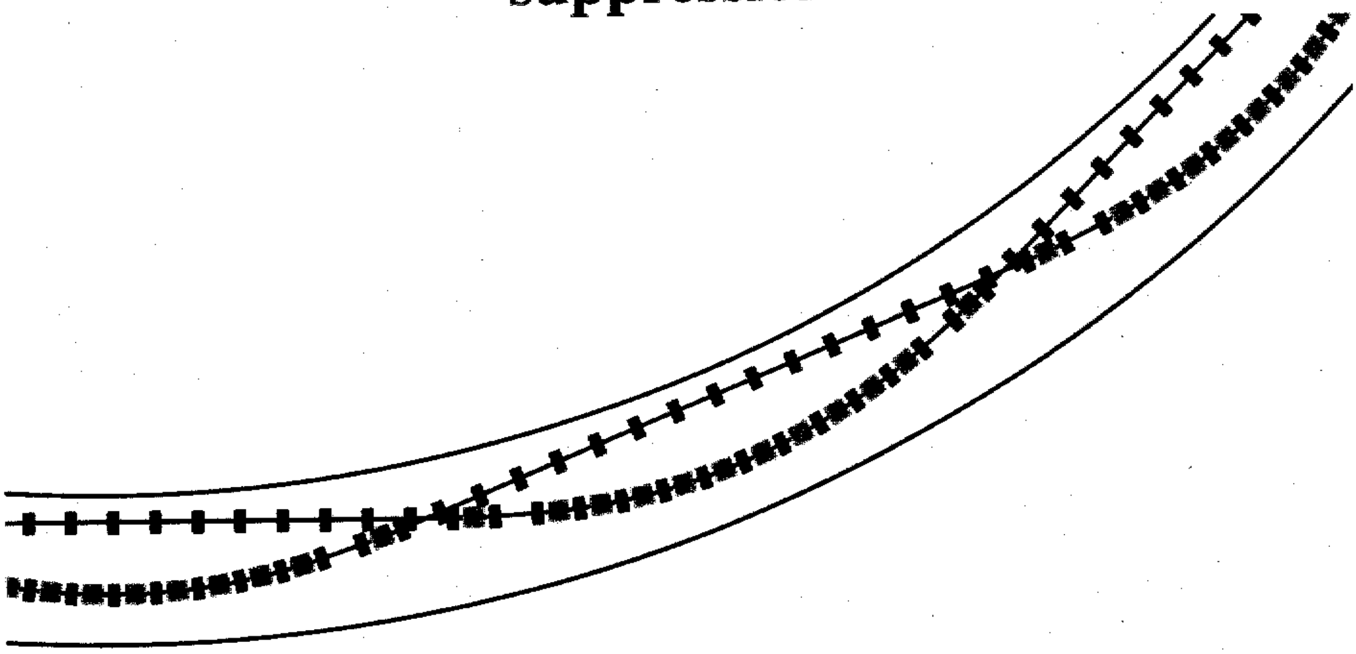
Non-isochronous lattices - Reasons to adopt non-isochronous rings

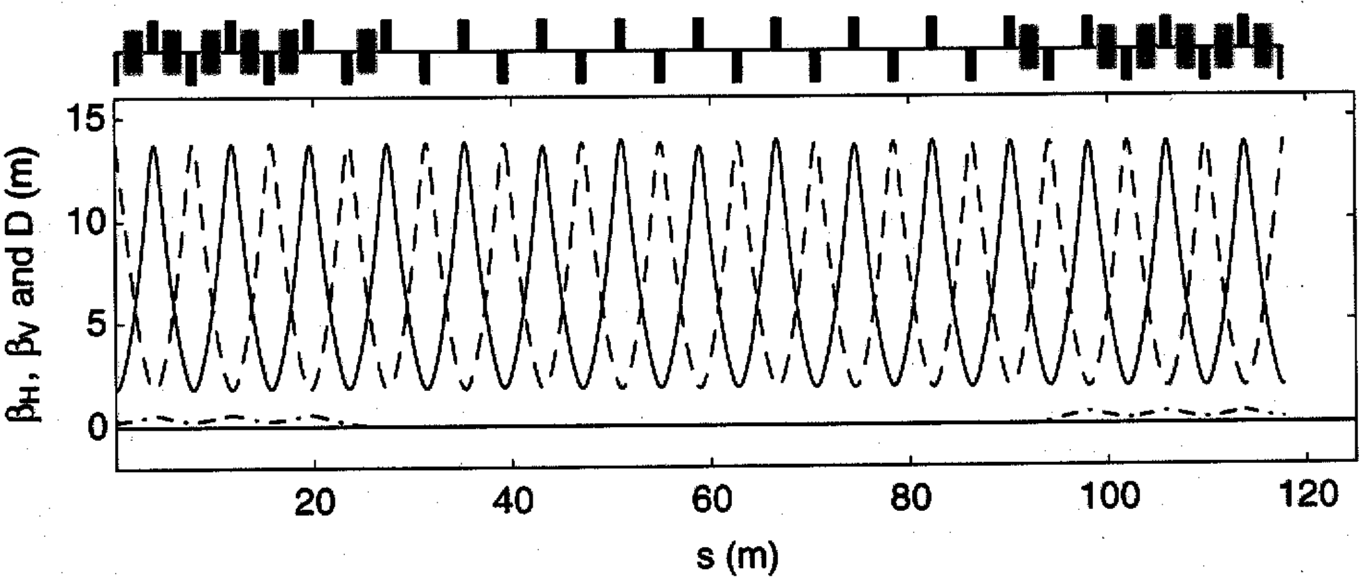
- **Problems with quasi-isochronous machines :**
  - Small momentum compaction denotes also small Landau damping.
    ⇒ Expect problems with instabilities.
  - Standard formulas appropriate at transition ?
  - Bunch rotation is slow
    ⇒ long time with a large Laslett tune shift.
  - Bunch rotation affected by potential wall distortions.
  - Search for isochronous optics led to exotic machines.
- **Adapt a solution with two rings :**
  - Accumulator with a modest RF system
    ⇒ small impedance improves stability
  - Compressor with high RF voltage available
    ⇒ together with the large momentum compaction, the bunch rotation is fast
    ⇒ Instabilities do not harm, unless the raise time is very short (shorter than bunch rotation)

⇒ Rather conventional lattices are suitable and have been chosen.

Non-isochronous lattices - Lattice with one missing magnet for dispersion suppression

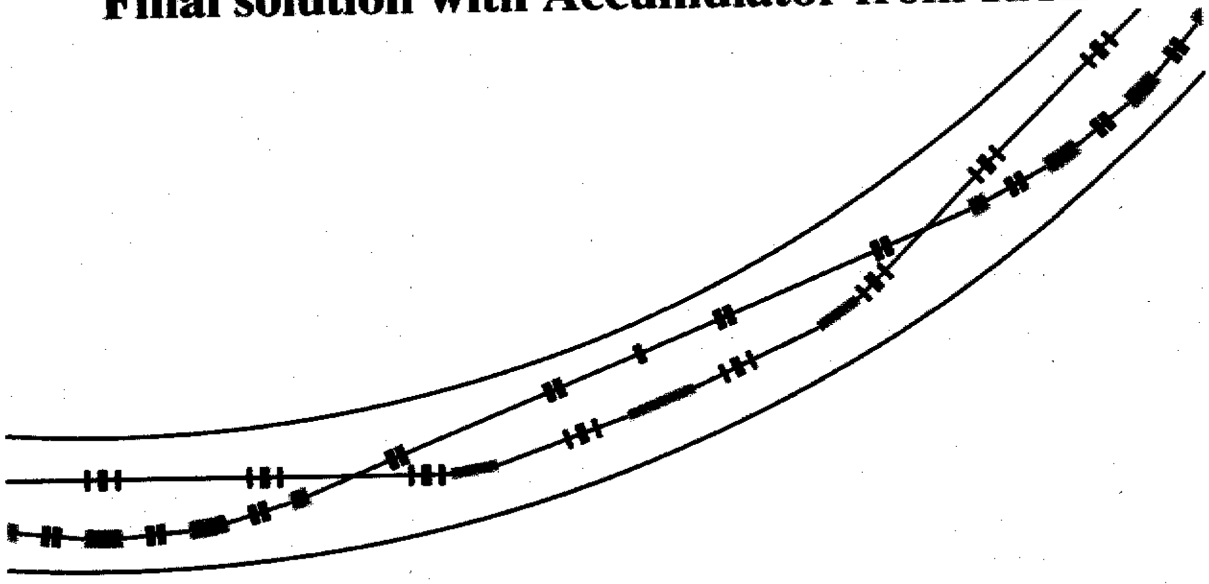


Geometry of the two rings in the same tunnel

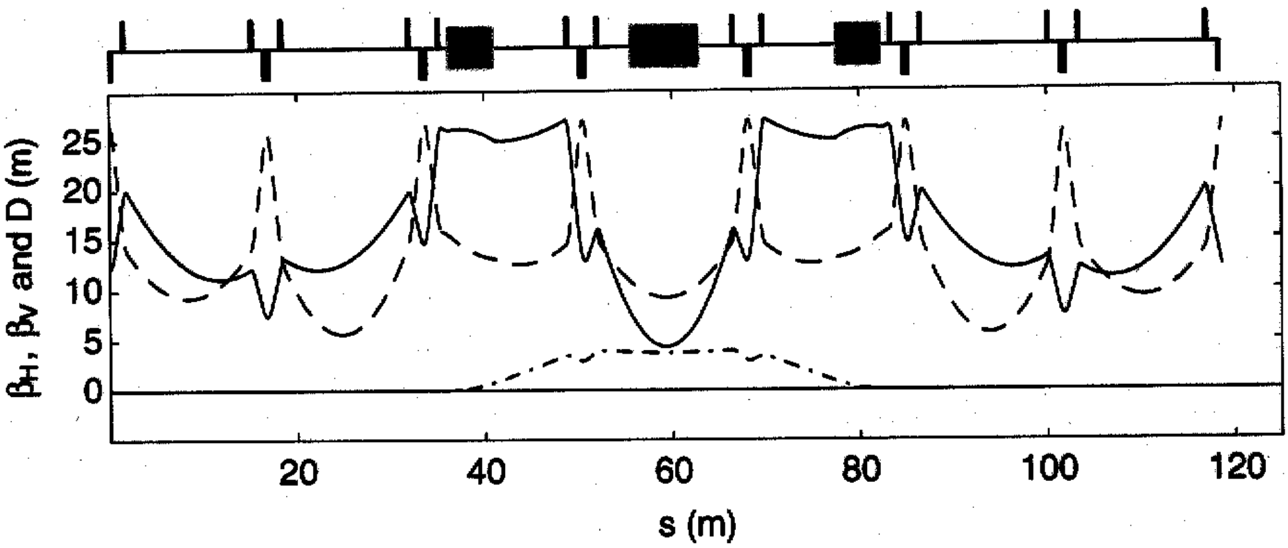


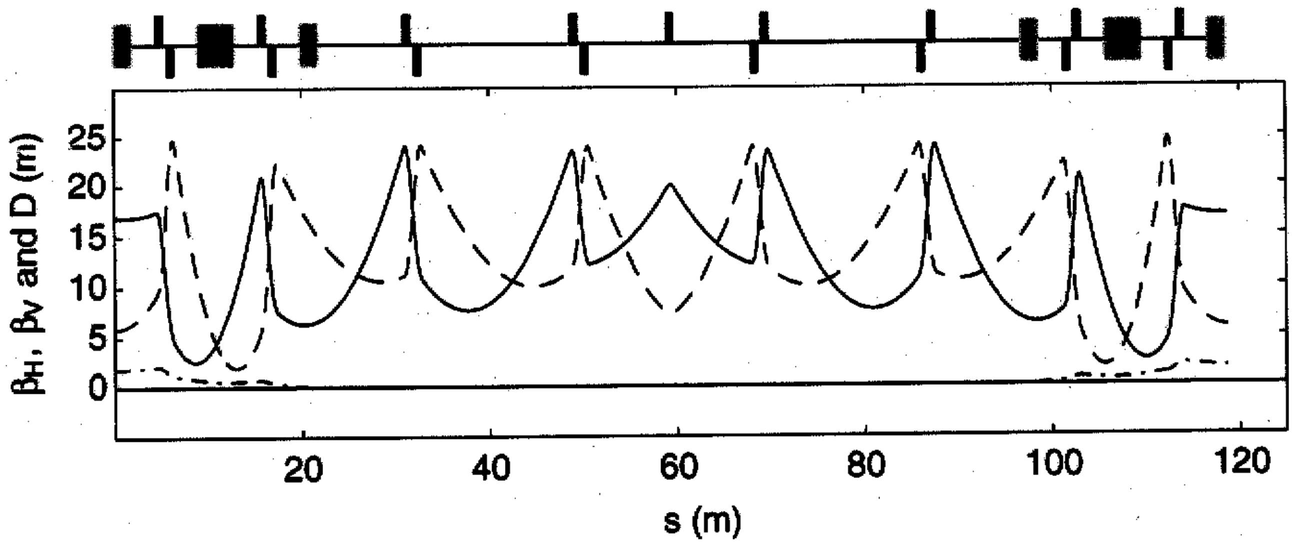
Lattice functions along one period

Non-isochronous lattices - Final solution with Accumulator from RAL



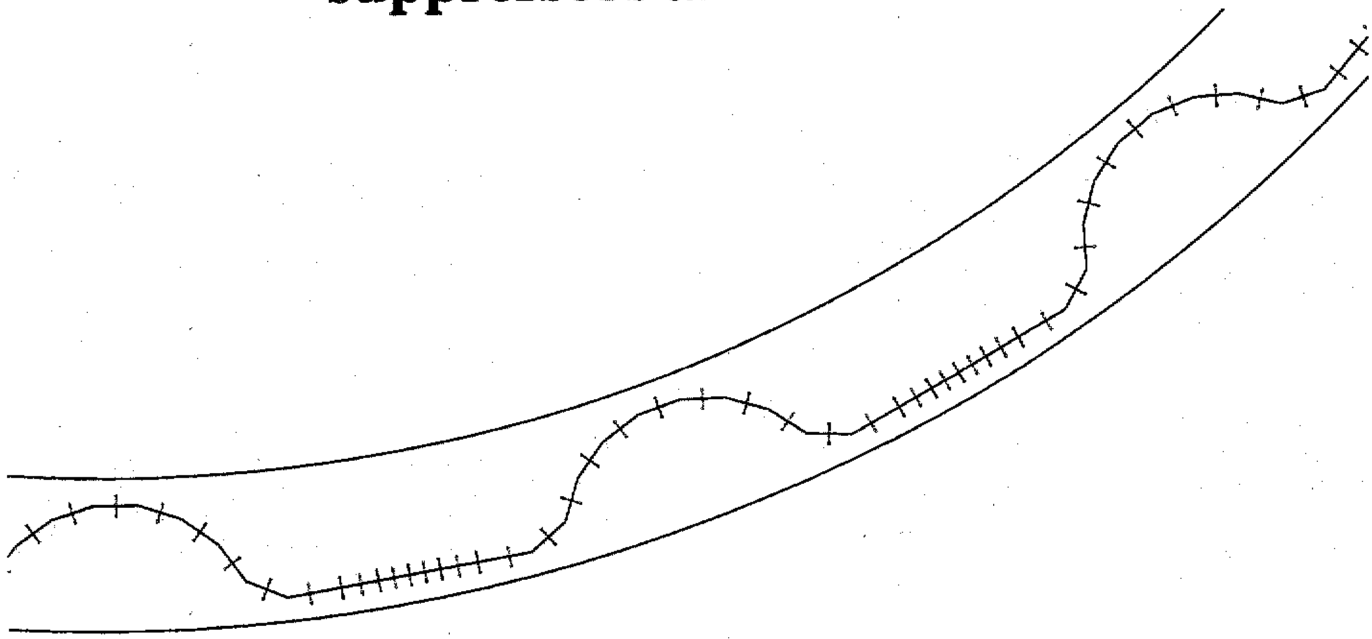
Geometry of the two rings in the same tunnel



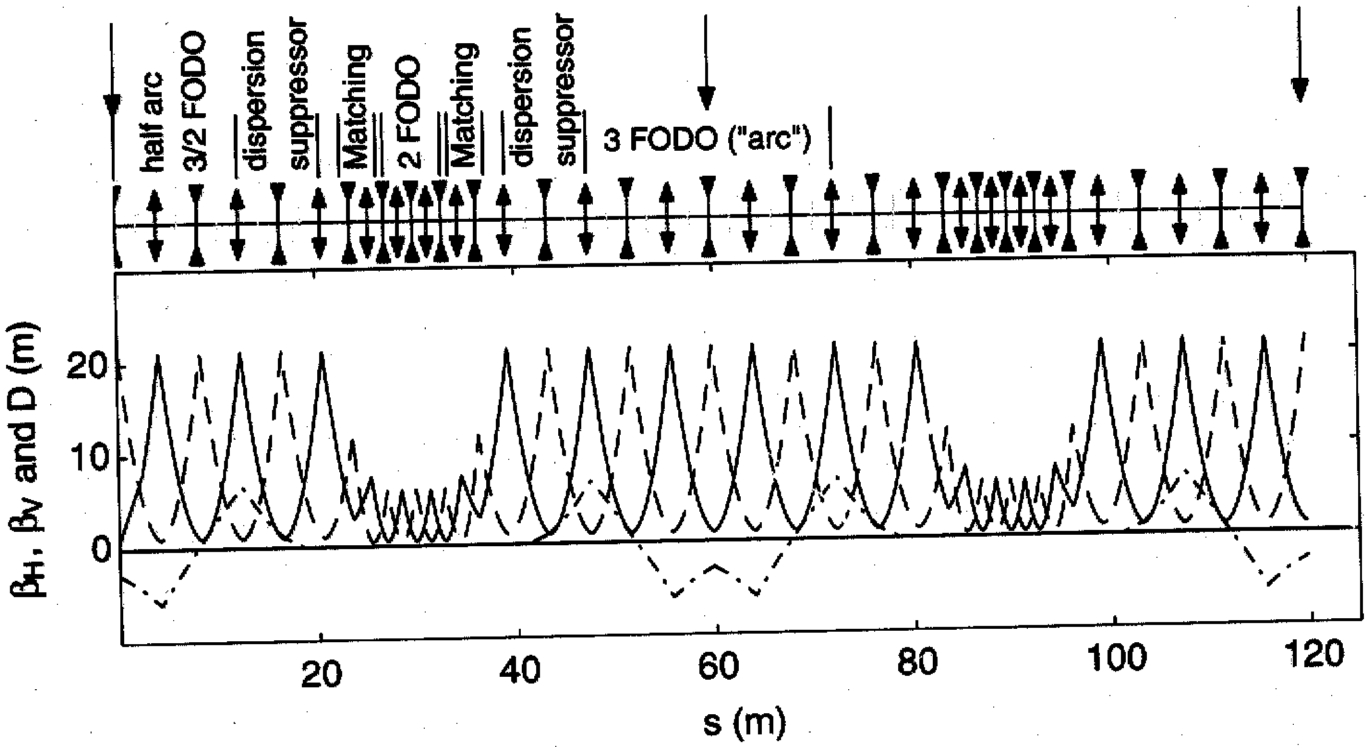


Lattice functions along one period

Quasi-Isochronous Lattices - Lattice with negative bends, dispersion suppressors and insertion



Geometry of the lattice with negative bends, dispersion suppressors and insertions

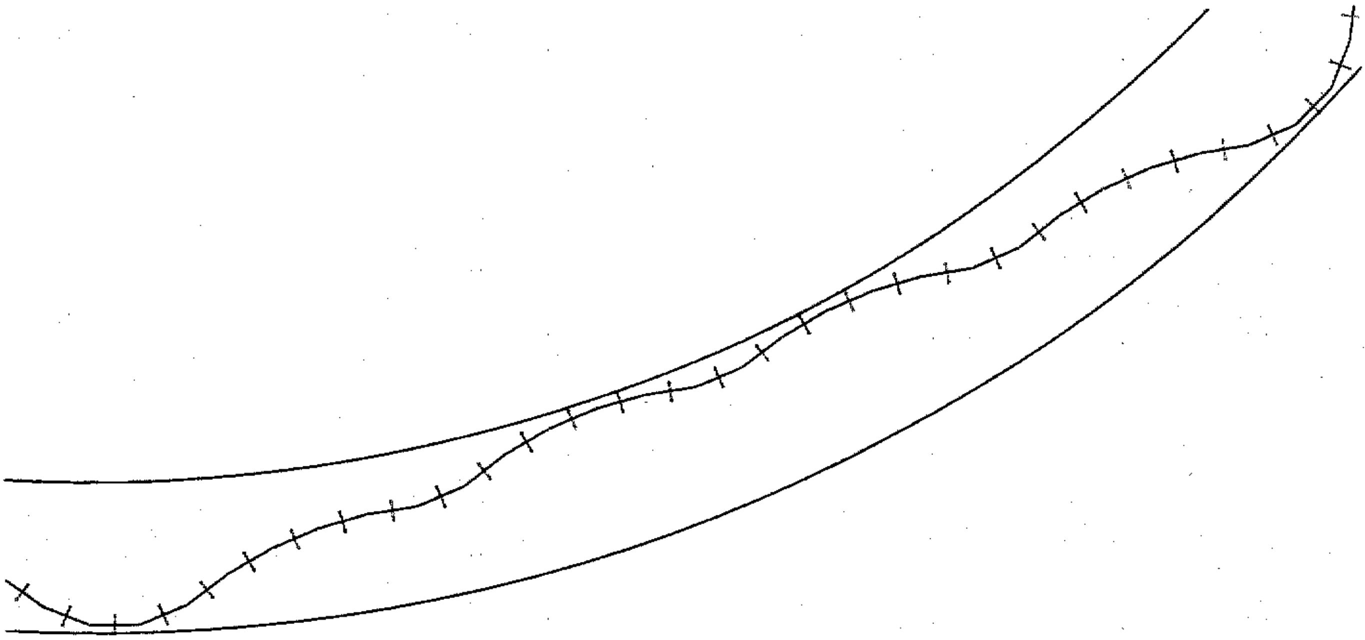


Lattice functions along two periods of the lattice

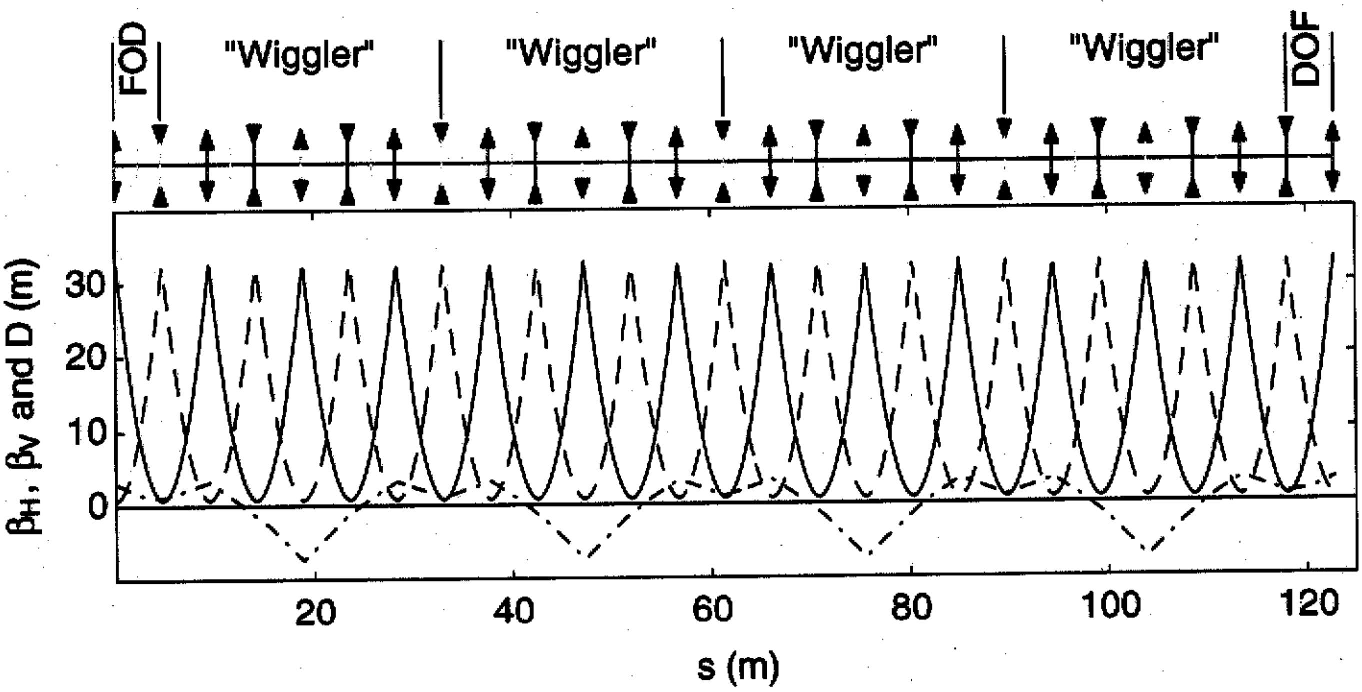
Quasi-Isochronous Lattices - Lattice with negative bends, dispersion suppressors and insertion

- Construct a lattice combining modules :
  - regular "arc" (3 FODO),
  - dispersion suppressors (1 FODO on both sides of arc),
  - Matching section (doublet) and
  - Insertion (low beta - 2 FODO).
- Adjust bending angles (in arc and of the two bends in the dispersion suppressor) to get no dispersion in insertions and isochronicity.
- Two (similar) solutions. The one shown here has negative bending angles in the "arc".
- Strong focusing ($\Rightarrow$ high tunes around 60),
- Many Periods (18) ($\Rightarrow$ little space),
- Total deflection angle very large.

Quasi-Isochronous Lattices - Lattice with "Wigglers"



Geometry of the lattice with "Wigglers" (and no dispersion suppressors)



Lattice functions along the line -
Half a FODO cell + 4 "Wiggler" modules + half a FODO cell

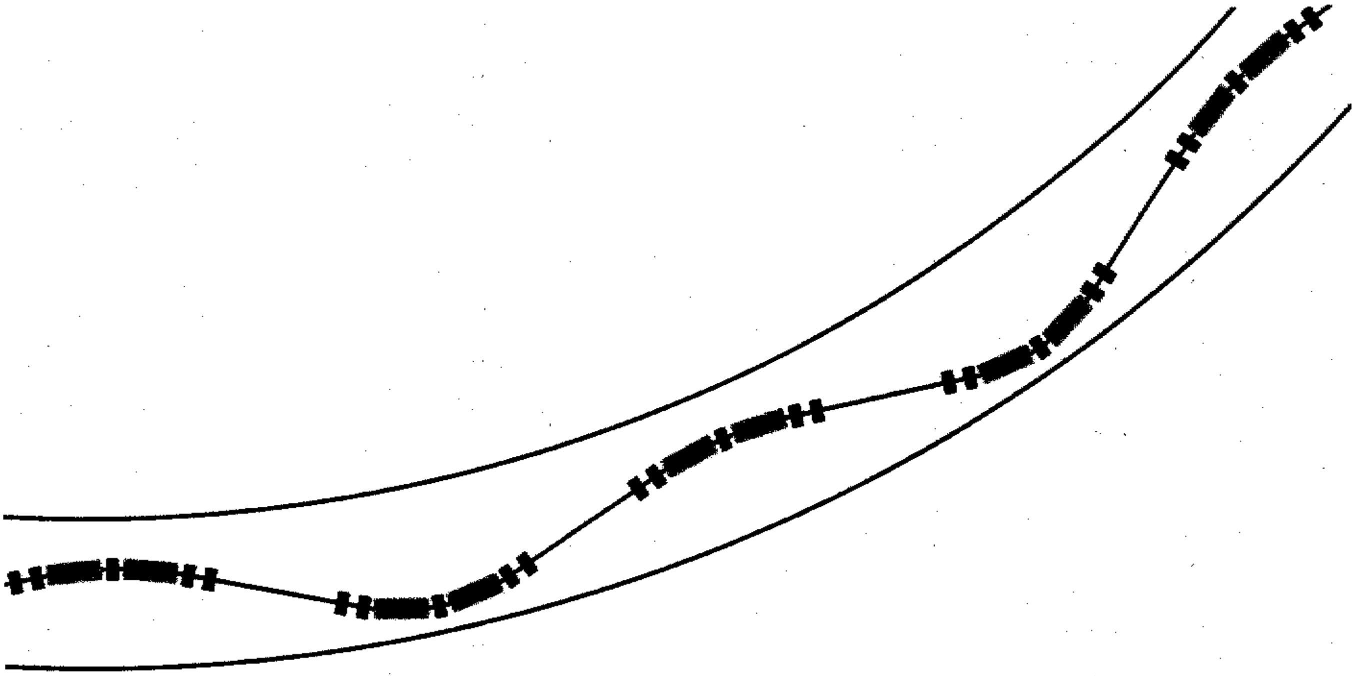
Quasi-Isochronous Lattices - LEAR like solution

- A LEAR like lattice,
  i.e. Focusing mainly by doublets on both sides of bending sections (plus a D-quad at centre of bending sections).
- Alternate bending sections with positive and negative angle. Adjust such that the dispersion has the right sign at the bending sections.
- Solutions reducing the maximum dispersion by a factor 3 with a total bending angle of 6 π were found.
- Much space for equipment.

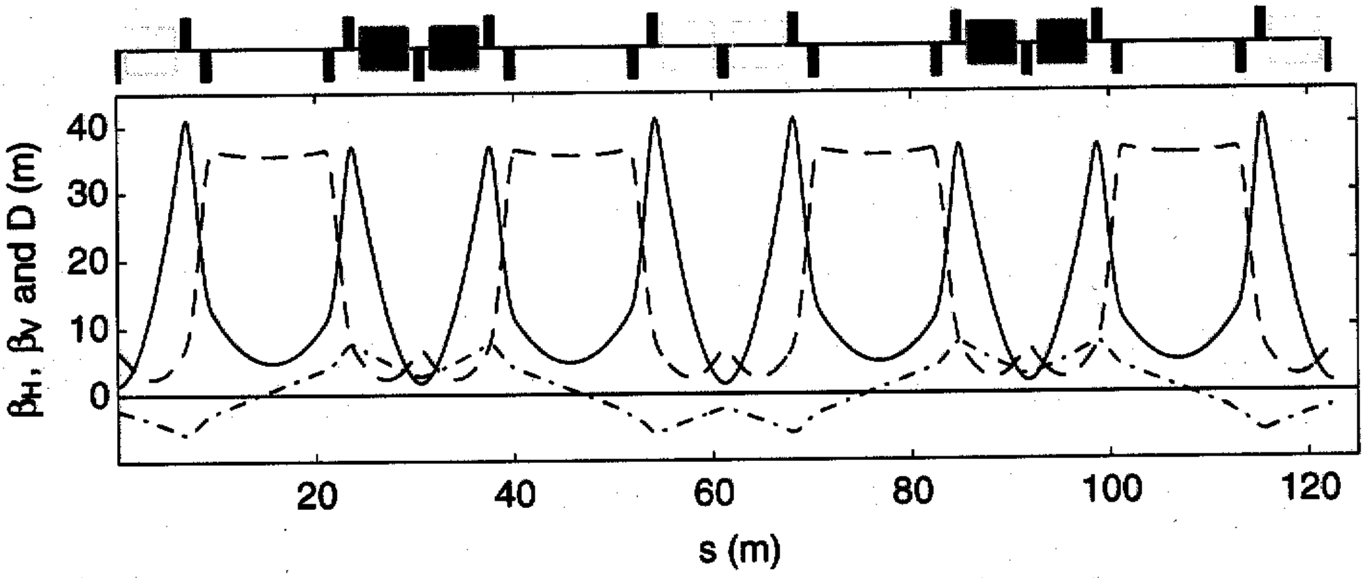
Quasi-Isochronous Lattices - FODO with bends at appropriate places

- Use a regular (apart from bendings) FODO lattice.
- Distribute bending magnets such that the phase advance between sections with positive and negative deflection is between π and 2π.
- Allows solutions with (relative) smooth betatron functions.

Quasi-Isochronous Lattices - LEAR like solution



Geometry of the LEAR like lattice

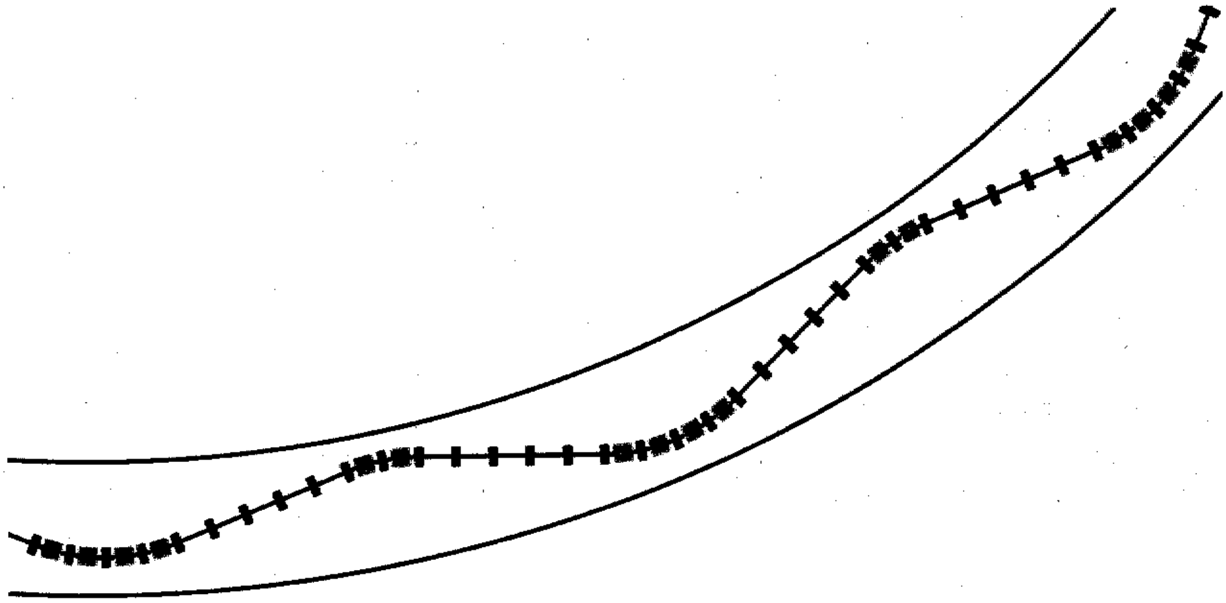


Lattice functions of the (2 Periods of the) LEAR like lattice

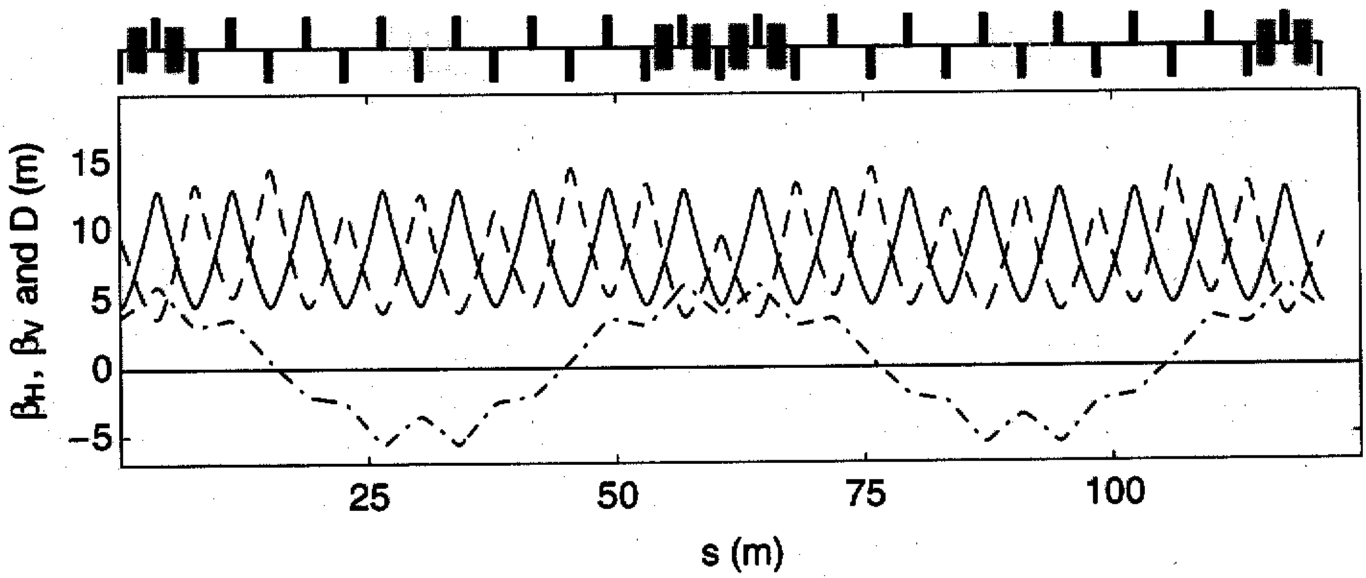
Quasi-Isochronous Lattices - Lattice with "Wigglers"

- Starting from a FODO lattice, insert sections with positive and negative bends = "Wigglers".
- Total bending of Wiggler is zero (respect geometry).
- Dispersion in FODO should not be affected by "Wiggler".
- Symmetric "Wiggler" extending 3 FODO periods allows to have 3 independent bending angles. In addition to dispersion matching and the geometry, γ_{tr} may be adjusted.
- Bends partly not in between, but at the location of quads $\Rightarrow$ needs combined function magnets.
- Solution (only with thin elements) shown here has 4 "Wiggler" (with 3 FODO each) between regular FODO cells.
- Working point : $Q_H = Q_V = 42.18$
- Circumference : 980 m
- To reach the transition, $\gamma_{tr} = 3.35$, requires strong focusing, i.e. large oscillations of the betatron functions. ~~as desired).~~

Quasi-Isochronous Lattices - FODO with bends at appropriate places



Geometry of the lattice Bends at appropriate places inside a FODO



Lattice functions for 2 periods of the FODO with appropriately placed bends

Quasi-Isochronous Lattices - Why negative Bends ?

- Main problem of the plain FODO lattice was the large dispersion.
- To reach a given transition γ_{tr}, the following condition applies :

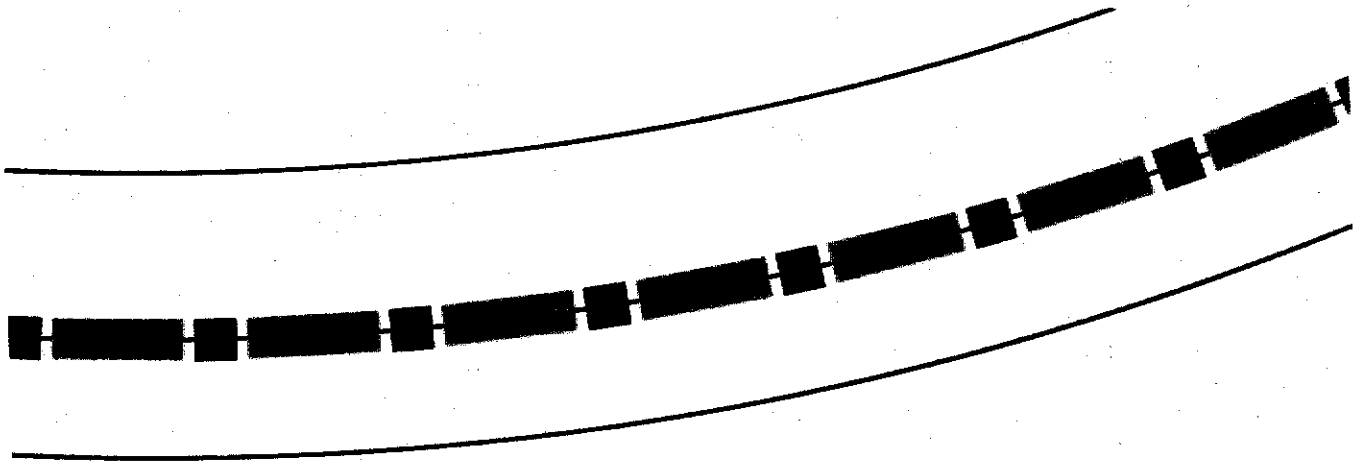
$$\alpha = \frac{1}{C} \int_0^C ds \frac{D(s)}{\rho(s)} = \frac{1}{\gamma_{tr}^2} \quad ,$$

  with C the circumference (in our application $\approx$ 1000 m), $D(s)$ the dispersion and $\rho(s)$ the curvature.
- Above can be expressed by deflection angles and mean dispersion in bending magnets :

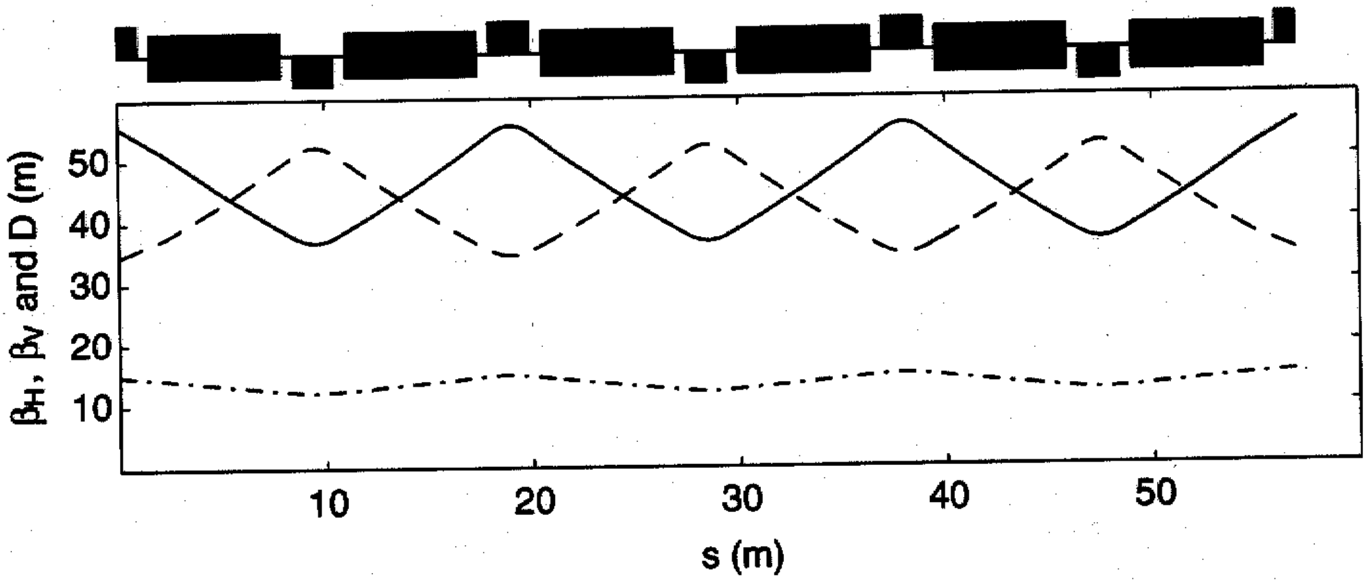
$$\alpha = \frac{1}{C} \sum_n \theta_n \overline{D}_n$$

- Assuming only positive bending, the only way to obtain a large α is a large dispersion.
- As a way out, add negative bends (with negative dispersion).

Quasi-Isochronous Lattices - Plain FODO lattice



Geometry of the plain FODO lattice



Lattice functions along the line

Quasi-Isochronous Lattices - Motivation

- **Use one ring for both accumulation and bunch compression.**
- **Work with ~~reasonable~~ modest RF voltages during accumulation and compression.**

$\Rightarrow$ **Need for a lattice with** $\eta = 0$**, i.e. working at transition and thus with** $\gamma_{tr} \approx 3.35$.

Quasi-Isochronous Lattices - Plain FODO lattice

- **As a first attempt, try a standard FODO lattice - adjust gradients to obtain isochronicity.**
- **To reach the low** γ_{tr}**, large dispersion is needed leading to little focusing and low tunes.**

$\rightarrow$

$$\gamma_{tr} \approx Q_H \frac{\mu_H/2}{\sin(\mu_H/2)}$$

- **Mainly the large dispersion leads to large beams, especially after bunch compression.**

PDAC (Proton Driver Accumulator Compressor)

Aim : proton beam of 4 MW on target with a time structure suitable for ionisation cooling.

The CERN Scheme :

- H^- Linac accelerating up to 2.2 GeV to provide the beam power.
- Ionisation cooling channel working with a fundamental frequency 44 MHZ determines the time-structure target.
- Accumulator and Compressor converts the long Linac pulse into a series of short pulses (Charge exchange injection and bunch rotation in long. phase space).
- Length of Accumulator and Compressor :
  Shorter than the μ decay ring,
  Long to limit the foil traversals of the proton.

⇒ The existing ISR tunnel has the right length and should be reused.

- Initially, one single isochronous ring (for accumulation and compression) was considered, but finally abandoned (Instabilities ...).

Lattice Design Studies for the CERN Proton Driver Accumulator and Compressor

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CERN/PS

- PDAC (Proton Driver Accumulator Compressor)
- Quasi-Isochronous Lattices
  - Motivation
  - Plain FODO lattice
  - General Consideration on Dispersion - Why negative bends ?
  - LEAR like lattice
  - FODO with Bends at appropriate phases
  - Lattice with "Wigglers" (thin lens)
  - Lattice with "Wigglers" and dispersion suppressors (thin lens)
- Non-isochronous lattice
  - Motivation to adopt two rings far below transition
  - The lattices