

# Systematic Studies for the $\pi^0$ Calibration of the Crystal-Ball Detector

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# The Process

$$\gamma + p \rightarrow \pi^0 + p \rightarrow p + \gamma_1 \gamma_2 \quad (1)$$

$$m_{\pi^0} = \sqrt{2E_1 E_2 (1 - \cos(\alpha))} \quad (2)$$

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- How can it be checked if there is a energy dependency in the CB?  
 $\rightarrow |E_1 - E_2| < 25 \text{ MeV}$
- What are the reasons for the dependency?

# Crystal-Ball-Function / Reduction of the Underground

- Gaussian Fit Function  $\rightarrow$  Crystal-Ball Fit Function

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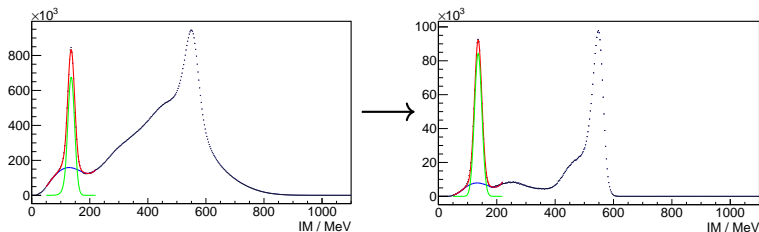


Figure: Beamtime: Example for not reduced and reduced underground

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→ There is no package with enough events
- Creating a new package with enough events would take to much time (multiple days on blaster)
- It would be better if the same generator is used for all studies  
→ The generator should be able to simulate MAMI-Beam and isotropic decay

# Event Generator

```

auto cmd_Emin      = cmd.add<TCLAP::ValueArg<double>> ("", "Emin", "Minimal incident energy [MeV]", false, 0.0, "double [MeV]");
auto cmd_Emax      = cmd.add<TCLAP::ValueArg<double>> ("", "Emax", "Maximal incident energy [MeV]", false, 1.6*GeV, "double [MeV]");
auto cmd_events     = cmd.add<TCLAP::ValueArg<int>> ("n", "", "number of events", false, 10000, "n");
auto cmd_reqsym     = cmd.add<TCLAP::SwitchArg> ("", "sym", "Require symmetric photon energies");
auto cmd_zboost     = cmd.add<TCLAP::SwitchArg> ("", "zboost", "Boost the Pions in z-Direction; True or False");
auto cmd_Prod       = cmd.add<TCLAP::SwitchArg> ("", "Prod", "Get the Product of the Pion; Change Beam Energy with E_min and E_max" );
  
```

Figure:  $\pi^0$ -Event Generator: Commands

- Emin: Minimal energy of the beam or the  $\pi^0$ , if Prod is false
- Emax: Maximal energy of the beam or the  $\pi^0$ , if Prod is false
- Events: Number of events
- Reqsym: Require  $|E_1 - E_2| < 25 \text{ MeV}$
- ZBoost: Boost the  $\pi^0$  in  $z$ -Direction
- Prod: Get the production of the  $\pi^0$

# No Additional Cut

- Beamtime October 2014
- No additional cut

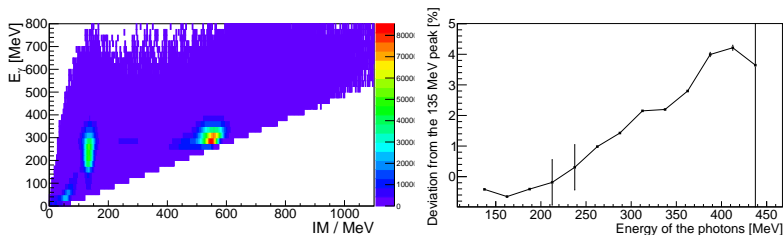
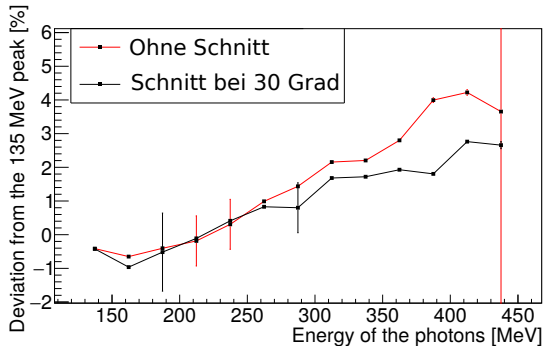


Figure: Beamtime: No additional cut

# Detectors on the Edge

- Beamtime October 2014
- Neglect the detectors at the edge

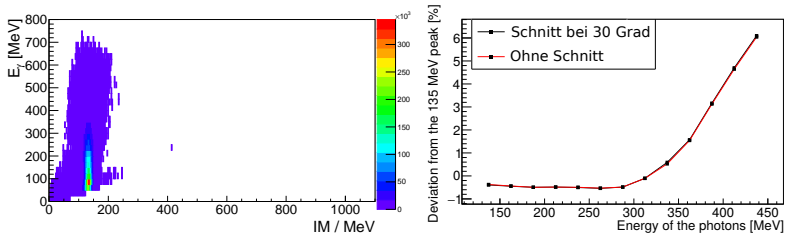


**Figure:** Beamtime: With and without considerations of the detectors on the edge of the beam entrance and exit



# Detectors on the Edge

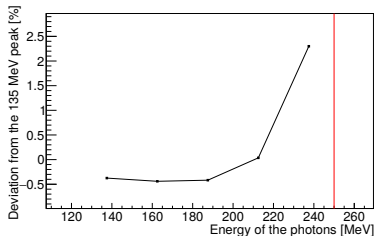
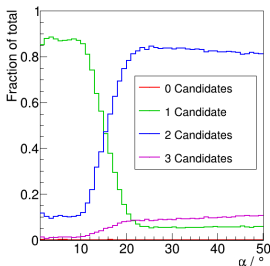
- Simulation
- Red: No additional cut  
Black: Neglect the detectors on the edge



**Figure:** Simulation: Left: Example for the two dimensional histogram with simulated data. Right: Deviation with and without the detectors on the edge

# Minimum Opening Angle

- Simulation
- Opening angle  $\alpha$  has to be bigger than  $30^\circ$  degree
- $m_{\pi^0} = \sqrt{2E_1E_2(1 - \cos(\alpha))}$  with  $E_1 \approx E_2$   
 $\rightarrow E_{max} \approx 250 \text{ MeV}$



**Figure:** Left: Number of reconstructed candidates for different opening angles. Right: Deviation with  $\alpha > 30^\circ$

# Isotropic Decay

- Simulation
- $\pi^0$  decay in the origin of the target
- $\pi^0$  are boosted isotropic with an energy of 1420 MeV to 1580 MeV

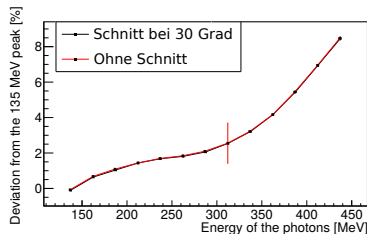
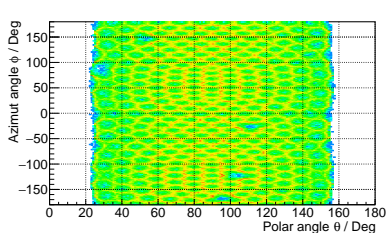


Figure: Simulation: Isotropic decay in the origin of the target

# $z$ -Vertex Dependency

- Simulation
- Neglect the detectors on the edge
- Devide the target in smaller sections of 1 cm

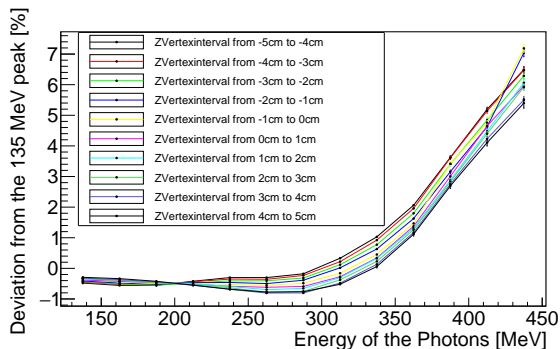
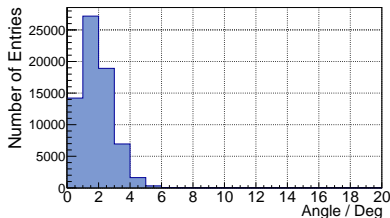
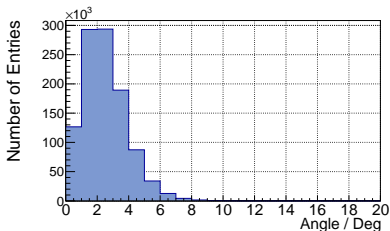


Figure: Simulation: Deviations for different  $z$ -Vertices

# Angle between Generated and Reconstructed Candidates

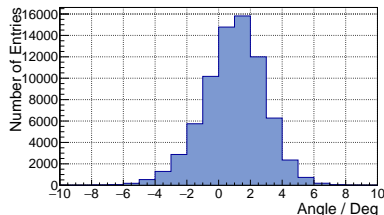
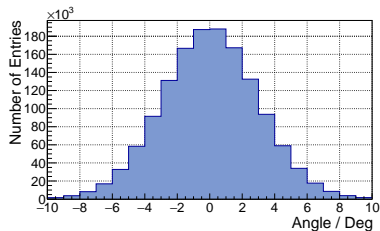
- Simulation
- The angle between generated and reconstructed candidate is calculated



**Figure:** Simulation: Angle between gen. and rec. candidates. Left: Photon energy between 125 MeV and 150 MeV. Right: Photon energy between 425 MeV and 450 MeV

# Difference between Generated and Reconstructed Opening Angle

- Simulation
- $\Delta\alpha = \alpha_{rec} - \alpha_{gen}$



**Figure:** Simulation:  $\Delta\alpha$  for different photon energies. Left 125 MeV to 150 MeV. Right from 425 MeV to 450 MeV

# $\Delta\alpha$ for Different $z$ -Vertices

- Simulation
- $\Delta\alpha$  for different  $z$ -Vertices

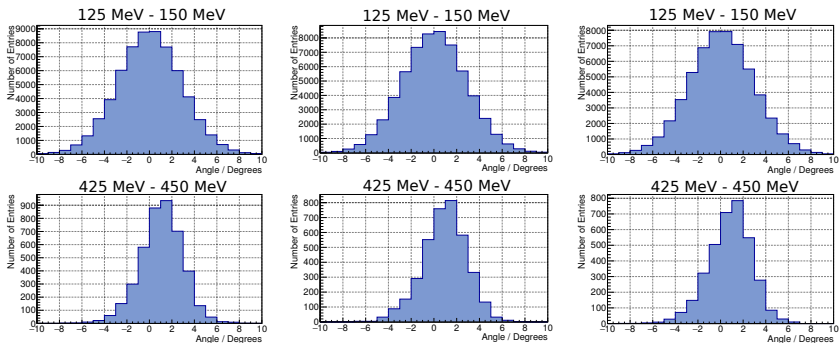


Figure: Simulation:  $\Delta\alpha$  for different photon energies. Decay at different  $z$ -Vertices (Beginning, Center and End)

# Hot Crystals

- Beamtime October 2014
- Photon energy between 0 MeV and 100 MeV

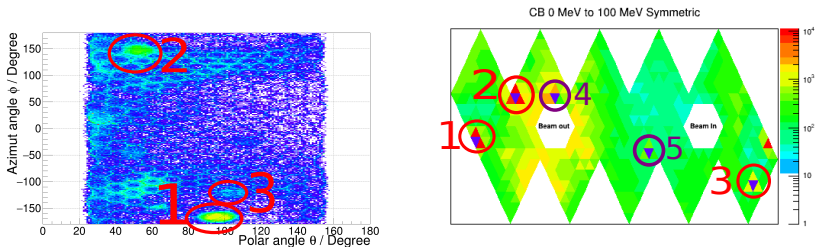


Figure: Beamtime: Marked are Hot and known Dead Crystals

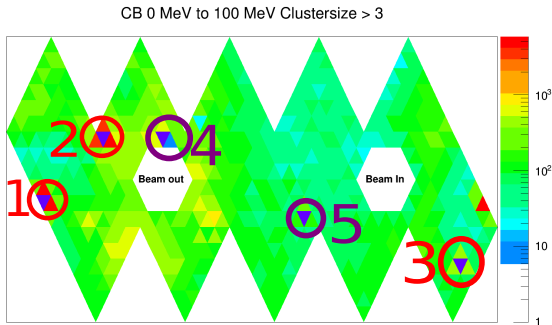
Table: Beamtime: Element No. and No. in figure

Number in the figures	1	2	3	4	5
Element Number	549	565	597	677	265



# Hot Crystals and Clustersize > 3

- Beamtime October 2014
- Photon energy between 0 MeV and 100 MeV
- Clustersize > 3



**Figure:** Beamtime: Marked are Dead and Hot Crystals. The Clustersize must be bigger than 3

# Hot Crystals for Higher Energies

- Beamtime October 2014
- Photon energy between 300 MeV and 400 MeV

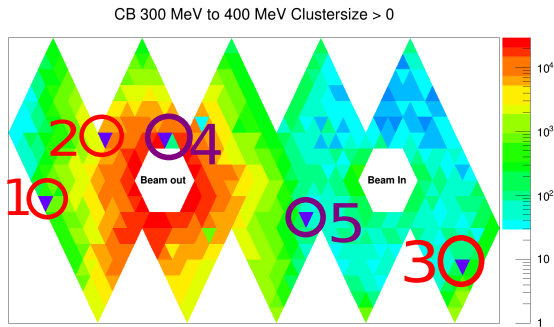


Figure: Beamtime: Marked are Dead and Hot Crystals for high energies

# Dead Crystals

- Beamtime October 2014
- Photon energy between 300 MeV and 400 MeV

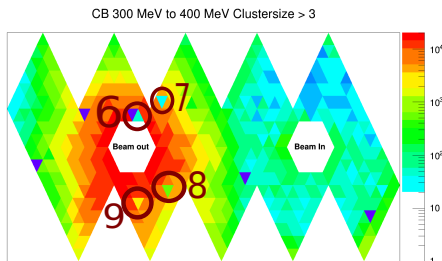


Figure: Beamtime: Marked are probably Dead Crystals

Table: Beamtime: No. of events for the Dead Crystals and their neighbors

No. in Fig.	Element Number	No. of Hits
6	678	48
	677	0
	676	11808
7	17	21
	16	3311
	18	7175
	19	3439
8	125	513
	122	6613
	128	5307
	126	4103
9	89	2500
	88	8591
	90	7975
	91	4652

# $\phi$ -Distribution in the CB

- Beamtime October 2014
- Photon energy between 200 MeV and 225 MeV

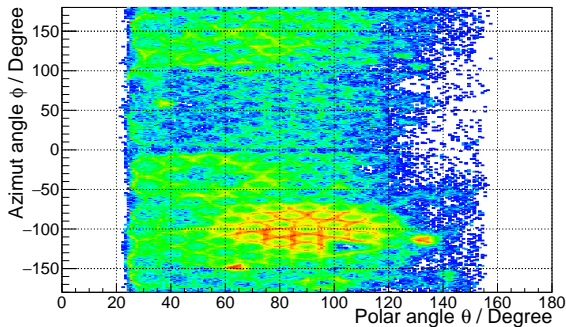
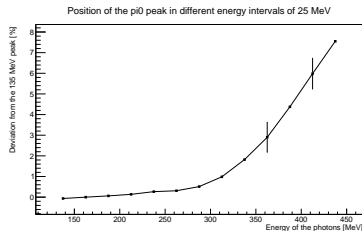
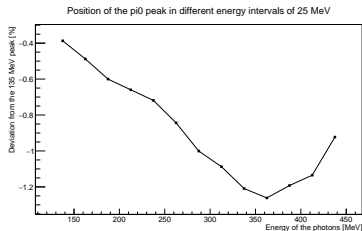


Figure: Beamtime: Distribution in the CB

# Conclusion

- There is a energy dependency in the detector
- The reconstructed opening angle is too big for high energies  
→ wrong reconstruction of the photon impact position is probably the reason for the dependency (Clustering Algorithm)
- The hardware of some PIDs has to be checked (too few or too many events)
- There is a strange  $\phi$ -distribution in the detector  
→ reason for this has also to be determined

# Appendix



**Figure:** Simulation: Left: Reconstructed energy and true opening angle.  
Right: True energy and reconstructed opening angle