

Proton Therapy: The Next (3rd) Generation

Thomas Bortfeld and Jay Flanz

Massachusetts General Hospital

Department of Radiation Oncology

TBortfeld@mgh.harvard.edu

Is

% %

0 1

Moore's +

Exponential % +

, - .



MASSACHUSETTS
GENERAL HOSPITAL

RADIATION ONCOLOGY

Is proton therapy going to replace x-rays?

ACTA ONCOLOGICA LECTURE

POINT/COUNTERPOINT

Suggestions for topics suitable for discussion by the Point/Counterpoint panel, selected for their knowledge and ability to reflect their personal opinion

Within the next 10 years, will proton therapy replace x-rays?

Richard L. Maughan
Department of Radiation Physics
Pennsylvania State University
(Tel: 717-863-7887, E: rmaughan@psu.edu)

Frank Van den Heuvel
Department of Experimental Radiation Physics
Leuven B-3000, Belgium
(Tel: 32 16 34 76 40, E: frank.vandenheuvel@kuleuven-leuven.be)

Colin G. Orton, PhD
(Received 9 June 2012)
[DOI: 10.1118/1.2951118]

OVERVIEW

Interest in proton therapy has increased in the past couple of years, especially in the context of the obvious physical benefits of reducing the cost of proton therapy. The promise of improved outcomes with proton therapy has made it a treatment of choice at some centers. This is the premise of the Point/Counterpoint.



IOP A community website from IOP Publishing

medicalphysicsweb
RESEARCH • TECHNOLOGY • CLINICAL APPLICATIONS

Home | Opinion | Journals | Multimedia | Jobs | Buyer's guide | Events | Contact

LATEST NEWS ARTICLES

- ▶ Breast cancer: multimodality imaging is key
- ▶ Histotripsy offers selective tissue ablation
- ▶ 3D-2D registration enables surgical guidance
- ▶ Plan incorporates tumour shrinkage
- ▶ Innovation: patent applications review

[More news articles](#)

RELATED STORIES

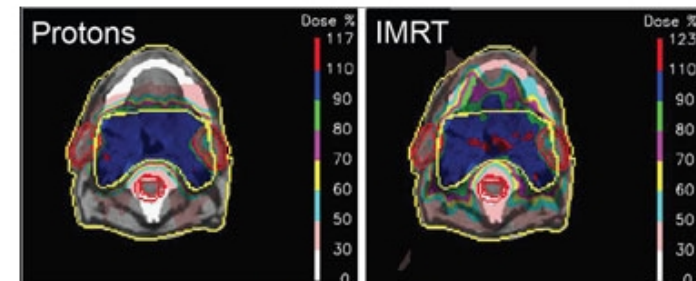
- ▶ Future prospects for proton therapy
- ▶ Five years on: advances in proton therapy
- ▶ Proton therapy: is randomization needed?
- ▶ How to build a proton therapy facility
- ▶ Proton therapy: scattering versus scanning

RESEARCH

Aug 22, 2012

Will protons gradually replace photons?

The dose distribution advantages offered by proton therapy, particularly with the introduction of pencil-beam scanning, have stimulated increasing interest in this modality. But is the large capital expenditure required to build a proton therapy facility hindering the widespread implementation of this technique? And how big a problem is range uncertainty, which can prevent proton therapy from meeting its full potential?



Protons versus IMRT

These were just some of the questions considered at the recent AAPM annual meeting in Charlotte, NC, where three experts in the field presented on the theme "Will proton therapy gradually replace photon therapy?"

Why hasn't proton therapy replaced x-rays in 2015?

- Protons have been used for 50 years!
- Over 100,000 patients have been treated !
- **Lack of clinical evidence?** (Compared to x-rays)
 - Late start of trials – wasn't thought to be needed

• 7 8 9. : ;<==? ;
6/ # % 8 ;<==? +

Why proton therapy hasn't taken over yet



MASSACHUSETTS
GENERAL HOSPITAL

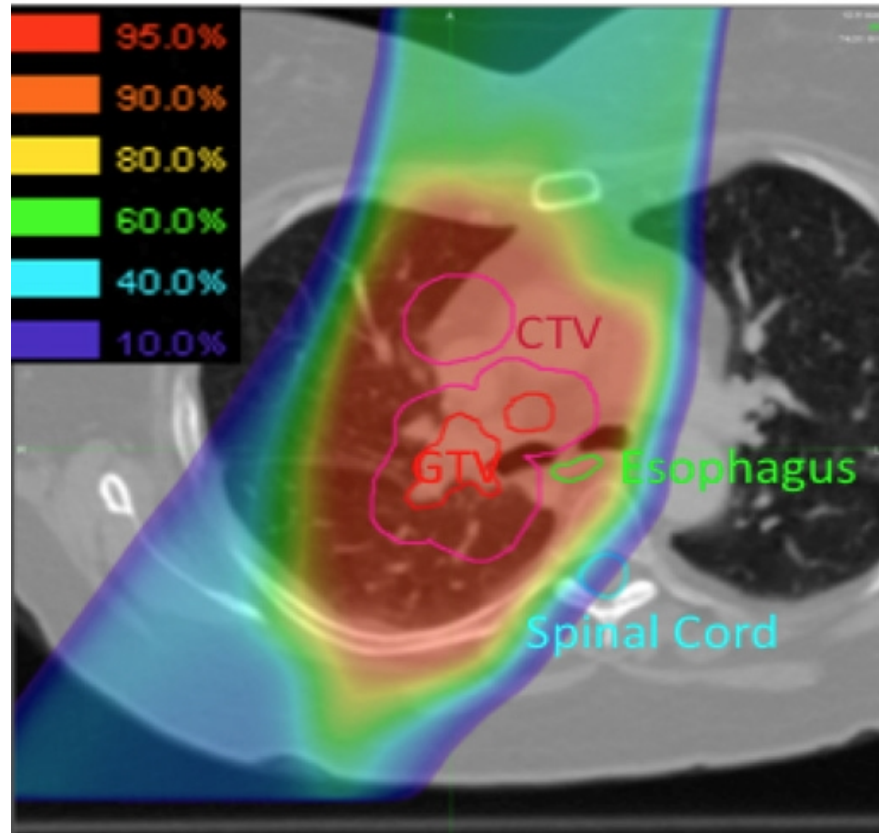
RADIATION ONCOLOGY

Proton therapy generations

A. Gap between physical potential and clinical reality

clinical reality today

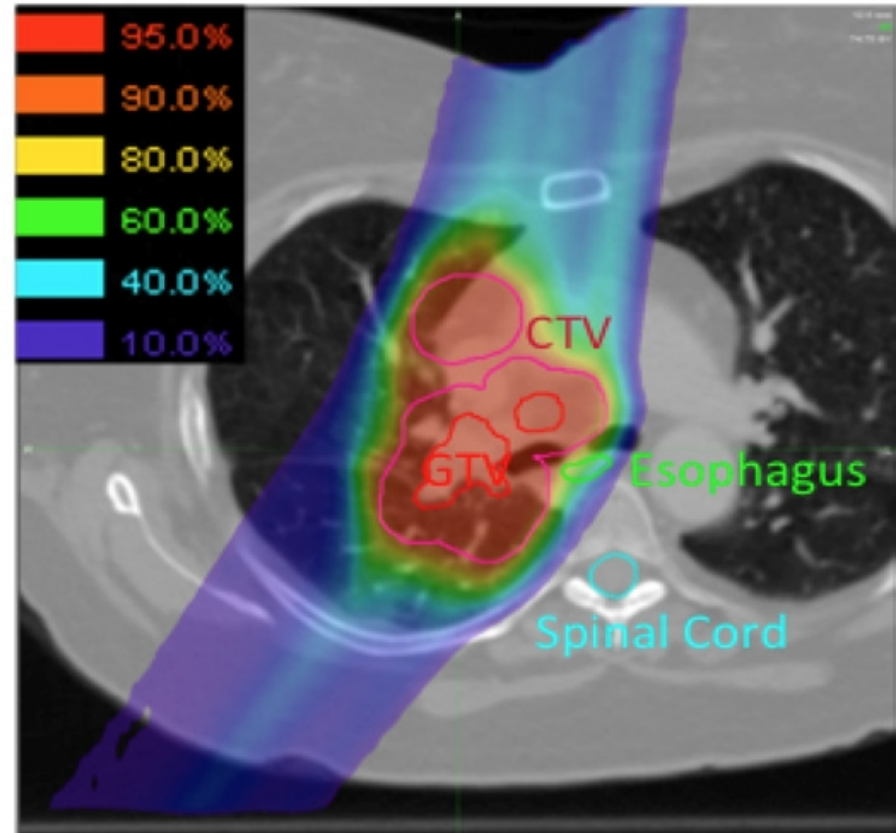
2nd Generation



2nd generation

physical potential

3rd Generation



3rd generation



A.

Gap

between

physical

potential

and



MASSACHUSETTS
GENERAL HOSPITAL

RADIATION ONCOLOGY

Lateral dose fall-off: areas for improvement

What affects the lateral penumbra ?

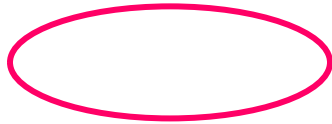
- Machine-related
 - Scattering:
 - Effective Source Size
 - Aperture location (if used)
 - Materials in the beam path (scatterers /bolus)
 - Scanning
 - Beam Size and Shape
- Patient-related
 - Material in the patient
 - Setup error, motion

Improvements

- Machine-related
 - Scattering
 - Longer SAD (\$\$)
 - Close to Patient
 - Optimize Scattering
 - Scanning (NO Penumbra)
 - Sharp Edge
 - Smaller beam sigma
 - Smaller Emittance
- Patient-related
 - Can't change?
 - Improve dose algorithms (Inhomogeneity)
 - Reduce

$$\Delta x = \frac{L_2}{L_1} x_b$$

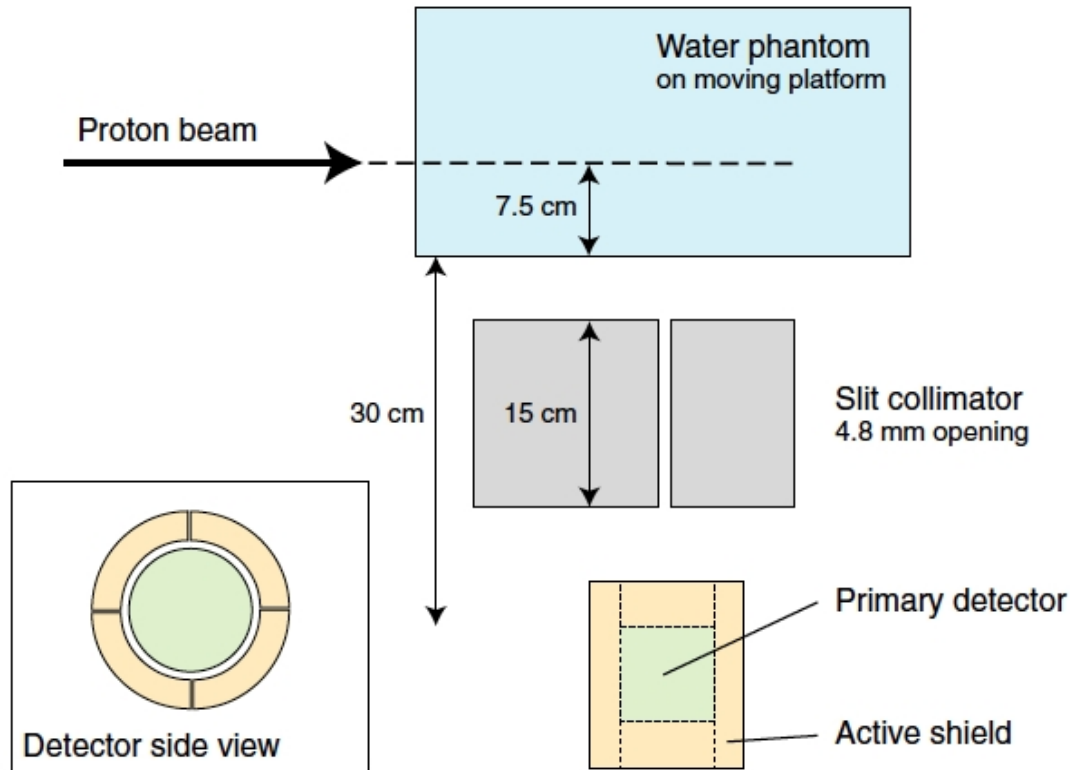
A. Gap between physical potential and clinical reality



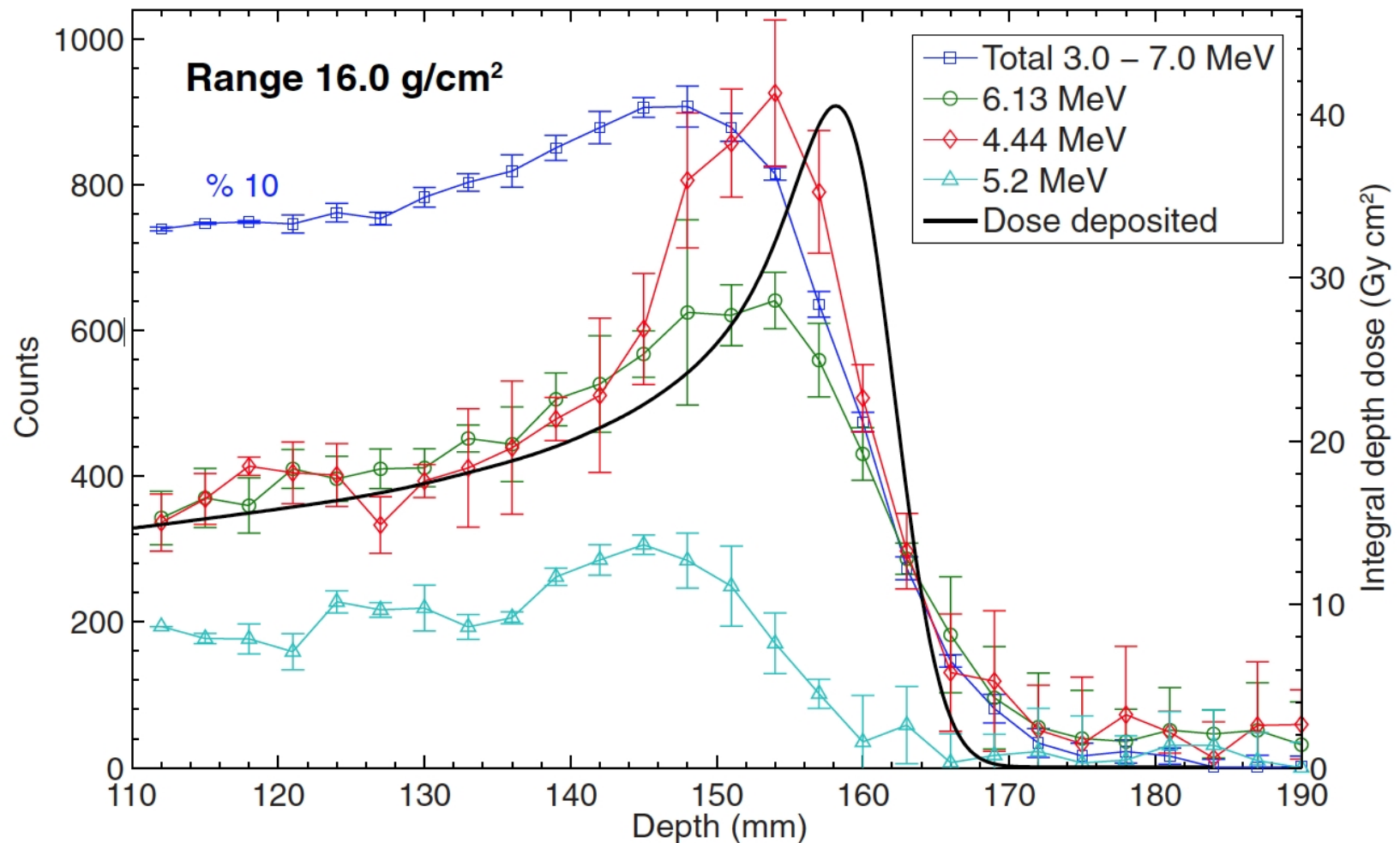
Distal fall-off: areas for improvement

What	0 1	How / (1
60 6H % 6* % H @ 6 @ 6H % 6* % H @ 6/ @ 1	60 6H % 6 \$ ' G* @ KK H %% % 6\$ H 1 6H % 6 \$ H ' G* @ KK H %% % 6 \$ H @	
60 6 6J %	60 68 2 % 1 6# J 6/ (/ % % 6" * % 8 6 # % 6/ (" D % 6 8 % 6 8 I @ B 6 * I MI# % I / 0((	

Recent results from prompt- γ imaging (Energy- and time-resolved detection)



Recent results from prompt- γ imaging (Energy- and time-resolved detection)

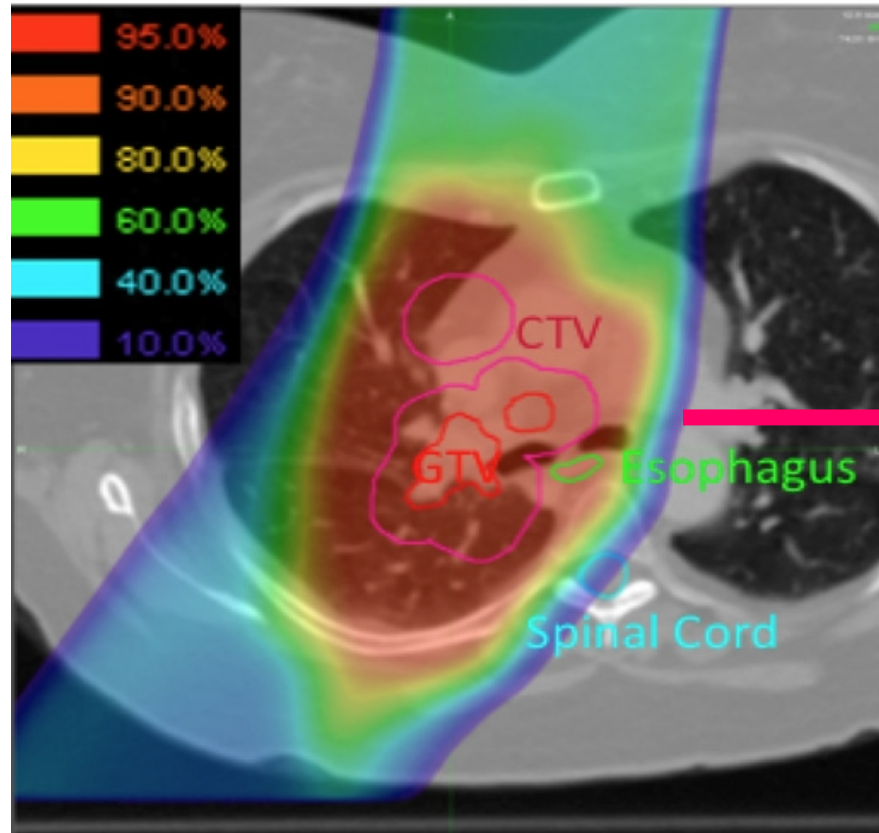


Verburg et al, PMB 58, L37-L49, 2013

A. Close the gap between physical potential and clinical reality

clinical reality today

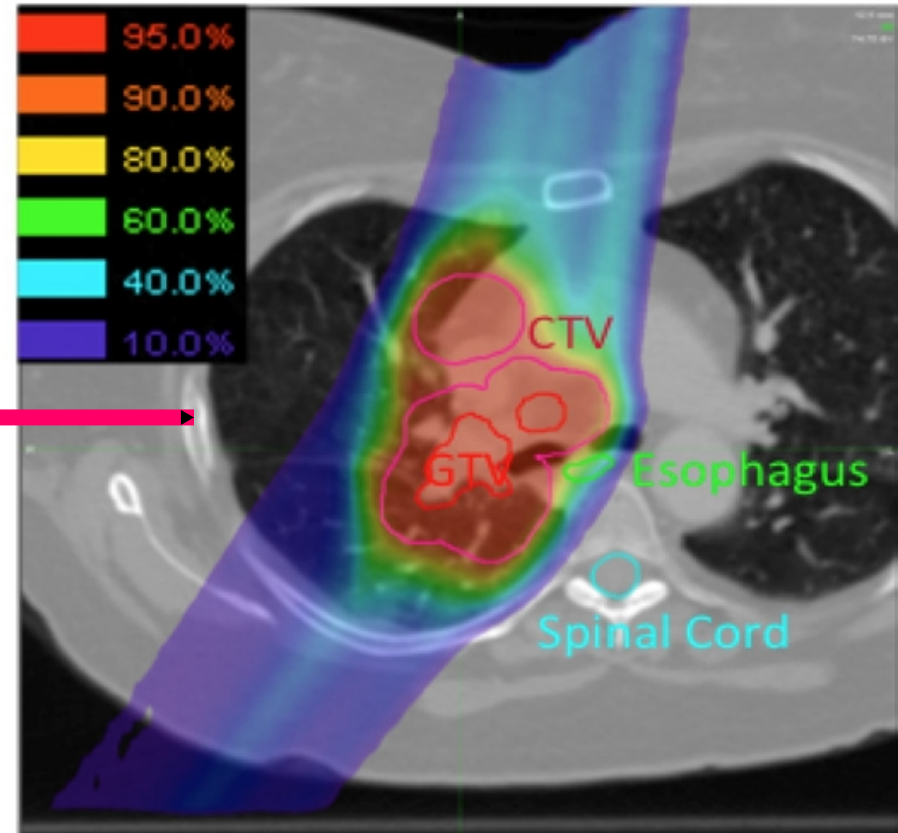
2nd Generation



2nd generation

physical potential

3rd Generation



3rd generation

Why proton therapy hasn't taken over yet

- Capital cost, size

B.1: Minimizing Cost

1\$ $\approx$ 1€ $\approx$ 3TRY

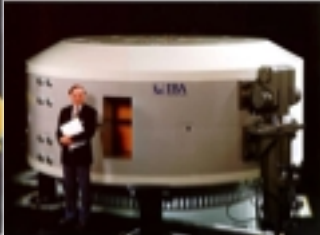
B.1: Minimizing Cost – Accelerator

Cyclotrons

\$\$\$\$



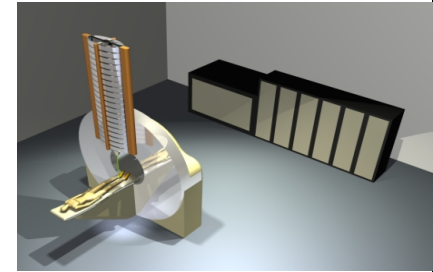
\$\$



\$\$

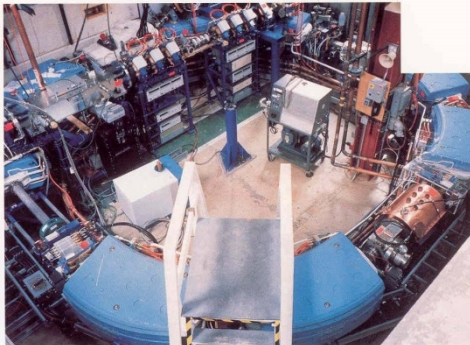


\$\$



Synchrotrons

\$\$



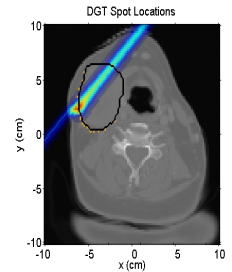
\$\$



\$+(\$/2)

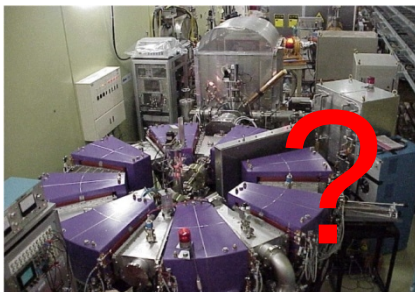


DWA



FFAGs

\$\$\$



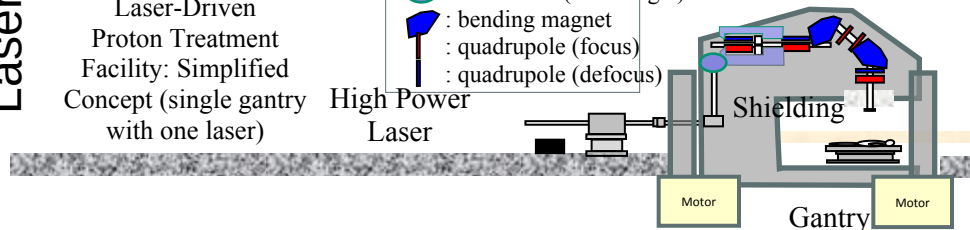
\$\$\$\$

Laser

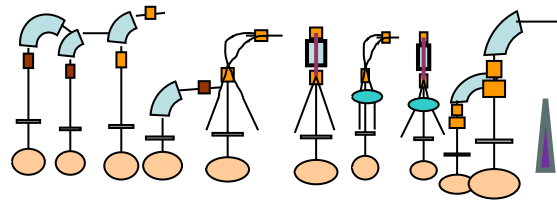
Laser-Driven
Proton Treatment
Facility: Simplified
Concept (single gantry
with one laser)

High Power
Laser

-  : ion source (laser target)
-  : bending magnet
-  : quadrupole (focus)
-  : quadrupole (defocus)



B.1: Minimizing Cost – Gantry



FFAG
Gantry?

B.1: Minimizing Equipment Cost

Note: cheaper
no-gantry systems
also possible
with x-rays
© (Nano-X)



B.2: Minimizing Size

- Recent developments of compact proton systems:
 - Mevion Systems (Still River) (Monarch 250)
 - IBA (Proteus One)
 - ProTom (Radiance 330)
 - ProNova (SC360)

B.2: Minimizing Size

“Compact” systems – not so compact



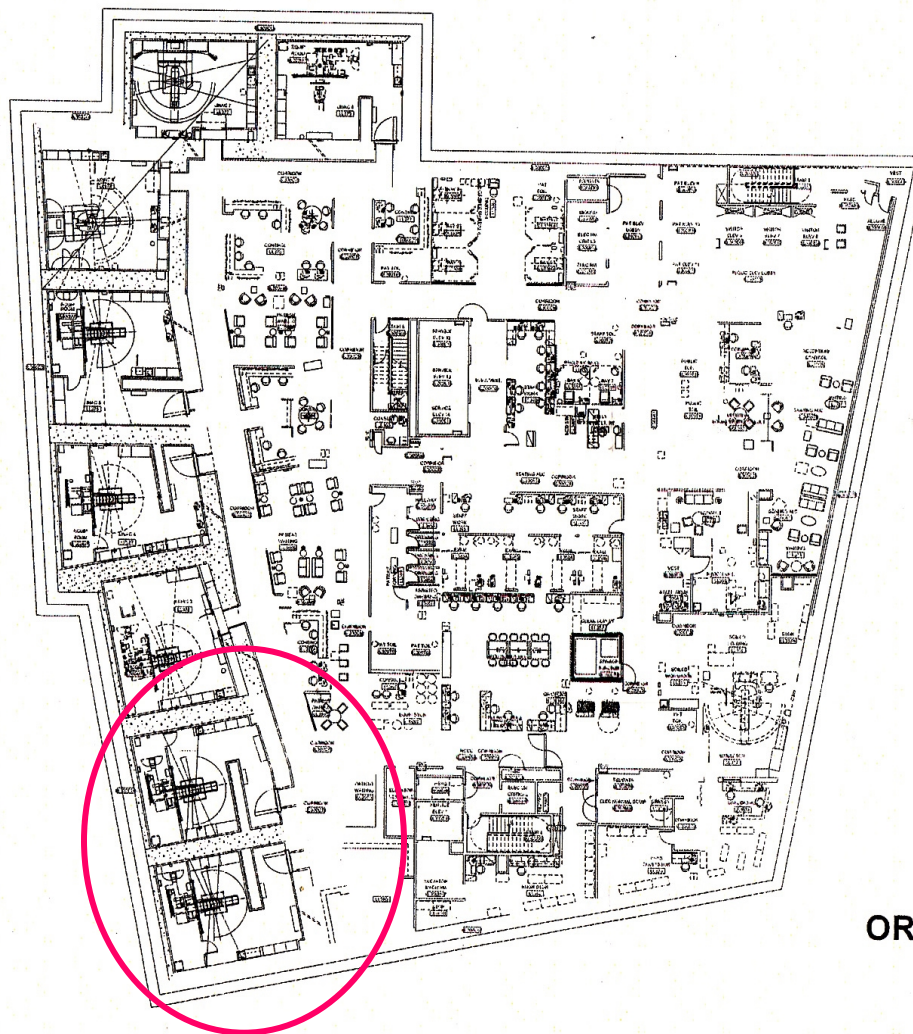
B.2: Minimizing Size

- Does a proton system fit in a conventional treatment room?

MGH new proton facility



RADIATION ONCOLOGY



ORIGINAL PLAN

DRAWING NOTES

1. The first step is to identify the problem or question that needs to be answered. This involves understanding the context and the specific requirements of the task.



BUILDING FOR THE THIRD CENTURY

nbbj

2 RECTOR STREET, 25TH FLOOR
NEW YORK NY 10006
PHONE 212 924 1400

4500 JEEB ROAD, 7th FLOOR
CHUAN KUEGER BUILDING, INC.
8 STORY STREET
CAMBRIDGE, MA 02138
PHONE (617) 354-8715
FAX (617) 354-3252

W.F. FINE, INC.
THOMPSON CONSULTANTS, INC.
525 MILL STREET
MURKIN, MA 02738
PHONE (508) 743-2920
FAX (508) 748-0020

ENGINEERING SOLUTIONS INC.
6 UNION STREET
NATICK, MA 01760
PHONE (508) 647-6200
FAX (508) 652-1900

SINHA LASSI ENGINEERING
INC. MAHARAJA SALVA, BOC
100 FEDERAL STREET, 5TH FL.
BOCA RATON, FL 33433
PHONE (407) 737-4000
FAX (407) 737-4002

2000
 2001
 2002
 2003
 2004
 2005
 2006
 2007
 2008
 2009
 2010
 2011
 2012
 2013
 2014
 2015
 2016
 2017
 2018
 2019
 2020
 2021
 2022
 2023
 2024
 2025
 2026
 2027
 2028
 2029
 2030
 2031
 2032
 2033
 2034
 2035
 2036
 2037
 2038
 2039
 2040
 2041
 2042
 2043
 2044
 2045
 2046
 2047
 2048
 2049
 2050
 2051
 2052
 2053
 2054
 2055
 2056
 2057
 2058
 2059
 2060
 2061
 2062
 2063
 2064
 2065
 2066
 2067
 2068
 2069
 2070
 2071
 2072
 2073
 2074
 2075
 2076
 2077
 2078
 2079
 2080
 2081
 2082
 2083
 2084
 2085
 2086
 2087
 2088
 2089
 2090
 2091
 2092
 2093
 2094
 2095
 2096
 2097
 2098
 2099
 2100
 2101
 2102
 2103
 2104
 2105
 2106
 2107
 2108
 2109
 2110
 2111
 2112
 2113
 2114
 2115
 2116
 2117
 2118
 2119
 2120
 2121
 2122
 2123
 2124
 2125
 2126
 2127
 2128
 2129
 2130
 2131
 2132
 2133
 2134
 2135
 2136
 2137
 2138
 2139
 2140
 2141
 2142
 2143
 2144
 2145
 2146
 2147
 2148
 2149
 2150
 2151
 2152
 2153
 2154
 2155
 2156
 2157
 2158
 2159
 2160
 2161
 2162
 2163
 2164
 2165
 2166
 2167
 2168
 2169
 2170
 2171
 2172
 2173
 2174
 2175
 2176
 2177
 2178
 2179
 2180
 2181
 2182
 2183
 2184
 2185
 2186
 2187
 2188
 2189
 2190
 2191
 2192
 2193
 2194
 2195
 2196
 2197
 2198
 2199
 2200
 2201
 2202
 2203
 2204
 2205
 2206
 2207
 2208
 2209
 2210
 2211
 2212
 2213
 2214
 2215
 2216
 2217
 2218
 2219
 2220
 2221
 2222
 2223
 2224
 2225
 2226
 2227
 2228
 2229
 2230
 2231
 2232
 2233
 2234
 2235
 2236
 2237
 2238
 2239
 2240
 2241
 2242
 2243
 2244
 2245
 2246
 2247
 2248
 2249
 2250
 2251
 2252
 2253
 2254
 2255
 2256
 2257
 2258
 2259
 2260
 2261
 2262
 2263
 2264
 2265
 2266
 2267
 2268
 2269
 2270
 2271
 2272
 2273
 2274
 2275
 2276
 2277
 2278
 2279
 2280
 2281
 2282
 2283
 2284
 2285
 2286
 2287
 2288
 2289
 2290
 2291
 2292
 2293
 2294
 2295
 2296
 2297
 2298
 2299
 2300
 2301
 2302
 2303
 2304
 2305
 2306
 2307
 2308
 2309
 2310
 2311
 2312
 2313
 2314
 2315
 2316
 2317
 2318
 2319
 2320
 2321
 2322
 2323
 2324
 2325
 2326
 2327
 2328
 2329
 2330
 2331
 2332
 2333
 2334
 2335
 2336
 2337
 2338
 2339
 2340
 2341
 2342
 2343
 2344
 2345
 2346
 2347
 2348
 2349
 2350
 2351
 2352
 2353
 2354
 2355
 2356
 2357
 2358
 2359
 2360
 2361
 2362
 2363
 2364
 2365
 2366
 2367
 2368
 2369
 2370
 2371
 2372
 2373
 2374
 2375
 2376
 2377
 2378
 2379
 2380
 2381
 2382
 2383
 2384
 2385
 2386
 2387
 2388
 2389
 2390
 2391
 2392
 2393
 2394
 2395
 2396
 2397
 2398
 2399
 2400
 2401
 2402
 2403
 2404
 2405
 2406
 2407
 2408
 2409
 2410
 2411
 2412
 2413
 2414
 2415
 2416
 2417
 2418
 2419
 2420
 2421
 2422
 2423
 2424
 2425
 2426
 2427
 2428
 2429
 2430
 2431
 2432
 2433
 2434
 2435
 2436
 2437
 2438
 2439
 2440
 2441
 2442
 2443
 2444
 2445
 2446
 2447
 2448
 2449
 2450
 2451
 2452
 2453
 2454

SYNKA HENRIK Józef
1 BROADWAY, 9TH FLOOR
CAMBRIDGE, MA 02112
PHONE (617) 577-6000
FAX (617) 577-6101

LOCK FINGERPRINT
VIA USC PASSPORT
UNION INC.
89 NORTH STREET 10TH FLOOR
ROSTON, MA 02110
PHONE (617) 222-7777
FAX (617) 222-7742

LANDSCAPE ARCHITECT
SILVIA VALLI WALKERSON
ASSOCIATES
251 CONCORD AVE
CAMBRIDGE, MA 02102
PHONE (617) 494-2075
FAX (617) 492-3728

GENERAL ENGINEERING
ASSOCIATES
330 NORTON STREET
CAMBRIDGE, MA 02140
PHONE (617) 866-1428
FAX (617) 866-1422

CONSTRUCTION
DOCUMENTS

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466
---	---	---	---	---	---	---	---	---	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

100

[illegible][illegible][illegible]

1. The first step is to identify the problem or question that needs to be answered. This involves understanding the context and the specific requirements of the task.

Ex

[illegible]

182	6-1	1-14-60
183	6-1	1-14-60

WALL 75049/22

1. $\frac{1}{2} \log_2 2$

EQ PLAN:
BASEMENT D
PLAN (000)

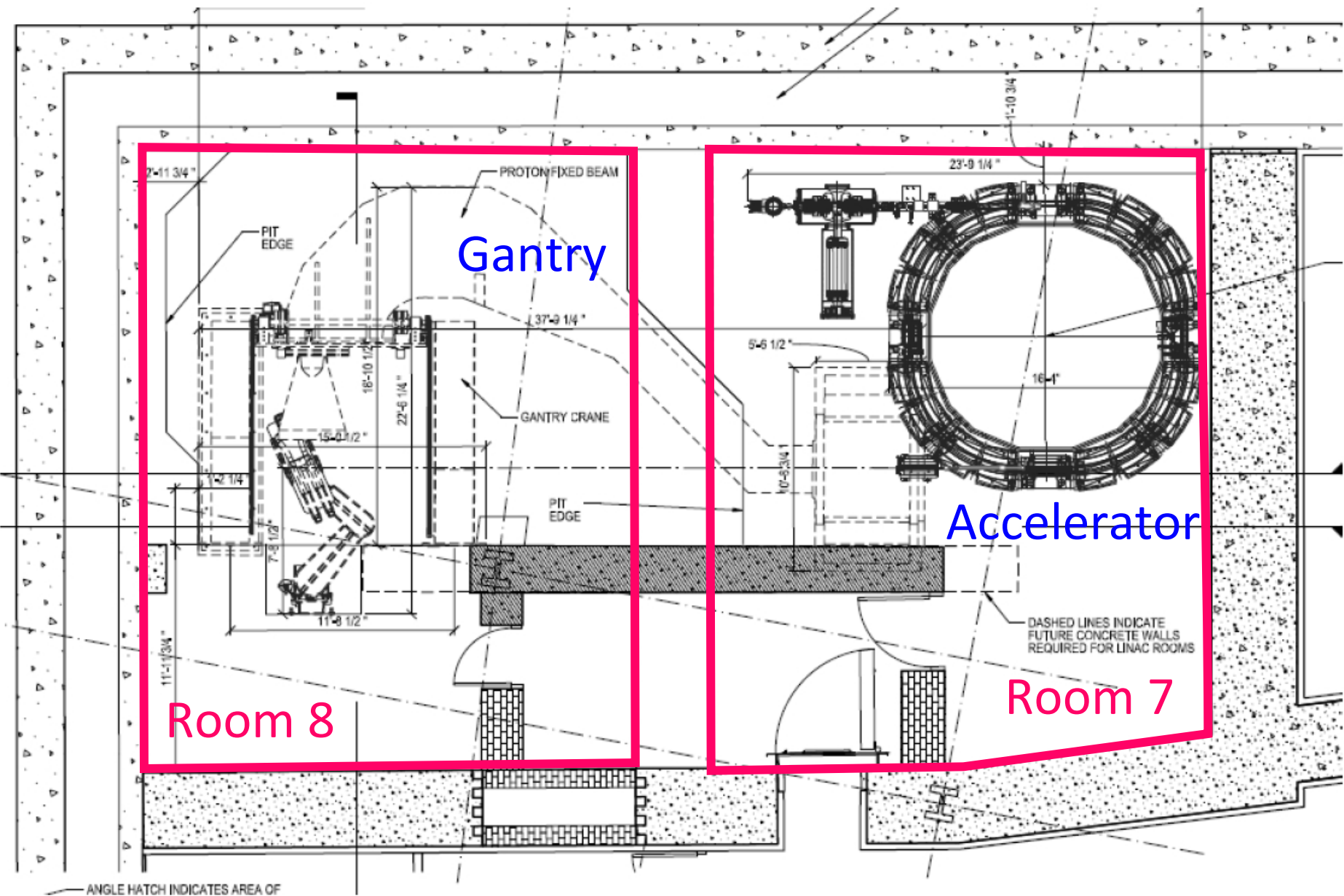
PLAN (000)
RAD/ONC
EL: 33'-1"

100-443888-1

EQ200

4. Results

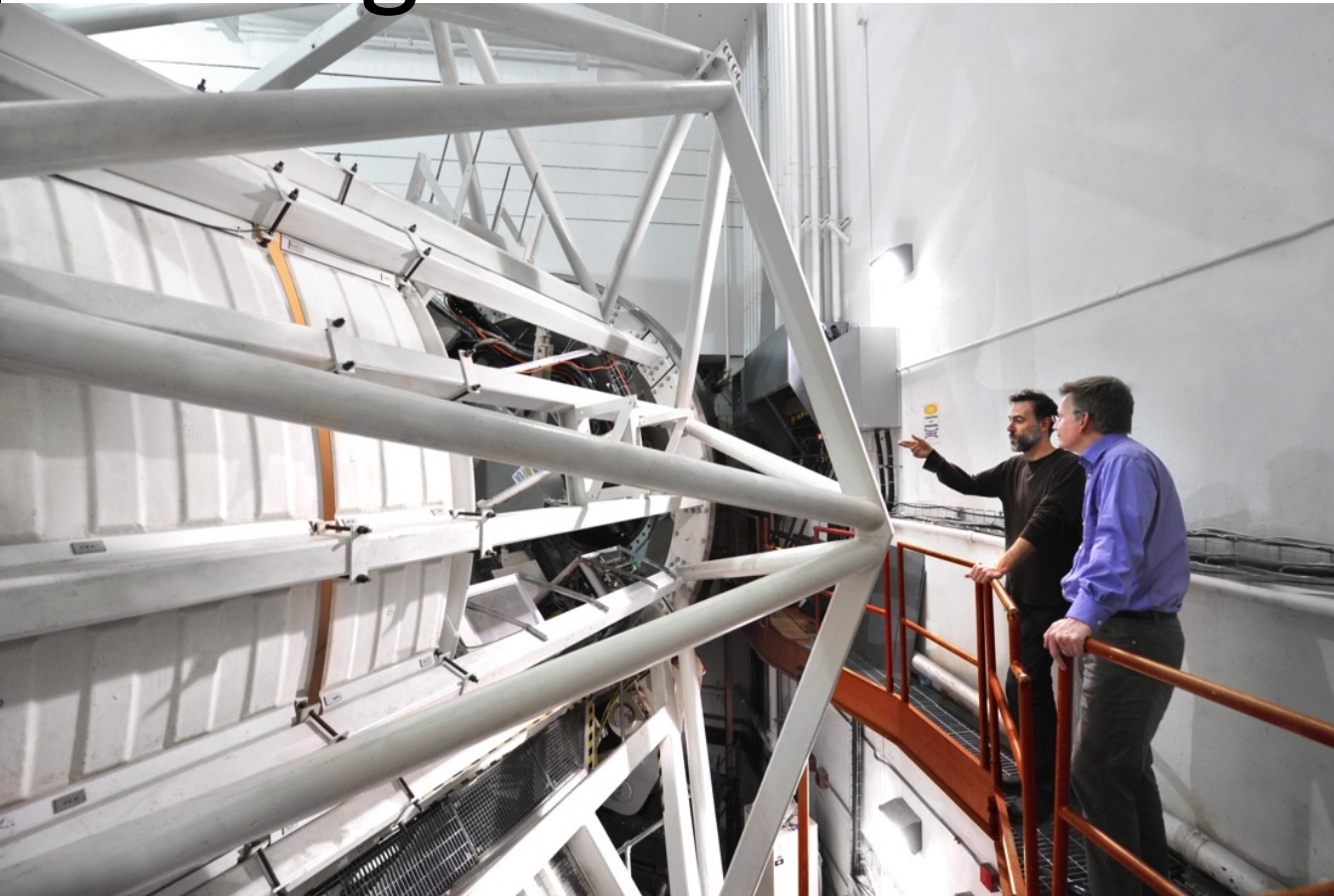
Protons in existing linac rooms (MGH)



B.2: Minimizing Size

- Does a proton system fit in a SINGLE conventional treatment room without digging a deeper hole for the gantry ?

Big Gantries



Accelerators are quite compact



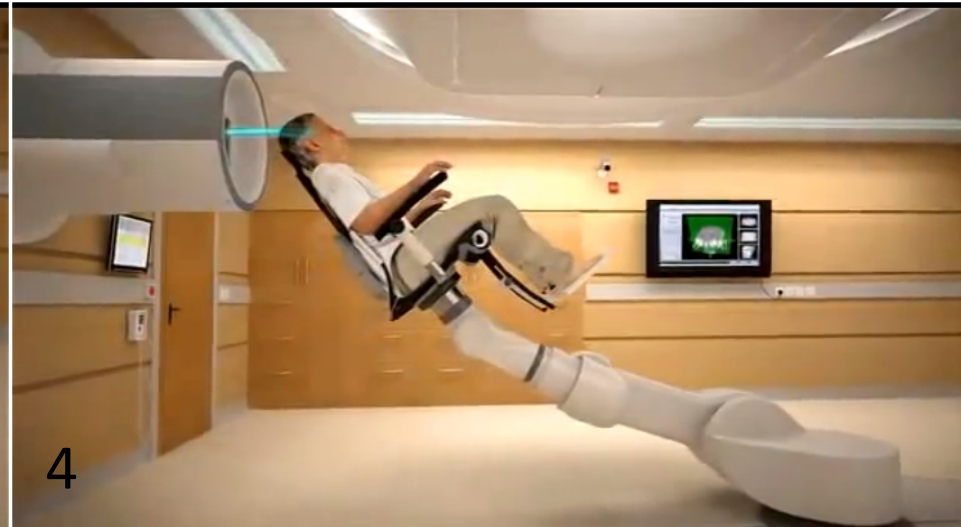
B.2: Minimizing Size

- Does a proton system fit in a SINGLE conventional treatment room without digging a deeper hole for the gantry ?
- Only without a gantry.

No gantry:
rotate the patient around the beam.



No gantry: rotate the patient around the beam



Summary:

3rd Generation of Proton Therapy



MASSACHUSETTS
GENERAL HOSPITAL

RADIATION ONCOLOGY

More info:
Flanz, Bortfeld
Sem Rad Onc 23(2):
142-153, 2013



MASSACHUSETTS
GENERAL HOSPITAL

RADIATION ONCOLOGY



Seminars in RADIATION ONCOLOGY

Volume 23 / Number 2 / April 2013

Joel E. Tepper, MD *Editor*

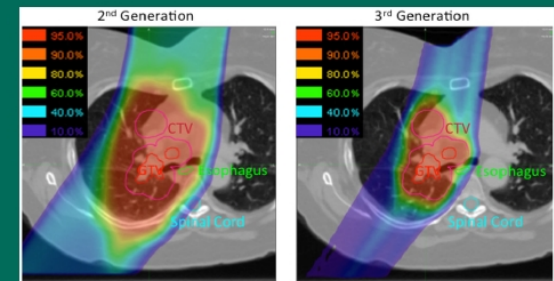
Controversies in Proton Therapy

Guest Editors

Michael Brada, FRCP, FRCR, DSc
Thomas Bortfeld, PhD, FInstP, FAAPM

Contributing Authors

Harald Paganetti	Michael Brada
Peter van Luijk	Robert C. Miller
Martijn Engelsman	Mark Lodge
Marco Schwarz	Mohammad Hassan
Lei Dong	Murad
Thomas E. Merchant	Bleddyn Jones
Kent W. Mouw	Yolande Lievens
Alexei Trofimov	Madelon Pijls-
Anthony L. Zietman	Johannesma
Jason A. Elfstathiou	Jacob Flanz
Dirk De Ruyscher	Thomas Bortfeld
Joe Y. Chang	Daniel Zips
Stephanie E. Combs	Michael Baumann
Normand Laperriere	



<http://www.semradonc.com>