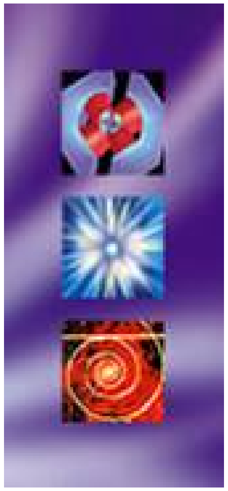
Power Dissipated in the Vacuum Vessel

Duncan Scott
Magnetics and Radiation Sources group
ASTeC
STFC Daresbury Laboratory



Introduction

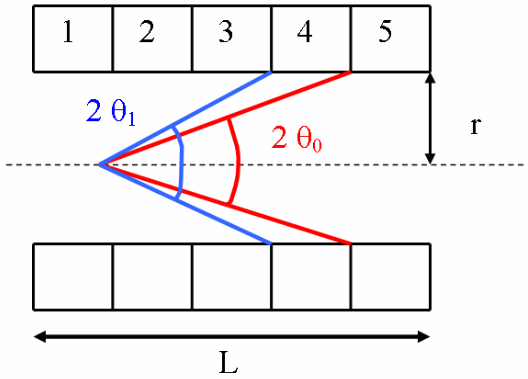
- Concerns raised by ILC-MAC:
  - Too much incident power on the Super-Conducting undulator vessel walls will cause the magnet to quench
- Two sources of heat considered
  - Synchrotron Radiation
  - Image current heating (resistive wall wakefields)
- This has been considered before (EPAC 2004) and is now updated

Synchrotron Radiation Heating

- The SR power can be calculated from the angular distribution of the radiation intensity for a single electron:

$$\frac{\mathrm{d}I}{\mathrm{d}\Omega}(\theta) = \frac{2Ne^2\gamma^4\omega_u}{4\pi\epsilon_0 c}\frac{K^2}{(1+K^2+\gamma^2\theta^2)^3}\sum_{n=1}^{\infty} n^2\left(J_n'^2(x_n) + \left(\frac{\gamma\theta}{K} - \frac{n}{x_n}\right)^2 J_n^2(x_n)\right)$$

- In suitable co-ordinates: $\mathrm{d}\Omega = \sin(\theta)\mathrm{d}\theta\mathrm{d}\phi$
- Giving, P, into an annulus defined by, θ_0 θ_1



$$P = N_e 2\pi \int_{\theta_0}^{\theta_1} \frac{\mathrm{d}I}{\mathrm{d}\Omega}(\theta)\sin(\theta)\mathrm{d}\theta$$

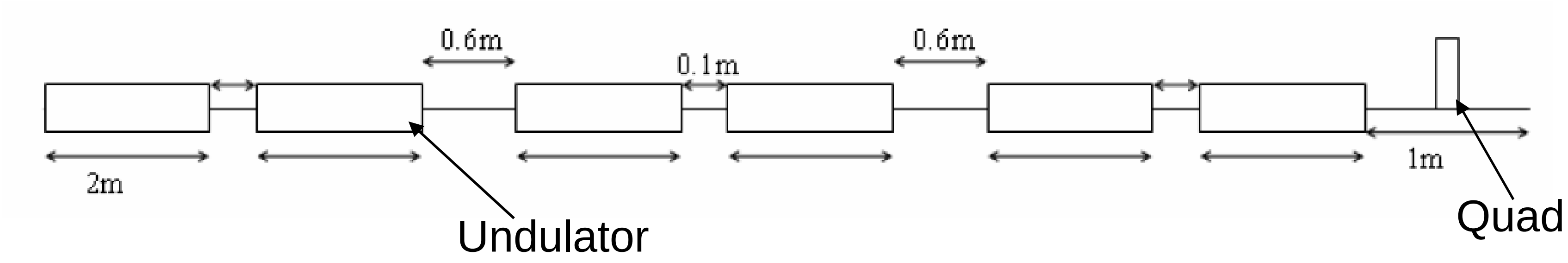
Number of electrons

Parameters

- Considered BCD and RDR undulators

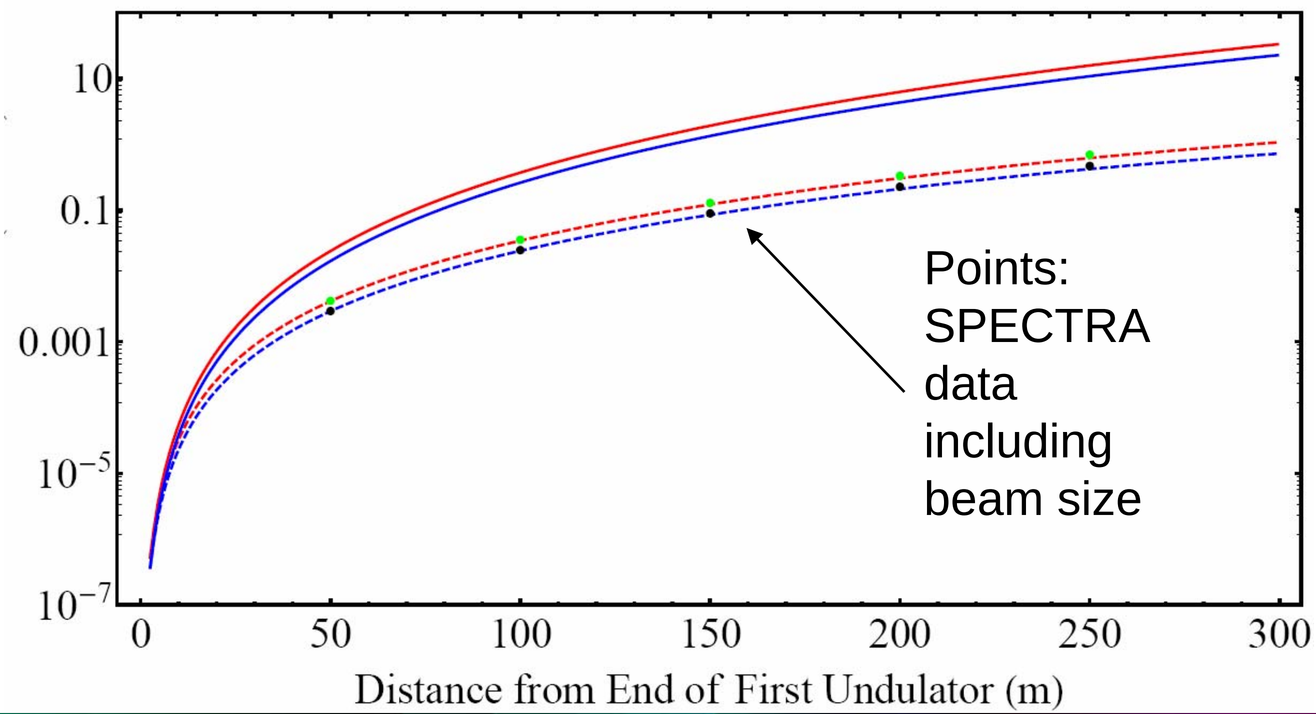
Parameter	Unit	ILC-BCD	ILC-RDR
Undulator Period	mm	10	11.5
Undulator K		1	0.966
Undulator Aperture	mm	5.85	5.85
Undulator length	m	2	2
N_e		$2.82\ 10^{-14}$	$2.82\ 10^{-14}$

- And a nominal half-cell



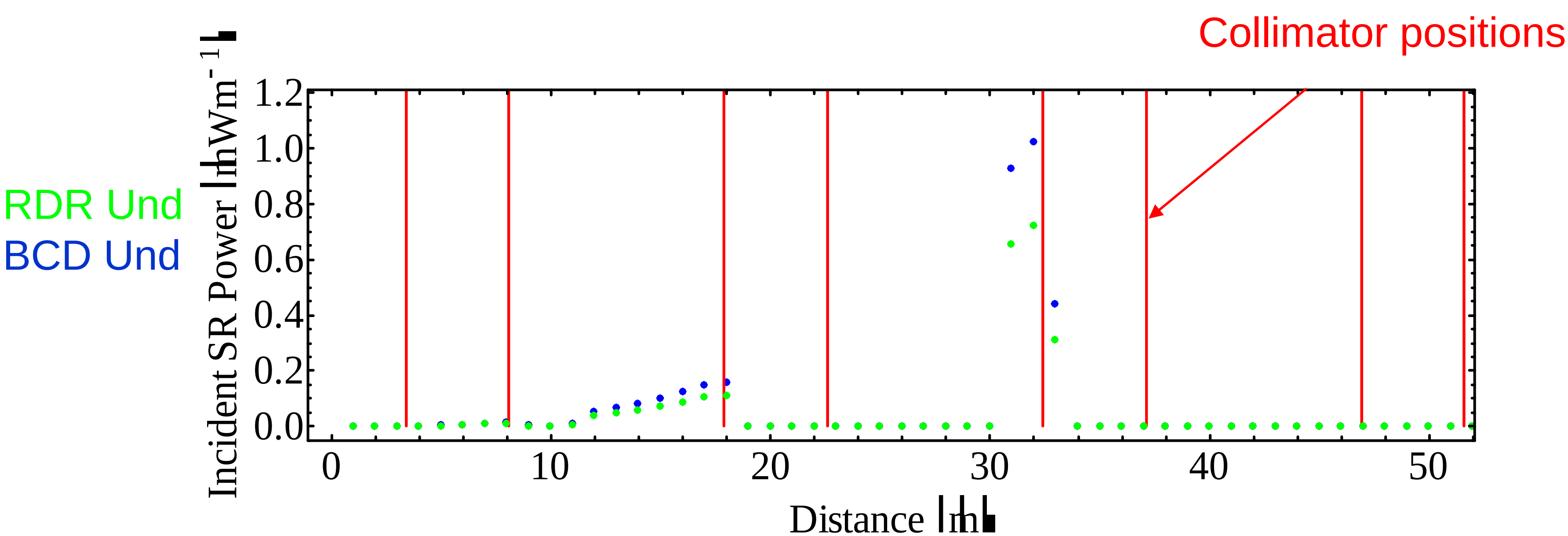
Incident Power per m

- Incident power for 1 undulator (dashed) and a line of 20 half-cells (solid)
- Peak power: BCD, blue, ~22.5, RDR, red, 33 W m^{-1}
- Collimation required



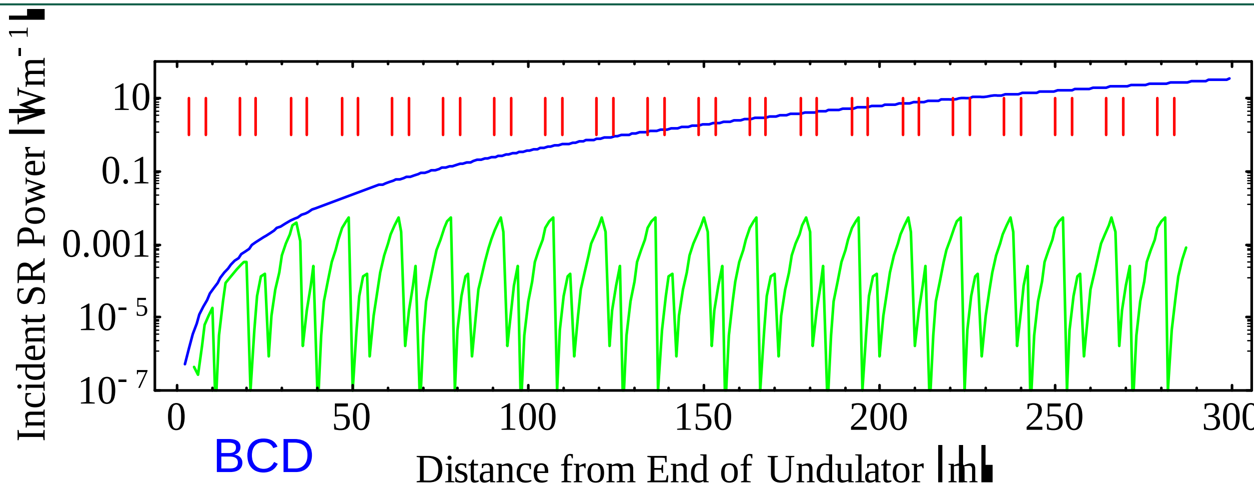
Collimators

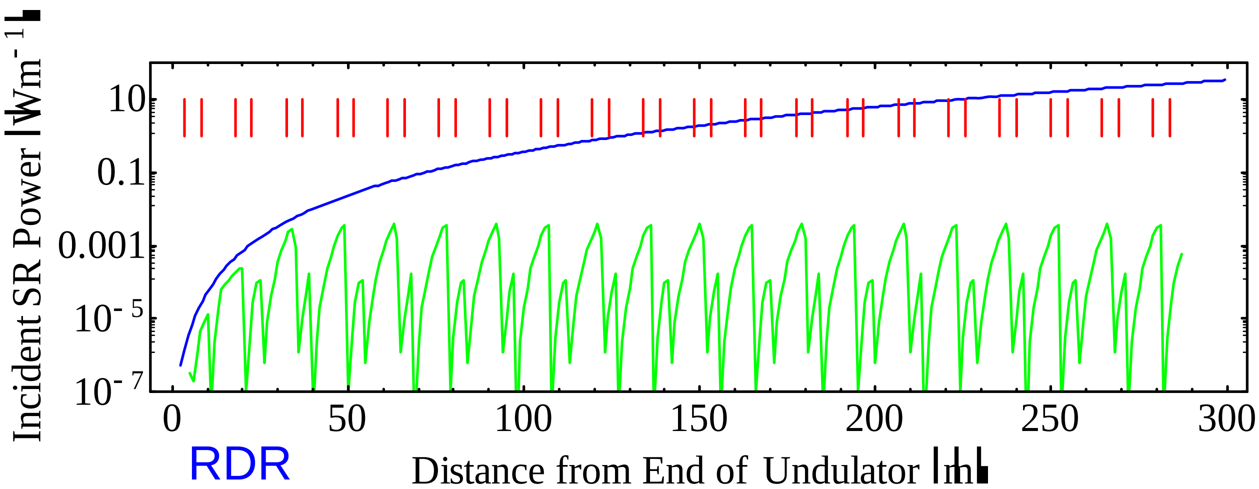
- 4.4~mm aperture photon collimators (required to reach required vacuum) were systematically placed in the line at the 60cm gaps
- Significant power is absorbed near the start
- Power (1 und) reduced to zero after ~30 m



Incident Power per m with collimation

- Incident power for 10 cell line with and without collimation
- With collimation the peak power is less than 5.5 and 3.9 mW m^{-1}

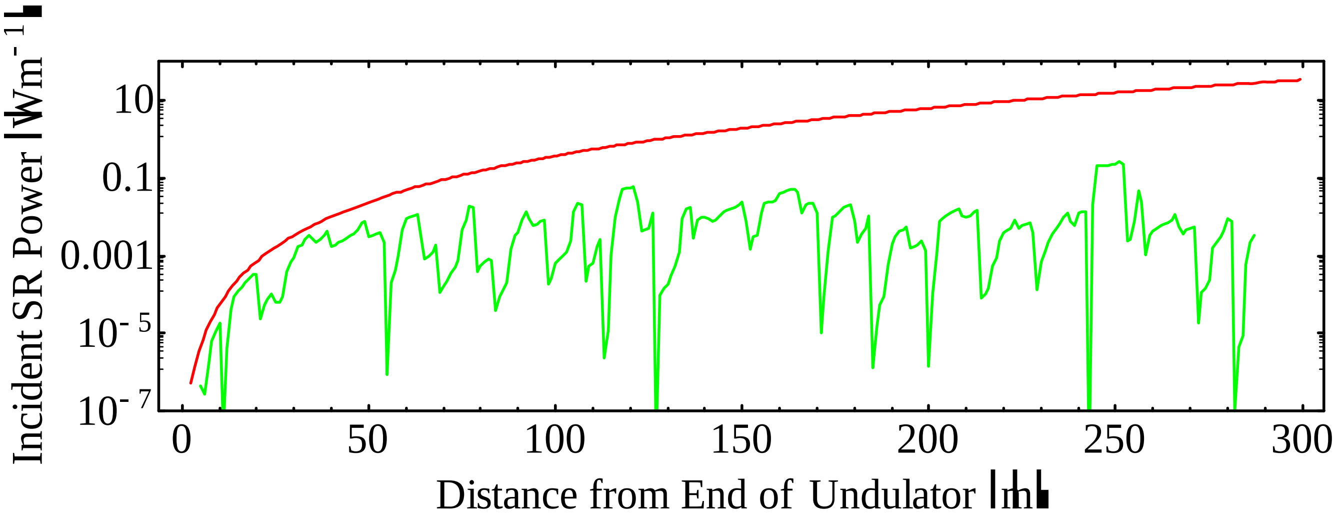




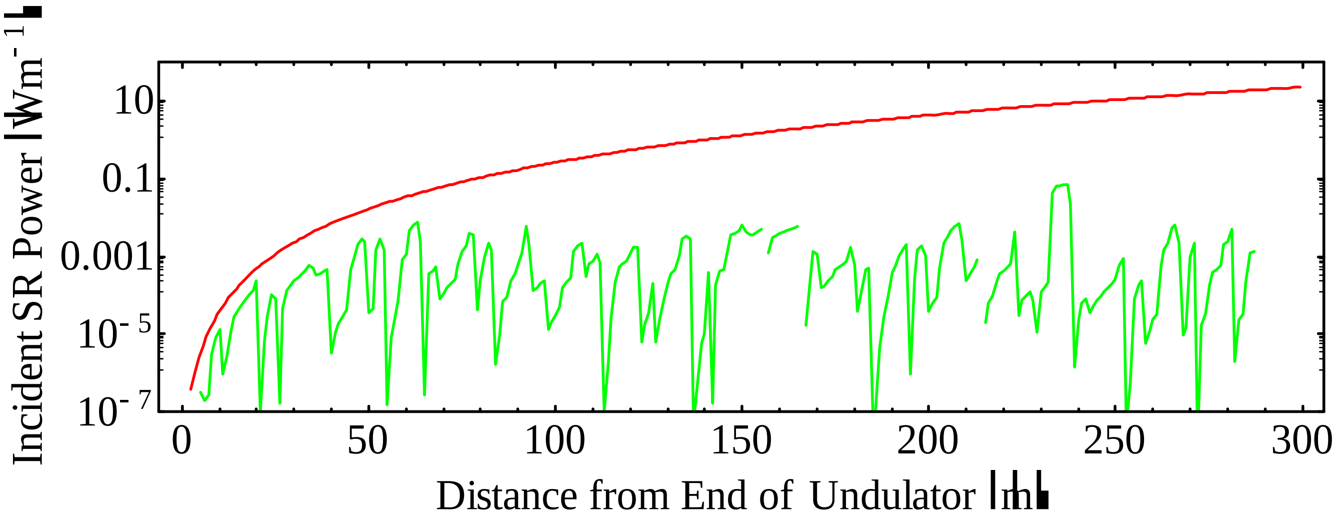
Errors

- There will be some spread in collimator position and size.
- An attempt to account for this has been made by letting the radius of each collimator vary by a random amount.
- The radius of each collimator was varied following a Gaussian distribution with a σ value of 500 μm truncated at 3σ.
- 1000 different random undulator lines were created for each parameter set

‘Worst’ of the 1000 Iterations

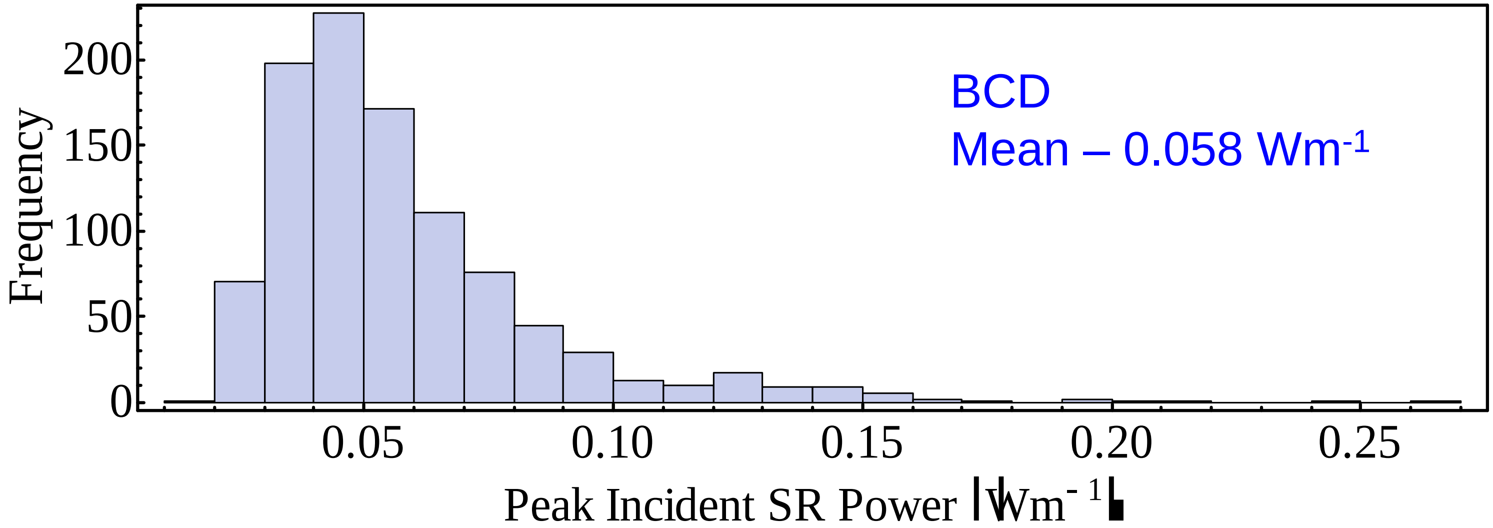


BCD – maximum power 0.27W m^{-1}



DR – maximum ower 0.07W m-1

Histogram of peak power per m for each iteration



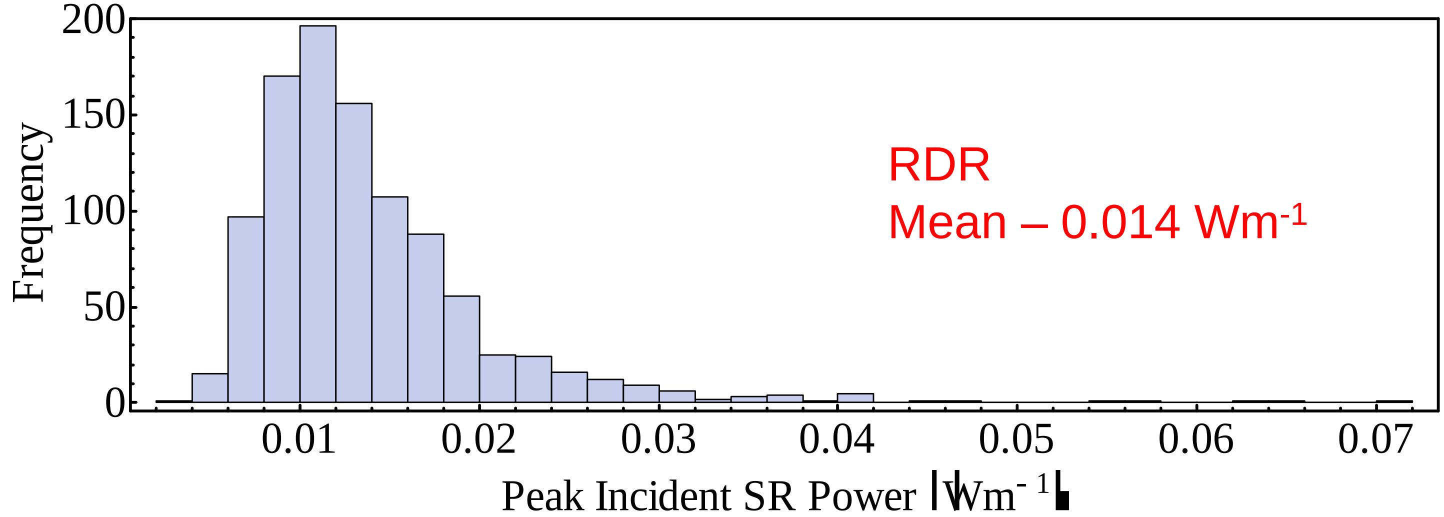


Image Current Heating

- Power, P_T due to AC field in vessel of radius r and surface resistance R_s:

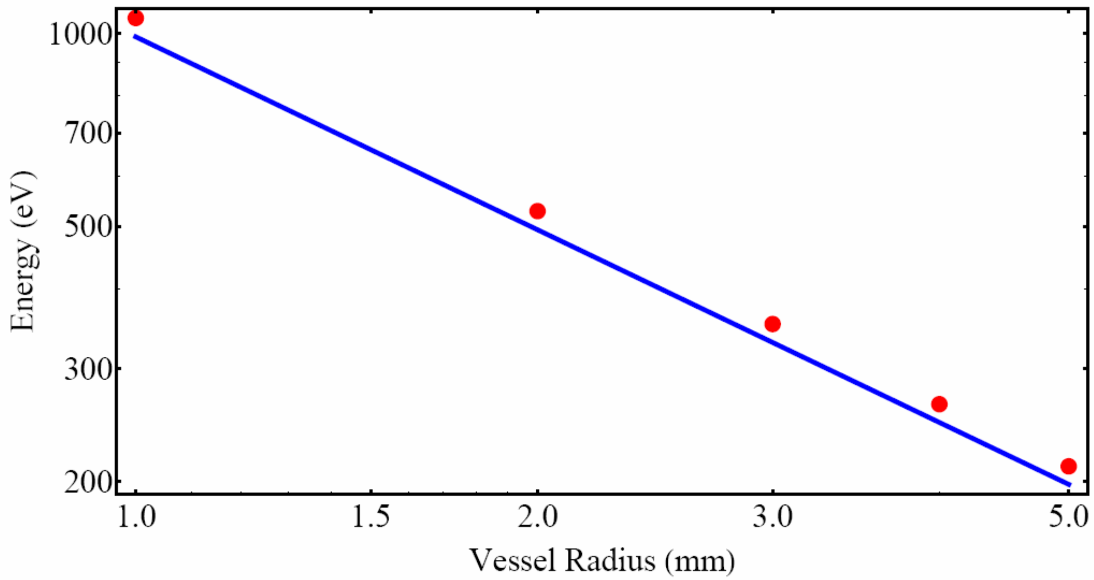
$$P_T = \sum_{n=0}^{\infty} P_{s,n},$$

$$P_{s,0} = \frac{1}{2\pi r} R_s(0) I_0^2 \qquad P_{s,n} = \frac{1}{2\pi r} R_s(n\omega_0) 2 I_0^2 \mathrm{e}^{-\frac{n^2\sigma_b^2\omega_0^2}{c^2}}$$

- Where:
  - ω_0 is 2π divided by the bunch spacing in seconds
  - σ_b is the rms bunch length,
  - I_0 is the time averaged current
  - c is the speed of light.
- R_s depends upon the frequency of the applied field, operating temperature and any external magnetic field

Image Current Heating

- The heating of the vessel due to RW-wakes should be (roughly) equivalent to the energy lost by the beam due to RW-wakes. Compared with copper



- RW Wake energy lost per electron per meter (points),
- Energy deposited due to image current heating per electron per meter (line)

ICH results for nominal parameters

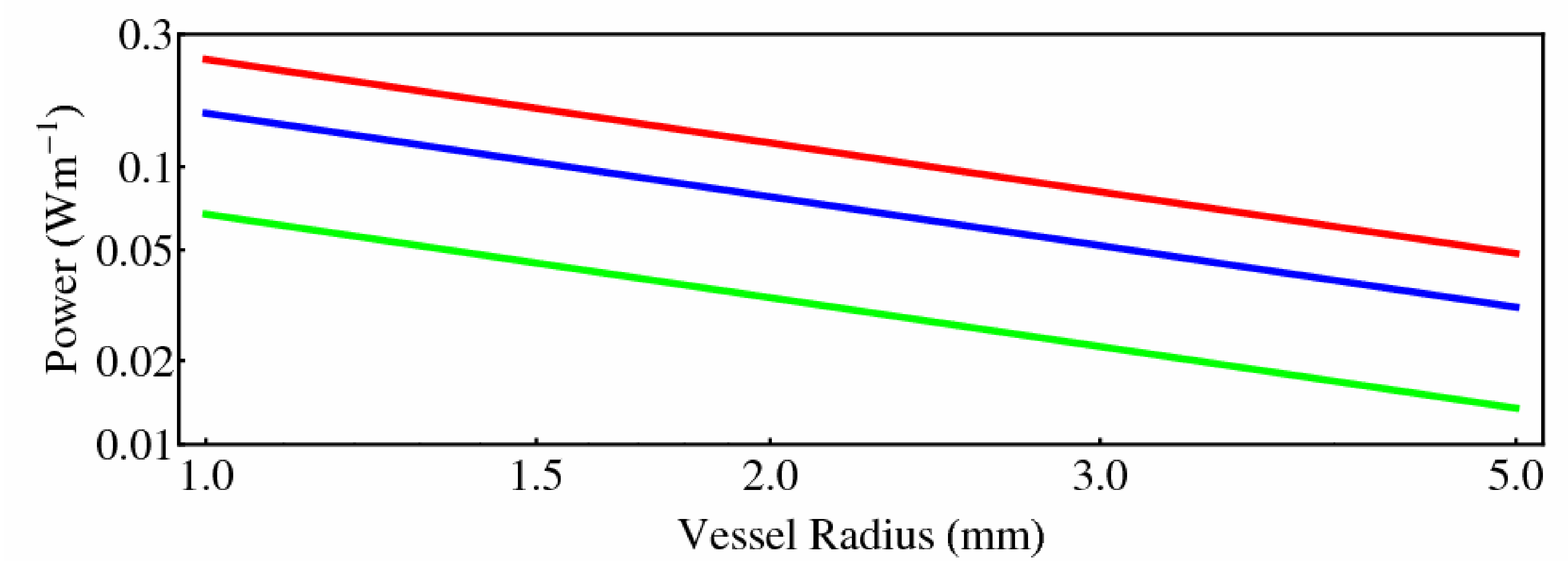
- As the ILC is pulsed some assumptions must be made:
  - Calculate heating for CW operation and then factor in the % of beam there actually is (Fill Factor)
  - Assumed: Anomalous Skin Effect, 1T external field for R_s

Parameter	Unit	Pattern 1	Pattern 2	Pattern 3
Repetition Rate	Hz	5	5	5
Bunch Spacing	ns	150	300	500
Bunch Length	μm	150	300	500
Particles per Bunch	10^{10}	1	2	2
Peak Bunch Frequency	MHz	6.66	3.33	2
Bunches per pulse		5640	2820	2820
Fill Factor		1.41×10^{-2}	4.23×10^{-3}	7.05×10^{-3}
Power per metre	W m^{-1}	0.081	0.052	0.022

- (Low average current, 45 μA, is what saves us here!)

ICH results vs. Vessel Radius

- Power deposited for the three different fill patterns



Conclusions

- Maximum peak power in the line deposited in 4m module
  - 1.4 W (BCD)
  - 0.61 W (RDR)
- Average peak power in the line deposited in a 4m module
  - 0.56 (BCD)
  - 0.38 (RDR)
- Most modules will have much less power deposited than this
- Errors in field, trajectory etc still to be considered…