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MuGrid: a novel plastic scintillator detector with light guide array and WLS fibers

Tao Yu[1], Aiyu Bai[1], Yi Yuan[1], Yunsong Ning[1], Mingchen Sun[1], Shihan Zhao[1], Zhencheng Huang[1], Yu Chen[1], Jian Tang[1]

[1] School of Physics, Sun Yat-sen University, Guangzhou 510275, Guangdong, China

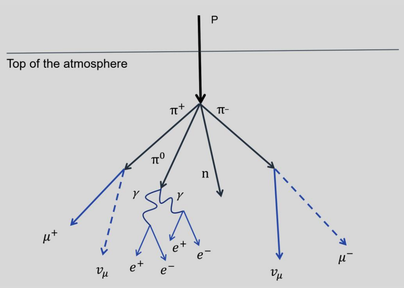
Abstract: *As muography has spawned many novel interdisciplinary applications, we developed a scintillator detector named MuGrid, designed for enhanced stability and cost-effectiveness. It is adept at functioning optimally in a variety of challenging environments. By coupling the plastic scintillator with the light guide array, MuGrid could achieve a higher spatial resolution and a larger acceptance angle with fewer readout channels. Simulation results indicate that a spatial resolution better than 3mm is attainable on a 30cm x 30cm planar scintillator.*

Abstorption muography for interdisciplinary applications

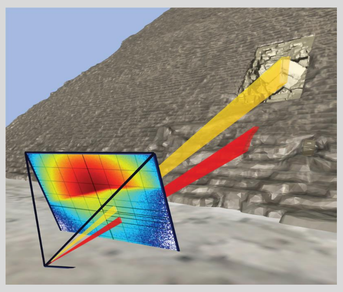
- Cosmic muons interact with matter primarily through ionization and its energy loss over the mass thickness dE/dx is described by Bethe-Bloch formula. [1]

$$-\frac{dE}{dx} = Kz^2\frac{Z}{A}\frac{1}{\beta^2}\left[\frac{1}{2}ln\left(\frac{2m_e c^2\beta^2\gamma^2 W_{max}}{I^2}\right) - \beta^2 - \frac{\delta}{2}\right]$$

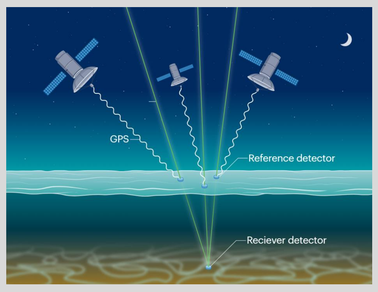
- Based on the formula above, muons can be used to probe the internal composition of overburden. Muography is considered to have broad application prospects in different fields like archaeology and geology.
- In recent years, various interdisciplinary applications such as underground navigation have emerged, which benefited from the specific properties of cosmic-ray muons.



Air shower created by primary cosmic-ray

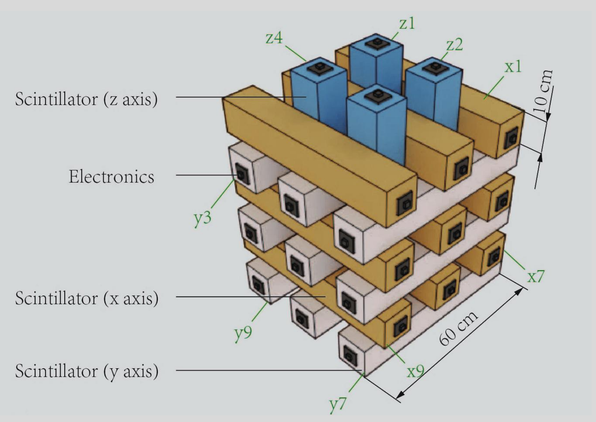


Use muography to probe the inner structure of Khufu Pyramid[2]

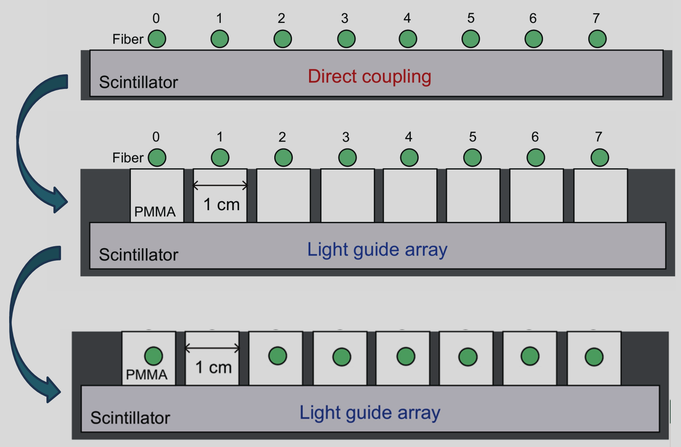


Cosmic ray muon underwater navigation[3]

The improvements of MuGrid-v2 over previous generation



MuGrid-v1 Structure diagram

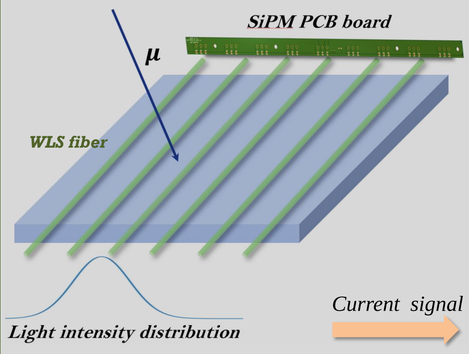


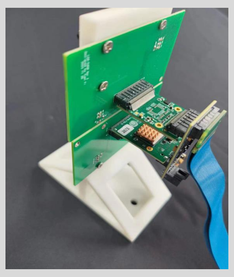
Design evolution of MuGrid-v2.

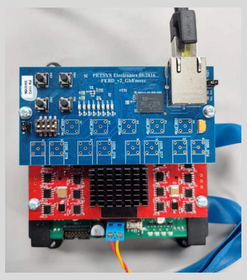
- Assembled with several pieces of scintillator strips(10 x 10 x 60 cm).
- Spatial resolution is about 10cm.
- Electronics readout system with MIDAS contains a maximum of 64 channels.
- Heavy, usually need to be reassembled at the deployment site.

- Use a light guide array to split a whole block scintillator to pixels.
- Spatial resolution is **better than 1cm**
- Adopt PETsys TOF evaluation kit which allows us to read out most **1024 SiPM channels**.
- **Lightweight** and can be transported as a whole detector.

MuGrid lectronic system

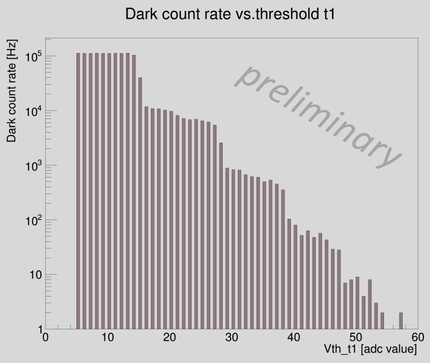






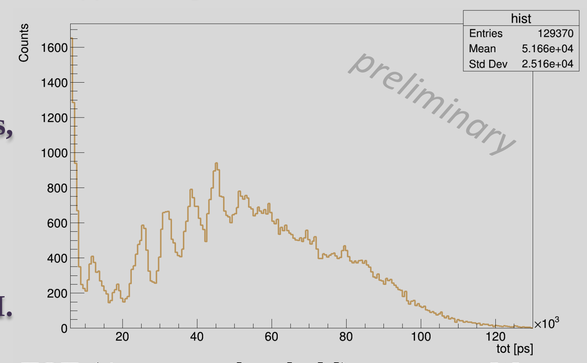
Current signal → FEB module& TOFPET ASIC → *Digital signal* → Mother board → *Gigabit Ethernet* → Upper computer

- PETsys TOFPET2 ASIC offers discrimination for 64 independent channels.
- We choose tot mode rather than qdc mode as our typical signal is small.



We can see the dark count rates abruptly decreases correspond to the levels of 1 p.e. and 2p.e.

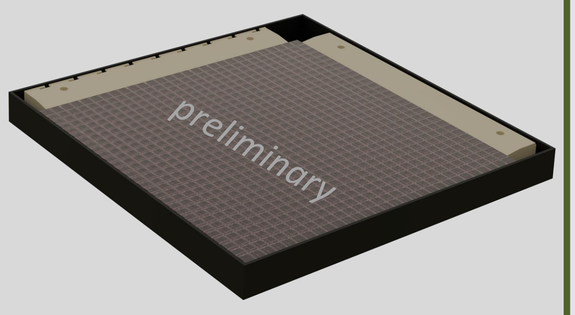
Combining these two sets of results, we can convert the TOT data to the number of photoelectrons detected by SiPM.



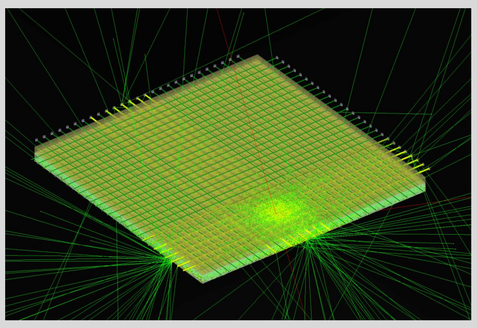
TOT (time over threshold) spectrum. We can clearly identify several photon peaks but we can not assert exact numbers as smaller peaks may be rejected by the threshold.

Simulation and test of MuGrid-v2

- We produced a 30 cm x 30 cm MuGrid-v2 prototype, and it was replicated in Geant4.
- There are 27 WLS fibers on each side, and each end of the fiber is connected with a SiPM.
- We compared different surface treatments in Geant4 and find that diffuse reflection surface can collect more photons than specular reflection surface, so we sprayed TiO_2 on the scintillator surfaces.

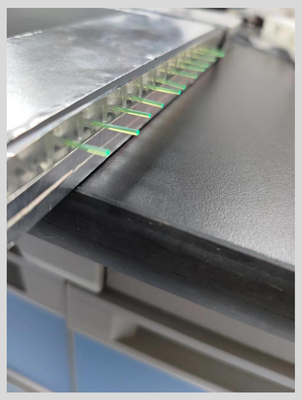


Structure of MuGrid-v2. The white part is the 3d printed WLS fiber coupling module. The black part is the shell, which also acts as a light shield.



A trigger event in Geant4, we can see fibers near the hit position emit photons, so we can reconstruct the hit point from SiPM's signal amplitude.

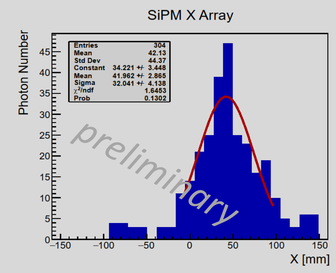
Compact
Low weight
Low cost
Easy Deploy

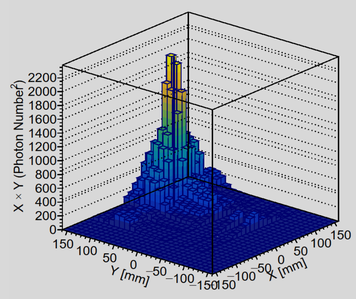


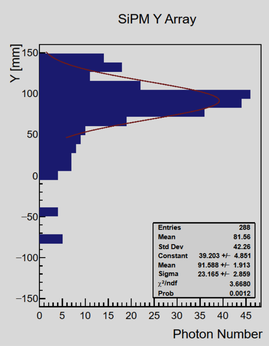
Assembly process

- We can see the reconstruction results both in simulation and experiment.
- Because of diffuse reflection, some channels far from the hit location can also detect photon signals, which can be removed by setting appropriate thresholds.

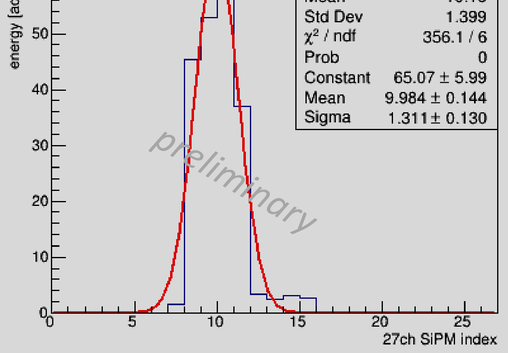
Geant4 simulation results show the resconstruction in x and y directions. Bottom left figure shows a two-dim distribution of photon numbers.

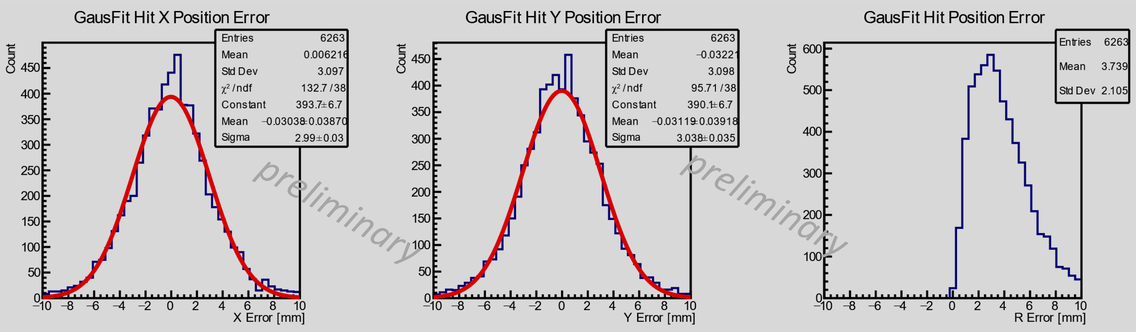






Experiment results, close to the simulation. Note that the energy means the amplitude of the signal.





Error analysis: we calculate the difference between reconstructed position and true hit position. Using Gaussian distribution to fit the error in the x and y directions, the FWHM is about 3mm. Right figure shows the distance error.

The current experiment results validate the usability of MuGrid, and we hope to soon carry out muography applications. We Look forward to utilize MuGrid to various disciplinary scenarios!!

Acknowledgements

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Team

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2. Morishima, K., Kuno, M., Nishio, A. et al. Discovery of a big void in Khufu's Pyramid by observation of cosmic-ray muons. *Nature* 552, 386–390 (2017).
3. Tanaka, H.K.M., Bozza, C., Bross, A. et al. Muography. *Nat Rev Methods Primers* 3, 88 (2023).