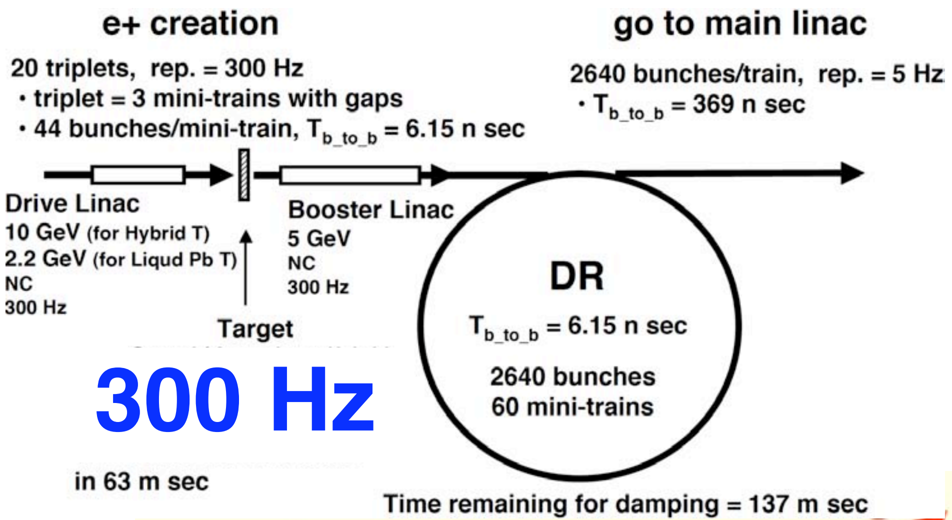
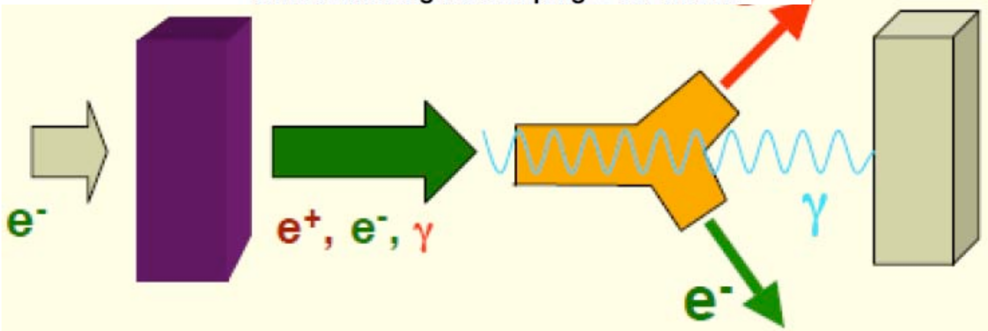
Advanced Conventional e+ Sources for ILC





Hybrid Target

T. Omori (KEK)

18-April-2008, GDE meeting, Tsukuba

Many thanks to Chehab-san, Logachev-san, Wanming-san, Wei-san, James-san, Ian-san,
Susanna-san, Louis-san, Urakawa-san, Kuriki-san, Takahashi-san, Kamitani-san

Conventional e+ Source

- only e+ source which we have experience in real accelerators
- Independent
- No polarization
- target survivability?

Two Proposals to Mitigate Target Problem

- LowE e- driven
- 300 Hz generation

Two Proposals

- **LowE e- driven: e+ generation in 1 ms**
  - Liquid Pb target + Li lens
  - Drive e- beam: 2.2 GeV, 4.5 nC, 5 Hz, SC Linac
  - e+ booster : 5 Gev, 5 Hz, SC Linac
  - Aiming cheap.
  - Timing structure in source&inj is the same as the baseline.
  - Risks in target & Li lens --> need R/D

- **300 Hz generation: e+ generation in 63 ms**

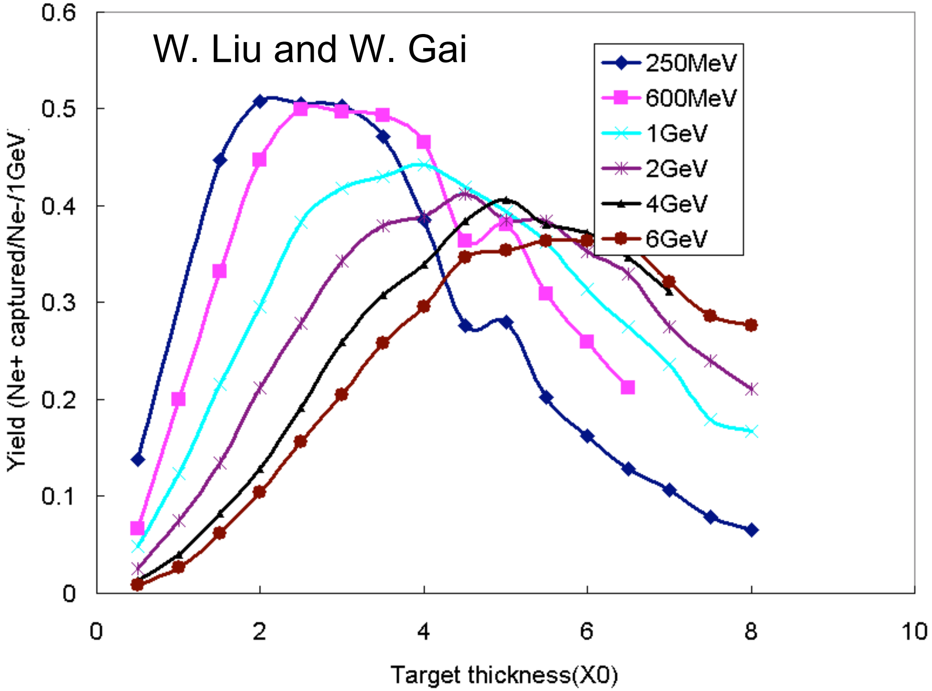
  (a) Liquid Pb target + Flux concentrator
  - Drive e- beam: 2.2 GeV, 5.9 nC, (LowE) 300 Hz, NC Linac
  - e+ booster : 5 Gev, 300 Hz, NC Linac

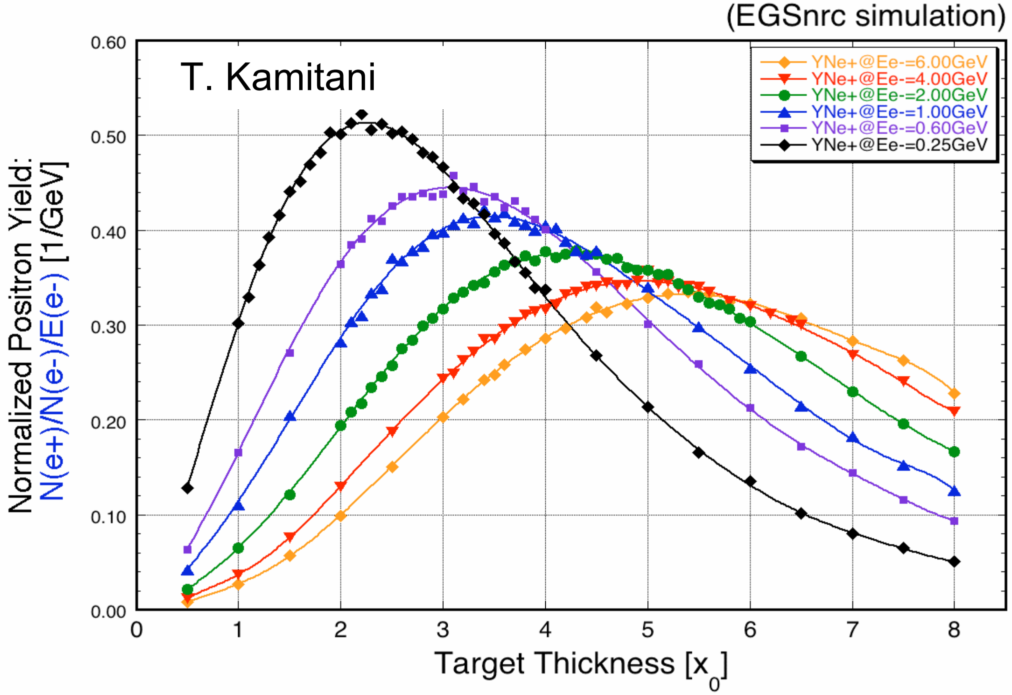
  (b) Hybrid Target + Flux concentrator
  - Drive e- beam: 10 GeV, 2.1 nC, 300 Hz, NC Linac
  - e+ booster : 5 Gev, 300 Hz, NC Linac

  - Aiming mature and low risk.
  - Need R/D of targets

Low E e^- driven

Energy Normalized Positron Yield





Energy Normalized Positron yield *η*/GeV (N_{e+}/N_{e-}/GeV)

- 0.6 GeV : 0.50
- 1.0 GeV : 0.45
- 2.0 GeV : 0.40

- 0.6 GeV : 0.44
- 1.0 GeV : 0.39
- 2.0 GeV : 0.37

How to Choose Beam Energy

Drive Beam Energy ↘
Energy Normalized Positron Yield ↗

Drive Beam Energy ↘
Target Damage ↘

Drive Beam Energy ↘
Positron Yield ↘
We need bunch charge ↗ (drive beam)

Positron Yield

Choose drive beam energy as low as possible unless the bunch charge is not too large.

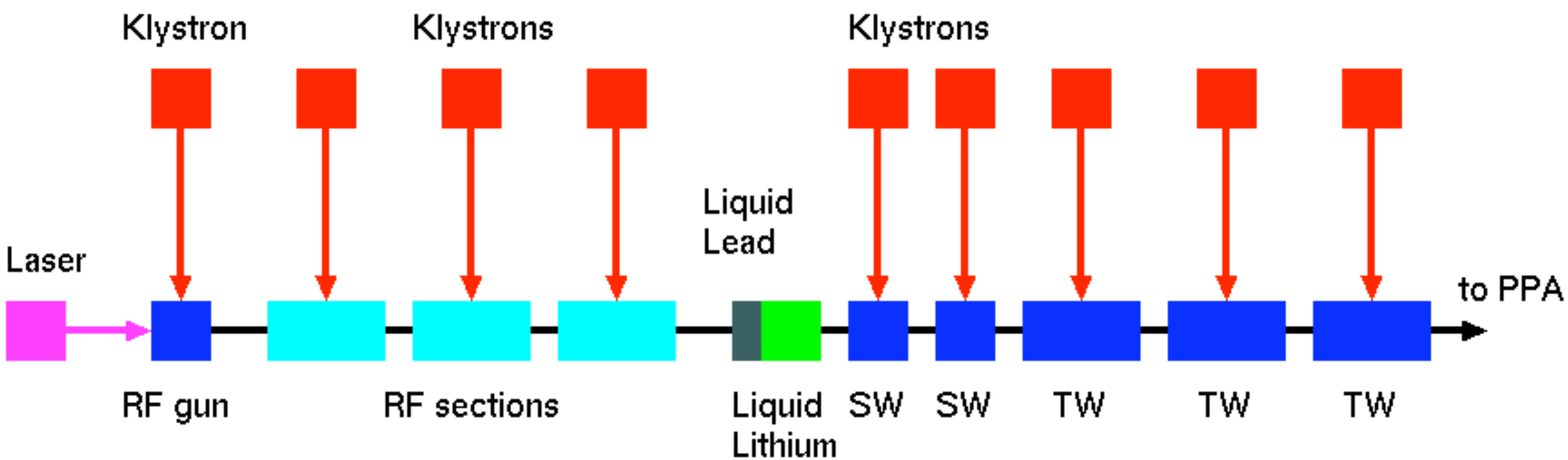
Ee- (GeV)	η	Ne- (nC)
0.7	0.27	11.85
1.4	0.48	6.67
2.2	0.71	4.51

Kuriki's choice → 2.2

- ►The positron yield at the shower max for each energy is taken from the simulation.
- ►DR acceptance is smaller than AMD acceptance. The real yield is 87%, which corresponds to 1.5σ .
- ►No Enhancement by Lithium lens is assumed.
- ►The required drive beam intensity was obtained.

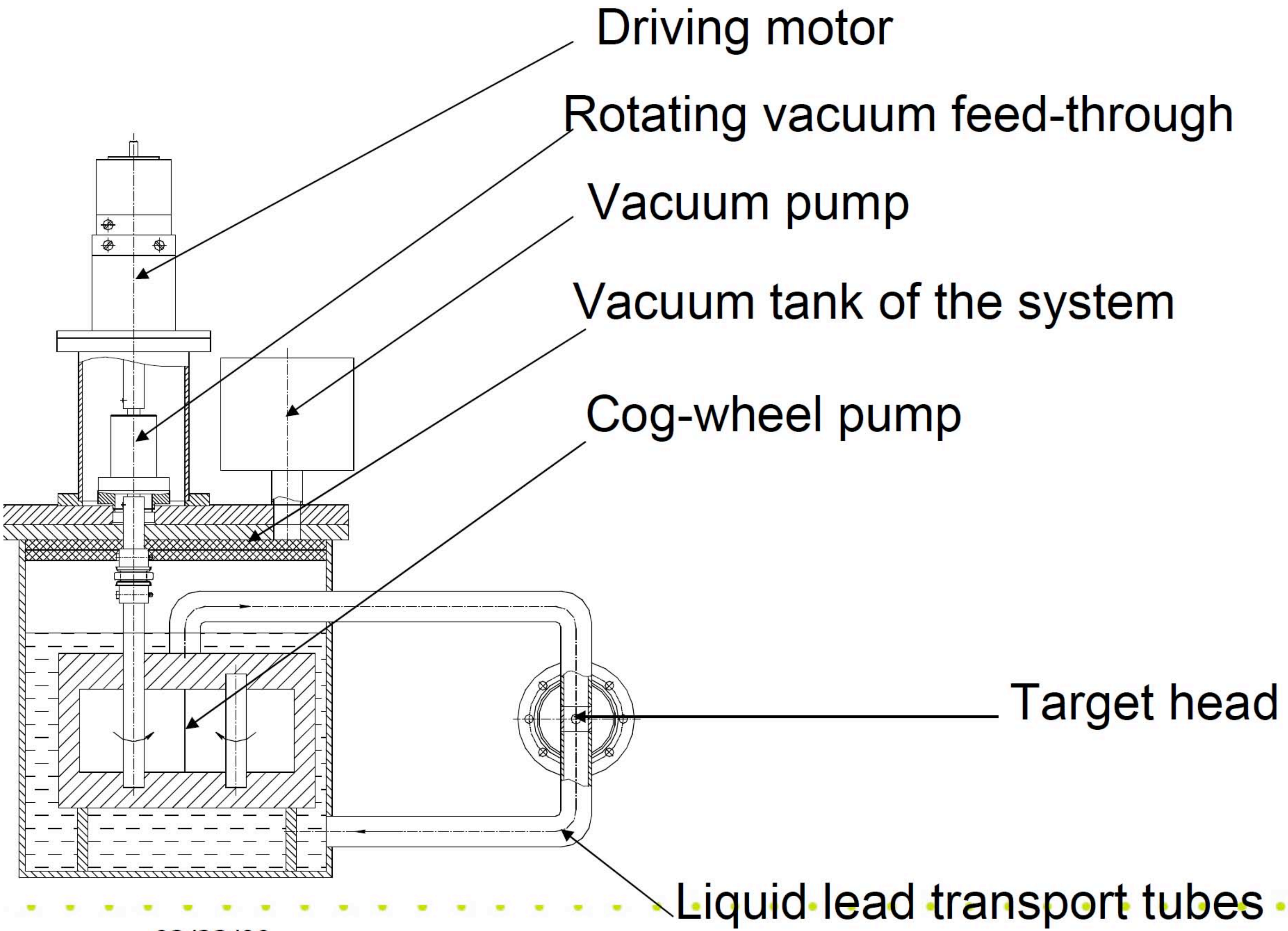
Low E e^- driven source (M. Kuruki)

- L-band RF gun (FLASH type) generates ILC format beam with 4.5nC bunch intensity.
- Three RF sections (2 klystron + 3 cryomodules, 24 cavities) accelerate it up to 2.2 GeV.
- Liquid lead target + Liquid Lithium lens.

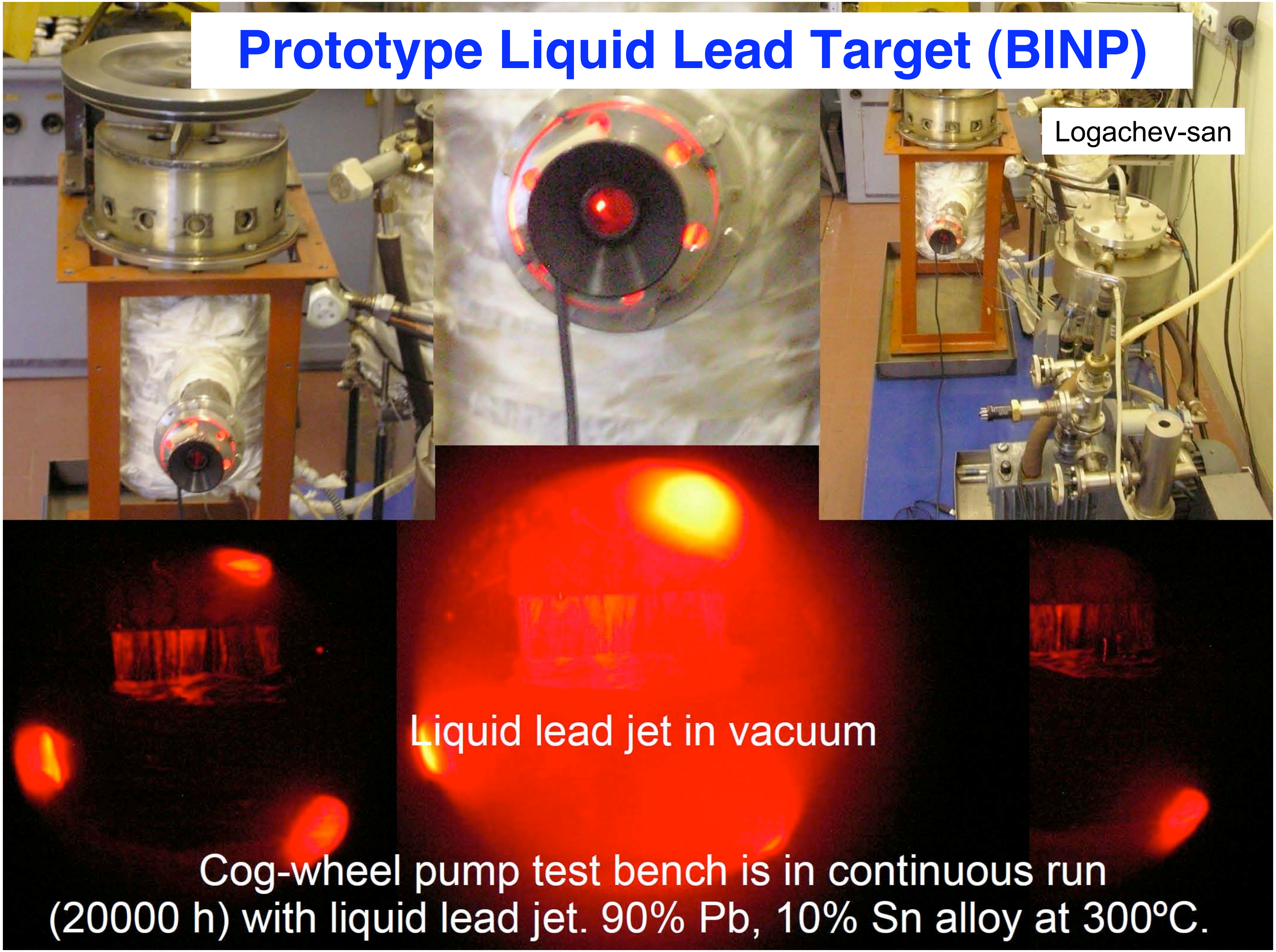


Prototype Liquid Lead Target (BINP)

Logachev-san

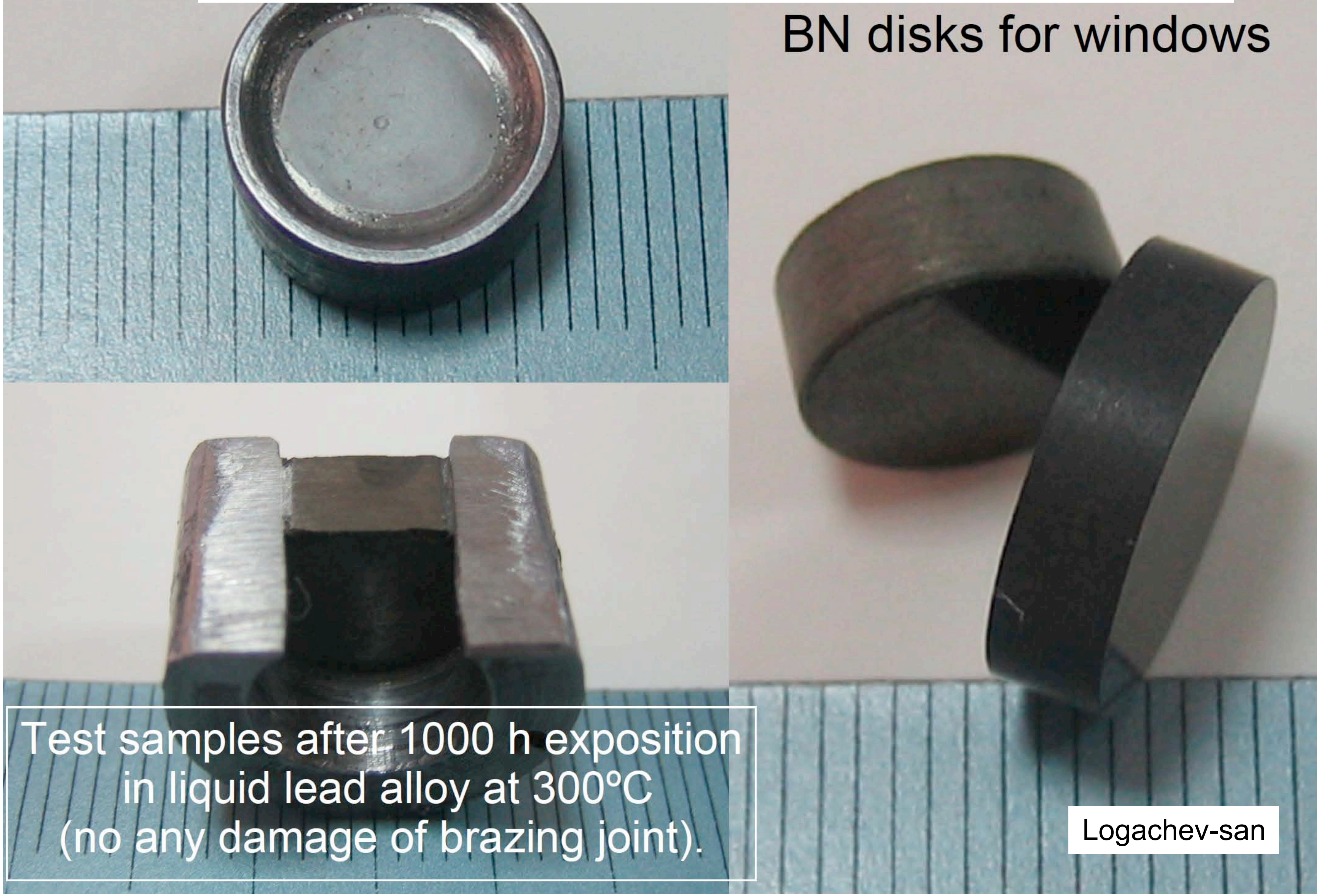


Prototype Liquid Lead Target (BINP)

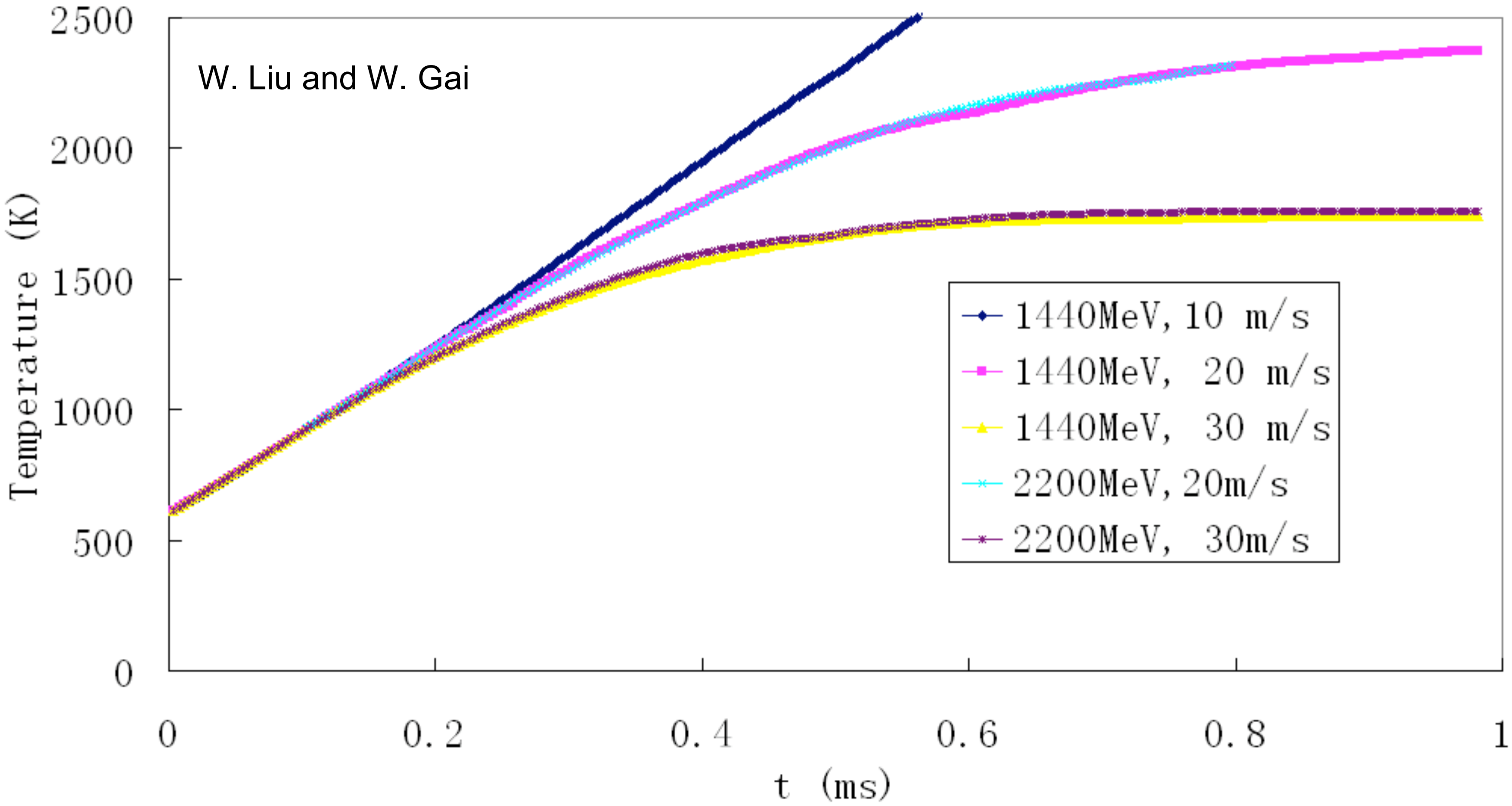


Cog-wheel pump test bench is in continuous run (20000 h) with liquid lead jet. 90% Pb, 10% Sn alloy at 300ºC.

Prototype Liquid Lead Target (BINP)



Evolution of Temperature(ANL)



Drive beam spot size: rms 3mm for both 1440MeV and 2200MeV.
Target thickness: 3X0 for 1440MeV, 3.5X0 for 2200MeV

Pb boiling estimation

Kuriki-san estimated Number-of-Bunches (NB) Limit of Pb boiling from the ANL's simulation.

Name	e- (GeV)	Thickness (X_0)	Spot (mm)	Pb flow (m/s)	Yield e+/e-	Ne- (nC)	NB limit
MKV1	2.2	3	1.0	10	0.80	4.00	250
MKV2	2.2	3	3.0	10	0.80	4.00	1670
MKV3	2.2	3	3.0	30	0.80	4.00	Saturated at 1590K
MKV4	2.2	3	4.0	30	0.80	4.00	Saturated at 1300K
ANLV1	1.4	3	3.0	20	0.55	5.82	1600
ANLV2	2.2	3.5	3.0	30	0.86	3.7	Saturated at 1800K

Method of estimation

- **2.2GeV, 4.0nC drive beam cause 1.65 J energy deposition per bunch.**
- **ANL's Pb boiling study was made with 2.30 J energy deposition per bunch.**
- **Kuriki assumes that temperature rise is scaled as the energy deposition.**

Pb boiling estimation (2)

Name	e- (GeV)	Thickness (X_0)	Spot (mm)	Pb flow (m/s)	Yield e+/e-	Ne- (nC)	NB limit
MKV1	2.2	3	1.0	10	0.80	4.00	250
MKV2	2.2	3	3.0	10	0.80	4.00	1670
MKV3	2.2	3	3.0	30	0.80	4.00	Saturated at 1590K
MKV4	2.2	3	4.0	30	0.80	4.00	Saturated at 1300K
ANLV1	1.4	3	3.0	20	0.55	5.82	1600
ANLV2	2.2	3.5	3.0	30	0.86	3.7	Saturated at 1800K

- **MKV1: no way?**
- **MKV2, ANLV1: Acceptable for LowP set.**
- **MKV3, MKV4, ANLV2: Acceptable for Nominal set.**
- **Still Big "?" on the window: BN, Be, Ti, ...**

Summary of LowE e- driven

- Kuriki-san's study shows 2.2 GeV drive beam is a solution.
- ANL's study shows that Pb boiling is a serious issue. Larger spot size and higher flow speed avoid the boiling.
- Brazing of the BN window will melt much lower than Pb boiling, if Pb flow is touching. We need the design to protect the window brazing.

300 Hz generation

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

Comparison to Warm Machines

GLC/NLC (warm LC)

Ne+/bunch = 0.7 x 10^{10}
Nbunch/tarin = 200
3 targets (conventional)
150 Hz (6.7 m sec train to train)

x 3

x 1/1.5

ILC (cold LC)

Ne+/bunch = 2 x 10^{10}
Nbunch/tarin = 2640 = 10 x 132

300 Hz generation: similar to warm machines

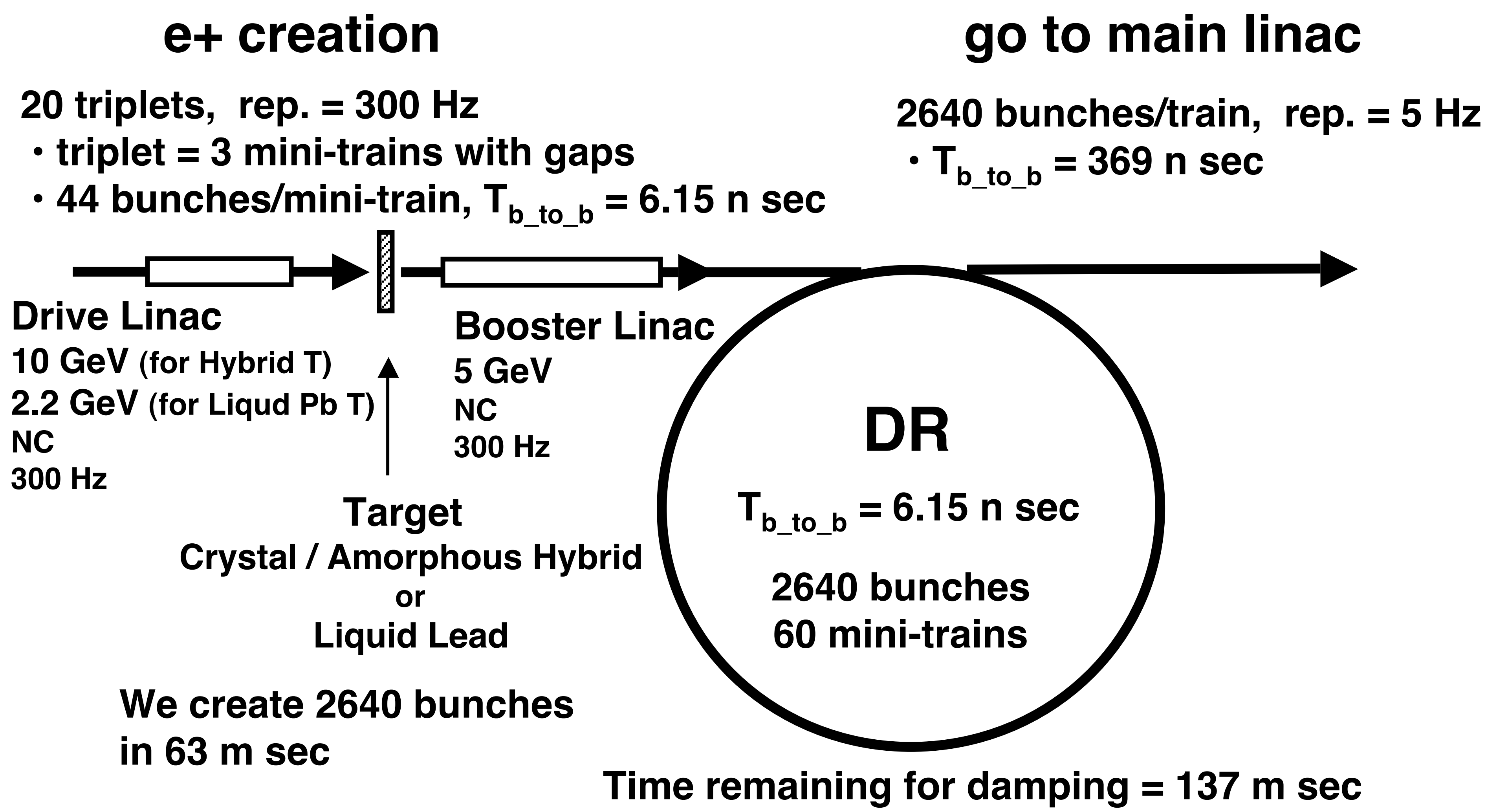
in it's time structure
in view point of target thermal/shock issues

300 Hz generation: takes 63 m sec

3.3 m sec(300 Hz) x (20-1) = 63 m sec

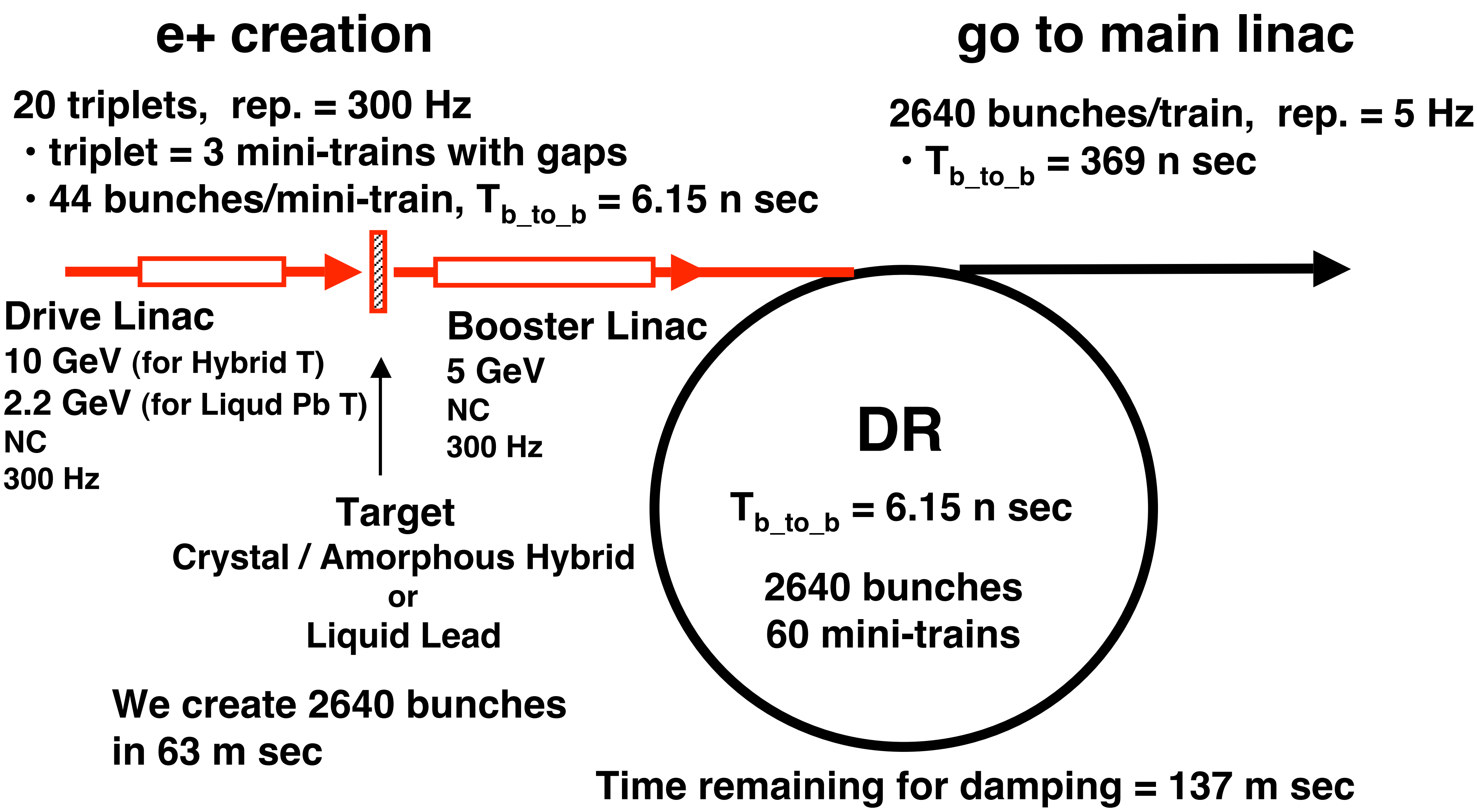
Advanced Conventional e+ Source for ILC

Crystal/Amorphous Hybrid Target or Liquid Lead Target
Normal Conducting Drive and Booster Linacs in 300 Hz operation

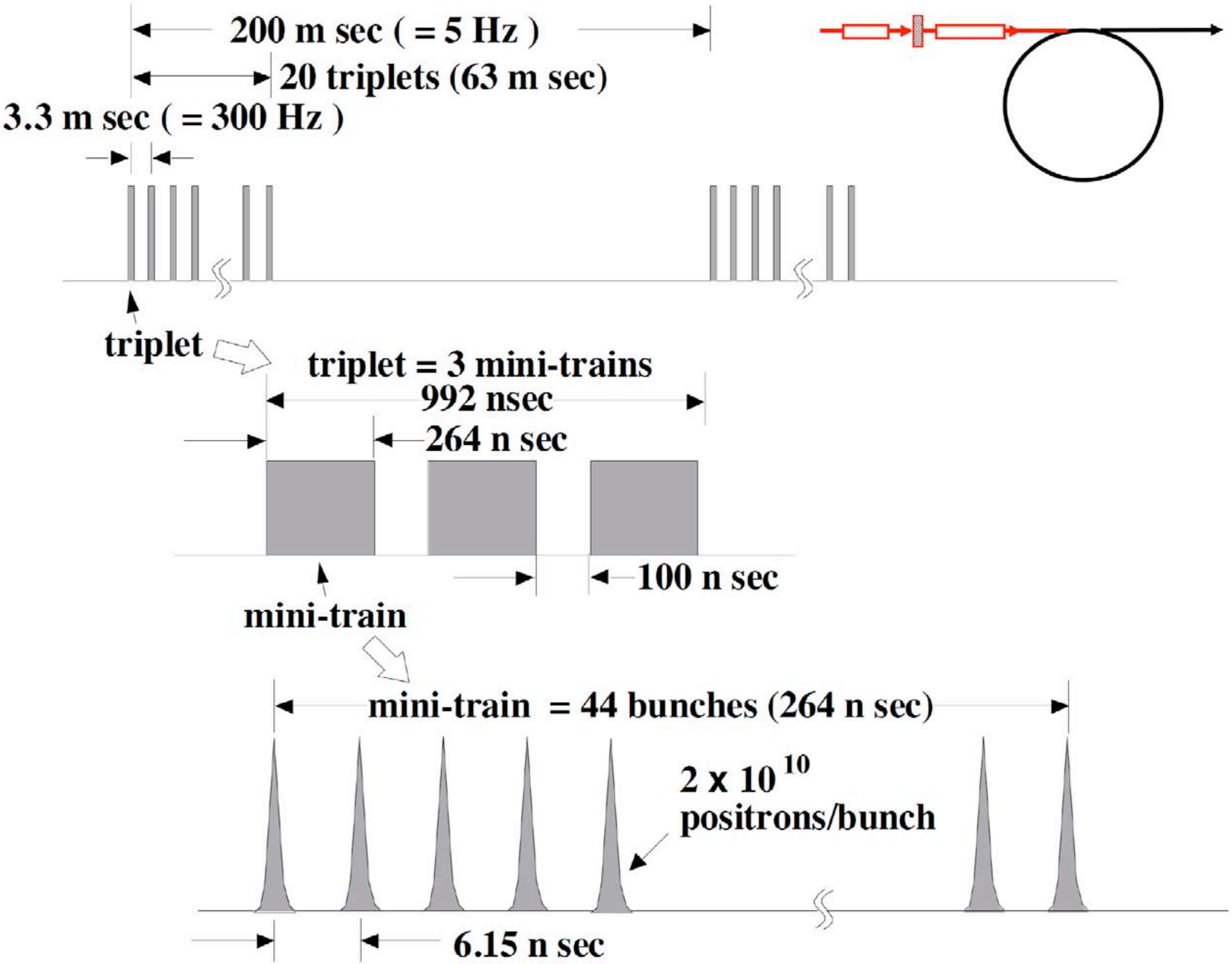


Advanced Conventional e+ Source for ILC

Crystal/Amorphous Hybrid Target or Liquid Lead Target
Normal Conducting Drive and Booster Linacs in 300 Hz operation

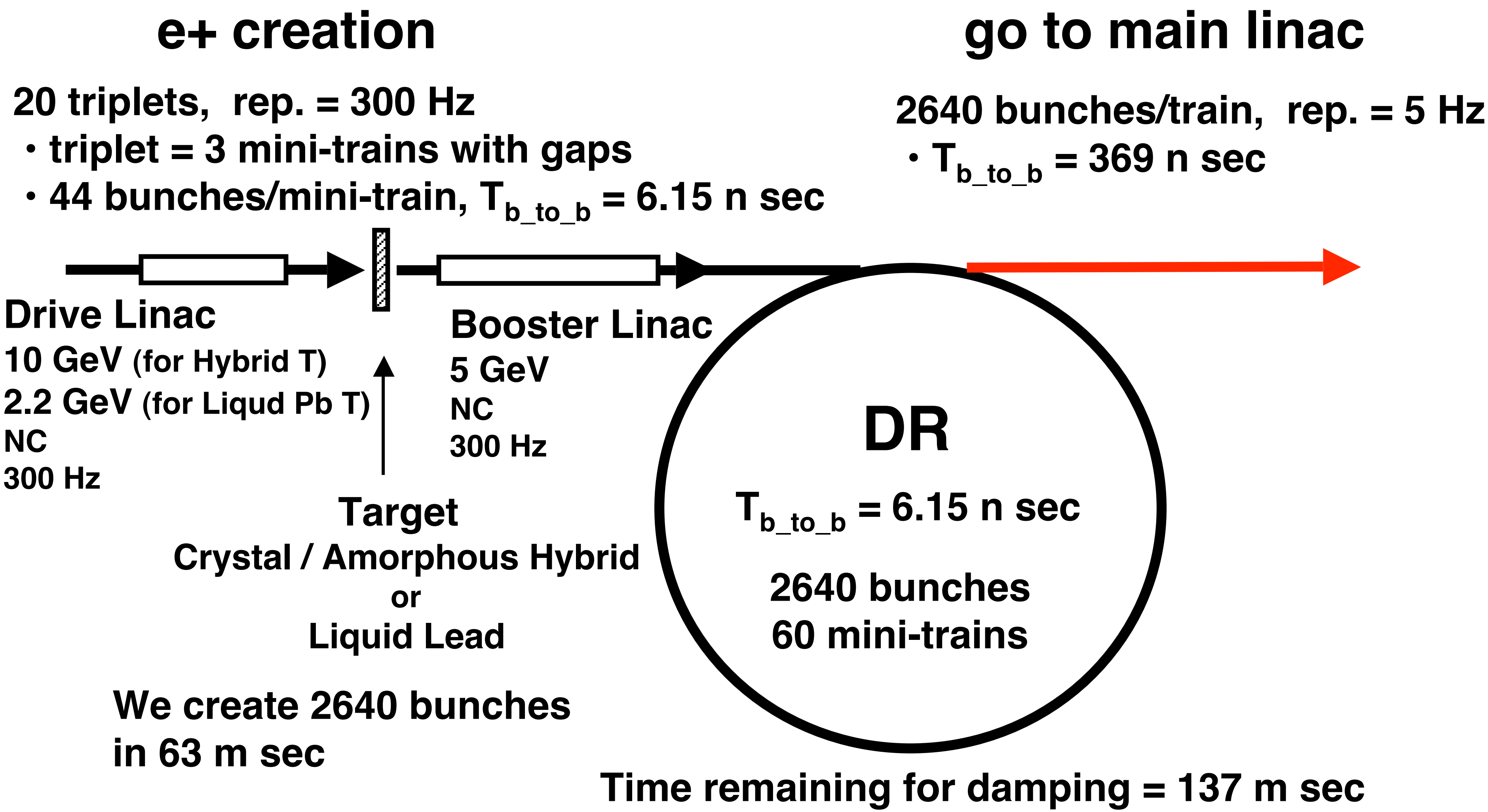


Beam before DR

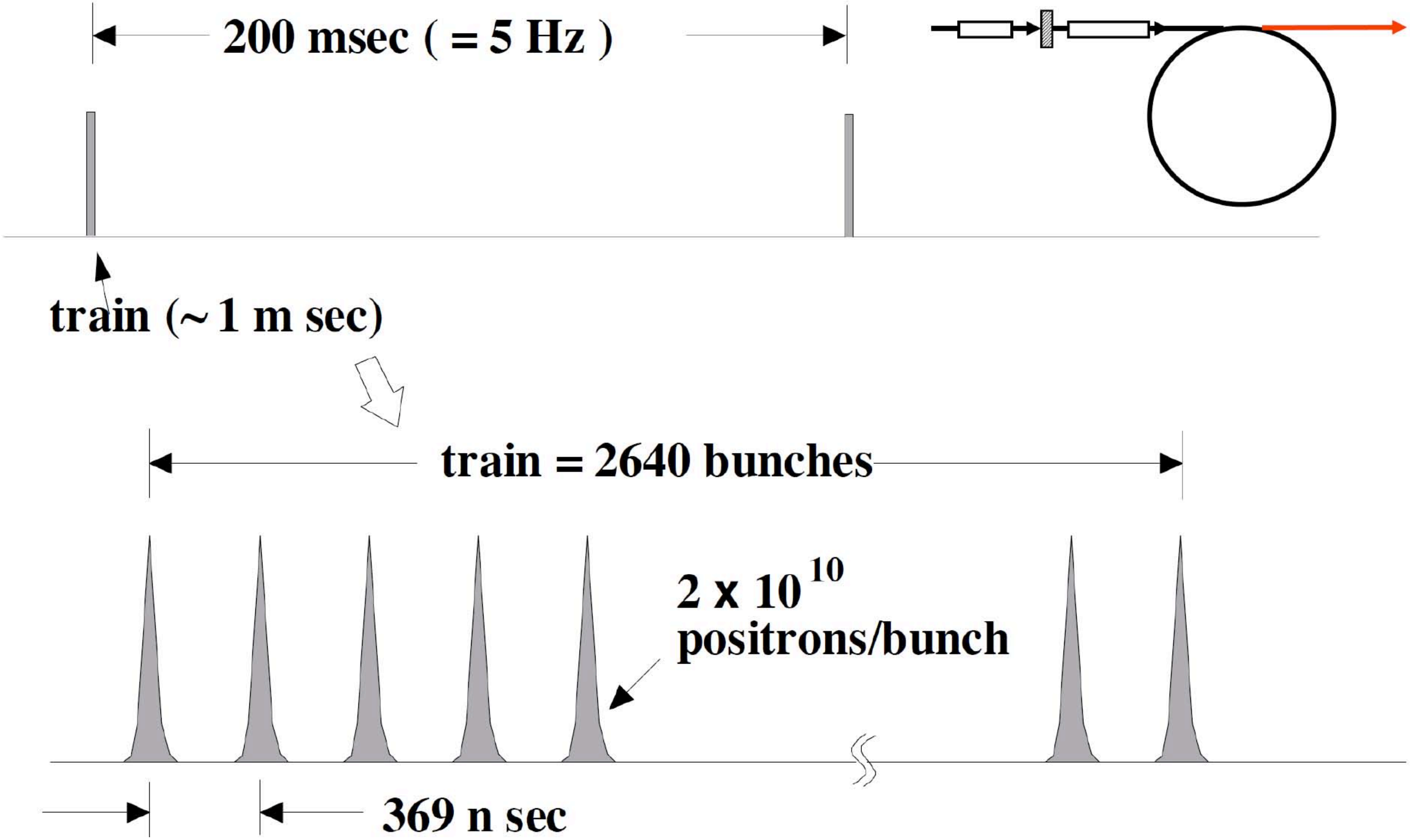


Advanced Conventional e+ Source for ILC

Crystal/Amorphous Hybrid Target or Liquid Lead Target
Normal Conducting Drive and Booster Linacs in 300 Hz operation



Beam after DR



Comparison to Warm Machines

GLC/NLC (warm LC)

Ne+/bunch = 0.7 x 10^{10}
Nbunch/tarin = 200
3 targets (conventional)
150 Hz (6.7 m sec train to train)

x 3

x 1/1.5

ILC (cold LC)

Ne+/bunch = 2 x 10^{10}
Nbunch/tarin = 1320 = 10 x 132

300 Hz generation: similar to warm machines

in view point of target thermal/shock issues (diff = x2)

Need 6 targets ?

1 target --> Hybrid or Liquid-Lead target

Advanced Conventional e+ Source for ILC

Crystal/Amorphous Hybrid Target or Liquid Lead Target

Normal Conducting Drive and Booster Linacs in 300 Hz operation

e+ creation

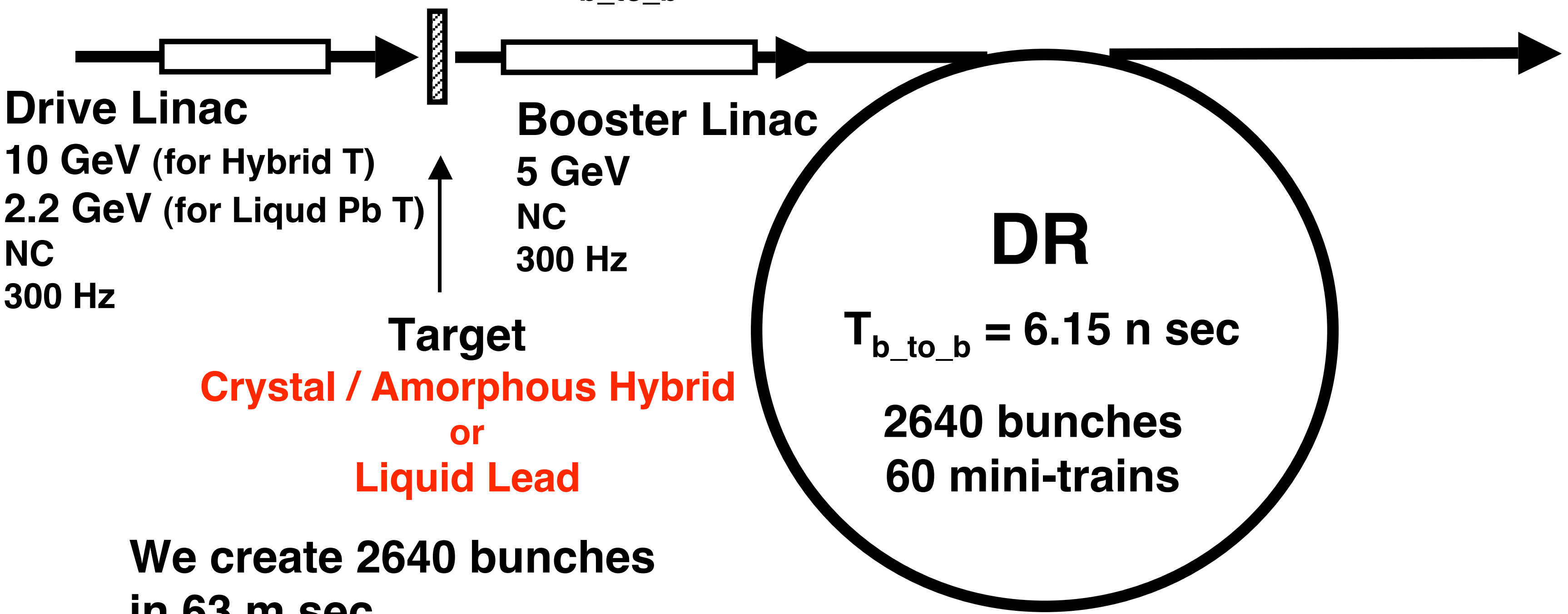
20 triplets, rep. = 300 Hz

- 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



We create 2640 bunches in 63 m sec

Time remaining for damping = 137 m sec

Advanced Conventional e+ Source for ILC

Crystal/Amorphous Hybrid Target or Liquid Lead Target
Normal Conducting Drive and Booster Linacs in 300 Hz operation

e+ creation

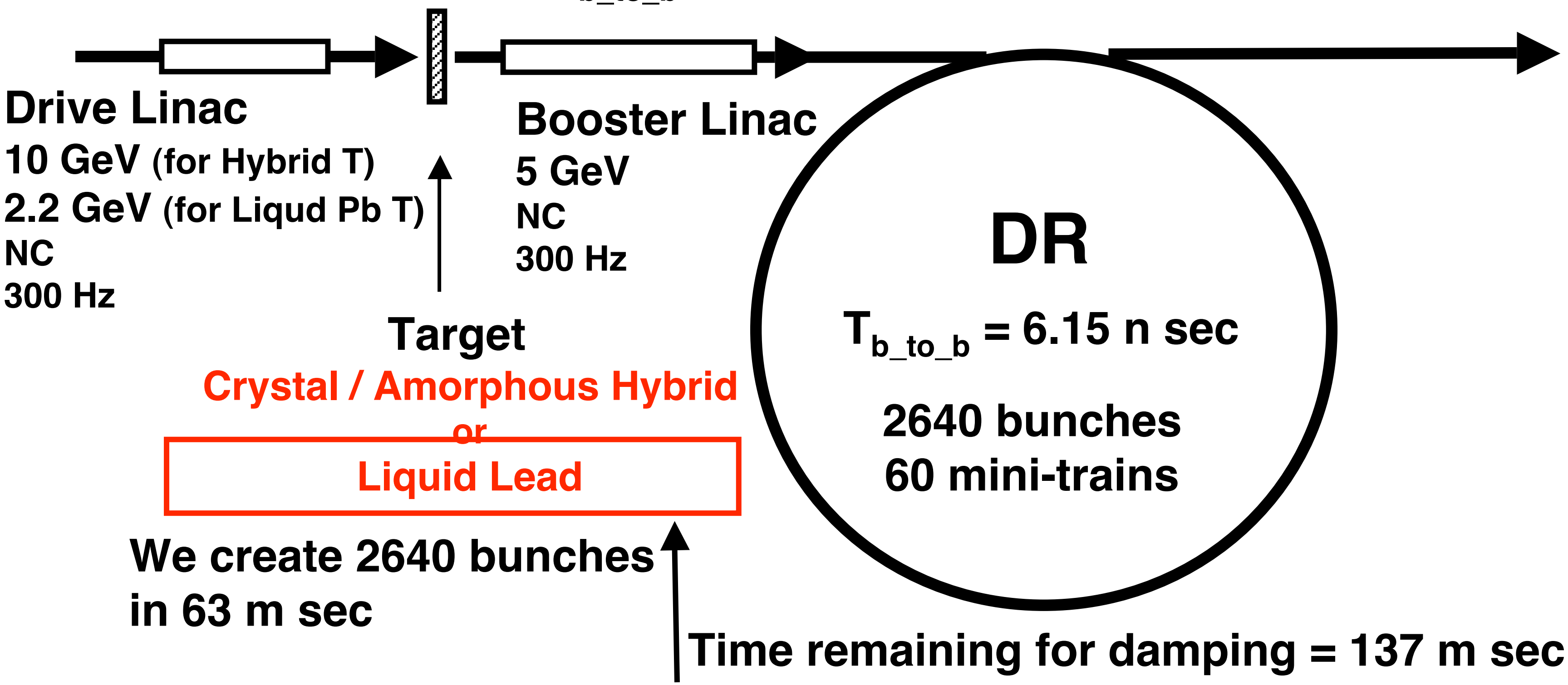
20 triplets, rep. = 300 Hz

- **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**

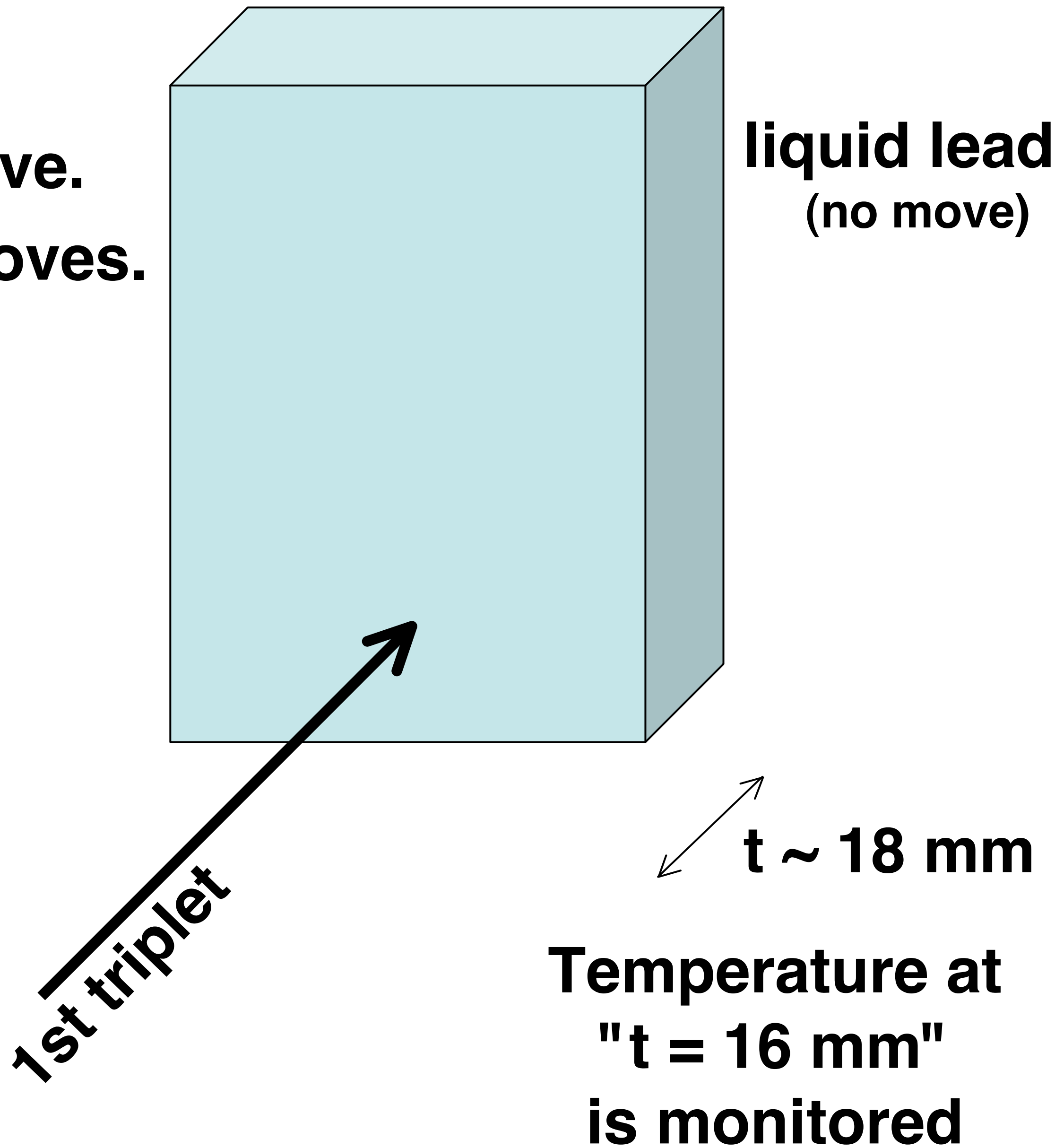


Simulation of heating by beam (Wanming-san)
Simulation of eddy current (James-san)

Simulation of heating by beam (Wanming-san)

Model

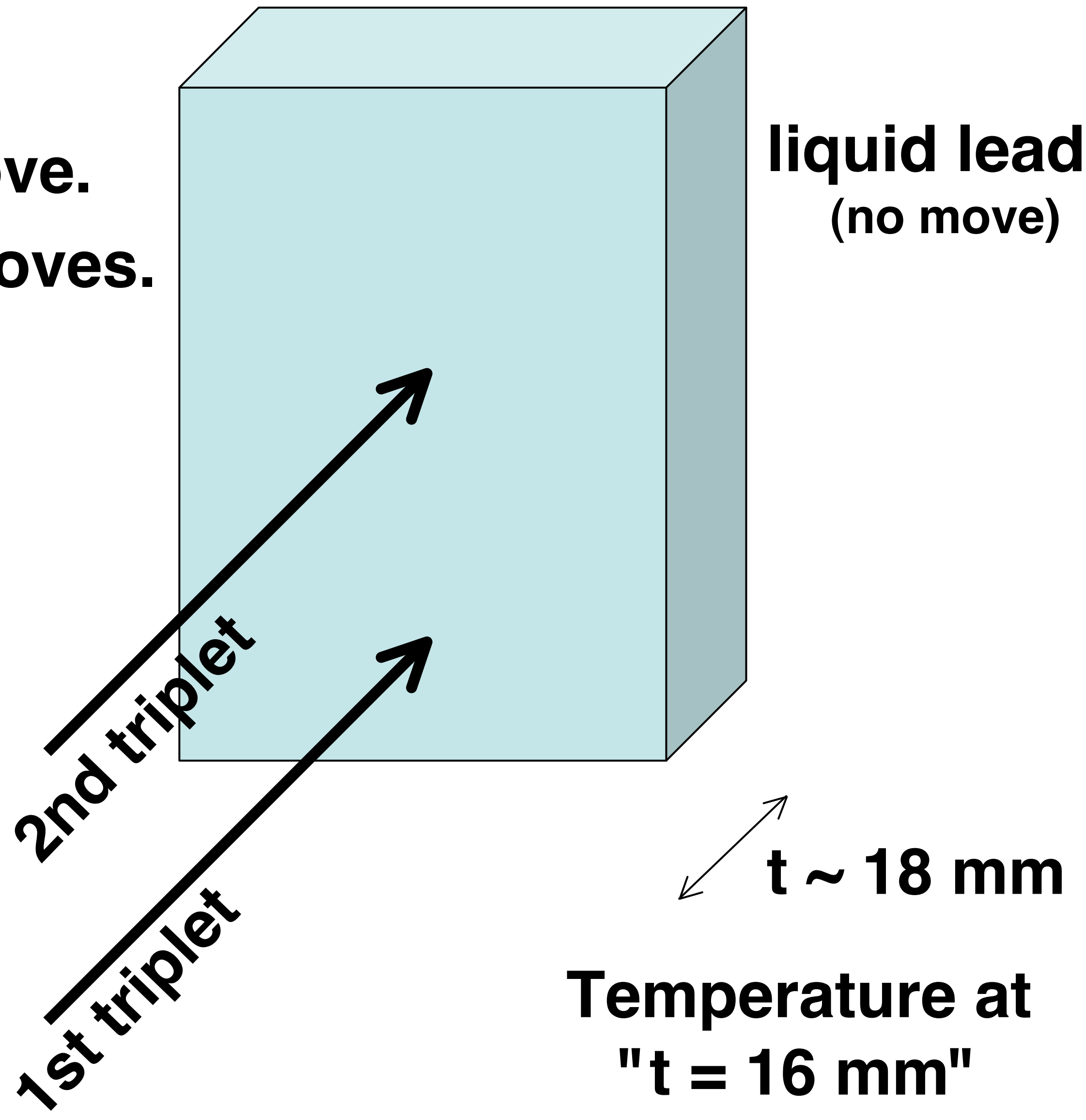
- Liquid Lead doesn't move.
- Beam injection point moves.



Simulation of heating by beam (Wanming-san)

Model

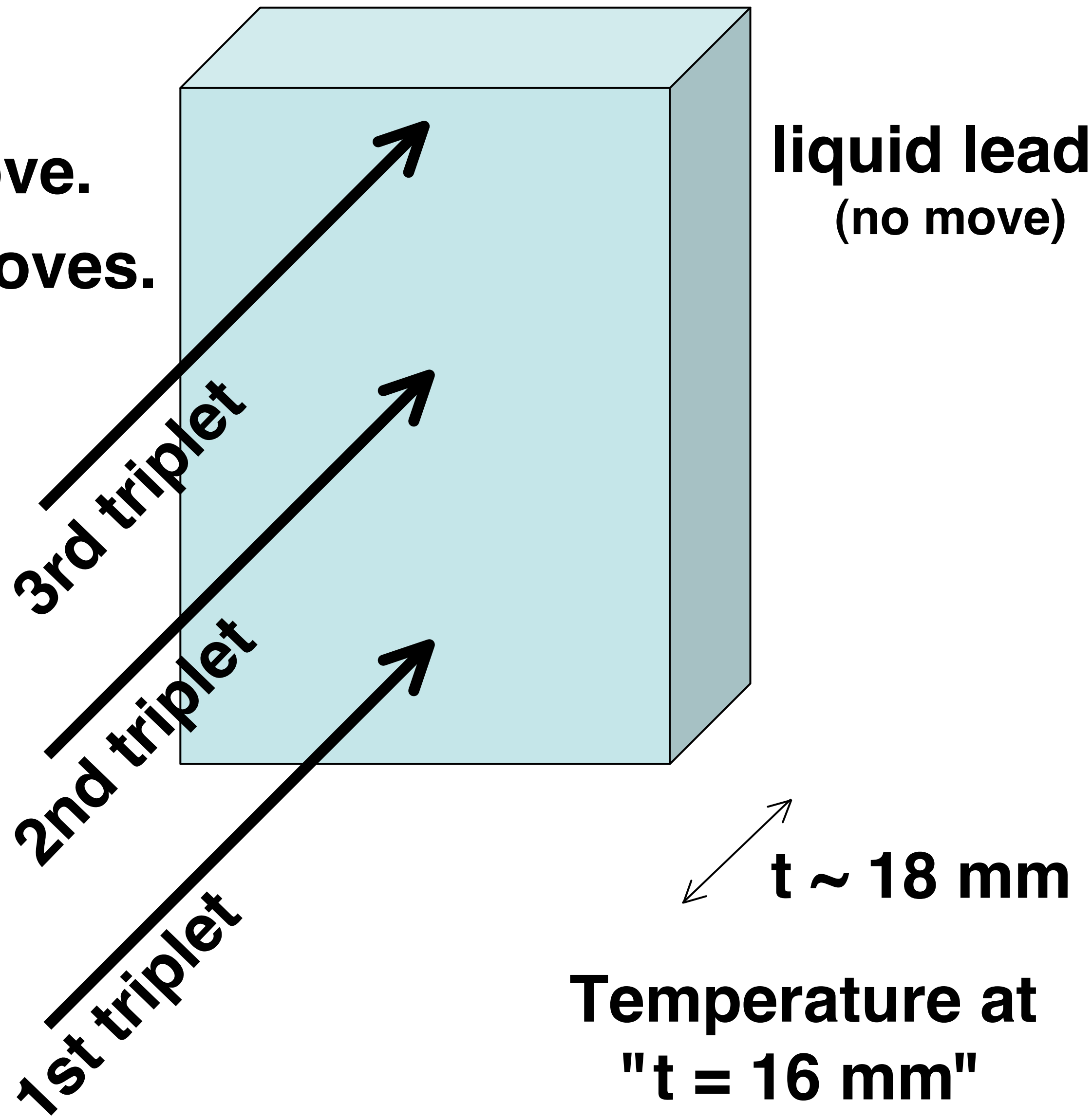
- **Liquid Lead doesn't move.**
- **Beam injection point moves.**



Simulation of heating by beam (Wanming-san)

Model

- **Liquid Lead doesn't move.**
- **Beam injection point moves.**



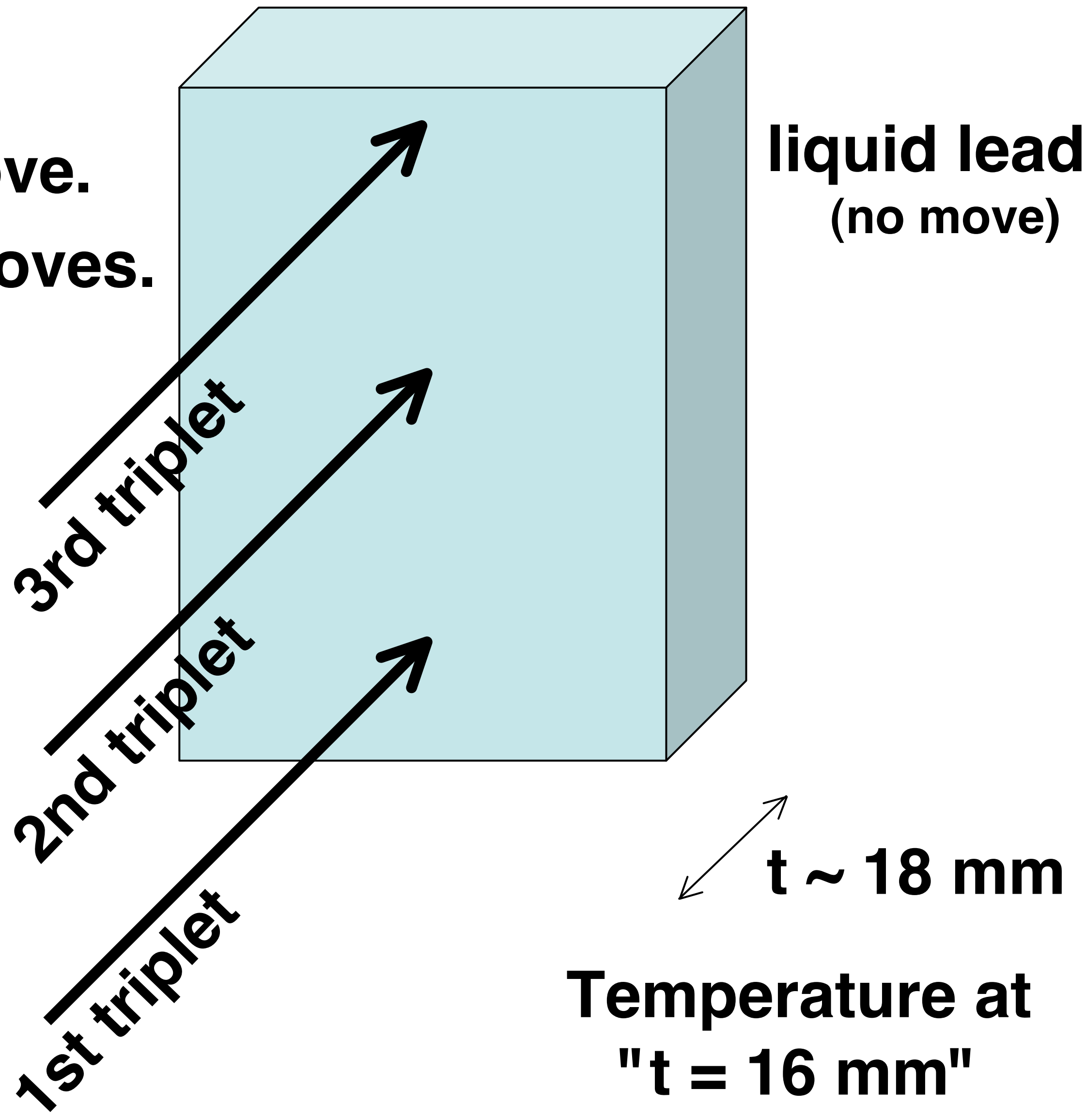
Temperature at "t = 16 mm" is monitored

Simulation of heating by beam (Wanming-san)

Model

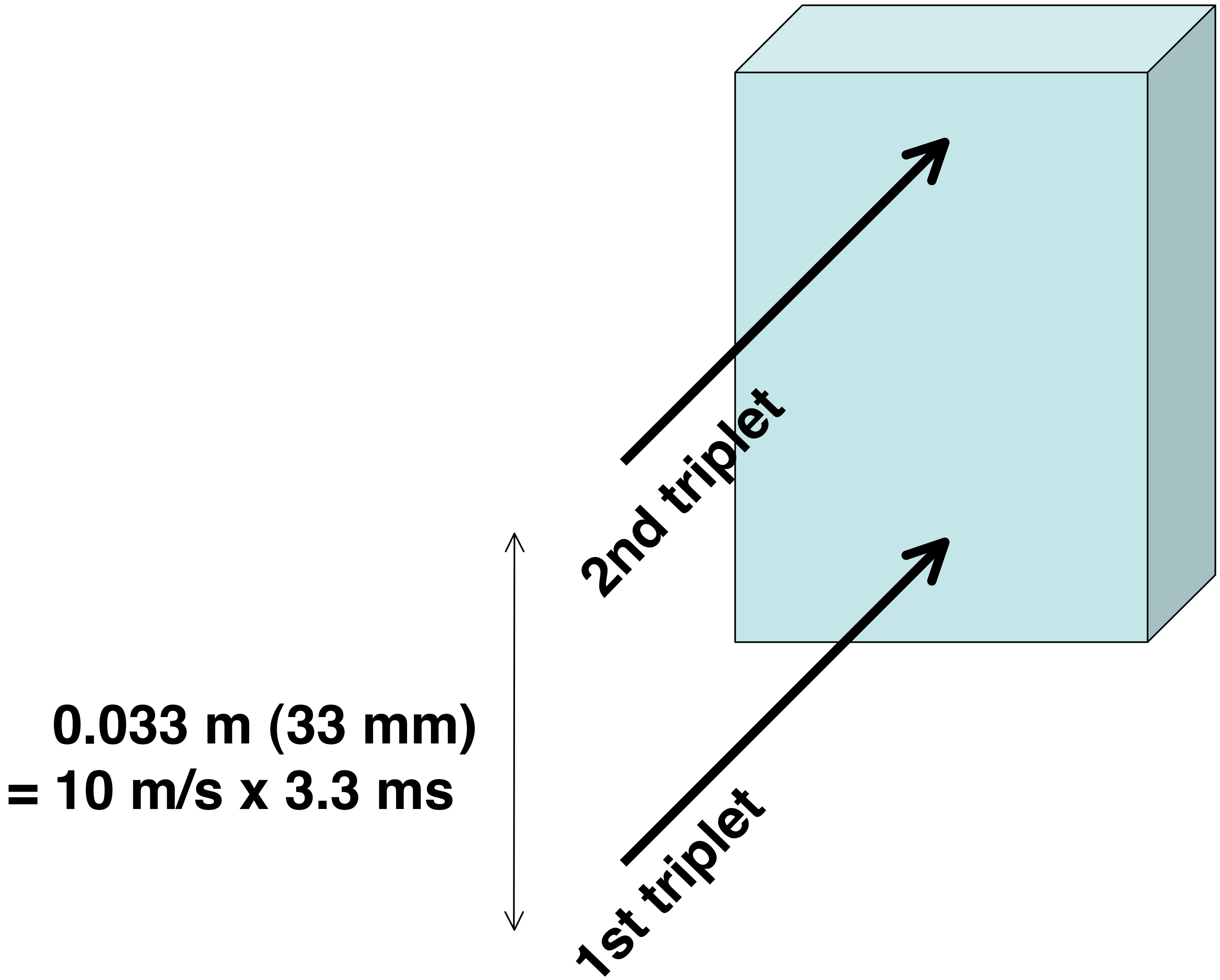
- **Liquid Lead doesn't move.**
- **Beam injection point moves.**

It is not written in this figure, however bunch structure in the triplet (= 3 mini-trains) is reproduced in the simulation.

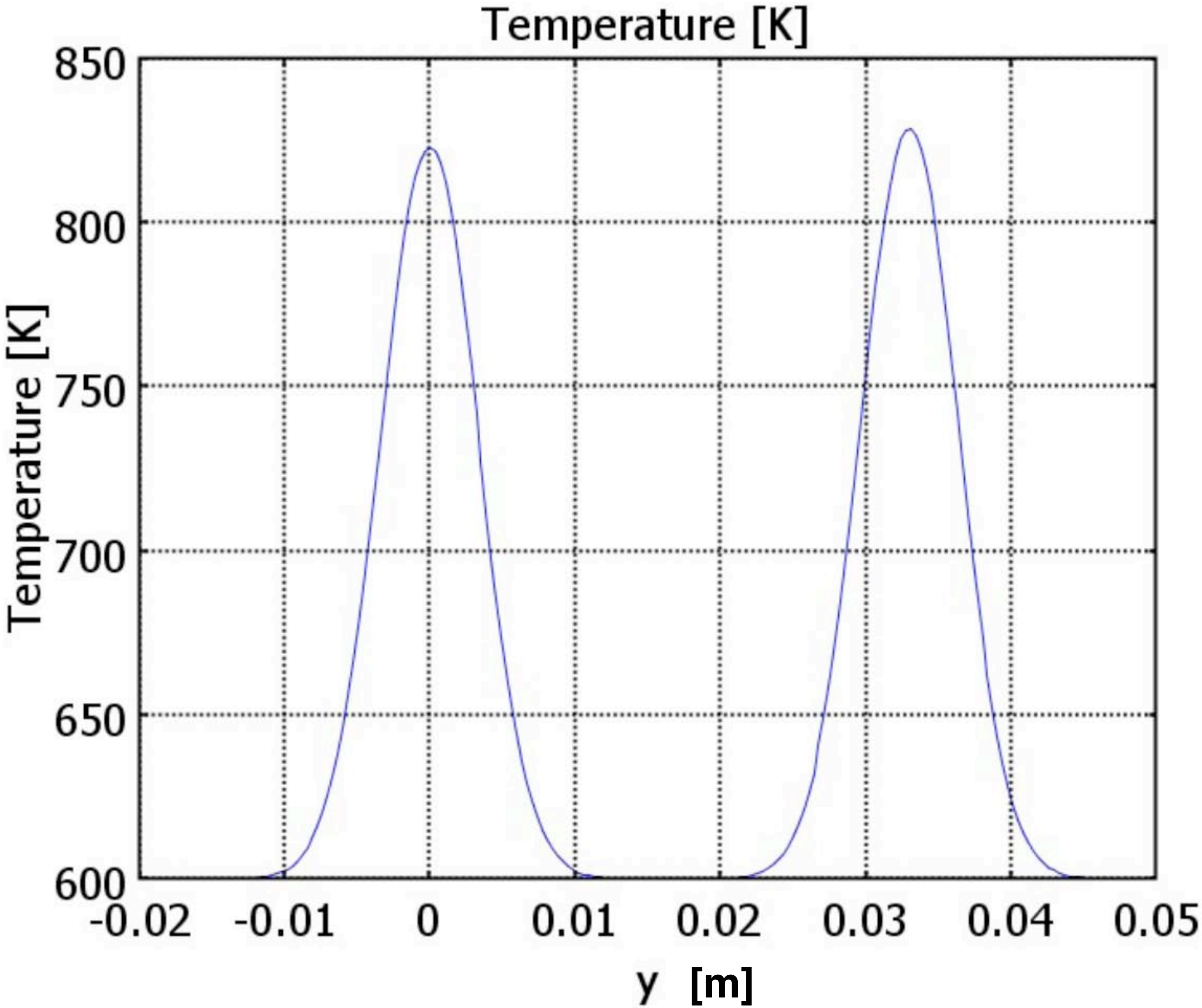


Temperature at "t = 16 mm" is monitored

10 m/s, after 2 triplets

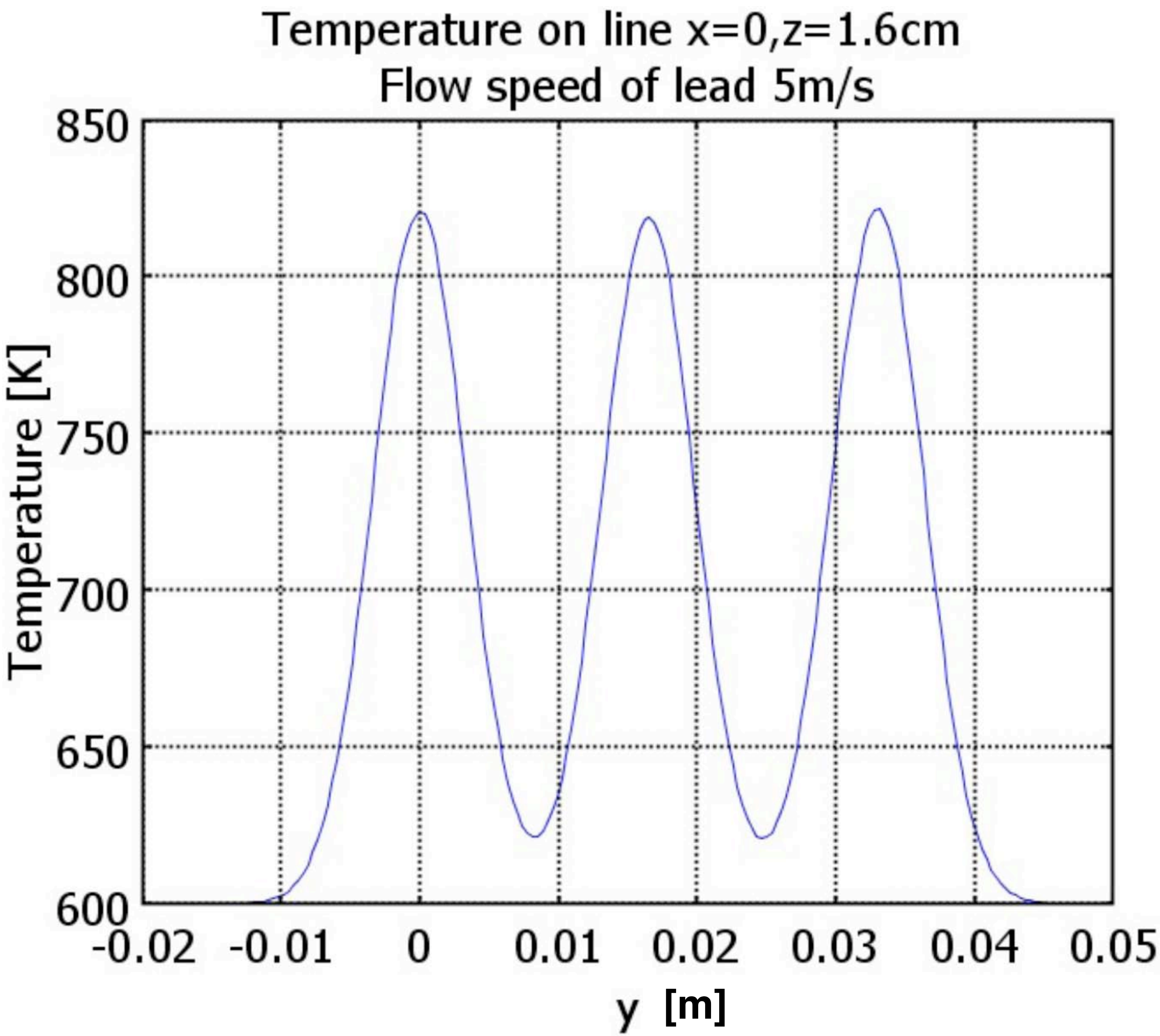


10 m/s, after 2 triplets



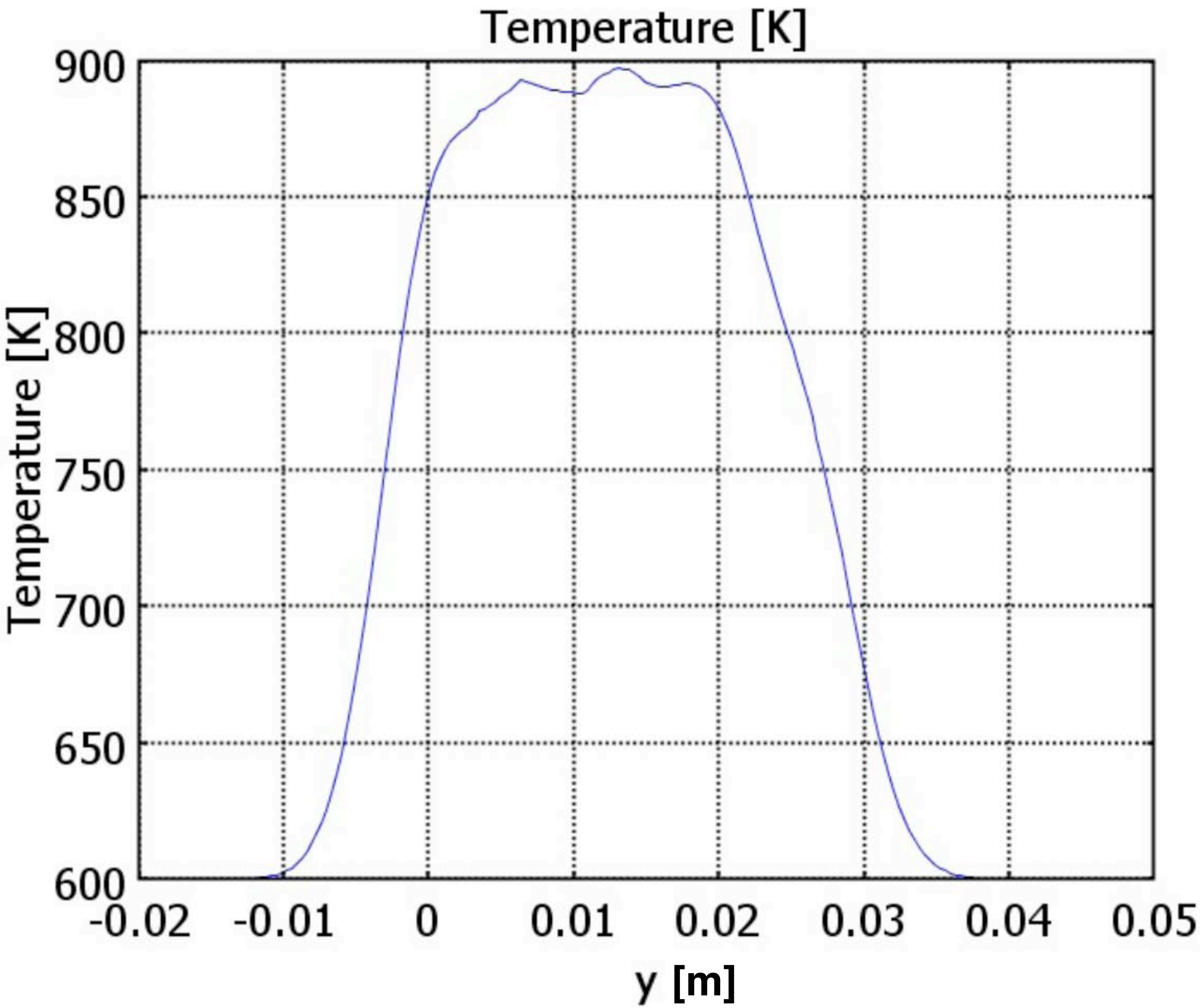
Wanming (ANL)

5 m/s, after 3 triplets



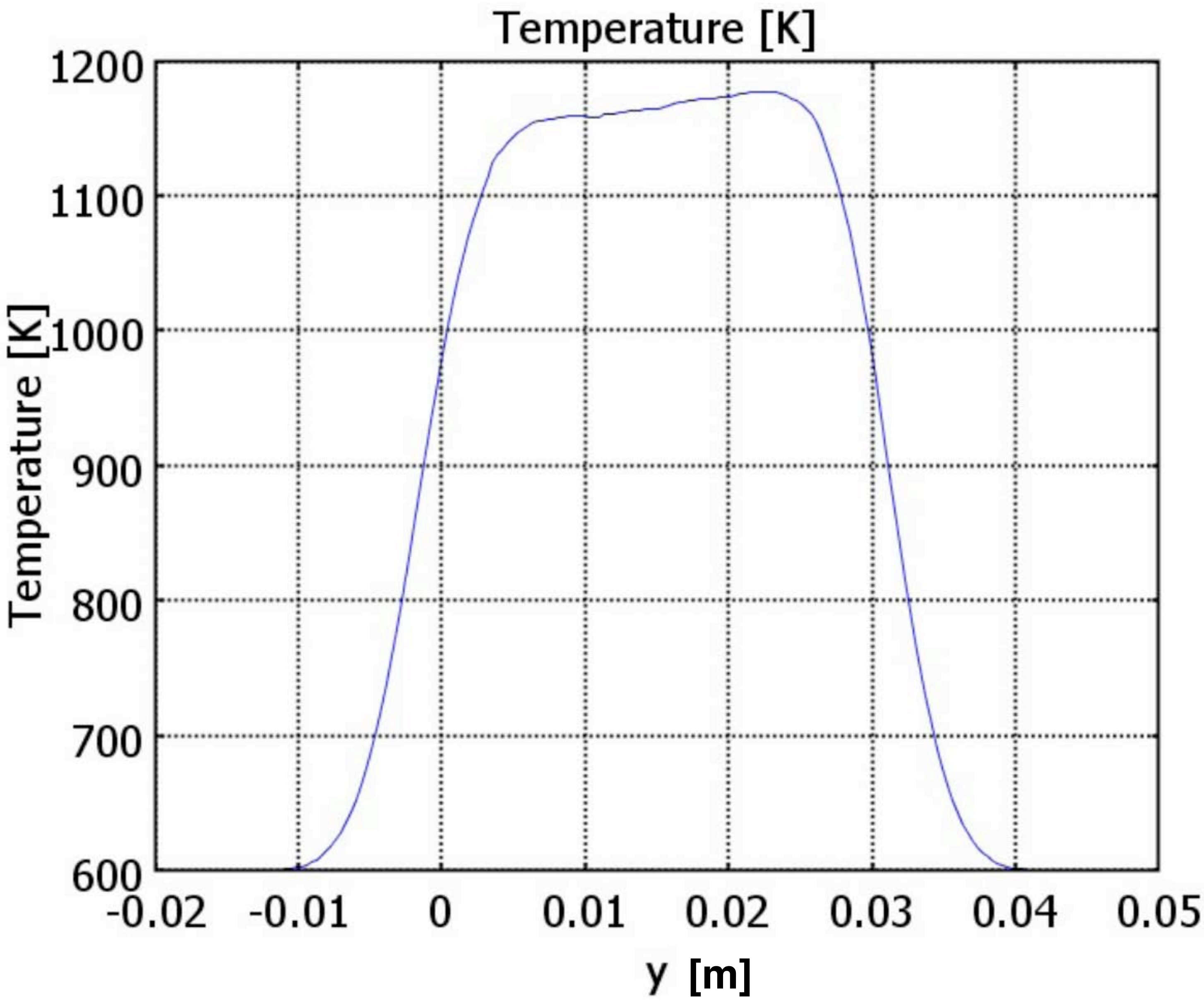
Wanming (ANL)

2 m/s, after 5 triplets



Wanming (ANL)

1 m/s, after 10 triplets



Wanming (ANL)

Simulation of heating by beam (Wanming-san)

- No heat problem in 300 Hz generation
- Flow speed can be low.
  10 m/s is not necessary.
  Probably 2 m/s is OK.
- Temperature is 900 K (= 600 C)
  if flow speed = 2 m/s.
  Lower than brazing melting temp. (800-900C).

Heating by eddy current (James Rochford)

Model

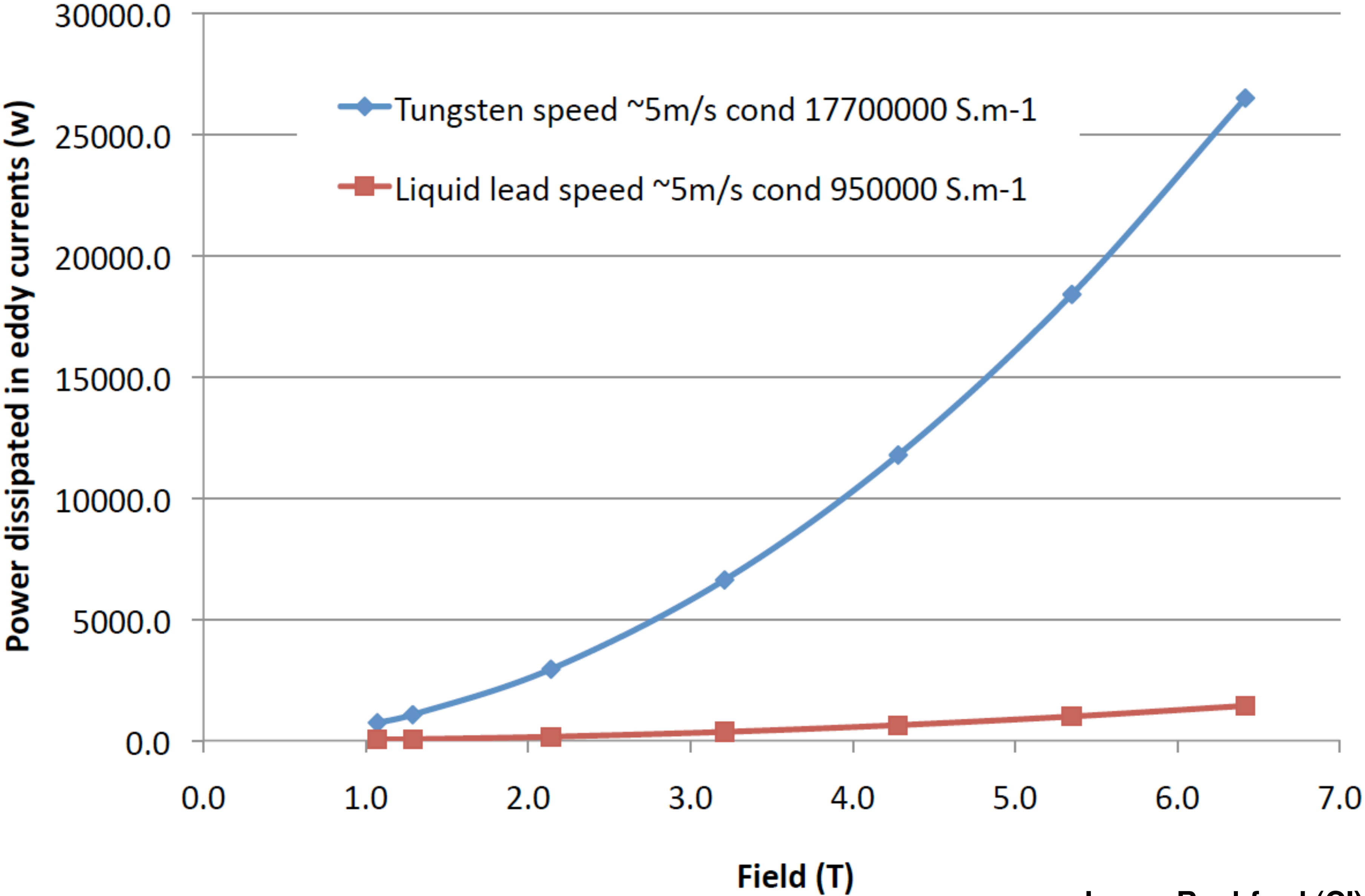
- a rotating rim (solid)
- mean diameter 0.955m
- angular velocity 99rpm
- rim speed of 4.95 m/s.
- the radial thickness of the rim = 4.5cm
- the longitudinal thickness =14mm

Result of simulation

5 m/s, solid lead, 6 Tesla immerse target

--> ~ 1 kW

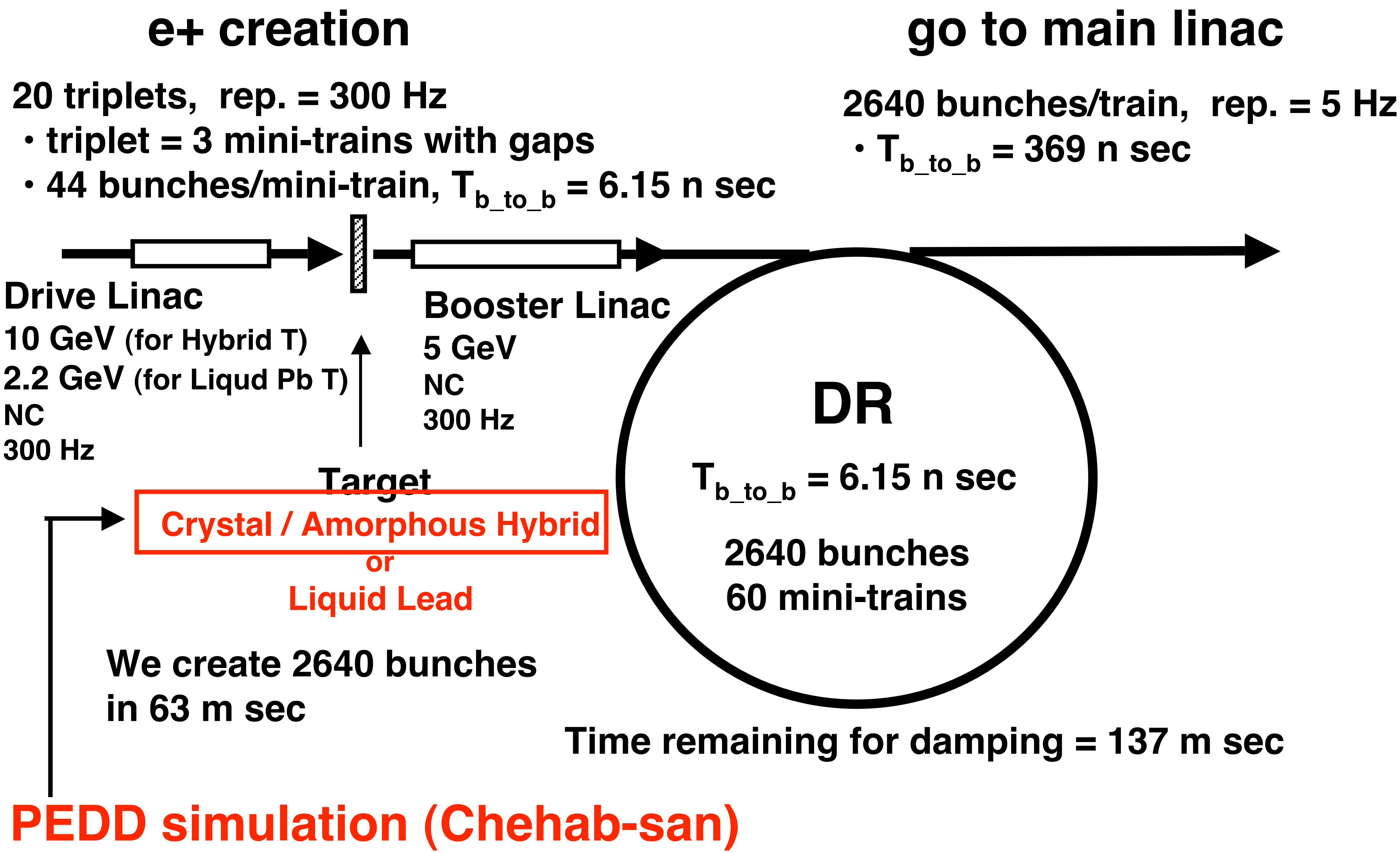
Heating by eddy current (James Rochford)



James Rochford (CI)

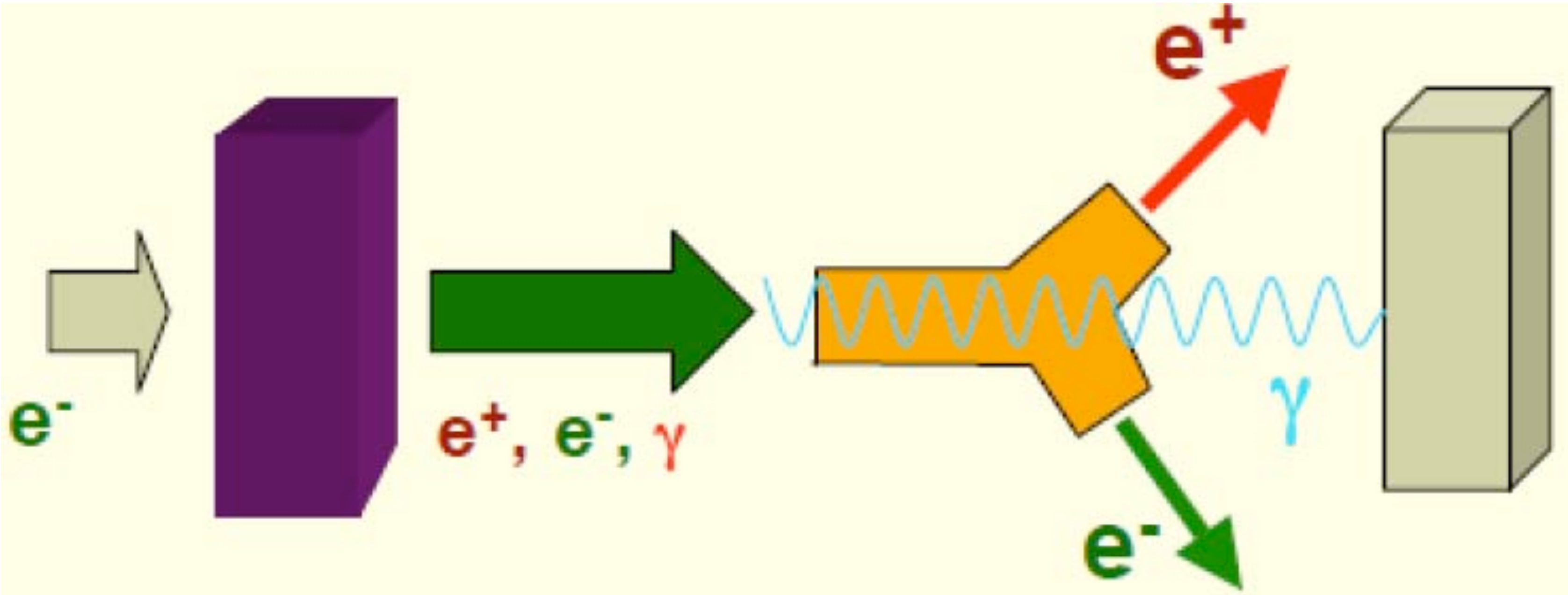
Advanced Conventional e+ Source for ILC

Crystal/Amorphous Hybrid Target or Liquid Lead Target
Normal Conducting Drive and Booster Linacs in 300 Hz operation



Hybrid Target

Chehab-san



"Radiator"
Thin CRYSTAL

"Converter"
Thick AMORPHOUS

Hybrid Target

Chehab-san

HYBRID SCHEME FOR ILC & CLIC

- **RECALL:** it might be interesting to remind a comparison made in the case of CLIC between purely amorphous, purely crystal and hybrid targets in the case of an incident beam with σ=1mm [CLIC WORKSHOP OCTOBER 2007]
  - COMPARISON WITH PURELY AMORPHOUS AND CRYSTAL TARGETS GIVING THE SAME YIELD (at E- = 5 GeV)
  - If we consider an amorphous target giving almost the same total positron yield η+ [~8 e+/e-], the target thickness is: 9 mm
  - A purely crystal source giving the same total e+ yield is 4 mm thick
  - Comparison of the 3 kinds of e+ sources for CLIC conditions [$3.4x10^{12}$e-/pulse]: we compare for same total η+ :

	Total Dep. En.(%)	PEDD(Gev/cm3/e-)	PEDD (J/g)[pulse]
Purely amorp.	4.5%	7	200
Purely crystal	2.4%	7.2	204
Hybrid	6%	1.5	42

  - We recall that these results correspond to an incident e- beam with σ= 1mm
  - We can see the interesting advantage of the hybrid source on the others for the PEDD. If we consider the maximum limit of 35 J/g for W, we are led to multiple targetting: 6 for the to first cases and 1-2 for the third. (see discussion later). Comparisons related to accepted yields instead of total yields lead to analog conclusions.
  - The intensity in this table is larger ($3.4x10^{12}$e-) than in the former ($2.34x10^{12}$)

Hybrid Target

Chehab-san

HYBRID SCHEME FOR ILC & CLIC

- **RECALL:** it might be interesting to remind a comparison made in the case of CLIC between purely amorphous, purely crystal and hybrid targets in the case of an incident beam with σ=1mm [CLIC WORKSHOP OCTOBER 2007]
  - COMPARISON WITH PURELY AMORPHOUS AND CRYSTAL TARGETS GIVING THE SAME YIELD (at E- = 5 GeV)
  - If we consider an amorphous target giving almost the same total positron yield η_+ [~8 e+/e-], the target thickness is: 9 mm
  - A purely crystal source giving the same total e+ yield is 4 mm thick
  - Comparison of the 3 kinds of e+ sources for CLIC conditions [3.4×10^{12}e-/pulse]: we compare for same total η_+ :

	Total Dep. En.(%)	PEDD(Gev/cm3/e-)	PEDD (J/g)[pulse]
Purely amorp.	4.5%	7	200
Purely crystal	2.4%	7.2	204
Hybrid	6%	1.5	42

PEDD important

  - We recall that these results correspond to an incident e- beam with σ= 1mm
  - We can see the interesting advantage of the hybrid source on the others for the PEDD. If we consider the maximum limit of 35 J/g for W, we are led to multiple targetting: 6 for the to first cases and 1-2 for the third. (see discussion later). Comparisons related to accepted yields instead of total yields lead to analog conclusions.
  - The intensity in this table is larger (3.4×10^{12}e-) than in the former (2.34×10^{12})

Hybrid Target

Chehab-san

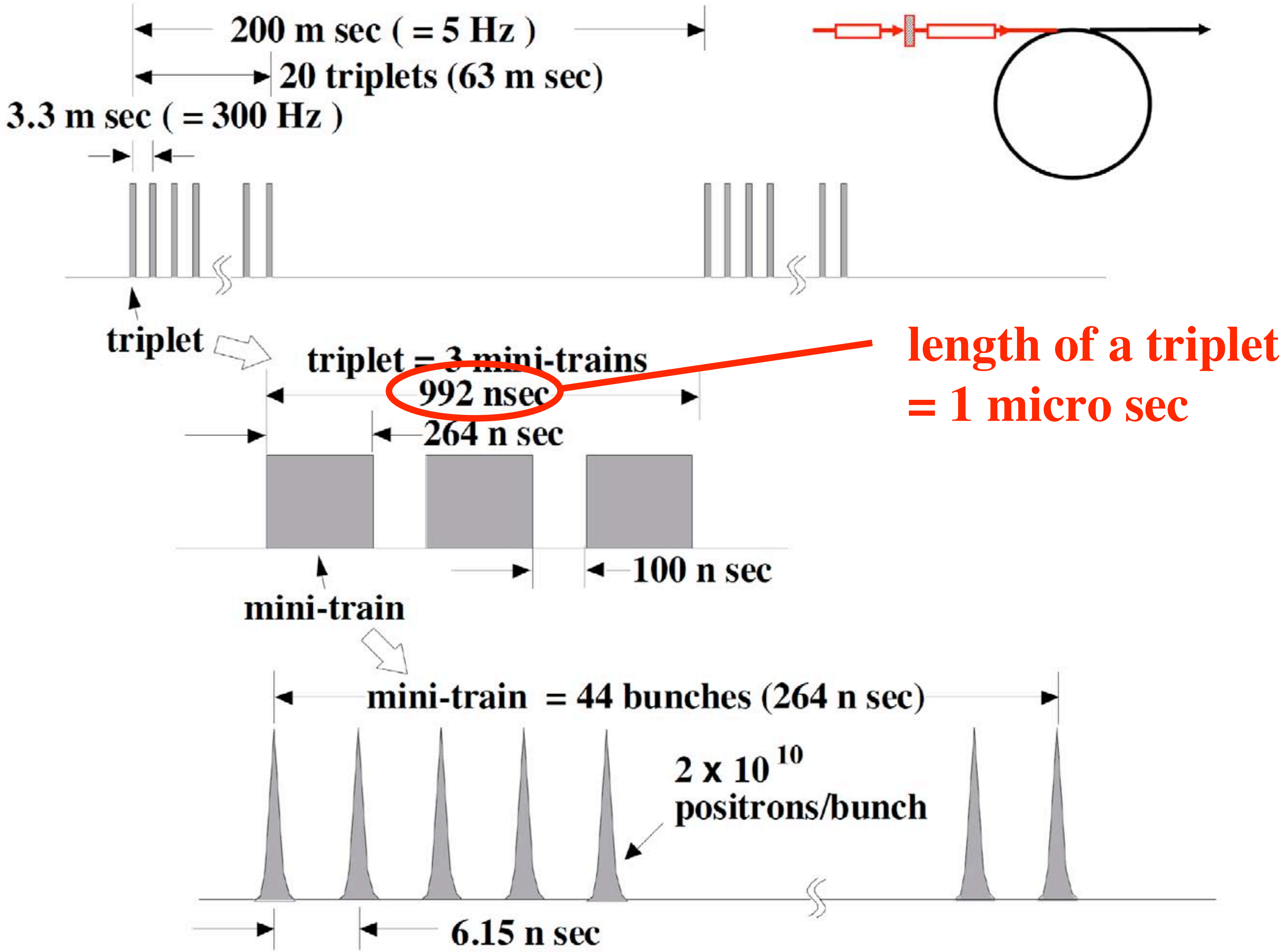
	Total Dep. En.(%)	PEDD(Gev/cm3/e-)	PEDD (J/g)[pulse]
Purely amorp.	4.5%	7	200
Purely crystal	2.4%	7.2	204
Hybrid	6%	1.5	42

Hybrid Target reduces PEDD ~ 1/5

300 Hz e^+ Generation solves flux Concentrator issue

- 1 micro sec flux concentrator <-- existing technology
  - It was working at SLC.
    6 T, 60 Hz (120 Hz)
  - Prototype study is ongoing for SuperKEKB
    10 T, 50 Hz, need long time operation test
- Baseline design assumes 1m sec flux concentrator
  ---> jump 1000 times
- 300 Hz generation use 1 micro sec flux concentrator

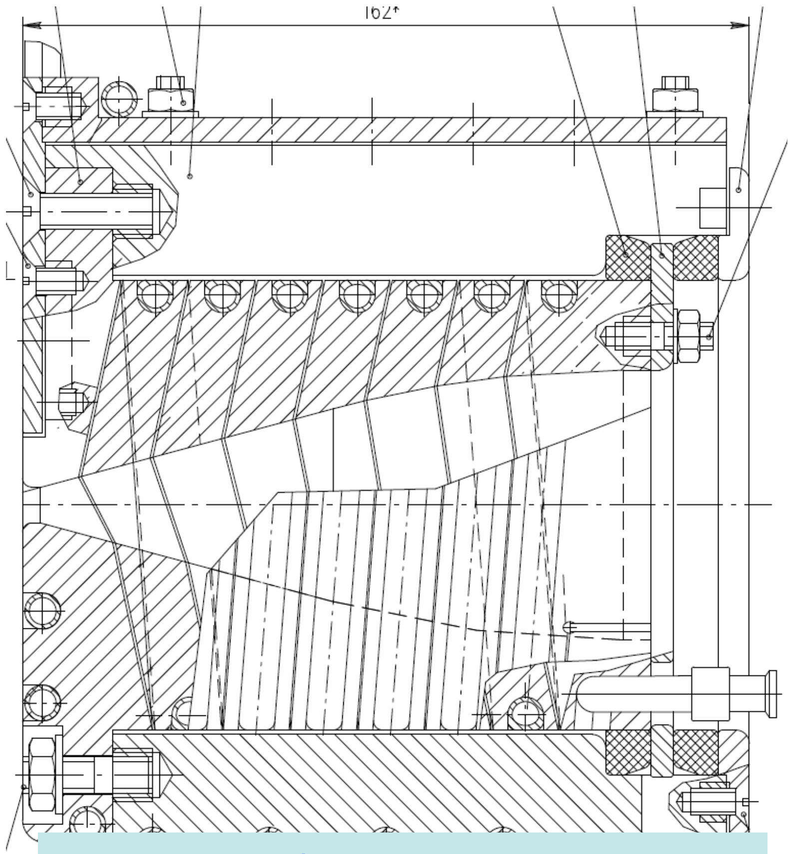
Beam before DR



Flux concentrator R&D in collaboration with BINP

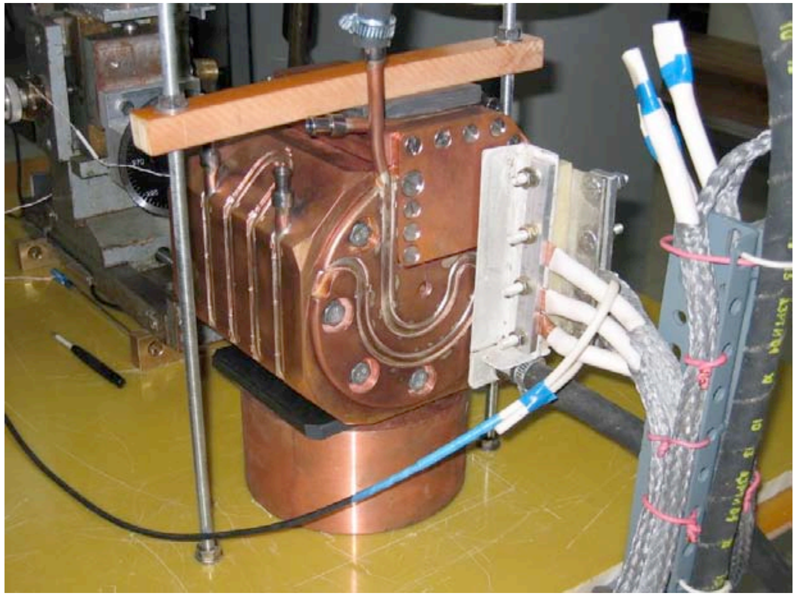
1. Developing for KEKB e^+ source upgrade in collaboration with BINP
2. Based on a BINP design originally for NLC e^+ source
3. First full-power prototype had a problem of large transverse field. ($B_T \sim 0.75T$ @$B_Z = 5T$)
4. Second full-power prototype with reduced BT ($B_T \sim 0.45T$ @$B_Z = 5T$) is under high-field operation test at BINP.
5. Discharging problem found -> needs small modification in the layout of the components inside a vacuum chamber.
6. The second prototype and a pulse power supply will be transferred to KEK in 2010 spring. Operation test and beam focusing study will be performed at KEK.

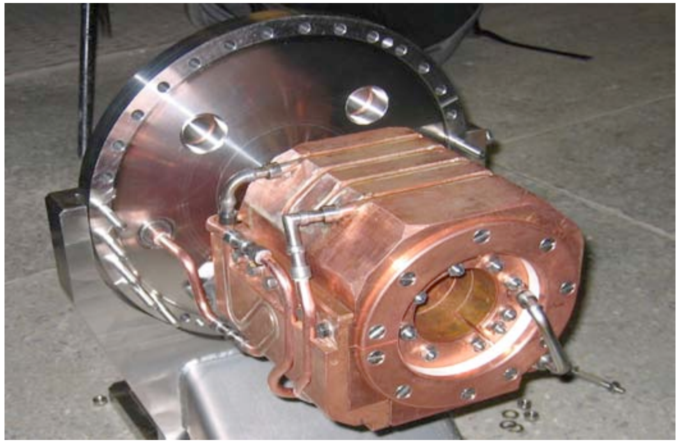
Kamitani-san

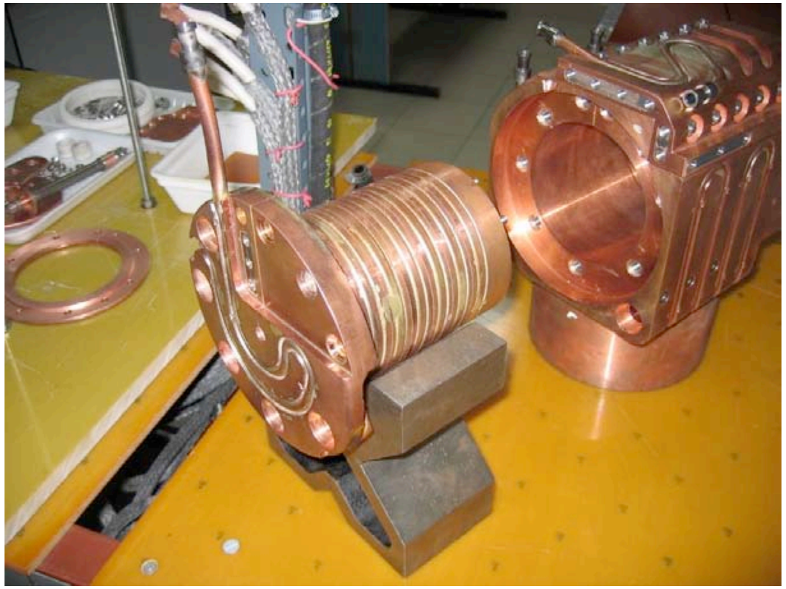


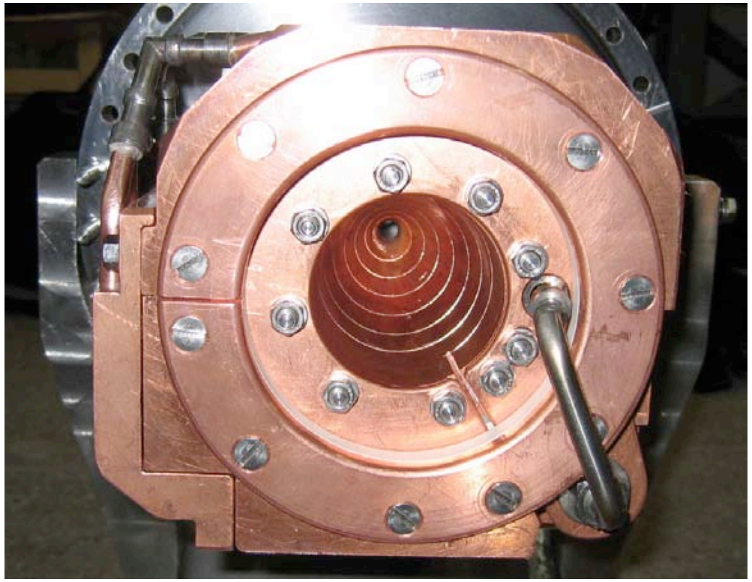
•Magnetic field B_Z	10 Tesla
•aperture diameter	8 mm
•Pulse duration	25 μs
•Repetition rate	50 Hz
•Voltage	2.5 kV
•Peak current	30 kA
•Power dissipation	18 kW

Flux concentrator full-power prototype



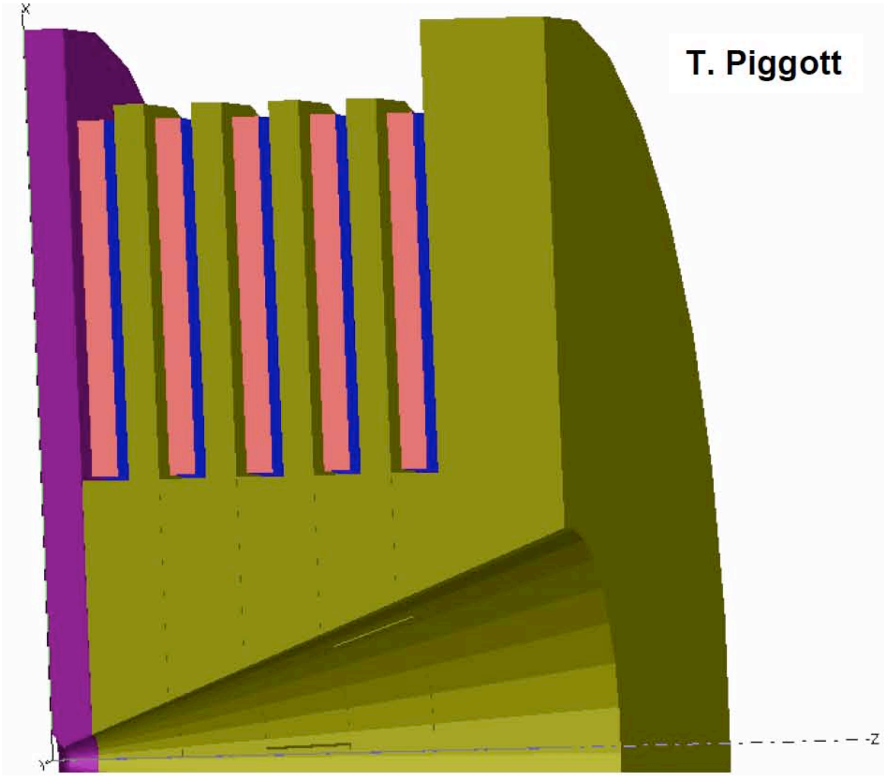


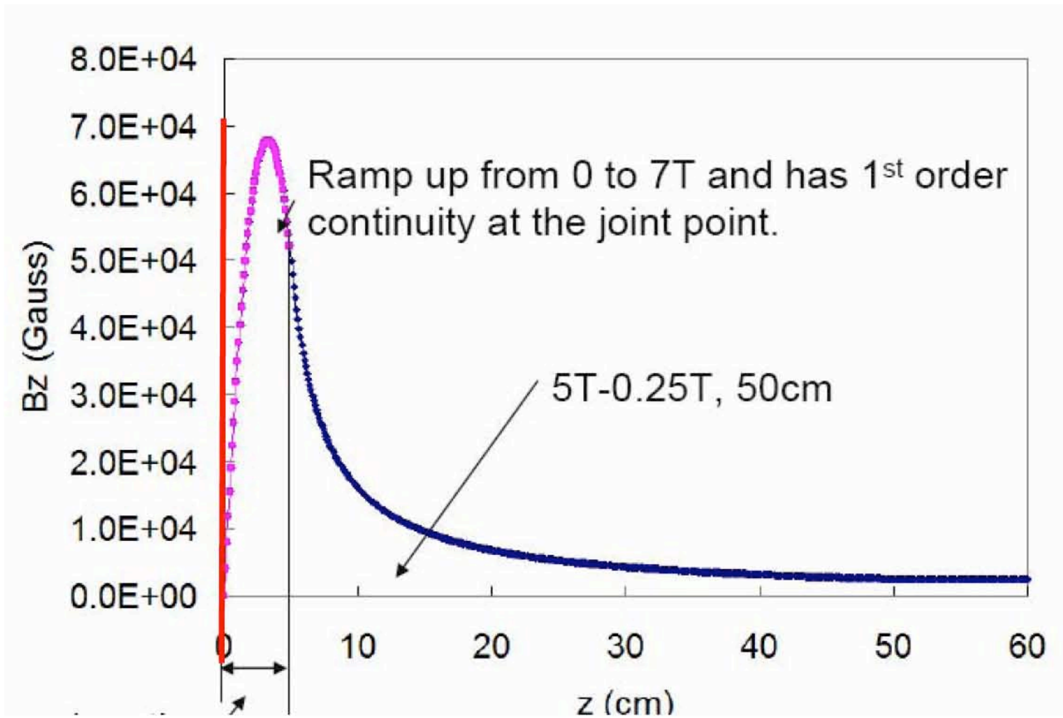




Built at BINP

OMD 2: Pulsed Flux Concentrator



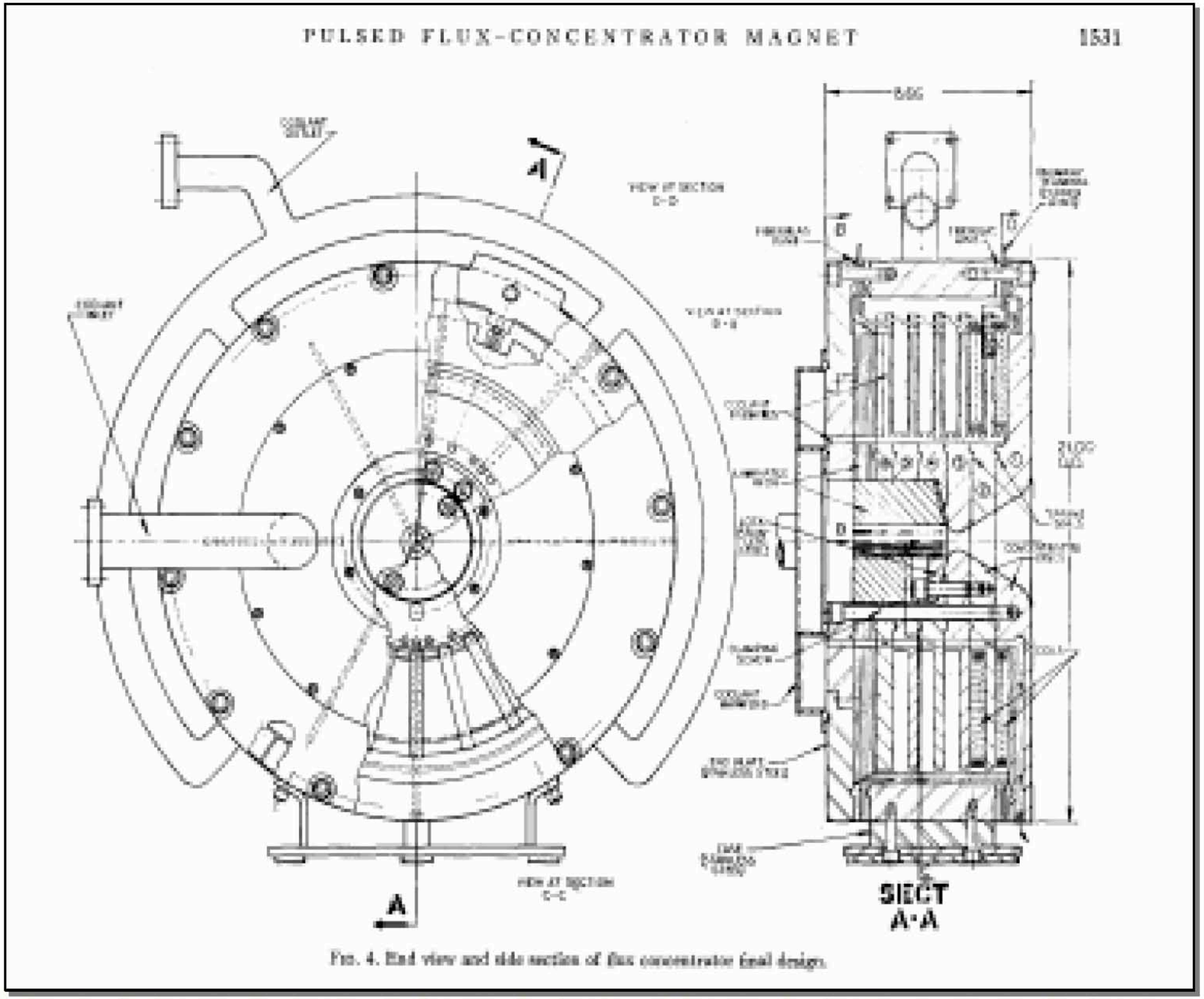


W. Liu

- Reduces magnetic field at the target
  - **Reduced capture efficiency, ~21%**
- Pulsed flux concentrator used for SLC positron target
  - **It is a large extrapolation from SLC to ILC**
  - **1μs -> 1ms pulse length**

Jeff (POSIPOL 2008)

Similar devices have been created before



- Brechna, et al.
  - **1965**
  - **Hyperon experiment**
- Very preliminary ANL and LLNL simulations do not indicate showstoppers
- No one has stepped up to claim this is "doable"

Jeff (POSIPOL 2008)

ILC parameters are close to Brechna

Jeff (POSIPOL 2008)

Parameter	Brechna	ILC	Units
Field Strength	10	7	T
Pulse Length	40	1	ms
Repetition Rate	1/3	5	Hz

J. Sheppard

- Extrapolation from Brechna to ILC is not large
  - **Lower field**
  - **Lower pulse length**
  - **Pulse length x repetition rate is similar**
- Requires significant design and prototyping effort

Brechna device has 400000 shots operation experinence

---> ~ 1 day at 5 Hz

Advanced Conventional e+ Source for ILC

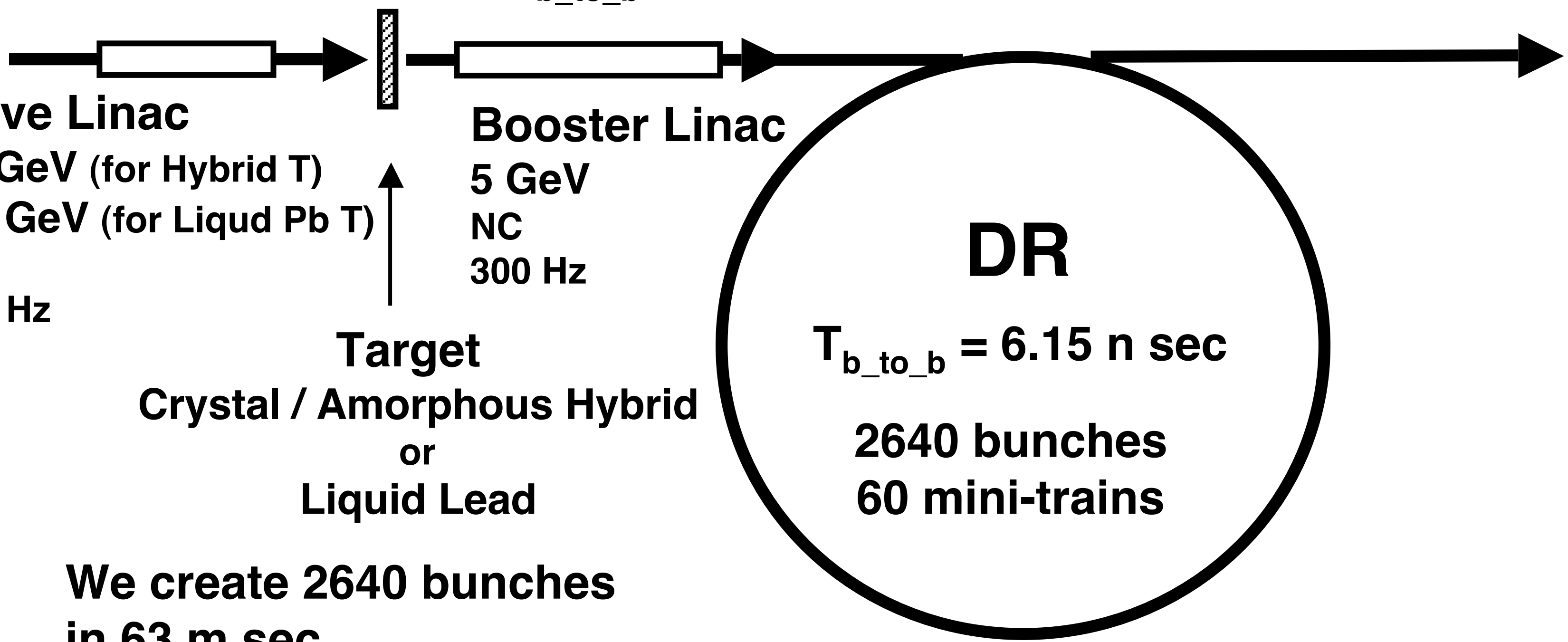
Crystal/Amorphous Hybrid Target or Liquid Lead Target
Normal Conducting Drive and Booster Linacs in 300 Hz operation

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



We create 2640 bunches in 63 m sec

Time remaining for damping = 137 m sec
Is this OK?

Advanced Conventional e+ Source for ILC

Crystal/Amorphous Hybrid Target or Liquid Lead Target
Normal Conducting Drive and Booster Linacs in 300 Hz operation

Time remaining for damping = 137 m sec
Is this OK?

Answer from Susanna-san

present DCO lattice has a transverse damping time of 21 ms, i.e. 140 msec corresponds to 6.7damping times. This should be enough to get the extracted vertical emittance near enough to the equilibrium emittance.

For the minimum machine the wiggler is reduced and it is easier to get a short damping time.

Summary of 300 Hz generation

1. Target survivability is the issue in conventional source.
2. Ease the survivability issue by 300 Hz gen.
   make e^+s in 63 m sec
3. Advanced Targets Technology
   Crystal/Amorphous Hybrid Target
   Liquid Target
4. We can use existing flux concentrator tech.
5. Advanced Targets Tech. + 300 Hz gen.
   maybe the most mature solution

SUMMARY

Summary

1) Conventional e+ Source

- only e+ source which we have experience in real accelerators
- Independent
- No polarization
- target survivability?

2) Two Proposals to Mitigate Target Problem

- LowE e- driven
- 300 Hz generation

3) Advanced Target Technology is a Key

- Liquid Lead Target
- Hybrid Target

These technologies can be tested in existing accelerators.

--> Urakawa-san's talk on 19th morning