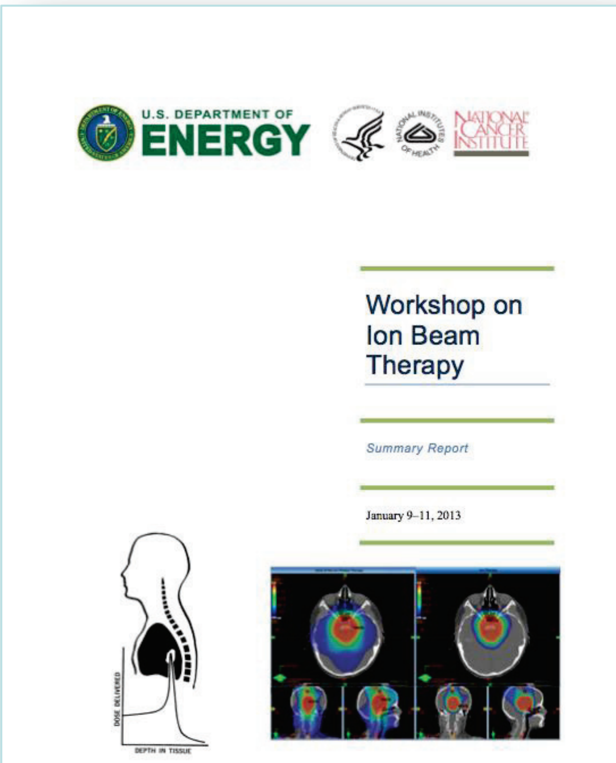
Report on the Workshop on Ion Beam Therapy



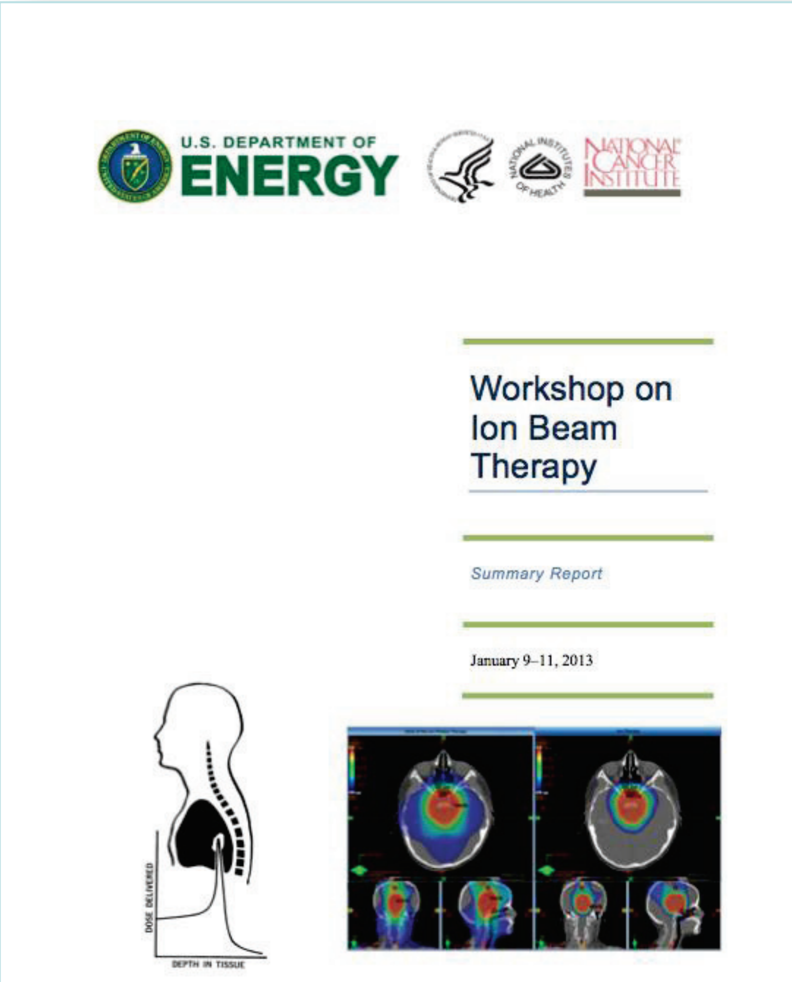
January 9-11, 2013
National Cancer Institute
Bethesda, MD

Co-sponsored by
SC/HEP and NIH/NCI

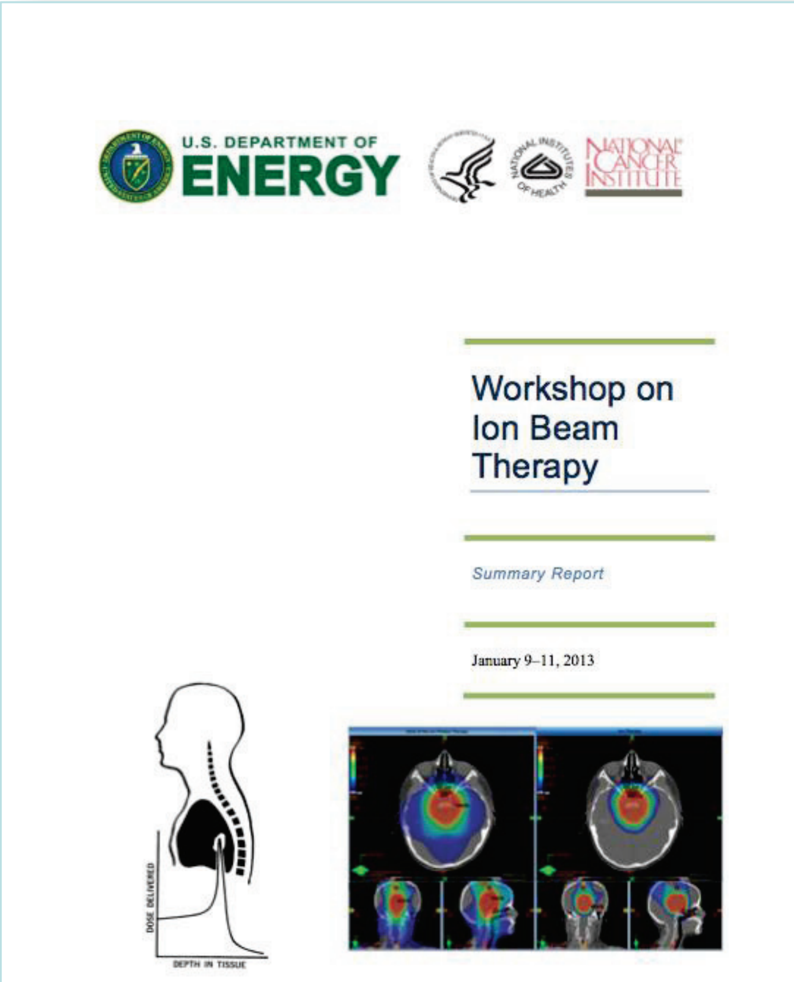
David Robin
Lawrence Berkeley National Laboratory

BERKELEY LAB
Lawrence Berkeley National Laboratory

Outline



- **Motivation and background for the workshop**
- **Workshop preparation**
- **Workshop**
- **Summarize the report**



- **Motivation and background for the workshop**

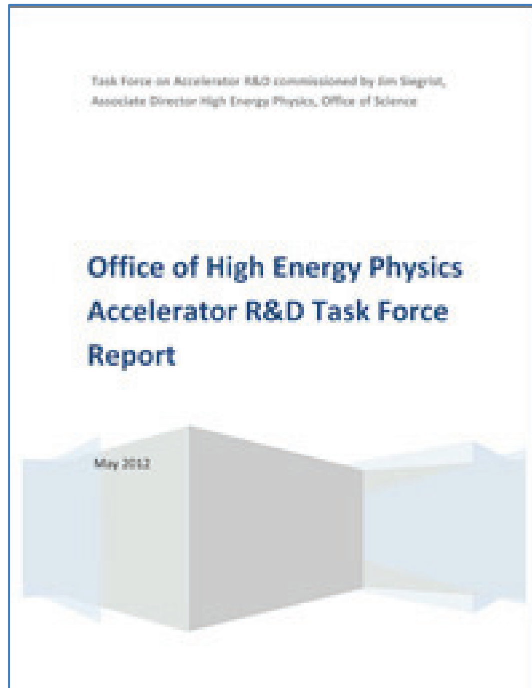
Building the HEP stewardship program (talk by M. Zisman)

Goal is to have world-leading program in accelerator R&D not only for discovery science applications but serving all of the nation's accelerator needs

2010

Accelerators for Americas Future

2012



Accelerator R&D Task Force

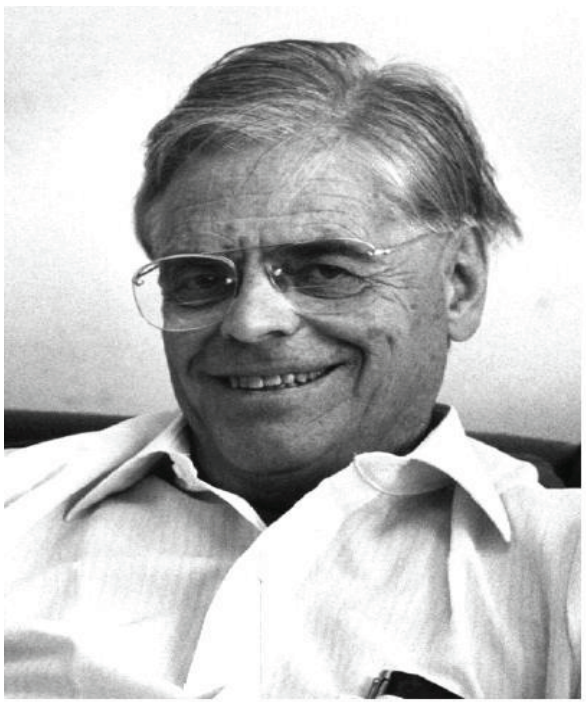
2013

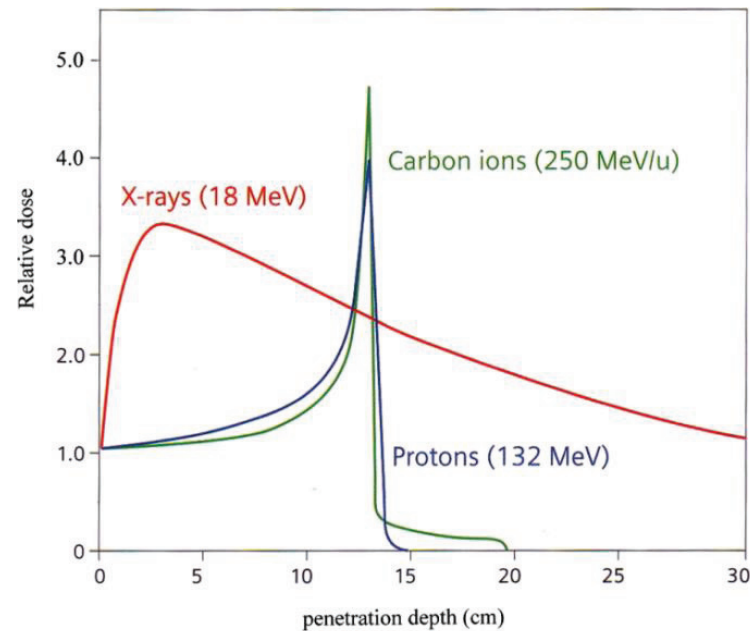
Workshop on Ion Beam Therapy

*http://science.energy.gov/hep/research/accelerator-rd-stewardship/workshop-reports/

Ion Beam Cancer Therapy

- Ion Beam Therapy (IBT) is the use of ion beams (protons and other ions) to treat tumors.
- IBT was proposed by Robert Wilson to take advantage of the Bragg Peak.



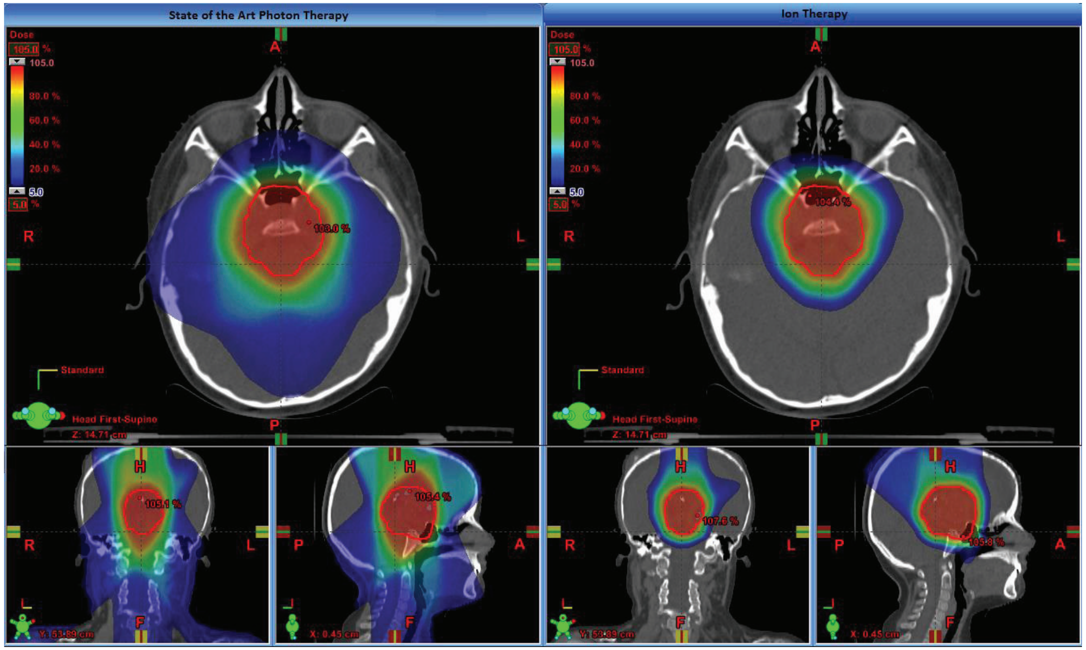


Radiology 47, pp. 487–491, 1946

Motivation for the Ion Beam Therapy Workshop

- Majority of radiation treatment is performed with photons (X-rays)
- Reports of impressive local control rates for difficult to treat cancers using ion beam therapy *(protons, carbon, …)*
  - liver, pancreas, lung, head and neck, and pediatric neoplasms

Treatment plan*



Photon Therapy Ion Beam Therapy

*Courtesy of Chris Beltran, Mayo Clinic

- Ion beam therapy is not fully optimized and more costly than photons
  - Potential for both improved performance and reduced costs

Is this an area where developments in accelerator technology can help?

Workshop charge

- **Charge 1:** Identify pertinent clinical applications and radiobiological requirements for future use of ions in cancer therapy.

- **Charge 2:** Assess corresponding beam requirements for future treatment facilities

- **Charge 3:** Assess the corresponding beam delivery system requirements for future treatment facilities and compare these with the current state-of-the-art.

- **Charge 4:** Identify R&D activities needed to bridge the gap between current capabilities and future requirements and identify which will have the highest near-term performance gain.

The timeframe

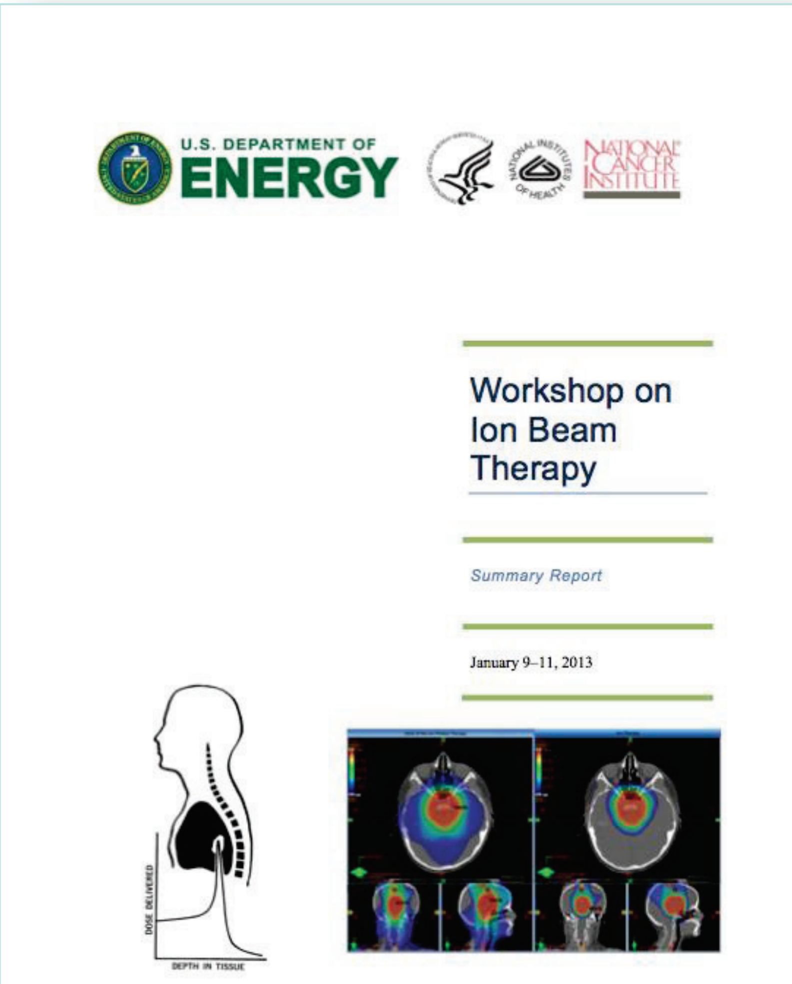
What capabilities would we like a multi-ion facility have in 10 – 15 years?

What R&D might be done in the next 5 – 10 years?

Preparation for the workshop began in September 2012

Mike Zisman – (SC/HEP) and Jim Deye – (NIH/NCI)

- **Workshop charged developed**
- **Organization committee formed**
  - **Chris Beltran (Mayo Clinic)** - *Medical Physicist*
  - **Thomas Bortfeld (MGH)** - *Medical Physicist*
  - **Kathryn Held, (MGH)** - *Radiobiologist*
  - **Tom Kroc (FNAL)** – *Accelerator Physics*
  - **John O’Connell (WRNMMC)** - *Clinician*
  - **David Pistenmaa (UTSW) co-chair** - *Clinician*
  - **David Robin (LBNL) co-chair** – *Accelerator Physics*



- **Workshop preparation**

First task – the workshop participants

Participation was by invitation only

Wanted a mix of

- Clinicians
- Radiobiologists
- Medical Physicists
- Accelerator Technologists

More than 60 participants from the U.S., Japan, Sweden, Italy Germany, and the Netherlands

The strategy

How do we take advantage of having many of the world experts but only a 2 ½ day meeting?

- **A lot of work up front**
  - A pre-workshop survey of ideas was collated to stimulate the participants to consider the range of required parameters.
- **Make it a work shop not a talk shop**
  - Only 3 plenary talks
  - Work through the charge with parallel mixed working groups

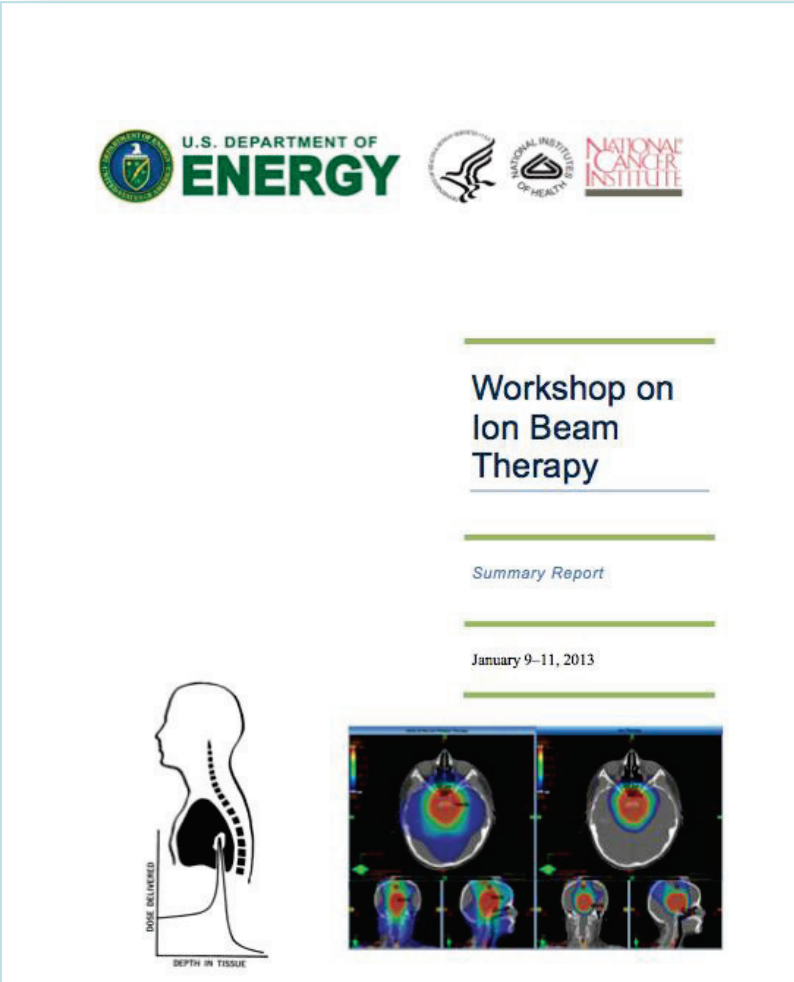
Development of the Pre-report

December 3, 2012 – A survey was developed by the organizing committee and sent to the participants

December 14, 2012 – Responses were collected (more than 200 pages!)

January 6, 2012 – Responses were collated into a 21 page pre-report and send out to the participants

Outline


U.S. DEPARTMENT OF ENERGY

NATIONAL CANCER INSTITUTE

Workshop on Ion Beam Therapy

Summary Report

January 9–11, 2013

DOSE DELIVERED

DEPTH IN TISSUE

- **Workshop**

Workshop Agenda

Start with three opening lectures on clinical, radiobiological and physics aspects

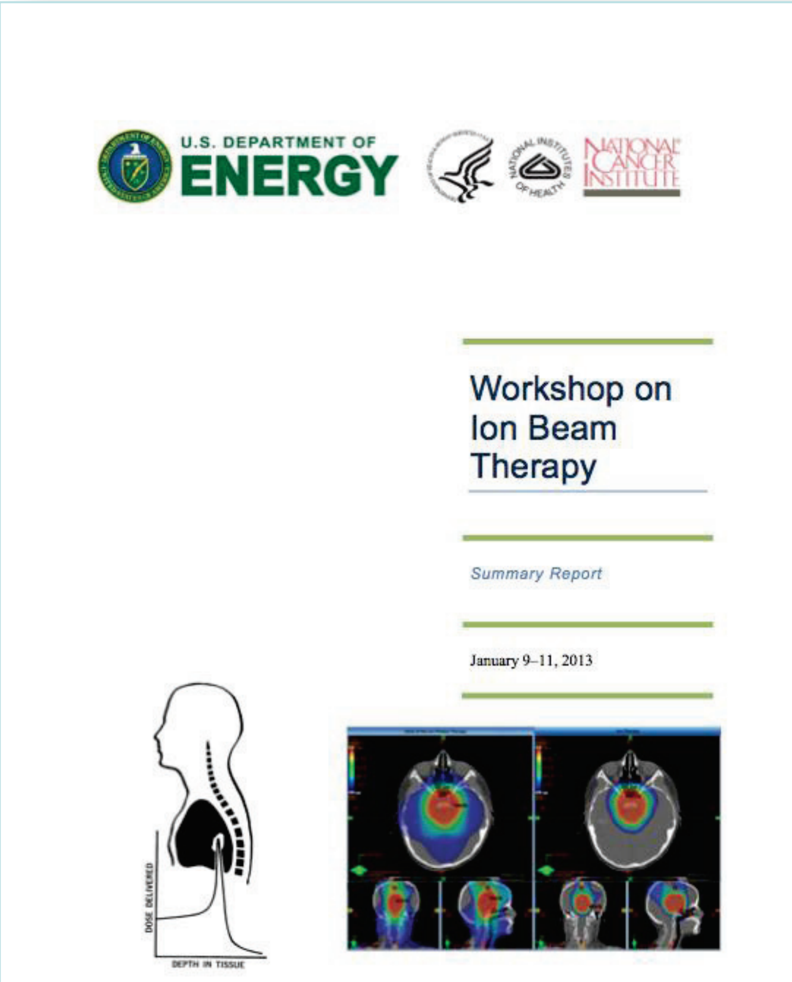
- **Clinical – Dr. Stephen Hahn (Upenn)**
- **Radiobiology – Dr. Eleanor Blakely (LBNL)**
- **Physics – Dr. Sandro Rossi (CNAO, Pavia)**

Next the participants were parceled into subject break-out panels to debate the issues and priorities over two intense days.

The conclusions of each break-out panel were presented to all of the participants for further discussion and debate.

Breakout Session	Moderator	Co-Moderator
Charge 1 (3 Panels) Jan 9 (Morning)		
Panel 1: Clinical Requirements	John O'Connell	Chris Beltran
Panel 2: Clinical Requirements	David Pistenmaa	Thomas Bortfeld
Panel 3: Biological Research Requirements	Kathy Held	Tom Kroc
Charge 2 (4 Panels) Jan 9 (Afternoon)		
Panel 4: Ion species	Tom Kroc	Anders Brahme
Panel 5: Beam requirements	Thomas Bortfeld	Jim McDonough
Panel 6: Beam delivery considerations of clinical importance	John O'Connell	Jay Flanz
Panel 7: Biology and treatment planning	Chris Beltran	Kathy Held
Charge 3 (4 Panels) Jan 10 (Morning)		
Panel 8 : Source and Accelerator	Chris Beltran	Jay Flanz
Panel 9 : Beamlines (Rotating and Fix)	David Robin	Marco Pullia
Panel 10 : Beamlines (Rotating and Fixed)	Tom Kroc	Thomas Haberer
Panel 11 : Motion control, Imaging and Dosimetry	Thomas Bortfeld	Katia Parodi
Charge 4 (2 Panels) Jan 10 (Afternoon)		
Panel 12 : R&D Discussion	Tom Kroc	Thomas Bortfeld
Panel 13 : R&D Discussion	Chris Beltran	David Robin

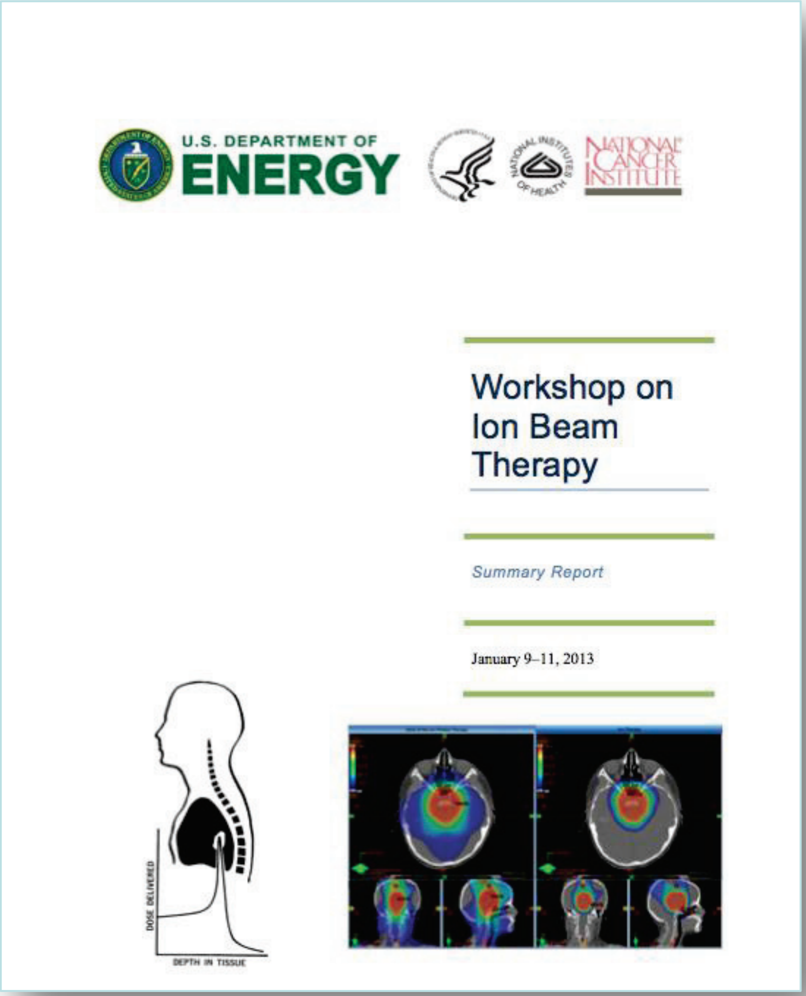
Workshop Report



January 25, 2012 – First draft of report sent out to workshop participants for comments

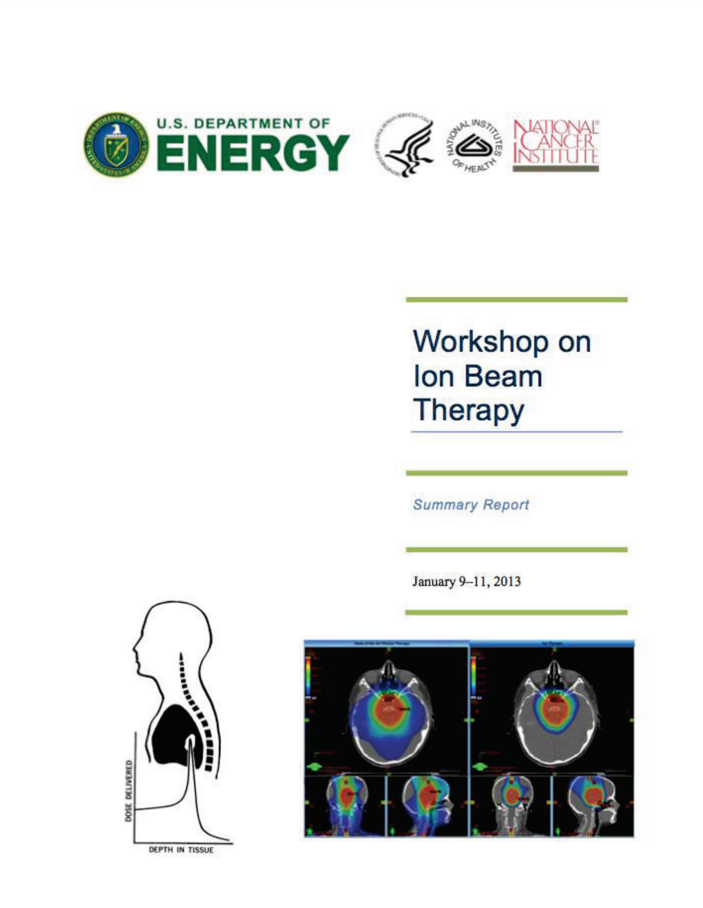
February 7, 2013 – Report finalized and sent to SC/HEP, NIH/NCI, and the participants

Outline



- **Summarize the report**

The Report highlighted 9 themes:



A substantial amount of wide-ranging R&D is required in order to contribute in a meaningful way to efforts already underway in other countries

Further studies of radiobiology and clinical efficacy are needed

Machine R&D leading to

- **cost and size reduction**
- **faster beam control and diagnostics**
- **faster 3D scanning**
- **smaller, less costly gantries**
- **real-time range and dose verification**

Future facilities will need multiple ion species

International operational & clinical experience should be leveraged

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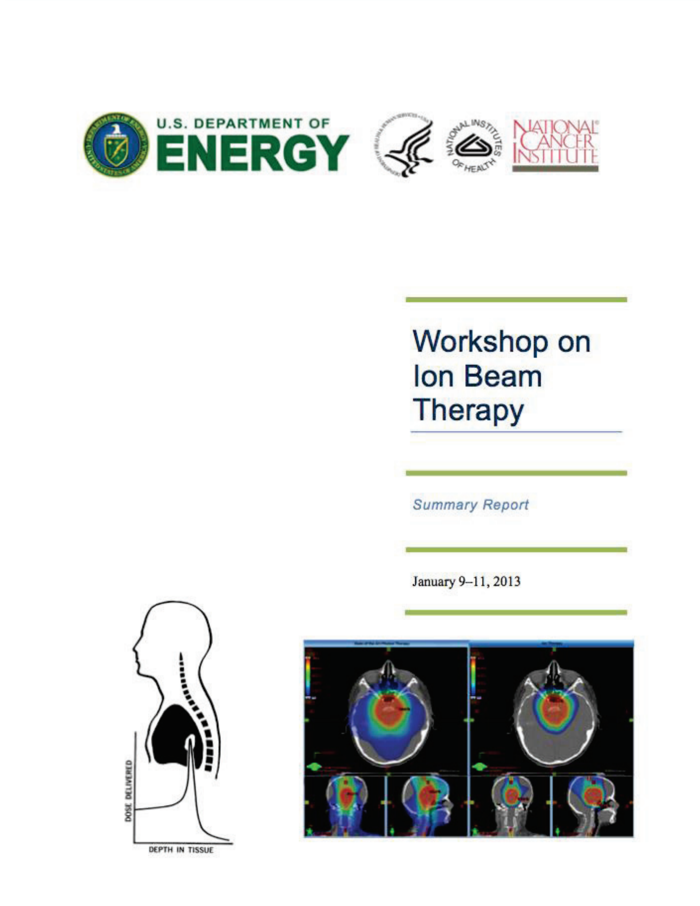

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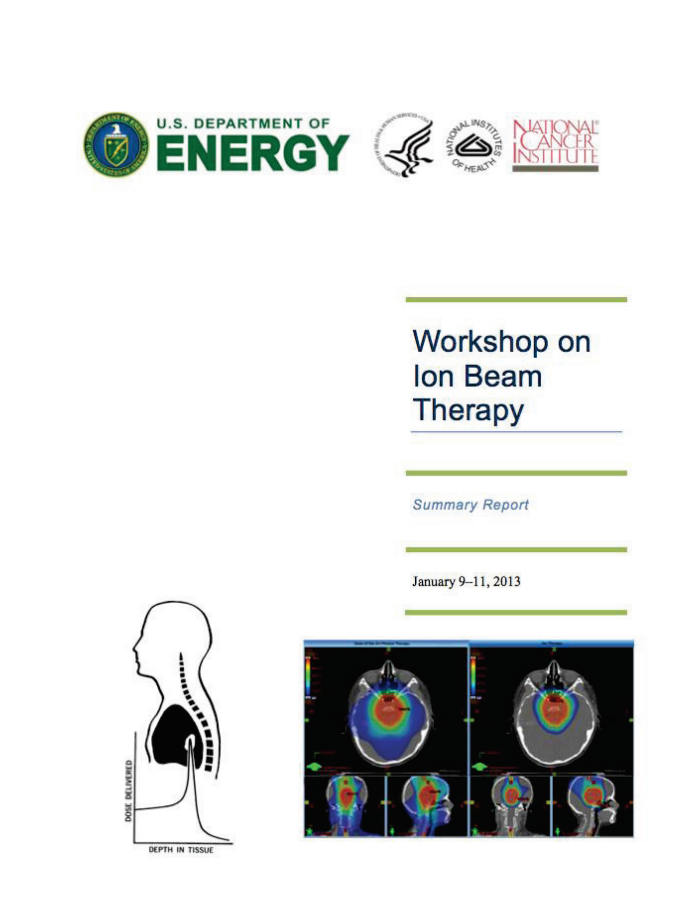
→ **Future facilities will need multiple ion species (at least protons and carbon)**

International operational & clinical experience should be leveraged



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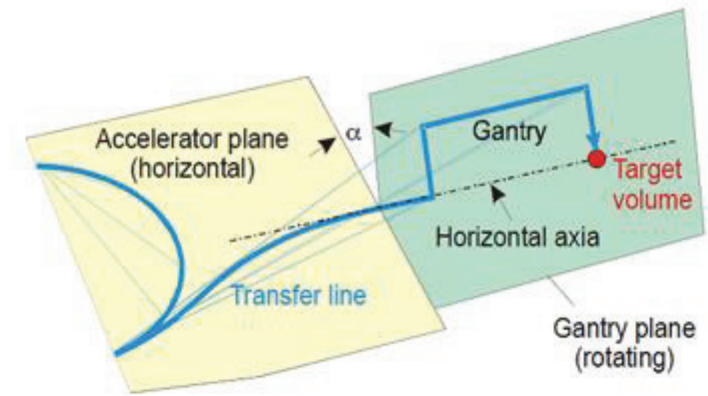
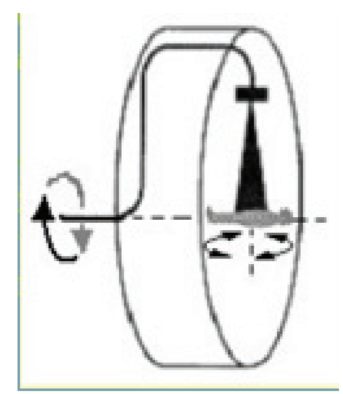
What is a Gantry

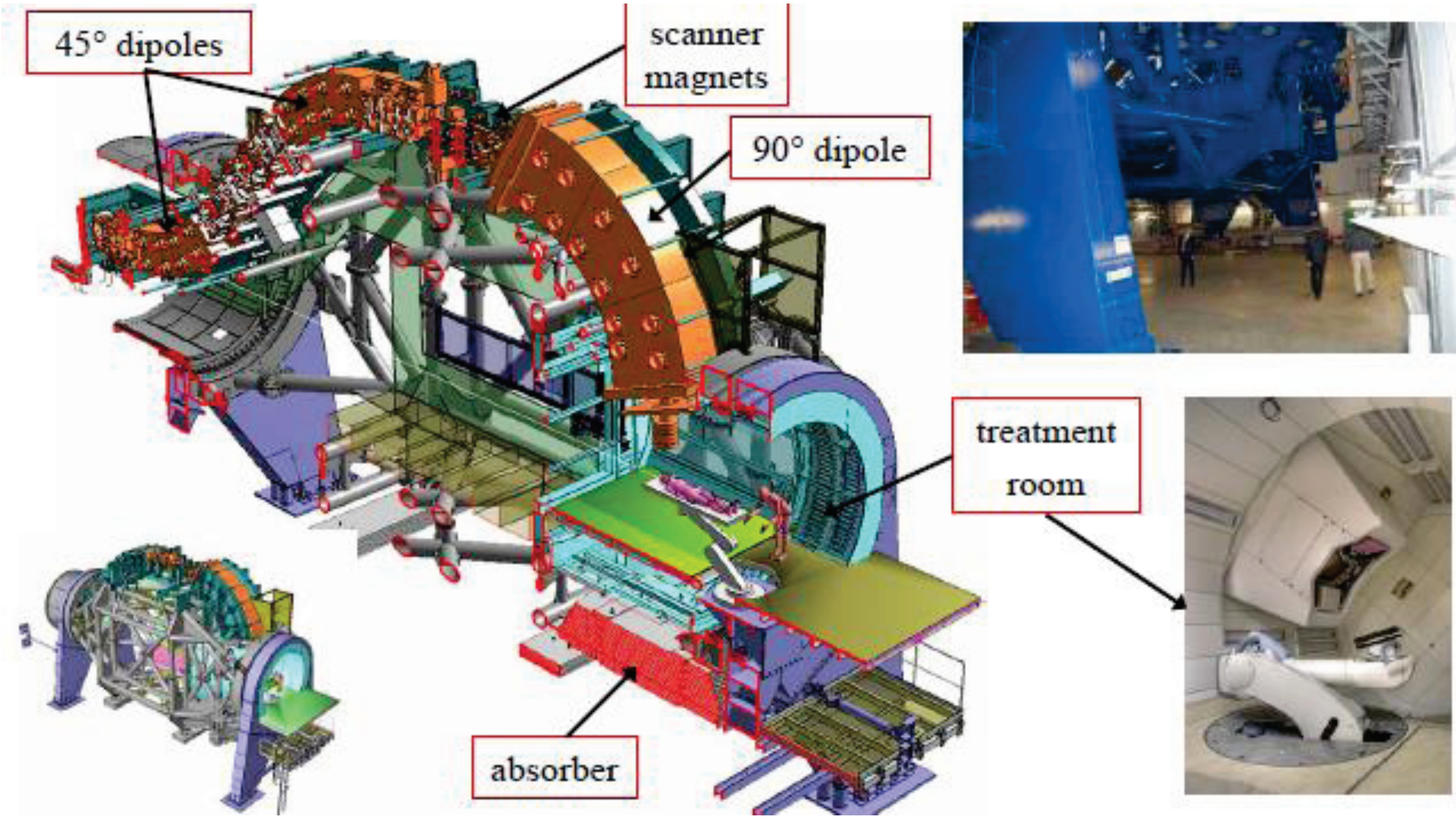
- A gantry is a beam line that directs and focuses the beam onto the patient at whatever angle is required for the treatment plan optimization.



- Possible to access the full 4 π solid angle with a combination of gantry and patient rotation.

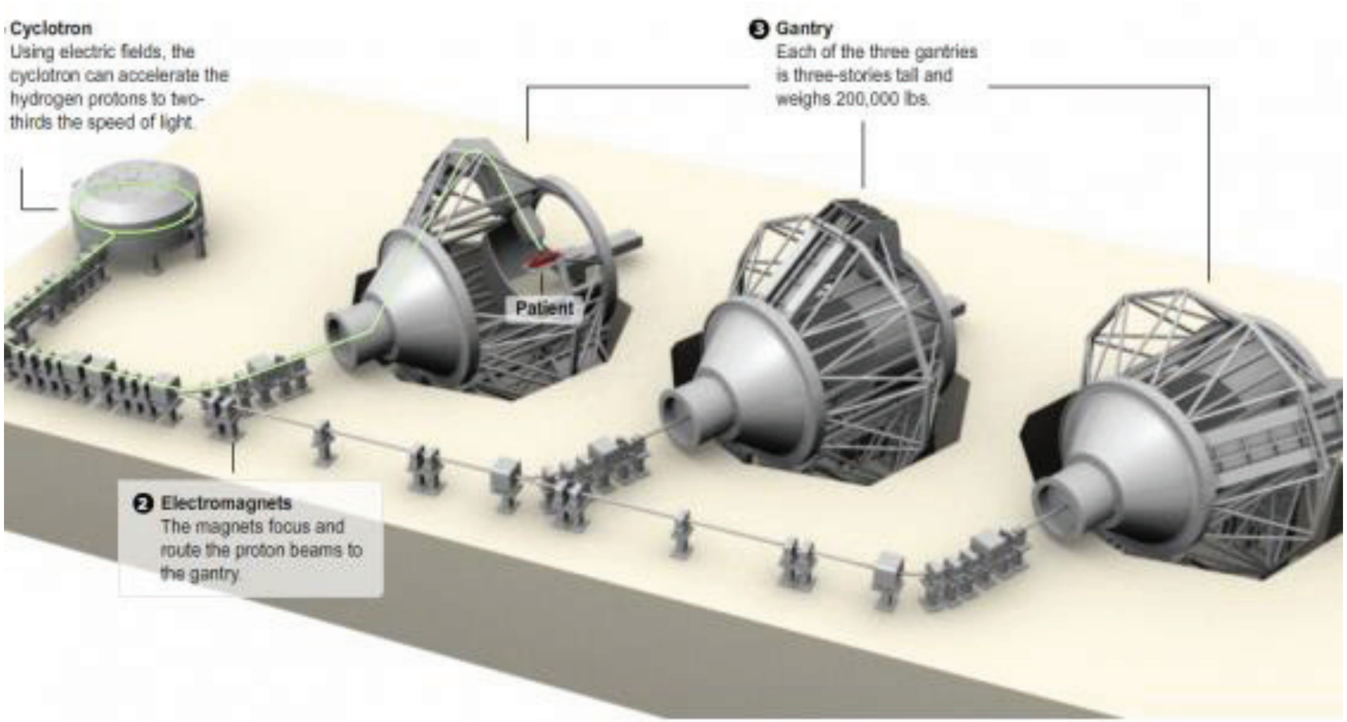


Heidelberg Ion Therapy Carbon Ion Gantry



- **HIT carbon gantry weighs 600 tons** ← ***1/10 of the Eiffel Tower***

Gantries are larger than the accelerator



University of Florida proton therapy center

Potential For Improvement

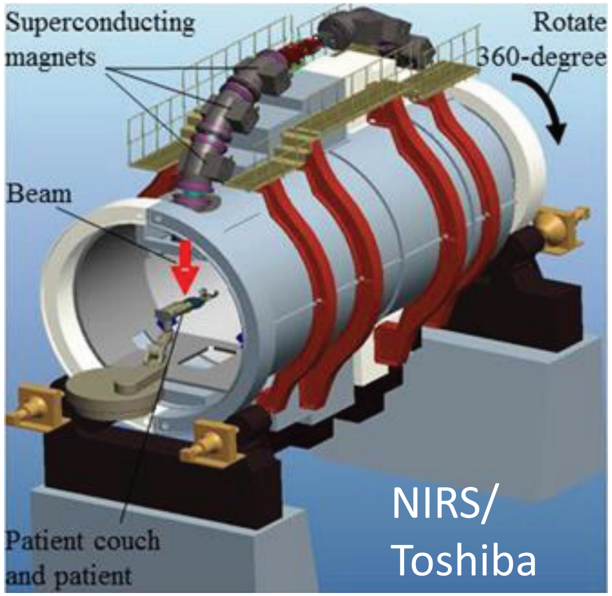
- Gantries are expensive – particularly for carbon
  - Large structures
  - Requiring big heavily shielded (~5m thick) rooms
  - Substantial operating costs (up to 0.8 MW for HIT Gantry)

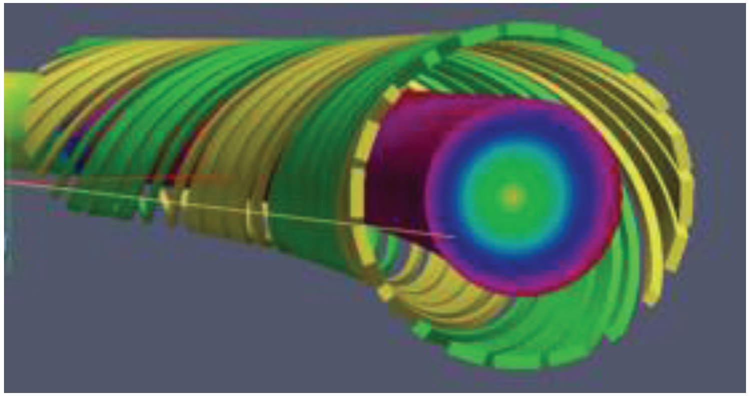
- Advantages of gantries are such that many new proton facilities are being built with multiple gantries

- Gantry development has potential for achieving significant gains in size reduction and cost

Some possible directions

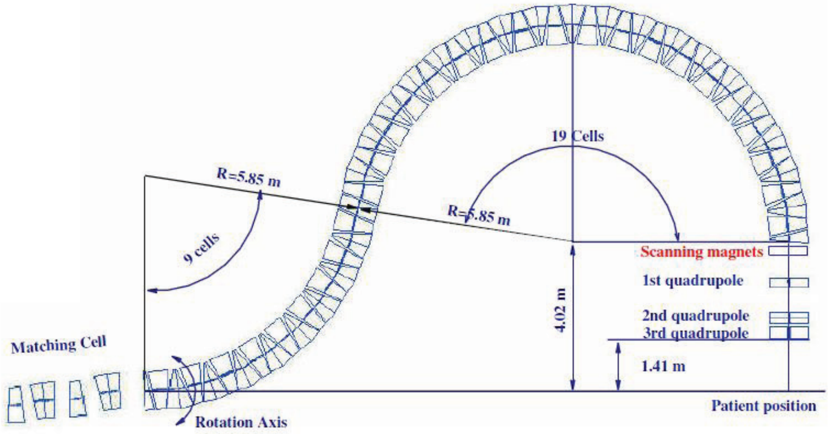
1. **More compact gantries using superconducting magnets (Y. Iwata)**



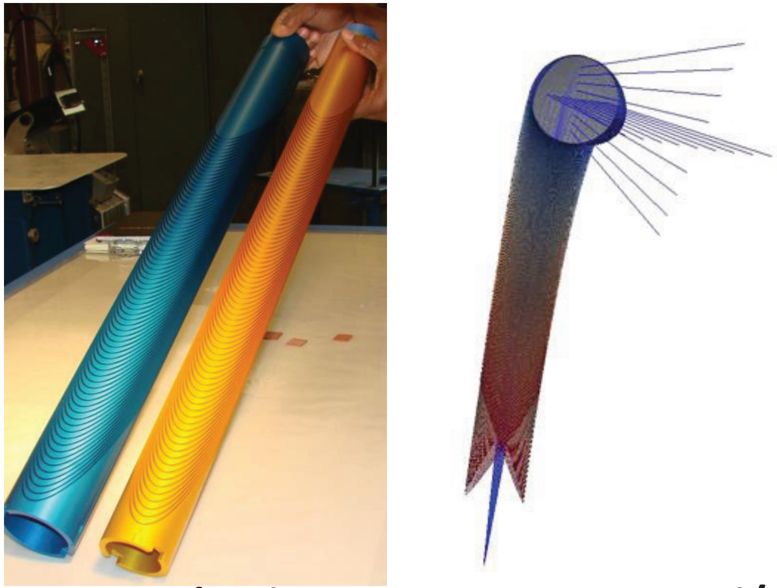


Helical focusing channels – Brouwer/LBL

2. **Faster energy scanning using FFAG magnets (talk by D. Trbojevic)**



FFAG – Trbojevic/BNL



Superconducting CCT magnets – Caspi/LBL

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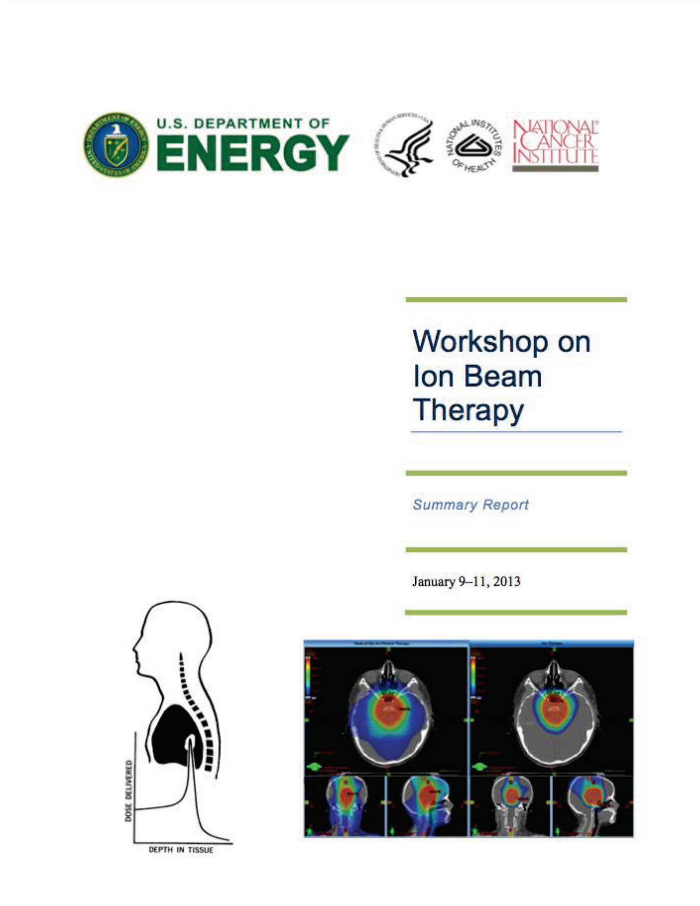

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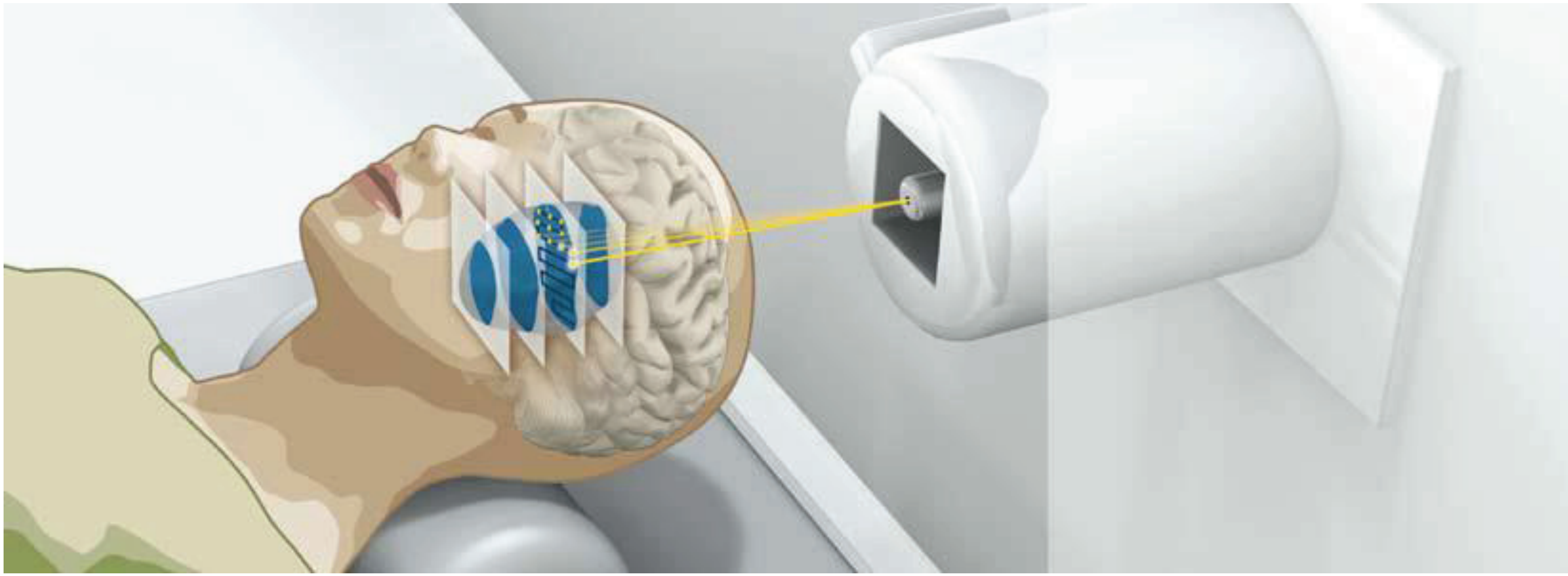
Future facilities will need multiple ion species (at least protons and carbon)

International operational & clinical experience should be leveraged

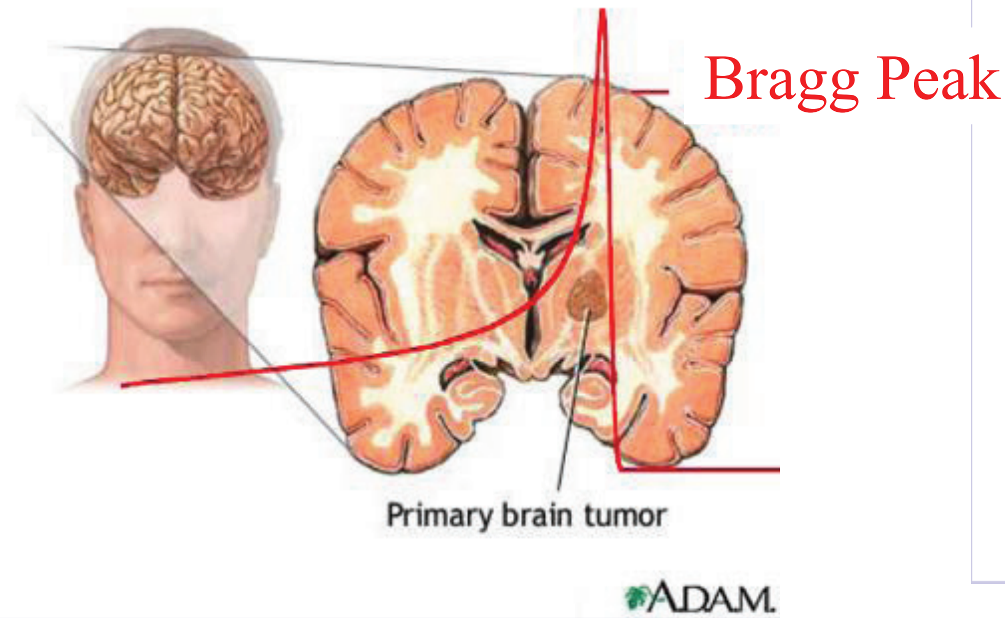
Fast 3D active scanning

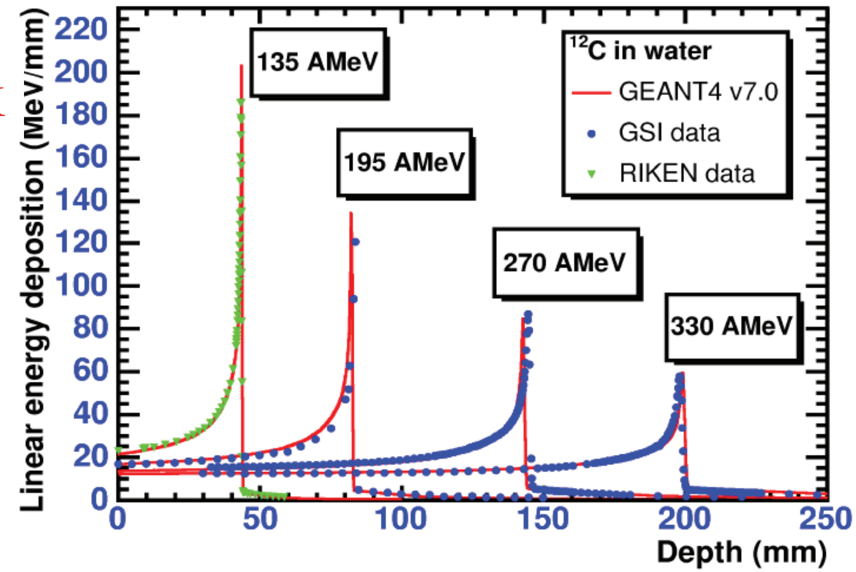


To deliver the desired dose to the tumor while minimizing dose the healthy tissue

- **The desired dose is delivered by scanning a small (few mm) beam in all 3-dimensions ➔ conform dose to the tumor**

Tuning the penetration depth with ions





- **The depth of the energy deposition peak (Bragg peak) can be efficiently tuned by changing the ion energy**

Changing the energy (depth) is slow for conventional synchrotrons

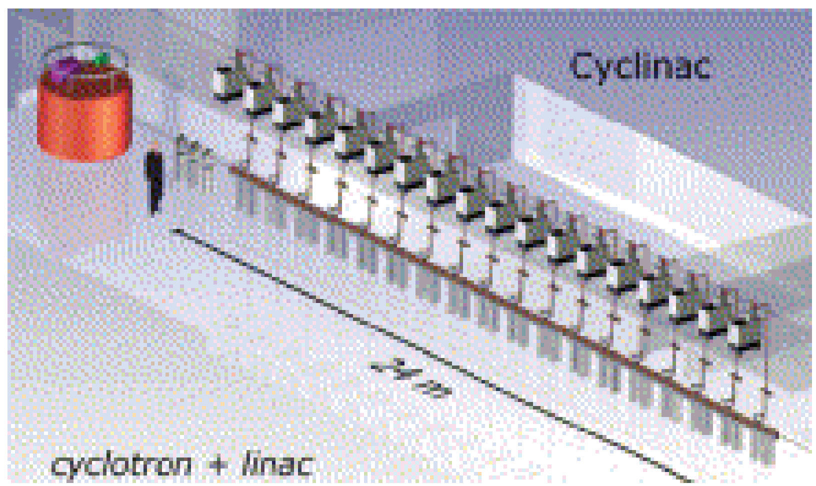
Accelerators other than conventional synchrotrons for carbon

Possibilities might be

- Cyclotrons (see Y. Jongen talk)
- Cyclinacs
- Rapid cycling synchrotrons
- FFAGs
- other

IBA C400

Mevion 9T proton synchrocyclotron



TERA Cyclinac

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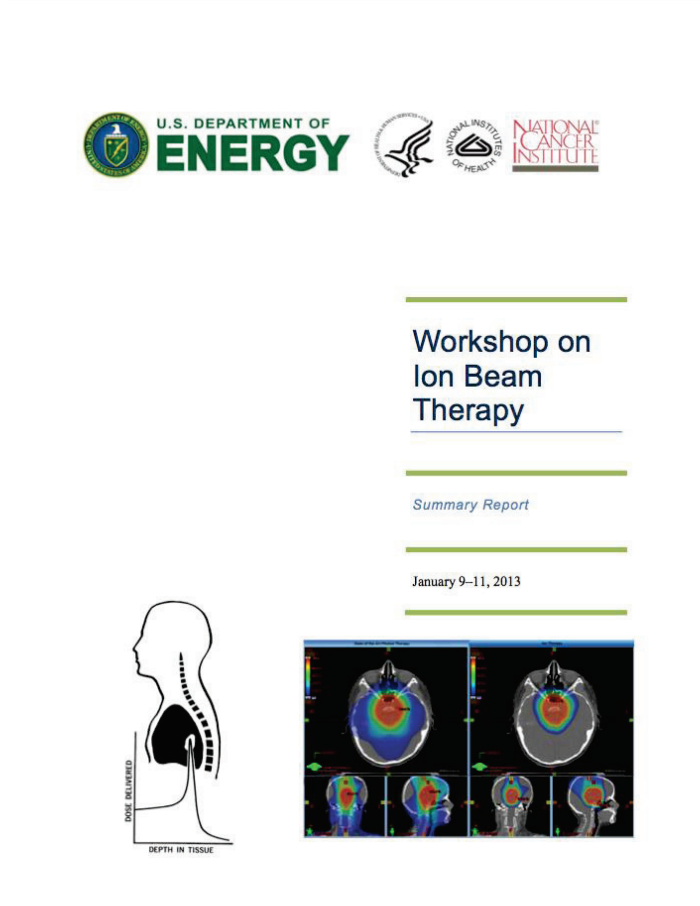

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Treatment uncertainty in ion beam therapy

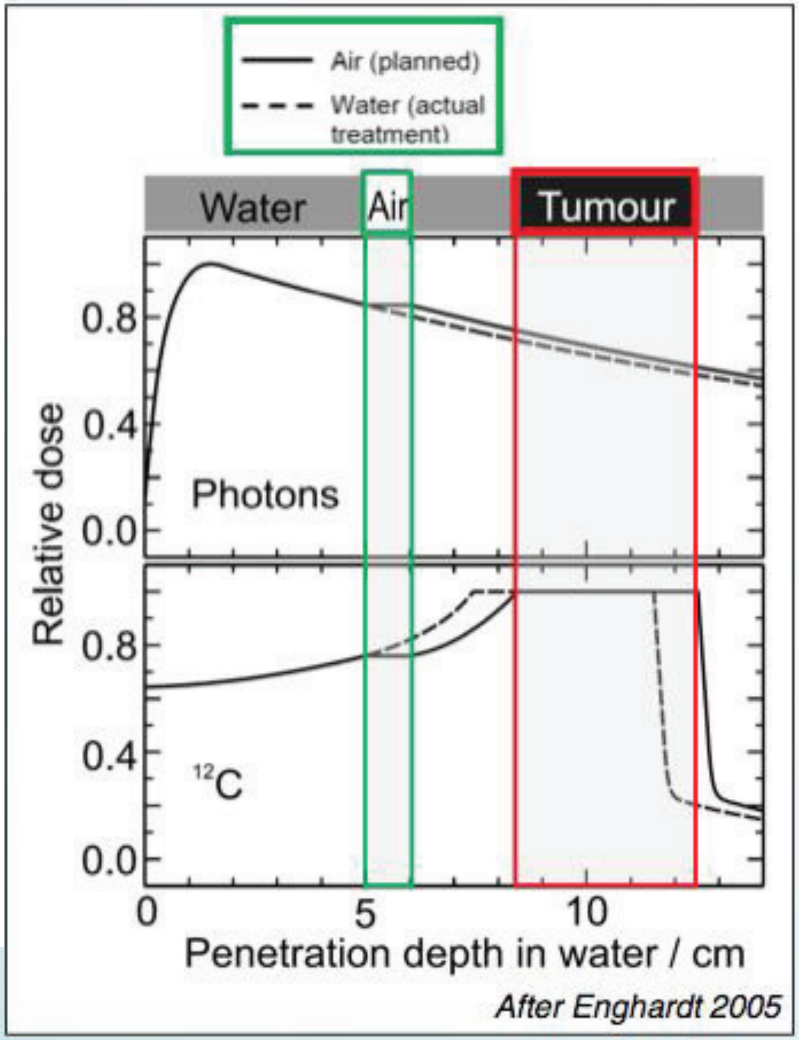
Treatment planning system dose calculation errors

- Inhomogeneities,metallic implants
- Conversion HU in ion range
- CT artifacts

Difference Treatment Plan / delivery

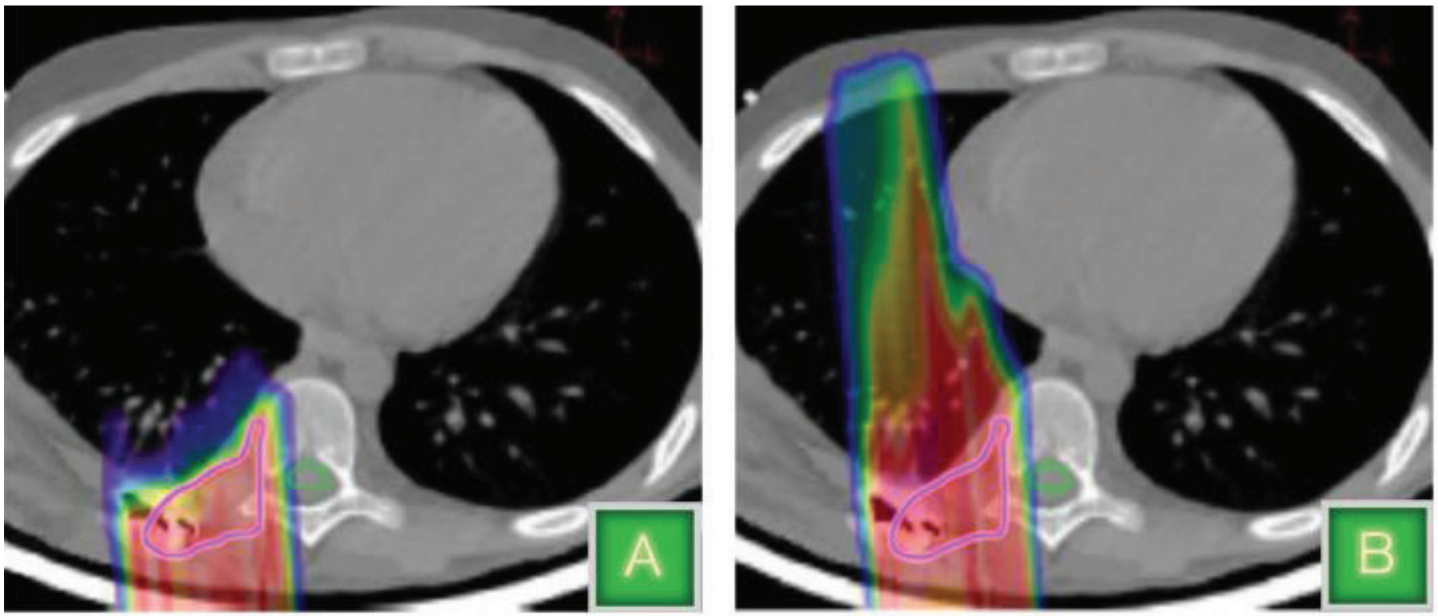
- Daily setup variations
- Internal organ motion
- Anatomical / physiological changes

Daily practice of compromising dose conformality for safe delivery



(courtesy of Katia Parodi)

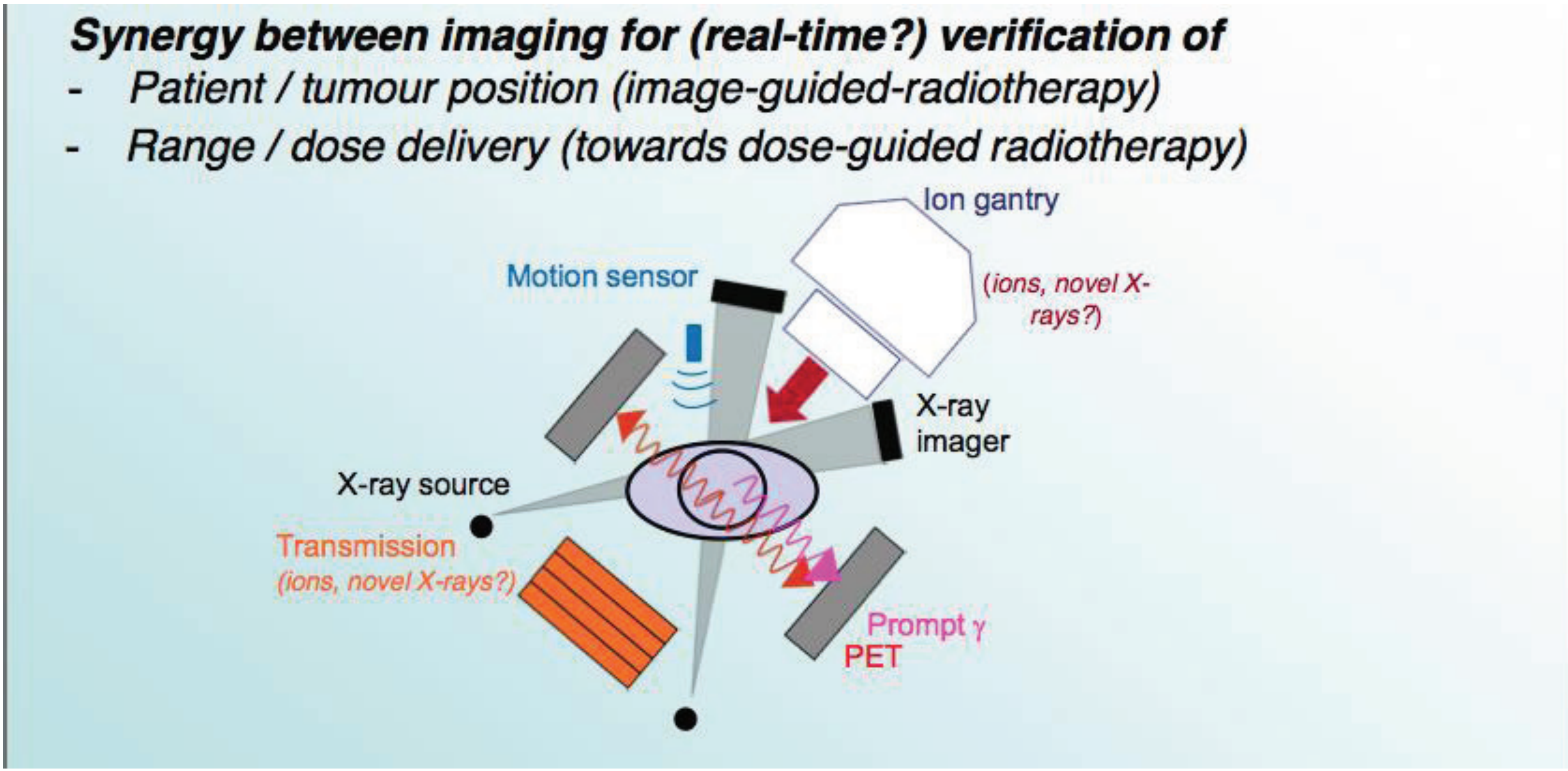
Range uncertainty can be a serious issue



These images illustrate the problem that imprecise CT scans can cause in cancer treatment. They show the simulated proton therapy treatment of a tumor (outlined in pink) near the spinal cord based on a CT scan that shows the patient from above. In image A, the proton beam is on target and affects very little healthy tissue. Image B illustrates how an error in the body density map obtained with an X-ray CT scan and the additional margin of uncertainty added to ensure the entire tumor is covered with an adequate proton dose causes the proton beam to overshoot its target and penetrate the healthy, left lung of the patient. Scientists aim to reduce this uncertainty by switching to proton CT scans. The red color in the images indicates the deposit of 100 percent of the dose chosen to treat the tumor. Other colors show the deposit of lower doses, with blue indicating the lowest dose.
Courtesy of Dr. Reinhard Schulte, Dept. of Radiation Medicine, Loma Linda University Medical Center

Courtesy of Reinhard Schulte

Real-time in vivo dose and tumor verification, and adaptive therapy for moving tumors.

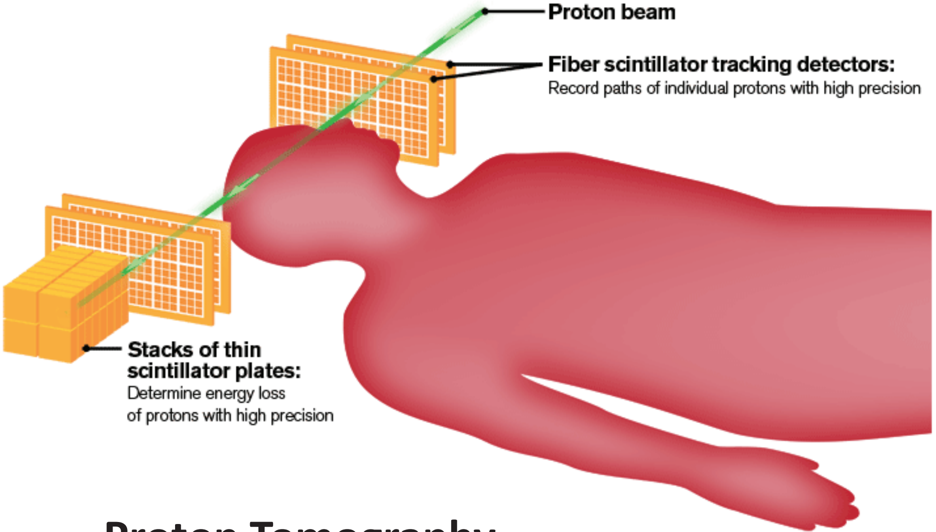


(courtesy of Katia Parodi, Munich)

Some dose location verification techniques

- PET scan of radioactive by-products (C11, O15)
- Particle (proton) radiography using fully penetrating beams
- Acoustic Detection
- Gamma Imaging
- Charged particle vertex detection
- Other?

HIT offline PET



Proton Tomography

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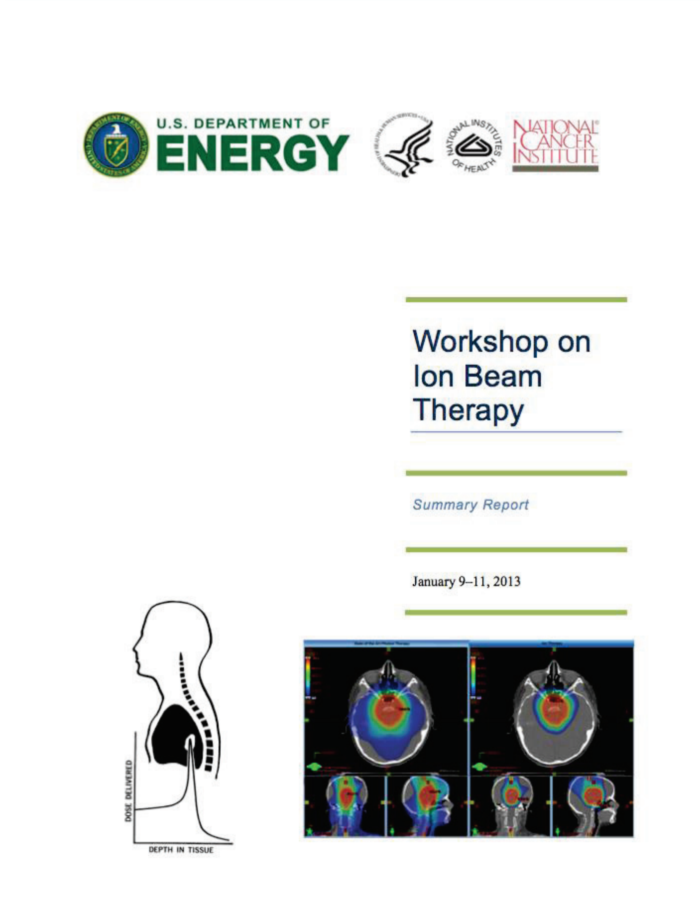

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Need for multiple ions

- **Ideally the facility should provide ions up to oxygen**
  - **Protons and carbon ions should be included because of the significant differences in the biological responses they induce.**
  - **Other ions such as lithium may be advantageous**
- **Some workshop participants advocated the using multiple ions in the same treatment**

Summary

- **Report is an important step in informing the stewardship program**
- **Encourage you to read the report**
- **Possibility that there will a call for support (SC/HEP) in the future (M. Zisman's Talk)**

Hopefully this will help with the development of Ion Beam Therapy in the US

Acknowledgement

- SC/HEP and NIH/NCI for financial support for the workshop
- Mike Zisman (SC/HEP), Jim Deye (NIH/NCI), Christie Ashton (SC/HEP)
- Organizing Committee – David Pistenmaa, Chris Beltran, Thomas Bortfeld, Kathryn Held, Tom Kroc, John O'Connell
- Plenary Speakers – Stephen Hahn, Eleanor Blakely, Sandro Rossi
- Additional Moderators – Anders Brahme, Jim McDonough, Jay Flanz, Katia Parodi
- Rest of the workshop participants

Thanks for your attention

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