Accelerator Laboratory: Introduction to Beam Diagnostics and Instrumentation

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DESY / MDI

- Introduction
- Beam Position Monitor
- Transverse Emittance / Beam Profile

Diagnostics and Instrumentation

- **instrumentation**
  - catchword for all technologies needed to produce primary measurements of beam parameters
- **diagnostics**
  - making use of these instruments in order to
    - operate the accelerators
      → orbit control
    - improve the accelerator performance
      → feedback, emittance preservation
    - deduce additional beam parameters or performance indicators of the machine by further data processing
      → chromaticity measurements, betatron matching, … (examples for circular accelerator)
    - detect equipment faults

H. Schmickler, Introduction to Beam Diagnostics, CAS 2005

- **outline**

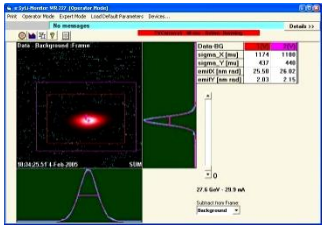
➡ **emphasis on beam instrumentation**

Beam Instrumentation for…

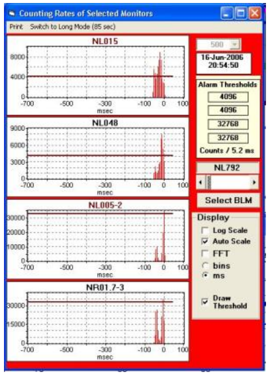
- **beam position**
  - orbit, lattice parameters, tune, chromaticity, feedback,…

- **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,…



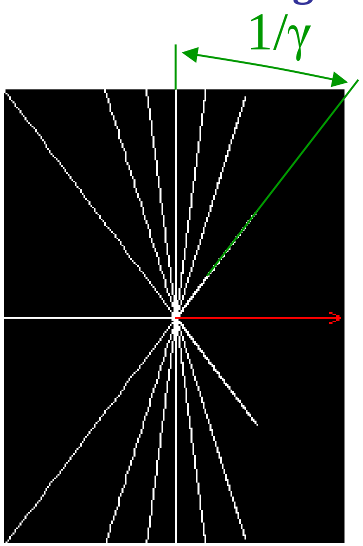
- **beam energy**
  - mainly required by users,…
- **luminosity (collider)**
  - key parameter, collision optimization…

and even more: charge states, mass numbers, timing…

Beam Monitors: Physical Processes

- influence of particle electromagnetic field
  - non-propagating fields, i.e. electro-magnetic influence of moving charge on environment
    → beam transformers, pick-ups, …
  - propagating fields, i.e. emission of photons
    → synchrotron radiation monitors, (OTR), …

particle electromagnetic field



electric field lines in LAB frame

relativistic contracion characterized by Lorentz factor

$$\gamma = E / m_0 c^2$$

E : total energy

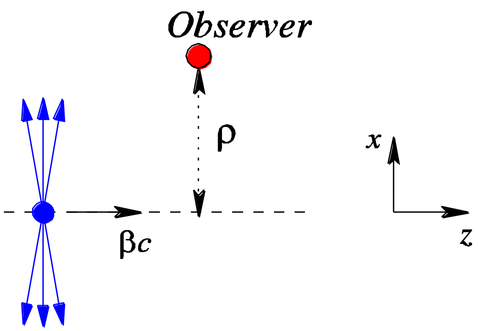
$m_0 c^2$: rest mass energy

proton: $m_p c^2 = 938.272\,\text{MeV}$

electron: $m_e c^2 = 0.511\ \text{MeV}$

Beam Monitors: Physical Processes

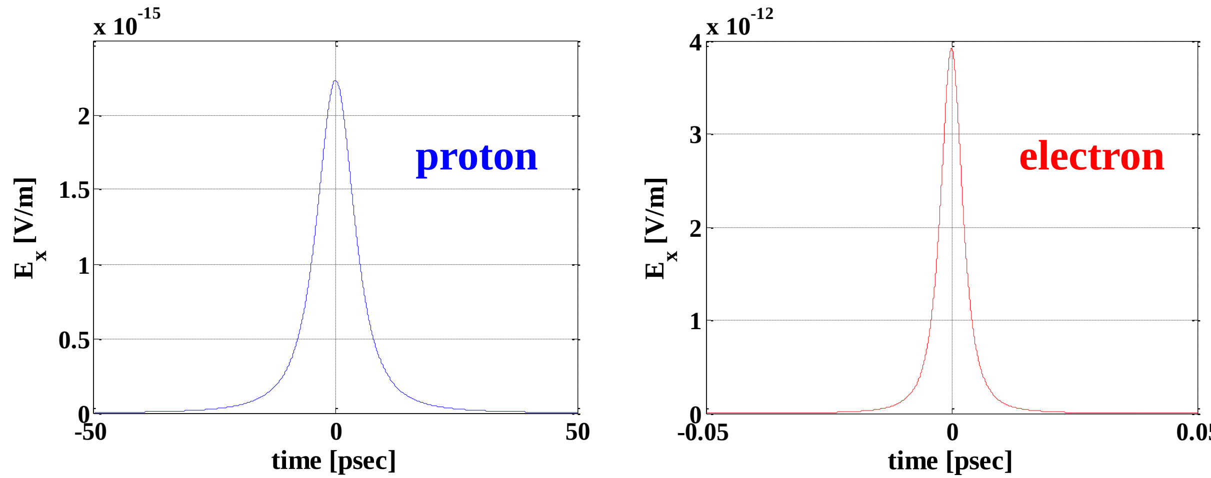
- non-propagating field



E_{kin} = 20 GeV

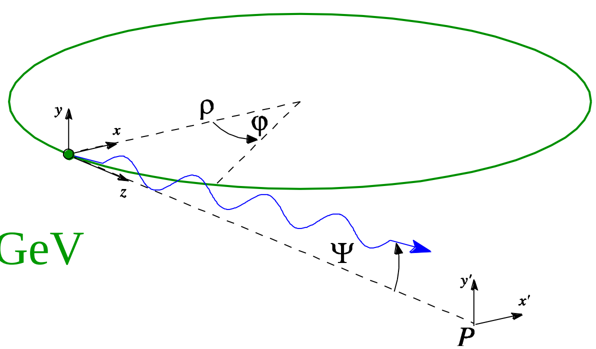
ρ= 40 mm

transverse electrical field components



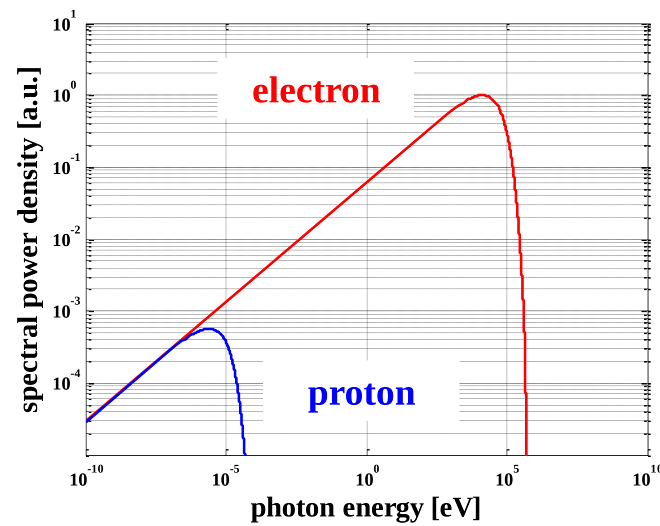
- propagating field

(synchrotron radiation)



E_{kin} = 20 GeV

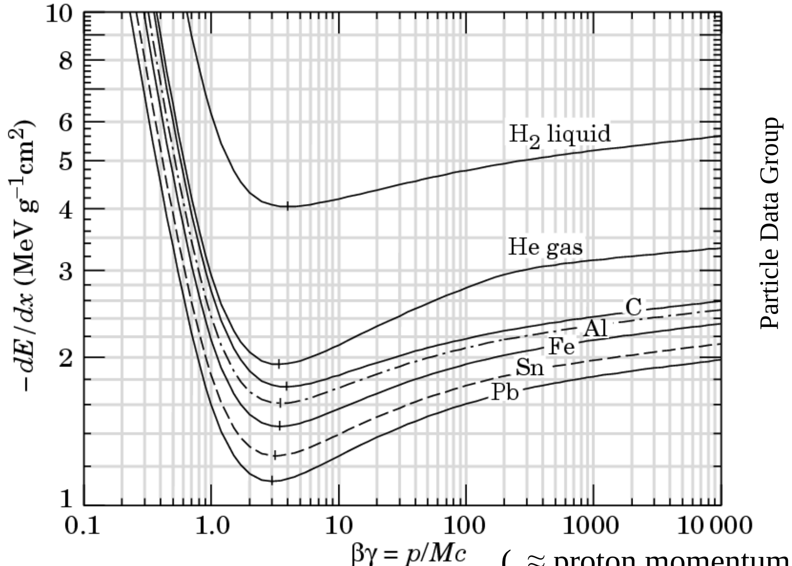
ρ= 370 m



Beam Monitors: Physical Processes

- Coulomb interaction of charged particle penetrating matter

→ viewing screens, residual gas monitors, …

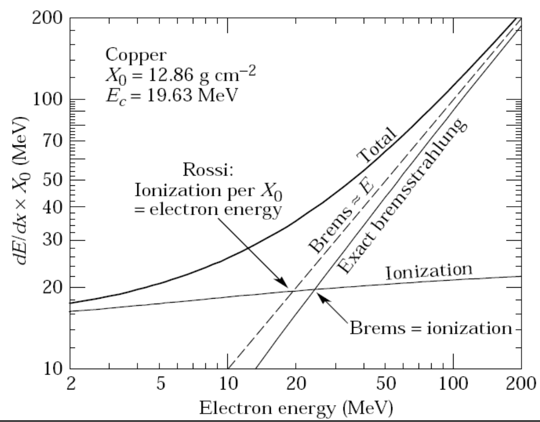


(≈ proton momentum [GeV/c])

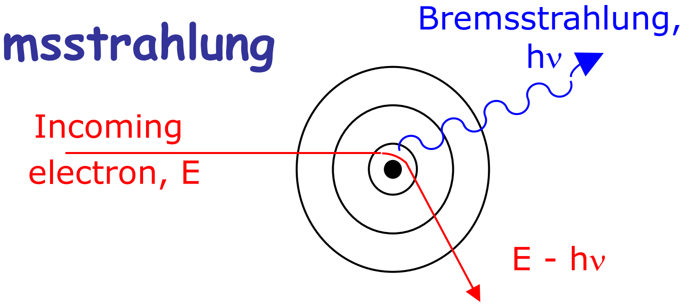
$$-\frac{dE}{dx}=4\pi N_A r_e^2 m_e c^2 \frac{Z_T}{A_T}\rho\frac{Z_p^2}{\beta^2}[\ln\frac{2m_e c^2\gamma^2\beta^2}{I}-\beta^2]$$

Bethe Bloch Equation („low-energy approximation")

- **constants:**
  - N_A: Avogadro number
  - m_e, r_e: electron rest mass, classical electron radius
  - c: speed of light
- **target material properties:**
  - ρ: material density
  - A_T, Z_T: atomic mass, nuclear charge
  - I : mean excitation energy
- **particle properties:**
  - Z_p: charge
  - β: velocity, with $\gamma^2=\frac{1}{1-\beta^2}$



- **Electrons : Bremsstrahlung**



Beam Monitors: Physical Processes

- nuclear or elementary particle physics interactions

  → beam loss monitors, luminosity monitors…

electrons

- simple (point) objects
- interaction cross sections into final states can be calculated precisely

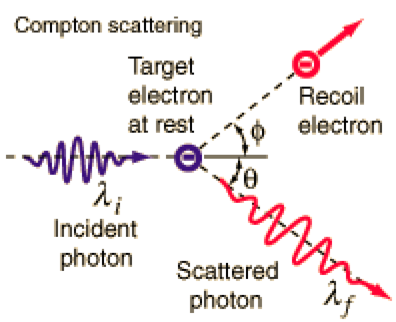
hadrons

- constituent nature (collection of quarks and gluons)
- interaction cross sections not precisely calculable

- interaction of particles with photon beams

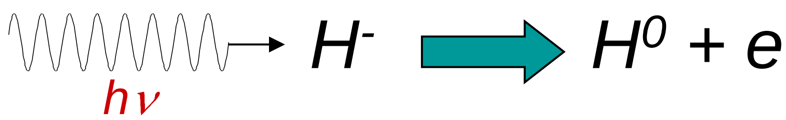
  → laser wire scanners, Compton polarimeters, …

electrons: Compton scattering



$$\frac{d\sigma}{d\Omega} \propto \left(\frac{e^2}{m_0 c^2}\right)^2$$

hadrons: laser photo neutralization (H^- beam)



applied for high power H^- beam profile diagnostics

Beam Position Monitor (BPM)

Beam Position Monitors

- short version of E-XFEL BPM specification

specified charge range: 0.1 – 1nC

	Number	Beam Pipe	Length	Type	Single Bunch Resolution (RMS)	Train Averaged Resolution (RMS)	Optimum Resolution Range	Relaxed Resolution Range	x/y Crosstalk	Bunch to Bunch Crosstalk	Trans. Alignment Tolerance (RMS)
		mm	mm		µm	µm	mm	mm	%	µm	**µm**
Standard BPM	219	40.5	200/ 100	Button	50	10	± 3.0	± 10	1	10	**200**
Cold BPM	102	78	170	Button/ Re-entrant	50	10	± 3.0	± 10	1	10	**300**
Cavity BPM Beam Transfer Line	12	40.5	255	Cavity	10	1	± 1.0	± 2	1	1	**200**
Cavity BPM Undulator	117	10	100	Cavity	1	0.1	± 0.5	± 2	1	0.1	**50**
IBFB	**4**	**40.5**	**255**	**Cavity**	**1**	**0.1**	**± 1.0**	**± 2**	**1**	**0.1**	**200**

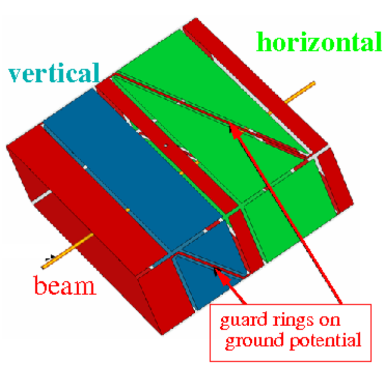
➡ different BPM types to meet different requirements

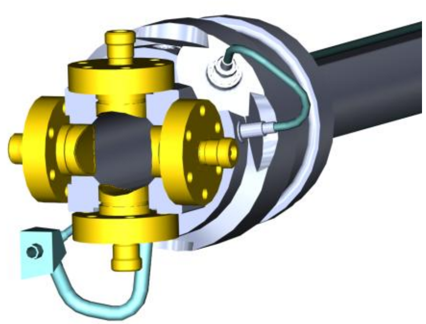
courtesy: D.Nölle (DESY)

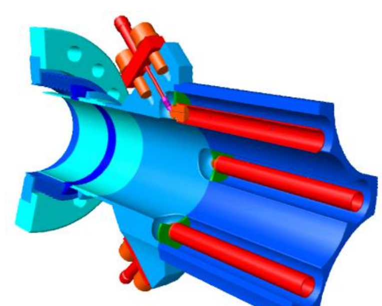
Comparison of BPM Types

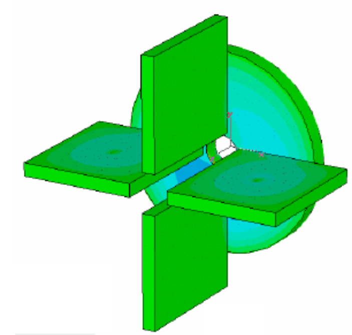
BPM Type	Application	Precaution	Advantage	Disadvantage
Shoe-Box	p-synchrotrons heavy-ion accelerators	long bunches $f_{RF} < 10$ MHz	very linear no x-y coupling sensitive	complex mechanics capacitive coupling between plates
Button	p-linacs all e-accelerators	$f_{RF} > 10$ MHz	simple mechanics	non-linear x-y coupling possible signal deformation
Stripline	colliders p-linacs all e-accelerators	best for $\beta \approx 1$ short bunches	directivity large signal	complex 50 Ω matching complex mechanics
Cavity	e-linacs (e.g. FELs)	short bunches, special applic.	very sensitive	very complex high frequency

P. Forck, “Lecture Notes on Beam Instrumentation and Diagnostics”, JUAS 2011









Beam Position Monitor

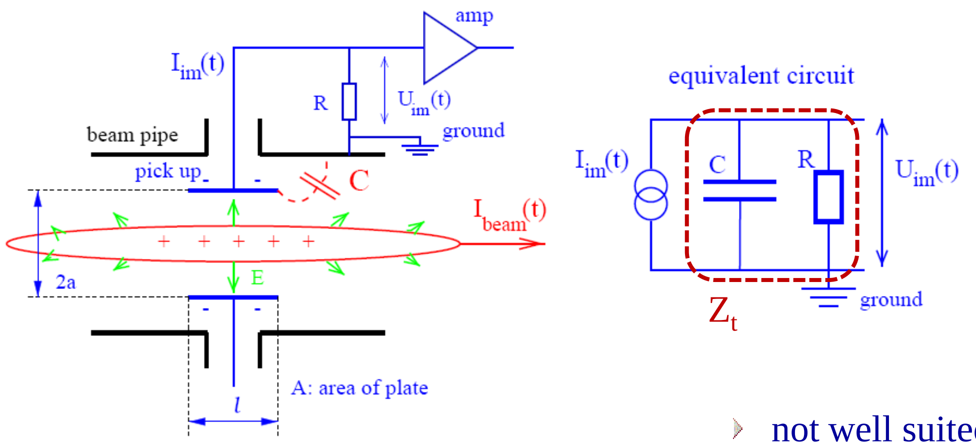
- most common: capacitive pickups
  - signal generation via beam electric field
  - popular design: **button-type pickup**
    - → simple, cheap, …
    - → moderate resolution

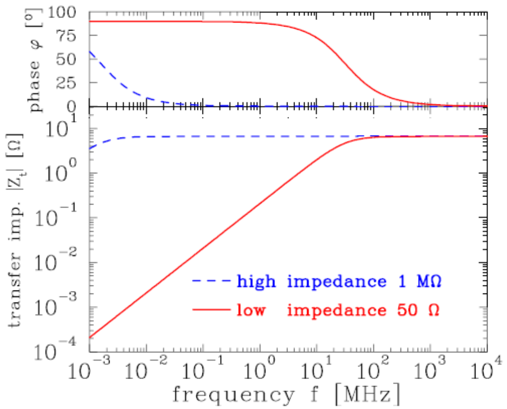
LHC button pickup

courtesy: R.Jones (CERN)

- operation principle
  - electric field induces image charge on pick-up
    - → pick-up mounted isolated inside vacuum chamber
    - → amount of induced charge depends on distance between beam and pick-up

- button pickup: high pass characteristics



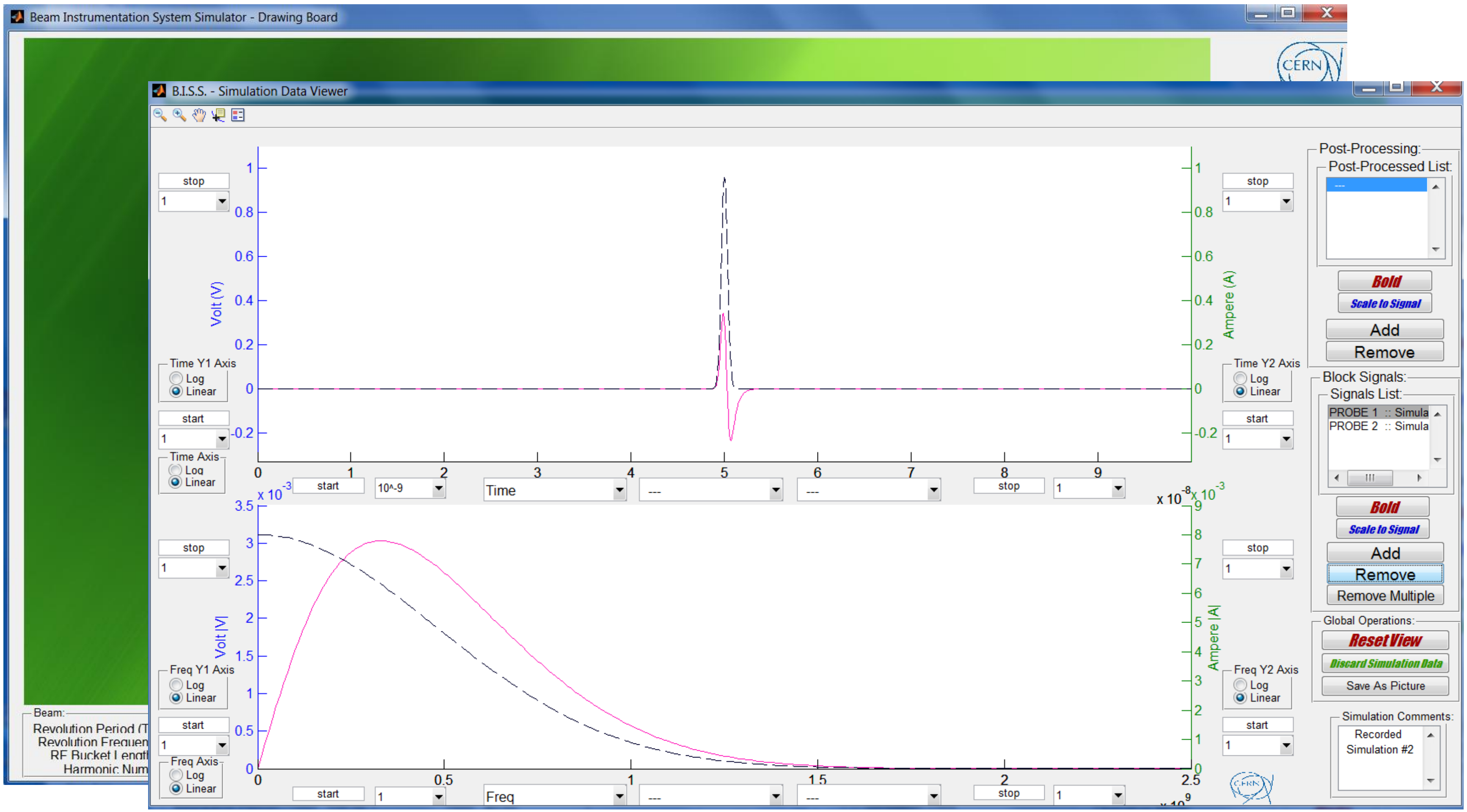


P. Forck, "Lecture Notes on Beam Instrumentation and Diagnostics", JUAS 2011

- not well suited for long bunches
  - → especially: low energy hadron beams, i.e. heavy ion beams
  - → small coupling between pickup and bunch

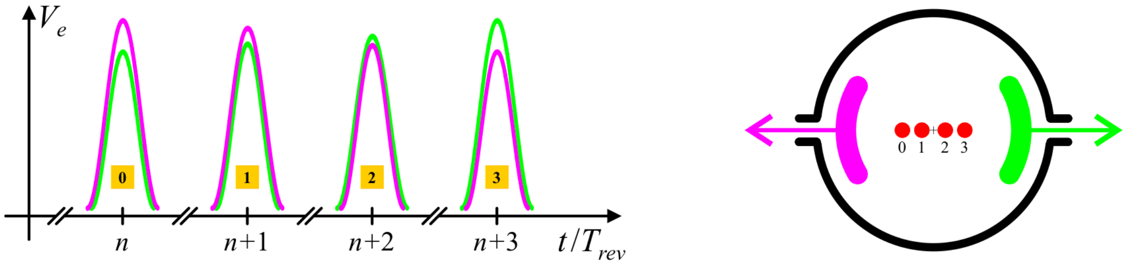
BPM Signal Calculation

- Beam Instrumentation System Simulator (B.I.S.S.)
  - calculation from BPM signals in time- and frequency domain
  - study influence of various parameters



BPM Signals

- observation (1): singnals are short with small modulation
  - single bunch response → nsec or sub-nsec pulse signals
  - beam position information → **amplitude modulated** on large (common mode) beam intensity signal!



courtesy: *M. Gasior (CERN)*

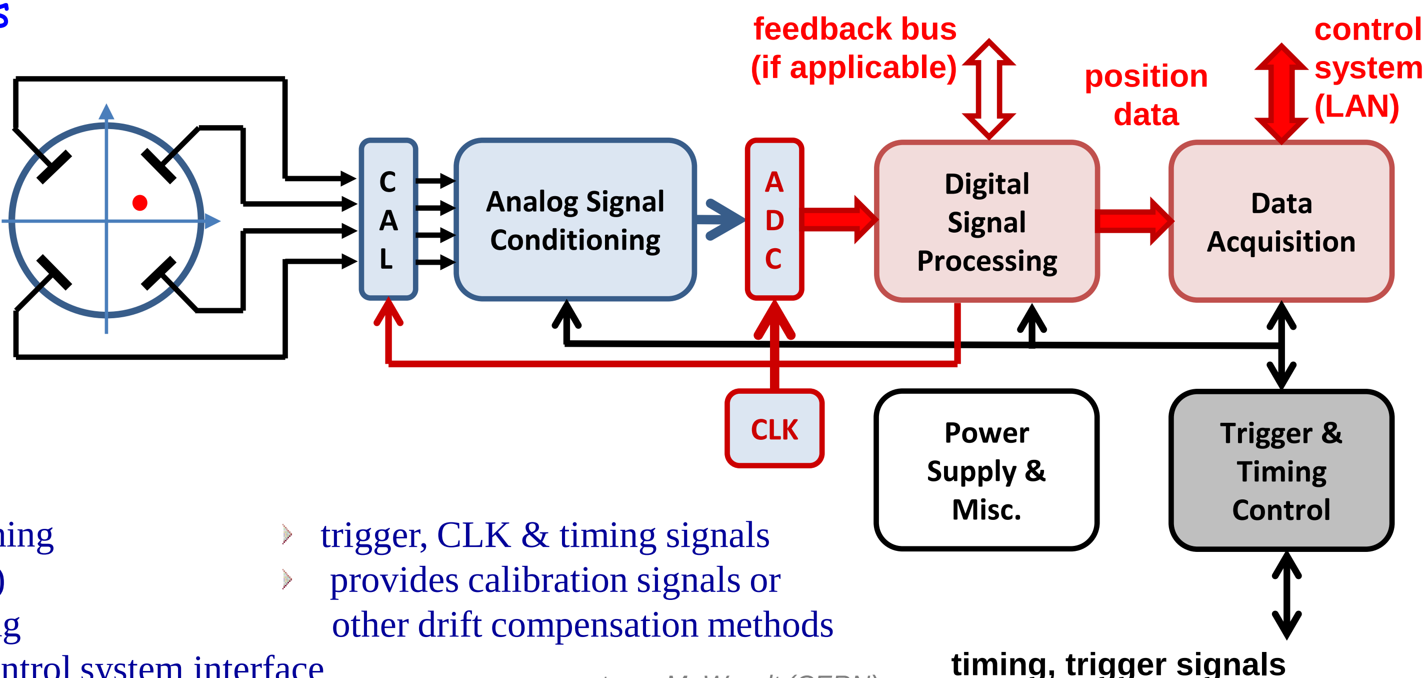
- BPM building blocks

BPM Pickup

- RF device, EM field detection, center of charge
- symmetrically arranged electrodes or resonant structure

Read-out Electronics

- analog signal conditioning
- signal sampling (ADC)
- digital signal processing
- data acquisition and control system interface
- trigger, CLK & timing signals
- provides calibration signals or other drift compensation methods

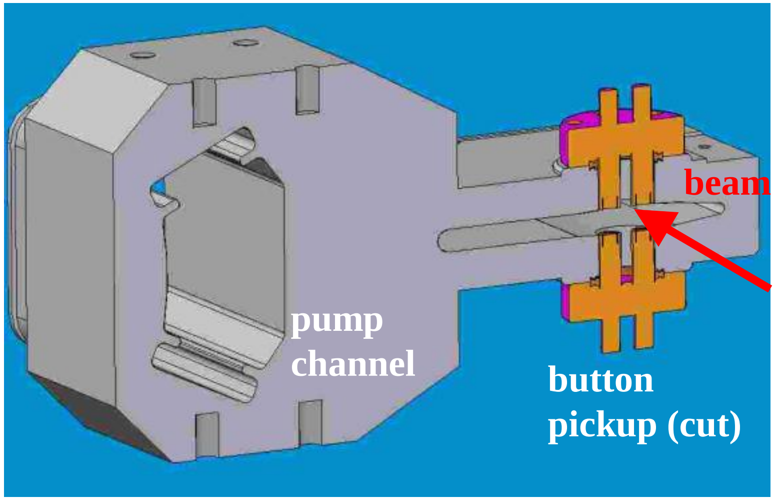


courtesy: *M. Wendt (CERN)*

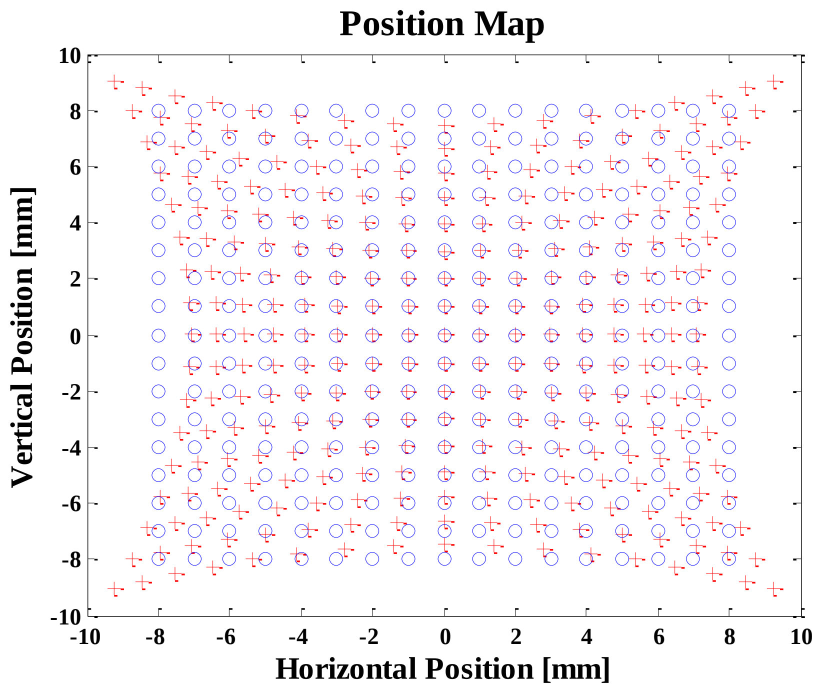
BPM Signals

- observation (2): nonlinearities ➡ especially BPMs for circular e-accelerators
  - synchrotron radiation emission
    → pickups mounted **out of orbit plane**
  - vacuum chamber not rotational symmetric
    → $\varepsilon_{hor} >> \varepsilon_{vert}$ (SR emission in hor. plane)
    → injection oscillations due to off-axis injection (allows intensity accumulation)

courtesy: A.Delfs (DESY)



PETRA-III BPM close to ID

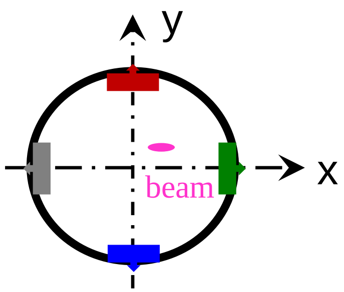


➡ correction of strong non-linearities in beam position required

Position Reconstruction

- two common monitor geometries
  - difference in position reconstruction

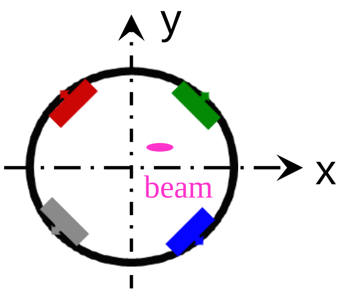
linac-type



$$x = K_x \frac{P_1 - P_3}{P_1 + P_3}$$

$$y = K_y \frac{P_2 - P_4}{P_2 + P_4}$$

storage ring-type



$$x = K_x \frac{(P_1+P_4) - (P_2+P_3)}{P_1+P_2+P_3+P_4}$$

$$y = K_y \frac{(P_1+P_2) - (P_3+P_4)}{P_1+P_2+P_3+P_4}$$

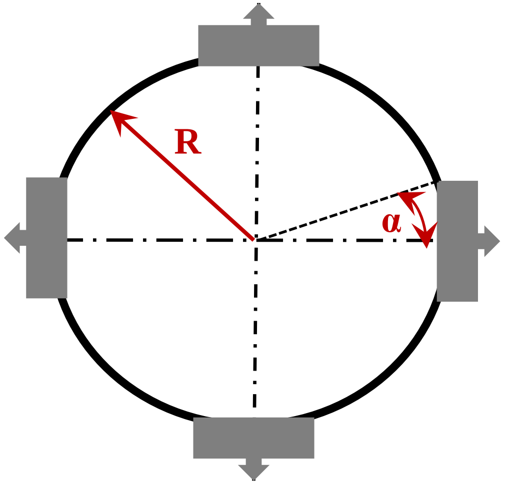
$\Rightarrow$ difference-over-sum or $\frac{\Delta}{\Sigma}$

- position information
  - requires knowledge of monitor constant K_x, K_y

    $\rightarrow$ rule of thumb (circular duct)

$$K_{x,y} = \frac{R}{2}\frac{\alpha}{\sin\alpha}$$ **linac-type**

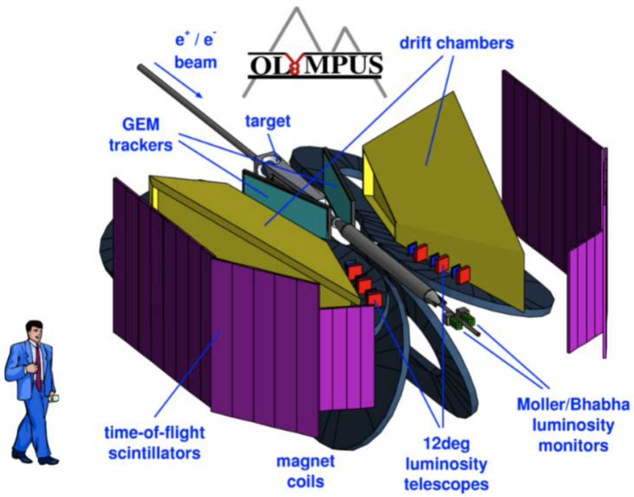
$$K_{x,y} = \frac{R}{\sqrt{2}}\frac{\alpha}{\sin\alpha}$$ **storage ring-type**

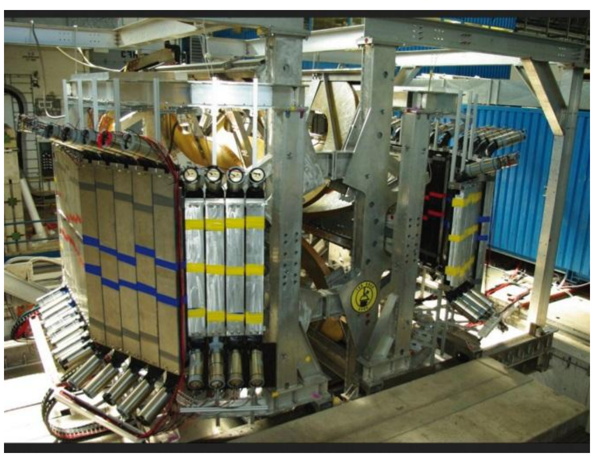


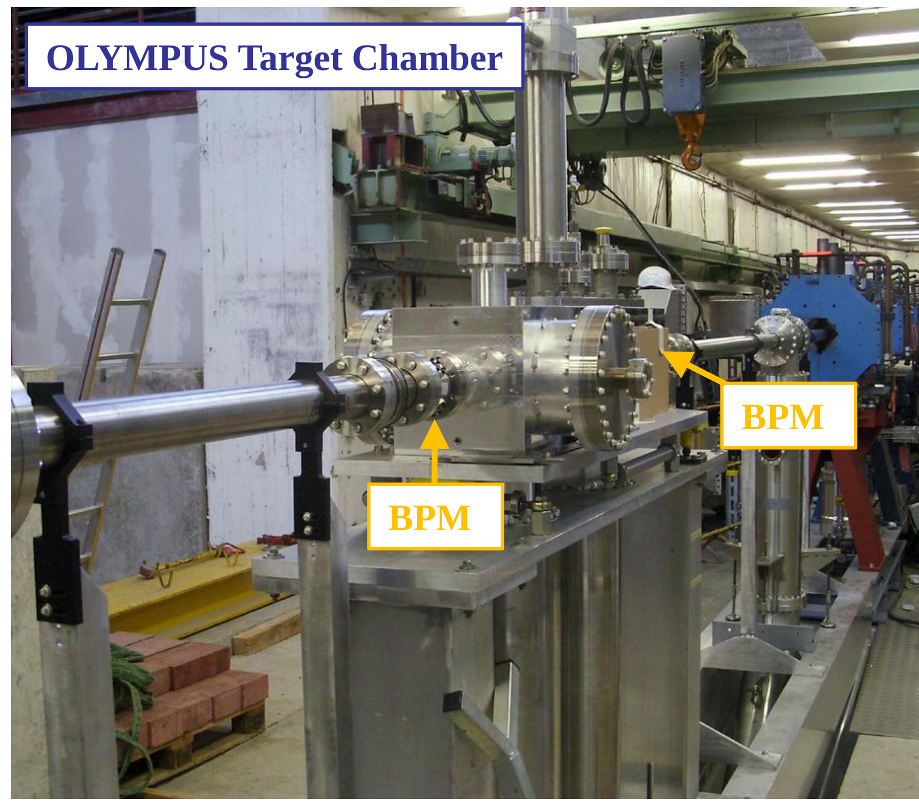
OLYMPUS @ DORIS (DESY)

- two-photon exchange in lepton scattering
  - compare e^+p and e^-p elastic scattering

R. Milner et al., „The OLYMPUS experiment“, Nucl. Instrum. Methods **A741** (2014) 1

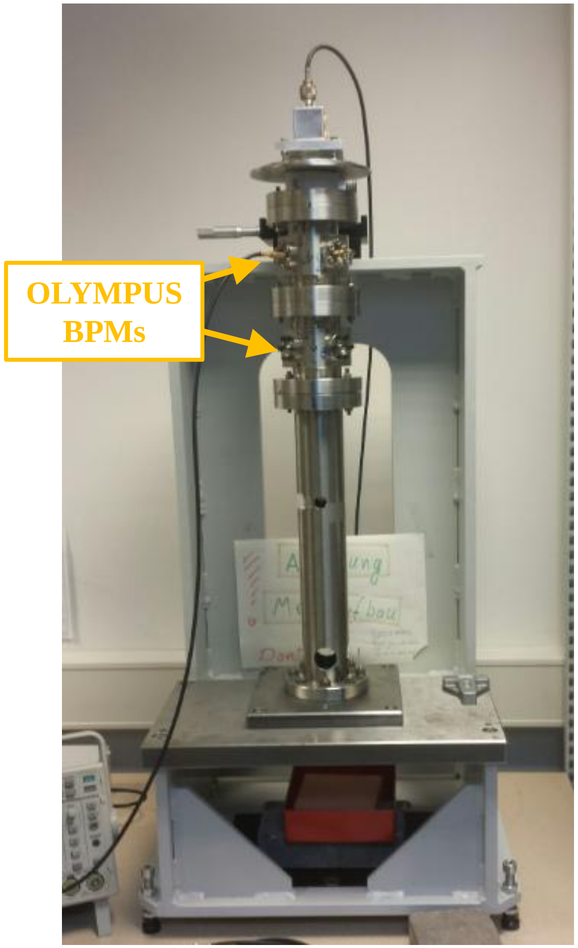


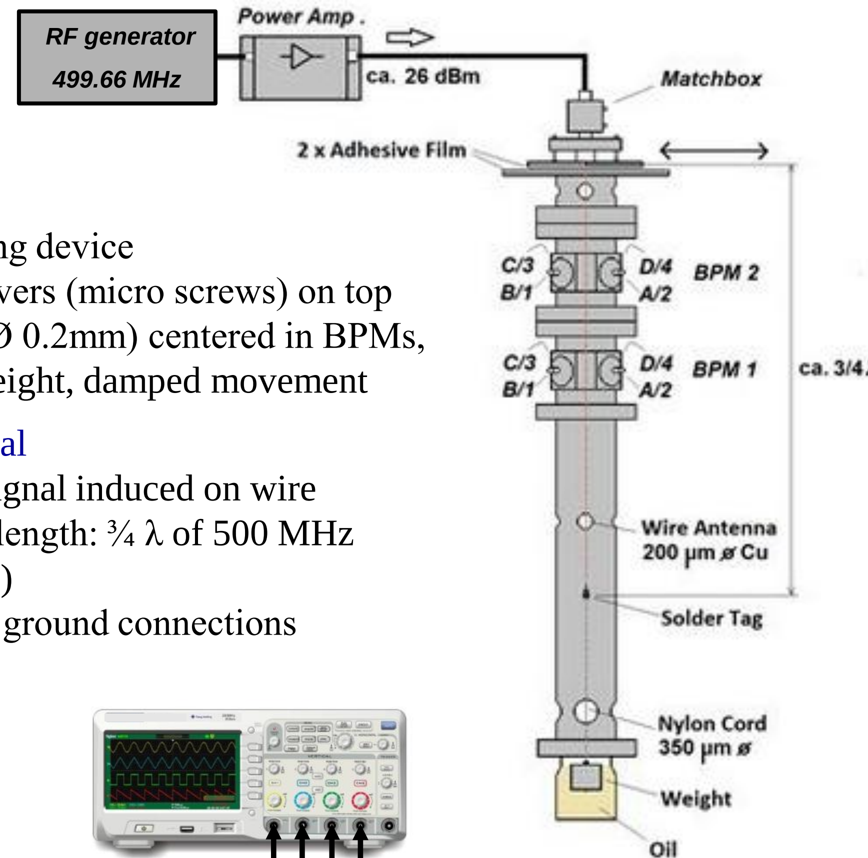




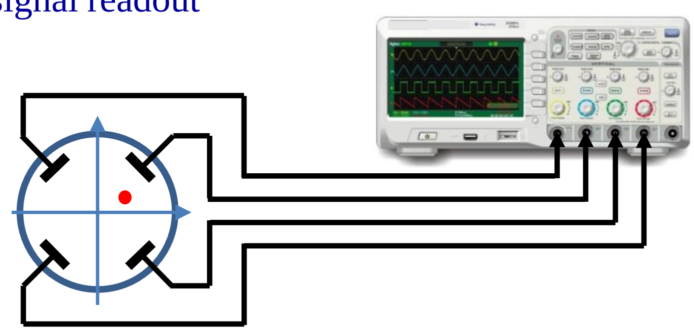
Monitor Constant Measurement

- BPM test stand   U. Schneekloth et al., Proc. IBIC 2014, Monterey (Ca), USA, (2014) 324





- test stand
  - → vertical scanning device
  - → 2 precision movers (micro screws) on top
  - → wire antenna (Ø 0.2mm) centered in BPMs, stretched by weight, damped movement
- electrical input signal
  - → 500 MHz cw signal induced on wire
  - → electrical wire length: ¾ λ of 500 MHz (standing wave)
  - → essential: solid ground connections
- signal readout



Tasks: BPMs

- calculate BPM signals using B.I.S.S
  - get a first impression about BPM signal forms
    - → chamber geometry influence
    - → non-linearities
    - → output impedance
- calculate monitor constants for OLYMPUS BPMs
  - use rule-of-thumb formulae for both geometries
    - → compare with simulation results
- measure OLYMPUS BPM monitor constants (both geometries)
  - define electrical center of both BPM bodies (origin)
  - perform 1-dim. scan along one axis → max. wire position: ± 15 mm (!!!)
    - → measure signal amplitudes from each button
    - → calculate Δ/Σ from measured signals
    - → plot Δ/Σ versus wire position and compare with simulation results
  - determine monitor constant from slope at origin
- (measure 2-dim. position map)

Transverse Phase Space: Beam Size and Emittance

Accelerator Key Parameters

- **light source: spectral brilliance**
  - measure for phase space density of photon flux

$$B = \frac{\text{Number of photons}}{[\text{sec}][\text{mm}^2][\text{mrad}^2][0.1\%\,\text{bandwidth}]}$$

  - user requirement: high brightness
    → lot of monochromatic photons on sample
  - connection to machine parameters

$$B \propto \frac{N_\gamma}{\sigma_x \sigma_{x'} \sigma_z \sigma_{z'}} \propto \frac{I}{\varepsilon_x \varepsilon_z}$$

- **collider: luminosity**
  - measure for the collider performance

$$\dot{N} = L \cdot \sigma$$

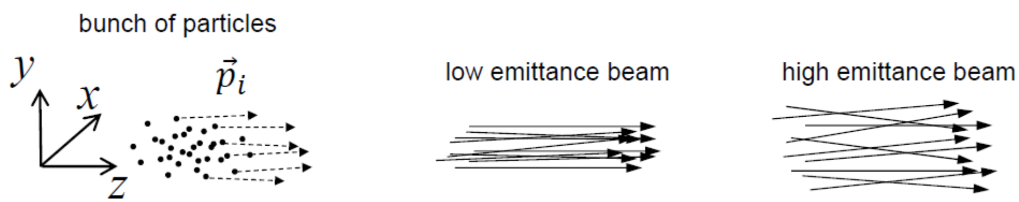
relativistic invariant proportionality factor between cross section σ (property of interaction) and number of interactions per second

  - user requirement: high luminosity
    → lot of interactions in reaction channel
  - connection to machine parameters

$$L \propto \frac{I_1 \cdot I_2}{\varepsilon}$$

for two identical beams with emittances $\varepsilon_x = \varepsilon_z = \varepsilon$

- **requirements**
  - design of small emittance machine
    → proper choice of magnet lattice
  - preserve small emittance
    → question of stability
    → require active feedback systems / careful design considerations

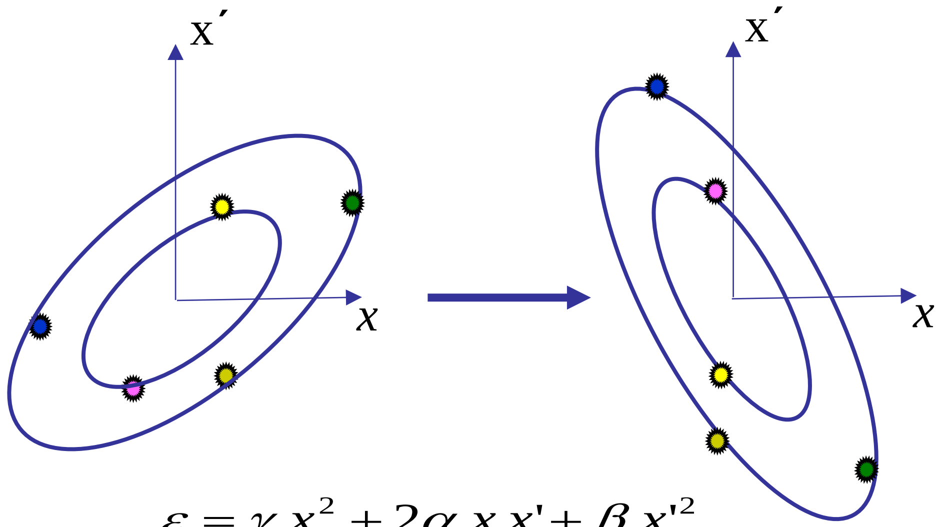


  - measure small emittance

Transverse Emittance

- projection of phase space volume
  - separate horizontal, vertical and longitudinal plane
- accelerator key parameter
  - defines **luminosity** / **brilliance**
- linear forces
  - any particle moves on an ellipse in phase space (x,x´)
  - ellipse rotates in magnets and shears along drifts

    → but area is preserved: **emittance**



$$\varepsilon = \gamma x^2 + 2\alpha x x' + \beta x'^2$$

(α, β, γ, ε: Courant-Snyder or Twiss parameters)

- transformation along accelerator
  - knowledge of the magnet structure (beam optics) → transformation from initial (i) to final (f) location

→ single particle transformation

$$\begin{pmatrix} x \\ x' \end{pmatrix}_f = \underbrace{\begin{pmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{pmatrix}}_{R} \cdot \begin{pmatrix} x \\ x' \end{pmatrix}_i$$

→ transformation of optical functions

$$\begin{pmatrix} \beta \\ \alpha \\ \gamma \end{pmatrix}_f = \begin{pmatrix} R_{11}{}^2 & -2R_{11}R_{12} & R_{12}{}^2 \\ -R_{11}R_{21} & 1+R_{12}R_{21} & -R_{12}R_{22} \\ R_{21}{}^2 & -2R_{21}R_{22} & R_{22}{}^2 \end{pmatrix} \cdot \begin{pmatrix} \beta \\ \alpha \\ \gamma \end{pmatrix}_i$$

Transverse Emittance Ellipse

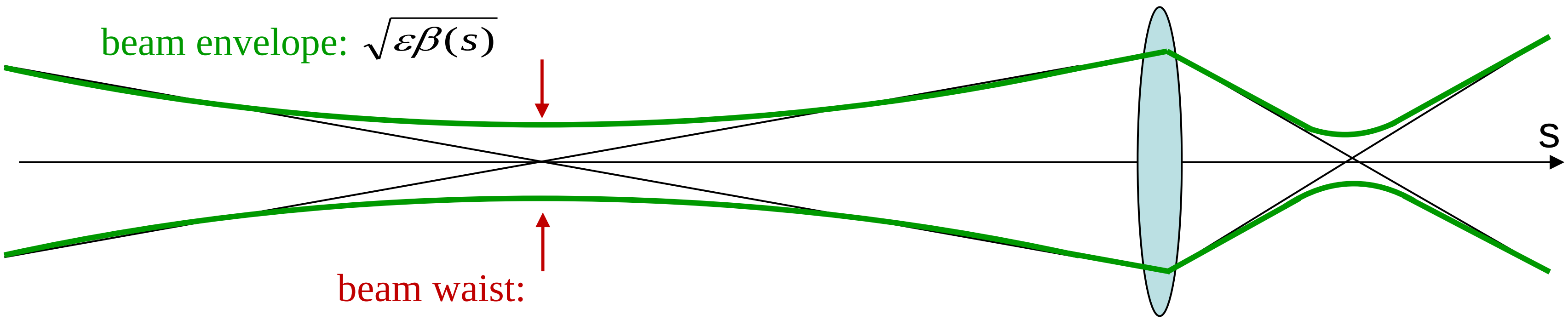
- propagation along accelerator
  - change of ellipse shape and orientation → area is preserved

$$\alpha(s) = -\frac{\beta'(s)}{2}$$

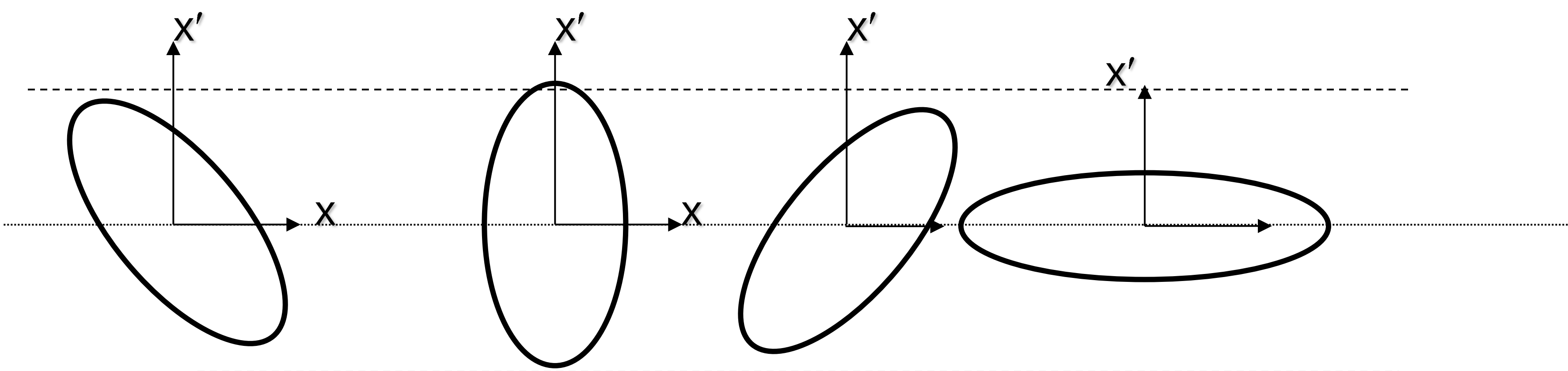
$$\gamma(s) = \frac{1+\alpha^2(s)}{\beta(s)}$$

$$\varepsilon = \gamma(s)\,x(s)^2 + 2\alpha(s)\,x(s)\,x'(s) + \beta(s)\,x'(s)^2$$

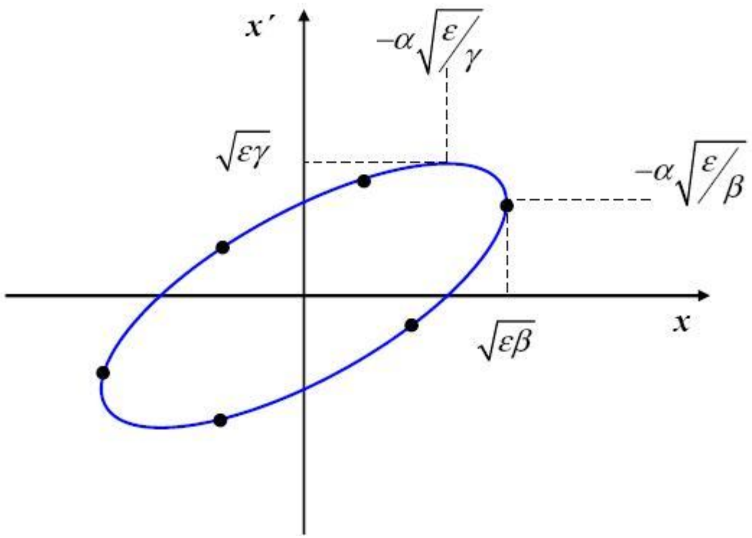
$$x(s) = \sqrt{\varepsilon\beta(s)} \cdot \cos\left(\Psi(s) + \Phi\right)$$



→ minimum in envelope → minimum in β → β´ = 0 → α = 0



Emittance and Beam Matrix



- via Twiss parameters

$$\varepsilon = \gamma x^2 + 2\alpha x x' + \beta x'^2$$

- statistical definition

P.M. Lapostolle, IEEE Trans. Nucl. Sci. NS-18, No.3 (1971) 1101

$$\varepsilon_{rms} = \sqrt{\langle x^2\rangle\langle x'^2\rangle - \langle xx'\rangle^2}$$

2nd moment of beam distribution ρ(x)

$$\langle x^2\rangle = \frac{\int_{-\infty}^{\infty} dx\, x^2 \cdot \rho(x)}{\int_{-\infty}^{\infty} dx\, \rho(x)}$$

- ε_{rms} is measure of spread in phase space
- root-mean-square (rms) of distribution

$$\sigma_x = \langle x^2\rangle^{1/2}$$

- ε_{rms} useful definition for non-linear beams

  → usually restriction to certain range

  (c.f. 90% of particles instead of [-∞,+∞])

- beam matrix

$$\Sigma = \begin{pmatrix} \Sigma_{11} & \Sigma_{12} \\ \Sigma_{21} & \Sigma_{22} \end{pmatrix} = \begin{pmatrix} \langle x^2\rangle & \langle xx'\rangle \\ \langle xx'\rangle & \langle x'^2\rangle \end{pmatrix} = \varepsilon \begin{pmatrix} \beta & -\alpha \\ -\alpha & \gamma \end{pmatrix}$$

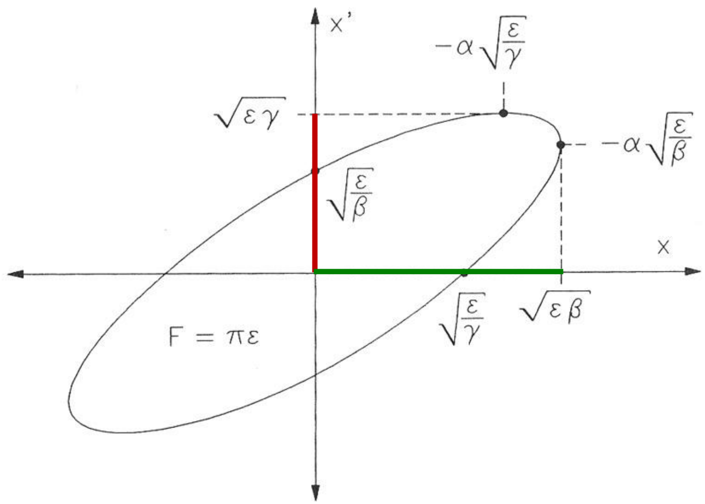
$$\varepsilon = \sqrt{\det\Sigma} = \sqrt{\Sigma_{11}\cdot\Sigma_{22} - \Sigma_{12}^2}$$

- transformation of beam matrix

$$\Sigma^1 = R\Sigma^0 R^T \qquad R = \begin{pmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{pmatrix}$$

Emittance Measurement: Principle

- emittance: projected area of transverse phase space volume
- not directly accessible for beam diagnostics

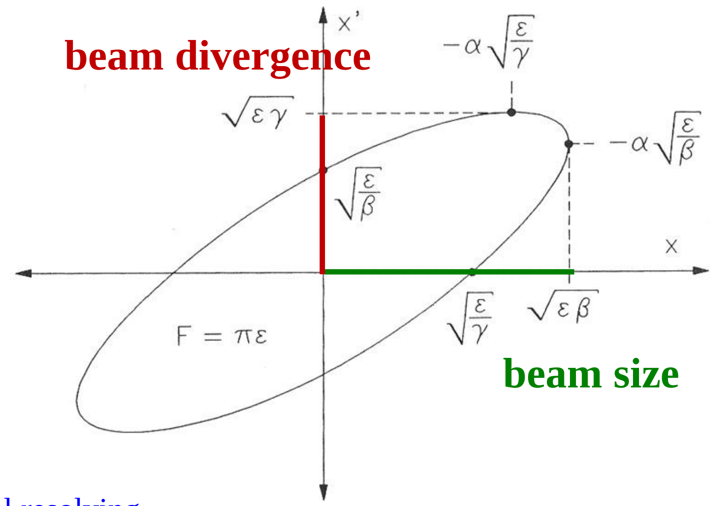


- measured quantity
  - beam size $\sqrt{\Sigma_{11}} = \sqrt{\langle x^2 \rangle} = \sqrt{\varepsilon\beta}$
  - beam divergence $\sqrt{\Sigma_{22}} = \sqrt{\langle x'^2 \rangle} = \sqrt{\varepsilon\gamma}$
  - divergence measurements seldom in use
    → restriction to profile measurements

- measurement schemes
  - beam matrix based measurements
    → determination of beam matrix elements: $\varepsilon = \sqrt{\det \Sigma} = \sqrt{\Sigma_{11} \cdot \Sigma_{22} - \Sigma_{12}^2}$
  - ~~mapping of phase space~~
    ~~→ restrict to (infenitesimal) element in space coordinate, convert angles x' in position~~

Circular Accelerators

- **emittance diagnostics in circular accelerators**
  - circular accelerator: periodic with circumference L
    - → one-turn transport matrix: R(s+L) = R(s)
    - → Twiss parameters α(s), β(s), γ(s) uniquely defined at each location in ring
  - measurement at one location in ring sufficient to determine ε
    - → measured quantity: beam profile / angular distribution



- **classification**

beam spot | wavefront manipulation | spatial resolving detector (CCD)

  - imaging
    - → beam size

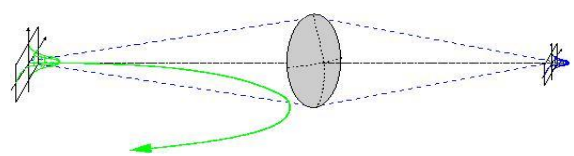
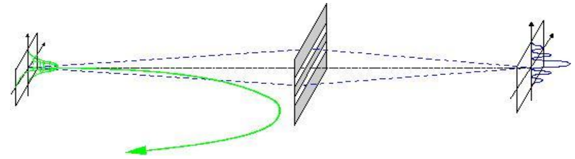
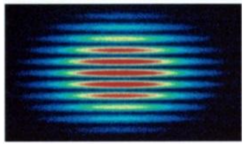


image size

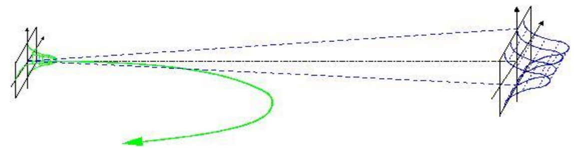
  - interference
    - → beam size

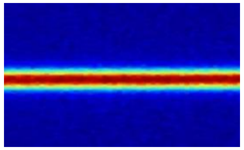




interference pattern

  - projection
    - → beam divergence





angular distribution

Beam Matrix based Measurements

- starting point: beam matrix $$\Sigma = \begin{pmatrix} \Sigma_{11} & \Sigma_{12} \\ \Sigma_{21} & \Sigma_{22} \end{pmatrix} = \begin{pmatrix} \langle x^2 \rangle & \langle xx' \rangle \\ \langle xx' \rangle & \langle x'^2 \rangle \end{pmatrix} = \varepsilon \begin{pmatrix} \beta & -\alpha \\ -\alpha & \gamma \end{pmatrix}$$
- emittance determination
  - measurement of **3** matrix elements $\Sigma_{11}, \Sigma_{12}, \Sigma_{22}$
  - **remember:** beam matrix Σ depends on location, i.e. $\Sigma(s)$

    → determination of matrix elements at same location required

$$\varepsilon = \sqrt{\det \Sigma} = \sqrt{\Sigma_{11} \cdot \Sigma_{22} - \Sigma_{12}^2}$$

- access to matrix elements
  - profile monitor determines only $\sigma = \sqrt{\Sigma_{11}}$
  - other matrix elements can be inferred from beam profiles taken under various transport conditions

    → knowledge of transport matrix R required $\Sigma^b = R \cdot \Sigma^a \cdot R^T$ $R = \begin{pmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{pmatrix}$
- measurement of at least 3 profiles for 3 matrix elements

$$\Sigma_{11}^a$$
$$\Sigma_{11}^b = R_{11}^2 \cdot \Sigma_{11}^a + 2R_{11}R_{12} \cdot \Sigma_{12}^a + R_{12}^2 \cdot \Sigma_{22}^a$$
$$\Sigma_{11}^c = \overline{R}_{11}^2 \cdot \Sigma_{11}^a + 2\overline{R}_{11}\overline{R}_{12} \cdot \Sigma_{12}^a + \overline{R}_{12}^2 \cdot \Sigma_{22}^a$$

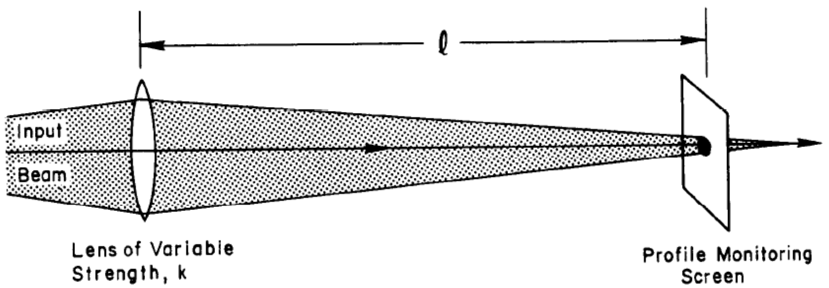
- **measurement :** profiles $\sigma^{a,b,c} = \sqrt{\Sigma_{11}^{a,b,c}}$
- **known:** transport optics $R, \overline{R}$
- **deduced:** matrix elements $\Sigma_{11}^a, \Sigma_{12}^a, \Sigma_{22}^a$

→ more than 3 profile measurements favourable, data subjected to least-square analysis

Beam Matrix based Measurements

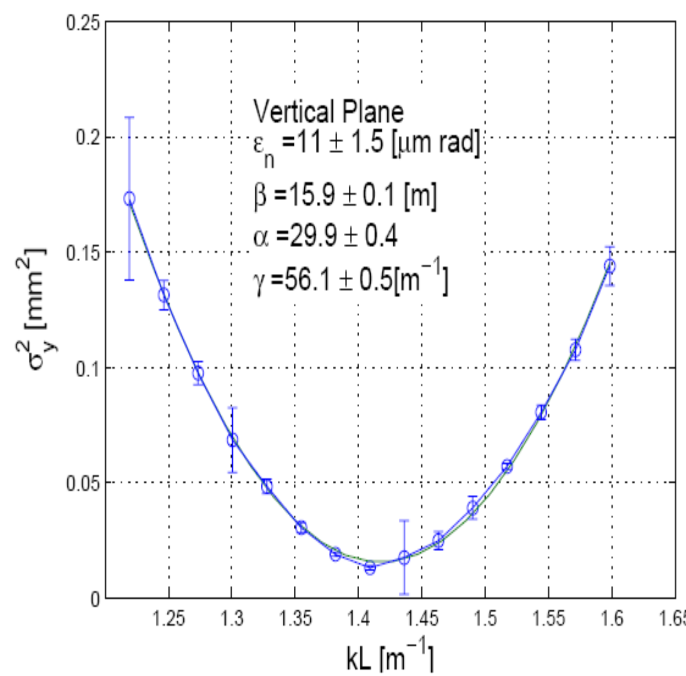
- „quadrupole scan“ method
  - use of variable quadrupole strengths

    → change quadrupole settings and measure beam size in profile monitor located downstream



Q (f = 1/K) **S** (drift space)

- Σ_{11} depends quadratically on quadrupole field strength



G. Penco et al., Proc. EPAC'08, Genoa (Italy), p.1236

<u>quadrupole transfer matrix</u>

$$Q = \begin{pmatrix} 1 & 0 \\ \pm 1/f & 1 \end{pmatrix}$$

<u>drift space transfer matrix</u>

$$S = \begin{pmatrix} 1 & l \\ 0 & 1 \end{pmatrix}$$

→ **R = SQ**

Beam Matrix based Measurements

- „multi profile monitor“ method
  - fixed particle beam optics

    → measure beam sizes using multiple profile monitors at different locations

  - example:

    emittance measurement

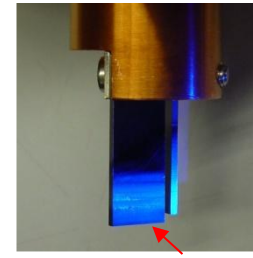
    setup at FLASH injector (DESY)

    courtesy: K. Honkavaara (DESY)

- task
  - beam profile measurement

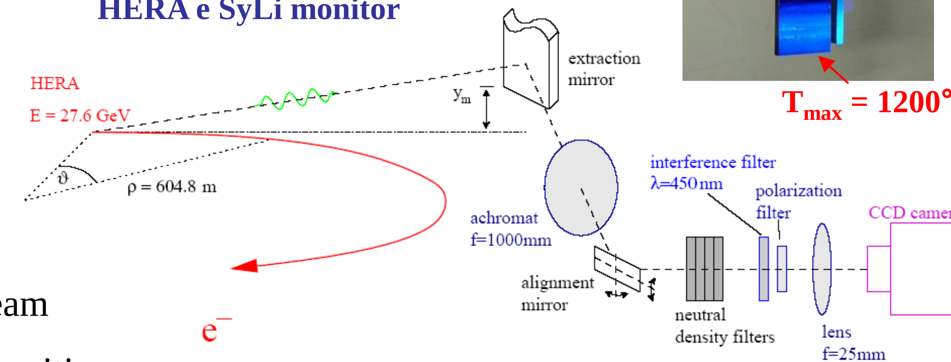
Storage Ring: Profile Measurement

- circular accelerator
  - only non- or minimum-invasive diagnostics → otherwise beam loss after few turns
- e^-/e^+ ring
  - working horse: synchrotron radiation
    → problem: heat load @ extraction mirror

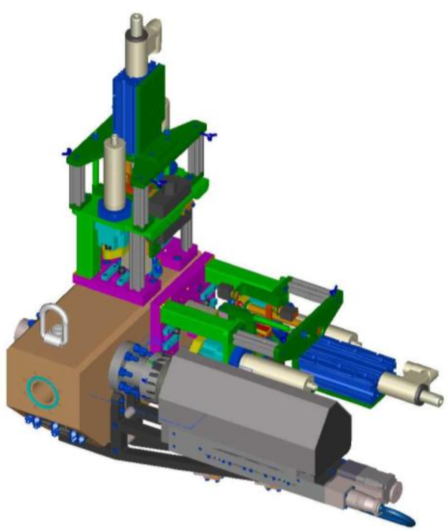


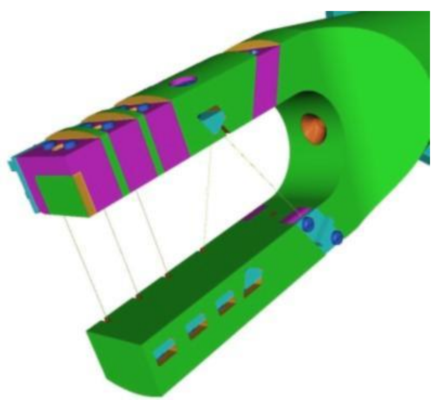
T_{max} = 1200°C

HERA e SyLi monitor

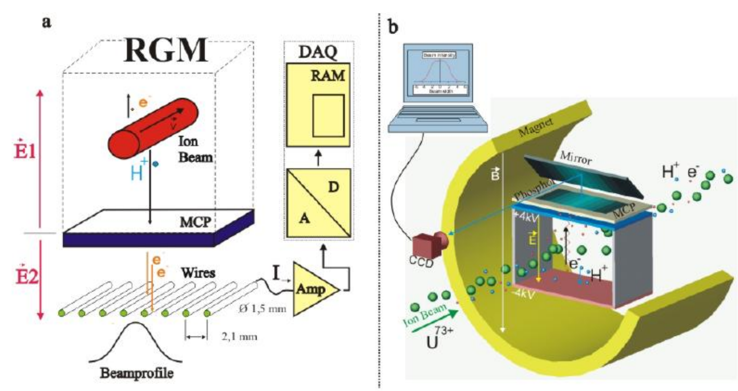


- hadron ring
  - **wire scanners:** scan of thin wire across the beam
  - detect beam-wire interaction as function of wire position





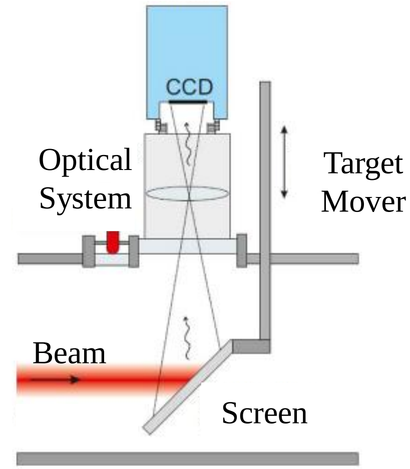
- **residual gas monitor:**
- residual gas ionization / luminescence



T. Giacomini et al., Proc. BIW 2004, p.286

Linac or Transport Line: Profiles

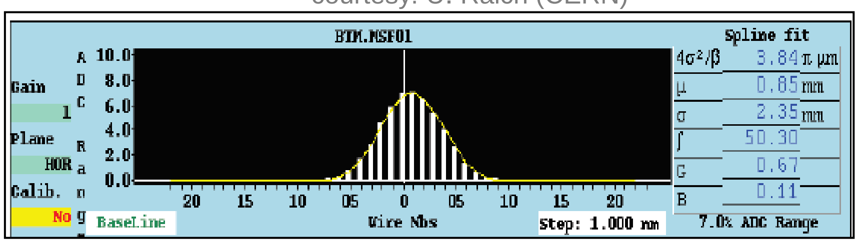
- linear machine
  - single pass diagnostics → interaction with matter (care has to be taken)

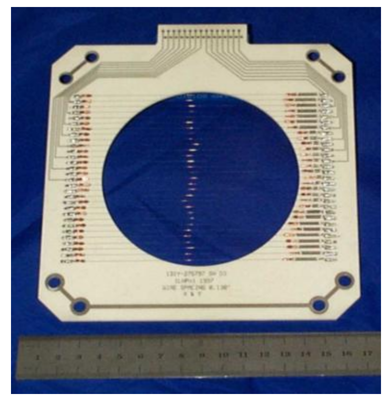


B. Walasek-Höhne et al., IEEE Trans. Nucl. Sci. **59** (2012) 2307

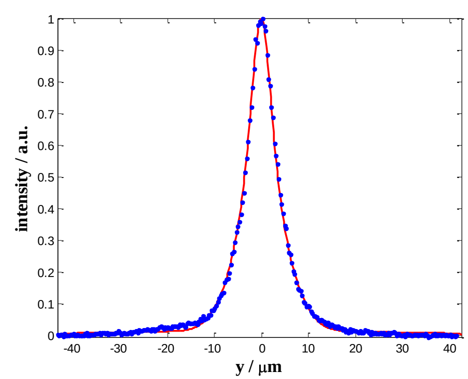
- hadron accelerators
  - working horse: screen monitors
    → scintillating light spot intensity corresponds to beam profile
  - wire harp
    → extension of wire scanner

courtesy: U. Raich (CERN)





- electron accelerators
  - screen monitors → lower resolution (?)
  - working horse: OTR monitors
    → even potential for sub-micron beams

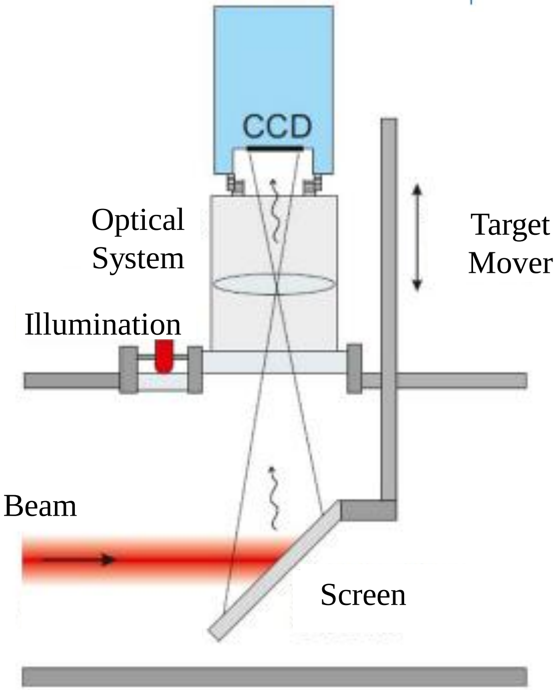


$\sigma = 1.44\ \mu m$

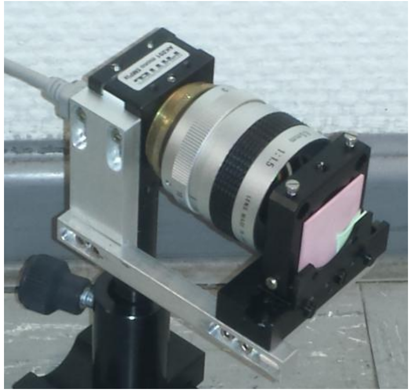
G. Kube et al., Proc. IBIC 2015, Melbourne (Australia), TUPB012

Screen Monitors

- principle
  - radiator
    - → scintillator / OTR screen
    - → generation of light spot: intensity distribution reflects particle beam density (i.e. linear light generation mechanism)
  - optical system / CCD
    - → imaging / recording of light spot
  - target mover
    - → move screen in / out of particle beam
  - illumination
    - → check system performance



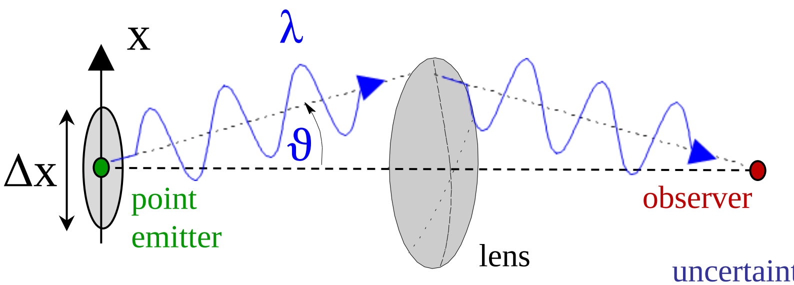
B. Walasek-Höhne et al., IEEE Trans. Nucl. Sci. **59** (2012) 2307



- screen monitor setup
  - radiator → Al_2O_3:Cr (Chromox) screen (thickness 1.0 mm / 0.5 mm / 0.3 mm)
  - CCD → USB camera
  - optics → CCTV lens

Size Measurement: Resolution

- fundamental resolution limit
  - point observer detecting photons from point emitter → location of emission point ?



$$\Delta x$$

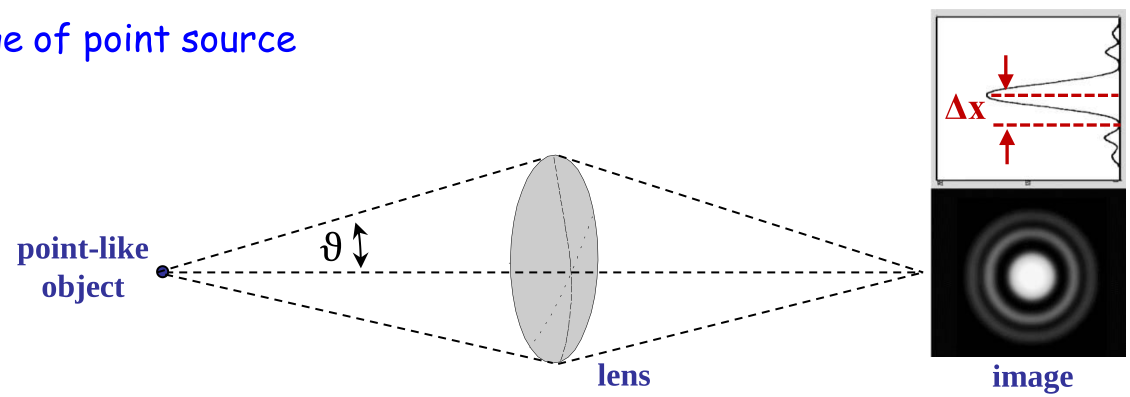
$$\Delta p_x = 2\hbar k \cdot \sin\vartheta \approx 2 \cdot \frac{h}{2\pi} \cdot \frac{2\pi}{\lambda} \cdot \sin\vartheta$$

NA = sinϑ: numerical aperture

uncertainty principle: $\Delta x \cdot \Delta p_x \approx h \quad \Rightarrow \quad \Delta x \approx \frac{\lambda}{2\sin\vartheta}$

high resolution: (i) **small λ** (ii) **high NA**

- image of point source



http://www.astro.ljmu.ac.uk

Airy pattern:

→ Point Spread Function

$$\Delta x = 0.61 \frac{M\lambda}{\sin\vartheta}$$

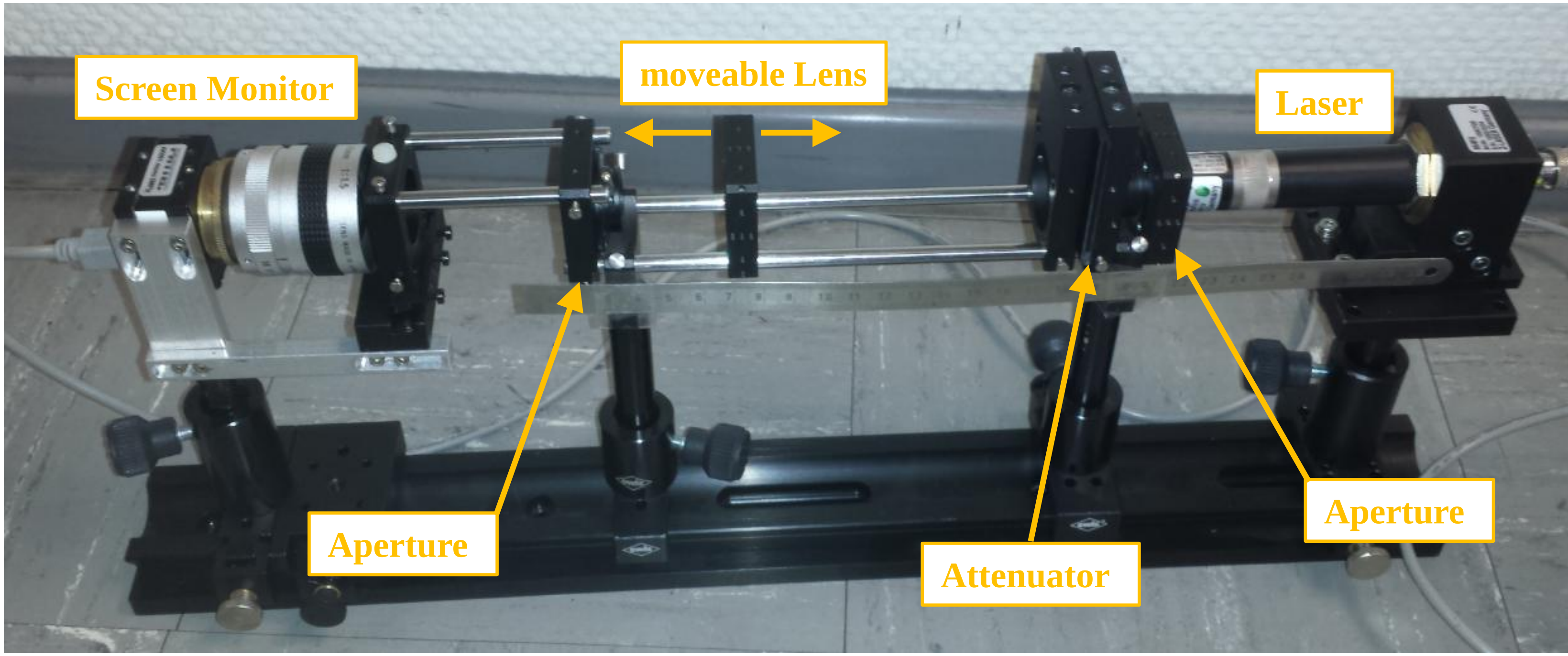
magnification M

- resolution broadening: additional contributions
  - depth of field
  - radius of curvature

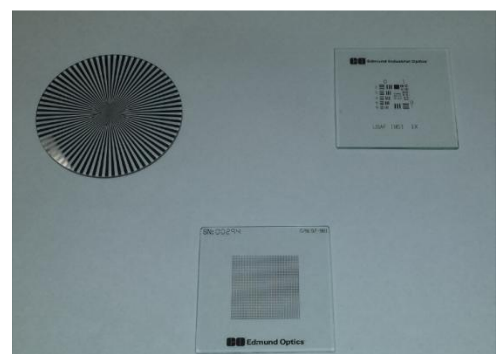
→ mainly for synchrotron radiation based diagnostics

Emittance Measurement Test Setup

- emittance of laser beam: „multi-profile monitor" method



- calibration / resolution targets
  - check system performance of detector system



Tasks: Emittance Diagnostics

- estimate the image resolution for an optical synchrotron radiation profile monitor
  - modern 3rd generation light source: $E = 6$ GeV, $\lambda_{obs} = 500$ nm , $\sigma_y = 10$ µm

    → assume „self diffaction“, i.e. aperture limitation imposed by radiation angular distribution (1/γ)

- derive the single particle transport matrix for a drift space
  - assume paraxial approximation

    → $\sin(x') \approx x'$

- calculate the evolution of the beam size after a drift space
  - use the beam matrix transformation together with the transport matrix R for a drift space

- investigate the performance of the CCD
  - spatial calibration → dot grid target (0.5 mm spacing)
  - resolution → Siemens star, USAF 1951 target

- measure the emittance of the laser beam
  - measure spot sizes for different distances of the lens
  - analyse the horizontal profiles as function of the lens position
  - calculate the laser beam emittance → use the simplest way with only 2 values
  - (repeat with a different scintillator thickness)