Photomultipliers: Uniformity measurements

L. Pereira[1], A. Morozov[1], M. M. Fraga[1], L. M. S. Margato[1], P. Assis[2], R. Conceição[2], F. A. F. Fraga[1]

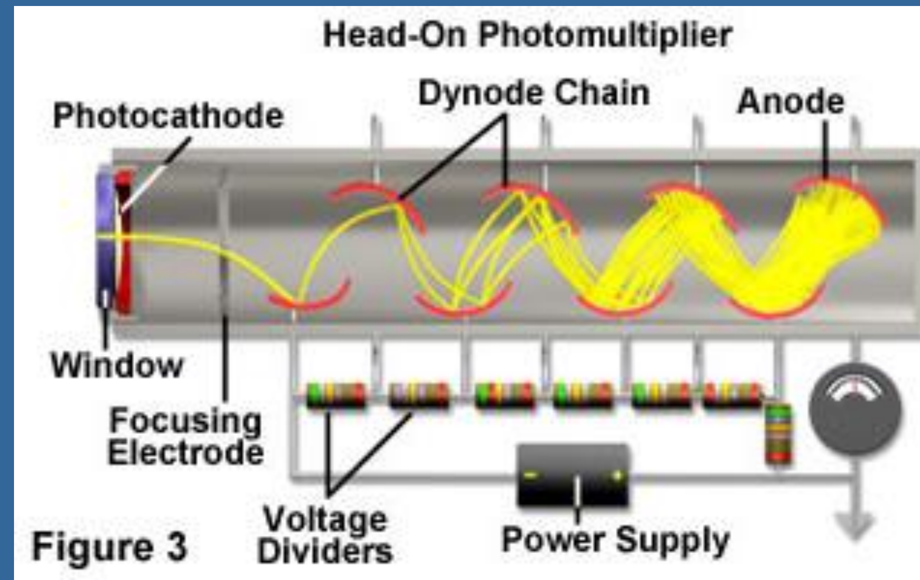
[1] LIP - Coimbra

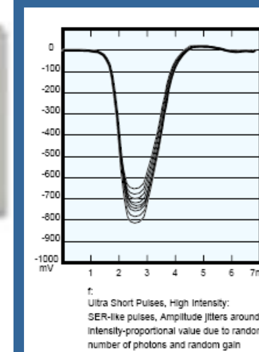
[2] LIP - Lisboa

Outline

- Photomultiplier tubes
- The discovery of the cosmic radiation
- Air fluorescence in the context of the cosmic radiation detection
- Uniformity of the Auger FD PMTs
- Position sensitive micropattern gaseous neutron detector with optical readout
- Simulations with ANTS: Anger-camera Neutron detector Toolkit for Simulation

Photomultiplier Tubes (PMT)





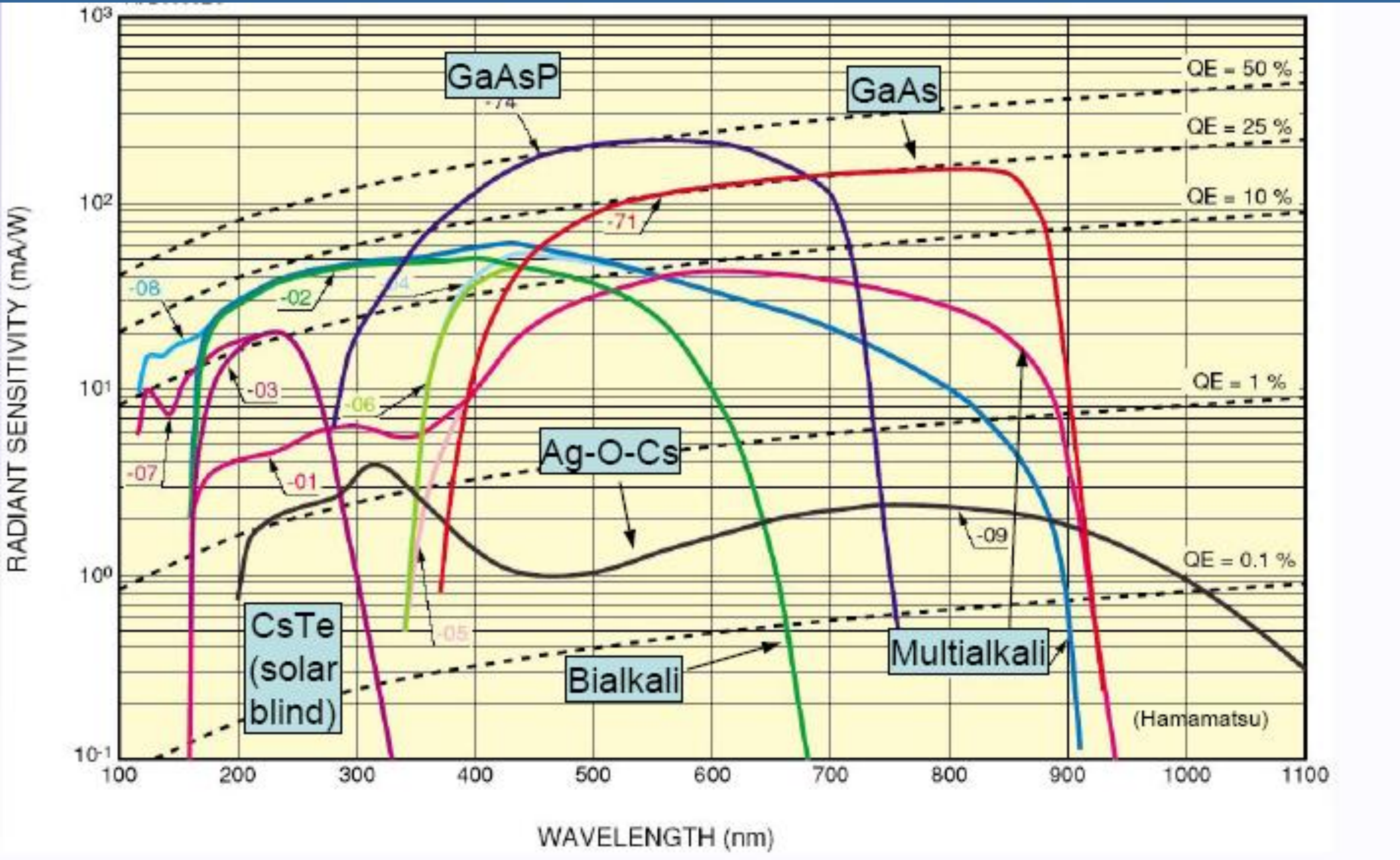
Good

- High gain: up to 10^7
- Low dark count
- Fast response time: RT&FT<1ns
- Large sensitive areas

Bad

- Bulky
- Unstable
- Sensitive to magnetic fields
- High voltage

Radiant Sensitivity and Quantum Efficiency



The discovery of cosmic rays

For some time it was believed that Earth was the only source of natural radiation.

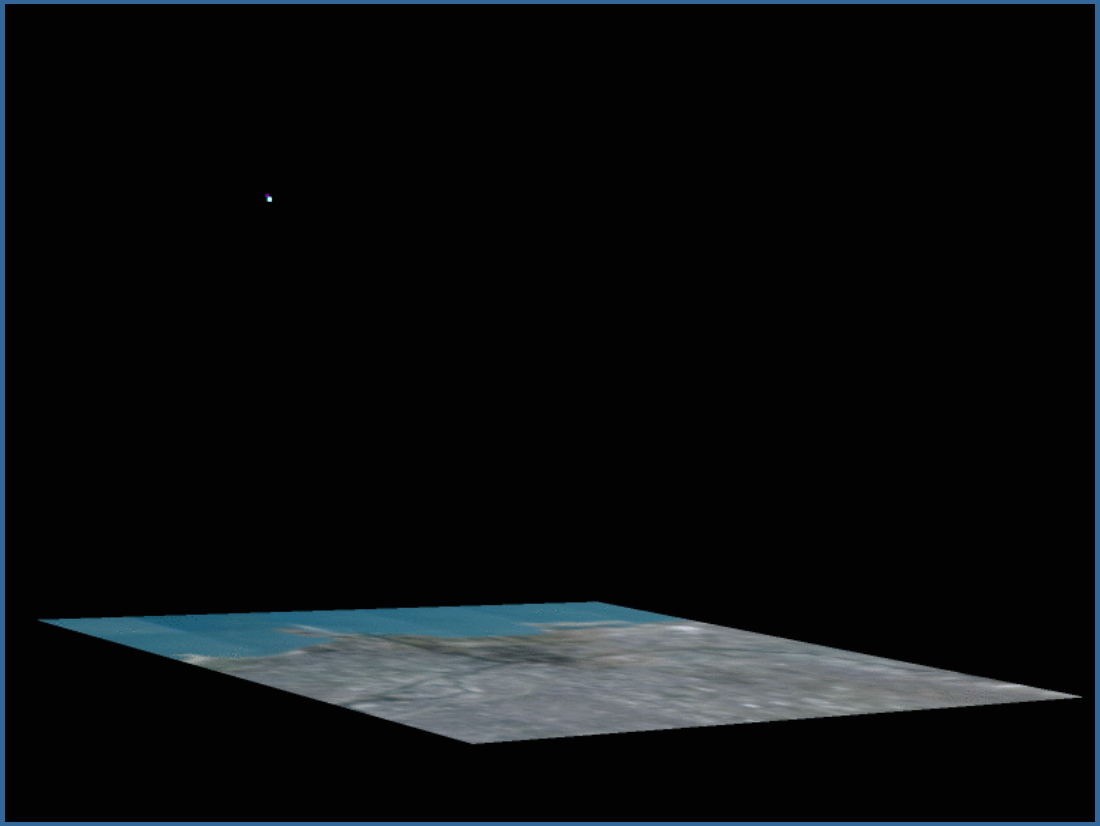
Between 1911 and 1912 Viktor Hess climbed into a balloon up to altitudes higher as 5000 m, and proved that there was a penetrating radiation that crossed the atmosphere and increased with altitude.

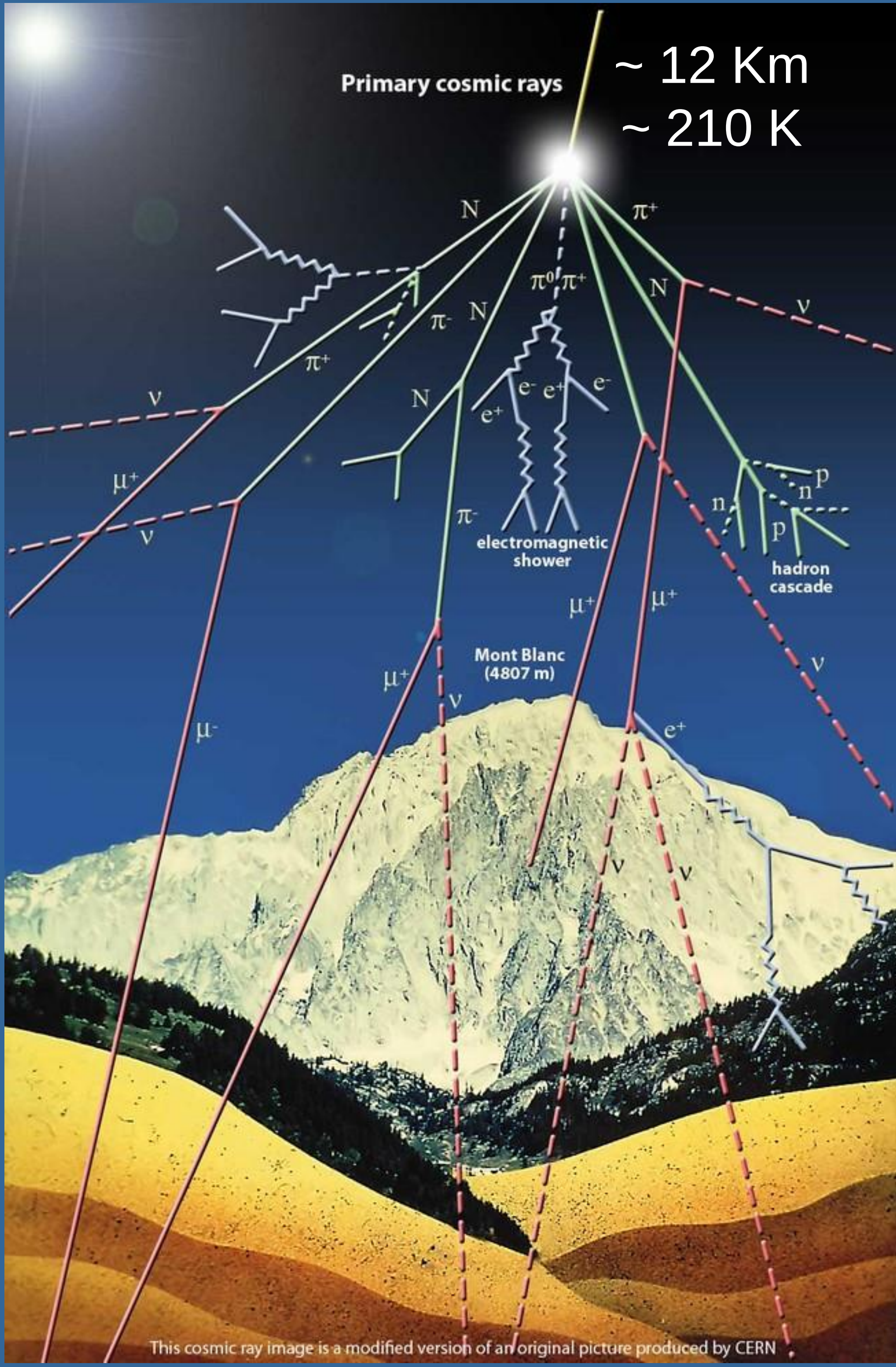
He gave this phenomenon the name "Cosmic Radiation", which later evolved to "Cosmic Rays".

Hess received the Nobel prize in 1936 for the discovery of the cosmic rays.

Years later in 1938, Pierre Auger discovered that cosmic rays interact with the atmosphere creating a particle shower.

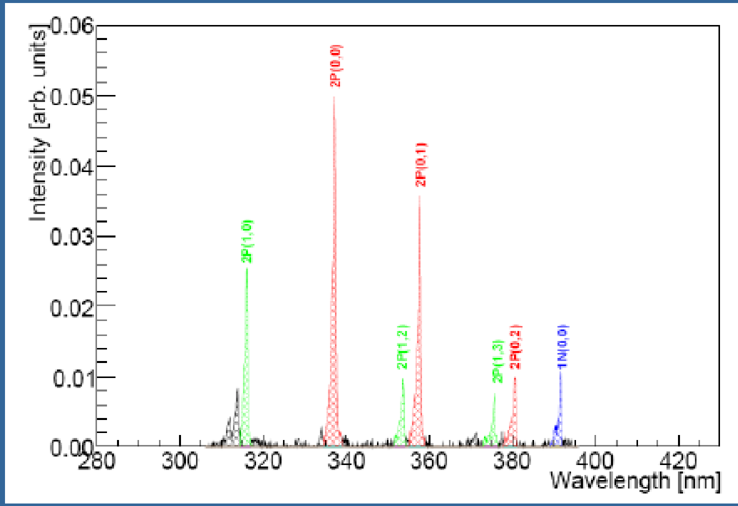
He estimated that the primary particles (i.e. the particles that create the shower) should be very energetic (10^{15} eV).

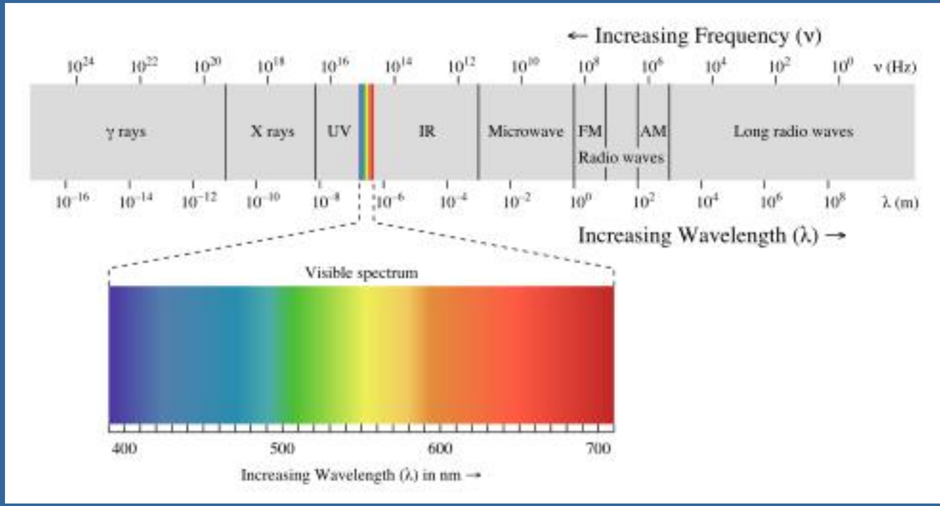




- The particle shower is accompanied with the emission of light due to the interaction with the air molecules.

- Almost all light is emitted between 300 and 400 nm, and is produced during the de-excitation of the nitrogen molecules.



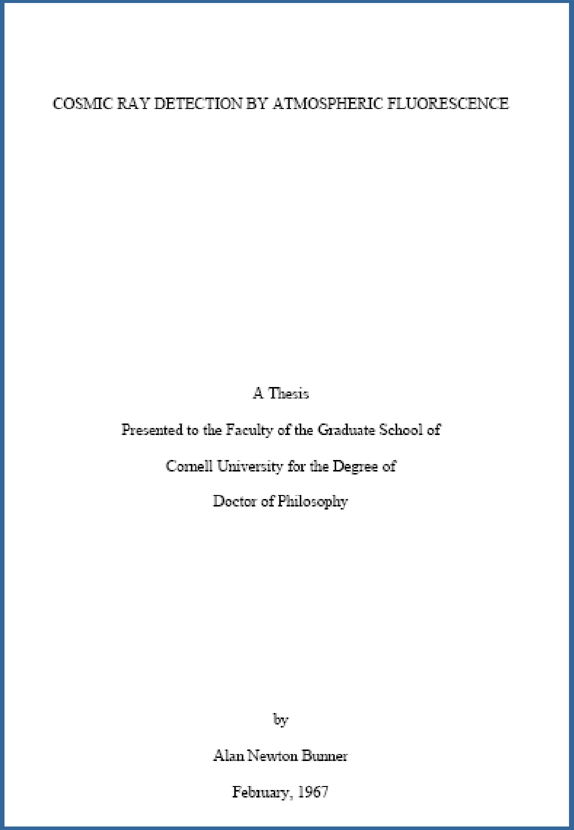


- The scintillation light yield is proportional to the energy of the cosmic ray.

Which means that…

> If we are able to measure the amount of light during an air shower we can determined the energy of the cosmic: Fluorescence Telescopes.

The first attempts to observe the extensive air showers through the observation of the scintillation date from the 60’s, in the University of Cornell (USA). The research group included the Post-Graduated student Alan Bunner, who’s PhD thesis became a reference.


COSMIC RAY DETECTION BY ATMOSPHERIC FLUORESCENCE

A Thesis

Presented to the Faculty of the Graduate School of

Cornell University for the Degree of

Doctor of Philosophy

by

Alan Newton Bunner

February, 1967

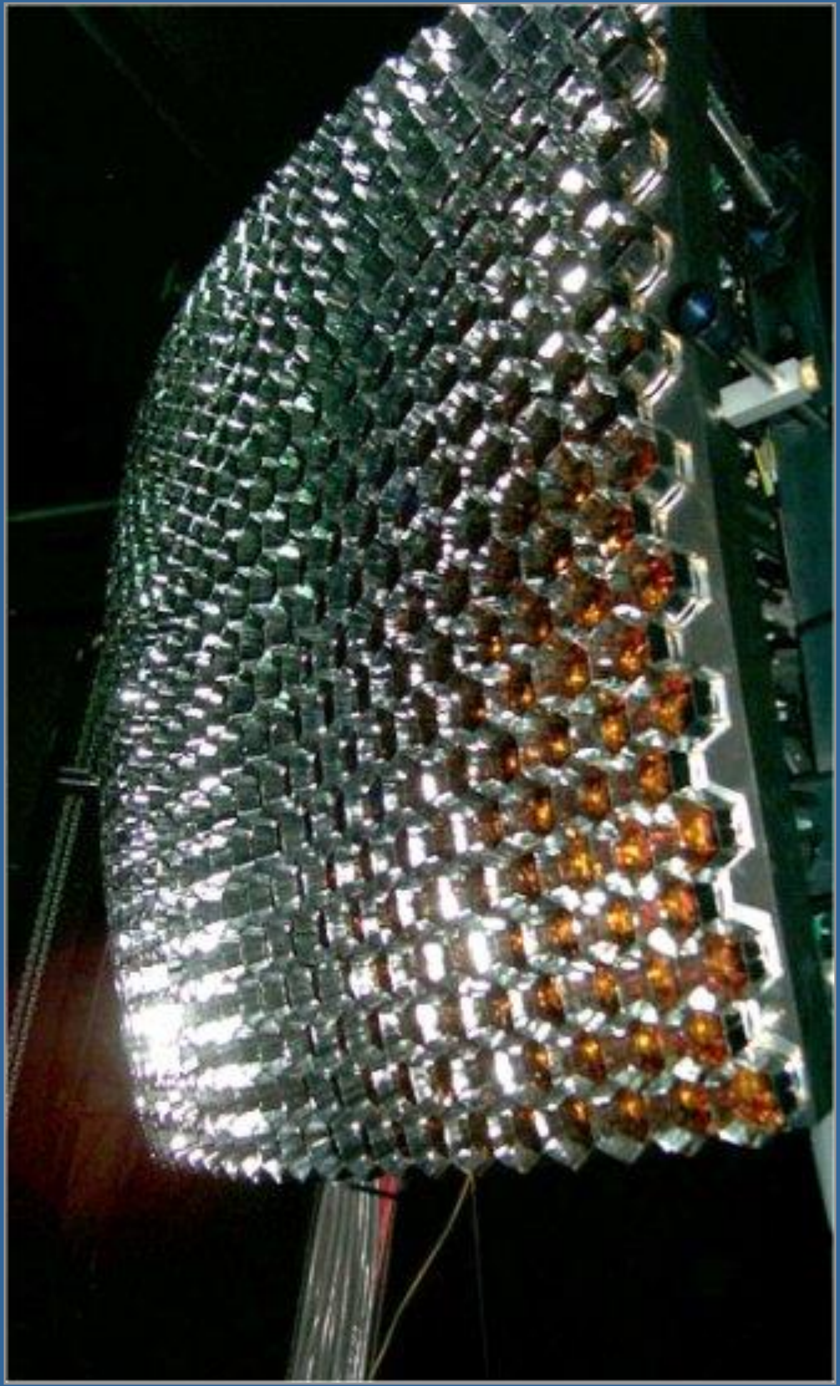
Bunner, A. N., *Cosmic Ray Detection by Atmospheric Fluorescence*, Ph. D. Thesis, Cornell University (1967).

Pierre Auger Observatory

Fluorescence detector camera: 440 PMT

Photonis XP3062

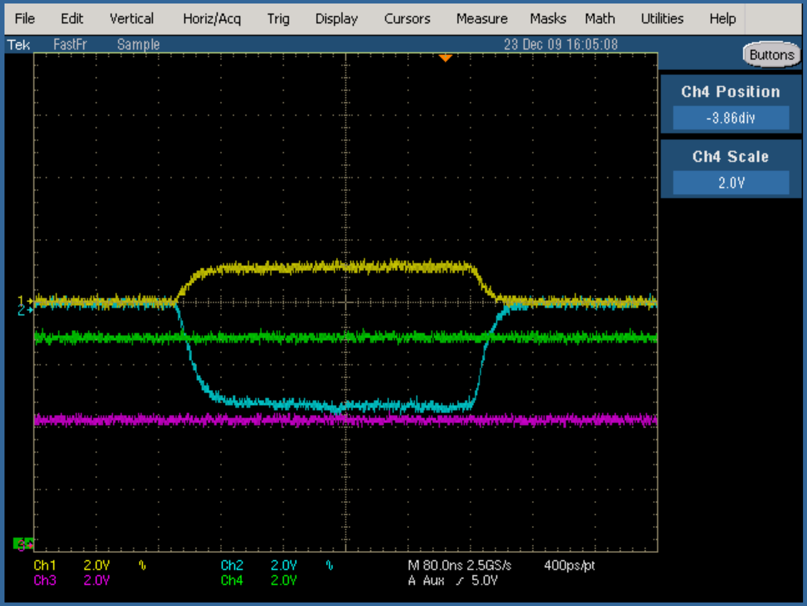
- Hexagonal
- bi-alkali
- 8 stage

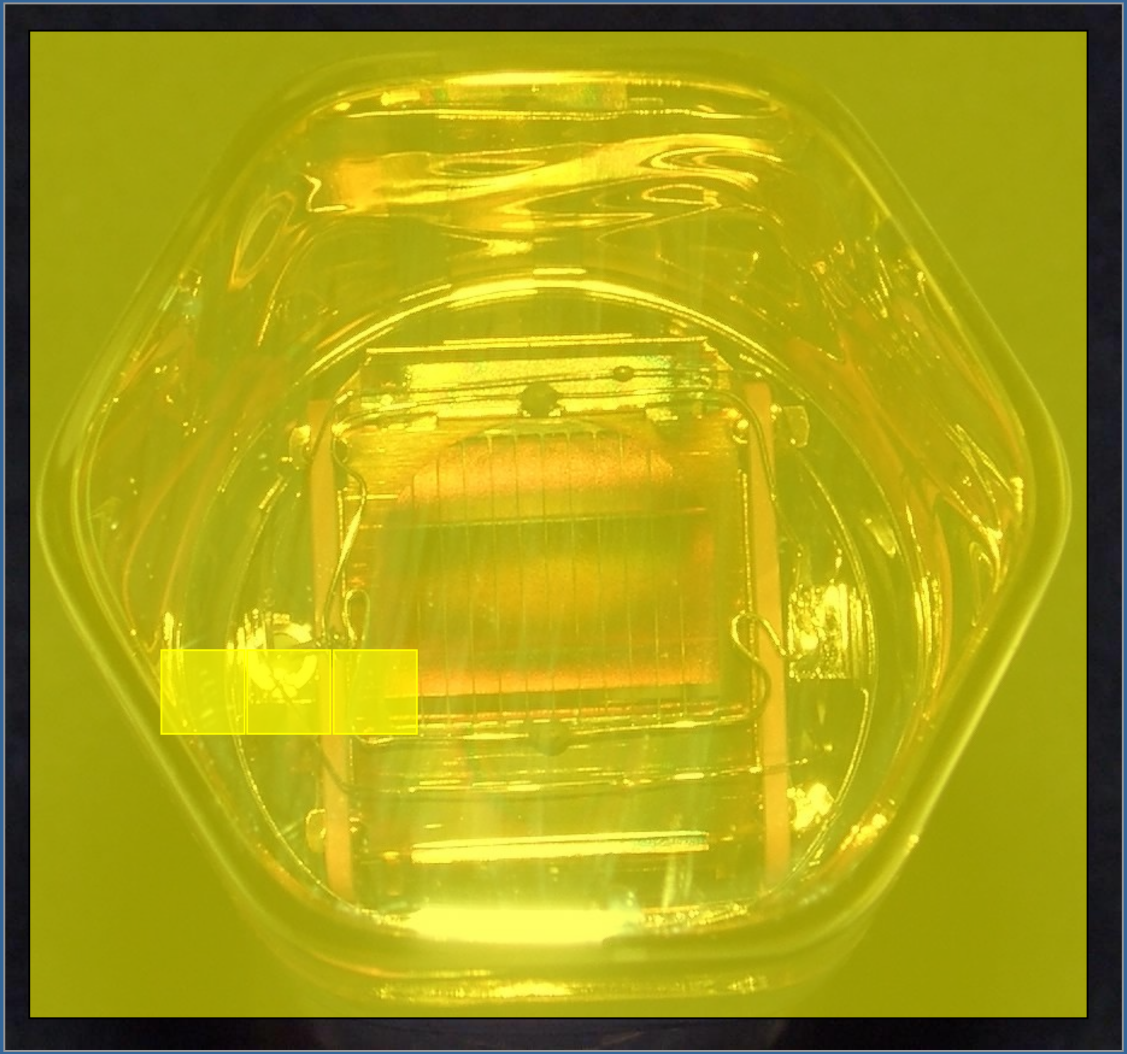


PMT Uniformity

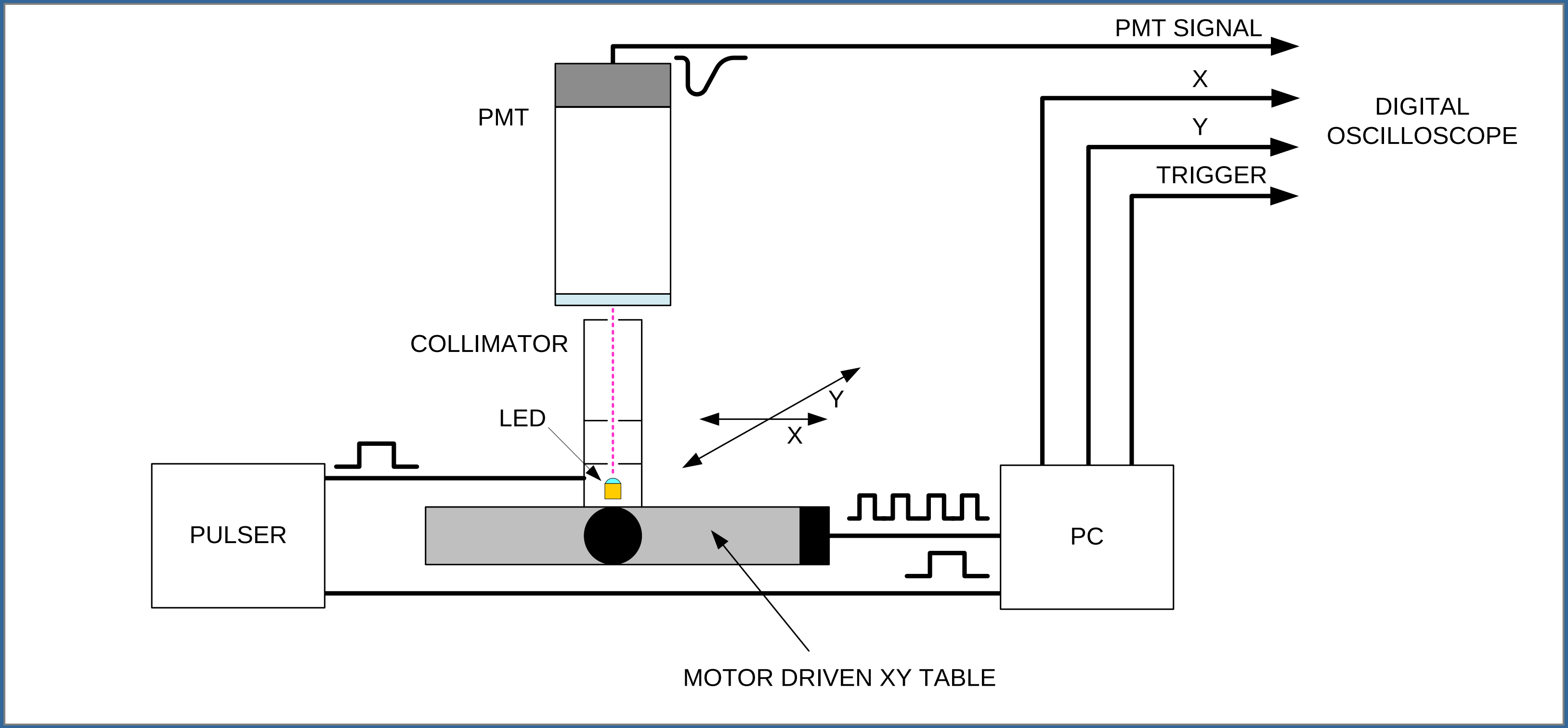
Variation of the anodic signal

along the photocathode's surface



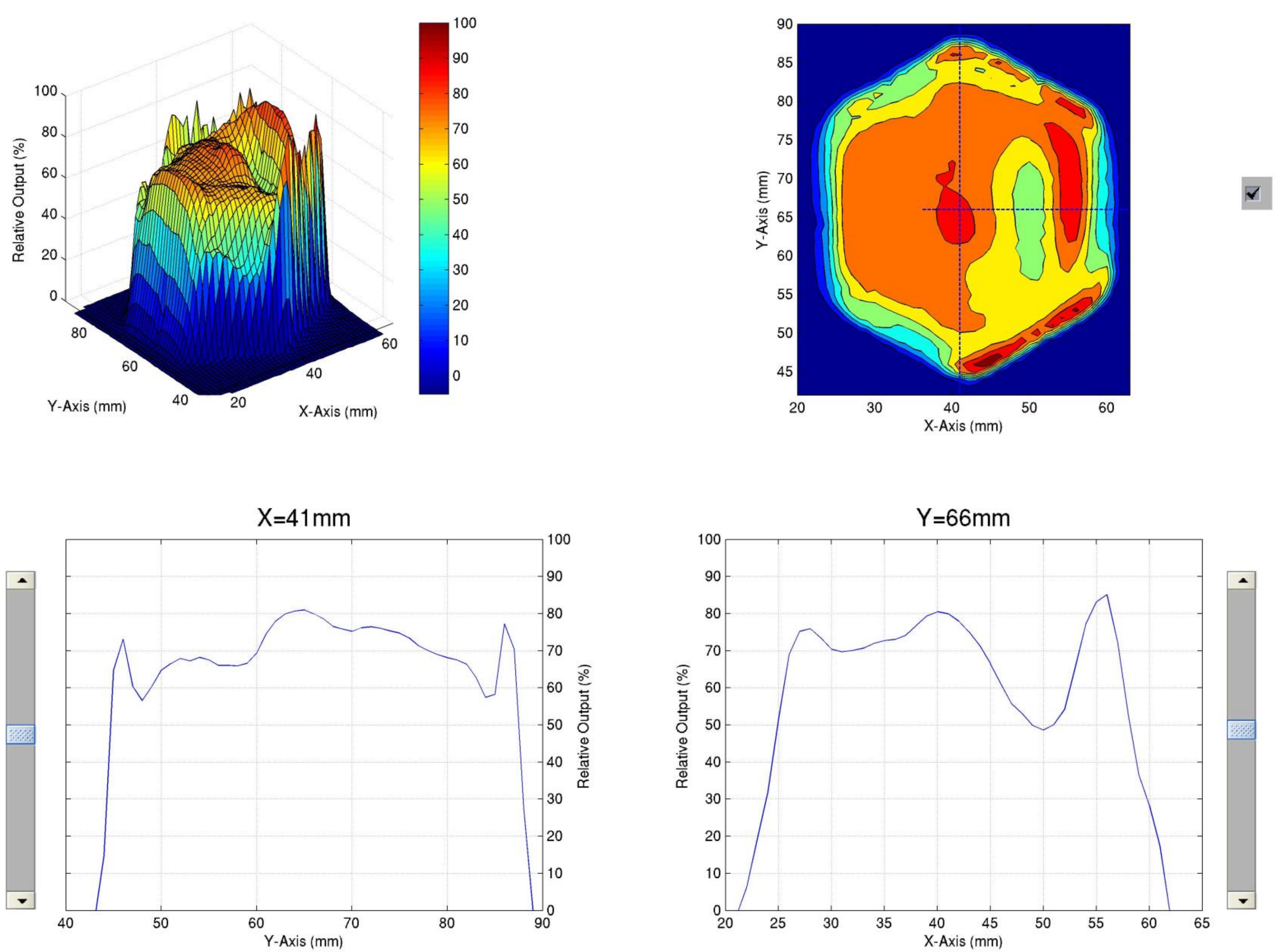


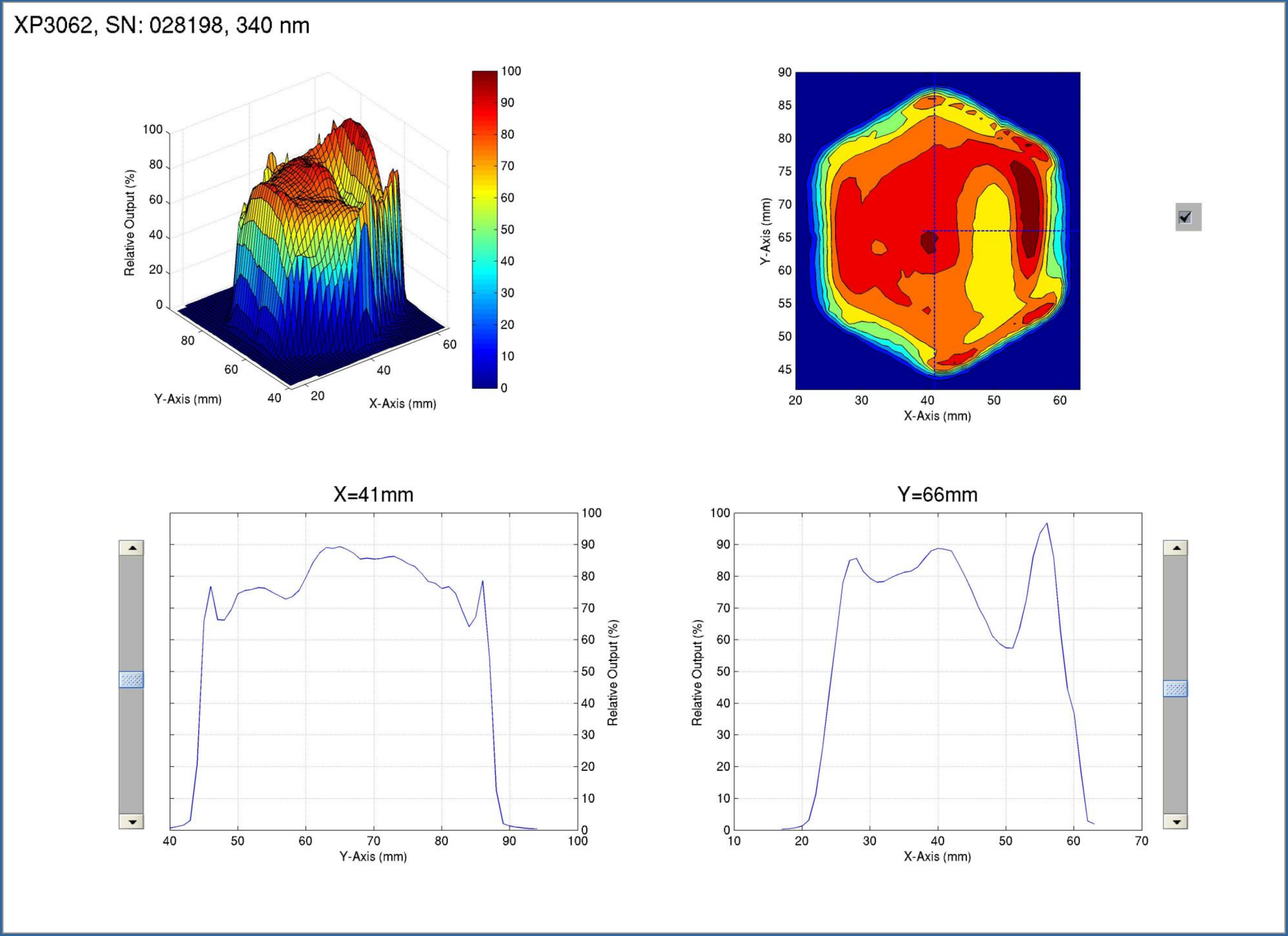
Area dependence of the anode sensitivity: Experimental system



- XY table, ~ 25 μm resolution
- Multistage collimator, 1 mm holes, 1 mm FWHM beam profile
- LEDs: 340 ± 15 nm, 370 nm ± 10 nm and 395 nm ± 15 nm …
- Bursts of several 200 ns width pulses per position
- The read out linearity was checked for the whole dynamic range using neutral density filters

XP3062, SN: 028198, 370 nm

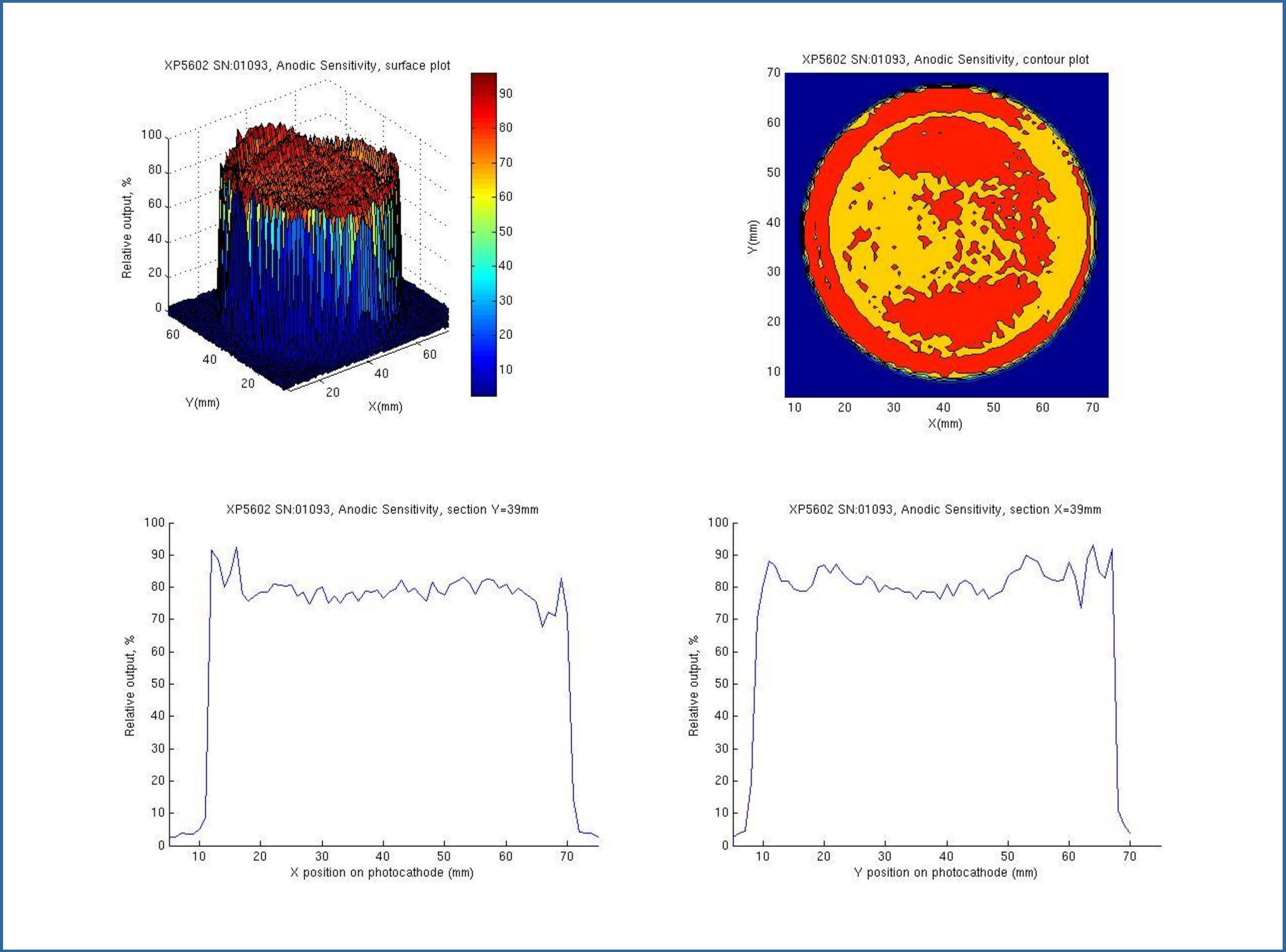



XP3062, SN: 028198, 340 nm
Relative Output (%)
Y-Axis (mm)
X-Axis (mm)
X=41mm
Y=66mm

However for an Gama Camera grade PMT…

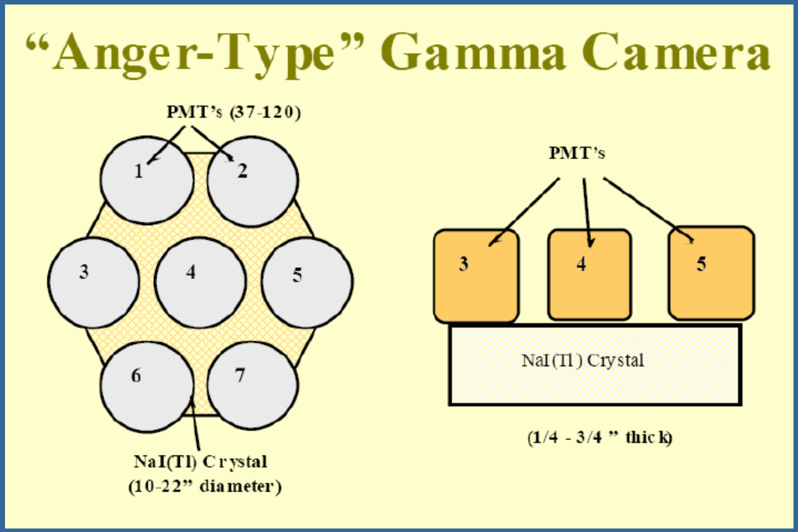
Photonis XP5602

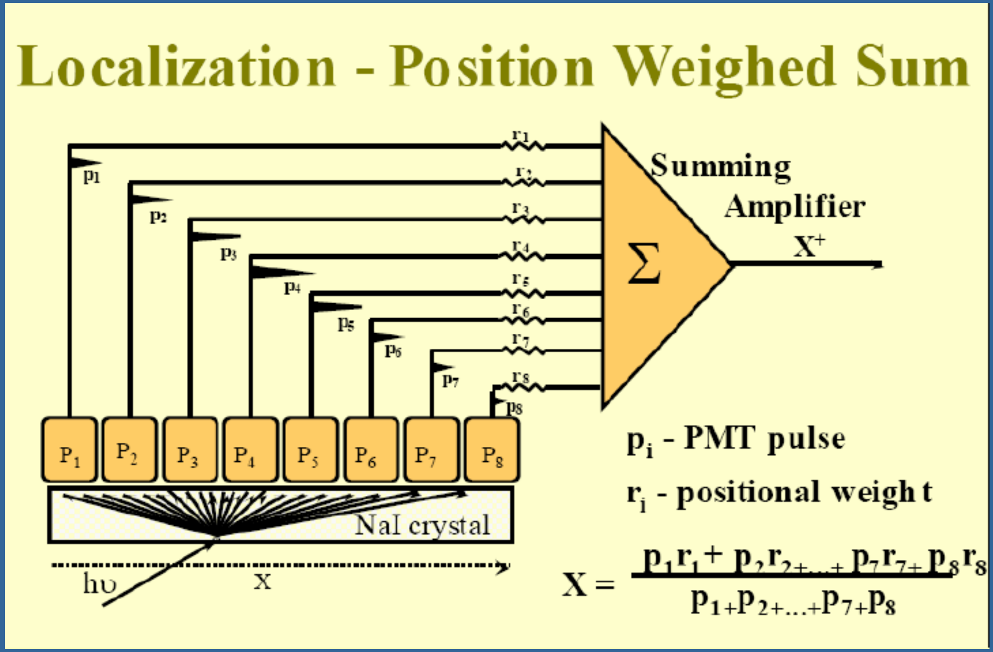
- Round
- Ø effective = 56 mm
- bi-alkali
- 8 stage

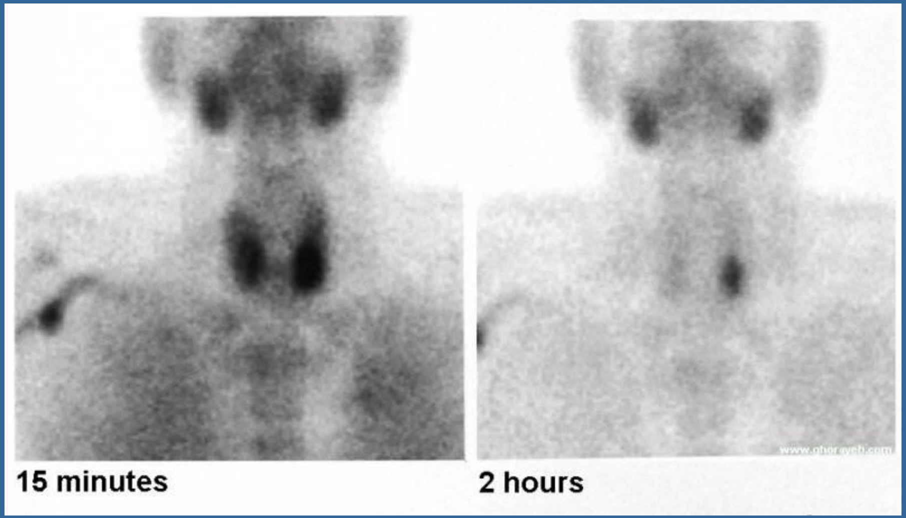

XP5602 SN:01093, Anodic Sensitivity, surface plot
Relative output, %
Y(mm)
X(mm)
XP5602 SN:01093, Anodic Sensitivity, contour plot
Y(mm)
X(mm)
XP5602 SN:01093, Anodic Sensitivity, section Y=39mm
Relative output, %
X position on photocathode (mm)
XP5602 SN:01093, Anodic Sensitivity, section X=39mm
Relative output, %
Y position on photocathode (mm)

The Anger Camera

In 1957 Hal Anger invented the scintillation camera known also as the gamma camera or Anger camera







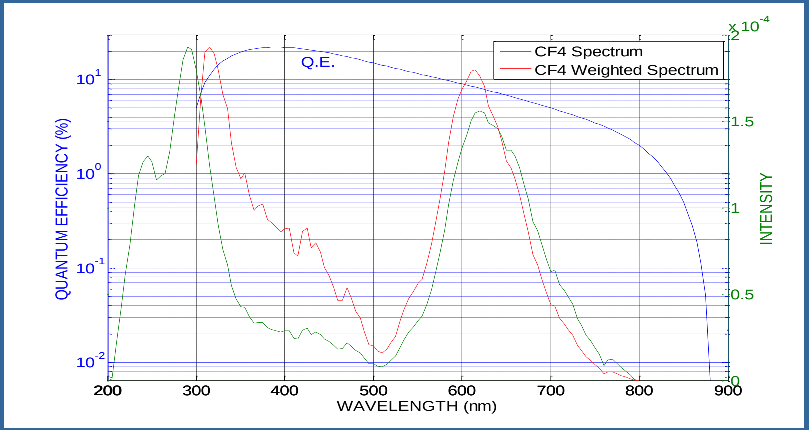
Technetium (99mTc) sestamibi upper body scan for thyroid evaluation.

An Anger type optical readout, micropattern gaseous neutron detector

$$^{3}_{2}He + ^{3}_{1}n \rightarrow \; ^{3}_{1}H + ^{1}_{1}p$$

Q-value = 0.764 MeV

Cross section: 5330 barns



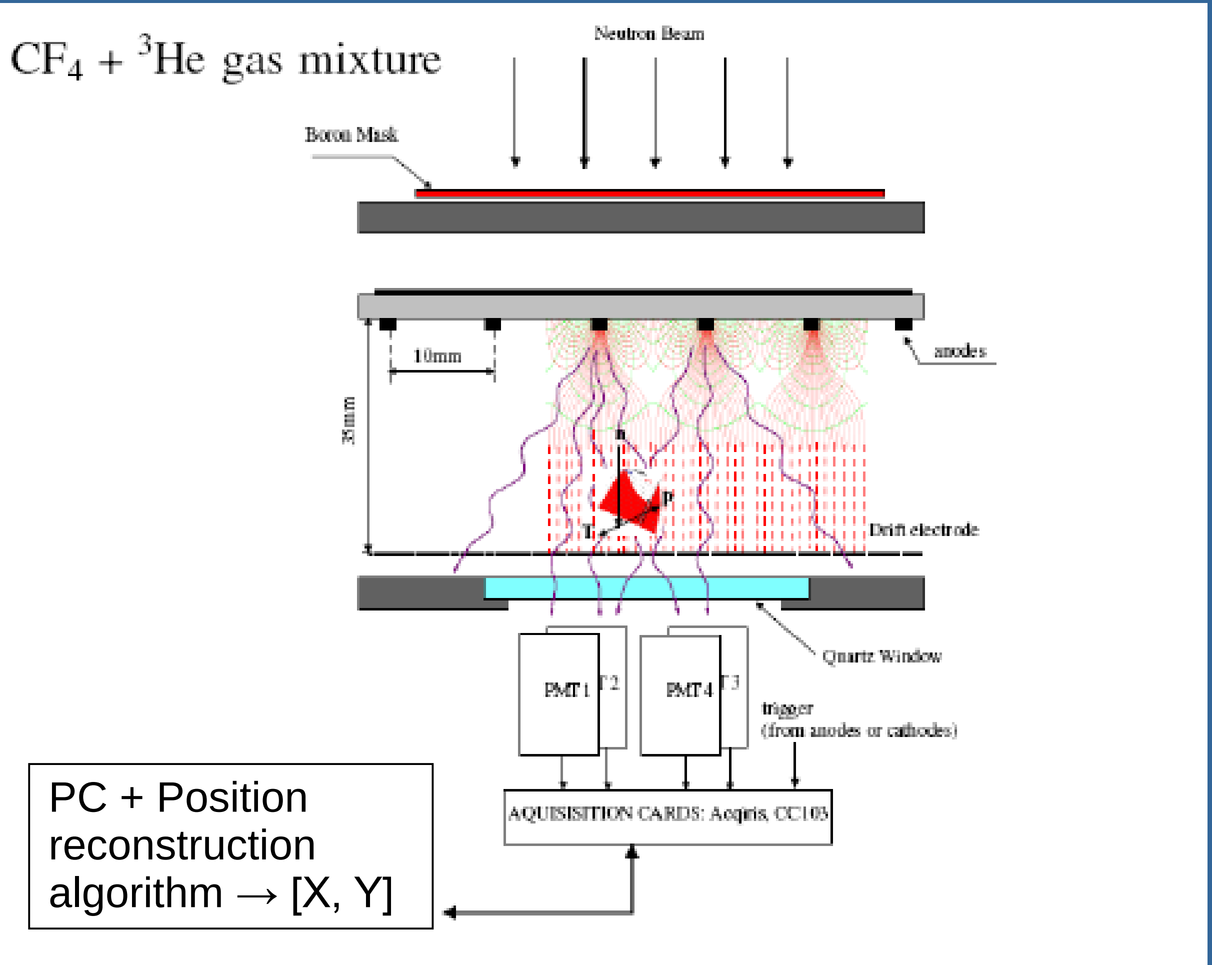
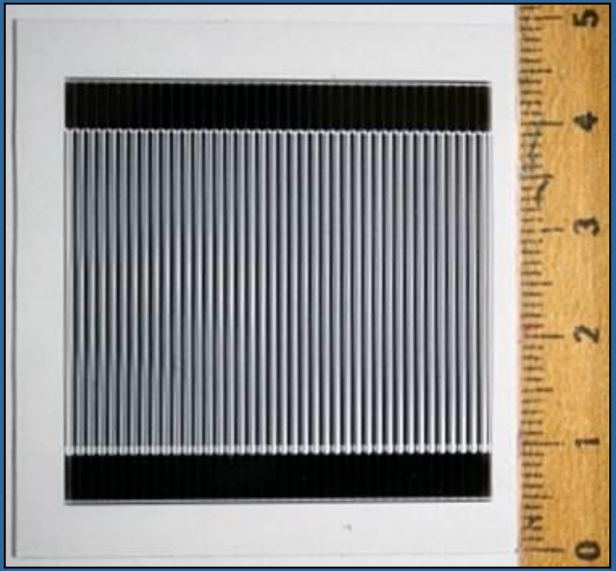


Fig. 4. Scheme of a gaseous neutron detector based on a MSGC with Anger type readout.

Microstrip: IMT, Masken und Teileungen AG
SN: 850771396
Pitch = 1 mm
Anode width = 10 μm
Cathode width = 600 μm



Avalanche light

- 3 bar CF_4
- $V_{\text{Anode - Cathode}}$ = 1.85 kV
- I ~ 80 nA

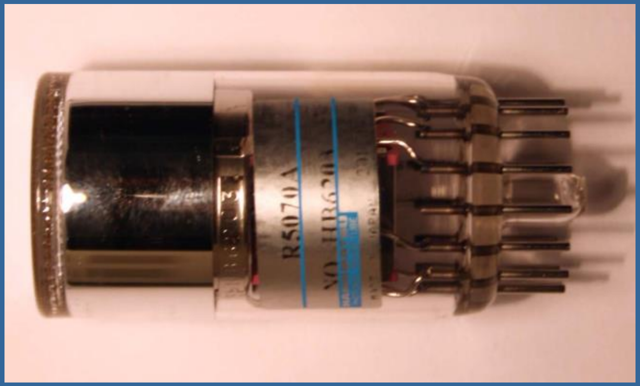
No zoom

Zoomed

The irradiated area spanned ~16 anodes

Hamamatsu R5070A

Ordered by ILL to the large scale prototype



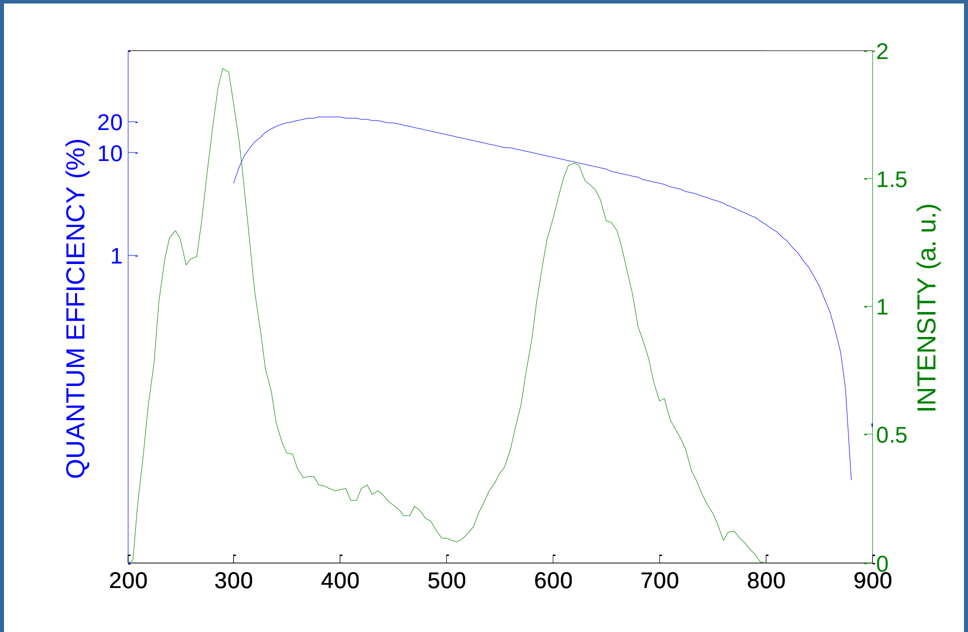
General caracteristics

Ø 25 mm

Multialkalli photocathode

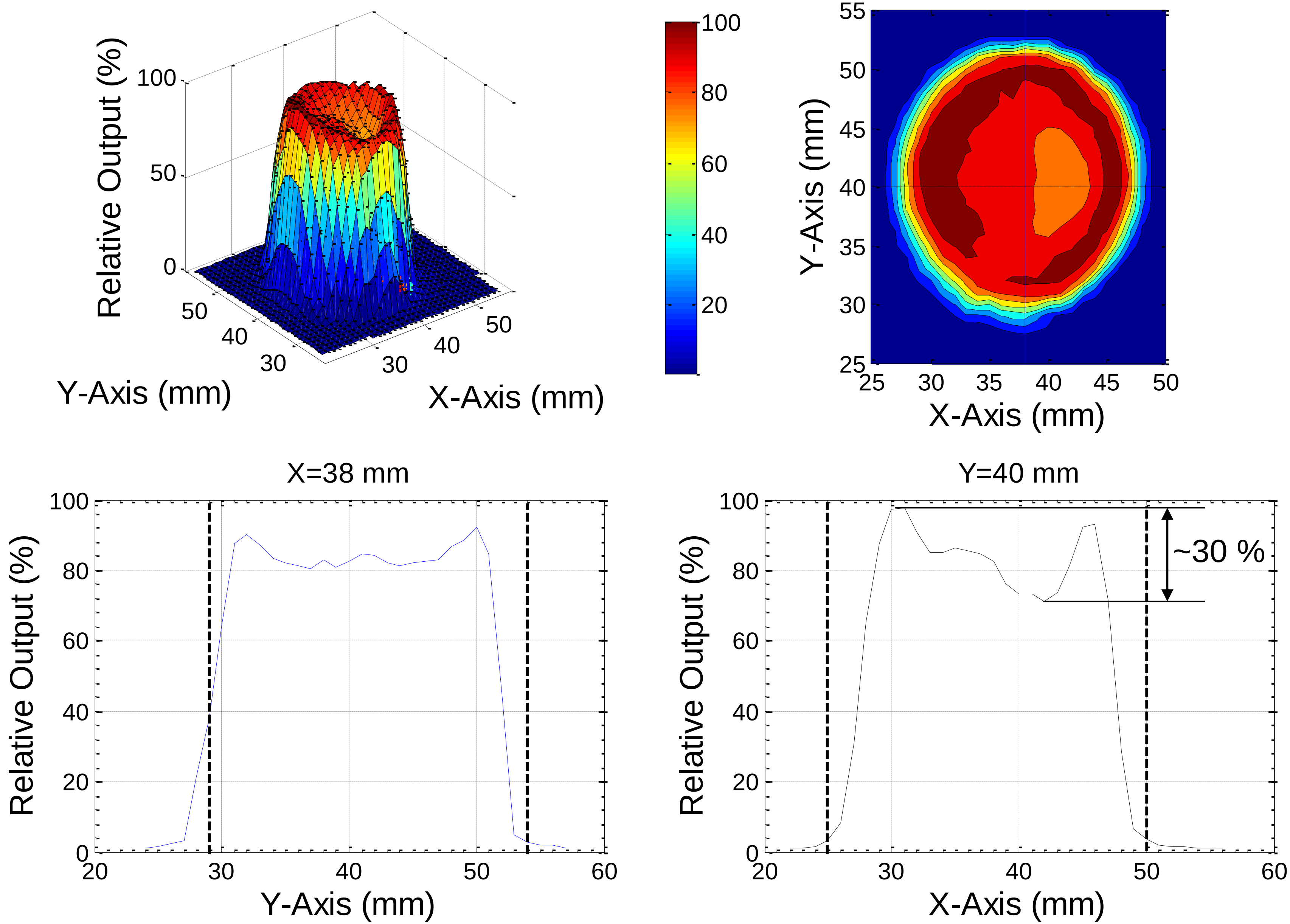
Q.E. : ~10% at 300 nm
maximum of ~20% at 420 nm
~2% at 800 nm

Prismatic borosilicate window
Square pyramids 1 x 1 mm^2 base, 45º half angle

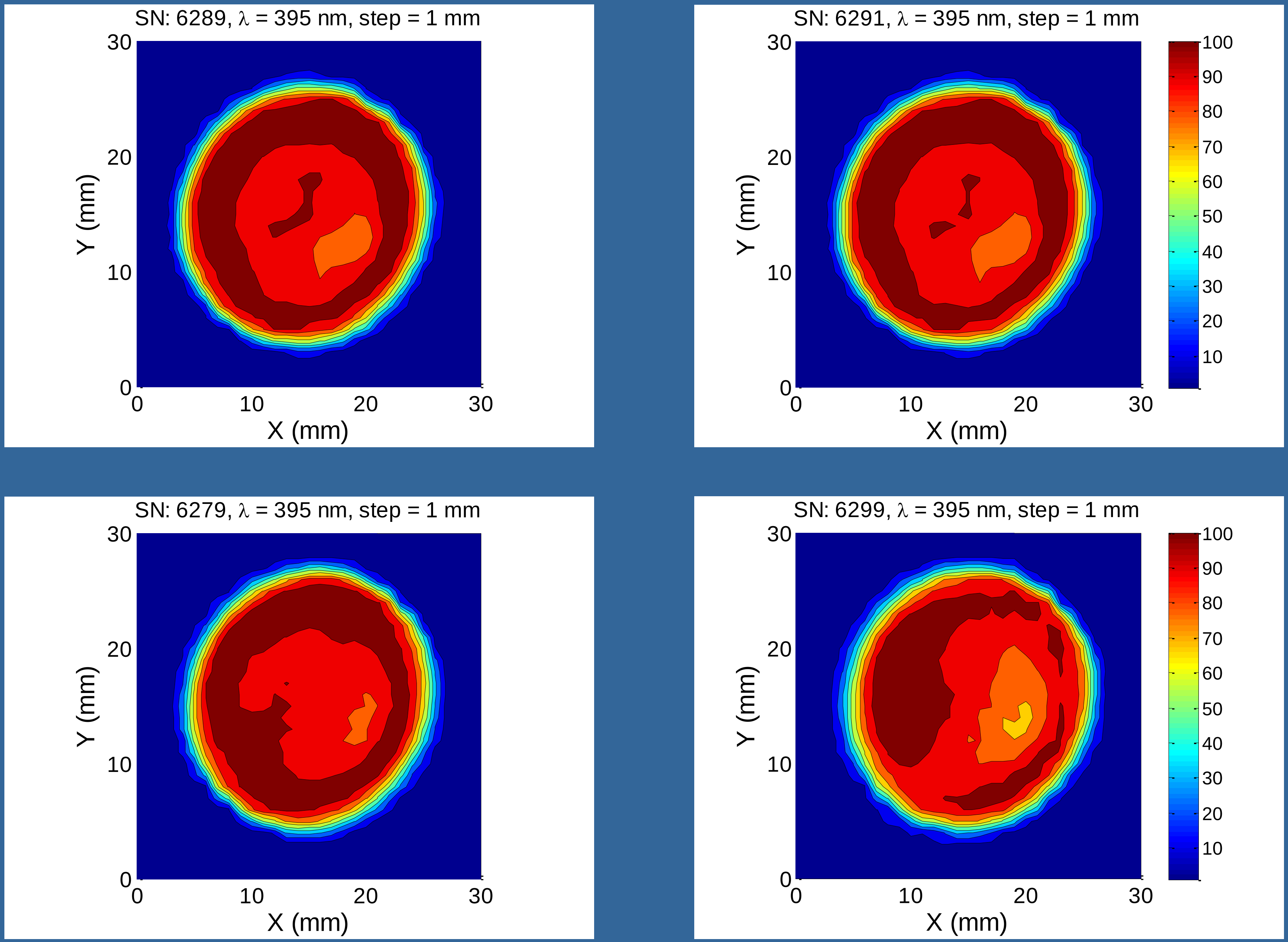


Cathode radiant sensitivity and quantum efficiency of the Hamamatsu R5070A as a function of the wavelength of the incident light

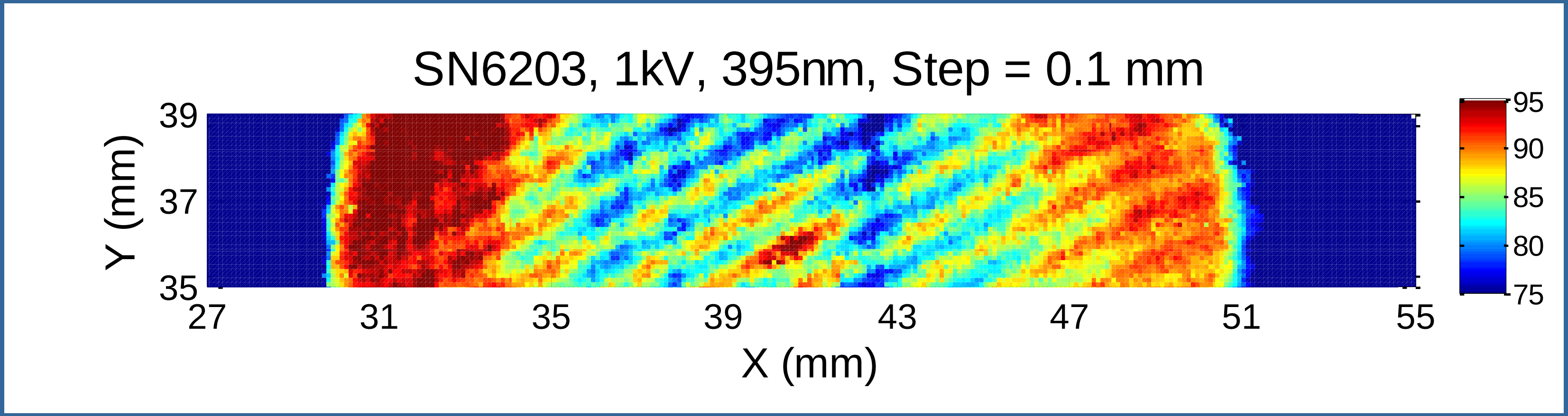
SN 6203, λ = 395 nm



PMT-to-PMT variation for the same model

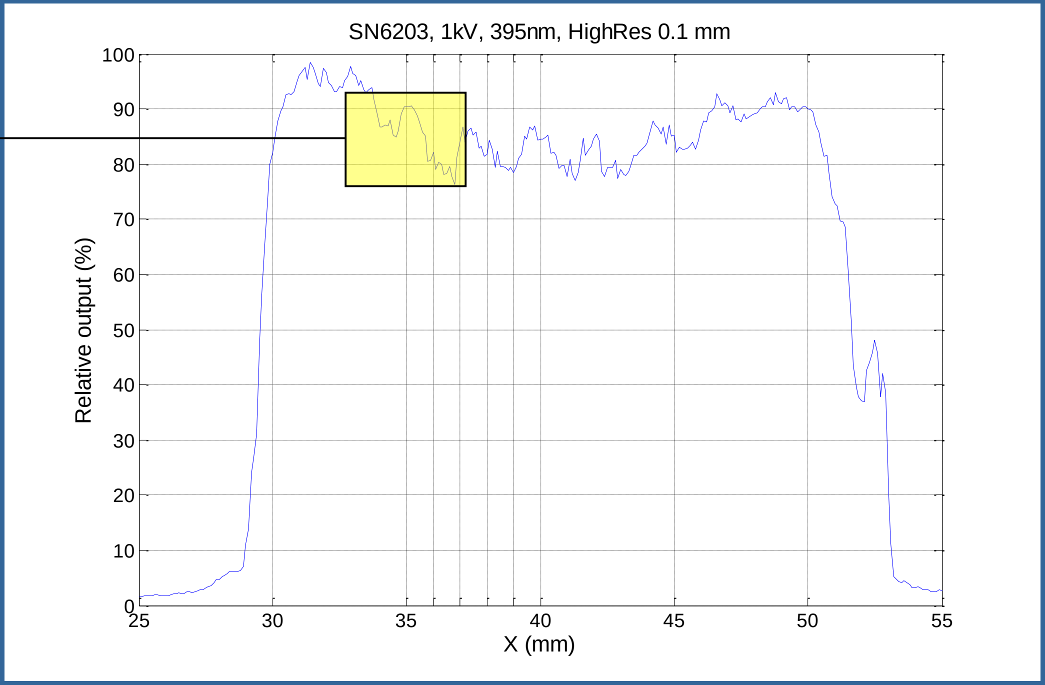


Fine detail analysis



Relative anode sensitivity of an 18 × 4 mm^2 area scanned with a 0.1 mm step.

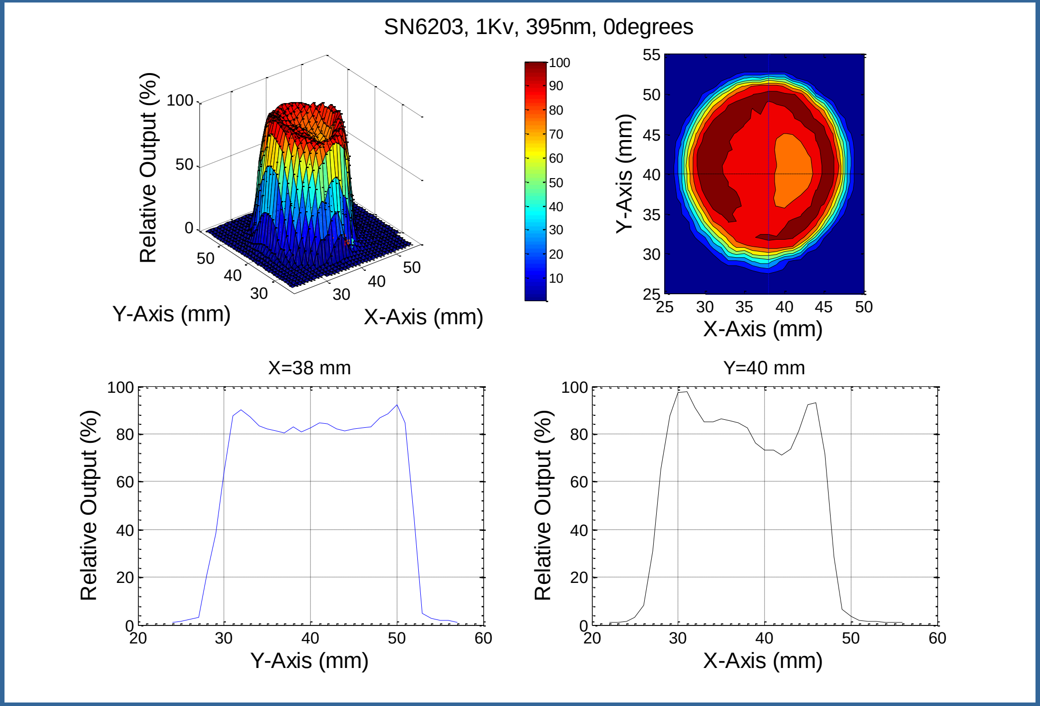
~ 10 %



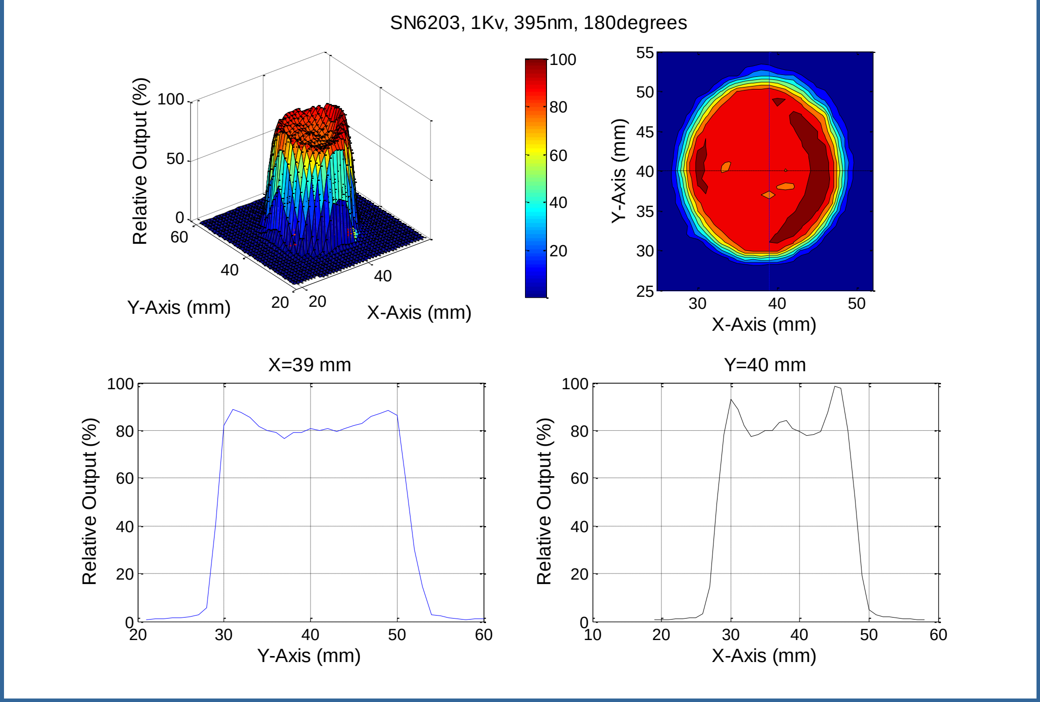
Sensitivity varies according the prismatic structure pitch. These variations may be larger than 10 %.

Effect of the earth magnetic field in the sensitivity pattern

Position 1, 0º

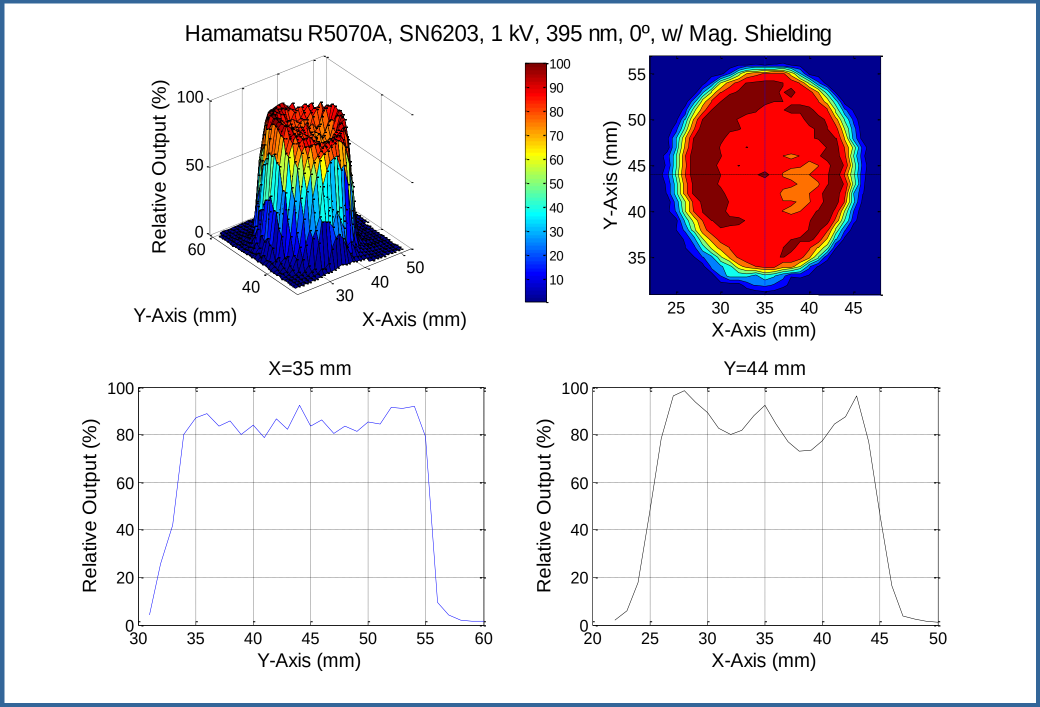


Position 2, 180º

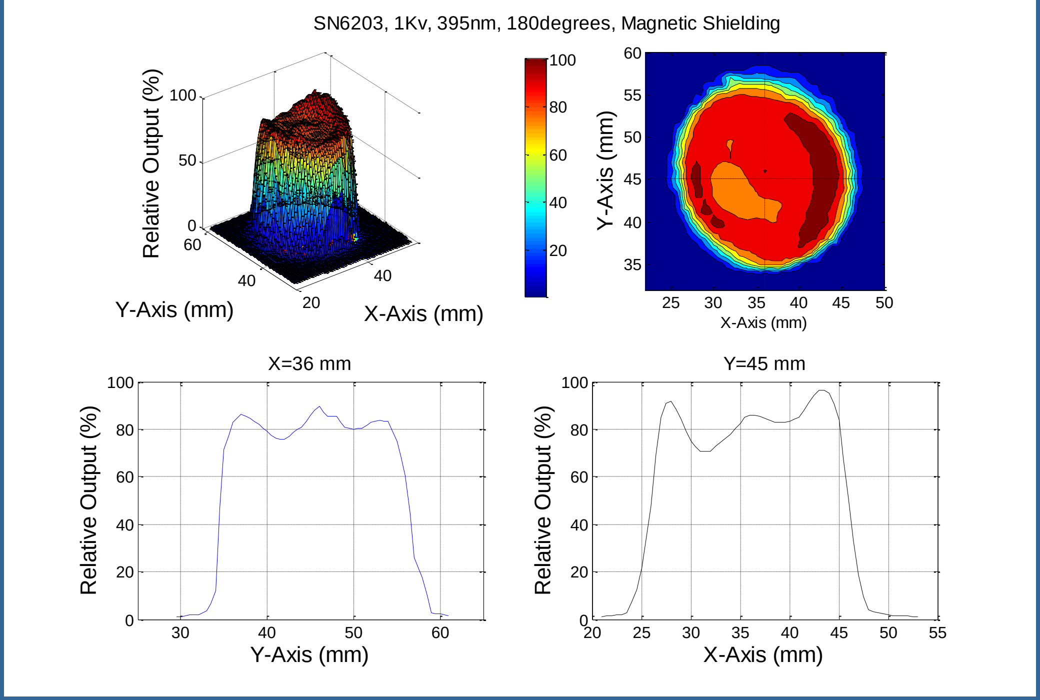


With magnetic shielding (mu-metal)

Pos 1 , 0º

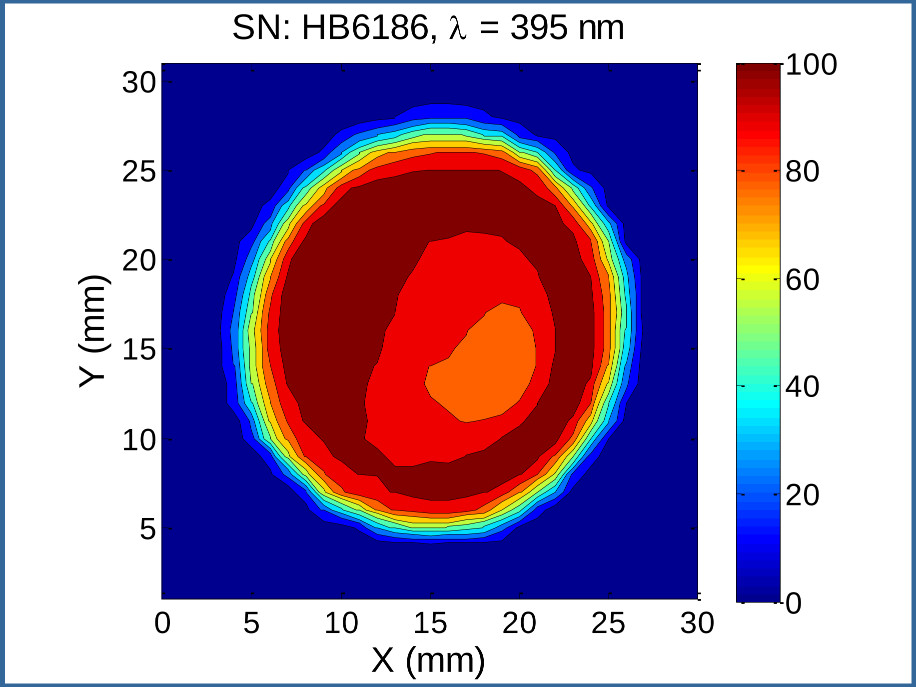


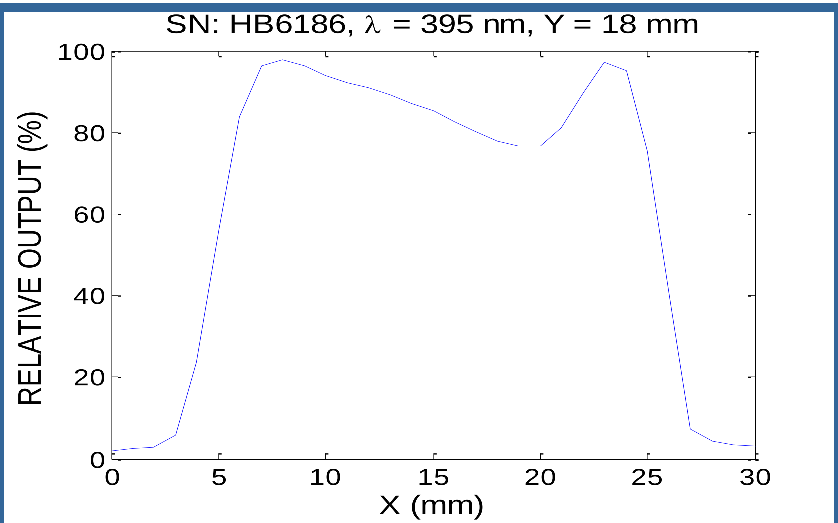
Pos 2 , 180º



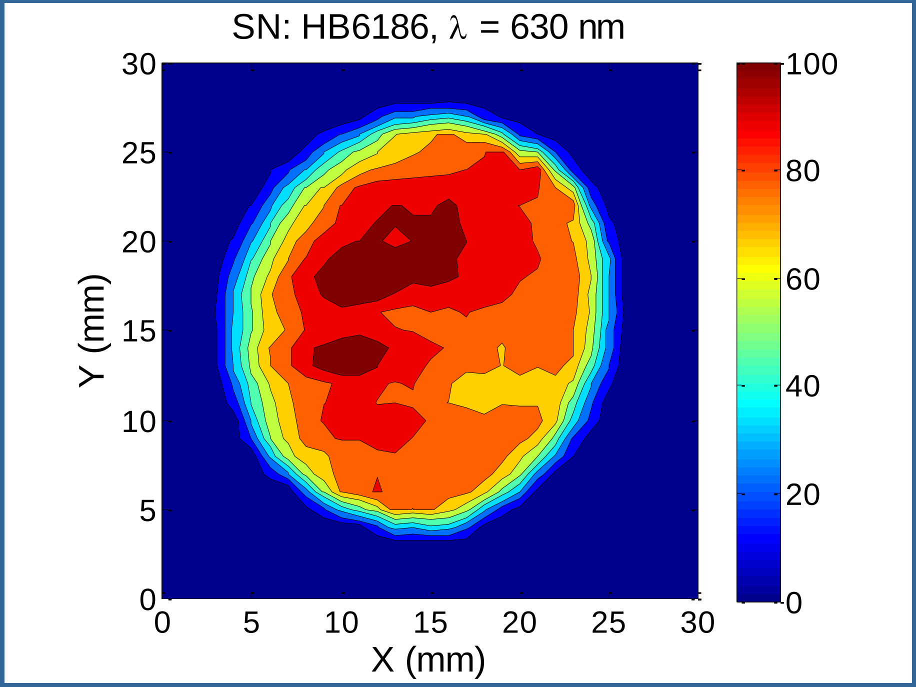
Wavelength dependence

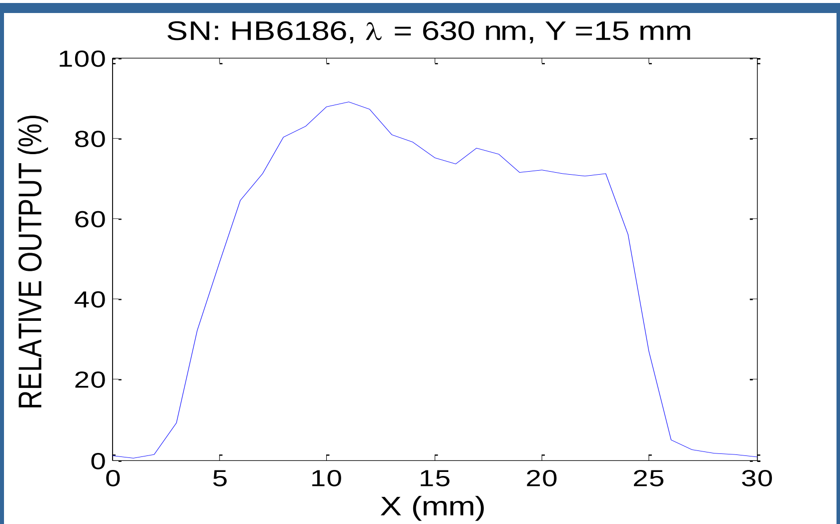
λ = 395 nm



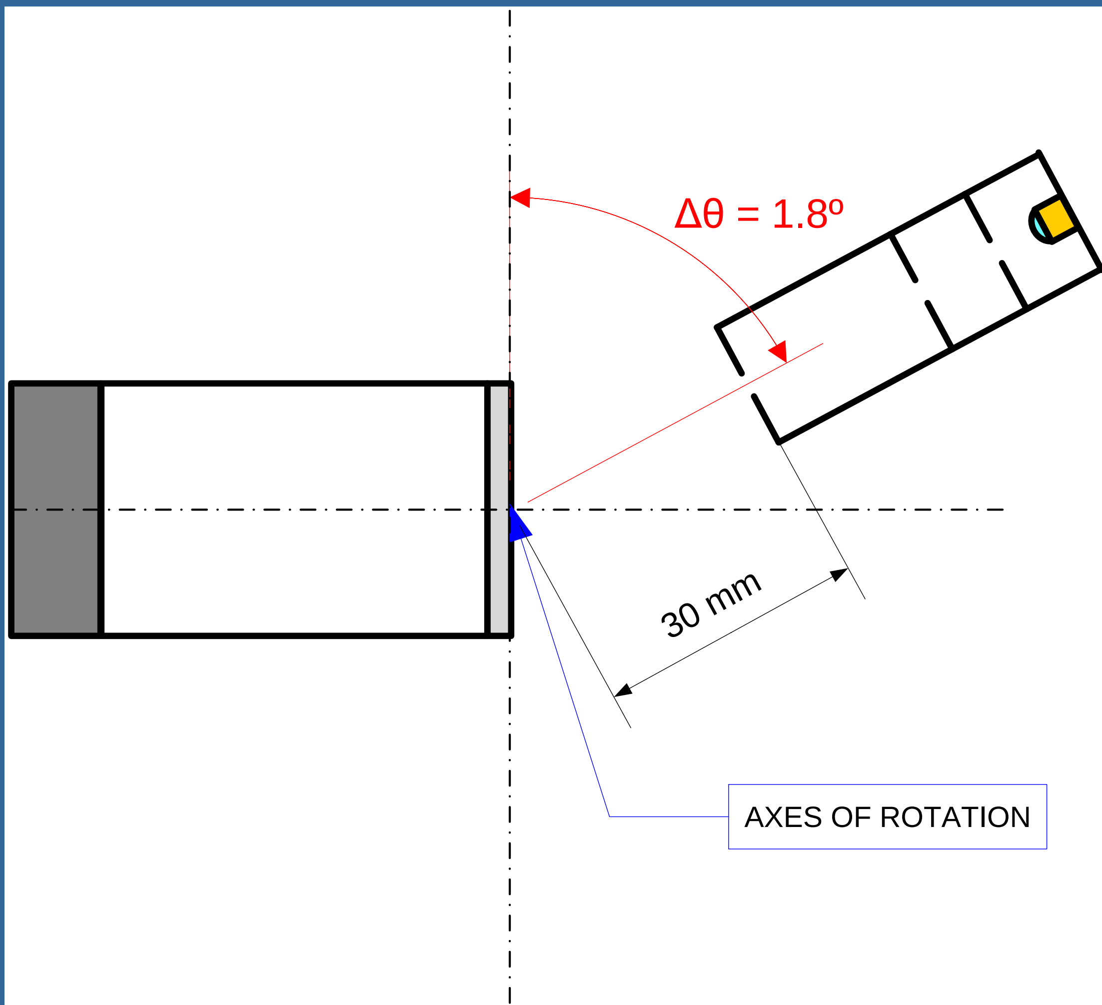


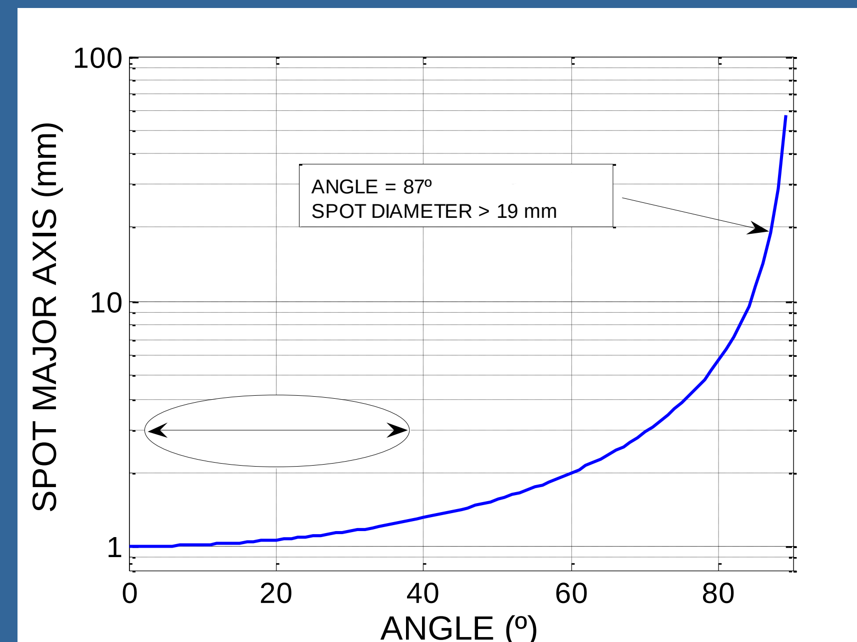
λ = 630 nm





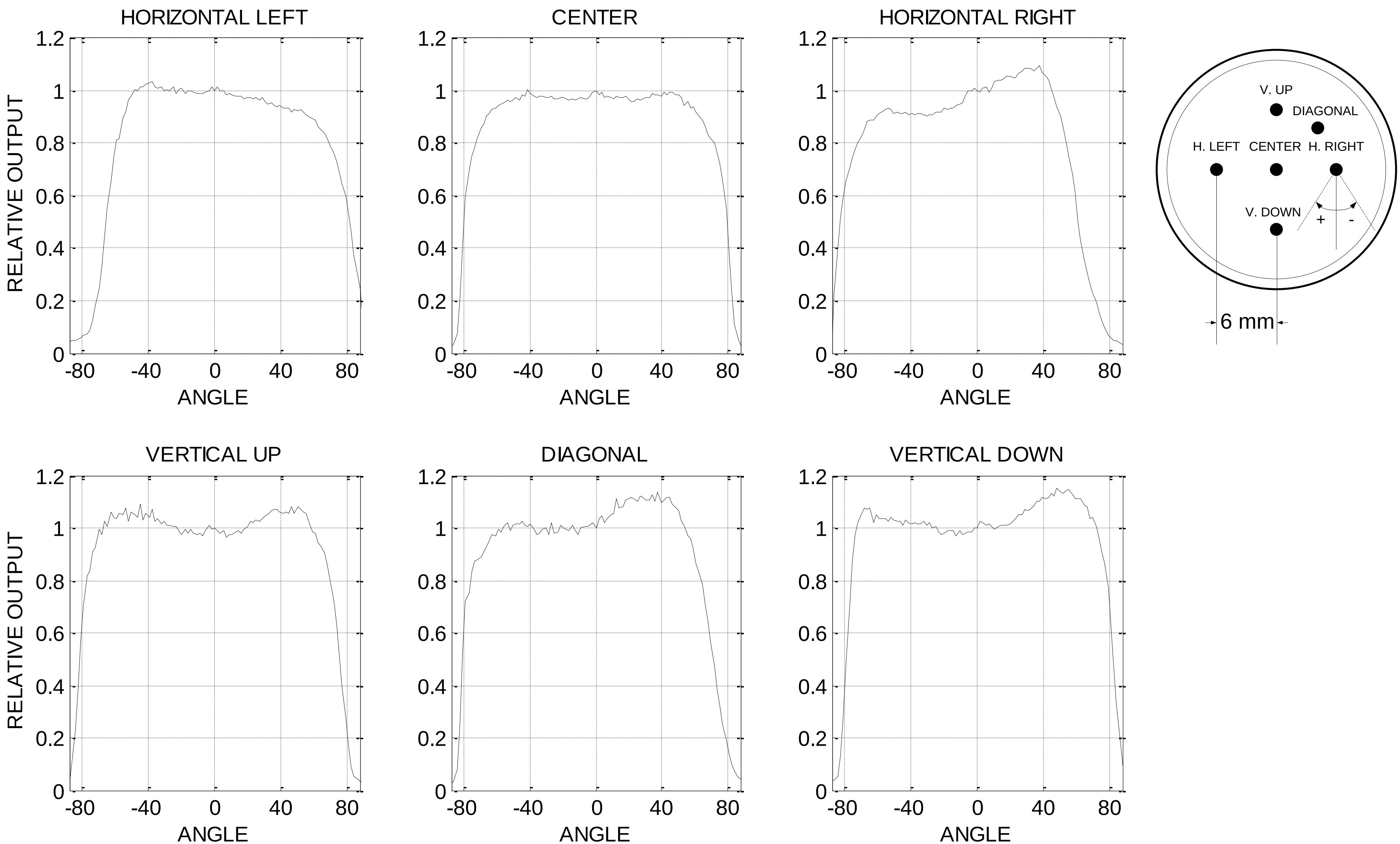
Angle dependence of the anode sensitivity: Experimental system



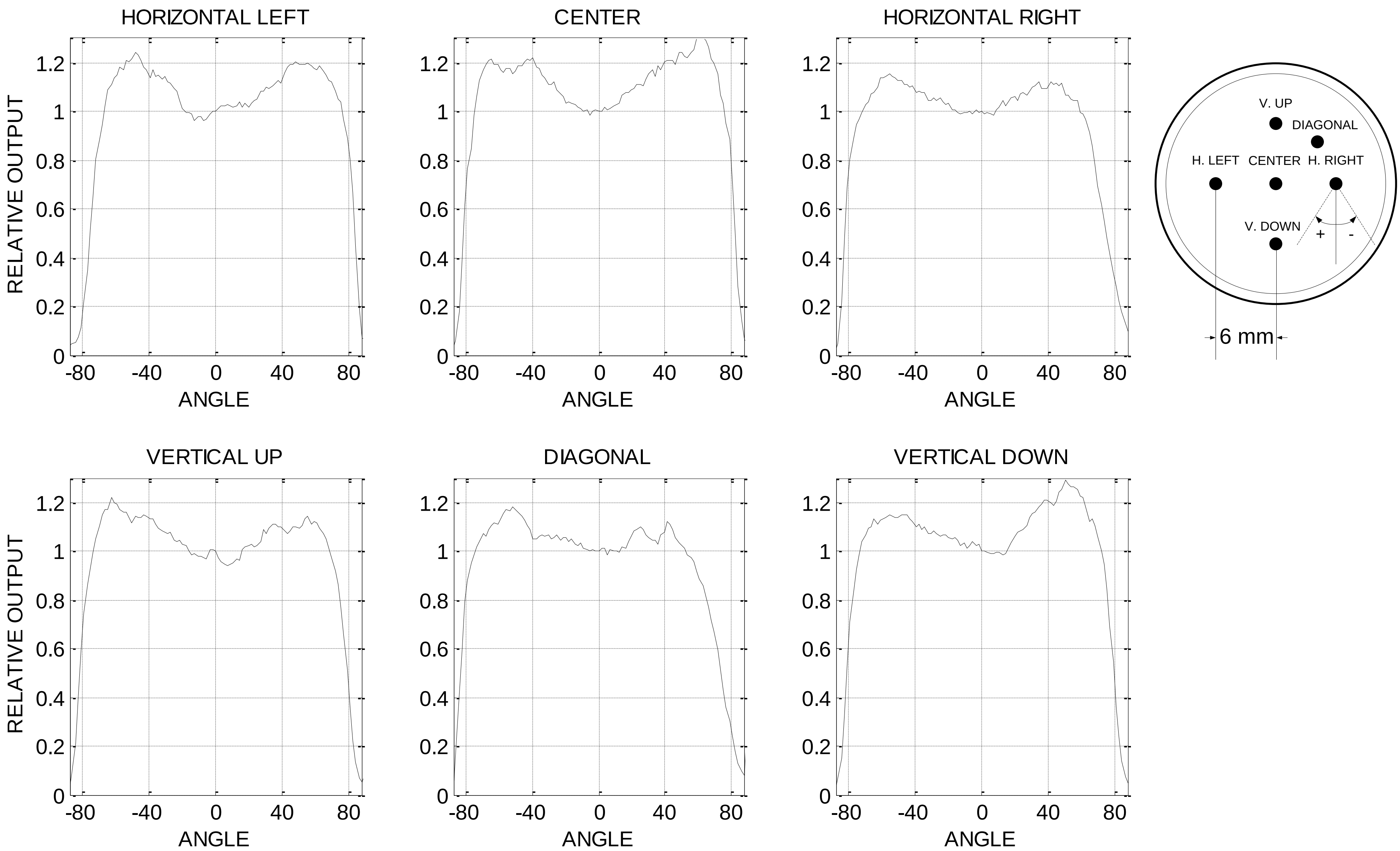


Step motor: 1.8º / step

λ = 395 nm


HORIZONTAL LEFT
CENTER
HORIZONTAL RIGHT
VERTICAL UP
DIAGONAL
VERTICAL DOWN
RELATIVE OUTPUT
ANGLE
0
0.2
0.4
0.6
0.8
1
1.2
-80
-40
0
40
80
V. UP
DIAGONAL
H. LEFT
CENTER
H. RIGHT
V. DOWN
+
-
6 mm

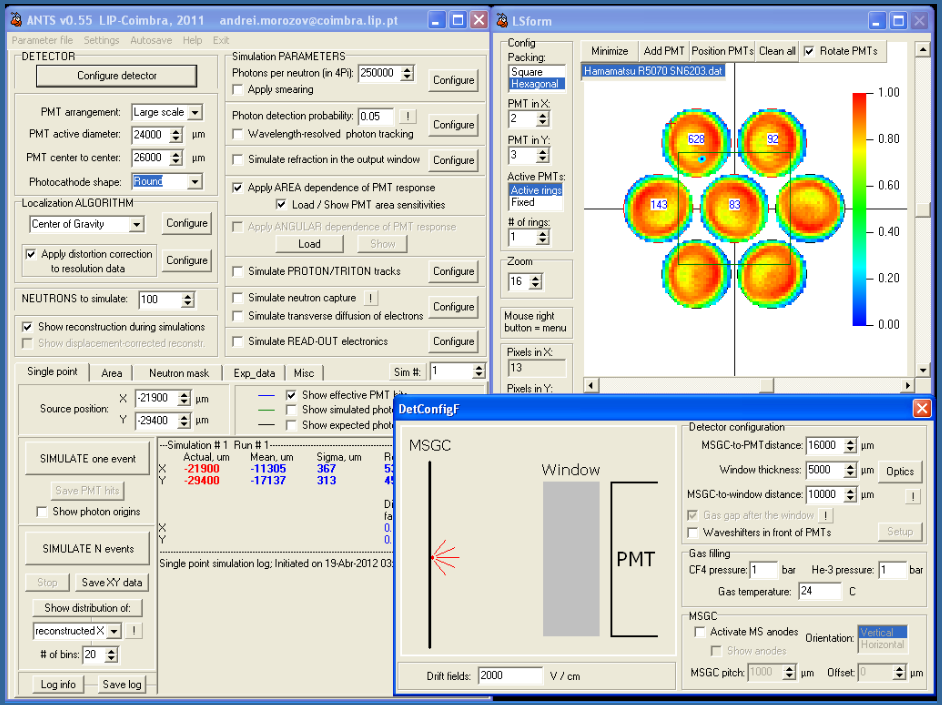
λ = 630 nm


HORIZONTAL LEFT
CENTER
HORIZONTAL RIGHT
VERTICAL UP
DIAGONAL
VERTICAL DOWN
RELATIVE OUTPUT
ANGLE
0
0.2
0.4
0.6
0.8
1
1.2
-80
-40
0
40
80
V. UP
DIAGONAL
H. LEFT
CENTER
H. RIGHT
V. DOWN
+
-
6 mm

Simulations with ANTS

Anger-camera Neutron detector Toolkit for Simulation

[Andrei Morozov: **andrei@coimbra.lip.pt**]



Main parameters

Fix

PMTs

Configuration: 7 Hexagonal
d_{PMT} center-to-center: 27 mm
Window: borosilicate
Window thickness: 5mm

Simulation parameters

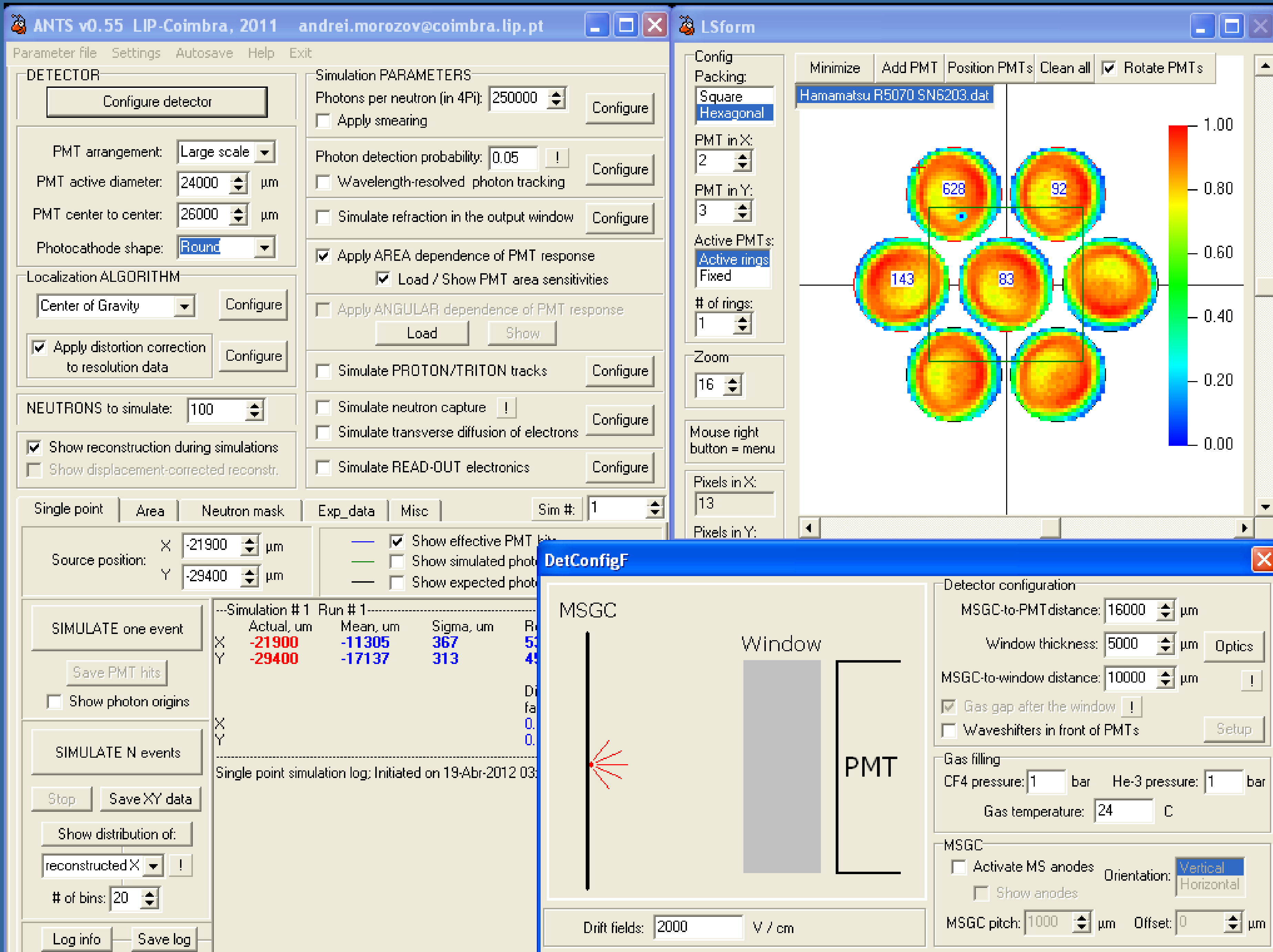
Nº of neutrons: 1000
Photons per neutron in 4π: 360000
Event location algorithm: Center of gravity (Anger)

Scintillation spectrum

CF_4 - 5 bar

Variable

PMT diameter: 21 mm (effective) or 25 mm (w/ experimental uniformity maps)
PMT-MS : 10 mm e 15 mm
Angular dependence: ACTIVATEd (w/ exp. data) / NOT ACTIVATED
Uniformity: ACTIVATED (w/ exp. data) / NOT ACTIVATED


ANTS v0.55 LIP-Coimbra, 2011 andrei.morozov@coimbra.lip.pt
Parameter file Settings Autosave Help Exit
DETECTOR
Configure detector
PMT arrangement: Large scale
PMT active diameter: 24000 µm
PMT center to center: 26000 µm
Photocathode shape: Round
Localization ALGORITHM
Center of Gravity
Configure
Apply distortion correction to resolution data
NEUTRONS to simulate: 100
Show reconstruction during simulations
Show displacement-corrected reconstr.
Simulation PARAMETERS
Photons per neutron (in 4Pi): 250000
Apply smearing
Photon detection probability: 0.05
Wavelength-resolved photon tracking
Simulate refraction in the output window
Apply AREA dependence of PMT response
Load / Show PMT area sensitivities
Apply ANGULAR dependence of PMT response
Load
Show
Simulate PROTON/TRITON tracks
Simulate neutron capture
Simulate transverse diffusion of electrons
Simulate READ-OUT electronics
Single point
Area
Neutron mask
Exp_data
Misc
Sim #: 1
Source position: X -21900 µm Y -29400 µm
Show effective PMT hits
Show simulated phot
Show expected phot
SIMULATE one event
Save PMT hits
Show photon origins
SIMULATE N events
Stop
Save XY data
Show distribution of:
reconstructed X
# of bins: 20
Log info
Save log
--Simulation # 1 Run # 1
Actual, um Mean, um Sigma, um
X -21900 -11305 367
Y -29400 -17137 313
Single point simulation log; Initiated on 19-Abr-2012 03:
LSform
Config
Packing:
Square
Hexagonal
PMT in X: 2
PMT in Y: 3
Active PMTs:
Active rings
Fixed
# of rings: 1
Zoom 16
Mouse right button = menu
Pixels in X: 13
Pixels in Y:
Minimize
Add PMT
Position PMTs
Clean all
Rotate PMTs
Hamamatsu R5070 SN6203.dat
628
92
143
83
1.00
0.80
0.60
0.40
0.20
0.00
DetConfigF
MSGC
Window
PMT
Drift fields: 2000 V / cm
Detector configuration
MSGC-to-PMT distance: 16000 µm
Window thickness: 5000 µm
Optics
MSGC-to-window distance: 10000 µm
Gas gap after the window
Waveshifters in front of PMTs
Setup
Gas filling
CF4 pressure: 1 bar
He-3 pressure: 1 bar
Gas temperature: 24 C
MSGC
Activate MS anodes
Show anodes
Orientation:
Vertical
Horizontal
MSGC pitch: 1000 µm
Offset: 0 µm

Distance between the MSCG plane and PMTs = 15 mm

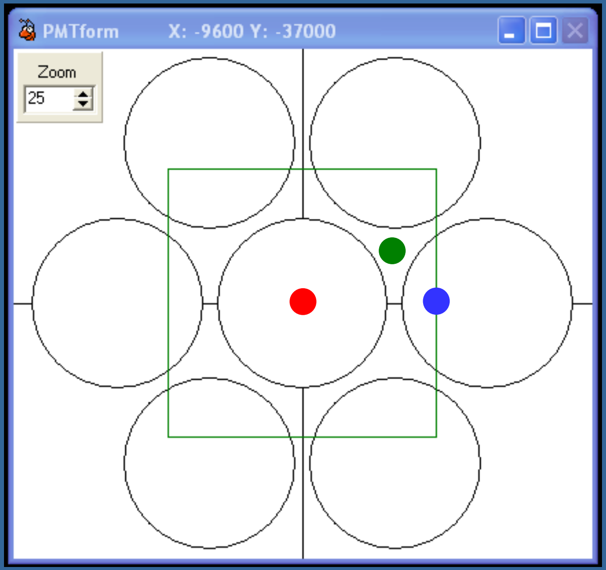


Table 1 Flat uniformity and angular dependence.

X (mm)	Y (mm)	Res. X (mm)	Res. Y (mm)
0	0	0.717	0.742
19.5	0	0.655	0.786
13.5	6.5	0.605	0.601

Table 2 Angular dependence.

X (mm)	Y (mm)	Res. X (mm)	Res. Y (mm)	Var. Res. X (%)	Var. Res. Y (%)
0	0	0.635	0.623	**-9**	**-12**
19.5	0	0.343	0.556	**-8**	**-11**
13.5	6.5	0.282	0.290	**-8**	**-5**

Table 3 Uniformity and angular dependence considered.

X (mm)	Y (mm)	Res. X (mm)	Res. Y (mm)	Var. Res. X (%)	Var. Res. Y (%)
0	0	0.636	0.623	**-7**	**-13**
19.5	0	0.365	0.550	**0**	**-2**
13.5	6.5	0.293	0.315	**-6**	**-1**

$\sigma < 2\%$

The End