Status of the HZB Cyclotron

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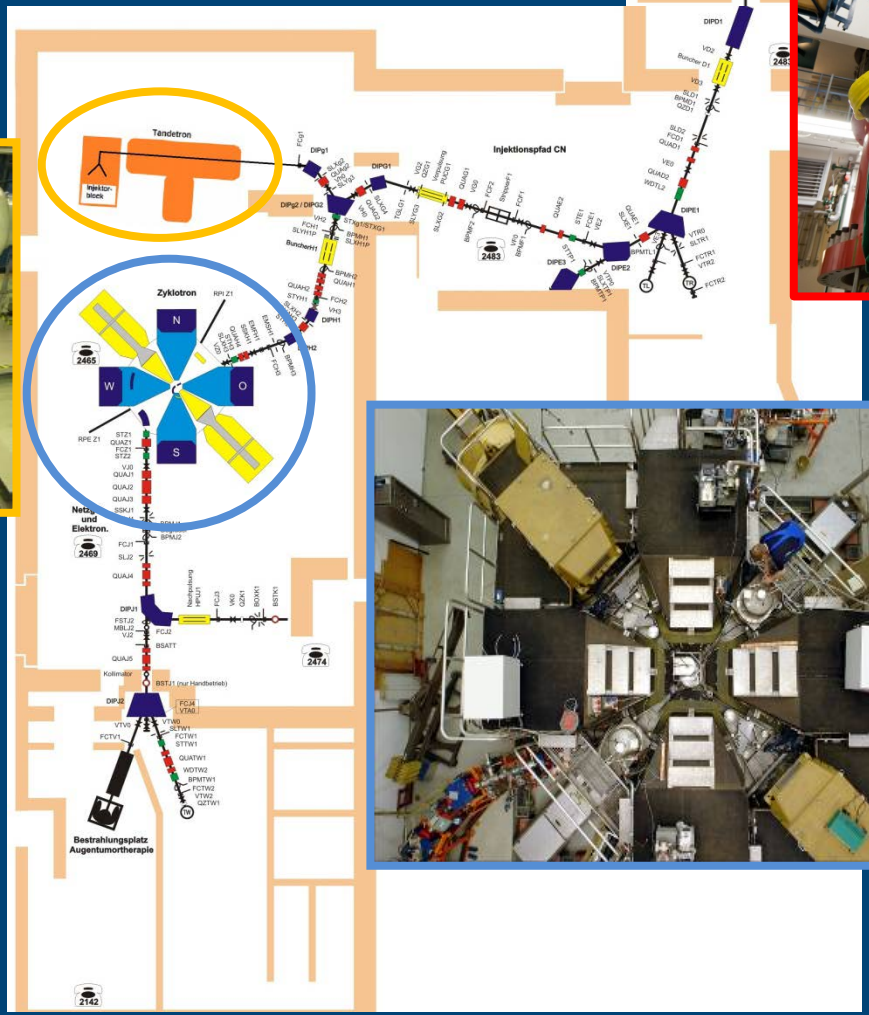
Helmholtz-Zentrum Berlin, Protons for Therapy

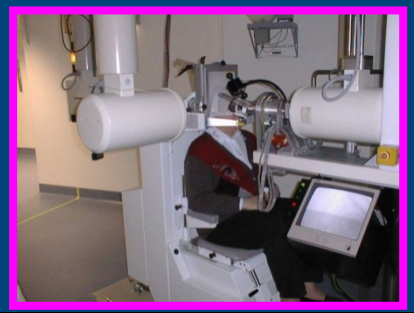
Accelerator Layout

- k=130 cyclotron (former VICKSI, ISL)
- two injectors:
  - 2 MV Tandetron™, standard for therapy
  - 6 MV Van-de-Graaff, backup, time structures



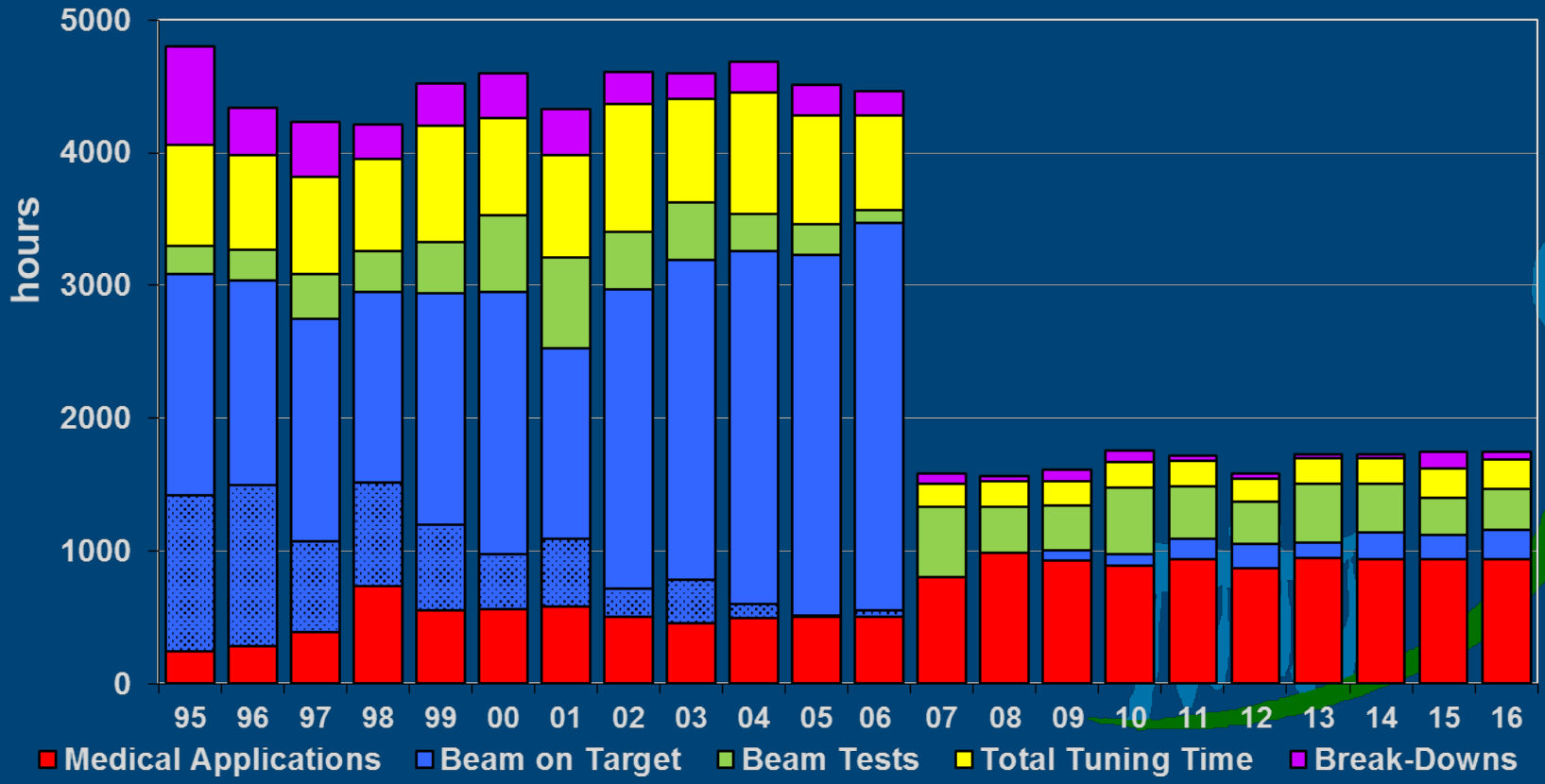
Accelerator Layout

- k 130 cyclotron (former VICKSI, ISL)
- two injectors:
  - 2 MV Tandetron™, standard for therapy
  - 6 MV Van-de-Graaff, backup, time structures
- three target stations:
  - treatment room
  - experimental station (I_{max} = 10 nA)
  - beam line end for tests in cyclotron vault



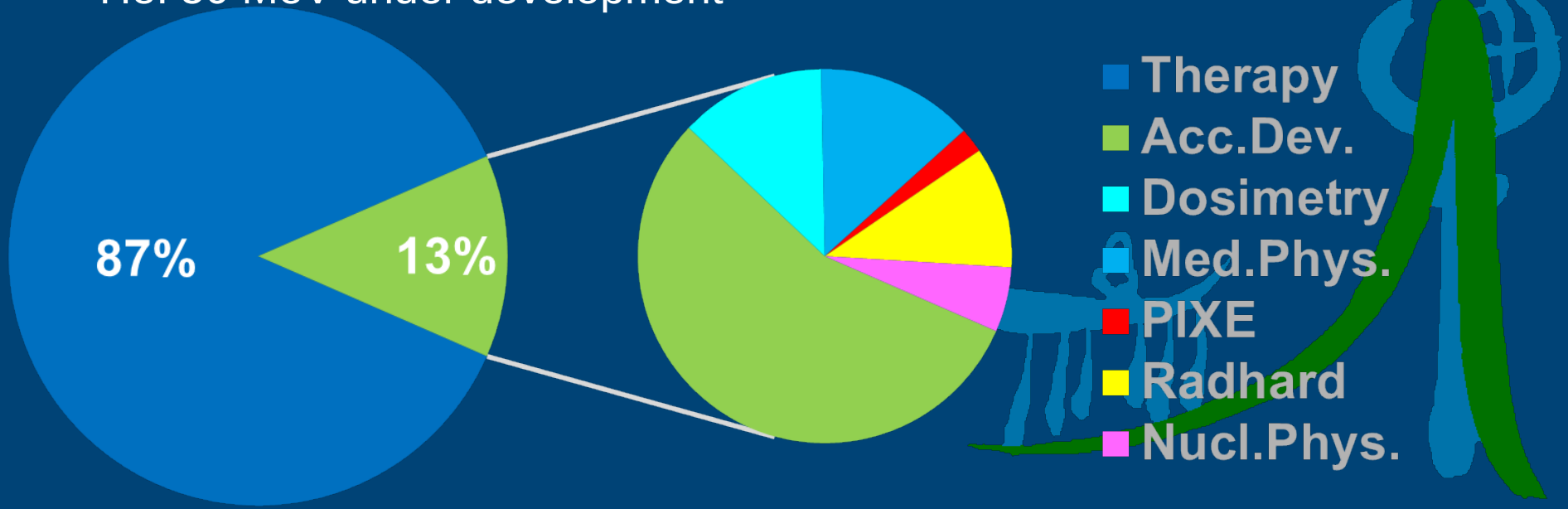
Accelerator Operation

- since 2007:
  accelerator financed by external means (hospital, third party funds)
- since 2009: accelerator R & D again part of HZB's research portfolio
  - bachelor and master theses, PhD students
  - small budget for research



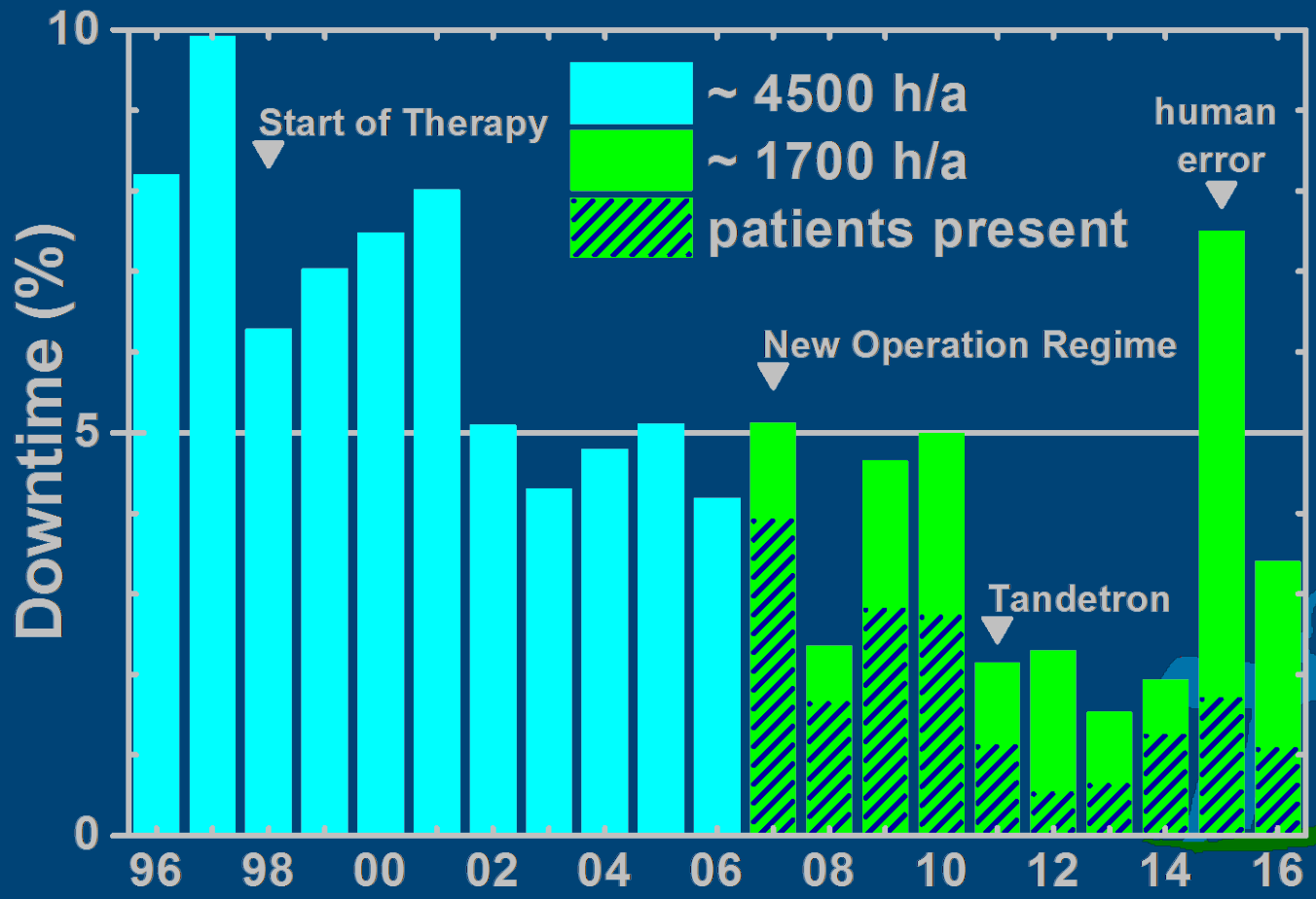
Beam for Experiments

- 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
  - ^{3}He: 50 MeV under development



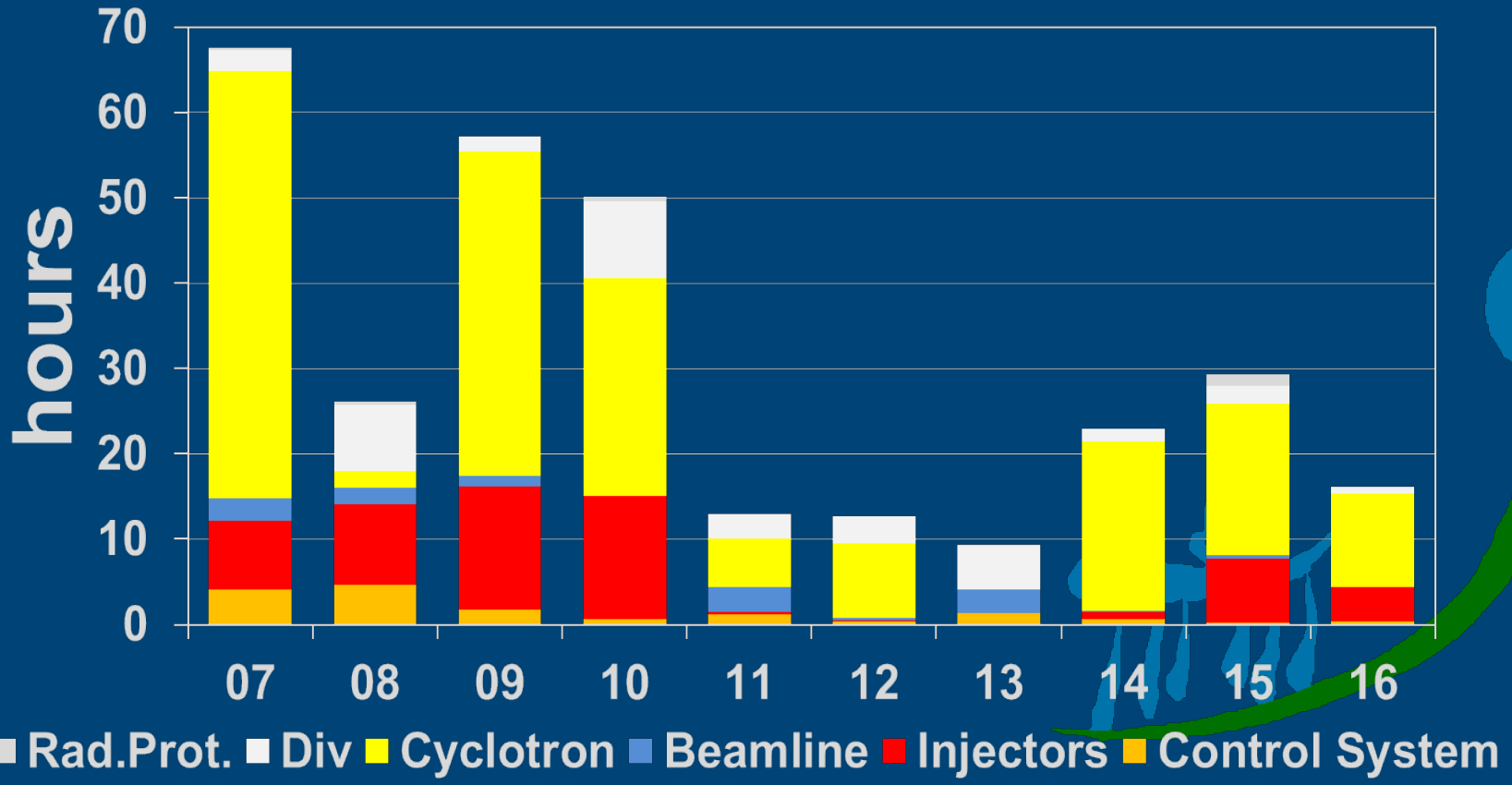
Accelerator Performance

- less 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: less than 5% when patients present



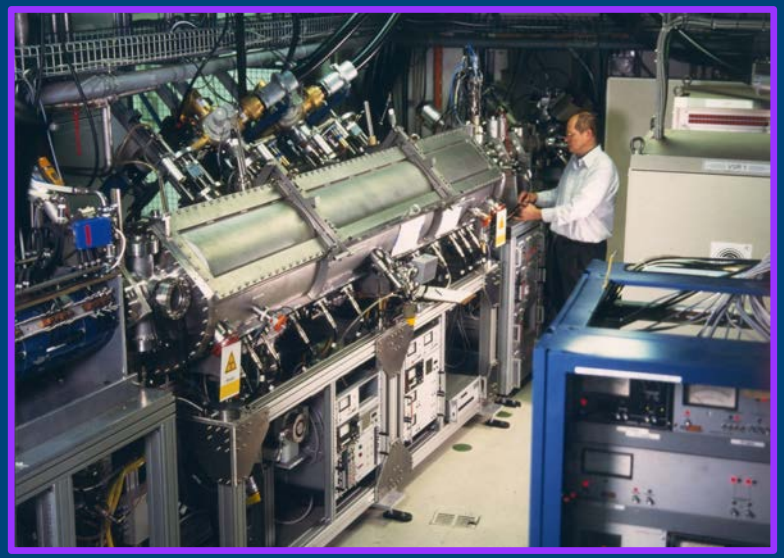
Accelerator Performance

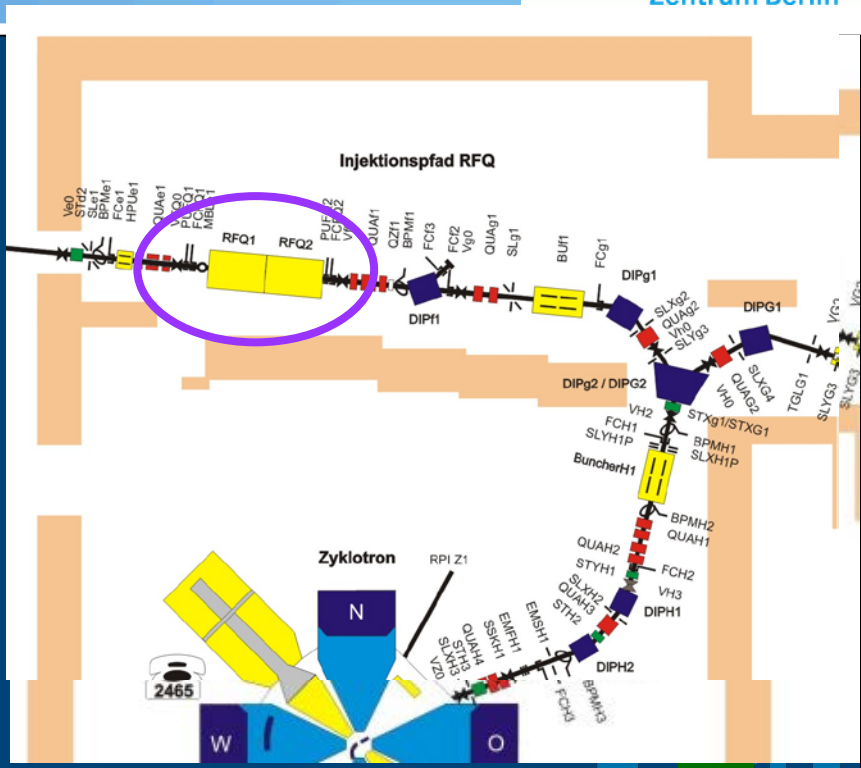
- most years: cyclotron, especially RF, is main “culprit”
  - modernize RF electronics: replacement of old low level control with modern system from iThemba labs (poster)
- external power failures
- since 2011: Tandetron = standard injector for therapy



Accelerator Layout

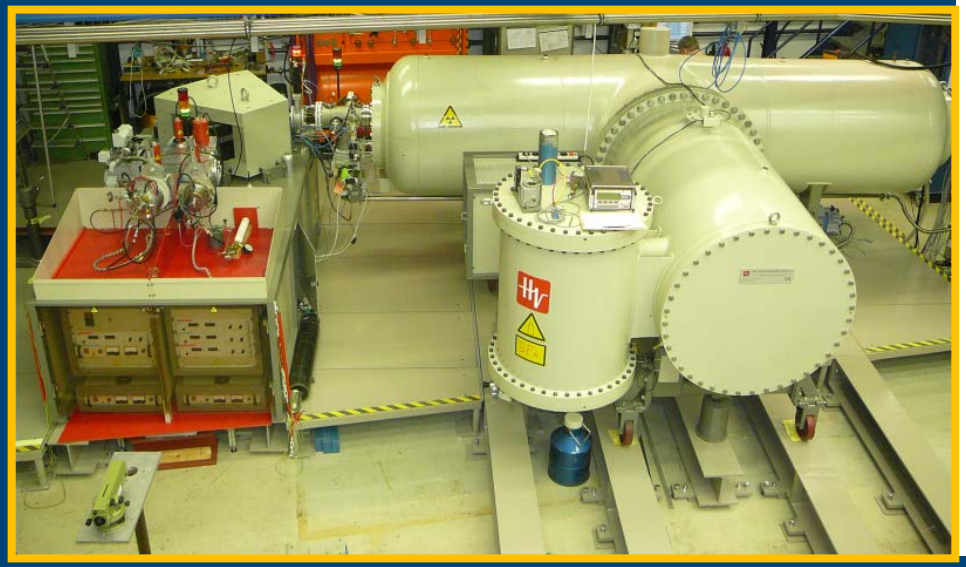
- until 2006: 14 GHz ECR plus RFQ as injector for heavy ions

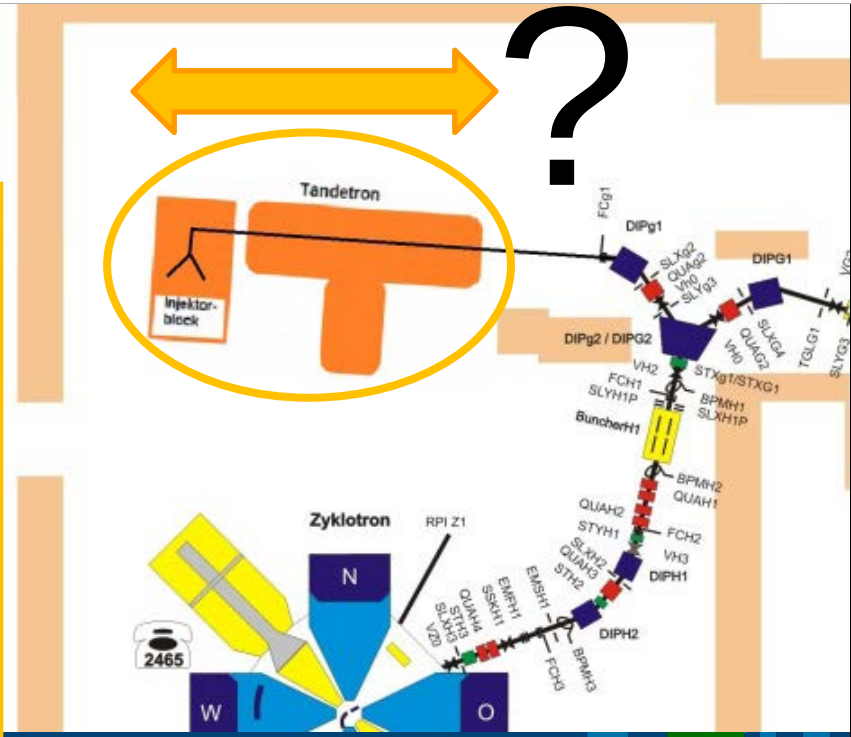




Accelerator Layout

- 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

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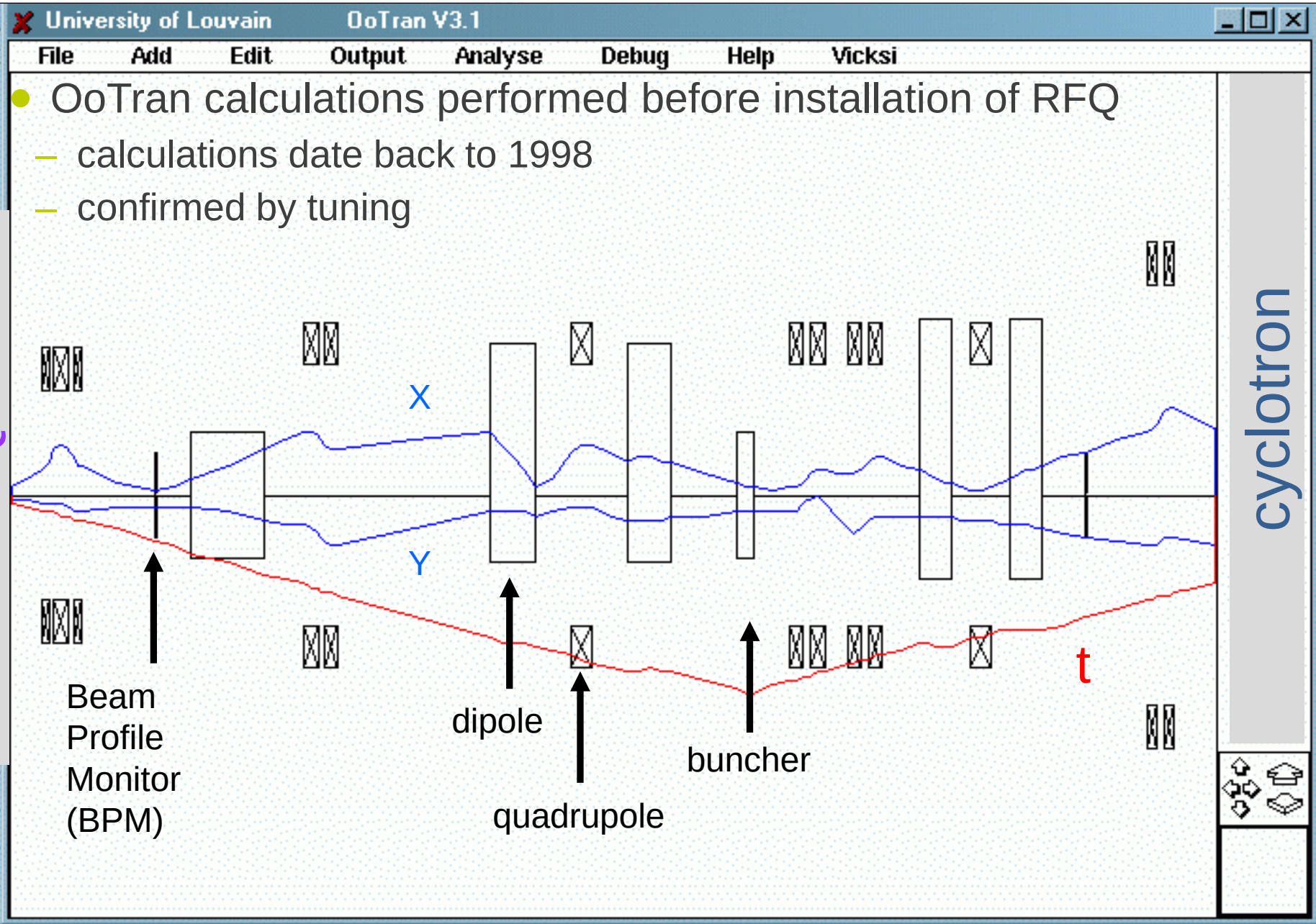
- OoTran calculations performed before installation of RFQ
  - calculations date back to 1998
  - confirmed by tuning



Beam Transport Tandetron → Cyclotron

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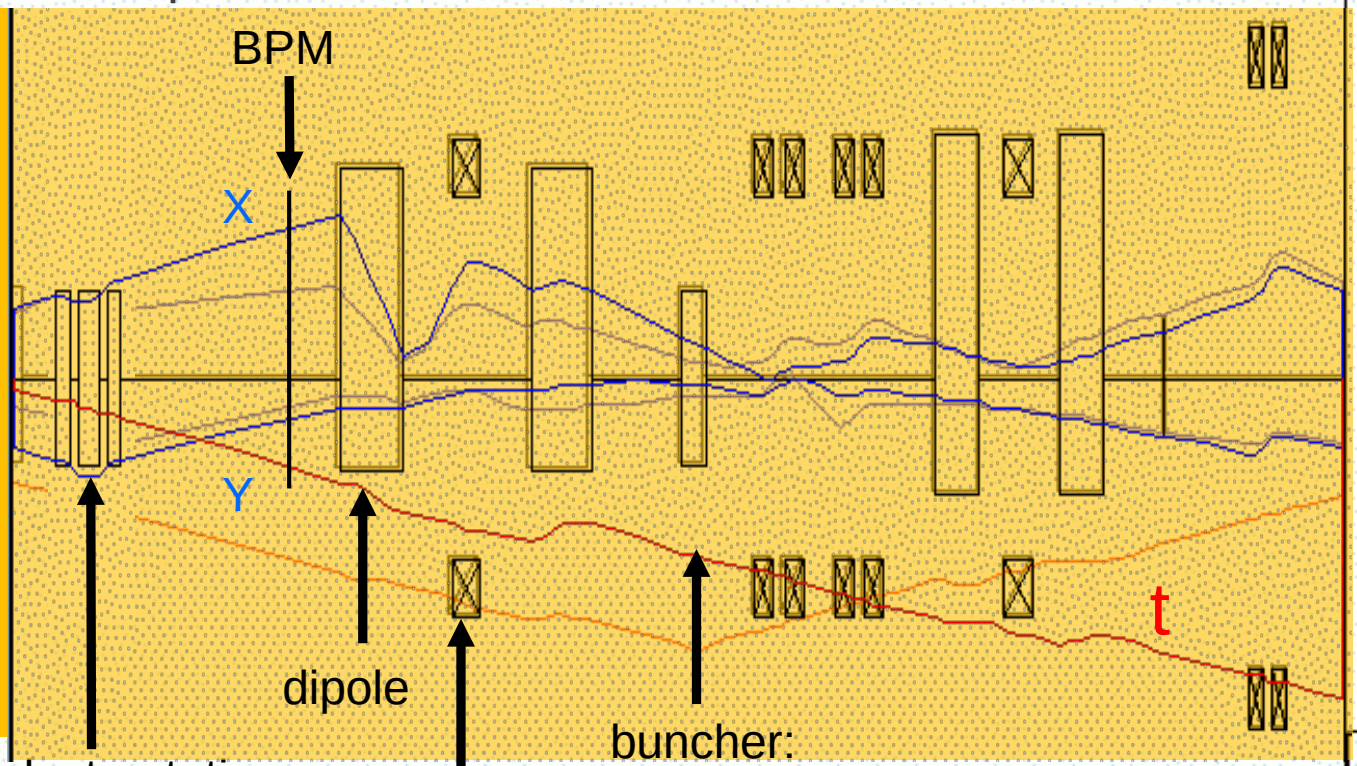
University of Louvain OoTran V3.1

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

Tandetron

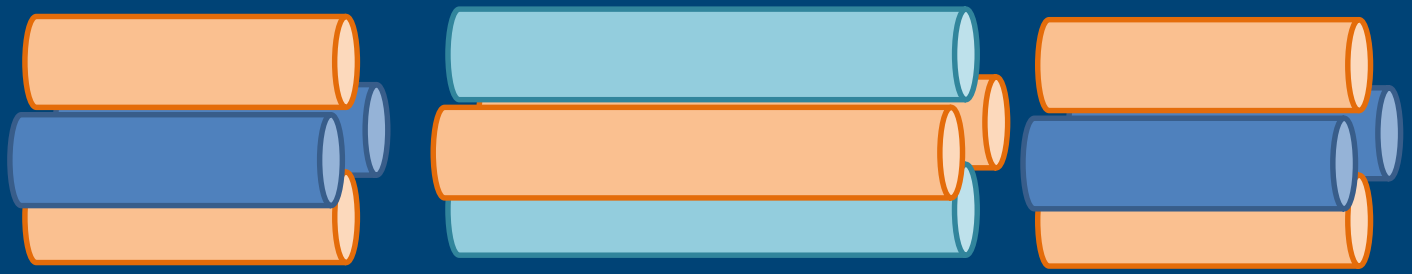


cyclotron

  - envelope not confirmed by tuning

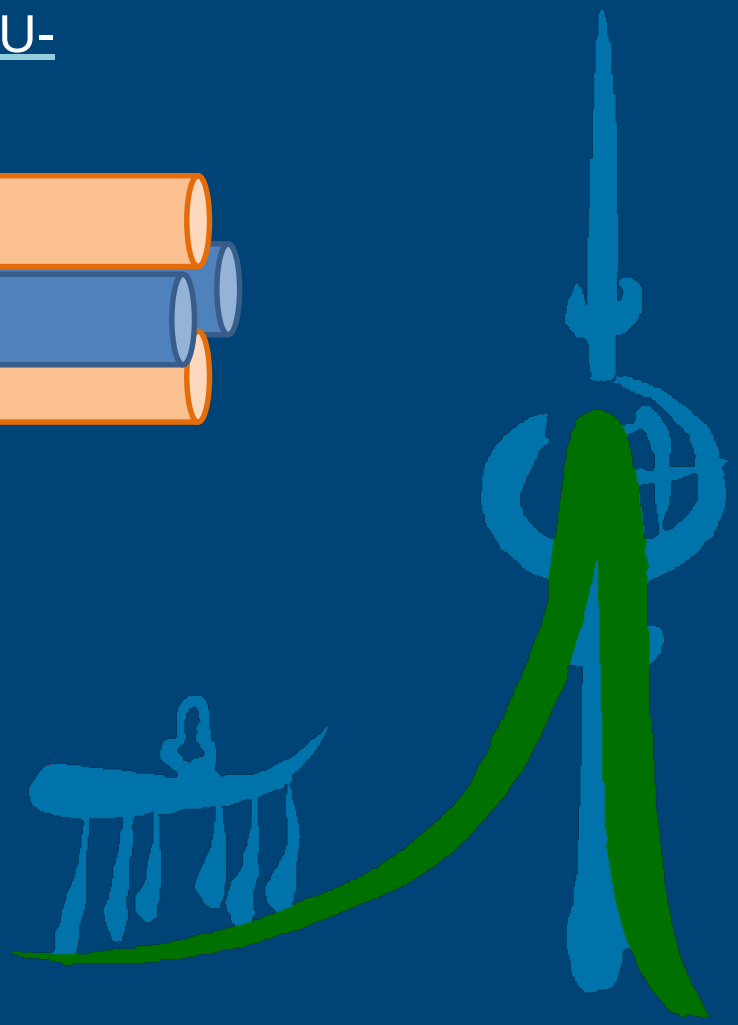
Tandetron → Cyclotron: Tuning Issues

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



- difficult to calculate

➲ asymmetric beam



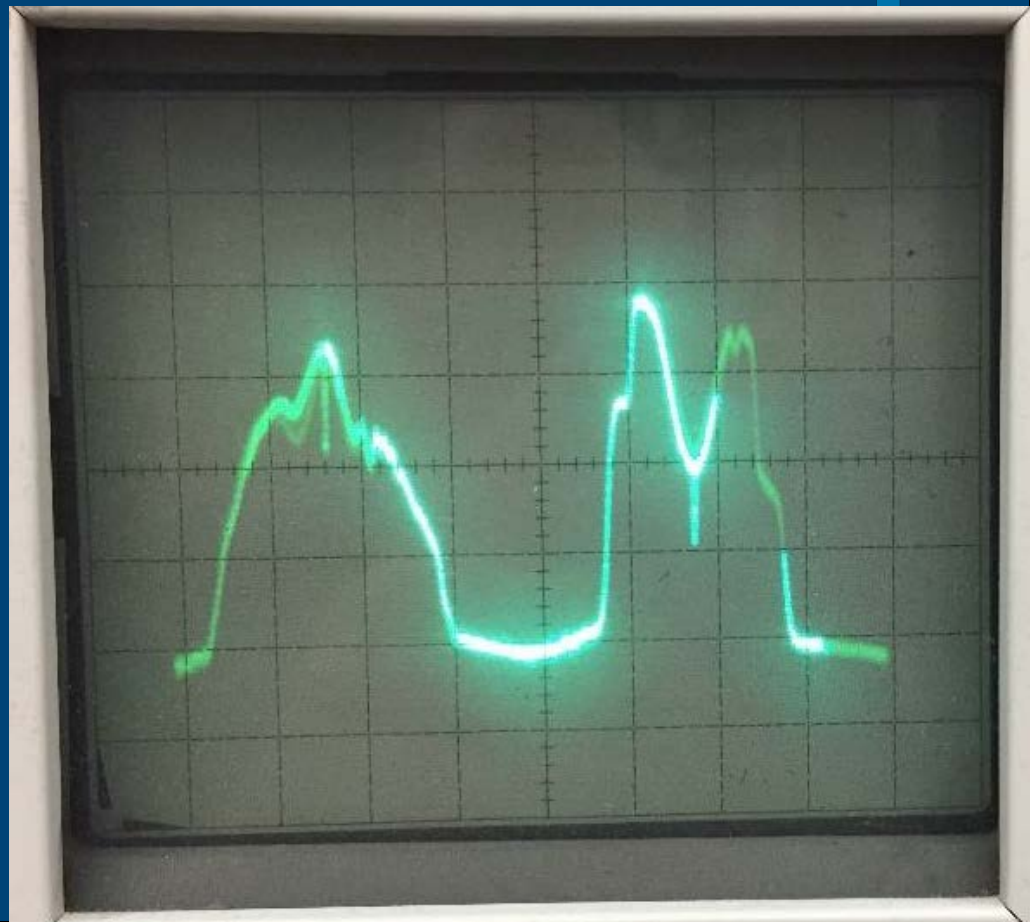
Tandetron → Cyclotron: Tuning Issues

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

➲ asymmetric beam

- was observed on beam profile monitor
- interpreted as broad x and narrow y beam,
- slightly off axis in y
  - possible off set in alignment
- “experimental” tuning: good transmission to and through cyclotron

➲ low priority



Installation of a Harp

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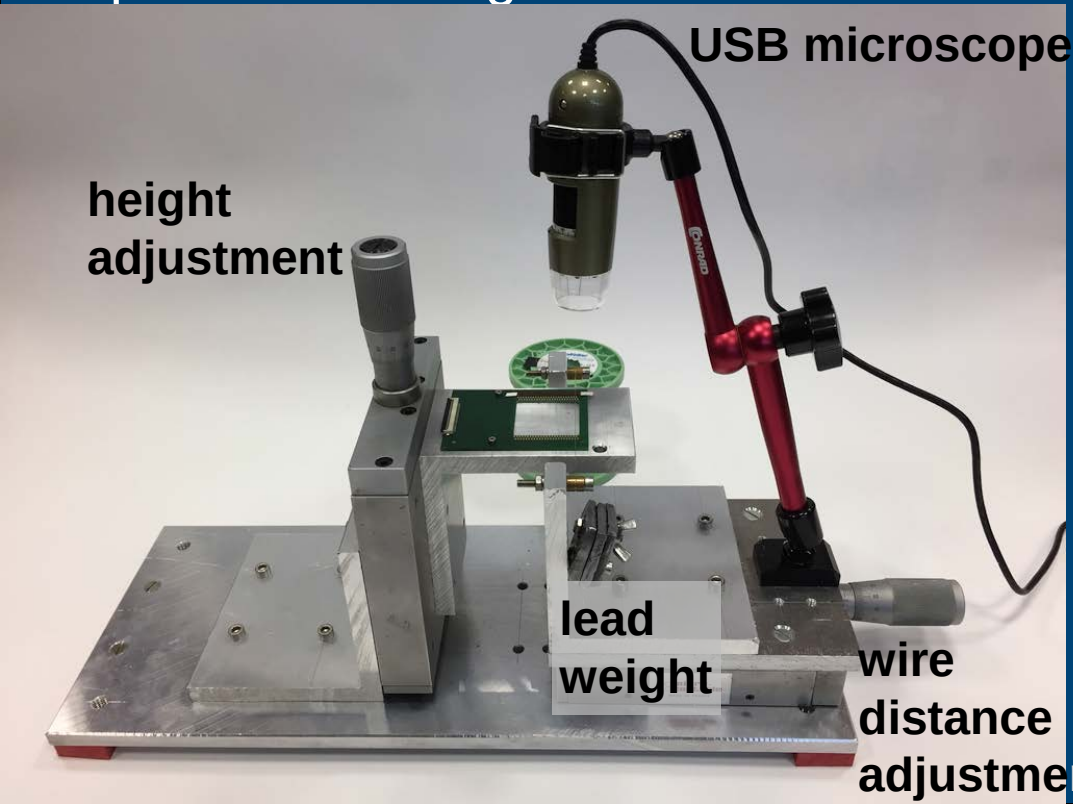
BPM not at focal point + beam emittance defined close to BPM

→ tuning ambiguous

- installation of a harp for better reproducibility
- master thesis of M. Burmeister (now at Stryker)
- 48 wires in x and y (broad beam)
- special soldering unit: Δ wire = 0.5 mm

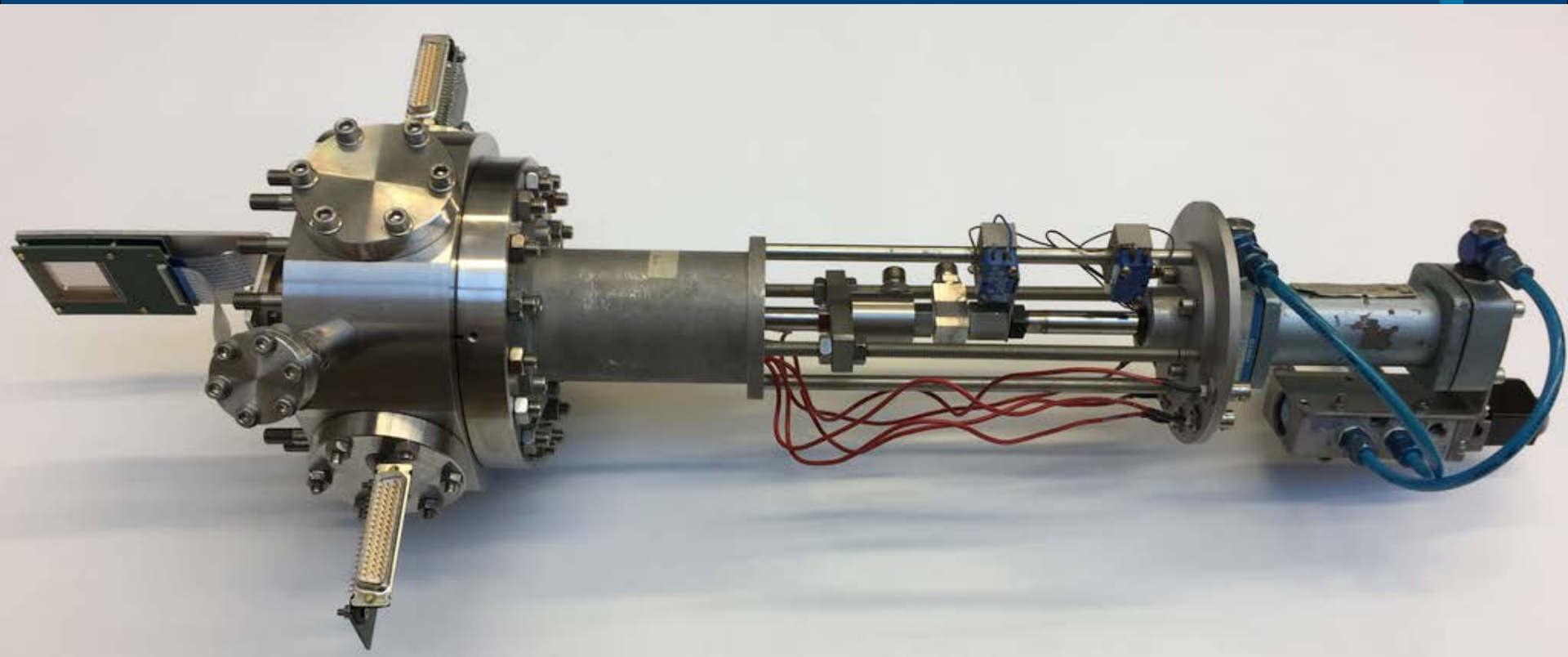


Installation of a Harp

BPM not at focal point + beam emittance defined close to BPM

→ tuning ambiguous

- installation of a harp for better reproducibility
- 25 wires in x and y (broad beam)
- mounted on standard movement unit (150 mm travel)



Installation of a Harp

BPM not at focal point + beam emittance defined close to BPM

→ tuning ambiguous

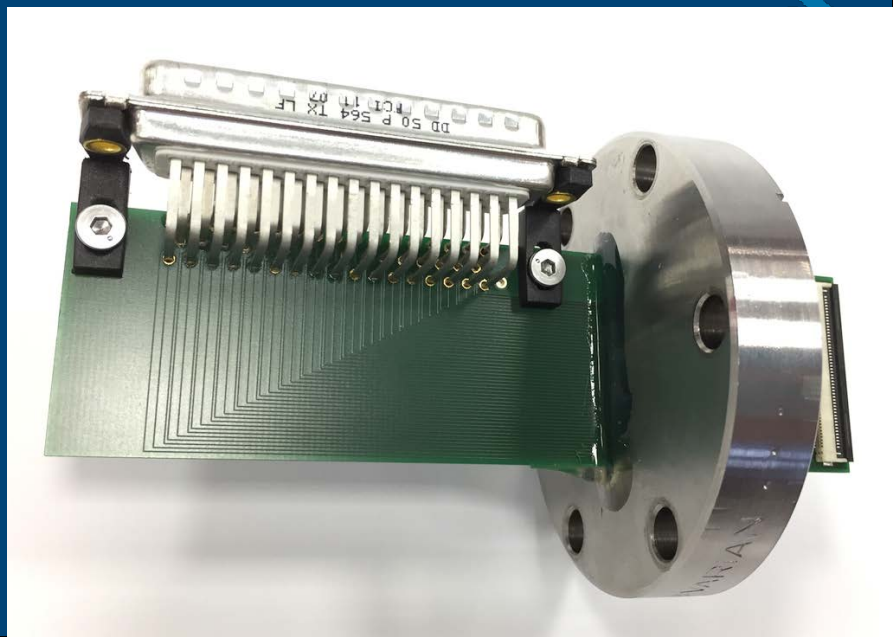
- installation of a harp for better reproducibility
- 25 wires in x and y (broad beam)
- mounted on standard movement unit
- connection via flat cable (Würth Elektronik) and PCB boards

Installation of a Harp

BPM not at focal point + beam emittance defined close to BPM

→ tuning ambiguous

- installation of a harp for better reproducibility
- 25 wires in x and y (broad beam)
- mounted on standard movement unit
- connection via flat cable and PCB boards
- vacuum feed through: PCB board and epoxy
  - after 6 hours: vacuum better than $2 \cdot 10^{-7}$ mbar
  - leak tested: $1 \cdot 10^{-9}$ mbar/(l s)
  - mass spectrometer: nothing dangerous for electrostatic quadrupole nearby

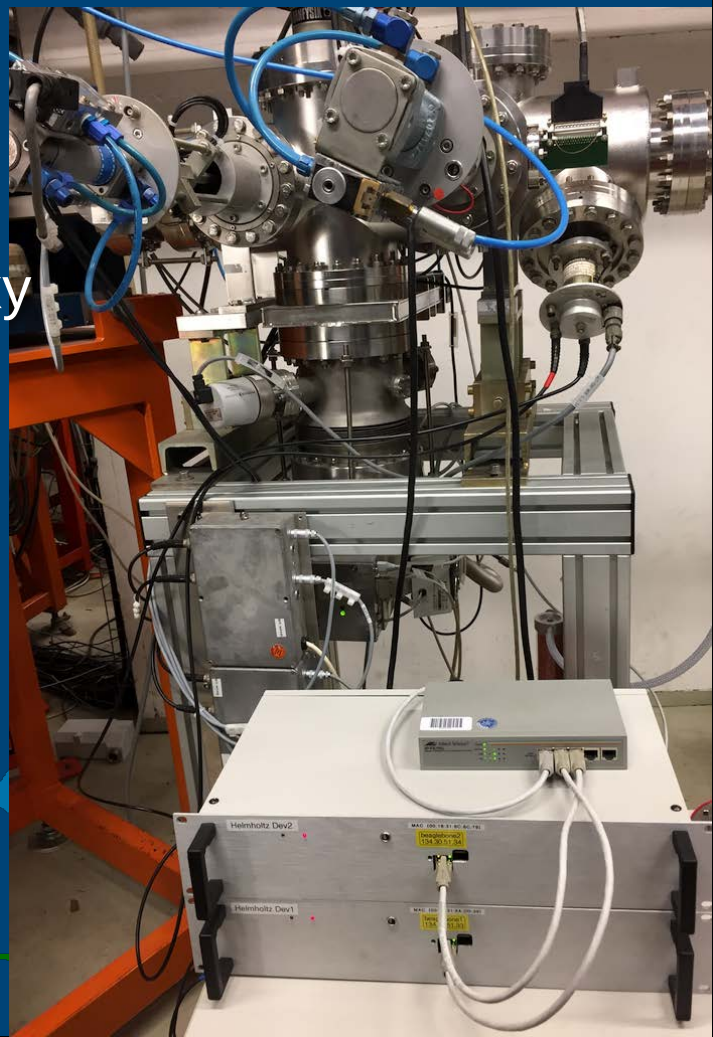


Installation of a Harp

BPM not at focal point + beam emittance defined close to BPM

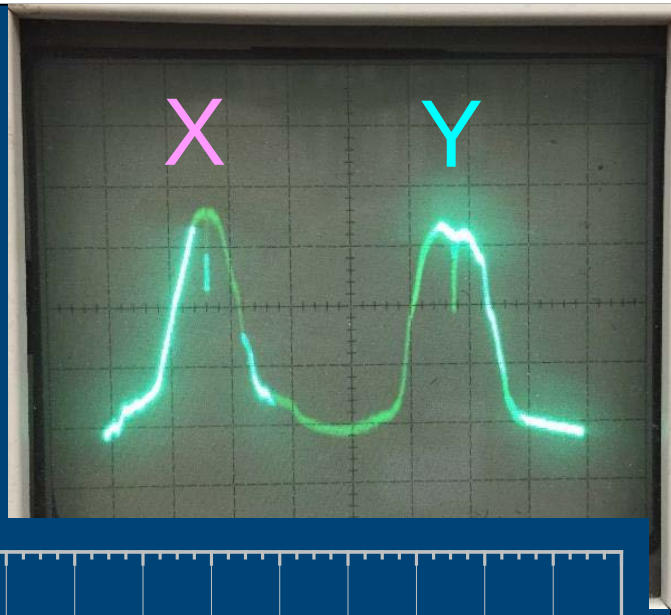
→ tuning ambiguous

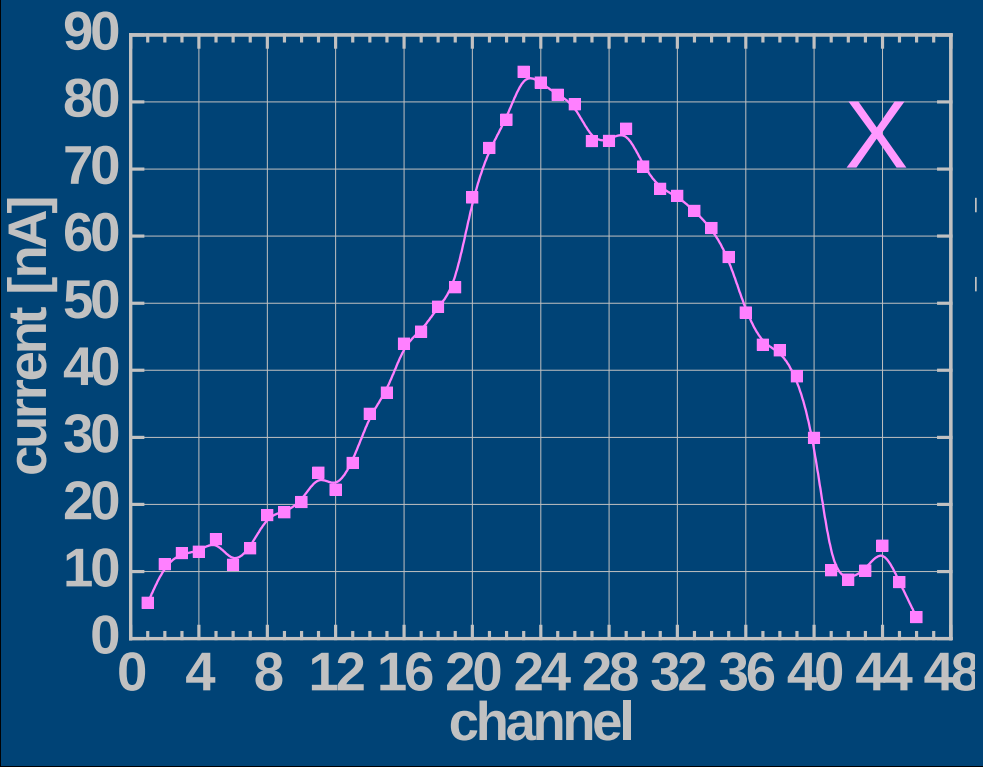
- installation of a harp for better reproducibility
- 25 wires in x and y (broad beam)
- mounted on standard movement unit
- connection via flat cable and PCB boards
- vacuum feed through: PCB board and epoxy
- electronics: “harp box” iThemba Labs

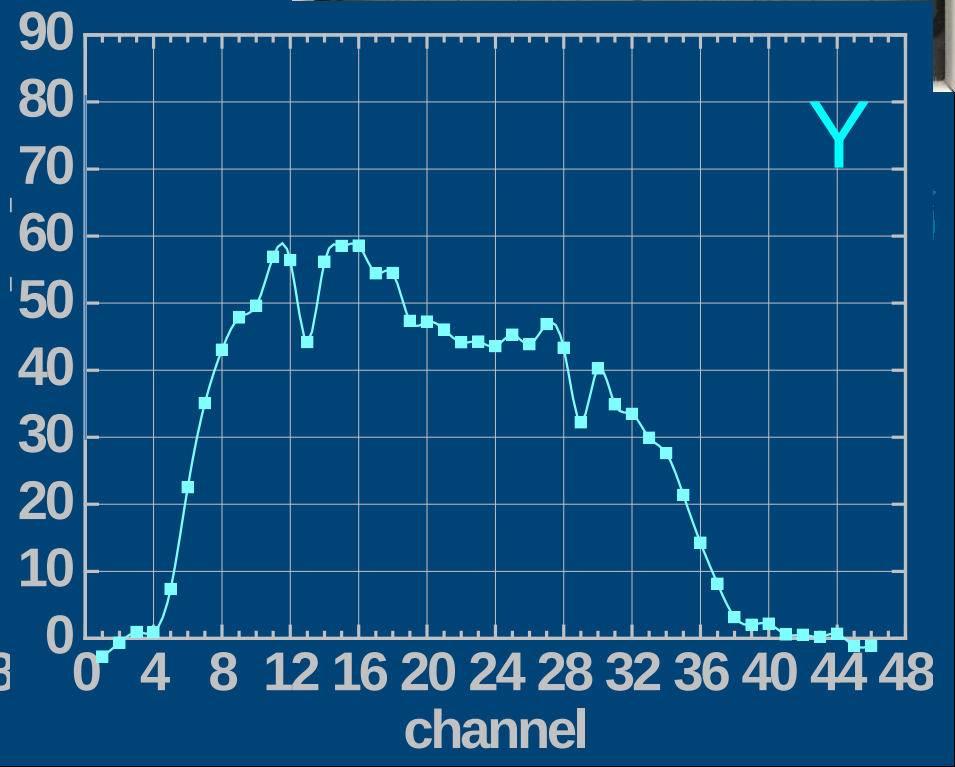


Harp: Beam Measurements

- similar profiles for harp and BPM
- beam as calculated, however:
  beam does not match into cyclotron
- operators can quantify beam width
- ➲ better reproducibility

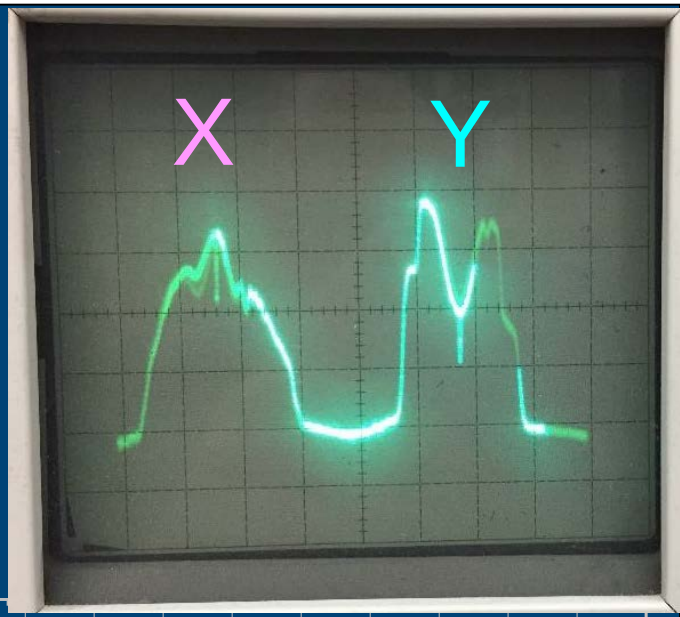


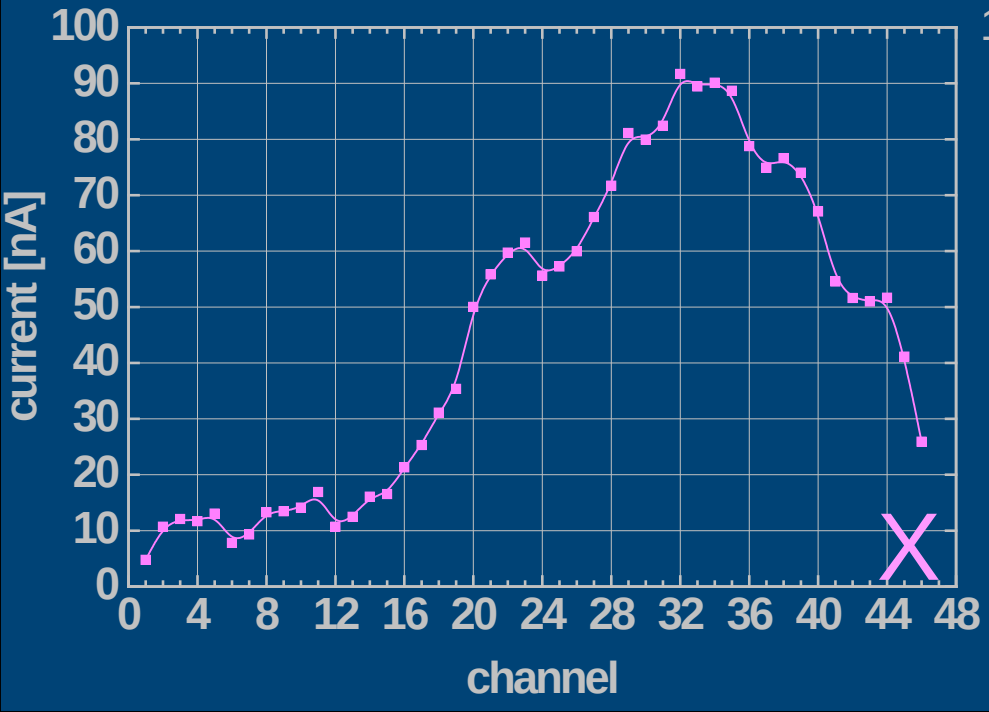


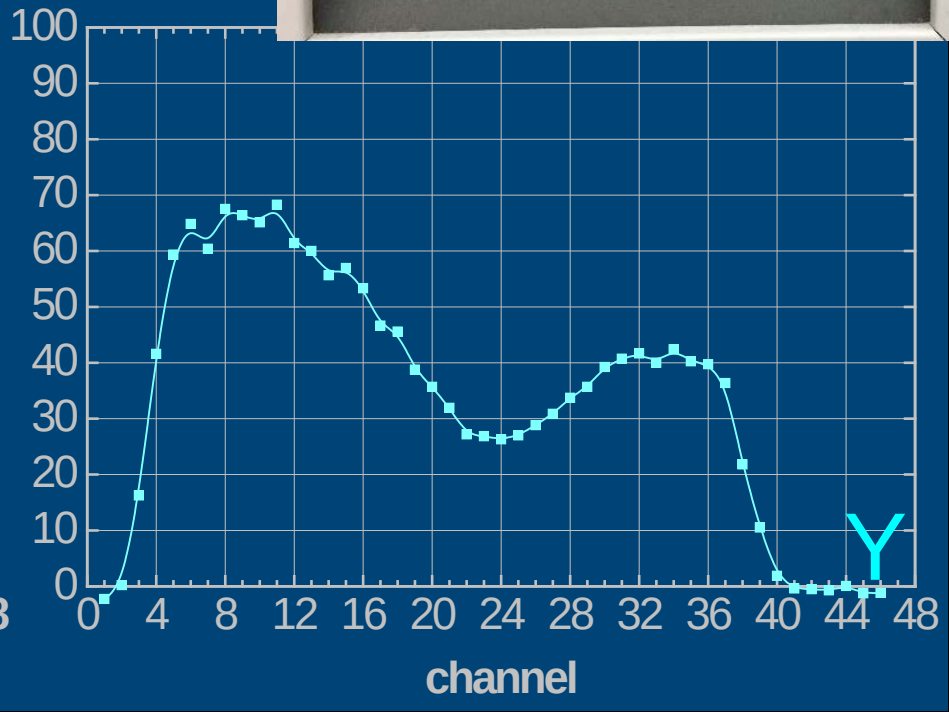


Harp: Beam Measurements

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

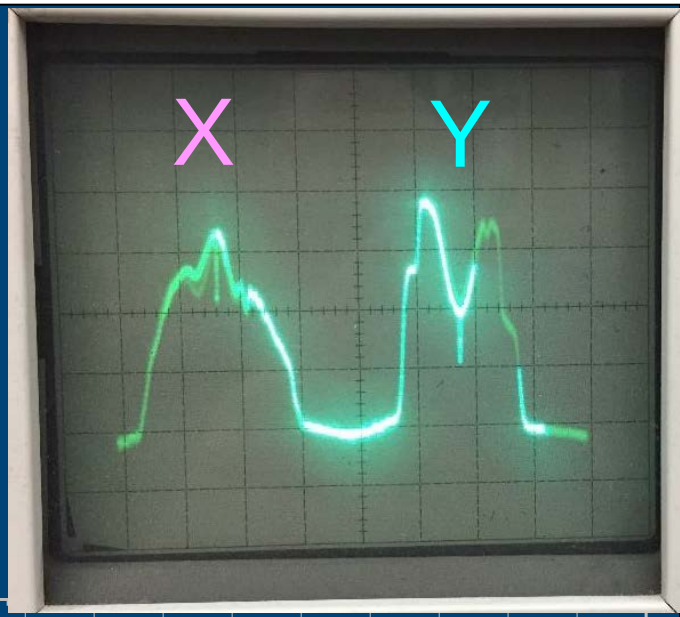


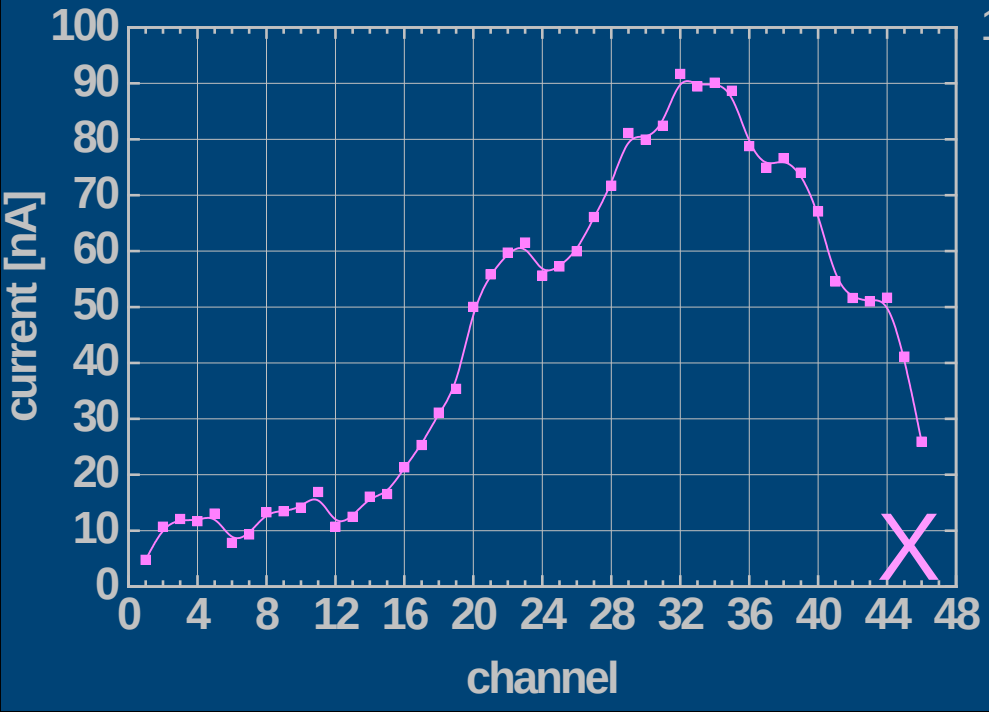


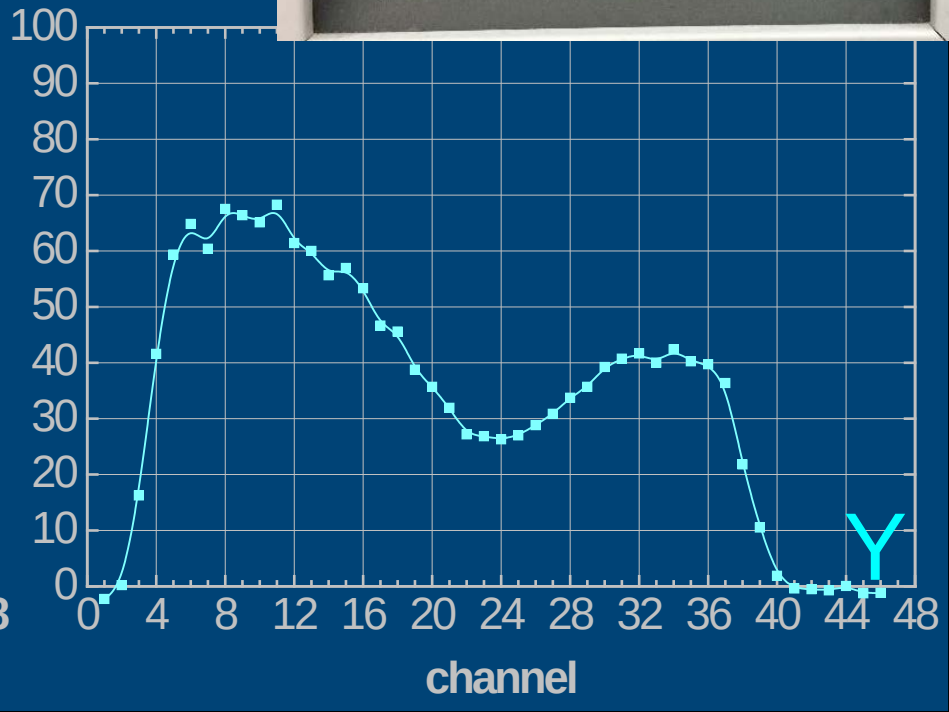


Harp: Beam Measurements

- perfect transmission through cyclotron
- in X and Y: harp profile identical to BPM!
- why double peak in Y?
- nevertheless:
  beam fully fulfils requirements of therapy
- data for reverse beam line calculations available

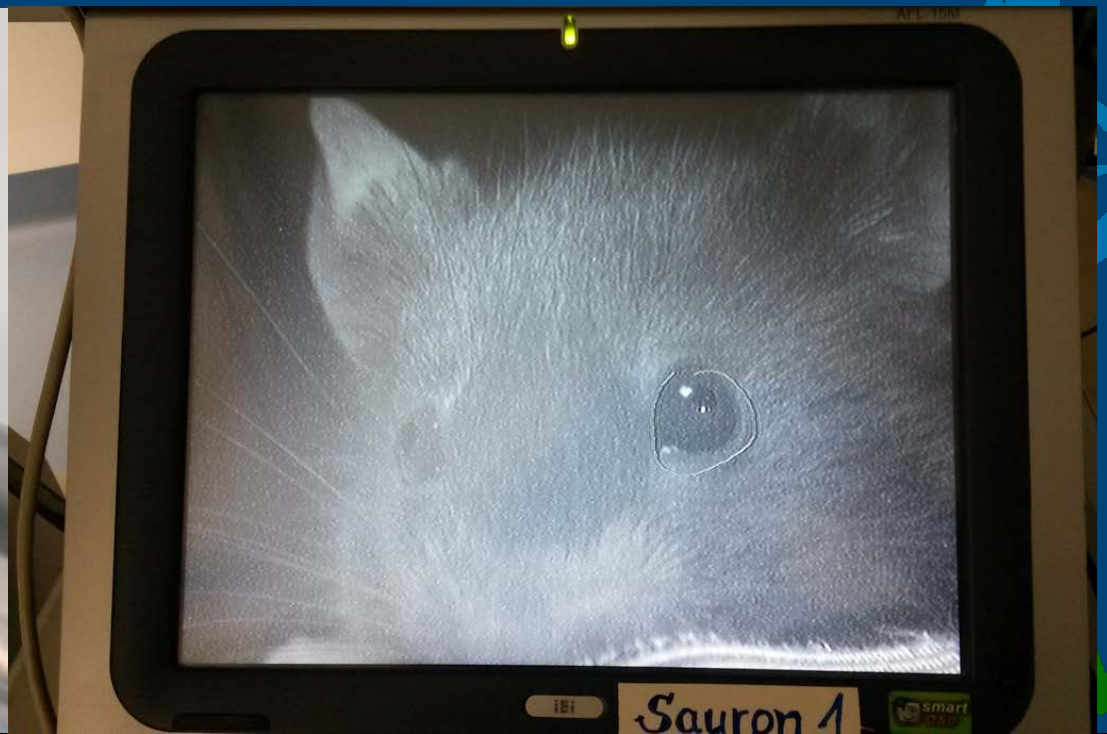






Tumour Therapy

- on-going mission: 12 therapy weeks per year, ~ 210 patients/year
- in addition to treatment:
  master students for medical physics
  - Beuth Hochschule für Technik
  - Martin-Luther-Universität Halle
- irradiation of mice (one eye) for investigation of radiation retinopathy



Conclusion

- reliable accelerator operation, past years: uptime usually > 95 %
- new ion species and energies: all light ions
- new installations
  - harp → beam line calculations now verifiable
  - new LLRF control for the cyclotron
- students for research

- 27. Jan. 2017: 3000. patient

Thank you for your attention!