DEVELOPMENT OF A MOVABLE COLLIMATOR WITH LOW BEAM IMPEDANCE

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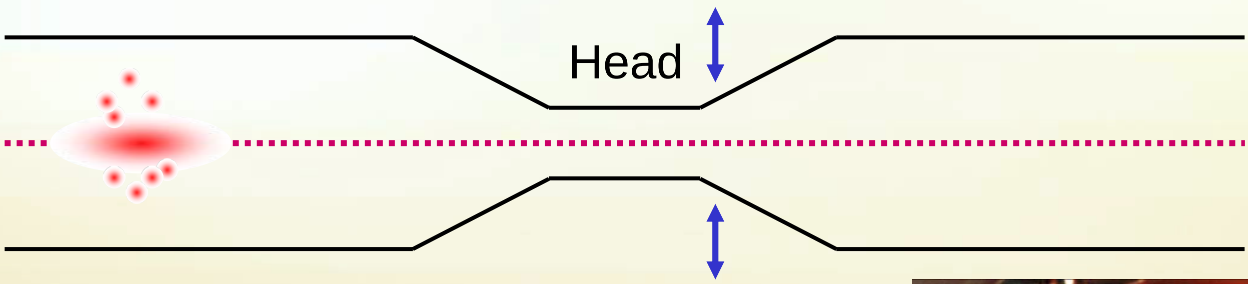
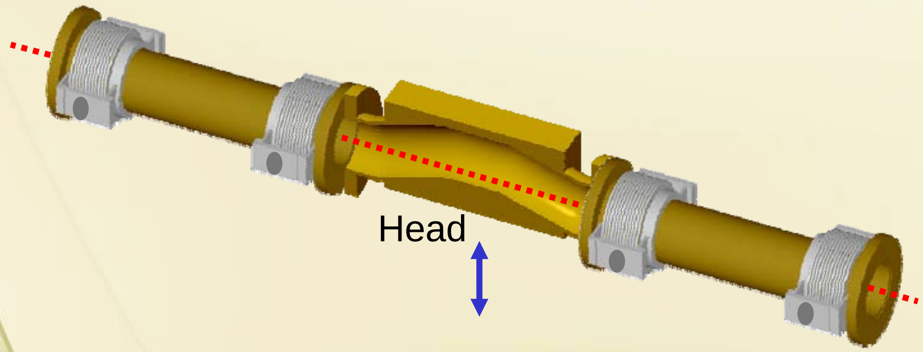
Contents

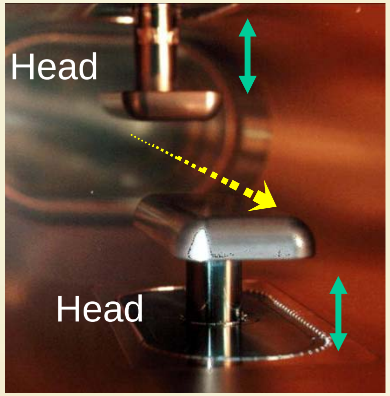
1. Introduction

- Collimator
  - Called as a mask or a scraper.
  - A vacuum component equipped in colliders to cut off spent particles around a nominal beam orbit, and then to decrease the background of the detector.

Collimators (Masks, Scrapers)



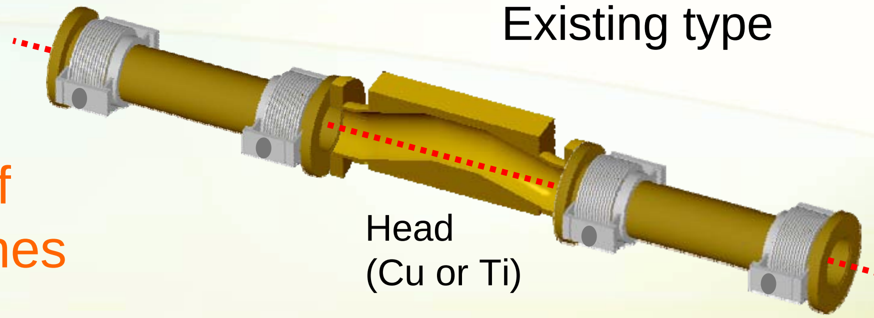




1. Introduction

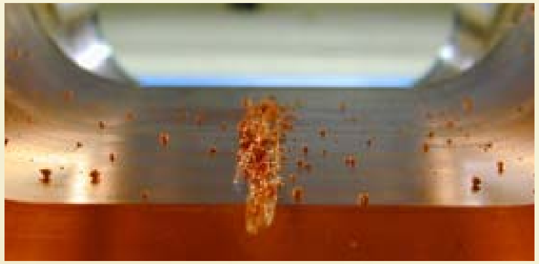
- Problem in high-intensity colliders:
  - Structurally high beam impedance.

Loss Factor ~1×10^{12} V C^{-1}
(@σ_z = 3 mm)
200 kW for a beam current of
10A with 5000 bunches

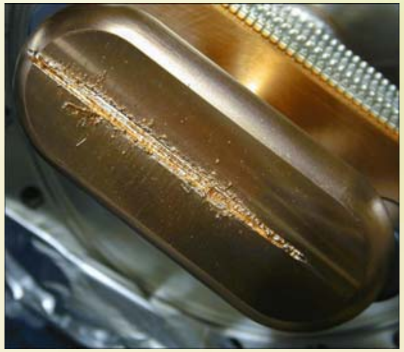


  - Damage to the head due to direct striking of the intense beam.

New ideas?



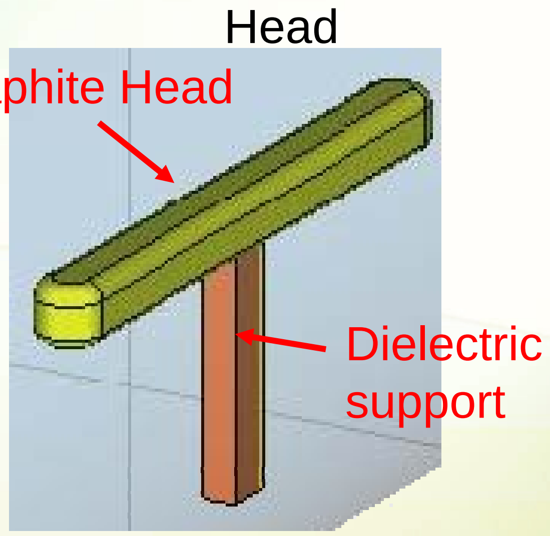
Cu (Observed even in Ti)

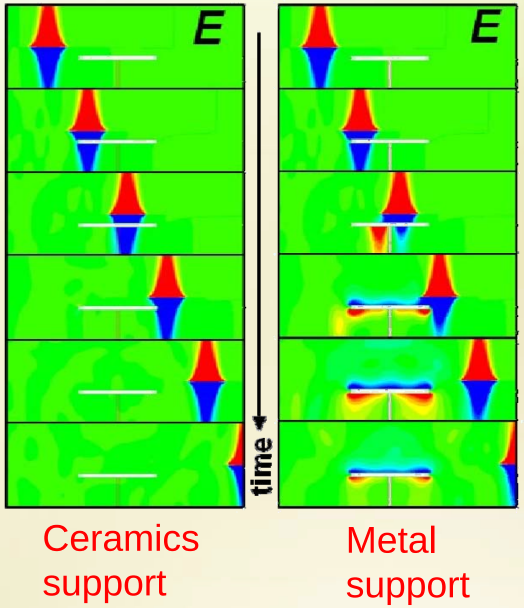


Cu

2. New Structure

- Proposed here*
  - Dielectric (ceramics) support:
    - Reduce interference with beam
    - Similar idea to an "invisible electrode" by F. Caspers (1987)
  - Graphite head:
    - Higher thermal strength than other metals
  - Thin conductive layer on the support to avoid the unnecessary charge up of the head.
  - HOM (Higher Order Modes) absorber (SiC, for example) near to the head.

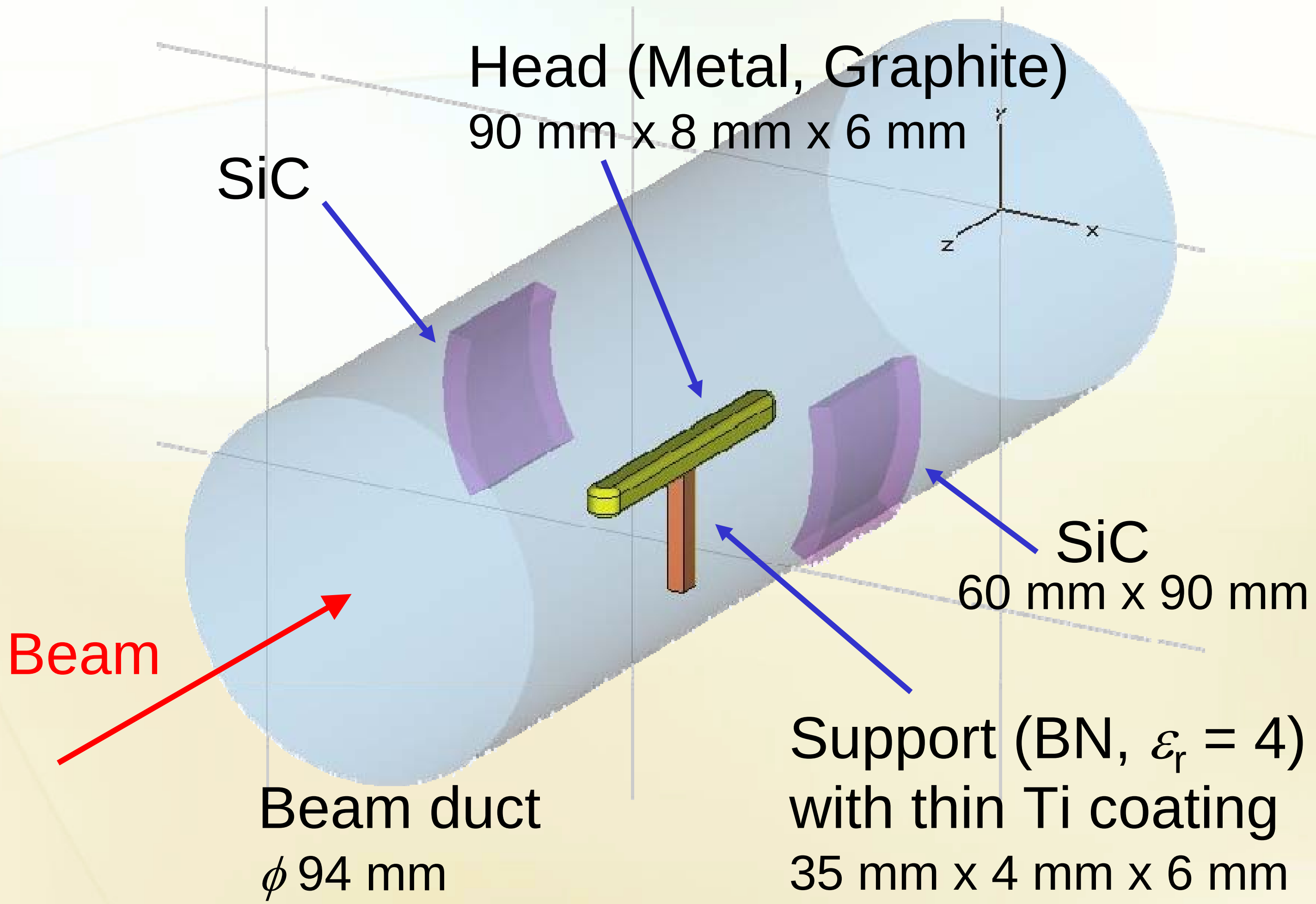




*Y. Suetsugu, K. Shibata, A. Morishige, Y. Suzuki and M. Tsuchiya, PRST-AB, 9 (2006) 103501.

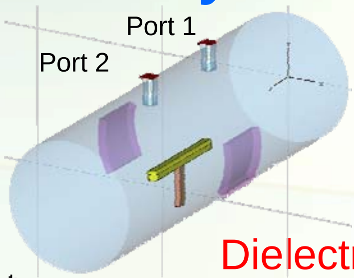
2. New Structure

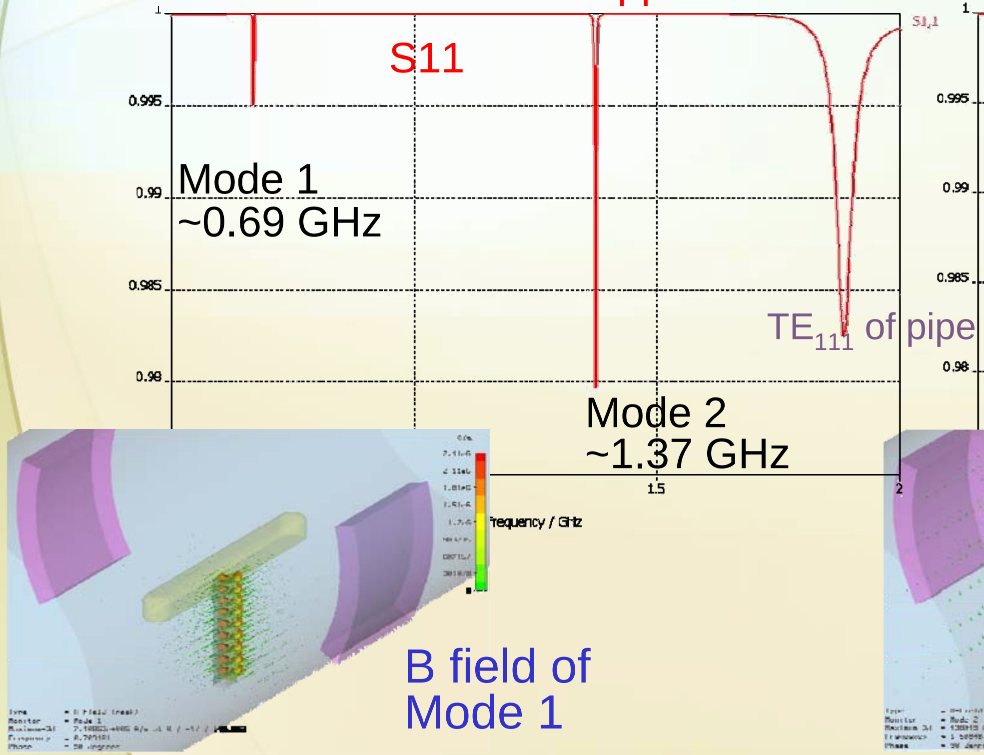
- Design Model
  - Used for simulation

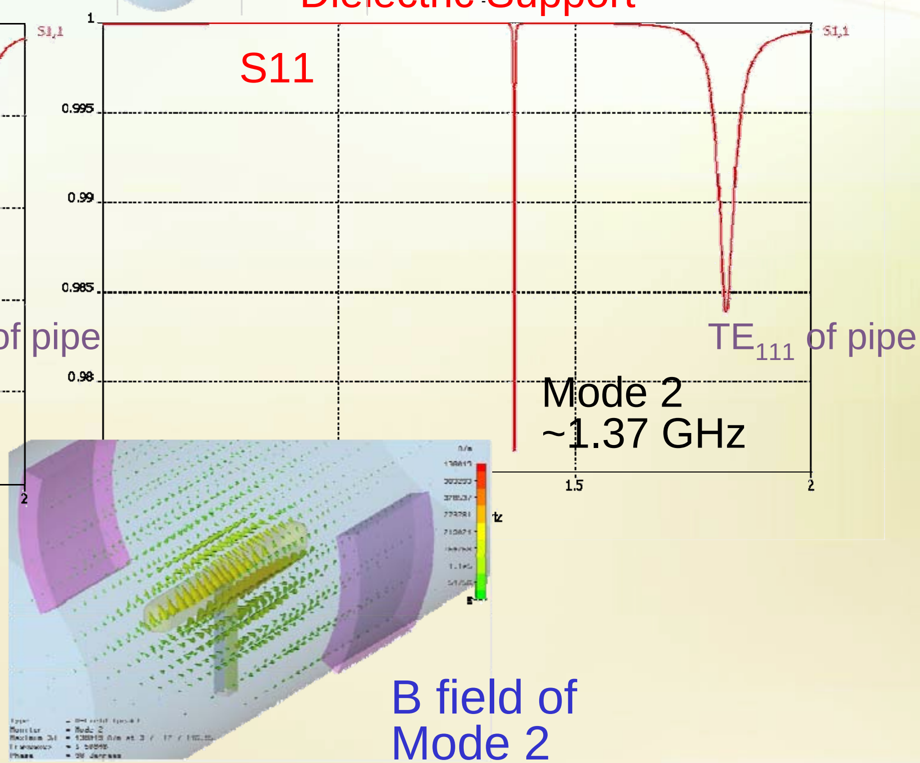


3. Properties

- RF properties were calculated by MAFIA and Microwave Studio [MWS].
- Trapped Modes





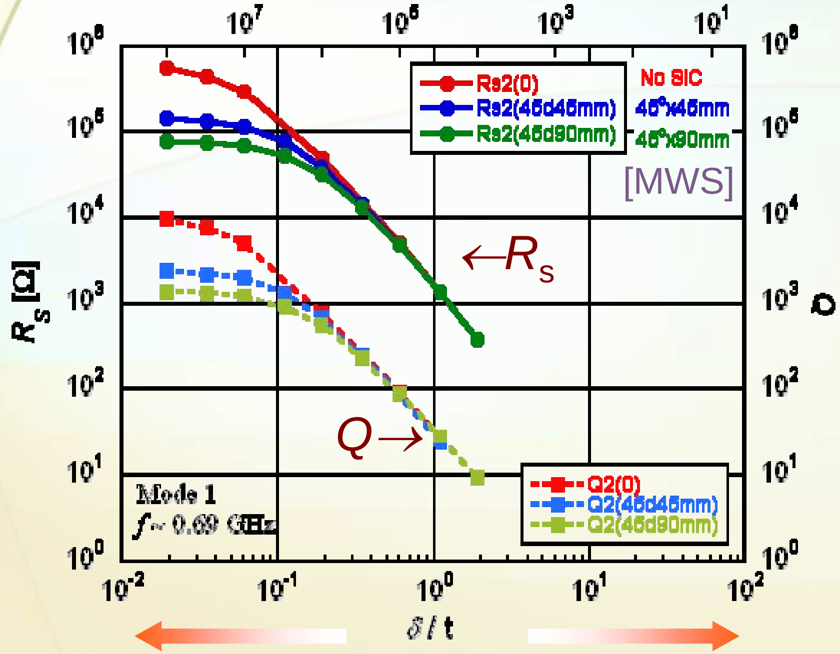


3. Properties

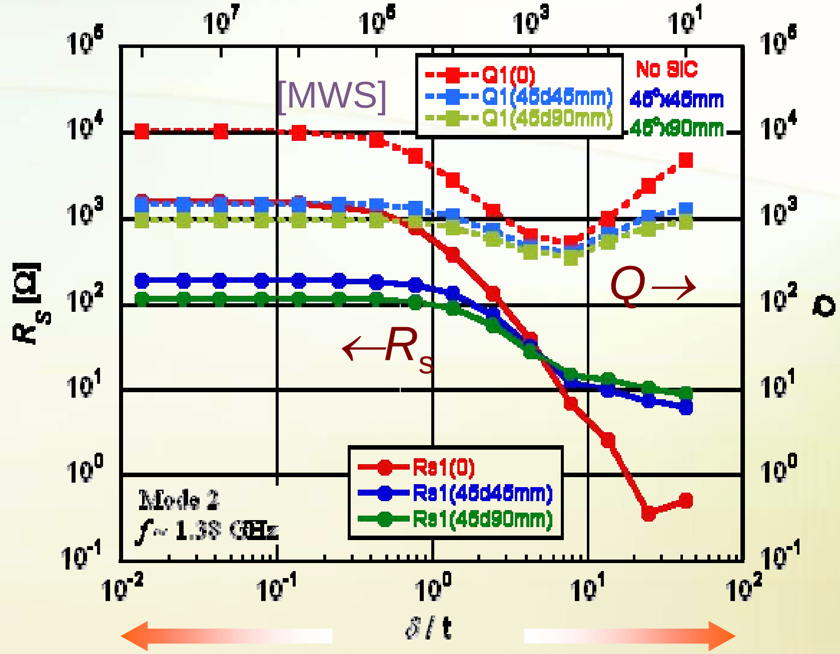
- Longitudinal Impedance of Trapped Modes

δ = skin depth
t = thickness of coating

Mode 1



Mode 2 σ [Ω⁻¹m⁻¹] (t=0.1 mm)



Metal support Dielectric support

At $\delta/t \sim 1$

- $R_S \sim 1$ kΩ, $R_S/Q \sim 50$ [MWS]
- $R_S \sim 1$ kΩ, $R_S/Q \sim 200$ [MAFIA]

Metal support Dielectric support

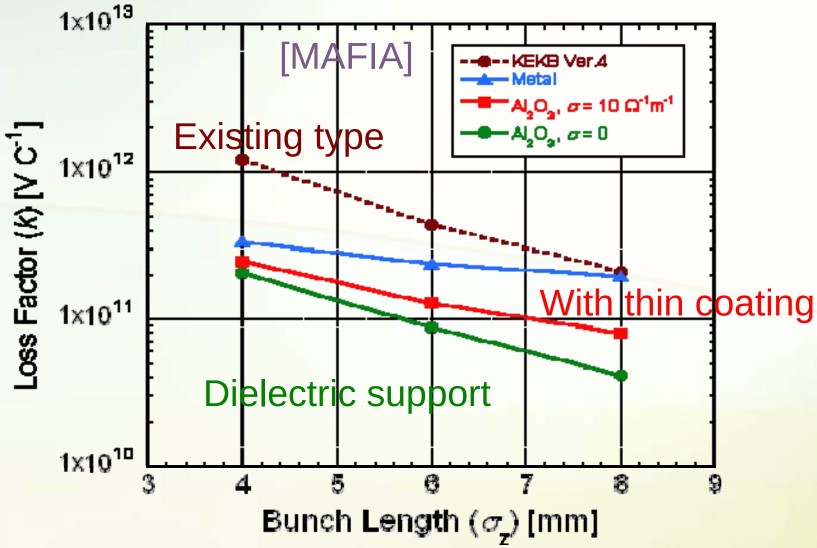
At $\delta/t = 1\sim10$

- $R_S = 100 \sim 10$ Ω, $R_S/Q = 0.1 \sim 0.02$ [MWS]
- $R_S = 100 \sim 10$ Ω, $R_S/Q = 0.5 \sim 0.05$ [MAFIA]

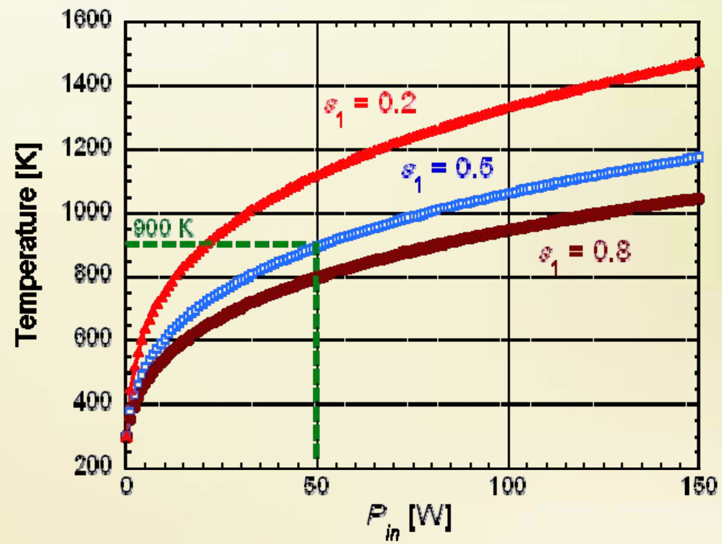
No longitudinal multi-bunch instability for $\delta/t > 3$
Similar results for transverse instability

3. Properties

- Loss factors (without SiC)
  - Loss factor reduce to about 1/4 of conventional type.

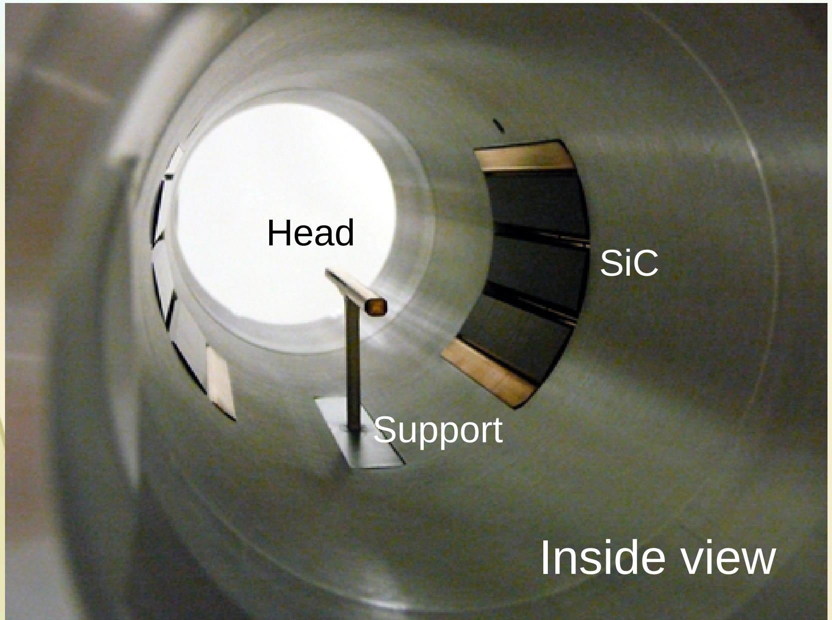


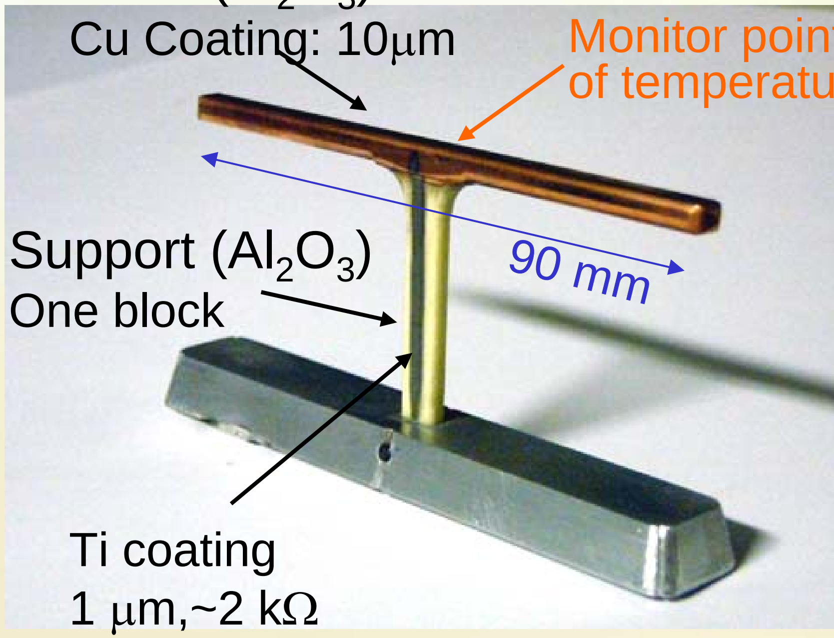
- Heating
  - Heat transfer
    - Radiation
  - Considered input power
    - Trapped mode (Mode 2)
    - Joule loss
    - Negligible dielectric loss
  - Expected temperature
    - Input power ~ 50 W even at 10 A (5000 bunches)
    - ~1200 K, at most



4. First Test Model

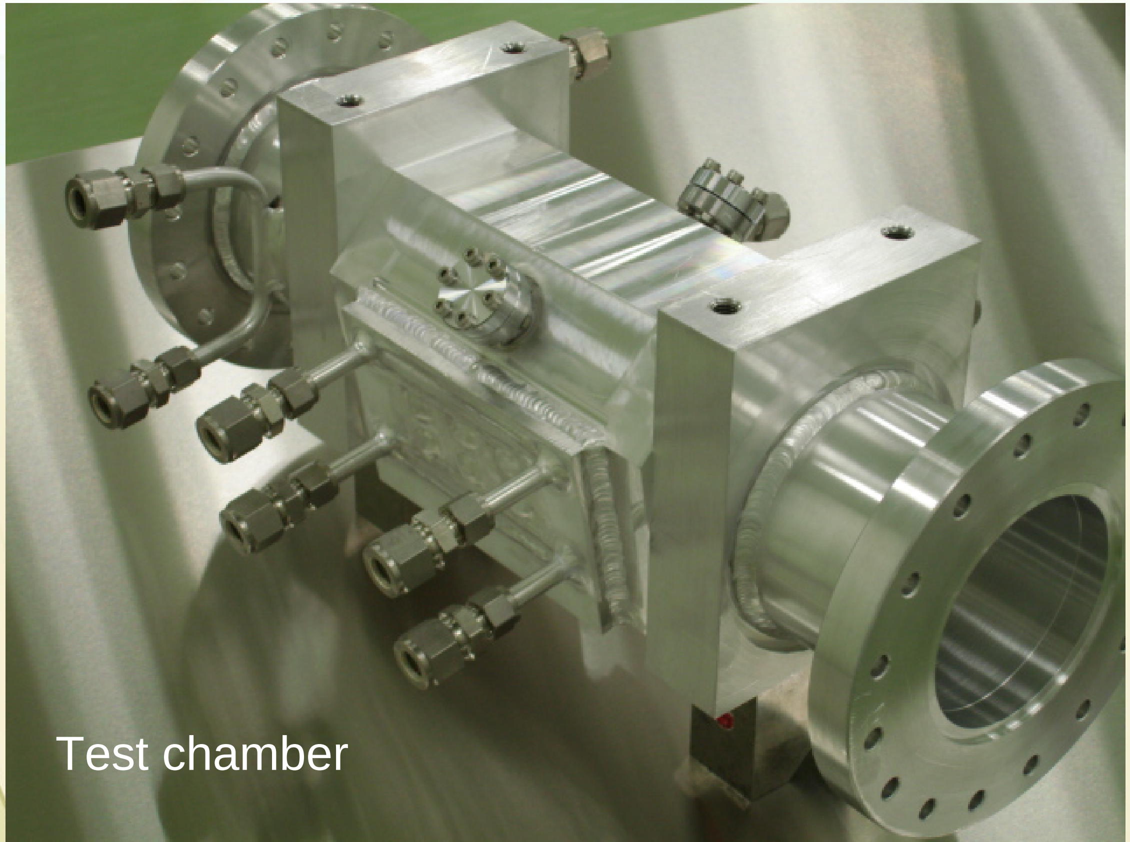
- Based on the simulation study, the first test model was manufactured.
- Simplified structure:
  - Aim proof of principle at low beam current
  - Make assembly easy

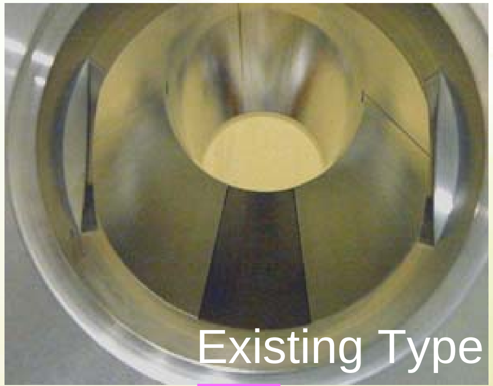


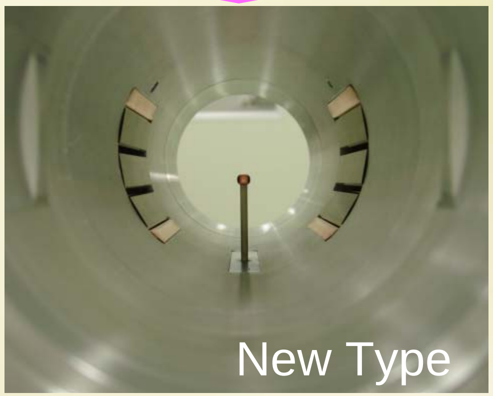


4. First Test Model

- Installed into the KEK B-factory ring
  - 3.5 GeV positron ring (LER)
  - Typically, I = 1700 mA, N_b = 1389 bunches, σ_z = 6 mm

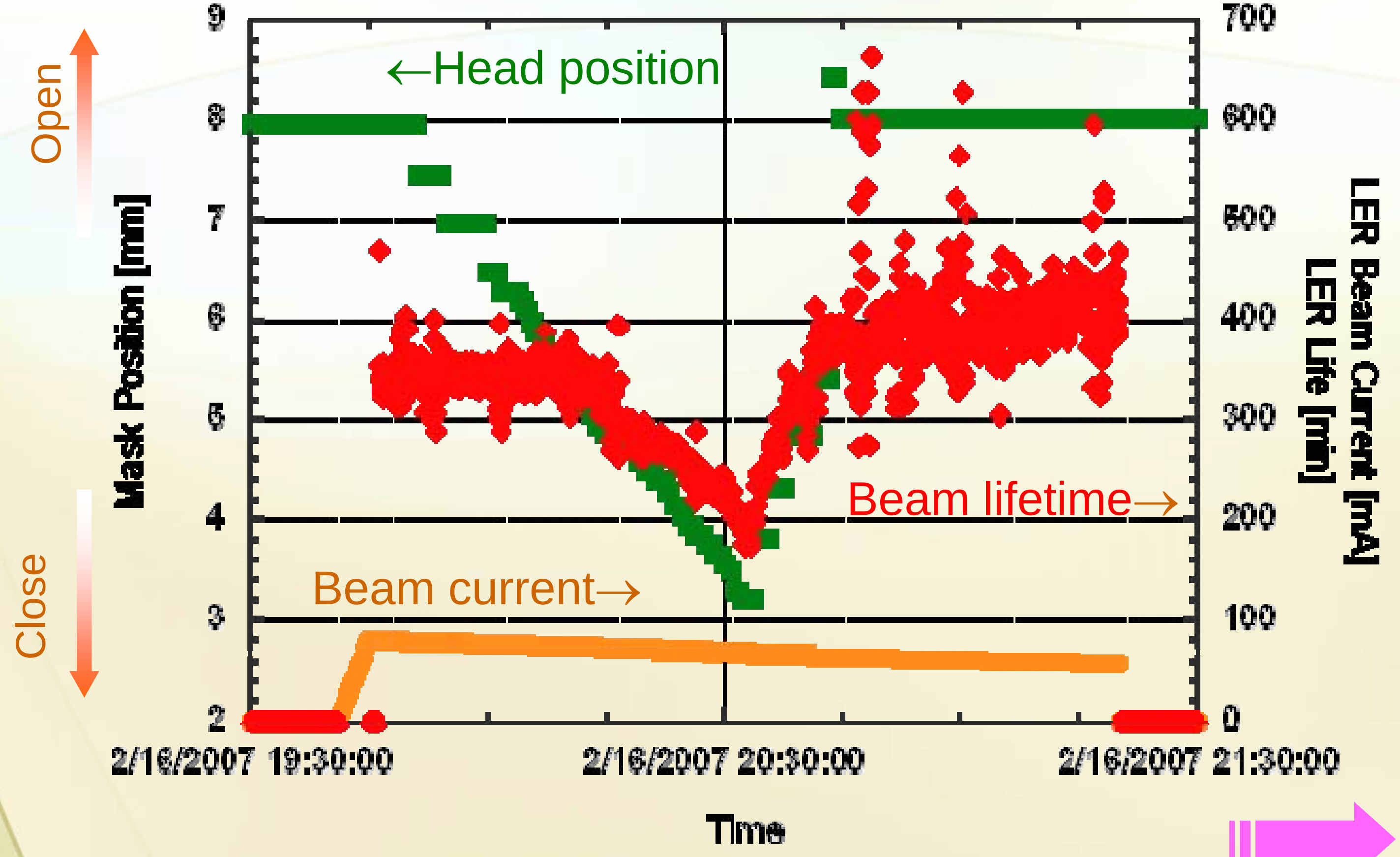






4. First Test Model

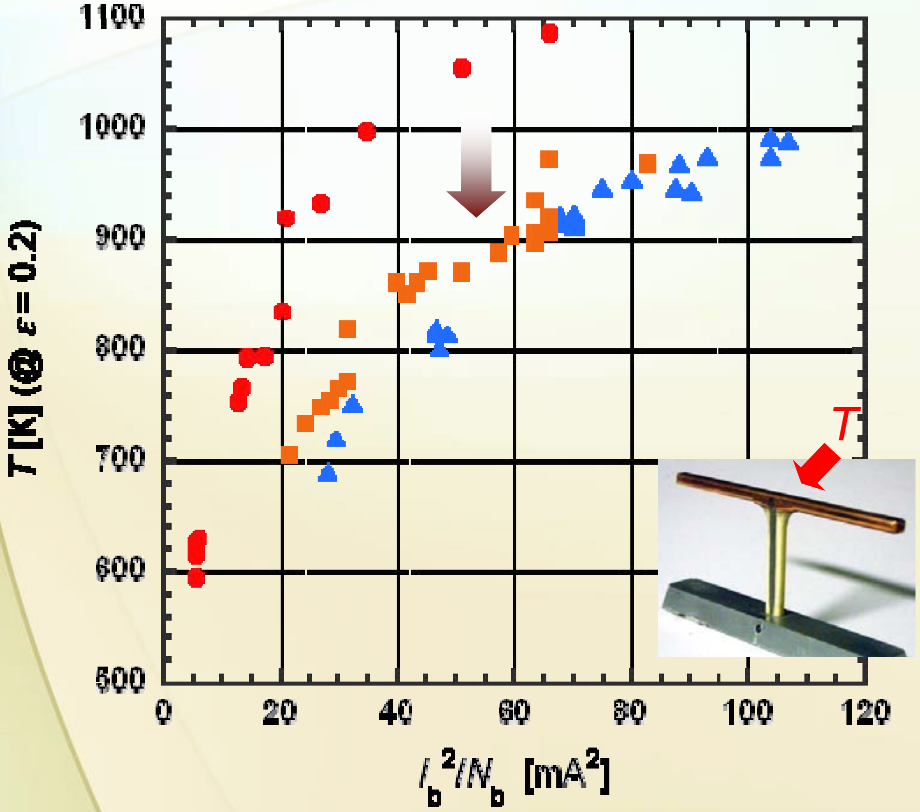
- Function as a collimator
  - Beam lifetime vs. head position



Work

5. Problem

- Heating problem
  - Contrary to our expectation, extra heating was observed from the beginning of beam operation

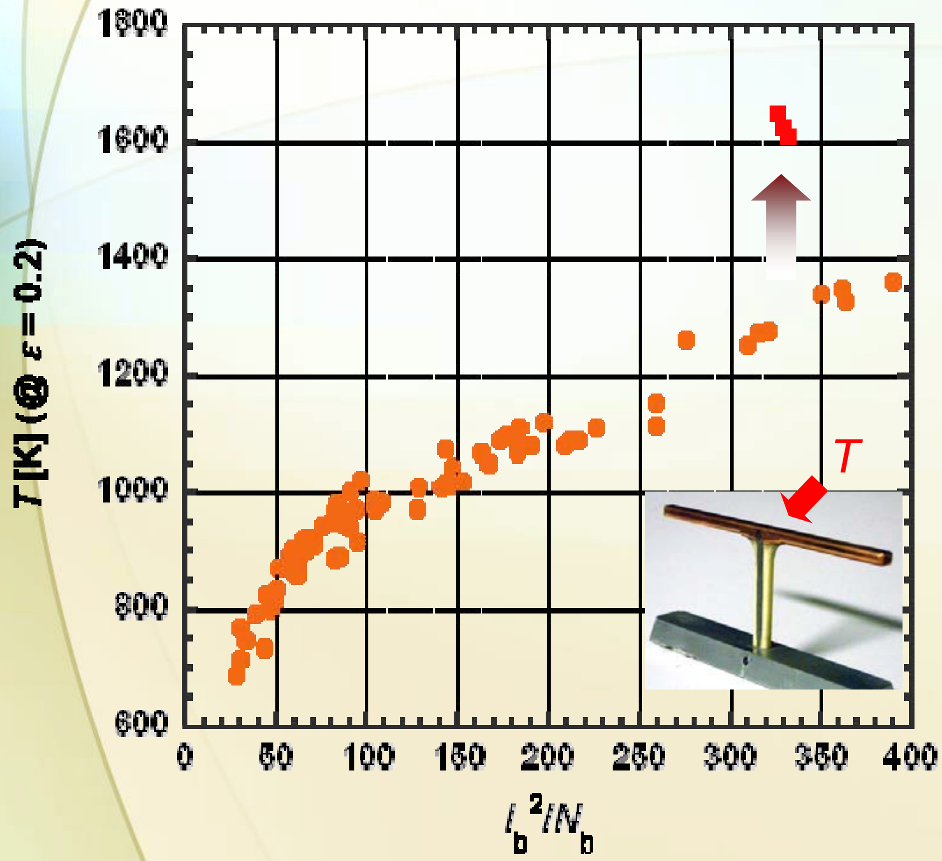


- At 42 mA (51 bunches) [I^2/N_b = 35 mA²], T ~ 1000K! (ε = 0.2 was set)
- After several days operation, the temperature decreased.

Change of surface condition or structure ?

5. Problem

- Heating problem



- Temperature was stable for a while.
- Temperature depends on I^2/N_b rather than I.

➡ Input power = HOM

- At 700 mA (1389 bunches) [I^2/N_b = 353 mA^2], a pressure burst, and then extra heating was observed.

⬇

Inside Inspection by breaking vacuum

5. Problem

- Inside Inspection
  - Damage of head was found!

Side view

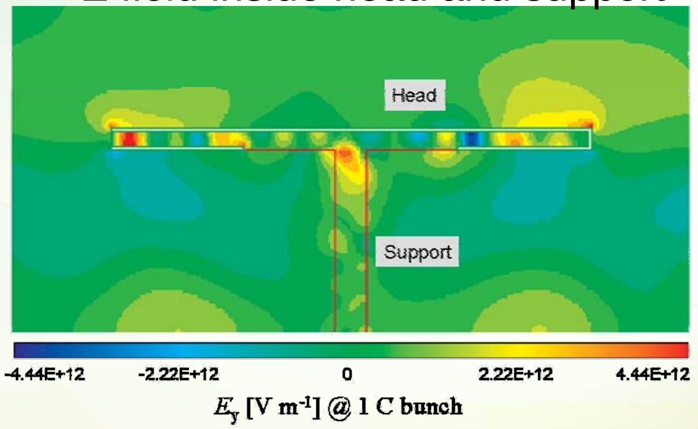
Original structure

Actually heated up!

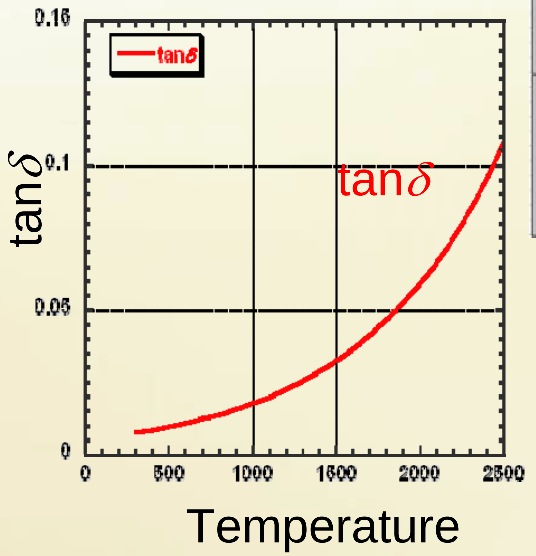
5. Problem

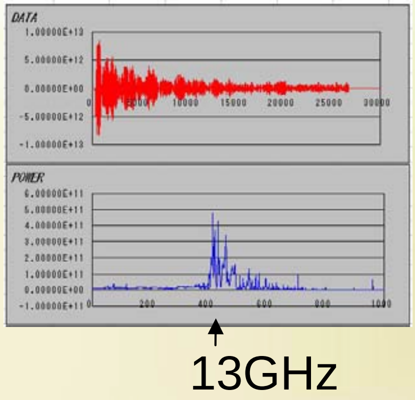
- What is the cause of failure?
  - Structure of head; the Al_2O_3 head with Cu coating formed an rf cavity. The connection part of the support became a window of the cavity.

E field inside head and support



  - Increase of tanδ (loss tangent); the increase of tanδ at high temperature and also high frequencies was under estimated.



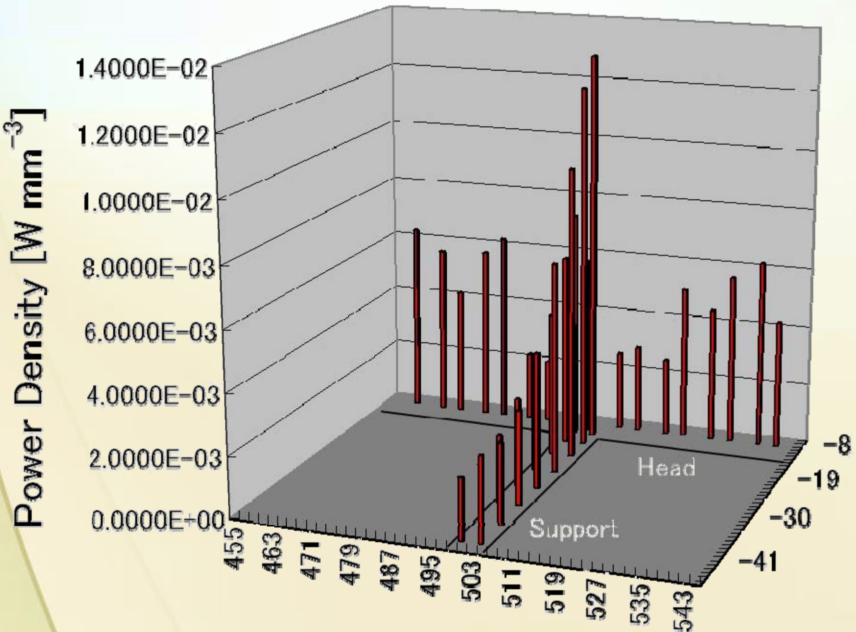


  - Overestimation of heat transfer by radiation.
  - HOM from adjacent collimators

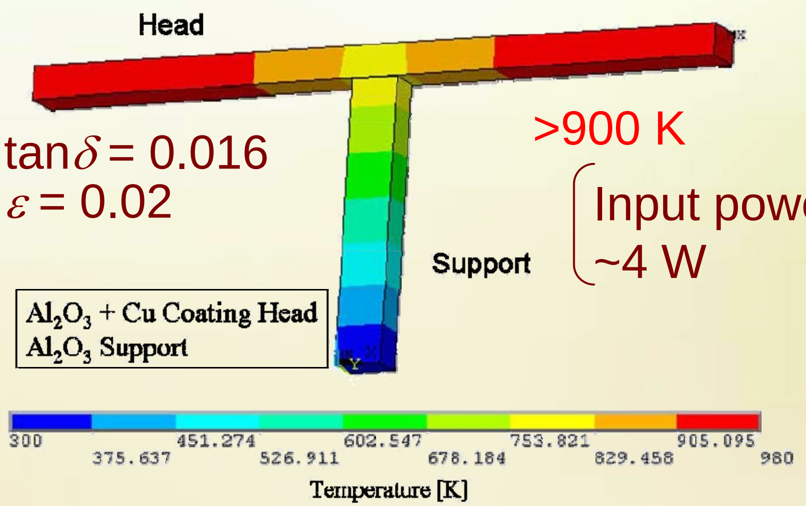
5. Problem

- Thermal Analysis-1
  - Including dielectric loss considering the temperature dependence of tanδ
- For the original structure of the first test model

Power density (tanδ = 0.04)



Temperature @ 42 mA (51 bunches)
I^2/N_b = 35 mA^2



tanδ = 0.016
ε = 0.02

>900 K

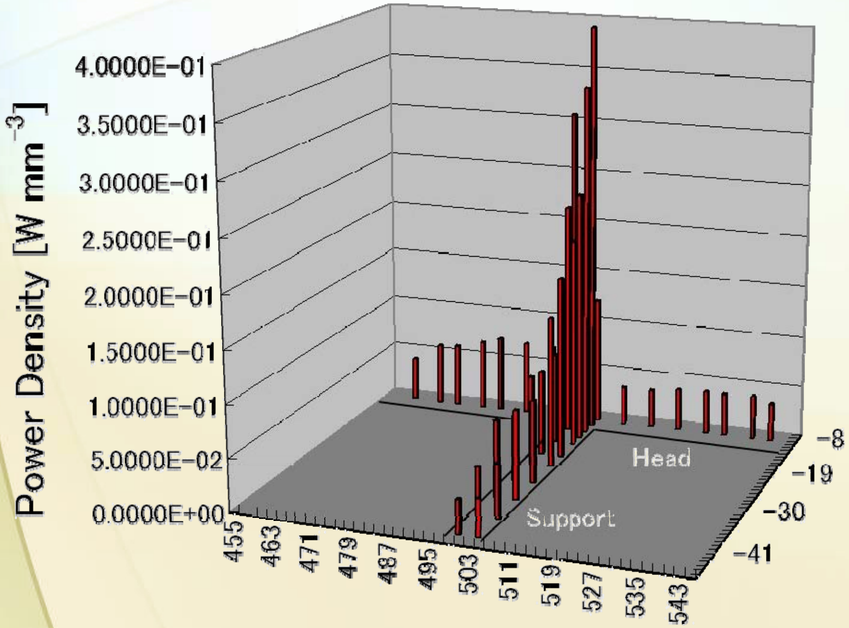
Input power ~4 W

Enough to evaporate Cu
(Vapor pressure ~ 1x10^{-6} Pa at 800 K)

5. Problem

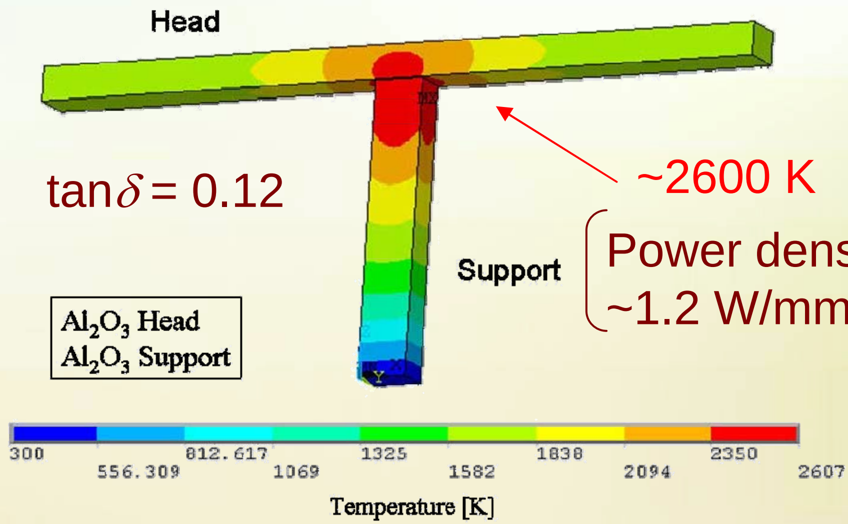
- Thermal Analysis
  - After evaporation of copper coating

Power density ($\tan\delta = 0.04$)



Temperature @ 700 mA (1389 bunches)

I^2/N_b = 353 mA^2



$\tan\delta = 0.12$

~2600 K

Power density ~1.2 W/mm^3

➡ Highest at connection
Enough to melt Al_2O_3

➡ Heating phenomena was well explained using reasonable parameters

6. Next Models

- Designed based on experiences in the first model
  - The same structure in principle, but appropriate choice of materials.
  - Temperatures for several promising materials were estimated similarly.

Promising materials

	Materials	Electric Conductivity (1/Ωm)	Thermal Conductivity* (W/m/K)	Relative dielectric constant	Emissivity
Head	Copper	5.8×10^{7}	(400)		0.02
	Graphite	1×10^{5}	50		0.7
Support	Al_2O_3 (99%)		10	10	0.5
	BN		20	4	0.5
	Quarts (SiO_2)		1.5	4	0.5
	AlN		100	9	0.5
	Diamond		500	6	0.4

* ~1/2 of the values at room temperature

6. Next Models

- Expected temperatures
  - Most promising combination is Graphite head and Diamond support.
  - Good thermal conductivity of diamond stabilizes the performance.

Material of Head	Material of support	Max. T (K) (I^2/N=353)	Max. T(K) (I^2/N=2000)	Loss Factor (V/C)
Cu (Coating)	Al_2O_3	(980 @42mA,#51)	Present KEKB	1.4×10^{11}
Al_2O_3	Al_2O_3	2607		3.7×10^{11}
Graphite	Al_2O_3	800		7.9×10^{10}
Graphite	Quarts Glass	706		2.7×10^{10}
Graphite	AlN	~480	1220	7.9×10^{10}
Graphite	BN	~580	1078	2.7×10^{10}
Graphite	Diamond*	~410	~730	2.1×10^{10}

*1.2 mm x 5 mm x 35 mm

Second model is now under testing (Brazing of diamond etc.)

7. Conclusions

- New structure of movable collimator was proposed.
- First test model was designed and tested with beam at the KEKB positron ring.
  - Extra heating was observed at considerably lower beam current than expected.
  - Provided a valuable experience, and taught us a renewed recognition of the difficulty in dealing intense HOM.
- Next model was designed based on the experience.
  - The Most promising structure is graphite head supported by diamond.
  - The second model was under design.

- End

- Estimation of temperature taking into account the temperature dependence of tanδ