Particle Therapy using Proton and Ion Beams – From Basic Principles to Daily Operations and Future Concepts

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Academic Training Lectures

CERN, 11th – 13th September 2012

HIT Betriebs GmbH am
Universitätsklinikum Heidelberg

http://www.hit-centrum.de

Outline – Part 3

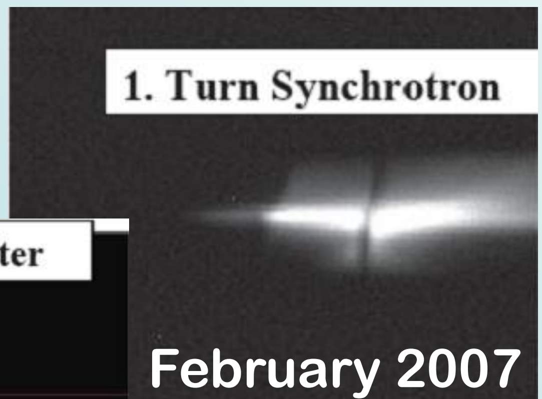
- Daily operations of a particle therapy centre: Experiences from the first five years at HIT in Heidelberg, from commissioning to the treatment of the first 1000 patients so far
- Future enhancements for synchrotron-driven particle therapy facilities: Magnetic field control and feedback, dynamic spill shaping and multi-energy operation within one synchrotron cycle
- Outlook to new accelerator concepts proposed for particle therapy: FFAGs, laser plasma accelerators, dielectric wall accelerators and others

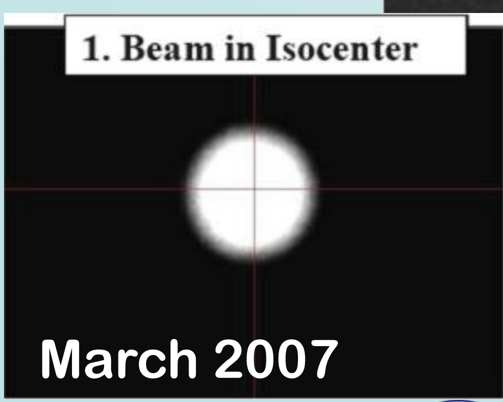
From Commissioning by GSI to Operation by HIT

Commissioning Steps:

2006 Ion Sources and Linac
Hand-over to HIT: 06/2007

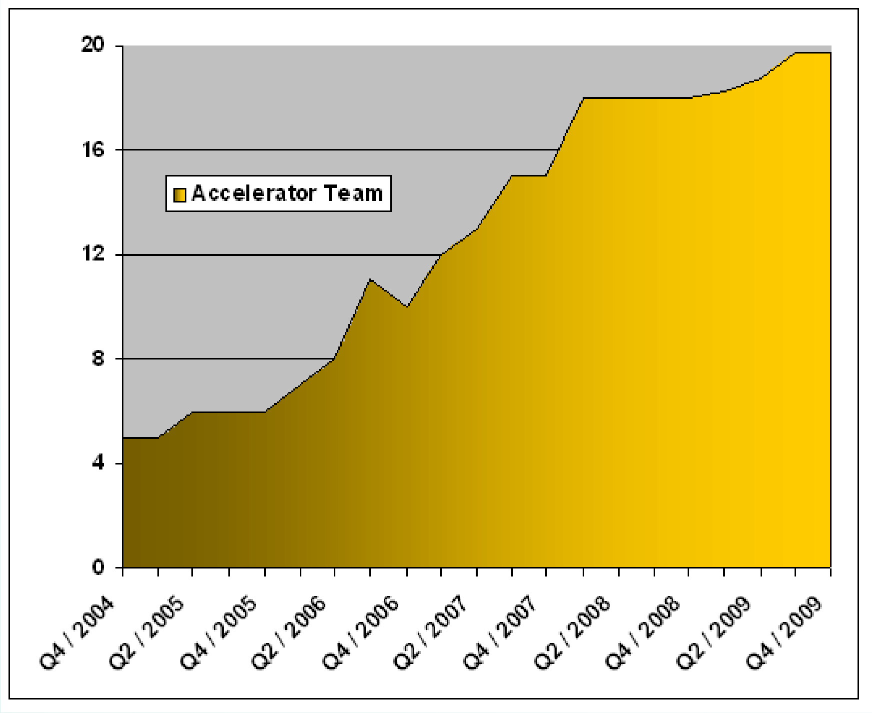
2007/08 Synchrotron and HEBT Lines
Hand-over to HIT: 04/2008





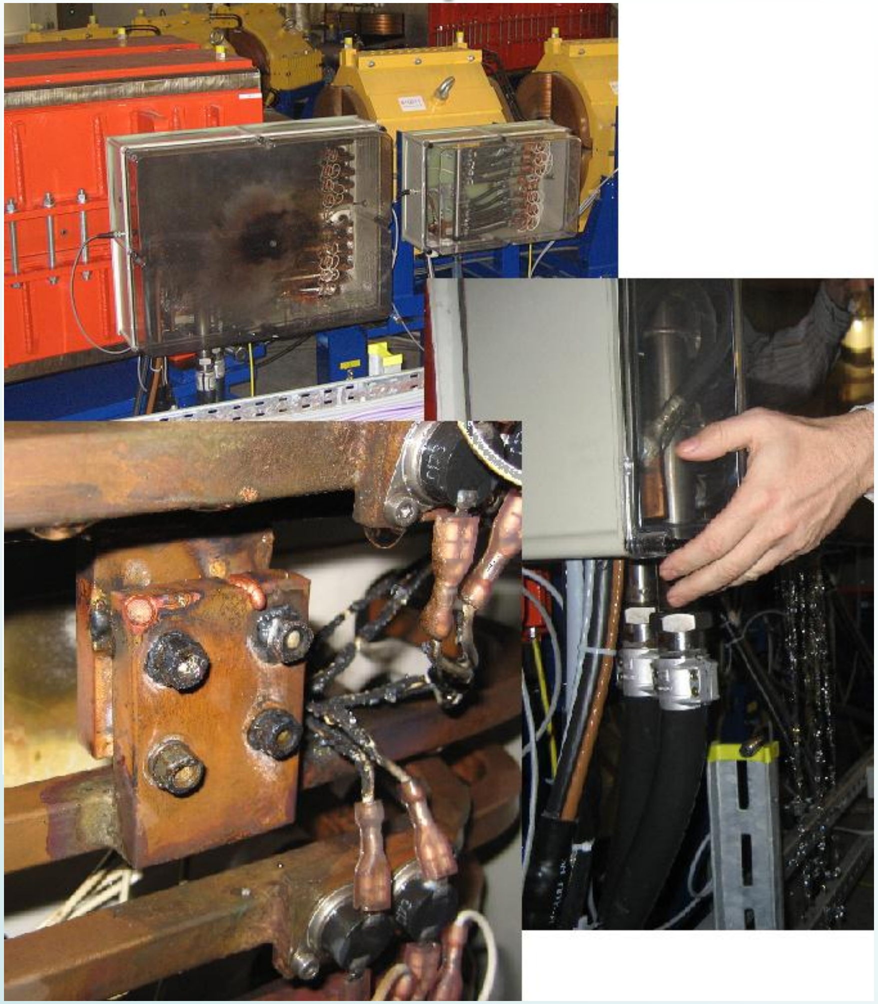
Five Years of HIT Accelerator Operation

- Building up of the team from a core to the full operating crew
- Training of the team done by GSI, companies and “in-house”
- Internal organization of three technical teams



Five Years of HIT Accelerator Operation

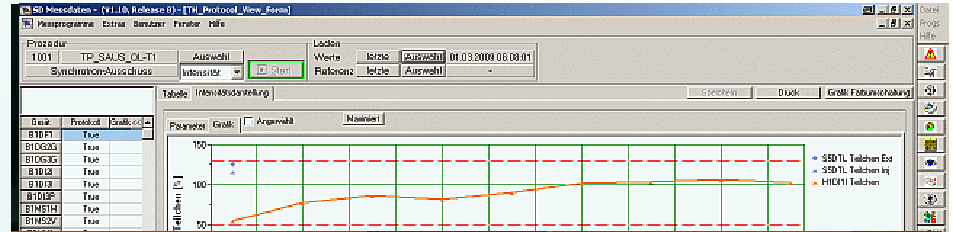
- Building up of the team from a core to the full operating crew
- Training of the team done by GSI, companies and "in-house"
- Internal organization of three technical teams
- Establish regular shift operation from 16/5 to 24/7 for further commissioning steps including therapy control system evaluation
- Troubleshooting: e.g. a destroyed magnet connection box – repair within two days



2006 **2007** **2008** 2009 2010 2011 2012

Five Years of HIT Accelerator Operation

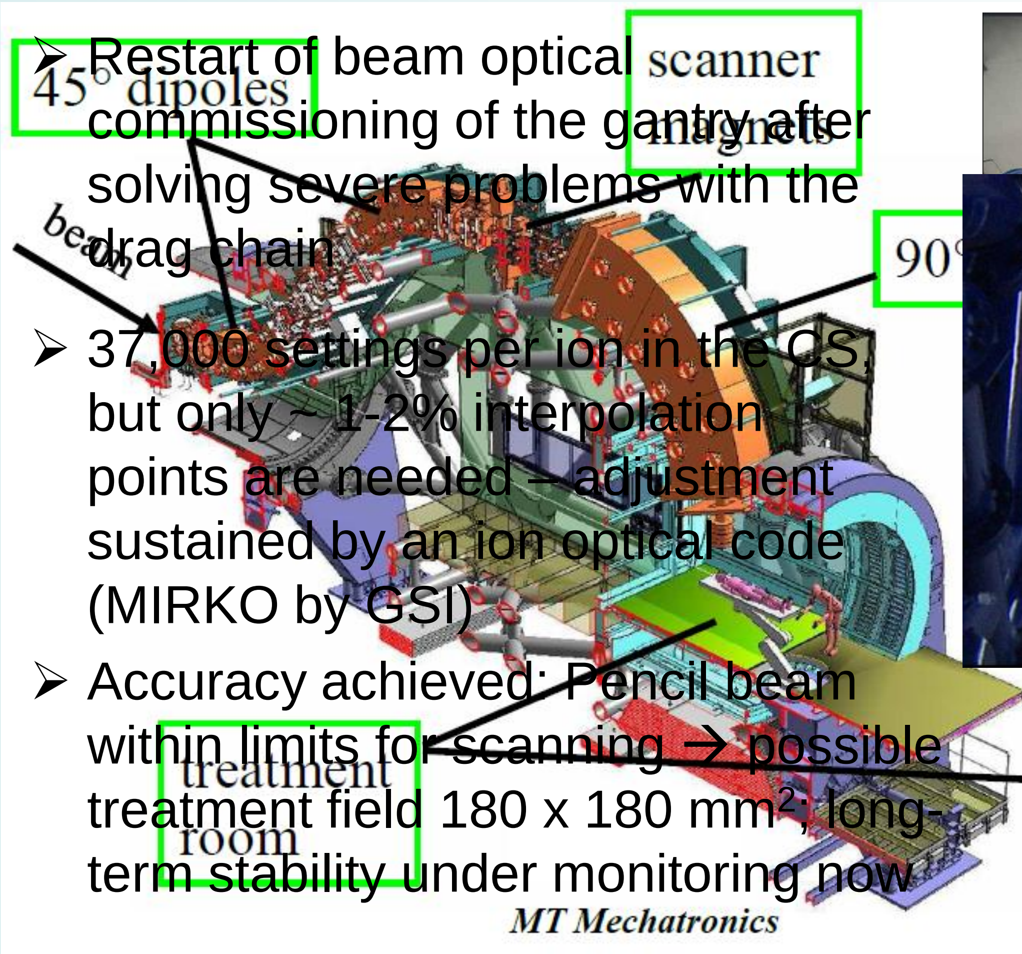
- Establish routine operation of the accelerator, especially consolidation of control system
- Achieved availability of about 98% in average – no longer break than 3 hours at daytime
- Daily Accelerator QA → retuning of linac, synchrotron and HEBT only every 3 – 4 months except intensity readjusting (daily – weekly)
- Patients treatment started on 15th November 2009 in one horizontal room, 1000 patients treated end of July 2012



2006 | 2007 | 2008 | **2009** | 2010 | 2011 | 2012

Five Years of HIT Accelerator Operation

- Restart of beam optical commissioning of the gantry after solving severe problems with the drag chain
- 37,000 settings per ion in the CS, but only ~ 1-2% interpolation points are needed → adjustment sustained by an ion optical code (MIRKO by GSI)
- Accuracy achieved: Pencil beam within limits for scanning → possible treatment field 180 x 180 mm^2; long-term stability under monitoring now

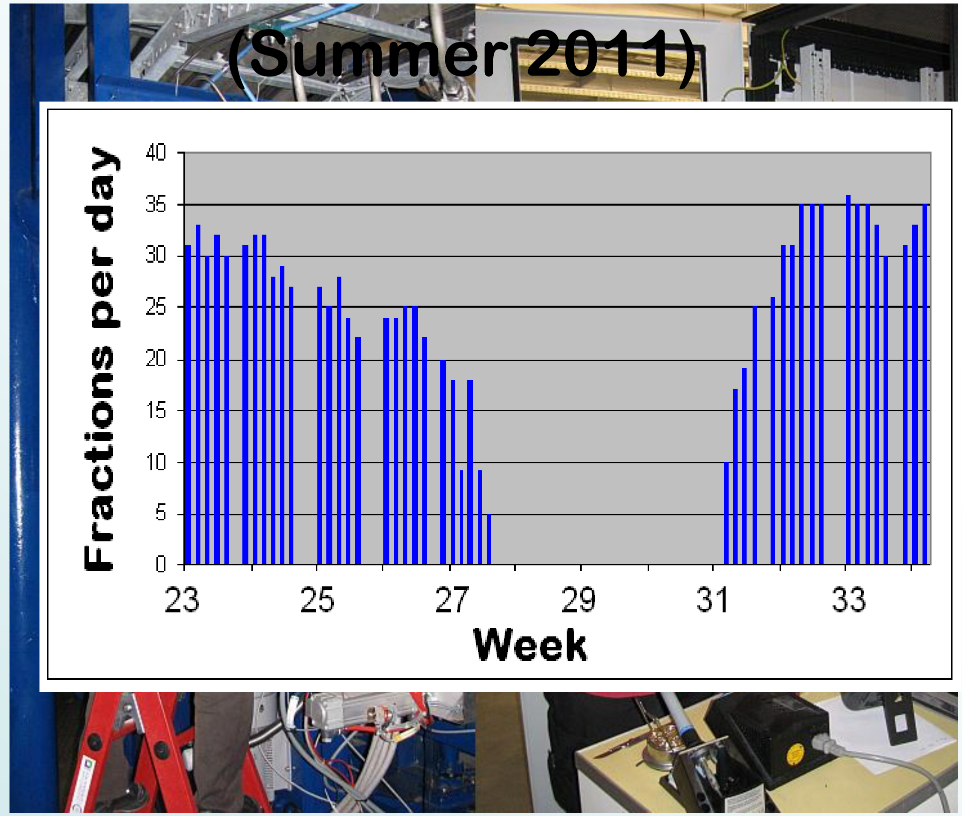


Courtesy by A.v.Knobloch, Siemens

2006 2007 2008 2009 **2010** **2011** 2012

Five Years of HIT Accelerator Operation

- "2012 – Year of the Gantry": Patient treatment start scheduled for mid/end of October
- Major change in shutdown strategy – during longer maintenance breaks of 2-3 weeks patients have to be phased out →"Ramping down" and "ramping up" necessary
- Since 2012 instead of two long shutdowns now six short maintenance periods of four days each (effectively 2.5 days) →Feasibility was successfully demonstrated!



HIT accelerator team members during May shutdown

2006 2007 2008 2009 2010 2011 **2012**

HIT Beam Time Schedule 2012
(July – December)

Legend:

patient treatment	maintenance	beam other than patients	shutdown

Juli			August			September			Oktober			November			Dezember		
So	1	KW 26	Mi	1	KW 31	Sa	1	KW 35	Mo	1	KW 40	Do	1	KW 44	Sa	1	KW 48
Mo	2	KW 27	Do	2		So	2		Di	2		Fr	2		So	2	
Di	3		Fr	3		Mo	3	KW 36	Mi	3	Tag d. dt. Einheit	Sa	3		Mo	3	KW 49
Mi	4		Sa	4		Di	4		Do	4		So	4		Di	4	
Do	5		So	5		Mi	5		Fr	5		Mo	5	KW 45	Mi	5	
Fr	6		Mo	6	KW 32	Do	6		Sa	6		Di	6		Do	6	
Sa	7		Di	7		Fr	7		So	7		Mi	7		Fr	7	
So	8		Mi	8		Sa	8		Mo	8	KW 41	Do	8		Sa	8	
Mo	9	KW 28	Do	9		So	9		Di	9		Fr	9		So	9	
Di	10		Fr	10		Mo	10	KW 37	Mi	10		Sa	10		Mo	10	KW 50
Mi	11		Sa	11		Di	11		Do	11		So	11		Di	11	
Do	12		So	12		Mi	12		Fr	12		Mo	12	KW 46	Mi	12	
Fr	13		Mo	13	KW 33	Do	13		Sa	13		Di	13		Do	13	
Sa	14		Di	14		Fr	14		So	14		Mi	14		Fr	14	
So	15		Mi	15		Sa	15		Mo	15	KW 42	Do	15		Sa	15	
Mo	16	KW 29	Do	16		So	16		Di	16		Fr	16		So	16	
Di	17		Fr	17		Mo	17	KW 38	Mi	17		Sa	17		Mo	17	KW 51
Mi	18		Sa	18		Di	18		Do	18		So	18		Di	18	
Do	19		So	19		Mi	19		Fr	19		Mo	19	KW 47	Mi	19	
Fr	20		Mo	20	KW 34	Do	20		Sa	20		Di	20		Do	20	
Sa	21		Di	21		Fr	21		So	21		Mi	21		Fr	21	
So	22		Mi	22		Sa	22		Mo	22	KW 43	Do	22		Sa	22	
Mo	23	KW 30	Do	23		So	23		Di	23		Fr	23		So	23	
Di	24		Fr	24		Mo	24	KW 39	Mi	24		Sa	24		Mo	24	KW 52
Mi	25		Sa	25		Di	25		Do	25	WB 5	So	25		Di	25	1.Weihnachtstag
Do	26		So	26		Mi	26		Fr	26		Mo	26	KW 48	Mi	26	2.Weihnachtstag
Fr	27		Mo	27	KW 35	Do	27		Sa	27		Di	27		Do	27	WB 6
Sa	28		Di	28		Fr	28		So	28		Mi	28		Fr	28	
So	29		Mi	29		Sa	29		Mo	29	KW 44	Do	29		Sa	29	
Mo	30	KW 31	Do	30	WB 4	So	30		Di	30		Fr	30		So	30	
Di	31		Fr	31					Mi	31					Mo	31	KW 1

Typical Day at HIT

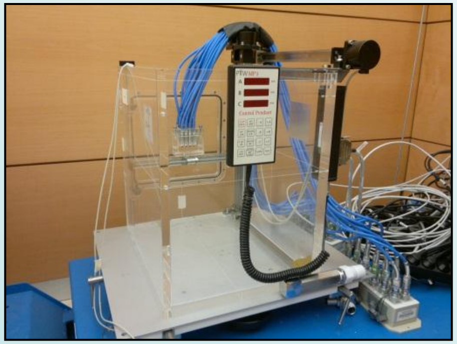
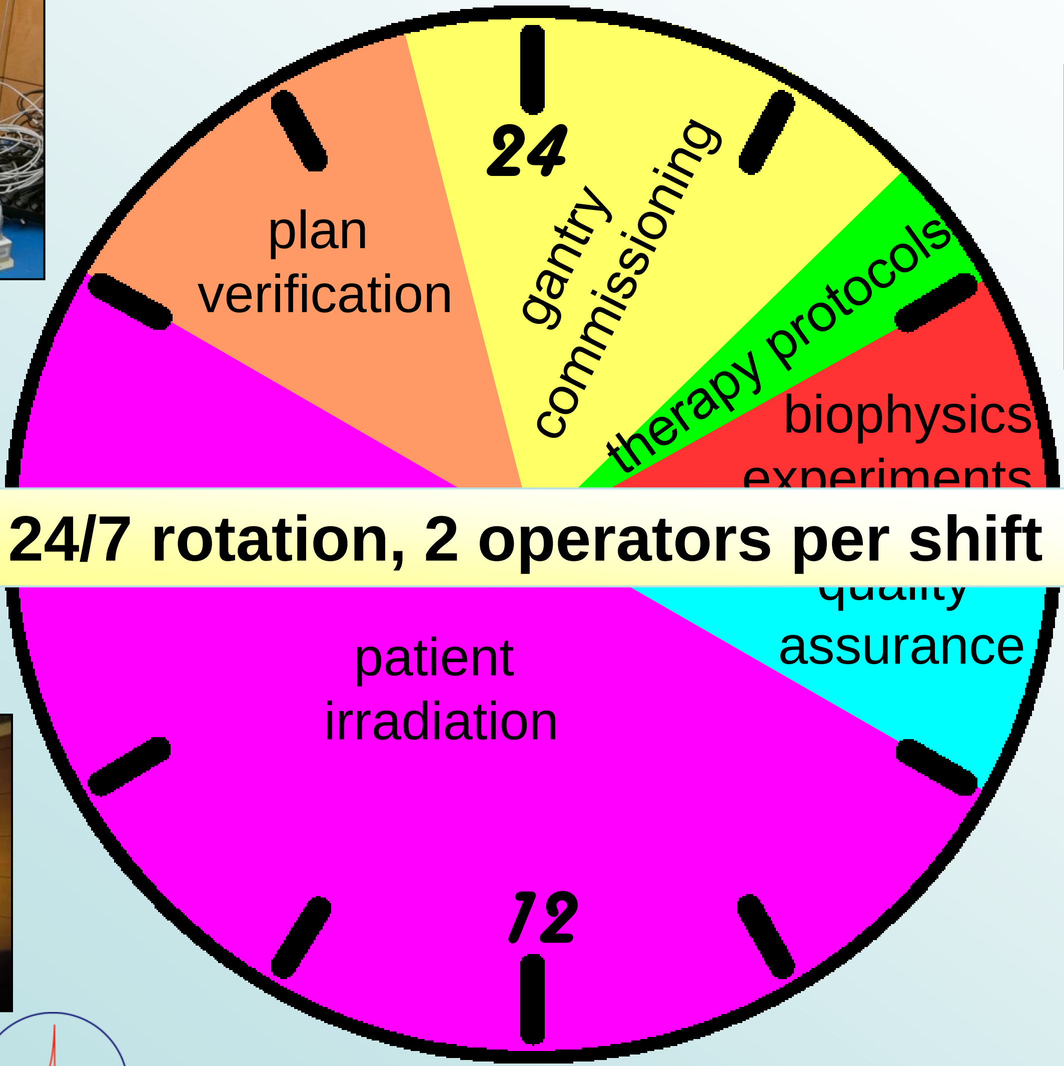
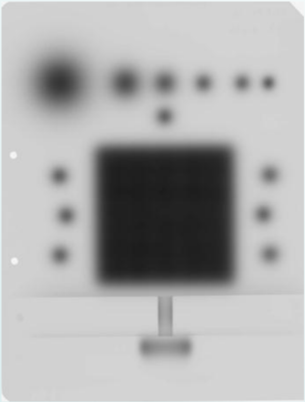


photo by R. Cee

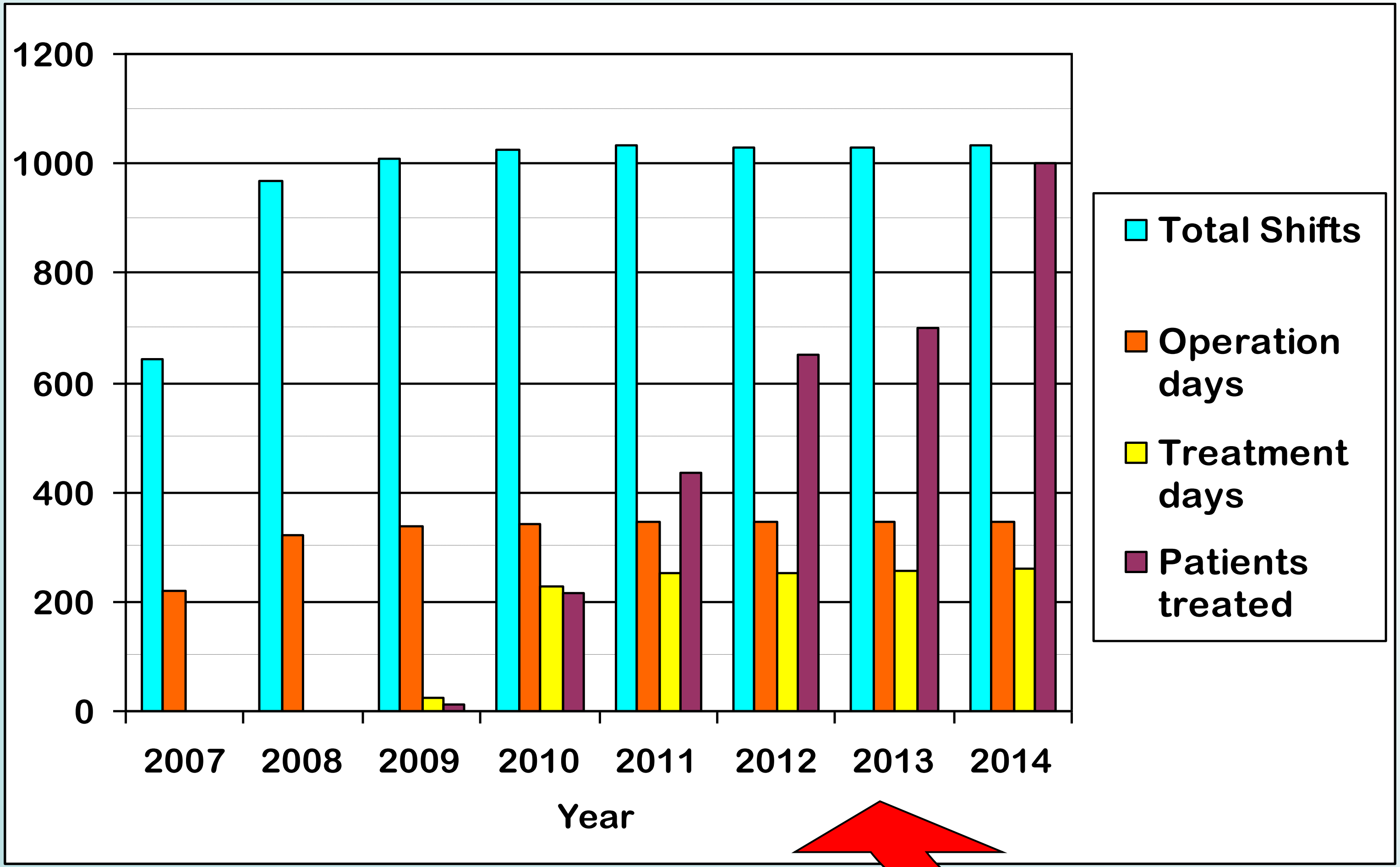


24/7 rotation, 2 operators per shift



film by P. Heeg

HIT Operation - Statistics



(Numbers for 2012-2014 estimated)

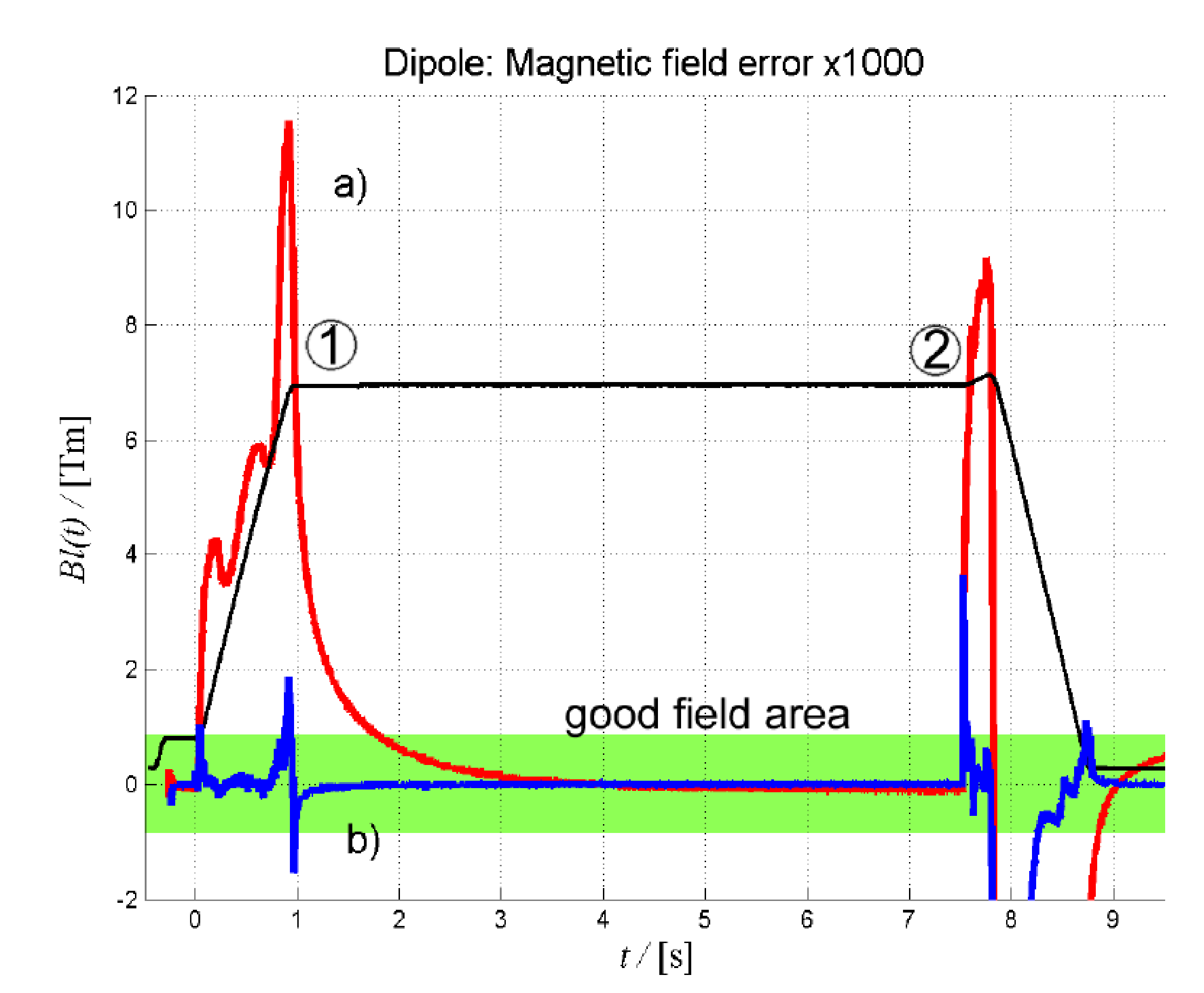
2013: Major Upgrade of IONTRIS Treatment Software

Enhancements of the HIT Accelerator facility

Magnetic Field Control in the Synchrotron

Goal: Reducing dead times in synchrotron cycle

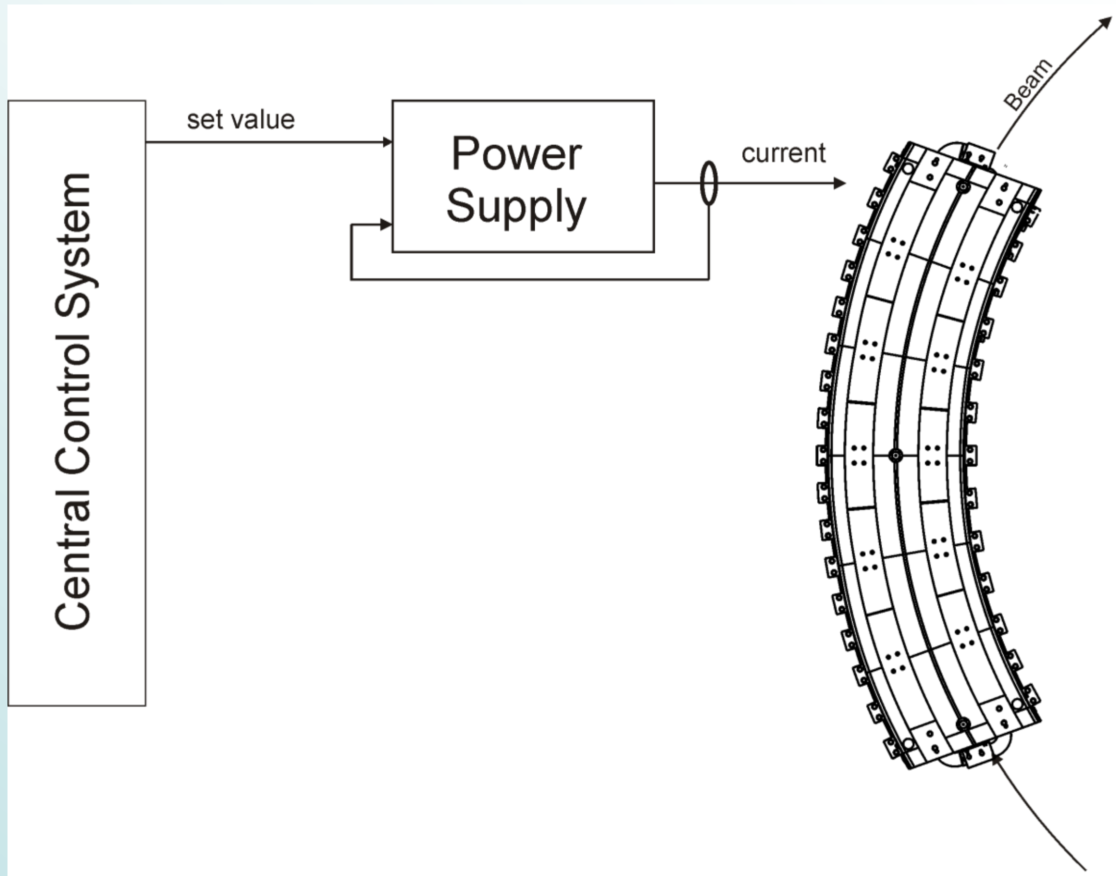
Magnetic effects cause dead times: Dipoles → Eddy currents have to die out (a/1) before extraction process → Development of high sensitive measuring and feedback system



Heidelberger Ionenstrahl-Therapiezentrum

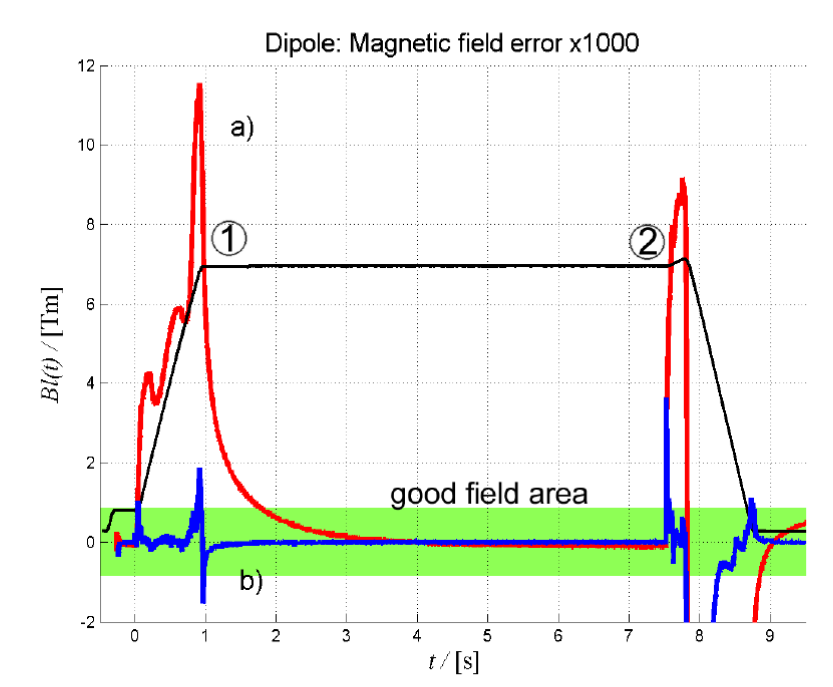
Magnetic Field Control in the Synchrotron

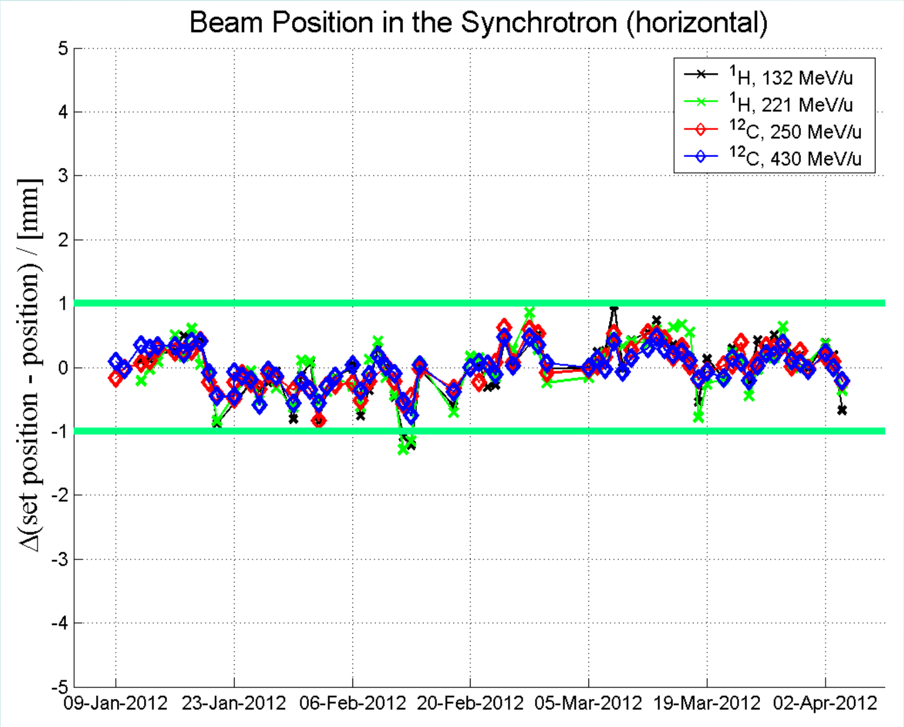
Development of high sensitive measuring and feedback system: Normal feed forward system retrofit with pick-up coil, hall sensor and HIT integrator



Magnetic Field Control in the Synchrotron

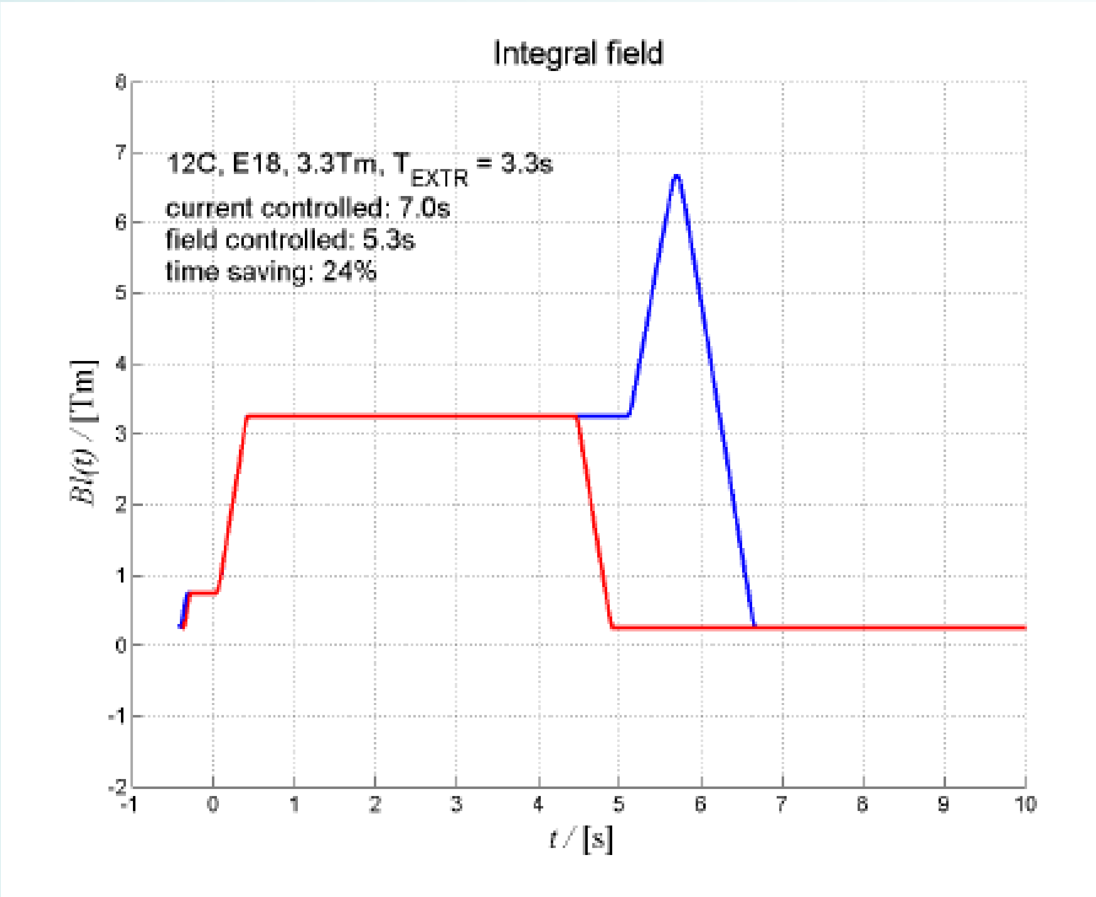
Magnetic field compensation at work (b) → good field region reached within a few ms.





System in use since end of 2011: Long-term stability (+/- 1mm) successfully demonstrated;
Time saving per synchrotron cycle: 700 ms

Magnetic Field Control in the Synchrotron

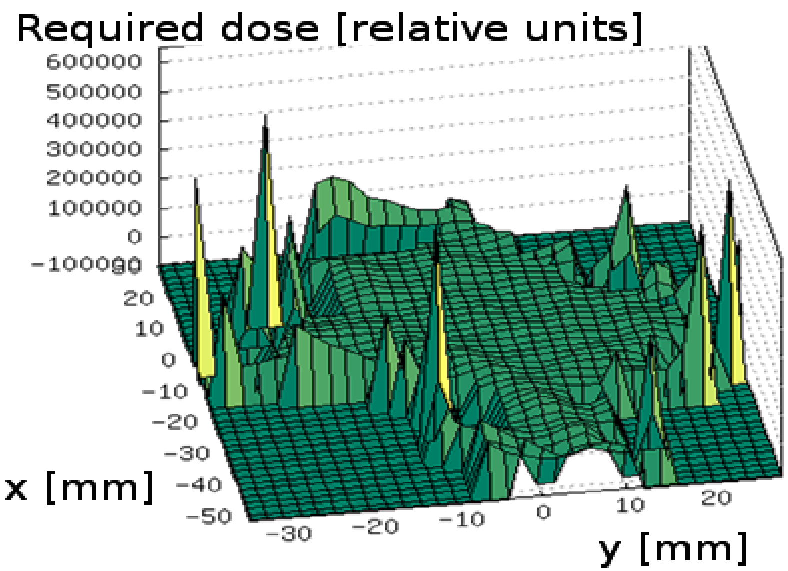


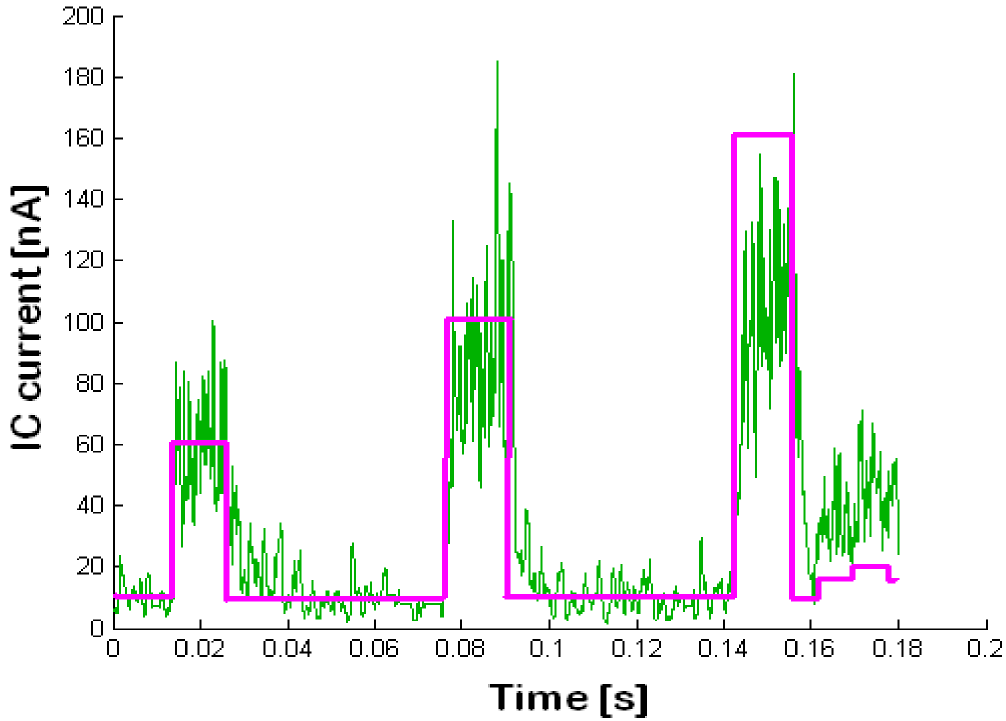
A similar system will be used for the four groups of quadrupoles to avoid "washing procedures" (see blue curve portion) needed because of hysteresis effects (including dipoles)

Possible time saving per synchrotron cycle: 950 ms (average)

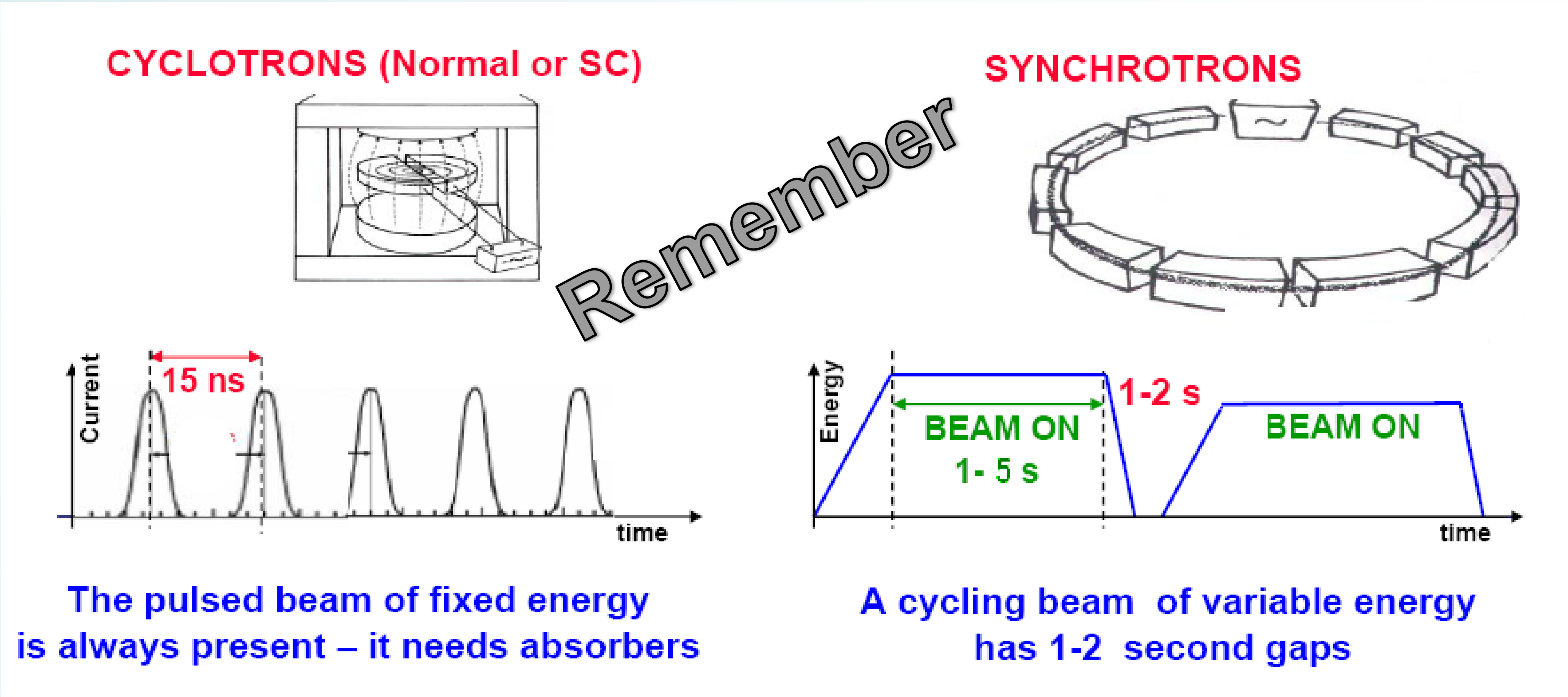
[available: end of 2012]

Dynamic Intensity Control



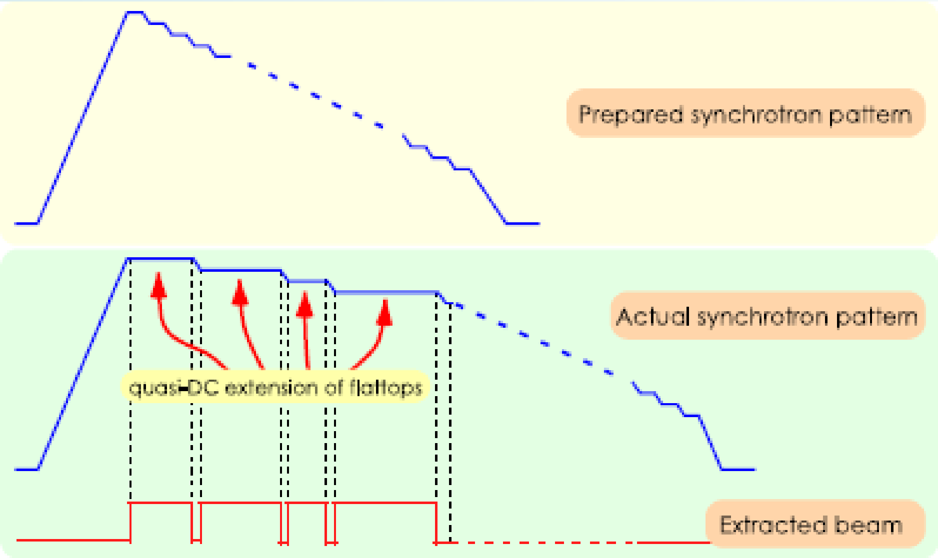


Comparison: Cyclotrons vs. Synchrotrons

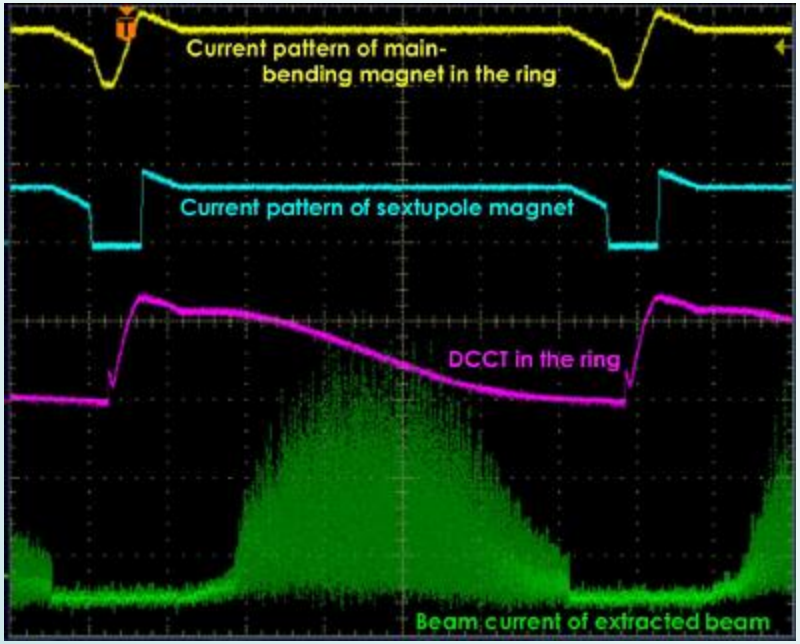


Cyclotrons	Synchrotrons
Persisting cw beam	Discontinuous “dc beam”
Fixed A/Q	Variable A/Q
Passive energy variation	Active energy variation

Multiple Energy Operation within one Cycle



Developments at HIMAC/NIRS; fixed pattern of energies, stepwise deaccelerating of the beam → Goal: Minimize refilling of the synchrotron to save time



Current experiments under way to demonstrate the feasibility

→ Substantial extension of the control system necessary to achieve the needed flexibility!

Outlook to latest developments and new accelerator and s.c. gantry concepts

Latest Development: High-field s.c. Cyclotron

Main magnet material: Nb3Sn
B-Field: 8 – 10 T
Type: Synchrocyclotron
E_{max}= 250 MeV

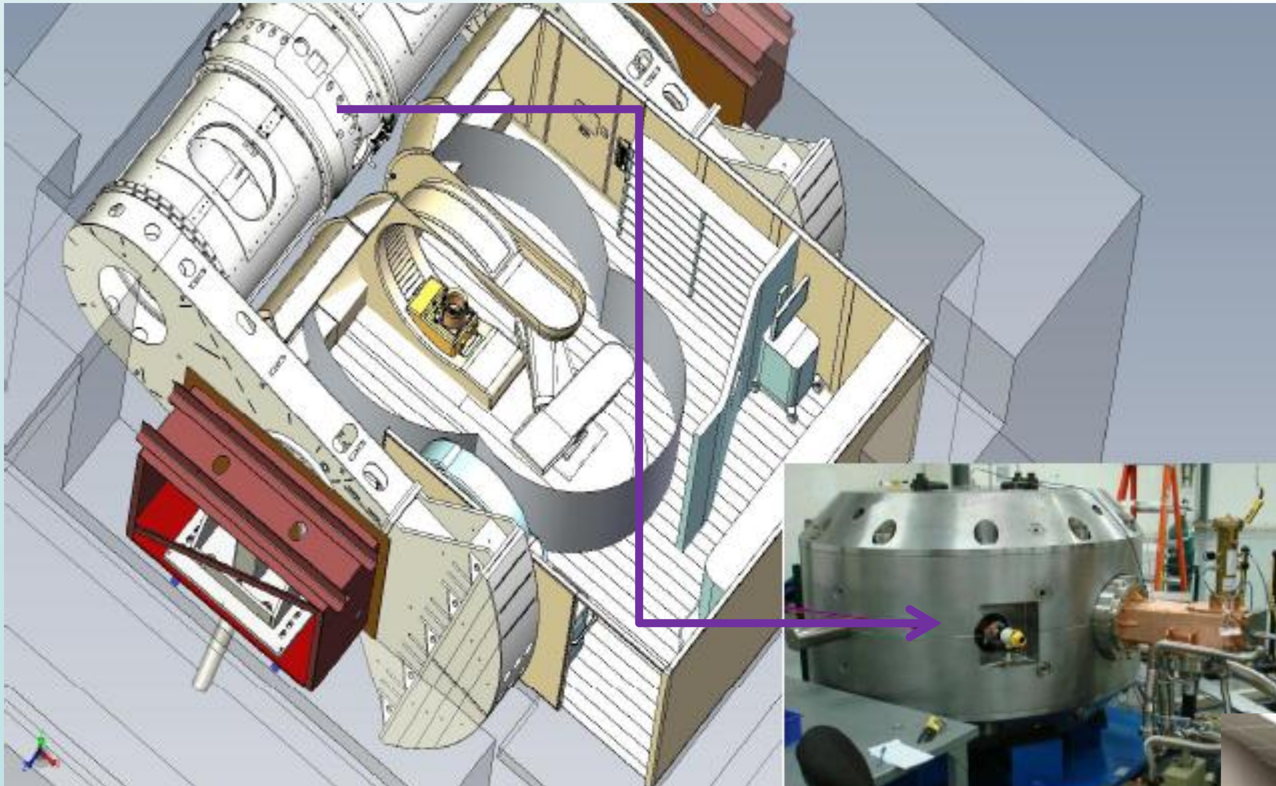
Energy selection in the near of patient → neutron background?

Only scattering technique used

With gantry structure → Single room solution possible!

Cost for such a facility: US $ 30 Million

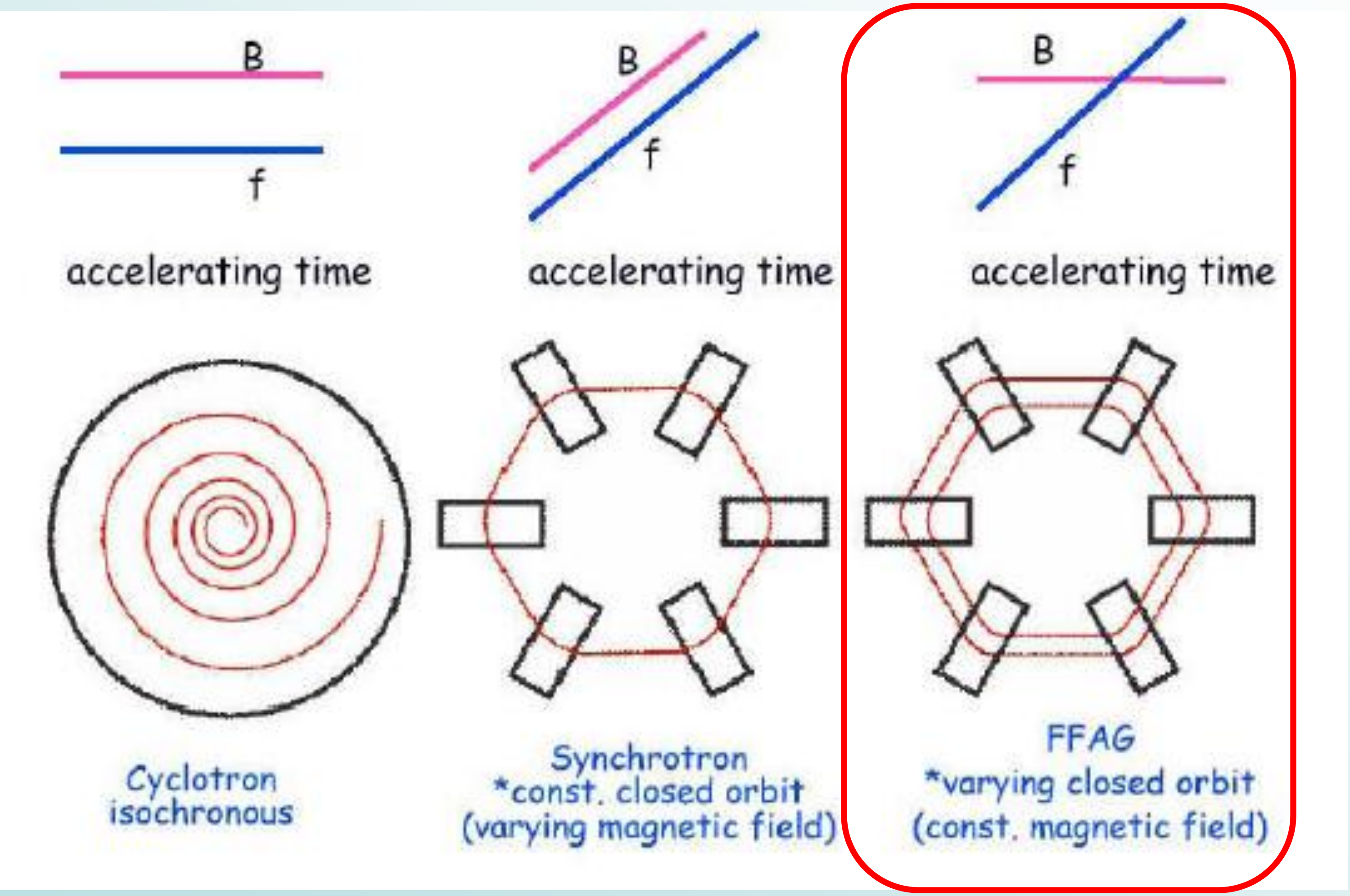
Latest Development: High-field s.c. Cyclotron



The MEVION S250 Proton Therapy System is USFDA 510(k) cleared and complies with MDD/CE requirements.

Installation at Washington University School of Medicine in St. Louis (2012)

New Accelerator Concepts - FFAGs



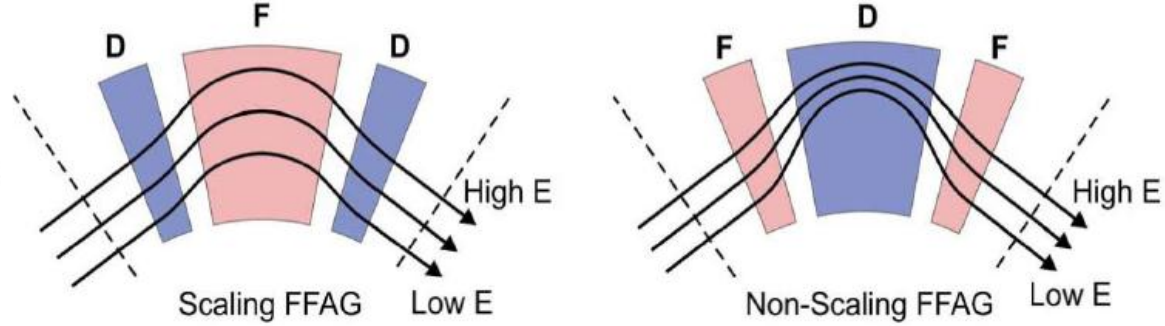
Idea:

Simplify control and operation, no synchro-nization necessary between B-field and RF

…but no savings in space!

New Accelerator Concepts - FFAGs

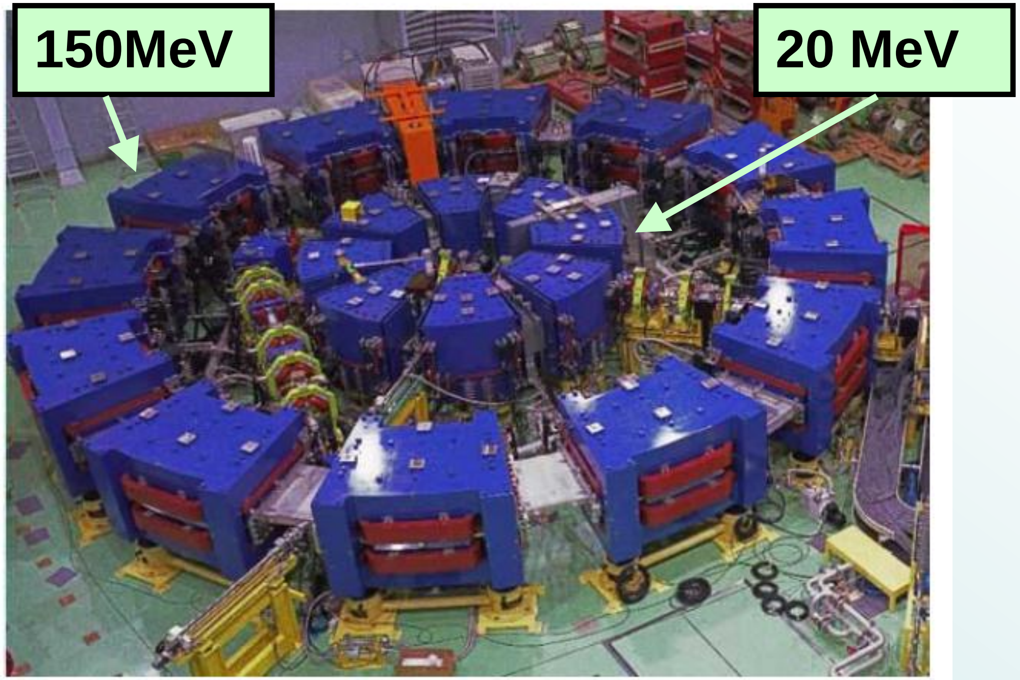
Fast acceleration



Compact footprint

Magnet aperture must accept large momentum range

KEK



Variable energy extraction?

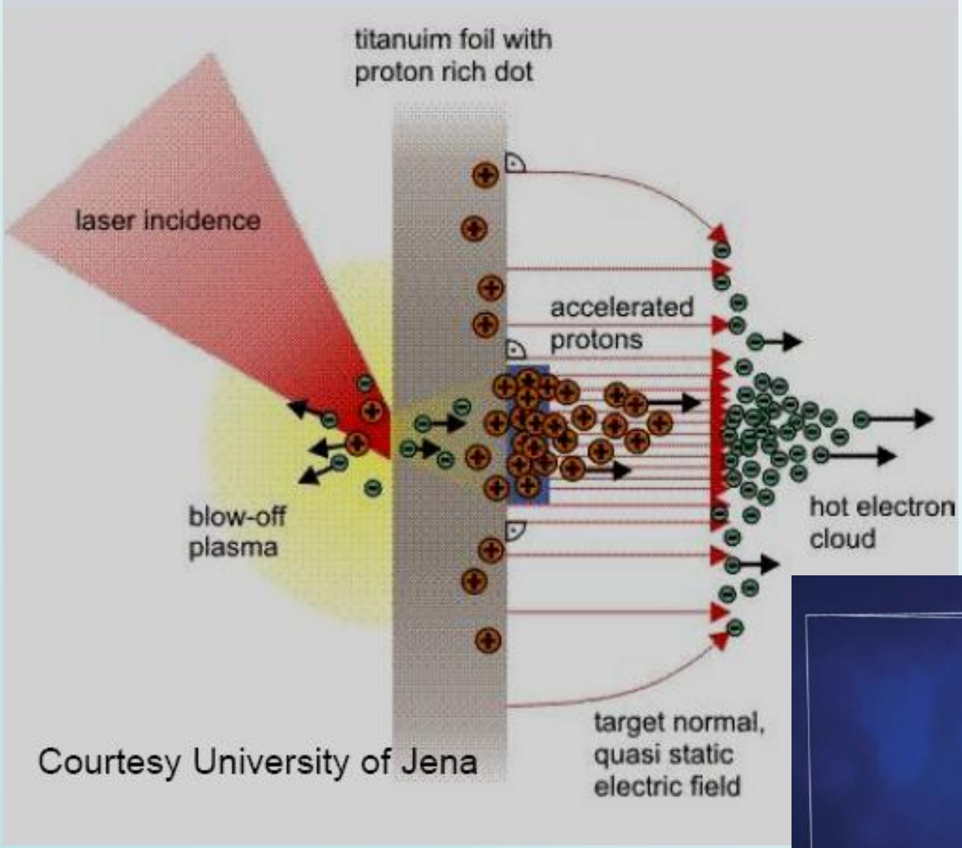
Possible very high rep rate

Much world wide interest.

Demo machines in early operation, construction & design

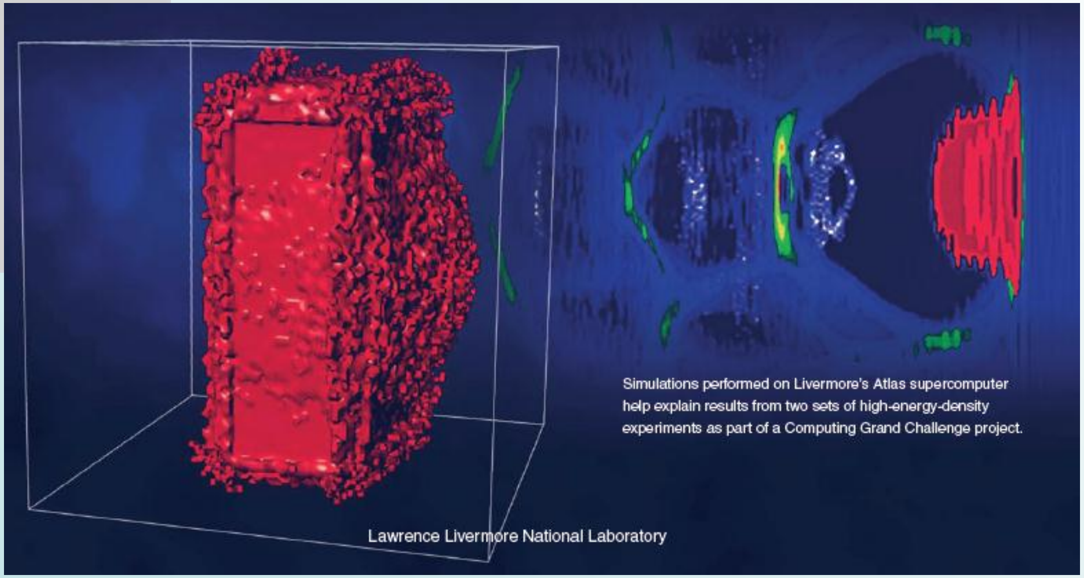
Further projects: EMMA (GB), RACCAM (F) and others

New Concepts – Laser Plasma Accelerators

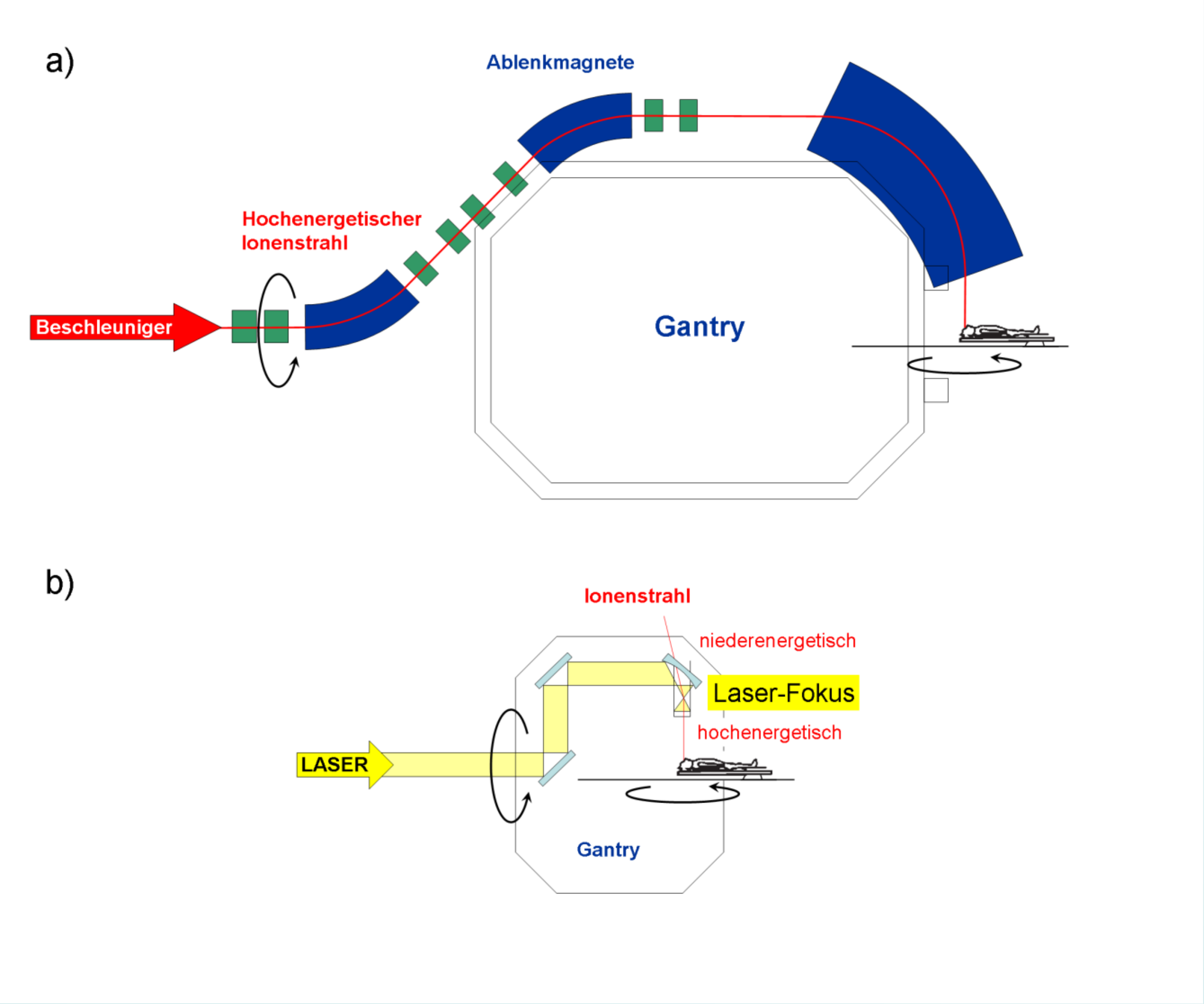


- Laser: 50 fs, 50 J (Petawatt!)
- I = 10^{21} W/cm^2
- 10^{11} protons up to 300 MeV should be possible (67 MeV reached end of 2009)

- Repetition rate?
- Intensity control?



New Concepts – Laser Plasma Acelerators



Serious proposal?

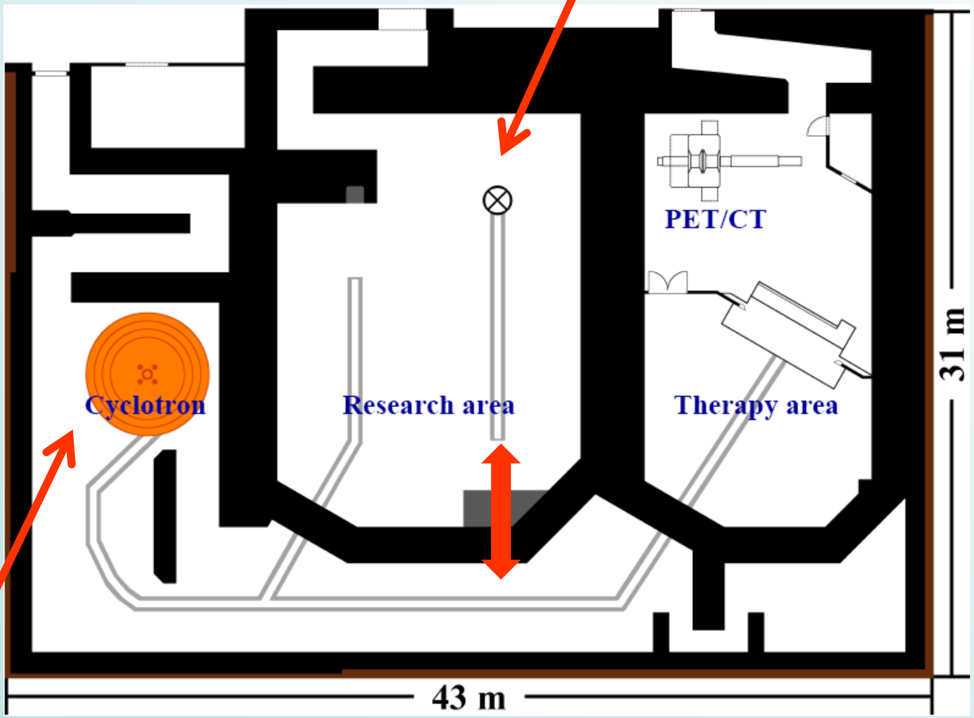
Mono-energetic beams possible in such a configuration?

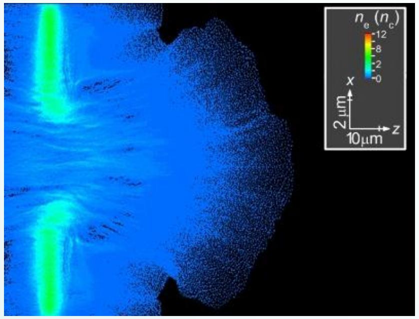
Radiation background?

Oncoray Activities in Dresden

150 TW Ti:Saphir Laser Draco (Dresden laser acceleration source) – extension to 500 TW under way, Petawatt regime in planning

New building under construction





Later connection foreseen

Courtesy of Stephan Helmbrecht, Oncoray, Dresden

New Concepts – Dielectric Wall Accelerators

G. Caporaso et al, LLNL

250 MeV protons in 2.5 m?

Pulse-to-pulse energy & intensity variation

"Hoping to build a full-scale prototype soon"

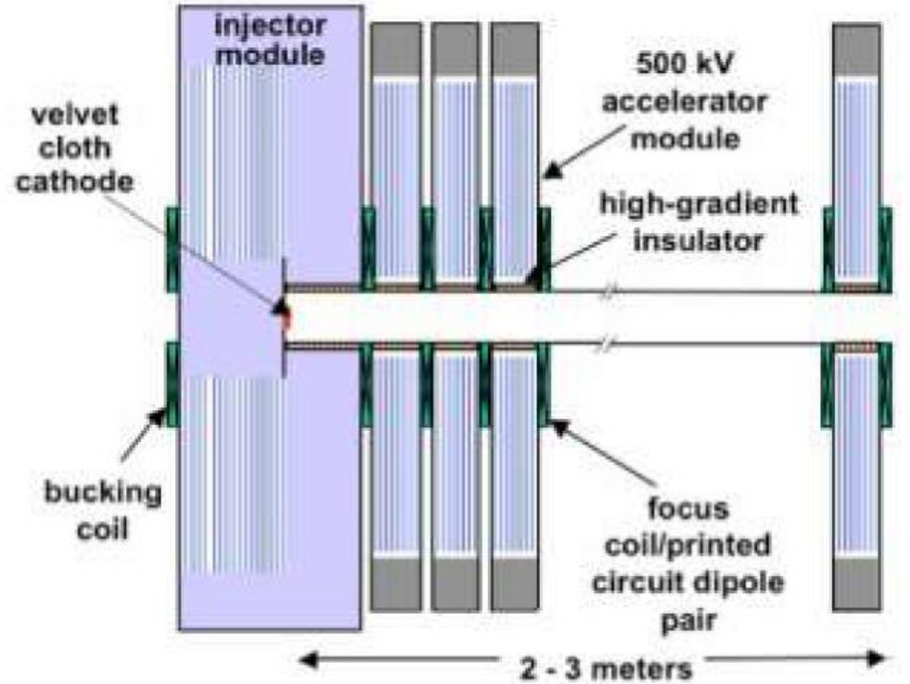
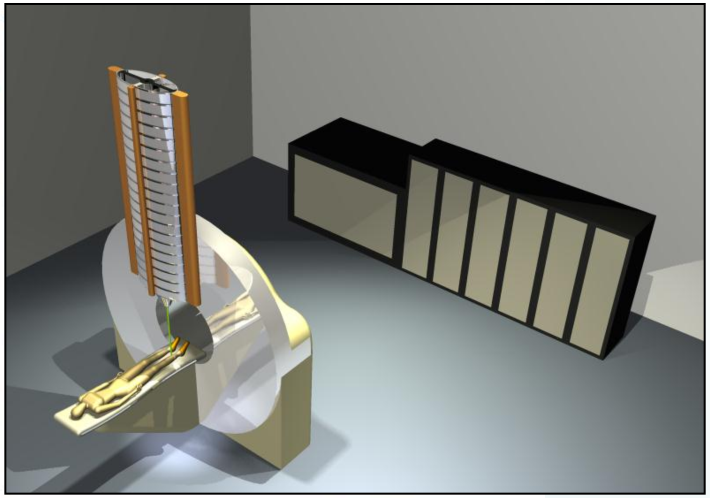
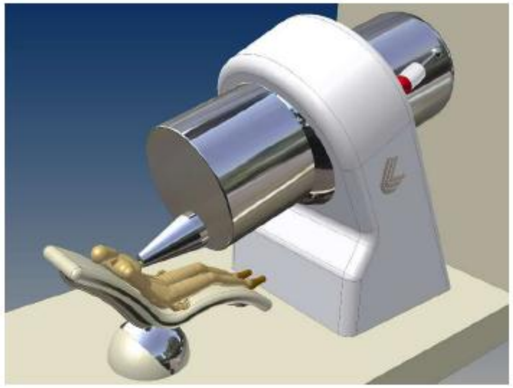
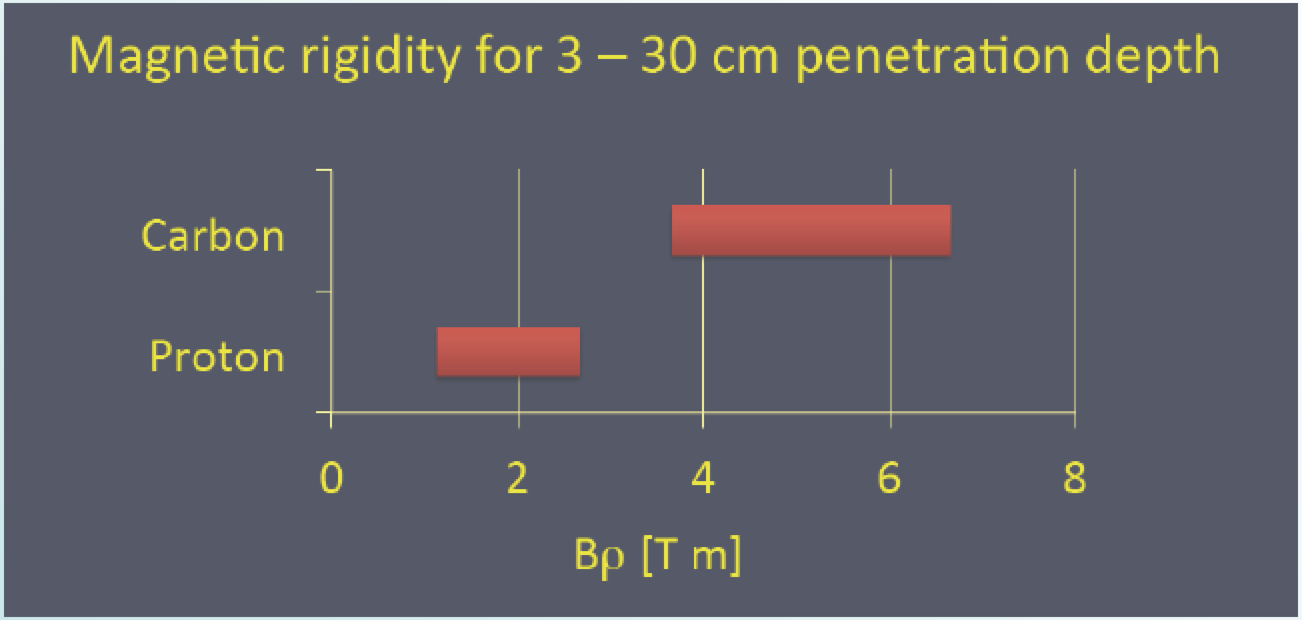


Figure 1: Dielectric wall induction accelerator configuration.



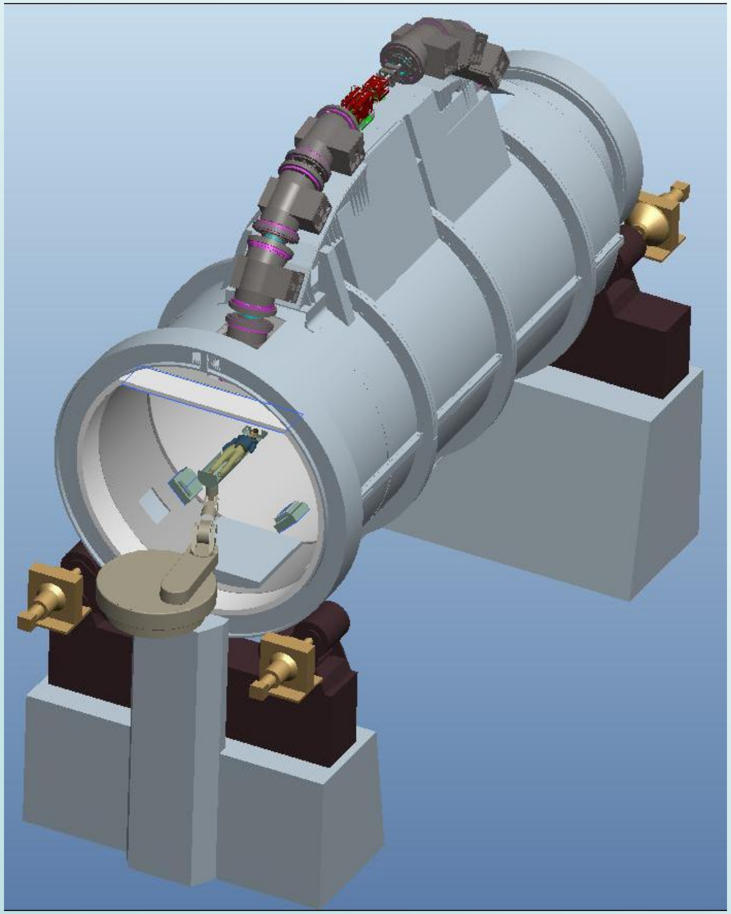


Design of Superconducting Gantries

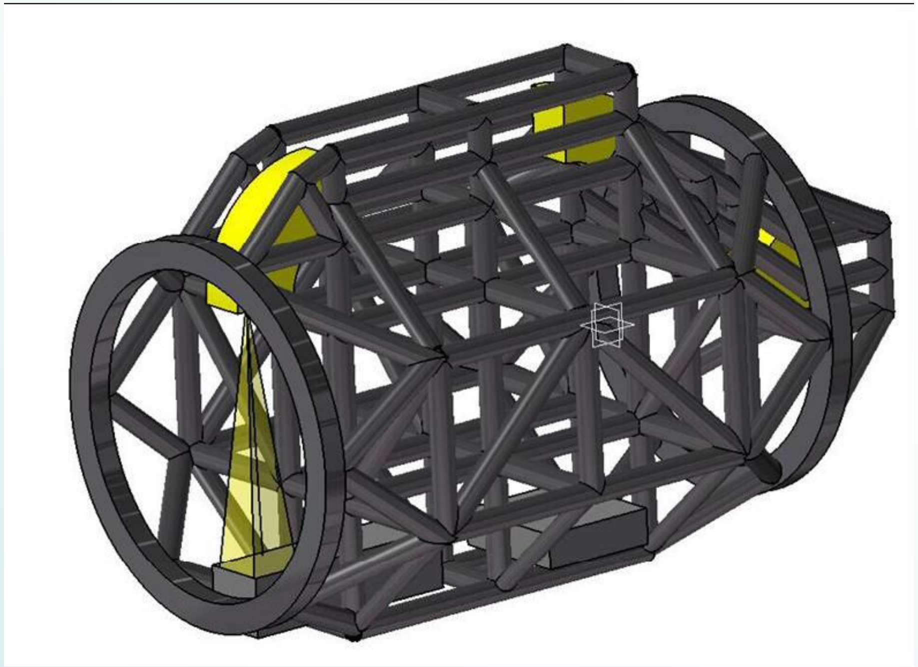


Carbon, 430 MeV/u (30 cm penetration depth)
Magnetic rigidity $B*\rho = 6.6$ T*m
Present (normal) dipole: $B = 1.8$ T, $\rho = 3.67$ m
If superconducting dipole: $B = 3.3$ T, $\rho = 2$ m

Design of Superconducting Gantries

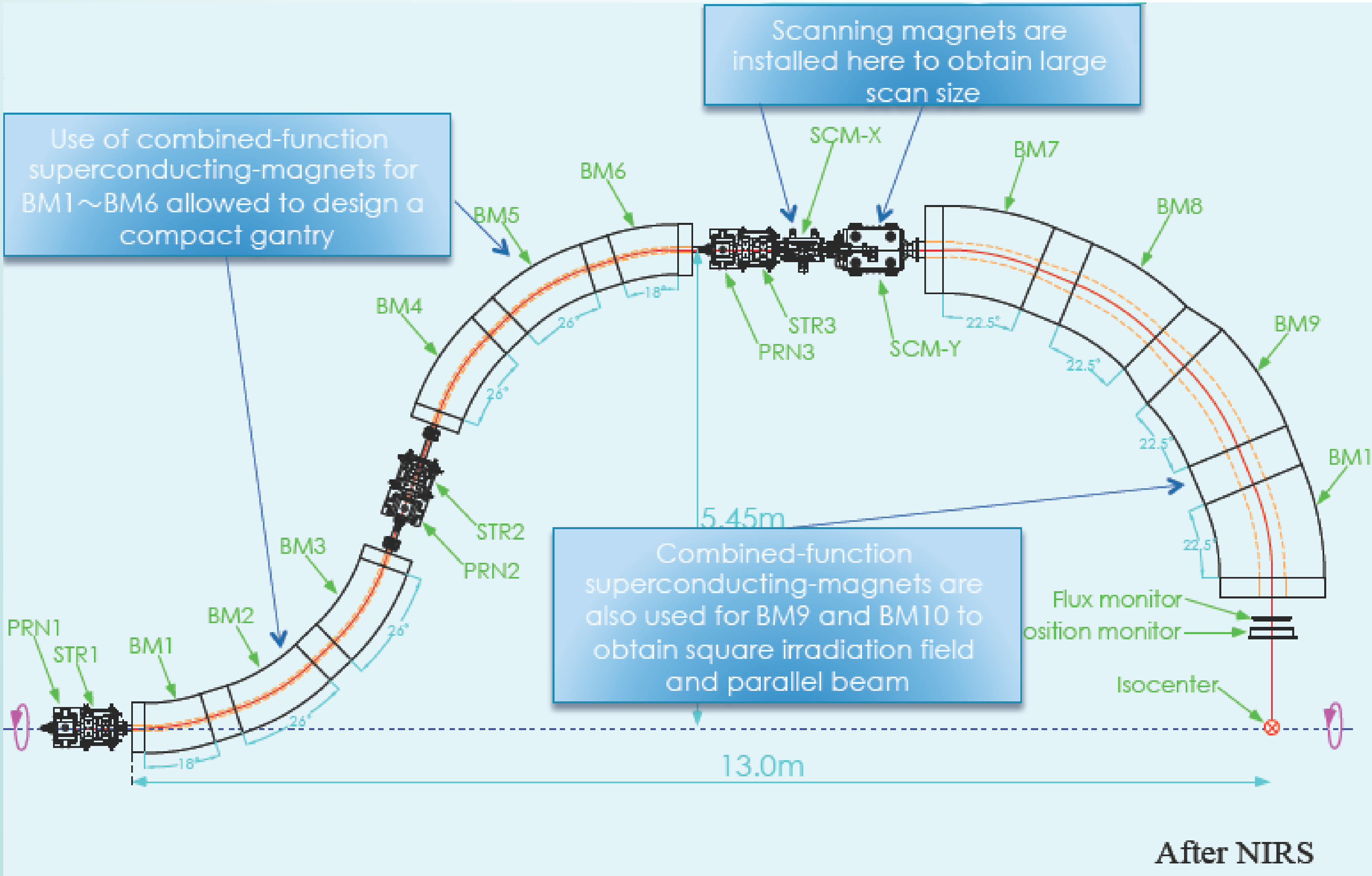


NIRS / HIMAC (J): 200 to,
Radius: 5.5 m, L: 13m, 3 T

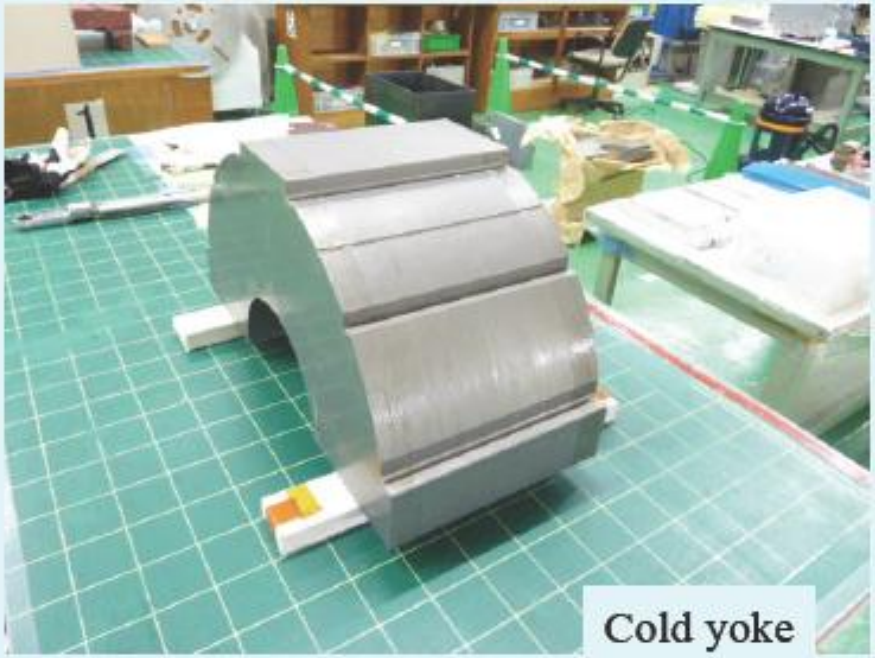


CEA (F) and IBA (B)): 210 to,
Radius: 4m, Length: 13m,
B_{max}(90°-Dipole): 5.39 T (NbTi)
Use of cryocoolers foreseen
→ Long recovery time in case of quenches!

NIRS Version of a s.c. Gantry



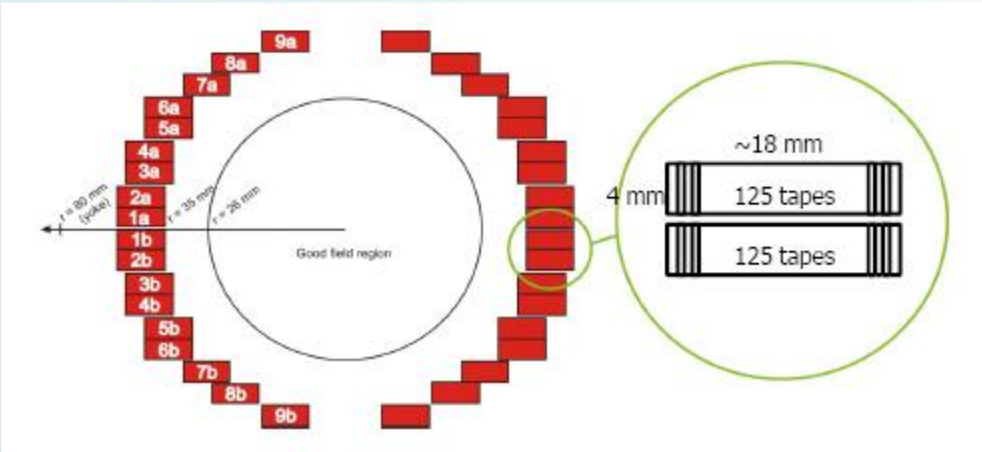
LTS based Magnet Development at NIRS

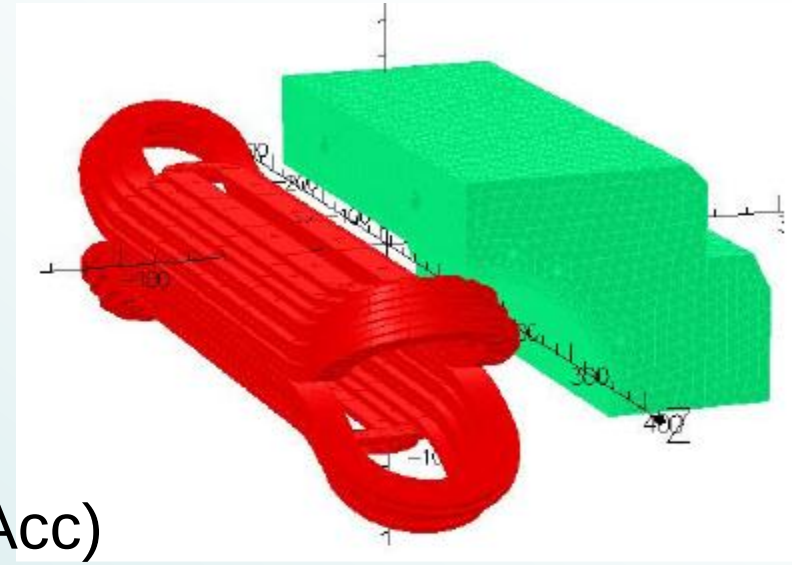


Two superconducting magnets are under construction, and will be completed by the end of March 2012

After NIRS

HTS based Magnets for s.c. Gantries





Small prototype by Danfysik (InnovAcc)
Straight magnet with HTS wires (YBCO)
B = 3.6 T at 15 – 18 K
Homogeneity dB/B < 10^{-3} (r = 25 mm)
Use of cryocoolers, very smooth behaviour in case of quenches in contrast to LTS magnets

Acknowledgement

Thanks to all people providing me their material: HIT (T. Haberer, R. Cee, M. Galonska, S. Scheloske, E. Feldmeier, J. Naumann, C. Schömers, K. Höppner et al.), GSI (U. Weinrich, H. Eickhoff, B. Schlitt, P. Forck, M. Schwickert, B. Voss et al.), CNAO (S. Rossi, E. Bressi, M. Pullia et al.), PSI (M. Schippers, E. Pedroni et al.), MGH (J. Flanz at al.), NIRS/HIMAC (K. Noda, Y. Iwata et al.), MedAustron (A. Koschik et al.), CEA (F. Kircher et al.), …

… and also the companies: Siemens PT, VARIAN Medical, IBA, Mitsubishi, Hitachi, Danfysik, SigmaPhi and some more not listed here.

Sources of Information

- http://ptcog.web.psi.ch/ (PTCOG home page)
- http://www.jacow.org/ (JACoW home page)
- https://indico.cern.ch/conferenceDisplay.py?confId=174714 (PARTNER workshop, CERN, March 2012)
- http://www.klinikum.uni-heidelberg.de/index.php?id=113005&L=1 (HIT home page)

Thank you for your attention !

(Intensity modulated raster scan, ^{12}C at 430 MeV/u), recorded on a film