Development of beam current monitor with HTS SQUID and HTS current sensor

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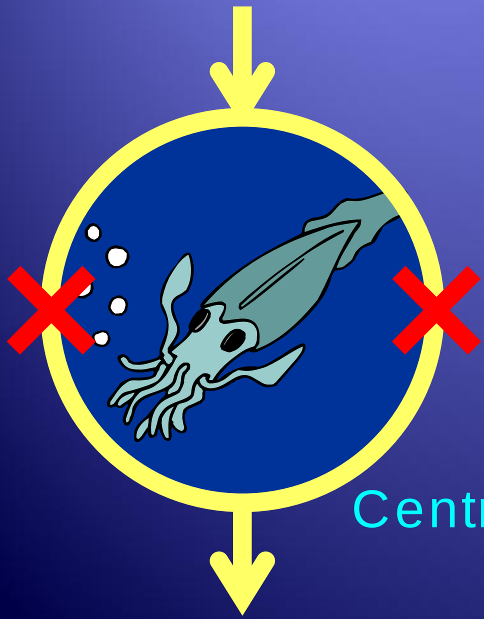


HIAT09
10 June 2009
Centro Culturale Don Orione Artigianelli,
Venezia (Italy)

SQUID :
Superconducting
QUantum
Interference
Device

Can a SQUID see a beam ?

Purpose and importance of HTS SQUID monitor

- What do we measure?

  ⇨ The current (position) of the DC beam

- What are the advantages of measuring a beam using a SQUID?

  ⇨ (1) Nondestructively, (2) Accurately, (3) In Real-time

- Why do we need to use a SQUID? Why ?
  - For high-energy heavy-ion beams,

    If a beam is stopped by a Faraday cup,

    (1) the beam can no longer be used;

    (2) there is a danger of melting and activation;

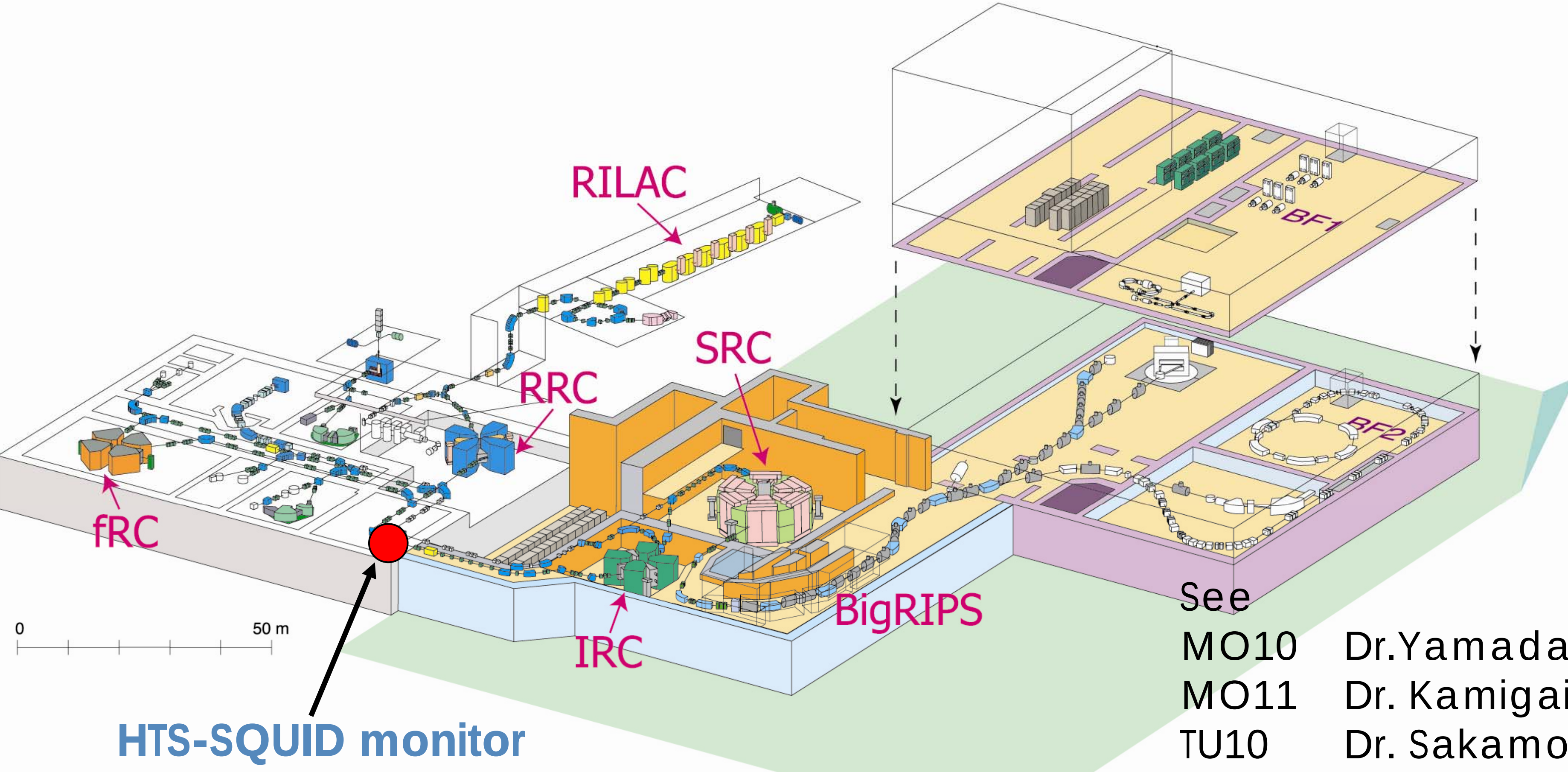
    (3) it is difficult to suppress secondary electrons.

- The SQUID monitor can resolve all these problems

Preview

- Purpose and importance of HTS SQUID monitor
- Accelerator complex of RIBF
- Technical issuers of using a Faraday cup
- HTS SQUID monitoring system and measurement results
  - Principles of monitoring system
  - Successful measurements of using heavy-ion beams
  - Real-time analysis
- Practical use of HTS SQUID monitor at RIBF
- Conclusion

Accelerator complex of RIBF



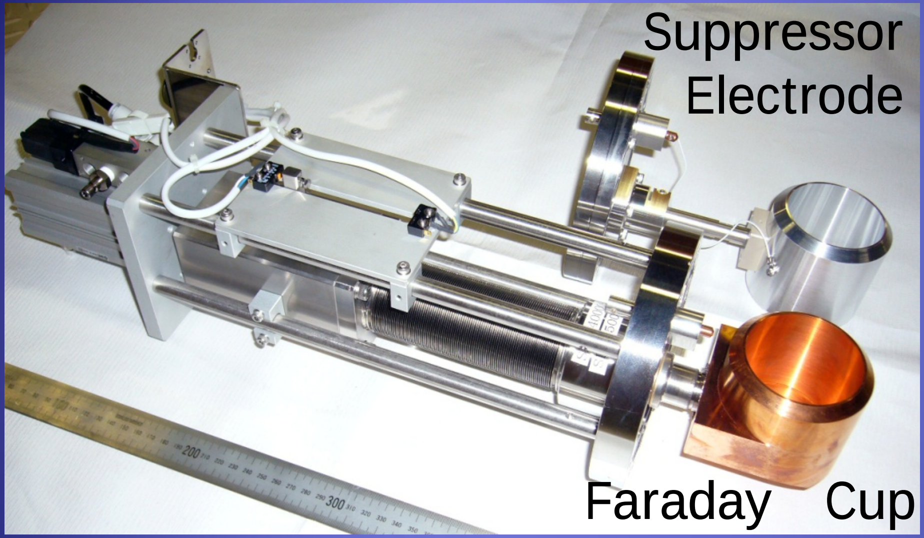
See
MO10 Dr.Yamada
MO11 Dr. Kamigaito
TU10 Dr. Sakamoto

1 Linac + 4 Cyclotrons+
BigRIPS (Superconducting RI Separator)

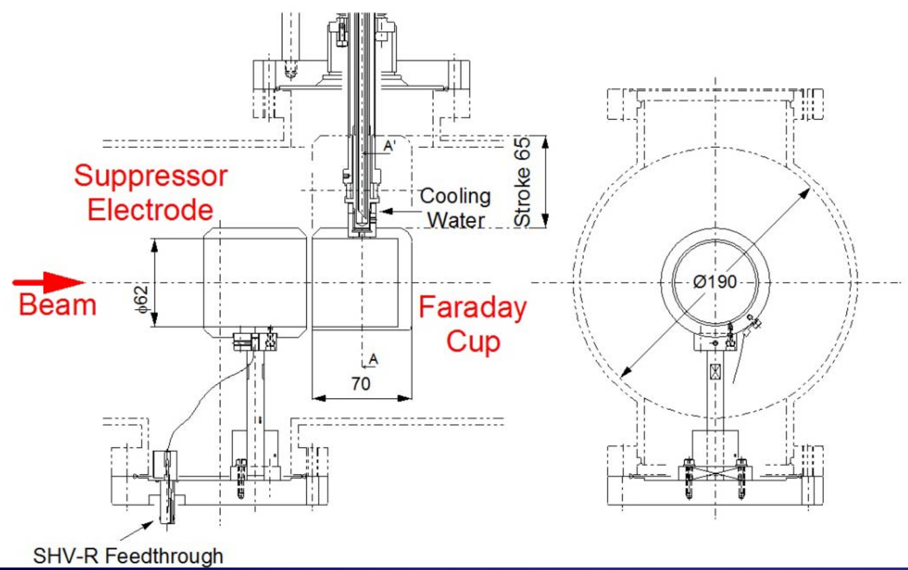
- Succeeded in accelerating a U beam to 345 MeV/u in 2007
- Discovery of Pd 125, a new RI

- Accelerator complex of RIBF
- Technical issues related to the use of a Faraday cup

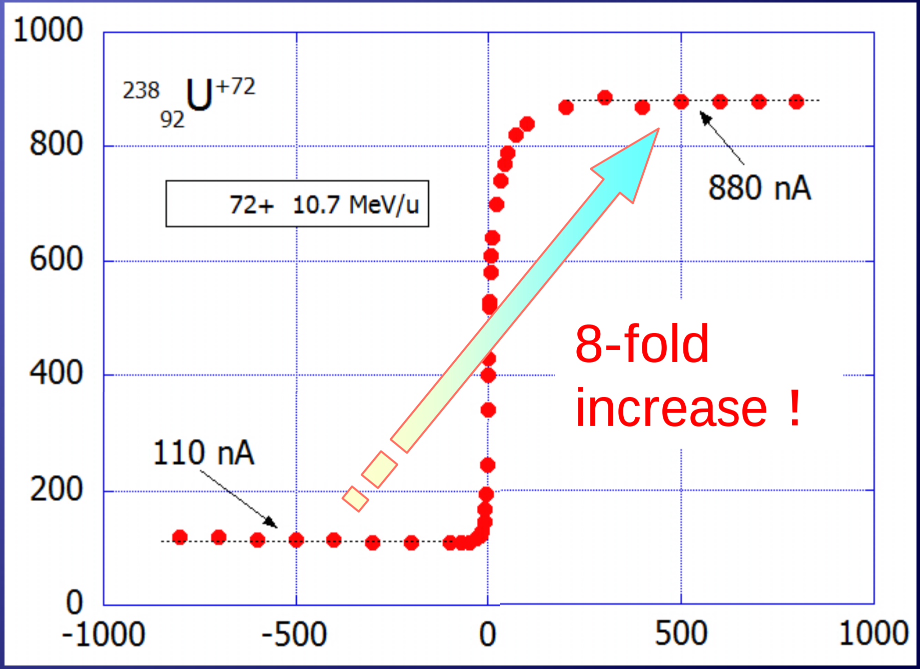
Technical issues of Faraday cup



- Beam cannot be used while it is being measured
- Danger of melting and activation
- Difficulty of suppression of secondary electrons



Beam current (enA)



Applied Suppressor Voltage (V)

- Technical issues of Faraday cup
- System of HTS SQUID monitor and measurement results

Principle of HTS SQUID monitor

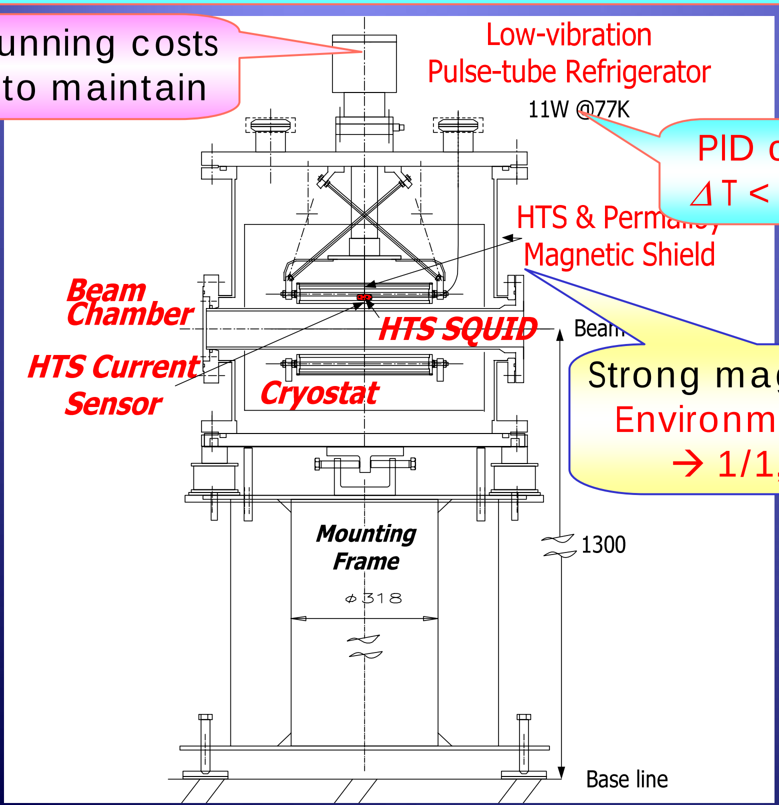
Irradiation of beam

Shielding current is produced by Meissner effect

HTS SQUID can detect azimuthal magnetic field with high S/N ratio and convert it to beam current

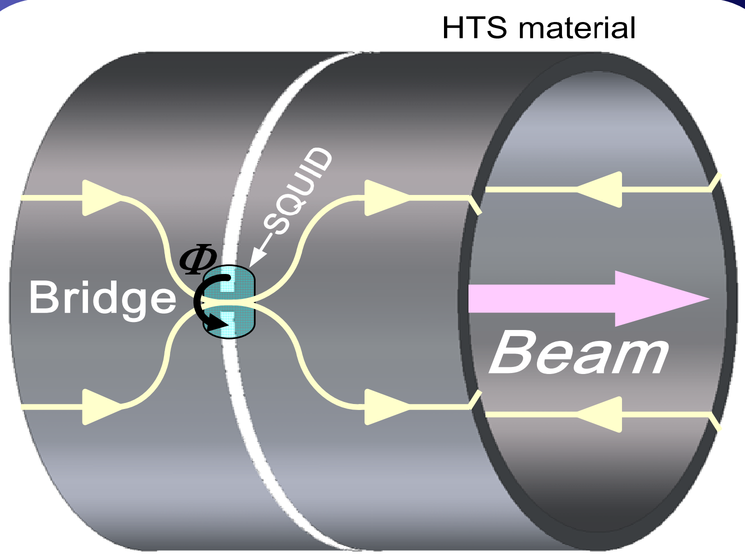
Superconductor: $Bi(Pb)_2$-Sr_2-Ca_2-Cu_3-O_x (Bi2223)
Substrate: 99.9% MgO ceramic

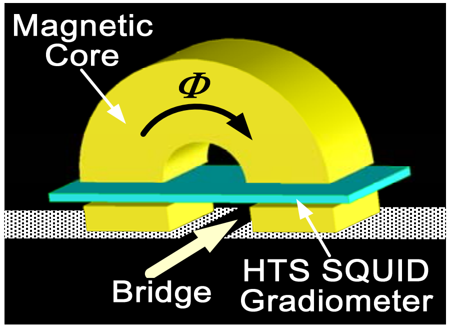
Low running costs
Easy to maintain



PID control
ΔT < 6.8 mK

Strong magnetic shield
Environmental noise
→ 1/1,000,000



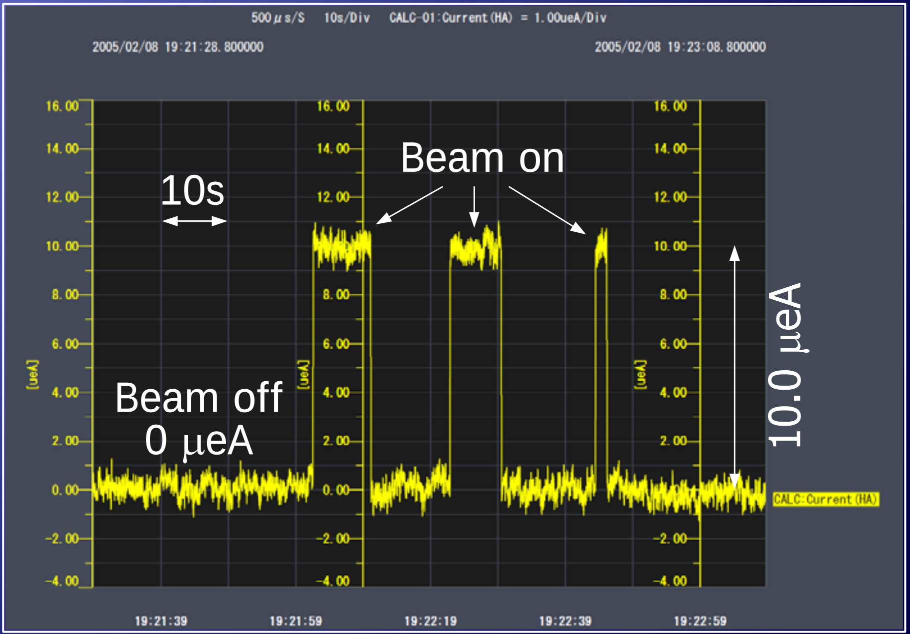


Successful measurements using ion beams

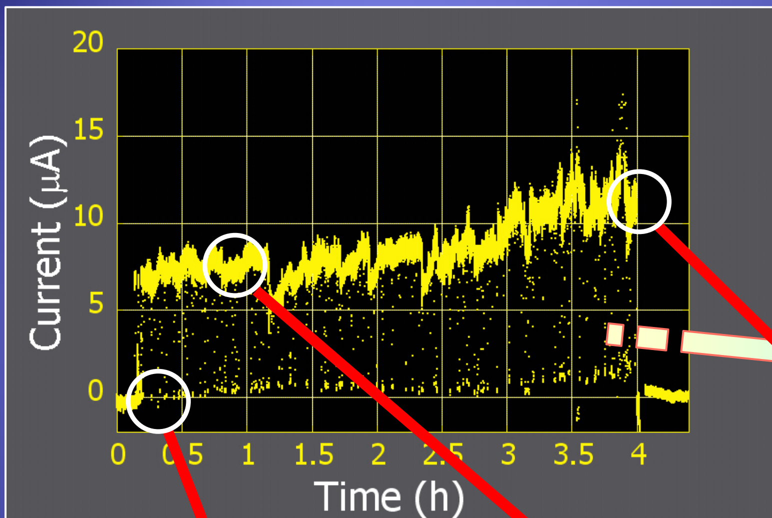
RF cavity:
Max. 0.6 MW
Main magnetic field:
Max. 1.7 T

Radiation dose (1 year):
3.0 Sv for γ radiation
25.5 Sv for neutrons

Beam $^{40}Ar^{+15}$ (63 MeV/u)

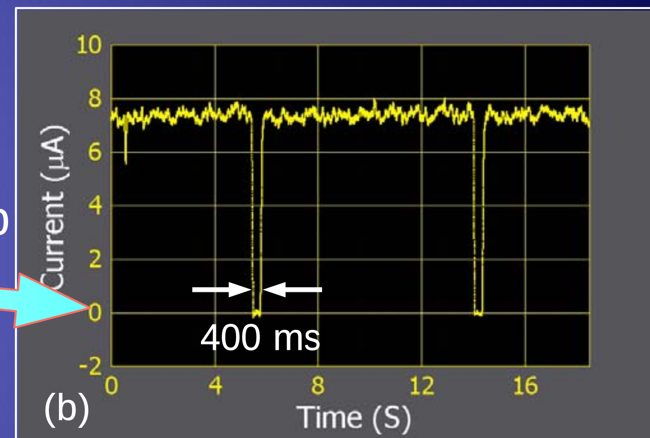


Real time analysis

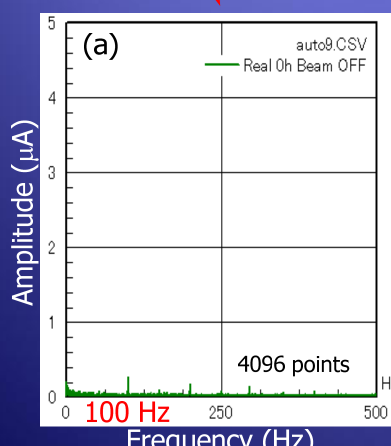


- Discharge of ECR ion source

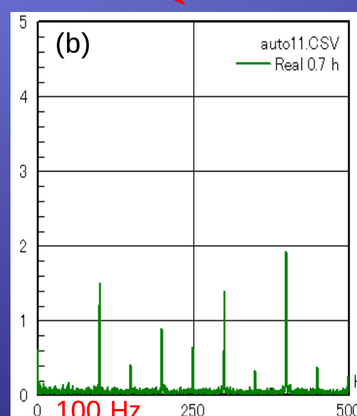
Close up



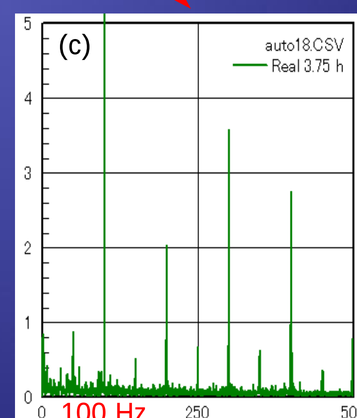
- Ripples in modulated beam



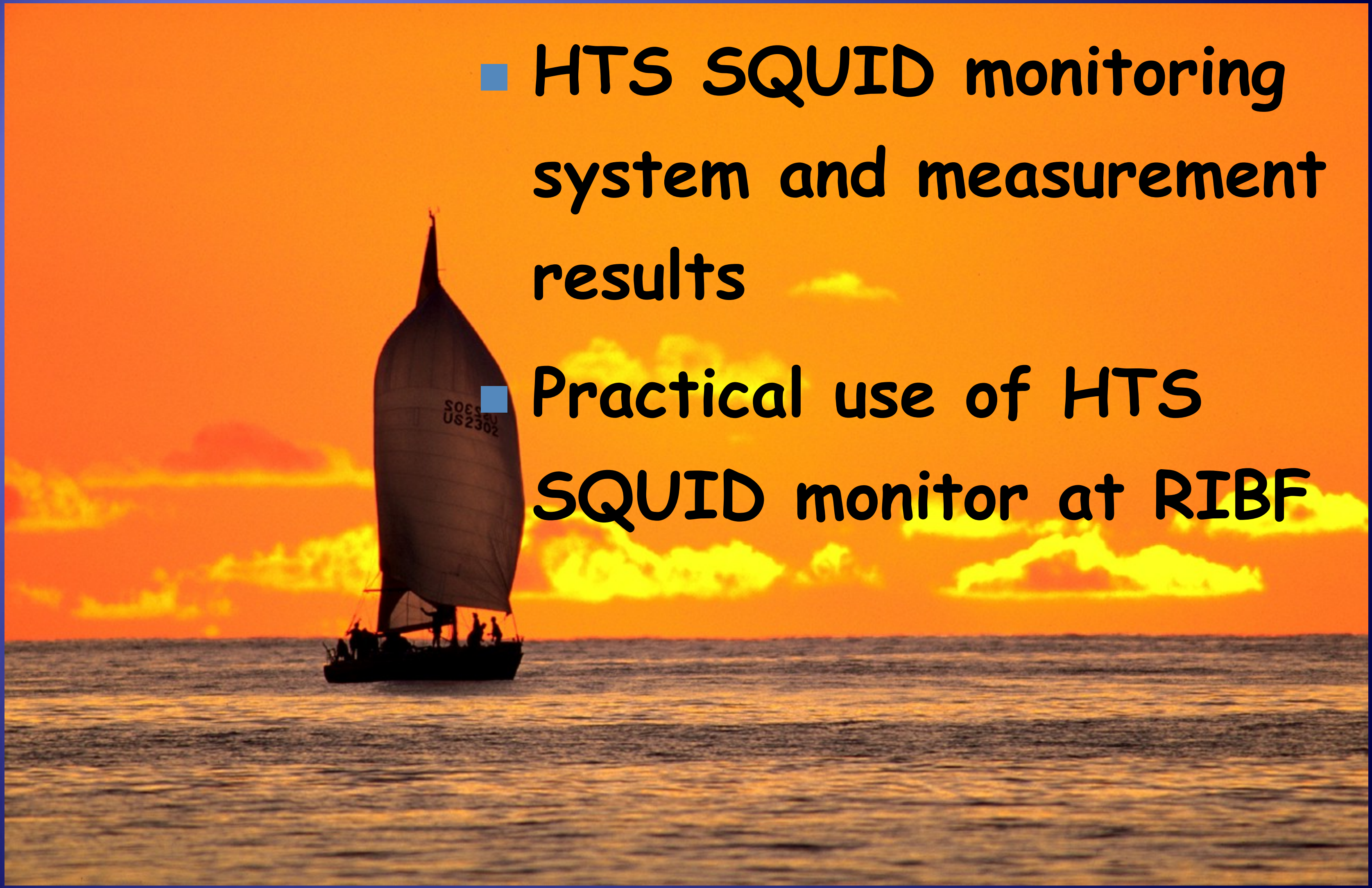
0 hour (beam off)



0.7 h



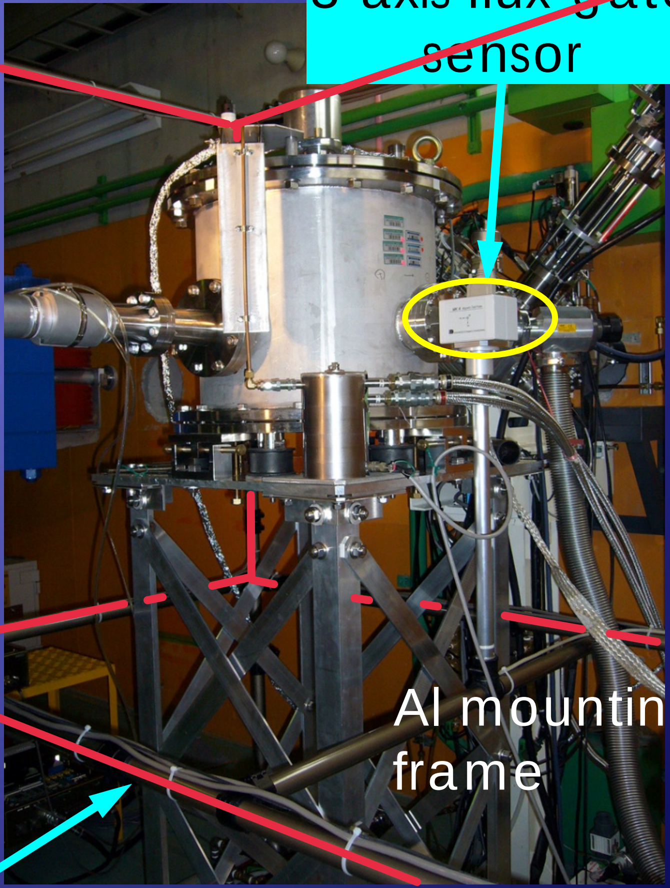
3.8 h



- HTS SQUID monitoring system and measurement results
- Practical use of HTS SQUID monitor at RIBF

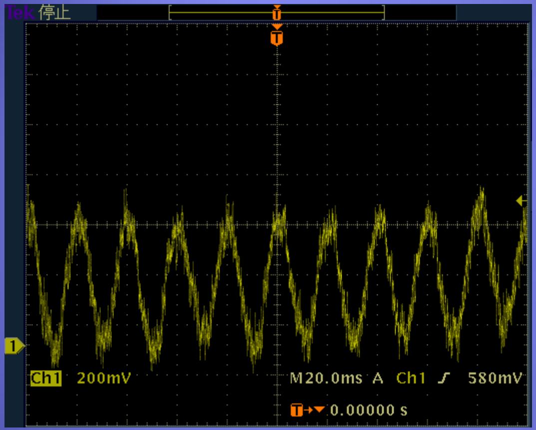
Practical use of HTS SQUID monitor at RIBF

HTS current sensor

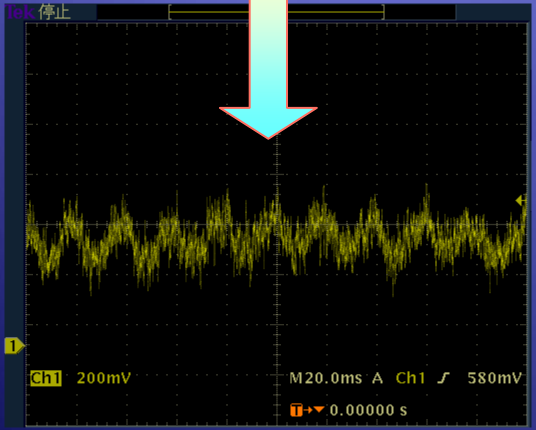


Noise cancellation system

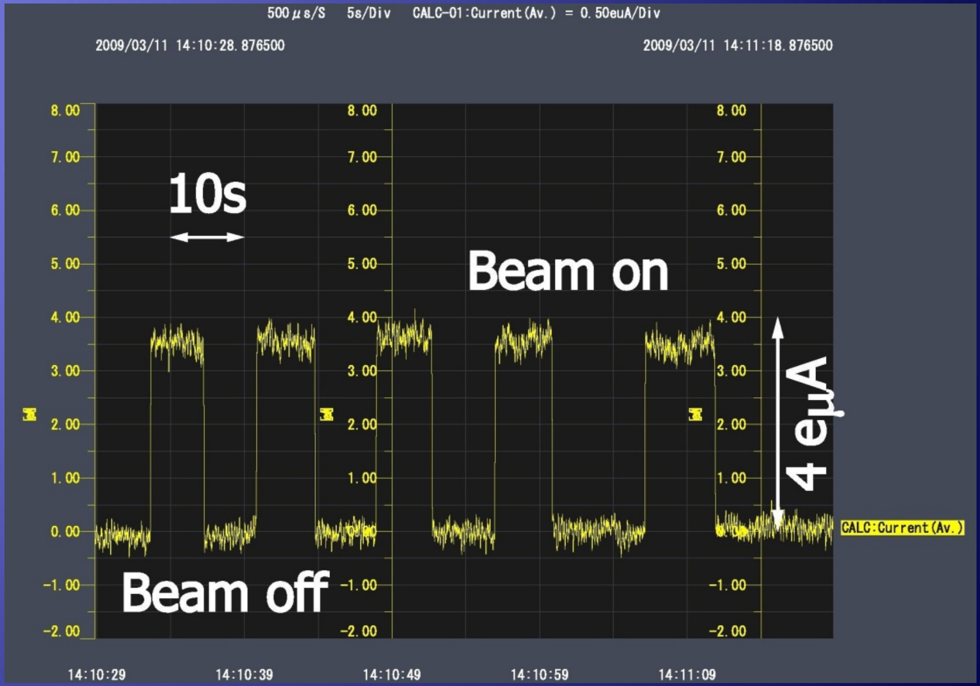
Practical use of HTS SQUID monitor at RIBF (Results)



Feedback off



Feedback on



3.6 μA $^{132}Xe^{20+}$ beam (10.8 MeV/u)

Conclusion

- Purpose and importance of HTS SQUID monitor
- Accelerator complex of RIBF
- Technical issues regarding the use of a Faraday cup
- System of HTS SQUID monitor and measurement results
- Practical use of HTS SQUID monitor for RIBF
- Conclusion

Can a SQUID see a beam ?

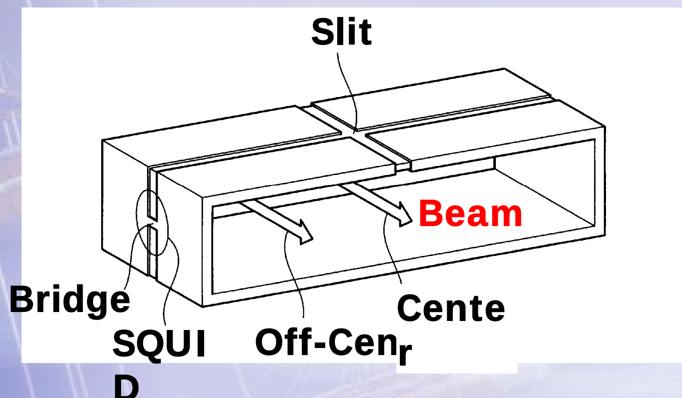
-> Yes, definitely !

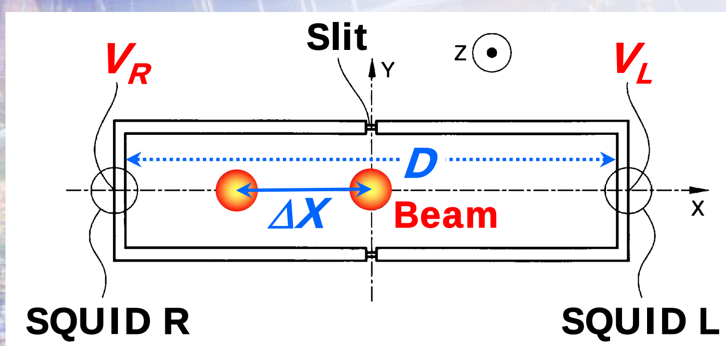
Thank you for your kind attention

Tamaki Watanabe

Beam Position

- **Dividing current sensor into two parts**



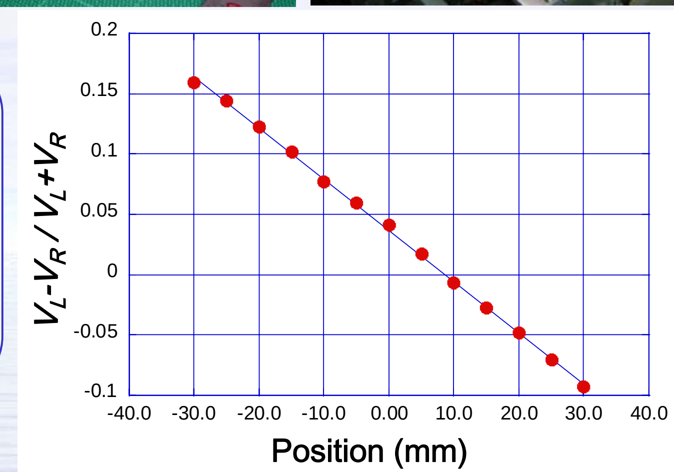


Beam position Δx

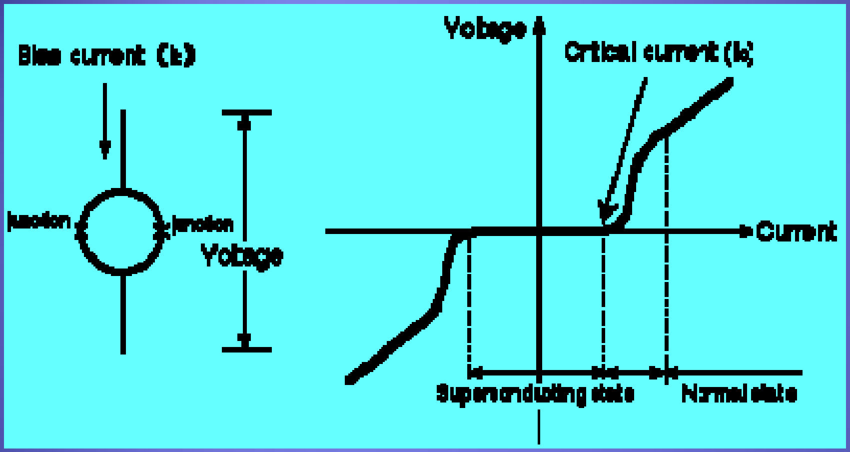
$$\Delta x = \alpha \cdot \frac{D}{2} \cdot \frac{\Delta_x}{\Sigma_x}$$

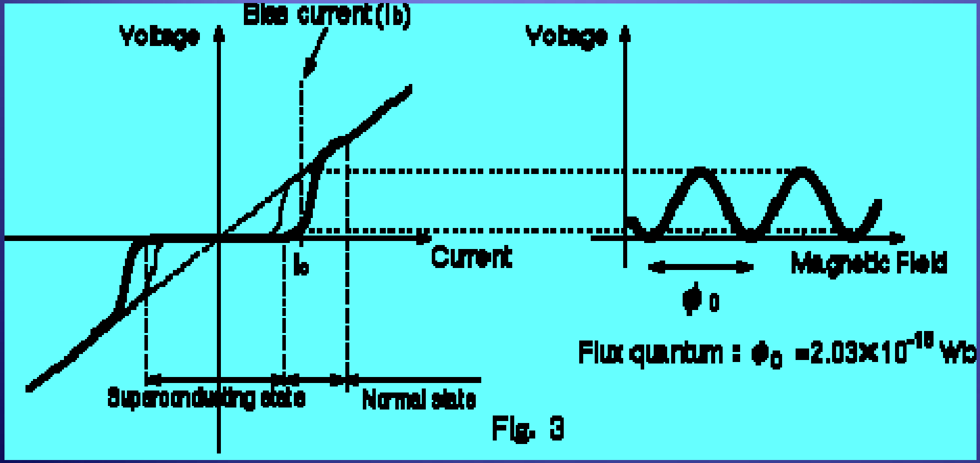
$$= \alpha \cdot \frac{D}{2} \cdot \frac{V_L - V_R}{V_L + V_R}$$

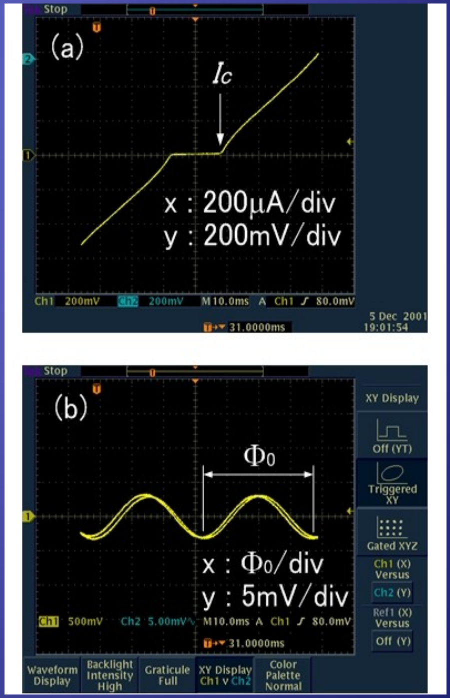
- **Experimental Results**



Principles of SQUID operation







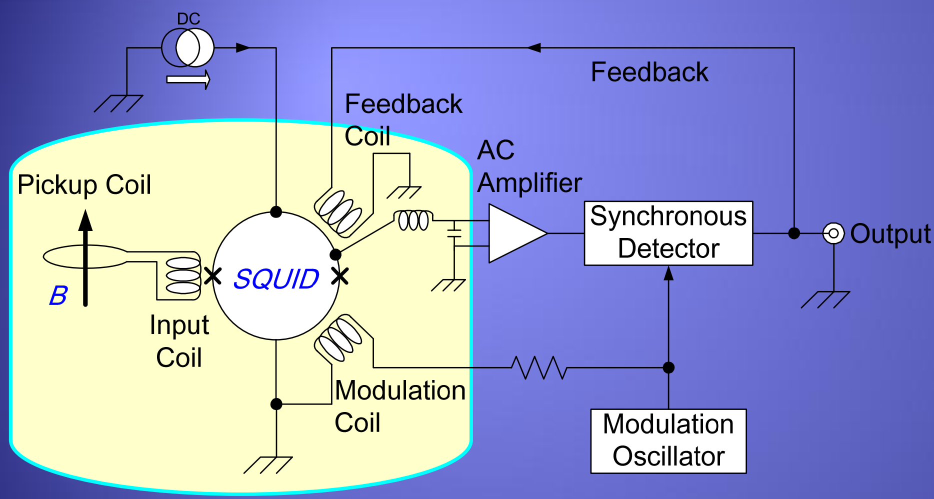
Characteristics of SQUID. The response of the sensitive SQUID loop is periodic with respect to a magnetic flux quantum, $\Phi_0 = h/2e = 2.068 \times 10^{-15}$ weber.

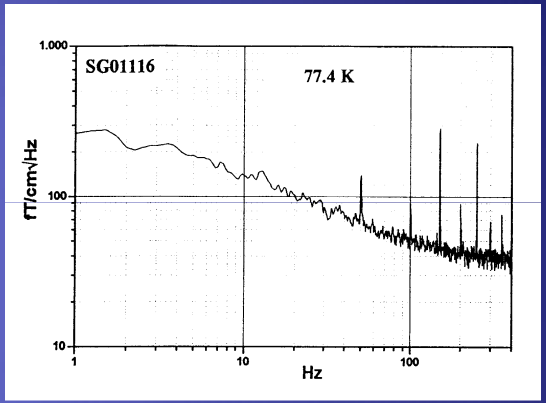
(a) Current (x-axis) *vs.* voltage (y-axis) appears across the Josepson junctions of HTS SQUID,

(b) Relationship of the magnetic field *B* (x-axis) at the input coil with voltage (y-axis).

System

- Circuit Diagram of a HTS DC SQUID and Flux-Locked Loop





Measured noise spectrum in the frequency domain.

The flux-locked loop can make a linear operation with respect to the HTS SQUID circuit because it cancels the external magnetic flux density B, with the aid of the bias current flowing in the feedback coil. Modulation and synchronous detector are used to create a flux-locked loop circuit similar to negative feedback phase-locked circuit. The voltage appearing in the resistance, if it appears in the figure, is measured in order to obtain the calibrated shield current, namely, the beam current passing through the HTS tube.

Table 1: The specifications of the HTS DC SQUID system.

Noise level	34 fT / $\sqrt{Hz}$ @ 5kHz
Operation temperature	77 K
Feedback gain	1, 2 ,5, 10, 20, 50, 100, 200, 500
High pass filter	DC, 0.3 Hz
Low pass filter	5 Hz, 200 Hz, 2kHz, 20kHz
Date accuracy (AD)	16 bit
Date acquisition rates	20000 words/s
Remote control	IEEE-488, RS-232