Determination of the polarization observables T, P and H in the reaction $\gamma p \to p\pi^0$

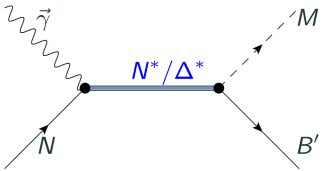
Sebastian Ciupka

University of Bonn

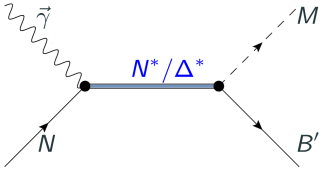
6. August 2022

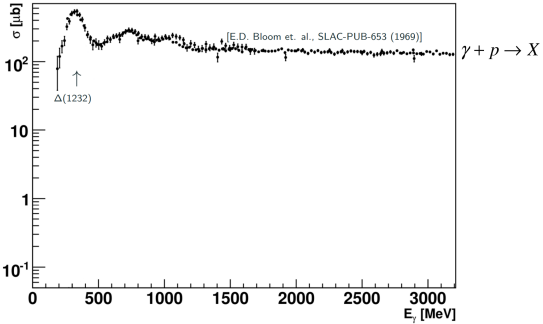
Introduction

- Study the constituents of the nucleus

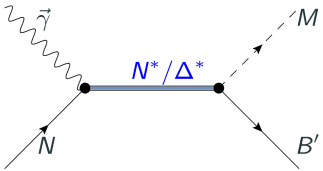


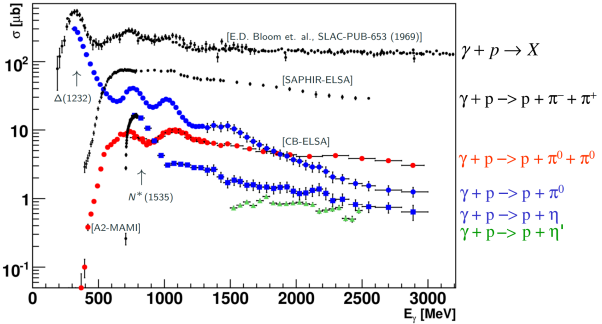
- Study the constituents of the nucleus
- Wide resonances with strong overlap



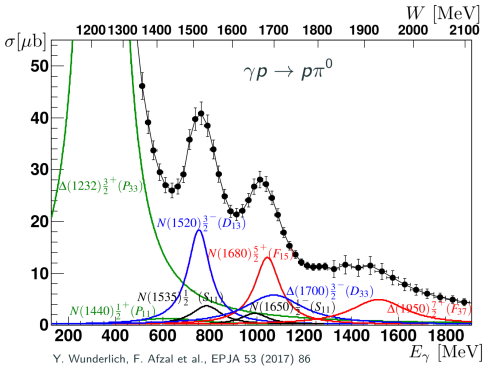


- Study the constituents of the nucleus
- Wide resonances with strong overlap



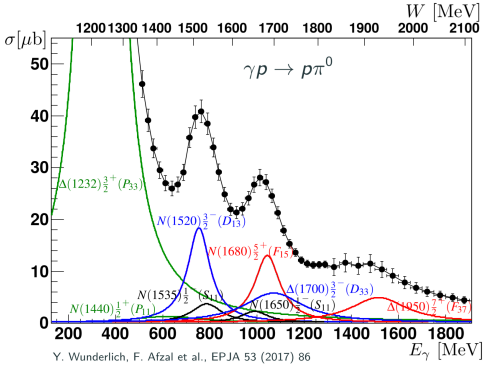


Resonances

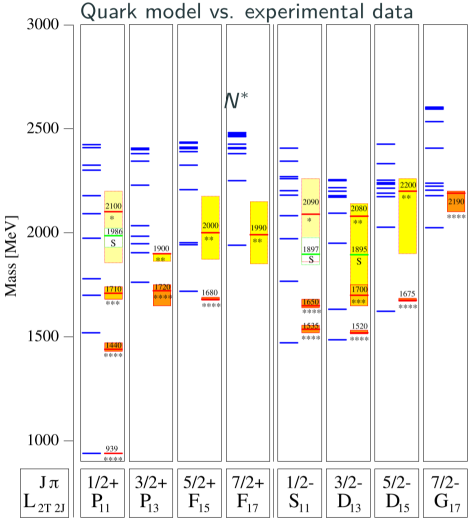


Y. Wunderlich, F. Afzal et al., EPJA 53 (2017) 86

Resonances



Y. Wunderlich, F. Afzal et al., EPJA 53 (2017) 86

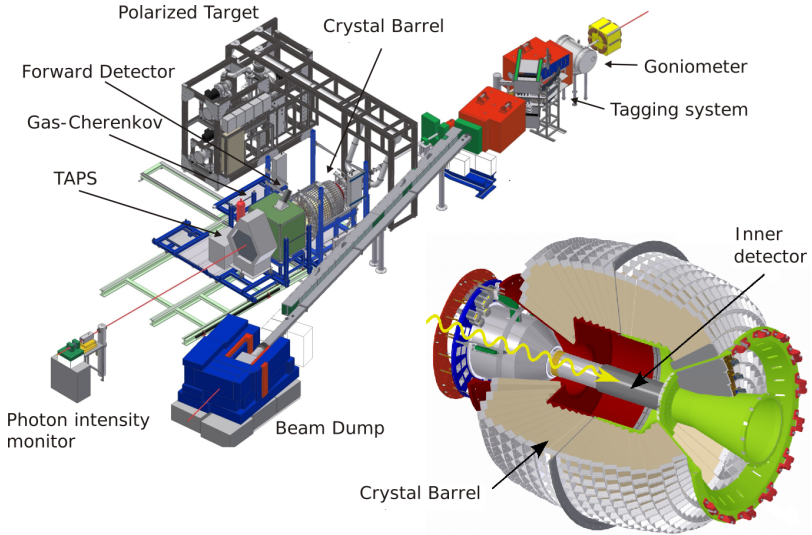


U. Loering, B.C. Metsch, H.R. Petry, EPJA 10 (2001) 395-446

Polarization Observables

Photon polarization		Target polarization			Recoil nucleon polarization			Target and recoil polarizations			
		X	Y	$Z_{(beam)}$	X'	Y'	Z'	X' X	X' Z	Z' X	Z' Z
unpolarized	σ	-	T	-	-	P	-	$T_{x'}$	$L_{x'}$	$T_{z'}$	$L_{z'}$
linear	$-\Sigma$	H	(-P)	-G	$O_{x'}$	(-T)	$O_{z'}$	$(-L_{z'})$	$(T_{z'})$	(L_x)	$(-T_x)$
circular	-	F	-	-E	$C_{x'}$	-	$C_{z'}$	-	-	-	-

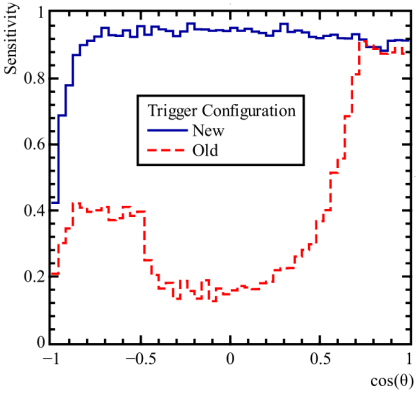
The Crystal-Barrel Experiment



Upgrade Motivation

- Main calorimeter not in first level trigger
- Inner Detector is not sensitive to neutral Particles

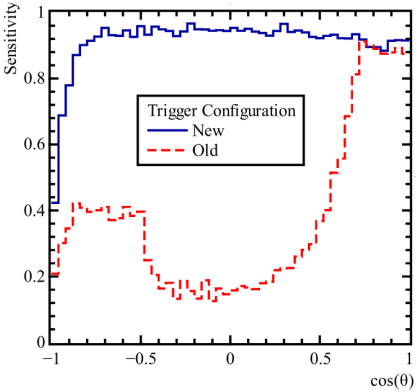
Detector angular coverage	
Inner Detector	$23.1^\circ < \theta < 166^\circ$
Forward Plug	$11.2^\circ < \theta < 27.5^\circ$
MiniTAPS	$1^\circ < \theta < 12^\circ$



Upgrade Motivation

- Main calorimeter not in first level trigger
- Inner Detector is not sensitive to neutral Particles

Detector angular coverage	
Inner Detector	$23.1^\circ < \theta < 166^\circ$
Forward Plug	$11.2^\circ < \theta < 27.5^\circ$
MiniTAPS	$1^\circ < \theta < 12^\circ$

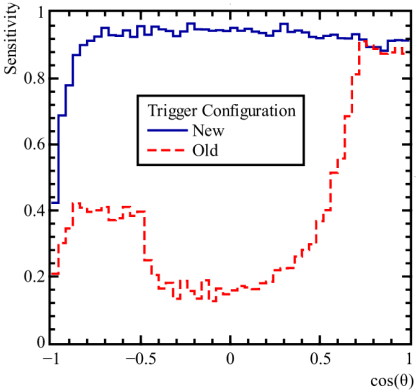


- CB calorimeter needs to be included in the first level trigger

Upgrade Motivation

- Main calorimeter not in first level trigger
- Inner Detector is not sensitive to neutral Particles

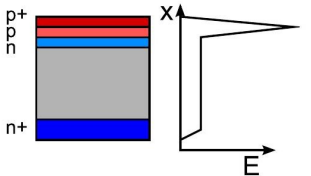
Detector angular coverage	
Inner Detector	$23.1^\circ < \theta < 166^\circ$
Forward Plug	$11.2^\circ < \theta < 27.5^\circ$
MiniTAPS	$1^\circ < \theta < 12^\circ$



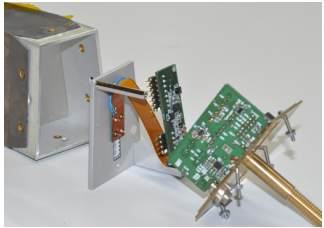
- CB calorimeter needs to be included in the first level trigger
- Information on number of clusters has to be available within < 700ns

Improving Signal to Noise

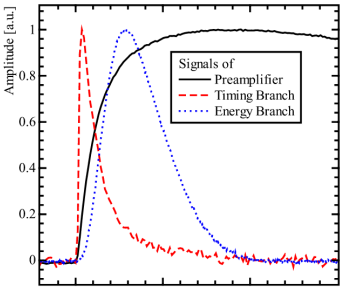
- Pin diodes are replaced by Avalanche Photo Diodes (APDs).
- Reverse bias voltage, high doping creates strong electric field
  $\Rightarrow$ Drifting electrons create an avalanche
  $\Rightarrow$ High internal gain



APD (Reverse Type)



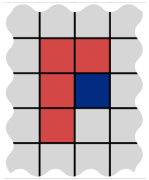
Splitting the Signal



[1]

- Signal from the preamplifier is shaped and split up:
  - Timing branch: Very fast rise and decay time, used for the trigger decision.
  - Energy branch: Slower signal allows for better signal-to-noise ratio when measuring the integral, which is proportional to the deposited energy

- Timing branch signal is used to detect clusters with an FPGA and a defined pattern
- Old charge integrating circuit is replaced with sampling ADCs for the energy readout


[1]

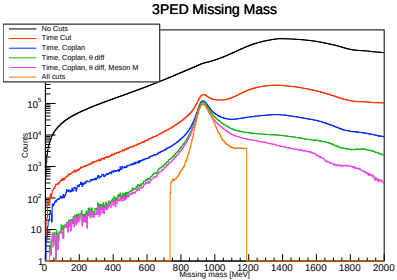
Analysis

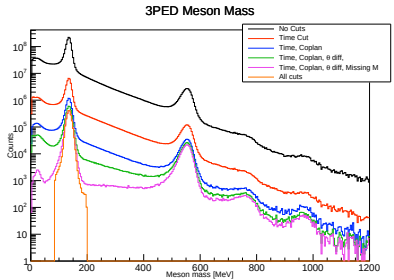
Event Selection

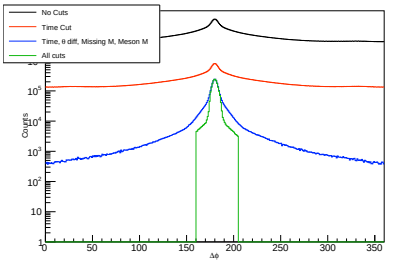
To remove background events some cuts are applied:

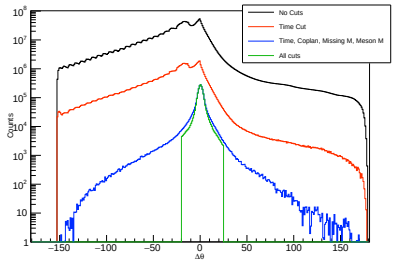
- Timecut: The event should coincide with an tagged photon
- Kinematic restraints require the incident photon, the proton and meson to be coplanar
- Predicted and measured angle of the Proton must be equal
- Invariant mass of the two photons equal to one pion
- Mass of the proton from known initial state

Event Selection



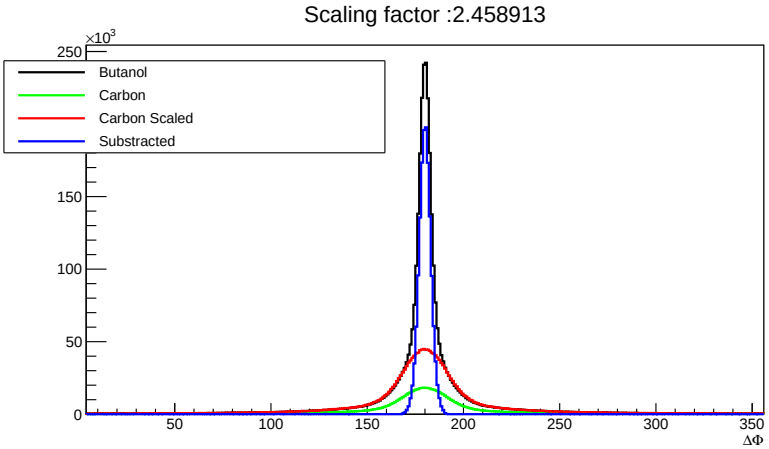




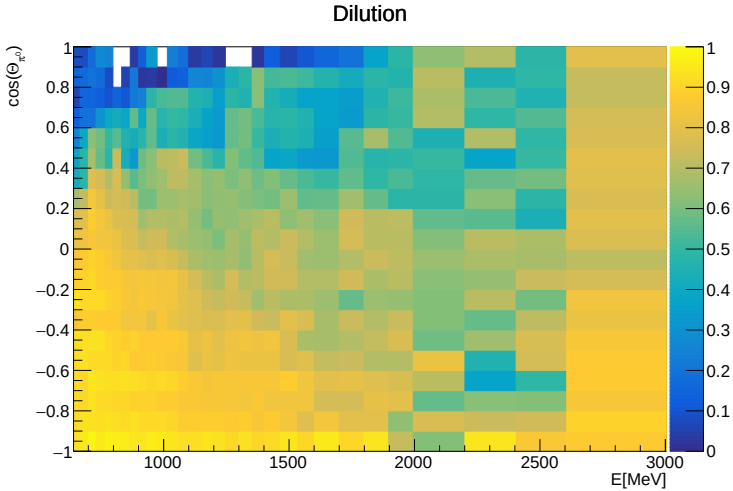


Background Subtraction

- Background is determined with a carbon target.
- The same event selection is applied
- More time with the butanol target ⇒ Background has to be scaled!

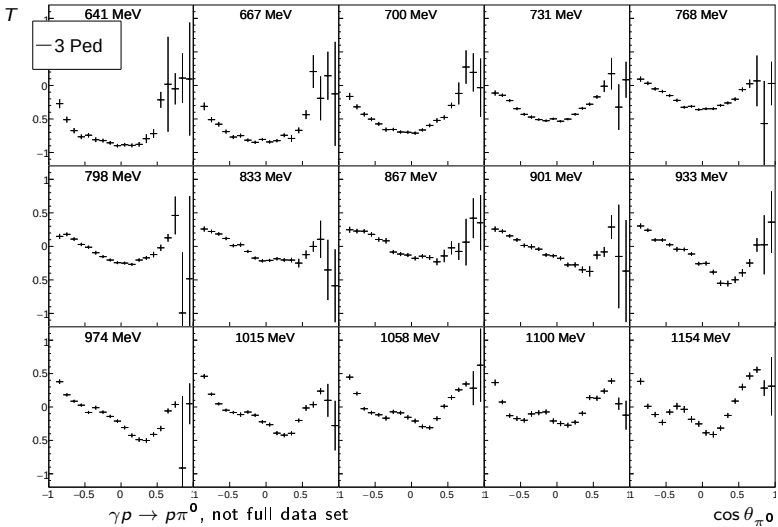


Dilution



$$d = \frac{N_{\text{butanol}} - s \cdot N_{\text{carbon}}}{N_{\text{butanol}}}$$

Getting Results


T
3 Ped
641 MeV
667 MeV
700 MeV
731 MeV
768 MeV
798 MeV
833 MeV
867 MeV
901 MeV
933 MeV
974 MeV
1015 MeV
1058 MeV
1100 MeV
1154 MeV
$\gamma p \to p\pi^0$, not full data set
$\cos\theta_{\pi^0}$

Forward Directions

3 PED

- measured all final states: 2 γ and proton
- in forward directions proton might get lost

Forward Directions

3 PED
- measured all final states: 2 γ and proton
- in forward directions proton might get lost

To get the forward direction, we need to look at 2.5 PED and 2 PED events.

Forward Directions

3 PED
- measured all final states: 2 γ and proton
- in forward directions proton might get lost

To get the forward direction, we need to look at 2.5 PED and 2 PED events.

2.5 PED
- Only the track information of the Proton could be reconstructed.
- Same event selection and background subtraction as 3 PED.

Forward Directions

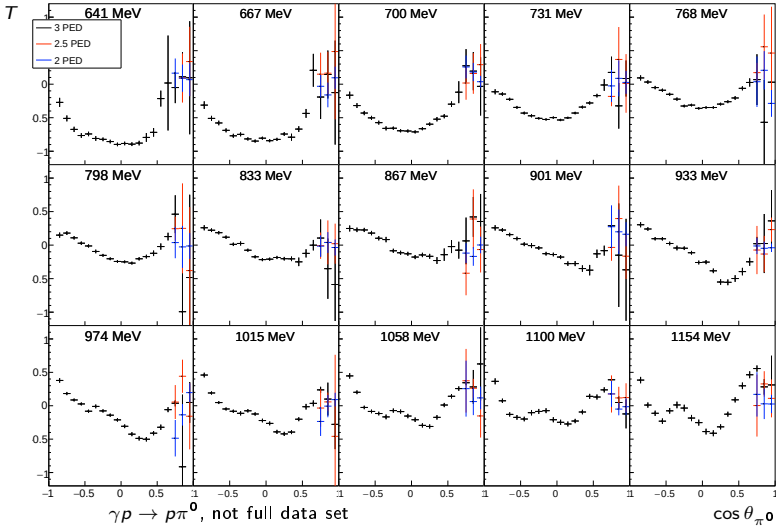
3 PED
- measured all final states: 2 γ and proton
- in forward directions proton might get lost

To get the forward direction, we need to look at 2.5 PED and 2 PED events.

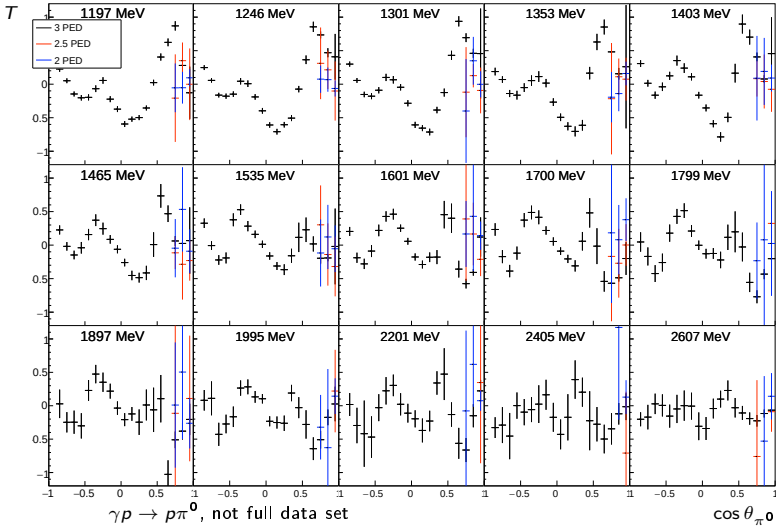
2.5 PED
- Only the track information of the Proton could be reconstructed.
- Same event selection and background subtraction as 3 PED.

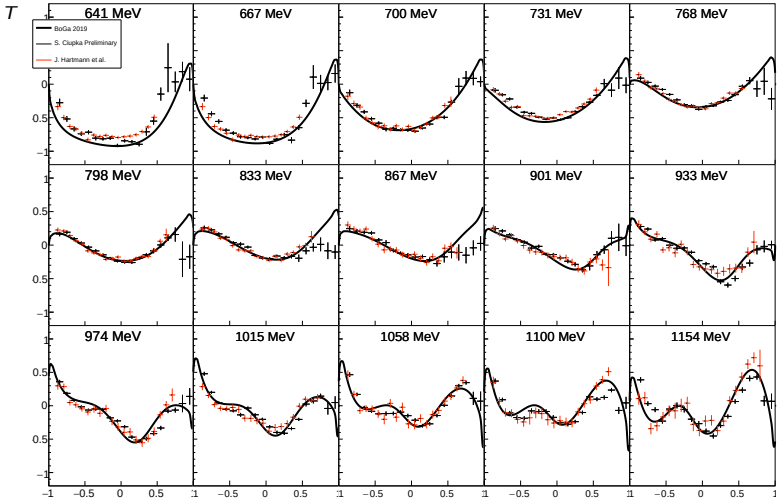
2 PED
- Proton could not be measured
- Direction can be reconstructed, since initial state is known
- Some cuts can not be used

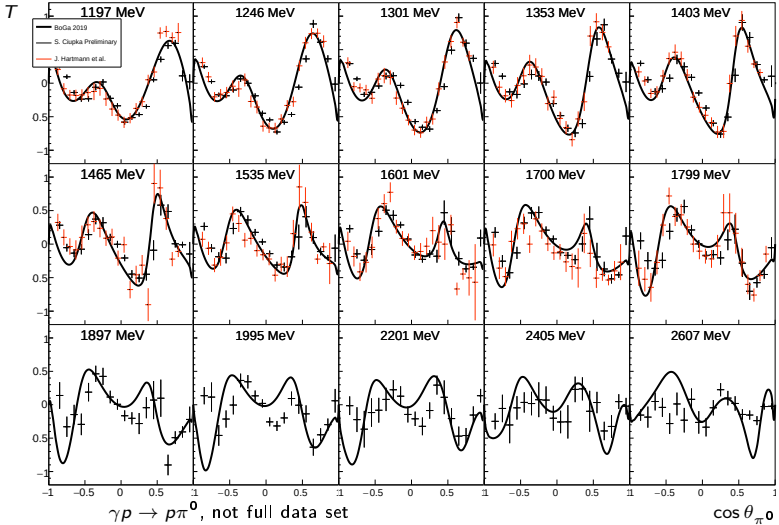
T Combined

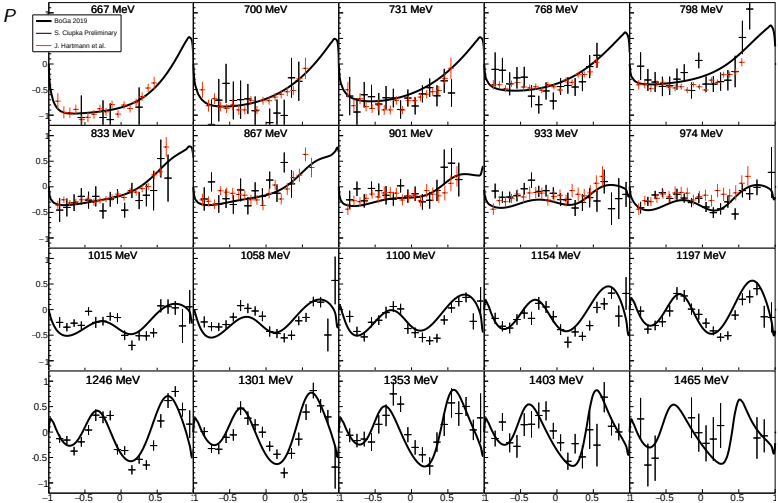

T
3 PED
2.5 PED
2 PED
641 MeV
667 MeV
700 MeV
731 MeV
768 MeV
798 MeV
833 MeV
867 MeV
901 MeV
933 MeV
974 MeV
1015 MeV
1058 MeV
1100 MeV
1154 MeV
$\gamma p \to p\pi^0$, not full data set
$\cos\theta_{\pi^0}$

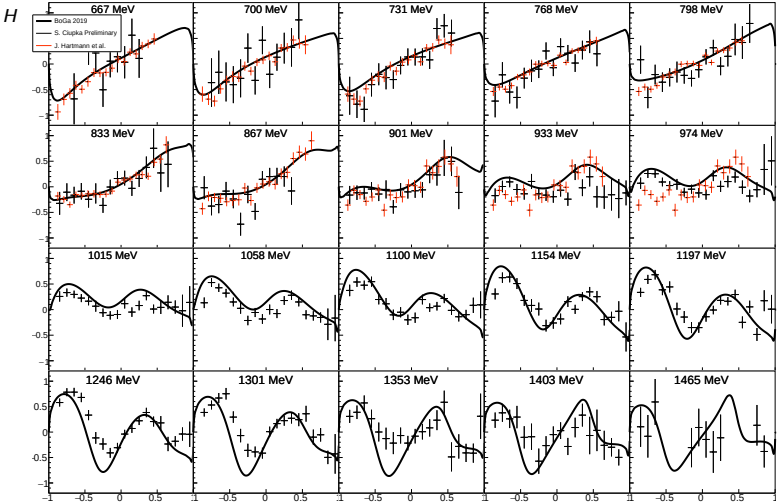
T Combined


T
3 PED
2.5 PED
2 PED
1197 MeV
1246 MeV
1301 MeV
1353 MeV
1403 MeV
1465 MeV
1535 MeV
1601 MeV
1700 MeV
1799 MeV
1897 MeV
1995 MeV
2201 MeV
2405 MeV
2607 MeV
$\gamma p \to p\pi^0$, not full data set
$\cos\theta_{\pi^0}$


T
BoGa 2019
S. Ciupka Preliminary
J. Hartmann et al.
641 MeV
667 MeV
700 MeV
731 MeV
768 MeV
798 MeV
833 MeV
867 MeV
901 MeV
933 MeV
974 MeV
1015 MeV
1058 MeV
1100 MeV
1154 MeV
$\gamma p \to p\pi^0$, not full data set
$\cos\theta_{\pi^0}$


T
1197 MeV
1246 MeV
1301 MeV
1353 MeV
1403 MeV
1465 MeV
1535 MeV
1601 MeV
1700 MeV
1799 MeV
1897 MeV
1995 MeV
2201 MeV
2405 MeV
2607 MeV
BoGa 2019
S. Ciupka Preliminary
J. Hartmann et al.
$\gamma p \to p\pi^0$, not full data set
$\cos\theta_{\pi^0}$

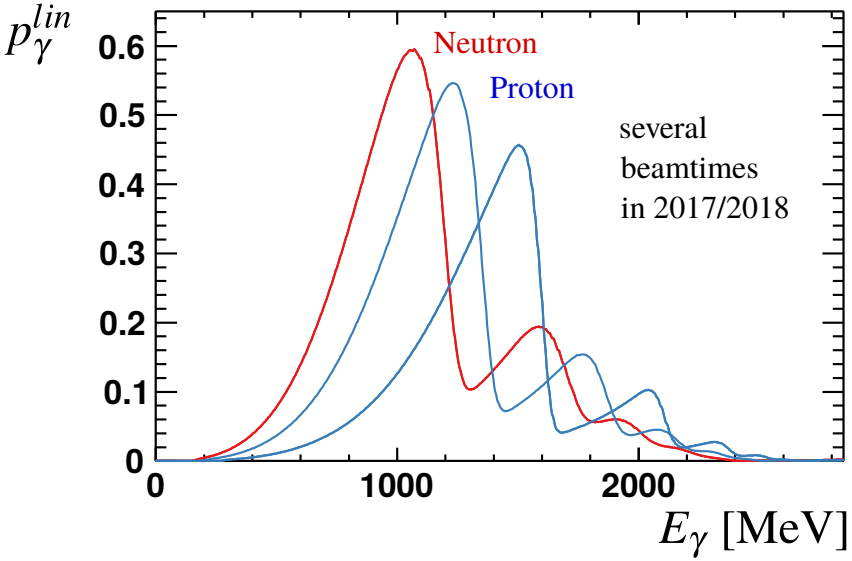

P
BoGa 2019
S. Ciupka Preliminary
J. Hartmann et al.
667 MeV
700 MeV
731 MeV
768 MeV
798 MeV
833 MeV
867 MeV
901 MeV
933 MeV
974 MeV
1015 MeV
1058 MeV
1100 MeV
1154 MeV
1197 MeV
1246 MeV
1301 MeV
1353 MeV
1403 MeV
1465 MeV
$\gamma p \to p\pi^0$, not full data set
$\cos\theta_{\pi^0}$


H
BoGa 2019
S. Ciupka Preliminary
J. Hartmann et al.
667 MeV
700 MeV
731 MeV
768 MeV
798 MeV
833 MeV
867 MeV
901 MeV
933 MeV
974 MeV
1015 MeV
1058 MeV
1100 MeV
1154 MeV
1197 MeV
1246 MeV
1301 MeV
1353 MeV
1403 MeV
1465 MeV
$\gamma p \to p\pi^0$, not full data set
$\cos\theta_{\pi^0}$

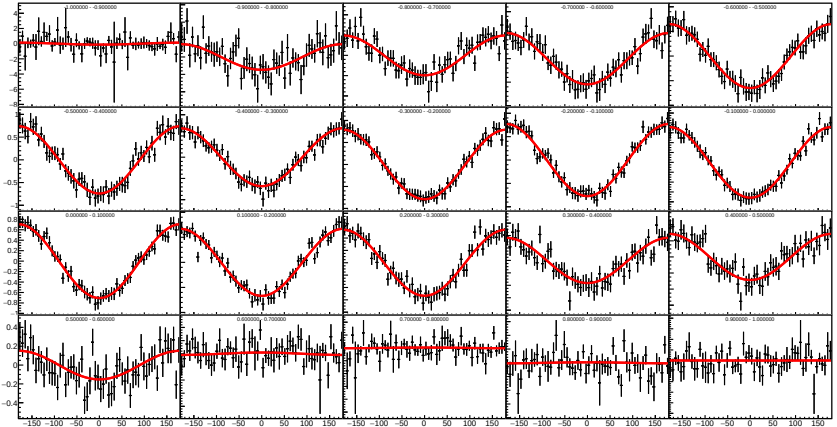
Thank you for your attention!

[1] C. Honisch et al. 'The new APD-Based Readout of the Crystal Barrel Calorimeter - An Overview' (forthcoming)

[2] J. Hartmann et al., PLB 748, 212 (2015)


p_γ^{lin}
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1000
2000
E_γ [MeV]
Neutron
Proton
several
beamtimes
in 2017/2018

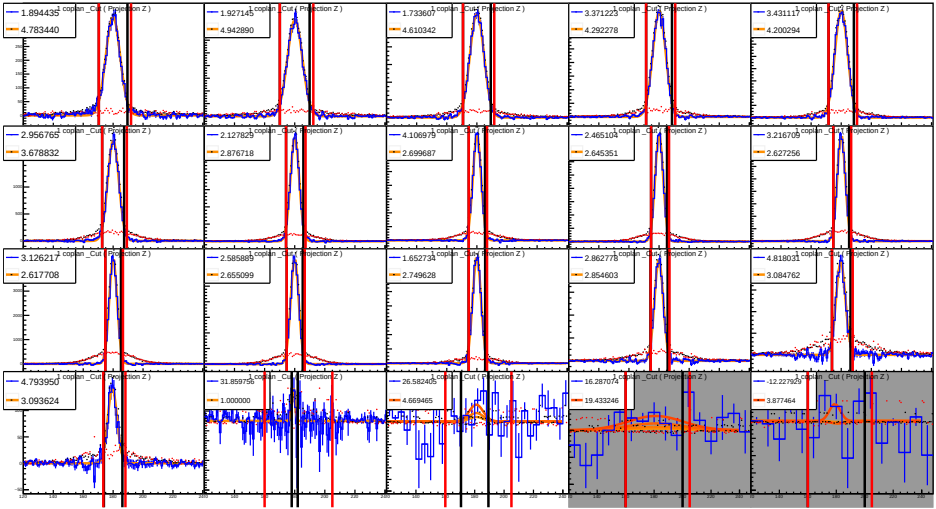
$A(\phi)$



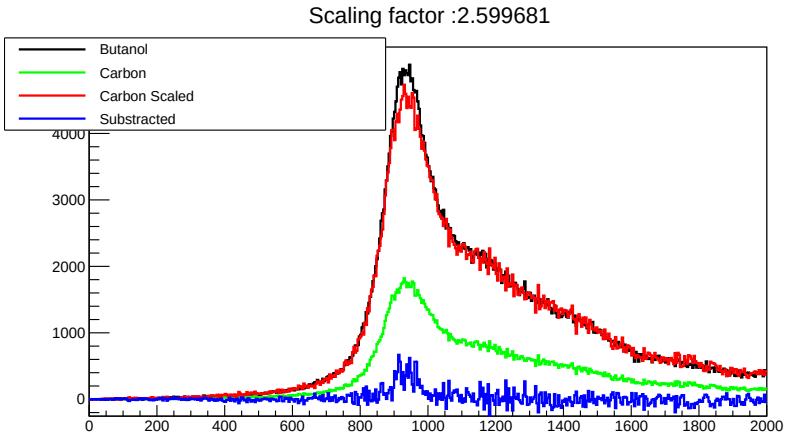
$$A(\phi) = \frac{1}{\Lambda} \cdot \frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow} = d \cdot T \cdot sin(\beta - \phi)$$

Cut Ranges

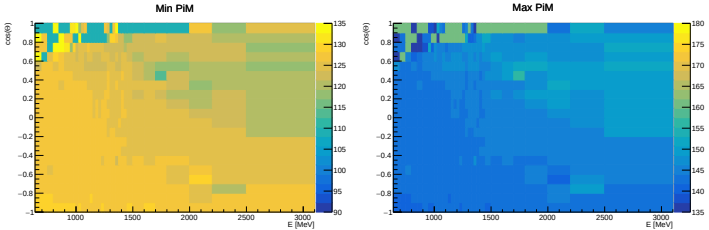
E=640MeV



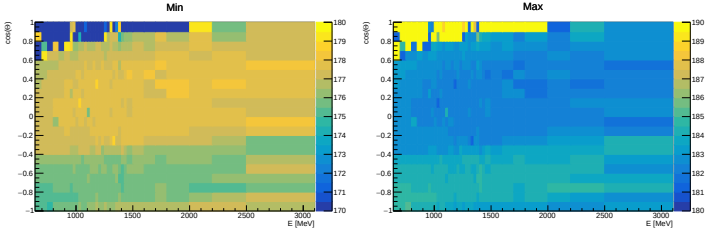
2 Ped Scaling



Cut-ranges

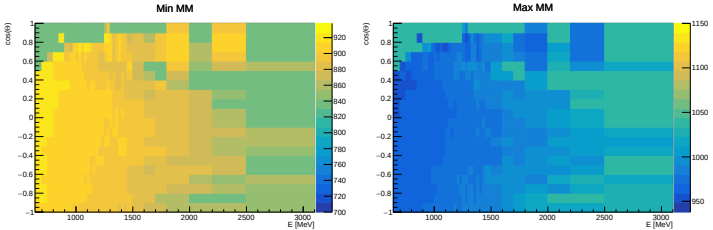


Meson Mass lower and upper cut

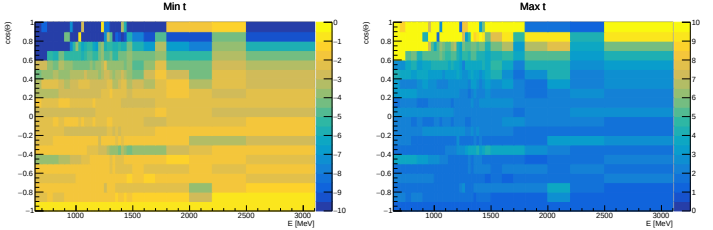


Coplanarity lower and upper cut

Cut-ranges 2



Missing Mass lower and upper cut



Theata difference lower and upper cut