Modular detector for gamma-neutron imaging

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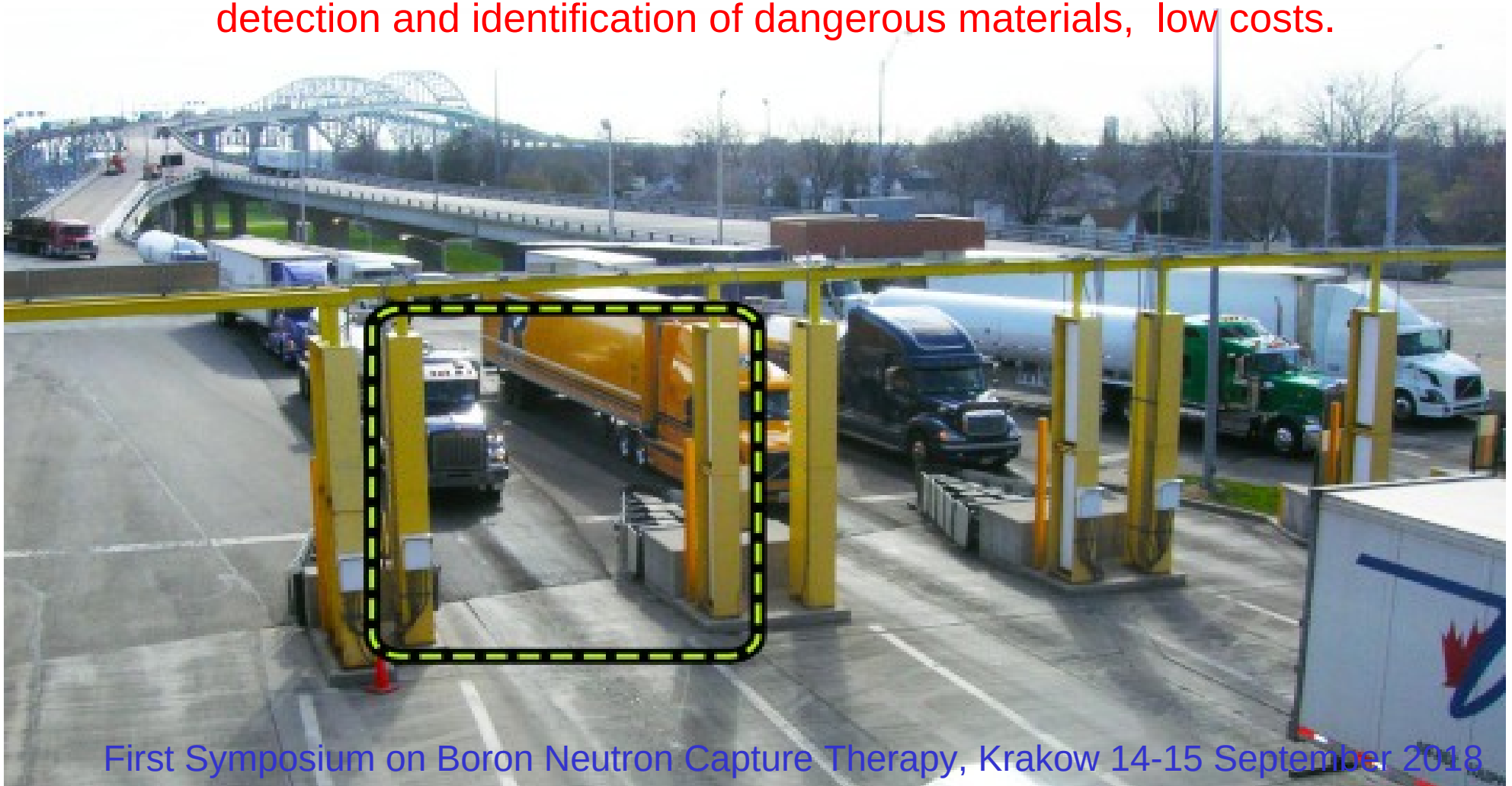
Homeland security - radiation portal monitors

Radiation portal monitors (RPM)—large stationary radiation detectors through which trucks and cargo containers pass. **Inspection of trucks and containers is one of the most time consuming and expensive procedures.**

Need for new techniques for the inspections of containers – fast, sensitive, allow the detection and identification of dangerous materials, low costs.

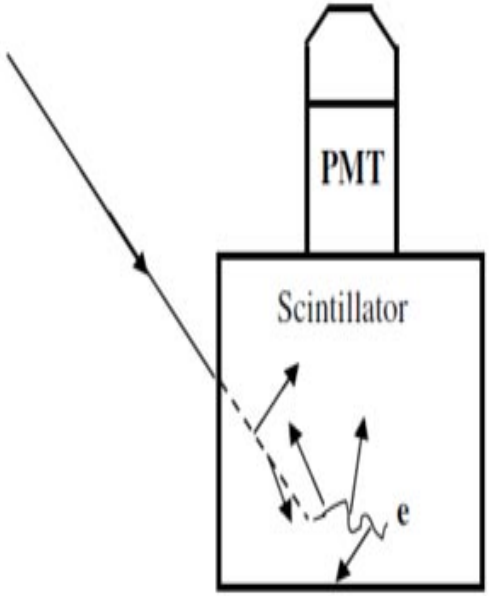


Screening a Truck with a Handheld Detector

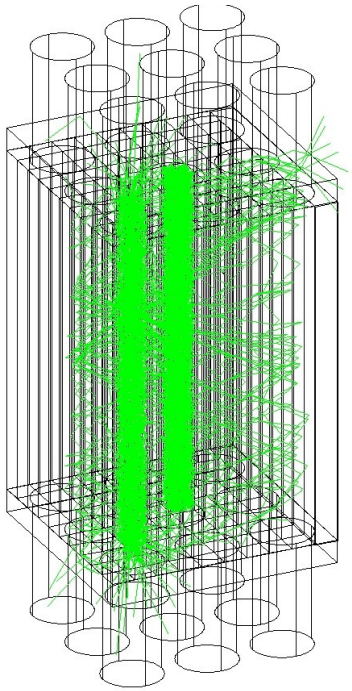
Cargo that has triggered an alarm during the initial (“primary”) screening is sent for additional inspection (i.e., “secondary” screening), first by another RPM to confirm the alarm and then by a CBP officer using a handheld radiation detector—about the size of a shoe box—that can identify the source of the radiation

CBP Officer Screening a Truck with a Handheld Detector That Can Identify Sources of Radiation takes 30 minutes

Modular detector design



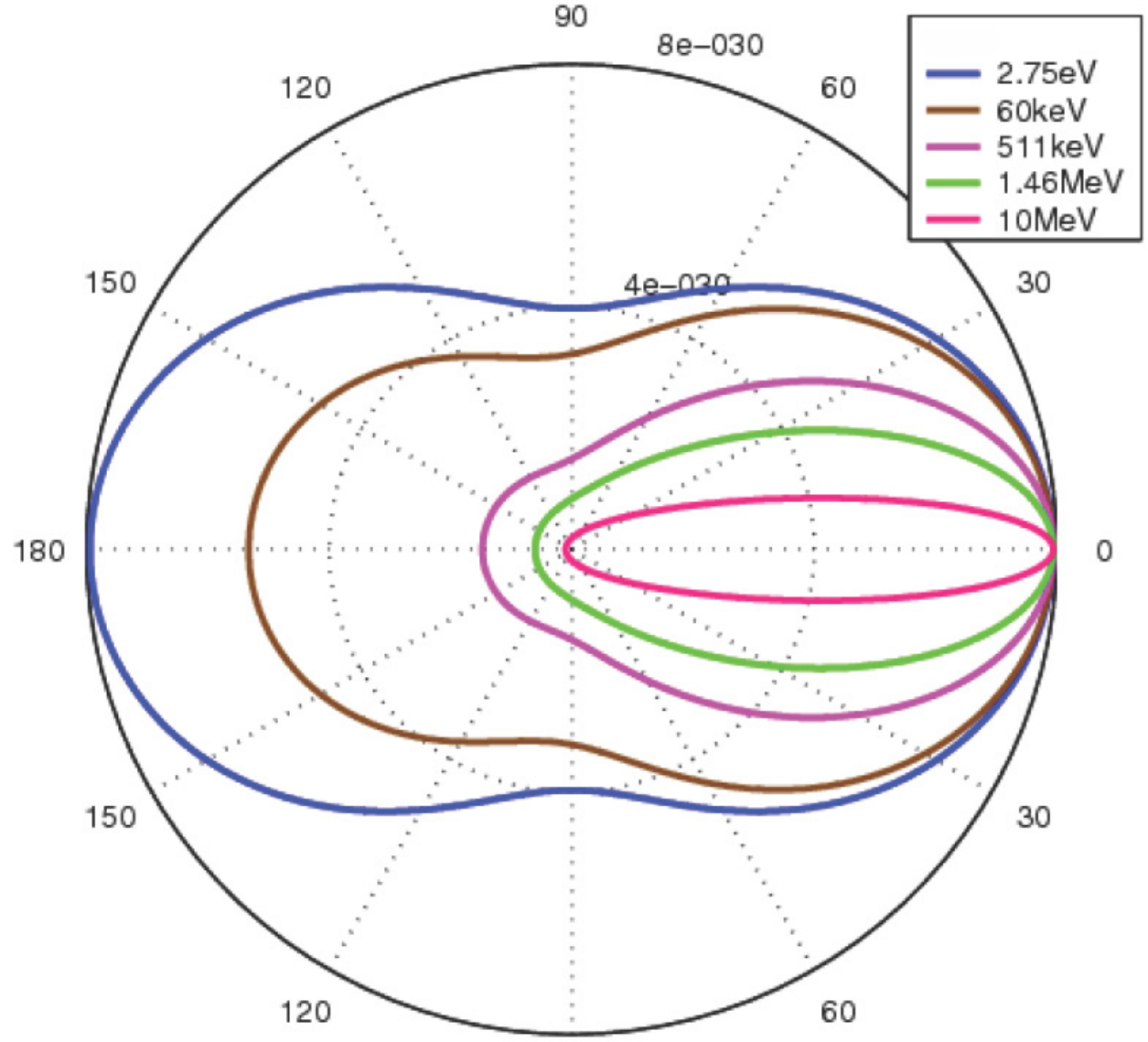
Now used simple design – no directional information, radioactive source detected if intensity high than natural background

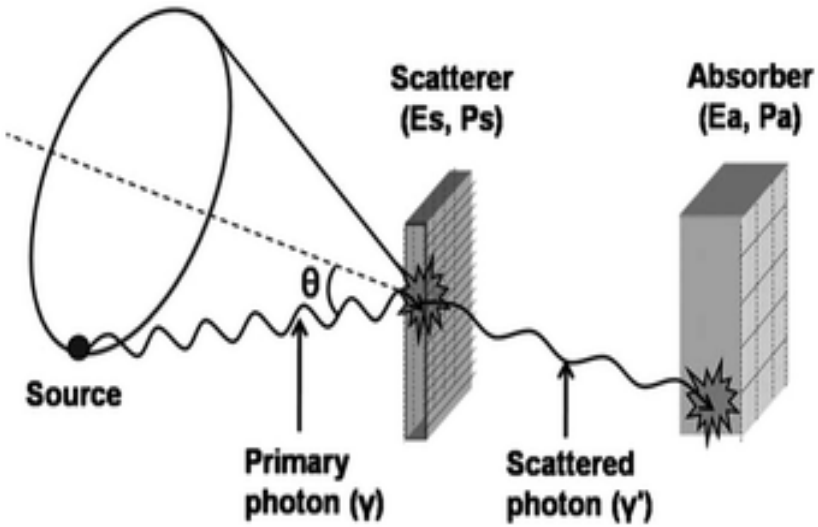


Proposed modular design more complicated but radioactive source can be detected with intensity lower than natural background due to localization of the radioactive source in space.

This design allow to use layers with gadolinium neutron converter – no need for separate He-3 based neutron counter

Compton imaging of gamma-ray sources – electronic collimation



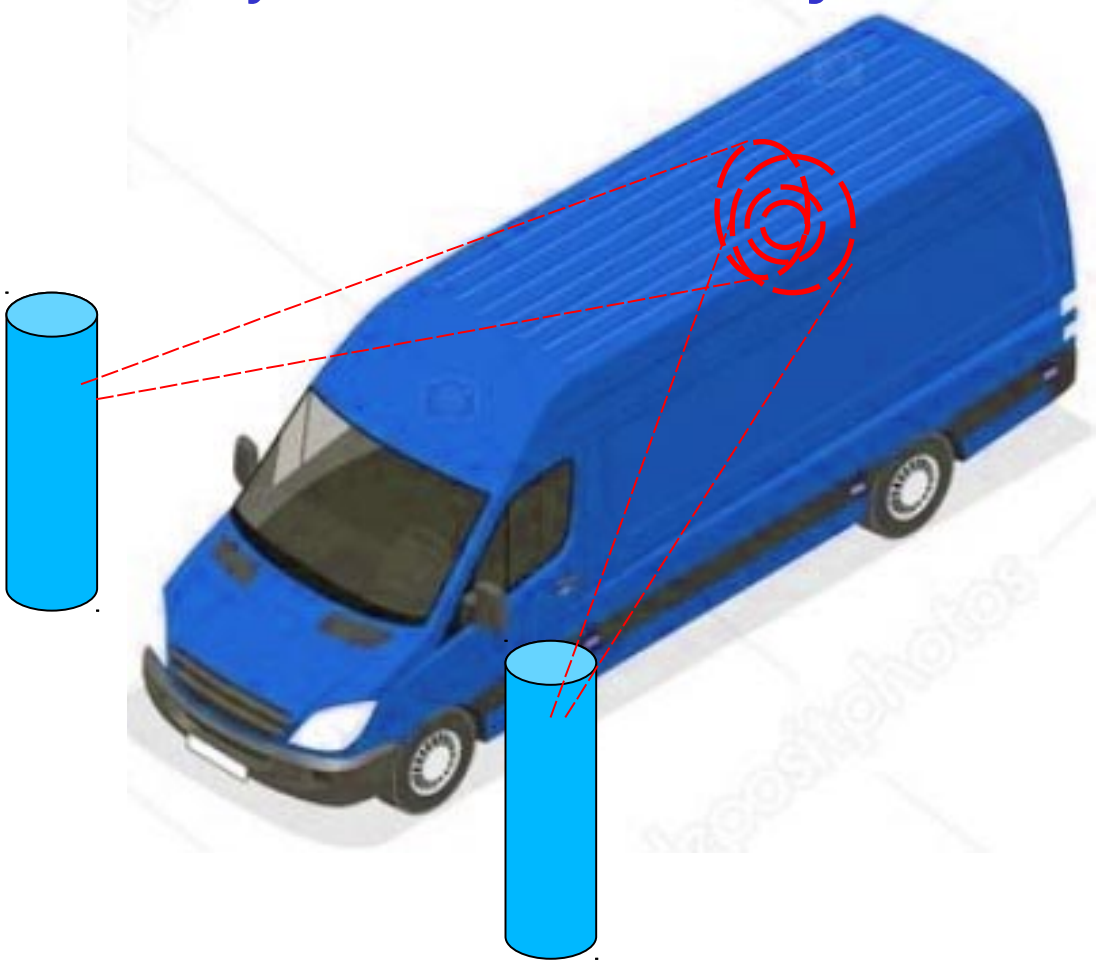


$$\theta = \cos^{-1}\left[1 + m_0 c^2\left(\frac{1}{E_\gamma} - \frac{1}{E_{\gamma'}}\right)\right]$$

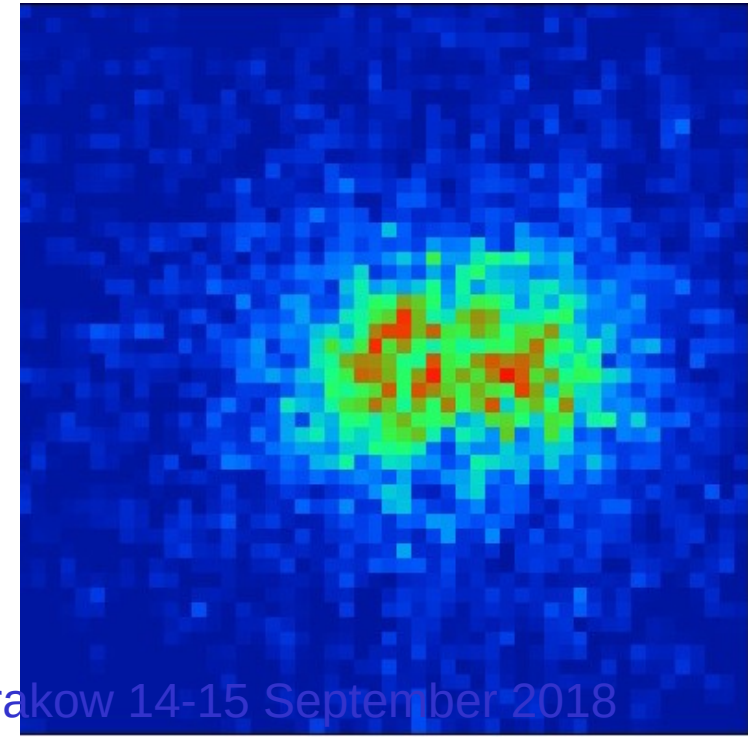
The two detectors based tomography system for radiation source 3D imaging

Due to spatial resolution two detector design allow 3D localization of radioactive materials – this will shortage the handheld inspection time.

Potentially save **1 Billion $ / year**



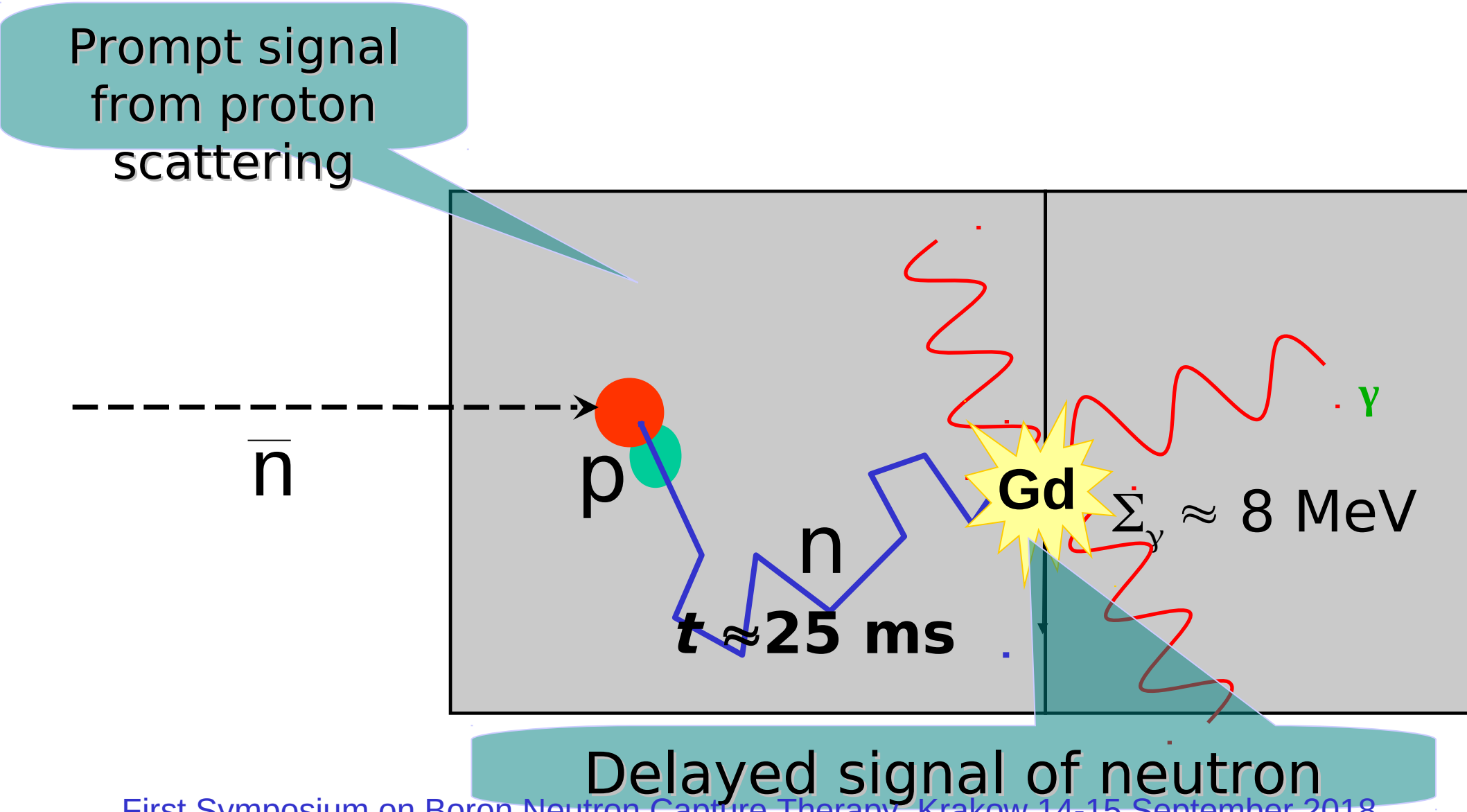
Potential need –
USA – 1400 RPM
Europe – 800 RPM
Ukraine – 500 RPM
Asia 1000 RPM



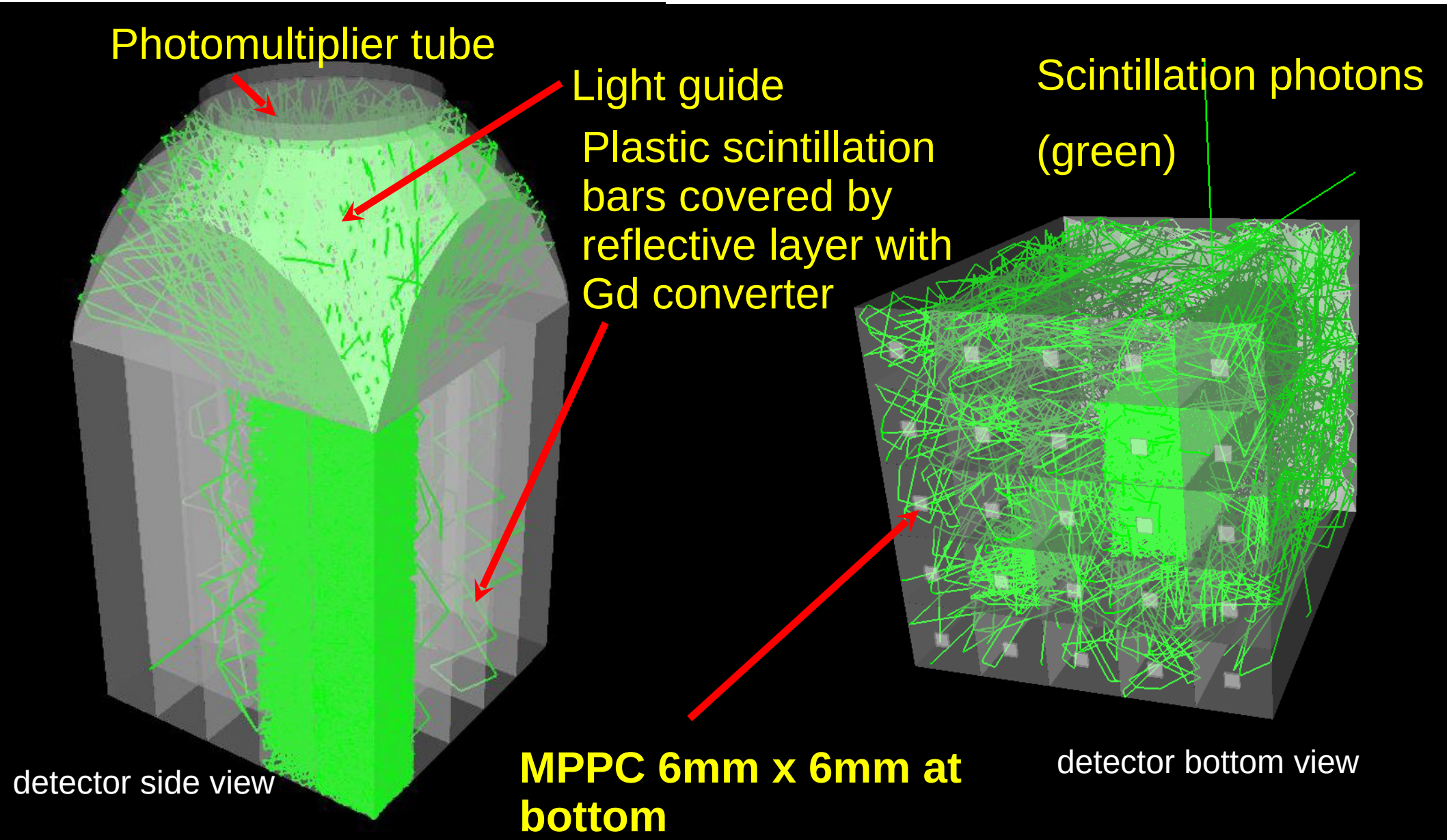
Capture gated principle of neutron detection

$$n + {}^{157}\mathrm{Gd} \rightarrow {}^{158}\mathrm{Gd}^{*} \rightarrow {}^{158}\mathrm{Gd} + \gamma\text{'s}$$

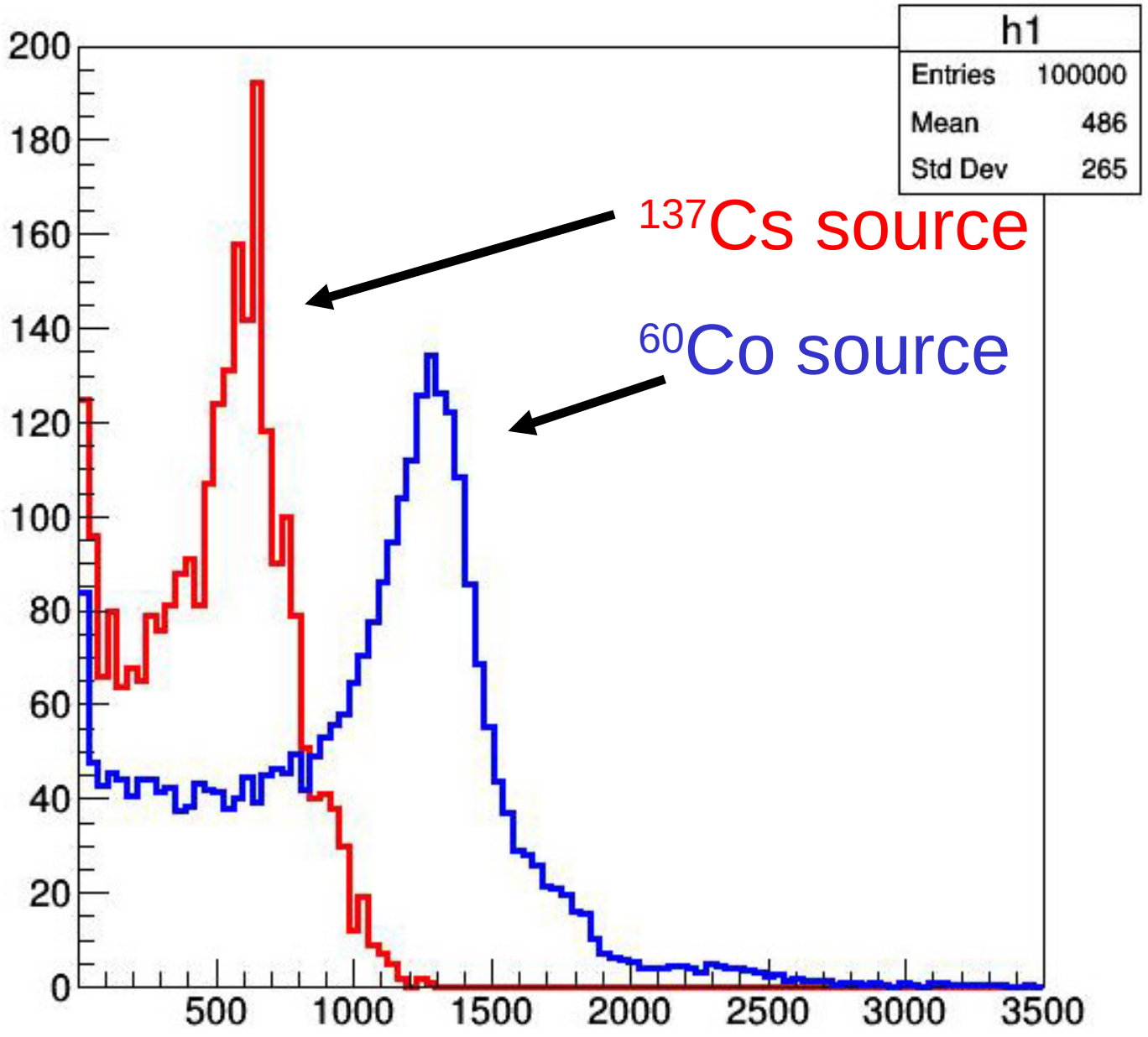
$$n + {}^{155}\mathrm{Gd} \rightarrow {}^{156}\mathrm{Gd}^{*} \rightarrow {}^{156}\mathrm{Gd} + \gamma\text{'s}$$



GEANT4 simulation of RPM based on modular detector with plastic scintillator bars

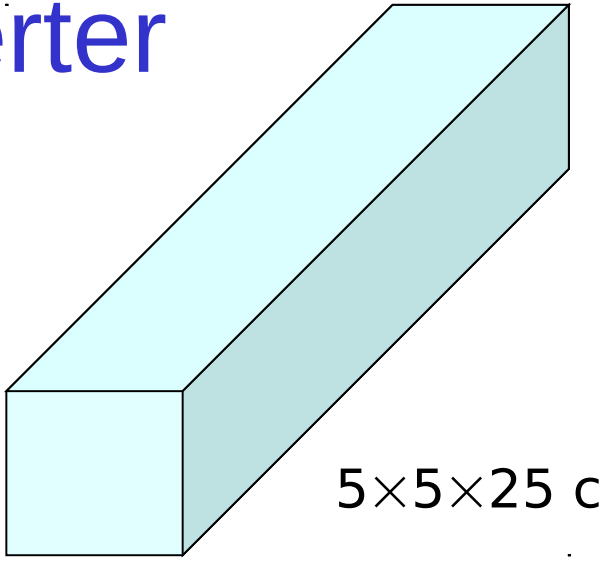


Simulated calibration spectra of PMT

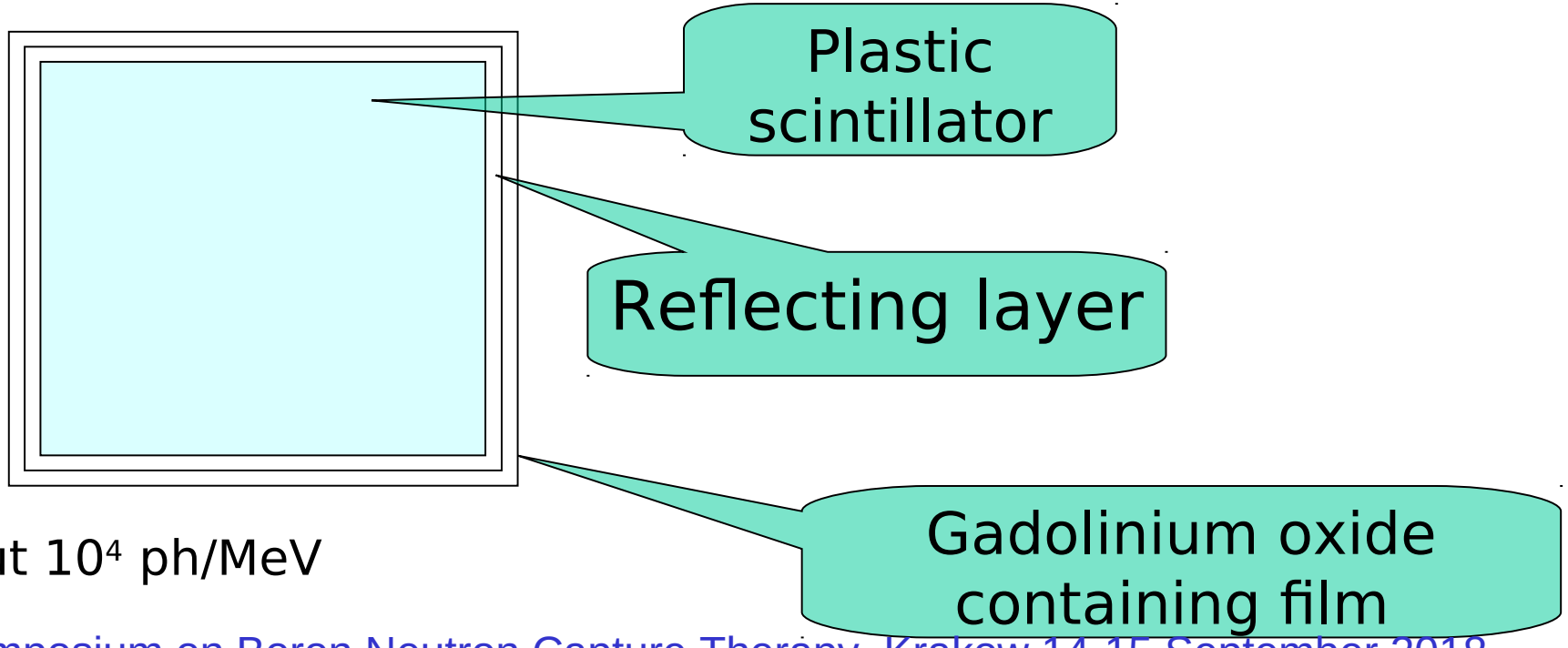


Scintillation bar enclosing with gadolinium converter

	Neutrons captured by Gd [%]	mean time until the capture [μs]
5 × 5 cm	88	25



5×5×25 cm³

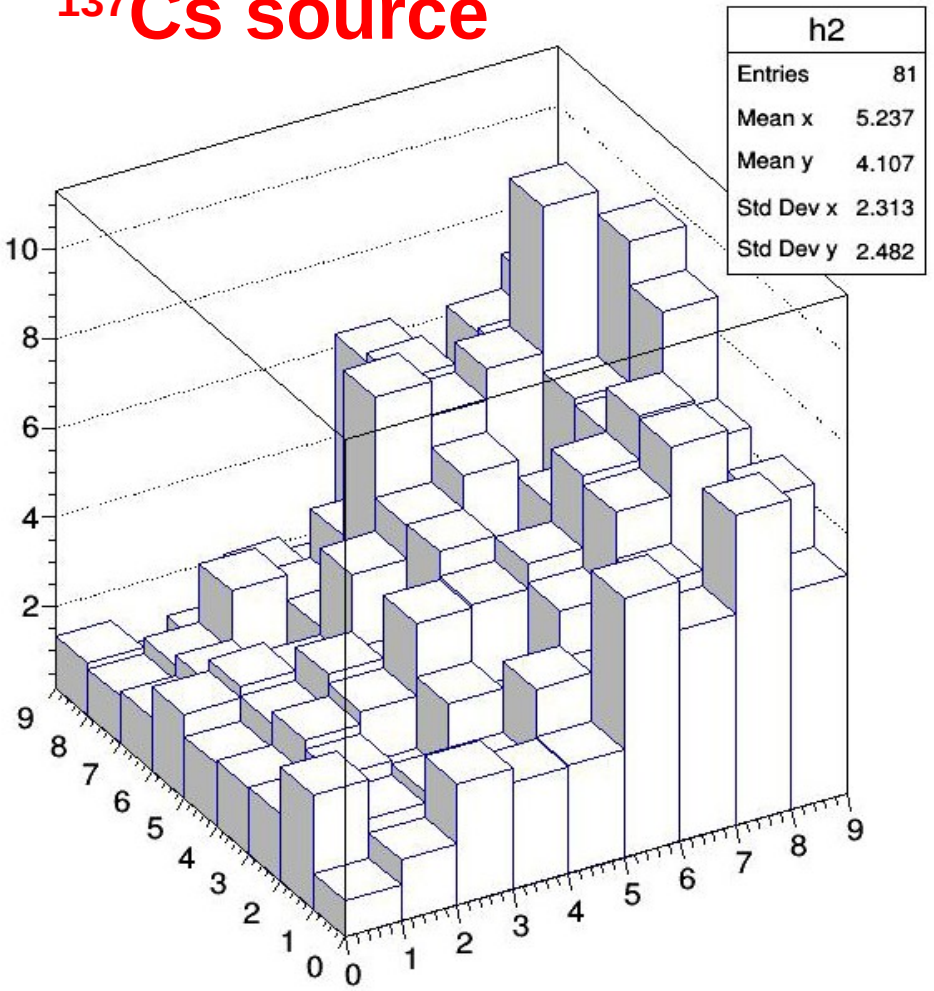


Light output 10^4 ph/MeV

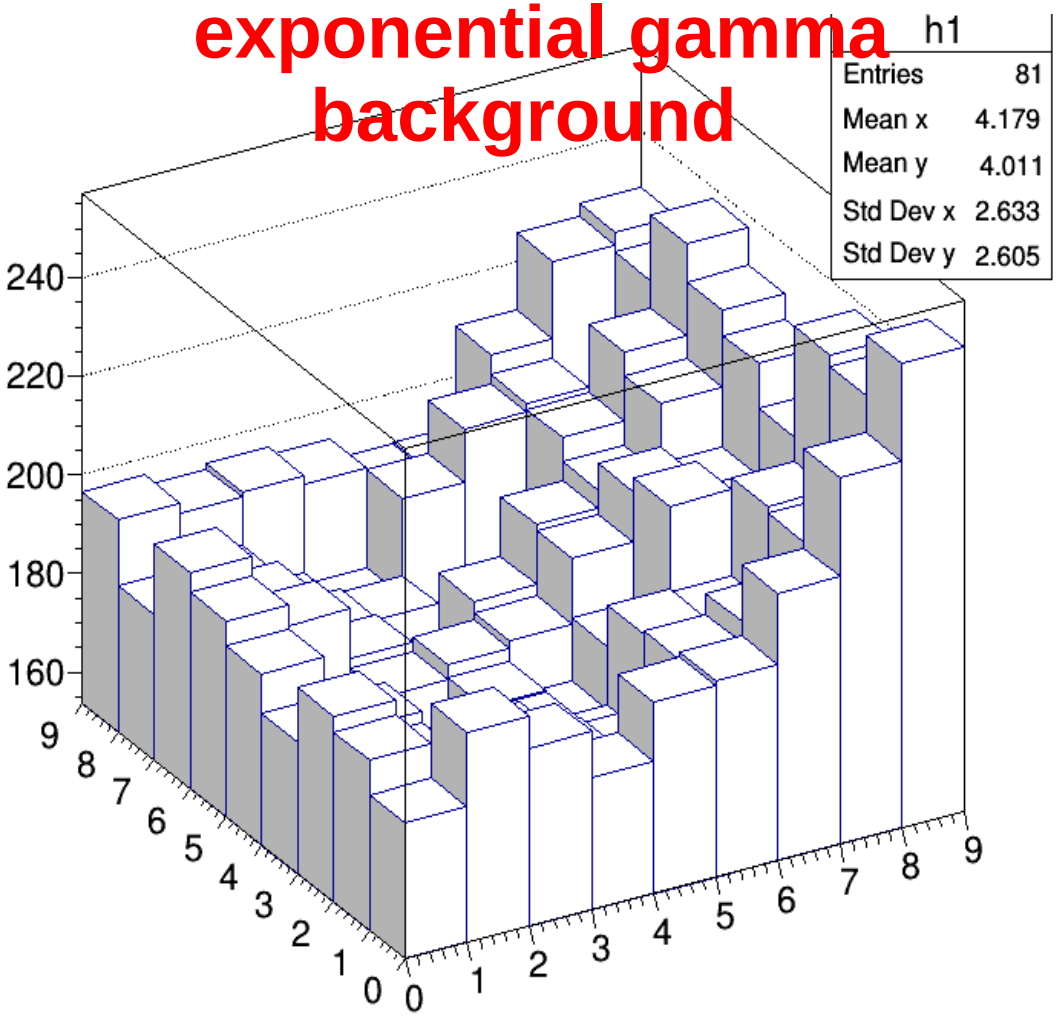
Directional sensitivity to gamma-rays

When using active masking the direction to the source is determined to ~ 20 degrees in for a 1 mCi Cs-137 source at a distance of 5 meters.

^{137}Cs source

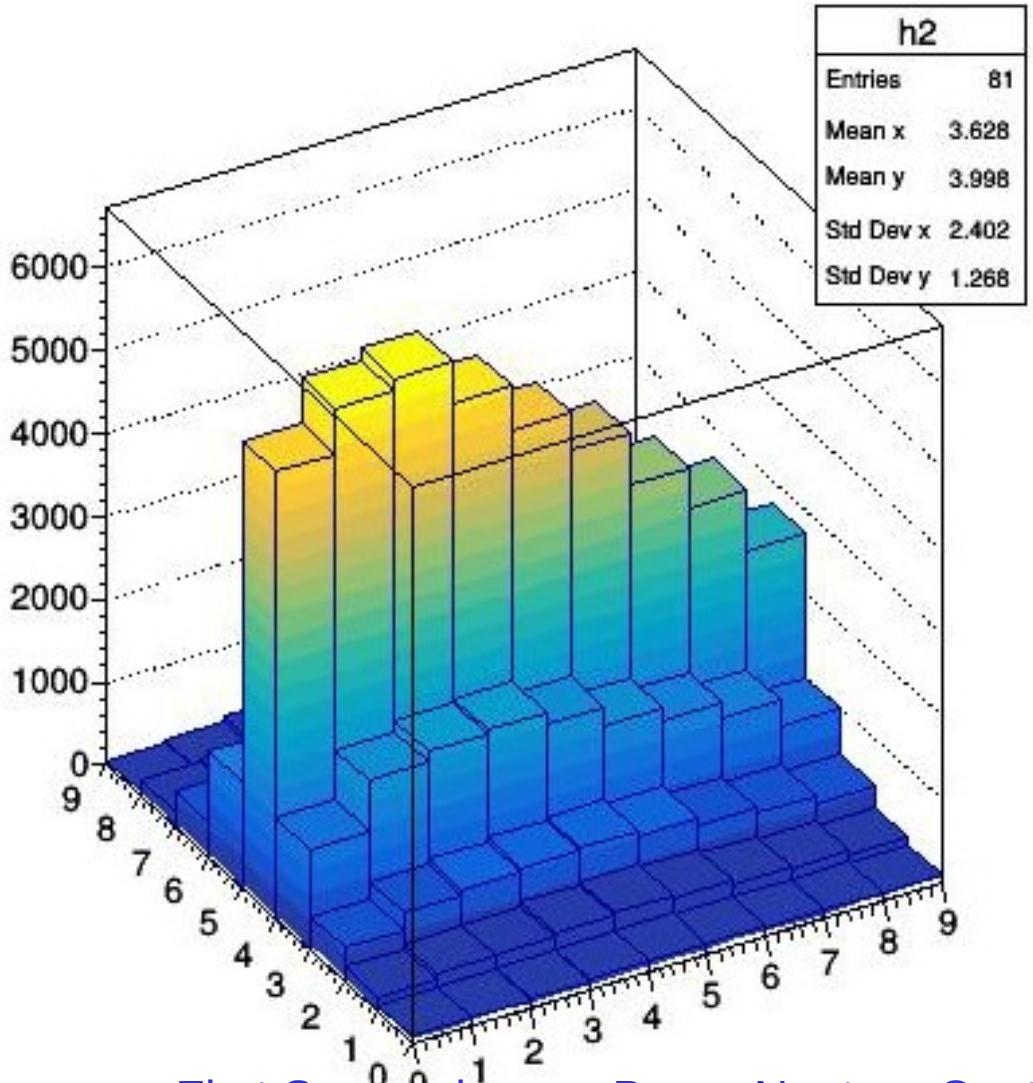


^{137}Cs source and exponential gamma background

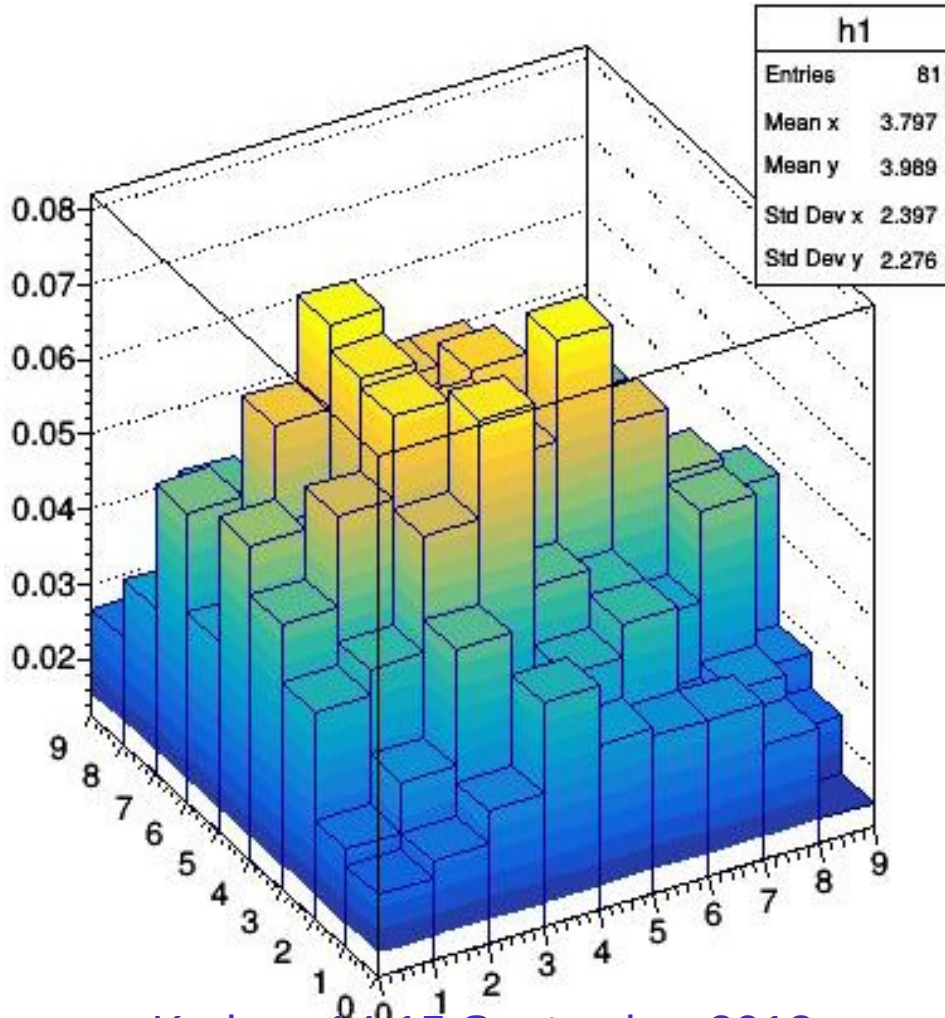


Directional sensitivity to neutrons

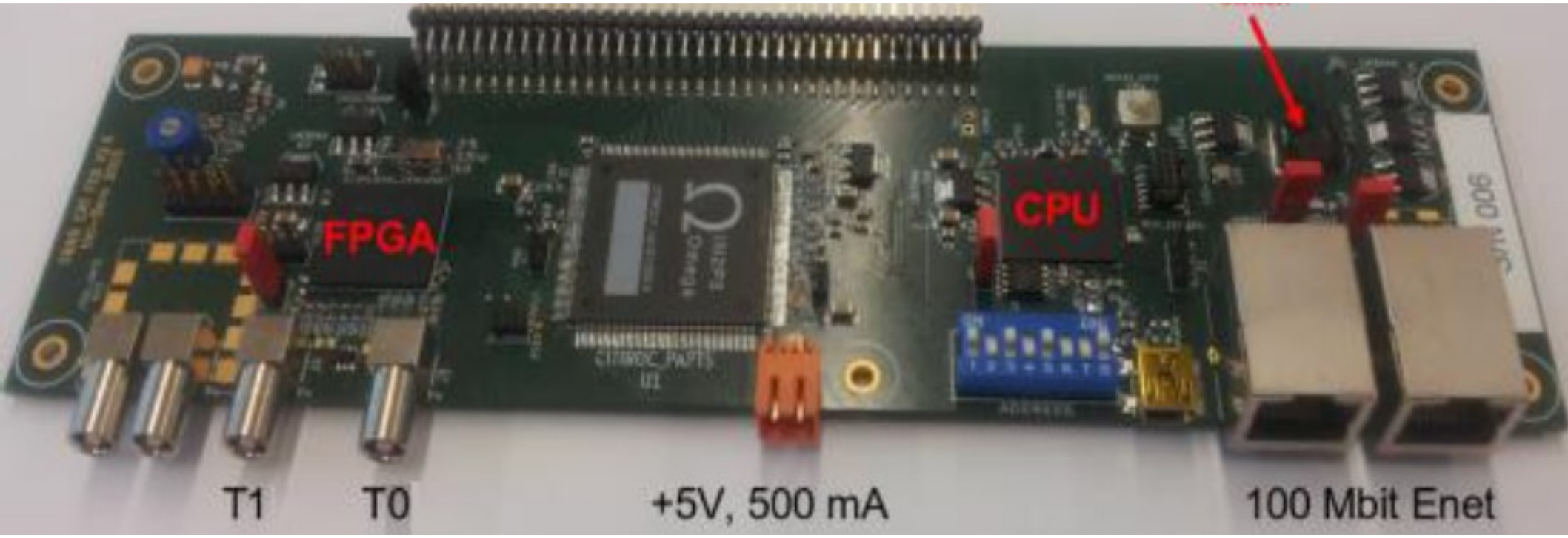
Prompt proton scattering event topology



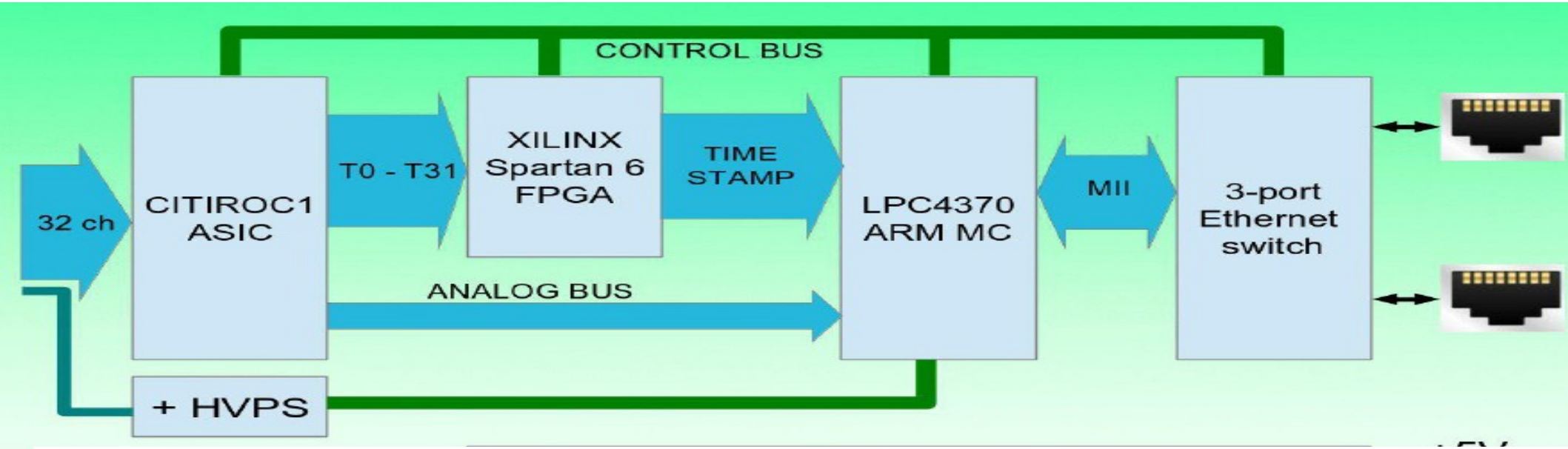
Delayed neutron capture event topology



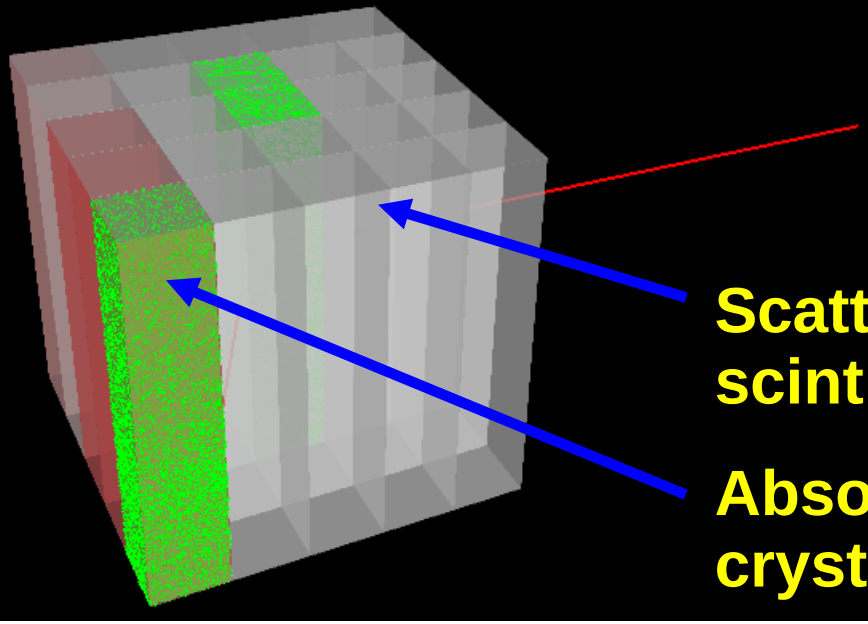
Possible solution of SiPM readout board



CAEN A1702 32-channel SiPM Readout Front-End Board



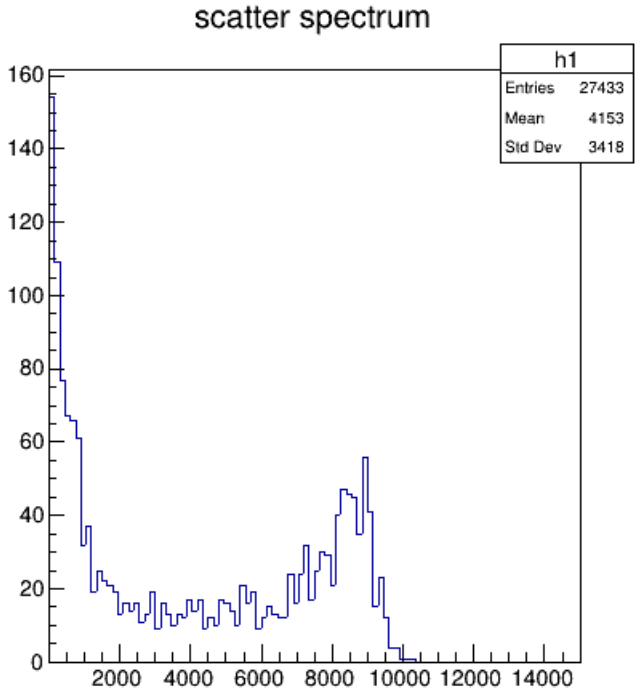
Advanced modular RPM design for spectral measurements

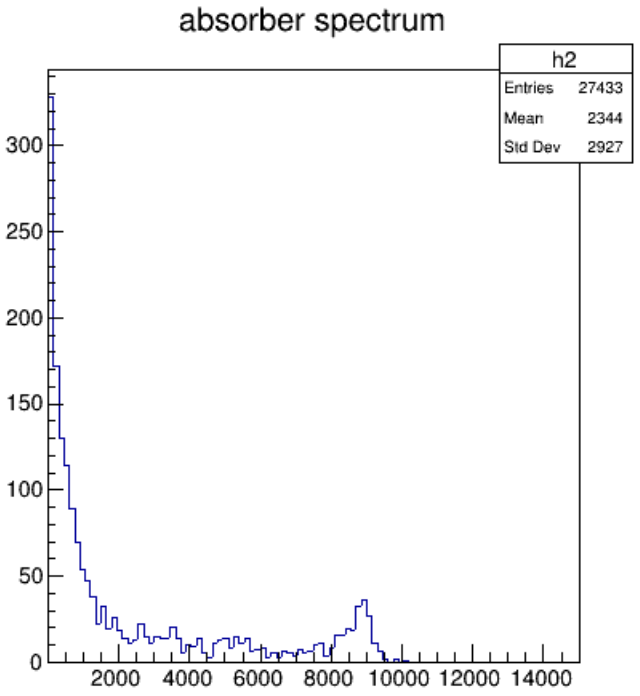


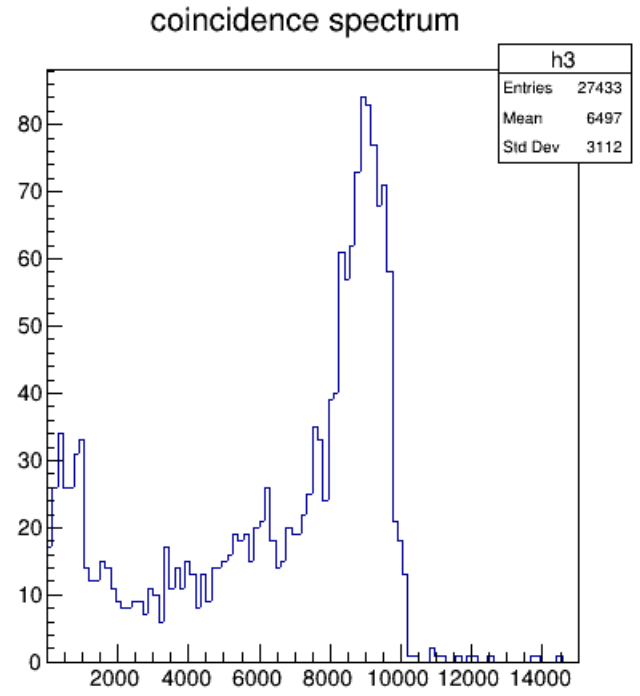
137Cs source

Scatter – 4 raws of plastic scintillator

Absorber – raw NaI or BGO crystal scintillator







Lawrence Livermore National Laboratory

FACILITATING PRACTICAL IMPLEMENTATION OF NATIONAL NUCLEAR FORENSICS LIBRARIES

JERRY DAVYDOV

- May – October 1992 - 100 kg of Uranium (unknown enrichment) was stolen; 80 kg could be recovered later – origin Chepetsk Mechanical Factory
  - Suspects say the material was apparently destined for the Middle East
- April 1993 - 80 tons of nuclear fuel were seized by the Ukrainian customs service on its way to Libya via Bulgaria – origin most likely Russian Federation
- 1995 – 10 pipes and 10cm bar - nuclear fuel rod fragments stolen – origin Chernobyl NPP
  - Incident reported on 28 September 2005
  - 4 suspects arrested (1995)
    - Material had been missing since 1995
- March 1996 - 6 kg of Uranium (~20% enriched U-235) were seized in Kiev, Ukraine, in March, 1996 – origin most likely Russian naval fuel storage facility
- 1 March 2005 – 582g of U238 interdicted at the Boryspil International Airport in Ukraine – origin unknown
  - Incident reported on 2 March 2005
  - 1 suspect arrested
- 17 March 2010 – 2.5kg Depleted uranium (3 pieces) OR 2.5kg U235 were interdicted in the Donetsk Oblast – origin unknown
  - Incident reported 12 May 2010
  - 6 Ukrainian citizens arrested

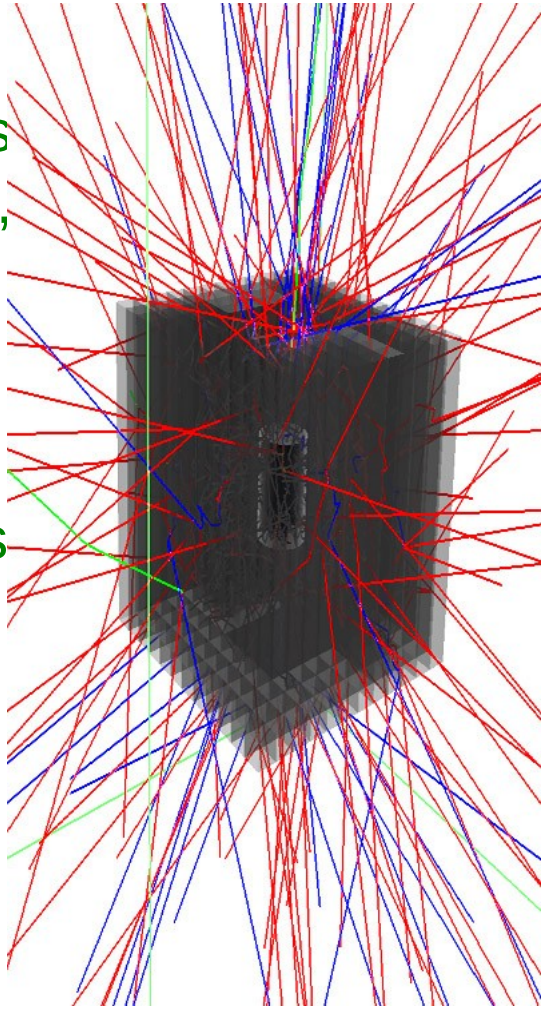
Nuclear Safeguards Systems

Well Neutron Coincidence Counter

Neutron coincidence counters based on He-3 tubes are used to make active neutron measurements on items such as bulk UO_2 samples, high-enrichment uranium metals, UAl alloy scraps, LWR fuel pellets and ^{235}U and ^{238}U fuel materials.

Due to supply shortage of He-3 gas used in neutron detectors an alternative technologies are under development.

Developed gadolinium lined plastic scintillation modular detector to replace 3-He based neutron multiplicity counters.



Gd lined modular plastic scintillation Neutron Coincidence Counter

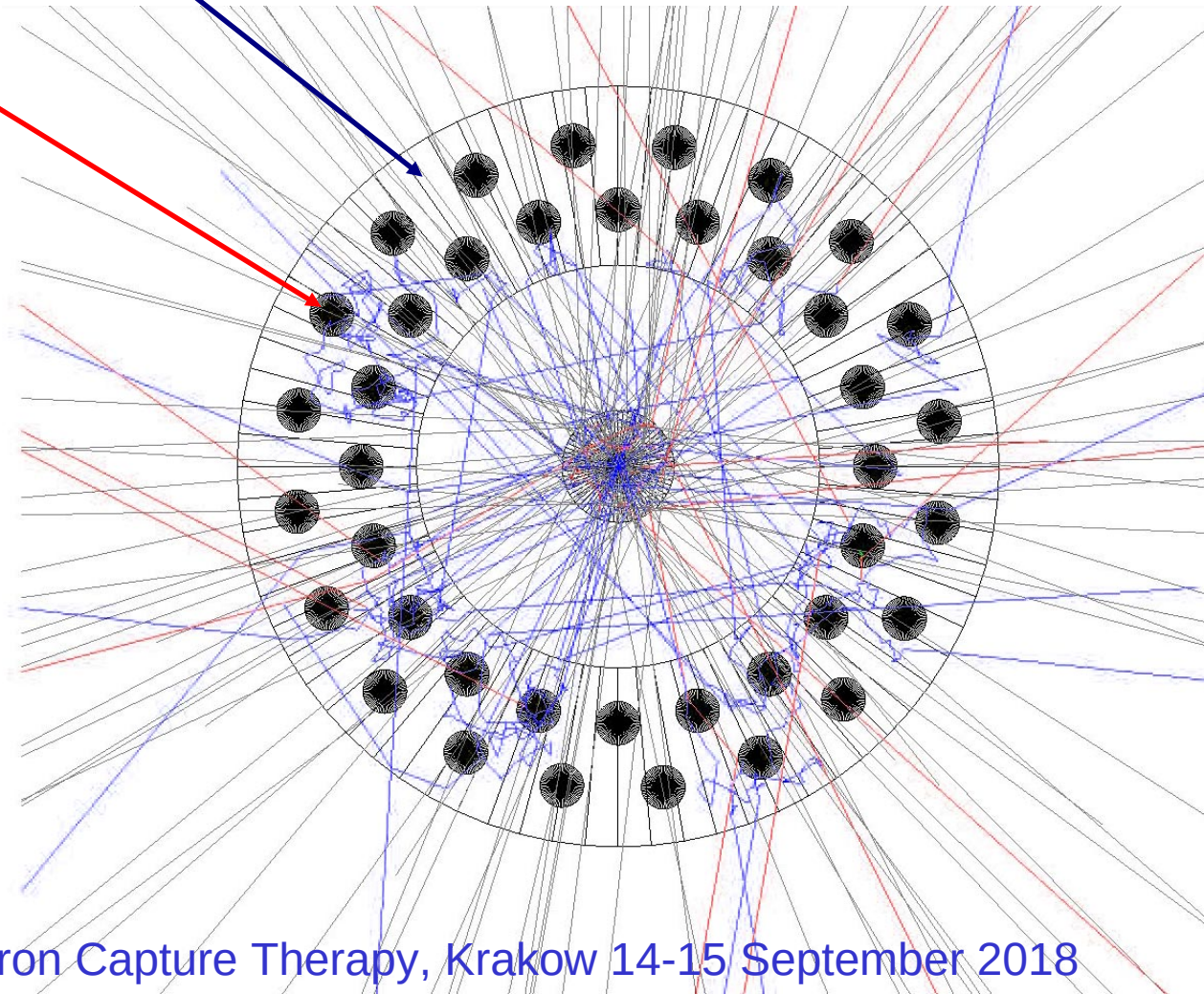
Geant4 simulation of He-3 neutron multiplicity counter

1 kg of fission material can be detected but for correct detection of 3 kg additional Monte-Carlo simulations are needed .

HD polyethylene

^{3}He tubes

Fissile materials calibration Standards NBS-SRM-969

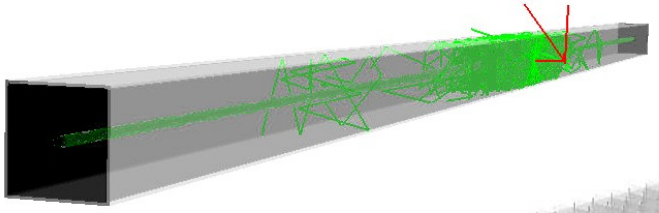


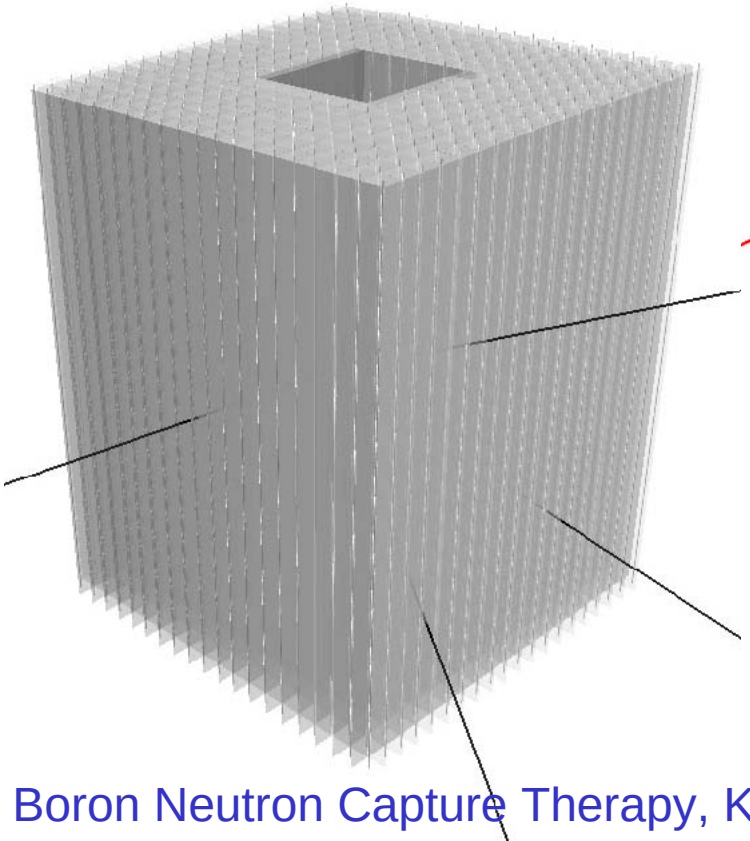
Detector with plastic scintillator strips with gadolinium neutron converter

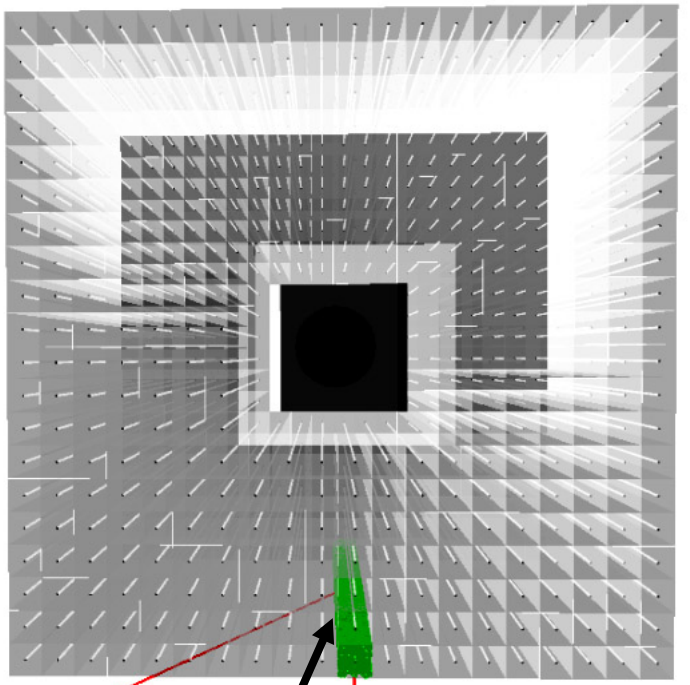
2×2×40 cm³ plastic scintillator strips

20 × 20 plastic scintillator strips with embedded wls-fibers

Reflective layer : TiO_2+Gd_2O_3





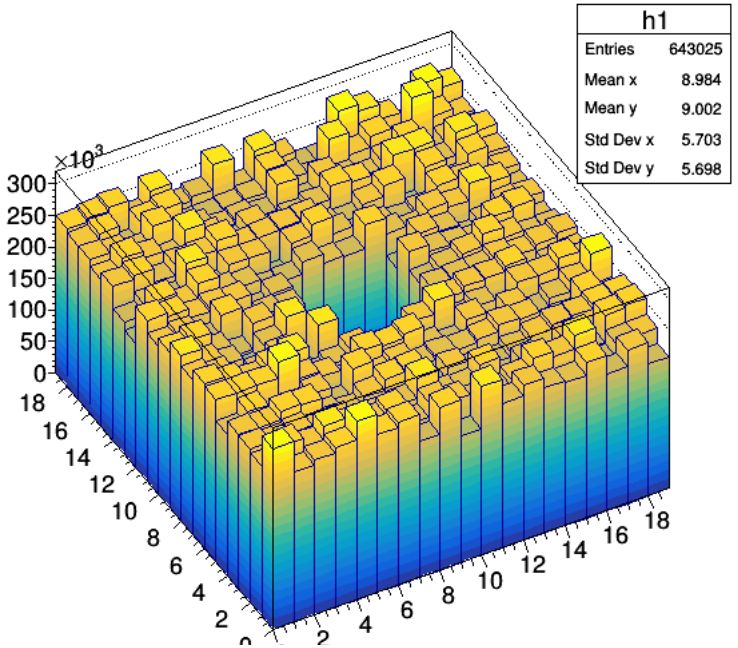


Gamma-ray

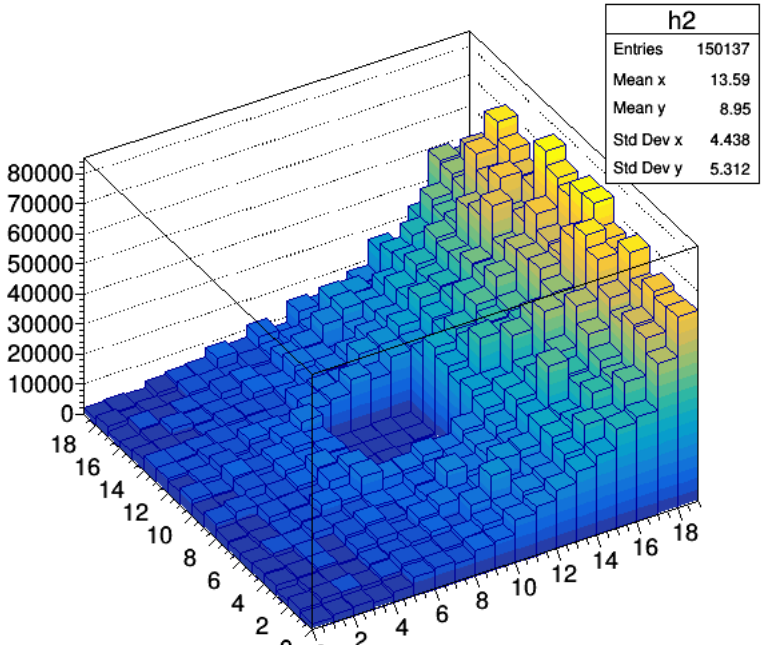
Scintillation photons are green

Event topology in plastic scintillator modular detector

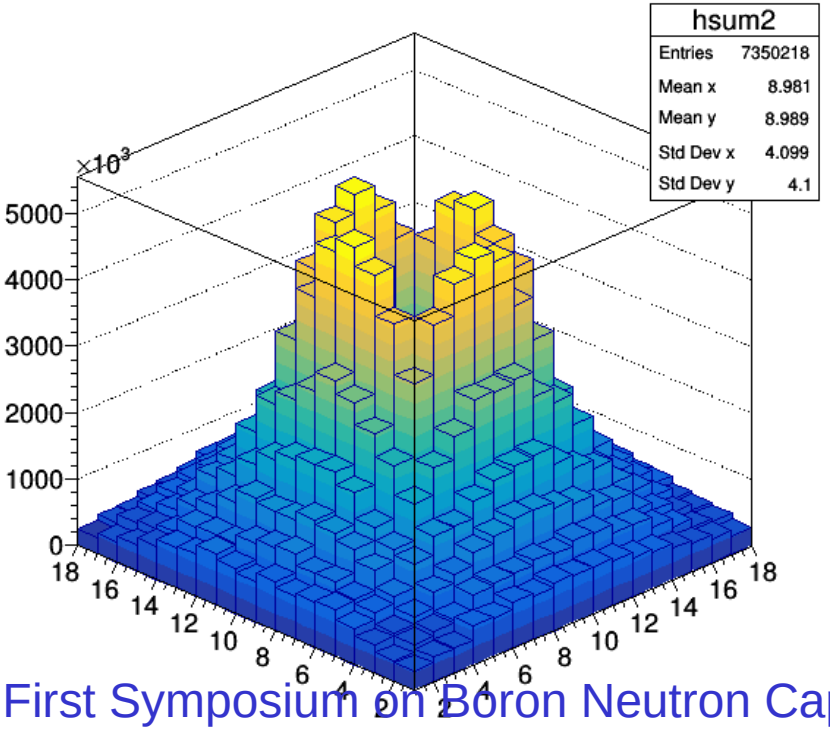
gamma background



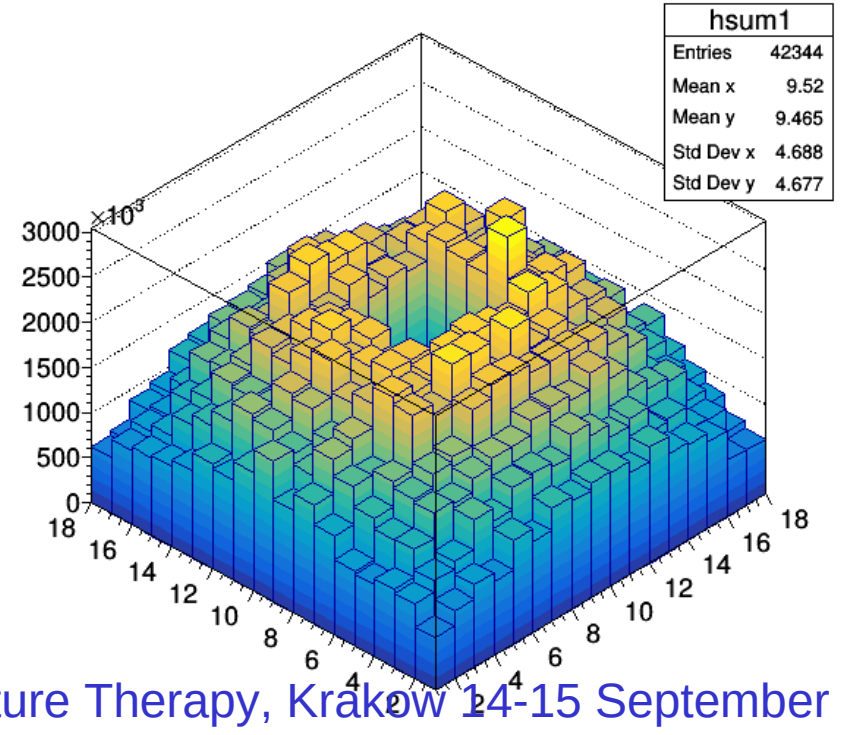
Cs-137 source

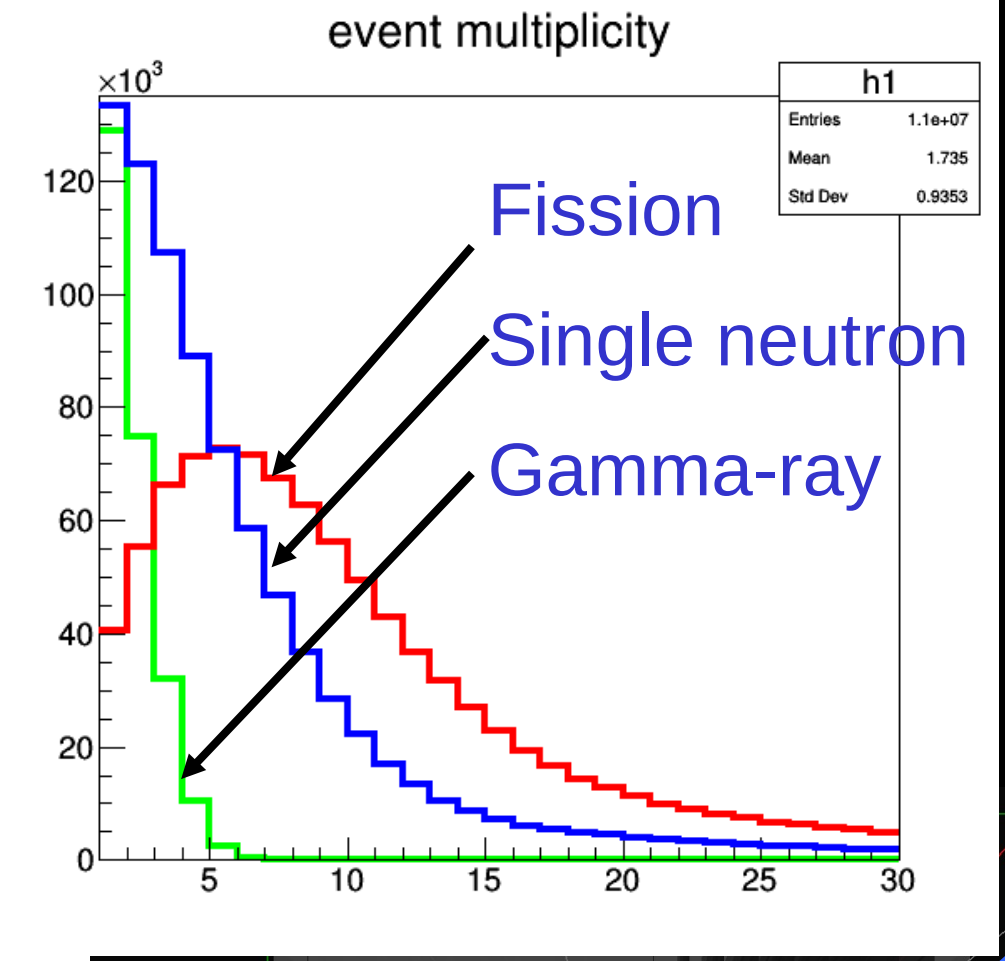


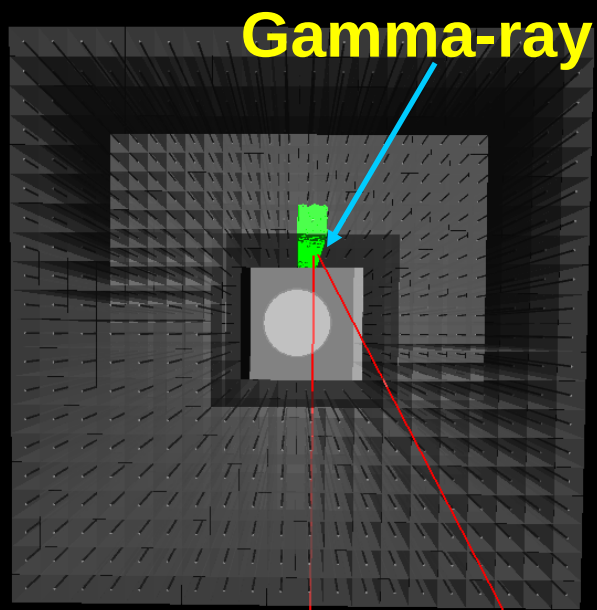
Plutonium fission prompt event

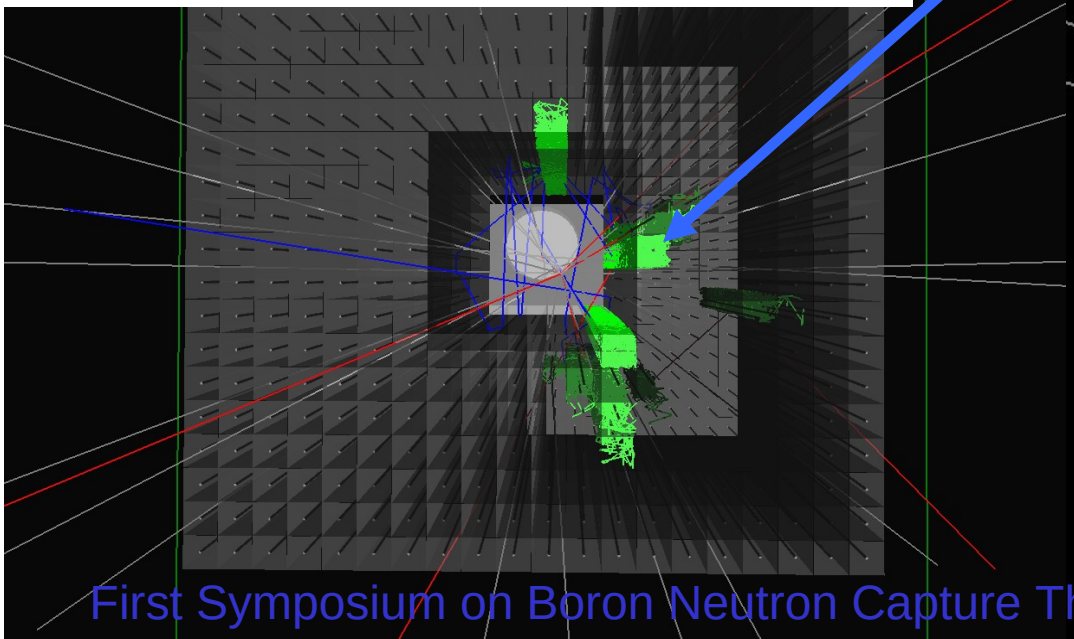


Plutonium fission delayed event

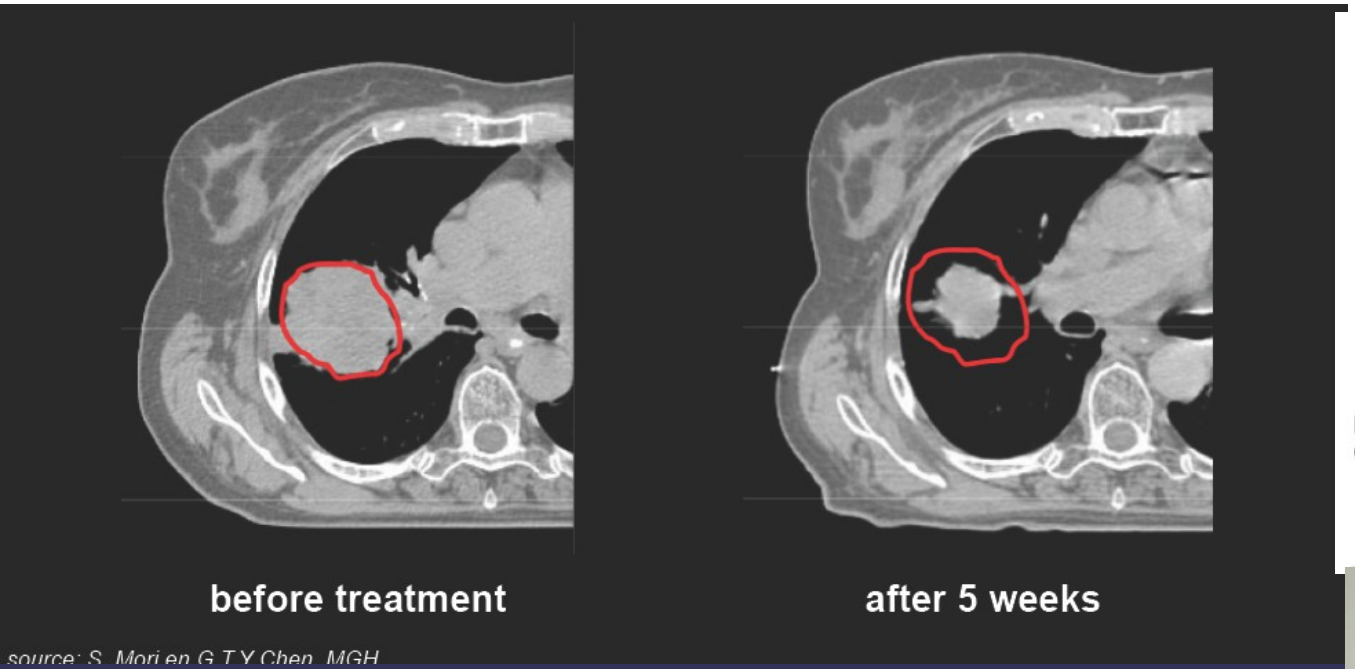


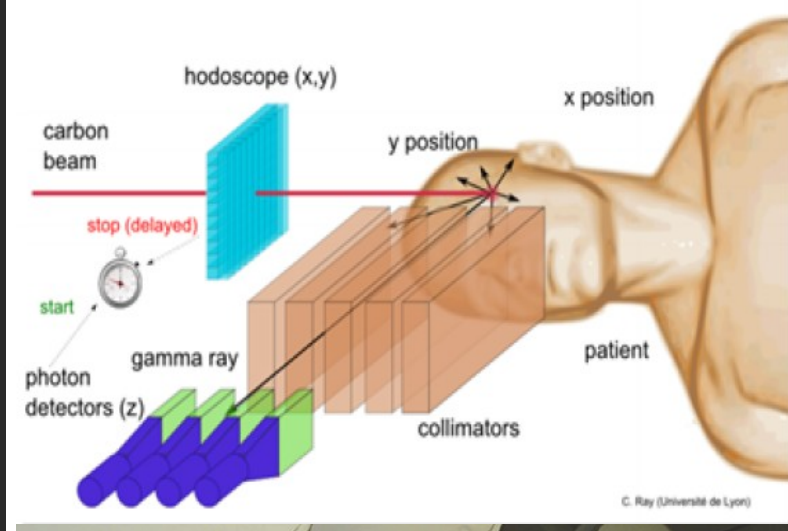

event multiplicity
×10^3
h1
Entries 1.1e+07
Mean 1.735
Std Dev 0.9353
120
100
80
60
40
20
0
5
10
15
20
25
30
Fission
Single neutron
Gamma-ray

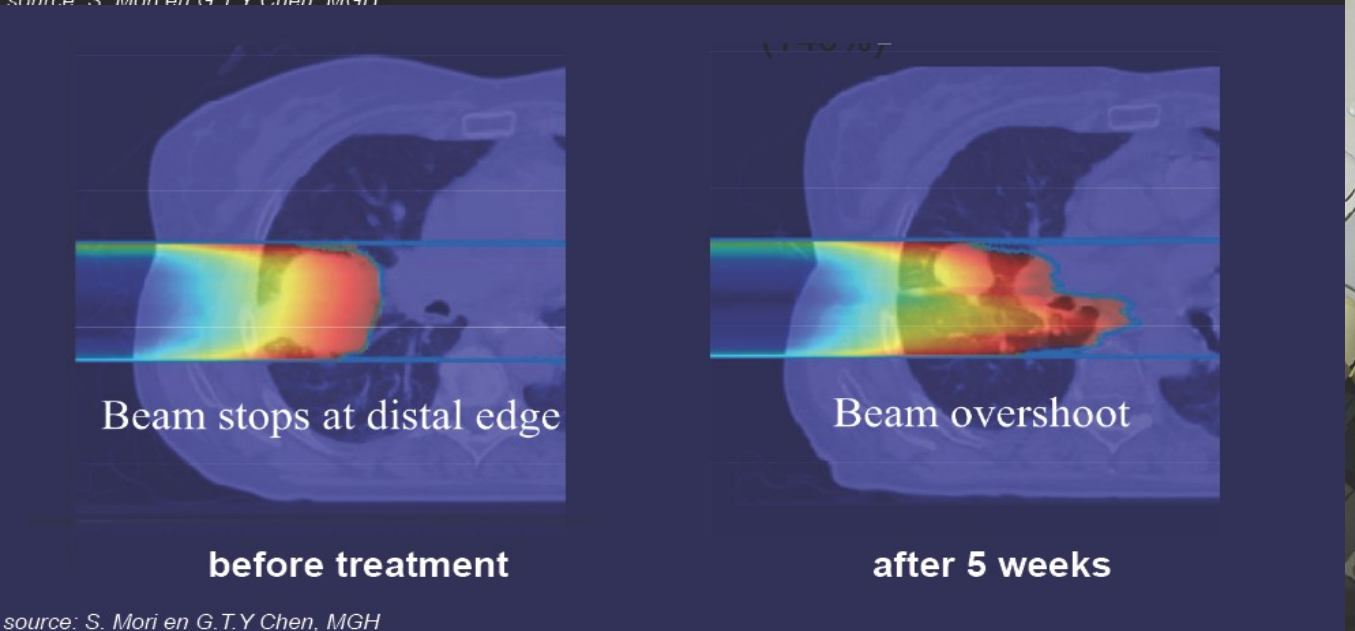

Gamma-ray event

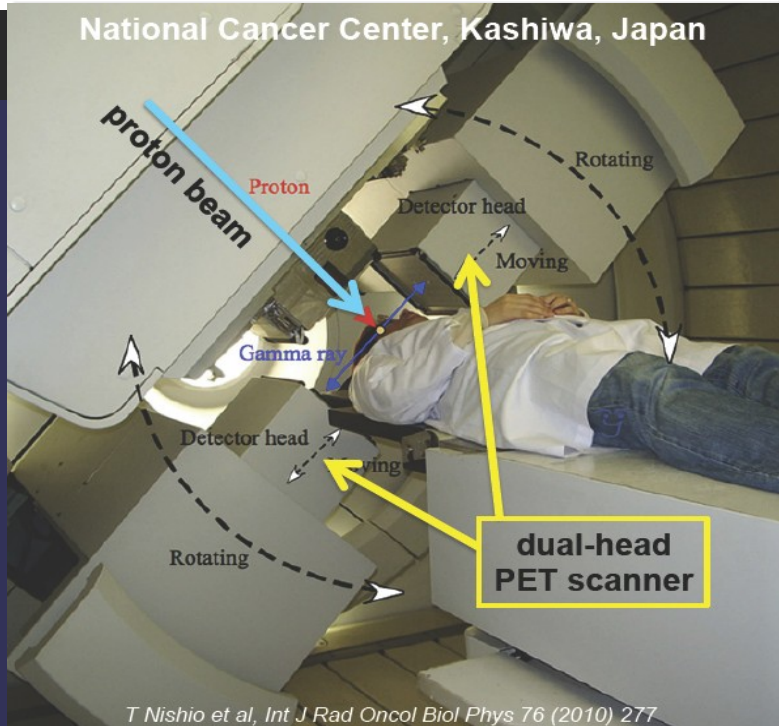

Fission events
(neutrons- blue, gammas- red,
scintillation photons - green)

In-vivo monitoring of absorbed dose in proton teraphy

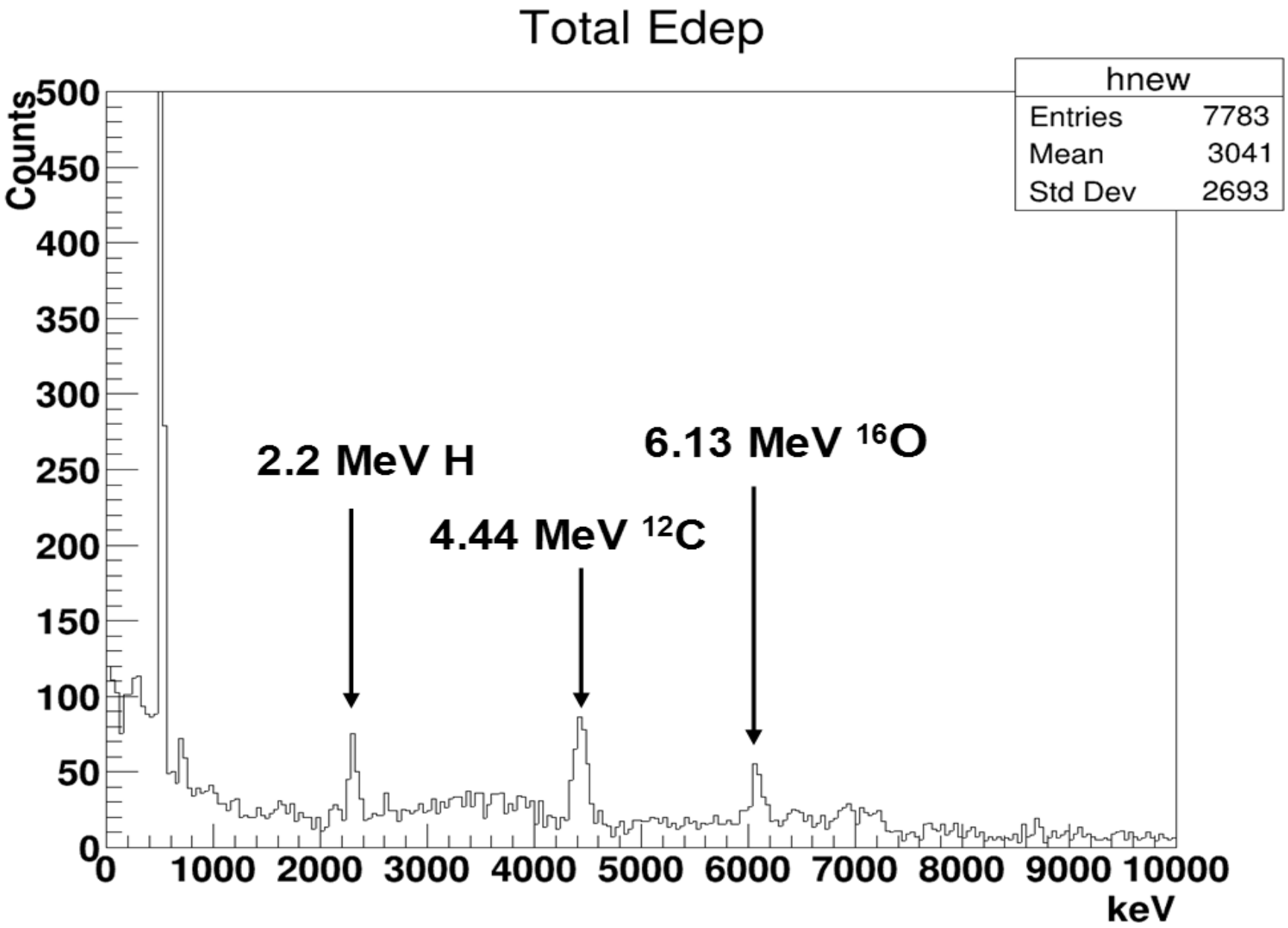




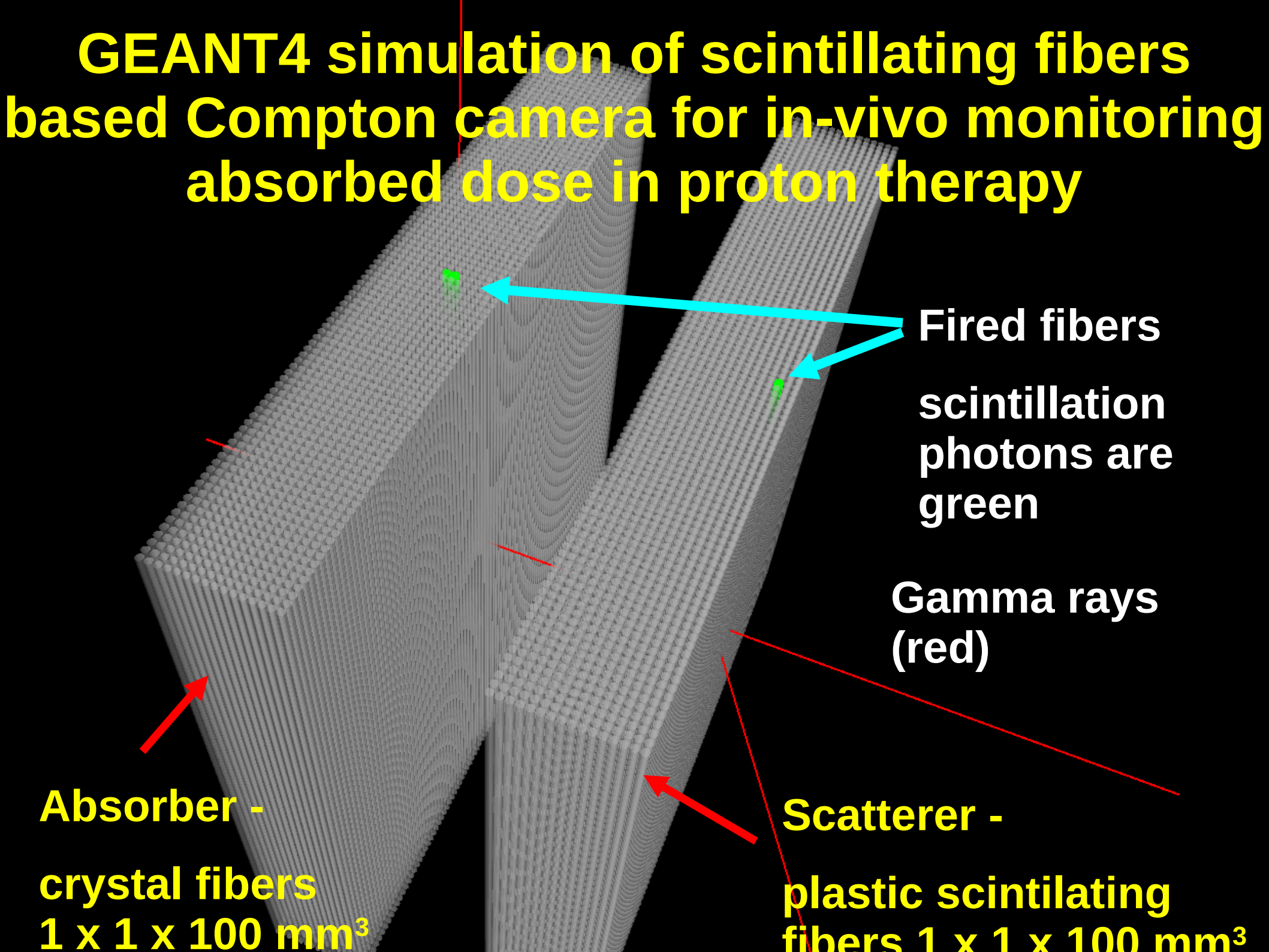


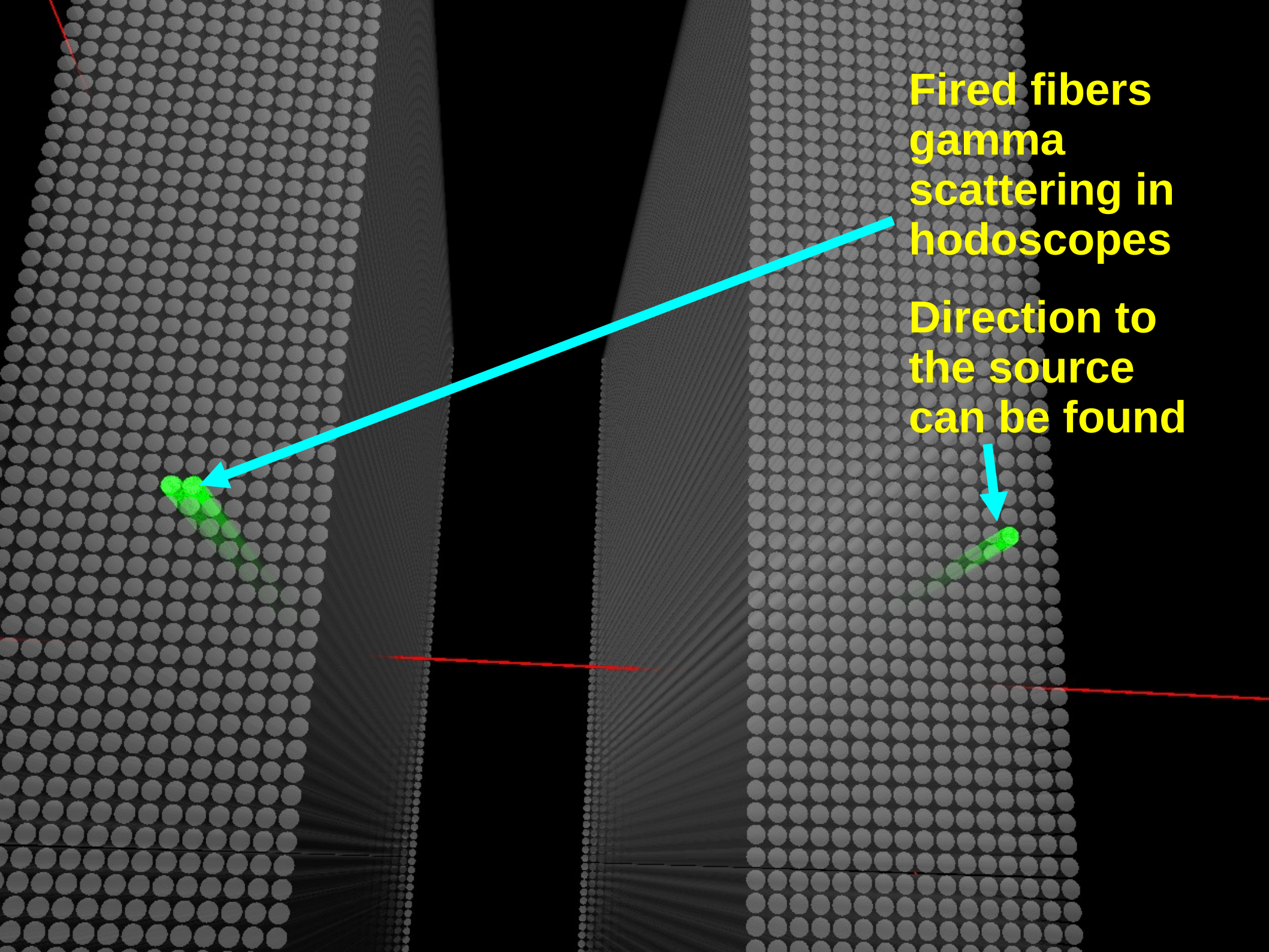


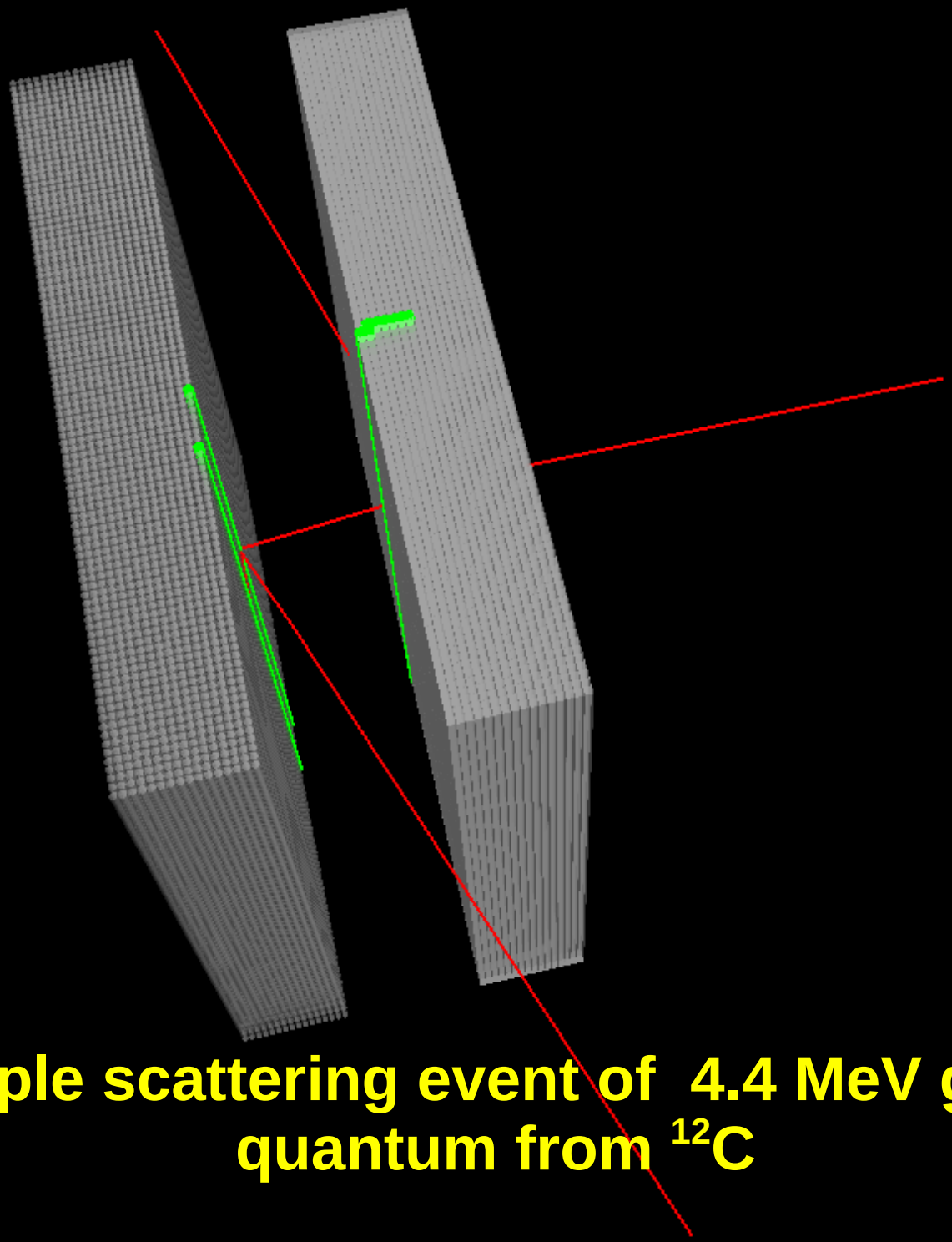
Geant4 simulation of 100 MeV proton beam hitting PMMA phantom



GEANT4 simulation of scintillating fibers based Compton camera for in-vivo monitoring absorbed dose in proton therapy




Fired fibers gamma scattering in hodoscopes
Direction to the source can be found



Multiple scattering event of 4.4 MeV gamma quantum from ^{12}C