

The 7th International Conference  
"Charged & Neutral Particles  
Channeling Phenomena Channeling  
2016"



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**Geant 4**

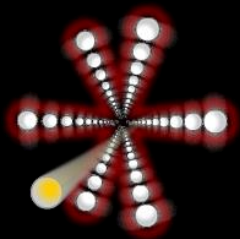


# Geant4 simulations of the full-size calorimeter for muon G-2 experiment

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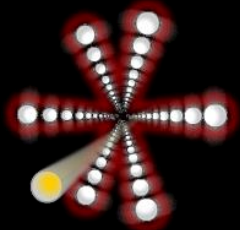
Sirmione - Desenzano del Garda, Italy  
29 September 2016



# Overview



1. Geant4 simulation toolkit
2. The g-2 experiment
3. Calorimeter system
4. Geant4 simulation
5. Conclusion



# Geant4 simulation toolkit



European Organization for Nuclear Research

## Geant4

A toolkit to simulate the interaction of particles with matter

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**Technical questions:**

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**Usage questions:**

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**Concept**

Geant4 simulates the passage of particles through matter. It provides a complete set of tools for all domains of radiation transport:

- Geometry and Tracking
- Physics processes and models
- Biasing and Scoring
- Graphics and User Interfaces
- Propagation in fields.

Geant4 physics processes describe electromagnetic and nuclear interactions of particles with matter, at energies from eV to TeV. A choice of physics models exists for many processes providing options for applications with different accuracy and time requirements.

The toolkit is developed, maintained and supported by Geant4, a world-wide collaboration of about 100 scientists from many institutions, contributing in their area of expertise. Developers interact constantly with users, and combine efforts to validate physics results for application in high energy physics experiments, space and medical studies.

A visualization of the CMS detector (Courtesy of S. Durr, CERN Collaboration)

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**Applications**

**High energy and nuclear physics detectors**

- ATLAS, CMS, HARP and LHCb at CERN and Babar at SLAC

**Accelerator and shielding**

- Linacs for medical use

**Medicine**

- Radiotherapy
  - photon, proton and light ion beams
  - brachytherapy
  - boron and gadolinium neutron capture therapy
- Simulation of scanners
  - PET & SPECT with GATE (Geant4 Application for Tomographic Emulsion)

**Space**

- Satellites
  - effect of space environment on components (especially electronics)
  - shielding of instruments
- Space environment
  - cosmic ray cut-offs
  - Astronauts
    - dose estimates

**Advantages**

- Simulates the geometries of complex setups efficiently
- Provides configurations of physics processes for application areas
- Enables user to tailor simulation components and address accuracy needs
- Performant and adaptable
- Easy to embed into specific applications

The Beq/Columbus Mercury satellite (Courtesy of ESA)

Simulation of small PET scanner using GATE (Courtesy of the OpenMC/IN2P3/CEA)

A view of the ATLAS detector (Courtesy of S. Durr, ATLAS Collaboration)

ALMA-10000 X-ray telescope: the effects of the radiation environment on its instruments was modeled with Geant4 prior to launch in 1999 (Courtesy of ESA)

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CERN Technology Transfer

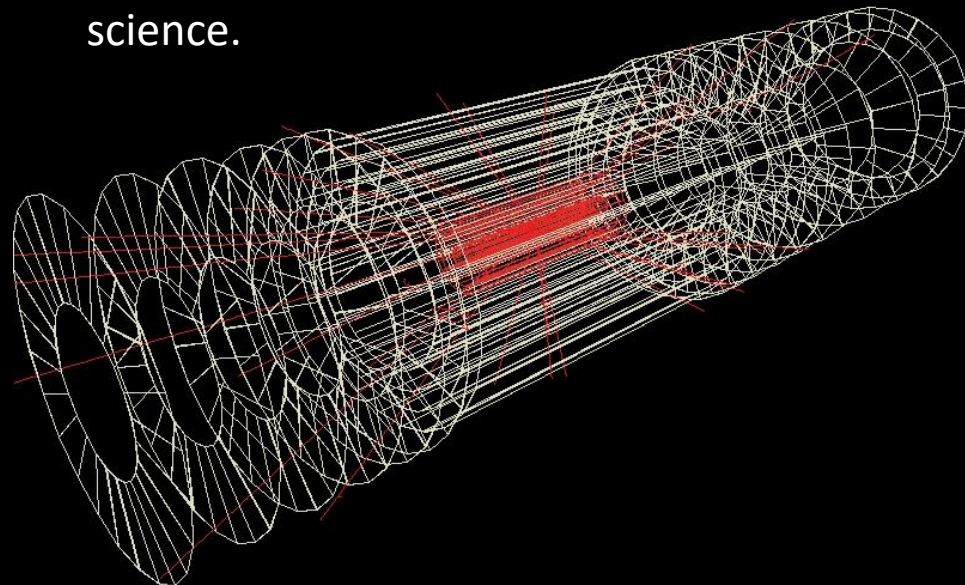
<http://knowledge-transfer.web.cern.ch/technology-transfer/external-partners/geant4>

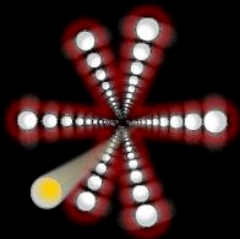
The European Organization for Nuclear Research (CERN), one of the world's foremost particle physics laboratories, has introduced an active Technology Transfer policy to attach its competence in European industrial and scientific environments, and to demonstrate clear benefits of the results obtained from the considerable resources made available to particle physics research.

Technology Transfer is an integral part of CERN's principal mission of fundamental research.

# Geant 4

Geant4 areas of application include high energy, nuclear and accelerator physics, as well as studies in medical and space science.

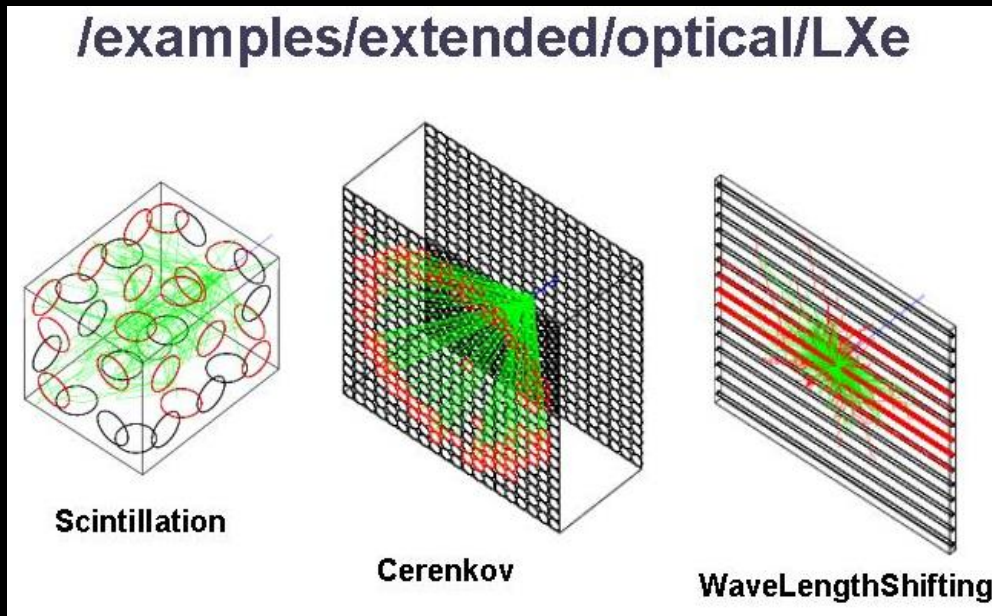




# Geant4 simulation toolkit



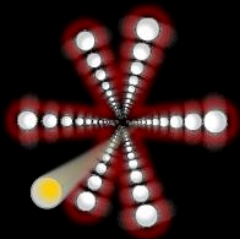
Geant4 is written in C++ and runs on Linux, Mac OS, Windows and different types of UNIX flavours, 32 or 64 bits, and on modern parallel architectures.



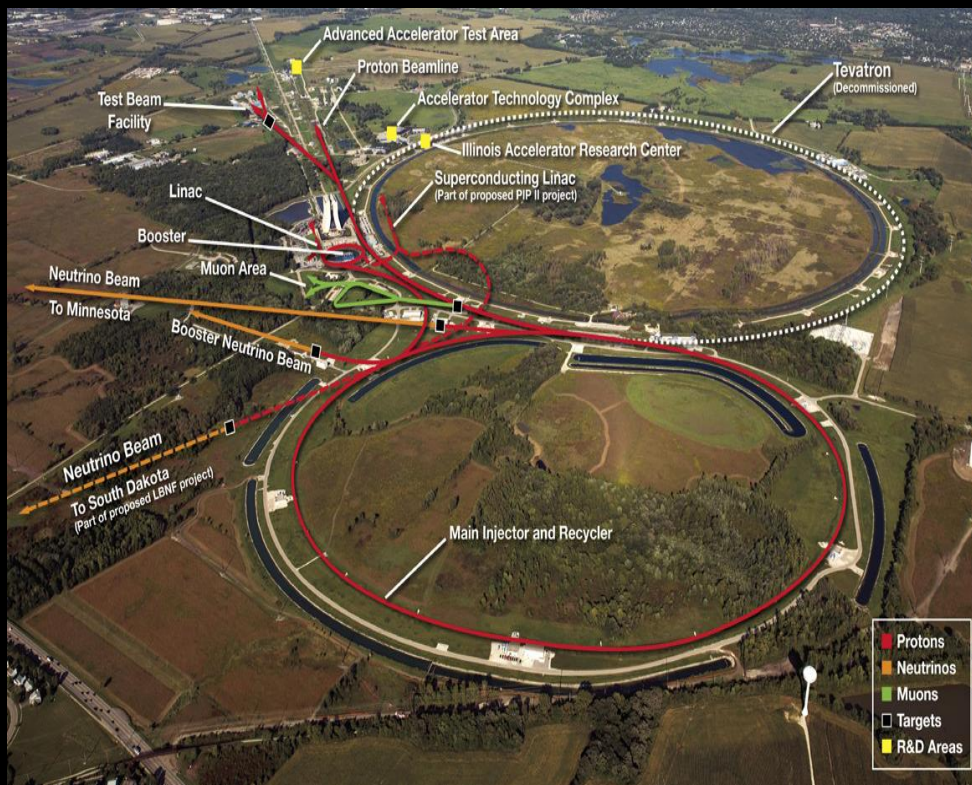
Geant4 source code and libraries are freely available, along with manuals, from the Geant4 **home** page.



Ability to work with optical photons in Geant4 is the foundation for our work;

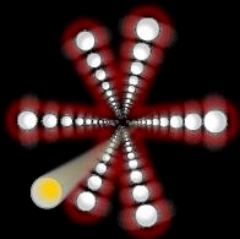


# The g-2 experiment



Fermi National Accelerator Laboratory, located 40 miles west of Chicago in Batavia, Ill.

Conceptual drawing of the buildings on the Fermilab site that will host the new Muon g-2 and Mu2e experiments.



# The g-2 experiment



*Credit: Brookhaven National Laboratory.*

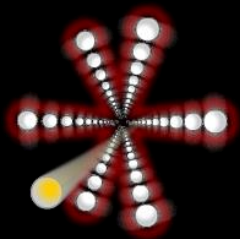


The Muon g-2 ring attached to the barge at the Smith Point Marina on Long Island, preparing for its sea voyage.

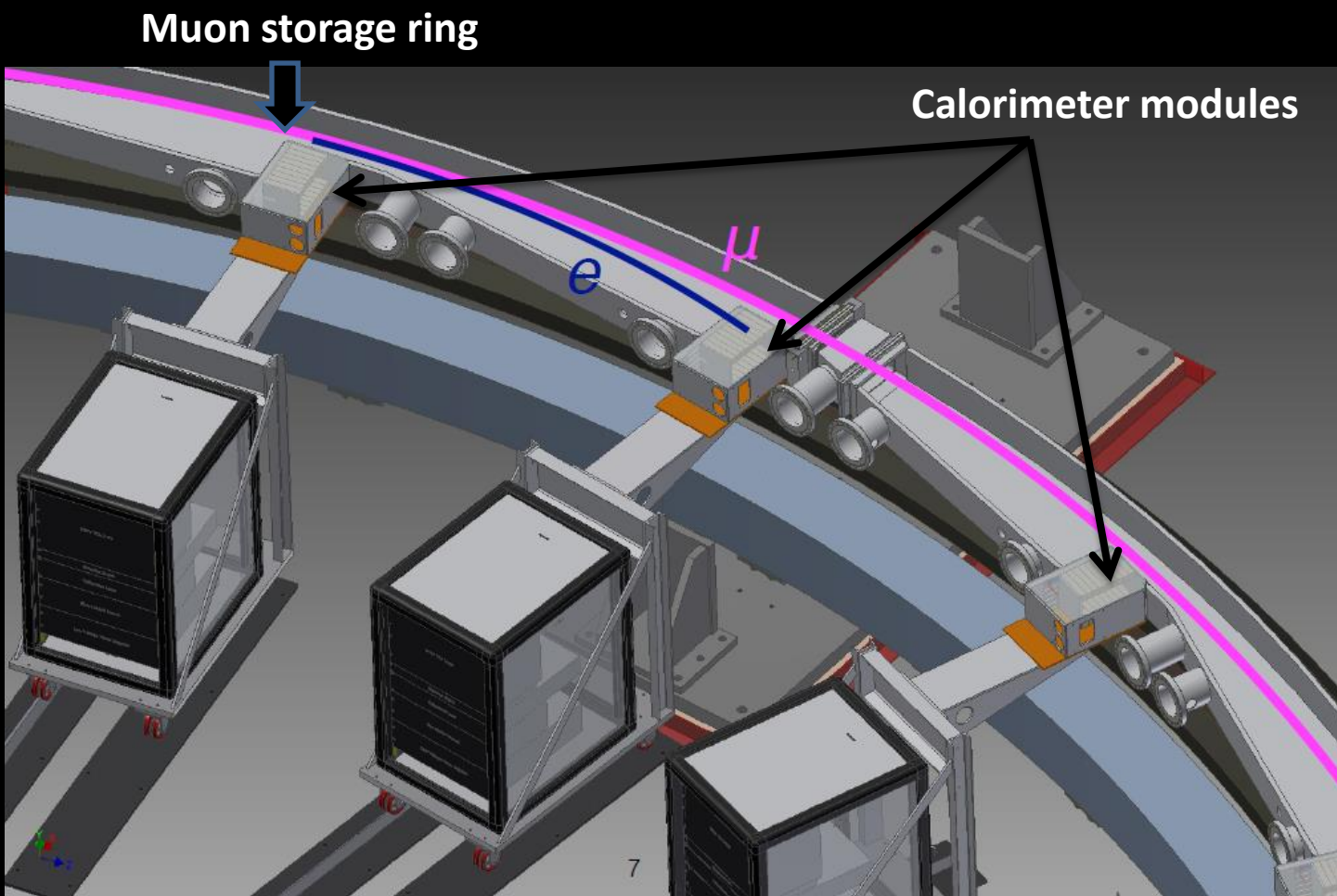
*Credit: Fermilab*

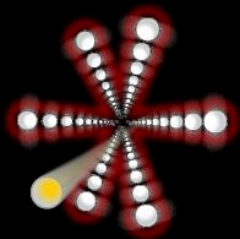


Clouds roll in over Wilson Hall and the Muon g-2 magnet shortly after the celebration on Friday, July 26, 2013 commemorating the end of the Big Move.



# The g-2 experiment





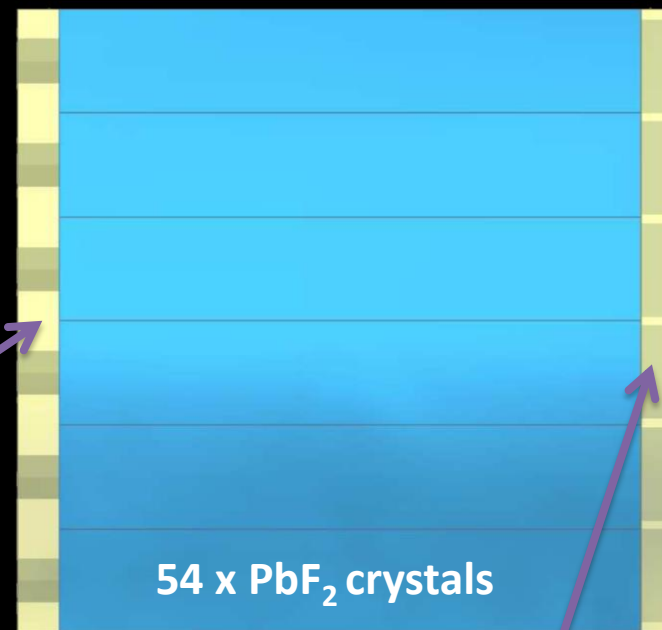
# Calorimeter system



Lead fluoride crystals ( $\text{PbF}_2$ ):  
Density -  $7.77\text{g/cm}^3$ ;  
Radiation length -  $0.93\text{cm}$ ;  
Moliere radius -  $2.2\text{cm}$ ;

Al vacuum chamber  
of the storage ring

Delrin front panel  
for installation of  
the laser  
calibration system



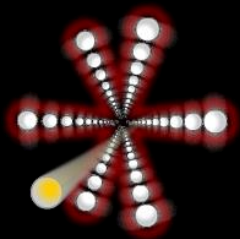
54 x  $\text{PbF}_2$  crystals

SiPM

$\text{PbF}_2$  – pure Cherenkov radiator

SiPM – counts photons; magnetic field compatible

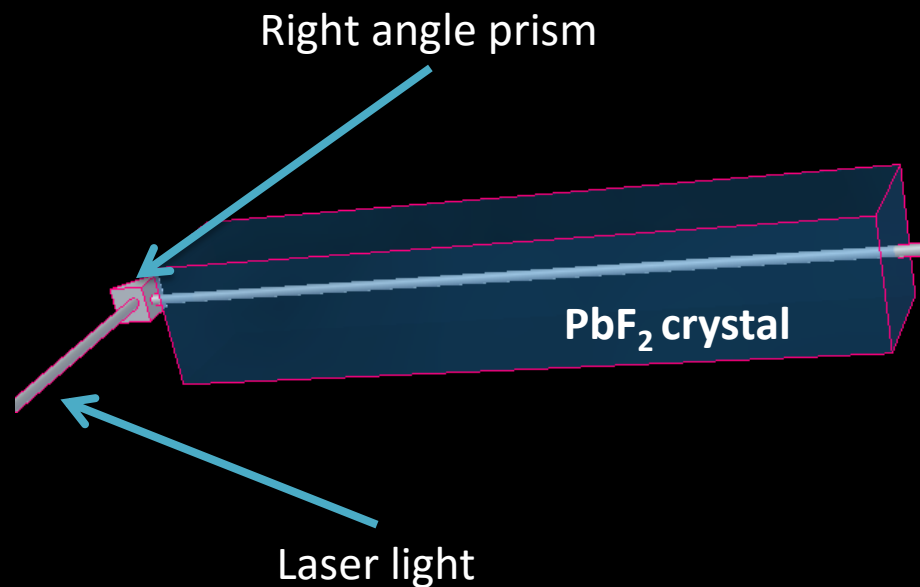
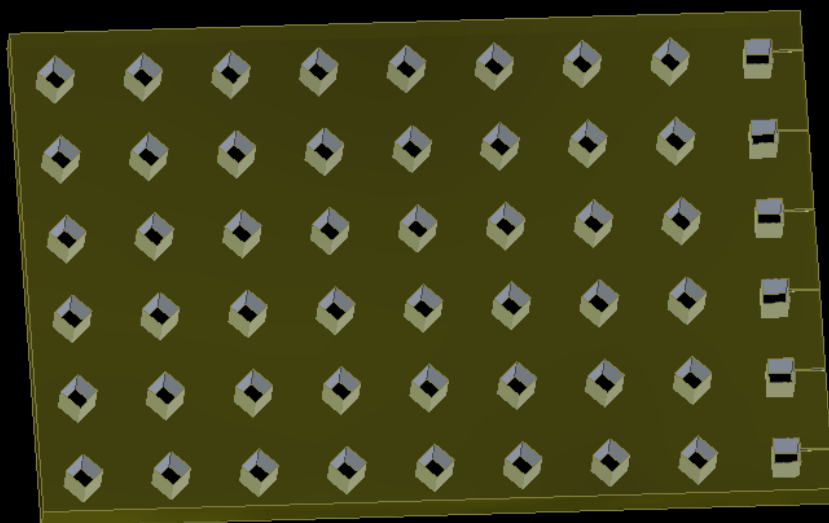




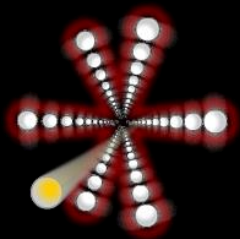
# Calorimeter system



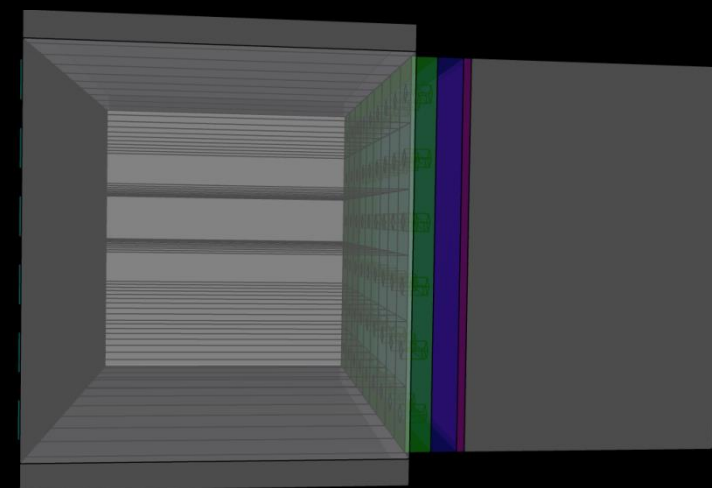
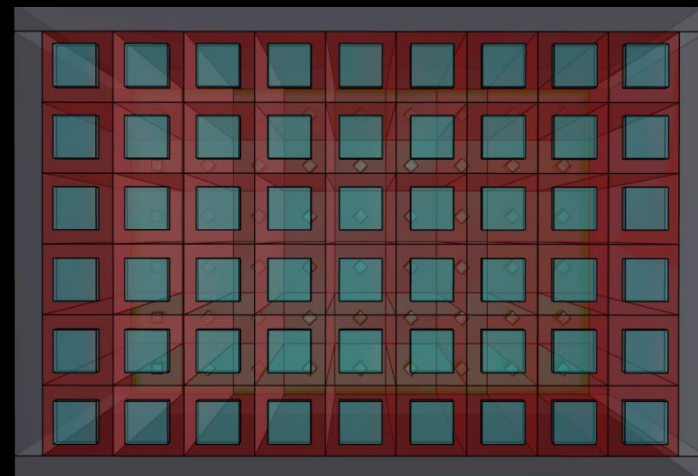
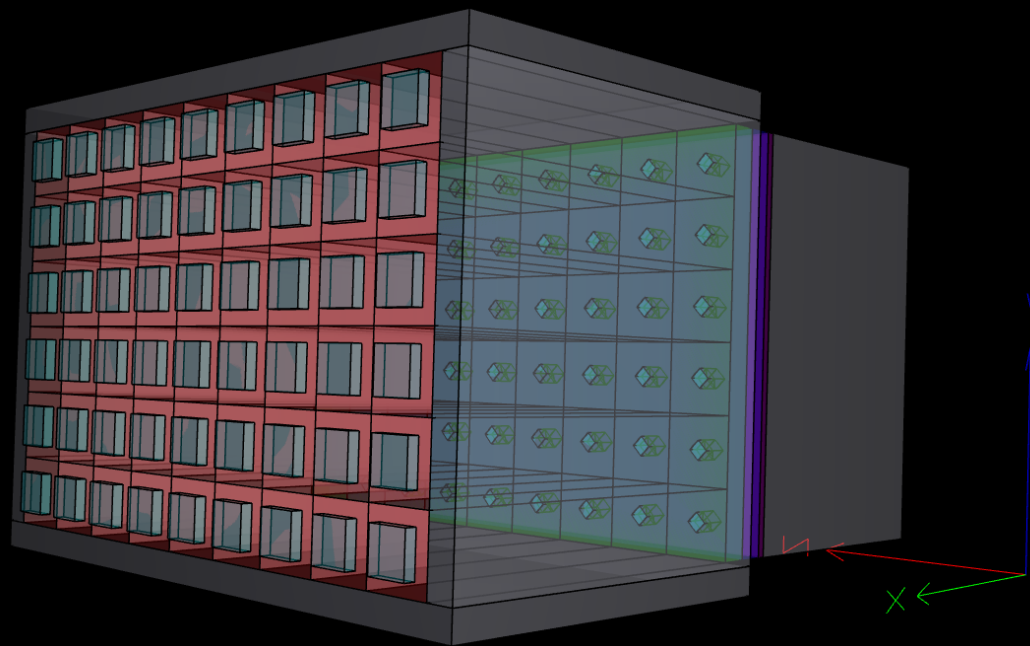
Delrin front panel for installation of the laser calibration system



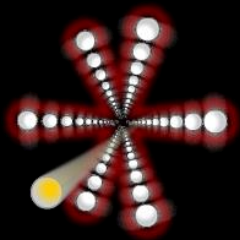
$\text{PbF}_2$  crystal – 14 x 2.5 x 2.5 cm<sup>3</sup>



# Calorimeter system in Geant4



At this step of the work we do not consider simulation for calibration system.

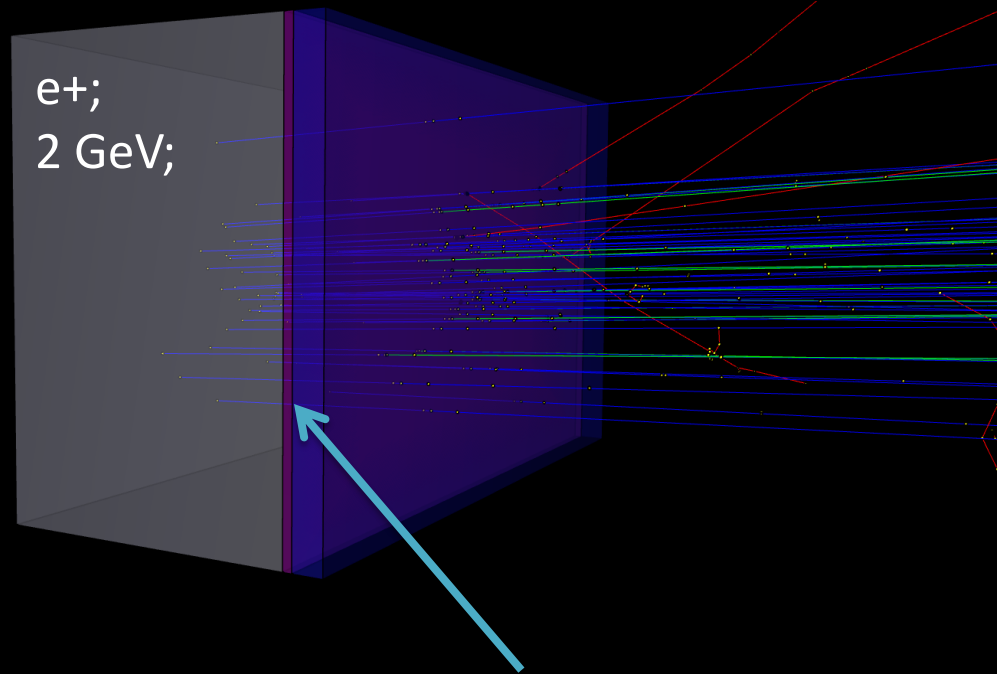
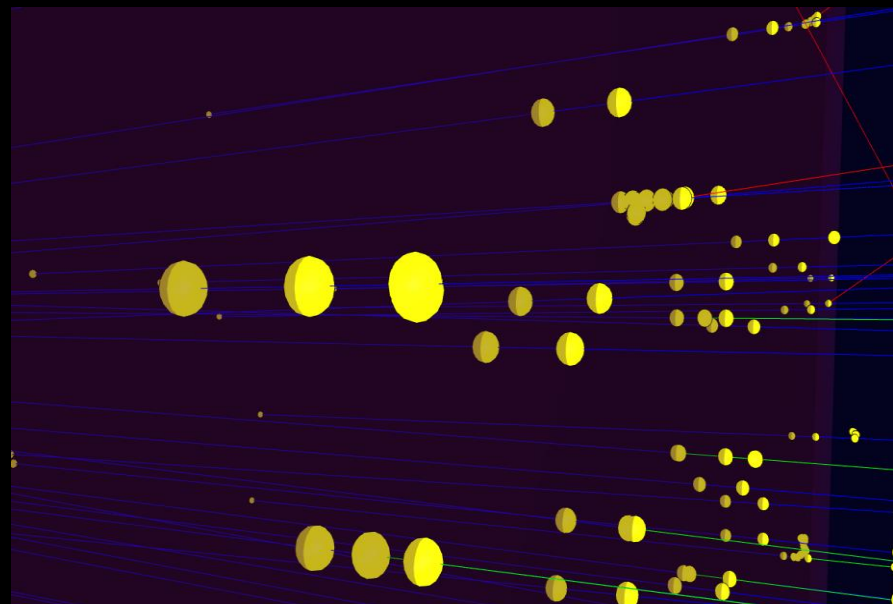


# Geant4 simulation

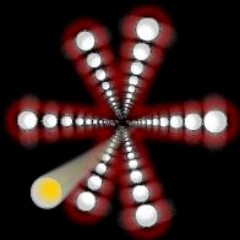


beamOn 50

Secondary particles production inside the Aluminum plate



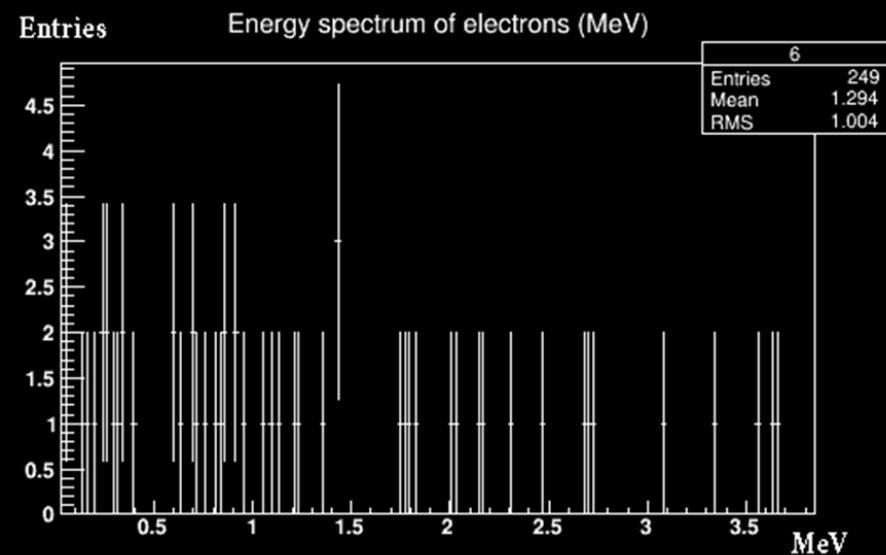
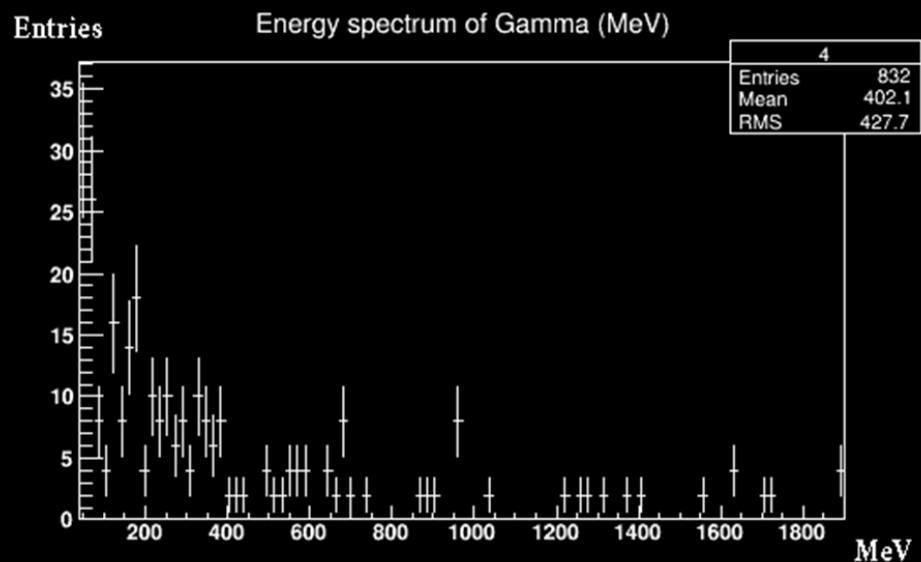
Aluminum vacuum chamber of the storage ring(violet)

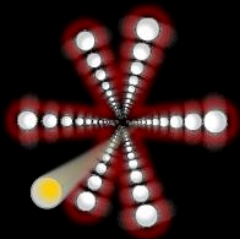


# Geant4 simulation



## Secondary particles energy spectrums





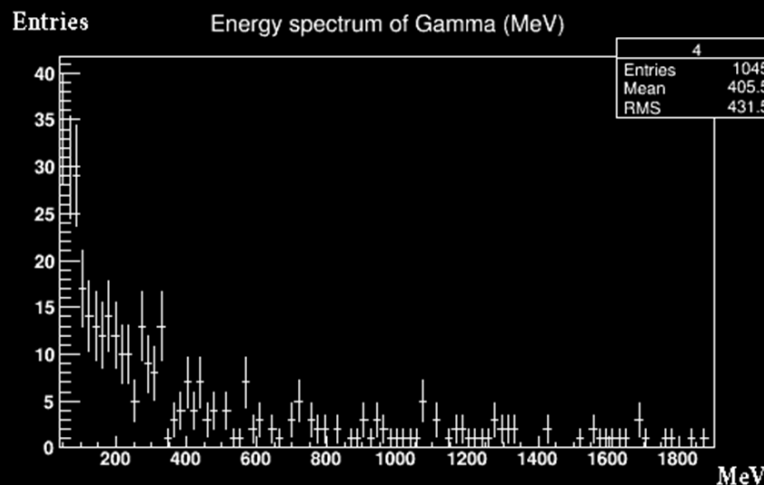
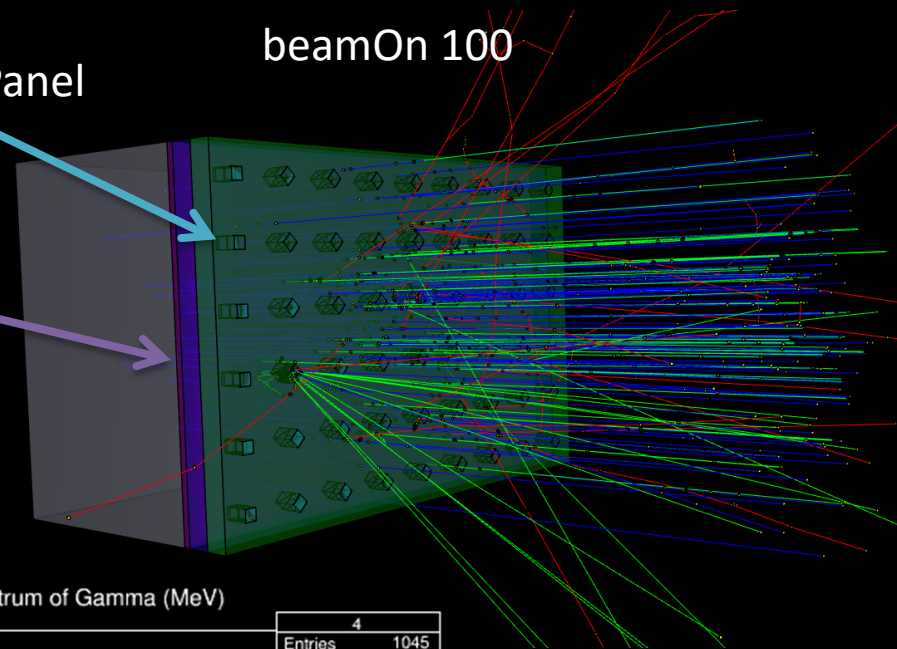
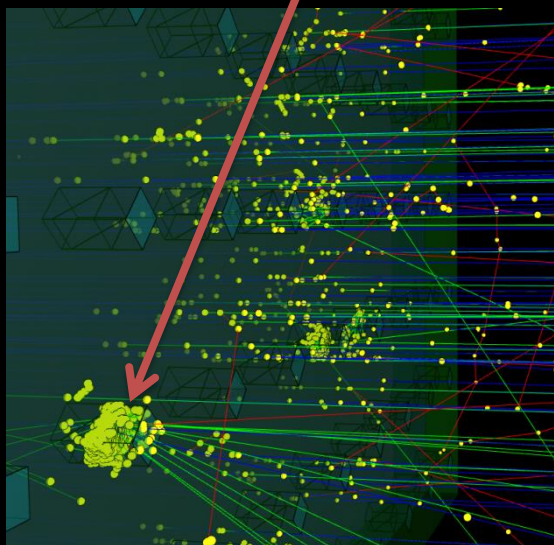
# Geant4 simulation



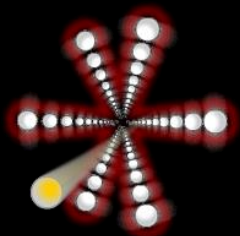
Al vacuum chamber of the storage ring + Delrin Panel

beamOn 100

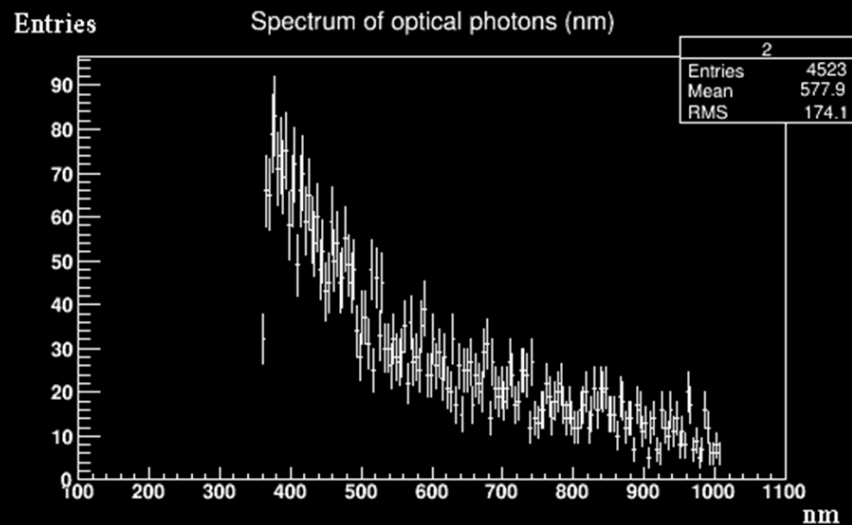
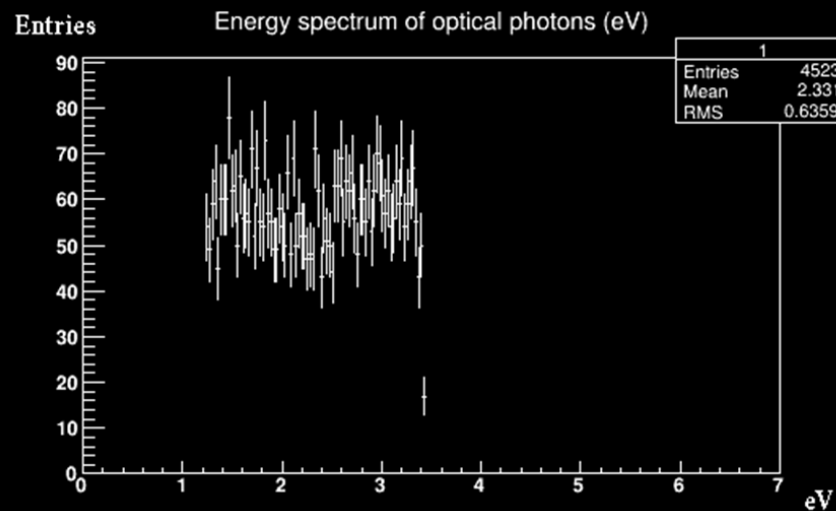
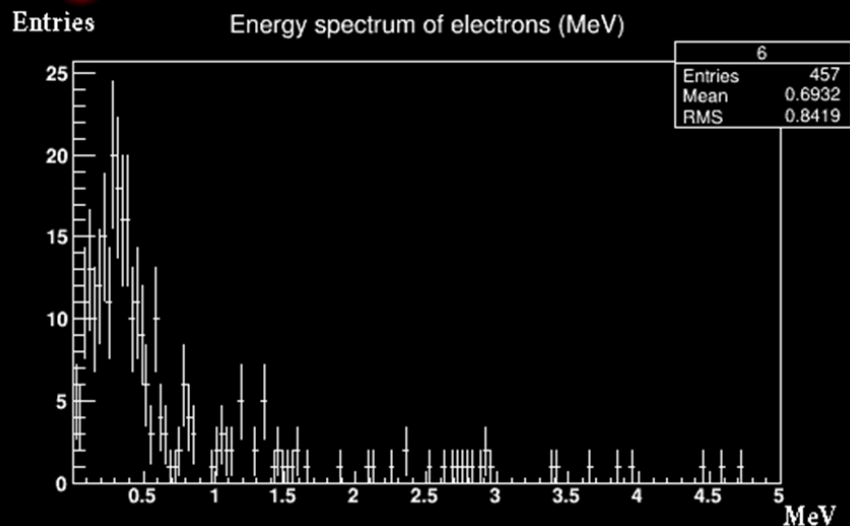
Photon production in NBK-7 prism

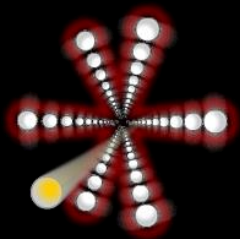


e+;  
2 GeV;



# Geant4 simulation



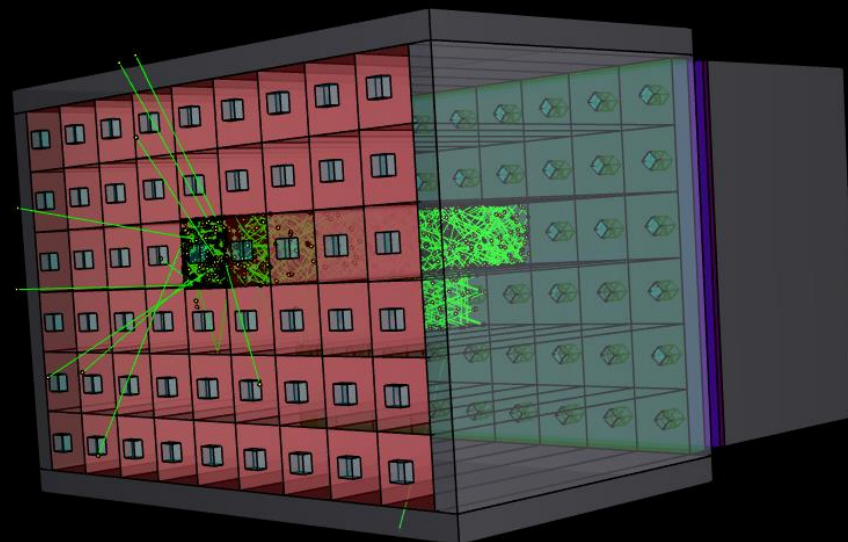
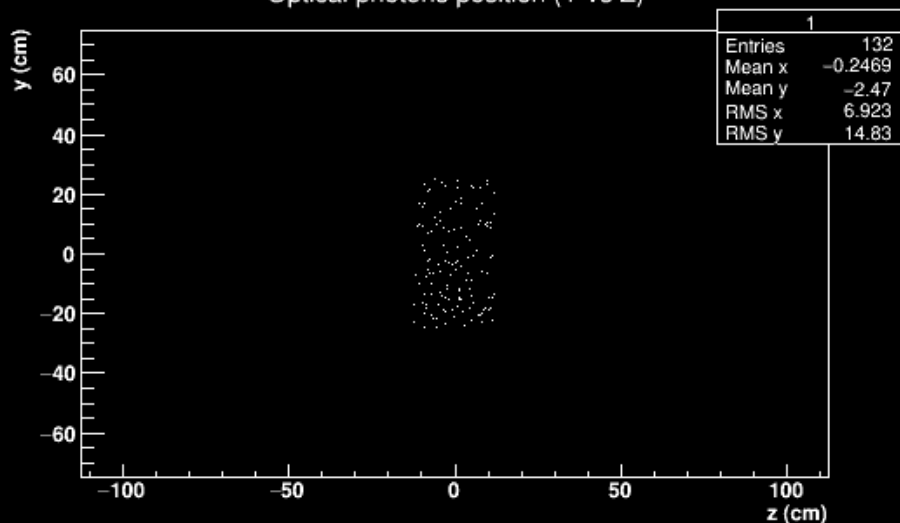


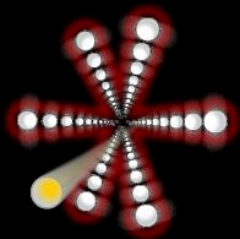
# Geant4 simulation



Al vacuum chamber of the storage ring + Delrin Panel + 54 crystals + positron energy 10 MeV

Optical photons position (Y vs Z)

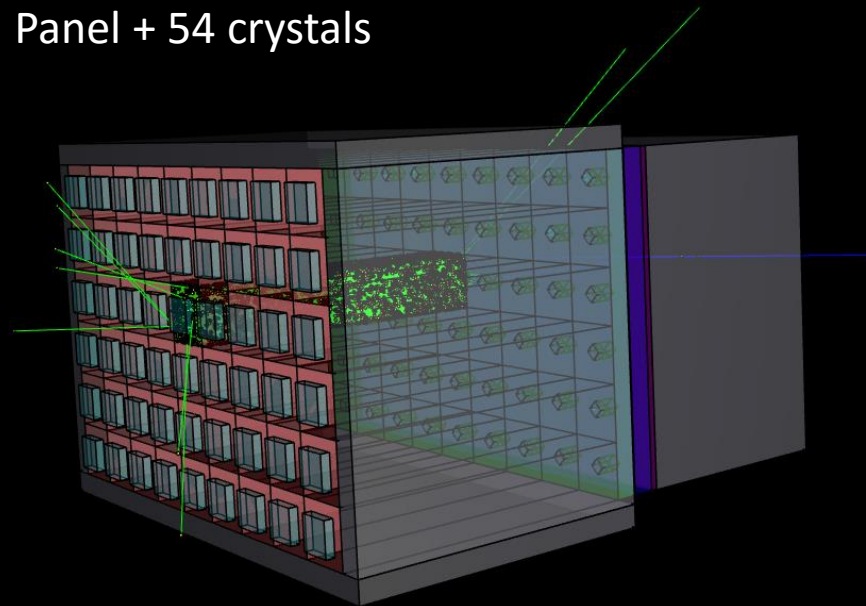




# Geant4 simulation

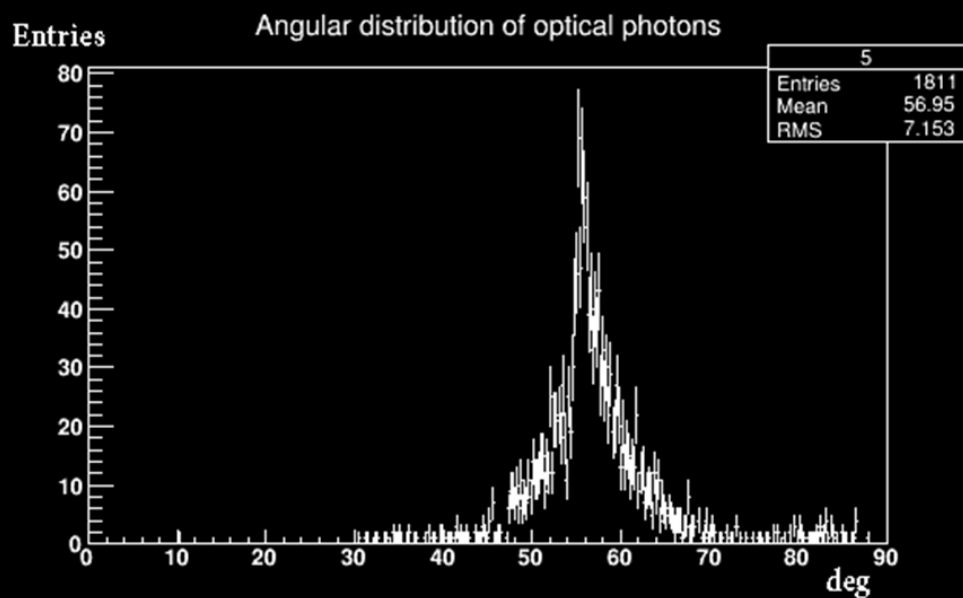


Al vacuum chamber of the storage ring + Delrin Panel + 54 crystals

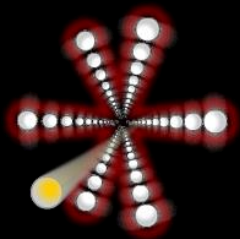


Cherenkov angle for PbF2 = 56.83

e+;  
2 GeV;



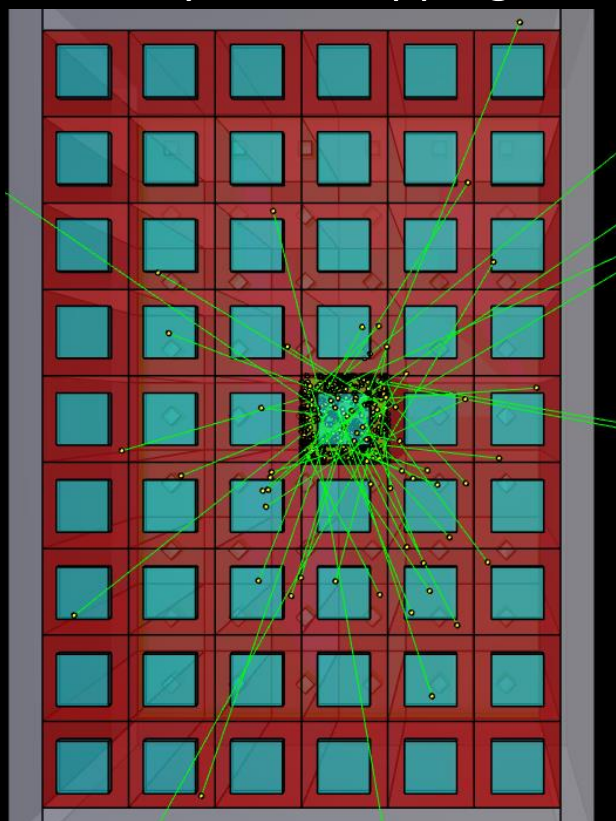




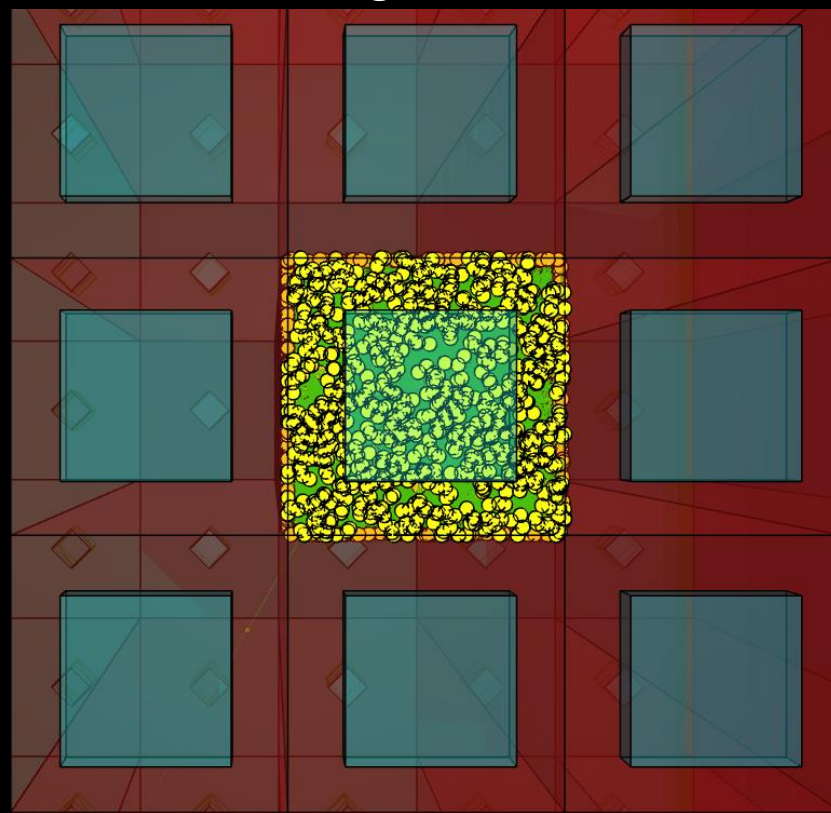
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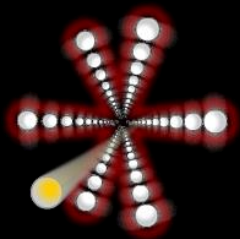


Physical wrapping

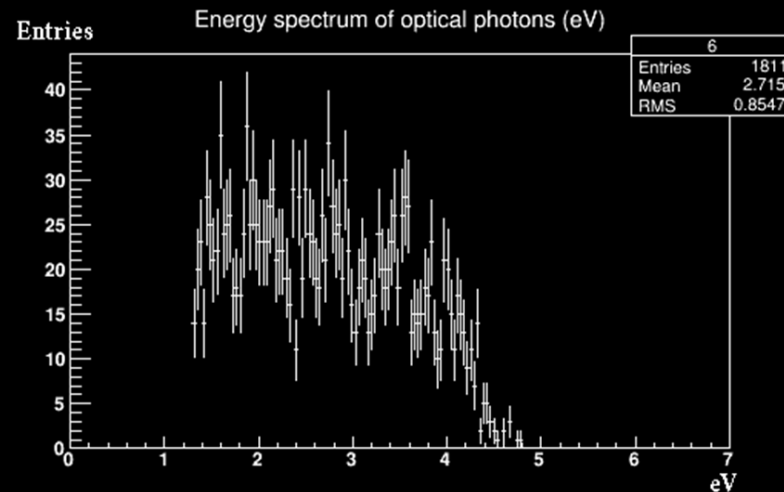
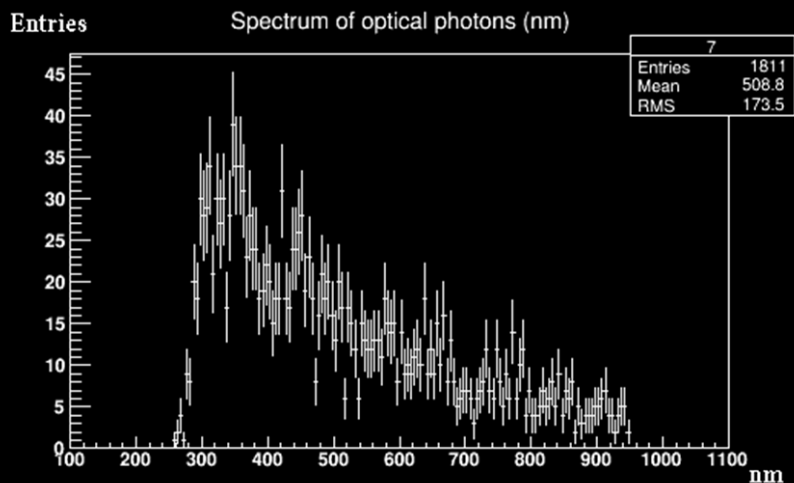
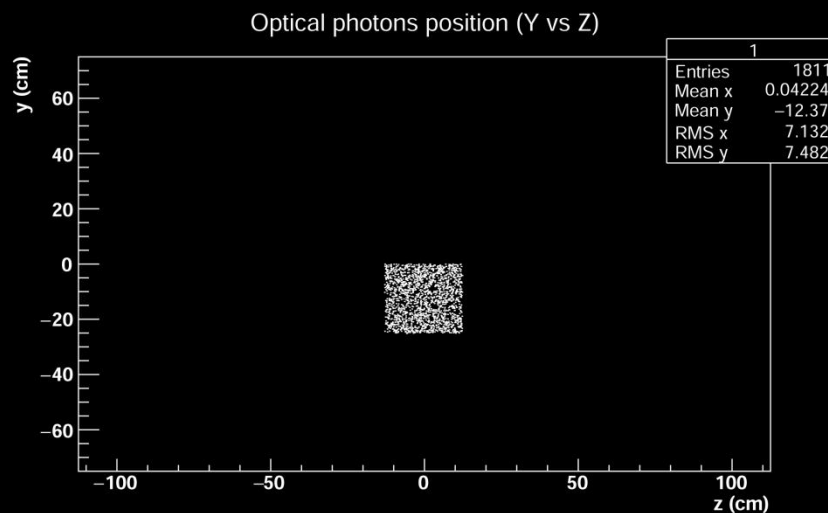
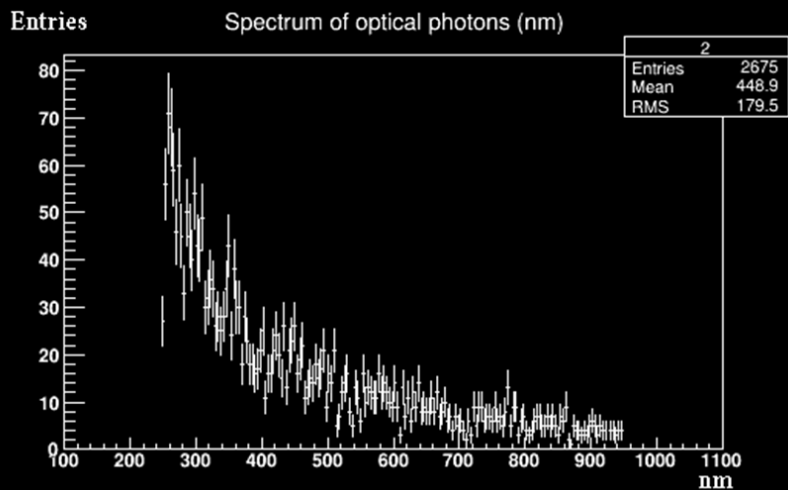


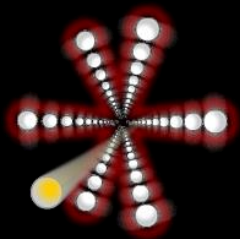
Logical skin





# Geant4 simulation





# Conclusion



- In this current work we have simulated the full size electromagnetic calorimeter for the muon G-2 experiment at Fermilab.
- It was shown that both pre-showers from the AI exit of the storage ring and the Delrin front panel contribute to optical photon production.
- We obtained spectral and angular distributions of Cherenkov optical photons and of another secondary particles in different parts of the calorimeter system.
- It was shown that for low energies less than 20 MeV optical photons can arise not only in the one crystal but in the group of neighbor ones.



THANK YOU  
FOR YOUR  
ATTENTION!!!