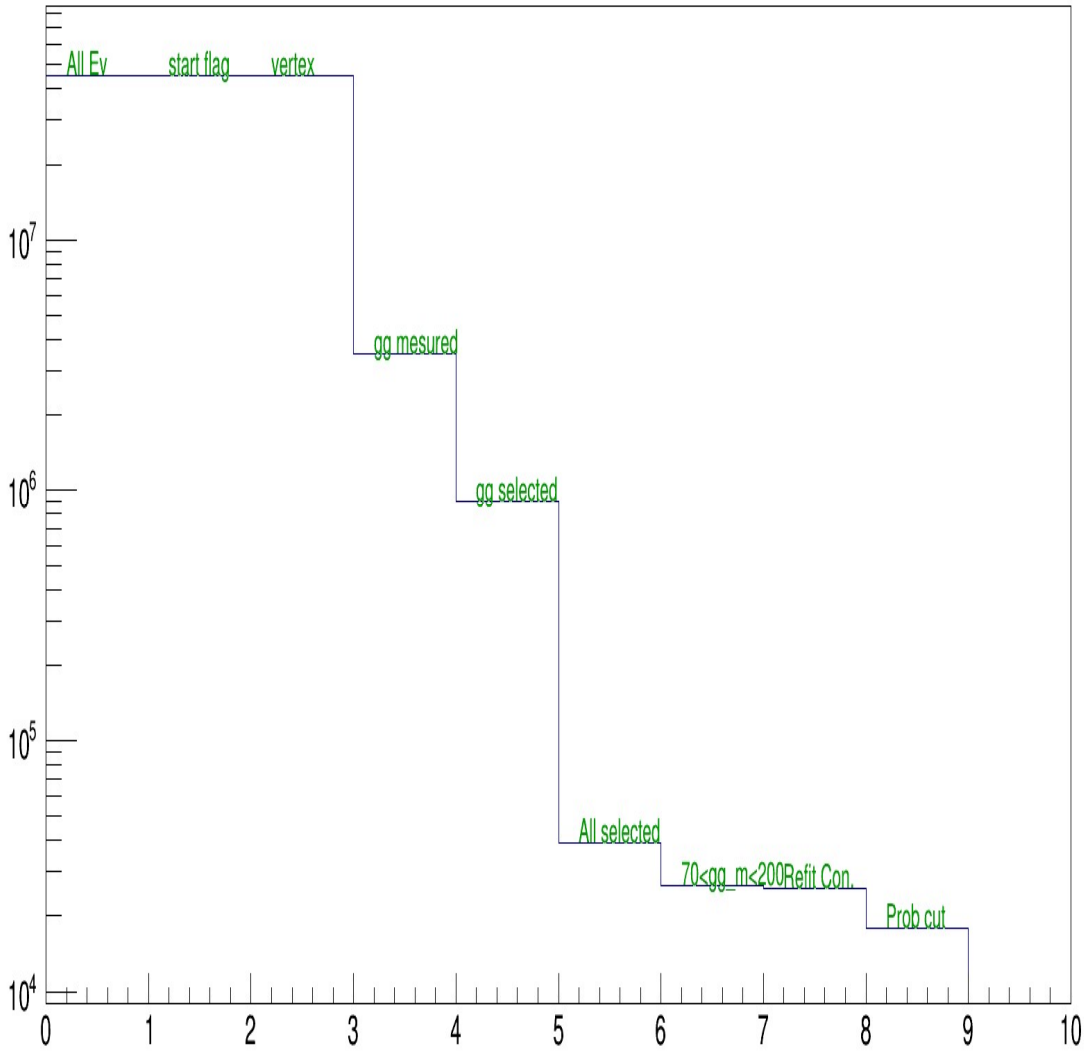
# $\eta$ mass reconstruction-simulations




Refited $\eta$ integrated in $\pm 1\sigma$ -10000 $\Rightarrow$ procedure efficiency=0.01%

Refited $\eta$ integrated in $\pm 2\sigma$ -14400 $\Rightarrow$ procedure efficiency=0.0144%

# Statistic losses-backup




Gg-measured-at least 2 $\gamma$ mesured
Gg-selected-at least 2 $\gamma$ mesured with E>100 and $0.8 < \beta < 1.2$
All selected- at lest 2 $\gamma$ selcted and at least 1 $\pi^+$and $\pi^-$ inside graph cuts 70<gg_m<200- 70 MeV/c^2 <$\gamma\gamma$ inv mass<200 MeV/c^2
Reift con.- refit procedure converged
Prob cut-prob of refit>5%