HZB Helmholtz Zentrum Berlin
BESSY VSR

Button BPMs @ HZB : BESSY II experiences and BESSY VSR design

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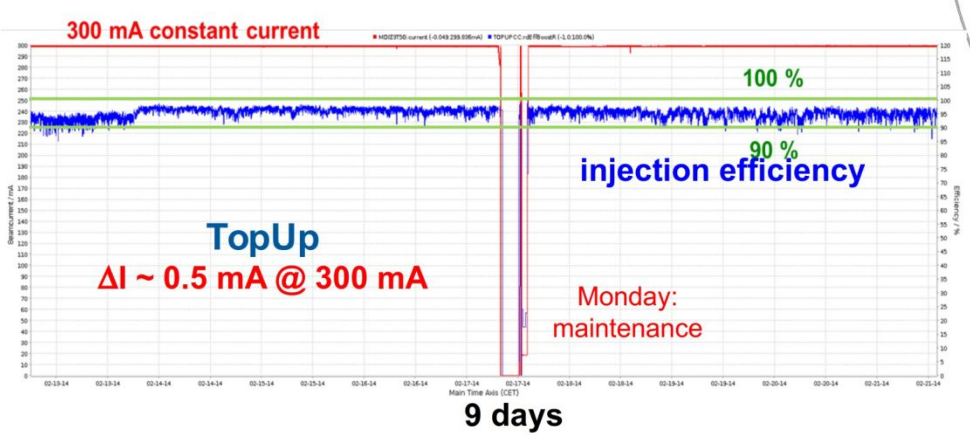
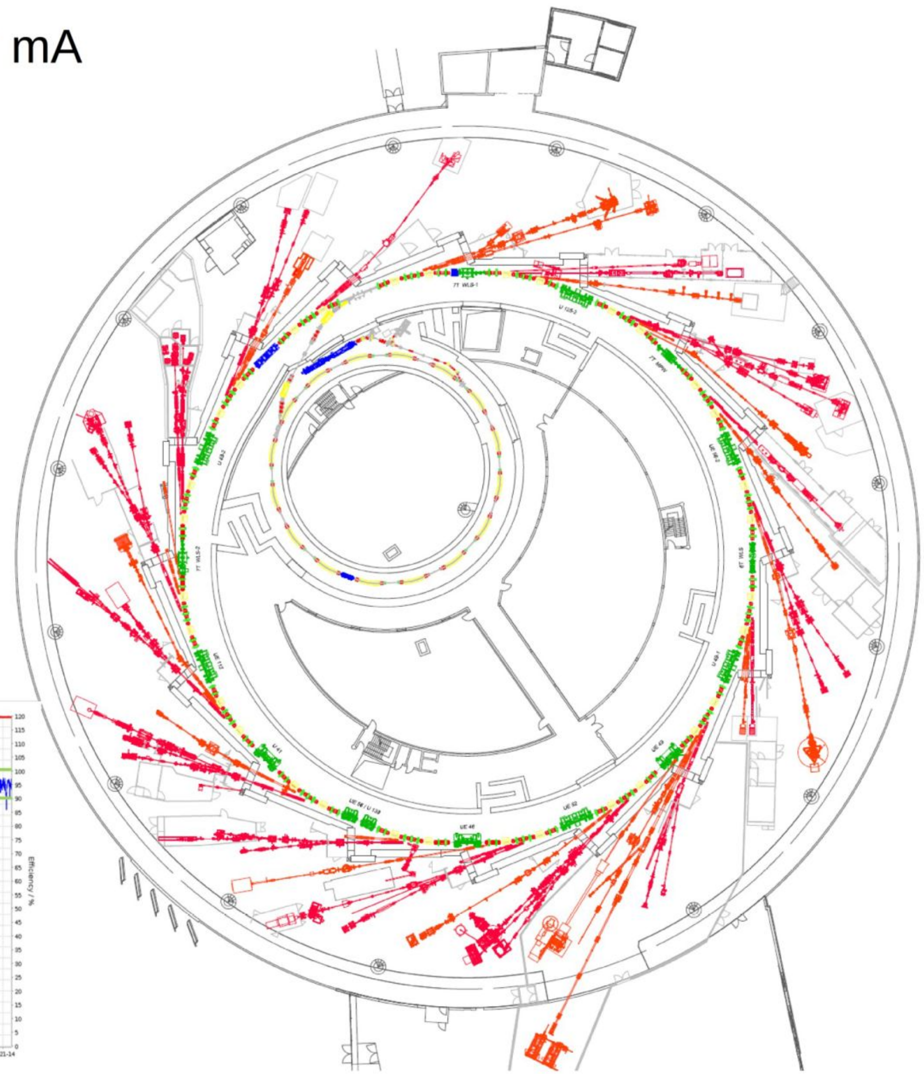
BESSY II : 3rd generation light source (UV / XUV / soft X-ray)

Successor of BESSY I, construction 1992 – 1998, user operation 1999

• Energy / Current	1.7 GeV / 300 mA
• Circumference	240 m (DBA)
• Emittance	5 nm rad
• Pulse length	15 ps
• Straight sections	16 / 14
• Undulat./MPW+WLS	12 / 1+2
• Beamlines (ID, Bend)	30, 20

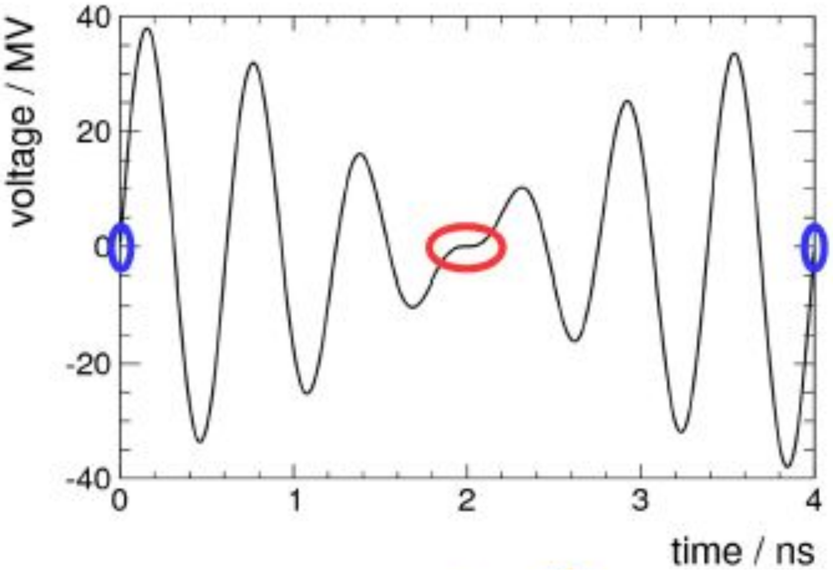
5000 h user operation and
3000 user visits / year





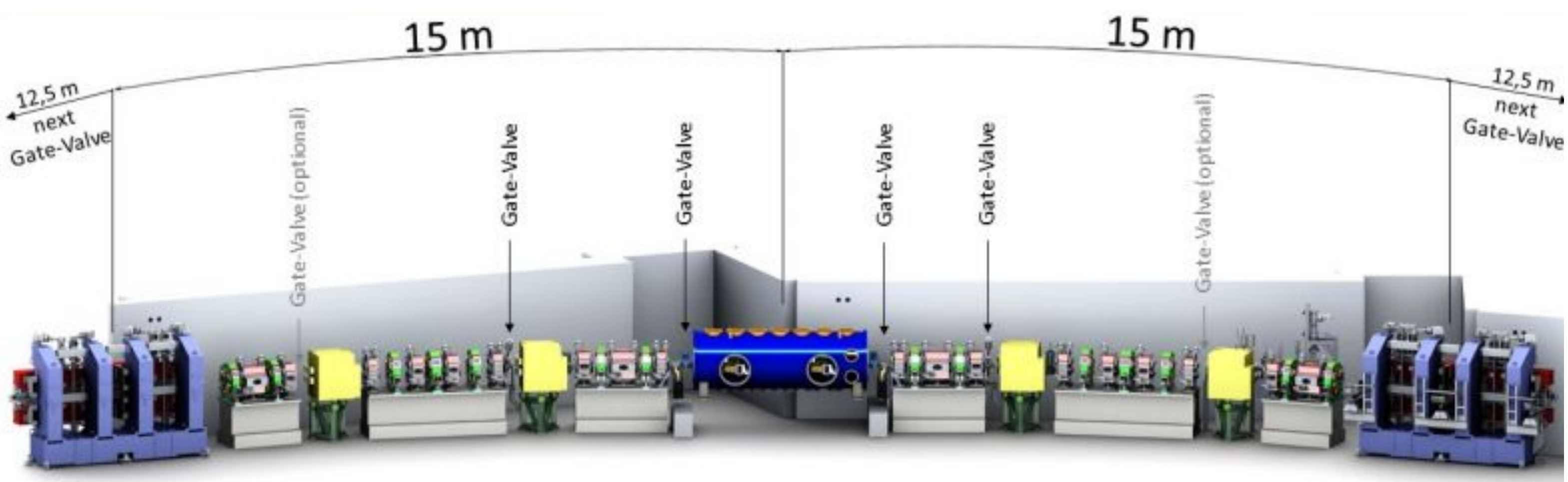
BESSY Variable pulse-length Storage Ring (BESSY VSR)

Short and long bunches simultaneously



Cavity system for gradient manipulation

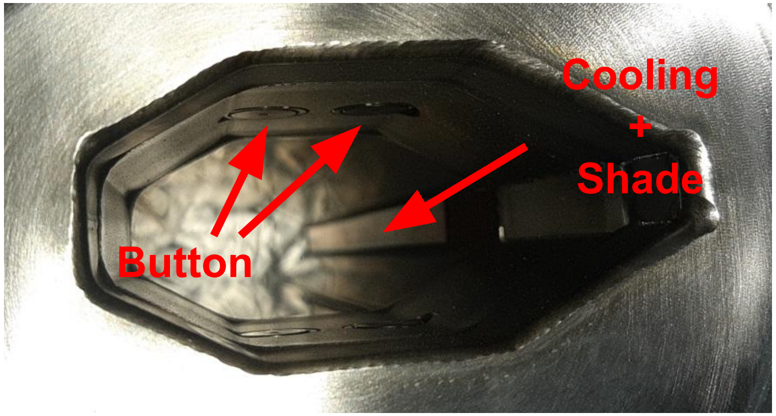
- Normal installed RF cavity
  V' = 2 π 0.5 1.5 GHz MV
- 1st SC RF cavity, 3rd harmonic
  V' = 2 π 1.5 20 GHz MV
- 2nd SC RF cavity, 3.5th harmonic
  V' = 2 π 1.75 17 GHz MV
- In total V' (BII) = 0.75 GHz MV
  V' (VSR) = 60 GHz MV
- Voltage beating results in alternating large and small V'

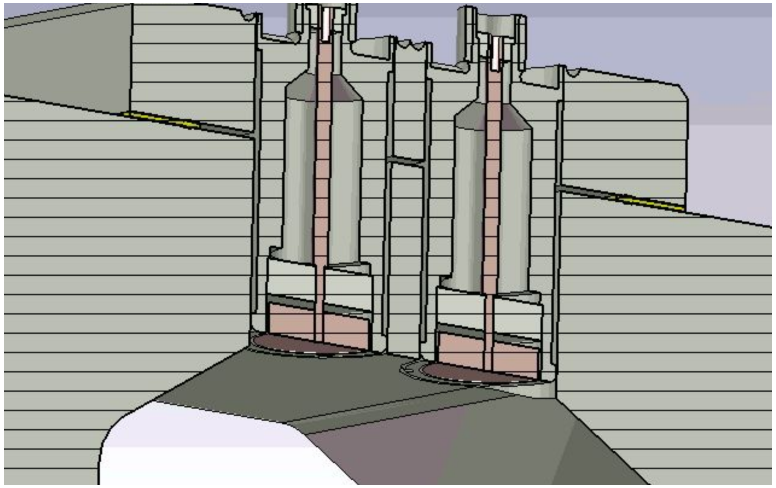


Refurbishment of vacuum system including BPMs

Mature button-type BPM in BESSY II

construction 1992 – 1998





20 years-old "Mature" button-BPM

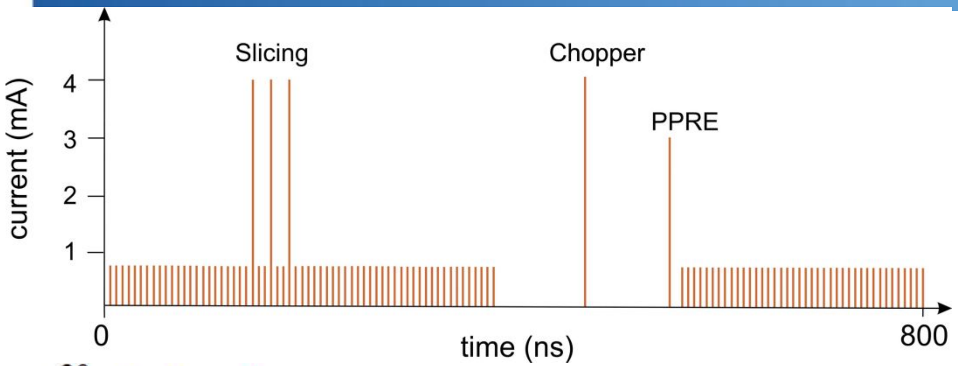
SUS(housing) – Molybdenum (Button)
(* to reduce the power on button)
Insulator : Alumina
Chamber : 69 (H) x 35 (V) mm
Button diameter : 10.6 mm
H-Gap : 400 μm
Distance between two buttons : 18.3 mm

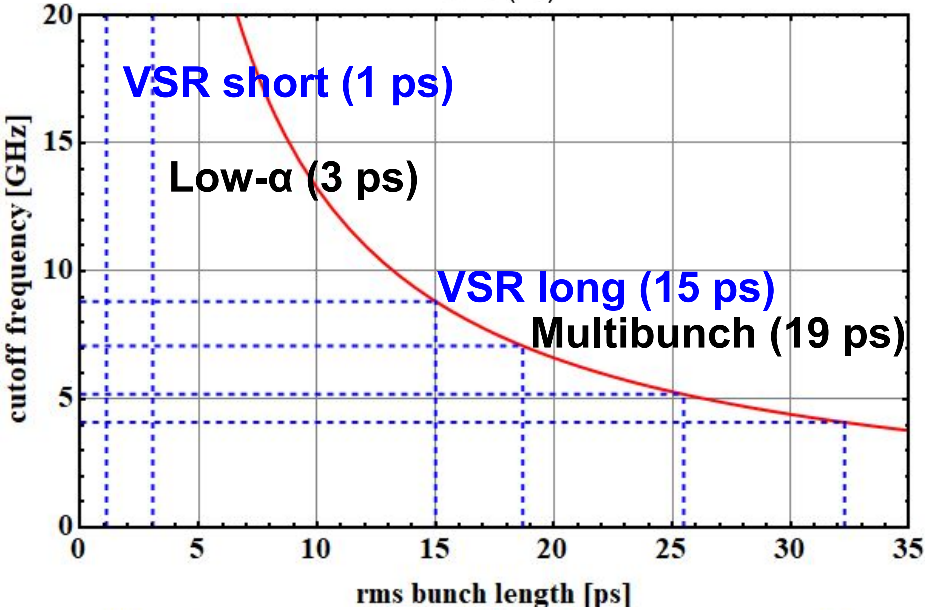
Shade is placed on the side to mitigate heat caused by synchrotron radiation.

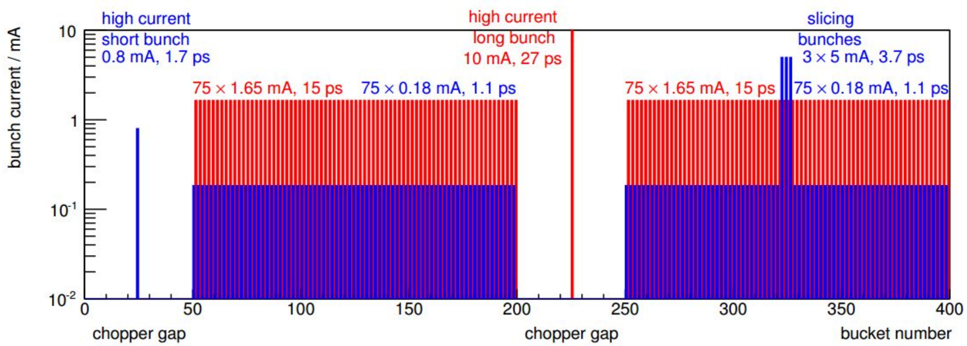
Issues for new BESSY VSR straight

1. Button size for small chamber
2. Short bunch length in VSR scheme
3. Signal contamination by preceding bunches

Mature button-type BPM in BESSY II







In case of M equi-spaced and equi-populated bunched, the power loss can be written*

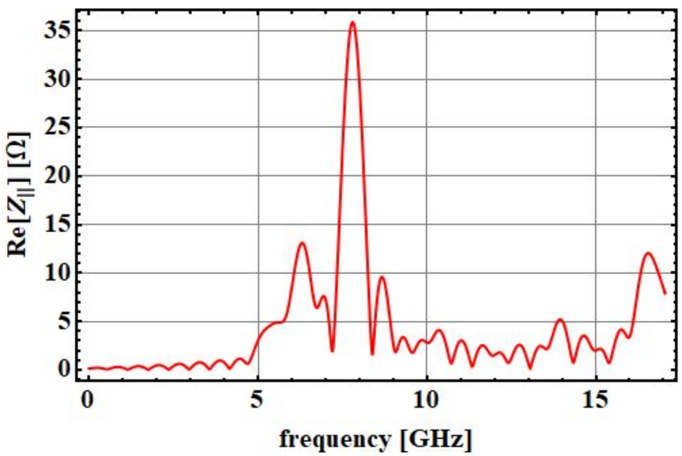
$$P_{loss} = M I_b^{\ 2}\, Z_{loss}$$

with

$$Z_{loss} = 2\, M \sum_{p=0}^{\infty} Re[Z_{||}(pM\omega_0)]\, e^{-(p\sigma M\omega_0)^2}$$

where I_b is the bunch current, $\omega_0 = 2\pi f_{rev}$, σ is the bunch length.

In BESSY II, the beam current and harmonic number in the storage ring are 300 mA and 400, respectively.



In the conservative estimation, the power loss in whole BPM block is 9.5 W (0.48 W in button).

* **E. Metral, in proceedings of IBIC 2013, THBL1.**

Mature button-type BPM in BESSY II

Since the conductivities ratio is about 20 for steel and molybdenum, the button made of molybdenum will receive about 20% of the total power dissipated in the stainless steel button*.

	σ_t [ps]	I_{avg} [mA]	P_{total} [W]	P_{button} [W]
BESSY II	19	300	9.5	**0.48**
Low-alpha	3	100	3.0	0.15
VSR long	15	~ 260	9.9	0.5
VSR short	1.1	~ 40	0.5	0.03

From the conservative estimation, the power loss in the button at VSR operation is VSR long + VSR short = **0.53 W** which is 10 % higher than BESSY II operation.

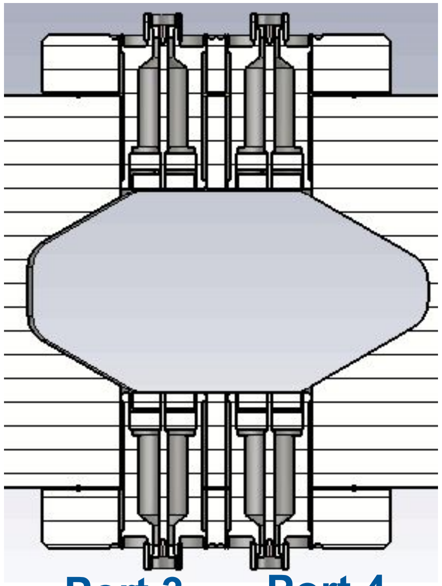
Since the 20-years old “Mature” button BPM was well designed and the BESSY II storage ring operates on relatively low current and long bunch length, the noticeable issues with the heating of the button has not been.

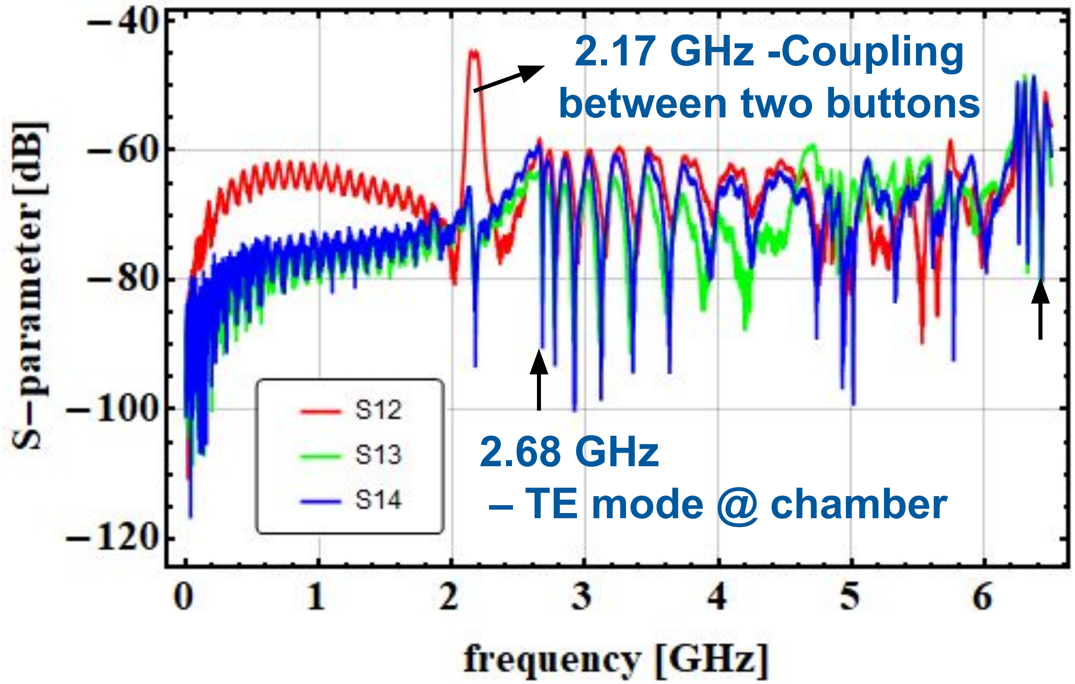
Therefore, it is the reference point for “New” BPM design.

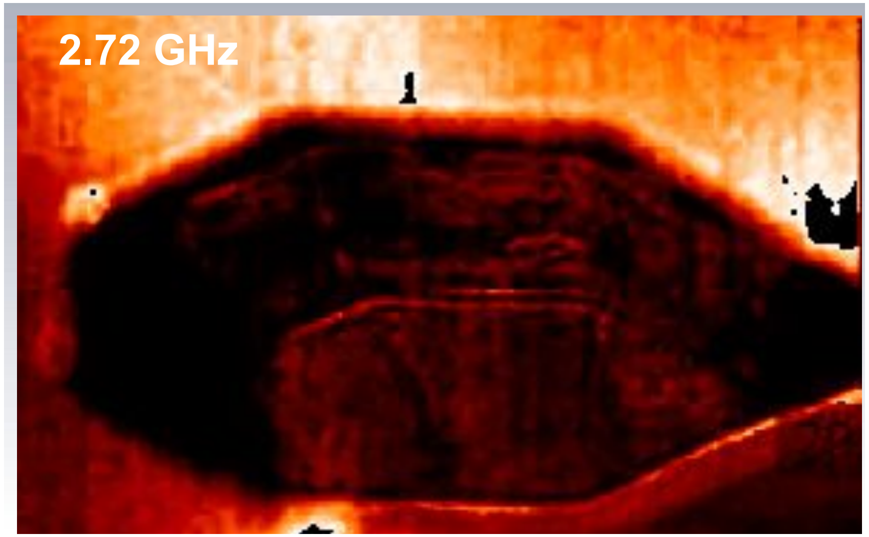
$$P_{button} = 0.48\ \mathrm{W}$$

*** I. Pinayev and A. Blednykh in proceedings of PAC09, TH5RFP014.**

Mature button-type BPM in BESSY II



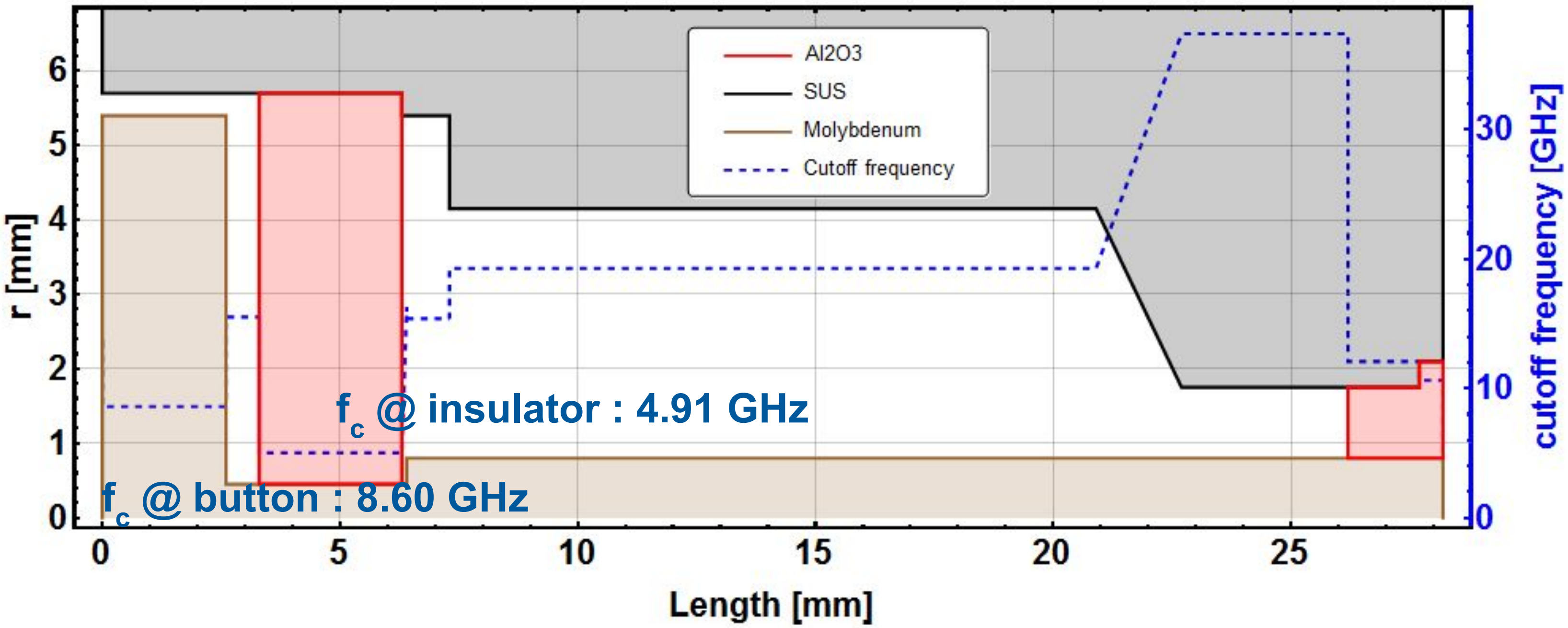




@ off-frequency (BG Subtracted)

@ resonance (BG Subtracted)

Trapped mode in insulator in mature BPM

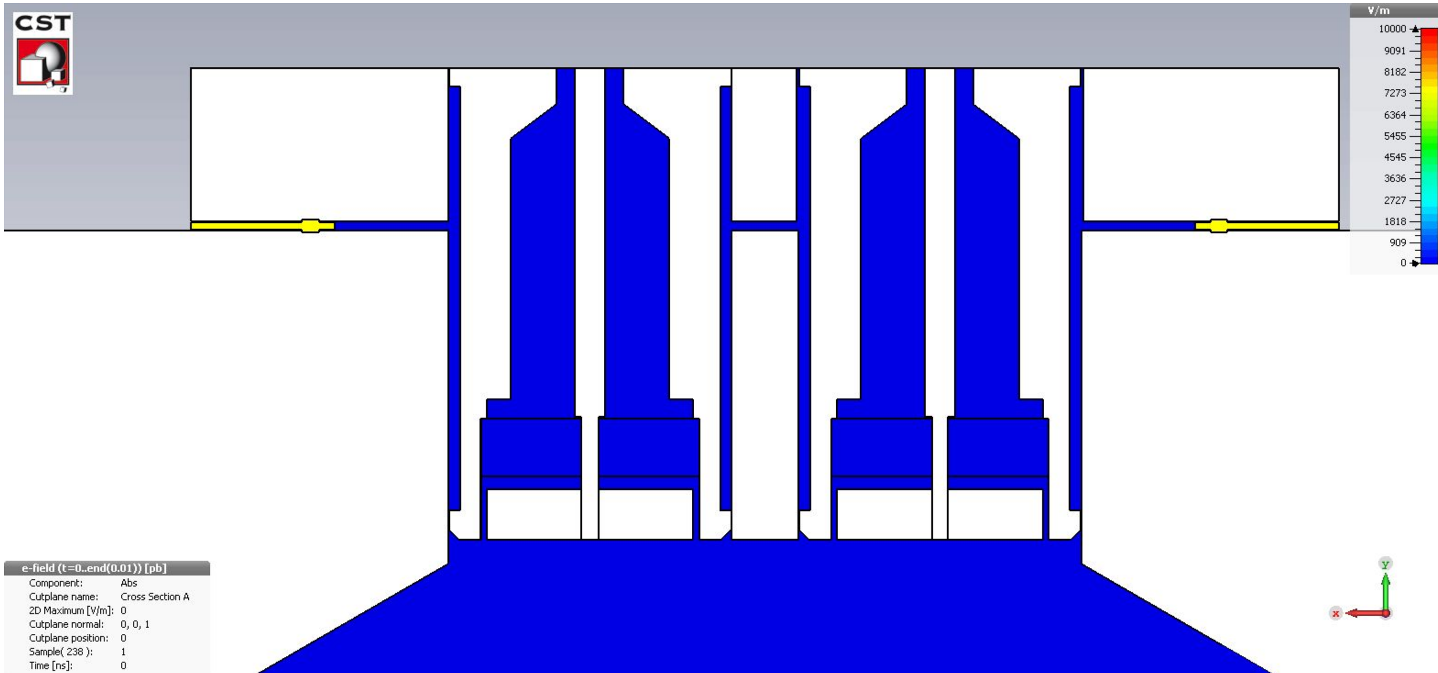


Since it may cause multiple modes with different phase velocities to propagate, interfering with each other, above a certain cutoff frequency, it is usually undesirable to transmit signals.

$$f_c^{H_{m1}} \approx \frac{1}{\sqrt{\varepsilon_r}} \frac{c}{\pi} \frac{m}{(r_i + r_o)}$$

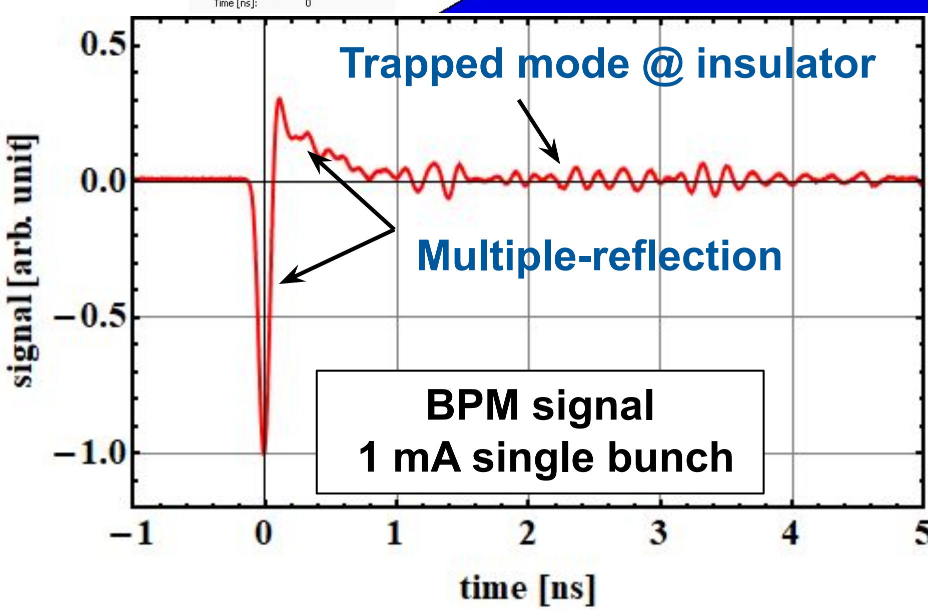
where r_i and r_o are the outer radius of inner conductor and the inner radius of outer conductor, respectively.

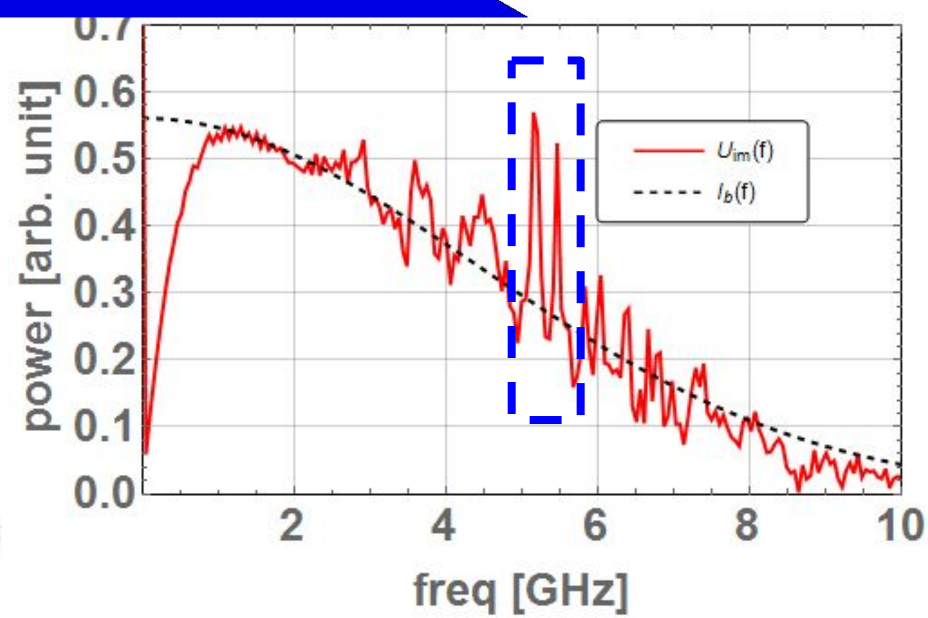
Trapped mode in insulator in mature BPM



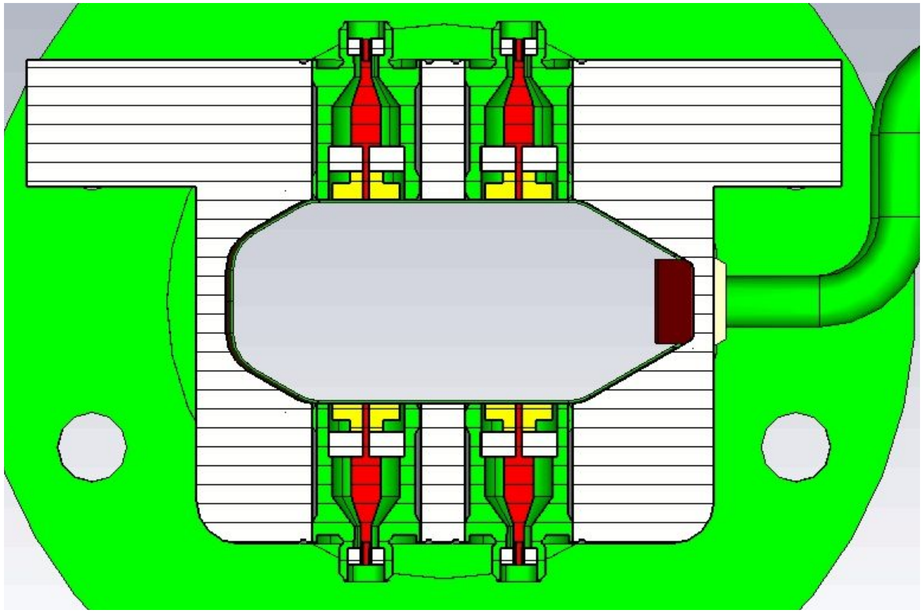
utton
60 GHz
neter)

4.91 GHz





New button-type Beam Position Monitor



Contacted Vendors for 10 buttons + test chamber

1. **Friatec : Buttons + Chamber**
2. PMB : Buttons
3. BC-tech : Buttons

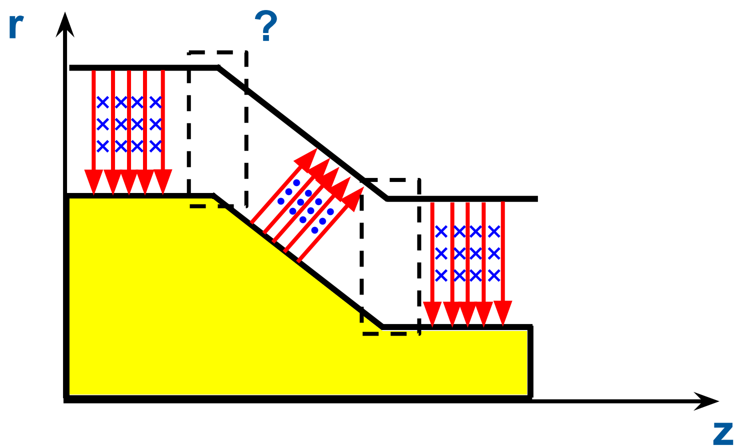
All vendors can not guarantee the mechanical stability of SiO2 + BESSY II is user machine → **Alumina**

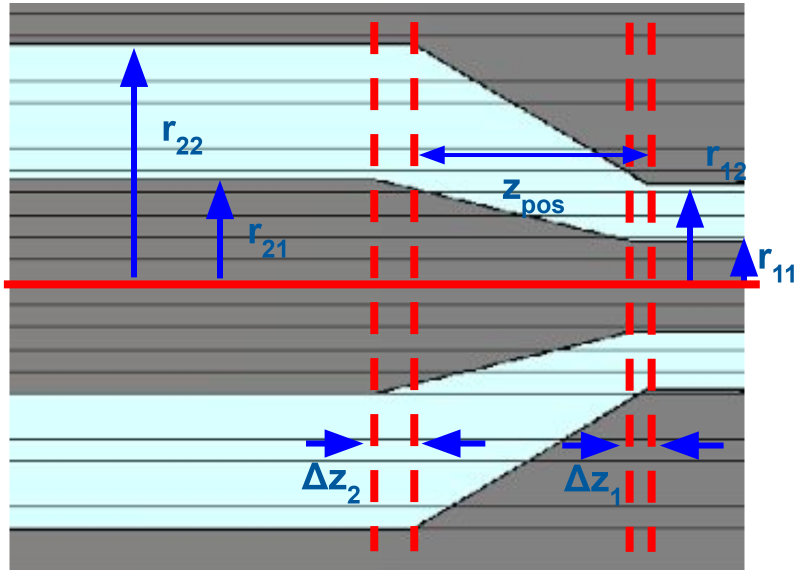
Are there any vendors for "SiO2"?

New BPM design considerations

1. Fit into small chamber dimension : 69 (H) x 35 (V) → 55 (H) x 24 (V) mm
   → small button head : Wakefield↓ and signal ↓
2. Mitigate signal inference between bunches for BbB system.
   → **Low Permittivity insulator : SiO2 / Cutoff frequency ↑**
3. Mitigate internal reflection
   → Button structure : impedance matching
4. Improve the crosstalk → Distance between buttons ↑ : Resolution ↓
5. Trapped mode in gap @ button lodging hole → **Gap ↓ (* 30 ~ 40 um)**

New button-type Beam Position Monitor (impedance matching)



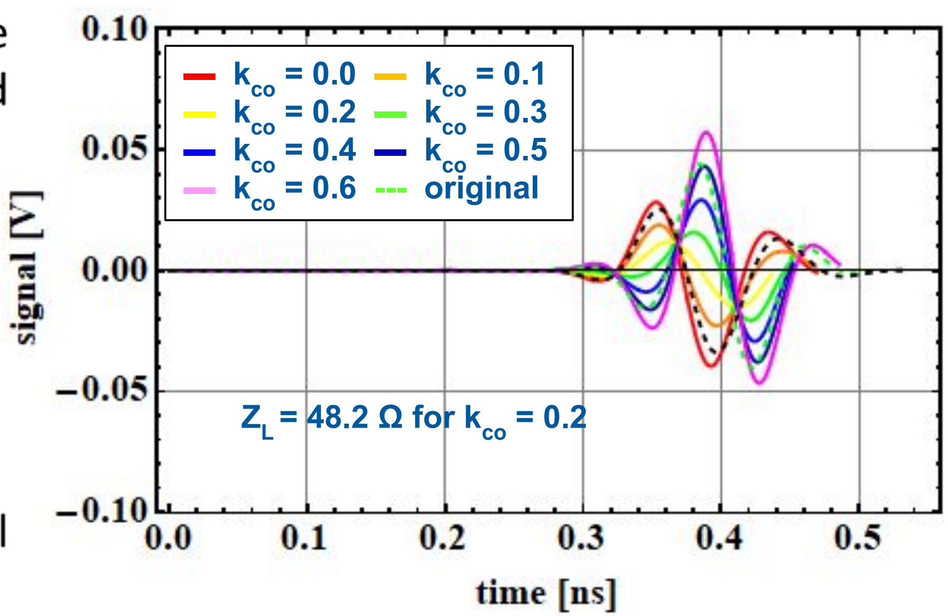


Since the wave direction is varied due to the angle (radius change), the optimization of the relative edge position between inner and outer conductor is required.

$$\Delta z_1 = k_{co} \frac{(r_{22} - r_{21})}{z_{pos}} (r_{21} - r_{11})$$

$$\Delta z_2 = k_{co} \frac{(r_{22} - r_{21})}{z_{pos}} (r_{22} - r_{12})$$

, where k_{co} is a coefficient. The numerical calculation is performed for various k_{co}.



The mode decays proportional to

$$|H(t)| = e^{-\frac{\omega}{2\,Q}t}$$

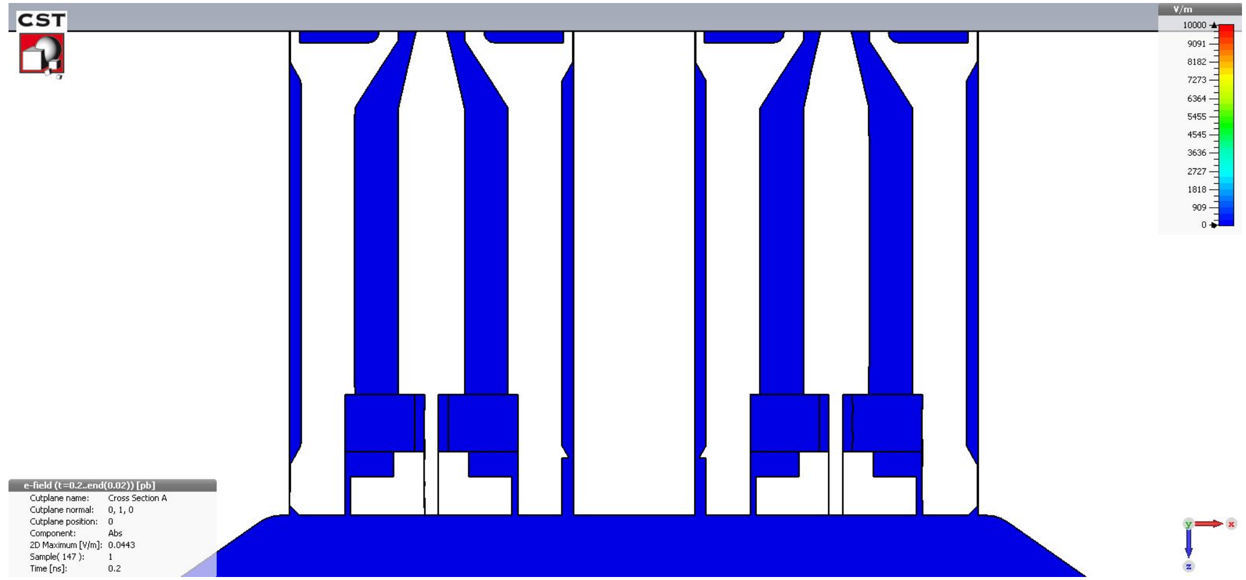
Aluminum Oxide (Al_2O_3)

$\varepsilon_r{}' = 9.5$

$\varepsilon_r{}'' = 0.00343$

$Q = \varepsilon_r{}' / \varepsilon_r{}'' \sim 2741$

$f_c = 6.4$ GHz



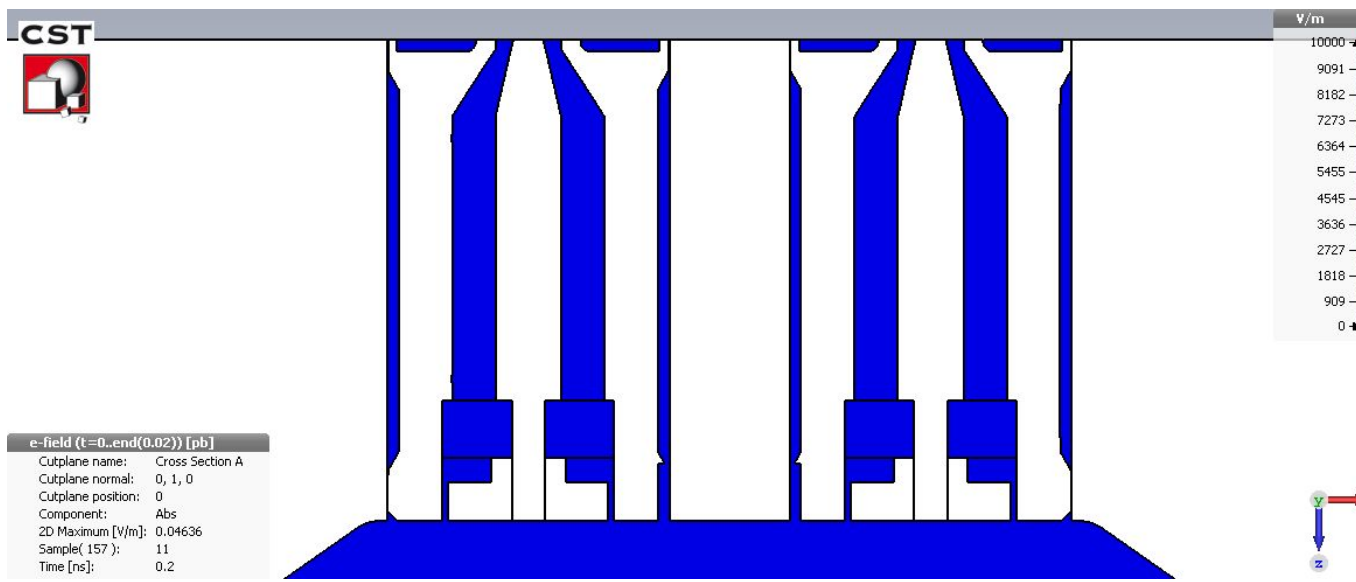
Fused silica (SiO_2)

$\varepsilon_r{}' = 3.74$

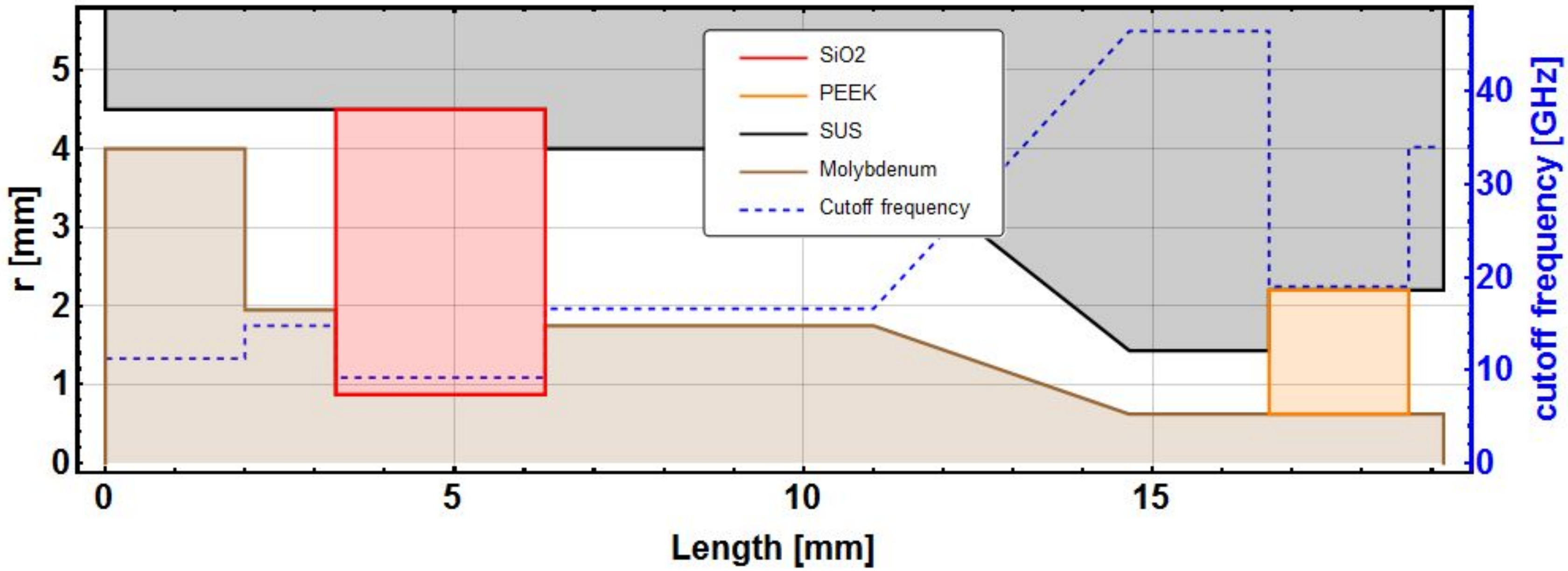
$\varepsilon_r{}'' = 0.00144$

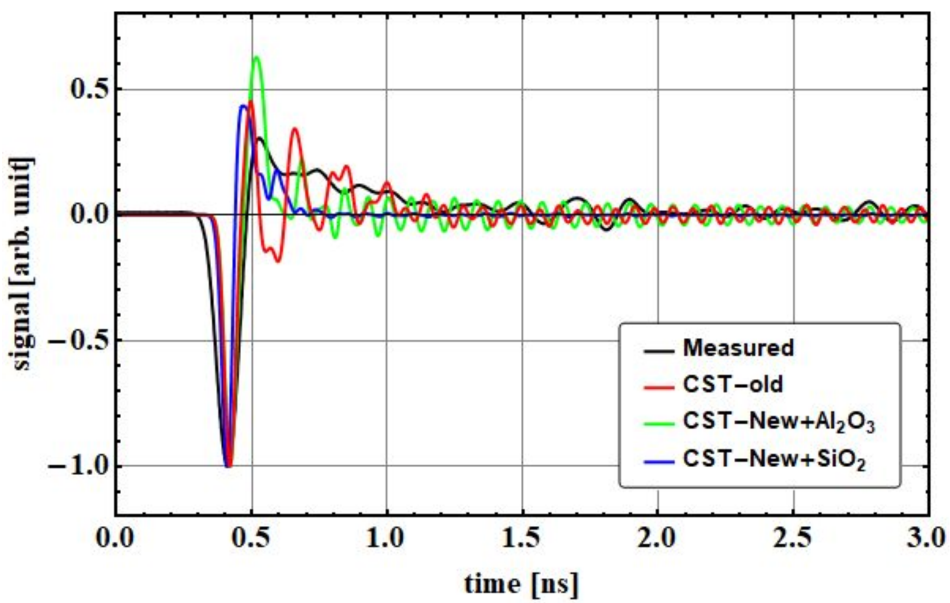
$Q = \varepsilon_r{}' / \varepsilon_r{}'' \sim 2597$

$f_c = 9.2$ GHz



New button-type Beam Position Monitor (insulator)

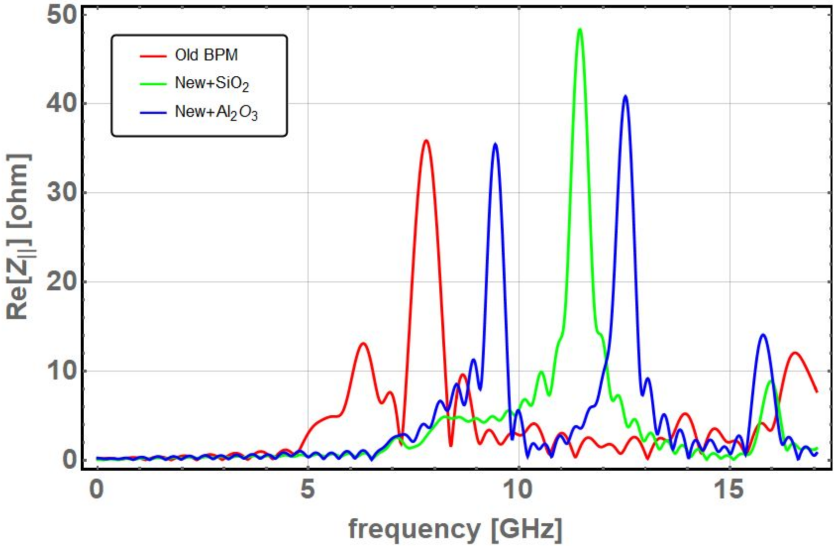


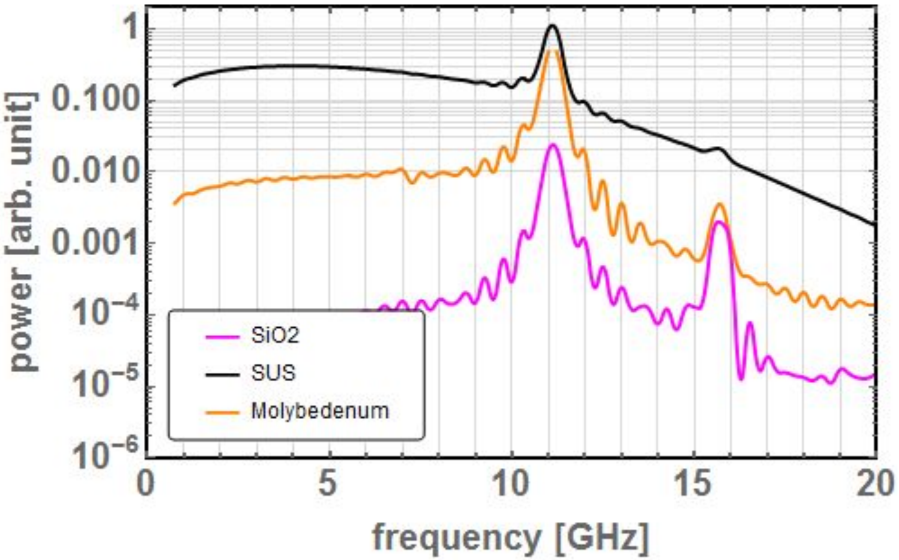


Dielectric constant of materials of useable insulator

- Zirconia : 10 ~ 23
- Magnesium oxide : 9.0 ~ 10.1
- **Aluminum oxide (Al2O3) : 9.0 ~ 9.8**
- Aluminum nitride : 9.0
- Nitride : 7.5
- Silicon nitride : 7.5
- Diamond : 5.7
- **Fused silica (SiO2) : 3.74**

New button-type Beam Position Monitor (heating)





The cutoff frequency of the trapped mode at the insulator was shifted to a higher frequency by reducing the diameter of the button. In addition, more than one order magnitude of the power is dissipated on the SUS chamber.

P_{button} [W]			
	BESSYII BPM	New+Al_2O_3	New+SiO_2
BESSY II	0.48	0.31	0.20
Low-alpha	0.15	0.16	0.09
VSR long	0.50	0.39	0.25
VSR short	0.03	0.03	0.02

The dissipated power by the Wakefield at the new BPM during the BESSY VSR scheme is **0.42 W** which is lower than the power on old BPM during the BESSY II operation.

Summary

Many physical properties were learned from the 20-years old mature button BPM at the BESSY II storage ring .

Important features :

1. Heating : below 0.48 W / button
2. Signal contamination by preceding bunches
3. Multiple internal reflection due to the impedance mismatching
4. Low frequency (~1.5 GHz) trapped mode @ button lodging hole

Our partial solutions for the issues on button BPM

1. Heating : can be reduced by selecting the material properly
   Mo (2×10^7 S/m) – SUS (1.45×10^6 S/m) / Cu (6×10^7) - SUS/ Al(4×10^7) - SUS
2. Ringing signal : SiO2 ($\varepsilon_r = 3.74$) or low permittivity insulator
3. Impedance matching : can be optimized
4. Trapped mode @ button lodging hole :
   RF spring in NSLS-II → We reduce the gap (* mainly by vacuum experts)

Thank you for your attention