Andrea Denker and

- the accelerator team

- the medical team

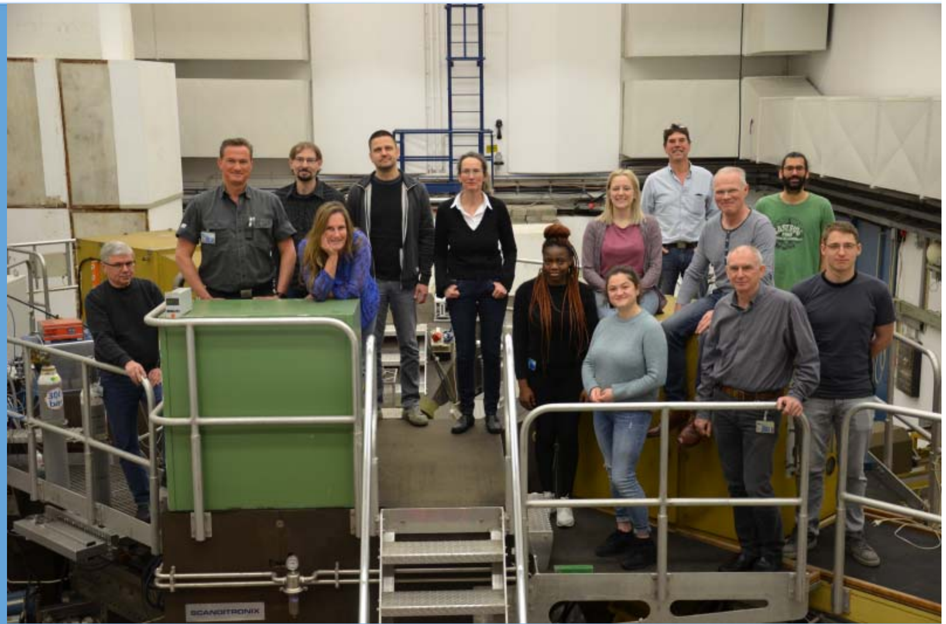
- the students

HZB Helmholtz Zentrum Berlin

CHARITÉ

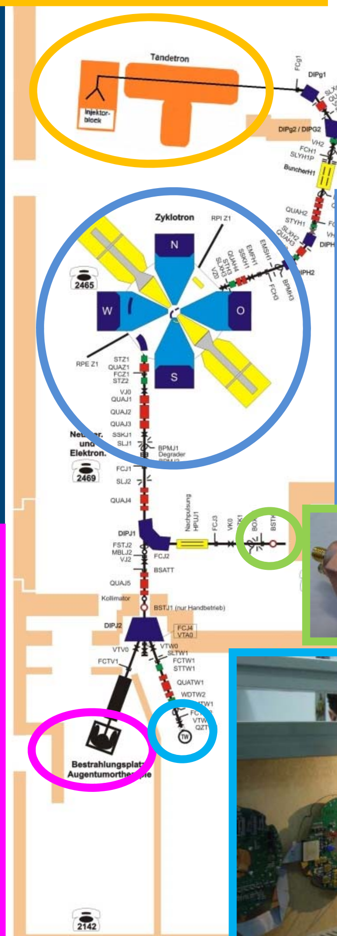
BEUTH HOCHSCHULE FÜR TECHNIK BERLIN
University of Applied Sciences

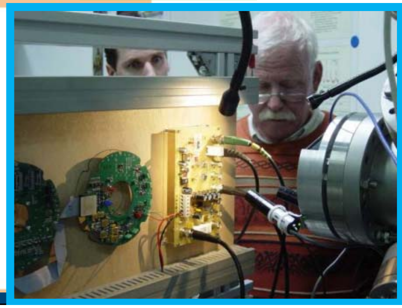
Status of the HZB cyclotron



Proton Accelerator Complex

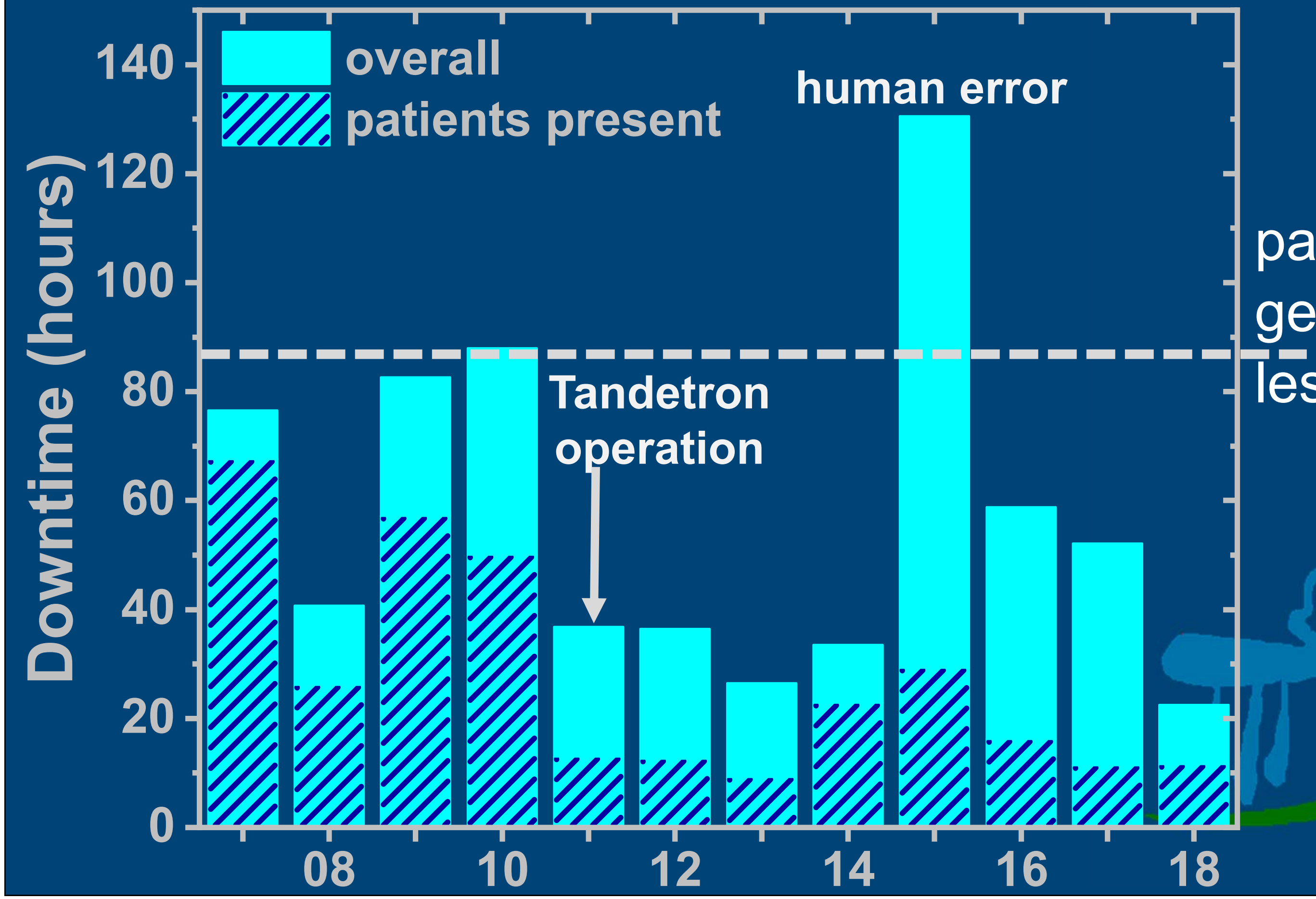
- k = 130 isochronous sector cyclotron
  10 – 20 MHz
- two injectors:
  - 2 MV Tandetron™
  - 6 MV Van-de-Graaff, backup, time structures
- three target stations:
  - treatment room
  - experimental station (I_{max}(DC) = 10 nA)
  - beam line end for tests in cyclotron vault





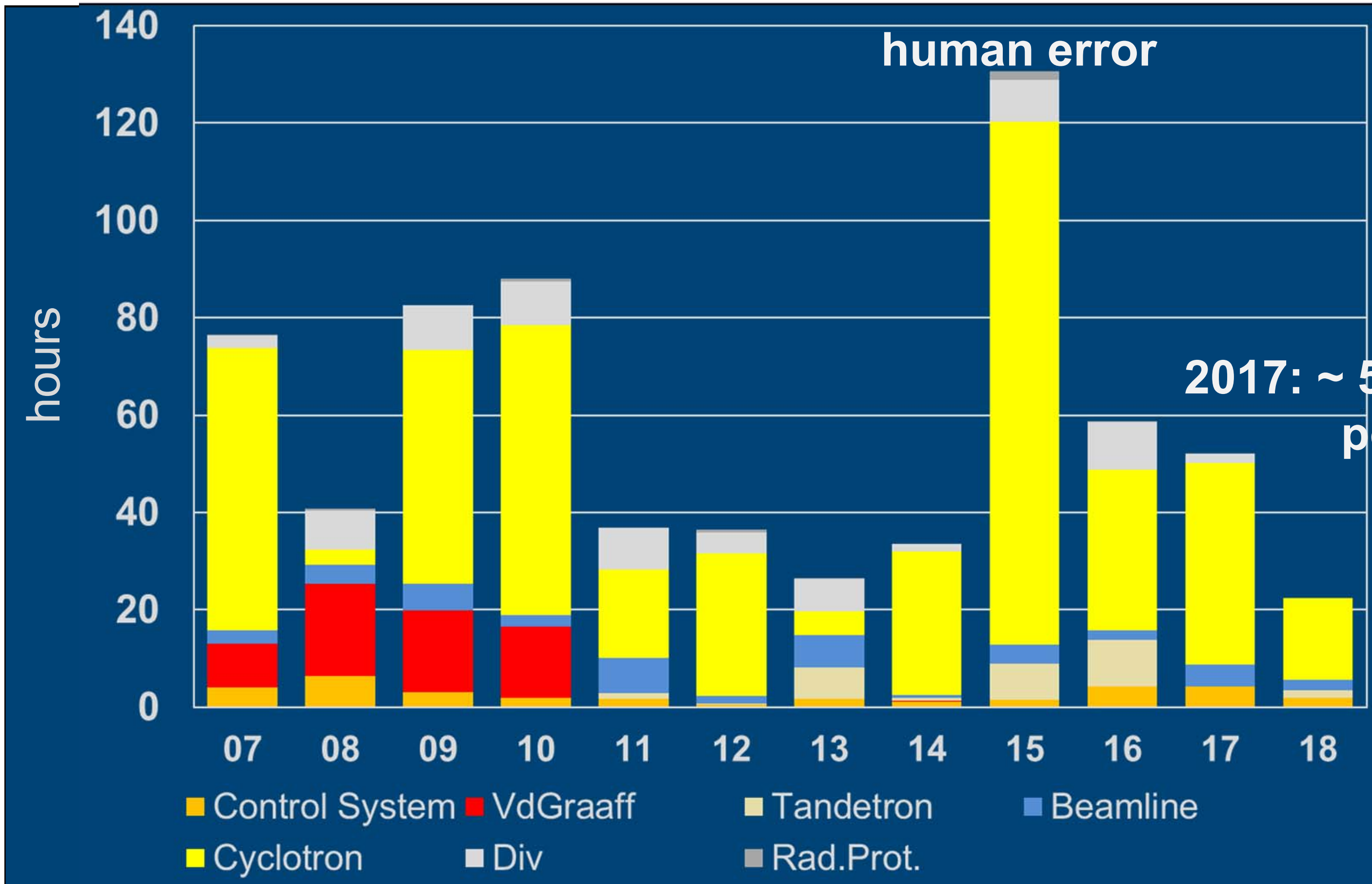
Accelerator Performance

- only 1700 hours of scheduled beam time: major events → huge impact on statistics
  - in 2015: human error – increase of injector voltage too fast
  - many errors appear during start-up of accelerator



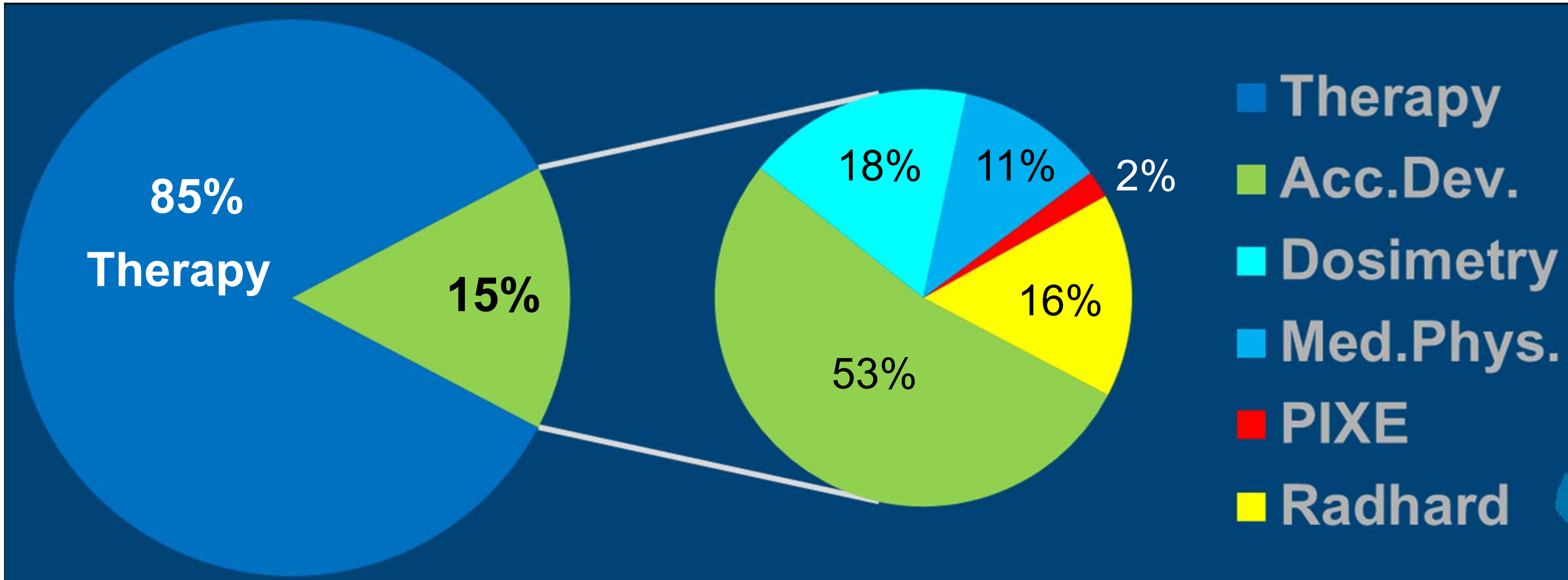
past years: generally less than 5%

Accelerator Performance



- main “culprit” for most years: cyclotron (yellow)
- especially RF
  - replacement of old low level control with modern system from iThemba labs in 2017 (poster TUP007)

Beam Time: Utilization



- therapy:
  - 68 MeV protons, quasi-DC, broad beam (Ø 50 mm), $I_{patient}$ < 3 nA
  - deliverable by either Van-de-Graaff or Tandetron as injector
- experiments:
  - broad or focused beam
  - quasi DC to single pulses with t < 1 ns (single turn extraction)
  - changes in intensity: 0.1 pA ≤ I_{target} ≤ 1500 nA
  - 68 MeV protons, ^{4}He: 50 MeV, 75 MeV, 90 MeV

Therapy:
Treatment of ocular melanomas

CHARITÉ | HZB Helmholtz Zentrum Berlin

- past 10 years: ~ 220 patients each year in 12 therapy blocks
- 2018: 20 years of eye tumour therapy in Berlin
- overall (8/2019): more than 3600 patients
- special cases: children, pregnant and breast-feeding patients
- accompanying R&D for Medical Physics & Dosimetry
  - e.g.: Determination of the radiation exposure to the fetus of a pregnant patient

Therapy: Clinical Results

Tumour control after 5 years:

- Ru-106: 91%[1] (Charité: ca. 92%[7])
- I-125: 91%[1]
- Protons: 96%[1,2] (Charité: ca. 96%[3])
- LINAC (SRT): 94%[1,9]
- Cyberknife (SRS): 73%[4,5]

eye retention after 5 years:

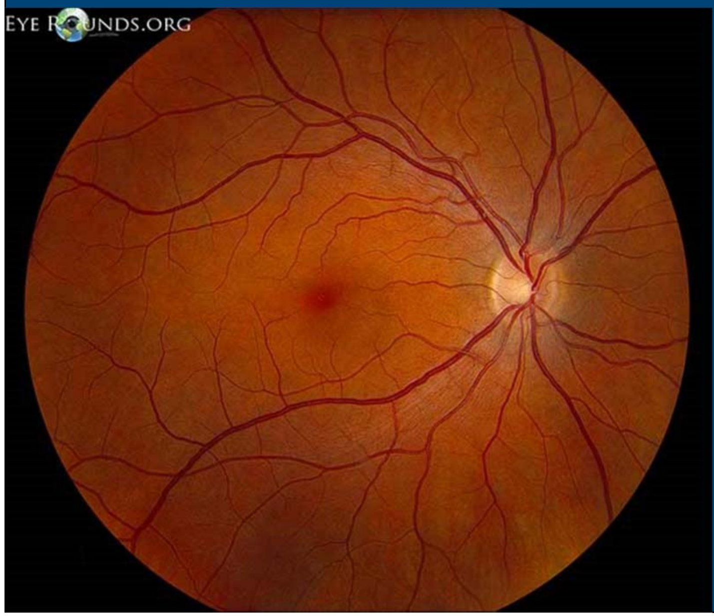
- Ru-106: >90%[10] (Charité: ca. 95%[7])
- I-125: ~90%[8]
- Protons: >90%[2,6] (Charité: ca. 95%[3])
- LINAC (SRT): ~78%[9]
- Cyberknife (SRS): ~73%[4,5]

Literature:

[1]Chang MY: Brit J Ophthalmol. 2013; [2]Egger E: Int J Radiat Oncol Biol Phys 2001; [3]Seibel I: Am J Ophthalmol 2015; [4]Eibl-Lindner K: Melanoma Res. 2016; [5]Yazici G: Int J Radiat Oncol Biol Phys 2017; [6]Mishra KK: CCO 2016; [7]Krause N: Diss.2015 [8]Vonk DT: Brachytherapy 2015; [9]Dunavoelgyi R: Int J Radiat Oncol Biol Phys 2011; [10]Verschueren KMS: Radiother Oncol 2010

Experiments: Medical Physics
Mice Irradiations – Motivation

- side effect of radiation therapy:
  radiation induced retinopathy 1 -2 years after treatment
- ophthalmologists want to irradiate single mice eyes to observe the chemical and biological changes in eye tissue
- first step:
  obtain necessary permits

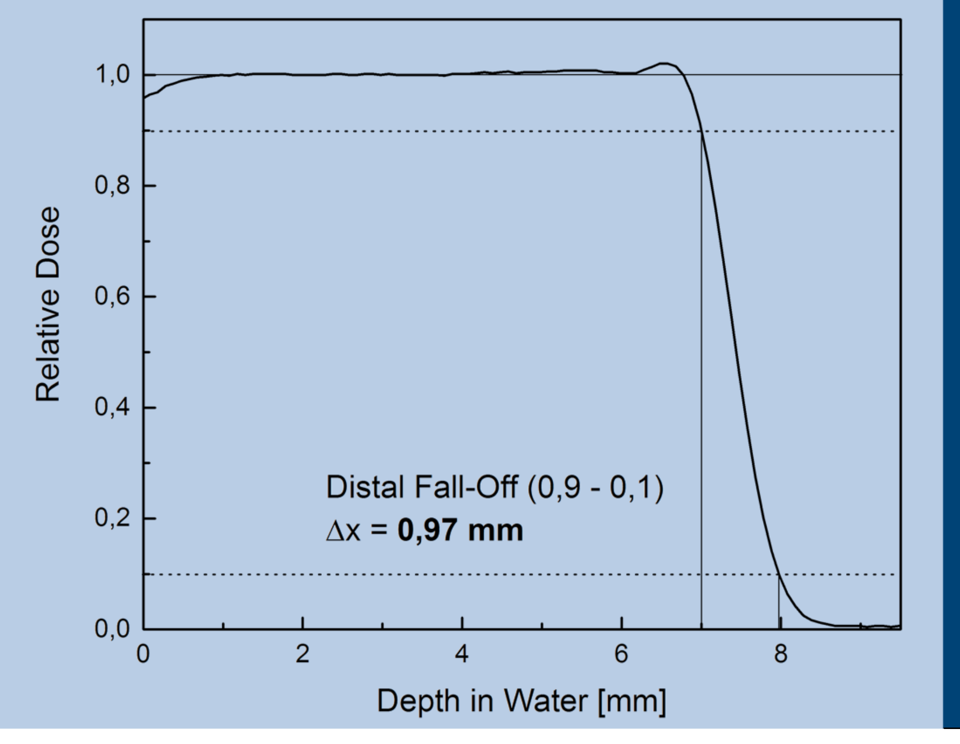


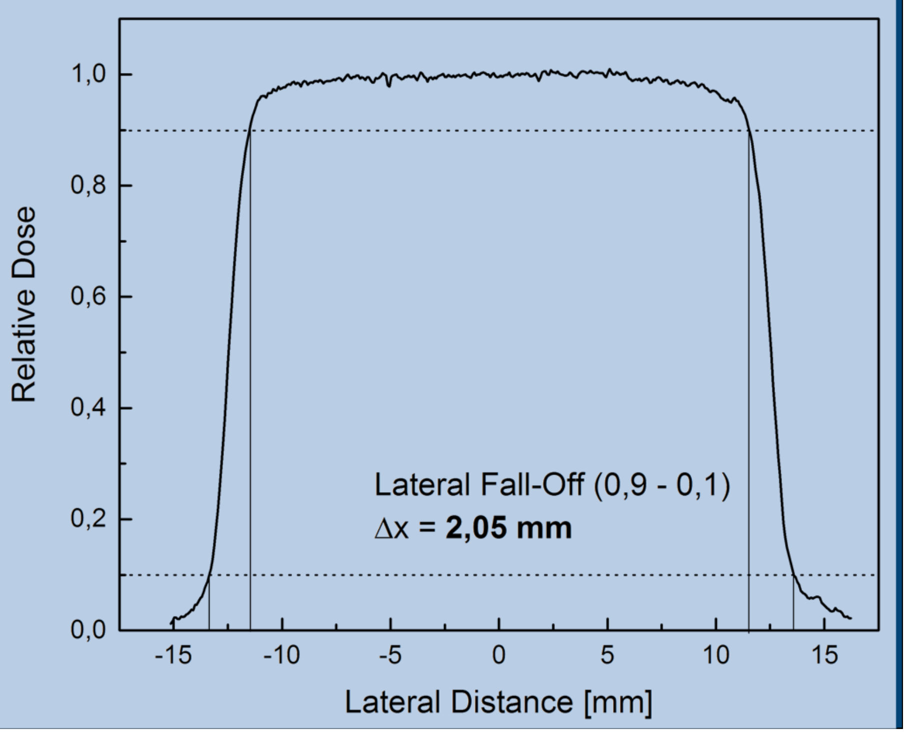
Experiments: Medical Physics

Mice irradiation – technical challenges

CHARITÉ HZB Helmholtz Zentrum Berlin

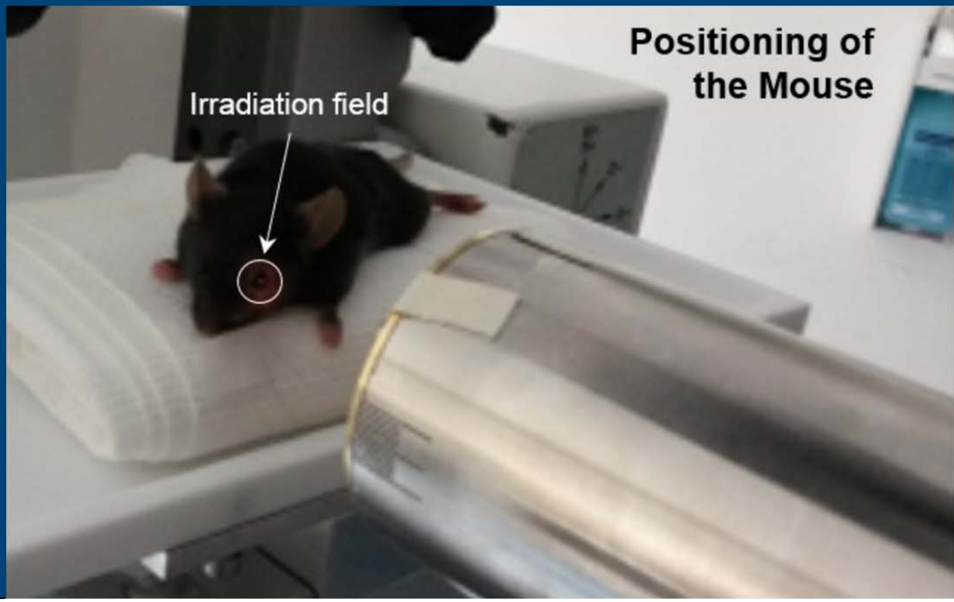
- relatively small size of a mouse eye compared to human eyes: 3 - 4 mm in diameter
- very small irradiation field with sharp dose fall-offs to the sides as well as in depth required
- Spread Out Bragg Peak with a maximum range of 7 mm and full modulation length





Experiments: Medical Physics
Mice irradiation – technical details

- pre-absorber of 2 mm thickness reduces the maximum proton range further to 5 mm
- very sharp distal dose fall-off of less than 1 mm: the second eye can by spared
- position of the mouse during irradiation is monitored using the same camera as for clinical treatment



Experiments: Medical Physics
Mice irradiation – ambulant procedure

CHARITÉ

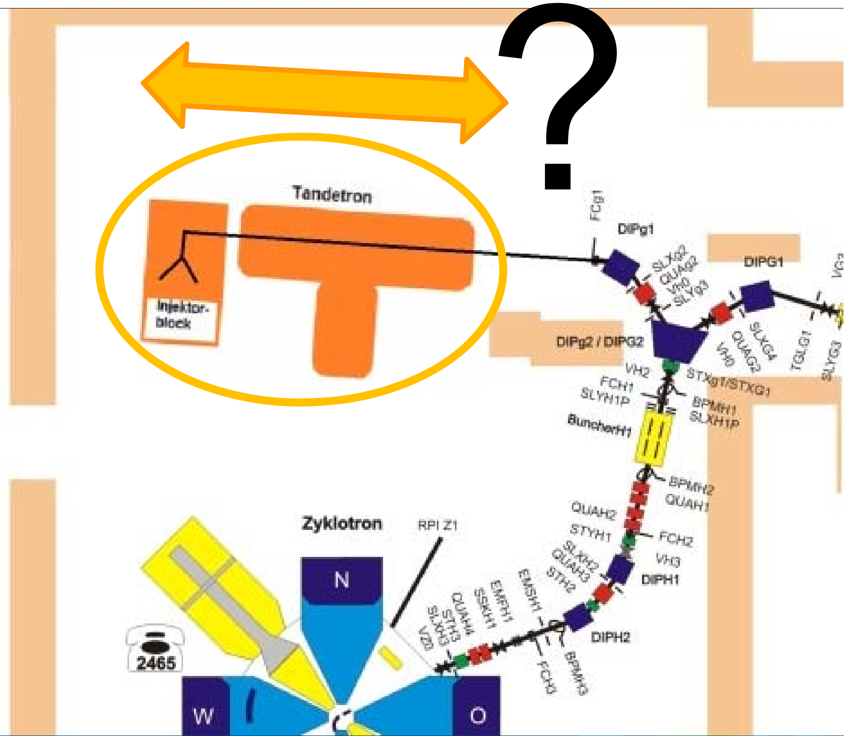
HZB Helmholtz Zentrum Berlin

- transport to the HZB from the animal husbandry of the Charité
- short period of time (1 to 2 hours) for acclimatization
- one mouse after the other is anesthetized and brought into the treatment room for irradiation
- mouse is positioned in front of the beam line with one eye placed at the isocenter
- after irradiation: mouse is brought back to her box and woken up
- transport back to Charité
- second eye, non-irradiated due to sharp distal fall-off → used as a control
- about 60 mice have been irradiated with doses from 0 CGE to 15 CGE

- about 6 months after irradiation →

Accelerator Development

- 2007/08: replacement of RFQ with 2 MV Tandetron



- mechanical constraints in positioning
  - emergency exit
  - access to cyclotron
  - …
- at the end: compromise

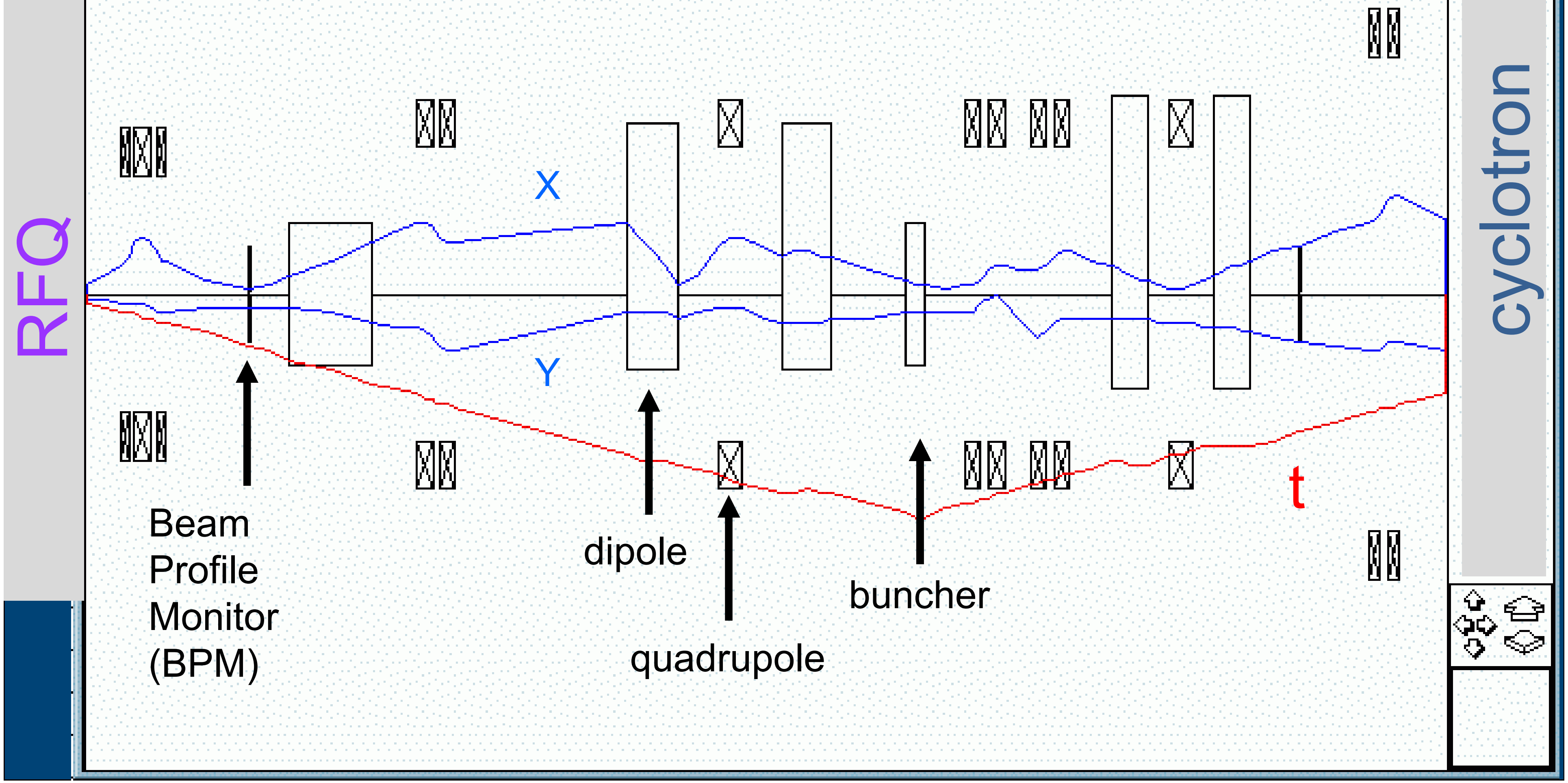
Beam Transport RFQ → Cyclotron

HZB Helmholtz Zentrum Berlin

University of Louvain OoTran V3.1

File Add Edit Output Analyse Debug Help Vicksi

- OoTran calculations performed before installation of RFQ
  - calculations date back to 1998
  - confirmed by tuning

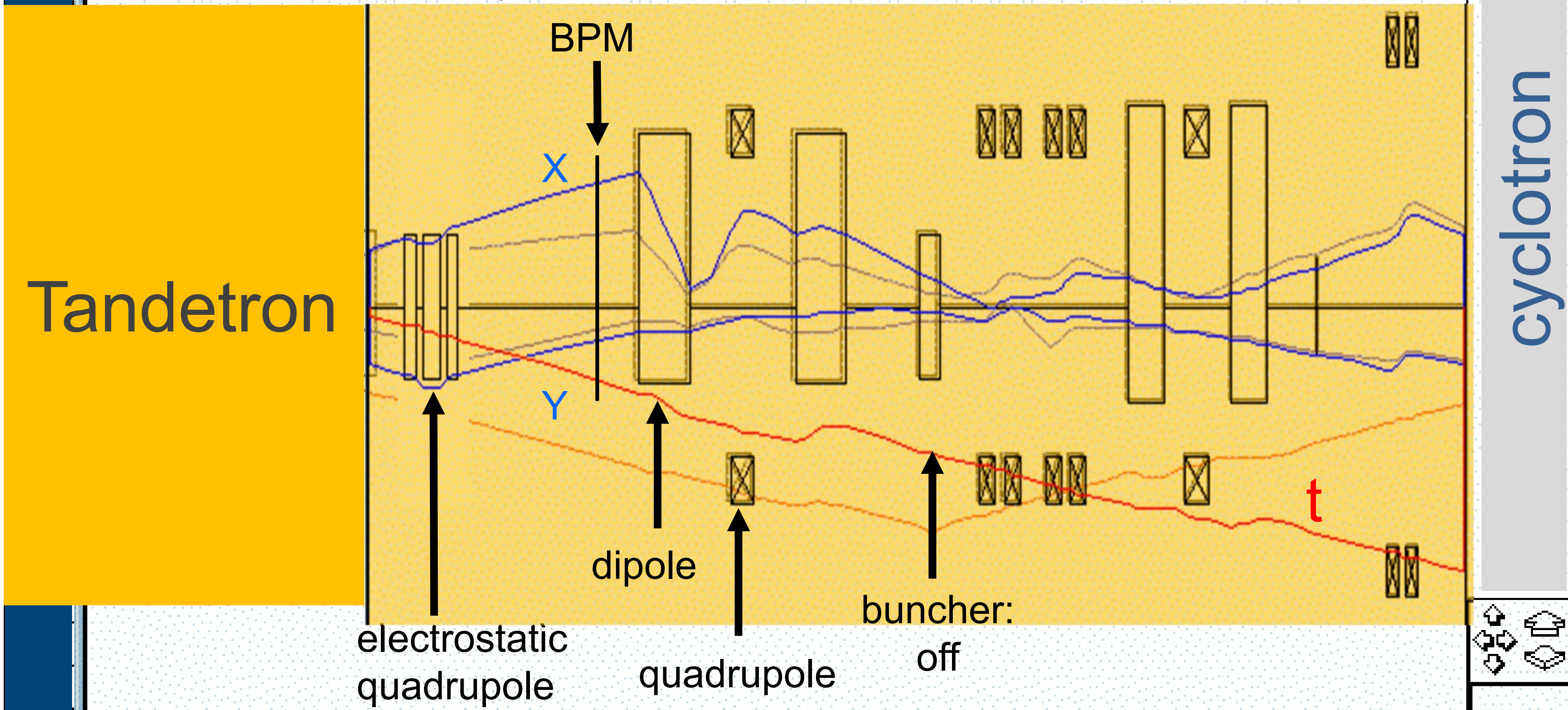


Beam Transport Tandetron → Cyclotron

University of Louvain OoTran V3.1

File Add Edit Output Analyse Debug Help Vicksi

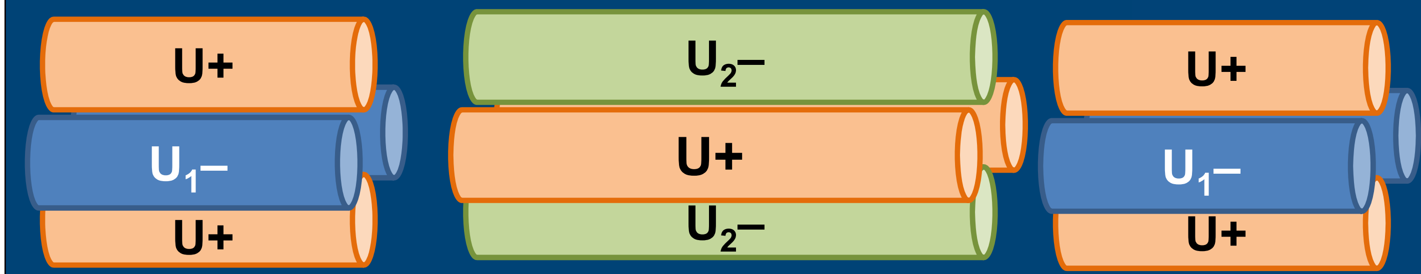
- OoTran calculations for position of tandetron
  - DC injection to cyclotron (standard for therapy)
  - BPM not at focal point



  - big differences between calculation and setting

Tandetron → Cyclotron: Tuning Issues

- start parameters from Tandetron not well known
  - parameters from Cadarache
- electrostatic quadrupole:
  - triplet with 3 (three!) power supplies: asymmetric quadrupole
  - ➲ asymmetric quadrupole

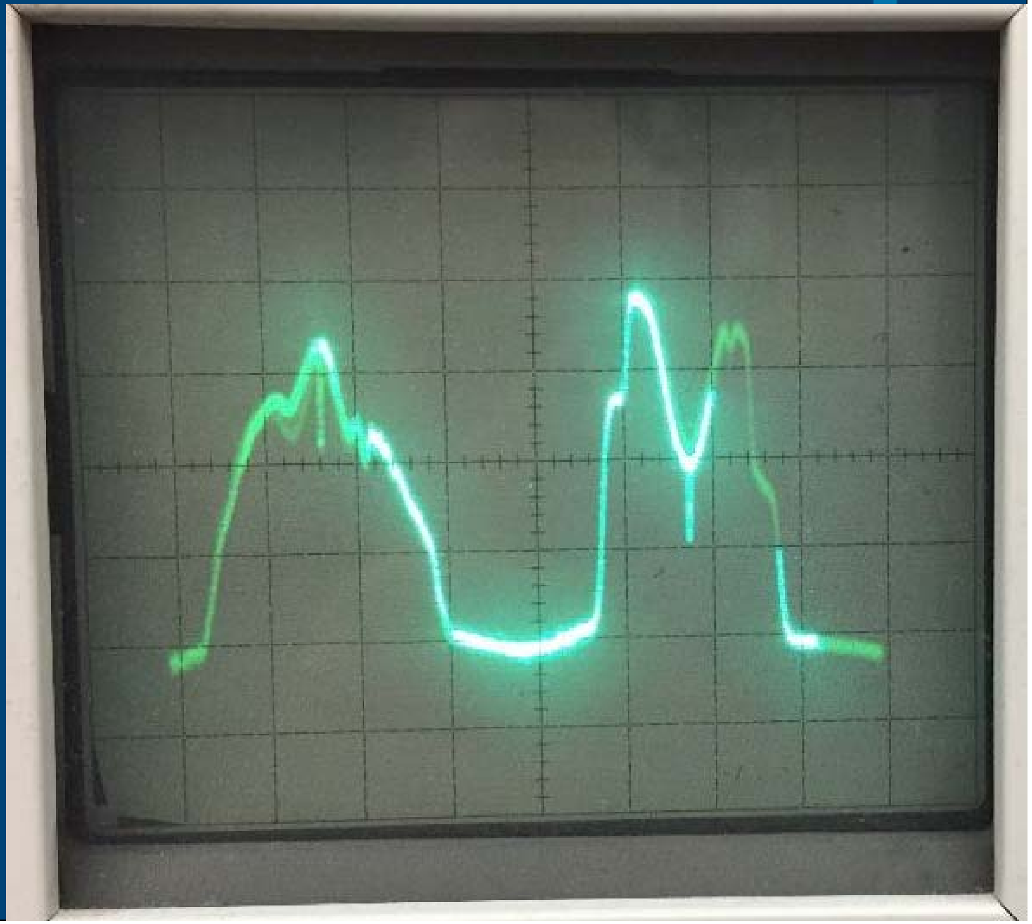


➲ asymmetric beam

Tandetron → Cyclotron: Tuning Issues

HZB Helmholtz Zentrum Berlin

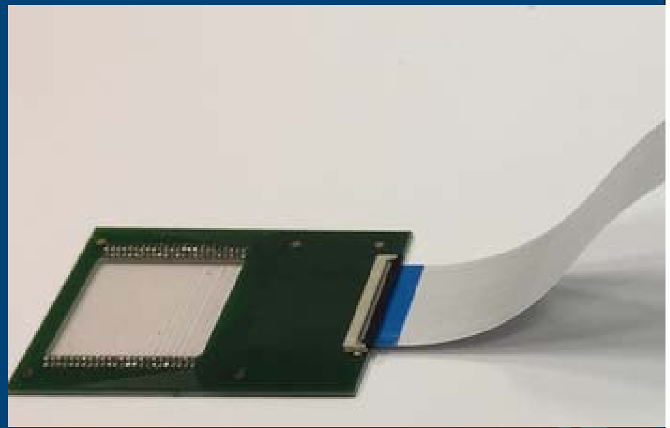
- start parameters from Tandetron not well known
  - parameters from Cadarache
- electrostatic quadrupole:
  - triplet with 3 (three!) power supplies: asymmetric quadrupole
  - ➲ asymmetric beam
- was observed on beam profile monitor (BPM)
- tuning for a good transmission to and through cyclotron
- interpreted as broad x and narrow y beam
- slightly off-axis in y: slight offset in alignment

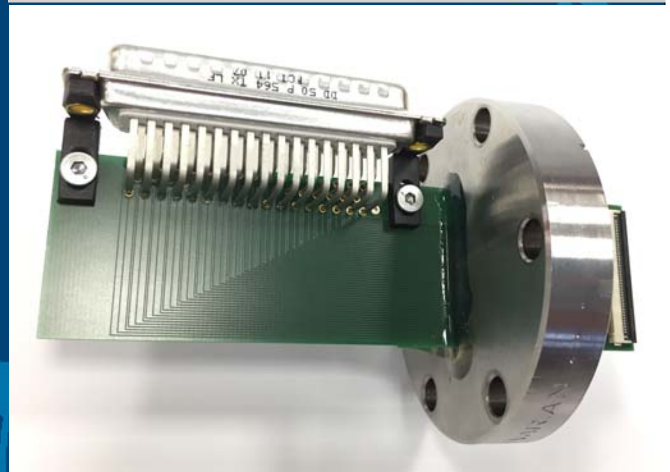


Installation of a Harp

BPM not at focal point
+ beam emittance is defined close to BPM
→ tuning ambiguous

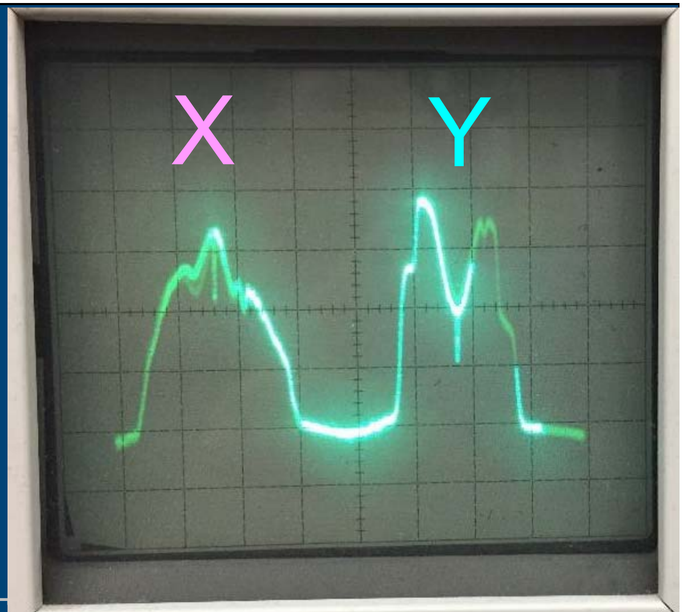
- installation of a harp for better reproducibility
- 48 wires in x and y (broad beam)
- mounted on standard movement unit
- connection via PCB boards and flat cables
- vacuum feed through: PCB board and epoxy
  - after 6 hours: vacuum better than 2 • 10^{-7} mbar
  - leak tested: 1 • 10^{-9} mbar/(l s)
  - mass spectrometer: nothing dangerous for electrostatic quadrupole nearby (30 kV)
- harp electronics from NRF National Research Foundation | iThemba LABS Laboratory for Accelerator Based Sciences

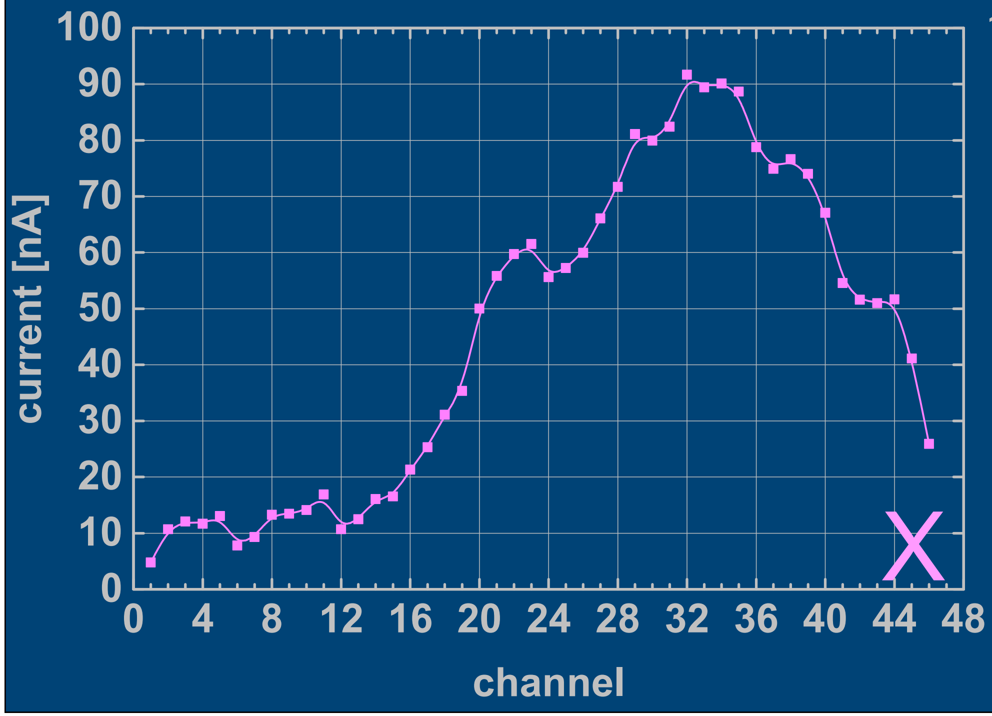


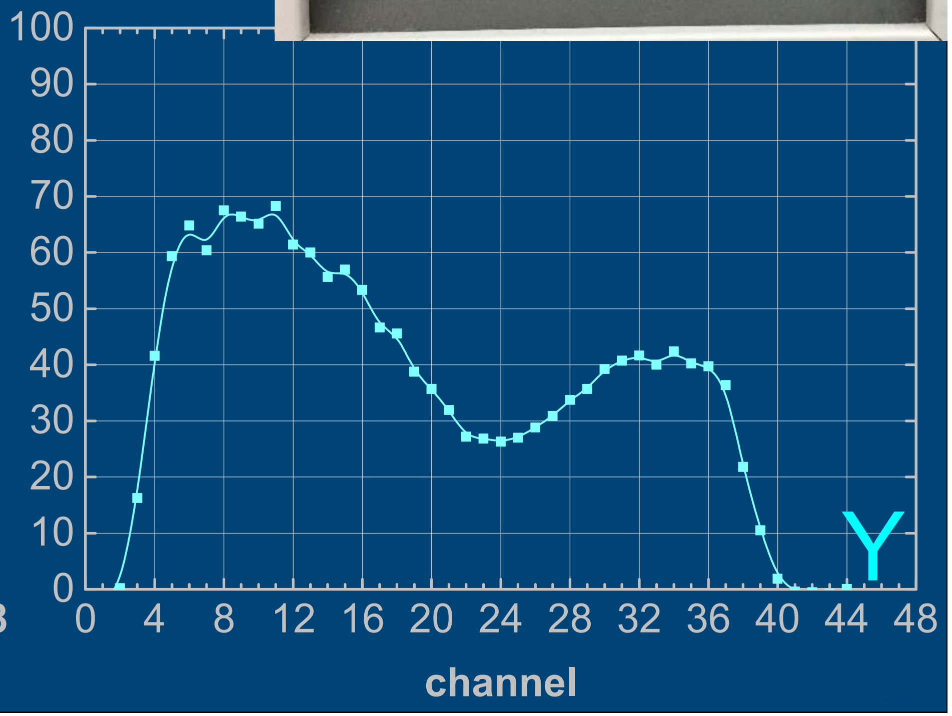


Harp: Beam Measurements

- in X and Y: harp profile identical to BPM!
- why double peak in Y?
  - until now: explained as slight misalignment
- ➲ two beams ??

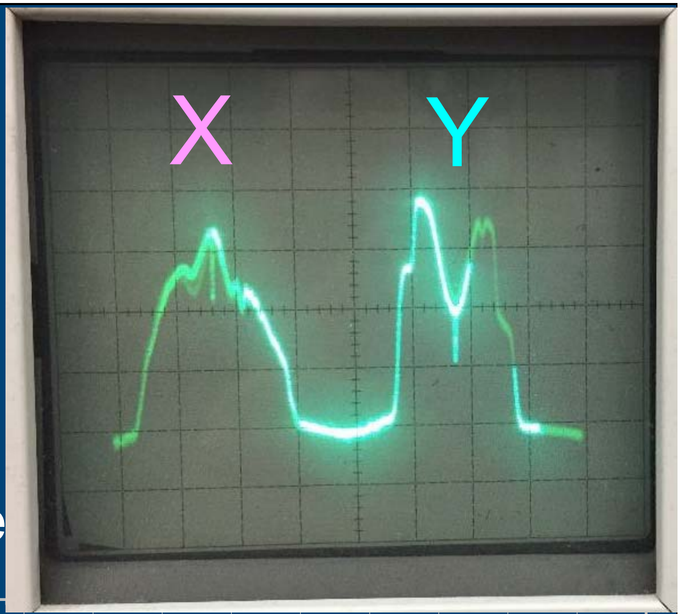


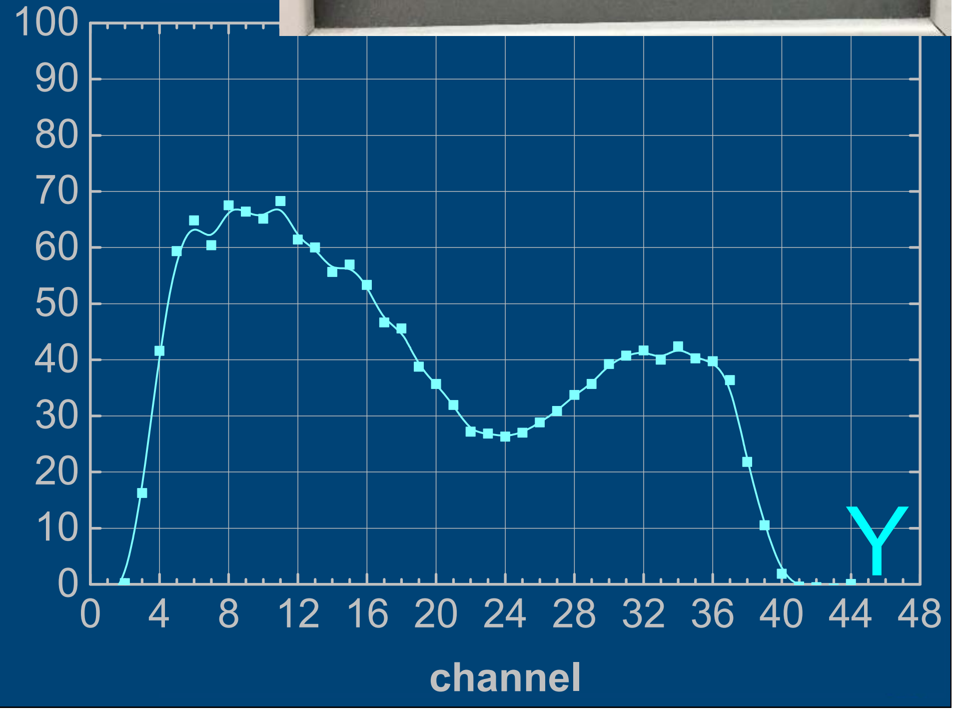


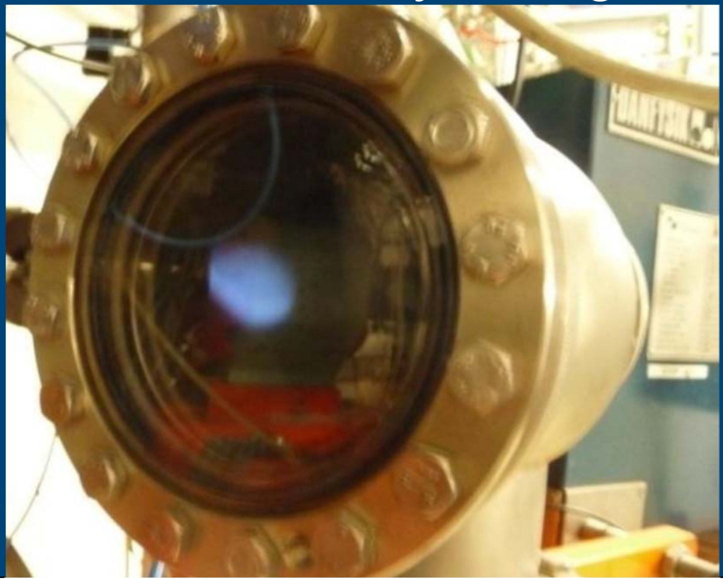


Harp: Beam Measurements

- in X and Y: harp profile identical to BPM!
- why double peak in Y?
  - until now: explained as slight misalignment
- ➲ two beams ??
- yes: neutral particles (incomplete stripping)
- measurements & finite element calculations: start conditions after electrostatic quadrupole
- beam line calculations possible and confirmed by tuning

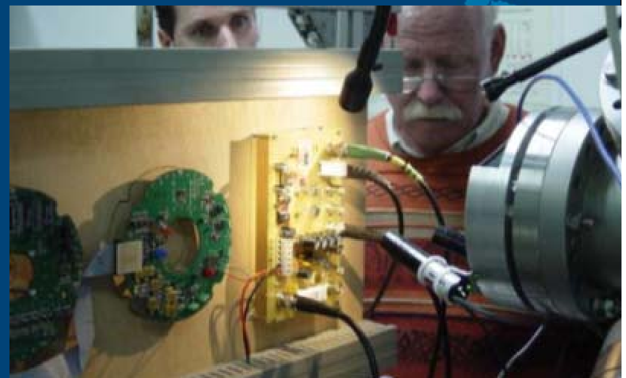


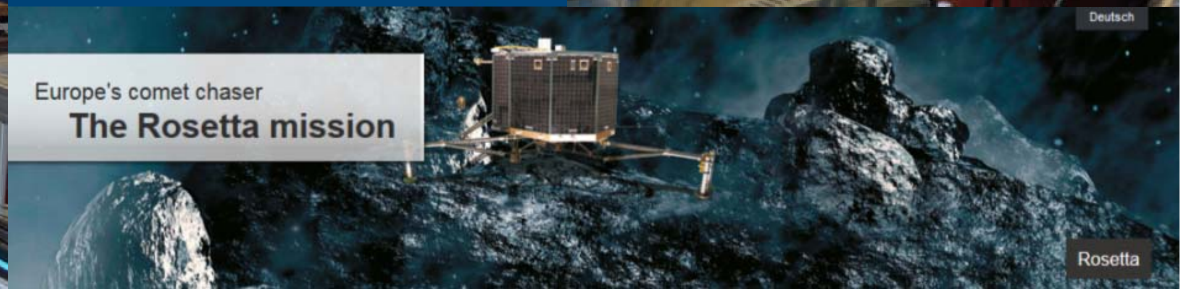




Experiments: Further Examples

- Accelerator Development:
  - preparation for FLASH experiments: dose rate > 40 Gy/s, $t < 0.5$s (poster TUP021)
  - beam delivery for experiments (poster TUP020)
- Radiation Hardness tests, e.g. for DLR:
  - 2004 parts of the Rosetta electronics irradiated
  - 2014: successful end of hibernation
- Proton Induced X-ray and γ-ray Emission:
  - helmets and silver coins from the Berlin Museums





Conclusion

- first proton therapy installation in Germany
- since 06/1998 treatment of patients
  - Aug. 2019: > 3600 patients
  - past years: ~ 220 patients per year
- reliable accelerator operation, uptime generally better than 95 %
- on-going experiments for
  - investigation of retinopathy
  - dosimetry
  - rad hard tests
  - ….

Thank you for your attention!