The Optical Matching Device (OMD) for the ILC Undulator Driven Positron Source and its Perspectives.

LCWS2021, 15.-18. March 2021

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Introduction.

- Time structure of the beam for the Undulator driven source: 1300 (2600) bunches contained in a pulse of 1.0 ms, and a rep-rate of 5 Hz.
- Cyclic temperature and stress loads spread around the target wheel.
- No thermal shocks, in contrast to the SLC-tumbling target and the e-driven ILC rotating wheel, both submitted to sub-μs-pulses at 60 Hz resp. 300 Hz.
- Fast spinning Ti-wheel to spread the beam energy deposition: 100 m/s.
- Wheel in vacuum and cooled by thermal radiation: 2 kW.
- $W = \sigma \cdot \varepsilon \cdot F \cdot (T^4 - T_0^4)$; $dT/T \approx$ 1/4 (dW/W; dε/ε; dF/F), impact on T is reduced.
- Total unit in vacuum (no penetration of vacuum tank) and in common with the downstream magnetic matching device.
- Rotating magnetic bearings, vacuum compatible. Rotating at 32 Hz.

Magnetic Bearings: vacuum compatible, lubricant free, radiation resistant by use of inorganic materials. Ref.: Okugi san- KEK.

Magnetic bearing feature

- Payload capacity
  - **Magnetic bearings can support a heavy rotor.**
  - Ex. 9 MW gas turbine
    - Speed: 6090 r/min
    - **Total rotor weight: 10 tons**
    - Total rotor length: 10 m
- Vacuum
  - **Oil free:** No lube oil system
  - **Vacuum sealing is simple.** Magnetic bearings and a motor can be hermetically sealed.
- High rotation speed
  - ex. Fermi chopper : Up to 600Hz.

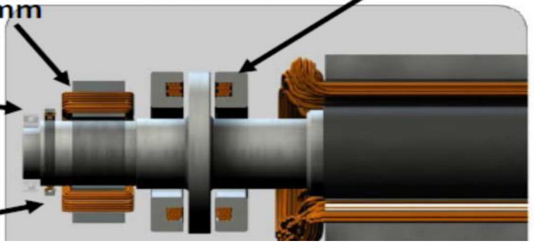
The magnetic bearing is made of electromagnets which is attached to the rotor.
The bearing is contactless with a radial clearance of 0.5 to 1mm.

Radial bearing
- At least two bearings are needed.
- **Radial clearance: 0.5 – 1.0mm**

Thrust bearing

MAGNETIC SYSTEM

Touch down bearing
- Oil-free ball bearing
- **The clearance is a half of that of the radial bearing to prevent the rotor touching sensors or magnets**

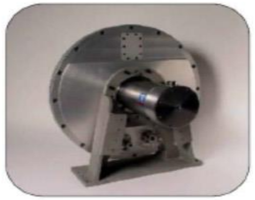


Magnetic bearing applications

The neutron choppers are used in various laboratories.
It is the most similar application to the positron rotating target.

Neutron chopper
- Payload capacity of 45 kg
- Operation up to 300 Hz (18,000 rpm)

g5 Systems
Disk Choppers (0-300Hz): 10
Spare Controllers: 16

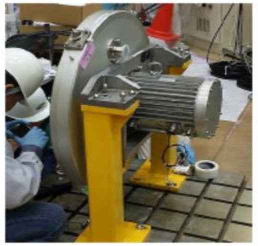


g3 Systems
Disk Choppers (0-300Hz): 62

SKF global installations bring experience

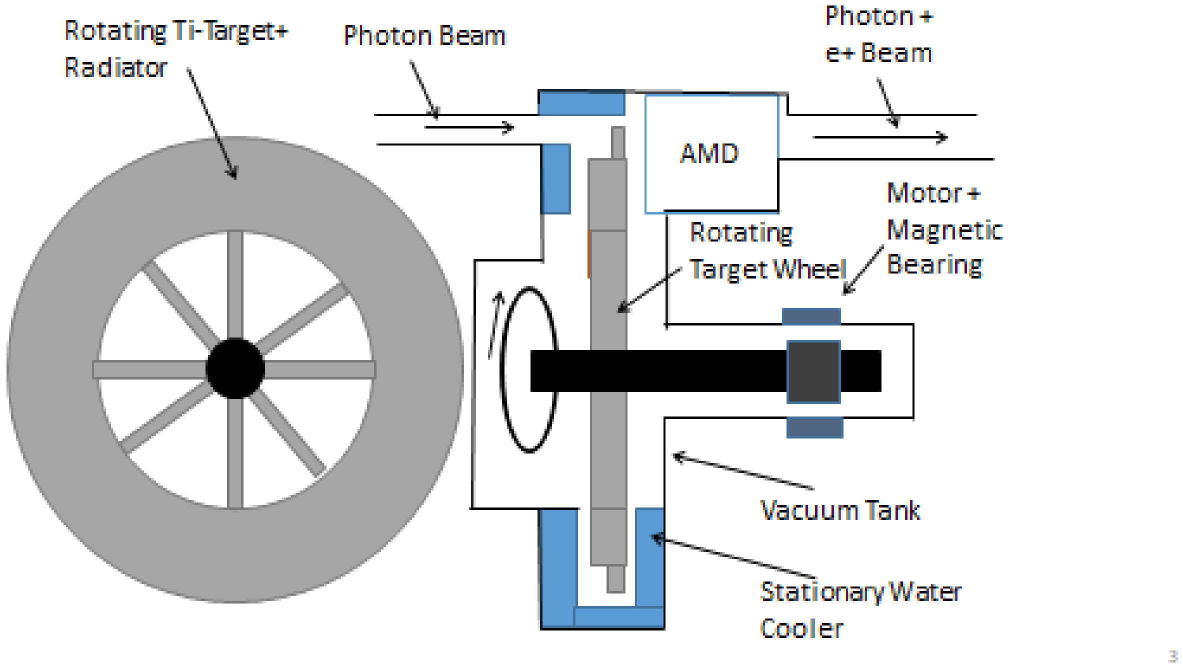
100+ neutron choppers delivered and operational

S2M magnetic bearings are used in Neutron choppers of J-Parc.



Layout of the Undulator Driven Positron Source

Principal Layout: Ti-Wheel with a Diameter of 1.0 m, rotating at 100 m/s, 2000 rpm.



Ti-alloy target with a thickness of 7 mm.

Optical Matching Device-OMD

- Flux Concentrators are efficient for short current pulses: eddy currents, skin effect in massive Cu-bulk material, however shocks and HV.
- For long current pulses it is difficult to achieve stable, reproducible magnetic fields in massive Cu-bulk material: skin depth propagates with time.

- Basic Idea: Consider a solenoid coil with rather long pulses and limited conductor cross section, to achieve a uniform current density in the conductor while tolerating the average Joule heating.
- Balance pulse duration against Joule heating.

First Aproach: Ref.: POSIPOL WS 2018 at CERN, 3.-5.Sept. 2018

Use a long current pulse of 4 ms or above at 5 Hz to achive a uniform current density across the Cu- conductor cross section of 10 x 10 mm^2 of the solenoid, and thus approach a stable magnetic field over 1 ms.

Example: Half sine current pulse with 50 kA peak

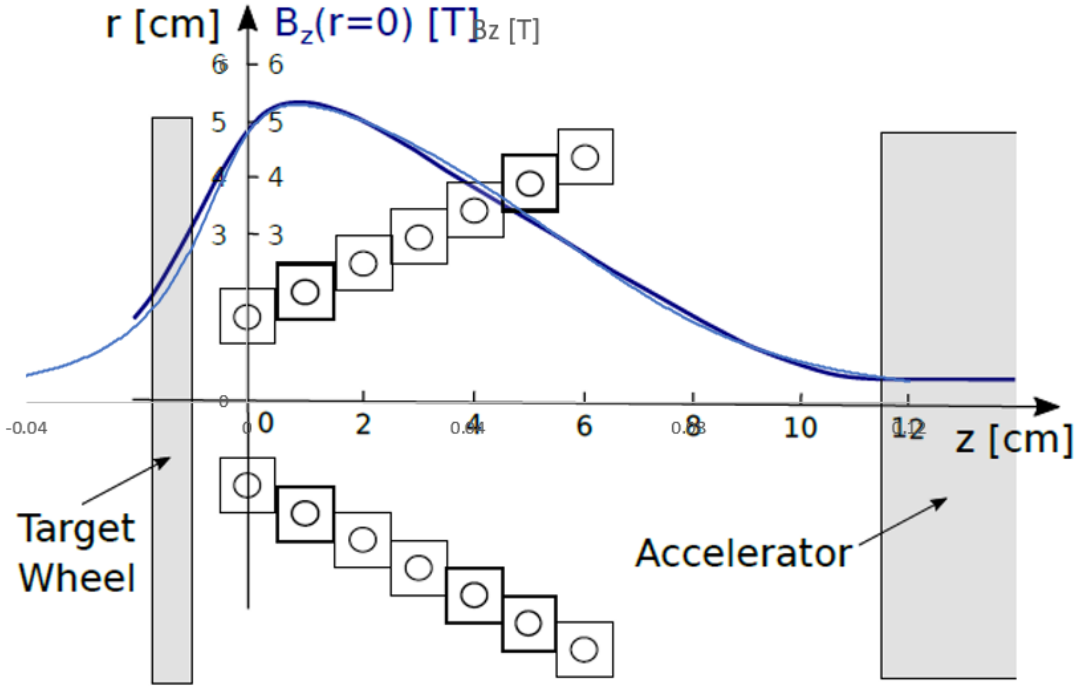
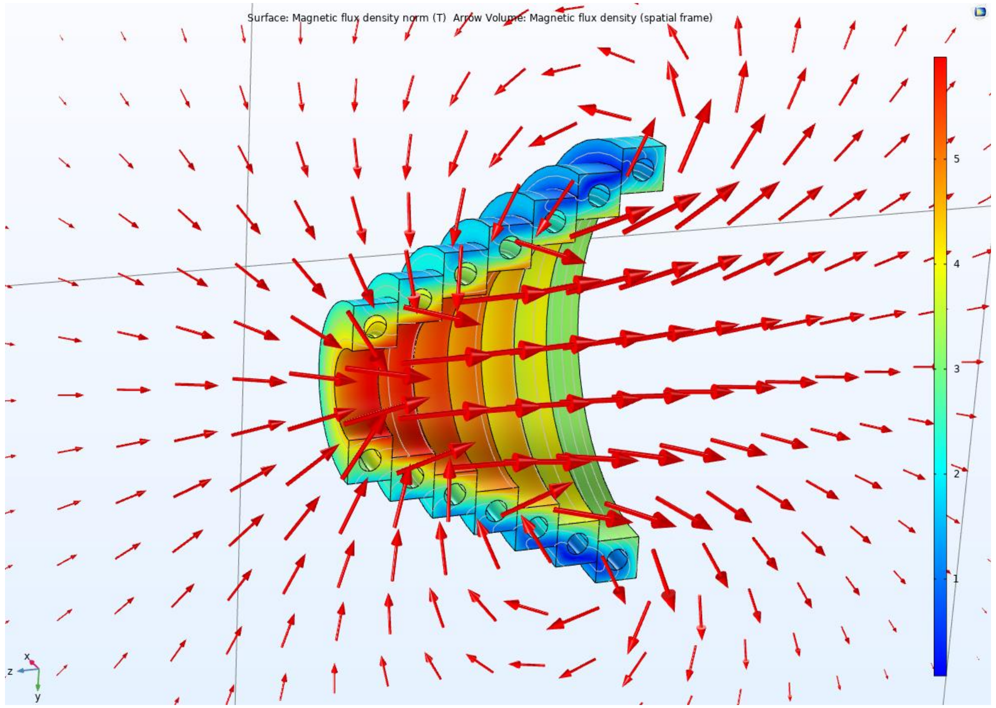


Figure 7: B field as used for the studies to increase the positron yield.

Ref.: M. Mentink-CERN (Priv. Comm. 21.1.2021). COMSOL-Multyphysics Code.

Half sine current pulse with 4 ms and a Peak Current of 50 kA and Peak Field of 5.3 T.

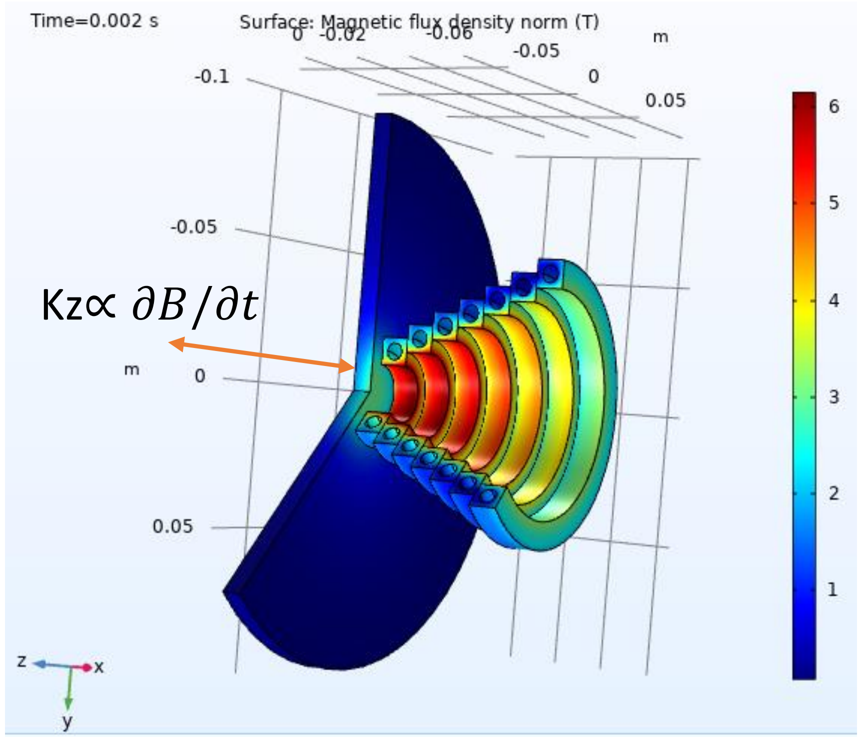
- Operating current [kA]
  - 50.5
- Inductance [μH]
  - 1.4
- Stored magnetic energy at full current [J]
  - 1750
- Volume [m^3]
  - 1.1e-4
- Conductor cross-sectional area (not including hollow core)
  - 7.2e-5
- Conductor length [m]
  - 1.3
- Assumed conductor resistivity [Ω×m]
  - 1.7e-8
- Average dissipation, when considering skin effect [kW]
  - **9.0**

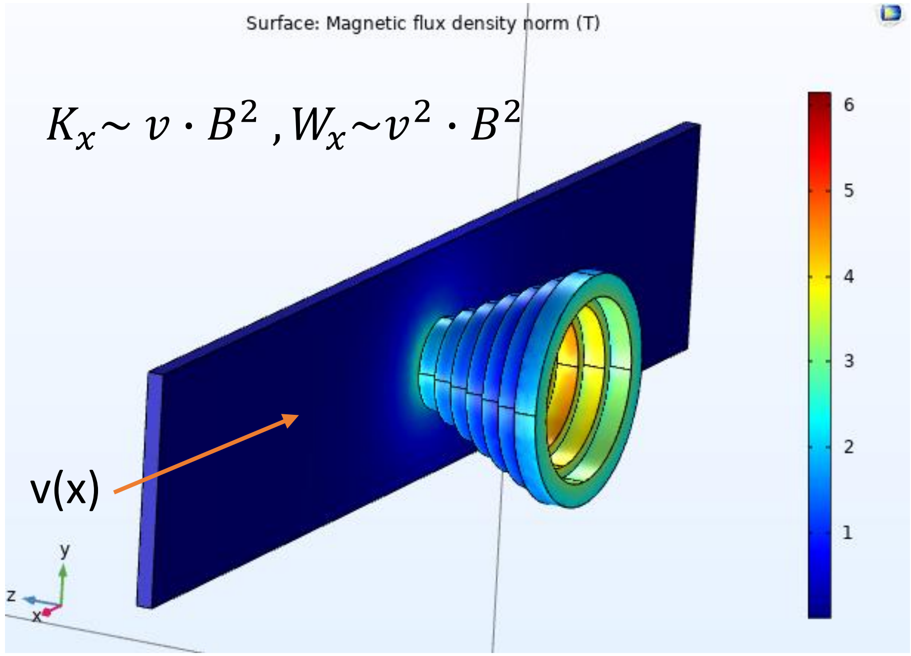


Preliminary values for the wheel with R=0.5 m, a peak field of 3.2 T and a pulse of 4 ms.

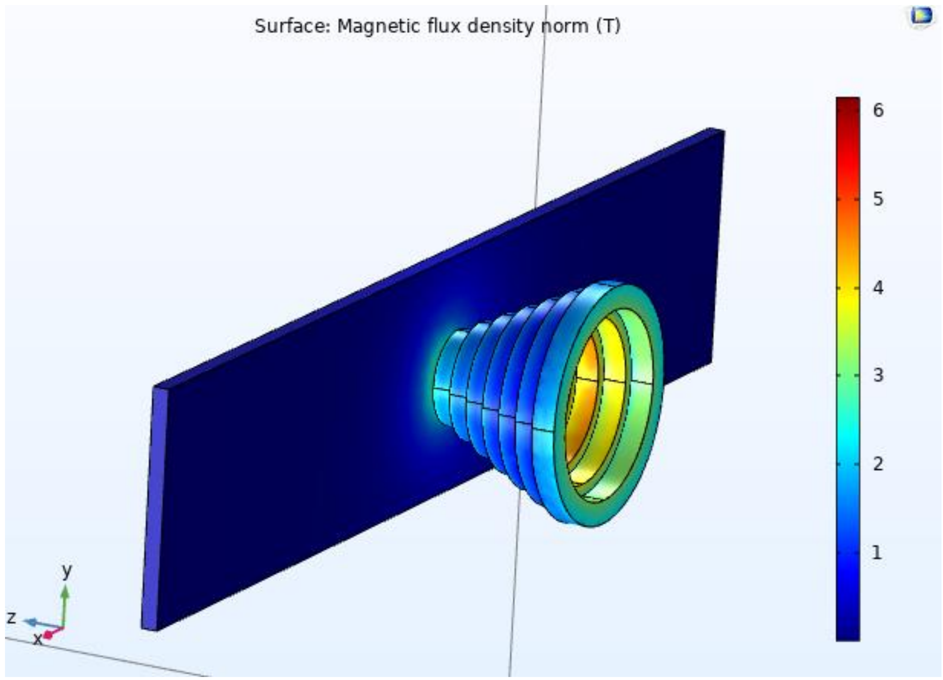
Due to the pulsed solenoid: Axial peak forces Kz and av. power Wz, deposited in the wheel: $\ll$+/- 100 N/pulse and $\ll 100\, W$.

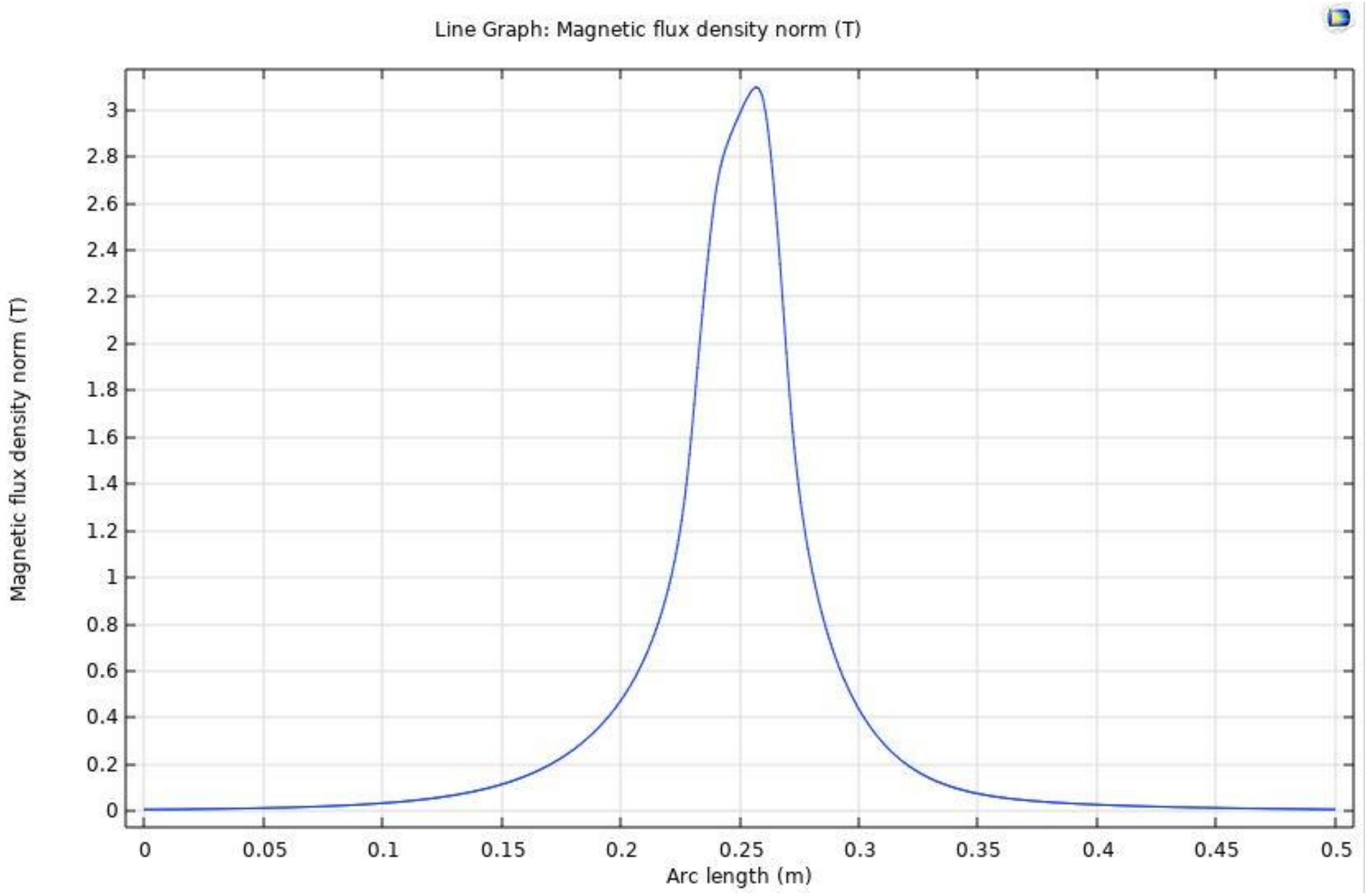
Due to the velocity of the wheel: Braking force Kx and power Wx, deposited in the wheel: < 200 N/pulse and < 200 W av.



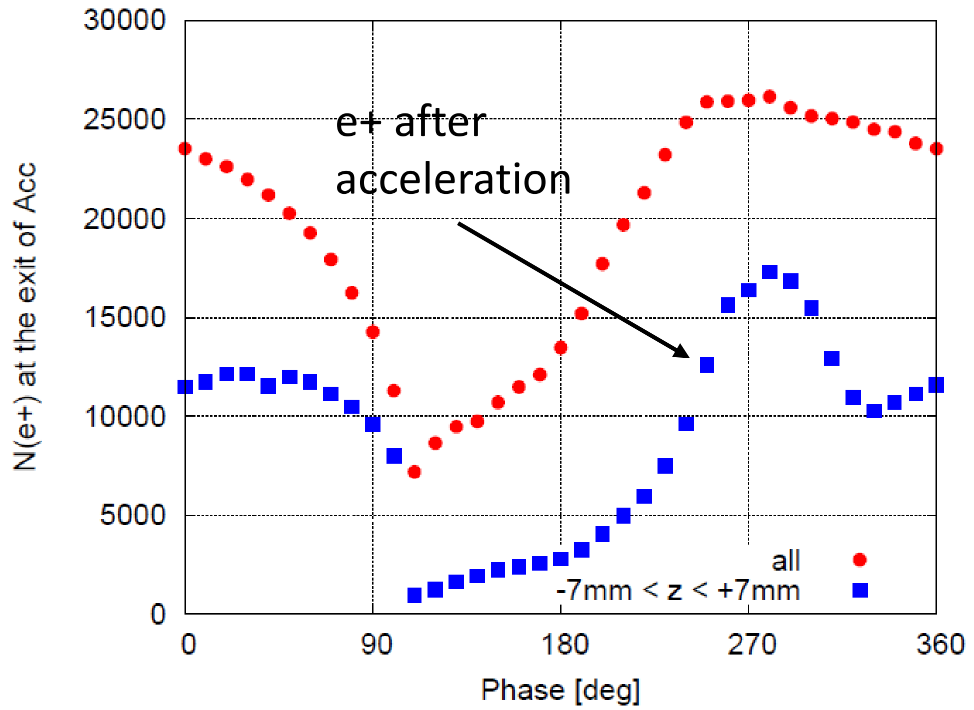


Field Drag in the Target-Solenoid Gap (A. Michailichenkov).

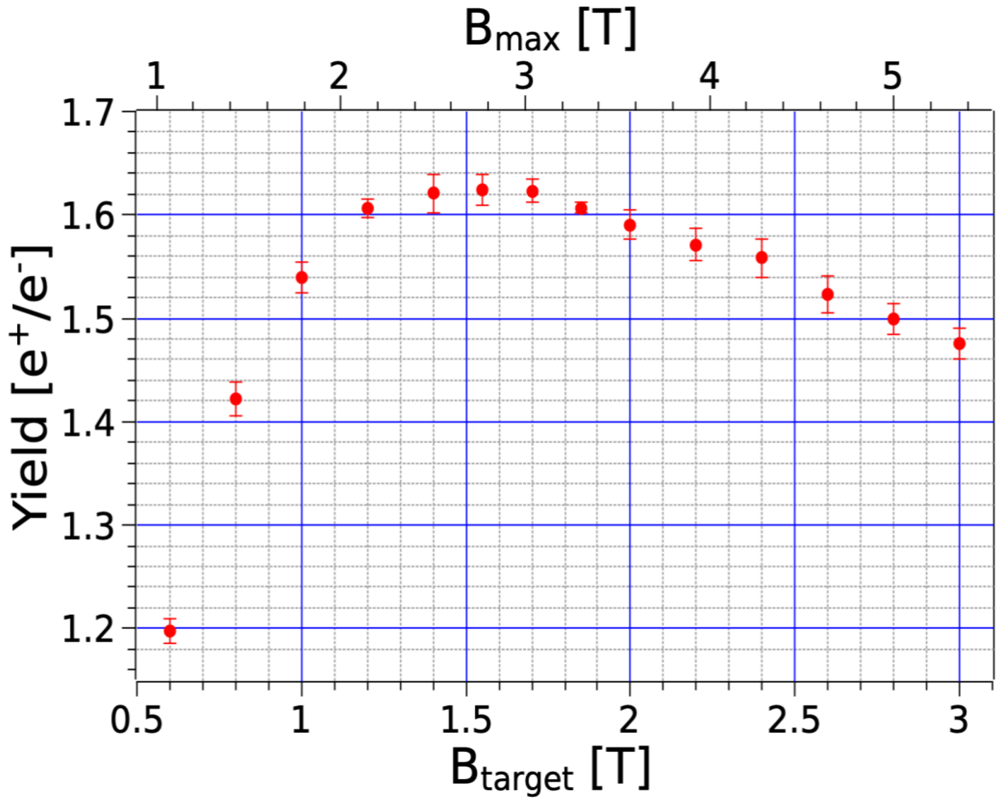




Trends of positron yields vrs. peak field B-max and field B-target in the target/solenoid gap. Aim at B-max of 3.2 T. Gap between target and solenoid: 4 mm.



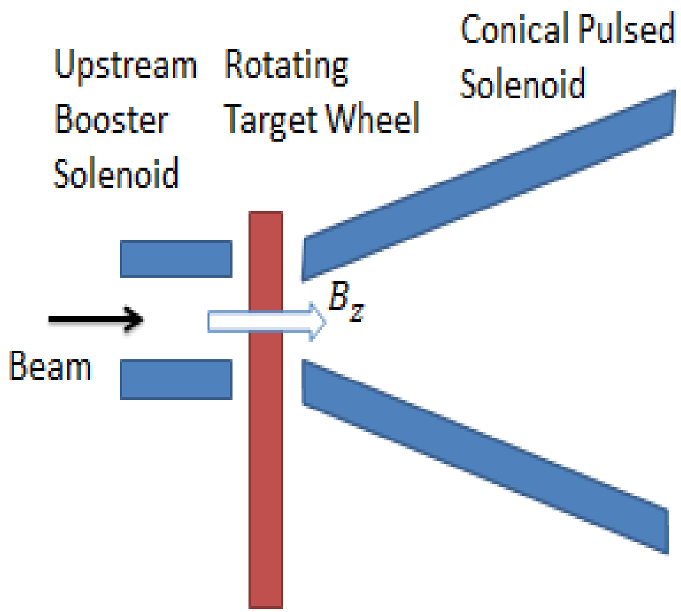
Yield with pulsed Solenoid (5.2 T) increased by a factor of 1.5 as compared to the QWT at 1. T.
Ref.: M. Fukuda-KEK



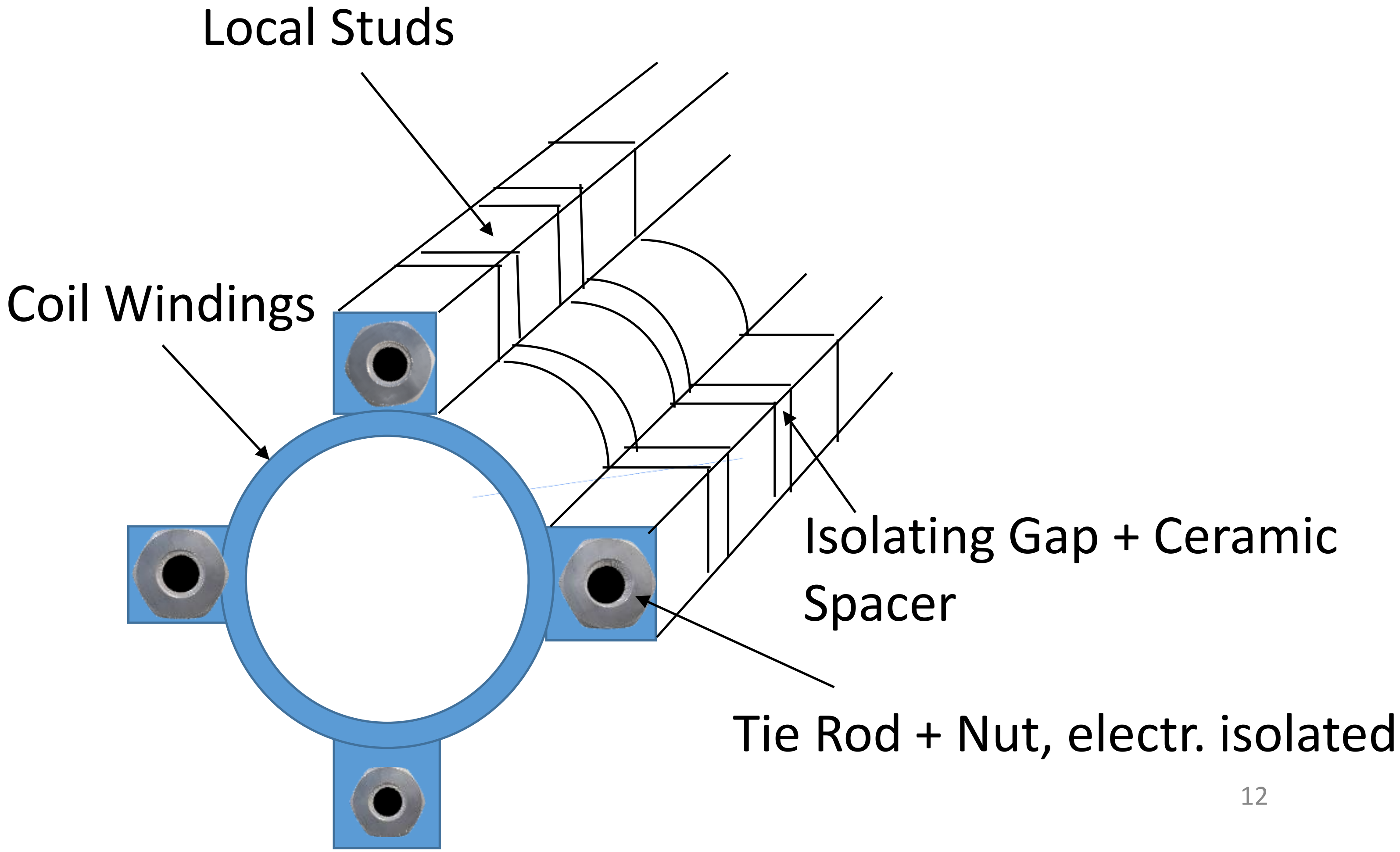
Ref.: A. Ushakov- Univ. Hamburg

Possibility to optimise Field and Yield by superposing an upstream Booster Coil

Increase Aperture of Conical Solenoid and Compensate Field Loss by Adding an Upstream Booster Coil.



Engineering Design of the Pulsed Solenoid: a proposal.



Engineering of the Pulsed Solenoid.

- Pulse duration should be above 4 ms. Expected limit 9 kW or above?
- For 5 ms (4 ms half sine plus 1 ms flat top) at 3.3 T: W=5 kW, looks ok.
- Pulsed magnetic forces at 5 Hz look conservative, but t.b.c.
- The heating of the solenoid at its entrance aperture of 20 mm diameter by the cascade from the target t.b.c. (Power dissipated in the target only 2 kW).
- Radiation damage, dpa to be checked.
- Simulations will guide the design. A prototype coil should be tested with a pulsed current and equivalent power.
- Stripline to be designed and global field quality to be checked.

Loads in the Spinning Wheel, magnetically induced by the Pulsed Solenoid.

- Simulations by COMSOL are very reliable.
- However, a scaled down prototype wheel unit (equivalent wheel of reduced size) with magnetic bearings and motor, rotating at 2000 rpm in vacuum should be built and tested.
- Foresee means to provoke pulsed braking and vibrations of the rotating unit.
- Finally, a full size unit should be prototyped.

Conclusion

- Each issue of this source has been or must be further studied by simulation.

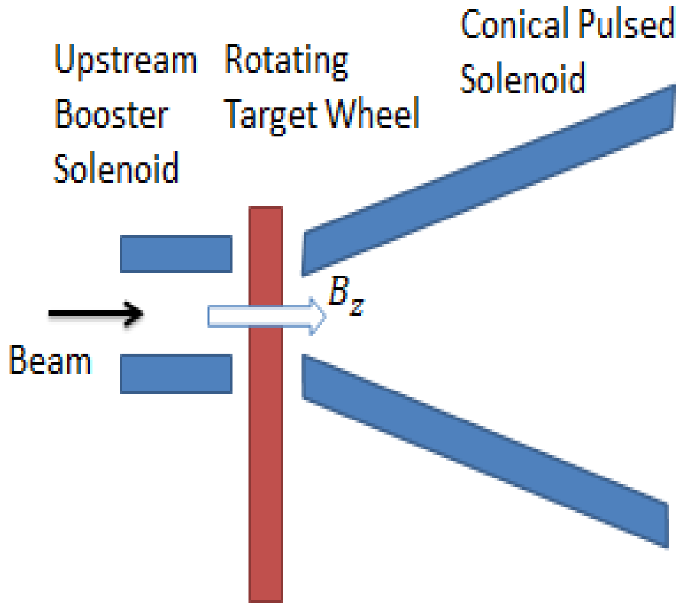
- For the salient components, prototypes to be built and lab test to be devised:
-
- Target wheel and magnetic bearings, rotating at 2000 rpm in vacuum.
- Pulsed OMD.
- Cooling by thermal radiation.

- For none of these items, a show stopper has been identified, nor do any of them require a «Proof of Principle».
- Engineering, prototypes and lab tests of individual components and finally a completed unit serve to optimise performance, robustness and availability.
- And the final goal of the above is to achieve a Positron Yield with sufficient margin.

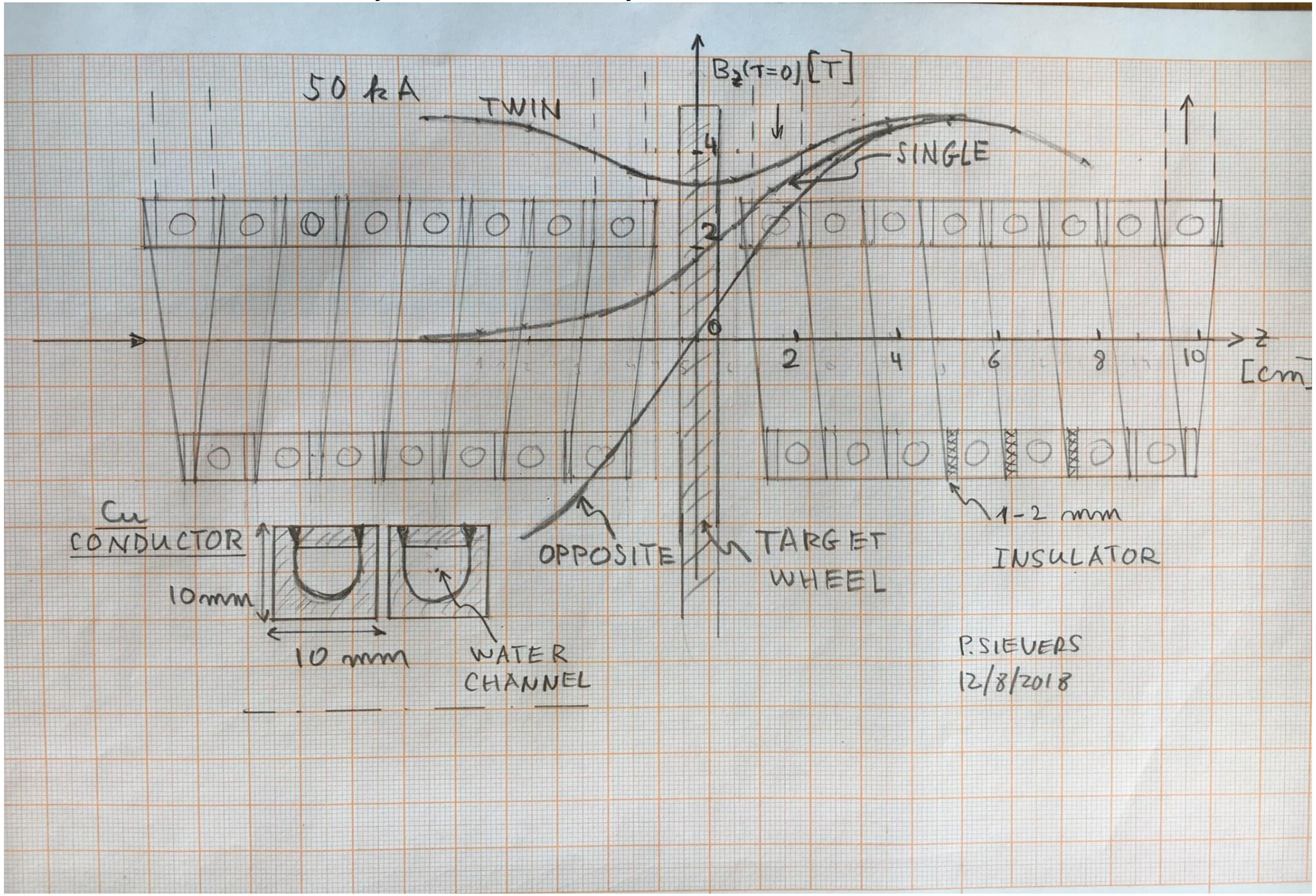
Back ups

Possibility to optimise Field and Yield by superposing an upstream Booster Coil

Increase Aperture of Conical Solenoid and Compensate Field Loss by Adding an Upstream Booster Coil.



Aperture 4 cm, 50 kA, 7 Turns.



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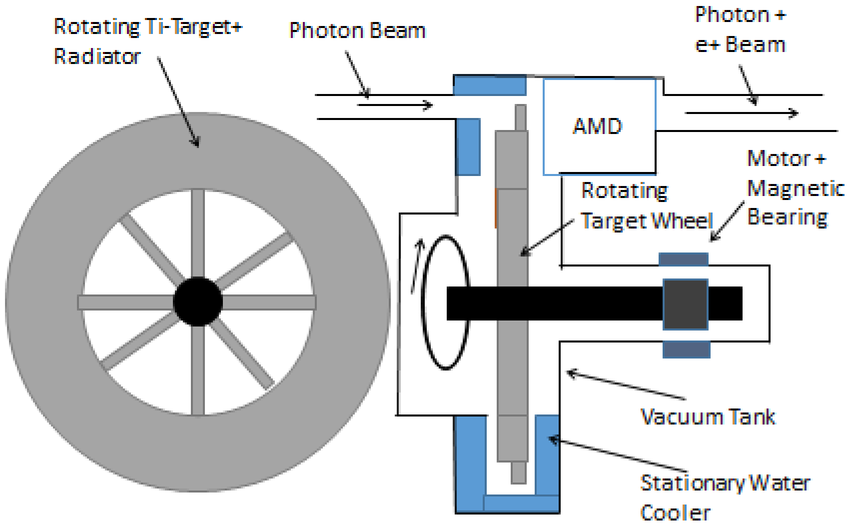
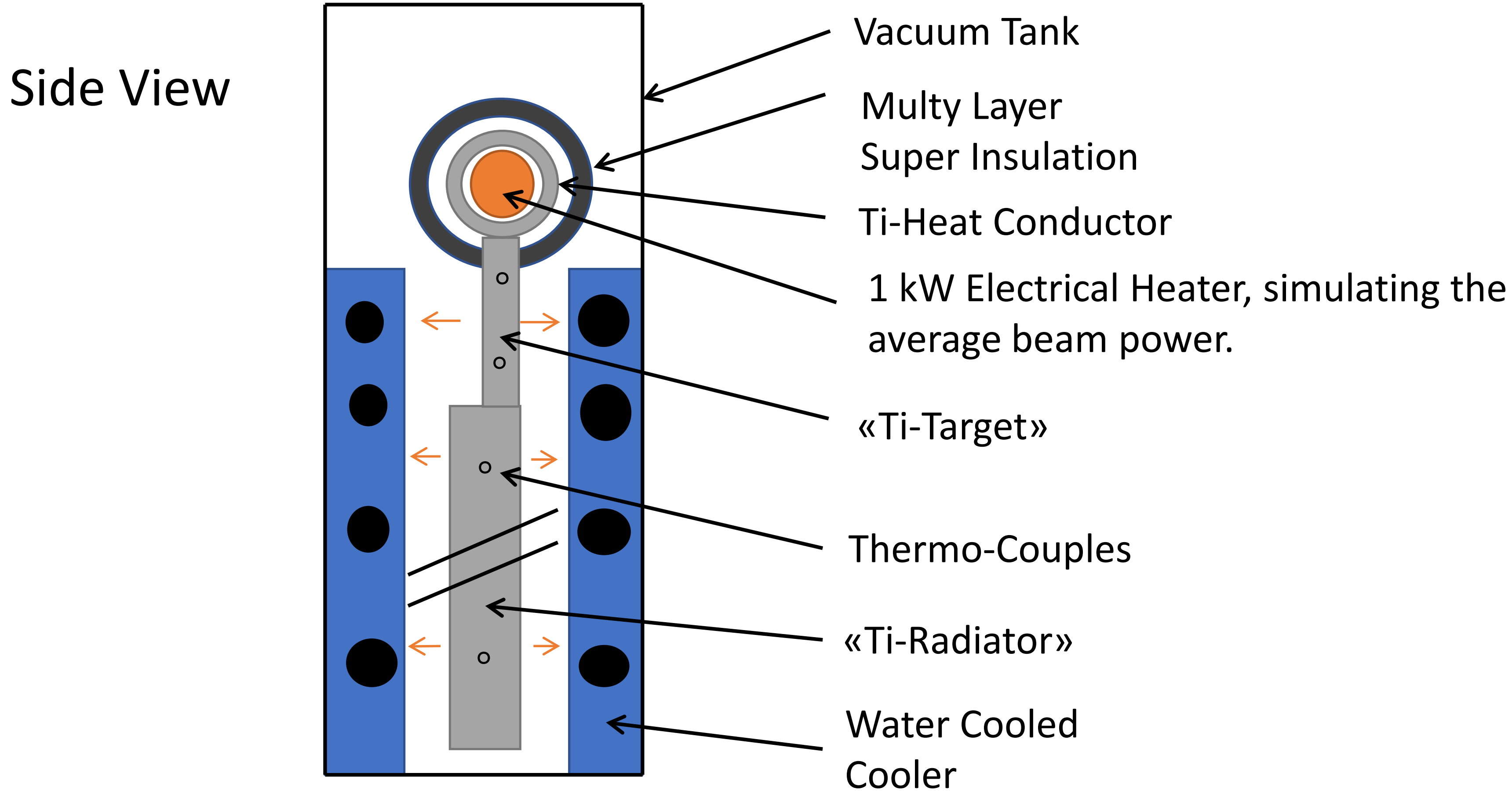
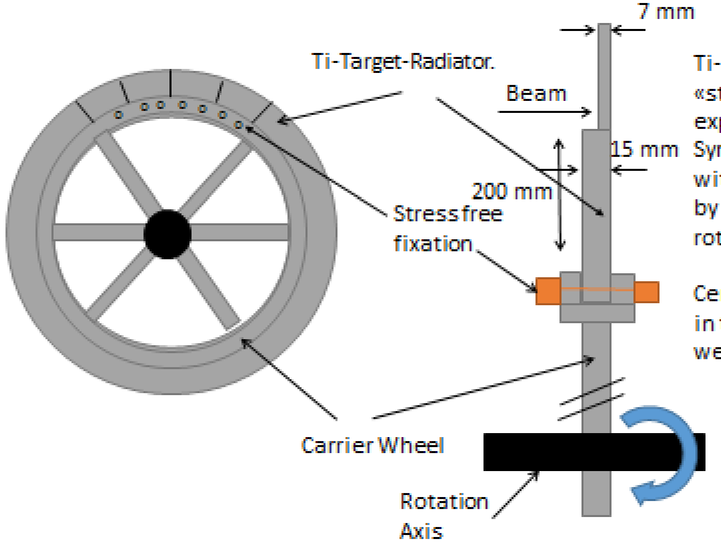


Ti-alloy target with a thickness of 7 mm.

Laboratory Set Up for Test of Radiation Cooling of a Target Sector.



Ti-Target Sector Modules, mounted onto a «Carrier Wheel»

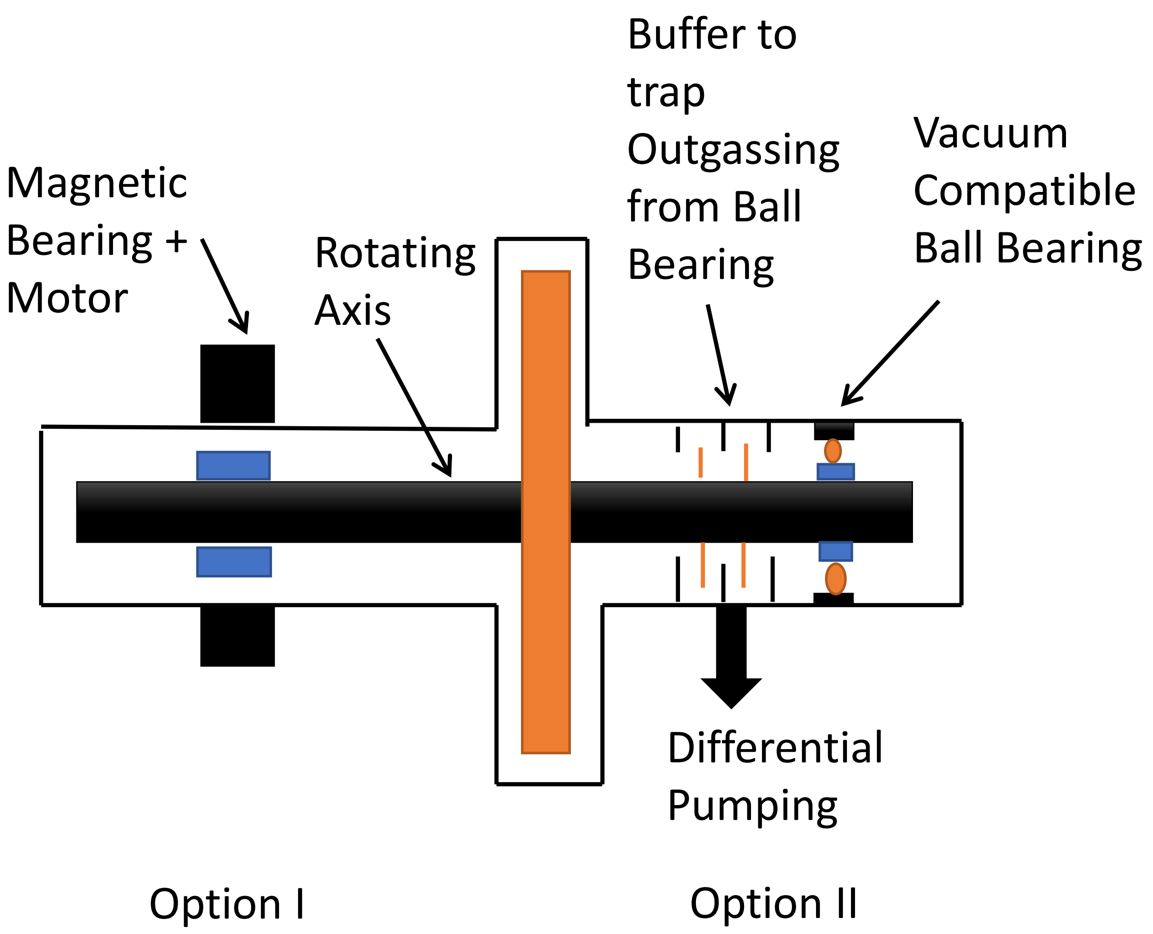


Ti-sectors mounted «stress free», free to expand thermally. Synchronise rotation with beam pulses by fine tuning the rotation velocity.

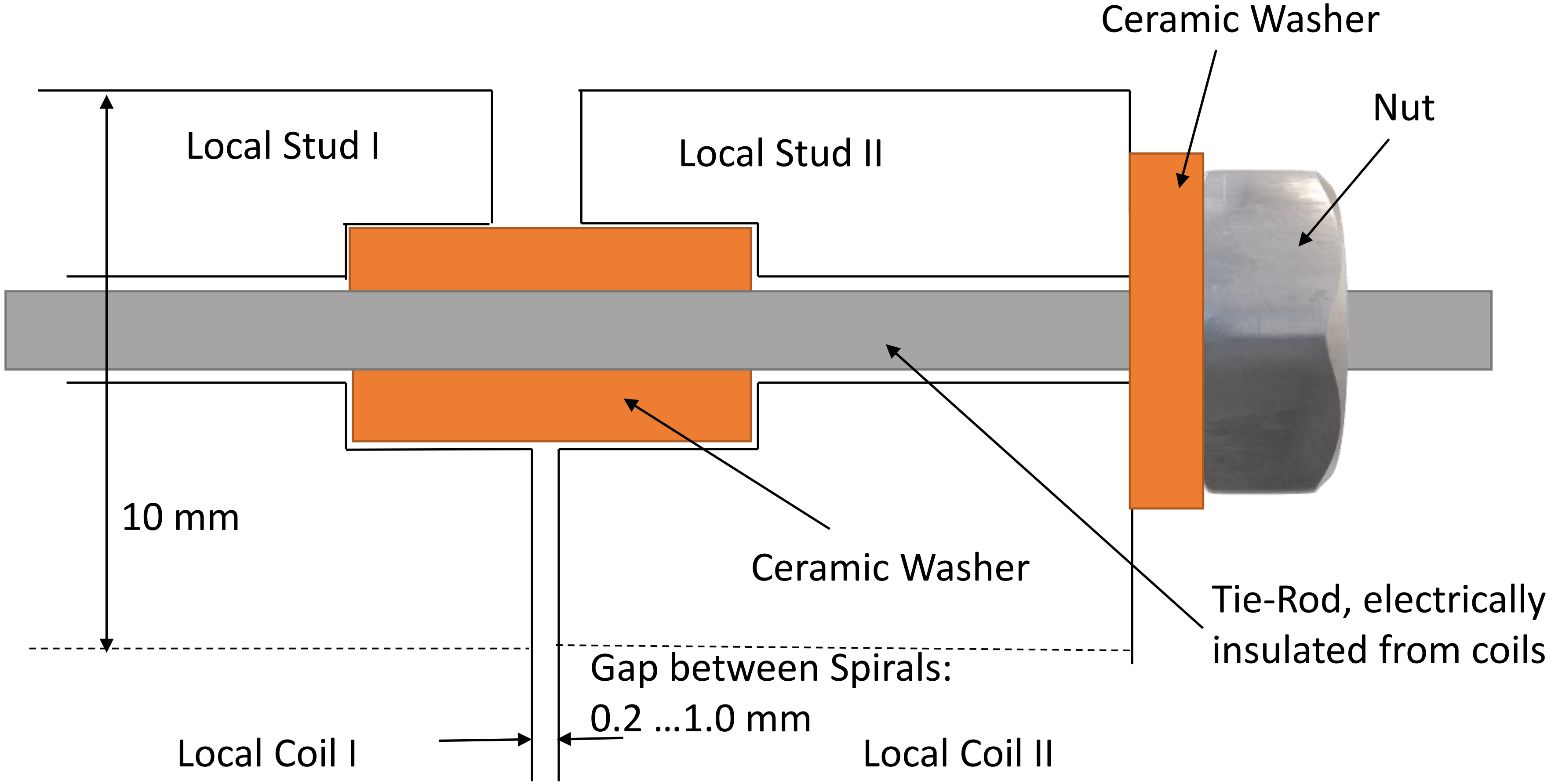
Centrifugal stresses in the Ti –target are well below 10 MPa.

Not to scale!

Reduced Model for Laboratory Tests of the Spinning Wheel



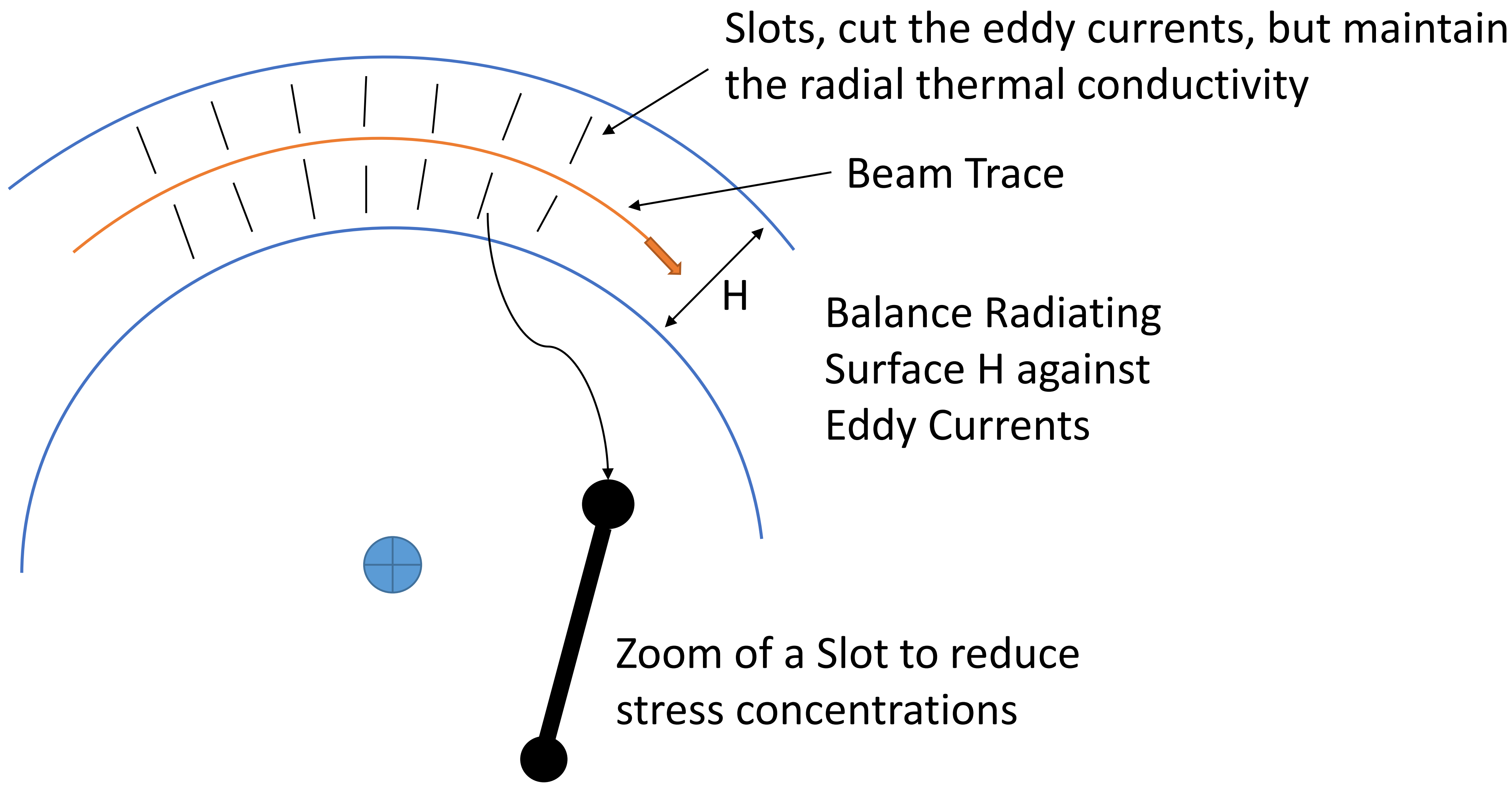
Layout for Clamping and Retaining the Coil Windings by Tie Rods



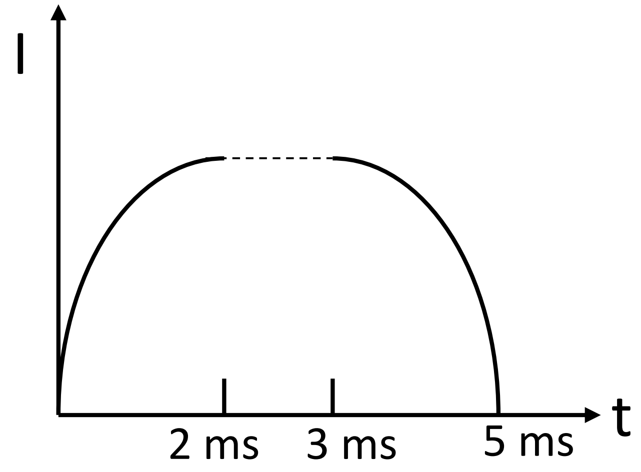
Possibilities to reduce magnetic forces and power in the spinning wheel:

-Laminations, slots.

-Iron flux trap to bypass the (return) flux around the wheel.



- Half sine Pulse with Flat Top of 1 ms.



SLC positron target after decommissioning