

# $\eta \rightarrow 3\pi^0$ at MAMI-B

- Experimental Setup
- Analysis
- Results
- Summary

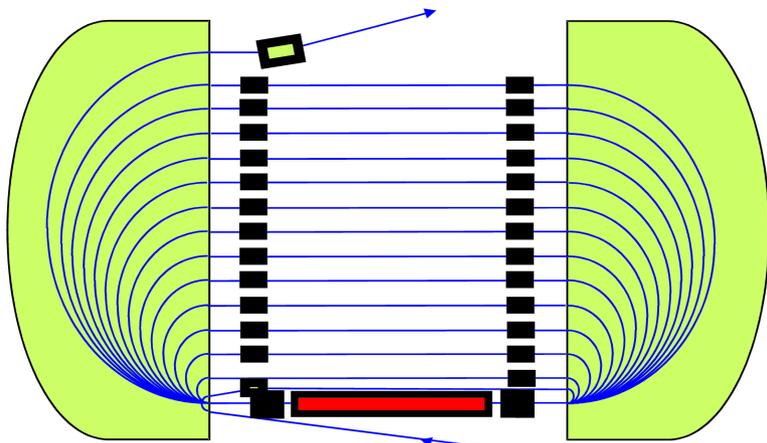


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University Mainz

Frascati, 08.04.2009



# MAMI



MAMI-A: 180 MeV

RTM2

MAMI-C: 1558 MeV

HDSM

A2

A4

10 m

RTM3

X1

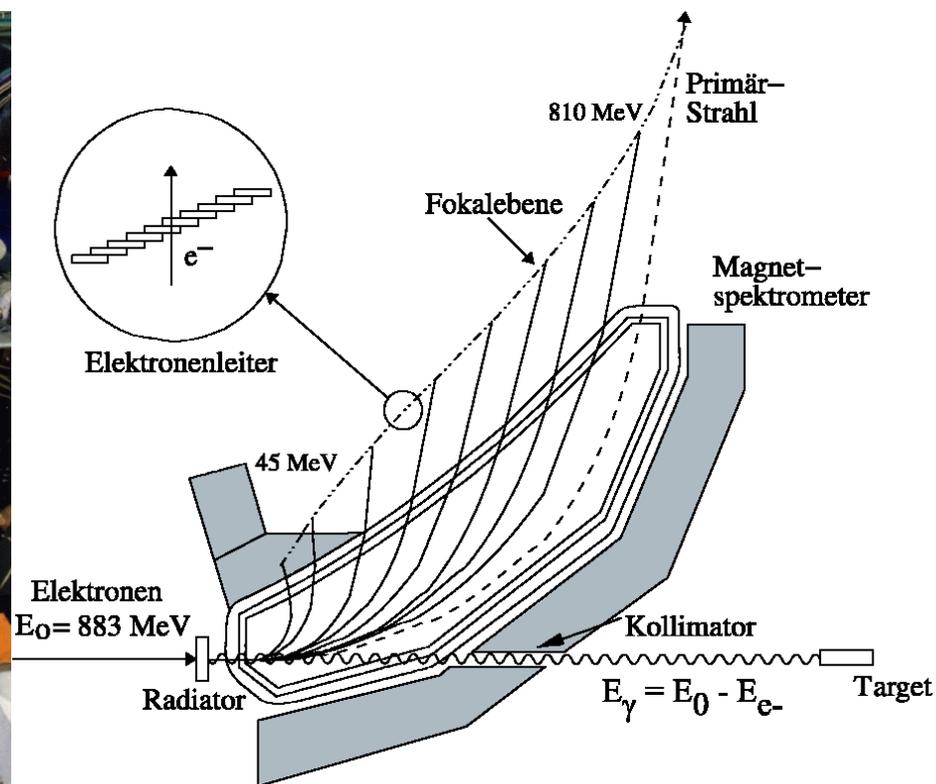
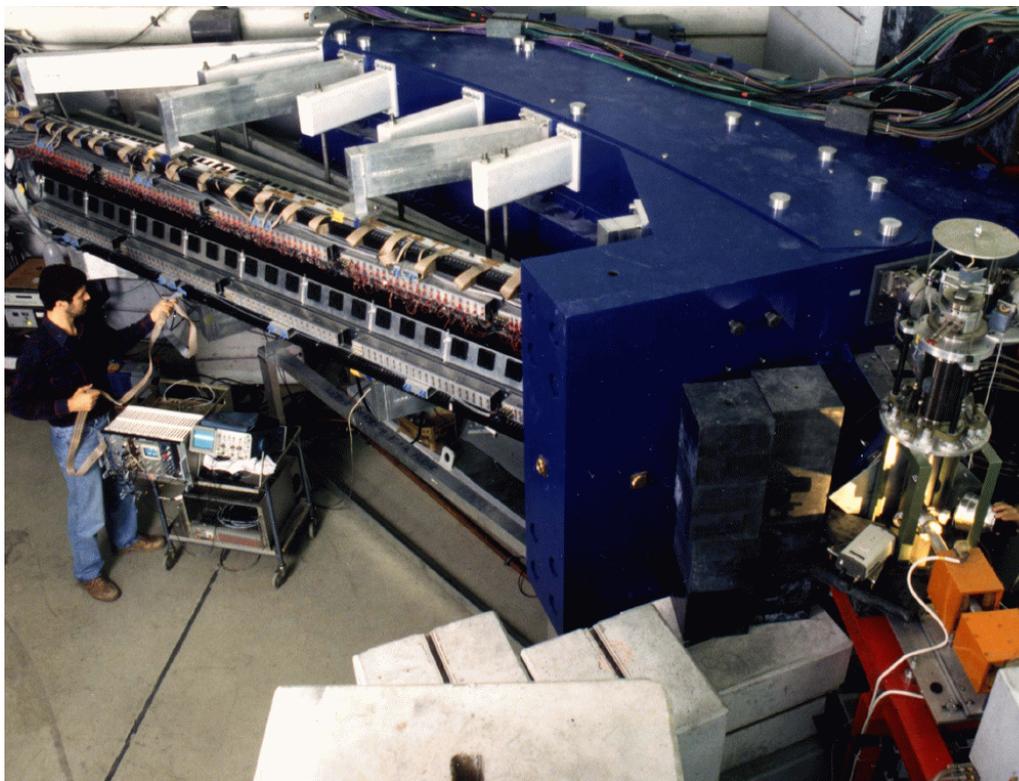
MAMI-B: 883 MeV

A1



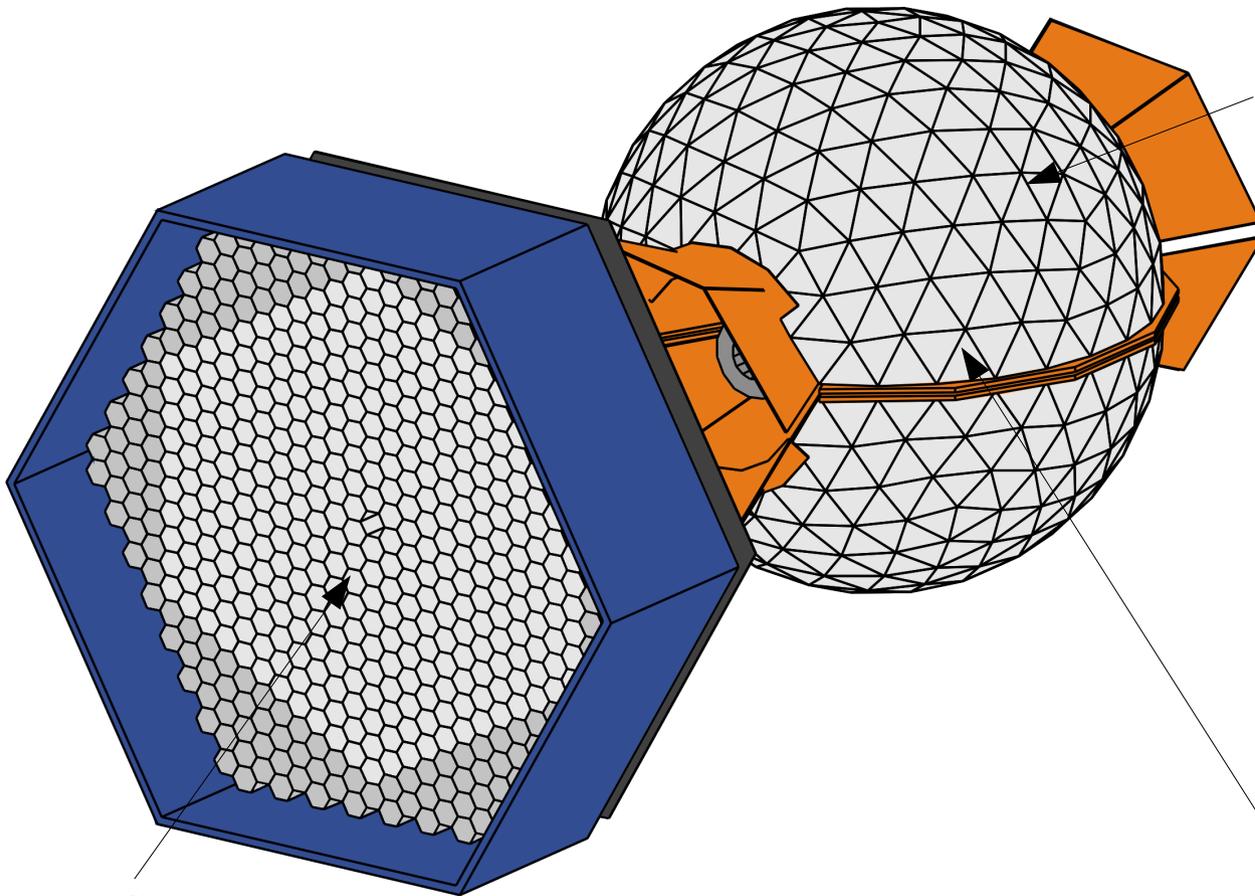
- Electron accelerator
- Cascade of 3 RTMs ( $E_{\text{max}} = 883 \text{ MeV}$ )
- Since 2006: HDSM ( $E_{\text{max}} = 1558 \text{ MeV}$ )
- Duty factor: 100%
- Very stable beam conditions

# Glasgow-Mainz-Tagger



- Photon beam produced by Bremsstrahlung at radiator:  $e^- + A \rightarrow e^- + A + \gamma$
- 353 overlapping scintillators  $\rightarrow$  352 channels
- Electrons momentum analysed in magnetic spectrometer
- Energy tagging through  $E_\gamma = E_0 - E_{e^-}$
- $\Delta E_\gamma \approx 2$  MeV at 883 MeV electron energy,  $\Delta E_\gamma \approx 4$  MeV at 1558 MeV electron energy
- Tagging range: 5 to 92% of the electron beam energy

# Detectors



## TAPS:

- 510 (MAMI-B) or 384 (MAMI-C) BaF<sub>2</sub> crystals
- Plastic scintillator in front of every crystal
- Polar acceptance: 4-20°
- Energy resolution:

$$\frac{\sigma}{E_\gamma} = \frac{0,79\%}{\sqrt{E_\gamma / \text{GeV}}} + 1,8\%$$

- Time resolution: 0.5 ns FWHM

## Crystal Ball:

- 672 NaI(Tl) crystals
- CB covers 93,3% of total solid angle
- Each crystal read out by individual PMT

$$\text{Energy resolution: } \frac{\sigma}{E_\gamma} = \frac{2\%}{(E_\gamma / \text{GeV})^{0.25}}$$

Time resolution: 2.5 ns FWHM

Angular resolutions:  $\sigma(\theta) = 2^\circ \dots 3^\circ$

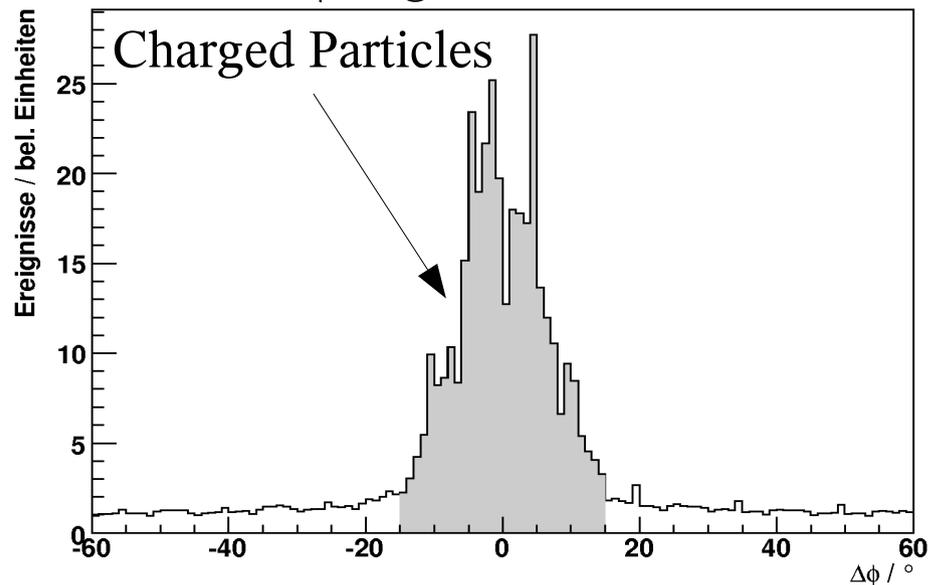
$$\sigma(\phi) = \frac{2^\circ \dots 3^\circ}{\sin(\theta)}$$

## PID:

- Inside CB around 1H<sub>2</sub> target
- 24 scintillator strips
- $\Phi$  acceptance of one strip:  $\Delta\Phi = 15^\circ$
- 30cm long, 2mm thick

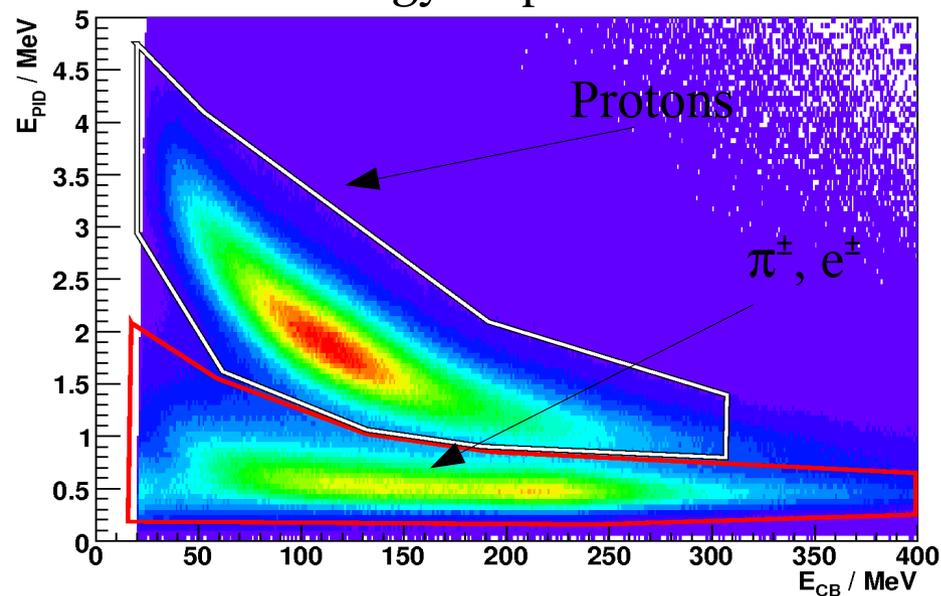
# Particle Identification

$\phi$ -angle difference

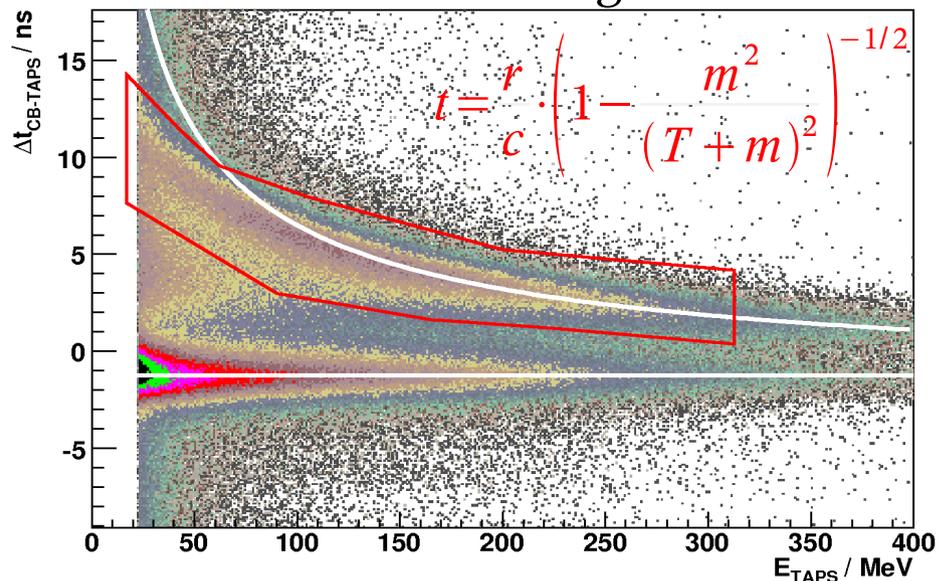


**CB**

Energy Dependence



Time-of-Flight



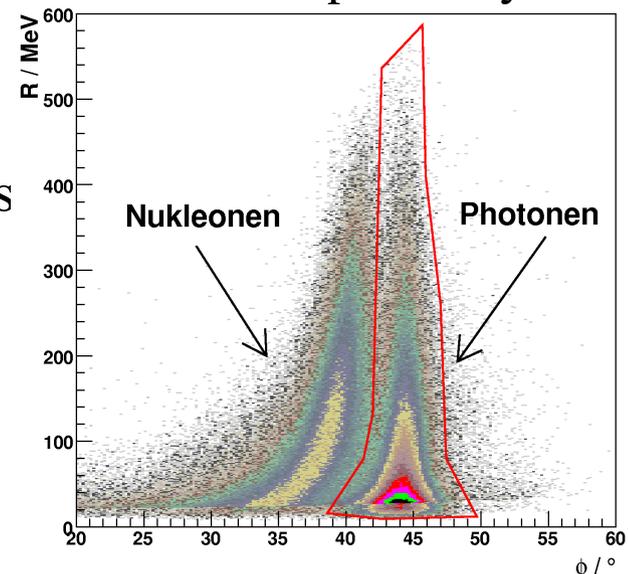
**TAPS**

Vetos distinguish between photons and charged particles

$$R = \sqrt{E_{kurz}^2 + E_{lang}^2}$$

$$\phi = \arctan\left(\frac{E_{kurz}}{E_{lang}}\right)$$

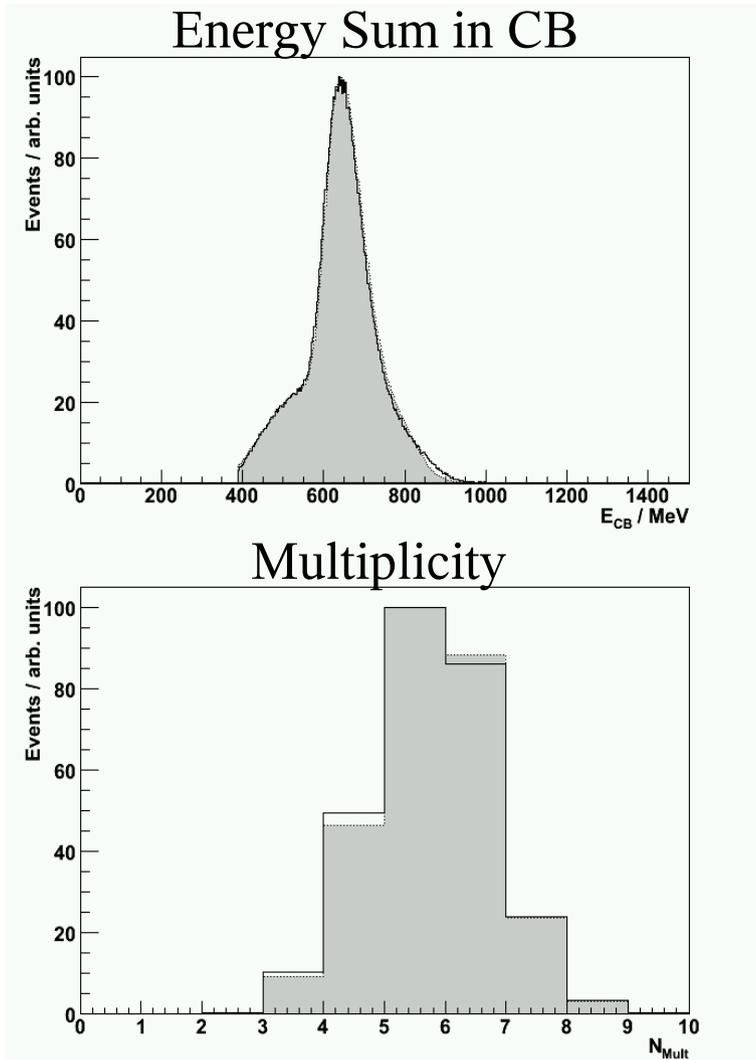
Pulse-Shape-Analysis



# Event Preselection

Experiments: neutral  $\eta$  decays, radiative  $\pi^0$ -photoproduction  
with different trigger conditions and tagged energy ranges

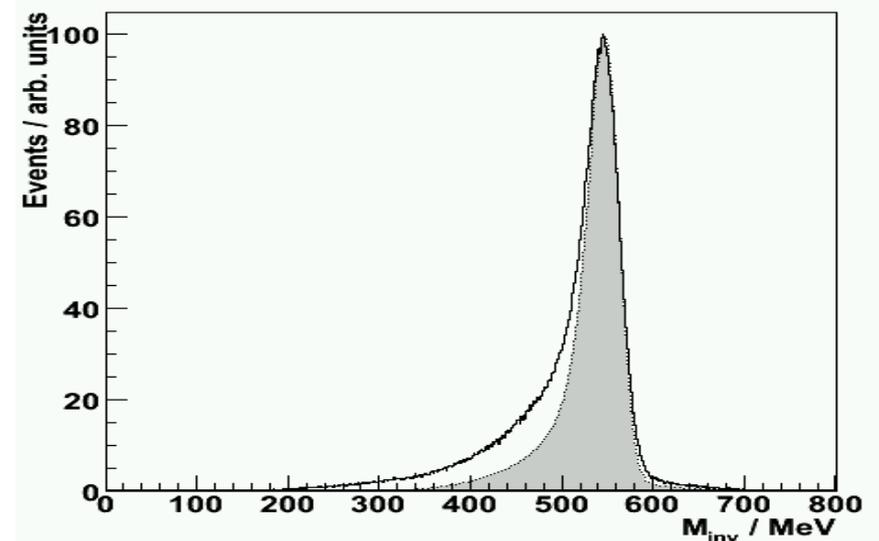
## Trigger:



## Simulation:

- 100 million  $\eta \rightarrow 3\pi^0$  events
- 10 million  $\gamma p \rightarrow 3\pi^0 p$  production events for background studies
- 10 million  $\gamma p \rightarrow \pi^0 p$  production events for background studies

## Invariant Mass of $6\gamma$ -Events



# Kinematic Fit

## Constraints:

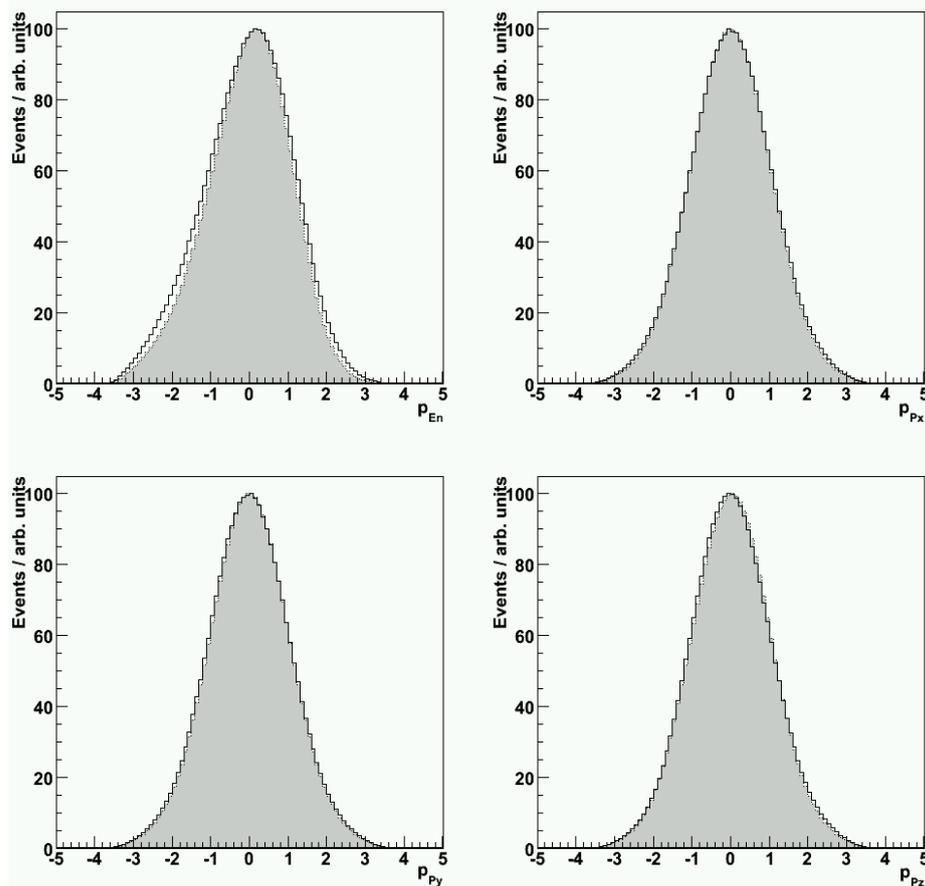
- Invariant mass =  $\eta$  mass
- Missing mass = proton mass
- Invariant mass  $\gamma$  pairs =  $\pi^0$  mass

Test all 15 possible  $\gamma$  combinations  
Confidence level cut: 2%

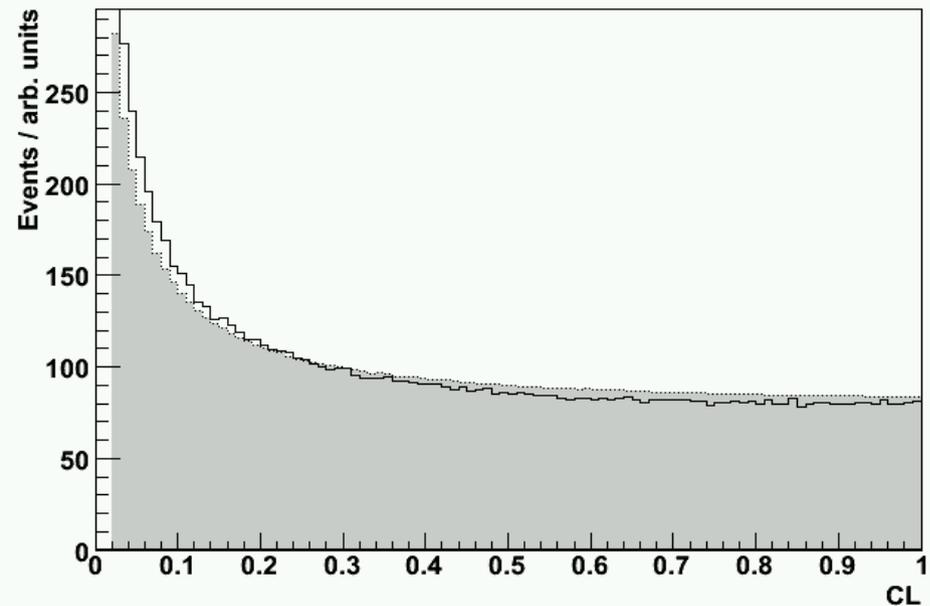
$1.15 \cdot 10^6$  events pass cut in  $\eta$  experiment

$0.65 \cdot 10^6$  in radiative  $\pi^0$  experiment

### Pulls

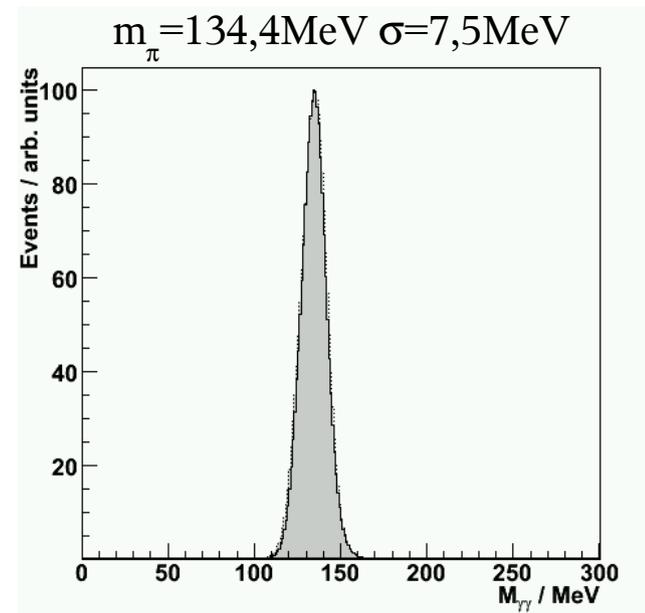
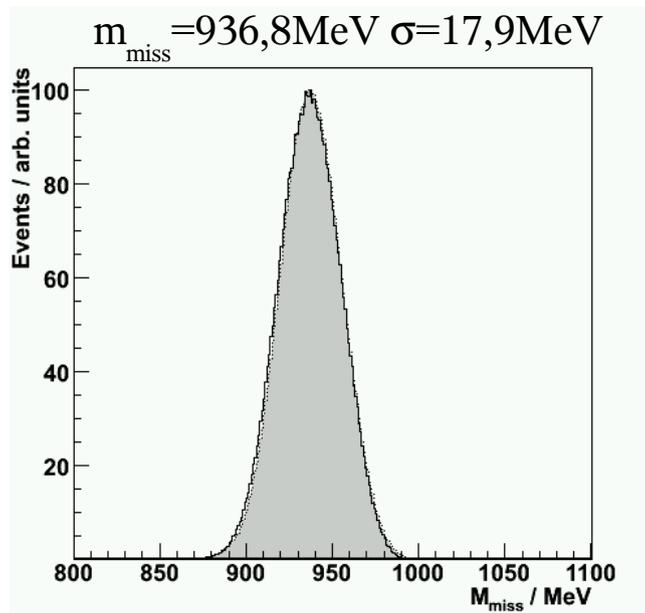
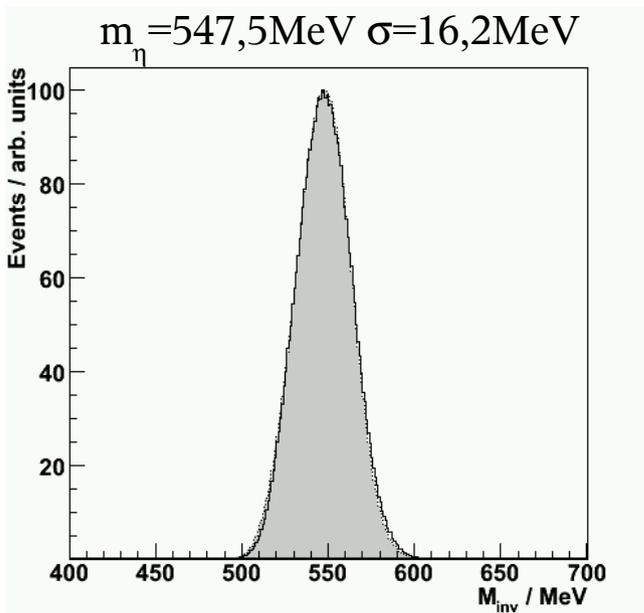
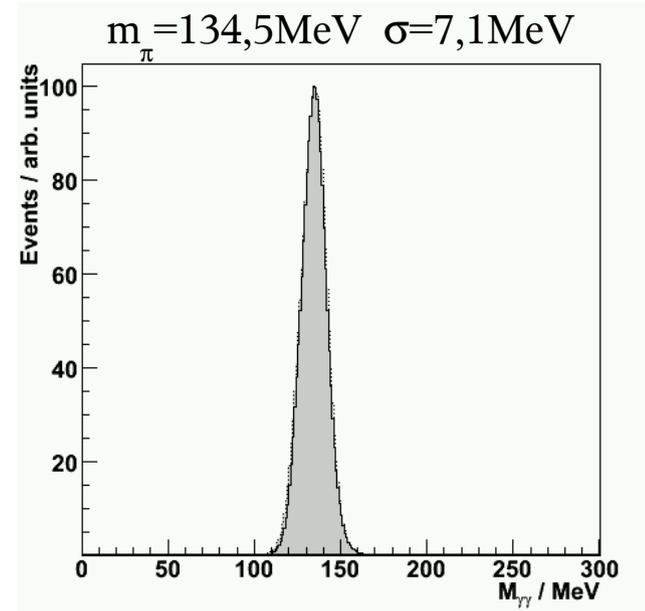
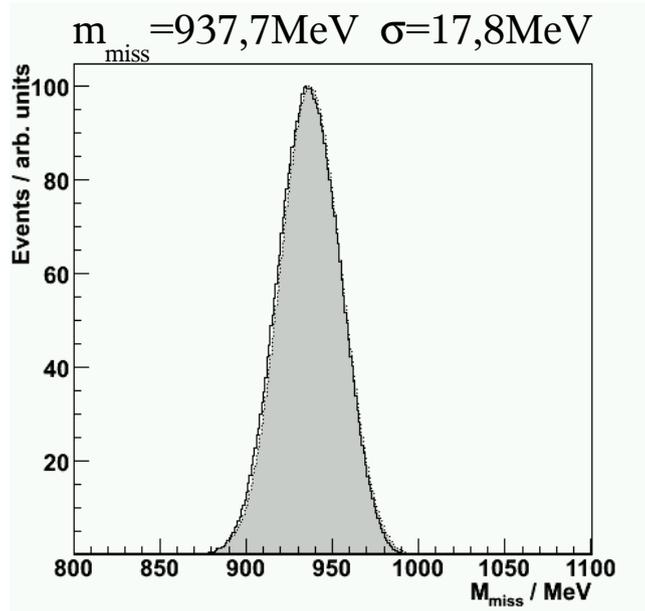
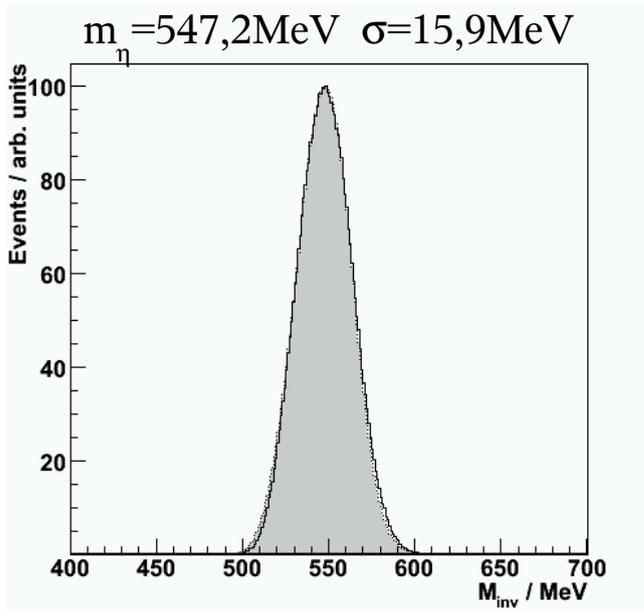


### Confidence Level

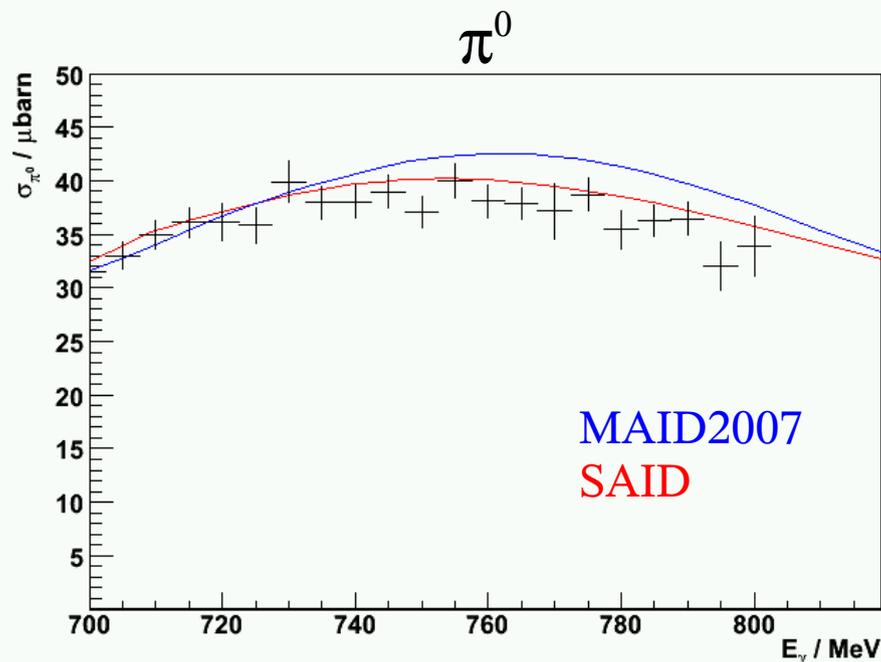
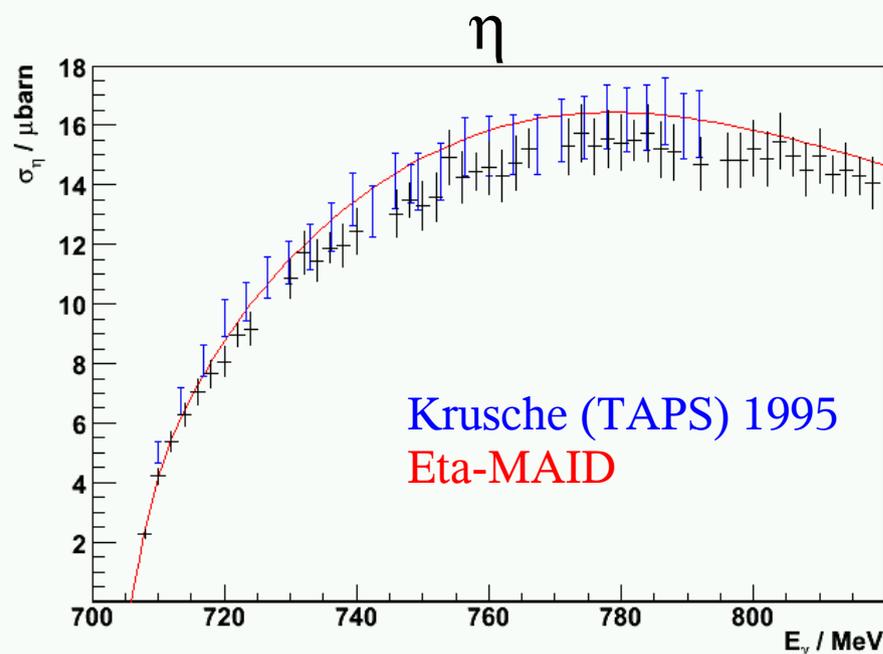
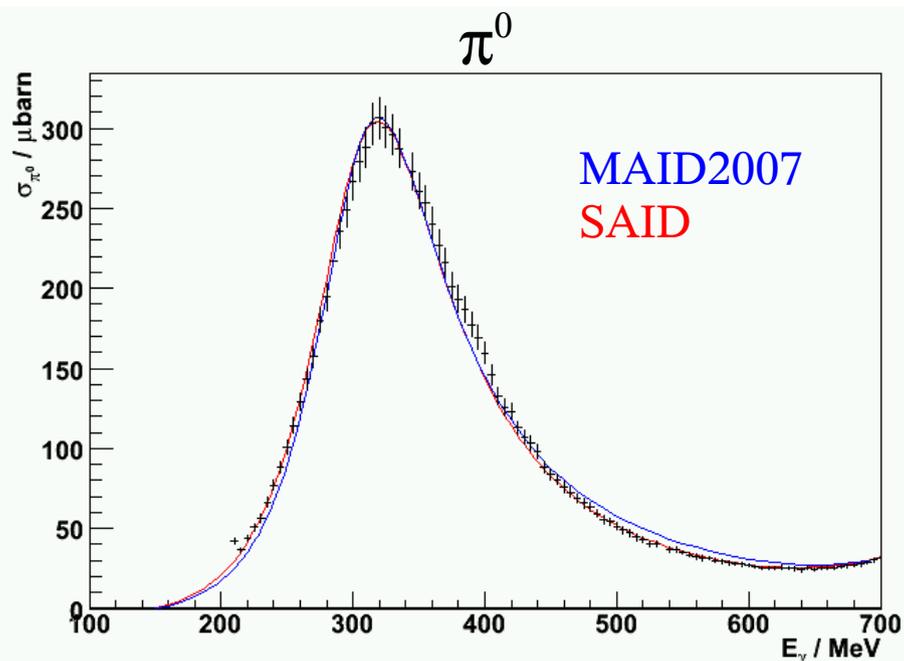


Nice agreement between experimental  
and simulated data!

# Selection Results



# Total Cross Sections

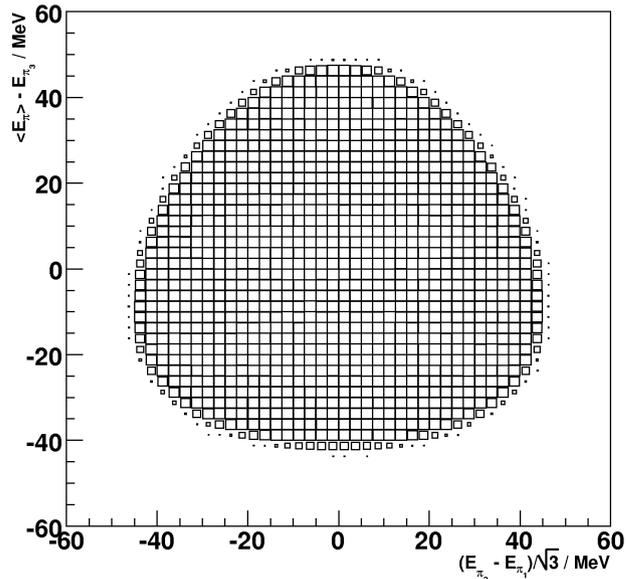


Total  $\pi^0$  cross section confirmed  
by independent analysis.

Absolute normalisation under  
control!

# Dalitz Plot

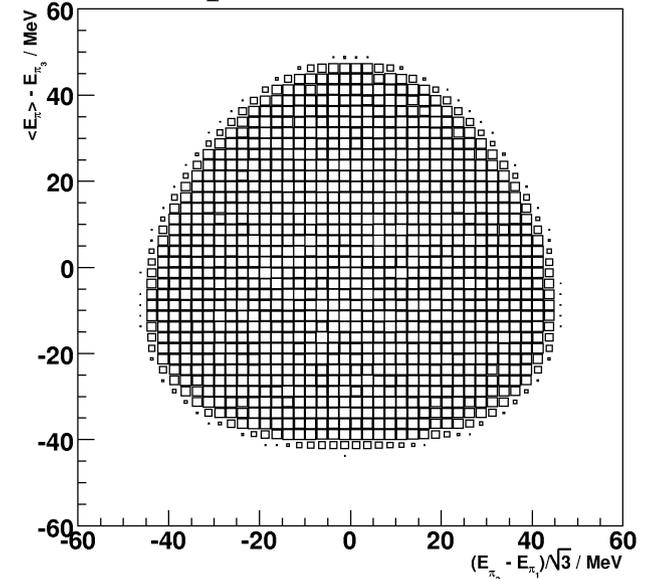
Simulation



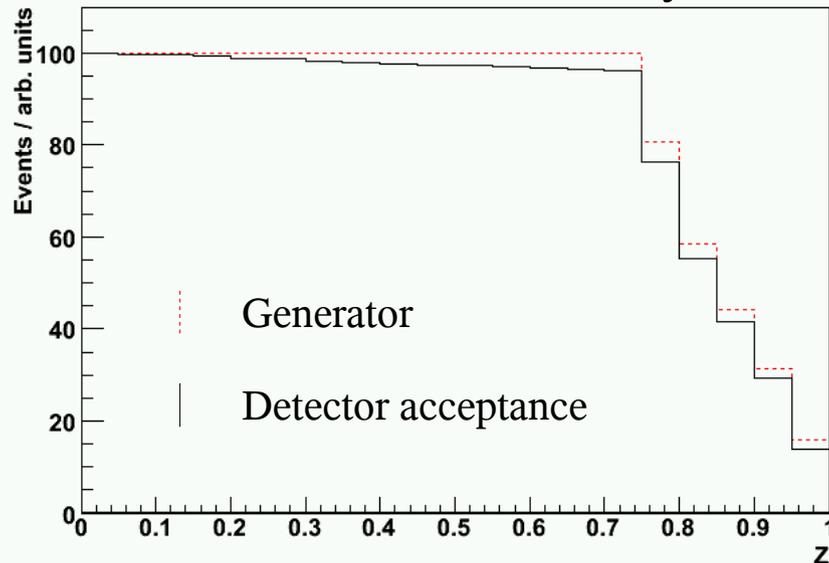
$$z = 6 \sum_{i=1}^3 \left( \frac{E_i - m_{\eta}/3}{m_{\eta} - 3m_{\pi^0}} \right)^2 = \frac{\rho^2}{\rho_{max}^2}$$

$$|A(\eta \rightarrow 3\pi^0)|^2 \sim c[1 + 2\alpha z]$$

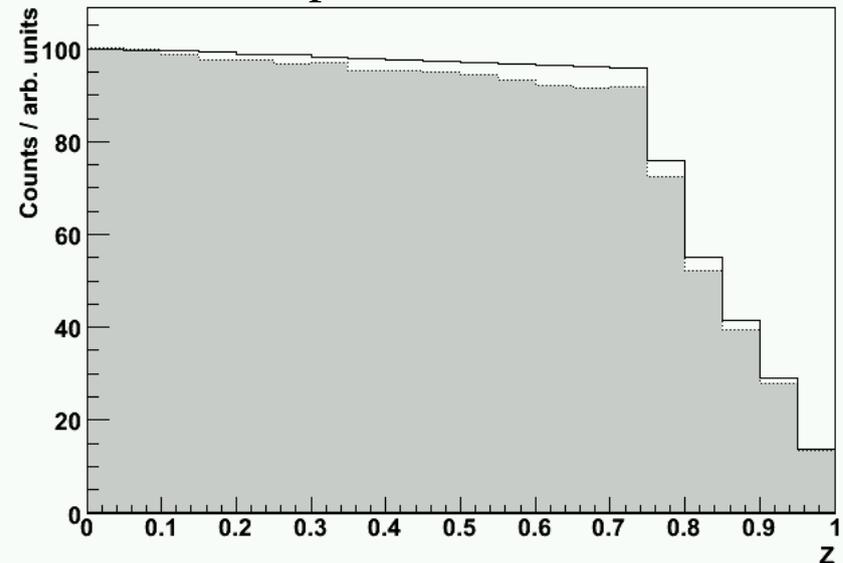
Experimental data



Simulated Event Density

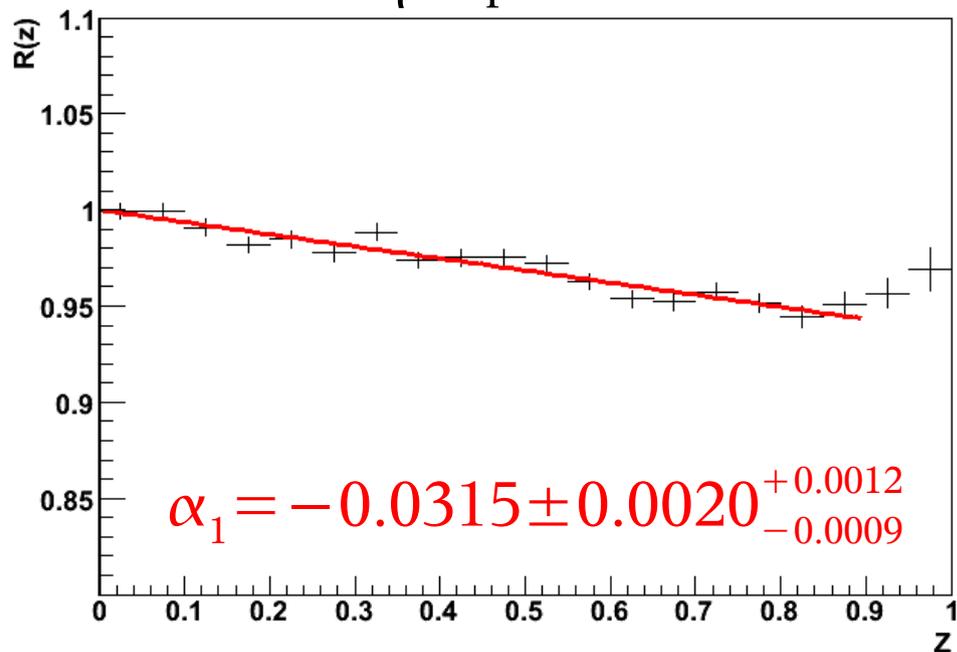


Comparison: Sim/Meas

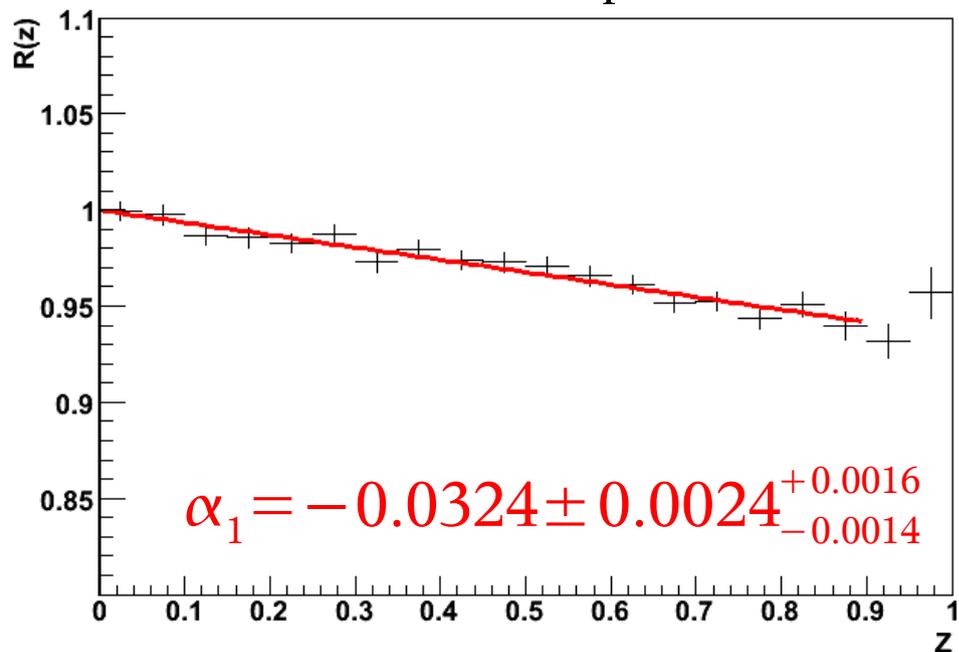


# Slopes

$\eta$ -Experiment



Radiative  $\pi^0$ -Experiment

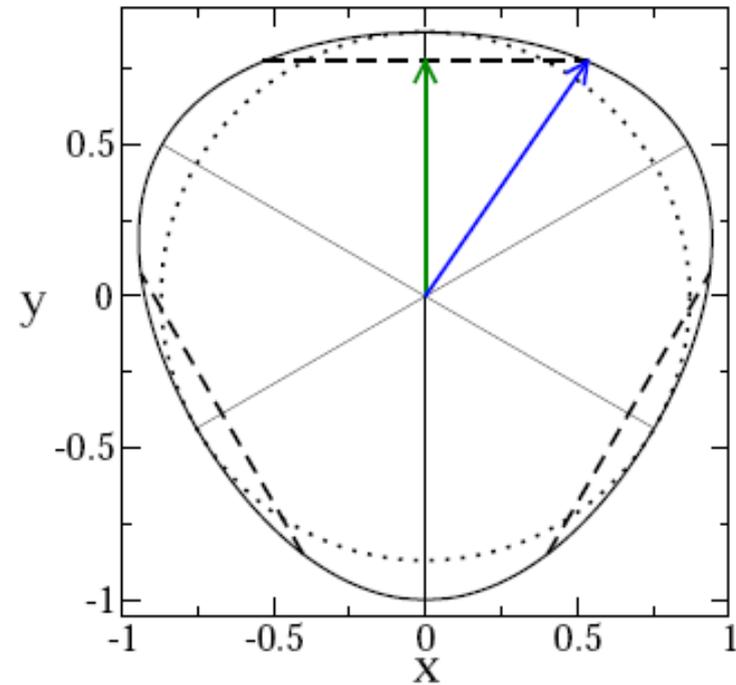
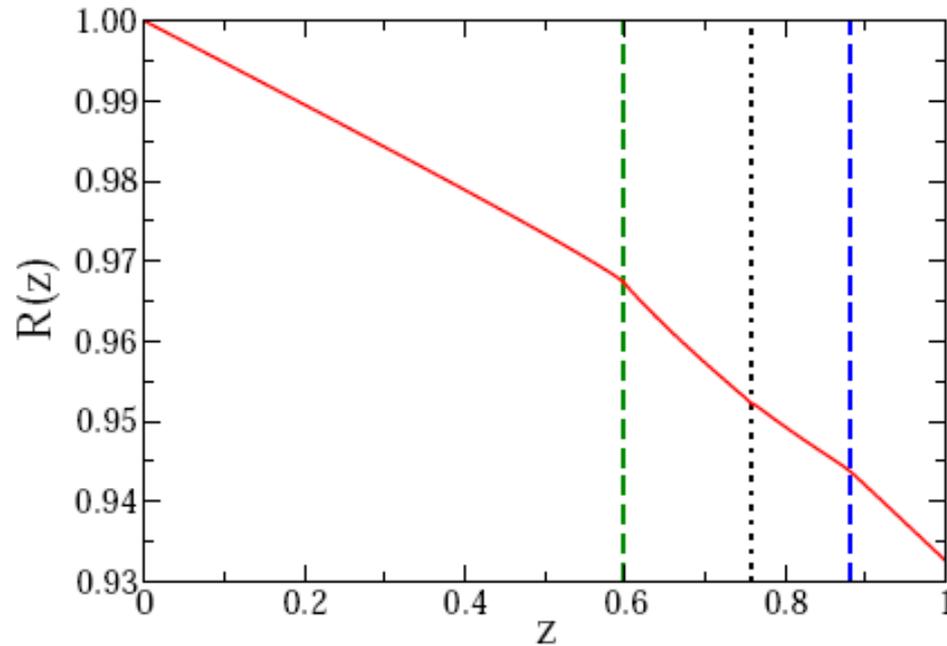


Test	$\alpha_1$	$N_1 / 10^3$	$\chi^2/\text{ndf}$	$\alpha_2$	$N_2 / 10^3$	$\chi^2/\text{ndf}$	
1	Standard	-0.0315 ± 0.0020	1120	20/16	-0.0324 ± 0.0024	724	10/16
2	6 $\gamma$ +1p	-0.0323 ± 0.0033	430	15/16	-0.0357 ± 0.0035	322	18/16
3	CL=1	-0.0308 ± 0.0020	1177	20/16	-0.0331 ± 0.0023	759	9/16
4	CL=5	-0.0327 ± 0.0021	1022	22/16	-0.0336 ± 0.0025	663	12/16
5	CL=10	-0.0328 ± 0.0022	919	21/16	-0.0322 ± 0.0026	600	11/16
6	CL=20	-0.0332 ± 0.0024	774	17/16	-0.0296 ± 0.0028	510	16/16
7	CL=50	-0.0295 ± 0.0031	453	20/16	-0.0297 ± 0.0036	303	11/16
8	$E_{\text{thr}} = 380$ MeV	-0.0323 ± 0.0020	1121	20/16	---	---	---
9	$E_{\text{thr}} = 388$ MeV	-0.0316 ± 0.0020	1120	20/16	---	---	---
10	$E_{\text{thr}} = 392$ MeV	-0.0313 ± 0.0020	1119	20/16	---	---	---
11	$E_{\text{thr}} = 400$ MeV	-0.0307 ± 0.0020	1117	21/16	---	---	---
12	no TAPS	-0.0300 ± 0.0024	797	13/16	-0.0316 ± 0.0028	516	11/16
13	no ID	-0.0311 ± 0.0023	838	12/16	-0.0306 ± 0.0027	556	12/16
14	$z \leq 1$	-0.0295 ± 0.0019	1149	31/18	-0.0322 ± 0.0022	742	13/18
15	$z < 0.75$	-0.0319 ± 0.0024	1005	19/13	-0.0312 ± 0.0029	650	8/13
16	$z < 0.6$	-0.0284 ± 0.0034	812	13/10	-0.0277 ± 0.0041	524	7/10

$$\Delta_{\text{syst}}(\alpha_i) = \frac{\sum_k (\alpha'_{ik} - \alpha_i) \cdot N_{ik}}{\sum_k N_{ik}}$$

$$\alpha = -0.032 \pm 0.002 \pm 0.002$$

# Cusp



R. Nißler, PhD thesis Helmholtz-Institut für Strahlen-und Kernphysik, Rheinische Friedrich-Wilhelms-Universität Bonn, 2008.

Test	$\alpha_1$	$N_1 / 10^3$	$\chi^2/\text{ndf}$	$\alpha_2$	$N_2 / 10^3$	$\chi^2/\text{ndf}$
1 Standard	$-0.0315 \pm 0.0020$	1120	20/16	$-0.0324 \pm 0.0024$	724	10/16
14 $z \leq 1$	$-0.0295 \pm 0.0019$	1149	31/18	$-0.0322 \pm 0.0022$	742	13/18
15 $z < 0.75$	$-0.0319 \pm 0.0024$	1005	19/13	$-0.0312 \pm 0.0029$	650	8/13
16 $z < 0.6$	$-0.0284 \pm 0.0034$	812	13/10	$-0.0277 \pm 0.0041$	524	7/10

For the test with  $z < 0.6$  Ditsche, Kubis and Meißner (arXiv:0812.0344 [hep-ph]) predict a drop in the slope by **5%** for a fit up to  $z=0.6$  compared to a fit up to  $z=1.0$ .

# Summary

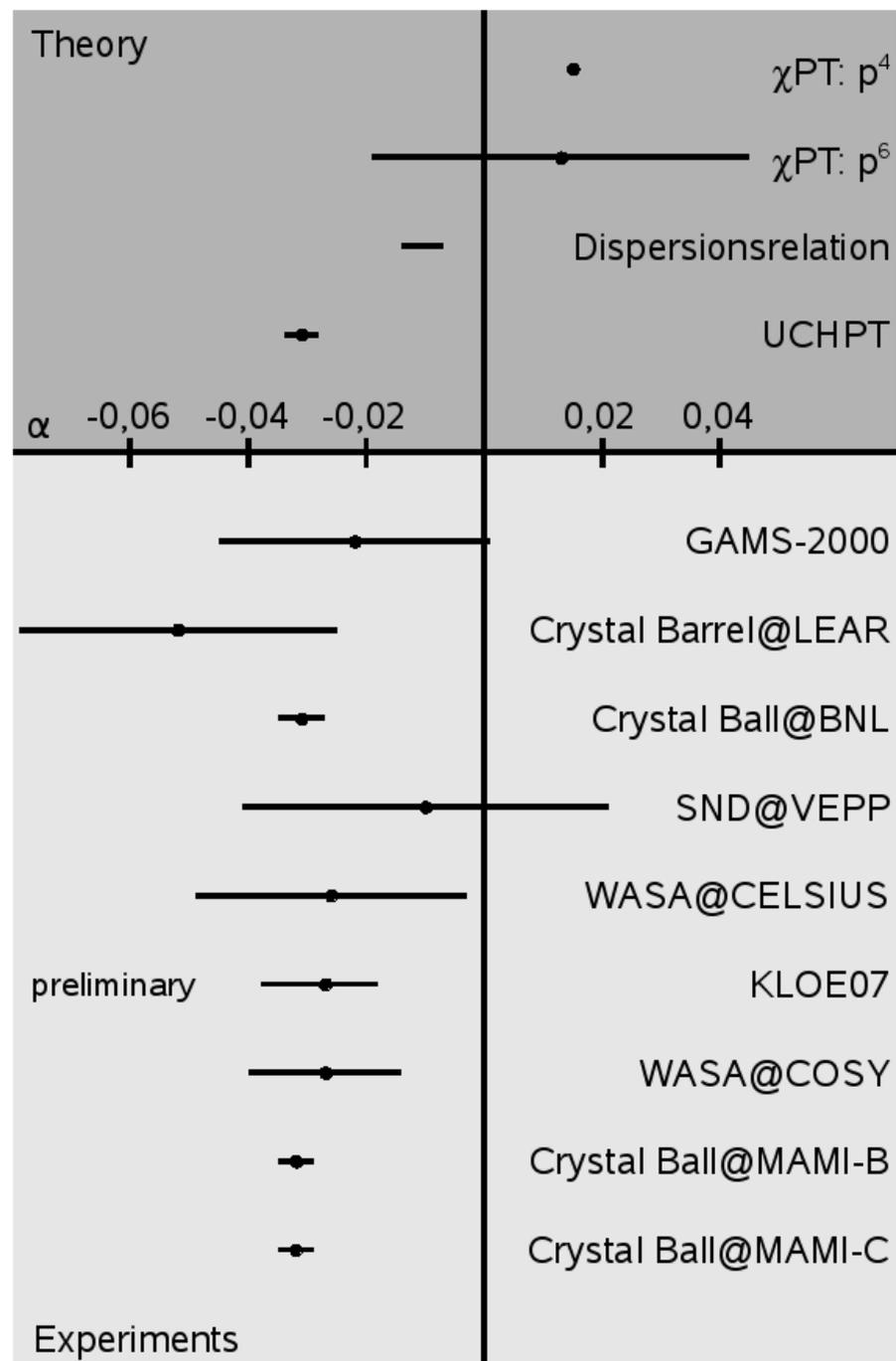
- Determined Dalitz plot parameter with MAMI-B
- Clean event selection ( $3\pi^0$  background:  $\sim 2\%$ ,  $\pi^0\pi^0$ -production negligible)
- Analysis with kinematic fitting technique
- Result:

$$-0,0319 \pm 0,0015 \pm 0,0016$$

- Agreement with other statistically relevant experiments
- Agreement with new measurement with MAMI-C

$$-0,0322 \pm 0,0012 \pm 0,0022$$

- Only one theoretical calculation (UCHPT) agrees with experiments
- Evidence for influence of cusp on slope!?
- Paper published:  
M. Unverzagt *et al.*, Eur. Phys. J. A39, 169 (2009)  
arXiv:0812.3244 [hep-ex]
- Still an open field. Especially in theory!



# $3\pi^0$ Production

10 Mio events simulated

Background fraction:

$$A_{3\pi^0} = \frac{N_{3\pi^0}}{N_{\eta \rightarrow 3\pi^0}} = \frac{\sigma_{3\pi^0}}{\sigma_\eta \cdot BR(\eta \rightarrow 3\pi^0)} \cdot \frac{\epsilon_{3\pi^0}}{\epsilon_{\eta \rightarrow 3\pi^0}} \approx 2\%$$

