Liquid Lead Target R/D

T. Omori (KEK)

29-Mar-2010

GDE Meeting Beijing

for Collaborators:

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Target Issues
of
ILC e+ Source

Target Issues

Two Issues

- Heat Load (by beam): Time Scale ~ 1 m sec.
- Thermal shock wave: Time scale ~ sub micro sec.

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  - It creates 2600 bunches of e+s in 1 m sec.
  - Heat load is a serious problem.
  - It requires a challenging rotation target (100 m/s).

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    (spreads 2600 bunches in 100 mm length)
- 300 Hz Scheme w/ liq. lead target (alternative)
  - It creates 2600 bunches of e+s in 63 m sec.
  - Heat load is not a problem.
  - It requires a window between liq. lead and acc.
  - Does the window (material BN) survive under shock wave?

300 Hz scheme

e+ generation in 63 m sec (cf. undulator : in 1 m sec)

How?

- Total Number of bunches: 2640
- Divide into 20 triplets
  (1 Triplet = 3 Mini-Trains)
- Each triplet contains 132 bunches
- 2640 = 20 x 132
- 300 Hz creation of triplets
  triplet to triplet = 3.3 m sec
- Create 20 triplets : 63 m sec

Conventional e+ Source for ILC

Normal Conducting Drive and Booster Linacs in 300 Hz operation

e+ creation

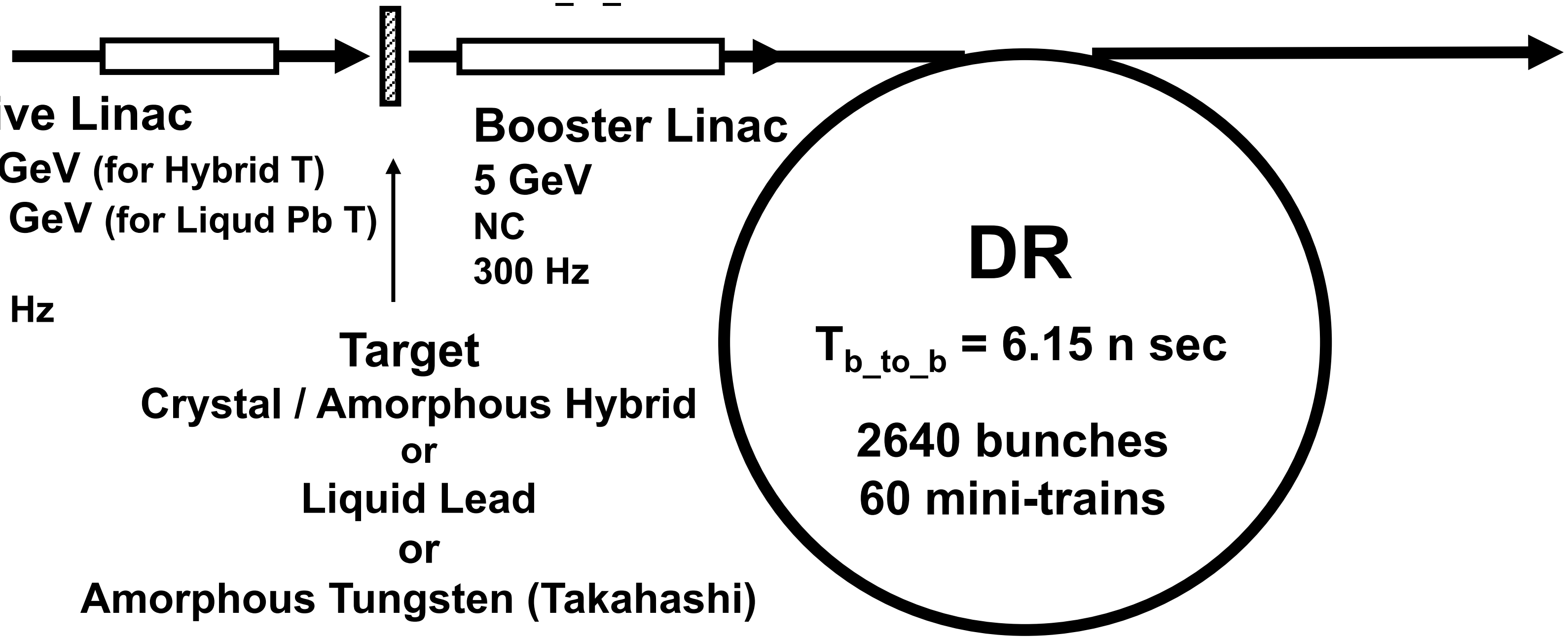
20 triplets, rep. = 300 Hz

- **triplet = 3 mini-trains with gaps**
- **44 bunches/mini-train, $T_{b\_to\_b}$ = 6.15 n sec**

go to main linac

2640 bunches/train, rep. = 5 Hz

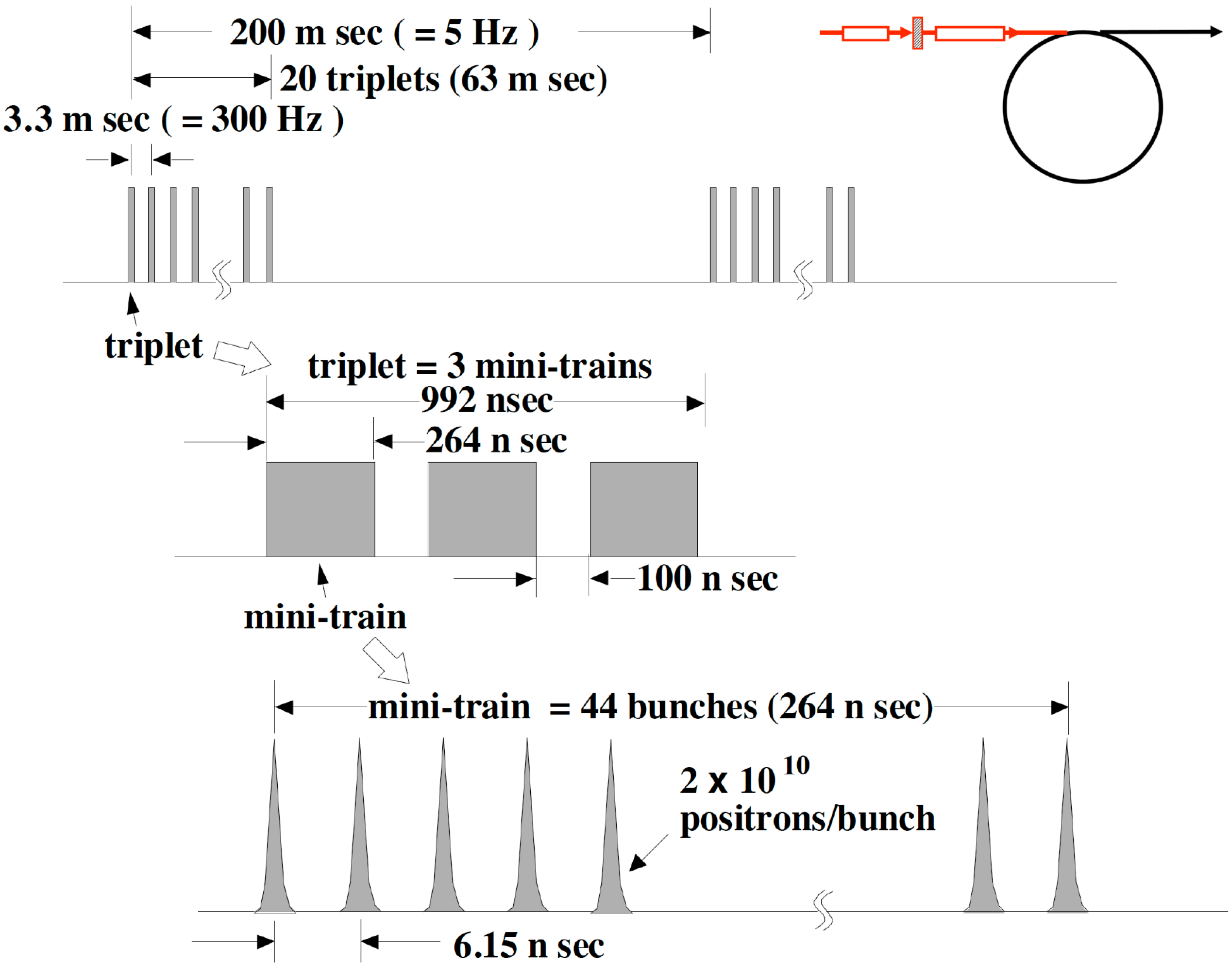
- **$T_{b\_to\_b}$ = 369 n sec**



Time remaining for damping = 137 m sec

We create 2640 bunches
in 63 m sec

Beam before DR



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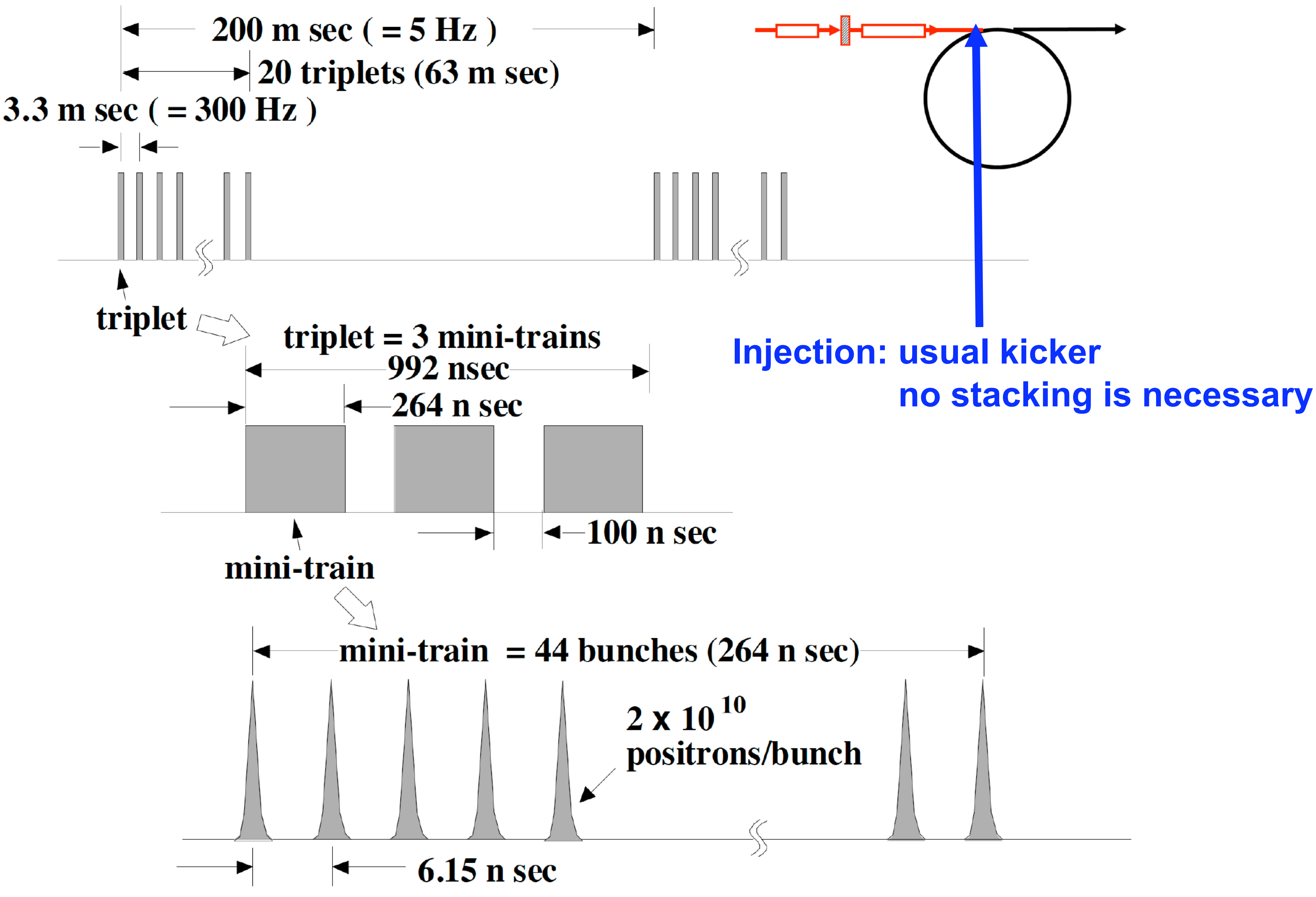

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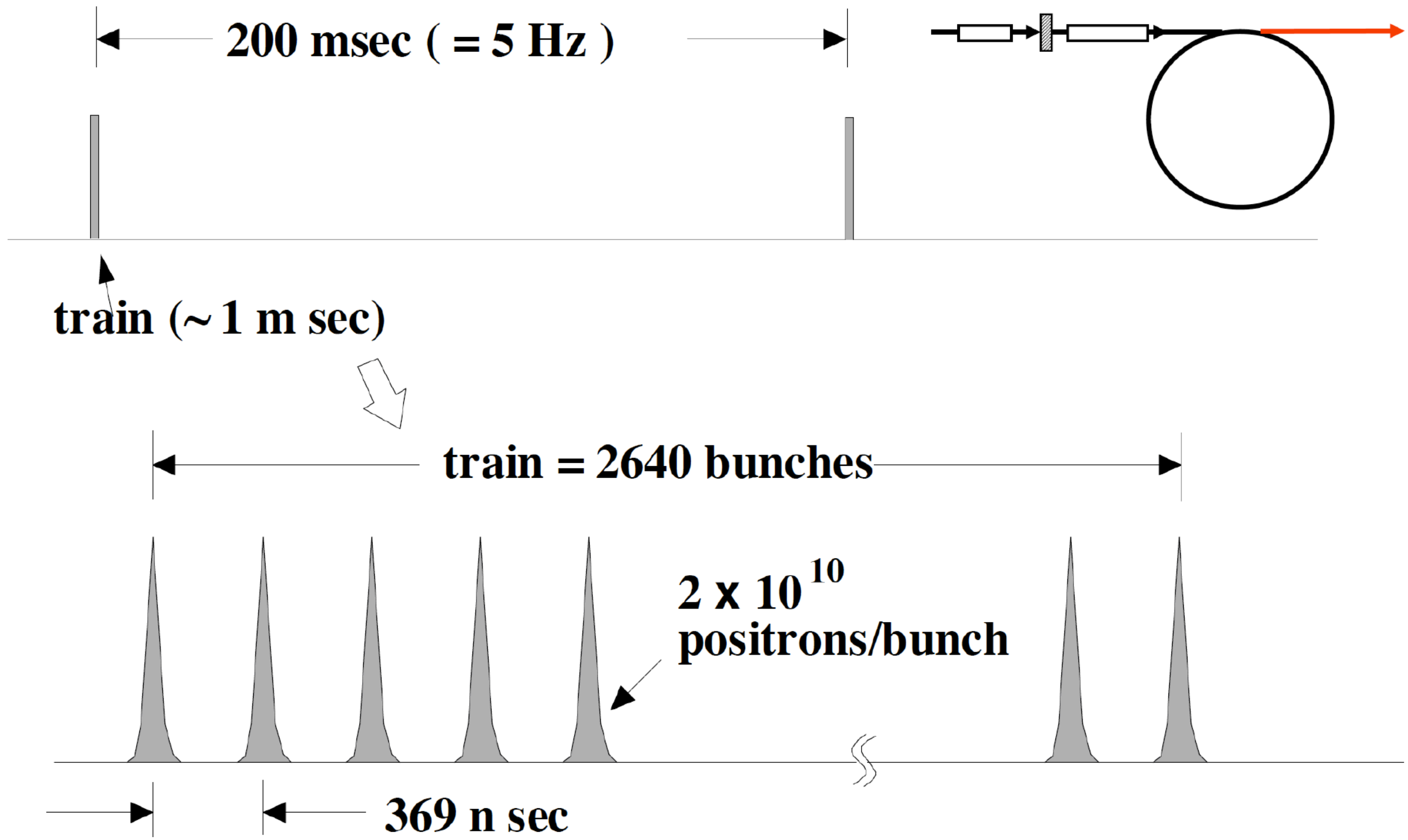

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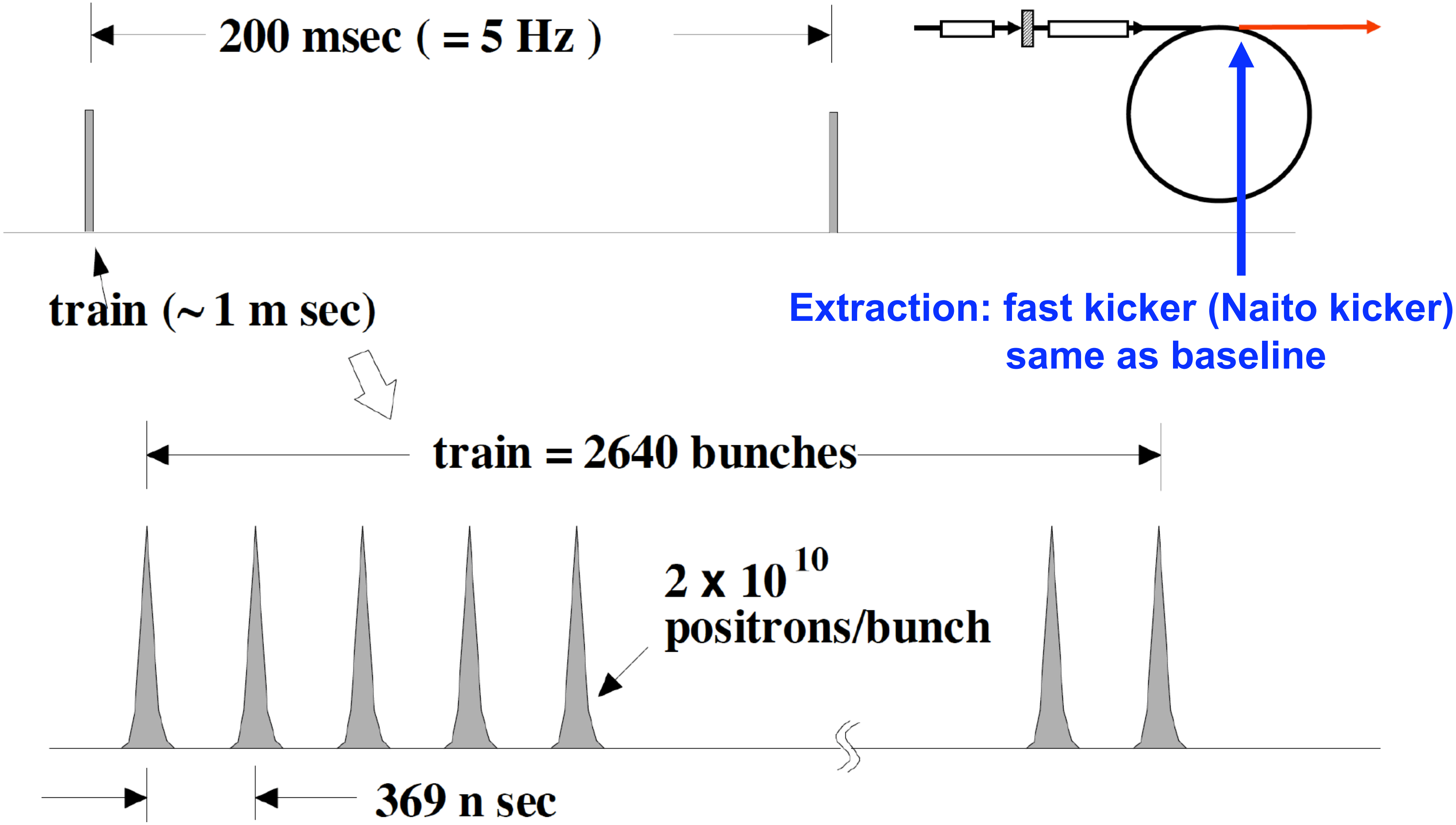

Conventional e+ Source for ILC

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e+ creation

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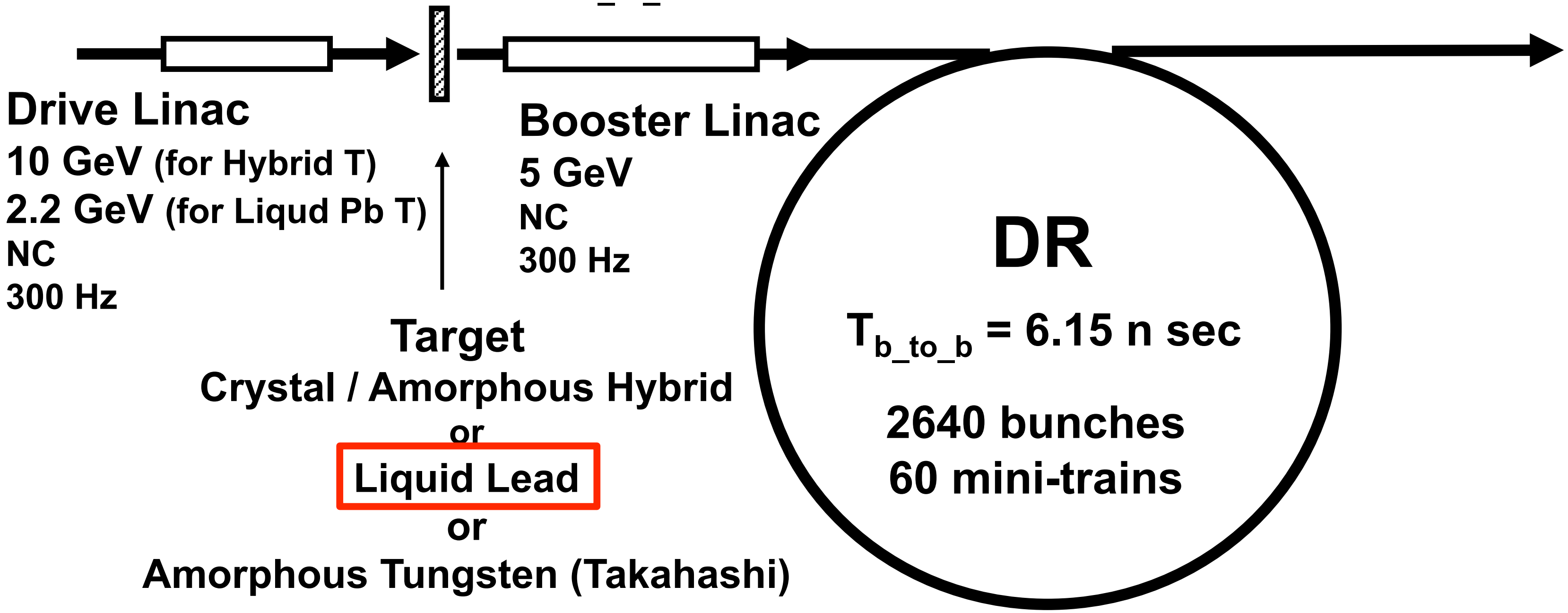

Time remaining for damping = 137 m sec

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R/D of Liq. Pb Target

Liquid Lead Target R/D

Three Activities

- Heat Load (reported at TILC09):
  - By beam
    - Simulation (ANL) : done --> no problem (no report today)
  - By eddy current
    - Simulation (CI) : done --> no problem (no report today)

- Thermal shockwave on BN window:
  - Test at KEKB High Energy Ring (today's report)
  - Simulation is in preparation (no report today)

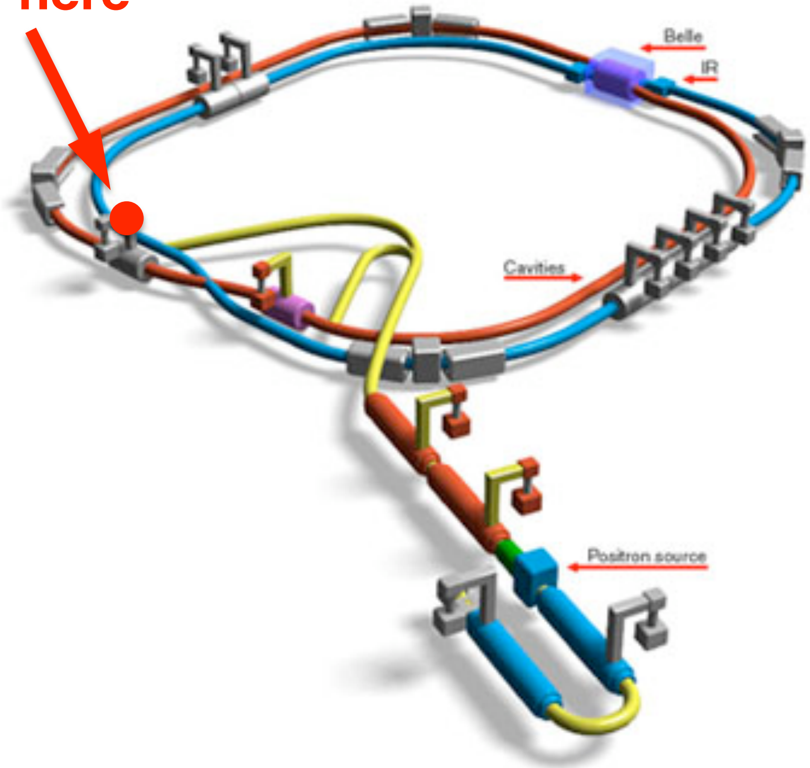
- Operation experience with beam:
  - Install Liq. Lead Target in ATF Linac (today's report)

Shockwave on BN window

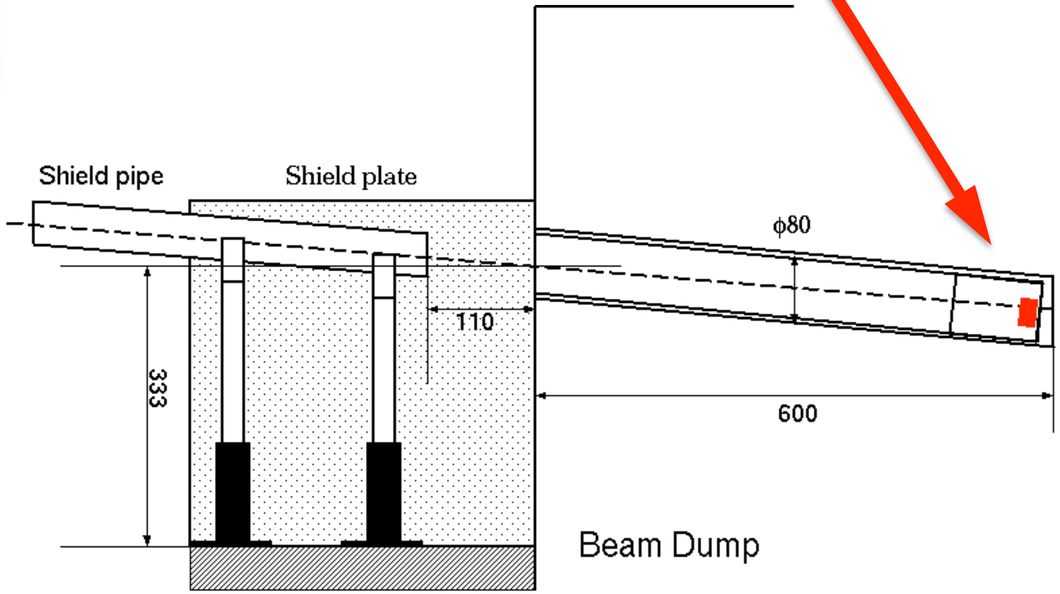
Test at KEKB ring

Liq. Pb Window Test at KEB

here



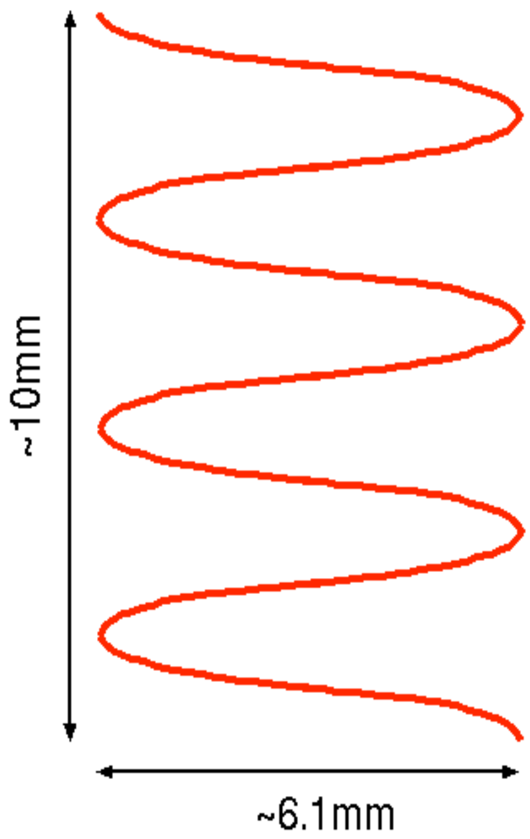
put a target sample in hole for beam dump (depth 600 mm)



- KEKB-HER: 8GeV, 10nC (Max), 1600 bunches (1600mA)
- The beam is deflected by the abort kicker as shown when it is dumped.

Beam Condition

- 10nC, ~1600 bunches, 10μs
- Bunch-by-bunch impossible
- Unable to change beam size (~1mm rms?)
- Swept by kicker (protect extraction window)
- Moves 7μ ~ 45μ/bunch on target (0.9mm ~ 6mm over 132 bunches)



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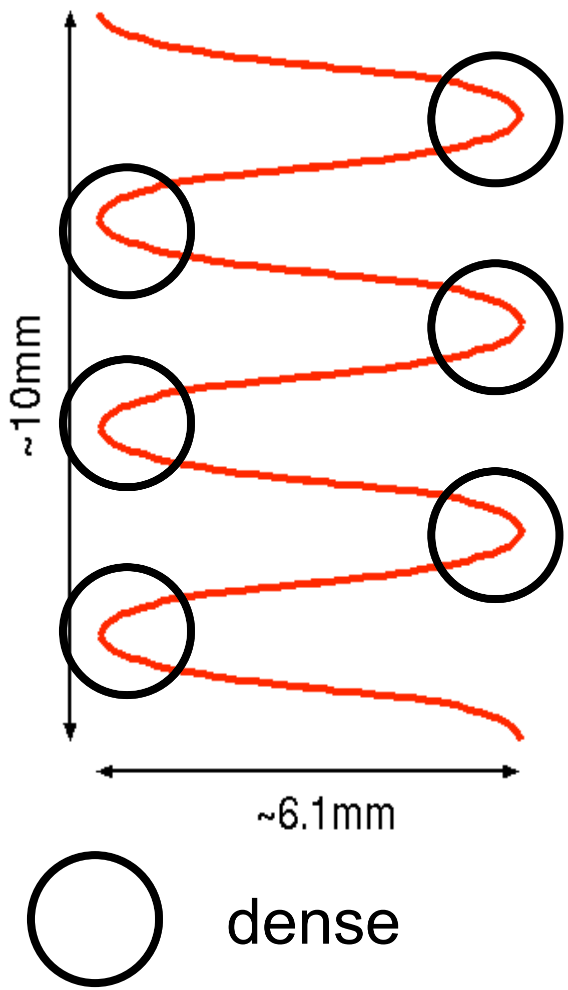


The first test was done on 22nd Oct 2009

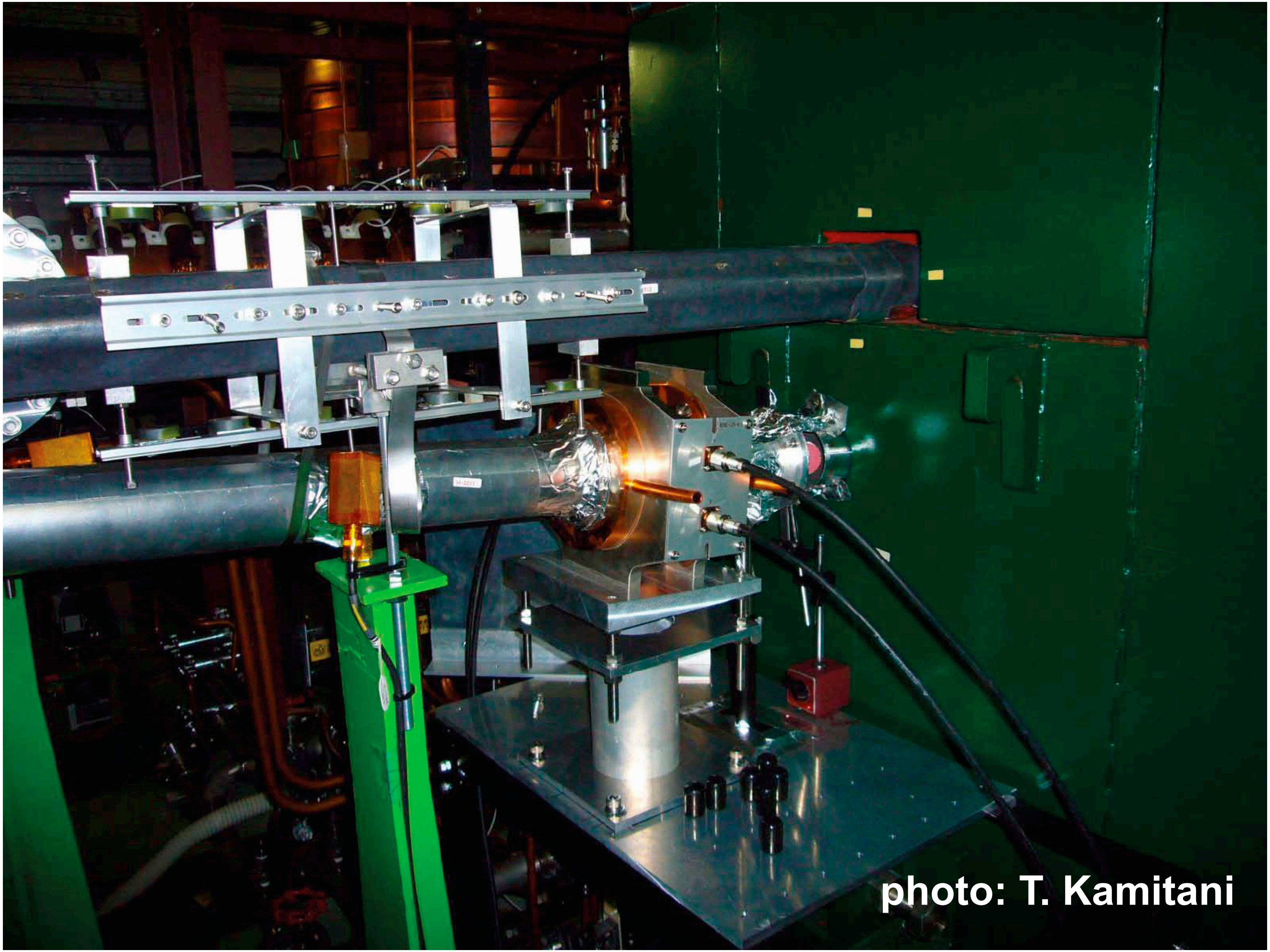
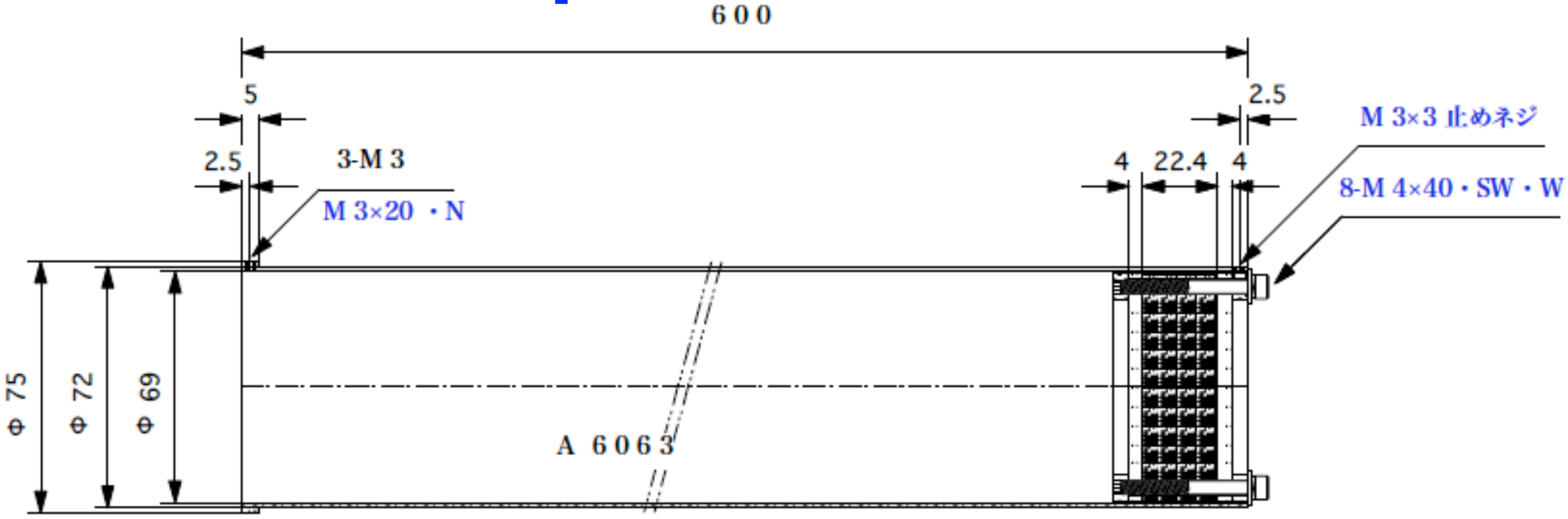


photo: T. Kamitani

Sample and Holder



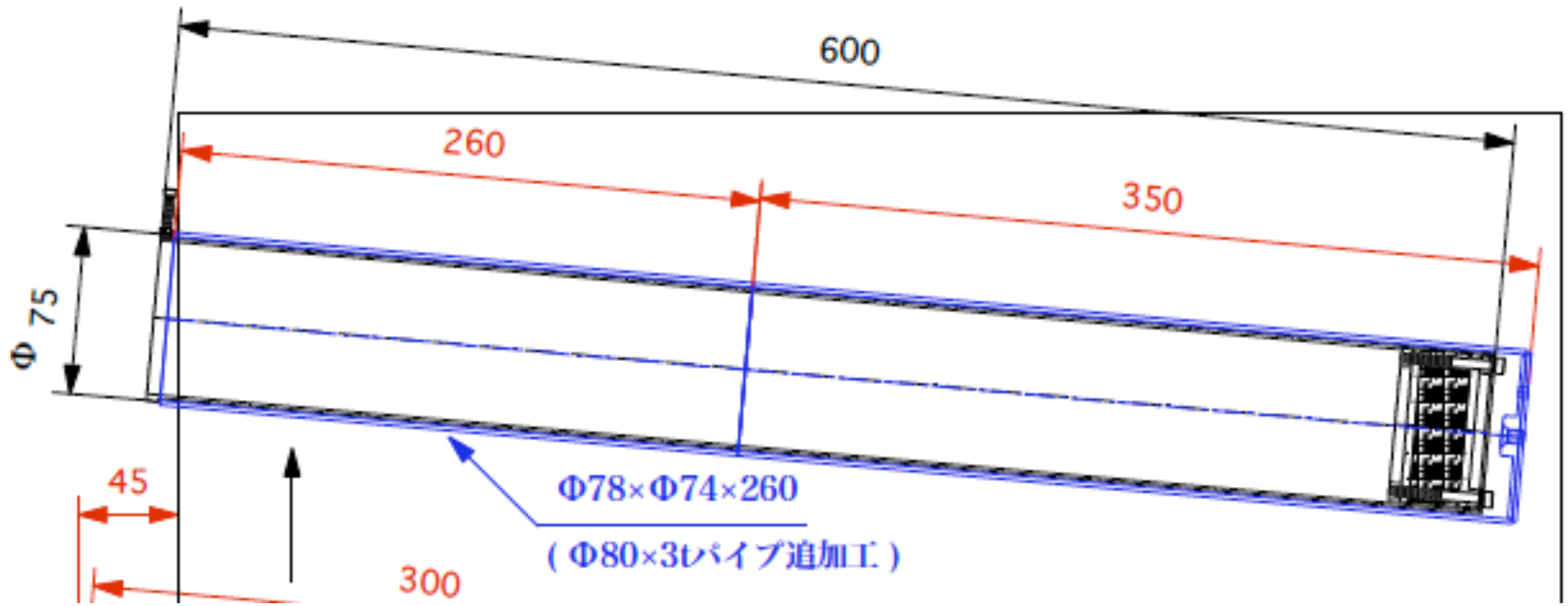



photo: M. Kuriki


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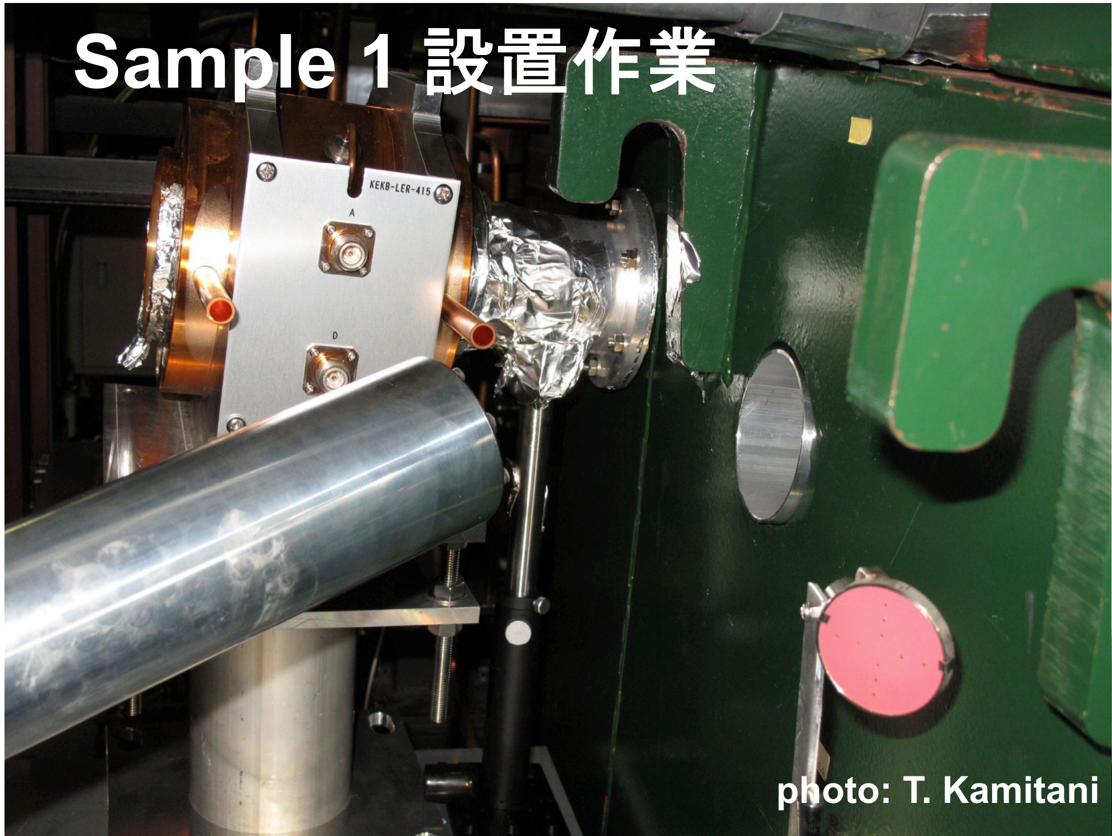
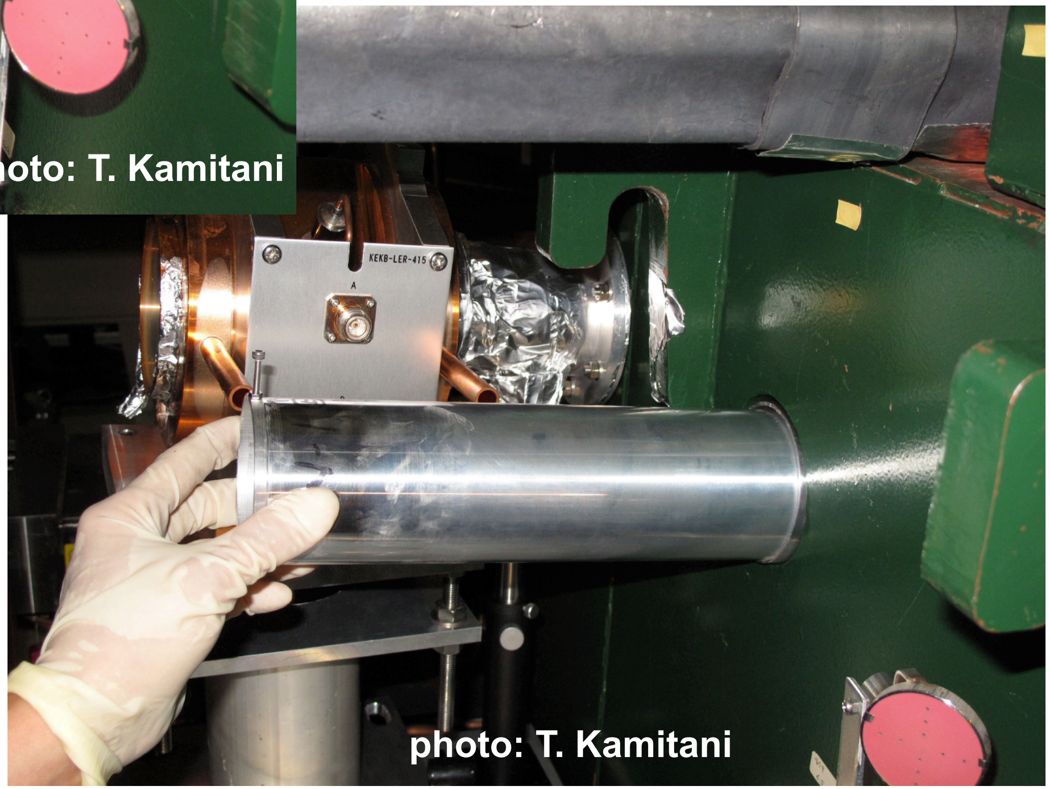
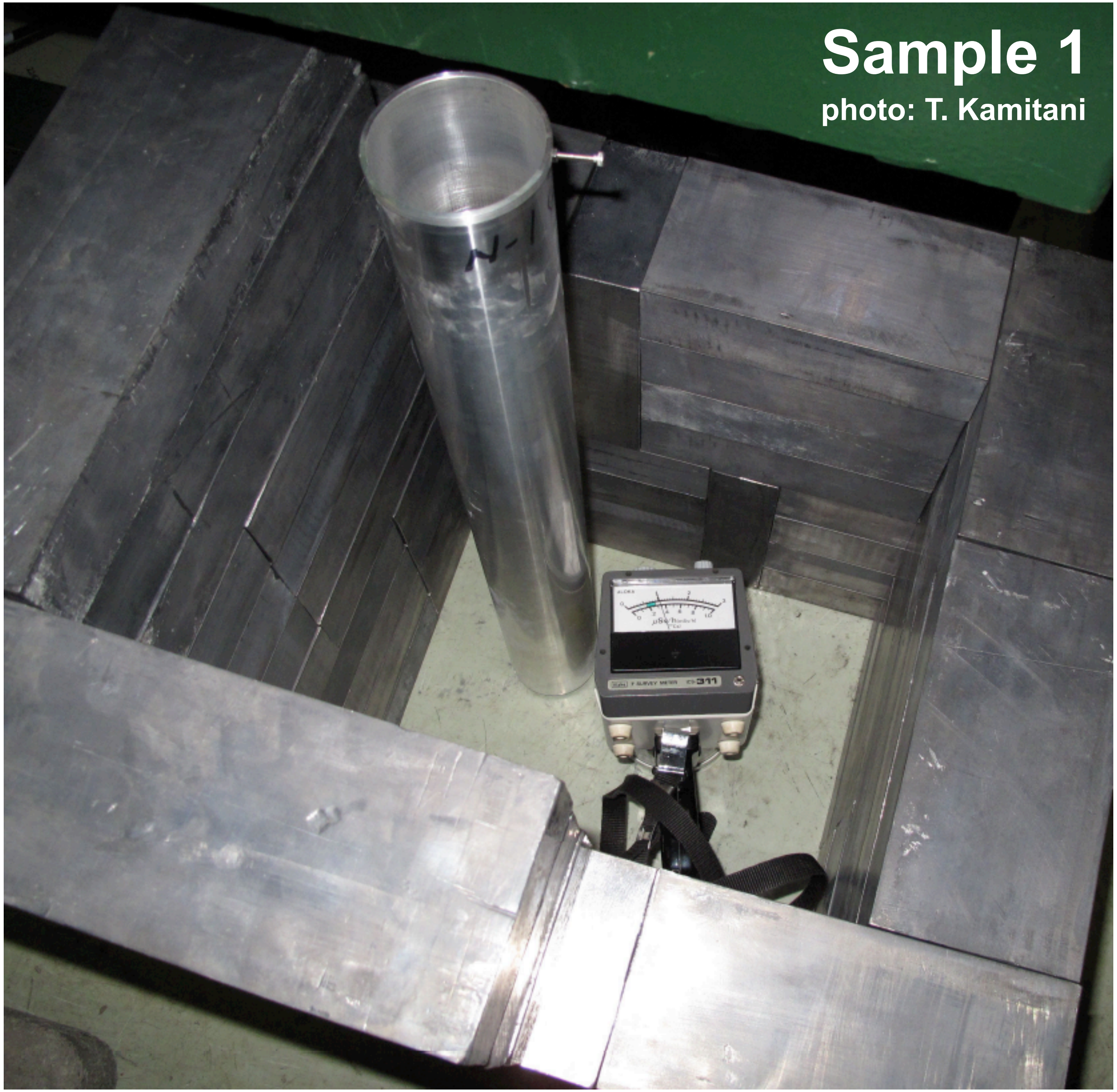
photo: T. Kamitani

Sample 1 設置作業

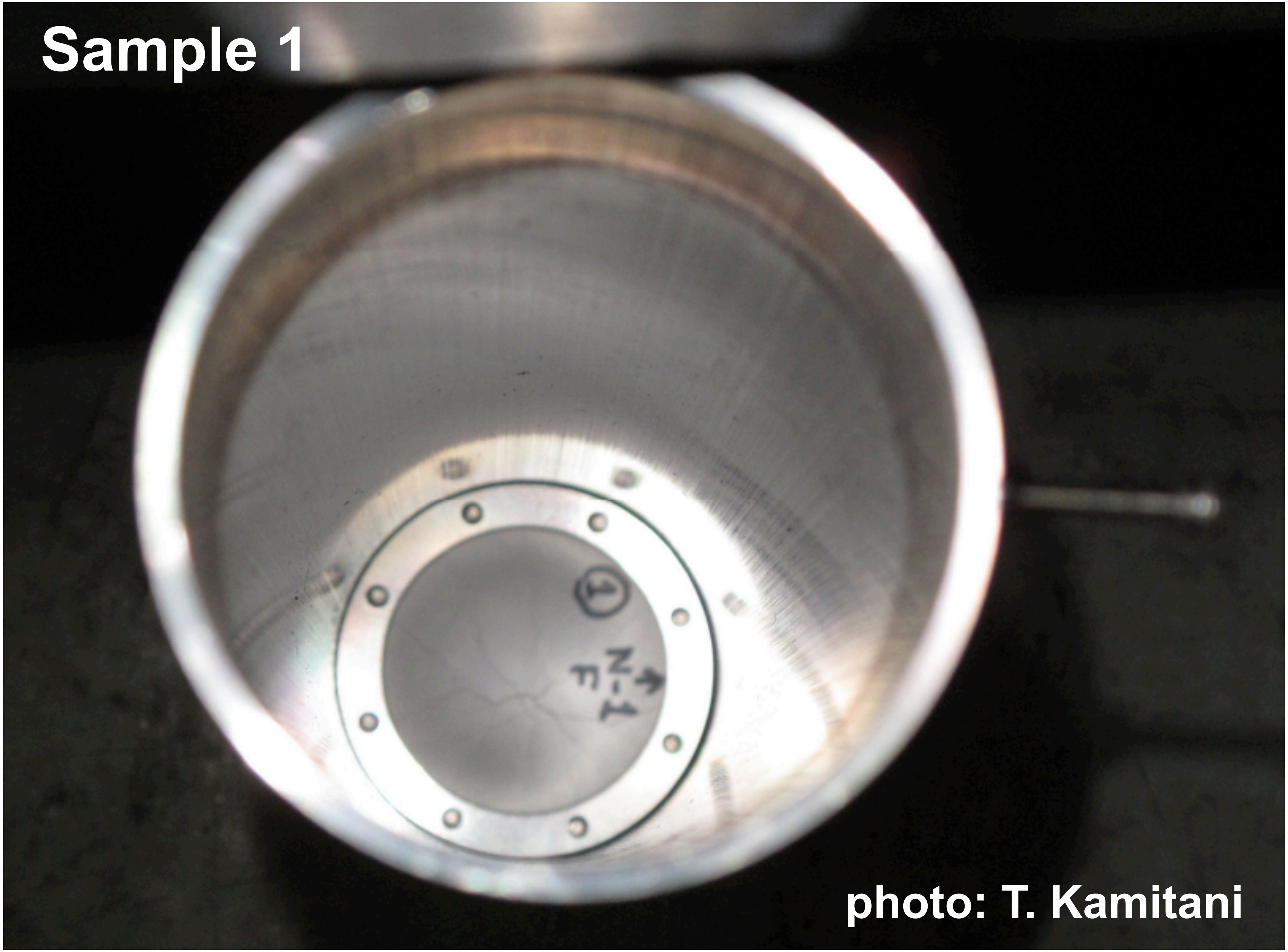






Sample 1
photo: T. Kamitani


Sample 2
photo: T. Kamitani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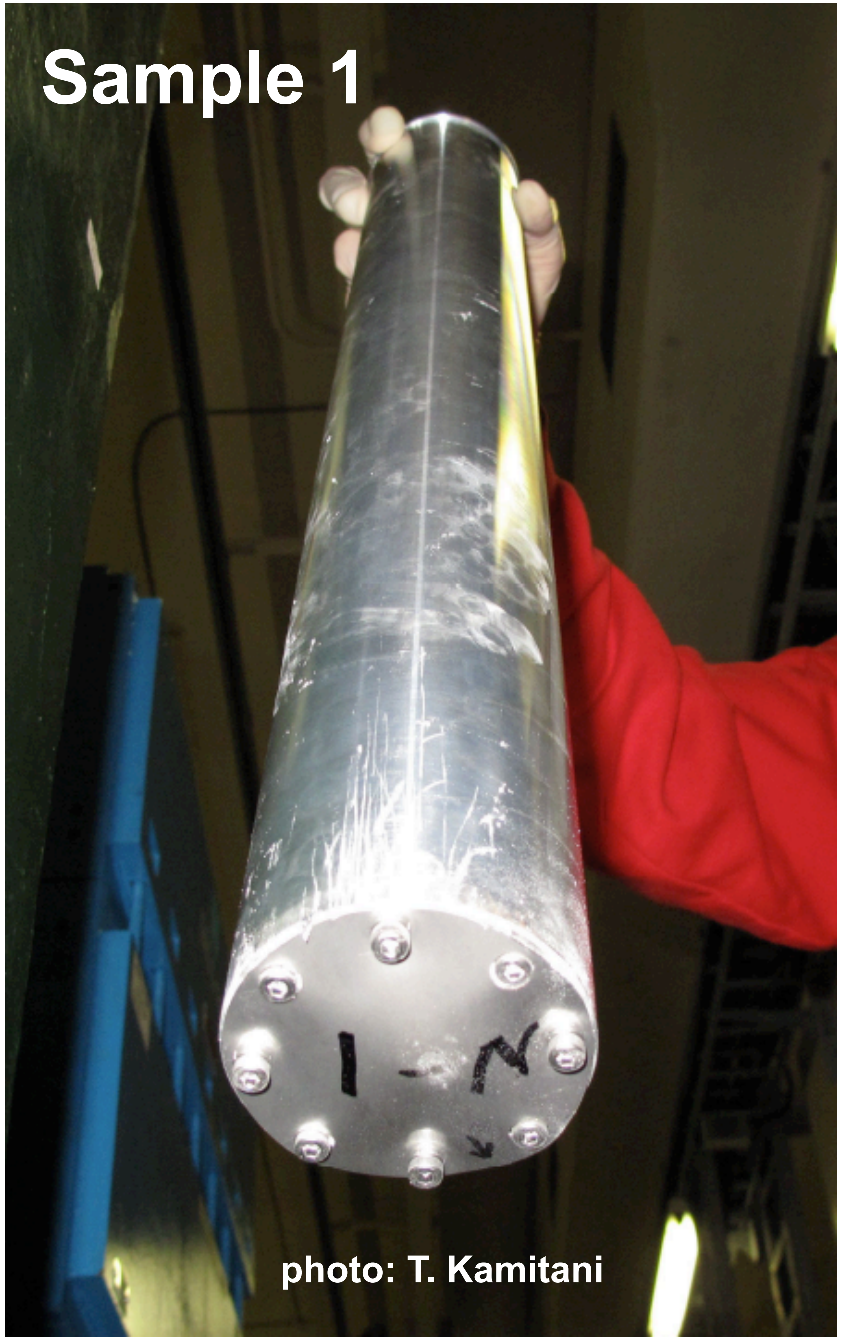
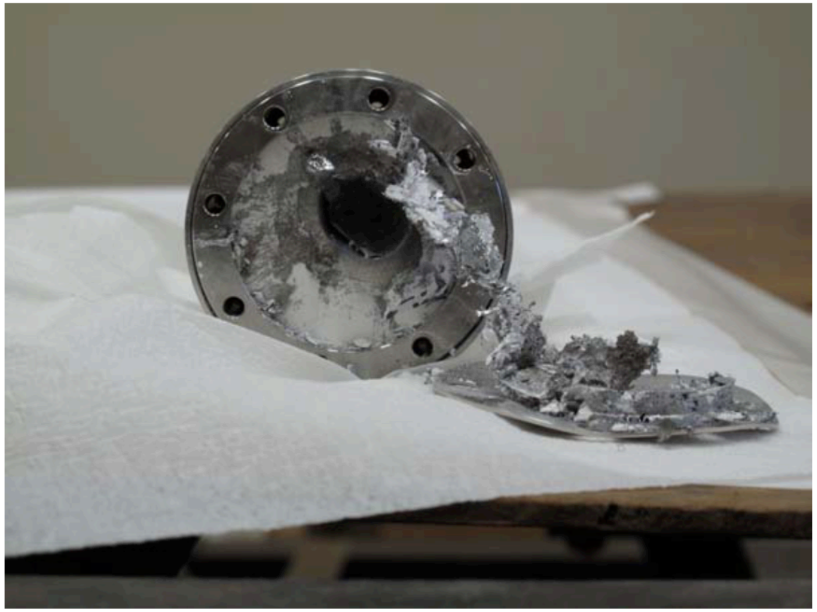
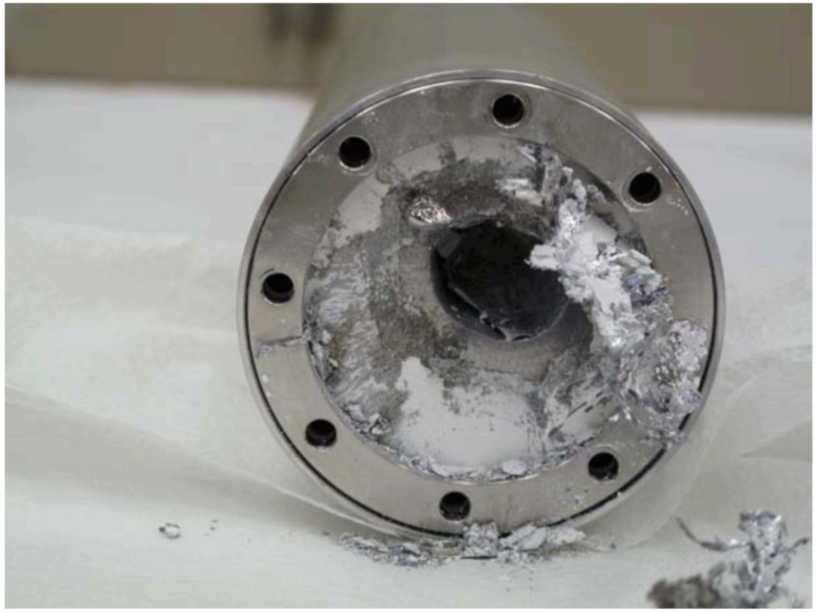
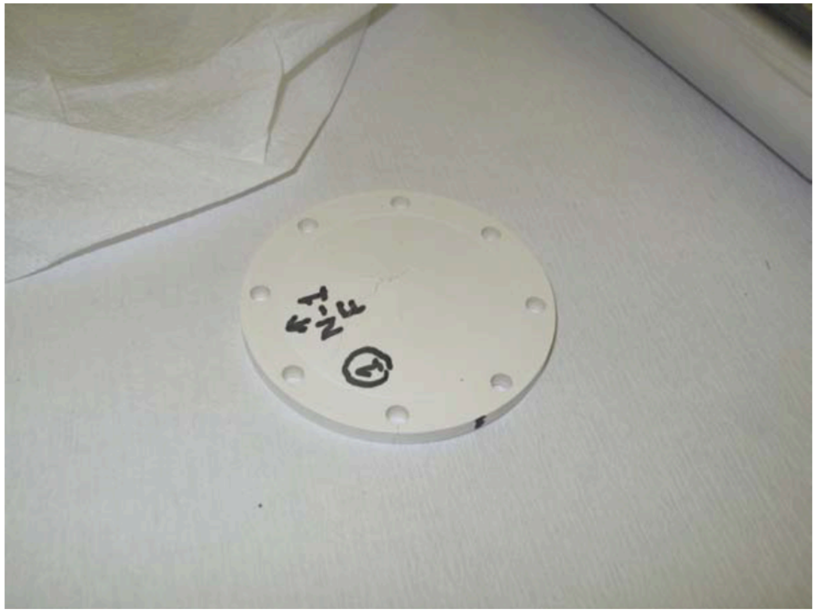
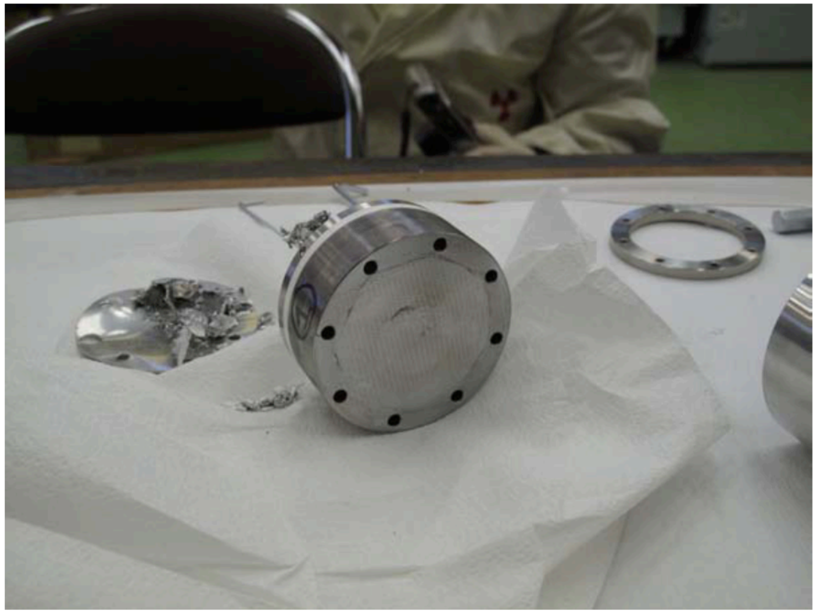

Sample 1
1-N
photo: T. Kamitani

Sample 1 (460mA + 800mA)









Sample 2 (800mA)




Total Energy of the Beam

8 GeV, 5 nC/bunch (= 800 mA), 1600 bunches --> 64 kJ

Energy deposit of the target (~12 % of Energy of the beam)

~ 7.7 kJ

↓

Target Destruction

In the experiment on Oct/22nd, we did not test the BN strength against shock wave.

We are planning the new experiment

Plan of New Experiment

1. We will use material (metal) which melting point is higher than that of lead.
2. We consider several metals.
   Ti, Fe, Cu, W
3. Which is suitable metal in view point of safety ?
4. Which is the suitable metal, in the view point of the emulation of the liquid lead target ?

Peak Energy Deposit Density of 300 Hz w/Liq Pb

Parameters : 300 Hz Scheme w/Lig Pb Target

- Eb = 3.5 GeV, 5.9 nC/bunch
- 132 bunches hit target in 0.8 micro sec at almost the same point of the target.
- Liq Pb Flow Speed = 4 m/s
  Liq Pb runs 13 mm before the next pulse
  (132 bunches) hit target.
  We ignore hit of the next pulse.
- Beam Size : Sigma = 2 mm
- Target Thickness = 4 X0

PEDD = 96 J/g (GEANT4 simulation)

KEKB experimental condition

- Eb = 8GeV
- Beam Size: Sigma =1.17mm
- Use all 1581 bunches with sin-wave sweeping
- Bunch Charge : adjustable (Max 10 nC)
- Target Thickness = 4 X0

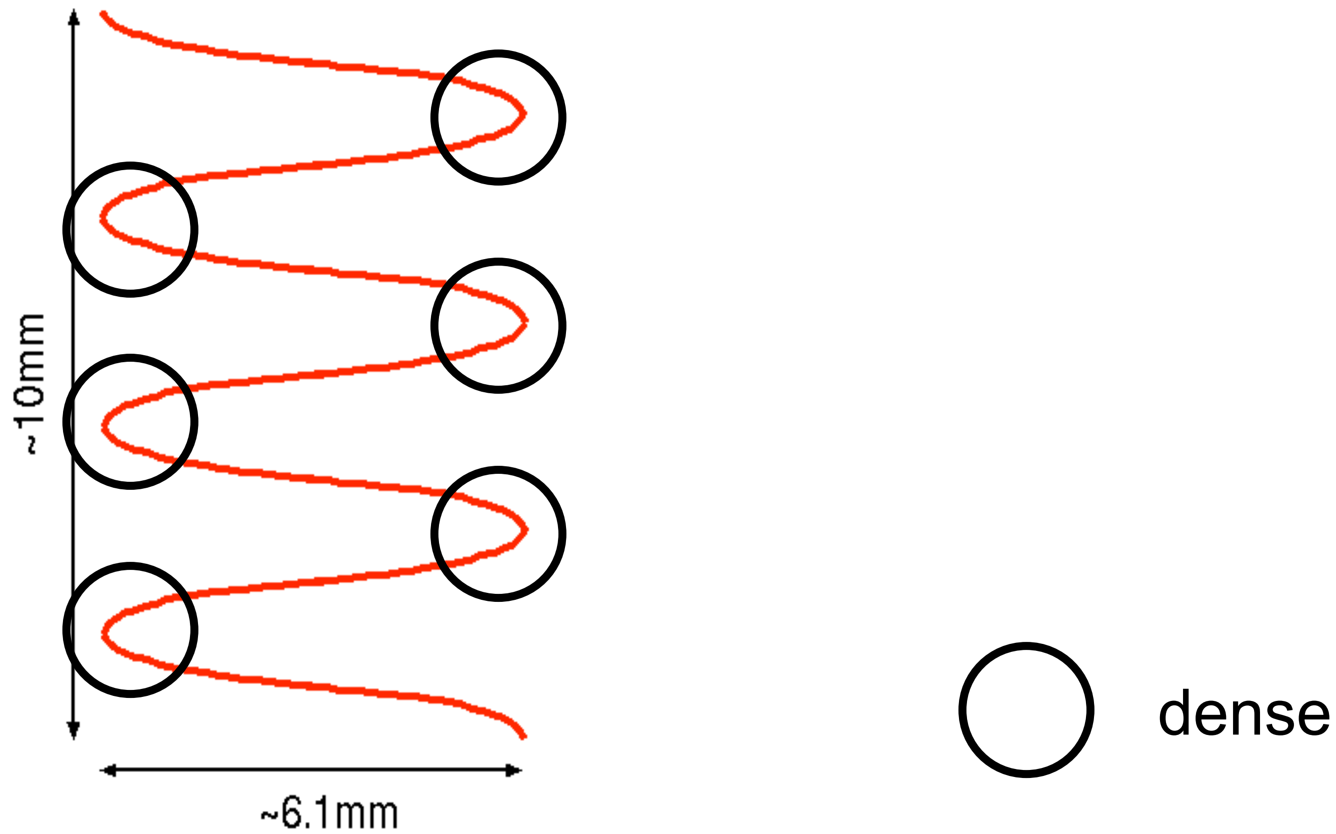
(1) Calculate "Bunch Charge" which gives 96 J/g

(2) Calculate "Temperature Rise" with "Bunch Charge" given in (1).

Two "96 J/g" condition

(a) Σ (all bunches in 1 ms) = 96 J/g

(b) Σ (132 bunches near peak of sin-wave in 0.8 μs) = 96 J/g



Results of shower simulation

Results of shower simulation on various metals

	Ti	Fe	Cu	W	Pb
Melting Point (K)	1941	1808	1358	3695	601
Radiation Length (mm)	35.6	17.5	14.3	3.5	5.6
(a1) Charge/b (nC) for 96 J/g (10 ms)	0.33	0.72	0.89	0.60	0.63
(a2) Temp at Max. Point (K)	458	472	534	1020	826
(b1) Charge/b (nC) for 96 J/g (132 b)	3.41	3.22	2.82	1.24	1.7
(b2) Temp at Max. Point (K)	1920	1070	1040	1790	1850

Evaluation of the results

- Tungsten (W) has very large margin.
- Iron(Fe) and (copper (Cu) has reasonable margin.
- Titanium (Ti) has no margin.

Experiment using metals other than Pb
Is the experiment useful?

EM shower :

deposit energy in very short time
We ignore movement of each part of material.
Temperature and pressure rise, but density stay constant.

After EM shower, each part of material starts moving (sound in material).

Temperature Rise : ΔT

$$\Delta T = \frac{\Delta E}{c_v}$$

ΔE : Energy Deposit
Cv : Specific Heat Capacity (at Constant Volume)

Pressure Rise (Linear Approximation)

$$\Delta P = \left(\frac{\partial P}{\partial T}\right)_v \Delta T$$

$$= -\left(\frac{\partial P}{\partial V}\right)_T \left(\frac{\partial V}{\partial T}\right)_P \frac{\Delta E}{c_v}$$

$$= \frac{K}{V}\beta V \frac{\Delta E}{c_v}$$

$$= \frac{K\beta}{c_v}\Delta E$$

ΔE : Energy Deposit
Cv : Specific Heat Cap.
β : Vol. Thermal Exp. Coeffi.
K : Bulk Modulus

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If the energy deposit is same,

Pressure rise (force on BN window)
$\propto$ (K x β) /Cv

Comparison of Metals

		Ti	Fe	Cu	W	Pb	Liq. Pb
Atomic Number		22	26	29	74	82	
Density(g/cm^3)		4.51	7.87	8.92	19.3	11.3	10.7
V. T. Exp. Coef. (10^{-6} K^{-1})	β	26	35.4	50	13.5	86.7	112
Bulk Modulus (GPa)	K	108	111	138	310	45.8	33.3
Specific Heat (J g^{-1} K^{-1})	C_V	0.52	0.44	0.38	0.132	0.129	0.146
β x K		2808	3929	6900	4185	3971	3730
(β x K) / C_V		5400	8930	18160	31700	30800	25500
β / C_V		50	80	130	100	670	770

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＜Evaluation＞

- Pressure on the window ~ $(\beta \times K) / C_V$
- Pressure of W and Cu ~ Pressure of Liq. Pb
  W／LiqPb ~ 1.3、 Cu／LiqPb ～0.7。
- Ti and Fe give too small pressure.

Pressure at ΔE = 96 J/g

	Cu	W	Liq. Pb
ΔP(GPa)	1.5	3.1	2.3

Summary Table

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Plan of New Experiment

1. **We will use material (metal) which melting point is higher than that of lead.**
2. **We consider several metals.**
3. **According to the simulation, tungsten (W), copper (Cu), and iron (Fe) are good in a view point of safety.**
4. **In the view point of the emulation of the liquid lead target, a simple analytic model tell as W and Cu are good.**
5. **We are planning to perform an experiment by using W and/or Cu as a target emulator in late May and/or June.**

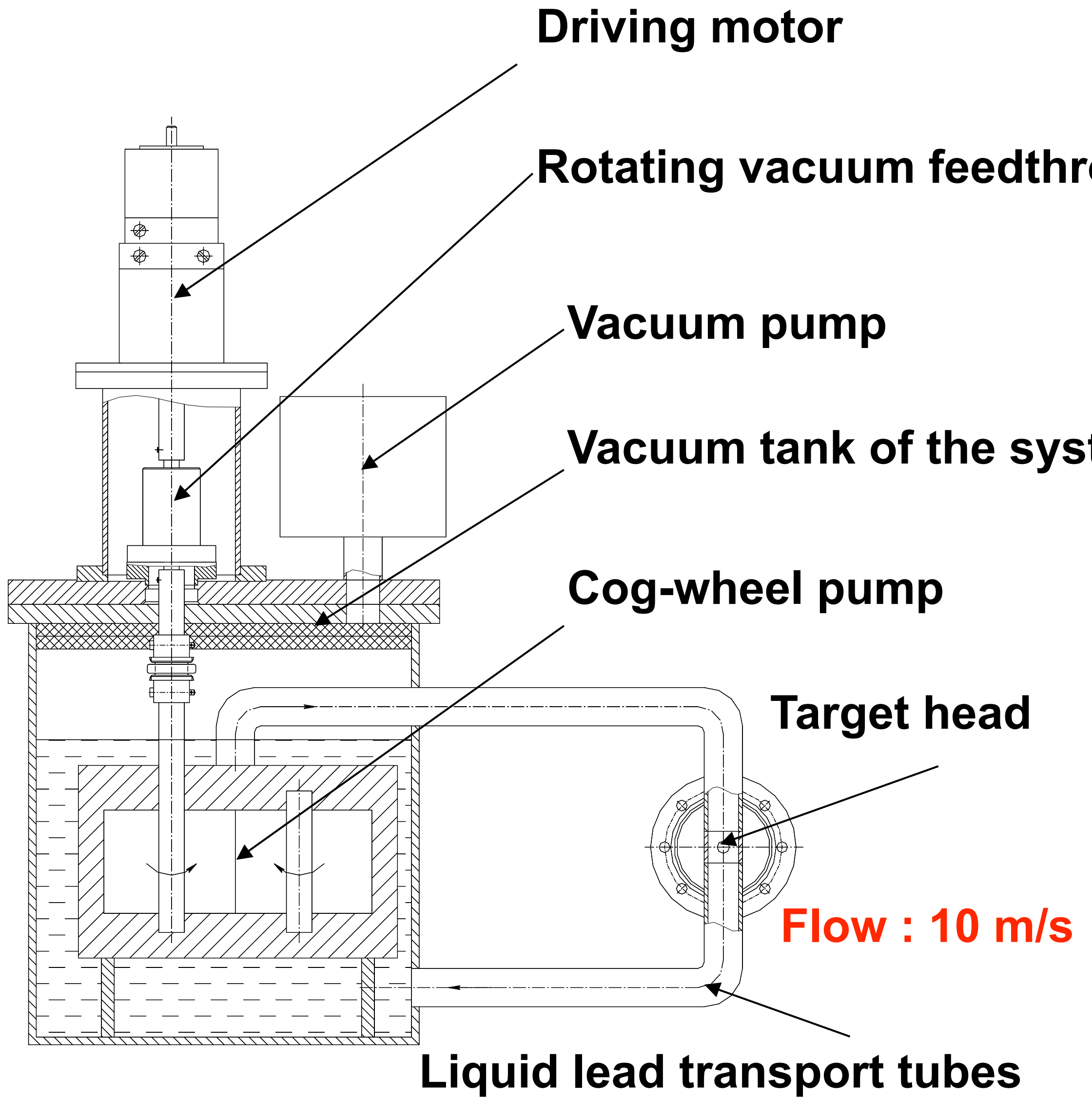
Liq. Pb target R/D

Test at ATF Linac

Prototype of Liquid Lead Positron Production Target

Logachev-san et al, BINP

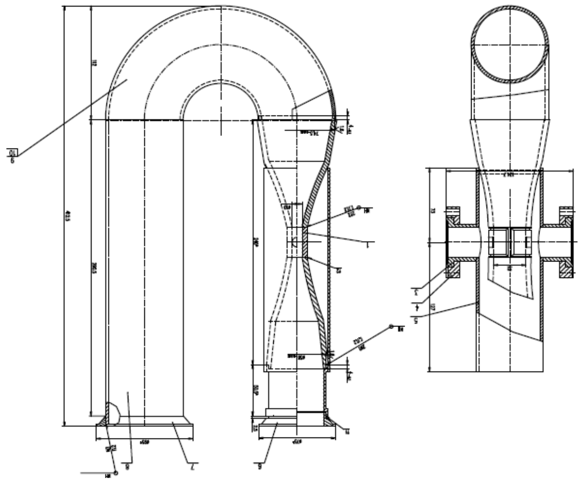
Operation experience 20000 h



Window thickness 4mm
BN disks for windows
Diameter 12mm

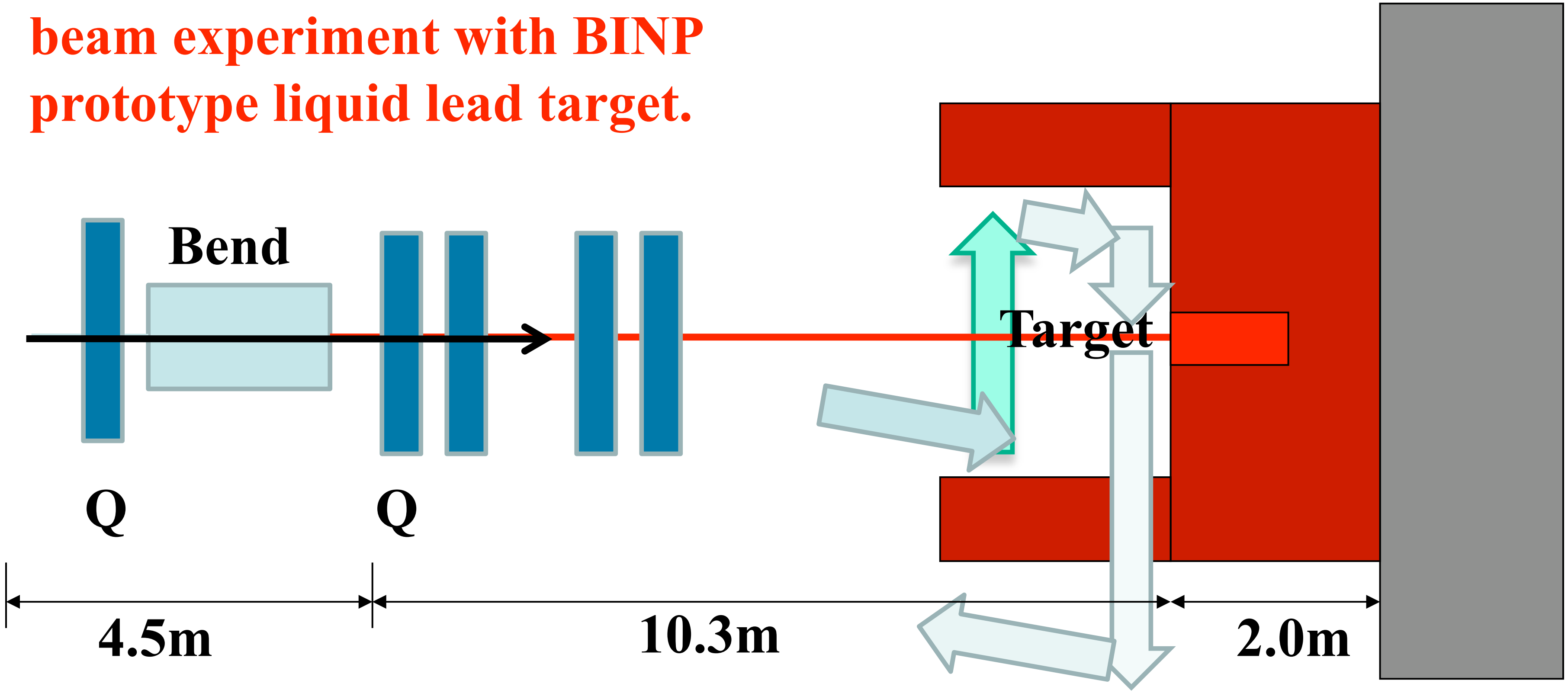
Liquid lead target test

at ATF Linac End



Liquid lead 300℃

We kek decided to do the beam experiment with BINP prototype liquid lead target.



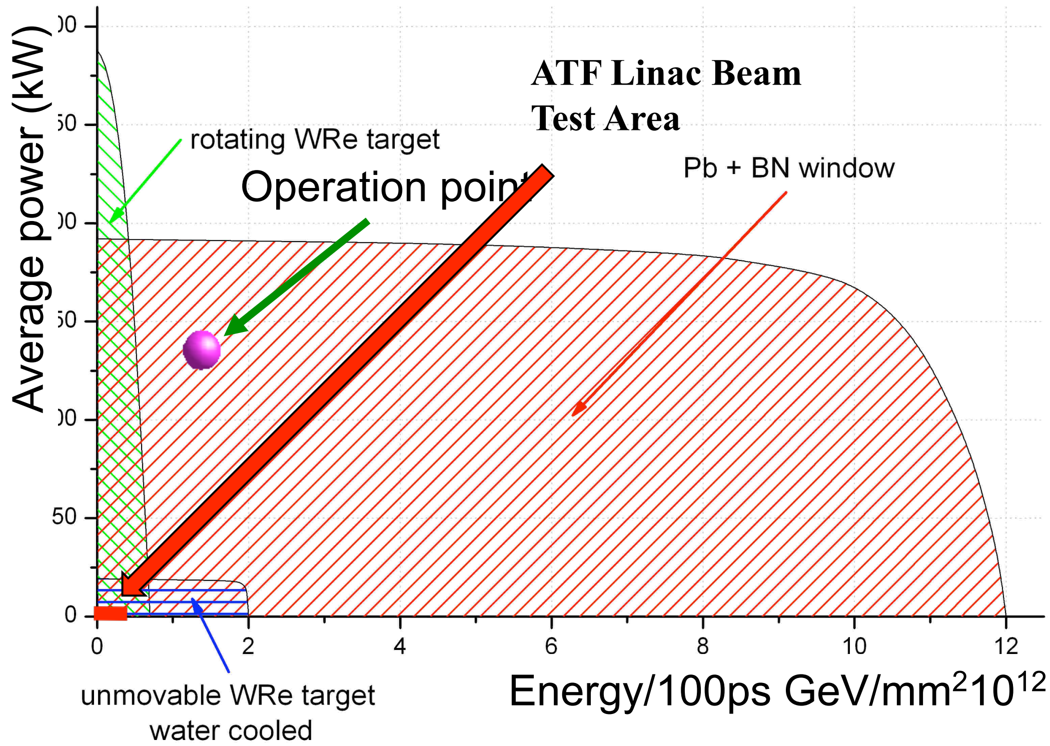
ATF Linac Beam Parameters

β function tuning range : 0.1m to 10m
Bunch structure : 1 to 20 bunches/train
Bunch charge : 0.5 to 2.0 x 10^{10} electrons/bunch
Beam energy : 1.3GeV
Repetition rate : 0.7 to 6.25Hz
Usual normalized emittance : less than 10πmmmrad
Beam size : 0.2 to 2.0mm

Energy density on target
0.006 to 48 x 10^{10} GeV/mm^2
Power deposit on target
0.004 to 300 x 10^{10} GeV/mm^2 s
Acceptable beam rep. rate?

Liquid Pb-Sn Target

- Liquid Pb target + BN window is very strong against high peak power, but less average power.
- Pulsed operation (e.g. 100 bunches with 6.2ns spacing, 0.6μs, 150Hz) moderates thermal effects.
- In the pulse operation, capture efficiency is higher and incident electron can be fewer.



P. Logachov et al. in APAC2007

Status and Schedule

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- Two engineers, M. F. Blinov san and V. Golikov san, came ATF, made discussion with KEK people, and checked the area where the prototype will be installed.

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Schedule

- Coming June, M. F. Blinov-san and V. Golikov-san will visit ATF again to assemble the proto type.
- The prototype will be installed at the end of ATF linac coming summer.

Test of Liq. Pb Target at ATF Linac

Systematic experimental studies on Liquid 90%Pb+ 10%Sn target system with BN window will start from autumn 2010 at ATF using beam from ATF linac.
We are still discussing what kind of measurements are necessary for ILC target system and detail schedule.

To learn the operation of this liquid target is important for the evaluation of the reliability and the maintainability and we can propose very reliable target system for ILC e+ source with a lot of simulation and some proofs of experimental results.

Summary

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- Two Issues on Target
  - Heat Load (by beam): Time Scale ~ 1 m sec.
  - Thermal shock wave: Time scale ~ sub micro sec.

- 300 Hz Scheme w/ liq. lead target (alternative)
  - It requires a window between liq. lead and acc.
  - Does the BN window survive under shock wave?

- Thermal shockwave on BN window:
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- Operation experience with beam:
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