The preliminary results of the Proton-ICCHIBAN-2 experiments for luminescence detectors

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(3) German Aerospace Center, Institute of Aerospace Medicine, Cologne, Germany

(4) Institute of Atomic and Subatomic Physics, Technical University Vienna, Austria

(5) Nuclear Physics Institute, Prague, Czech Republic

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ICCHIBAN Project

一番

(InterComparison for Cosmic-ray with Heavy Ion Beams At NIRS)

NASA-JSC, JAXA, IBMP, DLR, … 13 countries, 21 institutes

- Determine the response of space radiation dosimeters to heavy ions of charge and energy similar to that found in the galactic cosmic radiation (GCR) spectrum.
- Compare response and sensitivity of various space radiation monitoring instruments. Aid in reconciling differences in measurements made by various radiation instruments during space flight.
- Establish and characterize a heavy ion "reference standard" against which space radiation instruments can be calibrated.

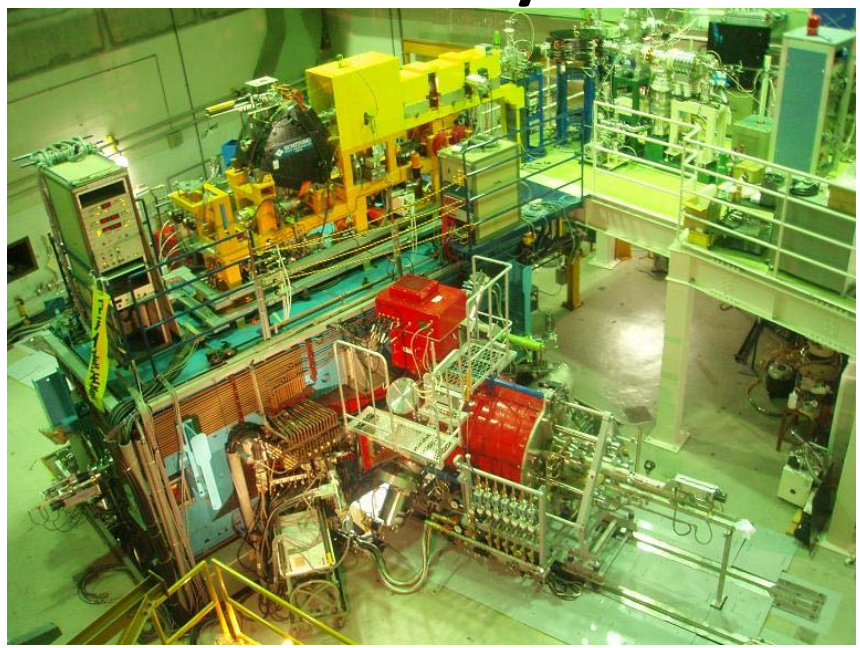
http://www.nirs.go.jp/ENG/rd/1ban/index.html

Proton ICCHIBAN 2

- To understand responses of luminescence detectors for Low LET components
  - Main objects: TLD, OSL, glass, etc.
  - To expose detectors with same conditions, the ICWG prepared “Standard Packages”.
- NIRS Cyclotron (NIRS-930)
  - Construction of radiation field for low energy protons in NIRS Cyclotron
- Beam
  - proton 70 MeV (Jan.29th 2010)
  - Proton 40 MeV (Feb. 5th 2010)

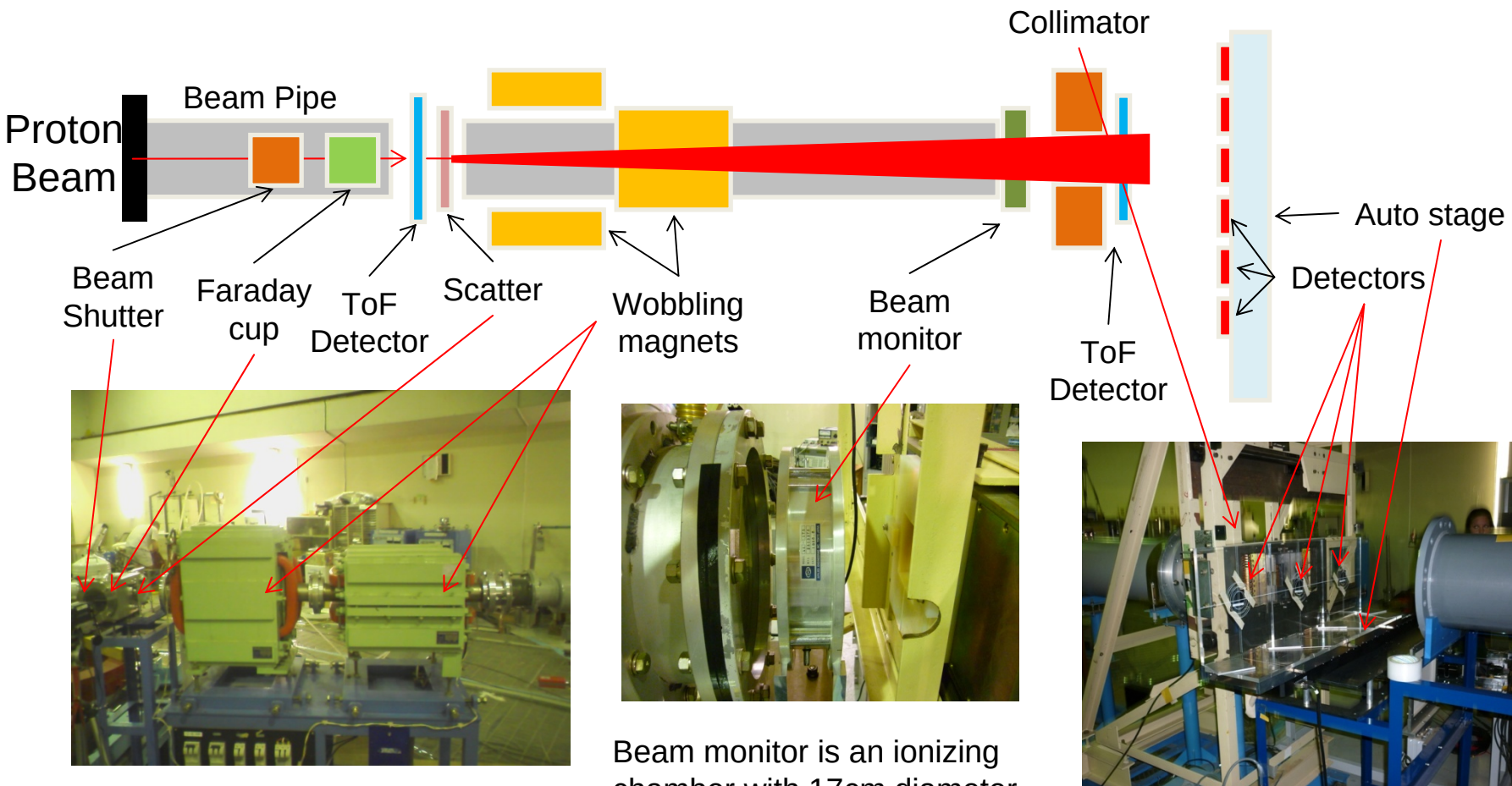
Specification of the NIRS-Cyclotron

- Type: AVF Cyclotron
- Beams:
  - proton 5-80 MeV
  - deuteron 10-55 MeV
  - ^{3}He 18-147 MeV
  - ^{4}He 20-110 MeV
  - Heavy ions …



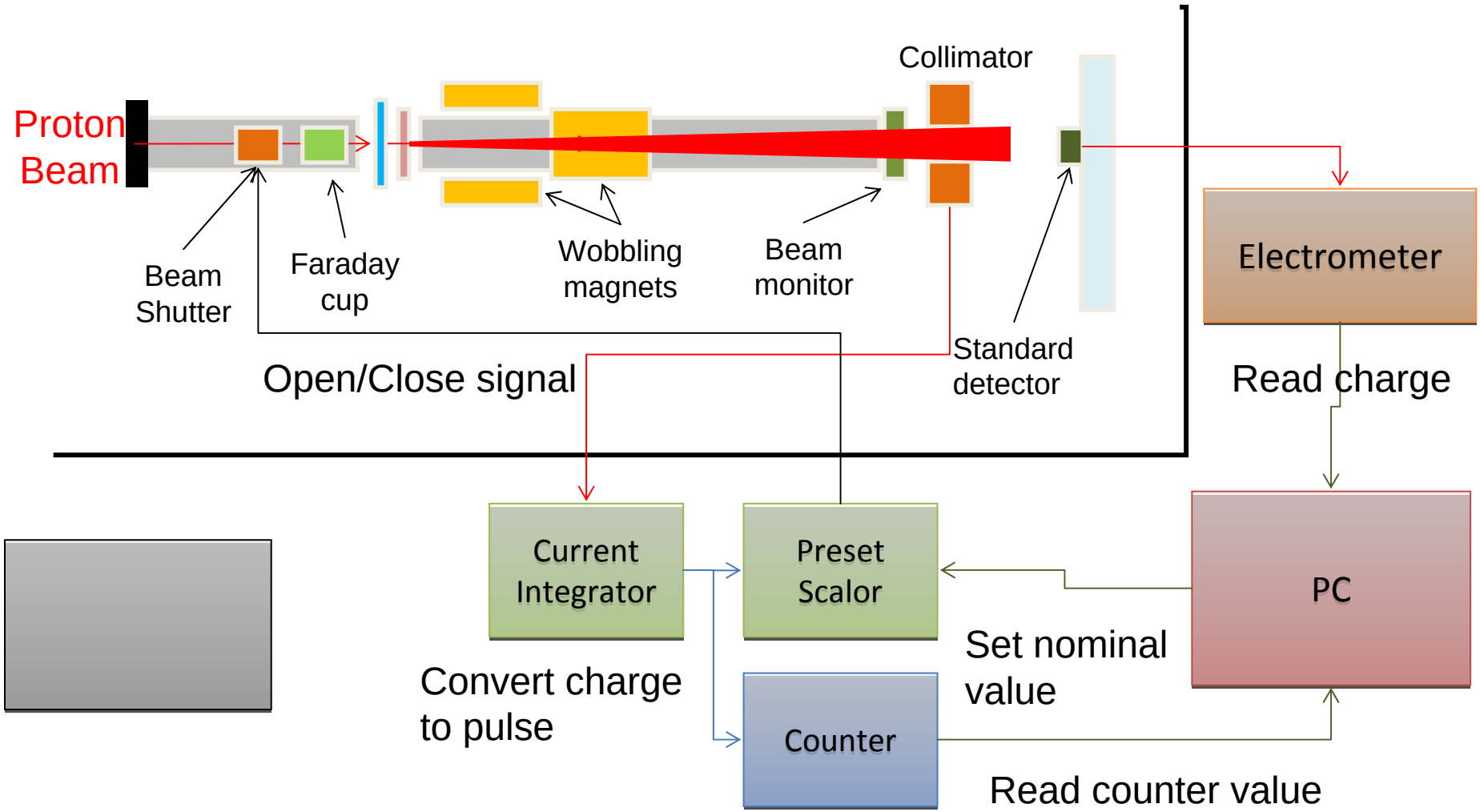
- This cyclotron is used to produce radioisotopes for SPECT/PET mainly.
- It is usable for scientific experiments about one day per a week.
- Typical experiment time is from 11 am to 7 pm (8 hours).

Reference Radiation Field (C-8 course)



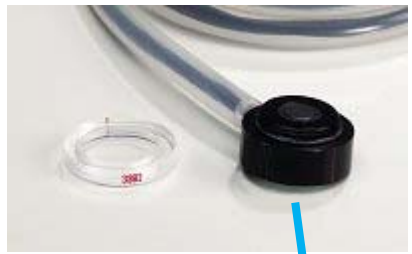
Beam monitor is an ionizing chamber with 17cm diameter aperture.

Beam Monitoring and Controlling

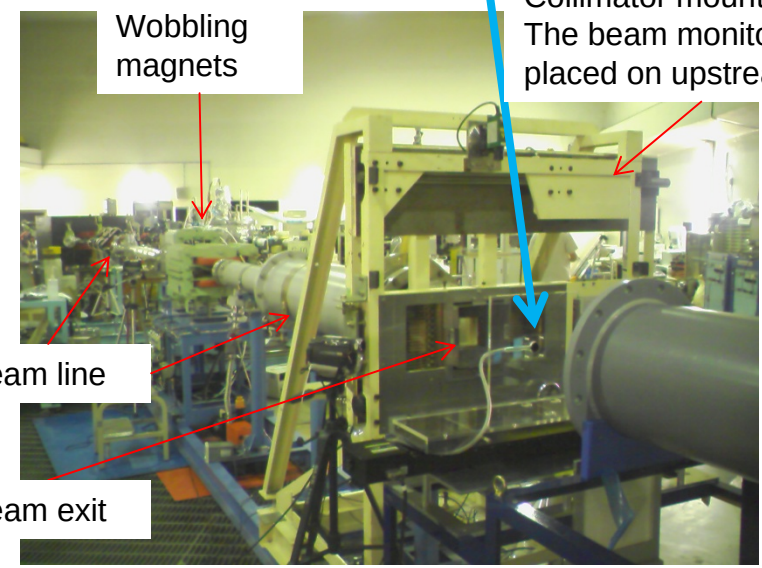


Calibration of the Beam Monitor

- Before a beam time, the beam monitor is calibrated by the "Standard Markus chamber" placed on the center of the radiation field using the beam.
- The standard Markus chamber was calibrated at the NIRS ^{60}Co facility.
- We followed HIMAC's method to establish the calibration protocol in the Cyclotron.

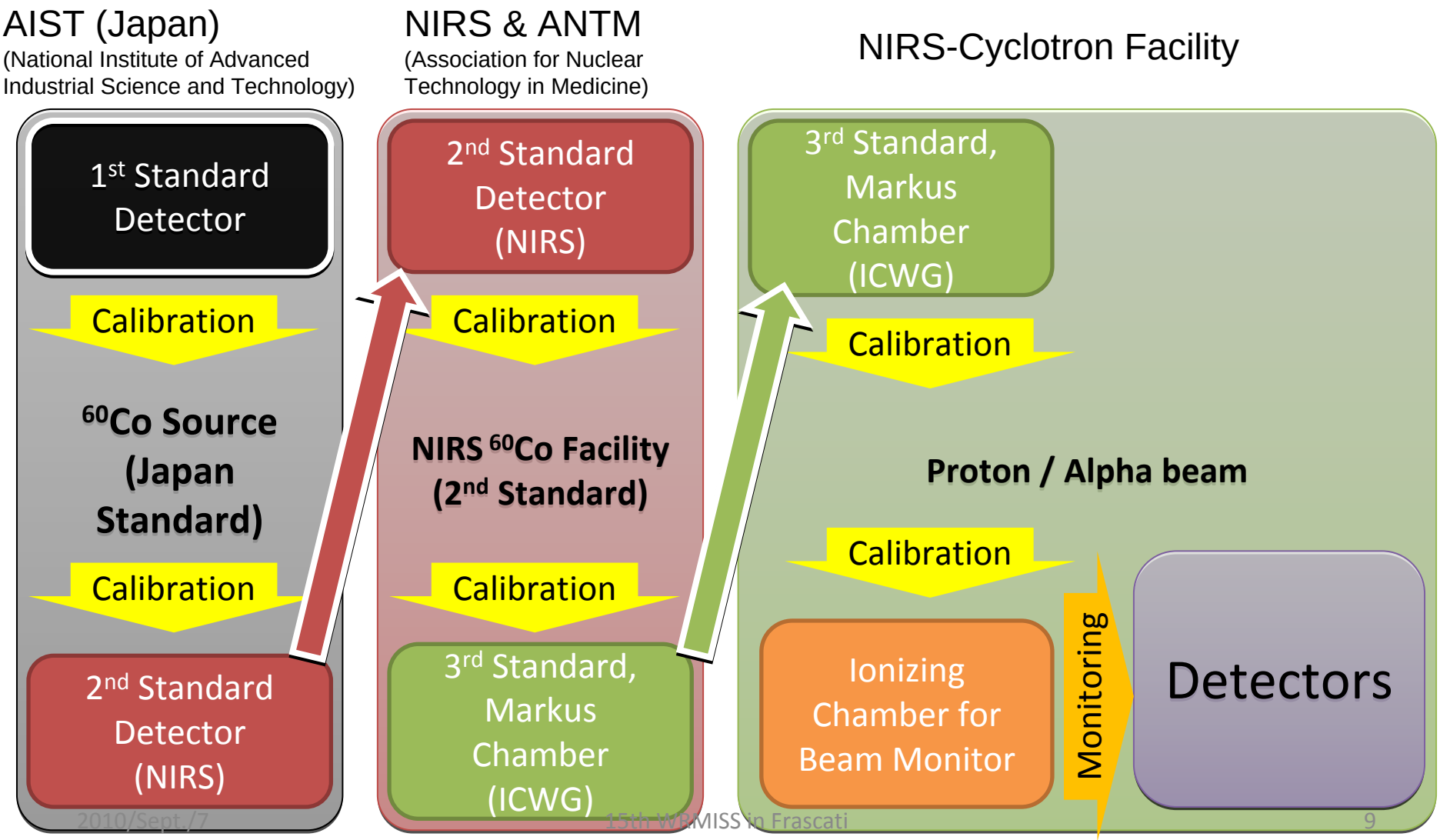


Markus Chamber (PTW 23343)
Parallel Plate Ionizing Chamber



Calibration of the beam monitor

Traceability of Detectors in Japan



Characteristics of The Reference Field

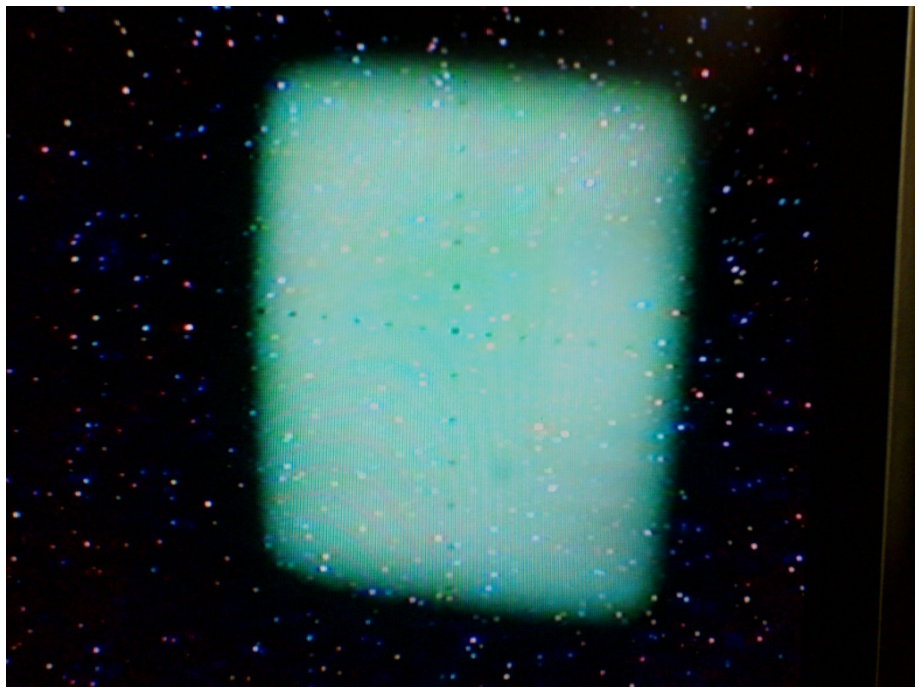


Photo of the beam image using a luminescence plate.
The beam was 10x10cm^2 size.

Modeling of the Radiation Field

Model of the radiation field
using the scatter-wobbler method

- Beam spot is scattered to Gaussian shape and rotating along circular or ellipsoidal path.

See, *H.Tomura, et al., Jpn. J. Med. Phys. 18: 42–56.1998*

$$\Phi(x,y) = A\oint e^{-\frac{(x-(X-x_0))^2+(y-(Y-y_0))^2}{2\sigma^2}} ds(X,Y)$$

- Circular path with radius R

$$\Phi(x,y) = A' e^{-\frac{(x-x_0)^2+(y-y_0)^2}{2\sigma^2}} L_0\left(\frac{R\sqrt{(x-x_0)^2+(y-y_0)^2}}{\sigma^2}\right)$$

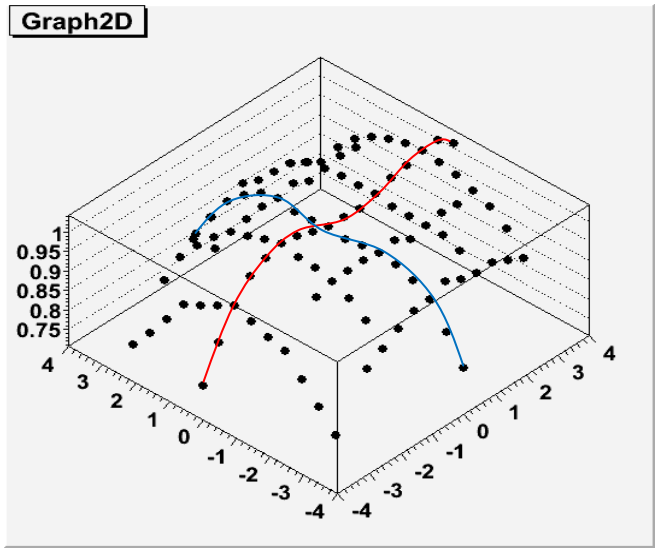
Modified Bessel functions of 1st kind

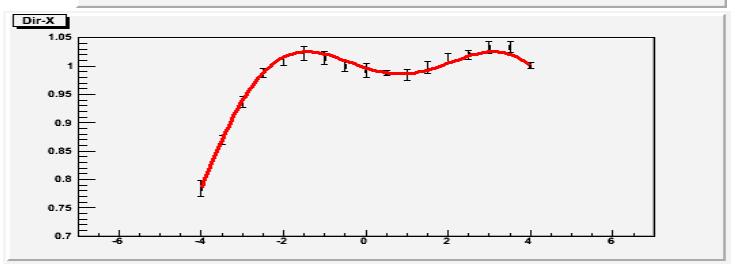
- Ellipsoidal path with semi-major axis a and semi-minor axis b

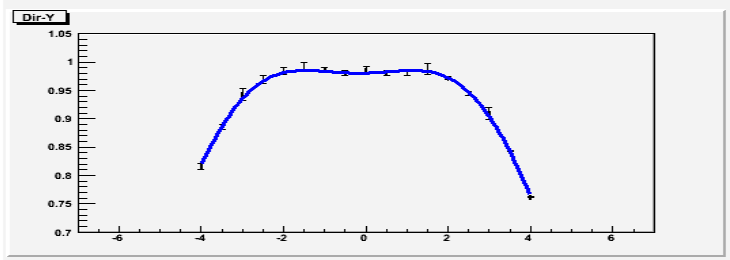
$$\Phi(x,y) = \sum_{n=0}^{N}\left(A' e^{-\frac{(x-x_0-a\cos(\theta_n))^2+(y-y_0-b\sin(\theta_n))^2}{2\sigma^2}} \Delta s(\theta_n)\right)$$

$$\Delta s(\theta_n) = \sqrt{(a\cos(\theta_{n+1})-a\cos(\theta_n))^2+(b\sin(\theta_{n+1})-b\sin(\theta_n))^2}$$

$$N >> 1, \theta_n = 2\pi m / N$$

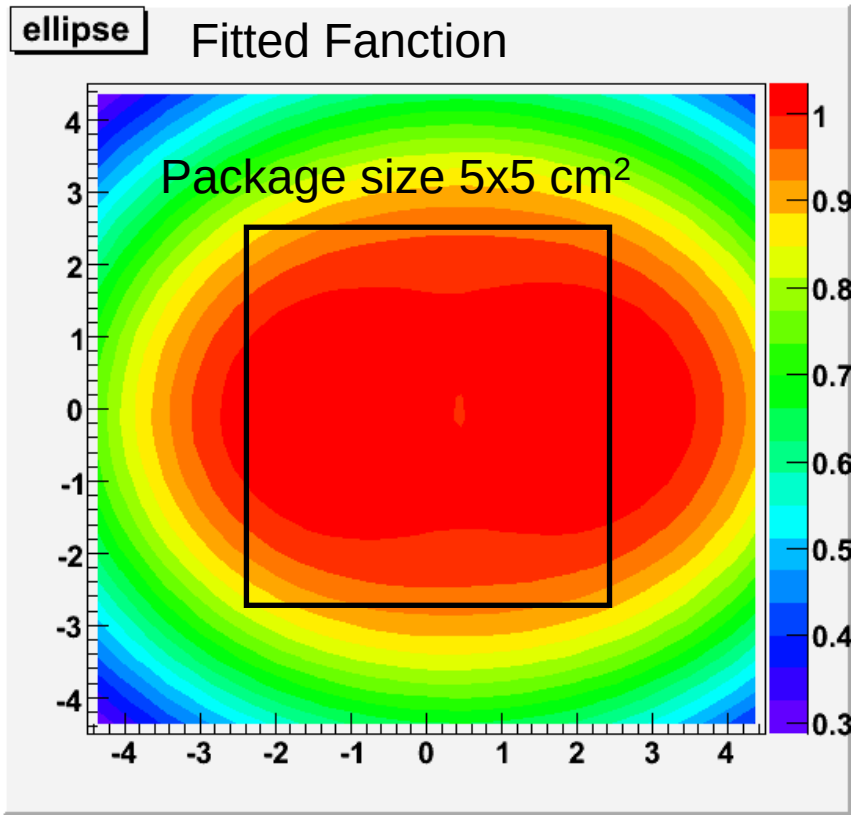


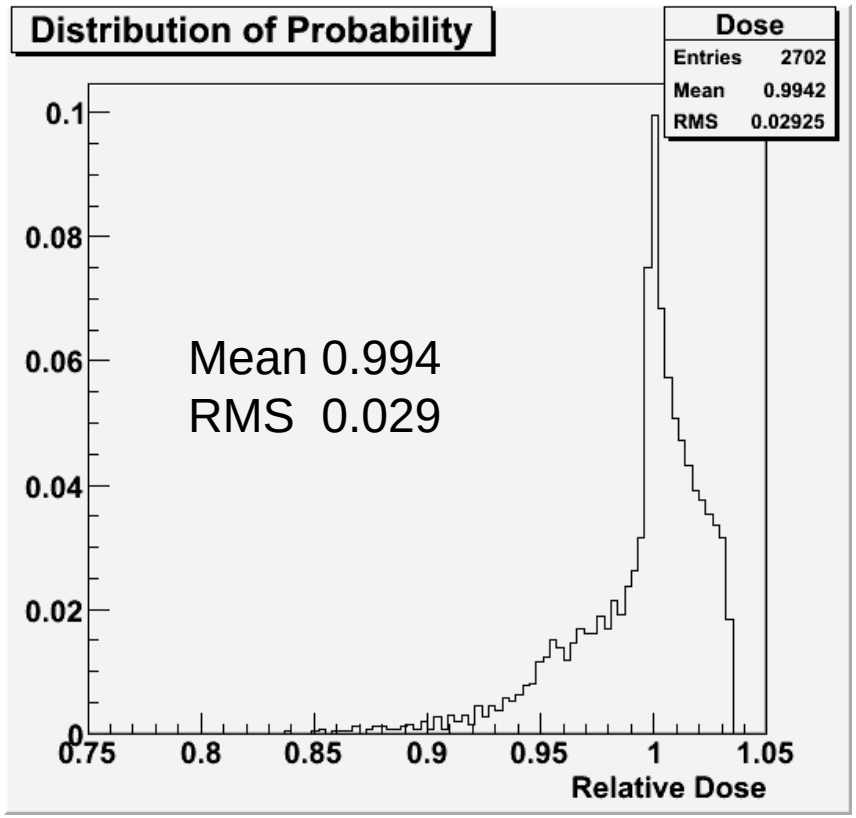




Measured by scintillators

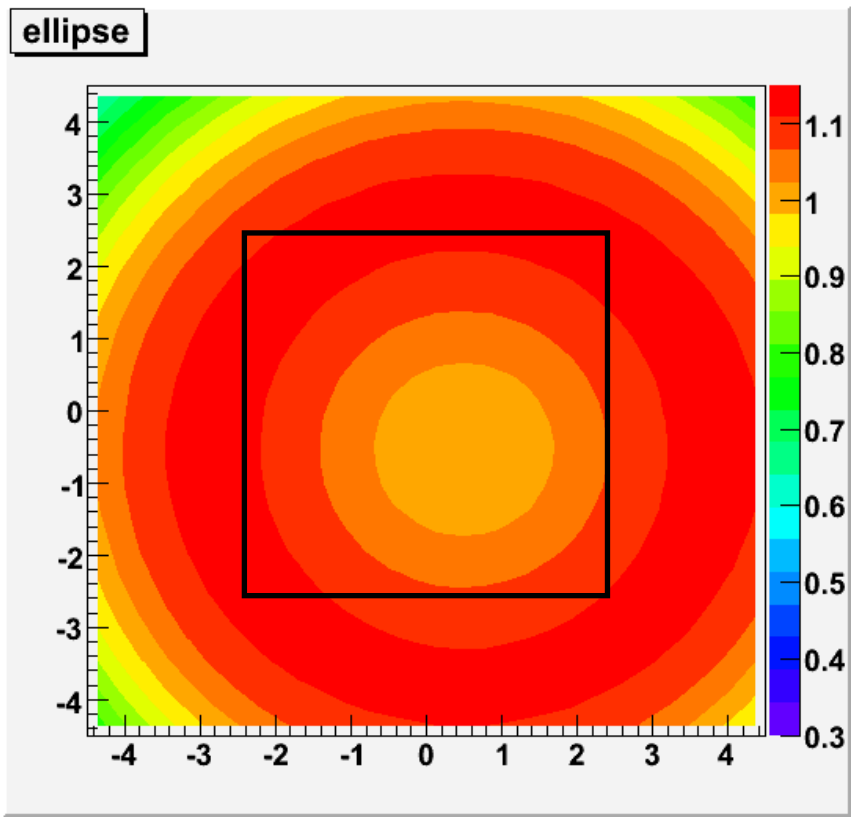
Position Dependency of Exposed Dose (70 MeV proton)

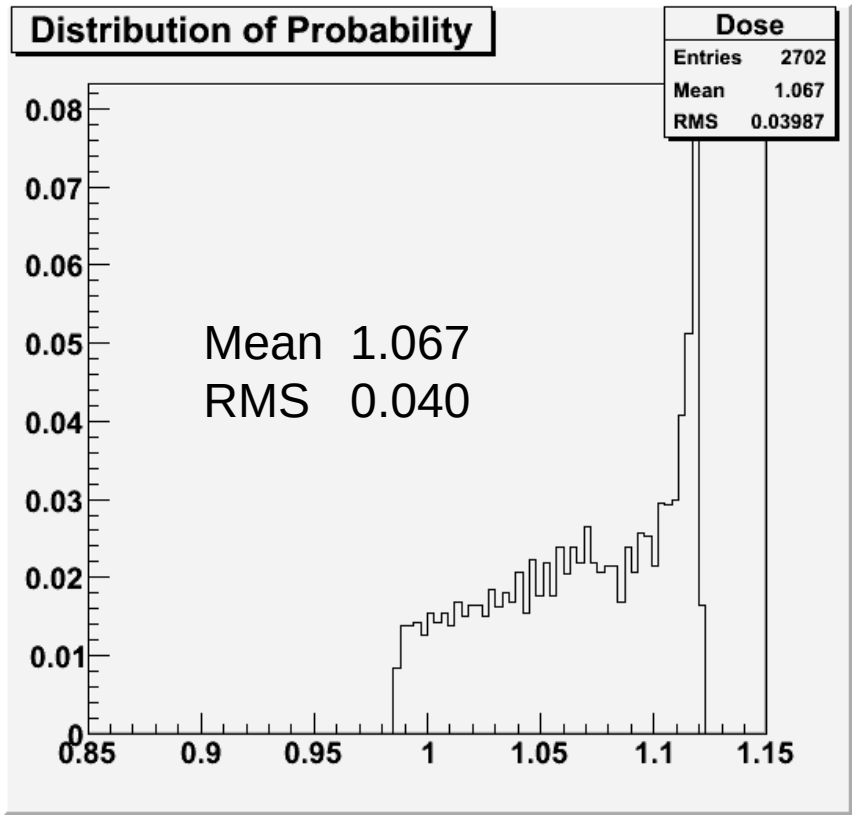




A' = 0.140836, sigma = 2.31716,
a = 4.10076,b = 3.05004,
x = 0.414715,y = -0.0313771

Position Dependency of Exposed Dose (40 MeV proton)





A' = 0.138053, sigma = 2.81862,
a = 4.80978, b = 4.74062,
x = 0.496765, y = -0.532401

Error Assumption of Exposed Dose

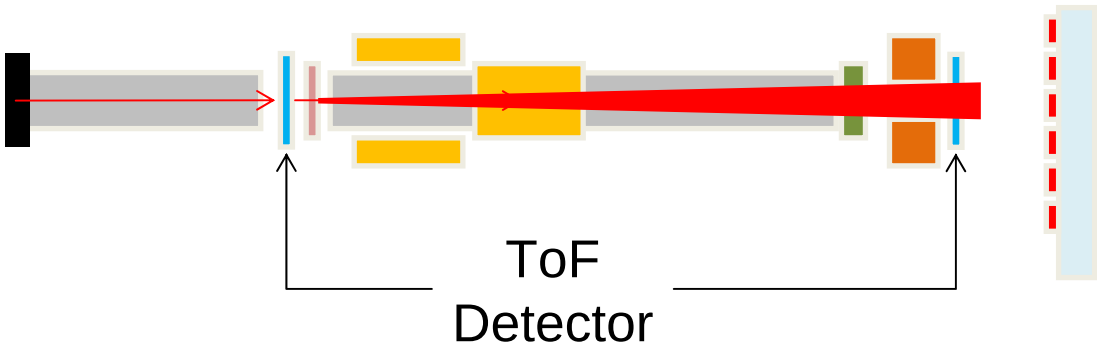
Uncertainty of Dose

- Uncertainly of the standard Markus chamber > 1.5 %
- Statistic error of the conversion factor from the standard Markus chamber to the beam monitor > 0.2 %
- Leakage current and background ~ 0.1 mGy/min

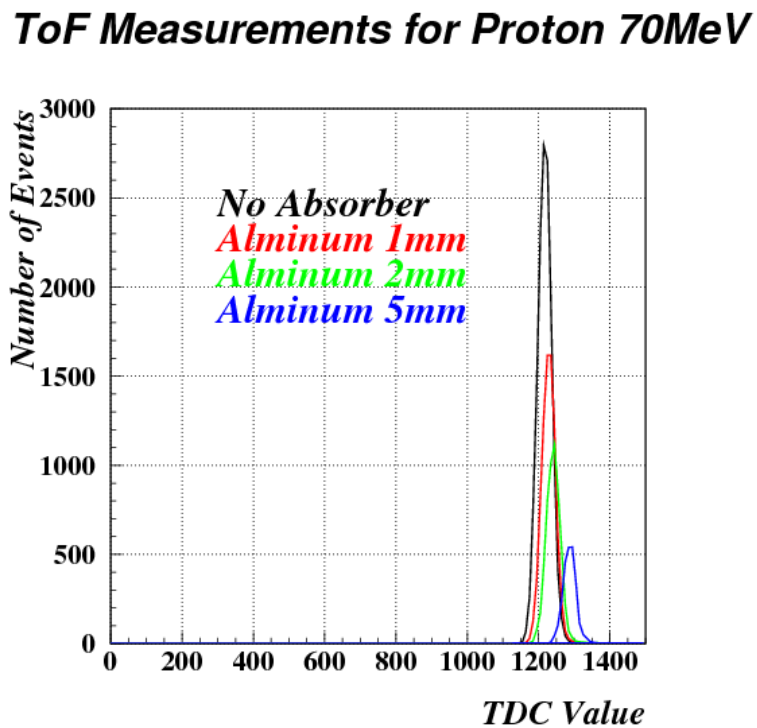
Position dependence

- Proton 70 MeV
  - Fitting Error ~2.0%
  - Position Dependency within 5x5cm2 ~2.9 %
- Proton 40 MeV
  - Fitting Error ~ 3.1%
  - Position Dependency within 5x5cm2 ~4.0%
  - Real dose is about 6.7 % higher than the measured dose.

Energy Distribution



We have measured the energy of the beam by means of ToF (Time of Flight)

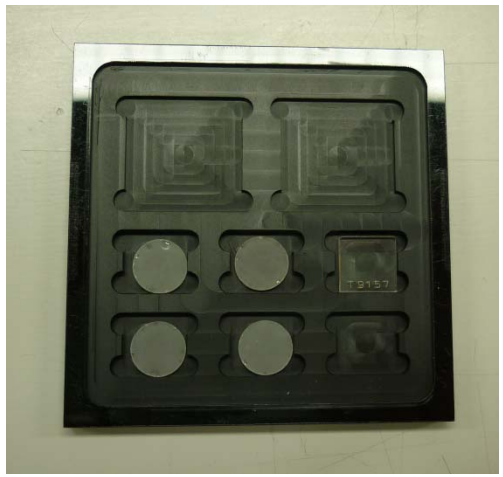


Energy Estimation from ToF Measurements

Beam	Estimation by ToF	Aluminum 1mm	Aluminum 2mm	Aluminum 5mm
proton 30 MeV	26.7 ±0.7MeV (28.0MeV)	22.1 MeV (22.2 MeV*)		
proton 70 MeV	69.8±3.5 MeV (68.4MeV)	67.8 MeV (67.8 MeV*)	65.6 MeV (65.8 MeV*)	58.5 MeV (59.3 MeV*)

Error shows statistic error as the standard deviation.
Bracket values show calculated value from nominal energies.
Values with asterisk(*) show estimated value from ToF estimation.

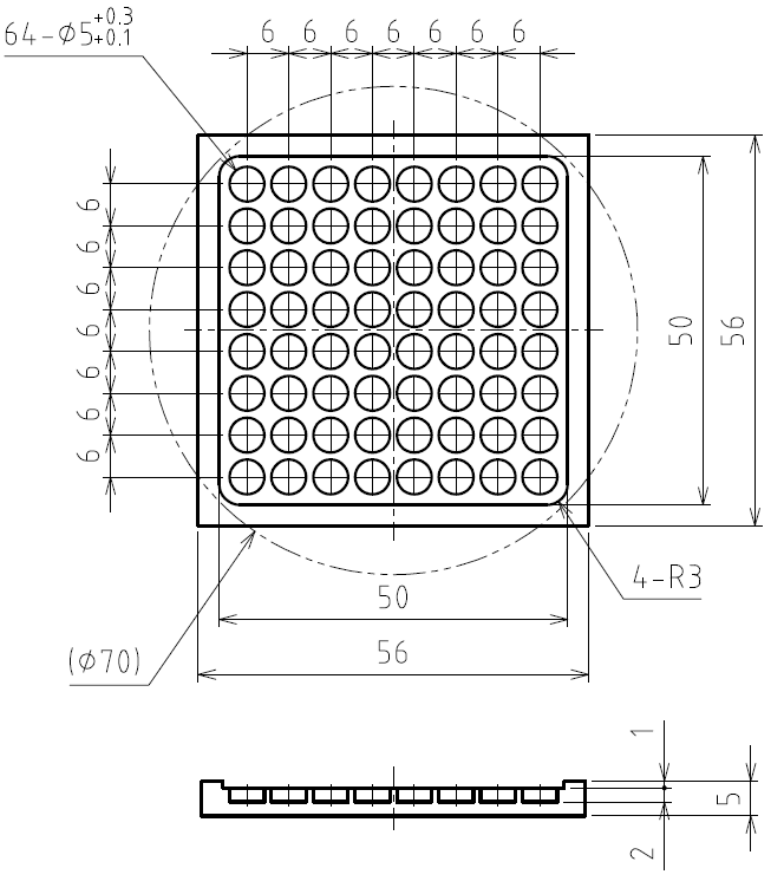
Proton ICCHIBAN 2



List of Participants

1	Armenia	YPI (Yerevan Physics Institute, Yerevan)
2	Austria	ATI (Atomic Institute of the Austrian Universities, Vienna)
3	Belgium	SCK-CEN (Belgian Nuclear Research Center, Mol)
4	Czech Rep.	NPI (Nuclear Physics Institute, Prague)
5	Germany	DLR (German Aerospace Center, Cologne)
6	Greece	AUT (Aristotle University of Thessaloniki)
7	Hungary	KFKI AEKI (KFKI Atomic Energy Research Institute, Budapest)
8	Japan	JAXA (Japan Aerospace Exploration Agency, Tsukuba)
9	Japan	NIRS (National Institute of Radiological Sciences, Chiba)
10	Poland	INP (Institute of Nuclear Physics, Krakow)
11	Russia	IMBP (Institute of Biomedical Problems, Moscow)
12	USA	Eril Research Inc. (Stilwater)
13	USA	NASA-JSC (NASA Johnson Space Center, Houston)
14	USA	Oklahoma State University (Stilwater)

Package Type-A



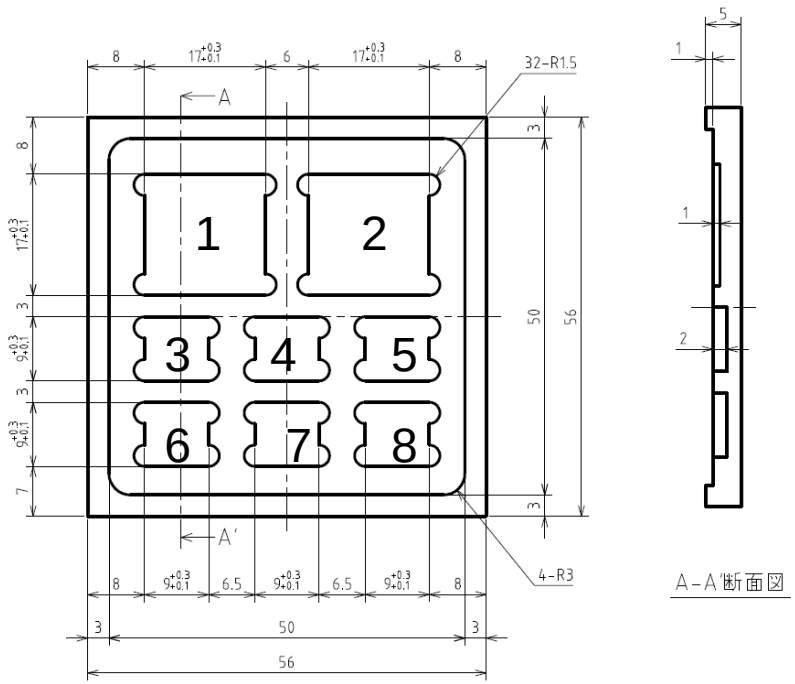
Proton 70 MeV

0.926	0.957	0.972	0.977	0.979	0.980	0.978	0.969
0.980	1.000	1.003	1.000	0.998	1.000	1.005	1.006
1.012	1.022	1.016	1.006	1.000	1.003	1.014	1.023
1.027	1.031	1.019	1.005	0.997	1.001	1.014	1.029
1.029	1.032	1.020	1.005	0.997	1.000	1.013	1.028
1.017	1.026	1.018	1.007	1.000	1.002	1.012	1.022
0.988	1.007	1.008	1.003	0.999	1.000	1.004	1.005
0.938	0.968	0.980	0.983	0.982	0.982	0.979	0.970

Proton 40 MeV

1.114	1.119	1.114	1.107	1.103	1.104	1.11	1.117
1.12	1.112	1.095	1.08	1.072	1.074	1.085	1.102
1.116	1.096	1.07	1.047	1.036	1.038	1.054	1.079
1.108	1.08	1.047	1.019	1.005	1.008	1.027	1.058
1.103	1.071	1.034	1.004	0.989	0.992	1.013	1.046
1.104	1.072	1.036	1.006	0.991	0.994	1.015	1.048
1.11	1.083	1.051	1.025	1.011	1.014	1.033	1.062
1.117	1.1	1.076	1.055	1.044	1.046	1.061	1.084

Type C

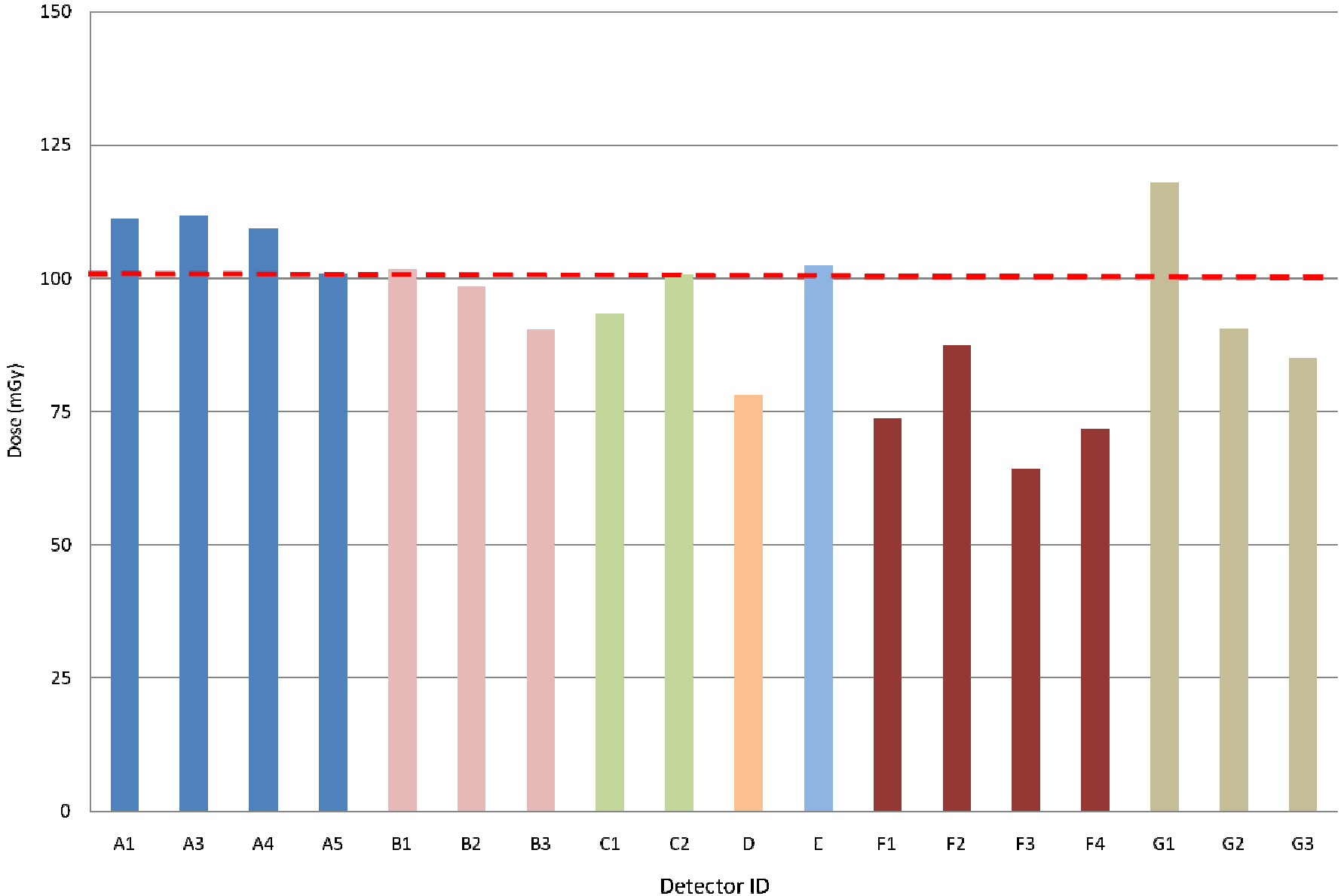


	Proton 70 MeV	Proton 40 MeV
1	1.008	1.089
2	1.007	1.064
3	1.029	1.076
4	1.002	0.997
5	1.013	1.015
6	0.990	1.093
7	0.996	1.029
8	0.996	1.043

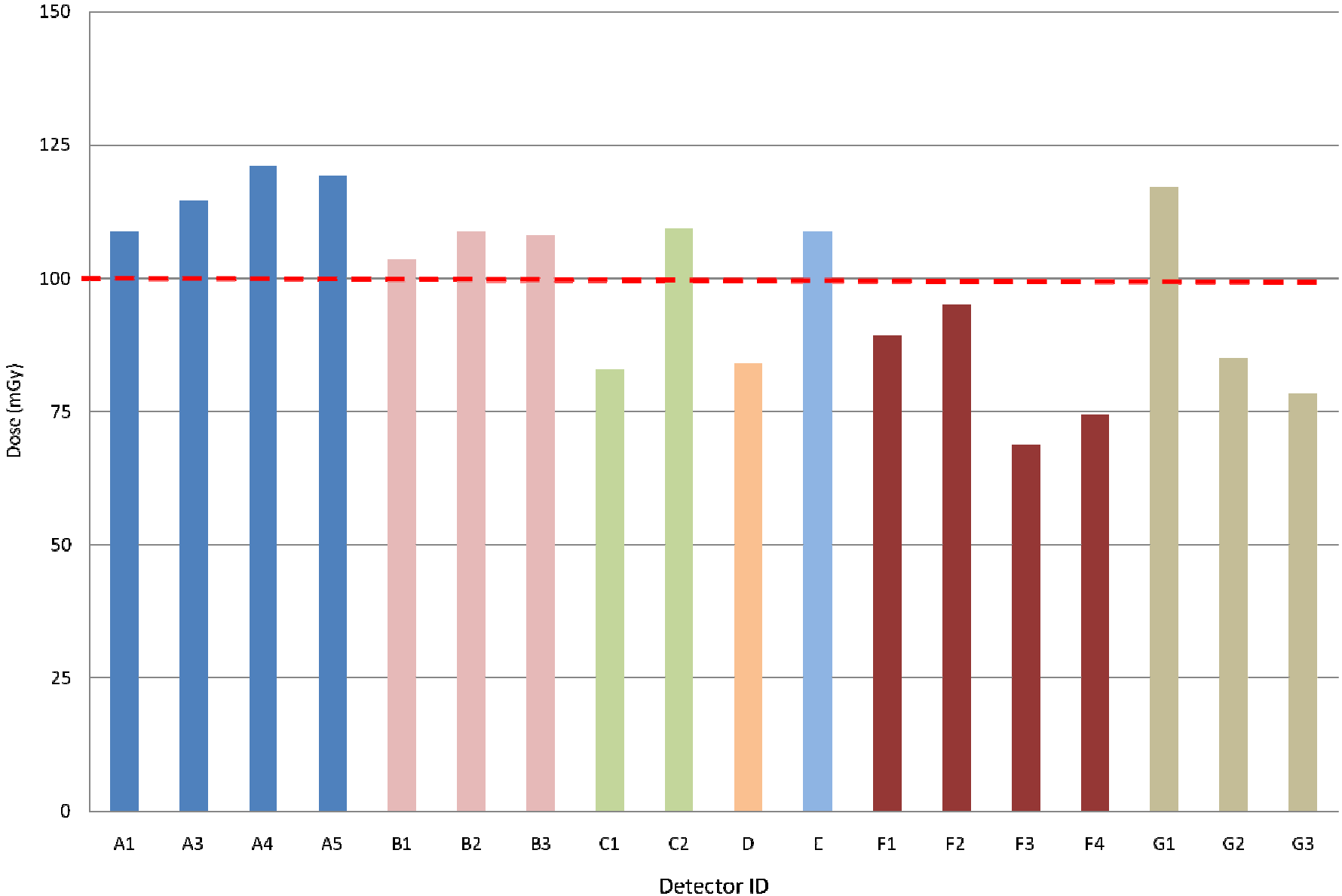
Exposure list

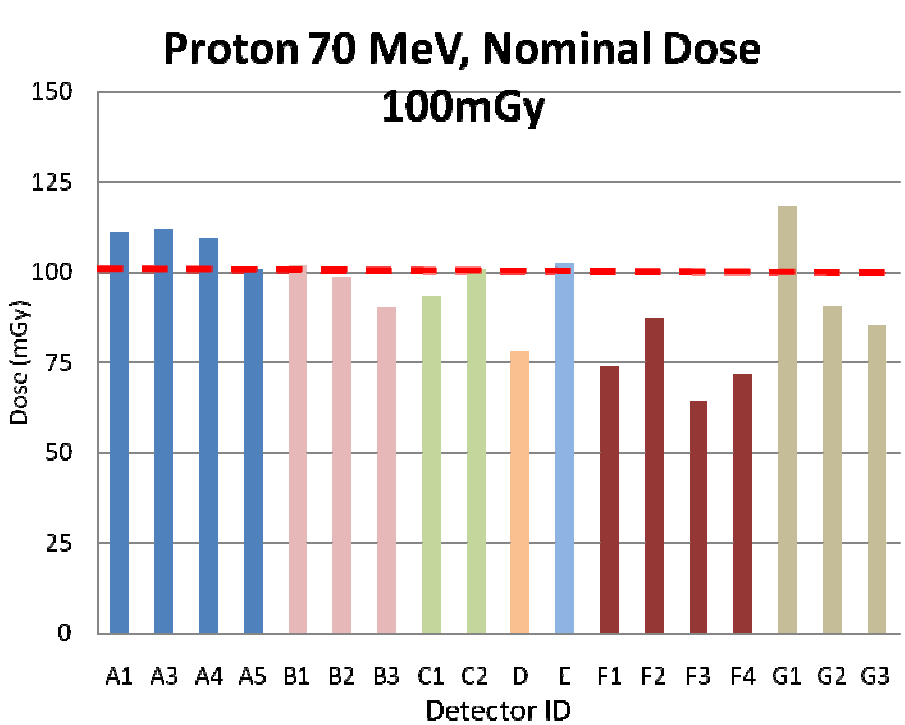
- Proton 70 MeV
  - 1mGy, 10 mGy, 50 mGy, 100 mGy
  - 50 mGy with 5 mmt aluminum
- Proton 40 MeV
  - 1mGy, 10 mGy, 50 mGu, 100 mGy
  - 50 mGy with 3 mmt Alminum
- Blind
  - #1 70 mGy Proton 70 MeV
  - #2 50 mGy ^{4}He 2.2keV/u
  - Extra #3 52 mGy ^{12}C 11 keV/µm,
  - Extra #4 200 mGy Proton 40 MeV, 20 mGy ^{12}C 11 keV/µm, 10 mGy ^{28}Si 55 keV/µm

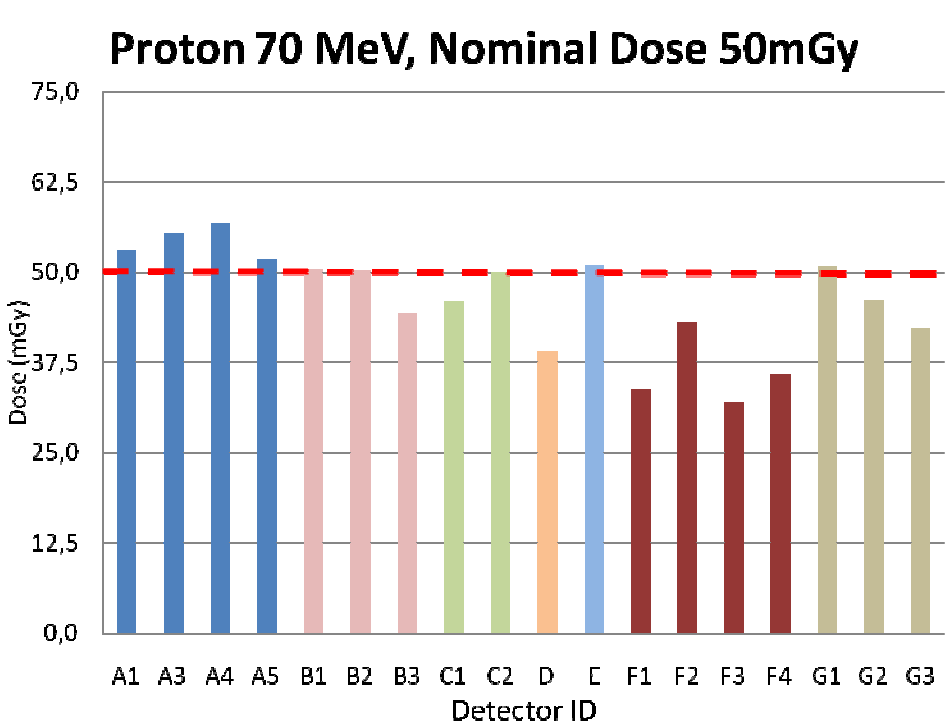
Proton 70 MeV, Nominal Dose 100mGy

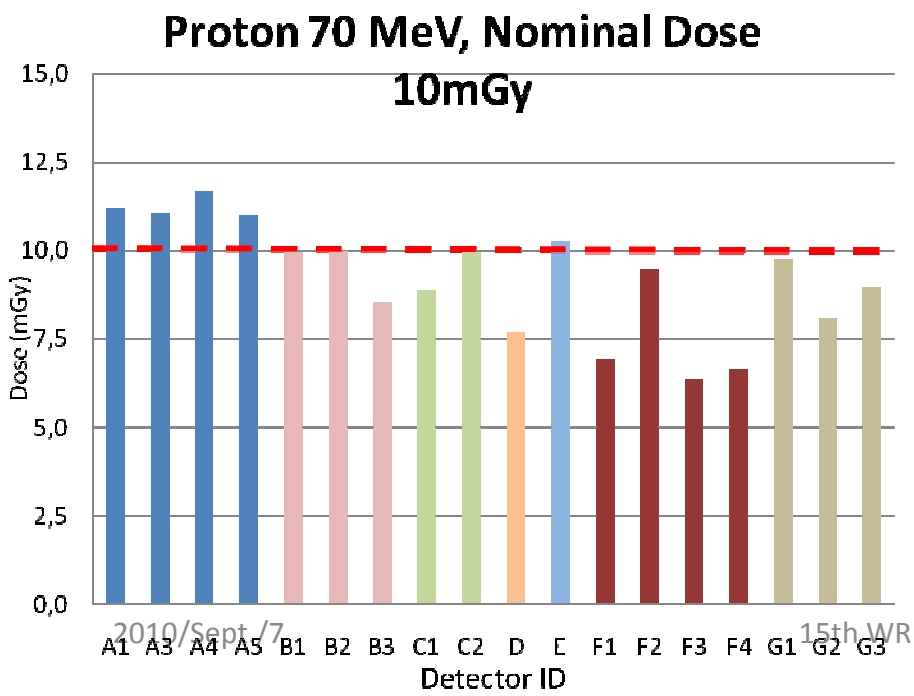


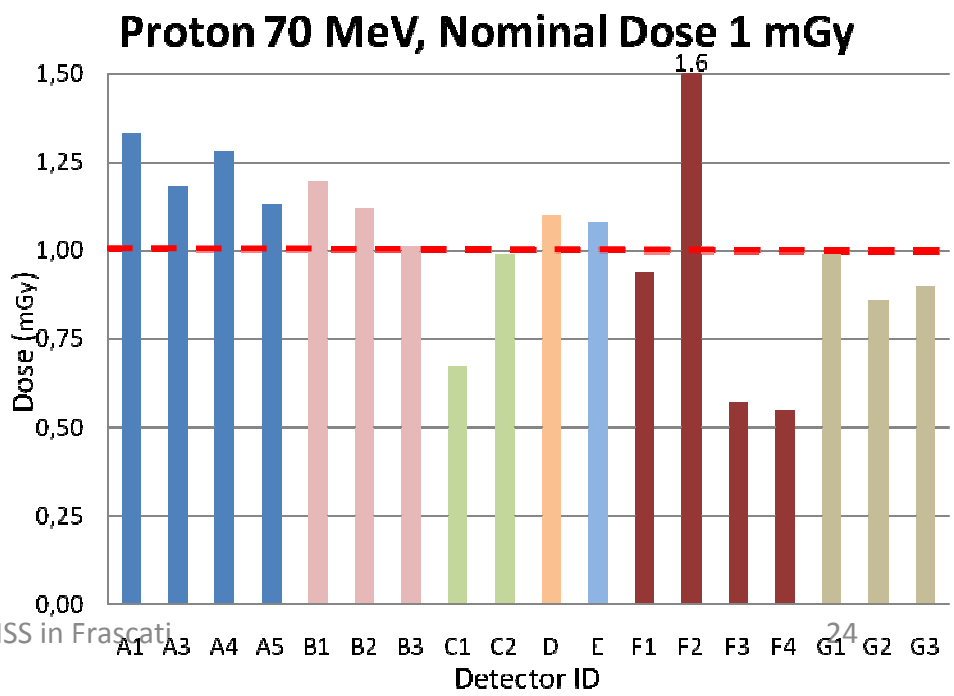
Proton 40 MeV, Nominal Dose 100mGy

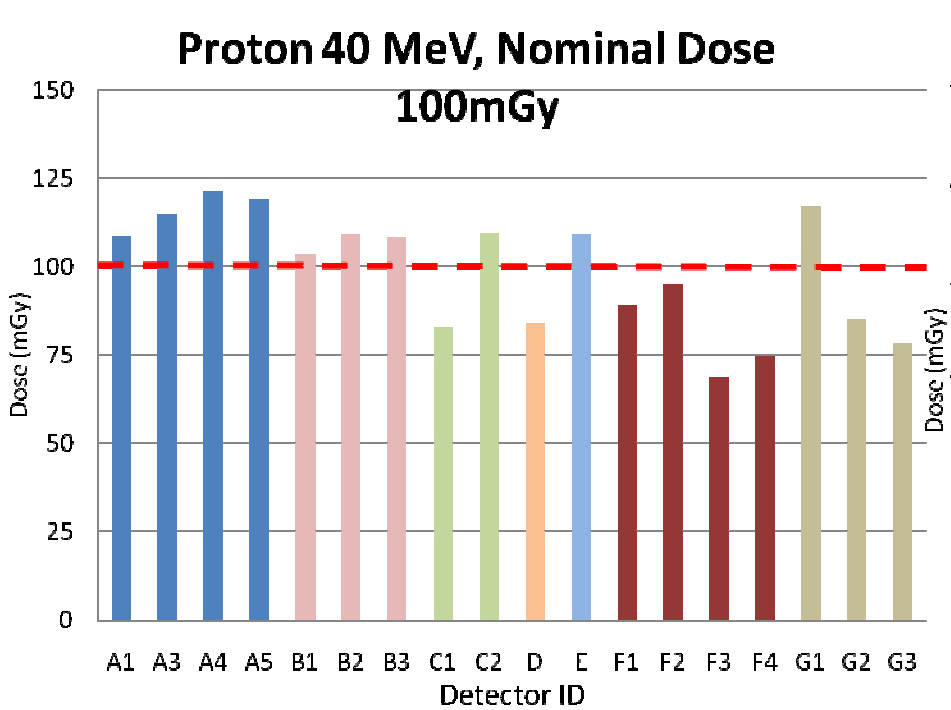


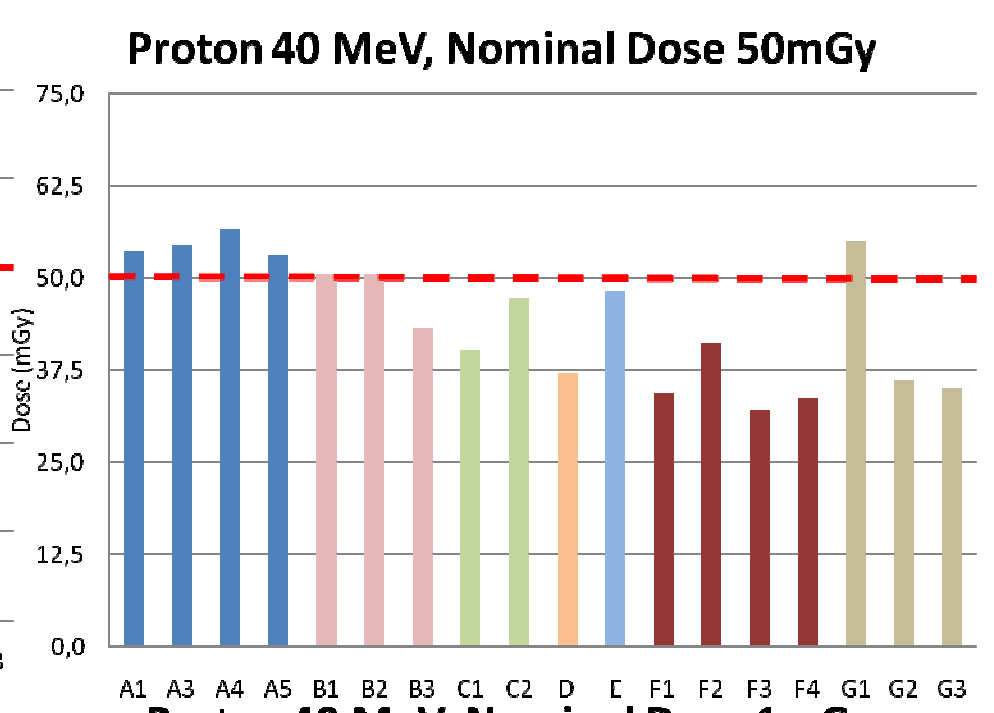

Proton 70 MeV, Nominal Dose 100mGy
150
125
100
75
50
25
0
Dose (mGy)
A1 A3 A4 A5 B1 B2 B3 C1 C2 D E F1 F2 F3 F4 G1 G2 G3
Detector ID

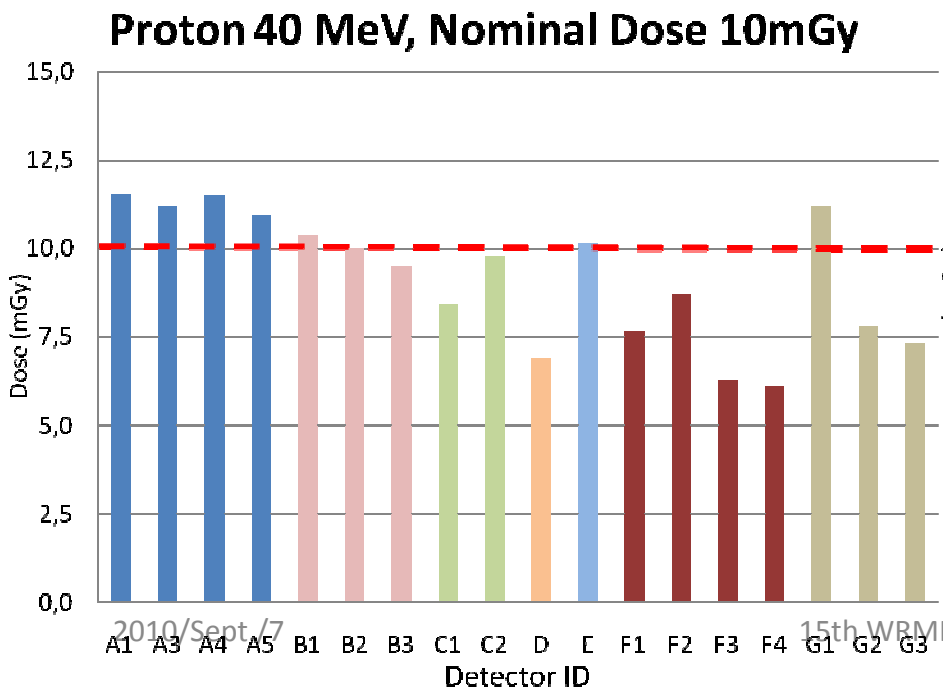

Proton 70 MeV, Nominal Dose 50mGy
75,0
62,5
50,0
37,5
25,0
12,5
0,0
Dose (mGy)
A1 A3 A4 A5 B1 B2 B3 C1 C2 D E F1 F2 F3 F4 G1 G2 G3
Detector ID

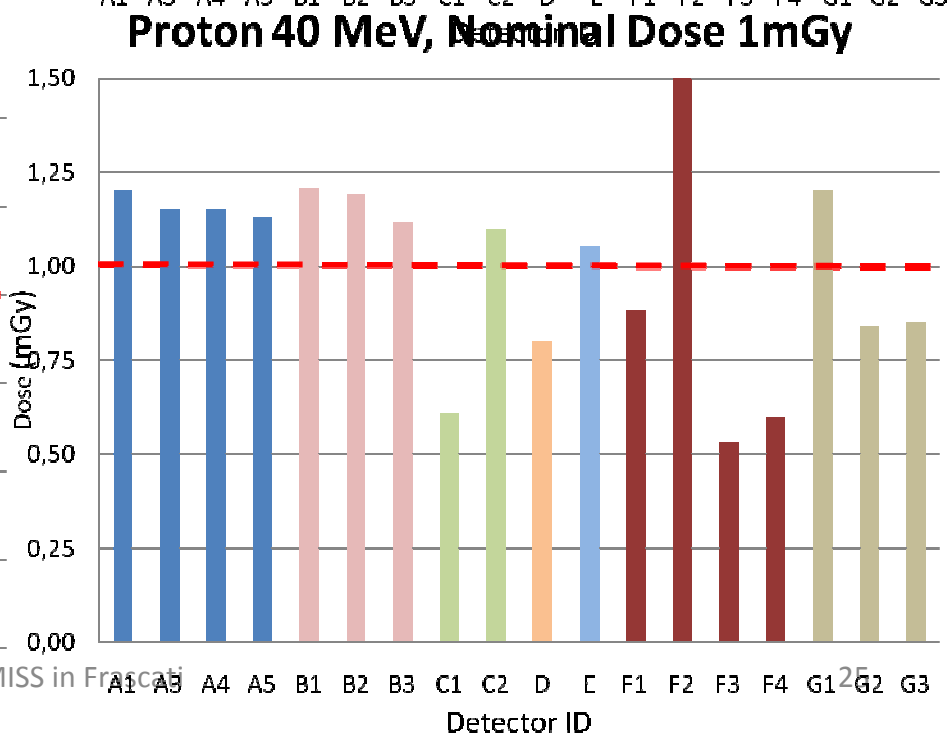

Proton 70 MeV, Nominal Dose 10mGy
15,0
12,5
10,0
7,5
5,0
2,5
0,0
Dose (mGy)
A1 A3 A4 A5 B1 B2 B3 C1 C2 D E F1 F2 F3 F4 G1 G2 G3
Detector ID

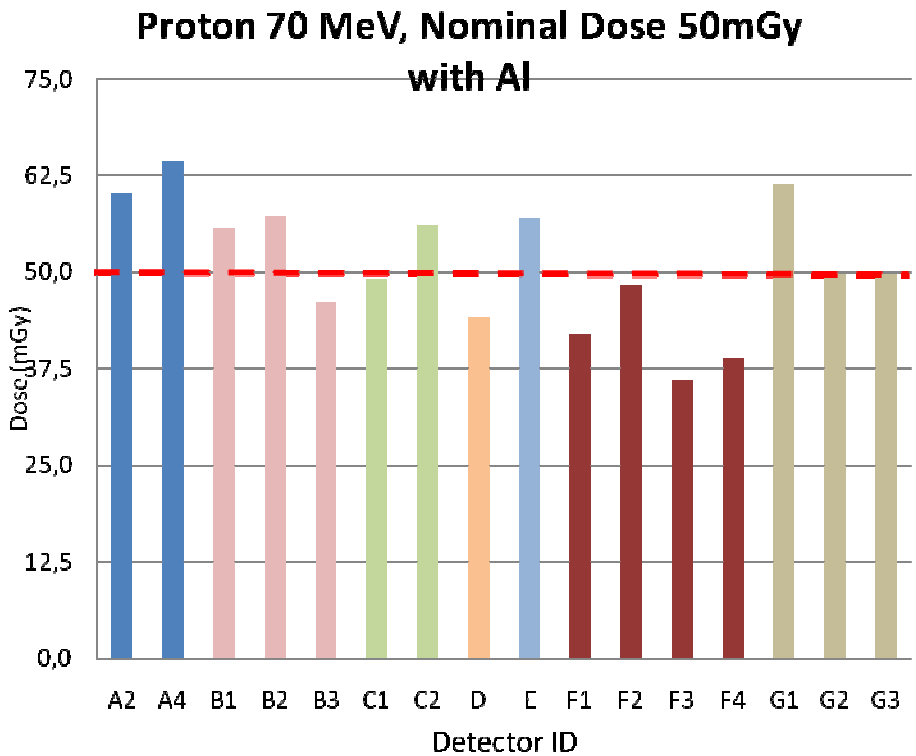

Proton 70 MeV, Nominal Dose 1 mGy
1,50
1,25
1,00
0,75
0,50
0,25
0,00
1.6
Dose (mGy)
A1 A3 A4 A5 B1 B2 B3 C1 C2 D E F1 F2 F3 F4 G1 G2 G3
Detector ID

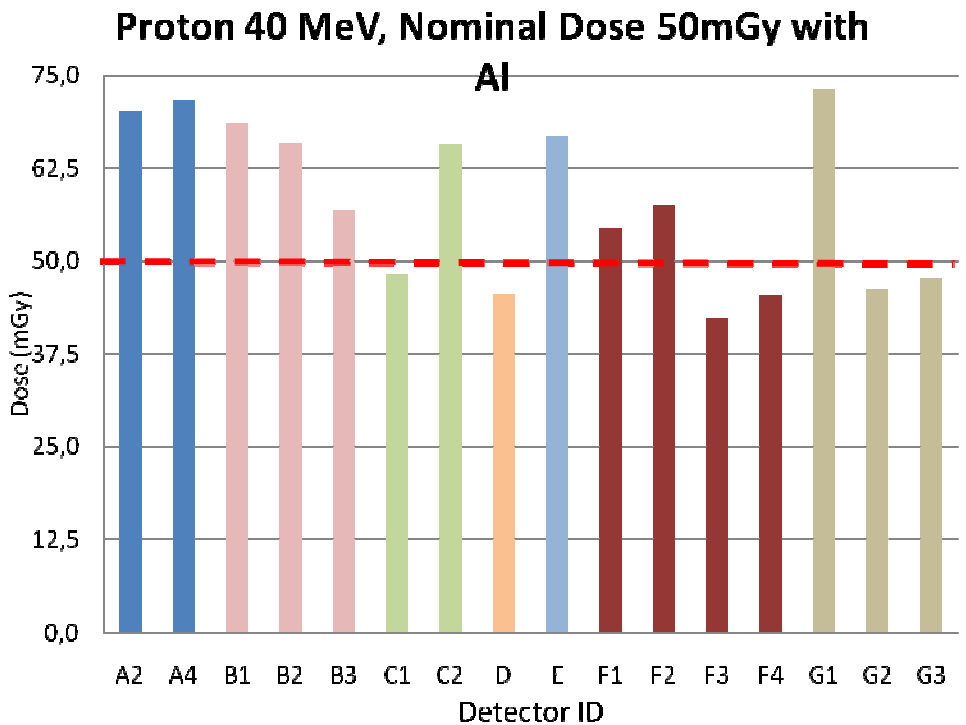

Proton 40 MeV, Nominal Dose 100mGy
Dose (mGy)
150
125
100
75
50
25
0
A1 A3 A4 A5 B1 B2 B3 C1 C2 D E F1 F2 F3 F4 G1 G2 G3
Detector ID

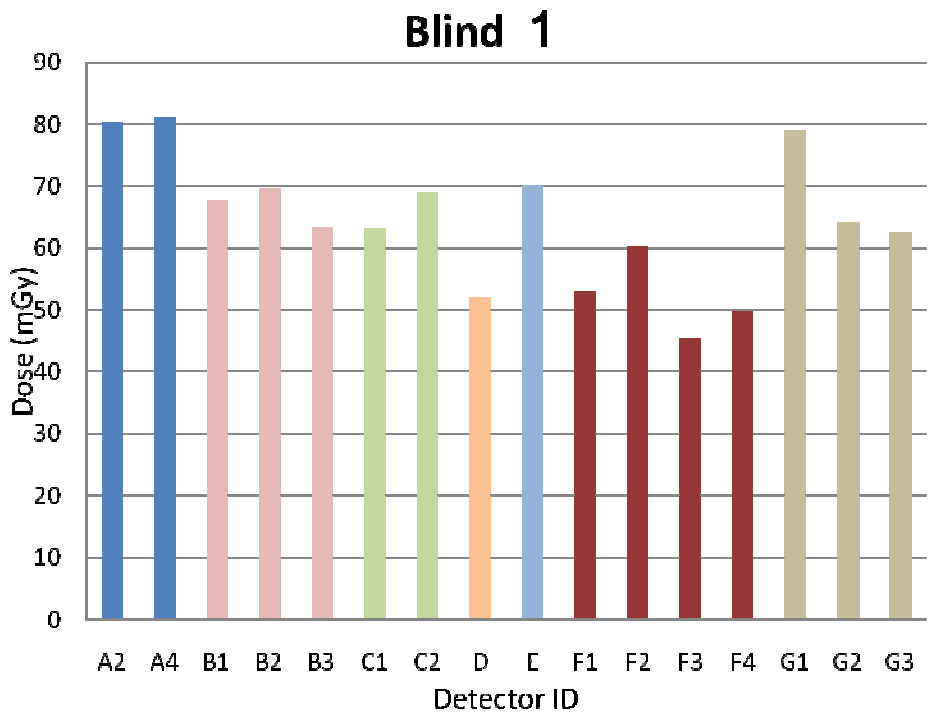

Proton 40 MeV, Nominal Dose 50mGy
Dose (mGy)
75,0
62,5
50,0
37,5
25,0
12,5
0,0
A1 A3 A4 A5 B1 B2 B3 C1 C2 D E F1 F2 F3 F4 G1 G2 G3
Detector ID

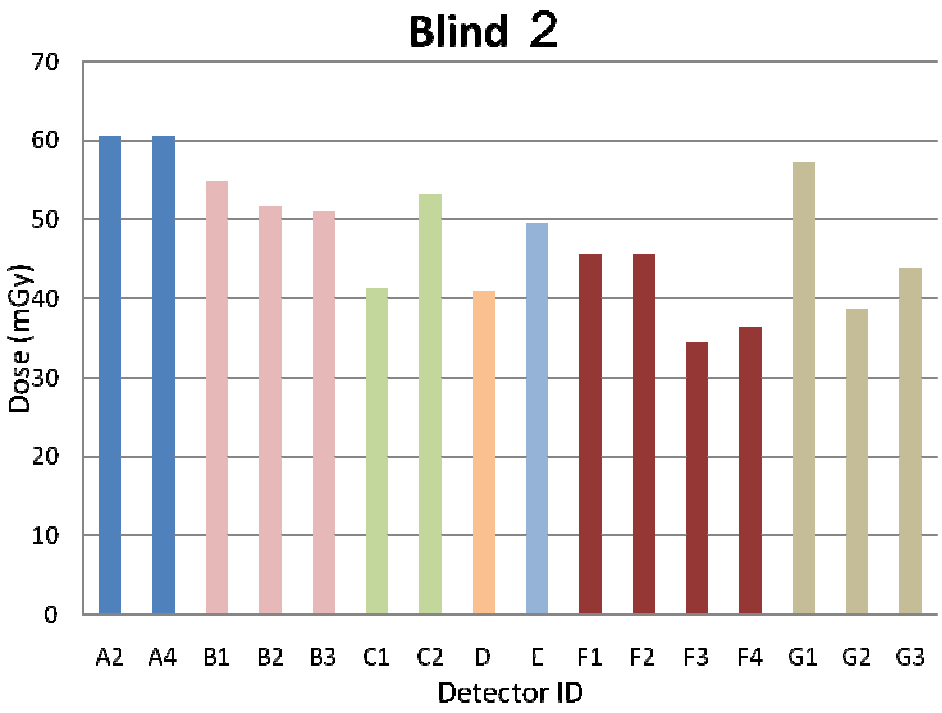

Proton 40 MeV, Nominal Dose 10mGy
Dose (mGy)
15,0
12,5
10,0
7,5
5,0
2,5
0,0
A1 A3 A4 A5 B1 B2 B3 C1 C2 D E F1 F2 F3 F4 G1 G2 G3
Detector ID

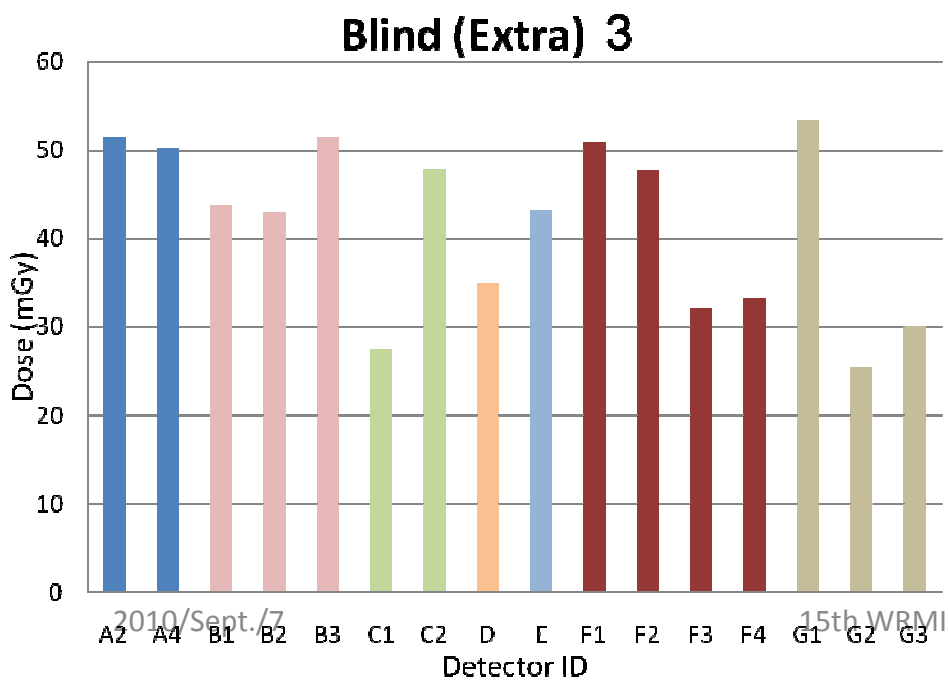

Proton 40 MeV, Nominal Dose 1mGy
Dose (mGy)
1,50
1,25
1,00
0,75
0,50
0,25
0,00
A1 A3 A4 A5 B1 B2 B3 C1 C2 D E F1 F2 F3 F4 G1 G2 G3
Detector ID

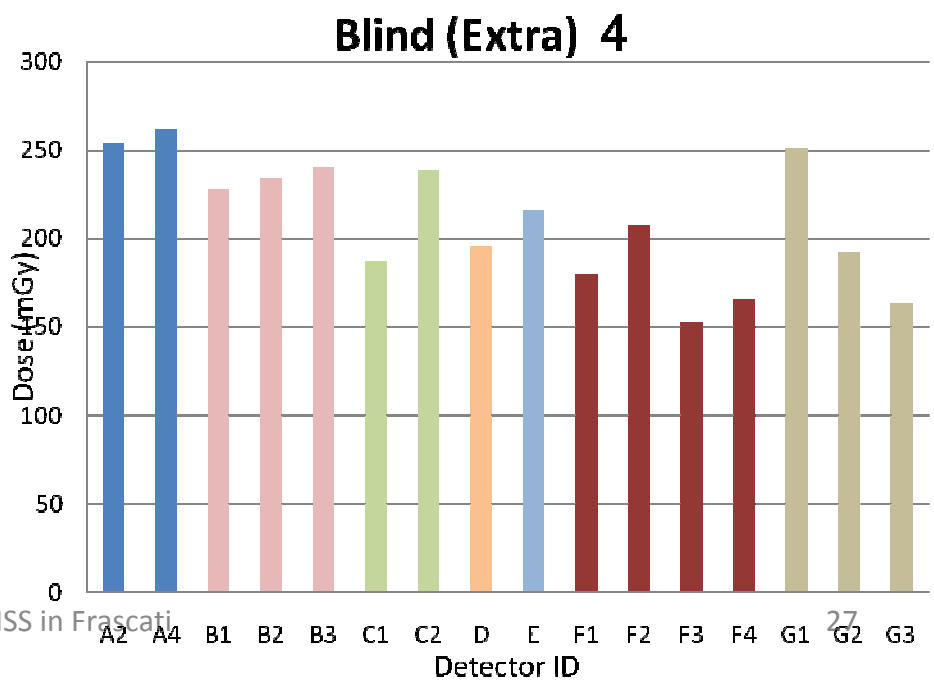

Proton 70 MeV, Nominal Dose 50mGy with Al
75,0
62,5
50,0
37,5
25,0
12,5
0,0
Dose (mGy)
A2 A4 B1 B2 B3 C1 C2 D E F1 F2 F3 F4 G1 G2 G3
Detector ID

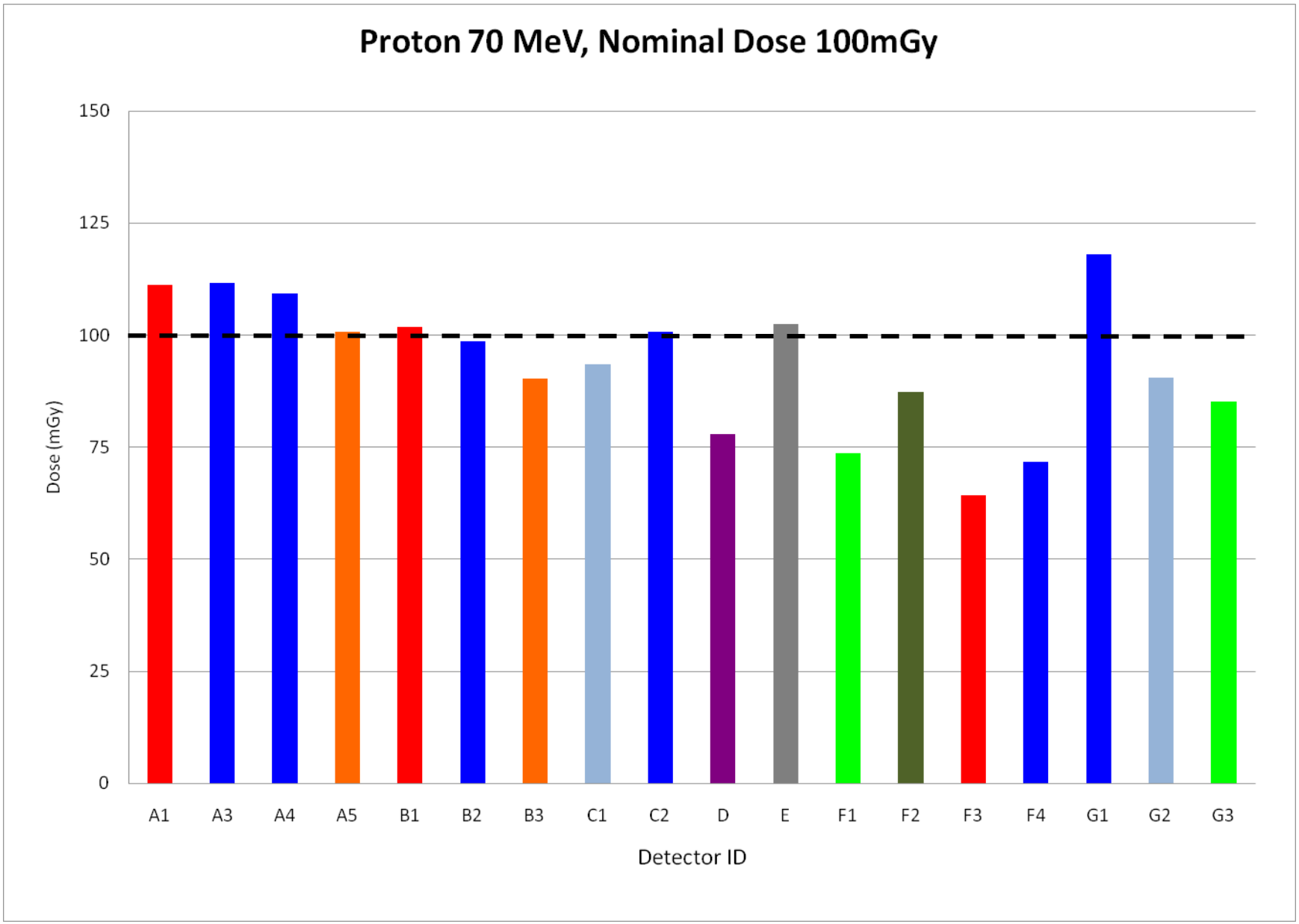

Proton 40 MeV, Nominal Dose 50mGy with Al
75,0
62,5
50,0
37,5
25,0
12,5
0,0
Dose (mGy)
A2 A4 B1 B2 B3 C1 C2 D E F1 F2 F3 F4 G1 G2 G3
Detector ID

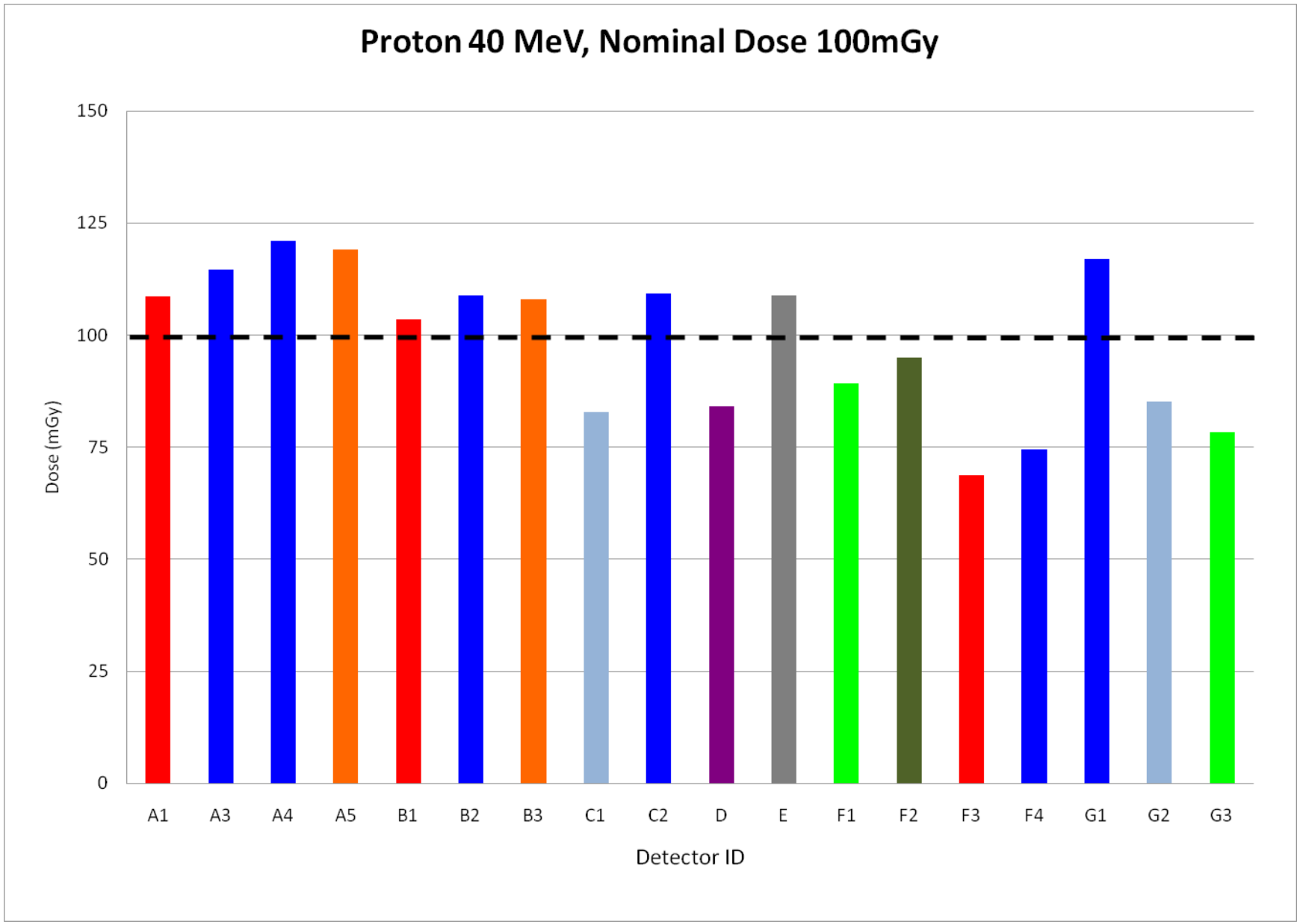

Blind 1
Dose (mGy)
Detector ID
A2 A4 B1 B2 B3 C1 C2 D E F1 F2 F3 F4 G1 G2 G3

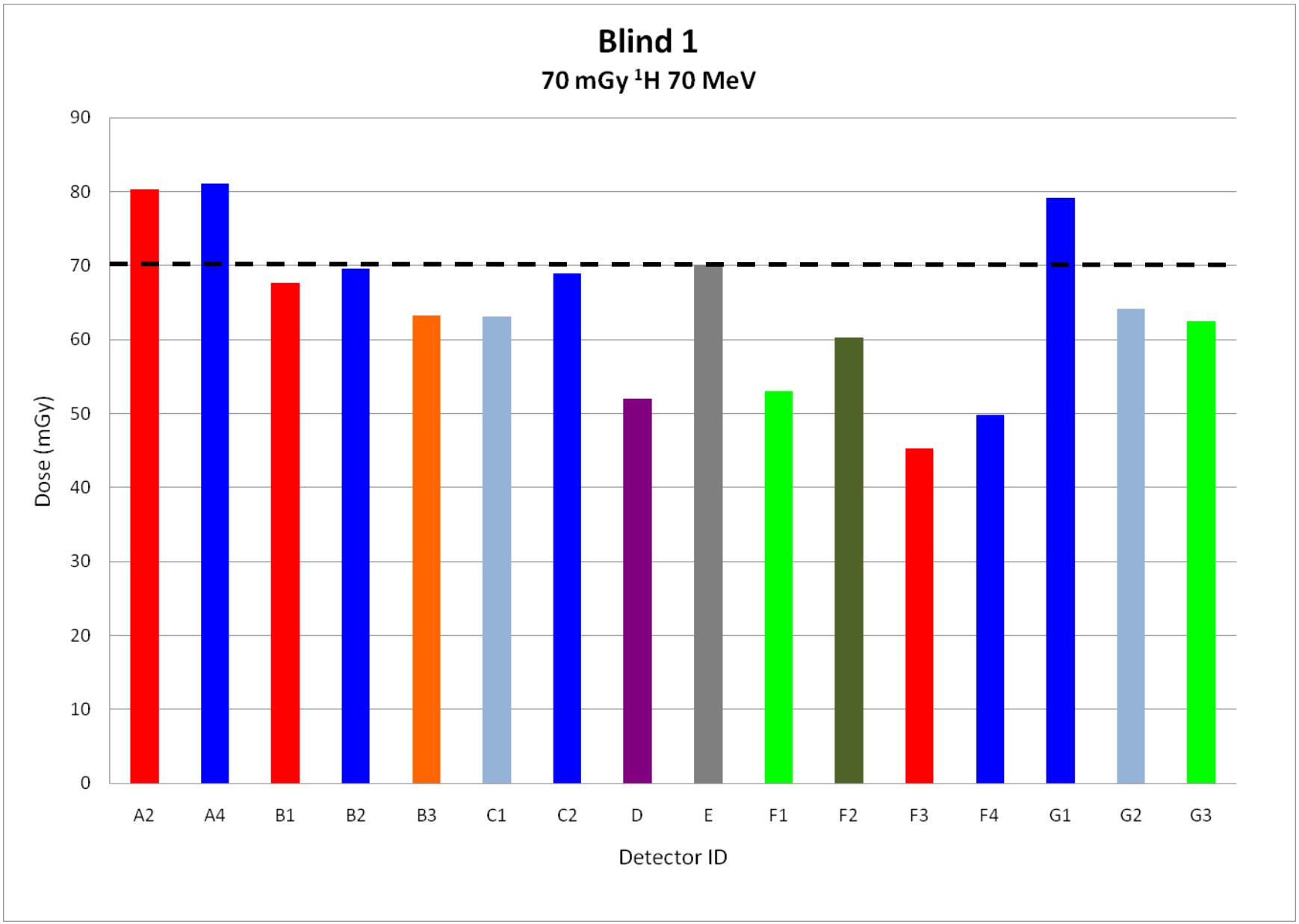

Blind 2
Dose (mGy)
Detector ID
A2 A4 B1 B2 B3 C1 C2 D E F1 F2 F3 F4 G1 G2 G3

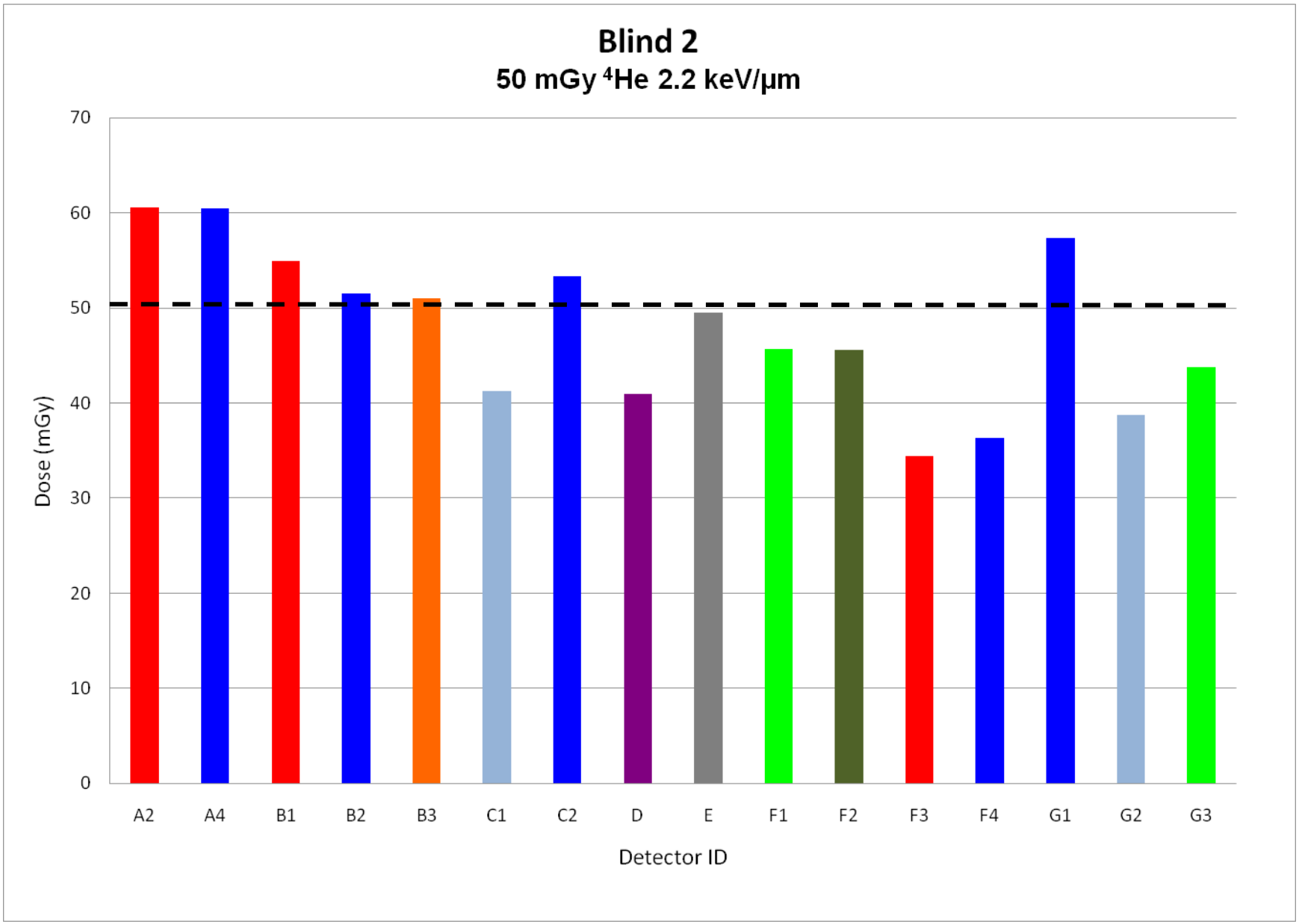

Blind (Extra) 3
Dose (mGy)
Detector ID
A2 A4 B1 B2 B3 C1 C2 D E F1 F2 F3 F4 G1 G2 G3

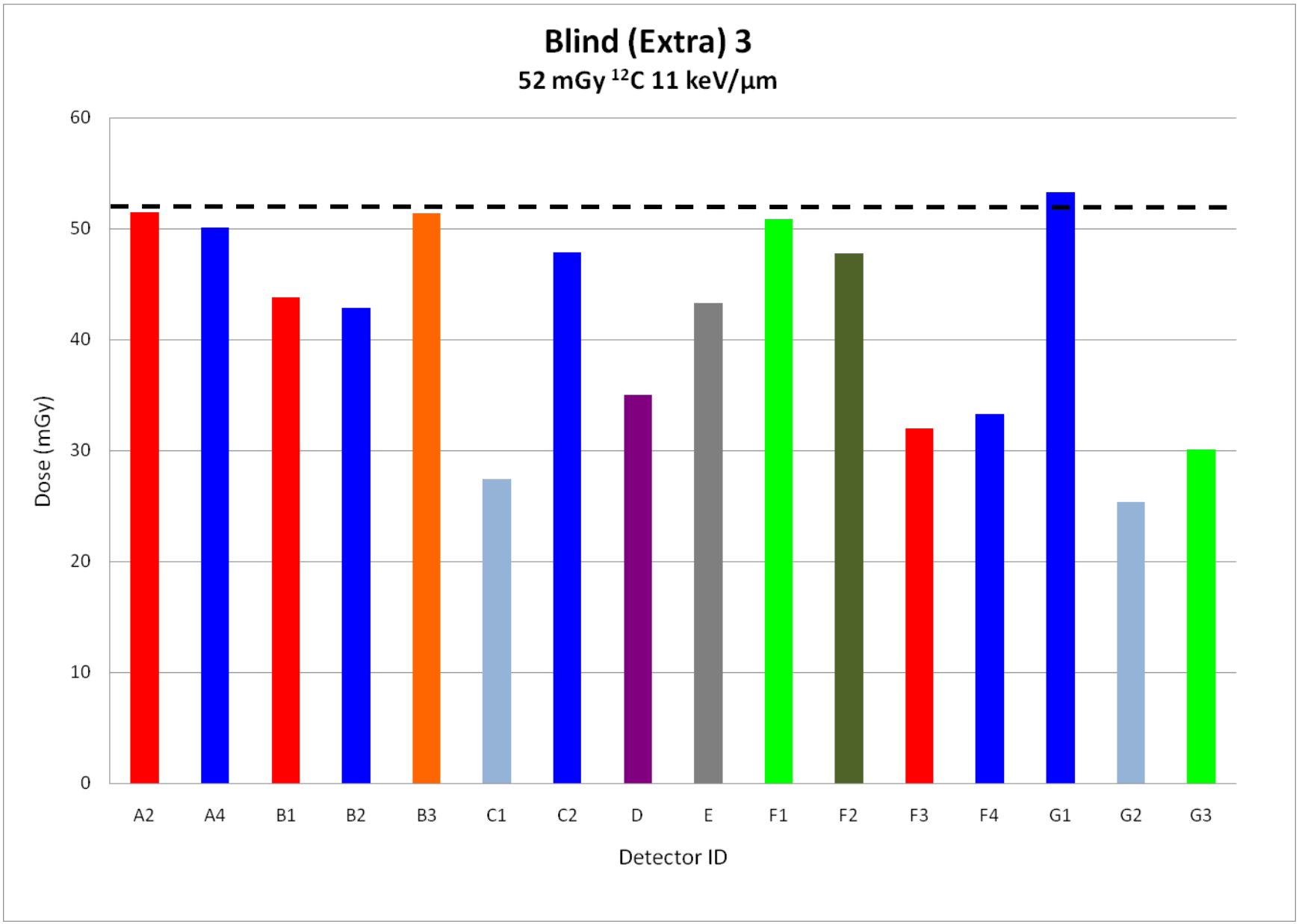

Blind (Extra) 4
Dose (mGy)
Detector ID
A2 A4 B1 B2 B3 C1 C2 D E F1 F2 F3 F4 G1 G2 G3

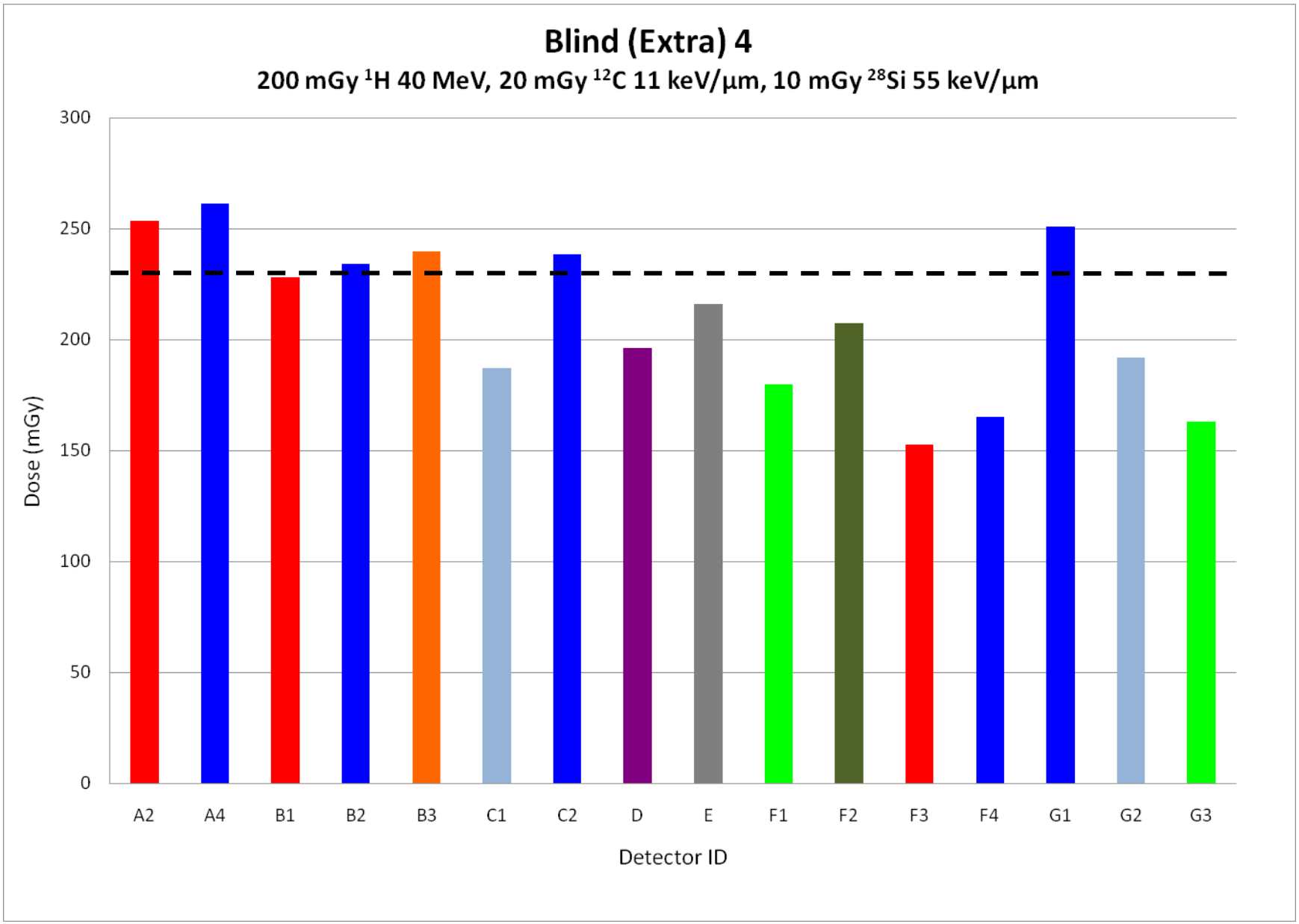

Proton 70 MeV, Nominal Dose 100mGy
150
125
100
75
50
25
0
Dose (mGy)
A1
A3
A4
A5
B1
B2
B3
C1
C2
D
E
F1
F2
F3
F4
G1
G2
G3
Detector ID


Proton 40 MeV, Nominal Dose 100mGy
150
125
100
75
50
25
0
Dose (mGy)
A1
A3
A4
A5
B1
B2
B3
C1
C2
D
E
F1
F2
F3
F4
G1
G2
G3
Detector ID


Blind 1
70 mGy 1H 70 MeV
90
80
70
60
50
40
30
20
10
0
Dose (mGy)
A2
A4
B1
B2
B3
C1
C2
D
E
F1
F2
F3
F4
G1
G2
G3
Detector ID


Blind 2
50 mGy 4He 2.2 keV/µm
70
60
50
40
30
20
10
0
Dose (mGy)
A2
A4
B1
B2
B3
C1
C2
D
E
F1
F2
F3
F4
G1
G2
G3
Detector ID


Blind (Extra) 3
52 mGy 12C 11 keV/µm
Dose (mGy)
60
50
40
30
20
10
0
A2
A4
B1
B2
B3
C1
C2
D
E
F1
F2
F3
F4
G1
G2
G3
Detector ID


Blind (Extra) 4
200 mGy ^{1}H 40 MeV, 20 mGy ^{12}C 11 keV/µm, 10 mGy ^{28}Si 55 keV/µm
Dose (mGy)
300
250
200
150
100
50
0
A2
A4
B1
B2
B3
C1
C2
D
E
F1
F2
F3
F4
G1
G2
G3
Detector ID

Conclusion

- In order to intercompare and calibrate luminescence detectors for space radiation dosimetry, Proton-ICCHIBAN-2 has been started.
- We have developed new radiation field for high energy (from 10 to 80 MeV) proton beams in the cyclotron facility in NIRS. The radiation field is useful for not only physics experiments but also biology experiments.
- The 1st series of the P-IC-2 was performed in 2010 and preliminary results were obtained.
- To compare the same type of detectors, they have good agreement within uncertainly.
- We will continue other series of P-IC-2 using other energy proton beams (30, 80 and …) and light ion beams (Alpha, D, Carbon and etc.) in near future. The first candidate is a beam time at the NIRS-Cyclotron on Feb. 2011.

Acknowledgement

- Staffs of the NIRS-Cyclotron for their efforts to provide excellent beams.
- Members of the Quality Control Section in HIMAC for advices of calibrations.

Heavy Ion Symposium 2011 Chiba

(Heavy Ion Therapy and Space Radiation Symposium 2011, HITSRS2011)

The 6th International Workshop for Space Radiation Research (IWSRR)
The 14th Workshop on Ion Beam in Biology and Medicine (IBIBAM)
The 22nd Annual NASA Space Radiation Health Investigators' Workshop (SRHIW)
The 2nd ESA Space Radiation Investigators' Meeting (ESRAD)

Organized by the Japanese Association of Space Radiation Research and IWSRR2011 Committee

May 26th – 31st, 2011
Keiyo Bank Culture Plaza, Chiba, Japan

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