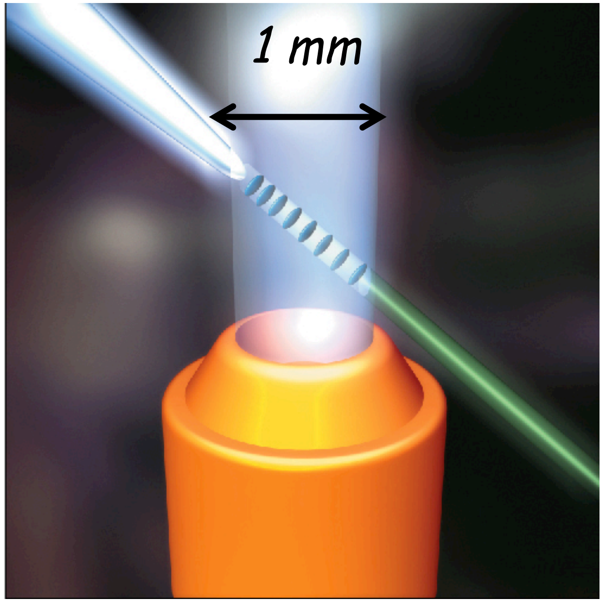
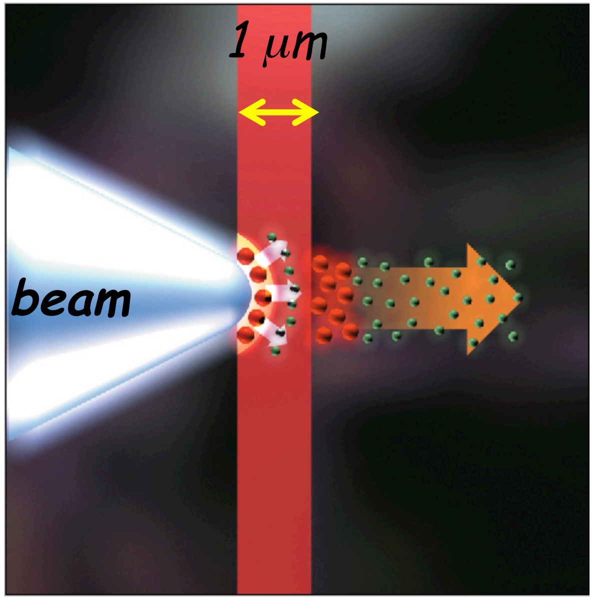
laboratoire d'optique appliquée

Palaiseau - FRANCE

Medical Applications with Laser Plasma Accelerators

Victor Malka





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EUCARD, first annual meeting, RAL, UK, April 13-16 (2010)

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Summary

Part 1 : Short review of laser produced electron/ proton beams

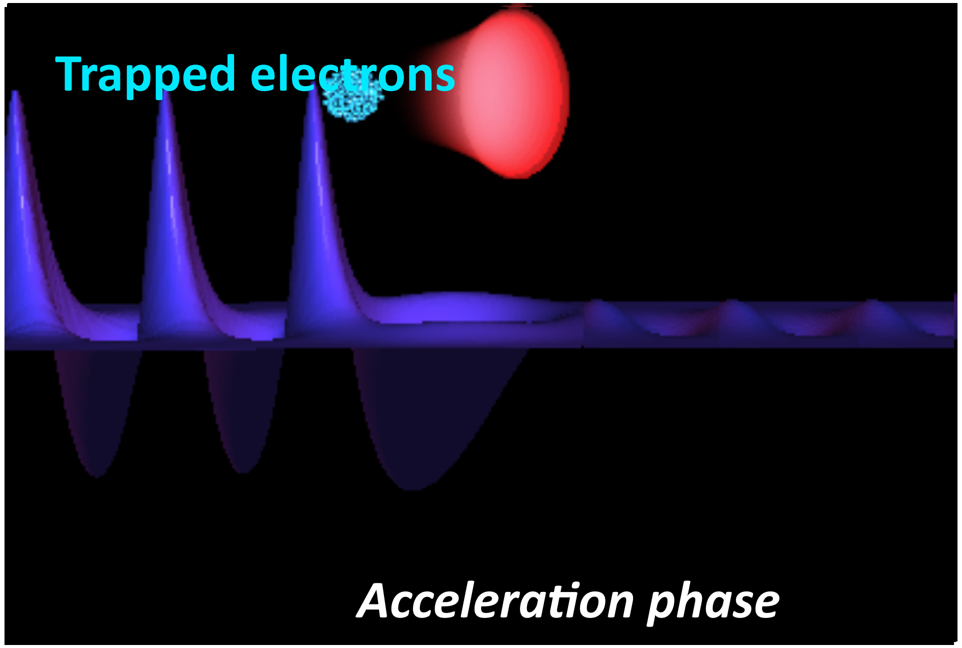
Part 2 : On the use of electron beam for oncology

Part 3 : On the use of proton beam for oncology

Part 4 :Conclusion and perspectives

Controlling the injection

A second laser beam is used to heat electrons

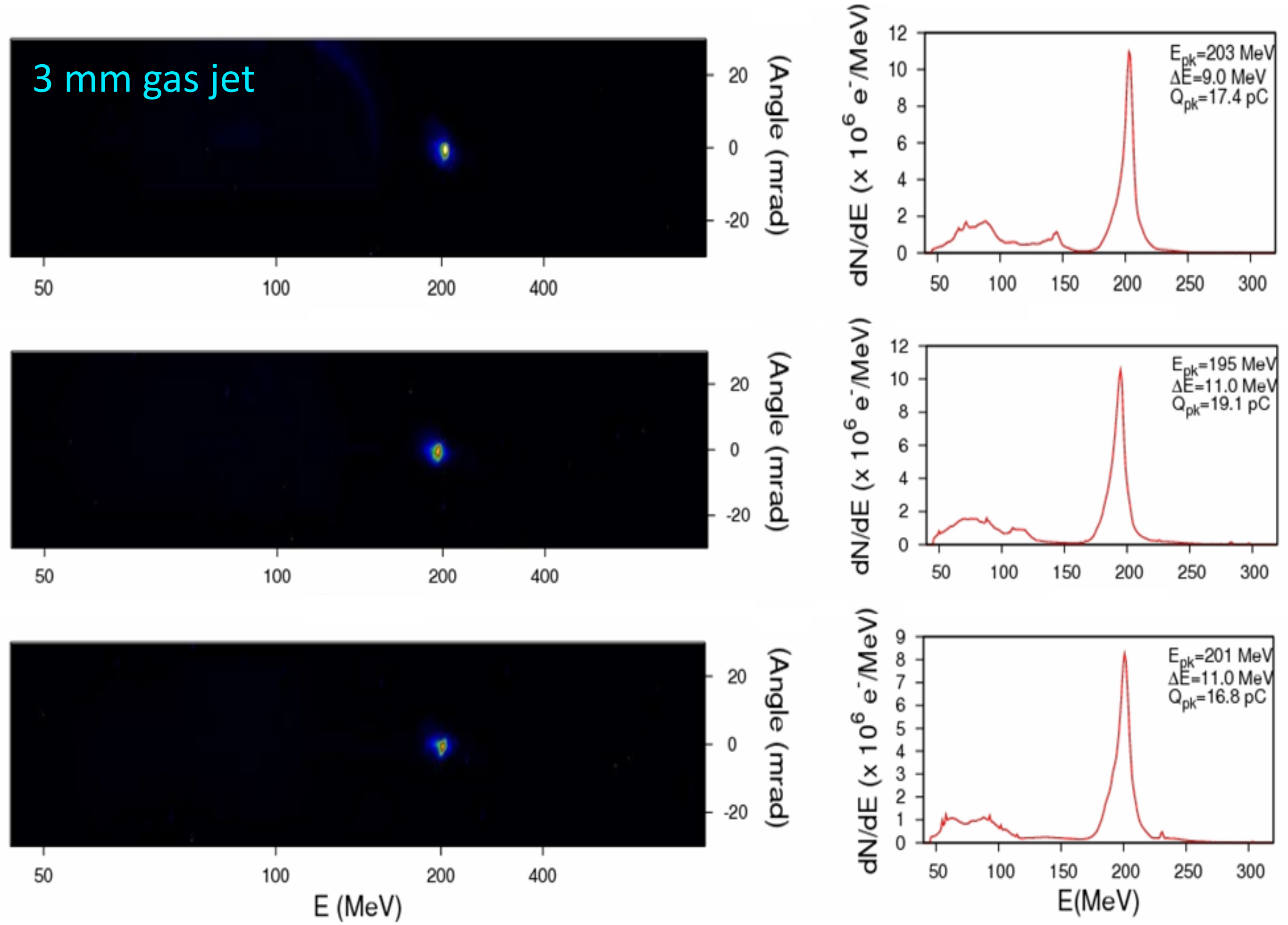


Ponderomotive force of beatwave: $F_p \sim 2a_0a_1/\lambda_0$ (a_0 et a_1 can be "weak")

Boost electrons locally and injects them INJECTION IS LOCAL and IN FIRST BUCKET

E. Esarey *et al.*, PRL **79**, 2682 (1997), G. Fubiani *et al.*, PRE **70**, 016402 (2004), H. Kotaki *et al.*, PoP **11** 3296 (2004), J. Faure *et al.*, Nature (2006)

Stable monoenergetic beams @200 MeV



Statistics (30 shots):

E = 206 +/- 11 MeV

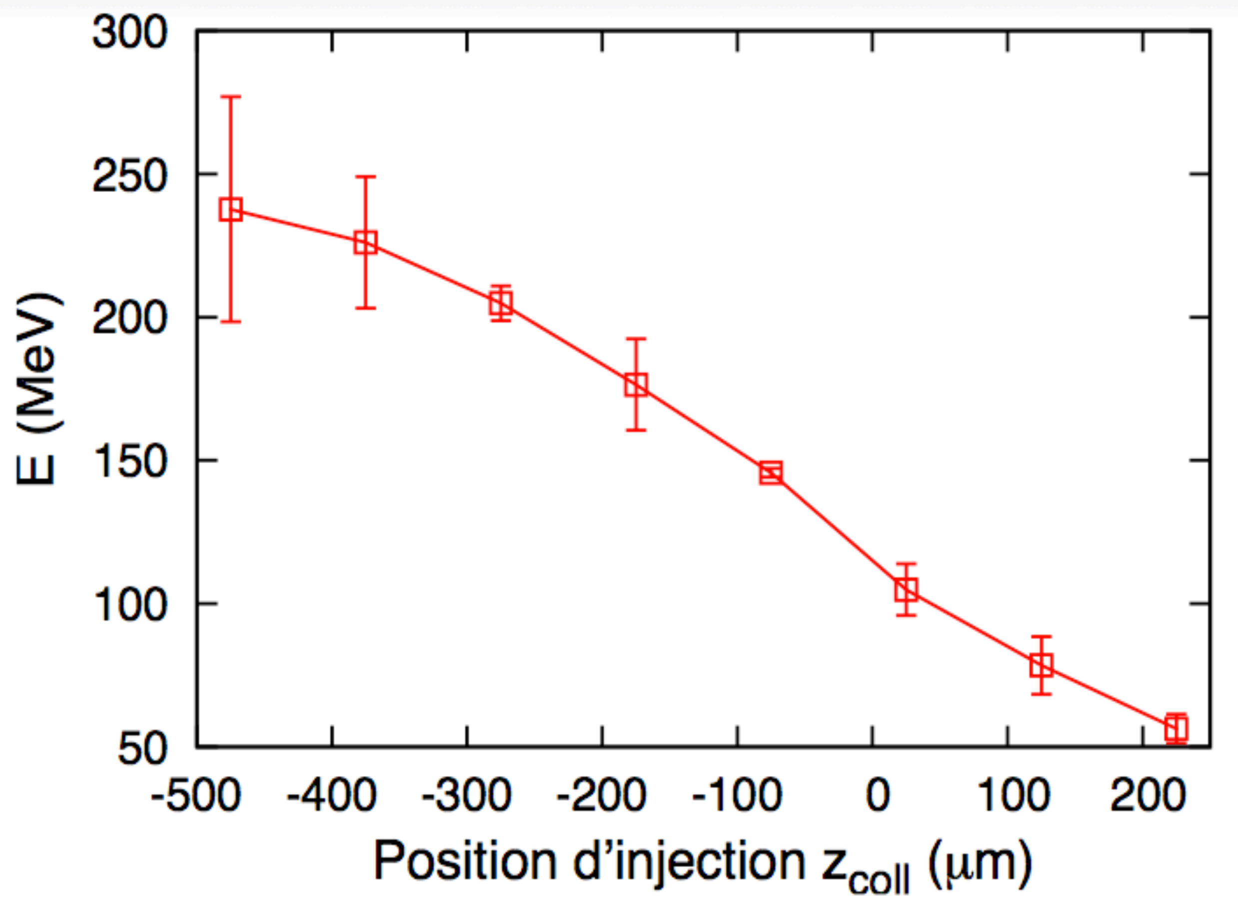
Qpk = 16.5+/- 4.7 pC

δE = 14 +/- 3 MeV

δE/E = 6%

Very little electrons at low energy, δE/E=5% limited by spectrometer

Tunable energy of the e-beam



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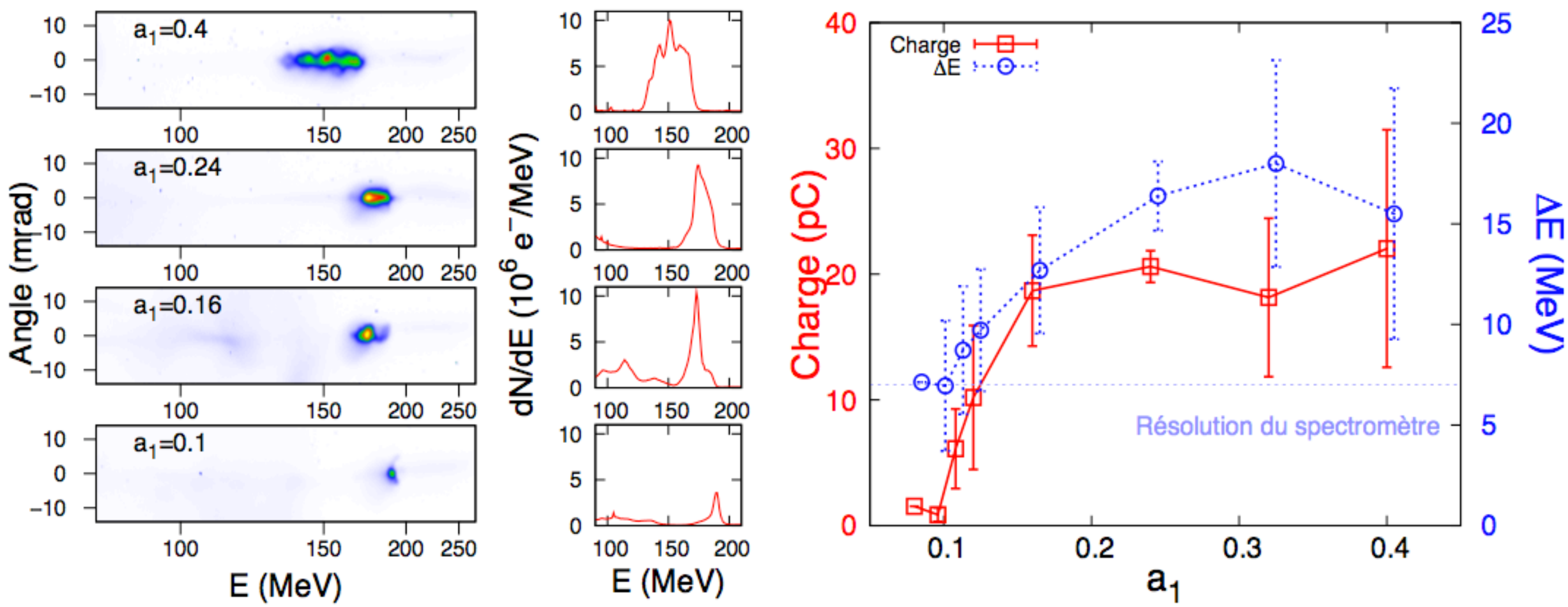
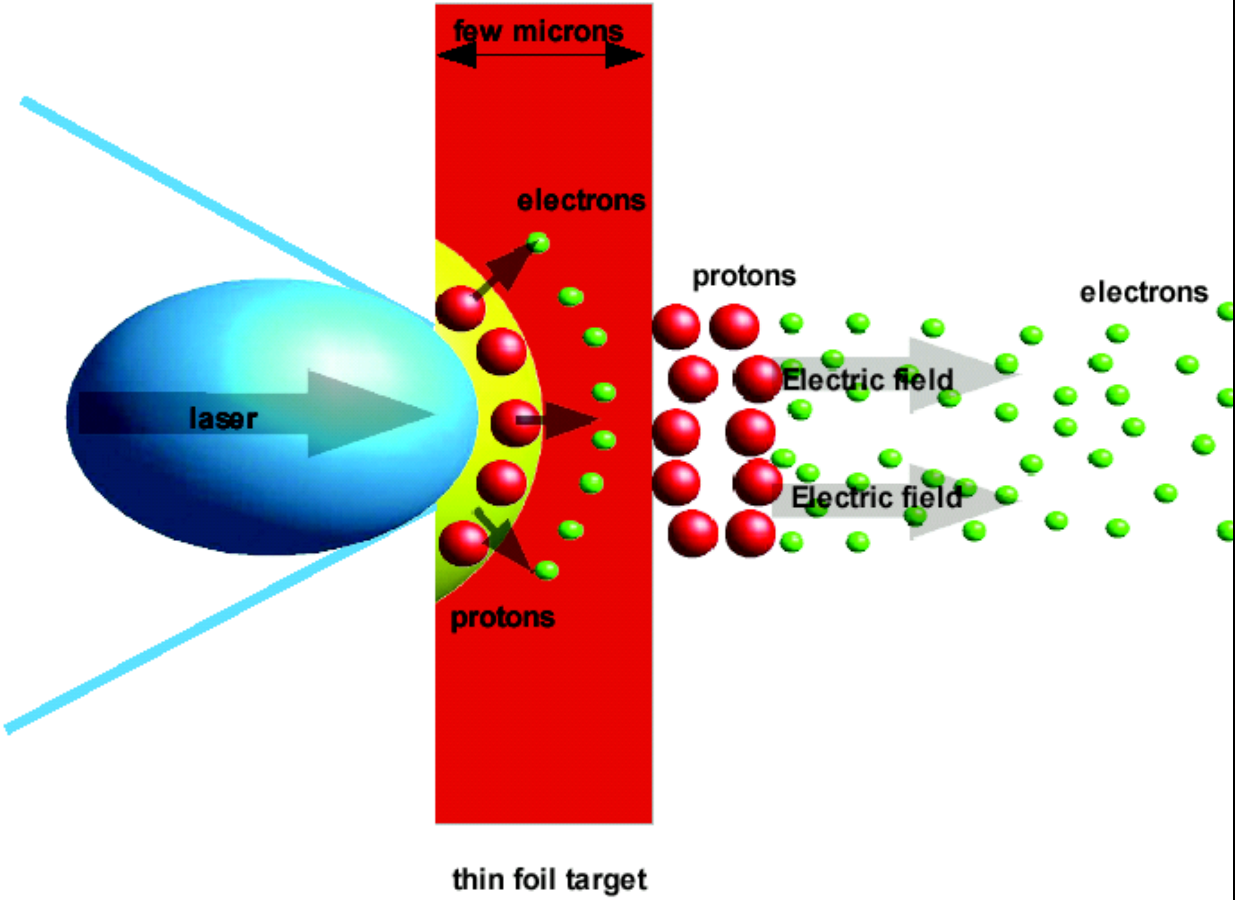
Tuning the charge and the energy spread with injection beam intensity a_1

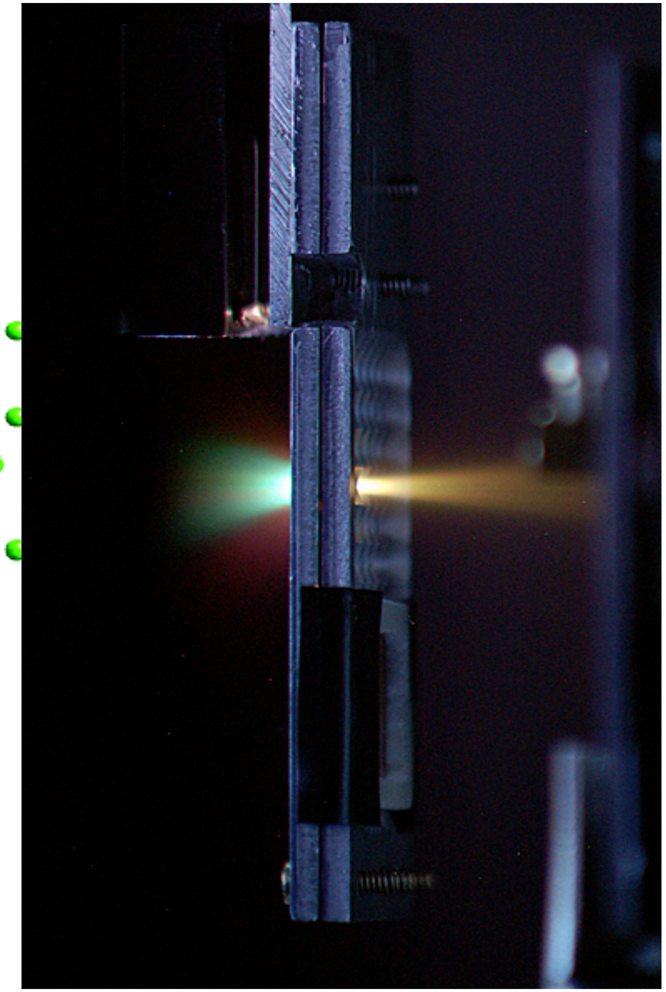


Charge from 60 pC to 5 pC, ΔE from 20 to 5 MeV

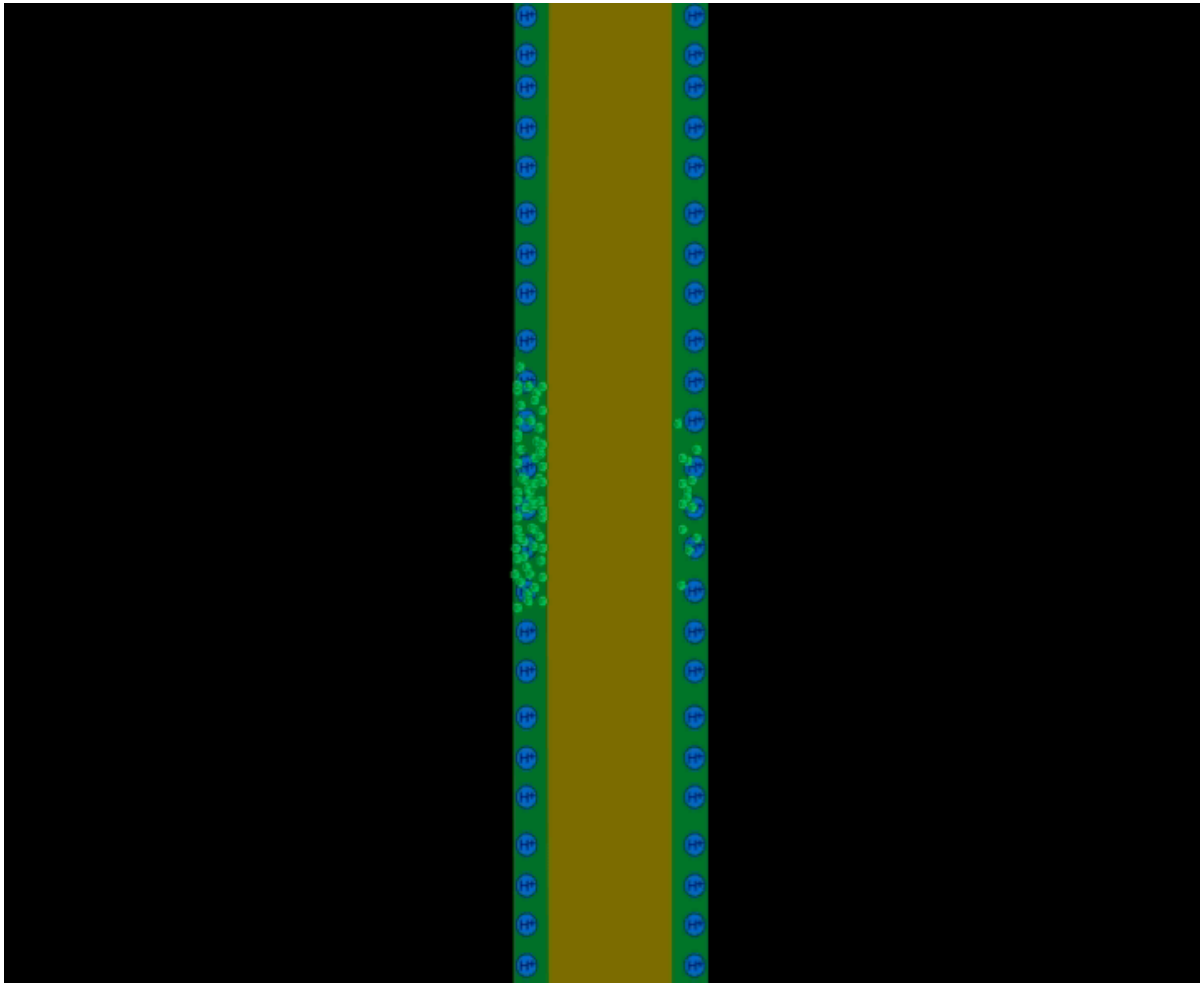
C. Rechatin et al., Phys. Rev. Lett. 2009

Protons acceleration with lasers : Static electric fields



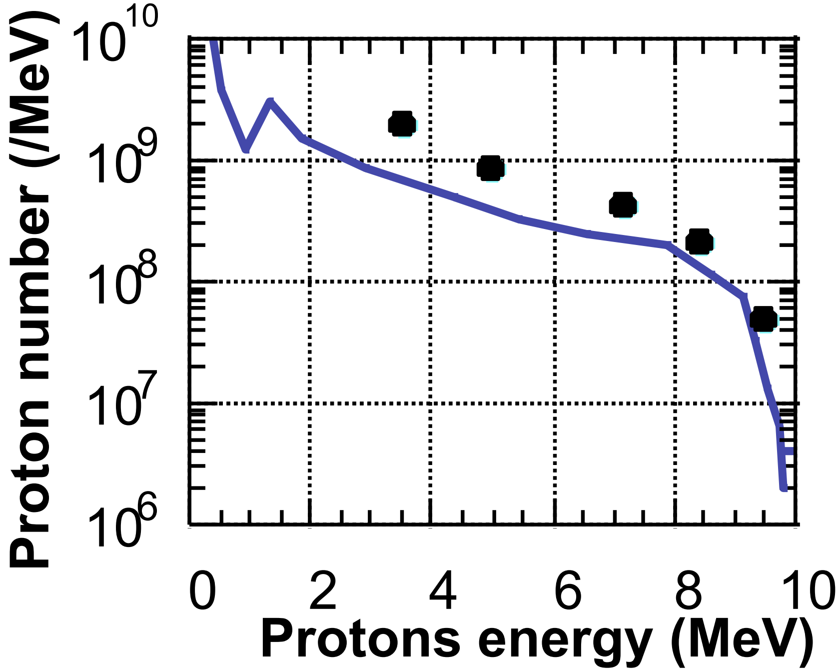


Protons are accelerated from both side :



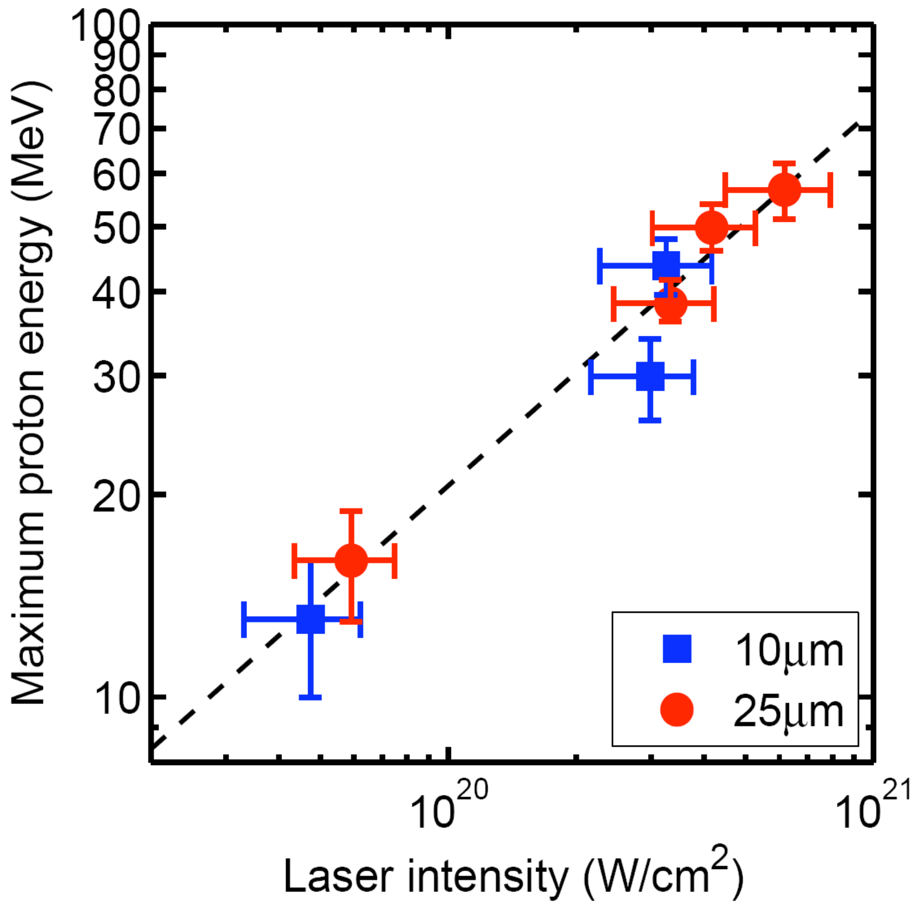
Courtesy of E. D'Humières

Experimental results : Maxwellian spectra



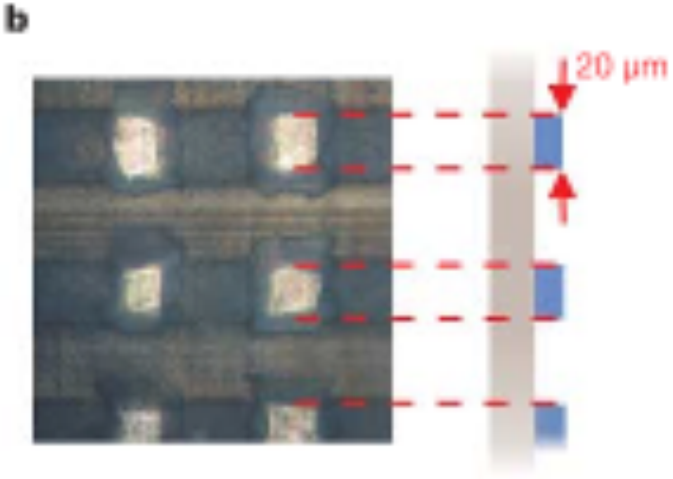
10 Hz laser at LOA

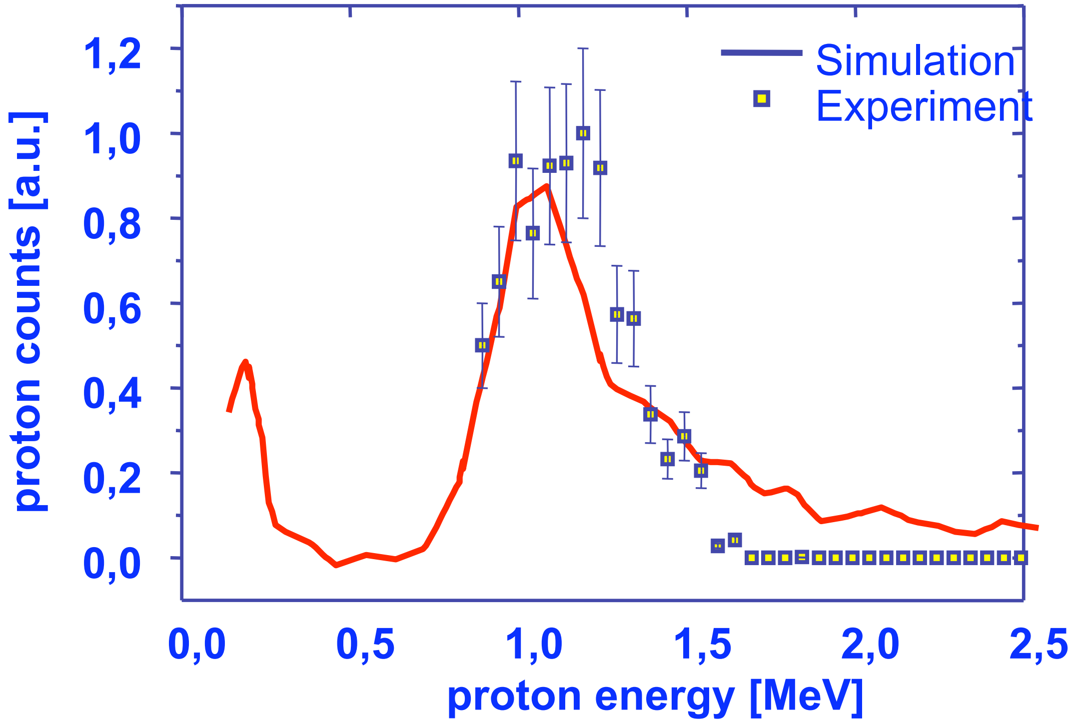
V. Malka *et al.*, Appl. Phys. Lett. 83, 15 (2003), Med. Phys. 31, 6 (2004)



Robson *et al.*, Nature Physics 3 (2007)

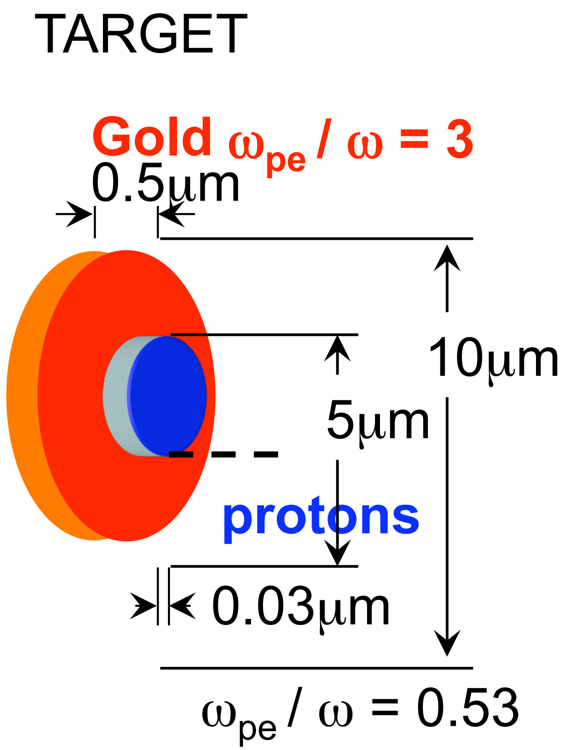
Experimental results : quasi mono energetic spectra

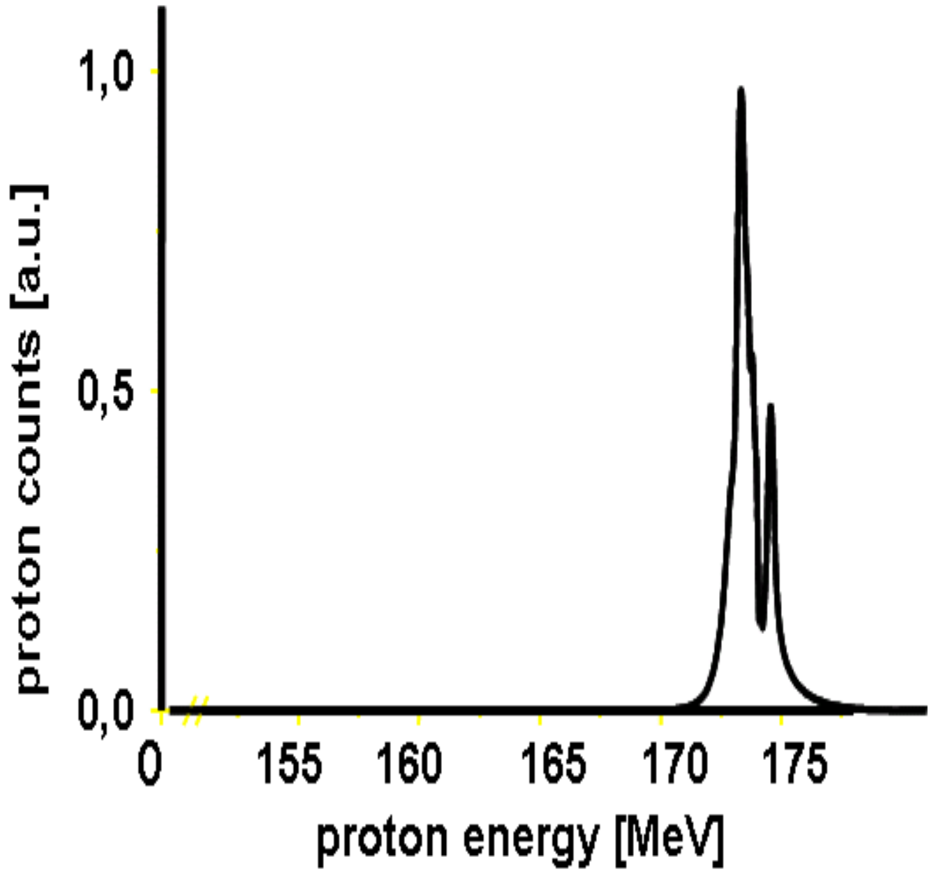




Schwoerer, H. et al., Nature, 439 (2006)

3D Simulations : quasi mono energetic Spectra @ 170 MeW with PW laser





Schwoerer, H. et al., Nature, 439 (2006)

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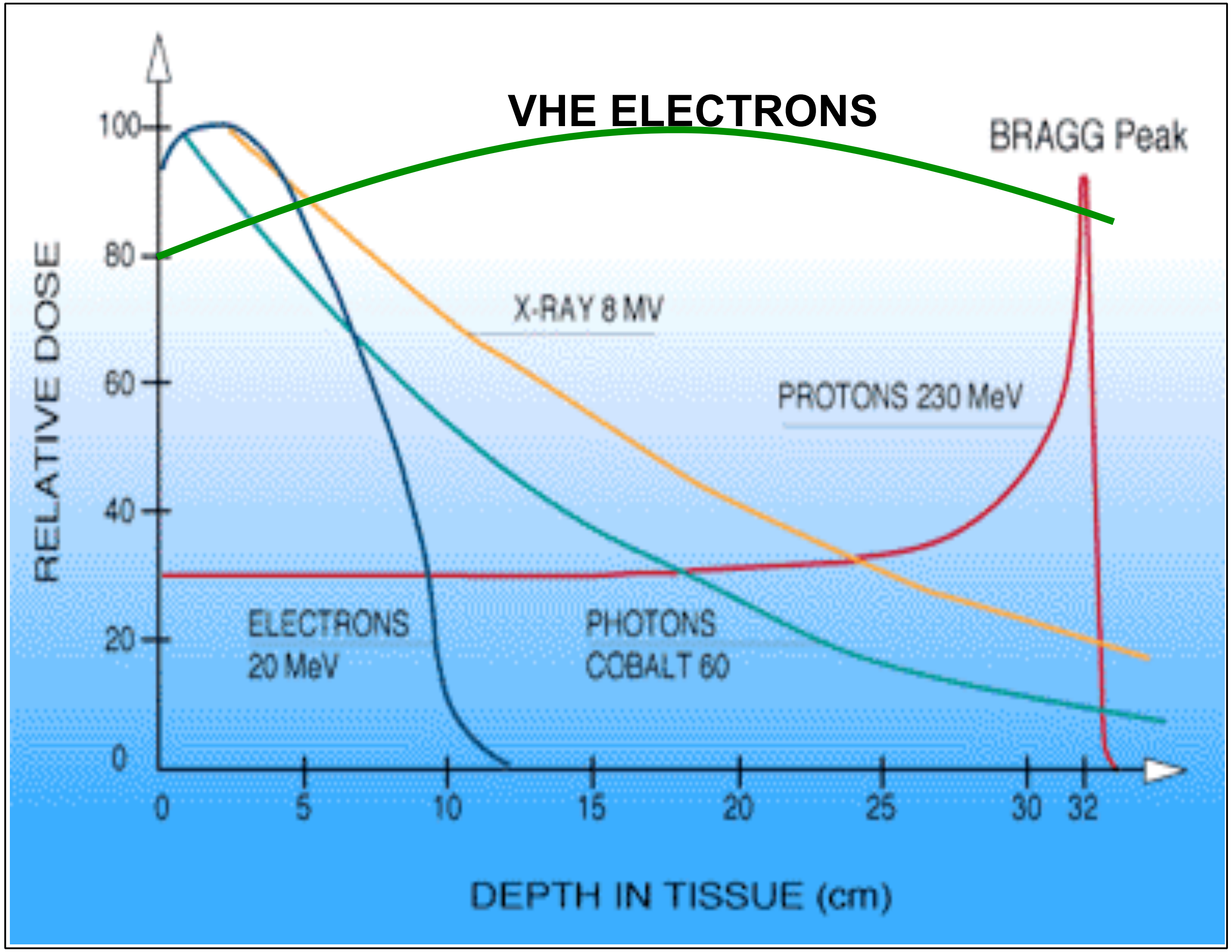
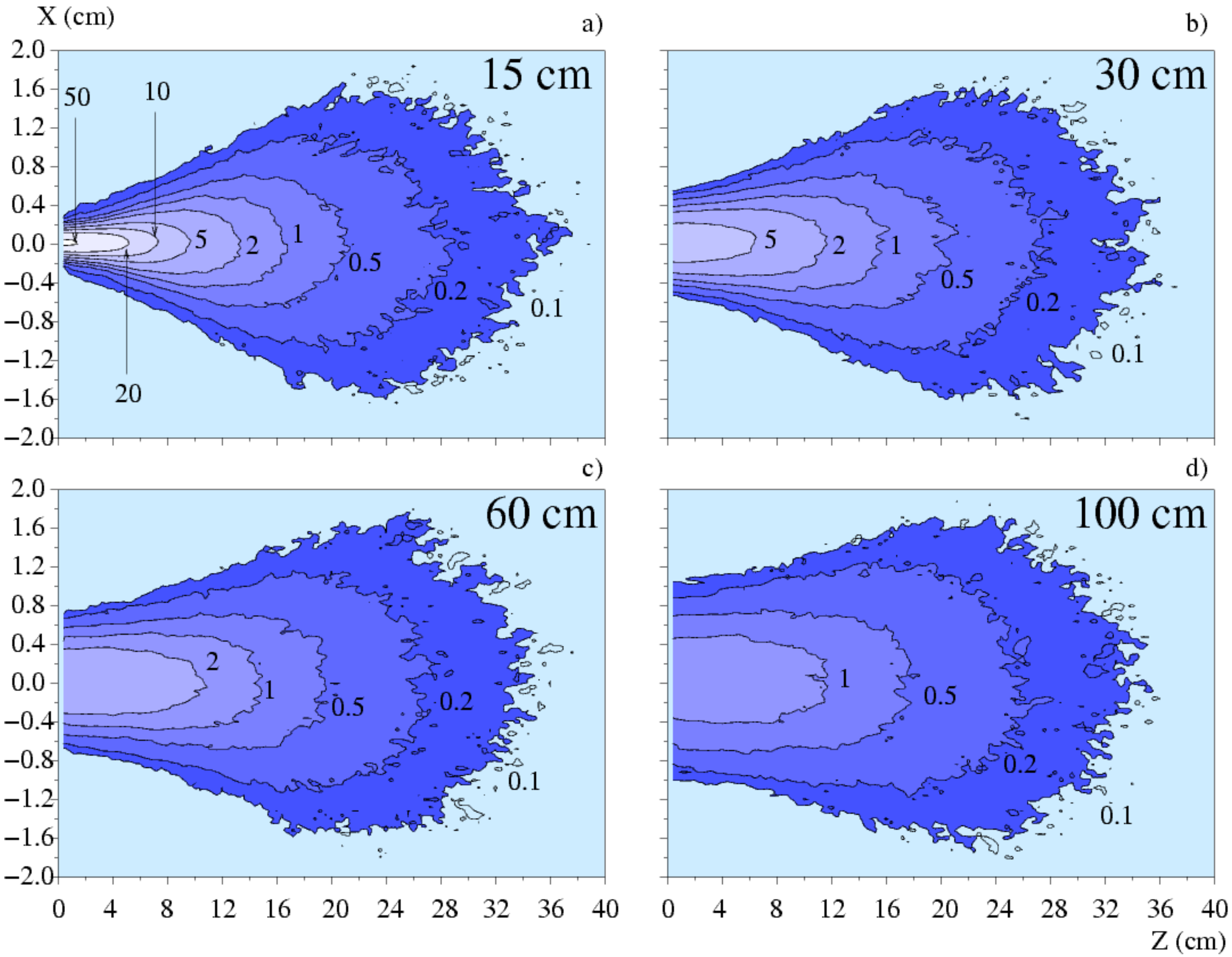
Dose deposition : Photon X, electrons VHE (very high energy) electrons, & ions



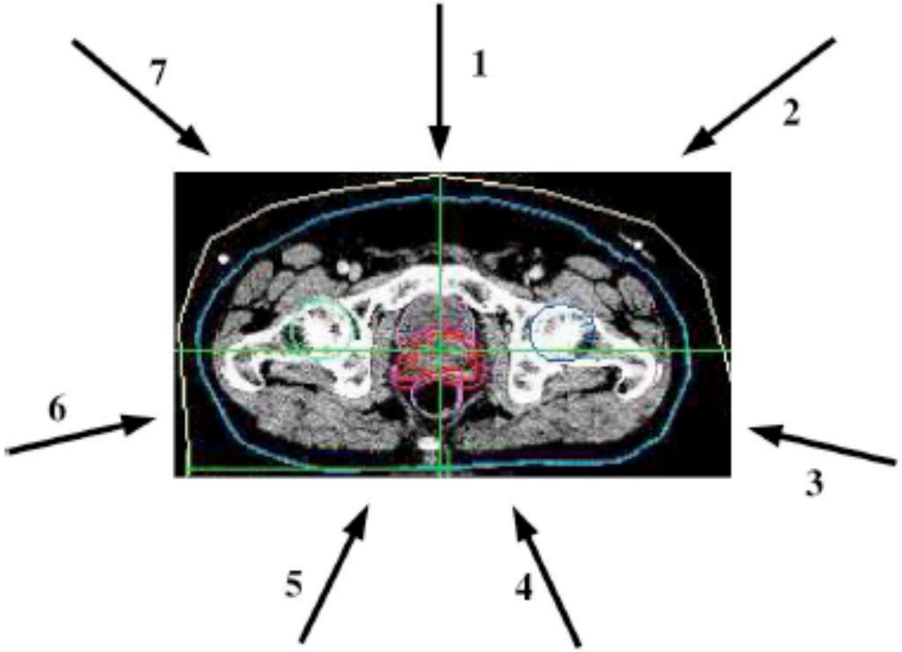
EUCARD, first annual meeting, RAL, UK, April 13-16 (2010)

Dose deposition profile in water

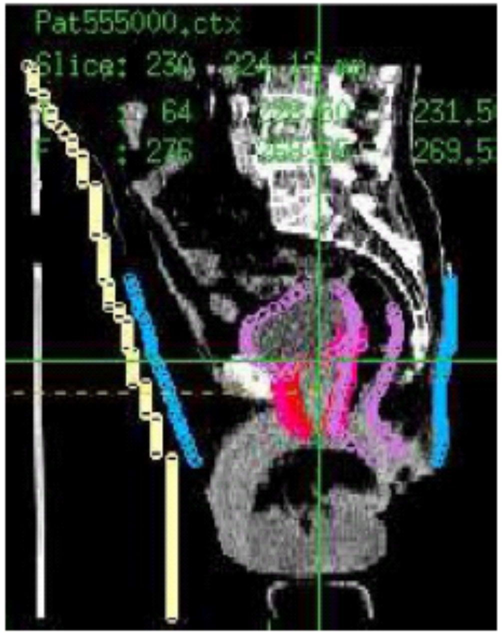


Glinec et al., Med. Phys. 33, 1 (2006)

Clinically approved prostate treatment with seven fields irradiation (simulations)



Transversal view



(b)

Sagittal view

Application to radiotherapy (simulations): Improvement of some cancer treatments

A typical transversal dose distribution with 7 beams.

(a) (b) (c)

Electrons **Photons** **Difference**

A comparison of dose deposition with 6 MeV X ray an improvement of the quality of a clinically approved prostate treatment plan. While the target coverage is the same or even slightly better for 250 MeV electrons compared to photons the dose sparing of sensitive structures is improved **up to 19%.**

T. Fuchs, et al. Phys. Med Bio 54, (2009), in collaboration with DKFZ

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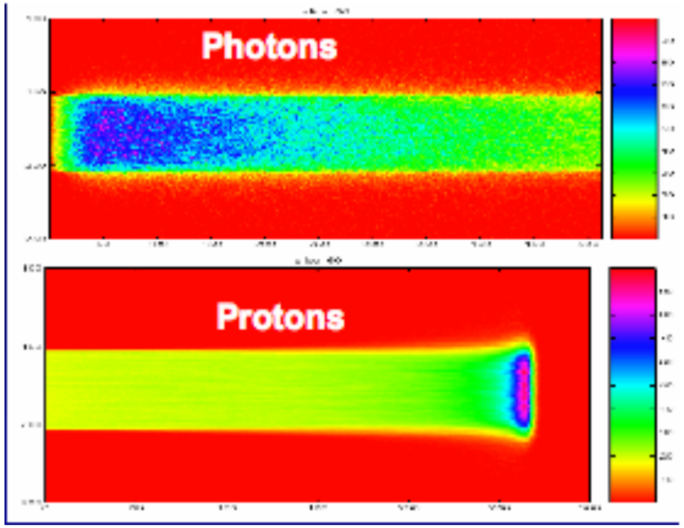
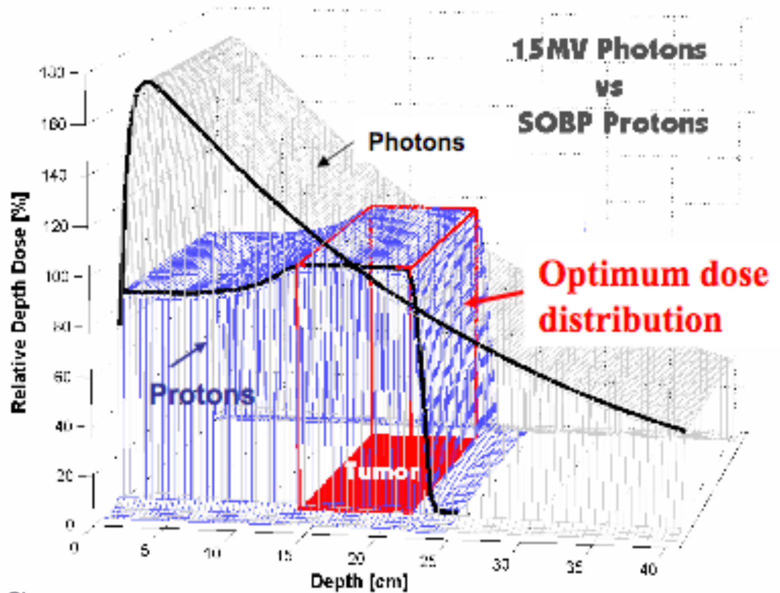
Causes of Local Cancer Failure

The primary cause for local failure is our inability to deliver a letal dose of radiation to the tumour cells. The reasons for this include :

- **We cannot determine the exact location and extend tumor cells and their route to spread**
- **Inadequate treatment.**
- **Proximity of dose limiting normal tissues and organs (brains stem, optics, lung, gut, etc.)**
- **Less that optimum dose distribution of the radiation beam used for treatment.**

Protons provide superior dose distributions





Protons Stop

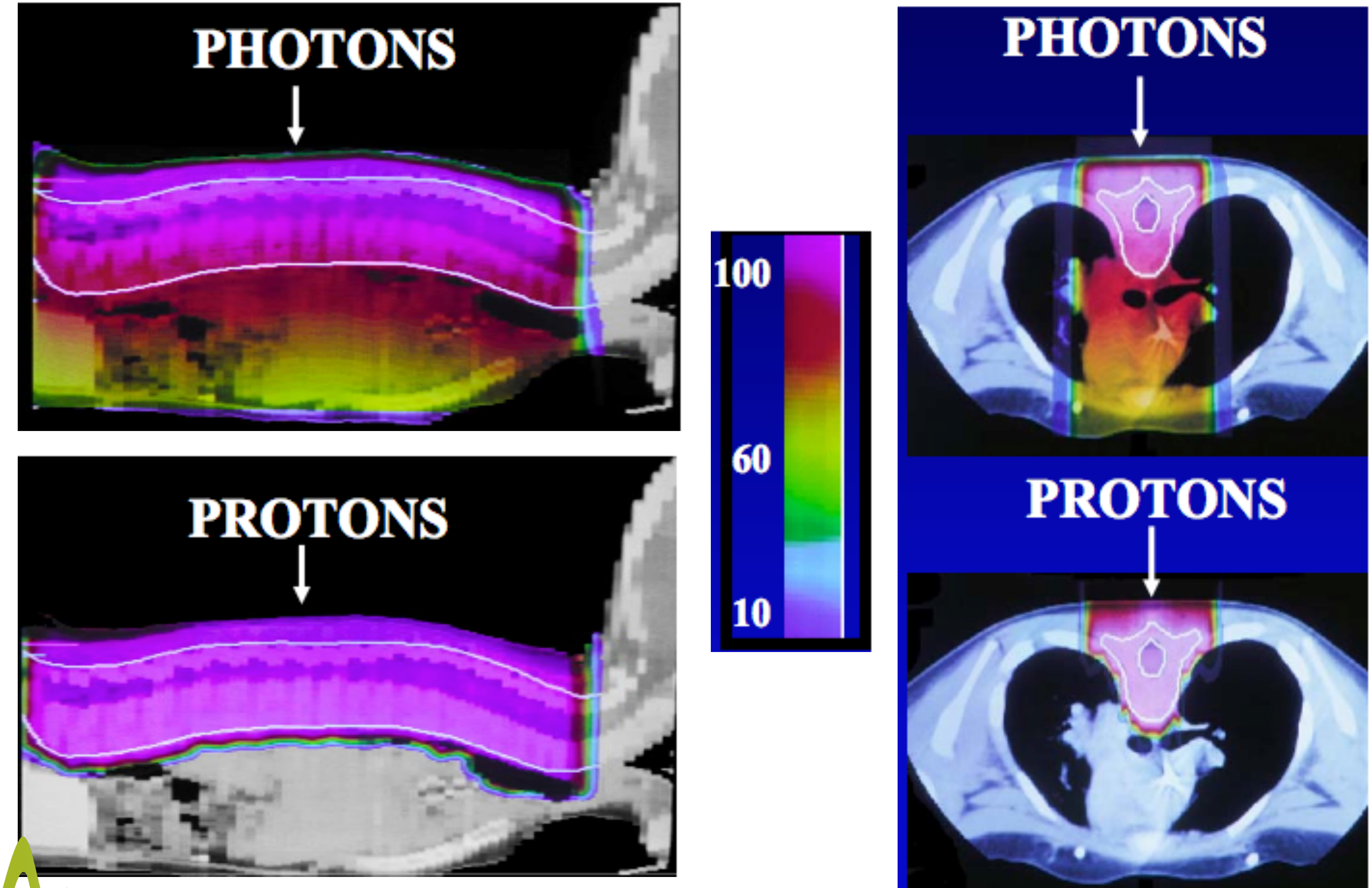
Photons don't stop

The « optimum » dose distribution delivers 100% dose to the tumour target and not to critical normal tissues.

Proton beams deliver dose distribution that are more optimum than those from photon beams

This should result in improved clinical outcomes when proton beams are used.

Protons provide superior dose distributions

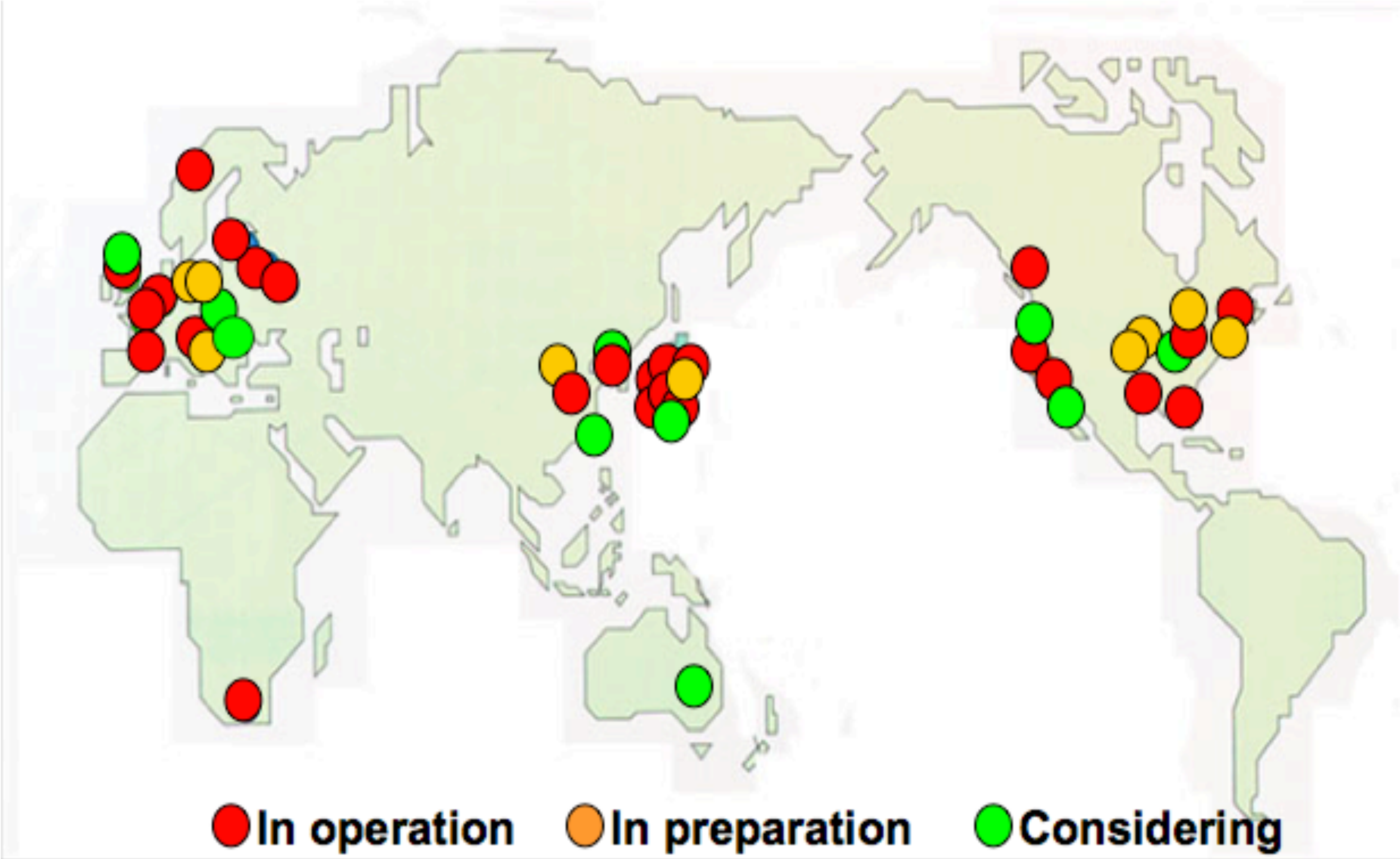


Protontherapy Facilities in the World

26 facilities worldwide treating patients

- **6 in Japan (4 hospital-based) : Chiban, NCC East-Kashiva, HIBMC-Hyogo, PMRC-Tsukuba, WERC-Wakasa, Shizuoka,Cancer Center**
- **6 in the United States (4 hospital-based) : LLUMC, MGH, MDACC, Univ. of Florida, Univ. of Indiana, UC Davis**
- **10 in Europe/Russia**
- **4 additional facilites (UK, China, Korea, South Africa)**
- **> 55,000 patients have been treated with proton beams**
- **22 additional Institutions worldwide are developing new facilities**

Protontherapy Facilities in the World



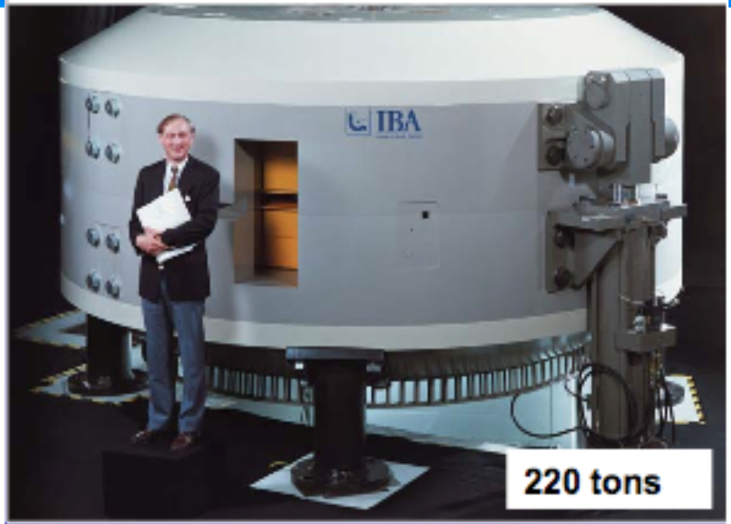
TREATING : PROTONS 26, CARBON IONS 3

Protontherapy center : large & expensive & performant

Accelerators used in protonthrapy

Hitachi 250 MeV synchrotron

IBA 230 MeV Cyclotron



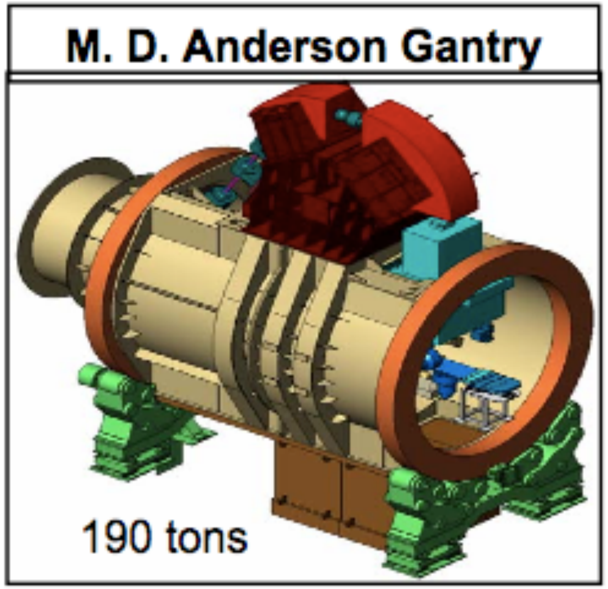
Varian/ACCEL Superconducting Cyclotron

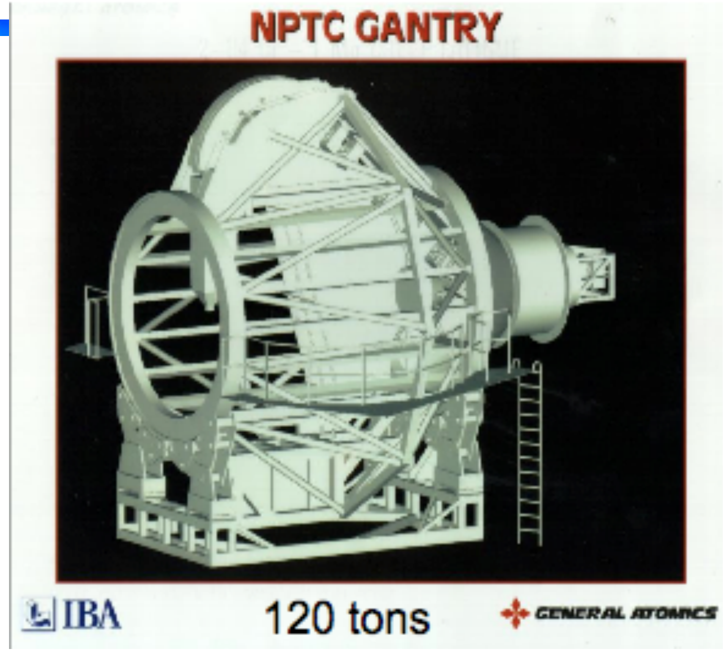
Still River Superconducting Synchrocyclotron

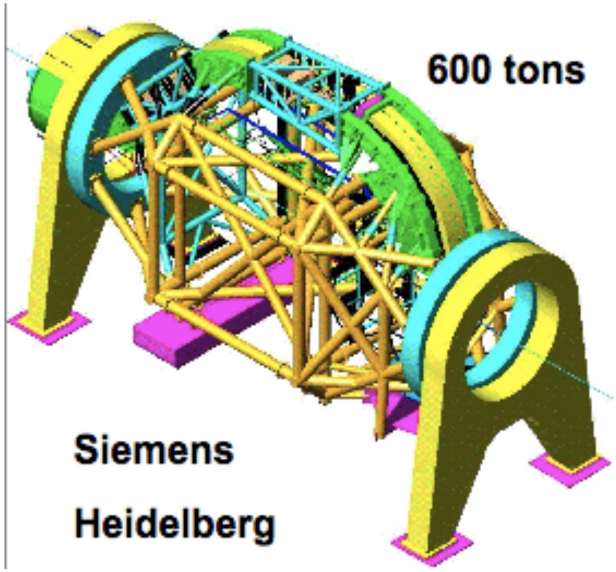
Accelerators specifications protontherapy

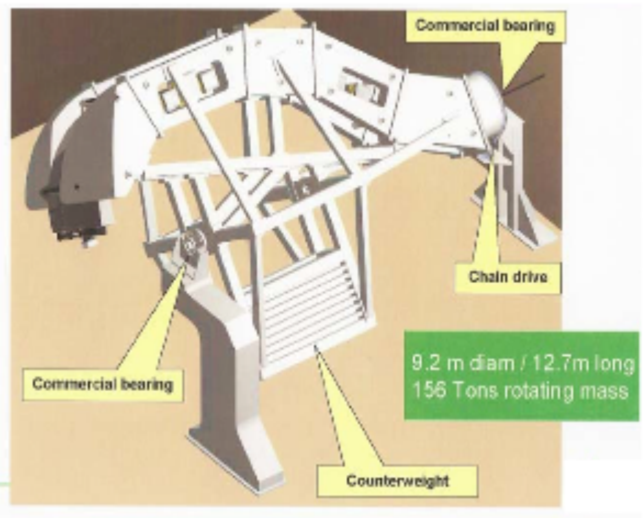
- Diameter : 3,4 m
- Weigth 60 tons
- « self » radioprotection
- Courant max : 500 nA (3. 10^{12} p.s^{-1})
- Output Energiy : 250 MeV
- Extraction efficiency : 80 %
- Emittance : few p-mm.mrad
- 95 % reliability (garanty by the compagny)
- 6 compagnies in the world
- Cost ~10 M€

Accelerators specifications protonthrapy









Need for improvement in cancer treatment

Tumor Site	Deaths/year	Deaths due to local failure of treatment
Head/Neck	22,000	13,200 (60%)
Gastrointestinal	135,000	54,000 (40%)
Gynecologic	28,000	14,000 (50%)
Genitourinary	55,000	27,500 (50%)
Lung	160,000	40,000 (25%)
Breast	41,000	4,920 (12%)
Lymphoma	20,000	2,400 (12%)
Skin, Bone, Soft Tissue	15,000	5,000 (33%)
Brain	12,000	10,800 (90%)
Total	**488,000**	**171,820 (35%)**

350,000 new cancer patients per year in the US

Laser based protontherapy projects around the world

- Projet Fox Chase Center (USA)
- LIBRA (UK consortium)
- Dresden (Germany) : OnCOOPtics
- MPQ (Germany)
- JAERI (Japon): « Medical laser Valley »: PMRC
- Russia
- Italy (Bologna, Prof. G. Turchetti)
- Etc…?

Conclusion (1/2)

Accelerators point of view : Two laser beams allow the control of many e-beam parameters

- Good beam quality & **Monoenergetic dE/E down to 1 %** √
- Beam is very stable √
- Energy is tunable: 20-300 MeV √
- Charge is tunable: 1 to tens of pC √
- Energy spread is tunable: 1 to 10 % √
- Ultra short e-bunch : 1,5 fs rms √

Physics point of view : many new aspects of the interaction have been revealed :

Heating processes with crossed polarized lasers √
Inhibited plasma waves effect √
Beam loading effect : optimum charge of 20pC √

Conclusion (2/2)

Proton beam are produced by plasma accelerators :

- Stability has been improved by improving the laser contrast ☺
- They produce quasi monoenergetic beam ☺
- Peak energy still moderated (no evolution in 6 years) : 12MeV with 10 Hz laser, 70 MeV with PW large scale laser ☹: 20 MeV with 50fs ☺
- Number of proton per second can be a problem ?
- Target fabrication and alignement at high repetition rate ? In progress (LIBRA)
- Biological response with high current dose?

V. Malka et al., Nature Physics 2008