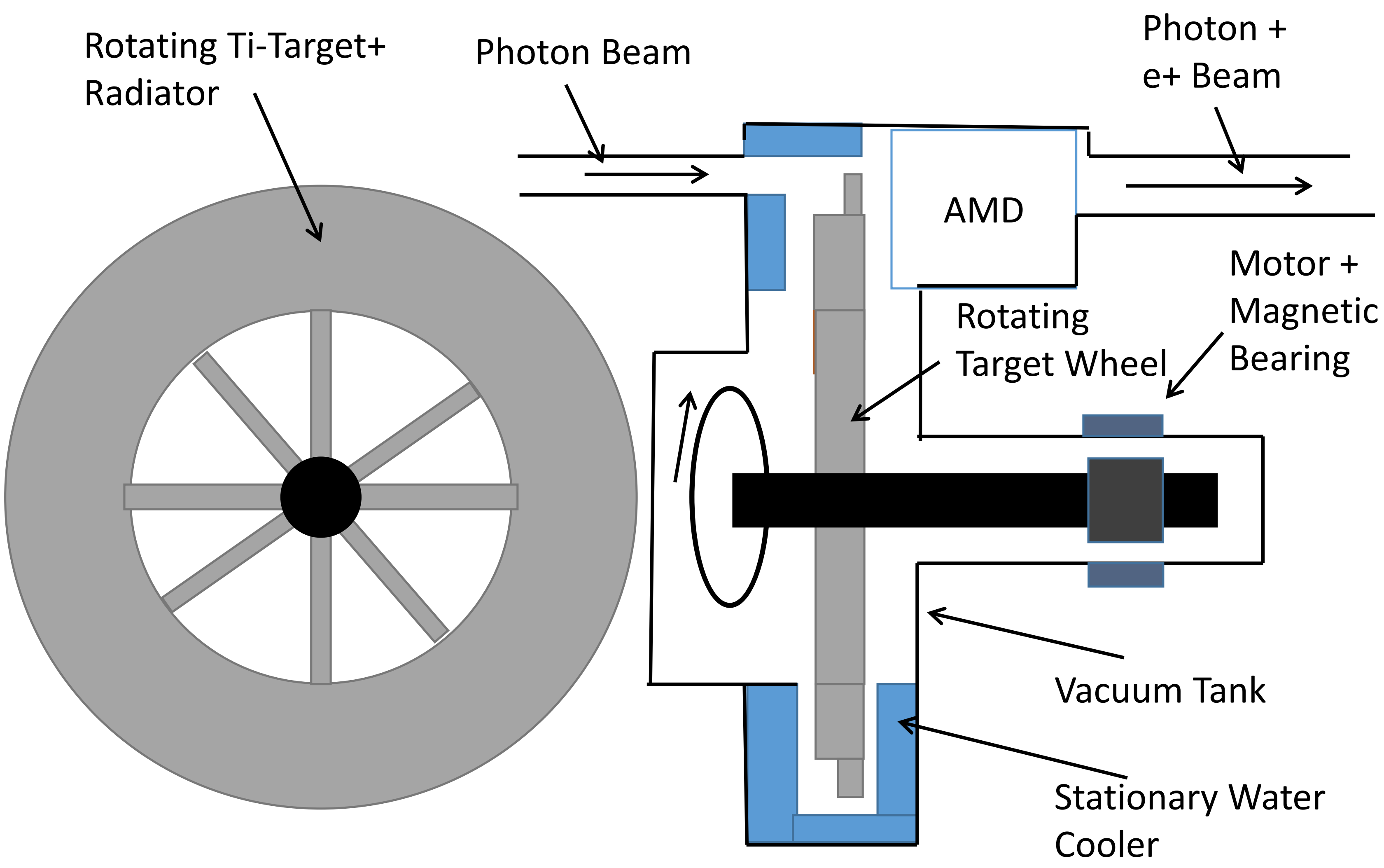
Design Options for the Undulator Driven, Radiation Cooled Positron Target for the ILC.

P. Sievers-CERN-Ret. , S. Riemann-DESY

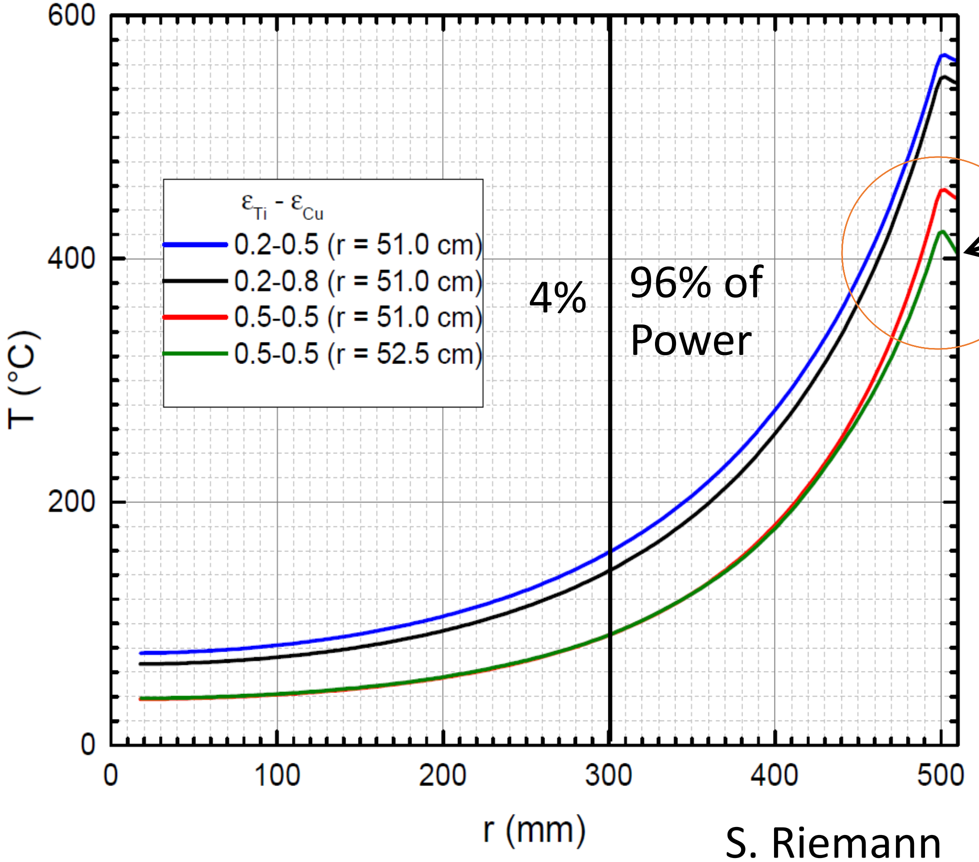
1.Introduction and Design Options.

- In the initial proposal (see POSIPOL 2013), Cu was considered for the radiator: good th. Conductivity and reasonable Emissivity. But heavy and temperature limited to about 300 oC.
- Following the reduction of the number of bunches and the thickness of the Ti-target, a monolytic Ti-Target-Radiator Wheel was studied (S. Riemann et al.).
- Starting from this, in the following possible design and engineering options are discussed.
- Finally, the use of a Pulsed Solenoid as an AMD ist considered.

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



There is room for improvement.



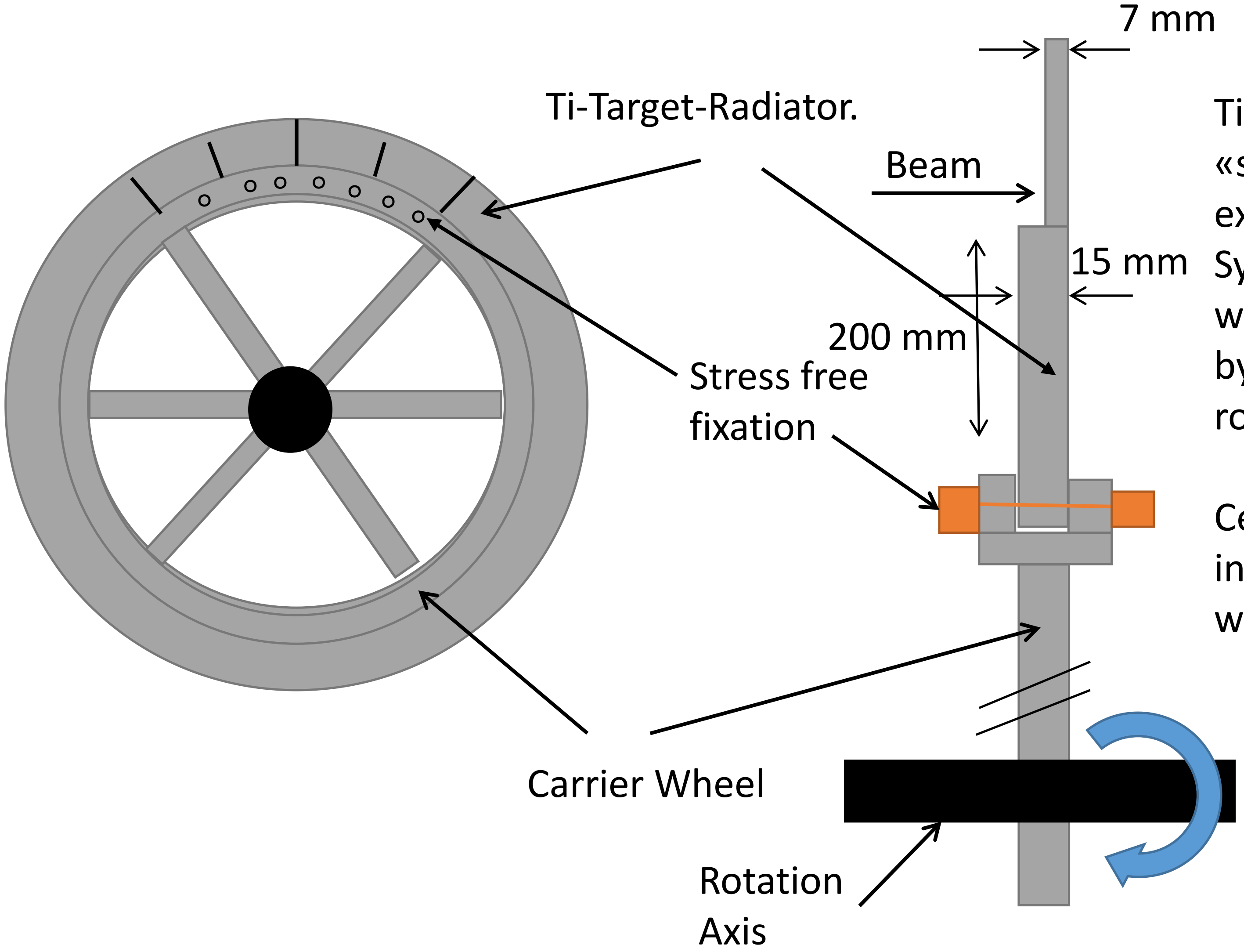
S. Riemann

Most of the power radiated between r=300-500 mm. Can reduce weight.

Increase radiating surface $R_a > R\ by + 2.5\ cm \div 40C^0$. Extend the target towards larger radius and increase the wheel thickness in the area outside the beam impact. This increases the effective radiating surface.

Increasing the effective radiating surface by a factor 2-3 could reduce the average temperature from 400 to 280-240 oC.

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.

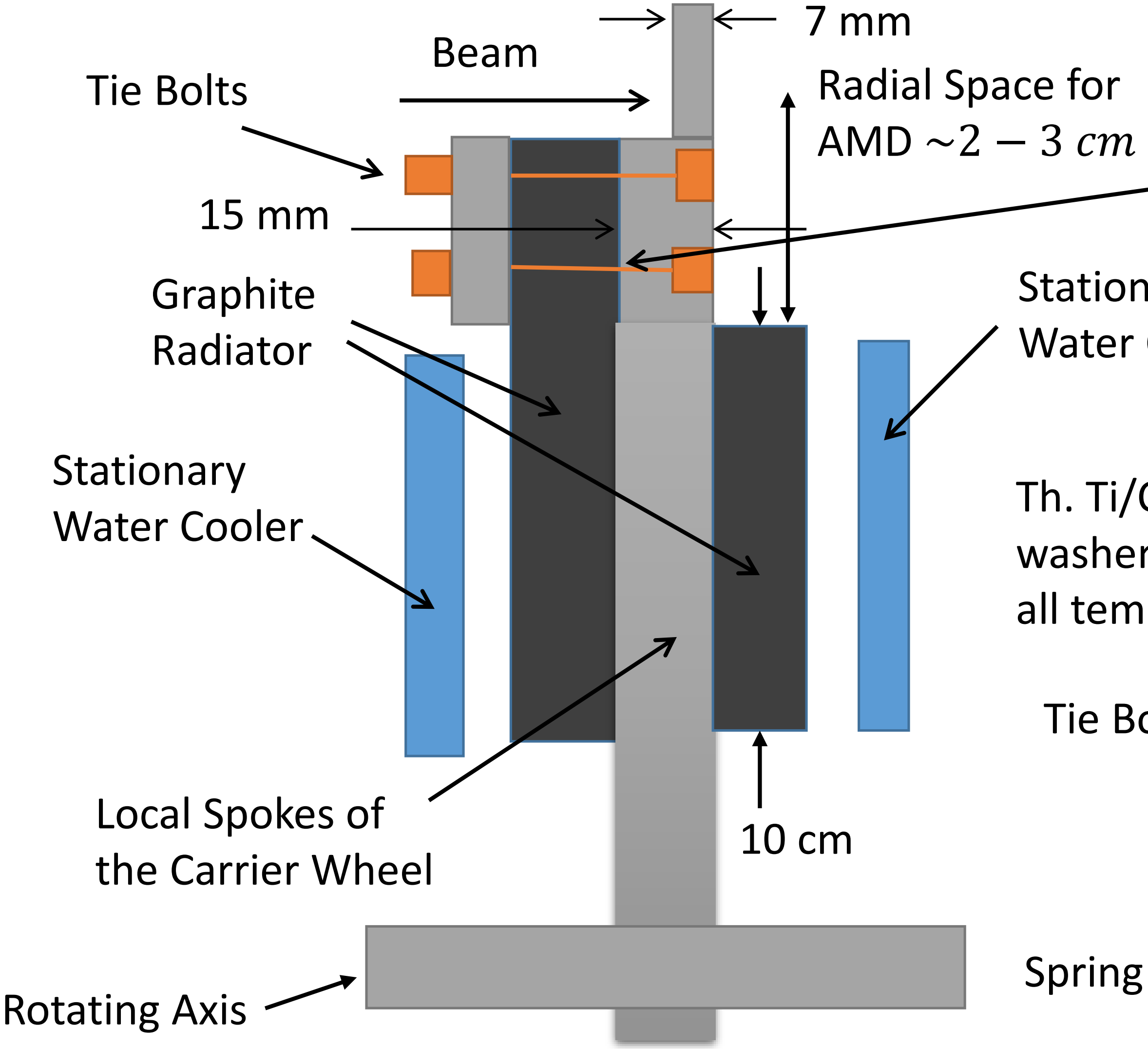
Centrifugal stresses in the Ti –target are well below 10 MPa.

Not to scale!

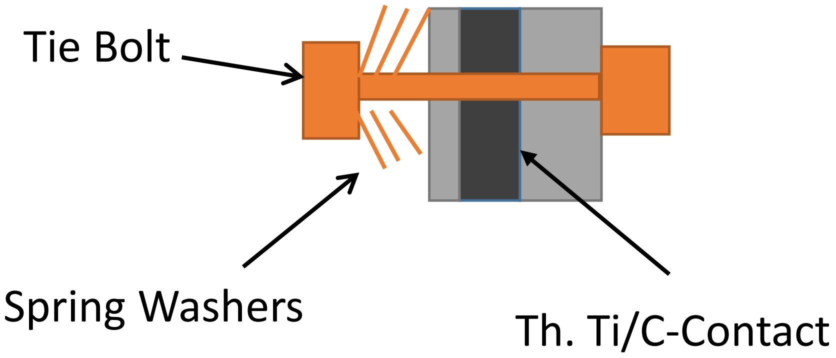
Further Improvements.

- Replace Ti-Radiating Part (low thermal conductivity, λ=0.07 W/cm K, and low emissivity, $\varepsilon \leq 0.5$), by Radiator with high thermal conductivity and emissivity: GRAPHITE.
- λ=1.6 W/cm K, $\varepsilon = 0.8$, Light material $\rho = 1.8\ g/cm^3$.
- Comment on Radiation Resistance of Graphite:
- In a thin Ti-window, 0.23 dpa were accumulated over 5000 h, when the beam is spread over a circle of 5 cm in diameter (tumbling window).
- On the target wheel, the beam is spread over a diameter of 100 cm!
- The Graphite is placed away from the beam impact!
- The lifetime of the Graphite will be much longer than the actual Ti-Target!

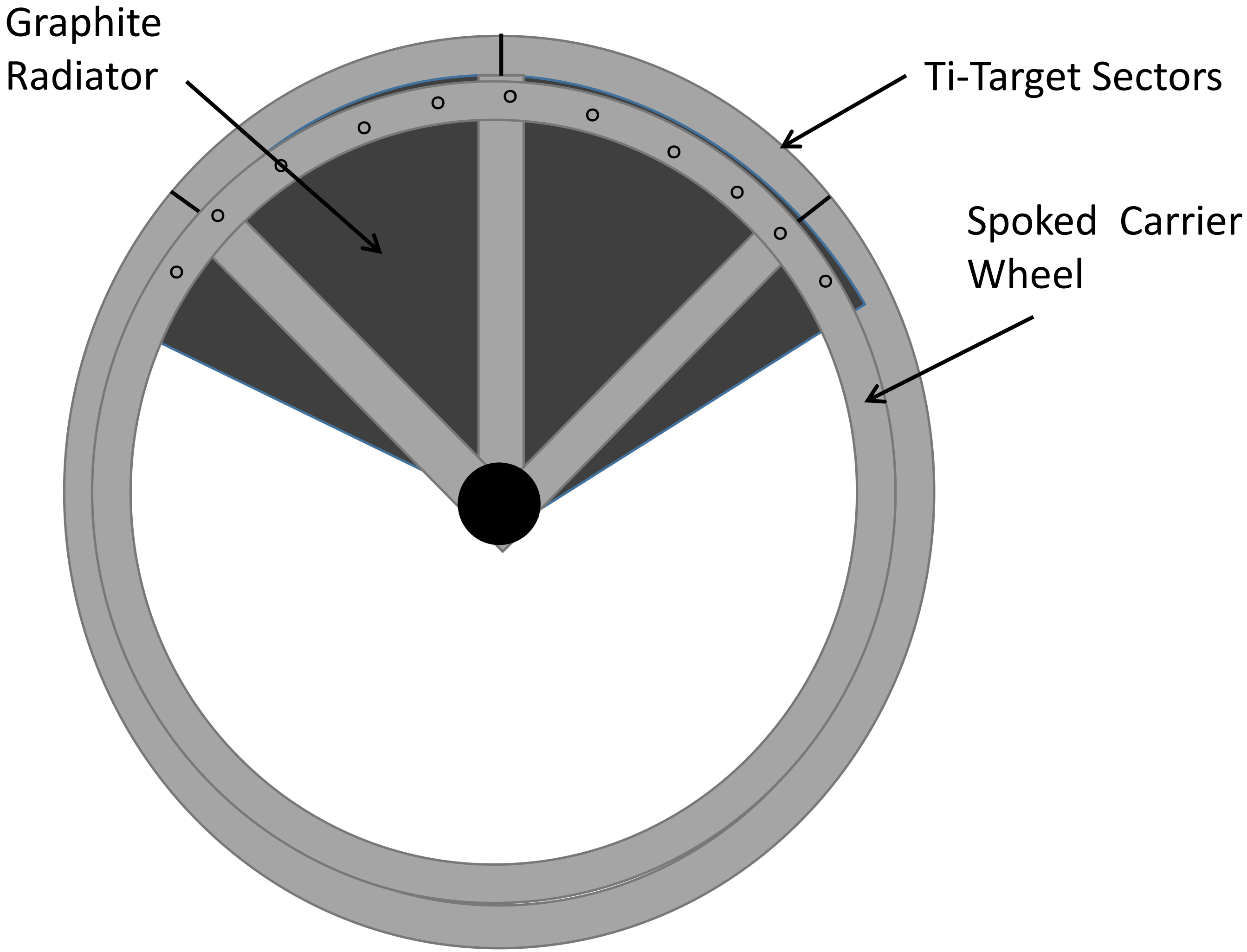
Replace Ti-Radiator by a Graphite Radiator: High Emissivity and Th. Conductivity.



Th. Ti/C-Contact by bolts with spring loaded washers: pressure of ~ 5 MPa maintained at all temperatures.



Undulator Wheel with Graphite Radiator, Downstream Side.

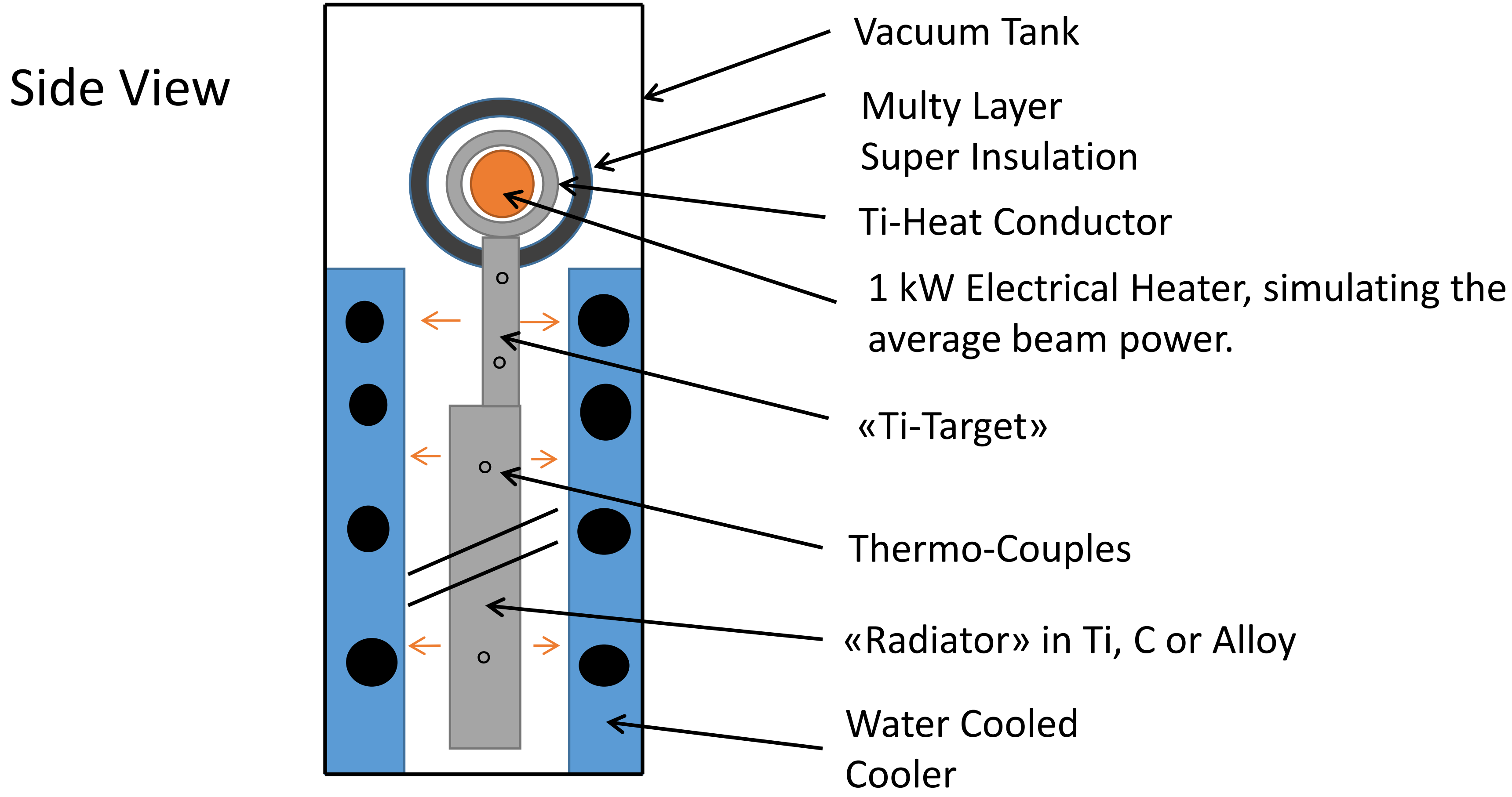


- Assume an Average Temperature in Ti and Graphite of 280 oC (580 K):
- Average Radiated Power: 0.4 kW(Ti) +1.7 kW(C)= 2.1 kW.
- However: To maintain the heat flow from the Ti into the Graphite Radiator, the Temperature in the Ti will be above the Average of the Graphite.
- This ΔT may well be aout 50-100 K, tbc by further simulation.
- Thus the power balance would be 0.7 kW(Ti)+1.7 kW(C)=2.4 kW.
- Weight of the Wheel: 40-50 kg.

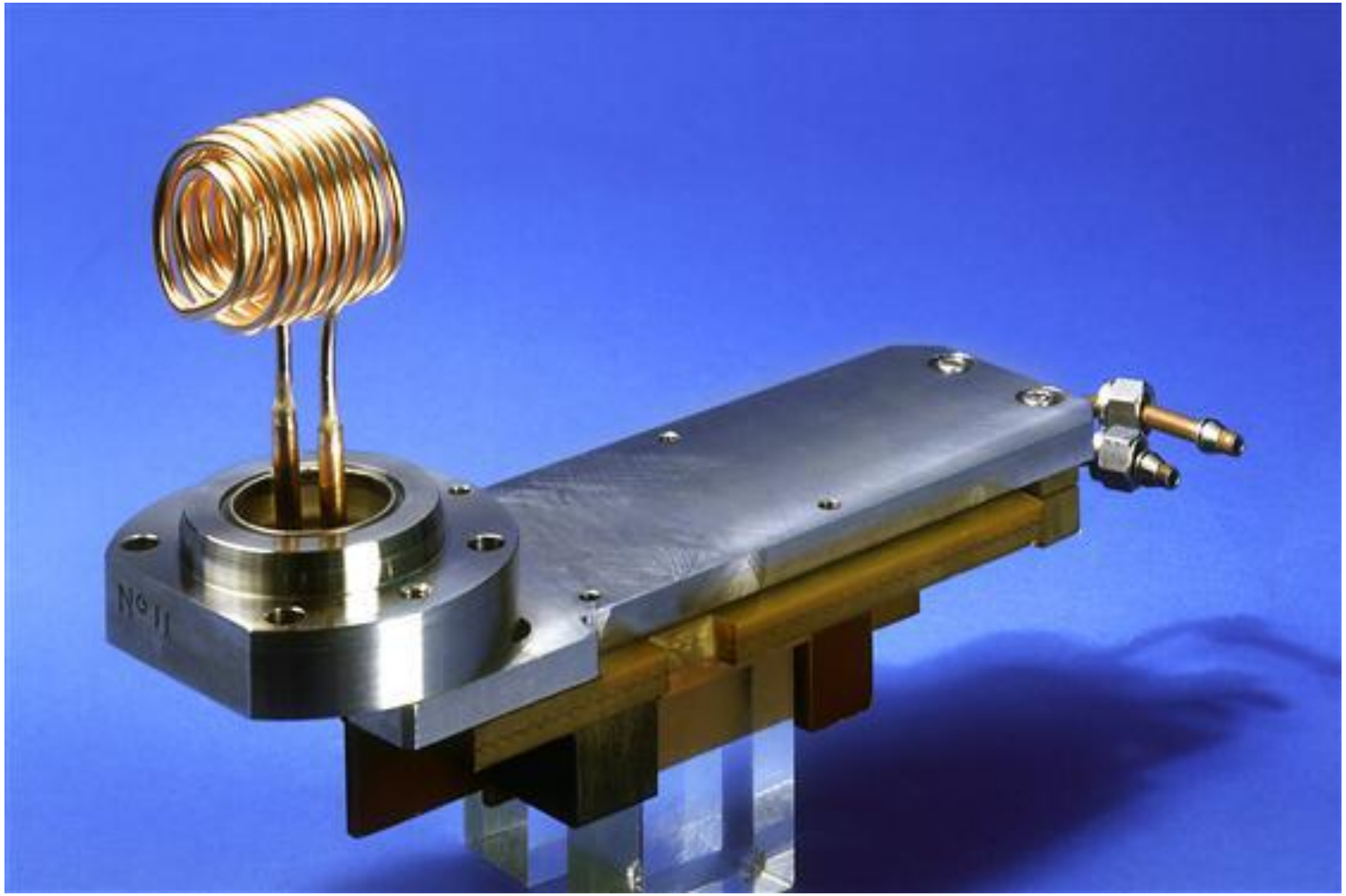
- Consider other Alloys as Target Materials: High Temperature Ni- and Co-Alloys.

- Density 8-9 g/cm^3 (2 x of Ti).
- Th. Conductivity $\sim x\ 2$ of Ti.
- Good Mechanical and Creep Resistance up to 800 oC and above.
- The equivalent Target Thickness (0.2 Radiation Length) would be $\mathrm{d}{\sim}3-4\ mm$.
- Could allow for higher Beam Power and for a more robust design?!
- Increasing the average temperature from 280 oC to 700 oC would increase the radiated power by a factor 9!
- However, the limit will be defined by the PEDD in the alloy at beam impact!

Laboratory Set Up for Test of Radiation Cooling of a Target Sector with different Radiators: Ti, C or Alloys.



2. Collection of Positrons by a Solenoid as an Adiabatic Matching Device AMD.

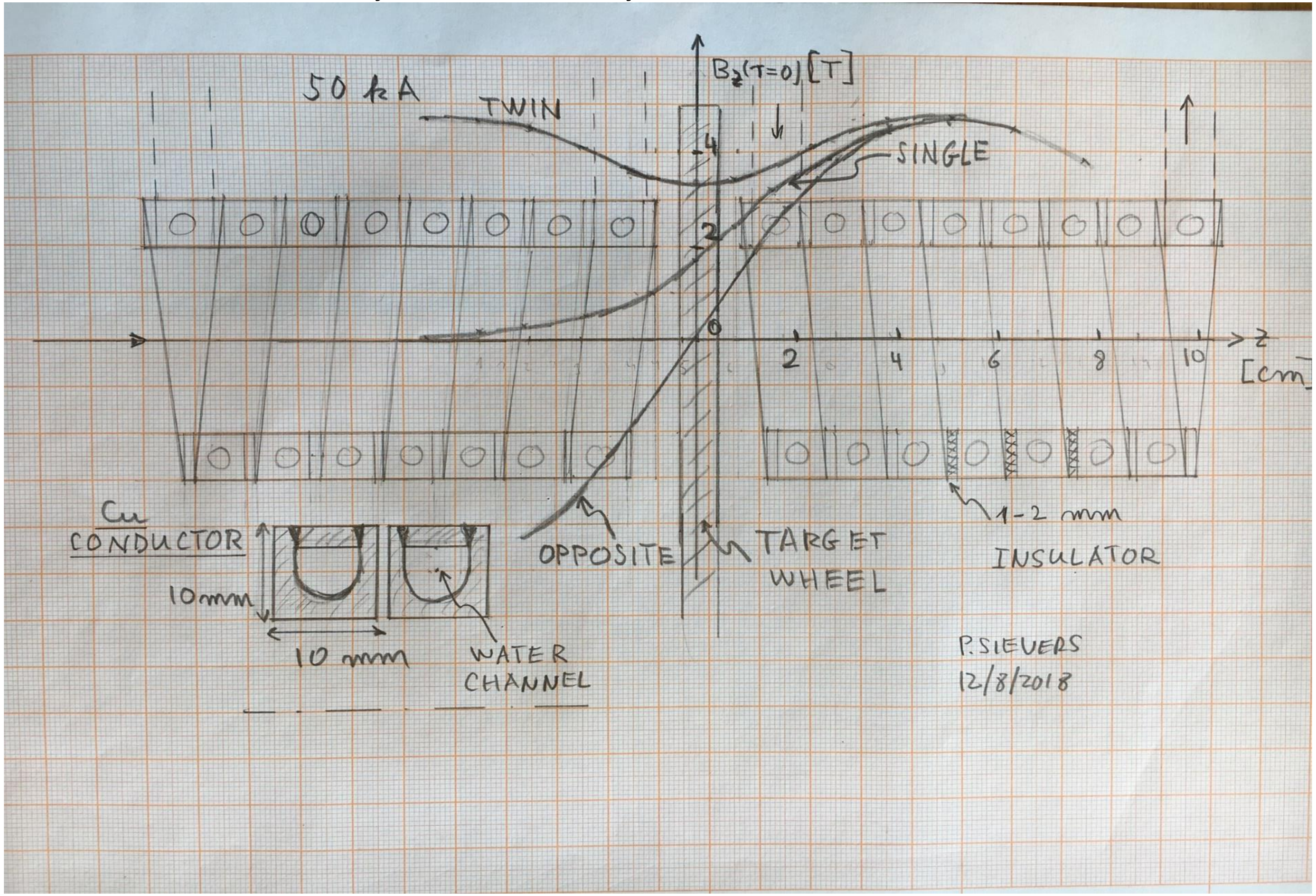


The LEP-Pulsed Solenoid- L. Rinolfi.
I=2.5 kA, Bo=0.83 T, 100 Hz with 20 μs.

A Pulsed Solenoid for the ILC-Undulator Target.

- The Magnetic Field must be stable during the Beam Pulse over 1 ms!
- This is difficult to achieve in a “classical” Flux Concentrator, due to the Time Varying Skin Effect in the Bulky Cu-Material (Ref. P. Martyshkin-BINP).
- Therefore the Radius R of the Cu-Cross Section of the Solenoid Conductor must be smaller than the Skin Depth δ from the Half Sine Current Pulse with a Duration τ: $\mathrm{R} \leq \delta$.
- For a Cu Conductor of 10 x 10 mm: τ= 4 ms and δ=6 mm is acceptable.

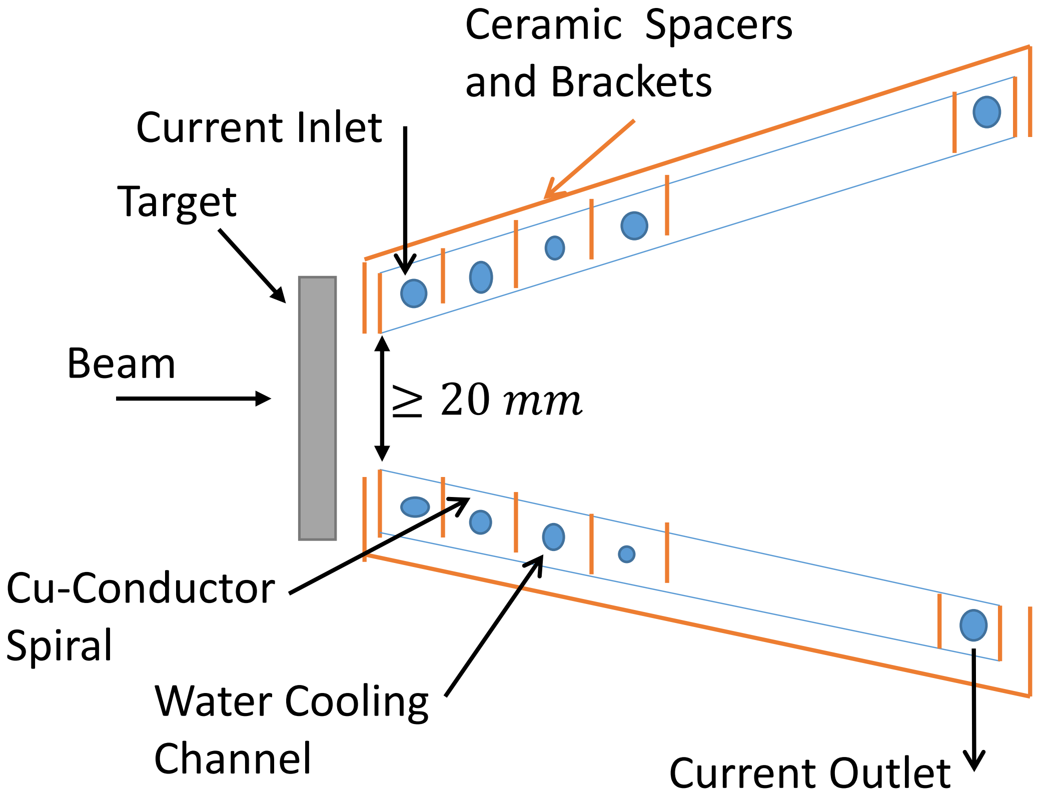
Aperture 4 cm, 50 kA, 7 Turns.



Electrical Parameters	Water Cooling Circuit	Temperatures of Conductor	Thermal and Magnetic Loads
Conductor 10 x 10 mm^2, Water Channel $\emptyset = 6\ mm.$	Water Flow 0.17 kg/s; v= 6 m/s.	El. ΔT/pulse= 4.8 K	$\sigma(el) \leq$ 10 MPa
Current Pulse: Half sine Pulse with $\tau = 4\ ms\ and$ 5 Hz.	Inlet Temperature 20 oC, Outlet 28 oC.	Av. El. Power density 83 W/cm^3.	$\sigma(magn) \leq 40\ MPa$
Skin Depth δ= 6 mm. δ/R=1.2.	Pressure Drop 6 bar.	Beam ΔT/pulse 35 K (At Entrance of Solenoid with a Diameter of 2. cm). Small for 4 cm.	$\sigma(beam)$ $close\ to\ limit$
Ohmic Resistance 0.23 mΩ.		Beam Power Density 609 W/cm^3 at Entrance.	Radiation Damage: 0.15 dpa/5000 h (Solenoid Diameter 2. cm).
Av. Power 6.0 kW. Power Density 83 W/cm^3.		Peak Temperature in Cu : 40 oC av+ 40 K pulsed	

Power Supply has still to be considered!

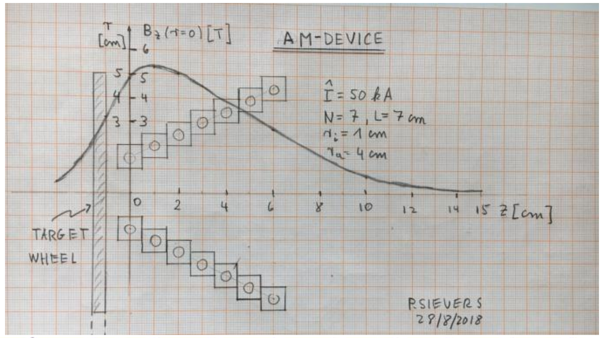
Conical Pulsed Solenoid



Solenoid Coils must be well constrained by a ceramic insulating Strucure, to resist to pulsed Magnetic Forces.

Magnetic field calculated by POISSON, Ref. Fukuda-san.

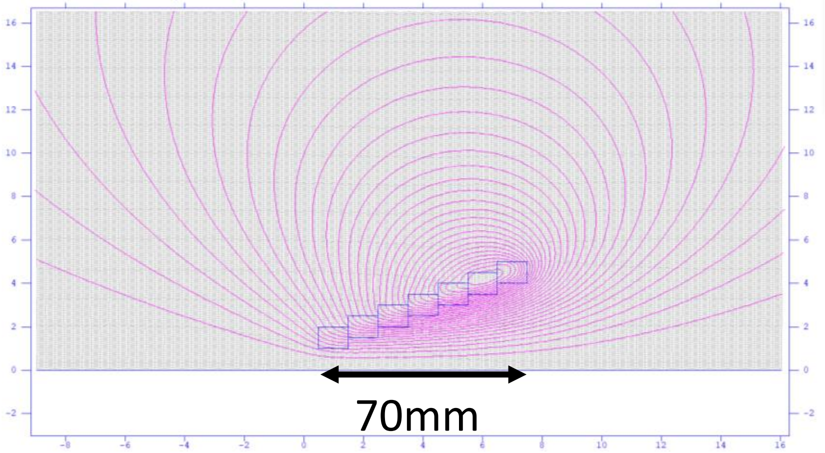
The magnetic field of the pulse solenoid was calculated by POISSON.
The coil current is 50kA.
The cross section of the coil is 10mm x 10mm square.



Field at the rear of the target 2.-2.5 T.
With an additional upstream solenoid could go up to 4 T.

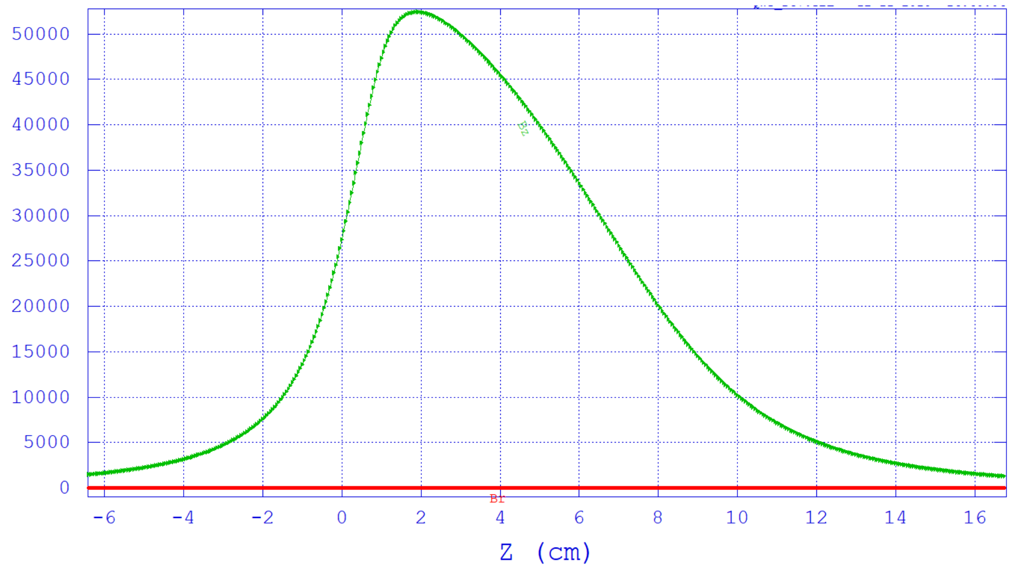
Flux Return to be considered!

Field of the FC is Dragged by the rotating Wheel. To be studied!



70mm

Bz on the Z-axis

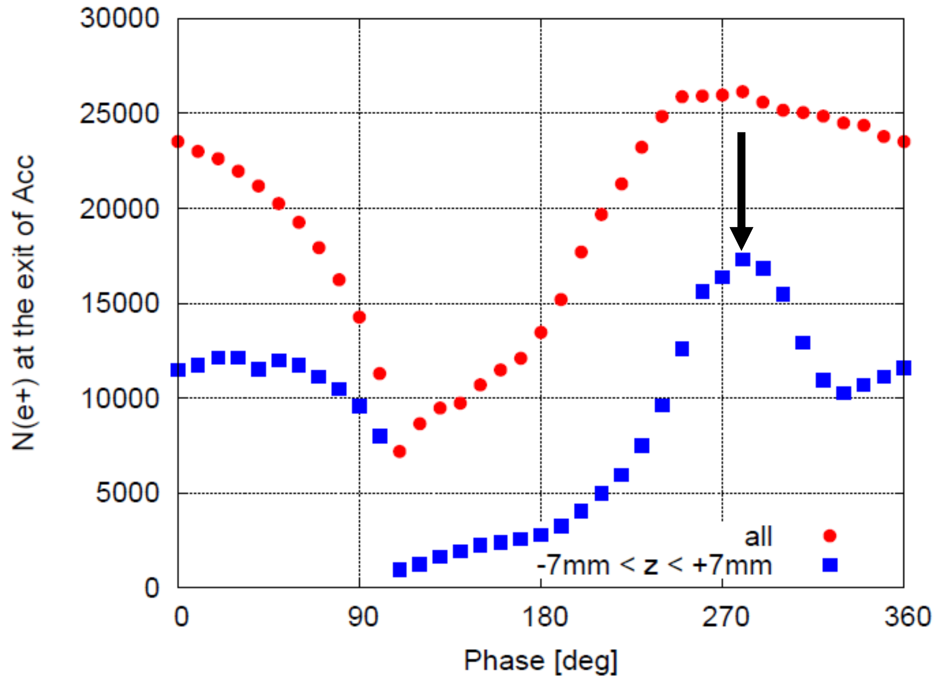


Z=0: Target rear surface

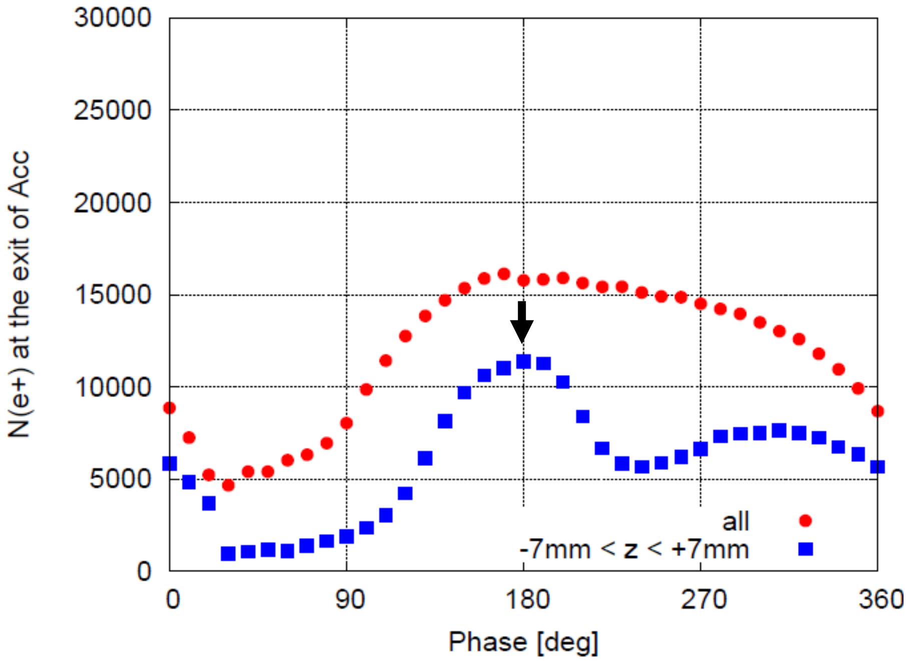
Number of positrons after acceleration (125MeV)

I scanned the phase of accelerating field to find the maximum point of number of positrons. The best phase is 280deg.
Number of positron has increased 1.5 times when the pulse solenoid is used.

Pulse solenoid (5.3T)



QWT (1.04T)



Power and Forces, induced in the Rotating Wheel by the Quasi Static Magnetic Field of the Pulsed Solenoid.

An axial field in rotational symmetry is assumed, similar to the field at the upstream side of a solenoid.

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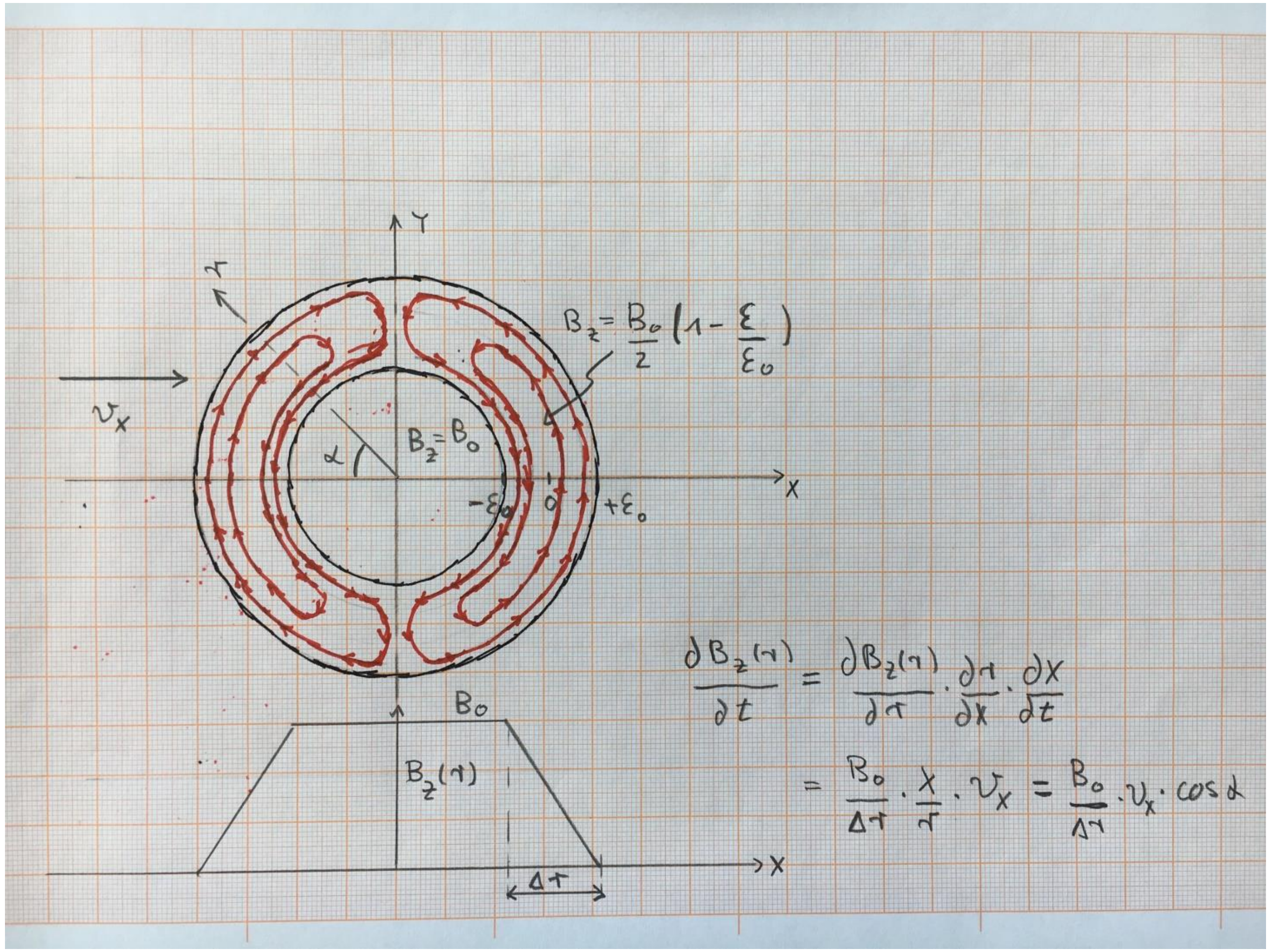
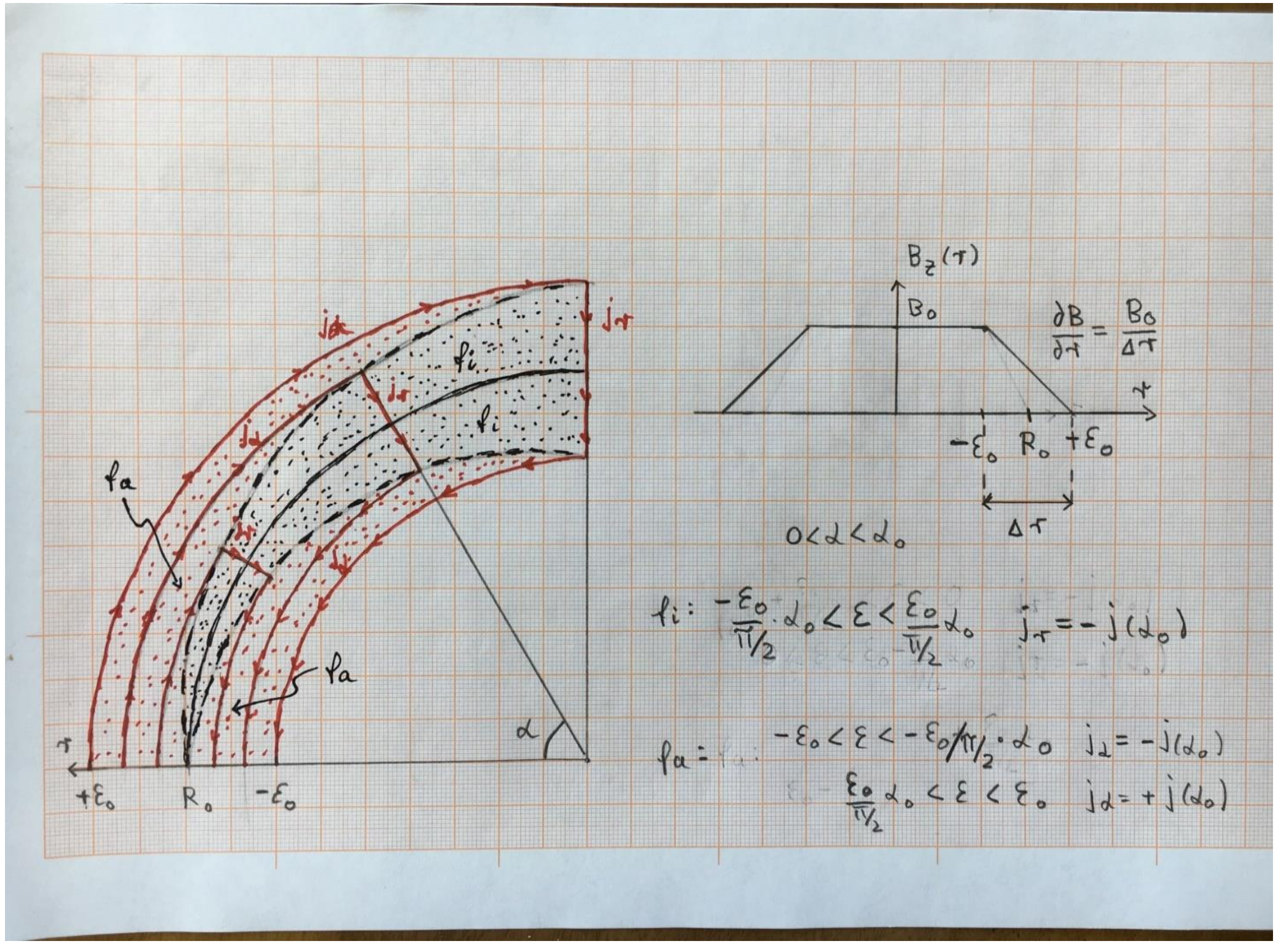
Principal Geometry and Magnetic Field



Induced currents, in red, only where $\partial B_r / \partial r \neq 0$



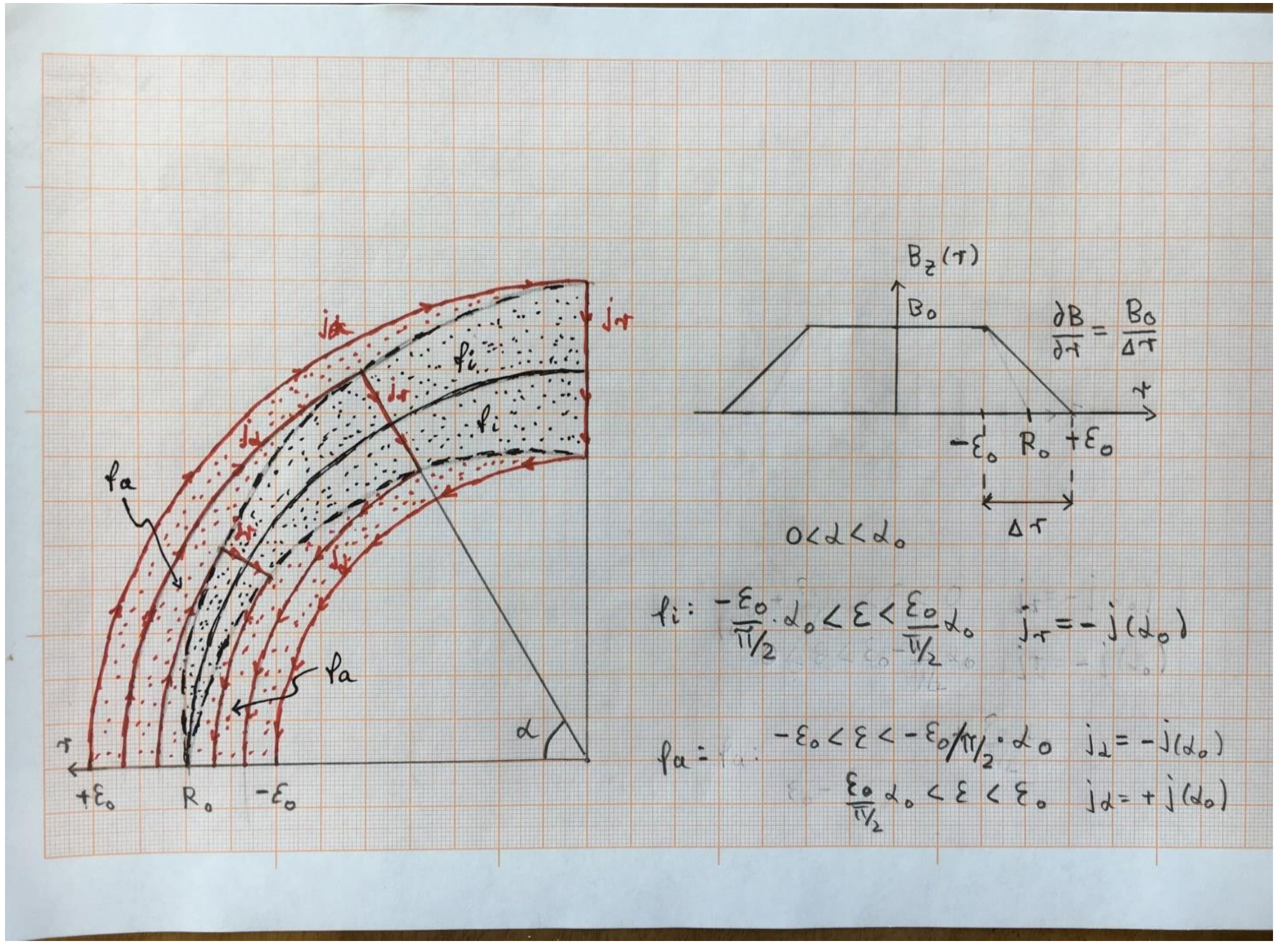
$Azimuthal\ j_{\alpha}$ inside red zone f_a, radial j_r inside black zone f_i.
Boundary between $f_i\ and\ f_a\ dashed\ line\ in\ black$.

Consider Cylindrical Symmetry.

- $\partial B/\partial t = \partial B/\partial r \cdot \partial r/\partial x \cdot \partial x/\partial t$
- $\frac{\partial B}{\partial t} = \frac{\partial B}{\partial r} \cdot \cos(\alpha) \cdot v$, $\frac{\partial B}{\partial r} = \frac{B_0}{\Delta r} = \frac{B_0}{2\varepsilon_0} = const.$
- $\partial\emptyset/\partial t = \partial/dt \int B\, df$.

- *Define the surface f enclosed by the path s of each current loop $j(r,\alpha)$.*
- *Use the j -patterns as suggested in the Fig. below.*
- *Is this close enough to comply with rot(j)~$\partial B/\partial t$? Tbc.*

- $\partial\emptyset/\partial t = B_0/\Delta r \cdot v \cdot \int_0^{\alpha} \int_{r_n}^{r_m} \cos\alpha\, r\, dr\, d\alpha \cdot$,
- $r_{n,m} = r_0 \pm \varepsilon_0 \alpha/(\pi/2)$
- $j = \partial\emptyset/\partial t \cdot \sigma \cdot \frac{1}{\oint ds} = K \cdot \sigma \cdot f(\alpha)/\alpha$ *(Ohm's Law)*
- $K = B_0\, v/\pi(1 + \varepsilon_0/(r_0\pi/2)$*)*, $f(\alpha) = \cos\alpha + \alpha\, sin\,\alpha\, - 1$



$Azimuthal\ j_\alpha$ inside red zone f_a, radial j_r inside black zone f_i.
Boundary between $f_i\ and\ f_a\ dashed\ line\ in\ black$.

- Power induced in ¼ sector: $\mathrm{w} = 1/\sigma \cdot \int j^2\, dV \sim B_0^2 \cdot v^2 \cdot \sigma \cdot g(r_0, \varepsilon_0, z)$. *This is the power deposited by a d.c. magnetic field.*
- B_0 *Peak Field*, v *Velocity*, σ *El. Conductivity*, g *describes the zone where* $\partial B/\partial r \neq 0$, z *Target Thickness*.
- *With Pulse Durations of 4 ms at 5 Hz, the Duty Cycle is only 1%.*
- *Thus the average power, deposited by the pulsed Magnetic Field in all four quarters is* $W_p = 4 \cdot 0.01 \cdot w$.
- *Plug in parameters :* $B_0 = 4\, T$, $v = 100\, m/s$, $r_0 = 1.5\, cm$, $\varepsilon_0 = 0.5\, cm$, $z = 0.7\, cm$, $\sigma = 5.3\; 10^5 \frac{A}{Vm}$.

- Average power during the electrical pulse of 4 ms is W=2.8 kW.
- Time average power is only: 2.8 $kW \cdot 4$ ms/200 ms = 56 W. This is small compared to the average beam power of about 2 kW.
- El. Powers of up to 200 W should be acceptable.
- This allows for some margin for the shape and size of the magnetic field. For larger radial extensions r_0 of the magnetic field , the power increase with $\sim r_0^2$.

Mechanical Response of the Wheel to the Pulsed Magnetic Braking.

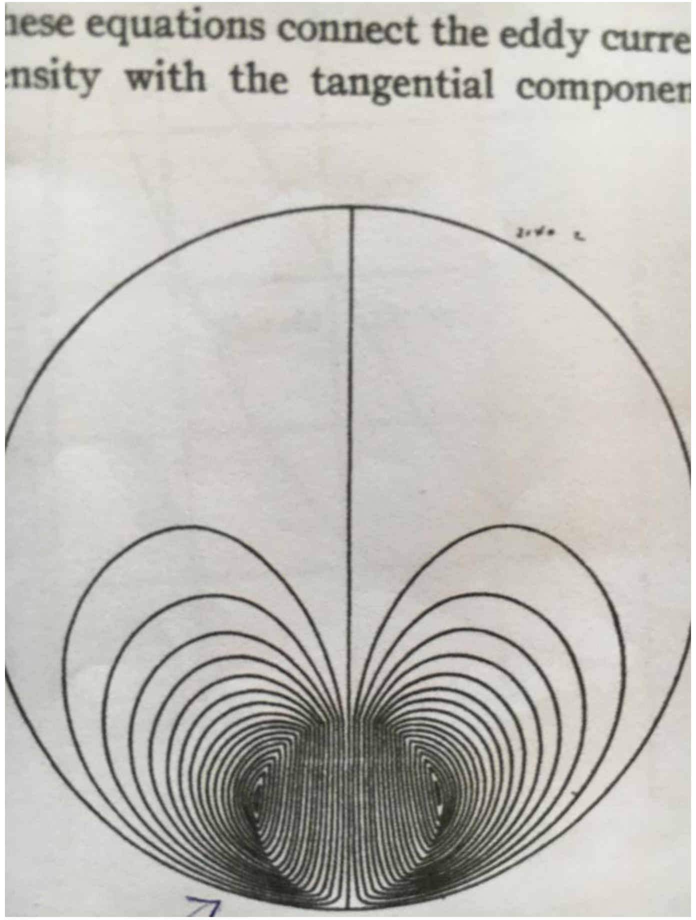
- The energy per pulse E_p, deposited as heat in the wheel, will lead to its braking: $E_p = W \cdot \tau = 2.8\ kW \cdot 4\ ms = 11.2\ J$/pulse.
- The energy E_W, stored in the fast rotating wheel, is about 0.6 MJ.
- $E_p \ll E_W : E_p/E_W = 18.7\ 10^{-6}\ per\ pulse$.
- So, the “knocking” by each single pulse on the wheel or transmitted to its axis and the change in rotation velocity will be small.
- However, over longer durations of say 100 s, 500 kicks, such effects will accumulate to $\sim 1\ \%$, and an on-line control of the velocity will be necessary.

3. Conclusion.

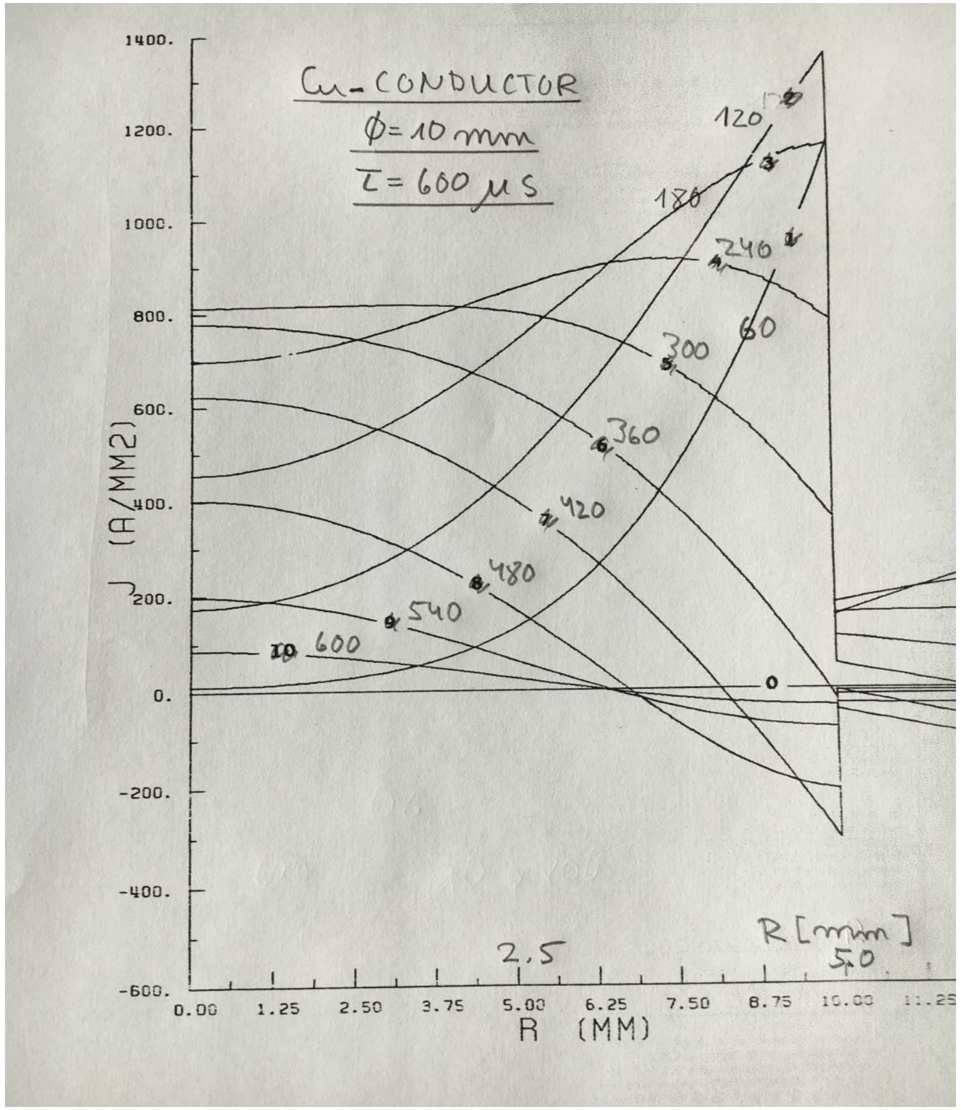
- Based on the initial studies of the temperatures and cooling by radiation of the Ti-target wheel (Ref. S.Riemann et al.), some design aspects have been revisited:
- Reduction of the weight of the target.
- Proposals to improve the cooling by more efficient radiators:
- Increase the diameter and thickness of the Ti-wheel at the location beyond the beam impact.
- Use Graphite or high temperature alloys.
- These considerations must still be verified by simulations and validated by experimental laboratory tests.

- For the Adiabatic Matching Device, AMD, a solenoid, pulsed at 5 Hz is proposed.
- With a 4 ms current pulse, a sufficiently stable magnetic field can be achieved over the duration of the beam pulse of 1 ms.
- With 50 kA pulses, magnetic fields close to the target of about 4 T can be reached.
- The engineering and cooling of this solenoid looks possible.
- The power and forces, induced by the pulsed solenoid in the fast rotating Ti-wheel, are tolerable.
- The pulsed network has still to be designed.
- The field qualiy and its imperfections have to studied in detail.
- These are very important issues for the positron yield.

Thank You for Your Attention.



Backups



Cu-CONDUCTOR
ϕ= 10 mm
τ = 600 μs
J (A/MM2)
R (MM)
R [mm]
1400.
1200.
1000.
800.
600.
400.
200.
0.
-200.
-400.
-600.
0.00
1.25
2.50
3.75
5.00
6.25
7.50
8.75
10.00
120
180
240
300
360
420
480
540
600
60
2.5
5.0

Some Old Style Wheels.