An optical matching device for the undulator-based ILC positron source

Development status of a pulsed solenoid (and a plasma lens)

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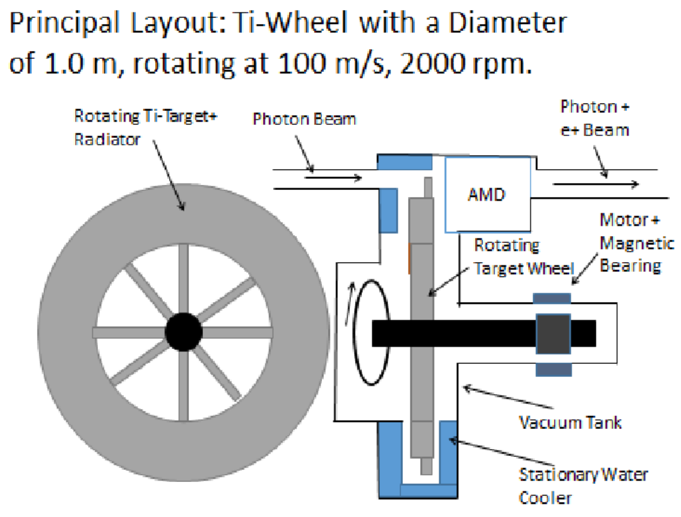
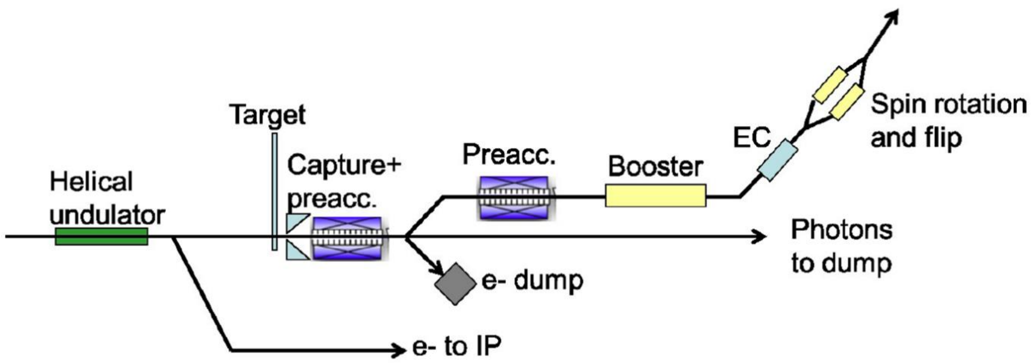
ILC undulator-based positron source

Introduction to layout and technical challenges

- Fast rotating target wheel
- 1ms-positron pulse duration
- OMD for positron capturing
  - Flux concentrator
    - *Focus variation during long pulses*
  - Quarter-wave transformer
    - *Limited yield*



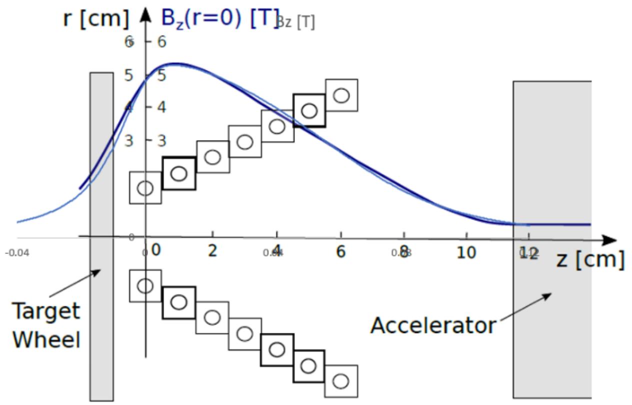


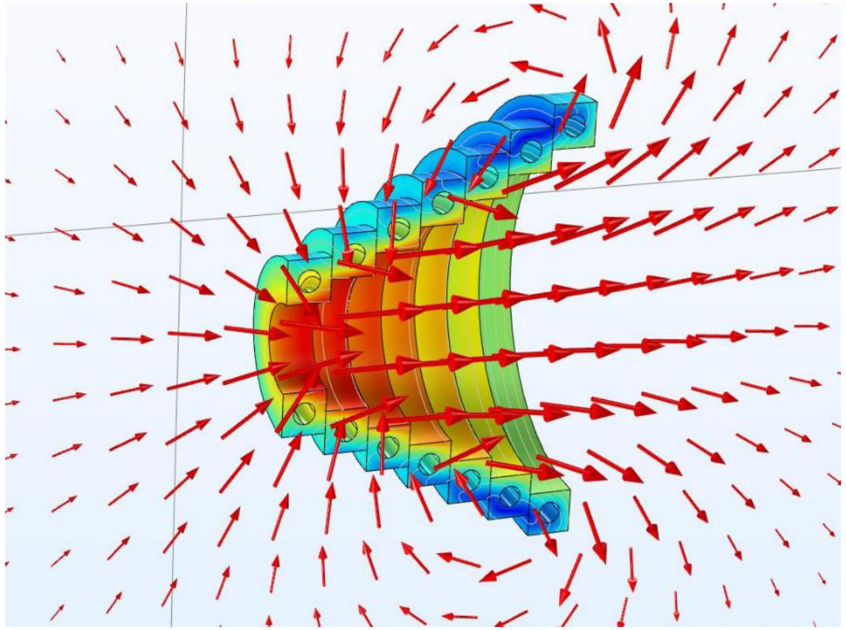
- "New" approach: Pulsed solenoid
  - Stable and reproducible focus
  - High magnetic flux density
  - Compatible with long pulse duration
  - Manageable heat load in solenoid
  - Manageable heat load on target (!?)

Pulsed solenoid for positron focusing

Background and previous work

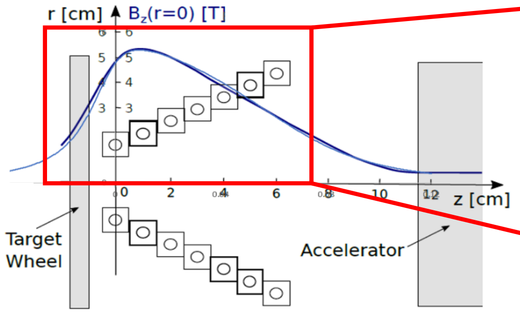
- Pulsed solenoid was e.g. used at LEP
- Constant, small coil winding cross-section for uniform current density
- Pulsed to reduce power/thermal load
- Potentially higher yield (!?)
- Prel. parameters:
  - ~50 kA peak current
  - 4 ms half-sine pulse + 1ms flat-top
  - 7 turns, linear taper (20mm → 80mm)
  - Peak field ~5 T
  - Average heat load on target: 73 W + 711 W
  - Peak force on wheel 612 N

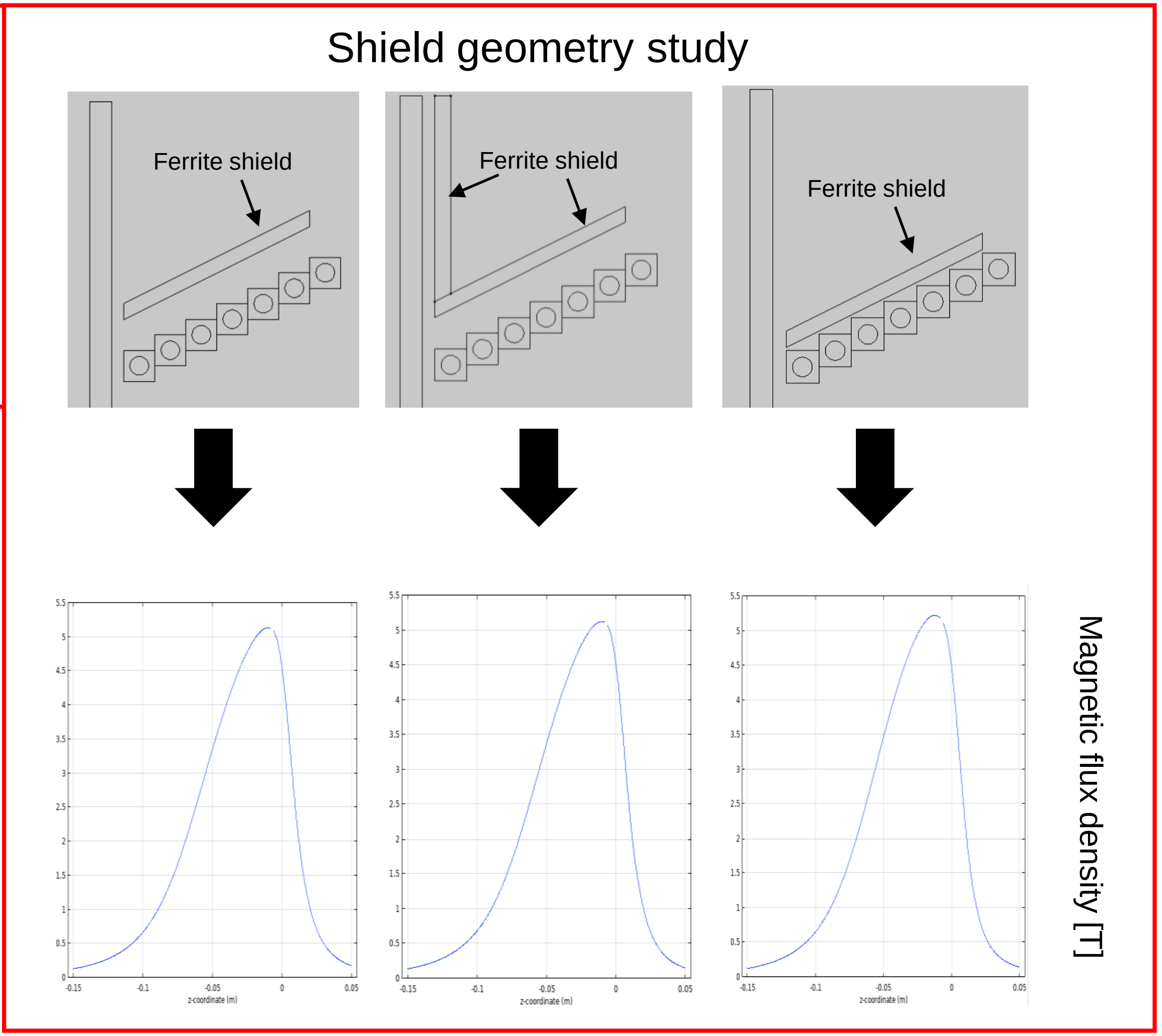




Ferrite shielding

Concentration of field in solenoid

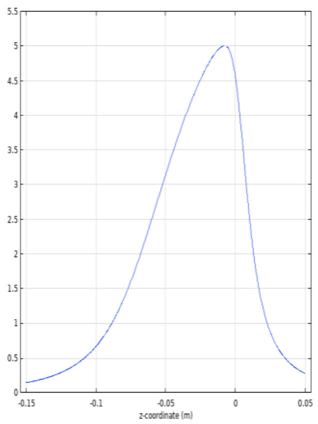




▶ Ferrite shield plates around solenoid

▶ Increase of magnetic flux density <10% (peak)

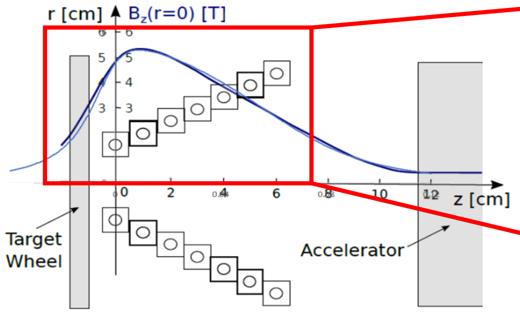
▶ Shielding material:
Alloy Powder Core Ferrite H 150000 Mu (Comsol)

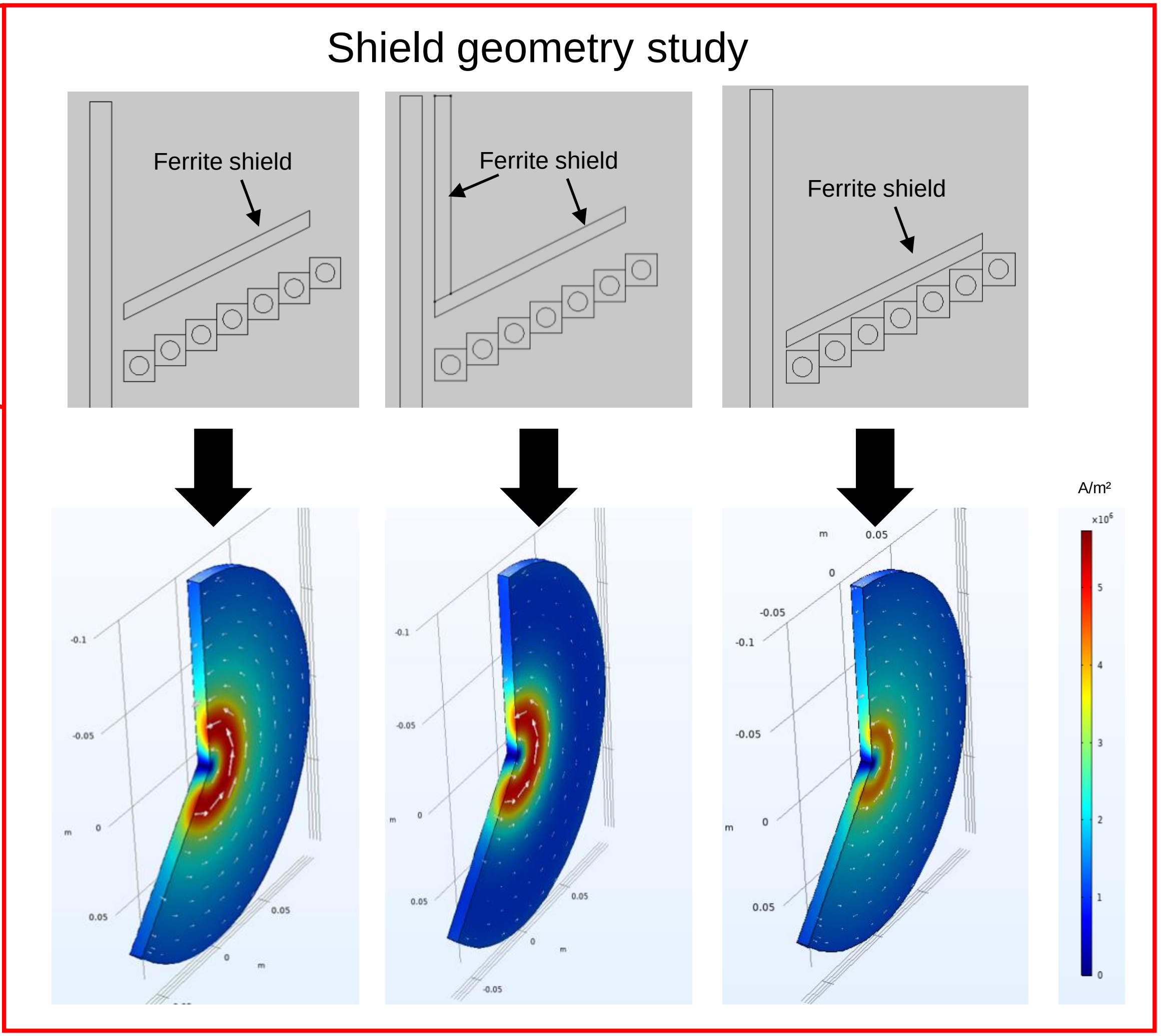


Magnetic flux density [T] without shield

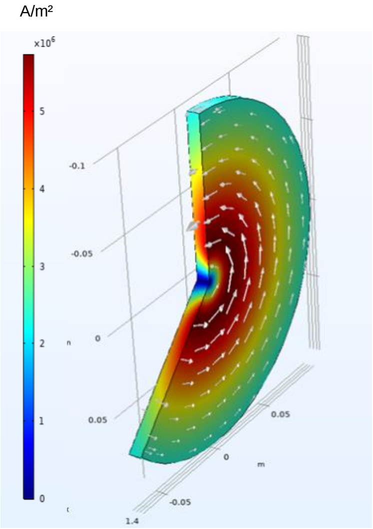
Ferrite shielding

Shielding of field from target wheel





- ▶ Field on target → eddy currents → heating of target wheel
- ▶ Reduction peak field on target by ~10%
- ▶ Reduction of target area with magnetic field by collar shield

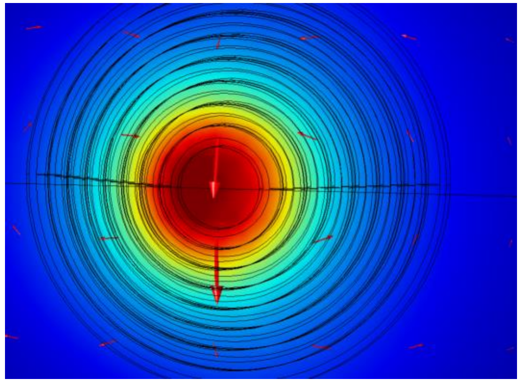


Eddy current density without shield

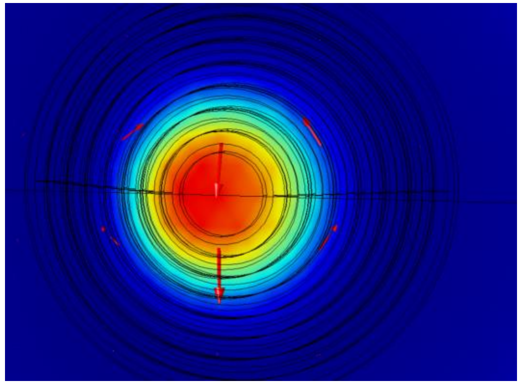
Ferrite shielding

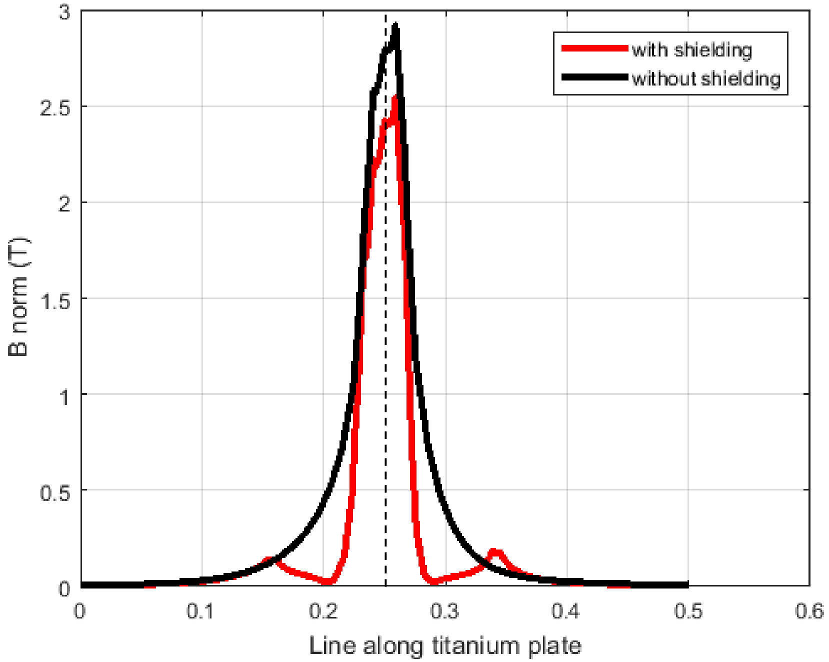
Heating of titanium wheel

Without shielding



With shielding





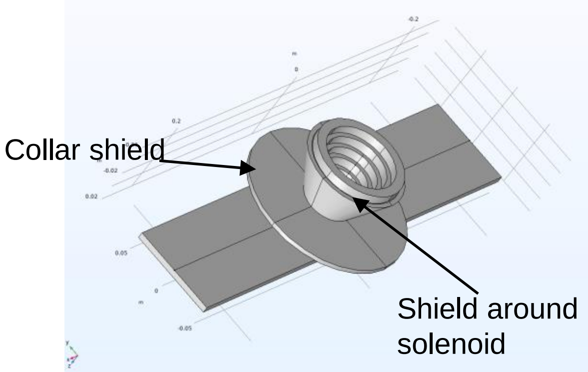
Magnetic flux density B(z) on titanium shield [T]

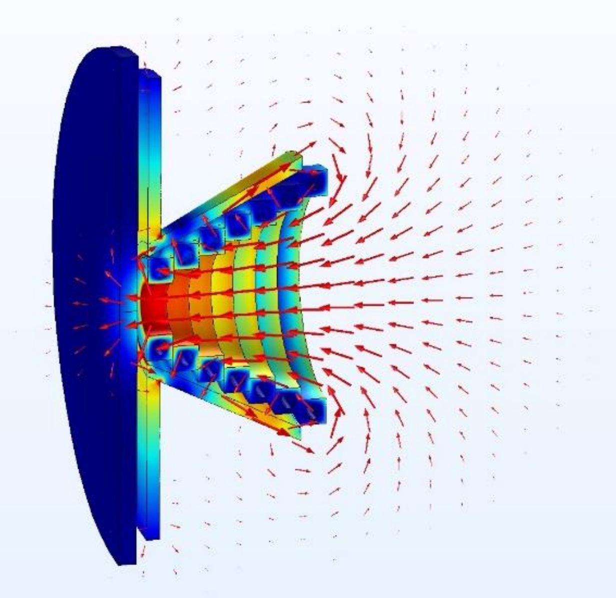
- Reduction of induced heat 73W + 711W → 31W + 298W
- Reduction of peak force on target 612N → 263N
- Mag. flux “wings” due to finite width of collar shield
- Slight field drag (by target movement)
- → Further optimisation along with mechanical design

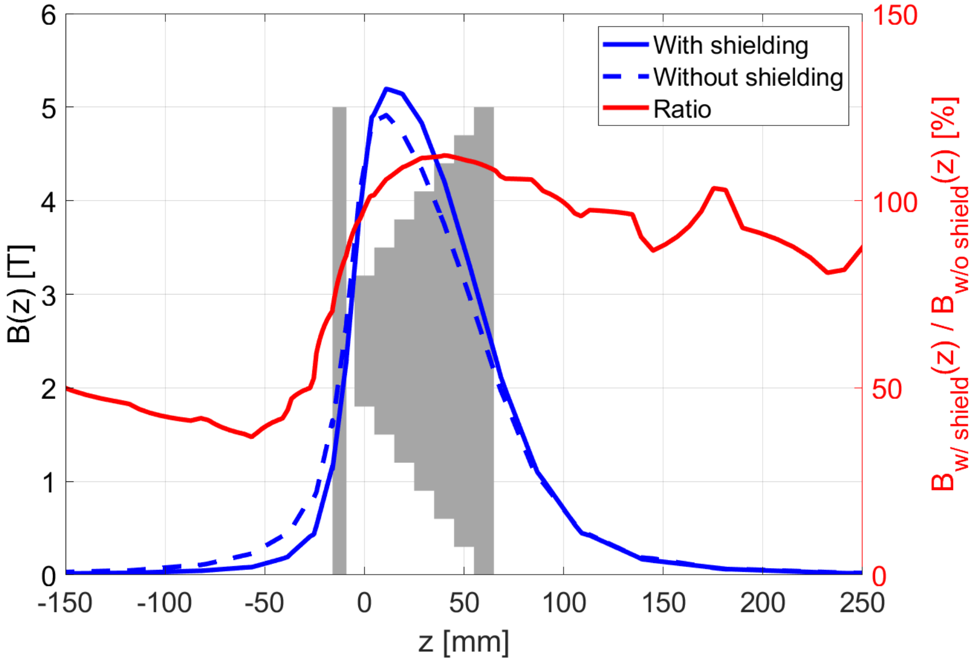
Ferrite shielding

Summary

- ▶2D & 3D simulation in Comsol
- ▶Movement of titanium plate included (100m/s)
- ▶Peak solenoid current: 46886 A
- ▶Combined shield geometry model: coild shield w/ min. distance to shielding (~1mm) + collar shield
- ▶→ reduction of force & heat load on target
- ▶→ Increase of peak B(z) ~10%



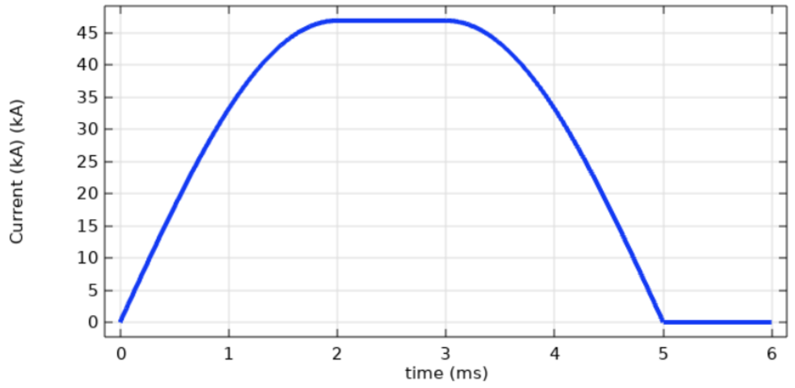


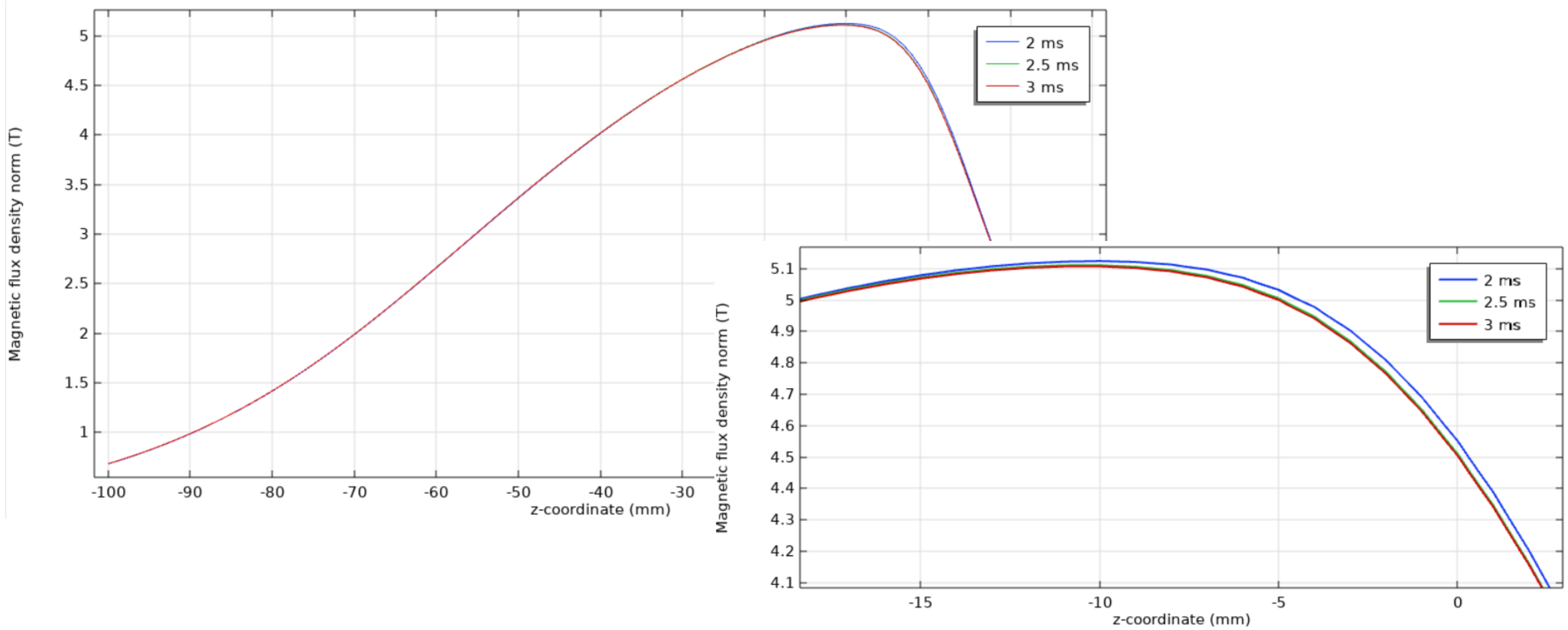


Magnetic field stability

Variation of magnetic field during flat-top current

- ▶ Transient current distribution subject to skin-effect
- ▶ Skin depth @125 Hz ~6 mm → current distribution should be stable
- ▶ < 1% deviation of field simulated





Yield simulations: summary

Brief overview of simulations target → damping ring

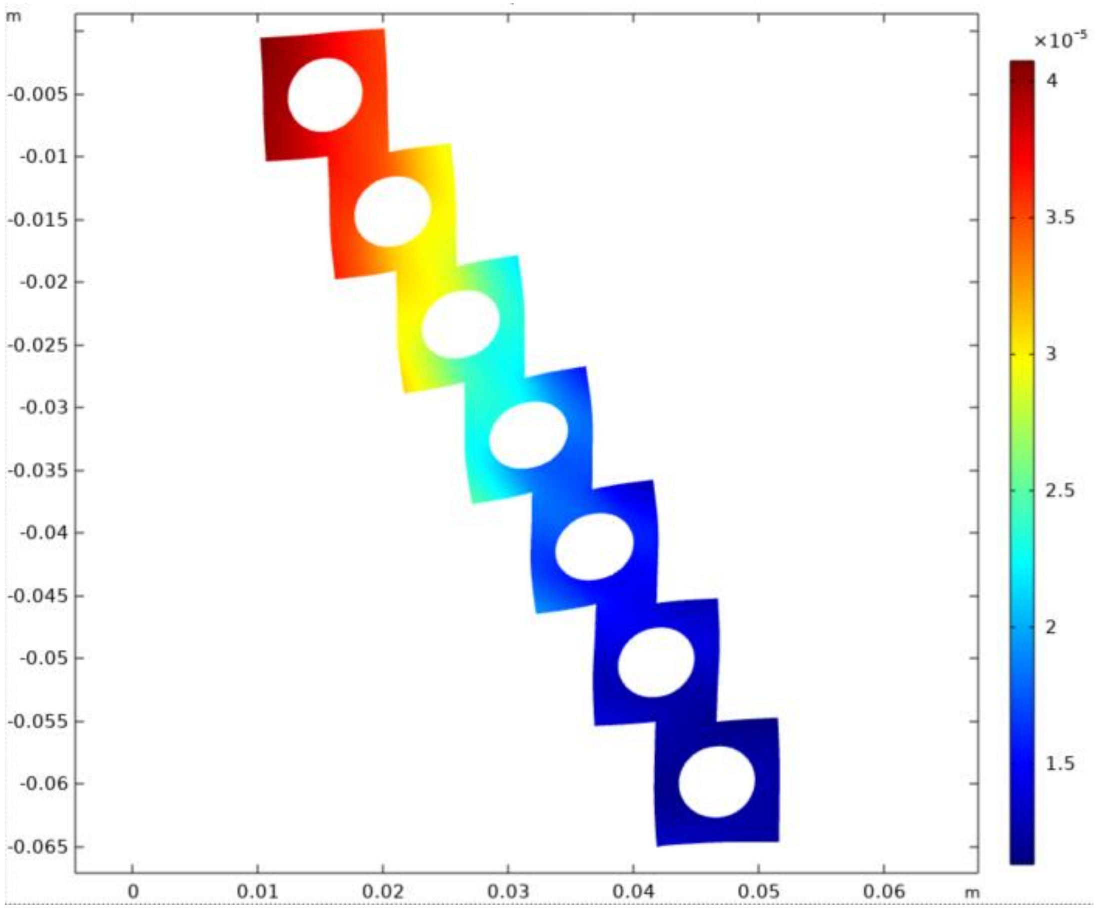
- Yield of undulator-based positron source w/ solenoid matching device simulated
- Significant yield improvement to QWT
- Possible trade-off: target heatload ↔ yield
- Further optimisation maybe possible

	Beamloss Power				Positron Yield	
	@dogleg	**@booster**	**@EC**	**@DR**	**@capture (|Z|<7mm)**	**@DR**
QWT	0.677 kW	0.014 kW	4.01 kW - 5.56 kW	13.15 kW - 14.3 kW	1.07	**~1.1**
Pulse solenoid w/o shield	0.927 kW	0.055 kW	5.86 kW - 7.93 kW	17.39 kW - 16.01 kW	1.81	**1.91**
Pulse solenoid with shield	0.871 kW	0.064 kW	5.58 kW - 7.90 kW	17.73 kW - 16.24 kW	1.64	**1.74**

Coil stress

Dynamic deformation w/o support & heat load

- Max. peak von-Mises stress ~146 Mpa
  - Soft Cu tensile strength ~200MPa
- Average power dissipation in Cu coil: ~11.5 kW

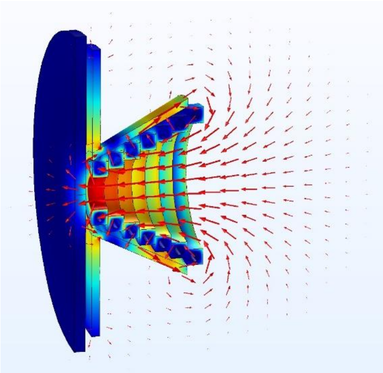


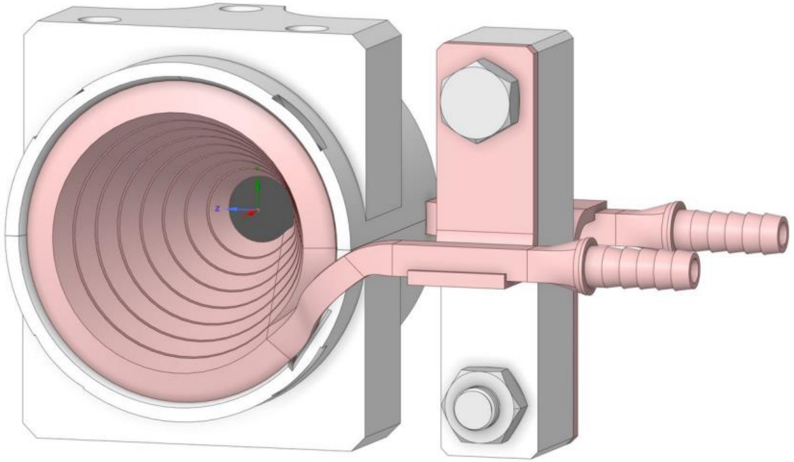
Prototype manufacturing

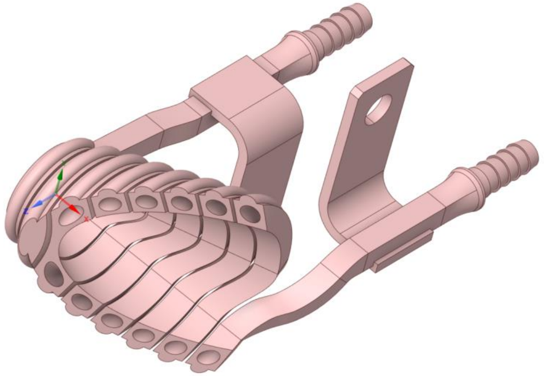
Mechanical design of main in-vacuum components

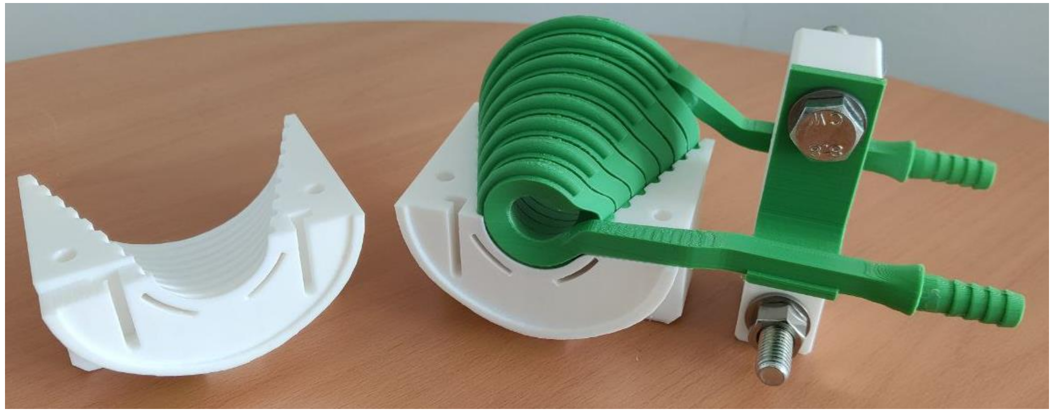
- Solenoid coil
  - 7 canted, tapered windings
  - Conductor cooled from inside
  - Mechanical stability through supporting “rim”

- Ceramic enclosure to support and insulate coil
- Magnetic shielding at solenoid entrance aperture
  - Outer shielding currently sacrificed for less complexity
  - Main shielding to target unaffected





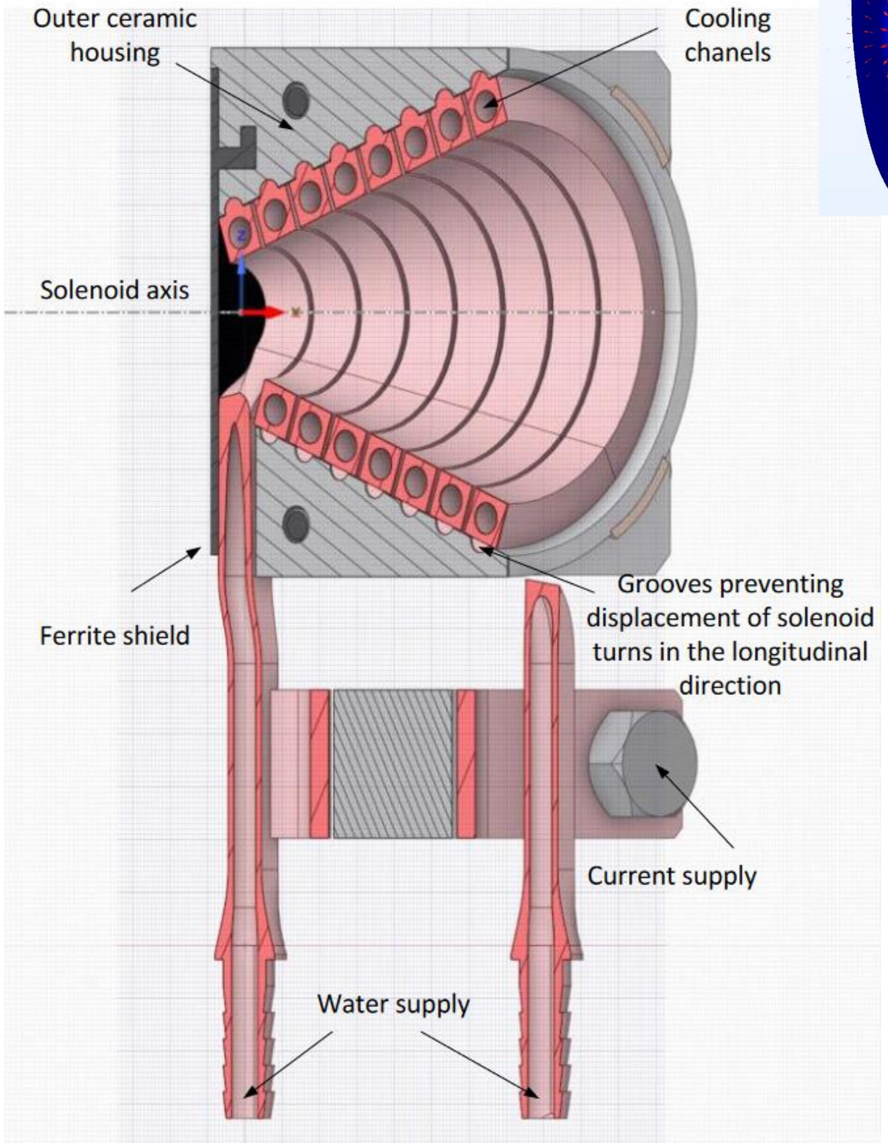


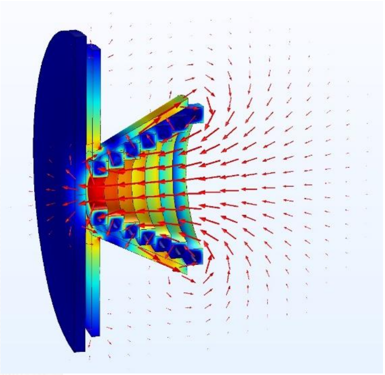


Prototype manufacturing

Mechanical design of main in-vacuum components

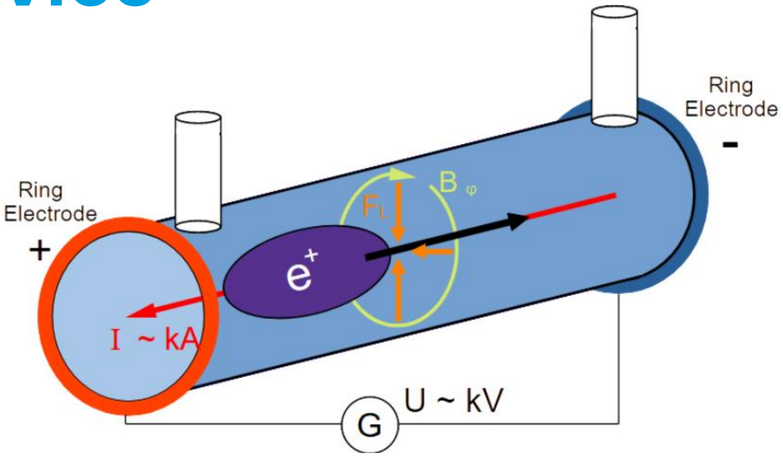
- ▶Simulation of prototype to be done
- ▶2nd prototype foreseen
  - ▶Optimised geometry for field homogeneity
  - ▶Materials and mechanical stability optimisation with 1st prototype
- ▶3D-printing of coil (and possibly ceramic)
- ▶Alumina ceramic, SiN if higher stability required



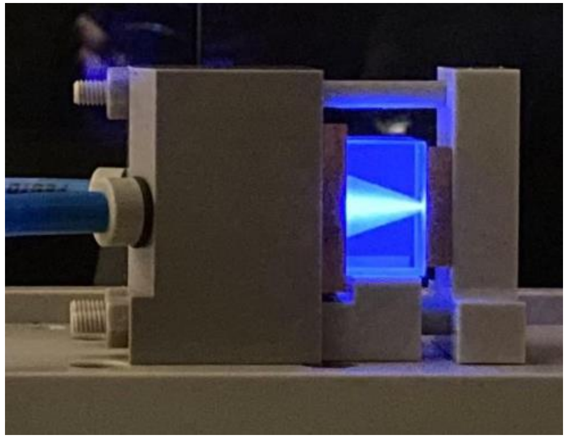


(Active) Plasma lens as optical matching device

Ongoing development of tapered, large aperture, active plasma lens

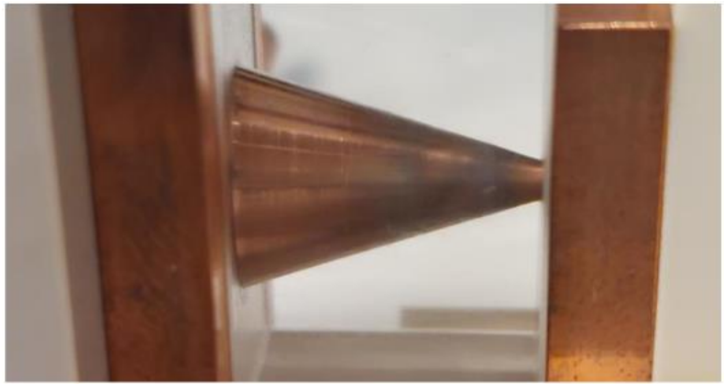


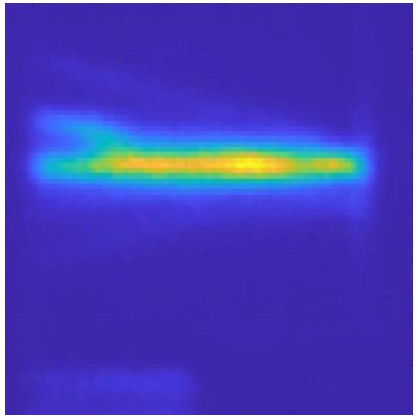
- Active plasma lens allows strong focusing forces
- In simulations superior to QWT
- Several requirements not yet investigated
  - MHz repetition rate
  - Millisecond macro pulse length
  - Operation close to cavity (gas load..)
  - Strong taper (d ≈ L)



- Scaled-down prototype built
- Transverse plasma instabilities & electrode erosion observed

→ Fundamental questions now being addressed





Summary & Outlook

Status and next steps for solenoid and plasma lens

- No show stoppers for solenoid found so far
- Simulations now concentrating on design details
  - Magnetic field homogeneity
  - Distribution of mechanical forces

- Prototype mech. design finished, manufacturing starting
- Magnetic field diagnostics being set up
  - Field homogeneity
  - Field stability (skin effect..)

- Fundamental questions of plasma lens being addressed
  - Discharge stability
  - Repetition rate/pulse length limits

Thank you for your attention!

Contact

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