Mapping of the New IBA Superconducting Synchrocyclotron (S2C2) for Proton Therapy

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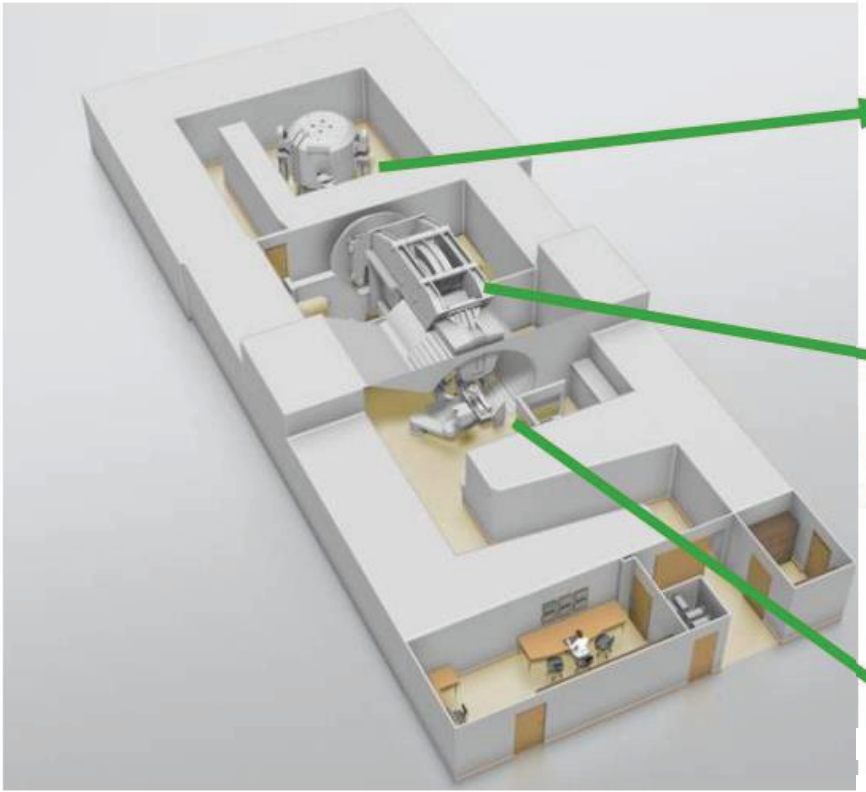
Mapping of the S2C2

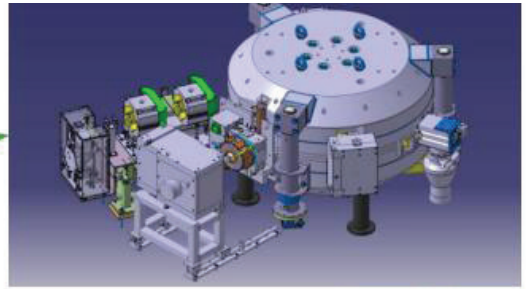
Layout

- Introduction to ProteusONE® and the S2C2
- The mapping system
- Mapping results
- Shimming and forces
- Conclusions

Mapping of the S2C2

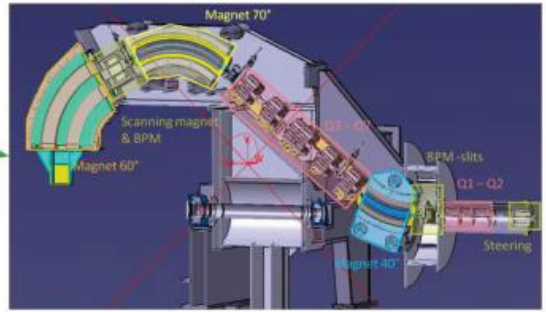
Introduction to ProteusONE®





Synchrocyclotron with superconducting coil: S2C2

New Compact Gantry for pencil beam scanning

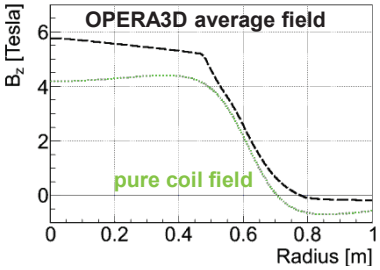


Patient treatment room

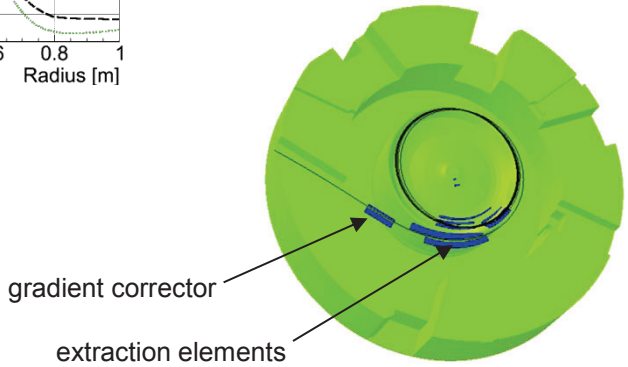
Mapping of the S2C2

Introduction to the S2C2

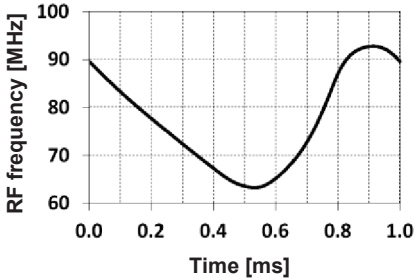
✓ weak-focussing, non-isochronous machine, equipped with a superconducting coil.



✓regenerative slow extraction, based on Q_H=1 resonance
✓ horizontal focusing with gradient corrector in extraction channel with strongly decreasing field

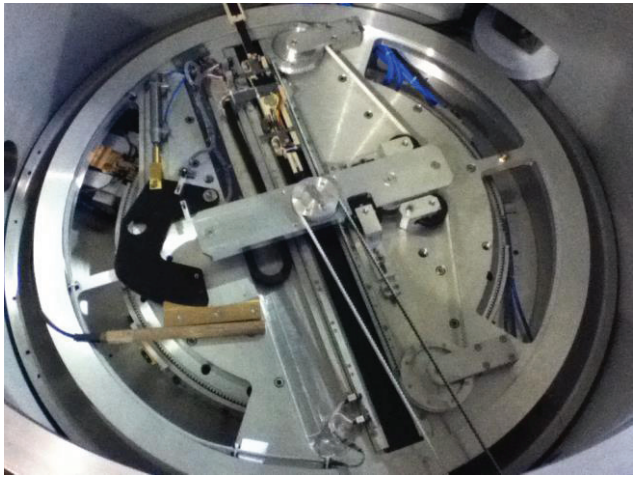


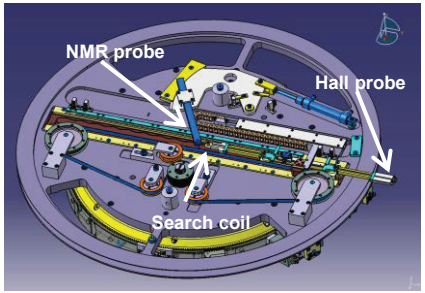
✓ RF modulation from 62-90 MHz at a repetition rate of 1 kHz.
✓ Peak Dee voltage = 10 kV
✓ Power = few kW
✓ RF bias = 1 kV
✓ RotCo : measured frequency evolution :



Mapping of the S2C2

The mapping system





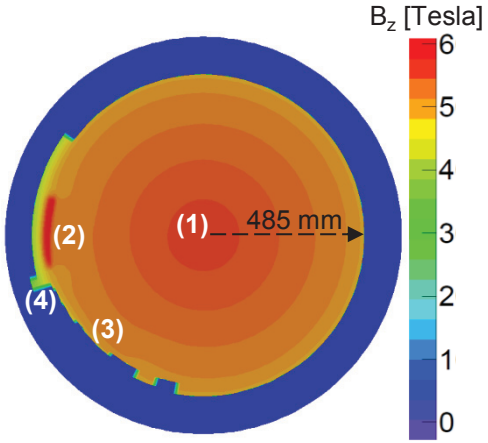
$$B(r) - B_0 = \int_{t_1}^{t_2} (V - V_{offset})/A_{eff} \, .dt$$

- ✓ search coil with appropriate dimensions to eliminate finite dimension errors
- ✓ A_{eff}, effective surface of the search coil ≈ 0.3 m^2, calibrated separately
- ✓ voltage from search coil integrated by METROLAB PDI5025
- ✓ reference NMR probe in the center (B_0)
- ✓ Hall probe for comparison and benchmarking
- ✓ Offset measurement on the integrator performed prior to each radial track
- ✓ 360° degrees mapping in 0.5° steps and 1 mm radial resolution
- ✓ typical full mapping of the S2C2 takes about 24h with the search coil

Mapping of the S2C2

Mapping results : 2D map

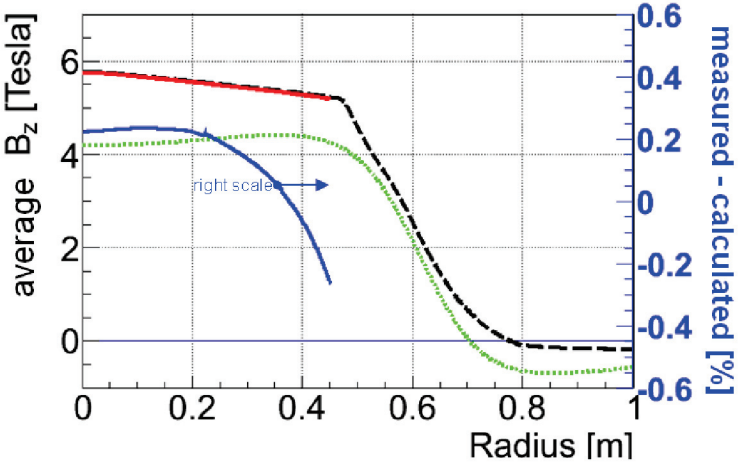
✓ **measured S2C2 field map**



(1) magnetic field in the center = 5.72 Tesla
(2) the regenerator region : 1 Tesla field "bump" driving the regenerative extraction
(3) the septum region : limited radial range for the search coil
(4) entrance of the extraction channel

Mapping of the S2C2

Mapping results : average field



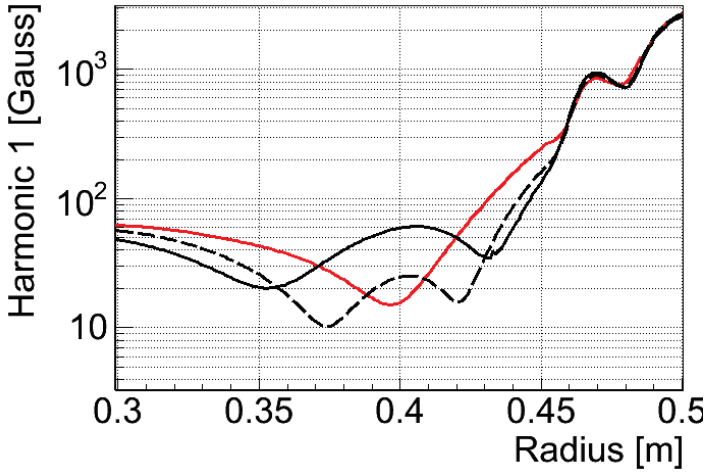
✓ The measured average field (red line) is within 0.3% of the calculated average field in the OPERA3D model (blue line).

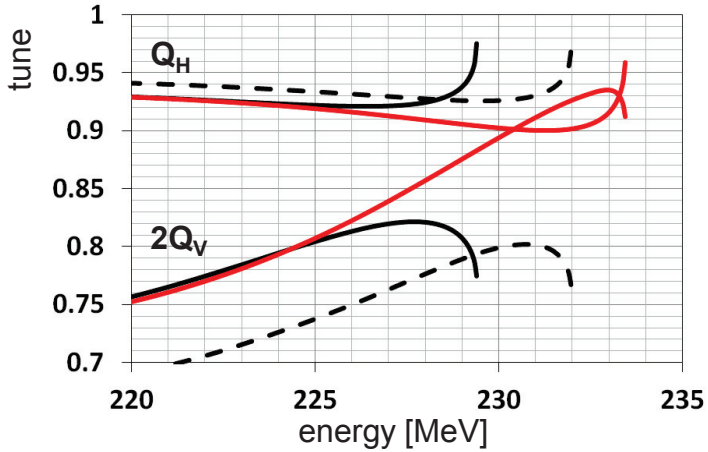
✓ The coil field contributes about 80% of the total field around 50 cm (green dashed line). This is the radius where particles enter the extraction channel.

Mapping of the S2C2

Mapping results : first harmonic and tune functions

mapping with slightly de-centered main coil (~2-3 mm off-center)
mapping with centered coil
OPERA reference





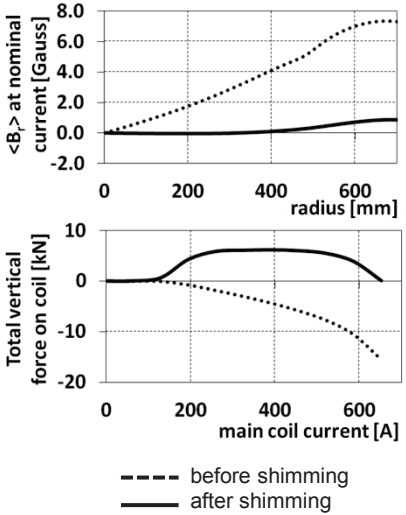
- ✓ for a slightly de-centered main coil (2-3 mm), the Walkinshaw resonance is crossed
- ✓ for a centered coil, the resonance is avoided and the tune functions are close to the design values
- ✓ 1st harmonic is particular sensitive to coil displacements around 40-45 cm (within the mapping range)

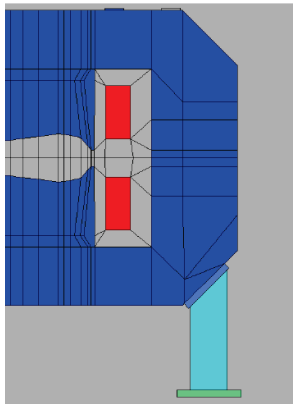
Mapping of the S2C2

Shimming and forces

✓ Radial fields within the machine are very difficult to measure directly.
✓ Major sources for radial fields in the median plane are :
- the vertical position of the main coil
- the iron asymmetries around the machine.

✓ With OPERA2D simulations, it was found that the introduction of iron shims on the top yoke eliminates radial fields in the median plane, which are present due to iron asymmetry around the S2C2.
✓ At the same time, the introduction of these (symmetric) shims on the topyoke reduces the vertical force on the main coil to zero at nominal current.





OPERA2D model

Mapping of the S2C2

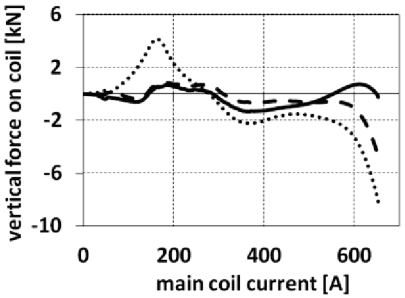
Shimming and forces

✓ The plot on the right shows the evolution of the vertical force on the main coil :

- at the initial ramp-up (dotted)
- after precise vertical positioning of the main coil (dashed)
- after full shimming of the S2C2 (full)

✓ symmetric shims on top of the S2C2 were calculated in OPERA2D and are crucial to eliminate radial fields

✓ asymmetric "chamfer shims" are introduced to reduce torques on the main coil.



OPERA3D : full model incorporating all shims: symmetric and non-symmetric "chamfer shimming". The latter was introduced to eliminate torques on the main coil

Mapping of the S2C2

Conclusions

- The mapping of the S2C2 has been successfully concluded in may 2013
- The superconducting main coil position was found to be a crucial parameter in order to obtain proper beam dynamics
- Forces and median plane errors have been reduced at nominal current by adding shims and by accurate positioning of the main coil
- Beam tests and further commissioning of sub-systems of the S2C2 are ongoing at IBA

Thank you !