Conventional Positron Production
Possible Risk and R&D / IPPAK

KURIKI Masao (KEK)

- Possible risk
- IPPAK experiment
- Summary

Possible Risk on Conventional Scheme

- Drive beam source : No Risk.
  - It could be identical to TTF type RF gun.
- Driver linac: No Risk.
  - It could be identical to ILC main linac.
- Production target : Risk.
  - Because of the huge amount of the beam in a pulse, target break is possible.

- Capture section : Risk.
  - The large radiation flux comes from the target. Need to qualify the radiation hardness of the used material.
  - 1ms operation of L-band warm structure with such high gradient is not confirmed.
- Injector linac : No Risk.
  - The cavity iris is even large to avoid frequent quenching with the beam operation failure.

Target Damage

- This is the largest risk in the conventional scheme.
- Target break threshold is not understood well. -> IPPAK
- There are several ways to reduce the risk.
  - Rotating target.
  - Pulse lengthening.
  - Alternative target system.

Pulse Lengthening
-Naive case-

- An operation mode with a large bunch spacing giving a long pulse, e.g. 2ms pulse with 620ns spacing.
- It relieves the target damage, but several trade offs.
- Capture section :
  - Long pulse operation of the pulsed magnet might be difficult.
  - Long pulse operation of L-band warm cavities might be difficult. Need to reduce the input power which lower the capture efficiency.

Pulse Lengthening
- Pulsed Operation -

- The naive pulse lengthening (e.g. 2ms) might cause other problems, e.g. L-band structure operation.
- Pulsed operation solves this problem because of the short pulse duration.
  - 1 pulse : 280 x 3nC bunches with 620 ns spacing, 143us duration.
  - This pulse is repeated 10 times with 10ms interval: 100Hz operation, it takes 100ms to make a full pulse of the main linac.

Cost of Pulse Lengthening
- Pulsed Operation -

- The pulsed operation solves the difficulty on the pulsed magnet and L-band cavities by increasing the average cooling ability.
- That is true for the RF-Gun.
- Heat-load to SC-linac is increased. It is not a technical difficulty, but we have to increase the cooling power.
- The damping time is enough unless a long DR.

Summary for the Pulse Lengthening

- It is a relief for the possible target damage.
- There are many trade offs in the naive lengthening. It might introduce new risks.
- The pulsed operation solves the difficulties by paying an additional cost for the cooling power.

ILC Positron Project At KEKB
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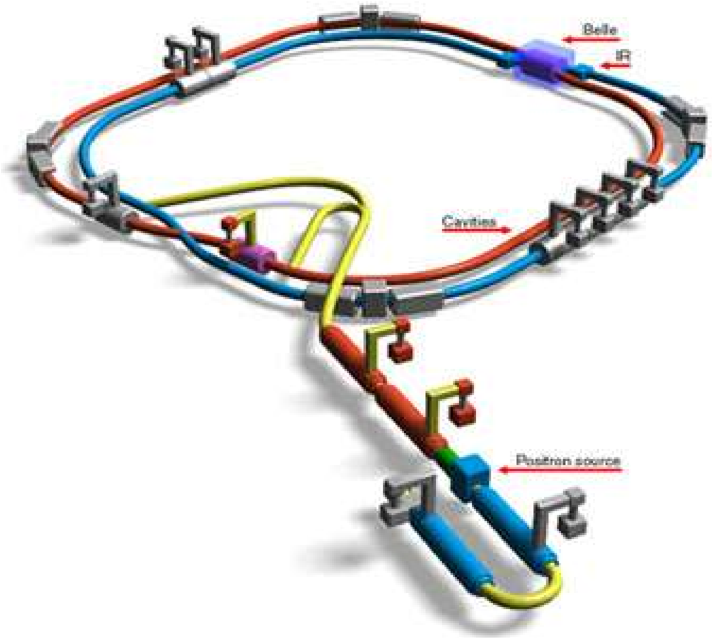
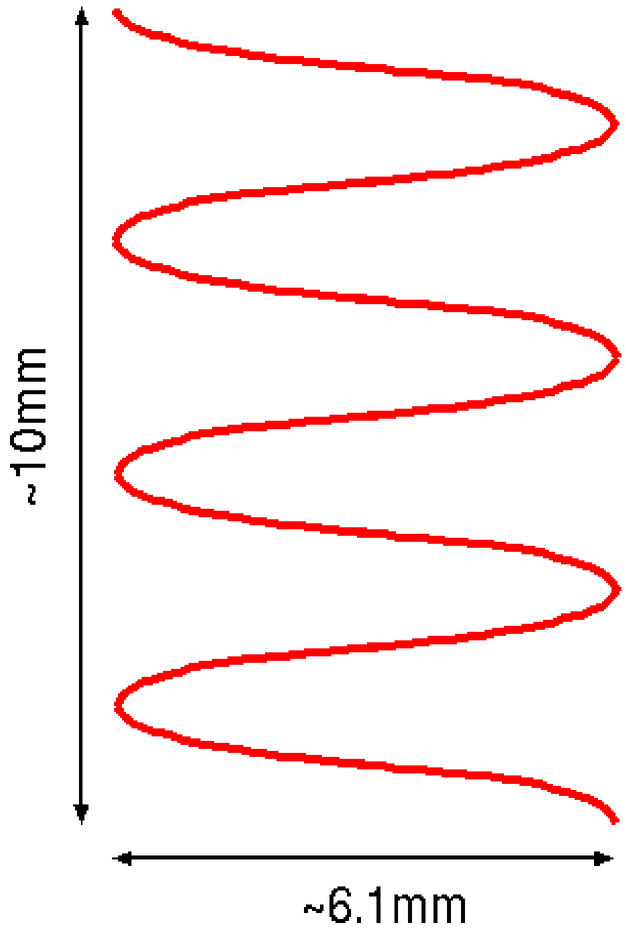


- By injecting the KEKB stored beam into a test target, damages on the ILC e+ production target is reproduced.
  - KEKB mode : just inject KEKB stored beam.
  - ILC mode : modify the abort kicker and bunch fill pattern to reproduce more realistic ILC drive beam.

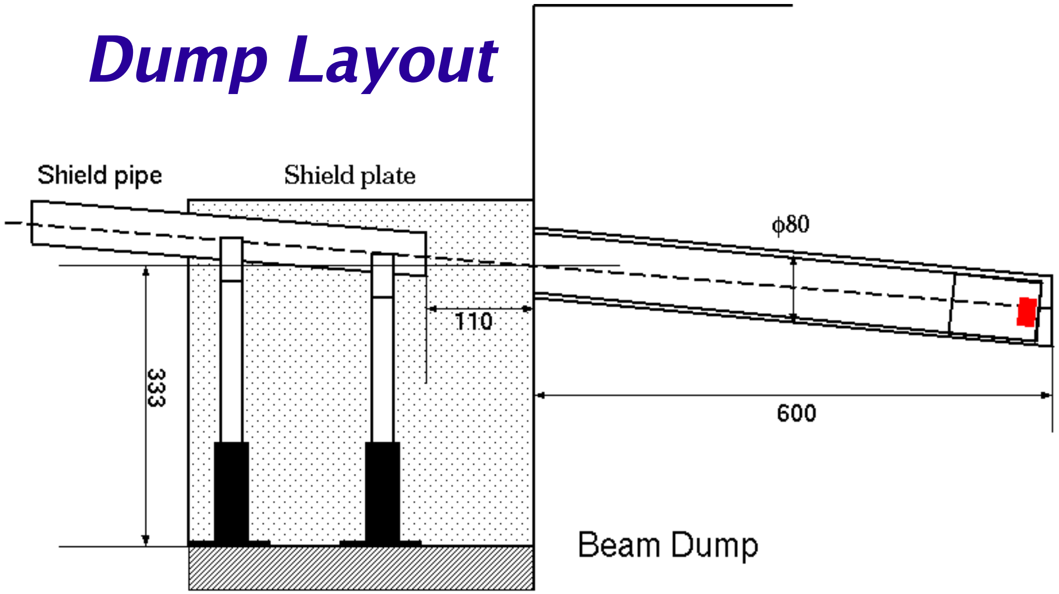
Beam Dump

Dump pattern



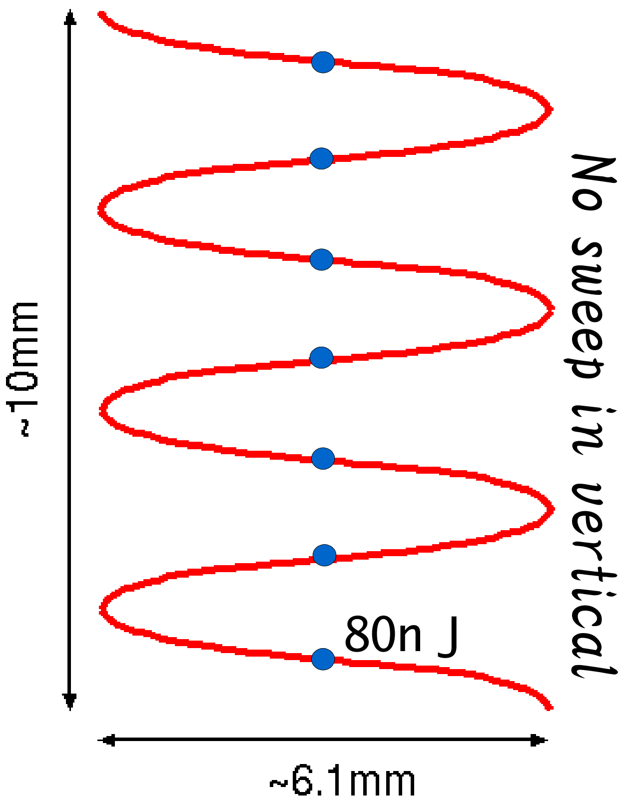
- KEKB-HER: 8GeV, 10nC, 1300 bunches (1300mA)
- Because of "Step size" variation, the energy density is varied from 1810 to 13700 J/mm2.

Dump Layout



Beam image

Experimental Modes



- KEKB mode
  - No modification from the KEKB operation except the stored current.
  - The energy density is reproduced, but it is made with a much shorter duration.
- ILC mode
  - Turning off the vertical kicker.
  - Fill 1 or 2 bunches only at zero-cross.
  - These bunches hit a same spot every 1430ns .
  - Reproduce density and flux.

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Density and Flux

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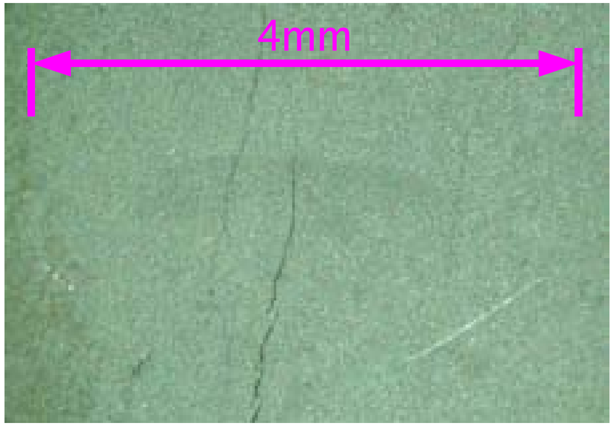
Mode	KEKB current (mA)	Energy density (J/mm2)	Energy flux (J/us)
KEKB390	390	540-4100	3400
ILC2	14	1120	130.54
ILC1	7	560	65.27
ILC0.7	4.9	392	45.69

ILC

Bunch spacing (ns)	Target rotation (m/s)	Energy density (J/mm2)	Energy flux (J/us)
310	50	1270	58.06
310	100	630	58.06
310	150	423.33	58.06
310	360	176.39	58.06
200	50	1905	90
400	50	472.5	45

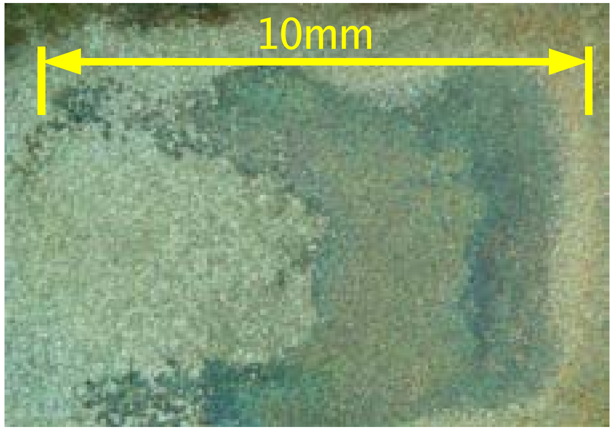
Investigation

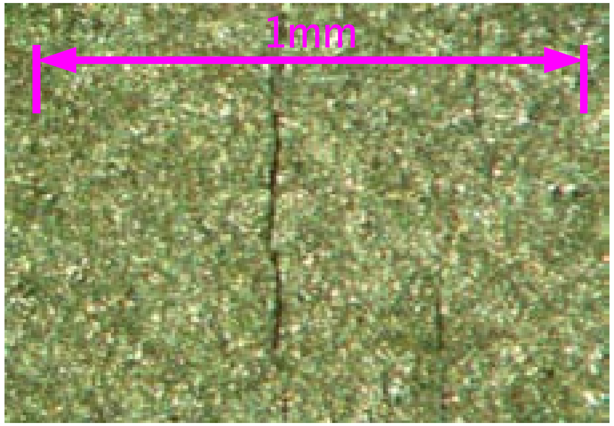
- Investigation with an optical scope (up to x300).
- Burned out. Many cracks.
- Cracks are in a same direction.



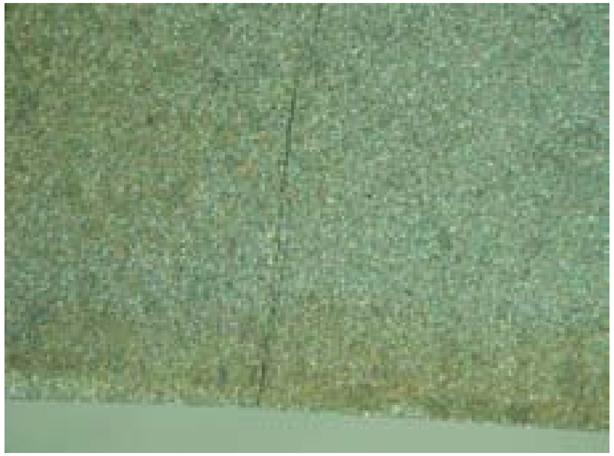
Upstream

KEKB mod(390mA)



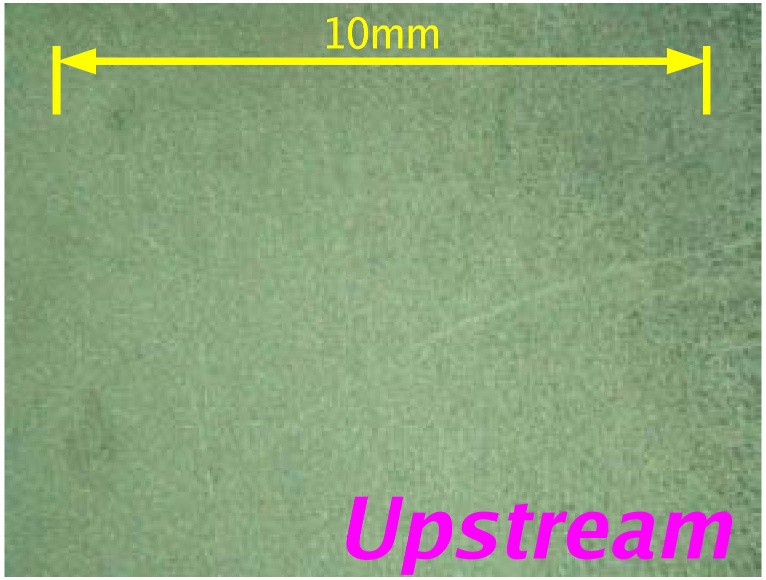


Downstream

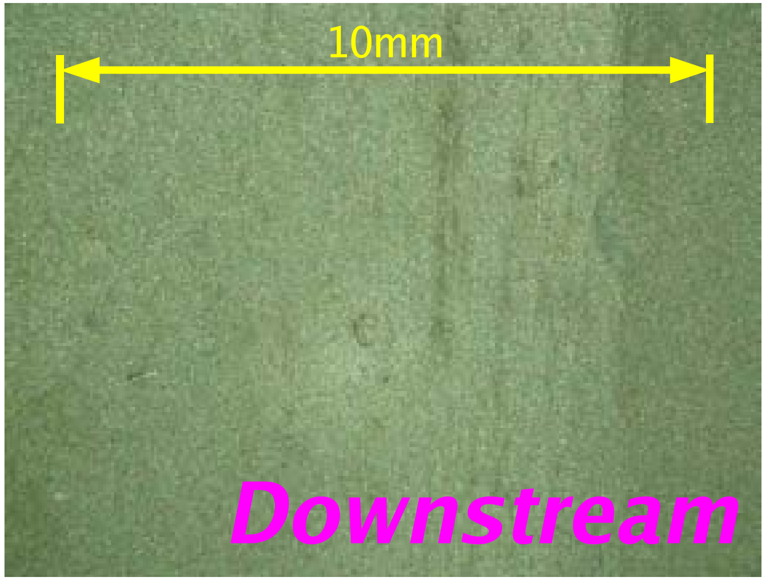


Side

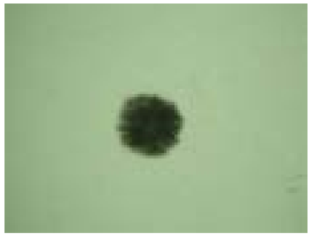
ILC2

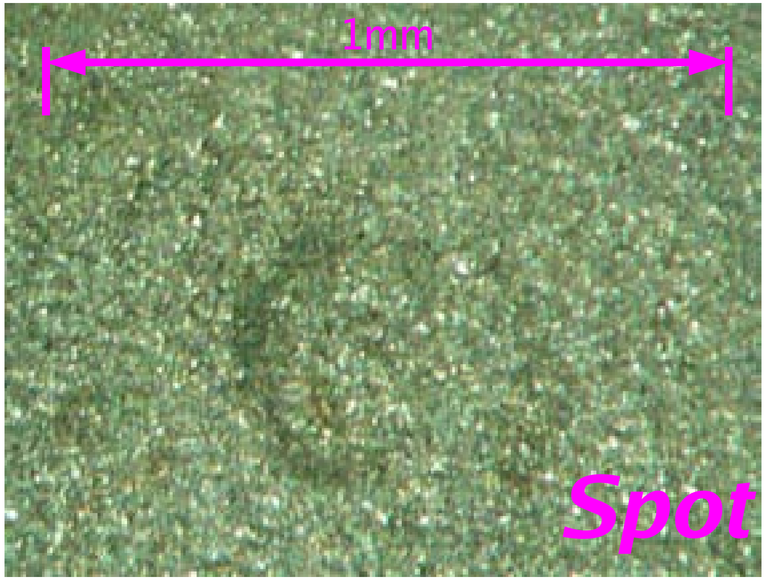


- No crack was observed.
- A colored area was observed.
- A clear spot on the thermal paper.

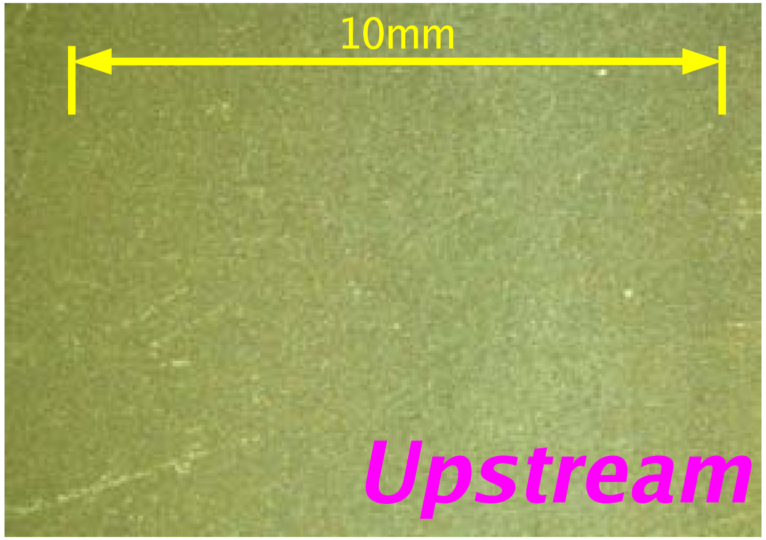


Thermal paper

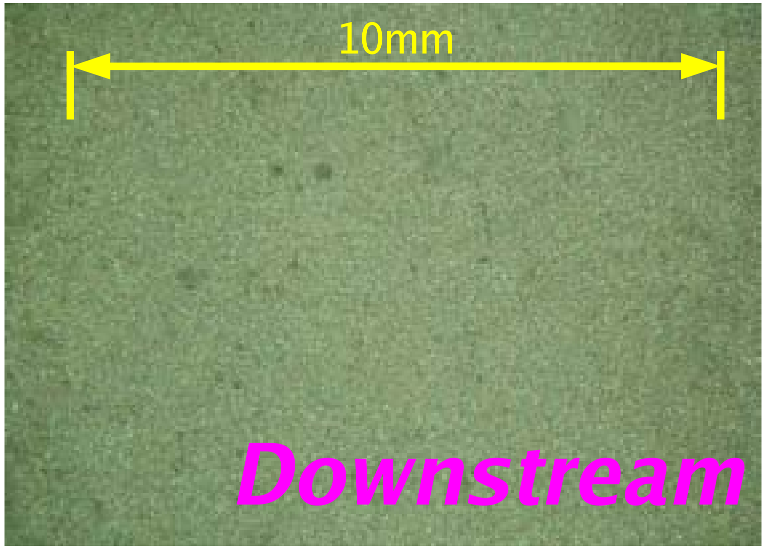




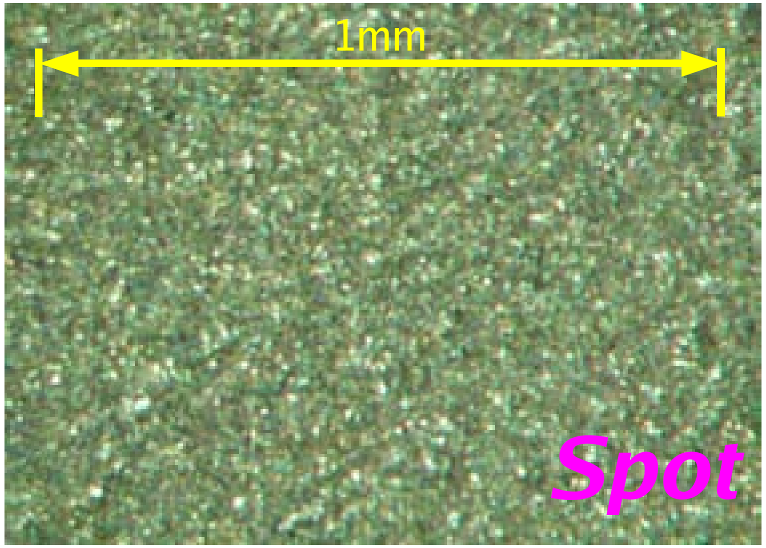
ILC1



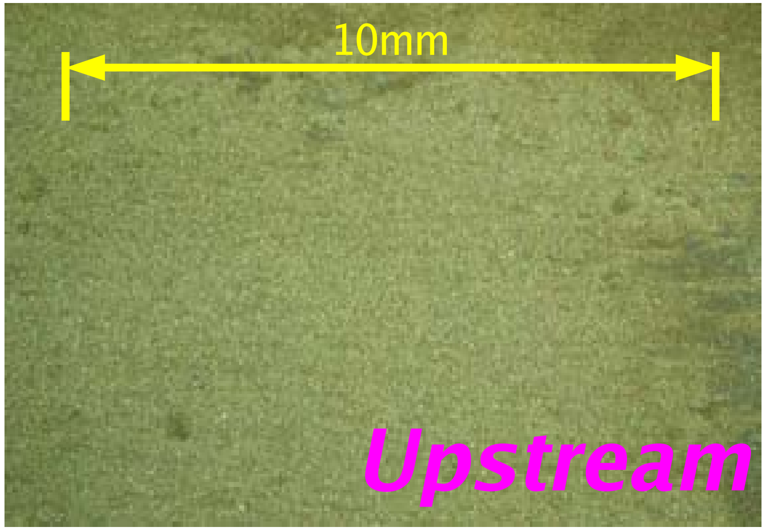
- Unclear spot was observed at the downstream surface.
- A tiny spot was observed on the thermal paper.



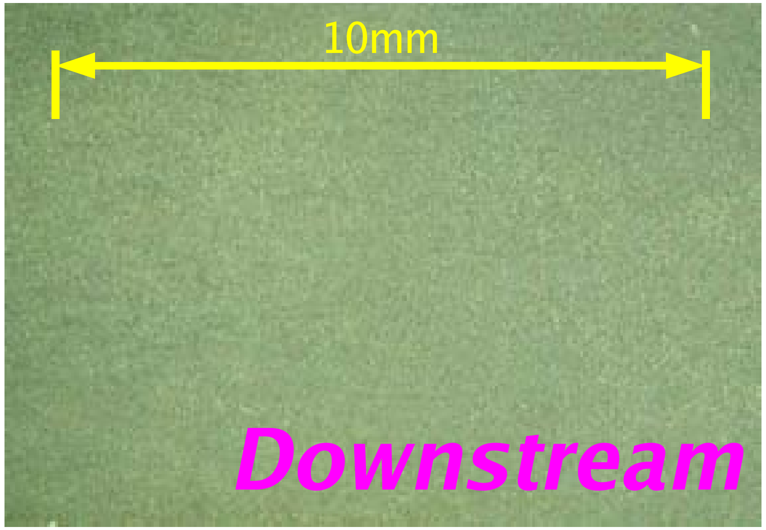
Thermal paper



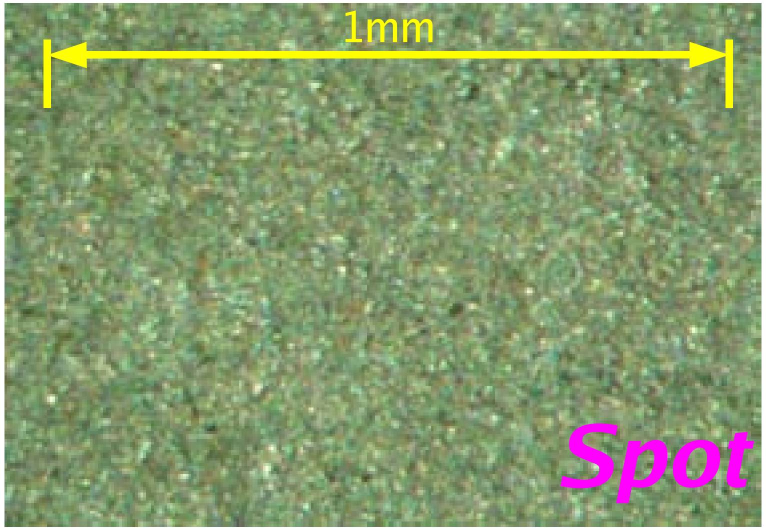
ILC 0.7



- Nothing on the target.
- Nothing on the paper.



Thermal paper



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Summary of Results

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Mode	KEKB current (mA)	Energy density (J/mm2)	Energy flux (J/us)	Result
KEKB390	390	540-4100	3400	Damaged
ILC2	14	1120	130.54	Colored
ILC1	7	560	65.27	Some
ILC0.7	4.9	392	45.69	None

ILC

Bunch spacing (ns)	Target rotation (m/s)	Energy density (J/mm2)	Energy flux (J/us)
310	50	1270	58.06
310	100	630	58.06
310	150	423.33	58.06
310	360	176.39	58.06
200	50	1905	90
400	50	472.5	45

IPPAK Conclusion

- IPPAK carried out at KEKB, did not dis-confirm the feasibility of the conventional method.
- If the result of IPPAK can extrapolate to ILC positron target with helps of simulations and additional experiments, the target load corresponding to those in ILC1 and 0.7 are acceptable.
  - ILC1 : 110m/s rotation and 3nC/bunch with 250ns spacing.
  - ILC07 : 160m/s rotation and 3nC/bunch with 360ns spacing.

Fatigue
-Post IPPAK-

- To fully establish the reliability, fatigue on the target has to be understood well.
- Generally, fatigue is a phenomena developing small cracks in metal caused by stress.
- The cracks are born in sub-micron scale. They grow up to more than 10 um.
- The fatigue progress can be accounted as number and size of the cracks.

Fatigue on Production Target

- Assuming 1m radius rotating target with 100m/s speed.
- One pulse (1ms) spreads 10cm length.
- On a spot in the target, the beam hits in 0.08 Hz. The beam hits 2.4M times in a year operation.
- If it was confirmed that the target resists 2.4M times impacts, the system is feasible.
- This number varies according to the rotating speed.

Reproduce Fatigue on Target

- The fatigue can be reproduced experimentally with a mechanical (dynamic) stress.
- Fatigue by several Mega times stresses can be easily examined.
- The stress made by the injected beam, can be estimated with a computer simulation.
- Several 100 shots with KEKB beam, can be made. The consistency between the effects by the mechanical stress and the beam stress, can be confirmed.

Summary

- In Conventional method, the target damage is the biggest risk.
- Pulsed mode operation eases the risk.
- IPPAK was carried out at KEKB successfully. It did not dis-confirm the conventional method.
- Fatigue on the target has to be understood well to establish fully the feasibility. It can be made with the mechanical stress experiment and IPPAK2.

Backup Slides

L-Band Warm Cavity

- The L-band cavities in the capture section has to be operated in 1ms duration with 14.5MV/m gradient.
- It is essential to achieve an enough capture efficiency.
- It is possible according to a simulation, but it is never demonstrated.
- If this high-field operation was not achieved,
  - Lower the field : Less positron yield.
  - Shorten the pulse : Modify the bunch spacing. Need re-optimization.

Rotating Target

- A first rotating target can reduce the damage by spreading the energy density.
- 360 m/s rotation (3600 rpm) is technically possible. This high speed is even to prevent the fatigue for W-Re. (-> W. Stein)
- Need to qualify the technical detail.

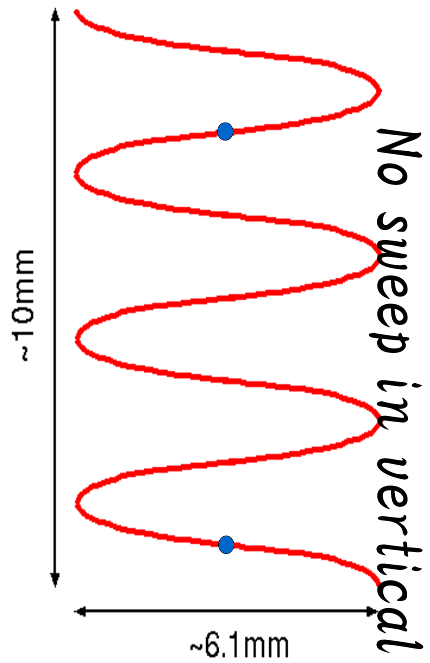
Alternative Target

- Good target material is
  - High Z and A
  - High density
  - Hard to damage
- Liquid target is good for the damage. Lead in BINP, mercury in SNS/JPARC.
- Their density is less than that of W or Re. It is not a silver bullet. Re-optimization is needed to meet the ILC requirements with those targets.

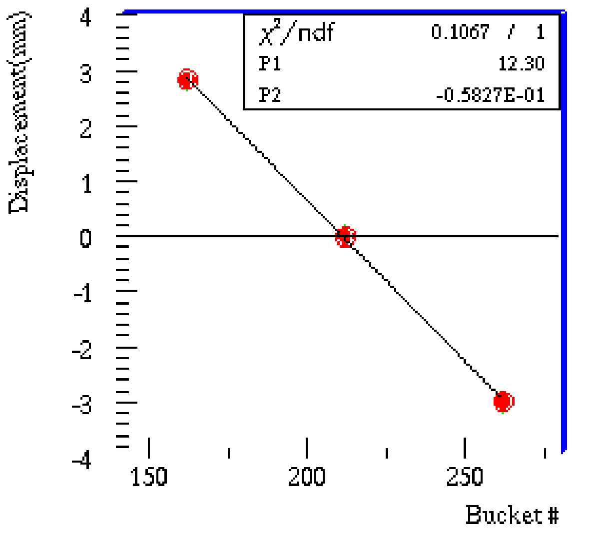
Spatial Resolution on Display

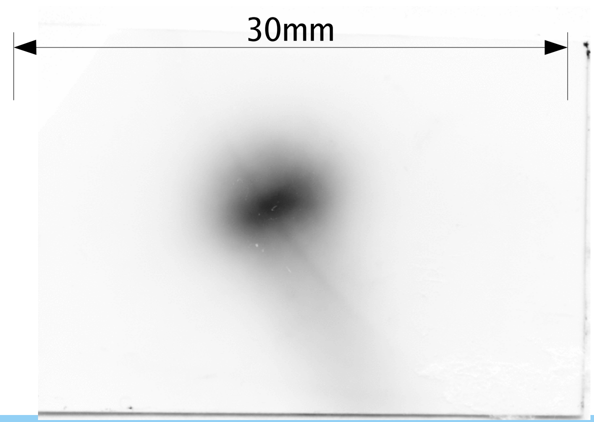
- Relative bunch position was observed by an alumina plate monitored with CCD camera and Display.
- In the display, 5mm tick on the alumina plate was 37mm. The magnification is 7.4.
- Horizontal direction has additional magnification of 1.41 by 45 degree gradient to the beam axis.
- Total mag. 10.4 (horizontal) and 7.4 (vertical).
- Assuming the spatial resolution on the display is 2mm, the resolution is 0.19mm (horizontal) and 0.27mm (vertical).

Bunch Adjustment (ILC Mode)



- Scan the displacement of 1st and 5th bunches with the bucket number. The displacement is minimized at the expected bucket.
- 7 bunches were adjusted one by one.
- ILC mode profile (core) : 1.36mm x 0.66 mm on the paper. If the core corresponds to FWHM, the profile is 0.58 x 0.28 mm in sigma which is consistent to the beam profile in KEKB ring.

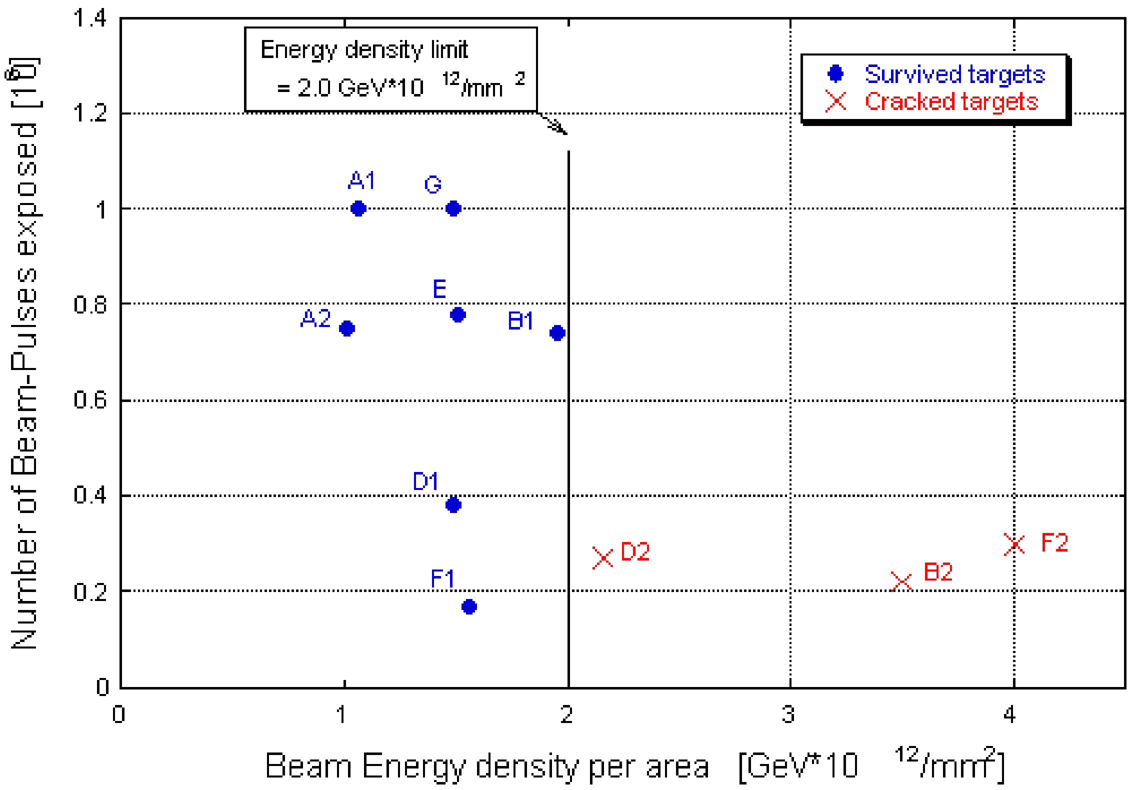




ILC mode profile
(0.58 x 0.28 mm in σ)

Damage Threshold

- Damage threshold is not understood well.
- Experiment at SLAC (S. Ecklund, SLAC-CN-128)
- Damage threshold for short bunch : 20GeV, 16nC ~ 320J/mm^2 for W(75)Re(25) alloy.



Pulse Lengthening -Naive mode-

- An operation mode with a large bunch spacing giving a long pulse, e.g. 2ms pulse with 620ns spacing.
- It relieves the target damage, but several trade offs.
- RF Gun for driver linac:
  - Need to reduce the RF power of Gun cavity.
  - Need additional R&D for laser.

Cost of Pulse Lengthening

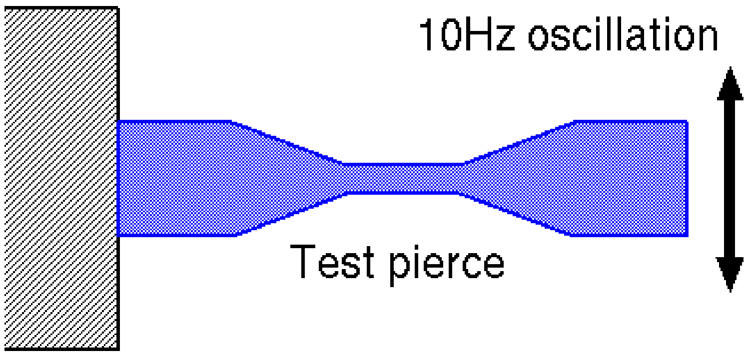
- Driver linac :
  - Since the average current is reduced, average RF power to SC linac is also reduced.
  - Coupling to SC linac becomes small. Less load to the coupler.
  - Q value is however increased for less coupling. The cavity tuning becomes harder.
  - Heat load is increased because of the long pulse. Extra cost, but not critical.

Cost of Pulse Lengthening

- Capture section :
  - Long pulse operation of the pulsed magnet might be difficult.
  - Long pulse operation of L-band warm cavities might be difficult. Need to reduce the input power which lower the capture efficiency.
- Positron Injector Linac :
  - Same trade offs as those in the driver linac.

Dynamic Stress

- Test piece is fixed between two bars.
- One of the bar is oscillating with 10Hz.
- Because of the waisted shape, the stress concentrates there.
- 10 days run makes 8.4 M times stresses which are enough to examine the fatigue in the target.



The Beam Stress

- The experiment with the beam stress, can be carried out at KEKB with the same manner as IPPAK.
- A shot with 7mA storage current takes supposedly 3 minutes.
- 160 shots can be made within one shift (8hours).
- The dosed target can be compared with that by the mechanical stress to check the consistency.