# Search for the $C$-violating meson decay $\eta \to \pi^0\, e^+\, e^-$ with WASA-at-COSY

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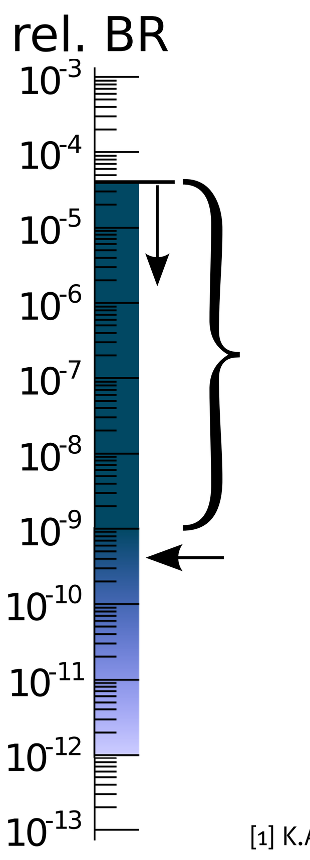
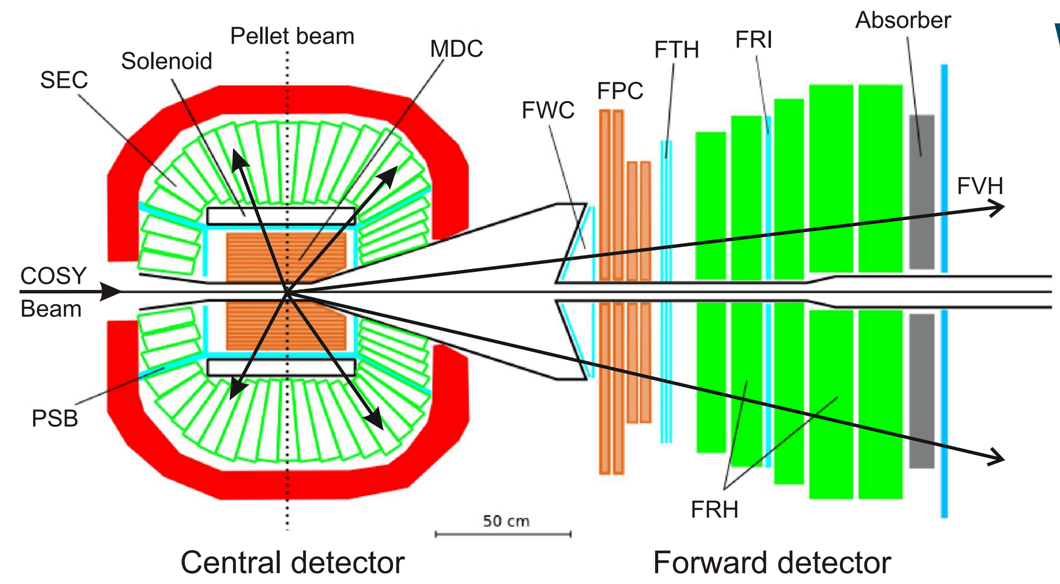
## Motivation




- The e.m./strong decay $\eta \to \pi^0\ \gamma^* \to \pi^0\ e^+\ e^-$ violates the $C$-parity $\to$ **forbidden in SM**
- Current upper limit assuming a phase space distribution: $BR(\eta \to \pi^0 + e^+ + e^-) < 4 \times 10^{-5}$ [1]
- **4 orders of magnitude between experimental limit and standard model expectation**
- **Room to search for non SM processes like dark boson**
- $C$-conserving reaction expected to have a rel. BR $\approx 10^{-12} \dots 10^{-9}$
- Two data sets taken with WASA-at-COSY
  - Proton-deuteron scattering: low background
  - Proton-proton scattering with high statistics: $pp \to pp\eta$

[1] K.A. Olive *et al.* (Particle Data Group), Chin. Phys. **C38**, 090001 (2014)

## WASA-at-COSY – The detector setup




### WASA – Wide Angle Shower Apparatus

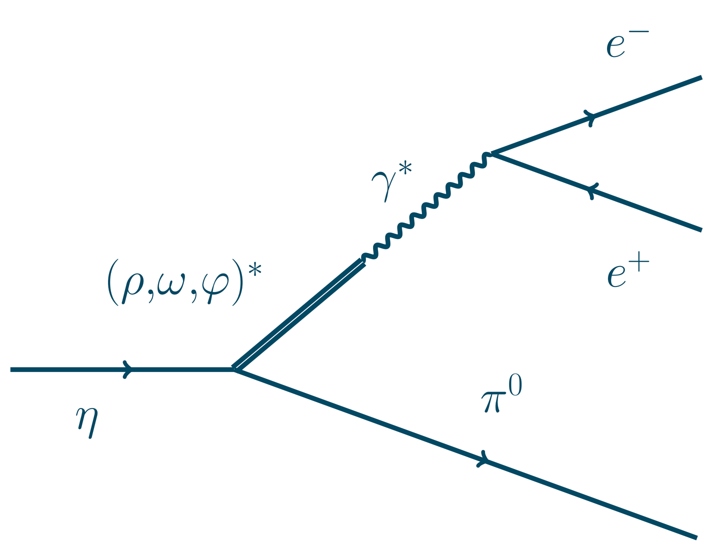
- Frozen hydrogen or deuterium pellets as an internal target
- Central detector: nearly $4\pi$-acceptance for neutral and charged decay particles
- Forward detector for heavy charged particles like protons, deuterons and He nuclei [5]
- Exclusive measurement of meson production and decay reactions

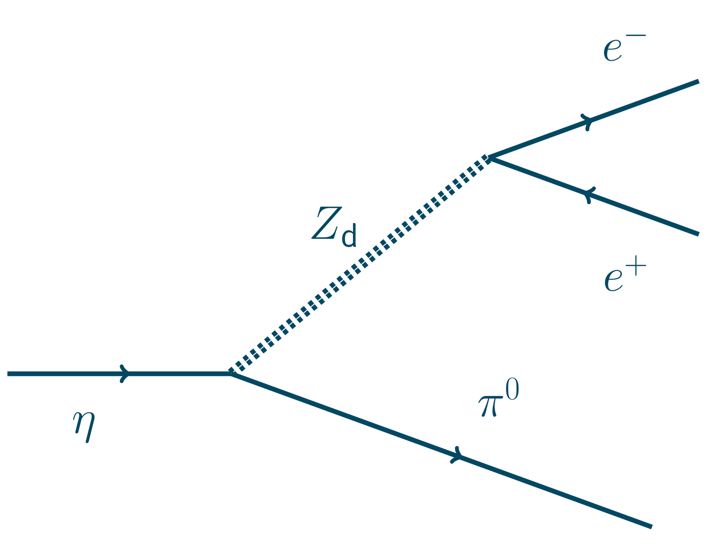
### COSY – COoler SYnchrotron

- Provides (un)polarized proton or deuterium beams with momenta of up to 3.7 GeV/c [4]

[4] Maier, Nuclear Inst. and Methods in Physics Research, A, 1997, Vol.390(1)
[5] H.-H. Adam et al. (WASA-at-COSY Collaboration), arXiv:nucl-ex/0411038

## Models for $C$-paritiy violation

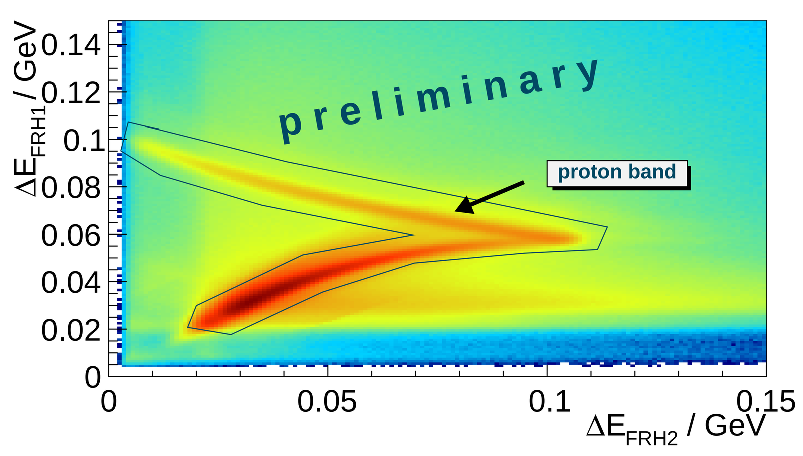


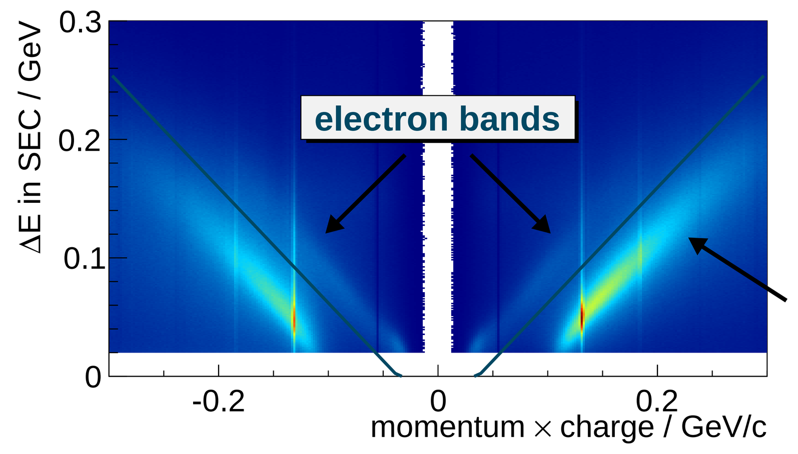

- Vector meson dominance model: assuming, e.g., a virtual $\rho$ in intermediate state [2]
- $Z$-like dark $U$-boson may violate the $C$-paritiy conservation – analogeous to weak interaction [3]

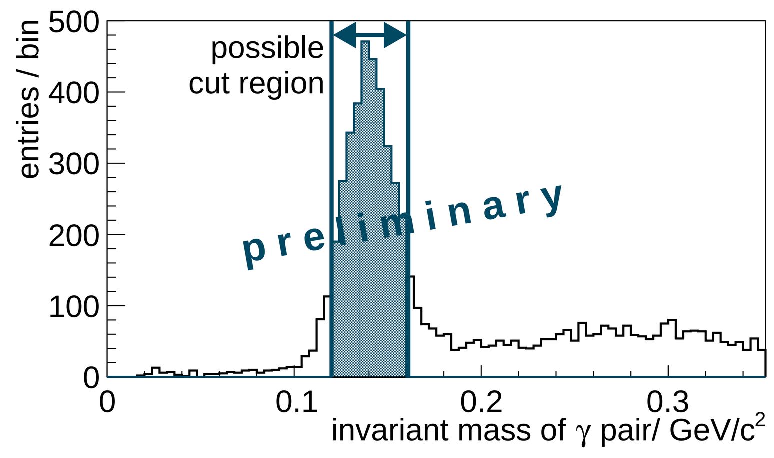
[2] Andrzej Kupčś and Andreas Wirzba, J. Phys. Conf. Ser. **335**, 012017 (2011) [arXiv:1111.5949]
[3] Hooman Davoudiasl, Hye-Sung Lee, and William J. Marciano, Phys. Rev. D **89**, 095006 (2014)

## Particle identification



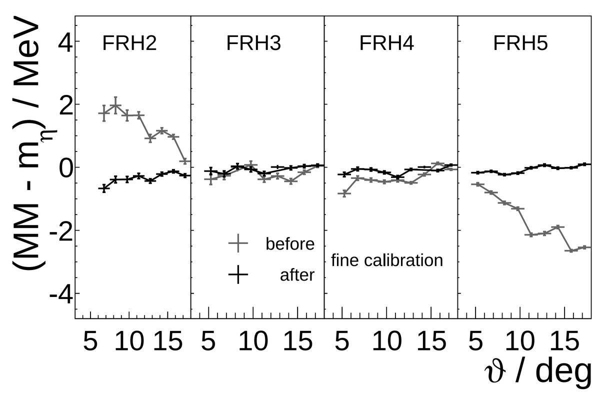

- Proton identification using energy loss correlation
- Pion-electron discrimination via $\Delta E$-$p$ method
- $\pi^0$ identification by invariant mass of $\gamma$ pair
- Decay signature: at least two oppositely charged and two neutral particles

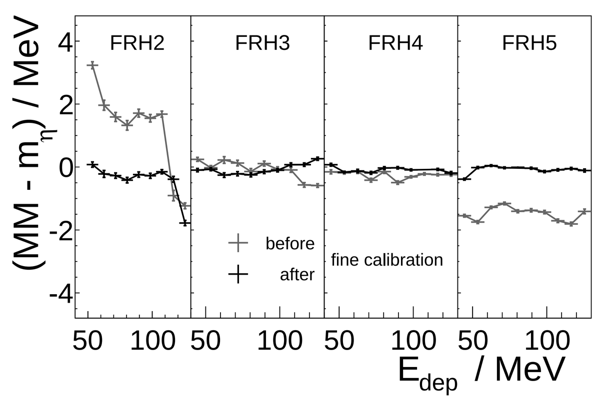


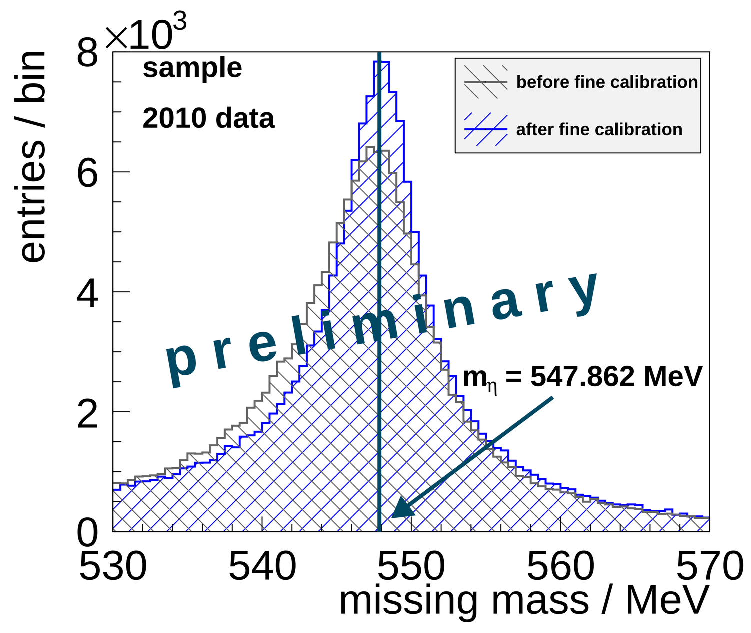

## Fine calibration

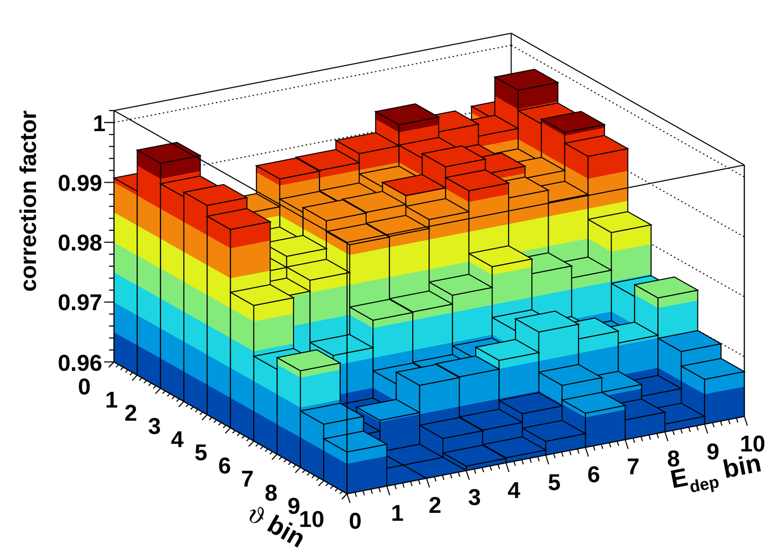
- The missing mass position depends on polar angle $\vartheta$ and $E_{\text{dep}}$ of both protons




- Apply correction factor for each $\vartheta$ and $E_{\text{dep}}$ bin
- Determine factors iteratively
- 2d correction table for each detector plane




- After energy fine calibration:

✔ symmetric peak shape

✔ significantly increased missing mass resolution $(+40\%)$

⇒ HWHM $< 1.9\,\text{MeV}$

## Analysis results

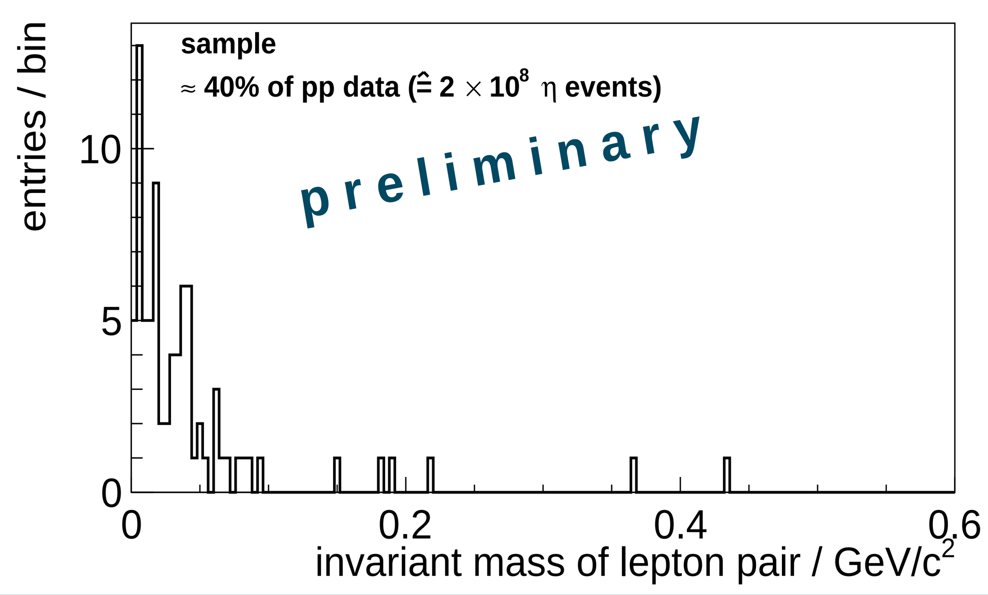
- Cut on $MM(pp) \approx m_\eta$

$\to$ Reduce background from multi-pion production

- Cut on $IM(\gamma\gamma) \approx m_{\pi^0}$ and $IM(e^+e^-\gamma\gamma) \approx m_\eta$
- Probability cut on kinematic fit $(pp \to ppe^+e^-\gamma\gamma)$

$\to$ Reduce background from other $\eta$-decays

$\to$ Only a few events out of $\approx 200 \times 10^6$ events left over after all cuts




## Summary & Outlook

### Summary

✔ High statistic data set from dedicated $\eta$ production runs

✔ Clear $\eta$ signal in missing mass spectra

✔ Successful fine calibration

✔ Efficient cuts for decay selection and background reduction (based on simulations)

### Outlook

- Data description by Monte Carlo simulations
- Optimize kinematic fit and cut condition based on simulations

➜ Extract new upper limit for $\eta \to \pi^0 + e^+ + e^-$ much lower than the current value

➜ Evaluate new constraints on coupling strengths and masses of dark bosons

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