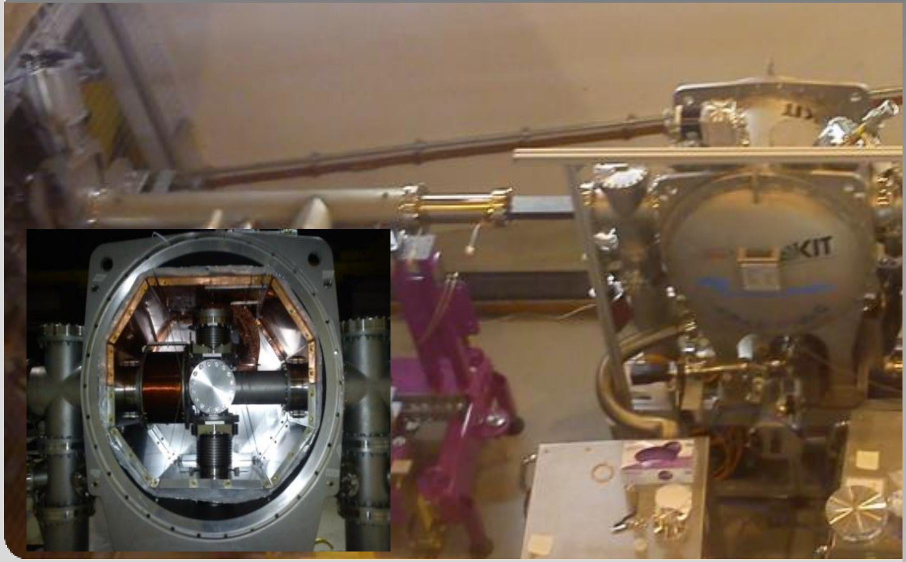
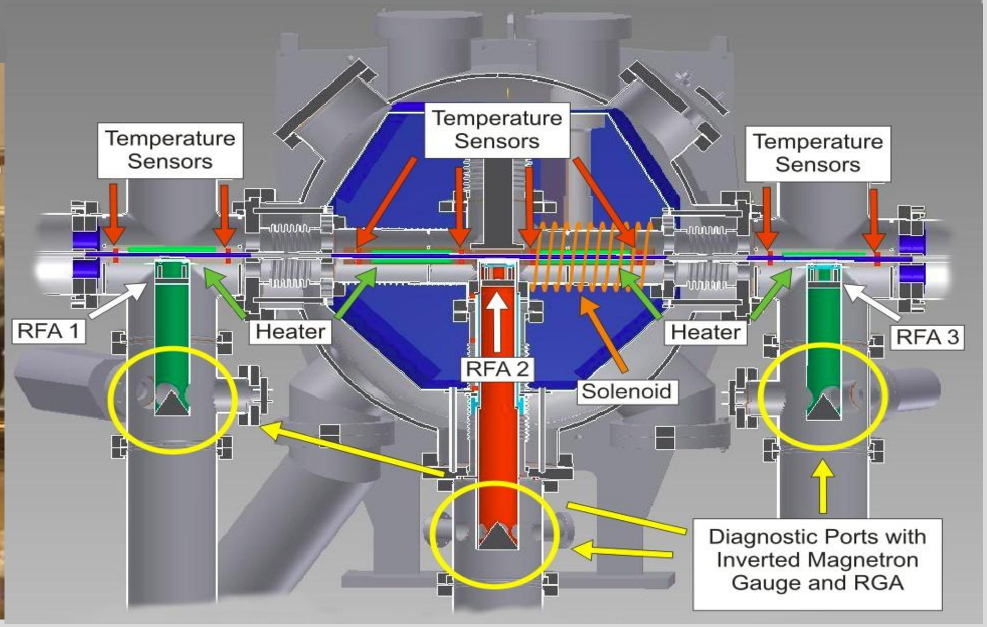
Beam heat load of superconducting wigglers

Sara Casalbuoni

ISS/ANKA





Outline

- Possible beam heat load sources
- Observations with superconducting wigglers/undulators.
  Experience at:
  - MAXII
  - DIAMOND
  - ANKA
- Dedicated experimental setups:
  - LBNL/SINAP calorimeter
  - COLDDIAG
- Conclusions and outlook

Possible beam heat load sources

- Synchrotron radiation from upstream magnets
- RF effects: geometrical and resistive wall impedance
- Electron and/or ion bombardment

Beam heat load sources: Synchrotron radiation from upstream bending

$$P_{\text{Synchrotron}} = I \cdot f(E, geometry)$$

$$I = \text{stored average beam current}$$

$$\text{E} = \text{electron beam energy}$$

Independent on filling pattern and on bunch length

Beam heat load sources: RF effects

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For M equally spaced Gaussian bunches

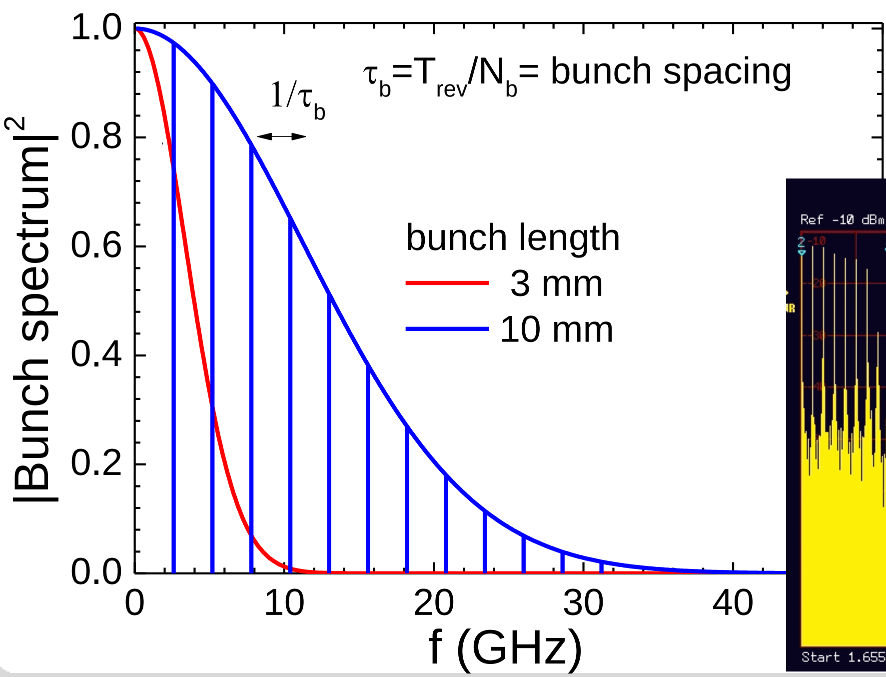
$$P_{\mathrm{RF\,effects}} = I^2 \sum_{n=-\infty}^{+\infty} \mathrm{Re}\, Z_{\parallel}(nM\omega_{rev}) \exp\left(-\left(\frac{\sigma_z nM\omega_{rev}}{c}\right)^2\right) \xrightarrow[\substack{M\omega_{rev}\to d\omega \\ nM\omega_{rev}\to\omega \\ \text{no resonant modes}}]{} \frac{I^2}{M}\cdot T_{rev}\cdot K_L$$

I = stored average beam current

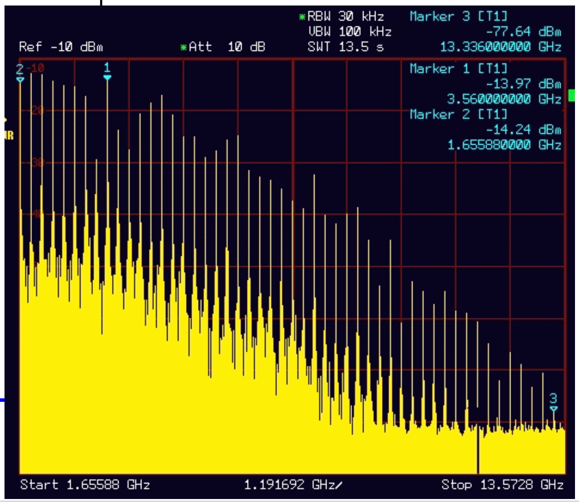
M = total number of bunches per revolution

$$T_{rev} = \frac{2\pi}{\omega_{rev}} = \text{revolution period}$$

$$\mathrm{K_L} = \frac{1}{\pi}\int_0^{\infty} \exp\left(-\left(\frac{\sigma_z \omega}{c}\right)^2\right)\cdot \mathrm{Re}\, Z_{\parallel}(\omega)\; d\omega$$



- **Dependence on average beam current I(σ_z)**
- **Dependence on number of bunches**
- **Dependence on bunch length**
- **Dependence on bunch spacing**



Geometrical imp.: can move away from resonance and considerably reduce losses by changing $1/\tau_b$ by the bandwidth of the resonance.

A. S. Fisher et al., SLAC-PUB-11230(2005)

Beam heat load sources: Resistive wall+anomalous skin effect

Resistive wall

$$\mathrm{Re}Z_{\parallel}(\omega) = \frac{L}{\pi \cdot g} \cdot R_{Surf}(\omega)$$

$L =$ length cold bore

$g =$ gap

Cylindrical = Rectangular beam pipe
W. Chou and F. Ruggiero, LHC Project Note 2 (SL/AP),CERN-Geneva, 9/8/1995.
E. Wallén, G. Le Blanc, Cryogenics,44, 879 (2004).

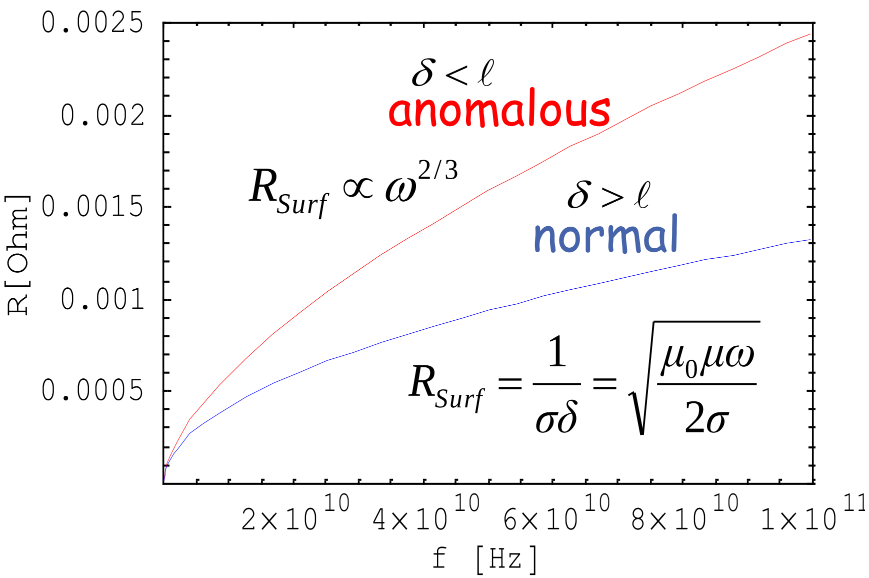
$$R_{Surf}(\omega) = R_{\infty}(\omega)(1+1.157\alpha^{-0.276}) \qquad \alpha \geq 3$$

$$\text{for Cu} \left(\frac{\ell}{\sigma_{RT}}\right) = 6.8\times10^{-16}\Omega\mathrm{m}^2$$

$$\sigma(4.2^{\circ}\mathrm{K}) = 5.7\times10^{9}\Omega^{-1}\mathrm{m}^{-1}$$

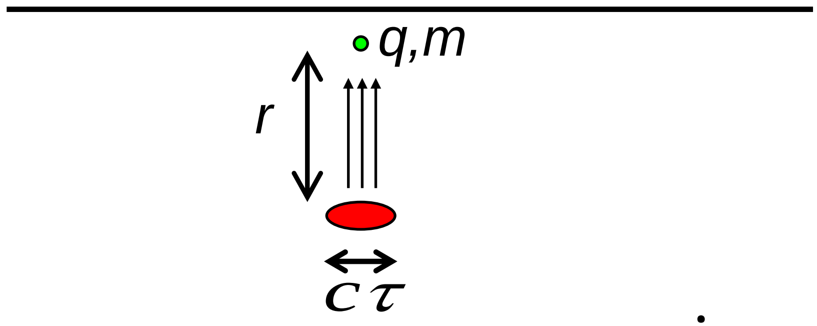
$$\alpha = \frac{3}{2}\left(\frac{\ell}{\delta(\omega)}\right)^2 = \frac{3}{4}\mu_r\mu_0\sigma(4.2^{\circ}\mathrm{K})\omega\ell^2$$

$$R_{\infty}(\omega) = \left(\frac{\sqrt{3}}{16\pi}\frac{\ell}{\sigma_{RT}}(\mu_r\mu_0\omega)^2\right)^{1/3}$$



- **H. London, Proc. Royal Society (London), A176, 522 (1940).**
- **A.B. Pippard, Proc. Royal Society (London), A191, 385 (1947).**
- **G.E.H. Reuter and E.H. Sondheimer, Proc. Royal Society (London), A195, 336 (1948).**
- **R.G. Chambers, Proc. Royal Society (London), A215, 481 (1952).**

Beam heat load sources: Ions and Electrons



$$P_{\text{Electron/ion bombardment}} = \Delta W \cdot \dot{N}$$

ΔW = energy of electron/ion hitting the wall

$\dot{N}$ = electrons/ion hitting the wall per sec

Interaction

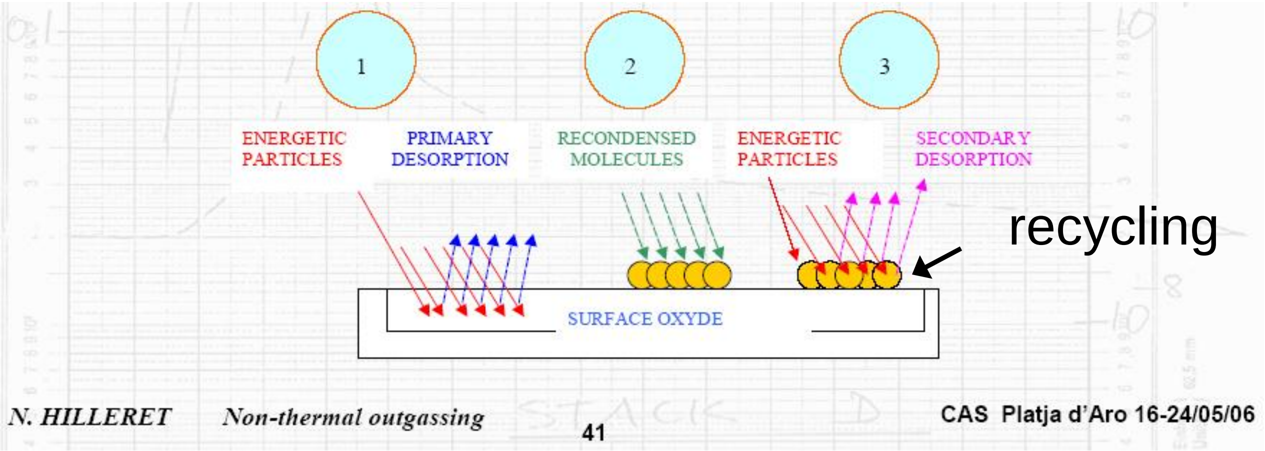
Beam - Electron cloud - Ion cloud

Beam heat load sources: Ions and Electrons

The two components influencing interaction beam – electron cloud – ion cloud:
- the beam
- the chamber surface characteristics

The surface properties as secondary electron yield, photoemission yield, photoemission induced electron energy distribution, are needed in the simulation codes to determine the eventual occurrence and size of an ecloud build-up.

Cryosorbed gas layer



These surface properties are only partly been measured for a cryosorbed gas layer.

Beam heat load sources: Ions and Electrons

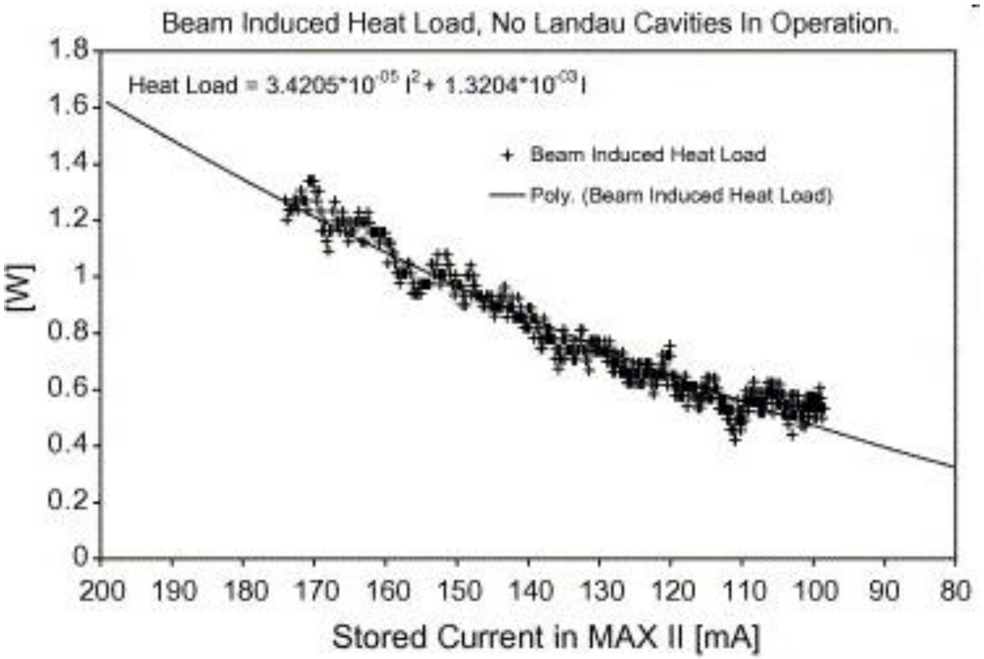
$$P_{\text{Electron/ion bombardment}} = \Delta W \cdot \dot{N}$$

Beam dynamics unknown

=> we do not know dependence of losses on different parameters as filling pattern, E, I, M, σ_z, τ_b

=> $P \propto I$ or I^2 not sufficient to prove that main contribution from synchrotron radiation, RF effects

Experience at MAXII: SC wiggler



E. Wallén and G. LeBlanc,
Cryogenics **44, 879–893 (2004).**

Table of estimated heat loads. The RRR value of the Cu coating is assumed to be 100 and I_B is assumed to be 200 mA with 24 mm RMS long bunches

	Temperature (K)	Source	Heat load (W)
The liquid He bath	4.2	Image currents	0.048
		Synchrotron radiation	0.122

‘The measured contribution to the total heat load from the stored beam in MAX II is 0.86 W instead of the predicted 0.17 W, and the contribution to the beam induced heating from the image current is 0.59 W, about 10 times larger than expected from calculations.’ **N. Mezentsev and E. Wallén, Sync. Rad. News Vol. 24, No. 3, 2011**

Experience at DIAMOND: SC wigglers

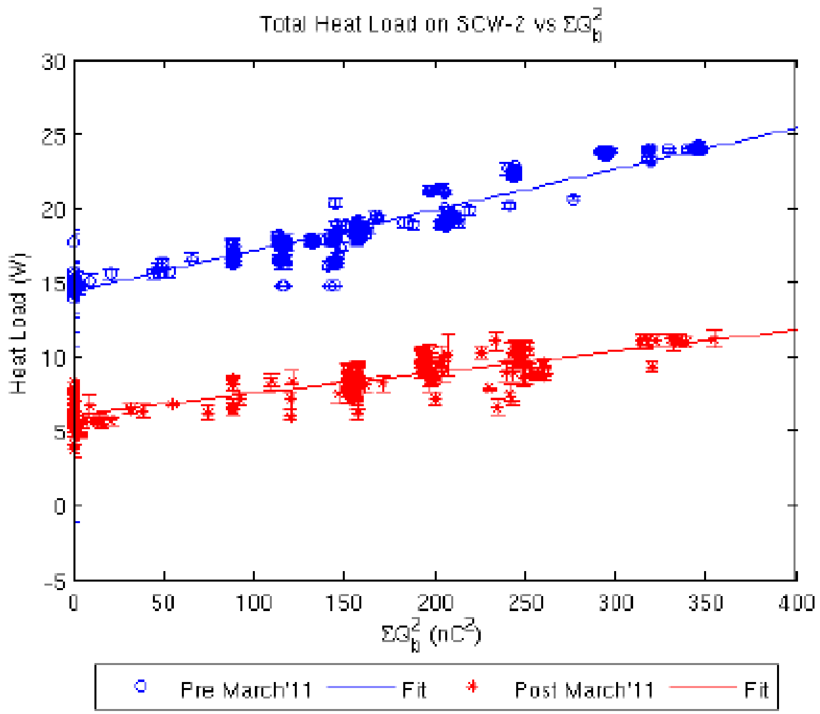


Figure 1: Total Heat Loads 10 K cryocoolers in SCW-2 before and after refurbishment

Refurbishment

Both: thermal connection shield 50K-taper

SCW-1: new liner

SCW2: installation recondensers, gold plated copper cylinders extending into the top of the helium vessel and connected to stage 2 of the current lead cryocoolers

Table 1: Predicted Heat Loads From Beam Heating Only for SCW-1 and 2 Using Eq. 1 vs. Measured

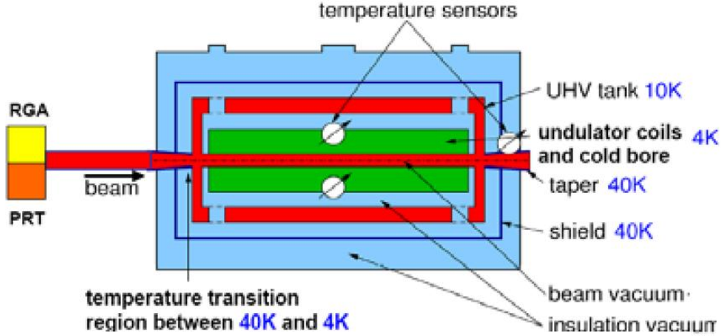
In Watt	Predicted	Actual before	Actual after
SCW-1: 10mm liner	3.62	15.7	
SCW-1: 9mm liner	4.03		11.77
SCW-2: 10mm liner	3.27	8.98	4.54

J.C. Schouten and E.C.M. Rial, IPAC2011

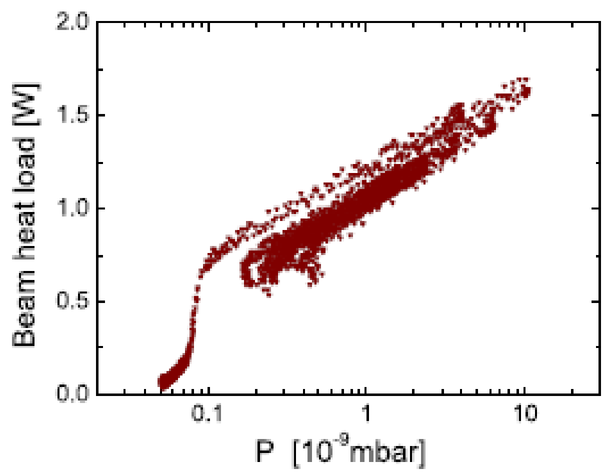
Experience at ANKA: SCU14 demonstrator

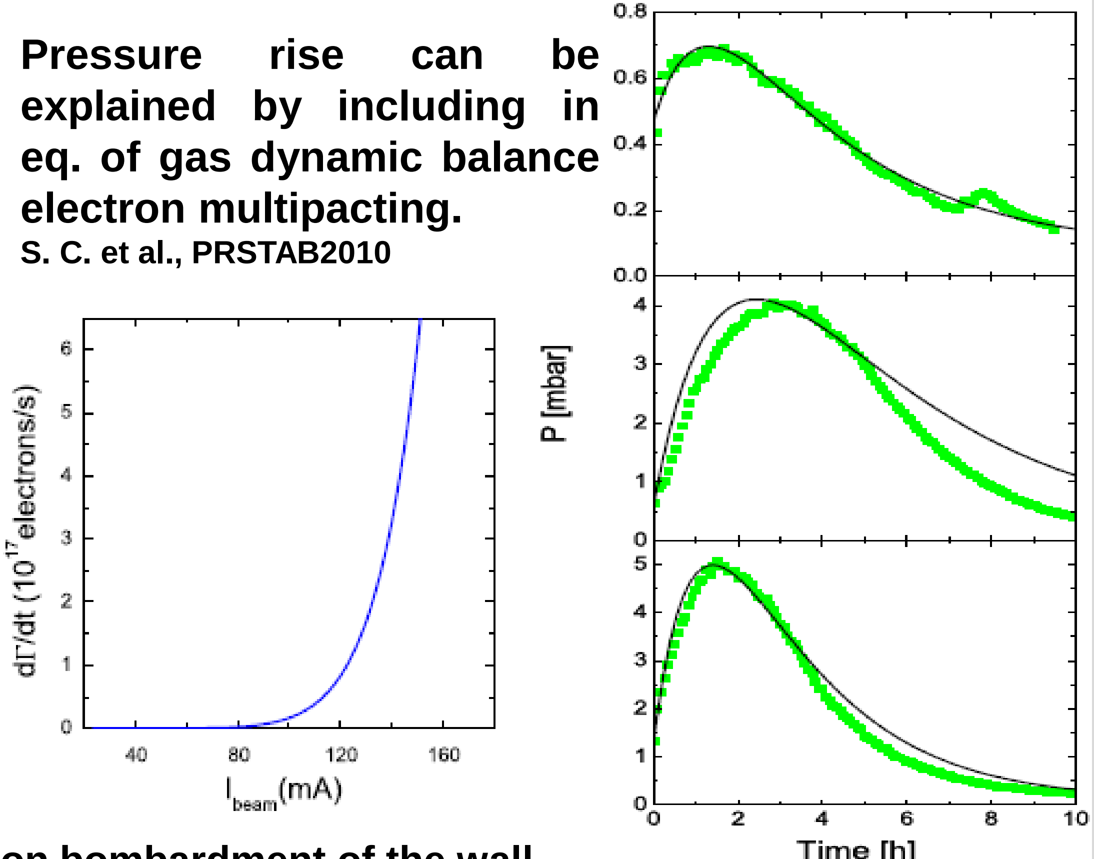
Beam heat load studies

Performance limited by too high beam heat load: beam heat load observed cannot be explained by synchrotron radiation from upstream bending and resistive wall heating. S. C. et al., PRSTAB2007



Pressure rise can be explained by including in eq. of gas dynamic balance electron multipacting.
S. C. et al., PRSTAB2010





Possible beam heat load source: electron bombardment of the wall, beam dynamics under study

Beam dynamics studies

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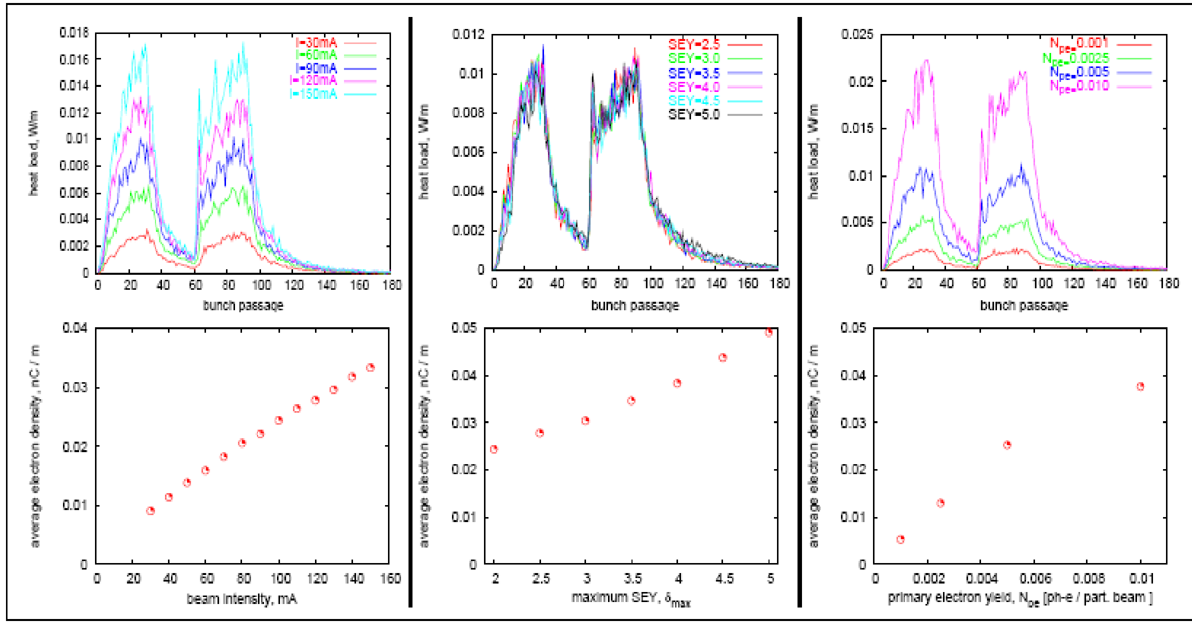
Simulations with ECLOUD code for the SCU14 demonstrator at ANKA

Table 1: ECLOUD input parameters.

Parameter	ref. value	scan
beam intensity (mA)	100	30 - 150
bunches / train	32	...
# trains	2	...
bunch charge (e-)	3.5e9	(1 - 5.4)e9
bunch spacing (ns)	2	...
energy (GeV)	2.5	...
rev. period (ns)	360	...
hor beam size (mm)	0.840	...
ver beam size (mm)	0.063	...
long beam size (mm)	12	...
hor aperture (mm)	80	...
ver aperture (mm)	30	8 - 30
SEY at zero energy, δ_0	0.5	0.5 - 0.9
max SEY, $\delta_{\max}$	2.0	1.5 - 5
energy for $\delta_{\max}$ (eV)	290	150 - 290
peak energy ph-e (eV)	7.0	...
energy ph-e, sigma (eV)	5.0	...
energy ph-e, sigma (eV)	1.8	...
primary e- yield, N_{pe} (ph-e/part. beam)	0.005	0.001- 0.01



The maximum heat load inferred from the ECLOUD simulations ~ 20mW.

The calculated energy spectrum shows that there are barely no electrons above 40 eV.

U. Iriso et al., PAC09, 2009

Beam heat load sources: Ions and Electrons

While ecloud build-up models have been well bench marked in machines with positively charged beams, in electron machines they do not reproduce the observations satisfactory.

This has been shown at ECLOUD'10 workshop by K. Harkay and by J. Calvey comparing the RFA data taken with electron beams in the APS and in CesrTA, respectively, with the simulations performed using the ecloud build-up codes POSINST (M.A. Furman and M.T. Pivi, Phys Rev ST Accel Beams 5,124404 (2002)) and ECLOUD (G. Rumolo and F. Zimmermann, CERN SL-Note-2002-016).

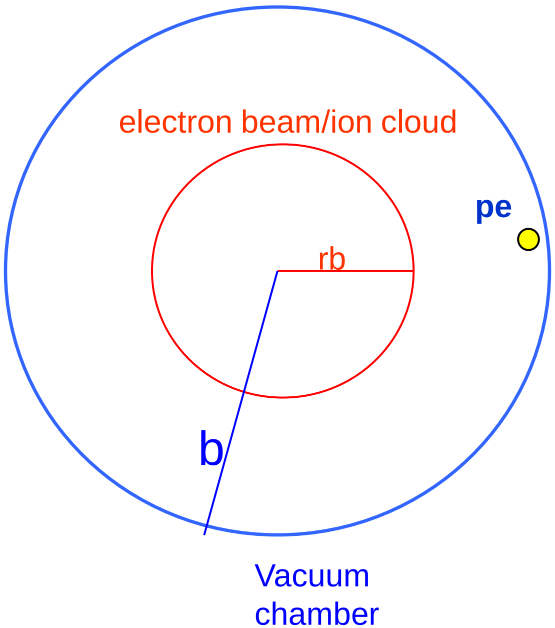
Do the ecloud build up codes contain all the physics going on for e- beams?
- APS change photoelectron model in POSINST (K. Harkay & L. Boon, ECLOUD10)
- ANKA include ion cloud potential in ECLOUD (S. Gerstl)

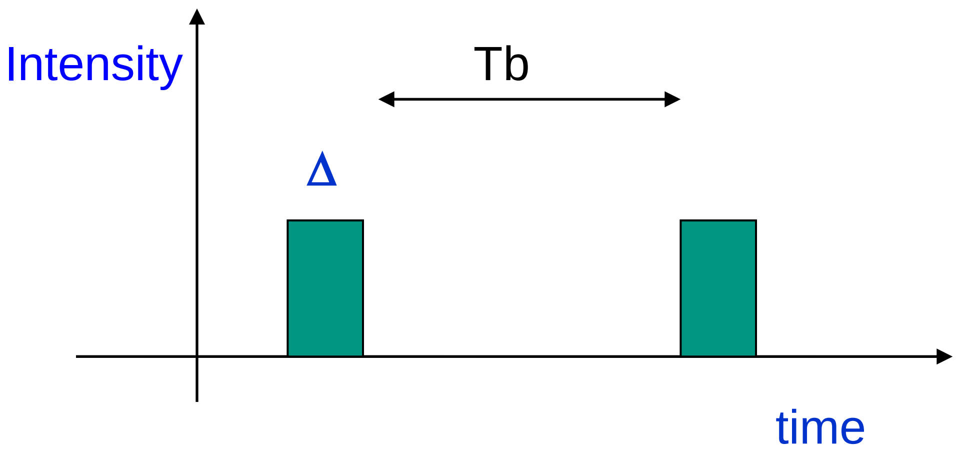
Beam dynamics studies

Can the presence of a *smooth ion background* (i.e. a partially neutralized electron beam) change the photo-electron dynamics so that the photo electrons can receive a significant amount of kinetic energy from the ion cloud + electron beam system ?

Photo-electron dynamics: A simple Model

I0 = average beam current



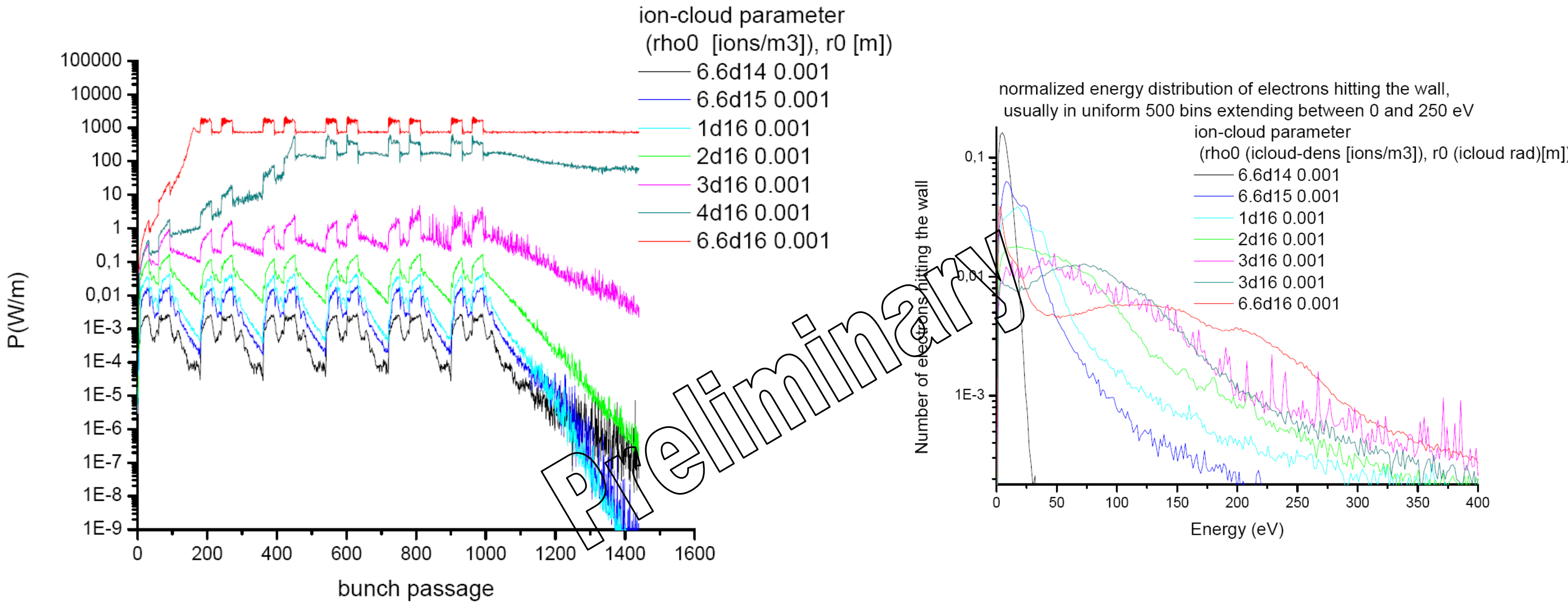


Courtesy P. Tavares

Beam dynamics studies

•First analytical results from P. Tavares showed that significant energy gain may be possible

•Inclusion of ion cloud potential in ECLOUD code



Next steps:

Check of neutralization values

Dedicated experiments: LBNL/SINAP calorimeter

LBNL proposal

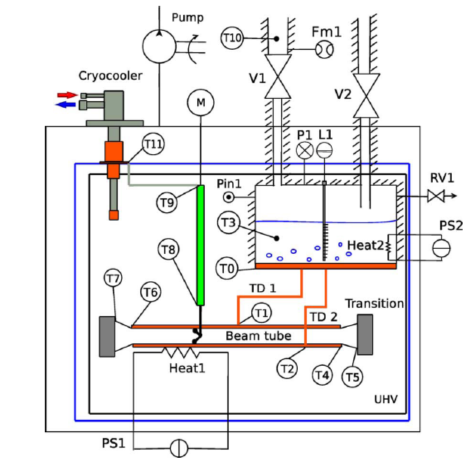


Fig. 3. Schematic drawing of the calorimeter based on boiler design.

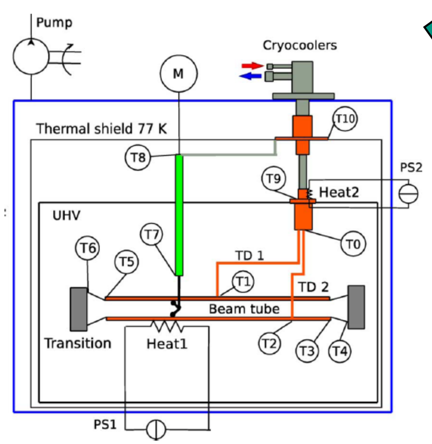
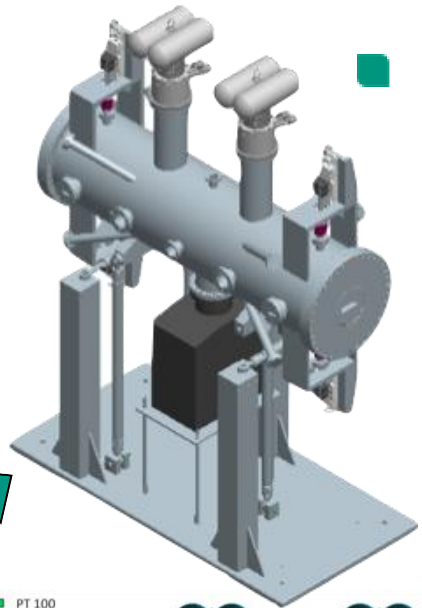
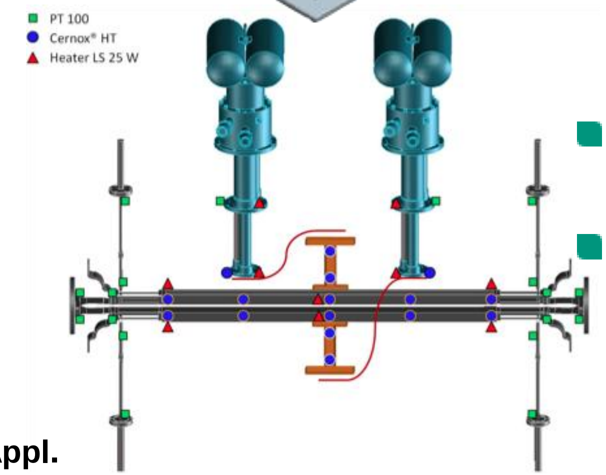


Fig. 4. Schematic drawing of the bolometer using conduction cooling.



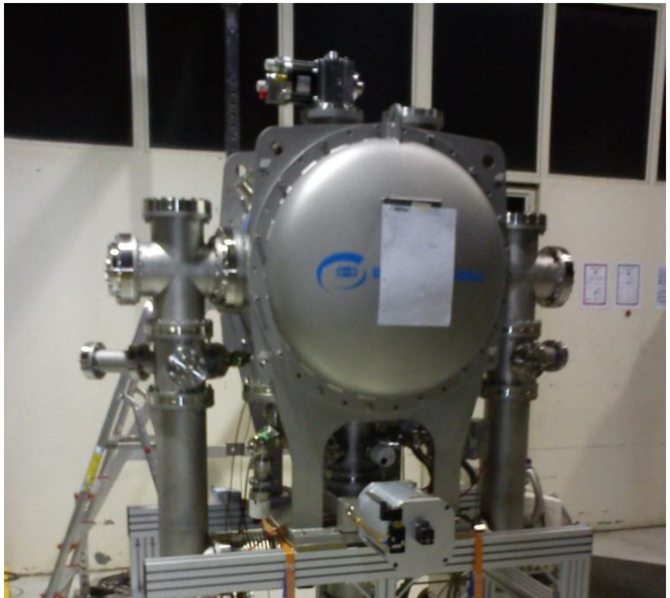


- Calorimetry:
  - SINAP/LBNL collaboration:
    - Measure heat loads via temperature gradients
    - Cooled by one or two cryocoolers
      - in-situ heaters:
        - constant-temperature operation
        - in-situ calibration checks
    - First installation planned summer 2012
    - Expect resolution <20mW

F. Trillaud et al., IEEE TRANS. on Appl. Supercond., VOL. 19, NO. 3, (2321-2324) JUNE 2009

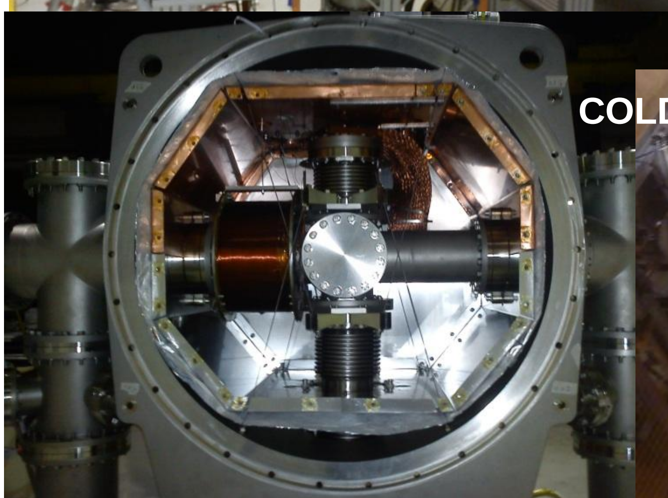
S. Prestemon, Talk FEL2011

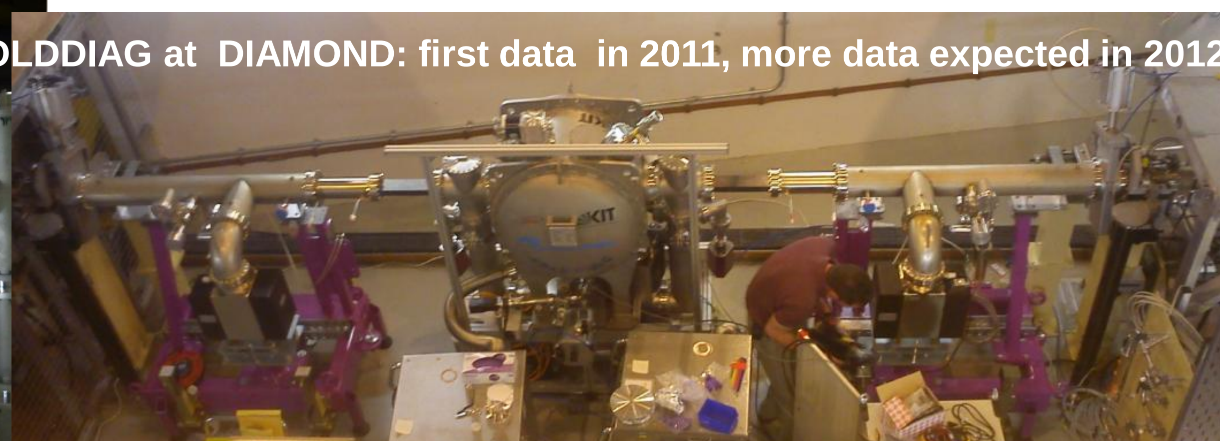
Dedicated experiments: COLDDIAG



Cold vacuum chamber for diagnostics to **measure the beam heat load** to a cold bore in a storage ring. The beam heat load is needed to specify the cooling power for the cryodesign of superconducting insertion devices.

In collaboration with
CERN: V. Baglin
LNF: R. Cimino, M. Commisso, B. Spataro
University of Rome ‚La sapienza': M. Migliorati
DIAMOND: M. Cox, J. Schouten, R. Bartolini, R. Walker
MAXLAB : Erik Wallèn
Max-Planck Institute for Metal Research: R. Weigel
STFC/DL/ASTeC: J. Clarke
STFC/RAL: T. Bradshaw
University of Manchester: I. Shinton





COLDDIAG at DIAMOND: first data in 2011, more data expected in 2012

Dedicated experiments: COLDDIAG

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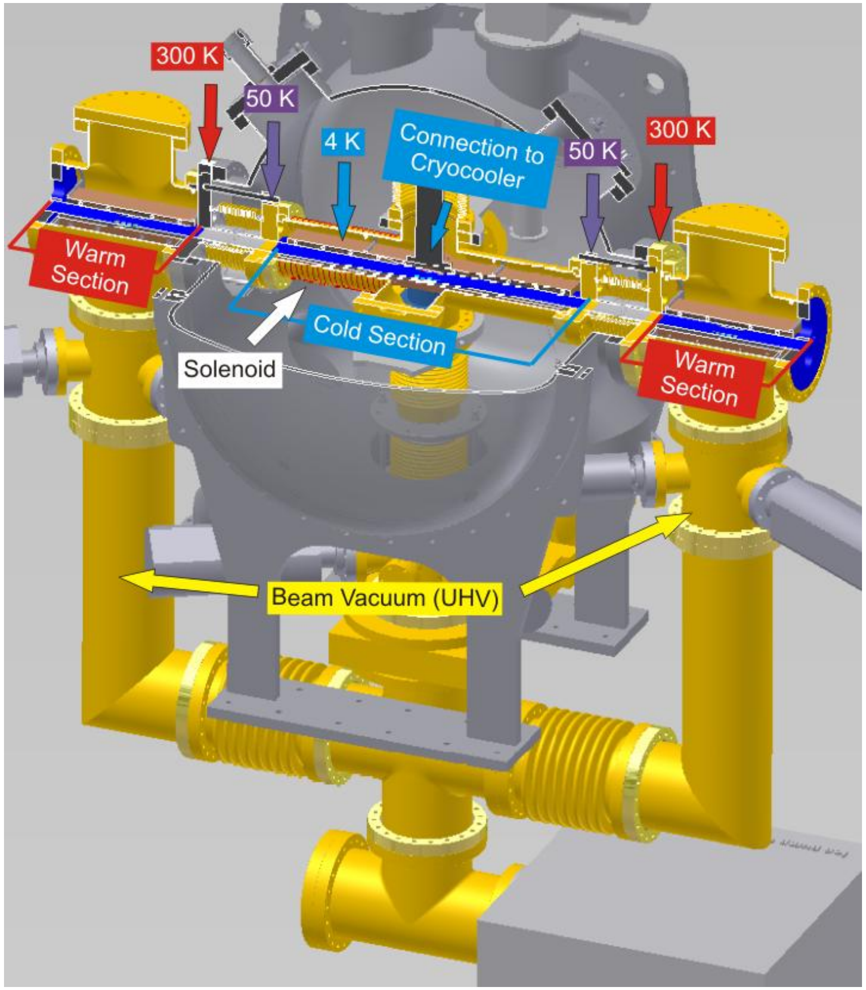
The vacuum chamber



•Cryogen free: cooling with Sumitomo RDK-415D cryocooler (1.5W@4.2K)

•Cold vacuum chamber located between two warm sections to compare beam heat load with and without cryosorbed gas layer

•3 identically equipped diagnostic ports with room temperature connection to the beam vacuum

• Exchangeable liner to test different materials and geometries

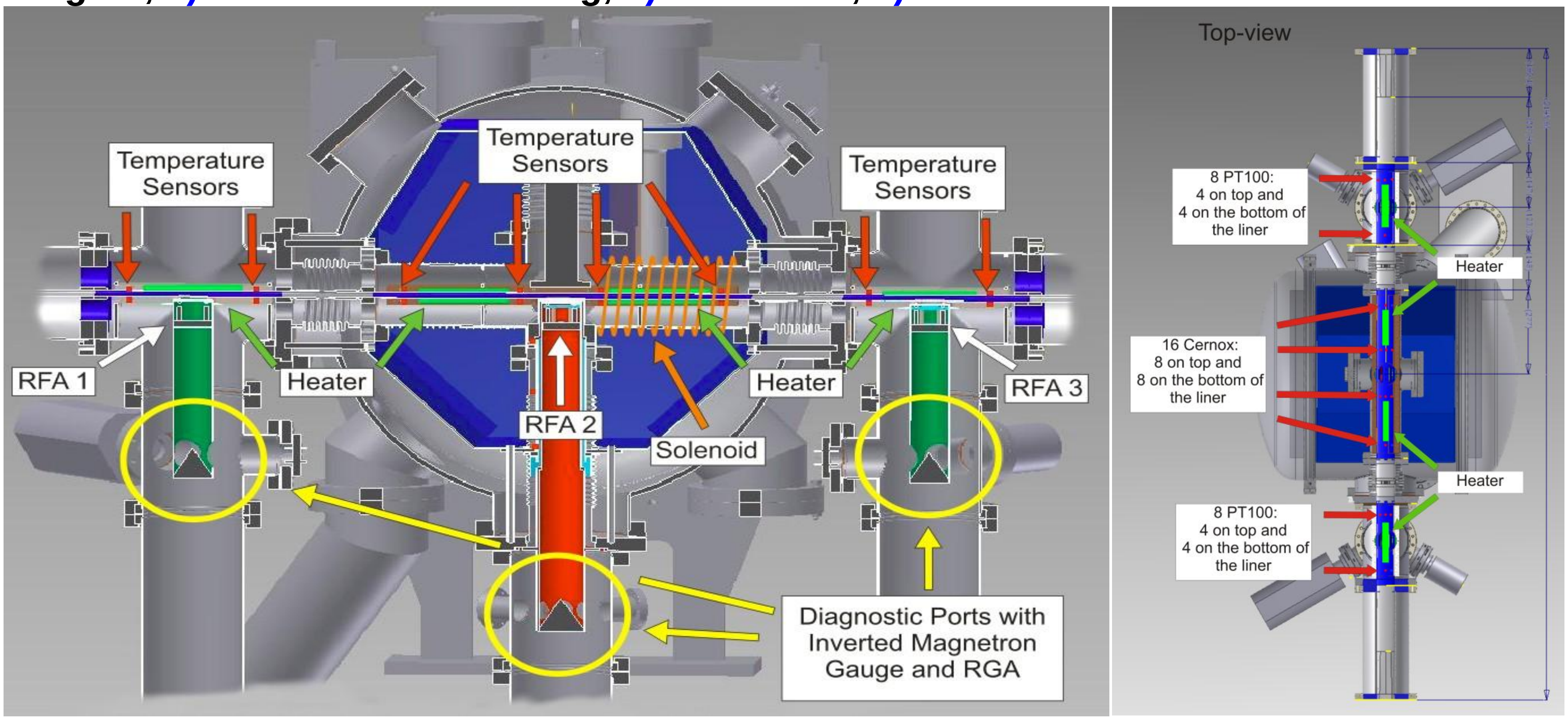
•Copper bar copper plated (50µm)

S.C. et al., IEEE Trans. on Appl. Supercond. 2300-2303 Vol. 21-3 (2011)

Dedicated experiments: COLDDIAG

Diagnostics

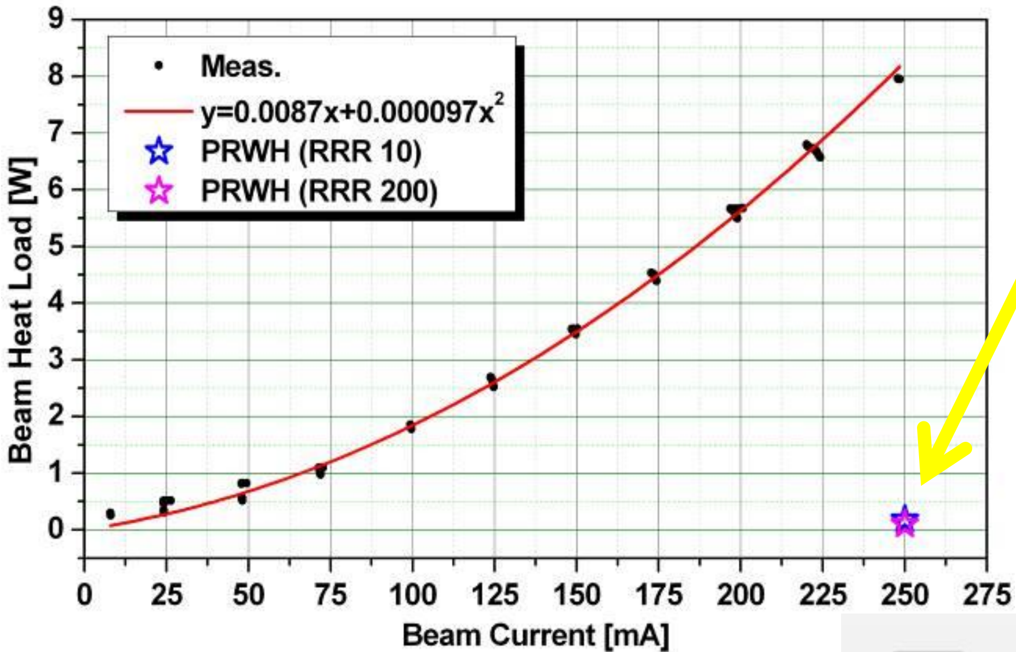
Possible Beam Heat Load Sources: 1) Synchrotron radiation from upstream bending magnet, 2) Resistive wall heating, 3) RF effects, 4) Electron and/ or ion bombardment



The diagnostics will include measurements of the heat load, the pressure, the gas composition, and the electron flux of the electrons bombarding the wall.

S.C. et al., IEEE Trans. on Appl. Supercond. 2300-2303 Vol. 21-3 (2011)

Dedicated experiments: COLDDIAG

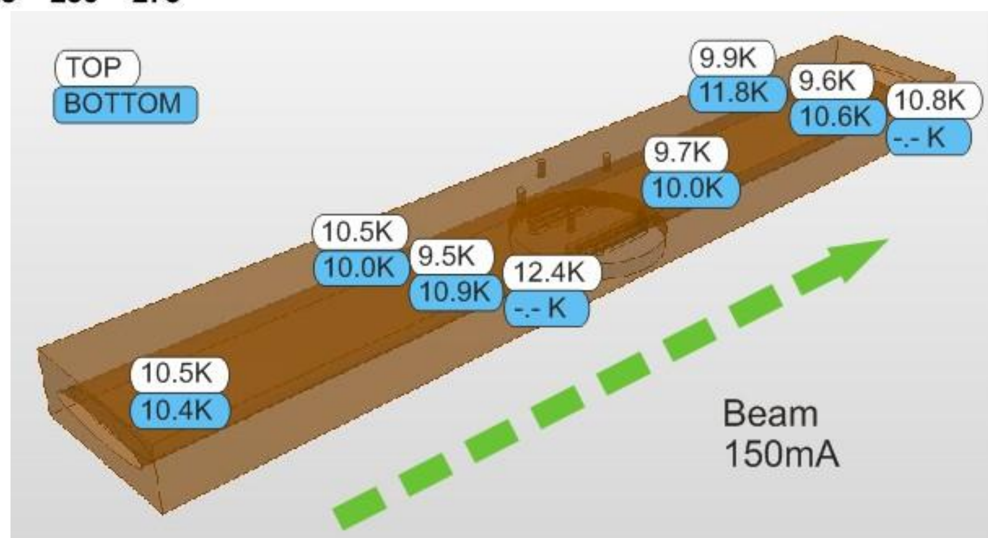


P_{RWH} (RRR=10) = 0.18W

P_{RWH} (RRR=200) = 0.1W

Without beam all temperature sensors indicate 4.05K±0.15K

Preliminary



S. Gerstl et al., IPAC2012

Dedicated experiments: COLDDIAG

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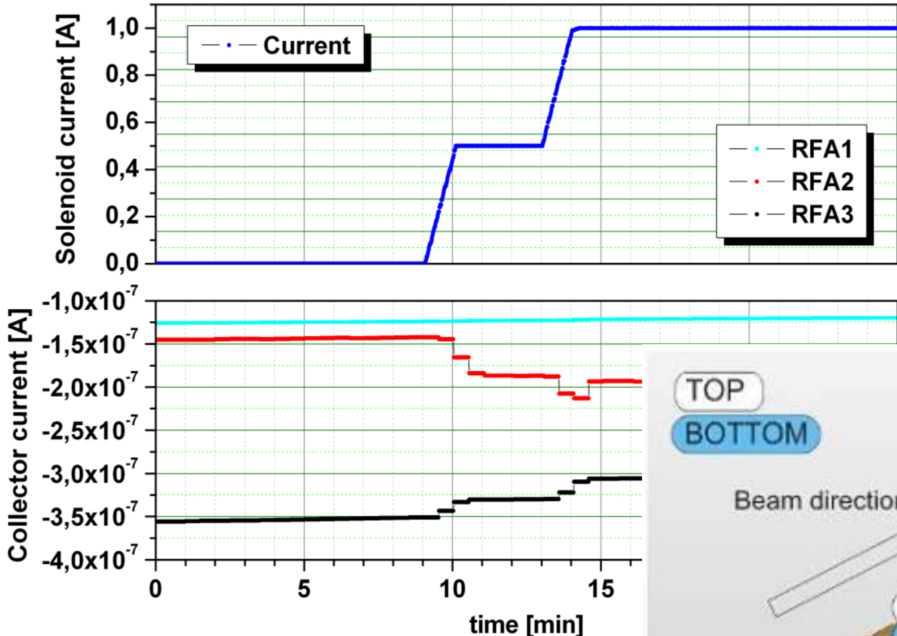
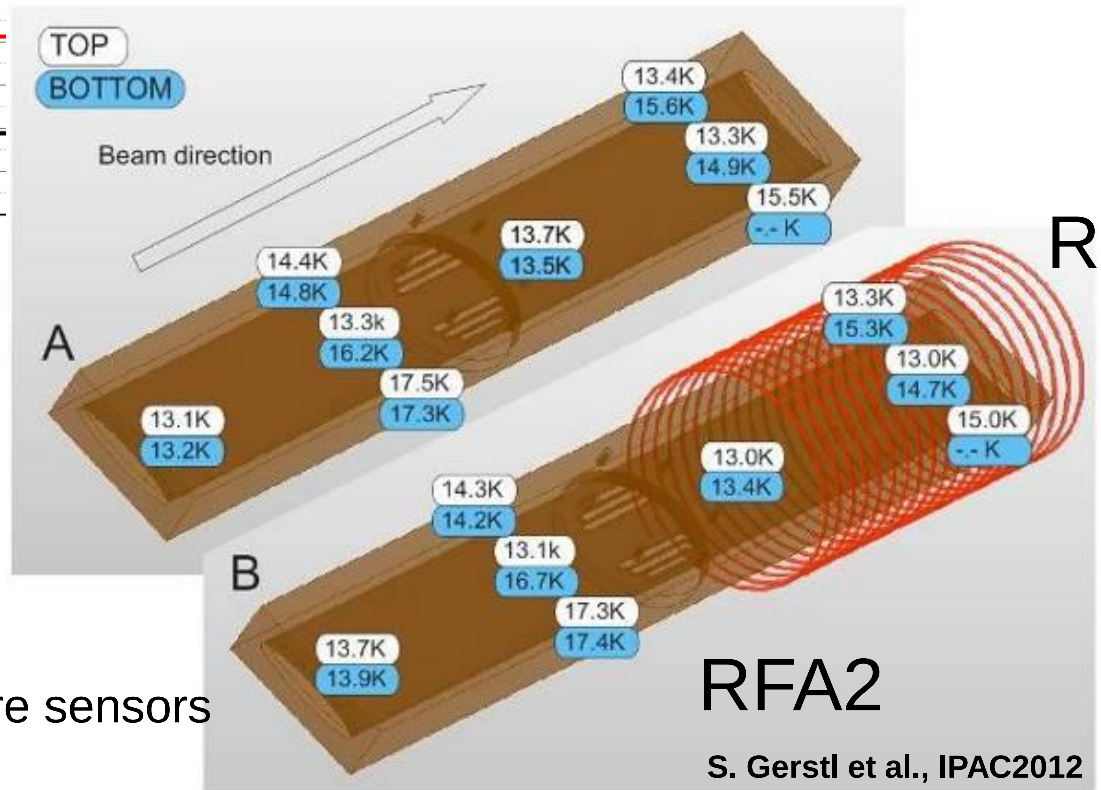


RFA1: upstream warm section
RFA2: cold section
RFA3: downstream warm section



RFA3

RFA2

S. Gerstl et al., IPAC2012

RFA1

Preliminary

Without beam all temperature sensors indicate 4.05K±0.15K

Dedicated experiments: COLDDIAG

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Planned measurements

Monitoring the temperature, the electron flux, pressure and gas composition with different:

- **average beam current** to compare the beam heat load data with synchrotron radiation and resistive wall heating predictions
- **bunch length** to compare with resistive wall heating predictions
- **filling pattern** in particular the bunch spacing to test the relevance of the electron cloud as heating mechanism
- **beam position** to test the relevance of synchrotron radiation and the gap dependence of the beam heat load
- **injected gases** naturally present in the beam vacuum (H_2, CO, CO_2, CH_4) to understand the influence of the cryosorbed gas layer on the beam heat load

Conclusions and outlook

- Beam heat load measurements not yet understood

- Upcoming dedicated experimental setups:
  - LBNL/SINAP calorimeter
  - COLDDIAG

- Additional information will come from:
  - Installed SCW
  - New SCUs to be installed at ANKA and APS

Thank you for your attention