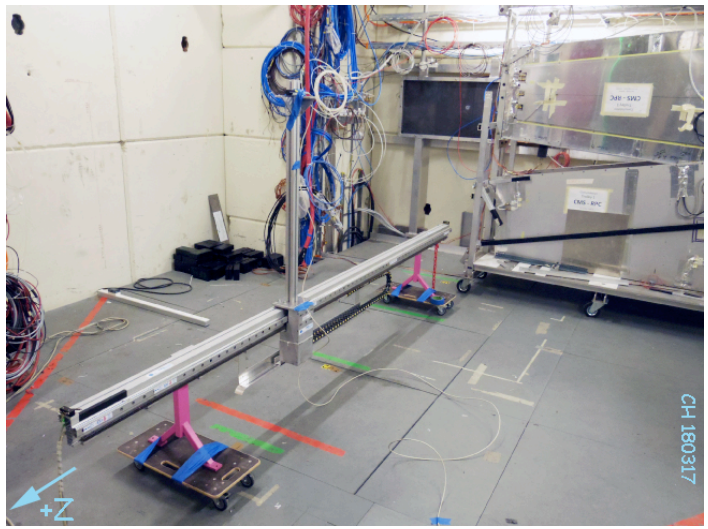
Dose Rate Profiles at GIF++

Mainly measurements with GM Counter and Linear Stage, in March 2018

Carsten Heidemann, Hans Reithler
180409, 180623, 181004

With thanks to:
Domenico Dattola
Martin Jaekel
Ekaterina Kuznetsova
Giuseppe Pezzullo
Dorothea Pfeiffer



GM counter (CERN):
Automess 6150AD-15/E, range 0.1 mSv/h - 10 Sv/h
65 keV - 3 MeV, +/-45 deg.

Linear stage (loan from Aachen):
330 cm range, 0.020 mm steps, about 55 cm/min

Method: run independently dosemeter and linear stage; synchronize offline via time stamps.

Knowledge on Irrad. Field at GIF++

Basic irradiation **ingredients** of GIF++:
- Strong (about 15 TBq) Cs^{137} source of 662 keV photons; all year available.
- High energy beam from the SPS (mainly muons); part time available.
- Filters permit to attenuate intensity of 662 keV photons by up to 46 000 times.
- Intensity of 662 keV photons from pointlike source shaped to be nearly homogeneous over planes (instead of spheres).
- Two independent irradiation outlets and attenuation systems.
- Devices providing trigger on particles from beam, beam halo, cosmics.
- Start of operation: March 2015.

Need for knowledge on irradiation field at GIf++:
- To plan irradiation campaigns.
- To analyse/interprete irradiation data.

—> **What** is needed (rate, orientation, energy, dose,...) and **how precisely**, for each detector study?

History of knowledge (first steps), as presented at GIF++ meetings:
- First meas. of dose and of energy spectrum, at single points: 150318.
- First simulation of dose, particle rate, energy spectrum: 150408, 150429.
- First dose profile meas. (for study of half-filter): 161110 (161106 at DT meeting).
- Overview published: **D. Pfeiffer et al., NIM_A_866(2017)91-103**.
- First extensive dose profiles: 180628.

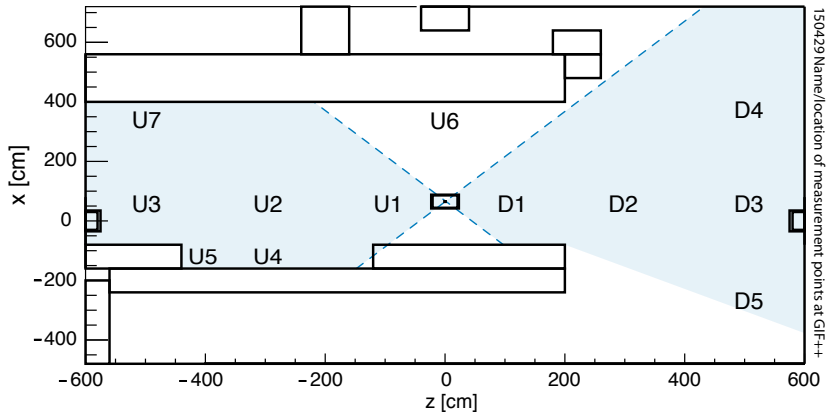
First Dose Rates, at Single Points

	Dose [mSv/h]					
	DS open, US open		DS open, US closed		DS closed, US open	
Name	measured	simulated	measured	simulated	measured	simulated
D1	-	736	470.0	779	-	-
D2	-	60	53.5	61	-	-
D3	21.3	22	21.2	23	-	-
D4	18.9	23	18.8	25	-	-
D5	15.5	24	15.5	24	-	-
U1	468.0	759	-	-	-	744
U2	55.8	69	-	-	-	57
U3	22.0	23	-	-	-	25
U3a	24.5	22	-	-	24.4	22
U3b	22.0	24	-	-	21.9	23
U4	53.0	57	-	-	53.0	60
U5	31.1	39	-	-	30.8	40
U6	1.8	6	-	-	1.3	5
U7	19.8	21	-	-	19.6	22

DP 150429

Comparison dose meas. and simulation (150429)

Dose rates, at **several positions**, for filters open on measuring side and open/closed on the opposite side. Position of points shown here:



Dose rates, at one position (D1), for **several attenuations** of 662 keV photons.

	Measured attenuation		
Attenuation of 662 keV gammas	Filter Combination	Dose [mSv/h]	Attenuation Dose
1	A1 B1 C1	470.00	-
1.5	A1 B2 C1	400.00	1.2
2.2	A1 B1 C2	211.00	2.2
4.6	A1 B1 C3	105.00	4.5
10	A2 B1 C1	55.00	8.8
100	A3 B1 C1	6.50	72.3
100	A1 B3 C1	6.20	75.8
464	A1 B3 C3	1.59	295.6
4642	A2 B3 C3	0.22	2156.0
46420	A3 B3 C3	0.05	9400.0

DP 150429

Comparison dose meas. and simulation (150429)

Good agreement; at high attenuation softer photons contribute much to the dose

Former Dose Rates

Data from single points measured March 2015, as published in **D. Pfeiffer et al., NIM A866 (2017) 91-103**:

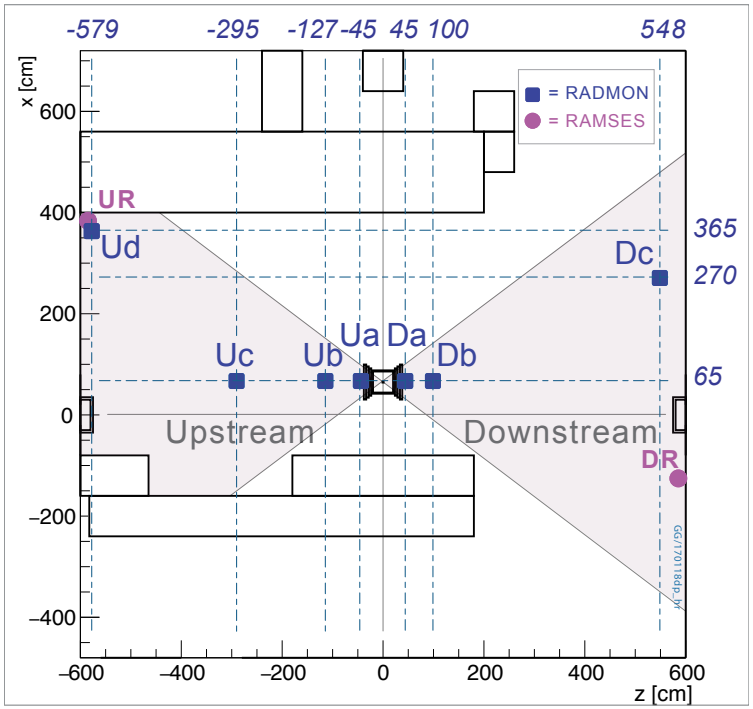


Fig. 8a, from D. Pfeiffer et al., NIM_A_866(2017)91–103

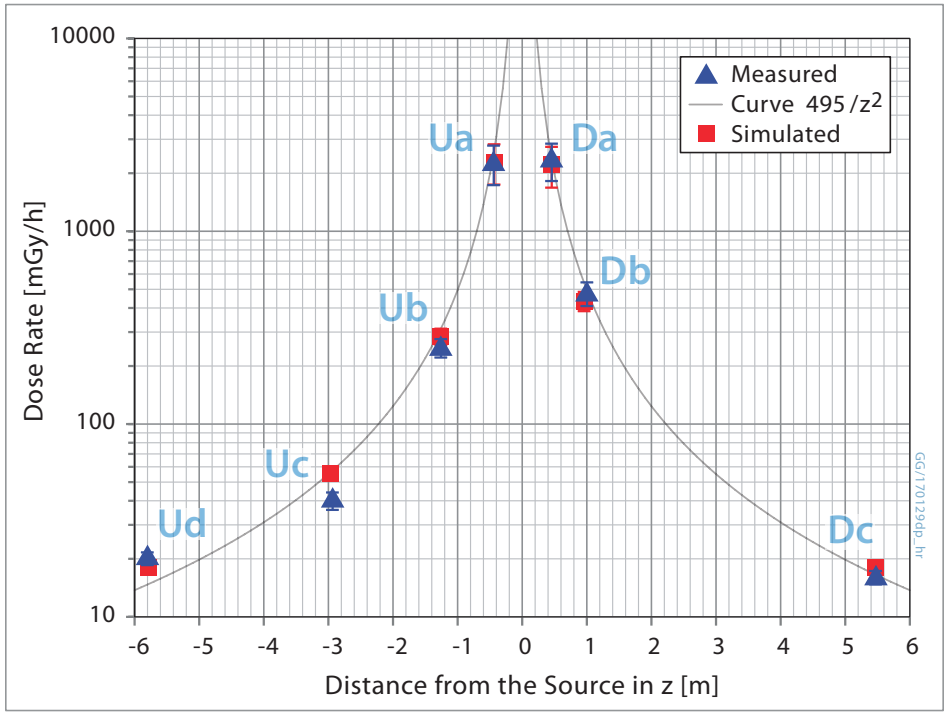
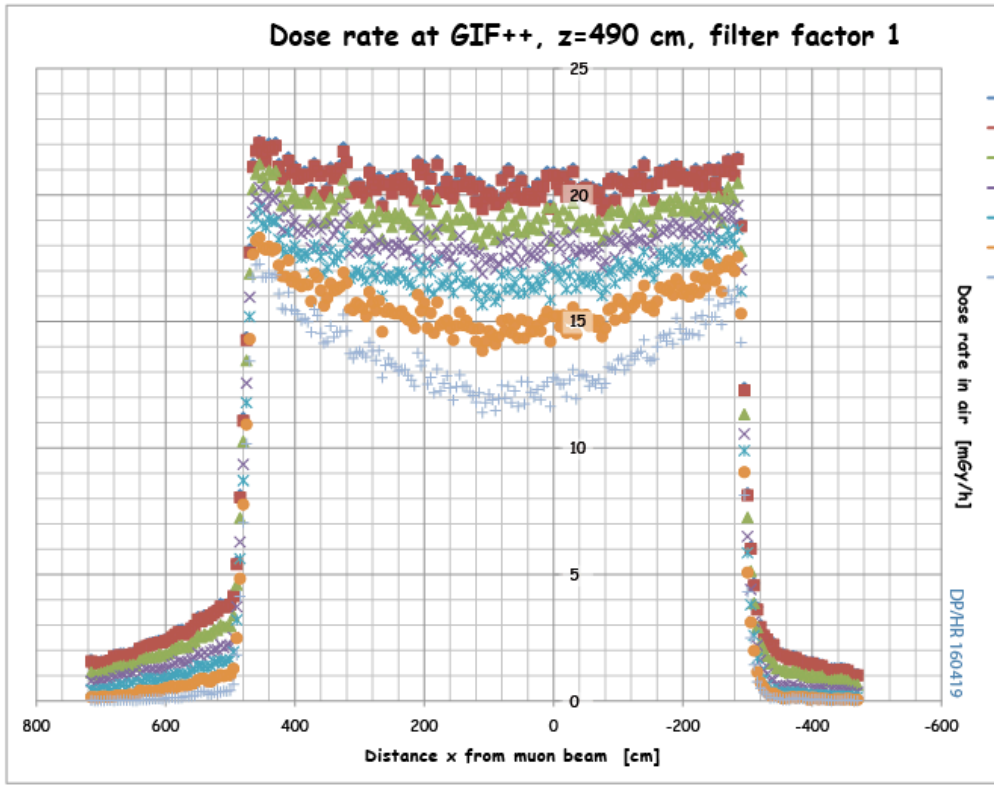


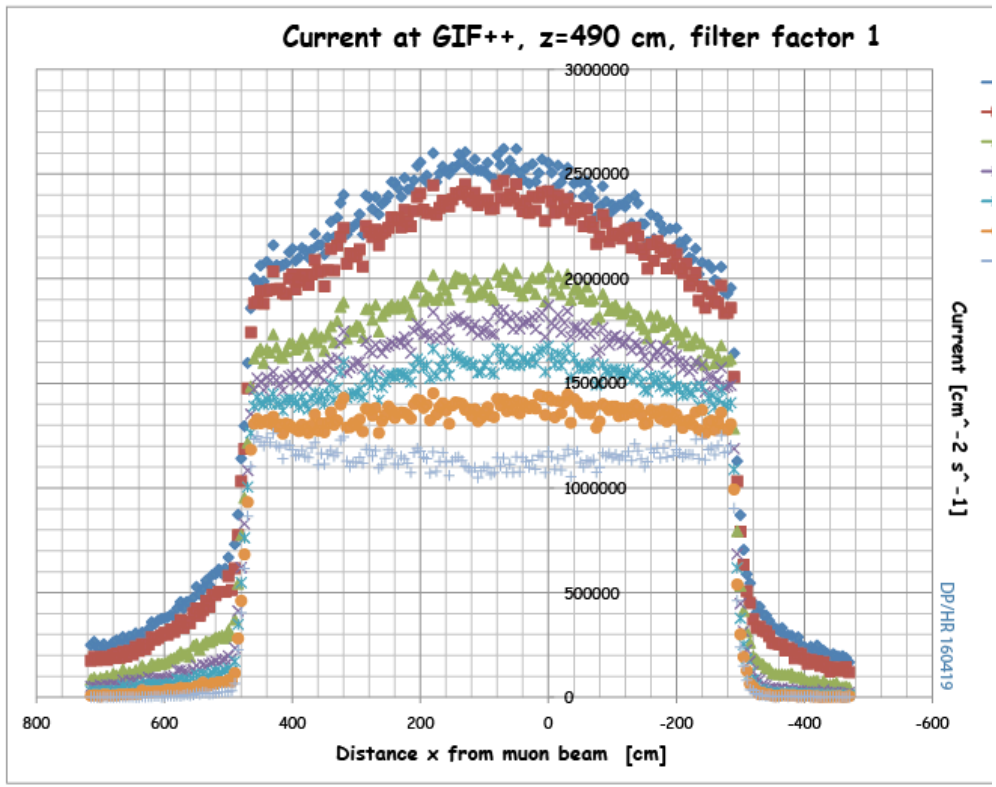
Fig. 8b, from D. Pfeiffer et al., NIM_A_866(2017)91–103

Note: measured with RadMon detector (instead of GM probe in Automess AD-15/E, used March 2018).

Dose Rate or Photon Rate?

Remember: albedo etc. produce (many) secondary (lower-energy) photons. Counting their total energy (—> **dose**) or their total number (—> „**current**") will lead to different results.





From simulation (all by DP): DOSE rate (left) and CURRENT (right) profiles, for distance z = +490 cm and attenuation factor 1. Curves (top to bottom) are for: all E, E(photon) > 100, 200, 300, 400, 500, 600 keV, respectively. Calculated for a flat detector.

The curve for number of >600 keV photons (right, bottom) is flat, i.e. the angular correction filter is doing his job. At larger angles, i.e. at the borders of the profile the same number of photons will deposit more energy (dose) in the detector of constant thickness (bottom left).

Albedo from Wall

File: 160425current_FW_BW.pdf
D. Pfeiffer (/ H. Reithler)

Simulation: Photon Current at GIF++

Current in downstream region. Shown is the current downstream, to plane at 4.9 m (FW), back from wall to the plane (BW, albedo) and the sum ("all")

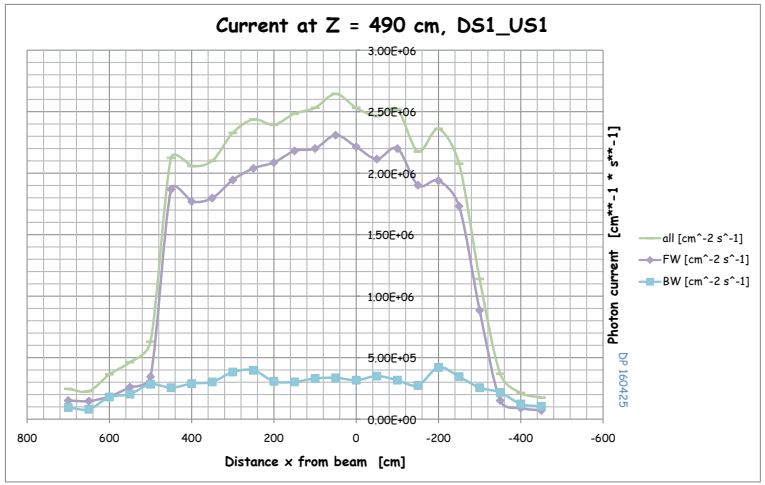


Fig. 1: Filter factor 1 downstream (DS1) and 1 upstream (US1).

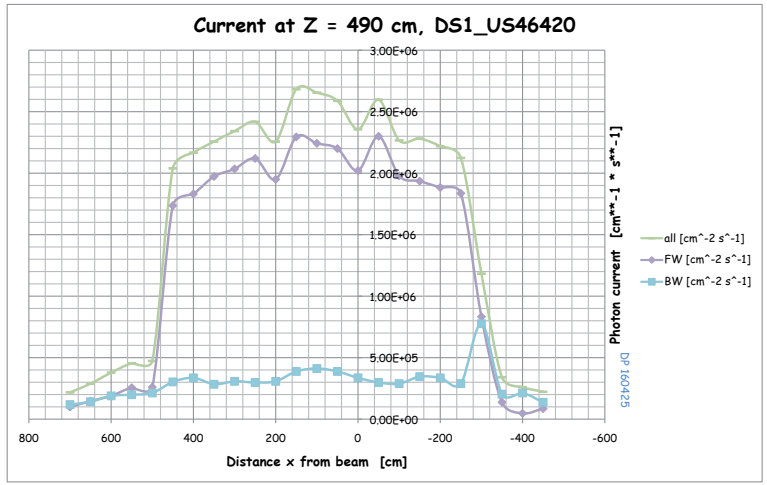


Fig. 2: Filter factor 1 downstream (DS1) and 46420 upstream (US1).

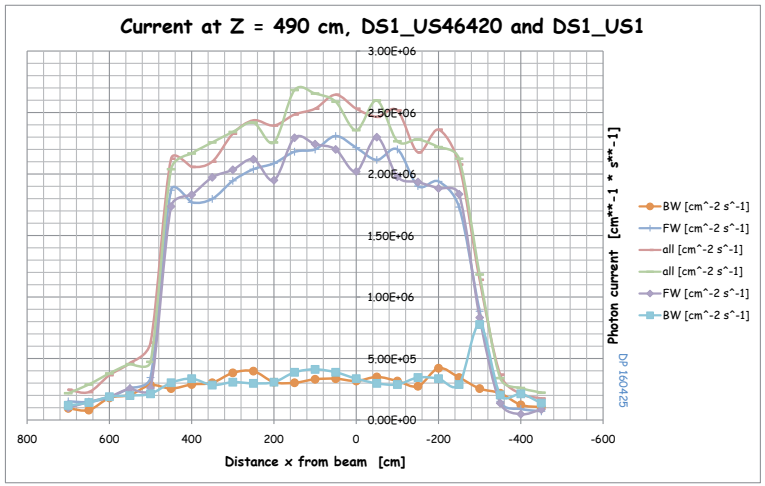


Fig. 3: Overlap of Fig. 1 and 2. They look identical.
The current in the upstream region has no impact on the downstream region.

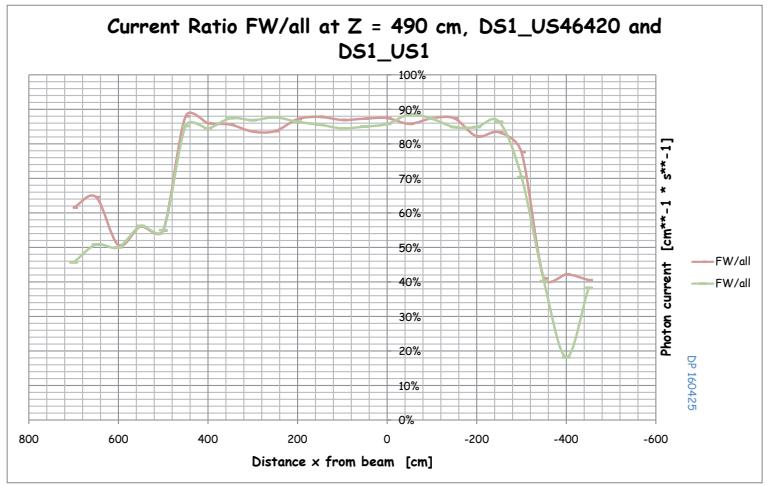
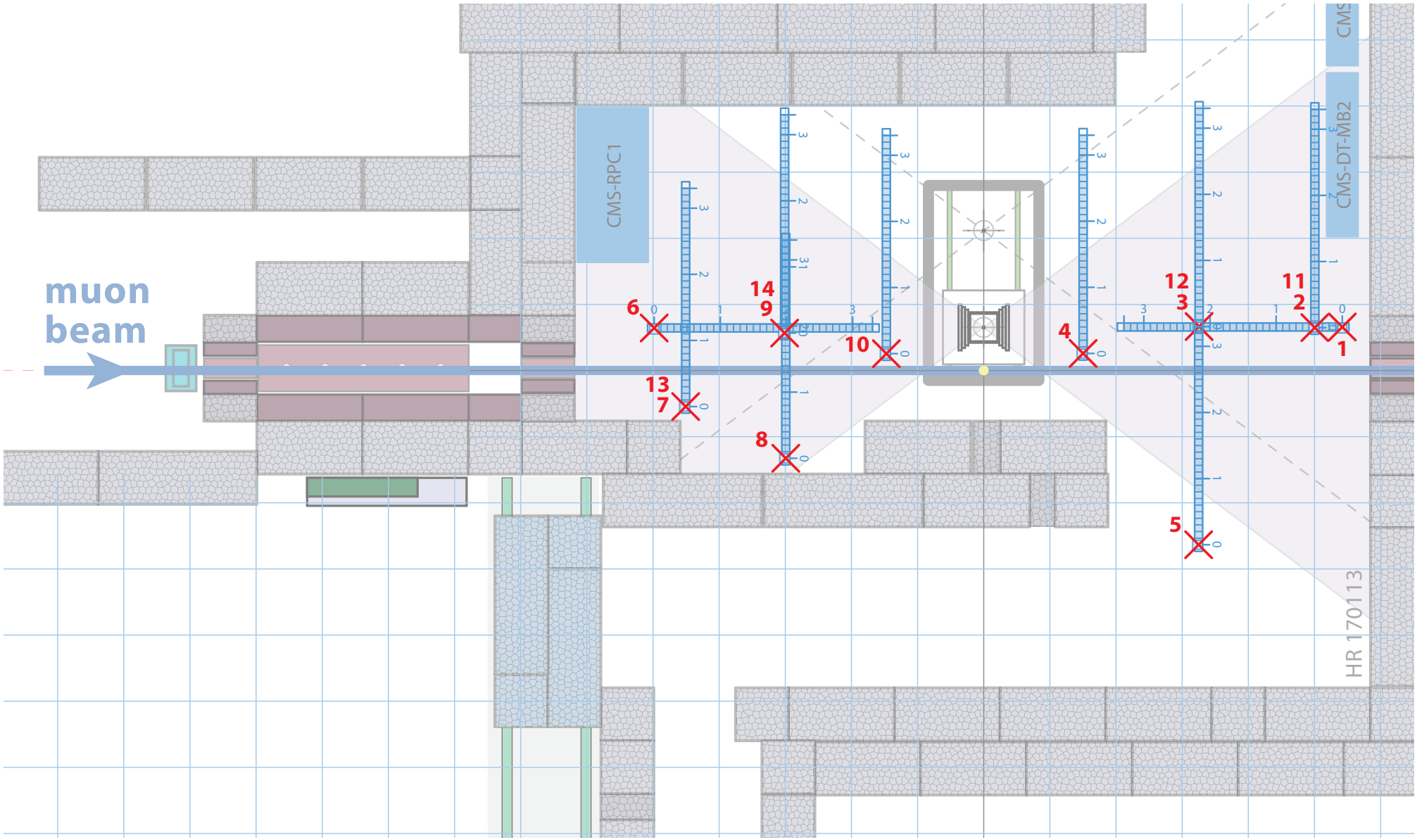


Fig. 4: From Fig. 1 and 2, in the irradiation region more than 85% of the photons go downstream. The albedo from the rear wall is thus less than 15%.

Simulation of photon current at Z = 490 cm, attenuation 1 (and attenuation 1 and 46k at the opposite side), showing separately the contribution from albedo photons from the wall.

Planned Positions of Linear Stage



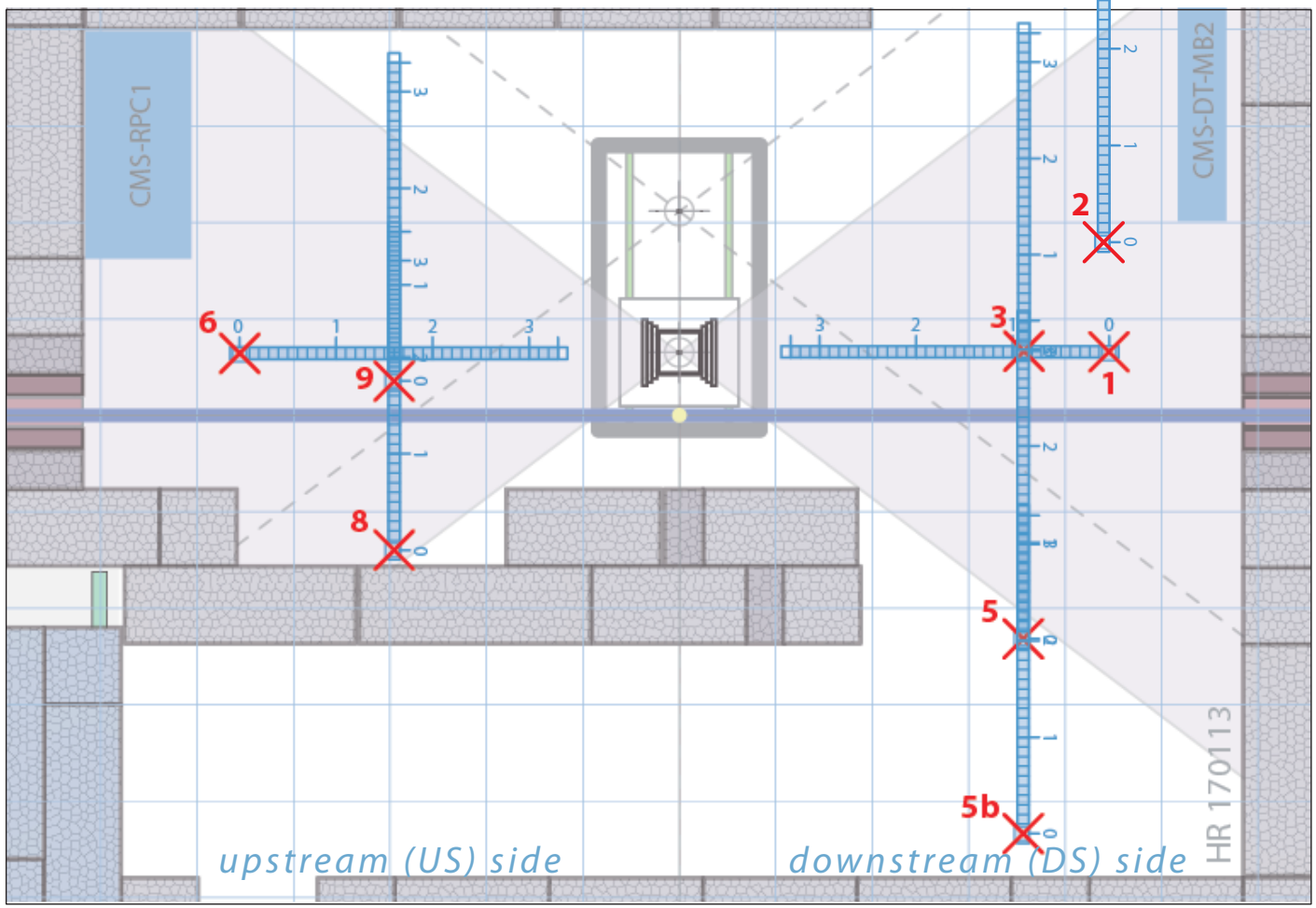
Envisaged possible positions of linear stage for profile measurements at GIF++ 180317-20.

Done: Positions of Linear Stage

GIF++ Irradiation Mapping
campaign March 2018
(measurement of profiles, along 3.3 m long linear stage)
page

Positions achieved 180317-19

Line numbering, direction and starting point						
Position number	GM counter / Falcon spectrometer	Side US / DS	Direction of meas.	X_0 [m]	Y_0 [m]	Z_0 [m]
5b	GM	DS	+x	-4.32	0.	+3.45
14	F	US	+x	+0.65	0.	-3
13	F	US	+x	-0.5	0.	-4.5
12	F	DS	+x	+0.65	0.	+3.25
11	F	DS	+x	+0.65	0.	+5
10	GM	US	+x	+0.3	0.	-1.5
9	GM	US	+x	+0.38	0.	-2.96
8	GM	US	+x	-1.47	0.	-2.96
7	GM	US	+x	-0.5	0.	-4.5
6	GM	US	+z	+0.65	0.	-4.60
5	GM	DS	+x	-2.32	0.	+3.45
4	GM	DS	+x	+0.3	0.	+1.5
3	GM	DS	+x	+0.65	0.	+3.45
2	GM	DS	+x	+1.75	0.	+4.39
1	GM	DS	-z	+0.65	0.	+4.49



1 m
1 m

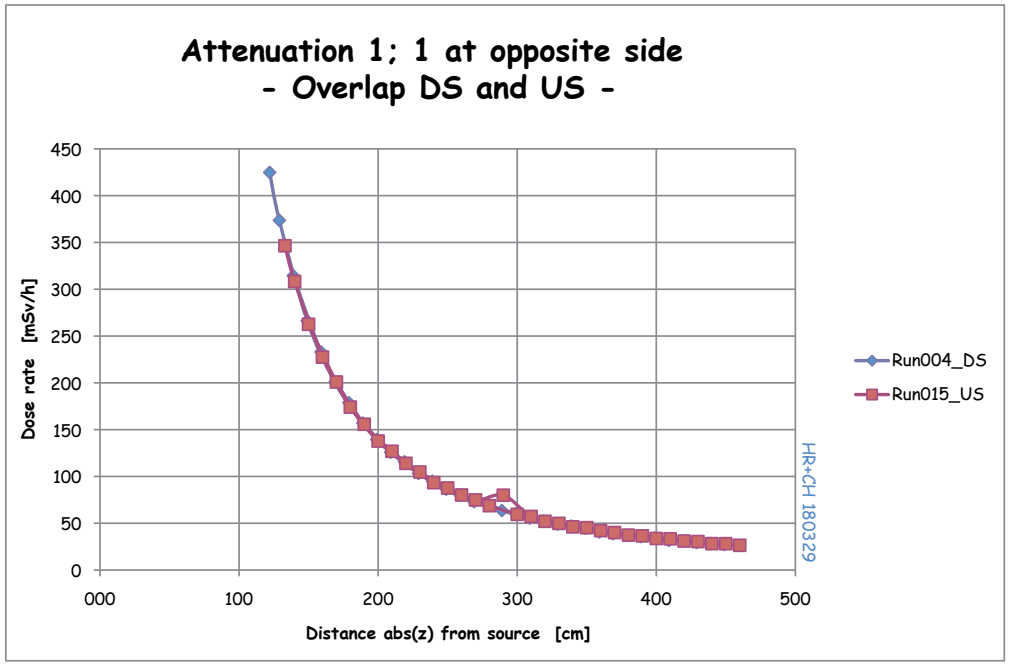
X
Y (vert.)
Z
(x,y,0) at source
(0,0,z) at beam

Origin of coordinate system:
on muon beam line
(yellow point),
i.e. 1.68 m above false floor;
at z position of source.

In ***red***: cross is 0-point of linear stage and number is position number as in Table.

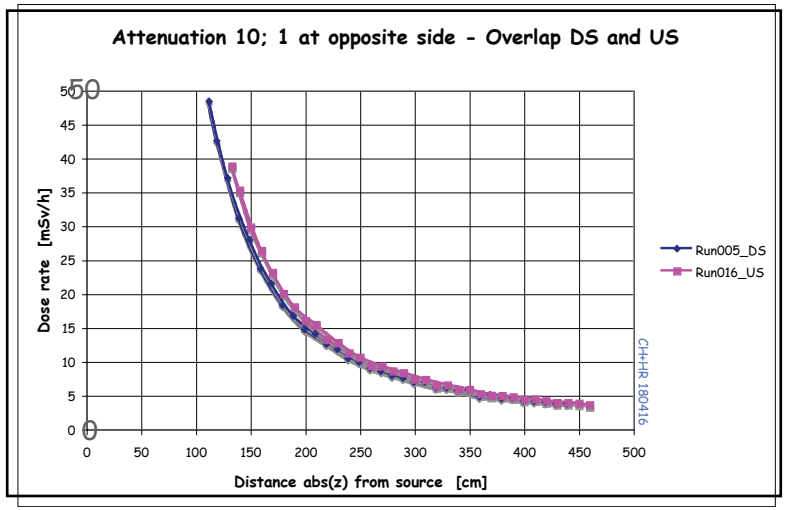
Positions of linear stage actually used for profile measurements 180317-20.

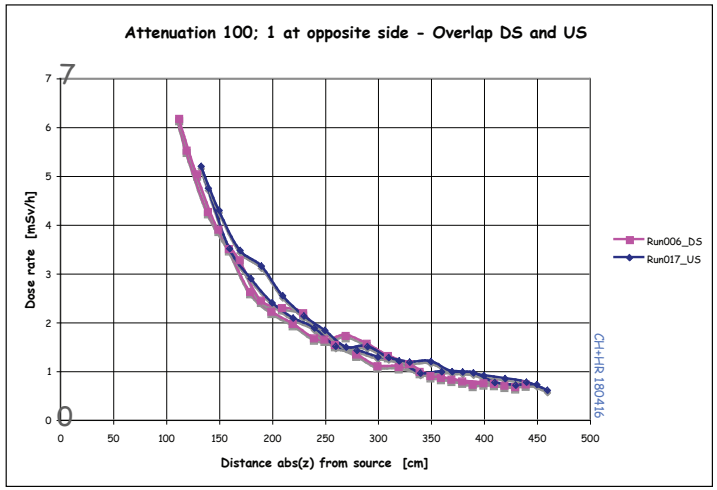
Longit. Profile: Dose Rates US = DS?



Dose rates along +Z/-Z, from mainly 662 keV photons, look very **symmetric**. At least when the relative contribution from albedo is not dominant, as is the case with attenuation 1. The attenuation on the opposite side of the irradiator, whether 1 or 46415, has no impact on this; the curves shown are with attenuation 1 at opposite side.

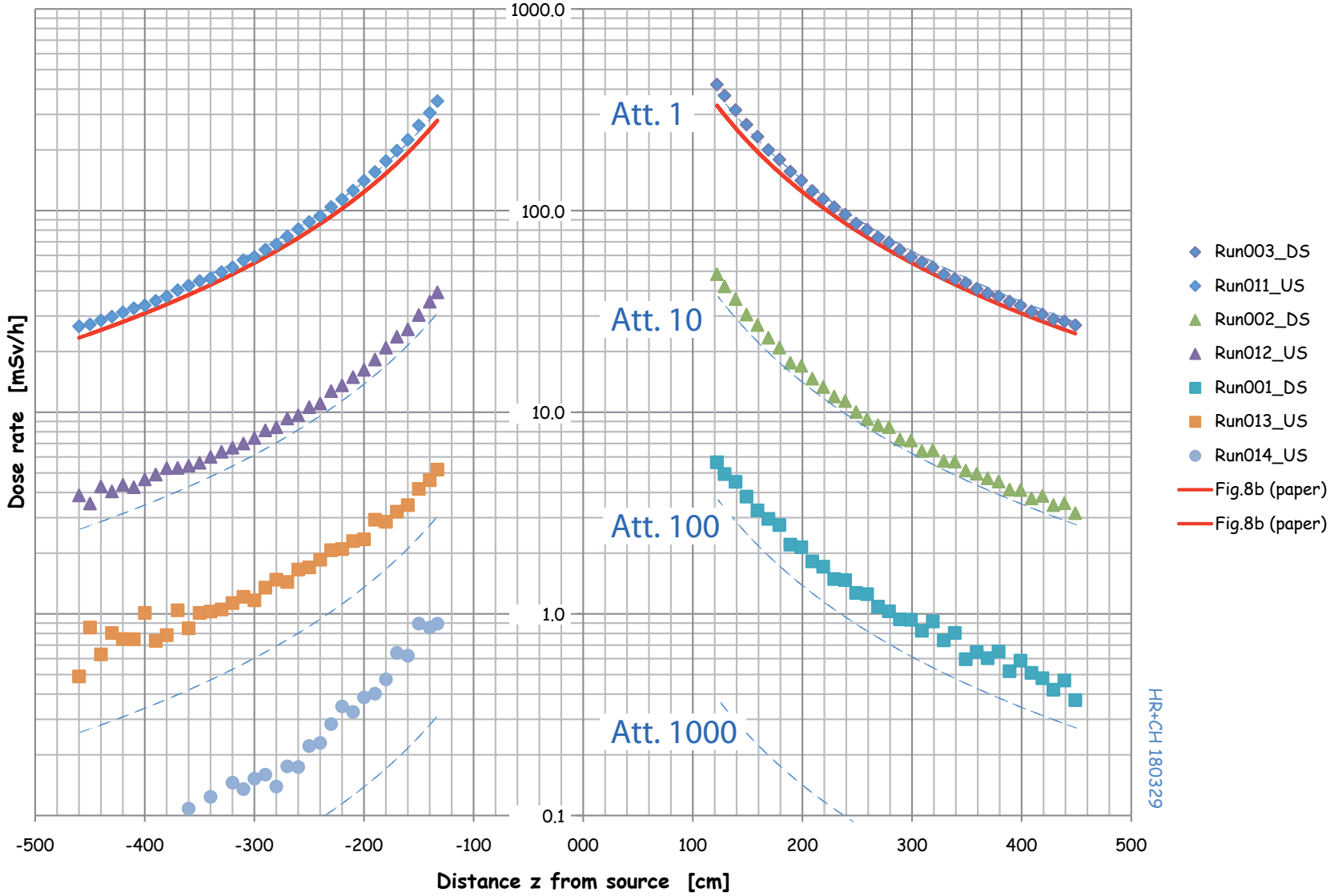
Curves for US and DS sides, along axis of irradiation cone, overlapped. Look symmetric.





Similar curves, for attenuation 10 and 100. Are symmetric as well.

Dose Rate Along Z (Opp. Side Closed)

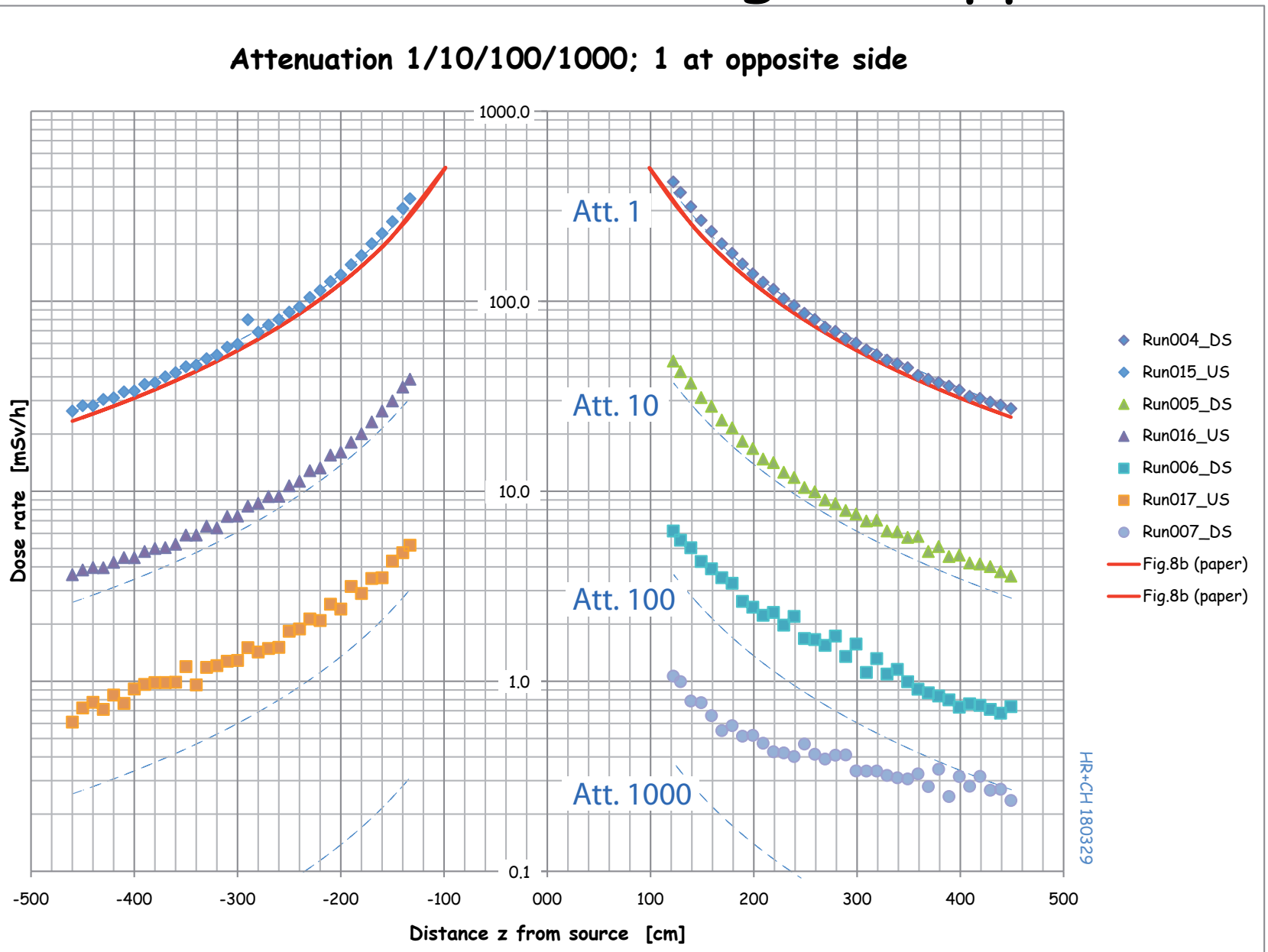


Profiles measured at positions 1 & 6.

Note:
- symmetric +z/-z
- agrees w. Fig. 8b of paper
- at higher attenuation the effective attenuation is less than the nominal one.

Measured dose rate profiles along Z, for several filter attenuations. The red curve is from Fig. 8b of the recent publication. It is also shown, as dashed blue lines, when scaled to the nominal attenuation factors. Here: opposite side is always "closed" (= attenuation 46415).

Dose Rate Along Z (Opp. Side Open)

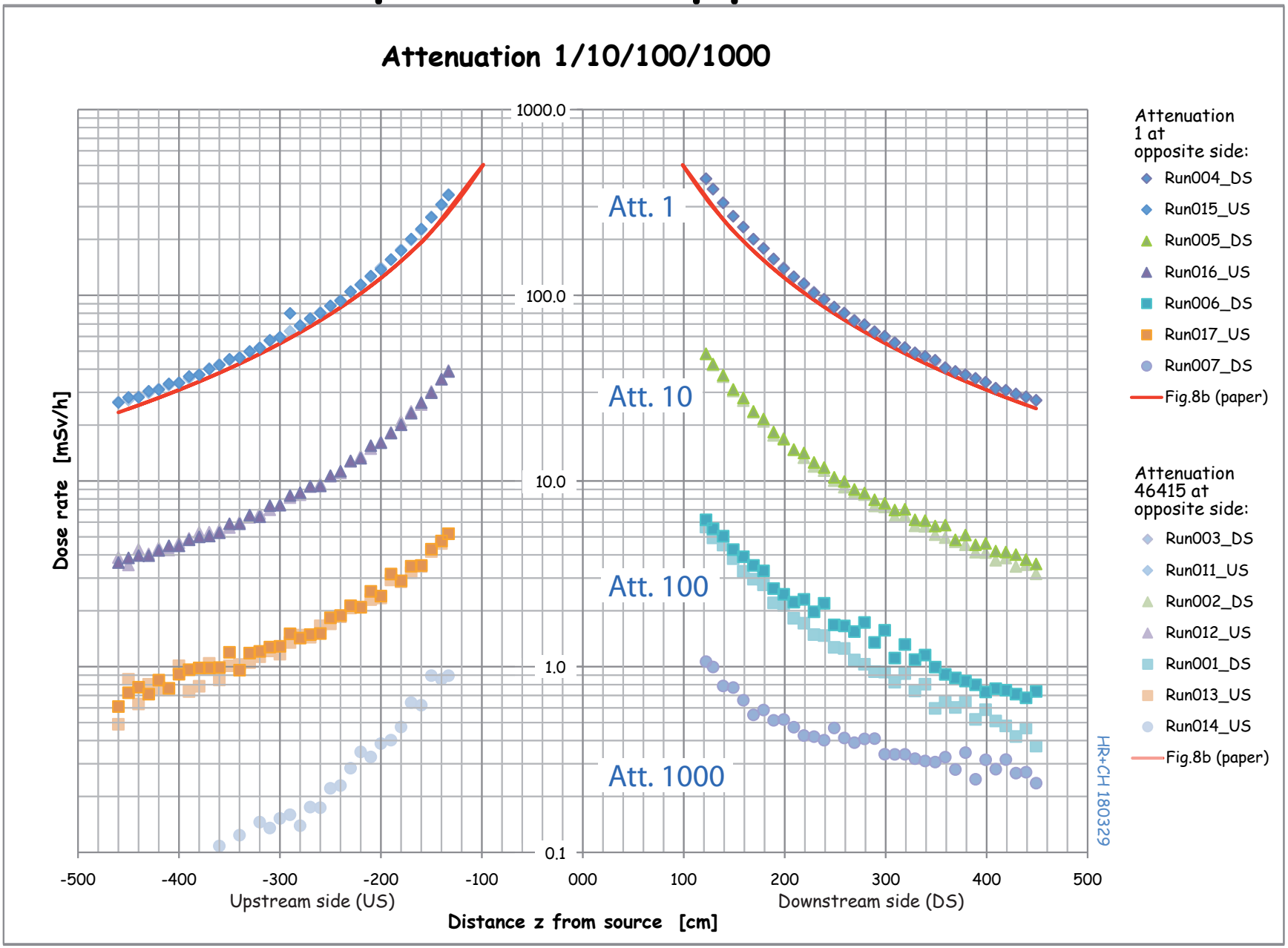


Profiles measured at positions 1 & 6.

Same as previous figure, but opposite side is open (attenuation 1).

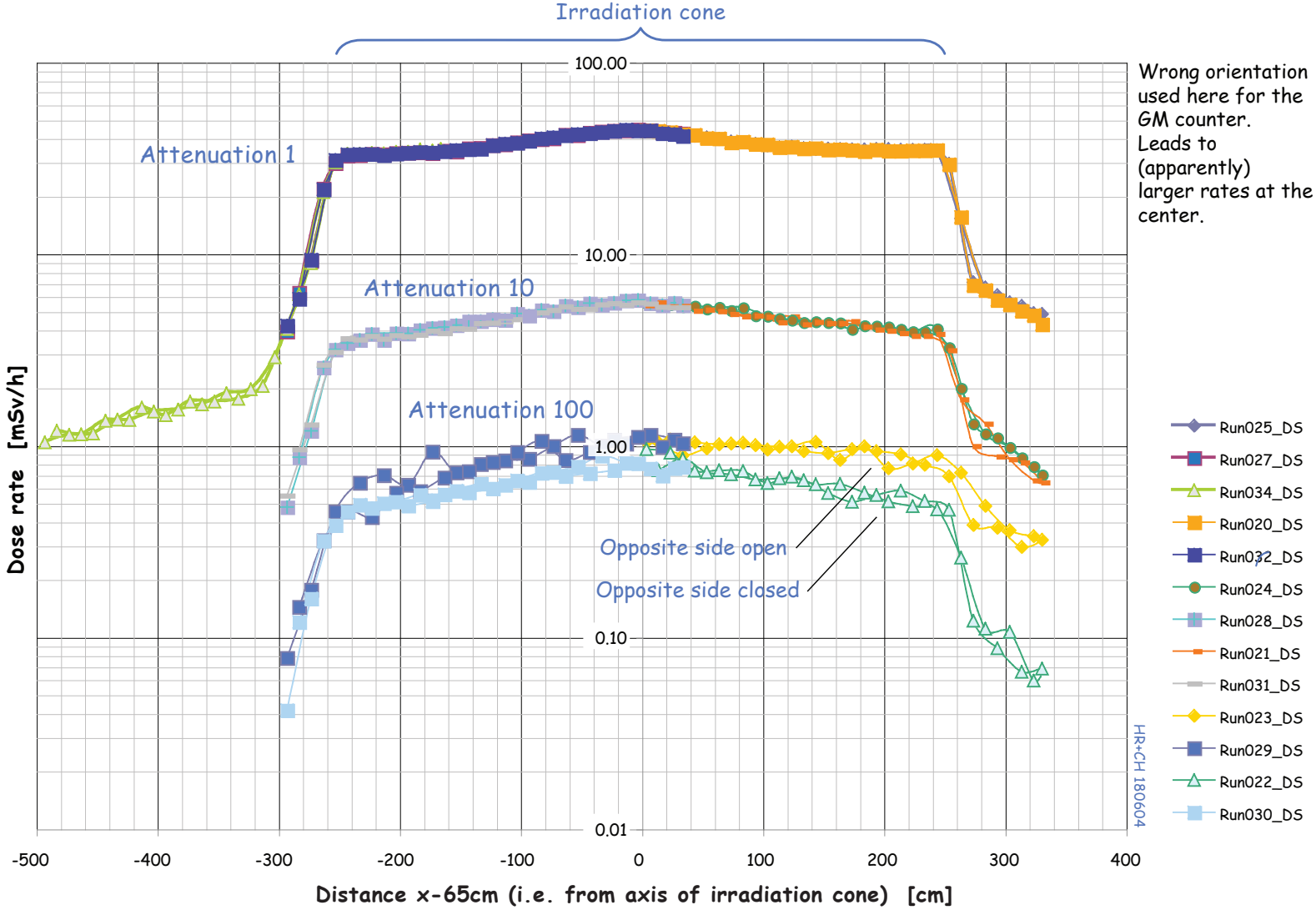
Measured dose rate profiles along Z, for several filter attenuations. The red curve is from Fig. 8b of the recent publication. It is also shown, as dashed blue lines, when scaled to the nominal attenuation factors. Here: opposite side is always "open" (= attenuation 1).

Impact of Opposite Side



Overlap of curves with attenuation at opposite side set to 1 (open) and to 46415 (closed).
Only at larger attenuation (small dose rate) some impact is visible.

Transversal Profiles at z = 345 cm



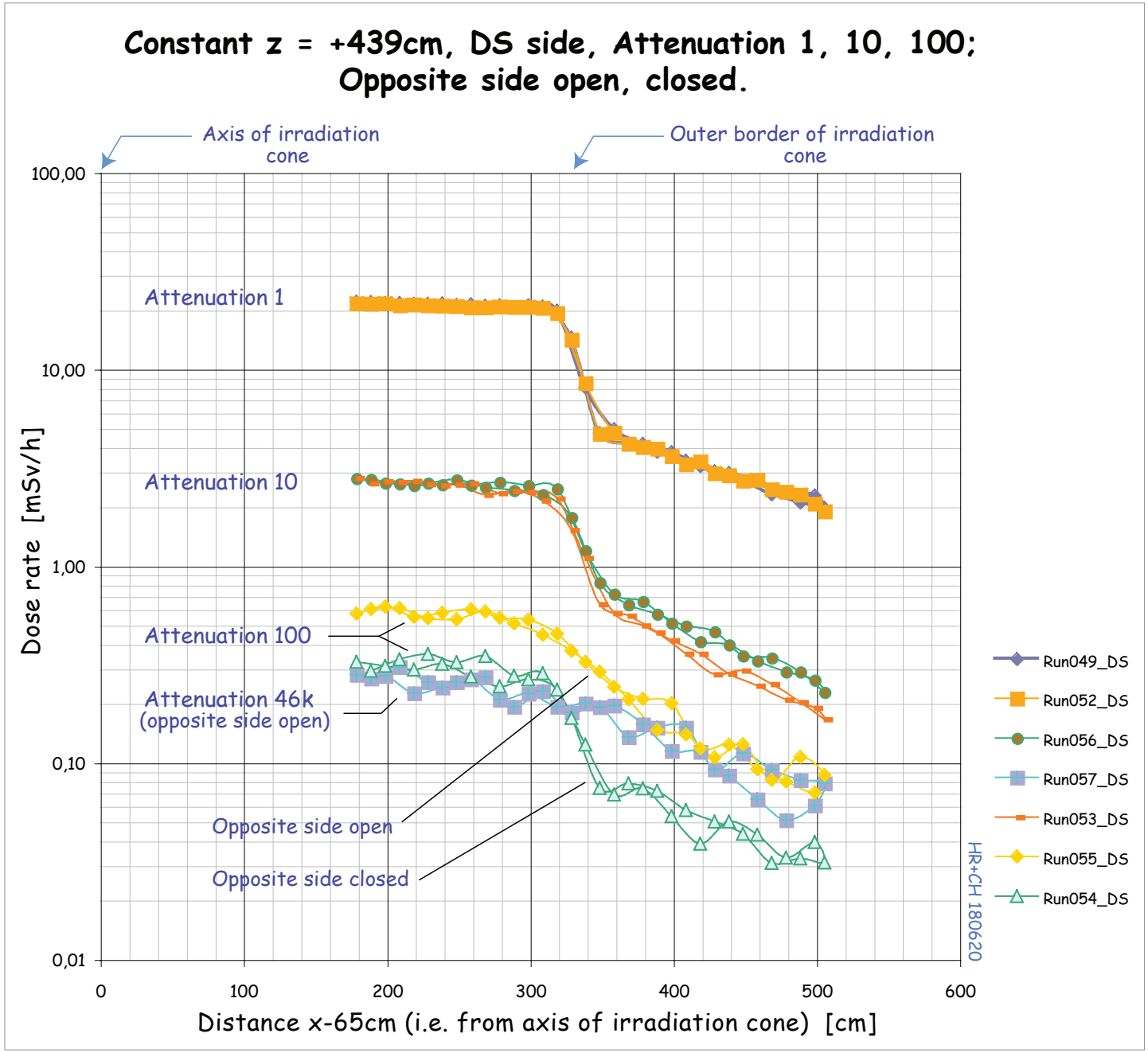
Data for opposite side OPEN and CLOSED.
Curves are overlapped, here.
Measured at positions 3, 5, 5a.

Irradiation field is symmetric w.r.t. axis of irradiation cone.
When filter at opposite side is fully open, it adds max. 0.3 mSv/h; this contribution is therefore only relevant at attenuation 100 or larger, at this distance...

Transversal Profiles at z = 439 cm

Same features at this larger distance.

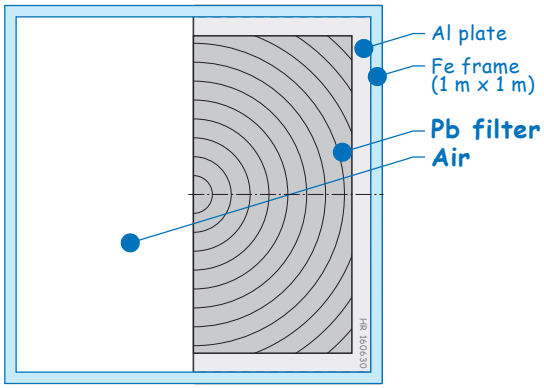
Here: show also profile of dose rate on closed side, when opposite is completely open.



Profiles (part) at distance z = 439 cm. Measured at position 2.

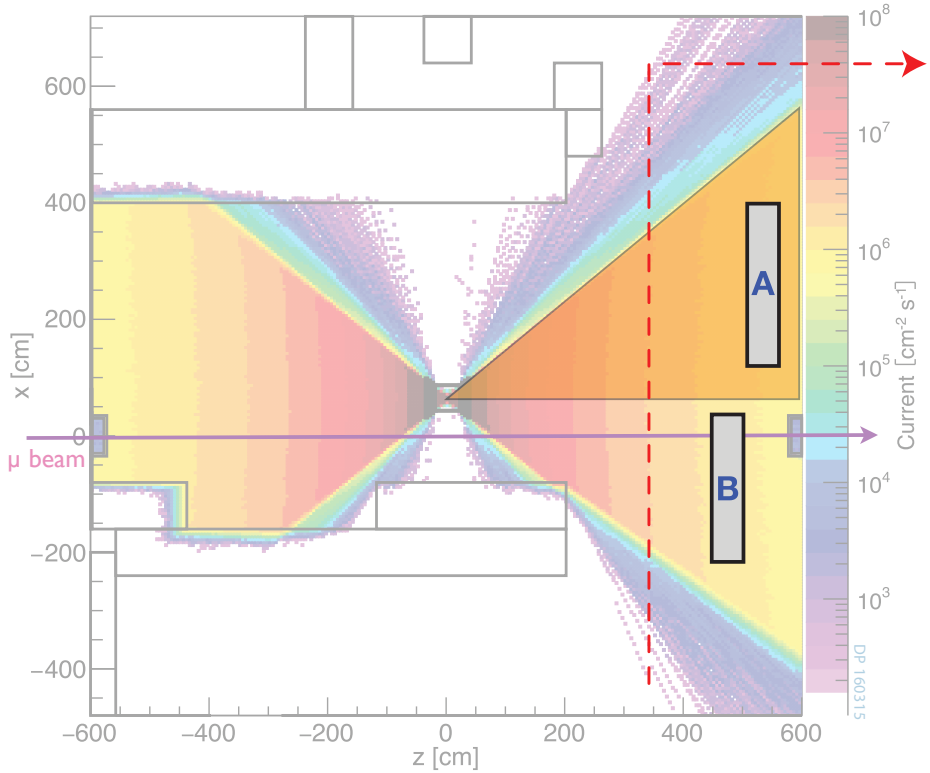
Half-Filter Downstream

To permit simultaneous operation with somewhat different attenuation, at the same downstream side, a HALF-FILTER with nominal att. 15 was proposed / constructed (see e.g. presentation HR at GIF++ meeting 160421). Now measured profile (at Z = +345 cm, positions 3, 5; 180320, D. Dattola).

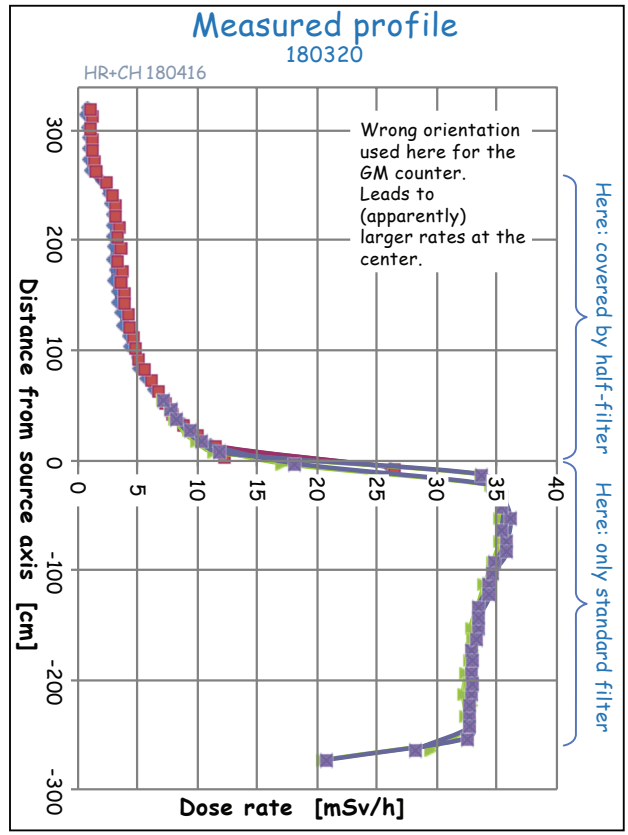


Shape of the half-filter. Design and construction are similar to the production method of the standard filter system.

A filter covering PART of the solid angle can provide a smaller intensity for detector "A" without reducing the intensity for detector "B".

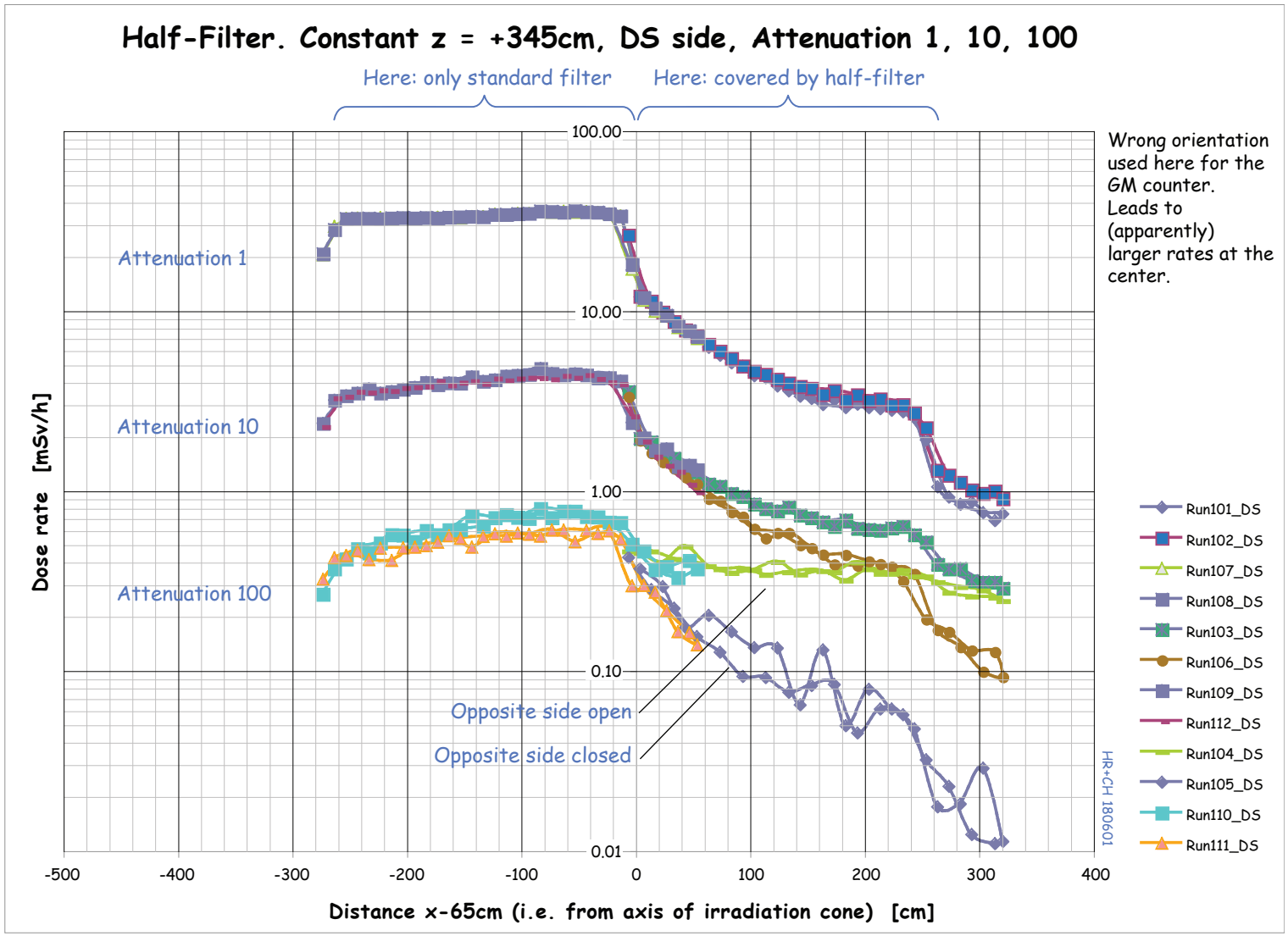


Note linear dose rate scale, on this figure.



Measured dose rate profile confirms lower dose on part covered by half-filter.

Profiles (transv.) with Half-Filter

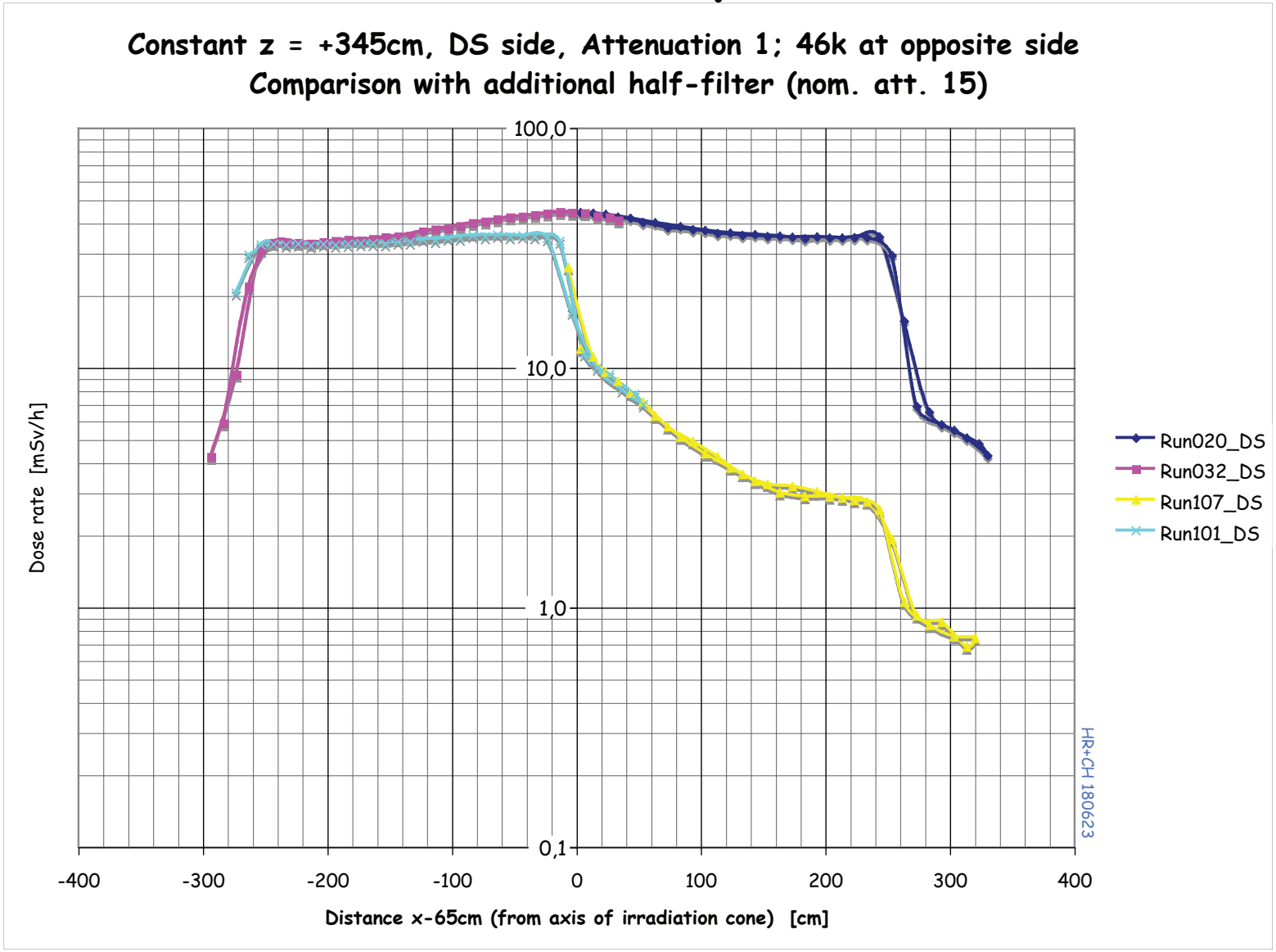


Profiles measured at positions 3 and 5, with half-filter installed; opposite side open/closed.

The max. contribution from the opposite side (when opposite side is fully open, max. 0.3 mSv/h) becomes visible for dose rates below 1 mSv/h, i.e. when total attenuation (filter + half-filter) is at least 100.

The impact of the half-filter is the same for different settings of the standard filters.

Direct Comparison



Transition to part covered by half-filter has shape similar to transition at borders of irradiation cone. Their width of +/-20 cm is related to the finite (although small) size of the source.

Details of deviation from flatness, on all curves, to be better understood/checked.

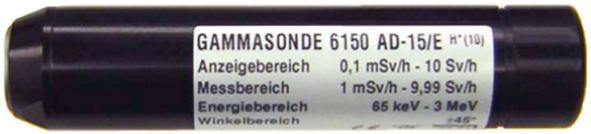
Summary

- Objective: assess **irradiation field mapping** (dose rate, particle rate, energy distribution, …) at GIF++ and confirm simulations with detailed measurements. Should serve as guidance to users.
- Long-awaited extensive measurement of longitudinal and transversal irradiation profiles done for the first time in March 2018, with a Geiger-Müller (GM) based dosemeter running on a 3.3 m long linear stage placed at several positions. **Dose rates** measured for **attenuation 1, 10, 100** mainly. Thanks to all participants!
- Attempted measurements in March with a Falcon 5000 spectrometer failed (beyond saturation).
- Chosen orientation of GM counter adds angle-dependent uncertainties of up to about 25%; desirable to repeat some measurements.
- Fair coverage of the GIF++ zone achieved, so far; more profiles desirable.
- **Good agreement** with points in Fig. 8b of publication (D. Pfeiffer et al., NIM A866 (2017) 91–103).
- See additional contribution - of **max. 0.3 mSv/h** - when filters at opposite side move from completely **closed** to completely **open**. Starts to be relevant, at large distance, for attenuation 100 which leads to this level of dose rates.
- Use of half-filter: uncovered part remains mainly unaffected, and transition to covered part has shape similar to transition at borders of irradiation cone.
- Watch that for most detectors under test at GIF++:
  - (a) detector cell geometry and dependence on incident photon energy and angle may differ from that of the used GM counter and
  - (b) the irradiation field varies depending on actual material present in the zone.Therefore, to obtain precise data it is recommendable to make profile measurements with a small version of the own detector.
  - It means: **need further profile measurements, especially with user's detectors.**

Addendum

GM Counter Used

Groove marks GM's center



Dose rate range:
0.1 mSv/h - 10 Sv/h.
About 300 Hz pulses at 10 mSv/h

Gamma probe 6510AD-15/E from Automess houses a Geiger-Müller (GM) counter ZP1300 from Centronic or National Electronics, to measure dose rate of gamma irradiation.

Precision, within range of energy and angle: +/-40%

Linearity, within dose rate range: +/-10%

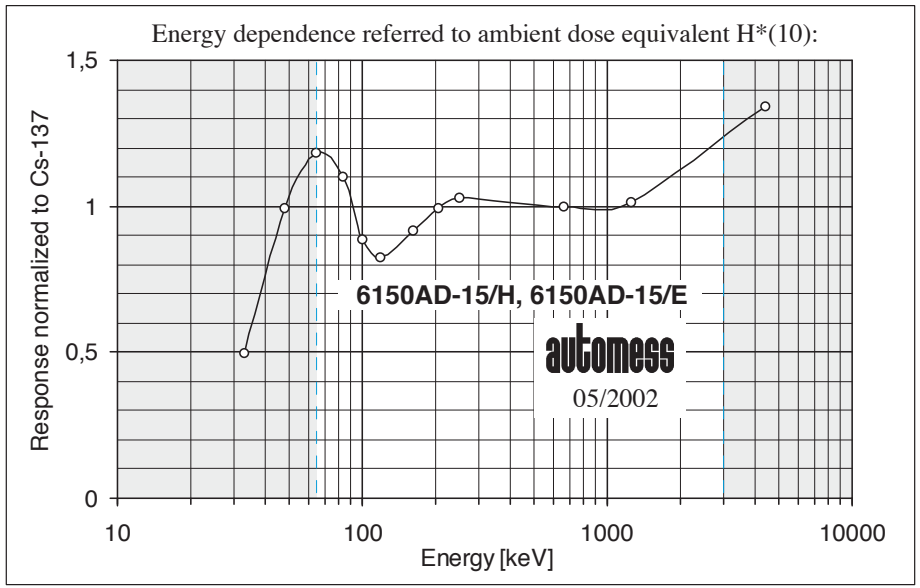
Energy range 0.065 - 3 MeV; response dependence

Orientation: +/-45° w.r.t. plane normal to GM axis

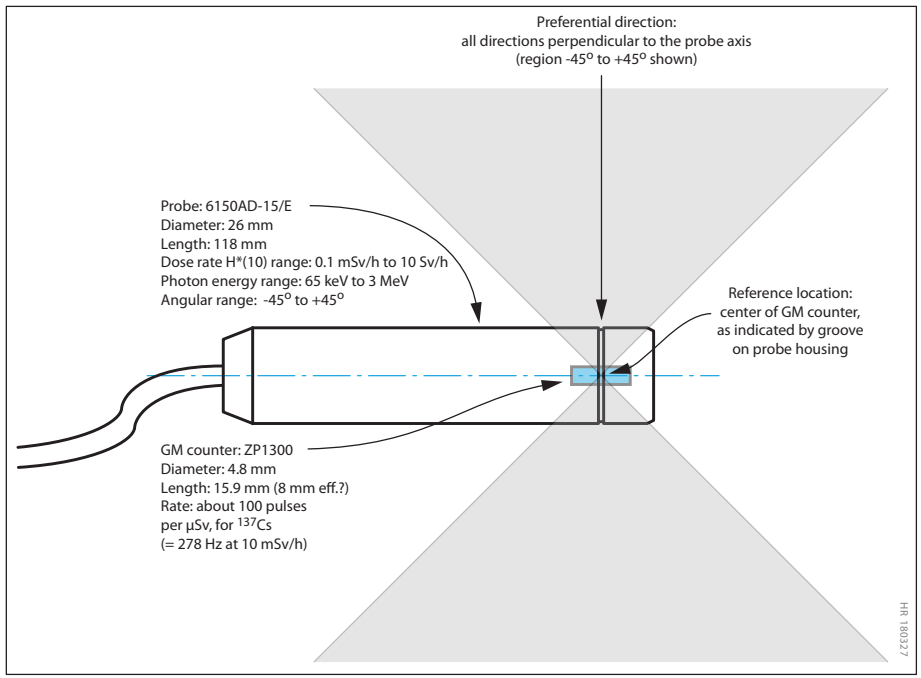
Warning 1: Wrong orientation (by 90°) was used in present measurements.
Readings become dependent on angle of incidence of photons.
Leads to increased dose rate readings of up to 25%, being largest at axis of irradiation cone.
(See Addendum, next slide.)

Warning 2: The sensitivity of thin planar detectors - both in terms of dependence on photon energy and incidence angle - may differ from that of the GM counter. For an accurate measurement it is therefore recommendable to measure profile(s) with the detector type under study.

GM Counter (1)



Energy range 0.065 - 3 MeV; response dependence



Angular range +/-45° w.r.t. axis (shaded)

Gamma probe 6510AD-15/E from Automess houses a Geiger-Müller (GM) counter ZP1300 from Centronic or National Electronics, to measure dose rate of gamma irradiation.

Precision, within range of energy and angle: +/-40%

Linearity, within dose rate range: +/-10%

Orientation: +/-45° w.r.t. plane normal to GM axis

Wrong orientation (90°) leads to increased dose rate readings:

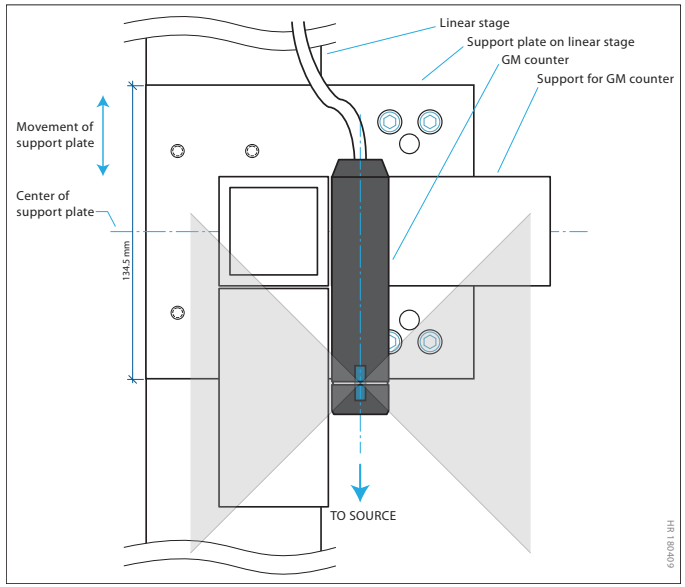
Change in dose rate readings when turning the gamma probe from orthogonal (correct) to axial (wrong) orientation:
(data 161221 M. Jaekel)

Distance fom source (DS side):	110 cm	110 cm	110 cm	closest
Filter US:	1	46415	46415	1
Filter DS:	1	1	10	1
Increase in „dose rate“:	24.6%	24.6%	18.6%	2.4%

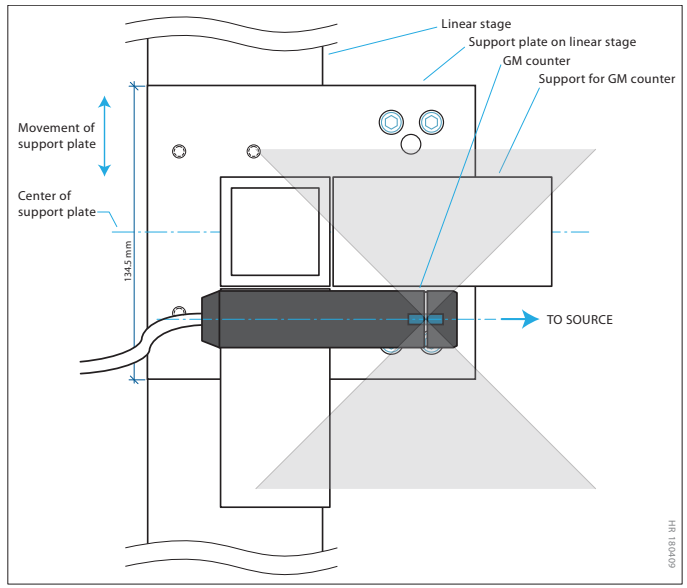
Groove marks GM's center

Dose rate range:
0.1 mSv/h - 10 Sv/h.
About 300 Hz pulses
at 10 mSv/h

GM Counter (2)



GM orientation for profiles along Z.
Offset of GM center about 8 cm.



GM orientation for profiles along X
Offset of GM center about 4 cm.

Actual orientation of GM counter had always axis pointing to the source... i.e. unfortunately wrong. Measurements along Z are least distorted.

Massive support close to GM counter may add an albedo contribution. Better: GM axis vertical and no material close-by.

Center of GM counter has offset of few cm w.r.t. linear stage coordinate. (To be included in reconstruction.)

Situation at GIF++ difficult:
- Photons below 65 keV present.
- Only 662 keV photons always point to the source.
- Actual dependence on GM orientation not well known yet.

Photo of GM mounting for profiles along X