MSSB for the NEA at CERN

MSSB septum splitter magnet for the North Experimental Area at CERN
in the context of the planned BDF/SHiP extraction line

TE-MSC Seminar
24th November 2020
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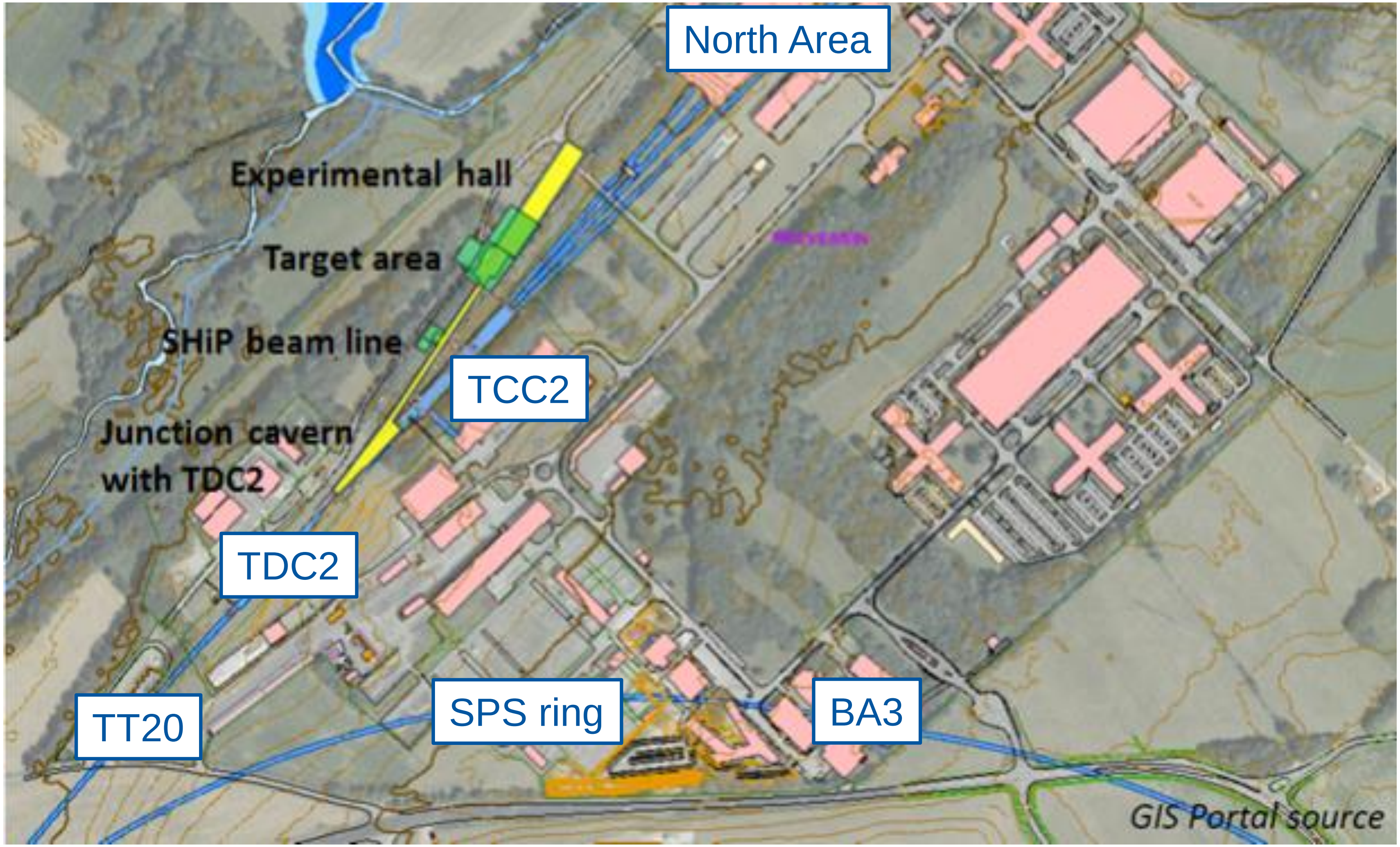
Introduction

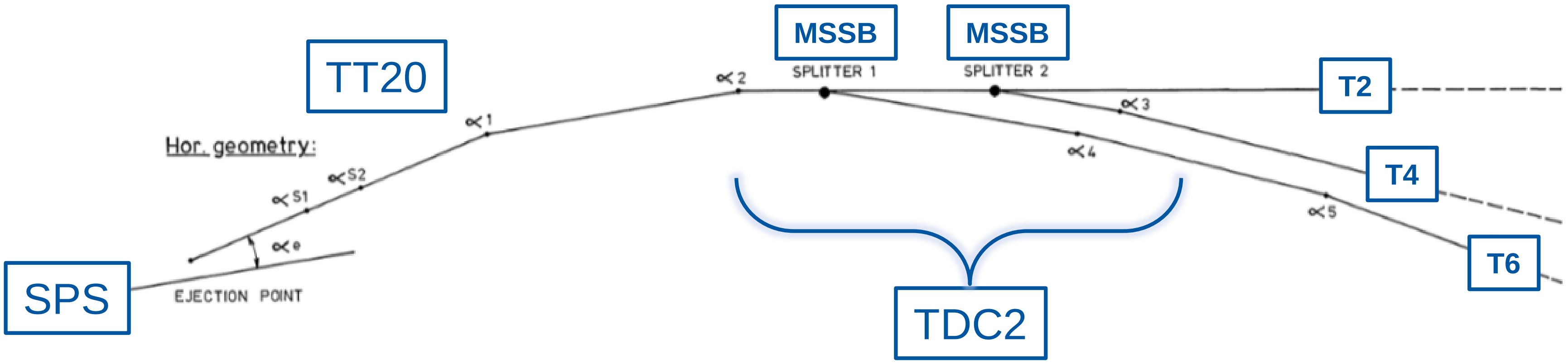
- Beam Dump Facility (BDF) – proposed fixed target facility currently in approval phase.
- The facility will be positioned to the left from the existing beam lines towards North Experimental Area (NEA).
- Beam transfer system allowing switching the beam in both directions (left and right) is required.

Future BDF / SHiP facility



Existing transfer lines to NEA

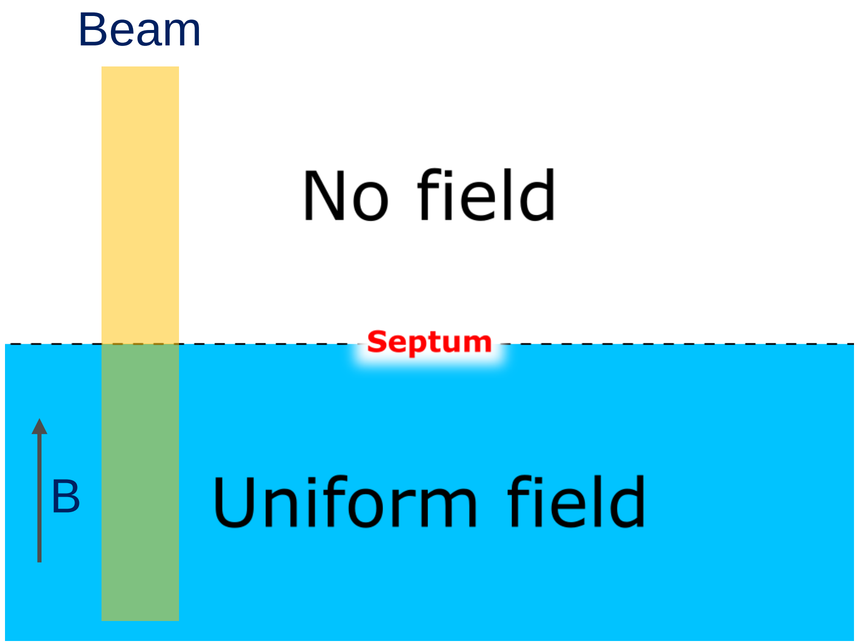
- Two MSSB splitters in TDC2 cut (split) the beam in two (each)
- Three beams towards three different targets (T2, T4, T6) can be supplied simultaneously



How do we split the beam?

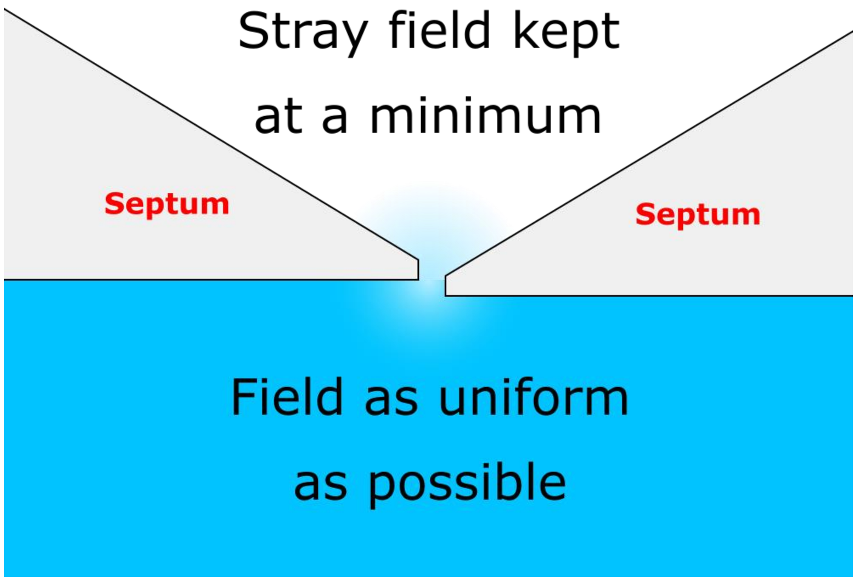
An ideal septum

- Two regions, one with uniform field and one with no field
- separated by a zero thickness partition - *septum*
- Electric field
  - Electrostatic septum
- Magnetic field
  - Septum magnet



A real Lambertson septum magnet

- Stray field in the no-field region is present
- Non-uniformities in the „uniform” field region
- Non-zero thickness septum blades
- Saturation - uniform field cannot go arbitrarily high



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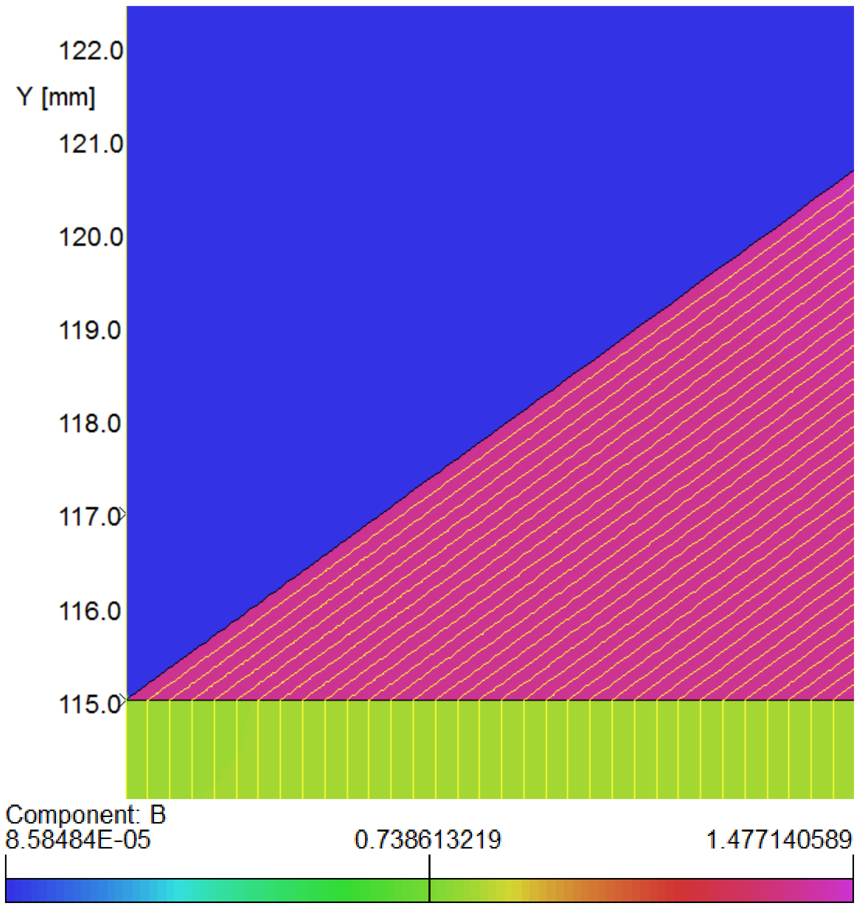
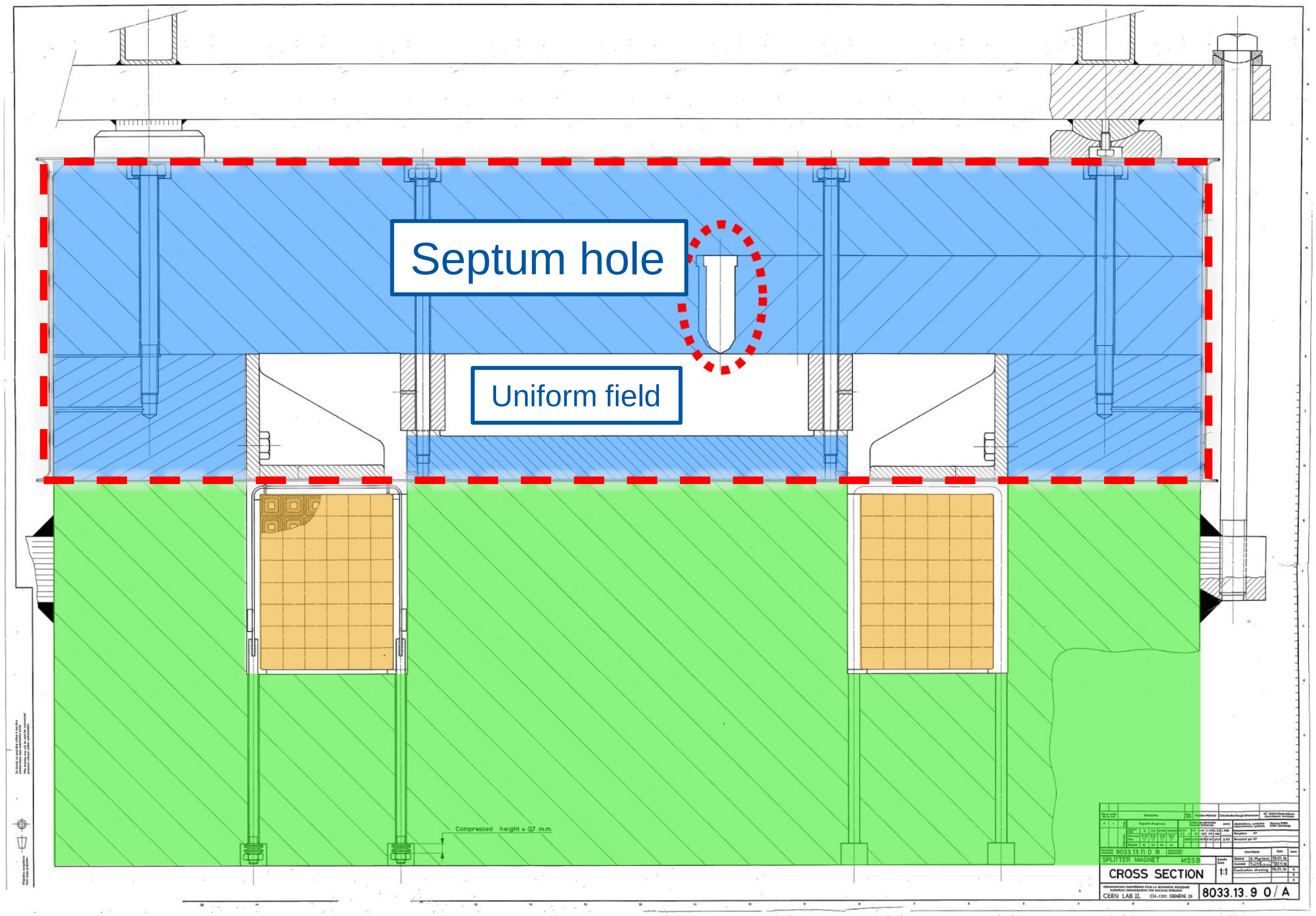


MSSB

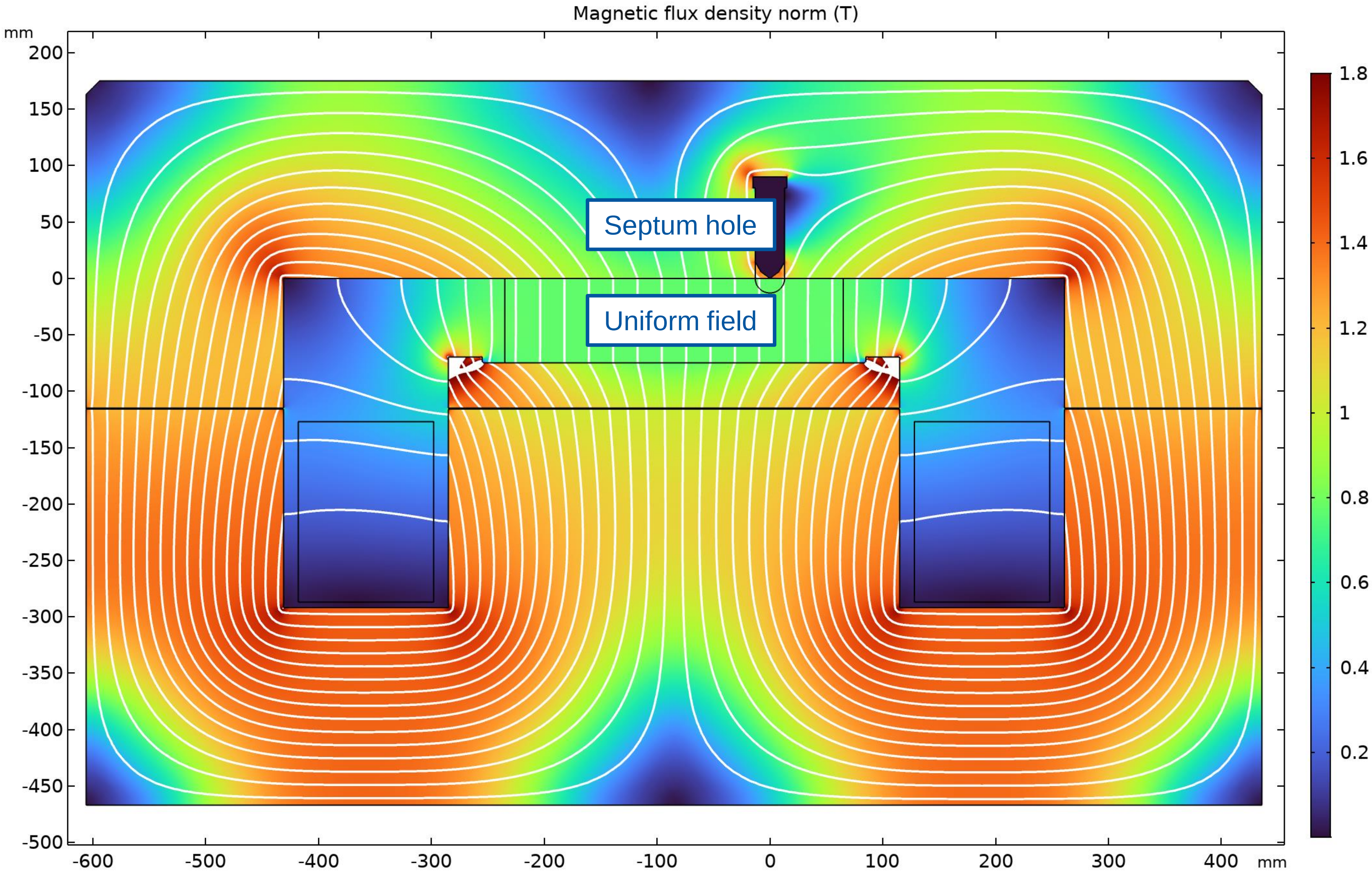
What is MSSB?

- MSSB is a design family of Lambertson septum splitter magnets
- Currently only installed in North Experimental Area (NEA) transfer lines (TDC2) – six units in packs of three
- These MSSBs supply different experiments during the same cycle of SPS by cutting the beam and deflecting one part of it.

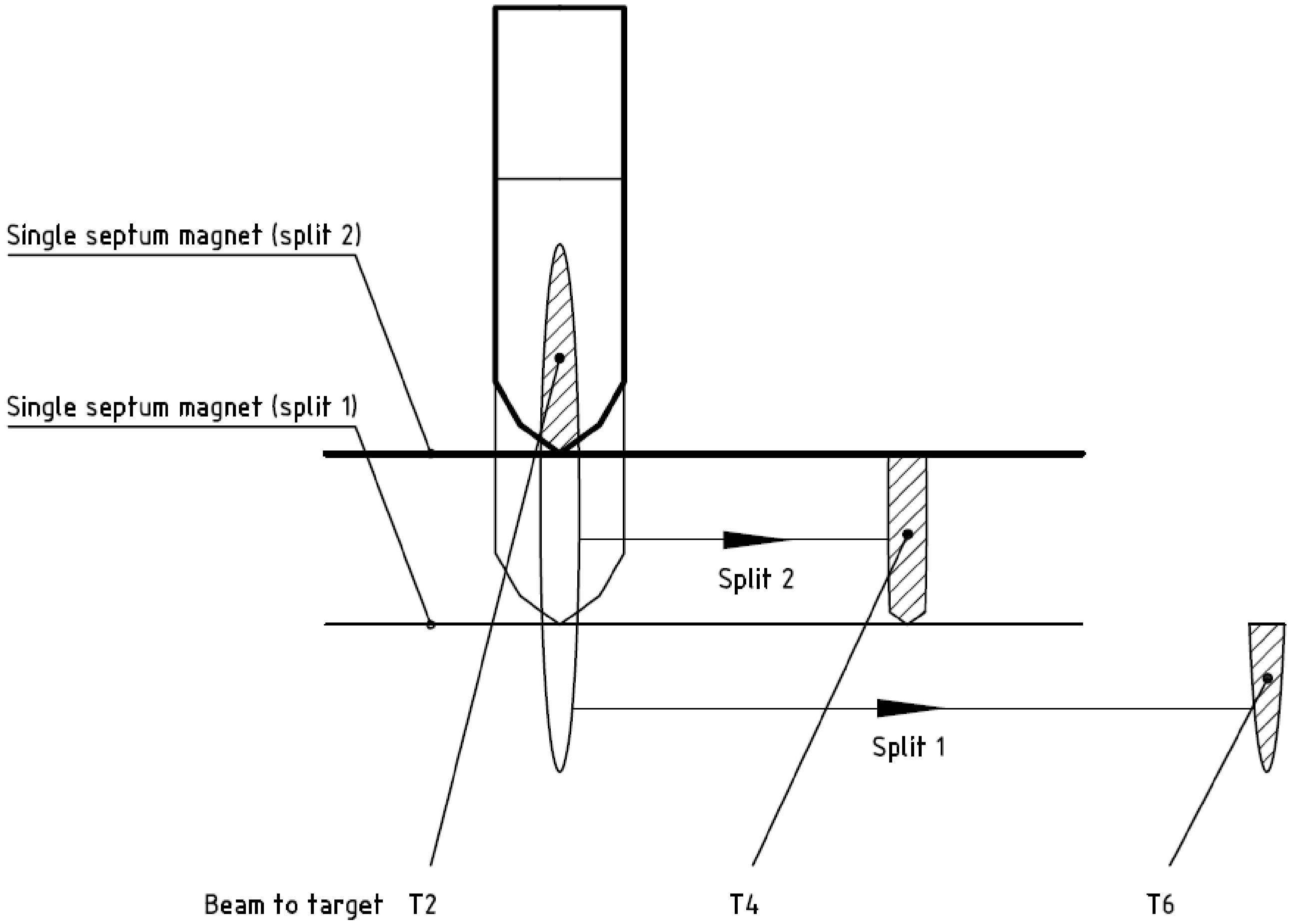
Current splitter (MSSB)



Current splitter (MSSB)

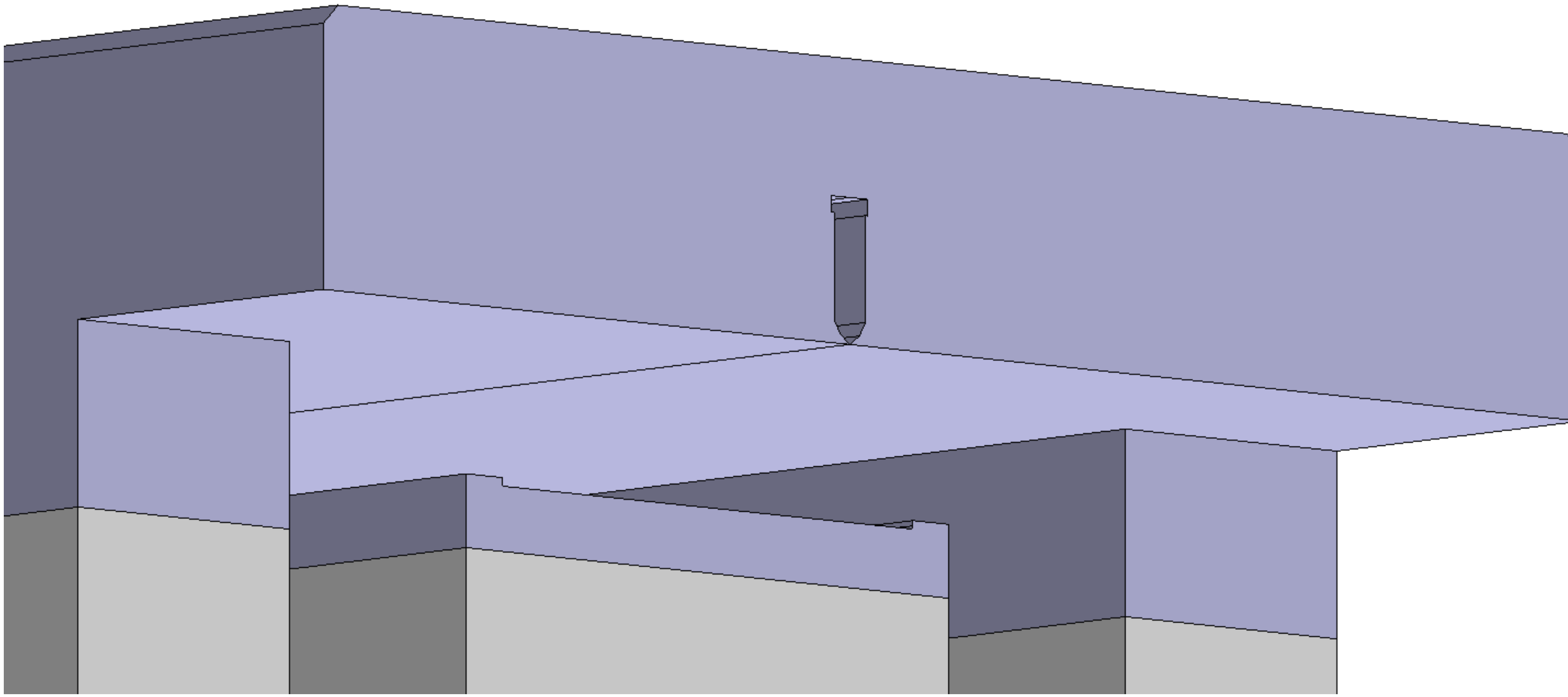


Beam size and shape



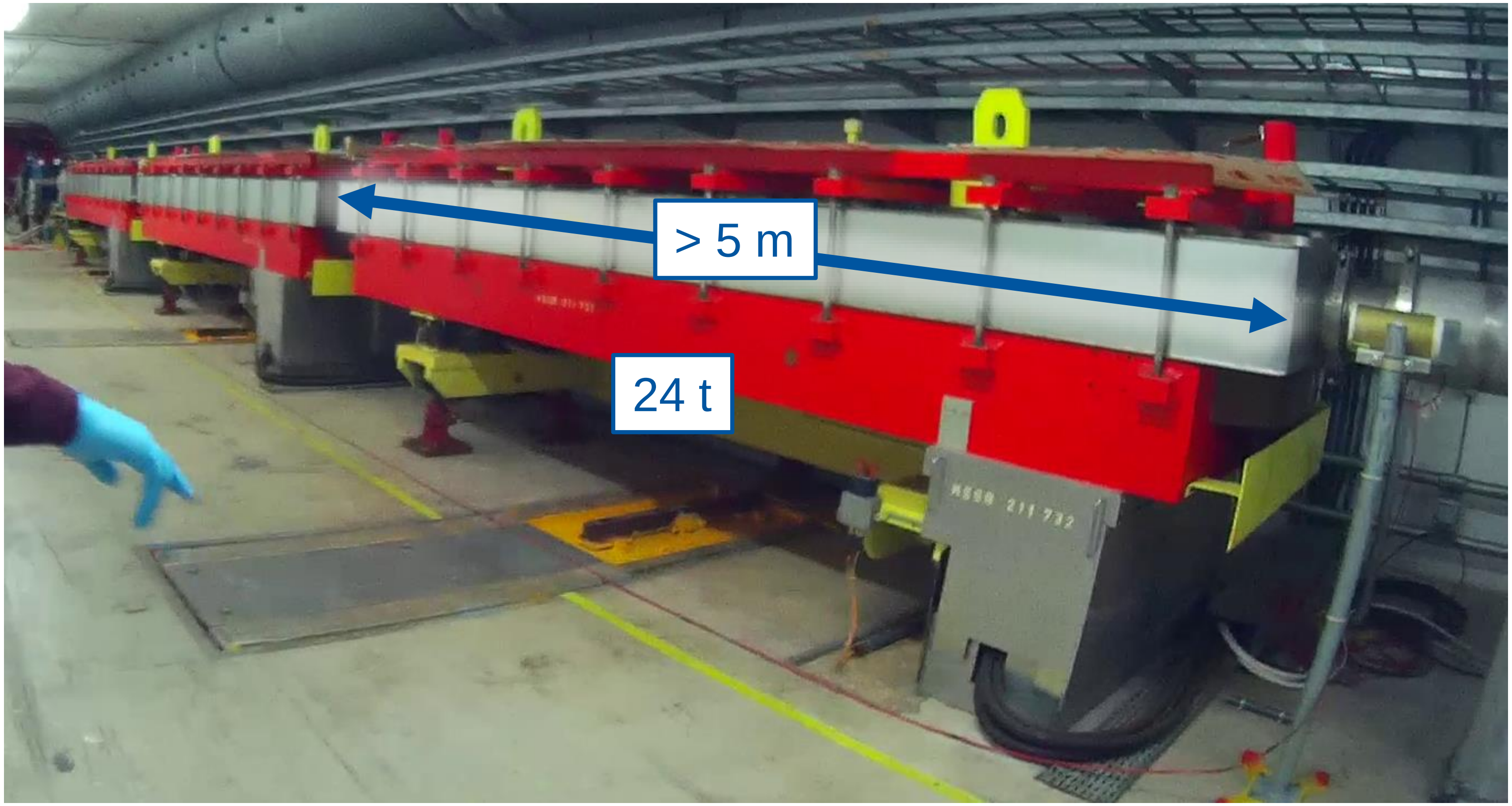
Current splitter (MSSB)

- Upper yoke length – 5140 mm (magnetic)
- Lower yoke length – 4700 mm



Current splitter (MSSB)

- 3 units of the first splitter

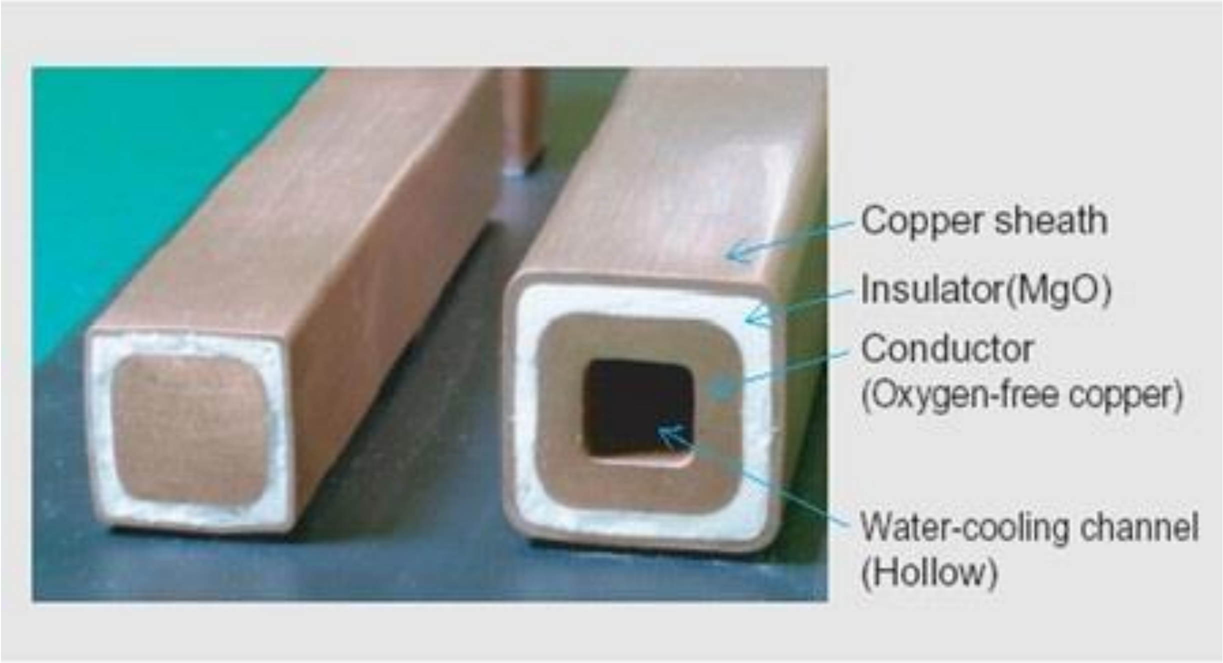


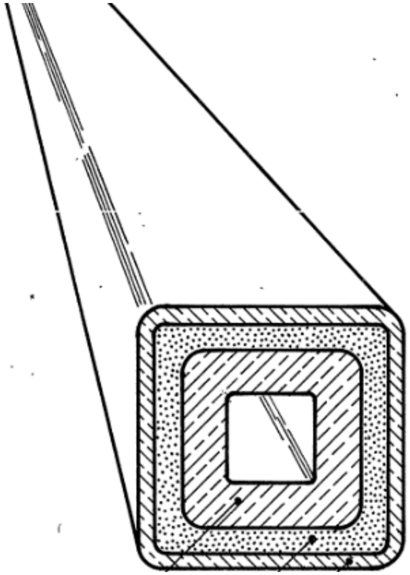
Challenges

- Minimisation of beam losses
  - Minimisation of the septum cross section area
    - Saturation of the septum blades
  - Minimum leakage field into the no-field region
  - Field quality in the dipolar region
- Mechanical tolerances
- High levels of radiation
- Vacuum compatibility of in-vacuum iron yoke

Mineral insulated coil

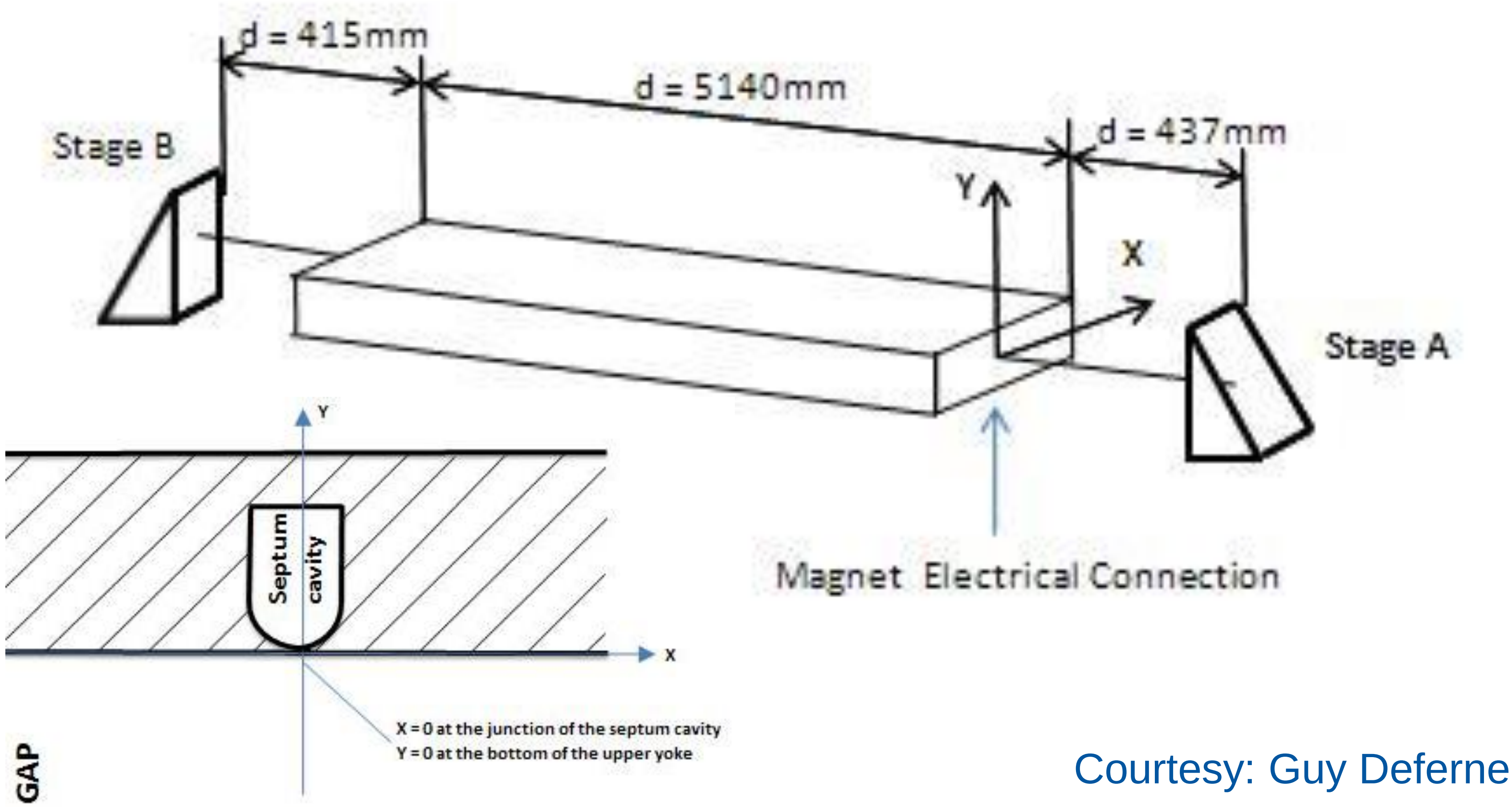
- Coil made of Mineral Insulated Copper Conductor (MICC) for radiation resistance
- No resin/glass fiber composite can be used





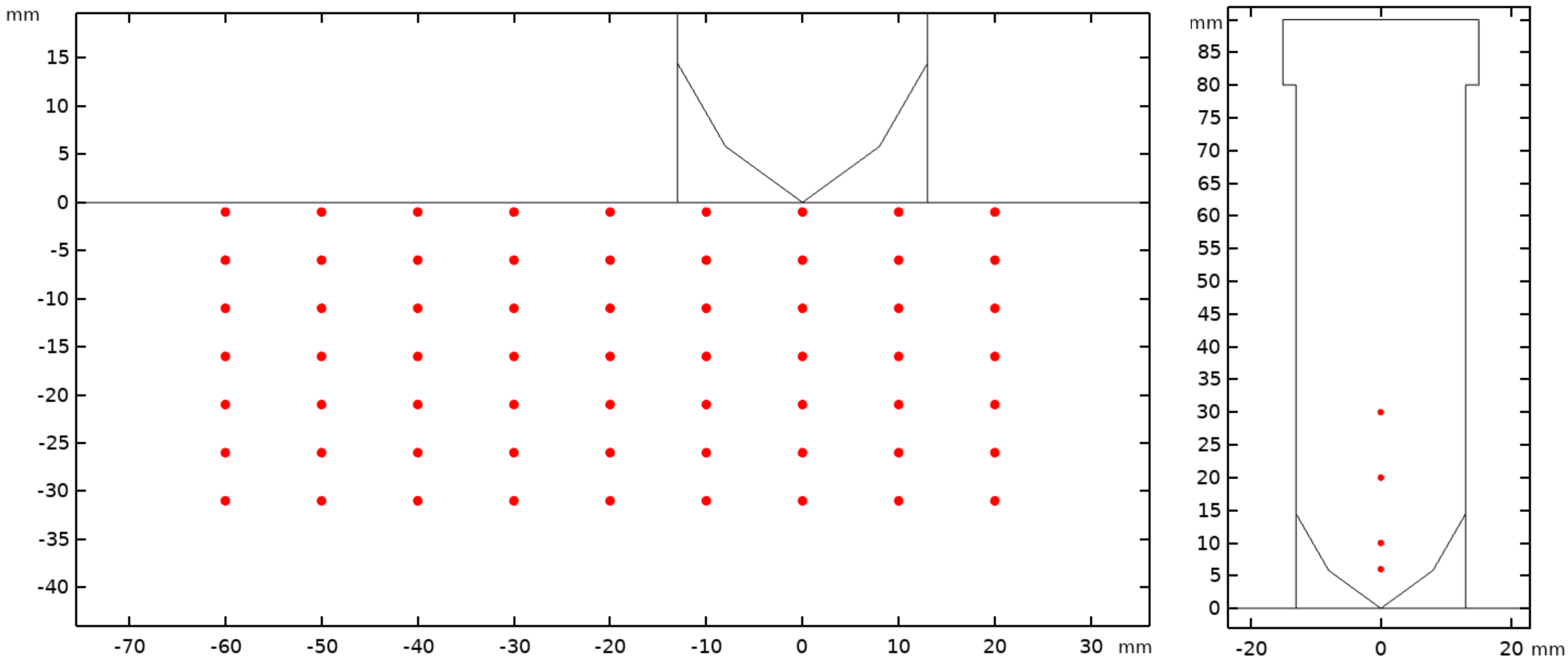
Measurements vs 2D simulations

Magnetic measurements

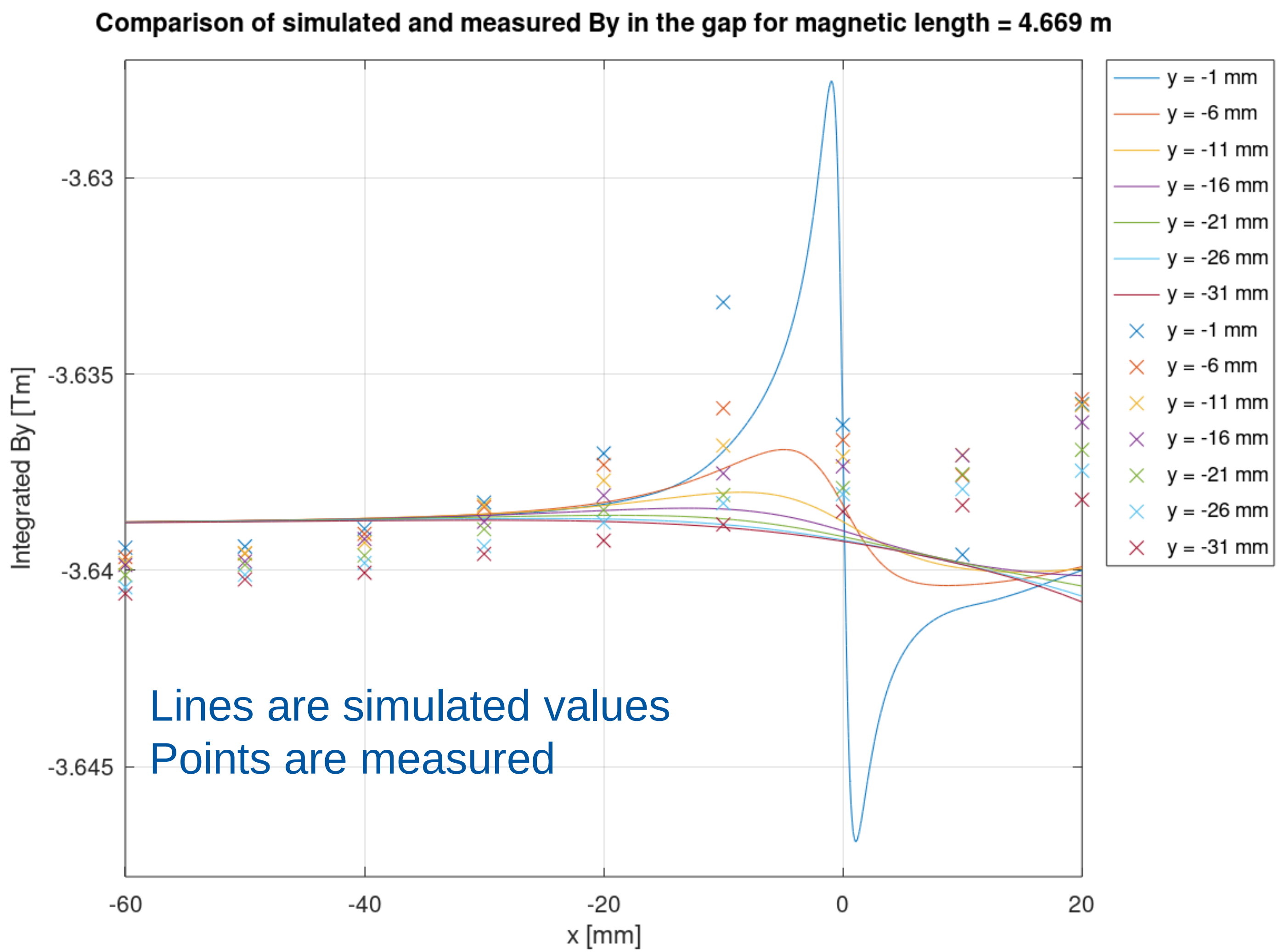


Courtesy: Guy Deferne

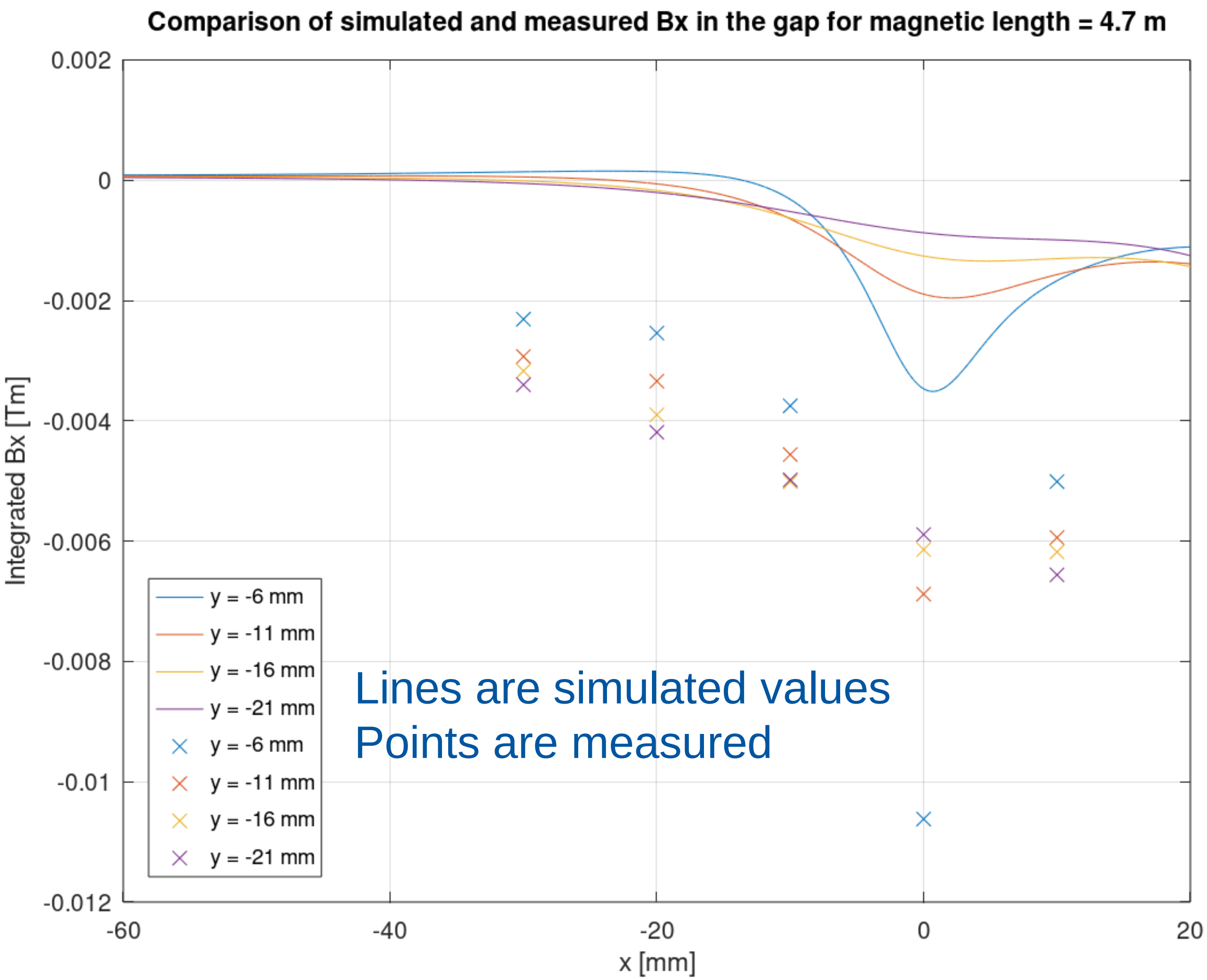
Locations of measurements



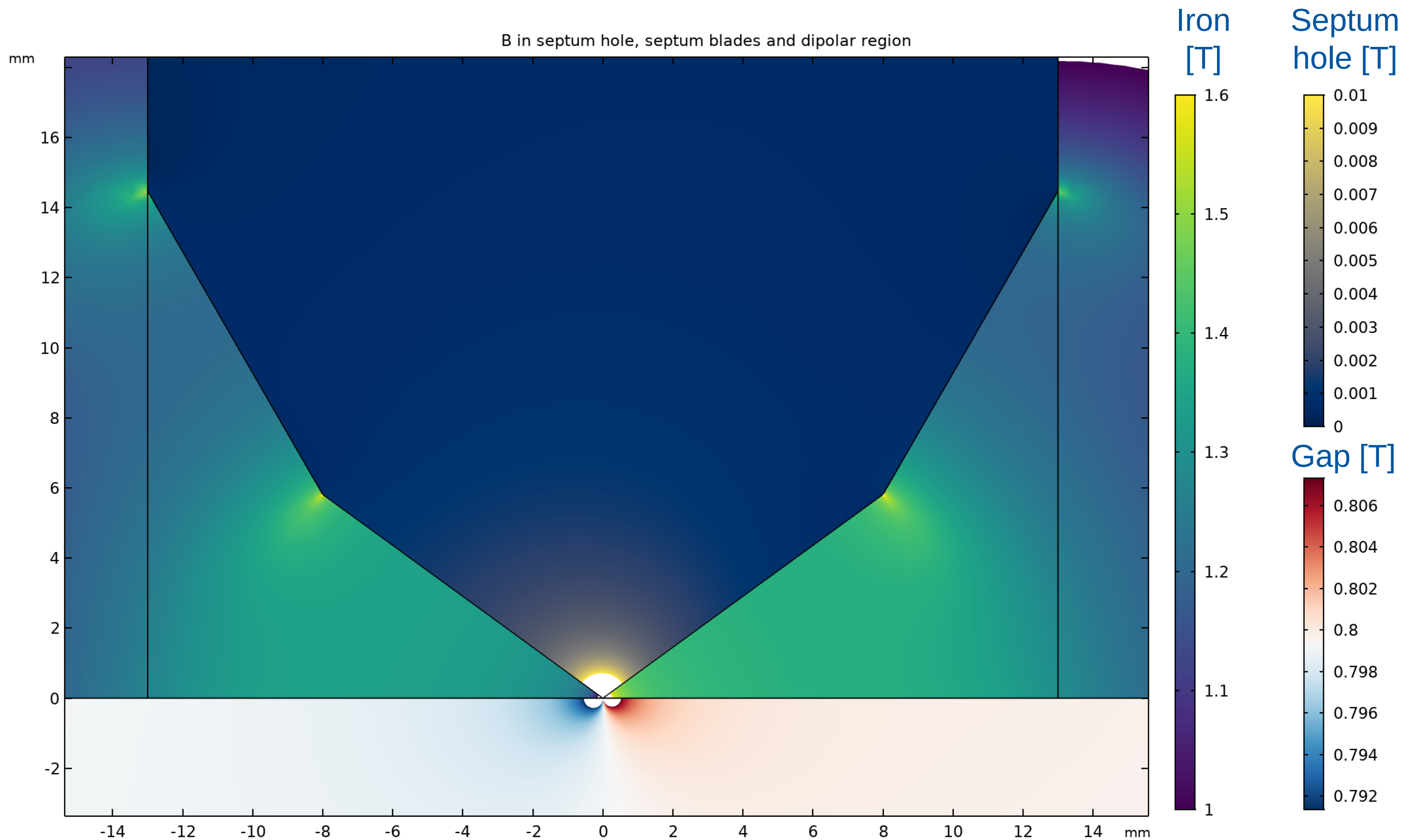
By in gap for 2D simulation



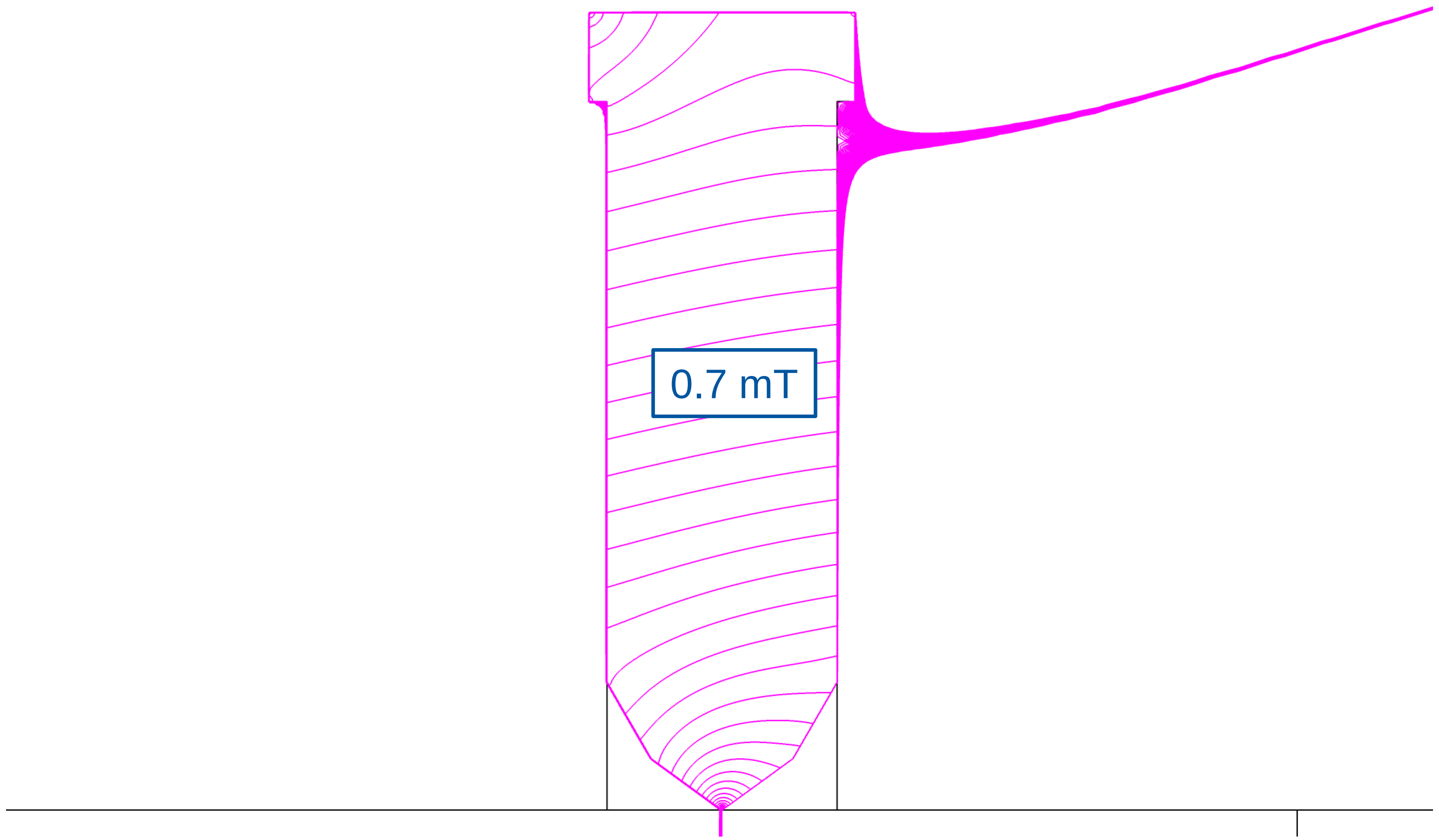
Bx in gap for 2D simulation



Zoom onto septum blades

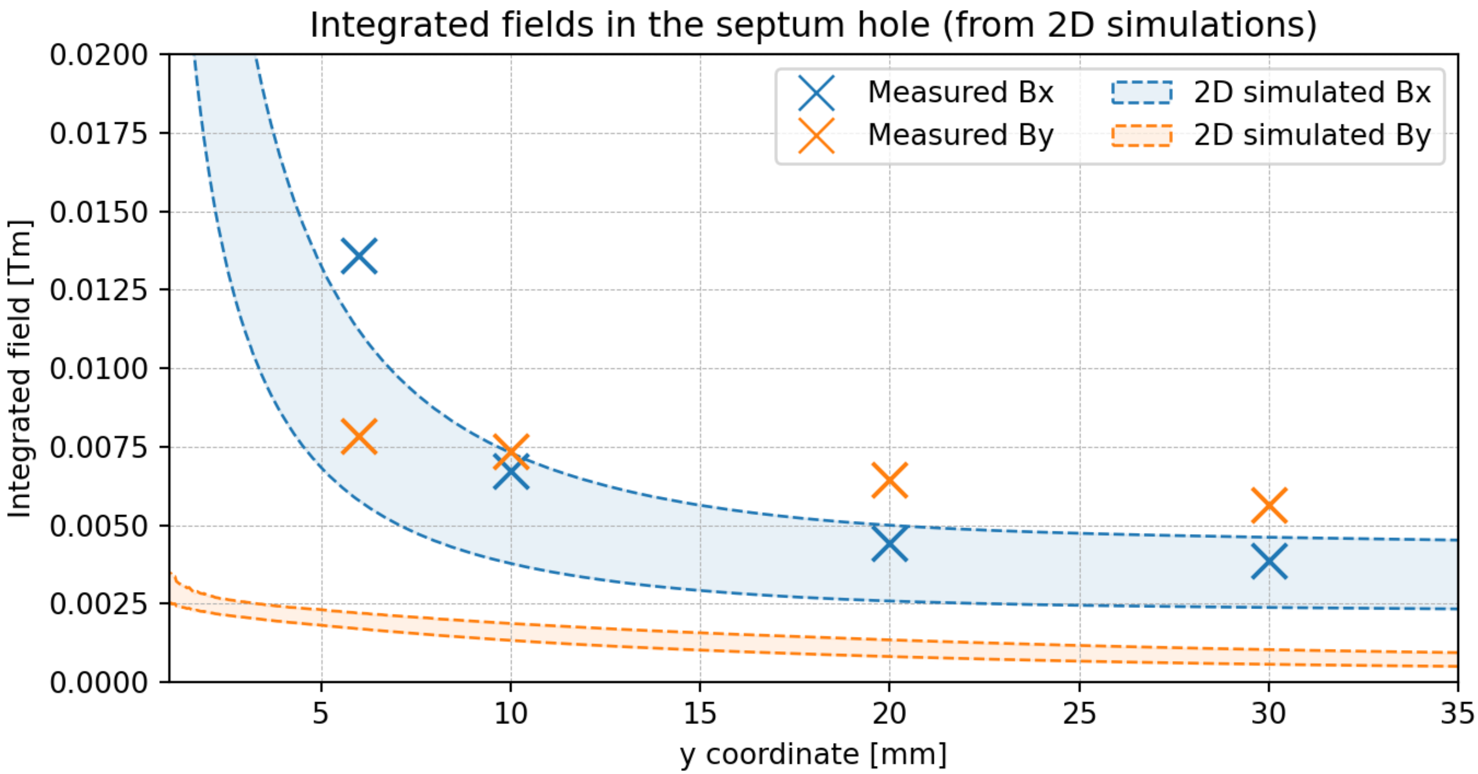


Field lines crossing the septum



Hole field in 2D simulation

- Coloured bands for uncertainty related to the BH curve of the material used for simulation



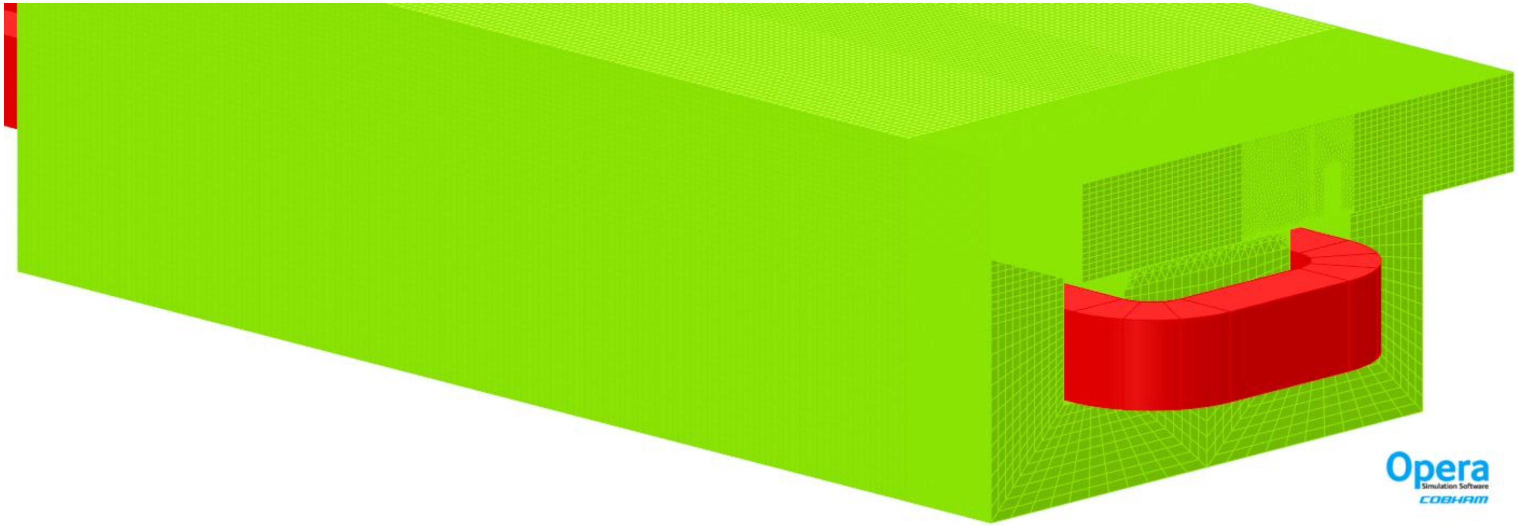
2D simulations summary

- Reasonable match between shape of simulated and measured By profiles in gap.
- Bx in the gap is underestimated by the simulation.
- Reversed situation for the septum hole
  - By is underestimated by simulation
  - Bx is in a relatively good agreement
- Bx in hole strongly affected by BH curve
- 3D simulations strongly recommended

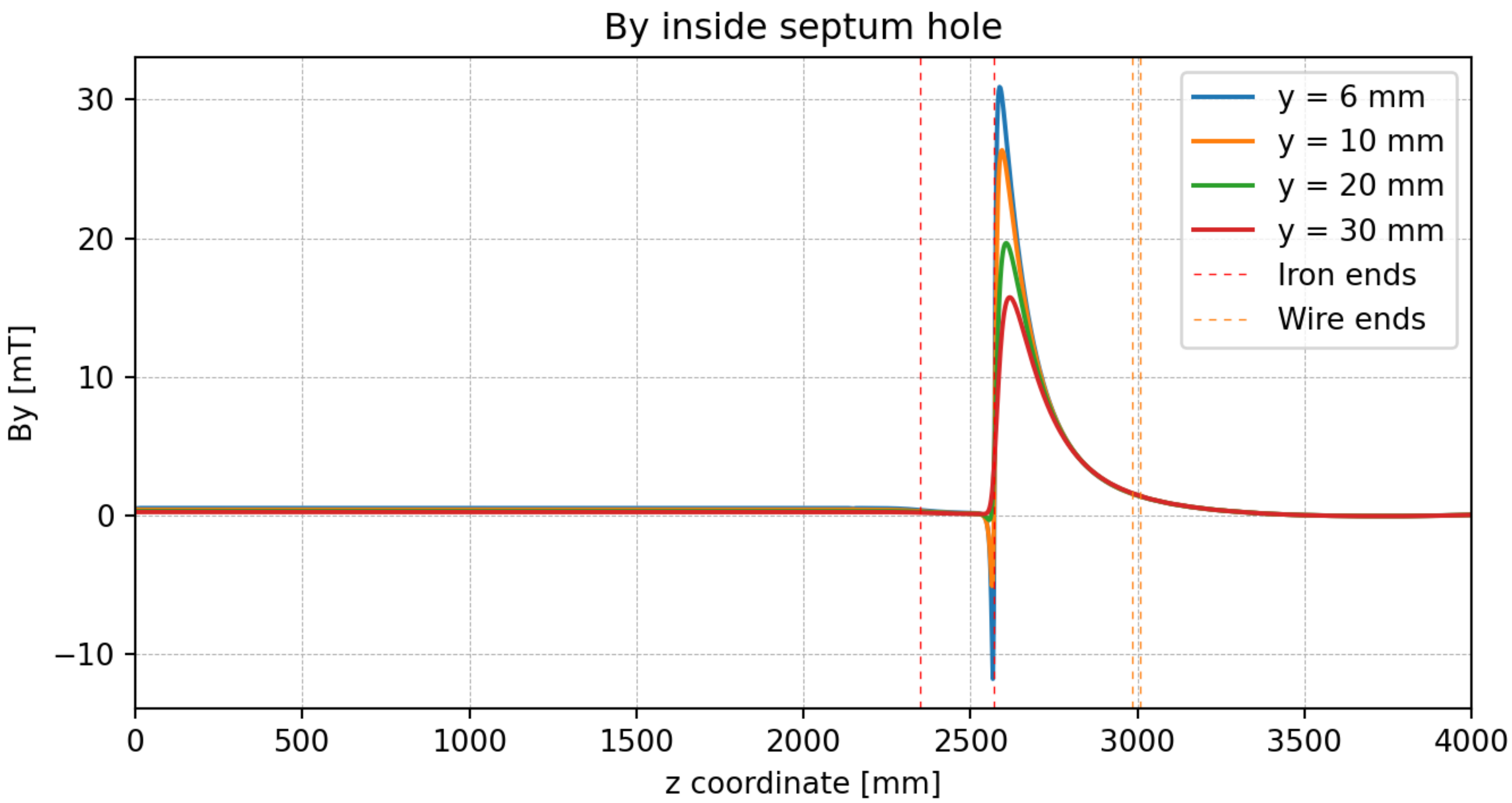
Measurements vs 3D simulations

3D simulations

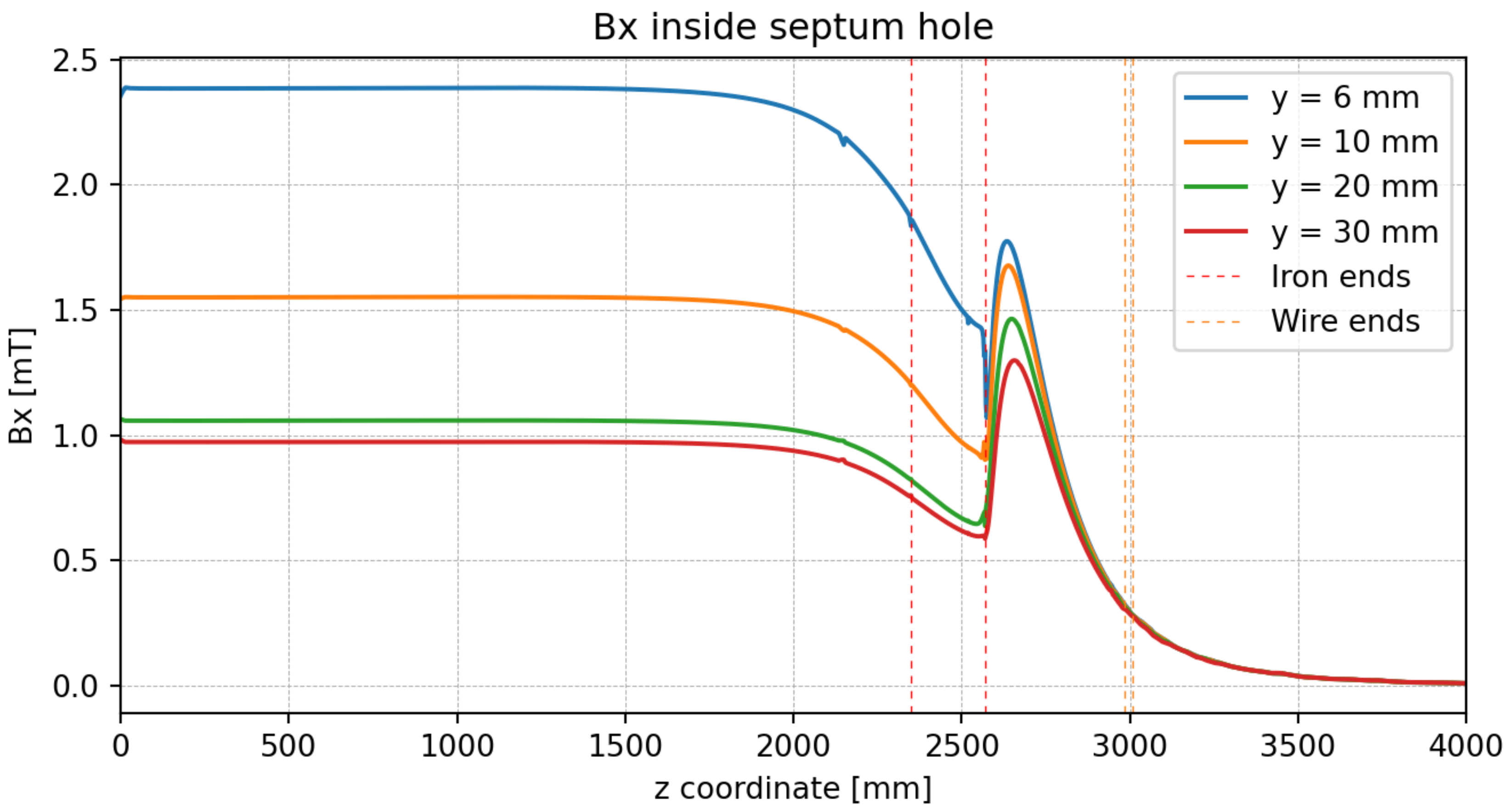
- Conducted in both Comsol and Opera
- SS vacuum chamber not simulated
- Simulated for both materials
- Max number of elements reaching 8 000 000



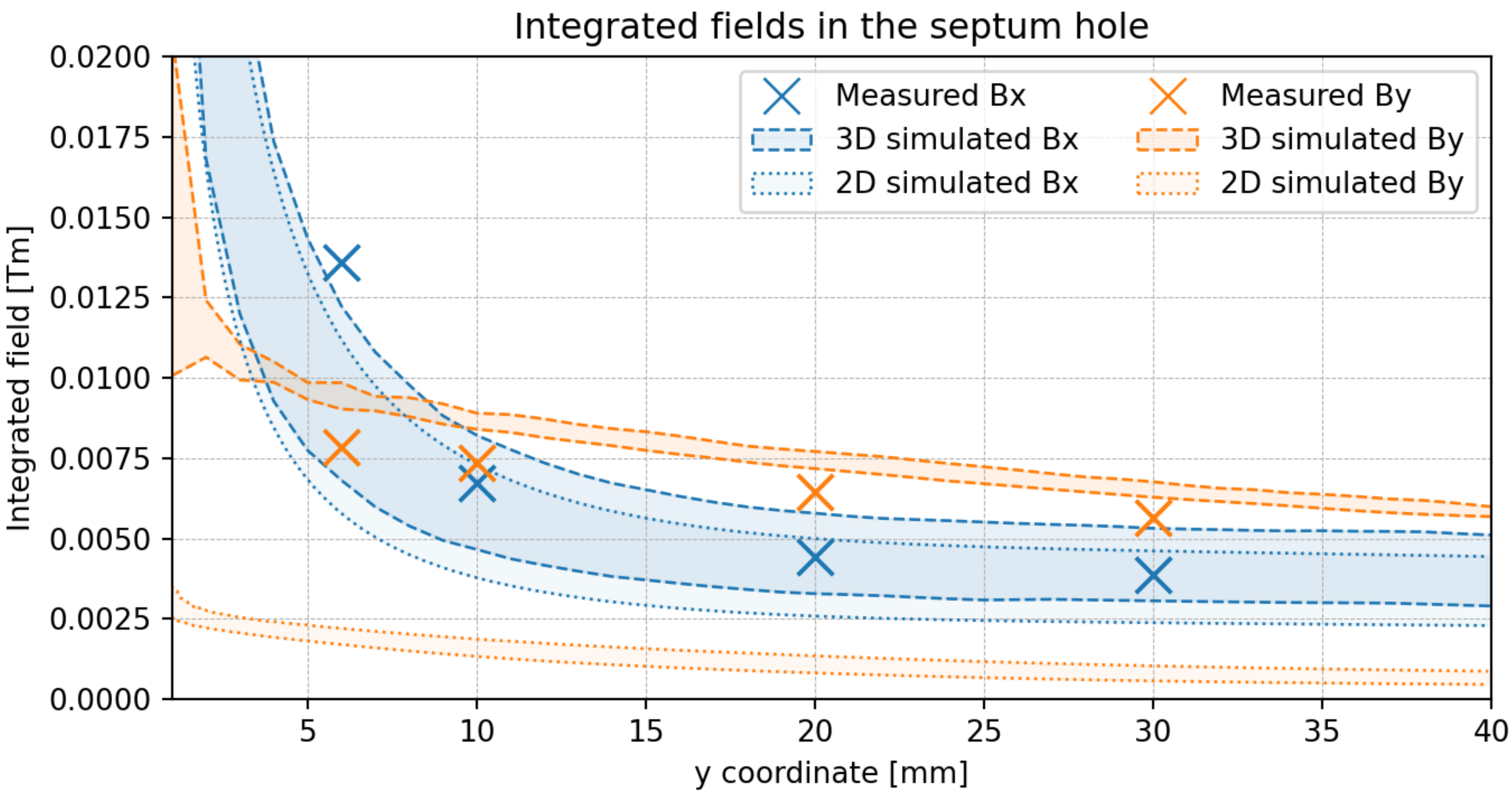
By in hole in 3D simulations



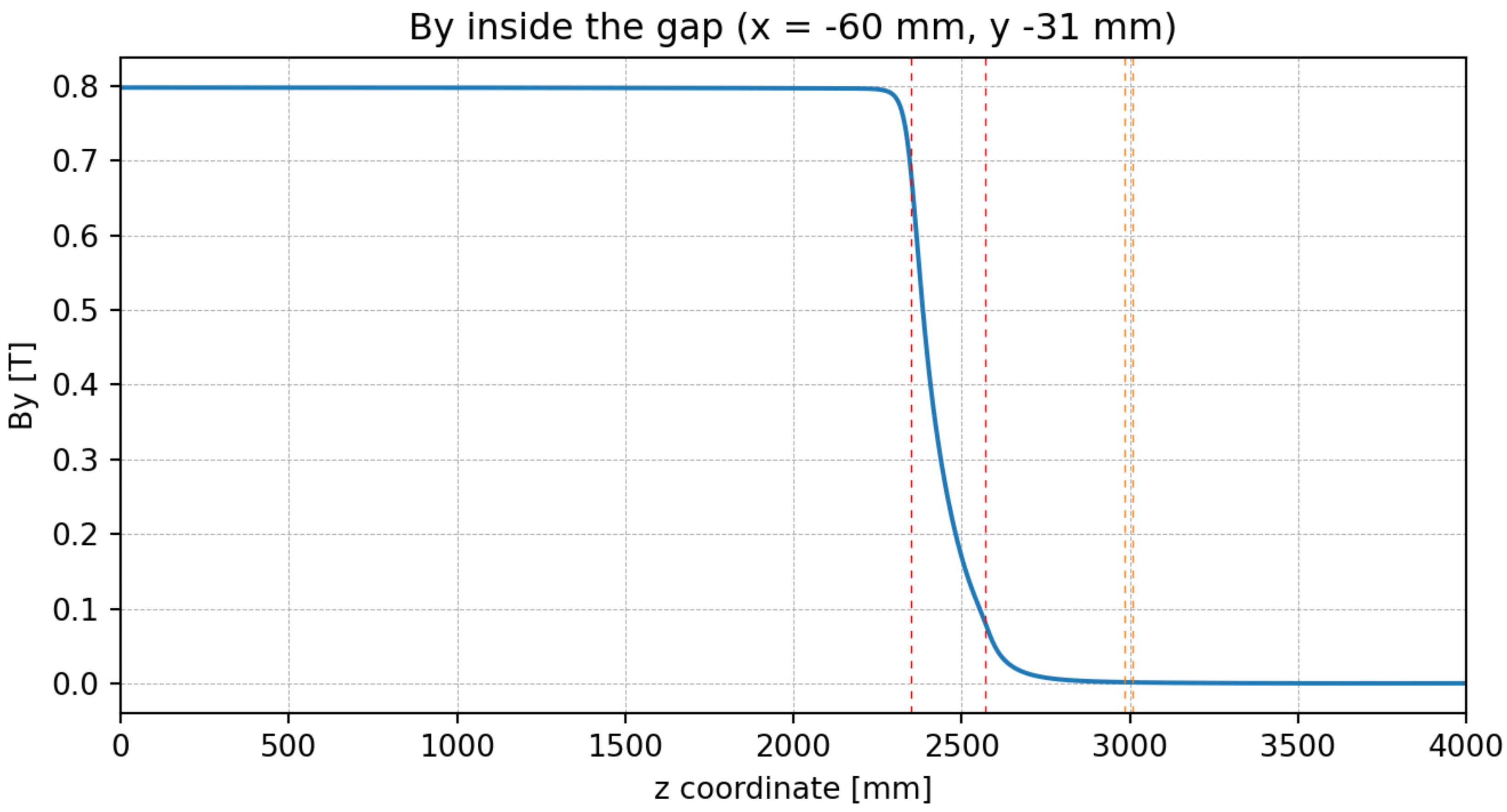
Bx in hole in 3D simulations



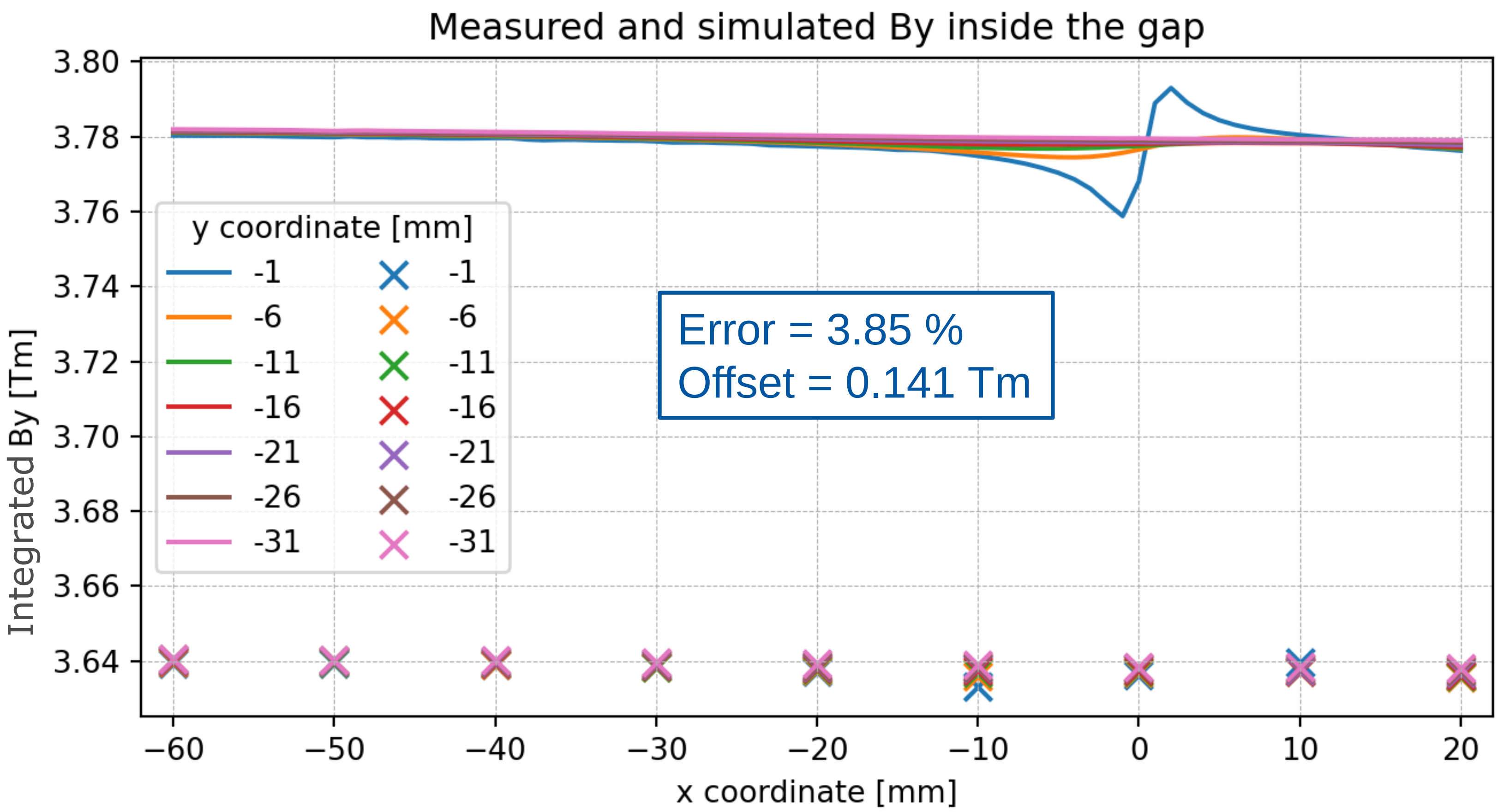
B in hole in 3D simulations



By in gap in 3D simulations

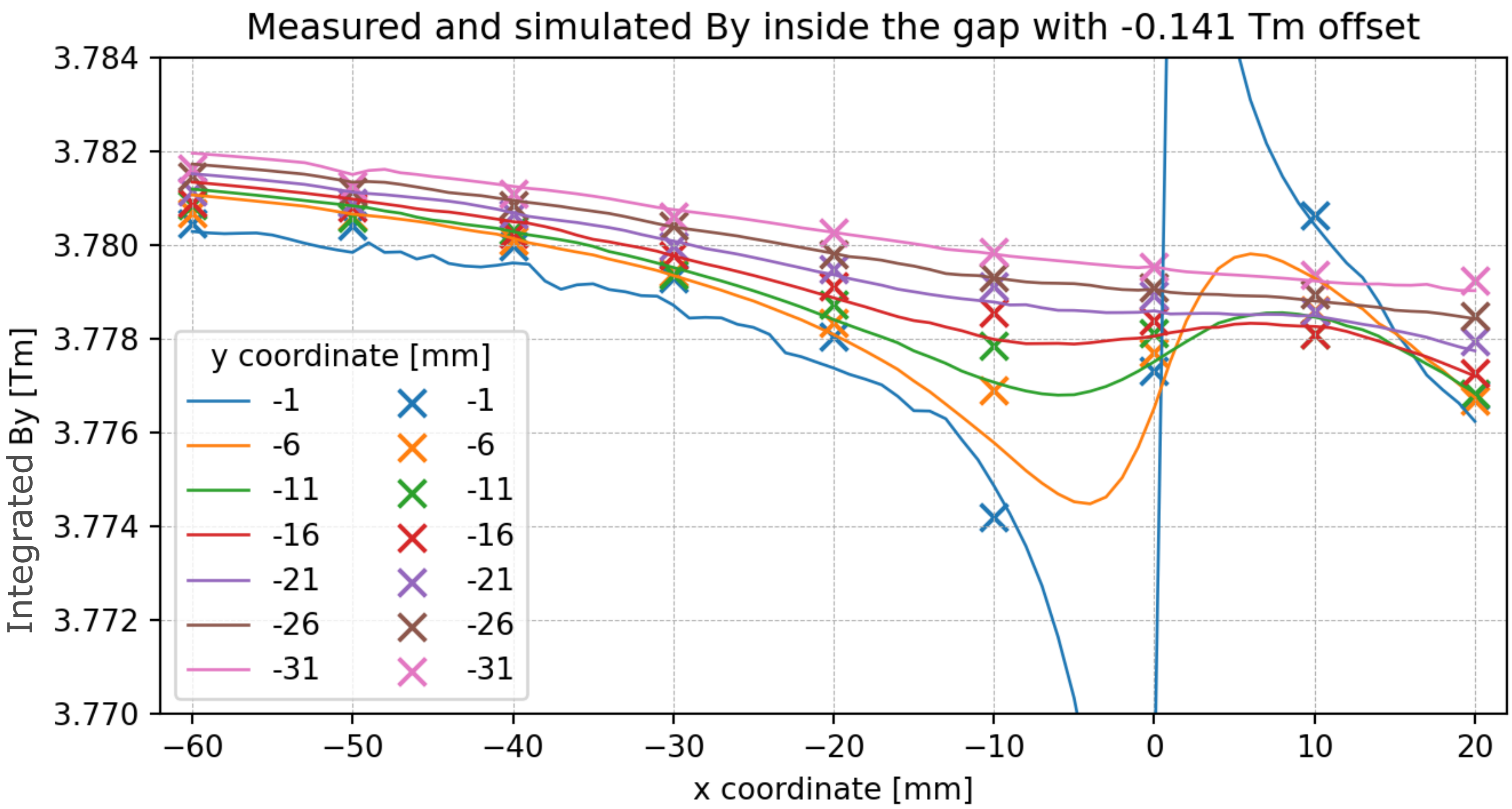


By in gap in 3D simulations



Lines are simulated values, points are measured

By in gap in 3D simulations

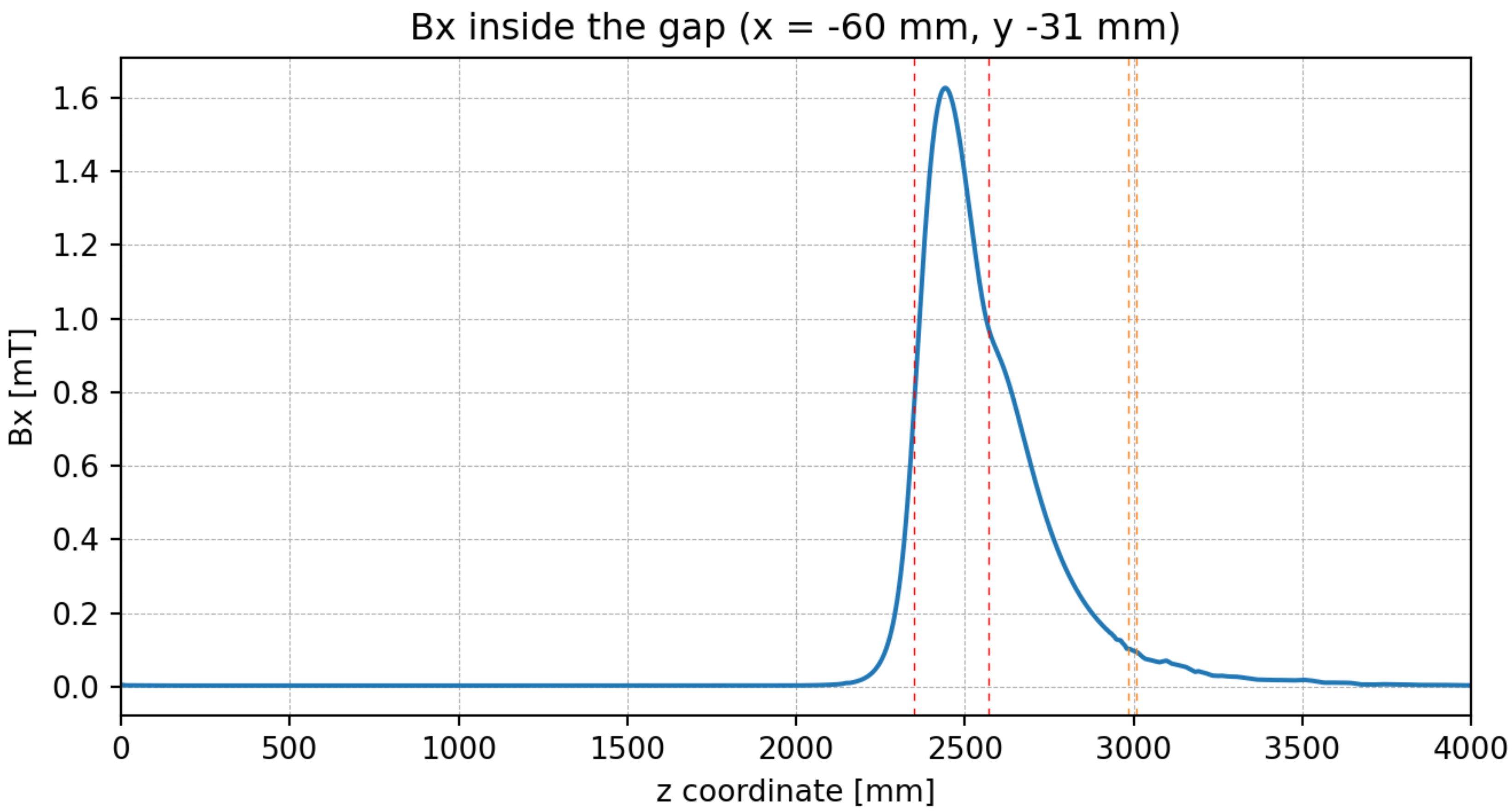


Lines are simulated values, points are measured

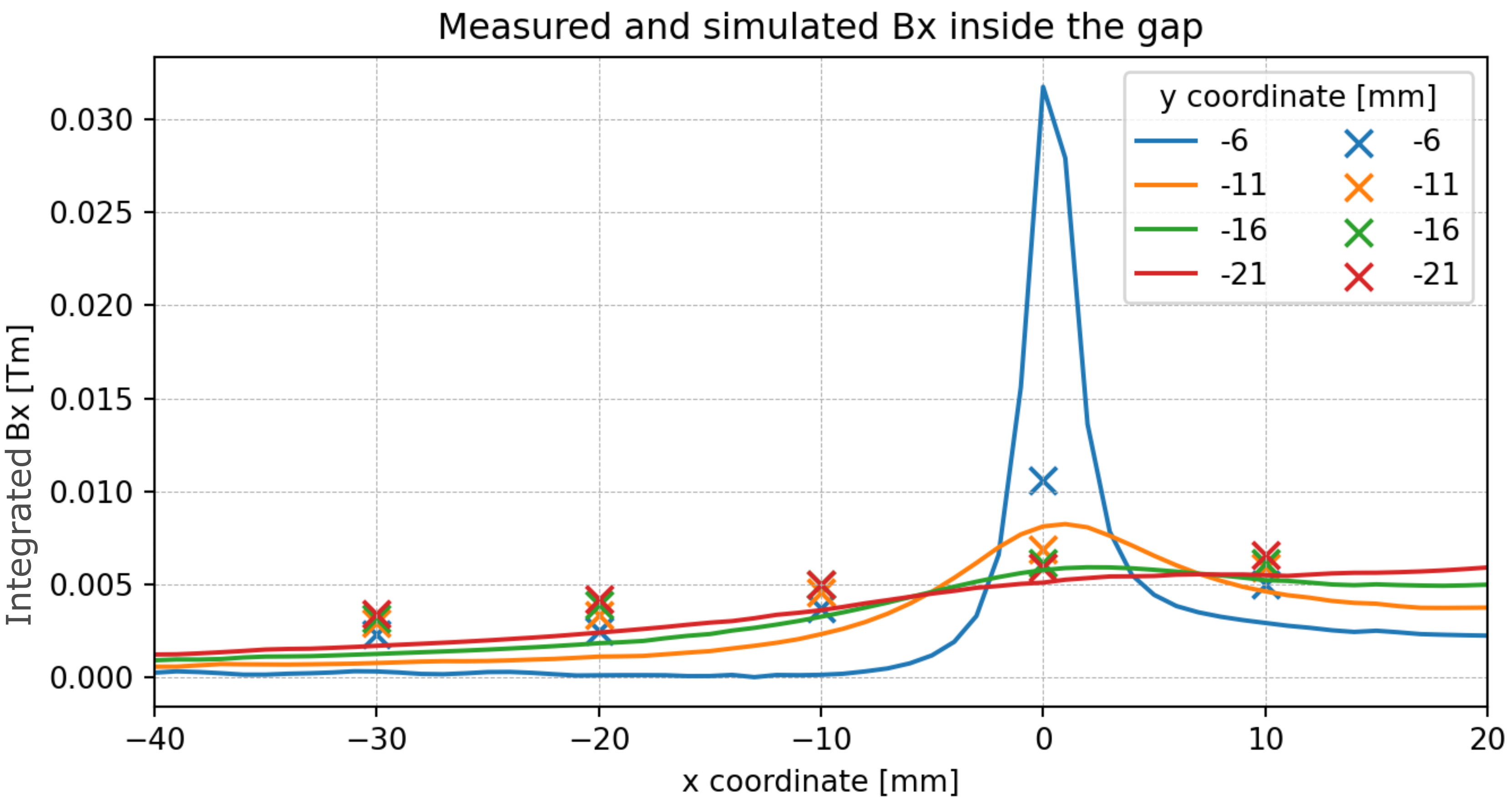
By in gap - remarks

- Vacuum tank of the top yoke not simulated.
- It adds 2 mm (1 mm skin cutting the iron twice) to the air length in the field lines .
- The error between measurement and simulation is ~3.85 %.
- After subtracting 2.67 % for the missing gap, the remaining error is 1.21 %.

Bx in gap in 3D simulations



Bx in gap in 3D simulations



Lines are simulated values, points are measured

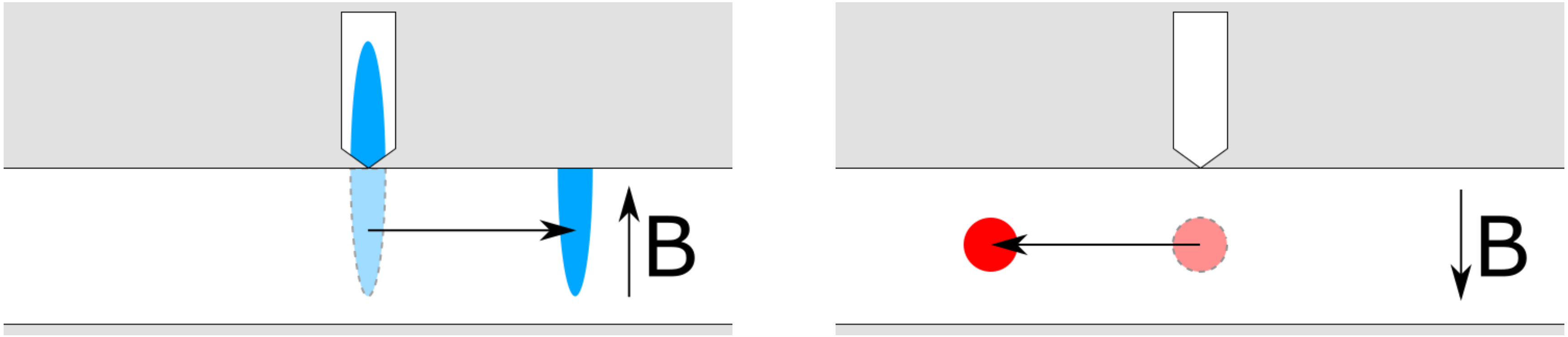
Conclusions on the simulations

- The 3D magnetic simulations are in good agreement with the measured values.
- Large relative errors for Bx, but Bx has very small absolute values.
- The impact of the ends of the magnet is very important, and cannot be neglected for practical purposes.

New design for the MSSB

Why new design?

- To send the beam to the left of existing lines, the first splitter pack has to switch polarity between SPS cycles (in seconds' time)



- Solid iron not compatible with relatively fast switching → the yoke must be laminated.

Challenges for laminated yoke

- Challenges are the same as for solid iron yoke, but due to laminations, they are more difficult to achieve
  - Hundred of µm precision over 5 m long **laminated** yoke
  - In-vacuum surface area greatly increased by laminations – increased outgassing
    - Inter-lamination insulation should not be organic

Requirements for new design

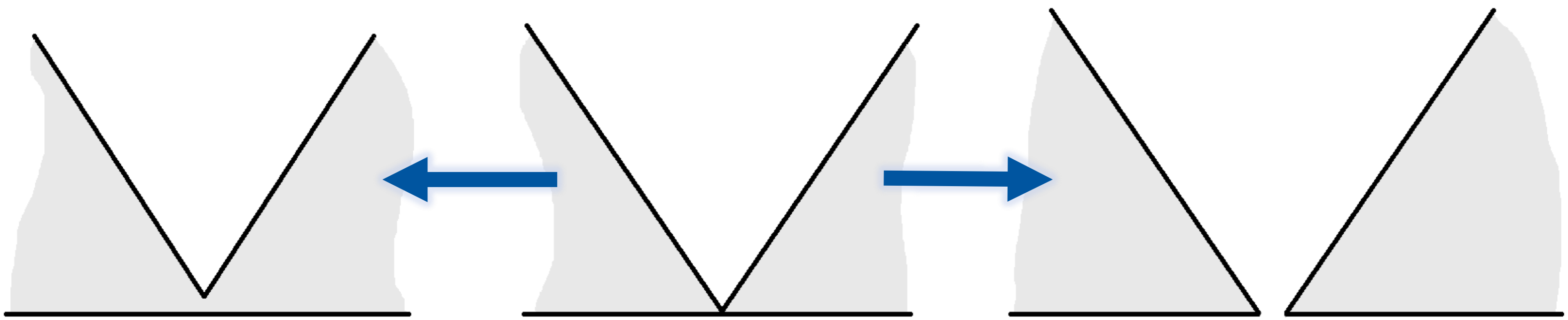
- Beam deflection in both directions (L and R)
- BDF operation without beam splitting (all particles in the gap)
- NA operation not affected by the new splitter
  - Same beam optics for the NA operation
  - Same or lower beam losses
  - Same or better field quality

Sensitivity studies for design optimisation

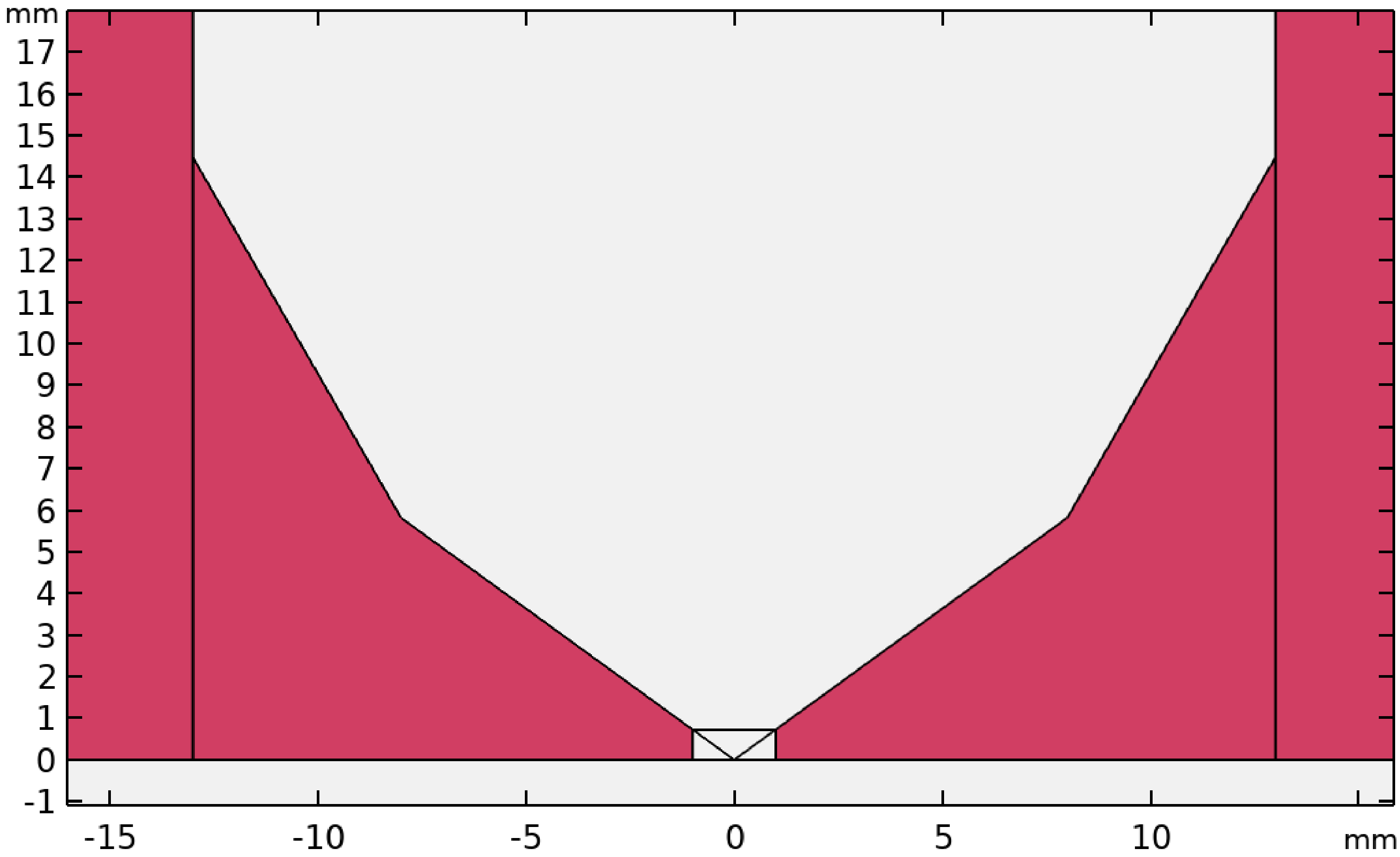
- Impact of the opening between blades on hole field (gap vs bridge), losses compared.
- Beam deflection in septum hole
- Pole shim geometry
- Operation with increased field

Desired septum geometry

- Septum blades geometry based upon:
  - magnetic performance
  - mechanical strength
  - beam performance



Septum gap/blade study



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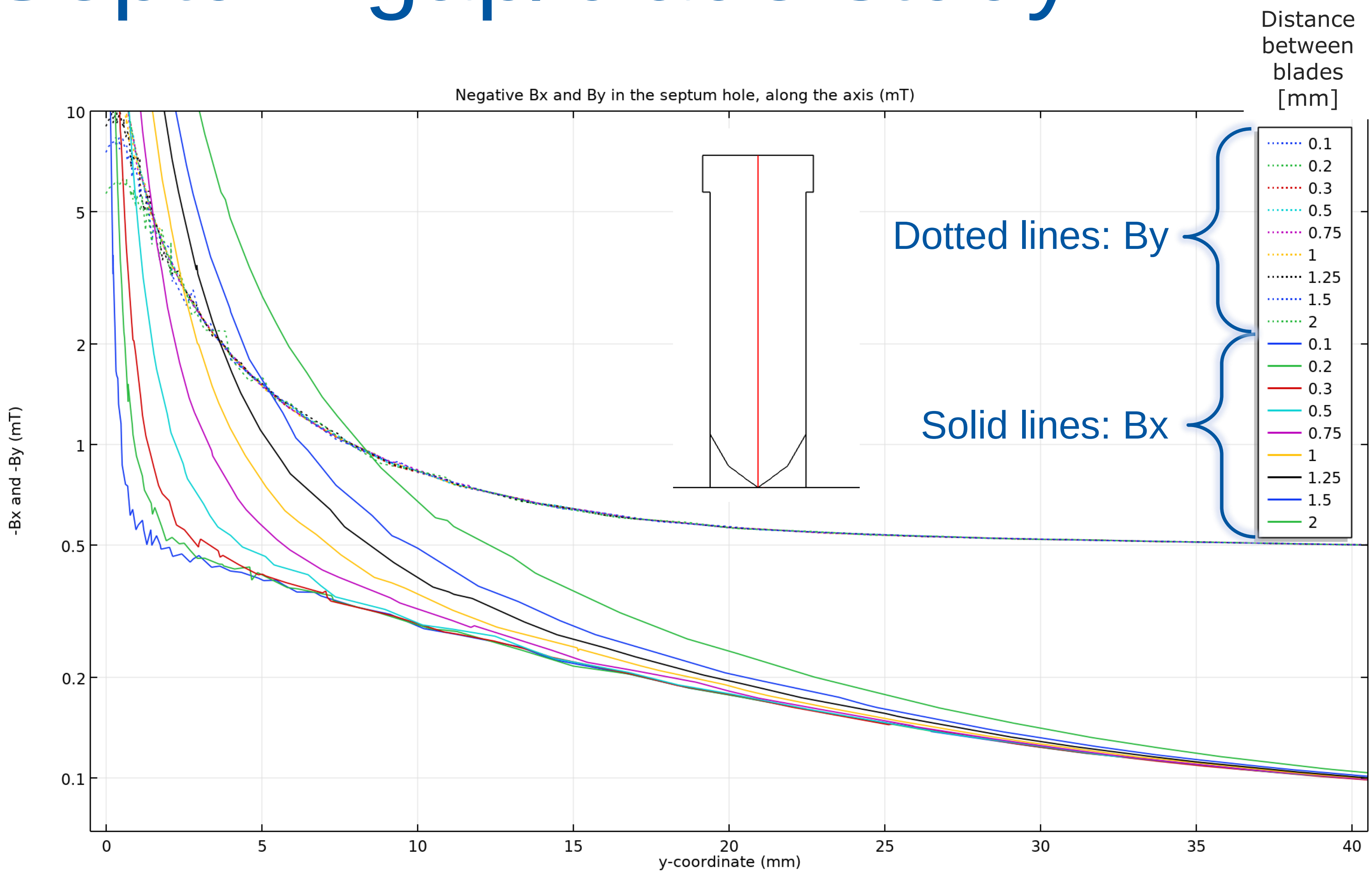
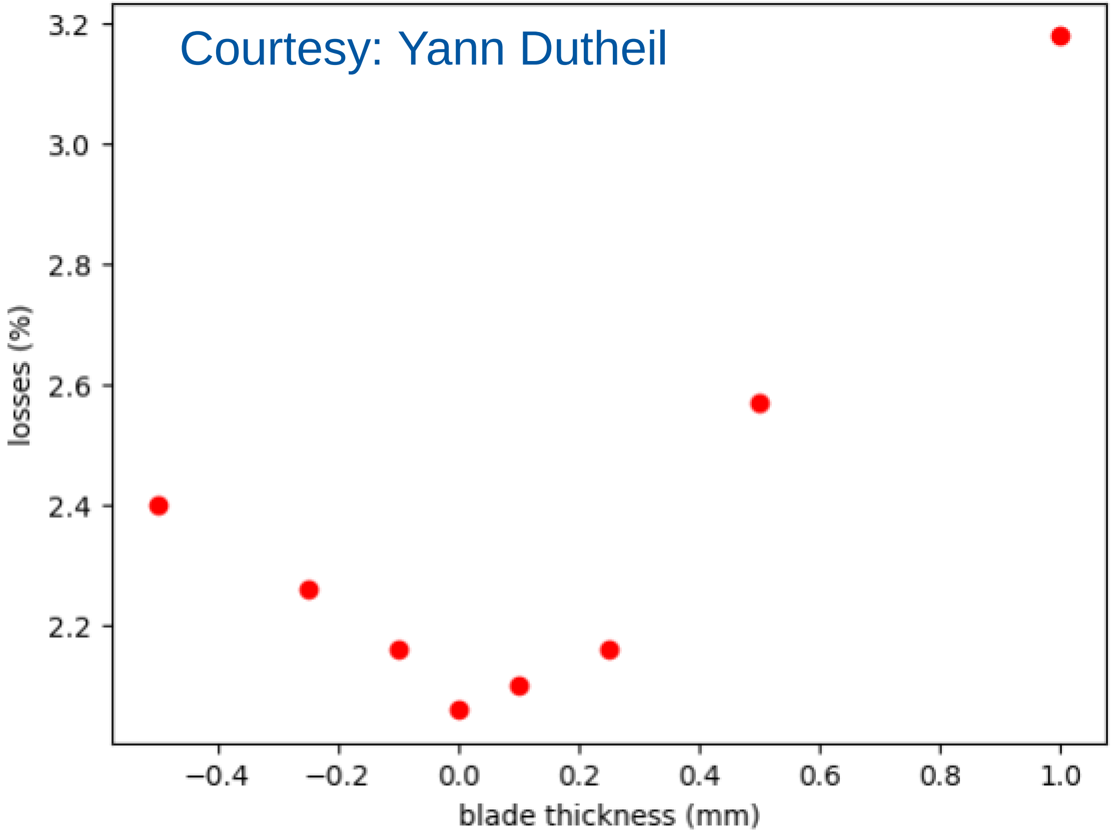
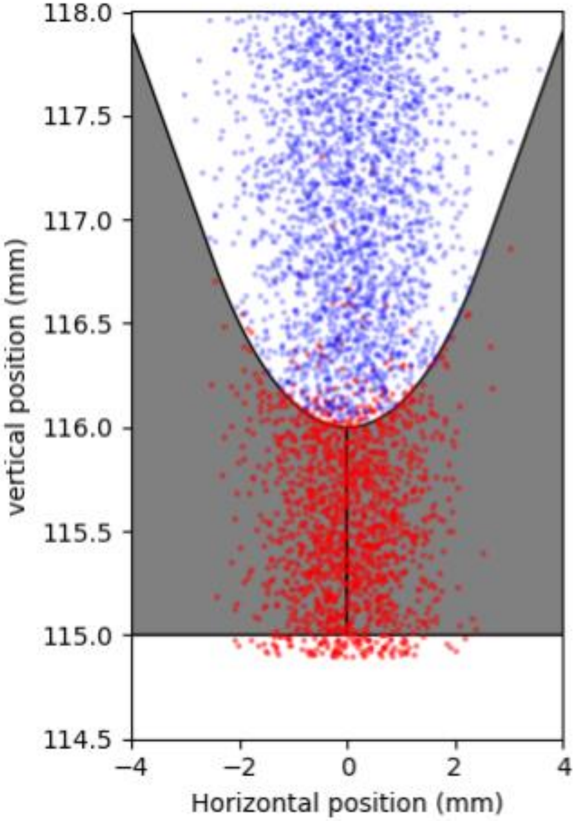


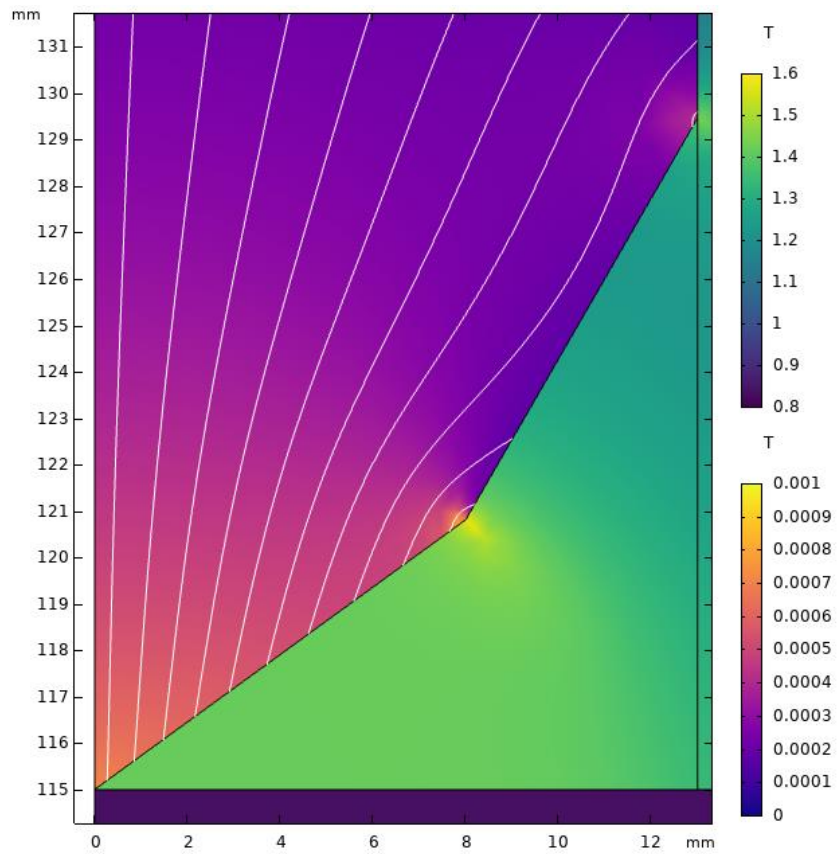
Septum gap study - losses



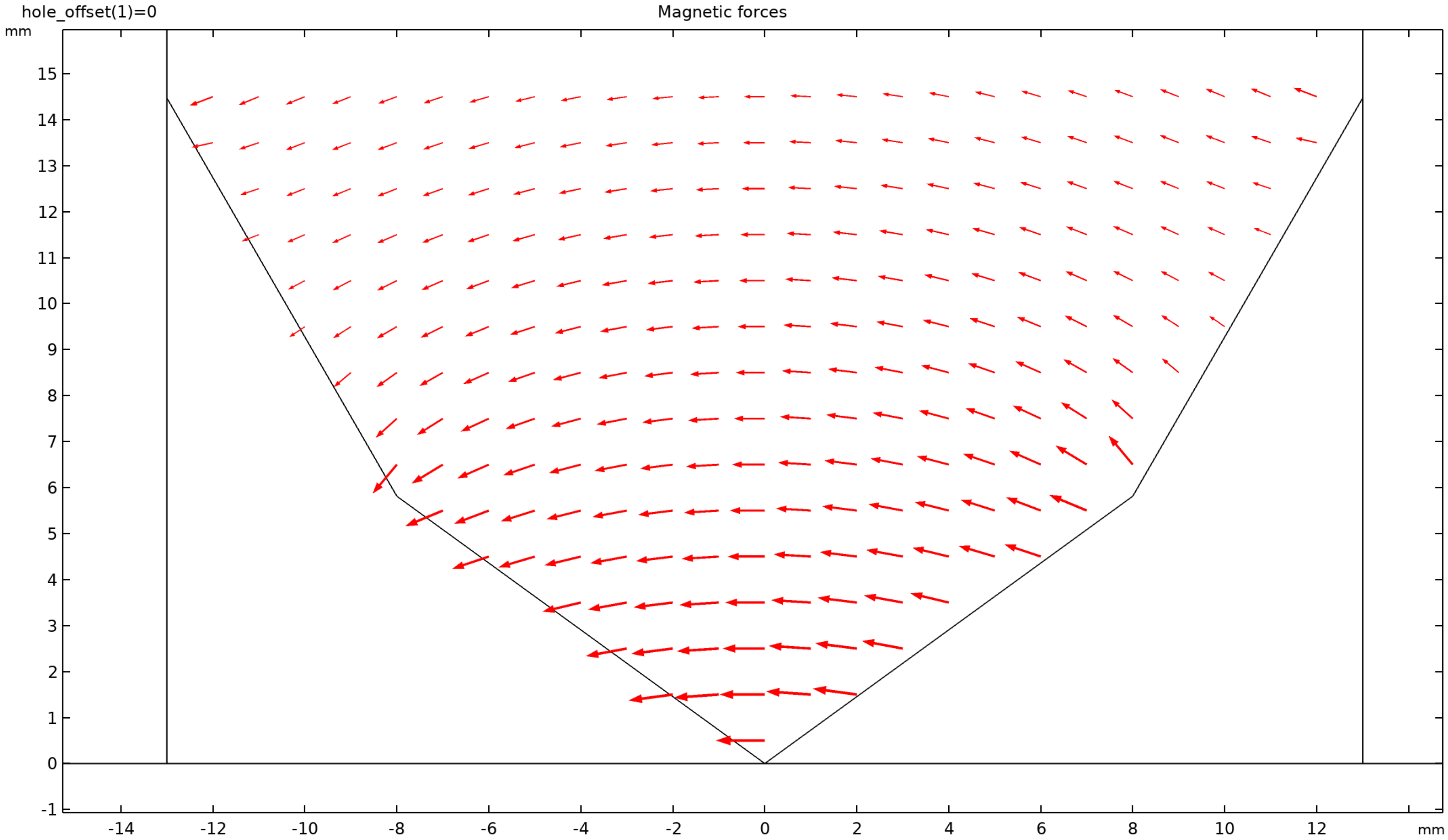


Hole offset study

- Centred hole → hole field mostly vertical
- Resulting Lorenz force is directed sideways
- Offset varied by 10 mm from 0 to 90 mm,
- Direction of beam deflection plotted



Hole offset vs Lorenz force



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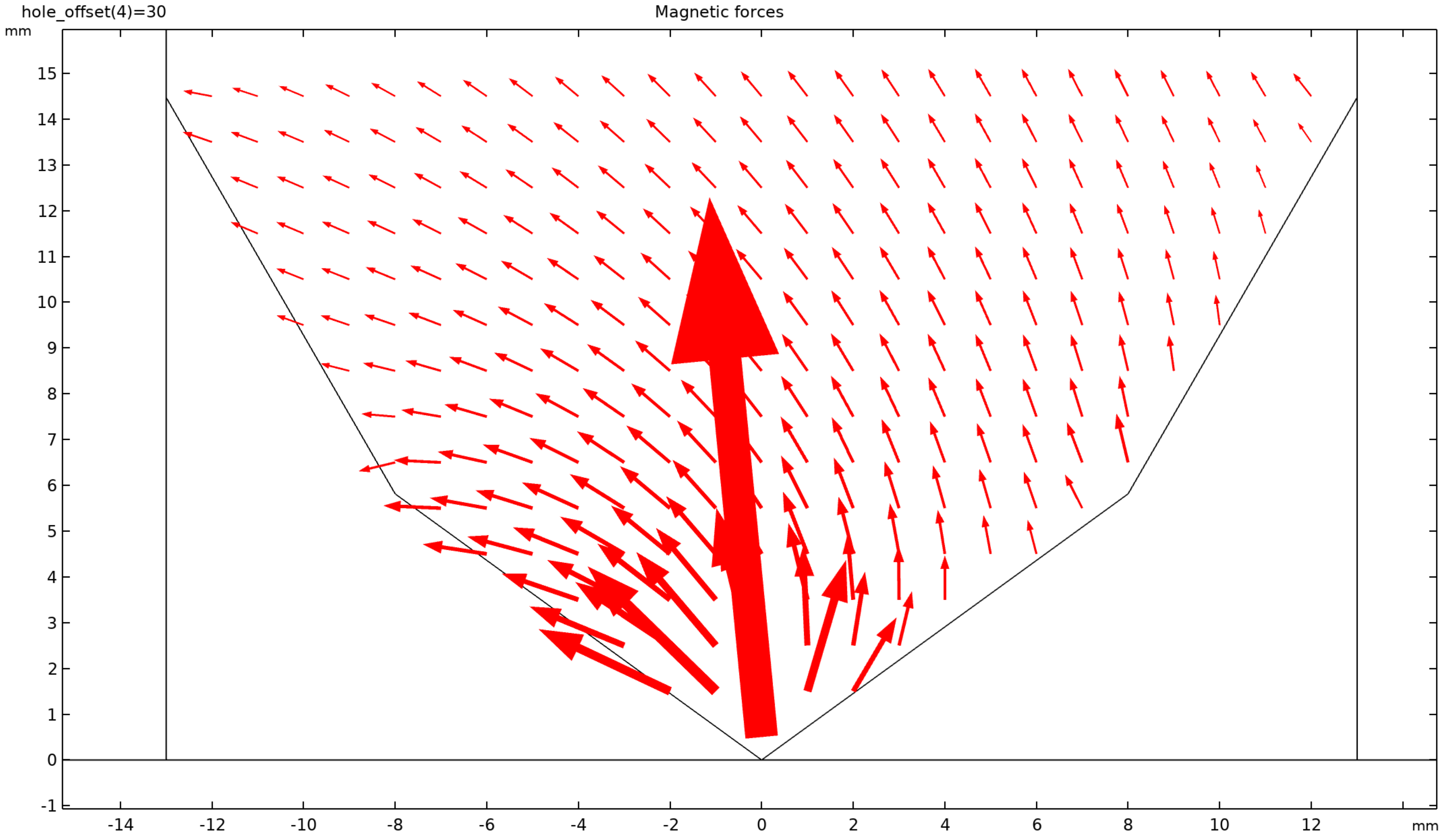

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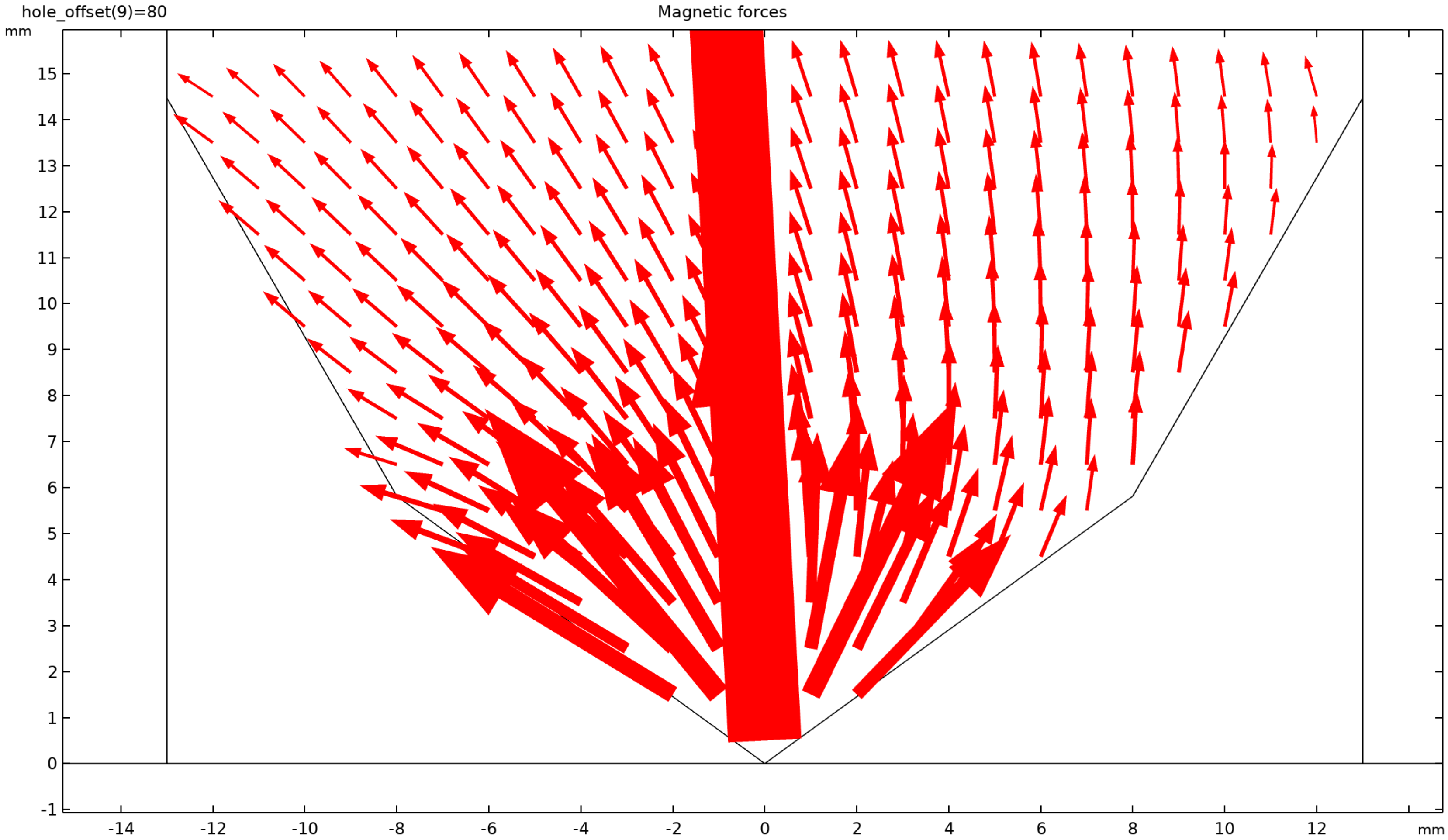
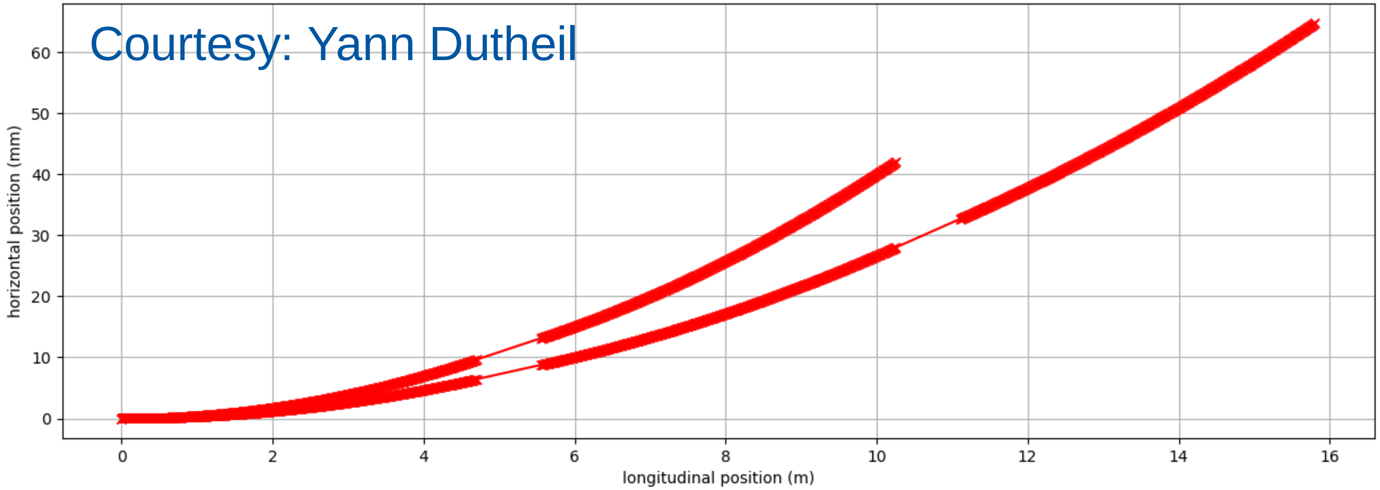


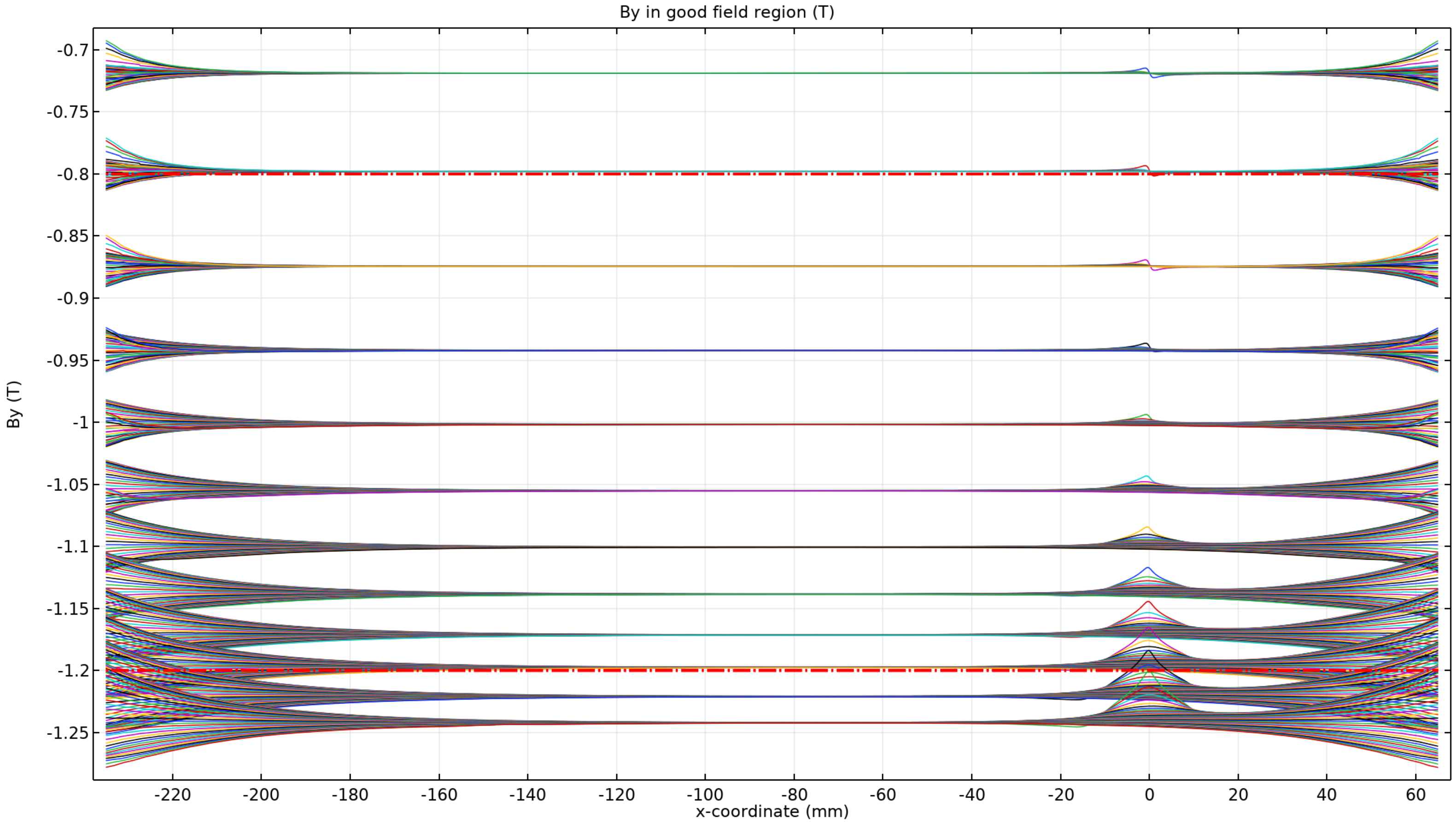
Increased field operation

- Proposed by Yann Dutheil (TE-ABT) for the BDF operation (no split)
- Field increased to 150 % gives same deflection angle at reduced offset (reducing the required pole width).



Increased field operation

- Around 1.8x current needed for 1.5x field



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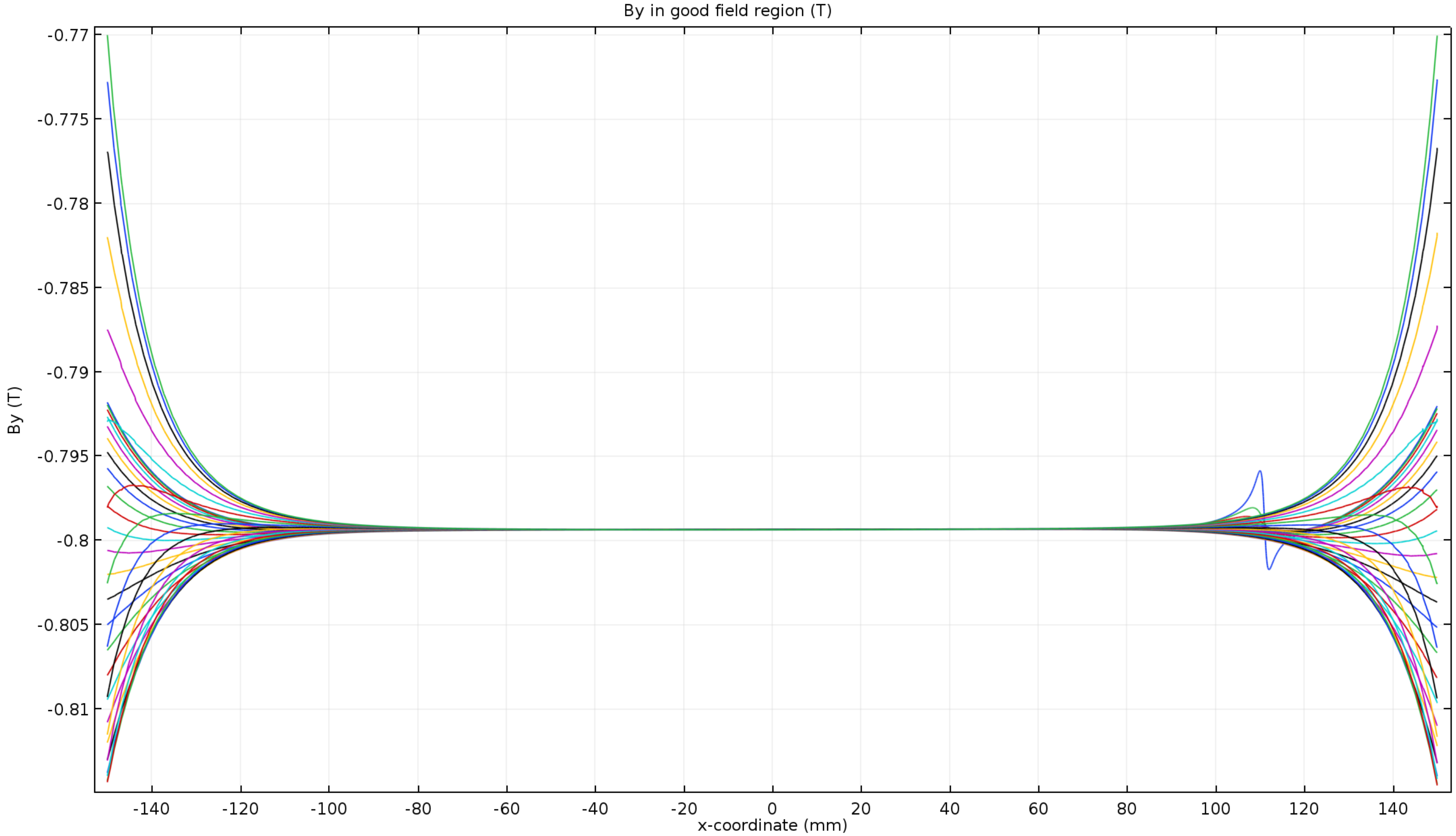
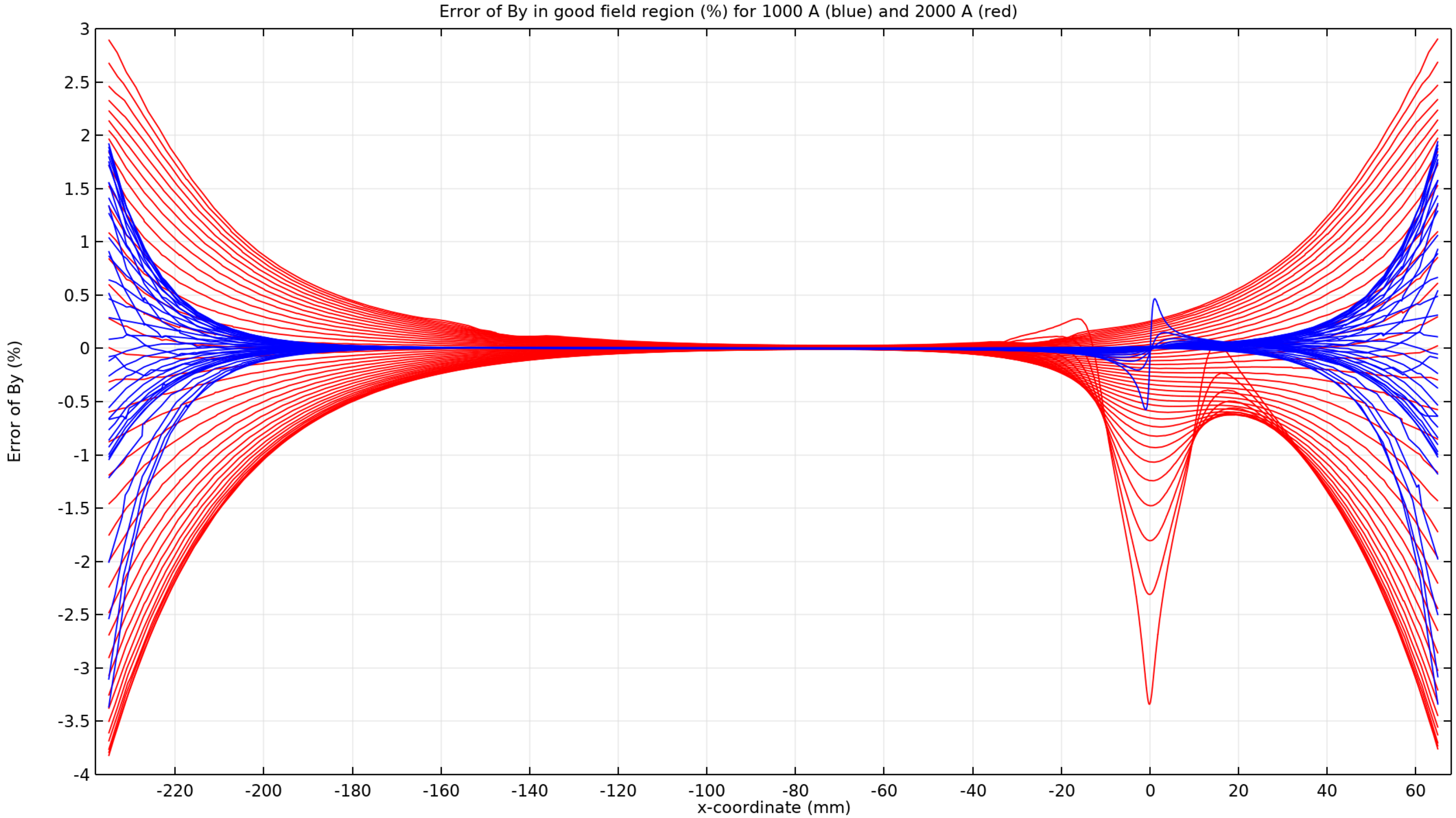


Increased field operation

- Field quality for offset hole



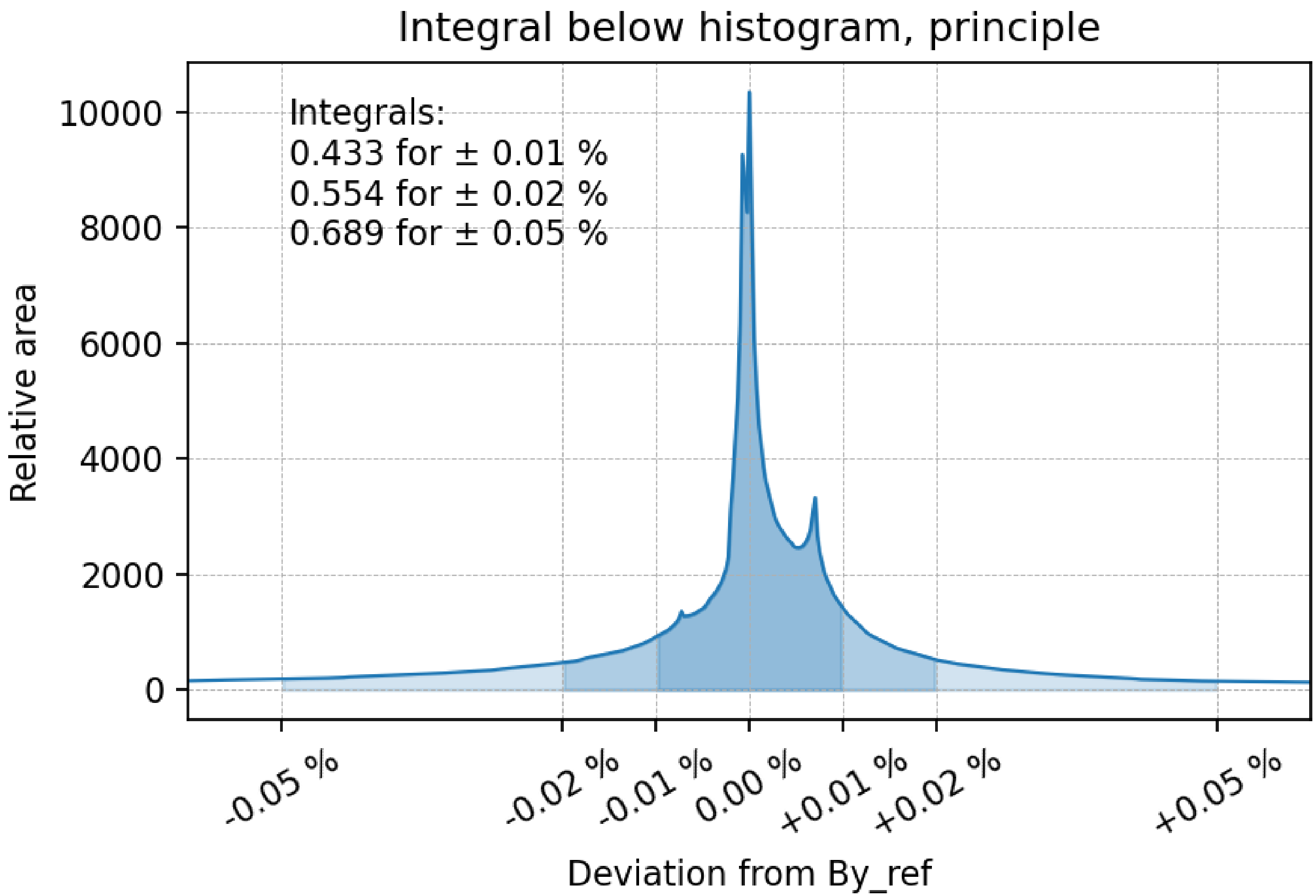
Increased field operation

- Even though the field quality is much worse than for nominal current operation, particle tracing results showed that it is acceptable from the beam optics point of view.
- Increased current operation to be used only for BDF operation, so stray field in the septum hole is not a concern.

Pole shims optimisation

- Assuming 295 mm pole width, a parametric study of shims widths and heights was run.
- Histogram of the By values in the gap prepared as a way to assess field quality
- Integrals of the histogram for various deviation ranges around the mean value were evaluated.

Pole shims optimisation



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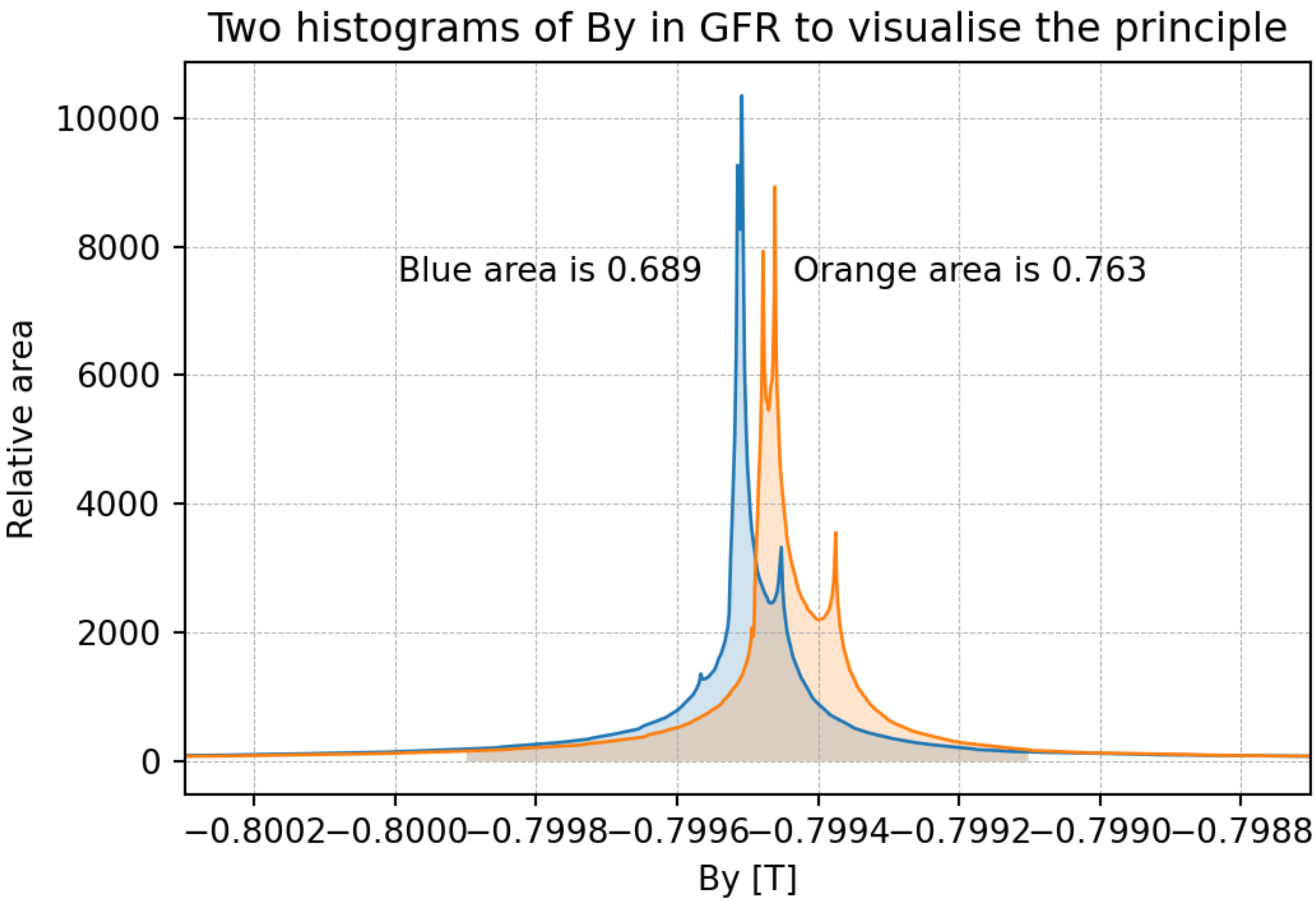

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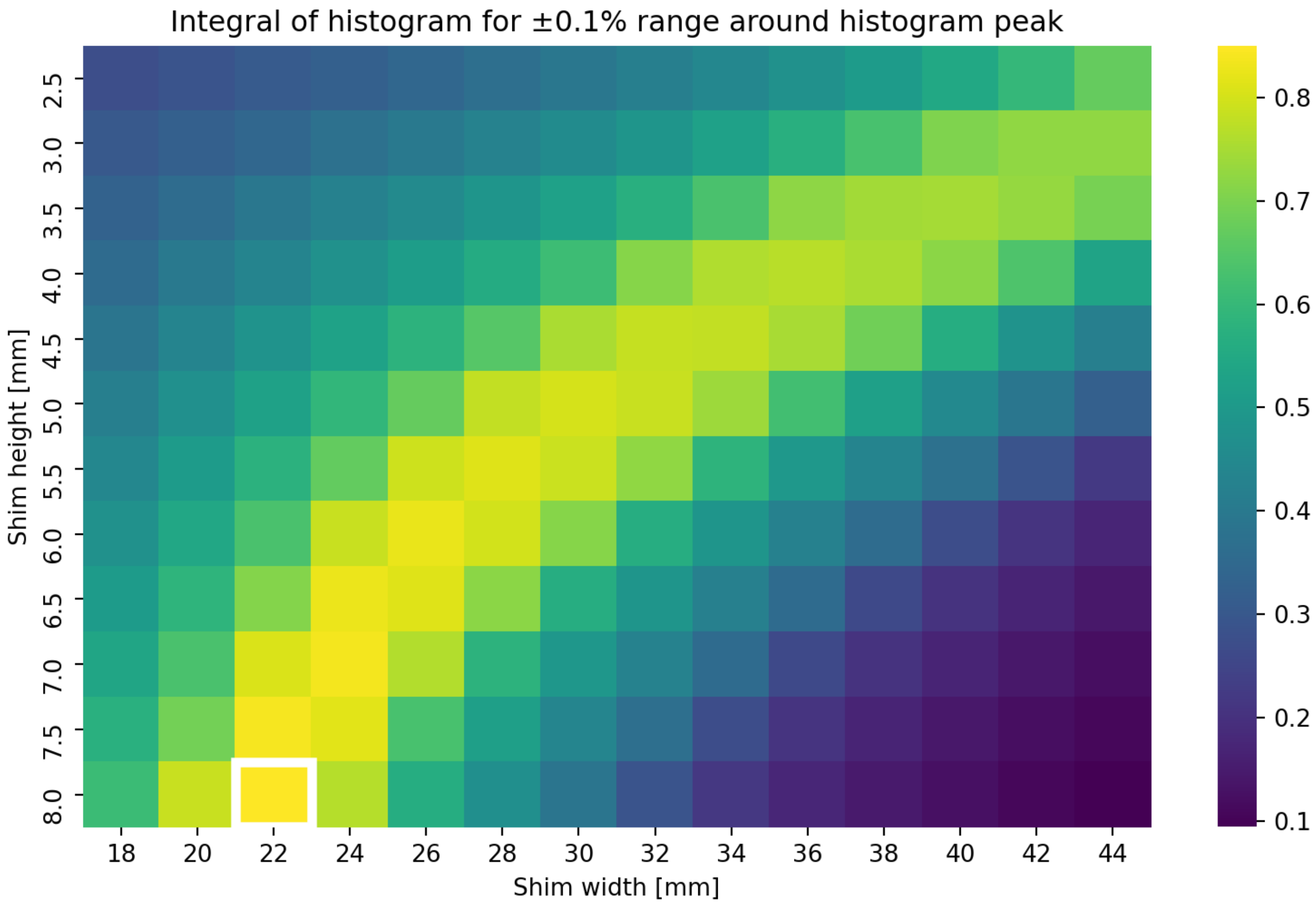

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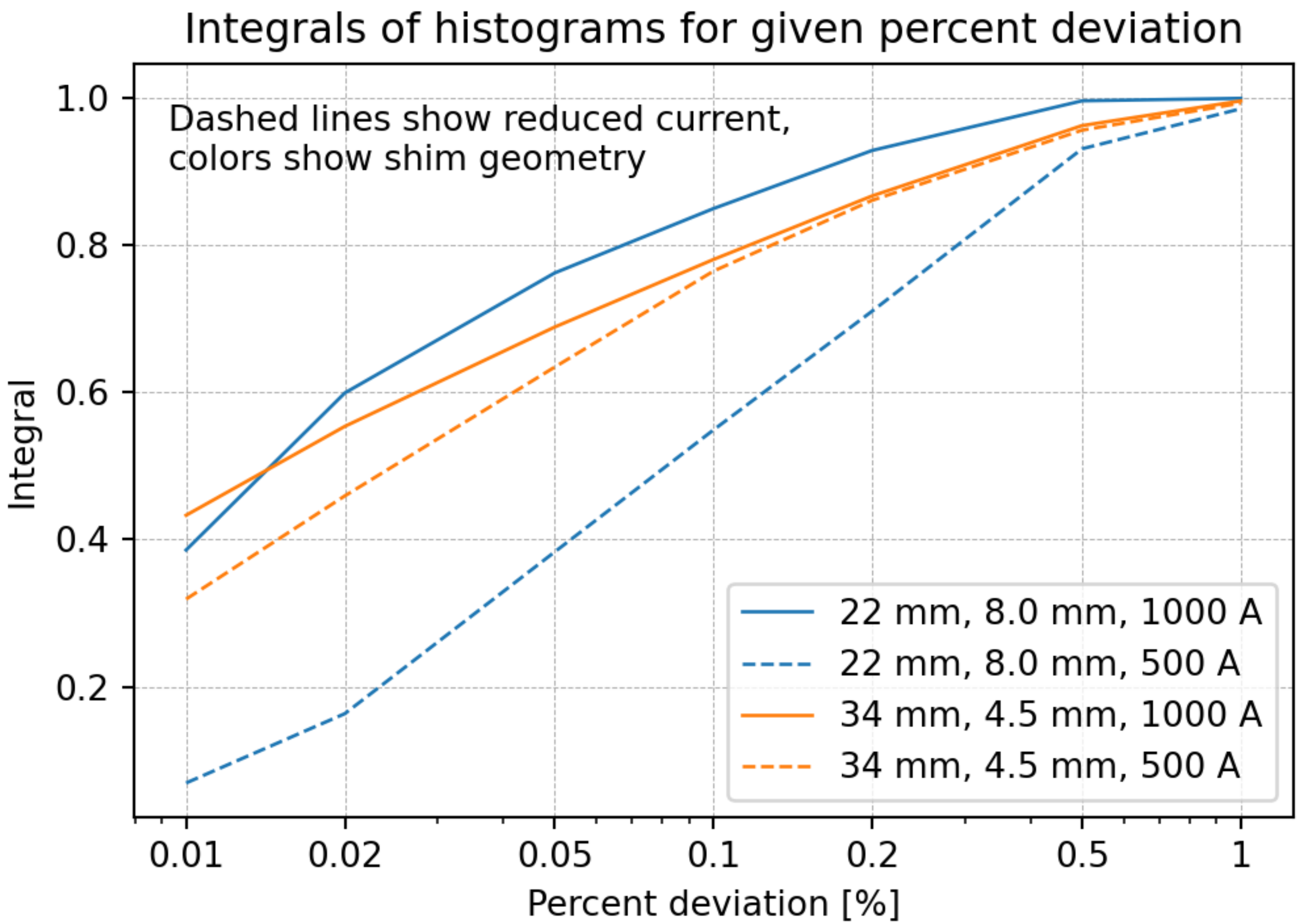
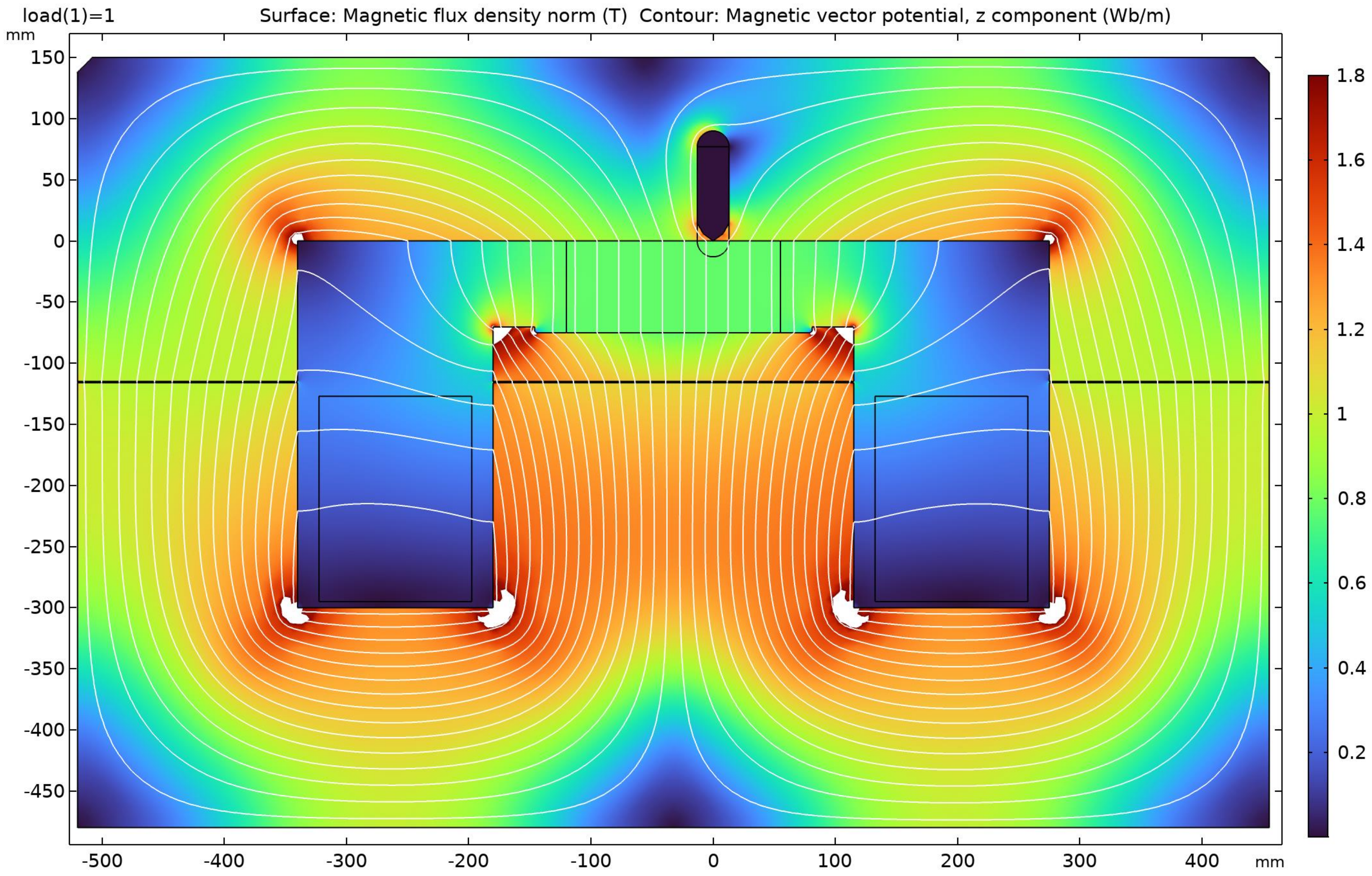


Final proposed design

- Pole width reduced to 295 mm
- Hole offset by 32.5 mm
- Side and bottom legs widened to 180 mm
- Top legs narrowed to 150 mm
- Coil window width increased to 171 mm
- Shims at 34 mm x 4.5 mm (W x H)
- Iron mass reduced from 21.4 t to 19.4 t

Final proposed design



Future developments

- Detailed magnetic design, fixing the design
  - Magnetic simulations taking mechanical features into account
- Electrical parameters, detailed coil design
- Detailed mechanical design
- Vacuum tests of steel and coatings
- Prototype construction

Acknowledgements

- Jérémie Bauche
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- Other people involved
  - Matthew Fraser, Pablo Andreas Arrutia Sota
  - Chiara Pasquino, Jose Antonio Ferreira Somoza
  - Jan Borburgh, Bruno Balhan, Miroslav Atanasov
  - TE-VSC-SCC

References

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