Brainstorming on Optics Layout for C-ion gantry

E. Felcini, G. Frisella, A. Mereghetti, S. Savazzi, M. Pullia

22/06/2021
Purpose of the Presentation

- Share the work we have done so far on the exploration of different (8+) gantry layouts
- Discuss together and collect possible input and recommendations from the different teams and points of view
Structure of the Presentation

- General overview of each layout
  - Overall dimensions
  - Beam optics properties
  - Requirements on the magnets

- Details on Beta functions and beam dimensions after corrections for
  - Matching Point to Point for 3 Magnification Factors (MF)
    - Different input beam size for a given MF
  - Matching Parallel to Point for 3 Magnification Factors (MF)
    - Different input beam size for a given MF
<table>
<thead>
<tr>
<th>Optics</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Locally achromatic</td>
<td>Allow you to use beam with larger momentum range. Allows separating the control of dispersion and betas.</td>
</tr>
<tr>
<td>Possibility of using different Magnification Factors (MF) i.e. changing spot size at isocenter with the same HEBT setting (acting only on the gantry)</td>
<td>More handles required → more quadrupoles or changing gradient on the dipoles</td>
</tr>
<tr>
<td>Dipoles with same gradient between MF</td>
<td>No need of separate circuits between dipole and quadrupole.</td>
</tr>
<tr>
<td>Dipoles with different gradients</td>
<td>How easy/expensive is to wind different gradient coils? Individual magnet coils to be considered (more spares)</td>
</tr>
<tr>
<td>Dipole with small gradient variation between MFs</td>
<td>A dipole/quadrupole trim can be used (i.e. two separate circuits)</td>
</tr>
<tr>
<td>Dipole with large gradient variation between MFs</td>
<td>Two separate circuits are required (nested magnet)</td>
</tr>
<tr>
<td>Varying the input beam size to change the spot size at isocenter</td>
<td>Beam size shall be kept under control along the whole range required. Flexibility/tunability pushed upstream, not removed. Orbit depends on beam size on a longer range.</td>
</tr>
<tr>
<td>Monitors and correctors to check and correct orbit errors along the line</td>
<td>Space required between the magnets → larger gantry</td>
</tr>
<tr>
<td>Larger SAD</td>
<td>Relax constraints on scanning magnets → larger gantry</td>
</tr>
<tr>
<td>Maximum beam size</td>
<td>Magnet aperture → field quality! (magnet radius = 3/2 beam size, i.e. 30 mm beam → 45 mm radius; 23 mm beam → 35 mm radius)</td>
</tr>
</tbody>
</table>
A few assumptions

- Dipole Field: 4 T
- Combined function dipole with 5-10 T/m gradient (peak field on conductor 5 T, considering additional gradient)
- Emittance $7\pi$ mm mrad (as in PIMMS)
- 3 beam dimension required at isocenter:
  - FWHM: 5 mm
  - FWHM: 8 mm
  - FWHM: 12 mm
- Matching procedures:
  - Point to point: $R_{12}=R_{34}=0$; $R_{11}$ and $R_{33}$ for beam size control
  - Parallel to point: $R_{11}=R_{33}=0$; $R_{12}$ and $R_{34}$ for beam size control
  - $D = 0$ and $D' = 0$ ($R_{16}=0$ and $R_{26}=0$)
• Locally achromatic YES

• Dipole with constant gradient in 3 MF
  • Same gradient in all dipoles

• $K_{\text{dip}} < 5 \text{ T/m}; \ K_{\text{quad-H}} < 20 \text{ T/m}; \ K_{\text{quad-C}} < 50 \text{ T/m}$

• Constant gradient sign for quadrupoles in 3 MF
  (NC quads change sign)

• Acceptable and coherent corrections in 3 MF
  (corr3 Y at 95% < 7.8 mrad)

• Envelope Radius + Max Error Radius < 90 mm (max 74mm)

• Acceptable behavior with different input Beta
  • Envelope Radius + Max Error Radius < 90 mm (max 82mm)

• Sufficient space for all the elements: L from 14.7m to 15.5m
  H from 5.84m to 6.42m
  slope from 6.1m to 6.9m
MF 1.5

Max Envelope = 33 mm

MF 1.0

Max Envelope = 31 mm

MF 0.6

Max Envelope = 37 mm
BetX = BetY = 22.5 m
Max Envelope = 33 mm

BetX = BetY = 10 m
Max Envelope = 31 mm

BetX = BetY = 2.5 m
Max Envelope = 41 mm

MF 1.0
Point to Point
• Locally achromatic NO

• Dipole with varying gradient < 0.5 T/m in 3 MF (±0.4 T/m)
• Same gradient in all dipoles

• $K_{dip} < 5$ T/m; $K_{quad-H} < 20$ T/m; $K_{quad-C} < 50$ T/m

• Constant gradient sign for quadrupoles in 3 MF

• Acceptable and coherent corrections in 3 MF even switching monitor and scanning – (just MF1.5 for now))

• Envelope Radius + Max Error Radius < 35mm

• Acceptable behavior with different input Beta
  • Envelope Radius + Max Error radius < 35mm

• Sufficient space for all the elements - elements repositioned, but total length not modified -> to be rematched.
\( \beta = 5 \)

**MF 1.0**

Max Envelope = 25 mm

**MF 1.5**

Max Envelope = 18 mm

**MF 2.0**

Max Envelope = 19 mm
**MF 1.5**

- **Best behaviour**

- **BetX = BetY = 1.1 m**

- **BetX = BetY = 5 m**

- **BetX = BetY = 10 m**

- **Max Envelope = 23 mm**

- **Max Envelope = 18 mm**

- **Max Envelope = 19 mm**

---

**EF** - 6 warm quad - config2

**Point to Point**
• Locally achromatic NO

• Dipole with constant gradient in 3 MF
• Dipole with varying gradient < 0.5 T/m in 3 MF (±0.2 T/m respect MF=1.5)
• Same gradient in all dipoles

• $K_{\text{dip}} < 5 \text{ T/m}; K_{\text{quad-H}} \leq 20 \text{ T/m}; K_{\text{quad-C}} < 50 \text{ T/m}$

• Constant gradient sign for quadrupoles in 3 MF

• Acceptable and coherent corrections in 3 MF (even switching monitor and scanning – (just MF1.5 for now))

• Envelope Radius + Max Error Radius < 35mm (21 mm)

• Acceptable behavior with different input Beta
  • Envelope Radius + Max Error radius < 35mm (24 mm)

• Sufficient space for all the elements - elements repositioned, but total length not modified -> to be rematched.
\[ \beta = 5 \]

**MF 1.0**

Max Envelope = 21 mm

**MF 1.5**

Max Envelope = 28 mm

**MF 2**

Max Envelope = 19 mm
**MF 1**

**Best behaviour**

- **BetX = BetY = 10 m**
- **BetX = BetY = 2.5 m**
- **BetX = BetY = 1.1 m**

**Max Envelope**
- 24 mm
- 21 mm

**Parallel to Point EF**

EF - 6 warm quad - config2
• Locally achromatic NO

• Dipole with varying gradient < 0.5 T/m in 3 MF (± 0.3 T/m)
• Same gradient in all dipoles (3 families)

• $K_{\text{dip}} < 5$ T/m; $K_{\text{quad-H}} < 20$ T/m; $K_{\text{quad-C}} < 50$ T/m

• Constant gradient sign for quadrupoles in 3 MF (1 changes)

• Acceptable and coherent corrections in 3 MF

• Envelope Radius + Max Error Radius < 35mm (max 27mm)

• Acceptable behavior with different input Beta
  • Envelope Radius + Max Error radius < 35 mm (max 28mm)

• Sufficient space for all the elements - elements repositioned, but total length not modified -> to be rematched.
BetX = BetY = 1.1 m

BetX = BetY = 5 m

BetX = BetY = 10 m

Max Envelope = 28 mm

Max Envelope = 22 mm

Max Envelope = 25 mm

DT1 – Config. 4

MF 1.5 best behaviour

Point to Point
- Locally achromatic NO
- Dipole with varying gradient < 0.5 T/m in 3 MF (± 0.3 T/m)
- Same gradient in all dipoles (3 families)
- $K_{\text{dip}} < 5$ T/m; $K_{\text{quad-H}} < 30$ T/m; $K_{\text{quad-C}} < 50$ T/m
- Constant gradient sign for quadrupoles in 3 MF (1 changes)
- Acceptable and coherent corrections in 3 MF
- Envelope Radius + Max Error Radius < 35mm (max 24mm)
- Acceptable behavior with different input Beta
  - Envelope Radius + Max Error radius < 35mm (max 27mm)
- Sufficient space for all the elements - elements repositioned, but total length not modified -> to be rematched.
Beta 5

MF 1.0

MF 1.5

MF 2.0

DT1 – Config. 4

Max Envelope = 24 mm

Max Envelope = 21 mm

Max Envelope = 22 mm
BetX = BetY = 2.5 m

BetX = BetY = 5.625 m

BetX = BetY = 22.5 m

Max Envelope = 24 mm

Max Envelope = 21 mm

Max Envelope = 27 mm

MF 1.5 best behaviour
- Locally achromatic NO
- Dipole with constant gradient in 3 MF (Only in 1 family)
- Dipole with varying gradient < 0.5 T/m in 3 MF (1 family varies ±0.5 T/m)
- Same gradient in all dipoles (2 families)

- \( K_{\text{dip}} \leq 5 \text{ T/m}; K_{\text{quad-H}} < 20 \text{ T/m}; K_{\text{quad-C}} < 50 \text{ T/m} \)

- Constant gradient sign for quadrupoles in 3 MF (NC quads change sign)

- Acceptable and coherent corrections in 3 MF

- Envelope Radius + Max Error Radius < 35mm (max 34mm)

- Acceptable behavior with different input Beta
  - Envelope Radius + Max Error radius < 35mm (max 34mm)
**DT1 – Config. 5**

- **BetX = BetY = 22.5 m**
  - Max Envelope = 34 mm

- **BetX = BetY = 10 m**
  - Max Envelope = 25 mm

- **BetX = BetY = 2.5 m**
  - Max Envelope = 25 mm
• Locally achromatic NO

• Dipole with constant gradient in 3 MF (Two family)
• Dipole with varying gradient < 0.5 T/m in 3 MF (Variation > 0.5 T/m)
• Same gradient in all dipoles (2 families)

• $K_{dip} \leq 5 \text{ T/m}; K_{quad-H} \leq 20 \text{ T/m}$

• Constant gradient sign for quadrupoles in 3 MF
  (NC quads change sign)

• Acceptable and coherent corrections in 3 MF

• Envelope Radius + Max Error Radius < 35 mm (max 27 mm)

• Acceptable behavior with different input Beta
  • Envelope Radius + Max Error radius < 35 mm (max 31 mm)
DT1 – Config. 5

**MF 1.36**

Max Envelope = 27 mm

**MF 1.0**

Max Envelope = 24 mm

**MF 0.64**

Max Envelope = 26 mm
$MF=1$

Best behaviour

$\text{BetX} = \text{BetY} = 4.5\text{ m}$

$\beta_x, \beta_y, D$

Max Envelope = 24 mm

$\text{BetX} = \text{BetY} = 10\text{ m}$

$\beta_x, \beta_y, D$

Max Envelope = 31 mm

$\text{BetX} = \text{BetY} = 40\text{ m}$

$\beta_x, \beta_y, D$

Max Envelope = 30 mm

DT1 – Config. 5

Parallel to Point
- Locally achromatic NO

- Dipole with constant gradient in 3 MF
- Same gradient in all dipoles (3 families)

- $K_{\text{dip}} < 5 \, \text{T/m}; K_{\text{quad-H}} < 20 \, \text{T/m}; K_{\text{quad-C}} < 50 \, \text{T/m}$

- Constant gradient sign for quadrupoles in 3 MF (1 SC quad changes sign)

- Acceptable and coherent corrections in 3 MF

- Envelope Radius + Max Error Radius < 35mm (max 27)

- Acceptable behavior with different input Beta
  - Envelope Radius + Max Error radius < 35mm (max 28)

- Sufficient space for all the elements
DT2 – Config. 1

Point to Point

Max Envelope = 27 mm

Max Envelope = 20 mm

Max Envelope = 18 mm
**DT2 – Config. 1**

**Best behaviour**

- **BetX = BetY = 22.5 m**
  - Max Envelope = 20 mm
- **BetX = BetY = 10 m**
  - Max Envelope = 28 mm
- **BetX = BetY = 2.5 m**
  - Max Envelope = 17 mm
• Locally achromatic NO

• Dipole with constant gradient in 3 MF
• Same gradient in all dipoles (3 families)

• $K_{dip} < 5 \text{ T/m}; K_{quad-H} < 20 \text{ T/m}; K_{quad-C} < 80 \text{ T/m}$

• Constant gradient sign for quadrupoles in 3 MF

• Acceptable and coherent corrections in 3 MF

• Envelope Radius + Max Error Radius < 45mm

• Acceptable behavior with different input Beta
  • Envelope Radius + Max Error Radius < 45mm

• Sufficient space for all the elements
DT2 – Config. 1

**MF 1.5**

Max Envelope = 30 mm

**MF 1.0**

Max Envelope = 29 mm

**MF 0.6**

Max Envelope = 42 mm
DT2 – Config. 1

**Best behaviour**

- **BetX = BetY = 4.5 m**
  - Max Envelope = 29 mm
  - Parallel to Point

- **BetX = BetY = 10 m**
  - Max Envelope = 33 mm

- **BetX = BetY = 40 m**
  - Max Envelope = 37 mm

---

**MF 1.0**

- **BetX = BetY = 4.5 m**
  - MF: 1.0 BetX=4.5
  - MAD: X=5.060.00 21/06/21 10:52:13

- **BetX = BetY = 10 m**
  - MF: 1.0 BetX=10
  - MAD: X=5.060.00 21/06/21 10:52:13

- **BetX = BetY = 40 m**
  - MF: 1.0 BetX=40
  - MAD: X=5.060.00 21/06/21 10:52:13
• Locally achromatic NO

• Dipole with large gradient variation (+1.3 T/m - 1.2T/m)
• Same gradient in all dipoles (each one is different)

• $K_{\text{dip}} < 9.0 \text{ T/m}; K_{\text{quad-H}} < 20 \text{ T/m}; K_{\text{quad-C}} < 50 \text{ T/m}$

• Constant gradient sign for nc quadrupoles in 3 MF

• Acceptable and coherent corrections in 3 MF

• Envelope Radius + Max Error Radius < 35mm (max 24mm)

• Acceptable behavior with different input Beta
  • Envelope Radius + Max Error radius < 35mm (max 33mm)

• Sufficient space for all the elements -> needs some fine adjustments (i.e. hor part = vertical part (from 140cm to 160 cm))
DT3 – Config. 1

**MF 1.0 best behaviour**

- **BetX = BetY = 22.5 m**
- **BetX = BetY = 10 m**
- **BetX = BetY = 2.5 m**

**Max Envelope**
- 33 mm
- 24 mm
- 18 mm

**Point to Point**
- Locally achromatic NO
- Dipole with large gradient variation (+1.6 T/m - 1.6T/m)
- Same gradient in all dipoles (each one is different)
- $K_{dip} < 9.2$ T/m; $K_{quad-H} < 20$ T/m; $K_{quad-C} < 50$ T/m
- Constant gradient sign for nc quadrupoles in 3 MF
- Acceptable and coherent corrections in 3 MF
- Envelope Radius + Max Error Radius < 35mm (max 35mm)
- Acceptable behavior with different input Beta
  - Envelope Radius + Max Error radius < 35mm
  - Envelope Radius + Max Error Radius < 45mm
- Sufficient space for all the elements: L from 10.4m to 11.1m
v.1 straight
Max Envelope = 35 mm

v.2 Straight and non zero @iso
Max Envelope = 26 mm

Max Envelope = 28 mm

Max Envelope = 25 mm
DT3 – Config. 2

MF 1.0
best behaviour

BetX = BetY = 22.5 m

BetX = BetY = 10 m

BetX = BetY = 2.5 m

Point to Point
• Locally achromatic YES

• Dipole with constant gradient in 3 MF (by construction)

• \( K_{\text{dip}} \leq 6 \text{T/m}; K_{\text{quad-H}} < 20 \text{T/m}; K_{\text{quad-C}} < 50 \text{T/m} \)

• Non-constant gradient sign for quadrupoles in 3 MF

• Acceptable and coherent corrections in 3 MF (not straight)

• Envelope Radius + Max Error Radius < 45mm (max 37 in SC section)

• Acceptable behavior with different input Beta
  • Envelope Radius + Max Error Radius < 45mm (max 37 in SC section)

• Sufficient space for all the elements: elements repositioned -> to be rematched

Point to Point

T4: 2x30degs + 4x37.5degs

SAD 1.65m from middle of last scanning
MF 1.5

Double correction with 1 MON + 1 CORR

Max Envelope = 37 mm

MF 1.0

Max Envelope = 29 mm

MF 0.5

Max Envelope = 26 mm

T4: 2x30degs + 4x37.5degs
BF = 1

**Best behaviour**

- BetX = BetY = 22.5 m
- BetX = BetY = 10 m
- BetX = BetY = 2.5 m

---

**Max Envelope**

- 37 mm
- 29 mm

---

**T4: 2x30\text{deg.} + 4x37.5\text{deg.}**

- Max Envelope = 29 mm
• Locally achromatic YES

• Dipole with constant gradient in 3 MF (by construction)

• $K_{dip} \leq 11 \text{ T/m}; K_{quad-H} \leq 21 \text{ T/m}; K_{quad-C} < 50 \text{ T/m}$

• Constant gradient sign for quadrupoles in 3 MF

• Acceptable and coherent corrections in 3 MF (not straight at isocenter)

• Envelope Radius + Max Error Radius < 45mm (max 39mm)

• Acceptable behavior with different input Beta
  • Envelope Radius + Max Error radius < 35mm (max 35mm)

• Sufficient space for all the elements: L from 11.8m to 12.48m
  H from 5.33m to 5.86m
T5: 2x30degs + 5x30degs

**MF 1.5**

Max Envelope = 39 mm

**MF 1.0**

Max Envelope = 26 mm

**MF 0.5**

Max Envelope = 27 mm
MF=1

Best behaviour

BetX = BetY = 22.5 m

BetX = BetY = 10 m

BetX = BetY = 2.5 m

Max Envelope = 27 mm

Max Envelope = 35 mm

Max Envelope = 29 mm
To think about

- Independent combined function magnets can help us to reduce dimensions.
- It is more effective to have combined functions (with separate circuits) than larger dipole field.
Thank you for your attention
Index of Configurations

- E. Benedetto at 4T
- EF - 6 warm quad - config2
- DT1-config4
- DT1-config5
- DT2- config1
- DT3-config1
- DT3-config2
- T4: 2x30degs + 4x37.5degs
- T5: 2x30degs + 5x30degs
- **WARM QUAD**
  - drift -> 0.06m
  - quad -> 0.5m
  - dirft -> 0.06m
- **SC DIPOLE**
  - drift -> 0.2m
  - dipole
  - dirft -> 0.2m
- **CRYOSTAT**
  - drift -> 0.15m
  - elements
  - dirft -> 0.15m
- **KICKERS**
  - drift -> 0.21m
  - kicker -> 0m
  - drift -> 0.21m
- **MONITORS**
  - drift -> 0.25m
  - monitor -> 0m
  - drift -> 0.25m
- **CHIARIRE con TOMMASINI: ingombri intorno a SC QUADS? (soprattutto per DT2-conf1)**