Overview and Target R/D of 300 Hz Conventional e^+ Source for ILC

T. Omori (KEK)

12-November-2013
LCWS13 at U. of Tokyo

Truly Conventional Collaboration
ANL, IHEP, Hiroshima U, U of Tokyo, KEK, DESY, U of Hamburg

NIM A672 (2012) 52—56

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 time space = 3.3 m sec
- Create 20 triplets : 63 m sec

⇒ **Stretching in time**

Conventional e+ Source for ILC

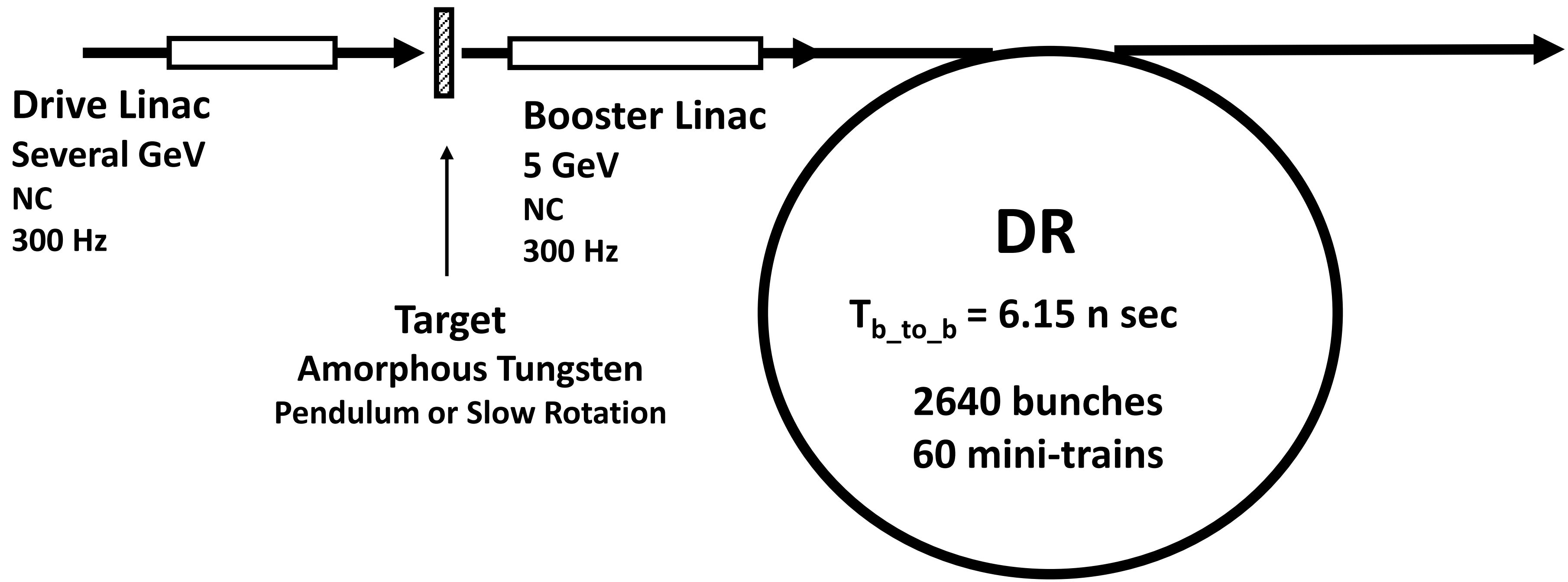
Normal Conducting Drive and Booster Linacs in 300 Hz operation

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

Conventional e+ Source for ILC

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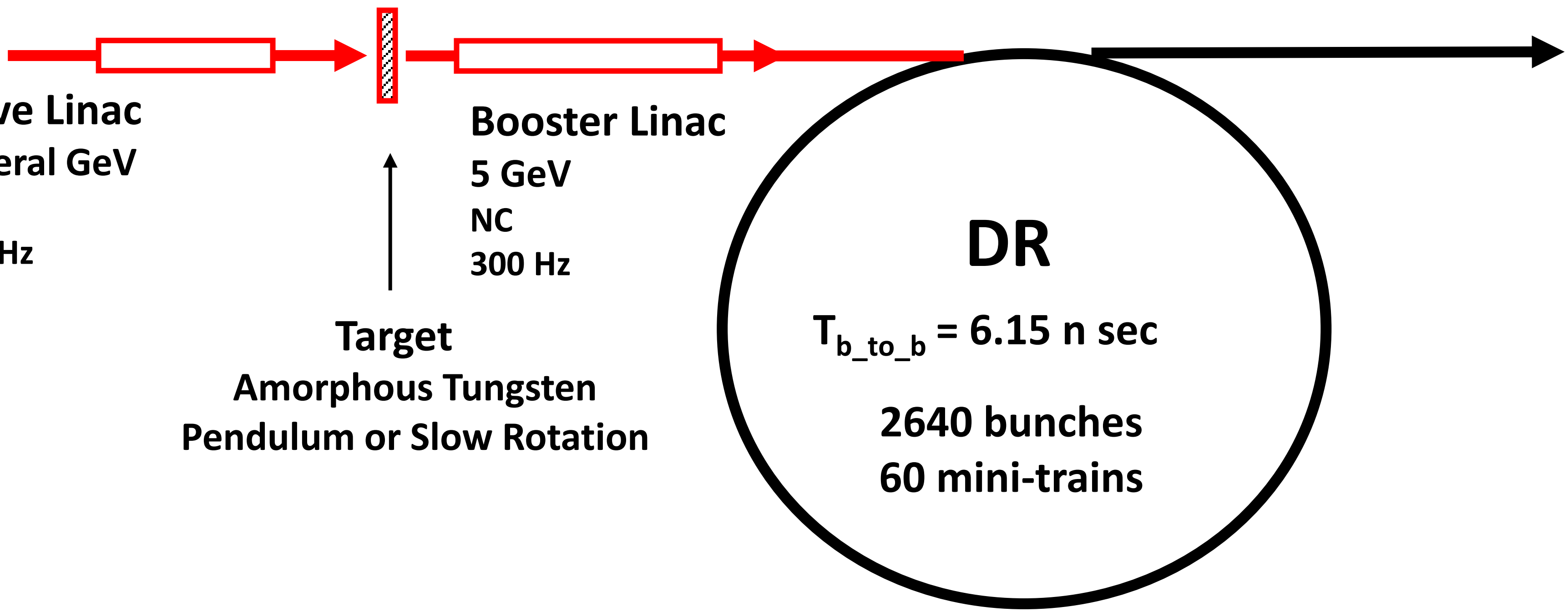

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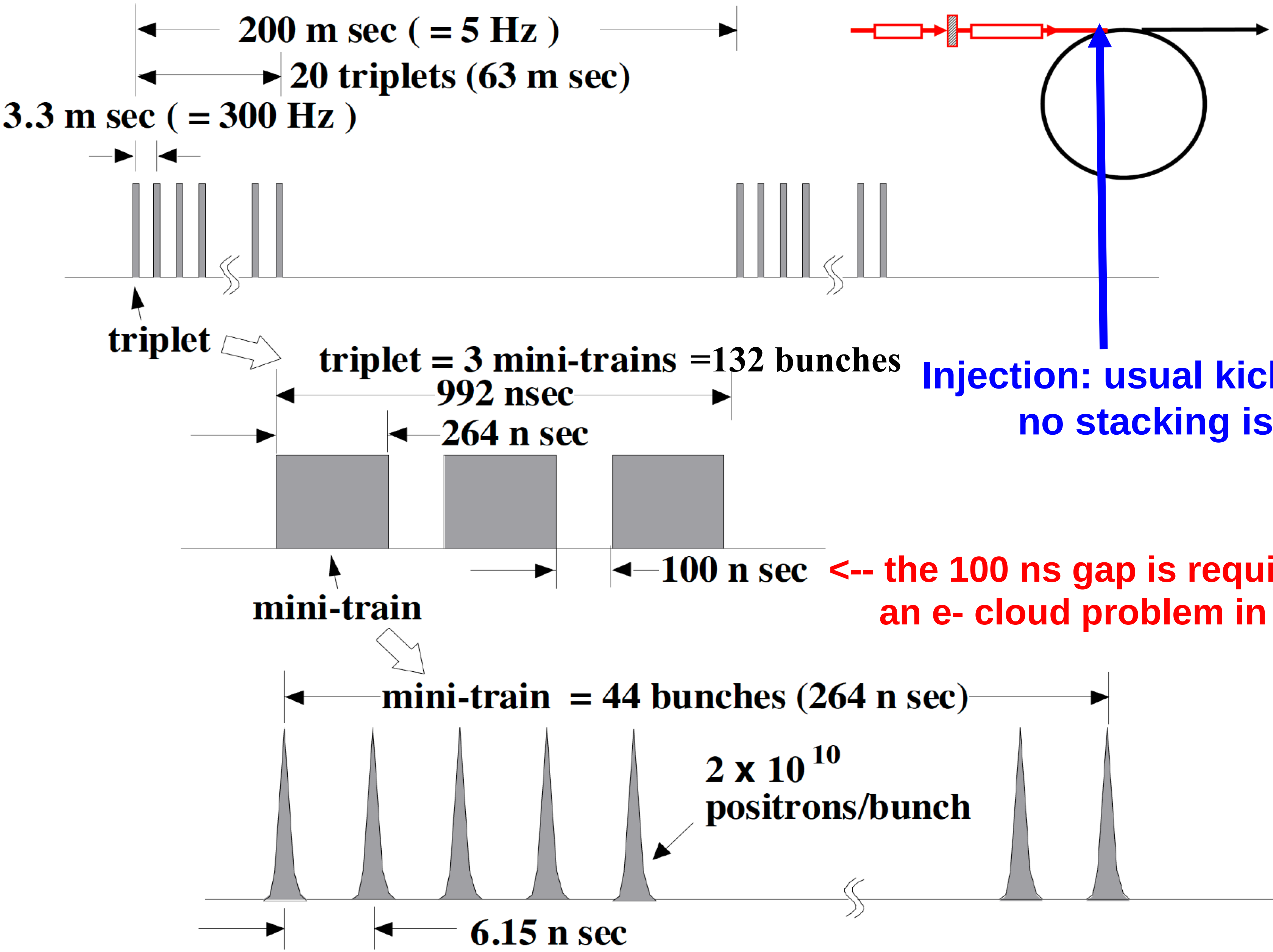
Stretching

Beam before DR



Injection: usual kicker (~ 1 us)
no stacking is necessary

<-- the 100 ns gap is required to cure an e- cloud problem in e+ DR.

Conventional e+ Source for ILC

Normal Conducting Drive and Booster Linacs in 300 Hz operation

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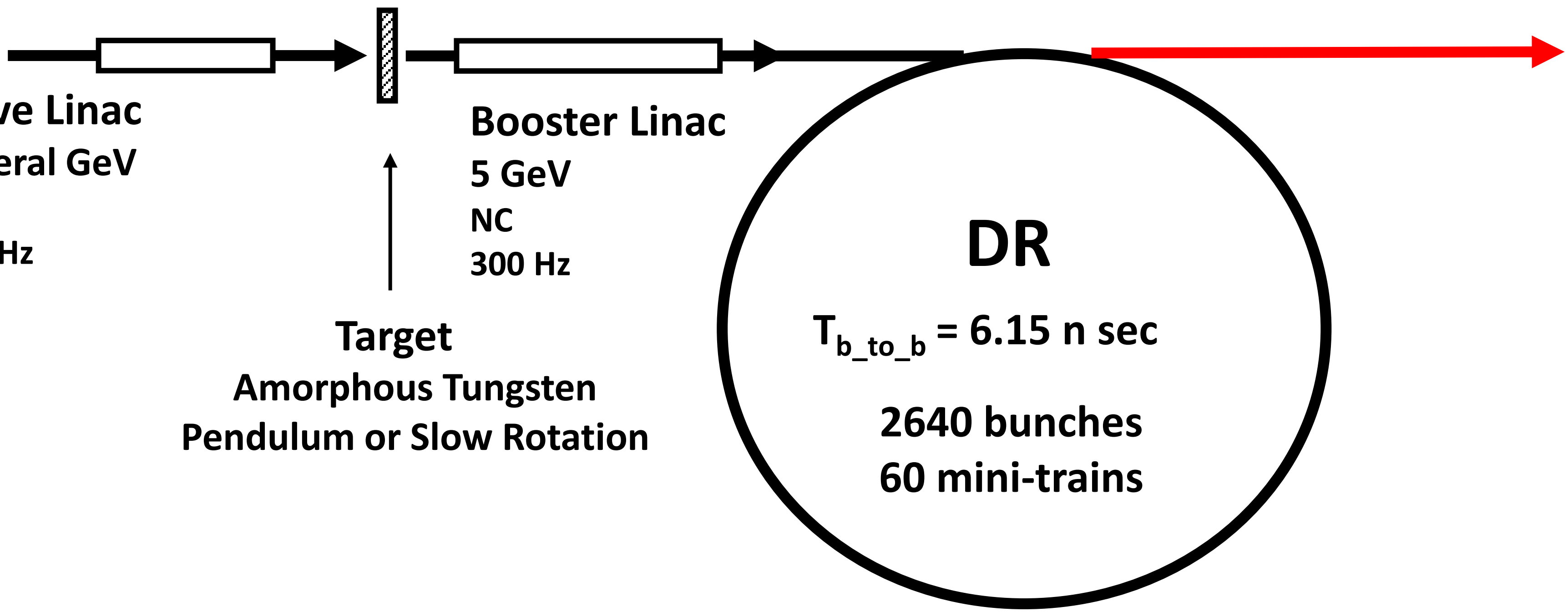


Drive Linac
Several GeV
NC
300 Hz

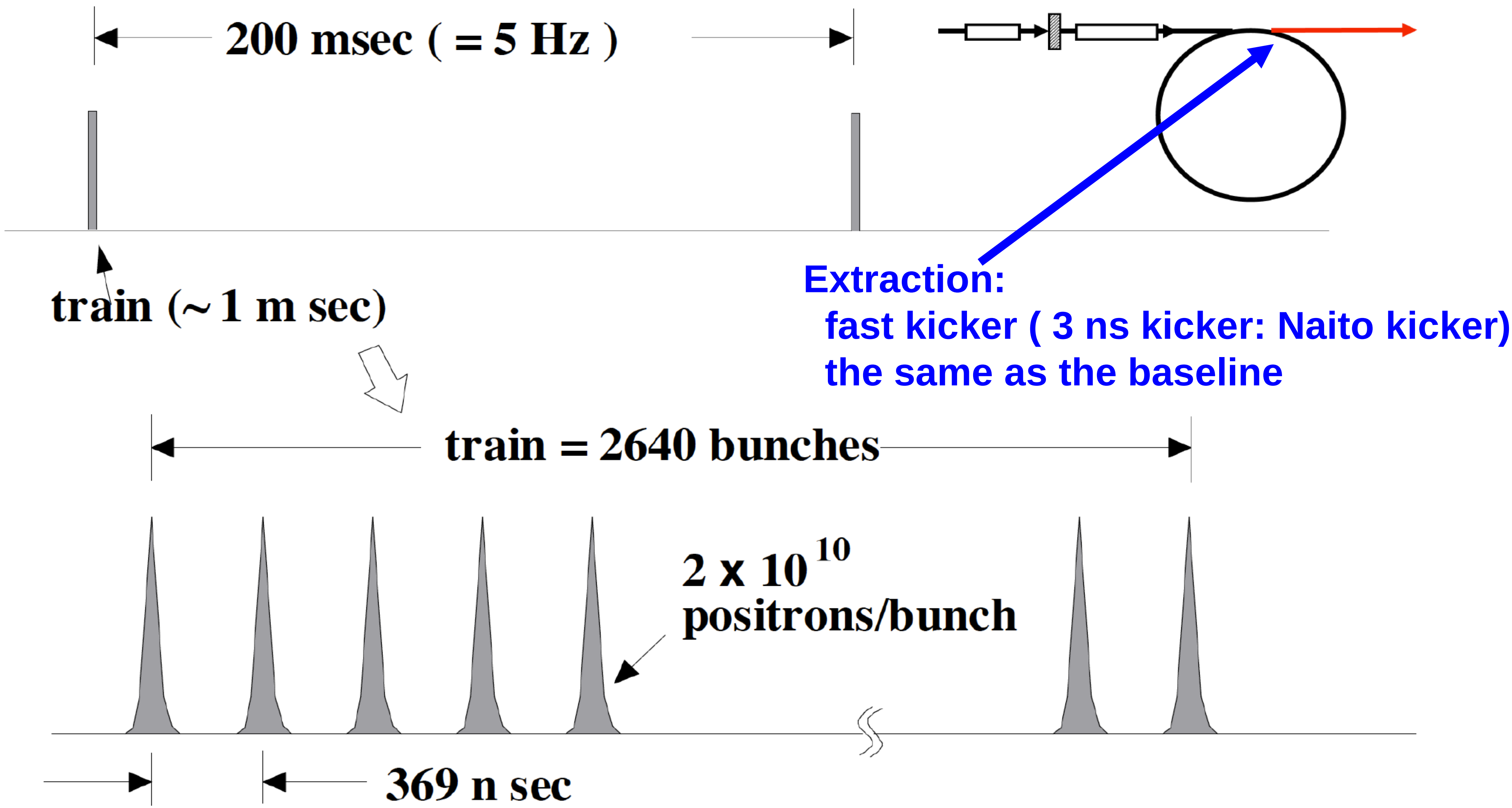
Booster Linac
5 GeV
NC
300 Hz

Target
Amorphous Tungsten
Pendulum or Slow Rotation

Time remaining for damping = 137 m sec

We create 2640 bunches in 63 m sec

Beam after DR



Target and Drive_Beam Optimization

Parameter Plots for 300 Hz scheme

e- directly on to Tungsten

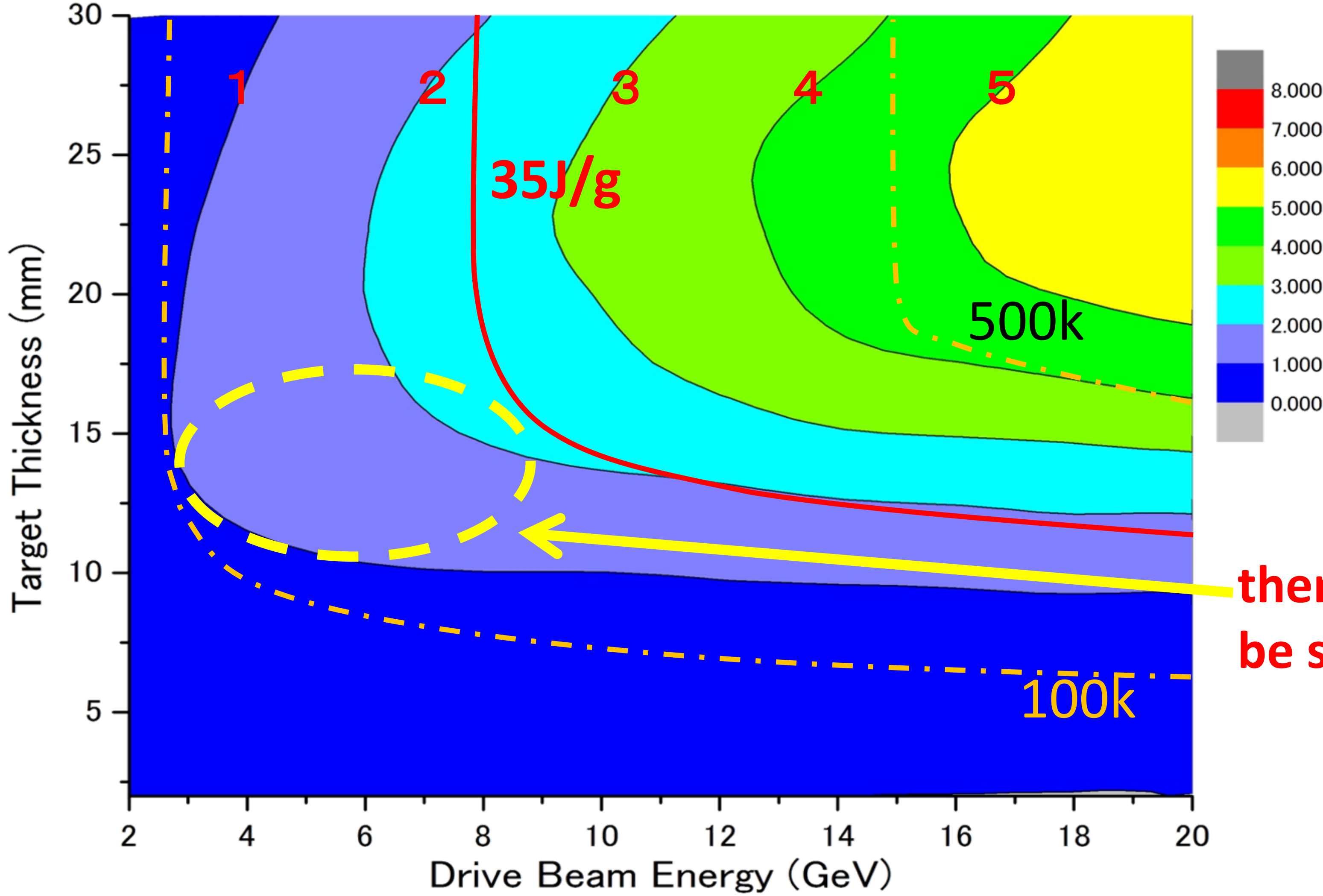
σ=4.0mm

Ne⁻(drive) = 2x10¹⁰ /bunch

colored band — accepted e+/e-

red line — PEDD J/g

yellow dash-dot line — dT max by a triplet



there seems to be solutions

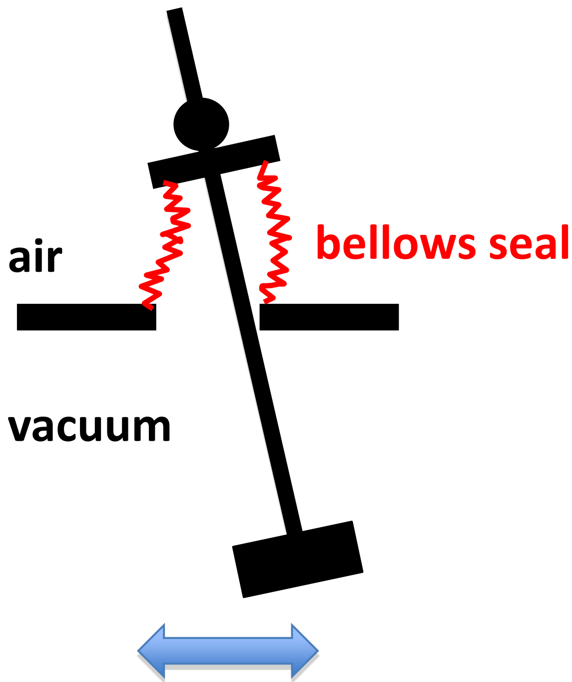
Target R/D

Pendulum Target and Rotation Target R/Ds

Moving Target

- ~1m/sec required (1/100 of undulator scheme) **(old assumption)**
- 2 possible schemes being developed at KEK

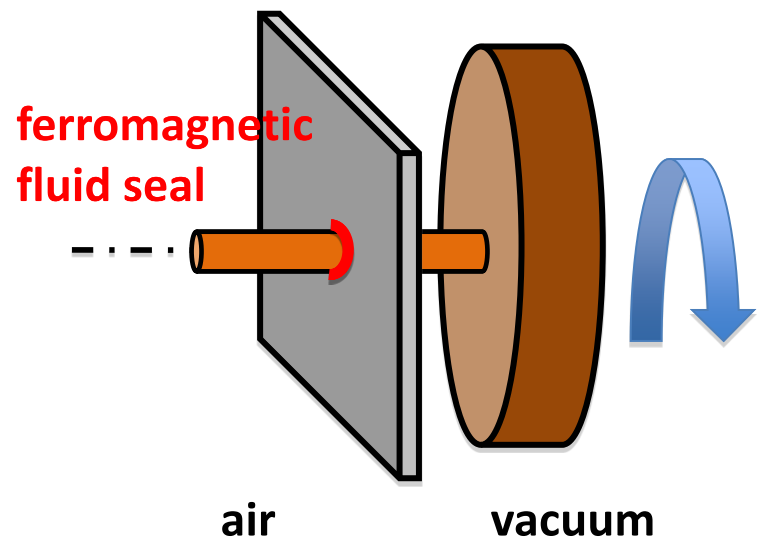
5Hz pendulum with bellows seal



main issue: life of bellows

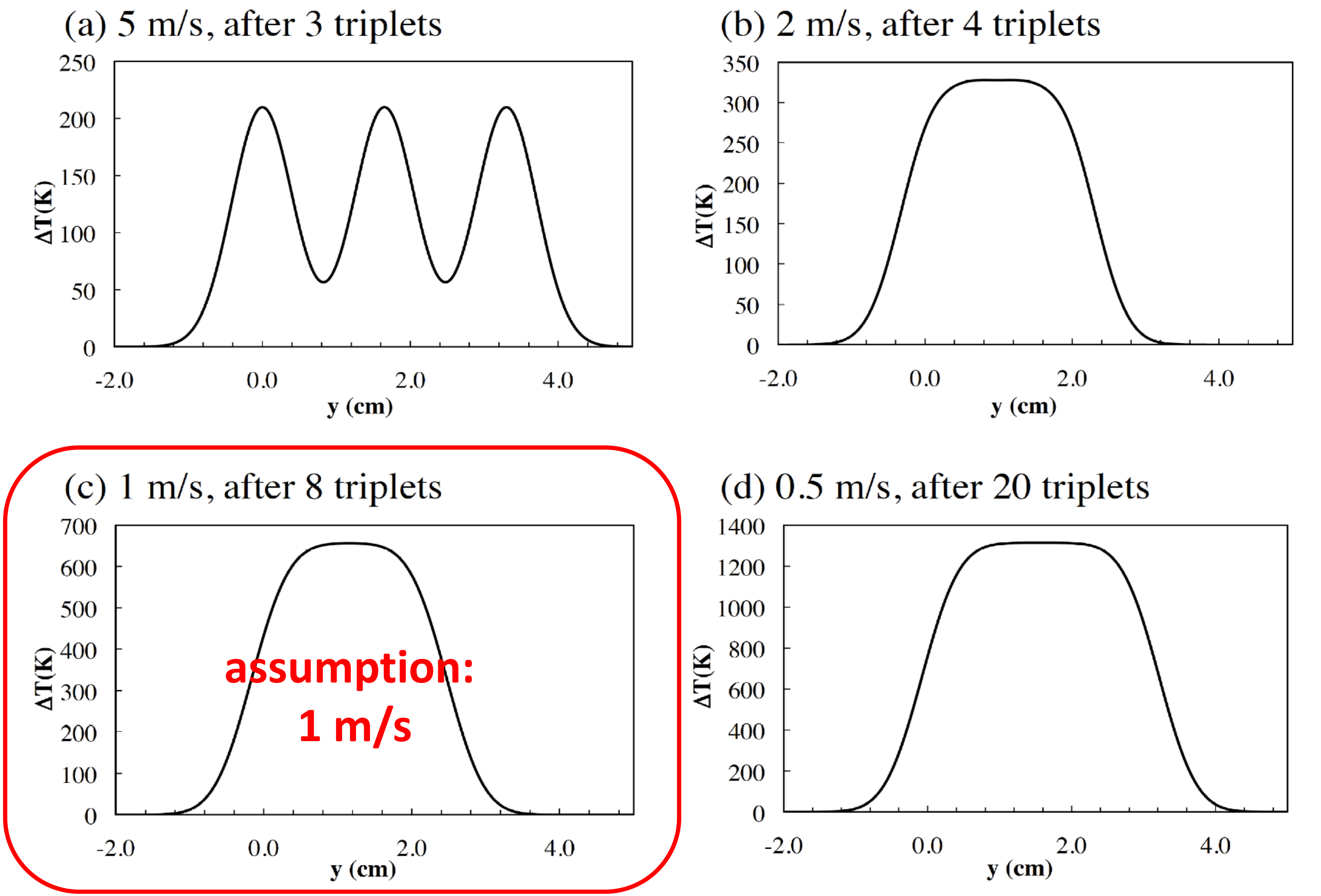
First step prototype fabricated

rotating target with ferromagnetic seal



main issue: vacuum

Target Heat Simulation (Wanming)



Why we assumed 1 m/s ?

1. Heat (static): melting.
   peak temperature < melting point.

   This is correct.

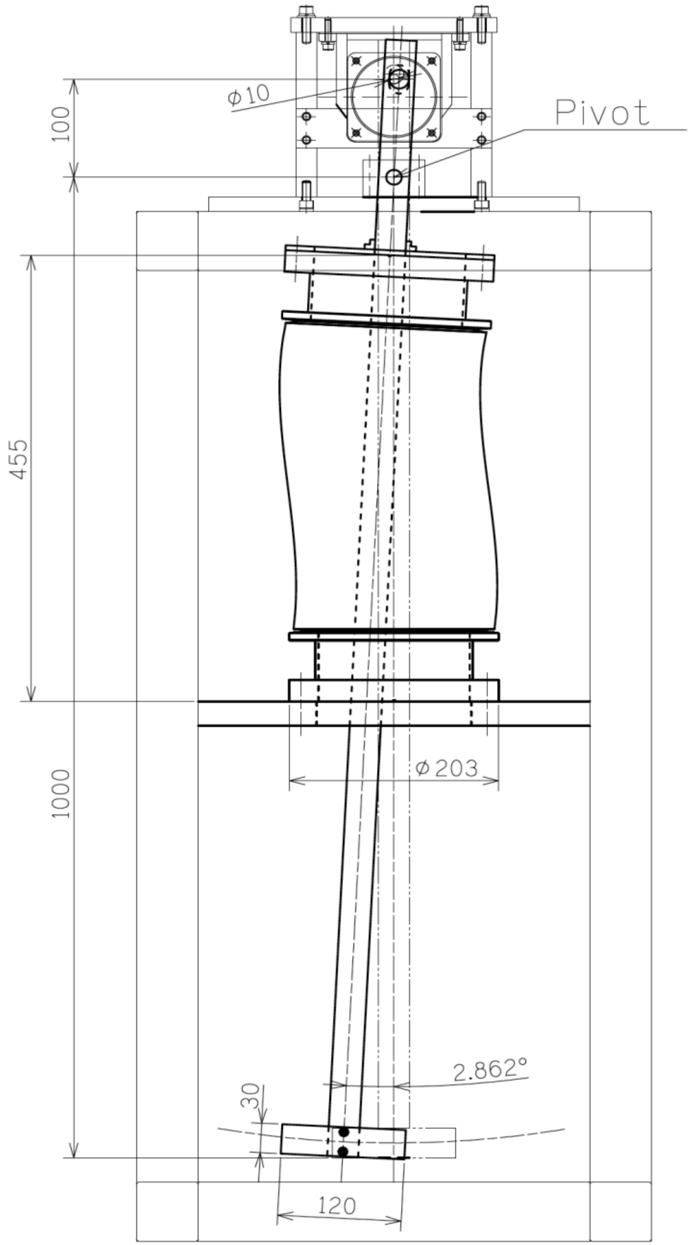
2. Shockwave (instantaneous):
   triplet-to-triplet ~ 3.3 ms >> duration of shockwave.
   no need to consider overlap of shockwaves,
   even triples overlap spatially.

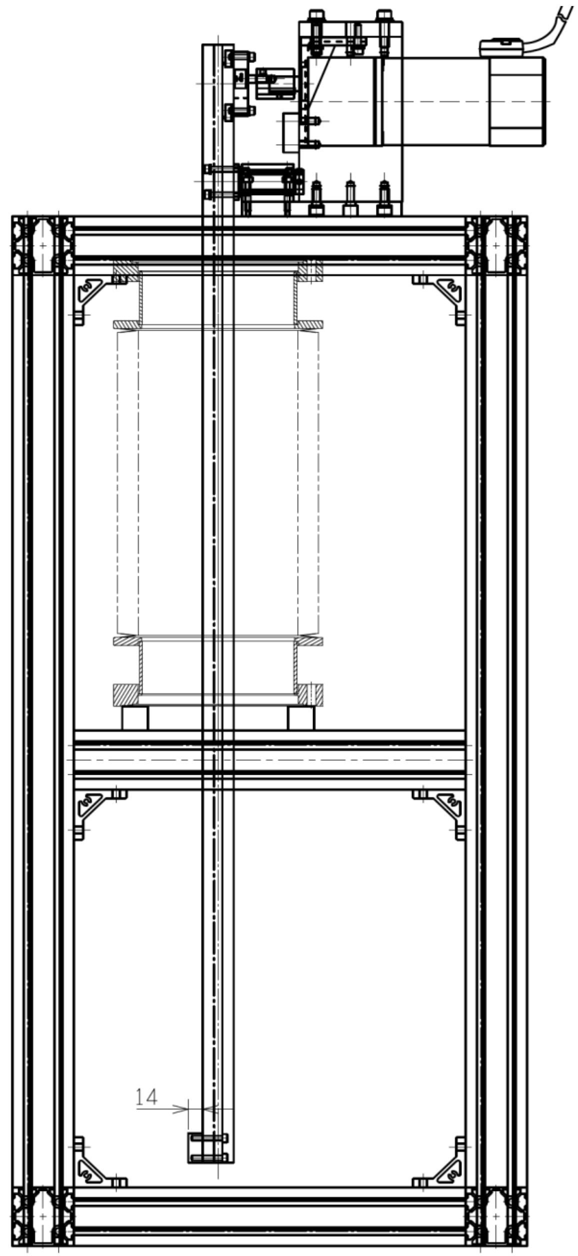
   PEDD/triplet = 23 J/g < 35 J/g

   This is correct.

Drawing of the model with bellows (in air)

17-May-2013





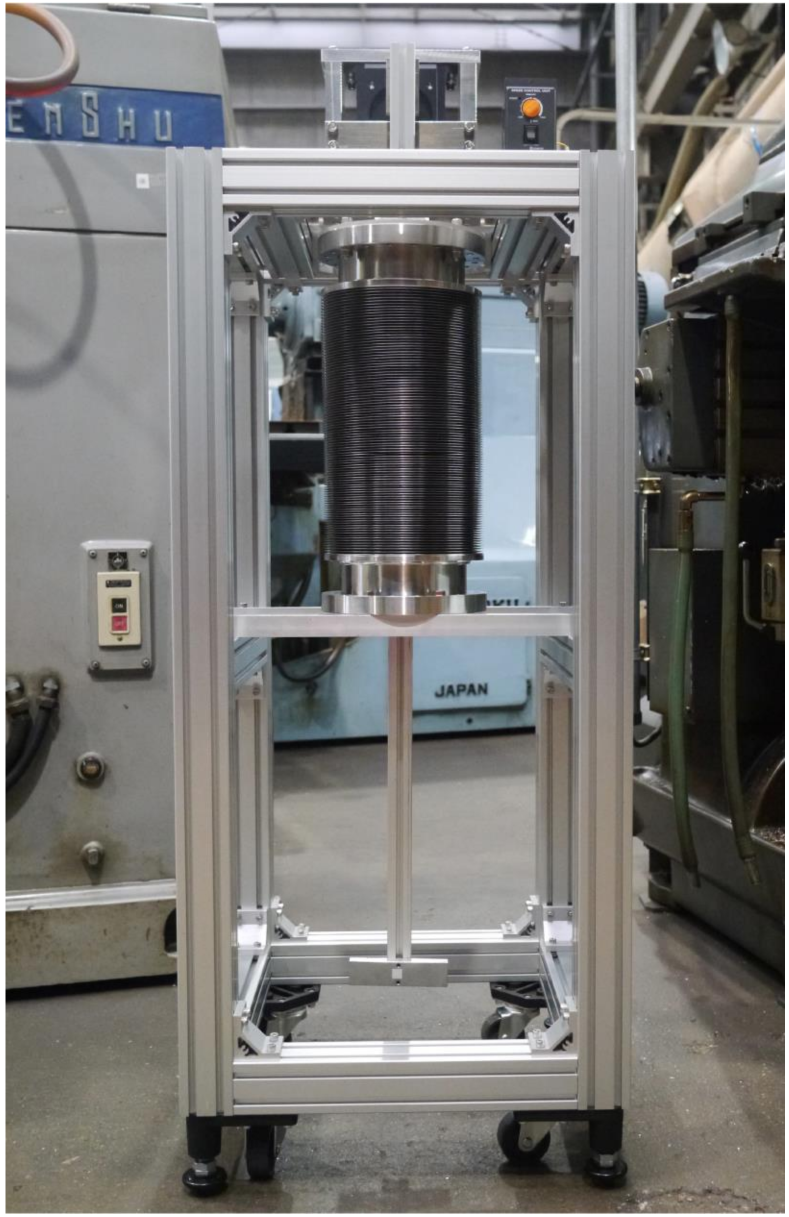
工作センター
山中さん＆吉田さん

speed = 1m/s

機械工学
'13.05.17
山中

5 Hz pendulum (with bellows, in air)

17-July-2013



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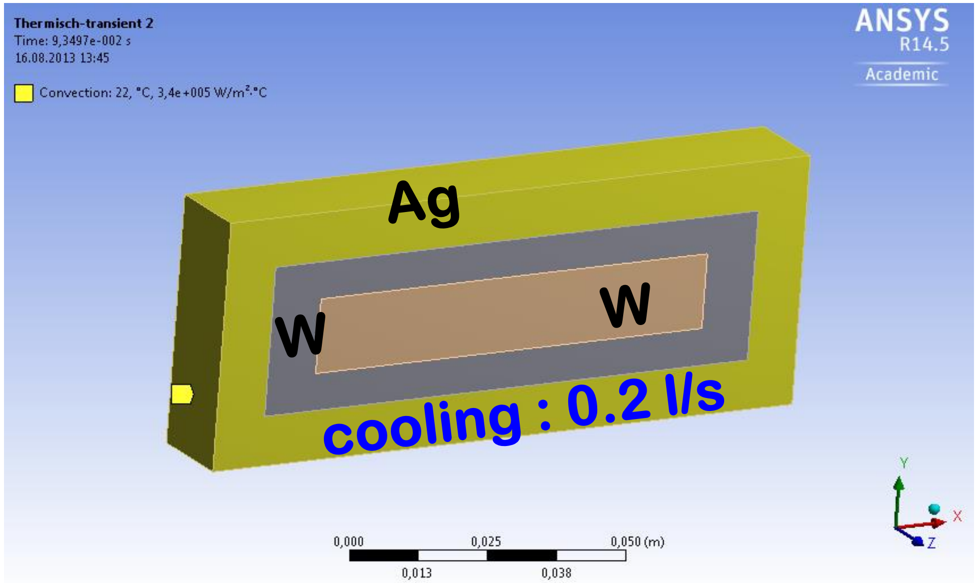
   PEDD/triplet = 23 J/g < 35 J/g

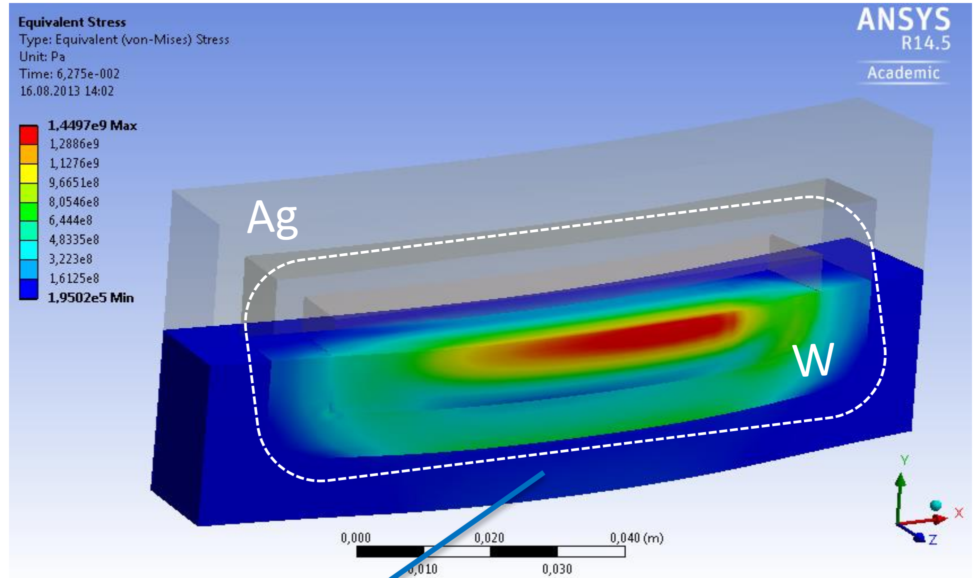
   This is correct.

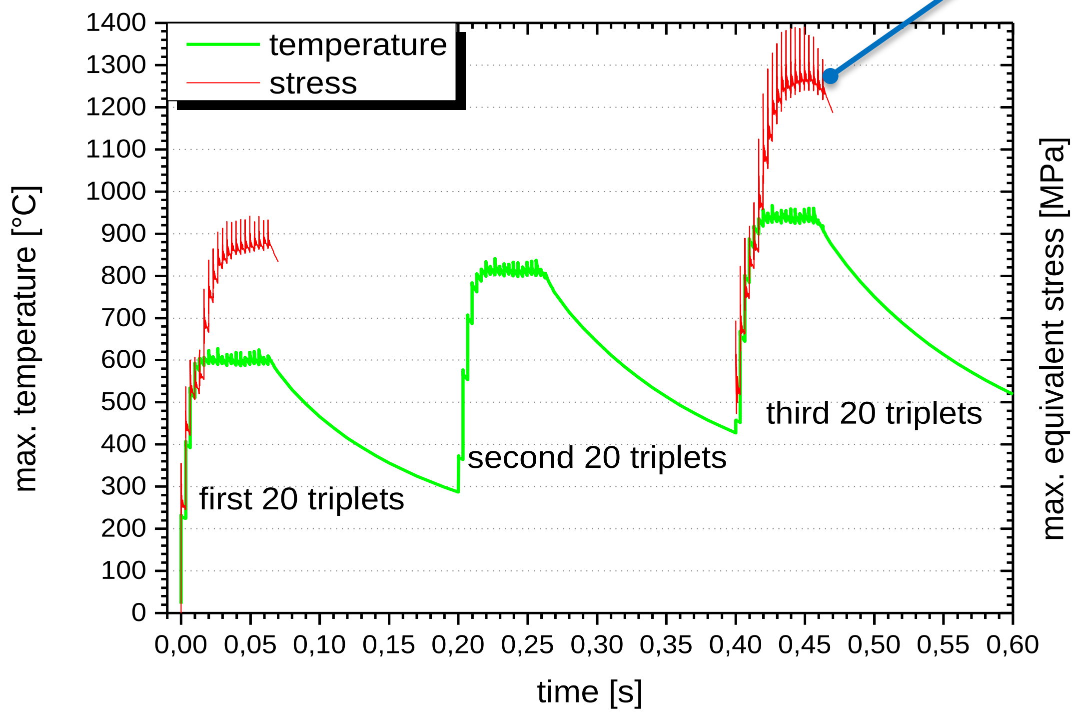
What was the issue in POSIPOL 2013 ?

3. **Heat (quasi-static): Stress by non-uniform temperature.**
   ANSYS calculation (Friedrich) revealed that overlap of triplets (and overlap of several "20xtriplets"s) did matter.
   Stress by non-uniform temperature dose matter.

Temperature and pressure evolution in the true conventional target



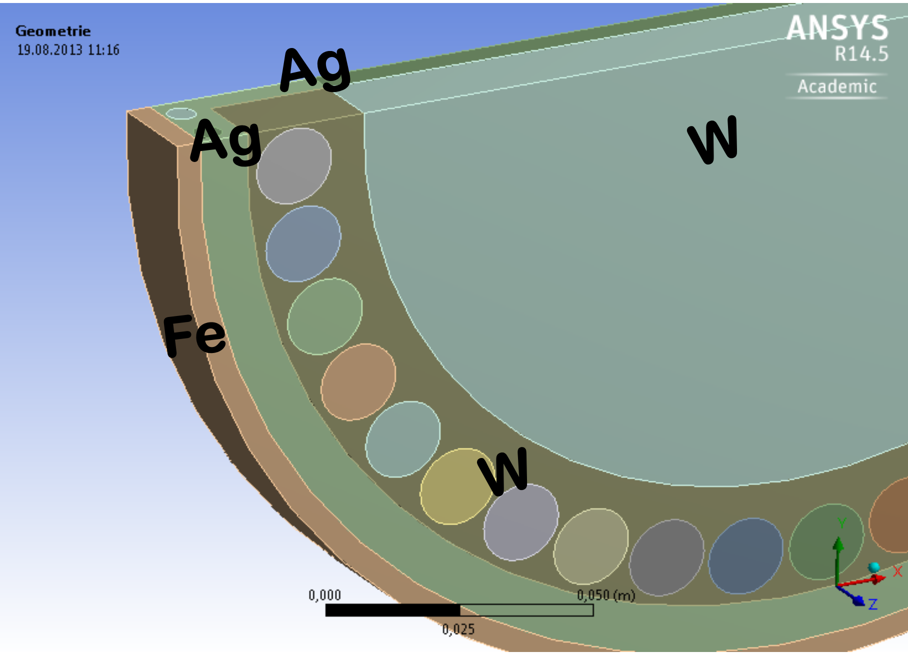


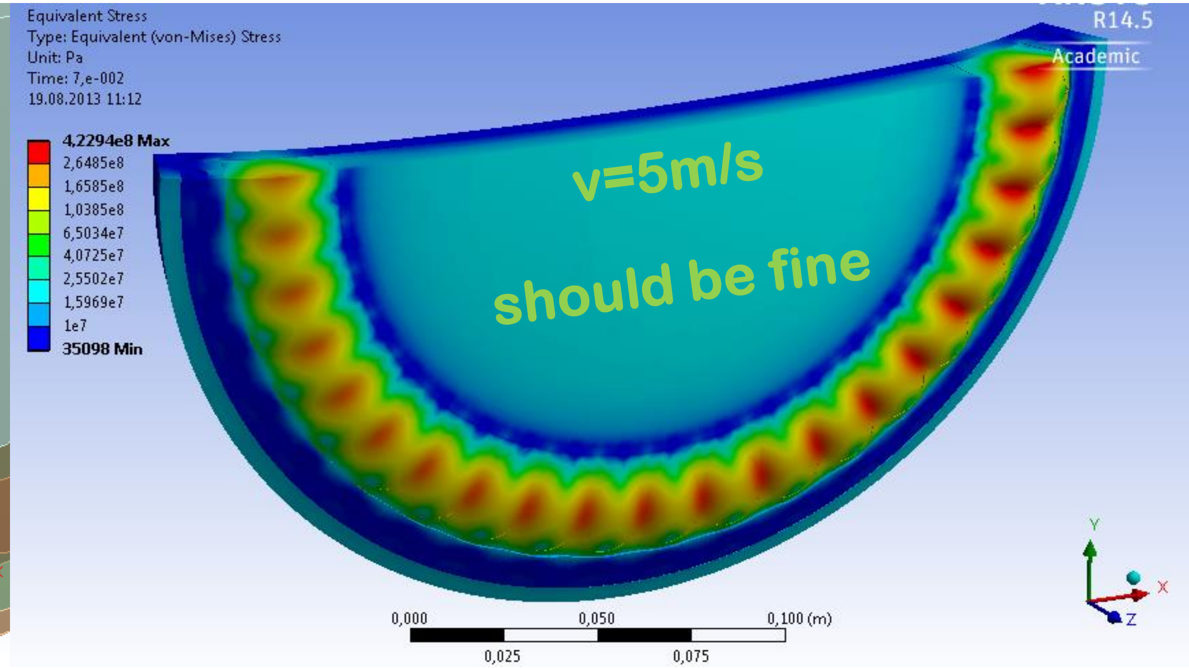


Pendulum with v=1m/s does not work!!

Freidrich Staufenbie さんの POSIPOL 2013 でのトークの抜粋

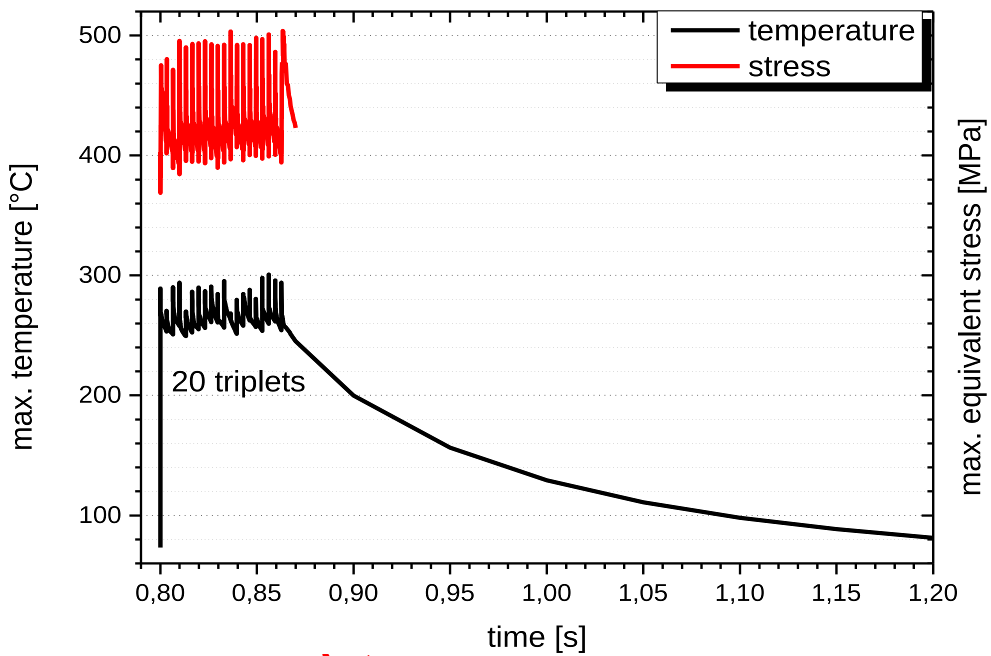
Temperature and pressure evolution in the true conventional target





cooling : 0.2 l/s

wheel ∅ 200mm



Wheel with v = 5 m/s

should work!!

Beam hits the same

place 2.5 times in a sec.

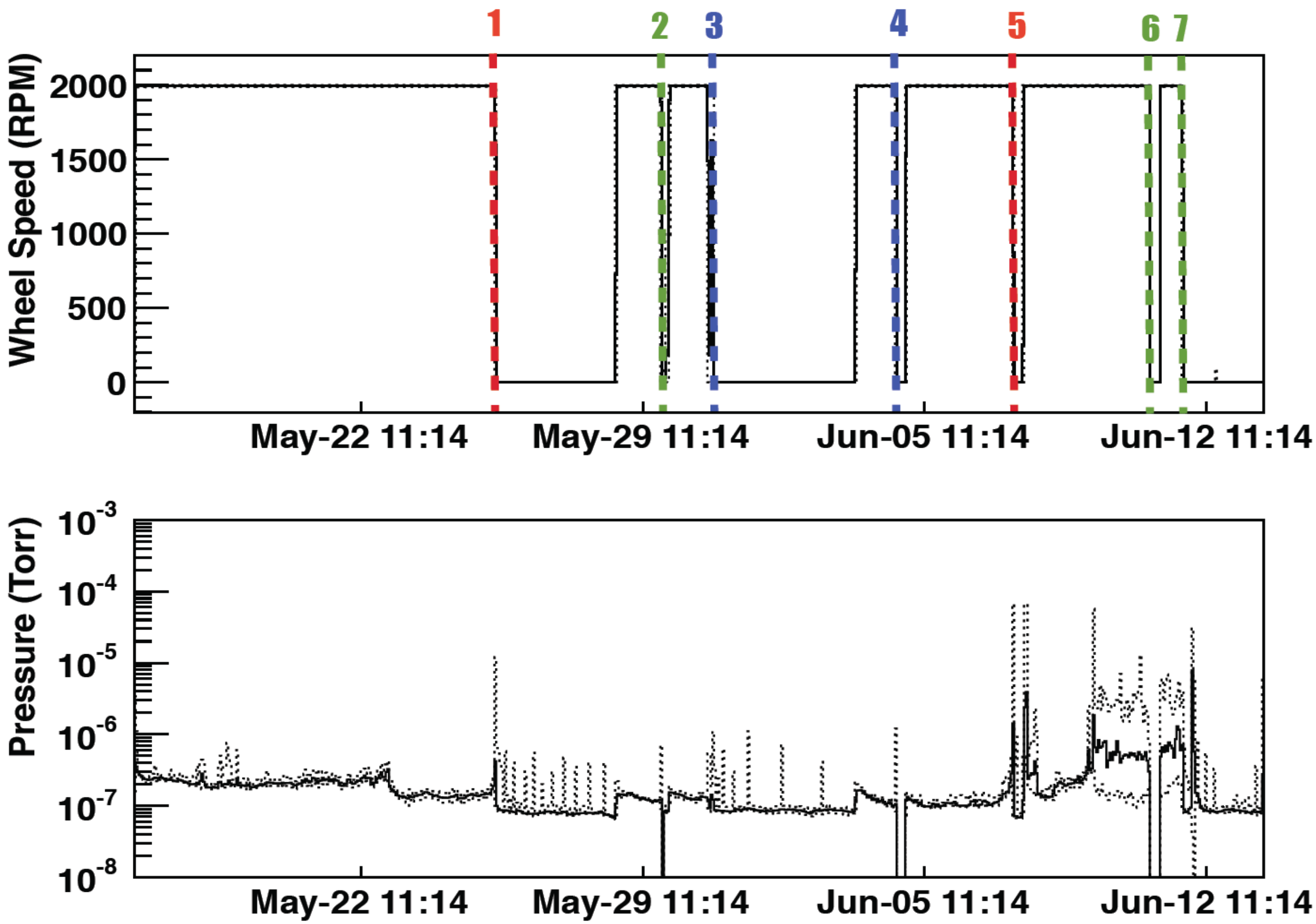
like the SLAC target

Freidrich Staufenbie さんの POSIPOL 2013 でのトークの抜粋

Rotation Target: Issue and R/D

Issue：Keep good vacuum

FerroTec Seal #1 ran for 1 month (450 hours up)



Pressure Trip

System Trip

Planned Down

1 - Pressure Spike

2 - DAQ software change

3 - Cooling water flow

4 - Vibration Limit

5 - Pressure Spike

6 - Wheel stopped for pressure test

7 - System down for rework

Rotation Target: Issue and R/D

Issue：Keep good vacuum

R/D 1：In JPY 2013 (end of March 2014)

Use off-the-shelf target for X-ray generator. Study vacuum performance (vacuum level, leak rate, mass spectrum) .

Study radiation effect on the fero-magnetic fluid.

R/D 2：JPY 2014-2015 (April 2014 – Mar 2016)

Construct ILC pre-prototype target. Study vacuum performance. The diameter will be around 0.4 m in order to accommodate to capture system.

Detail of R/D 1：In JPY 2013 (end of March 2014)

(1) Construct rotation seal test-bed:

Use off-the-shelf target for X-ray generator. Diameter 10 cm.

Vacuum level：2×10^{-6} Pa

Max rotation：1000rpm

(2) Systematic test of vacuum seal by using the test bed:

(a) Vacuum level:

Vacuum level, Gas leak rate:

as a function of rotation speed and temperature

(b) Mass spectrum of leak gas

(c) Long term operation:

at least 1000 hours of operation, see we have bursts or not.

(burst = sudden jump-up of the vacuum level)

(3) Radiation hardness test of the ferromagnetic fluid.

measure change of viscosity and evaporation rate after irradiation of radioactivity (collaboration with JAEA Takasaki-lab).

Detail of R/D 1：In JPY 2013 (end of March 2014)

Construct rotation seal test-bed (10 cm target and more):

Estimation of the Budget:

Rotation seal test-bed and Vacuum Test: 250 man-Yen ($25,000)
Mass spectrum analysis: 80 man-Yen ($ 8,000)
Long term operation test: 50 man-Yen
($ 5,000)Radiation hardness test of the fluid: 20 man-Yen
($ 2,000)

Total: 400 man-Yen ($40,000)

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($ 2,000)

Total: 400 man-Yen ($40,000)

The budget was secured

Detail of R/D 2：JPY 2014-2015 (Apr. 2014 – Mar. 2016)

Construct an ILC pre-prototype target and test it.

(1) Design 40 cm target (an ILC pre-prototype target) :
The design should be to accommodate to capture system.
location of bearing, diameter of the target disk,
heat & stress analysis, cooling

(2) Construct 40 cm target:
Whole disk made by Cu (for cost down).

(3) Systematic test of vacuum seal by using the 40 cm target:
(a) Vacuum level:
Vacuum level, Gas leak rate:
(b) Mass spectrum of leak gas
(c) Long term operation: at least 1000 hours of operation.

(4) Basic study of real ILC target
Cu & W bonding test

Detail of R/D 2：JPY 2014-2015

Construct an ILC pre-prototype target and test it.

Estimation of the Budget:

Design of 40 cm target:	500 man-Yen ($50,000)
Construct 40 cm target:	1500 man-Yen ($150,000)
Systematic test of vacuum:	1000 man-Yen ($100,000)
Cu & W bonding test:	500 man-Yen ($ 50,000)
Total:	3500 man-Yen ($350,000)

Detail of R/D 2：JPY 2014-2015

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Under Discussion

Pendulum Target Test Bed

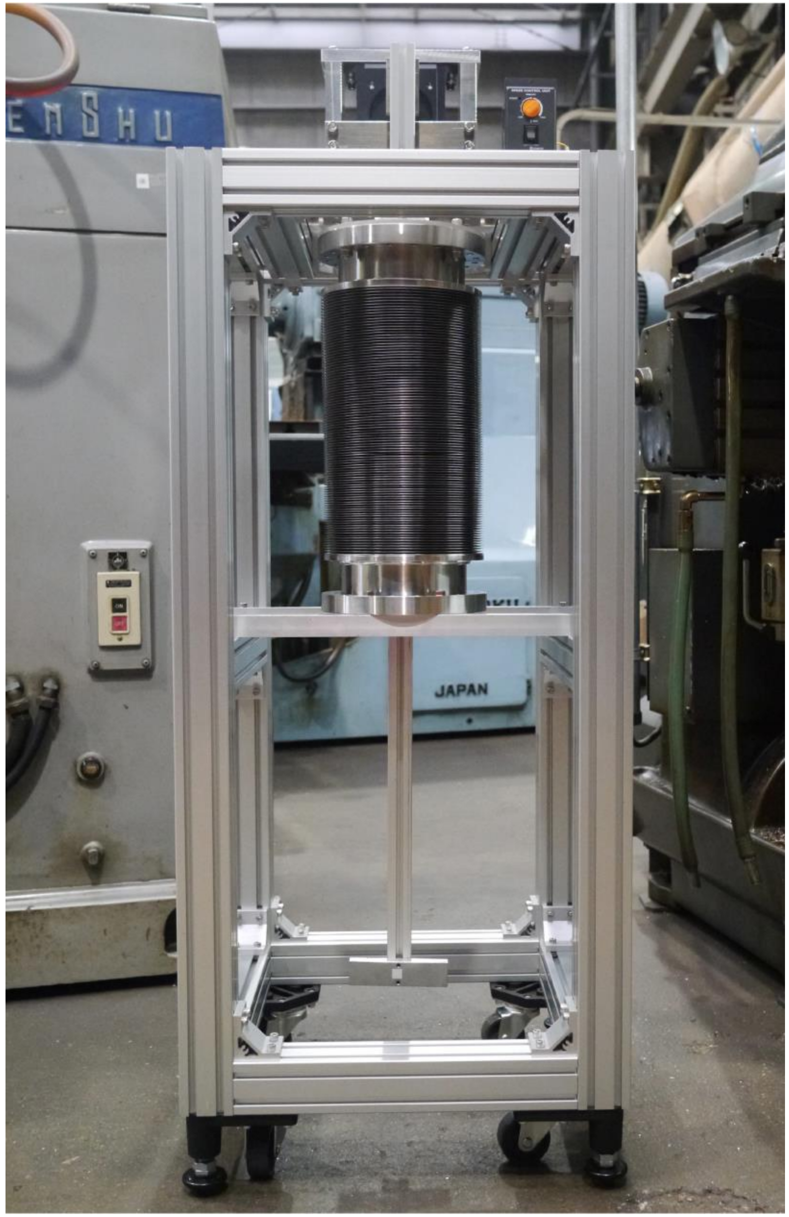
Target：Lifetime test of a Bellows

History：

Mid July	Completed
End July	Move to ATF building. fixed on the floor, made operation. -> A fixing bolt on the pivot broken in a very short time
End August	Finish cure (we modified the broken part)
September 2nd	Start operation again -> we found cracks on the arm soon.
September 19th	Finish cure (we modified the arm) -> Start operation again -> trouble on the cam
September 26th	Finish cure (we modified the cam) and remove target Start operation again
Up to yesterday	Long term operation since Sep. 26th in air. (day time of week days) No problem was found by eye inspection
November 11th	we found cracks on the arm and the frame

5 Hz pendulum (with bellows, in air)

17-July-2013

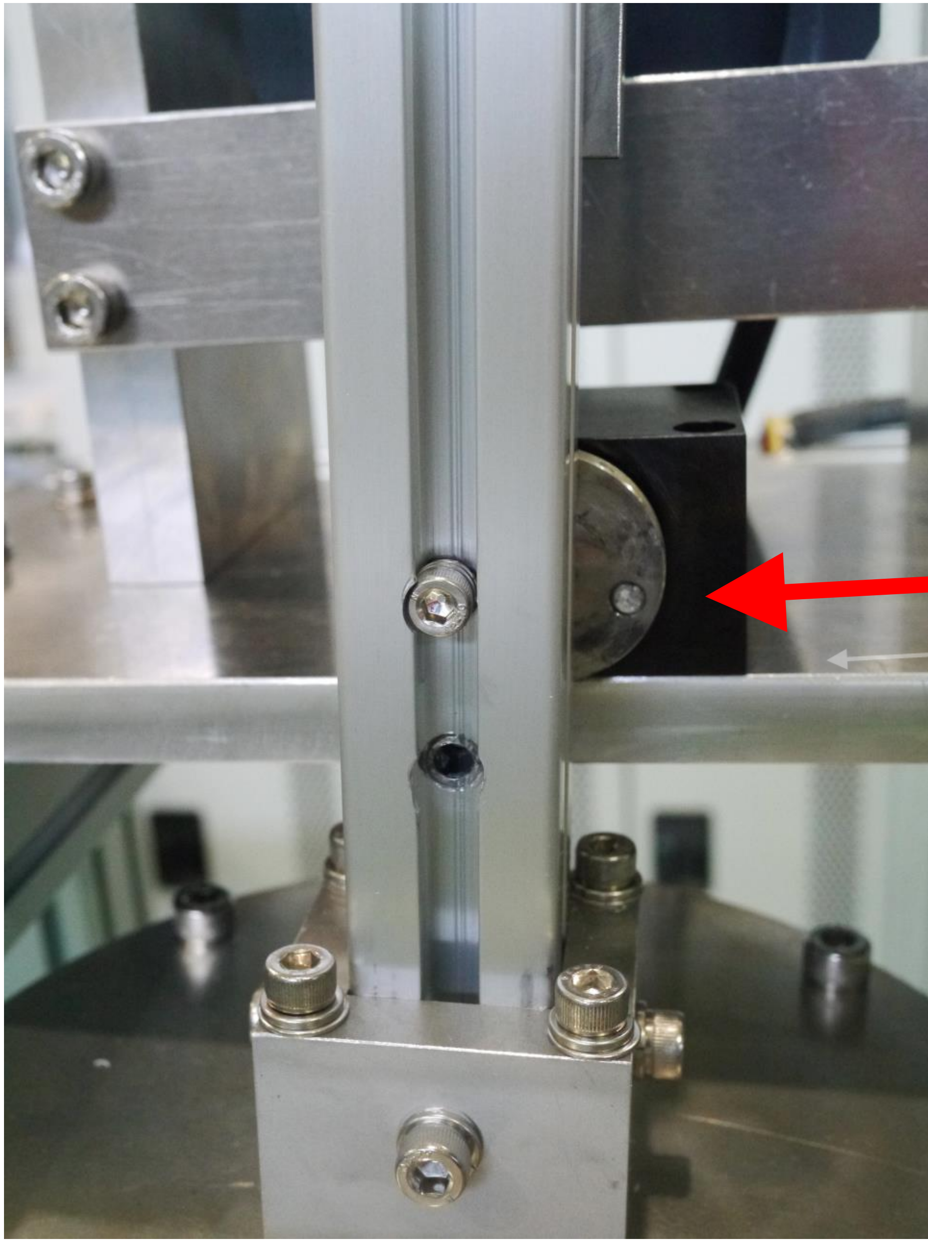


工作センター
山中さん＆吉田さん

speed = 1m/s

5 Hz pendulum (with bellows, in air)

26-July-2013



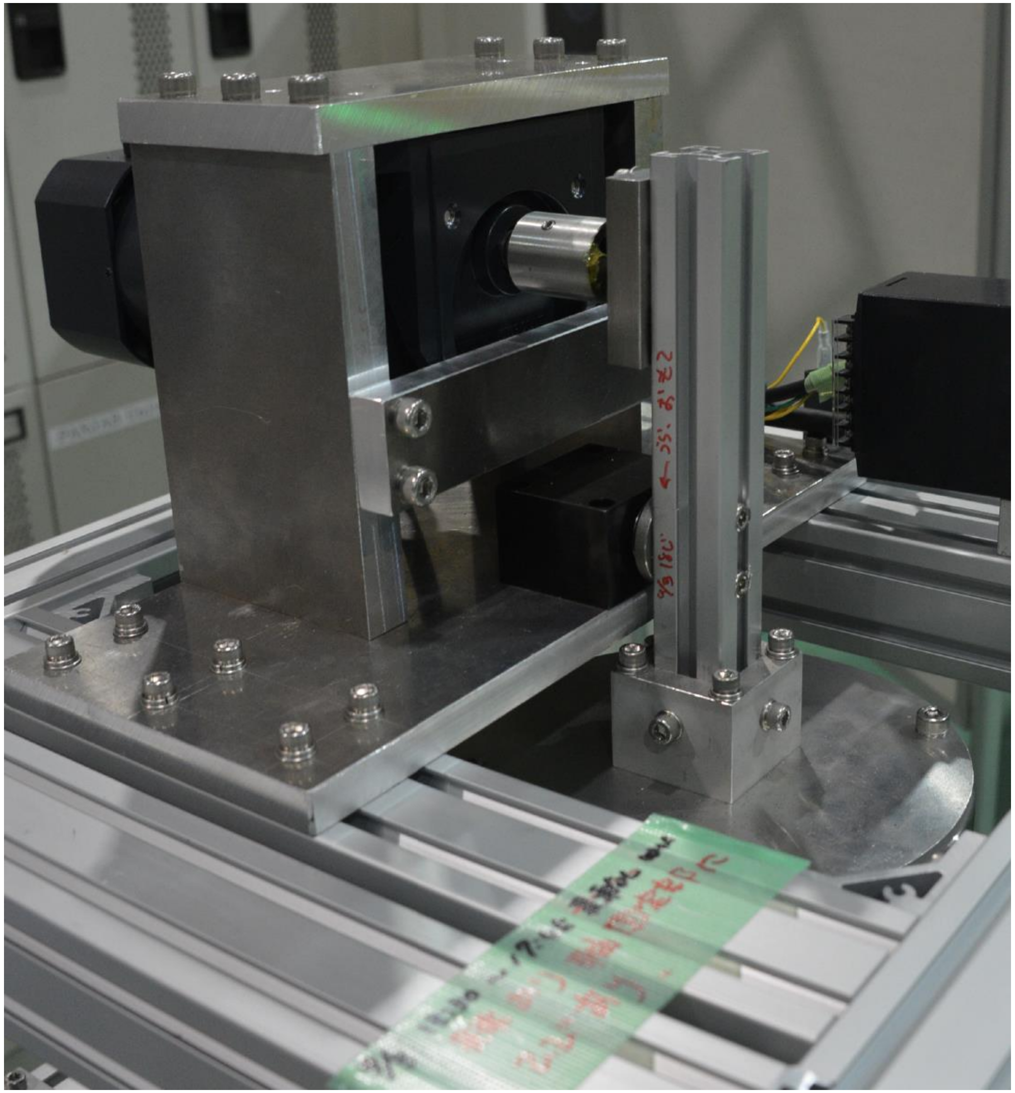
Moved to ATF building, fixed on the floor, made test.

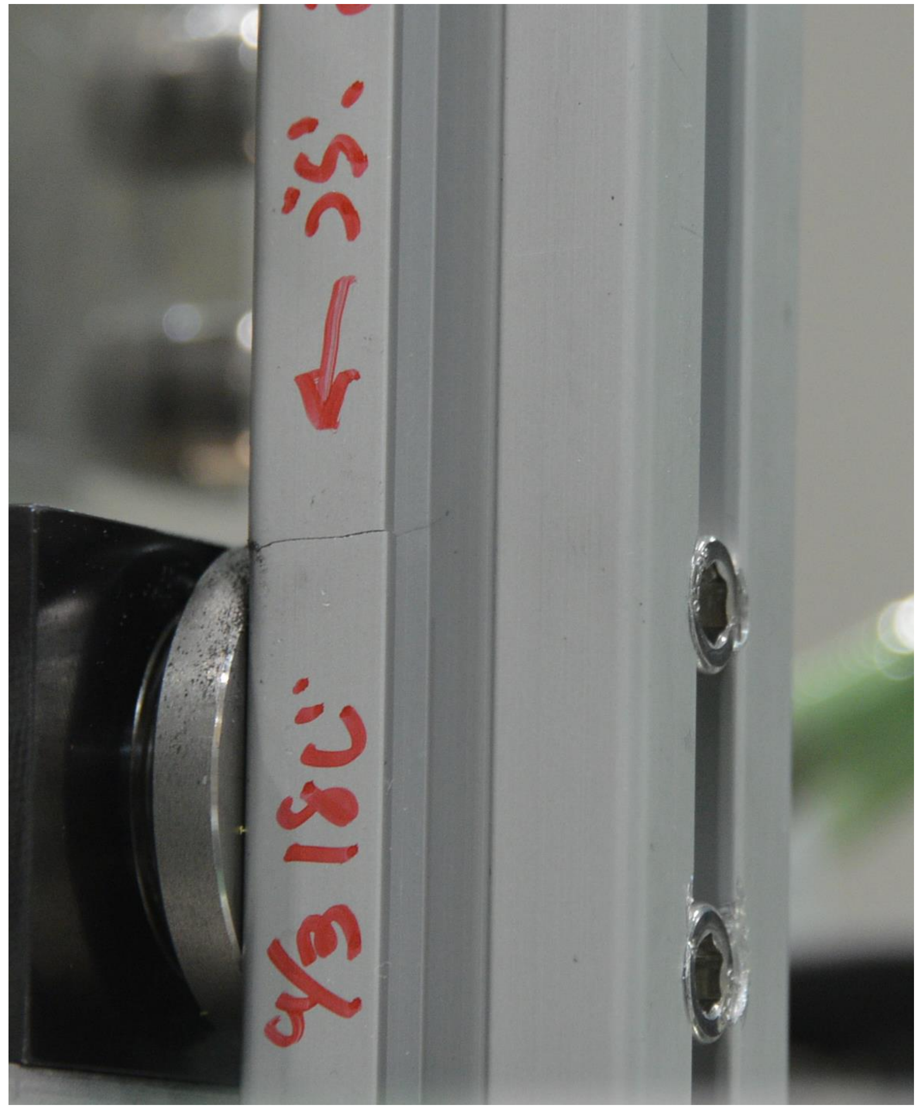
A fixing bolt on the pivot broken in a very short time

broken here

5 Hz pendulum (with bellows, in air) 2-Sep-2013

September 2nd was supposed to be the first day of the long term test.
But, after 4 hours of running, we found cracks on the arm.





Pendulum Target Test Bed

Target : Lifetime test of a Bellows

Issues :

Bellows :

very smooth movement -> good indication

Mechanical Concern:

Stress and vibration -> need some cure

Speed:

1 m/s is not sufficient <- Friedrich (POSIPOL 2013) and Peter

Can we make faster? Necessary speed? 3 m/s acceptable?

Mechanical difficulty ~ v^2

For the moment :

Continue bellows test -> need vacuum to give stress on bellows

New idea for higher speed -> Your ideas are welcome.

Summary

Summary

- Conventional e+ source can be a solution for ILC, with 300Hz scheme and optimized beam&target parameters.

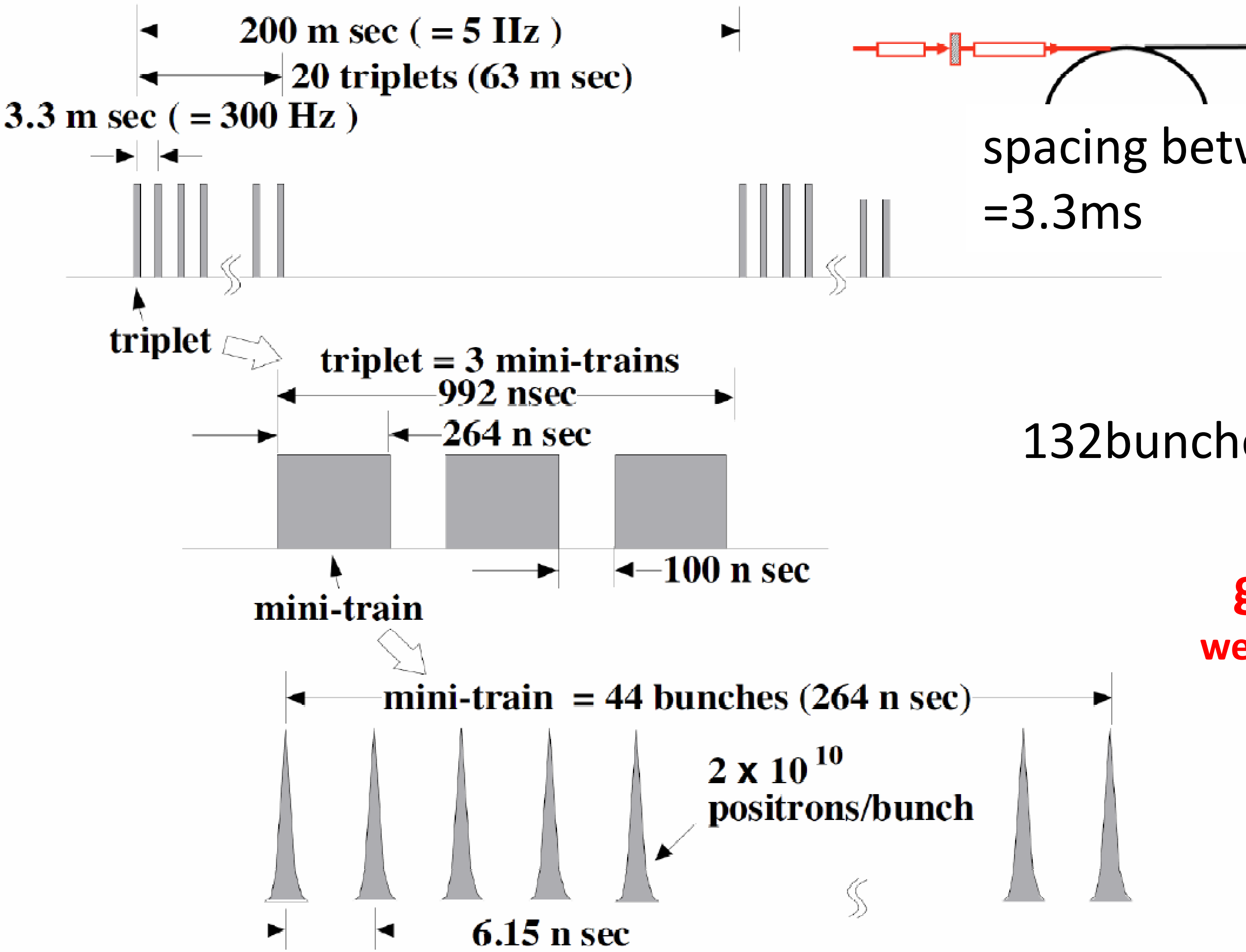
- to go forward -> We need R/Ds
  - High current, high rep rate driver linac
  - Moving target
  - Flux concentrator
  - Booster linac
  - Overall simulation

- Target R/D
  - Both Rotation target and Pendulum target R/Ds are ongoing.

backups

Target and Drive_Beam Optimization

In the case of 300Hz scheme



spacing between triplets
=3.3ms

132bunches in 992ns

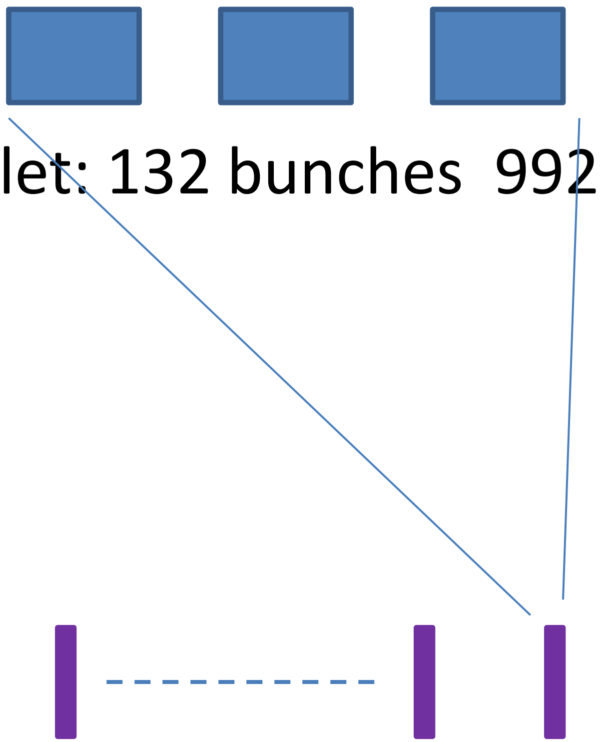
good for a FC

we can use existing FC technology

Assumptions

drive electrons

2×10^{10}/bunch

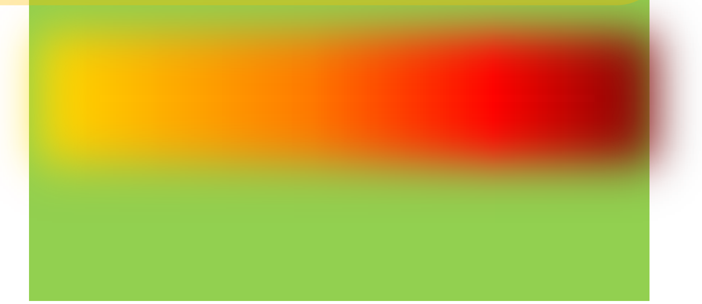


a triplet: 132 bunches 992ns

3.3ms

a train: 20 triplet
= 2640 bunches 63ms

132 bunches
make a shock wave
heat same position on the target



each triplet hits
different position on the target

pendulum or slow rotation target

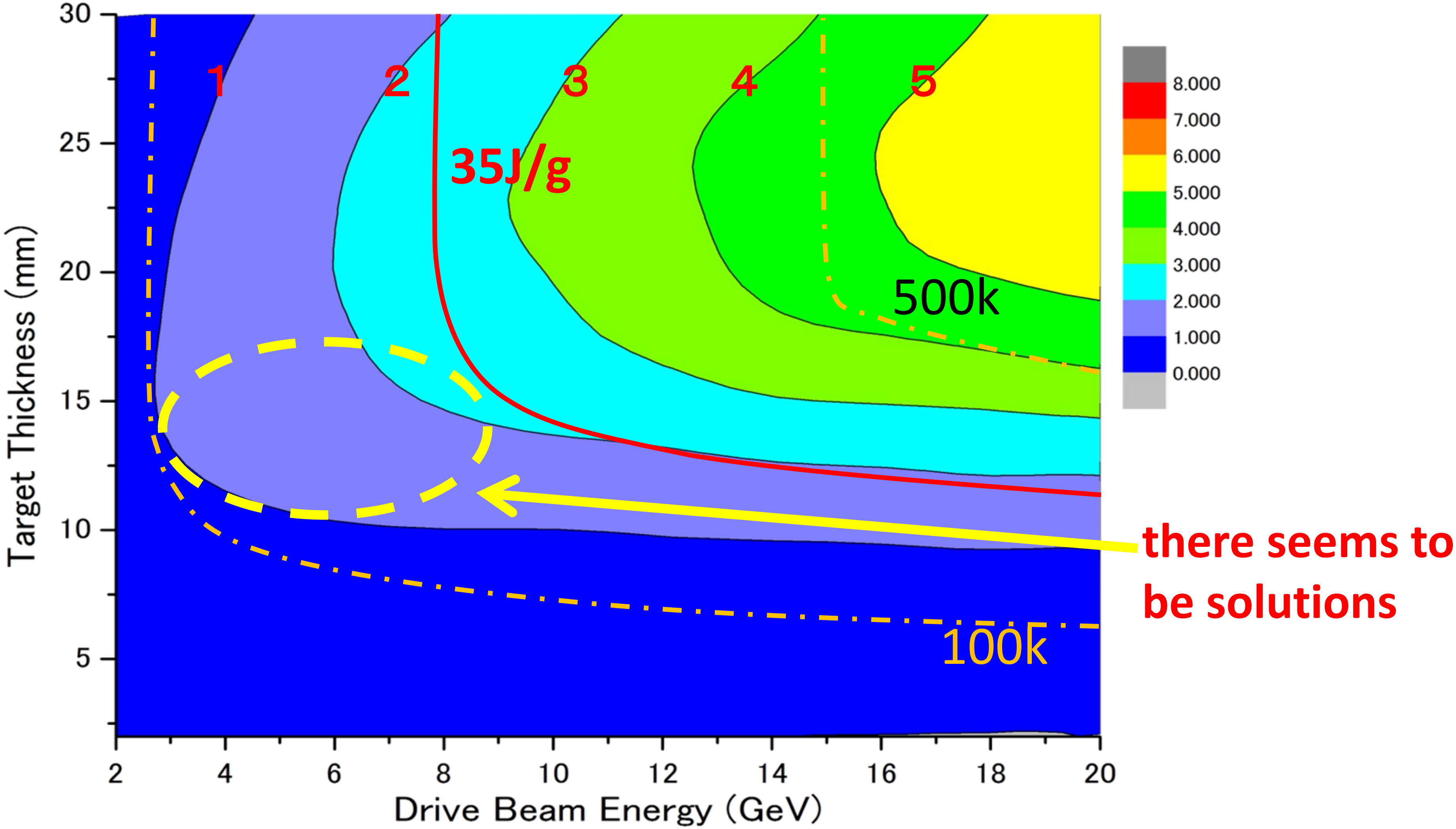
Parameter Plots for 300 Hz scheme

e- directly on to Tungsten

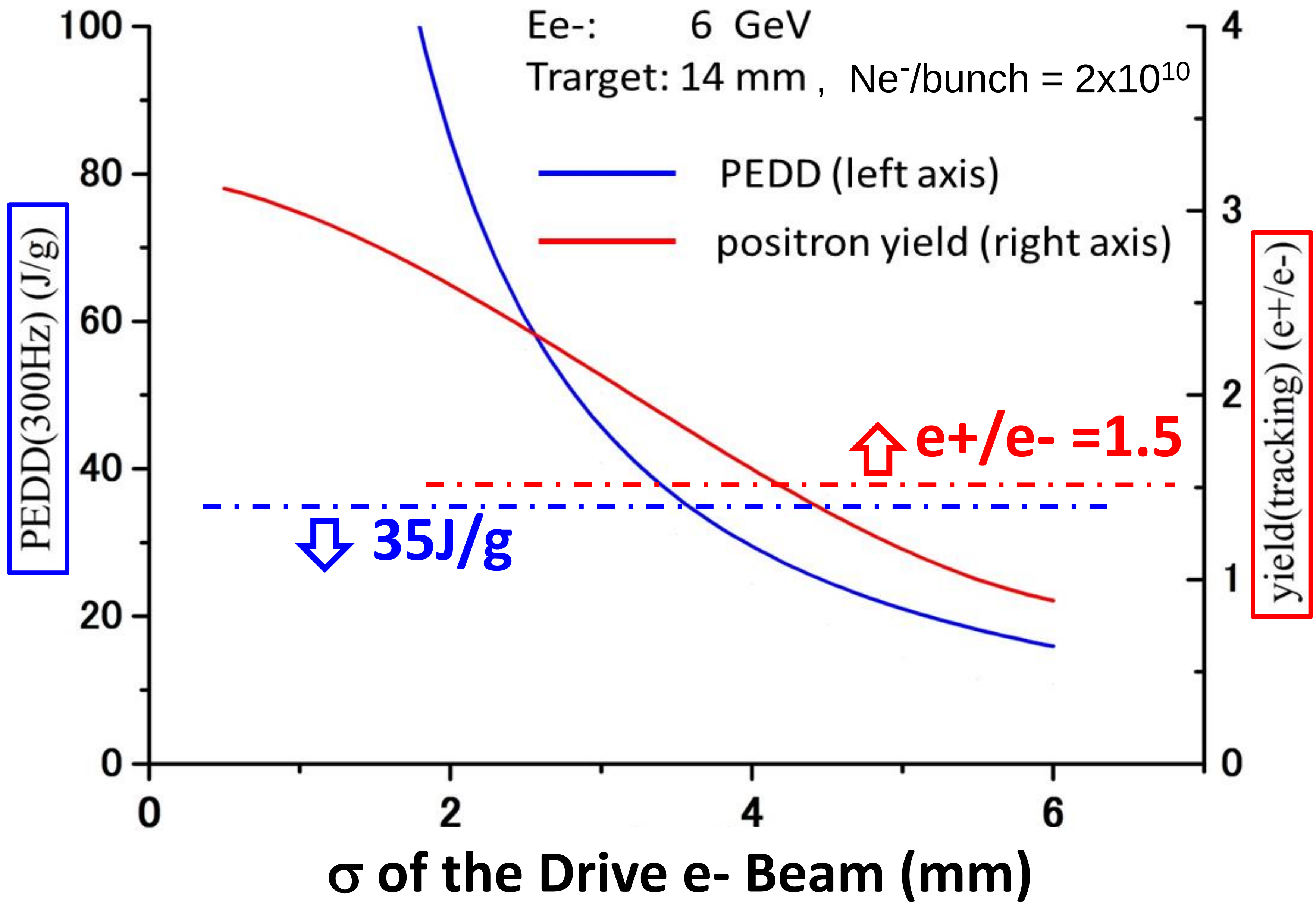
σ=4.0mm

Ne$^-$(drive) = 2x10^{10} /bunch

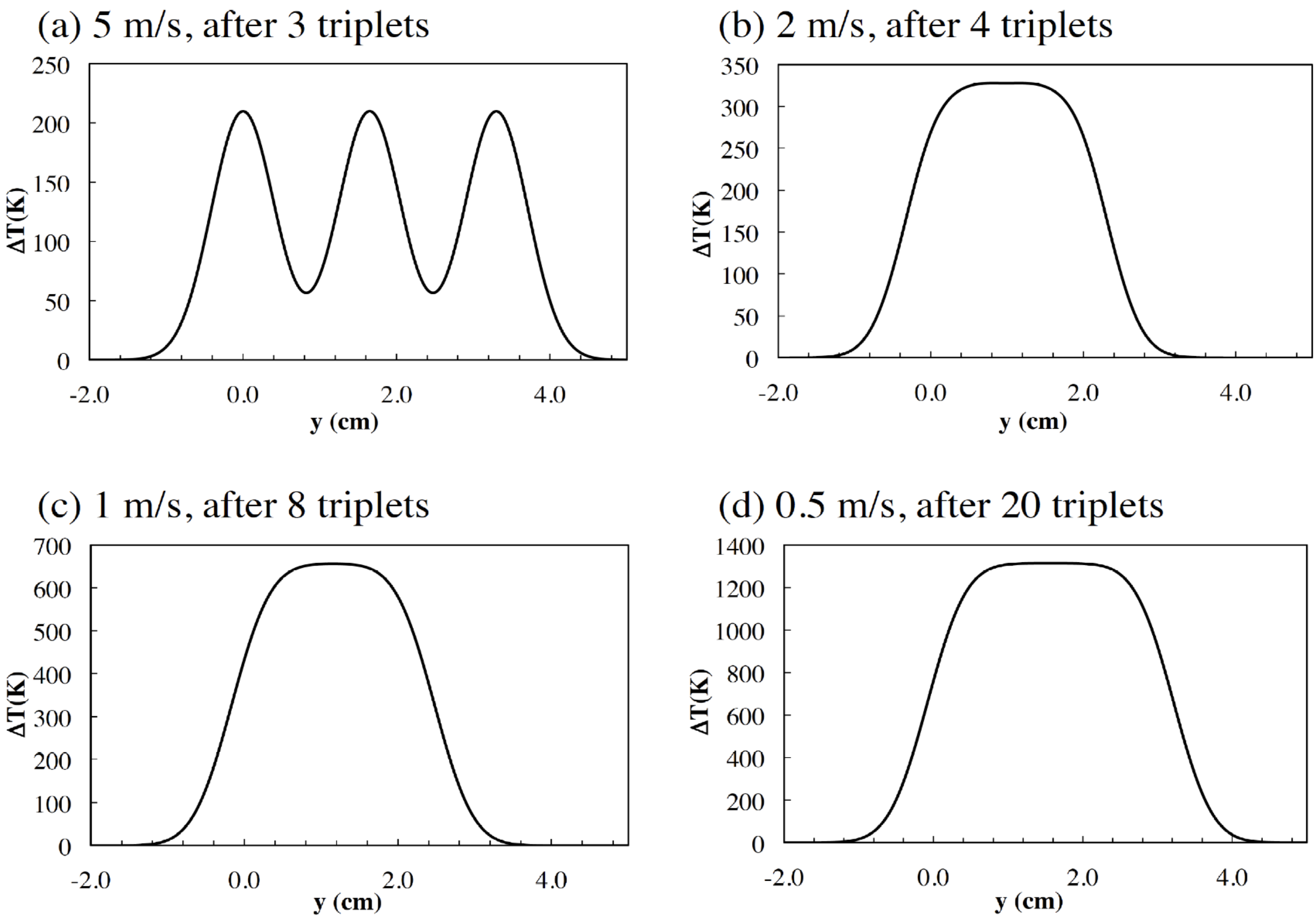
colored band	accepted e+/e-
(red solid line)	PEDD J/g
(orange dash-dot line)	dT max by a triplet



Dependence on Drive beam size



Target Heat Simulation (Wanming)



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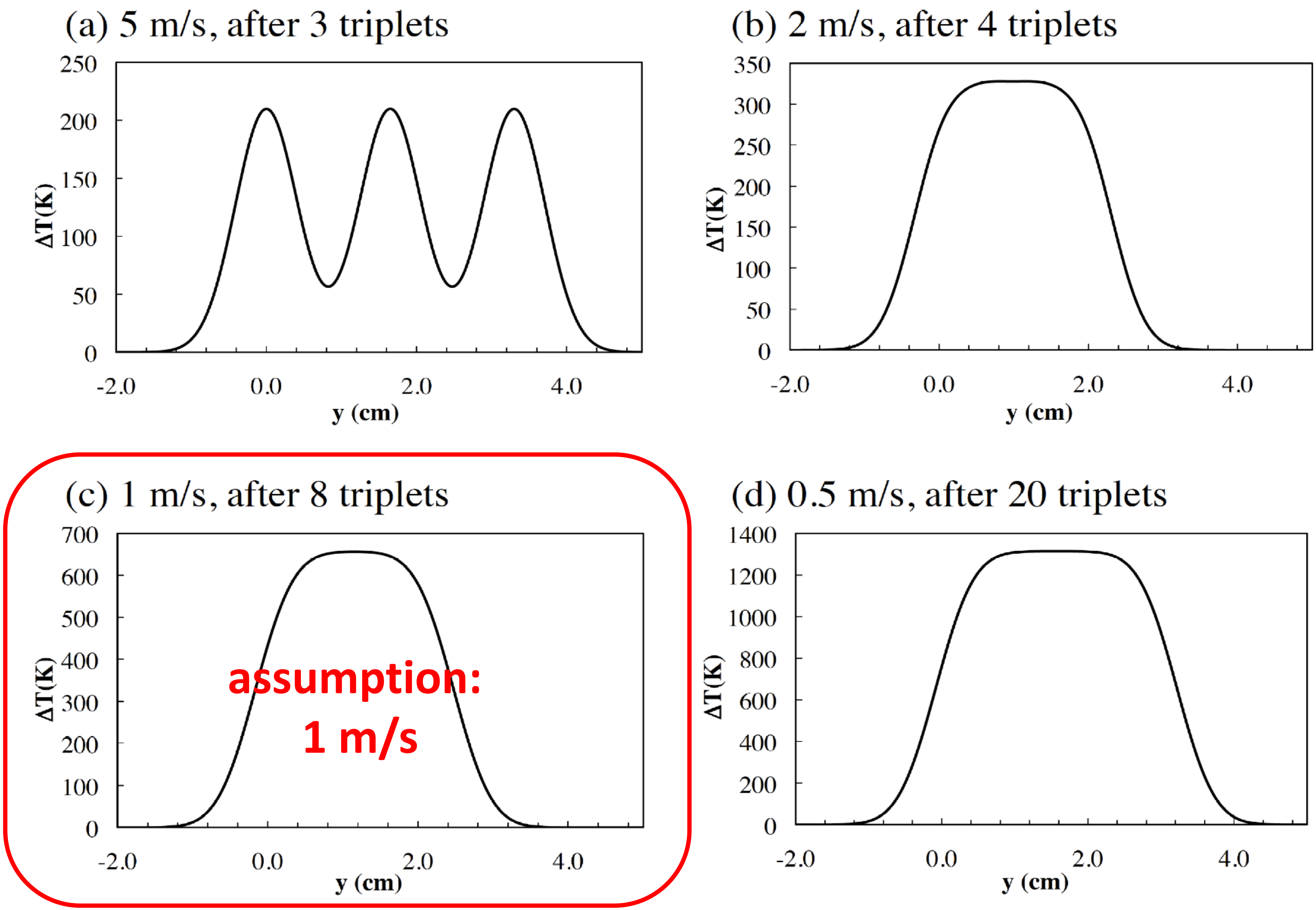

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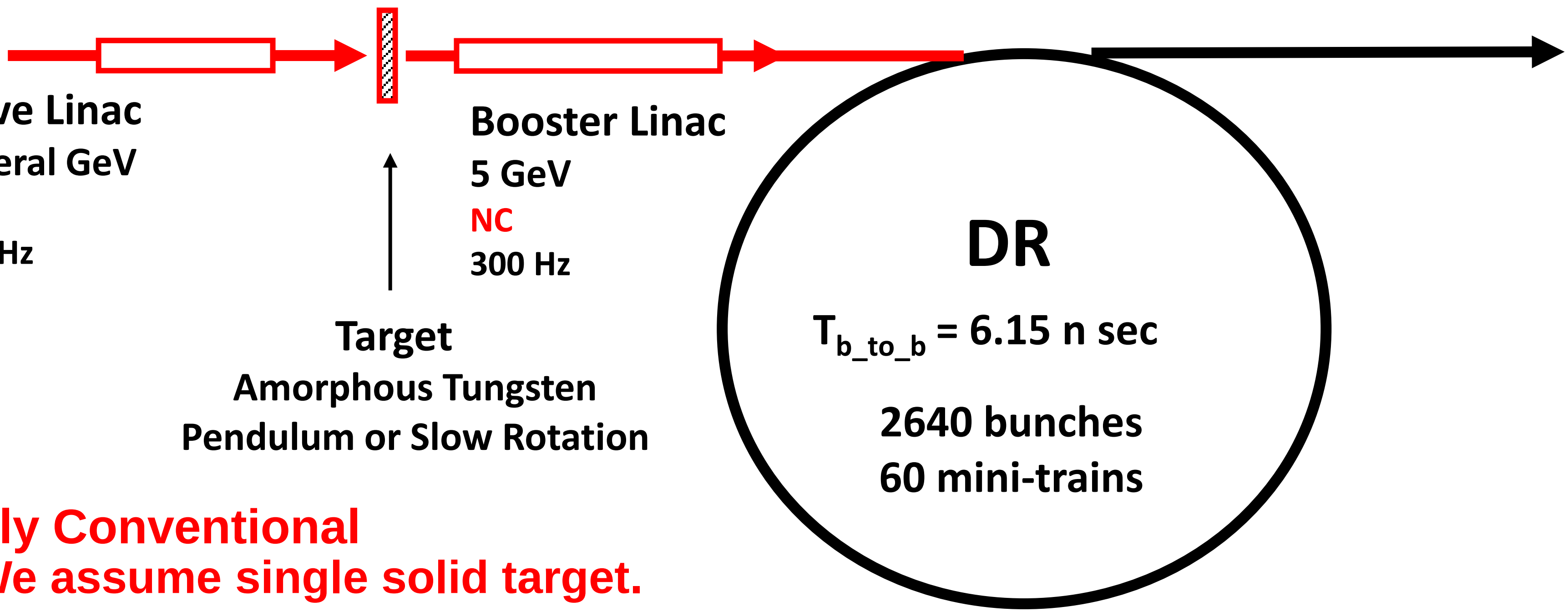


Time remaining for damping = 137 m sec

Truly Conventional
*** We assume single solid target.**
*** NO Liquid Target or NO Hybrid Target are assumed**

R/D items

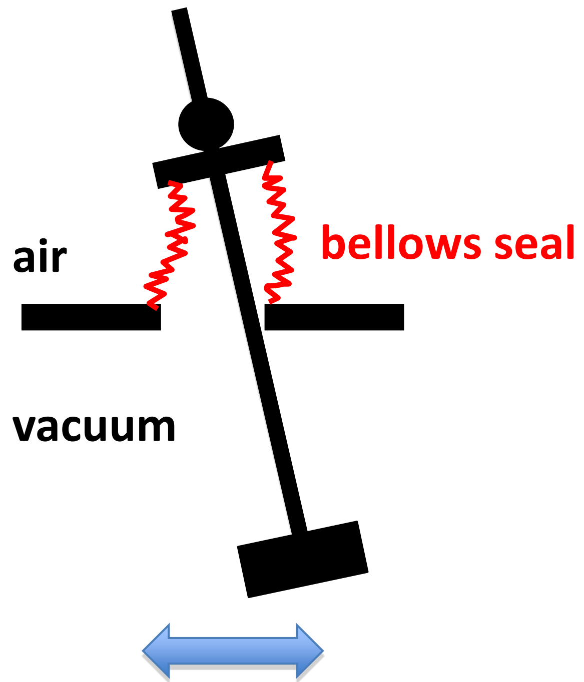
R&R Issues of the Conventional Source

- "conventional" but still needs some more R&D
- High current, high rep rate driver linac
- Moving target
- Flux concentrator
- Booster linac
- Overall simulation

Moving Target

- ~1m/sec required (1/100 of undulator scheme)
- 2 possible schemes being developed at KEK

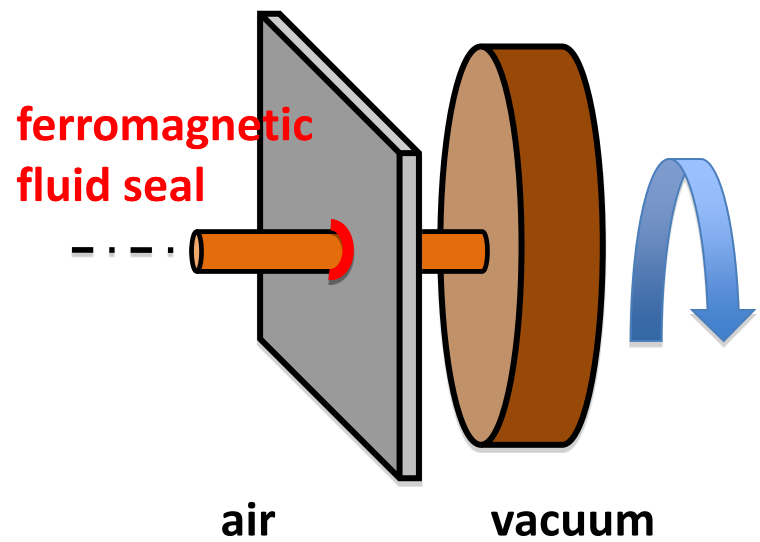
5Hz pendulum with bellows seal



main issue: life of bellows

First step prototype fabricated

rotating target with ferromagnetic seal



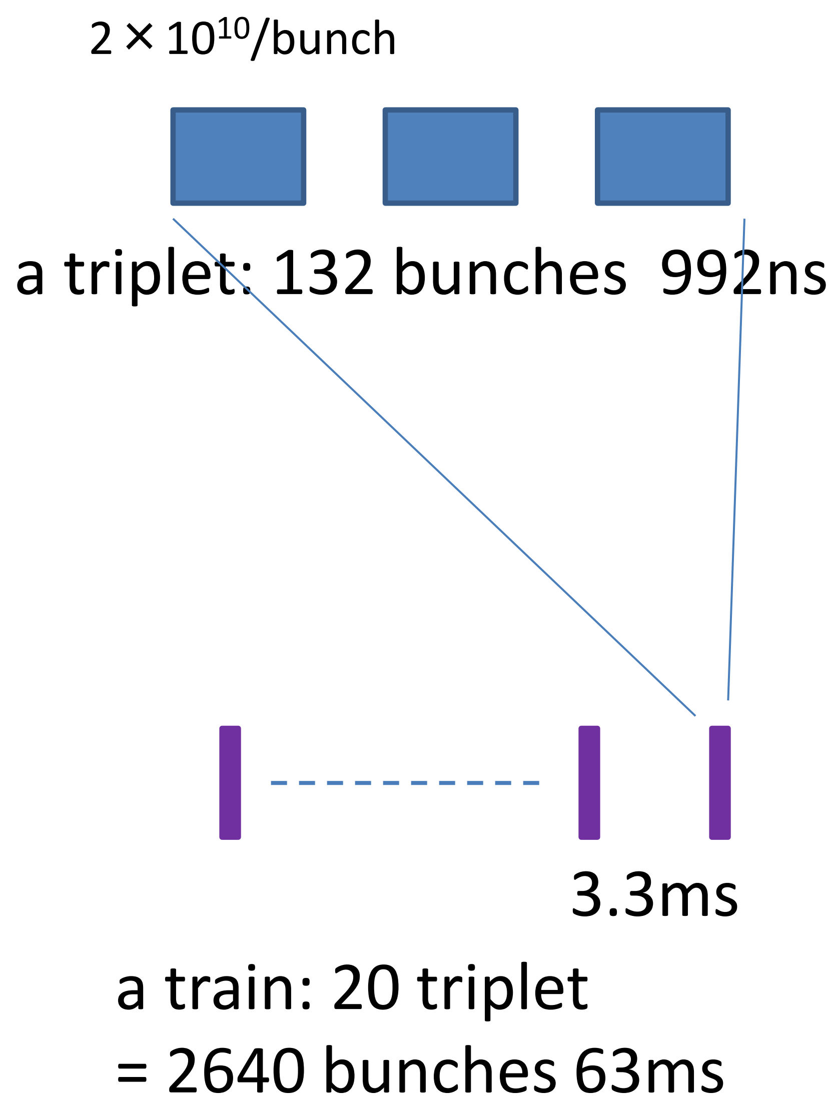
main issue: vacuum

Flux Concentrator

- Almost existing technology
  - pulse length ~1μsec (cf. ~1msec in undulator scheme)
- Beam aperture should be a bit larger
  - ~7mm → ~12mm
- Being developed for SuperKEKB
  - It has 14mm aperture

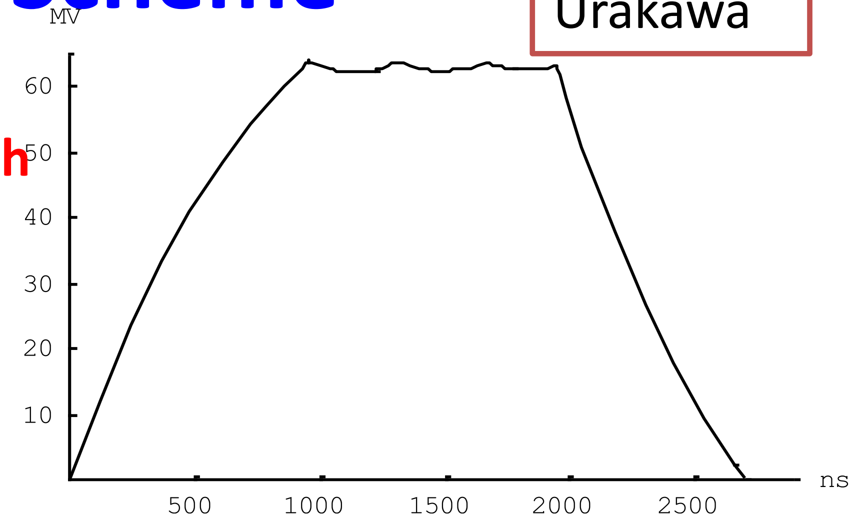
Linacs

- Driver linac (~6GeV)
  - high current
  - high rep rate (300Hz)
- Booster linac (~5GeV)
  - high rep rate
  - accurate loading compensation (due to uneven bunch structure)

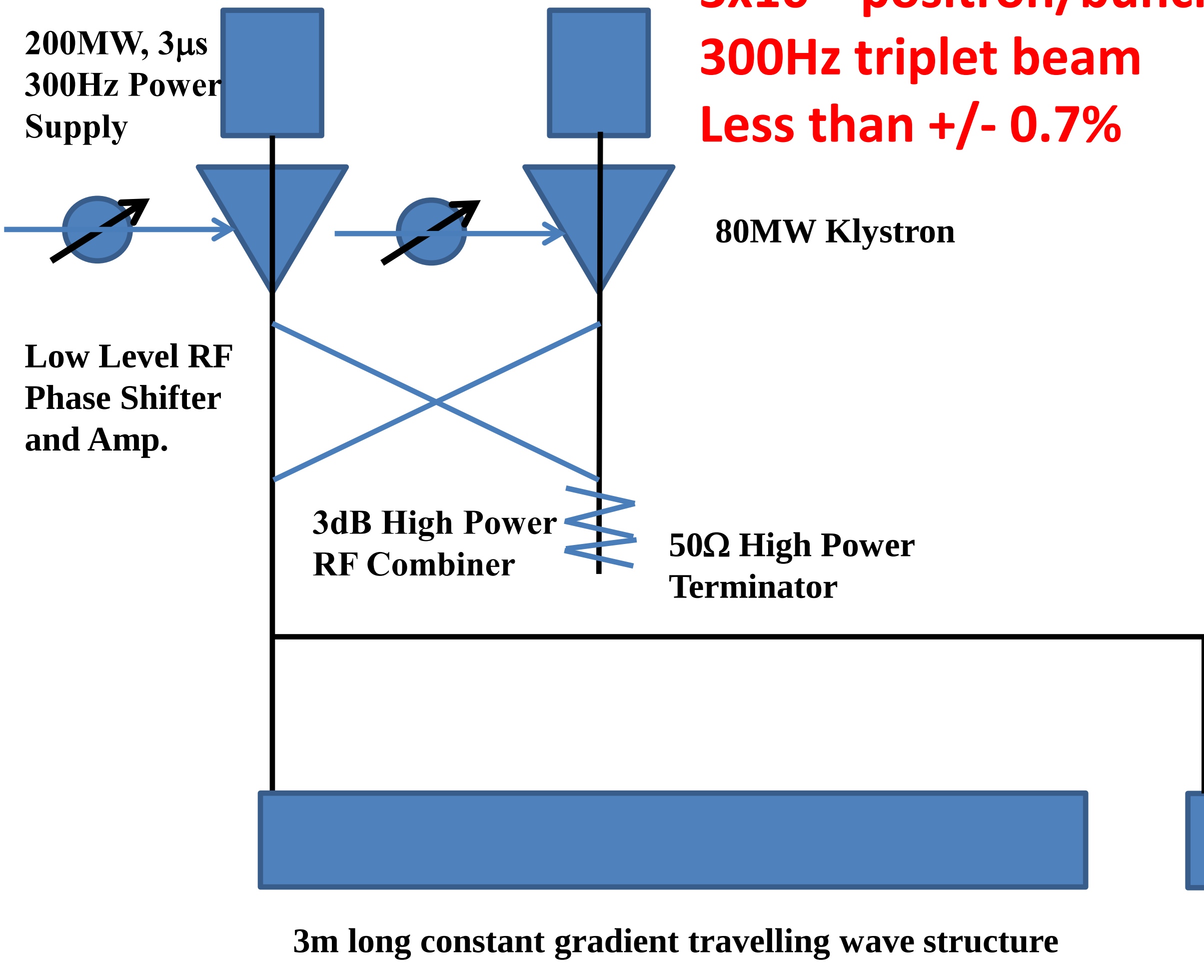


Loading Compensation Scheme

Urakawa



$3x10^{10}$ positron/bunch
300Hz triplet beam
Less than +/- 0.7%



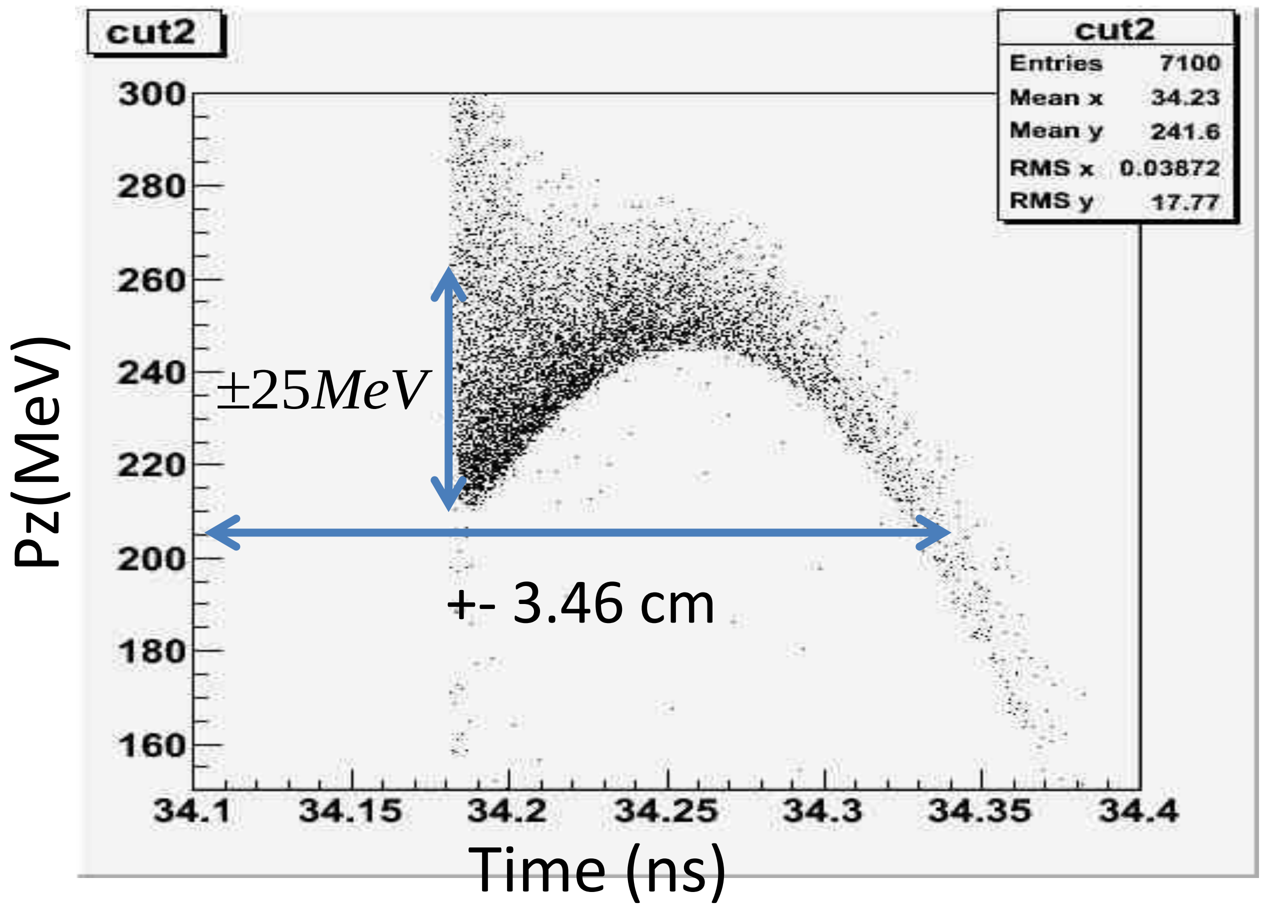
precise control of
the phase shifters needed

Test at ATF linac being planned

Overall Simulation

- DR aperture
  - $\Delta E < +\text{-}37.5MeV$
  - $\Delta z < +\text{-}34mm$
  - $A_x+A_y < 70\mu m$
- Must include
  - target simulation
  - loading compensation
- Is S-band linac acceptable?

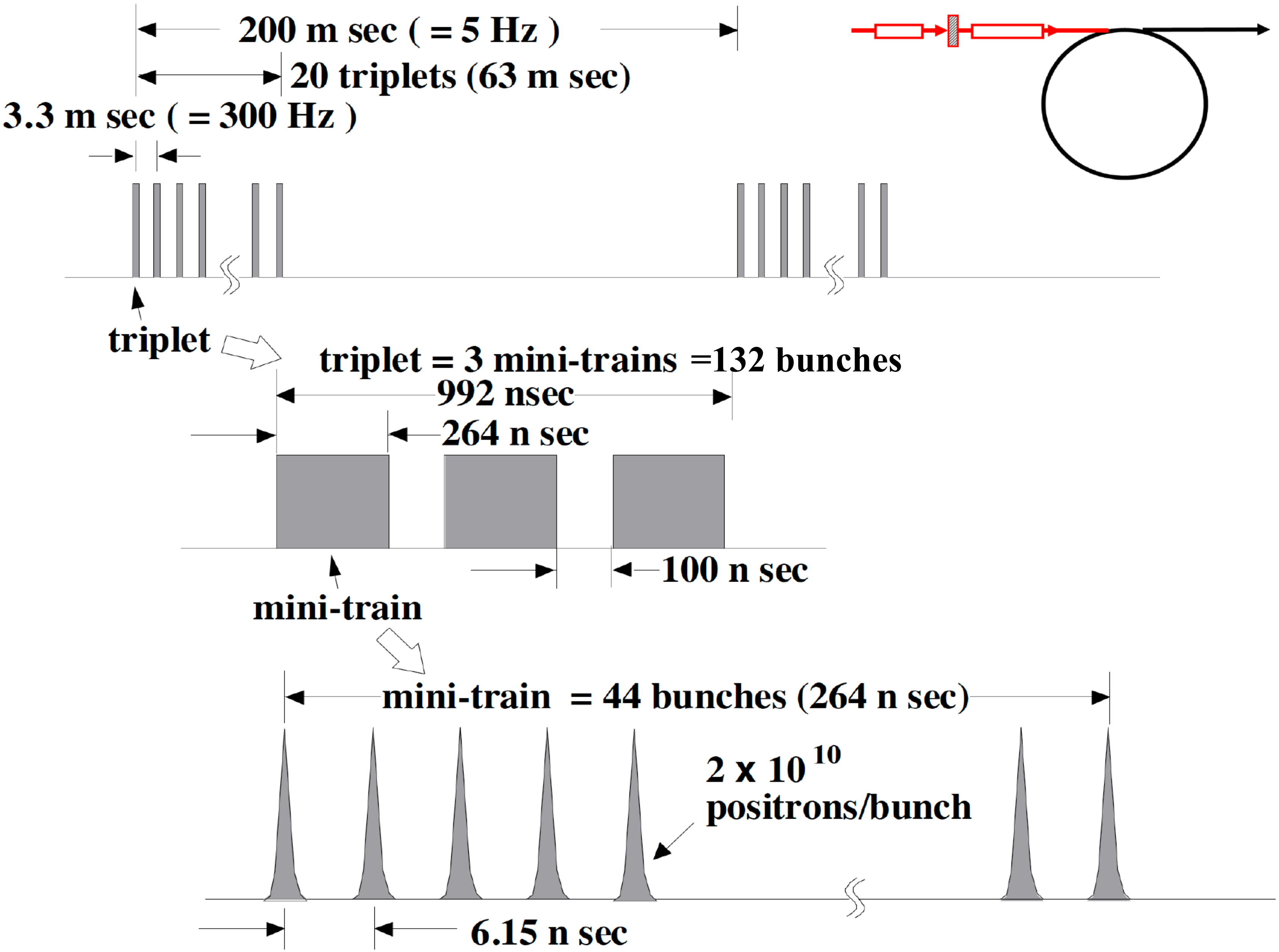
Longitudinal Phase Space



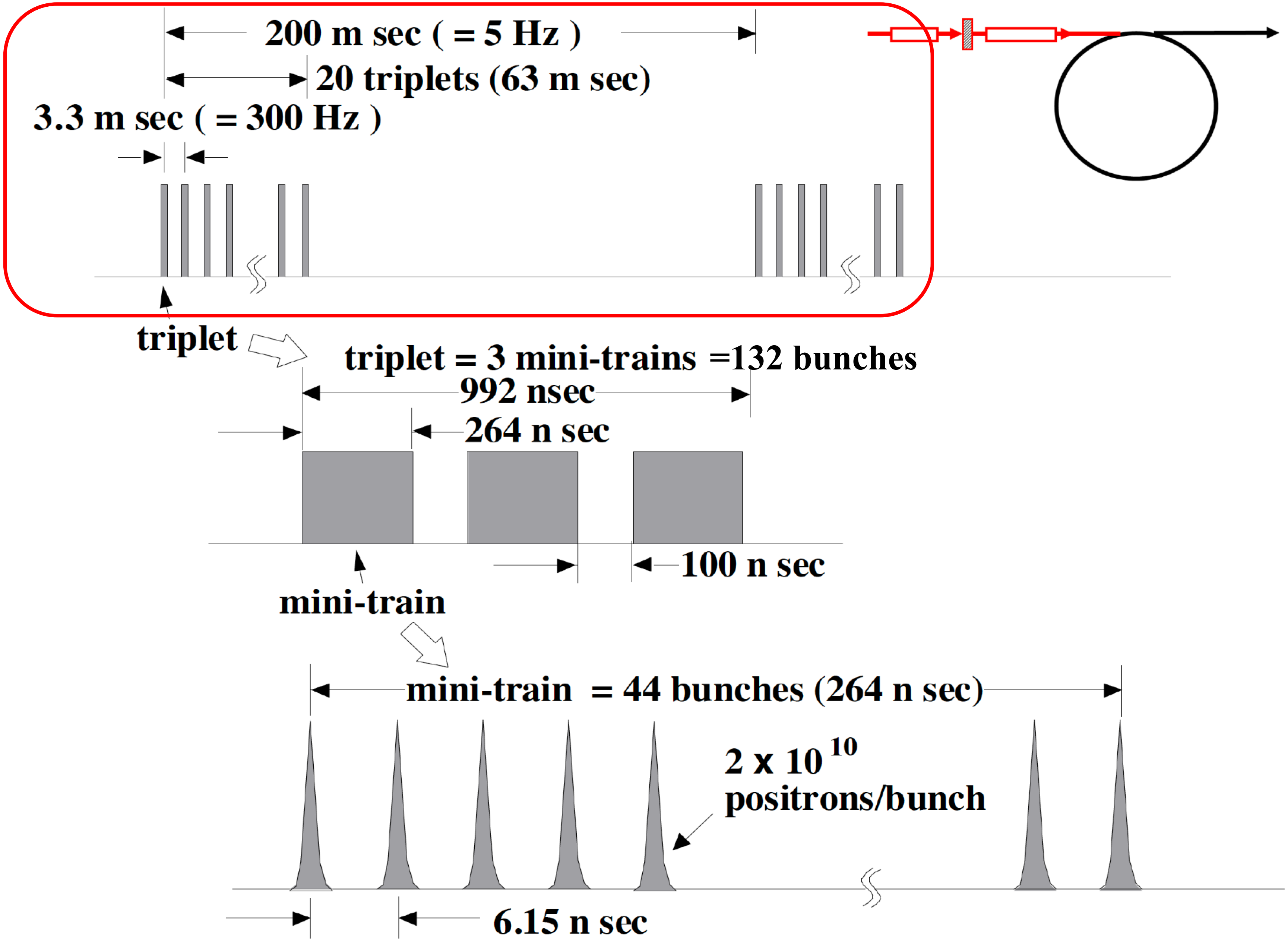
Higher Luminosity?

7.5 Hz main linac operation

Beam before DR

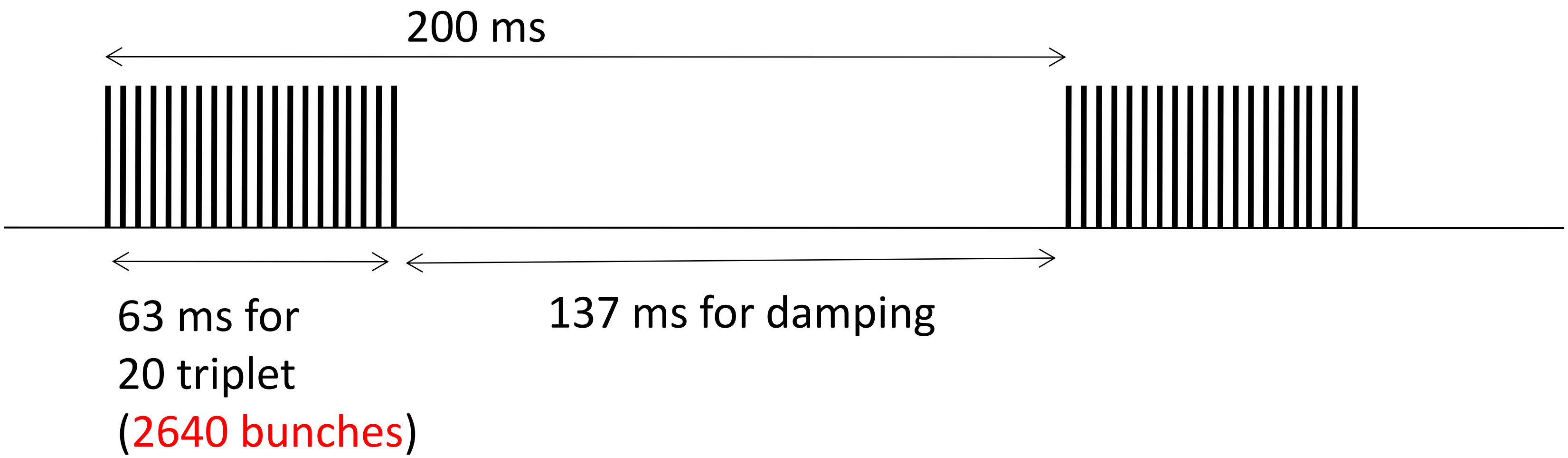


Beam before DR

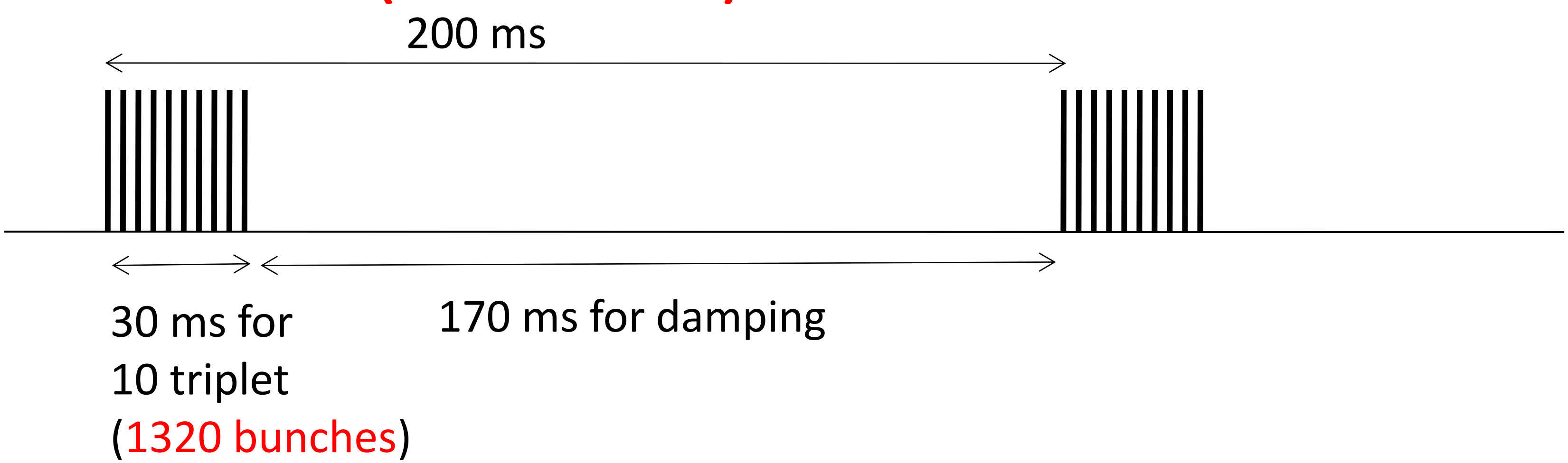


5 Hz Operation

For 2640 bunches (High Power Option), which I showed so far.

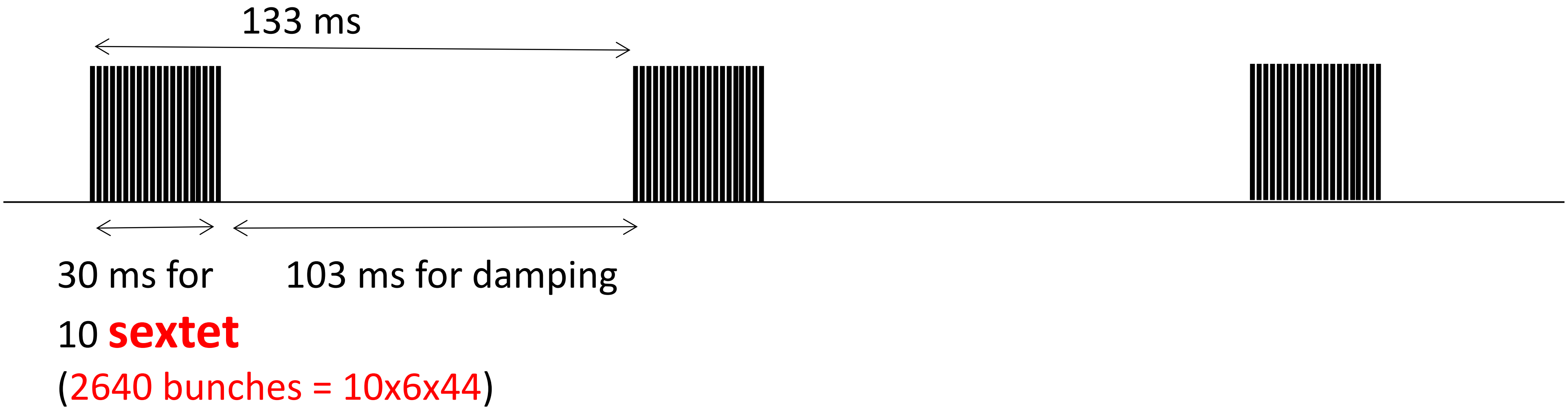


For 1320 bunches (TDR baseline)

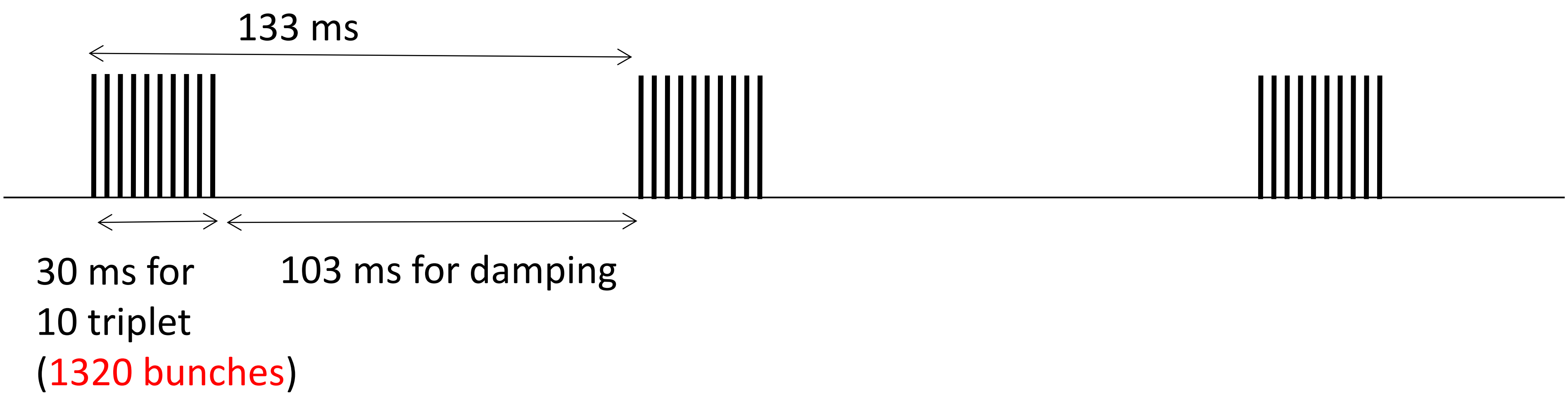


7.5 Hz Operation (x1.5 Lumi.)

For 2640 bunches (High Power Option)



For 1320 bunches (TDR baseline)



7.5 Hz Operation (x1.5 Lumi.)

For 1320 bunch:

* We can adopt 7.5 Hz main-linac-rep.-rate for 300 Hz scheme.
* Average heat load on the target increase, but no major difficulty.

For 2640 bunch:

* We can adopt 7.5 Hz main-linac-rep.-rate for 300 Hz scheme, if we can employ sextet time structure in 300 Hz linec instead of triplet.
* sextet : 44 bunches x 6 = 234 bunches , dulation ~ 2 usec.
* Need to increase pulse width of 300 Hz linac: 1 us -> 2us. Need careful consideration.
* Instantaneous heat load on the target increase (x2). Can be problem. Need careful consideration.

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Comparison with NLC/GLC

300 Hz scheme

- Stretching in time

300 Hz scheme

- **Stretching in time**

- **The Same as Warm colliders**

  NLC 120 Hz

  GLC 150 Hz

  CLIC 50 Hz

300 Hz scheme

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  NLC 120 Hz
  GLC 150 Hz
  CLIC 50 Hz

  Employs 3-4 targets
  Thermal Shockwave

- We try to employ single target.

  Amorphous Tungsten ← Truly Conventional

  Just solid tungsten target is OK
  with
  Pendulum Motion or Slow Rotation.

  We assume
  NO Liquid Target or
  NO Hybrid Target

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Why just single solid target is OK in ILC ?

What is the difference wrt GLC/NLC design

Old GLC/NLC design employed 3 targets.

Why single target can survive in ILC 300 Hz.

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Because, improved optimization in ILC 300 Hz.

	ILC 300 Hz	GLC(JLC) 3 targets (for each)	NLC 3/4 targets (for each)
Eb	6 GeV	10 GeV	6.2 GeV
Ne-/bunch	2×10^{10}	1×10^{10}	1.5×10^{10}
N of bunches	132 (triplet)	64 (192/3)	63 (190/3)
t_target	14 mm	21 mm	14 mm
spot (σ) on target	4 mm	2.5 mm	1.6 mm
DR/preDR accpt	$\Delta E<25$ MeV	$\Delta E<19.8$ MeV	$\Delta E<10$MeV
	$\Delta T<115$ps	$\Delta T<?$	$\Delta T<30$ ps
	$\gamma A_x+\gamma A_y=0.09$ m	$\gamma A_x \& \gamma A_x<0.03$ m	$\gamma A_x \& \gamma A_x<0.03$ m
PEDD	23 J/g	35 J/g	35 J/g
e+/e-	1.5	1	1.8

Comparison of ILC 300Hz w/ JLC and NLC studies

Parameters	ILC 300Hz	JLC 3 targets (for each target)	NLC 3 × 4targets (for each target)
Drive Beam			
energy	6 GeV	10 GeV	6.22 GeV
# e- /bunch	2.0×10^{10}	1.0×10^{10}	1.5×10^{10}
# bunches	132 (triplet)	64 (=192/3)	63(=190/3)
Beam size	4.0 mm	2.5mm	1.6mm
Target			
material	~W~	W75Re25	W75Re25
Thickness	4X0 (14mm)	6X0(21mm)	4X0
PEDD	22.7 J/g	35J/g	35J/g
Energy deposit	35kW		16kW
Capture Section			
Max FC field	7 T	7T	5.8T
FC aperture(diameter)	12mm	?	9mm
Max. RF field	25 MV/m	25MV/m	25MV/m
RF frequency	1.3 GHz	1.428GHz	1.428
Positron yield/e			
DR/ PDR acceptance	dE <25 MeV, dT<115ps, $\gamma Ax+\gamma Ay < 0.09m$	dE <1%, dT<?, $\gamma Ax, \gamma Ay < 0.027m$	dE <10 MeV, dT<30ps, $\gamma Ax, \gamma Ay < 0.03m$
e+/e-	1.5	0.99	1.8

Target Issues

Two Issues

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

- **Undulator Scheme (base line)**
  - In order to create e+s, it uses e- beam in the main linac.
  - 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).

    (spreads 2600 bunches in 100 mm length)

- **300 Hz Truly Conventional**
  - It creates 2600 bunches of e+s in 63 m sec. (stretching)
  - Heat load is not a problem.
  - Do we have a solution? Issue : shock wave

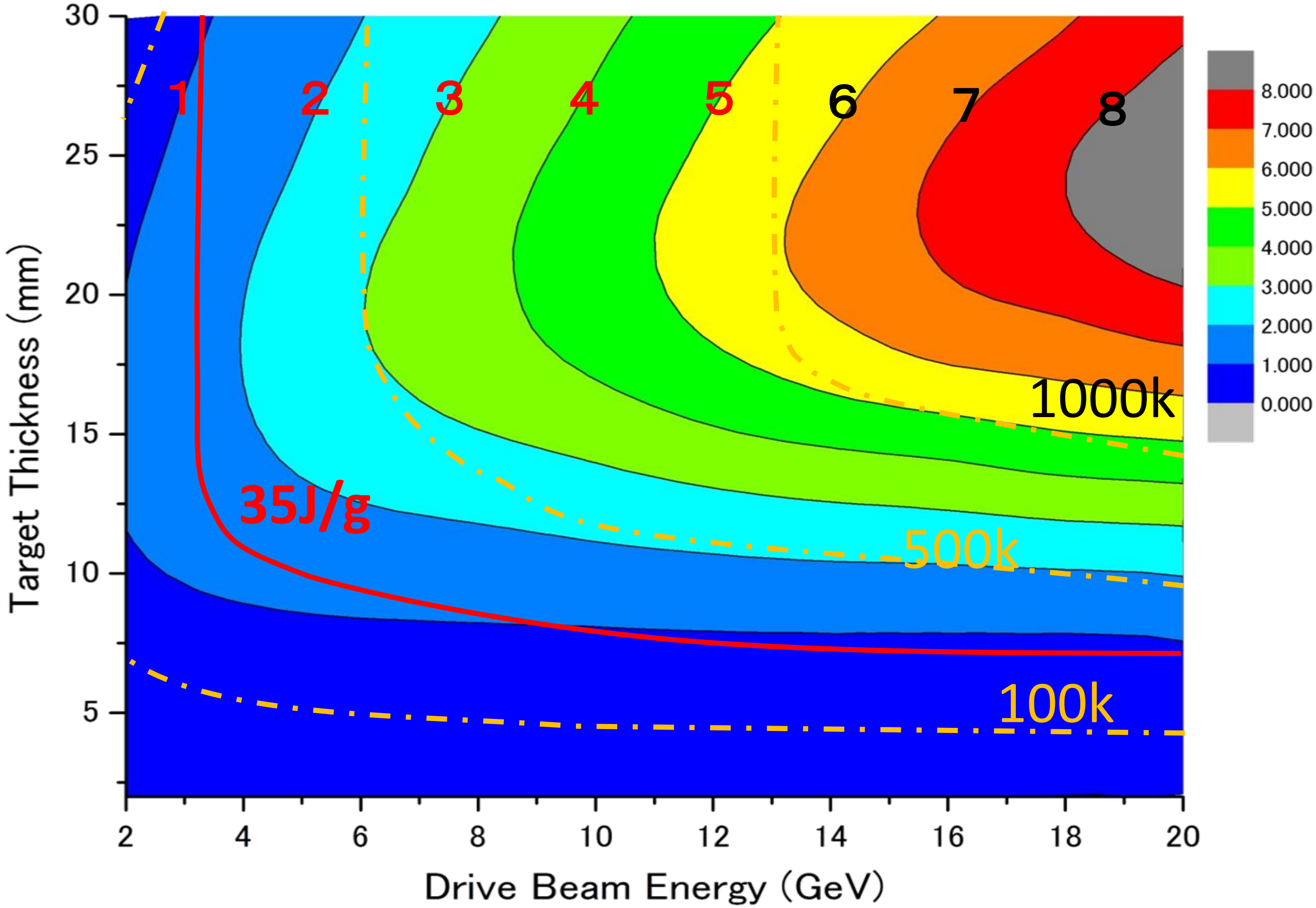
Parameter Plots for 300 Hz scheme

e- directly on to Tungsten

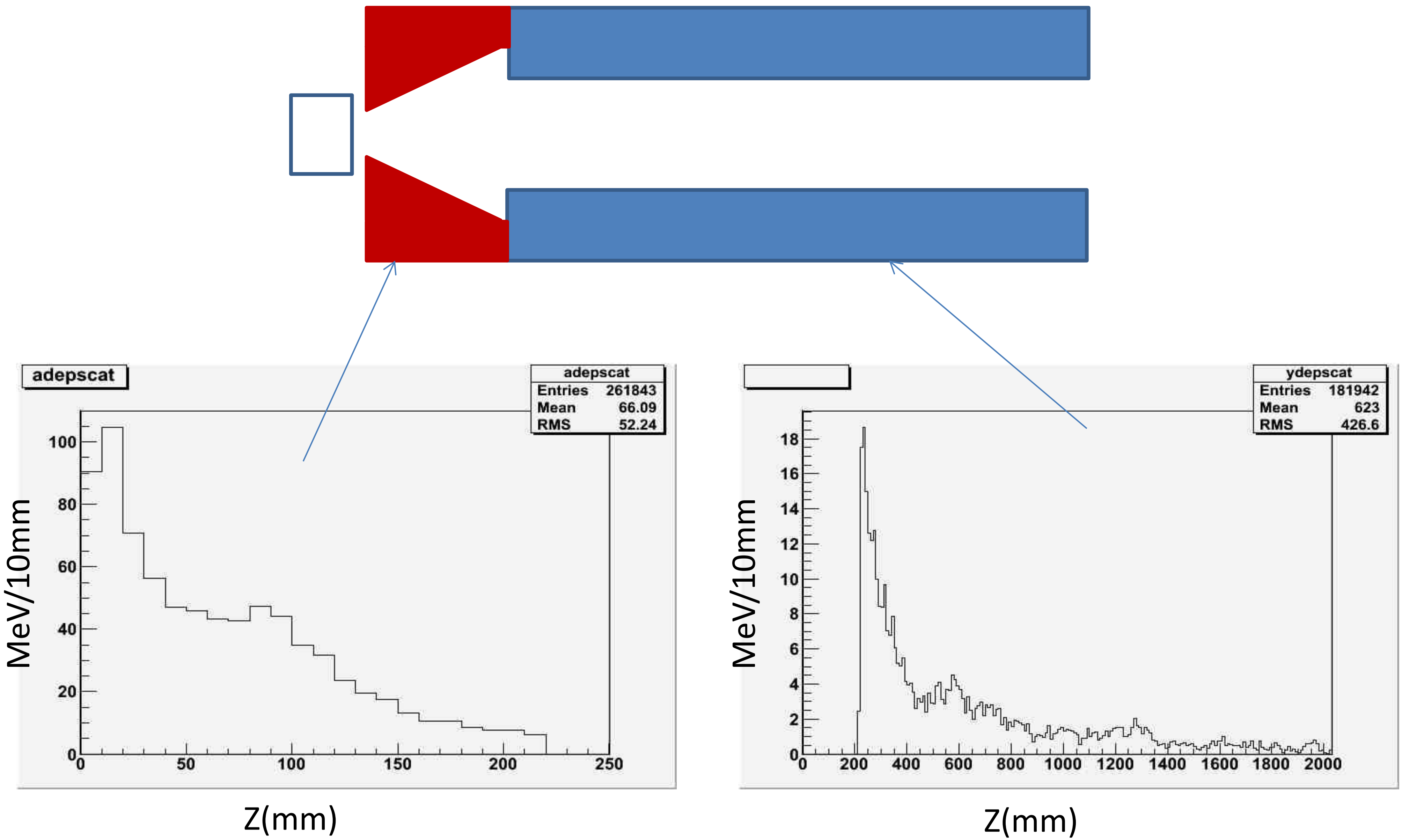
σ=2.5mm

Ne⁻(drive) = 2×10^{10} /bunch

colored band	accepted e+/e-
red solid line	PEDD J/g
orange dash-dot line	dT max by a triplet

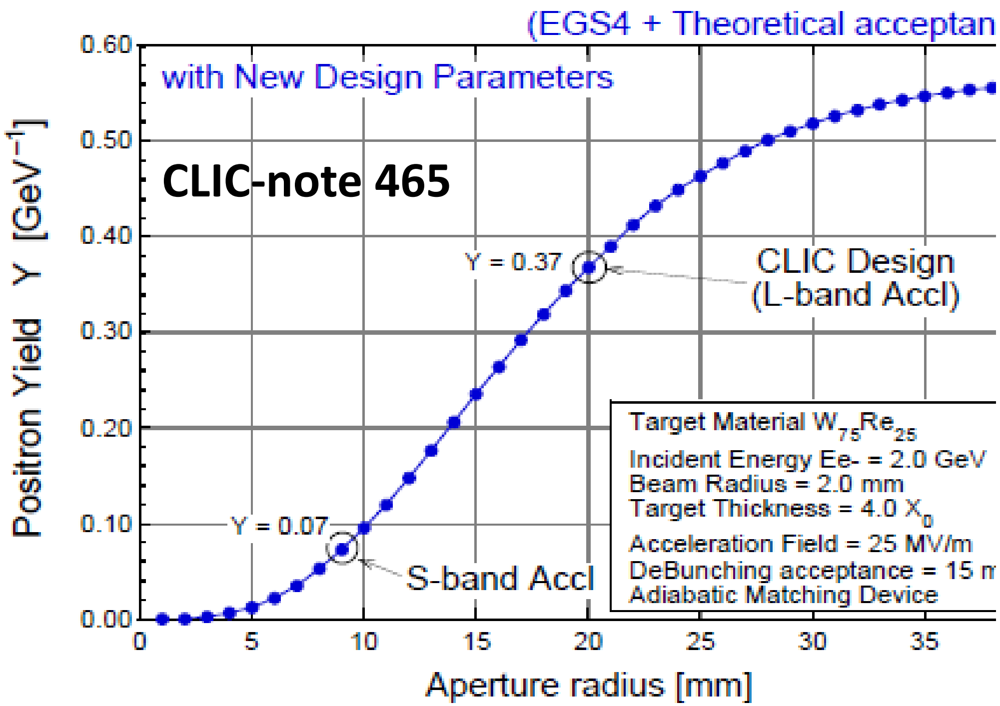


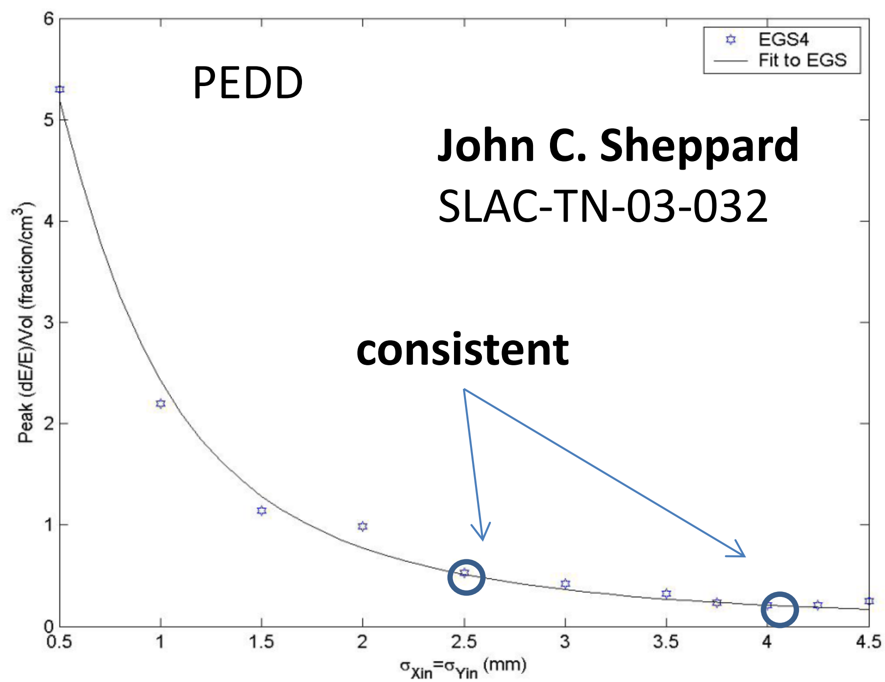
Energy deposit in capture section



a few comments

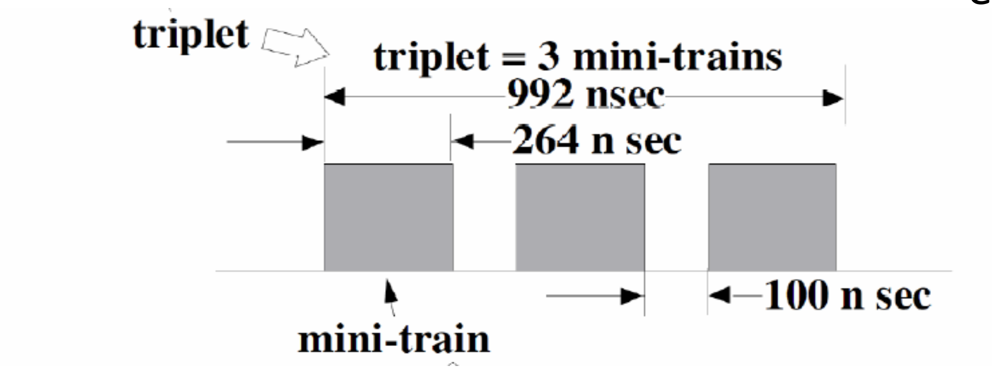
- numbers shown here are consistent w/
    - independent calculation by a colleague in KEK and French colleague for Hybrid
- comparison w/ SLC study
    – both assumed AMD but acceptance for linac is;
        - SLC S-band linac ←→ this study (CLIC) L –band

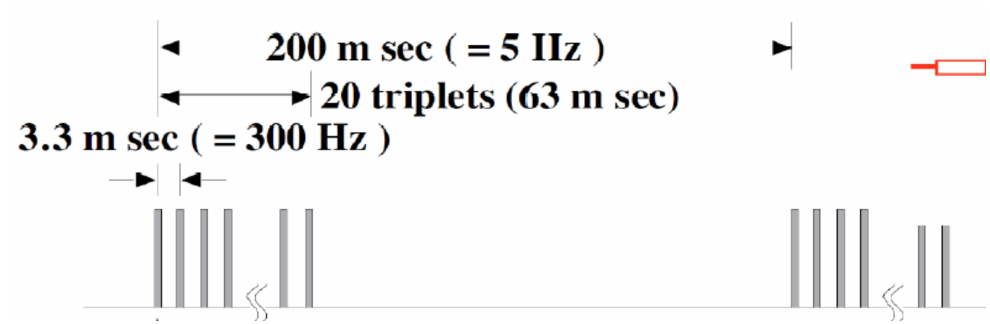




Assumption

each triplet hits different position on the target
ɘlatively low (1~2m/s)rotational target





duration of a triplet ~ dumping time of shock wave
shoter than time scale of thermal dissusion

132 bunches in a triplet contributes both shock wave and thermal damage

Target & Drive_Beam Optimization

Conventional e+ sources

Well established

used to be → thermal load, shock wave

300Hz scheme

e+ gen. in 60ms rather than 1ms

relax thermal problem for

targets

increase survivability w/ slow rotation targets

Capture section

larger aperture for RF section

larger acc. gradient

worth while looking into feasibility again

Acceptance estimate

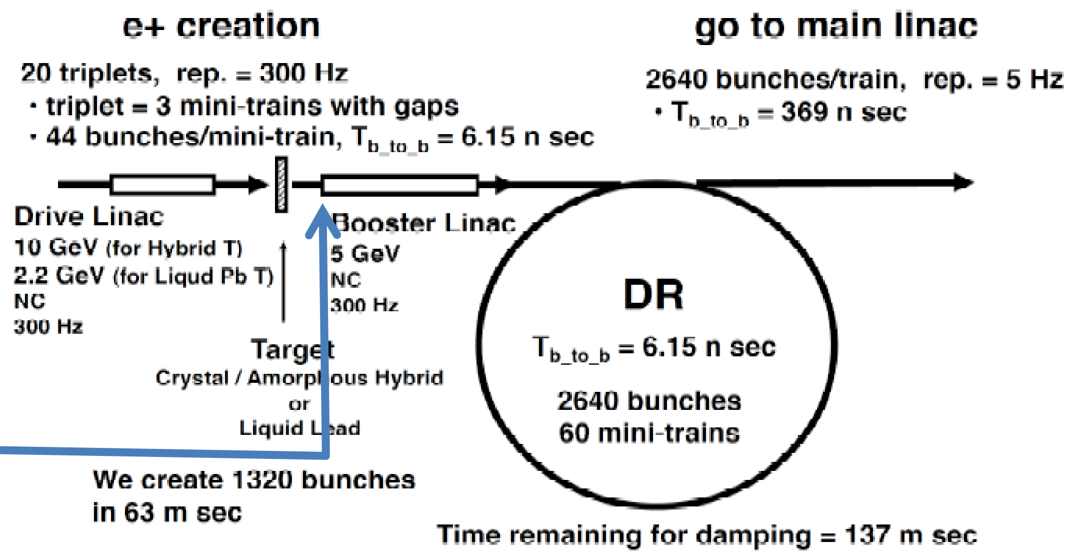
CLIC note 465

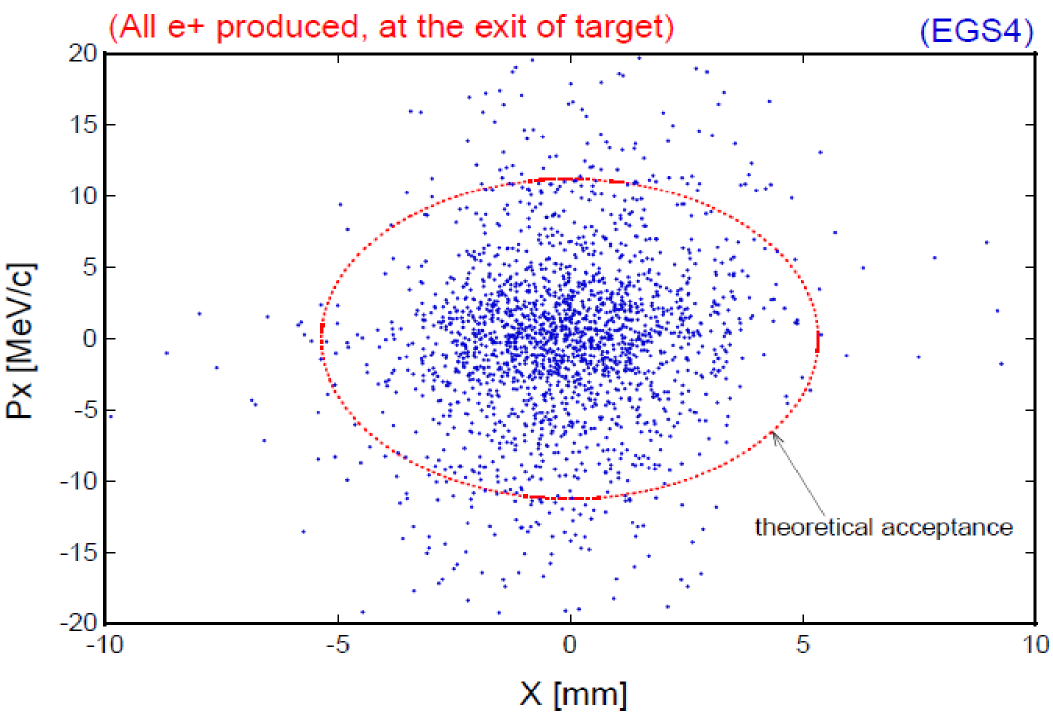
$[r/5.3[mm]]^2 + [pT[MeV]/11]^2 =< 1$

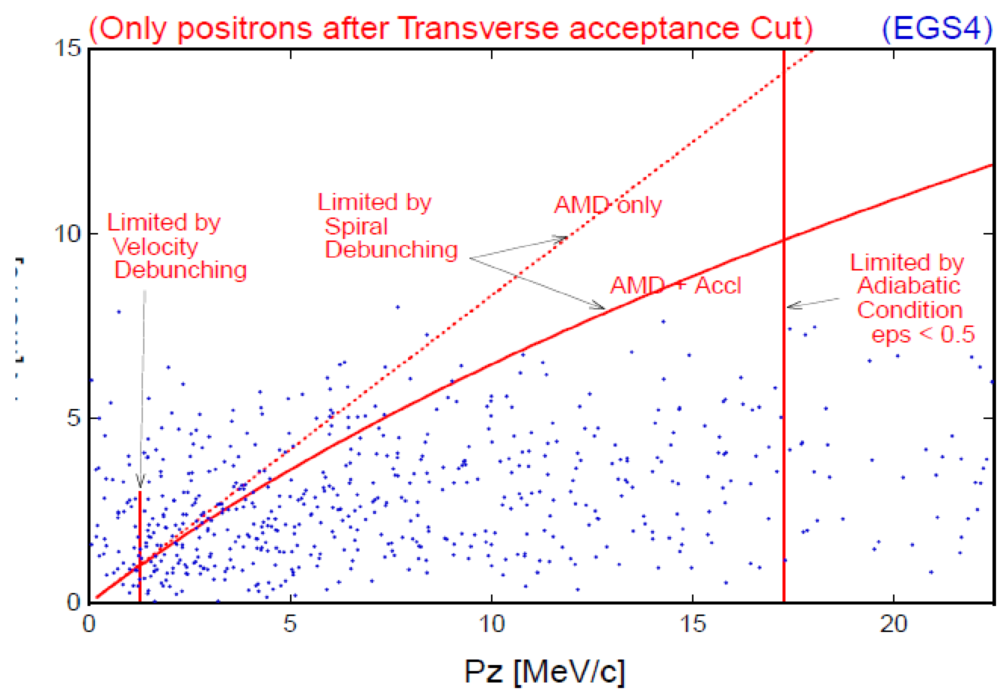
pT < 0.1875 MeV/c + 0.625 pL

1.5 MeV/c < pL < 17.5 MeV/c

～# of e+ in DR (or booter linac)







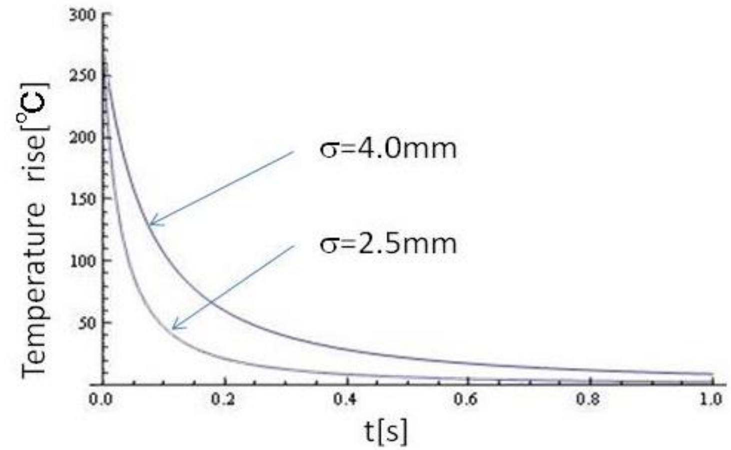
Thermal diffusion

$$T(t) \sim T_0 e^{\alpha t}$$
$$\alpha = -\frac{\lambda}{C_V}\beta^2$$

$$\lambda = 174 W/m \cdot K$$
$$C_V = 2.5 \times 10^6 J/m^3 \cdot K$$

time constant of the diffusion depends on beam spot size ~1/β

numerical calculation of
thermal diffusion shows



	1D	2D	3D
time constant σ=2.5mm σ=4.0mm	280ms 750ms	80ms 200ms	40ms 100ms

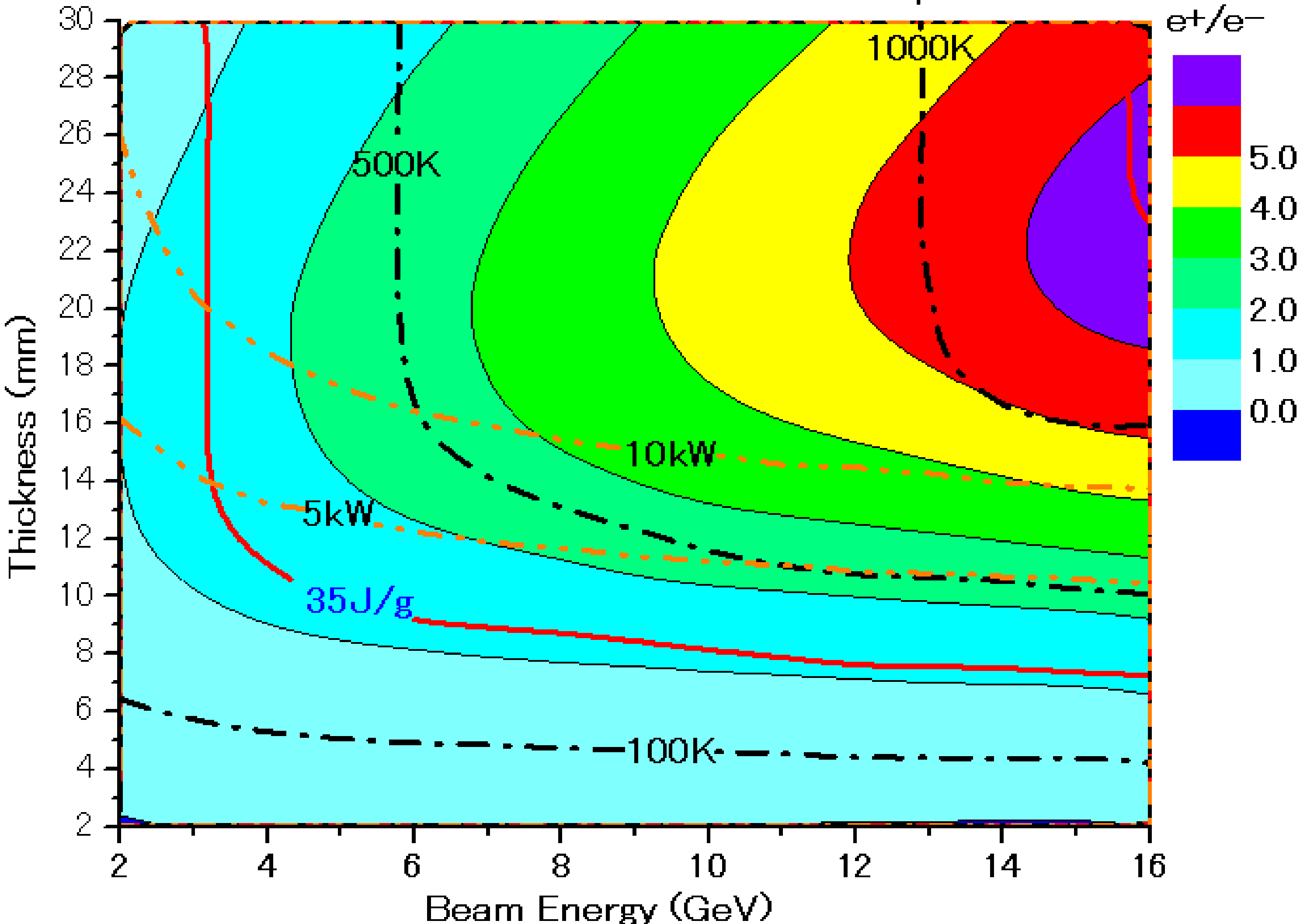
time constant is order of 100ms >> Ttriplet ~1μs

Parameter Plots for 300 Hz scheme w/ clic note formula

e- directly on to Tungsten

σ=2.5mm

colored band	accepted e+/e-
(red solid line)	PEDD J/g
(dash-dot line)	dT/triplet (132 bunc)
(dash-dot-dot line)	ToTal deposit kW



Parameter Plots for 300 Hz scheme w/ CLIC note formula

e- directly on to Tungsten

σ=4.0mm

colored band — accepted e+/e-
PEDD J/g
dT/triplet (132 bunc)
ToTal deposit kW