Investigation of the broken beam pipe

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KEKB Review, Feb/10, 2003

- Structure of IP beam pipe
- Searching for leak points
- Element analysis for remaining white powder
- Possible reasons for He leak
- Summary

Structure of the IP beam pipe in SVD1.4

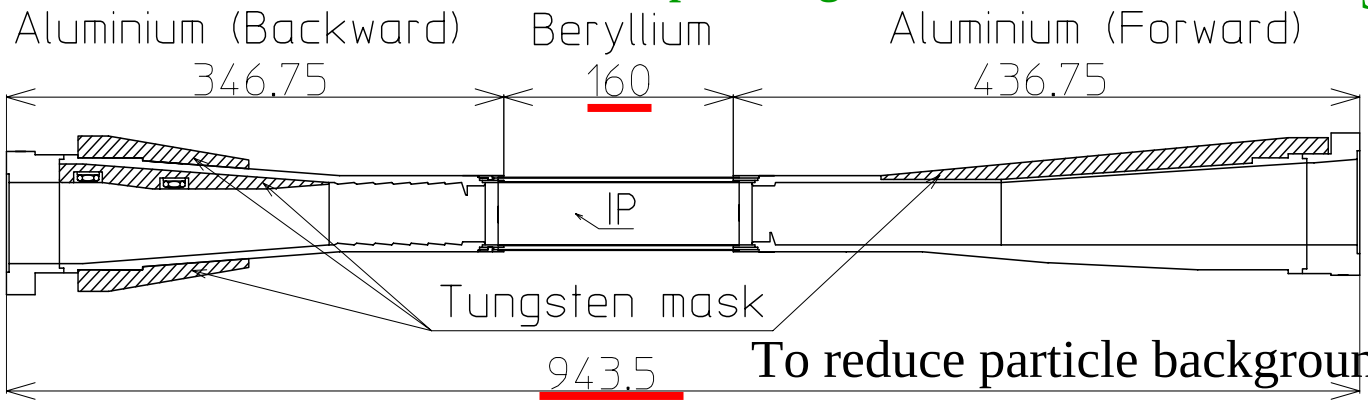
Inner Surface

10~30μm gold by chemical plating

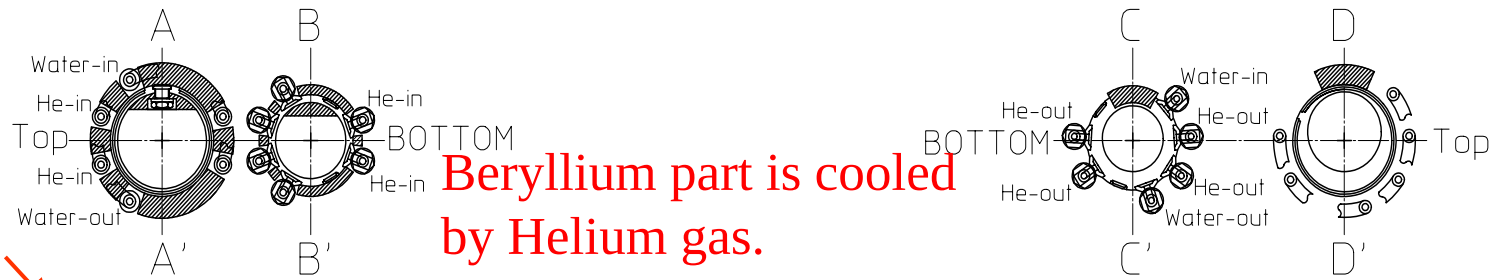
10μm gold by vacuum sputtering

200~230μm gold by chemical plating

To reduce SR

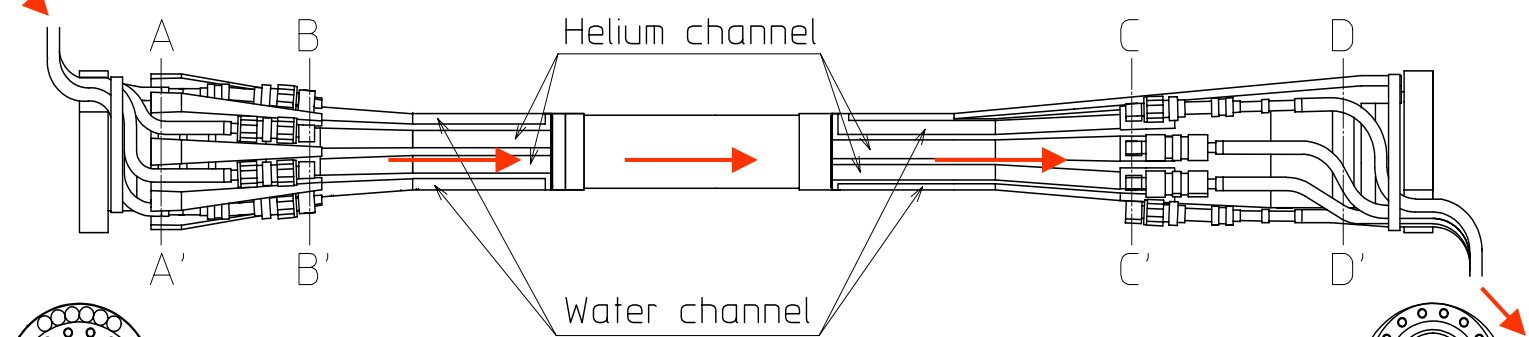


To reduce particle background



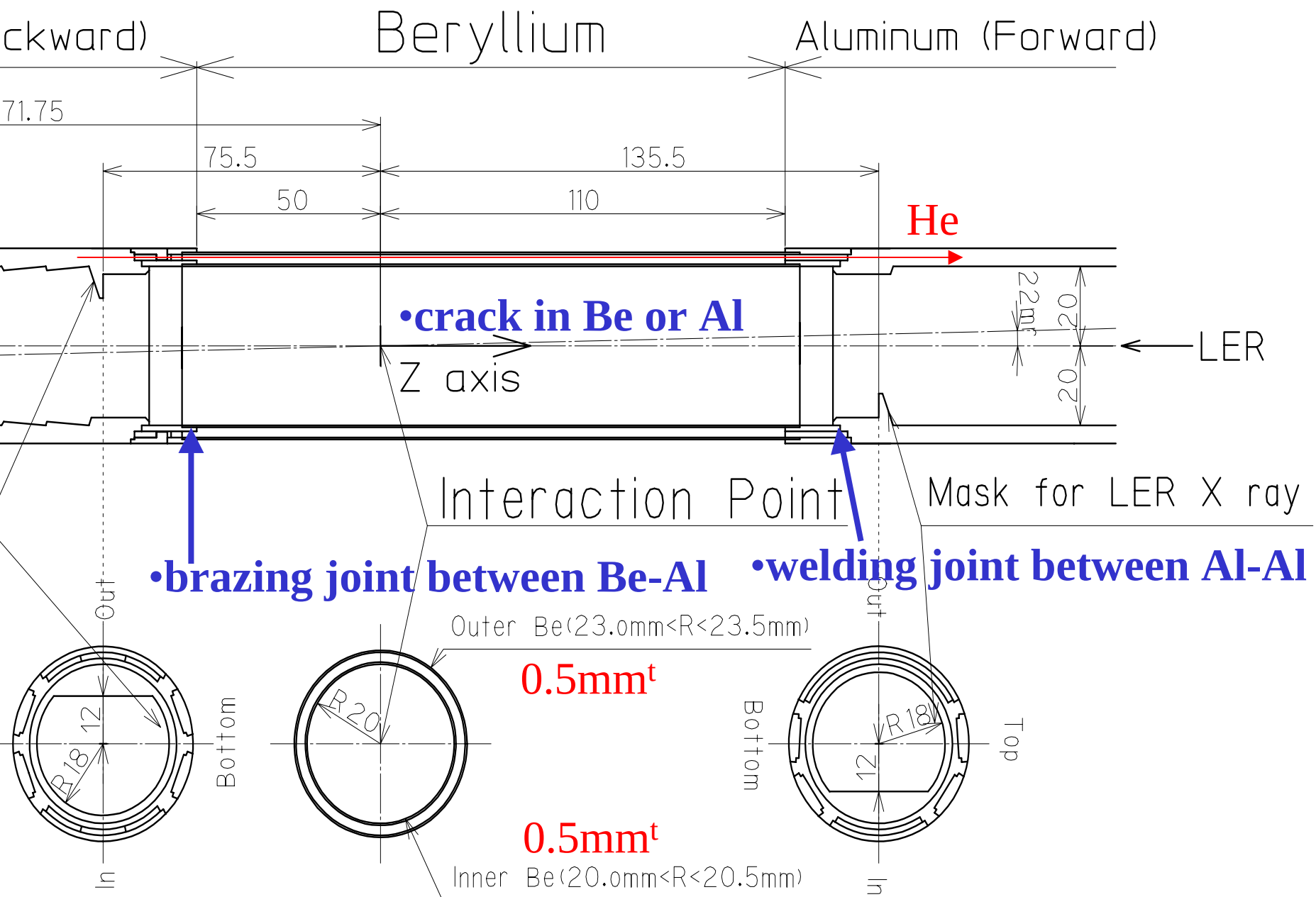
Beryllium part is cooled by Helium gas.

He



Aluminum part is cooled by water.

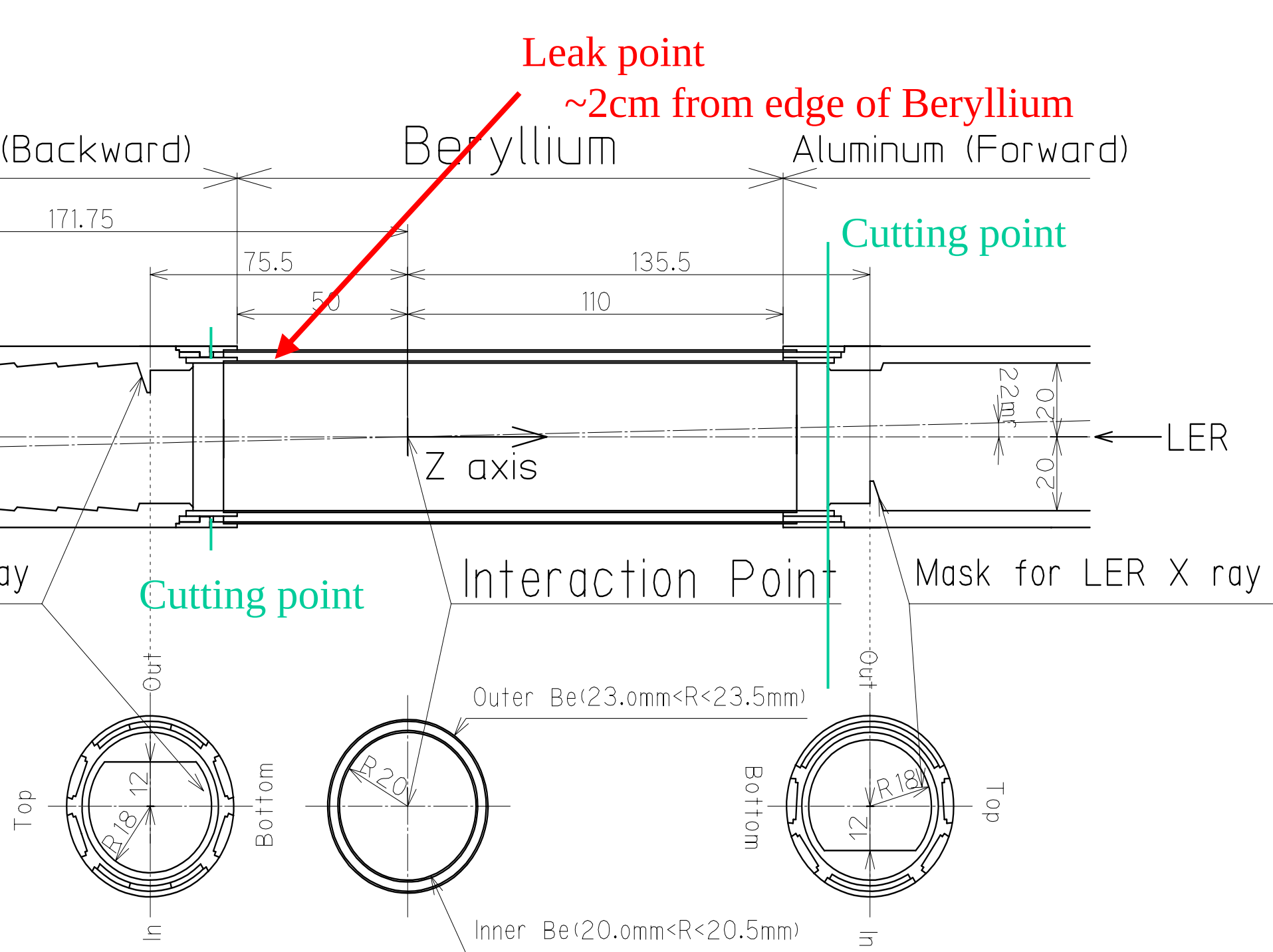
Possible sources of He leak to vacuum



Search for leak points

- After dismounting the beam pipe from Belle, a leak check was performed to identify the leak point.
  - He leak was confirmed in a normal leak test.
  - Bubbles could be seen on the inner gold sputtering surface of Beryllium, when liquid was supplied.

→ Not joint parts.


Leak point
~2cm from edge of Beryllium
(Backward)
Beryllium
Aluminum (Forward)
171.75
75.5
135.5
50
110
Cutting point
22mm
20
20
LER
Z axis
ay
Cutting point
Interaction Point
Mask for LER X ray
Out
Top
Bottom
In
12
R18
Outer Be(23.0mm<R<23.5mm)
R20
Inner Be(20.0mm<R<20.5mm)
Out
Bottom
Top
R18
12
In

Picture of the inner cylinder

- A large amount of white powder was found on the surface of the inner Beryllium cylinder.
- It looks like a pattern of water flow.
- There is white powder on the Al ring, also.
  - Large amount at backward ring
  - Small amount at forward ring

Leak points

- Leak position was confirmed from outside of inner beryllium beam pipe with various methods.
  - There are at least two separated leak points on Beryllium surface (~1cm distance).
  - It matches to position where was found from inside.

Leak points

Close up view of a leak point

- Any cracks could not be found near leak points.
  - Many tiny dips are seen.

Element analysis

- We found two types of powder.
  - Color of one powder is clearly white.
  - Another one is slightly yellow.

- Element analysis is in progress, separately.
  - Several methods are used for identify elements.
  - Preliminary results are available, now.

Preliminary results of element analysis

- White
  - Main components are Be and O.
  - Probably, it is BeO.
- Yellow
  - Main components are Al and O.
  - Probably, it is Al_2O_3.
- Common
  - C was also found.
  - Small amounts of P, K, Ca, S, Cl, Si, Mn, Fe, and Cu were found.
    - Si, Mn, Fe and Cu are components of Aluminum alloy.
  - S and Cl are dangerous elements for corrosion of Beryllium.
  - But, expert for element analysis says amounts of S and Cl are small and are consistent with normal metal. → No conclusion, now.

Check for inside of Al part

- We cut L angle connector in Helium line to see inside of Aluminum part.
  - One inlet connector was checked.
  - Inside surface shows white color without a metric luster.
- Nothing happens on the surface of SUS connectors.

Measurement of thickness

- Thickness of the inner Beryllium cylinder was measured.
  - We hope thickness may tell us something.
  - No significant difference was found.
    - Center : tend to be thick.
    - Both edges : tend to be thin.
    - No clear phi dependence.
- After cutting of Beryllium cylinder, more precise measurement will be done.

Photo before assembling

- Leaked Beryllium beam pipe is recycled from the first beam pipe, which had been used in May-July of 1999.
- Before assembling, a photo was taken.
  - White powder can be seen clearly on the Beryllium surface.
  - Amount of powder is much smaller.
  - Pattern is similar.
- At that time, we did not investigate the white powder. After that, we forgot this fact.

Corrosion

- Corrosion might occur on both of Al and Be.
  - At present, we do not know why corrosion occur.
  - Which components affect corrosion? Water, Cl or S? More careful investigation is necessary.
    - Analysis of circulation gas is in progress.
- Before the accident, we had not paid attention to corrosion.
  - Due point had not been monitored in circulated Helium gas.
  - We have never analyzed inpurity of the circulation gas.

- Present methods to avoid corrosion
  - Due point is monitored(~-20℃).
  - Additional filter will be added.
  - More frequently, fresh Helium gas is supplied to avoid accumulation of unlike gas. → Most effective.

Possible reasons of Helium leak

- Corrosion → most suspicious reason
- Heat stress
  - Two accidents
- Recycled Be pipe from BP#1

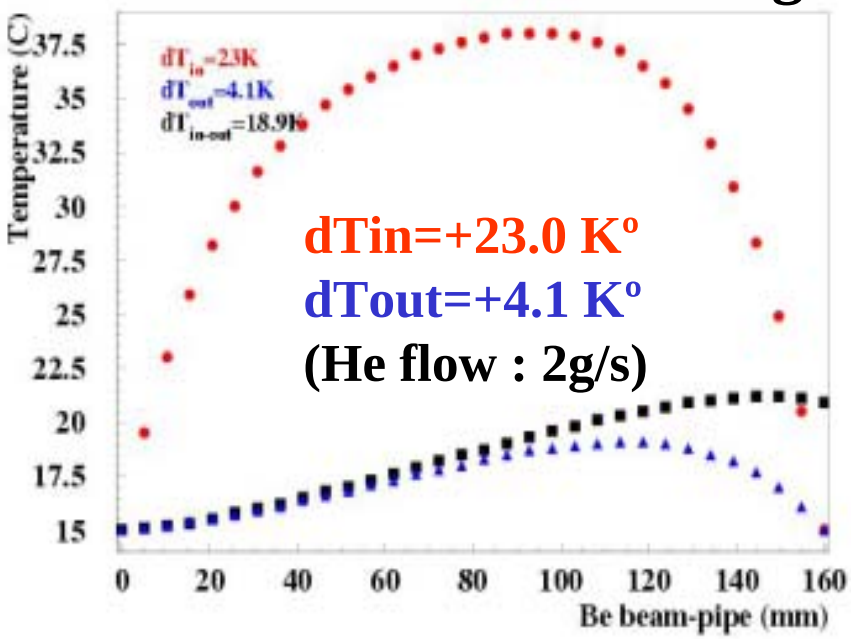
  Large stress at machining process (?)
- Very high temperature (~300 °C)

  by gold-spattering and welding with Aluminum section
- Defect of material (?)
- Dark spots which were found on Gold-plating

Temperature distribution with maximum allowed heat load

(Red:inner Be Blue:outer Be Black:He)

100 W with He cooling



- If He flow is 1 g/s,
  dTin=+25 Kº, dTout=+5 Kº
- Present situation: 1g/s,dTout=+3 Kº
  ⇒ 60W?

Maximum allowed temperature from stress analysis by IHI

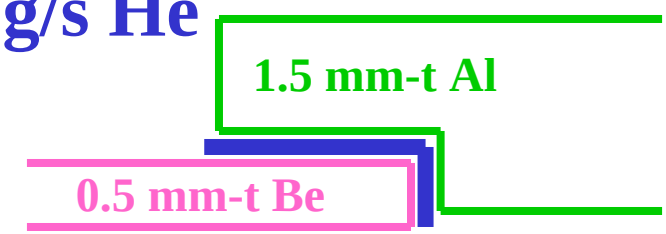
- Sm ≡ Min (1/4×Tensile strength, 1/1.5×Proof stress)
  Proof stress = stress at 0.2% yield point
- Stress should be smaller than 3×Sm for thermal case
- No worry(?) for heat cycle if stress < 3×Sm

At dTin = +25 K°

	Beryllium	Brazing	Aluminum
3×Sm (kgf/mm^2)	22.5	6.0	3.9
Stress (kgf/mm^2)	9.3	3.8	3.6

Temperature limit : dTin < +25 K°

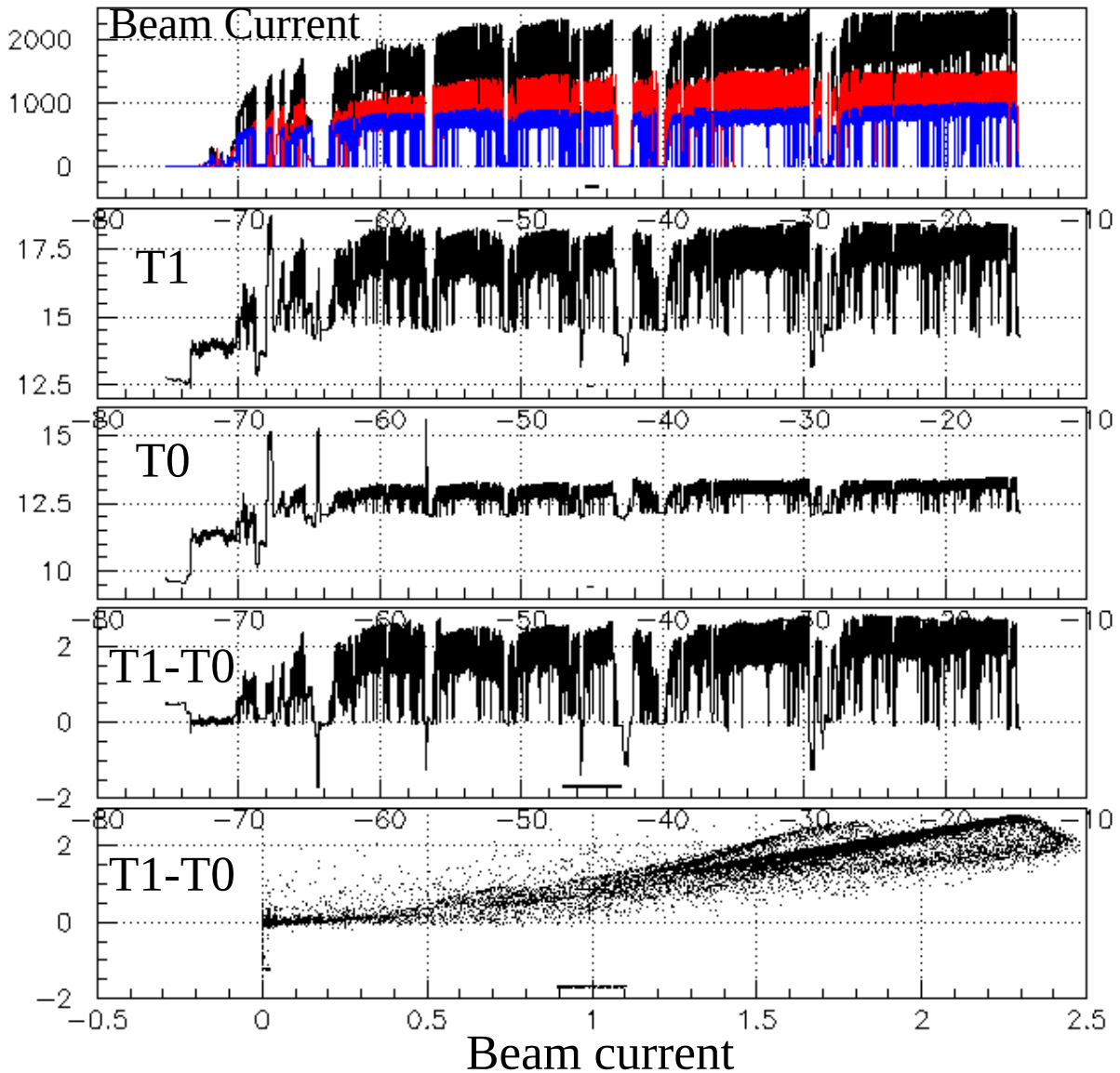
⇒ dTout < +4.2 K° ~ +8.1 K° with 1 g/s He
(+3~+6K°? for dTout@center)



Temperature of beam pipe

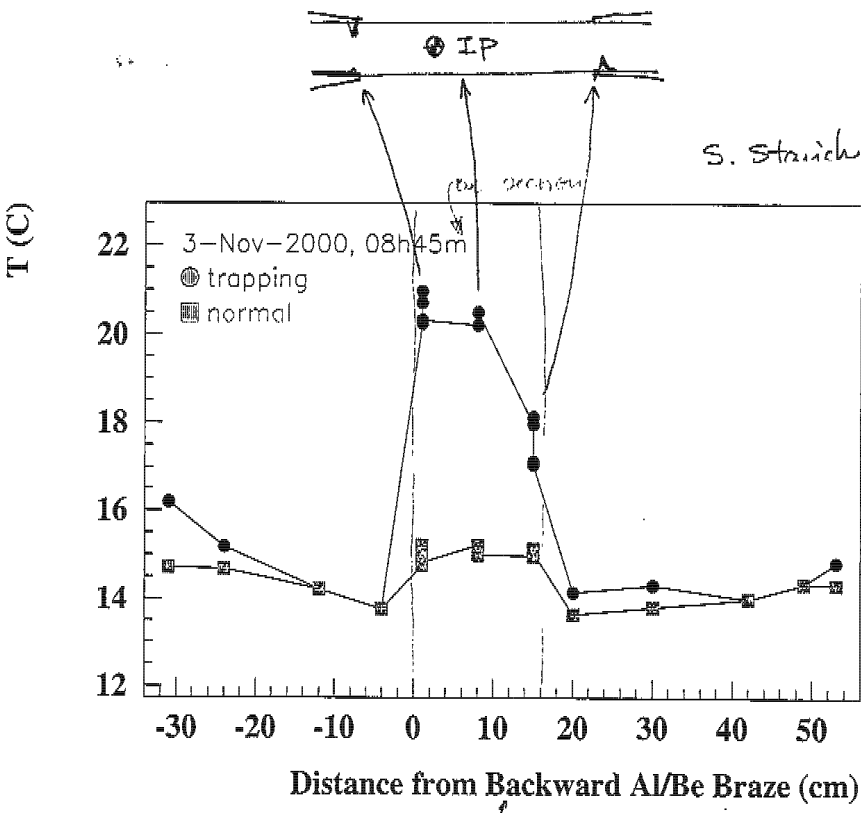
- Increase of current during 2002 fall run.

- T1(center) - T0(edge) ~2.5°C when a run starts LER+HER=2.5A.



Two temperature accidents

- **At 8:45 On Nov. 3, 2000**
- **dTout = 0 → +6 Kº with injection in 5-bucket spacing**



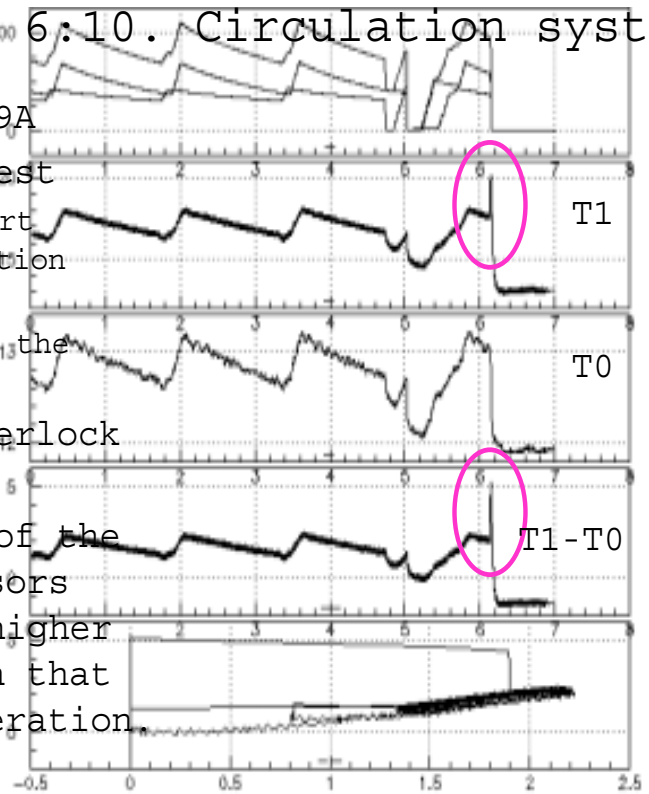
64~87 W?

dTin =+18~36 Kº?

- **At 6:10 On Sep. 30, 2002**
- **dTout = +2 Kº → +5 Kº when He flow stopped**

30 September, 6:10. Circulation syst

- Beam current~1.9A
- Beam abort request
  - The hardware abort from the circulation system.
  - 30 seconds after the system stops.
- Temperature interlock did not fire
- Condition: One of the temperature sensors shows 3 degree higher temperature than that in the usual operation.

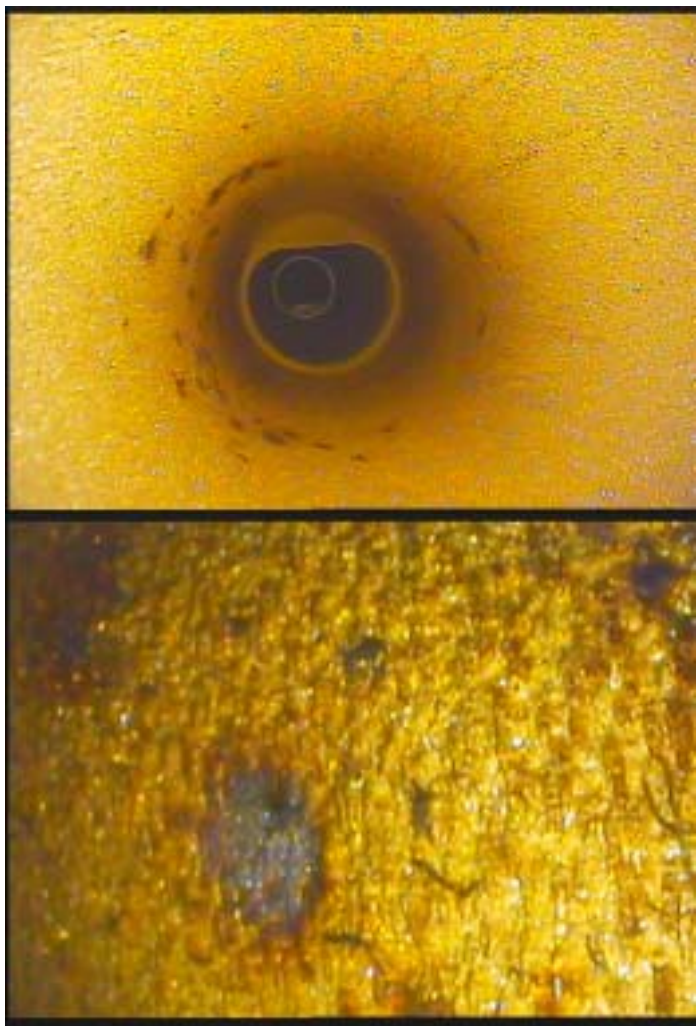


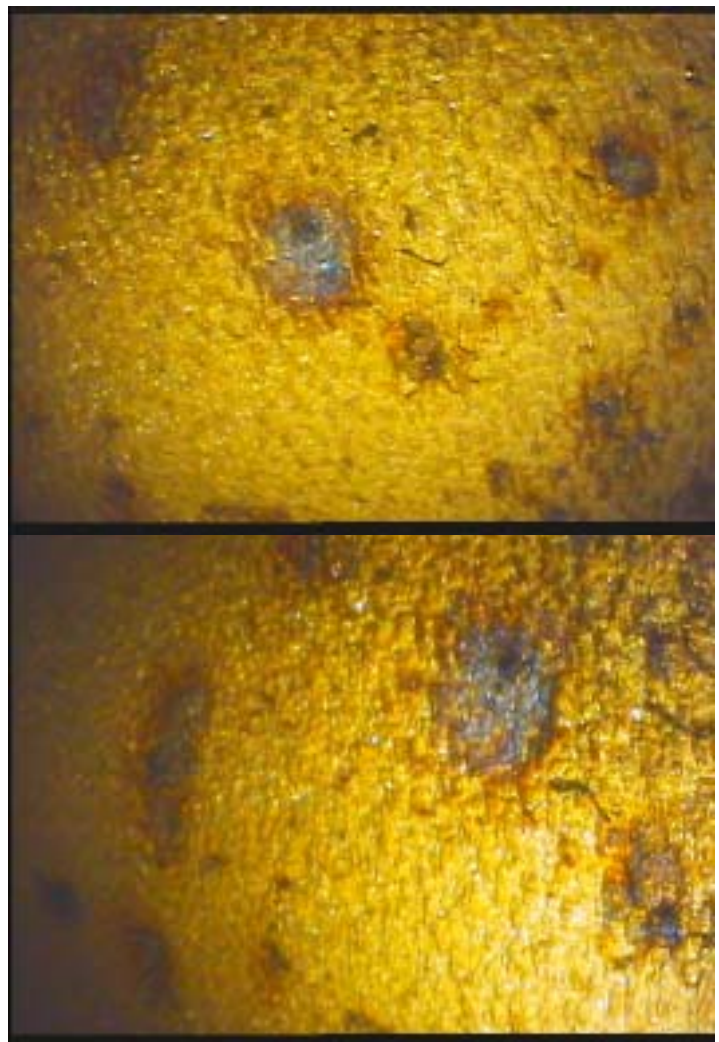
21~29 W?

dTin=+6~12Kº? ⇒ +28~+37Kº??

Dark spots on the Au-plating surface of forward Aluminum section were found after the Helium leak accident.

→ Large dynamic pressure?





Summary

- Leak points are Beryllium itself, not joint parts.
- Corrosion is most suspicious reason of He leak.
  - In order to avoid corrosion, several actions were done.
- Further investigation is in progress.
  - We will cut the Beryllium cylinder, soon.
  - Then, another element analysis will be performed and we can see detail of surface around leak points with microscopes.
- New beam pipe with SVD 2.0 will be installed in this summer. → T.Abe's talk.

History of the beryllium beam pipe at KEKB

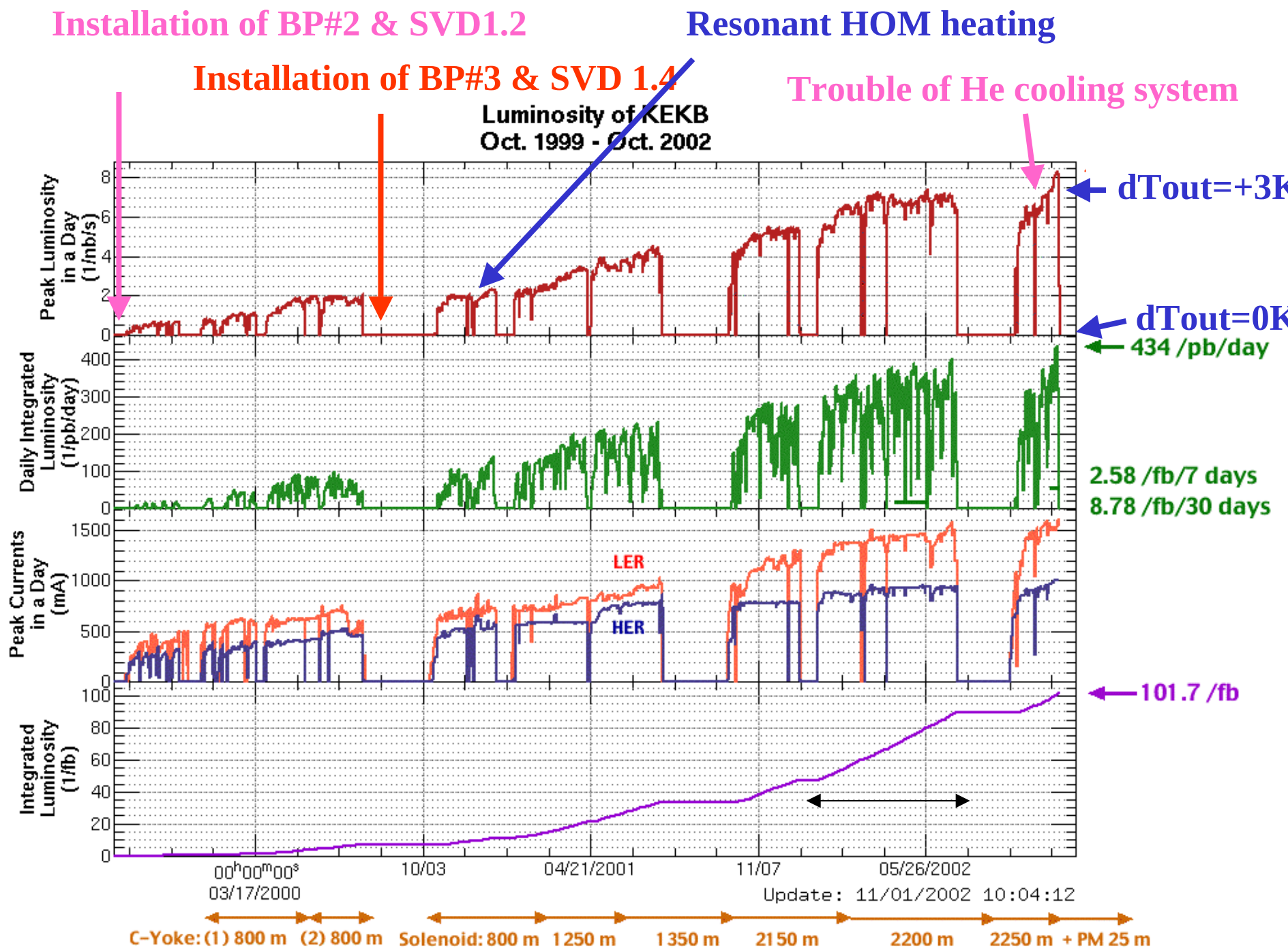
We constructed three Beam Pipes: BP#1, BP#2 and BP#3.
Basic mechanical structure is same in three pipes.

- BP#1 had been used with SVD1.0 from May 1999 to July, 1999.
  - 30 μm gold plating both for fwd/bwd Al sections.
- BP#2 had been used with SVD1.2 from Oct. 1999 to July, 2000.
  - 30 μm gold plating both for fwd/bwd Al sections.
  - 20 μm gold foil outside the Outer Be cylinder
- BP#3 had been used with SVD1.4 from Oct. 2000 to Nov. 2002.
  - 200/30 μm gold plating for fwd/bwd Al sections.
  - 10 μm gold sputtered inside the Inner Be cylinder
  - Hydrogen pressure in vacuum pipe increased on Oct. 31. 2002
  - Many black spots were found in fwd Al section on Nov. 3. 2002
  - He leak to vacuum happened on Nov. 8. 2002

Broken beam pipe (BP#3) in SVD1.4 was replaced

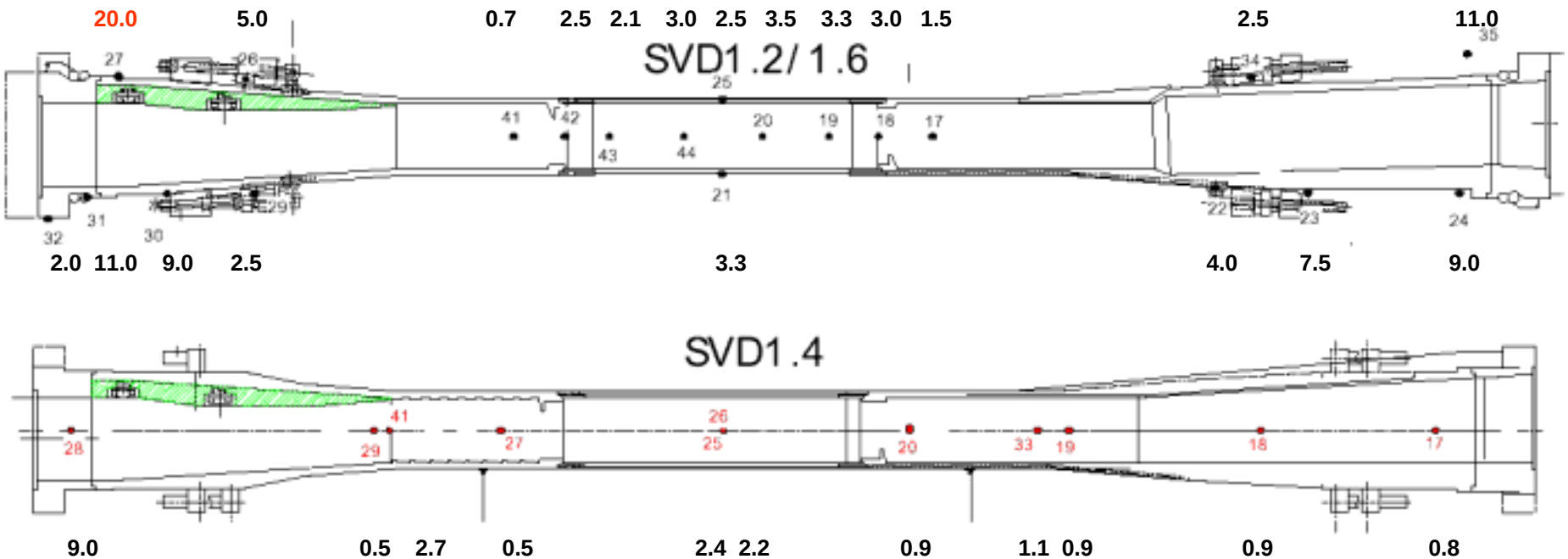
- with old one (BP#2) inside SVD1.2 in B4 clean room
- with new one (BP#4) for SVD2

	BP#3	BP#2	BP#4
cooling for Be	He	He	Paraffin
Au on Be	10μm inside	20μm outside	10μm inside
fwd/bwd	Aluminum	Aluminum	Tantrum
Au in fwd	200μm inside	20μm inside	no
Au in bwd	20μm inside	20μm inside	no
Res. HOM	5 buckets	5 buckets	No?
Saw tooth	bwd	no	bwd
Material (IP)	0.6% X_0	0.9% X_0	0.7% X_0
Particle mask	standard	tolerable?	better


Installation of BP#2 & SVD1.2
Resonant HOM heating
Installation of BP#3 & SVD 1.4
Trouble of He cooling system
Luminosity of KEKB
Oct. 1999 - Oct. 2002
Peak Luminosity in a Day (1/nb/s)
dTout=+3K
dTout=0K
Daily Integrated Luminosity (1/pb/day)
434 /pb/day
2.58 /fb/7 days
8.78 /fb/30 days
Peak Currents in a Day (mA)
LER
HER
Integrated Luminosity (1/fb)
101.7 /fb
00h00m00s 03/17/2000
10/03
04/21/2001
11/07
05/26/2002
Update: 11/01/2002 10:04:12
C-Yoke: (1) 800 m (2) 800 m
Solenoid: 800 m 1250 m 1350 m 2150 m 2200 m 2250 m + PM 25 m

Temperature rises at 1.5A

- Temperatures are plotted at LER+HER=1500mA



Direct comparison of the temperature rises (ΔT) of the Be chamber against the beam currant

- If we conservatively allow the maximum ΔT experienced in SVD1.4, the maximum current in SVD1.6 will be 2.2 A.
- If we allow ΔT=5, current limit will be 2.7 A. (need confirmation by further study)