

Medical FLASH Facilities

Alexander Malyzhenkov



May 11, 2026

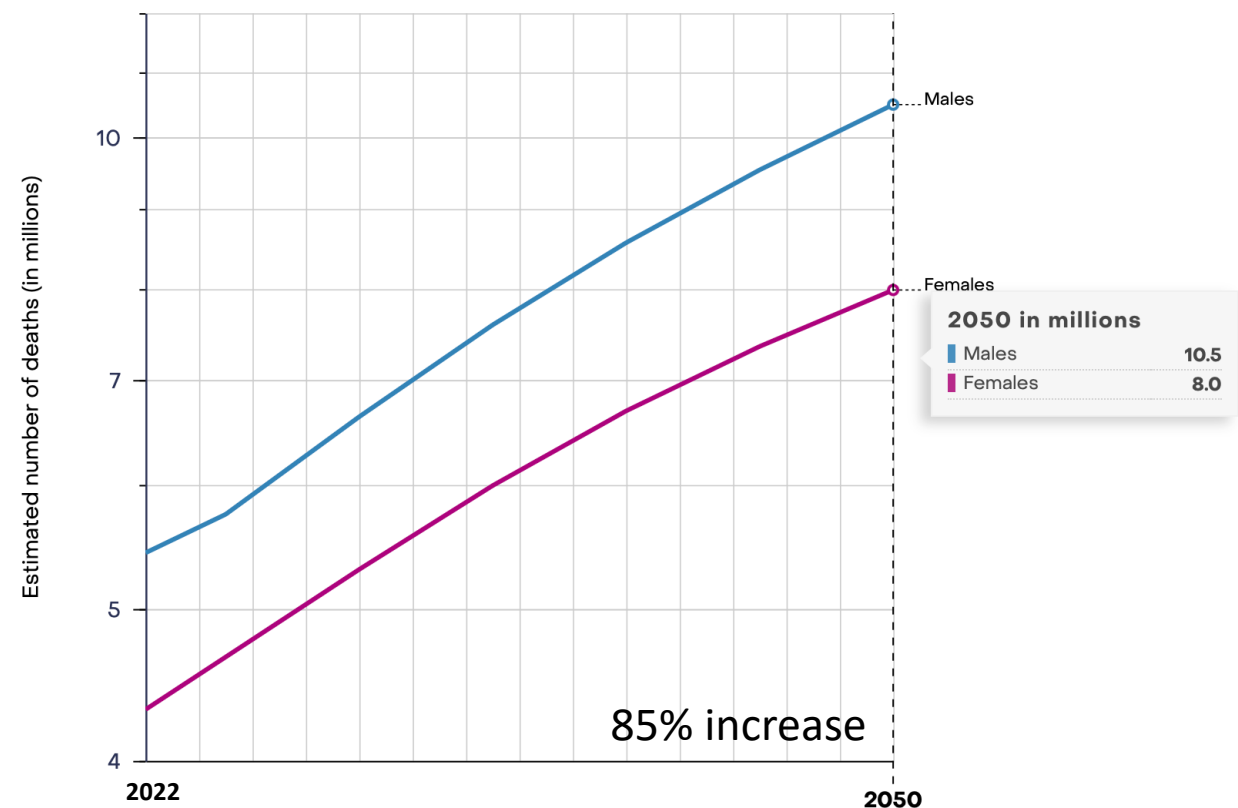
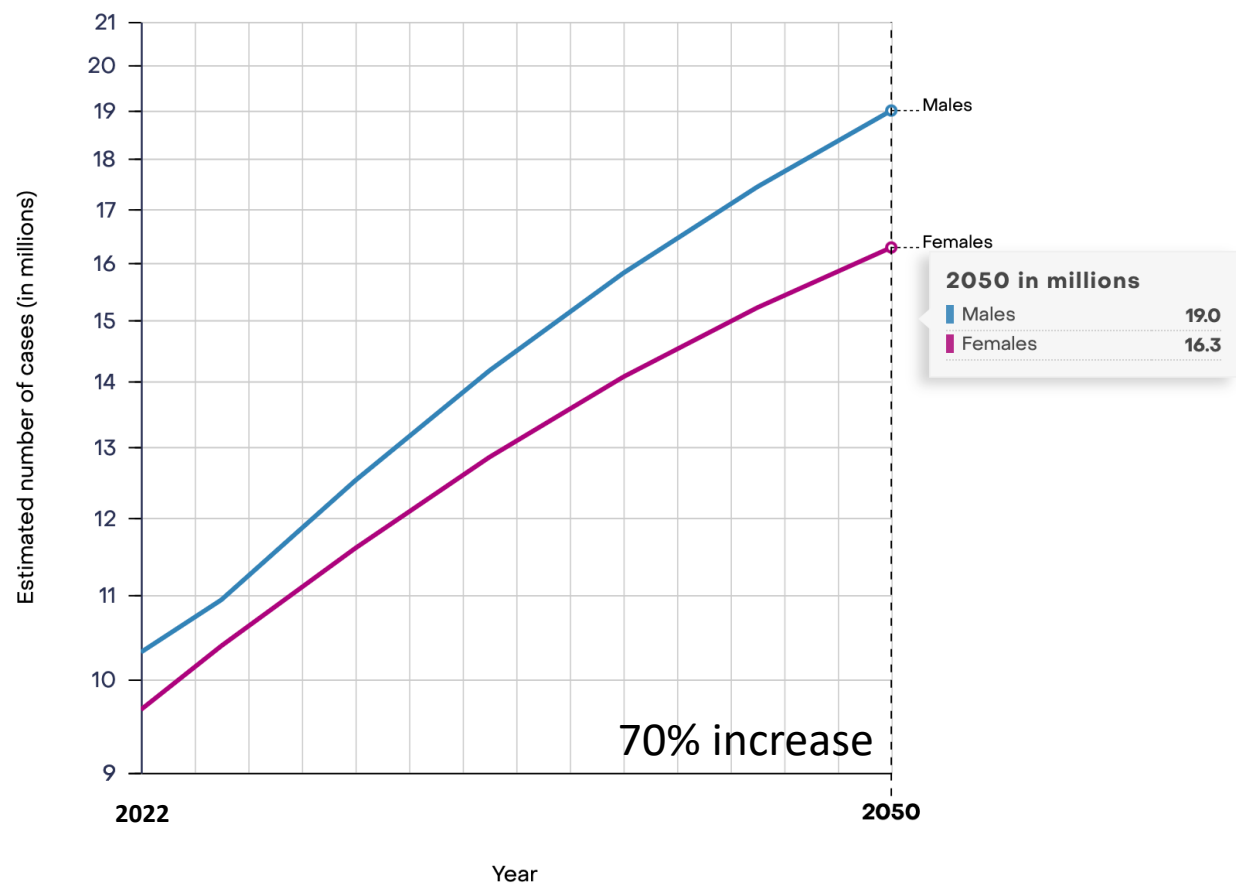
Is cancer one the most important problem to solve in the 21st century?

☐ Yes, absolutely!

☐ No

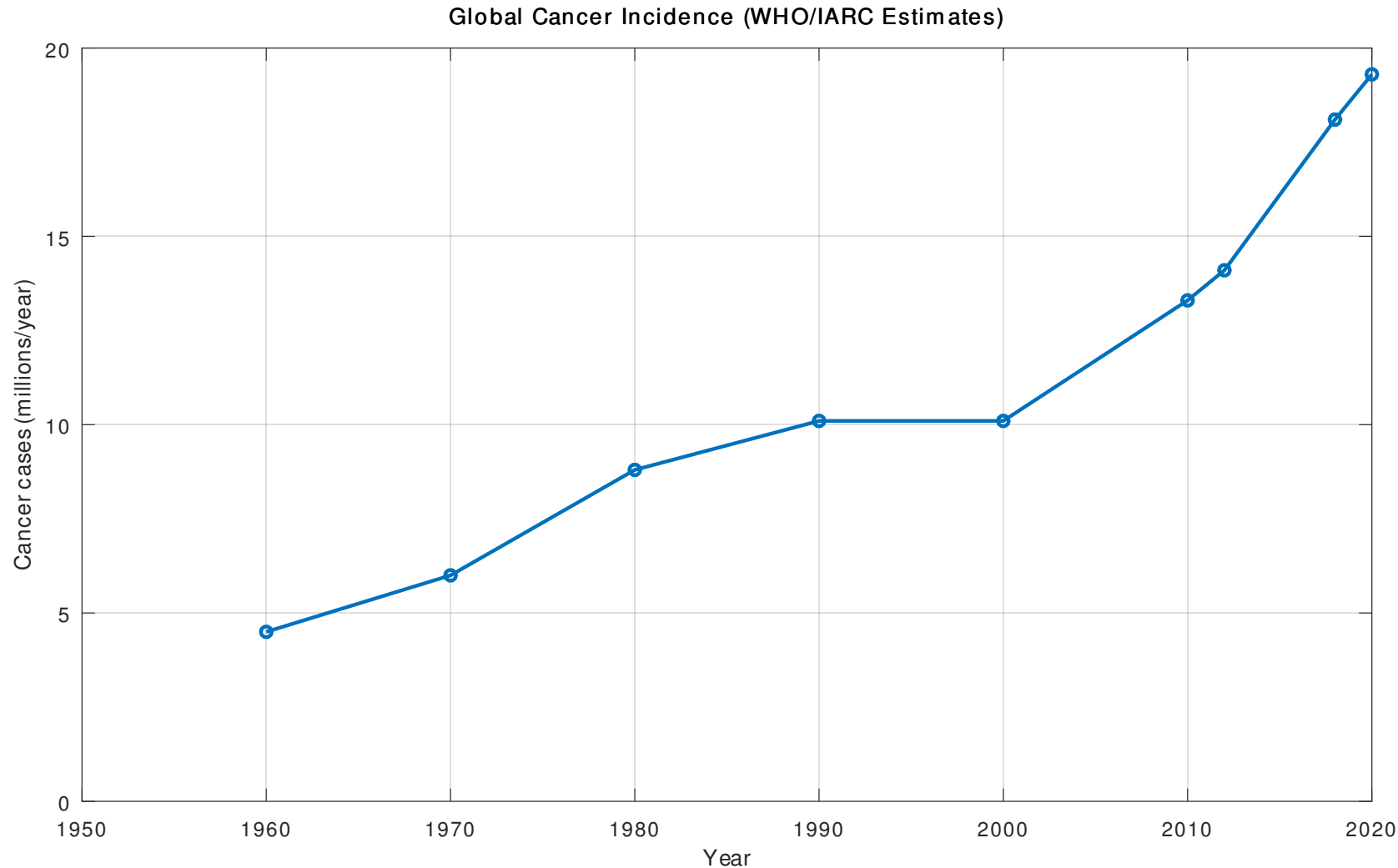
☐ I do not know !

Warning prediction from the World Health Organization



Let us rewind 70 years back ...

Number of cancer incidences per year: it grows!

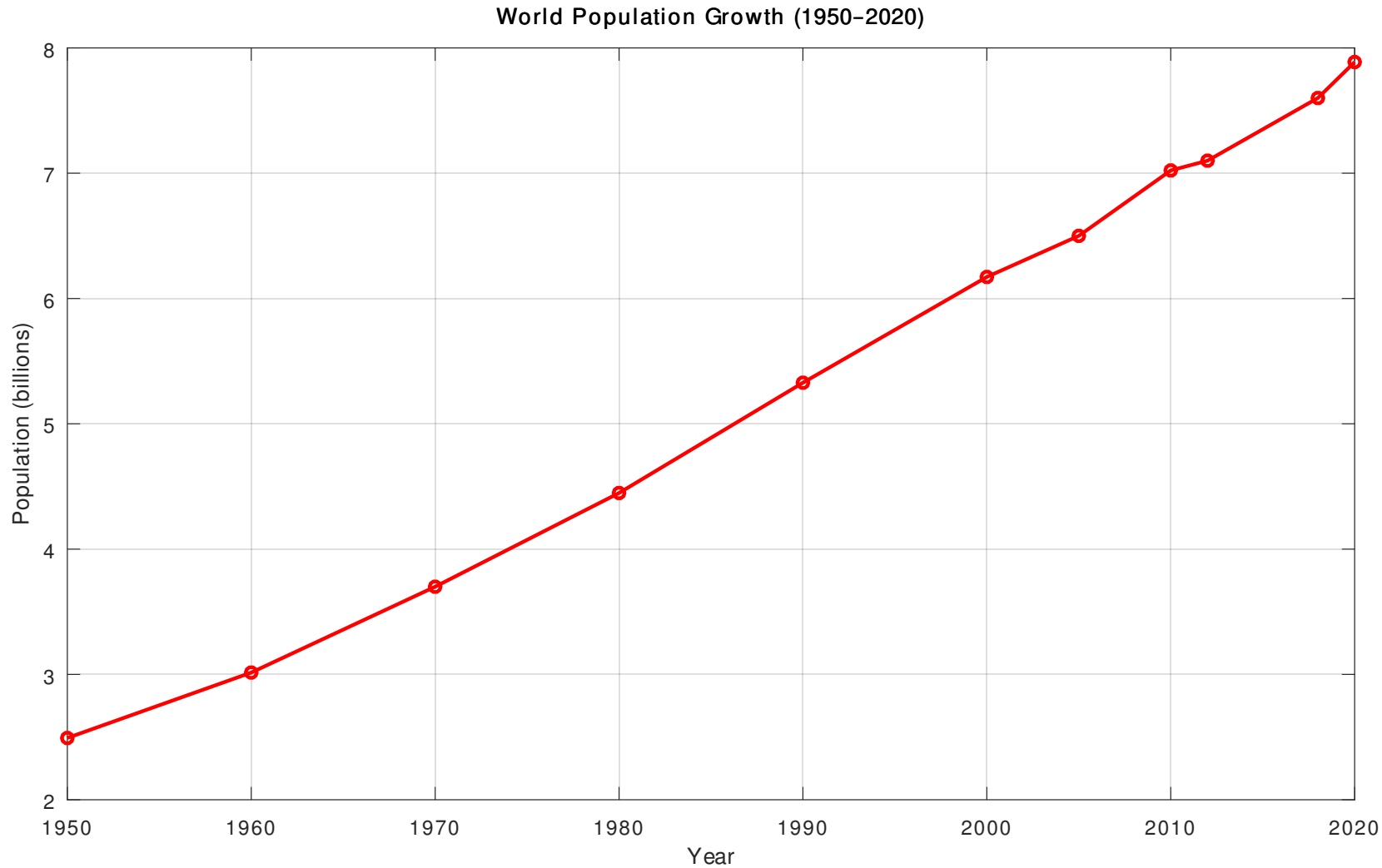


IARC = International Agency for Research on Cancer by WHO

Reasonable Remarks:

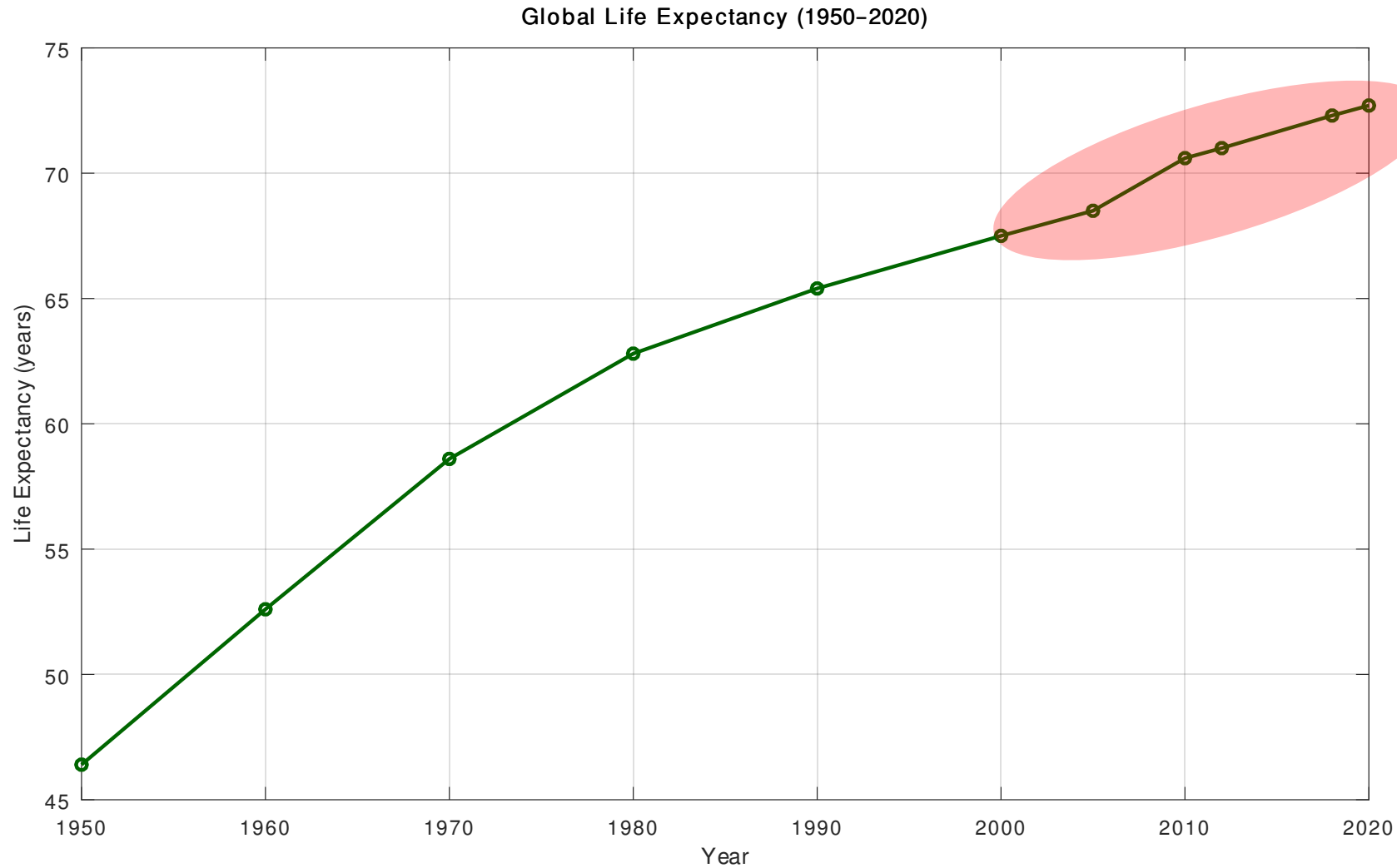
- What about population growth?
- What about life expectancy?

Population grows too!



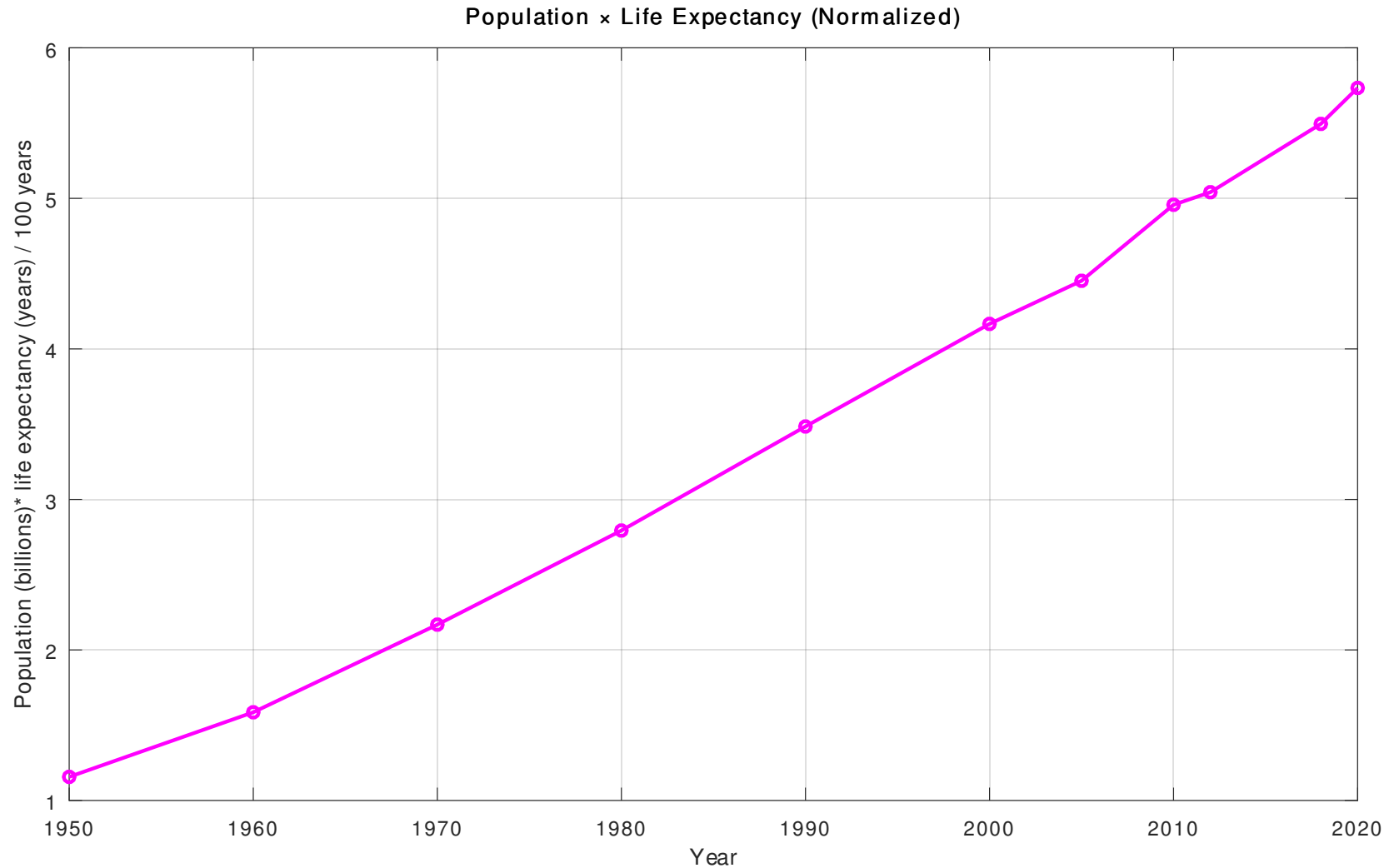
What about population growth? – Yes!

Life expectancy grows too ...



What about life expectancy?
– Yes!

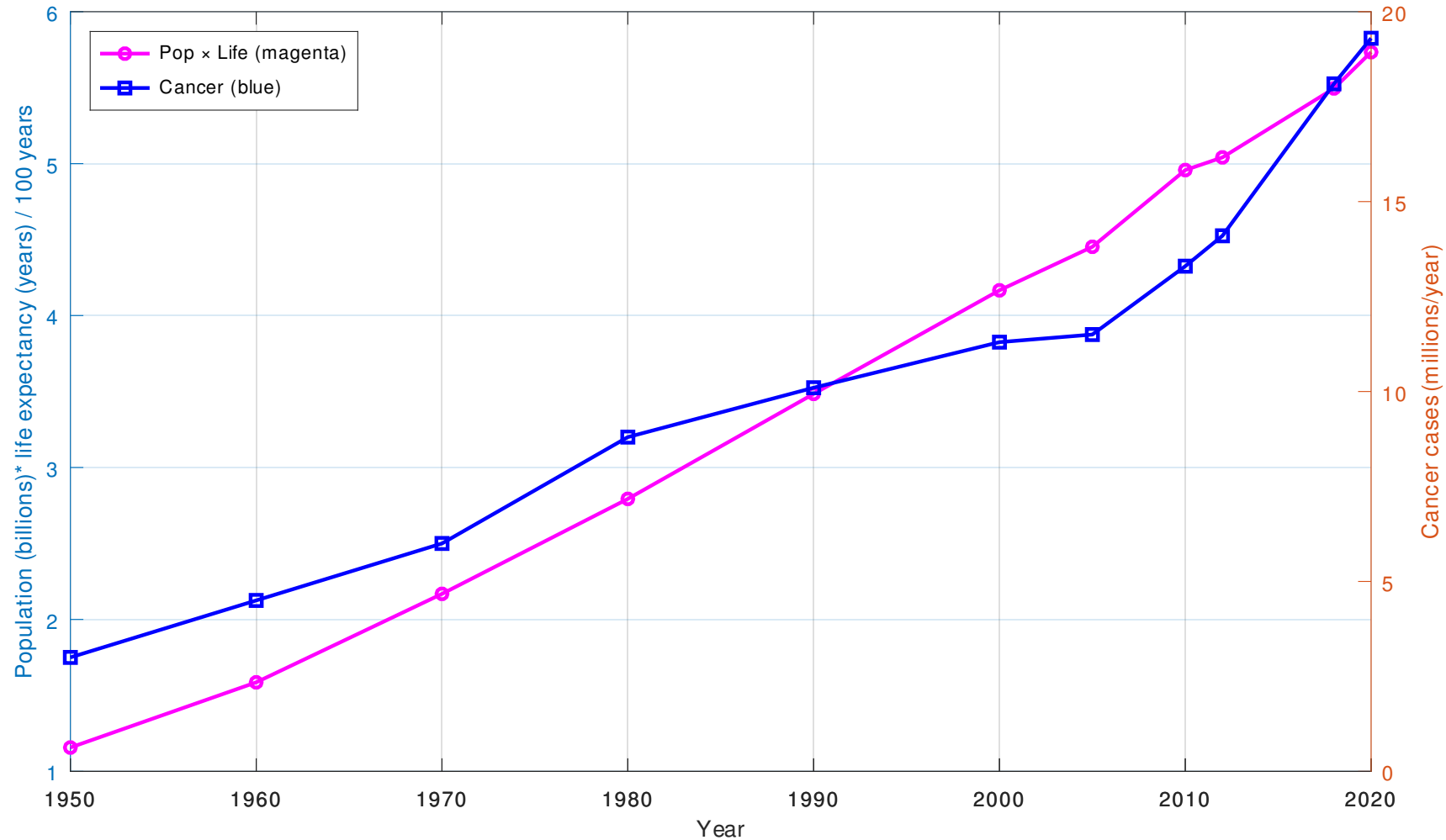
Population normalized to life expectancy



- Grows even faster than population

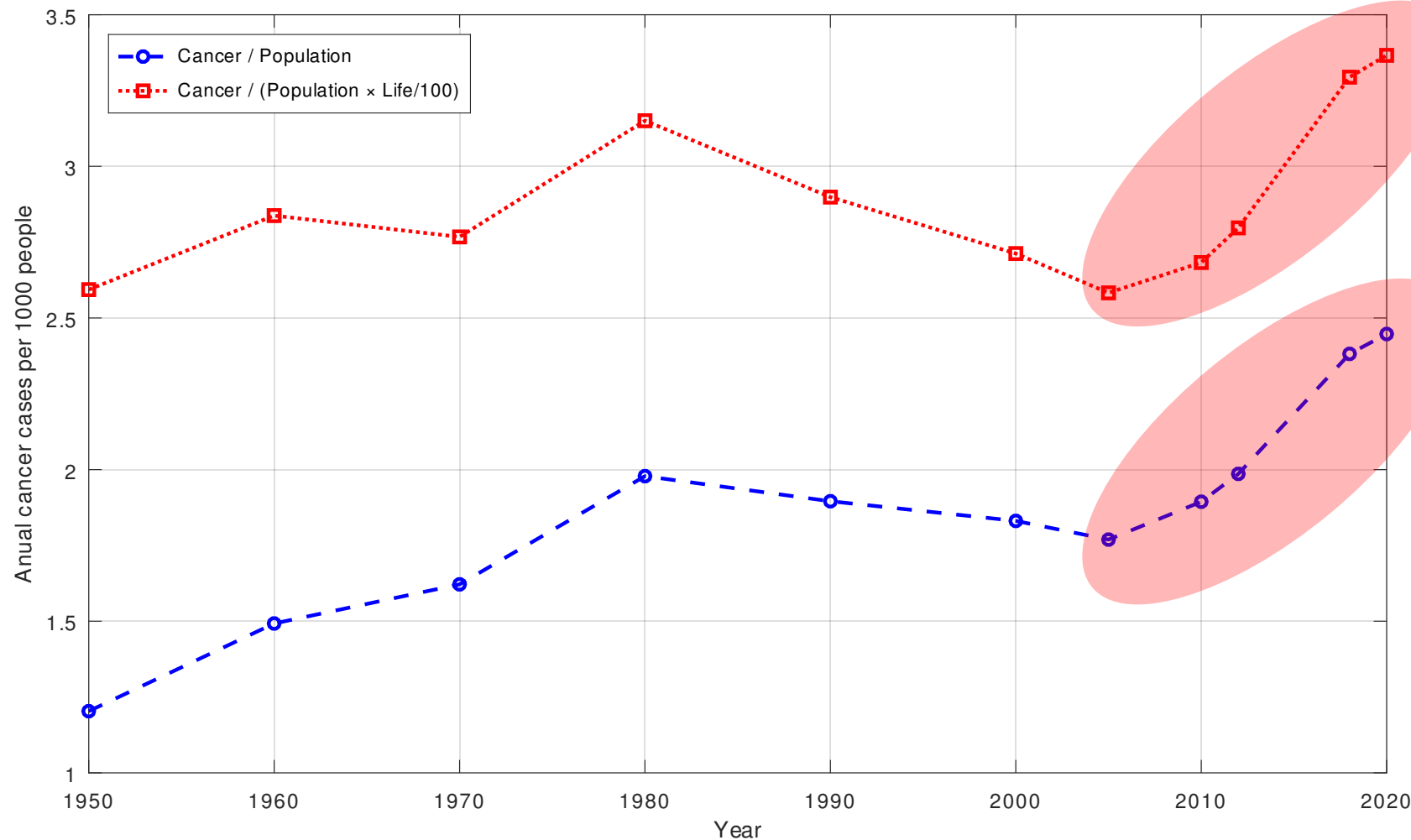
- Is it outgrowing cancer cases ?

Population growth normalized to life expectancy vs. Cancer incidences



- Is it outgrowing cancer cases ?
- Complicated!

Annual cancer incidences per 1000 people



Simple math:

- If XYZ plans to live up to 100 years
- Assuming 2020 numbers are frozen
- There is 25% chance that XYZ will have cancer during the lifetime
- Which is more than double from 70 years ago

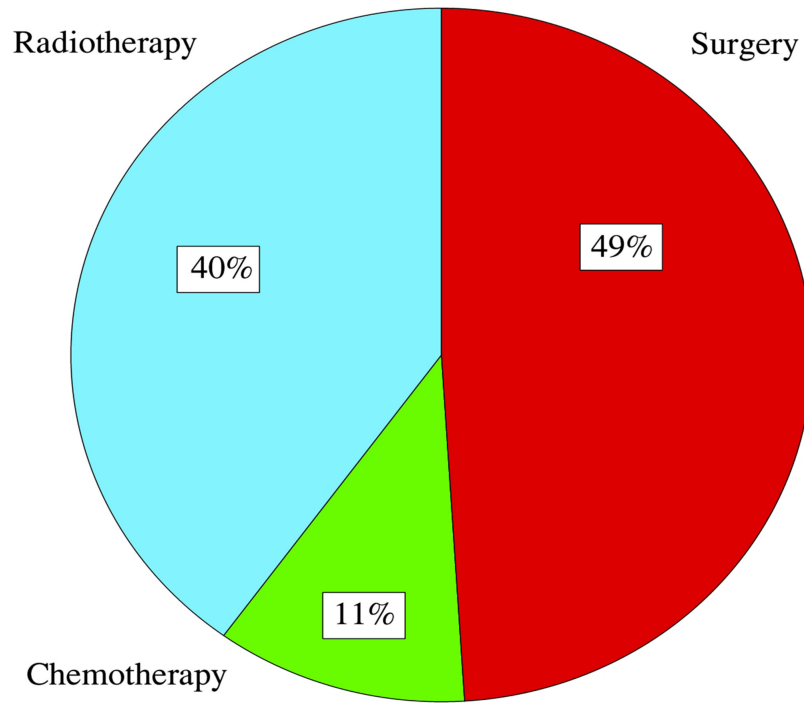
Is cancer one the most important problem to solve in the 21st century?

☒ Yes, absolutely! (In my humble opinion)

☐ No

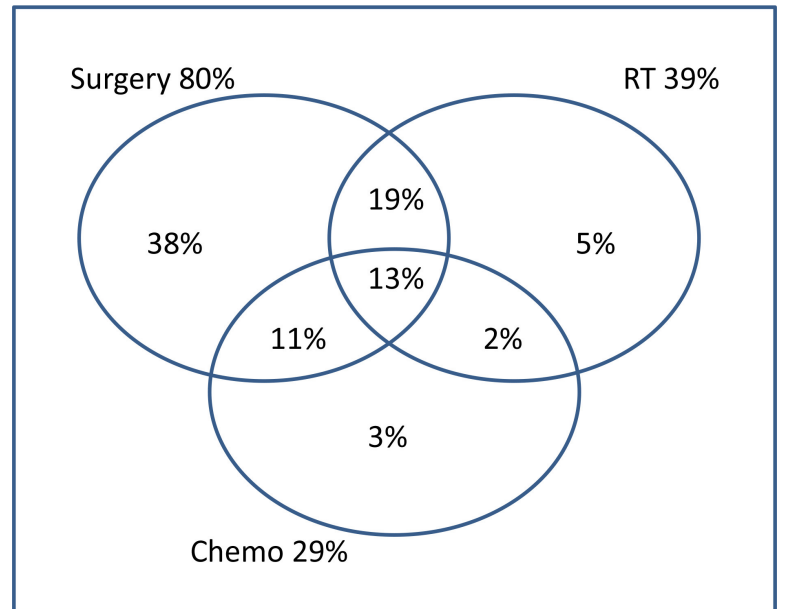
☐ I do not know !

Radiotherapy for cancer treatment: ~ 40%



Prevalence
of cancer
treatments in
the UK
(source
NHS)

Percentages of patients who survived at
least 5 years and who received at least
one treatment



Br J Radiol, Volume 96, Issue 1152, 1 December 2023,
20230334, <https://doi.org/10.1259/bjr.20230334>

Radiotherapy can be used to treat almost all type of cancers!

Particles in Radiation Therapy

1. Photons (X-rays, Gamma rays)
 - + Accessibility, works for nearly all tumors, relatively affordable, many built
 - No sharp dose deposition (no Bragg peak)
2. Protons
 - + Bragg peak
 - Expensive, bulky, not enough facilities built
3. Heavy ions
 - + Sharper Bragg Peak, stronger biological damage
 - Extremely sophisticated and expensive, even less built
4. Electrons
 - + Cheap and easy to deal with
 - No Bragg Peak, High energy needed to reach deep seated tumors



Particles in Radiation Therapy + UHDR?

1. Photons (X-rays, Gamma rays)

- + Accessibility, works for nearly all tumors, relatively affordable, many built
- No sharp dose deposition (no Bragg peak)
- Hard to reach ultra-high dose rate (UHDR)

2. Protons

- + Bragg peak
- Expensive, bulky, not enough facilities built
- Hard to reach ultra-high dose rate

3. Heavy ions

- + Sharper Bragg Peak, stronger biological damage
- Extremely sophisticated and expensive, even less built
- Very hard to reach ultra-high dose rate

4. Electrons

- + Cheap and easy to deal with
- + No Bragg Peak, High energy needed to reach deep seated tumors
- + Possible to reach ultra-high dose rate

Why UHDR is important?

Conventional irradiation assumes several minutes of treatment time, while UHDR irradiation allows to shrink treatment time bringing several benefits:

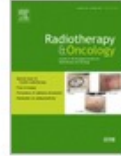
1. Simple time budget:
 - 1) Imagine that irradiation time is significantly reduced with all the dose delivered in split of a second: 100 – 200 ms
 - 2) Faster irradiation, more patients to be treated per active beamtime interval
 - 3) Less organ fluctuations during the irradiation time
 - 4) Patient comfort
2. Miracle of the FLASH effect with its two key ingredients:
 - 1) UHDR irradiation with under 100 ms time shows sparing of the healthy tissues in comparison with conventional irradiation
 - 2) UHDR irradiation shows as efficient (or better) tumor control (damage to cancerous tissue)

First clinical irradiation in FLASH: skin cancer treatment with electrons



Radiotherapy and Oncology

Volume 139, October 2019, Pages 18-22



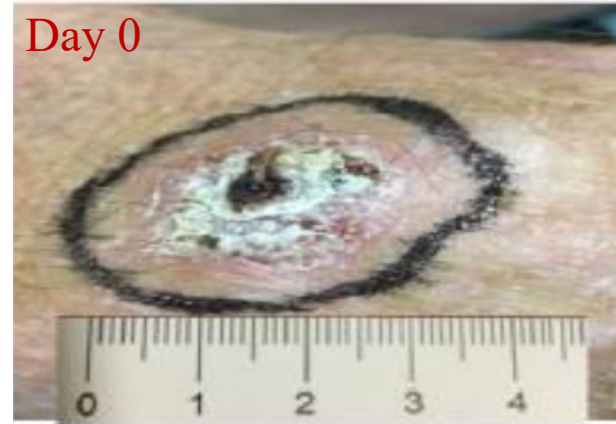
First in Human

Treatment of a first patient with FLASH-radiotherapy

Jean Bourhis^{a b}  , Wendy Jeanneret Sozzi^a, Patrik Gonçalves Jorge^{a b c}, Olivier Gaide^d, Claude Bailat^c, Frédéric Duclos^a, David Patin^a, Mahmut Ozsahin^a, François Bochud^c, Jean-François Germond^c, Raphaël Moeckli^{c 1}, Marie-Catherine Vozenin^{a b 1}

Using a 5.6 MeV electron linac 15 Gy were delivered to a 75-years old patient with a multi-resistant cutaneous lymphoma in 90 ms time interval:

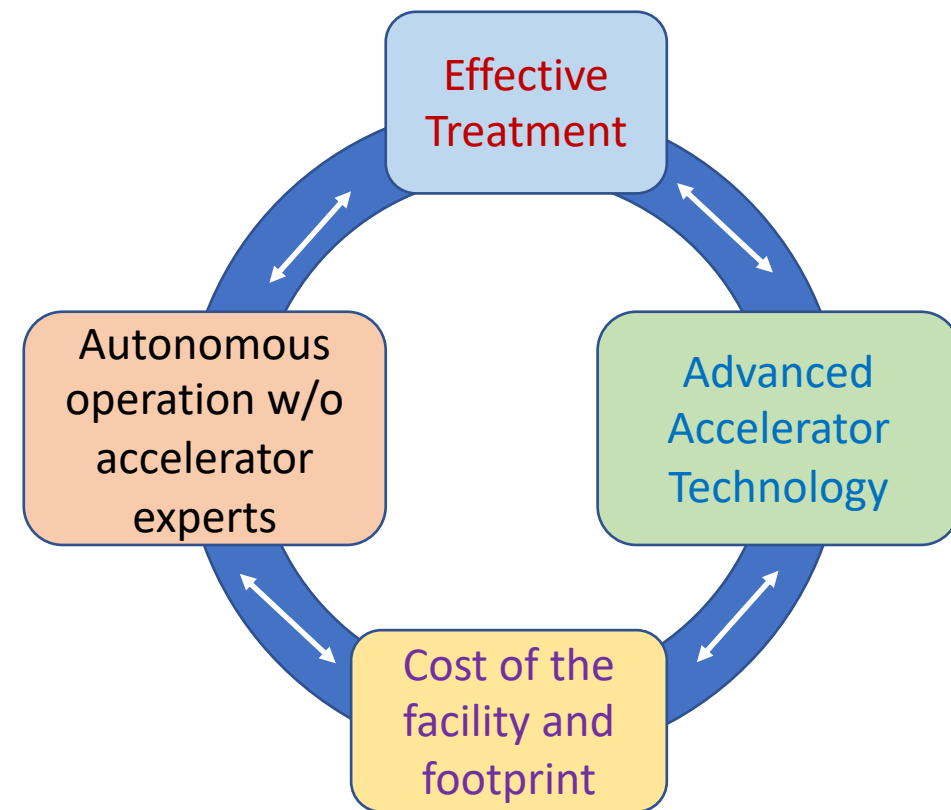
- *On healthy tissues:* no decrease of the thickness of the epidermis and no disruption at the basal membrane with limited increase of the vascularization.
- *On Tumor:* tumor response was rapid, complete, and durable with a short follow-up of 5 months.



This first FLASH-RT treatment was feasible and safe with a favorable outcome both on normal skin and the tumor

Ingredients of a potential solution

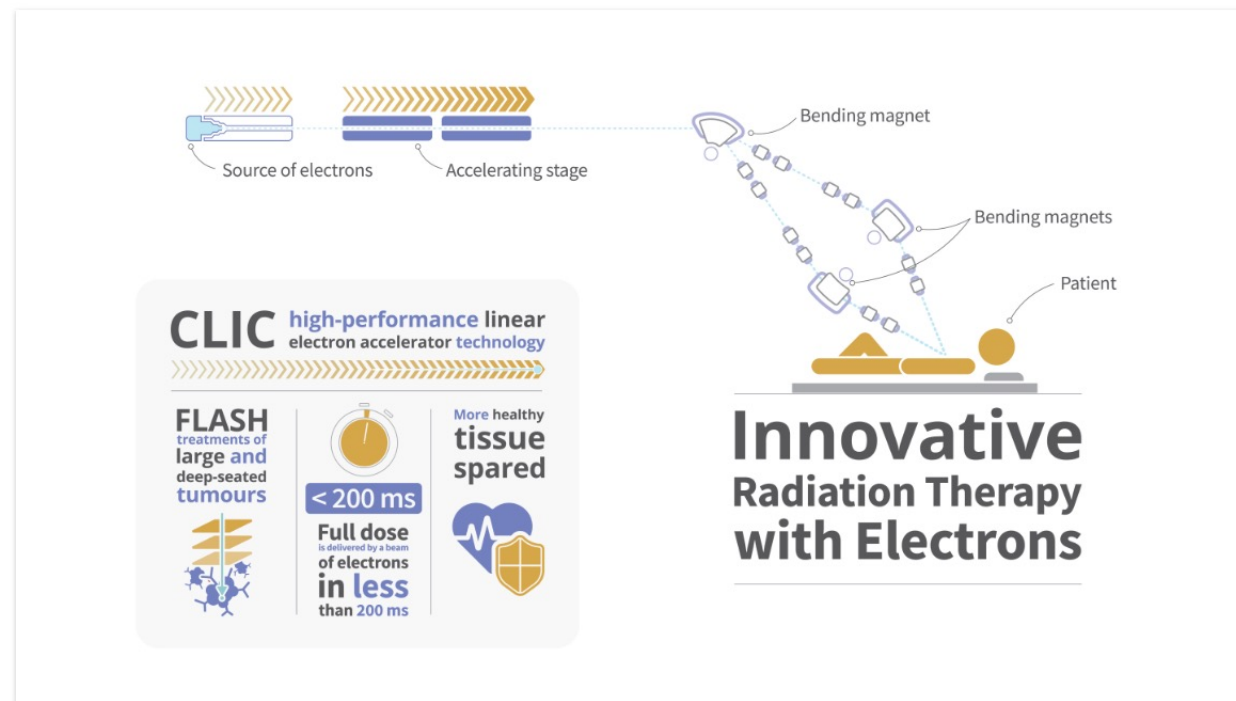
1. Electron beams in the 100-MeV range can reach even deep-seated tumours without the need for surgical intervention
2. Thanks to novel high-gradient acceleration technologies, clinical facilities for high-energy electron-based irradiation are actively under development
3. The ultra-high dose rate regime appears promising thanks to the FLASH (biological) effect, in which tumours can be treated efficiently with less damage to healthy tissue



CERN, CHUV and THERYQ join forces for a world first in cancer radiotherapy

CERN, CHUV and THERYQ have signed an agreement for the development of a revolutionary FLASH radiotherapy device

25 NOVEMBER, 2022



The schematic shows the concept of a new revolutionary VHEE FLASH radiotherapy device (Image: CERN)

CERN, the Centre Hospitalier Universitaire Vaudois(CHUV) and THERYQ (ALCEN group) have signed an agreement for the development of a revolutionary FLASH radiotherapy device that will use very high-energy electrons (VHEE) to treat cancers that are resistant to conventional treatments, with greatly reduced side effects. The device is the first of its kind. Based on CERN technology, it will be installed at CHUV when ready.

<https://home.cern/news/news/knowledge-sharing/cern-chuv-and-theryq-join-forces-world-first-cancer-radiotherapy>

<https://www.chuv.ch/en/journalistes/detail/chuv-cern-and-theryq-join-forces-for-a-world-first-in-cancer-radiotherapy>

Collaboration



+

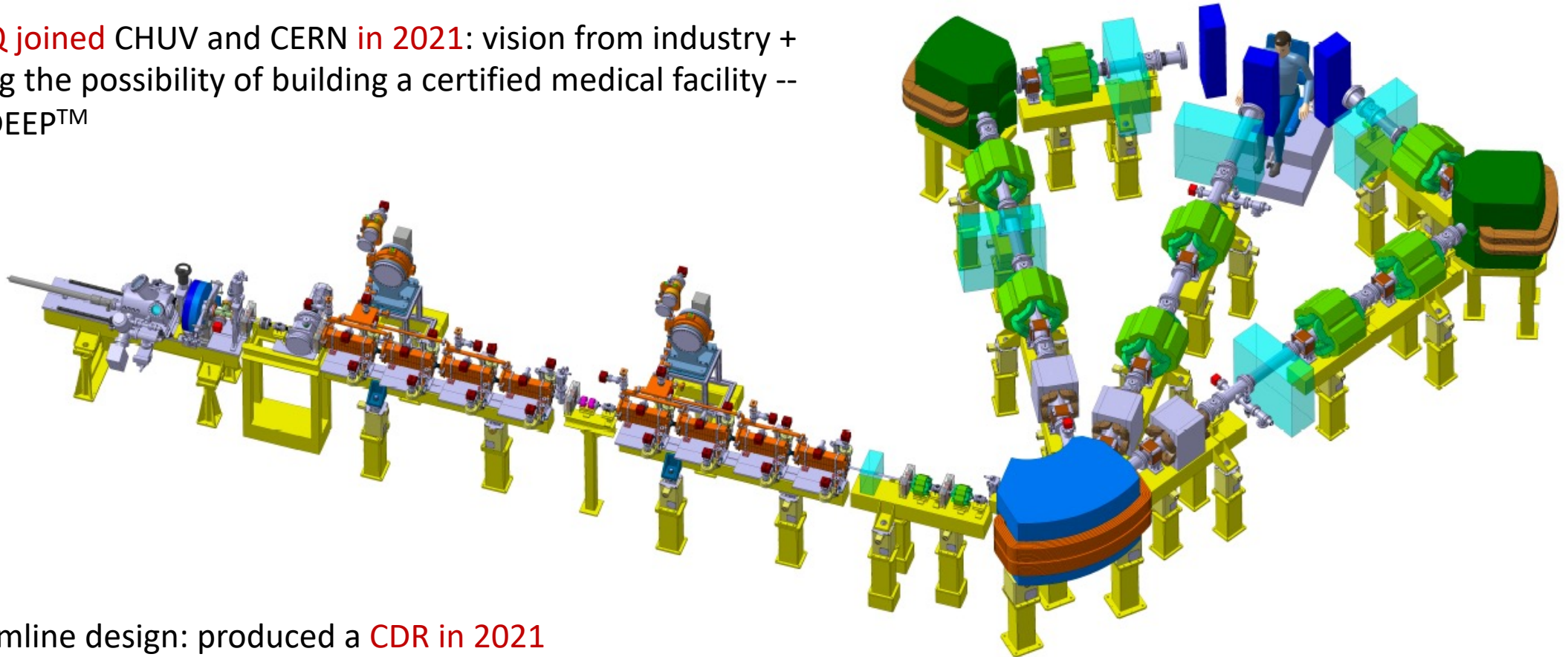


+

THERYQ

FOR HEALTH

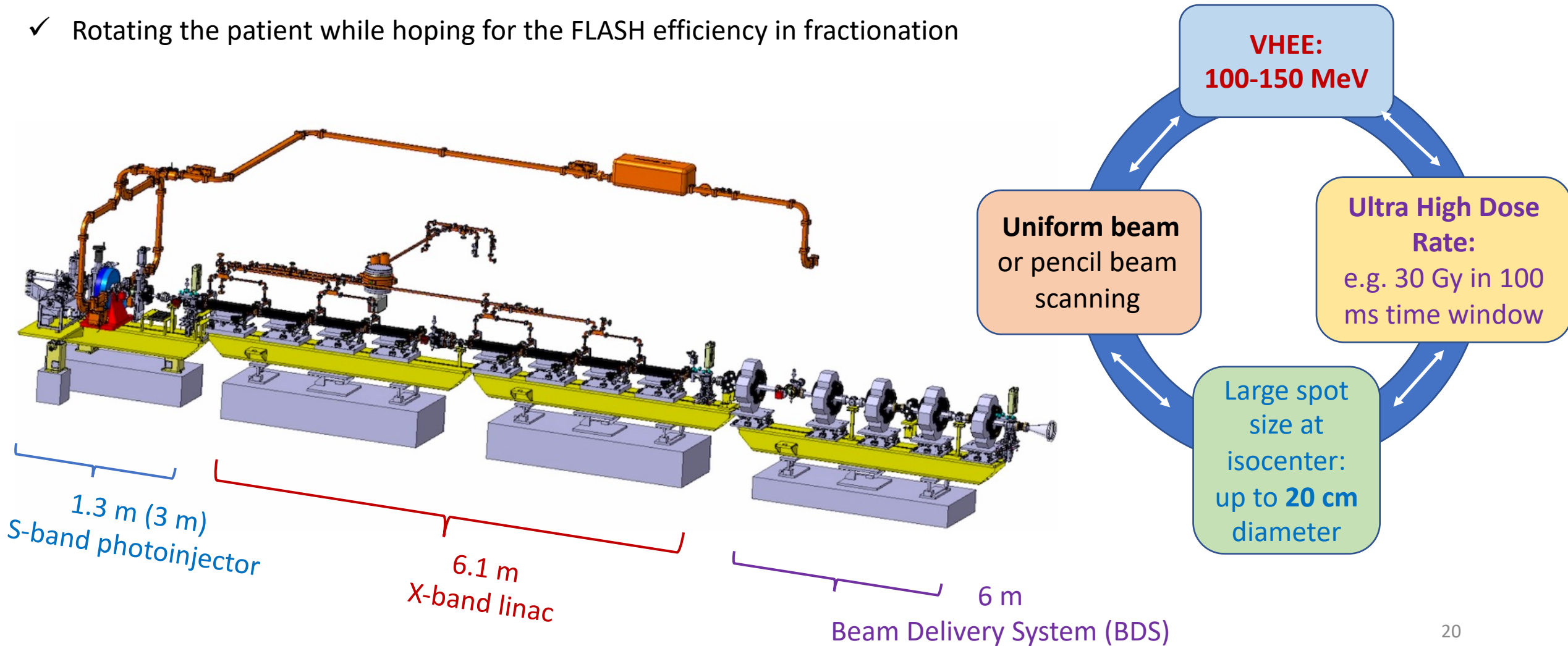
- ✓ Initial collaboration agreement signed between CHUV and CERN in 2020, supported by the donation of the Biltema Foundation and by the ISREC Foundation
- ✓ THERYQ joined CHUV and CERN in 2021: vision from industry + enabling the possibility of building a certified medical facility -- FLASHDEEP™



- ✓ 3-beamline design: produced a CDR in 2021 followed by a TDR delivered in 2023

Simplified design to reduce risks and costs (late 2023)

- ✓ From 3 beamlines to one: TDR delivered in January 2025
- ✓ Rotating the patient while hoping for the FLASH efficiency in fractionation



X-band based design: TDR

CERN Yellow Reports: Monographs

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Vol. 7 (2025): The DEFT facility: An accelerator for very-high-energy electron FLASH radiotherapy—Technical design report

Vol. 7 (2025): The DEFT facility: An accelerator for very-high-energy electron FLASH radiotherapy—Technical design report

Maria Elena Angoletta *et al.*

Corresponding editors: [Alexej Grudiev](#) and [Andrea Latina](#)

The design of an accelerator facility capable of delivering FLASH radiotherapy to large, deep-seated tumours is presented. The facility, called DEFT (Deep Electron Flash Therapy), produces 140 MeV electrons so is capable of treating tumours located at depths up to 25 cm. It is capable of delivering sufficient electron intensity to treat tumours up to 20 cm in diameter, in less than 0.1 s with doses up to 20 to 30 Gy. The full facility, including electron source, accelerator and beam delivery system are described along with extensive performance simulations.

DOI: <https://doi.org/10.23731/CYRM-2025-007>

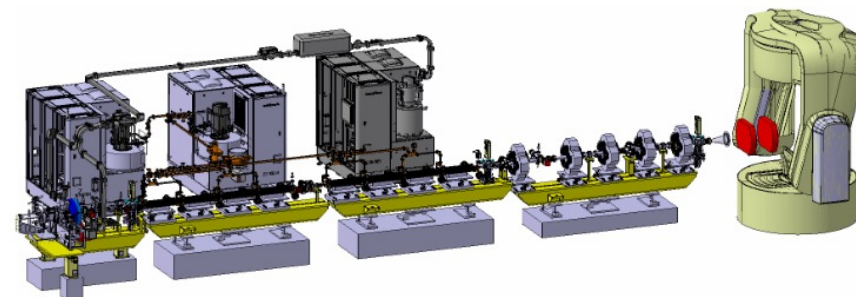
Published: 2025-09-30

<https://doi.org/10.23731/CYRM-2025-007>

The DEFT facility

An accelerator for very-high-energy electron FLASH radiotherapy

Technical design report



Maria Elena Angoletta, Jeremie Bauche, Olivier Brunner, Sergio Calatroni, Roberto Corsini, Jean-Marc Cravero, Steffen Doeber, Jose Antonio Ferreira Somoza, Maria Carmen Giordano, Eduardo Granados, Alexej Grudiev (Corresp. Ed.), Raul Key, Andrea Latina (Corresp. Ed.), Thibaut Lefevre, Stephane Burger, Michal Krupa, Alexander Malyzhenkov, Pablo Martinez Reviriego, Carlo Rossi, Igor Syratcev, Ping Wang, Markus Wadorski, Benjamin Woolley, and Walter Wuensch

CERN



Photocathode injector: some limited details

Challenges

- Create uniform beam in transverse plane x-y
- Provide high train charge with relatively low laser pulse energy
- Fit within the X-band aperture of the linac
- Provide with divergent beam at the linac entrance
- Make the design compatible within the non-academic but medical facility
- Compact design ~ 1 m

Triumphs

- Uniform beam generation is feasible
- Experimentally benchmarked at CLEAR
- 100 % transmission
- Sensitivity studies show great results

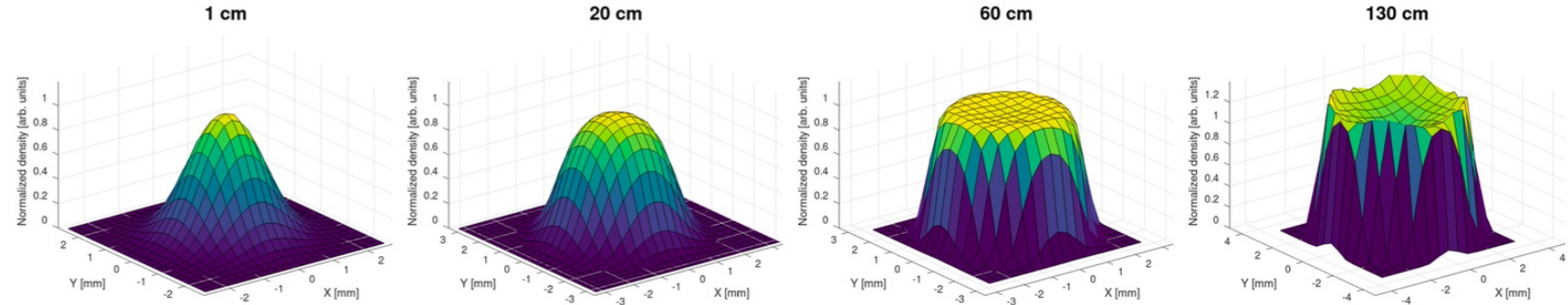
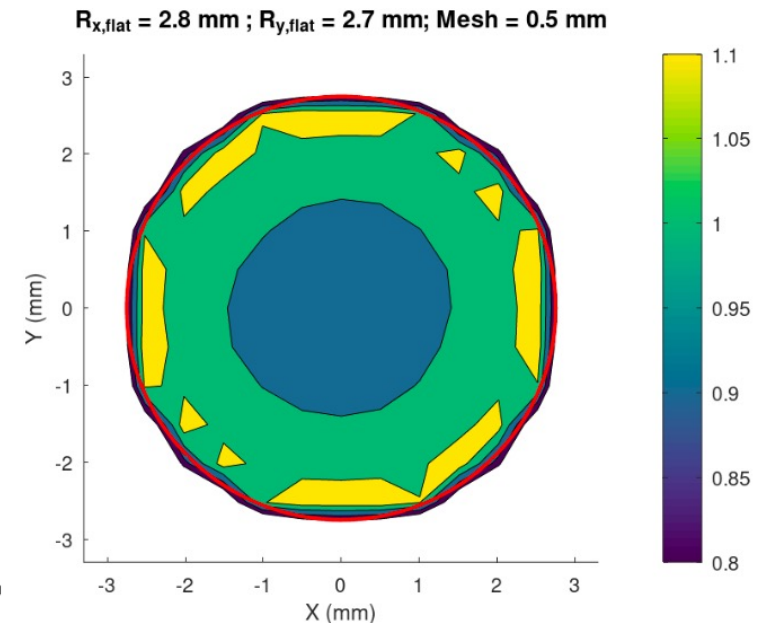
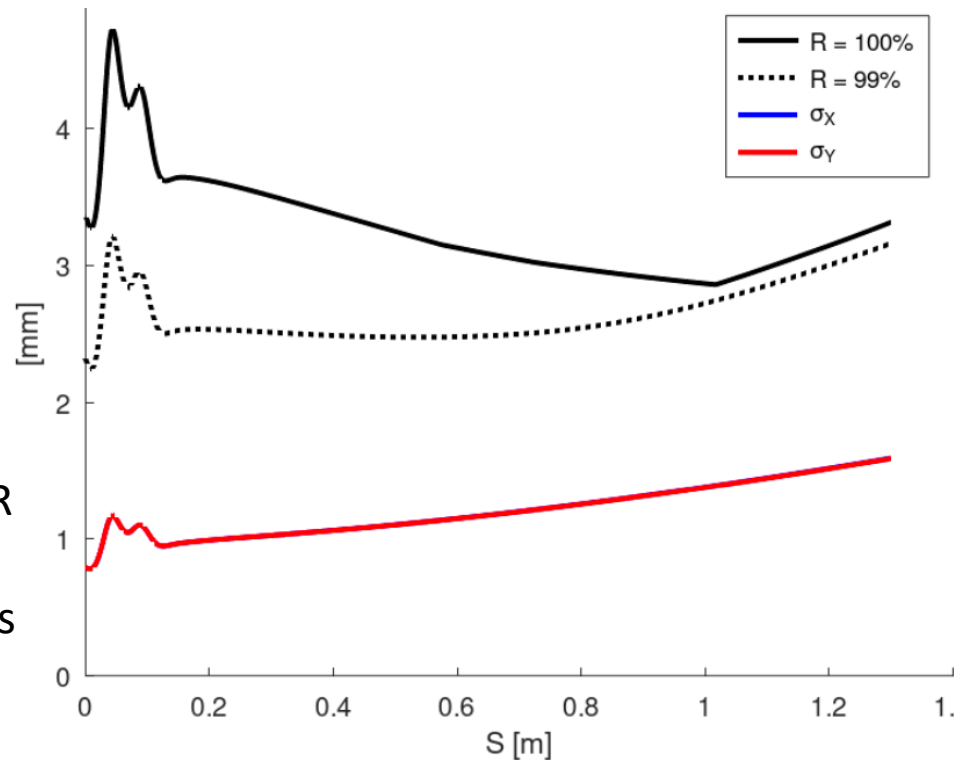
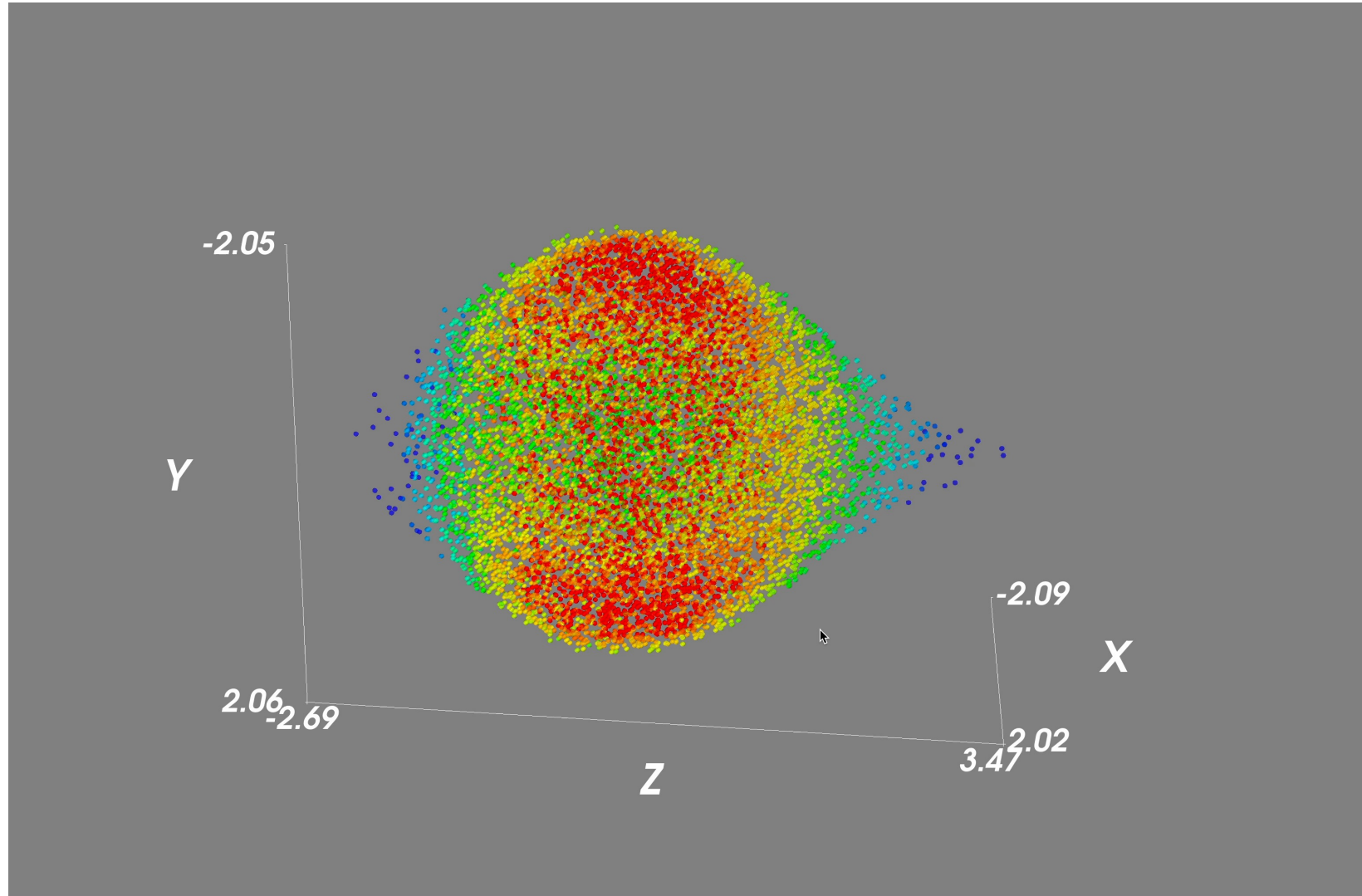


Figure 2.7: Bunch transverse profile evolution in the injector section.



From uniform beams in 2D to “bubble-beams” in 3D



Key parameters

Table 2.1: Main laser and beam parameters at the cathode and beam's time structure.

Parameter	Symbol	Units	Value
Bunch charge	Q	pC	190
Photon energy	E_{phot}	eV	4.73
Effective work function	Φ_{eff}	eV	3.5
Laser spot size at cathode, rms	σ_x, σ_y	mm	0.8
Laser pulse length, rms	σ_t	ps	1.6
Bunch repetition rate	t_{rep}	GHz	3
Number of bunches per train	n_b	-	~ 507

Table 3.1: Beam parameters at the end of the injector.

Parameter	Value
Gradient in the gun (MV/m)	90
RF pulse length (μs)	1.5
Momentum (MeV/c)	6.5
Charge per bunch (nC)	0.190
Bunches per train (max)	507
Bunch spacing (ns)	0.333
Number of trains (max)	40
Charge per treatment (max) (μC)	3.8
Homogeneity of the beam (%)	0.1
Emittance (μm)	5.8
Energy spread (%)	1
Repetition rate (Hz)	400
Bunch length (mm)	0.35
Laser spot size rms (mm)	0.8
Laser duration rms (ps)	1.6

Table 3.13: Parameters of the accelerating structures, nominal beam parameters and corresponding over-all system parameters.

Parameters	Units	Value
Active length	m	0.6
$\langle E_{\text{acc}} \rangle$ loaded	MV/m	29.2
Bunch charge	nC	0.19
Bunch spacing	ns	1/3
Pin	MW	20.3
τ_f	ns	61
$\tau_f + \tau_b$	ns	230
Number of bunches	–	507
Pulse charge	nC	96
Dose per pulse	Gy	0.85
Steady state RF-to-beam efficiency	%	49.7
RF pulse efficiency : $\tau_b / (\tau_f + \tau_b)$	%	73.7
Structure RF-to-beam efficiency	%	36.6
Overall RF-to-beam efficiency	%	16

Table 3.19: Parameters of the DEFT X-band RF unit.

Parameter	Value
No. of klystrons per RF unit	2
Klystron maximum peak power [MW]	25
Klystron nominal operation power [MW]	21.95
Pulse compression power gain	4.35
Waveguide loss [%]	15
No. of structures per RF unit	8
Structure input power [MW]	20.3

End of 2024 and early 2025: critical moment for DEFT collaboration

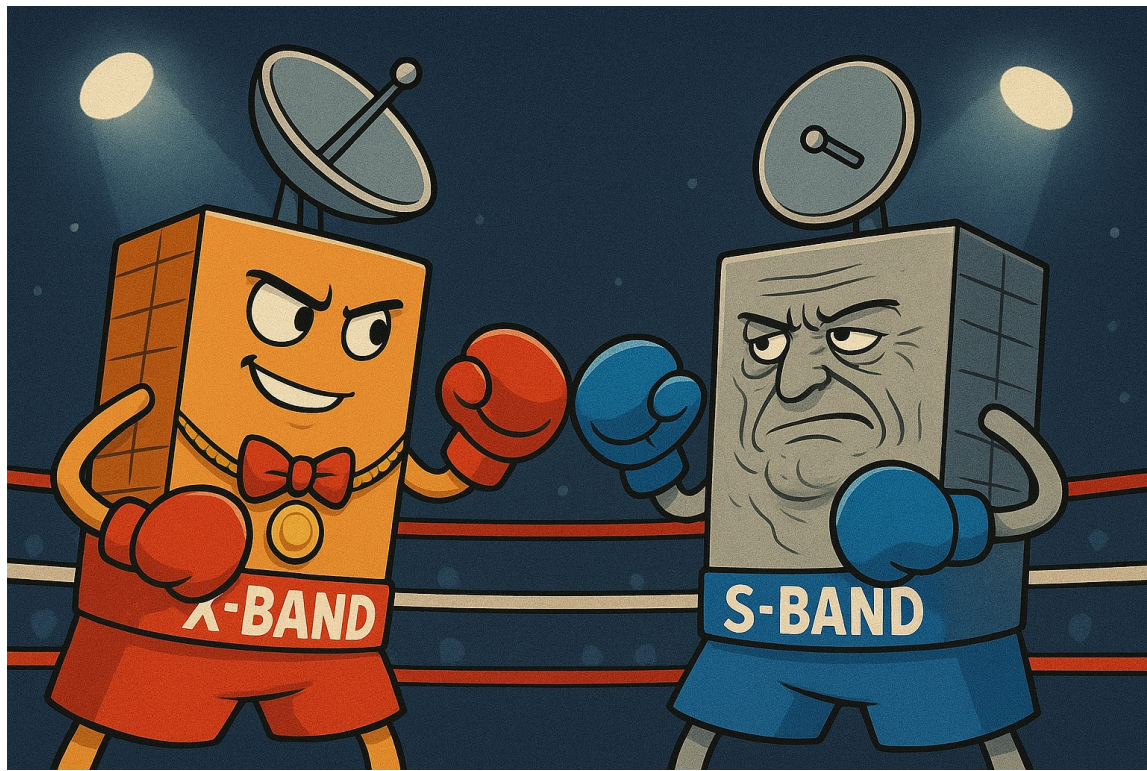
Original Plan:

- Finish TDR
- Start purchasing the components in 2025
- Finish bunker by 2025
- Start installing in 2026

Reality:

- TDR finished, but
- Budget freeze in CHUV hospital
- THERYQ is not sure X-band design can be competitive and affordable by hospitals
- X-band design is too complicated for industry
- Brainstorming alternatives and simplifications





We want the same:

- ☐ footprint ~15 m
- ☐ Uniformity and beam quality
- ☐ Total dose and dose rate
- ☐ Energy

X-band design is great, but ...

Can we make it cheaper and less sophisticated

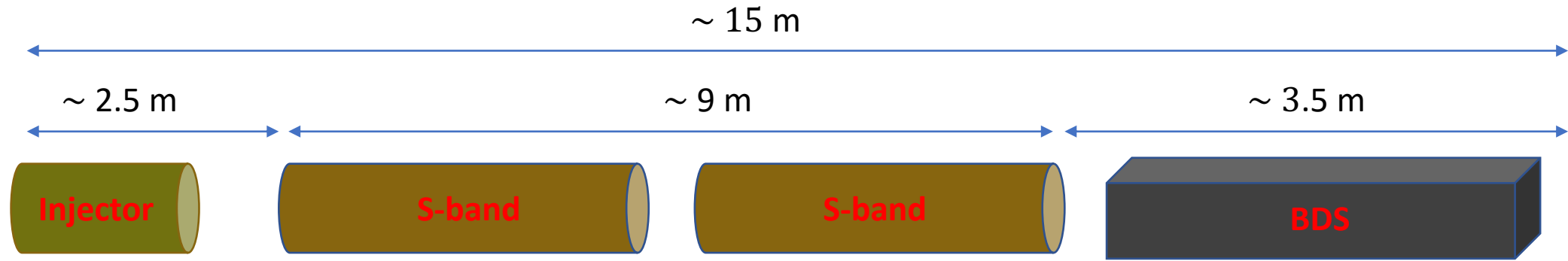
Meaning:

- No laser + no photocathode
- No x-band + no pulse compressor
- No space-charge-based uniformity

Antipode totale

- Thermionic gun
- S-band linac without pulse compressor
- Scattering approach for uniformity
- “Off-the-shelf components” where possible

S-band design in the nutshell



3 GHz --- 333 ps

$17.5 \text{ MV/m} \times 8 \text{ m} = 140 \text{ MeV}$

20-30 pC per bunch

$4.5 \mu\text{s}$

Up to 13514 bunches

Results 2025 - April 2026:

- S-band based design completed including the new TDR
- Thermionic gun as an injector as in low-energy UHDR machine
- Well-know and tested S-band structures currently used at electron linac facility
- Uniformity is reached by utilizing the conically shaped flattener approach extended to larger field sizes (20 cm diameter),
<https://www.sciencedirect.com/science/article/pii/S0168900225007454>
- The overall performance is on the same level as X-band design, but new machine is significantly cheaper and easier to realize

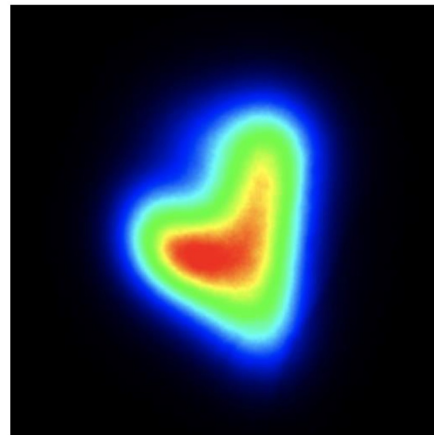
Critical viewpoint in 2026

Task 1: Search for investors (additional € 15M needed to reach the start of the clinical trials)

Task 2: Search for location to build the machine and conduct clinical trials

- Situation with CHUV bunker and project continuation with CHUV is very unclear (budget freeze, management change)
- Gustave Roussy Hospital (Villejuif, France):
 - Bunker to be completed by 2028?
 - Installation 2028-2029
- Alternative locations (Target: 2027):
 - Asia & Middle East
 - UK
 - United States: multiple hospitals/universities

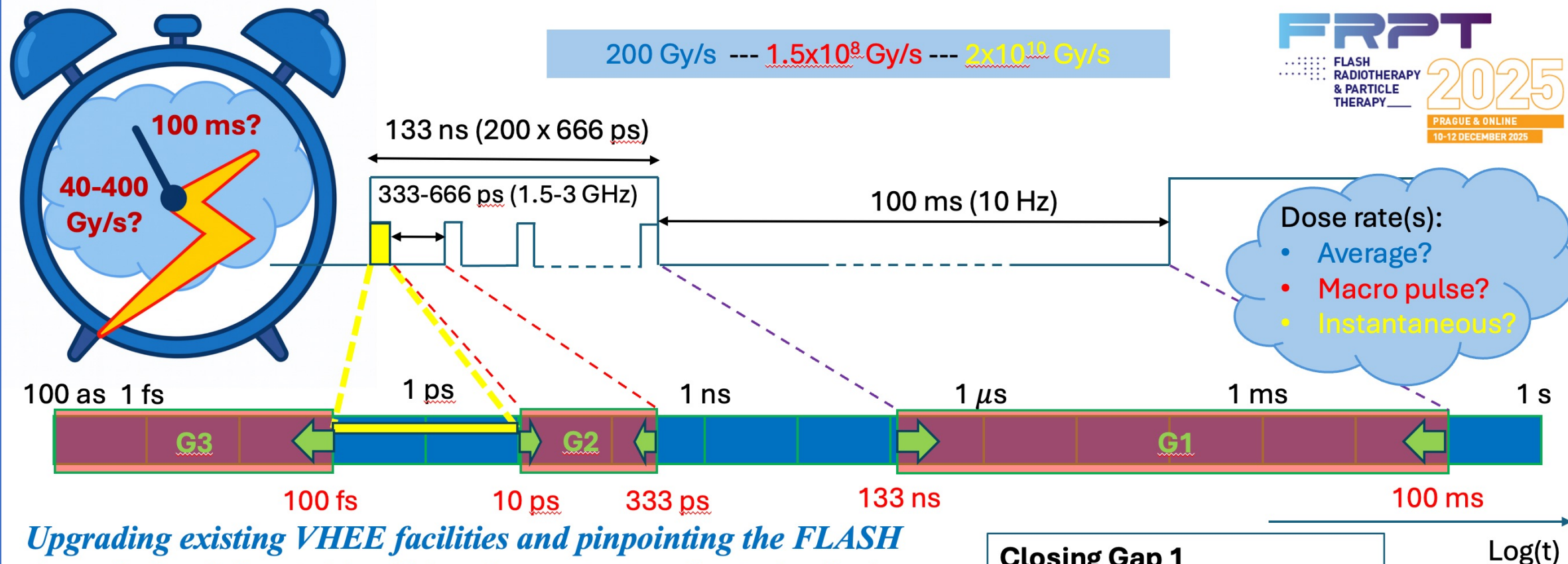
Thank you for your attention!



Extra slides

Abstract

In 2019, the annual number of cancer cases exceeded ~~100~~ 19 million, resulting in 10 million deaths worldwide. Radiation therapy stands out as one of the most effective methods for cancer treatment. Electron beams in the 100-MeV range can reach even deep-seated tumors without the need for surgical intervention. Thanks to novel high-gradient acceleration technologies, clinical facilities for high-energy electron-based irradiation are actively under development. In this talk, we give an overview of the existing low-energy electron and Very-High-Energy Electron (VHEE) machines capable of reaching ultra-high dose rates, thus enabling exploration of the potential FLASH effect. Furthermore, we shine a light on the planned VHEE UHDR medical facilities coming on stage in the next decade. We conclude by emphasizing the unsolved challenges associated with the exploitation of the FLASH effect, with special emphasis on the temporal structure of the delivered irradiation.



Upgrading existing VHEE facilities and pinpointing the FLASH time window is key to identifying the most attractive technologies for future medical facilities

Closing Gap 3

- Shifting left with shorter electron bunches (compression)

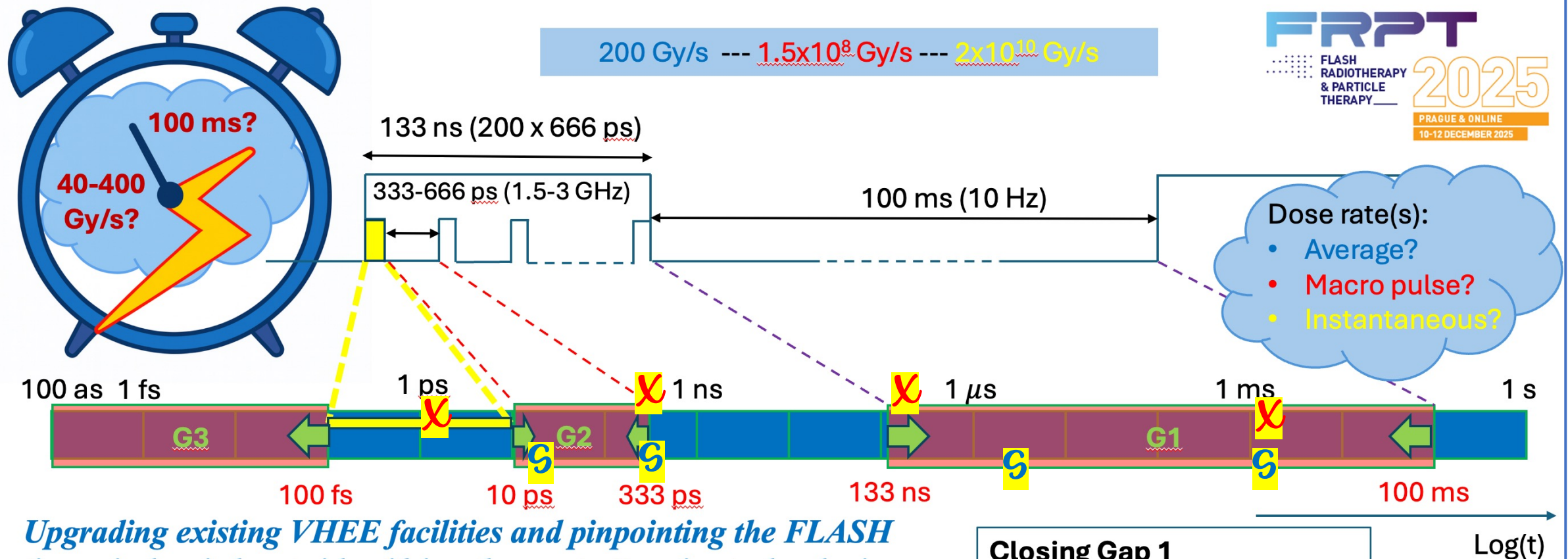
Closing Gap 2

- Shifting left with higher intra-train rep. rate: X-band (12 GHz)
- Shifting right with longer electron bunches (e.g. de-compression)

Closing Gap 1

- Shifting left with higher rep. rate: 100 Hz - 1 kHz
- Shifting right by increasing number of bunches upgrading the injector/laser and eventually RF systems





Upgrading existing VHEE facilities and pinpointing the FLASH time window is key to identifying the most attractive technologies for future medical facilities

Closing Gap 3

- Shifting left with shorter electron bunches (compression)

Closing Gap 2

- Shifting left with higher intra-train rep. rate: X-band (12 GHz)
- Shifting right with longer electron bunches (e.g. de-compression)

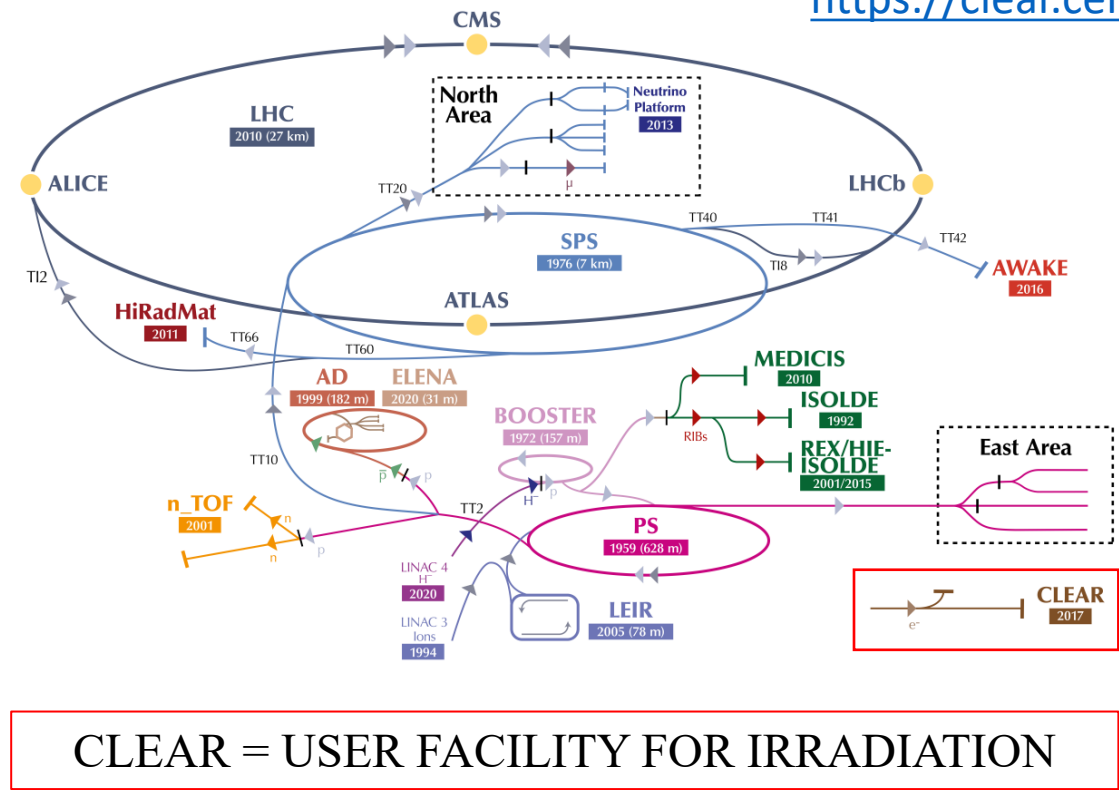
Closing Gap 1

- Shifting left with higher rep. rate: 100 Hz - 1 kHz
- Shifting right by increasing number of bunches upgrading the injector/laser and eventually RF systems

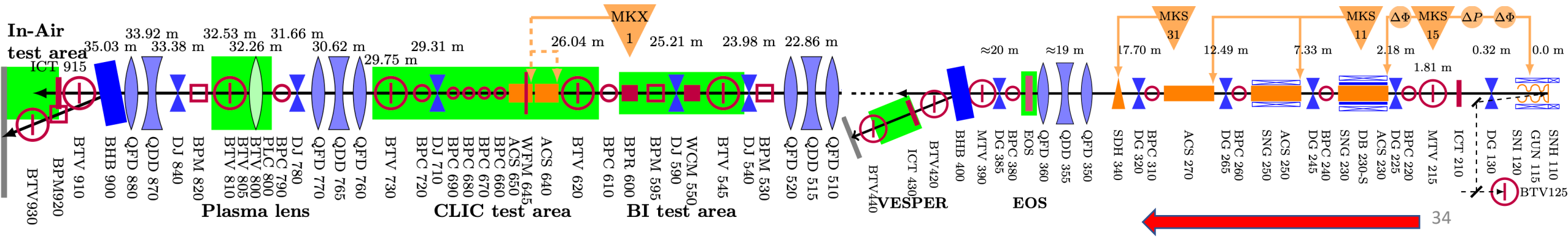


CLEAR: CERN Linear Electron Accelerator for Research

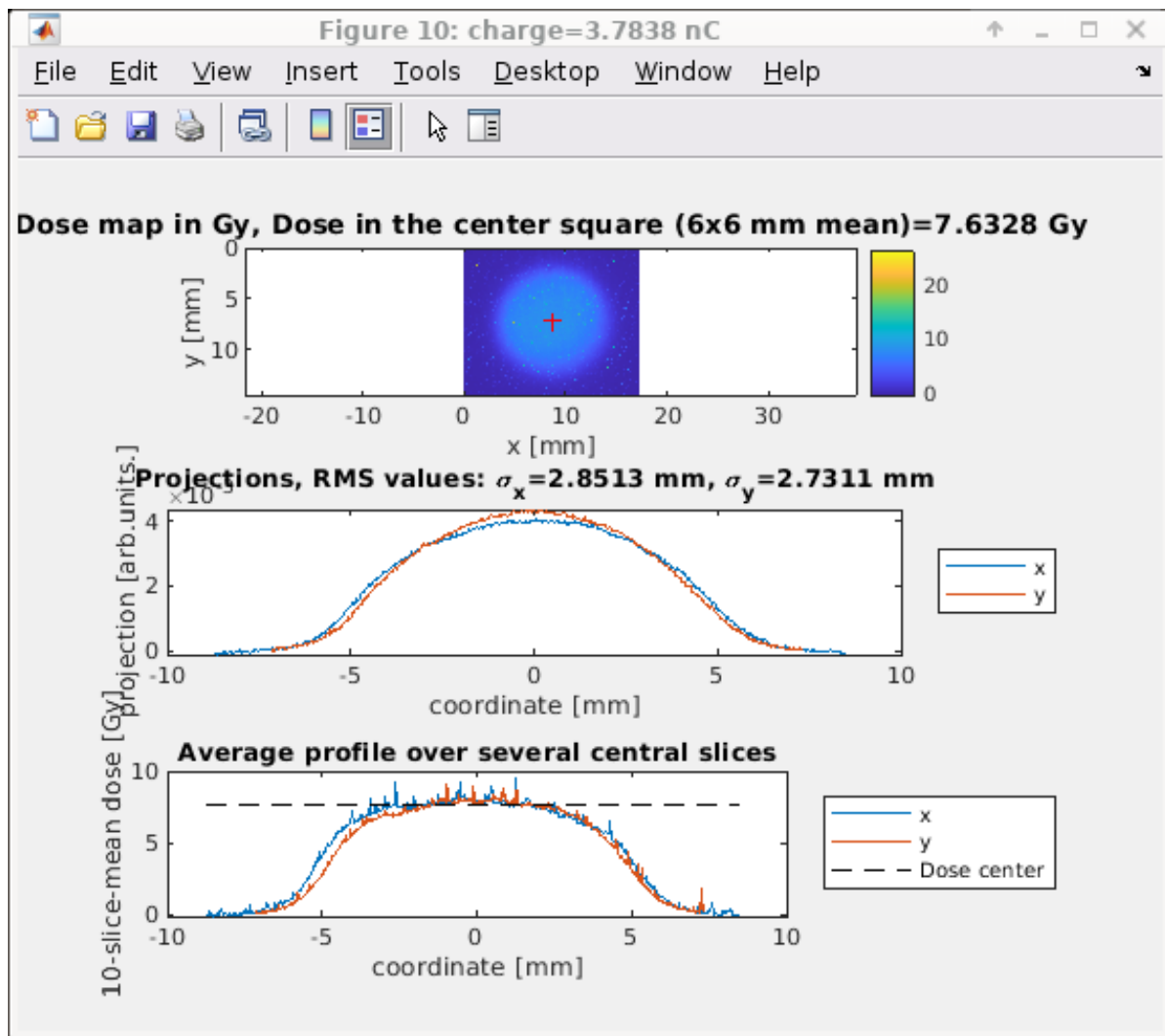
<https://clear.cern>



CLEAR = USER FACILITY FOR IRRADIATION

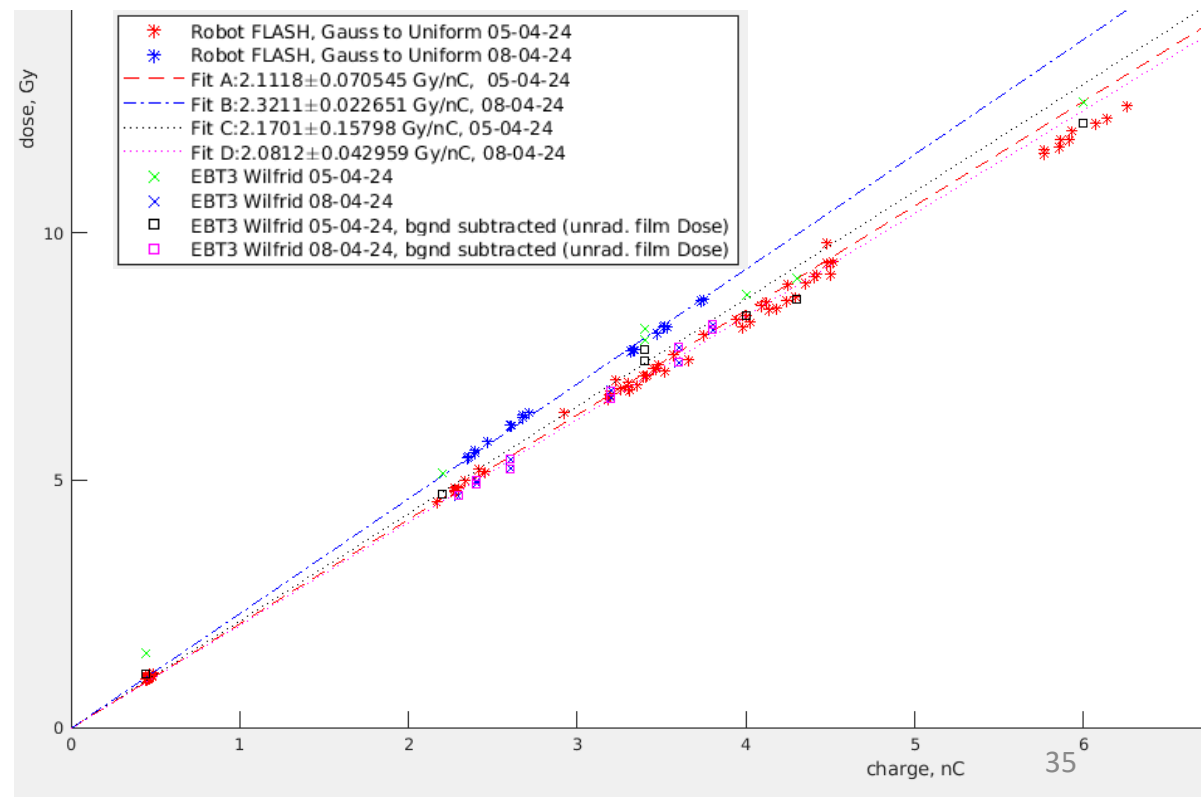


Development of the online dosimetry tools at CLEAR



Active dosimetry of the delivered dose through monitoring beam charge density:

- By measurements of the transverse profile on a YAG screen and
- bunch charge measurements
- Calibration of the charge density vs. the delivered dose on the radiochromic films





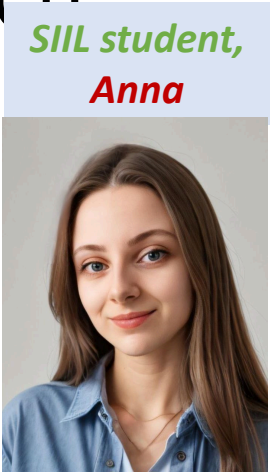
Calibration + Film Processing

Image Analysis + Dose Calculation



https://www.youtube.com/playlist?list=PL-VuIAyv77zQ_WpNVft4FE5Pq7kwkvGln

<https://github.com/annesteff/FilmDosimetryGUI>

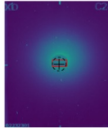
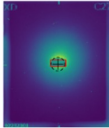
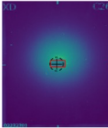
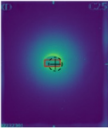


ROI shape: Circle Radius/Side length (mm): 2

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Archive info: 35 data files extracted

Image of the lead films: R0lead_25_26_27_28_from_11_10_2024_prep_EBTXD.png



C025
ROI: 13.798 ± 0.902 Gy
Ctr: 15.092 ± 1.827 Gy

C026
ROI: 11.348 ± 0.895 Gy
Ctr: 11.948 ± 1.401 Gy

C027
ROI: 13.614 ± 1.112 Gy
Ctr: 14.656 ± 1.929 Gy

C028
ROI: 10.324 ± 0.686 Gy
Ctr: 10.738 ± 0.881 Gy

Background Settings:

Select existing background

bgnr_avg_30-33_from_11_10_2024_prep_EBTXD.mat

Compute new background

Edge-based detection

File numbers for background: e.g., 30-33 or 31,32

File numbers for main image set: 1-28

Include calibration plot in the pdf report

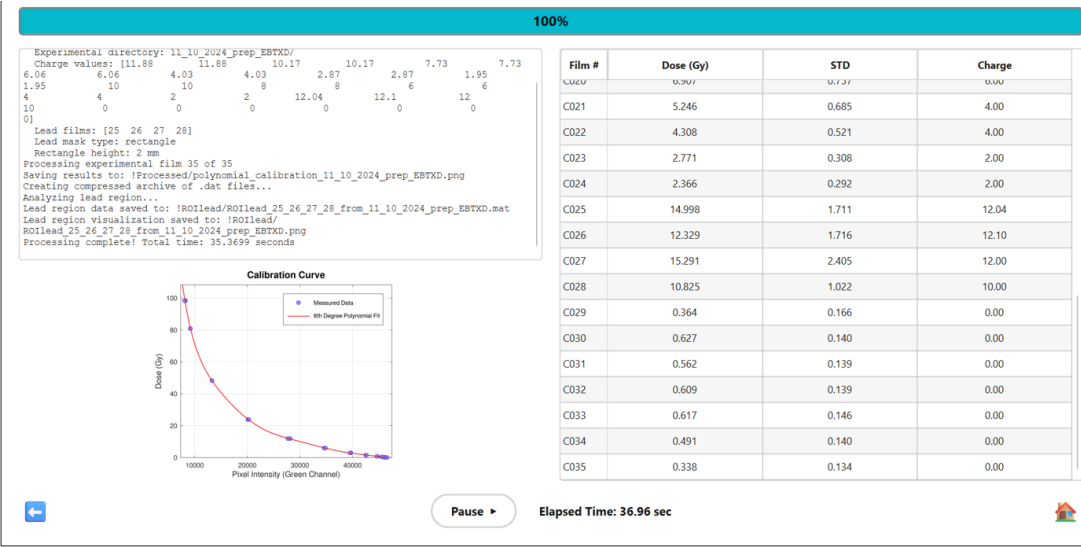
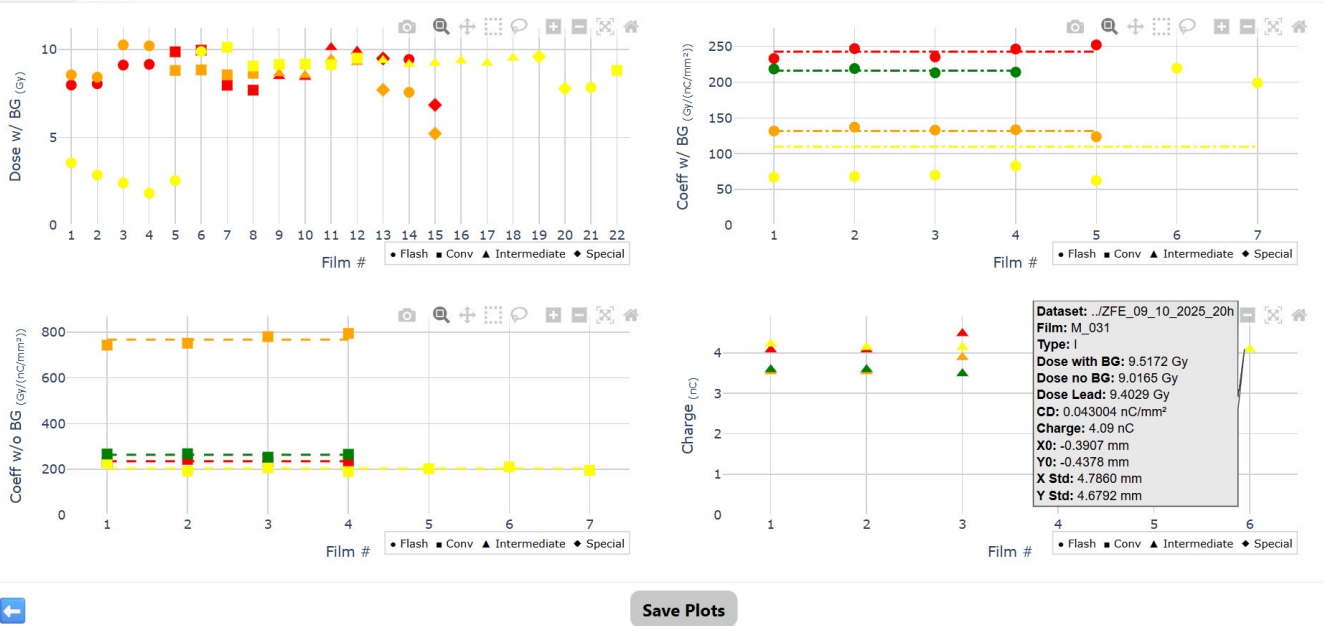
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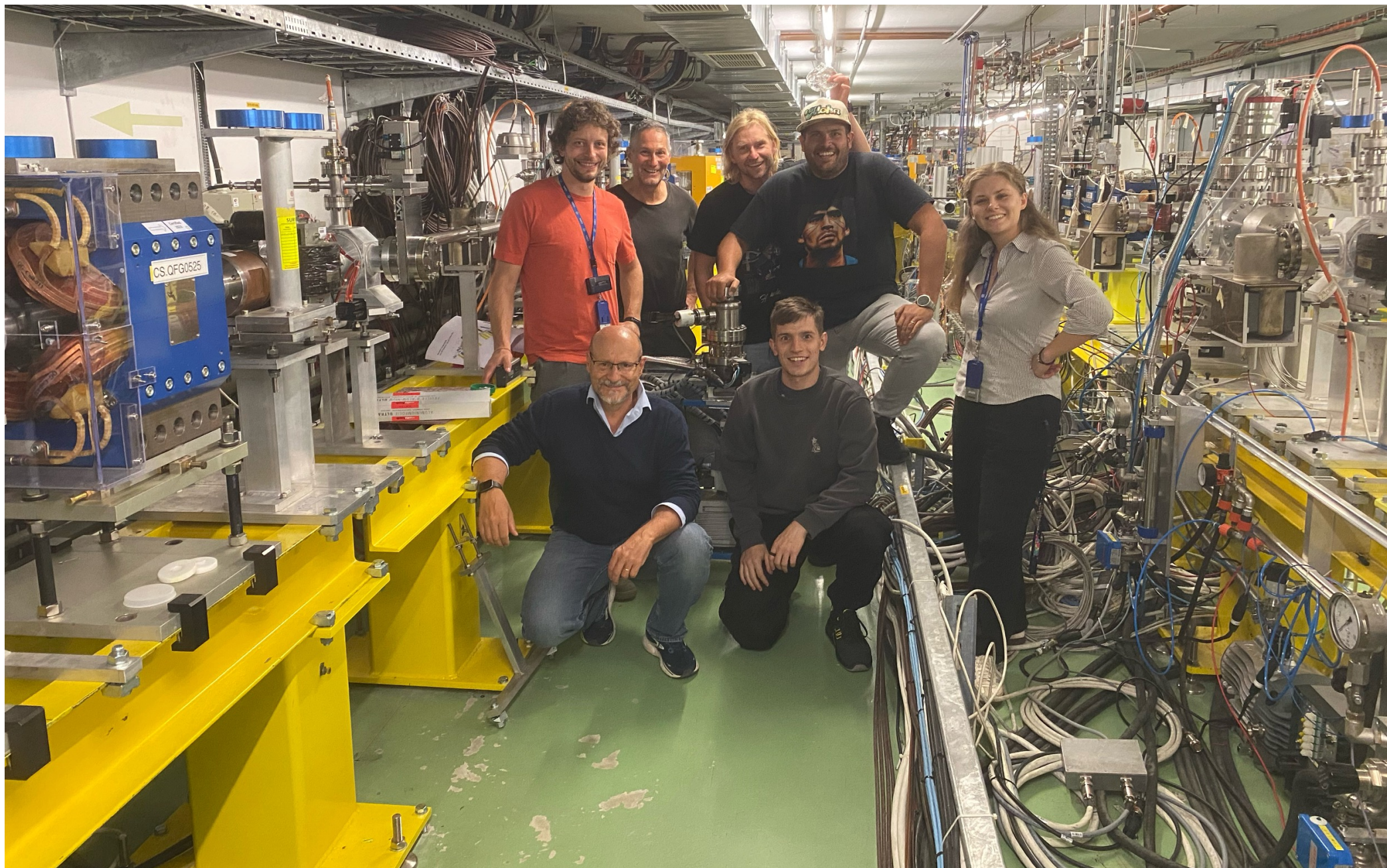
Optional notes separated by commas

Start analysis

ROI mask numbers: 27,28

→





- 1) VHEE = Very High Energy Electron Beams = 100-250 MeV
- 2) UHDR = Ultra High Dose Rate = 40-100-X? Gy/sec
- 3) Both needed/desired for enabling FLASH Therapy for deep seated tumors
- 4) FLASH effect = reducing damage to healthy tissue while maintaining (or improving) tumor control
- 5) Hospital Environment = COMPACT + AFFORDABLE + VERY ROBUST

X-band ~ 12 GHz

S-band ~ 3 GHz