LINEAR COLLIDER COLLABORATION

Designing the world's next great particle accelerator

A Design Study of ILC Positron Source by Electron Driven Scheme (300 Hz linac Simulation)

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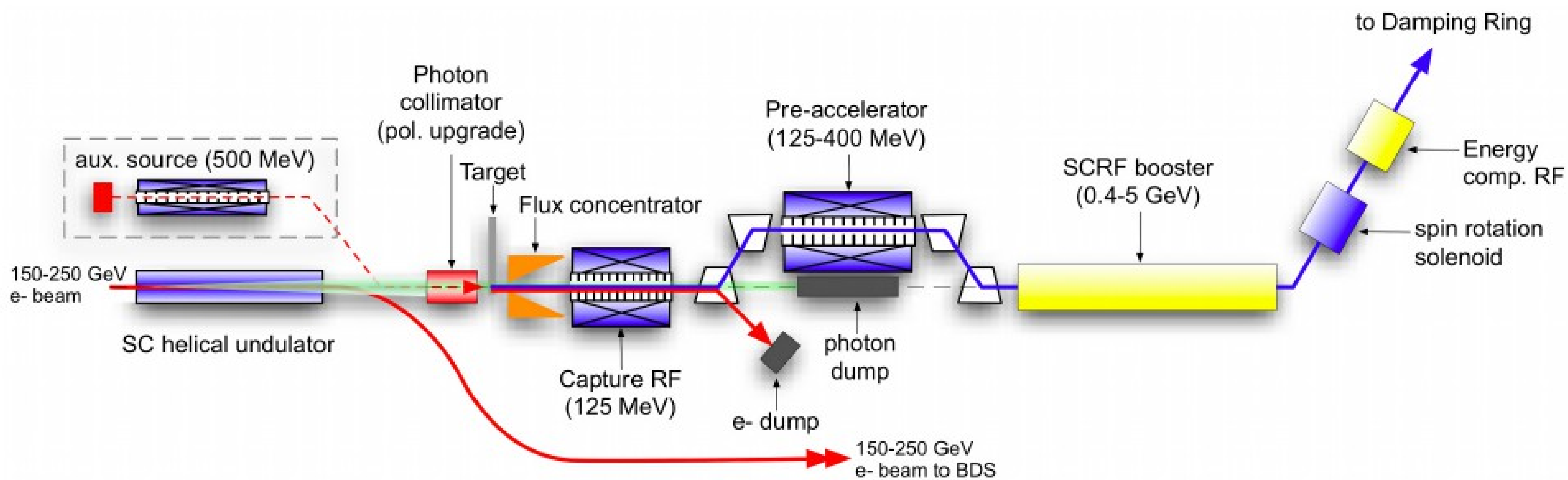
Undulator Positron Source

- Driven by >125 GeV beam.
- Polarized positron (30-60%) which is powerful tool for physics.
- There is no fundamental and technical difficulties.

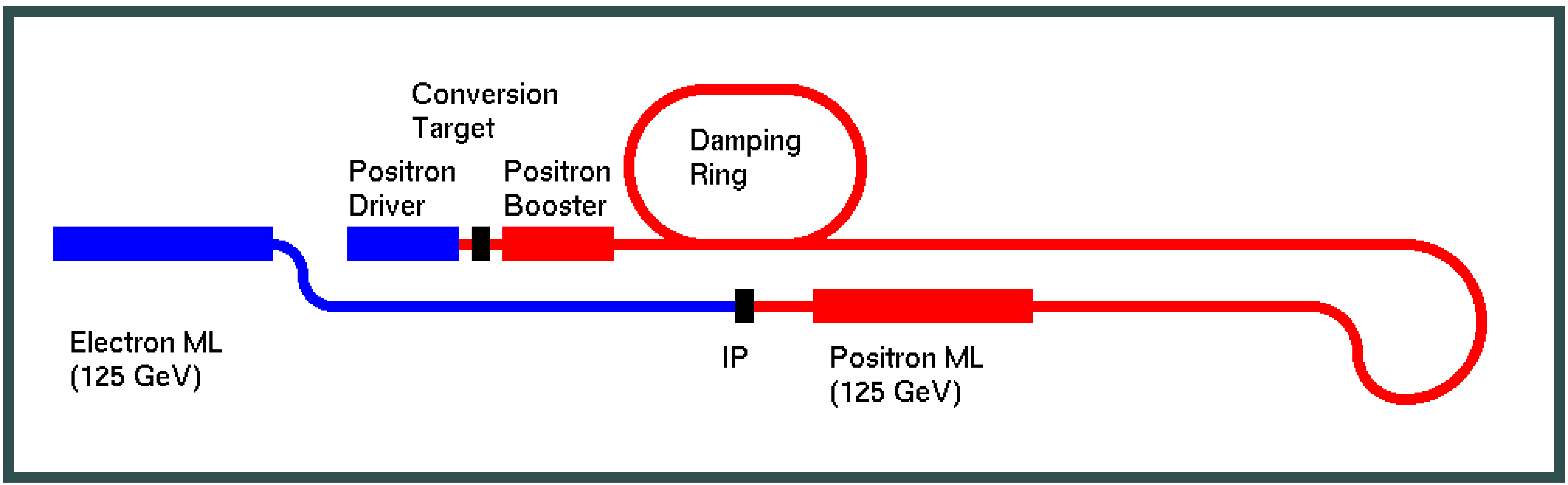


Undulator Positron Source
Pros and Cons

- Positron can be polarized (30-60%).
- Relatively less heat load on target.
- Require >130GeV drive beam. Share the e- beam for collision.
- The pulse structure is fixed, 1ms.
- Need physical path length adjustment.
- Undulator section is up to 230m.
- System demonstration prior to the construction is difficult.
- A technical backup is desirable.

Positron Source

- Staging approach to minimize possible risks and maximize physics potential.
  - 1st stage : Unpolarized e-driven e+ source .
    (no polarizatino, but “conventional”)
  - 2nd stage: Polarized undulator driven e+ source. (polarized, but totally new)



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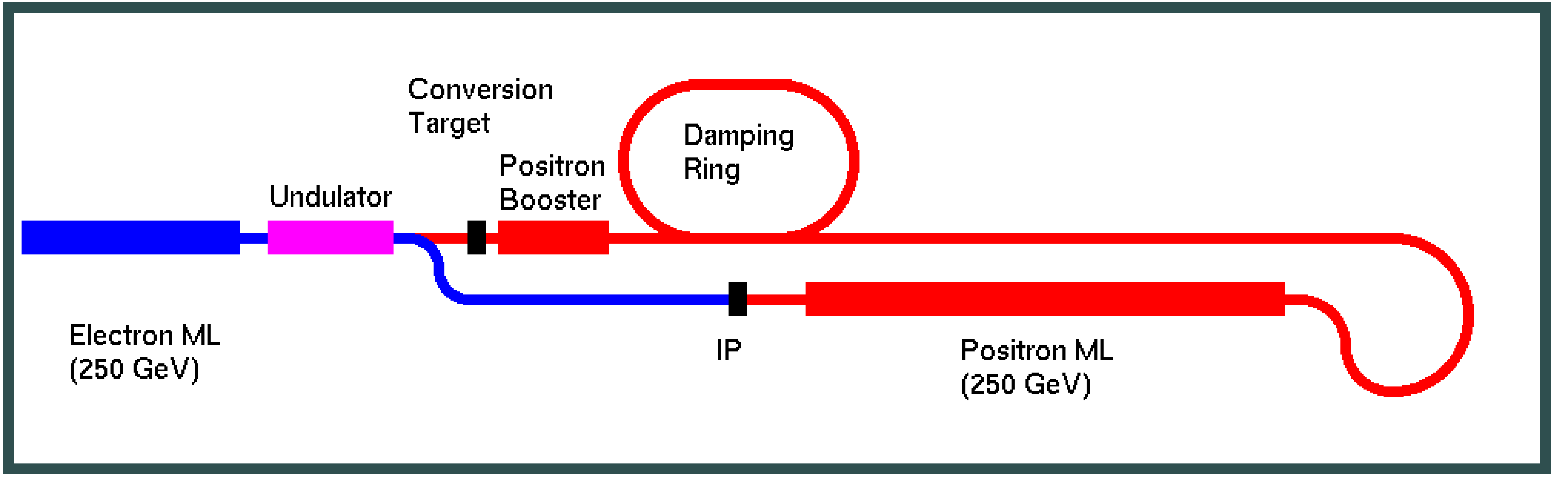
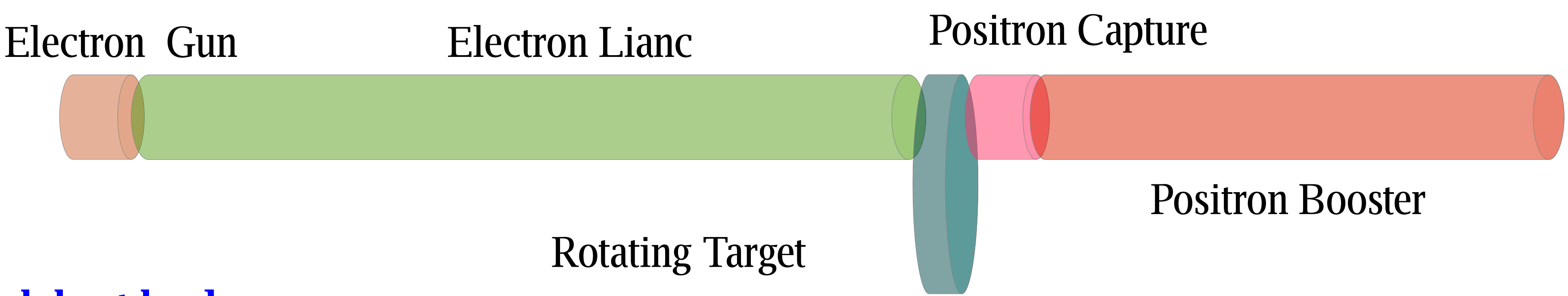
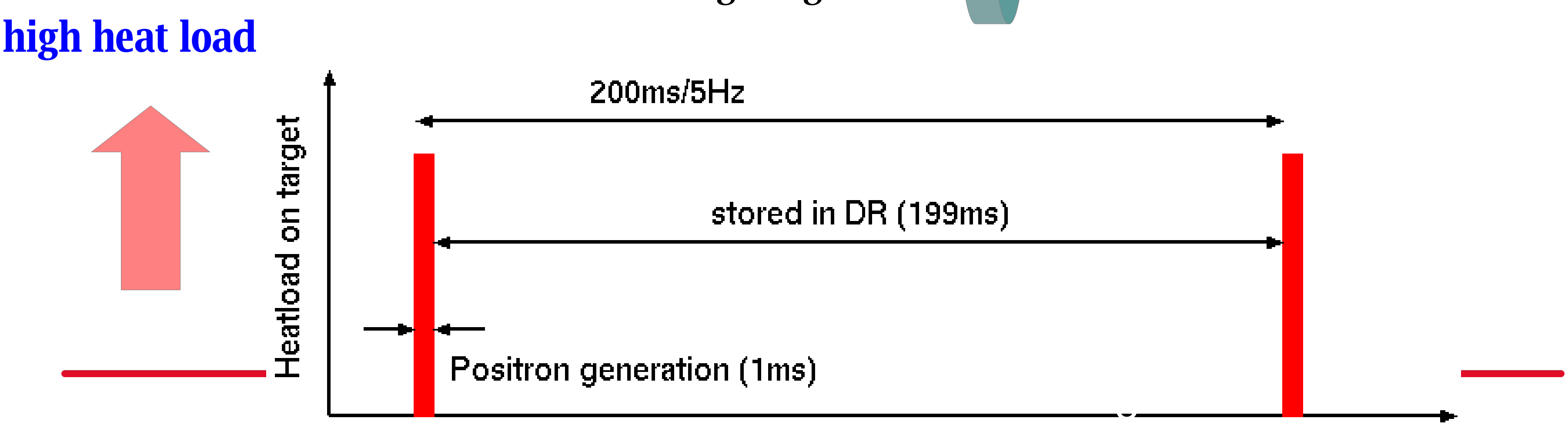


E-Driven ILC Positron Source

- 6 GeV electron with W-Re target.
- SC accelerator, 2700 bunches/1 ms with SC 5Hz $\rightarrow$ 300 m/s.
- Can we relax the condition?

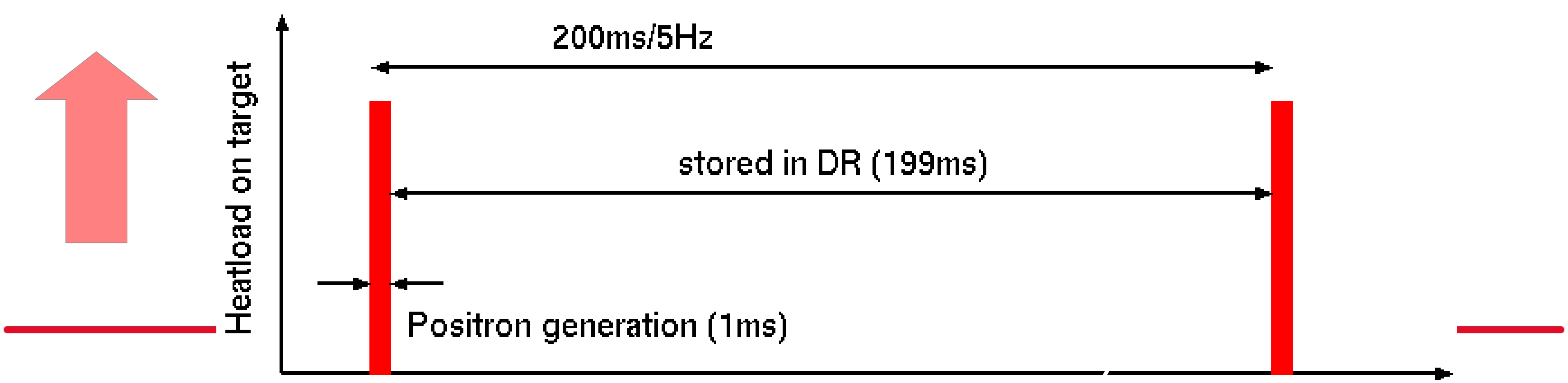




E-Driven ILC Positron Source

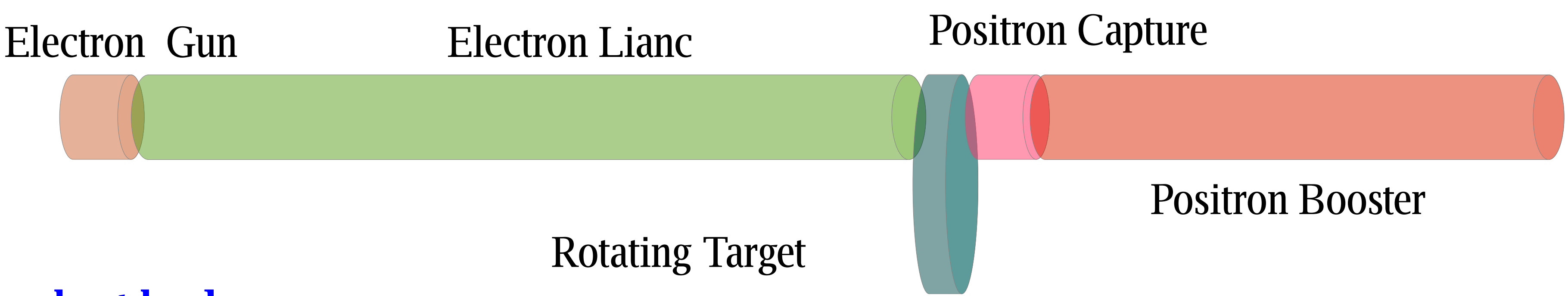
- 6 GeV electron with W-Re
- SC accelerator, 2700 bunc
- Can we relax the condition

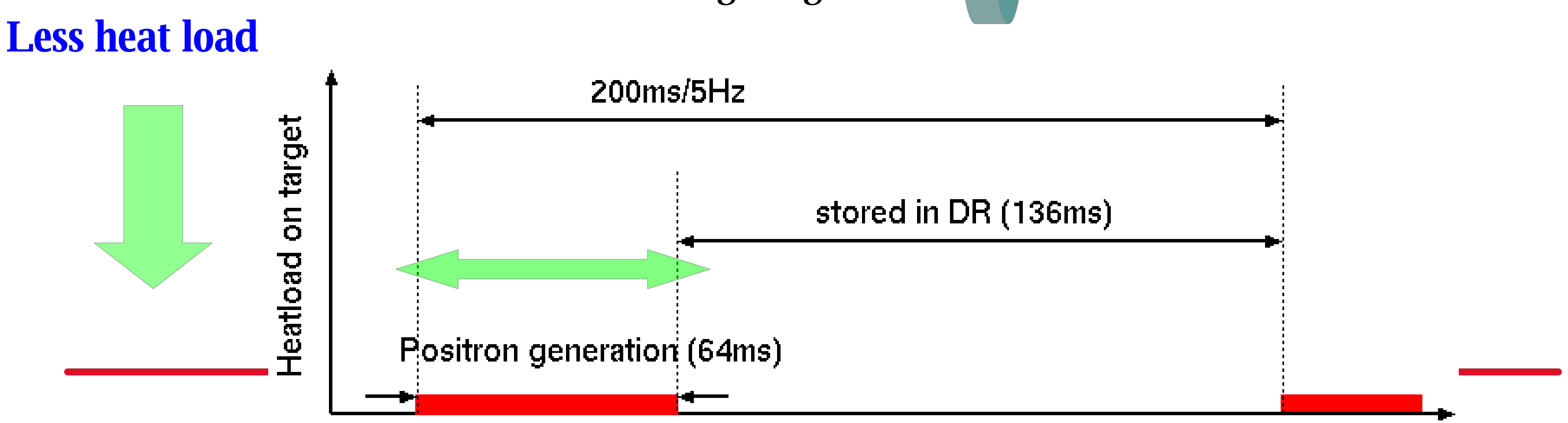
high heat load



E-Driven ILC Positron Source

- 300Hz NC accelerator → 2700/64ms (132 bunches x 300Hz , 64 ms).
- The heat load on the target is manageable.
- Tangential speed is 5 m/s.





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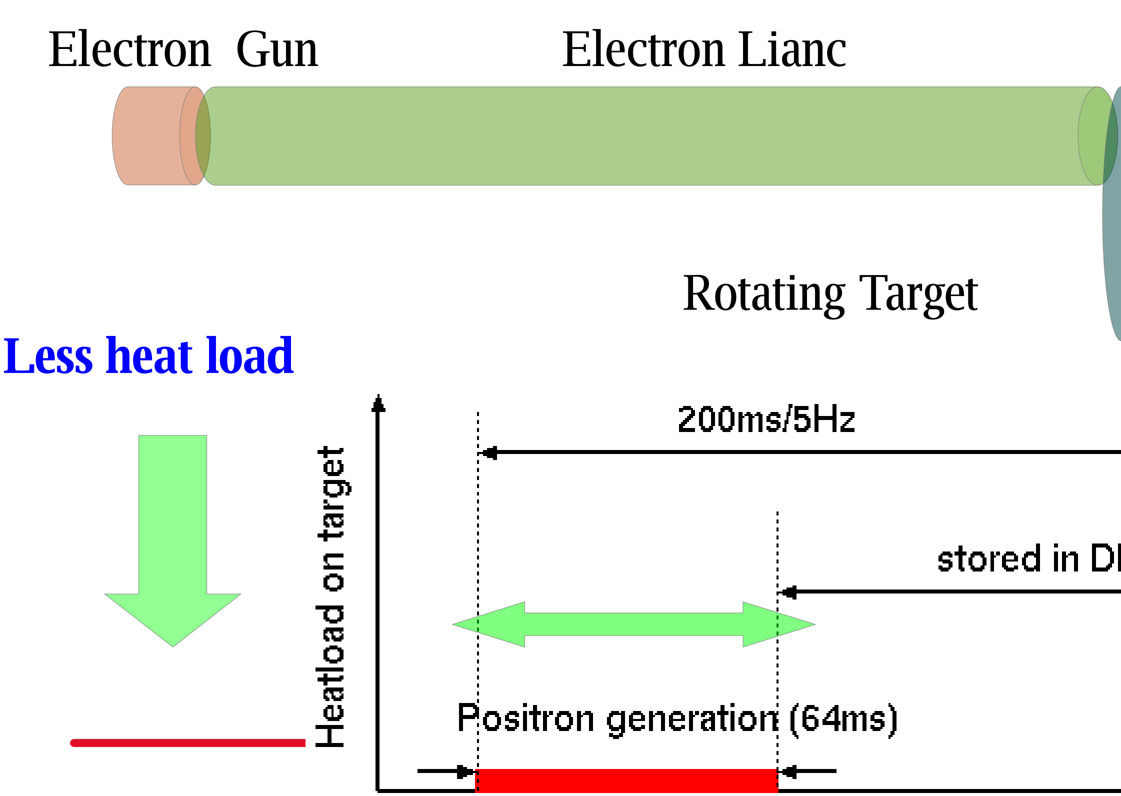
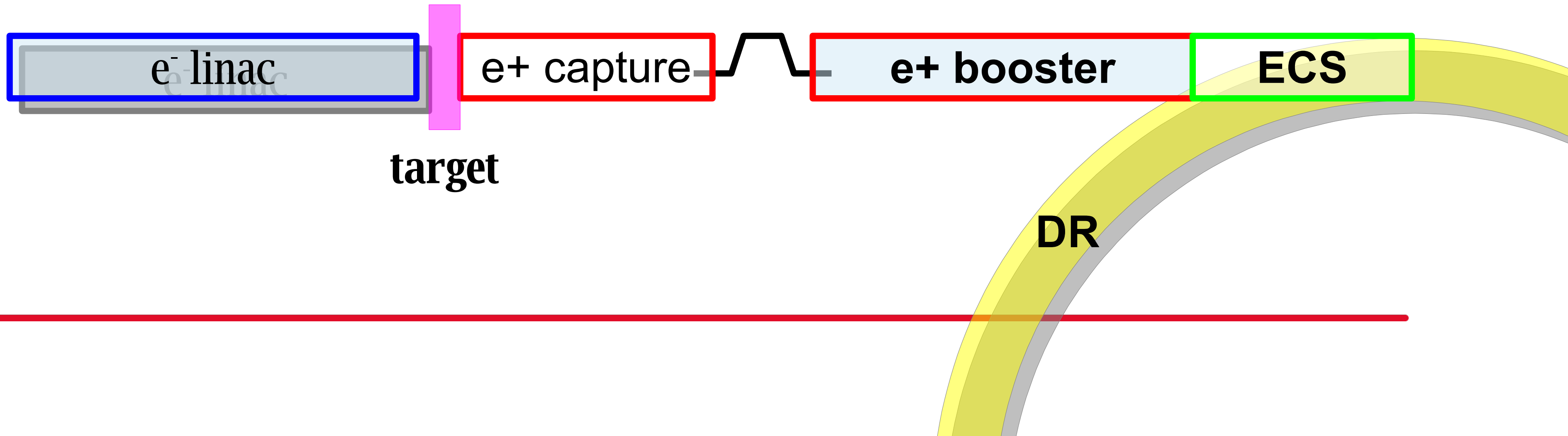


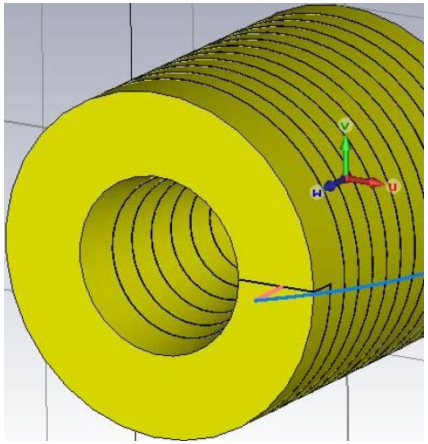
Positron Capture Simulation

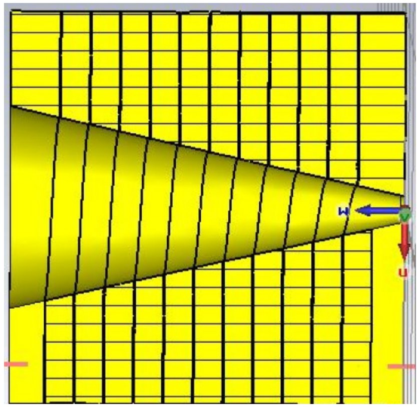
- E+ distribution was made by GEANT4.
- Tracking simulation in the injector section (<250MeV) by GPT; AMD positron capture (B_0~5.0T) followed by solenoid focusing section (0.5T) with L-band Acceleration up to 250 MeV.
- Chicane to remove electrons and lower energy positrons.
- Hybrid Booster linac (L- and S-band) and EC (Energy Compressor) by SAD.
- Positron yield is examined with DR acceptance.

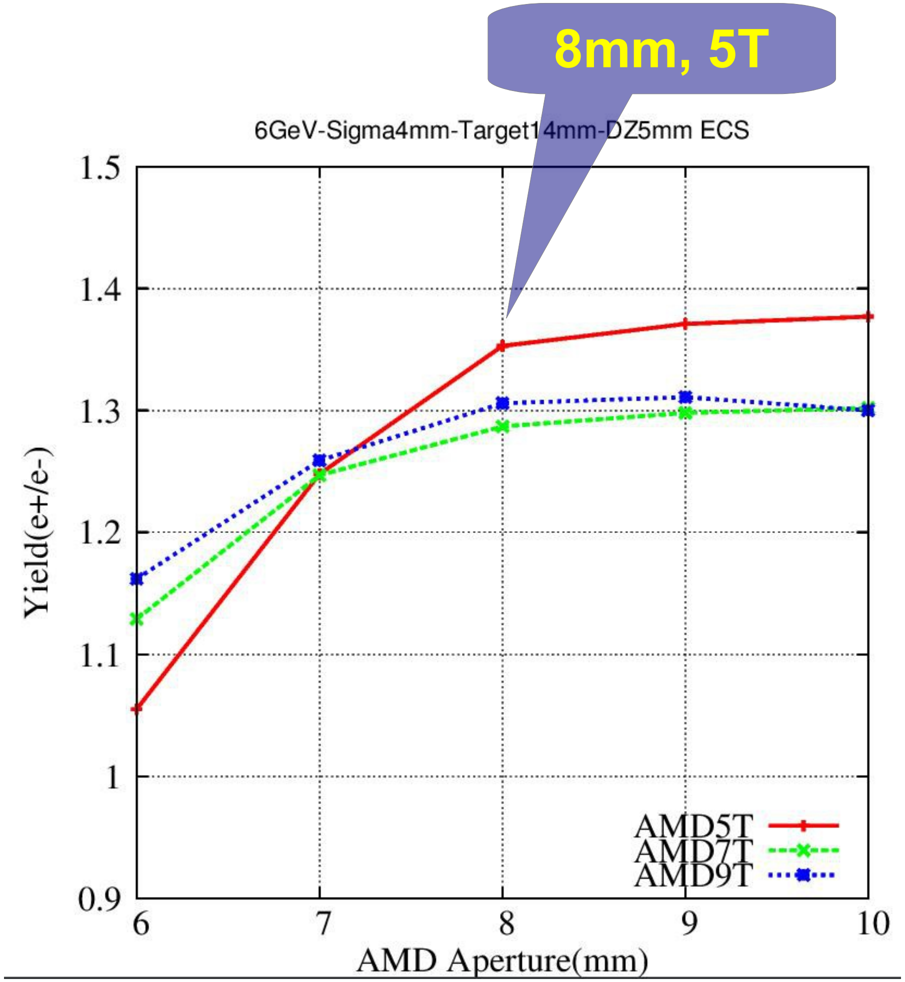


AMD (Adiabatic Matching Device)

- AMD is made by Flux Concentrator.
- Induce a strong solenoid-like B filed for transverse momentum suppression.
- It could be similar to that for S-KEKB.

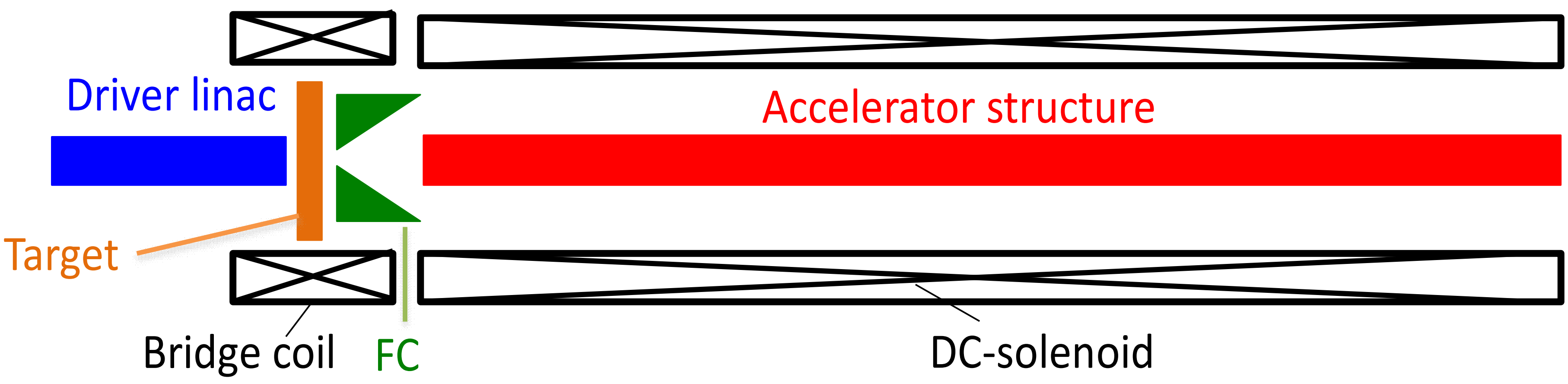






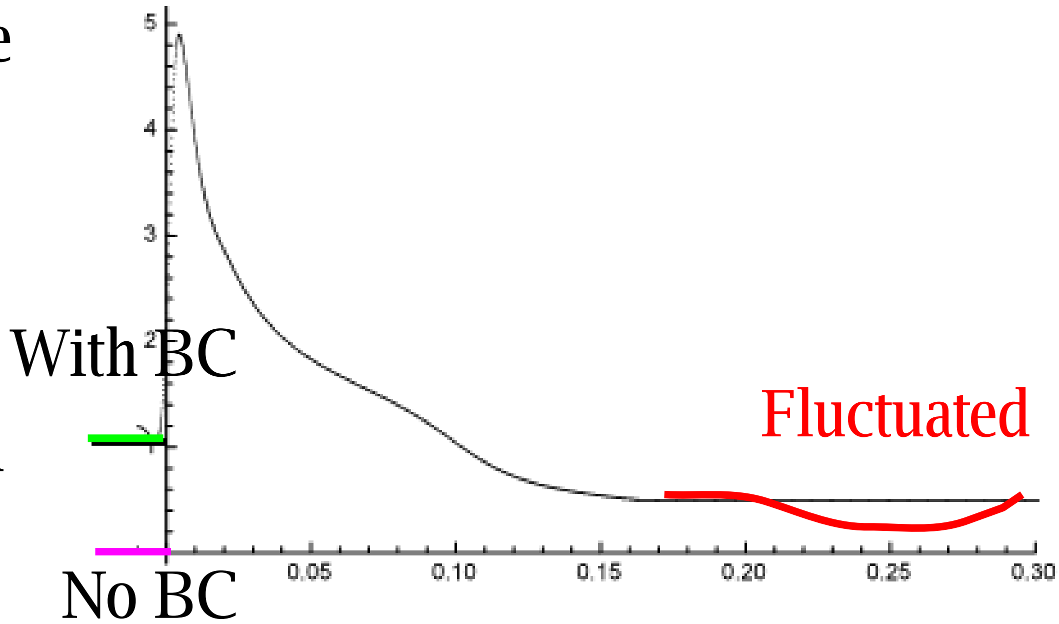
Impact of Near Target Configuration

- **Positron yield strongly depends on the near target configuration.**
  - Target Position wrt AMD peak field,
  - Solenoid field quality,
  - Existence of bridge solenoid coil,
- E=6GeV, t=14mm, σ=4mm, R_{AMD}=10mm、B_{AMD}=5T

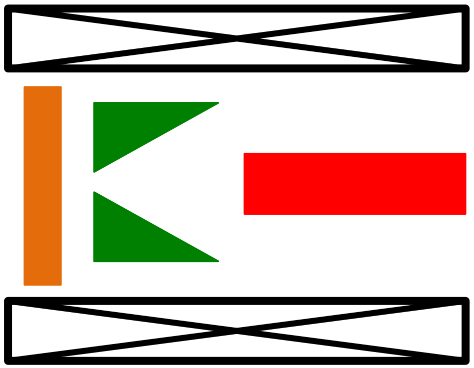


Caputure efficiency at the injector

- Positron yield is examined at the injector.
- AMD field by KEKB FC.
- Bz is smoothly connected.
- BC, dz, and solenoid fluctuation has strong impacts.



Dz	No BC, constant	With BC, constant	With BC, fluctuated
0 mm	1.45	1.65	1.05
5 mm	-	1.41	0.89
10 mm	1.10	1.18	-



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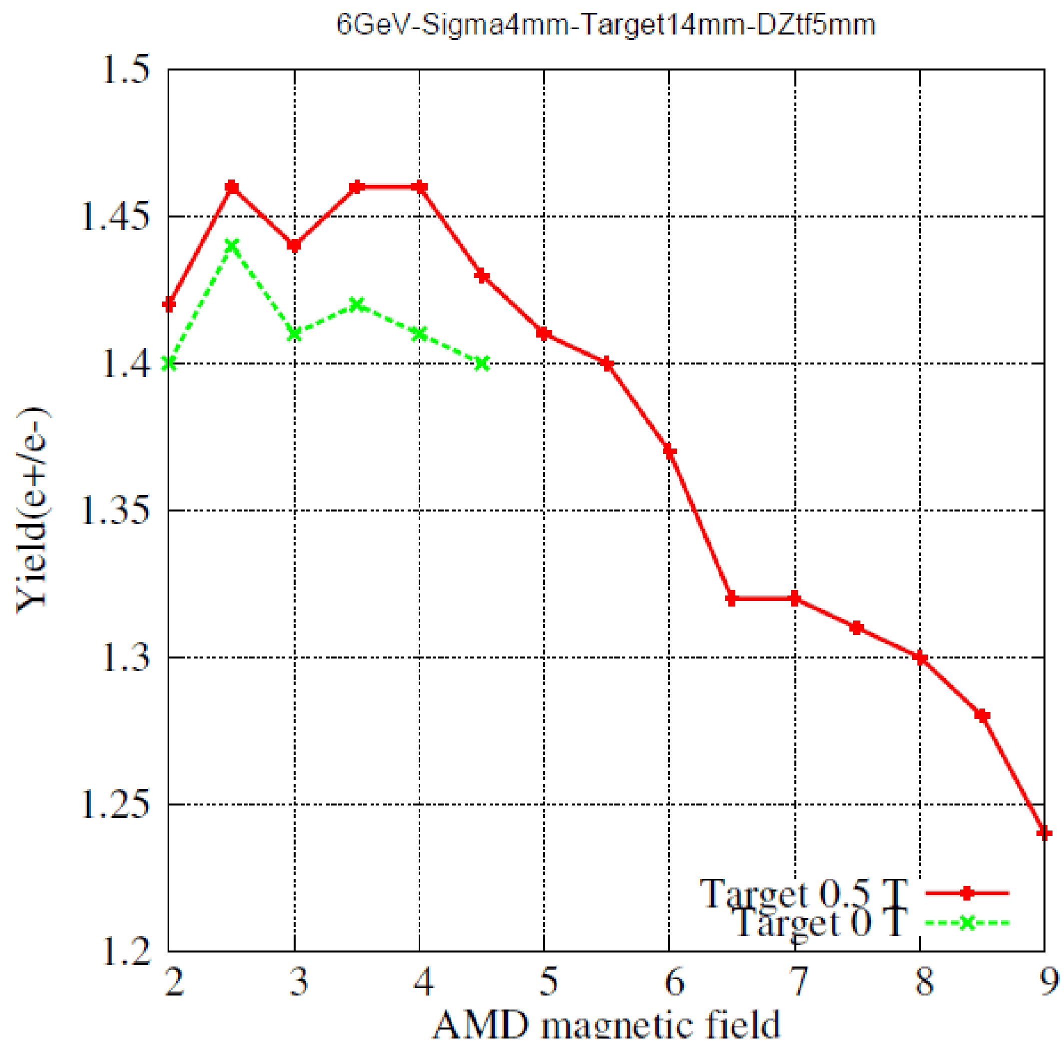
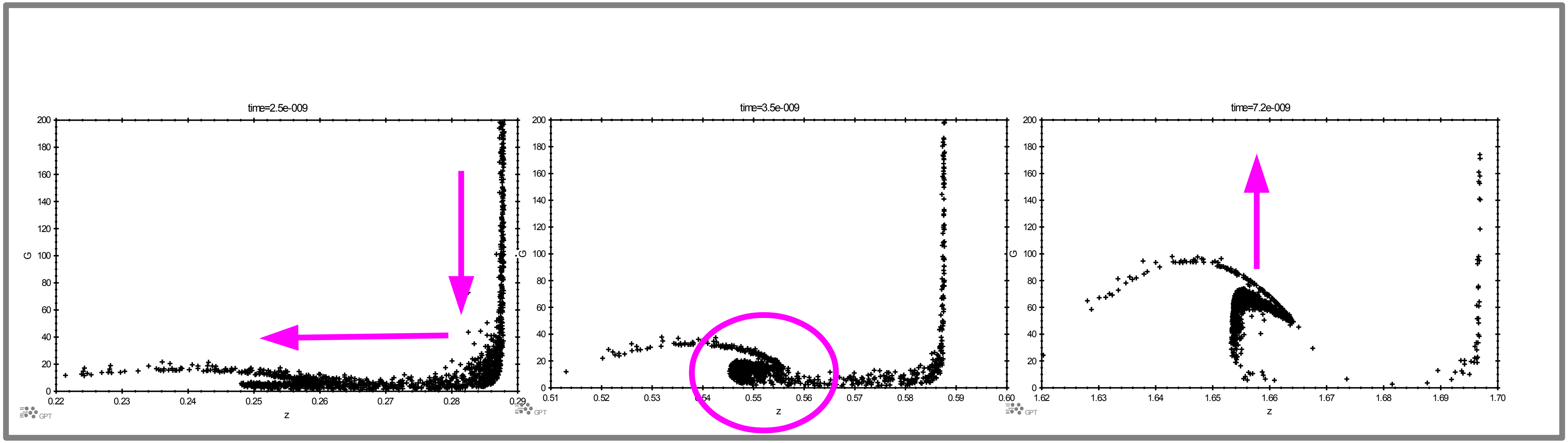


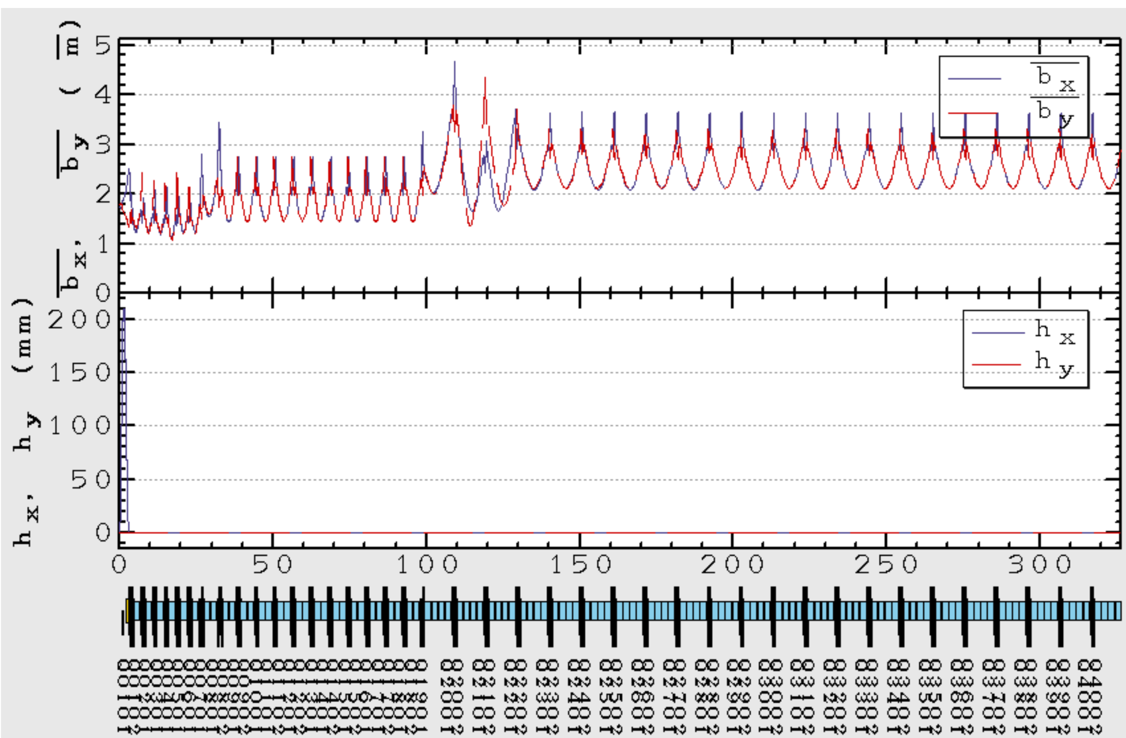
Positron Injector

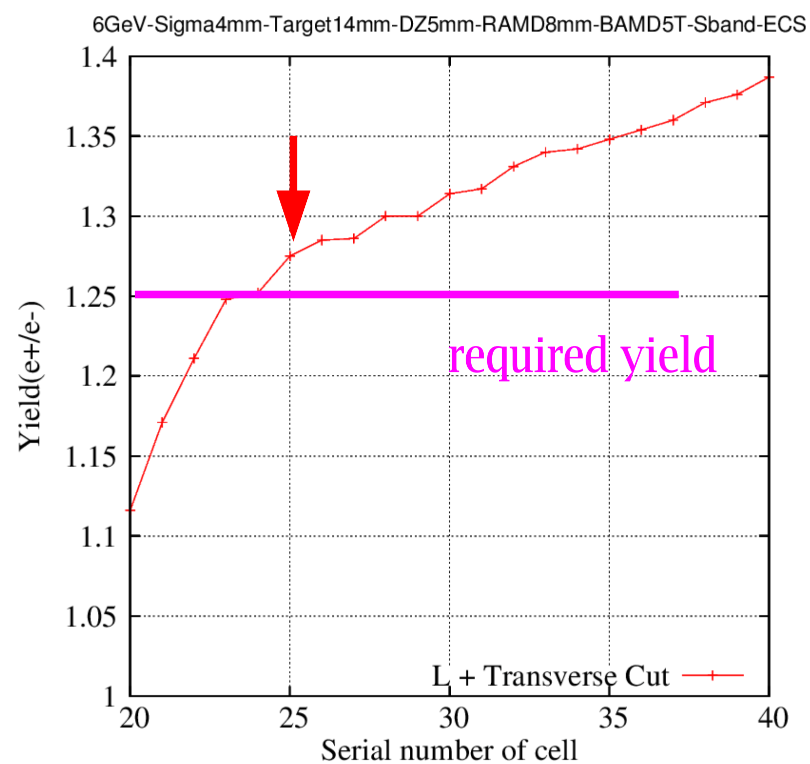
- 3 L-band tubes (20mm aperture, 25 MV/m) with solenoid focusing.
- Deceleration capuring.
  - The positron peak is on deceleration phase.
  - Positrons are sent to the acceleration phase by phase slipping.



Positron Booster

- Positron booster is hybrid :L-band (17mm aperture) and S-band (10 mm aperture) accelerators.
- 62 L-band and 56 S-band tubes give an enough efficiency.

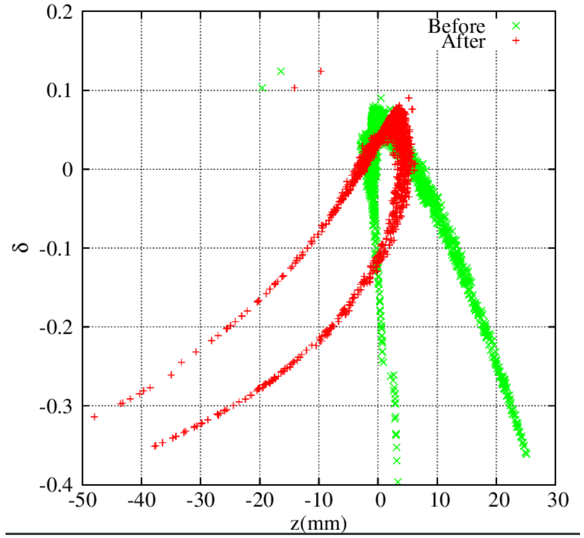


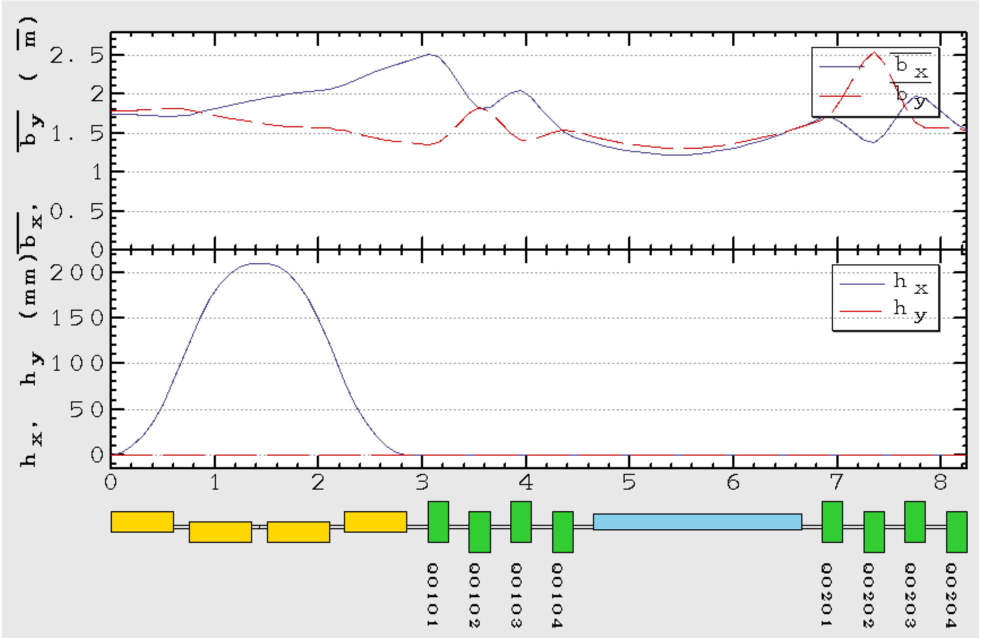


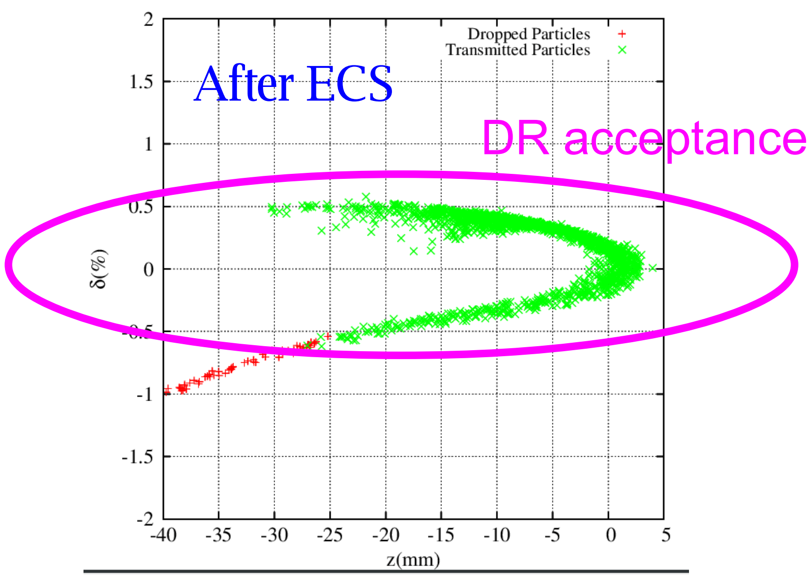
Chicane and ECS

- Chicane removes electrons and low energy positrons.
- ECS (Energy Compressor Section) optimize the longitudinal phase space distribution for better DR acceptance.

Before and after chicane

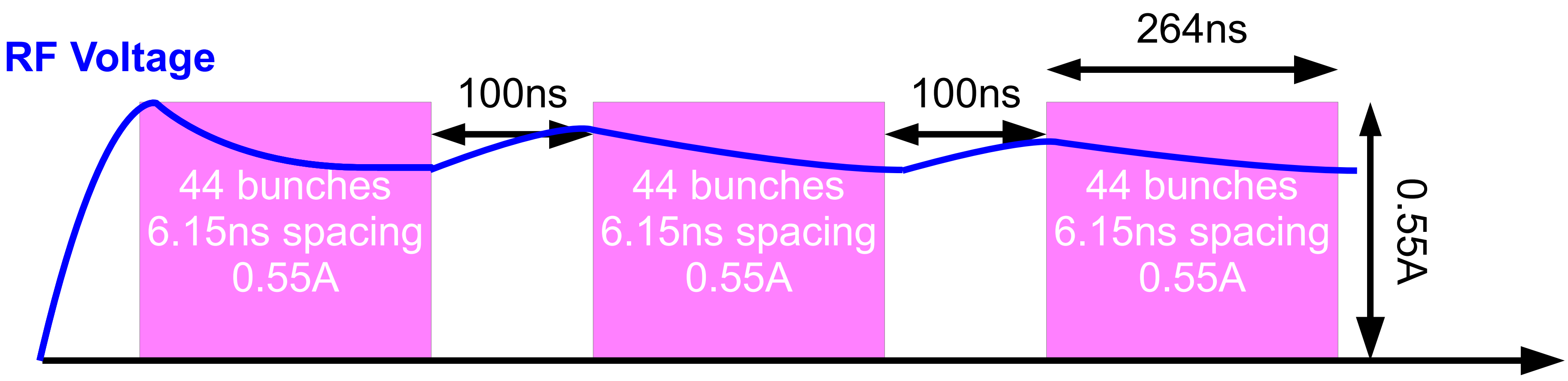






Pulse Structure and Beam-loading

- Positrons are accelerated by triplet multi-bunch pulse.
- The triplet pulse is repeated in 300Hz.
- Transient beam-loading should be compensated, otherwise, the beam is not accepted by DR.



Beam-loading Compensation by AM

Acceleration voltage by a flat RF (E_0),

Beamloading term

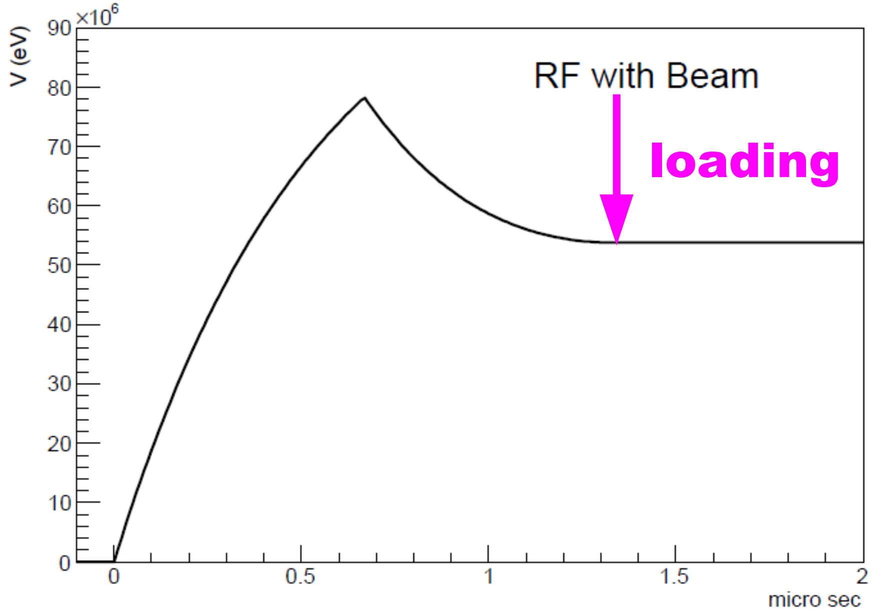
$$V(t) = E_0 L + \frac{r_0 L I_0}{2(1-e^{-2\tau})}\left[\frac{\omega}{Q}e^{-2\tau}(t-t_f) - 1 + e^{2\tau - \frac{\omega}{Q}t}\right].$$

AM to compensate the beam loading

$$E(t) = E_0 U(t) + E_1 U(t-t_f) - E_2(t-t_f)U(t-t_f) + E_2(t-2t_f)U(t-2t_f),$$

For steady component

For transient component



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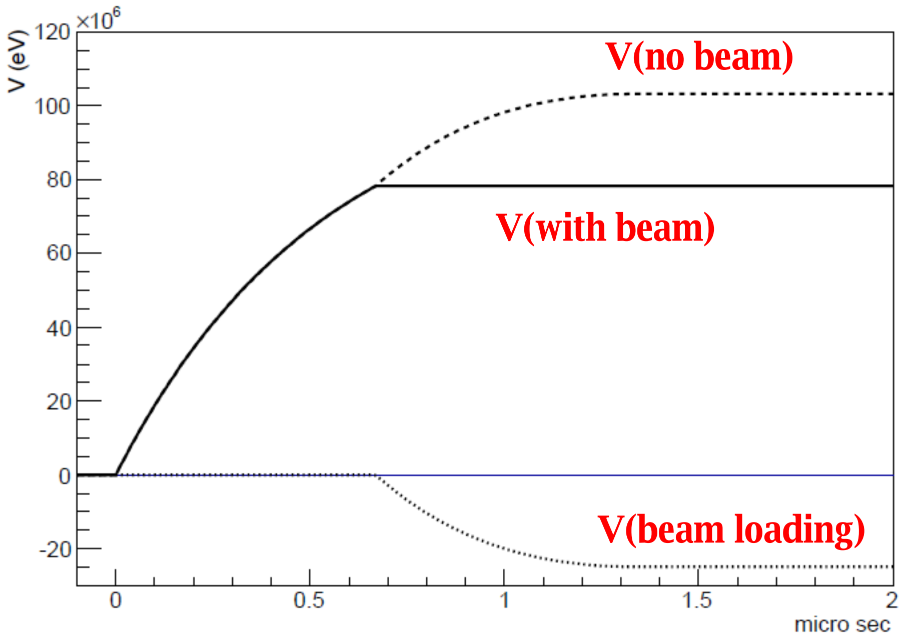

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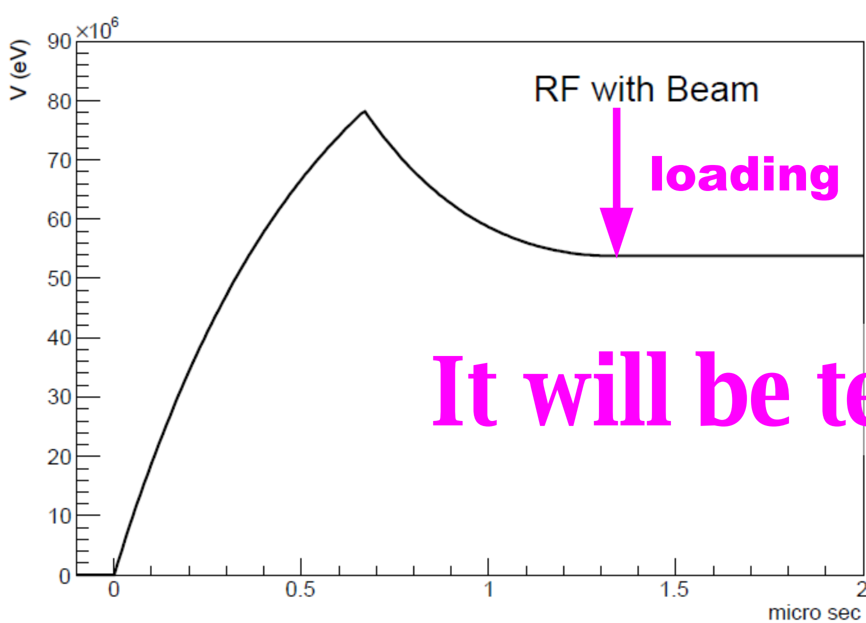

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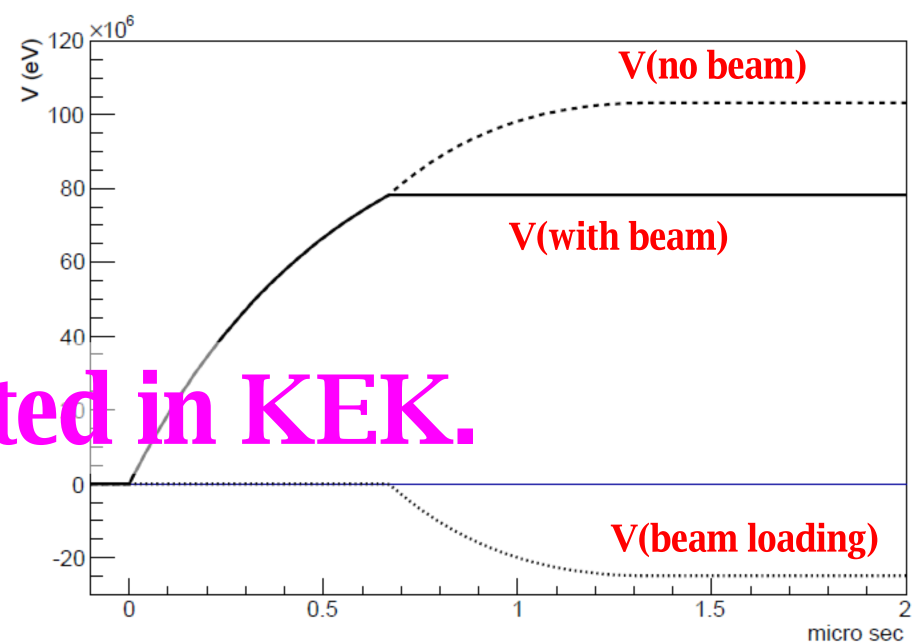
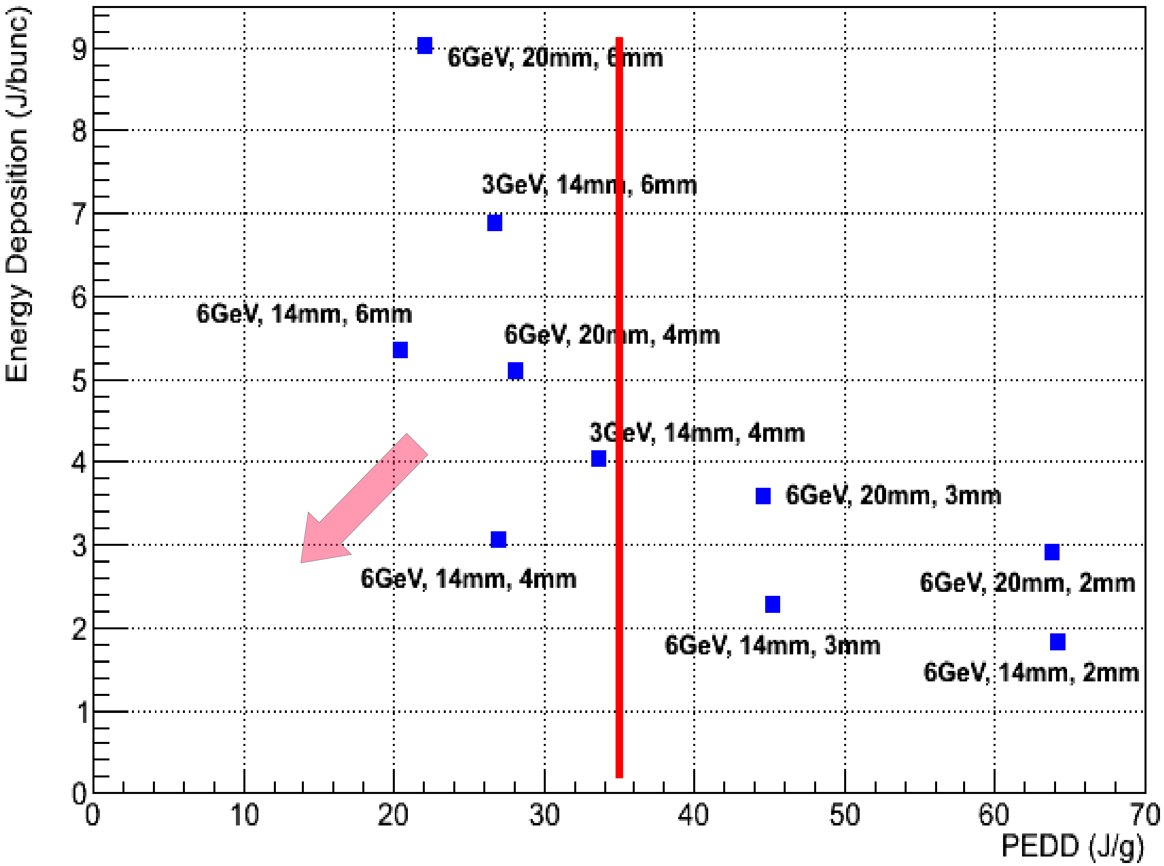


It will be tested in KEK.

Capture Efficiency and PEDD

- PEDD : Peak Energy Deposition Density. The practical limit by SLC is 35 J/g.
- PEDD and energy deposition on the target per bunch is estimated giving 3.0e+10 positron per bunch with 50% margin.
- 6GeV, 14mm target, 4mm spot is likely to be optimum.



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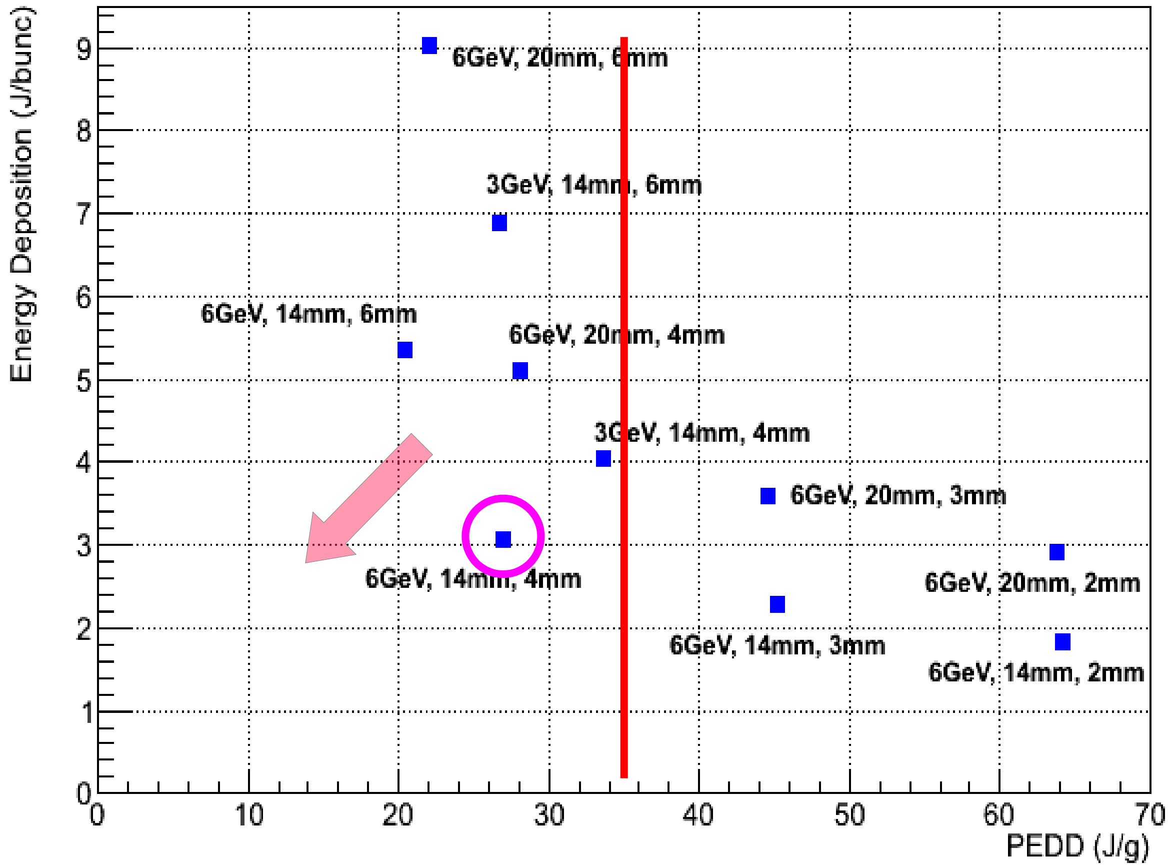
- 6GeV, 14mm target, 4mm spot is likely to be optimum. (e+ yield is 1.25 and e- bunch charge is 2.4e+10.)



Conclusion

- Electron driven ILC positron source is considered as a technical backup.
- According to the simulation, 3.0E+10 positron/bunch is obtained with a moderate parameter set.
- By manipulating the pulse structure, target load is much relaxed.
- Beam-loading compensation for the triplet pulse acceleration is likely to be promising (to be tested in KEK).
- This work is partly supported by Grant-in-Aid for Scientific Research (C 26400293) by MEXT Japan.

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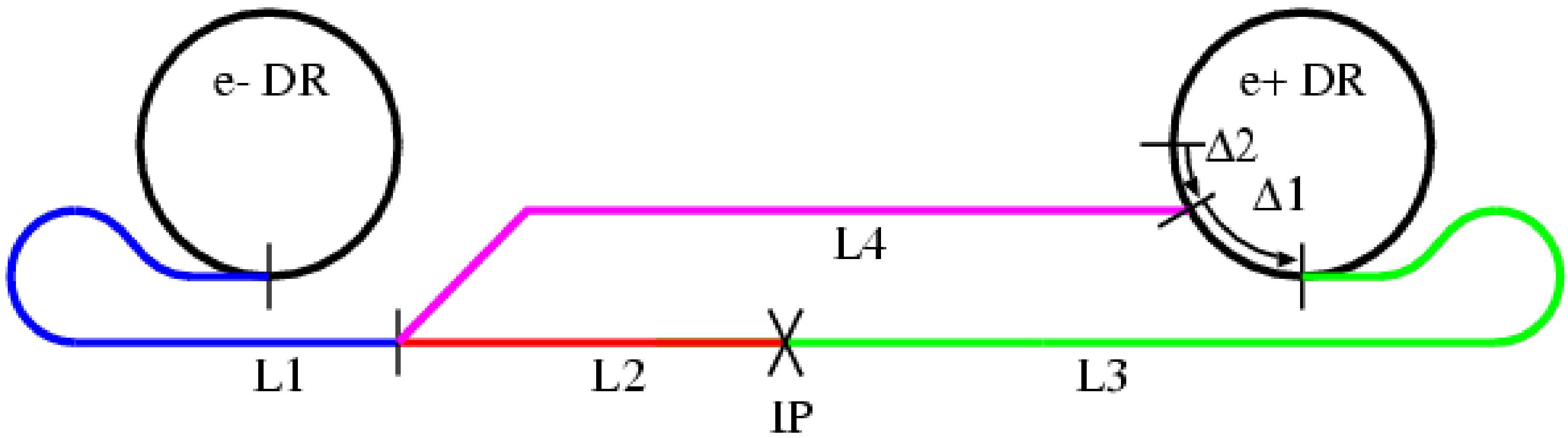
Path Length Condition



- DR Bucket for the generated positron should be vacant.
- Self-reproduction condition: Positron goes to a bucket where the collision partner (electron) was.
- Another condition is for collision.
- The path length adjustment has to be made by physical length adjustment (timing shift can not make it).

$$For\ collision: L_1 + L_2 = \Delta_1 + \Delta_2 + L_3,$$

$$For\ self-reproduction: L_1 + L_4 = \Delta_2 + nC_{DR},$$

$$L_3 + L_4 + \Delta_1 = L_2 + nC_{DR},$$

Beamloading Compensation by AM

- Beam-loading compensation by AM (Amplitude Modulation) is considered.
- By solving RF envelope giving a flat acceleration, it can be compensated perfectly.

Acceleration voltage by a flat RF (E_0),

Beamloading term

$$V(t) = E_0 L + \frac{r_0 L I_0}{2(1-e^{-2\tau})}\left[\frac{\omega}{Q}e^{-2\tau}(t-t_f) - 1 + e^{2\tau-\frac{\omega}{Q}t}\right].$$

To compensate the transient beam-loading, AM is introduced as follows

$$E(t) = E_0 U(t) + E_1 U(t-t_f) - E_2(t-t_f)U(t-t_f) + E_2(t-2t_f)U(t-2t_f),$$

For steady beam loading suppression

For transient beam loading suppression

Beam loading Compensation by AM

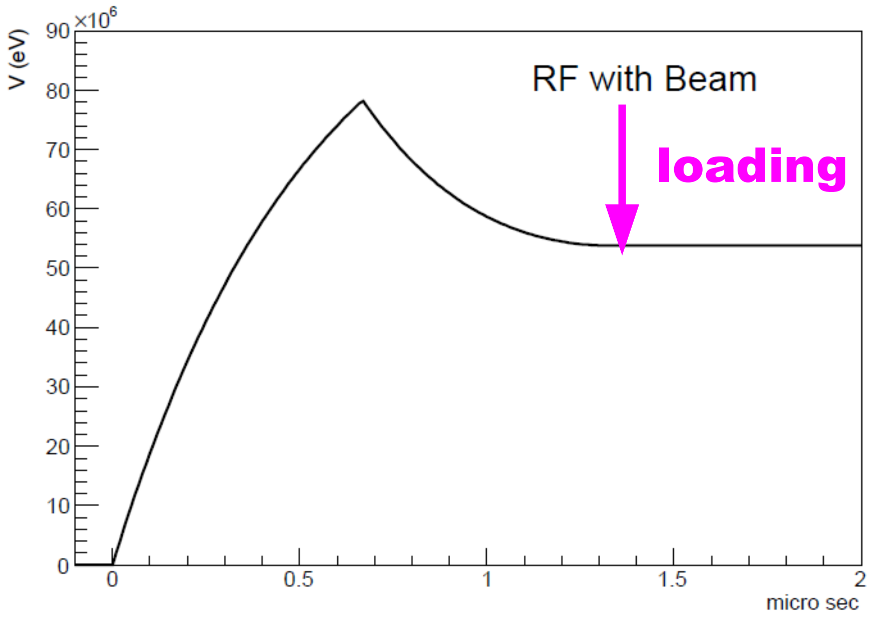
Acceleration voltage by AM RF (E_0 +E_1+E_2),

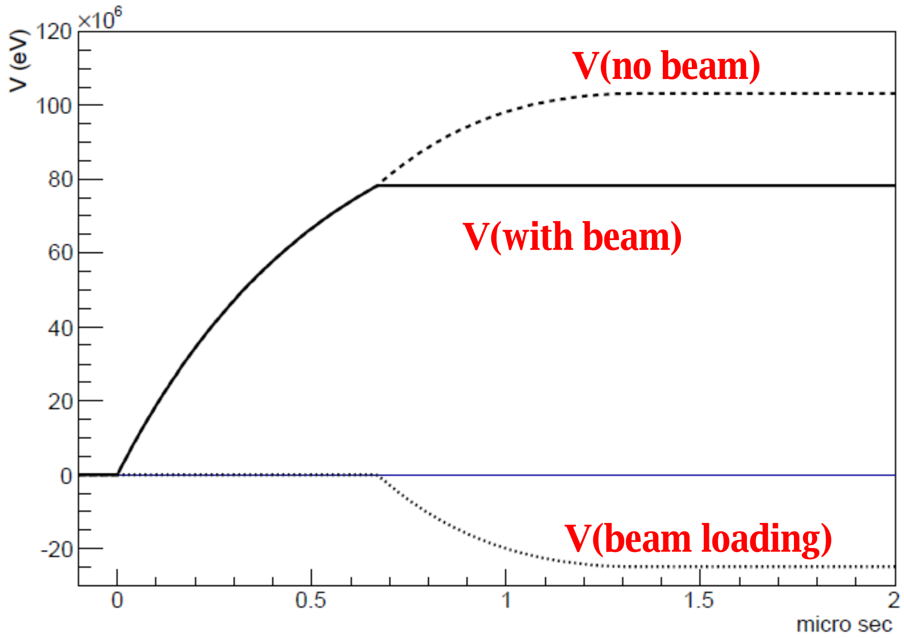
$$V(t) = E_0 L + \frac{L}{1-e^{-2\tau}}\left(E_1 + \frac{Q}{\omega}E_2\right)\left(1 - e^{-\frac{\omega}{Q}(t-t_f)}\right) - \frac{L}{1-e^{-2\tau}}E_2(t-t_f) + \frac{r_0 L I_0}{2(1-e^{-2\tau})}\left[\frac{\omega}{Q}(t-t_i) - 1 + e^{-\frac{\omega}{Q}(t-t_f)}\right],$$

Solution for the flat acceleration

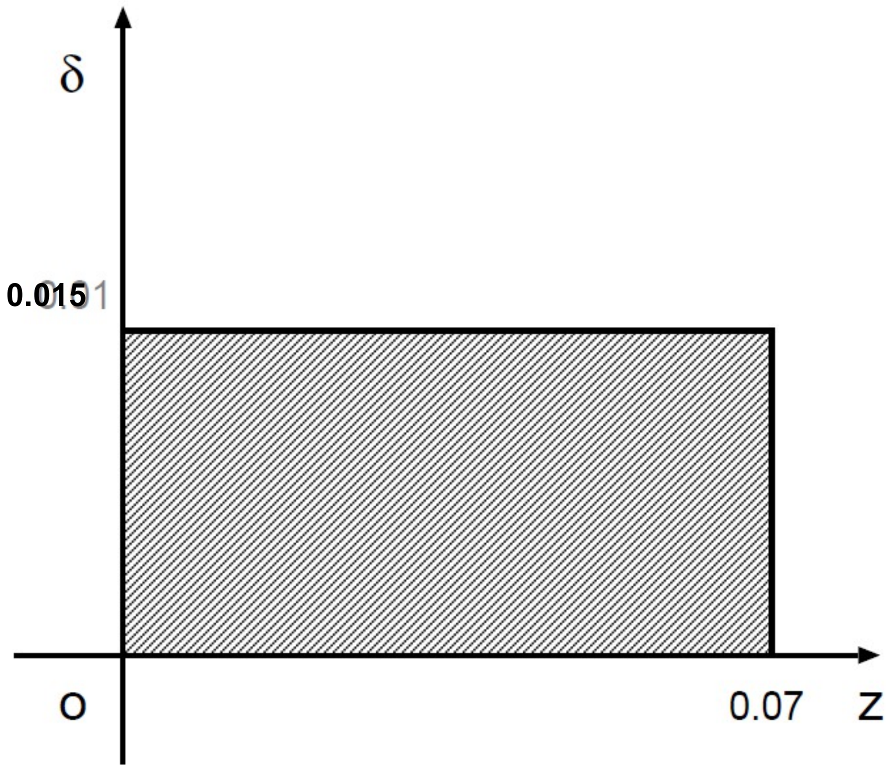
$$E_1 = \frac{r_0 I_0}{2}(1-e^{-2\tau}),$$

$$E_2 = \frac{r_0 I_0}{2}\frac{\omega}{Q}e^{-2\tau},$$





DR acceptance



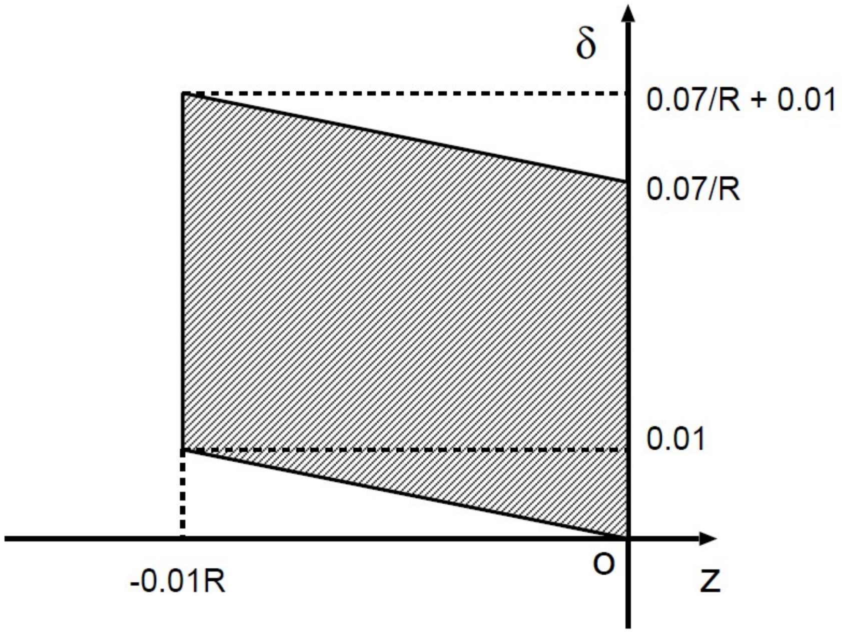
- **DR acceptance is**
  - $\gamma A_x + \gamma A_y < 0.07$m
  - dE<1.5%, dz<0.07m (FW)
- **By considering RF acceleration in S or L-band, wider dE is desirable even with less dz.**

Phase-space Matching with EC

- Matching with EC is considered.
- Transfer matrix of EC (R means R_{56}).
- r_1(EC entrance) is written by r_2 (EC exit).
- Effective DR acceptance is operable by EC(R).

$$M_{EC} = \begin{pmatrix} 1 & R \\ -1/R & 0 \end{pmatrix},$$

$$\boldsymbol{r_1} = (M_{EC})^{-1}\,\boldsymbol{r_2} = \begin{pmatrix} -R\delta_2 \\ \frac{z_2}{R} + \delta_2 \end{pmatrix}.$$



Optimization

$$\left[1-\cos\left(\omega\frac{0.01R}{2c}\right)\right]+\delta_{inj}<\frac{0.07}{R}+0.01,$$

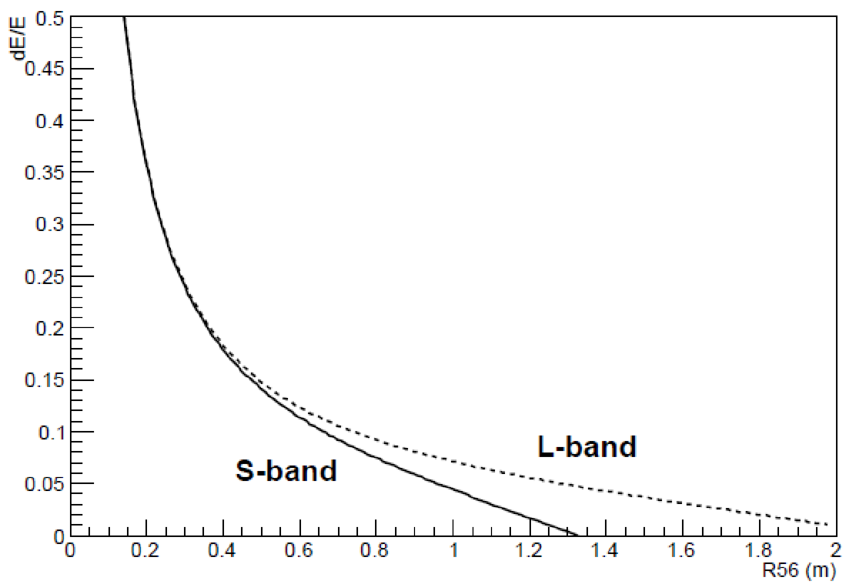
dE by RF

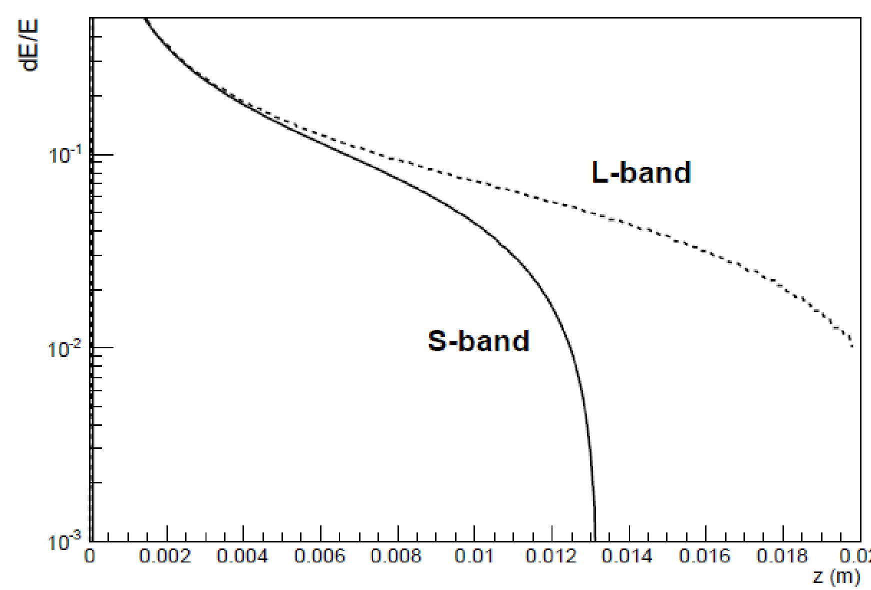
dE by Capture

dE Acc. with EC

$$f(R)=\frac{0.07}{R}-\left[1-\cos\left(\omega\frac{0.01R}{2c}\right)\right]+0.01,$$

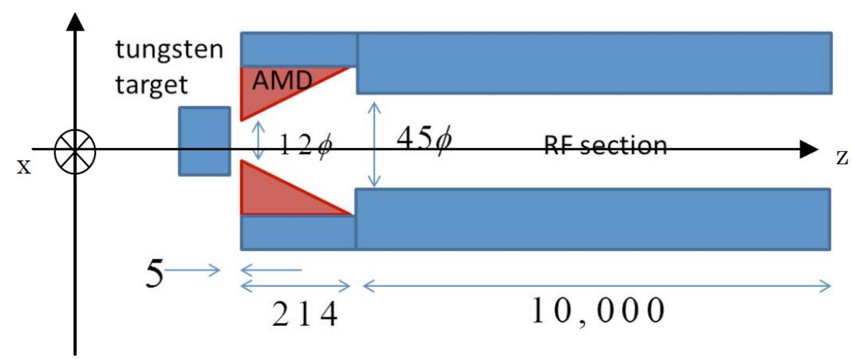
f shows the allowed δ_{inj}
R_{56}=1m is likely to be OK.

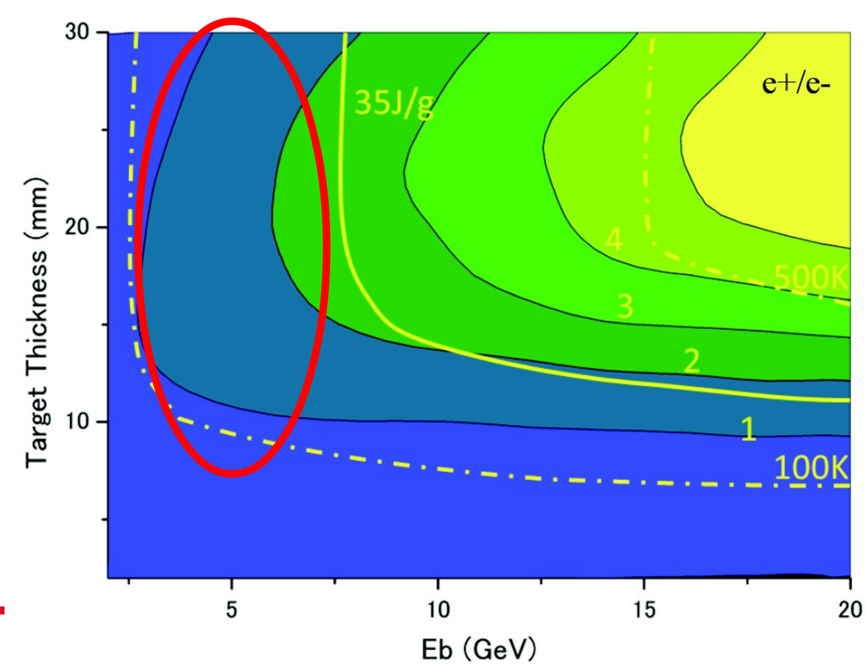




300Hz Conventional Positron Source

- Several GeV drive beam.
- Several X_0 conversion target.
- AMD(Adiabativ Matching Device) for p_t compenstaion; B_0~7.0T.
- S-band or L-band Standing wave linac for capture. 25MeV/m.
- 6GeV, 15mm (W) target, 4mm rms beam size as a working assumptions.

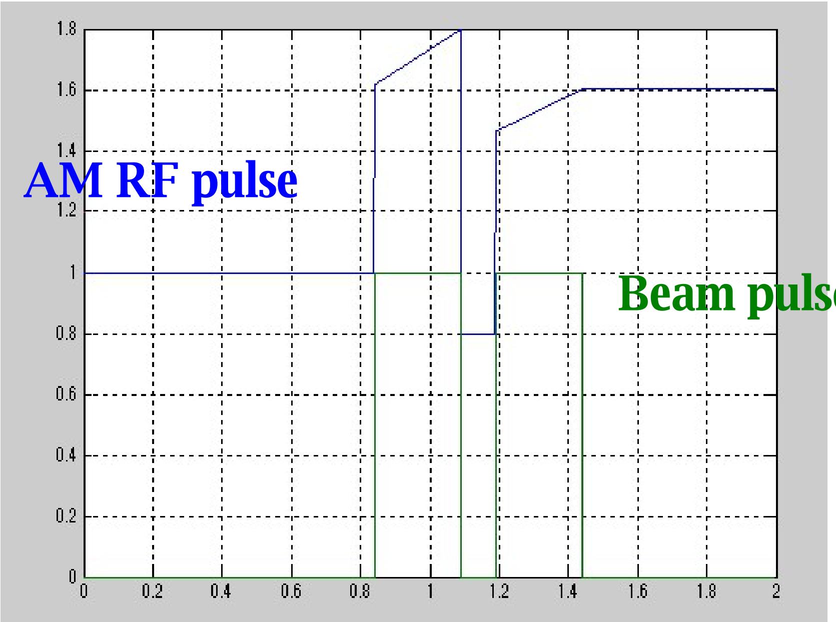


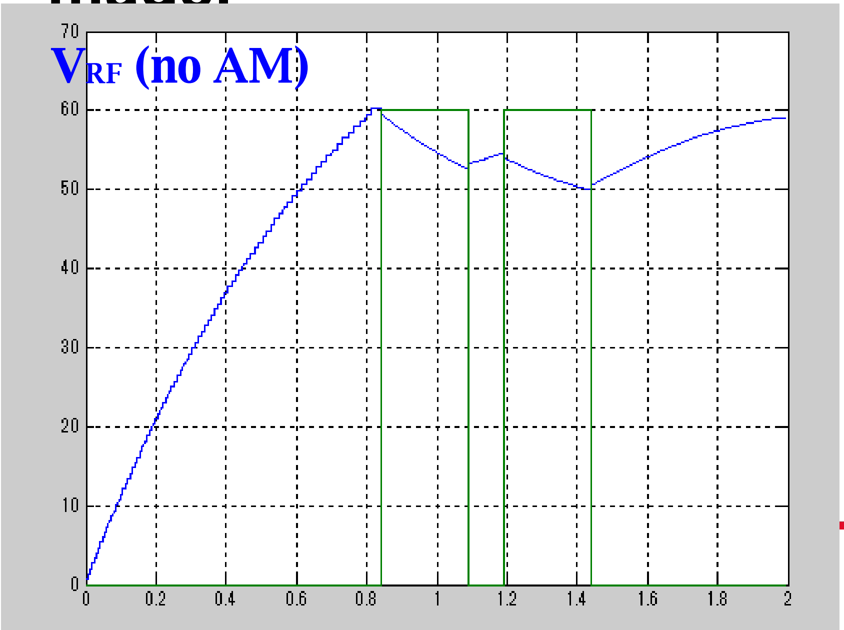


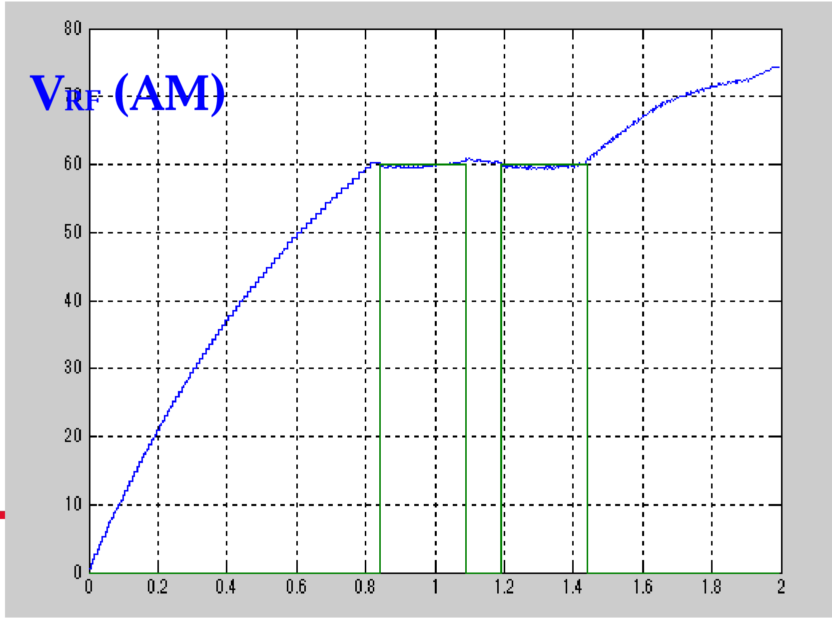
Multi-Pulse Acceleration

M. Satoh

- AM to compensate BL effect.
- AM should be applied to not only on the pulse head, but also the pulse interval.
- A flat acceleration is made.

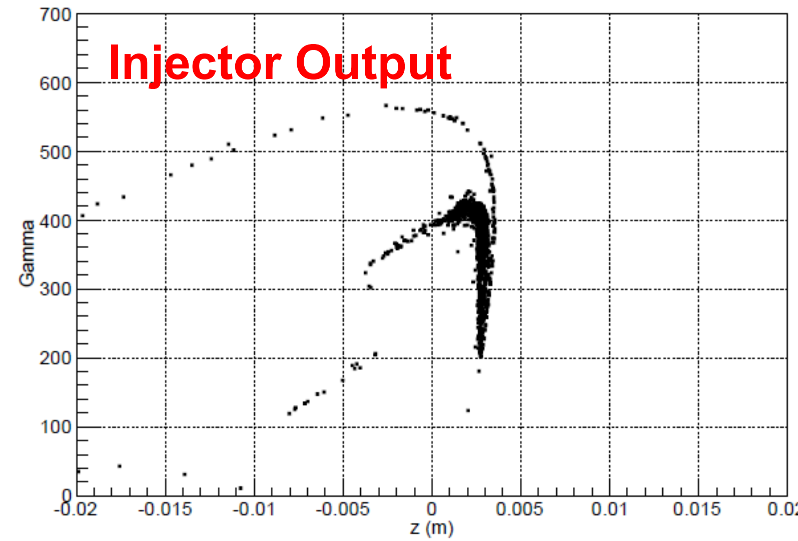


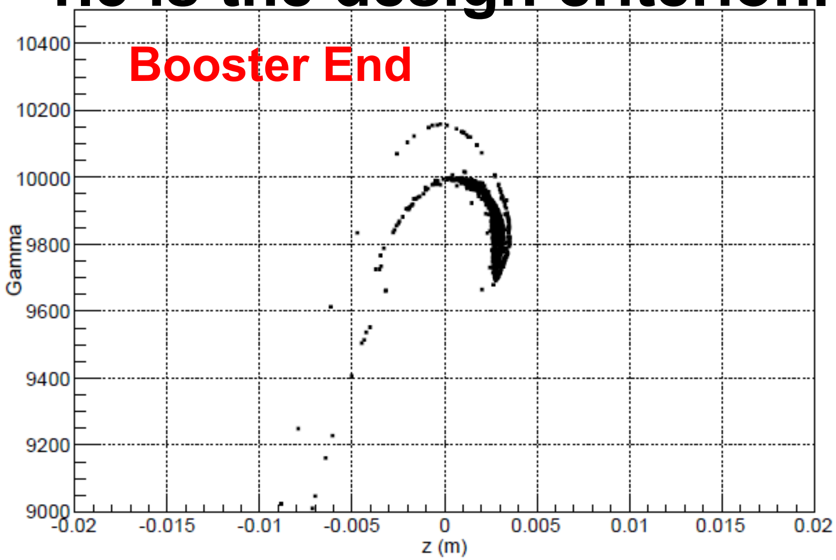


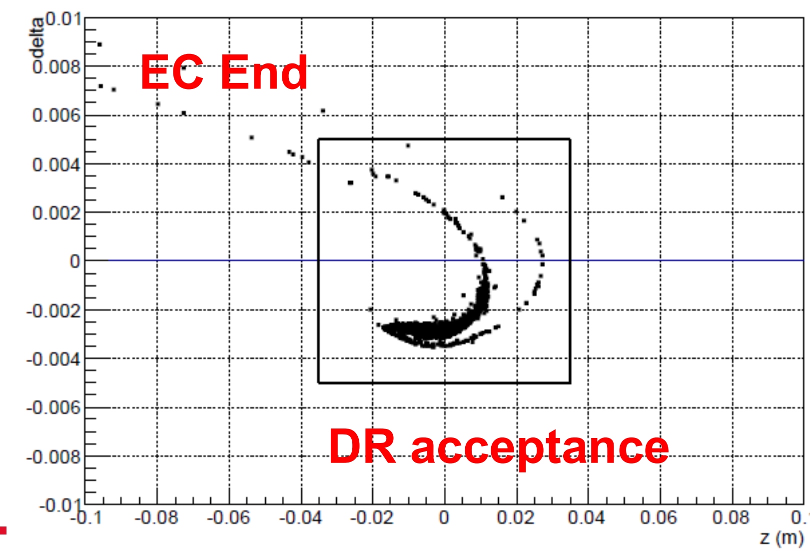


δ-z phase-space

- **1000 electrons impinge on the target.**
- **>8000 positrons are generated.**
- **1100 positrons are survived and accepted by DR.**
- **The yield is 1.1 (e+/e-).**
- **1.5 is the design criterion.**

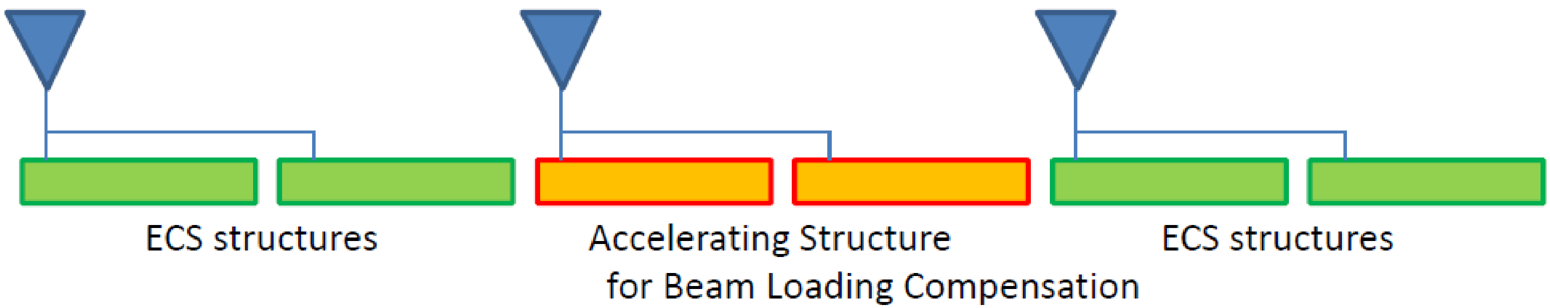


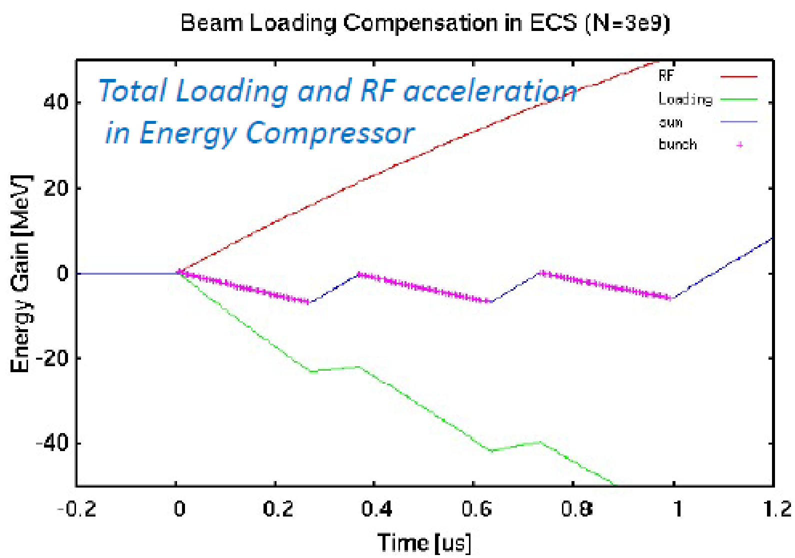




Beam loading Compensation at EC

Simple ΔT Energy Compensation Method





RF power is injected to RF structure just after 1st bunch is injected.

	ECS	Beam Load.
f	1.3 GHz	1.3 GHz
L	3 m	3 m
Q	18400	18400
R	42.4 MΩ	42.4 MΩ
τ	0.40	0.80
P /structure	32MW	32 MW

ΔE = 68MeV -> ΔE = 7MeV

ILC Luminosity

Event rate

$$N = \sigma \times L$$

$\sigma y \ll \sigma x$

Keep luminosity and surppress Beamstrahlung and Disruption.

Luminosity

$$L = \frac{f_{rep} n_b N^2}{4\pi \sigma_x \sigma_y}$$

Beamstrahlung

$$\frac{\Delta E}{E} \propto \frac{N^2 E}{(\sigma_x^2 + \sigma_y^2)\sigma_z}$$

Disruption

$$D_{x,y} = \frac{2Nr_e}{\gamma} \frac{\sigma_z}{\sigma_{x,y}(\sigma_x + \sigma_y)}$$

Parameter	Value
Luminosity	$1.8 \times 10^{34} cm^{-2} s^{-1}$
Horizontal size	640 nm
Vertical size	5.7 nm
Bunch length	300 µm
Vertical Disruption	19.4
RMS energy by BS	2.4%
Horizontal emi.	10 mm.mrad
Vertical emi.	0.04 mm.mrad