Positron Sources and Beam Dumps for the International Linear Collider-ILC

International HiRadMat Workshop
10-12 July 2019
CERN

Peter Sievers (CERN-Retired)

Outline

1.-Introduction

2.- e-Driven Positron Source

3.-Undulator Driven Positron Source

4.-Dump of the Photon Beam from the Undulator

5.-Main Dumps of the spent e- and e+ beams

6.- Comments and Conclusion

1.: Introduction: The International Linear Collider-ILC.

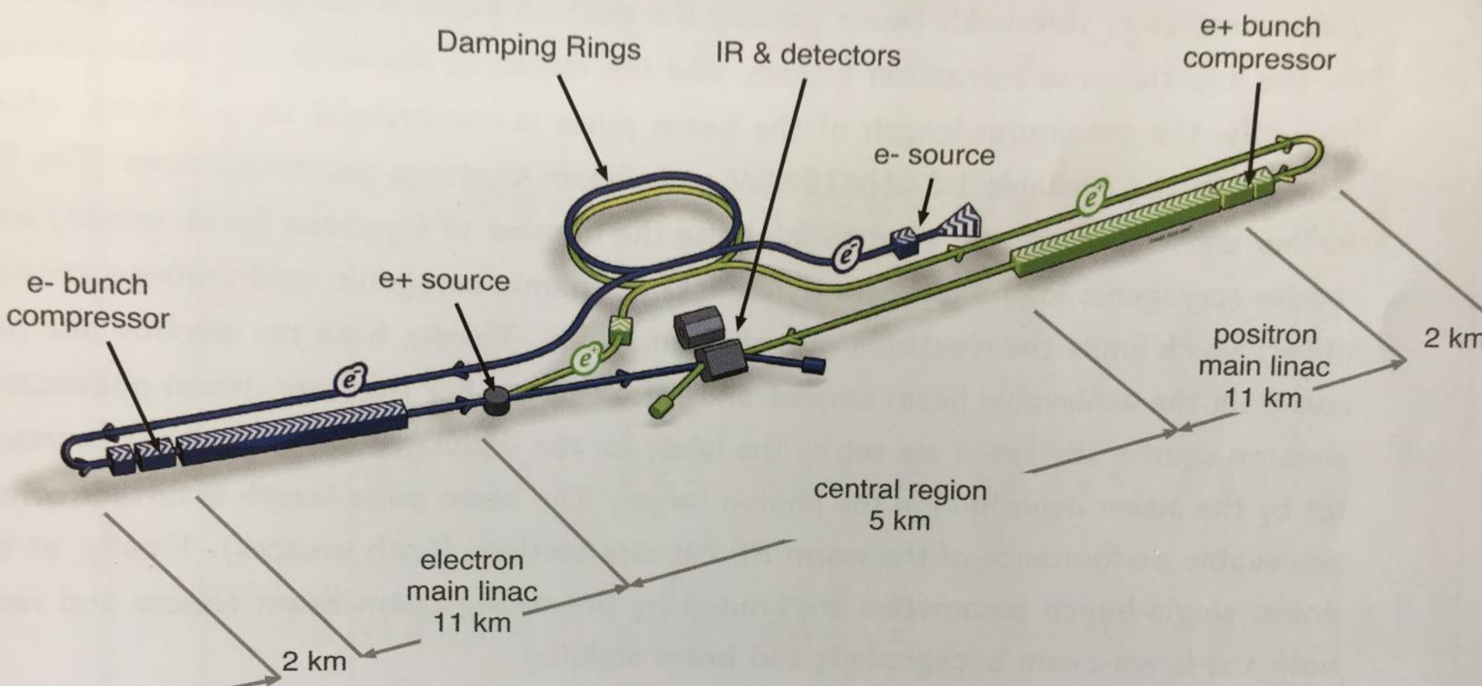


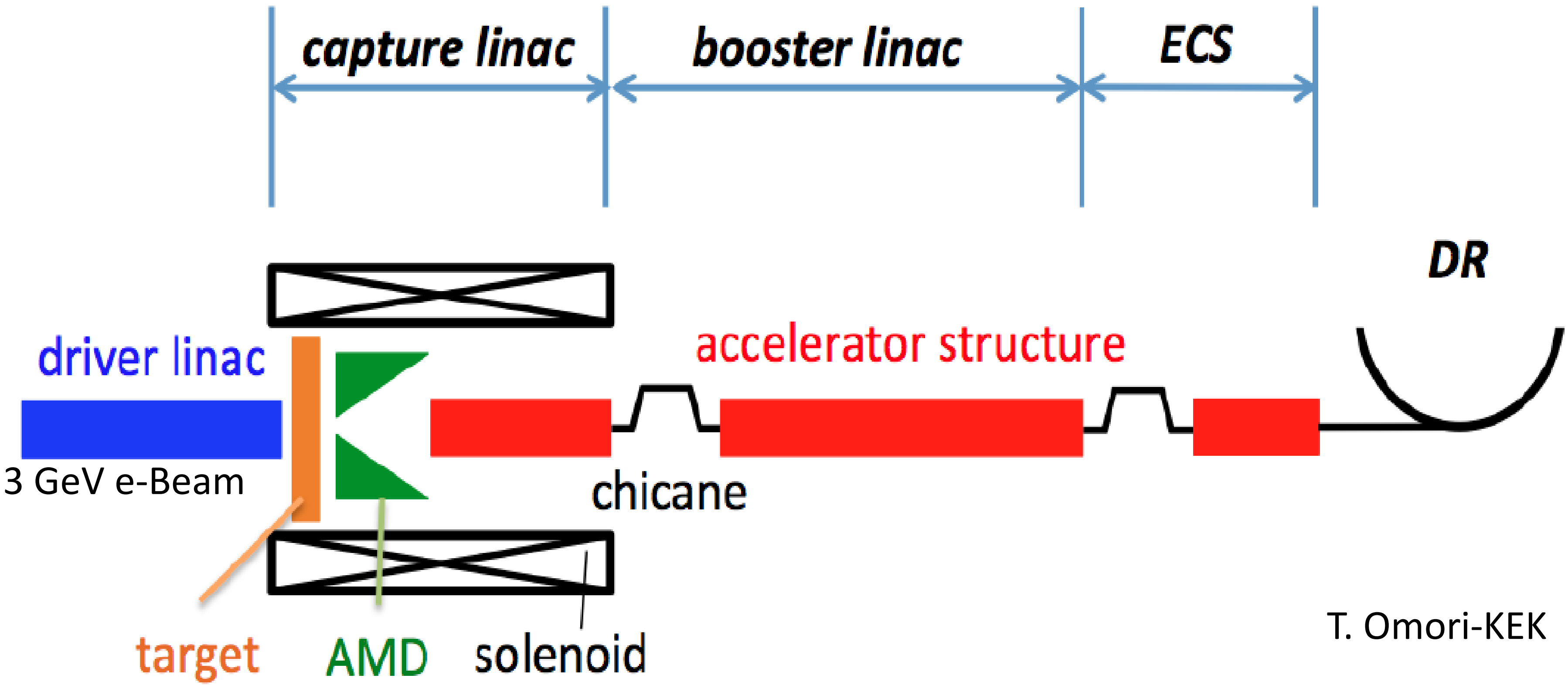
Figure 3.1. Schematic layout of the ILC, indicating all the major subsystems (not to scale).

- a polarised electron source based on a photocathode DC gun;
- a polarised positron source in which positrons are obtained from electron-positron pairs b converting high-energy photons produced by passing the high-energy main electron bean through an undulator;

Some Machine Parameters

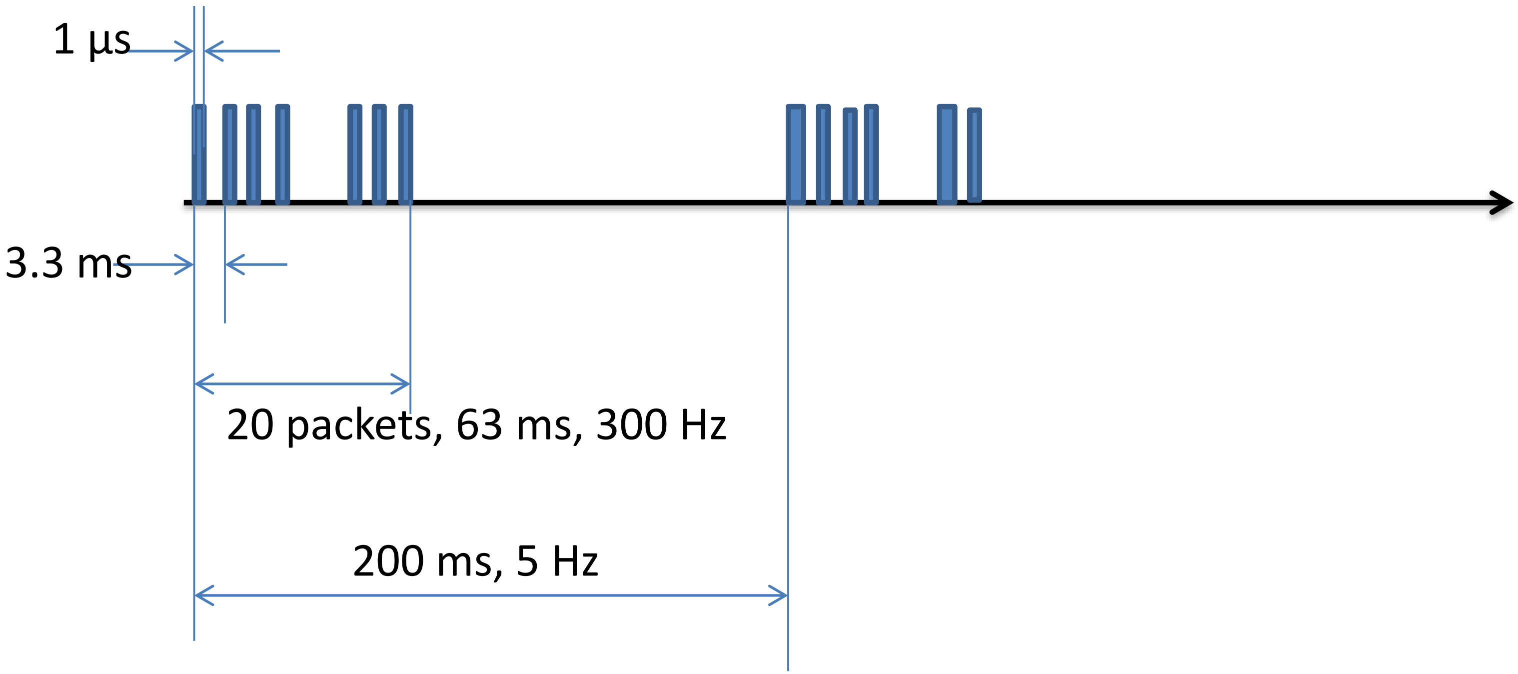
- Centre-of mass energy: 250-500 GeV
- Collision rate: 5 Hz
- Number of bunches: 1312-2625
- Bunch population: 2 x 10^{10}
- Average beam power: 17 MW (tbc).
- Positron source: e-driven and/or Undulator driven.
- Polarisation: 80% for e-; 30% for e+ (with Undulator).
- Luminosity: 1-2 x 10^{34} (tbc).

2.- e^{-}-Driven Positron Target



T. Omori-KEK

Pulse Structure for the Conventional e-driven Target



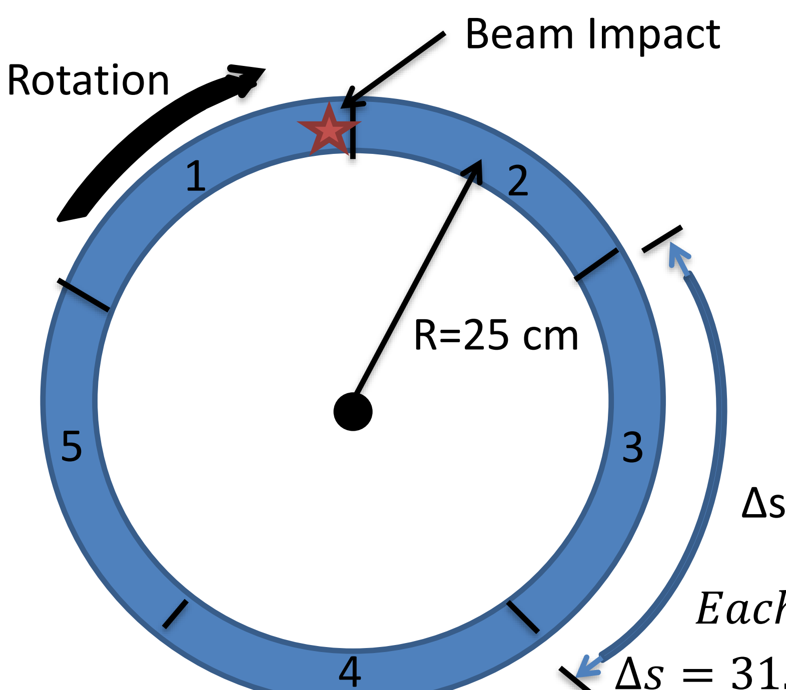
T. Omori-KEK

Design Parameters for the e-driven Positron Source (t.b.c.).

- e-Beam: 3-5 GeV, $4 \cdot 10^{13}$e- in a 63 ms burst at 5 Hz.
- Positron yield: about 1.5 e+/e- and 1-3 10^{14} e+/s.
- Each 1 µs pulse causes thermal shock. No pile up between pulses at 3.3 ms.
- Beam size of 4-5 mm cross section: PEDD of 20-35 J/g, thermal stress $\leq$ 500 MPa due to each 1µs pulse in the 1.4 cm thick W-Target.
- Average power in target: 20-35 kW. Water cooling.
- To avoid pile up of temperature jumps and stresses, a rotating, watercooled W-wheel is considered.
- Nearly all of the incident beam power of $\sim 60\ kW$ is deposited in the vicinity of the target station: very high radiation area!

T.Omori-KEK

Rotation of the Wheel



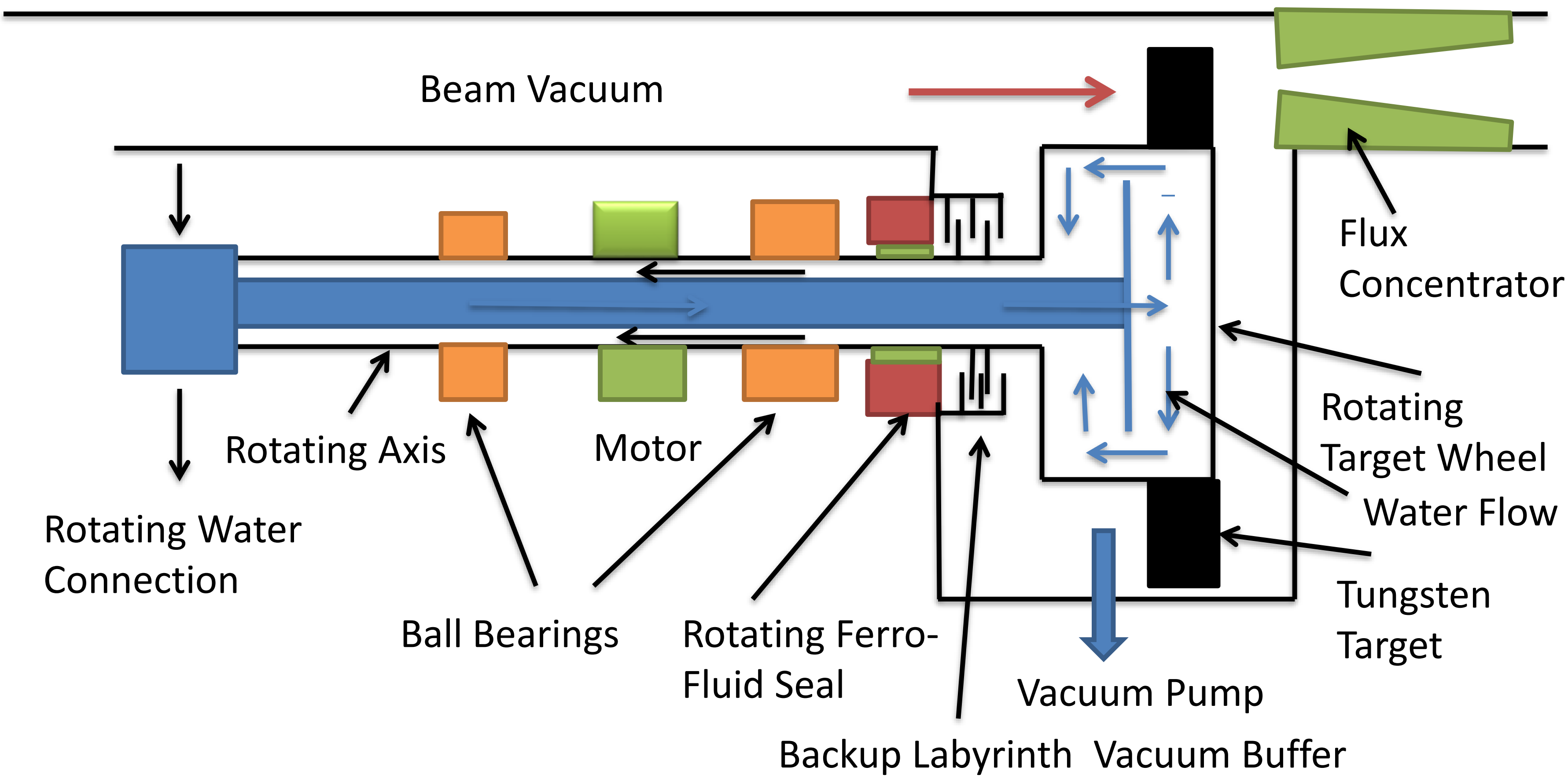
$v \sim 4 - 5\ m/s$ is required

Avoid that rotation frequency is in phase with beam frequency.
With $v = !\,4.7\ m/s$, the five equal sectors Δs are hit in sequence: 1,3,5,2,4,1,3,….
Each sector is hit once per second.

$Each\ burst\ of\ 63\ ms\ is\ spread\ over$
$\Delta s = 31.4\ cm = {}^{1}/_{5}\ \ of\ the\ circumference.$

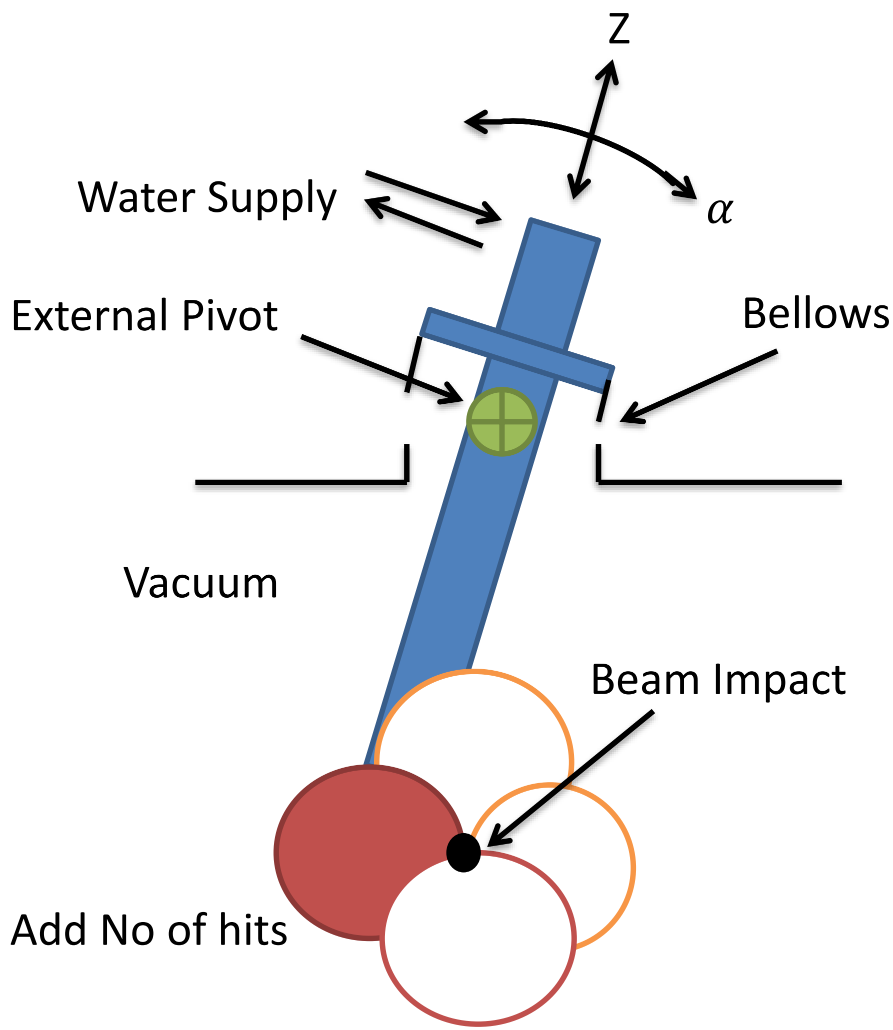
The average steady state target temperature is $\leq 450\ \ C^0$ and the temperature spikes are ≤ 250 K.
Scaling from SLC positron target, a sufficient lifetime for the ILC target can be expected.

Water Cooled e-Driven Target Wheel



Critical Issue of Rotating Seal: Leak tightnes for UHV. Radiation resistance and radiochemistry of iron powder in oil, and permanent magnets.

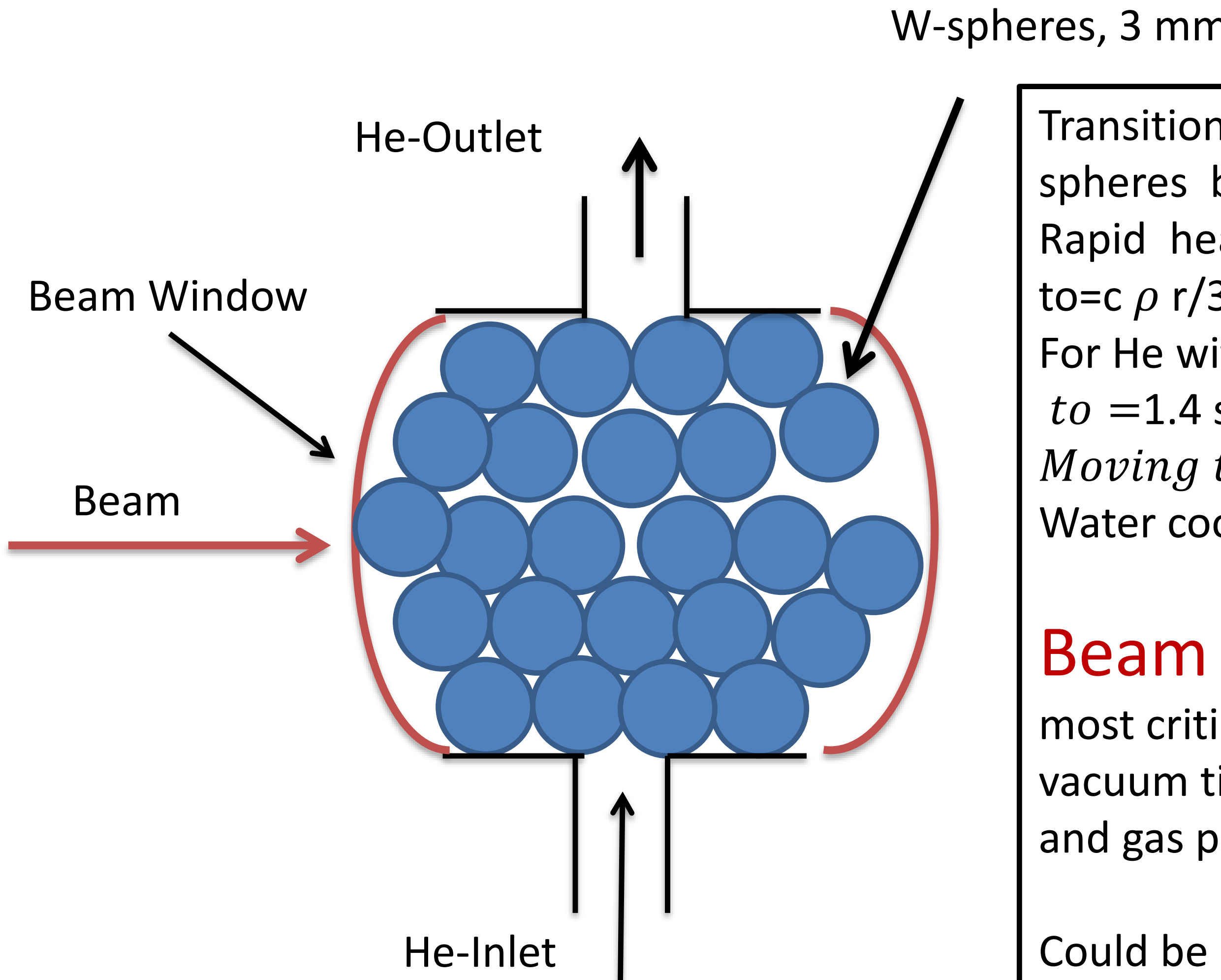
SLC-SLAC Water Cooled Tumbling Target



Tumbling: to prevent pile up between successive pulses.
Tumbling frequency : $\nu = \nu beam \cdot \theta beam/2\pi Rtumbling$.
For the ILC with 300 Hz a tumbling frequency of 10-15 Hz (a line velocity of 5 m/s) would be necessary. This is tough for mechanical reasons.

For pulses at 50 Hz, a tumbling frequency of about 1 Hz would be ok.

He-Cooled Granular Target

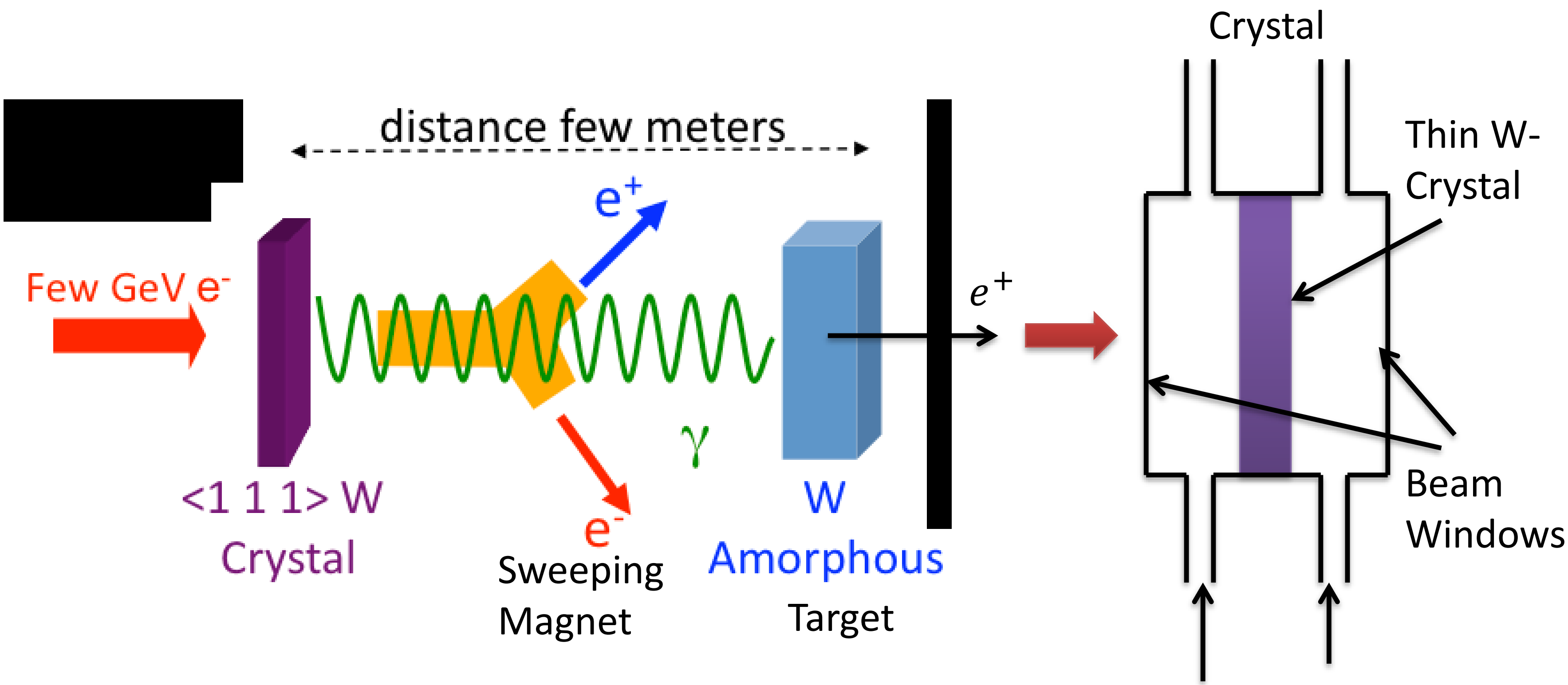


Transition time of sound through spheres below μs, small shock.
Rapid heat evacuation:
to=c ρ r/3 α .
For He with $\alpha = 0.1$ W/$cm^2\ K$:
to =1.4 s ≫200 ms. →
$Moving\ target$.
Water cooling too dangerous!

Beam Window is the most critical issue: must be vacuum tight and resist to beam and gas pressure.

Could be used for targets in air.

Hybrid e+ Source (Base Line for CLIC)

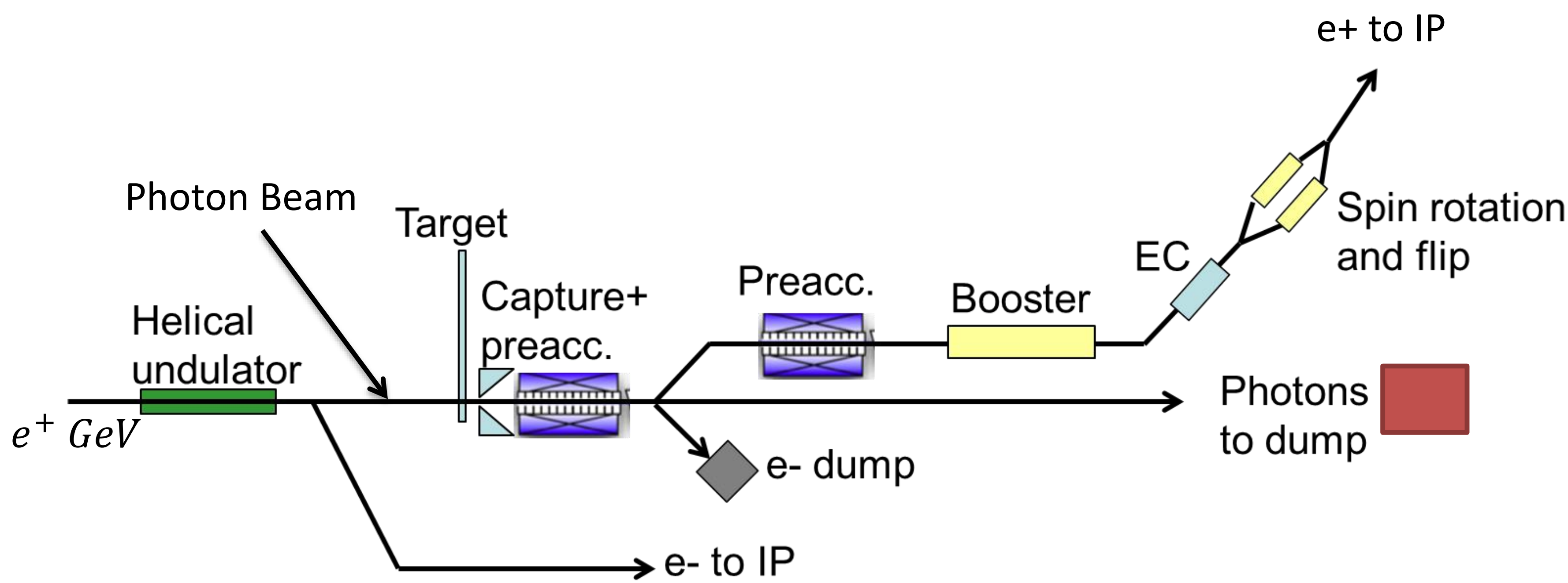


For the ILC: Power in the Crystal $\geq 100\ W$.
Power in the W-Target ~ 10 kW.
Crystal and Target must be moved.

He-Gas Cooling with windows or edge cooling without windows.

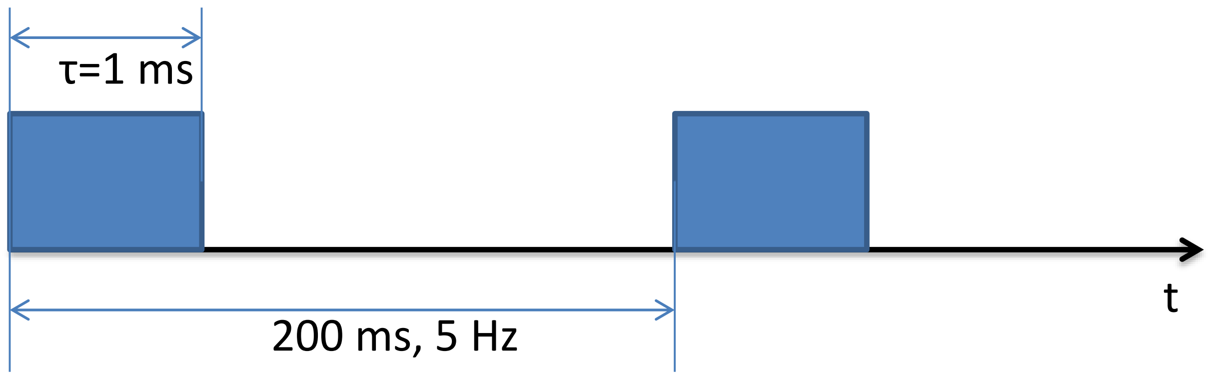
R. Chehab-LAL,
I. Chaikovska-LAL
Ch. Xu-IHEP

3.- ILC-Undulator Driven e+ Target

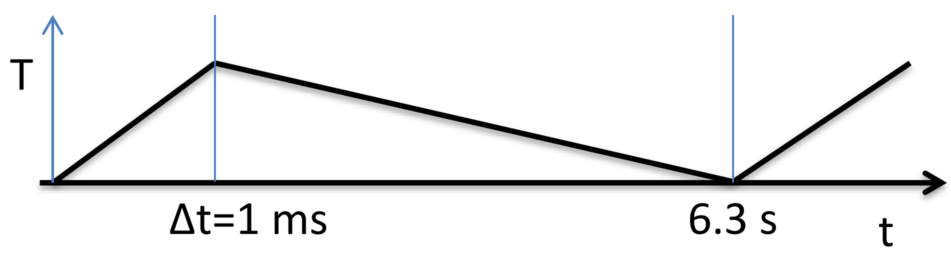


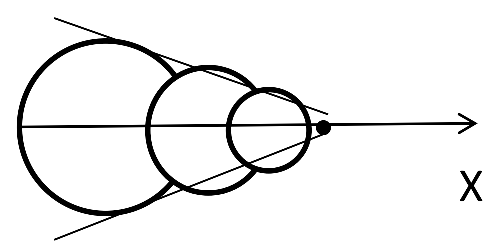
S. Riemann-DESY;
M. Kuriki-Hir.Univ.

Pulse Structure for the Undulator-Driven Target



Wheel, rotating at 100 m/s: each spot on the target is hit at 0.16 Hz, one hit spread over 10 cm every 6.3 s. Target radius 0.5 m, 1920 rpm. Helps cooling and life time.





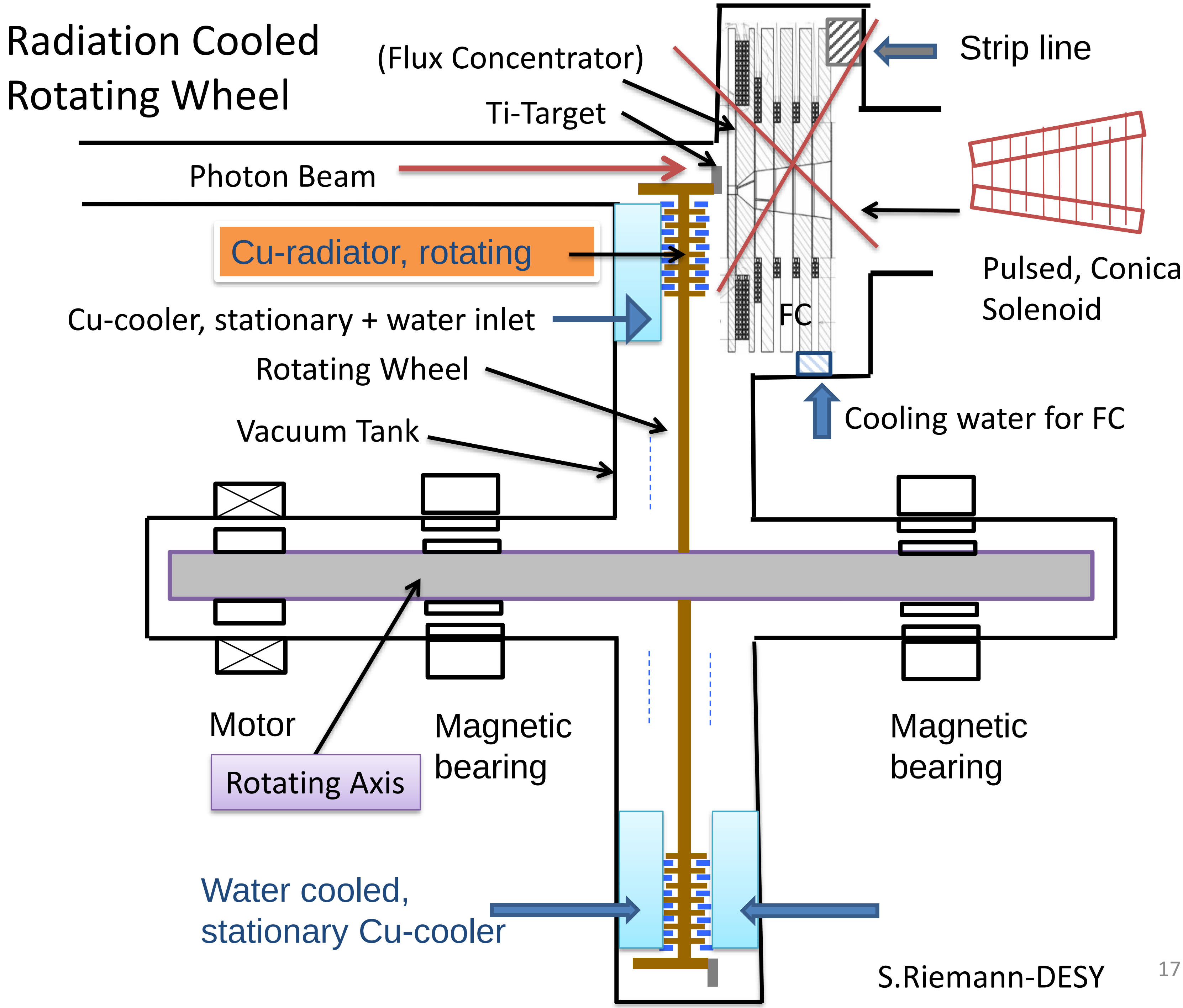
Small temperature spikes: $\Delta T = T_o \phi/\tau v = 2\% \, T_o$. $dT/dt = T_o/\tau$. Velocity of the 'plane' $\ll c$.

Design Parameters of the Undulator driven Positron Target.

- The 7-10 MeV photon beam from the Undulator with a pulse duration of 1 ms and a rep. rate of 5 Hz hits a Ti-Target.
- The Ti-Target Wheel with a diameter of 1 m and a thickness of 7 mm absorbes about 2 kW, only about 3% of the incident power. Cooling by Heat Radiation.
- To dilute the PEDD in the target to some 40-70 J/g, a rotation velocity of 100 m/s, 2000 rpm, is required, spreading the burst over a sector of 10 cm.
- Each sector of the wheel of 10 cm width is hit every 6.3 s, provided that the velocity is finely tuned to avoid «resonances»: wheel frequency = n beam frequency.

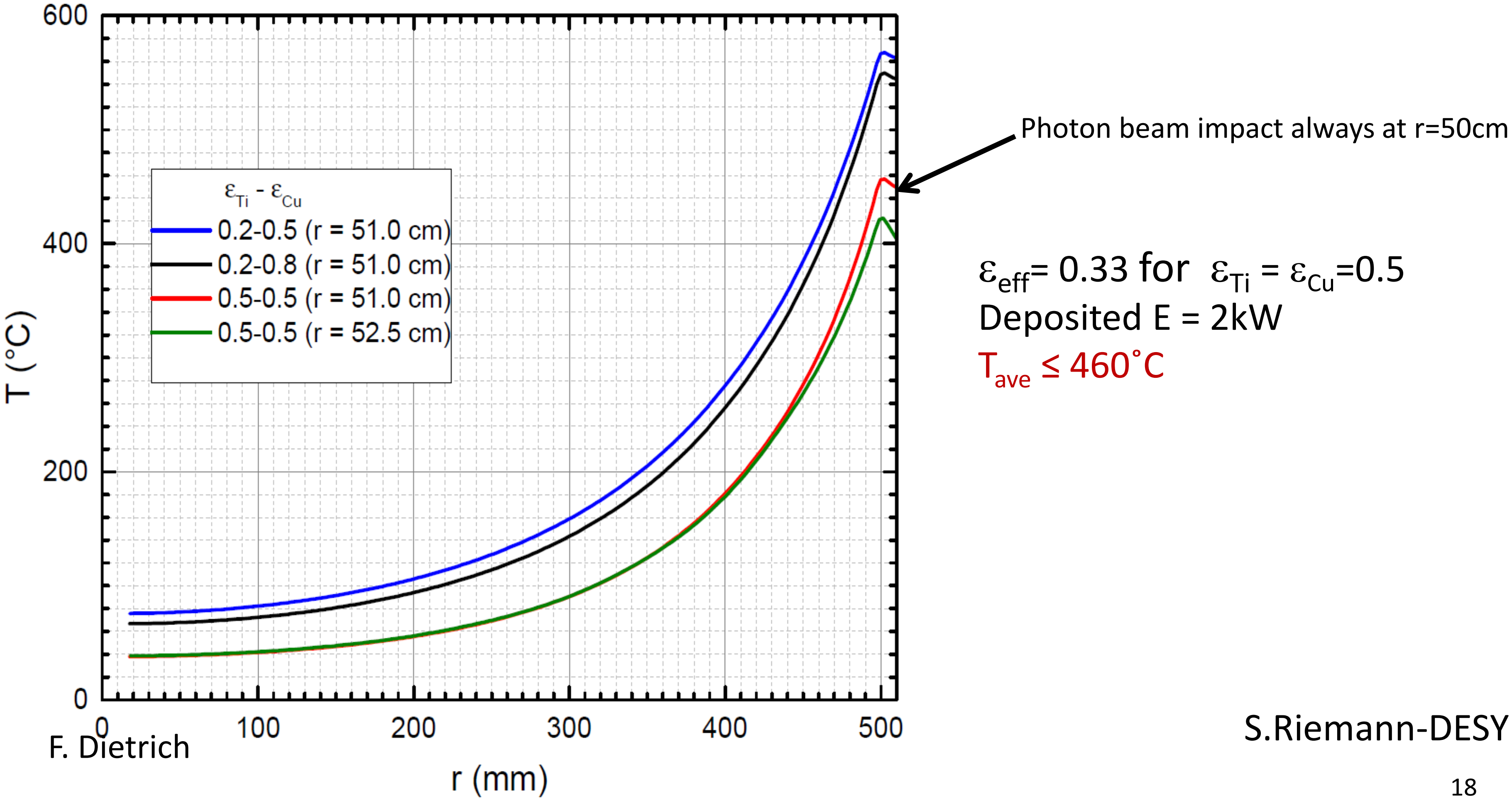
S.Riemann-DESY, A. Ushakov-Hmb. Univ.

- Irradiation tests of Ti are under way at the Microtron at Mainz/Germany with e- energies of 3.5-14 MeV. Ref. S. Riemann, A. Ushakov.
- The pulsed magnetic field from the Flux Concentrator downstream of the target will induce currents, additional power and forces in the fast rotating wheel. Under study.



Radiation Cooled Rotating Wheel
(Flux Concentrator)
Ti-Target
Strip line
Photon Beam
Cu-radiator, rotating
Cu-cooler, stationary + water inlet
FC
Pulsed, Conical Solenoid
Rotating Wheel
Vacuum Tank
Cooling water for FC
Motor
Rotating Axis
Magnetic bearing
Magnetic bearing
Water cooled, stationary Cu-cooler
S.Riemann-DESY

Average temperature in wheel as function of radius r for different surface emissivities of target and cooler (Cu)



ε_{eff}= 0.33 for $\varepsilon_{Ti} = \varepsilon_{Cu}$=0.5

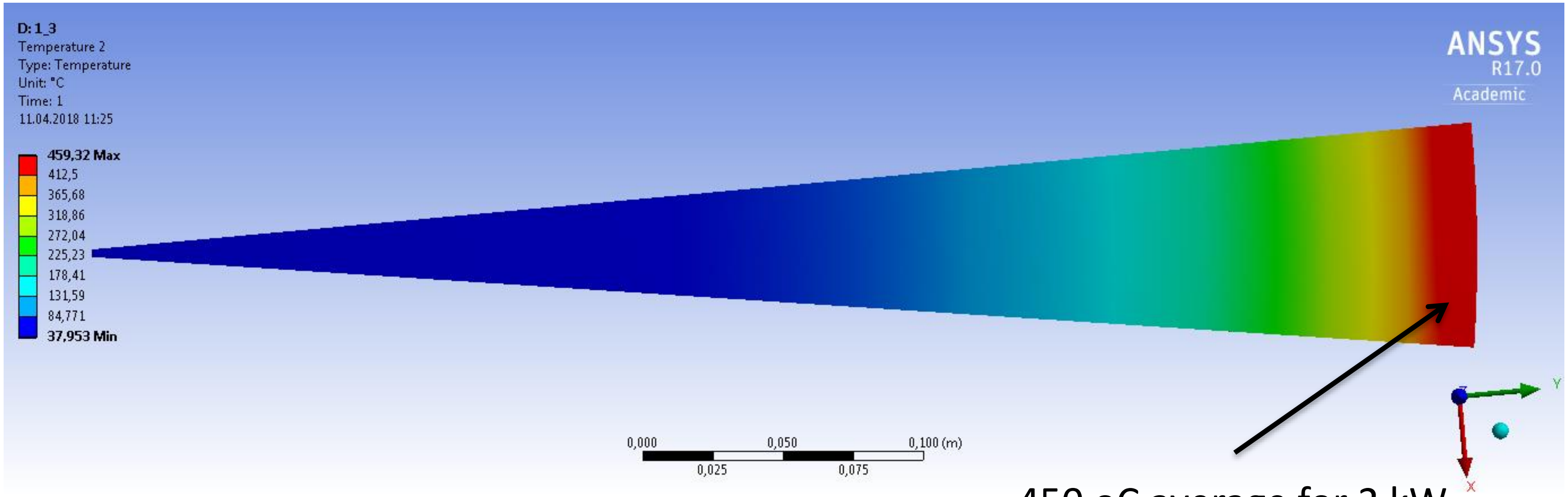
Deposited E = 2kW

$T_{ave} \leq 460^{\circ}C$

F. Dietrich

S.Riemann-DESY

Radial Temperature in Radiation Cooled Ti-Wheel



450 oC average for 2 kW

Thermal stress $\leq 400\ MPa$

S.Riemann-DESY

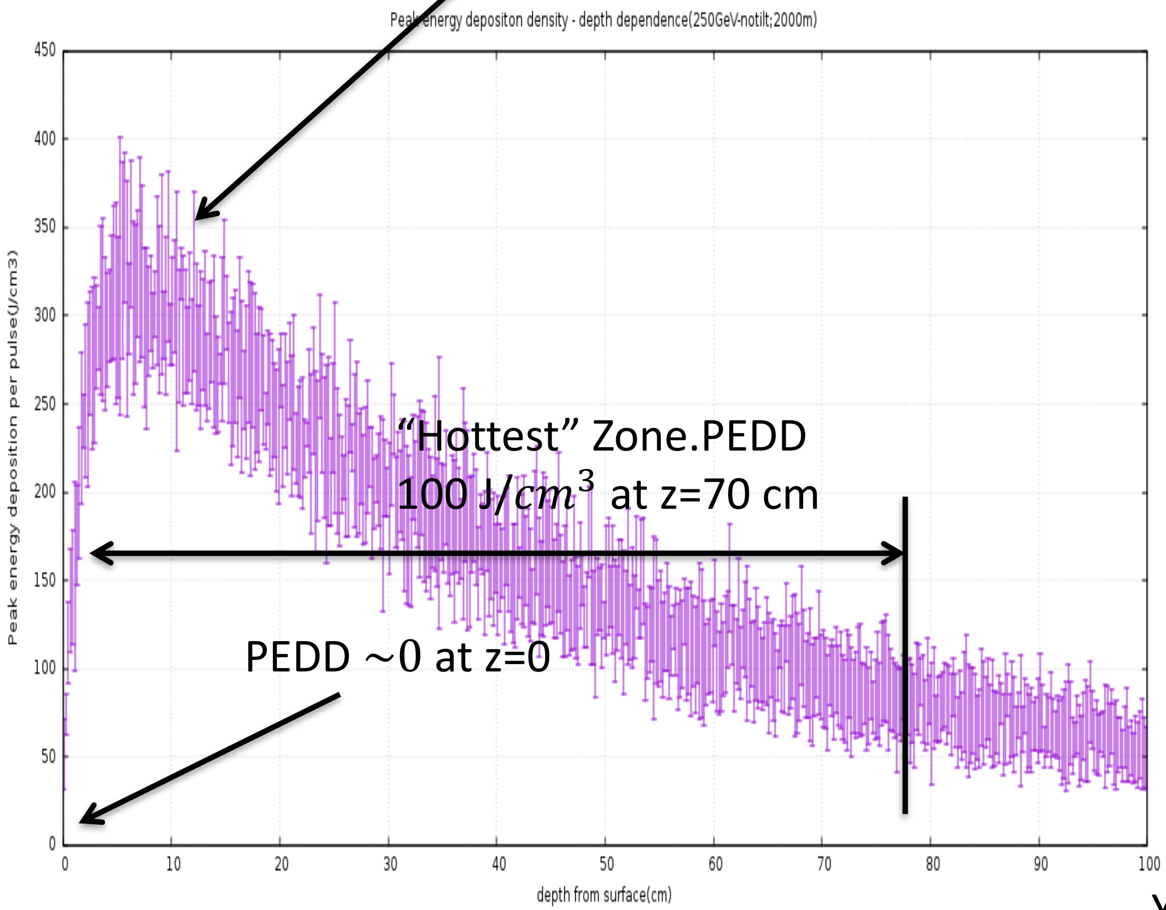
4.- The Dump for the Photon Beam from the Undulator .

- A possibility of a direct impact of the photon beam into a Graphite Dump without Window?
- Water cooling circuit tailored around a Graphite cylinder (XFEL?).
- The divergence of the photon beam is $\sim {}^{1}/_{\gamma}$.
- To reduce the PEDD in C, the dump should be placed at about 2 km downstream from the target.

Absorption of photon beam in far (2 km) Graphite.

342 J/cm^3, $\Delta T = 270\ C^0$ at z=5 cm. 500 GeV-case.
217 J/cm^3, $\Delta T = 183\ C^0$, 250 GeV-case.
Temperature cycles at 5 Hz!

No Tilt



Will the Graphite at the entrance between z=0-5 cm survive?

Steady state temperature?

Yu Morikawa/KEK

Design of a Tilted Graphite Photon Dump

【Base Idea】

①To enlarge the photon beam spot on beam dump

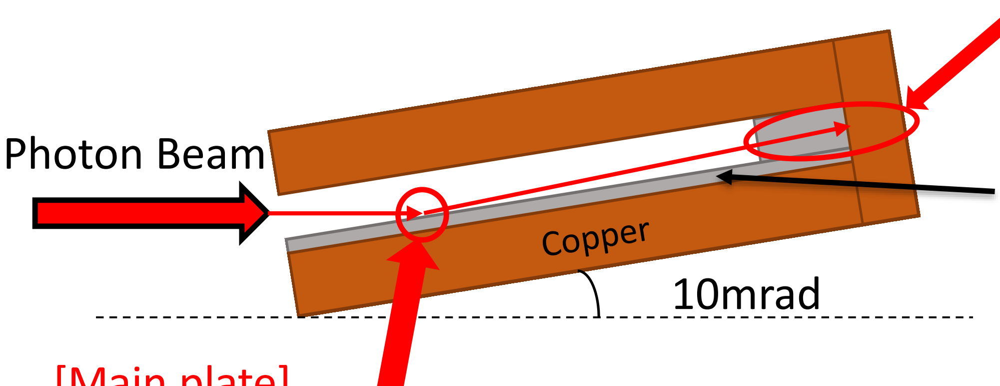
・**putting long distance** between positron target and beam dump(**2km**).

②To absorb beam heat only by thin Graphite

・**tilting beam dump** (almost horizontally:**10mrad**)

【Base Design】

[Back plate]Absorbing scattering beam



Thin Graphite of 1 cm thickness, brazed onto a water cooled Cu-bed.

[Main plate]

Absorbing⇒72kW(62%) of beam power@250GeV stage

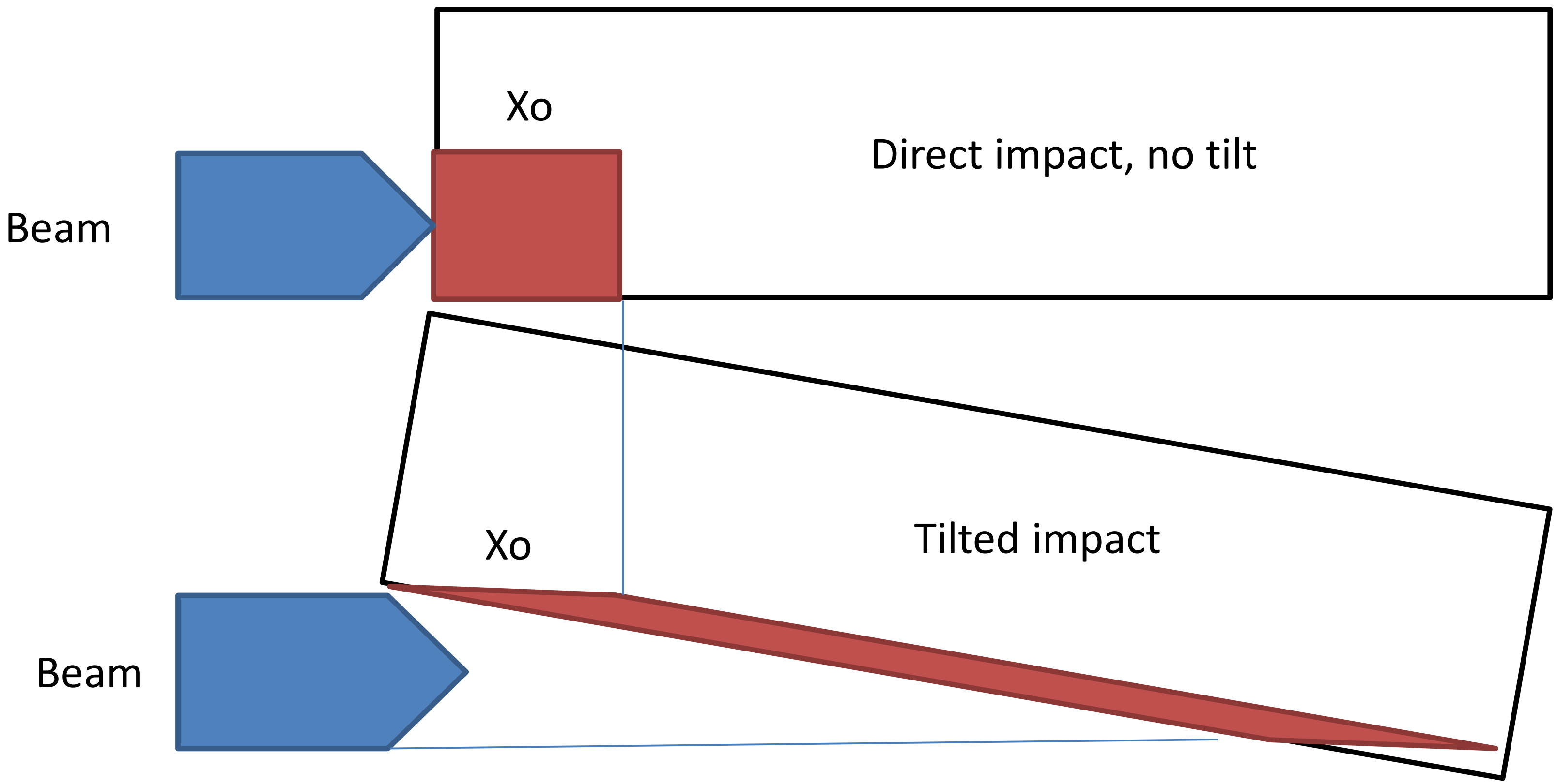
Scattering⇒84kW(38%) of beam power@250GeV stage

Cooling mechanism : Only cooling water in copper

No cooling, protection gas : No need to introduce to beam window

Yu Morikawa-KEK

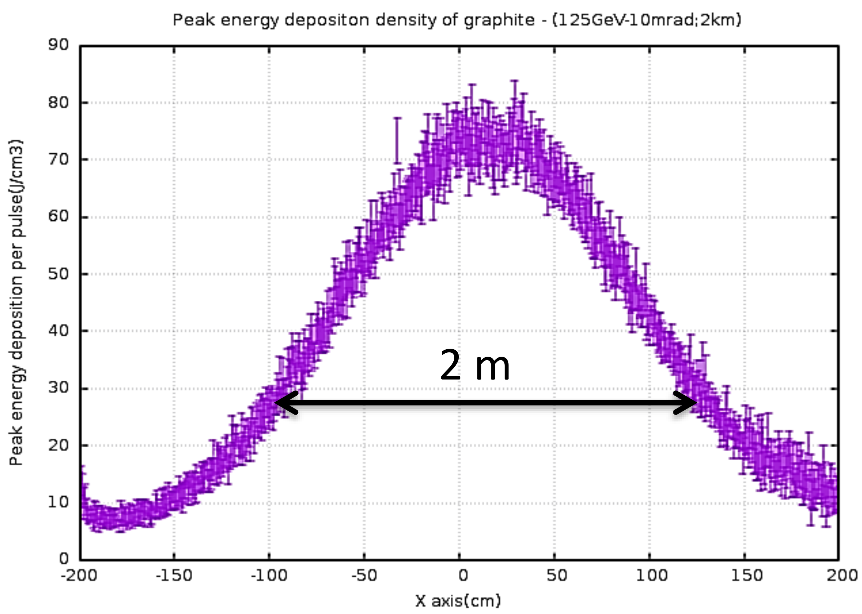
Tilted C-Dump



For ideal dE/dx energy deposition : no gain, the impacted volume remains the same.
Gain only due to lateral spread of cascade.

Absorption of Photon Beam in the far (2 km) tilted Graphite Beam.

PEDD = 83 J/cm^3, $\Delta T = 70\ C^0$. "Hot zone" at average temperature of 600-1000 oC (depending on λ) extends over a lateral depth of some 5 mm and over a length of about 2 m. Lifetime of the Graphite along the inner free surface and along the brazed Graphite/Cu-cooler interface still to be validated.



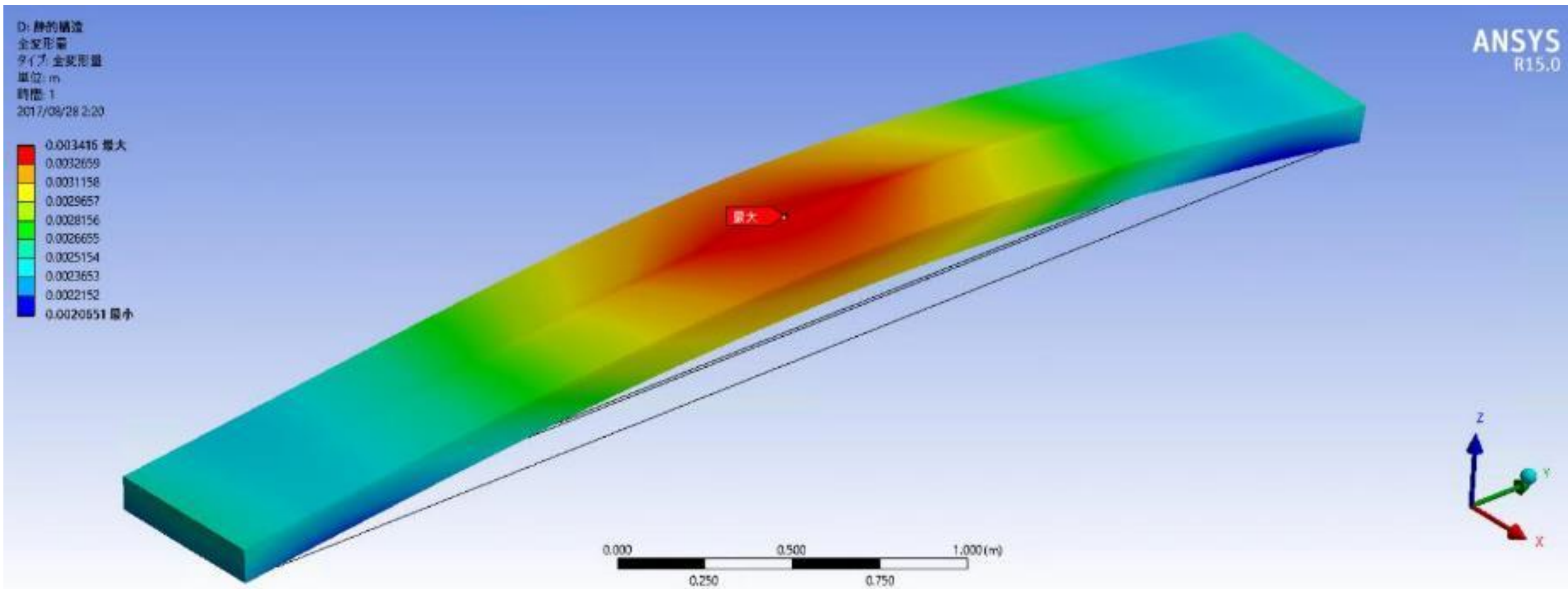
PEDD with tilted Dump is reduced by a factor 2.-2.5 as compared to direct impact

Yu Morikawa-KEK

Deformation, Stress, Cooling to be studied.

【Total Deformation】

Deformation by thermal expansion. (not including the self-weight)



Main plate is expanded and main plate is arched 3.4mm in the surface direction

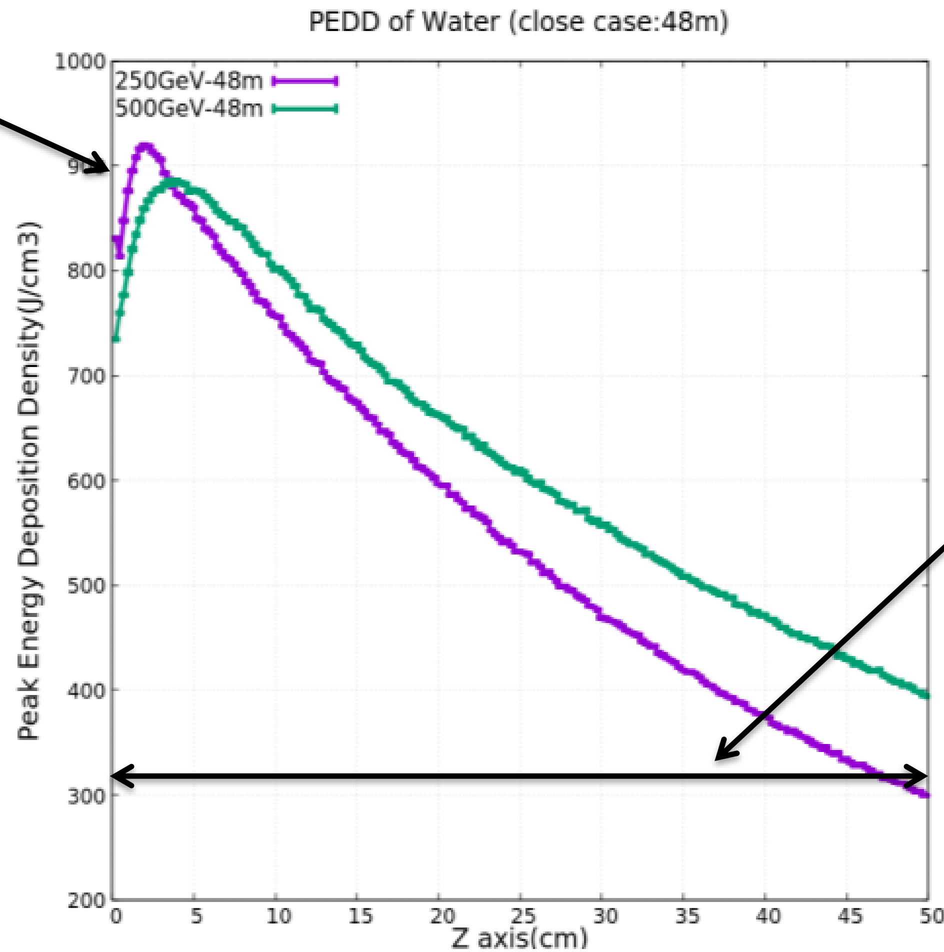
Yu Morikawa-KEK

Water Dump for the Photon Beam

- Create a vertical water flow (Waterfall) in a tank.
- With a water velocity of 5 cm between beam pulses at 200 ms, i.e. 0.25 m/s is trivial.
- If the water survives one single pulse, the water will live eternally?
- But one needs a vacuum window.

Water Dump placed at 48 m: boiling.

$\Delta T \sim 200\ oC$

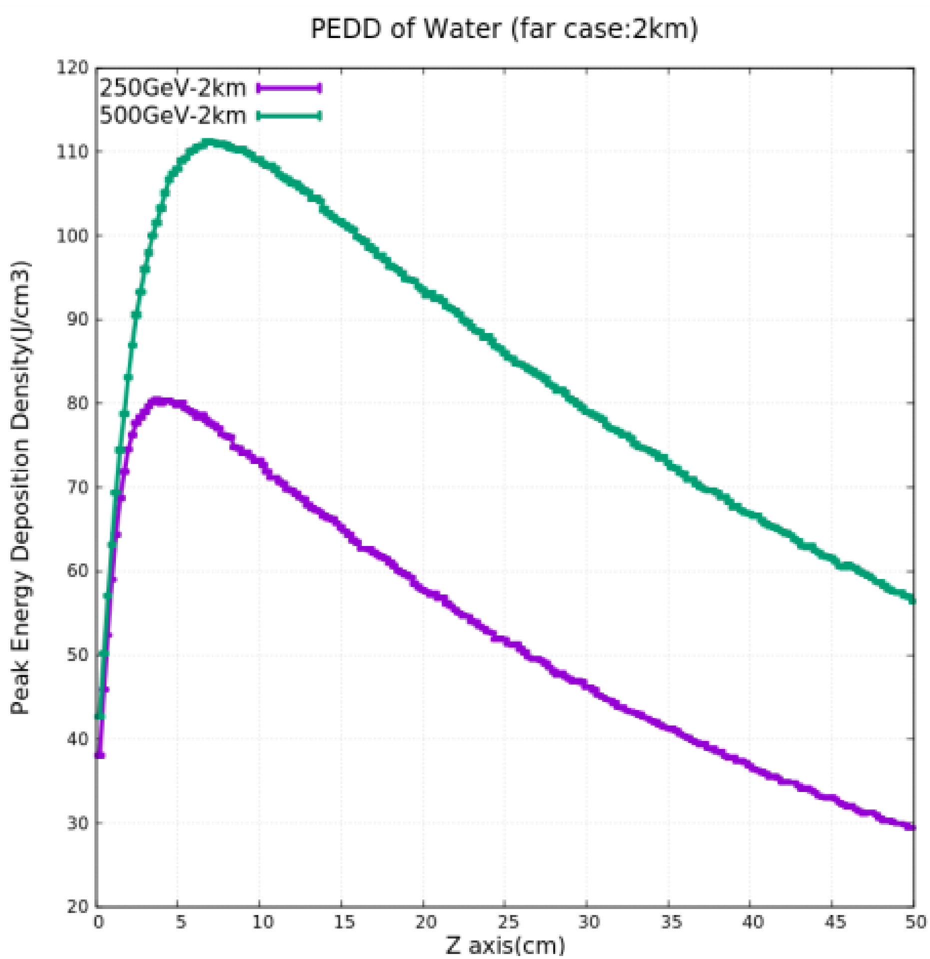


Zone of Boiling above 340 J/g

With a pre-load of above 10 bar, boiling of water at 200 oC can be prevented.

Yu Morikawa-KEK

Water Dump placed at 2 km, no boiling.

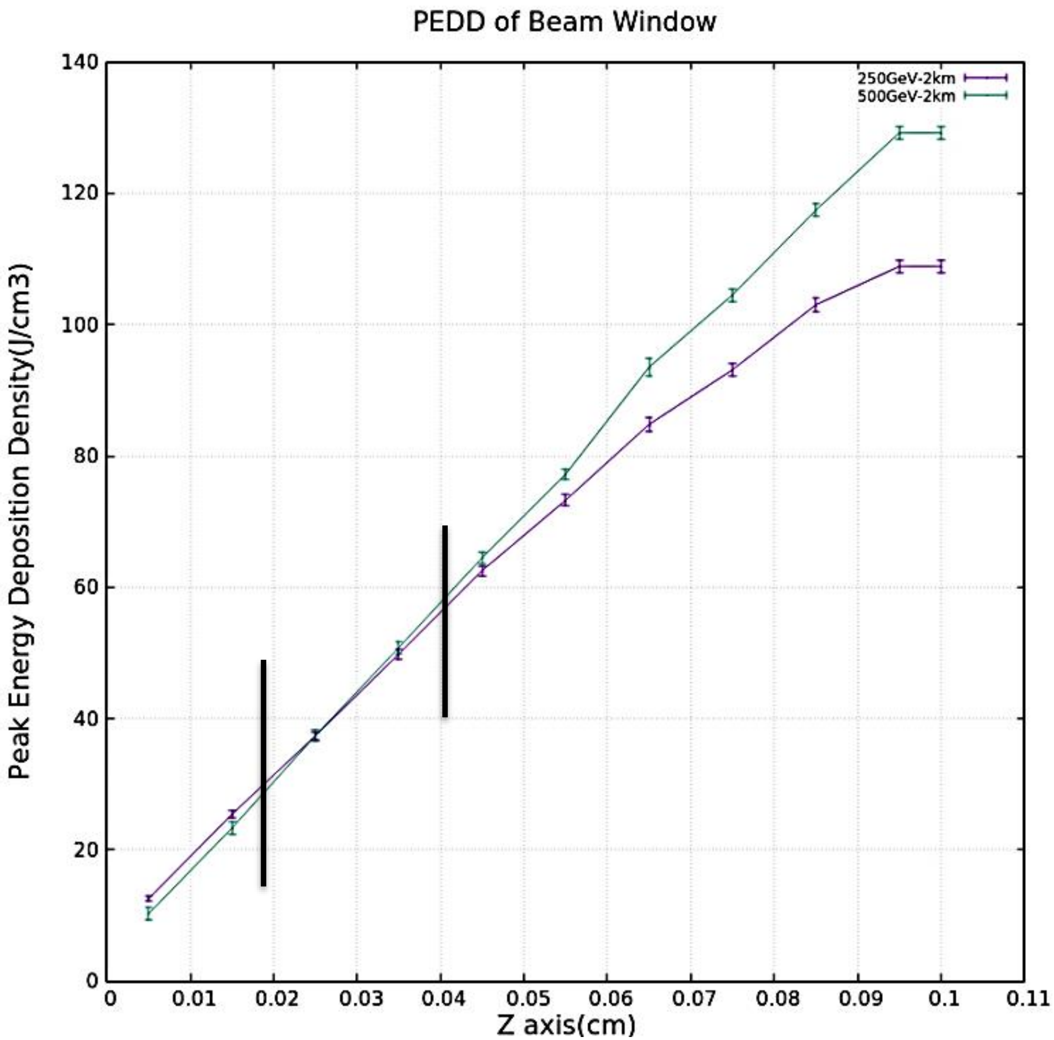


ΔT (K) at	250 GeV	500GeV
Z=0 cm	12. K	12. K
Z=5-10 cm	19.1 K	26.5 K

Water will not boil at 1 bar. Some slow dynamic response due to thermal expansion and mass inertia of the water can occur? Depleation waves and reduction of water density during the 1 ms pulse?

Yu Morikawa-KEK

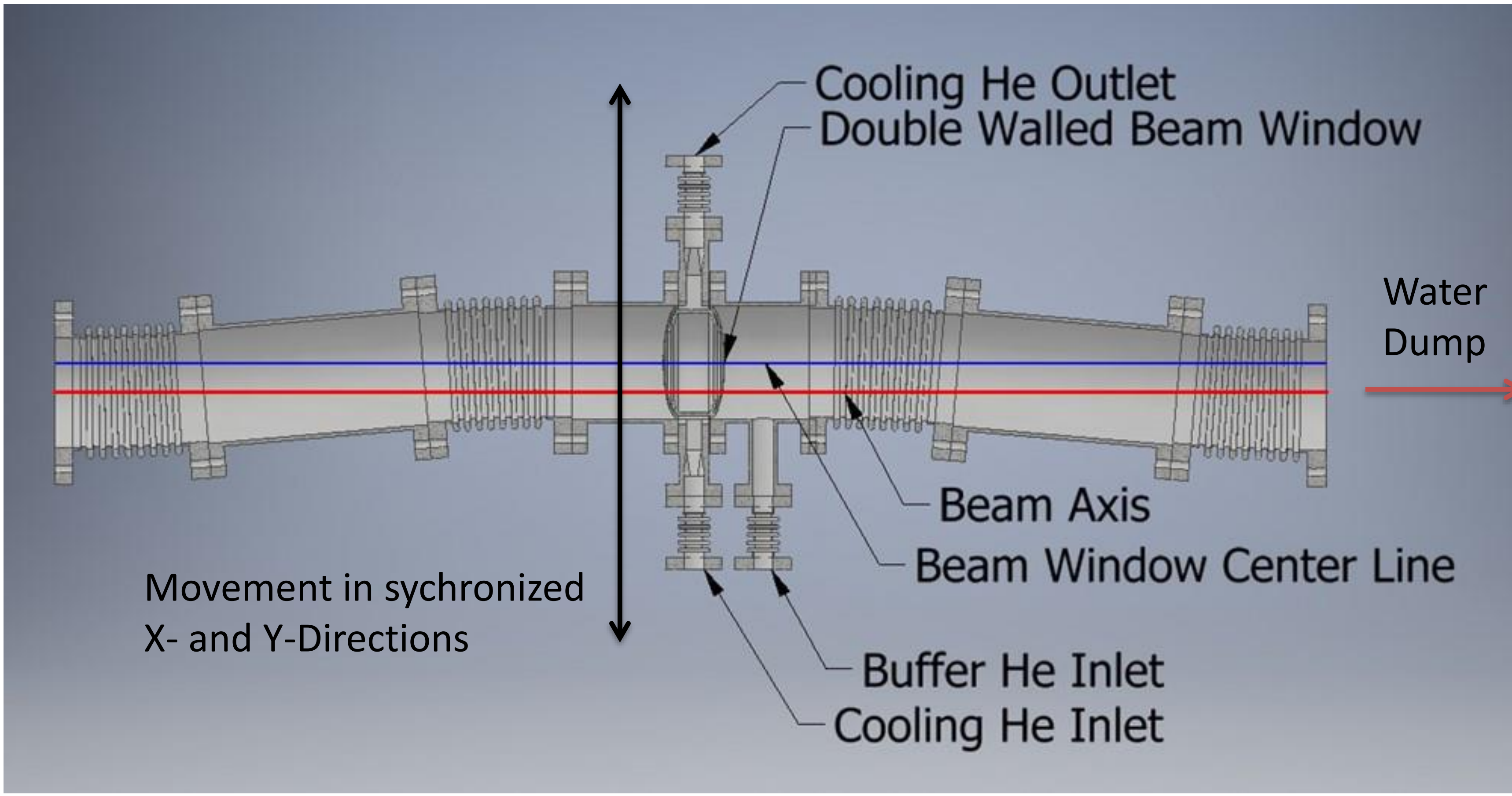
The Titanium Vacuum Window upstream of the Water Dump at the 2 km Position.



Only thin Ti-windows with 0.2-0.4 mm thickness will survive when displaced between pulses: Tumbling Window

Yu Morikawa-KEK

Tumbling Window 10 m upstream of the Far Photon Water Dump



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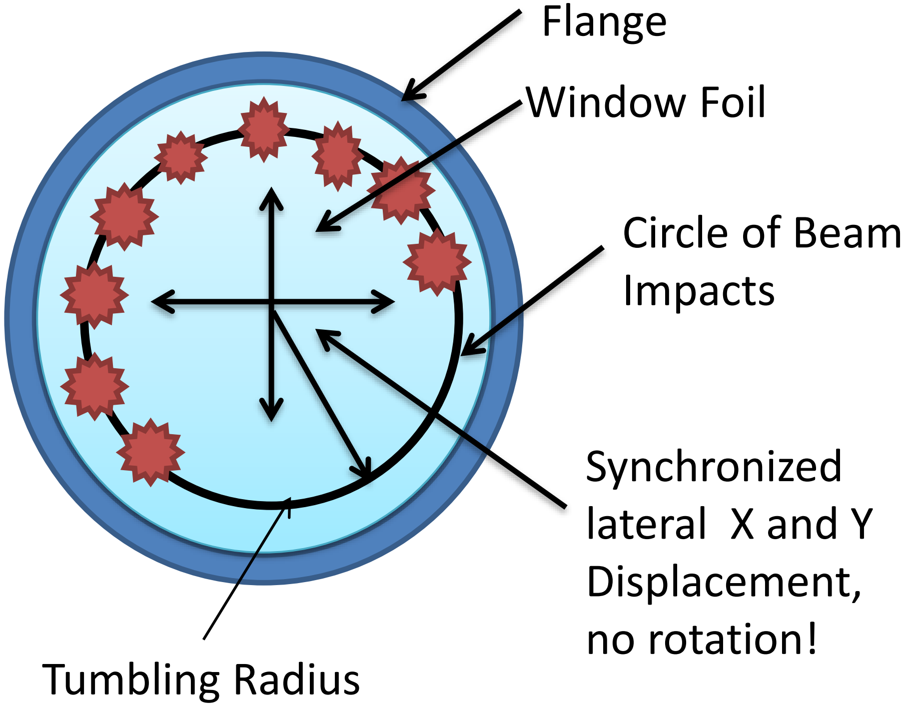
Tumbling Window



Tumbling Frequency:

For $\nu beam = 5\ Hz$ the tumbling frequency with a tumbling radius of 5 cm can be as low as 0.01 Hz with a displacement of 3 mm between beam pulses. 6 rpm will be good for tumbling mechanism!

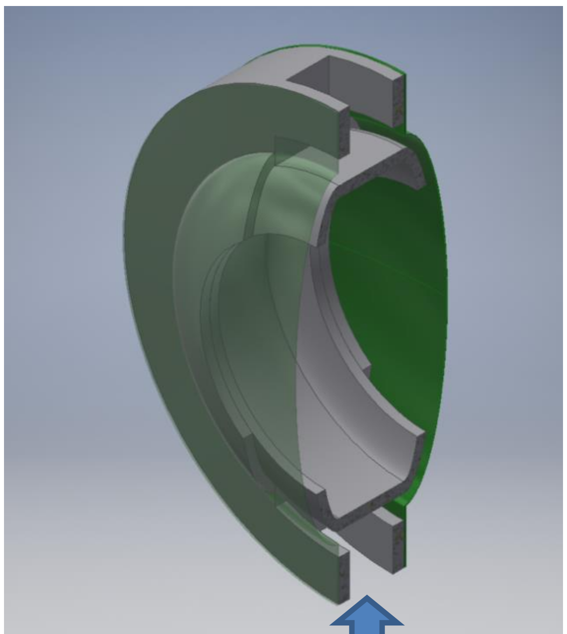
Design Values for a He-Cooled, Moving Window, displaced by 3 mm between Pulses.

Window Thickness (mm)	**0.2**	**0.4**
PEDD J/g	7.2	12.7
ΔT/Pulse	14.4	25.4
Pulsed Stress (MPa)	21.6	38.1
Av. Power (W)	16.2	43.3
Peak Temp. (oC), moving window + He-cooling.	34.5	48.5
Dpa/5000 h	0.25	0.25
Lifetime (h) for Dpa=0.5	10’000	10’000

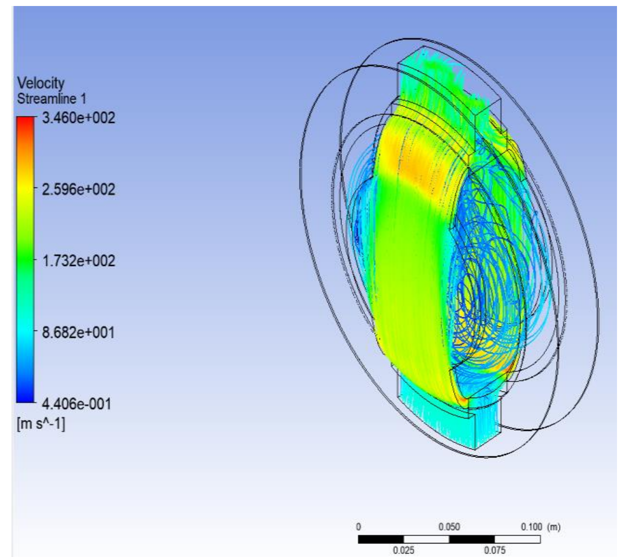
Yu Morikava-KEK

Double Walled He-Cooled Vacuum Window

He gas outlet



He gas inlet,
100 m/s, 1 bar.

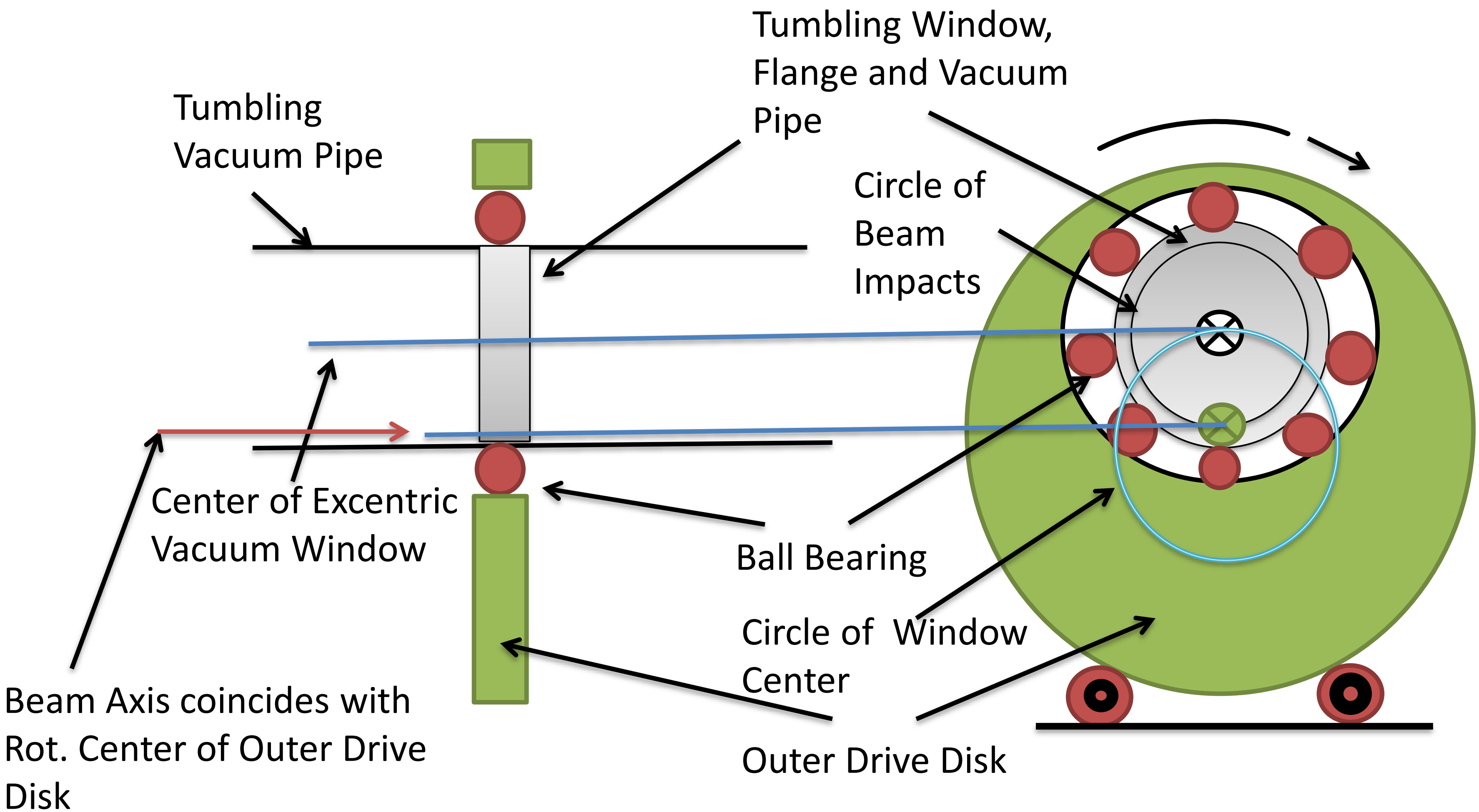


Hydro-formed 0.2 mm thick Ti-window

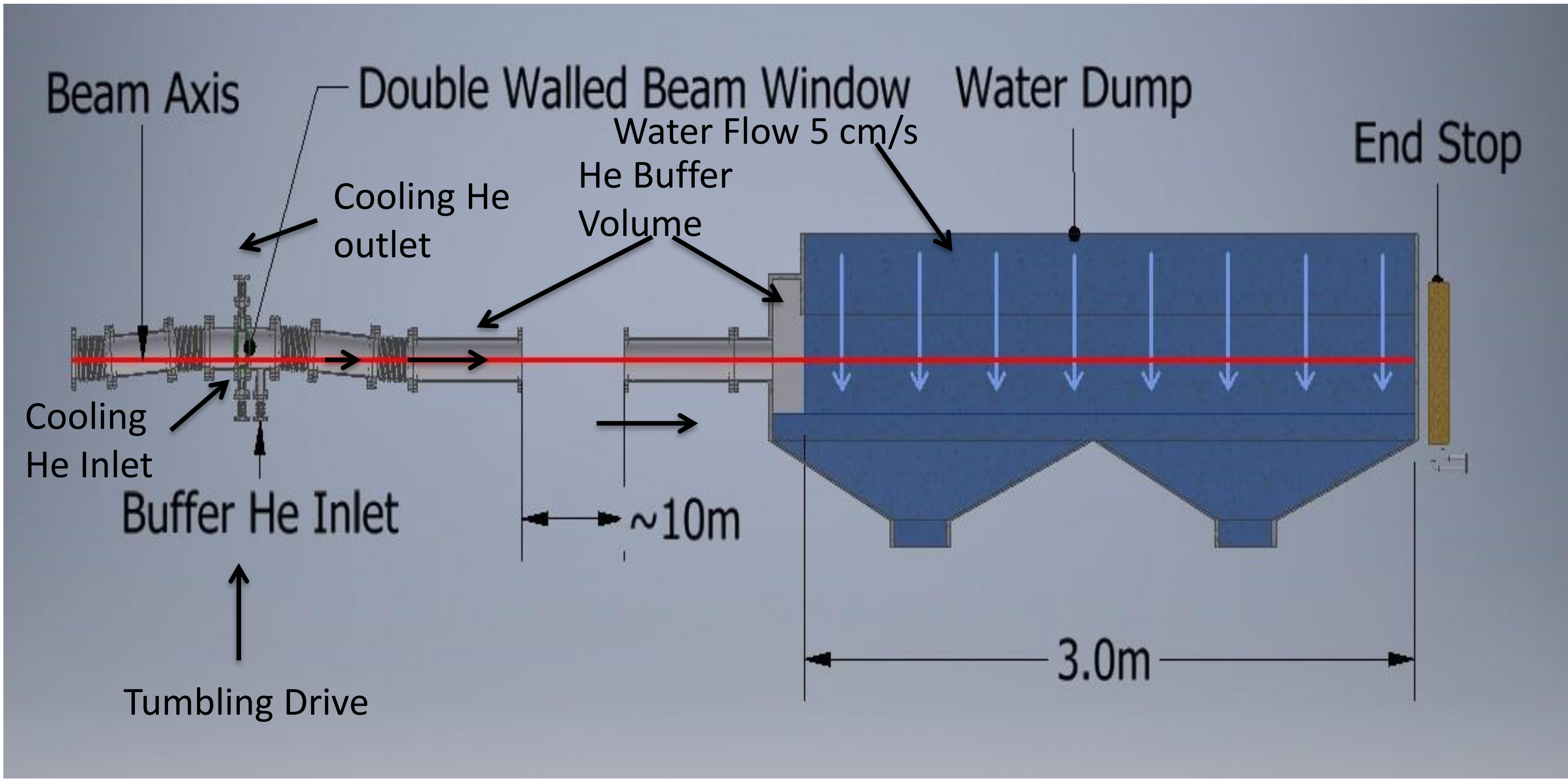
Vibrations and local buckling in thin membranes?

Yu Morikowa-KEK

Drive Mechanism for the Tumbling Window



Layout of Water Dump for the Photon Beam. Easy Access to the Window for Maintenance and Exchange. No direct Ti-Window/ Water Contact.

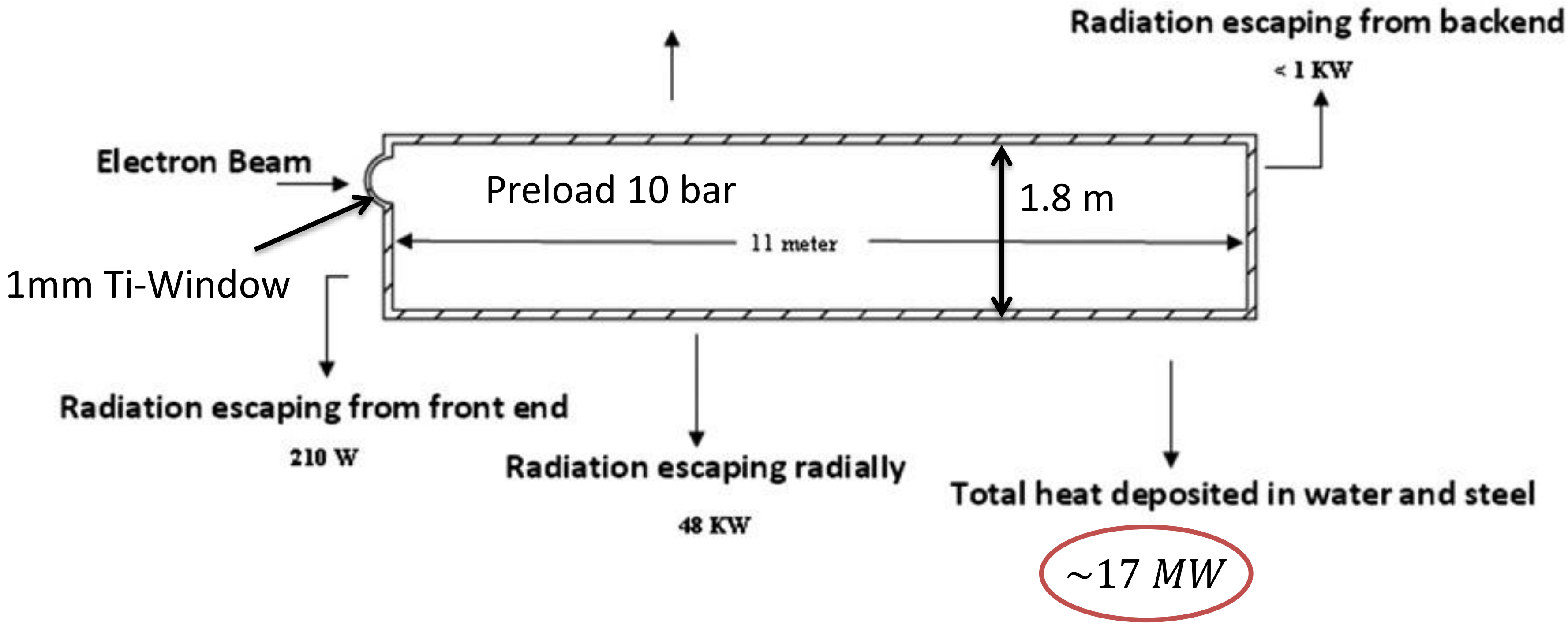


Yu Morikowa-KEK

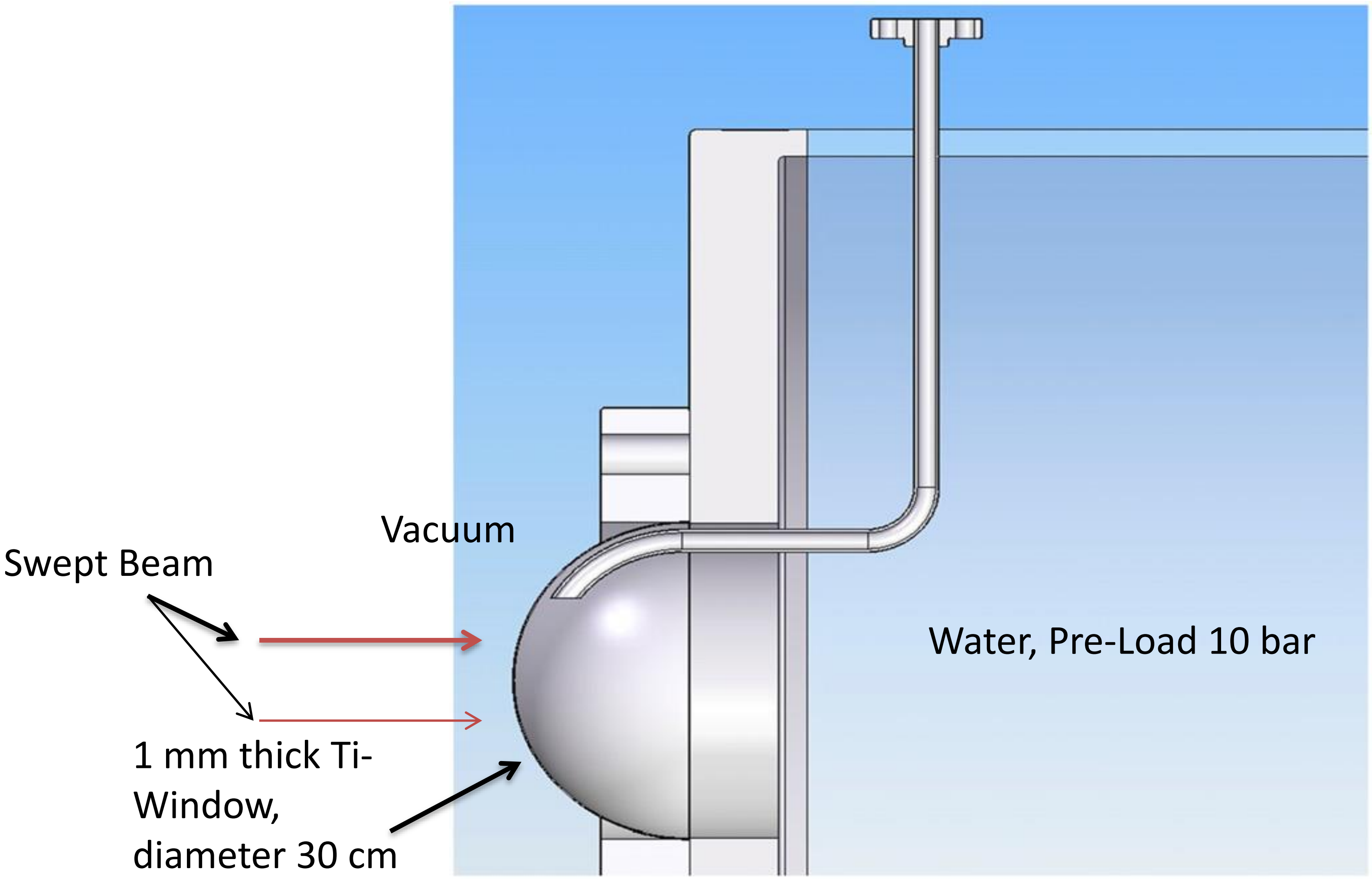
5.- 17 MW Water Dumps to absorb the spent e- and e+ Beams of up to 500 GeV at 5 Hz.

- See ILC TDR
- Publ. of P. Satyamurthy et al., Nucl. Instr. and Meth. A 679 (2012) 67-81.
- Recent Review by Yu Morikowa-KEK, Oct. 2018.

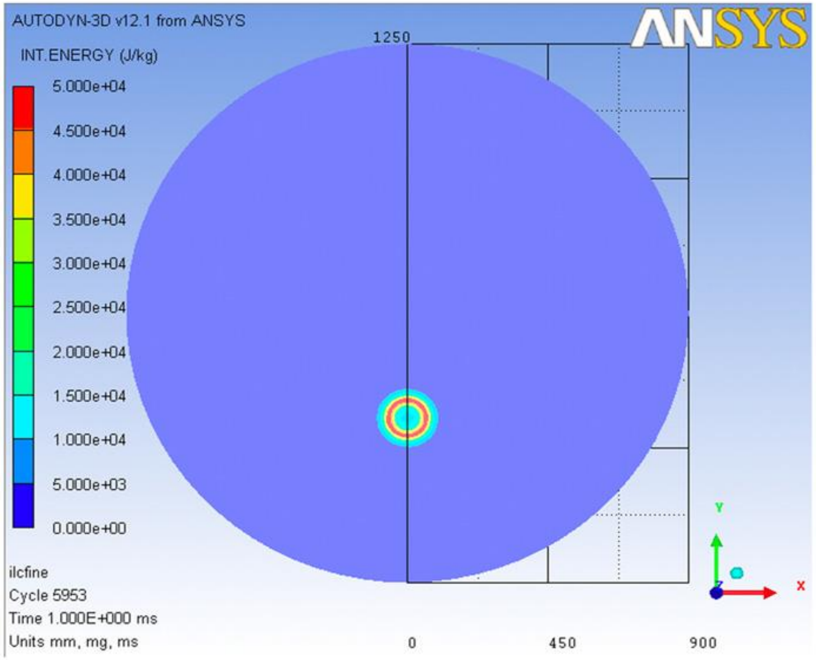
Layout of ILC-Water Dump



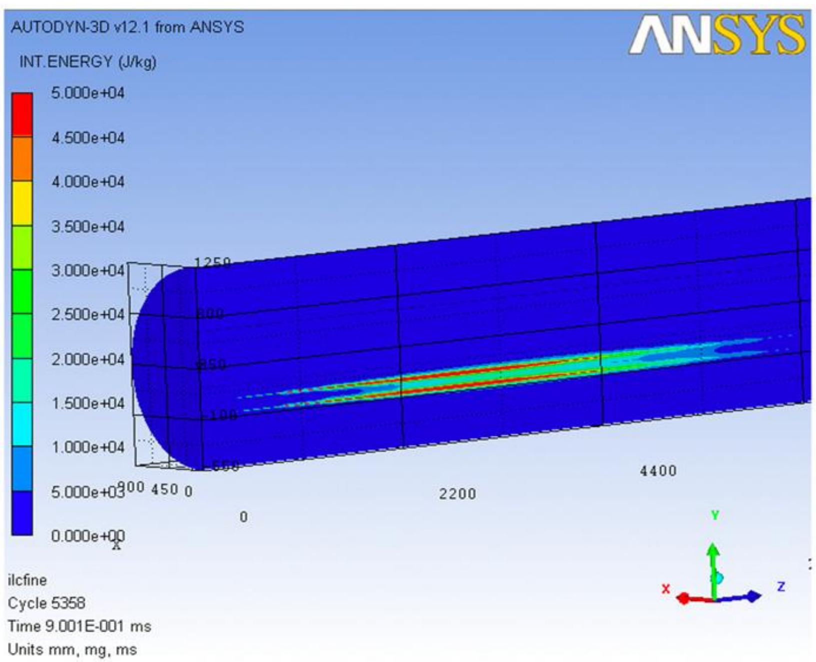
- Window for ILC 17 MW Main Dump



a

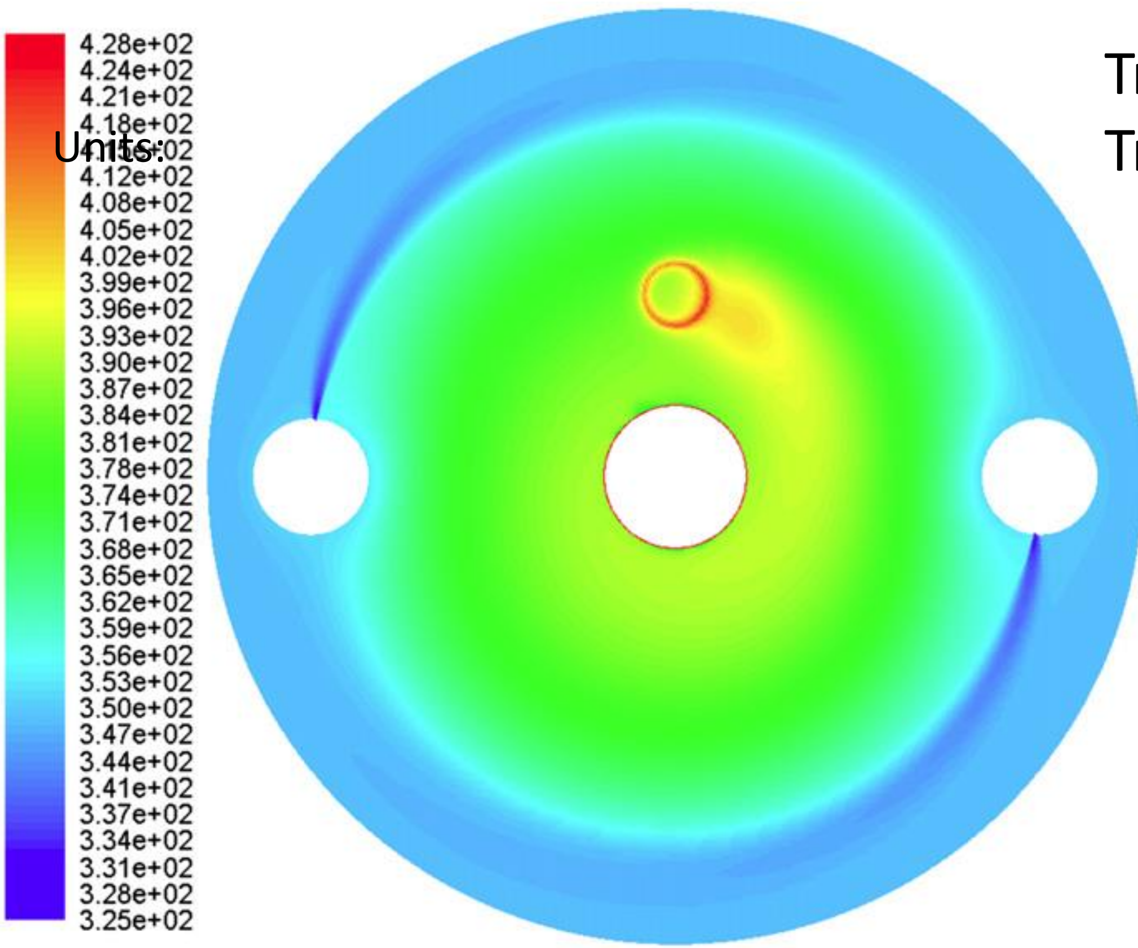


b



Beam is laterally swept with a radius around a circle of 6 cm radius at 1 kHz

Front View of the Water

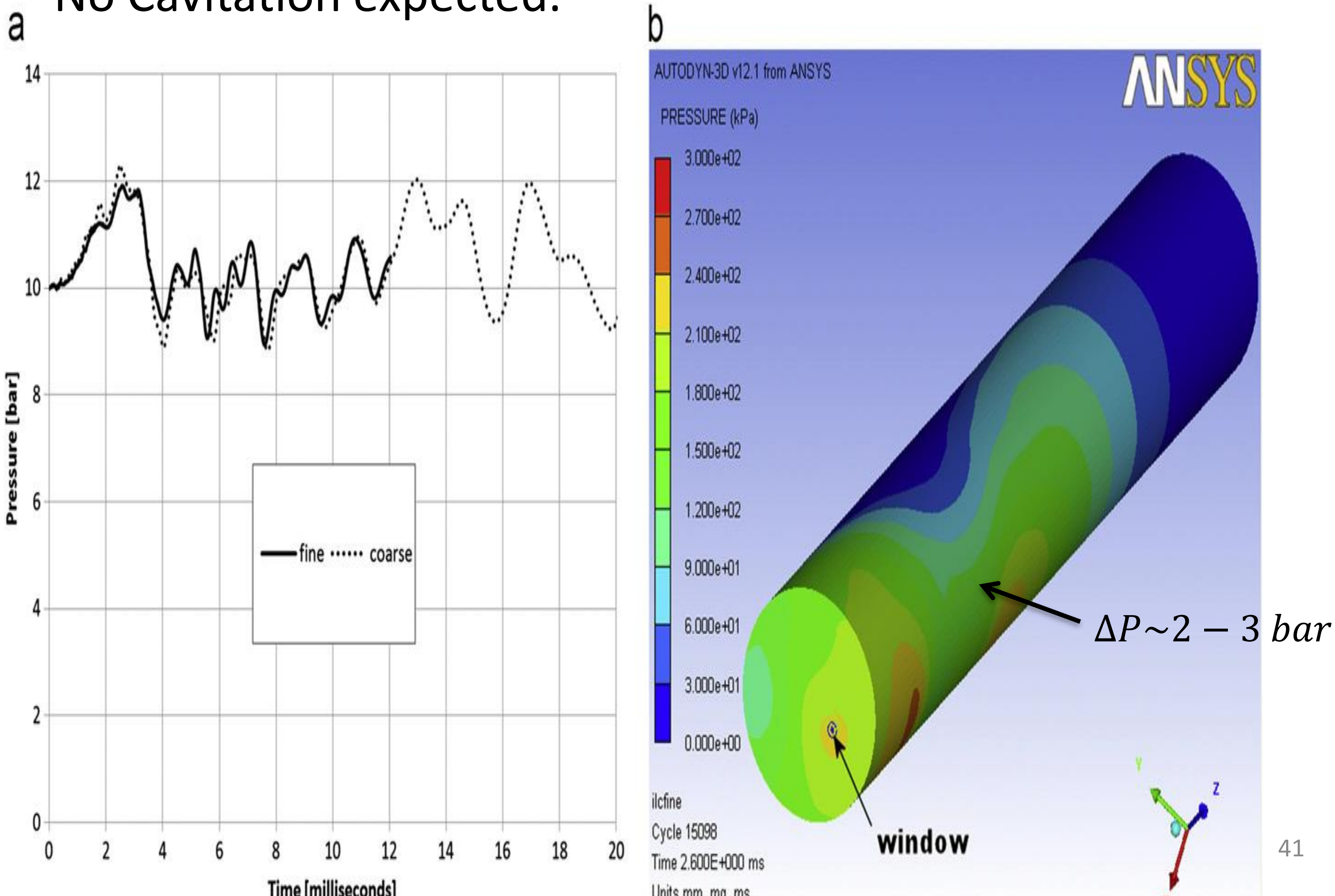


Tmax=68 oC for 125 GeV
Tmax=121 oC for 500 GeV

Pressure Waves: ± 3 bar with temporary peaks at +6 bar.

With a pre-load of 10 bar, pressure will never become negative. Brake up limit of water ~ -11 bar?

Pressure Waves at the Window-Water Interface. No Cavitation expected.



Water Dumps

- Prevent boiling by pressure preload. No phase change.
- Pressure waves governed by classical wave equation in an «elasic» continuum,involving:
- Volume forces due to pressure gradients, mass inertia, thermal expansion, compressibility.
- Fast beam impacts lead to ionisation, spallation, rapid heating, high local pressure rises,……
- Can this still lead to rapid depleation of water density, local boiling, cavitation,…..during the beam pulse?
- Are these phenomena reliably included in the codes?

- Water treatment plant. Heat exchanger, de-ioniser, recombiners,.....
- Radio Chemistry: production of H2, H2-O2, Tritium.Collection and controled release of these gases.
- Dpa $\leq$ 0.2/5000 h in the Ti-window.
- Scaling from the SLAC-water dumps.

- Risk of fatal accident:
- Failure of window: a leak will develop slowly, can be detected in time?
- Earthquake?
- Failure of sweeping magnets: 1 kHz, permanently oscilleting and under control. A sudden miss of one sweep at the wrong time is unlikely.
- Safety committee will decide.

6.-Comments and Conclusions.

- For the e-driven positron target with a thickness of 14 mm, a water cooled rotating Tungsten Alloy Wheel is rotating in vacuum. The W-bulk material is submitted to cyclic thermal shocks, stresses and elevated temperatures ($10^8 Pulses$/ 5000 h). Lifetime of the Ferro Fluid seal and of the W-target is an issue.
- Most of the incident e-beam power of 60 kW is deposited in the immediate vecinity of the target. High dose rates, remanent activity and remote handling to be considered.

- The Undulator driven target: to produce the required (polarized) photon beam, a supraconducting Undulator upstream of the target is required.
- The Ti-target, a 1 m diameter, high velocity wheel is rotating in vacuum and cooled by heat radiation.
- No thermal shocks, but still elevated temperature and stress cycles of 10^8/5000 h. Lifetime?
- Only a small amount of the power of the incident photon beam (some kW) is deposited in the vicinity of the target station. Radiation and handling problems around the station should be manageable.
- Provides a polarized e+-beam.

- For the Undulator scheme, a particular design of the Photon Dump is required.
- A Graphite dump, without beam window, and a water dump, with a thin Ti-vacuum window, are being studied at present.
- The Main Dumps for the up to 17 MW spent e-and e+ beams, swept across a vacuum window into water, look feasible.
- The risk of catastrophic failure of the window, should be acceptable , by tight controls and interlocks.

Material Tests for the ILC at HighRadMat?

- Lifetime of Ti- and W-Bulk material.
- Lifetime of thin Ti- (Be) vacuum windows. In-plane stress waves and axial buckling vibrations.
- Response of water to beam pulses. Not very popular! But to rely only on “classical” hydrocodes and simulations?
- Can effects, induced by electrons and photons reliably be benchmarked by GeV-protons?
- How reliable are the codes (FLUKA, GEANT,…) for very small beams (µm) and with extremely short time bins (ns)?

- Support a Hot Lab for timely inspection and post mortem tests somewhere near the beam test facility for fast feed back.

Thanks are due to the Members of the Positron Working Group:

Report on the ILC Positron Source.

May 23, 2018.

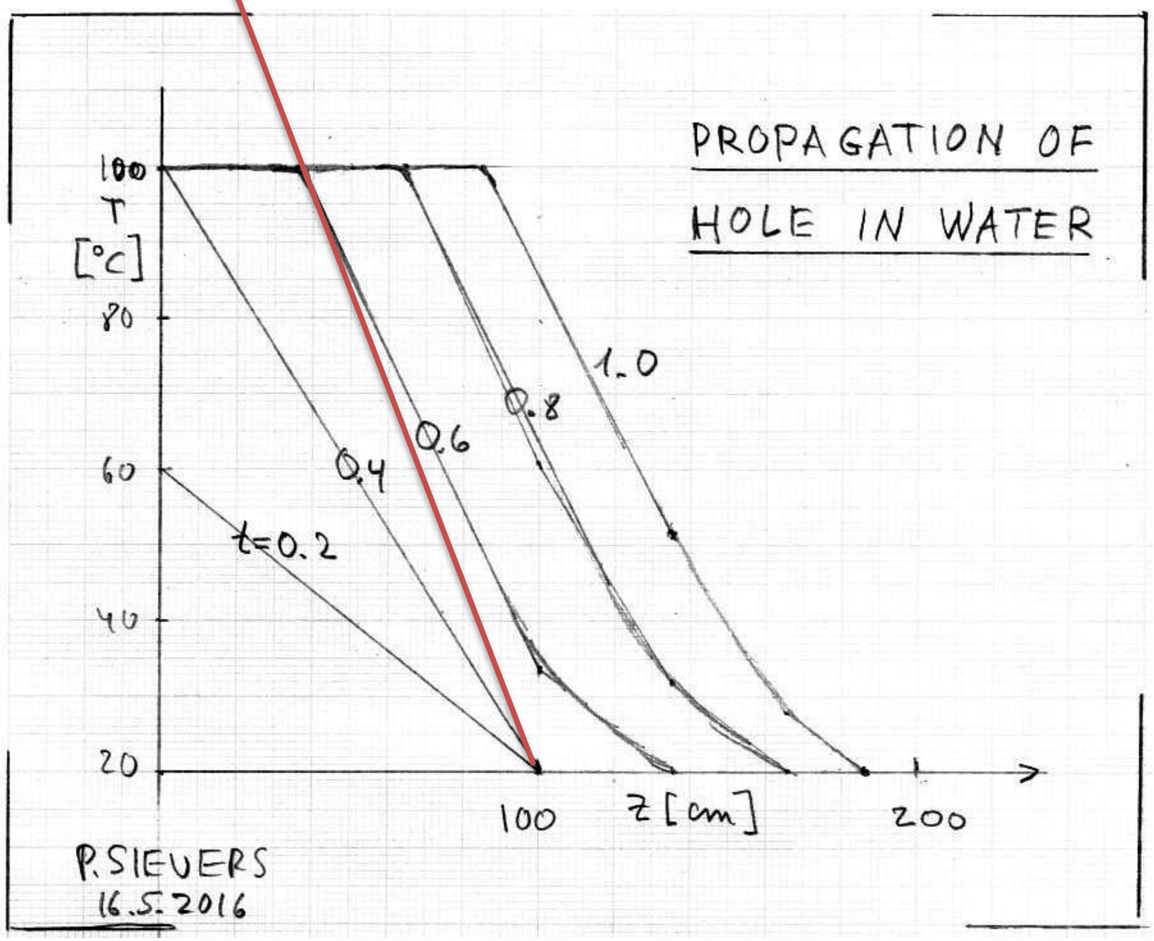
Convenor and Editor: K. Yokoya-KEK.

Thank You for Your Attention!

Back Ups

Close Water Dump at 48 m with Small Beam.
Temperature rise over 1 ms in water. As soon as 100 oC is reached, water has «disappeared», is evaporated. A hole of some $\sim m$ is created after 1 ms.

0.6, no evaporation



Backups

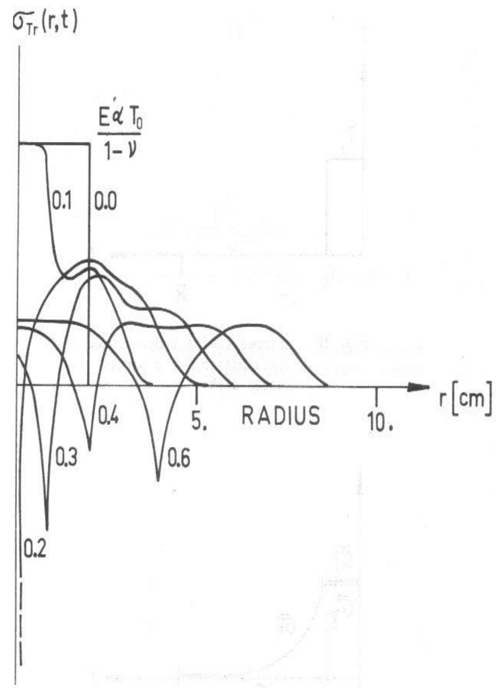
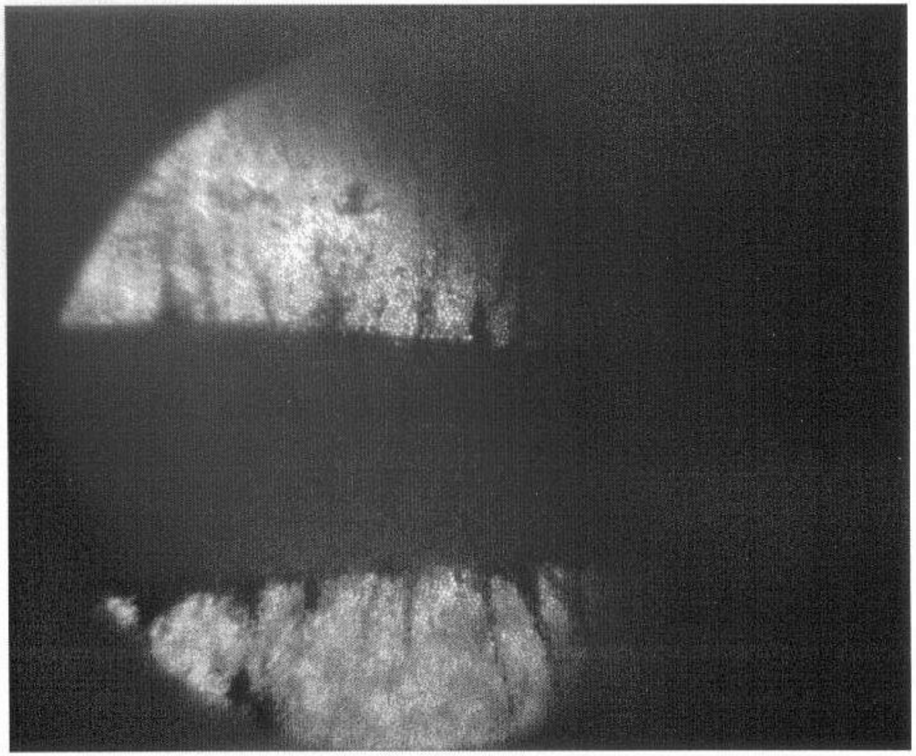
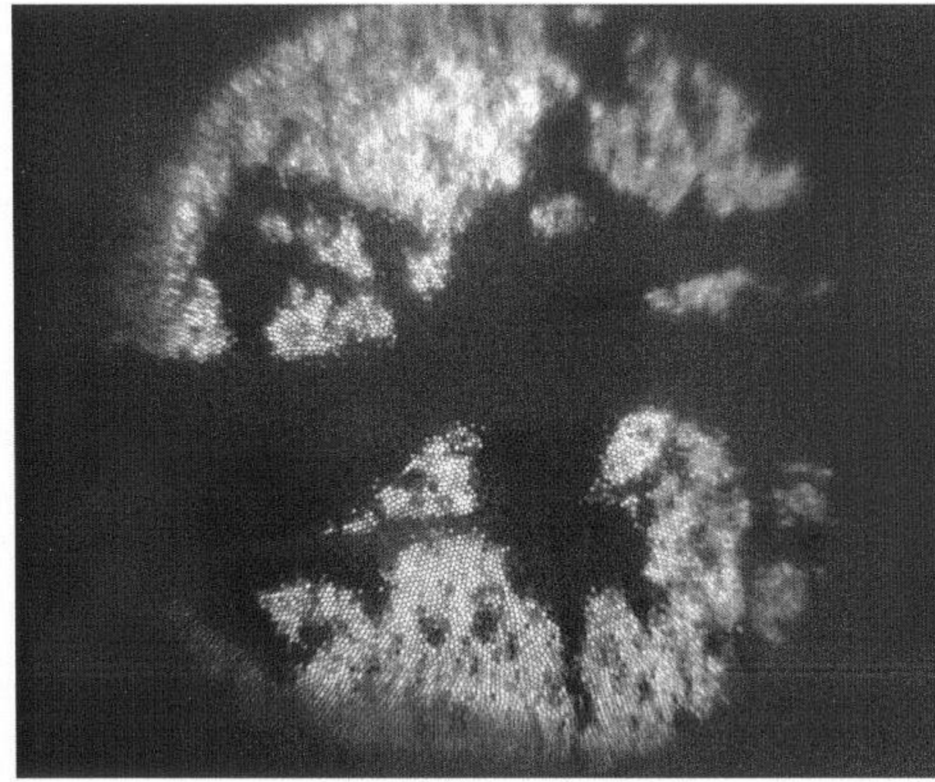


Fig. 13 The total (quasi-static plus dynamic) radial stress in an instantaneously heated Al disk of radius R at different times. The time parameters are given in units of R/c.

Viewport 1 at 2ms



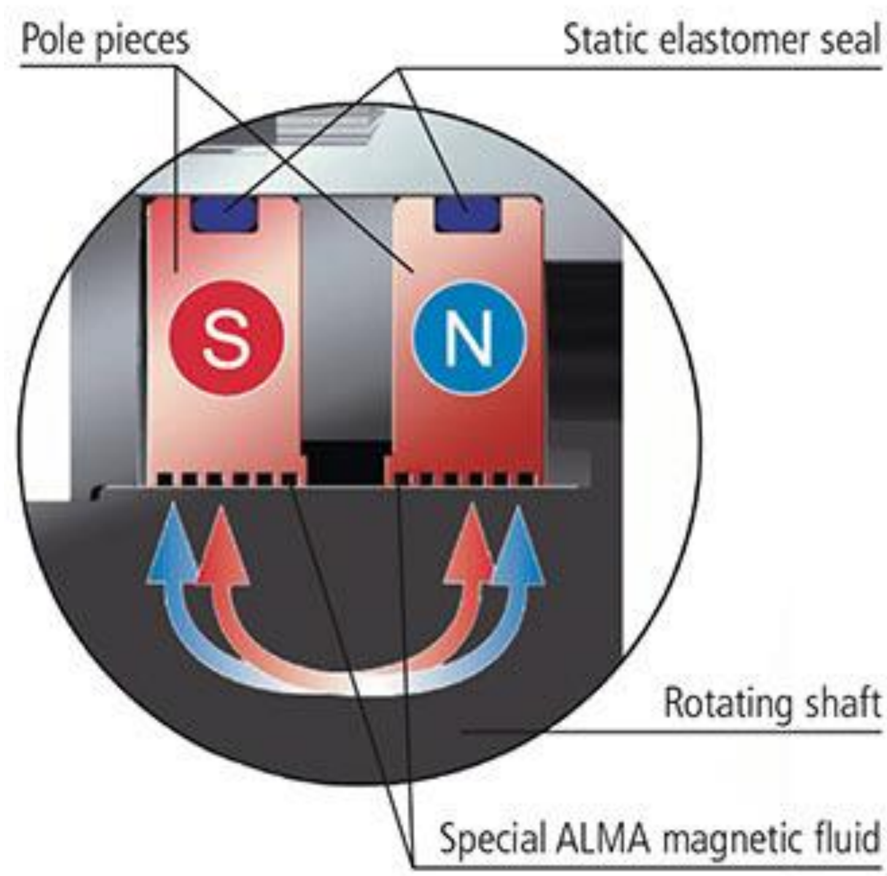
Viewport 3 at 26ms



October 26, 2007
Beam Pulse at 8:39pm
Mid-European Daylight Time

Hg Jet 15m/s
Solenoid Field 5T
Proton Intensity 10TP

Ferro Fluid Seal-ALMA/D



Magnetic Bearings. Juelich Forschungszentrum/D Weight of 100 kg supported by 0.2 kg ferromagnetic material.