Overview of 300 Hz Conventional e^+ Source for ILC

T. Omori (KEK)

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ECFA LC Workshop at DESY

Truly Conventional Collaboration

ANL, IHEP, Hiroshima U, U of Tokyo, KEK, DESY, U of Hamburg

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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

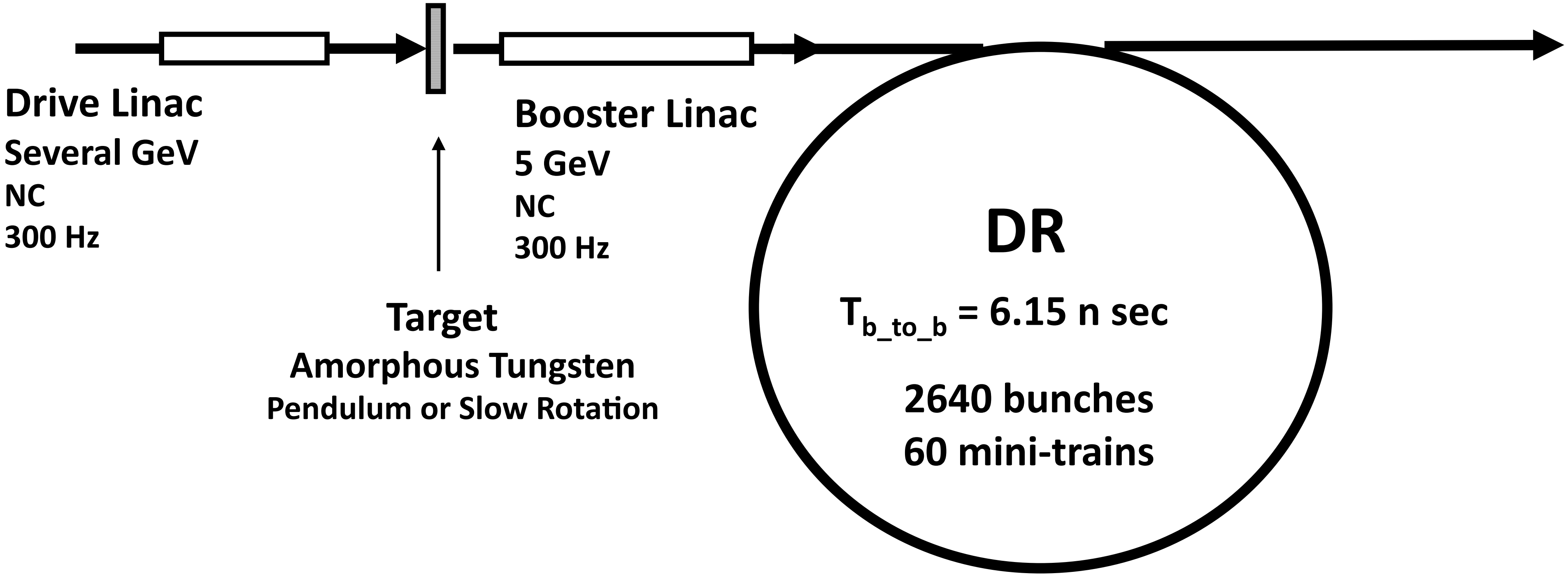
20 triplets, rep. = 300 Hz

- **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

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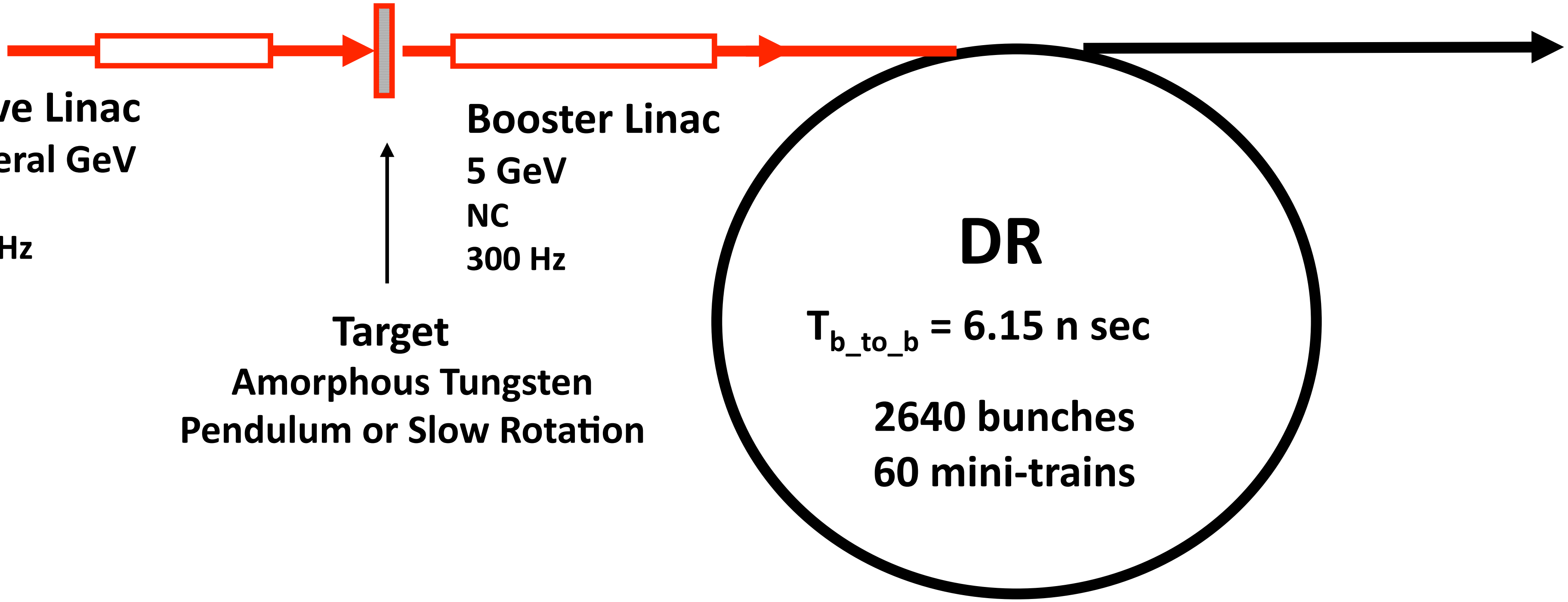


Drive Linac
Several GeV
NC
300 Hz

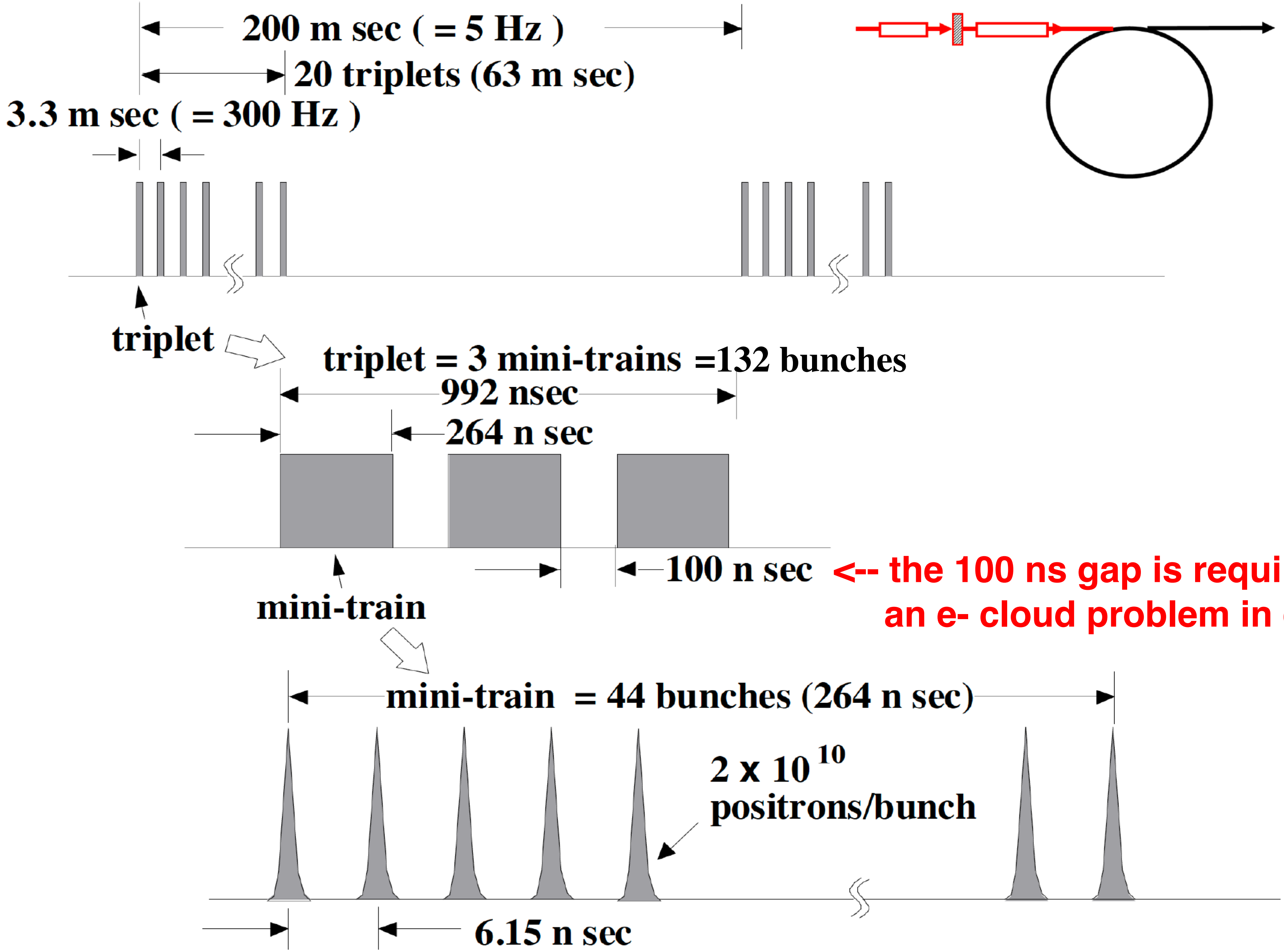
Booster Linac
5 GeV
NC
300 Hz

Target
Amorphous Tungsten
Pendulum or Slow Rotation

Time remaining for damping = 137 m sec

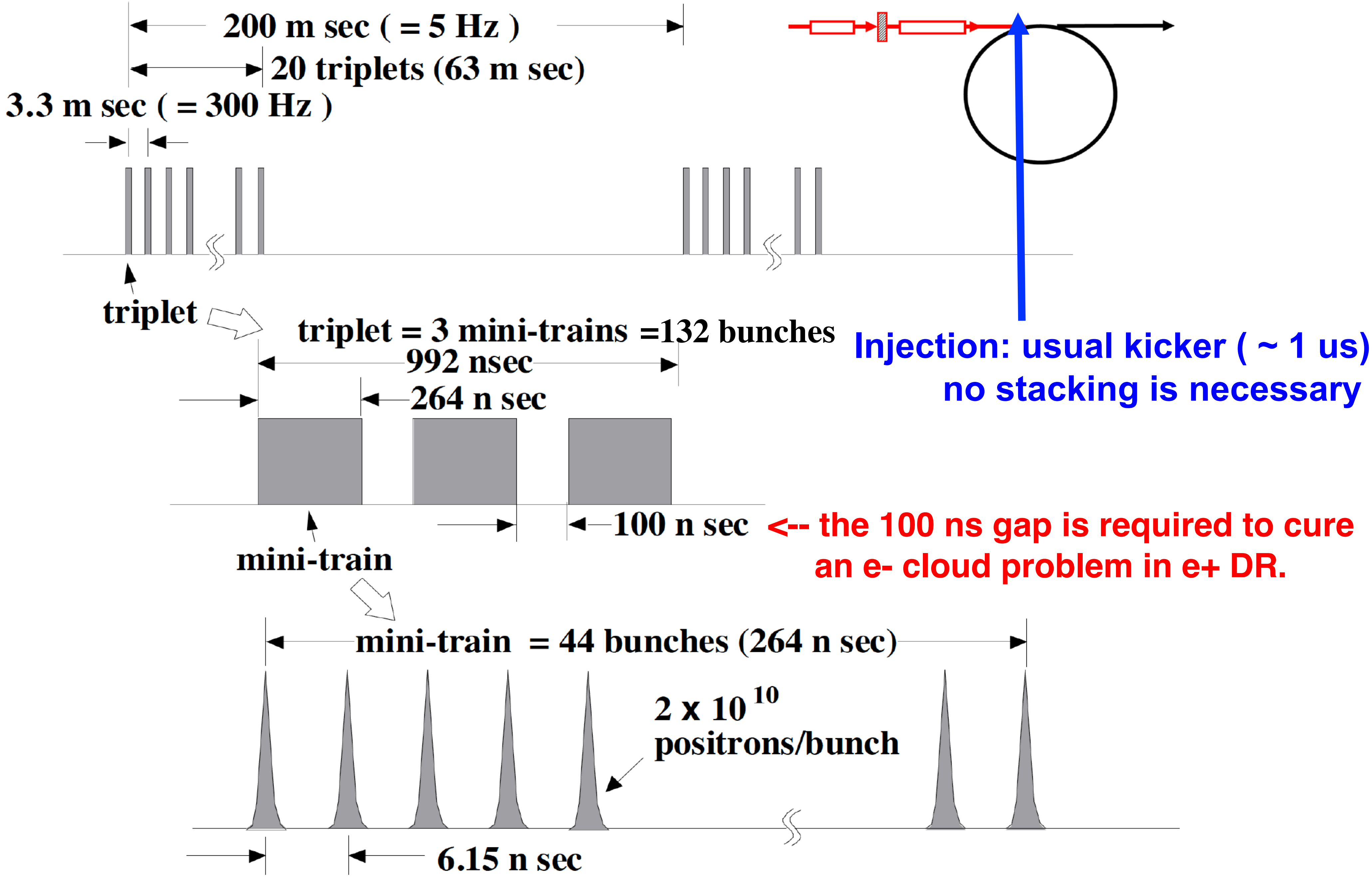
We create 2640 bunches
in 63 m sec ⇐ Stretching

Beam before DR



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

Beam before DR



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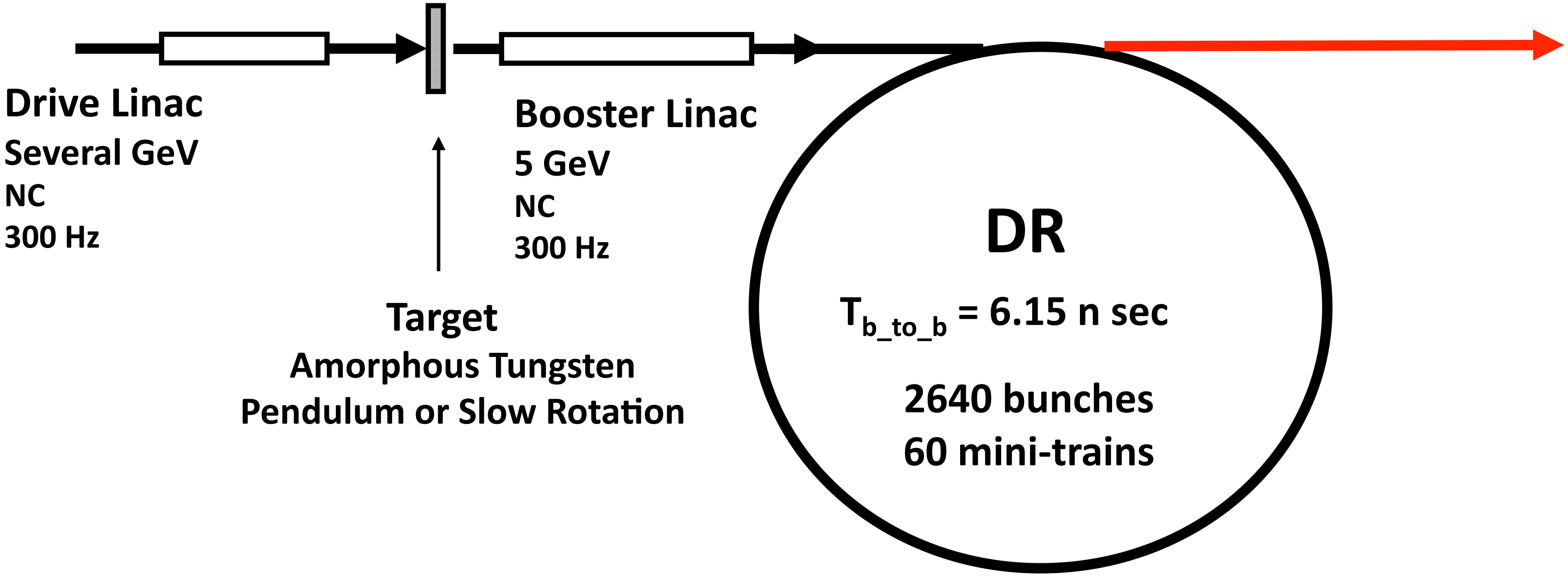

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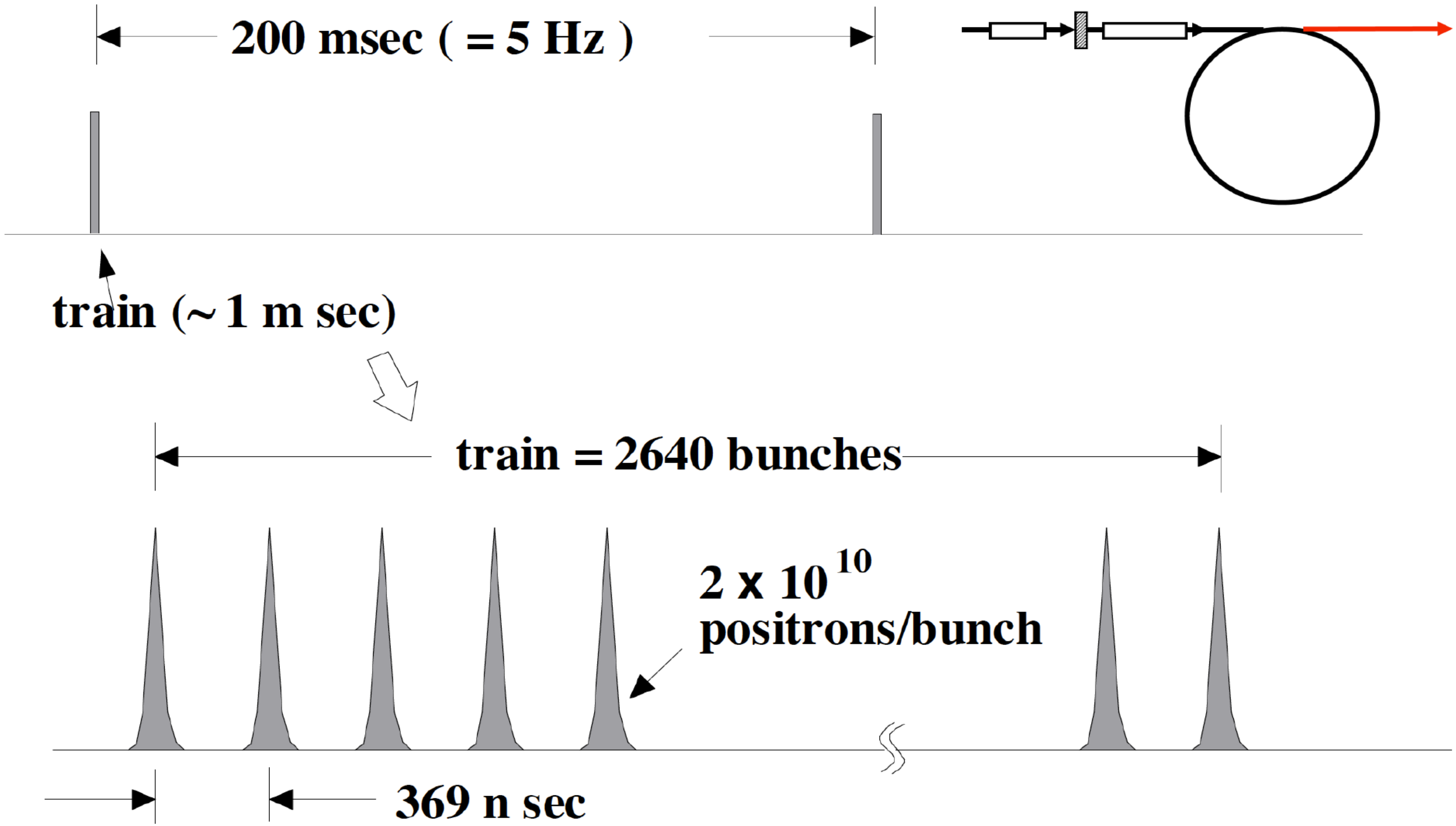

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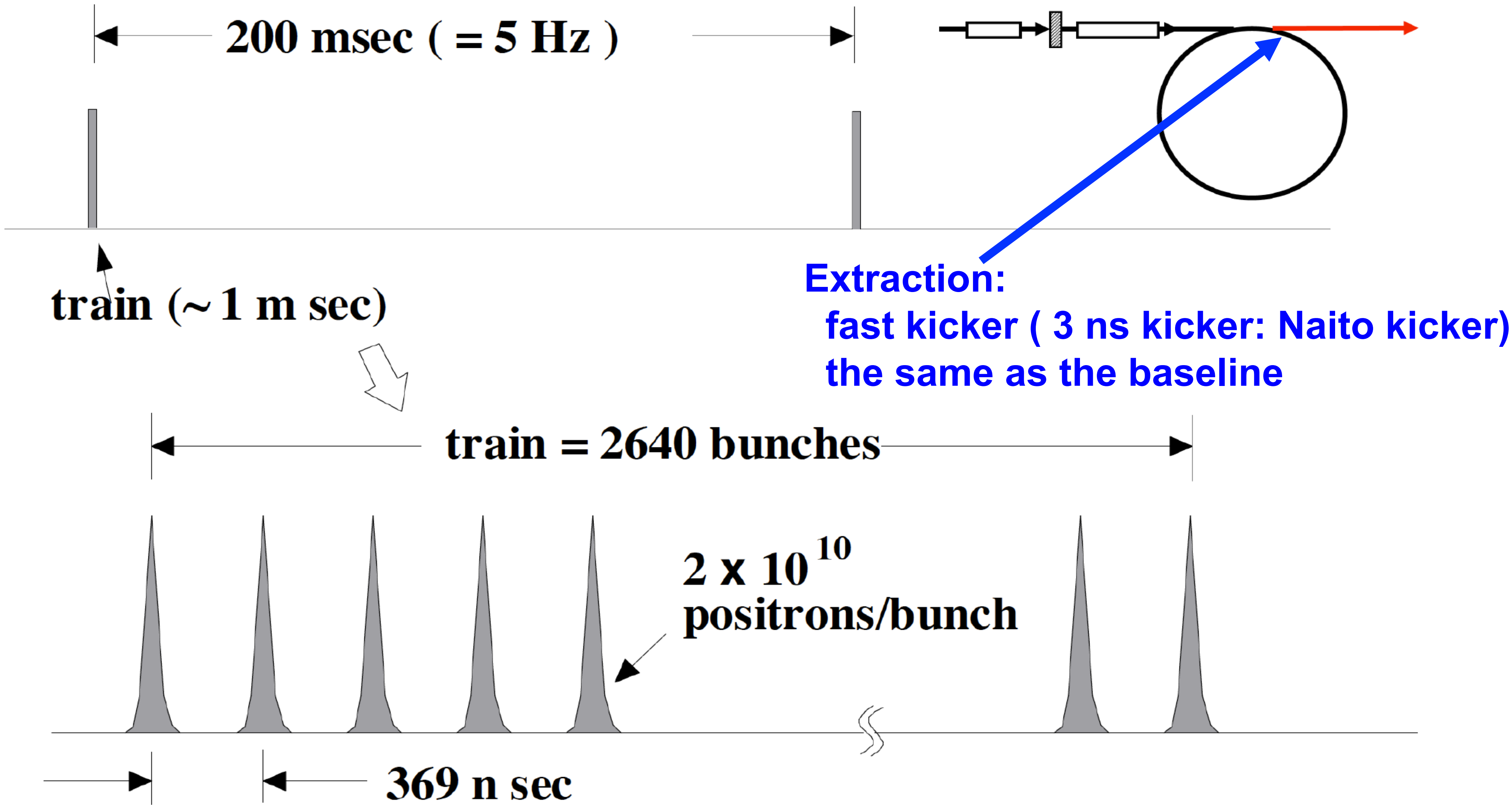


Target and Drive_Beam Optimization for Truly Conventional e+ Source

Method

EM shower simulation

e+ yields
Peak Energy Deposit Density (PEDD)
total energy deposit

e+ capture efficiency

of e+ in the Damping Ring

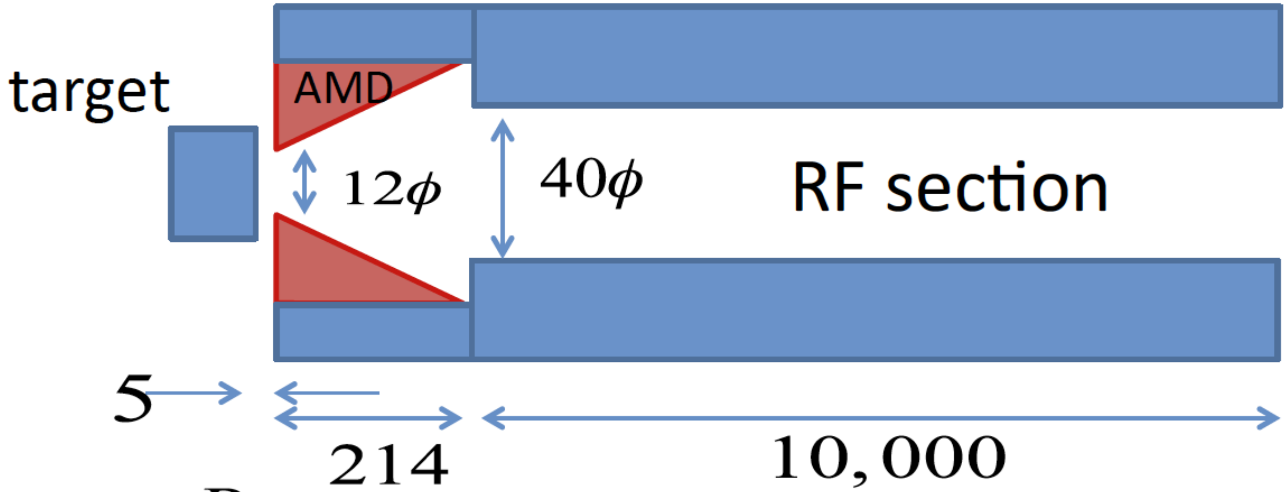
Geant 4 + Empirical formula by CLIC note 465

↓

EM shower and particle tracking w/ Geant 4

Parameters in capture section

300Hz scheme w/ slow rotation target ～ CLIC



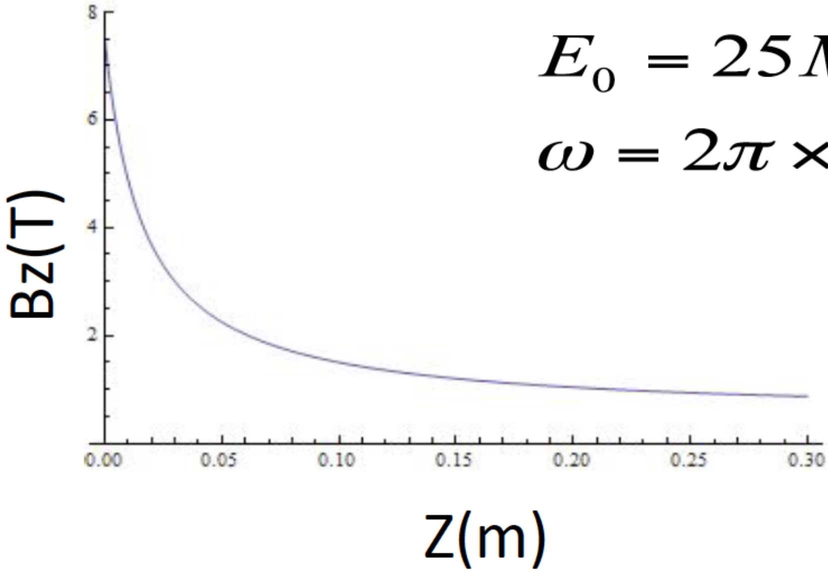
$$Bz(z) = \frac{B_0}{1+\mu z} + B_{sol}$$

$$B_0 = 7T$$

$$\mu = 60.1m^{-1}$$

$$B_{sol} = 0.5T$$

$$Br(r,z) = -\frac{1}{2} r \frac{\partial B_z(z)}{\partial z} + \frac{1}{16} r^3 \frac{\partial^3 B_z(z)}{\partial z^3}$$

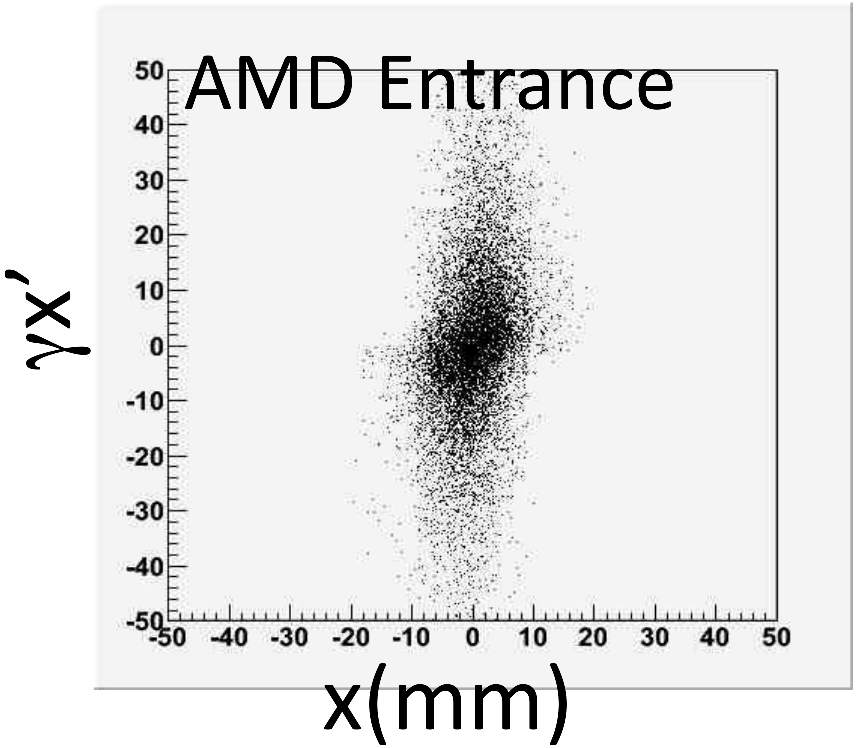


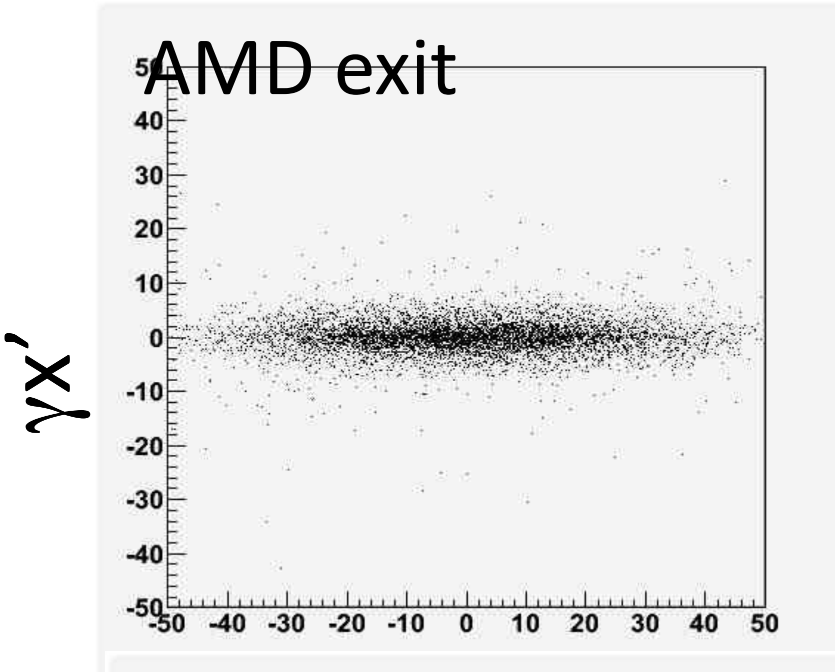
$$Ez = E_0 \cos(kz - \omega t + \varphi)$$

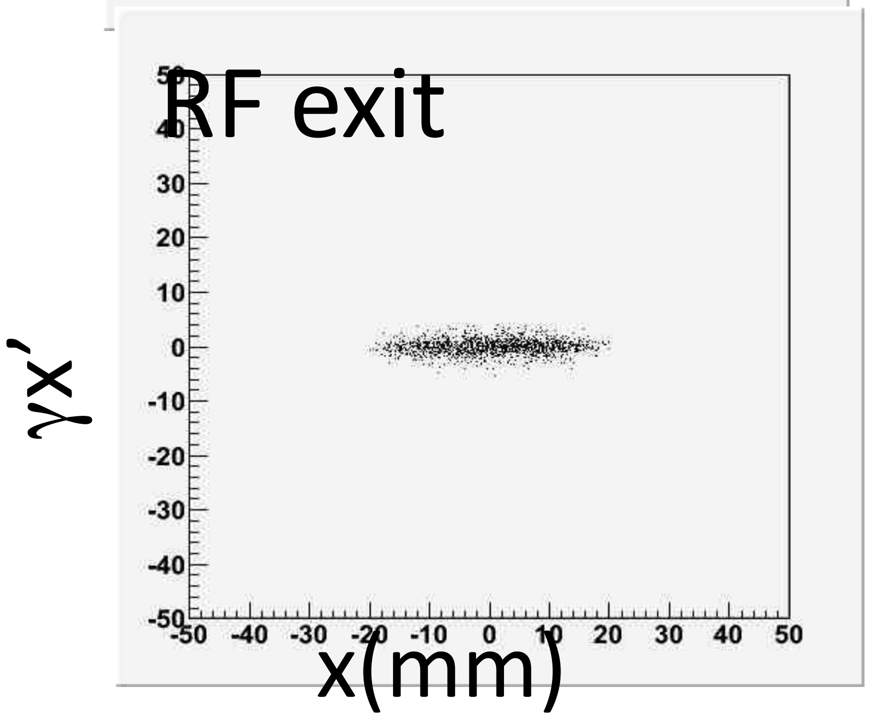
$$E_0 = 25MV/m$$

$$\omega = 2\pi \times 1.3GHz$$

Simulation: Transeverse phase space





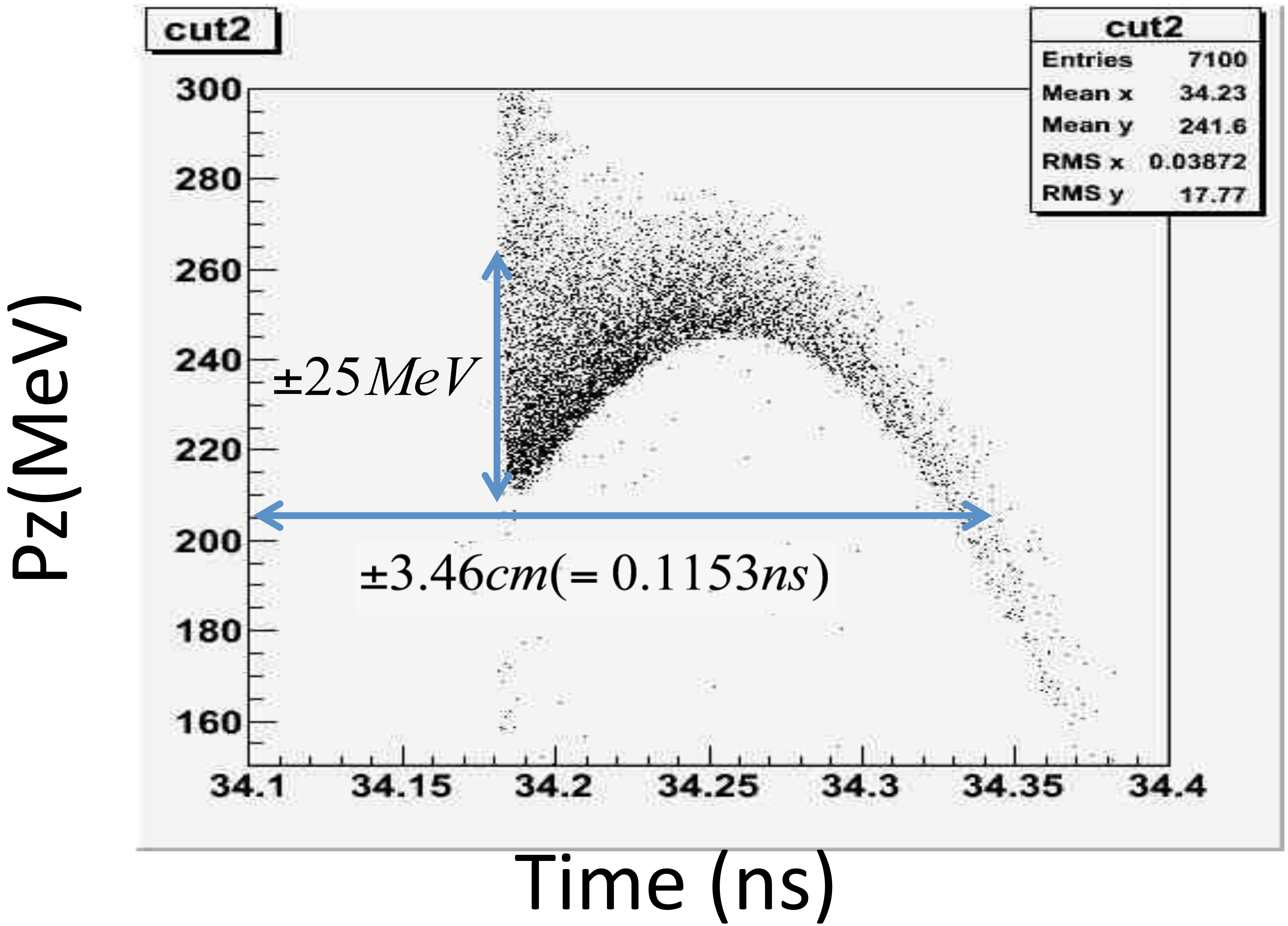


$$A_x = \gamma_x x + 2\alpha_x x(\gamma x') + \beta_x(\gamma x')^2$$

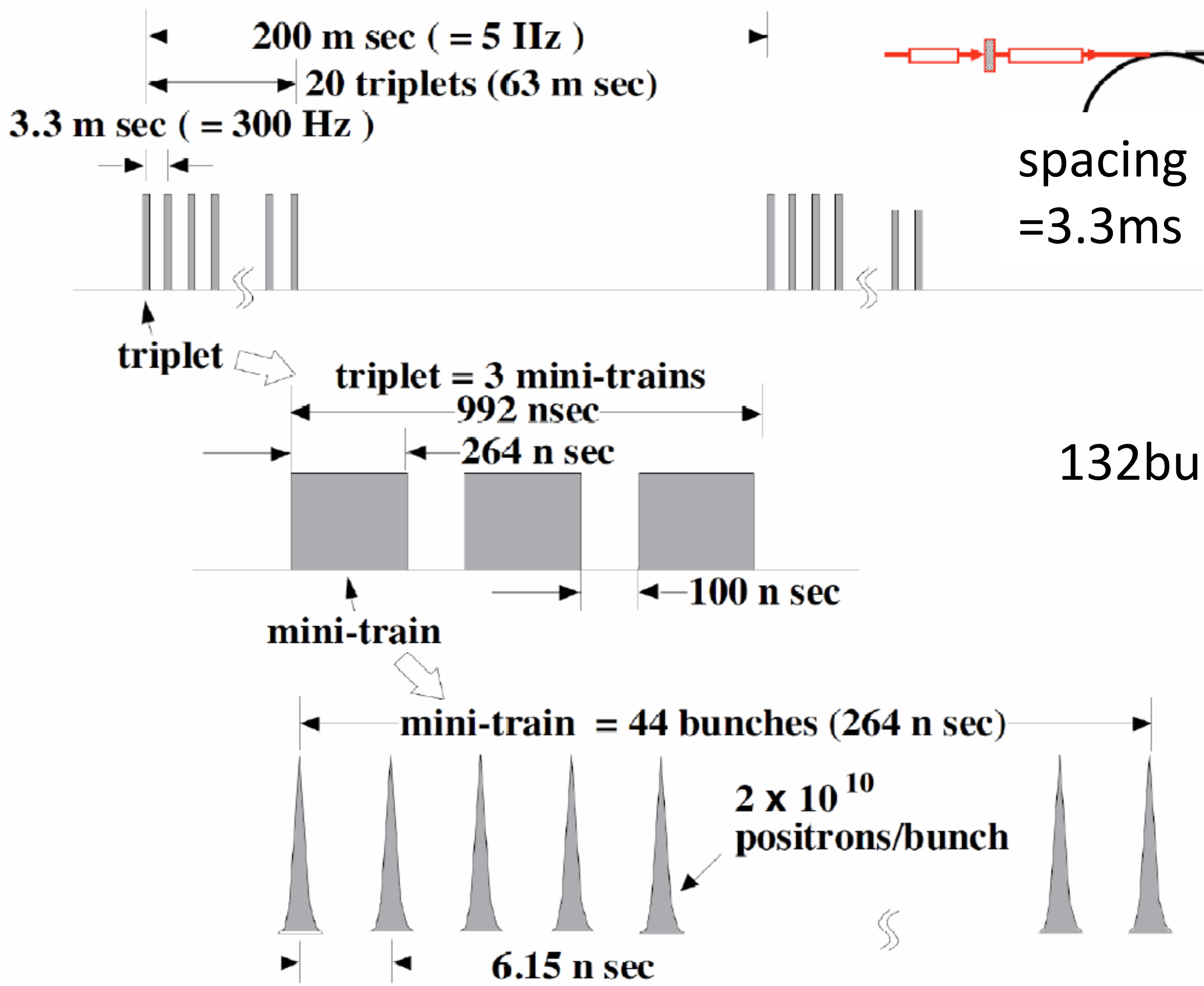
DR transverse acceptance :
fron RDR

$$A_x + A_y < 90mm \cdot rad$$

Longitudinal phase space



In the case of 300Hz scheme



spacing between triplets =3.3ms

132bunches in 992ns

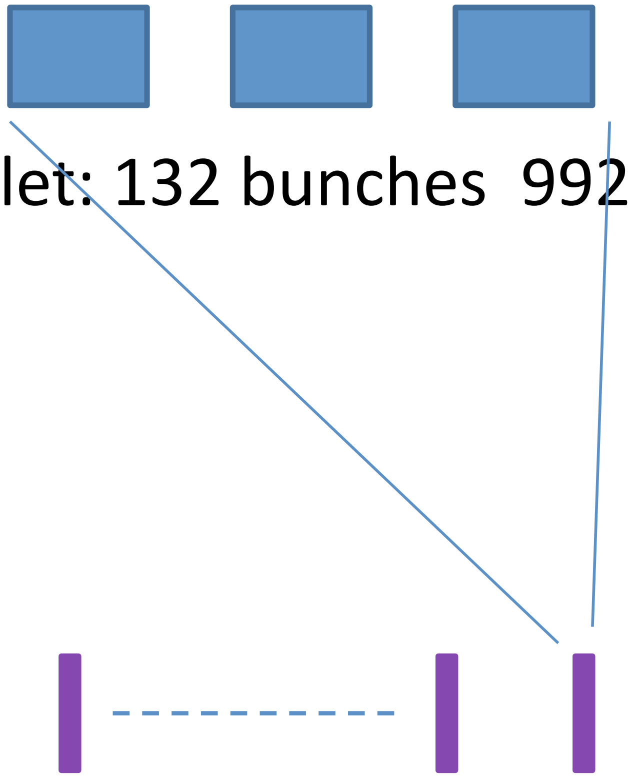
good for a FC

we can use existing FC technology

Assumptions

drive electrons

2×10^{10}/bunch



a triplet: 132 bunches 992ns

3.3ms

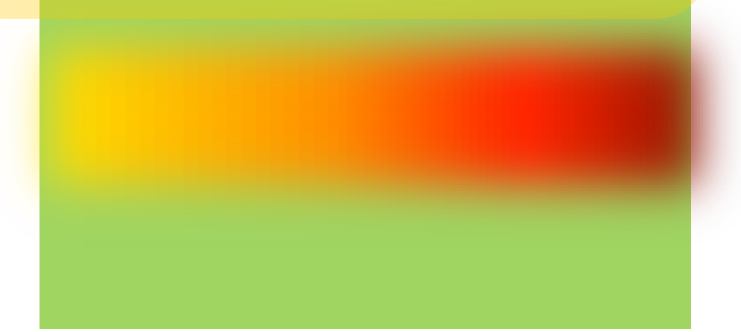
a train: 20 triplet

= 2640 bunches 63ms

132 bunches

make a shock wave

heat same position on the target



each triplet hits

different position on the target

slow rotation target

Parameter Plots for 300 Hz scheme

e- directly on to Tungsten

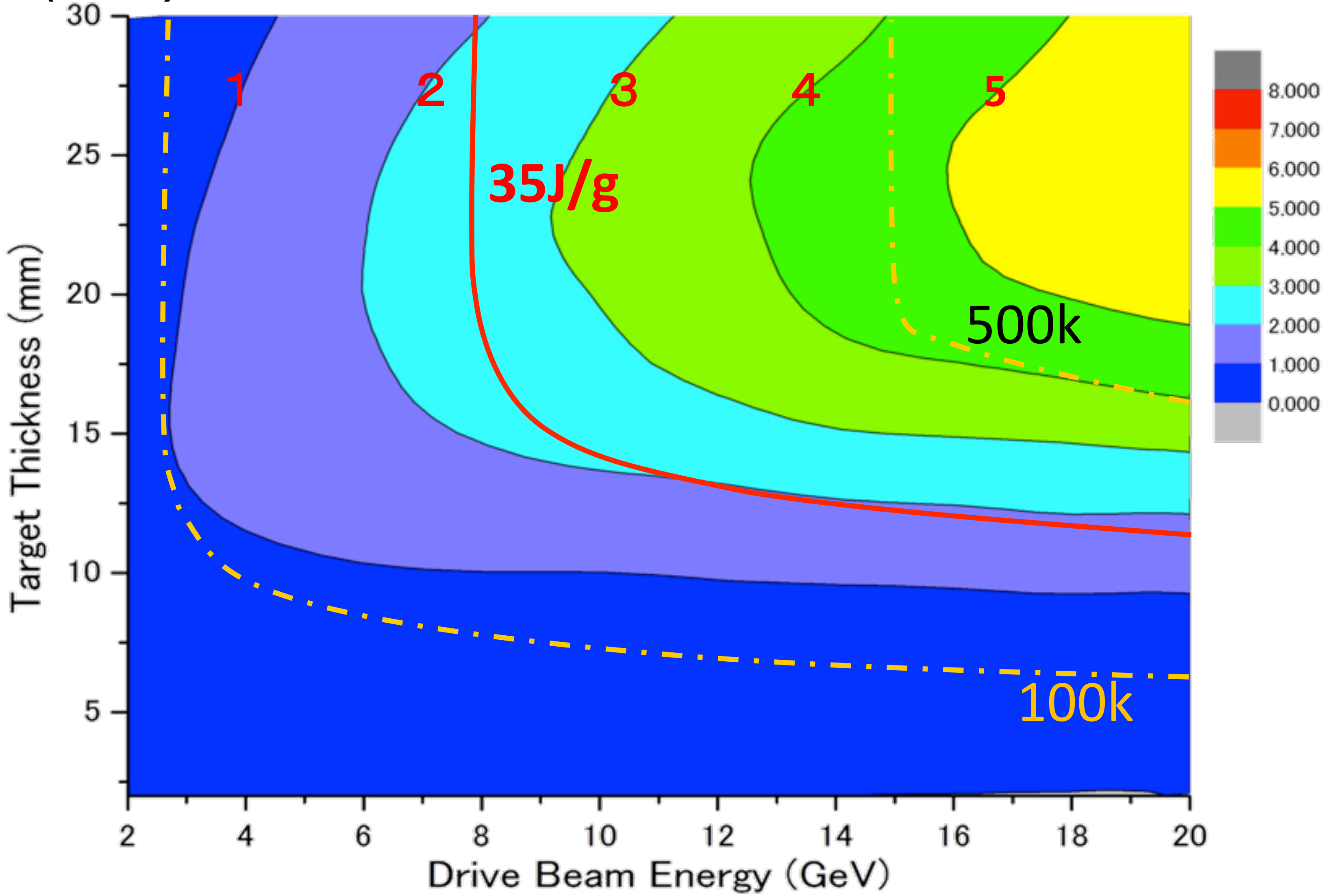
σ=4.0mm

Ne⁻(drive) = 2x10^{10} /bunch

colored band — accepted e+/e-

(red solid line) — PEDD J/g

(yellow dash-dot line) — dT max by a triplet



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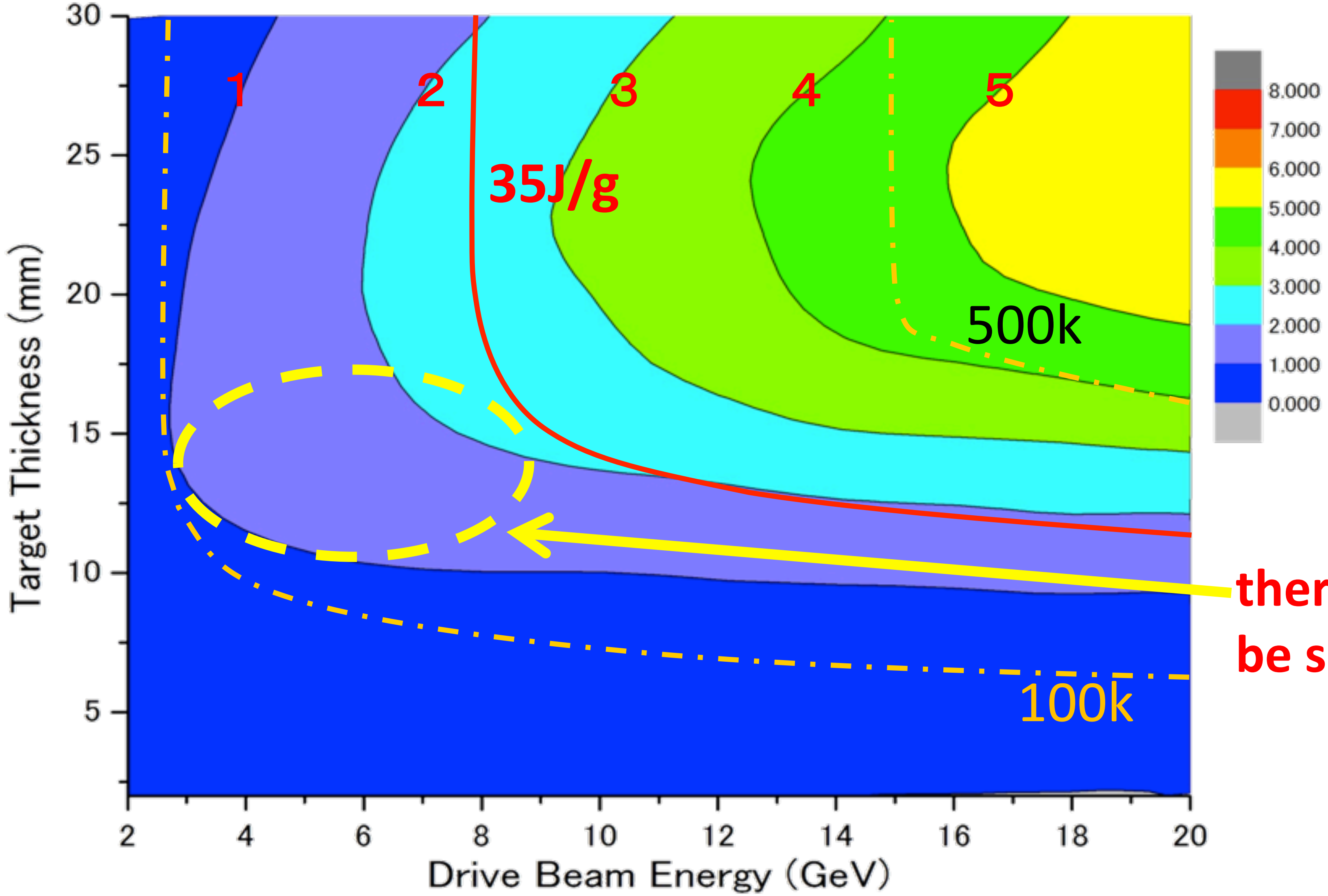
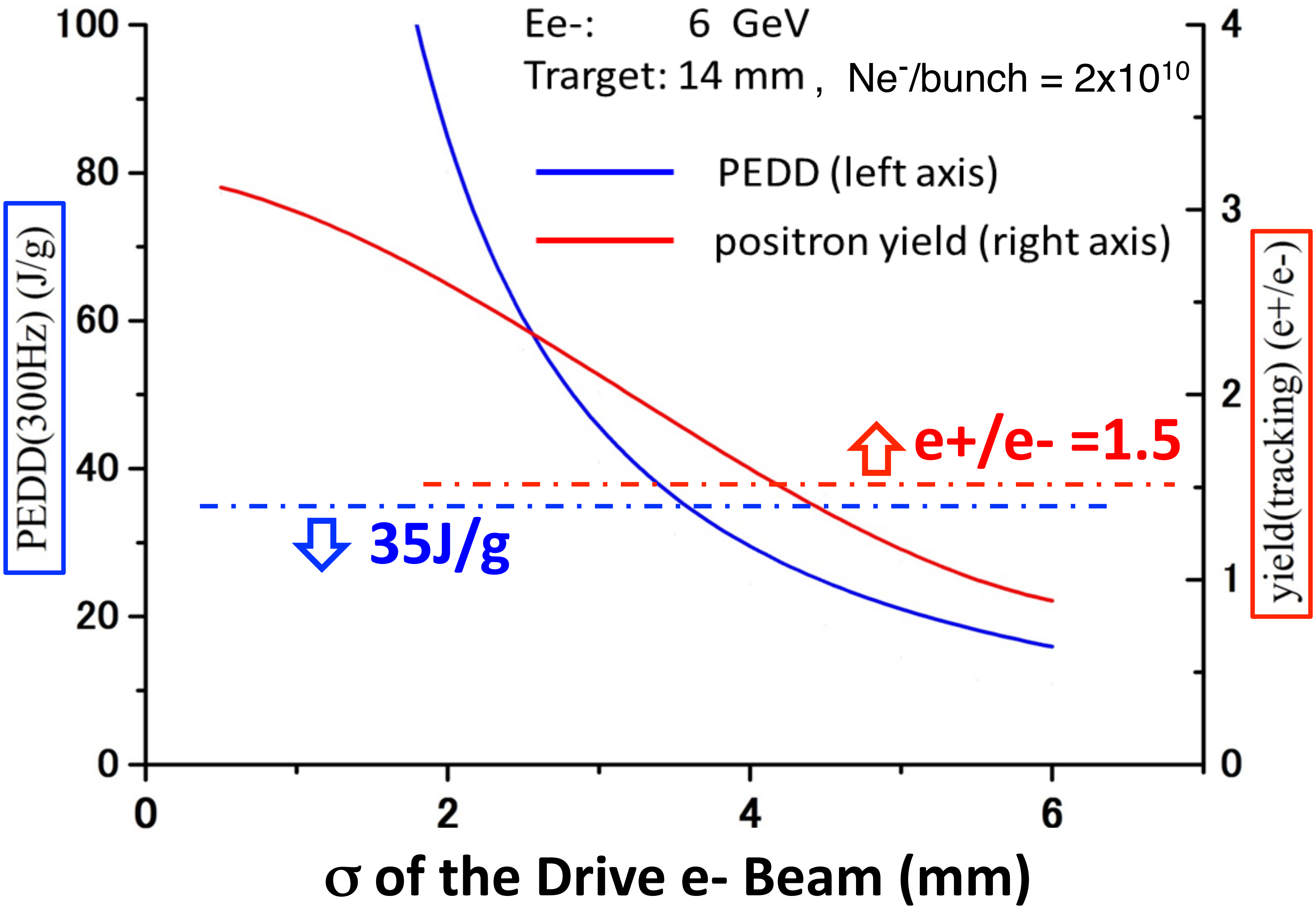


there seems to be solutions

Dependence on Drive beam size



Numbers for a Reference Point

Parameters for target and captures		Parameters for 300Hz scheme	
Drive beam energy	6 GeV	# drive e- /bunch	2×10^{10}
Beam size	4.0 mm (RMS)	# bunches/triplet	132 (in 996ns)
Target material	Tungsten	# bunches/train	2640 (in 63 ms)
Target thickness	14 mm	repetition	5 Hz
Max AMD field	7 T	Results numbers in () are for 300Hz operation	
Taper parameter	60.1/mm	e+ yield	1.6 /e-
AMD length	214 mm	PEDD in the target	1.04 GeV/cm^3/e- (22.7 J/g)
Const. field	0.5 T	E. deposit in the target	823 MeV/e- (35kW)
Max. RF field	25 MV/m	E. deposit in the AMD	780 MeV/e- (33kW)
RF frequency	1.3 GHz	E. deposit in the RF section	470 MeV/e- (20kW)

Target Tangential Speed

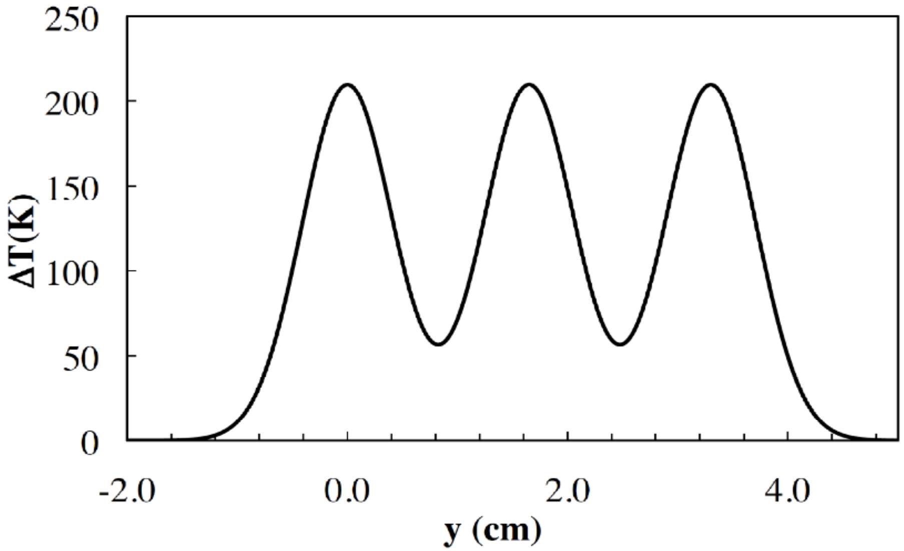
- SLC (actual achievement) :
  0.1 m/s (Swinging/Troll target: Not really rotating)

- ILC baseline (design: test is ongoing):
  100 m/s

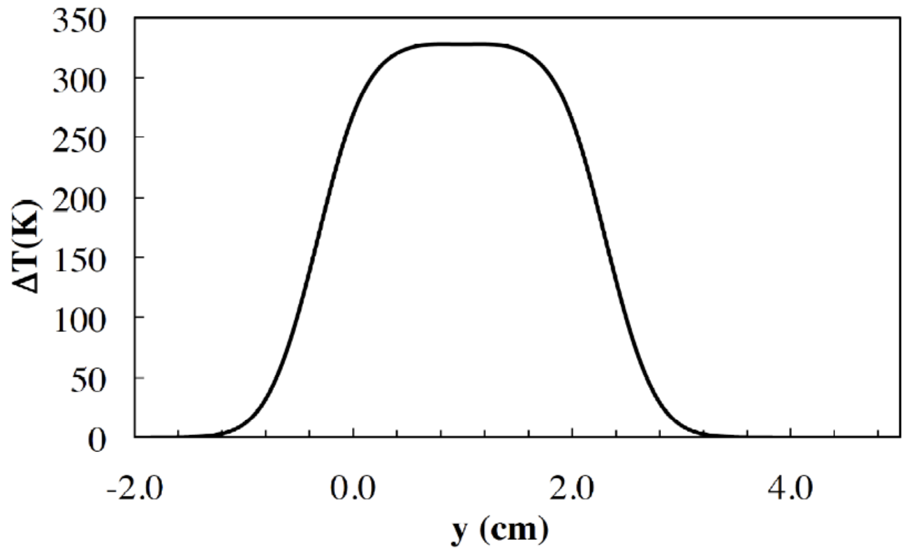
- Truly Conventional (assumption) :
  1 m/s
  large spatial overlap between triplets --> But OK in temperature.
  Design study on going.
  shockwave : OK because triplet to triplet separation 3.3 ms in time.
  Probably 0.5 m/s is OK.

Target Heat Simulation (Wanming)

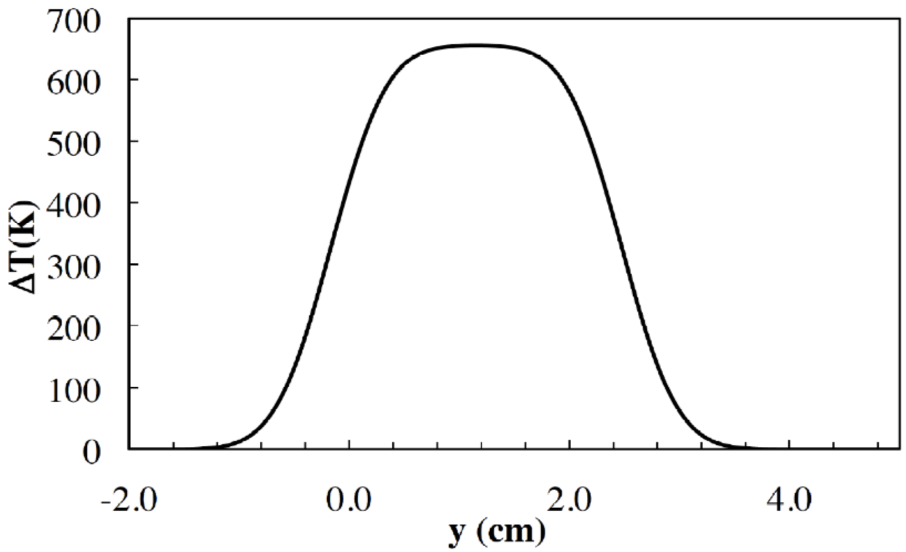
(a) 5 m/s, after 3 triplets



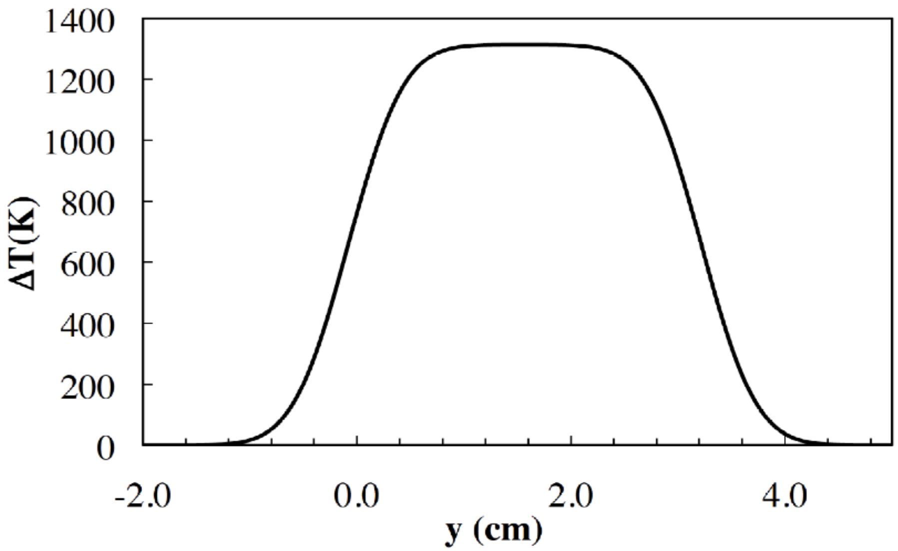
(b) 2 m/s, after 4 triplets



(c) 1 m/s, after 8 triplets



(d) 0.5 m/s, after 20 triplets



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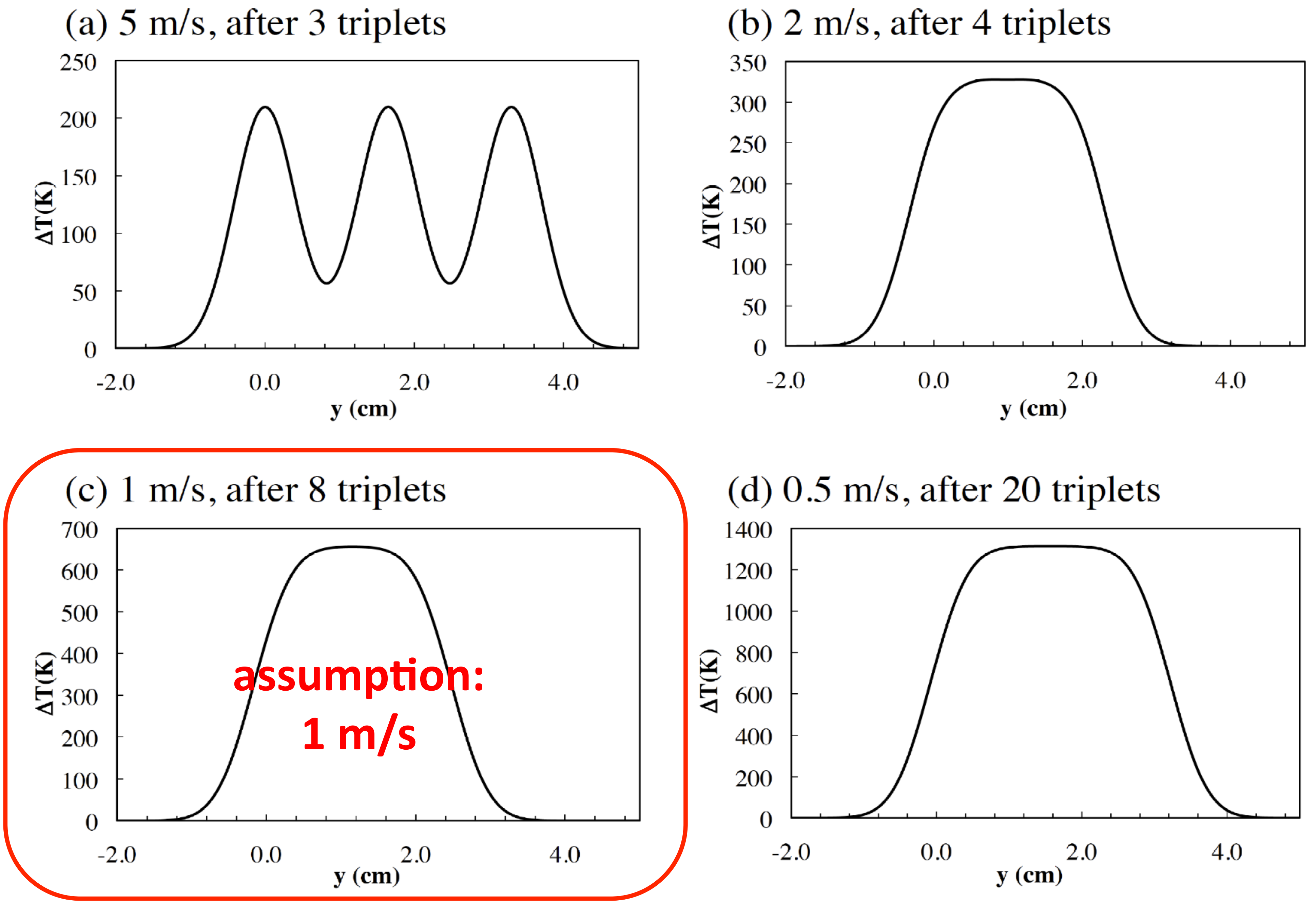

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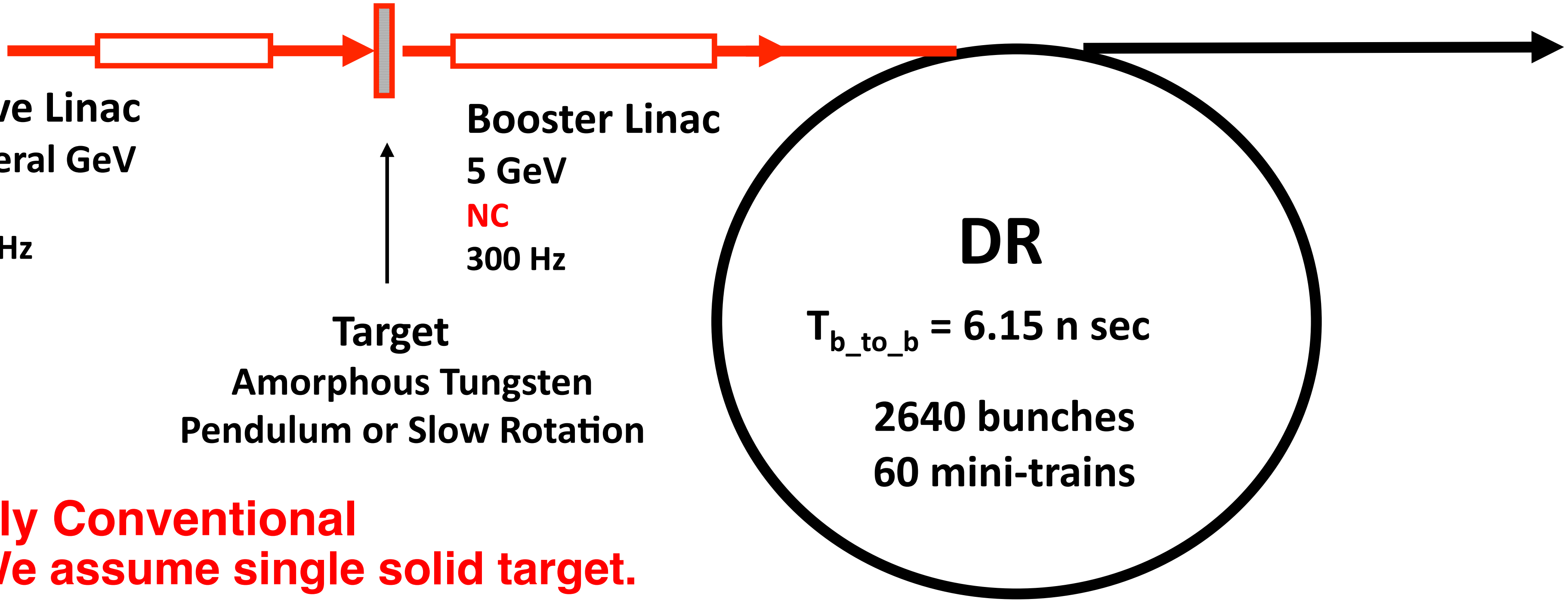


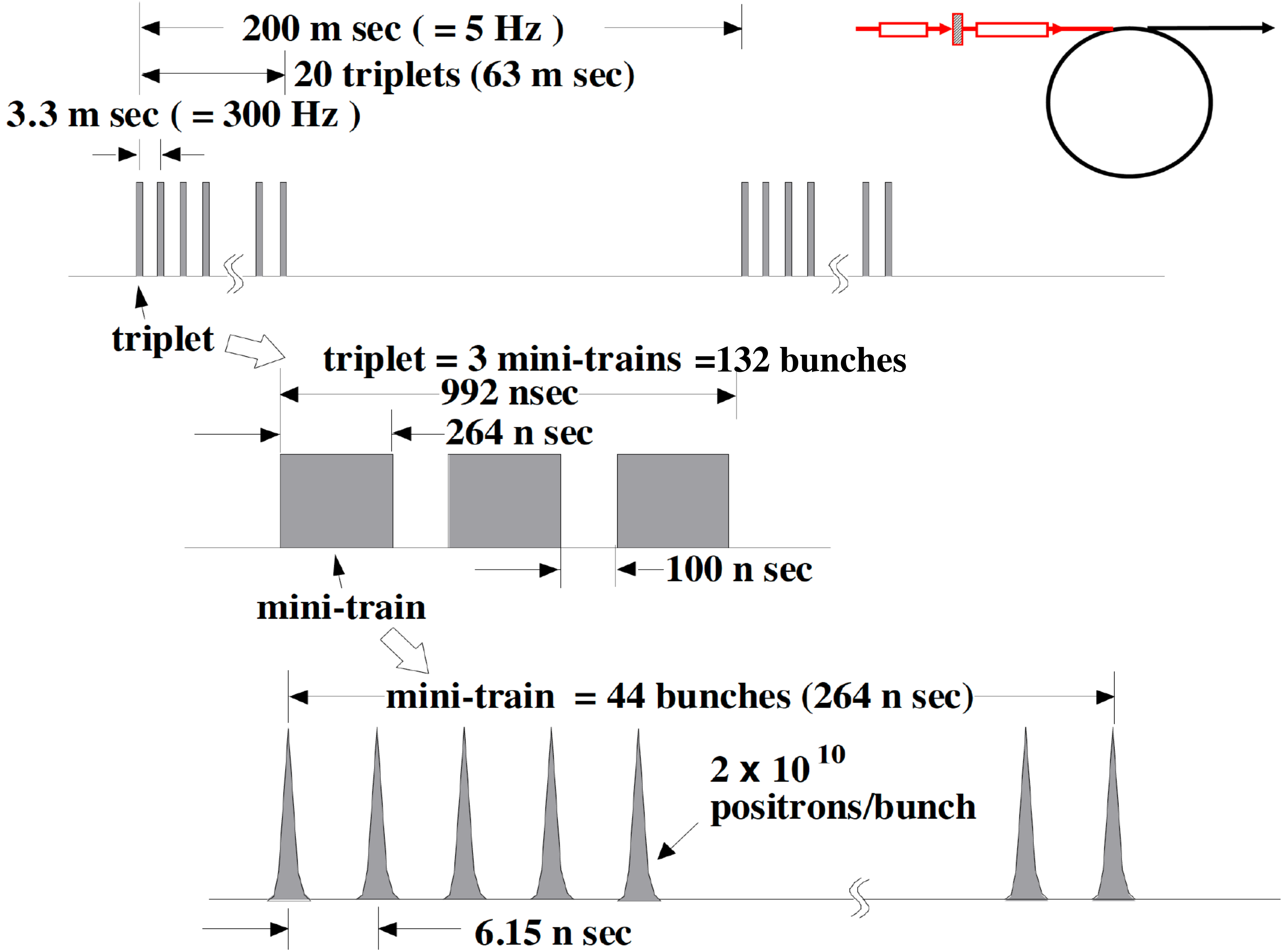
Truly Conventional
* We assume single solid target.
* NO Liquid Target or
  NO Hybrid Target are assumed

Time remaining for damping = 137 m sec

Higher Luminosity?

7.5 Hz main linac operation

Beam before DR



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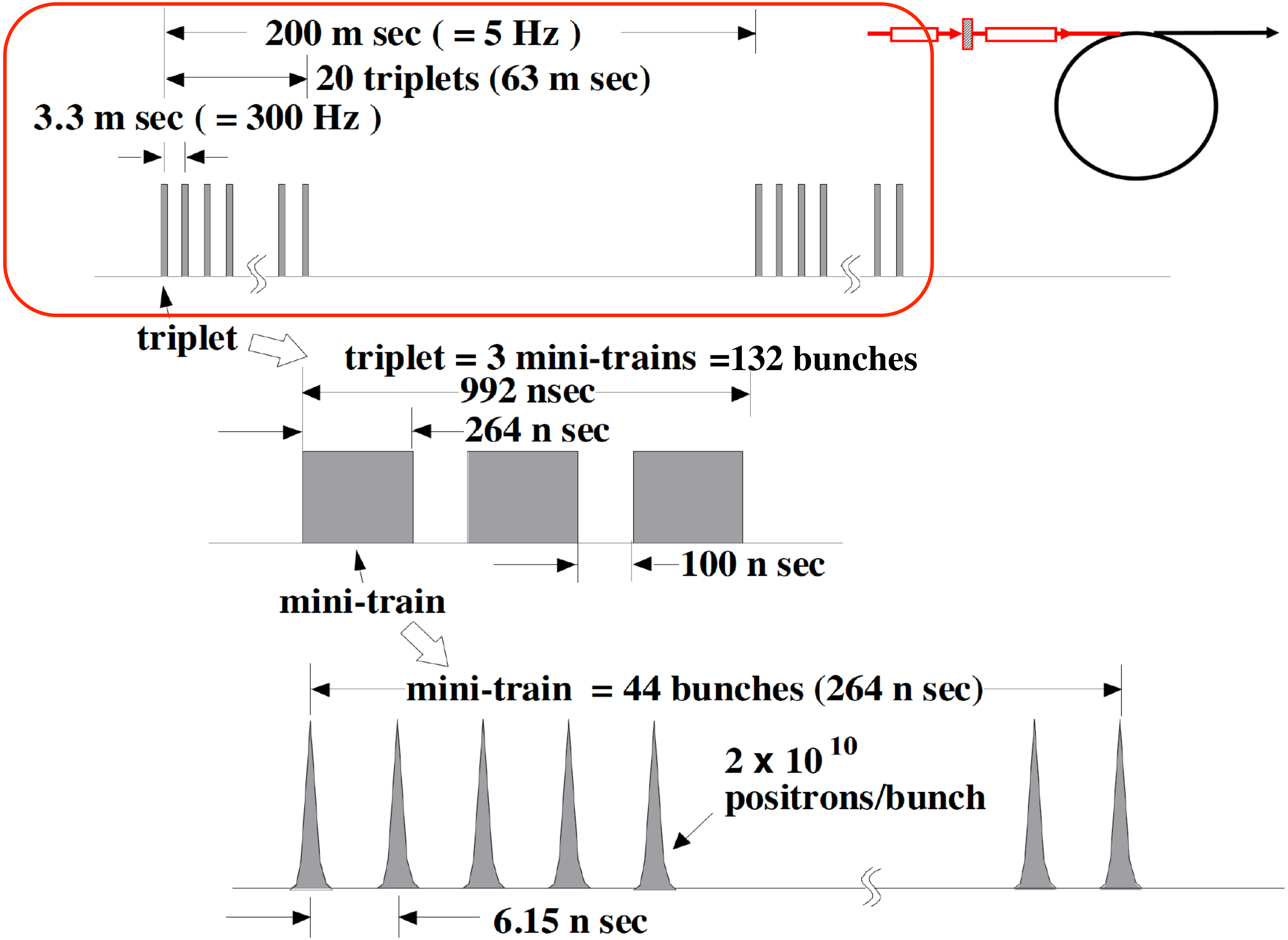
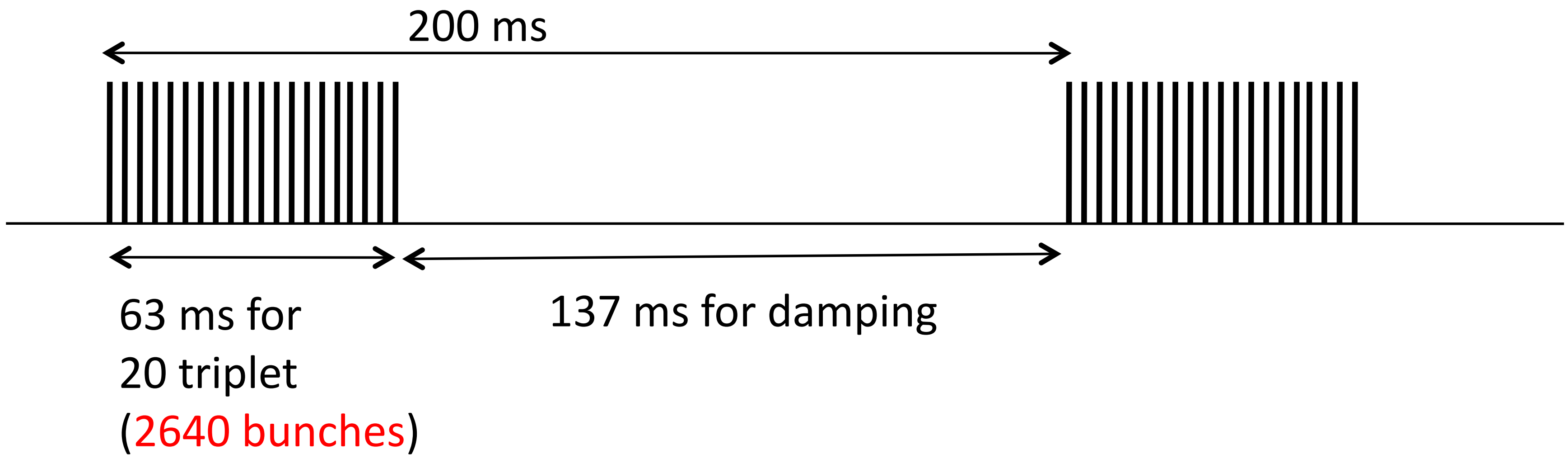
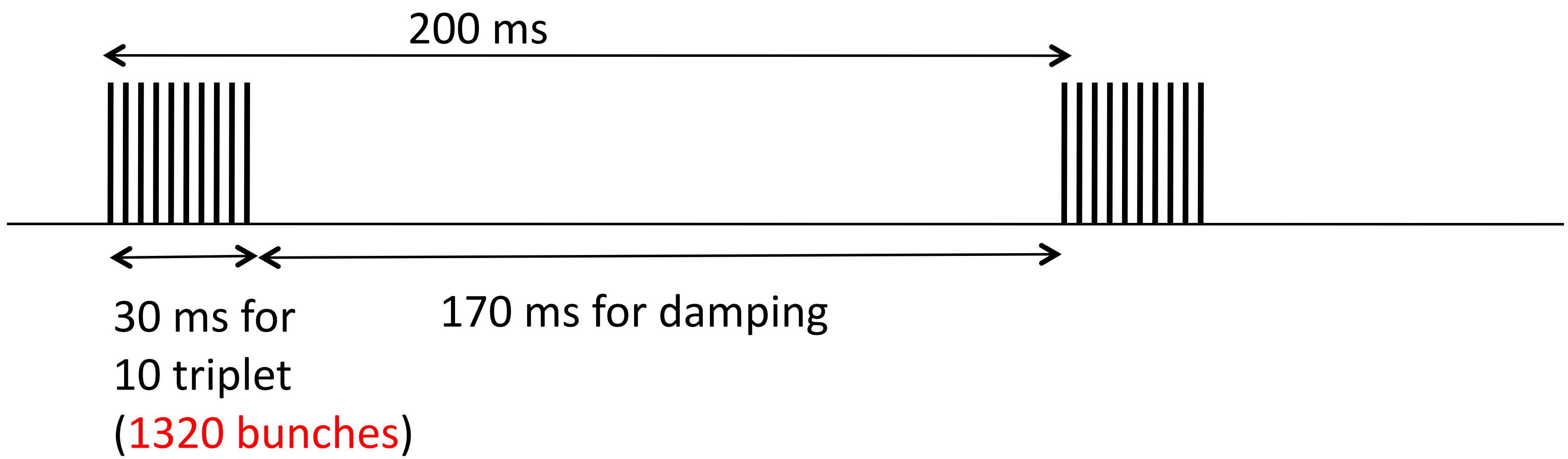


5 Hz Operation

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

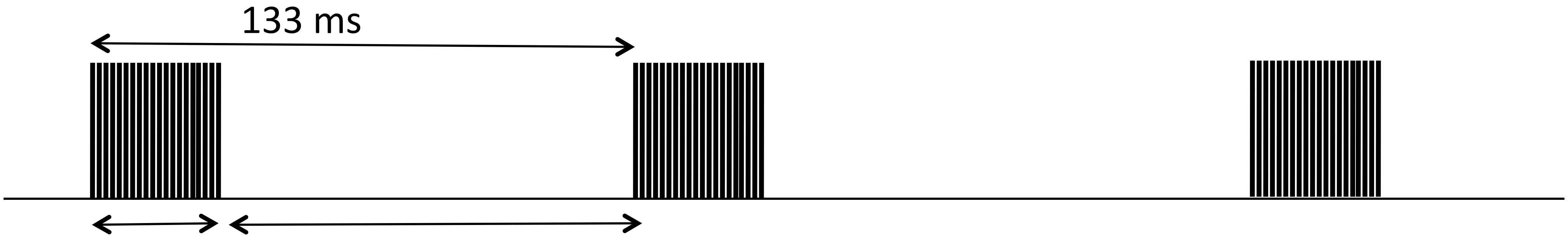


For 1320 bunches (TDR baseline)



7.5 Hz Operation (x1.5 Lumi.)

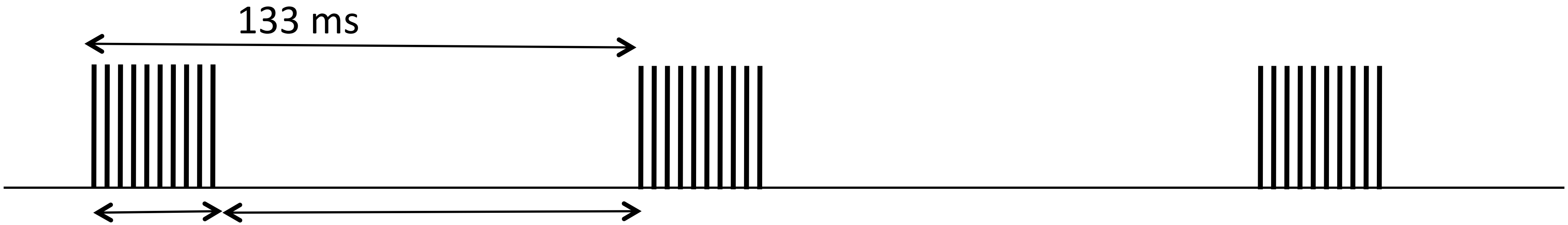
For 2640 bunches (High Power Option)



30 ms for 10 **sextet** (2640 bunches = 10x6x44)

103 ms for damping

For 1320 bunches (TDR baseline)



30 ms for 10 triplet (1320 bunches)

103 ms for damping

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.

7.5 Hz Operation (x1.5 Lumi.)

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* Instantaneous heat load on the target increase (x2).
  Can be problem.
  Need careful consideration on beam&target parameters.

Summary

Summary

- Conventional e+ source can be a solution for ILC, with 300Hz scheme and optimized beam&target parameters.
- to go forward
  - Target R/D: motion, cooling, etc.
  - shock wave tolerance ?
    - better than GLC/NLC design.
    - PEDD = 23 J/g (< 35 J/g)
    - But is it really OK
- 7.5 Hz main-linac operation for x1.5 luminosity.
  - Possible for 1320 bunches (TDR baseline).
  - Need careful consideration for 2640 bunches (High P).

backups

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.

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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)

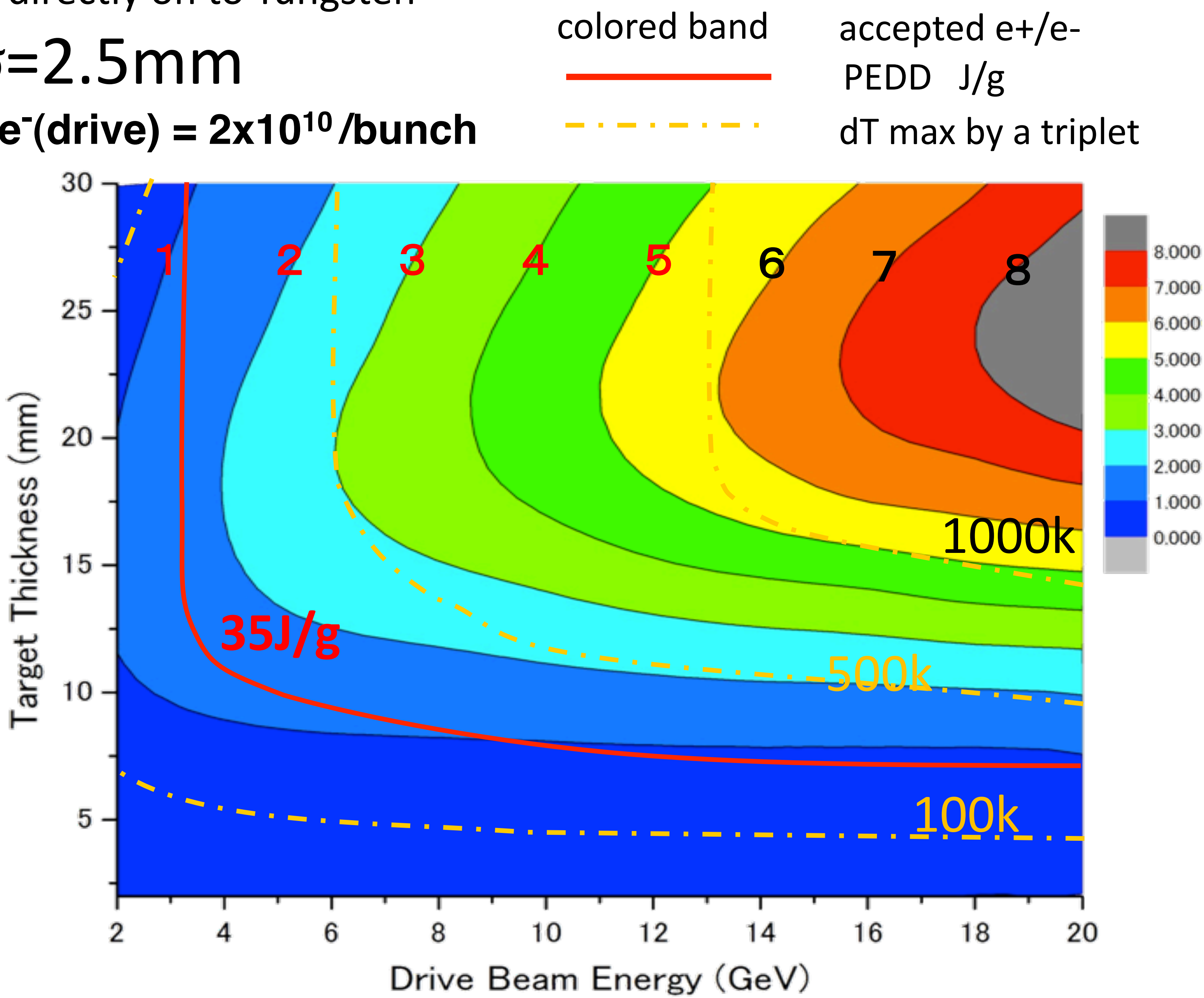
- **300 Hz Truly Conventional**
  - It creates 2600 bunches of e+s in 63 m sec. (stretching)
  - Heat load is not a problem.
  - Do we have a solution? **Issue : shock wave**

Parameter Plots for 300 Hz scheme

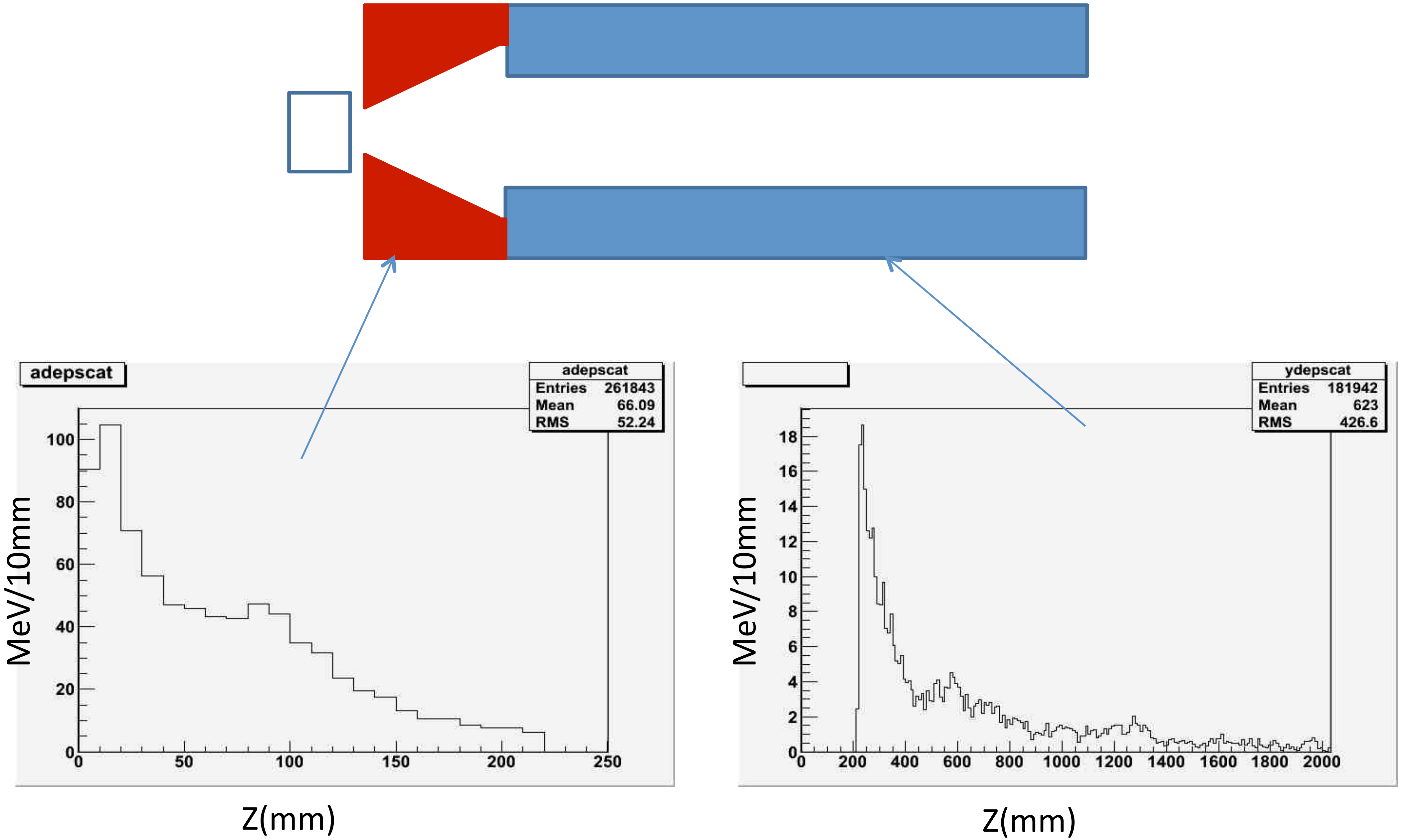
e- directly on to Tungsten

σ=2.5mm

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

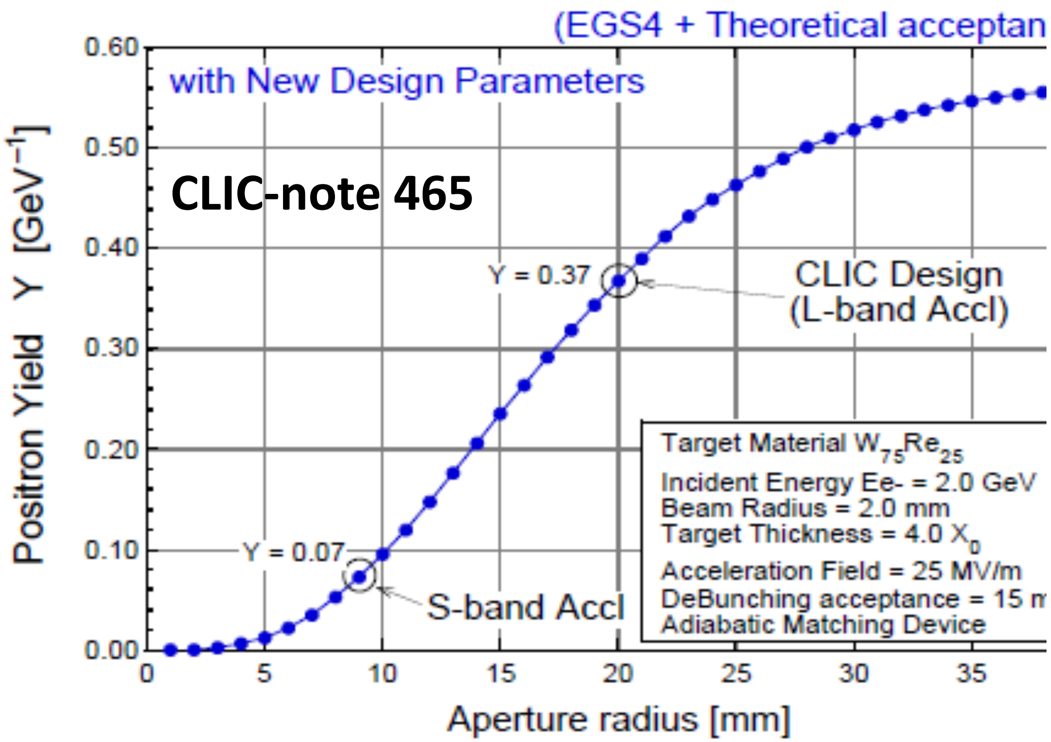


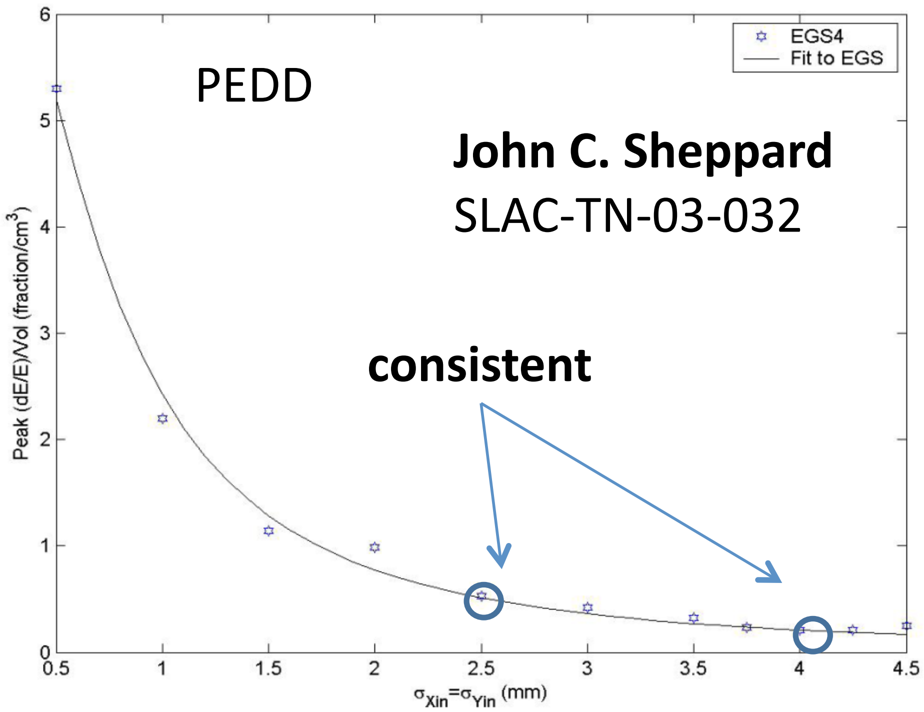
Energy deposit in capture section



a few comments

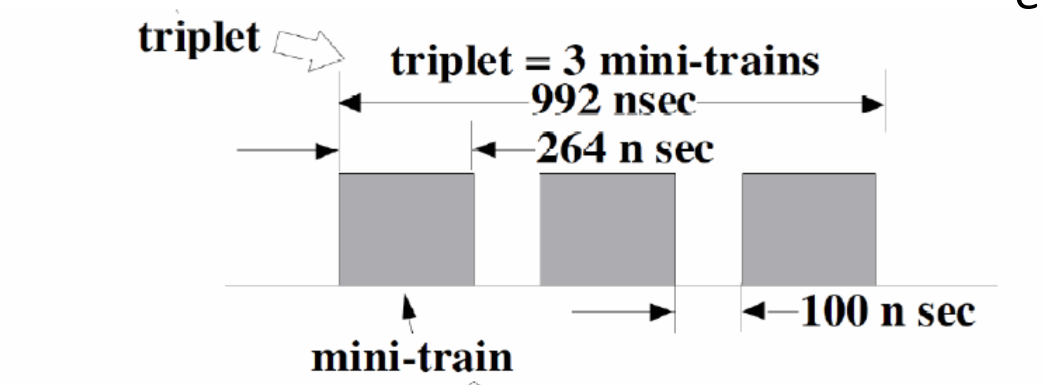
- numbers shown here are consistent w/
    - independent calculation by a colleague in KEK and French colleague for Hybrid
- comparison w/ SLC study
    - both assumed AMD but acceptance for linac is;
        - SLC S-band linac ←→ this study (CLIC) L-band

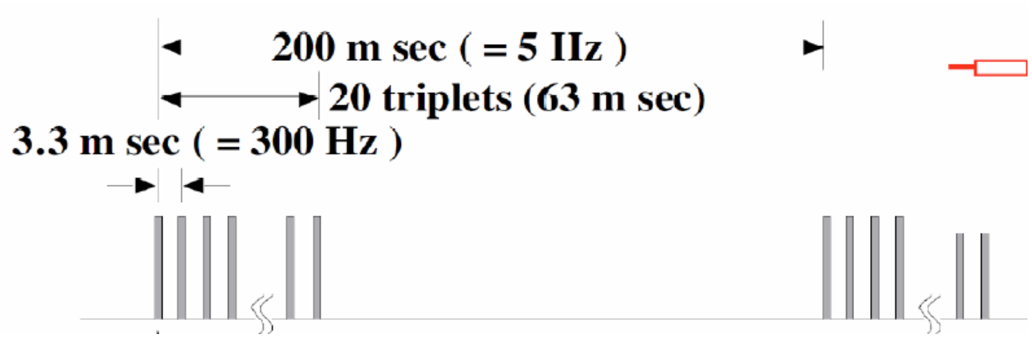




Assumption

each triplet hits different position on the target
elatively 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

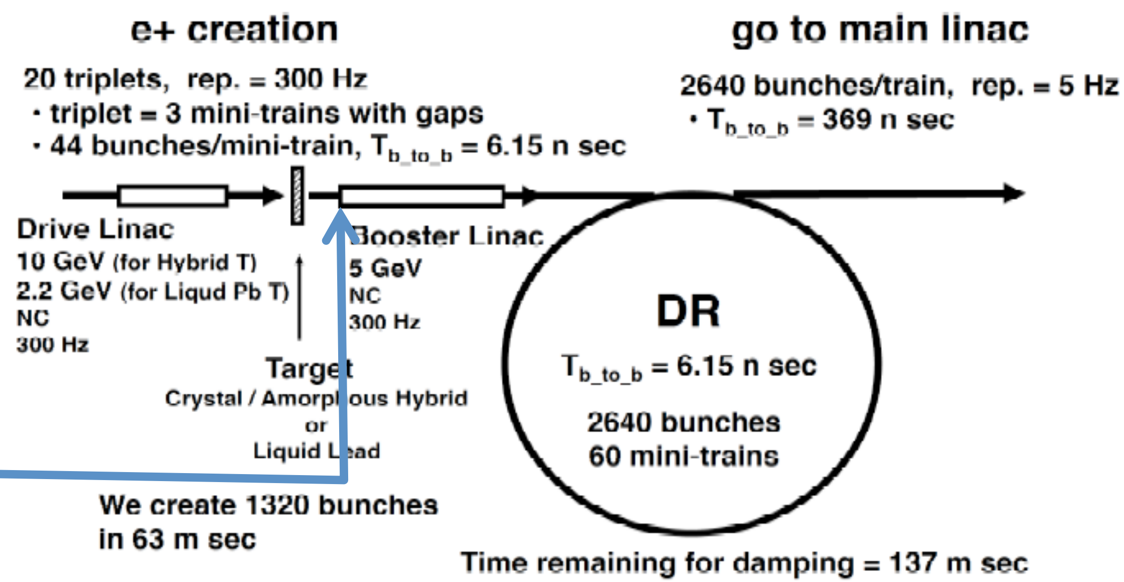
CLIC note 465

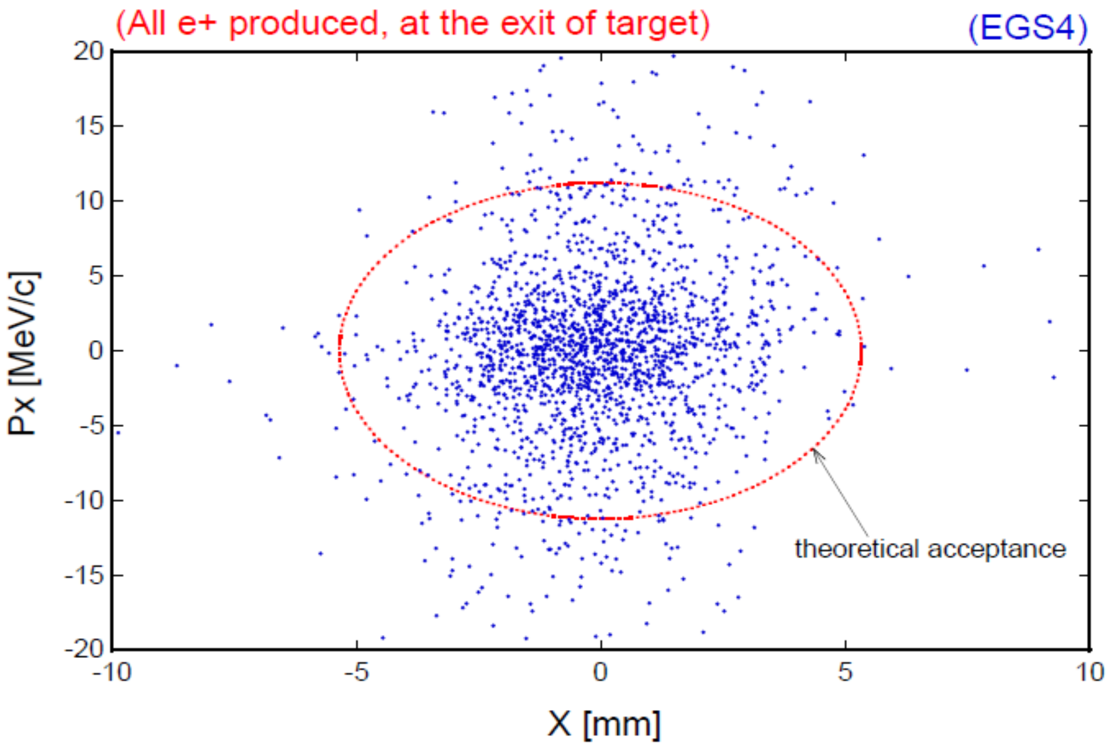
$[r/5.3[mm]]^2 + [pT[MeV]/11]^2 =< 1$

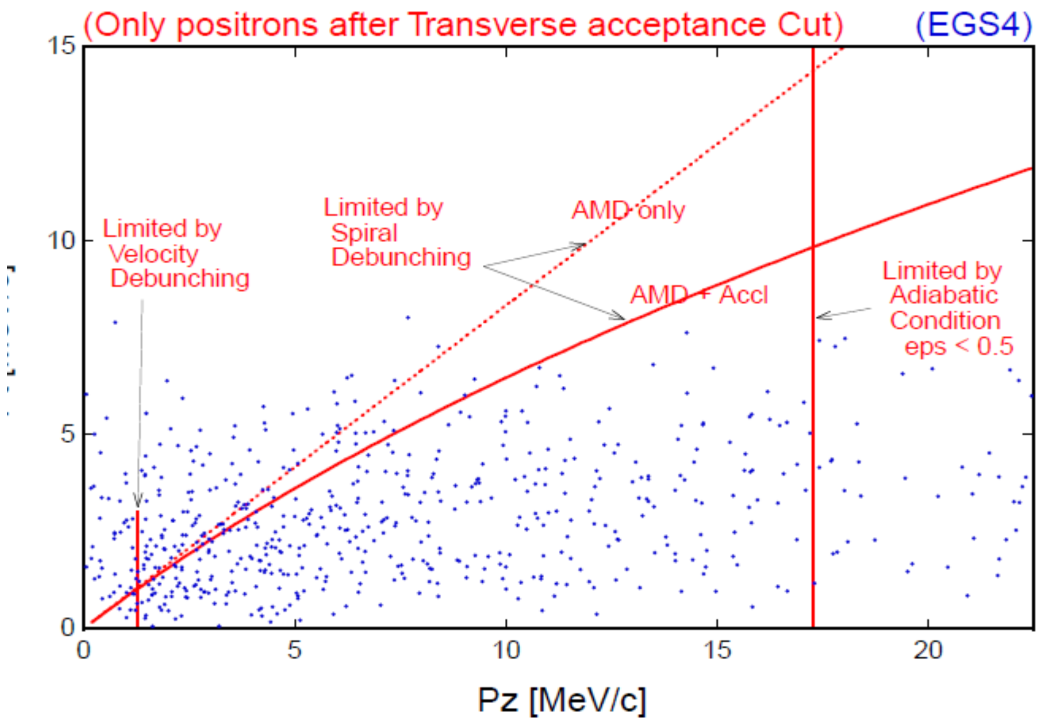
pT < 0.1875 MeV/c + 0.625 pL

1.5 MeV/c < pL < 17.5 MeV/c

～# of e+ in DR (or booter linac)







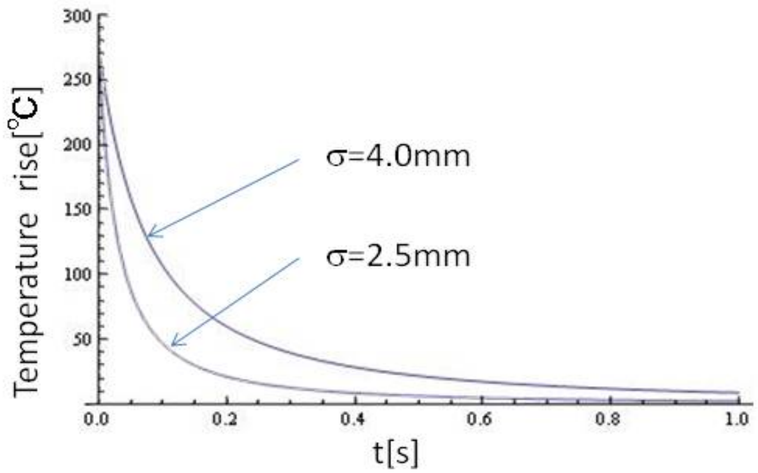
Thermal diffusion

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

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

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

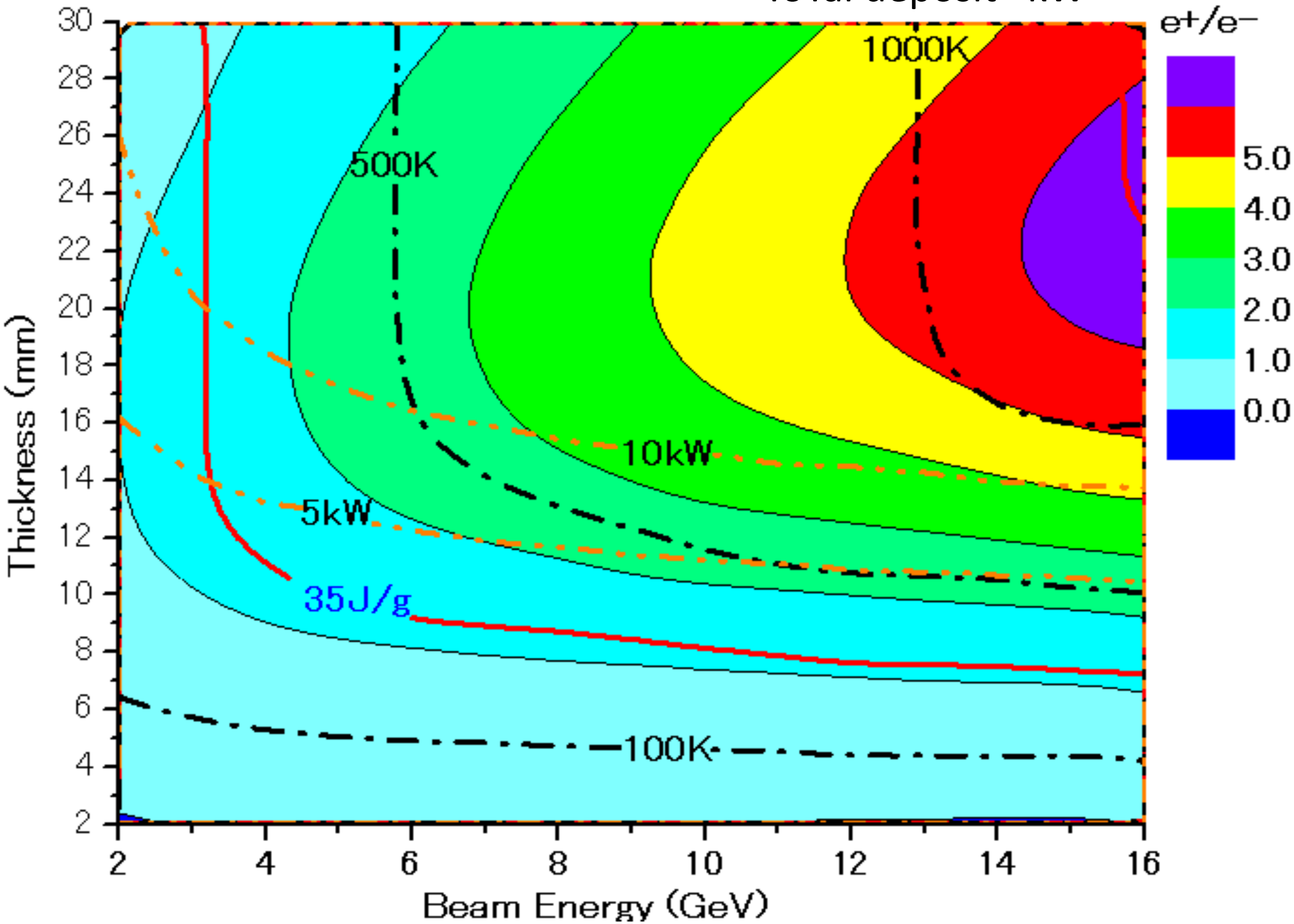
time constant is order of 100ms >> Ttriplet ~1μs

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