Accelerating the future: designing a robust and affordable radiation therapy treatment system for challenging environments

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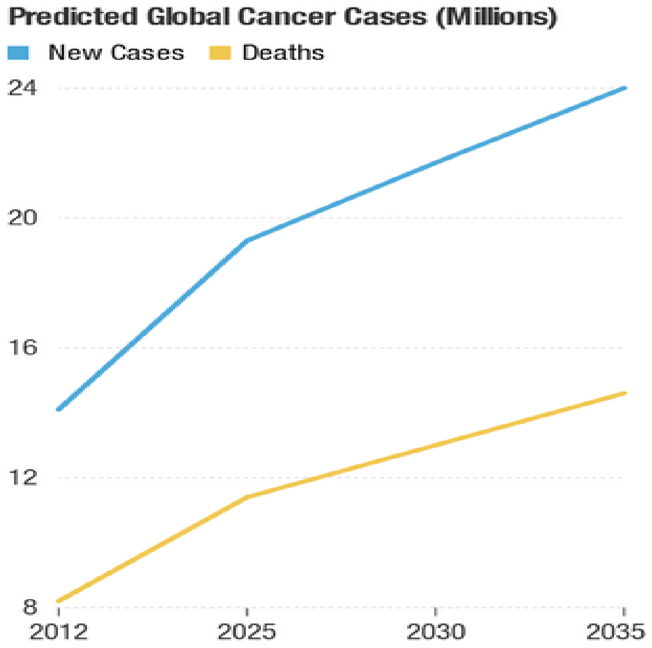
(on behalf of STELLA collaboration)

Cancer is a growing global challenge

- Globally **19.3** million new cases per year diagnosed and **10** million deaths in **2020**
- This will increase to **27.5** million new cases per year and **16.3** million deaths by **2040**
- **70% of these deaths** will occur in low-and-middle-income countries (LMICs)
- **9 out of 10 deaths** for cervical cancer and **7 out of 10** breast cancer are in LMICs



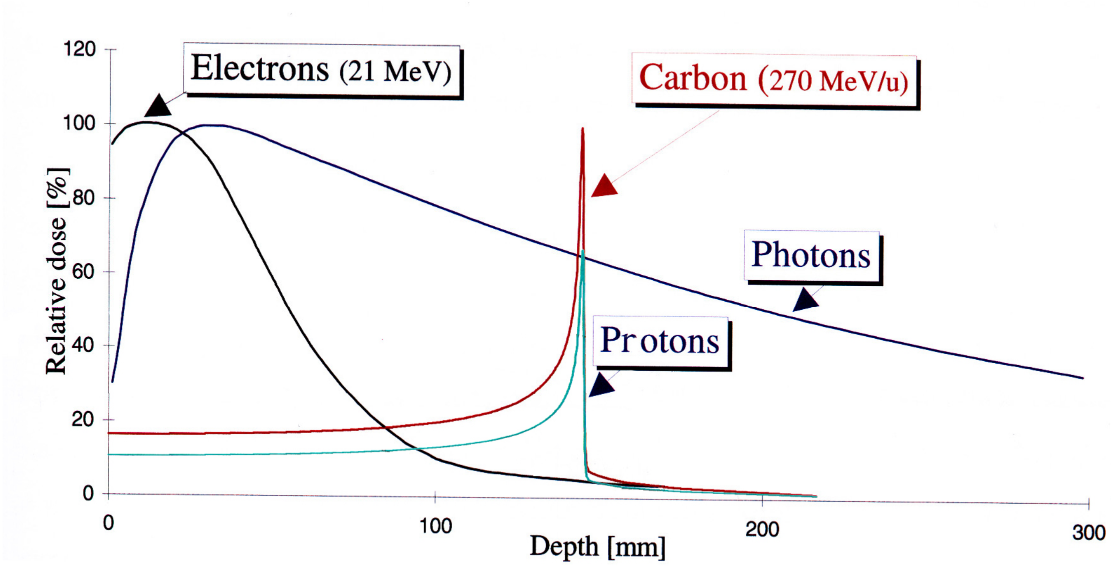
Radiation therapy is a key tool for treatment for around 60% patients

Aims of Radiotherapy:

- Irradiate tumour with sufficient dose to **stop cancer growth**
- **Avoid complications** and **minimise** damage to surrounding tissue

Current radiotherapy methods:

- 5 - 25 MV photons
- 5 - 25 MeV electrons
- 50 - 400 MeV/u hadrons



Radiation Therapy Today

Key external radiation therapy delivery systems

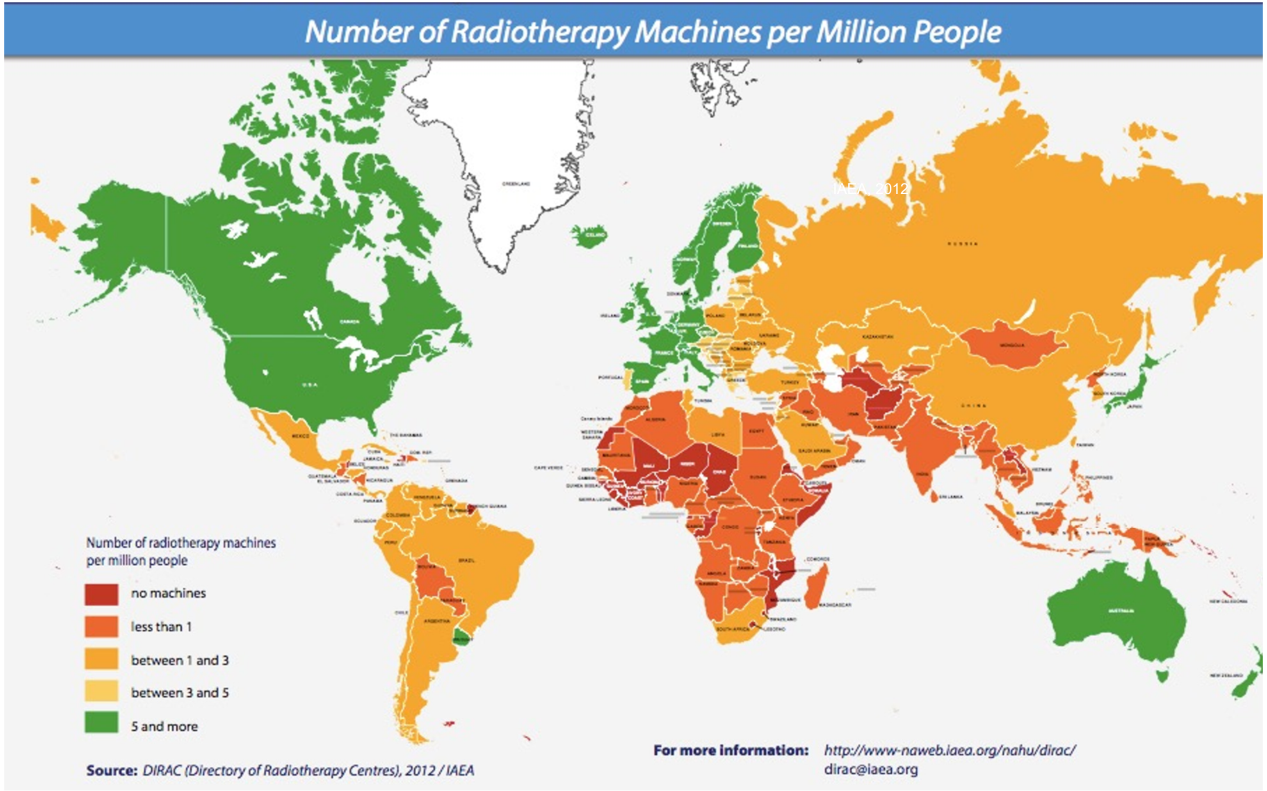
- Cobalt 60 machines
- **Linear accelerators (LINACs)**
- Image-guided radiotherapy (IGRT); MR-guided etc.
- Particle therapy (proton and carbon)…..new ideas presented here
  - ➢ Compact Accelerators: SLAC and Peking University talks
  - ➢ Compact synchrotron Helium (Vretener talk)
- VHEE – compact electron machine for deeper penetration
- FLASH therapy could be possible for all particles ---more patients

The Problem:
Much of the world has limited or no access to Radiation Therapy

- **For nearly 60% of cancers, RT is most useful tool** for cancer cure or pain-relief; inadequate supply of RT linear accelerators (LINACs).
  - Gap greatest in low-middle income countries (LMICs)
  - 70% of the cancer deaths will occur in LMICs
    - **- 9 out of 10 deaths** for cervical cancer and **7 out of 10** breast cancer are in LMICs
  - Only 10% of patients in LMIC have access RT
- Current LINAC technology is **complex, labor intensive, and high cost** to acquire, install, operate and service.[1]

[1] Atun, R., et al (2015). Global Task Force on Radiotherapy for Cancer Control. *The Lancet Oncology*, *16*(10), 1144-1146. [237].

Radiation Therapy is an essential part of cancer treatment



However only 10% of patients in low-income regions have access

Great strides have been made in the fight against cancer

However, there are dramatic disparities in Access

Country	LINACs	Population	People per LINAC
Ethiopia	1	115 M	115,000,000
Nigeria	7	206 M	29,000,000
Tanzania	5	59.7 M	11,900,000
Kenya	11	53.9 M	4,890,000
Morocco	42	36.9 M	880,000
South Africa	97	59 M	608,000
UK	357	67 M	187,000
Switzerland	83	8.6 M	103,000
US	3727	331 M	88,000

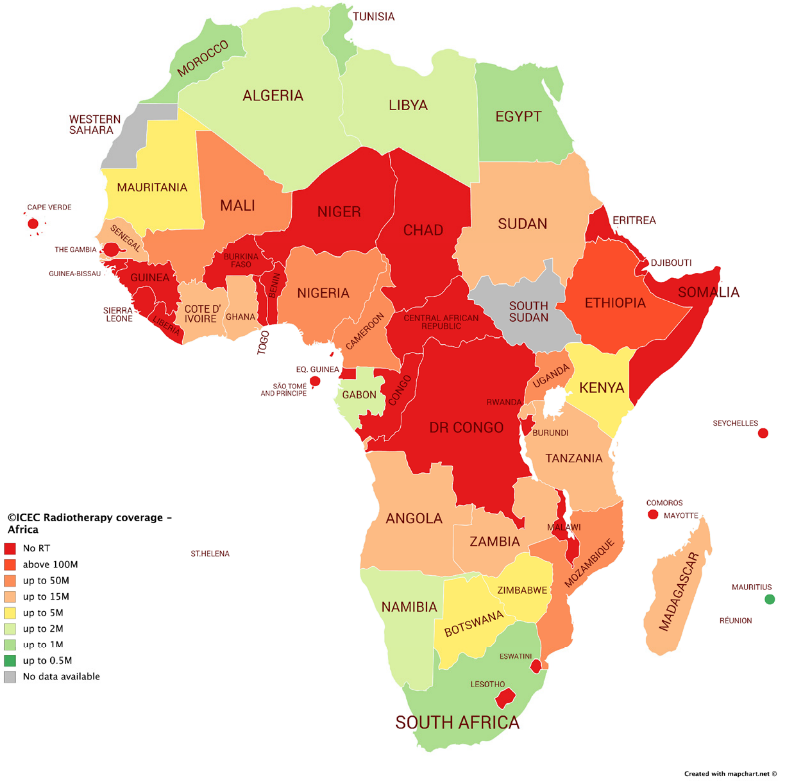
Examples of Disparity

Africa: 400 RT-LINACs for > **1 billion** people needs around 4000

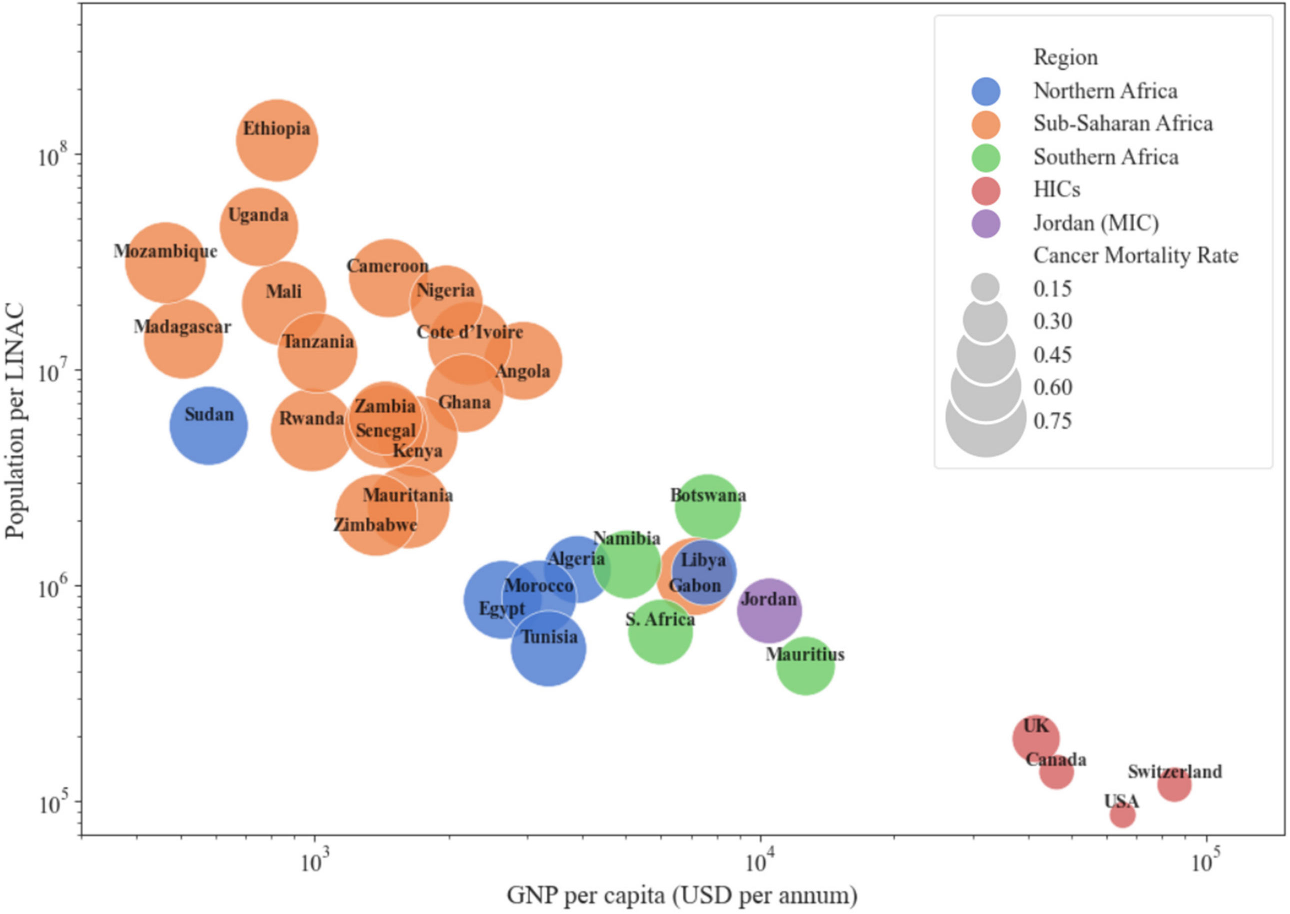
US : Around **4000 LINAC** for **330 Million** people

Ethiopia : 115 Million people – 1 LINACs

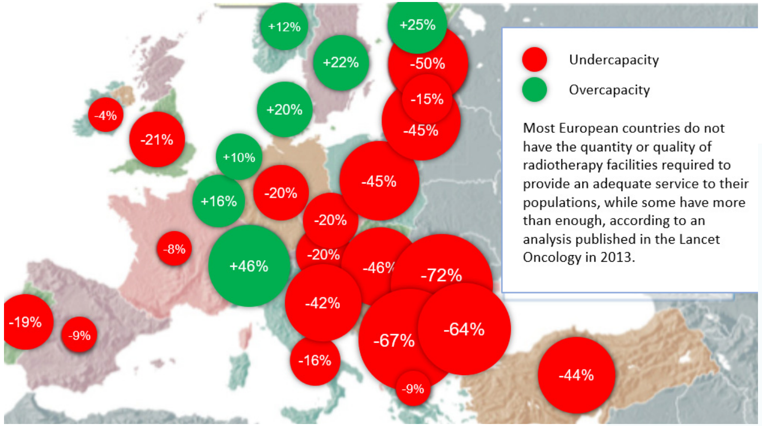
Nigeria **7 machines for 220 million** people only a **couple of trained linear accelerator maintenance engineers,** , has 85 radiation and clinical oncologists and Abuja is the only place that has Medical Physics Dept



GNP and Ratio of Inhabitants to Linacs and Cancer Mortality



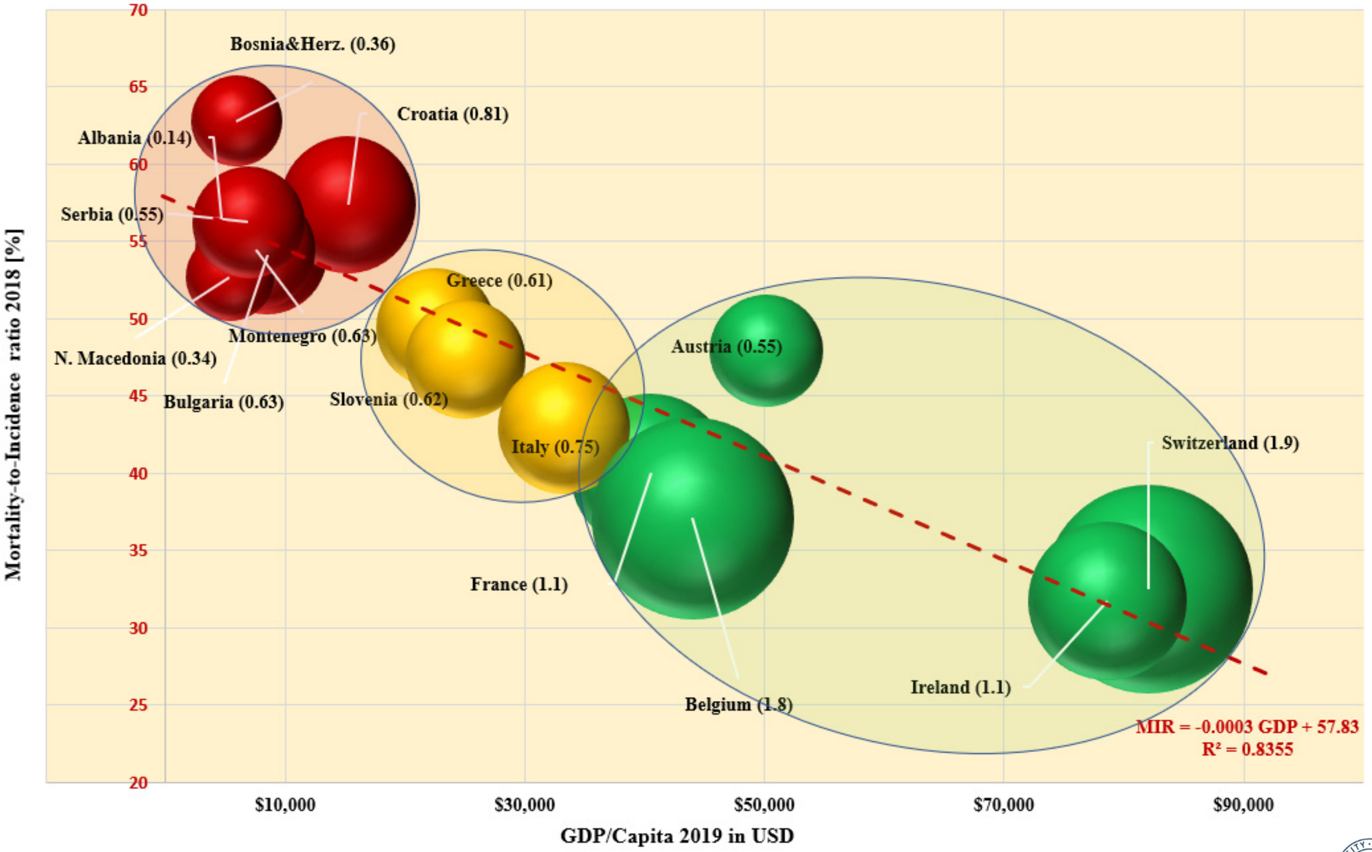
Shortage and challenge is not only in Africa



Radiation therapy capacities in Europe

Rosenblatt E, et al. Lancet Oncol 2013;14:e79–86

Linacs and Cancer Mortality in SEE Region (Balkan Peninsula)



Current status of RT

- Current Linacs provide very good treatment both in terms of technical capability and throughput.
- However current LINAC technology is **complex, labour intensive,** and **expensive** to acquire, install, operate and service in both LMICs and HICs.[1]
- Linac technology requires **strong, robust** and **reliable infrastructure** (power, clean water, supply chain etc.) to operate
- Many Linacs are purchased or deployed in Africa and LMICs without sufficient **training.** Many are never used or not close to their capacity
- LINAC **servicing** can be slow and very expensive. Service contracts are expensive and not always purchased. Long down times (months or more).

Atun, R., et al (2015). Global Task Force on Radiotherapy for Cancer Control. *The Lancet Oncology*, *16*(10), 1144-1146. [237].

Project STELLA

Smart Technologies to Extend Lives with Linear Accelerators

Project STELLA is a unique global collaboration involving some of the best physics and medical talent, expertise from leading laboratories in accelerator design and, importantly, input and collaboration from users in Africa, other LMICs and HICs.

The goal of this project is to enable cancer care through innovative technology that is disruptive and is centred in mentoring.

STELLA needs to be:

- Robust, modular, reliable and easier to use machine
- Affordable with the aim to expand access to RT global

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Building the STELLA collaboration and defining a strategy

- 1st Design Characteristics of a Novel Linear Accelerator for Challenging Environments, November 2016, CERN
- 2nd Bridging the Gap Workshop, October 2017, CERN
- 3rd Burying the Complexity Workshop, March 2018, Manchester

- 4th Accelerating the Future Workshop, March 2019, Gaborone

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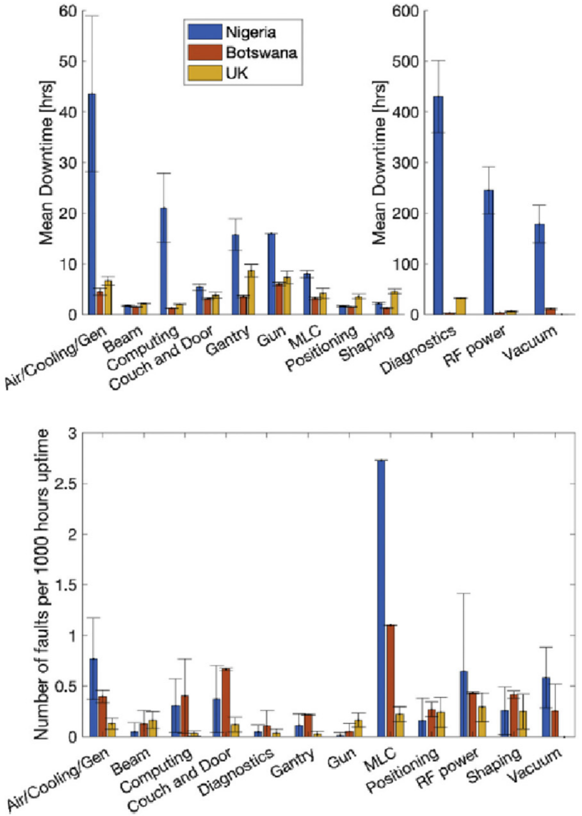
Partnering to transform global cancer care
UKRI
Science and Technology Facilities Council
Lancaster University

Initial Failure Report Gaborone (Botswana)-Abuja (Nigeria)-Oxford (UK) Wroe et al (S. Sheehy Melbourne/Oxford)

- Not all failures and repairs are created equal
- Nigeria has far longer repair times than in the UK, the repair hub is normally in a different continent or South Africa and maintenance is often not to the same standard
- Interestingly Botswana which is a fairly affluent country and pays for manufacturer's warranty, service and repair has similar downtime with more faults to LMICs
- MLC (multi-leaf collimator) has the most faults but diagnostics, RF and vacuum contribute to the longest downtime



Looking for solutions for building affordable RT

- **Define the problem**
- **Gather information** from African hospitals/facilities regarding challenges experienced in providing radiotherapy in Africa compare these to data from **HIC**.
- **Identify** the challenges from those who live with them day-to-day
- **Create design specifications** for a radiotherapy machine to meet these challenges for an improved design
- Assess applications of **ML, AI and use of cloud-computing** in African and LMIC settings
- Create **conceptual design report** for the radiotherapy system to enable technical design and prototyping in next phase

STELLA Questionnaire

Overview

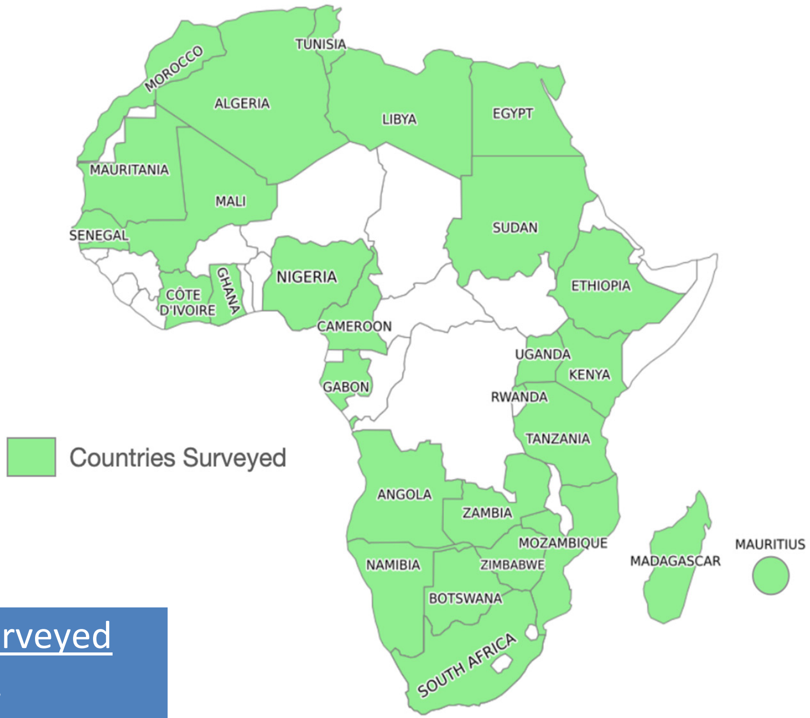
- We asked 36 questions in 5 key areas shown in the table to at least one facility in all African countries with RT access.
- Also sent the survey to facilities in the UK, Canada and the USA, for comparison.
- We examined: the LINAC model, environment, services, subsystems, treatment and imaging.

Focus	Questions
Model	What manufacturer and model? Year of installation?
	What number of treatments are performed per year on each machine?
Environment	What is the temperature and humidity in the area?
	What is the speed and availability of the internet connection?
	How reliable is the electricity supply?
	What is the floor area and ceiling height of the shielded area?
	What photon energy is your shielded area able to safely operate at?
Services	Do you have a service contract? Who provides it? What is the annual cost?
	How often does the machine have maintenance/tuning/calibration?
	What type of failures can you repair locally?
	Number of staff available for in-house repairs? Are staff formally trained?
Subsystems	How do you identify machine faults? Is it easy?
	Do you have problems with the vacuum system? How often?
	Do you have problems with the vacuum pump? Do you keep spares? Can you repair locally?
	Do you keep spare RF sources? Can you repair locally?
	Do you have problems with the MLC? Do you keep spares? Can you repair locally?
	Do you have problems with the electron gun? Do you keep spares? Can you repair locally?
	How much down-time do you experience?
	Do you have any software problems?
Treatment and Imaging	Does your hospital have diagnostic CT near the radiotherapy area?
	Do you use a tilting Couch? How important is this feature?
	How important is it for a LINAC to offer electron treatment mode?

A table highlighting the questions asked on the questionnaire

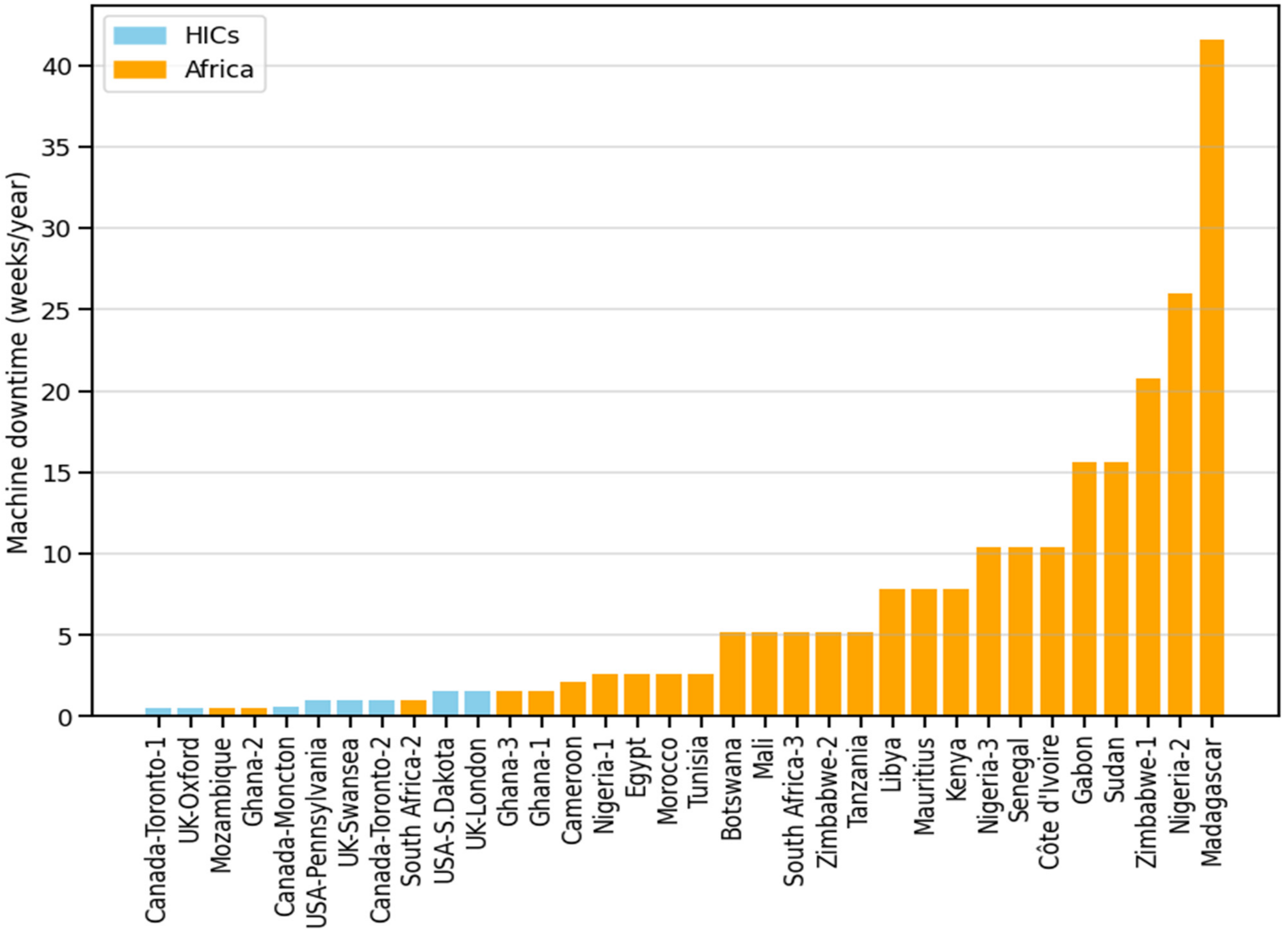
Data Obtained from African Countries That Have LINAC-based RT and from HICs

Country	Total number of LINACs surveyed
UK	25
USA	14
Canada	11
Switzerland	2
Jordan	1



Total LINACs surveyed
HICs: 52
Africa: 59

Downtime in weeks comparison African and HICs



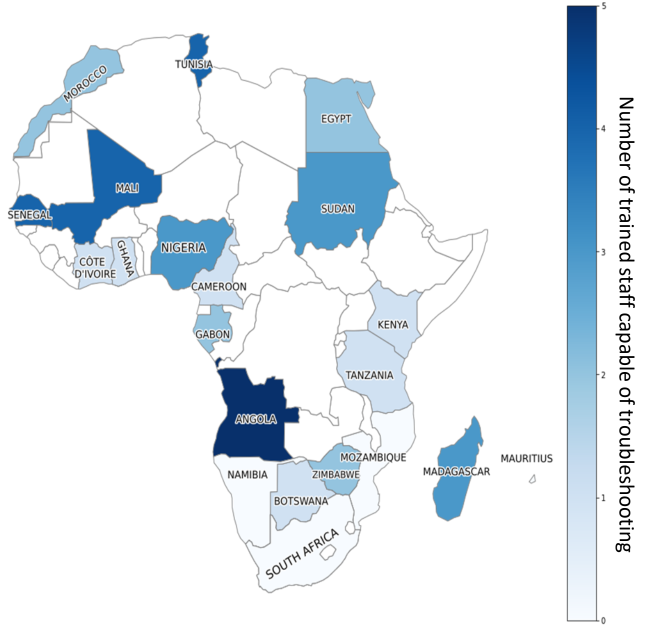
Education and Internet Connectivity

Are staff trained to troubleshoot the LINAC?

- **20/27** (74%) African facilities have staff who have attended a formal training course.
- **18/19** (95%) are supplied by the manufacturer, either on-site or online.

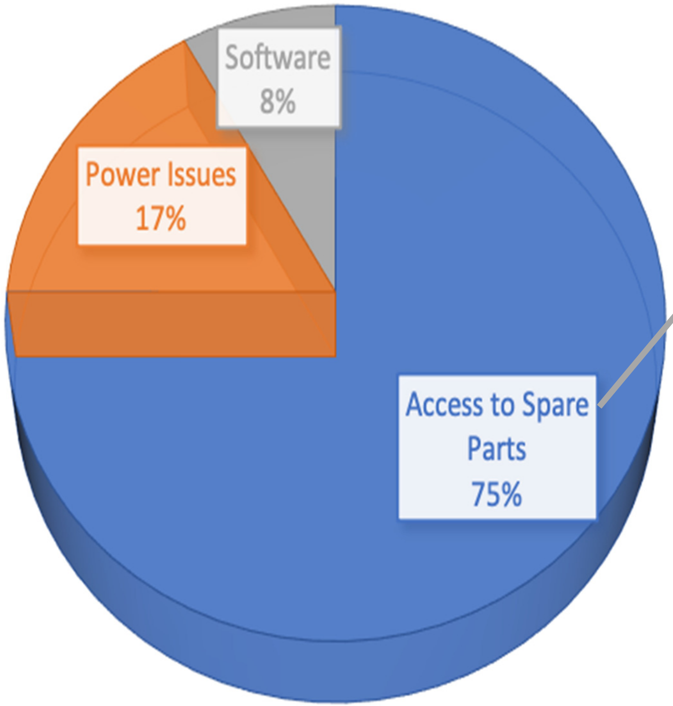
How fast is the internet connection?

- **28/30** (93%) African facilities have a medium or high internet speed (kb/s - Mb/s).
- Bandwidth may vary dramatically between facilities.



A choropleth map of the number of trained staff capable of troubleshooting

Overall Reasons For LINAC Downtime from Survey



- **69%** don't have access to spare **RF Sources**.
- **65%** don't have access to spare **Vacuum Pumps**.
- **63%** don't have access to spare **Electron Guns.**
- **32%** don't have access to spare **MLCs**.

Summary of Current Findings

- Local repair and access to parts a significant factor determining downtime
- Software problems are a major contributor to downtime
- Frequency and voltage fluctuations also appear important
- Current data suggests - component importance on downtime: **Electron Gun**, **Vacuum Pump, MLC, RF source, Software, Power Fluctuation**

Current Project Goals for STELLA LINAC

- **Key issues** from reviewing **the various surveys, data gathering exercises, failure mode data and discussions at workshops**
- It was clear that a single machine cannot be realised to encompass all aspects. Categorisation Priorities:

High Priority	• Staff training and skill requirements to run a RT machine • Severities and cost of repairing technical failures • Frequency of failures (i.e. component lifetime)
Medium Priority	• Making the electrical system robust to fluctuations and minimising the power requirements • Robustness to temperature fluctuations and dust • Delivering higher dose • Initial capital cost and the cost of spare parts
Lower Priority	• Size of the machine • Total machine lifetime (as opposed to component lifetime) • Easy upgradability

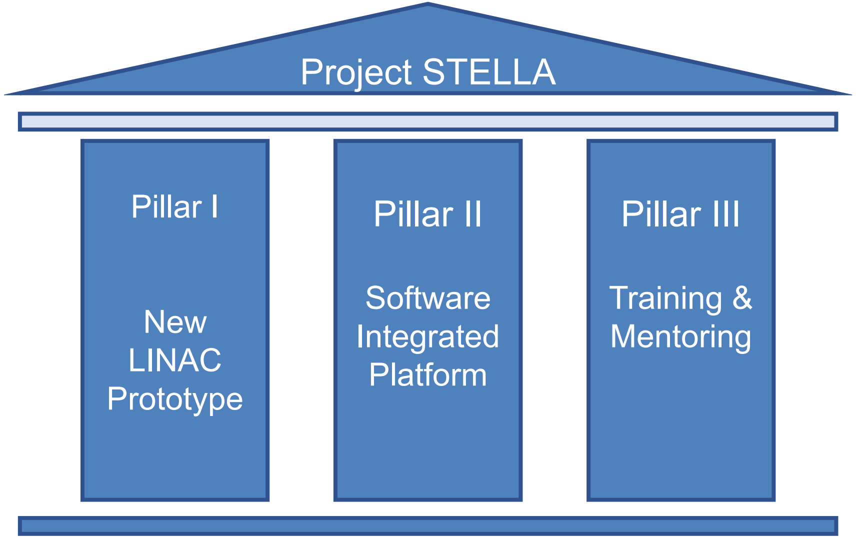
Key Design Choices

- **Key design goal is to offer Higher Availability and Reliability**
- **Repairs are difficult & reduce availability**
  - Choice of design and components to improve lifetime
  - Choose components that can be replaced in house with less-expensive spares
  - Use of machine learning to predict faults in advance to protect the machine and order spares
  - Use of AI to identify the cause of faults that have happened
  - Can we simplify the MLCs

Where are we now?

- Gathered information from African hospitals/facilities regarding challenges faced in providing radiotherapy in Africa
- Identified the challenges with those who live with them day-to-day
- Created design specifications for a radiotherapy machine to meet these challenges for an improved design
- Assessing applications of ML, AI and use of cloud-computing in African and LMIC settings
- Created conceptual design report for the radiotherapy system to enable technical design and prototyping in next phase
- **Securing funding for building and testing prototype**

A Unique Collaboration



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Ultimate Goal

- Robust, modular, reliable and easier to use machines

- Are affordable
  - ✓ Reduce Capital cost
  - ✓ Reduce Operating costs
  - ✓ Reduce Service and Maintenance costs
  - ✓ Reduce Number of experts needed
  - ✓ Increase Number of treated patients per year

- With the aim to

  - ✓ Improve patient through-put
  - ✓ Increase effectiveness
  - ✓ Decrease running cost, staff cost, machine cost
  - ✓ Expand access to RT

This work would not be possible without the great collaborators, so a huge thank you to ICEC, ITAR, STELLA and SEEIIST teams

Especially to:

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Thank you for listening