Study of the $\eta \to 3\pi^0$ decay with the Crystal Ball at MAMI-C

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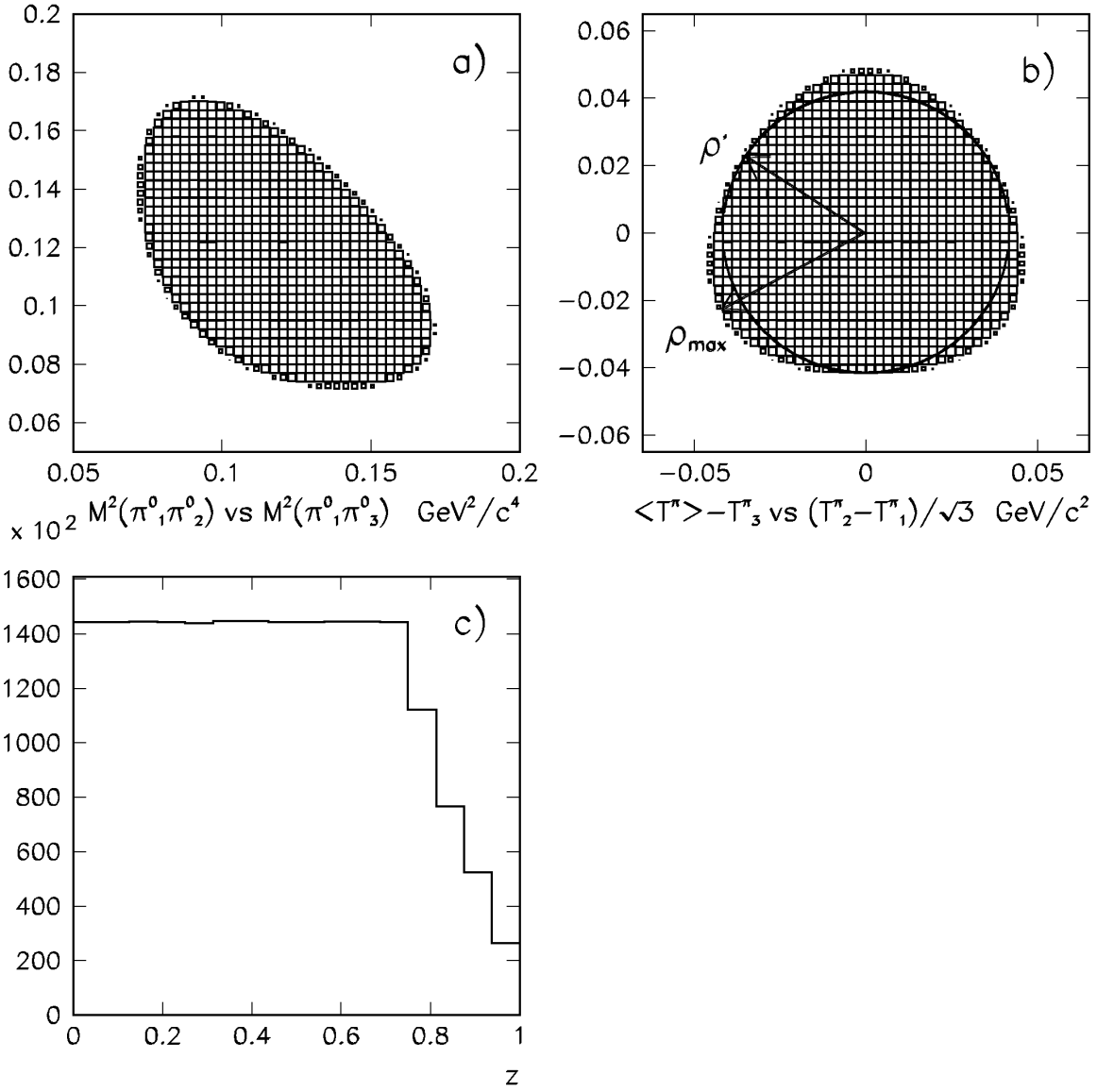
Talk outline

- Physical motivation for study of $\eta \to 3\pi^0$
- Current status on the experimental and theoretical study of the $\eta \to 3\pi^0$ decay
- Experimental setup: CB+TAPS at MAMI
- Analysis of the data from MAMI-C
- Result for the $\eta \to 3\pi^0$ slope parameter from the MAMI-C data
- A cusp-like structure in the $\pi^0\pi^0$ invariant mass from $\eta \to 3\pi^0$ decays
- Final remarks

Physical motivation for study of $\eta \to 3\pi^0$

- $\eta \to 3\pi^0$ violates isospin symmetry $\Rightarrow$ unique possibilities to study symmetries and symmetry-breaking characteristics of strong interactions
- $A(\eta \to 3\pi^0) \sim (m_d - m_u)(1+\alpha z)$,
  $\Gamma(\eta \to 3\pi^0) \sim (m_d - m_u)^2(1+2\alpha z+\ldots)$,
  $z = 6/(m_\eta - 3m_{\pi 0})^2 \, \Sigma_\iota (E^\iota_{\pi 0} - m_\eta/3)^2 = \rho^2/\rho^2_{max}$;
  precise measurements of $\Gamma(\eta \to 3\pi^0)$ and α are important tests of χPTh calculations
- Search for a cusp in $m(\pi^0\pi^0)$ in the vicinity of the $\pi^+\pi^-$ threshold in the light of the recent $K^+ \to \pi^+\pi^0\pi^0$ results providing a test of the χPTh prediction for the S-wave scattering length combination a0-a2

Variable $z=\rho^2/\rho^2_{max}$ reflects the density distribution along the radius of the $\eta\to 3\pi^0$ Dalitz plot



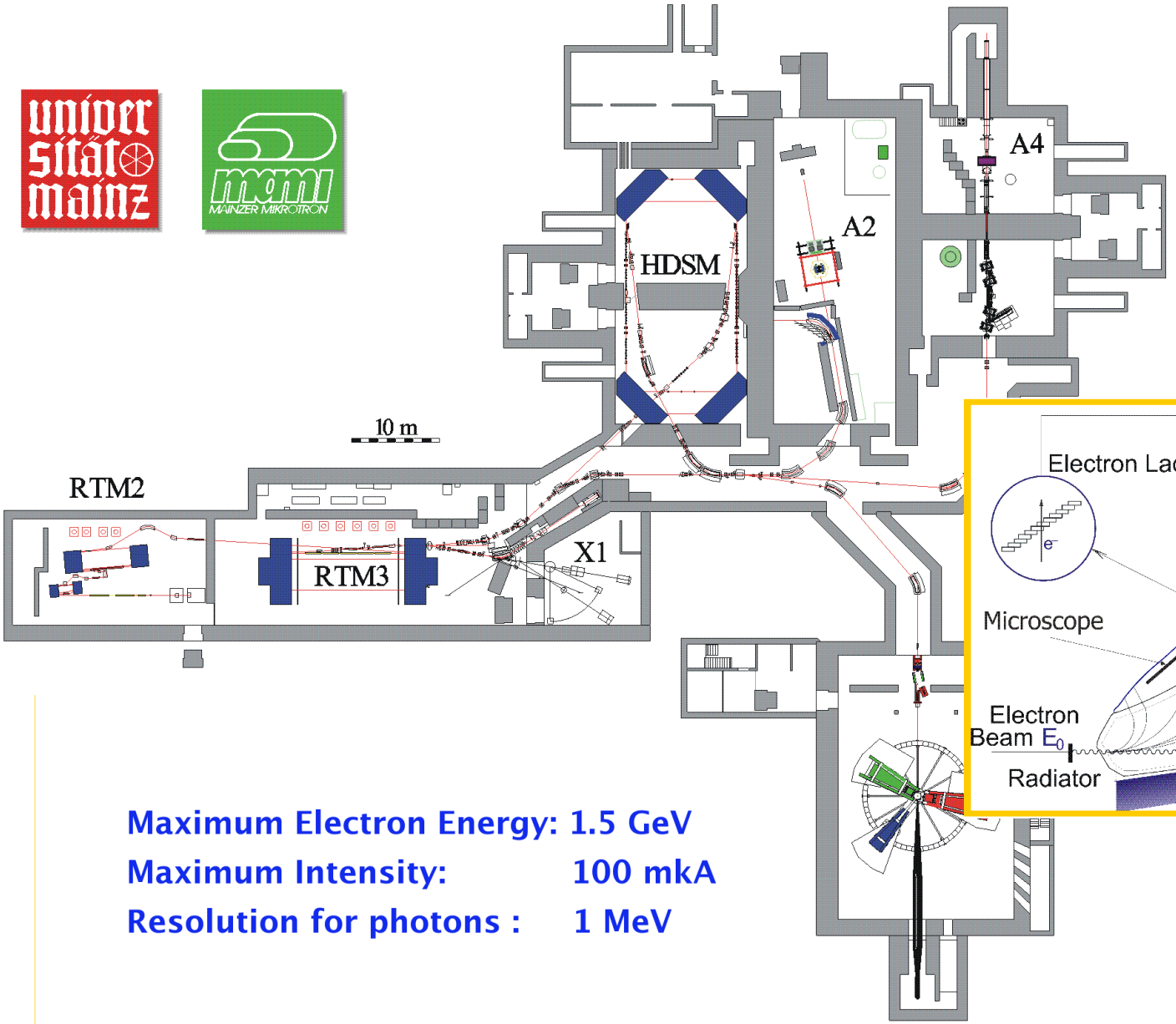
Experimental results and theoretical calculations for α

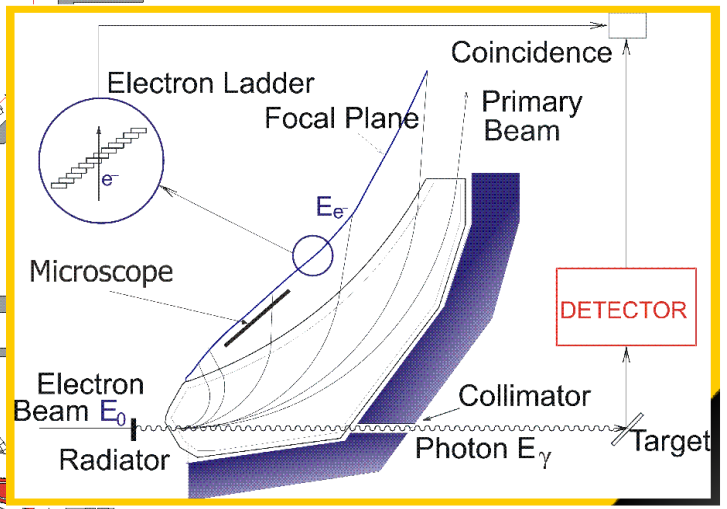
- Experimental results for α:
  GAMS2000 (1984): -0.022±0.023
  CBarrel at LEAR (1998): -0.052±0.017±0.010
  CBall at AGS (2001): -0.031±0.004
  KLOE (prelim.2005): -0.013±0.004±0.005
  CELSIUS-WASA (2007): -0.026±0.010±0.010
  KLOE (prelim.2007): -0.027±0.004±0.005
  CBall at MAMI-B (2009): -0.032±0.002±0.002
  CBall at MAMI-C (2009): -0.032±0.003

- Calculations for α:
  J.Kambor et al. (1996): -0.007 or -0.0014
  B.Borasoy et al. (2005): -0.031±0.003
  J.Bijnens et al. (2007): 0.013±0.032

- CBall at MAMI-C (2009): very small cusp in $m(\pi^0\pi^0)$

Mainz Microtron



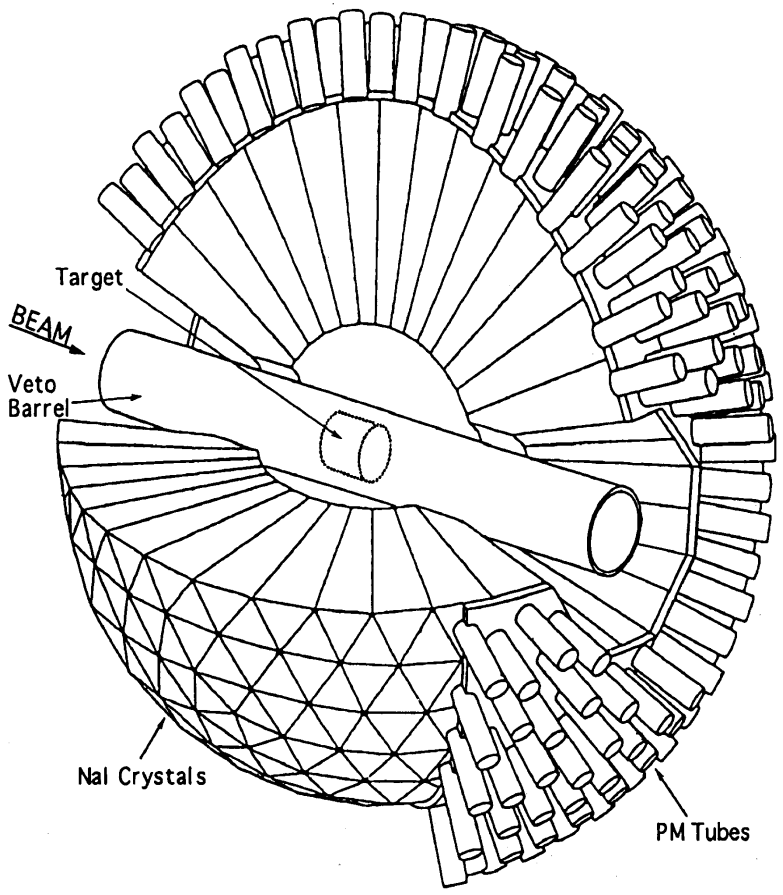


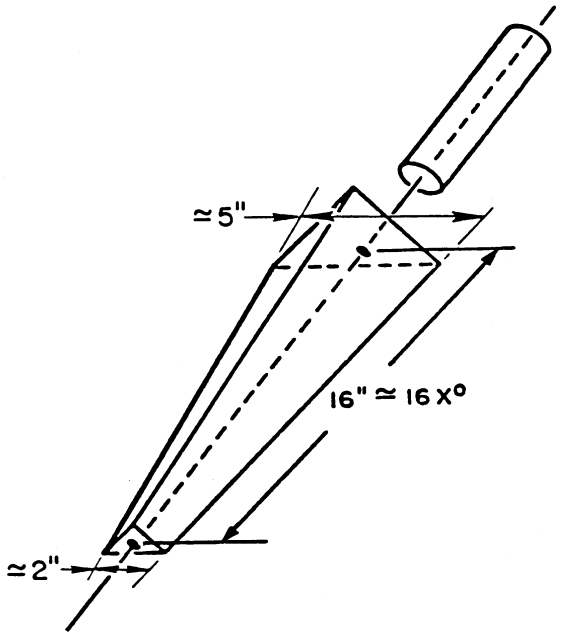
Maximum Electron Energy: 1.5 GeV

Maximum Intensity: 100 mkA

Resolution for photons : 1 MeV

Crystal Ball: 672 NaI(Tl) crystals (31-cm long or 15.7 rad. lengths) cover 93% of 4π, 50-cm inner Ø



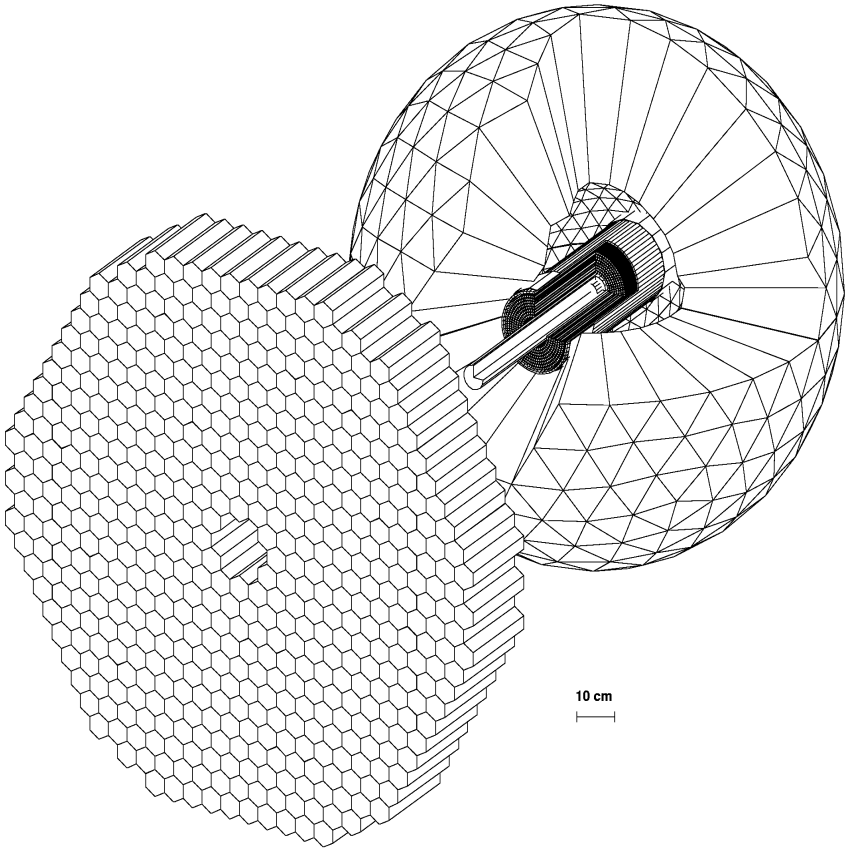


$\sigma E/E = 0.021/(E[\text{GeV}])^{0.36}$

$\sigma\theta = 2^{o}\text{-}3^{o}$

$\sigma\phi = \sigma\theta/\sin\theta$

CB@MAMI setup: Crystal Ball +TAPS(510 or 384 BaF_2 crystals: 6-cm inner Ø, 25-cm long or 12 rad. lengths)



$\sigma E/E = 0.018+0.008/(E[GeV])^{0.5}$

$\sigma\theta \approx 1^o$ (L_{TAPS}=175 or 147 cm)

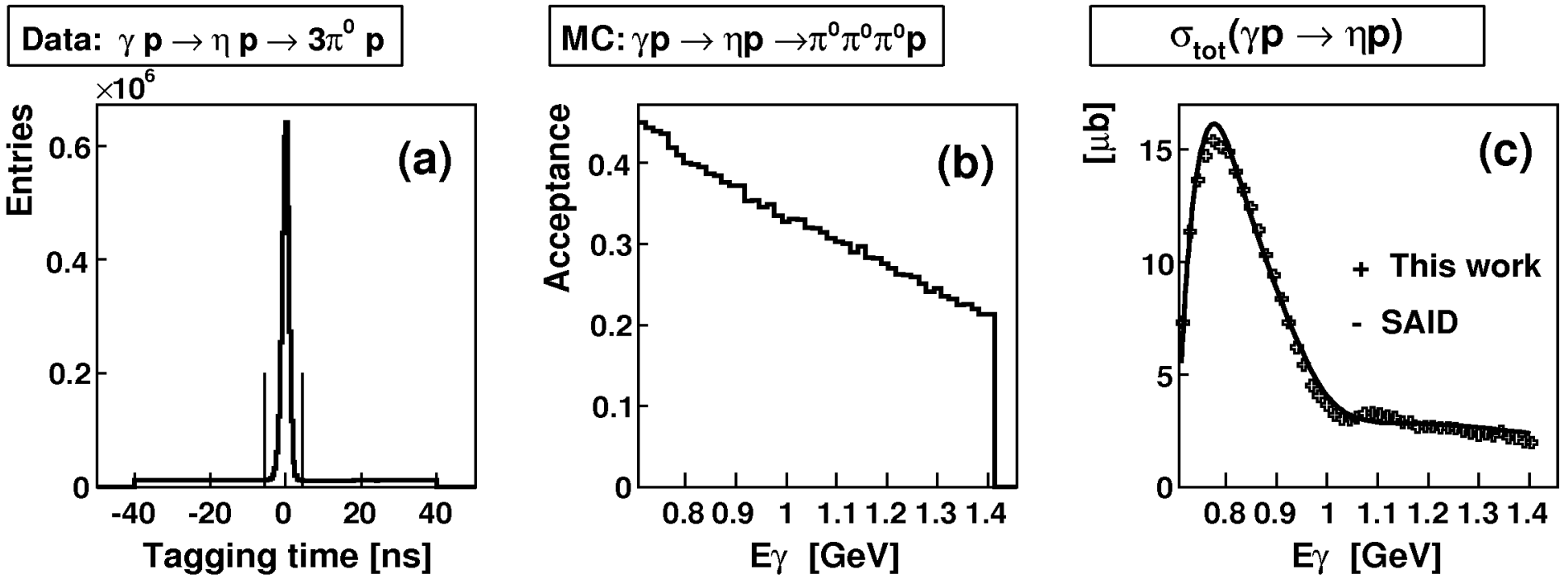
$\sigma\phi \approx 50^o/R[cm]$

Beam-energy range for $\gamma p \rightarrow \eta p$ with tagged γ's:

MAMI-B: E_γ=707-820 MeV/c, $\Delta E_\gamma \approx$1 MeV

MAMI-C: E_γ=707-1402 MeV/c, $\Delta E_\gamma \approx$2 MeV

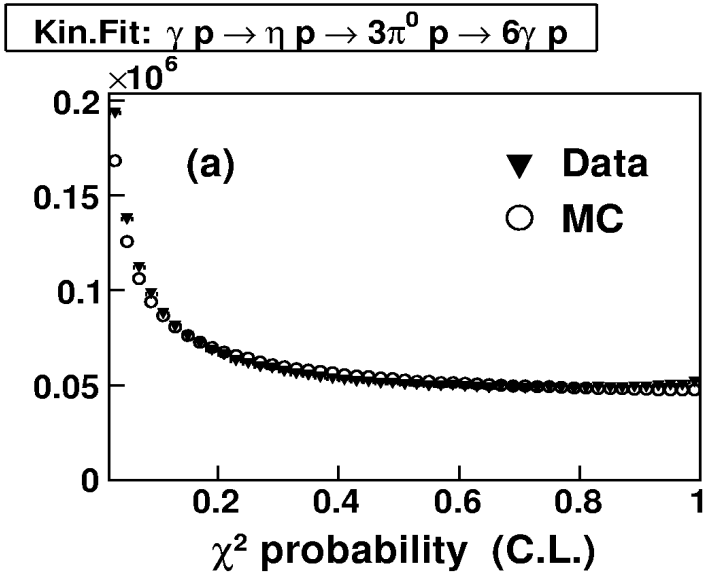
Production of $\eta \rightarrow 3\pi^0$ events at MAMI-C

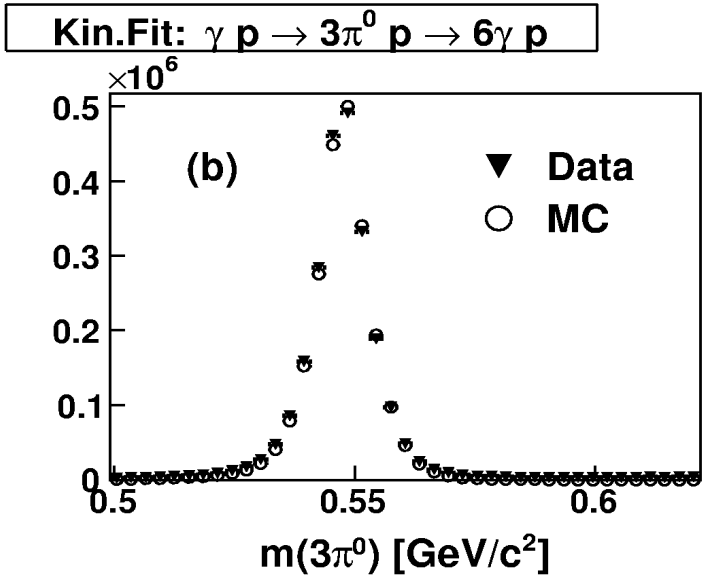


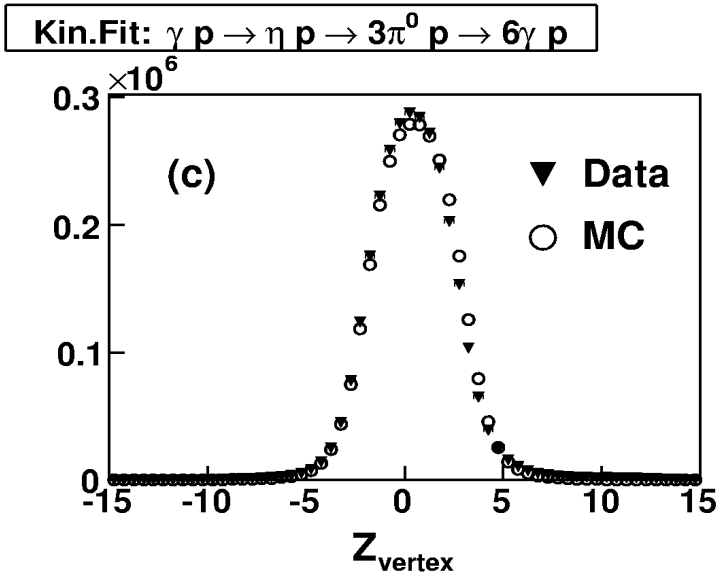
Selection of $\eta \to 3\pi^0$ events

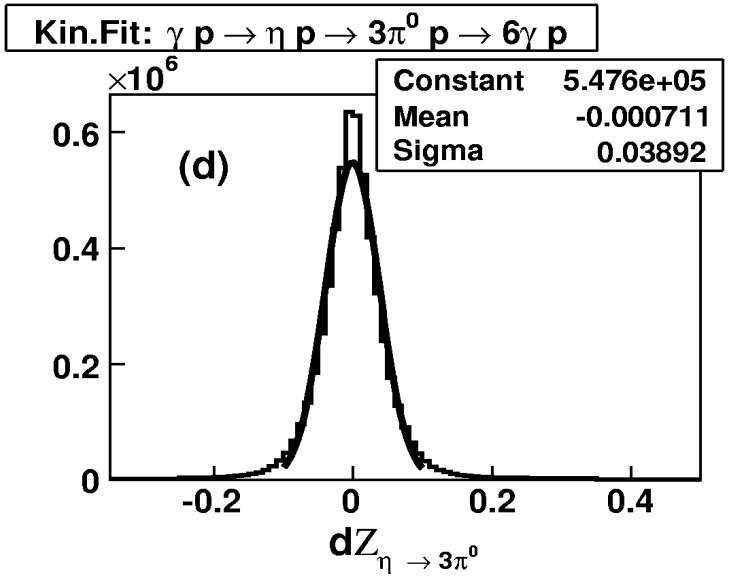
- reaction $\gamma p \to \eta p \to 3\pi^0 p$ at MAMI-C:
  E_γ=707-1402 MeV is tagged,
  CB+TAPS →30% average acceptance,
  80% of the protons are detected
- kinematic fit of $\gamma p \to \eta p \to 3\pi^0 p \to 6\gamma p$
  at the 2%CL is used to identify $\eta \to 3\pi^0$ events
- Background contributions:
  random coincidences in the tagger ~8%,
  $\gamma p \to 3\pi^0 p$ from 0.4% to 4%,
  empty target from 1% to 4%

Agreement between the data and MC for $\eta \to 3\pi^0$ events; Resolution in the invariant mass (6 MeV) and in parameter z

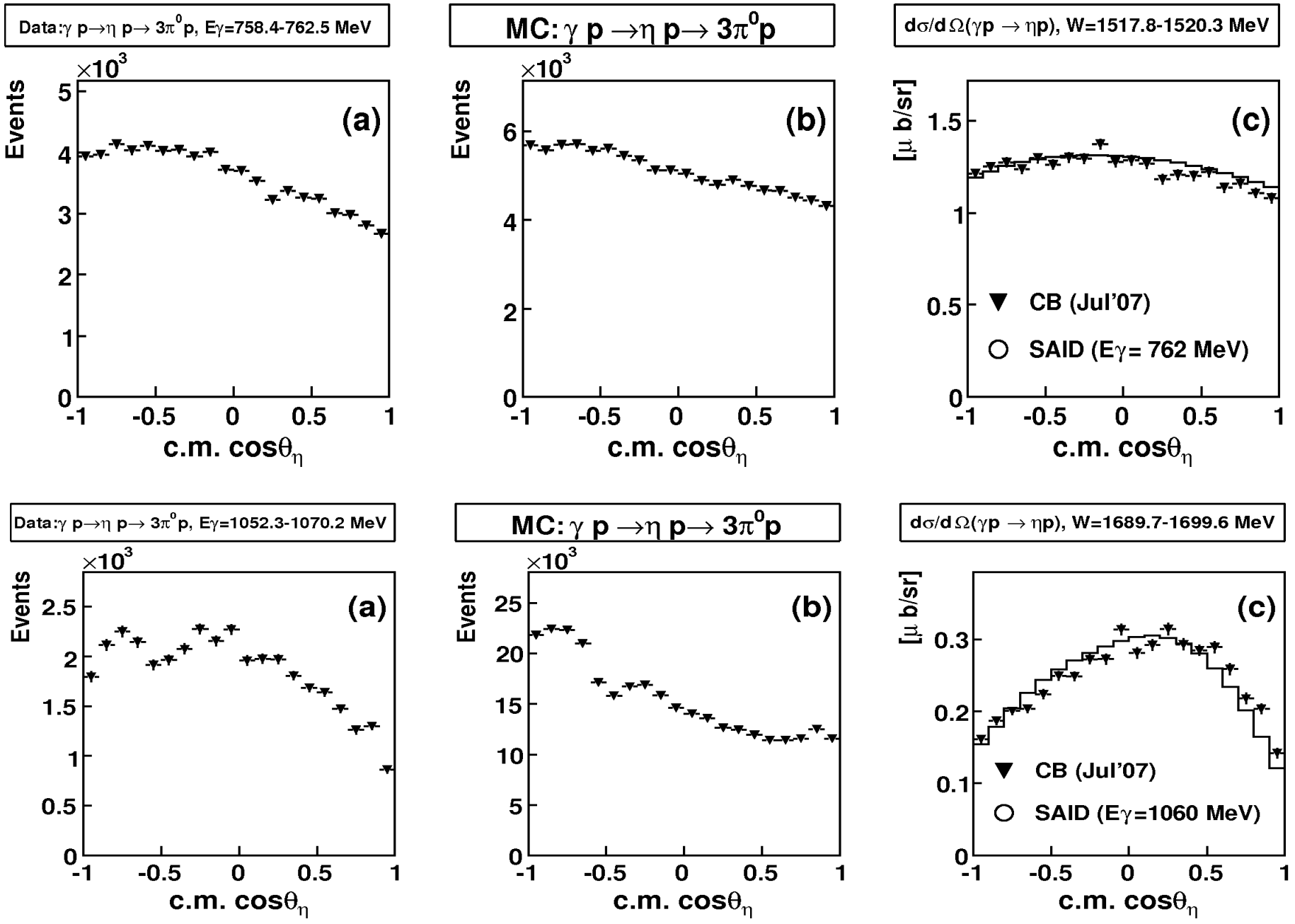




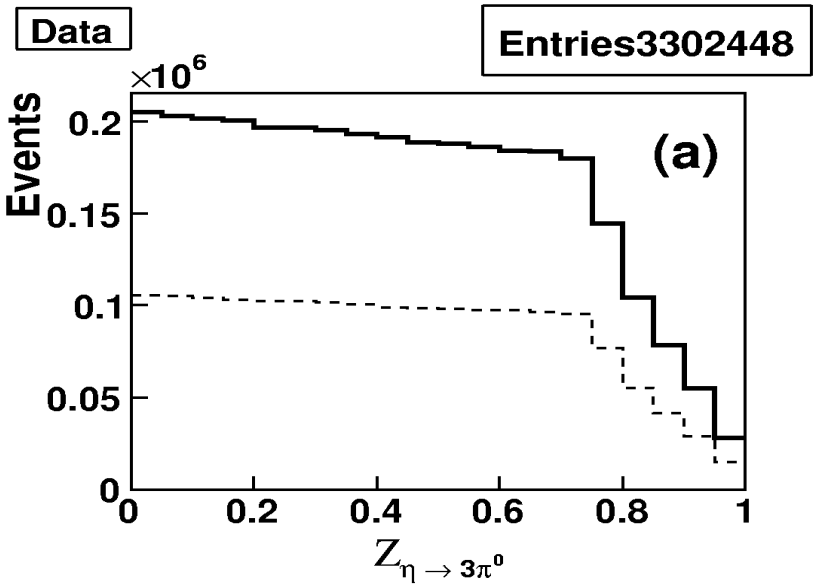


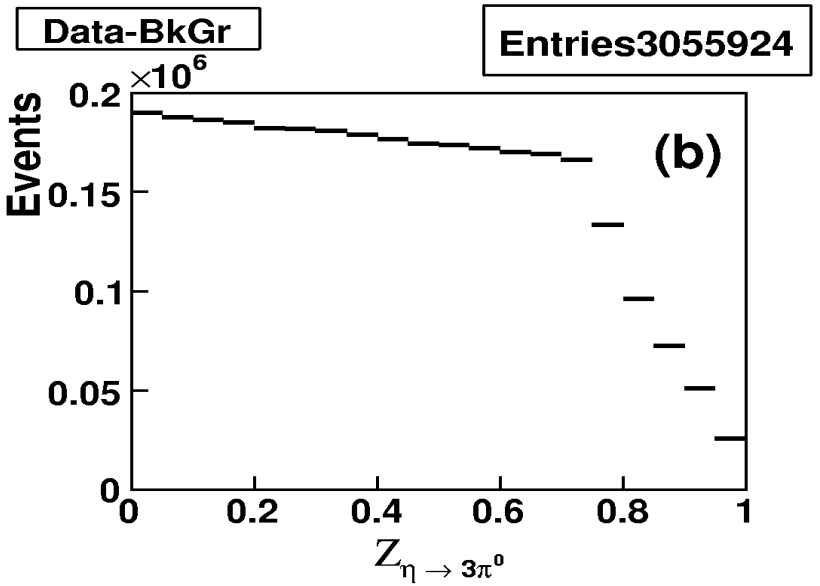


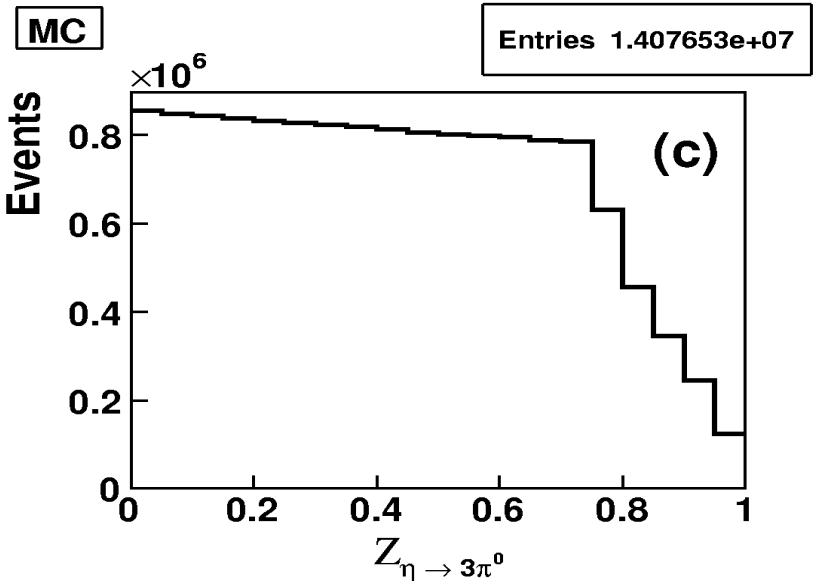
Production angular distributions for γp→ηp

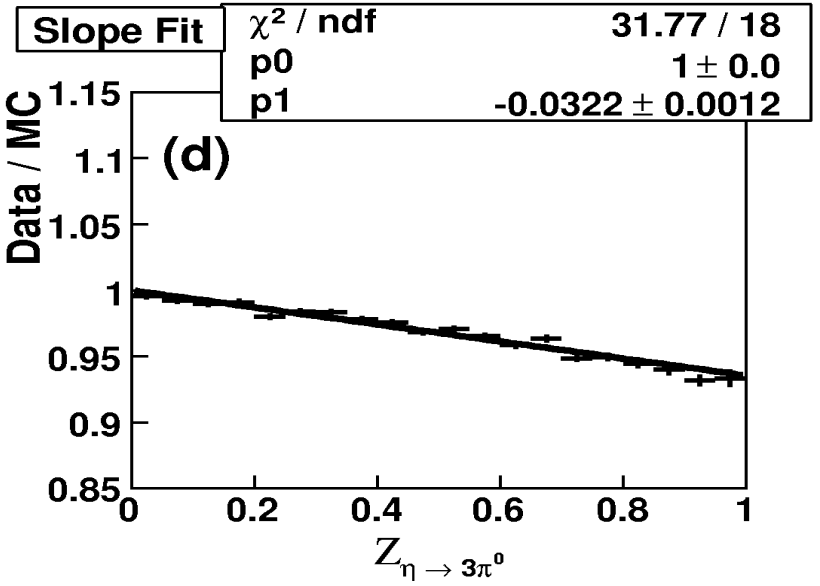


The published result (Phys.Rev.C79:035204,2009) is based on 3.1M $\eta \to 3\pi^0$ events of 26.6M η's produced (3 runs: 04.07–07.07)

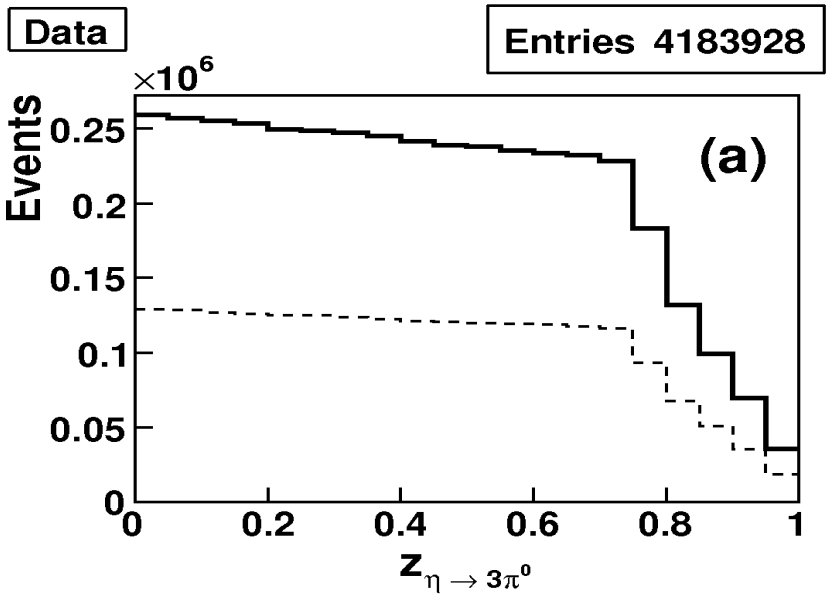


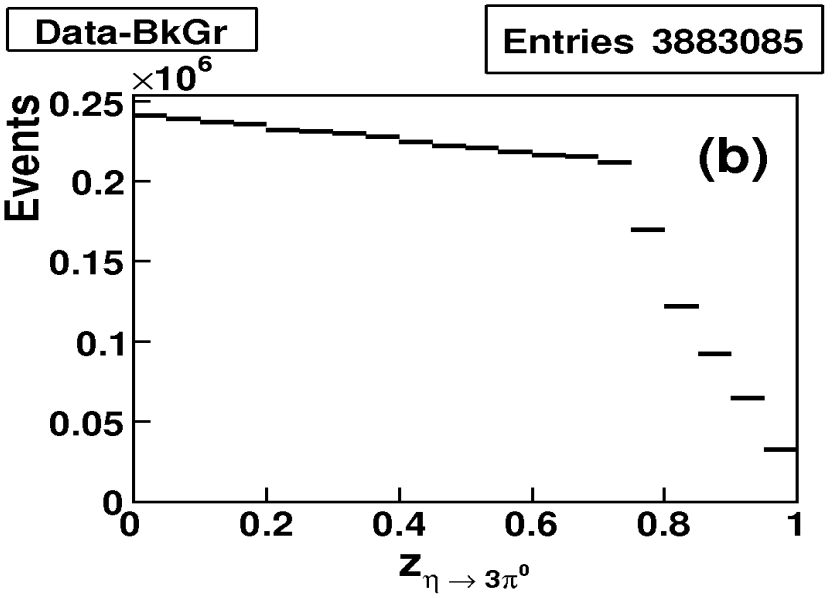


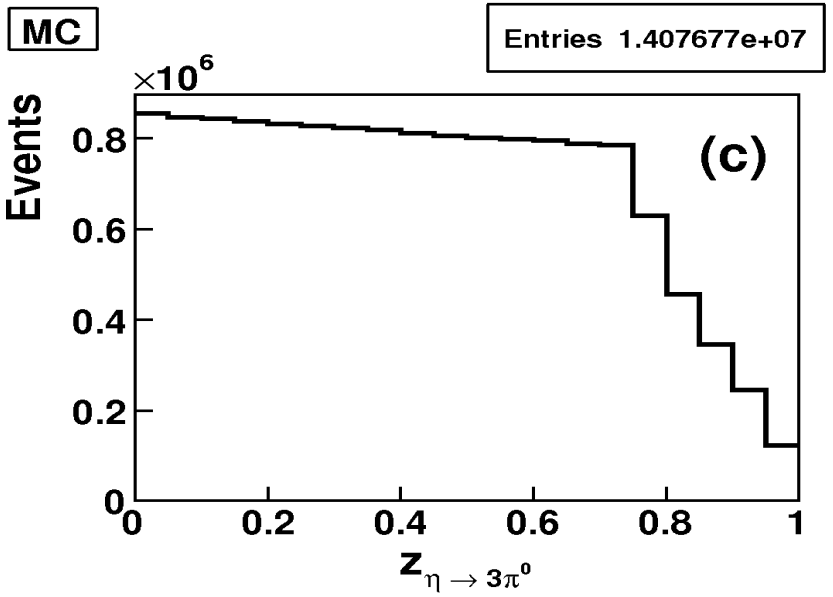


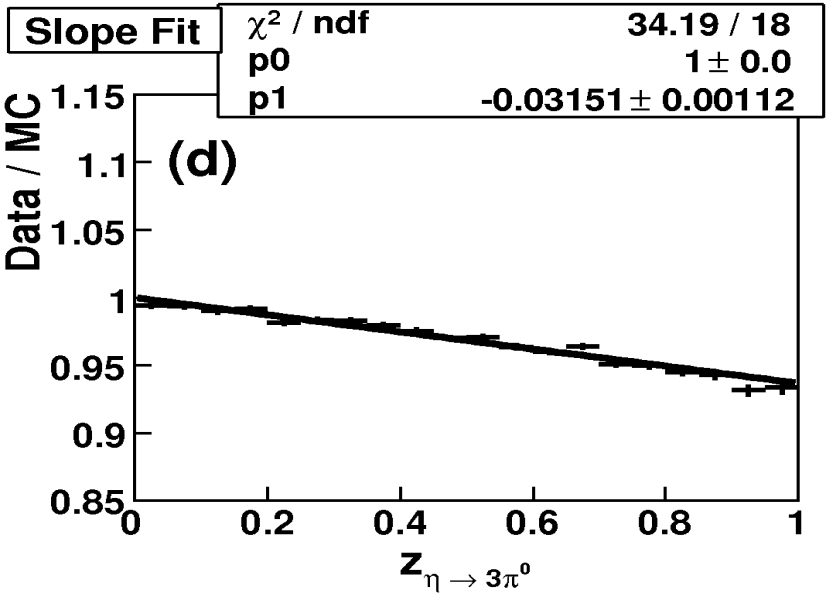


Full statistics collected at MAMI-C in 2007 is 3.9M $\eta \to 3\pi^0$ events





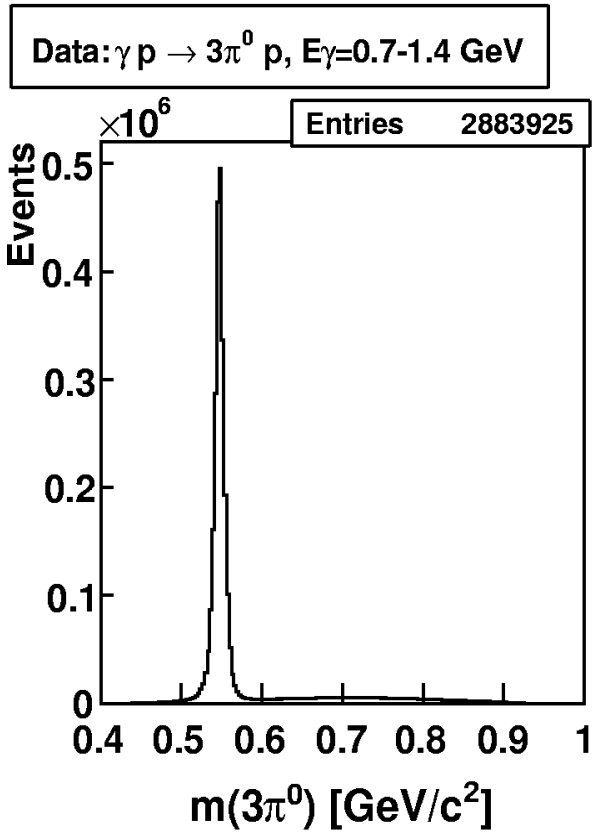


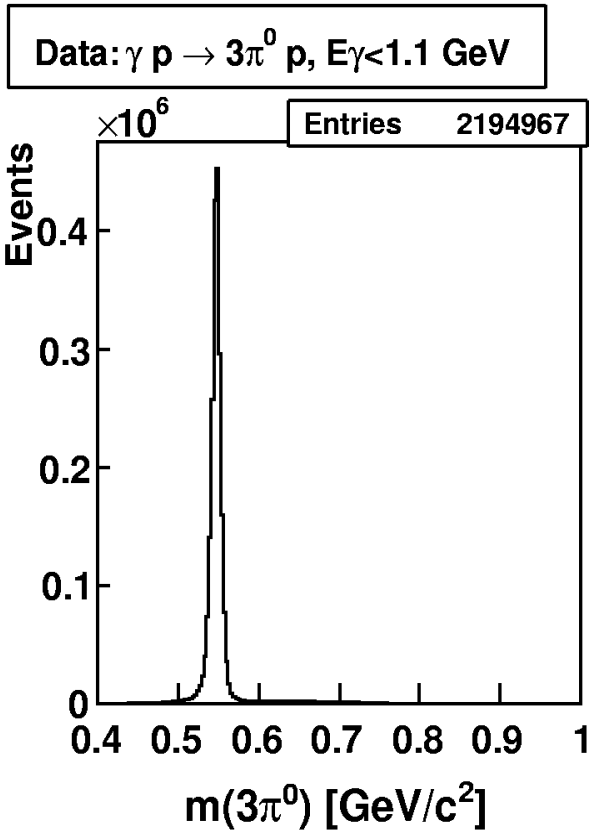


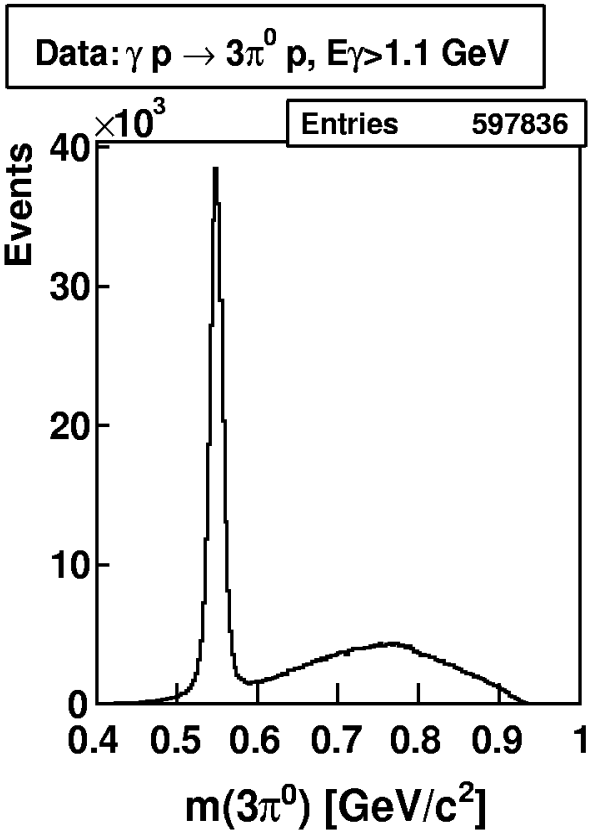
Stability of results for the $\eta \to 3\pi^0$ slope parameter depending on experimental conditions and selection cuts → $\alpha = -0.032 \pm 0.003$

Test	Cuts	Statistics	α	χ^2/ndf
1	CL=2%	3.06M	-0.0322±0.0012	31.4/18
2	CL=5%	2.78M	-0.0326±0.0013	32.2/18
3	CL=10%	2.50M	-0.0329±0.0014	30.0/18
4	CL=20%	2.11M	-0.0326±0.0015	25.9/18
5	CL=2%, E_γ <1.1GeV	2.76M	-0.0320±0.0013	26.9/18
6	CL=2%, E_γ <0.9GeV	2.18M	-0.0321±0.0015	20.2/18
7	CL=2%, Ecb<0.42GeV	2.83M	-0.0316±0.0013	29.1/18
8	CL=2%, Ecb<0.47GeV	2.60M	-0.0319±0.0013	30.7/18
9	CL=2%, $\cos\theta_\eta$ <0.	1.73M	-0.0334±0.0017	23.5/18
10	CL=2%, $\cos\theta_\eta$ >0.	1.32M	-0.0312±0.0019	14.5/18
11	CL=2%, 7cl	2.39M	-0.0323±0.0014	26.4/18
12	CL=2%, 6cl	0.663M	-0.0292±0.0027	22.0/18

The $3\pi^0$ invariant mass depending on the beam-energy range for $\gamma p \rightarrow 3\pi^0 p$ events





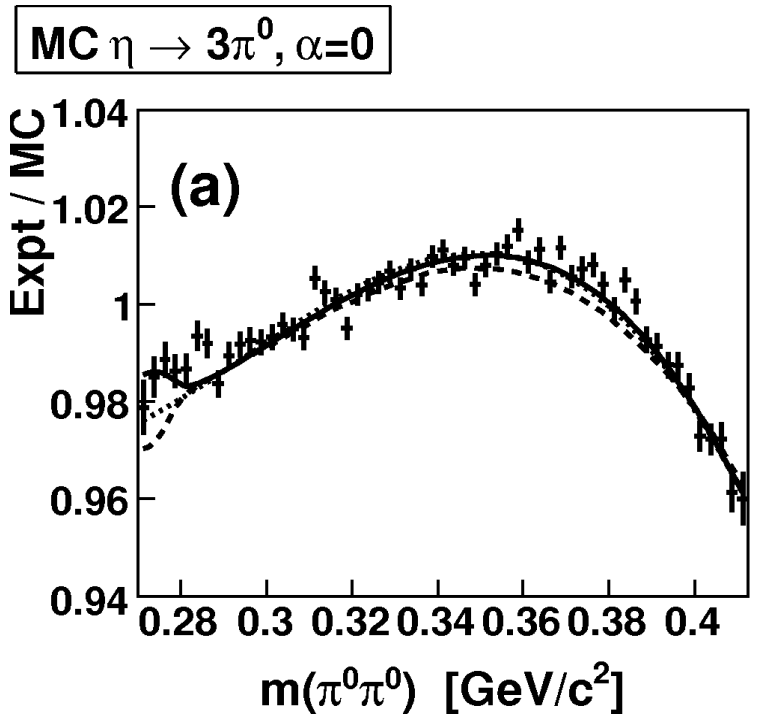


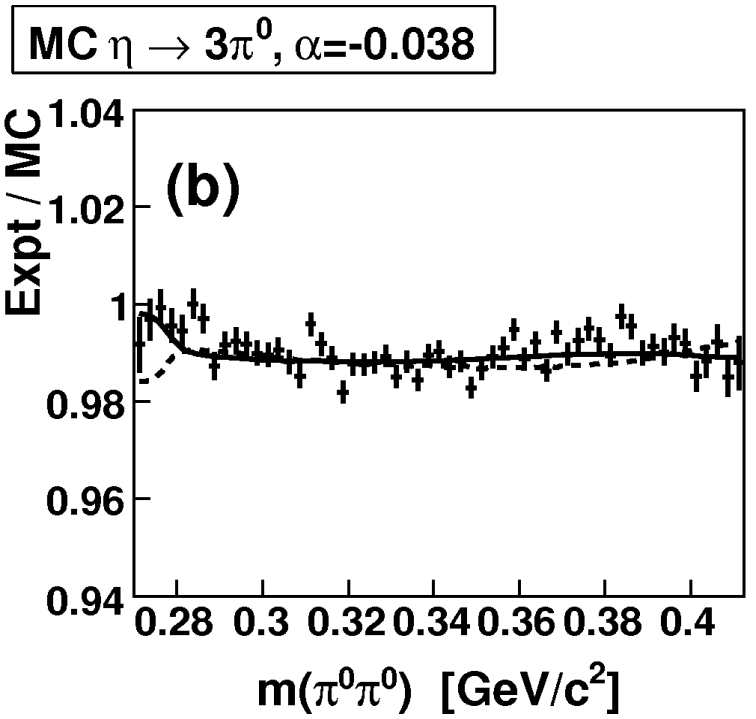
Looking for a cusp-like structure in $m(\pi^0\pi^0)$

Bissegger et al. Phys.Lett.B 659 (2008) 576 :

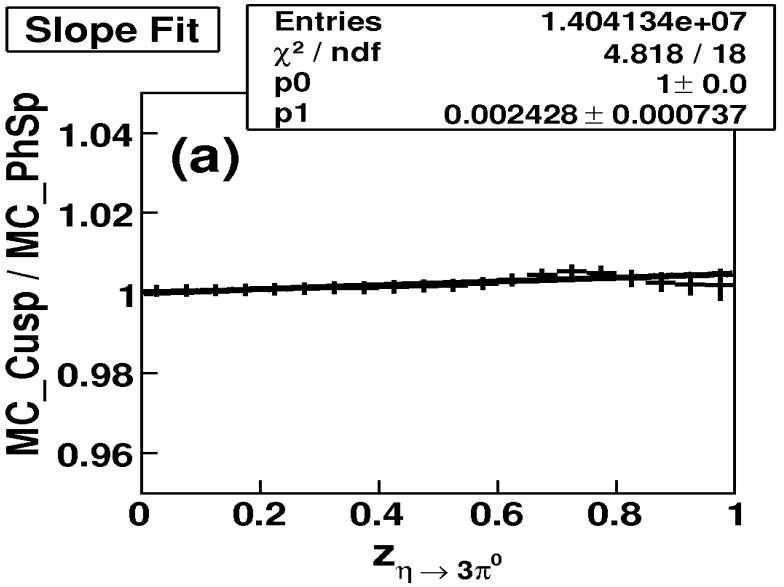
$A(\eta\to 3\pi^0) = u_0+u_1 z$; $A(\eta\to\pi^+\pi^-\pi^0) = v_0+v_1 y+v_2 y^2+v_3 x^2$;

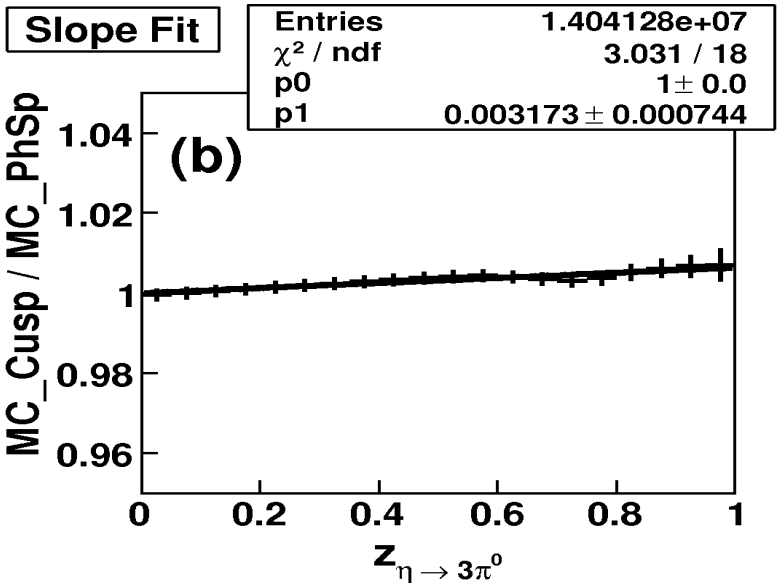
tried v_0/u_0=-1/3(+1/3) and v_0=1, v_1=-0.52*1.25, v_2=-0.063, v_3=0.025, α=-0.038 from $\eta\to\pi^+\pi^-\pi^0$ of KLOE (arXiv:0808.2642)

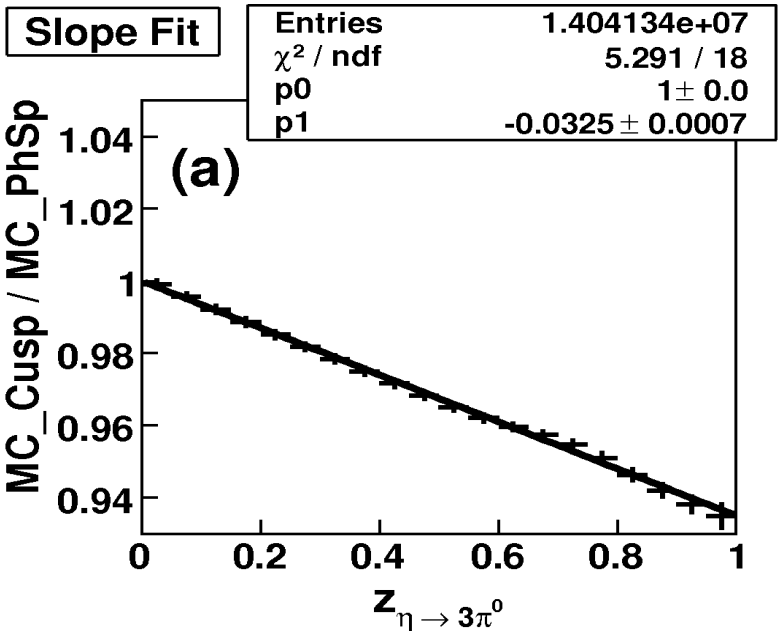


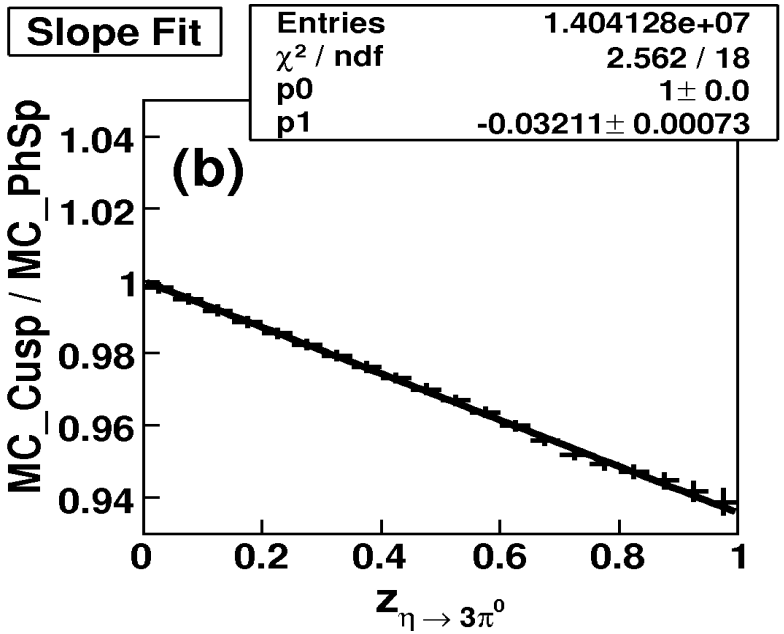


Dependence of the z distribution on the cusp structure: v_0/u_0=-1/3 (left), v_0/u_0=+1/3 (right), α=0 (top), α=-0.038 (bottom)

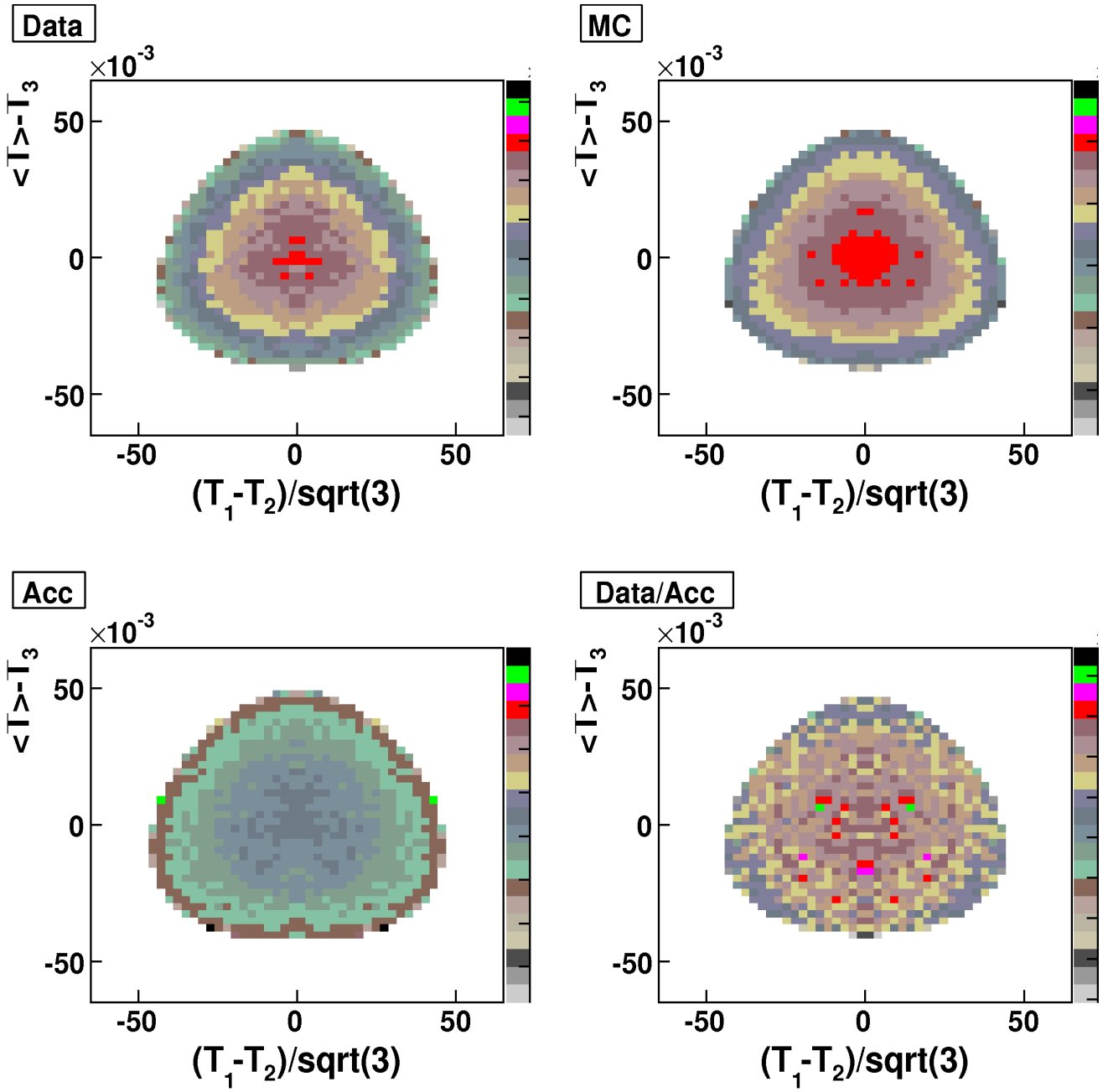








Experimental Dalitz plot for $\eta \to 3\pi^0$



Final remarks

- "Standard" analysis of $\eta \to 3\pi^0$ decays from the CB data at MAMI-C yields α=-0.032±0.003, confirming the PDG value, α=-0.031±0.004.
- A cusp-like structure in m($\pi^0\pi^0$) from $\eta \to 3\pi^0$ decays is seen on the level ≤1%, with the opposite sign from the expected. More statistics is needed for a better understanding.
- Neglecting the $\eta \to \pi^+\pi^-\pi^0$ contribution in the $\eta \to 3\pi^0$ analysis can results in a biased value for α.
- Joint analysis of the $\eta \to 3\pi^0$ and $\eta \to \pi^+\pi^-\pi^0$ Dalitz plots seems to be needed for more reliable results on their parameters.