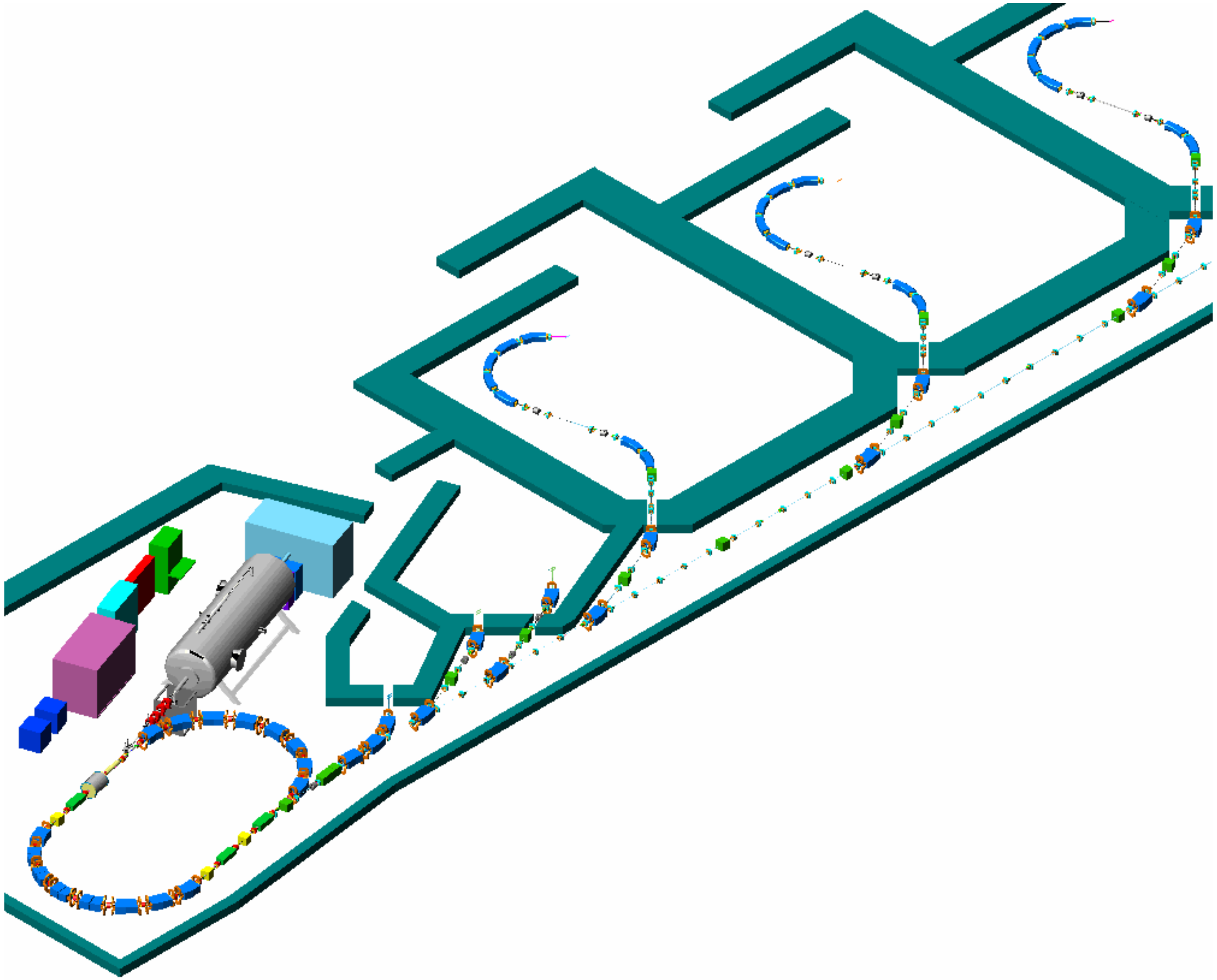
Protons for Cancer Therapy & Imaging

Steve Peggs, BNL



Summary – RCMS

1) US medical centers are now convinced that proton therapy works, and that there is a viable business model

2) A new wave of proton therapy facility construction has begun

3) Structural financial issues:
- finding a prime contractor
- finding a major medical center
- BNL seeks partners for RCMS

4) Structural technical issues:
- developing the virtues of the RCMS – read the CDR
- slow/fast extraction
- patient treatment/FDA/control system
- R&D prototyping, eg main magnet/vacuum chamber

The story so far

TM-1774, April 1992

Pre-conceptual Design of a Proton Therapy Accelerator

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Batavia, IL 60510
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Abstract

Design concepts for a particle medical facility centered on a rapid-cycling, strong-focusing proton synchrotron for radiation therapy are presented, with emphasis on the accelerator physics aspects of the synchrotron called the Proton Therapy Accelerator (PTA). The accelerator and its ancillary beam delivery systems are simple and robust, leading to a safe, reliable, economical and easily maintained machine capable of meeting high beam performance specifications. The injector can also produce neutrons for boron neutron capture therapy (BNCT) and isotopes for positron emission tomography (PET). The design presented here is "pre-conceptual" in the sense that a final optimization of the nominal parameters has not been carried out.

1. Introduction and Overview

In 1946 Robert R. Wilson, later to become the founding director of Fermilab, first suggested the use of charged-particle beams for radiation therapy[1]. The fundamental advantage of charged-particle therapy over conventional photon therapy derives from the so-called Bragg peak, i.e. from the fact that when charged particles heavier than electrons traverse matter, the rate of energy deposition along their path exhibits a pronounced maximum just before they stop. Thus charged particles stopping in a tumor can kill cancerous cells there without intolerable damage to intervening normal tissue and with no damage to critical structures beyond the tumor. Realizing Wilson's original vision was facilitated by the development of modern medical imaging capabilities, particularly X-ray CT scans, which provide the tissue density distributions needed to calculate beam stopping points. Two decades of clinical results, involving more than 10,000 patients worldwide, mostly at accelerators originally designed for nuclear physics research, have established the effectiveness of this mode of radiation treatment for a wide variety of cancers and similar maladies[2].

1

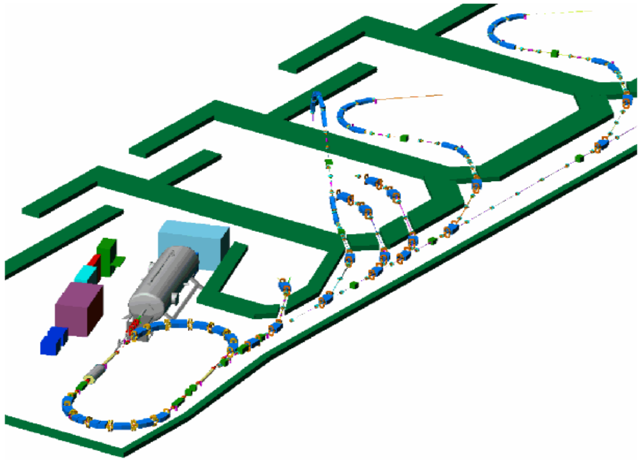
1992
TM-1774 offers a critique of the LL synchrotron, and suggests:
1) strong focusing
2) rapid cycling, fast extraction
3) high energy inject. (15 MeV?)

1999
U. Penn (Lockyer) contacts BNL (Peggs)

2003
"Conceptual Design of the Rapid Cycling Medical Synchrotron"
+ Cost & Schedule analysis

“RCMS Conceptual Design Report”, & Cost & (3 year) Schedule, exist

Conceptual Design of the RCMS



BNL C.Gardner, S.Peggs (editors),
D.Barton, J.Beebe-Wang, M.Brennan, J.Cardona, W.Fischer, D.Gassner, H.Hseuh,
J.Kewisch, I.Marneris, G.McIntyre, J.Morris, B.Oerter, D.Phillips, L.Snydstrup,
J.Tuozzolo, A.Zaltsman, J.van Zeijts, A.Zhang, S.Y.Zhang, Y.Zhao, N.Tsoupas,
ACCEL U.Klein, D.Krischel, M.Schillo
AES A.Favale, T.Myers, J.Sredniawski

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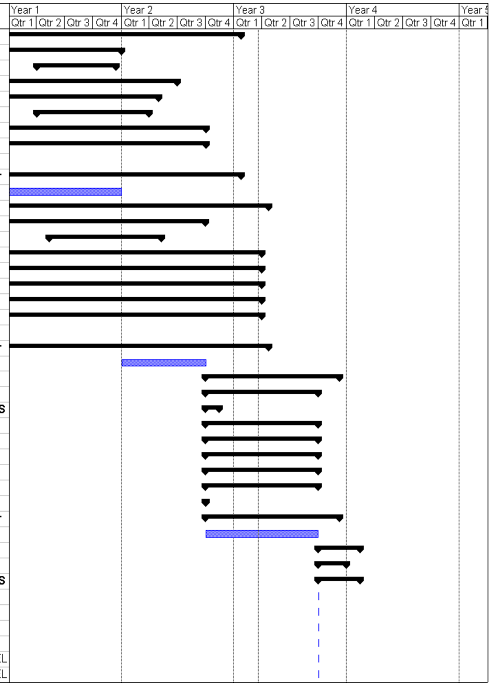
March 27, 2003

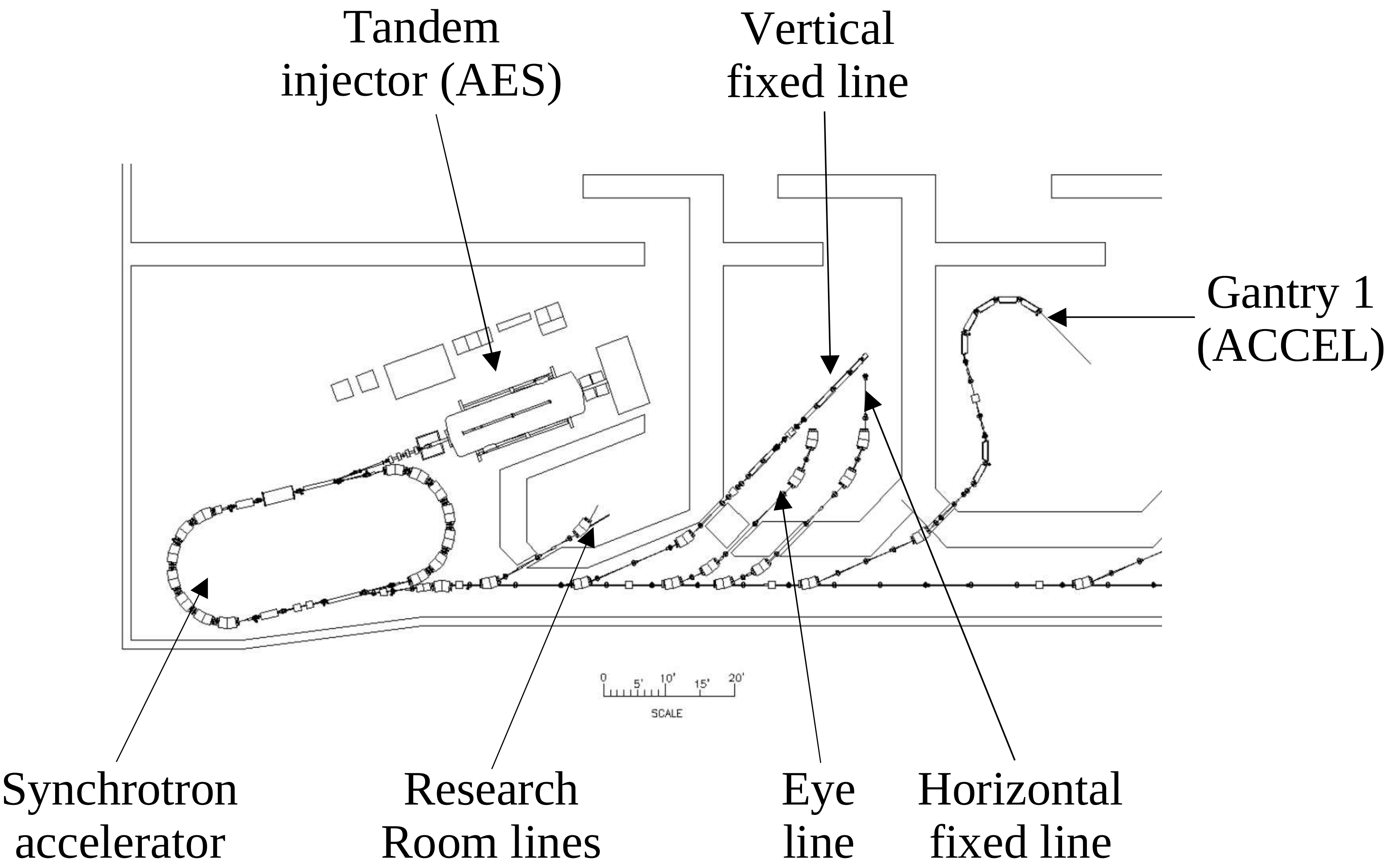
ID	Task Name	Resource Names
1	1 Design & Development	Peggs
2	1.1 Project Services	Peggs
5	1.2 Injector	
34	1.3 Synchrotron	McIntyre
50	1.4 Beam Transport	Kewisch
55	1.5 Research Room	Kewisch
57	1.6 Fixed Beam Room	Kewisch
60	1.7 Gantry	Kewisch
69	1.8 Nozzle	Ludewigt-LBL
75	1.9 Integrated Control System	Barton/Lockyer
83	1.10 Facility	Phillips
84	2 Fabrication	Peggs
85	2.1 Project Services	Peggs
88	2.2 Injector	
105	2.3 Synchrotron	McIntyre
121	2.4 Beam Transport	Kewisch
127	2.5 Research Room	Kewisch
132	2.6 Fixed Beam Room	Kewisch
138	2.7 Gantries	
151	2.8 Nozzles	
167	2.9 Integrated Control System	Barton/Lockyer
170	2.10 Facility	Phillips
171	3 Installation	Phillips
172	3.1 Project Services	Peggs
175	3.2 Injector	Sredniawski-AES
180	3.3 Synchrotron	McIntyre
187	3.4 Beam Transport	Phillips
193	3.5 Research Room	Schillo-ACCEL
198	3.6 Fixed Beam Room	Schillo-ACCEL
204	3.7 Gantries	Schillo-ACCEL
217	3.8 Nozzles	Ludewigt-LBL
233	3.9 Integrated Treatment & Control	Barton/Lockyer
236	3.10 Facility	Phillips
237	4 Commissioning & Final Acceptance	Peggs
238	4.1 Project Services	Peggs
242	4.2 Injector	Sredniawski-AES
254	4.3 Comm Synchrotron	Kewisch
255	4.4 Comm Beam Delivery	Kewisch
256	4.5 Comm Patient Treatment	Ludewigt-LBL
257	4.6 Training & Documentation	Peggs
258	4.7 Validation Testing	Schleiffer-BATTEL
259	4.8 FDA 510 (K)	Schleiffer-BATTEL



... but BNL faces structural issues, in competition with IBA, Siemens, Hitachi, ...

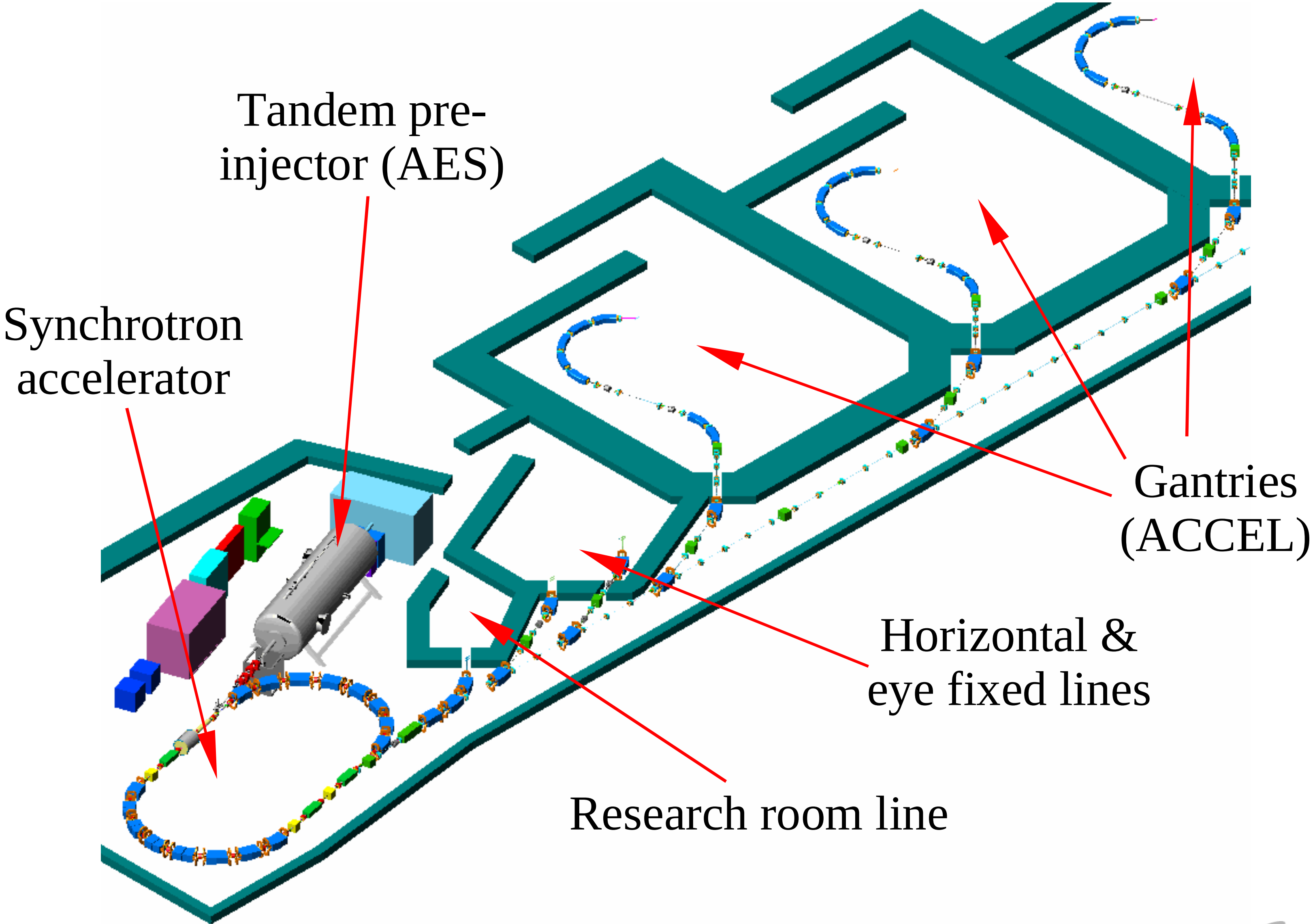
Rapid Cycling Medical Synchrotron

the second generation



Rapid Cycling Medical Synchrotron

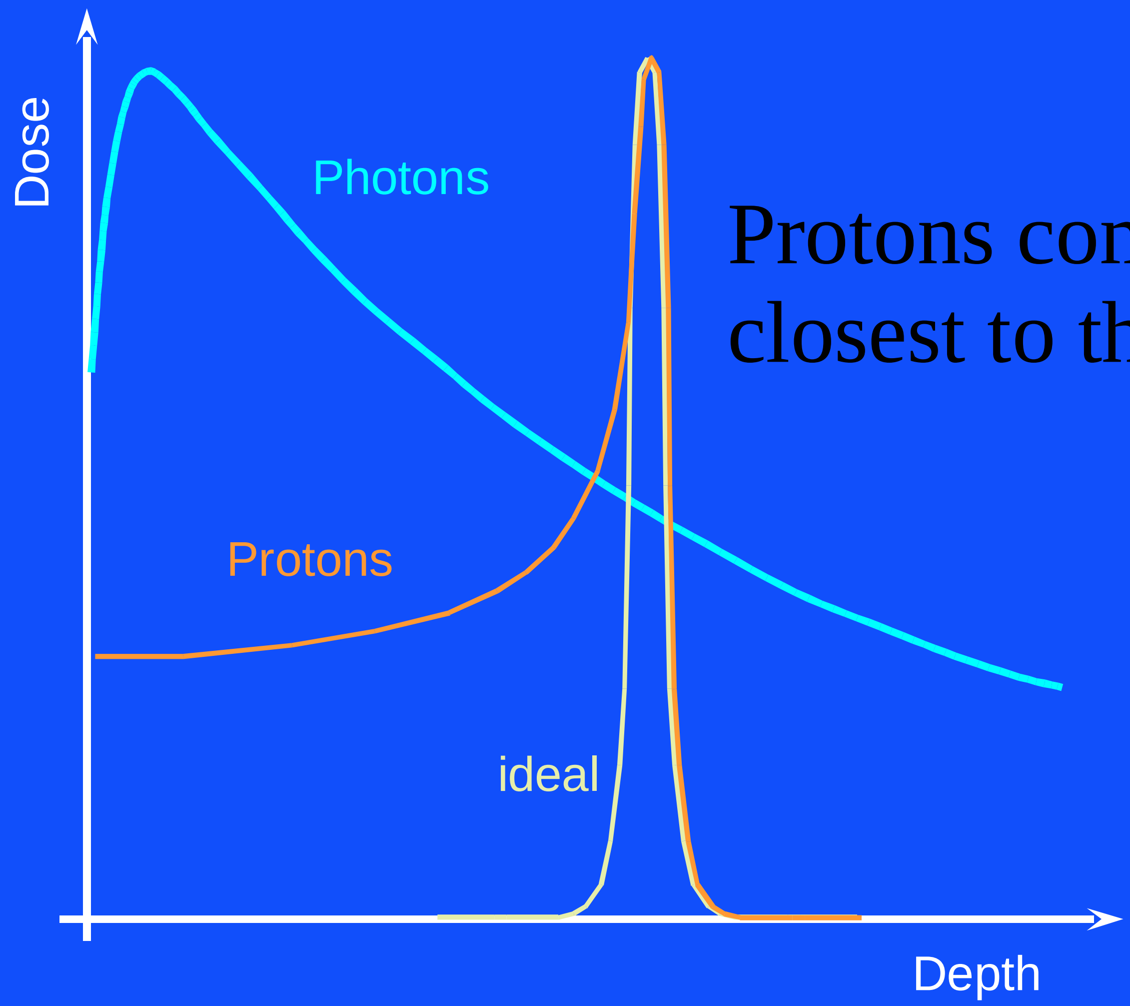
the second generation



The medical case for protons

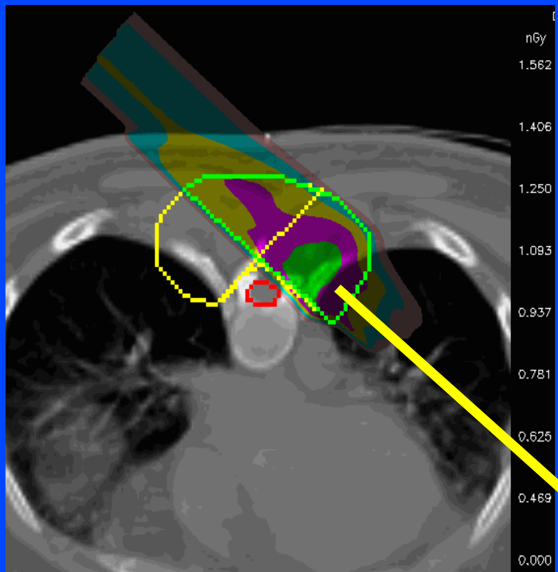
(versus X-rays in IMRT)

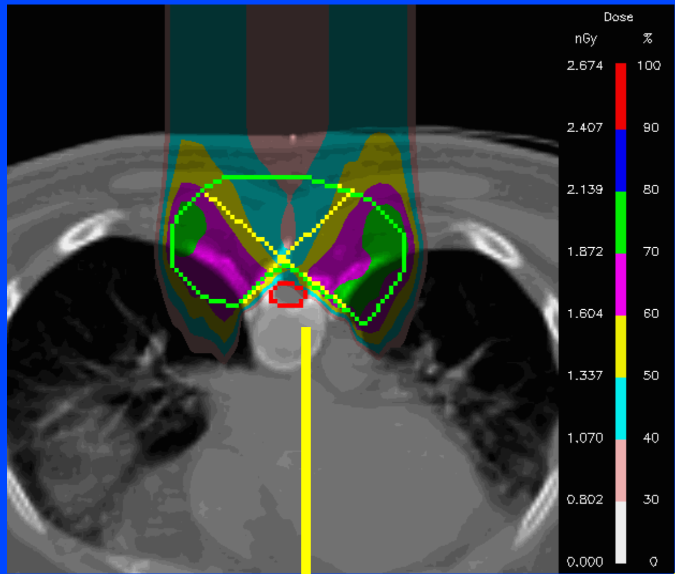
The ideal depth-dose distribution?

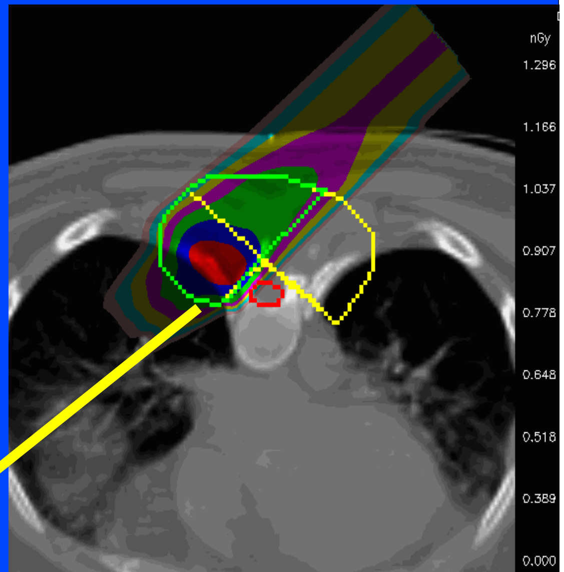


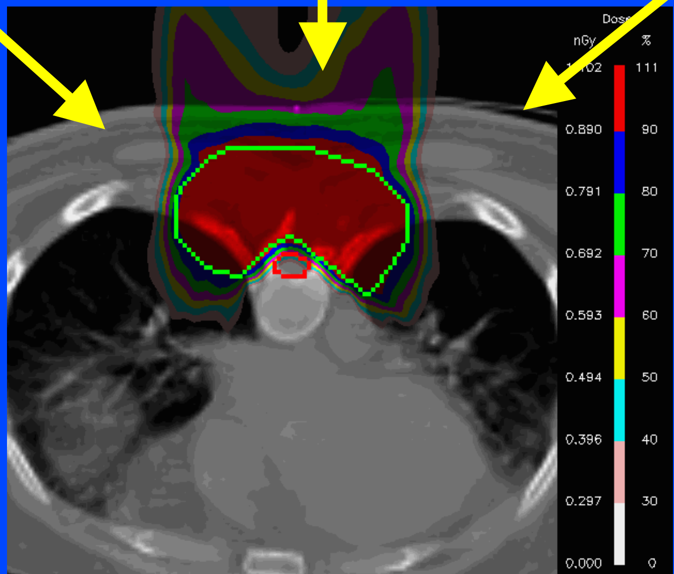
Protons come closest to the ideal

A clinical planning example – 3 fields









3 patched, intensity modulated fields....

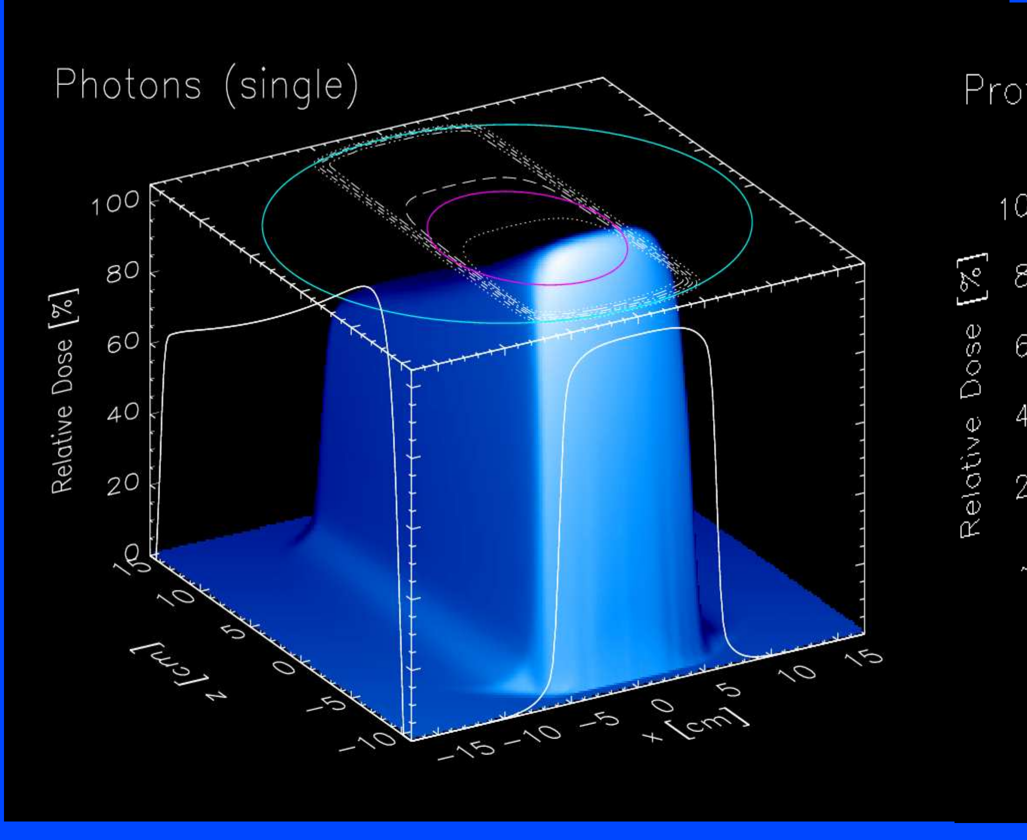
...give a homogenous dose without the use of fields that abutt distally against the spinal cord

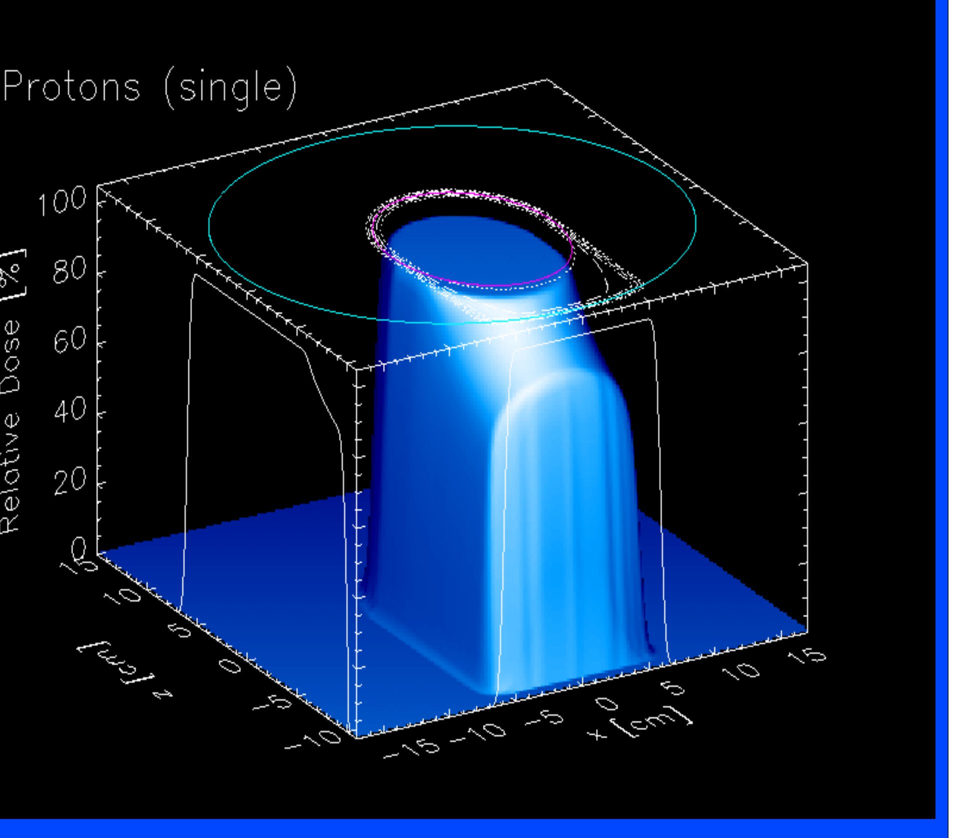
Slide courtesy of Tony Lomax, PSI

Compare protons with photons – 1

Photons

Protons



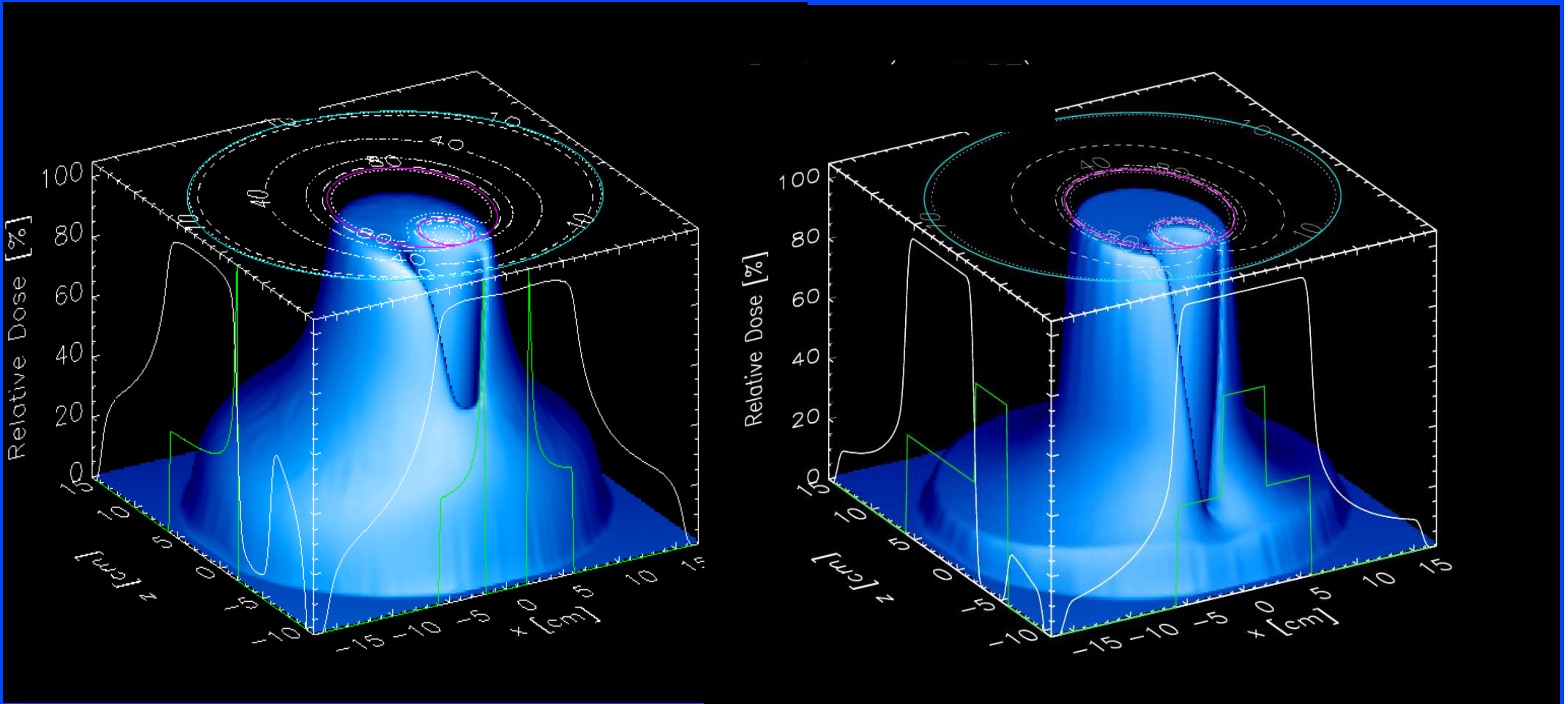


Photons (X-rays) do NOT “stop” at a well defined boundary

BROOKHAVEN NATIONAL LABORATORY

Compare protons with photons – 2

IMRT Photons | Protons



Multiple fields (angles): with PROTONS
- the "spine" is better protected
- dose to surrounding normal tissue is INTRINSICALLY much less

The business model for protons

the wave is (finally) here!

Operating & de-commissoned facilities

WHO	WHERE	WHAT	DATE FIRST RX	DATE LAST RX	RECENT PATIENT TOTAL
Berkeley 184	CA. USA	p	1954	— 1957	30
Berkeley	CA. USA	He	1957	— 1992	2054
Uppsala	Sweden	p	1957	— 1976	73
Harvard	MA. USA	p	1961	— 2002	9116
Dubna	Russia	p	1967	— 1974	84
Moscow	Russia	p	1969		3638
Los Alamos	NM. USA	π^-	1974	— 1982	230
St. Petersburg	Russia	p	1975		1029
Berkeley	CA. USA	ion	1975	— 1992	433
Chiba	Japan	p	1979		145
TRIUMF	Canada	π^-	1979	— 1994	367
PSI (SIN)	Switzerland	π^-	1980	— 1993	503
PMRC (1), Tsukuba	Japan	p	1983	— 2000	700
PSI (72 MeV)	Switzerland	p	1984		3712
Dubna	Russia	p	1987		198
Uppsala	Sweden	p	1989		311
Clatterbridge	England	p	1989		1201
Loma Linda	CA. USA	p	1990		8203
Louvain-la-Neuve	Belgium	p	1991	– 1993	21
Nice	France	p	1991		1951
Orsay	France	p	1991		2157
iThemba LABS	South Africa	p	1993		442
MPRI	IN USA	p	1993		34
UCSF - CNL	CA USA	p	1994		448
HIMAC, Chiba	Japan	C ion	1994		1187
TRIUMF	Canada	p	1995		77
PSI (200 MeV)	Switzerland	p	1996		99
G.S.I Darmstadt	Germany	C ion	1997		172
H. M. I, Berlin	Germany	p	1998		317
NCC, Kashiwa	Japan	p	1998		200
HIBMC, Hyogo	Japan	p	2001		105
PMRC (2), Tsukuba	Japan	p	2001		237
NPTC, MGH	MA USA	p	2001		425
HIBMC, Hyogo	Japan	C ion	2002		30
INFN-LNS, Catania	Italy	p	2002		52
Wakasa Bay	Japan	p	2002		6

USA

Japan

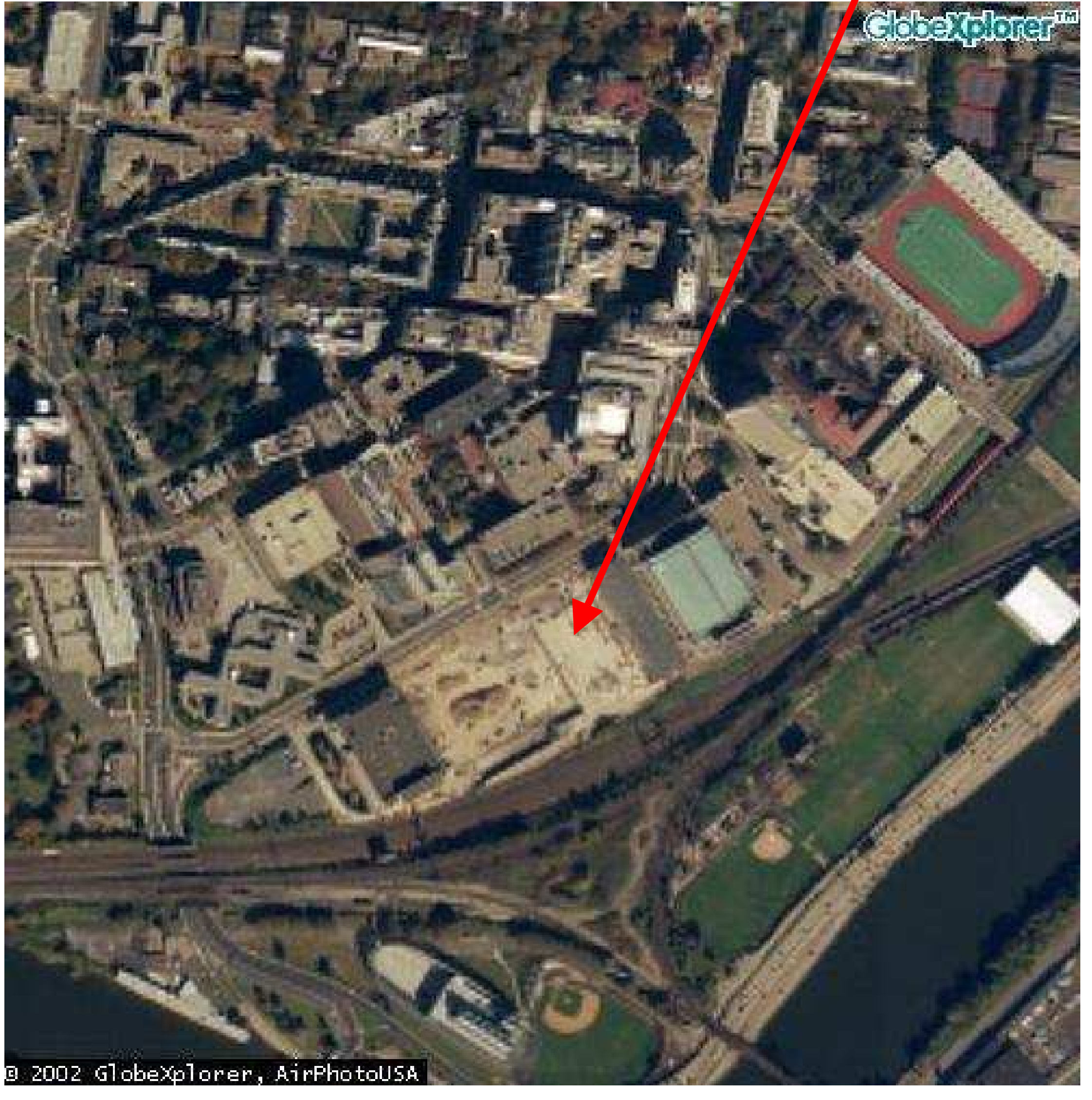
Volume leaders

Proposed new facilities (July 03)

INSTITUTION	PLACE	TYPE	1^{ST} RX?
IMP, Lanzhou	PR China	C-Ar ion	2003
Wanjie, Zibo	China	p	2003
PSI	Switzerland	p	2004
Shizuoka Cancer Center	Japan	p	2005
Rinecker, Munich	Germany	p	2005
NCC, Seoul	Korea	p	2005
Heidelberg	Germany	p, ion	2005
FPTI, U. of Florida	FL, USA	p	2005
IThemba LABS, Somerset West	South Africa	p	2006
M. D. Anderson Cancer Center	TX, USA	p	2006
Chang An Information, Beijing	China	p	2006
CGMH, Northern Taiwan	Taiwan	p	?
Bratislava	Slovakia	p, ion	2003?
Erlangen	Germany	p	?
CNAO, Milan & Pavia	Italy	p, ion	2004?
Med-AUSTRON	Austria	p, ion	2007?
Central Italy	Italy	p	?
TOP project ISS Rome	Italy	p	?
3 projects in Moscow	Russia	p	?
Krakow	Poland	p	?
Proton Development N.A. Inc.	IL USA	p	?

U. Penn will very soon be on this “confirmed” list

The U. Penn site



Active discussions also at:

- **Karolinska (Sweden)**
- **Sydney (Australia)**
- **TERA sites (Europe)**
- **Sloan Kettering (USA)**
- **Columbia-Presbyterian**
- **Chicagoland ?**

Structural issues

financial & technical, for BNL and/or FNAL

Structural issues – financial

1) DoE regulations prevent BNL and/or FNAL from being a prime contractor. National labs:
- cannot compete in the marketplace
- cannot take financial risk (can't raise capital or be bonded)

2) In the US environment
- a major medical center MUST lead, not follow, a hadron therapy project (FNAL learned this in 1992)
- there is little apparent interest in light ions or neutrons

3) BNL seeks a third party – FNAL, Siemens, ... – to get the RCMS built

4) DoE regs also explicitly require BNL/FNAL to be equally available to all potential RFP responders.

Structural issues – technical

1) No time, here, to go into all the technical virtues of the RCMS
   - please read the CDR!

2) Slow/fast extraction in 3D scanning
   - some say fast extraction can't scan fast enough (not true: eg see TNS paper)
   - others says slow extraction has intrinsic risks of dumping much beam into the patient (only slow slow scans are safe?)

3) The Patient Treatment/FDA/Control System challenge is huge
   - for Hitachi & Siemens more than IBA (& Optivus)

4) The ideal next (technical) step for RCMS would be to do some R&D prototyping on the main magnet/vacuum chamber system

Summary – RCMS

1) US medical centers are now convinced that proton therapy works, and that there is a viable business model

2) A new wave of proton therapy facility construction has begun

3) Structural financial issues:
   - finding a prime contractor
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   - R&D prototyping, eg main magnet/vacuum chamber

Proton Computed Tomography

(proton movies ~20 GeV not discussed here)

proton Computed Tomography (pCT)

Brookhaven National Laboratory
beam tests, tracking detectors,
calorimeter, simulation

Loma Linda University Medical Center
project coordination, calorimeter,
readout/DAQ, beam tests, simulation

Santa Cruz Institute for Particle Physics
tracking detectors, readout/DAQ,
simulation

Stony Brook University
tomographic reconstruction

NEED: “high” dose XCT gets planning wrong

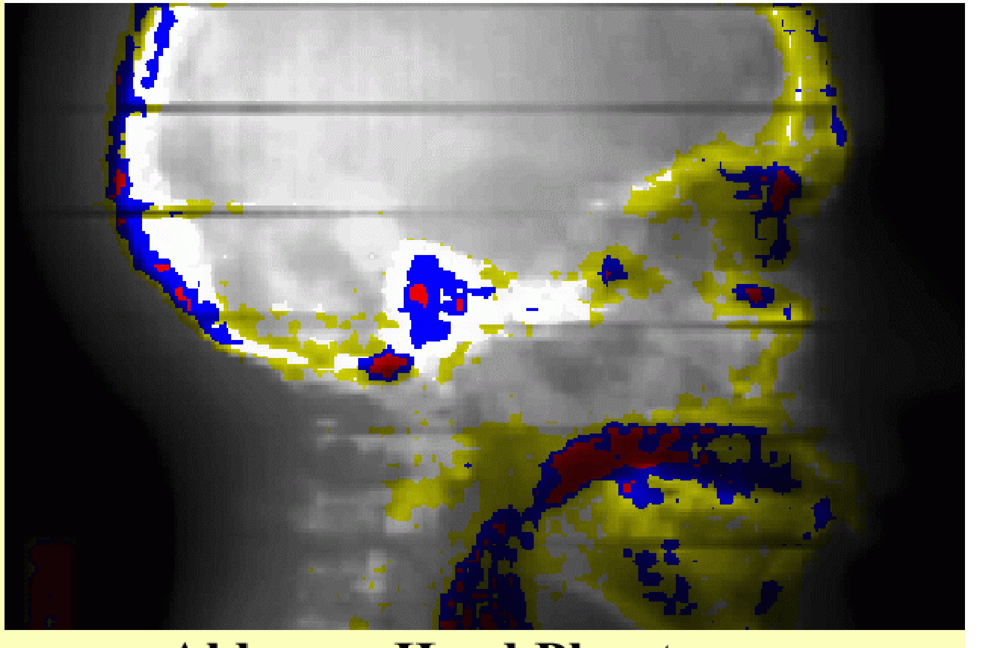
Use of Proton Beam CT: Treatment Planning

X-ray CT use in Proton Cancer Therapy can lead to large Uncertainties in Range Determination

Range Uncertainties (measured with PTR)

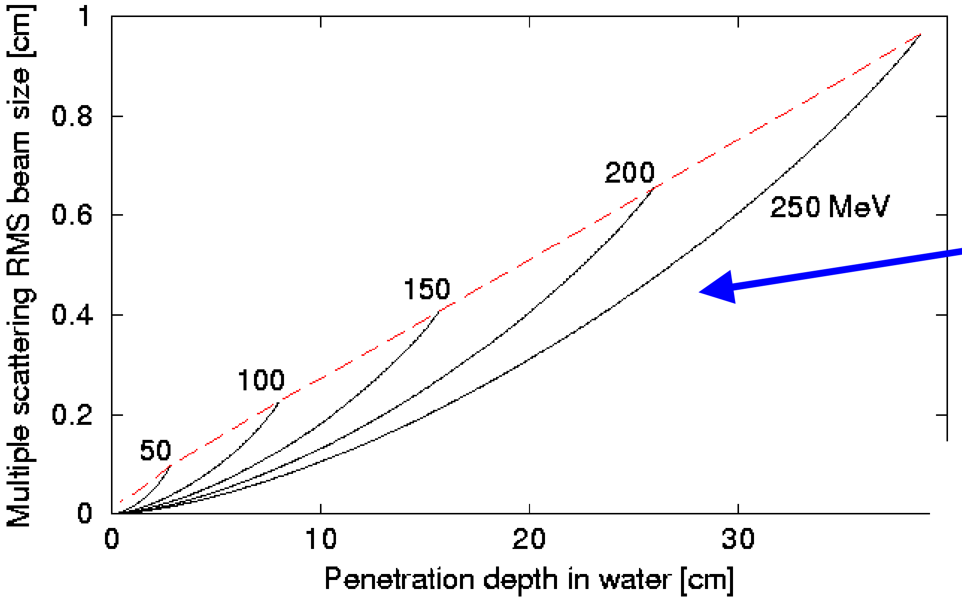
- > 5 mm (black)
- > 10 mm (blue)
- > 15 mm (red)

Schneider U. & Pedroni E. (1995), “Proton radiography as a tool for quality control in proton therapy,” Med Phys. 22, 353.



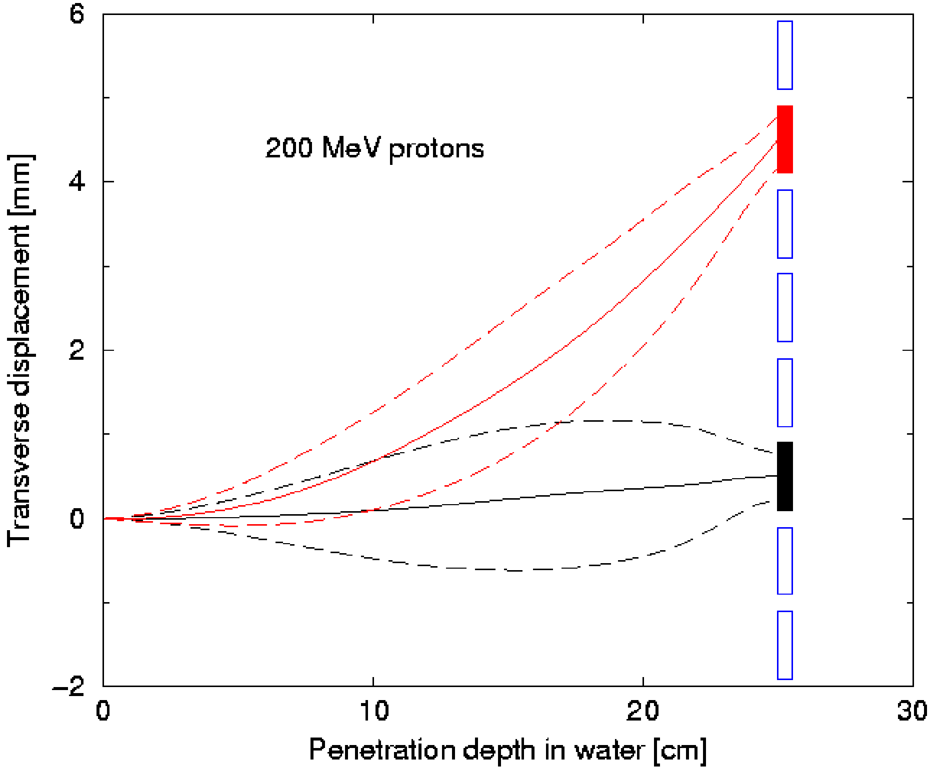
Alderson Head Phantom

NEW: silicon detector technology defeats blurring!



Historically, proton radiography was rejected because multiple scattering made blurry images

Modern detectors make sharp images through PROTON-BY-PROTON knowledge of incoming and outgoing displacements and angles



Proton Computed Tomography camera

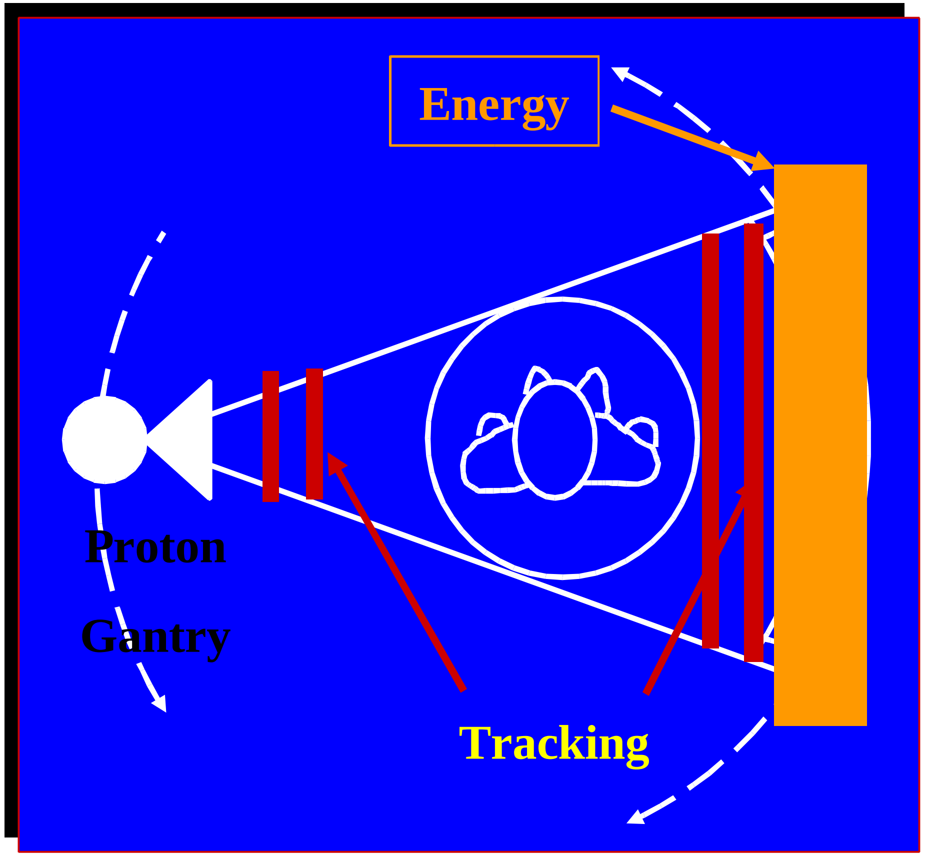
Proton computed tomography:

Take multiple projection images, as the gantry circulates around the patient

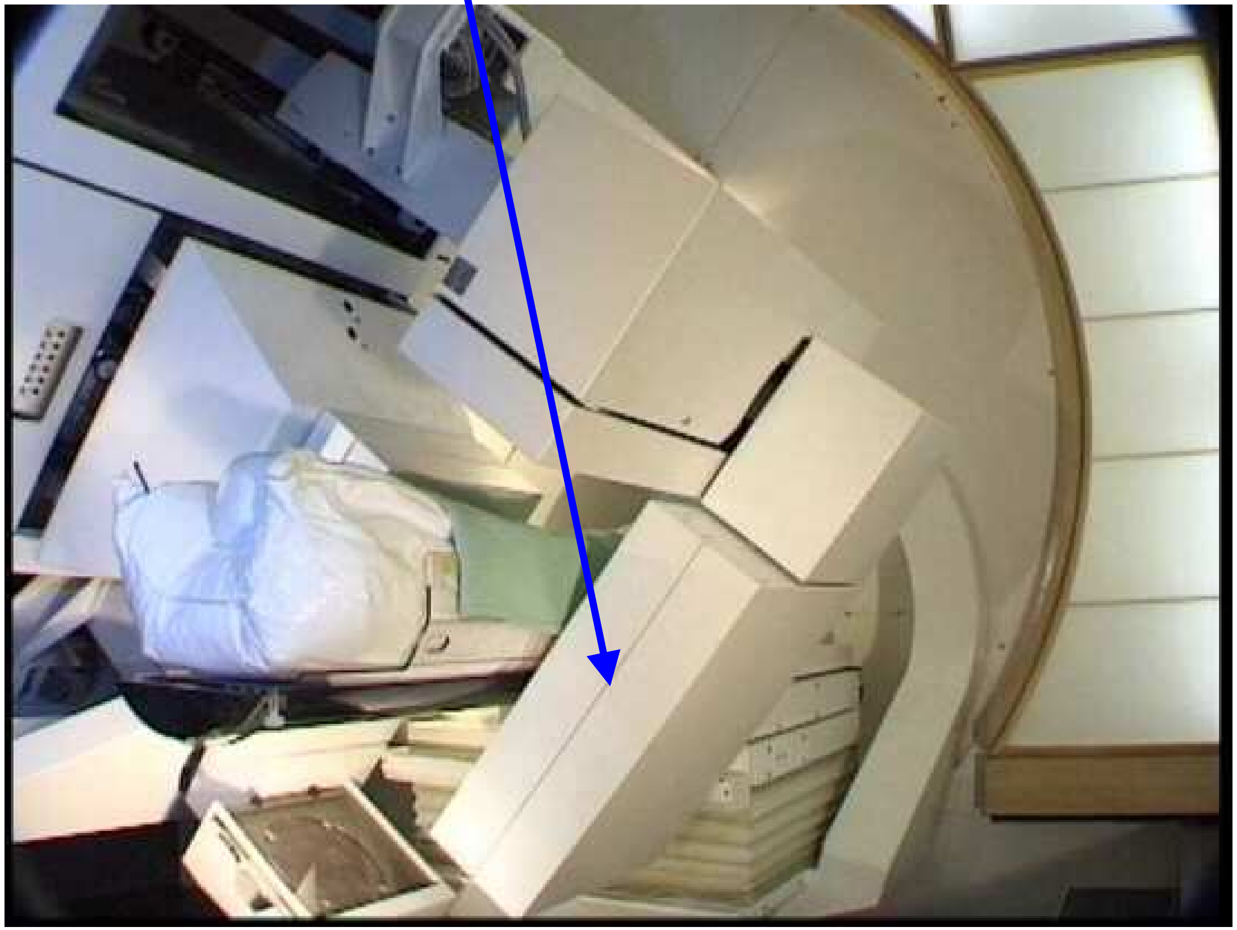
Camera:

4 silicon detector planes +

1 energy calorimeter

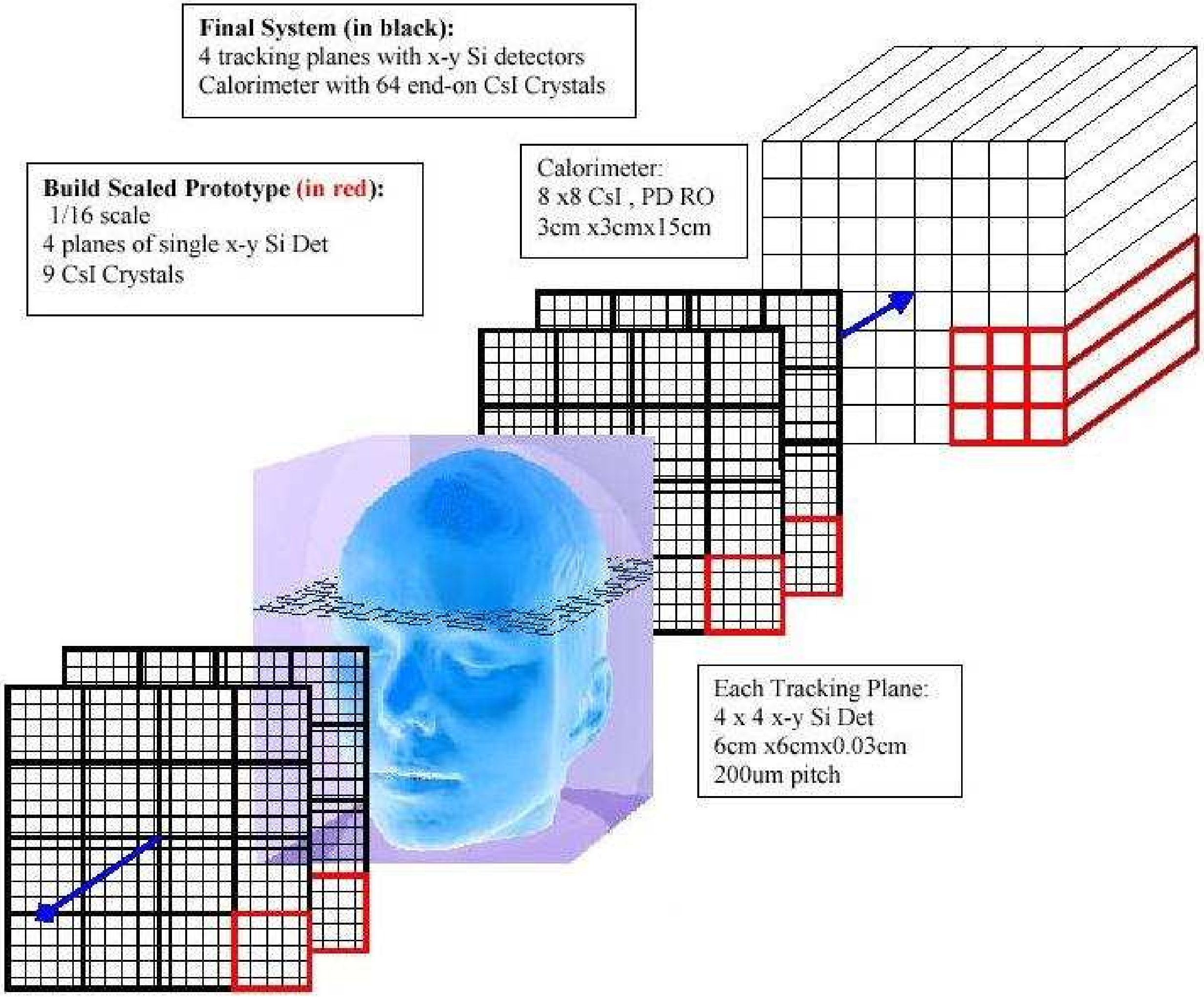


The PSI therapy gantry, with early prototype camera in place



The pCT collaboration seeks NIH funding

to build and test a scaled prototype (red) and then a final system (black)



Proton CT Funding Approach

- Research and Development
  - NIH R01 grant or multiple R21 grants
- Implementation and Commissioning
  - DOE and/or DOD
  - External funding organization (e.g., BV)

NIH application: Specific Aims

1: Design & build small proton-by-proton detector

2: Develop reconstruction algorithms based on simulated data sets

3: Measure radiography data with different phantoms

4: reconstruct & validate performance of detector & reconstruction

Summary – Proton Imaging

1) proton Computed Tomography is driven by proton therapy needs, but has a much broader potential
   - lower dose
   - more accurate

2) Proton-by-proton pCT is enabled by tech transfer from high energy and nuclear physics experiments (silicon micro-detectors)

3) There is also great potential in making "CT movies" of periodic THICK mechanical systems
   - auto engines, ...