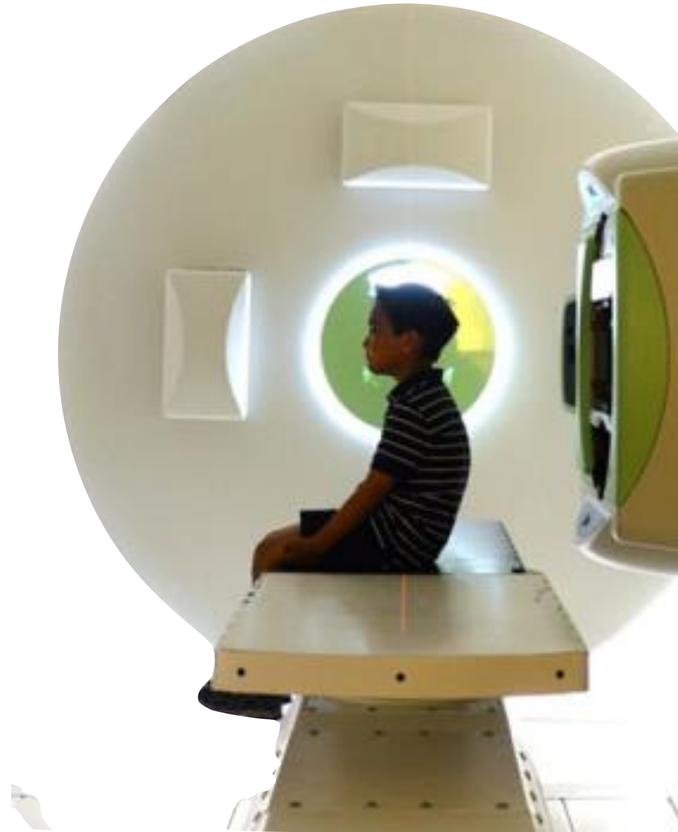
Protons, Perspex and Cancer

Nigel M Allinson, MBE

UNIVERSITY OF LINCOLN

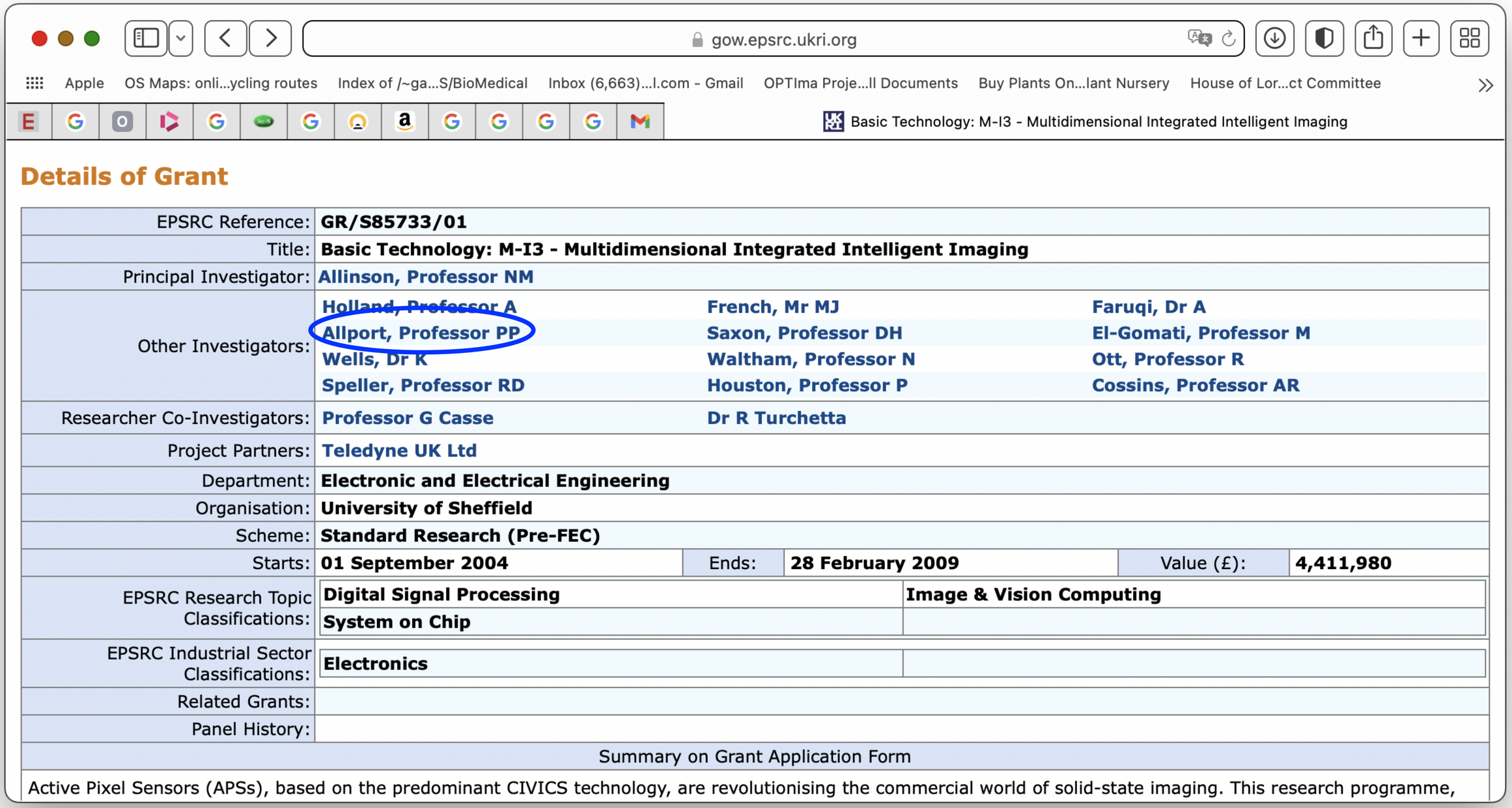
PRaVDA

OPTima



Allport-Fest – XXVII - II - MMXXIII

A Short Preamble

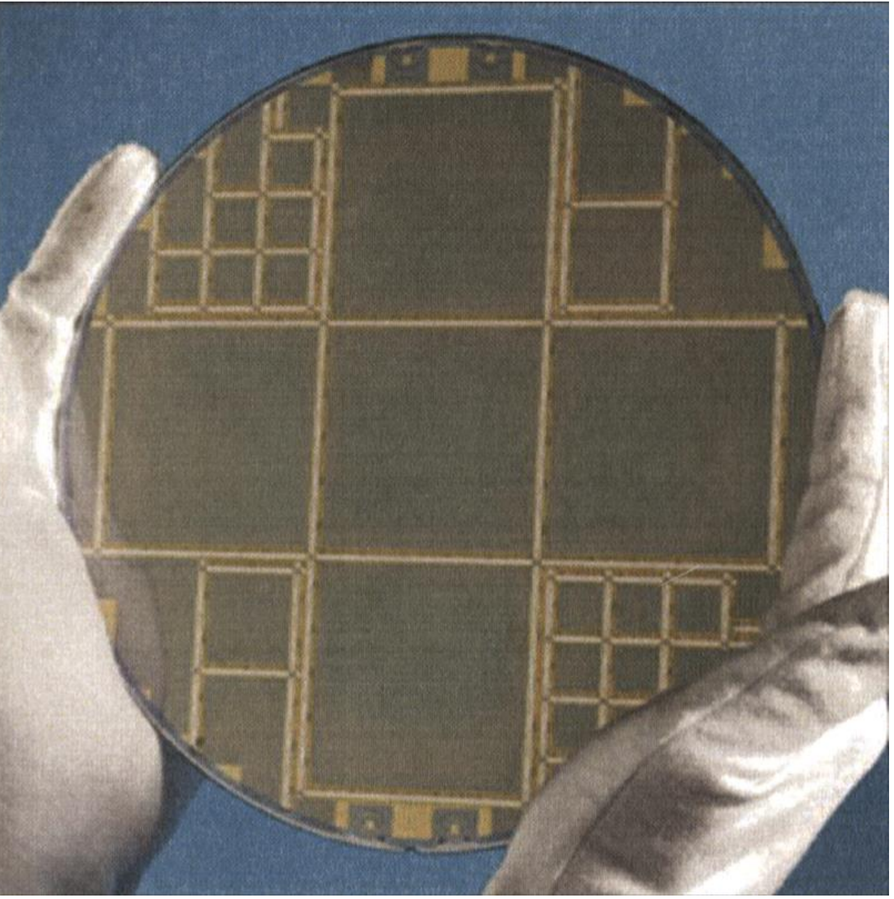


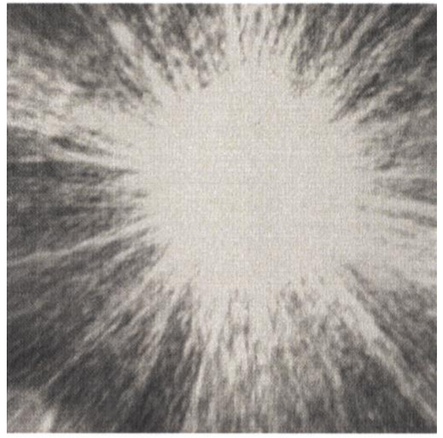
Details of Grant

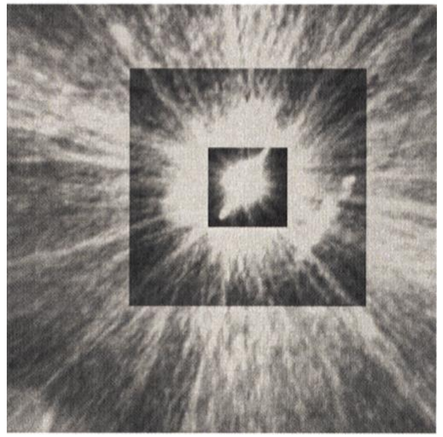
EPSRC Reference:	**GR/S85733/01**				
Title:	**Basic Technology: M-I3 - Multidimensional Integrated Intelligent Imaging**				
Principal Investigator:	**Allinson, Professor NM**				
Other Investigators:	**Holland, Professor A**	**French, Mr MJ**	**Faruqi, Dr A**		
	Allport, Professor PP	**Saxon, Professor DH**	**El-Gomati, Professor M**		
	Wells, Dr K	**Waltham, Professor N**	**Ott, Professor R**		
	Speller, Professor RD	**Houston, Professor P**	**Cossins, Professor AR**		
Researcher Co-Investigators:	**Professor G Casse**	**Dr R Turchetta**			
Project Partners:	**Teledyne UK Ltd**				
Department:	**Electronic and Electrical Engineering**				
Organisation:	**University of Sheffield**				
Scheme:	**Standard Research (Pre-FEC)**				
Starts:	**01 September 2004**	Ends:	**28 February 2009**	Value (£):	**4,411,980**
EPSRC Research Topic Classifications:	**Digital Signal Processing**		**Image & Vision Computing**		
	System on Chip				
EPSRC Industrial Sector Classifications:	**Electronics**				
Related Grants:					
Panel History:					

Summary on Grant Application Form

Active Pixel Sensors (APSs), based on the predominant CIVICS technology, are revolutionising the commercial world of solid-state imaging. This research programme,







A 54mm x 54mm – 1.8Megapixel CMOS Image Sensor for Medical Imaging

Andy T. Clark, Nicola Guerrini, Nigel Allinson, *Member, IEEE*, Sarah E. Bohndiek, Jamie Crooks, Tim Pickering and Renato Turchetta, *Member, IEEE*

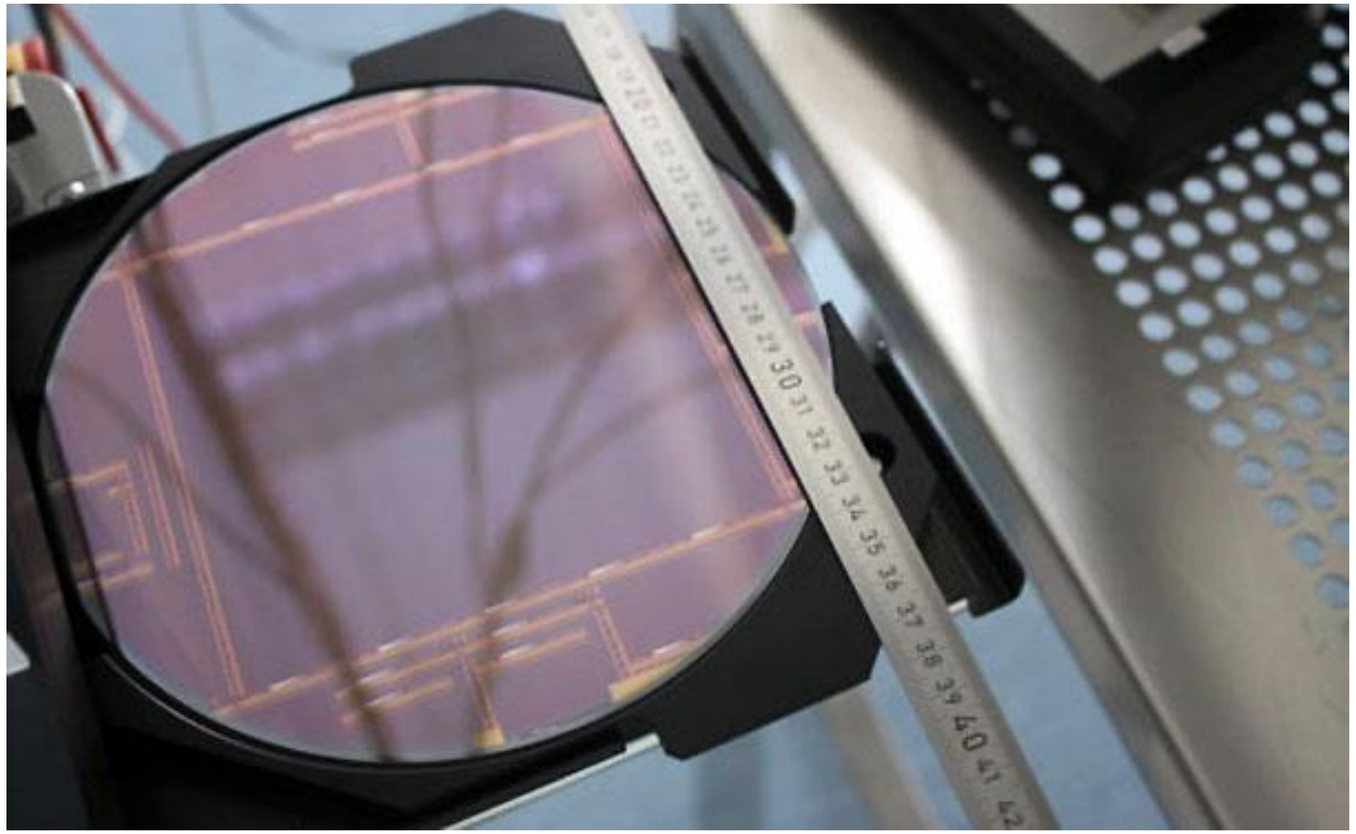
MI-3's Remit

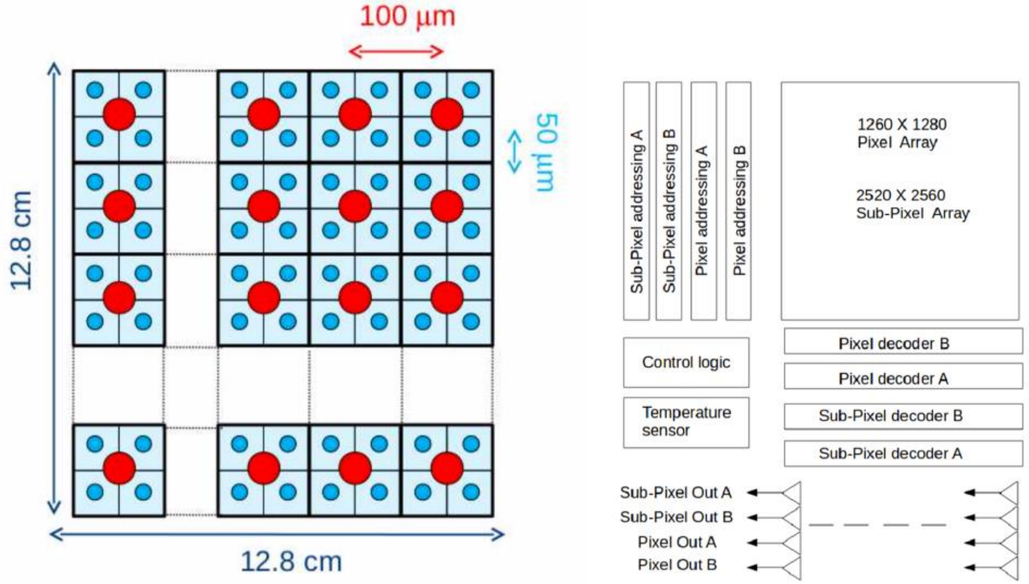
To exploit Active Pixel Sensors for Scientific, Medical and Security

Successful enough for EPSRC to ask us to submit a follow on proposal

MI-3 Plus

Produce wafer-scale CMOS imager for the healthcare sector





- World’s largest radiation hard CMOS imager
- Four independent cameras and two pixel sizes in one device

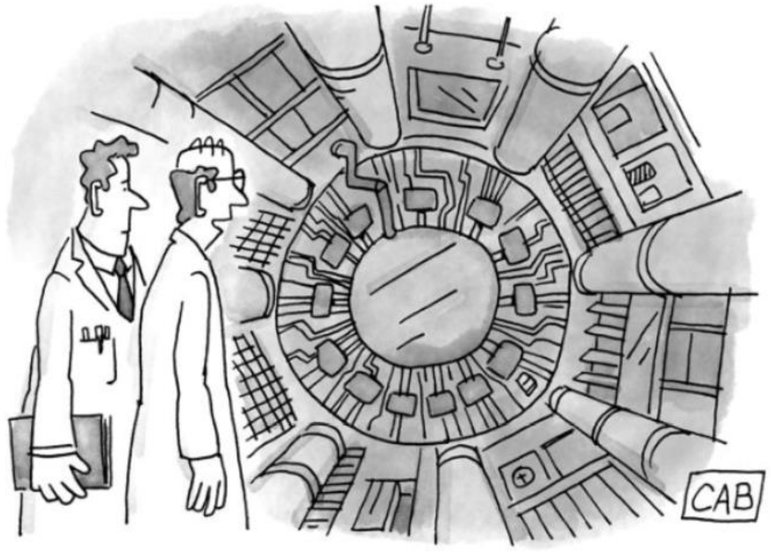
DynaMITe

Dynamic Range Adjustable for **M**edical **I**maging **T**echnology

Third Largest supplier of Scientific CMOS Imagers and Systems

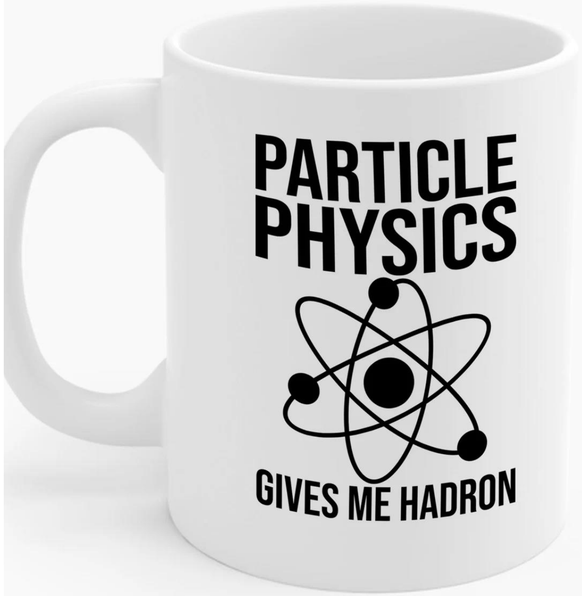
End of Preamble

Why Work with HEP Guys?



"Once you have a collider, every problem starts to look like a particle."

1. They find this cartoon amusing



2. Drink coffee out of mugs like this

Given the 121500 micron overall width and an edge distance of 500 microns gives the sensitive width can be 120500 microns.

If we go with 188.3 microns pitch then this could be 640 strips of 320 in each sector. (I therefore suggest 64 channel chips.) Note for the diagonal this means the wider ones would also be 320 strips but the narrow pair would be 180 strips so one chip would still need to be bonded to two sensors at a boundary between sensors.

(Alternatively could go for 235 micron pitch but then would need to check what pitch is reasonable and backplane capacitance starts to be higher.)

I also did a bit of calculation of capacitance and I do think we want to make the strips as reasonably narrow as we can so believe we can get away with roughly 70 micron width so the half gap is ~60 microns compared with 150 microns thickness.

(This is similar to the outer regions of the LHCb strip sensor.)

3. Give answers like this

The Big “C”

Over 18 million new cancer cases per year worldwide

Over 375,400 new diagnosis of cancer in the UK each year

One in two of us will have a diagnosis of cancer sometime in our life

Survial rate is about 50%

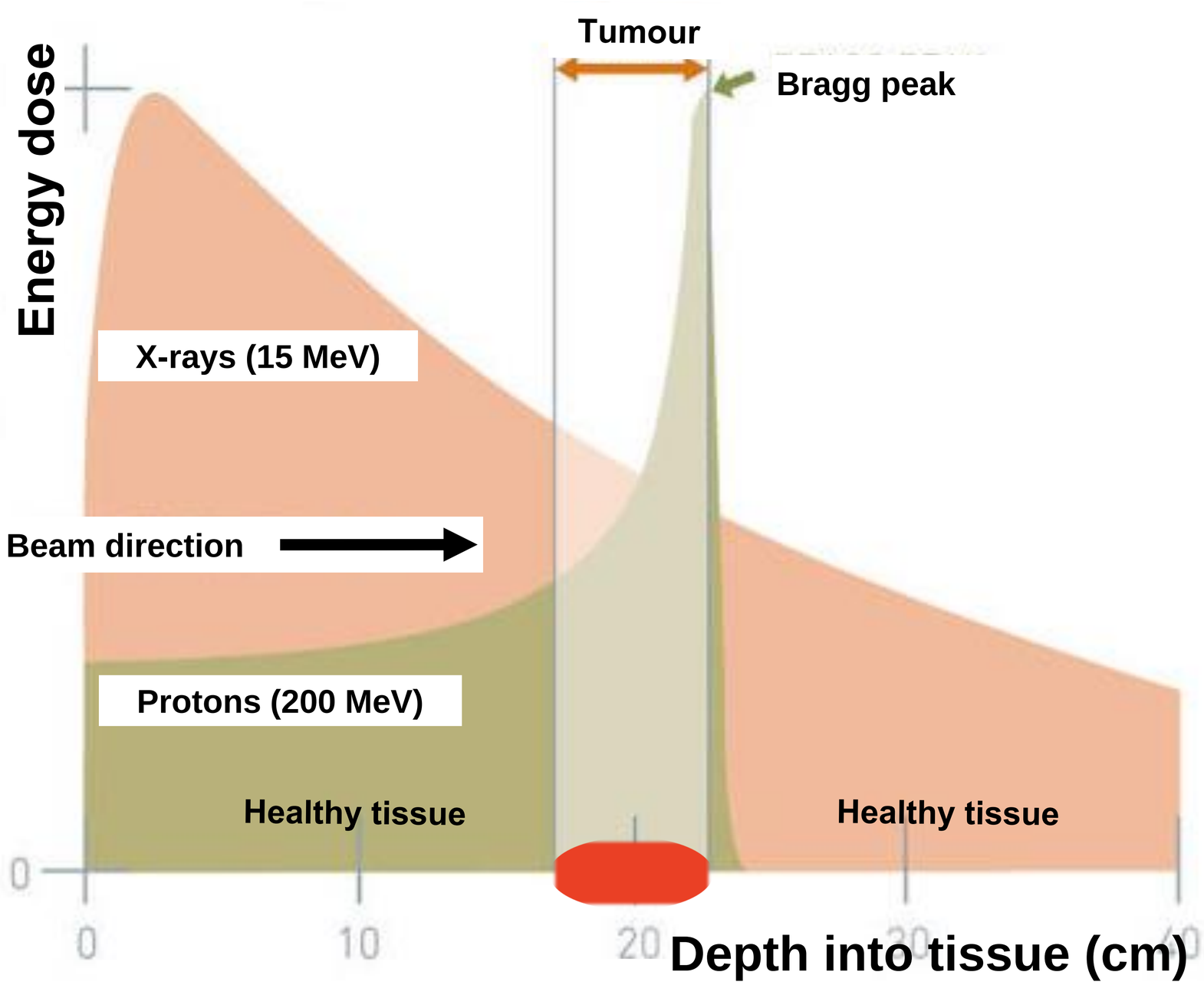
Single major cause of death for children between 2 and 15

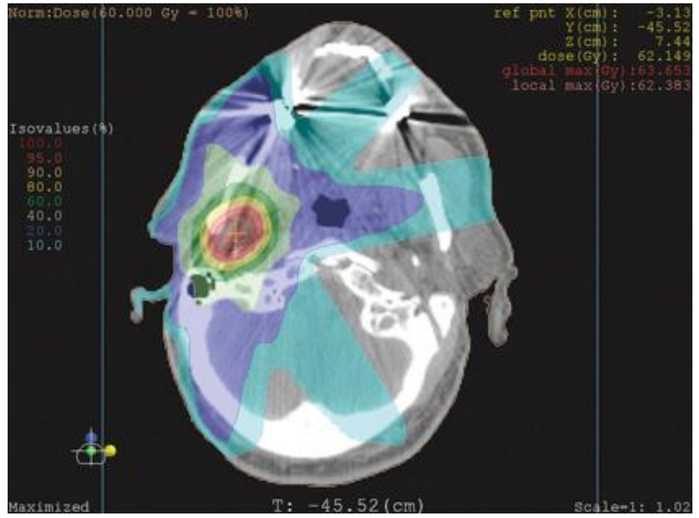
Treatment

Surgery

Radiotherapy

Chemotherapy



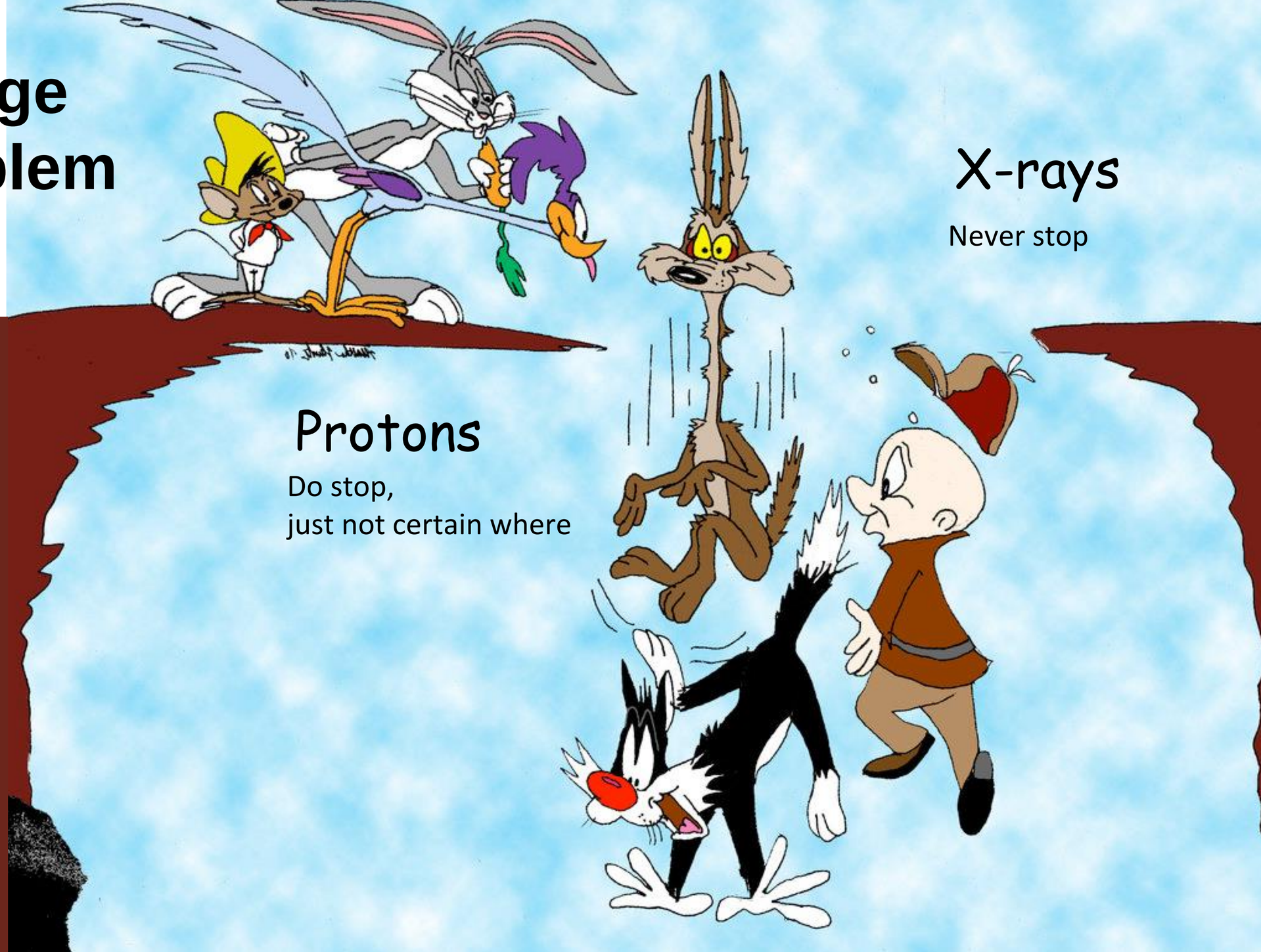


X-ray radiotherapy

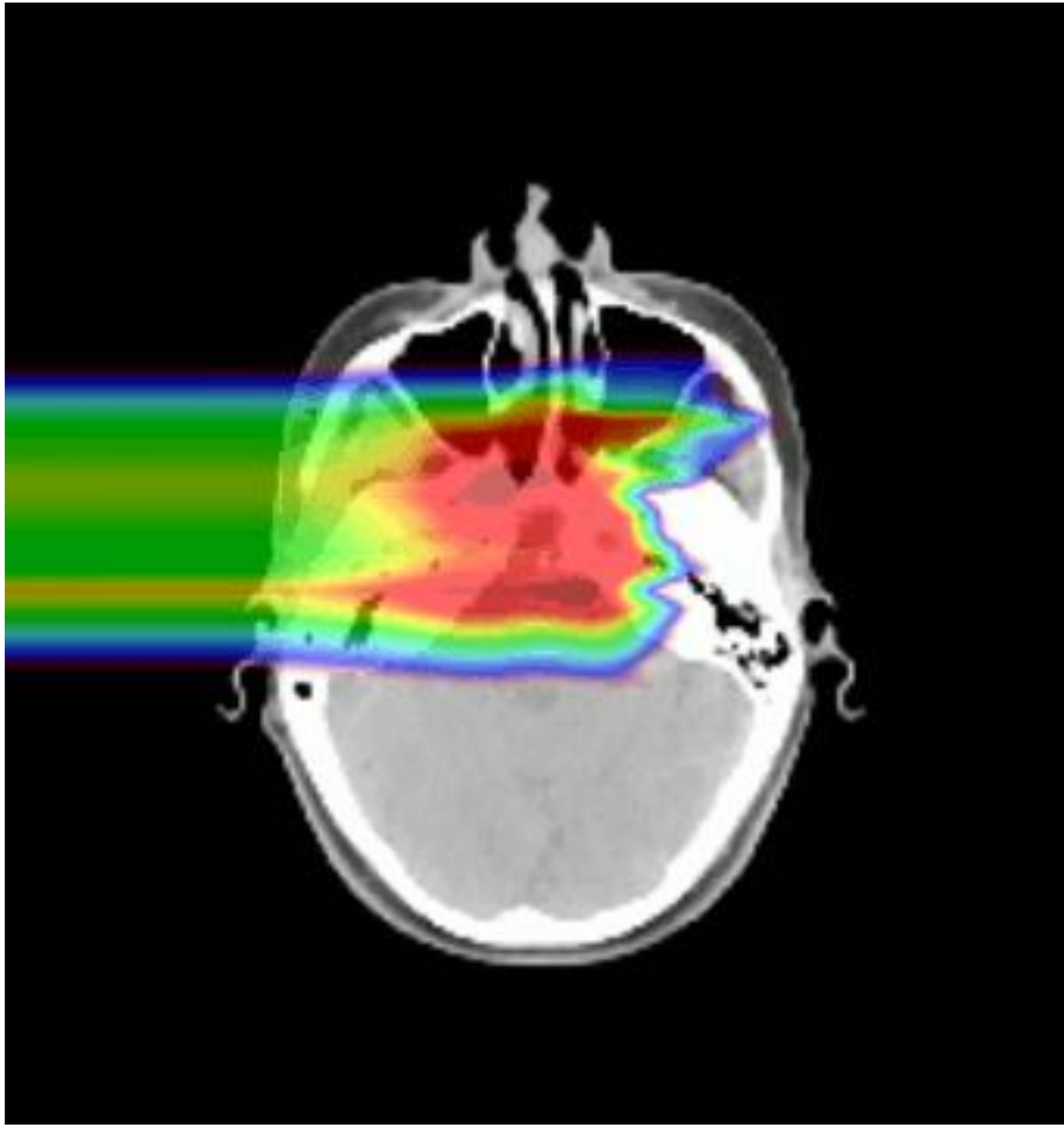
Proton radiotherapy

The ratio of proton to electron mass is $6\pi^5$

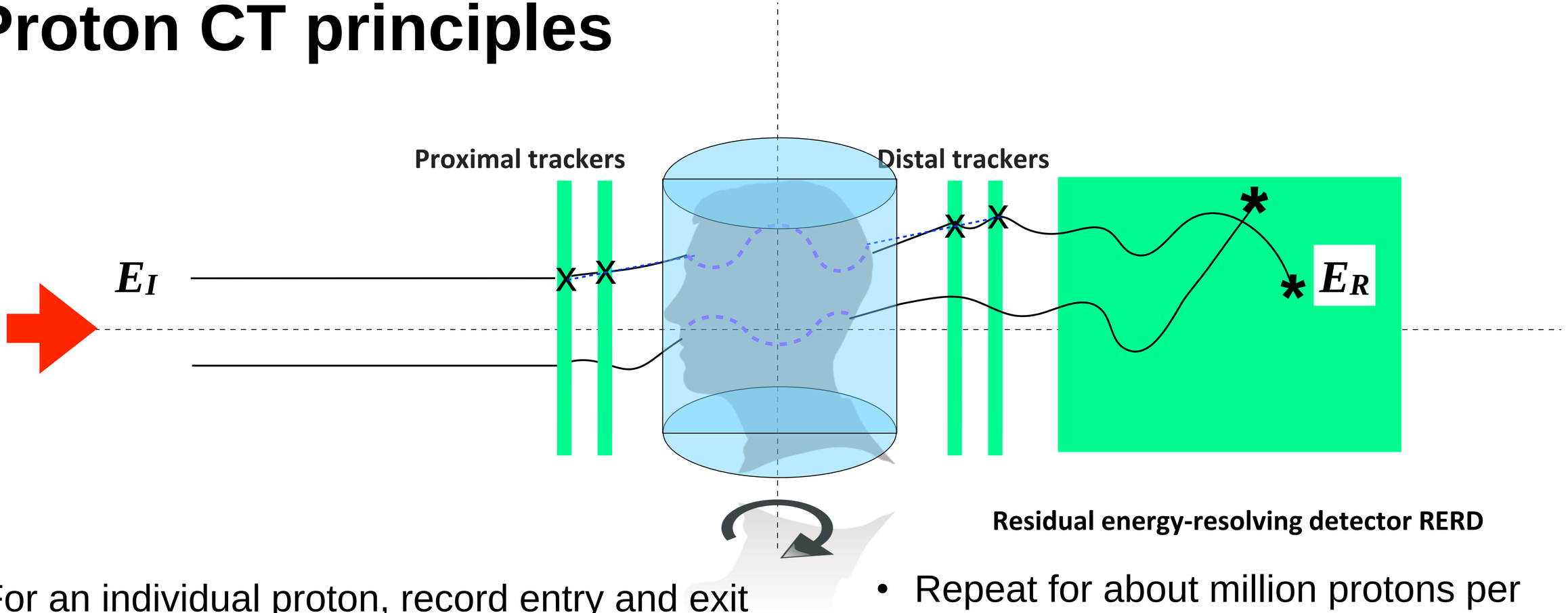
The advantage and the problem



- Treatment planning based on x-ray CT
- x-rays and protons behave differently in matter
- Even with calibration, there are uncertainties
- Typical range error is ±3.5%



Proton CT principles



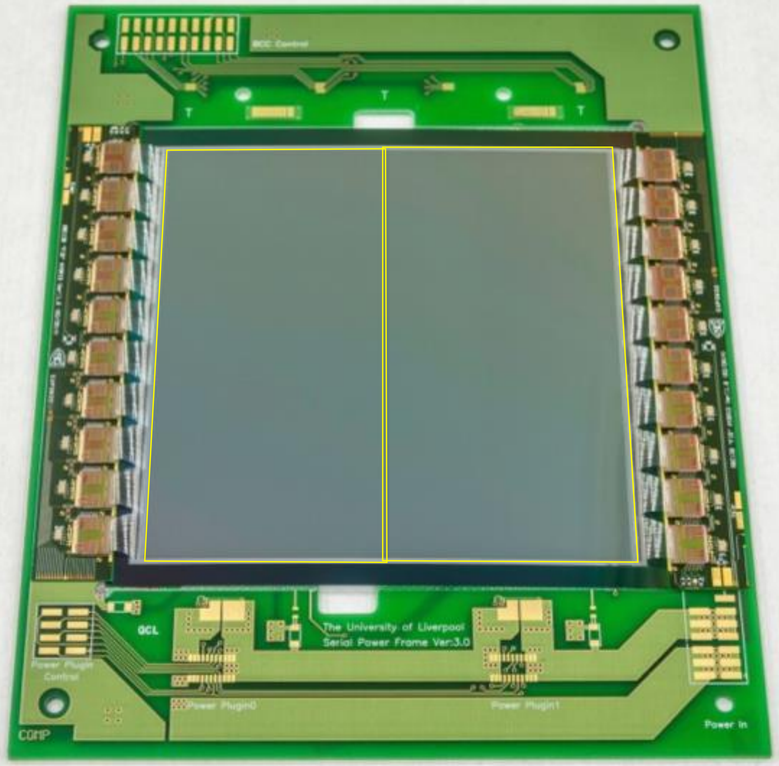
- For an individual proton, record entry and exit trajectories and its residual energy
- Estimate entry and exit points on reconstruction volume
- Calculate maximum likelihood path through patient and energy lost through patient…

- Repeat for about million protons per projection
- Rotate about one degree, and repeat
- Repeat to cover full 180 degrees

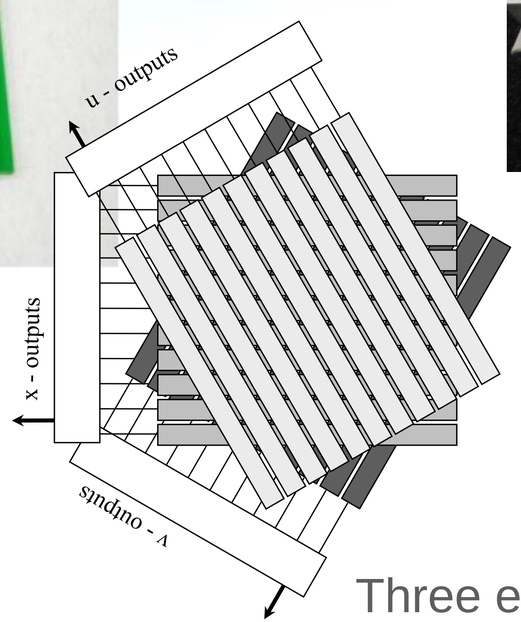
PRaVDA

Proton Radiotherapy Verification and Dosimetry Applications

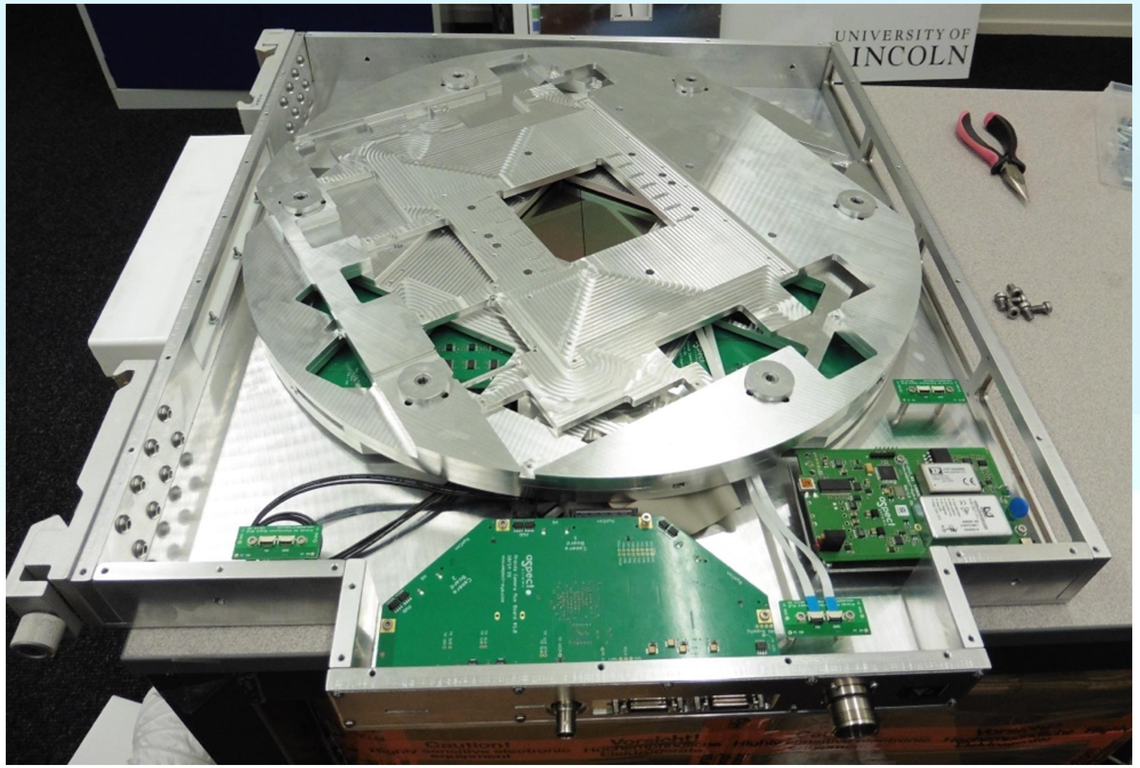
PRaVDA Strip Sensors



About 90 mm square *n*-in-*p* silicon segmented into 2,048 strips, with 1,024 readout on each side of the detector - pitch of 90.8 μm

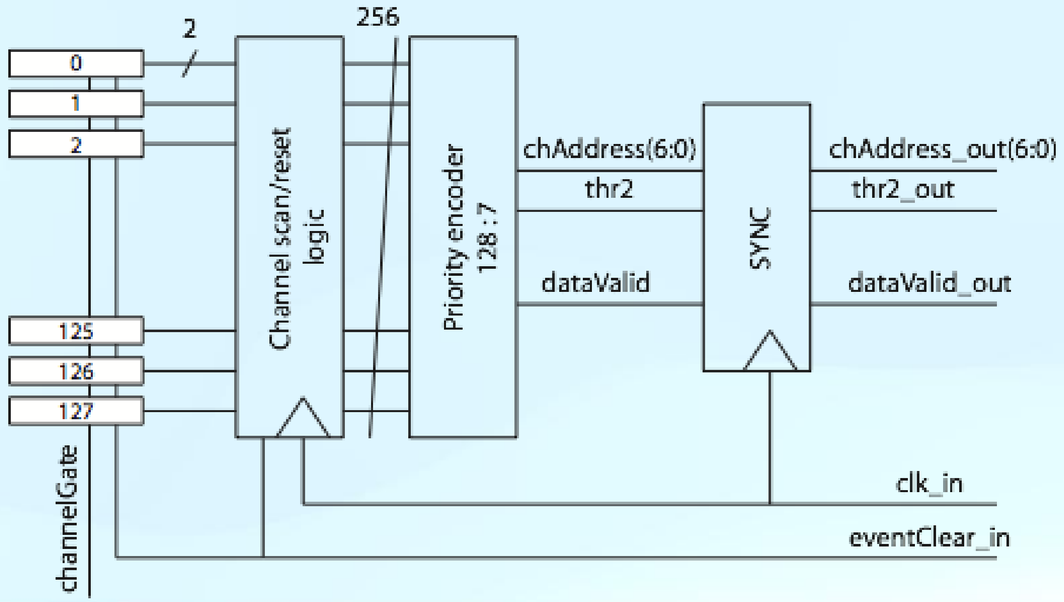


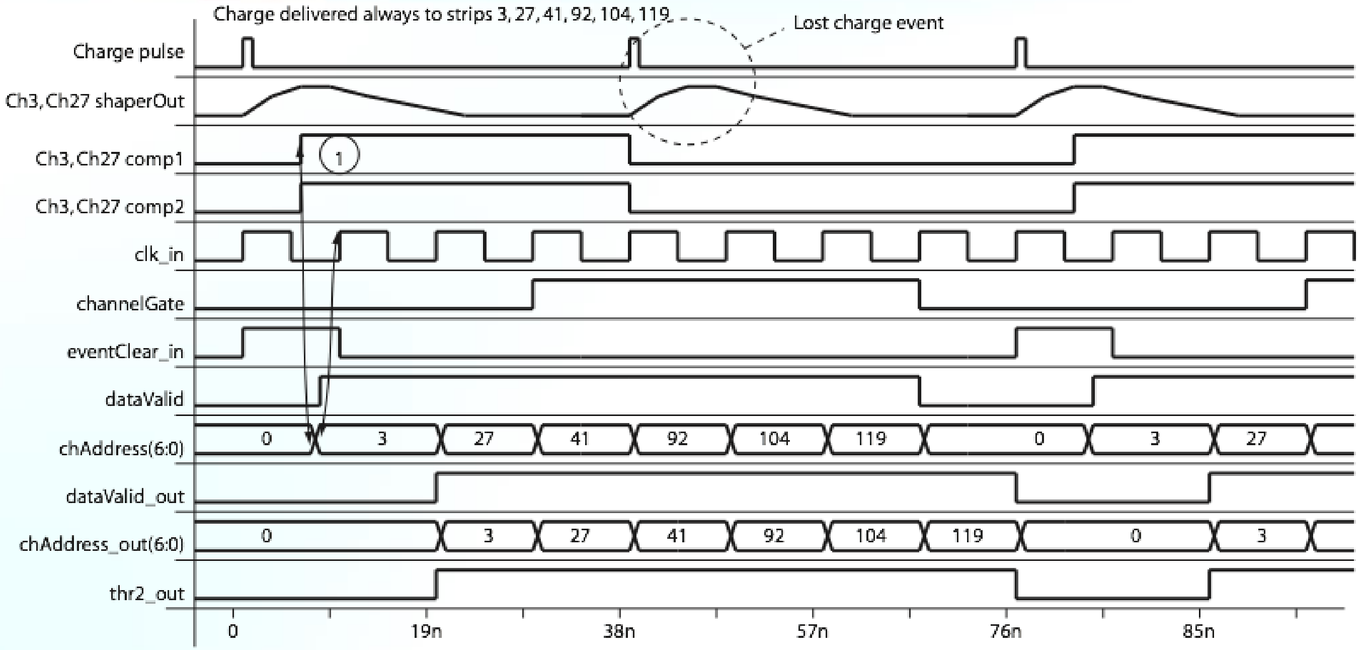
Three equi-rotated layers



Partially assembled tracker unit

ASIC – Rhea





Imaging mode
Every proton detected
Unto 4 protons per cycle

Treatment mode
Specified fraction of protons detected
Profile histograms to provide sufficient information for control feedback

The trackers

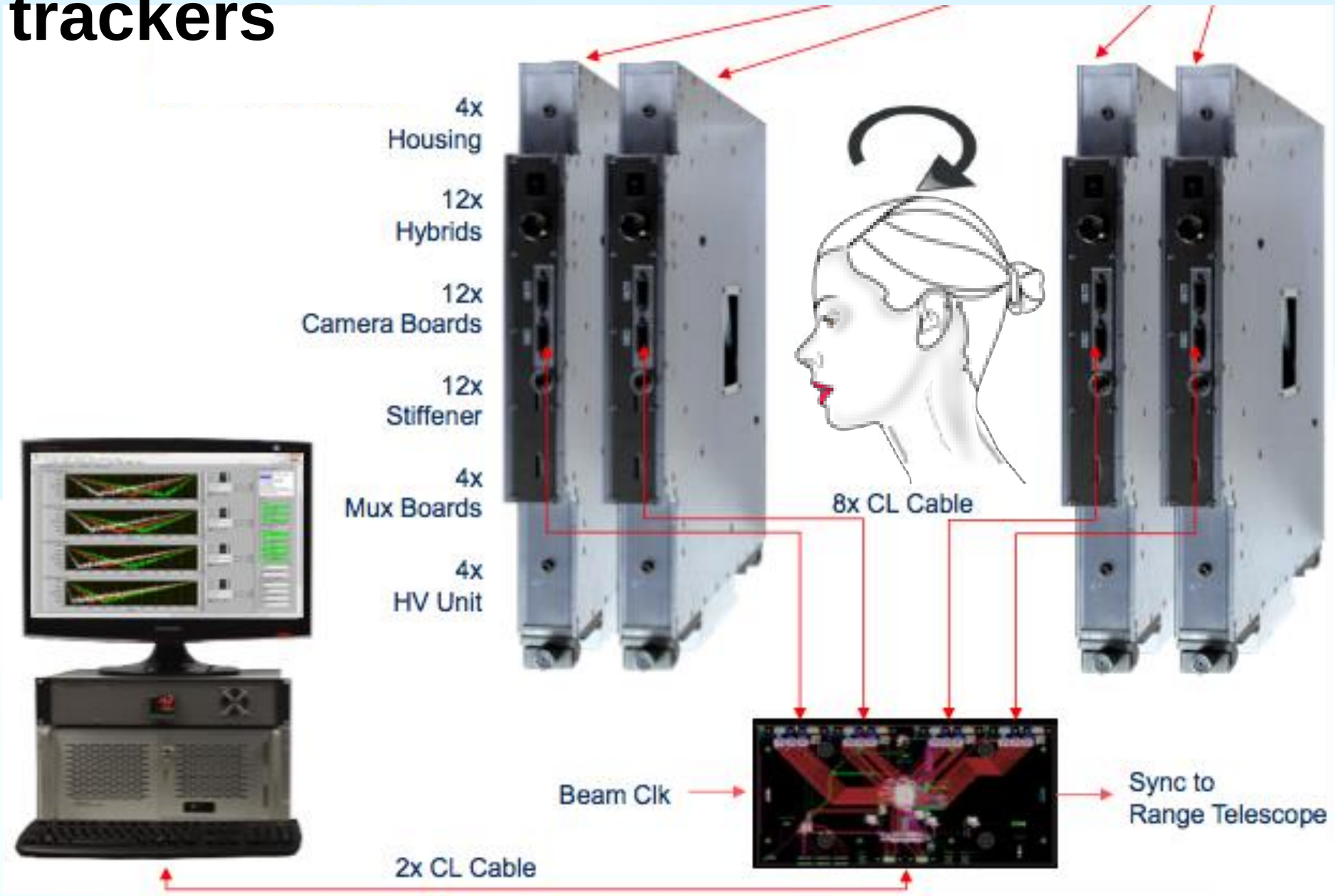
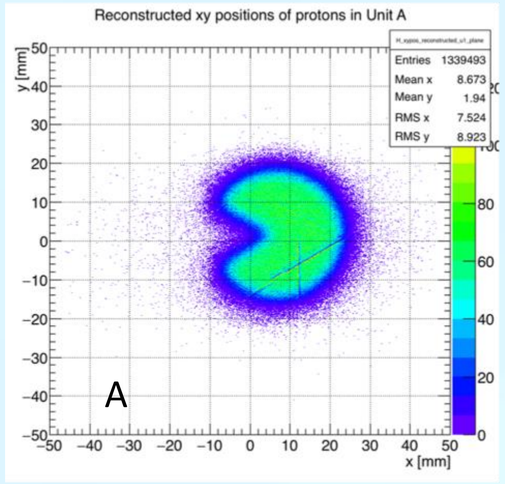
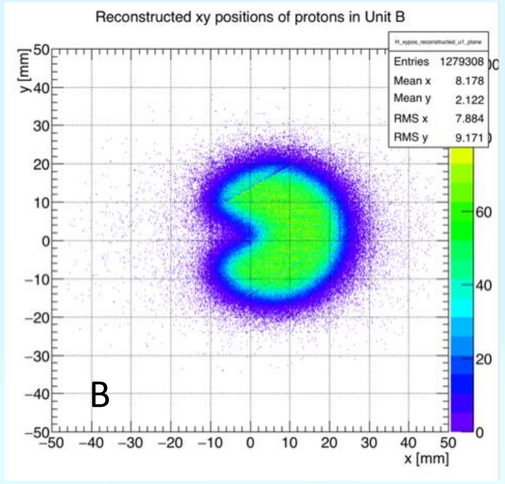
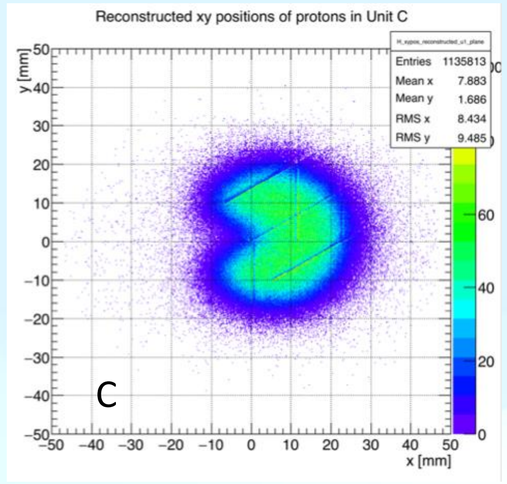
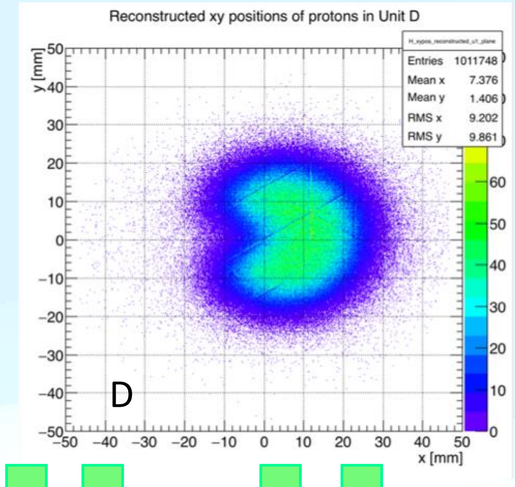


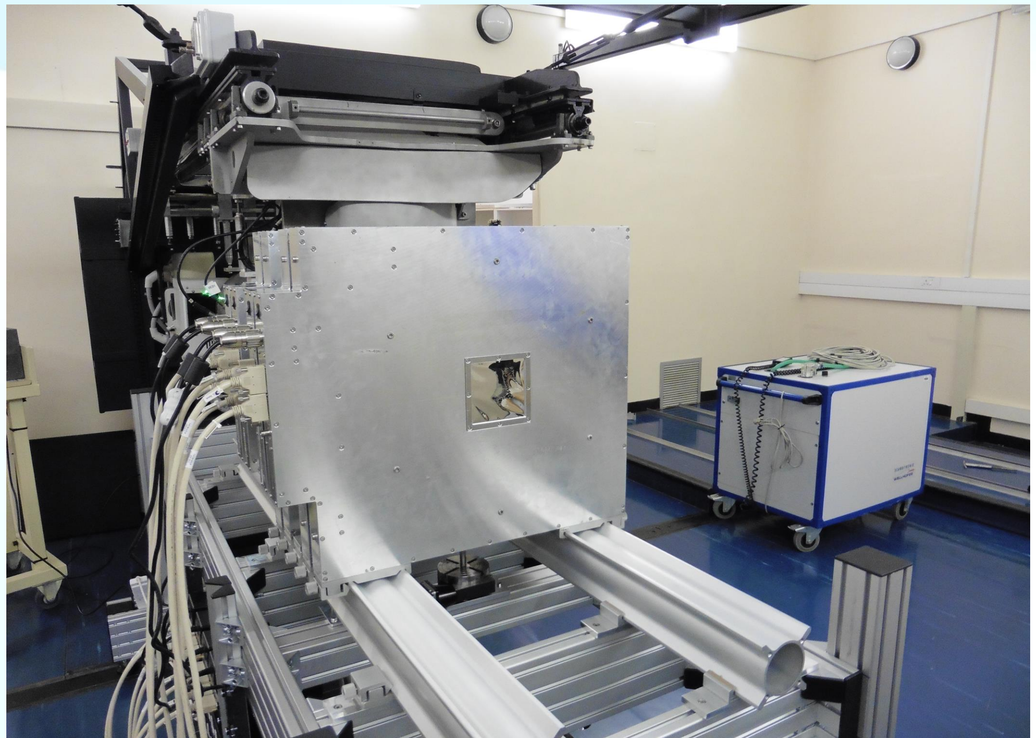
Image reconstructions: Pac-man collimator (29 MeV Birmingham)

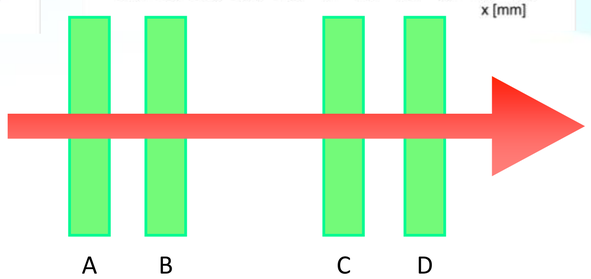






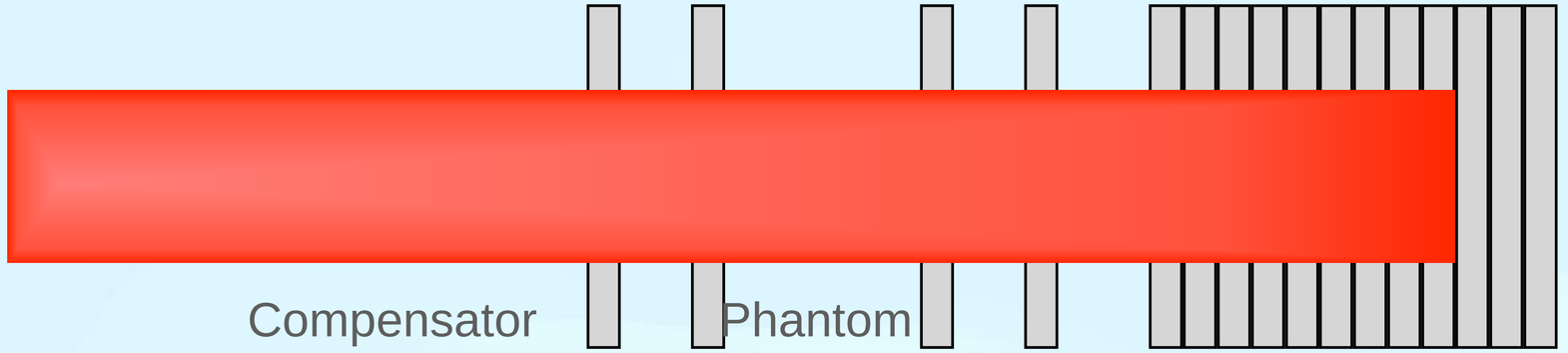


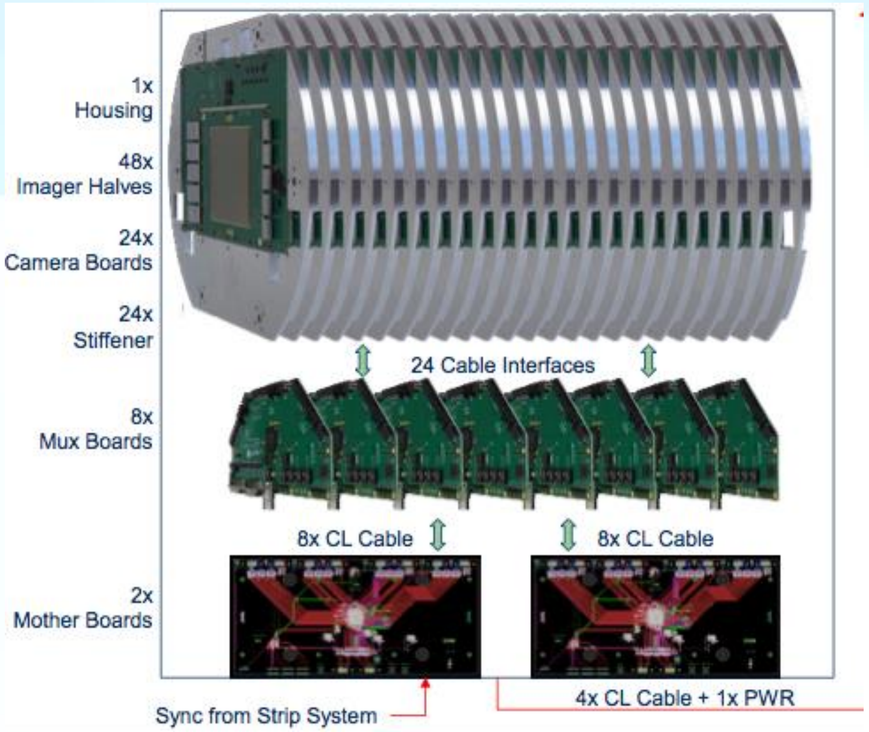




Four proton trackers
– iThemba Proton Therapy Vault

Residual Energy Resolving Device (RERD)*





*** TATE - Thing At The End**

Our phantom

More Perspex

PIPVDA wellcome trust




Modelling

University of Birmingham
BlueBEAR HPC cluster
and GridPP

Treatment Collimator

Treatment Nozzle

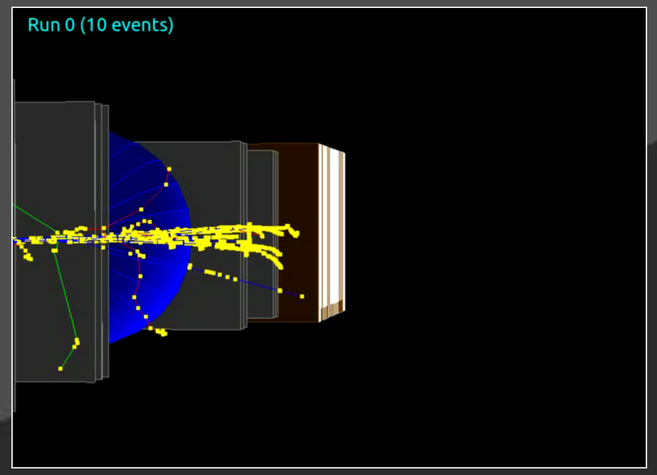
Compensator

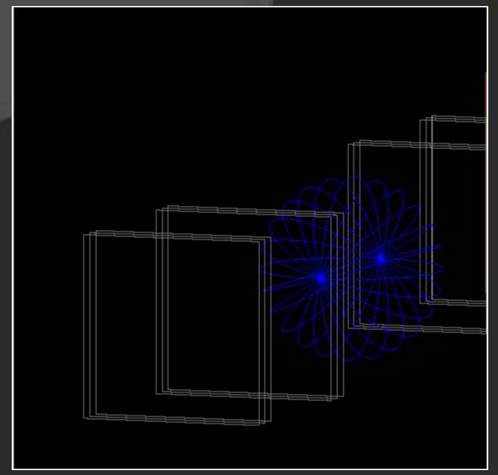
Strip Trackers
4 banks of three 10 cm x 10 cm Silicon strip detectors
100 um pitch
150 um thickness

SuSi

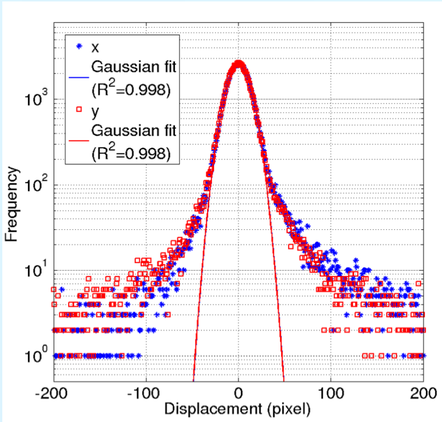
IET AWARDS
The Institution of Engineering and Technology
INNOVATION
WINNER 2014

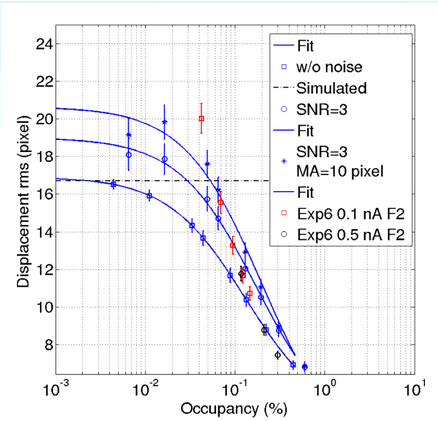
Phantom
75 mm diameter



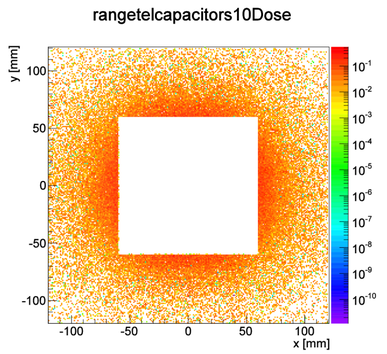


Range Telescope
24 layers CMOS images - each:
20 um epi
700 um substrate
200 um pitch (512 x 512 pixels)
1 mm perspex
1 cm separation

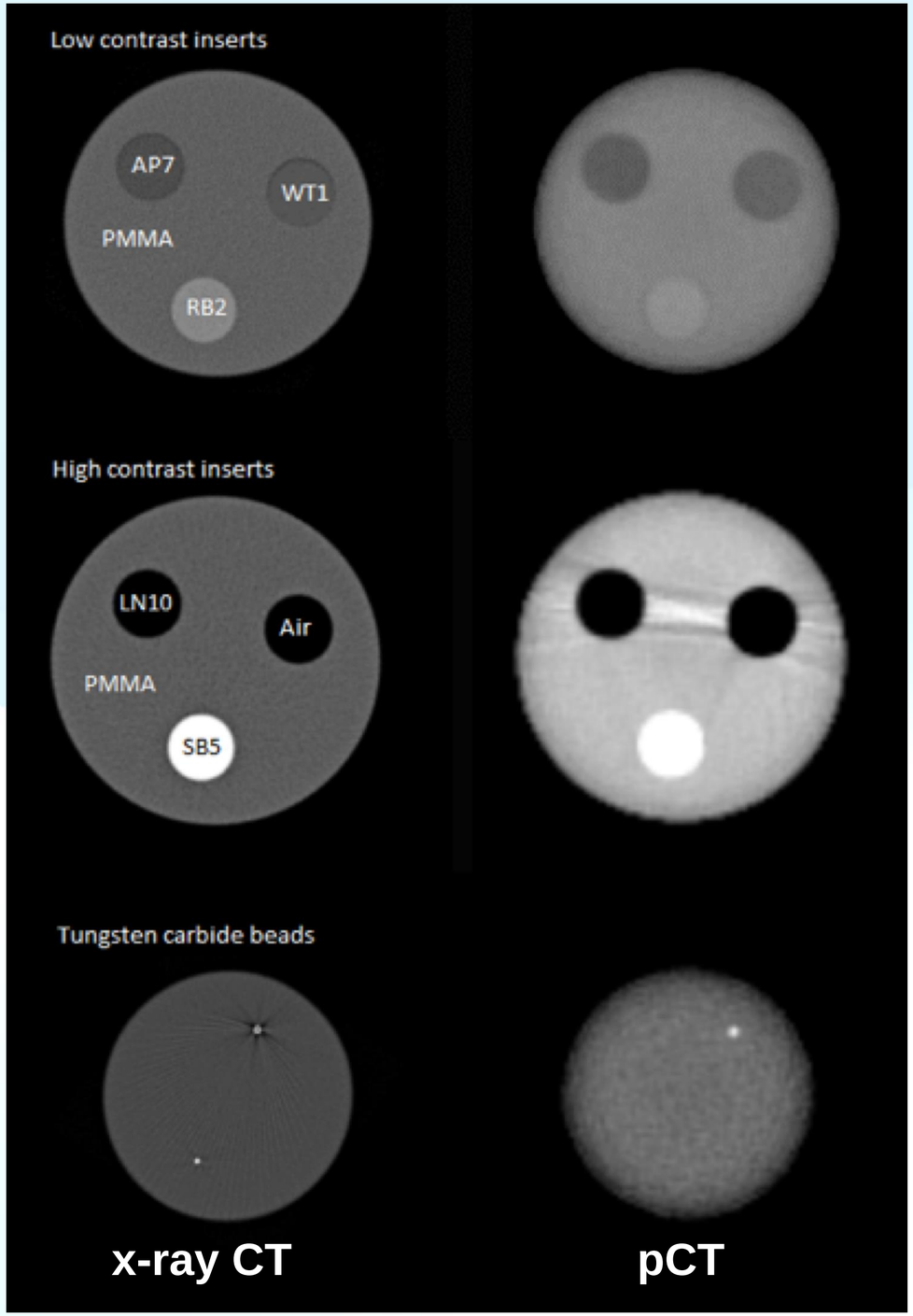




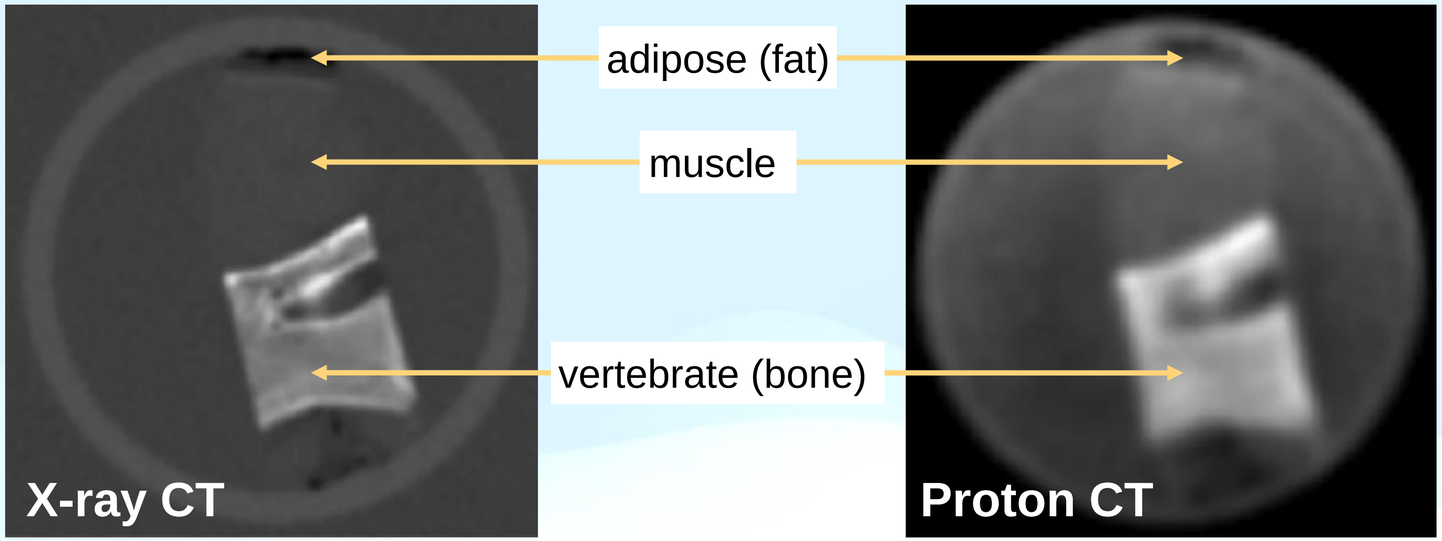
Proton displacement in Range Telescope



Radiation exposure simulations

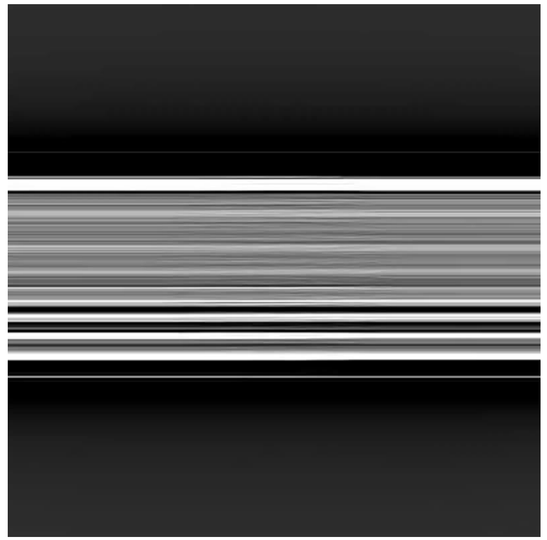


Proton CT Results



Biological Sample: Comparison

Phantom Skull
Transverse Section
Simulation

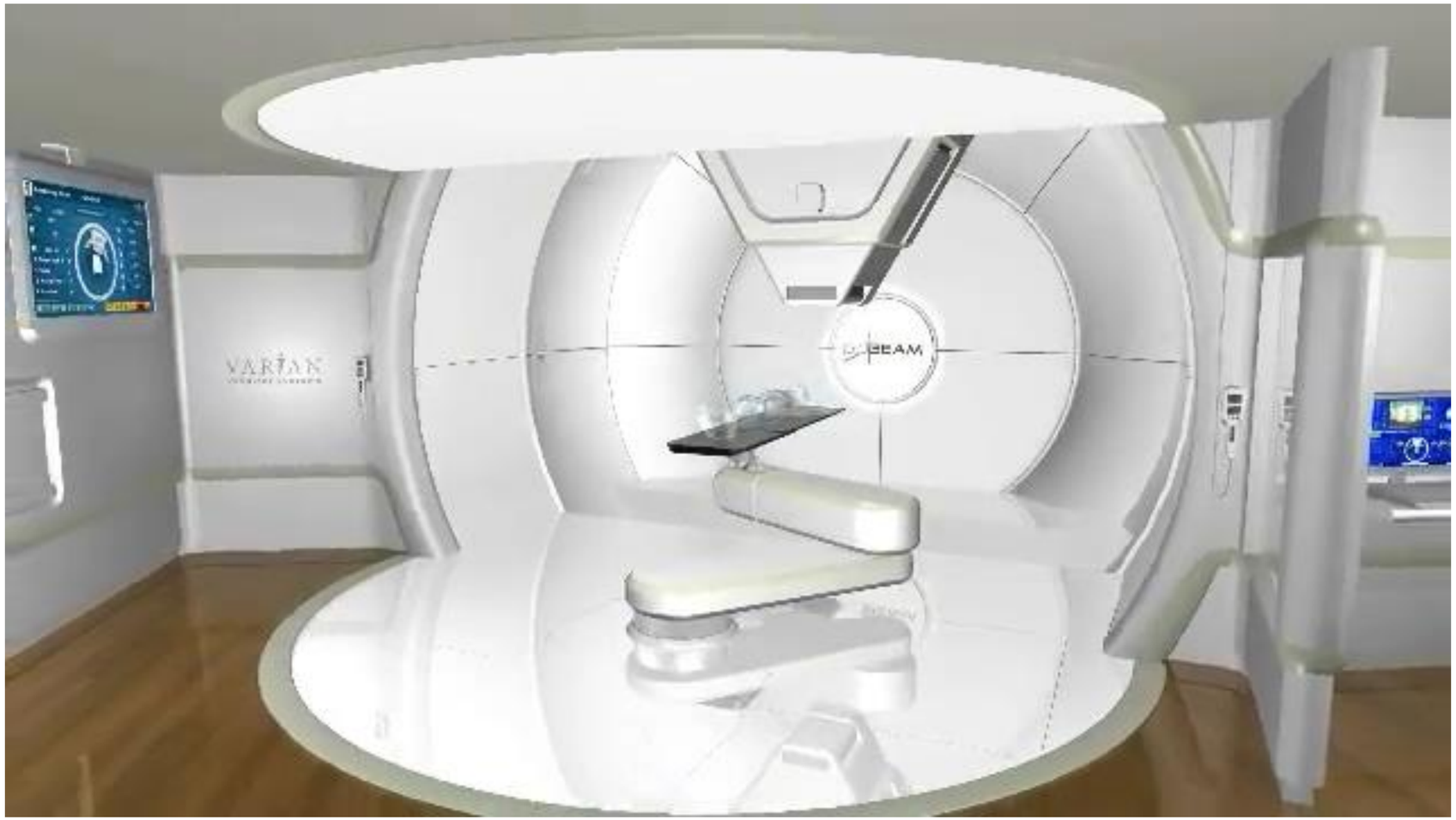


PRaVDA

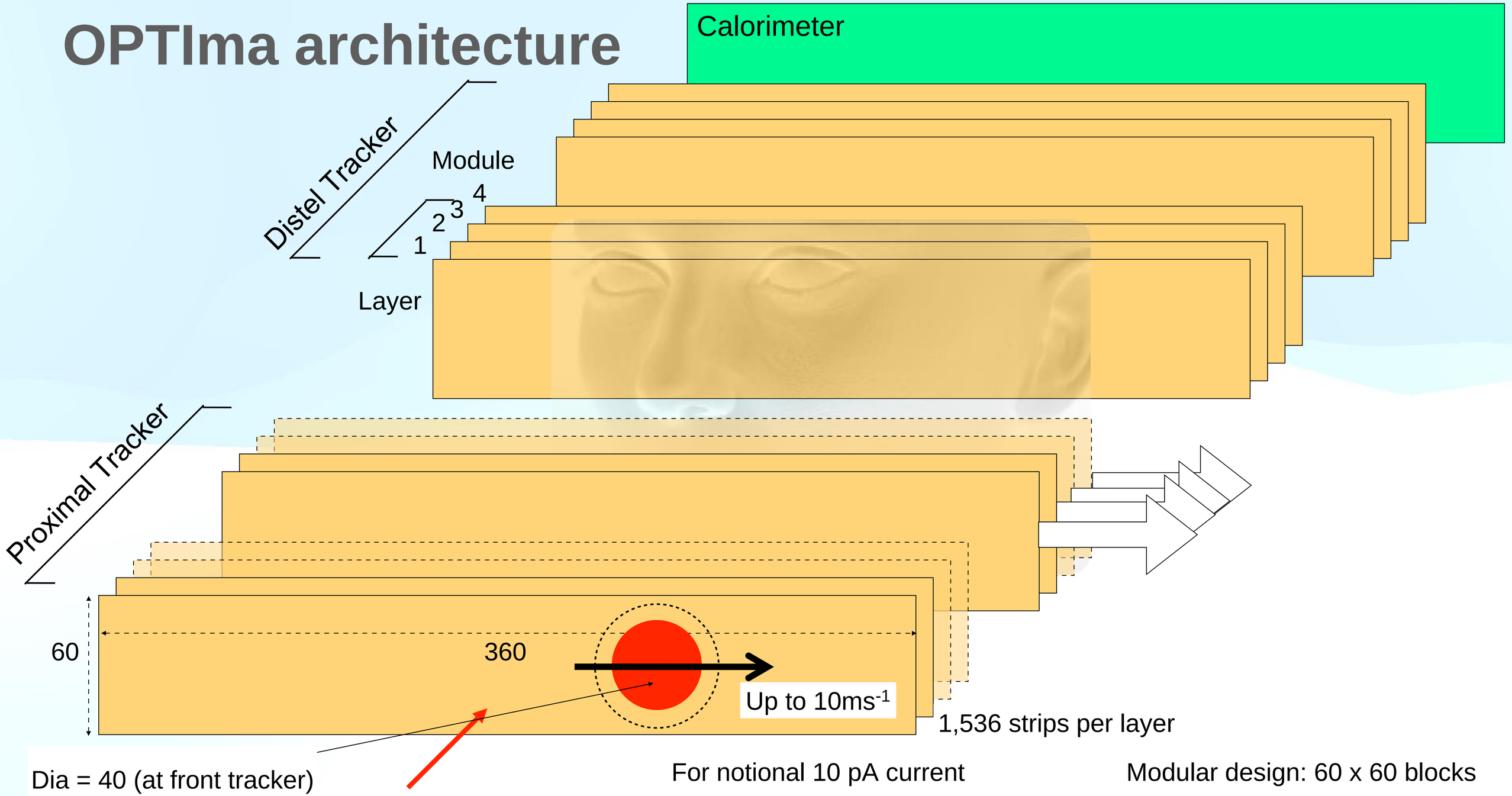
Five awarded technology patents

OPTima

Slow
Work in Progress



OPTIma architecture



Dia = 40 (at front tracker)

Average one proton per pulse

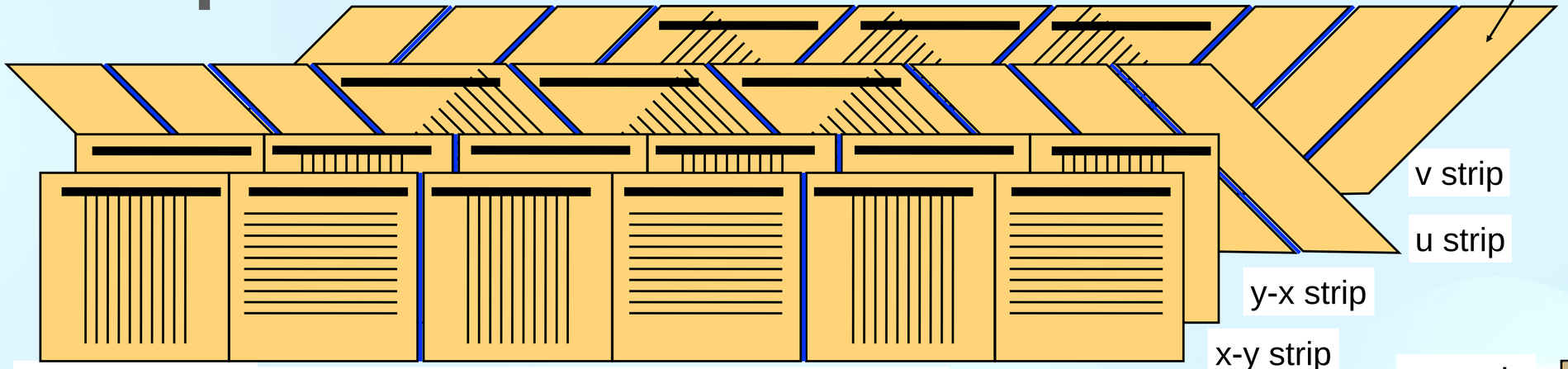
For notional 10 pA current

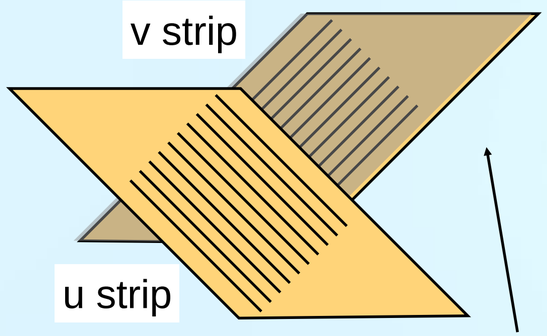
7.7 - 10 x 10^4 protons/ ms

Modular design: 60 x 60 blocks

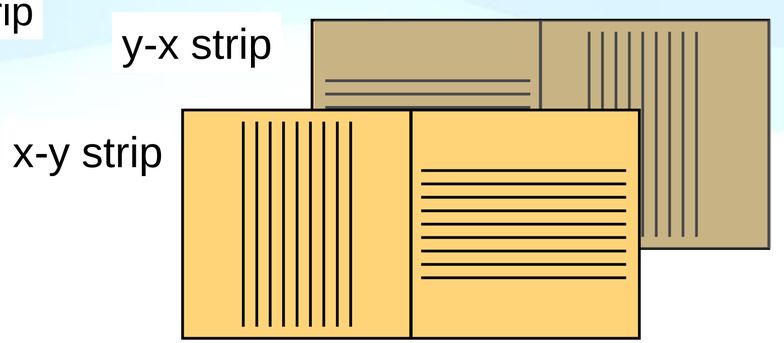
Strip ladders

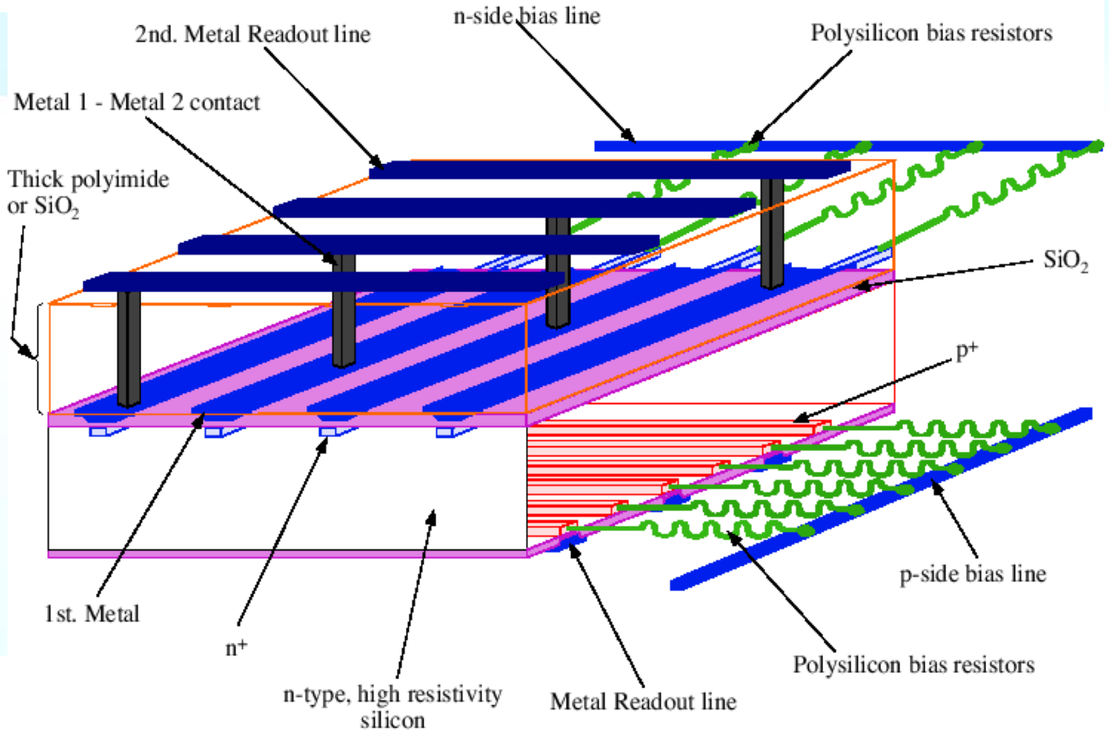
Mini UV dies (30 mm) make better use of wafer





Flip dies



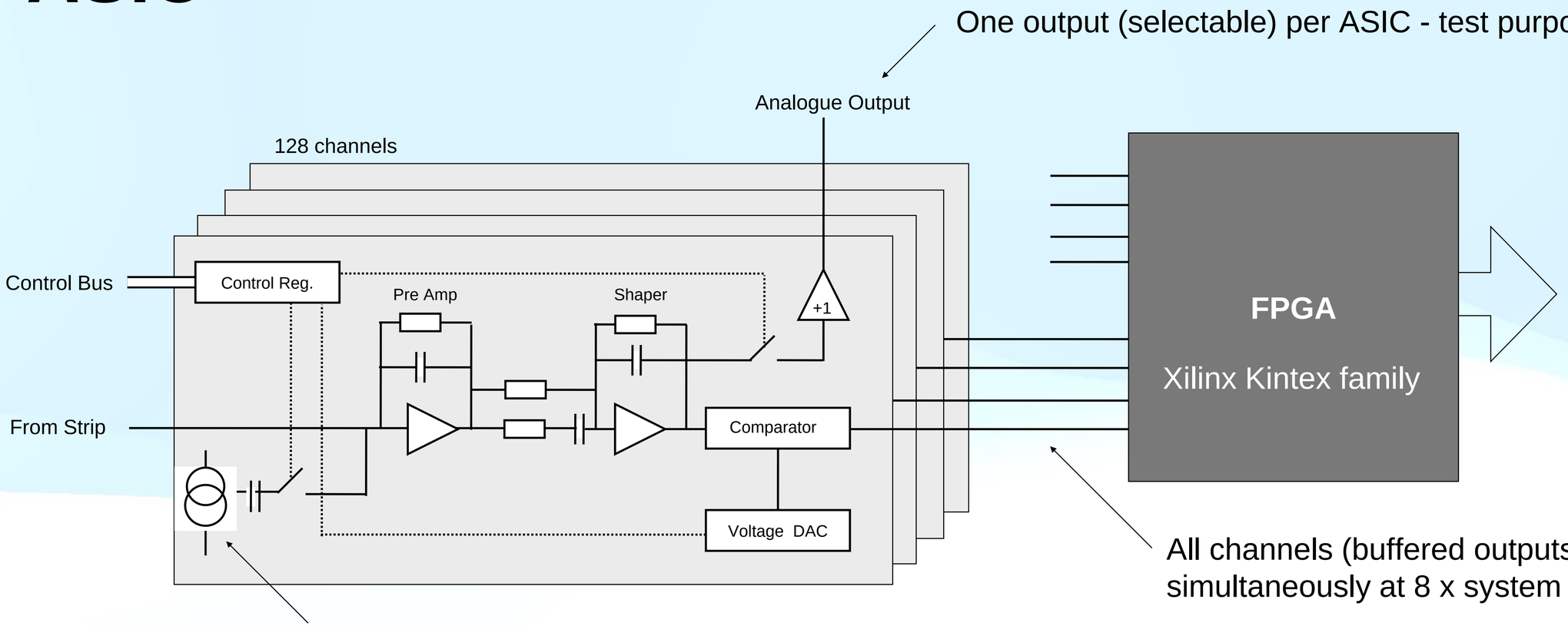


x and y channels brought to common edge for bonding

Pitch: 235 um (orthogonal to strip channel)
Thickness: 150 um
One ladder, total of 1,536 (11 bits).

ASIC

Designed and supplied by ISDI Ltd



Philosophy - separate analogue and logical elements, incorporate calibration functionality, and modular

Staring sensors – always active except for recovery time

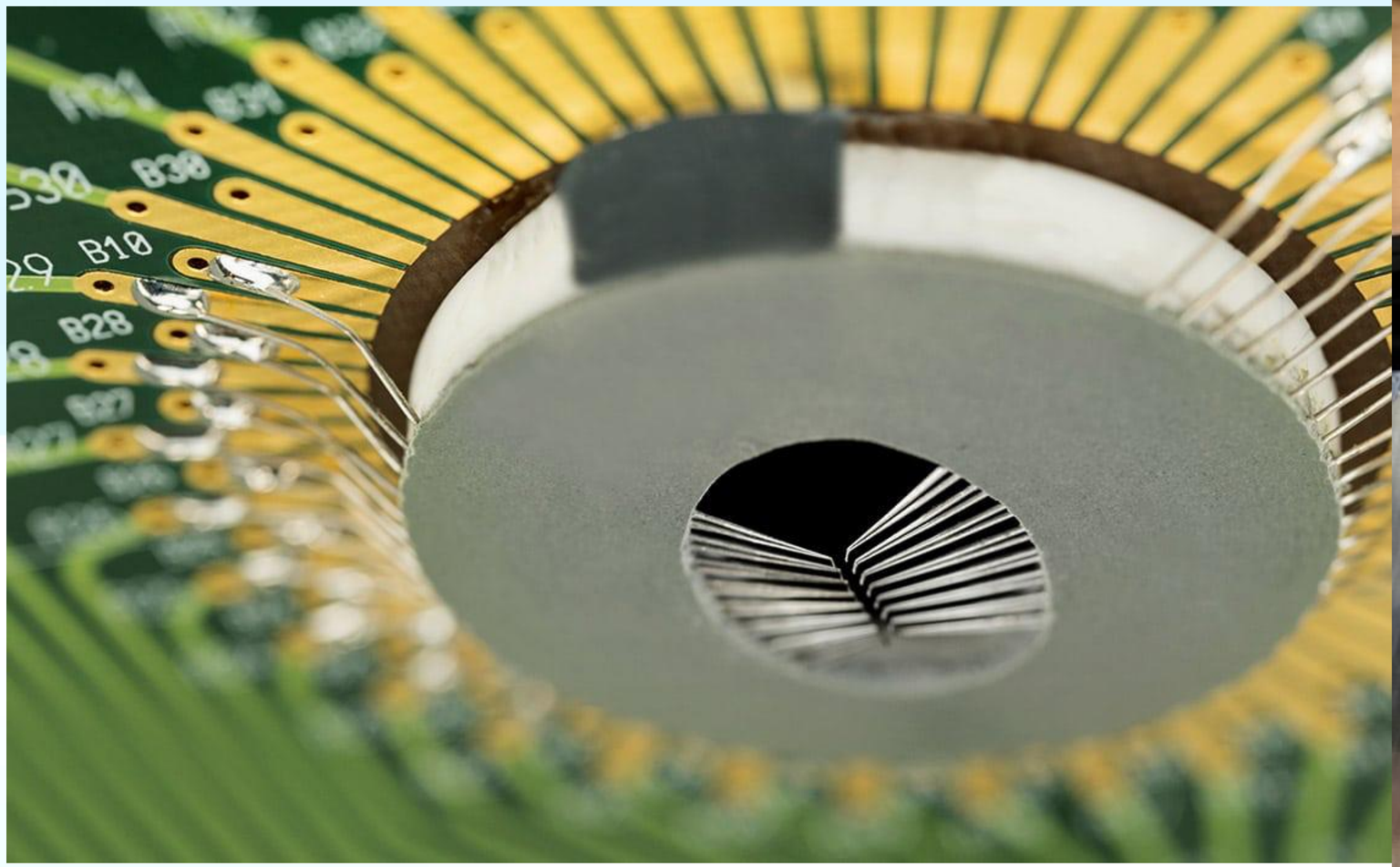
Operating modes – idle, set-up, calibrate and acquire

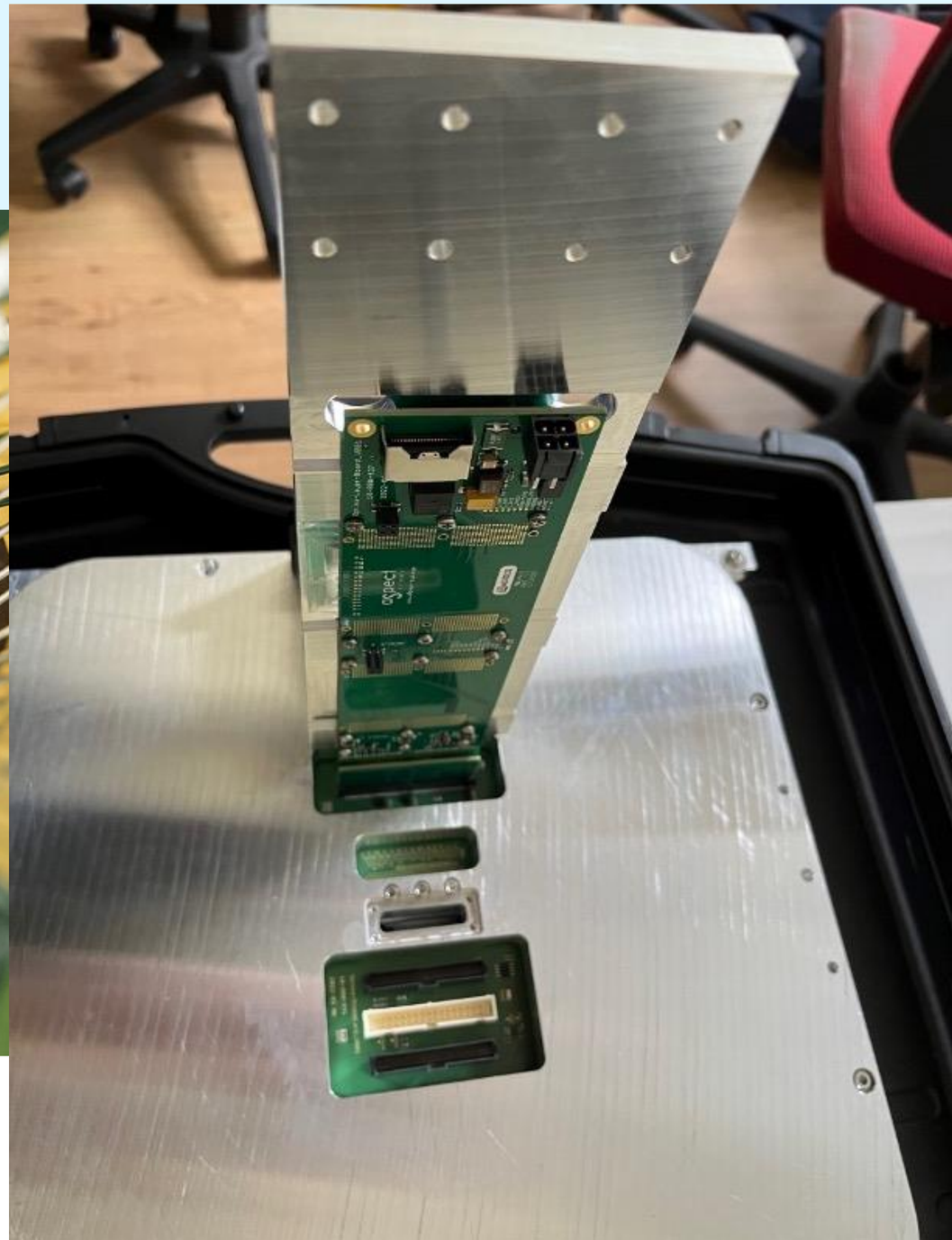
6-bit DAC, parameters held on-chip

Die dimensions ~24 x 2.5 mm

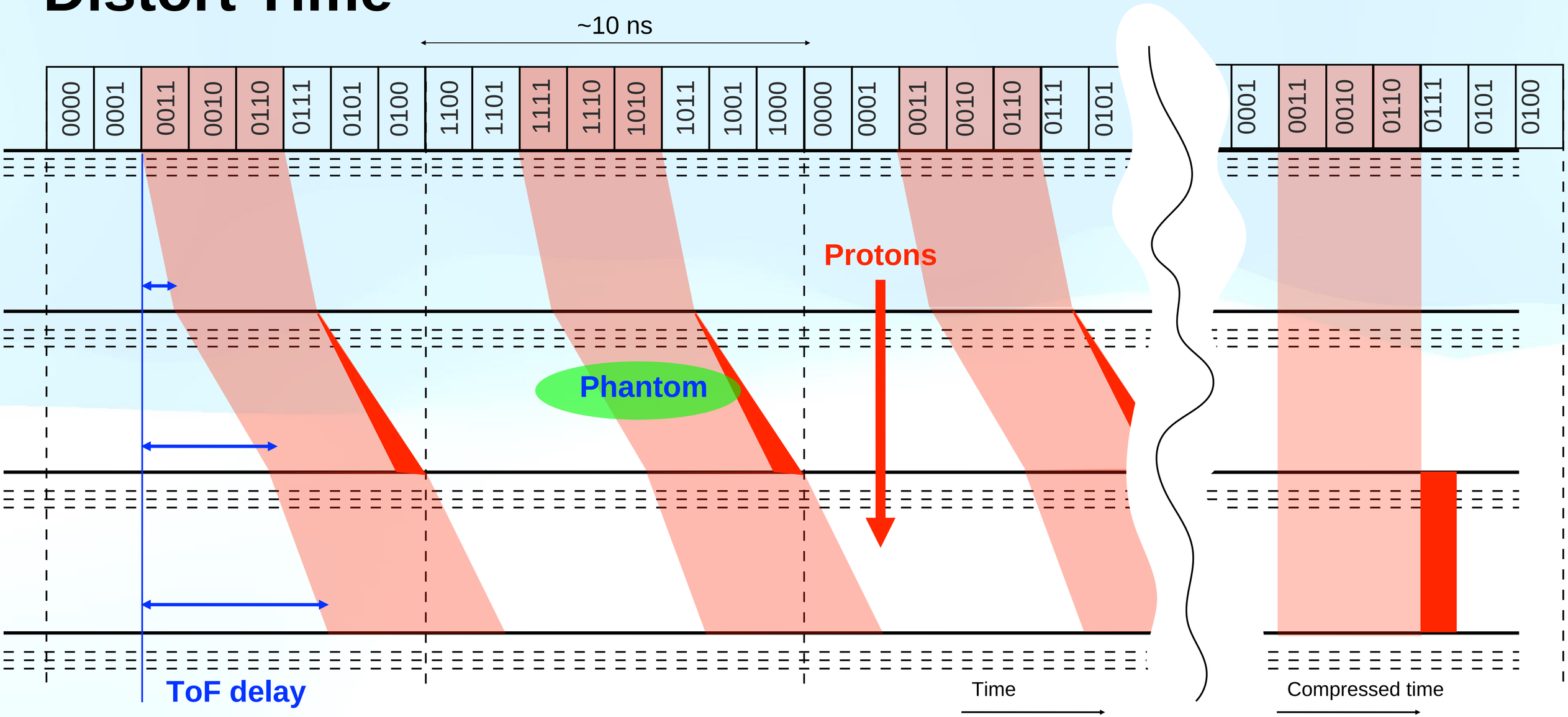
Wafer Probing

Just starting - at last





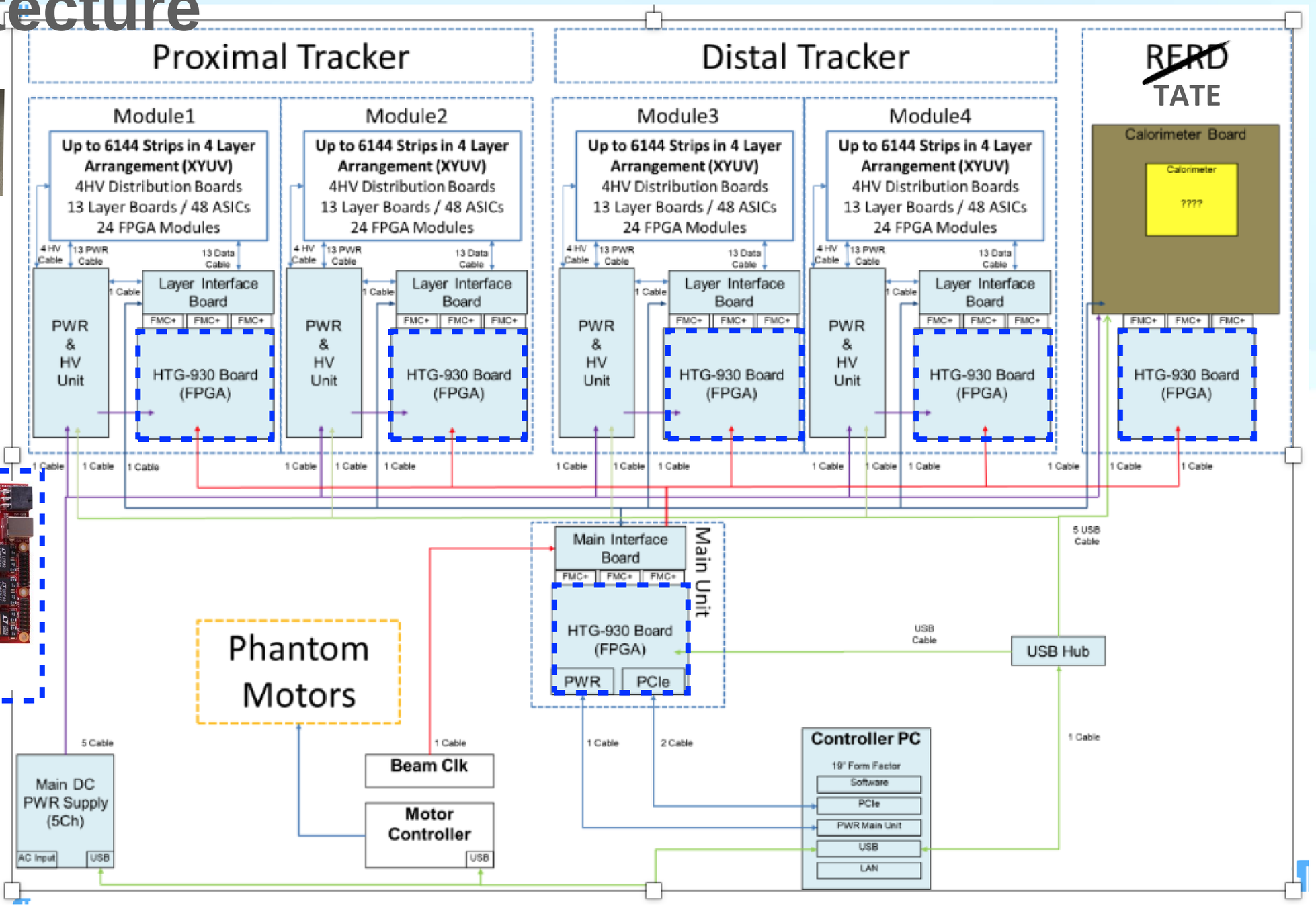
Distort Time



DAQ Architecture

Layer Boards – 52 off

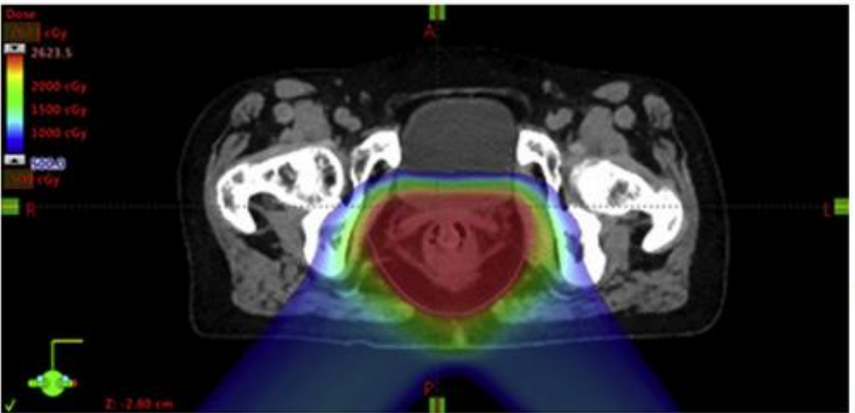
HTG-930: Virtex UltraScale+ PCI Express

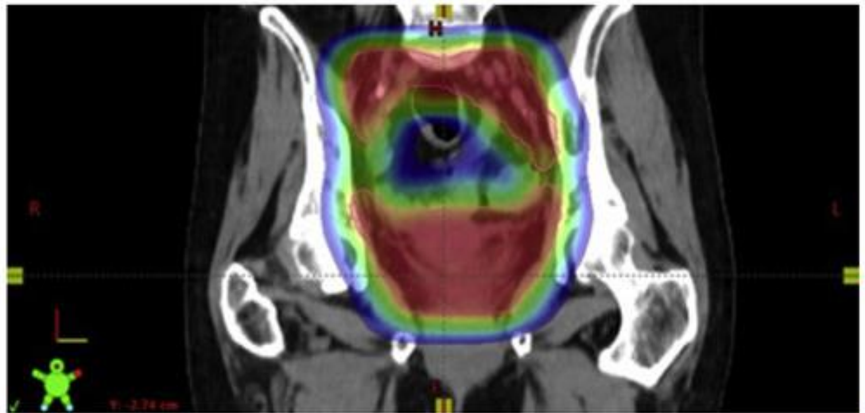


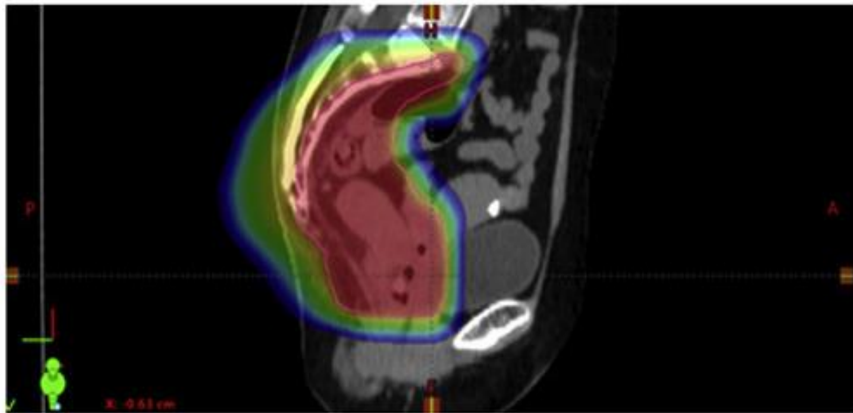
Summary

OPTima

- 24,576 strip channels sampled *simultaneously* at times as short as 1 ns
- Adjustment of individual channel timing at 78 ps resolution
- Can operate with beam current of up to ~30 pA (3 protons average per cycle)
- Up to 7 protons fully tracked across 12/16 layers per cycle
- Syncronise to any cyclotron or free-run at up to 125 MHz
- Little time for any *intelligence* - do cope with split events and synronise with beam spot position to reduce potential noise
- Calibrate all channels in a few mins







Conclusion

Instead of searching for preons, sfermions, dyons, magnetic monopoles, simps, wimps, wimpzillas, axions, flaxions, erebons, accelerons, cornucopions, giant magnons, maximons, macros, wisps, fips, branons, skyrmions, chameleons, cuscutons, planckons and sterile neutrinos, etc., etc., Proton Beam Therapy provides HEP guys with something useful to do!

University of Lincoln
Grainne Riley
Chris Waltham
Michela Esposito

University of Birmingham
Phil Allport
David Parker
Tony Price
Ben Phoenix

University of Liverpool
Jon Taylor
Gianluigi Casse,
Tony Smith,
Ilya Tsurin

University of Surrey
Phil Evans

University of Warwick
Sam Manager
Jon Duffy

Karolinska University Hospital, Sweden
Gavin Poludniowski

University of Cape Town
Steve Peterson

University Hospital Birmingham NHS Foundation Trust
Stuart Green

University Hospital Coventry and Warwickshire NHS Trust
Spyros Manolopoulos

iThemba LABS, SA
Jaime Nieto-Camero
Julian Symonds

University of Lincoln
Grainne Riley
Chris Waltham
Michela Esposito
art Vorselaars
Amir Badiee
Val Andrews

University of Birmingham
Phil Allport
Alastair Winter
Tony Price
John Cotterill
Simon Pyatt

University of Manchester
Karen Kirkby
Michael Merchant
Carla Winterhalter
Mike Taylor
Hywel Owen
Alex Herrod

Christie Hospital NHS Foundation Trust
Ran MacKay
Adam Aitkenhead

University Hospital Birmingham NHS Foundation Trust
Stuart Green

Paul Scherrer Institut
Tony Lomax
Psoroulas Serena

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