

# Measurement of $\sigma_{1/2}$ and $\sigma_{3/2}$ in Photoproduction of $\pi^0\pi^0$ Pairs off Neutrons in the Nucleon Resonance Region

Manuel Dieterle

PANIC 2014

Hamburg, August 28<sup>th</sup> 2014



# Outline

## ① Motivation

## ② Experiment

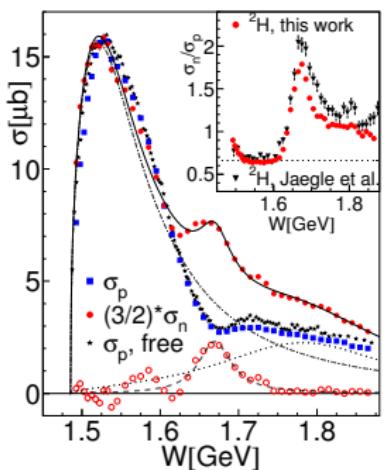
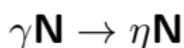
## ③ Analysis

## ④ Results

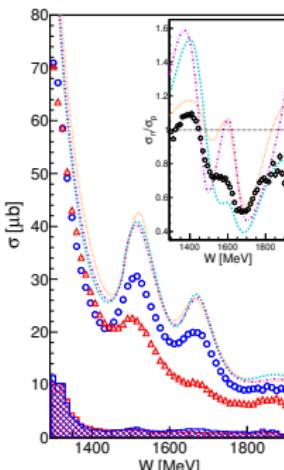
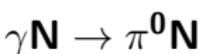
## ⑤ Summary & Conclusions

# Motivation

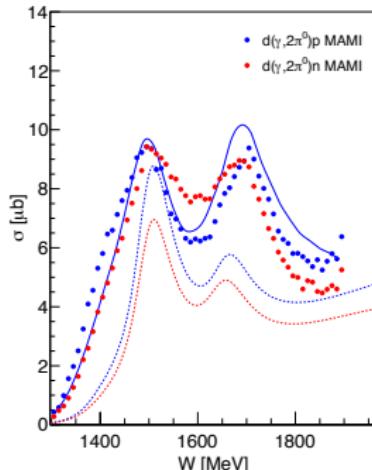
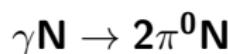
Different resonance contributions to proton and neutron



MAMI, D. Werthmüller et al.,  
PRL111,232001



MAMI, M. Dieterle et al.,  
PRL112,142001



MAMI, in preparation

⇒ Use polarization observables to identify amplitudes and quantum numbers

# Polarization Observables

$$\frac{d\sigma}{d\Omega}(\theta, \phi) = \frac{d\sigma}{d\Omega}(\theta) \cdot \left[ 1 - p_{\gamma}^{lin} \Sigma(\theta) \cos(2\phi) \right. \\ \left. + p_x \cdot \left( -p_{\gamma}^{lin} H(\theta) \sin(2\phi) + p_{\gamma}^{circ} F(\theta) \right) \right. \\ \left. - p_y \cdot \left( +p_{\gamma}^{lin} P(\theta) \cos(2\phi) - T(\theta) \right) \right. \\ \left. - p_z \cdot \left( -p_{\gamma}^{lin} G(\theta) \sin(2\phi) + p_{\gamma}^{circ} E(\theta) \right) \right]$$

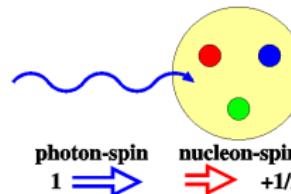
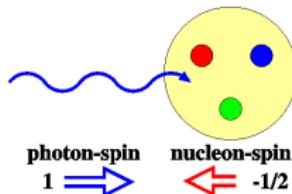
$P_{\gamma}$		$P_T \cdot \vec{e}_i$		
		$x$	$y$	$z$
unpol	$\sigma$	-	$T$	-
linearly	$-\Sigma$	$H$	$-P$	$-G$
circularly	-	$F$	-	$-E$

# Polarization Observables

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$P_{\gamma}$	$P_T \cdot \vec{e}_i$		
	x	y	z
unpol	$\sigma$	-	$T$
linearly	$-\Sigma$	$H$	$-P$
circularly	-	$F$	-

## Double Polarization Observable E

 $\sigma_{1/2}$  $\sigma_{3/2}$ 

$$E = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}$$

# Double Polarization Observable E

$C$ := Photon Spin     $Z$ := Target Spin     $\pm$ := in/against z-direction

$$\sigma(C, Z) + \sigma(C, -Z) = 2\sigma(C, 0)$$

$$\sigma(C, 0) = \sigma(0, Z) = \sigma_{unpol}$$

$$\sigma(C, Z) + \sigma(-C, Z) = 2\sigma(0, Z)$$

(only for two-body state)

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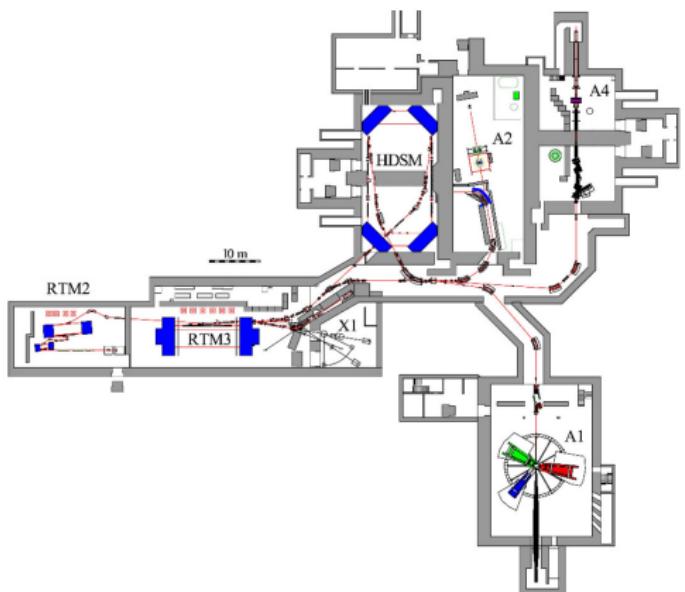
$$\sigma(C, Z) + \sigma(-C, Z) = 2\sigma(0, Z)$$

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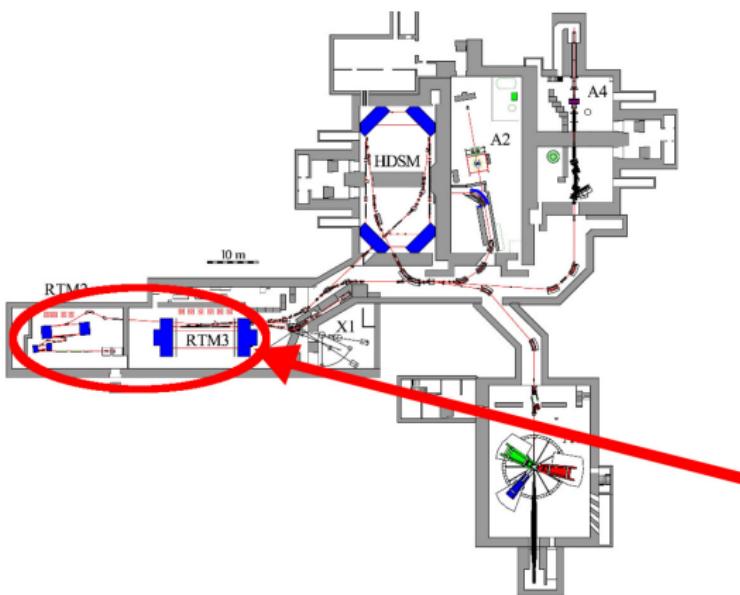
$$\Rightarrow E = \frac{\sigma_{1/2} - \sigma_{3/2}}{\underbrace{\sigma_{1/2} + \sigma_{3/2}}_{\text{Carbon}}} = \frac{\sigma_{1/2} - \sigma_{3/2}}{\underbrace{2\sigma_{unpol}}_{\text{direct}}}$$

► use quasi-two-body state ( $\pi^0\pi^0$ )

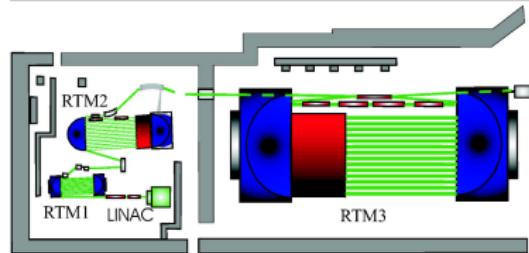
# MAinzer Microtron Electron Accelerator



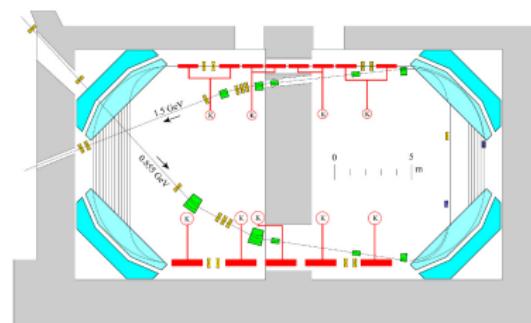
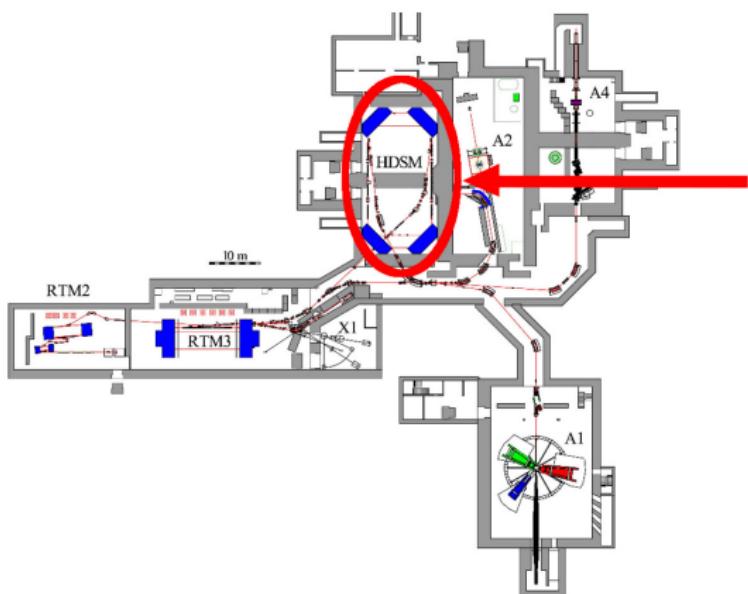
# MAinzer Microtron Electron Accelerator



Stage:	Turns:	Energy:
LINAC	—	3.97 MeV
RTM1	18	14.9 MeV
RTM2	51	180 MeV
RTM3	90	855.1 MeV

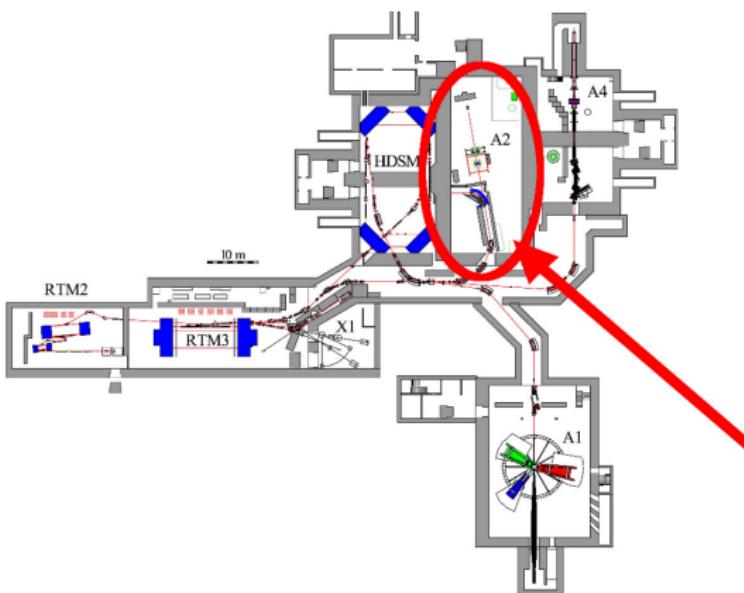


# MAinzer Microtron Electron Accelerator



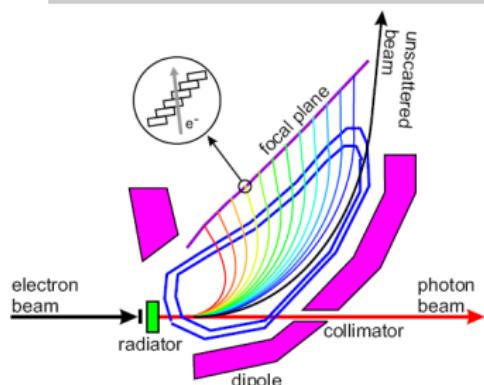
Stage: HDSM      Turns: 43      Energy: 1558 MeV

# MAinzer Microtron Electron Accelerator



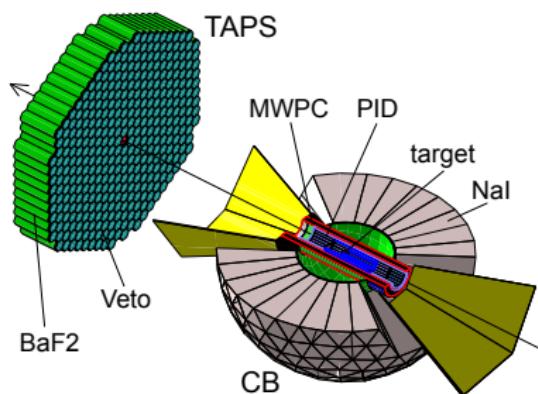
## A2 Experimental Hall Bremsstrahlung Tagging

$$E_\gamma = E_{e^-}^{\text{beam}} - E_{e^-}^{\text{tagged}}$$



# Experiment MAinzer Microtron

- ▶ Two Experiments: July 2013 / February 2014
- ▶ Photon beam energies [0.4, 1.5] GeV
- ▶ Target:  $\sim 2\text{cm}$  CD<sub>9</sub>OD (d-Butanol) / <sup>12</sup>C
- ▶ Detectors:
  - ▶ Crystal Ball (**CB**):
    - ▶ surrounding the target
  - ▶ Two Arm Photon Spectrometer (**TAPS**):
    - ▶ placed as forward wall
  - ▶  $\sim 4\pi$  steradian



# Reaction Identification

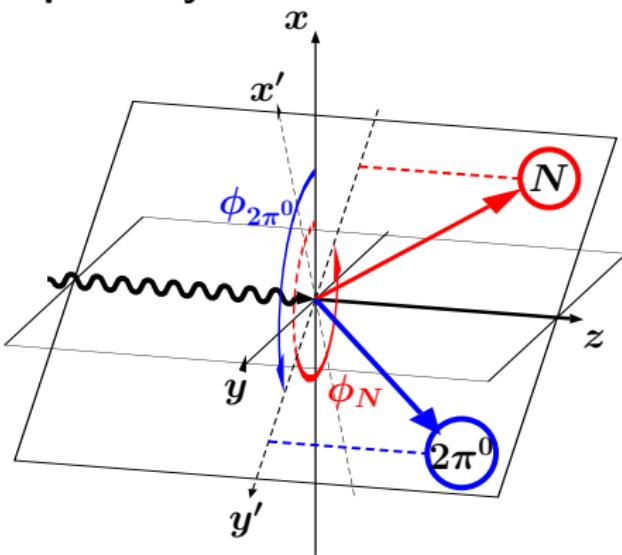


Reaction	Requirement
on Proton	4 neutral ( $2\pi^0$ ) 1 charged ( $p$ )
on Neutron	4 (5) neutral ( $2\pi^0 (+n)$ ) 0 charged

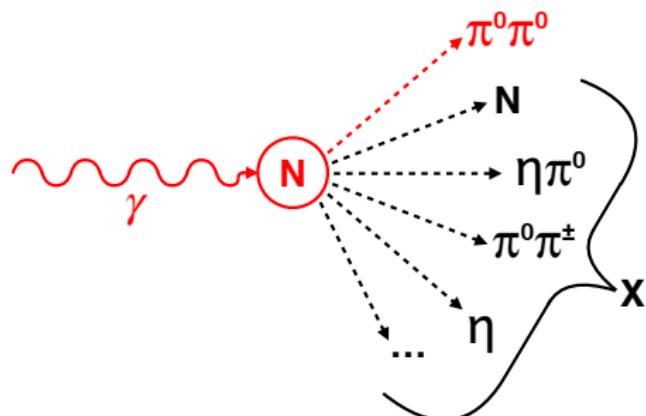
$\chi^2$ -test: Reconstruct the  $2\pi^0$  out of the neutral particles

# Reaction Identification

## Coplanarity



## Missing Mass



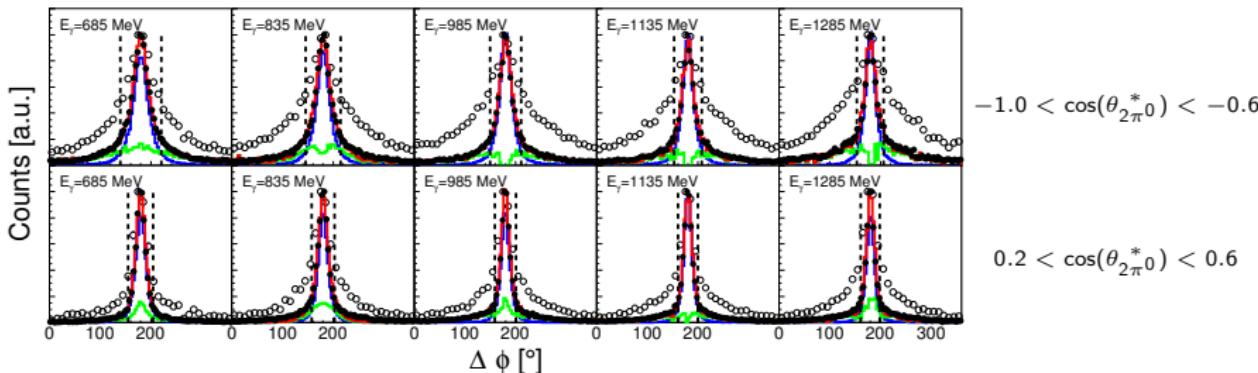
$$\Delta\phi = 360^\circ - |\phi_{2\pi^0} - \phi_N|$$

$$\Delta M = |P_{\text{Beam}} + P_N - P_{2\pi^0}| - m_N$$

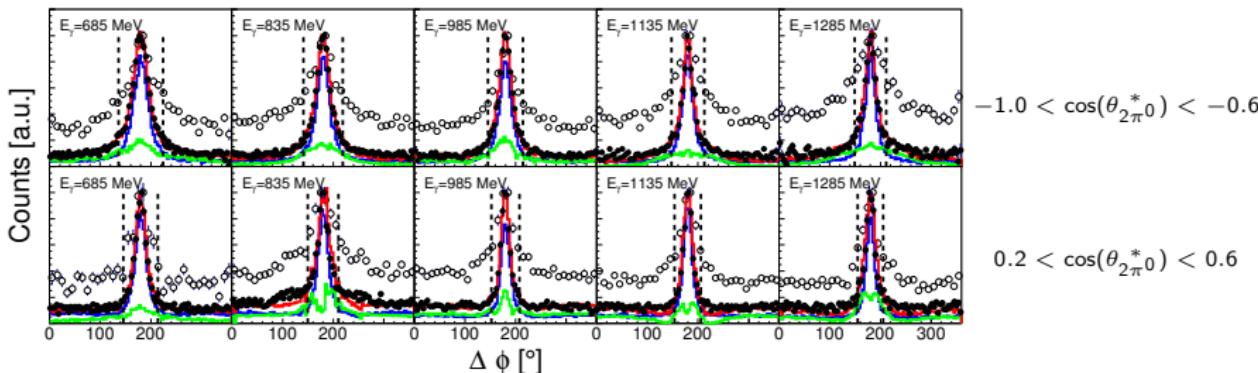
# Coplanarity Cut

○ dButanol ● LD2 — MC signal — MC bg — MC total —  $2\sigma$  cut

p

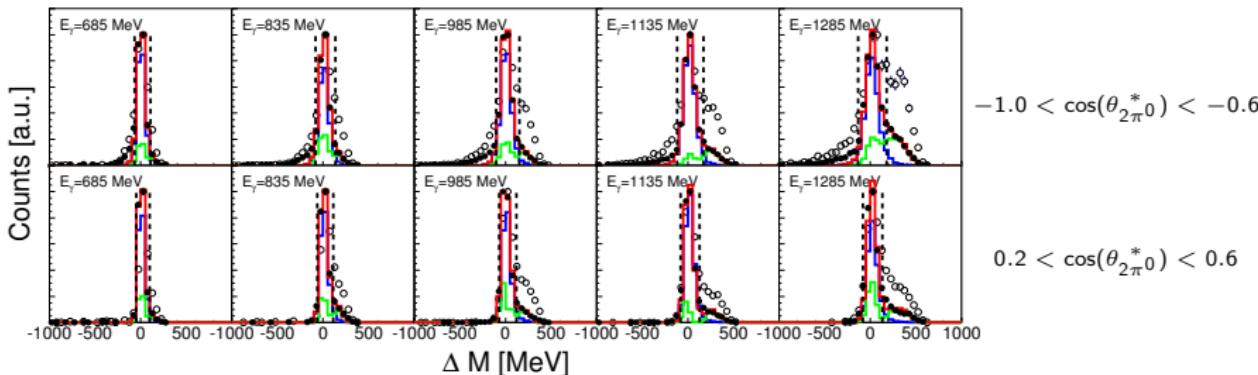
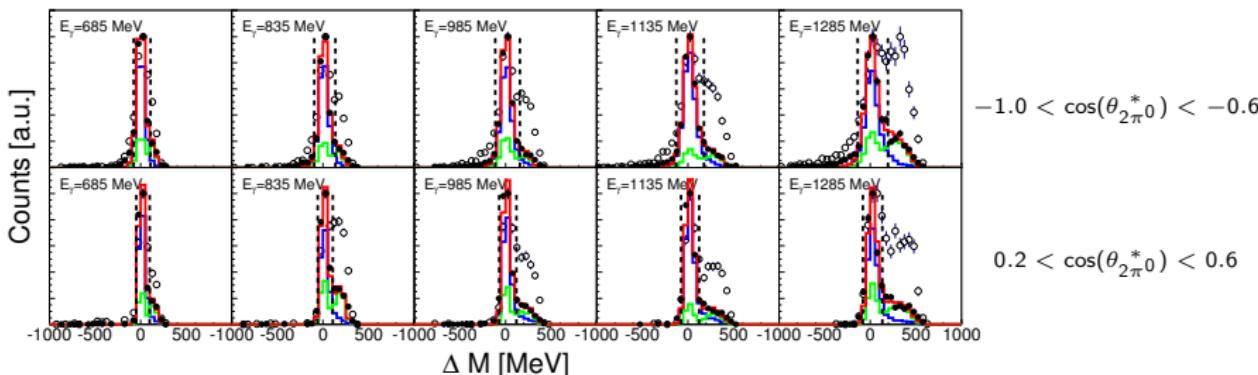


n



# Missing Mass

○ dButanol ● LD2 — MC signal — MC bg — MC total —  $2\sigma$  cut

**p****n**

# Final $\gamma\gamma$ Invariant Mass

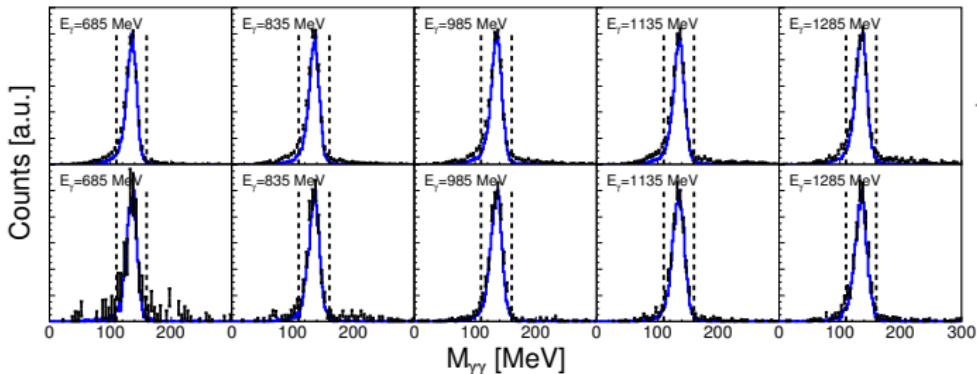
+ Data

— MC proton

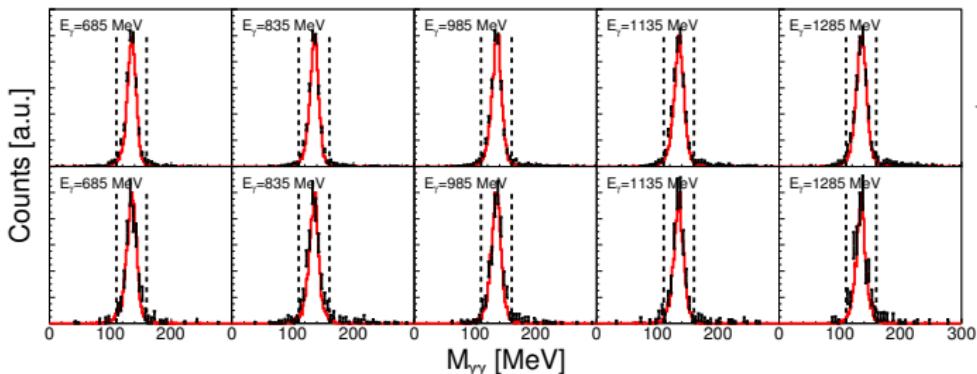
— MC neutron

— [110, 160] MeV cut

p



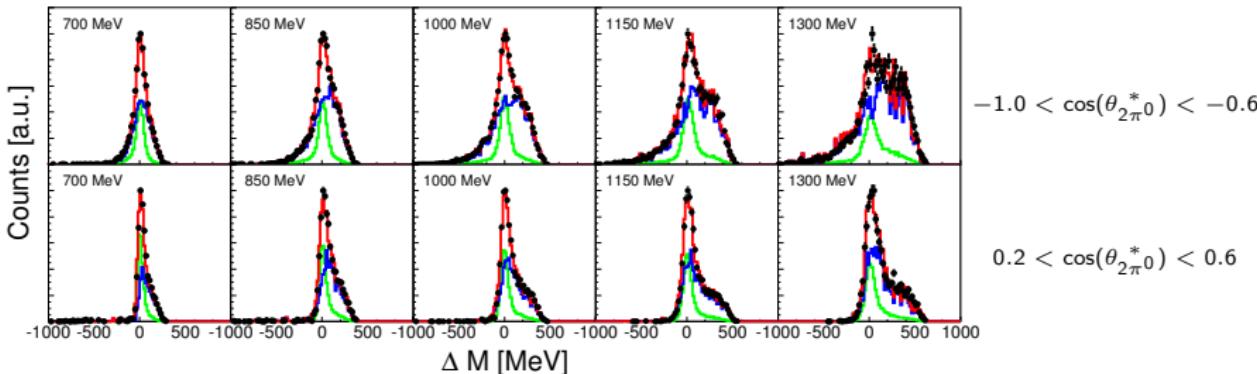
n



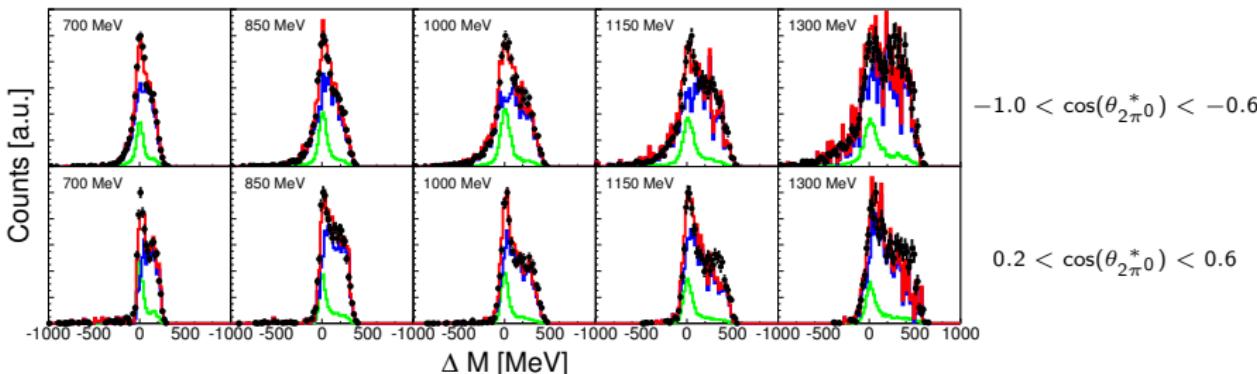
# Carbon Subtraction

•dButanol    — Carbon    — LD2    — LD2 + Carbon

p

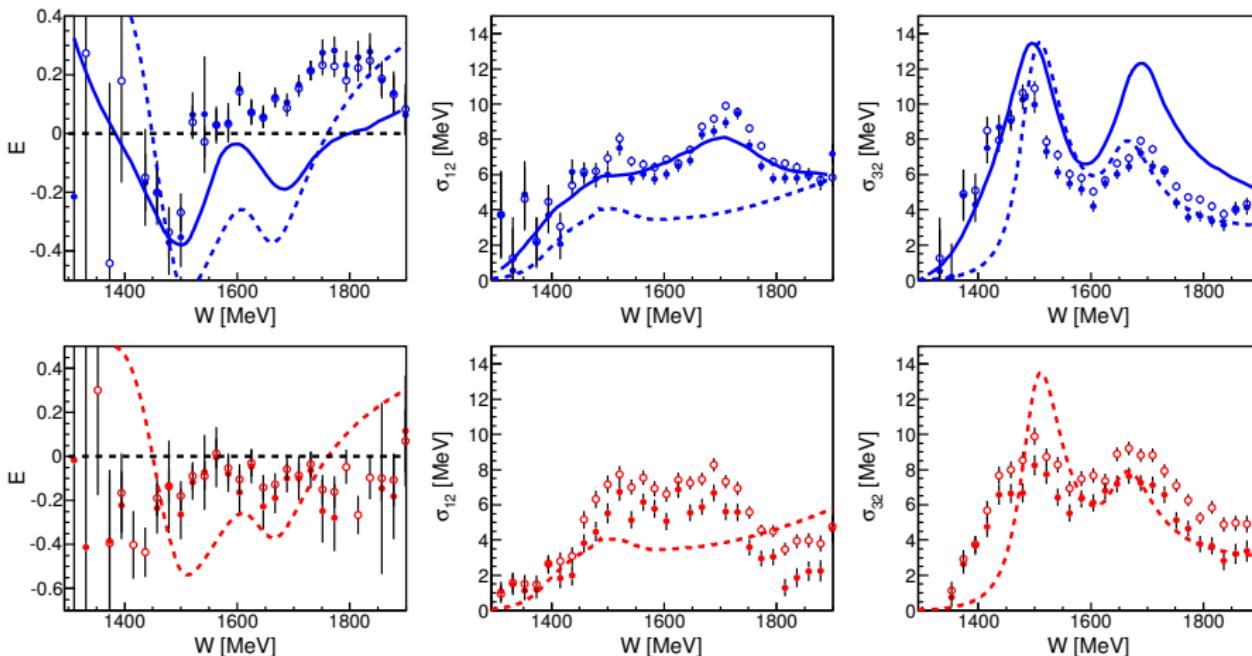


n



# Results

○ direct • Carbon — BnGa (BG2014-02) - - - MAID • Proton • Neutron



# Summary & Conclusions

- ▶ Clean reaction identification
- ▶ Carbon contribution under control
- ▶ Preliminary results of double polarization observable E on quasi-free protons and neutrons
- ▶ First results on the neutron
- ▶ Input for theoretical models

# Thanks for your attention

This work is supported by:



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FONDO NAZIONALE SVIZZERO  
SWISS NATIONAL SCIENCE FOUNDATION

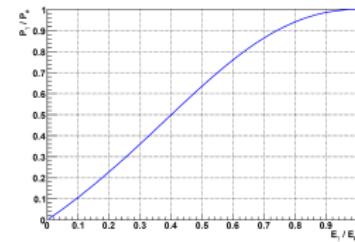
Deutsche  
Forschungsgemeinschaft



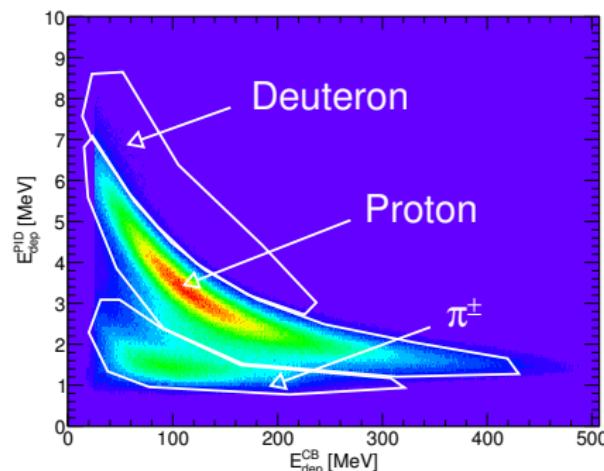
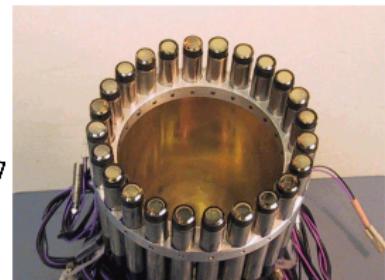
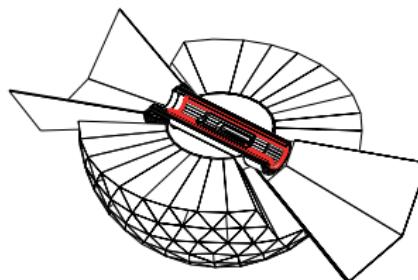
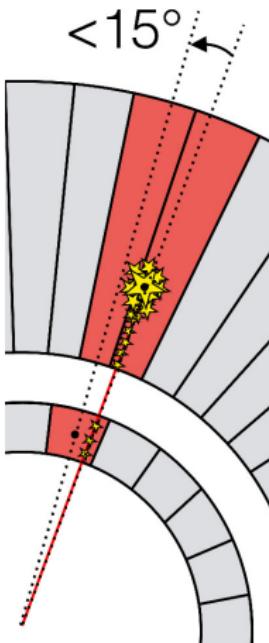
# Experimental Settings

Beam Energy	1558 MeV
Photon Beam	circularly polarized
Mean Beam Polarization	$\langle P_e \rangle \approx 85\% \quad (P_\gamma(1\text{GeV}) \approx 69\%)$
D-Butanol Target	longitudinally polarized
Mean Target Polarization	$\langle P_T \rangle \approx 65\%$
Duration	2 Weeks (9d 2013, 5d 2014)
Background Measurements	Carbon (3 days 2014) LD <sub>2</sub> (2 Weeks 2009)

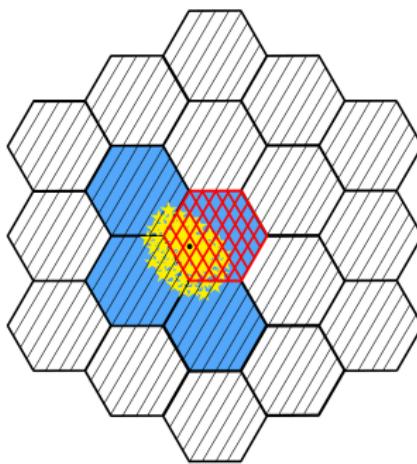
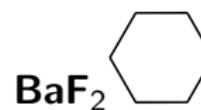
$$P_\gamma = P_e \cdot \frac{4E^* - E^* \cdot E^*}{4 - 4E^* + 3E^* \cdot E^*} \quad E^* = \frac{E_\gamma}{E_e}$$



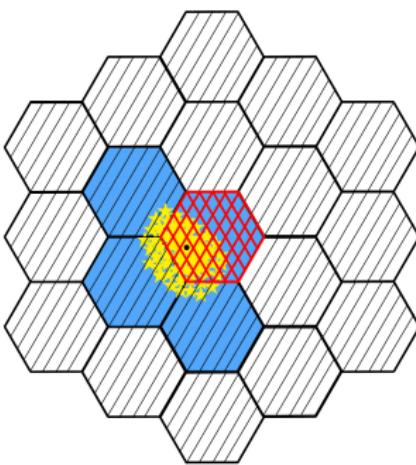
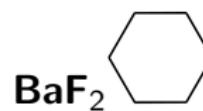
# Charged Particle Identification in CB



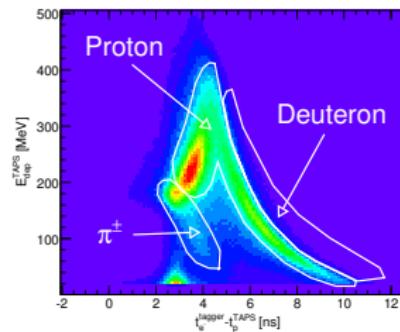
# Particle Identification in TAPS



# Particle Identification in TAPS



E vs ToF



# Particle Identification in TAPS

