A tapered pulsed solenoid as optical matching device for the undulator-based ILC positron source

Overcoming limitations of positron focusing elements

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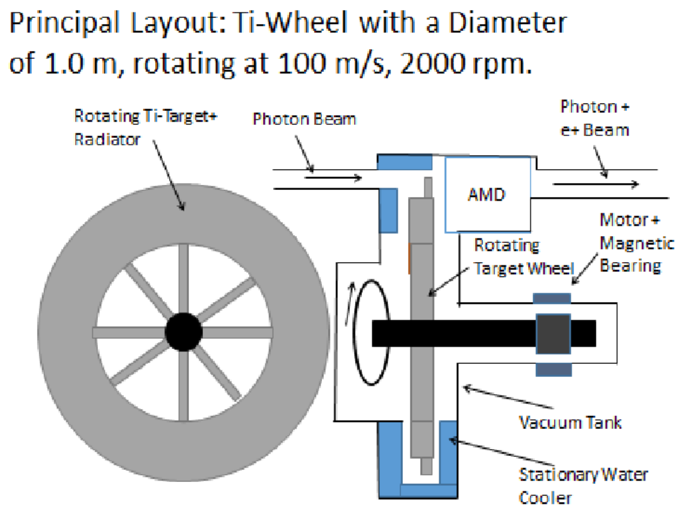
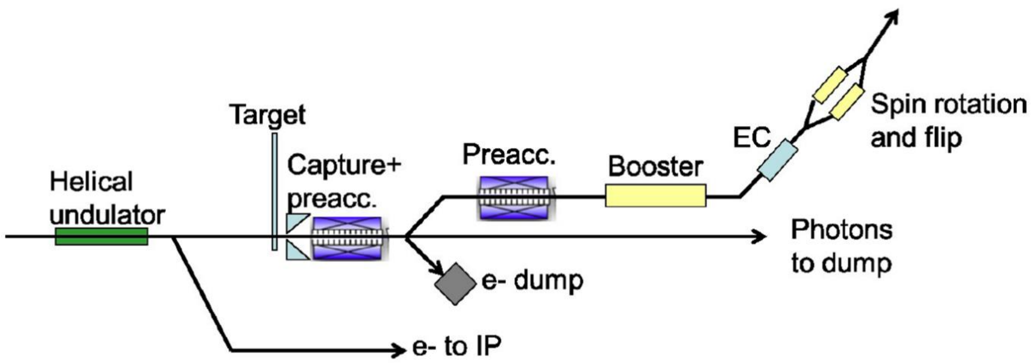
DESY.

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*



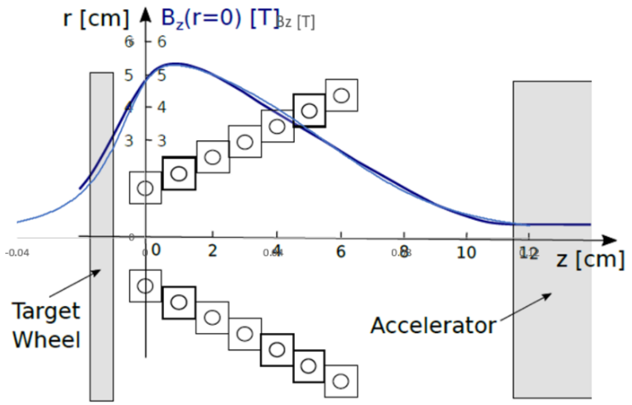


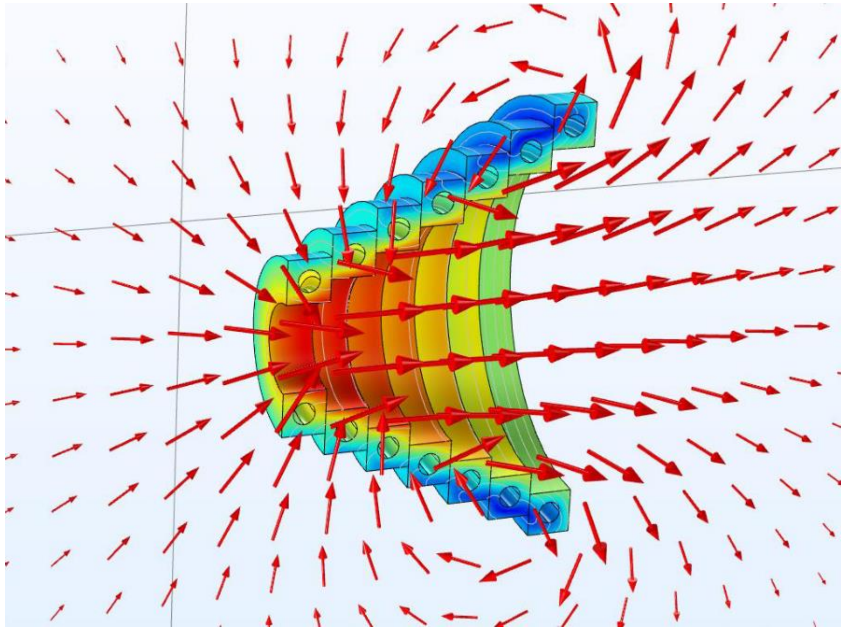
- New approach: Pulsed solenoid
  - Stable and reproducible focus
  - High magnetic flux density
  - Compatible with long pulse duration
  - Manageable heat load in solenoid
  - Manageable heat load on target (!?)

Pulsed solenoid for positron focusing

Background and previous work

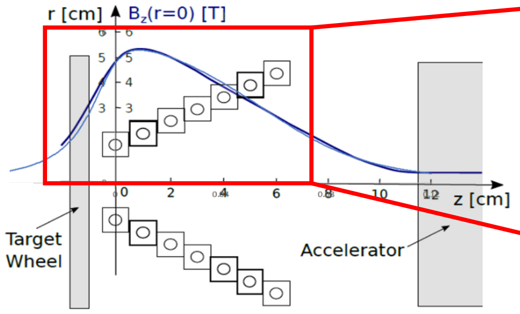
- Pulsed solenoid was e.g. used at LEP
- Constant, small coil winding cross-section for uniform current density
- Pulsed to reduce power/thermal load
- Potentially higher yield (!?)
- Prel. parameters:
  - ~50 kA peak current
  - 4 ms half-sine pulse + 1ms flat-top
  - 7 turns, linear taper (20mm → 80mm)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

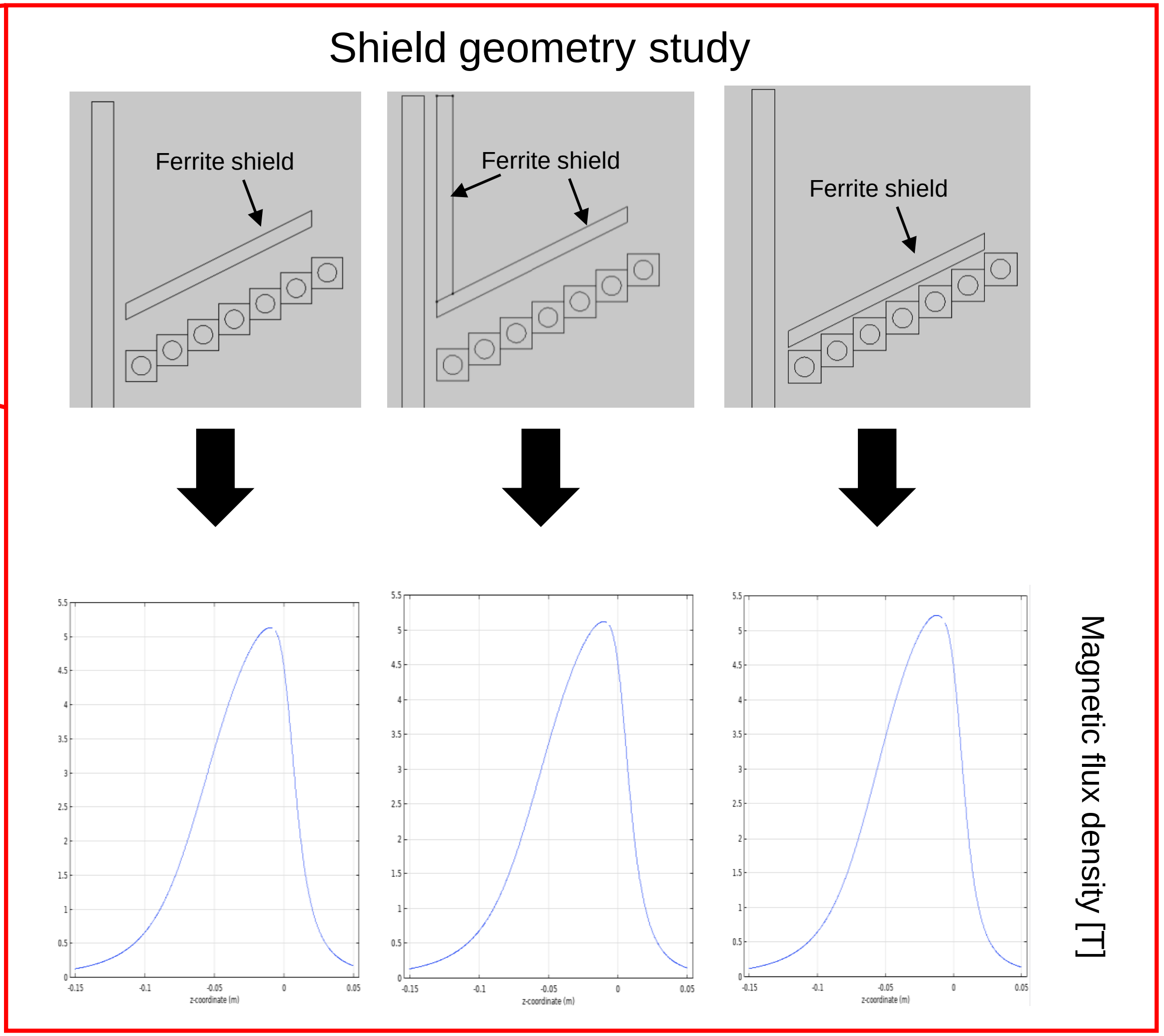




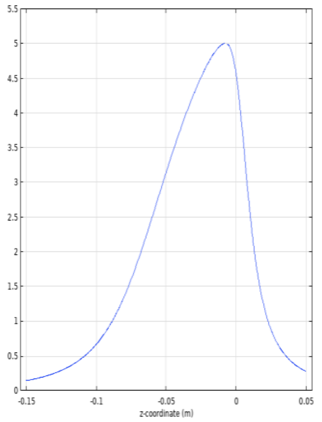
Ferrite shielding

Concentration of field in solenoid





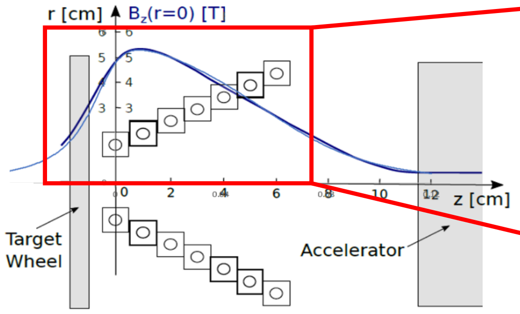
- ▶ Ferrite shield plates around solenoid
- ▶ Increase of magnetic flux density <10% (peak)
- ▶ Shielding material:
Alloy Powder Core Ferrite H 150000 Mu (Comsol)

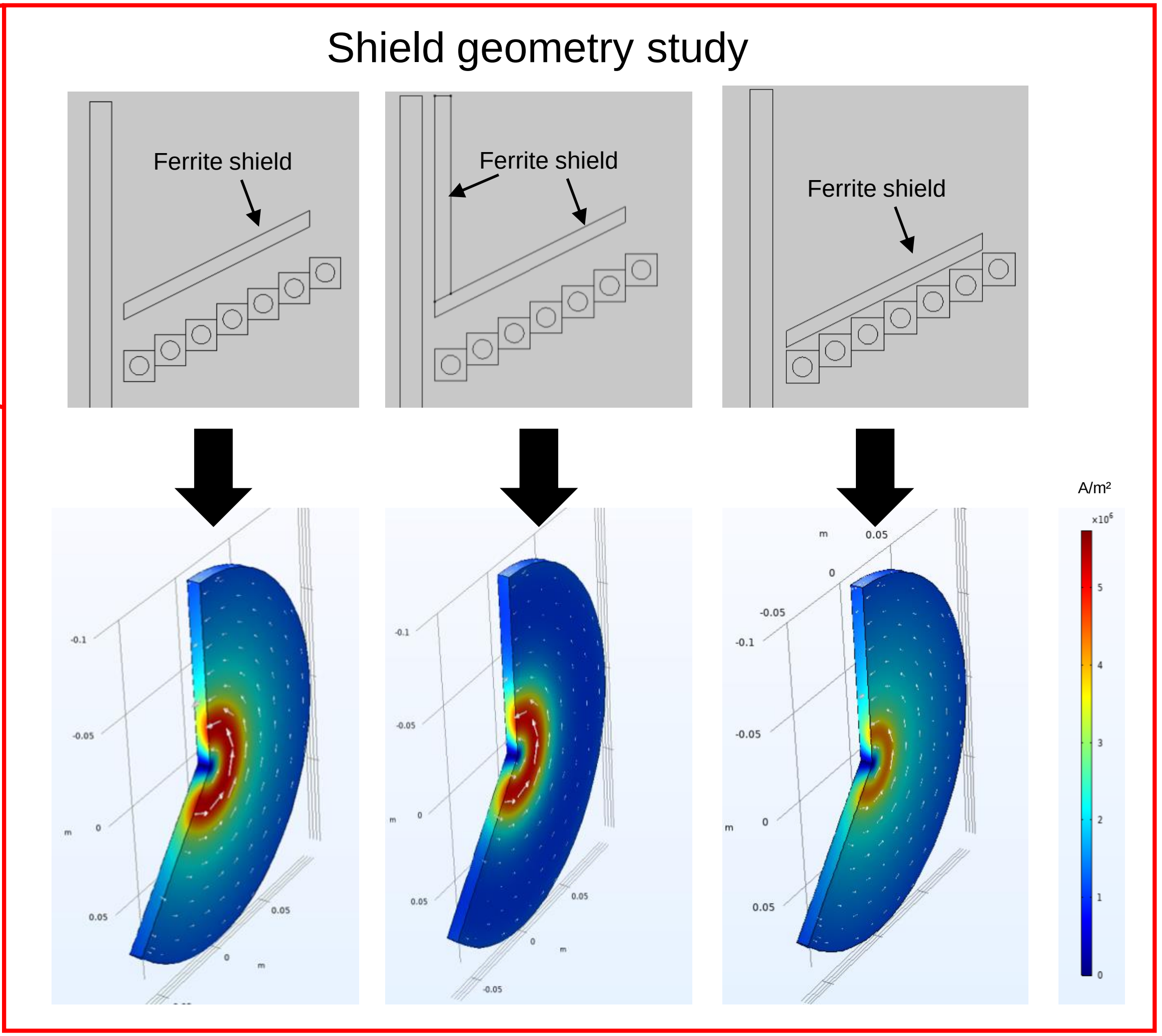


Magnetic flux density [T] without shield

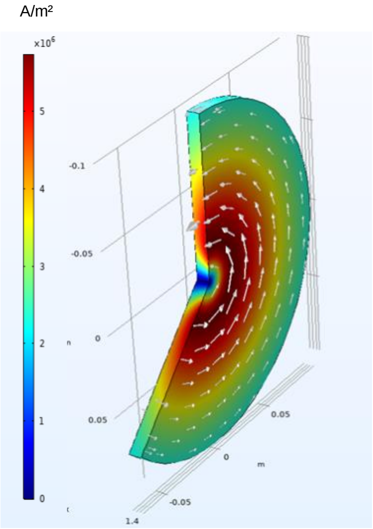
Ferrite shielding

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

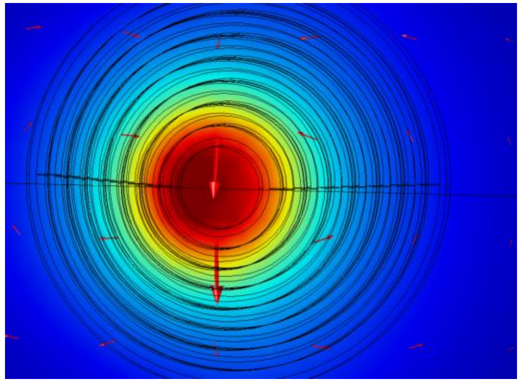


Eddy current density without shield

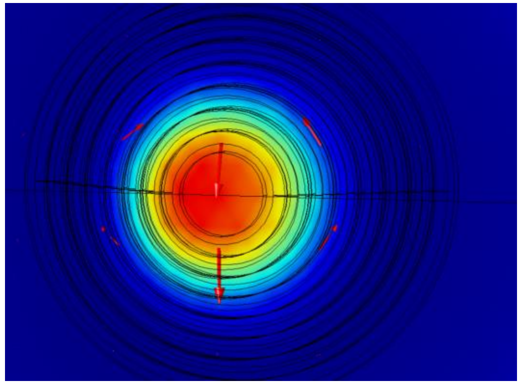
Ferrite shielding

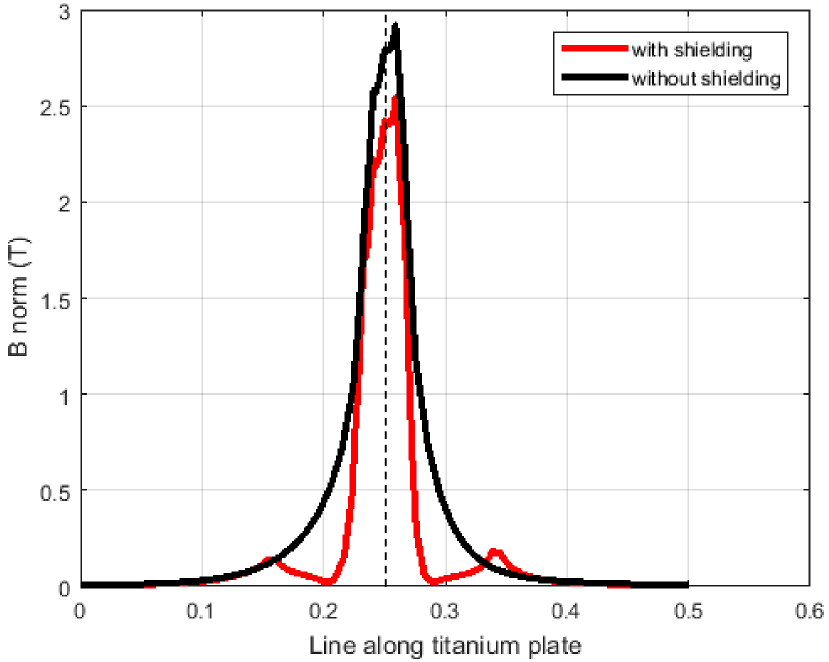
Heating of titanium wheel

Without shielding



With shielding





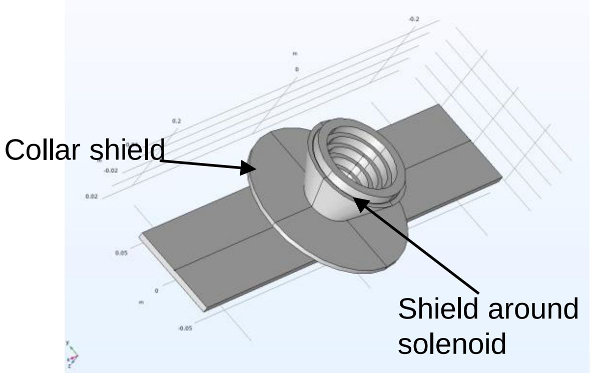
Magnetic flux density B(z) on titanium shield [T]

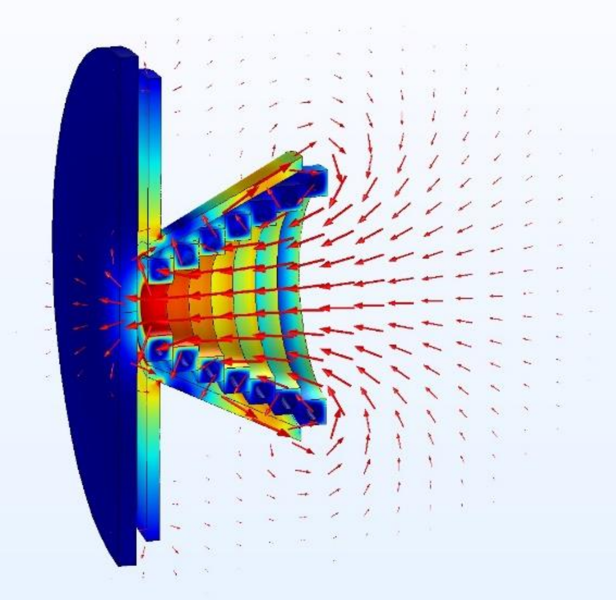
- Reduction of induced heat 73W + 711W → 31W + 298W
- Reduction of peak force on target 612N → 263N
- Mag. flux “wings” due to finite width of collar shield
- Slight field drag (by target movement)
- → Further optimisation along with mechanical design

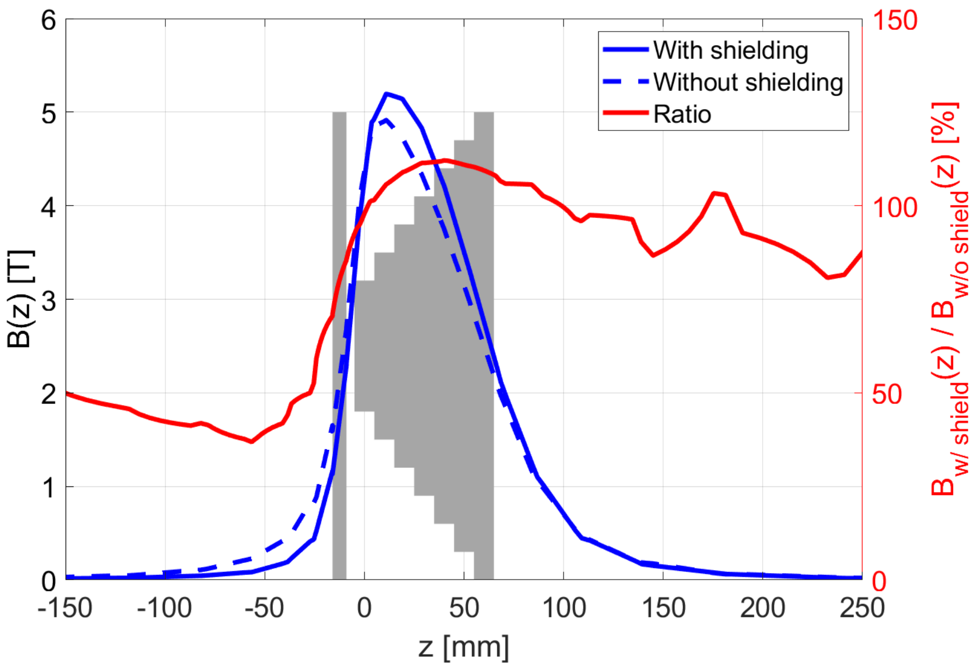
Ferrite shielding

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%



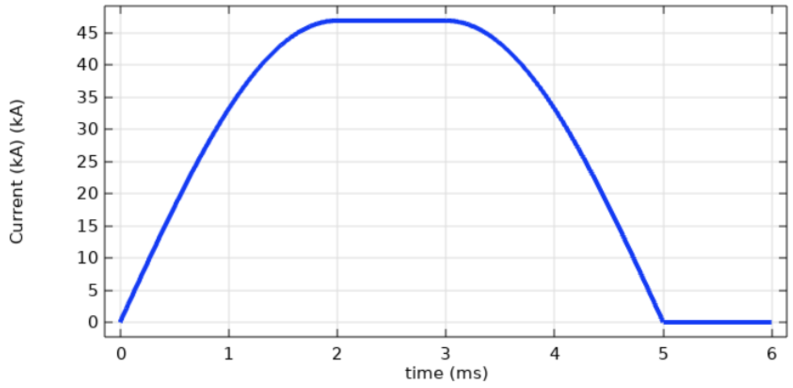


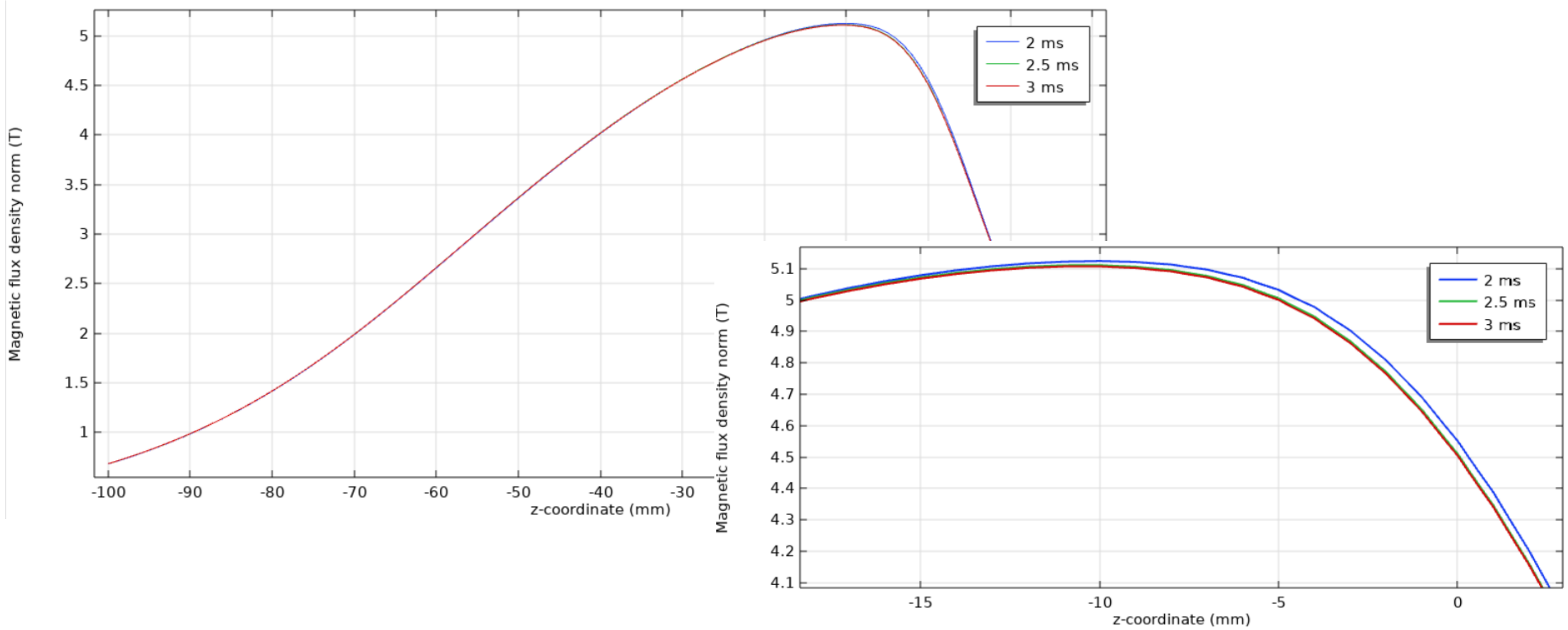


Magnetic field stability

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

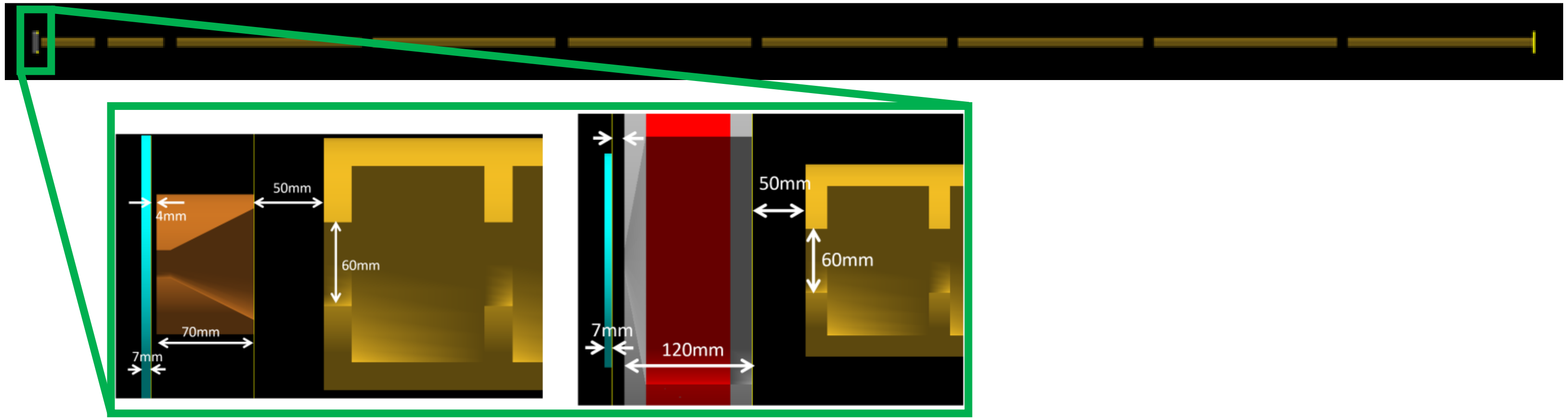




e+ yield simulations: OMD & capture linac

Simulation from target to end of pre-accelerator (M. Fukuda, K. Yokoya)

- So far only analytical calculations
- Now yield simulated for:
  - Shielded solenoid
  - Unshielded solenoid
  - Quarter-wave transformer (ref.)



- Simulation with
  - Geant4
  - Comsol (pulsed solenoid field, incl. target/eddy currents)
  - POISSON (magnetic field pre-accelerator, QWT)
- Cavity phases scanned for max. yield

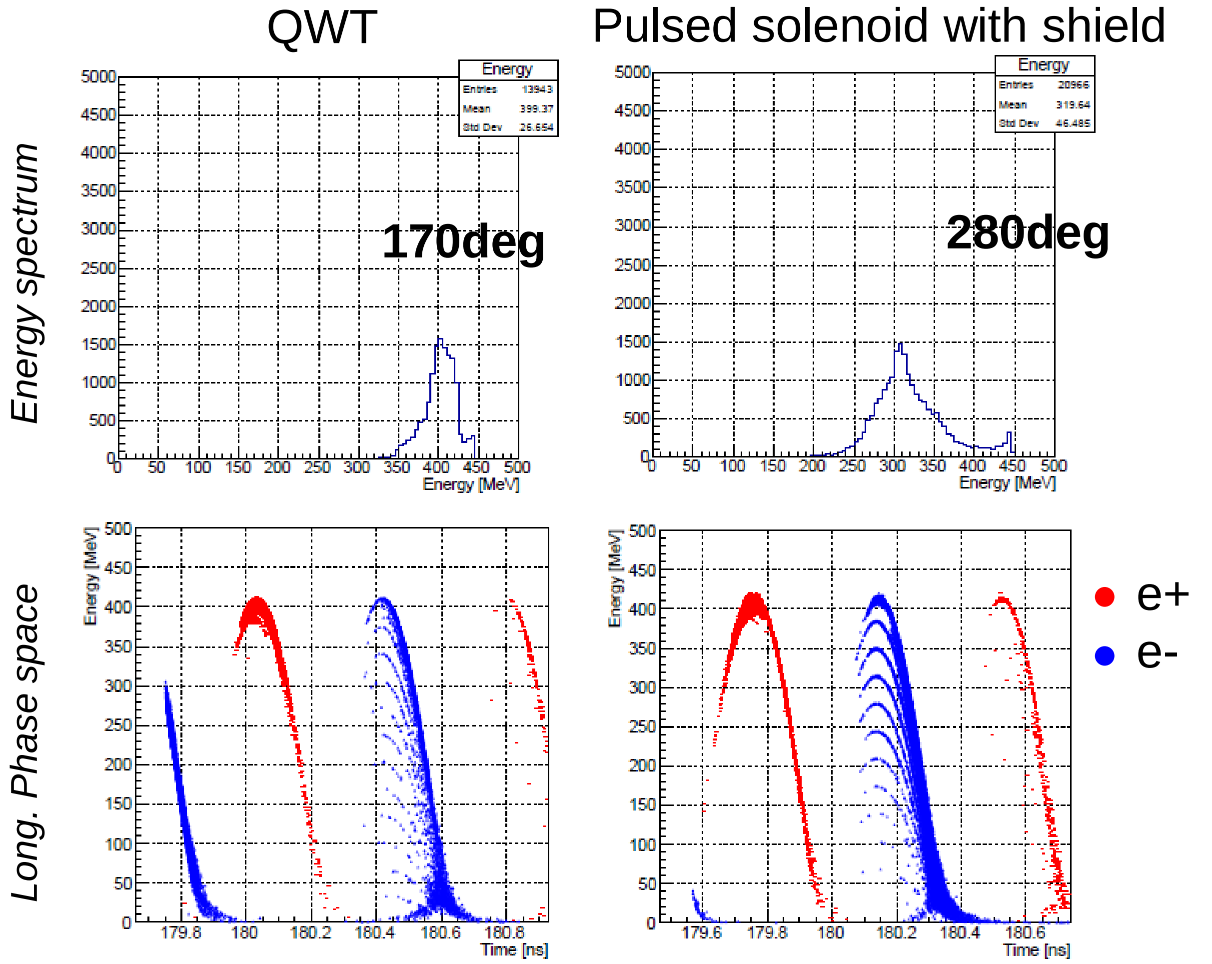
<u>Linac parameters:</u>

- 250 (400) MeV final energy
- 2 standing wave cavities *(~15.2 MV/m)*
- 7 (11) traveling wave cavities *(7.5-8 MV/m)*

e+ yield simulations: OMD & capture linac

Simulation from target to end of pre-accelerator (M. Fukuda)

- Energy spectrum narrower for QWT
- Bunch lengths similar
- Yields for 250/400 MeV similar



	QWT	Pulsed sol (w/ shield)	Pulsed sol (w/o shield)
Ne+ (|z|<7mm)	10713	16436	18052
Average energy [MeV]	394	393	394
Energy spread [%]	7.2	9.8	9.5
Bunch length (1σ)	16.6	16.4	15.5
Yield (|Z|<7mm)	1.07	1.64	1.81

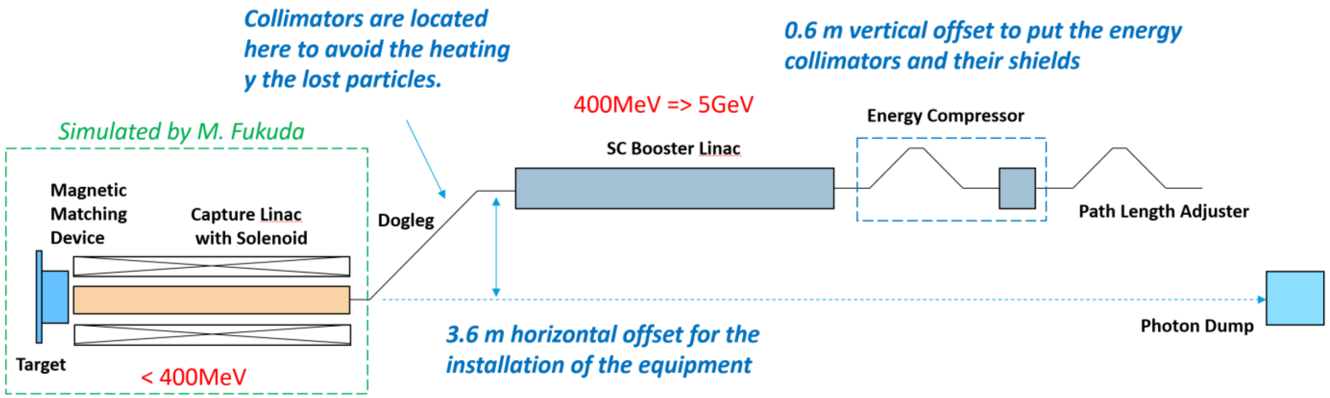
SW 170deg
TW +20deg
Eacc(TW): 7.9MV/m

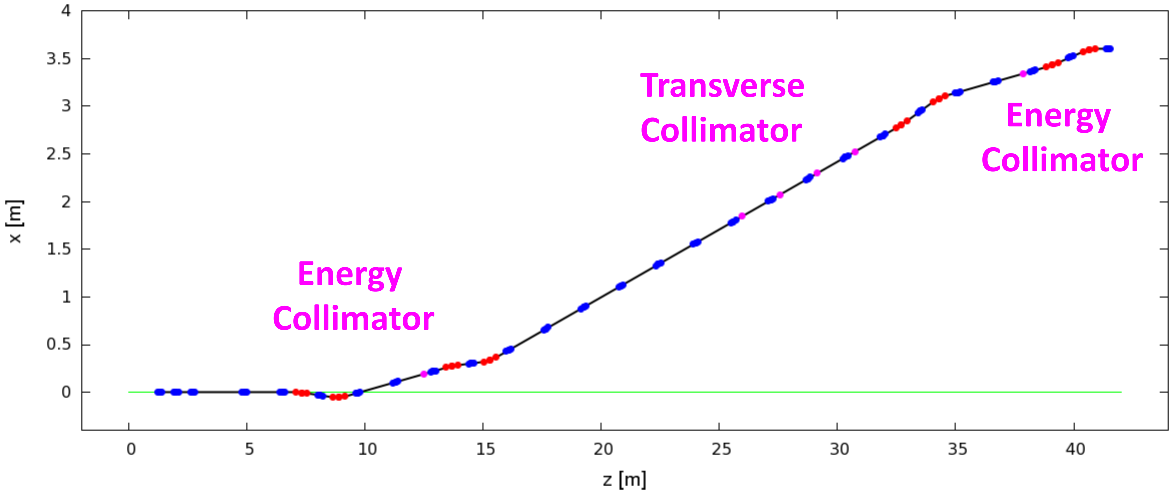
SW 280deg
TW +40deg
Eacc(TW): 8.1MV/m

Yield simulations: booster linac setup

Simulation from capture linac end to damping ring (T. Okugi)

- Energy increase to 5GeV
- Collimation in dogleg chicane
- Bunch compression
- Design adjusted to meet current technical layout (e.g. increased offset)

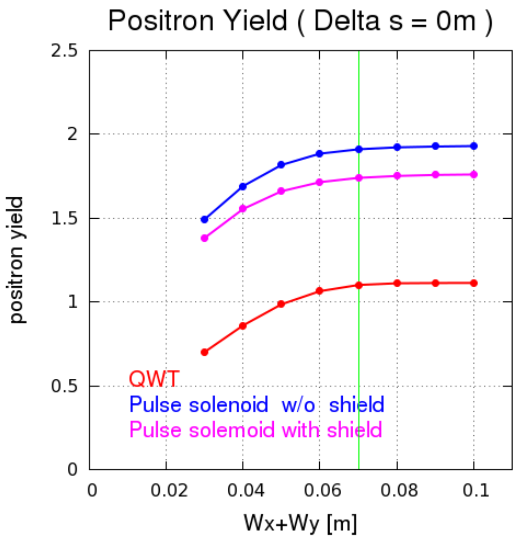


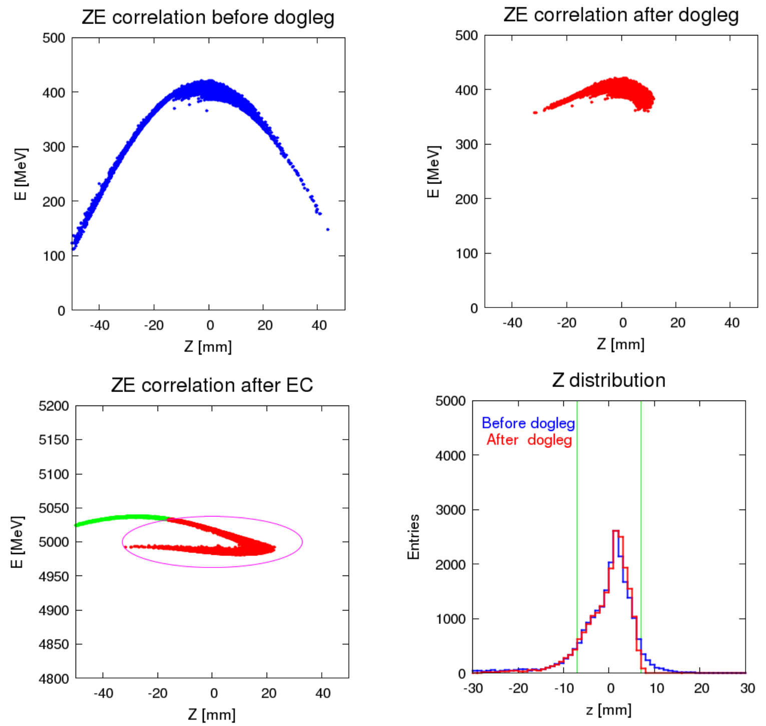


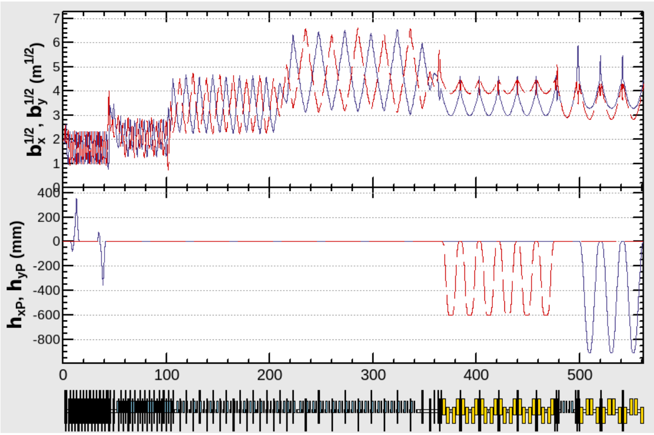
Yield simulations: booster linac results

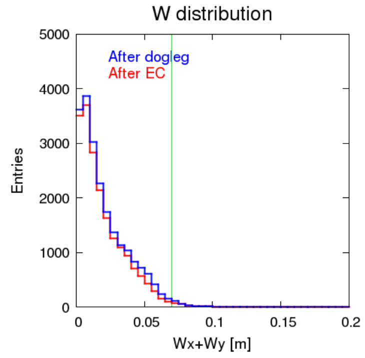
Simulation from capture linac end to damping ring (T. Okugi)

- Simulations for QWT, solenoid w/ & w/o shield
- Different settings of path length adjuster
  → merely any effect
- Minimal yield reduction in booster linac
- Power loss in linac minimised
  w/ collimators









Yield simulations: summary

Brief overview of simulations target → damping ring

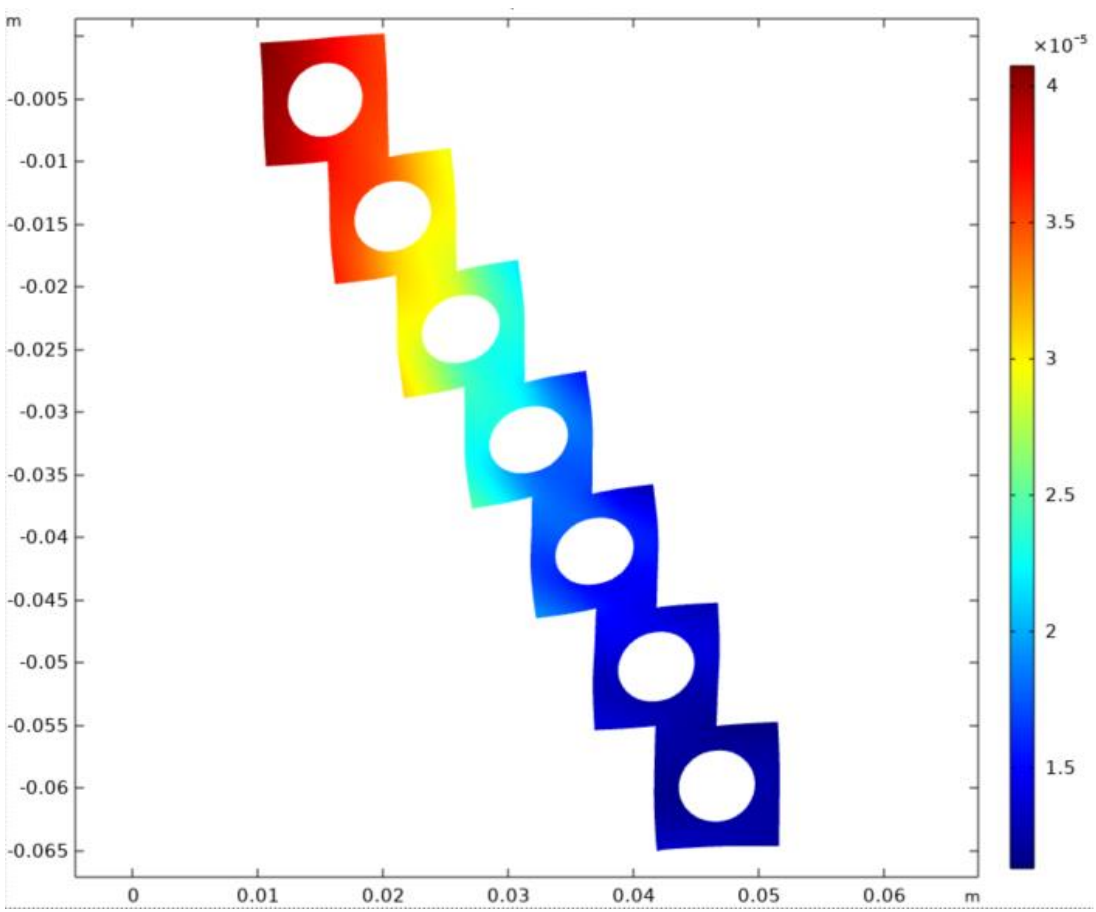
- Yield of undulator-based positron source w/ solenoid matching device simulated
- Significant yield improvement to QWT
- Possible trade-off: target heatload ↔ yield
- Further optimisation maybe possible

	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

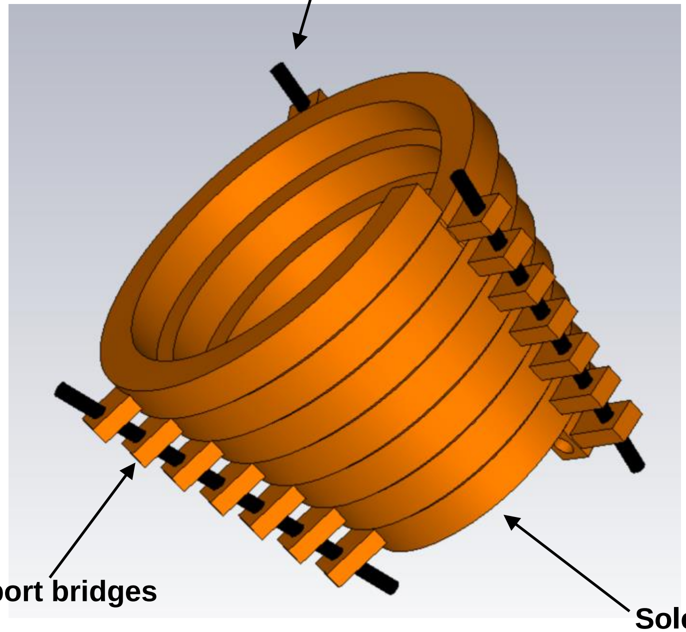
- Max. peak von-Mises stress ~146 Mpa
  - Soft Cu tensile strength ~200MPa
- Average power dissipation in Cu coil: ~11.5 kW

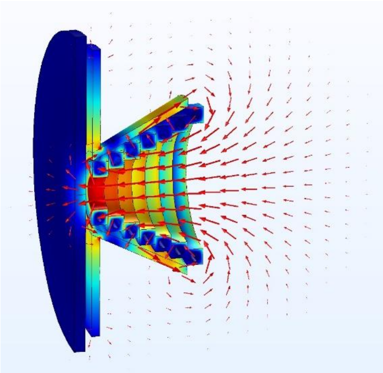


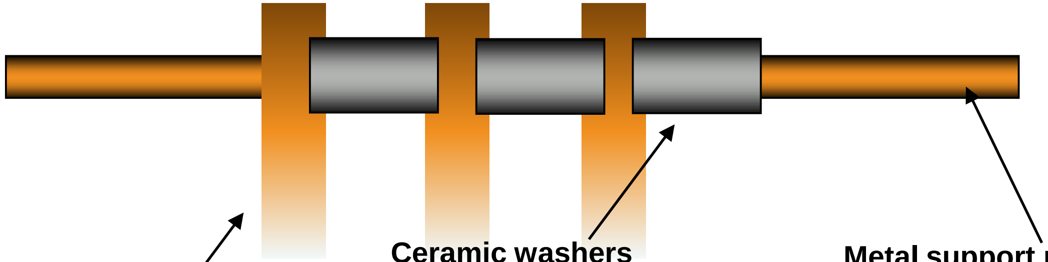
Solenoid construction

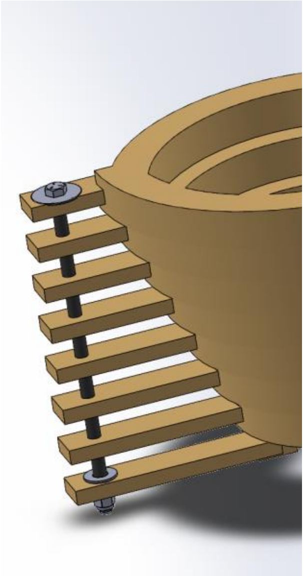
Possible mechanical design

- Solenoid coil
  - Tapered winding
  - 7 planar windings with interconnections
  - Conductor cooled from inside
- Metal supports to hold coil
- Support rods insulated from support bridges
  - Washers e.g. of SiN ceramics
- Magnetic shielding cut at support locations
  - Influence on field to be determined
  - Main shielding to target unaffected









Summary & Outlook

Recent progress and next steps

- Design of pulsed solenoid is evolving
  → *First fields*
  → *Heat load on target*
  → *Shielding for heat load reduction*
  → *Yield simulations*

- So far no show stoppers
  → *Target heat load under control*
  → *Head space in pulse length/shape*

- Significant yield improvement to quarter wave transformer

- Next steps
  - Prel. mechanical design
  - Influence of field variations on yield
  - Global optimisation

Thank you for your attention!

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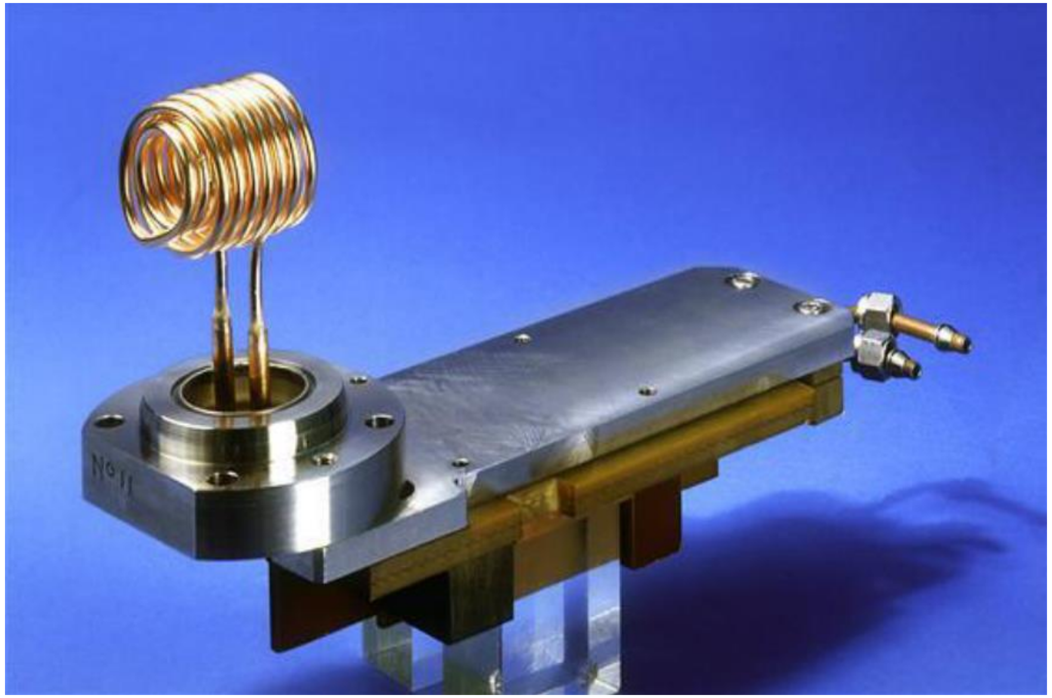
Previous designs

Other pulsed solenoids in accelerator applications

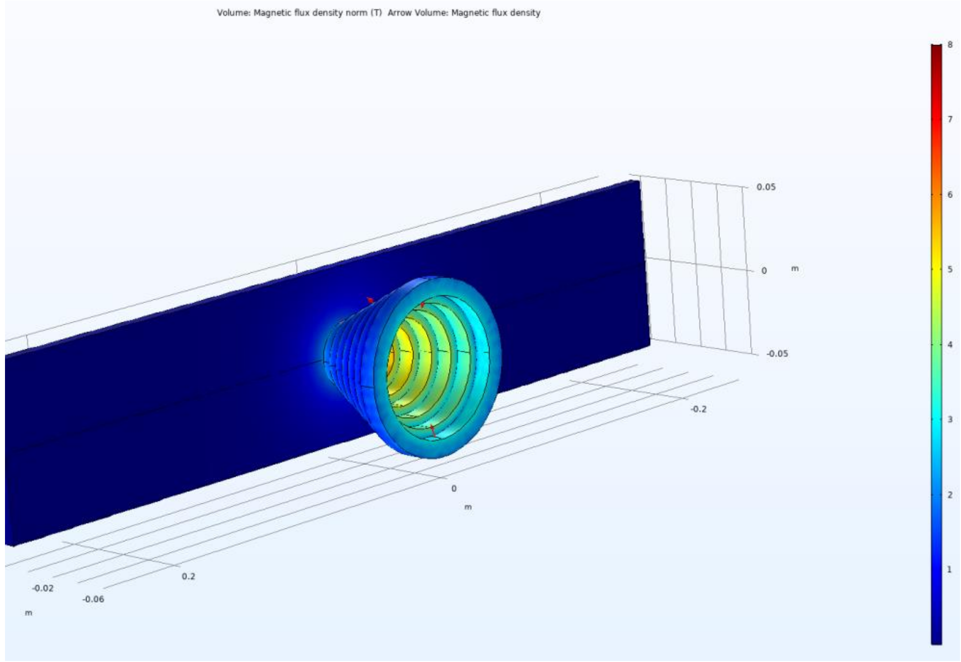
- LEP positron source capture device
  - 2.5kA, 20µs
  - 0.83T
  - 100Hz
- LAL
- DESY
- KEKB
- GSI
- …



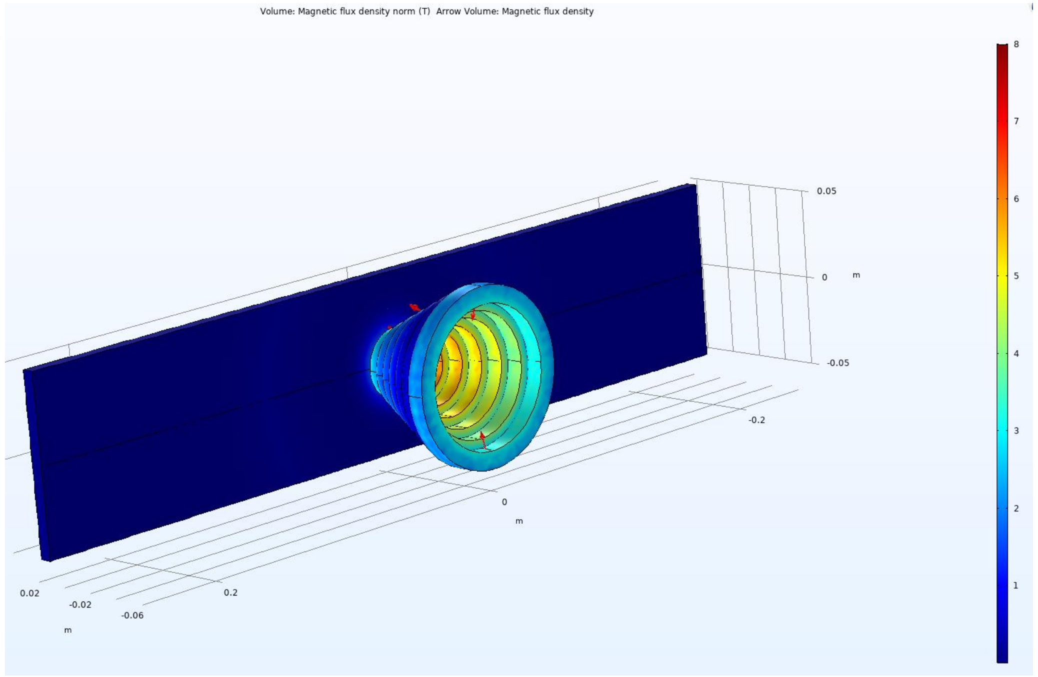
Induced current density/ magnetic flux

Titanium wheel

Without shielding



With shielding



Current distribution

Dynamic deformation w/o support