BazookaPET: A Prototype Detector for a Novel High-Resolution PET system

2012 Workshop on Small-Animal SPECT

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0

BazookaPET

Overview

1. What is BazookaPET?
2. Motivations
3. Experimental setup
4. Maximum likelihood estimation for SiPM signals
5. Experimental results
6. Challenges in association between SiPM and CCD signals
7. Conclusions
8. Future work

College of Optical Sciences

The University of Arizona, Center for Gamma-Ray Imaging

NIBIB

TRIF Technology & Research Initiative Fund

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1

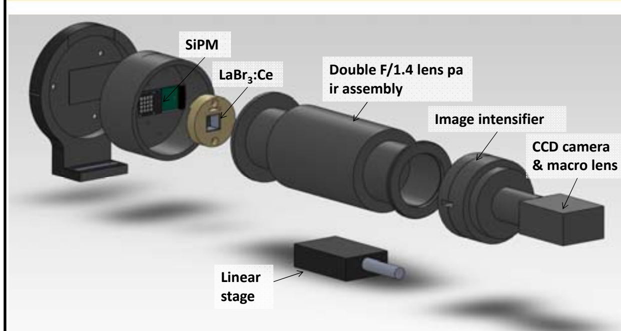
Item 1

What is BazookaPET?

2

BazookaPET

What is BazookaPET?



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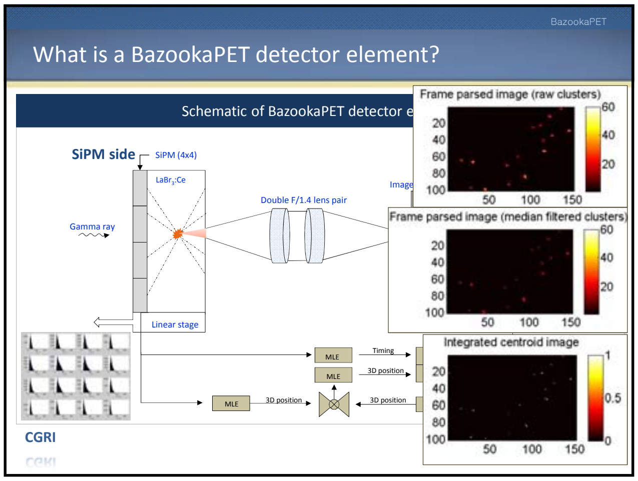
3


BazookaPET
What is a BazookaPET detector element?
Schematic of BazookaPET detector e
SiPM side
SiPM (4x4)
LaBr3:Ce
Gamma ray
Double F/1.4 lens pair
Image
Linear stage
MLE
Timing
3D position
Frame parsed image (raw clusters)
Frame parsed image (median filtered clusters)
Integrated centroid image
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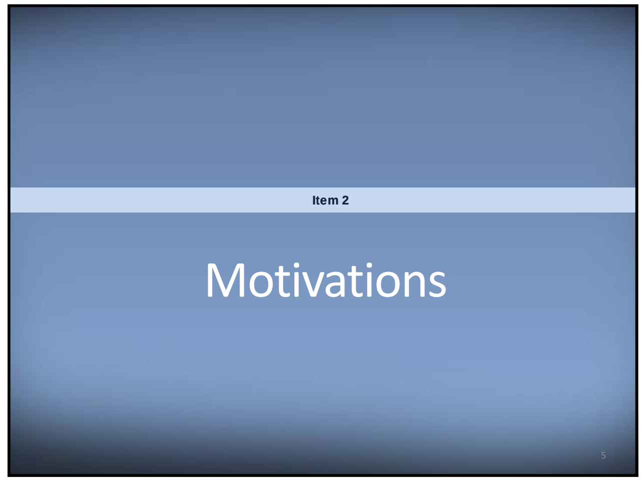
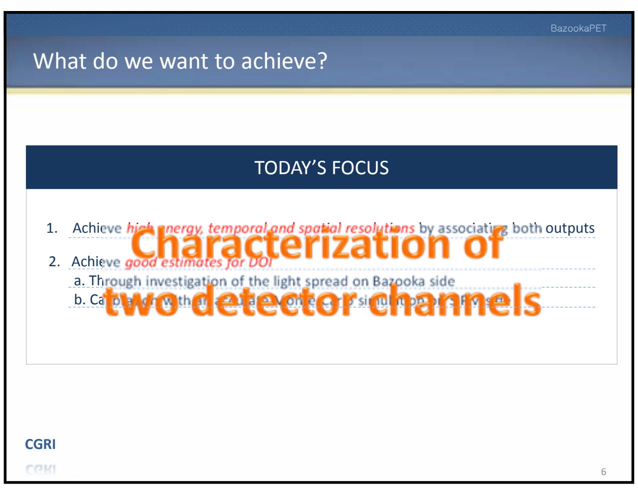

Item 2
Motivations


BazookaPET
What do we want to achieve?
TODAY'S FOCUS
1. Achieve high energy, temporal and spatial resolutions by associating both outputs
2. Achieve good estimates for DOI
a. Through investigation of the light spread on Bazooka side
Characterization of two detector channels
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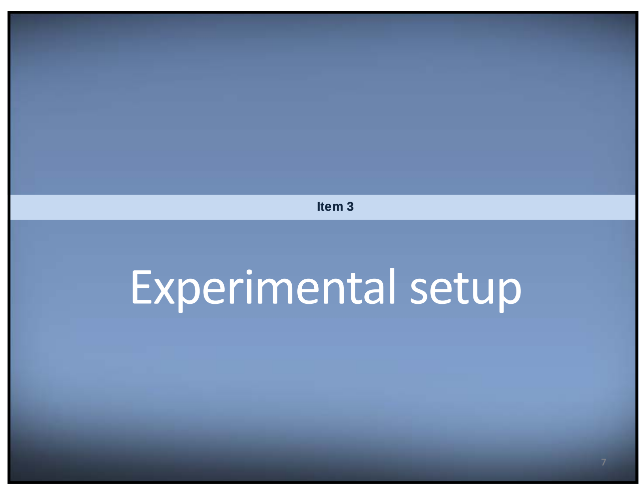
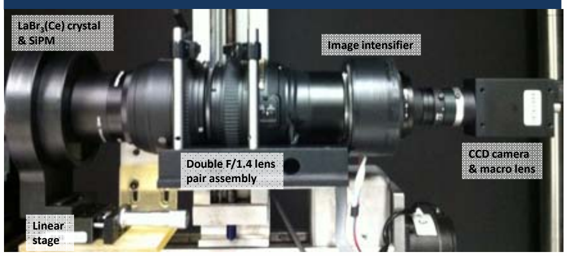
6


Item 3
Experimental setup

Detector element

BazookaPET detector element



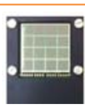
Scintillation crystal – monolithic $LaBr_3$:Ce

$LaBr_3$:Ce

Saint Gobain : BrillanCe 380	
Housing	Aluminum
Housing size	18 x 18 x 11 mm^3
Crystal size	13 x 13 x 5 mm^3
Light guide window size	13 x 13 x 3 mm^3
Side treatment	Absorptive (black)

SiPM side: module components

Silicon photomultiplier array / readout & DAQ system



SiPM array

SiPM active base

SiPM Interface Module/ FPGA-Based ADC

Hamamatsu	
Number of pixels	16 (4x4) pixels
Effective area/pixel	3.0 x 3.0 mm
Number of microcells/pixel	3600
Avg. gain	7.5 x 10^5

AiT Instruments

The sum of the 16 pixel outputs from the interface module is discriminated by the internal constant-fraction discriminator or an external trigger device

Bazooka side: module components

Bazooka side

Double f/1.4 lens pair

Image intensifier

CCD camera

Nikon	ProxiVision	PointGrey Research
Back-to-back configuration (reduces aberrations)	Double micro channel plate Input diameter: 25mm Photocathode: S20 on Fiber optic Phosphor screen : P43 on clear glass Gain at 480nm : 1.3 x 10^7	Up to 200 fps Pixel size: 7.4µm x 7.4µm Max. resolution: 640 x 480 pixels

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Maximum likelihood estimation for SiPM signals

Maximum likelihood estimation for SiPM signals

MLE maximizes the probability of the data given the parameter:

$$\hat{\theta}_{\mathrm{ML}} \equiv \underset{\theta}{\operatorname{argmax}}\ \mathrm{pr}(\mathrm{g}|\theta)$$

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Barrett, H. H. and Myers, K.J., 2004
Barrett et. al, 2009
Kupinski, M. A. and Barrett, H. H., 2005

Likelihood of SiPM signals

Gaussian model

Assumption : each pixel is statistically independent

$$\mathrm{pr}(\mathbf{g}|\,\boldsymbol{\theta}) = \frac{1}{\sqrt{(2\pi)^M \prod_{m=1}^{M} K_{mm}(\boldsymbol{\theta})}} \exp\left\{-\frac{1}{2}\sum_{m=1}^{M} \frac{[g_m - \bar{g}_m(\boldsymbol{\theta})]^2}{K_{mm}(\boldsymbol{\theta})}\right\},$$

where K_{mm} is the variance of the final pixel value in the m^{th} pixel
g_m is the final pixel value in the m^{th} pixel

Calibration data are obtained experimentally

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Barrett, H. H. and Myers, K.J., 2004
Barrett et. al, 2009
Kupinski, M. A. and Barrett, H. H., 2005

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Experimental results

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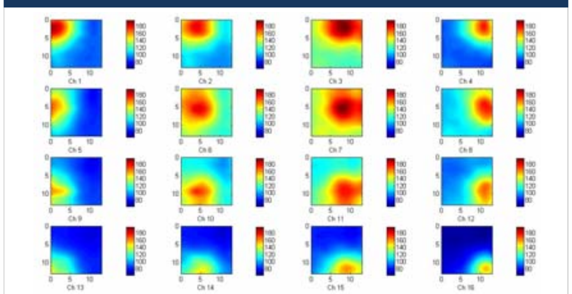
SiPM side: 2D MDRF(x, y, E= 662keV)

Mean detector response function (MDRF) [13mm x 13 mm @ 662 keV]



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16

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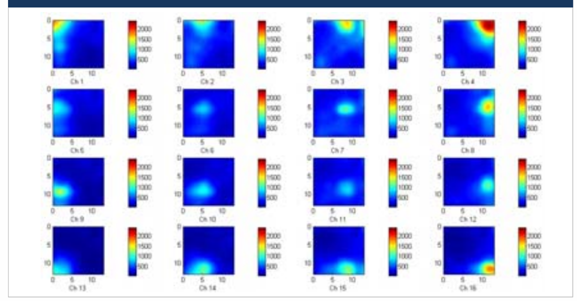
SiPM side: 2D VDRF(x, y, E= 662keV)

Variance detector response function (VDRF) [13mm x 13 mm @ 662 keV]



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17

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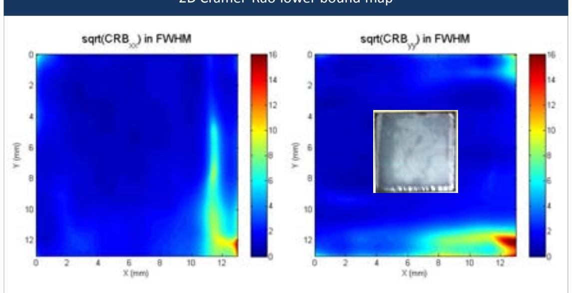
SiPM side: 2D Cramér-Rao lower bound

2D Cramér-Rao lower bound map



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18

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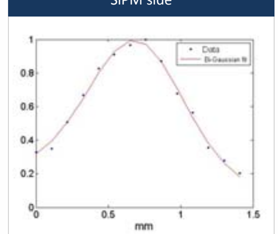
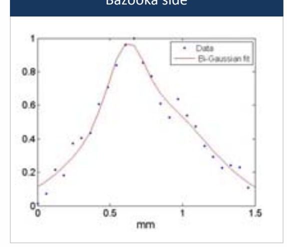
Trace comparison

Cs^{137} (662keV) Integrated trace of a slit beam image [Collimated 0.6mm slit beam]

SiPM side



Bazooka side



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19

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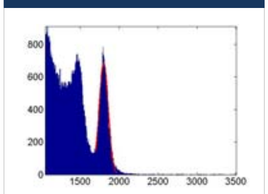
Energy resolution comparison

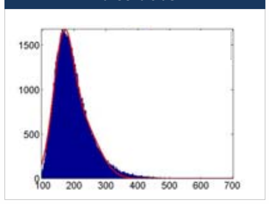
Cs^{137} (662keV) gamma-ray energy spectrum
[Collimated 1mm x 1mm cross-slit beam]

SiPM side



Energy resolution : ~ 5.3%

Bazooka side



Energy resolution : ~ 48%

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20

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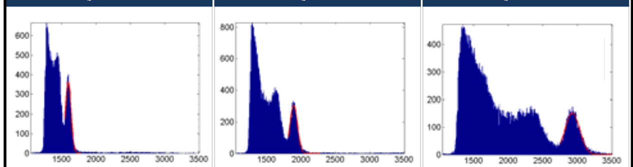
SiPM side: energy resolution

Cs^{137} (662keV) gamma-ray energy spectrum
[Collimated 508μm x 508μm cross-slit beam]

V_b= 71.8V	V_b= 72V	V_b= 72.5V



Overvoltage vs. Energy resolution

71.8V	72V	72.5V
4.2%	4.7%	6.0%

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21

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Challenges in association between SiPM and CCD signals

22

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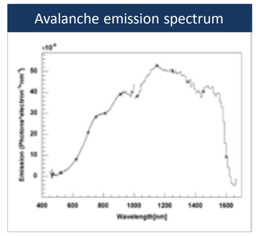
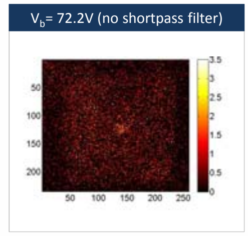
Challenges in association: Bazooka side

Difficult to discriminate between scintillation photons from avalanche emission photons from SiPM array

Avalanche emission spectrum



V_b= 72.2V (no shortpass filter)



Integrated centroid images with a collimated gamma-ray beam (1mm x 1mm)

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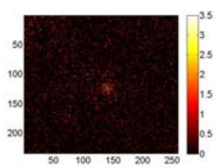
R. Mirzoyan et al., Nuclear Instruments and Methods in Physics Research Section A, 2009

23

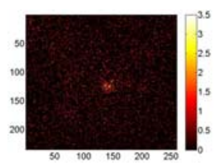
Challenges in association: Bazooka side

Filter photon emission from SiPM by inserting a shortpass filter with IR absorbing glass

V_b= 0V (with shortpass filter)



V_b= 72.2V (with shortpass filter)



Integrated centroid images with a collimated gamma-ray beam (1mm x 1mm)

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R. Mirzoyan et al., Nuclear Instruments and Methods in Physics Research Section A, 2009

Item 7

Conclusions

Conclusions

Summary

1. Completed the prototype detector element setup
2. Completed the initial calibration of both SiPM and Bazooka sides
   - SiPM side: obtained ML position estimates based on Gaussian model
   - Bazooka side: obtained centroid position estimates using frame parsing
3. Measured energy resolution for both SiPM and Bazooka sides
4. Even with defects in the crystal packaging, the spatial resolution advantage of the Bazooka side is evident

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Future work

Future work

1. Improve the stability of the SiPM side with temperature control
2. Optimize the rejection of the light emission from SiPM avalanches
3. Develop ML estimation of 3D interaction position and energy
4. Develop the synchronization mechanism
5. Complete the PET system configuration

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References

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