



## Attivita' TIFPA basate sul fascio protonico

### Prof. Dr. Marco Durante

17.3.2016



Under construction: 25 proton/ 4 heavy ion centers Only in USA, 27 new centers expected by 2017

LLP CC

8 000 - 4 000 patients

4 000 - 1 000 patients

<1 000 patients</p>

500 - 1 000 patients

< 500 patients</p>

NuPECC report "Nuclear Physics in Medicine", 2014

Population-Scaled Facility Distribution

Countries of the world resixed according to their total estimated GDP output in the year 2010 measured in purchasing power parity (PPP) Nap created by Benjamin Hennig (c) Sasi Research Grupp, University of Sheffield www.viewsofthewerisnet GDP PPPP 2010

Data sources: IMF (2010), Maddison (2003), UNDP (200

## Gross-Domestic-Product-Scaled Facility Distribution





## AAPM poll, August 2012







#### Reducing costs: accelerators

- All current facilities use either a cyclotron or a synchrotron and RFQ or low-energy linacs as injectors
- High-field superconducting magnets for compact, lightweight synchrocyclotrons (e.g. SRS, IBA, INFN)
- Fixed-field alternating gradient (FFAG) accelerators (e.g. KEK, Japan, and RACCAM, France)
- Cyclinac (TERA)
- Dielectric wall accelerators (CPAC)
- Far future: laser driven accelerators





Still Rivers single-room protontherapy unit



IBA-C400

## Improving benefit: new tumors and diseases

- Established clinical indications
- Skull base and spine tumors
- Hepatocellular carcinoma
- Eye tumors
- Pediatric tumors
- More research needed for
- Thoracic malignancies
- Head and Neck tumors
- Pelvic and abdominal sites
- Metastatic disease
- Noncancer diseases







ASTRO Model Policy, May 2014

#### JOURNAL OF CLINICAL ONCOLOGY

Phase II Trial of Stereotactic Body Radiation Therapy Combined With Erlotinib for Patients With Limited but Progressive Metastatic Non–Small-Cell Lung Cancer

Puneeth Iyengar, Brian D. Kavanagh, Zabi Wardak, Irma Smith, Chul Ahn, David E. Gerber, Jonathan Dowell, Randall Hughes, Ramzi Abdulrahman, D. Ross Camidge, Laurie E. Gaspar, Robert C. Doebele, Paul A. Bunn, Hak Choy, and Robert Timmerman

- Acceptable toxicity
  - 2 grade 3 radiation toxicities (pneumonitis and vertebral compression)
  - Most grade 3 toxicities were Erlotinib related rash, diarrhea, and fatigue
- First failure in new (untreated) sites is dominant pattern
  - Only 3/44 sites with existing failure
- Outcomes exceed historical controls
  - Median PFS = 14.7 mos vs. 2.3 mos.Erlotininb alone)



## Platforms Designed for Multiple Metastases



- Tomotherapy
- 7 Lesions
  - 8 Gy X 5 = 40 Gy



Multiple lesions are ideally treated with protons







Plan courtesy Rick Vaden

#### **Animal experiment:** GSI Cave M, July 2014

Groups	Dose	Pigs
AVN	0 Gy	3
	25 Gy	3
	40 Gy	3
	55 Gy	3
PV	40 Gy	3
LV	40 Gy	4

LV: only internal target volume (ITV)

AVN and PV: isotropic margins of 5 mm and ITV



1x

50

Бx

9x









## Range uncertainty







1 Gy(RBE) 3 Gy(RBE) 5 Gy(RBE) 9 Gy(RBE) 11 Gy(RBE) 13 Gy(RBE) 15 Gy(RBE)



В

Source of range uncertainty in the patient	Range
	uncertainty
Independent of dose calculation:	
Measurement uncertainty in water for commissioning	$\pm 0.3 \text{ mm}$
Compensator design	$\pm 0.2 \text{ mm}$
Beam reproducibility	$\pm 0.2 \text{ mm}$
Patient setup	$\pm 0.7 \text{ mm}$
Dose calculation:	
Biology (always positive)	+ 0.8 %
CT imaging and calibration	± 0.5 %
CT conversion to tissue (excluding I-values)	$\pm 0.5$ %
CT grid size	$\pm 0.3 \%$
Mean excitation energies (I-values) in tissue	± 1.5 %
Range degradation; complex inhomogeneities	- 0.7 %
Range degradation; local lateral inhomogeneities *	± 2.5 %
Total (excluding *)	2.7% + 1.2 mm
Total	4.6% + 1.2 mm









NuPECC report "Nuclear Physics in Medicine", 2014



dose plan



measured





Courtesy of Wolfgang Enghardt, HZDR, Dresden

## Real time monitoring of the Bragg Peak position during a treatment with <sup>12</sup>C beam **Rationale:**

Real time, high accuracy (spatial resolution <1 mm)









Proton radiography of a RANDO phantom head at PSI, Switzerland

PAUL SCHERRER INSTITUT

Proton radiography using <u>marginal range</u> <u>radiography</u> is currently under study for quality control in several protontherapy centers





#### **Mouse Proton Tomography**









#### Human phantom Tomography – 800 MeV protons LANL











#### "Hot topics" in particle radiobiology

- RBE
- Cancer stem cells
- Hypofractionation
- Combined treatments
- Radiogenomics
- Intra-tumoral heterogeneity
- Noncancer diseases
- Second cancers



Jakob et al., P. Nucl. Acids Re



## **RBE** in protontherapy



RBE













23

### **Experimental cave - today**













25

# Research with proton beams: beyond therapy



## Protection by passive shielding





#### Percent Dose Reduction per Unit Areal Density for Single Materials









# LIMADOU-CSES: earthquake monitoring in space

### LIMADOU-CSES: CHINA SEISMO-ELECTROMAGNETIC SATELLITE







## Electron bursts in inner belts

Correlations between EQ & ps:  $\Delta T_{EQ-PB}$  distributions



 $4 \le E_e \le 15 \text{ MeV}$ 





#### Wave – particles interaction mechanism







31

#### Detector calibration with 70-200 MeV protons









## Grazie! Vielen Dank!