

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

Martin Sobotzik

Johannes Gutenberg-Universität Mainz

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# The Process

$$\gamma + p \rightarrow \pi^0 + p \rightarrow \gamma_1 \gamma_2 + p$$

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- Is there an energy dependency in the CB?
- How can it be checked?  
 $\rightarrow |E_1 - E_2| < 25 \text{ MeV}$

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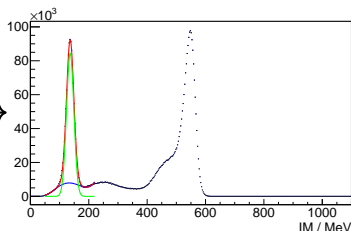
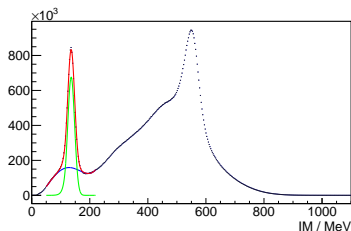
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- Is there an energy dependency in the CB?
- How can it be checked?  
 $\rightarrow |E_1 - E_2| < 25 \text{ MeV}$
- What are the reasons for the dependency?

# Reduction of the Underground / Crystal-Ball Function

- Check if the registered particles are uncharged  
→ Reduction of the underground
- Used signal line shape: Crystal-Ball Function



# Event-Generator

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# Event-Generator

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→ There is no MC sample with enough events
- Creating a new sample with enough events with an already existing Event-Generator would take too much time (multiple days on blaster). Not Efficient!
- It is better to use the same generator in all studies  
→ The generator should be able to simulate MAMI-Beam and isotropic boost

# Event-Generator in ANT

## New Event-Generator integrated in ANT

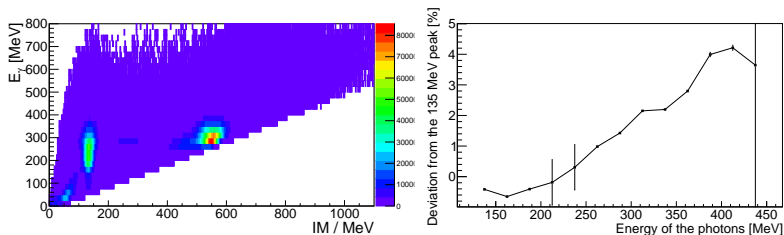
```

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" );
  
```

- Emin: Minimal energy of the beam/boost
- Emax: Maximal energy of the beam/boost
- Events: Number of events
- Sym: Require  $|E_1 - E_2| < 25$  MeV
- ZBoost: Boost the  $\pi^0$  in  $z$ -Direction, if false than isotropic boost
- Prod: Also takes the proton into account

# First look at real data

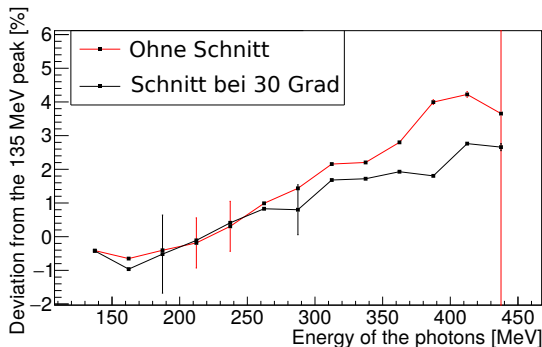
- Beamtime October 2014
- Well-calibrated



→ There is a energy dependency

# Detectors on the Edge

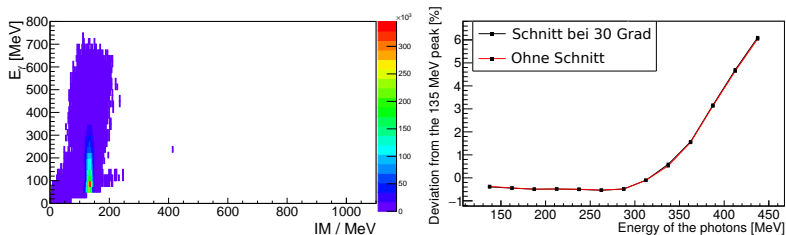
- Beamtime October 2014
- Neglect the detectors at the edge: They are difficult to calibrate because they have less neighbors



→ Slight improvement

# How does MC look like?

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

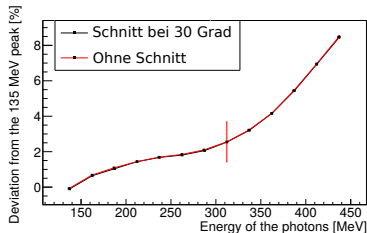
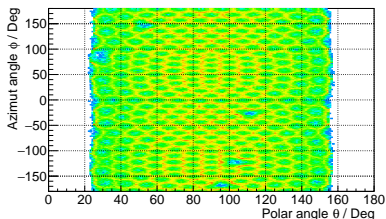


MC also shows this raise

→ it can be used for further studies

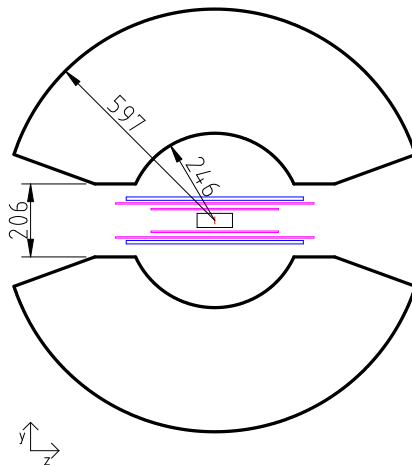
# Isotropic Boost

- $\pi^0$  decay in the origin of the target
- $\pi^0$  are boosted with an energy of 1420 MeV to 1580 MeV isotropically  
→ all detector elements are hit roughly equally



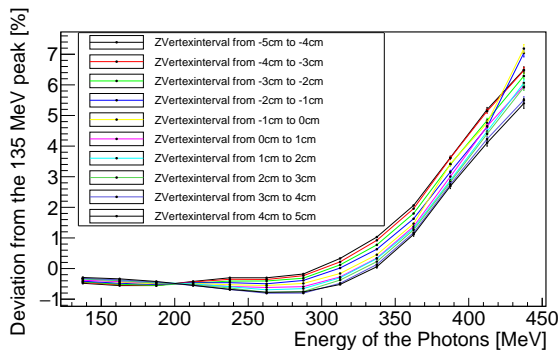
→ Raise is not caused by specific detector elements

# Dimension of the Target



# $z$ -Vertex Dependency

- Neglect the detectors on the edge
- Divide the target in sections of 1 cm

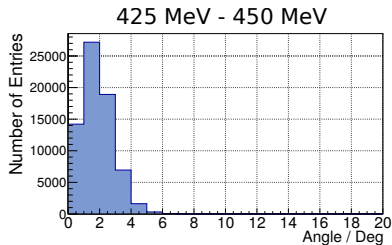
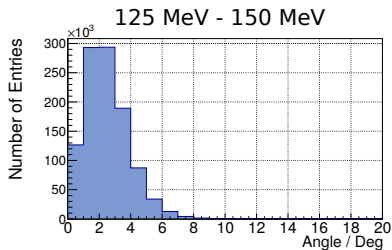


→ Some dependence but small in compared to the main effect



# Angle between Generated and Reconstructed Candidates

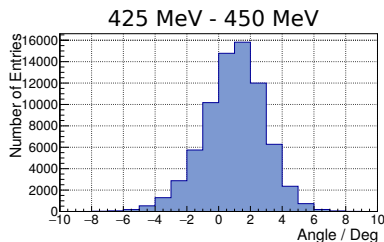
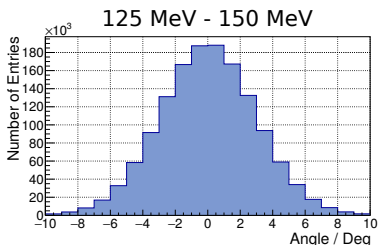
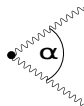
- The angle between generated and reconstructed candidate is calculated



→ Angular resolution  $\sim 1^\circ$  to  $2^\circ$

# Difference between Generated and Reconstructed Opening Angle

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



→ Systematic bias for high photon energies

# Reason for the Deviation?

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

$$\rightarrow \Delta m_{\pi^0} = \sqrt{E_1 E_2} \cdot \cos\left(\frac{\alpha}{2}\right) \cdot \Delta\alpha$$

with  $E_1 = E_2 = 450 \text{ MeV} \rightarrow \alpha \approx 17.3^\circ$

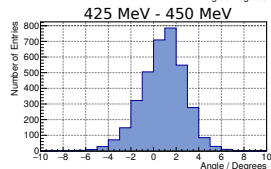
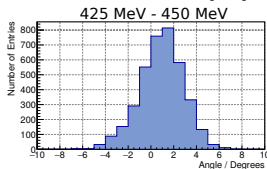
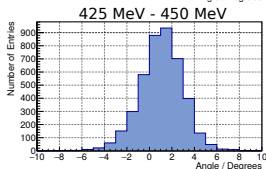
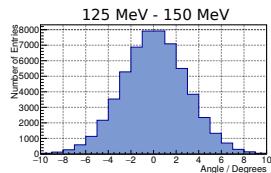
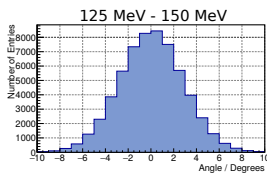
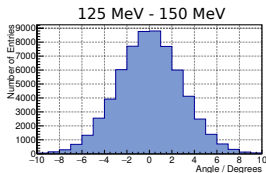
Lets assume:  $\Delta\alpha = 1.0^\circ \cdot \frac{\pi}{180^\circ}$

$$\rightarrow \Delta m_{\pi^0} = 7.8 \text{ MeV}$$

Which is a deviation of about 6% to the true  $m_{\pi^0}$  mass

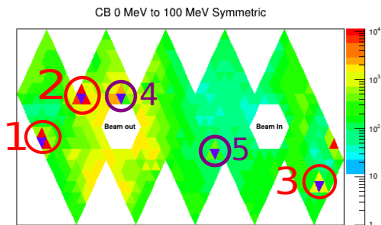
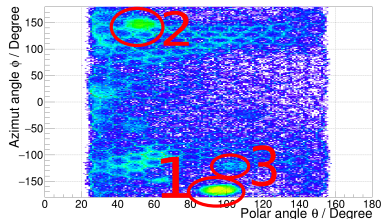
# $\Delta\alpha$ for Different $z$ -Vertices

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



# Hot Crystals

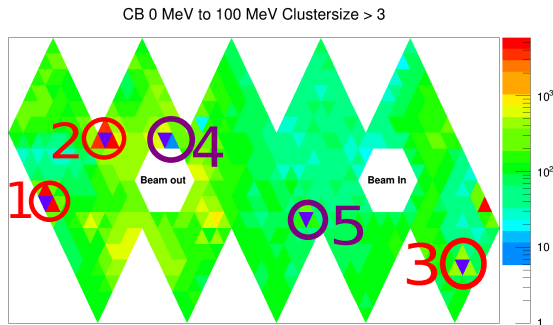
- Beamtime October 2014
- Photon energy between 0 MeV and 100 MeV



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

# Hot Crystals and Clustersize > 3

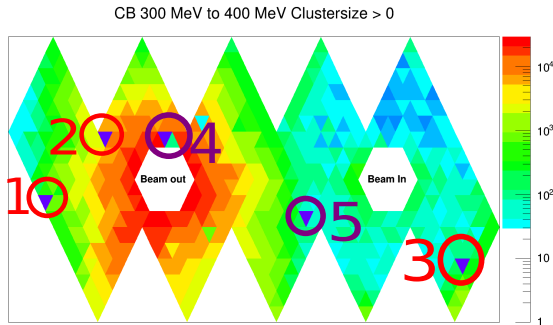
- Beamtime October 2014
- Photon energy between 0 MeV and 100 MeV
- Clustersize > 3



→ Neighbors of some dead crystals appear hot for low energies

# Hot Crystals for Higher Energies

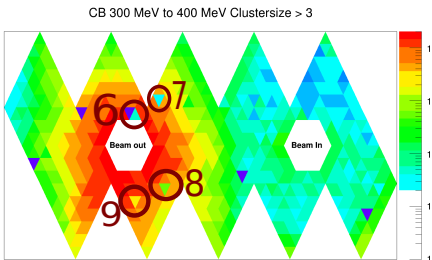
- Beamtime October 2014
- Photon energy between 300 MeV and 400 MeV



→ *Hot Neighbors* disappear at larger energies

# Additional Dead Crystals

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

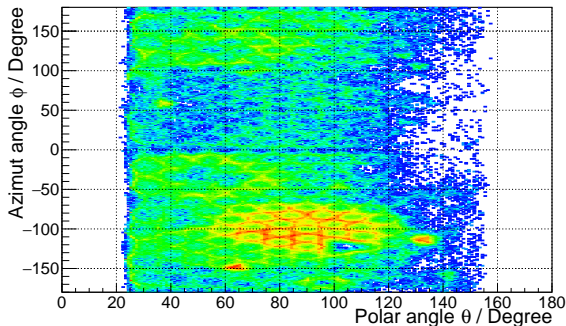


No. in Fig.	Element Number	No. of Hits
6	678	48
	677	0
	676	11808
7	17	21
	16	3311
	18	7175
	19	3439
8	125	513
	122	6613
	128	5307
	126	4103
9	89	2500
	88	8591
	90	7975
	91	4652



# $\phi$ -Distribution in the CB

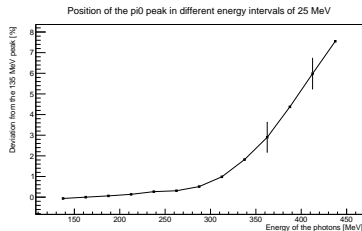
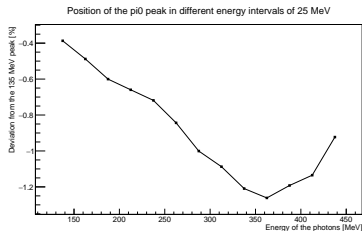
- Beamtime October 2014
- Photon energy between 200 MeV and 225 MeV
- Weird bump



# 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 detectors have to be checked (too few or to 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