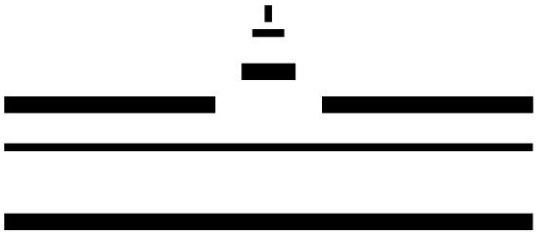

Westfälische
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Analysis of the forbidden decay $\eta \rightarrow \pi^0 + e^+ + e^-$ with WASA-at-COSY

Florian Bergmann

23.03.2011

Reminder: C-parity

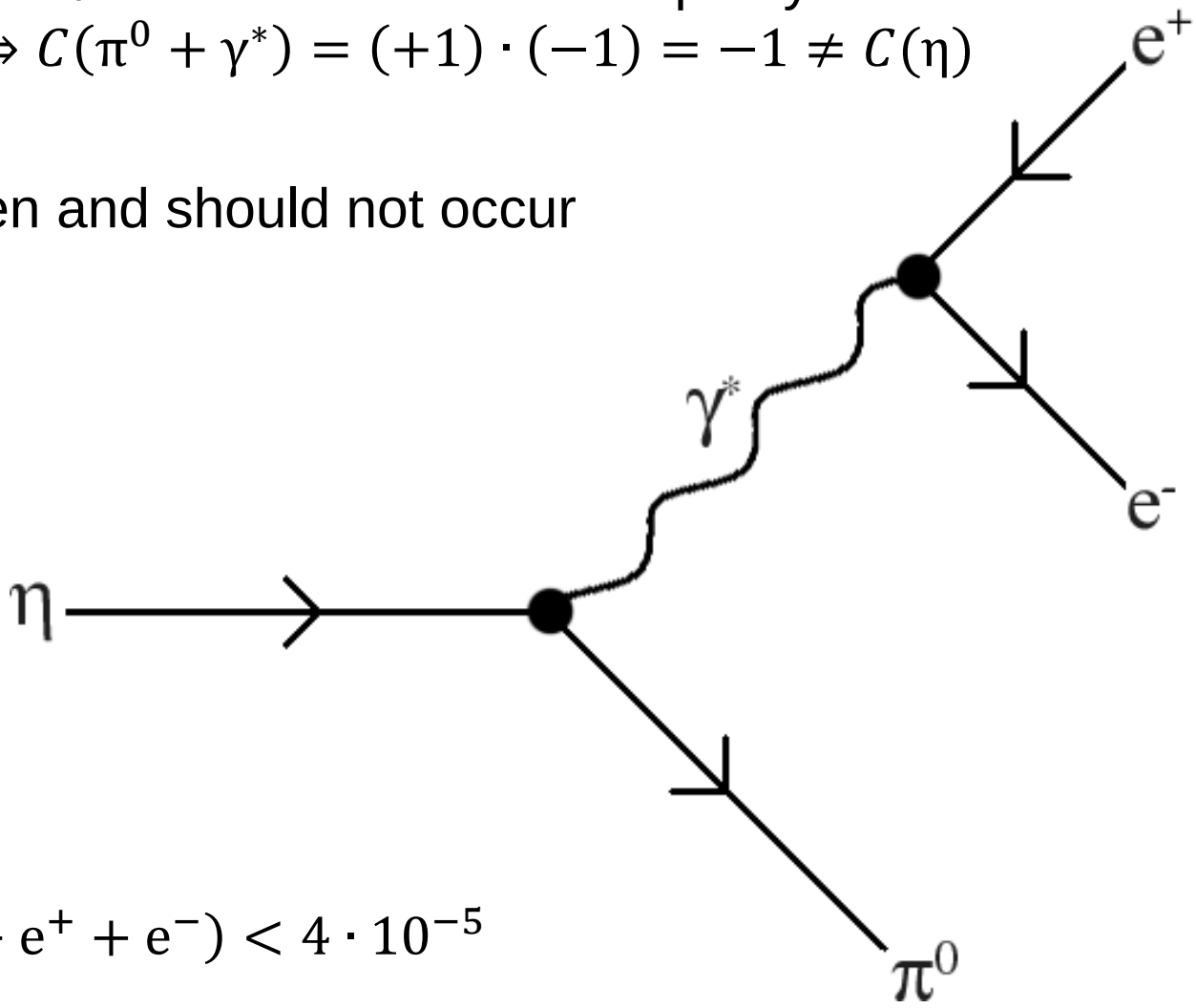
- $\hat{C}$-operator: turns particle into antiparticle
  - E.g.: $\hat{C}|e^-\rangle = C|e^-\rangle$ C: phase factor
- Majorana particle: Eigenstate of the $\hat{C}$-operator with the eigenvalue $C = \pm 1$
  - Necessary condition: $Q = I = B = S = L = 0$
  - E.g.: $\hat{C}|\gamma\rangle = -|\gamma\rangle$
  - η-meson: $\hat{C}|\eta\rangle = \hat{C}|\gamma\gamma\rangle = \hat{C}|\gamma\rangle \cdot \hat{C}|\gamma\rangle$
    $= (-1)|\gamma\rangle \cdot (-1)|\gamma\rangle$
    $= (-1)^2|\gamma\gamma\rangle = (+1)|\eta\rangle$
  - η-decay into 3 photons not observed yet
- C-parity violation in el. magn. / strong interaction not observed yet

Motivation for the analysis

- Decay $\eta \rightarrow \pi^0 + e^+ + e^-$ would violate the C-parity conservation

$$\eta \rightarrow \pi^0 + \gamma^* \Rightarrow C(\pi^0 + \gamma^*) = (+1) \cdot (-1) = -1 \neq C(\eta)$$

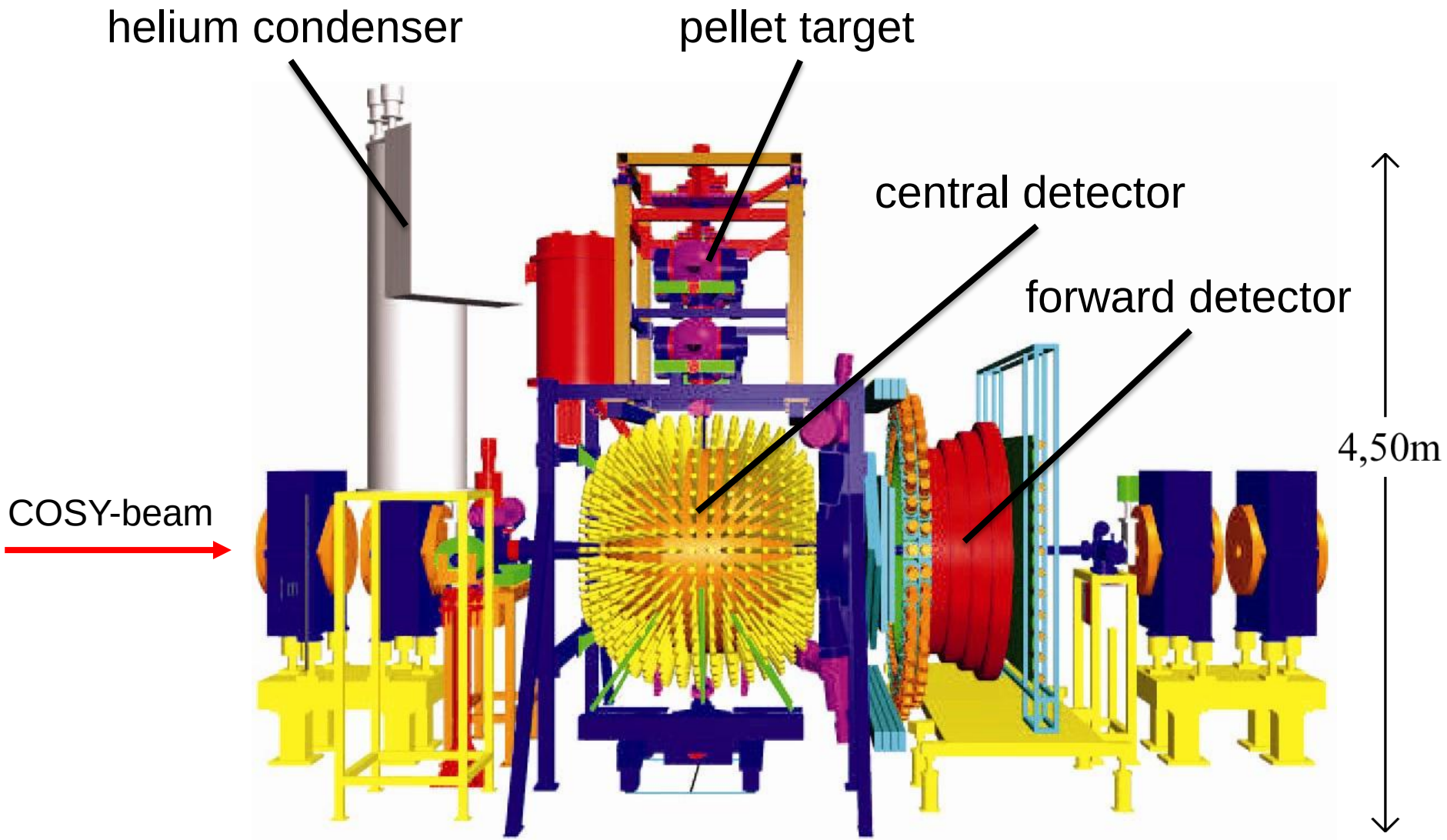
➔ Decay is forbidden and should not occur



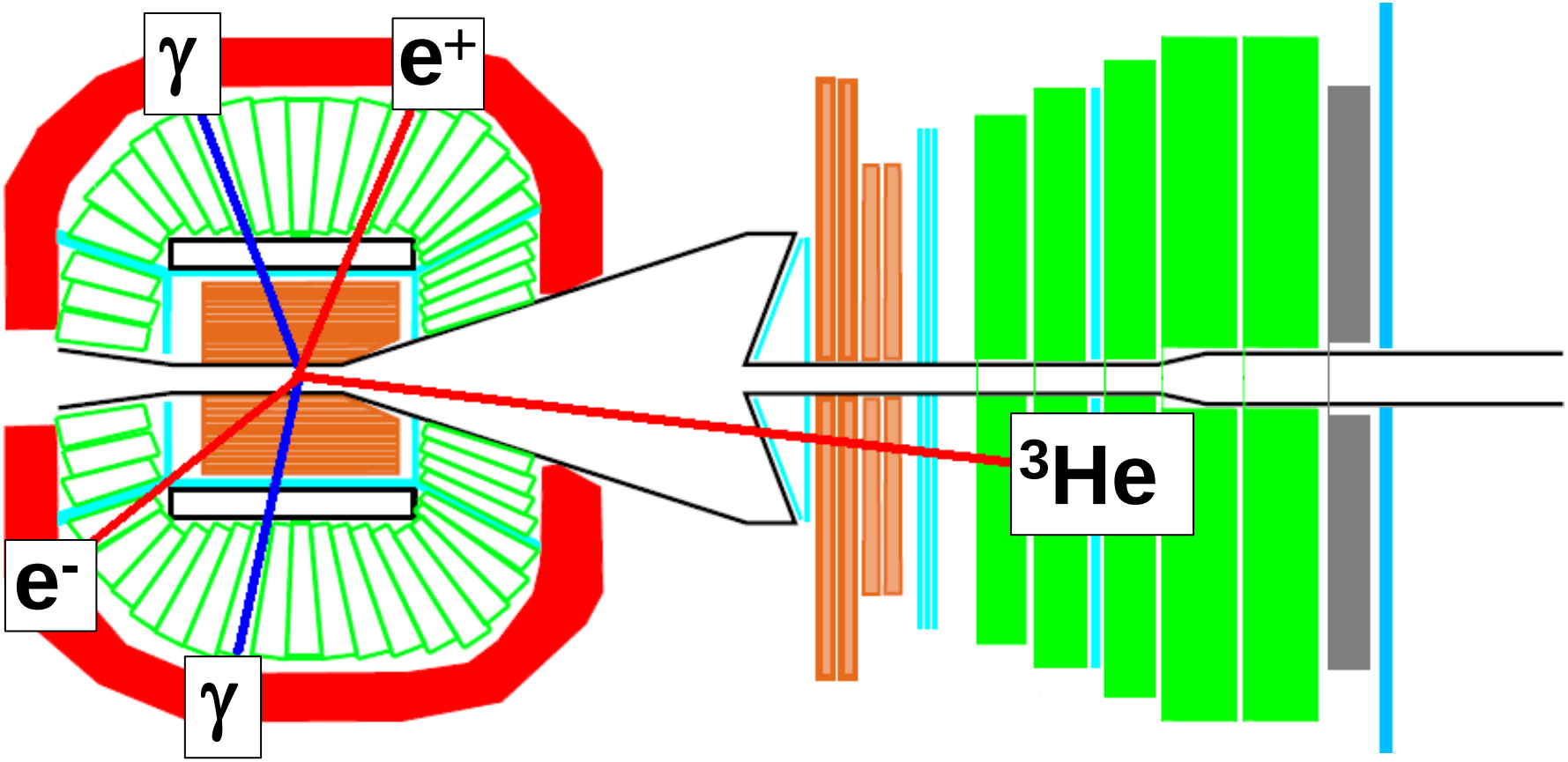
- Current value:

$$\mathrm{BR}(\eta \rightarrow \pi^0 + e^+ + e^-) < 4 \cdot 10^{-5}$$

WASA – Wide Angle Shower Apparatus



$p + d \rightarrow {}^3He + \eta \rightarrow {}^3He + \pi^0 + e^+ + e^-$



Analysis

- Goal of the analysis: Determination of the branching ratio of the forbidden decay $\eta \rightarrow \pi^0 + e^+ + e^-$

- Analysed data:
  - $1.7 \cdot 10^8$ events from $p + d \rightarrow {}^3He + X$ -beam time
  - Oct../Nov. 2008, 10^7 events with $X = \eta$

- Demands on the analysis:
  - Suppress background as much as possible
  - Suppress decay of interest as little as possible

- Background:
  - Direct pion productions: $X = \pi^0, 2\pi, 3\pi, 4\pi$
  - η-decays: $X = \eta,\ \eta \rightarrow 2\gamma, 3\pi^0, \pi^+\pi^-\pi^0, \cdots$

1. Simulation

Simulated reactions:

η-decays:

- $\eta \to \pi^0 e^+ e^-$
- $\eta \to \gamma\gamma$
- $\eta \to \pi^0 \pi^0 \pi^0$
- $\eta \to \pi^0 \pi^+ \pi^-$
- $\eta \to \pi^+ \pi^- \gamma$
- $\eta \to e^+ e^- \gamma$
- $\eta \to \pi^+ \pi^- e^+ e^-$
- $\eta \to \mu^+ \mu^- \gamma$
- $\eta \to \pi^0 \gamma\gamma$
- $\eta \to \mu^+ \mu^-$

Direct pion productions:

- π^0
- $\pi^0 \pi^0$
- $\pi^+ \pi^-$
- $\pi^0 \pi^0 \pi^0$
- $\pi^0 \pi^+ \pi^-$
- $\pi^0 \pi^0 \pi^0 \pi^0$
- $\pi^0 \pi^0 \pi^+ \pi^-$
- $\pi^+ \pi^- \pi^+ \pi^-$

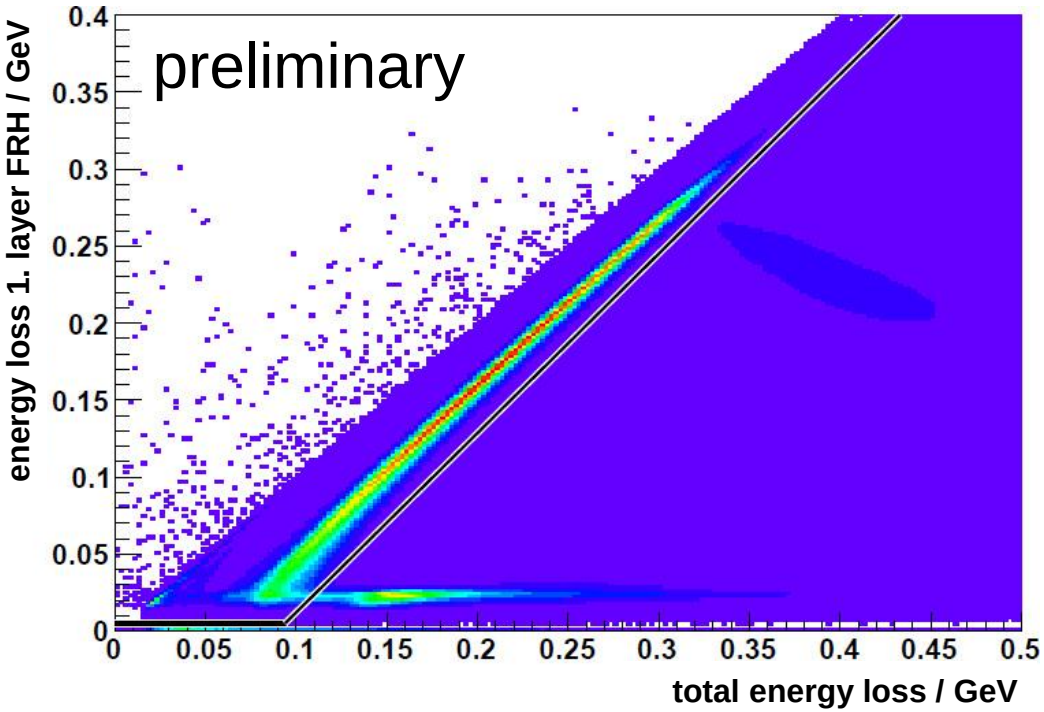
+ dalitz decays of the π^0 ($\pi^0 \to e^+ e^- \gamma$)

2. Preselection of the data

- Preselection on the signature: $p + d \rightarrow {}^3He + \eta$
  - 1 charged particle in the forward detector $({}^3He)$ $\downarrow$
  - 1 pos. charged particle in the central detector (e^+) $\pi^0 + e^+ + e^-$
  - 1 neg. charged particle in the central detector (e^-) $\downarrow$
  - 2 neutral particles in the central detector (2γ) $\gamma + \gamma$

- Cut on the energy loss to identify the ${}^3He$
- Invariant mass of the photons $> 90\ MeV/c^2$

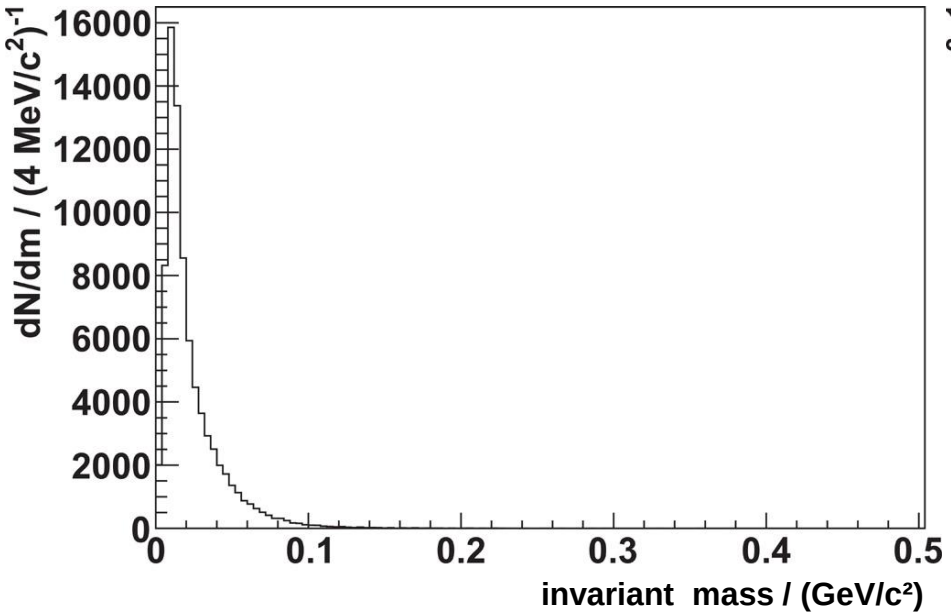
- Data reduced by a factor of 300



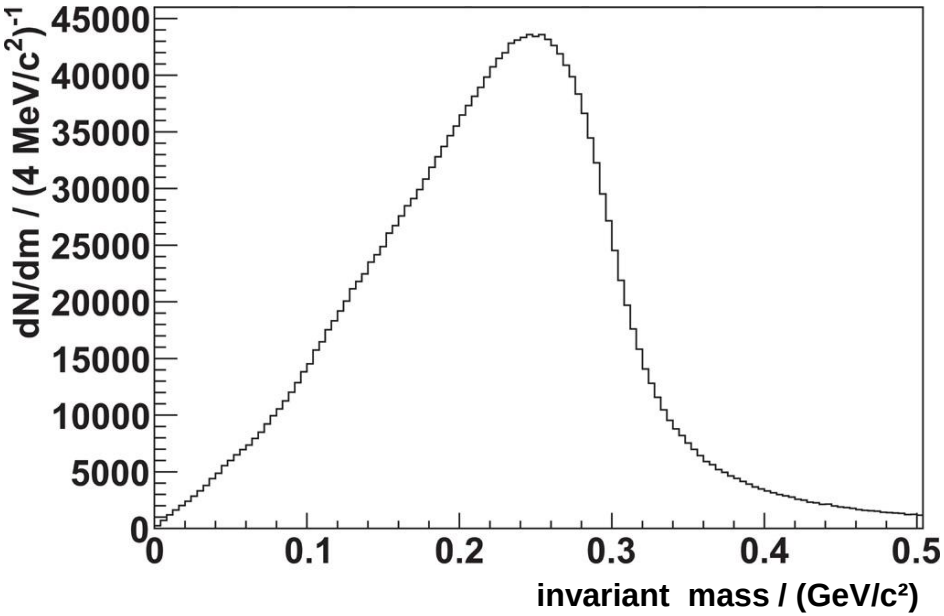
3. Determination of possible cuts

- Cut 1, 2: Preselection
- Cut 3: Invariant mass of 2 charged particles

MC: $\eta \rightarrow \pi^0 e^+ e^-$

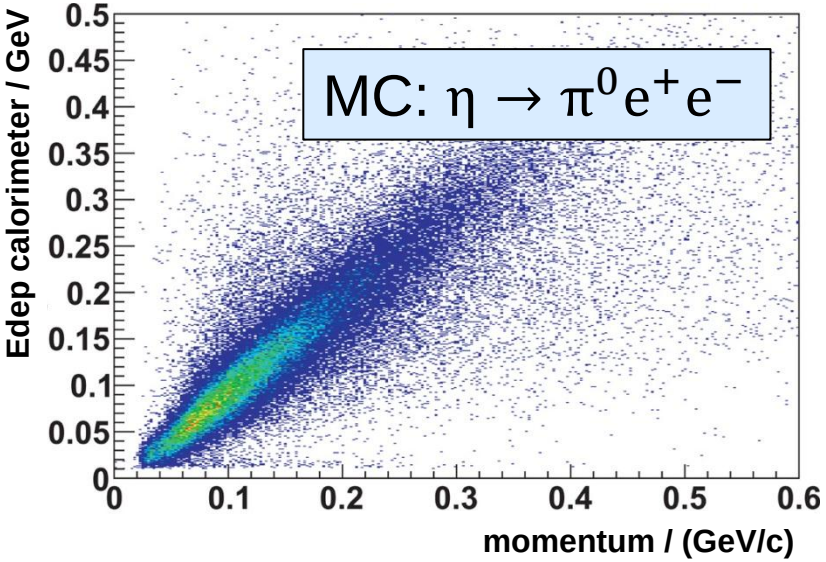


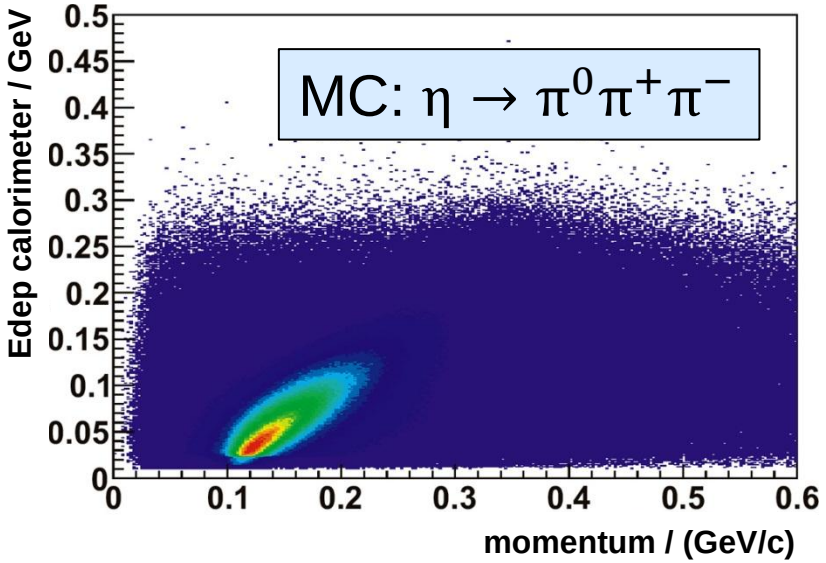
MC: $\eta \rightarrow \pi^0 \pi^+ \pi^-$

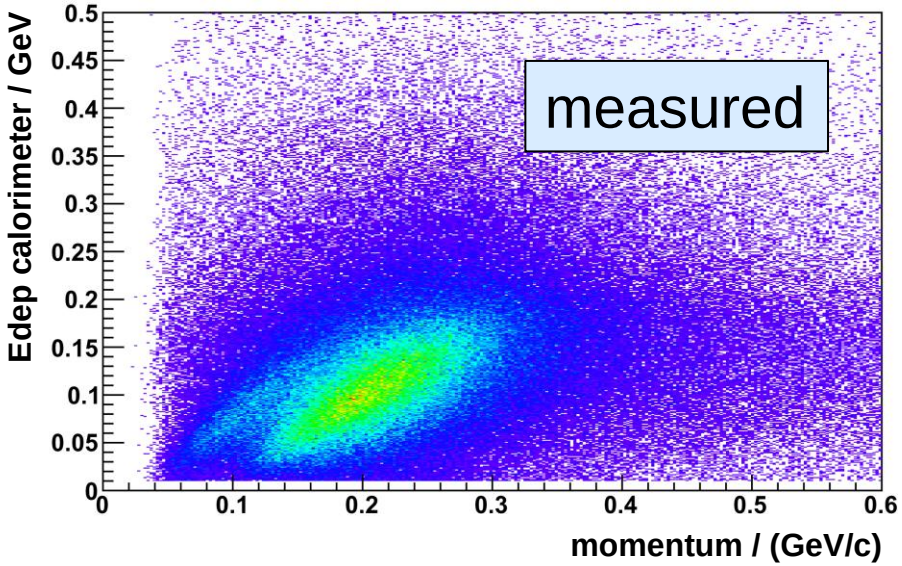


3. Determination of possible cuts

- Cut 4: Energy vs. momentum of the charged particles





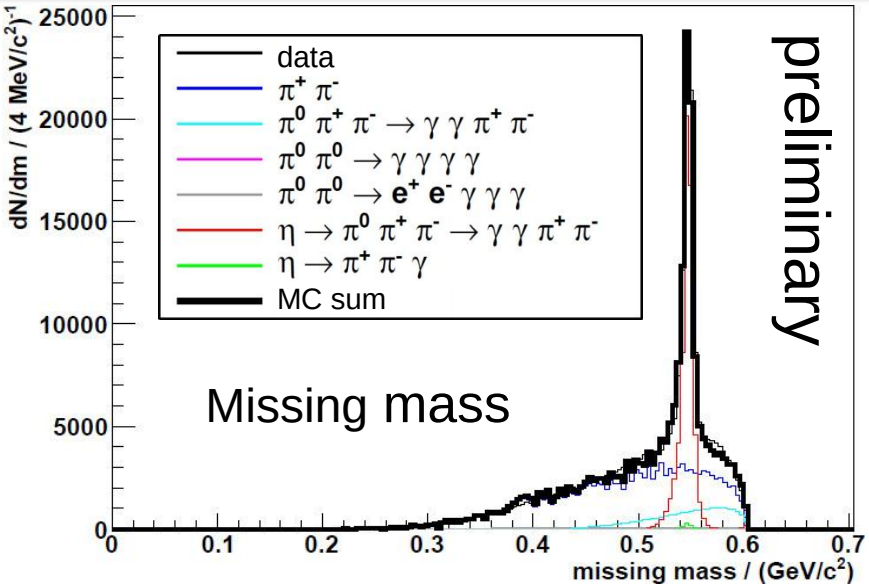


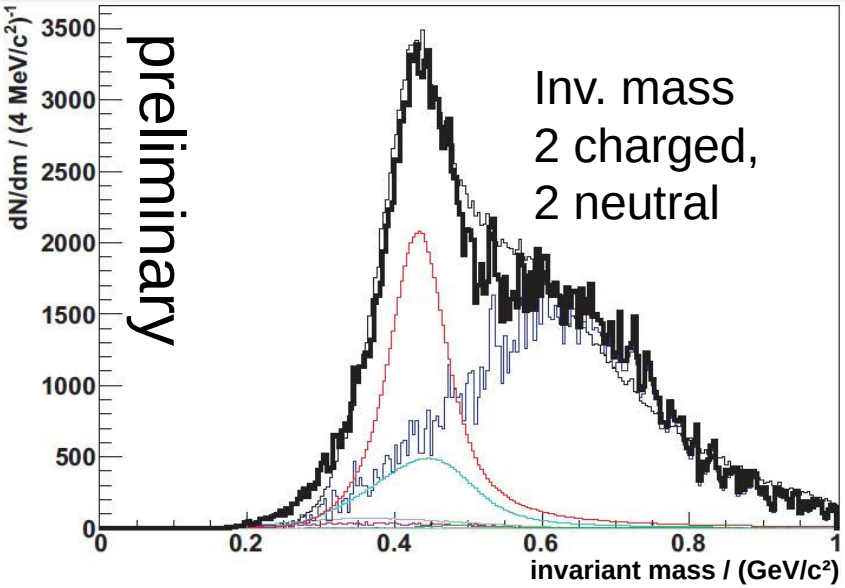
preliminary

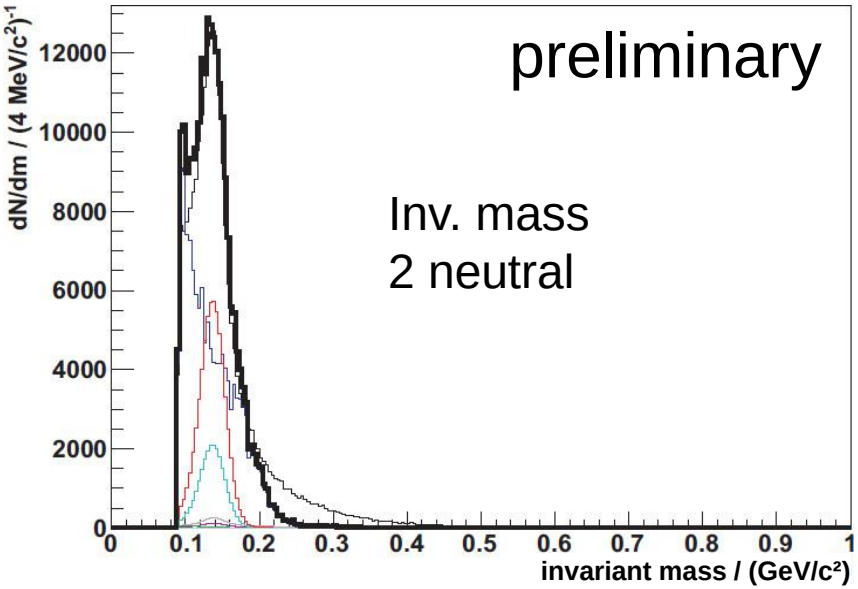
3. Determination of possible cuts

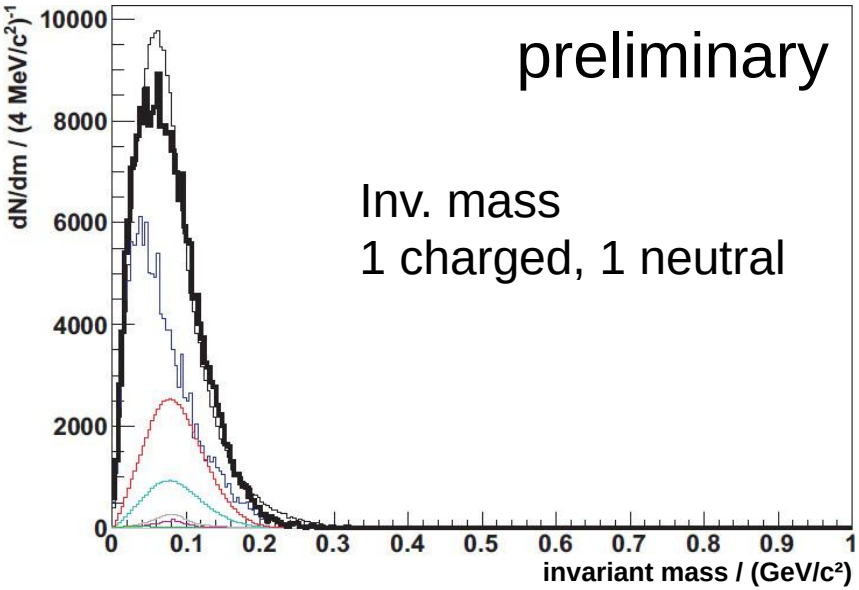
- Cut 5: Invariant mass of 2 neutral particles
  (π^0-meson)
- Cut 6: Min. invariant mass of 1 charged and 1 neutral particle
  (Bremsstrahlung)
- Cut 7: Missing mass of the $^3\mathrm{He}$
  (η-production)
- Cut 8: Invariant mass of all particles in the central detector
  (η-meson)

4. Fit of the MC data to the measured data





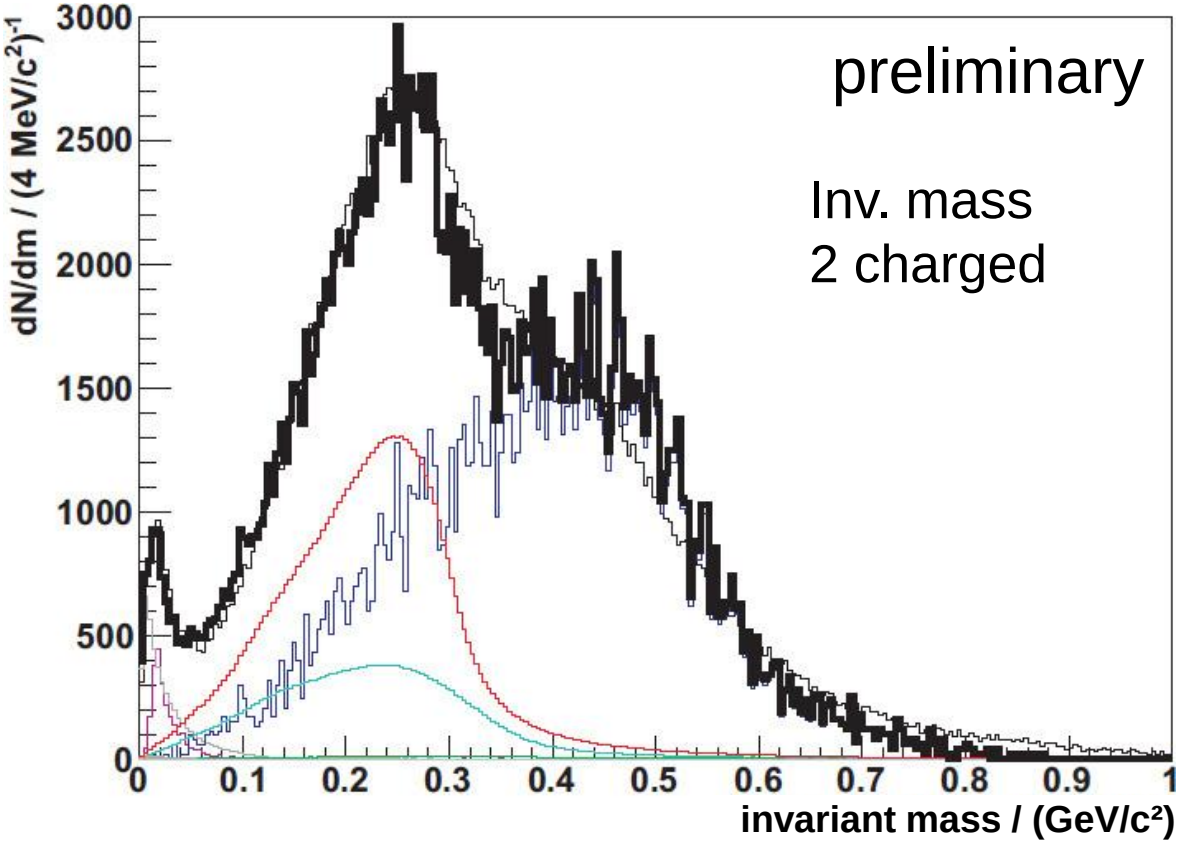




4. Fit of the MC data to the measured data

- Total number of events in the preselected data according to the fit:

$\eta \rightarrow e^+e^-\gamma$:	146 ± 15
$\eta \rightarrow \gamma\gamma$:	15 ± 1
$\eta \rightarrow \pi^+\pi^-\gamma$:	725 ± 6
$\eta \rightarrow \pi^+\pi^-\pi^0$:	63236 ± 174
$\eta \rightarrow \pi^0\pi^0\pi^0$:	39 ± 1



$\pi^0\pi^0 \rightarrow \gamma\gamma\gamma\gamma$:	2378 ± 11
$\pi^0\pi^0 \rightarrow e^+e\gamma\gamma$:	4697 ± 23
$\pi^+\pi^-$:	132035 ± 200
$\pi^+\pi^-\pi^0 \rightarrow \pi^+\pi^-\gamma\gamma$:	22973 ± 228

All other reactions: 0

5. Optimization of the cuts

- Software varies cuts and calculates evaluation function for every set of cuts
- Evaluation function: $G = S_R \frac{S_R}{B_R}$ S_R: relative signal

  B_R: relative background
- Goal: maximization of G

- Cuts also change the shape of the other distributions

➔ Several iterations required

- Result of the simulations:
  - With optimised cuts exactly 1 event should remain in the measured data; from the reaction $\pi^0\pi^0 \rightarrow e^+e^-\gamma\gamma\gamma$
  - Remaining $\eta \rightarrow \pi^0 e^+ e^-$-events: 9920 out of 10^6
  - Signal to background ratio: $1 \,/\, 1.7 \cdot 10^6$

6. Application of the cuts on the measured data

- Cuts are applied to the measured data
- Number of total events remaining after cuts in MC and measured data should be roughly the same

Cut	Number of remaining events
No cut	$1.7 \cdot 10^8$
Preselection	229601
Cut 3: Inv. mass 2 charged	3671
Cut 4: E_{dep} vs. momentum charged	2991
Cut 5: Inv. mass 2 neutral	1108
Cut 6: Inv. masse 1 ch., 1 neutr.	154
Cut 7: Missing mass	17
Cut 8: Inv. mass 2 ch., 2 neutr.	1

Summary / Outlook

- Result of the analysis of $1.7 \cdot 10^8$ events:
  - Signal to background ratio: $1 / 1.7 \cdot 10^6$
  - Monte Carlo: After all cuts 1 event remains; from the reaction $\pi^0\pi^0 \rightarrow e^+e^-\gamma\gamma\gamma$
  - Measured: After all cuts 1 event remains
- Data will allow for highest precision for the decay

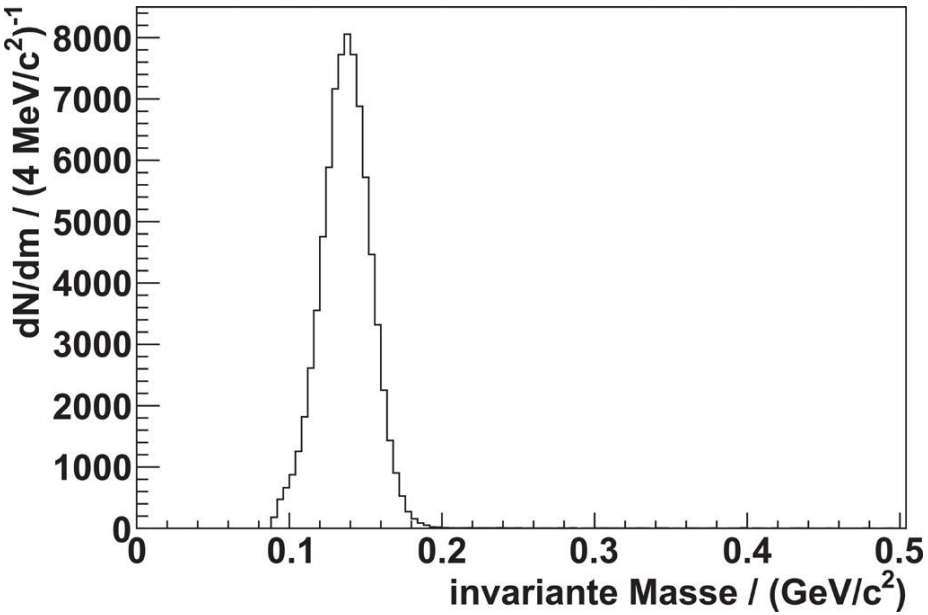
  $$\eta \rightarrow \pi^0 + \gamma^* \rightarrow \pi^0 + e^+ + e^-$$
- More measured data: $20 \cdot 10^6$ $pd \rightarrow {}^3He + \eta$ events from Aug./Sep. 2009
- Many more η-events from $pp \rightarrow pp + X$ data
- Cut optimization: n-dimensional instead of iterative

➔ Lowering the upper limit of the decay $\eta \rightarrow \pi^0 + e^+ + e^-$

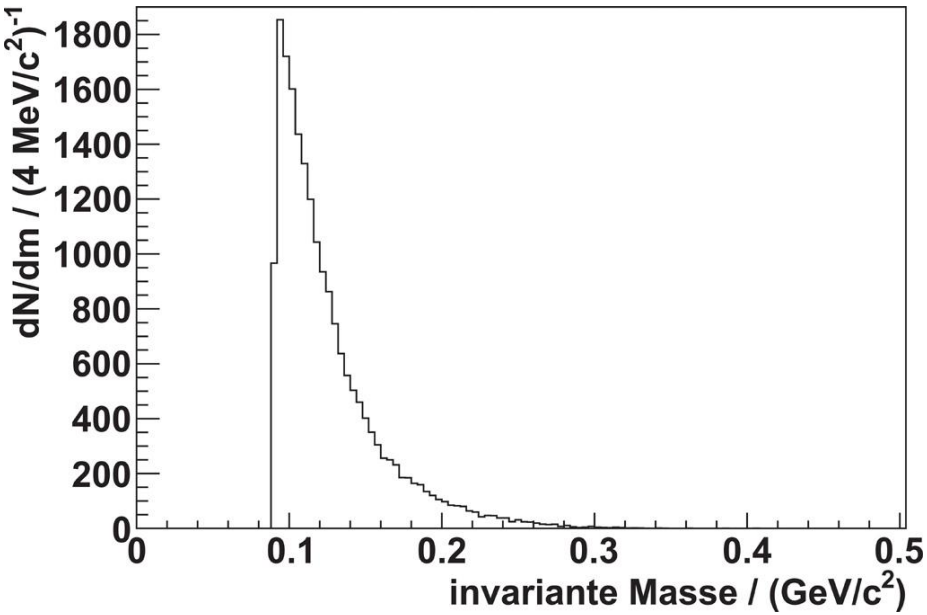
3. Determination of possible cuts

- Cut 5: Invariant mass of 2 neutral particles

MC: $\eta \rightarrow \pi^0 e^+ e^-$



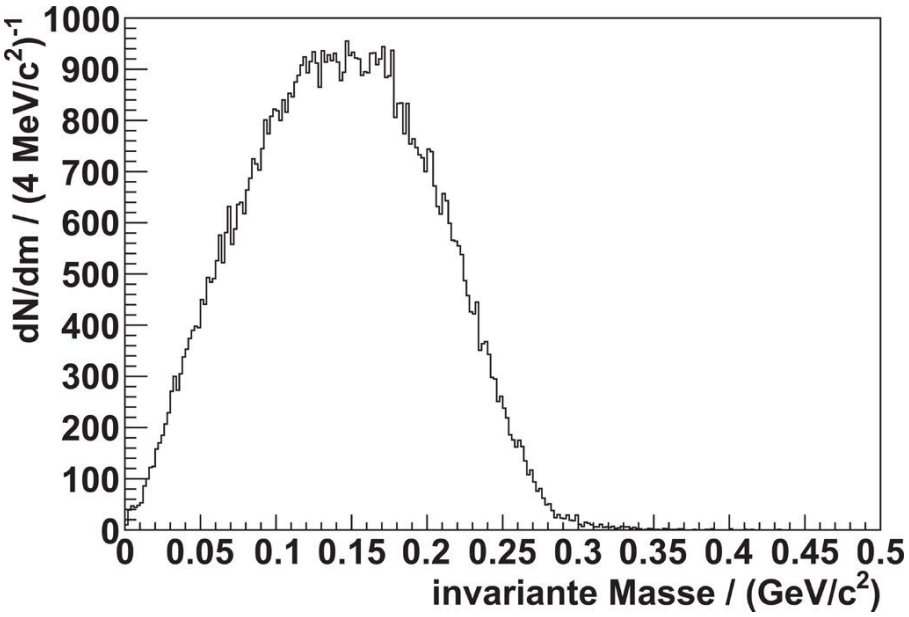
MC: $\eta \rightarrow \pi^+ \pi^- \gamma$



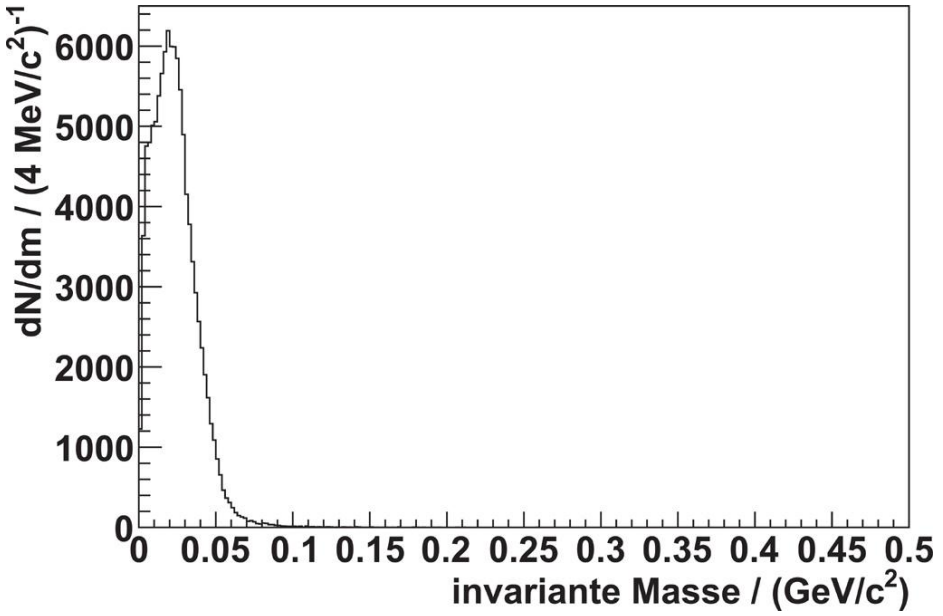
3. Determination of possible cuts

- Cut 6: Min. invariant mass of 1 charged and 1 neutral particle

MC: $\eta \rightarrow \pi^0 e^+ e^-$



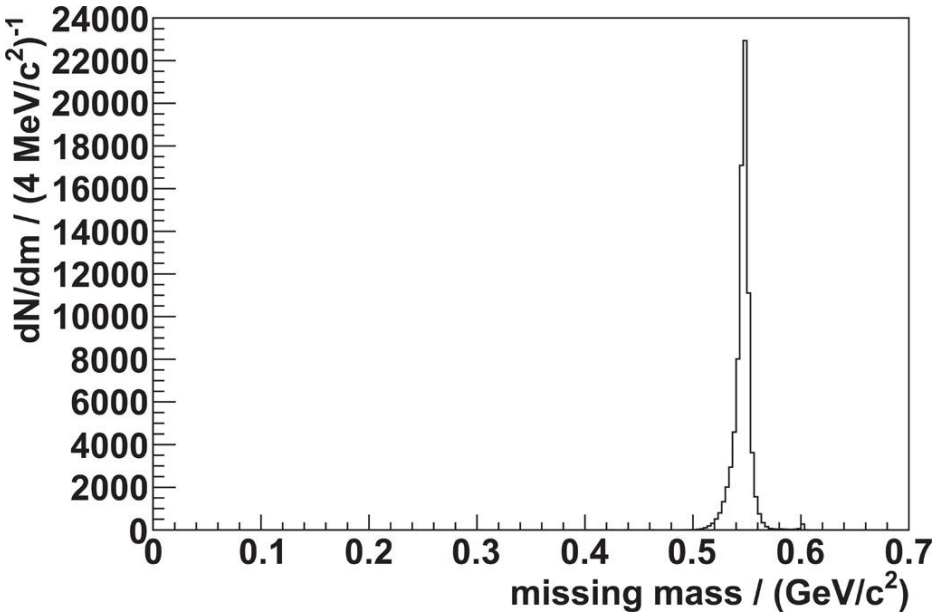
MC: $\eta \rightarrow e^+ e^- \gamma$



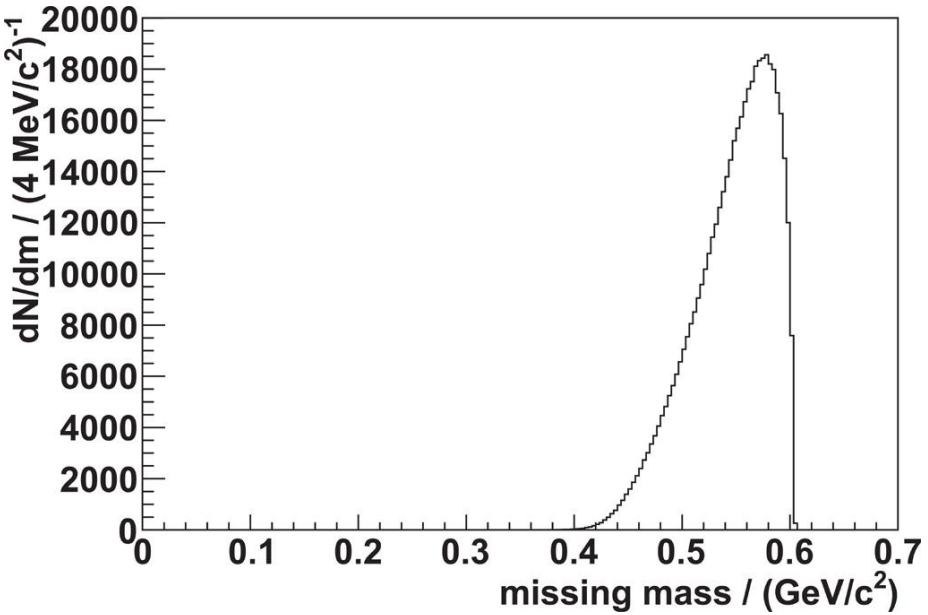
3. Determination of possible cuts

- Cut 7: Missing mass of the $^3\mathrm{He}$

MC: $\eta \to \pi^0 e^+ e^-$



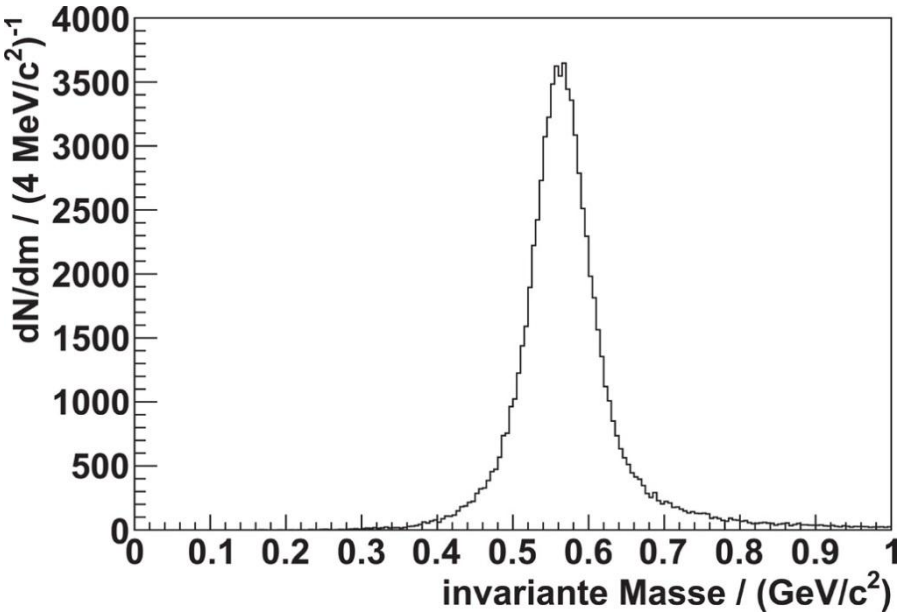
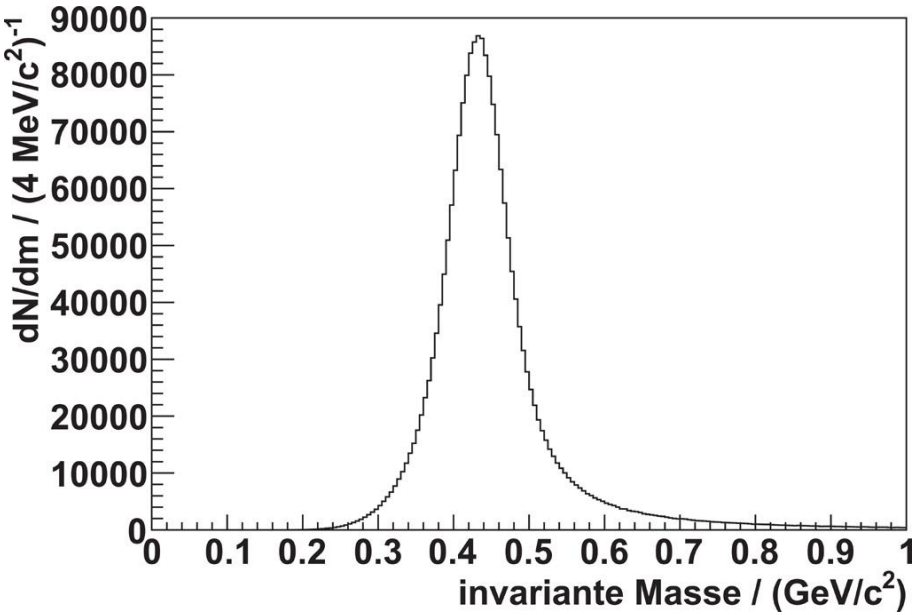
MC: $\pi^0 \pi^+ \pi^-$



3. Determination of possible cuts

- Cut 8: Invariant mass of all particles in the central detector

MC: $\eta \rightarrow \pi^0 e^+ e^-$



MC: $\eta \rightarrow \pi^0 \pi^+ \pi^-$