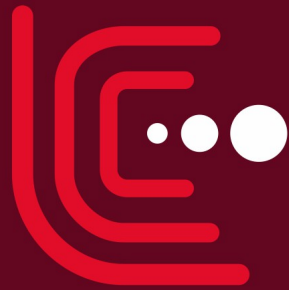


A Positron Capture Simulation for the E-driven ILC Positron Source



LINEAR COLLIDER COLLABORATION

Designing the world's next great particle accelerator

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Introduction

- Electron driven ILC Positron Source is considered to be a technical backup of the undulator ILC Positron source.
- It is designed based on NC accelerators operated in 300Hz.
- In the first simulation done by T. Omori, T. Tahakashi, et al.
 - Positron generation was simulated with GEANT4.
 - The positron capture is evaluated only with the capture linac up to 250 MeV.
 - Constant gradient 20MV/m is assumed and the beam-loading effect is not considered at all.



- Second simulation was done by Y. Seimiya, M. Kuriki, et al.
 - It was a start to end simulation including Chicane, booster, ECS, etc.
 - The lattice for each sections was designed.
 - The gradient is constant and the beam loading is not considered at all.
 - In the capture Linac (up to 250 MeV), SW L-band ($2a=40\text{mm}$, $E_0=25\text{MV/m}$) has been assumed.
- The capture efficiency is re-evaluated assuming a realistic and conservative RF configuration including the beam loading effect.



The Second Simulation

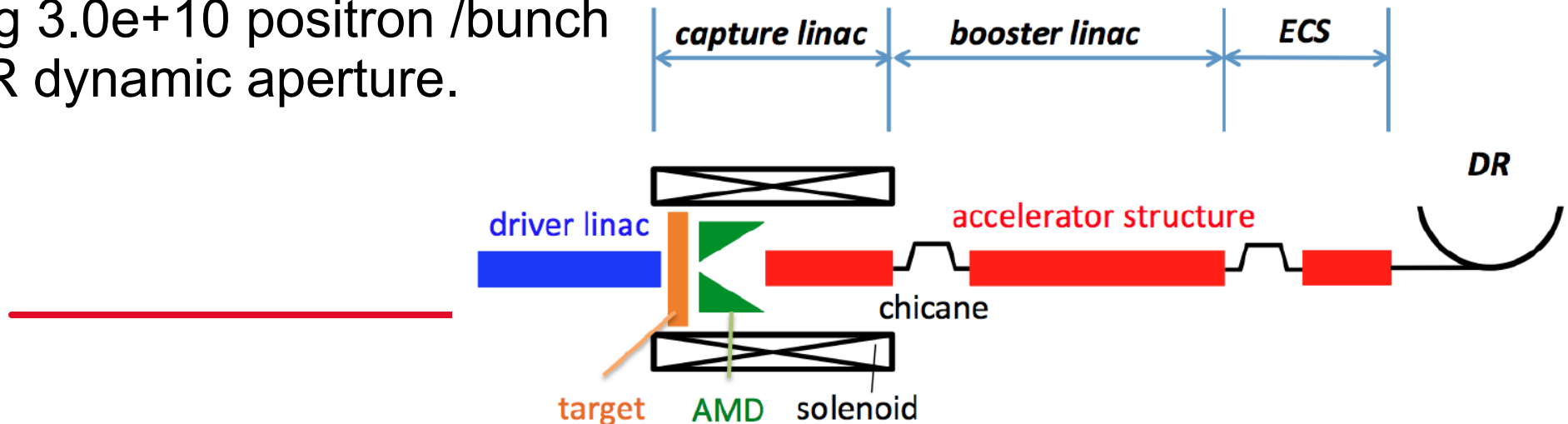
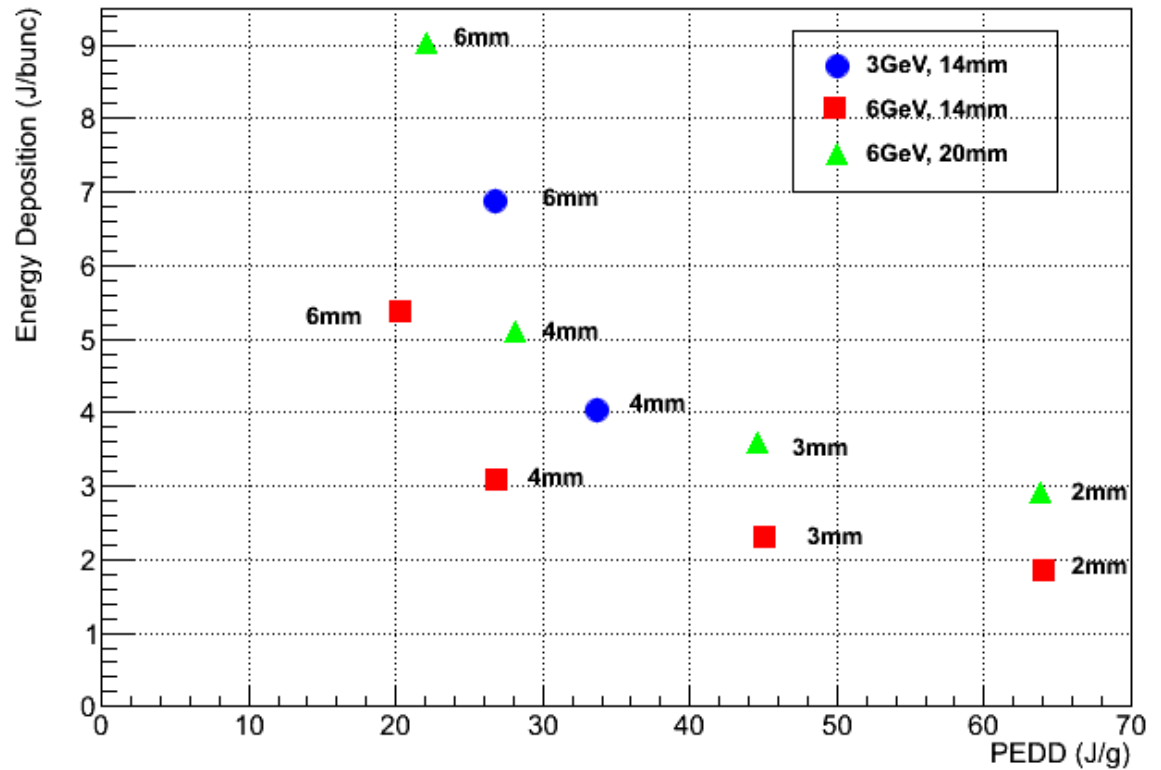
DR Acceptance

$$\left(\frac{z}{0.035}\right)^2 + \left(\frac{\delta}{0.0075}\right)^2 < 1$$

$$\gamma A_x + \gamma A_y < 0.07$$

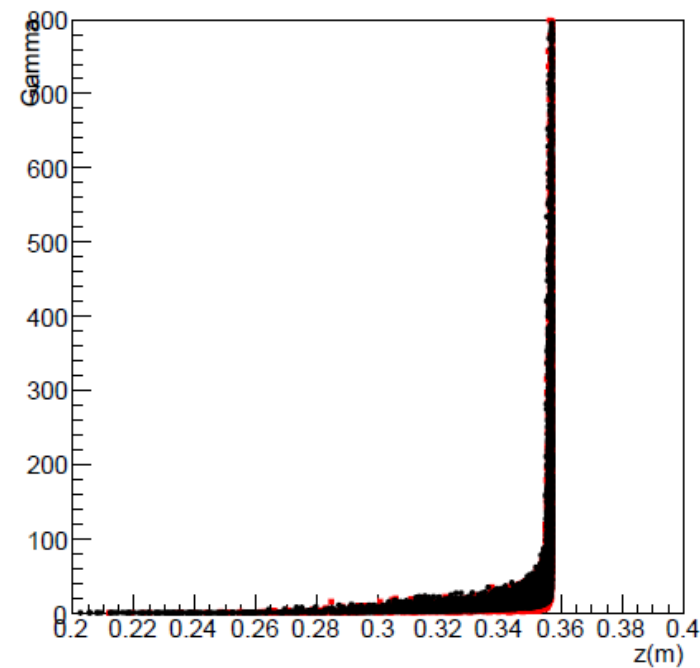
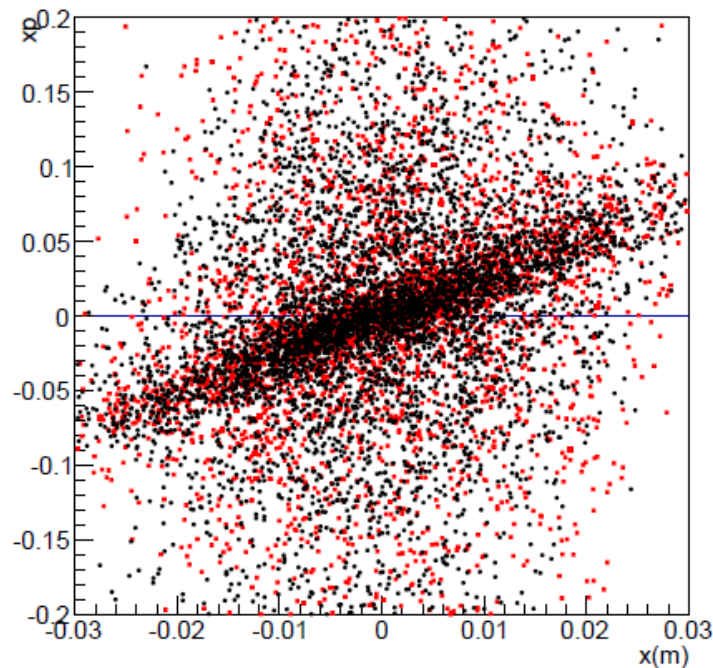
The typical yield was 1.25.

Electron intensity is normalized giving 3.0×10^{10} positron /bunch
In DR dynamic aperture.



The Simulation

- The simulation was performed with GPT (particle tracking by PULSAR physics).
- Input particle distribution was made by GEANT 4 with 1000 incident electrons on the target.
- Both electrons and positron are imported to the simulation.





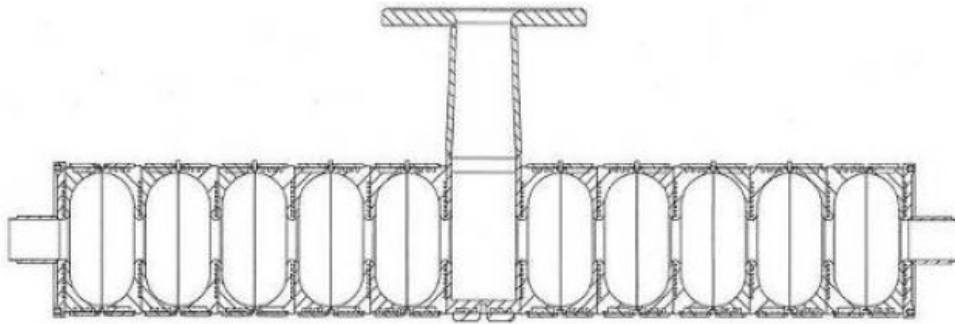
- The booster and ECS were simulated with simple transformation.
- Particles hitting physical aperture were removed from the simulation.
- The yield is evaluated for particles arrived at the ECS exit with the DR acceptance.

Parameter	Value	Unit
Drive Beam Energy	6.0	GeV
Target material	W-Re	
Target thicknesss	14	mm
Beam Size (rms)	4.0	mm
AMD peak field	5.0	T
R_{AMD} (smallest aperture of AMD, 2a)	16.0	mm
Average gradient (MV/m)	8.4 – 22	MV/m
Accelerator Aperture (2a)	60	mm
Solenoid	0.5	T
Booster	Hybrid (L-band + S-band)	



L-band SW structure

- The L-band SW structure designed by J. Wang (SLAC) for the undulator capture section is used.
- 2 of 1.27 m 11 cells L-band TW driven by 50 MW RF unit (10% loss by WG).
- It has a large aperture ($2a=60\text{mm}$) which is optimized for the positron capture.



Structure Type	Simple π Mode
Cell Number	11
Aperture $2a$	60 mm
Q	29700
Shunt impedance r	34.3 $\text{M}\Omega/\text{m}$
E_0 (8.6 MW input)	15.2 MV/m



Beam Loading Compensation

- The beam-loading decreases the accelerator gradient which is proportional to the beam current.
- It is quite serious in the capture section because both electron and positron contribute to the loading.
- Static beam-loading : the field is decreased. We need more input power to recover it, otherwise, we have to be patient with the low-field.
- Transient beam-loading : the field is gradually decreased by the effect during the pulse. It causes the energy spread.

- The field in SW accelerator

$$V(t) = \frac{2\sqrt{\beta P_0 r L}}{1+\beta} \left(1 - e^{-\frac{t}{T_0}}\right) - \frac{rIL}{1+\beta} \left(1 - e^{-\frac{t-t_b}{T_0}}\right)$$

RF

Beam Loading

$$T_0 = \frac{2Q}{\omega(1+\beta)}$$

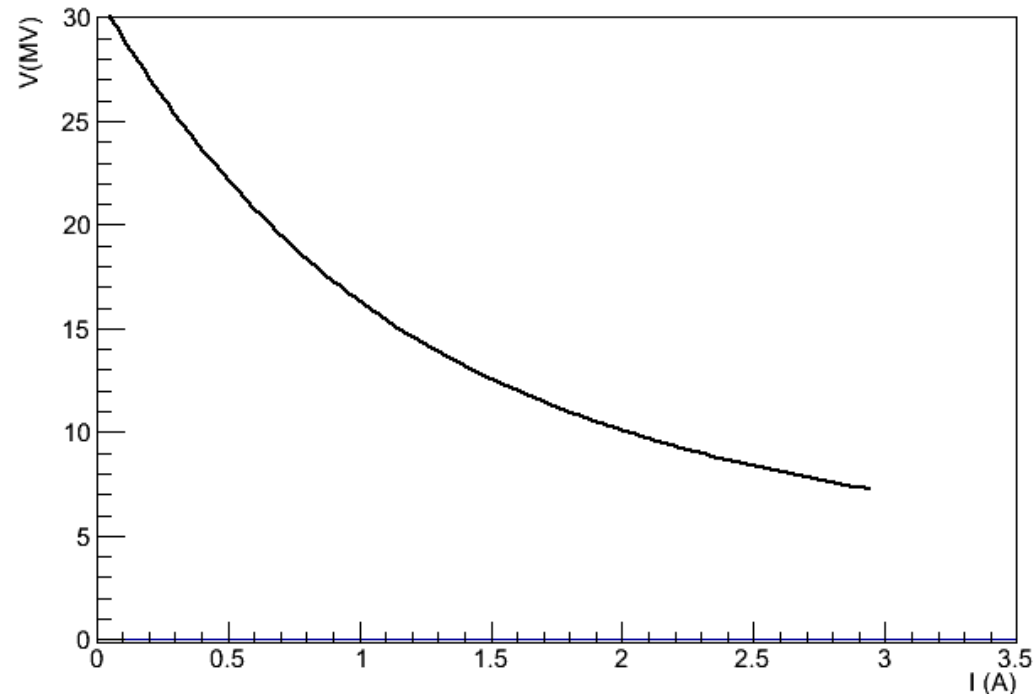
- The voltage becomes constant if

$$t_b = -T_0 \ln \left(\frac{I}{2} \sqrt{\frac{rL}{\beta P_0}} \right)$$

$$V_0 = \frac{2\sqrt{\beta P_0 r L}}{1+\beta} \left(1 - \frac{I}{2} \sqrt{\frac{rL}{\beta P_0}} \right)$$



- The field gradient (E MV/m) is obtained by assuming
 - $L=1.27$ m (11 cells, L-band SW)
 - $R=34 \times 10^6$ Ohm/m
 - $P_0=22.5$ MW (50MW at klystron, 5MW wave guide loss)
- The gradient is 30 MV/tube at zero current, but it becomes less than 10 MV/tube at 2.0 A beam loading.





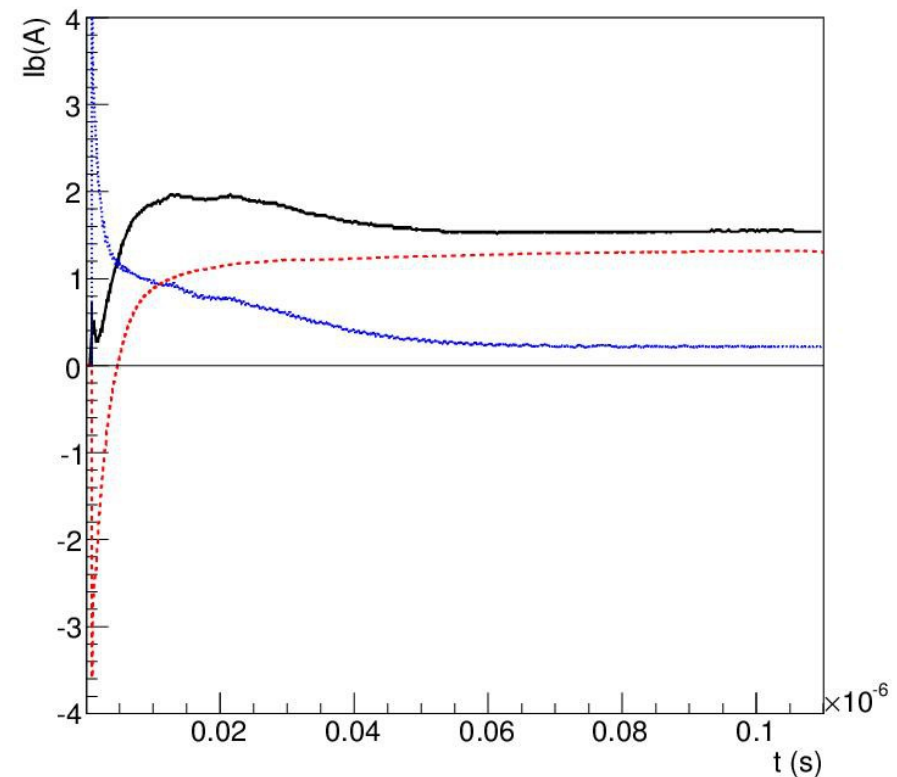
Beam Loading Current

- Beam loading current is not same as the beam current.

$$I_B = \frac{1}{t_b} \sum q_i$$

$$I_{BL} = \frac{1}{t_b} \sum q_i \cos(\omega t_i - k z_i)$$

- For each cells, $I_{BL}(t)_i$ is calculated in the simulation.



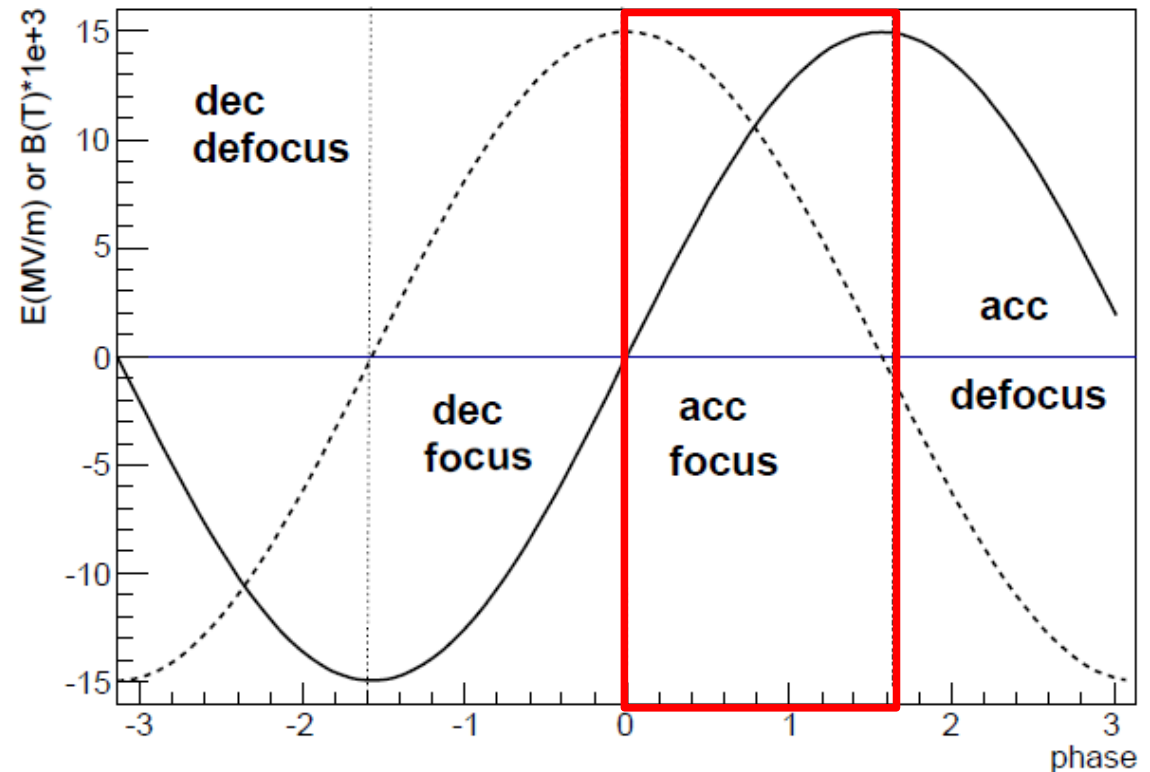
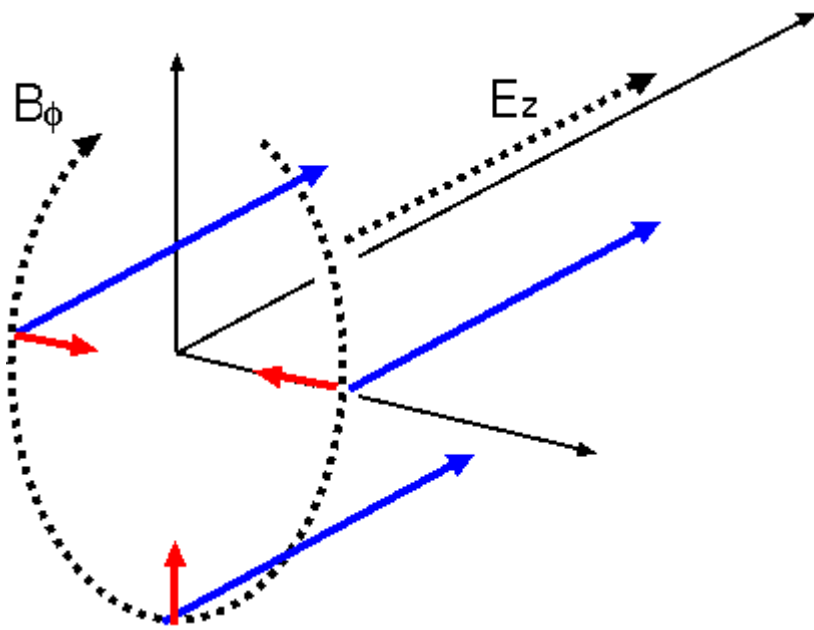
TM₀₁₀ mode

Acceleration and deceleration

Focusing and defocusing

$$E_z(t) = E_0 J_0 \left(\chi_{01} \frac{r}{b} \right) \sin(\omega t + \phi_0)$$

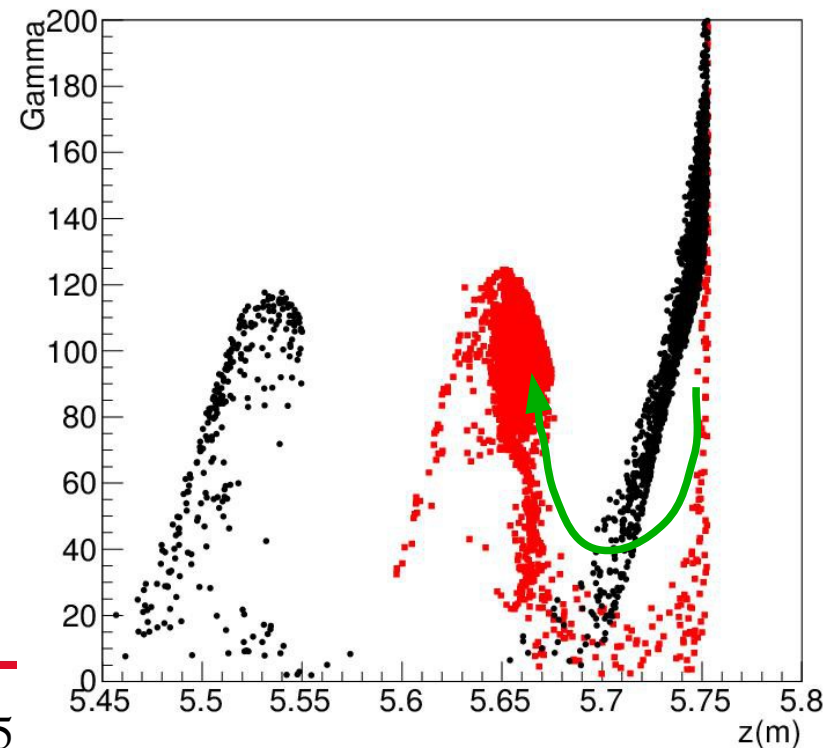
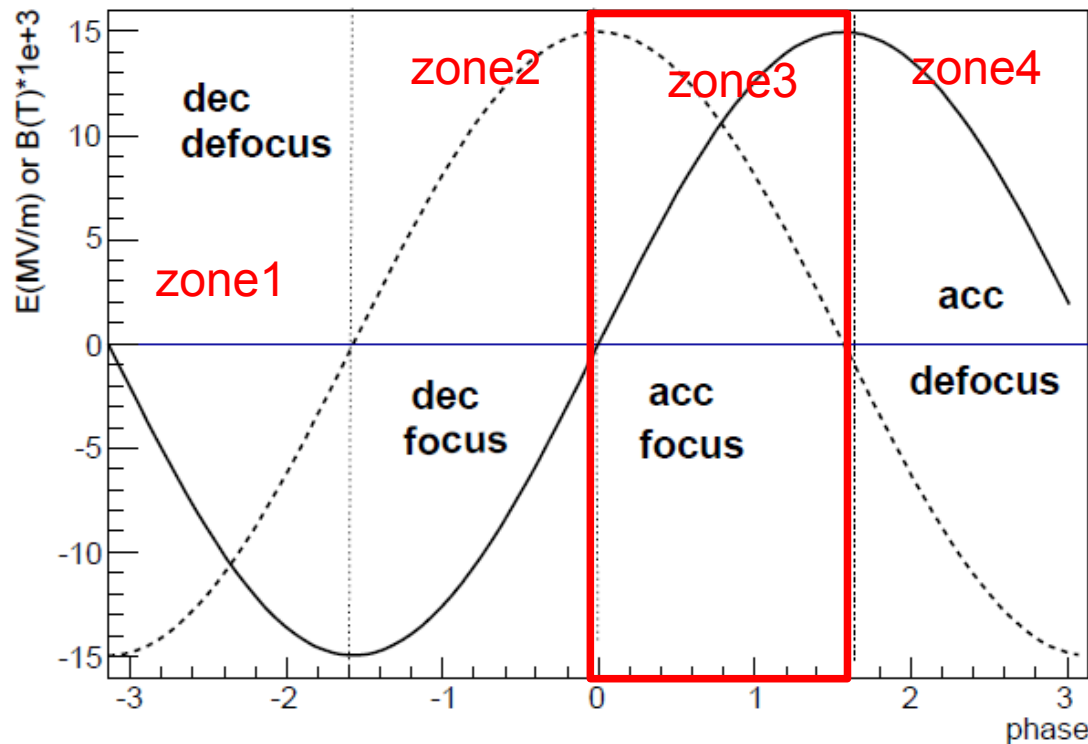
$$B_{\theta}(t) = \frac{E_0}{c} J_1 \left(\chi_{01} \frac{r}{b} \right) \cos(\omega t + \phi_0)$$





Capture Strategy

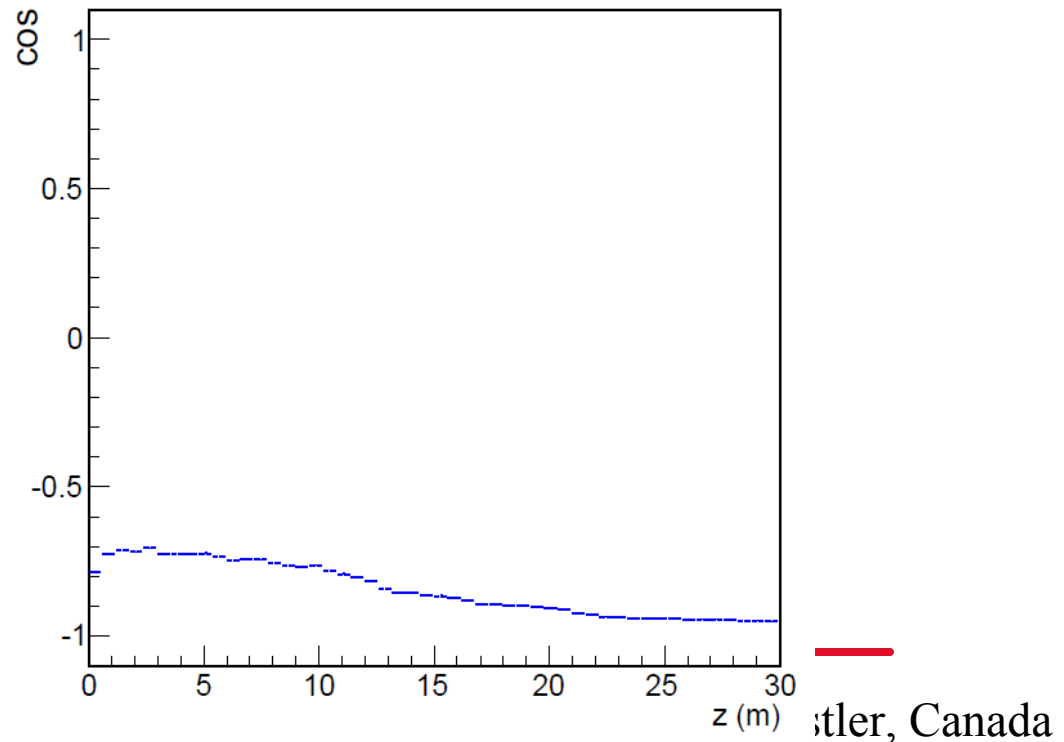
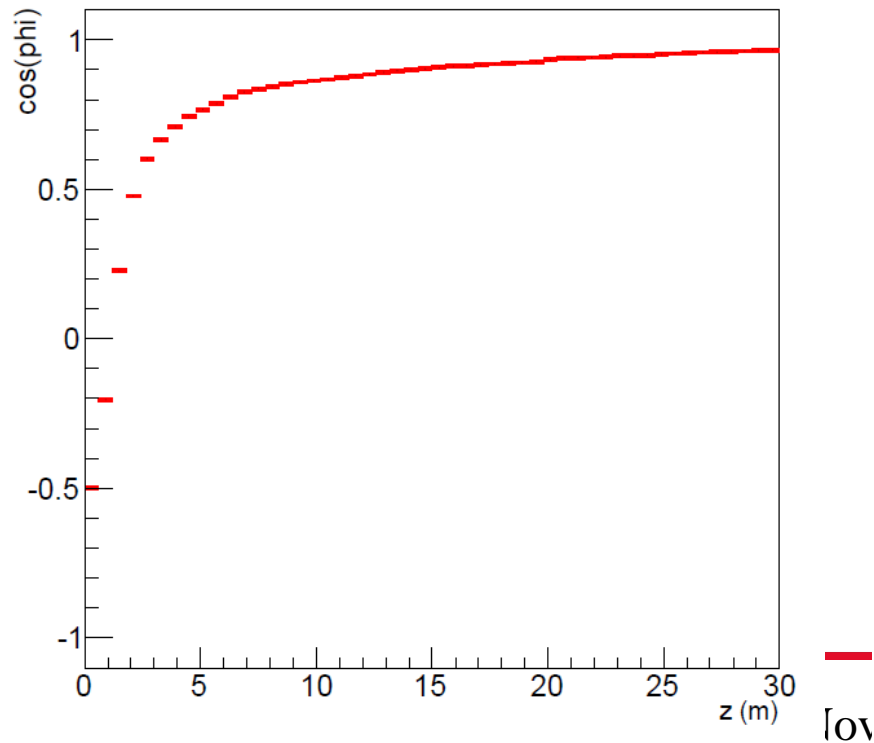
- Initial beam is placed at zone 2.
 - e+: dec. and focus.
 - e- : acc and defocus.
- Particles are slipped to zone 3 where
 - e+ : acc. and focus.
 - e- : dec. and defocus.
- e+ (e-) is continuously (de-) focused.





Particle Phase

- Positron is firstly in deceleration phase and slipped to the acceleration phase.
- Electron is firstly in acceleration phase and only who have small p_t and on high acc. phase are survived.



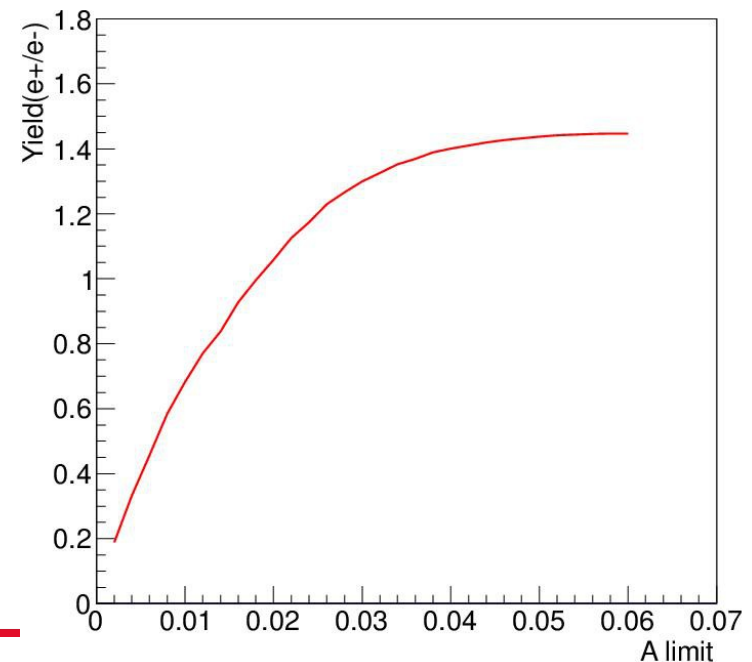
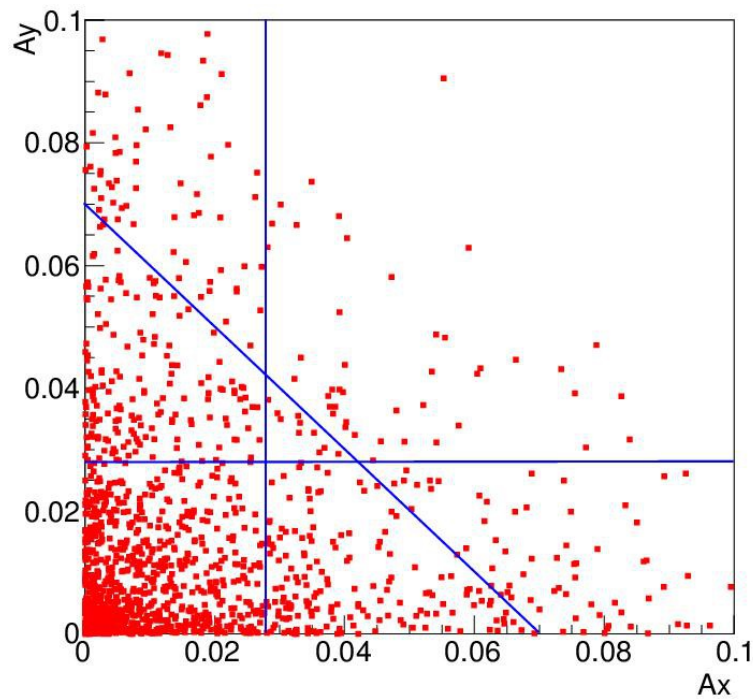


Booster

- Booster is simulated as energy enhancement with the following formula,

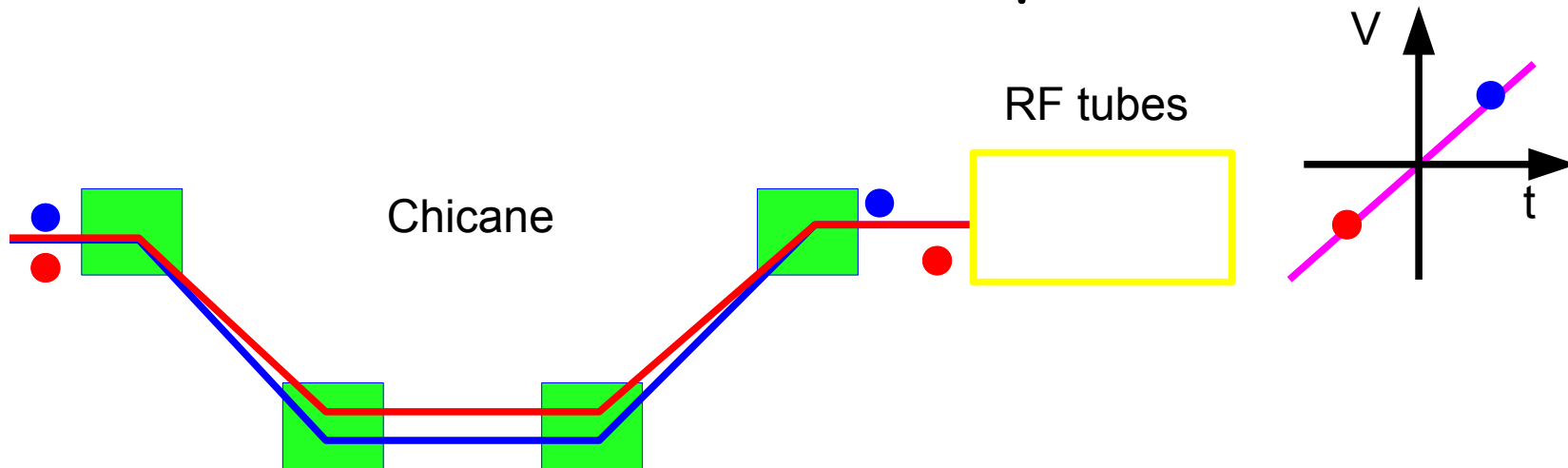
$$dE_i = eV_0 \cos(\phi_0 - k z_i)$$

- Particles with large actions (BA_x and BA_y) are removed. The threshold is determined to reproduce the tracking simulation done by Y. Seimiya.



Energy Compressor

- The booster linac consists from L-band and S-band RF accelerators.
- DR longitudinal acceptance ($\pm 35\text{mm}$ in z , $\pm 0.75\%$ in $\delta_{\pm/\pm}$) which are too wide in z and too narrow in $\delta_{\pm/\pm}$.
- Energy compressor makes a good matching to the acceptance.
- Energy Compressor consists from a dispersive section with a momentum compaction and RF tubes.





- Matrix representation: momentum compaction
RF cavity

$$M_d = \begin{pmatrix} 1 & R_{56} \\ 0 & 1 \end{pmatrix},$$

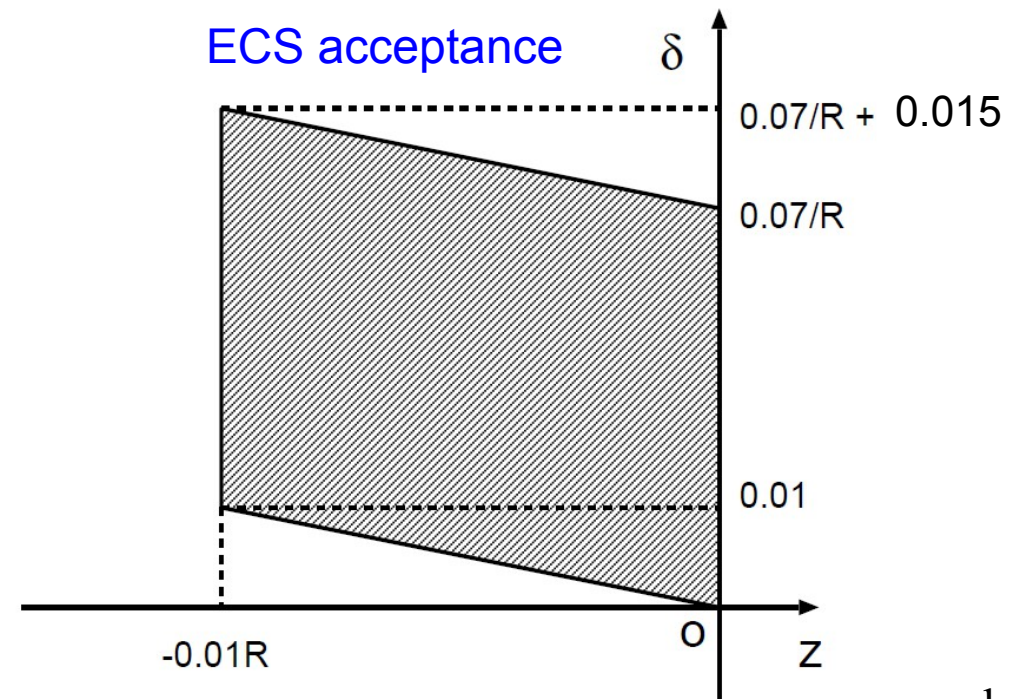
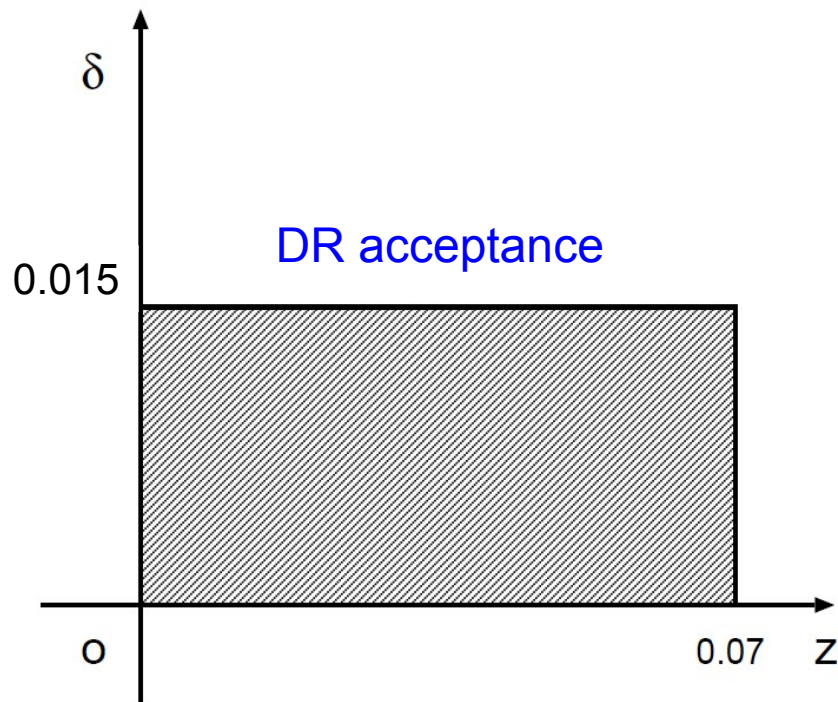
$$M_{RF} = \begin{pmatrix} 1 & 0 \\ R_{65} & 1 \end{pmatrix}.$$

- Transfer matrix of EC section
- With a matching condition,

$$M_{EC} = \begin{pmatrix} 1 & R_{56} \\ R_{65} & R_{56}R_{65} + 1 \end{pmatrix},$$

$$R_{56}R_{65} + 1 = 0$$

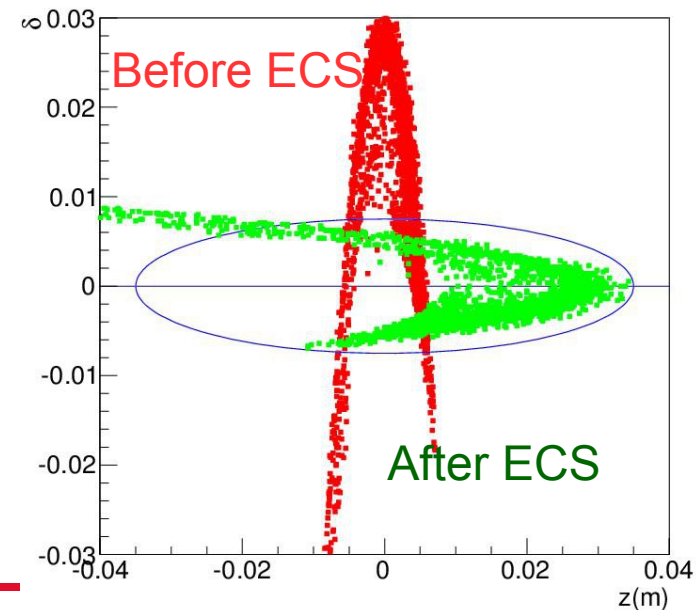
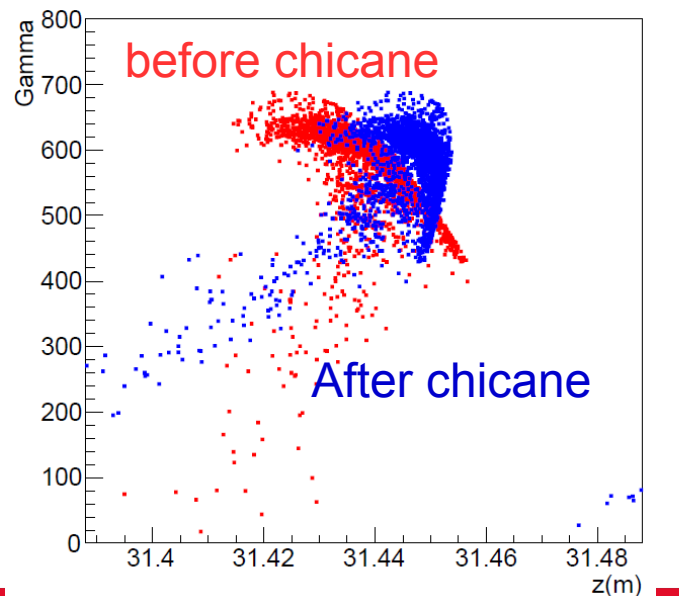
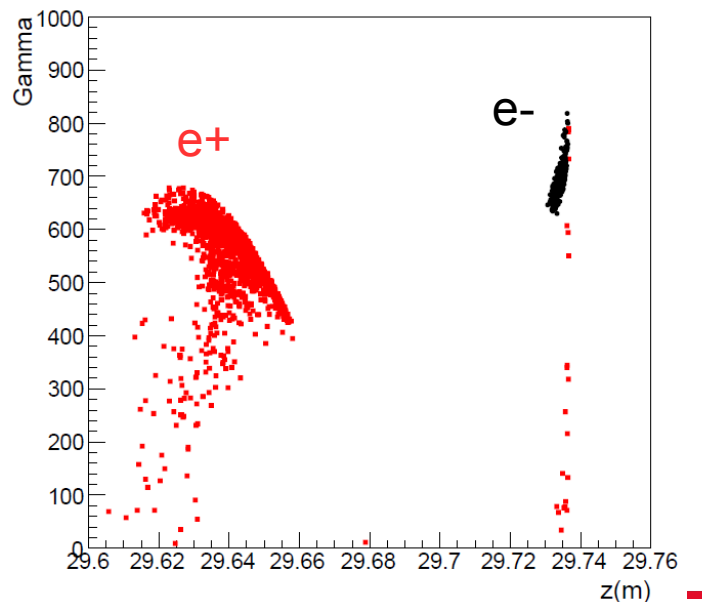
$$M_{EC} = \begin{pmatrix} 1 & R \\ -1/R & 0 \end{pmatrix},$$





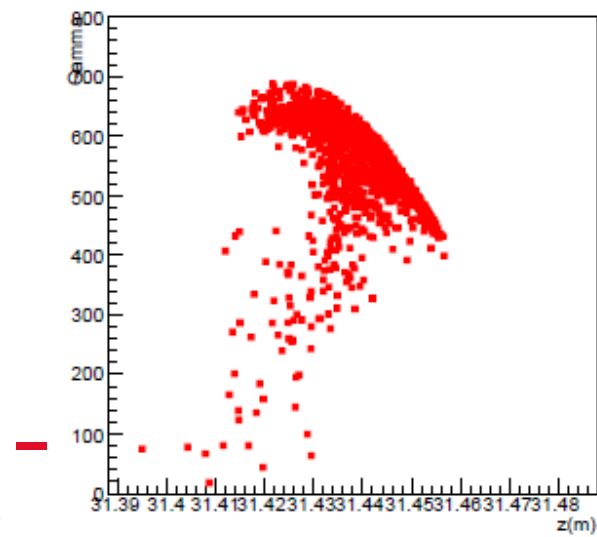
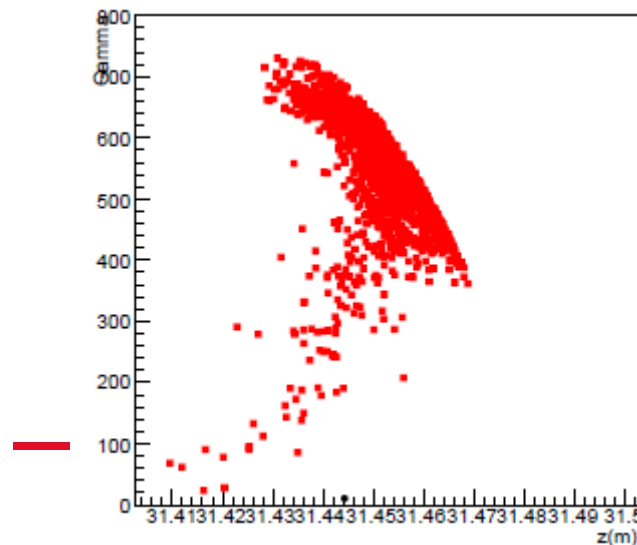
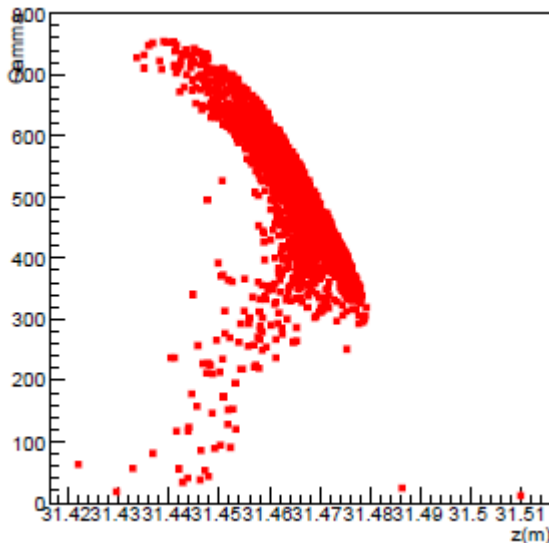
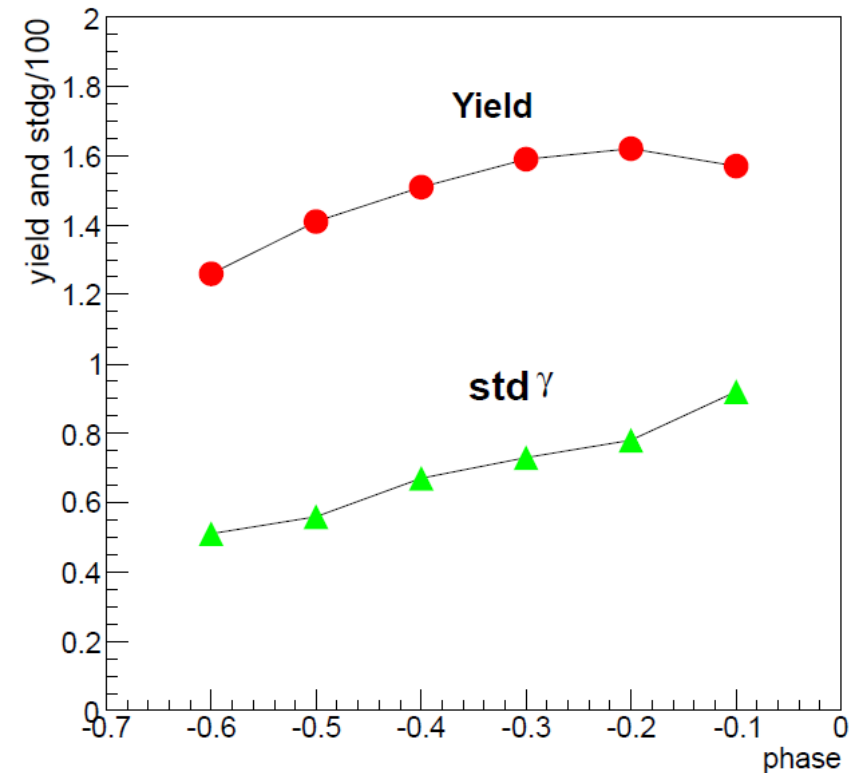
Particle Gymnastic

- Positron is captured at acc. and focusing phase, but with a large energy spread due to the low gradient.
- To suppress the energy spread induced by the booster RF which is dominant after the booster, the chicane is optimized.
- Finally, ECS improves much the yield.



Yield

- The yield is obtained as a function of the initial phase.
- The yield is maximized at some phase (-0.2 rad.).
- The energy spread after the capture is simply increased as phase increased.
- The yield is better than that by the high field (25 MV/m).
- The difference comes from the different aperture ($2a=40\text{mm}$).





Summary

- The positron yield is evaluated by assuming a realistic RF unit.
 - 45MW RF input to 2 of SW L-band tubes designed by J. Wang.
- The yield is better than the high-field case due to the large aperture ($2a=60\text{mm}$).
- Transverse motion in the booster and ECS is considered, but a tracking simulation is desirable to estimate exact yield.