Beam Diagnostic Requirements Overview

Gero Kube
DESY (Hamburg)

- Measurement Principles
- Specific Diagnostics Needs for Hadron Accelerators
- Specific Diagnostics Needs for Electron Accelerators
Accelerators world wide

accelerator applications

![Bar chart showing systems built for different applications]

- industrial applications
  - Ion Implantation: 10,000
  - E-Beam Material Processing: 7,000
  - Electron Beam Irradiation: 2,600
  - Neutron Generators: 1,500
  - Radioisotope Production: 1,500
  - Ion Beam Analysis: 1,000
  - Synchrotron Radiation: 250

particle species

- lepton beams: electrons, positrons
- hadron beams: protons, anti-protons, heavy ions


- industrial applications: \( \sum \approx 24000 \)
- medical applications: \( \sum \approx 11000 \)

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Accelerator Applications

- **cathode ray tubes**
  - Acceleration
  - Magnets as 'focusing lenses' as well as 'deflectors'

- **electron beam welding**
  - PAVAC Energy Corp., welding and machining

- **medical treatment**
  - Siemens Eclipse Cyclotron (11 MeV) marketed for PET isotope production

- **circular collider**
  - Beam Instrumentation CAS, Tuusula (Finland), 2-15 June 2018

- **linear collider**
  - 3rd / 4th generation light source

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Beam Parameters and Diagnostics

- **beam position**
  - orbit, lattice parameters, tune, chromaticity, feedback,…

- **beam intensity**
  - dc & bunch current, coasting beam, lifetime, efficiencies,…

- **beam profile**
  - longitudinal and transverse distributions, emittances,…

- **beam loss**
  - identify position of losses, prevent damage of components,…

- **beam energy**
  - mainly required by users,…

- **luminosity (collider)**
  - key parameter, collision optimization,…

  and even more: charge states, mass numbers,…
Reminder: Beam Signal Generation

- hadron / electron machines
  - difference in signal generation and underlying physical principles → rest mass
  - distinguish between hadron / electron beam diagnostics

- program for the following lectures
  - Hadron Accelerators
    → Collider, Storage Ring
    - incl. Injector Chain (Linac, Injector Synchrotron, Transfer Line)
    → Spallation Neutron Source
    → Hadron Therapy Accelerator
  - Electron Accelerators
    → Circular Collider
    → Synchrotron Light Source (3rd Generation)
    → Linac based Free Electron Laser
    → Outlook…
Hadron Collider (incl. Injector Chain)

- Linac
- Injector Synchrotrons
- Transfer Line
- Storage Ring
Hadron Collider (Storage Ring)

**HERA @ DESY**

- modern hadron collider (storage ring) with high beam energy
- Hadron Collider (Storage Ring)
- superconducting magnets to achieve required particle bending
  - parts of diagnostics located in cold vacuum
  - beam-loss monitor system for quench protection required
- long injector chain to reach final energy
  - pre-accelerators / transfer lines with different beam properties
  - different requirements for beam diagnostics

**LHC @ CERN**

- collider key parameter
- luminosity $\mathcal{L}$
  - collider performance
  - $\hat{N} = \mathcal{L} \cdot \sigma$
  - $\sigma$: cross section
    - (property of interaction)

**FAIR @ GSI**

- collider key parameter
Comments: Injector Chain (1)

- luminosity of collider
  - assumption (for simplicity)
  - identical beams: \( I_1 = I_2 = I, \quad \varepsilon_x = \varepsilon_y = \varepsilon \)
  - small beam emittances for high luminosity

- beam emittances in circular machines
  - lepton beams: formation of *equilibrium emittances* because of *radiation damping* and *quantum excitation* due to synchrotron radiation
  - hadron beams: *synchrotron radiation emission suppressed* because of large particle masses
  - emittance essentially determined in injector chain

- consequences for beam diagnostics in injector chain
  - i) accurate beam characterization already important in low energy machines
  - ii) minimum disturbing instrumentation in order to avoid emittance blow up
Comments: Injector Chain (2)

normalized emittance $\varepsilon_N$ conserved (Liouville)

absolute emittance: $\varepsilon = \frac{\varepsilon_N}{\beta\gamma}$ with $\beta\gamma = \frac{pc}{m_0c^2}$ (LHC: $\varepsilon_N = 3.75 \text{ mm mrad}$)

adiabatic shrinking with increasing beam energy

example LHC injector chain
- end of Linac II $50 \text{ MeV} \rightarrow \beta\gamma = 0.33 \downarrow$ x 1450
- extraction SPS $450 \text{ GeV} \rightarrow \beta\gamma = 480 \downarrow$ x 15
- maximum energy LHC $7000 \text{ GeV} \rightarrow \beta\gamma = 7460$

consequences for beam diagnostics
- large emittances:
  i) large beam spots and divergences
  ii) tight mesh of focusing magnets $\rightarrow$ little space for instrumentation
- low energies:
  i) particles have small magnetic rigidity $B\rho$ $\rightarrow$ easy to bend
  ii) change of particle speed with acceleration
  iii) space charge effects (especially heavy ions beams)
  iv) high energy deposition in matter (Bethe-Bloch)

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Source and Injector Linac

- example: $^3$He Injector Linac @ DESY
  - $^3$He Sources:
    - 18 keV magnetron source and rf-driven volume source
  - Low Energy Beam Transport (LEBT)
    - beam matching to acceptance of RFQ
  - Radio Frequency Quadrupole (RFQ)
    - acceleration from 18 keV up to 750 keV
  - Medium Energy Beam Transport (MEBT)
    - beam matching to acceptance of Linac
  - $^3$He Linac (Tank I – III)
    - conventional Alvarez Linac, end energy $E_{\text{kin}} = 50$ MeV
  - High Energy Beam Transport (HEBT)
    - measure beam properties for Linac tuning
    - match beam to synchrotron acceptance
  - Injection
    - $^3$He multi-turn injection using stripper foil ($\rightarrow p$ conversion)
Source and Linac Instrumentation

- key devices for
  - adjusting beam transport through linac sections
  - tuning the RF system (phase, amplitude,…)
  - indicate operating status

→ permanently installed diagnostic beamline behind linac sections

→ moveable diagnostic test bench
  (allows full 6d phase space characterization after each section)

- example

→ diagnostic bench for RFQ commissioning @ GSI

  courtesy: P. Forck (GSI)
Linac: Current and Transmission

**destructive: Faraday cup**
- low energy particles stopped in material (→ Bethe Bloch)
- very low intensities (down to 1 pA) can be measured

**non destructive: current transformer**
- beam acts as single turn primary winding of transformer
- measuring AC component of beam current

moveable Faraday cup for GSI linac

commercially available devices
Linac: Beam Position

- position information via electro-magnetic fields possible
- large bunch lengths, low acceleration frequencies
  - beam spectrum contains low frequencies (typically kHz – 100 MHz)
  - requires high sensitivity of pick-up at these frequencies
- small signals (non-propagating field with low $\gamma$)
  - capture as much field lines as possible, i.e. large electrodes

**capacitive pick-up**

**inductive pick-up**


W. Kriens, W. Radloff, DESY-S1-68/1

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**Linac: Transverse Beam Profile (1)**

- **luminescent screens**
  - destructive method
  - part of deposited energy results in excited electronic states $\rightarrow$ light emission (CCD)
  - used also for beam position (instead of BPMs)
  - high energy deposition ($\rightarrow$ Bethe Bloch)
    especially critical for heavy ion machines
  - degradation of screen material

- **profile grid, harp, secondary emission monitor**
  - less destructive method
    - **grid**: wires in both transversal planes
    - **harp**: wires in one transversal plane
    - **SEM**: strips, larger surface than wire

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P. Forck, Lecture Notes on Beam Instrumentation and Diagnostics, JUAS 2006
**Linac: Transverse Beam Profile (2)**

- **non-destructive: residual gas monitor**
  - beam interaction with residual gas
    - → creation of residual gas ions and electrons
  - electrostatic field accelerates ionization products towards Microchannel Plate
    - → secondary electron generation (multiplication \(\sim 10^6\))
  - readout via phosphor screen and CCD (optical) or via wire array and guide field (electrical)

- **variant: residual gas fluorescence monitor**

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residual gas fluorescence monitor: image of a 2.5 mA Ar\(^{10+}\) beam at vacuum pressure of 10\(^{-5}\) mbar from GSI LINAC
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Linac: Transverse Emittance

- **principle of slit-scan method**
  - low energy beams often space charge limited → cutting out small beamlet
  - slit produces vertical slice in transverse phase space
  - measure intensity as function of $x'$ (→ propagate beamlet along drift space)
  - moving of slit → scan of phase space ($N_x \times N_{x'}$ measurements)

- 2-dimensional extension: Pepper pot
  - monitor with $x'$ resolution instead of scan:
    - SEM, profile grid,…
    - $N_x$ measurements

- $\epsilon$, $x$, $x'$ monitor with $x'$ resolution instead of scan: SEM, profile grid,…
  - $N_x$ measurements

- $1$ measurement
  - $N_x \times N_{x'}$ holes

M.P. Stockli, Proc. BIW 2006, p.25

**Linac: Longitudinal Plane**

- momentum and momentum spread
  - dipole magnet spectrometer (small rigidity $B\rho$)
  - transformation of momentum (spread) into position (spread)
  - spatial resolving detector (screen, SEM,…)
    \[
    \frac{\Delta x}{x_0} = \frac{\Delta p}{p_0}
    \]

- bunch shape and time distribution
  - **Bunch Shape Monitor** (BSM)
  - primary beam hits thin wire $\rightarrow$ potential $-10$ keV
  - conversion of primary hadron beam into low energy secondary electrons
  - RF deflector converts time into space coordinates
    $\rightarrow$ operation close to RF zero-crossing
  - intensity profile $\rightarrow$ with spatial resolving detector

$\rightarrow$ alternative method: time of flight (TOF)
**Injector Synchrotron: DESY III**

- **Stripping Foil:** $H^- \rightarrow p$
- **Test Beam Area**

**First synchrotron in injector chain of HERA**
- Mean radius: 50.42 m
- RF frequency: $3.27 \rightarrow 10.33$ MHz
- Cycle time: 3.6 sec
- Injection energy: 0.31 GeV/c
- Extraction energy: 7.5 GeV/c

**Diagnostics purposes**
- Optimize injection / extraction
- Parameter control during ramp
- Fault finding

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Injector Synchrotron Diagnostics (1)

- **beam current**
  - measurement of injection efficiency (→ single bunch charge)
  - average current and coasting beam
  - AC current transformer (ACCT)
  - parametric or DC current transformer (DCCT)
  - circular accelerator → one monitor sufficient

- **beam position**
  - measurement of beam orbit (oscillation, closed orbit,…)
  - position monitors
    - usually 4 per betatron oscillation (phase shift 90°)
  - large bunch lengths, low acceleration frequencies
    - high pick-up sensitivity @ frequencies of interest

  DESY III: inductive pick-ups
  - other schemes: shoe-box types (capacitive)
  - higher acceleration frequencies and energies: striplines

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DCCT principle

~ 200 Hz

Demodulator

courtesy: F. Sannibale (LBNL)

stripline monitor

courtesy: M. Pelzer (DESY)
**Injector Synchrotron Diagnostics (2)**

- **tune**
  - eigenfrequency of betatron oscillations in circular machines
  - characteristic frequency of magnet lattice, produced by strength of quadrupole magnets

- **principle of tune measurement**
  - excite coherent betatron oscillations \(\rightarrow\) kicker
  - observe dipole moment due to (coherent) transverse beam oscillation
    \(\rightarrow\) primary observable: time sequence of turn-by-turn position
  - FFT of response

- **comments**
  - excitation leads to emittance blow-up
    \(\rightarrow\) small excitation required
  - \(\rightarrow\) high pickup sensitivity necessary
  - high space charge at injection (acceptance occupied)
    \(\rightarrow\) excitation can lead immediately to particle losses

- **example: DESY III**
  - no tune measurements in standard operation
  - tune measurements only in dedicated machine studies
    \(\rightarrow\) reproducible set-up of machine
**Injector Synchrotron Diagnostics (3)**

- **transverse profiles / emittances**
  - **screens** (destructive)
    - for commissioning, if doubts about signals from other monitor
  - **wire scanners** (less destructive)
    - thin wire quickly moved across the beam (> 1 m/sec)
    - simultaneous detection of secondary particle shower outside vacuum chamber with scintillator/photo-multiplier assembly
    - secondary particle shower intensity in dependence of primary beam energy
      - for beam energy below 150 MeV use instead secondary emission (SEM) current of isolated mounted wire

- **residual gas monitor** (non-destructive)
  - vacuum pressure in synchrotron much better (10^{-10} mbar) than in linac/transfer line (10^{-6} - 10^{-8} mbar)
  - much lower signal → local pressure bump…
Injector Synchrotron Diagnostics (4)

- bunch lengths and time structure
  - measure bunch length ($\rightarrow$ nsec) and longitudinal oscillations
  - wall current monitor
    $\rightarrow$ offers bandwidth up to a few GHz

- losses
  - indication of beam losses in specific critical places
    $\rightarrow$ optimization of injection and extraction
  - Beam Loss Monitors (BLMs)
    - comment: pbar and heavy ion machines
      - source emittance worse, adiabatic emittance shrinking not sufficient for final beam quality
        $\rightarrow$ emittance improvement (for bunched beams) by electron cooling
      - smaller cooling time at smaller beam energy
        $\rightarrow$ cooling performed typically in low energy synchrotron
  - Schottky diagnostics
    $\rightarrow$ exploit individual particle behavior (Schottky noise) in beam spectrum

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Example: LEIR @ CERN

Low Energy Ion Ring LEIR


C. Bal et al., Proc. of DIPAC'05, Lyon (France), 2005, p.258

Layout of the LEIR complex and instruments.

C. Bal et al., Proc. of DIPAC'05, Lyon (France), 2005, p.258
Transfer Line Diagnostics

- **transfer line**
  - linking circular machines while matching the optical beam parameters
  - adjust beam transport
    - control transfer efficiency:
      - **AC current transformers**
    - control beam position (steering)
      - **BPMs and/or screens**
  - determine beam quality
    - transverse emittance via beam profiles
      - i) measure beam size versus quadrupole field strength using one device
      - ii) measure beam size using multiple measurement devices for fixed optics
      - **screens, residual gas monitors,…**
  - protect machine
    - control of beam losses, machine interlock
      - **BLMs**

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**Transfer Line Diagnostics (2)**

**beam steering philosophy**

- entry of transfer line: *extracted beam information*
  - position/angle: *pair of pick-ups*
  - qualitative shape: *screen*

- central section: *stepwise steering & beam quality*
  - each steering magnet paired with *pick-up* (phase advance ~90°)
  - emittance measurement: *screen(s)* in dispersion-free section

- exit of transfer line: *precision steering*
  - two steerer magnets used as doublet
  - adjust angle/position at septum to match condition for closed orbit of next accelerator section

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P.J. Bryant, Proc. CERN Accelerator School, CERN 94-01, Vol.1
Storage Ring (Collider) Diagnostics

- **Intensity**
  - bunch charge, stored dc current: lifetime, coasting beam

- **Orbit**
  - lattice parameters (co): comparison between design and real machine
  - injection: elimination of mismatches (oscillations)

- **Tune, Chromaticity, Coupling**
  - working point: avoid instabilities and losses

- **Beam Distribution, Emittance**
  - beam profile: control of beam quality for luminosity
  - injection mismatch: optimization of injection
  - instabilities: observation of shape oscillations

- **Luminosity**
  - count rate in experiments: tuning of collision at IP

- **Energy**
  - cms energy for particle production

- **Quench Protection**
  - loss monitors: prevent damage of magnets
Storage Ring Diagnostics: Remarks

- **superconducting magnets and consequences**
  - cold environment because of liquid He
    
    HERA @ 4.4 K, LHC @ 1.8 K
  - consequence for beam diagnostics
    
    → beam instruments in cold environment
    
    → careful instrument design: minimum heat transfer from beam instruments to the environment (e.g. by HOM heating)
    
    → no intercepting diagnostics in (close to) cold sections because particle shower may lead to magnet quenches
    
    → protect beam intercepting monitors against possible misuse, i.e. *interlock system*

- **common strategy**
  - concentration of beam instrumentation in straight sections (*insertions*) without need for particle bending
    
    → most instruments can be placed in warm environment
  - BPMs (which has to be placed all around the ring for closed orbit) partly in cold environment
    
    → BLMs (not in vacuum) installed all around the ring
Storage Ring Diagnostics (1)

- **intensity**
  - bunch charge, filling pattern: AC current transformer (ACCT)
  - mean current: DC or parametric current transformer (DCCT)
  - examples: from HERA p diagnostics

- **intensity related parameters**
  - coasting (unbunched) beam: \[ I_{CB} = I_{DC} - \sum_{i=1}^{N_{bunch}} I_{AC(i)} \]
  - life time: \[ \frac{1}{\tau(t)} = - \frac{1}{N} \frac{dN}{dt} \]
Storage Ring Diagnostics (2)

- orbit, trajectory, oscillations
  - BPMs: for cold and warm environment
  - choice of type depends on:
    - linearity, dynamic range, resolution
  - → stripline monitor, button electrode pick-up

LHC resolution achieved:

- < 150 µm (single bunch & single turn), < 10 µm (avg. orbit of all bunches)

LHC orbit during commissioning

LHC cold button pick-up
courtesy: Ch. Boccard (CERN)

HERA p cold stripline
courtesy: S. Vïcins (DESY)
Storage Ring Diagnostics (3)

- Tune (chromaticity, coupling) → defines working point of accelerator
  - Principle: transverse beam excitation → excite coherent transv. oscillations
    → FFT mode / Swept Frequency mode / PLL mode
  - Constraint: minimize emittance blow up due to excitation
    → high sensitivity pick-up detector
    → minimum disturbing excitation scheme
- Excitations:
  i) Tune kicker: white noise kick, simple and robust (typically for commissioning)
  ii) Tune shaker: swept frequency (sine wave)

**HERA p tune spectrum** (repetitive chirp excitation & resonant „Schottky type“ pick-up)

- Comments
  - Chromaticity: via head-tail phase shift
  - Passive (without external excitation): Schottky spectrum contains informations about tune, chromaticity,…

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tune, chromaticity: dynamic effects in superconducting storage rings

- s.c. eddy currents / persistent currents: strong influence on storage ring performance at injection energy
  - affect multipole components of s.c. dipole magnet (HERA: most important sextupole component)
  - are not really persistent (decay with time)
  - need correction
- persistent currents are reinduced to their full strength on first steps of the ramp, approaching original hysteresis curve

"Snap Back": requires reliable control during ramp

- online measurements (magnetic multipole components), correction tables, ...

beam ramping up

- tune and chromaticity feedback
  - HERA @ DESY: "Brain Locked Loop" (BLL)
    - 6 knobs (2 x tune, 2 x chromaticity, 2 x coupling)
    - experienced shift crew (at least two people)
  - LHC @ CERN: Phase Locked Loop (PLL)
Storage Ring Diagnostics (5)

- transverse beam profile and emittance
  - single pass diagnostics
    - simple and robust, high sensitivity (single or few bunches only), modest demand on accuracy
    - luminescent screens
  - profile diagnostics for few turns
    - study of injection mismatch (betatron, dispersion matching on first turns observing shape oscillations)
      turn by turn acquisition (10-20 turns), modest demand on accuracy
      only moderate beam blow up allowed, energy deposition in screen is critical
    - Optical Transition Radiation (OTR) using thin foils
  - diagnostics for the circulating beam
    - evolution of the rms beam size, emittance measurements, tilt due to coupling
      minimum beam blow-up (→ non-intercepting measurements), high accuracy
    - residual gas (luminescence) monitors
    - fast wire scanners (flying wires, > 1 m/sec)
    - synchrotron radiation monitor
      (fringe field, short magnet, undulator)
Storage Ring Diagnostics (6)

- longitudinal beam distribution and time structure
  - longitudinal profile
    - classical longitudinal bunch parameters:
      - bunch center of gravity, rms bunch length, core distribution
  - examples (1σ values)
    - HERA $p$ @ 920 GeV: $\sigma_t = 1.6$ nsec
    - LHC @ 450 GeV: $\sigma_t \sim 0.425$ nsec
      @ 7 TeV: $\sigma_t \sim 0.250$ nsec
  - abort gap monitoring
    - continuous monitoring that rise time gap of dump extraction kicker is free of particles
      if particles in gap would not receive proper kick when dump system is fired:
        - damage of machine components
  - detection of ghost bunches
    - may disturb BPM system read-out or physics data taking

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Storage Ring Diagnostics (7)

- **luminosity**
  - need: determines accelerator performance
  - principle: choose reaction channel with known cross section $\sigma_{rc}$
    - count rate measurement for events $N_{rc}$ of this channel
    - $\rightarrow$ **luminosity:** $\mathcal{L} = \frac{N_{rc}}{\sigma_{rc}}$
  - problem: *hadronic* cross sections are **not precisely calculable** because of constituent particle nature
    - reaction rates do not serve as absolute luminosity monitors, i.e. only for optimization
    - absolute luminosity determination complicated task, often duty of experiments
  - example: ep collider *HERA*, absolute luminosity determination via *Bremsstrahlung* (Bethe-Heitler):
    - $e \ p = \gamma \ e' \ p'$
    - $\rightarrow$ cross section well known

- **energy**
  - importance: hadron-hadron collider absolute energy determination relatively unimportant
    - constituent nature of hadrons (quarks and gluons) which share beam momentum
    - total energy in reaction only loosely related to beam energies
  - measurement: beam momentum via dipole current is sufficient
quench protection / loss monitors

- stored beam energy:

\[
\begin{align*}
\text{Energy stored in the beam [MJ]} & \quad \text{Momentum [GeV/c]} \\
100.00 & \quad 10.00 \\
10.00 & \quad 1.00 \\
1.00 & \quad 0.10 \\
0.10 & \quad 0.01 \\
0.01 & \quad 1 \quad 10 \quad 100 \quad 1000 \quad 10000
\end{align*}
\]

- quench level of a cable: HERA @ 820 GeV

\[ \Delta T_c = 0.8 \text{ K} \] between He bath temperature \( T_b = 4.4 \text{ K} \) and quench temperature \( T_{cs} = 5.2 \text{ K} \)

- beam loss monitors

  \[ \rightarrow \] gas ionization chambers, PIN diodes, photomultipliers & scintillators, SE multiplier tubes…
Examples for Hadron Accelerator Diagnostics

- Spallation Neutron Source
- Hadron Therapy Accelerator
Spallation Neutron Source

- **motivation:** n production mechanisms
  - fission (reactor)
    - → chain reaction
    - → continuous flow
    - → 1 neutron / fission
  - spallation (accelerator driven)
    - → no chain reaction
    - → of interest: short pulse operation
      - allows time resolved experiments
    - → 20 ~ 30 neutrons / proton

- **beam characteristics**
  - proton beam energy
    - → number of neutrons proportional to E in range of 0.2 ... 10 GeV
  - average beam power:
    \[ P_{beam}[\text{MeV}] = E[\text{GeV}] \cdot I_{pulse}[\text{mA}] \cdot \Delta t_{pulse}[\text{sec}] \cdot f_{rep}[\text{Hz}] \]

E = 1 ... 3 GeV

\[ P_{beam} = 1 \ldots 5 \text{ MW} \]
Spallation Neutron Source

- general accelerator layout

- example: European Spallation Source ESS @ Lund (Sweden)

- Spallation Neutron Source SNS @ Oak Ridge (USA)

- Japan Spallation Neutron Source JSNS of J-PARK, Tokai (Japan)

- Swiss Spallation Neutron Source SINQ @ PSI (Switzerland): (continuous beam from cyclotron)

- implications on beam diagnostics: handling of high beam power

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High Power Diagnostics

- **achieving high beam power**
  - systems to help understanding dynamics of intense beams
    - → beam halo measurements, …

- **measuring high power beams**
  - diagnostic systems that can measure fundamental beam parameters during full power operation
  - challenging: transverse beam profiles
    - → laser systems for H\textsuperscript{-} beams, ionization profile monitors for p beams, …

- **protecting the diagnostics**
  - protect diagnostic systems that cannot survive high power beams
    - → machine protection interfaces for intercepting devices, …

- **protecting the facility**
  - diagnostics that protect the facility from beam-induced damage or activation
    - → loss monitors, beam-on-target diagnostics, …

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T. Shea (SNS/ESS), talk held at EPAC04

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Diagnostics for SNS @ ORNL

courtesy: T.Shea (ESS/SNS)

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Hadron Therapy Accelerator

- hadron therapy
  - damage DNA of tumor cells with high-energetic ion beams
  - requirement: constant and high dose profile at tumor
    low dose at critical organs

- 3D beam scanning over tumor region
  - transverse directions
    → pencil beam scanning
  - longitudinal direction
    → energy/intensity alignment of many Bragg-peaks allow creation of Spread-Out Bragg Peak (SOBP)

- implications on beam diagnostics
  - non destructive diagnostics during patient treatment
  - precise determination of position & size, energy & intensity

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Facility Layout

example: Heidelberger Ionenstrahl-Therapiezentrum (HIT), Germany

(1) ion sources
- 2 ion sources (p, H$_2$, C$^{4+}$, O$^{6+}$)
- typical 130 µA C$^{4+}$ DC-beam

(2) 2-stage linac
- four-rod RFQ-structure (400 keV/u)
- IH-DTL (7 MeV/u)
- 30µs-Macropulse: 50 µA C$^{6+}$

(3) synchrotron
- 64 m circumference
- magnetic rigidity: 6.6 Tm
- E= 48 - 220 MeV/u (proton)
- E= 88 - 430 MeV/u (carbon)
- $6 \times 10^8$ Carbon

(4) heading towards treatment room
(5) treatment room
(6) position control
(7) gantry
(8) treatment room in gantry


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Beam Diagnostics for Medical Accelerators

OMA: Optimization of Medical Accelerators

- EU project
  → https://www.liverpool.ac.uk/oma-project/
- organization
  → University of Liverpool

Workshop about Beam Diagnostics:

Topical Workshop on Diagnostics for Beam and Patient Monitoring

4-5 June 2018
CERN
Europe/Zurich timezone