A Geometry for a Rotating Solid Target for a Neutrino Factory

K. McDonald, *Princeton U.* (Nov 3, 2009)

Total length of W target, *A + B*, should be so long that unspent proton beam hitting the magnet has flux comparable to that of the secondary pions.

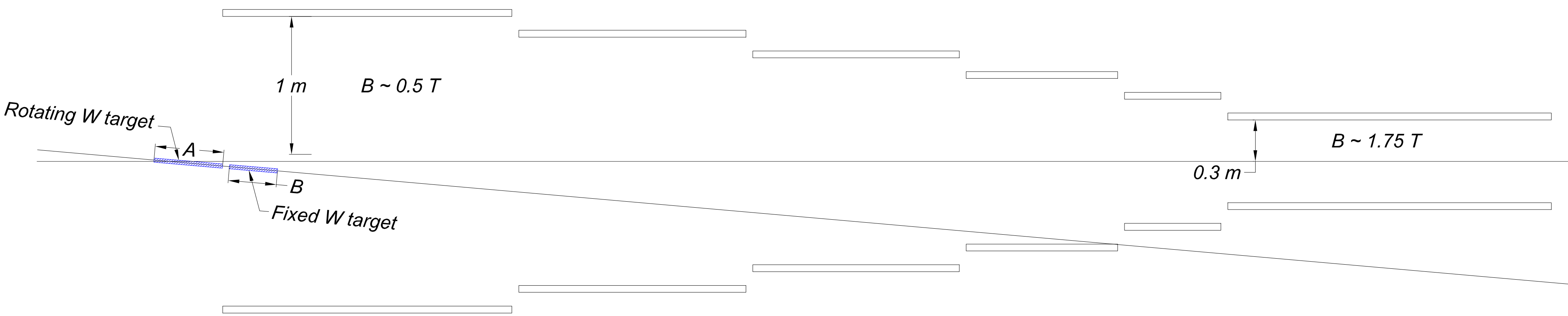
If need, say, $N = 200$ targets on the rotating wheel (axis parallel to the magnetic axis) to limit the radiation damage, then $A \approx 10\,\mathrm{cm} \cdot \ln(N) \approx 50\,\mathrm{cm}$.

Proton beam coaxial with target, and both tilted so the proton beam does not hit downstream beam window.

Target should be in magnetic field for good capture, but the field can be weak, say 0.5 T.

- Taper magnetic field from 0.5 T to nominal 1.75 T of pion transport solenoid.
- Rotating target can be upstream of first magnet
- Low field ⇒ long period for pion helices ⇒ reabsorption a minor issue.
- Target diameter can perhaps be larger than 2 cm

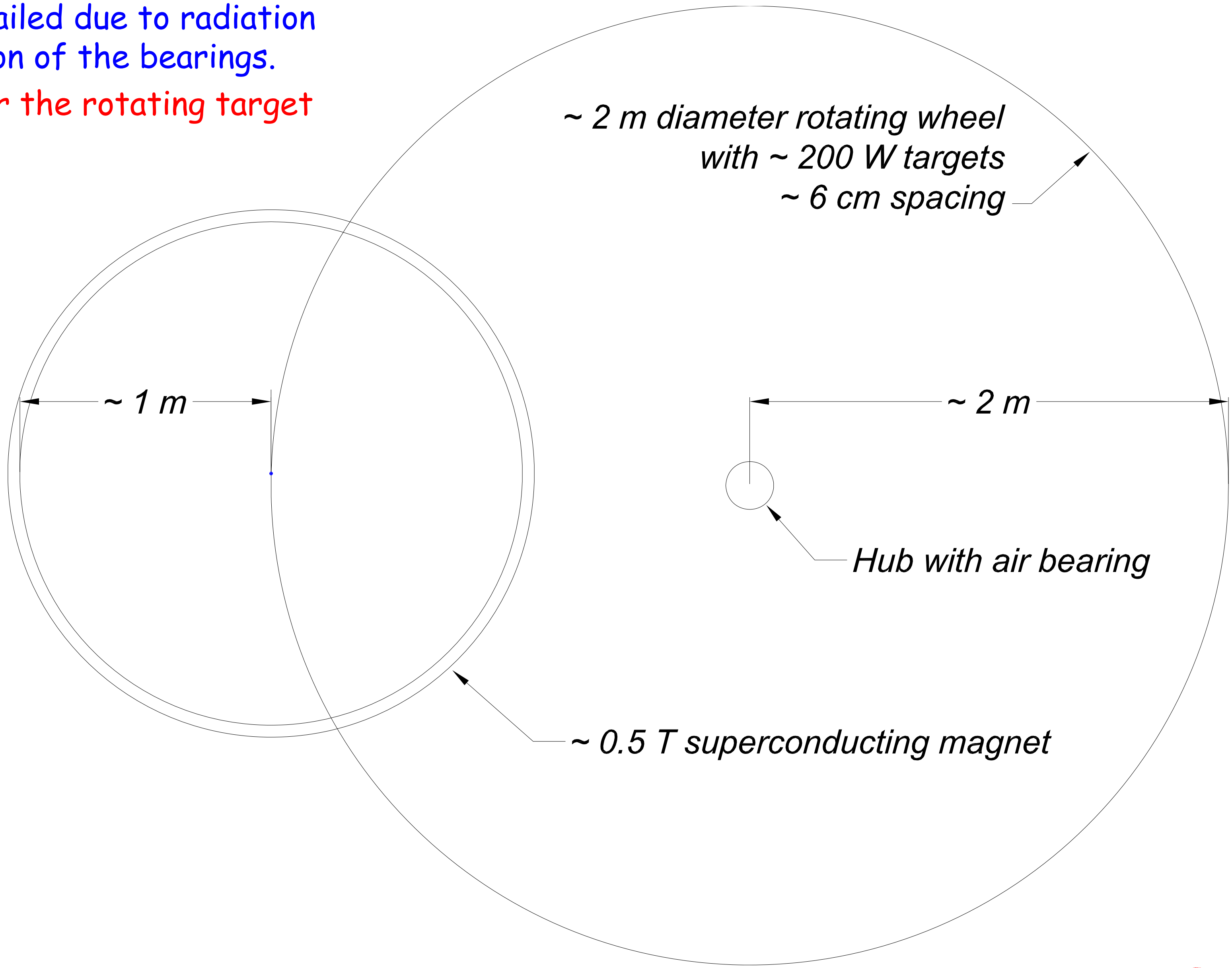
Serious flaw: For a pion transport channel of given *B* and *r*, the longitudinal-transverse momentum exchange due to the adiabatic invariant $r\,p_\perp$ implies that $p_\perp / p_{\perp 0} = (B/B_0)^{1/2}$ strongly favors use of B_0 much larger (not smaller) than *B* for maximal capture of pions.



Rotating Target Wheel Should Have an Air Bearing

CNGS rotating target failed due to radiation damage to lubrication of the bearings.

⇒ Use an air bearing for the rotating target wheel.



The Capture Solenoid as a Pseudo-Emittance-Reducing Element

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The Adiabatic Invariant of a Helical Orbit

If a particle is produced with transverse momentum $p_{0\perp}$ inside a solenoid of magnetic field strength B_0, then its trajectory is a helix of radius $R_0 = c\, p_{0\perp} / e\, B_0$ (in Gaussian units).

If the particle is produced close to the axis of the solenoid, then its maximum radius with respect to the magnetic axis is $2R_0$.

The magnetic flux through this helix is $\Phi_0 = \pi R_0^2 B_0 = \pi c^2 p_{0\perp}^2 / e^2 B_0 \propto 1 / B_0$ for a given transverse momentum.

If the solenoidal magnetic field is varied "slowly" with position, the motion of the particle has an "adiabatic invariant", $R\, p_\perp \propto \Phi_0$, where r = radius of helix (and not the radial coordinate of the particle with respect to the magnetic axis.

Pseudo-Emittance

Thus, use of a higher capture field implies a lower invariant quantity $R\, p_\perp$, which has the dimensions of a transverse emittance.

But $R\, p_\perp$ is not THE transverse emittance (and a magnetic field alone cannot reduce the true transverse emittance).

However, the quantity $r\, p_\perp$ is a kind of "pseudo-emittance" of practical relevance to the design of the magnetic transport system, such that a high field B_0 in the capture solenoid reduces the "pseudo-emittance" of the system.

Effect of Adiabatic Tapering of the Capture Field If No Pion Decay

If the field is reduced slowly from B_0 in the capture solenoid to B in the decay/cooling channel, and the pions didn't decay, the helical trajectory inside the cooling channel obeys
$e R^2 B / c = R p_\perp = R_0 p_{0\perp} = c^2 p_{0\perp}^2 / e^2 B_0$.

If the system is designed to accept particles up to a given $p_{0\perp}$, then the radius and magnetic field of the decay/cooling channel obey $r^2 B \propto 1 / B_0$ (recalling that $r = 2R$).

Hence, use of a larger field B_0 in the capture solenoid permits reduction of either r or B (or both) in the decay/cooling channel (⇒ cost savings, and increased technical feasibility).

Effect of Pion Decay

When pions decay to muons, $\pi \to \mu\nu$, the muons have 30 MeV/c momentum in the rest frame of the pion. [$p^*_\mu = E^*_\nu = (m_\pi^2 - m_\mu^2) / 2 m_\pi$], and 110 MeV energy [$E^*_\mu = m_\pi - E^*_\nu$].

Roughly speaking, the transverse momentum of the muon just after its creation by pion decay can differ from the pion's transverse momentum by 30 MeV/c in any transverse direction.

In the worst cases, the helix of the muon extends out to larger distance from the magnetic axis than that of the parent pion, and so the radius of the decay/cooling channel must be larger to maintain good acceptance.

As noted by Bob Palmer, this effect is mitigated if the pions decay in a region of stronger magnetic field, since the adiabatic invariant can also be expressed as $p_\perp^2 / B = p_{0\perp}^2 / B_0$.

This suggests that we should consider operating the decay channel at a magnetic field intermediate between that of the capture solenoid and the cooling channel (whose field could well be lower than that considered in Study 2 if the capture solenoid field is higher).

IDS-NF Target Studies

Follow-up: Engineering study of a CW mercury loop + 20-T capture magnet

- Splash mitigation in the mercury beam dump.
- Possible drain of mercury out upstream end of magnets.
- Downstream beam window.
- Water-cooled tungsten-carbide shield of superconducting magnets.
- HTS fabrication of the superconducting magnets.
- Improved nozzle for delivery of Hg jet