CARE-HHH-APD BEAM'07

# Optics considerations for PS2

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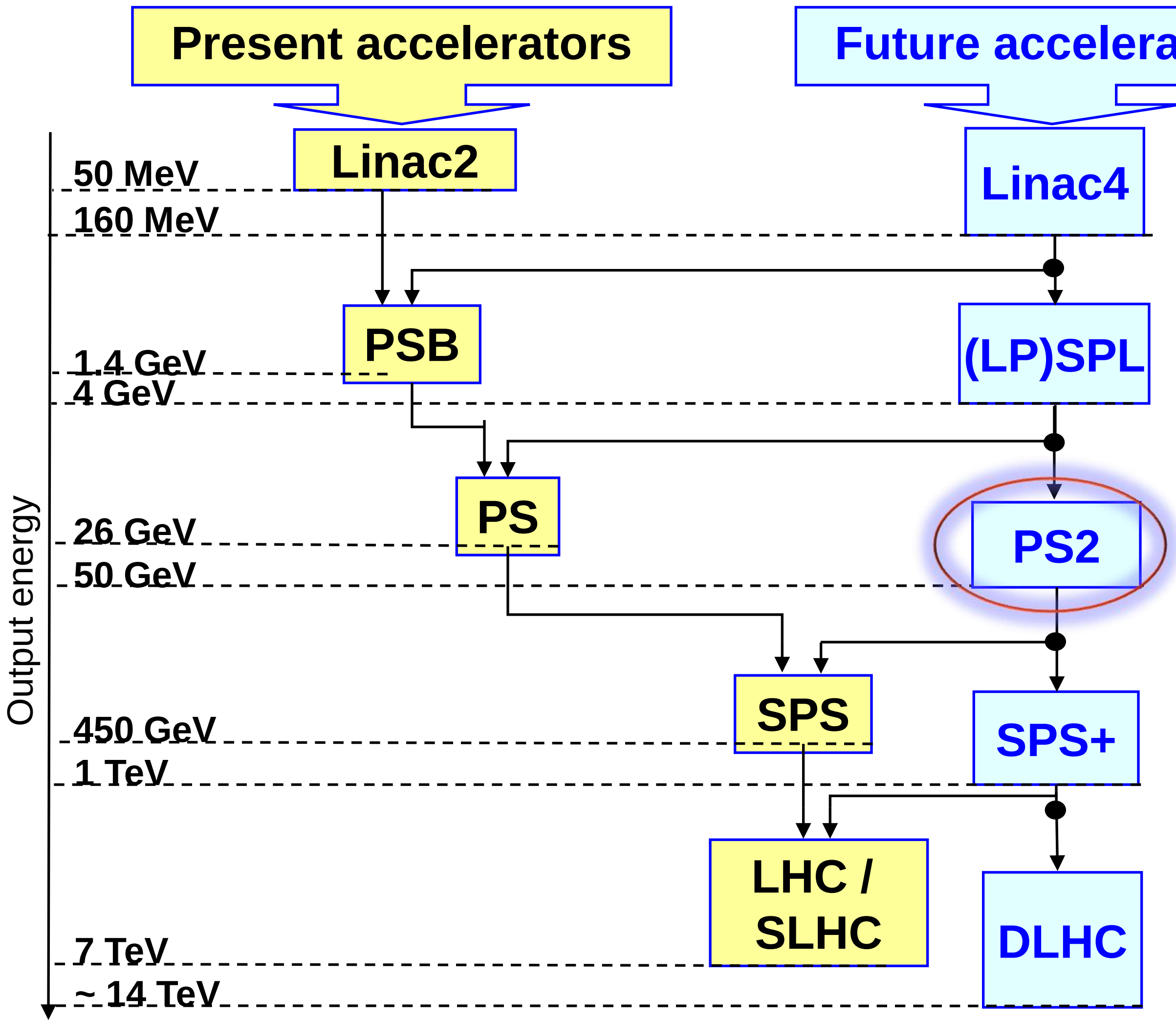
# Outline

- Motivation and design constraints for PS2
- FODO lattice
- Doublet/Triplet
- Flexible (Negative) Momentum Compaction modules
  - High-filling factor design
  - Tunability and optics' parameter scan
- PS2-SPS transfer line optics design
- Summary and perspectives

# Motivation – LHC injectors' upgrade

R. Garoby, BEAM' 07

- Upgrade injector complex.
  - Higher injection energy in the SPS => better SPS performance
  - Higher reliability




**(LP)SPL:** (Low Power) Superconducting Proton Linac (4-5 GeV)
**PS2: High Energy PS (~ 5 to 50 GeV – 0.3 Hz)**
**SPS+:** Superconducting SPS (50 to1000 GeV)
**SLHC**: "Super-luminosity" LHC (up to $10^{35}$ $cm^{-2}s^{-1}$)
**DLHC**: "Double energy" LHC (1 to ~14 TeV)

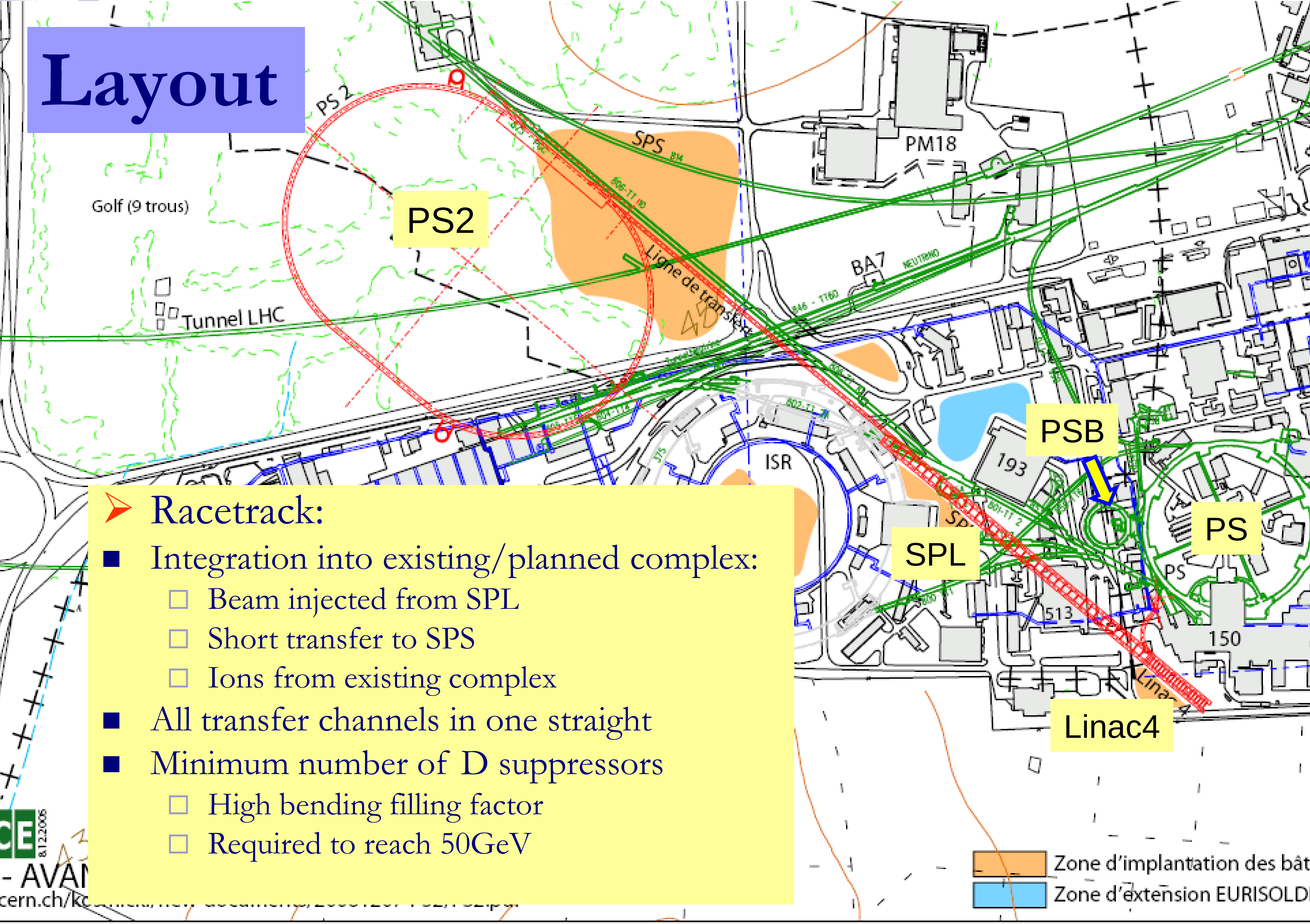
# Design and optics constraints for PS2 ring

- Replace the ageing PS and improve options for physics
- Integration in existing CERN accelerator complex
- Versatile machine:
  - Many different beams and bunch patterns
  - Protons and ions

| Basic beam parameters | PS2 |
|---|---|
| Injection kinetic energy [GeV] | 4 |
| Extraction kinetic energy [GeV] | ~ 50 |
| Circumference [m] | 1346 |
| Transition energy [GeV] | ~10/10i |
| Maximum bending field [T] | 1.8 |
| Maximum quadrupole gradient [T/m] | 17 |
| Maximum beta functions [m] | 60 |
| Maximum dispersion function [m] | 6 |
| Minimum drift space for dipoles [m] | 0.5 |
| Minimum drift space for quads [m] | 0.8 |

- Injection kinetic energy → Constrained by incoherent space-charge tune-shift (~0.2)
- Extraction kinetic energy → Improve SPS performance
- Circumference → Analysis of possible bunch patterns: $C_{PS2} = (15/77)\ C_{SPS}$
- Transition energy → Longitudinal aspects
- Maximum bending field, Maximum quadrupole gradient → Normal conducting magnets
- Maximum beta functions, Maximum dispersion function → Aperture considerations for high intensity SPS physics beam
- Minimum drift space for dipoles, Minimum drift space for quads → Space considerations

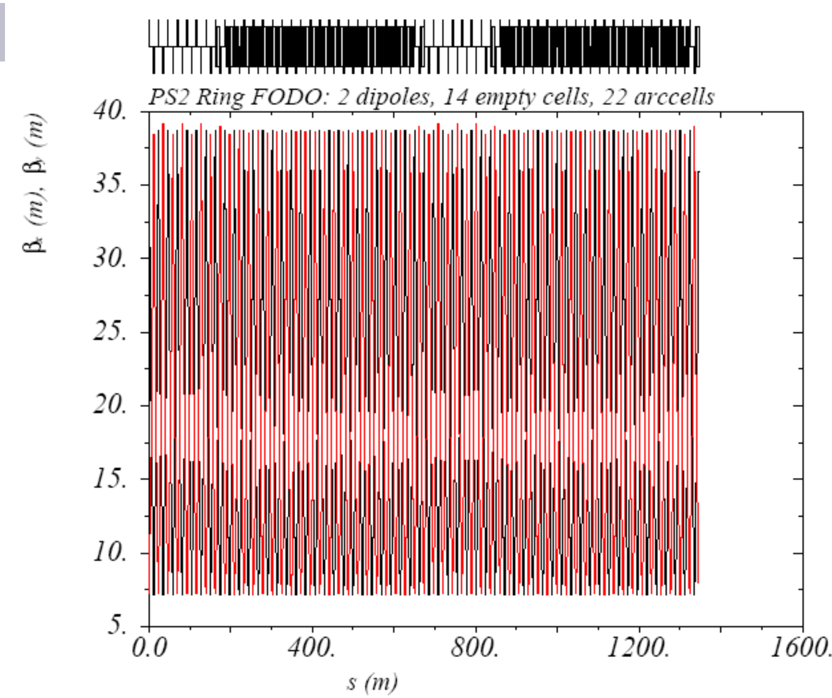
# Layout

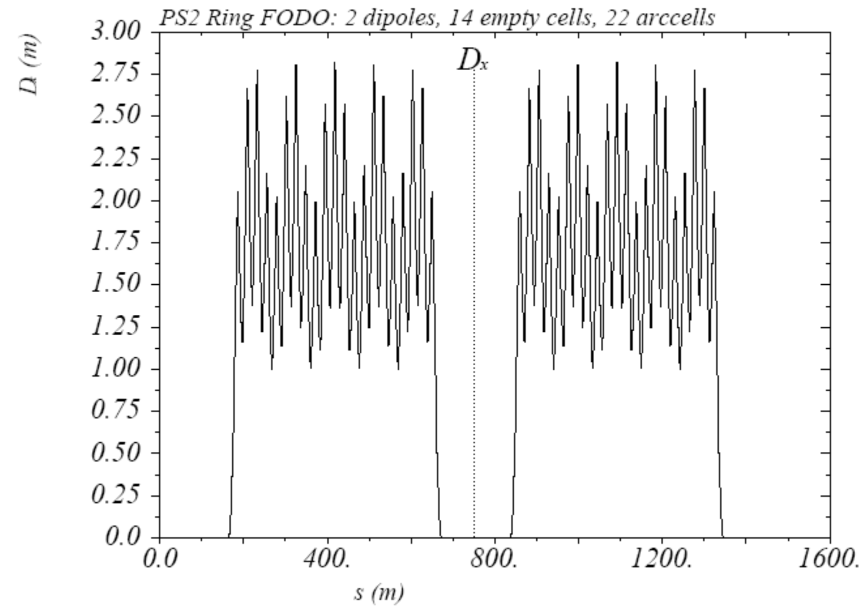



- ➢ Racetrack:
  - Integration into existing/planned complex:
    - Beam injected from SPL
    - Short transfer to SPS
    - Ions from existing complex
  - All transfer channels in one straight
  - Minimum number of D suppressors
    - High bending filling factor
    - Required to reach 50GeV

# FODO Lattice

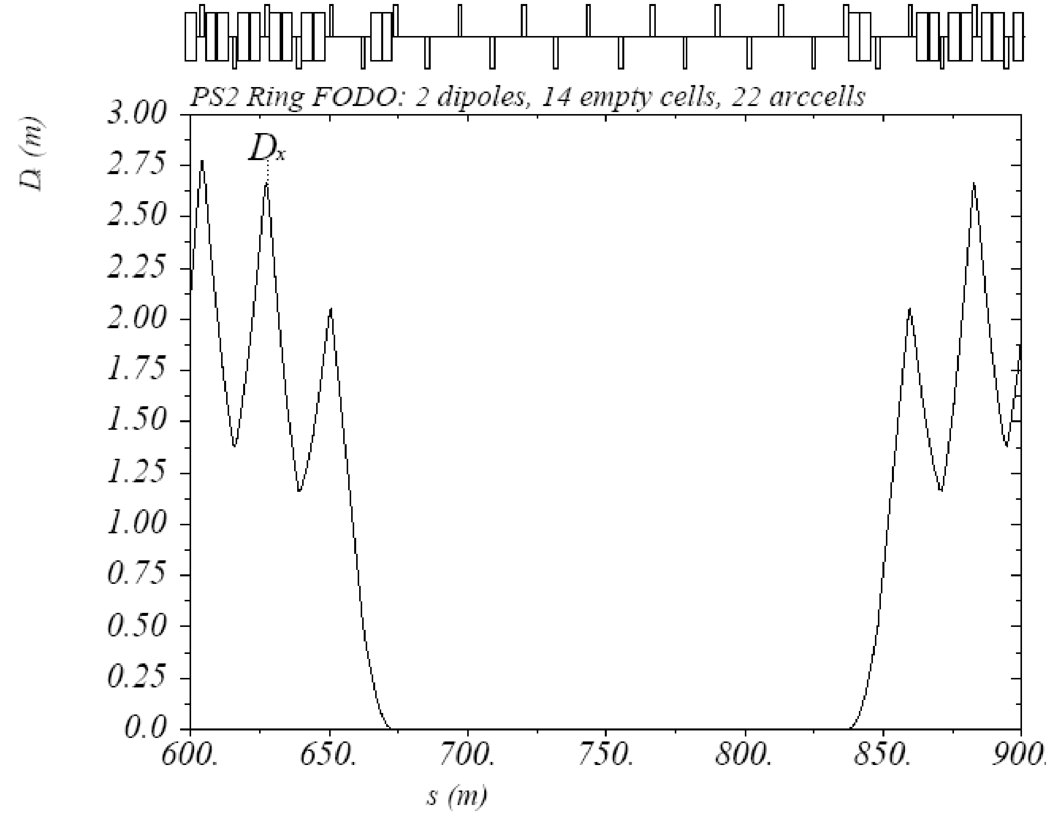
- Conventional Approach:
  - FODO with missing dipole for dispersion suppression in straights
  - 2 dipoles per half cell, 2 quadrupole families
  - Phase advance of **88°**, $\gamma_{tr}$ of **11.4**
  - 7 cells/straight and 22 cells/arc => in total 58 cells
  - $Q_{H,V}$ = **14.1-14.9**
  - Alternative design with matching section and increased number of quadrupole families

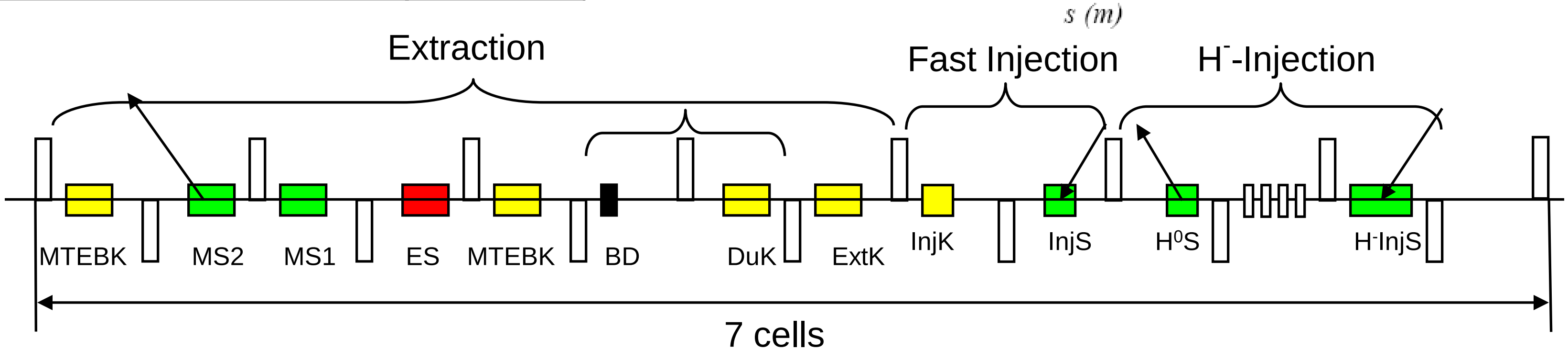


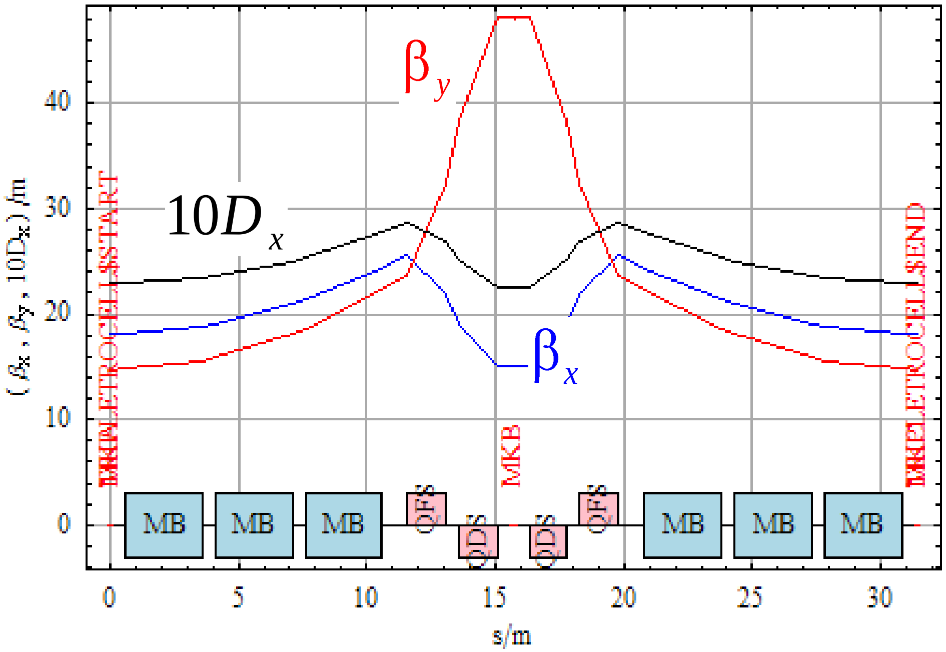
# Dispersion suppressor and straight section

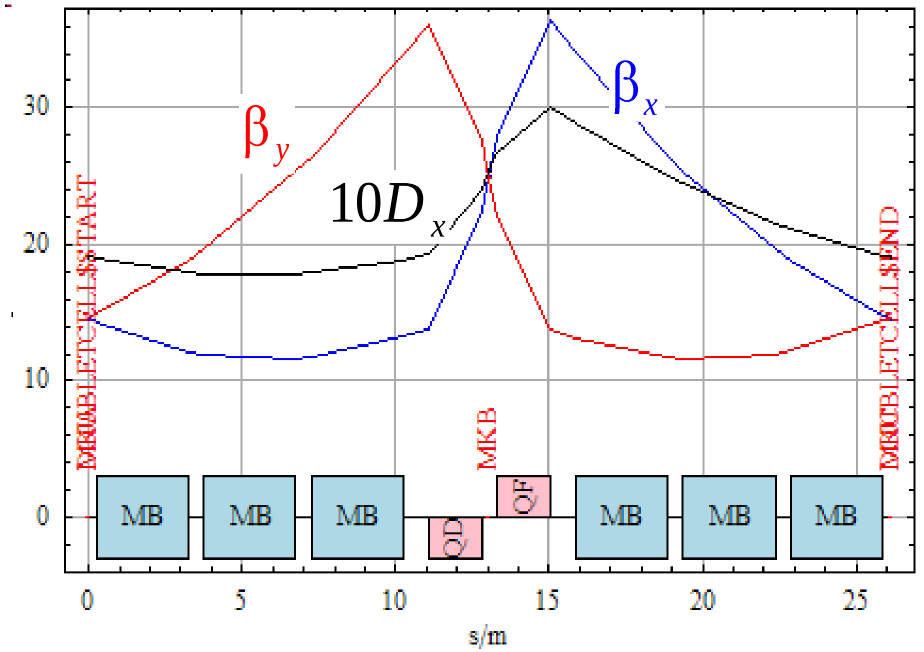
| | |
|---|---|
| Cell length [m] | 23.21 |
| Dipole length [m] | 3.79 |
| Quadrupole length [m] | 1.49 |
| LSS [m] | 324.99 |
| Free drift [m] | 10.12 |
| # arc cells | 22 |
| # LSS cells: | 7 |
| # dipoles: | 168 |
| # quadrupoles: | 116 |
| # dipoles/half cell: | 2 |



# Doublet and Triplet arc cells

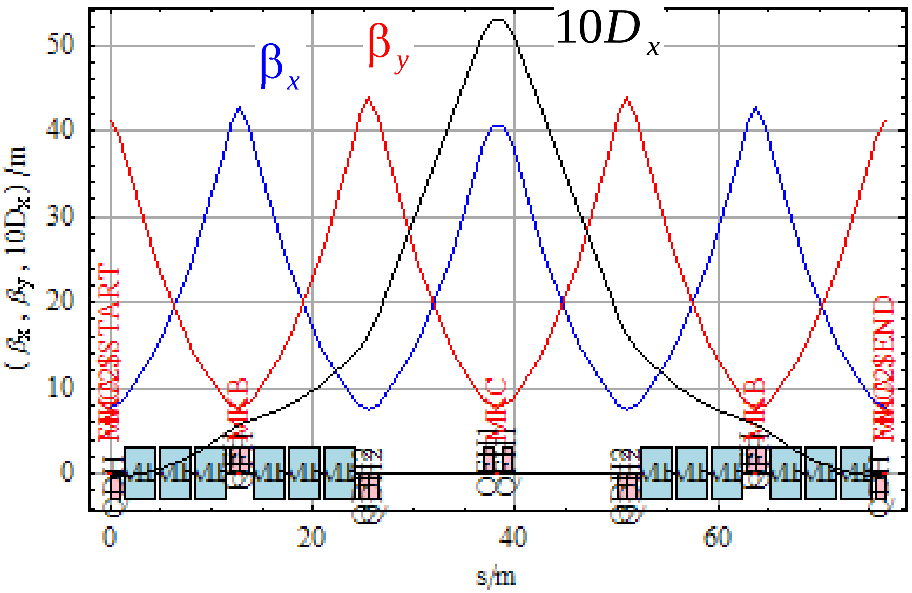


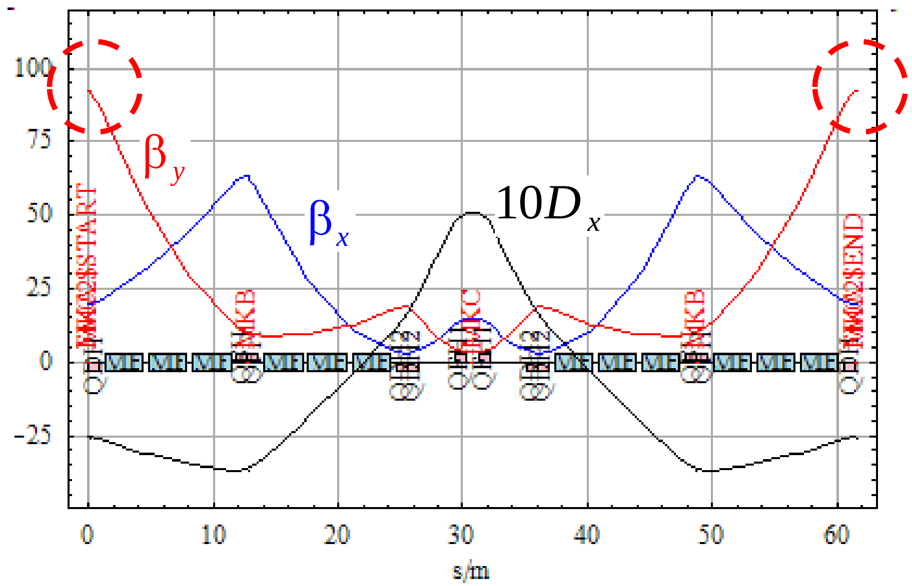

- Advantages
  - Long straight sections and small maximum β's in bending magnets (especially for triplet)
- Disadvantage
  - High focusing gradients (especially for doublet)

# Flexible Momentum Compaction Modules

- Aim at negative momentum compaction
- Similar to and inspired from existing modules (e.g. J-PARC, see also talk by Yu. Senichev)
- First approach (one module made of three FODOs):
  - Match regular FODO to 90° phase advance
  - Reduced central straight section without bends, re-matched to obtain phase advance (close to three times that of the FODO, i.e. 270°)
- Disadvantage: Maximum vertical β above **80m**




regular FODO 90°/cell
=> zero dispersion at beginning/end




reduced drift in center, average 90°/cell
=> negative dispersion at beginning/end with $\gamma_{tr}$ ~ 10i

# FMC modules with high filling factor

- Improve filling factor: four FODO per module
- Dispersion beating excited by "kicks" in bends
- Resonant behavior: total phase advance $< 2\pi$
- Large radii of the dispersion vector produce negative momentum compaction
- High phase advance is necessary

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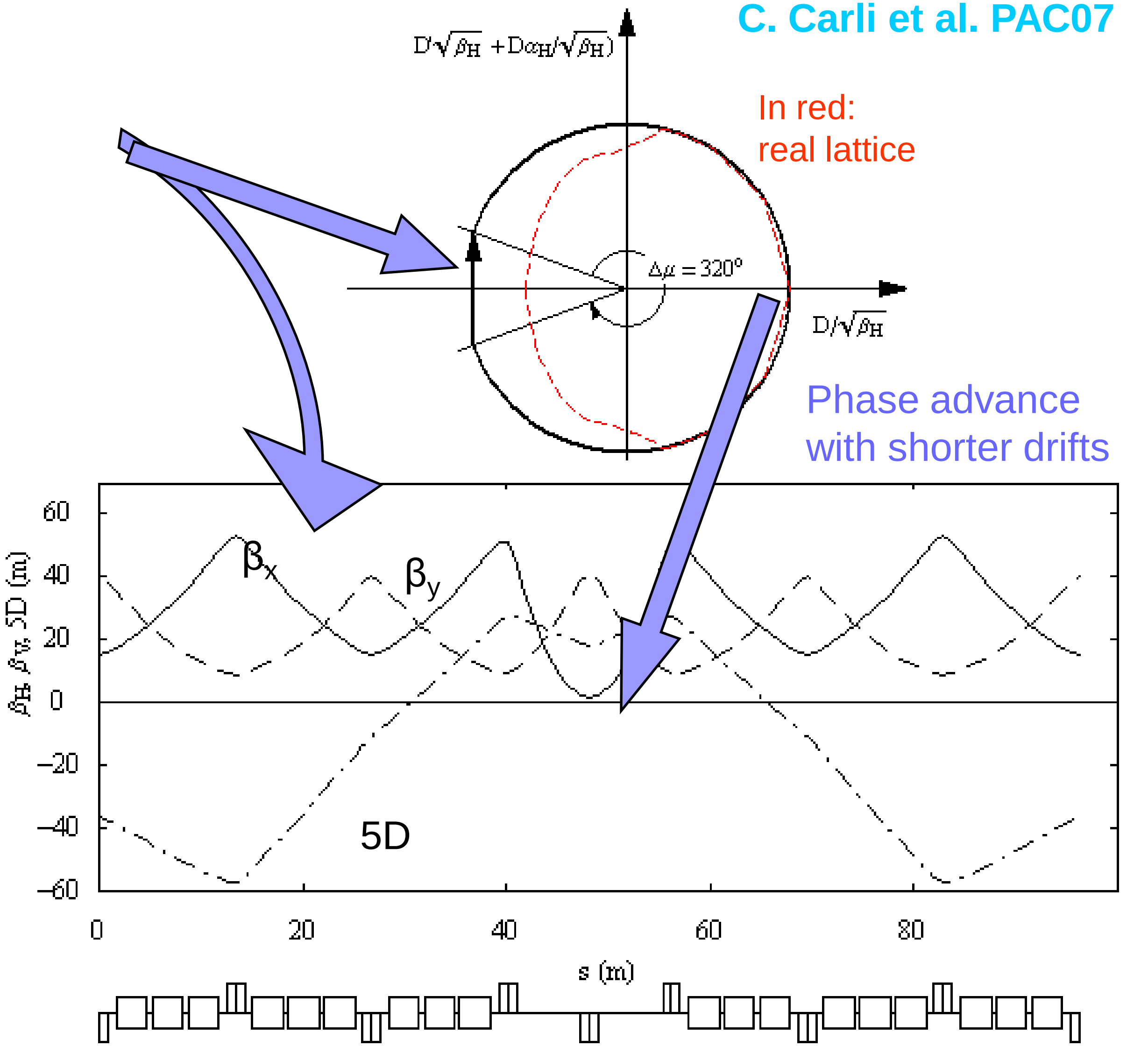
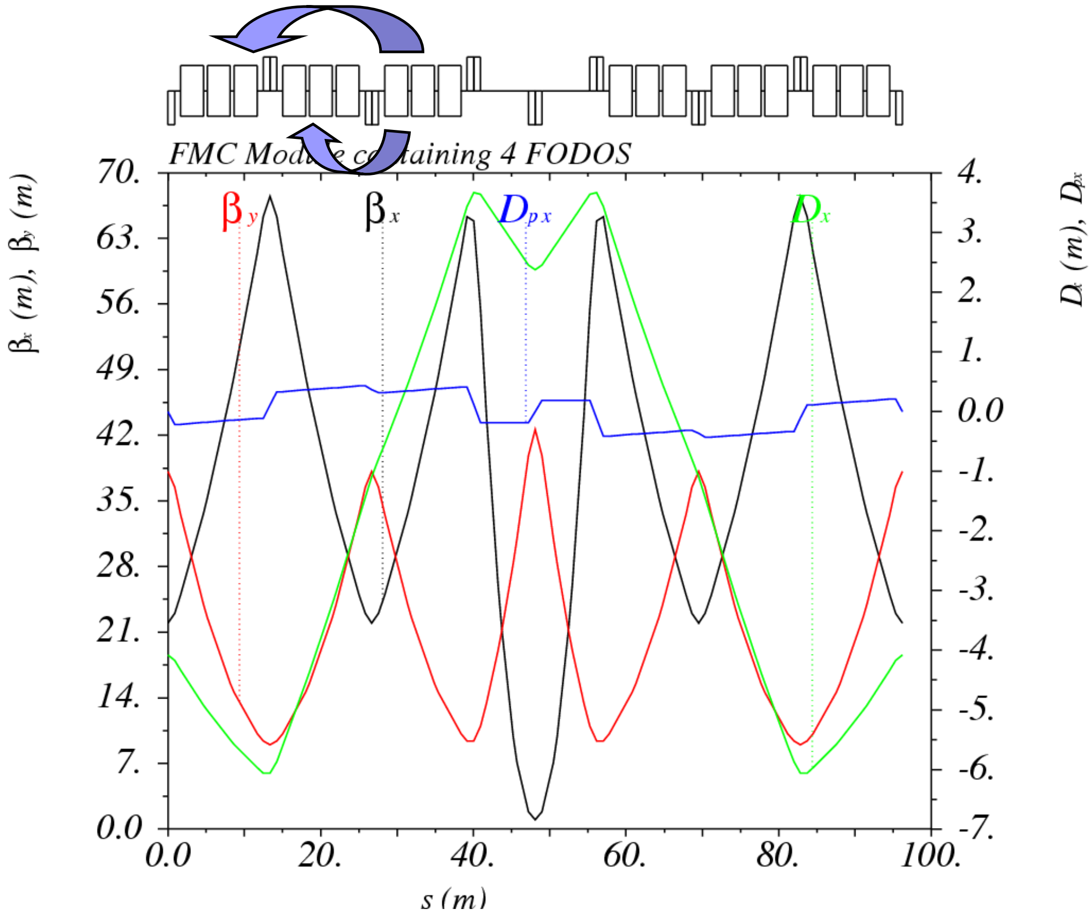


# Improving the high filling factor FMC

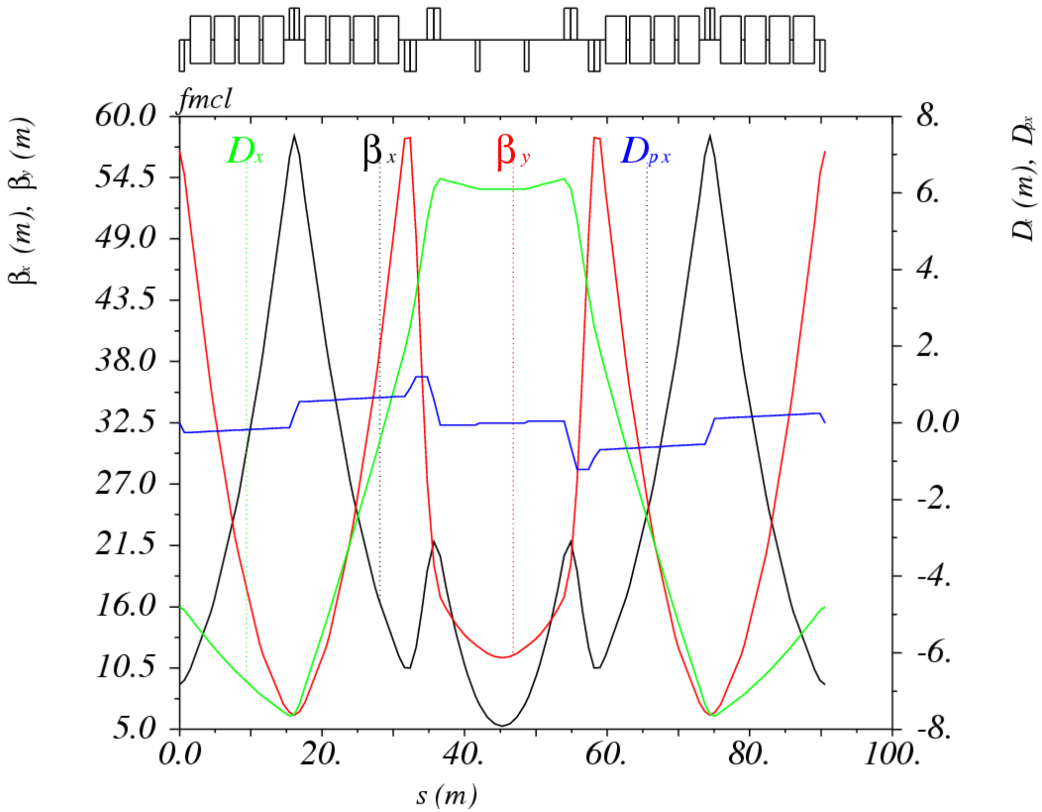
- The "high-filling" factor arc module
  - Phase advances of **280°,320°** per module
  - $\gamma_t$ of **8.2i**
  - Four families of quads, with max. strength of **0.095m$^{-2}$**
  - Max. horizontal beta of **67m** and vertical of **43m**
  - Min. dispersion of -6m and maximum of 4m
  - Chromaticities of **-1.96,-1.14**
  - Total length of **96.2m**
- Slightly high horizontal β and particularly long module, leaving very little space for dispersion suppressors and/or long straight sections




- Reduce further the transition energy by moving bends towards areas of negative dispersion and shorten the module

# Alternative FMC module

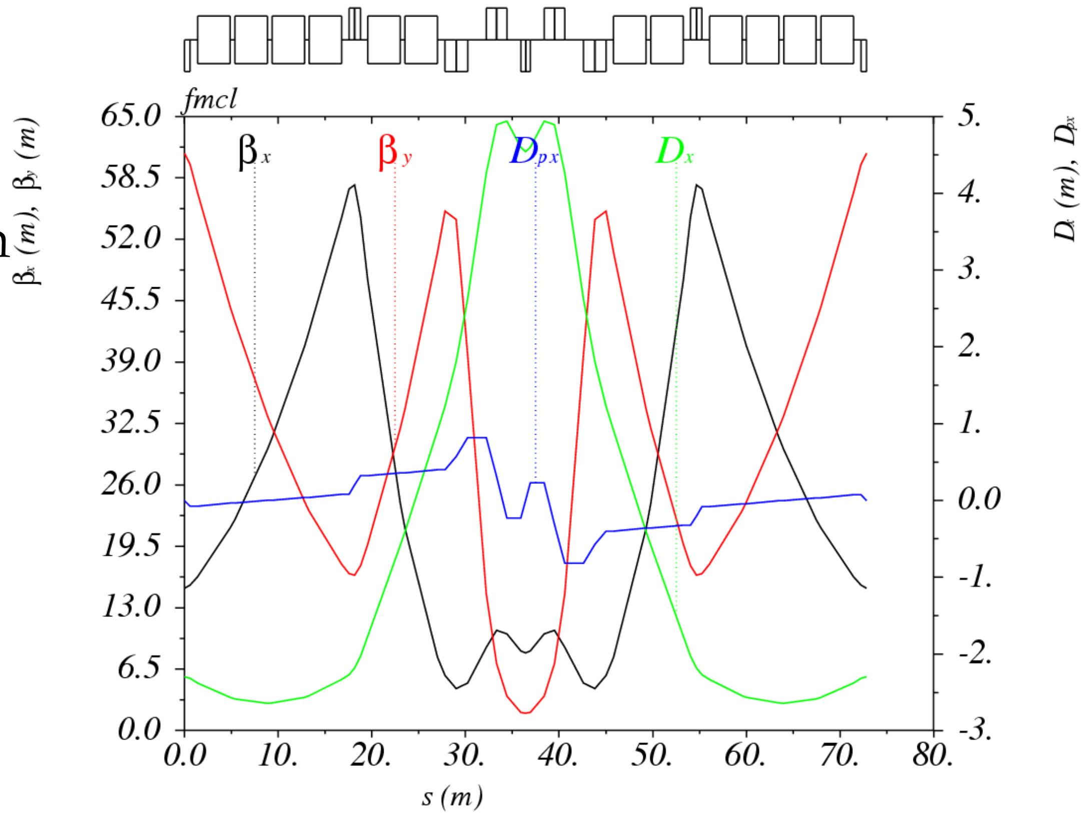
- 1 FODO cell with 4 + 4 bends and an asymmetric low-beta triplet
  - Phase advances of **320º,320º** per module
  - $\gamma_t$ of **6.2i**
  - Five families of quads, with max. strength of $\mathbf{0.1m^{-2}}$
  - Max. beta of **58m** in both planes
  - Min. dispersion of **-8m** and maximum of **6m**
  - Chromaticities of **-1.6,-1.3**
  - Total length of **90.56m**
- Fifth quad family not entirely necessary
- Straight section in the middle can control $\gamma_t$
- Phase advance tunable between **240º** and **330º**



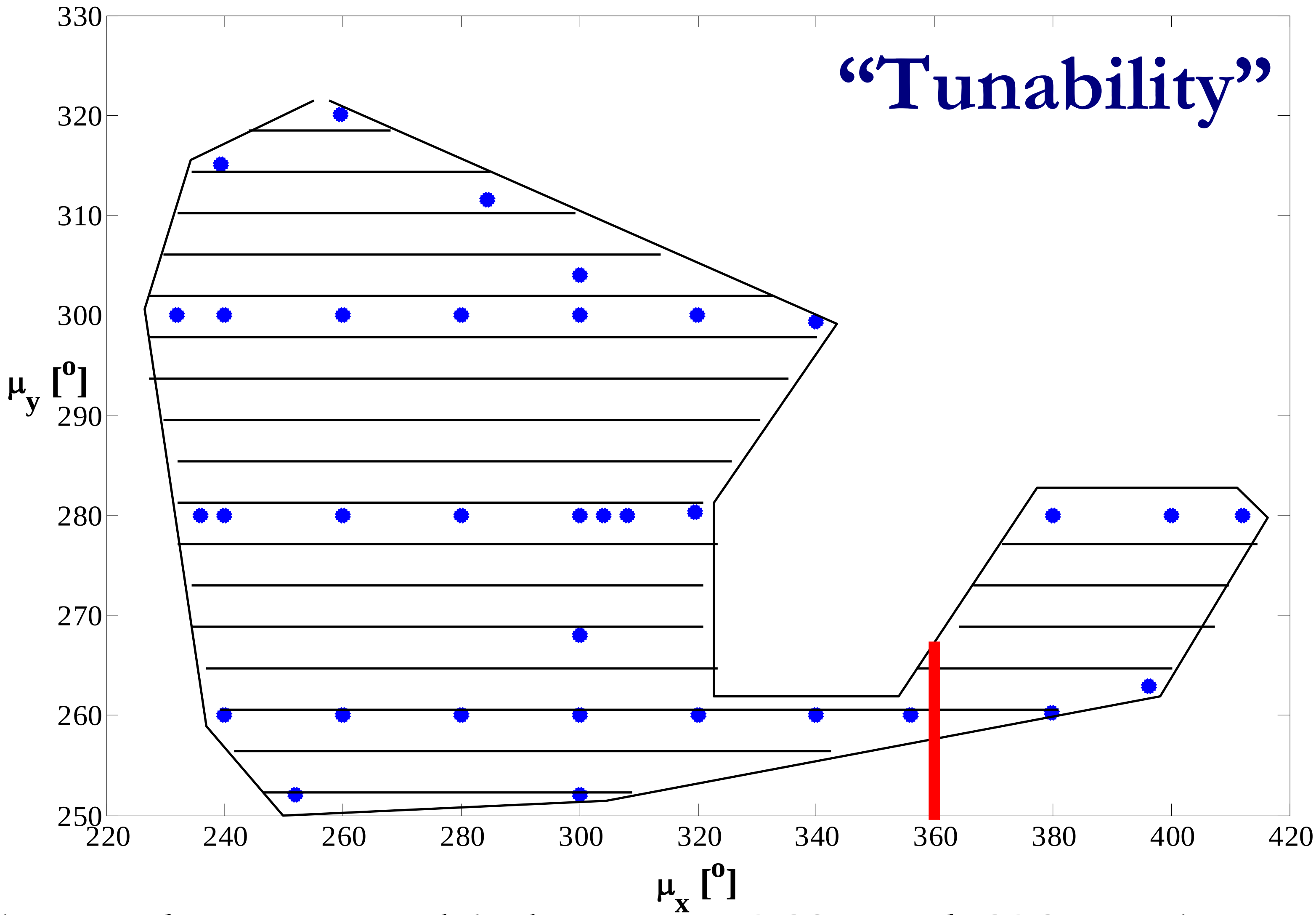

- Main disadvantage the length of the module, giving an arc of around **560m** (5 modules + dispersion suppressors), versus **510m** for the FODO cell arc

# The "short" FMC module

- Remove middle straight section and reduce the number of dipoles
- 1 asymmetric FODO cell with 4 + 2 bends and a low-beta doublet
  - Phase advances of **280,260°** per module
  - $\gamma_t$ of **9.4i**
  - Five families of quads, with max. strength of **0.1m$^{-2}$**
  - Max. beta of around **60m** in both planes
  - Min. dispersion of **-2.5m** and maximum of **5m**
  - Chromaticities of **-1.1,-1.7**
  - Total length of **72.84m**

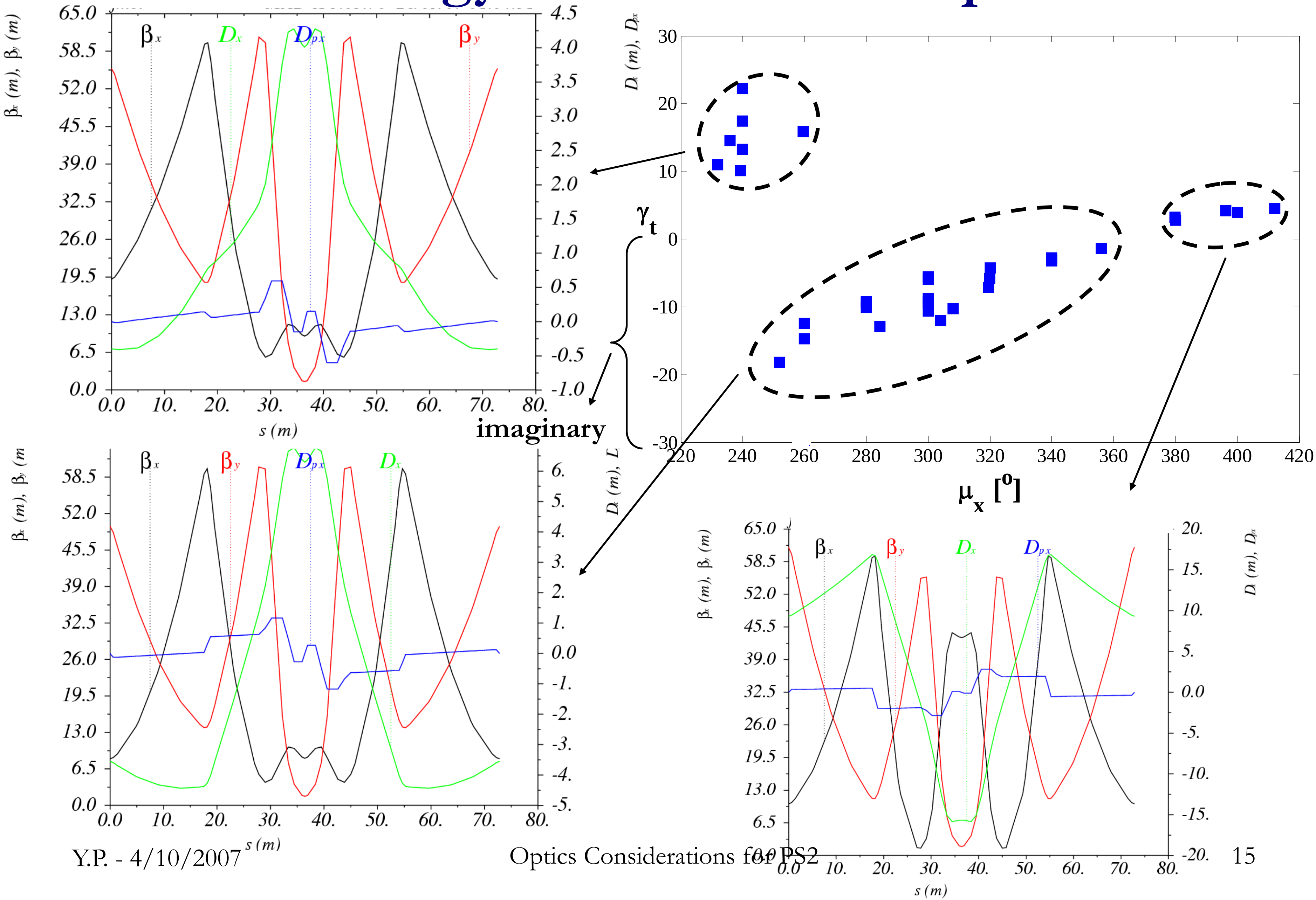



- Considering an arc of 6 modules + 2 dispersion suppressors of similar length, the total length of the arc is around **510m**

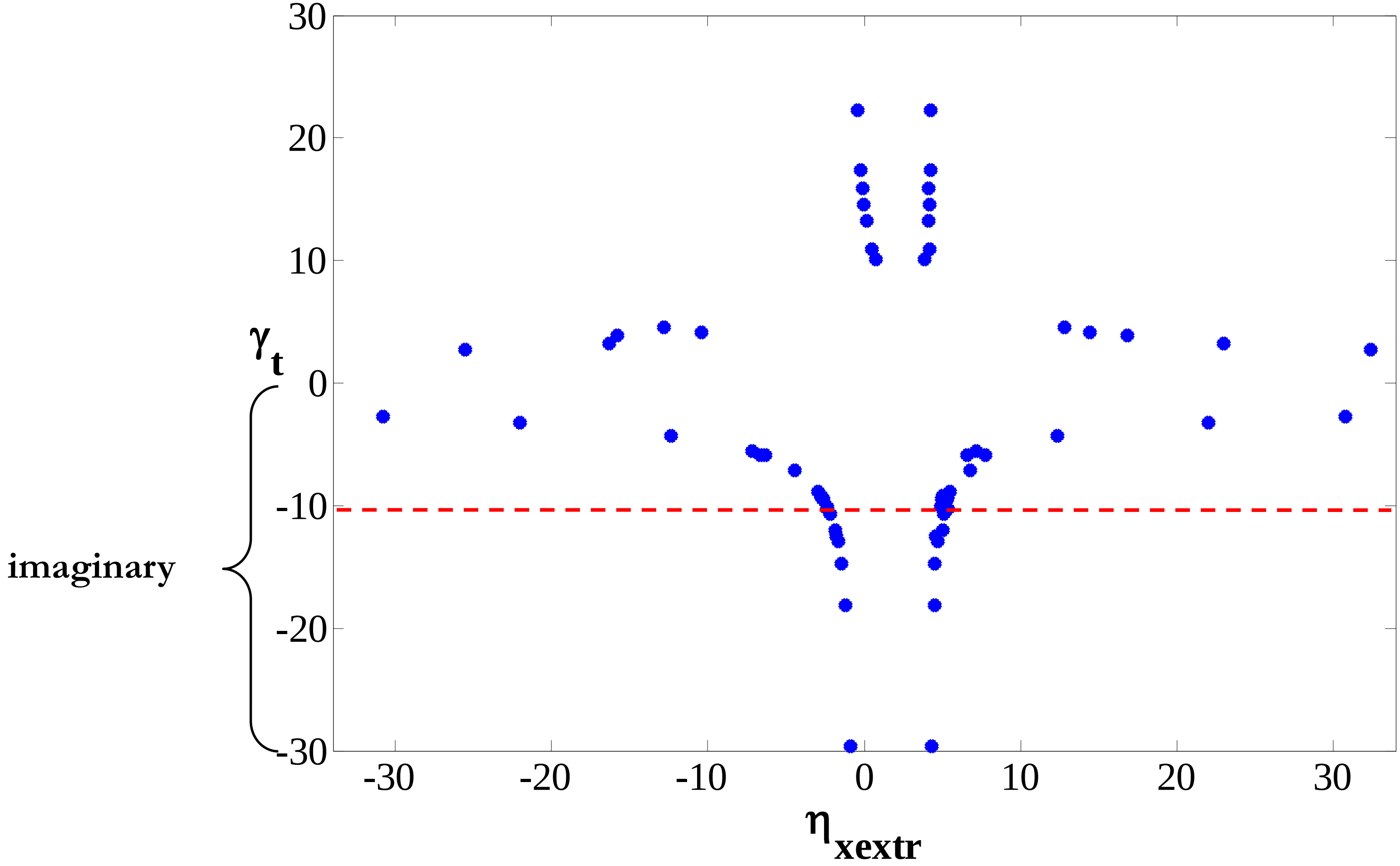



- Phase advance tunable between **240°** and **420°** in the horizontal and between **250°** and **320°** in the vertical plane

# Transition energy versus horizontal phase advance

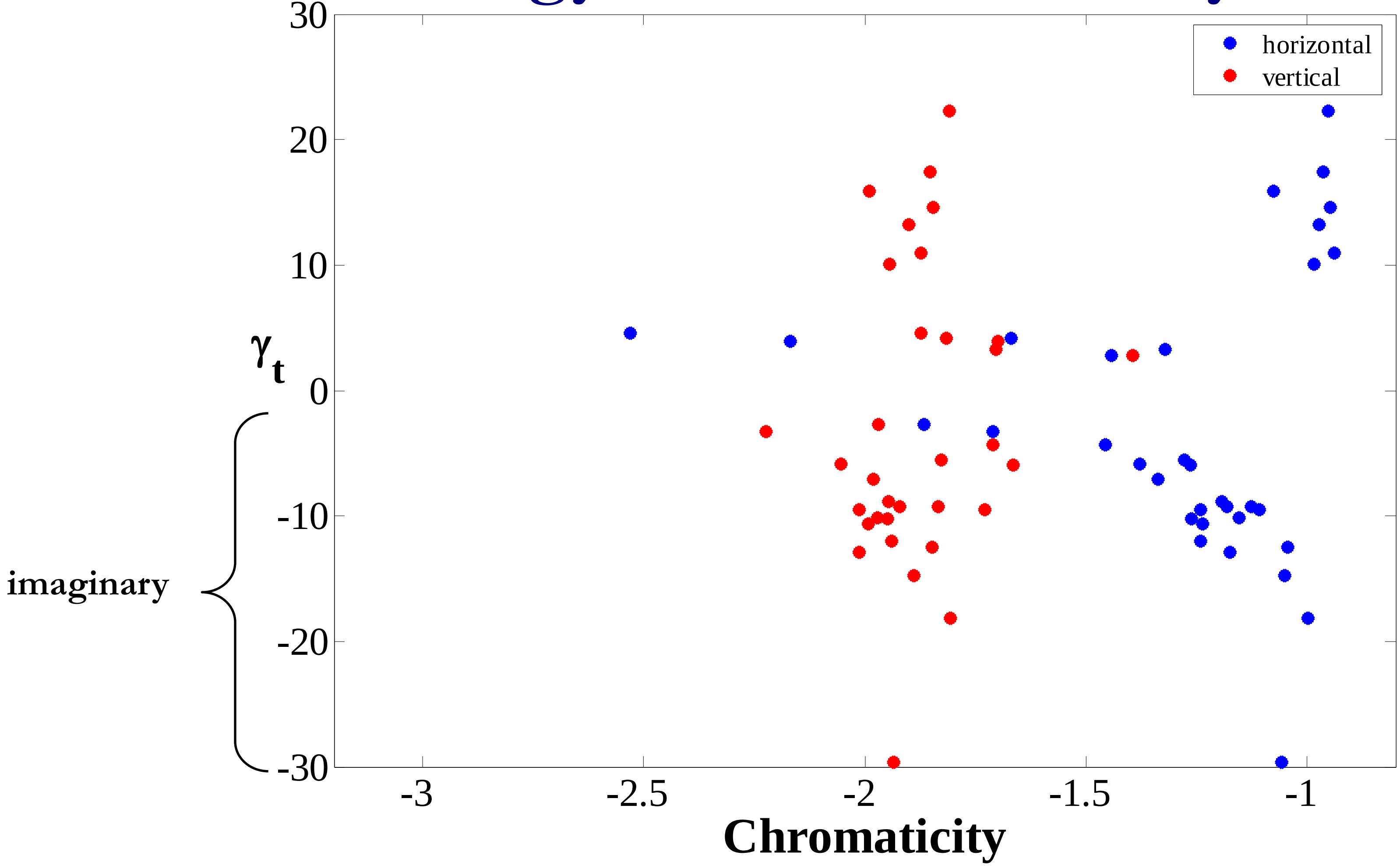


# Dispersion versus transition energy




- Almost linear dependence of momentum compaction with dispersion min/max values
- Higher dispersion variation for $\gamma_t$ closer to 0
- Smaller dispersion variation for higher $\gamma_t$

# Transition energy versus chromaticity



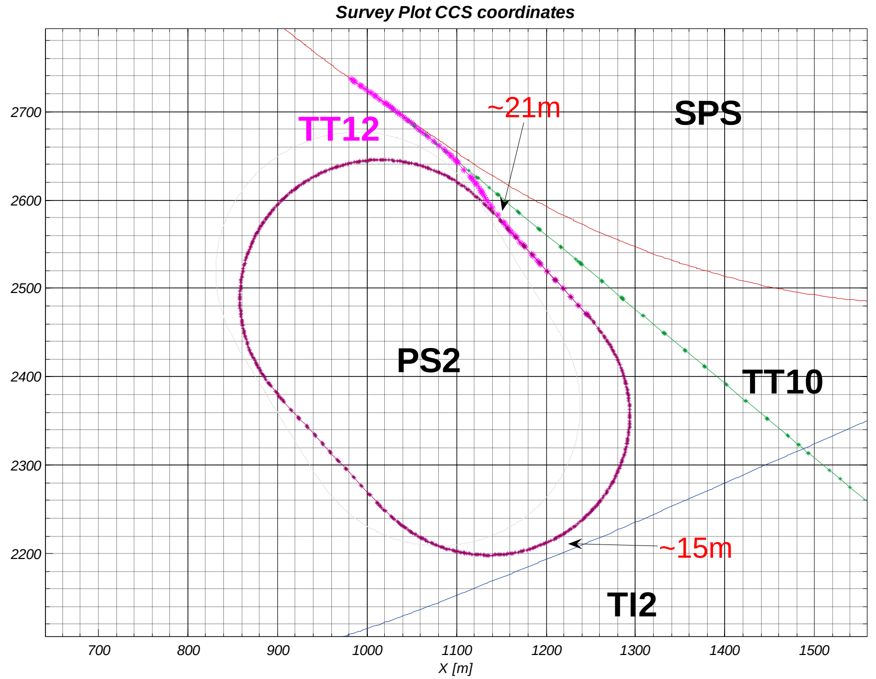

- Higher in absolute horizontal chromaticities for smaller transition energies
- Vertical chromaticities between -1.8 and -2 (depending on vertical phase advance)
- Main challenge: design of dispersion suppressor and matching to straights

# PS2 – SPS Transfer Line design goals

- Keep it **short!**
- **Matched optics (β, α, D, D')** at both ends (PS2, SPS)
  - ➔ *Get dispersion under control!*

| | $L_{cell}$ [m] | $\beta_{max}$ [m] | $\beta_{min}$ [m] |
|---|---|---|---|
| **SPS** | 64 | 110 | 19 |
| **PS2** | 25.89 | 45 | 8 |

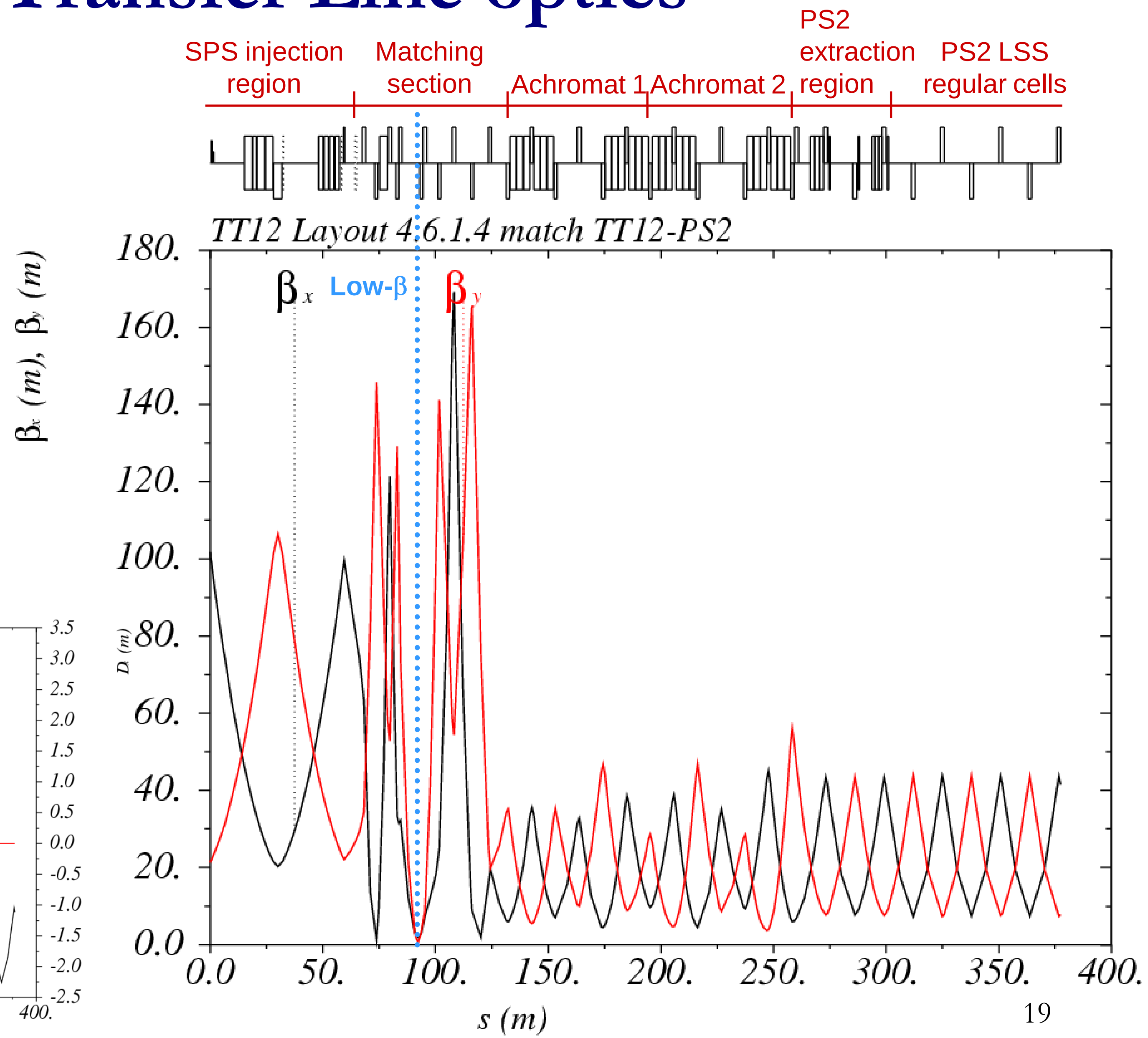
- **Match space/geometry requirements** (Transfer Line defines location of PS2)
  - 15m separation between TT10/TI2 and PS2 beam axis and same between PS2 and any other beam axis
  - ➔ *Length limits for TT12 + tight geometry constraints!!!*

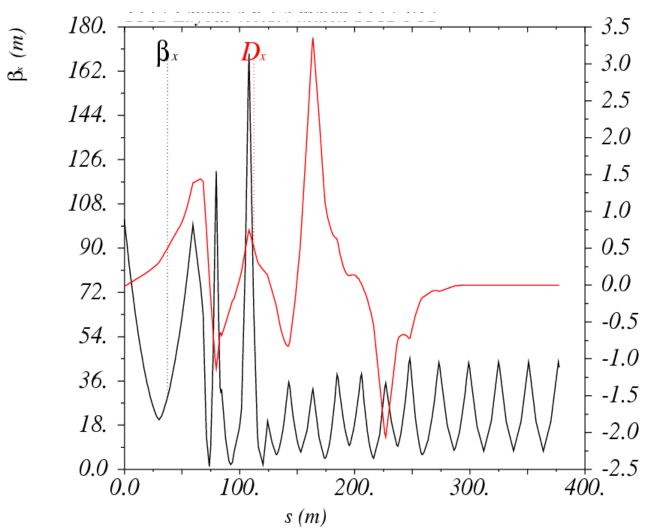



- Use **normal conducting** NC (dipole, quadrupole) magnets
- **Low β insertion** for ion stripping
- **Emittance exchange** scheme
- Branch-off to experimental areas
- No need for vertical bends,

# PS2 – SPS Transfer Line optics

- Matching section (with low-β insertion) near SPS
- 2 bending sections (opposite direction) as *achromats* *(D=D'=0 at each end)*



# Summary

- Different lattice types for PS2 optics investigated
  - FODO type lattice a straightforward solution
  - FMC lattice possible alternative
    - no transition crossing
    - challenge: matching to straights with zero dispersion
- Perspectives:
  - Complete the lattice design including chromaticity correction and dynamic aperture evaluation
  - Detailed comparison based on performance with respect to beam losses
    - Collimation system
    - Non-linear dynamics
    - Collective effects