FROM MEDICAL ACCELERATORS TO FRONTEIR ACCELERATORS… AND BACK AGAIN

JAI FEST
7th DECEMBER 2018

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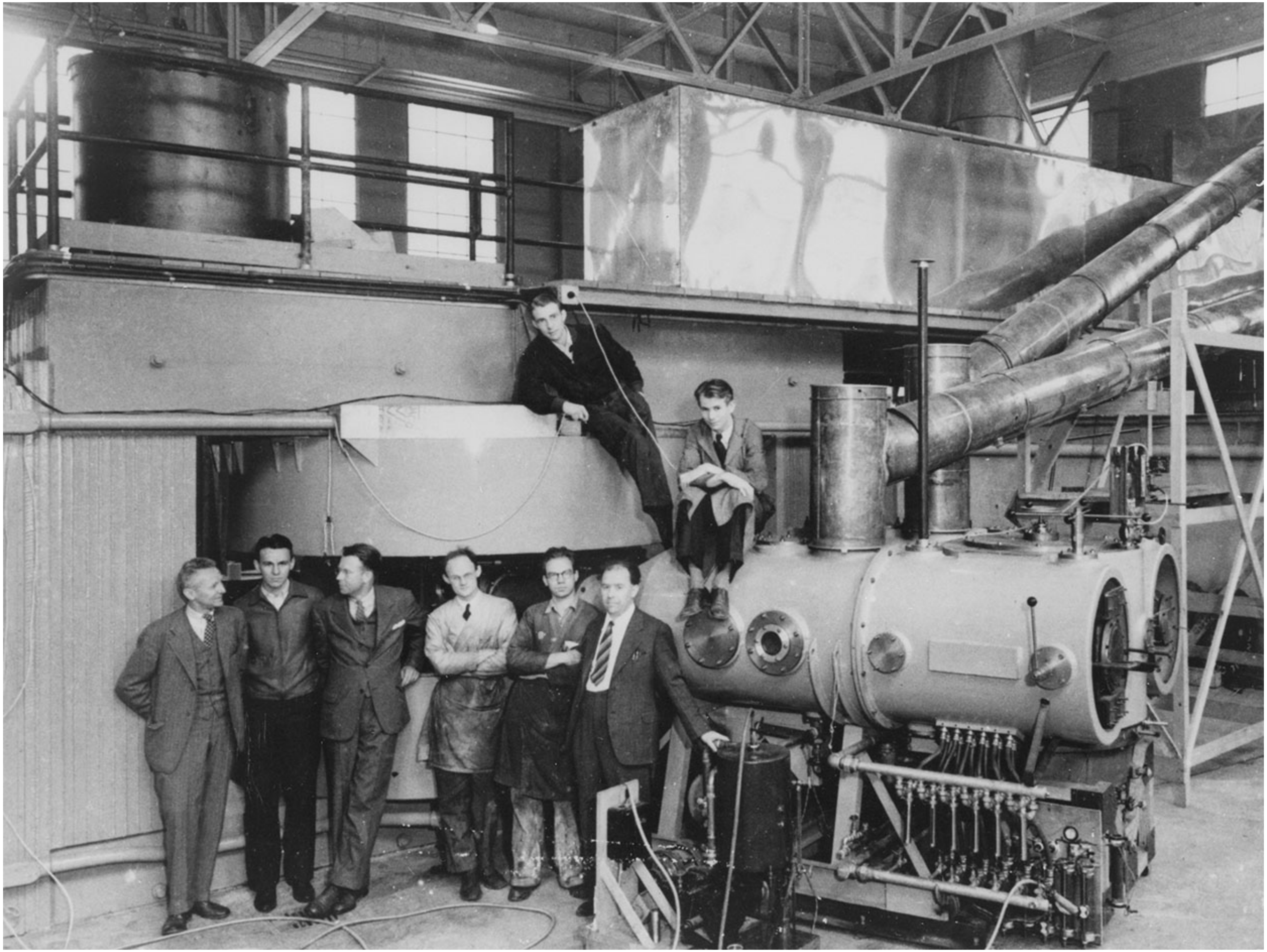
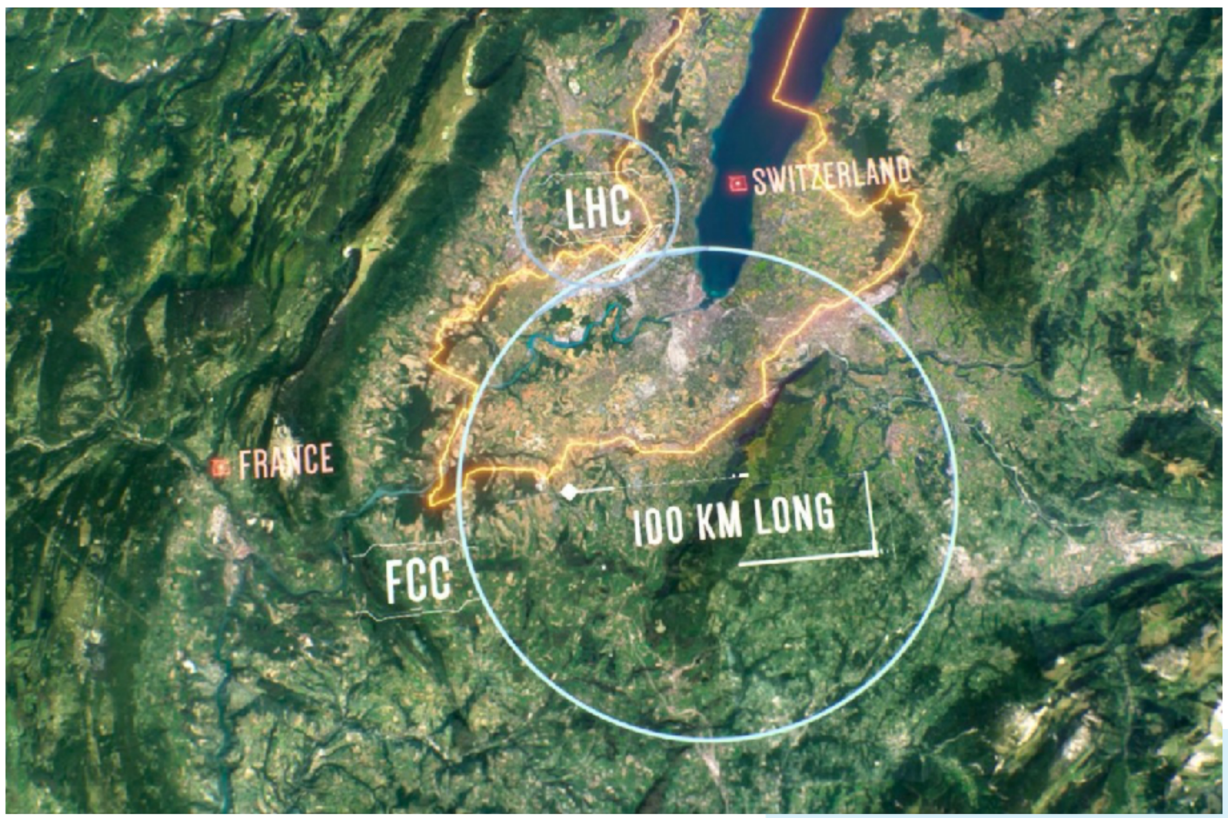
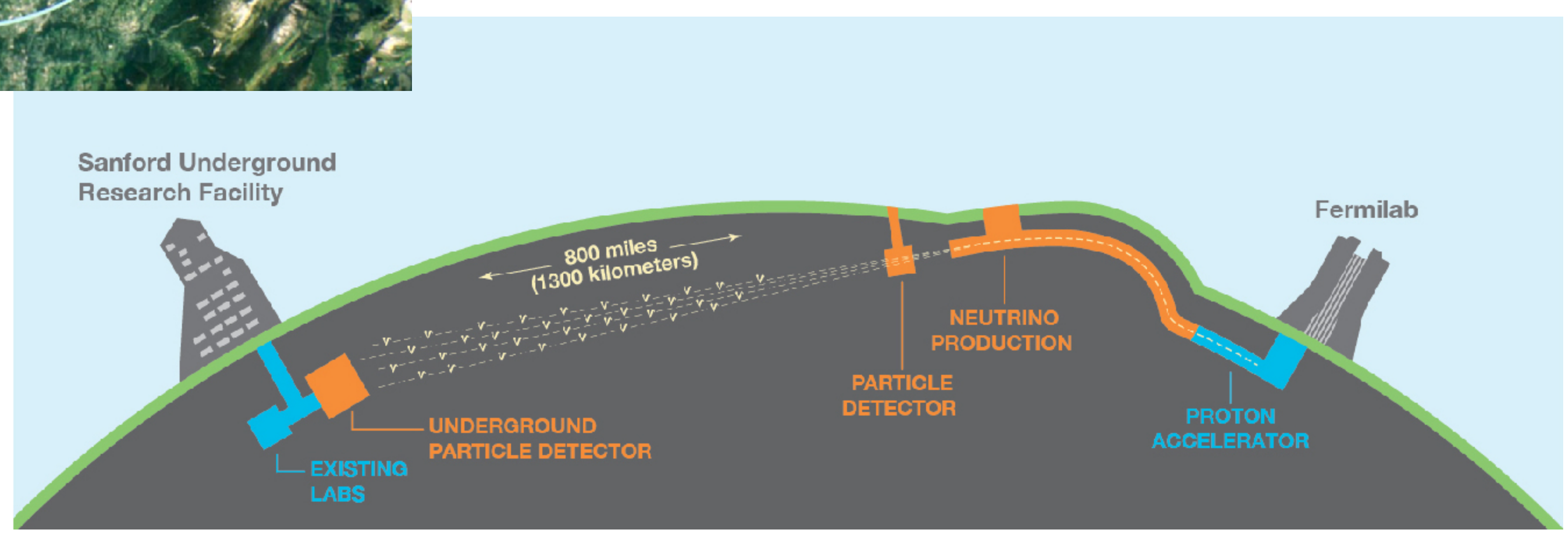
1940’s

2010’s



1930’s


LHC
SWITZERLAND
FRANCE
100 KM LONG
FCC


Sanford Underground
Research Facility
800 miles
(1300 kilometers)
Fermilab
NEUTRINO
PRODUCTION
PARTICLE
DETECTOR
UNDERGROUND
PARTICLE DETECTOR
EXISTING
LABS
PROTON
ACCELERATOR

2020s?

10 challenges for 21st century accelerators

(a non-exhaustive list, obviously…)

BEAM ENERGY

COMPLEXITY

BEAM INTENSITY

MAGNET STRENGTH

SIZE & COST

AUTOMATION & CONTROL

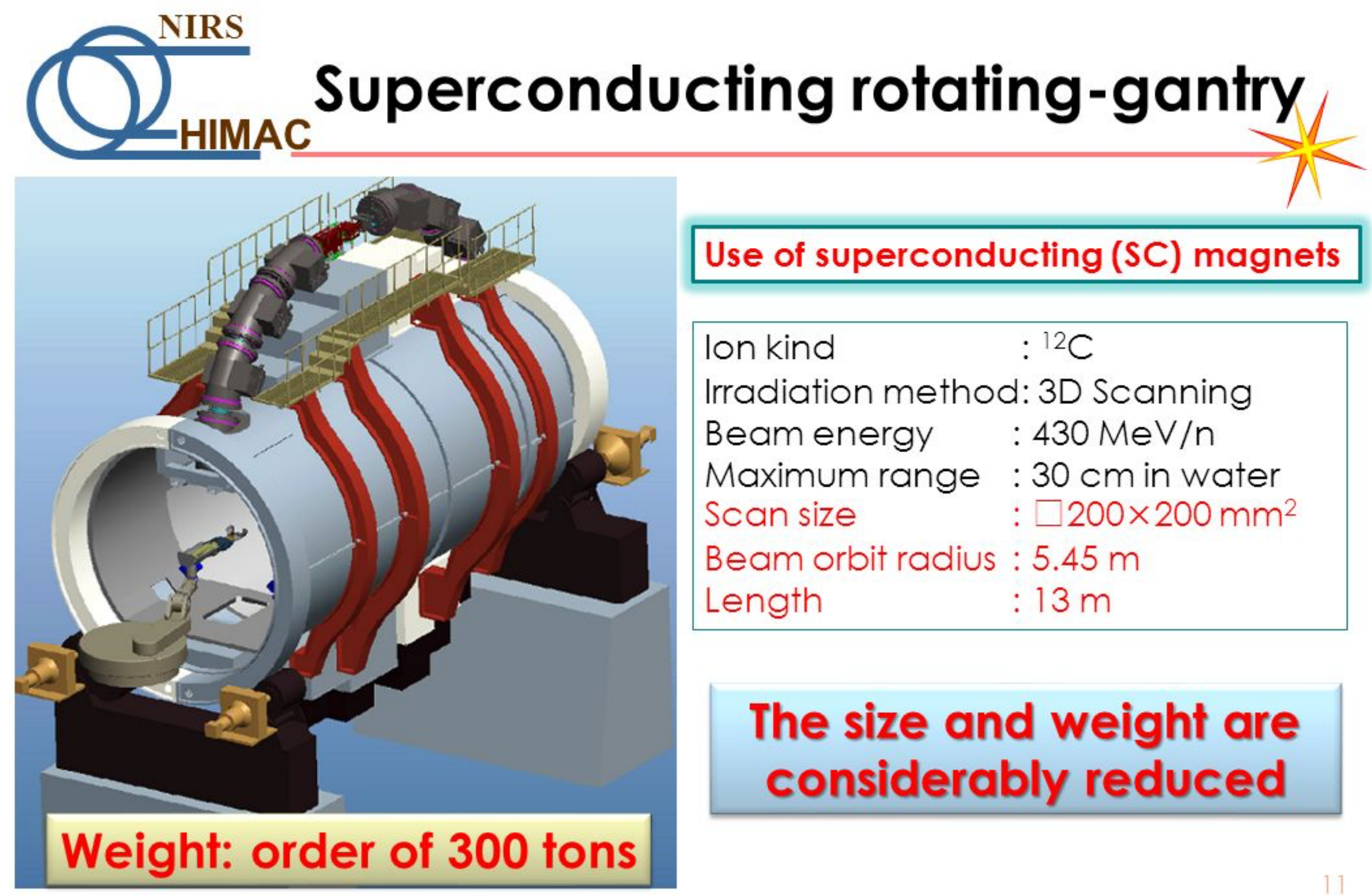
ACCELERATING GRADIENT

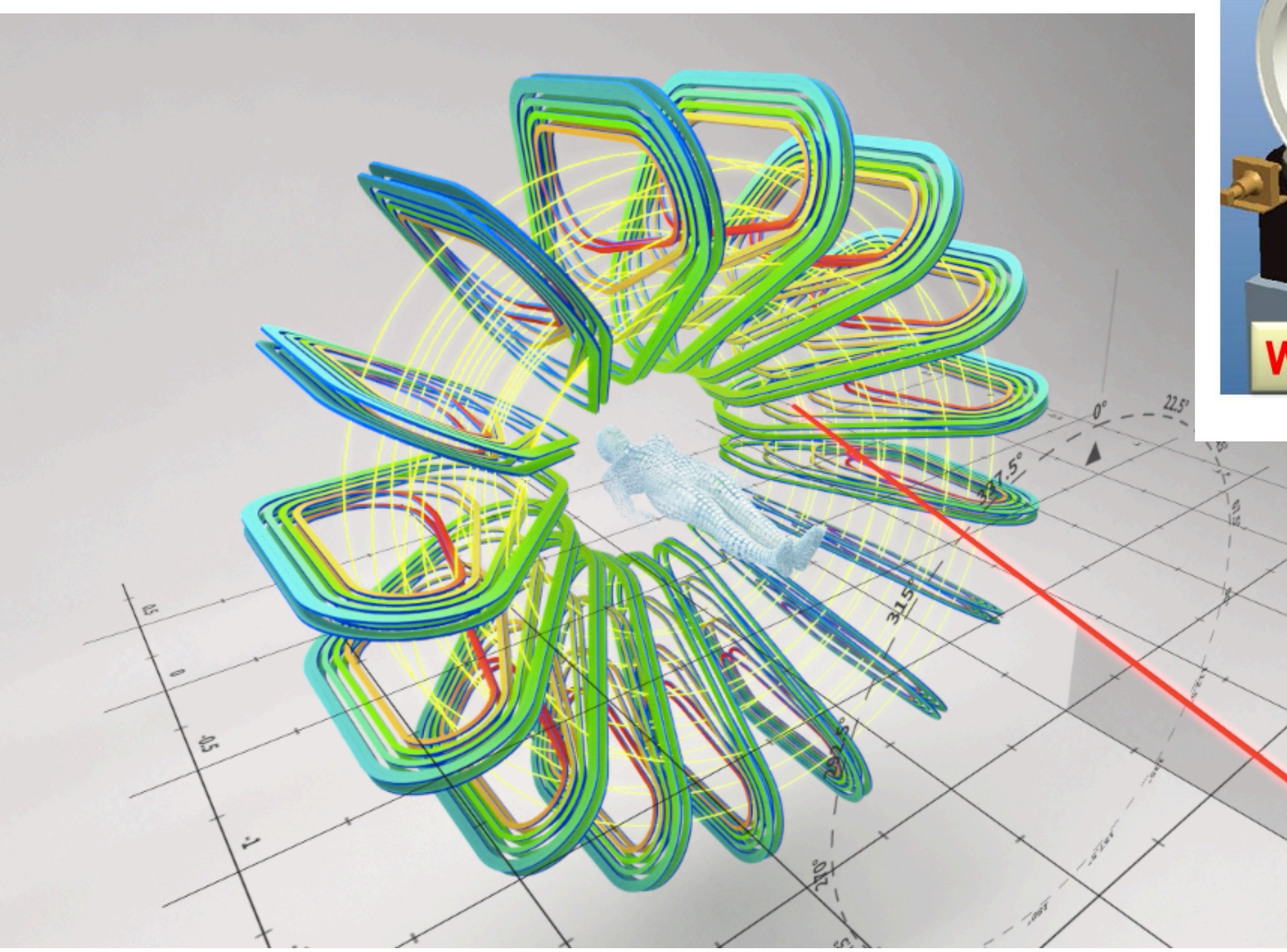
RELIABILITY

SIMULATION

MAGNET STRENGTH

What is achievable with (HT) superconductors?
Will we have to play off field strength and field quality?



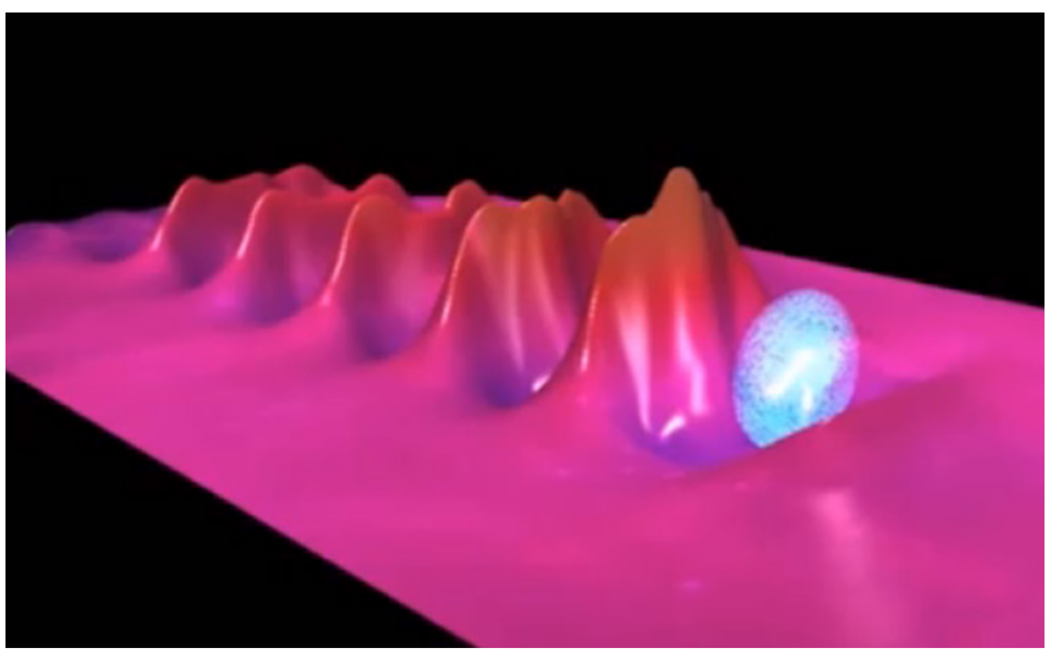


GAToroid, CERN KT

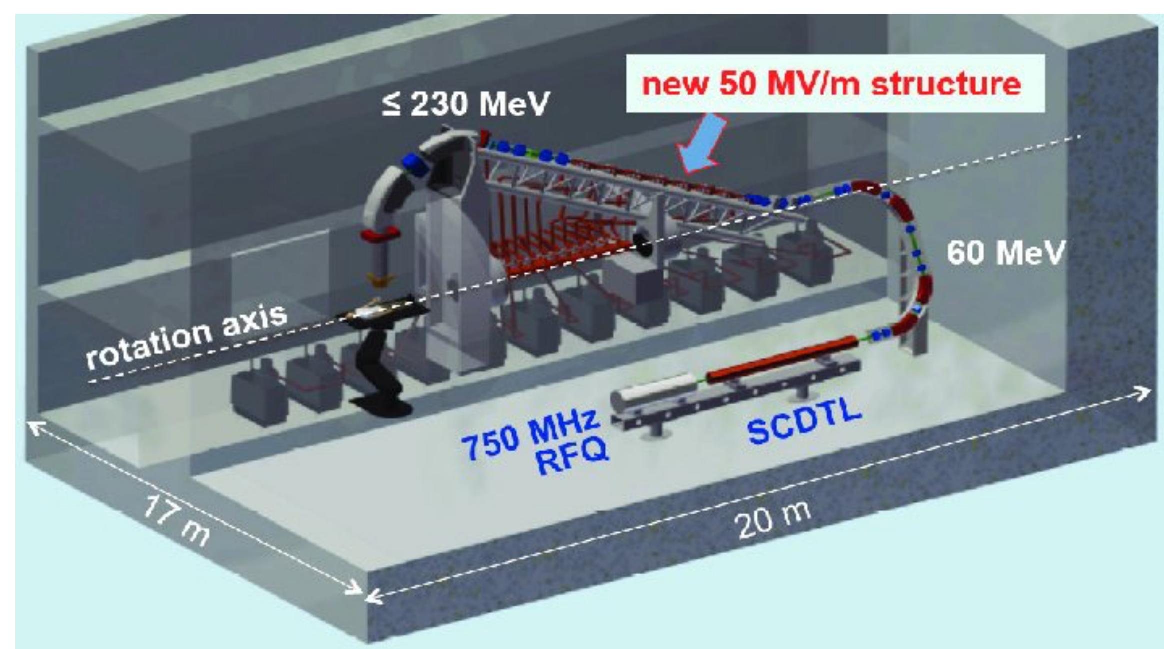
ACCELERATING GRADIENT

What is the ultimate limit in accelerating gradient with NC, SC and novel techniques?

High gradient, compact structures
(High frequency)



Laser driven sources



‘TULIP’ turning proton therapy LINAC

AUTOMATION

Can AI be used to control extremely complex systems? Will we always need operators?

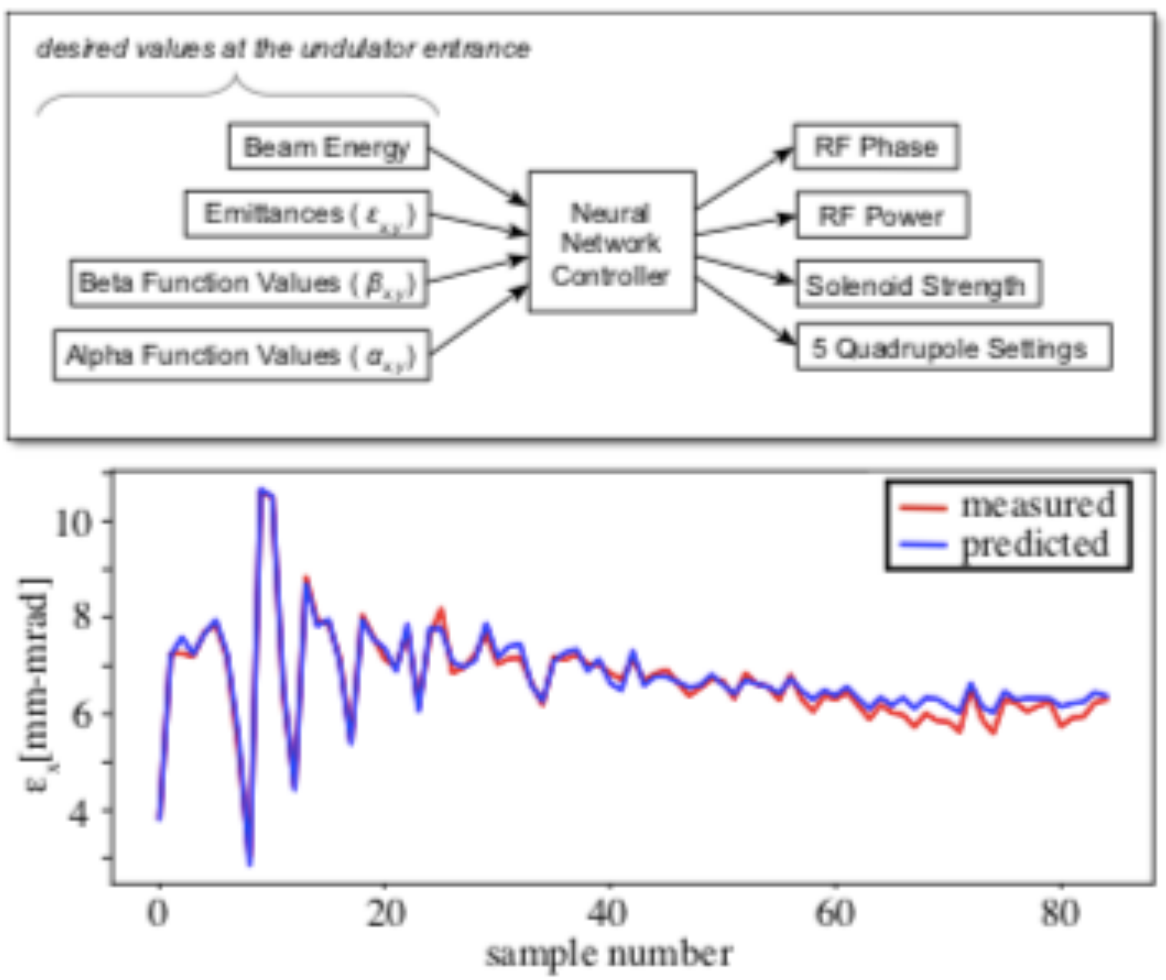
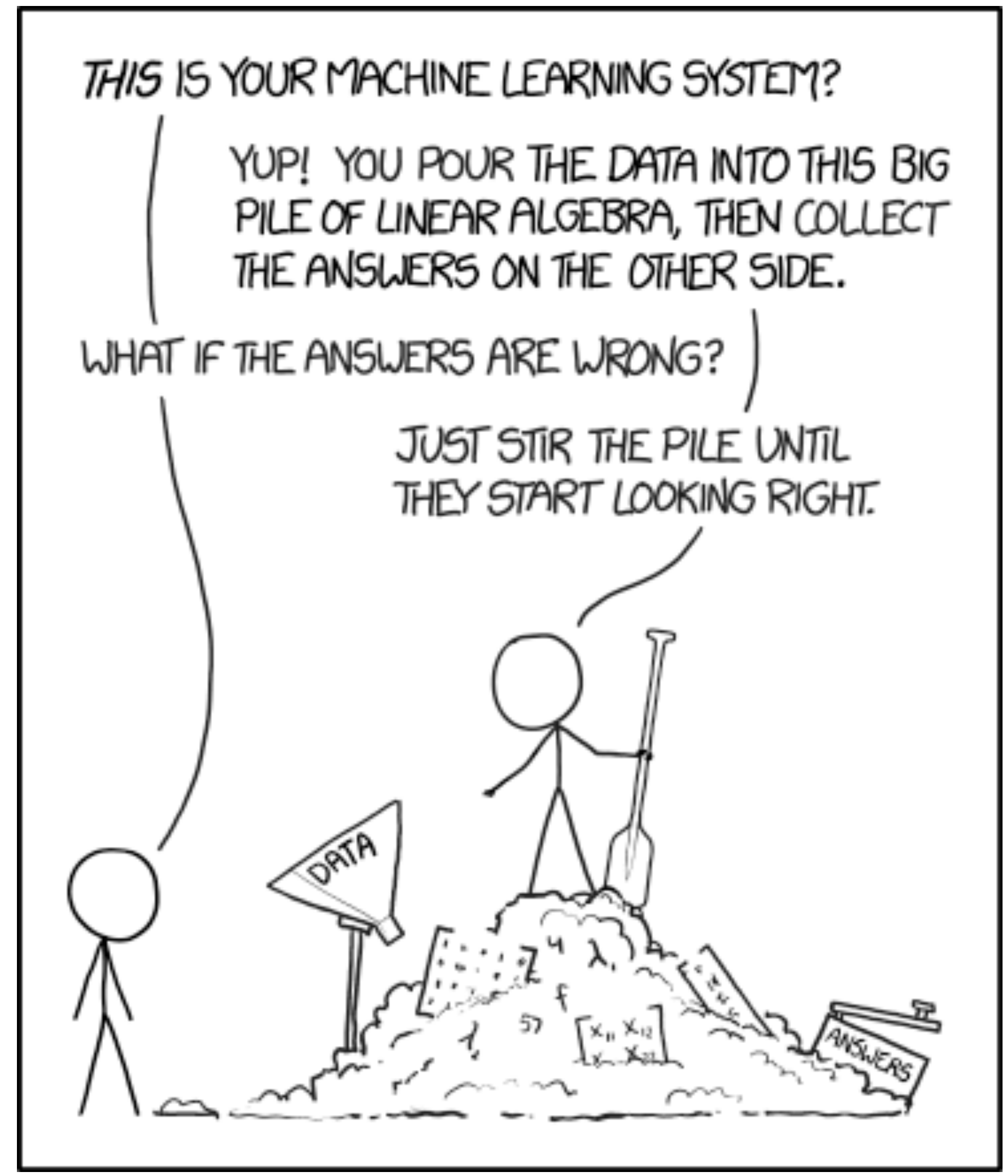
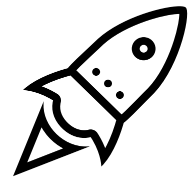


Figure 4: NN control policy for switching between operating conditions and predictions of surogate model.



http://accelconf.web.cern.ch/AccelConf/ipac2018/papers/thygbe1.pdf

RELIABILITY



COMPLEXITY

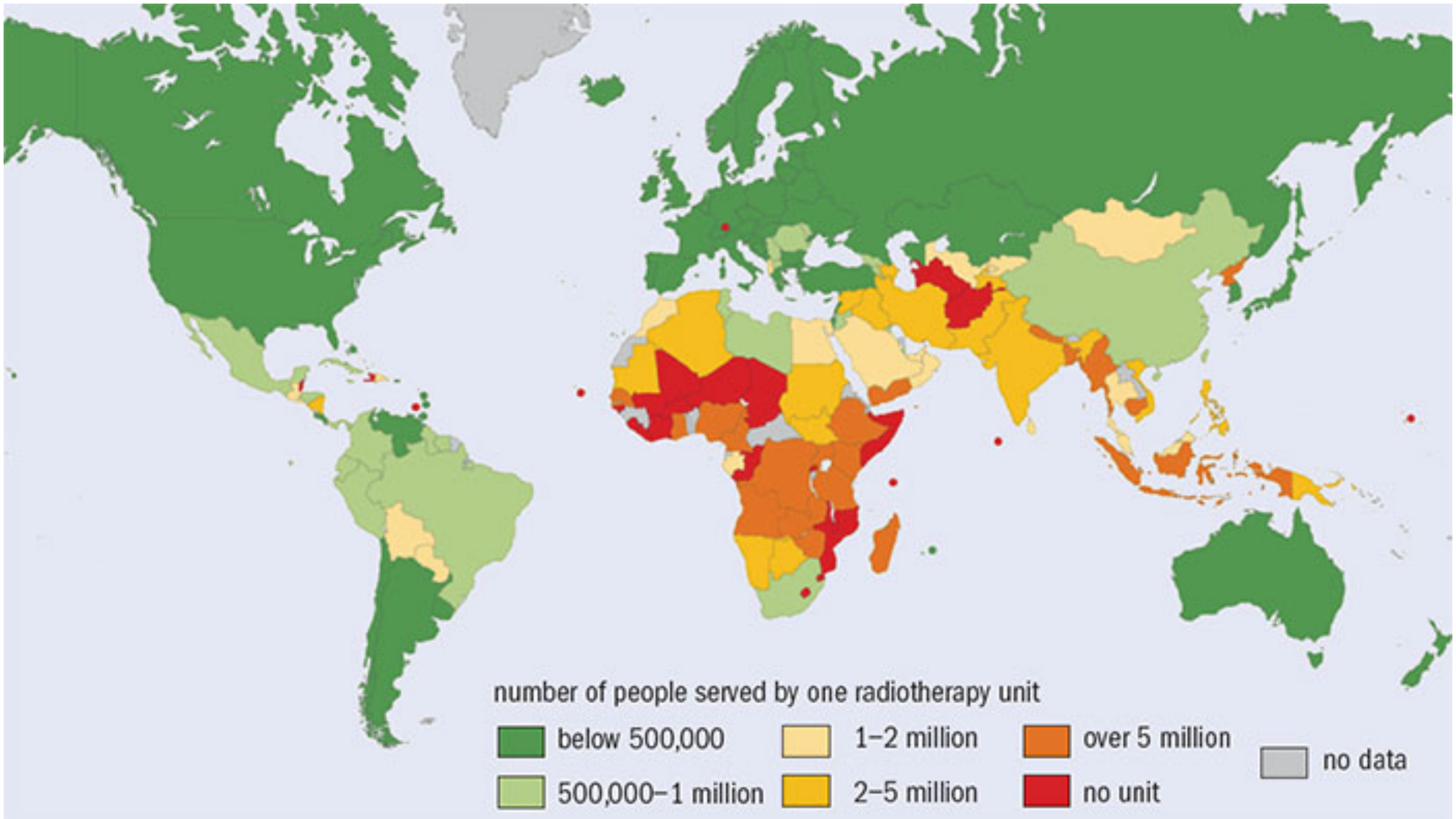
Trip duration	Max. number of trips
1 second - 6 seconds	120 trips per day
6 seconds - 1 minute	40 tips per day
1 minute - 6 minutes	5 trips per day
6 minutes - 20 minutes	350 trips per year
20 minutes - 1 hour	99 trips per year
1 hour - 3 hours	33 trips per year
3 hours - 8 hours	17 trips per year
8 hours - 1 day	6.7 trips per year
1 day - 3 days	2.9 trips per year
3 days - 10 days	1 every 4 years
more than 10 days	1 every 10 years

						Consequences			Reliability					Maintenance						
Level	Component	Number of component	Function	Failure mode	Possible causes	Locally	Next level	On the Beam	Random (data)	Random (level)	Lifetime (data)	Lifetime (level)	On demand	Corrective actions	Preventive actions	Spares and tools	Access time (h)	Time to repair (h)	Time to restart locally (h)	Time to restart next level (h)
1	Vacuum system	1																		
2	Vacuum beam pipe	1		Vacuum not good for operation																
3	Ion source	1																		
4	Turbo pump	4	Pump vacuum from ion chamber	Random mechanical problem	Random failure	Pump not operative	3 out of 4 must be operative otherwise the vacuum is not good enough	No beam		3				Replace pump		Pump	4	1	3	2
				Mechanical wear out	Wear out	Pump not operative	3 out of 4 must be operative otherwise the vacuum is not good enough	No beam				3			Current sensor. Replace pump	Pump	4	1	3	2
				Power supply failure (controller)	Random failure	Pump not operative	3 out of 4 must be operative otherwise the vacuum is not good enough	No beam		3				Replace controller		Controller	0	1	0.1	0.5
4	Multi roots	2	Pump vacuum from ion chamber	Random mechanical problem	Random failure	Pump not operative	1 out of 2 must be operative otherwise the vacuum is not good enough	No beam		3				Replace pump		Pump	4	1	3	2
				Mechanical wear out	Wear out	Pump not operative	1 out of 2 must be operative otherwise the vacuum is not good enough	No beam				4			Current sensor. Replace pump	Pump	4	1	3	2
4	Valves (not gate valve)	8	Isolete pump from beam vacuum for maintenance	Vacuum leak	Random failure	Air in beam pipe	Lose vacuum	No beam		4				Replace valve		Valve	4	1	3	2
4	Gauge	6?	Mesure vacuum	No signal/wrong signal	Random failure	No vacuum data at one point	If X gauges fail, we can't measure the vaccum	No beam (or maybe we can always continue if there are no loses detected by the BLM?)		3					Replace failed gauges	Gauge	4	1	3	2
3	RFQ	1																		
4	Turbo pump	8	Pump vacuum from beam pipe	Random mechanical problem	Random failure	Pump not operative	2 out of 3 must be operative otherwise the vacuum is not good enough	No beam		3										
				Mechanical wear out	Wear out	Pump not operative	2 out of 3 must be operative otherwise the vacuum is not good enough	No beam				3								
				Power supply failure	Random failure	Pump not operative (one ?)	Bad vacuum	No beam		2										
				Controls failure	Random failure	Pump not operative	2 out of 3 must be operative otherwise the vacuum is not good enough	No beam		4										

32

Bargallo. FMEA for ESS Neutron Source.

RADIOTHERAPY LINACS WORLDWIDE



25 MILLION CASES PREDICTED IN 2035

65–70% WILL OCCUR IN LOW-AND MIDDLE- INCOME COUNTRIES

**CERN hosted workshop on:
"Design Characteristics of a Novel Linear Accelerator for Challenging Environments"**

Norman Coleman, David Pistenmaa (ICEC) Manjit Dosanjh (CERN)
International Cancer Expert Corps &CERN

European Organization for Nuclear Research (CERN)
International Atomic Energy Agency (IAEA)
James Martin Center for Nonproliferation Studies (CNS)
National Aeronautics and Space Administration (NASA)
National Nuclear Security Administration (NNSA)

Task Forces

- **TF1: Technology (Bury the Complexity)**
  a) near term b) long term
- **TF2: Education, Training and Mentoring**
- **TF3: Global Connectivity and Development**

https://indico.cern.ch/event/560969/

https://home.cern/about/updates/2017/11/combatting-cancer-challenging-environments

Can we made a medical LINAC that is: cheaper, more robust, easier to maintain, modular, reliable while providing state-of-the-art treatment?

Uganda’s only (broken) radiotherapy unit in 2018

A MULTI-FACETED PROBLEM...

- EXPENSIVE MACHINES & MAINTENANCE
- LACK OF SPARE PARTS
- LACK OF TRAINED ENGINEERS
- POLITICS & BUREAUCRACY

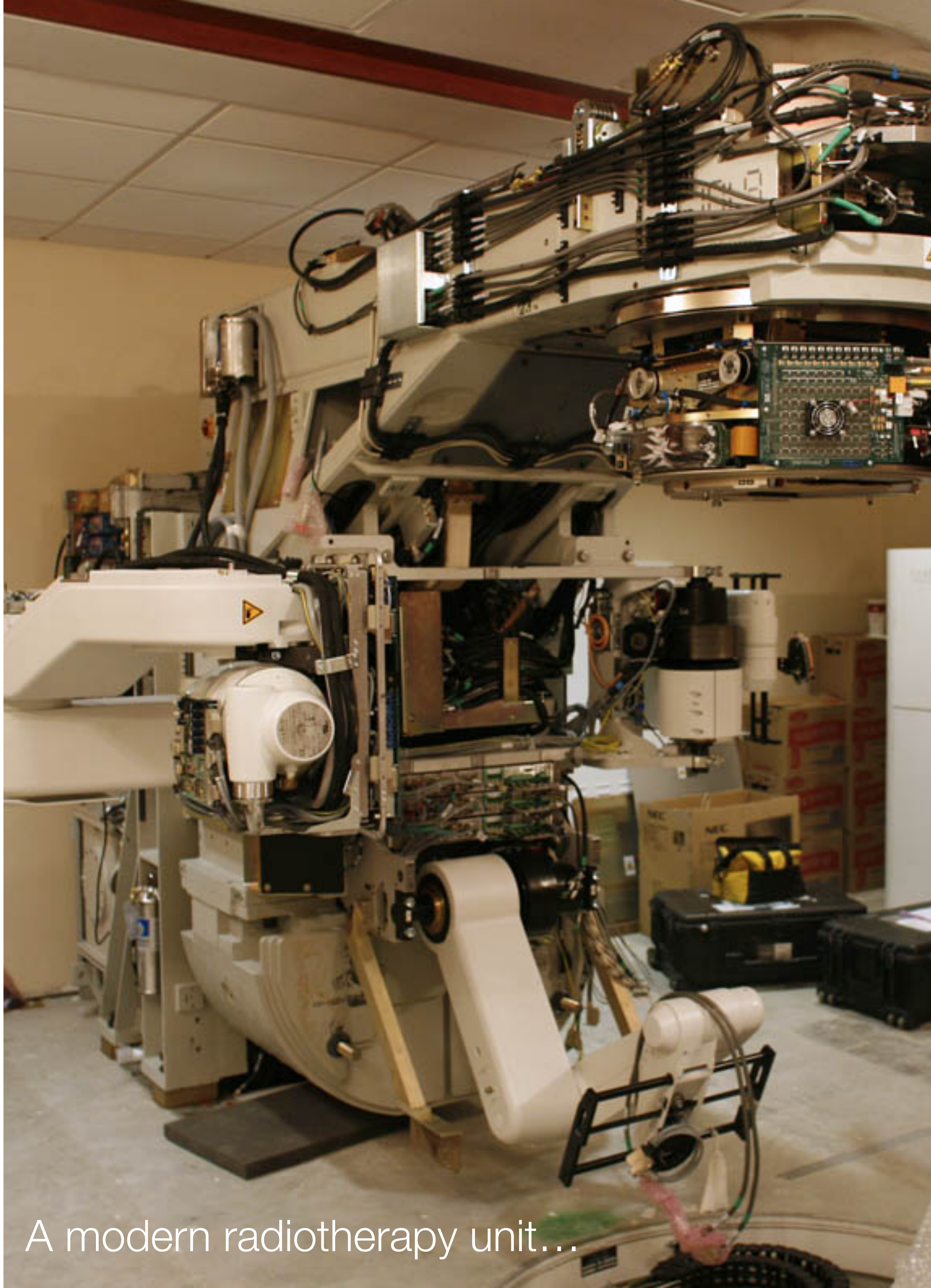
- ACCELERATOR PHYSICISTS & ENGINEERS
- ONCOLOGISTS, MEDICAL PHYSICISTS
- INTERNATIONAL CO-OPERATION
- TRAINING & EDUCATION
- COMMUNICATION & POLITICAL INFLUENCE

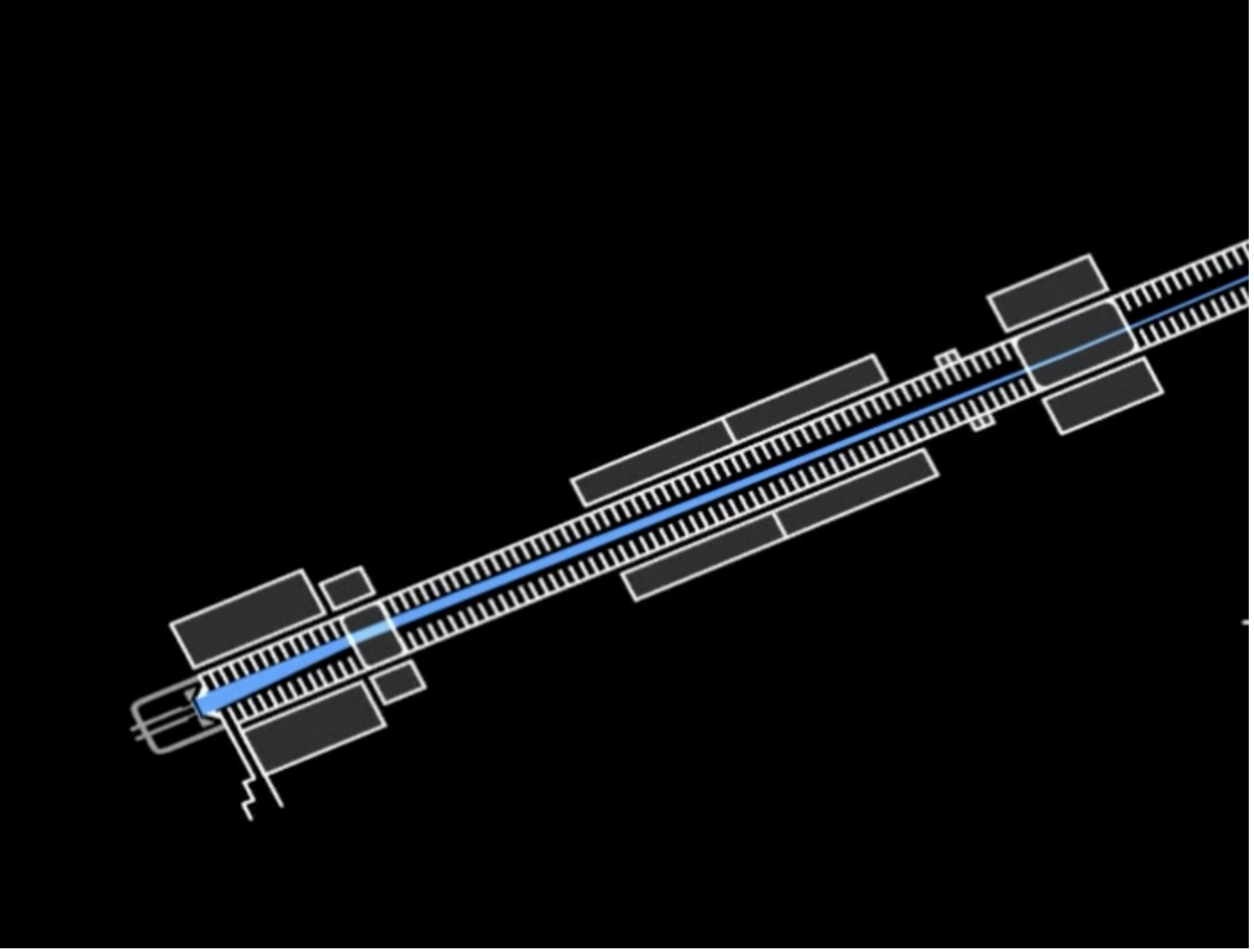
STFC & Global Challenges Research Fund

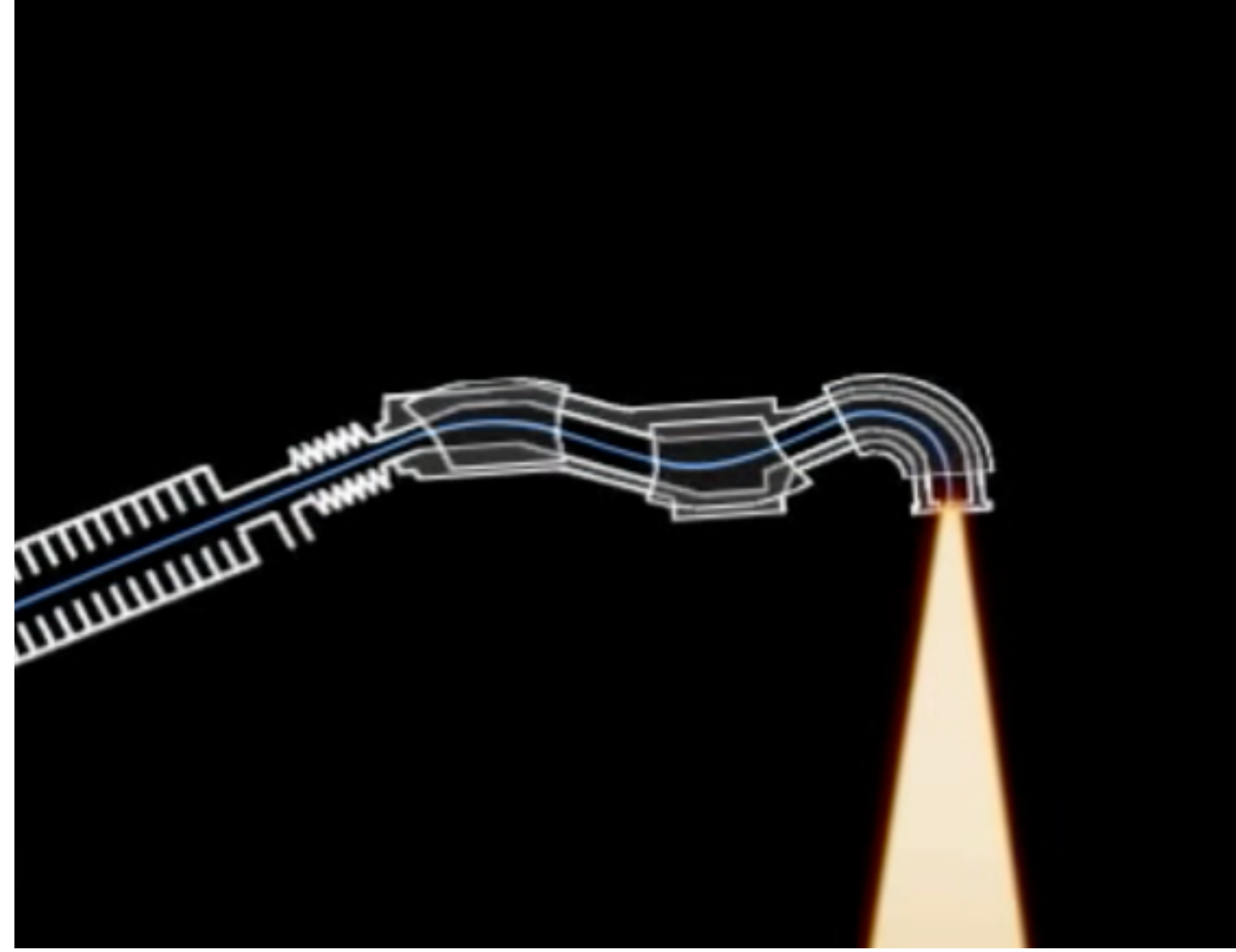
1. Study of Accelerator Technology Options - P. McIntosh, DL/STFC
2. **Robust permanent magnet beam delivery systems - S. Sheehy, Oxford/JAI**
3. RF Power Systems and Optimized RF Structures for Electron Beam Acceleration - I. Konoplev, Oxford/JAI
4. Linear Accelerator Simulations for Stable and Sustainable Operation of Developing Country Radiotherapy Linear Accelerators - S. Boogert, RHUL/JAI
5. Cloud-based Electronic Infrastructure in Support of Linac-based Radiotherapy in Challenging Environments, A. Aggarwal, KCL/Guys

+ 2 x STFC 'Opportunities' GCRF grants

Student (L. Wroe, MPhys) independently awarded funding by Laidlaw Scholarship to study failure modes of medical LINACs (will visit Africa during summer).


A modern radiotherapy unit…





FOCUSING MAGNETS

- Keeps the beam controlled through the main linac body
- In main linac section there are also a number of steering magnets
- Should be kept fairly simple in terms of beam dynamics

BENDING MAGNETS

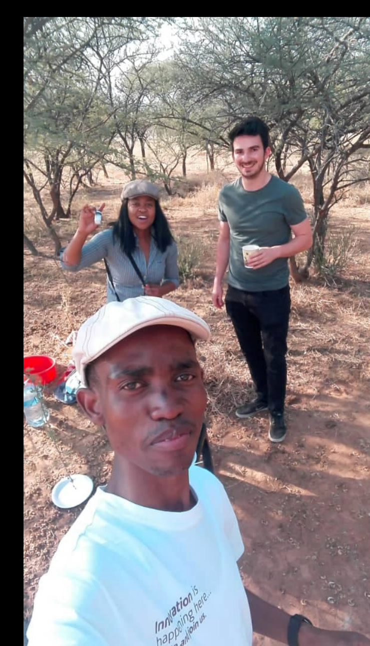
- Bring the beam around to the patient
- Different companies at present use different focusing systems
- Keeping the whole system compact can be achieved by thinking carefully about this part

WHAT CAN WE DO?

The current-generation sophisticated linear accelerators in use in upper-income countries often do not function well in the adverse conditions encountered in LMICs. In addition to

cancer treatment capacity can be met. There is a need to accelerate the adoption and deployment of new technologies that meet the contextual needs of low-income and middle-income countries, which can have regular interruptions to energy supply, lack of air temperature control in buildings, and weak health systems. For example, an environmentally friendly

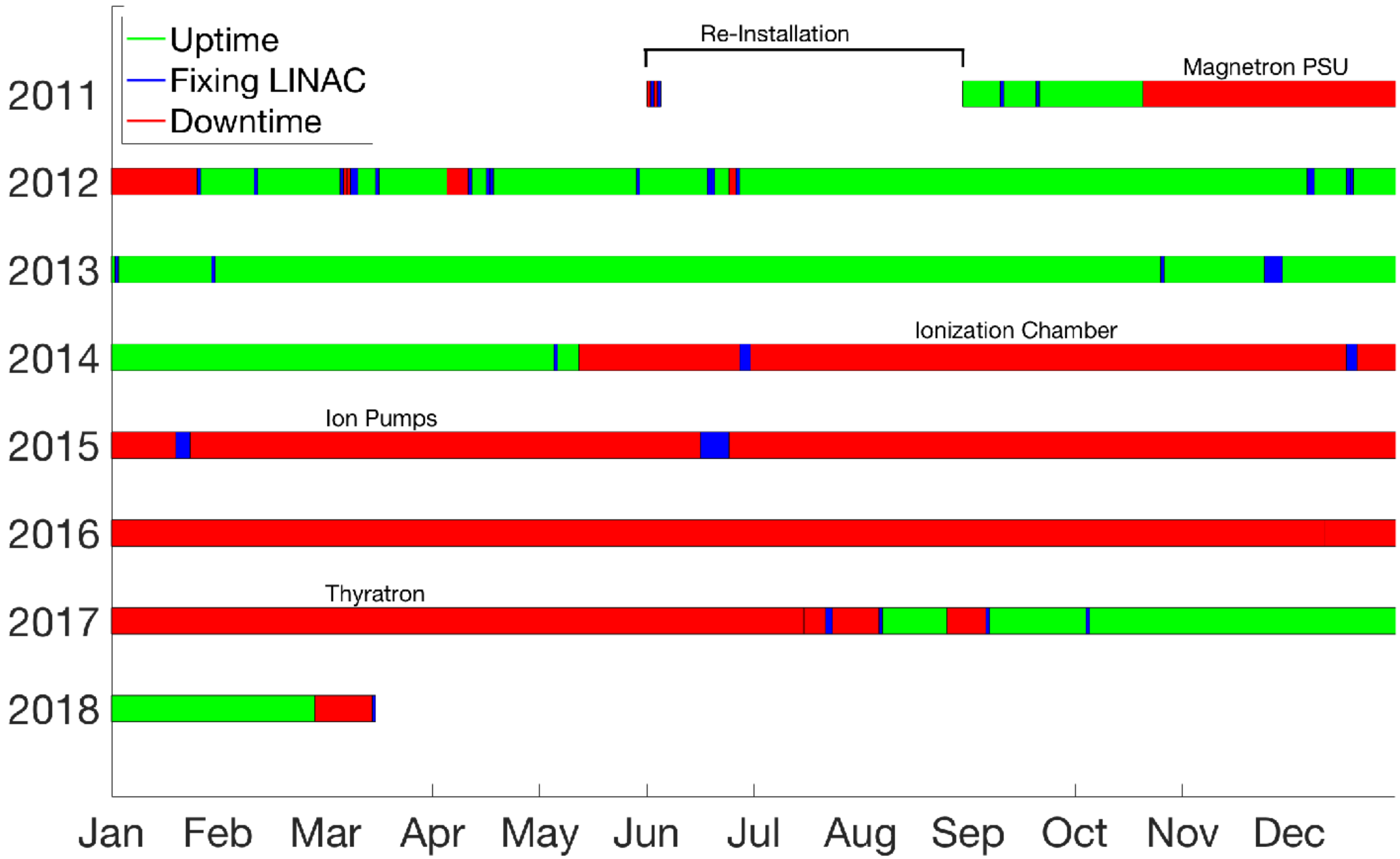
But no-one had any data to show this….



Laurence Wroe

Funded by Laidlaw Scholarship

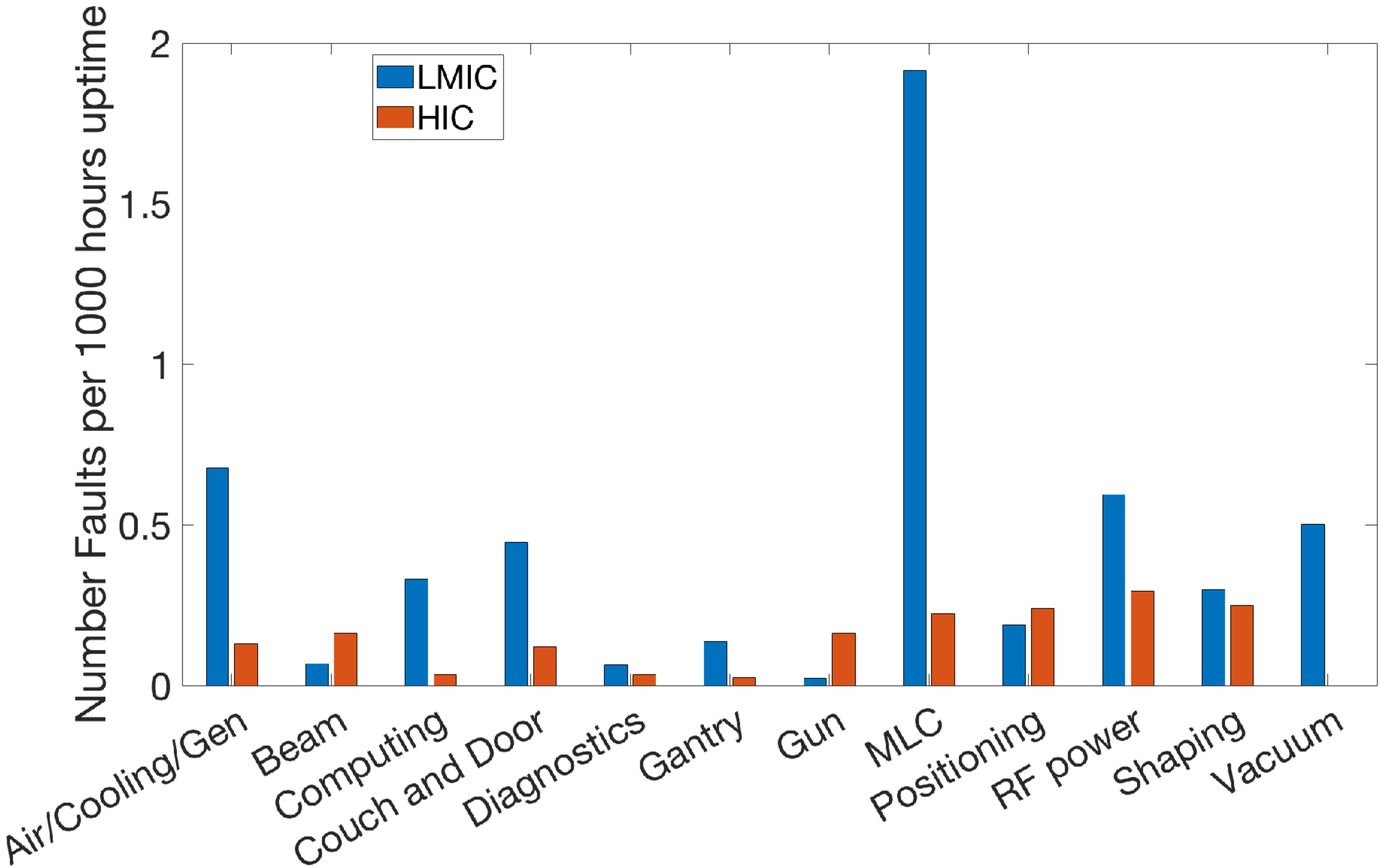
Abuja, Nigeria



Comparative analysis of radiotherapy LINAC downtime and failure modes in the UK, Nigeria and Botswana

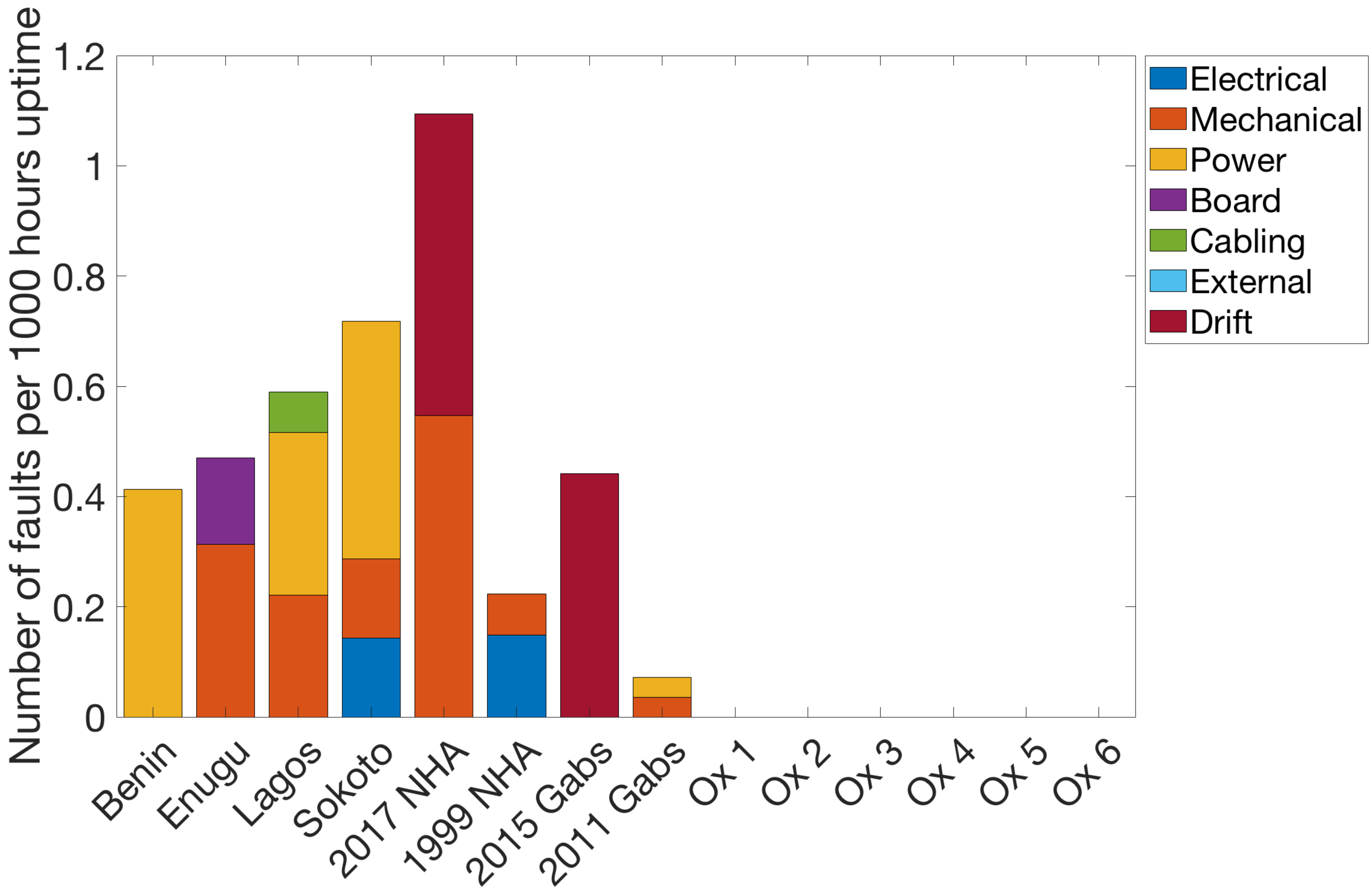
L. M. Wroe[a], C. S. Chinedu, T. A. Ige[b], S. Grover, R. Makufa[c], S. L. Sheehy[a], on behalf of the CERN-ICEC-STFC Medical LINAC collaboration

[a]*Department of Physics, University of Oxford*
[b]*National Hospital Abuja (NHA), Nigeria*
[c]*Life Gaborone Private Hospital (GPH), Botswana*

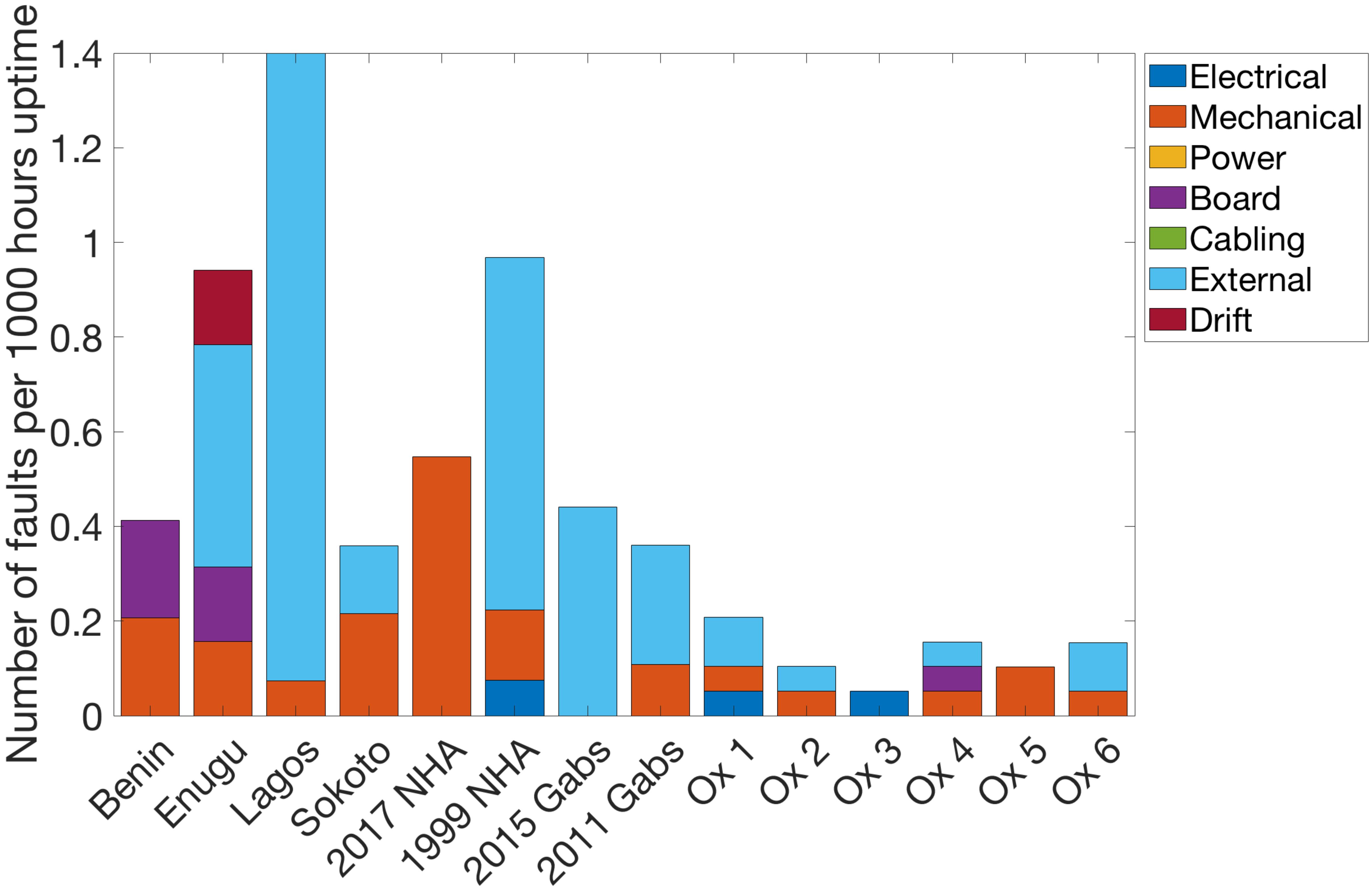


Number Faults per 1000 hours uptime
2
1.5
1
0.5
0
LMIC
HIC
Air/Cooling/Gen
Beam
Computing
Couch and Door
Diagnostics
Gantry
Gun
MLC
Positioning
RF power
Shaping
Vacuum

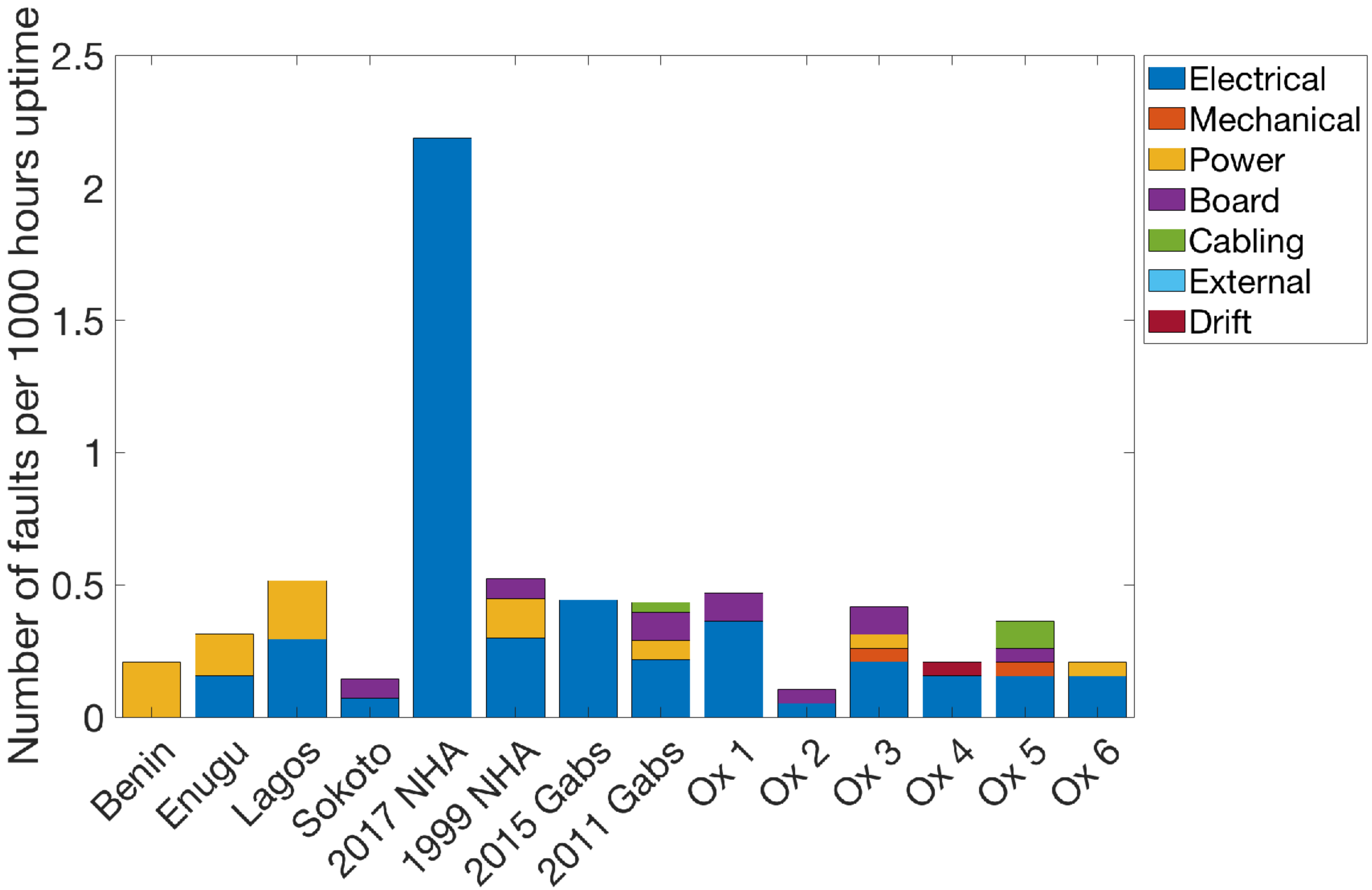
Vacuum subsystem



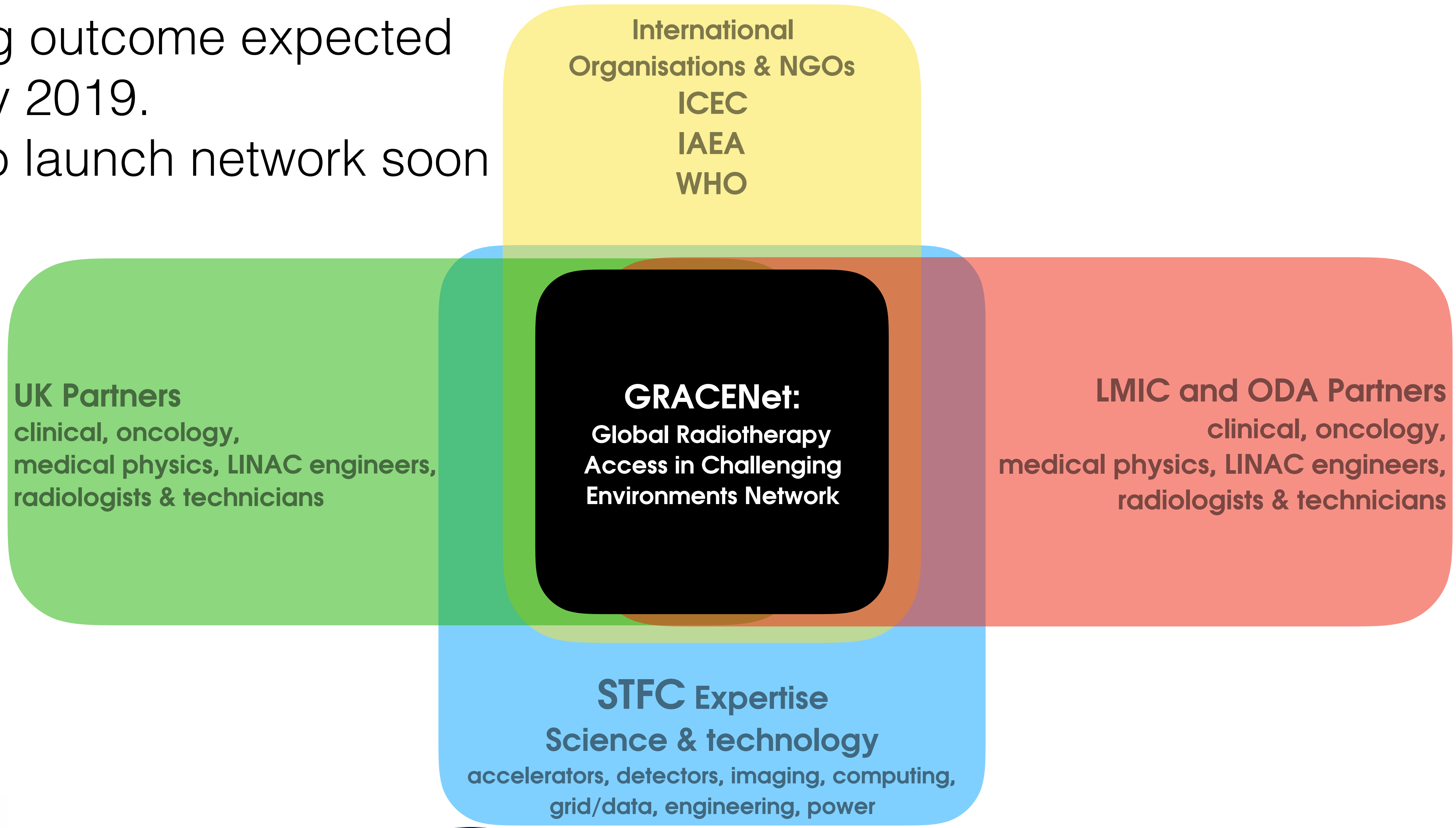
Air/Cooling/Generator subsystem



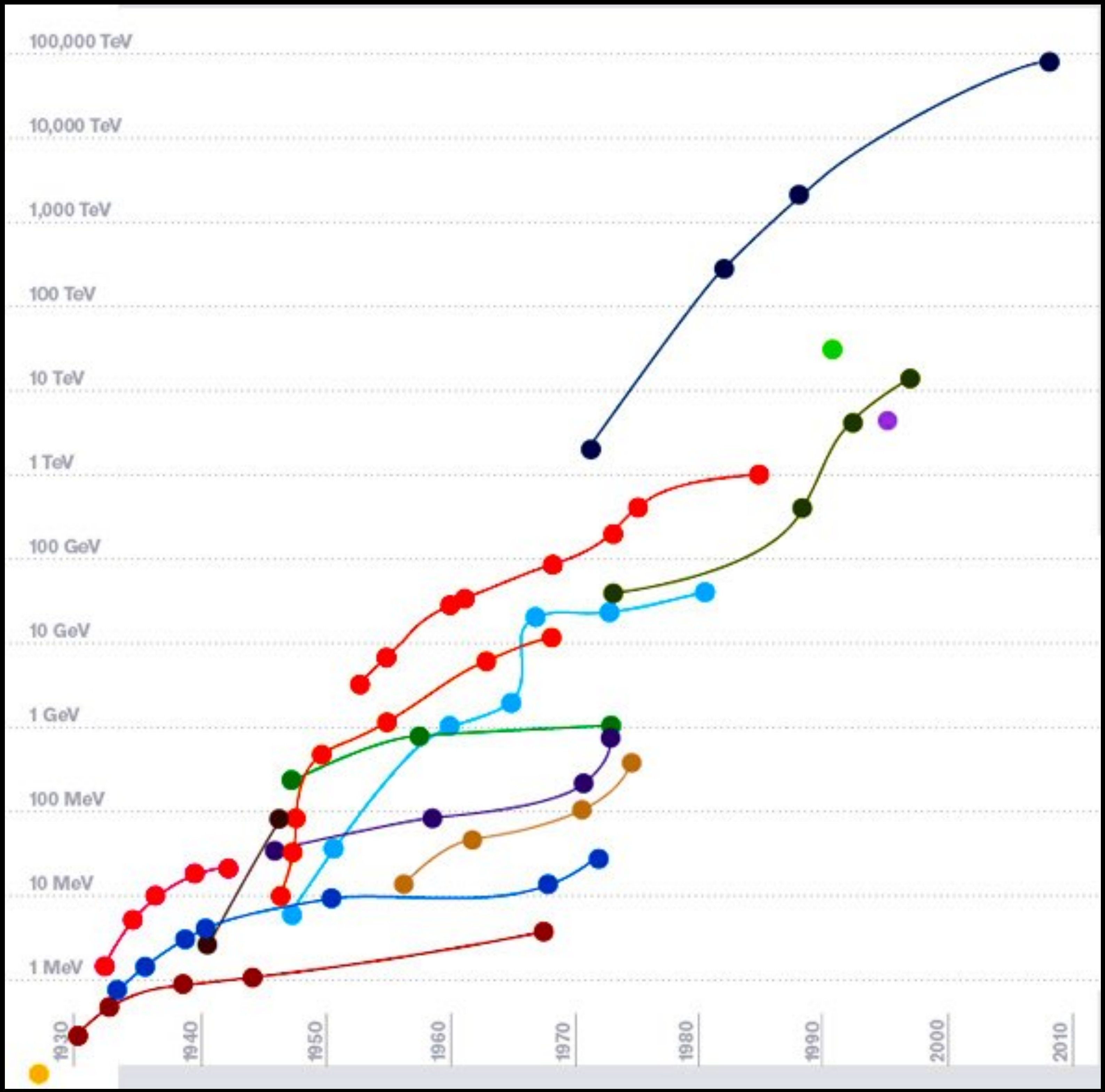
RF power subsystem



Funding outcome expected January 2019.
Hope to launch network soon after!



LIVINGSTON PLOT



particle physics

vaccines, archaeology, etc…

proton therapy

radiotherapy, security

water, food, materials

treatment, sterilisation

https://www.symmetrymagazine.org/article/october-2009/deconstruction-livingston-plot

10 challenges for 21st century accelerators

(a non-exhaustive list, obviously…)

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BEAM INTENSITY

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