Optics Considerations for the PS2

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Introduction - Motivation

- Proton Accelerators for the Future (PAF) study – identify upgrade scenario
  - Reliable operation for the LHC (allow ultimate LHC beam)
  - Options for future programs

From: PAF study group, in particular R. Garoby

Proton flux / Beam power

- Linac2
- Linac4
- SPL
- RCPSB
- PSB
- PS
- SPS
- SPS+
- SPS
- LHC / SLHC
- DLHC
- PS2 (PS2+)
- SPL: Superc. Proton Linac (~ 5 GeV)
- SPL': RCPSB injector (0.16 to 0.4-1 GeV)
- RCPSB: Rapid Cycling PSB (0.4-1 to ~ 5 GeV)
- PS2: High Energy PS (~ 5 to 50 GeV – 0.3 Hz)
- PS2+: Superconducting PS (~ 5 to 50 GeV – 0.3 Hz)
- SPS+: Superconducting SPS (50 to 1000 GeV)
- SLHC: “Superluminosity” LHC (up to $10^{35}$ cm$^{-2}$s$^{-1}$)
- DLHC: “Double energy” LHC (~ 14 TeV)
Introduction – Requirements for PS2

- Replace the ageing PS and improve options for physics
- Integration in existing complex
- Versatile machine:
  - Many different beams (and bunch patterns)
  - Protons and ions (performance if SPL injector ?)
- Transfer operations
  - Injections:
    - H- charge exchange injection for protons (assuming SPL as injector)
    - Fast injection for ions (low magnetic field)
  - Ejections:
    - Fast single turn ejection (e.g. LHC beams)
    - Multiturn ejection (beam cut transversally in ~5 pieces) for SPS fixed target
    - Slow ejection (~1s spill) for PS2 physics
Design Considerations

- Considerations on machine circumference $C_{PS2}$:
  - PS2 ejection energy: 50 GeV (improve SPS performance)
  - $C_{PS2} \sim 2 C_{PS}$ (no superconducting high field magnets for robust operation)
  - SPS filling (5 turn PS2 ejection) and abort gap: $C_{PS2} \sim C_{SPS}/5 = 2.2 C_{PS}$
  - Analysis of possible bunch patterns required: $C_{PS2} = (15/77) C_{SPS} = 1346.4$ m

- Required performance:
  - LHC scenarios: up to $4.0 \times 10^{11}$ per LHC bunch (20% reserve for losses), spaced by 25 ns (average line density fixed), normalized rms emittances $3.0 \mu$m
  - Fixes (with direct space charge tune shift: 0.2) injection energy: 4 GeV
  - High intensity SPS physics beam with single transfer from PS2 determines aperture

- RF for bunch pattern for LHC options
  - Extrapolation of present PS scheme:
    - Tunable “10 MHz” system and various RF gymnastics involving higher fixed frequency cavities
  - Single ~40 MHz RF system with little tuning for acceleration:
    - Incompatible with ion operation
    - Proton bunch structure implemented at injection with chopping of SPL
Longitudinal Aspects

- The increase of working range (PS: 1.4 -> 26GeV, PS2: 4 -> 50GeV):
  - Slows down longitudinal motion while increasing acceptances
  - Impacts on RF gymnastics
- Choice of $\gamma_{tr}$ and the lattice plays a major role:

  ![Graph showing acceptance and adiabaticity penalty functions]

  Acceptance (blue) and adiabaticity (red) penalty functions
  at injection (dashed) and ejection (solid)
  keeping RF Voltages of present PS (thin lines) and doubling gradients (thick lines)

- Search for lattices with imaginary $\gamma_{tr}$:
  - Avoid transition crossing
  - Extrapolation of PS scheme: $1/\gamma_{tr}^2 = -.01$ implies a factor 2 longer gymnastics at ejection
Optics Considerations for the PS2

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Racetrack:
- Integration into existing/planned complex:
  - Beam from Linac4 (close to PSB and PS) & SPL
  - Short transfer to SPS
  - Ions and protons from existing complex
- All transfer channels in one straight
- Minimum number of D suppressors
  - High bending filling factor
    (Required to reach 50GeV)
Plain FODO Lattice

- Conventional Approach:
  - FODO with dispersion suppressors for $D = 0 \text{ m}$ in straights
  - $90^\circ$ phase advance per cell for injection/ejection equipment
  - 7 cells/straight and 22 cells/arc -> in total 58 cells
  - $Q_H = 14.5$, $Q_V = 14.5$
  - Only complete lattice at present

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**Doublet and Triplet Lattices**

- **Doublet:**
  - Long straight sections
  - Inefficient focusing (high gradients)
  - Put aside at present

- **Triplet:**
  - Long straight sections
  - Small maximum $\beta$’s in bending magnets
  - Inefficient focusing (high gradients)
  - Put aside at present
Negative Momentum Compaction (NMC) Modules

- Negative dispersion in bendings needed
- Similar to and inspired from existing modules (e.g. J-PARC, many studies)
- First approach (one module made of three FODO cells):
  - Match regular FODO (no bends in central cell) to given phase advance
  - reduced distance and rematch only central quads to given phase advance (in general three times that of the FODO)

Regular FODO 90°/cell
- zero dispersion at beginning/end

Reduced drift in center, average 90°/cell
- negative dispersion at beginning/end
\[ \gamma_{tr} \approx 10 \text{ i} \] (for whole PS2)
Negative Momentum Compaction (NMC) Modules

- Second approach:
  - Dispersion beating excited by “kicks” in bends,
  - Resonant behavior: total phase advance < 2π
  - Improve filling factor: four FODO per module
  - Central drifts could be filled (price: increased momentum compaction)

- Challenges:
  - Filling factor
  - Straights with zero dispersion
Summary and Outlook

- Study on PS2 to replace the ageing PS started (in the frame of more general investigations on CERN complex upgrades)
- Different lattice types investigated
  - FODO type lattice a good candidate and well advanced
  - NMC lattice based on FODO a candidate
    - No transition crossing
    - Challenge: high dipole filling factor, matching to straights with zero dispersion
- Outlook:
  - Complete a lattice based on NMC modules
  - Revise longitudinal gymnastics (momentum compaction acceptable ?)
  - Thorough study of non-linear dynamics and instabilities
  - Foreseen schedule:
    - Completion of PS2 Study: 2010
    - Decision and start of construction: 2012 (?)