Centre for Medical Radiation Physics

University of Wollongong

Silicon Sensors Suite (3S) for characterization of hadron therapeutic beams

Anatoly B. Rosenfeld

Centre for Medical Radiation Physics

Australia

On behalf of CMRP hadron therapy collaboration

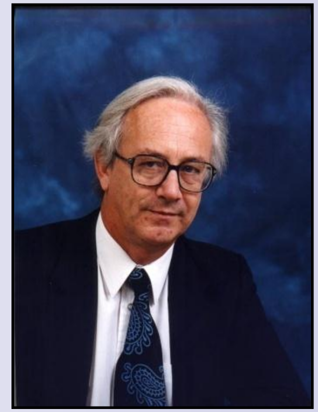
CNAO-ARDENT, Pavia , Italy , 19th October 2012

The CMRP

Prof AnatolyRozenfeld
Founder and Director

Prof Peter
Metcalfe

Karen Ford
Admin Officer



A/Prof Bill Zealey

Dr Michael Lerch

Dr George Takacs

Dr Marco Petasecca

Dr Susanna
Guatelli

Dr Yujin Qi

Dr Dean
Cutajar

Mitra Safavi
Naieni

The CMRP – Research students

Amir Othman

Amy Ziebell

Cheryl Lian

Plus many more …………….

28 PhD students, 22 Master (Res)

Alex Quinn , Jayde Livingstone, Emma Simpson *and many others…*

Medical Physics Education in Hadron Therapy

CMRP:12 years in proton and heavy ion therapy research

6 PhD students in PT
were trained at CMRP in collaboration with

LOMA LINDA UNIVERSITY MEDICAL CENTER

MASSACHUSETTS GENERAL HOSPITAL

Australian Government ansto

Outcome : 3 AINSE Gold Medals

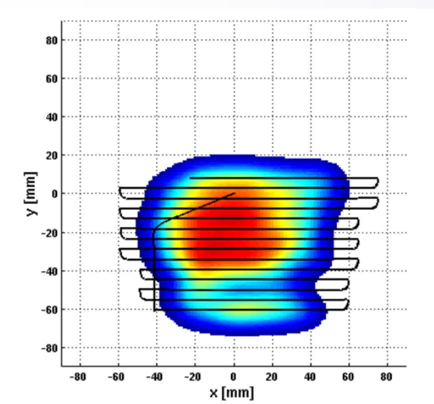
Peter Bradley
San Diego
1999

Greg Kaplan
2004

Iwan Cornelius
Austria
2005

Ben Clasie
MGH
2006

Andrew Wroe
LLUMC
2007



CENTRE FOR MEDICAL RADIATION PHYSICS

Technology
SOLUTIONS

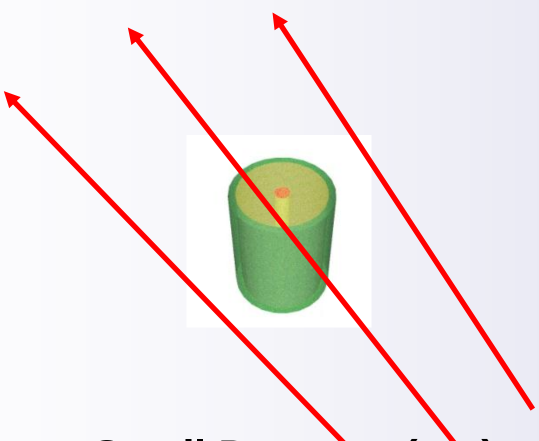
Radiation Detection Technology

Microdosimetry and Dose Equivalent

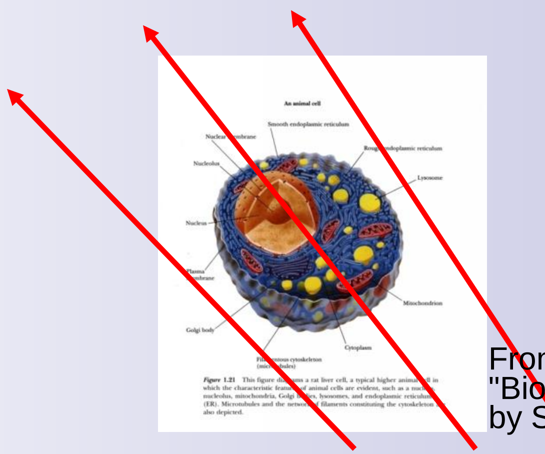
- **Microdosimetry**
  - Assumes the weighting factor is related to the energy deposited in the cell nucleus: ε
  - Measure this for each particle that crosses detector
  - Formulate dose distribution: $d(\varepsilon)$
  - Integrate with weighting factor to give **Dose Equivalent** : $H = \int Q(\varepsilon)d(\varepsilon)\, d\varepsilon$
  - Dose Equivalent can be used to predict biological effect of radiation

- **We require detectors with dimensions commensurate with cell nuclei**

Ionising particle tracks



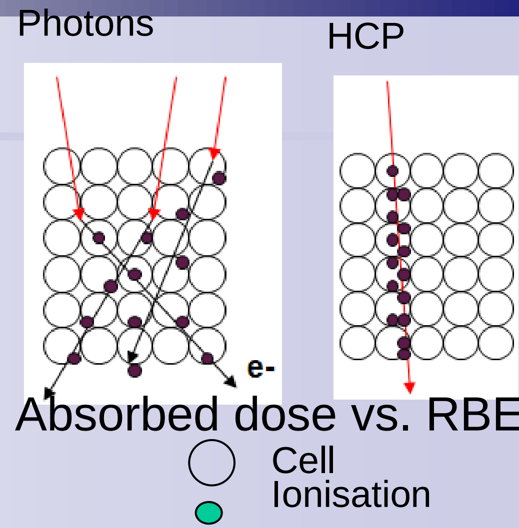
Small Detector (um)



From Garret and Grisham, "Biochemistry" Copyright 1995 by Sauders College Publishing

Biological Cell (um)

Microdosimetry

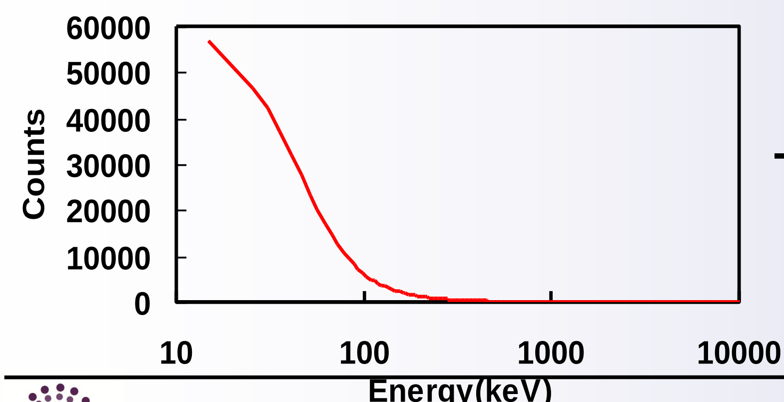


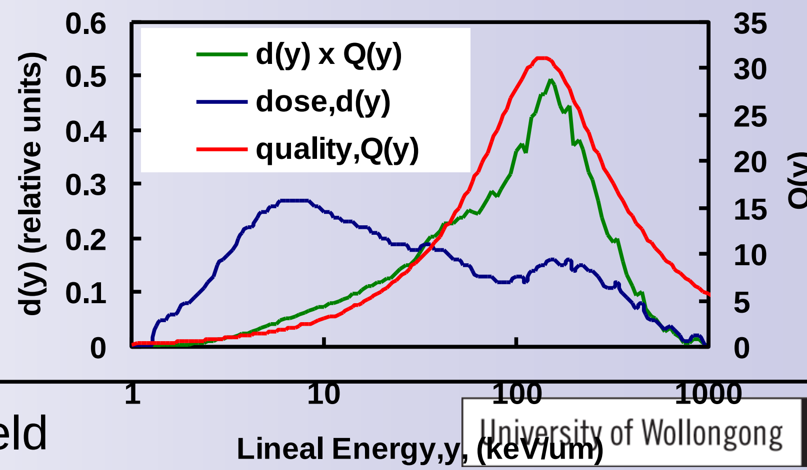
Study of dose deposition in microscopic volumes e.g. Human cells

- Stochastic deposition of energy not correlated with absorbed dose
- Important for radiation protection in radiotherapy and space radiation environments

Microdosimeter measures energy deposition events in small (cell-sized) volumes

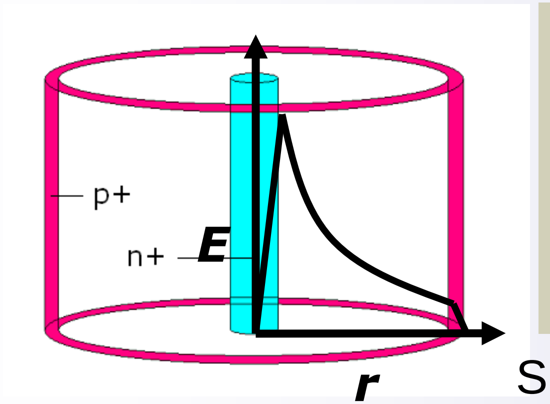
- Lineal energy, y = E/ <l> where <l> is mean chord length
- Most common representation in yd(y) vs. y. yd(y) indicates the dose delivered in the range y to y+dy
- Average Quality factor, Q can be calculated from y

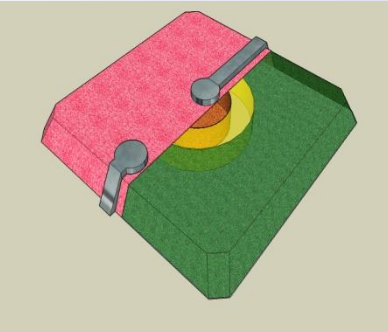




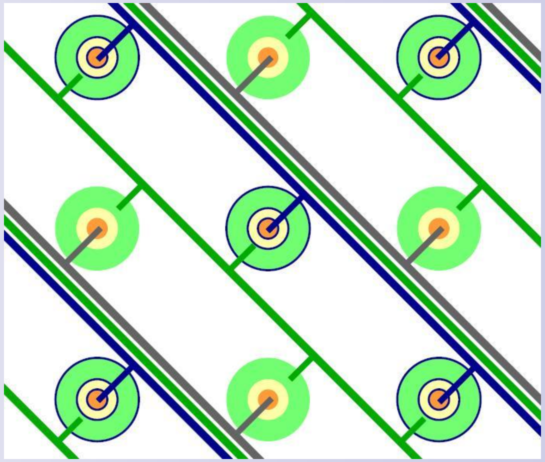
3D SOI silicon microdosimetry: generation 2/1

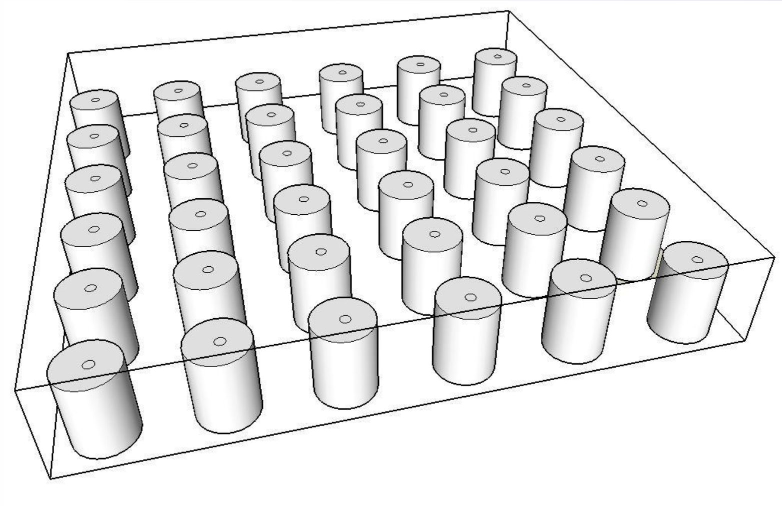
3D silicon mesa p-n junction array
with internal charge amplification
produced at UNSW SNF

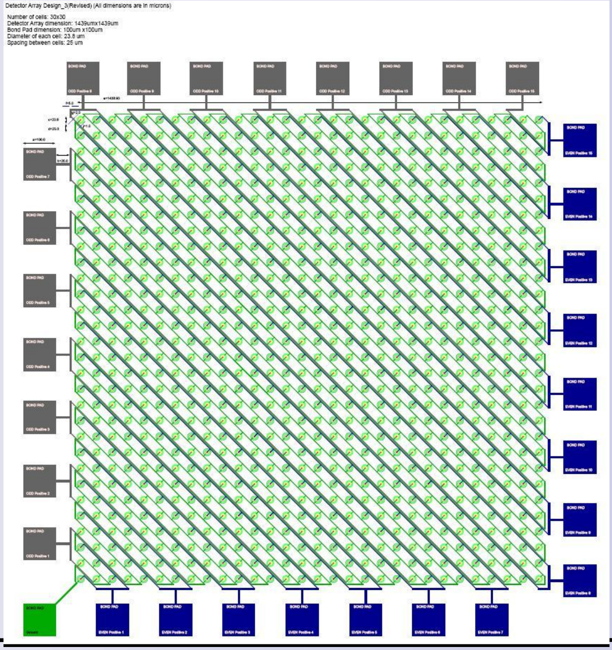




Single mesa 3D SV



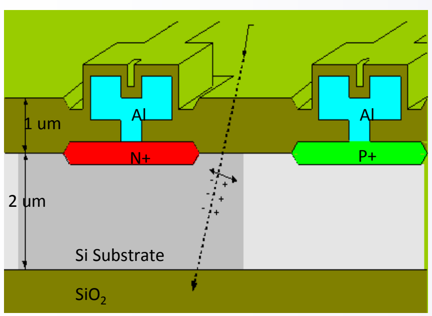




Silicon Microdosimetry at CMRP

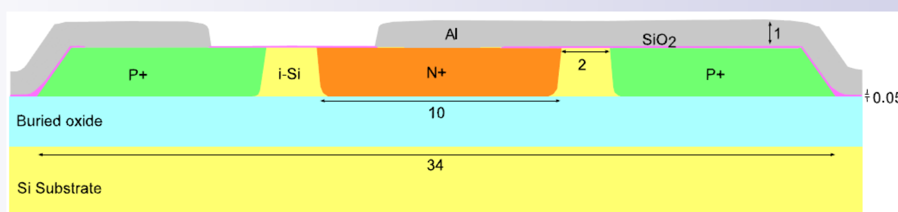
1st Generation

- Fabricated on bonded silicon-on-insulator (SOI) wafer
- As and B ions diffused to create p-i-n junctions
- Elongated Rectangular Parallelepiped Structure
- Array of 4800 cells
- Disadvantage: cross-talk between neighboring cells



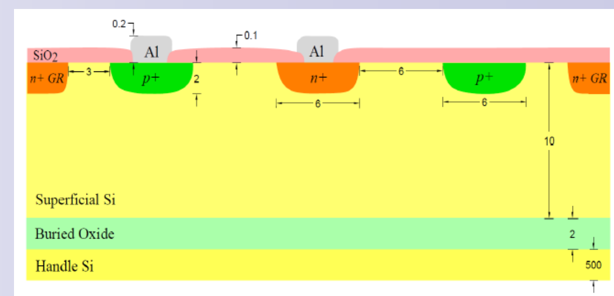
2nd Generation: MESA

- Fabricated on p-type SOI wafer
- Phosphorus and boron diffused to produce p-i-n diodes
- Array of 900 cylindrical cells
- Array of 3D raised mesa structures to reduce lateral diffusion and cross talk
- Cylindrical sensitive volume is a better approximation of spherical site
- Disadvantage: low yield due to difficulty evaporating Al track on raised mesa structure

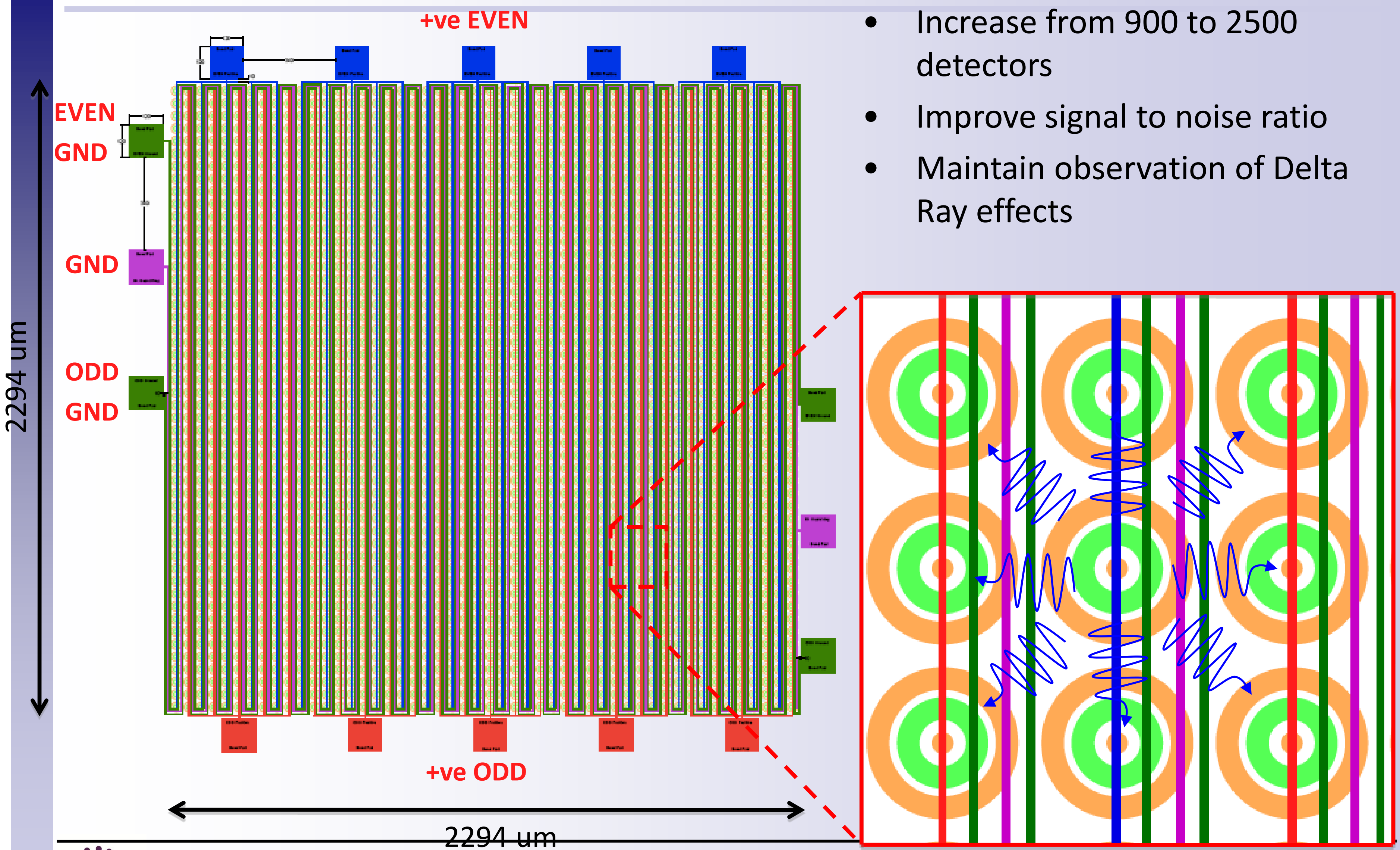


2nd Generation: PLANAR

- Fabricated on p-type SOI wafer
- Phosphorus and boron diffused to produce p-i-n diodes
- Planar topology incorporating guard ring structure
- Array of 3600 cells

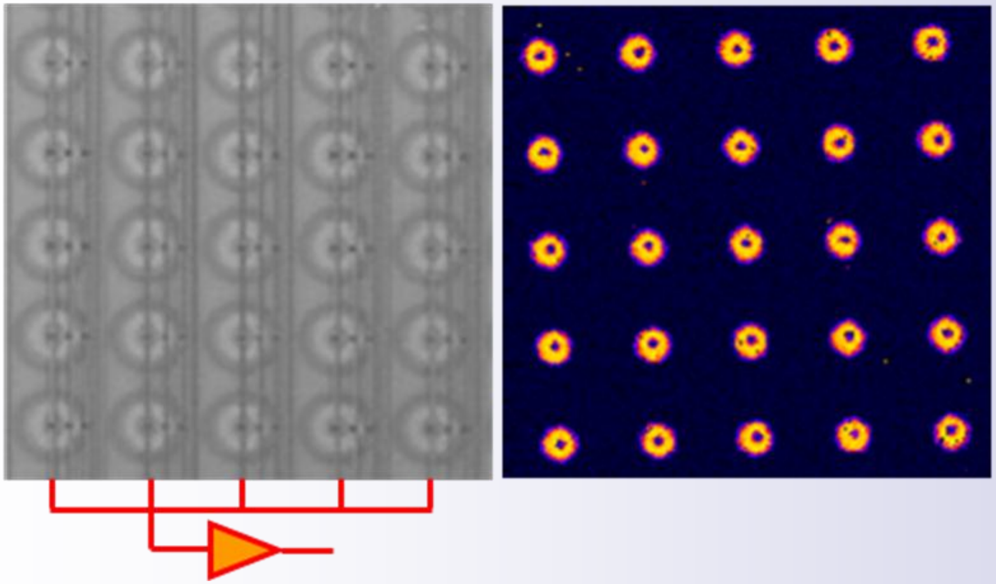


3D SOI planar silicon microdosimeter:generation 3/2



- Increase from 900 to 2500 detectors
- Improve signal to noise ratio
- Maintain observation of Delta Ray effects

SOI silicon microdosimetry:generation 2



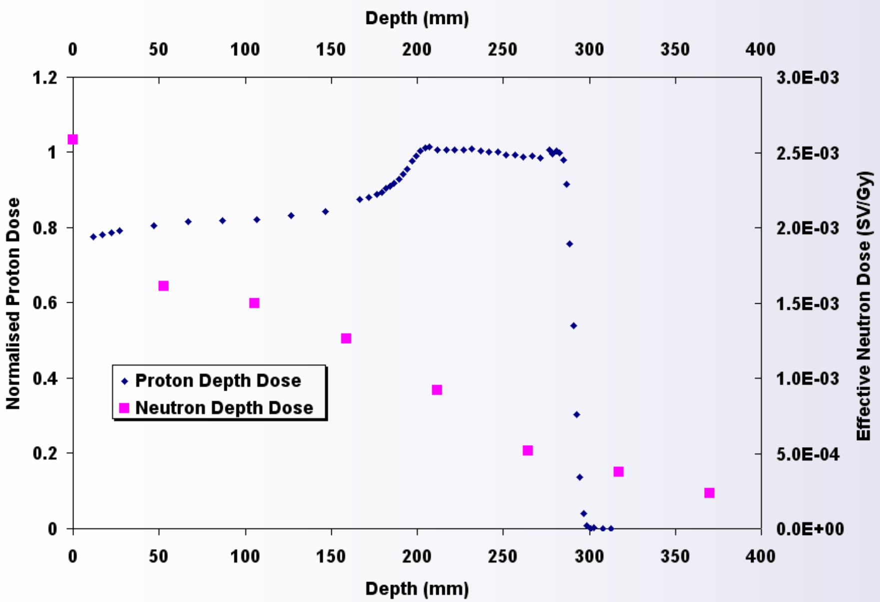
Results obtained by Using ANSTO microbeam heavy ion probe

Response of new 3D SOI microdosimeter on 1 μm diameter 3 MeV alpha particles scanning microbeam

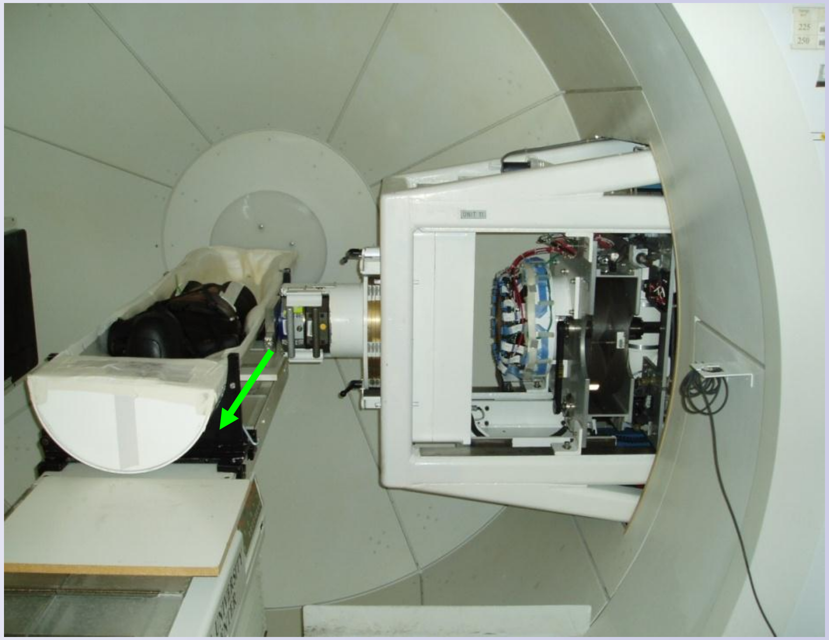
Each cell has sensitive volume with a radius of 6 μm and pitch about 20 μm

Proton Therapy: LLUMC

Firstly measured dose equivalent with silicon CMRP SOI microdosimeter



5 cm from the field edge



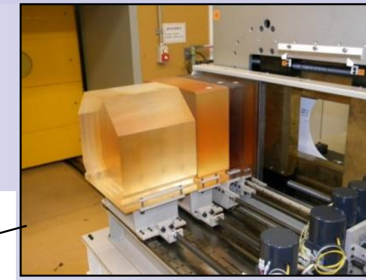
Out of field neutrons dosimetry:

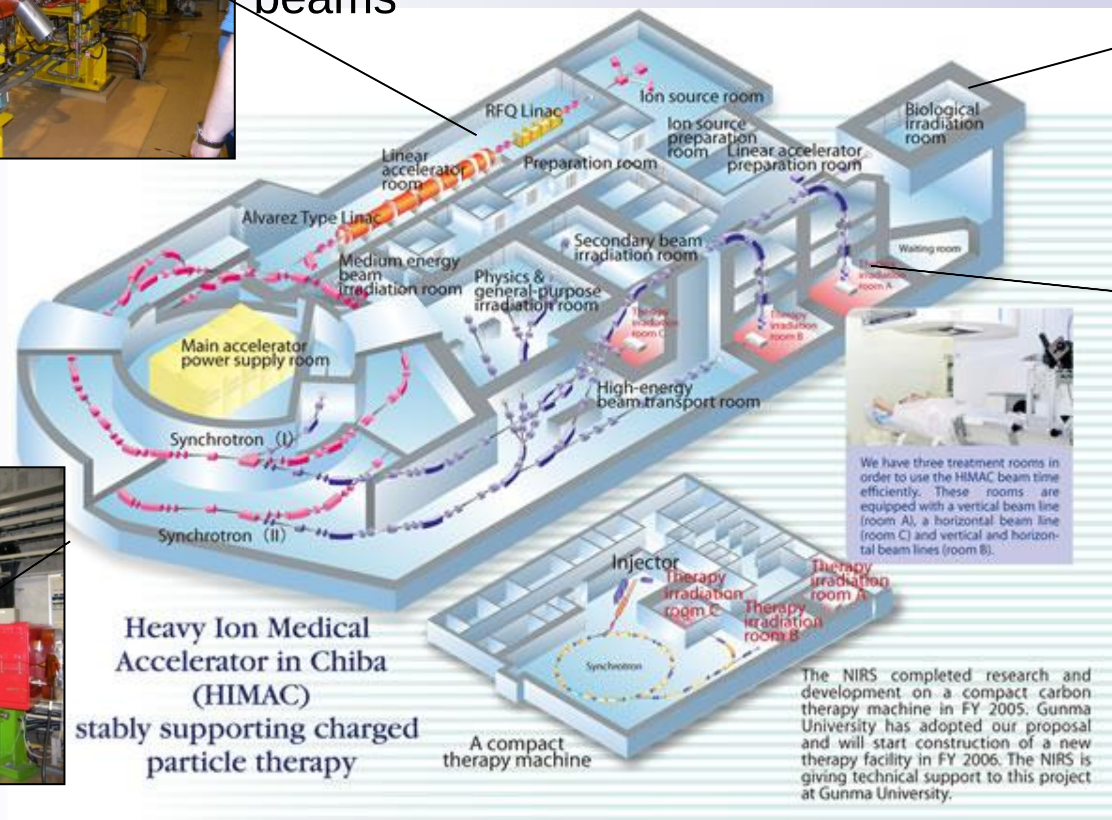
Experiments at LLUMC and MGH in clinical scenarios

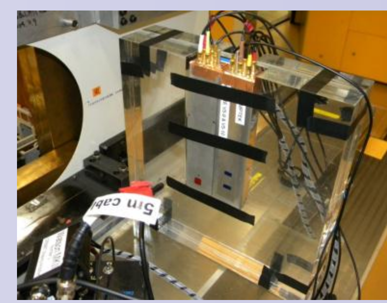
HIMAC heavy ion therapy facility

CMRP collaboration with NIRS, Japan (Dr Hiroshi Yasuda et al)

150 MeV/u He and 400 MeV/u C-12 ion beams



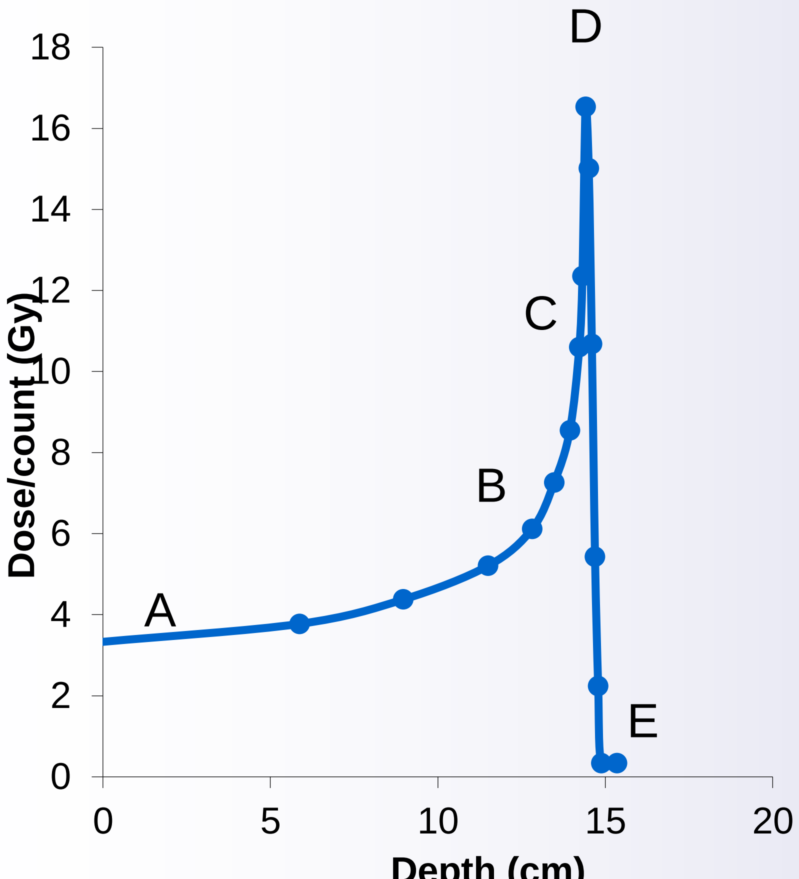




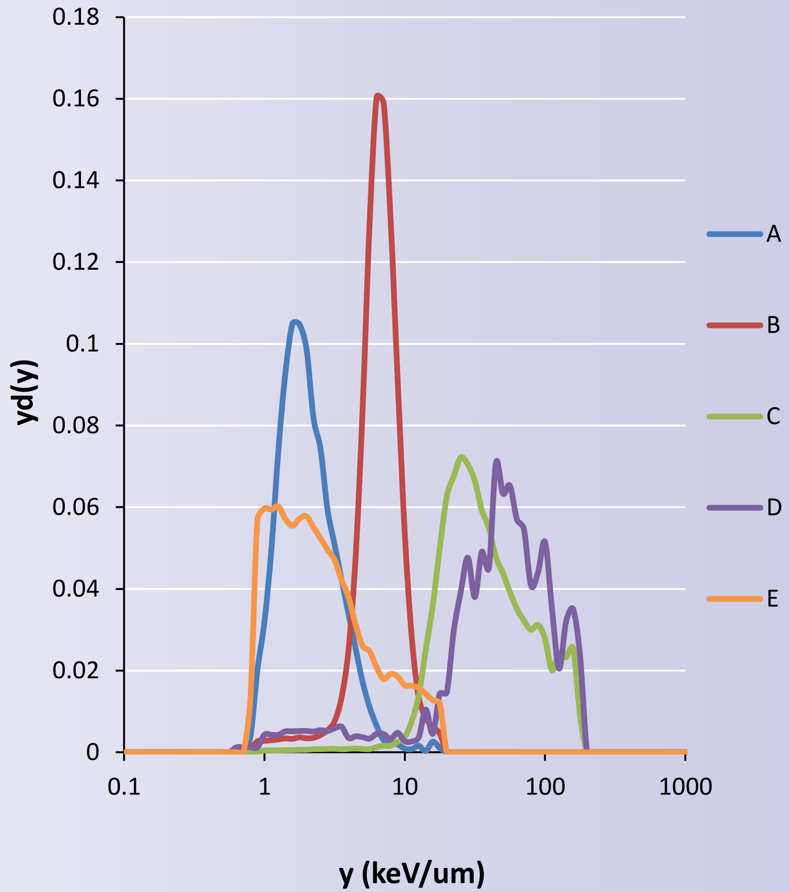
http://www.nirs.go.jp/ENG/research/charged_particle/index.shtml

HIMAC:150 MeV/u He

Microdosimeter placement along the Bragg Peak

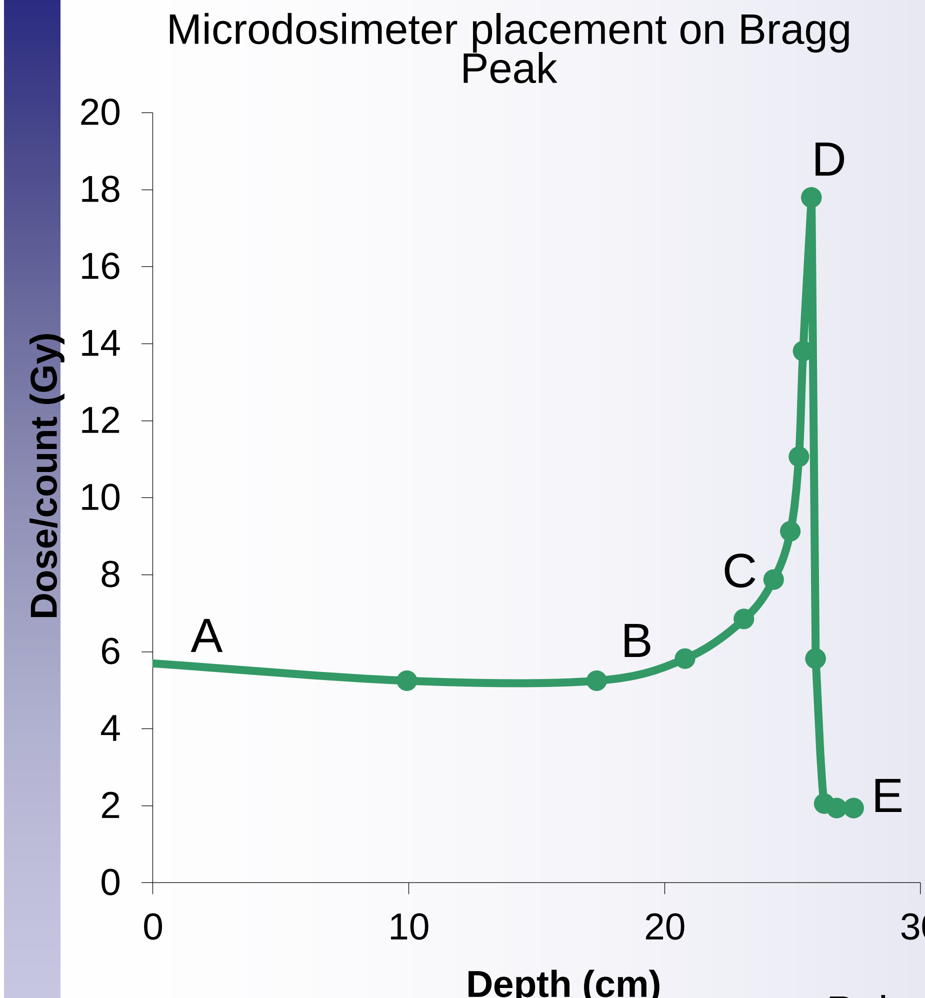


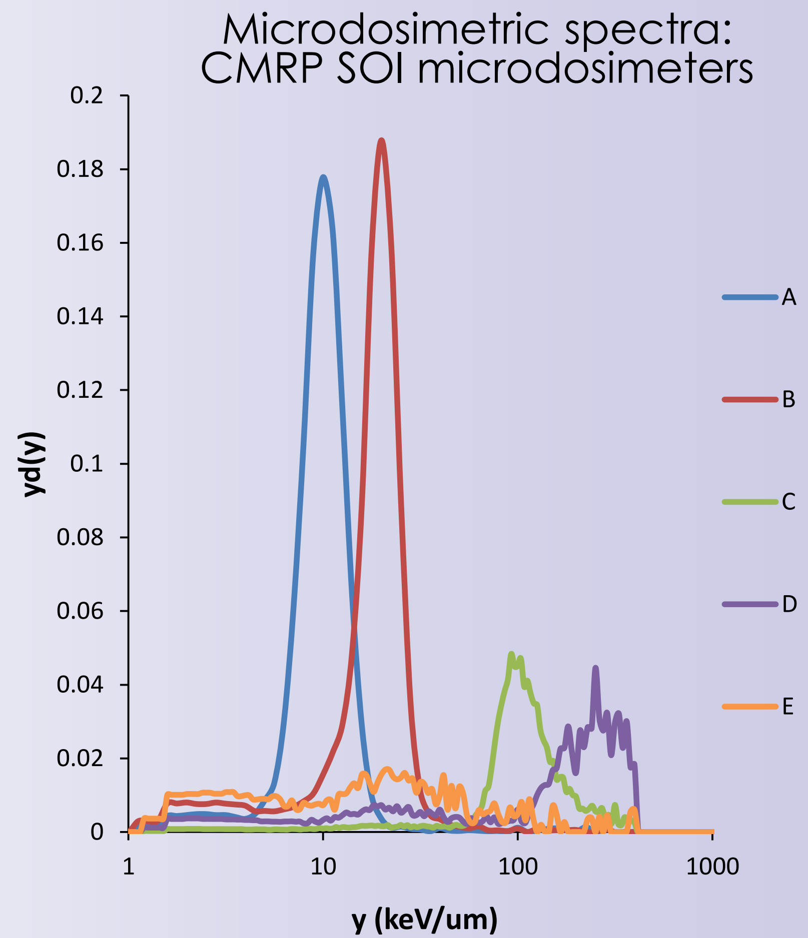
Microdosimetric spectr
CMRP SOI microdosimeters



- Hardening of the m/spectra with depth
- Point E- neutrons downstream of BP

HIMAC:400 MeV/u ^{12}C



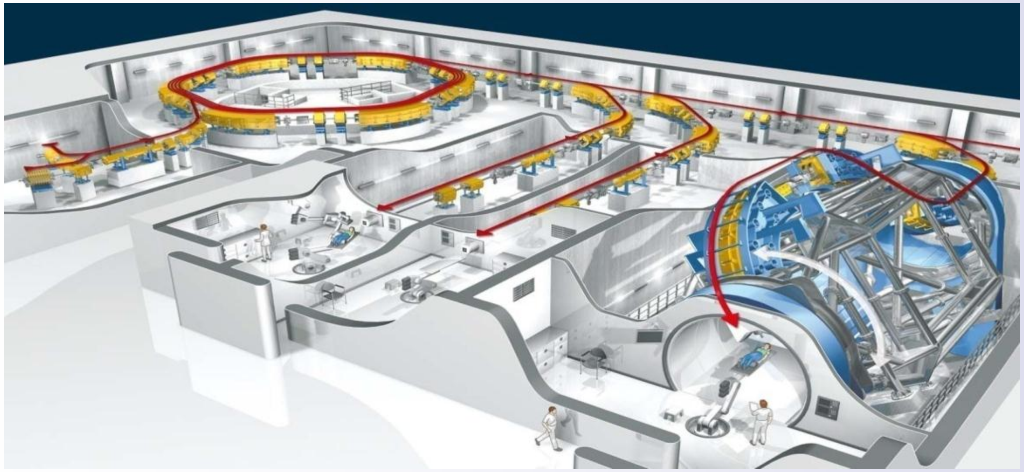


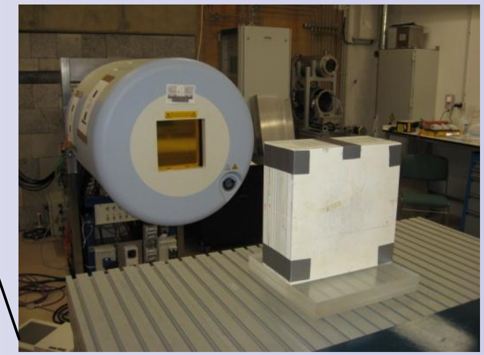
Point E-high LET fragments and neutrons

Heidelberg HIT Experiment

- Two treatment plans were used
  - **5 x 5 x 5 cm cubic irradiation using a Spread Out Bragg Peak (SOBP)**
    - Energy range from 125.25 MeV/u to 202.95 MeV/u in 18 energy steps or slices (4.32 MeV/u steps in energy)
    - Pencil beam profile of 6.7 mm FWHM in diameter
  - **Actual brain tumour treatment plan**
    - Energy range from 142.09 MeV/u to 266.08 MeV/u for brain treatment
- Both treatment plans calibrated for dose in water
  - 1.2 cm diameter ionisation chambers used for verification of dose plan in a water phantom
- PMMA phantom used for the experiment
  - $\rho_{PMMA} = 1.17\ g/cm^3$
  - $\rho_{Water} = 1\ g/cm^3$
  - Therefore range in PMMA ~85.47% that of range in water

Heidelberg Heavy Ion Therapy facility

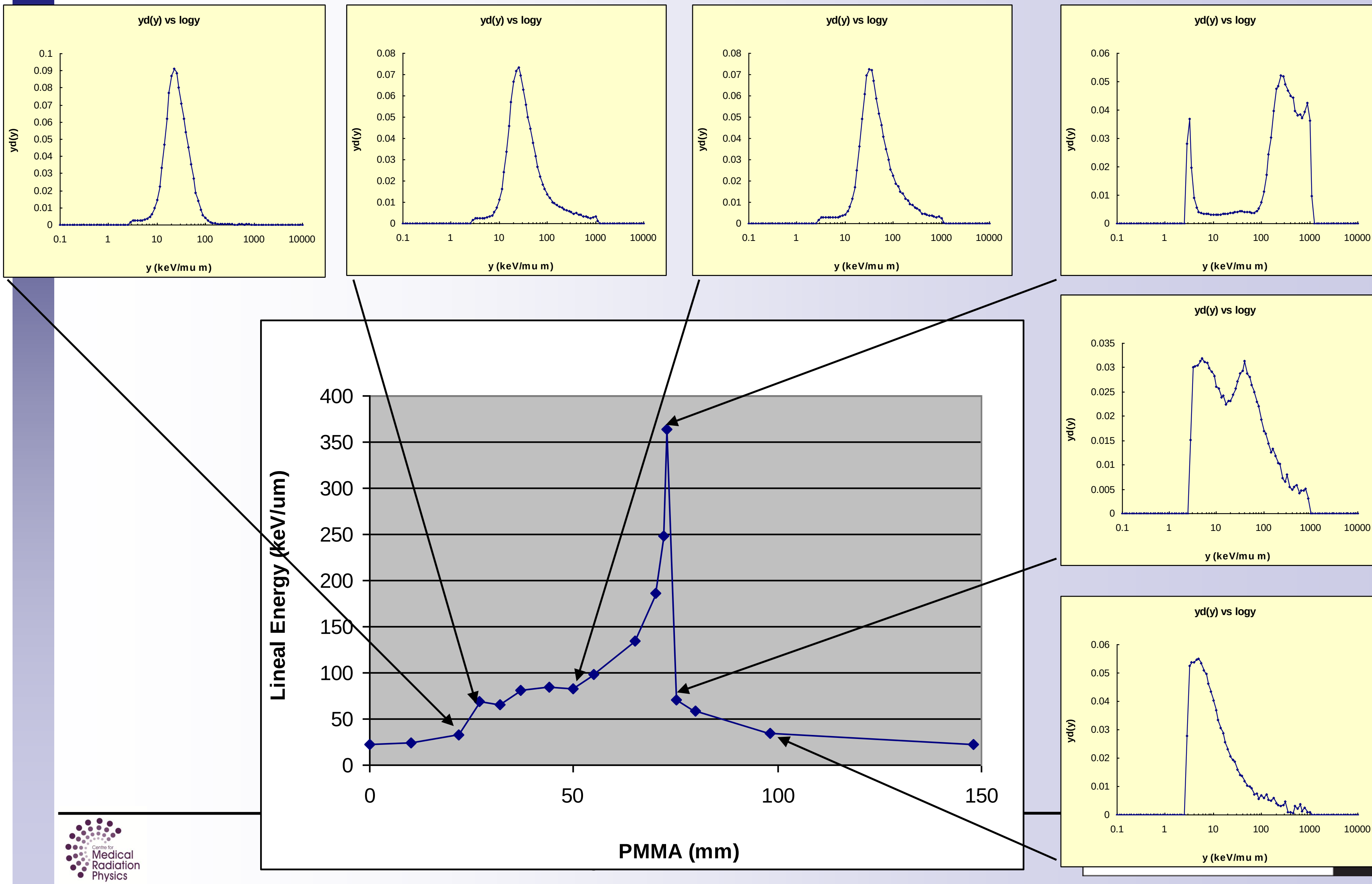




- Scanned carbon/proton with range in water
- Range 2-30 cm in 1 mm steps
- The beam can be delivered in 10 intensity steps
- Scanned field in the isocenter is 20 x 20 cm2
  FWHM of PSB 10mm

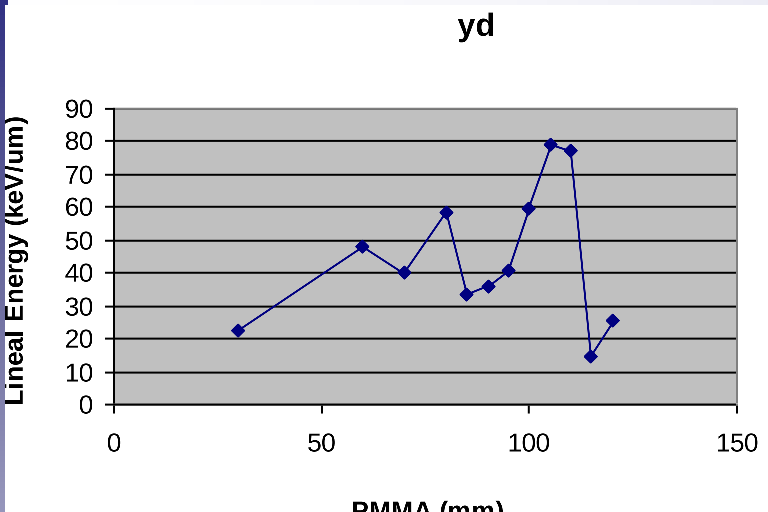
CMRP Collaboration with Heidelberg (Dr Maria Martisikova *et al* and Milano Politechnik (Prof S. Agosteo ,Prof A. Fazzi *et al*)

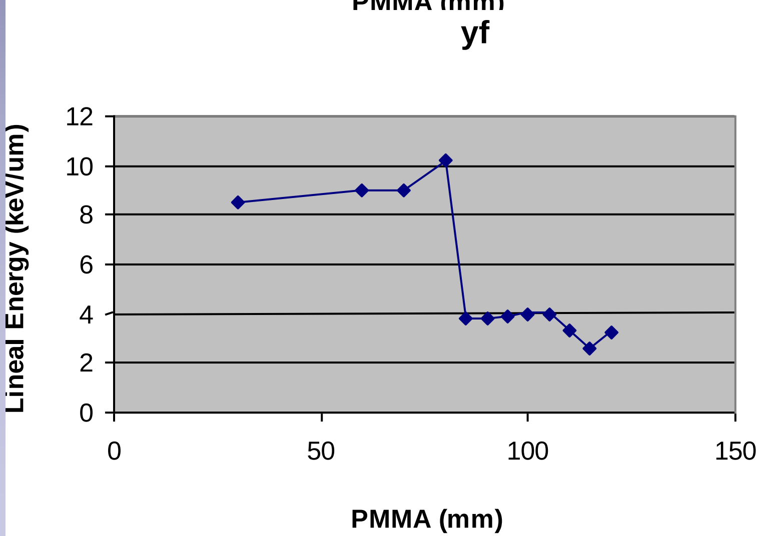
C -12 SPB :5 x 5 x 5 cm dose cube

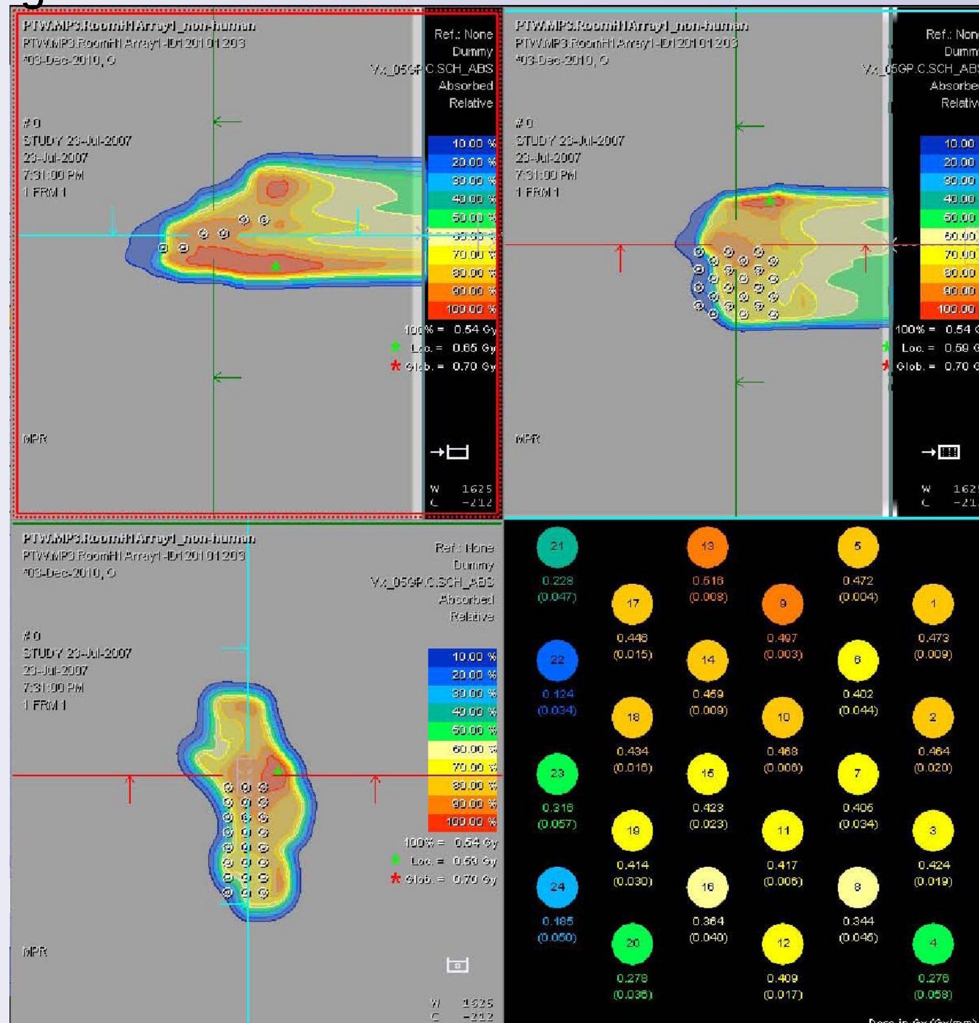


Brain Tumour Treatment Plan: PSB

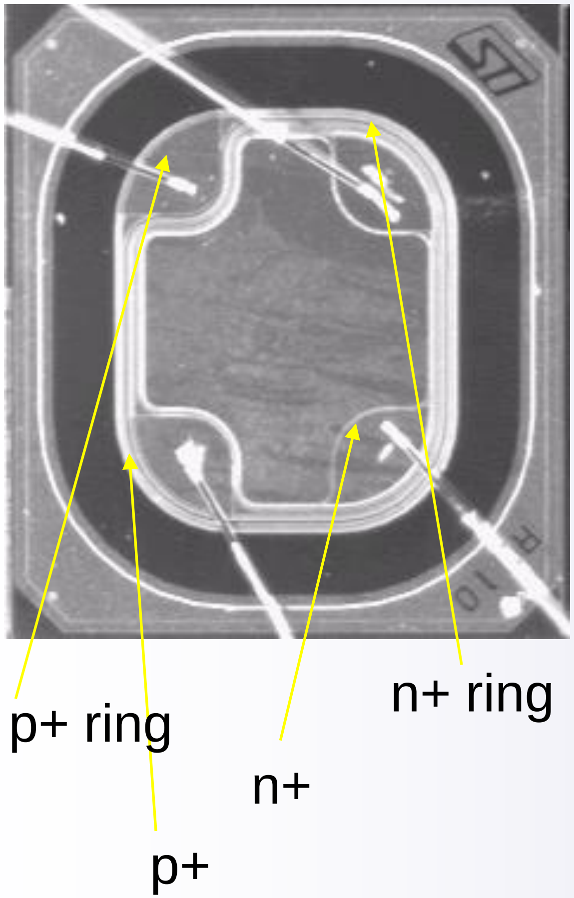
SOI Microdosimeter scanning along the central axis

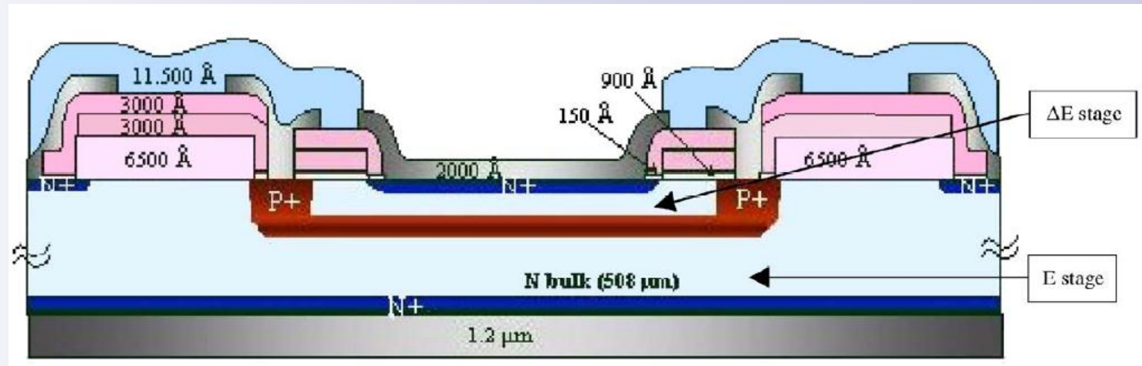






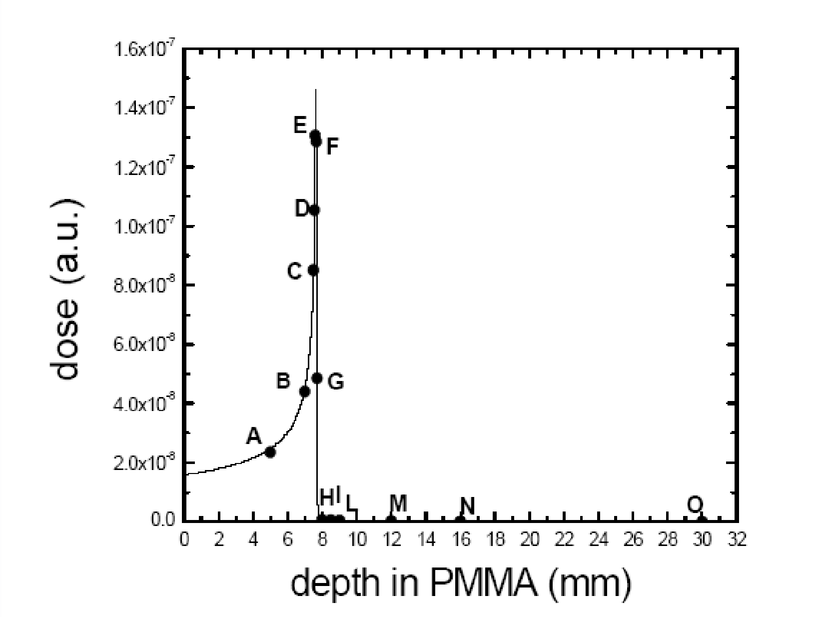
Monolithic Silicon Telescope

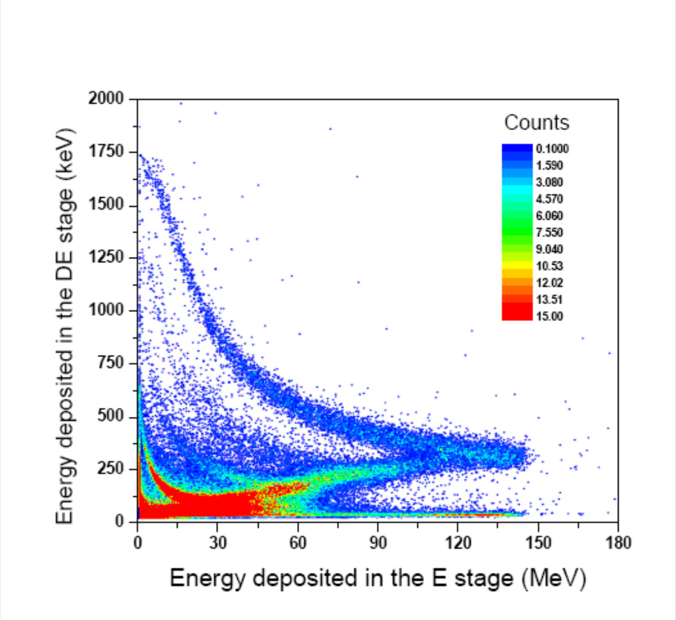




- B implantation to create buried p+
- thickness ΔE ~ 2 microns
- thickness E ~ 500 micron
- Developed by Tudisco et.al., S.Agosteo, A.Fazzi , P.Fallca et.al. (Politecnico di Milano, Italy)
- Characterized jointly at CMRP/ANSTO

62MeV/u C-12 beam line, INFN





Points of ΔE-E detector measurement along the Bragg peak

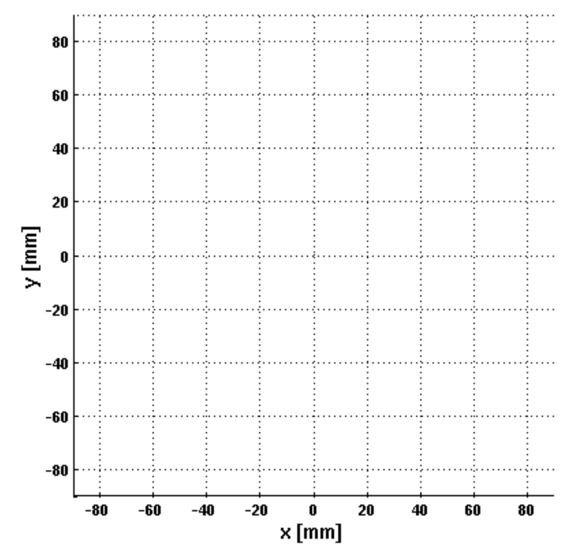
ΔE-E plot for detector at point I

ΔE/E scatter plots allow particle identification of the light ions, e.g. H, He, Li, Be, and B additionally to C-12 in carbon therapy
S Agosteo et al.

Courtesy of Prof S. Agosteo, Milan Polytec.
Presented at SSD 16

What is scanning?

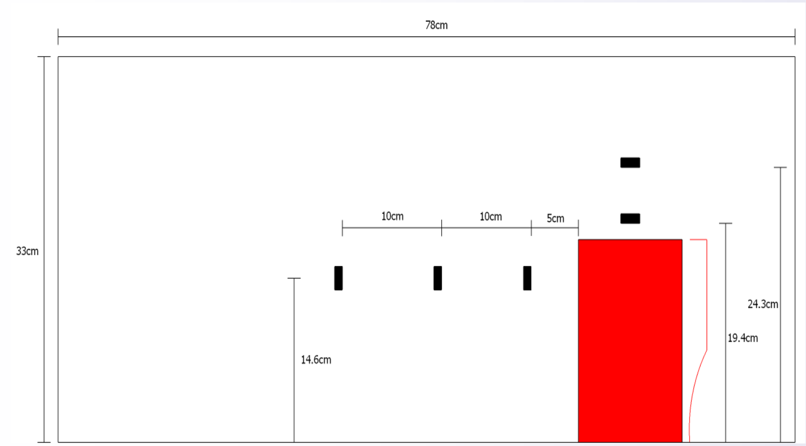
- Moving a charged particle beam of particular properties and/or changing one or more of the propertie
  - Energy
  - Position
  - Velocity
  - Size
  - Current
  - Dose

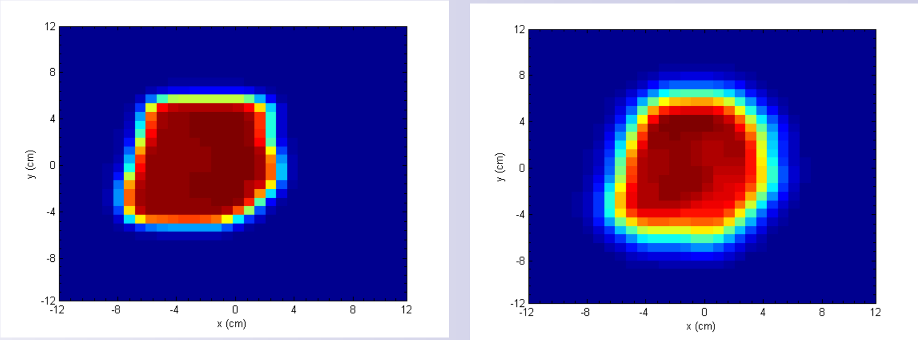


courtesy A. Trofimov, MGH

- Scanning is **not necessarily** IMPT
  - Single field uniform dose (SFUD)
  - Intensity modulated proton therapy (IMPT)

ΔE-E telescope: PBS vs Double Scattering

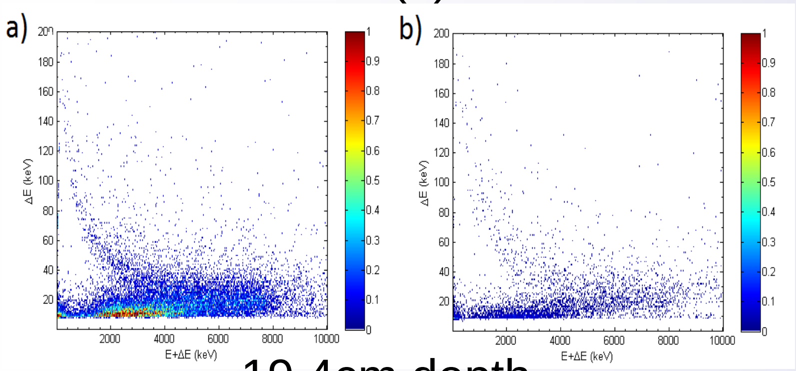




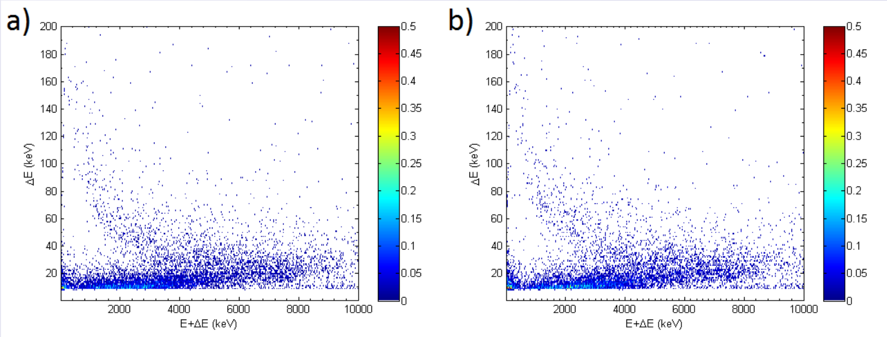
Beam shape for the double scattering (left) and pencil beam scanning (right) fields using the MatriXX detector (IBA dosimetry

The 5 measurement positions of the ΔE-E detector during the experiment.

ΔE-E spectra downstream of SOBP, on a the central axis:
(a) double scattering (b) pencil beam scanning



19.4cm depth

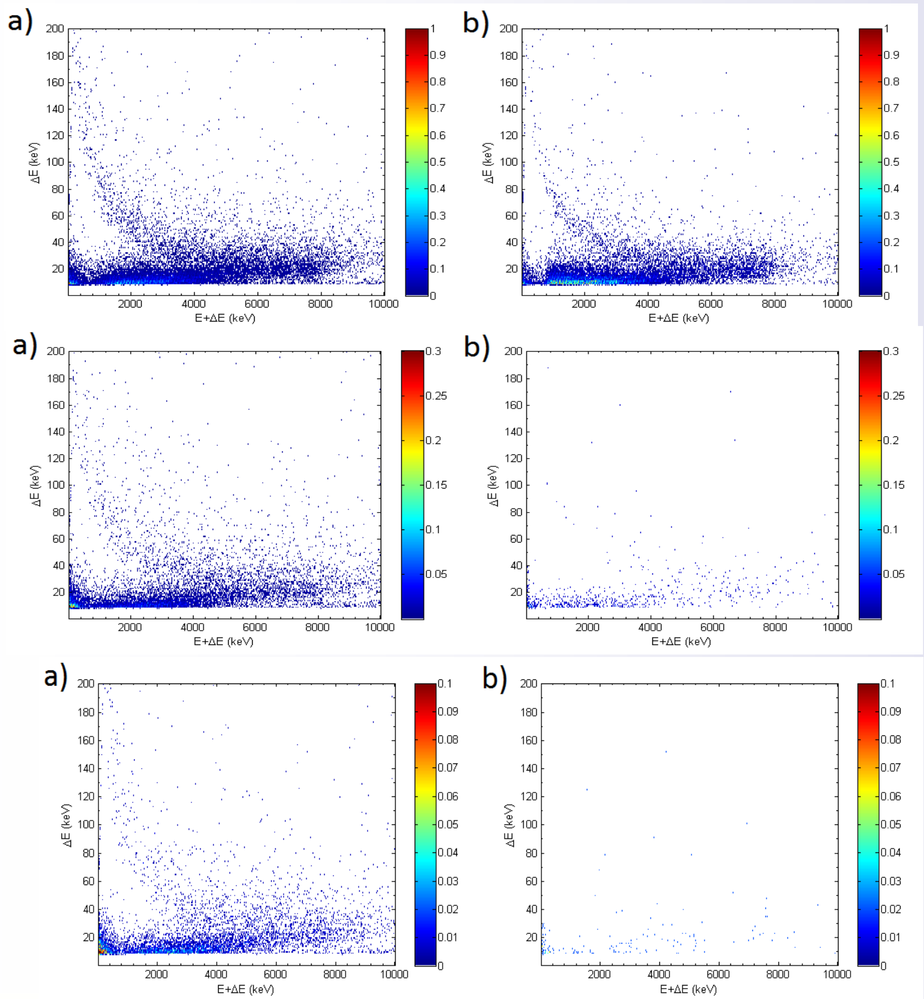


25 cm depth

Stephen Dowdell, PhD Thesis, CMRP UoW, May 2011
with B Clasie, J.Flanz, (MGH, Boston) S.Agosteo ,A Fazzi, A.Pola (MP, Italy)

ΔE-E telescope: PBS vs Double Scattering

ΔE-E spectra at a depth of 14.6cm in Lucite normalized counts/Gy in SOBP
(a) double scattering; (b).pencil beam scanning

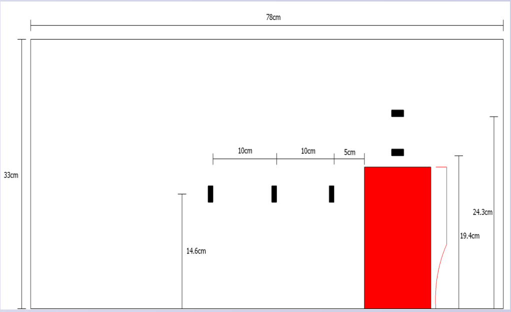


Lateral distance from the field edge

5 cm

15 cm

25 cm

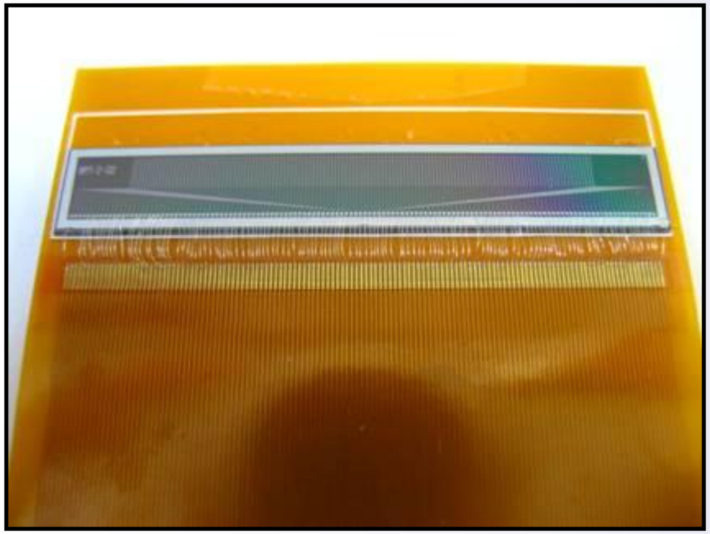


- Direct confirmation of essential reduction of neutrons laterally out of field for PBS vs passive delivery
- Closer to the field contribution from scattered protons for PSB higher due to larger penumbra in comparison with passive delivery

Conclusion

- Semiconductor dosimetry is an important part of radiotherapy quality assurance
- It has many advantages as high spatial and temporal resolution has possiblity of easy integration with multi-channel read-out systems and multifunctional with application for dosimetry and microdosimetry

Dose Magnifying Glass (DMG)



- 128 channel –p-type Si strip detector
- SV area of a single strip : 20 x 2000 μm
- Detector thickness: < 0.4 mm
- Kapton thickness: 0.1 mm
- Spatial resolution 0.2 and 0.1 mm

DMG in Stereotactic Proton Therapy

In collaboration with Loma Linda University Medical Center (LLUMC), Loma Linda, California

Prof R Schulte, Dr A.Wroe

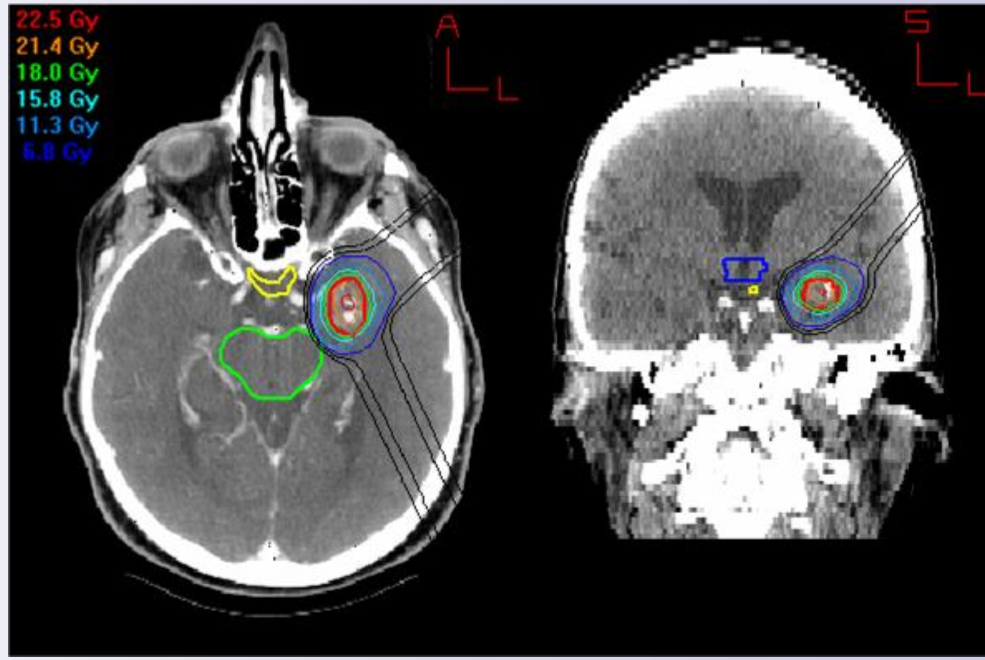
Work in progress

Stereotactic Proton Radiosurgery at LLUMC

- **Current**
  - Single-dose proton radiosurgery and two-fraction stereotactic proton radiotherapy using the Bragg-peak
    - Arteriovenous malformations
    - Brain metastases
    - No size limitations
- **Future**
  - Conformal proton Bragg-peak radiosurgery for Mesial Temporal Lobe Epilepsy (MTLE)
  - Single-dose functional proton radiosurgery with high-energy shoot-through beams
    - Trigeminal neuralgia, Thalamotomy, Callosotomy

Arteriovenous Malformations LLUMC Treatment Technique

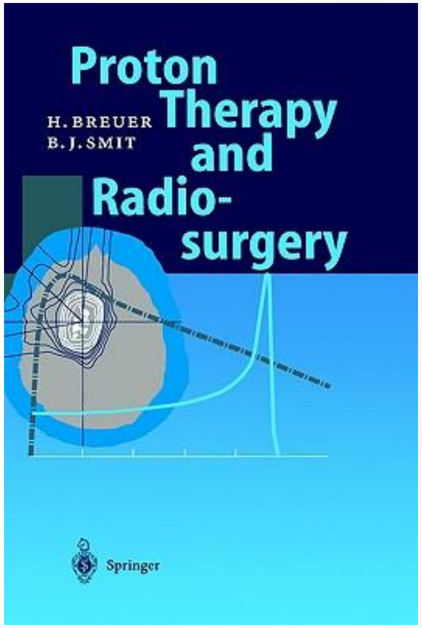
- 3-4 treatment beams
- 1-2 beam planes
- single or two fractions
- 20 - 25 GyE nominal dose (at isocenter)
- 80% treatment isodose (70% on brain stem/chiasm)

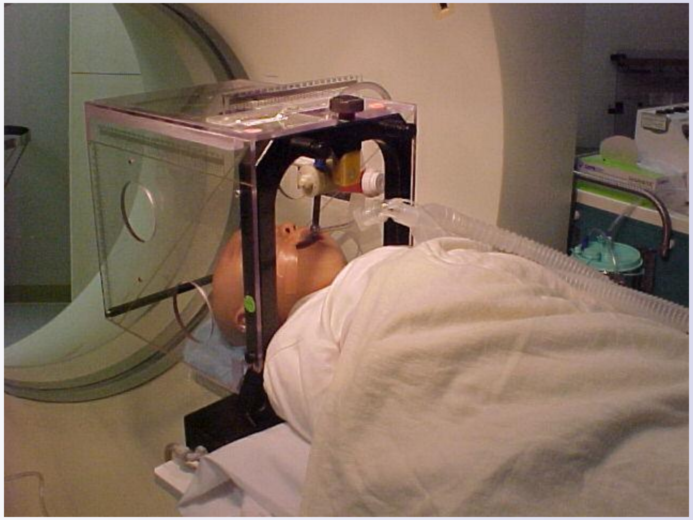


QA of small partial proton beams and total plan is paramount due to required accuracy

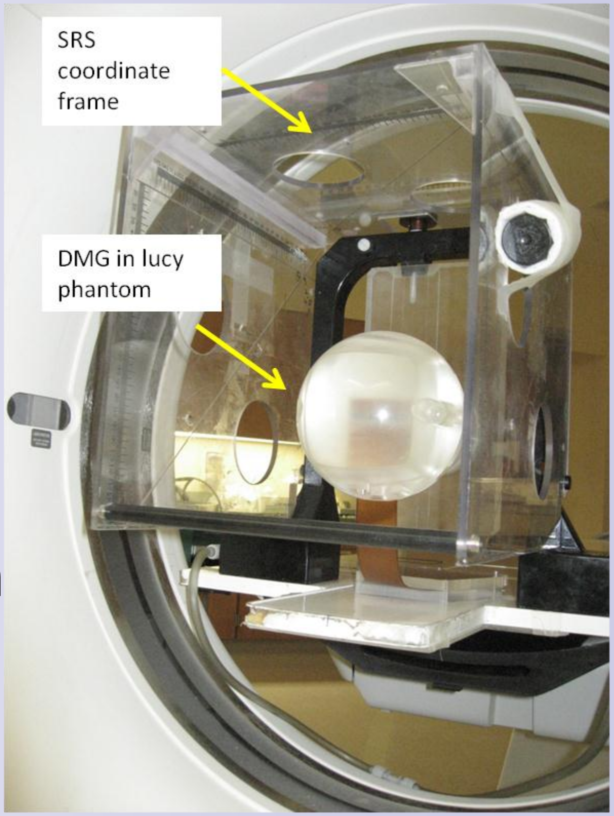
DMG is a perfect tool for QA in ion SRT

Proton radiosurgery: from planning to verification





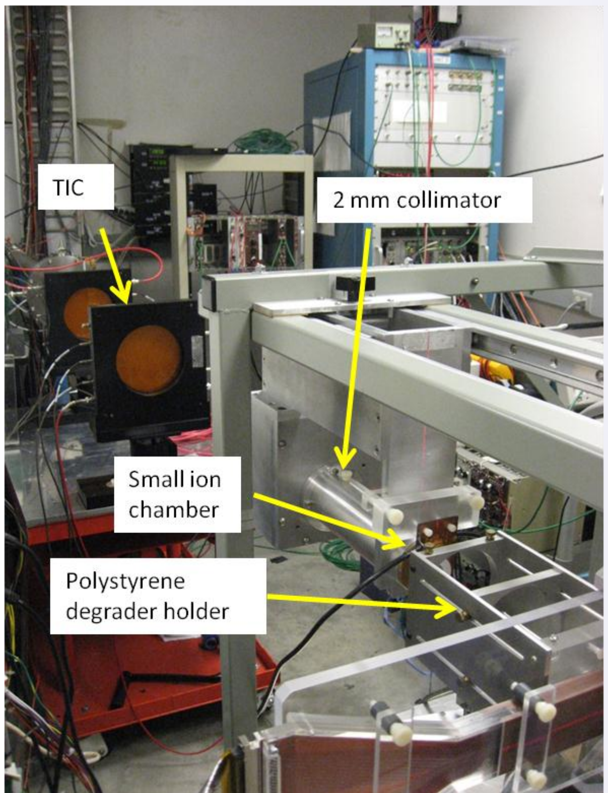
- CT required for proton dose calculations
- Stereotactic localization system (Z-box)
- Patient released from immobilization after imaging



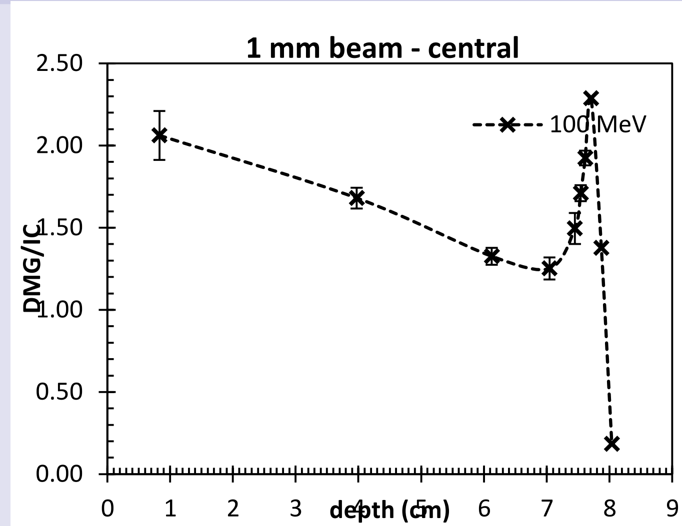
DMG in a LUCY phantom
- CT scanning
- Planning
- Dose Verification

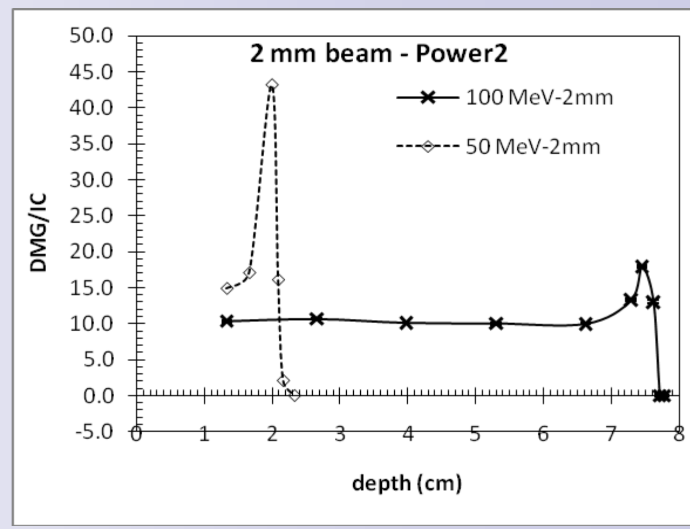
Small diameter proton beam depth dose profiles

- 1 & 2 mm diameter beam, 50 MeV and 100 MeV
- Research beam line
- Small animal SRS research



DMG -200

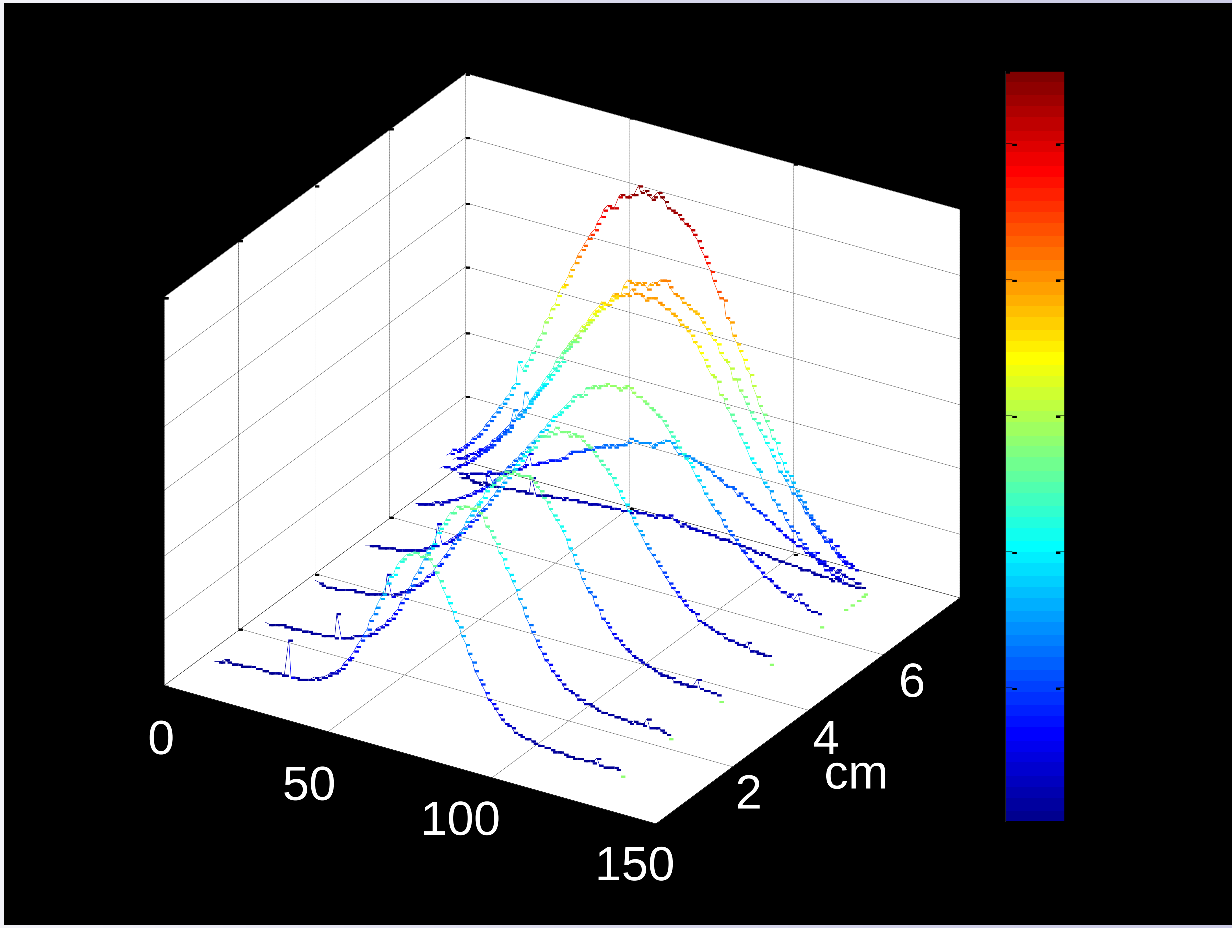




Small proton beam scattering with depth

- Scanning in water DMG 100
- Proton beam diameter: 2 mm
- Energy: 100 MeV
- Resolution: 0.1mm

DMG-100
1st application



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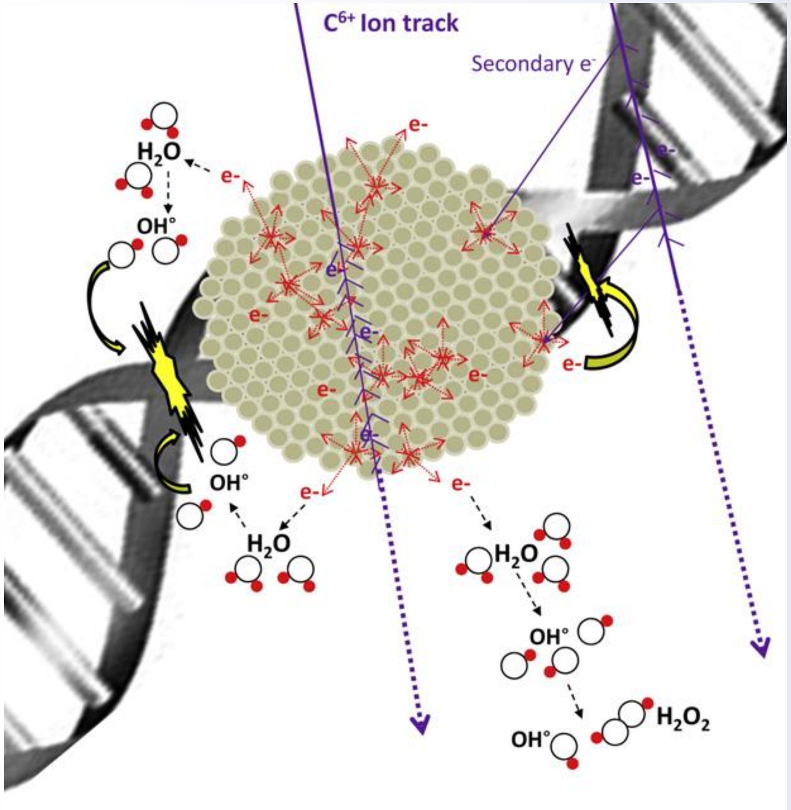
Nanoparticles for RBE enhancement

RBE Enhancement with NP



New direction of research at CMRP :

Radiation Physics of interaction of heavy ions and protons with Nano Particles (NP)

Effect of RBE enhancement modeling with GEANT DNA MC simulations

Radiobiology experiments are required on heavy ion and proton beams

Expected outcome –improvement of treatment with charged particles

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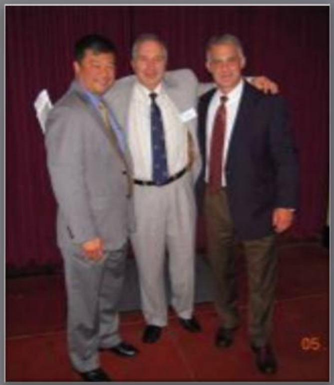
BUSINESS



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CMRP: Drs M.Lerch, M.Petasecca, S.Guatelli, Prof P Metcalfe

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