An Optimization of Positron Injector of ILC

Masao KURIKI[a)b)], J. Urakawa[b)], M. Satoh[b)], and S. Kashiwagi[c)]

a)AdSM, Hiroshima Uniersity,
b)KEK,
c)RCEPS, Tohoku University

1. ILC, International Linear Collider
2. ILC Positron Source
3. 300Hz conventional scheme
4. Injector Optimizatoin
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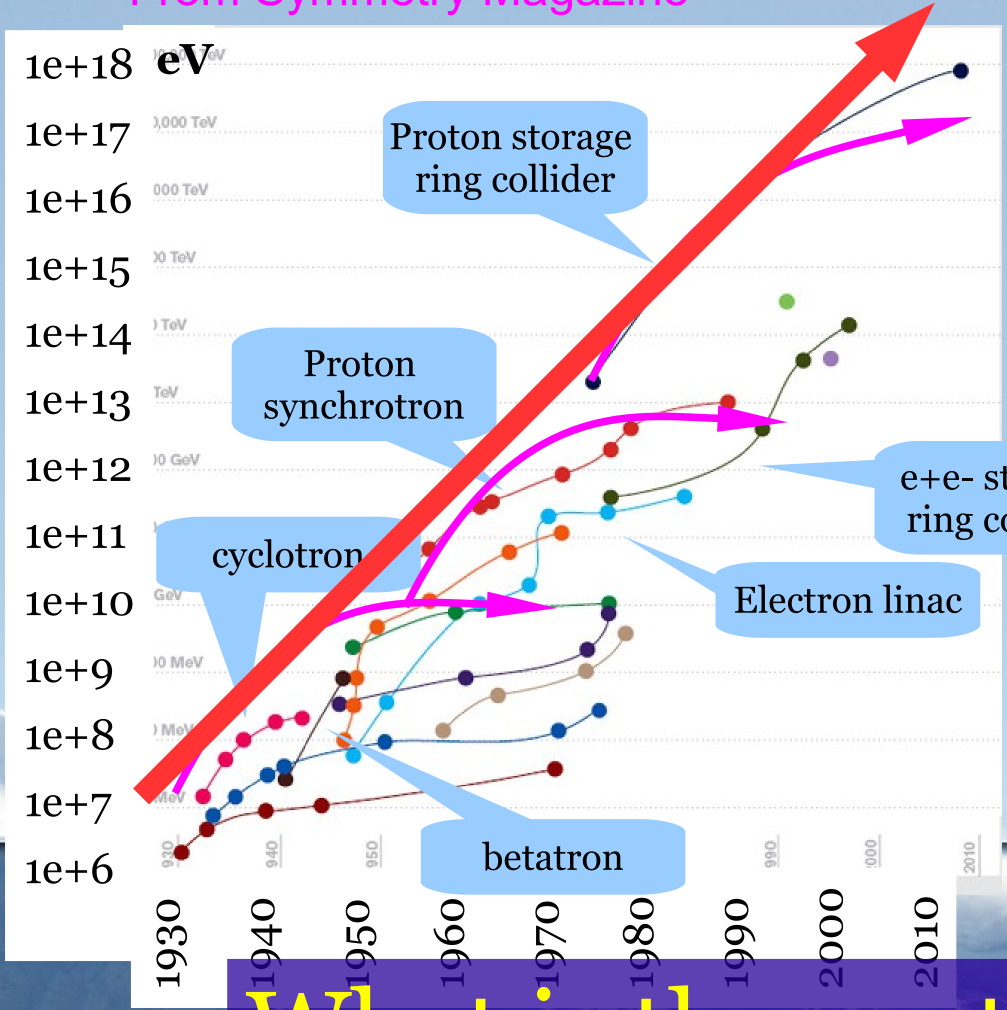
Livingston Plot :
Moore's law in Particel Accelerator

From Symmetry Magazine

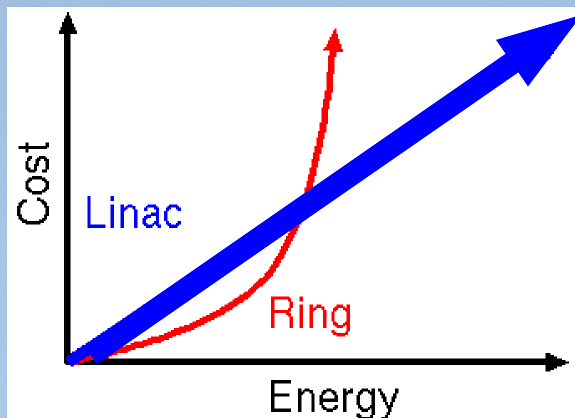


Rapid progress has been made by continous evolution.

like a multi-stage rocket!

What is the next stage?

Storage ring and LINAC



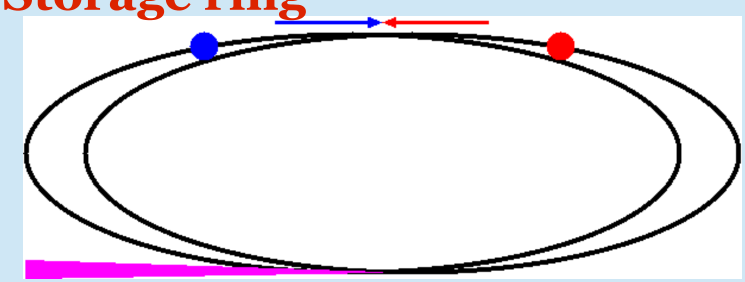
not at all

Energy loss

$$\Delta E = \frac{C_\gamma E^4}{\beta \rho}$$

LINAC

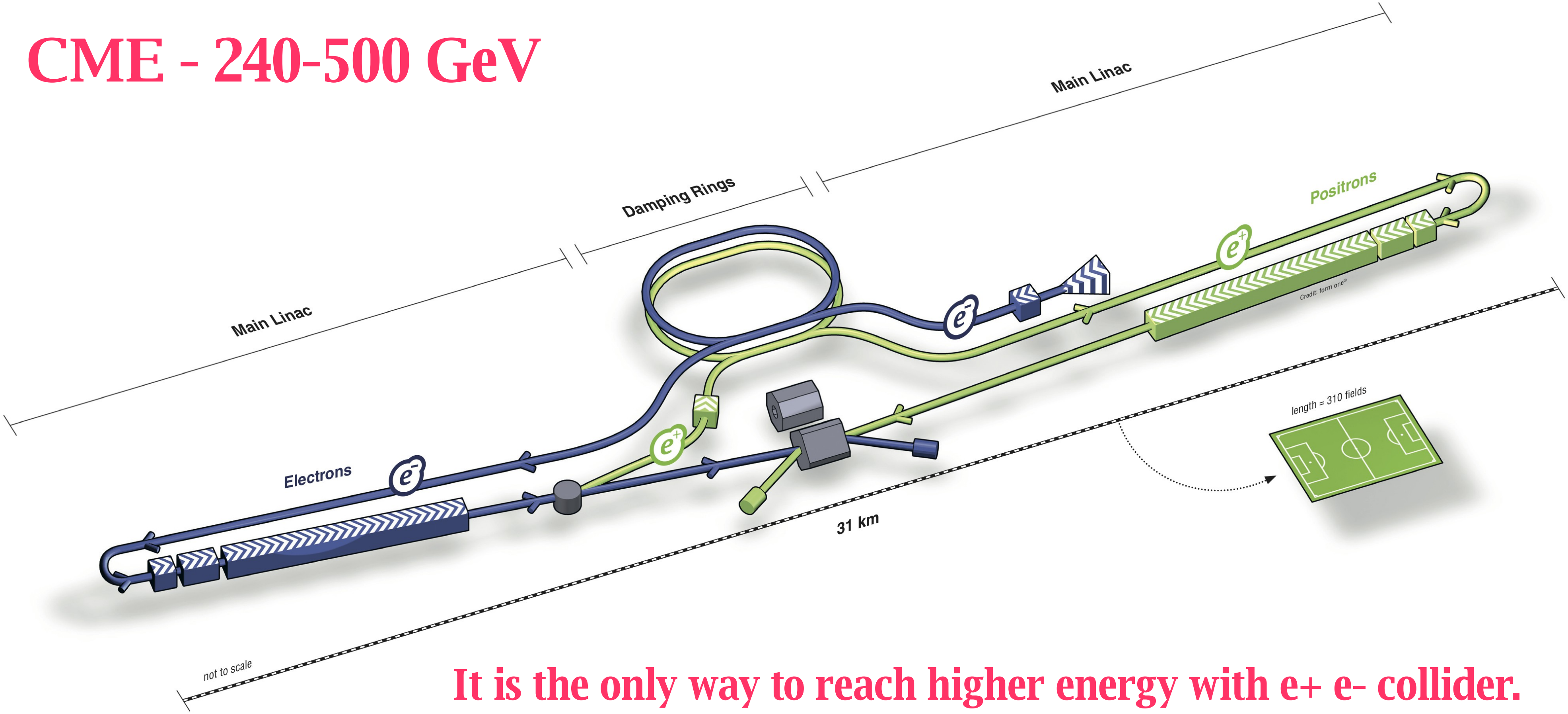
Storage ring



Linac is the only solution to reach higher energy!
(beyond LEP2 energy)

International Linear Collider

CME - 240-500 GeV



It is the only way to reach higher energy with e+ e- collider.

ILC Luminosity

Event rate

$$N = \sigma \times L$$

σy « σx

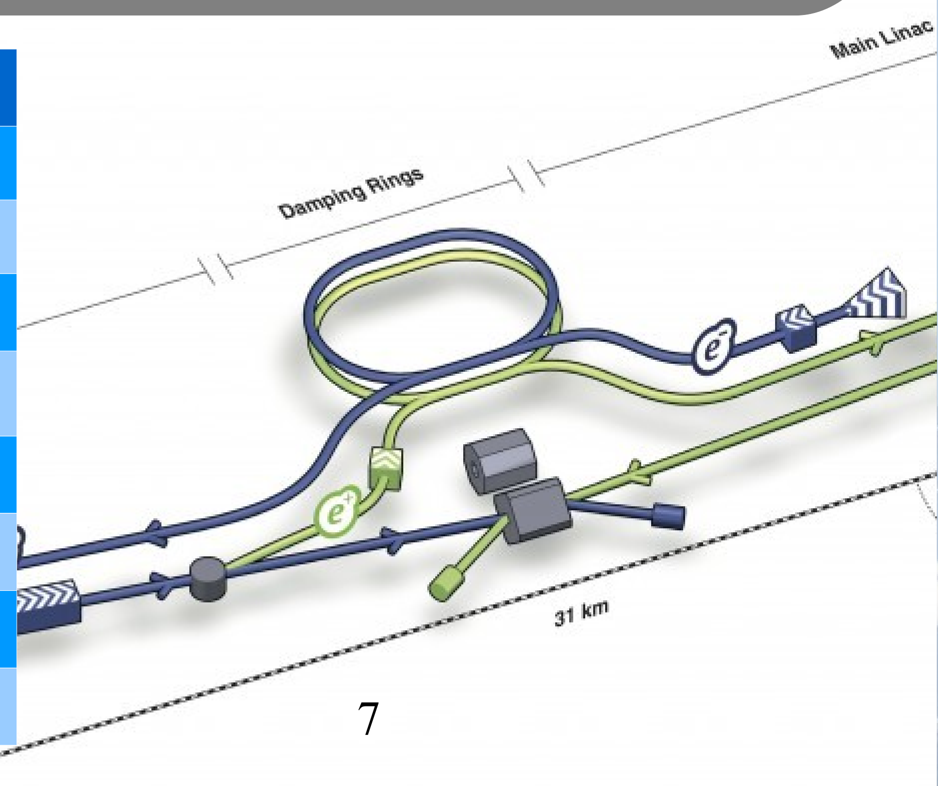
Keep luminosity and surppress Beamstrahlung and Disruption.

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

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

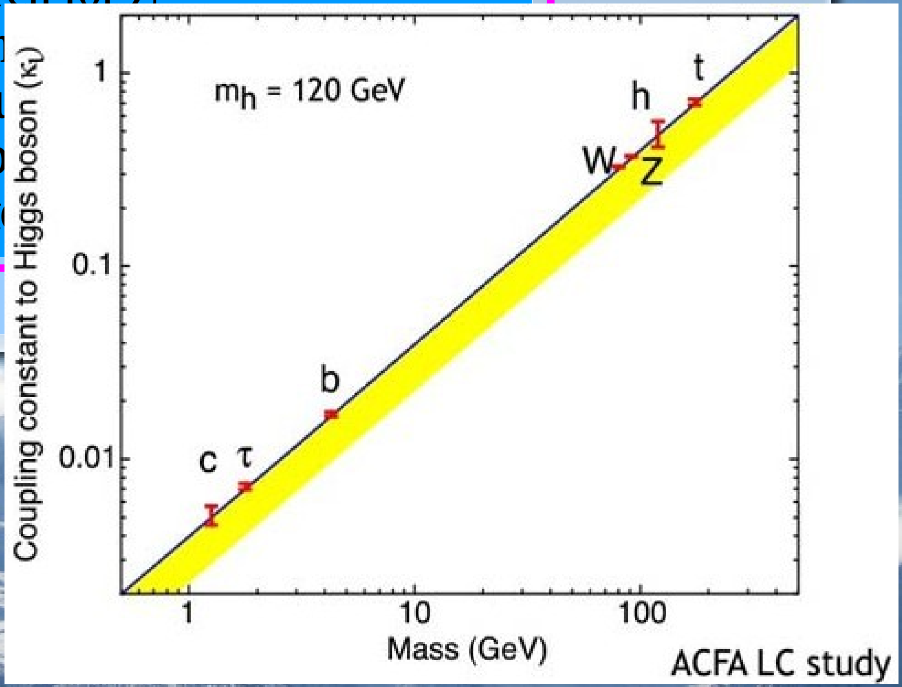
Disruption $$D_{x,y} = \frac{2 N r_e}{\gamma} \frac{\sigma_z}{\sigma_{x,y} (\sigma_x + \sigma_y)}$$

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



Major Physics Proces in ILC

Energy	Reaction	Physics Goal
91 GeV	$e^+e^- \to Z$	ultra-precision EW
160 GeV	$e^+e^- \to WW$	ultra-precision Wmass
250 GeV	$e^+e^- \to Zh$	precision Higgs coupling
350-450 GeV	$e^+e^- \to t\bar{t}$ $e^+e^- \to WW$ $e^+e^- \to \nu\bar{\nu}h$	top quark mass and coupling precision W coupling precision Higgs coupling
500 GeV	$e^+e^- \to f\bar{f}$ $e^+e^- \to t\bar{t}h$ $e^+e^- \to Zhh$ $e^+e^- \to \tilde{\chi}\tilde{\chi}$ $e^+e^- \to AH, H^+H^-$	precision search for Z' Higgs couplin Higgs self cou search for sup search for ext
1000GeV	*and more..*	



Confirm SM model-independently!
(Hopefully, it would be broken)

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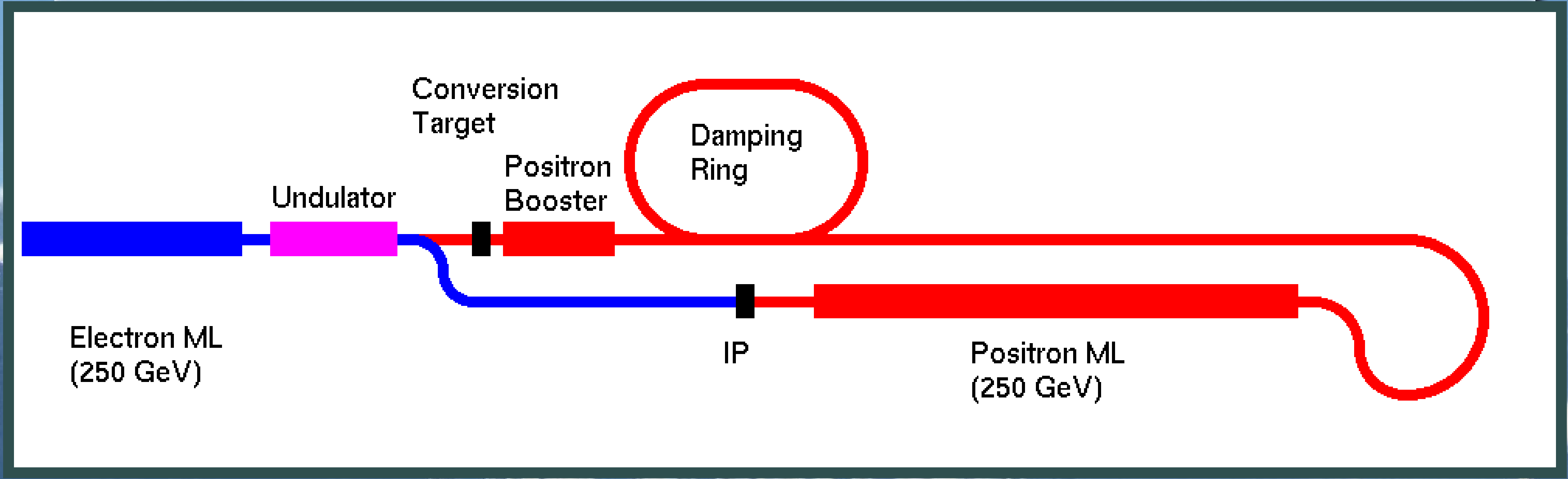
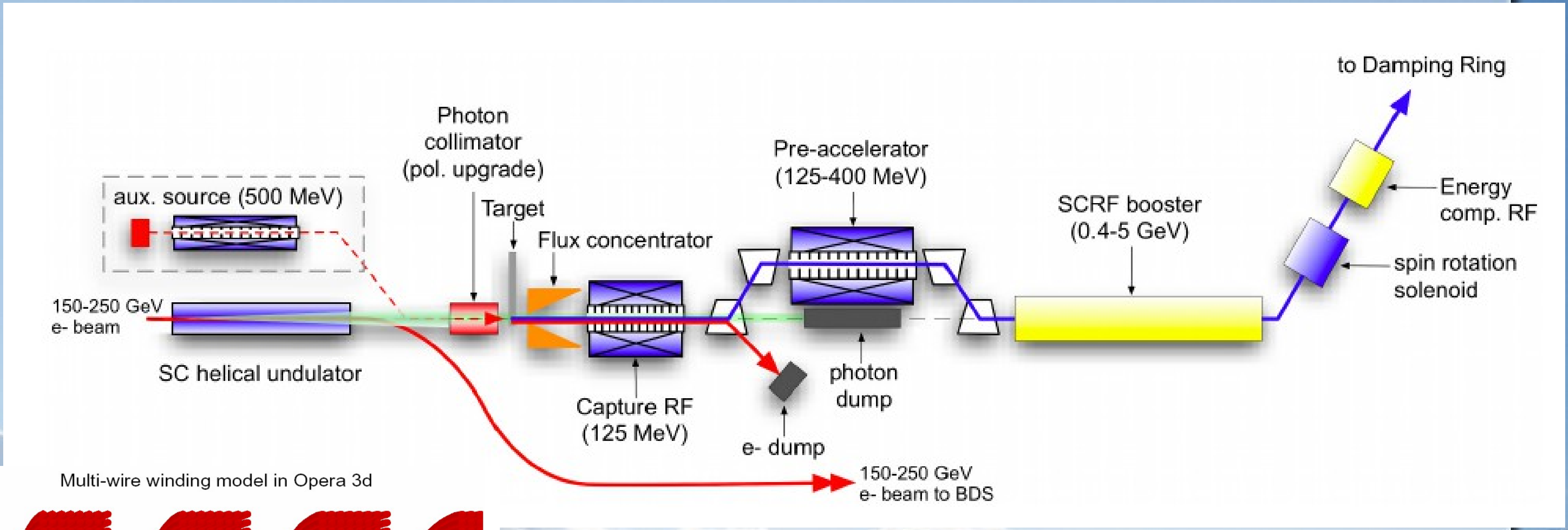
Positron Source

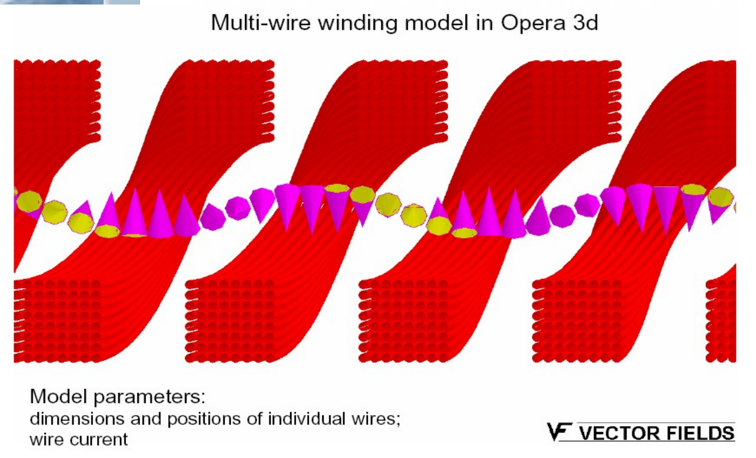
- Positron production is a complicated business.
- Amount of e+ is 50 times larger than that in SLC (SLAC Linear Collider, the first linear collider in the world).
- Staging approach to minimize possible risks and maximize physics potential.
  - 1st stage : Unpolarized e-driven e+ source .
    (no polarizatino, but "conventional")
  - 2nd stage: Polarized undulator driven e+ source. (polarized, but totally new)

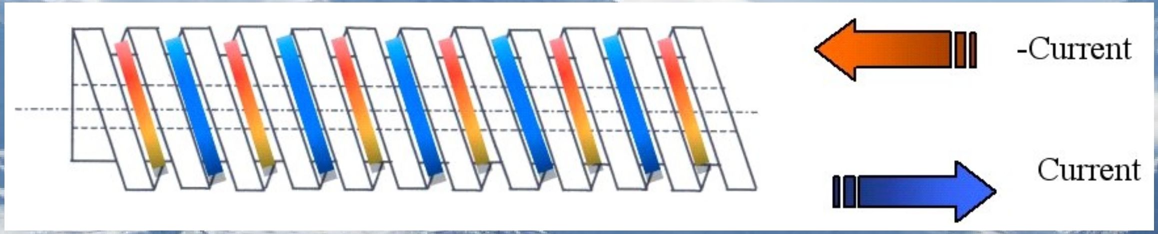


Undulator Positron Source

- To generate gamma ray from undulator (10mm λ_u) radiation, >130GeV electron beam for collision is shared.
- Helical undulator for polarized gamma ray generation.
- The beam structure has to be identical to that in ML, i.e. 1ms pulse duration.



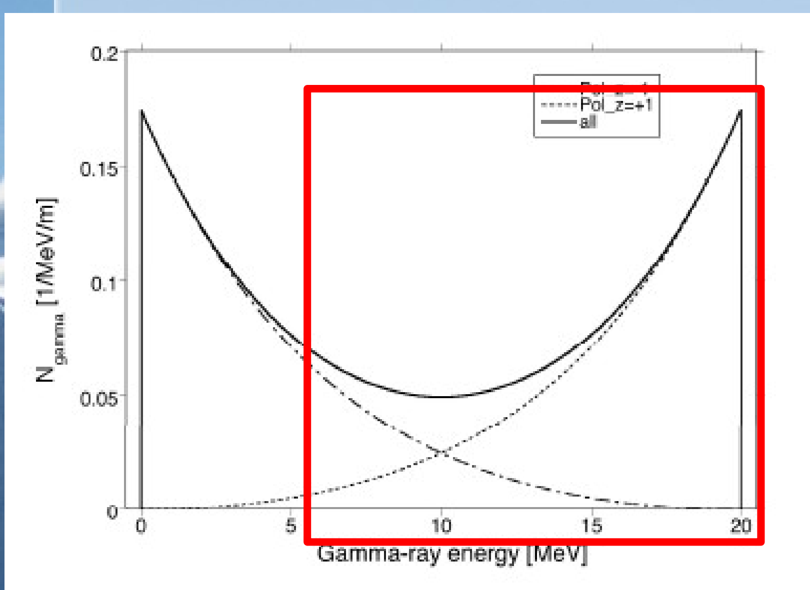


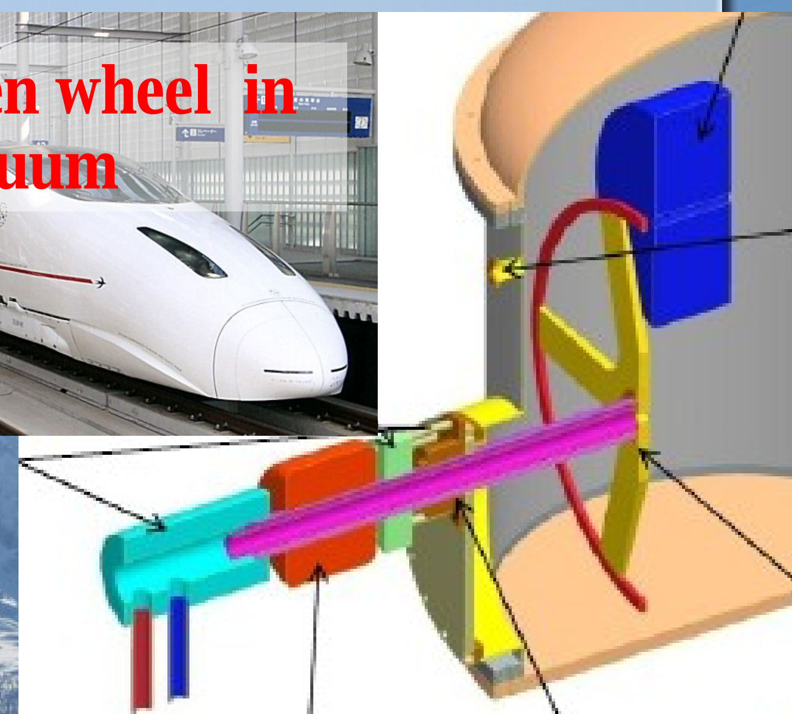


Undulator Positron Source

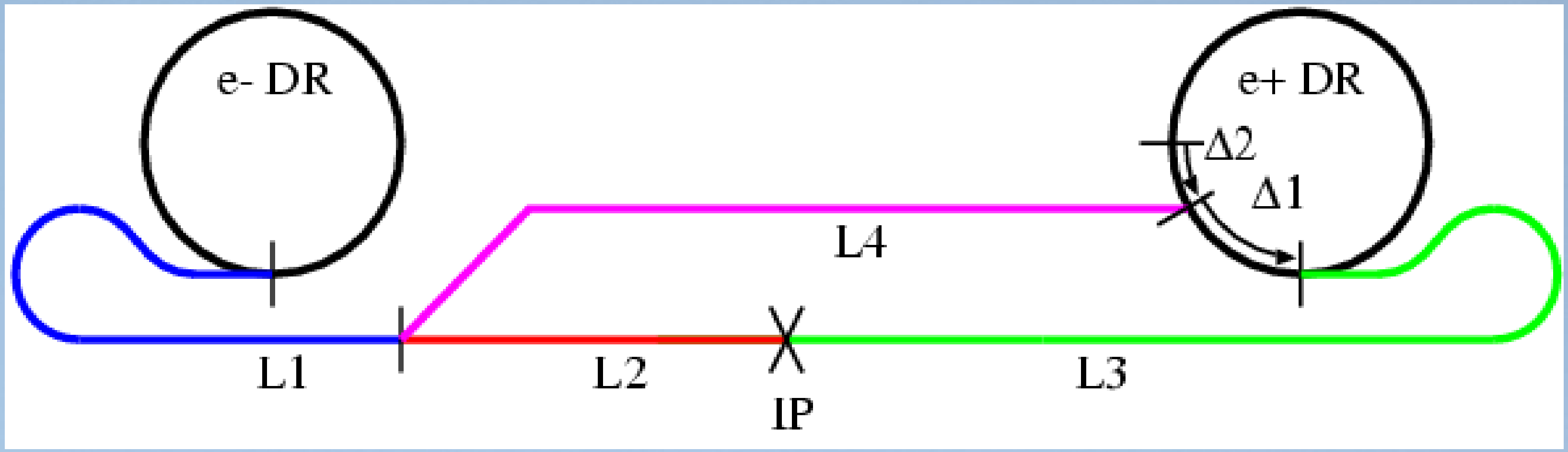
Pros and Cons

- 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.





Path Length Condition



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

$$For\ collision: L_1 + L_2 = \Delta_1 + \Delta_2 + L_{3,}$$

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

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

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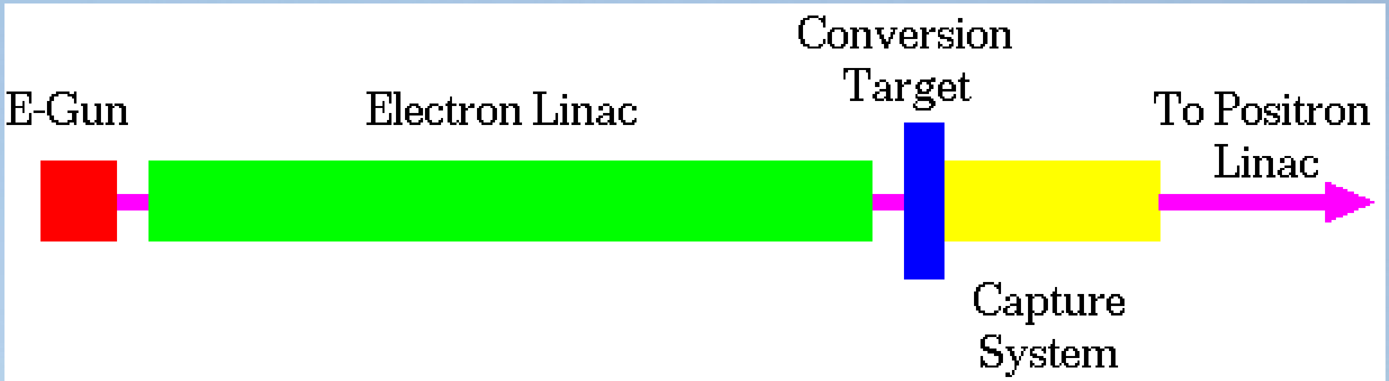
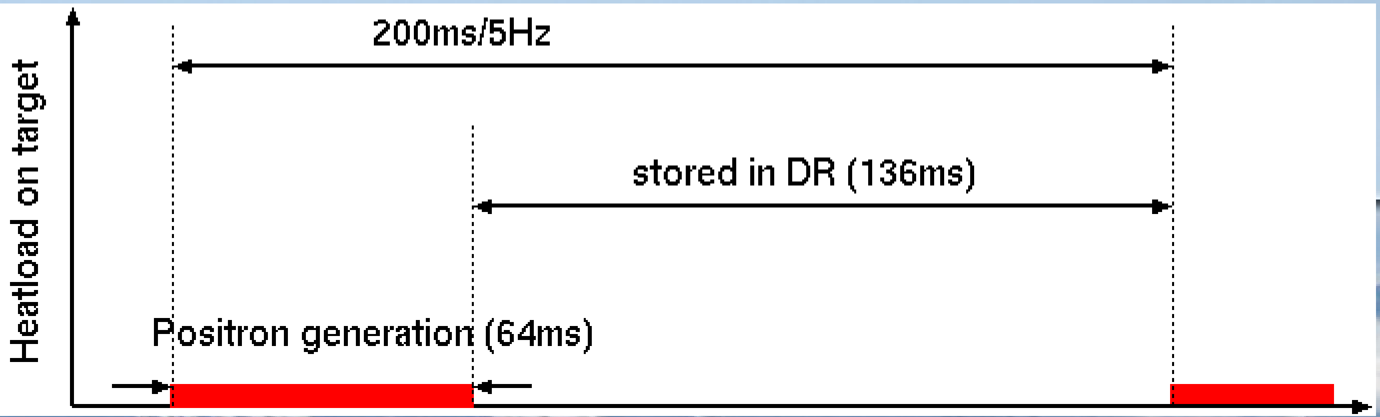
300Hz Conventional Positron Source

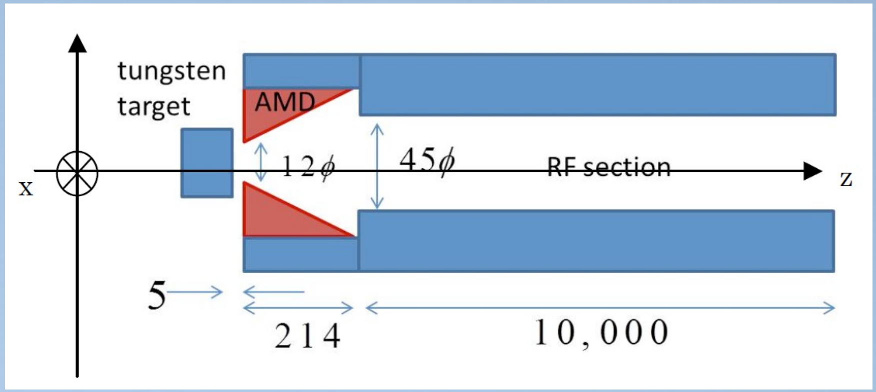
- Several GeV e- beam on W-Re target.
- By manipurating the beam structure (64ms pulses), heat load on the production target is manegeable. It could be 5 m/s.

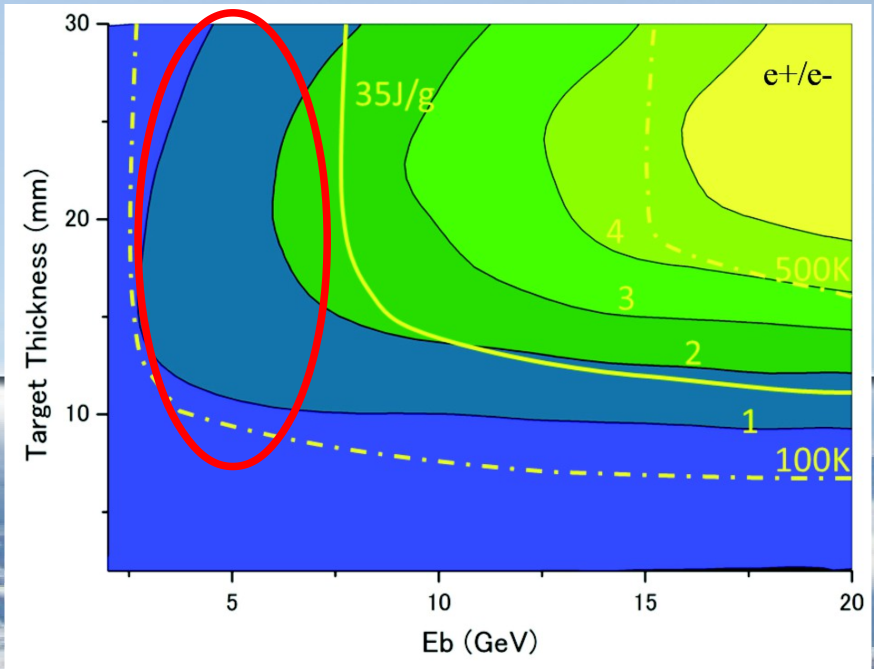




300Hz Conventional Positron Source

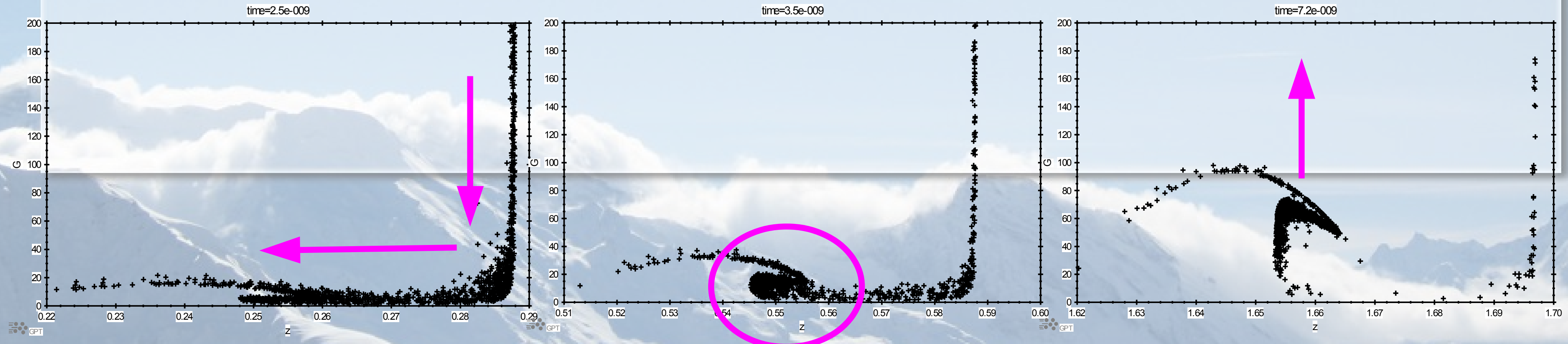
- Several GeV drive beam.
- Several X_0 conversion target.
- AMD(Adiabativ Matching Device) for p_t compenstaion; B_0~7.0T.
- S-band or L-band Standing wave linac for capture. 25MeV/m.
- 6GeV, 15mm (W) target, 4mm rms beam size as a working assumptions.





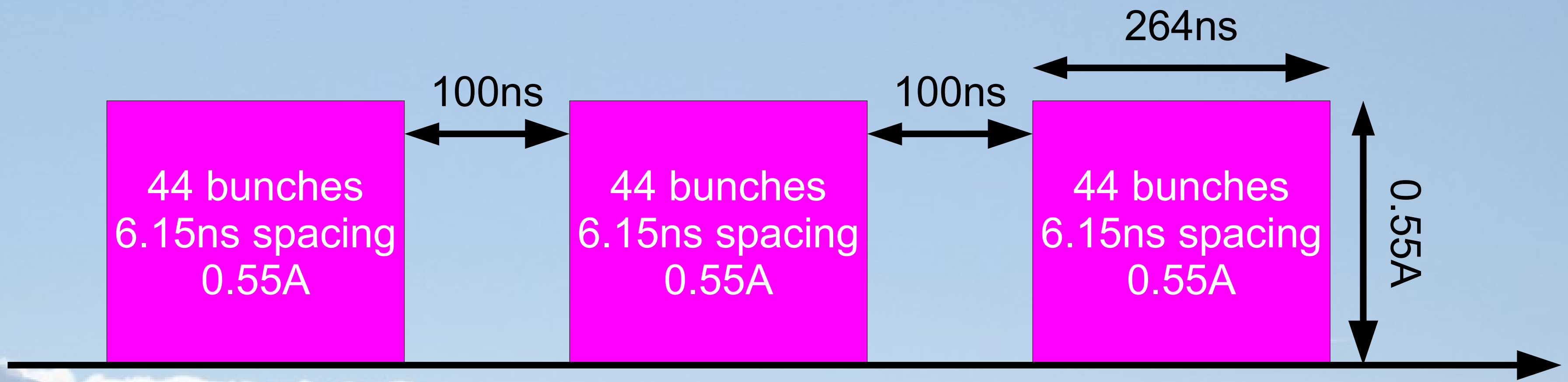
Decceleration Capture

- The positron peak is on deceleration phase.
- These positrons are slipped down to the acceleration phase where these positrons are captured.
- Slight enhancement on the capture efficienty, and less longitudinal emittance (z-d).



Pulse Structure and Beamloading

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



Beamloading Compensation by AM

- Beamloading compensation by AM (Amplitude Modulation) is considered.
- By solving RF enevelope giving a flat acceleration for the triplet, the acceleration field with the beamloading becomes flat.

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 beamloading, 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

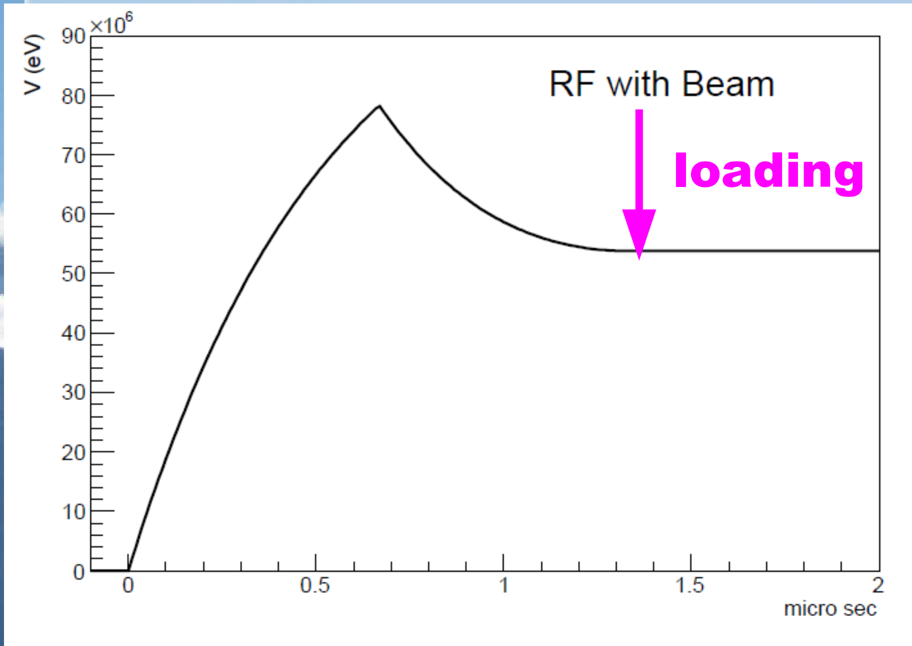
Beamloading Compensation by AM

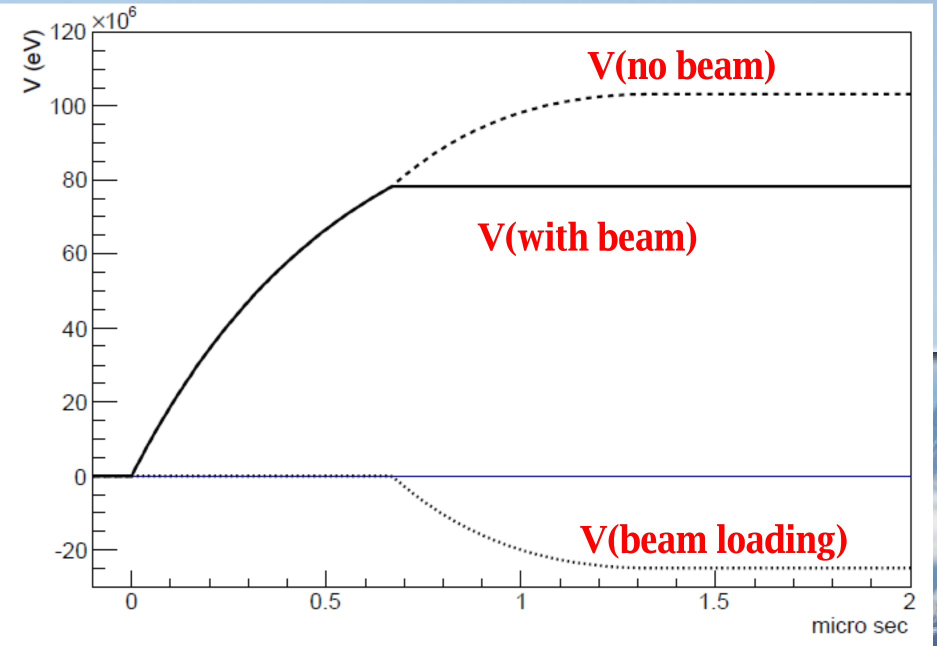
Acceleration voltage by AM RF ($E_0 + E_1 + E_2$),

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

Solution for the flat acceleration

$$E_1 = \frac{r_0 I_0}{2}(1-e^{-2\tau}),$$
$$E_2 = \frac{r_0 I_0}{2}\frac{\omega}{Q}e^{-2\tau},$$

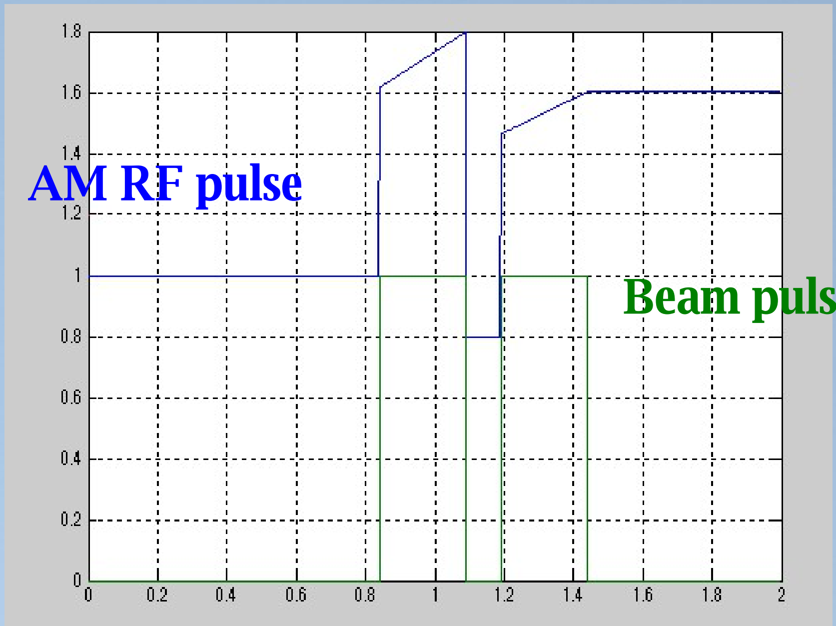


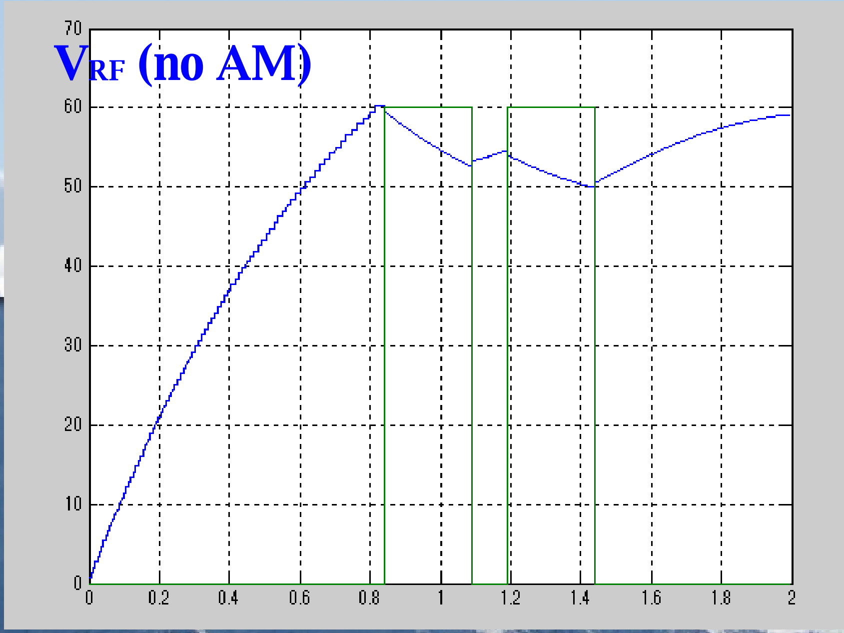


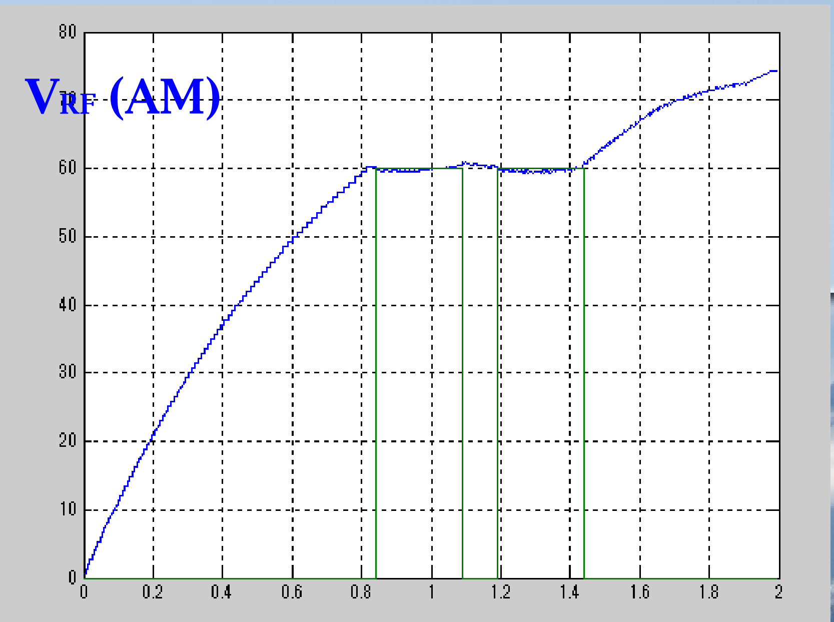
Multi-Pulse Acceleration

M. Satoh

- Same method can be extended to the multi-pulse case.
- AM should be applied to not only on the pulse head, but also pulse interval;







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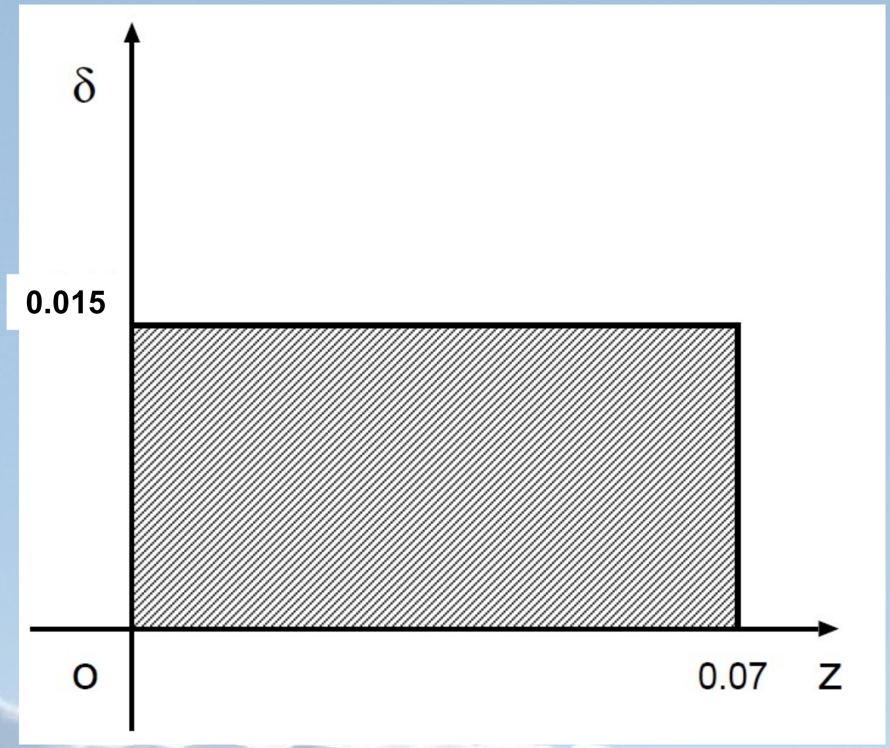
Positron Capture Simulation

- By assuming the beamloading compenstaion, any loading effect is not involved.
- e+ distribution was made by GEANT4.
- Tracking simulation in the injector section (<250MeV) by GPT; AMD positron capture (B_0~7.0T) followed by solenoid focusing section (0.5T) with S-band Acceleration tube (25MeV/m).
- Booster linac and EC (Energy Compressor) is treated as linear transformation.

DR acceptance



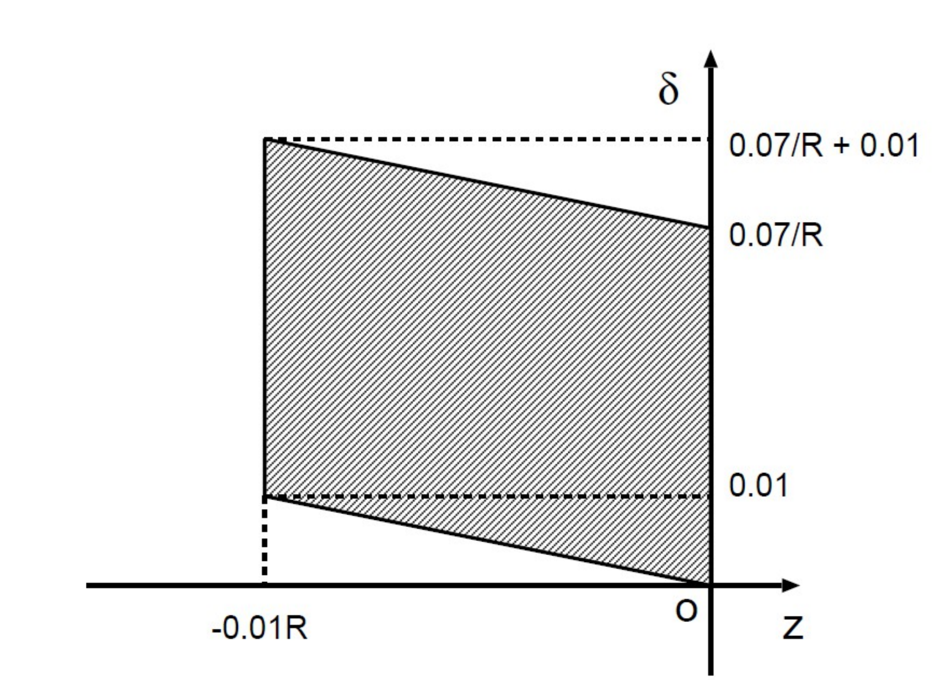
- DR acceptance is
  - $\gamma A_x + \gamma A_y < 0.07$m
  - dE<1.5%, dz<0.07m (FW)
- By considering RF acceleration in S or L-band, wider dE is desirable even with less dz.

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

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

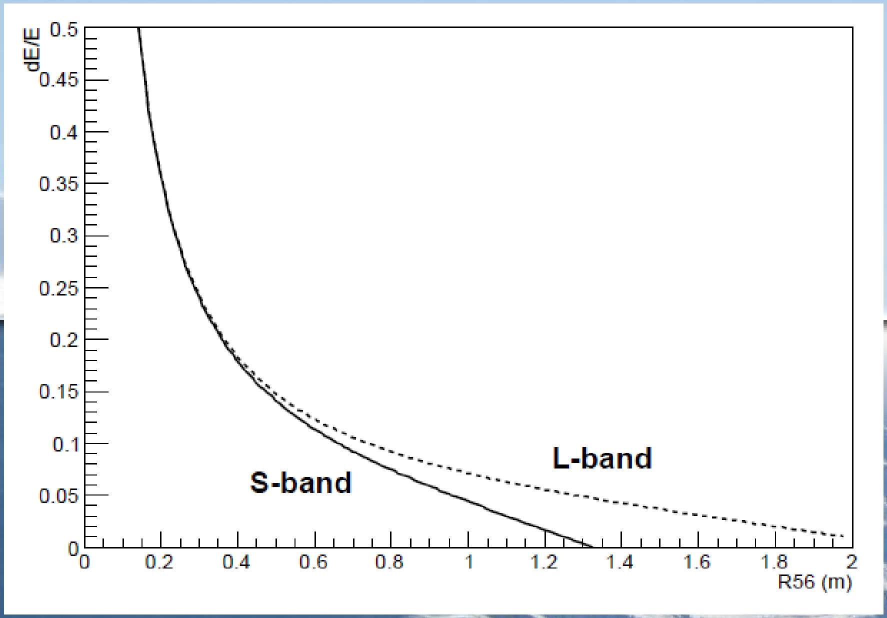
dE by RF

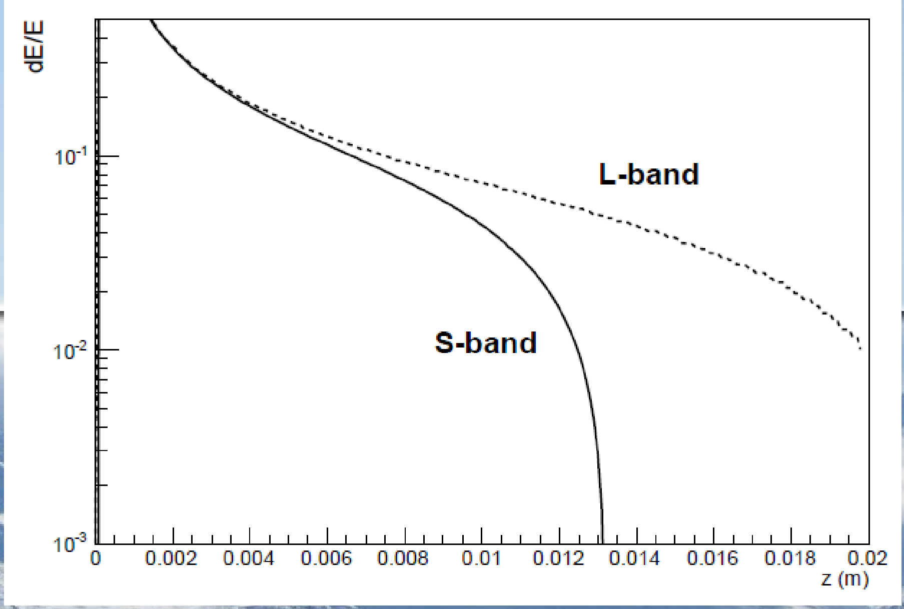
dE by Capture

dE Acc. with EC

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

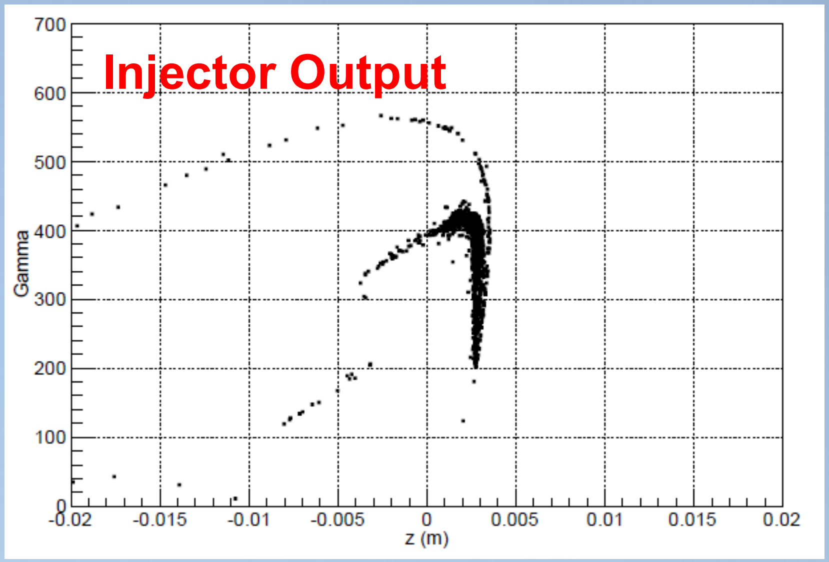
f shows the allowed δ_{inj}
R_{56}=1m is likely to be OK.

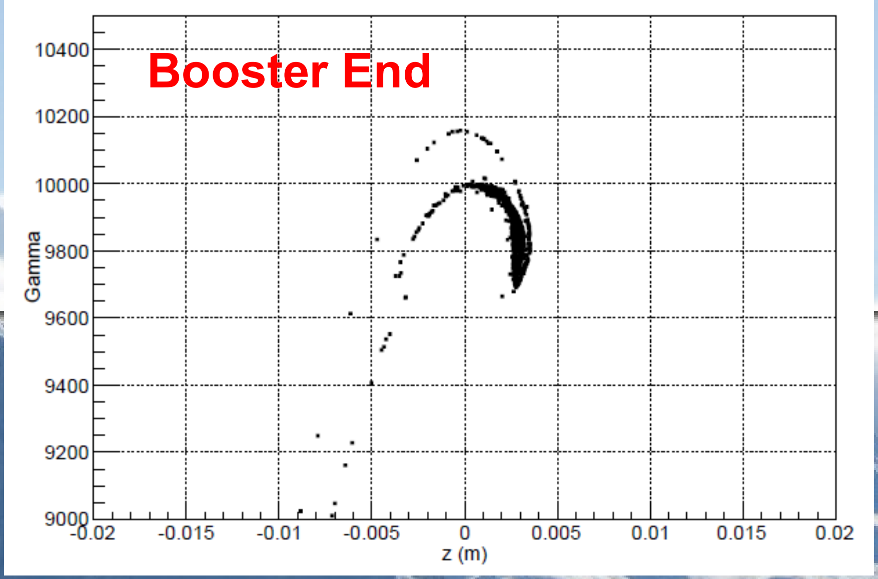


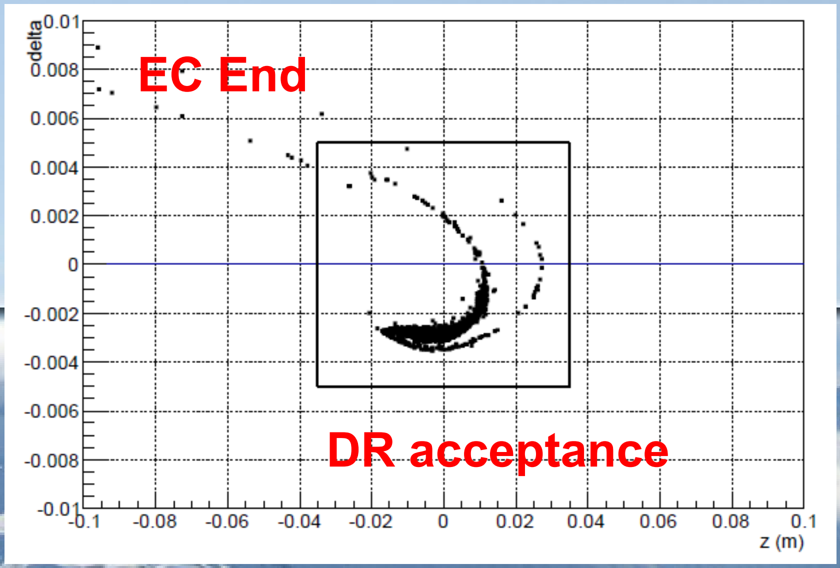


δ-z phase-space

- 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.



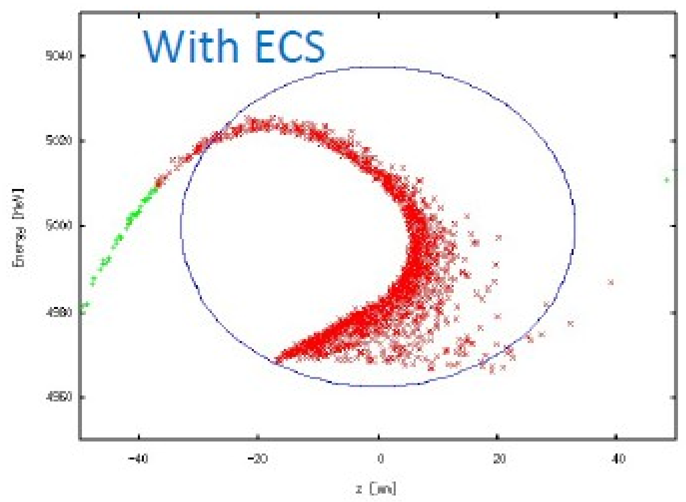




More Smart Simulation

- Full simulation with SAD.
- L-band Acc, transverse conditions.
- Y(e+/e-) is 1.5, but some parameters are extreme.
  - Bsol =2.5 T
  - Eacc = 40 MV/m
- Need more optimization for reasoable parameters.

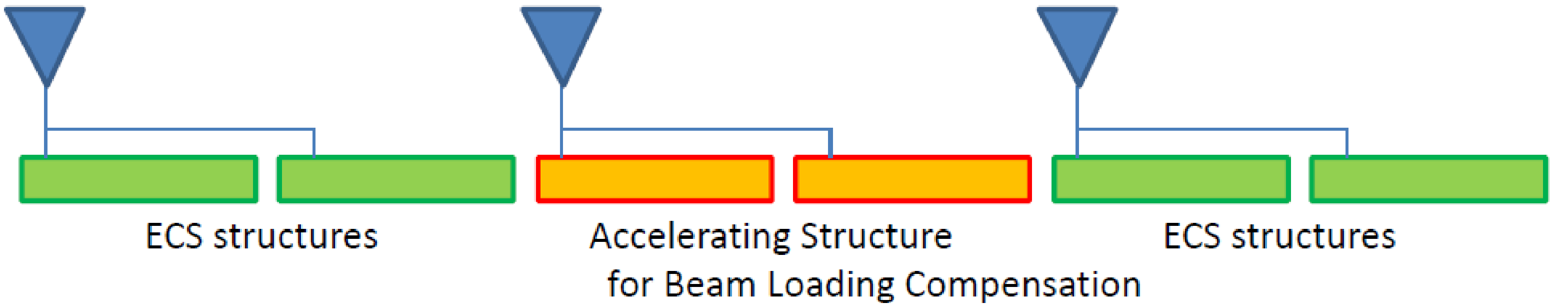
T. Okugi



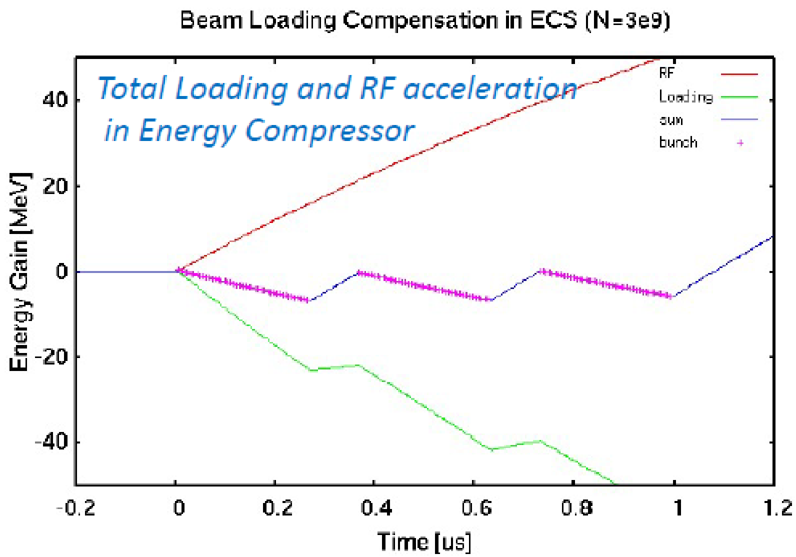
Location	Efficiency
Injection	3.957
After Booster	1.678
After ECS	1.604
Long. Cut	1.551
Long. & Trans. Cut	1.482

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

Conclusion

- Linear colliders are only solutions for next e+ e- collder.
- ILC positron source based on the conventional method is considered. It is feasible from the project management point of view.
- By manipulating the pulse structure, possible target damage is much suppressed.
- Beamloading compensation for the triplet pulse acceleration is likely to be promissing.
- EC is essential to make a good matching to DR.
- 1.5 e+/e- yield is required in the design criterion. Need further optimization to fulfill, but we are not so far from our goal.