A Design Study of the Electron-driven ILC Positron Source

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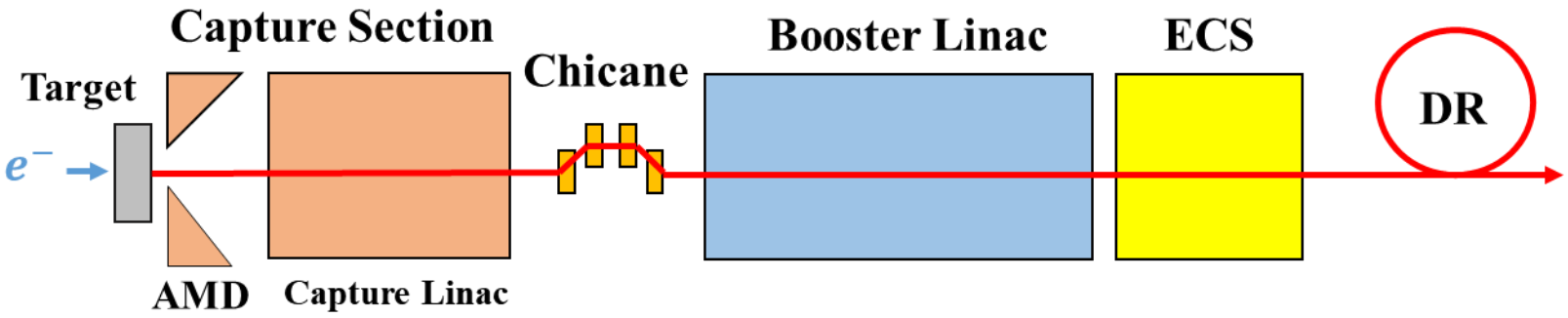
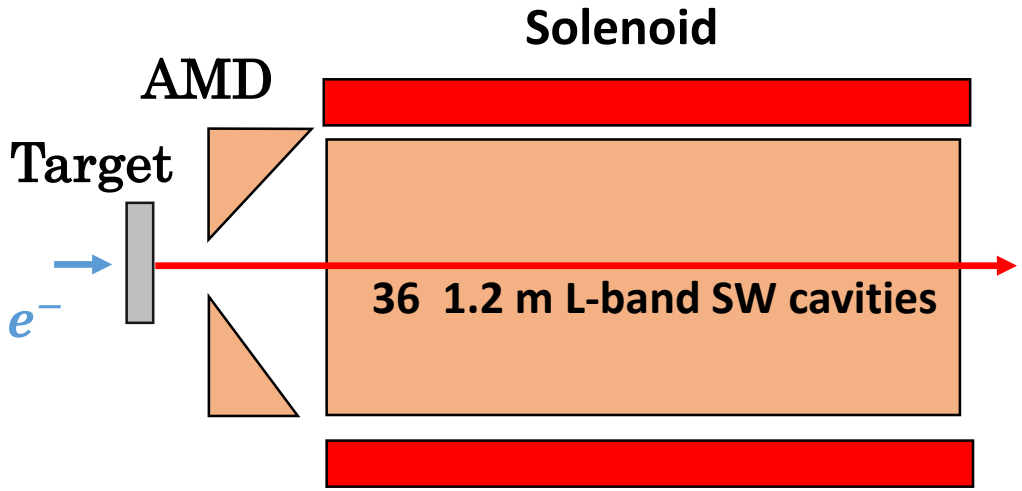
- Design of E-driven ILC positron source
- Simulation and Result
- Conclusion

Design and Criteria



- Positrons are generated by an electron drive beam.
- In Capture Section, positrons are captured and accelerated up to 250 MeV.
- Chicane removes electrons and limits the positron energy.
- Booster accelerates positrons up to 5 GeV.
- ECS (Energy Compressor Section) decreases the energy spread for better matching to DR acceptance.
- Positron in DR acceptance should be 4.8 [nC/bunch].

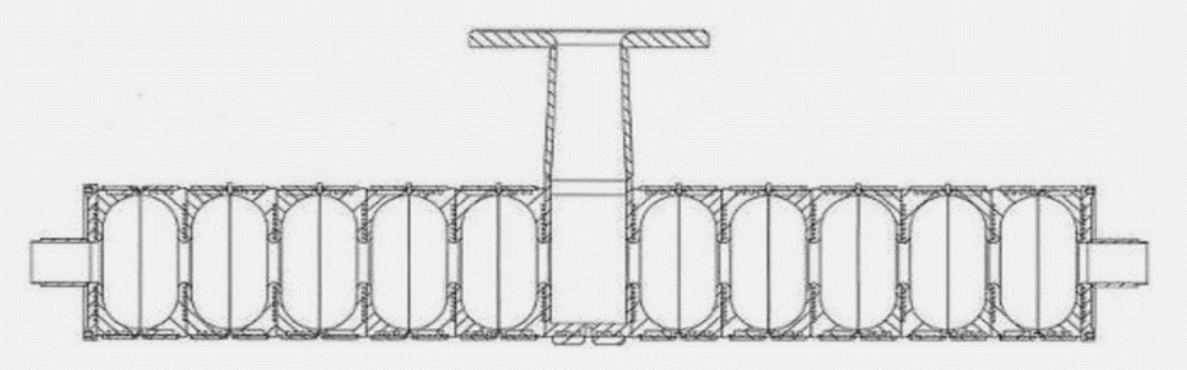
Electron Driver, Target, and Capture Section



Beam & Target	
Drive beam energy	3 GeV
Beam size	2.0 mm (RMS)
Target Material	W-Re (26%)
Target thickness	16 mm

AMD	
Length	100 mm
Aperture (2a)	16mm – 64mm
Peak B_z	5 T
Solenoid	
B_z	0.5 T

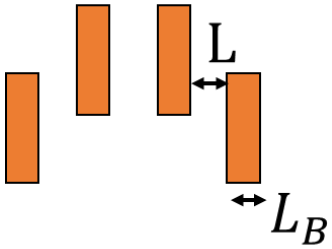
L-Band SW Cavity



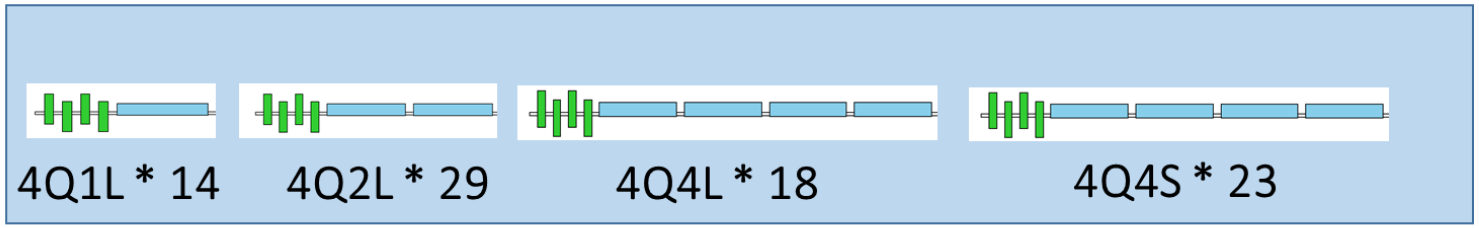
J. W. Wang, C. Adolphsen, V. Bharadwaj, G. Bowden, E. Jongewaard, Z. Li, R. Miller, J.C. Sheppard, SLAC-PUB-12412(2007)

Parameter	Value
Length	1.27 m
Cell Number	11
Aperture (2a)	60mm
Frequency	1.3 GHz (L-Band)
Types of RF	Standing wave

Chicane and Booster Linac



Chicane

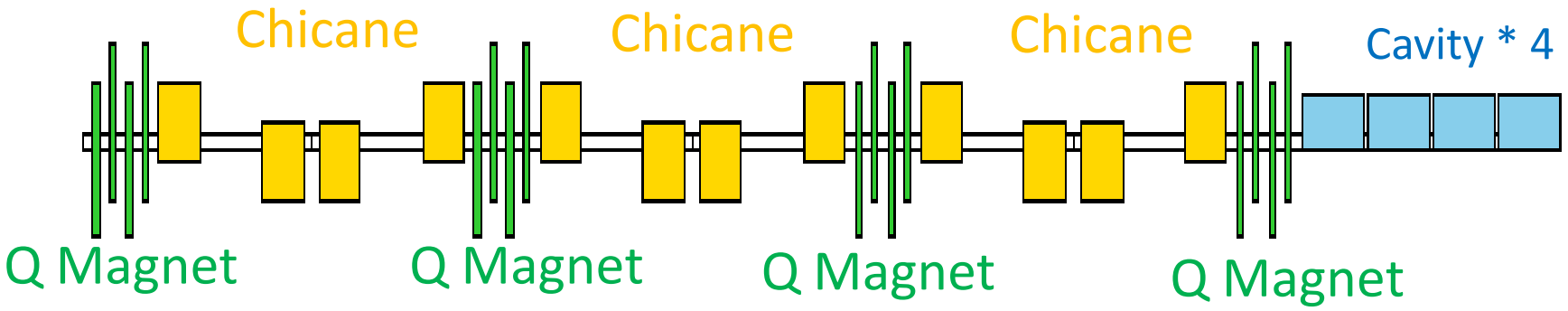


Booster Linac

Chicane	
Bending Magnet Length (L_B)	0.36 m
Distance Between Bending Magnet (L)	0.15 m
Magnetic Field	0.69 T
Beam Offset	0.145 m

	TW Acceleration Cavity	
	L-Band	S-Band
Length	2.0 m	1.959 m
Aperture (2a)	0.02 m	0.034 m
Frequency	1.3 GHz	2.6 GHz
Types of RF	Traveling wave	Traveling wave
Number of cavity	144	92
Shunt Impedance	47.2 MΩ/m	57.8 MΩ/m
Input Power	22.5 MW	36 MW

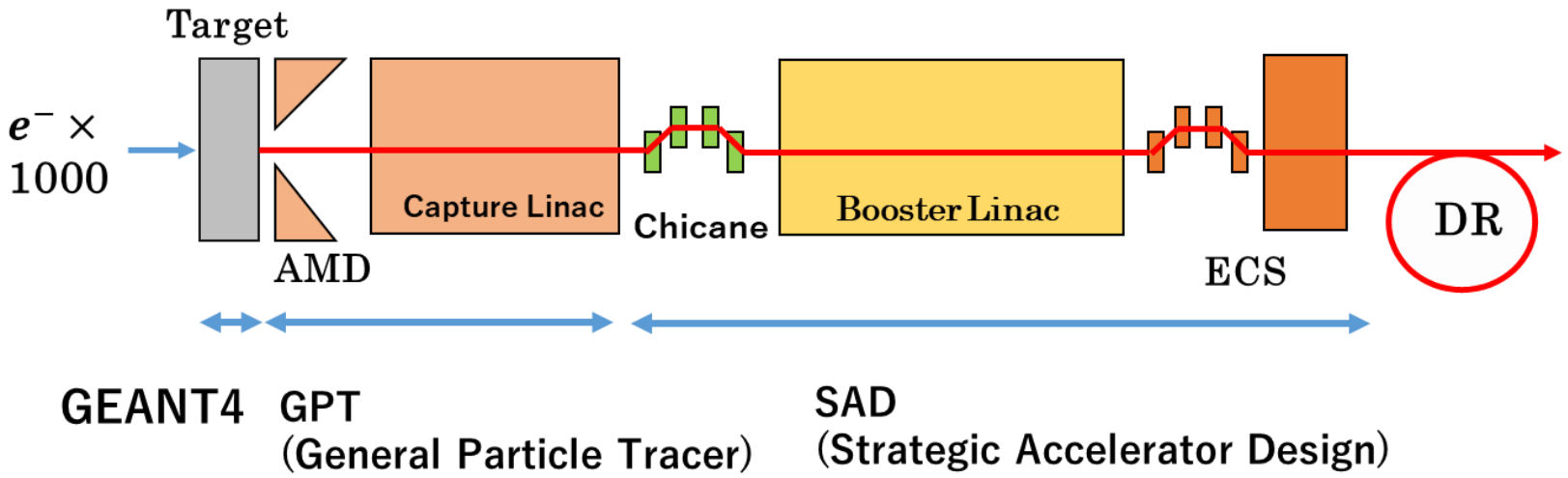
ECS



Chicane		Acceleration cavities	
Bending Magnet Length (L_B)	2 m	Length	3.0 m
Distance Between BM (L)	3.05 m	Aperture (2a)	34mm
Magnetic Field	10 T	Frequency	1.3 GHz (L-Band)
Number of Chicane	3	Number of cavities	4

R_{56} is 1.27 m .

Simulation Method



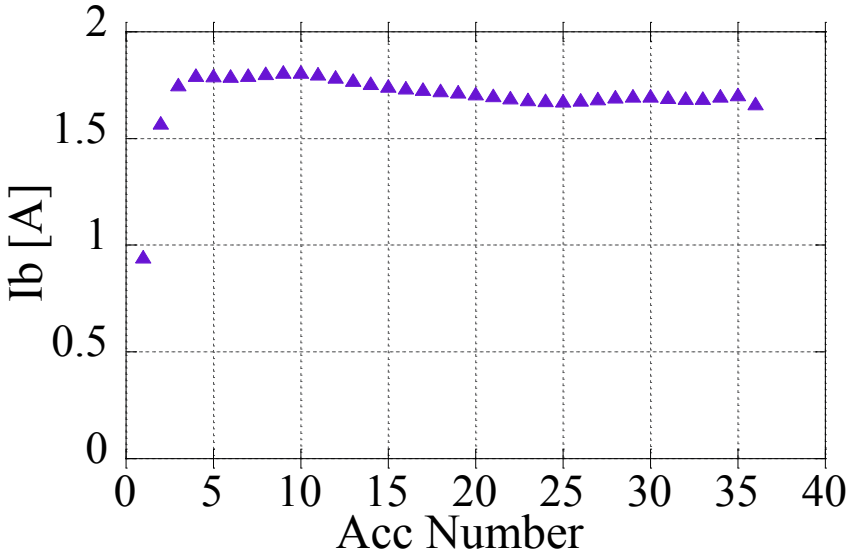
- Simulation of positron generation is performed by GEANT4. The number of electrons is 1000 / bunch.
- Tracking simulation down to the capture linac is performed by GPT.
- Tracking simulation down to ECS is performed by SAD.

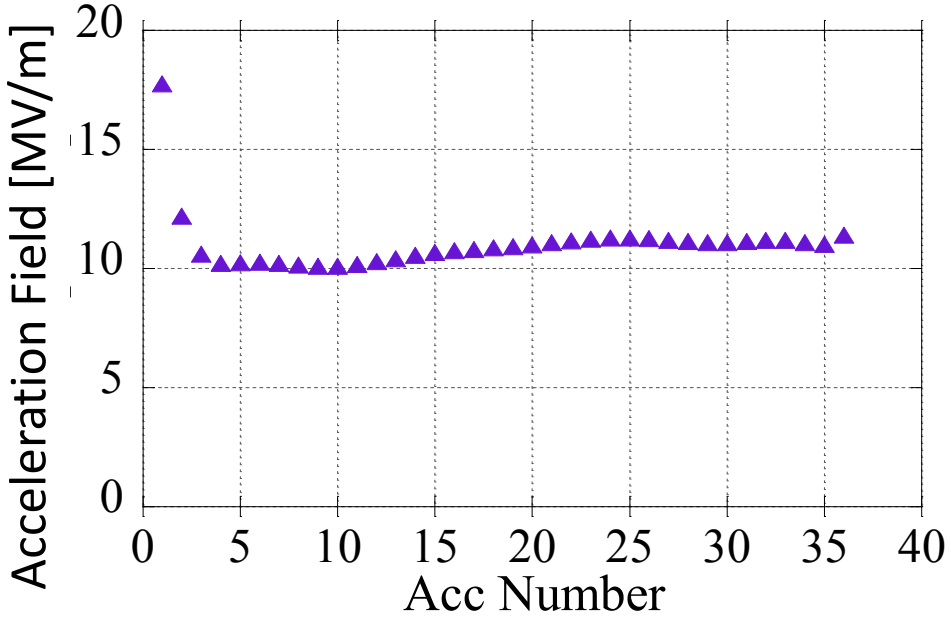
Capture Linac

Parameters	value
RF phase at 1st cavity	210 [degree]

$$V = V_0 \cos(\omega t + \varphi)$$

- Beam loading current I_b is preset in the simulation.
- Electric field is determined by I_b.





Booster and ECS

Booster Linac

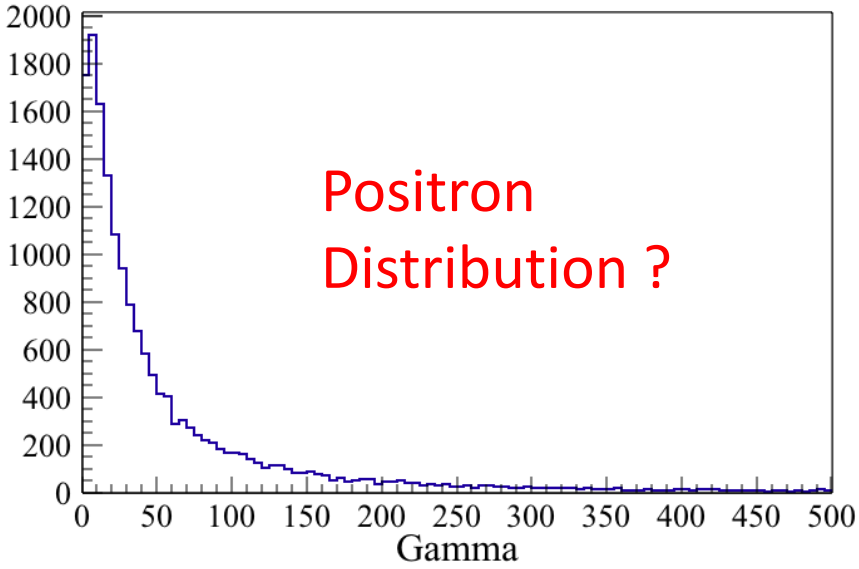
Parameters	value
Phase of Booster Linac	-1 degree
Acceleration voltage of L-Band (IB=0.78A)	17.2 [MV/cavity]
Acceleration voltage of S-Band (IB=0.78A)	25.24 [MV/cavity]

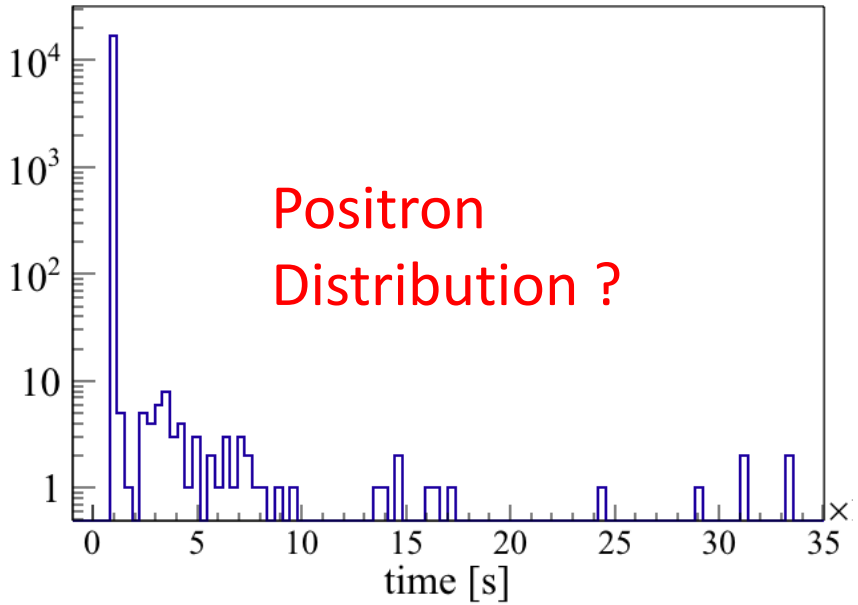
ECS

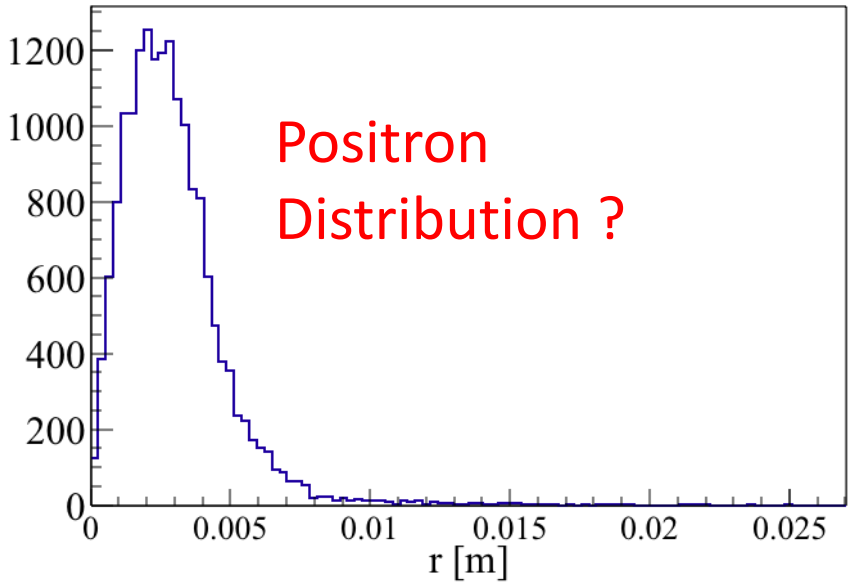
Parameters	value
Bending Angle	0.22 [rad]
RF Phase	Zero cross
Acceleration voltage of L-Band	38 [MV/cavity]

Particle Distribution on Target

Number of generated particles
All Particles : 17114
Positron : 7292
Electron : 9822

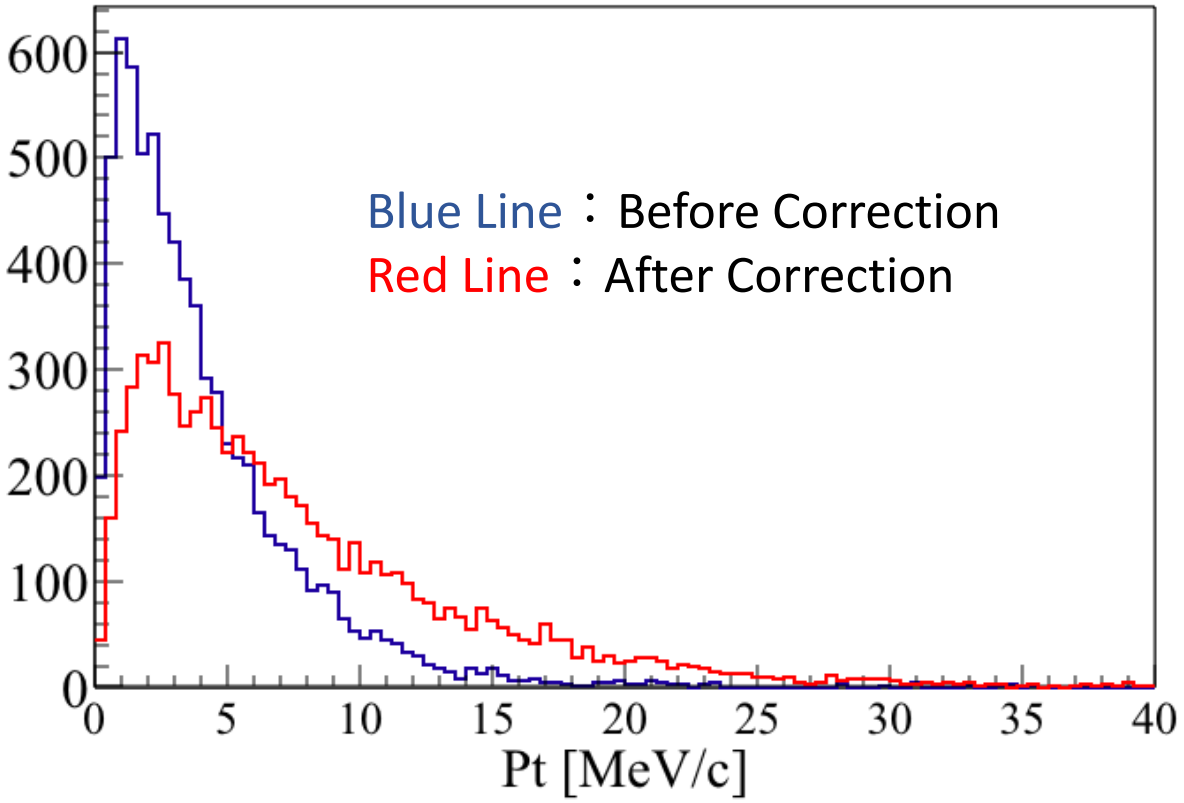






Transverse Momentum

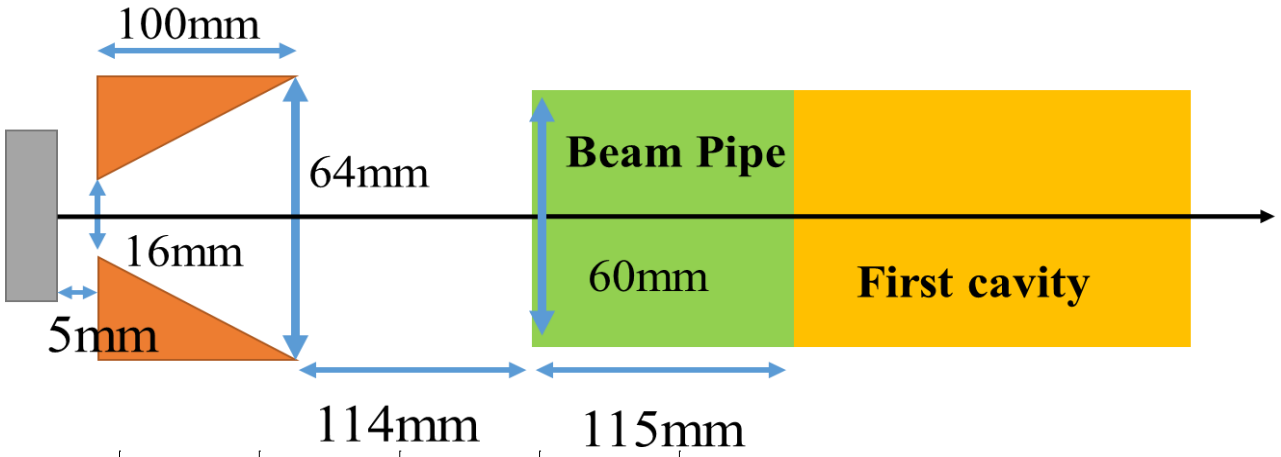
Transverse momentum in GEANT 4 is in MeV/c.
It has been confused as $\gamma\beta$ when it is imported to GPT.
This wrong treatment is corrected and resulting doubled transverse momentum.

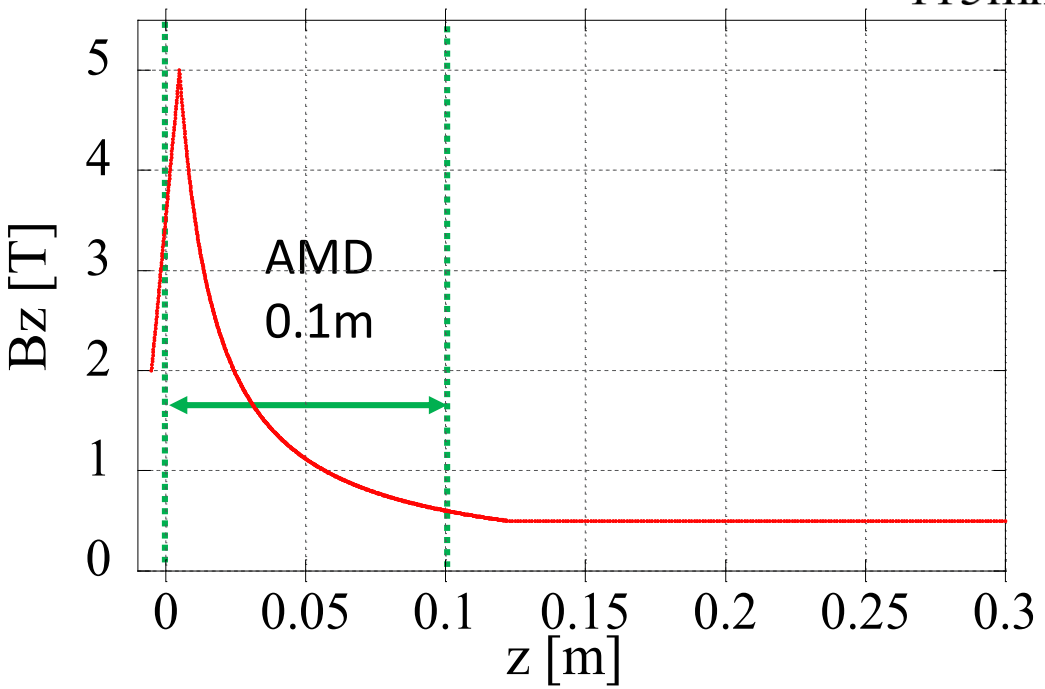


Magnetic field profile of AMD

Profile	Bz	Design
1	Ideal model + Solenoid, continuous	Length = 0.1 [m] Aperture(2a) = 16 ~ 64
2	AMD field calculation + Solenoid	Length = 0.1 [m] Aperture(2a) = 16 ~ 64
3	Ideal model + Solenoid, Truncated at the end of AMD	Length = 0.219 [m] Aperture(2a) = 16 ~ 64

Profile 1





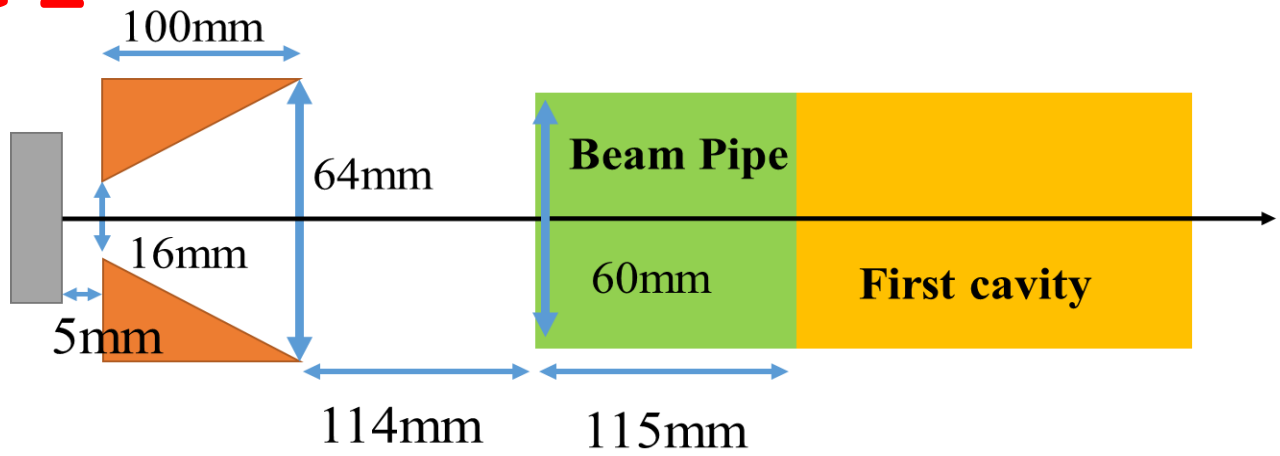
Bz(z=-0.005) = 2 [T]
It linearly rises to
5 T at z=0.005 .

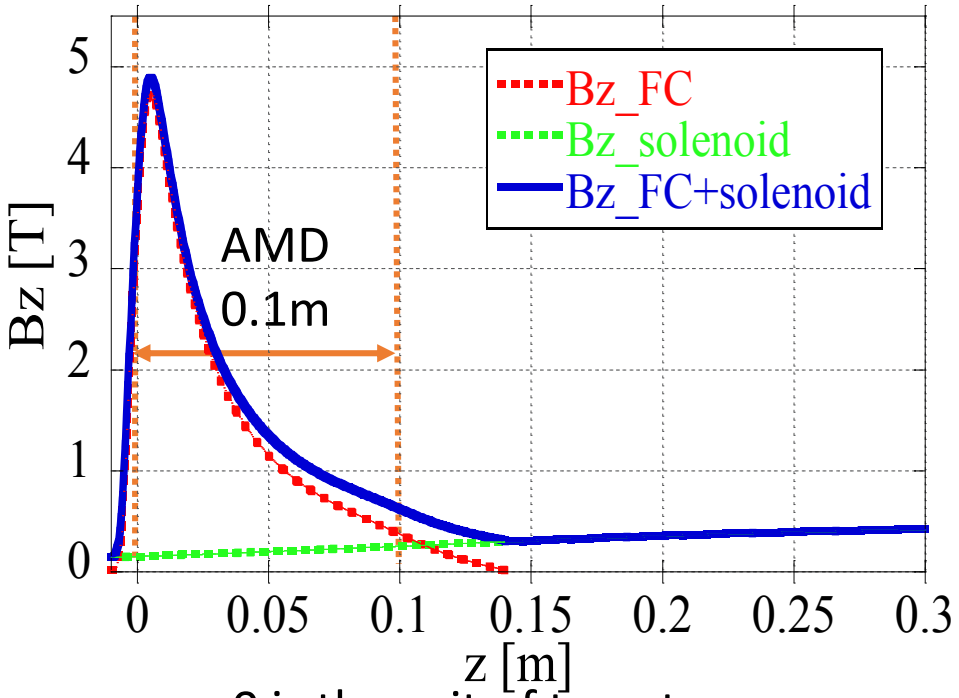
$$B(z) = \frac{B_{peak}}{1 + \mu(z - 0.005)}$$

$B_{peak} = 5\ [T]$
$\mu = 77\ [1/m]$

Connected to solenoid.

Profile 2

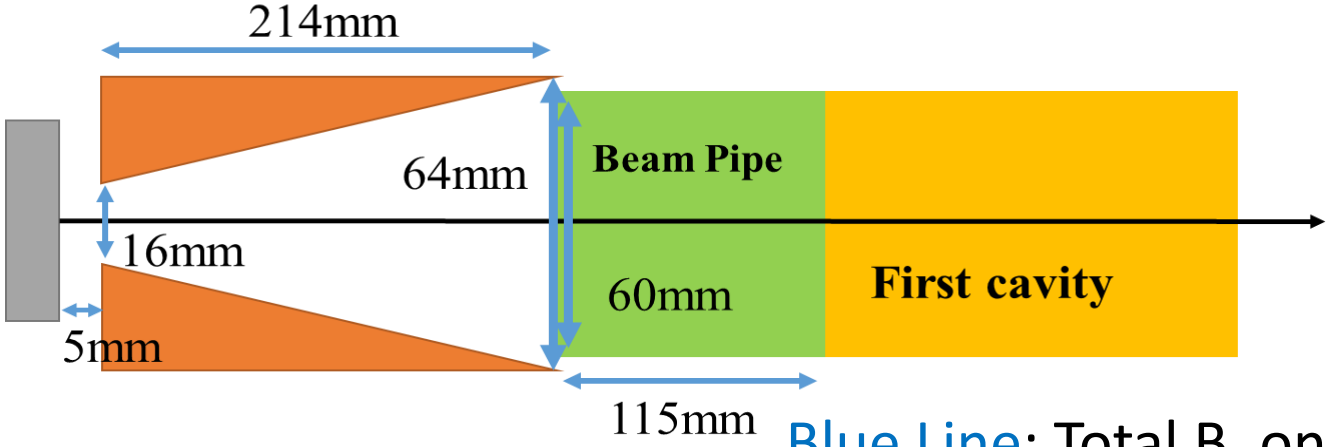


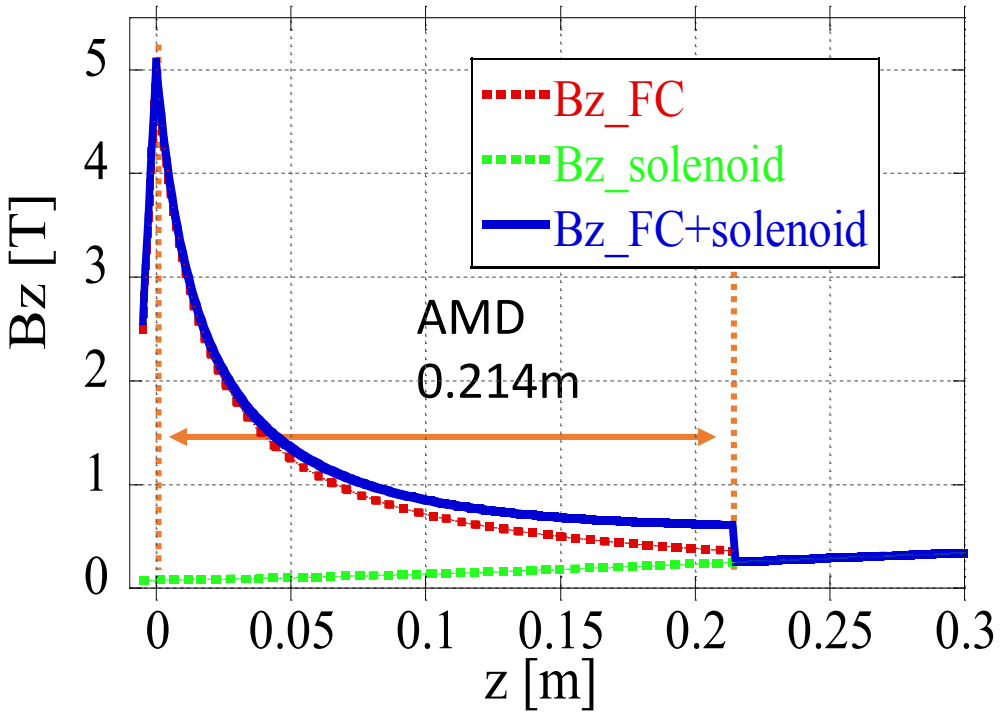


z=0 is the exit of target.

Blue Line : Total B_z on axis.
Red dotted line: Dr. Martishkin's calculation.
Green dotted line: Analytical solution of solenoid field.

Profile 3





Blue Line: Total B_z on axis.

Red dotted line: AMD filed with a simple formula truncated at 0.214 m.

Green dotted line: Solenoid filed by analytical solution.

Bz(z=-0.005) = 2.5 [T]
rises linearly to 5 T at z=0.

z=0 ~ 0.214,

$$B(z) = \frac{5}{1+\mu z} \qquad \mu = 60\ [1/m]$$

Simulation Set

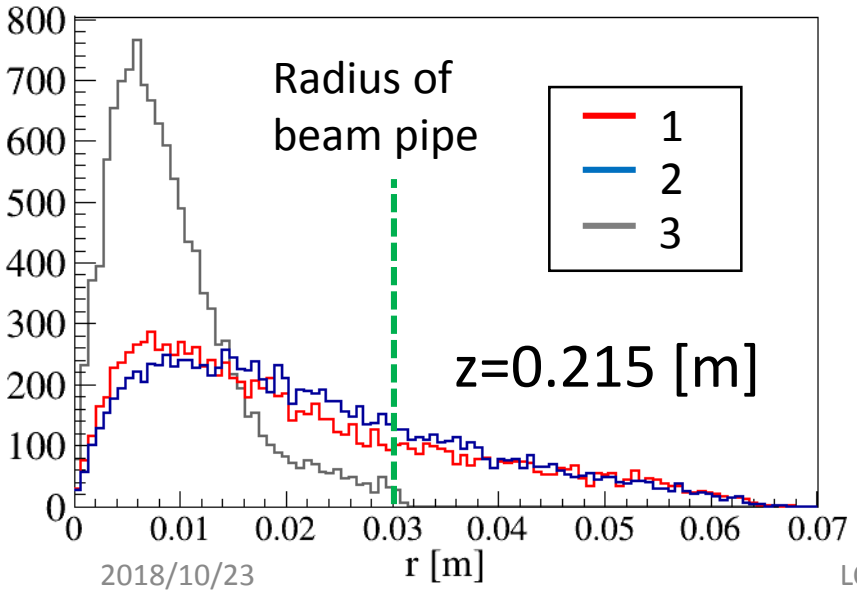
Simulation	AMD	Pt after Target
1	Profile 1	Corrected data
2	Profile 2	Corrected data
3	Profile 3	Uncorrected data

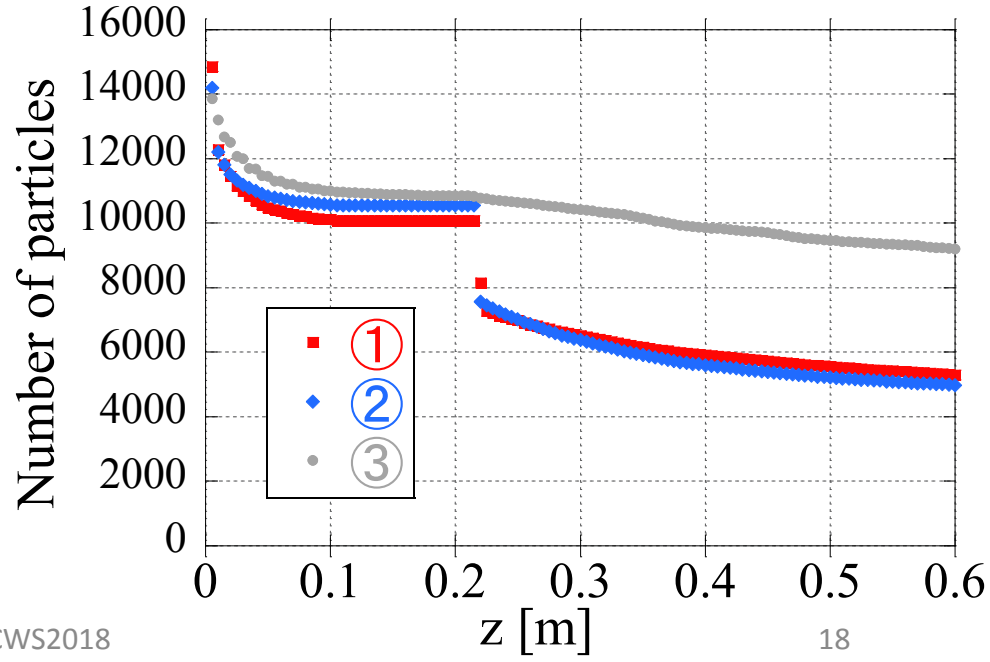
Simulation 2 is the most realistic among them.

Simulation results

Simulation	Yield	r_mean(z=0.215)
1		0.0092 m
2		0.0211 m
3		0.0220 m

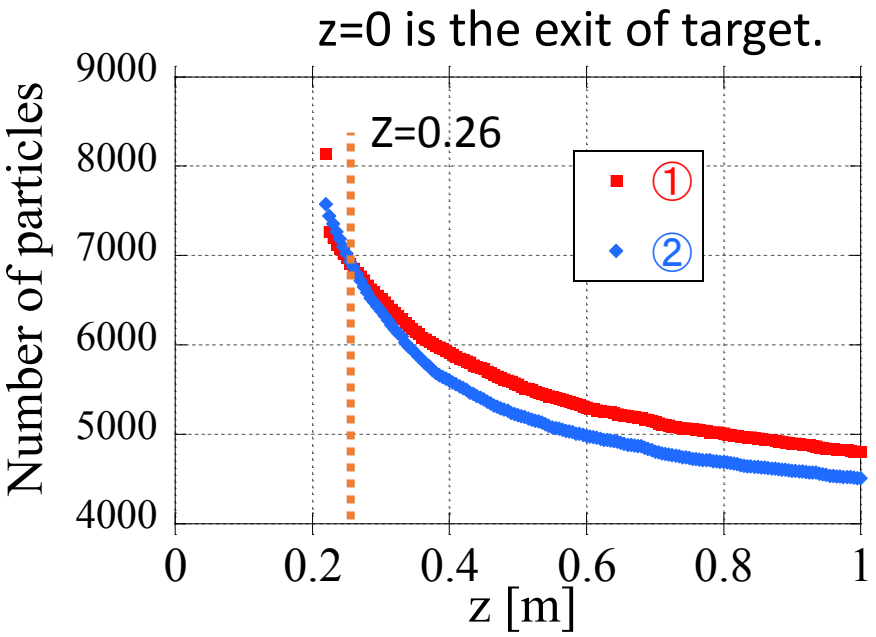
Large difference of the yield is due to the large beam size in the capture linac.

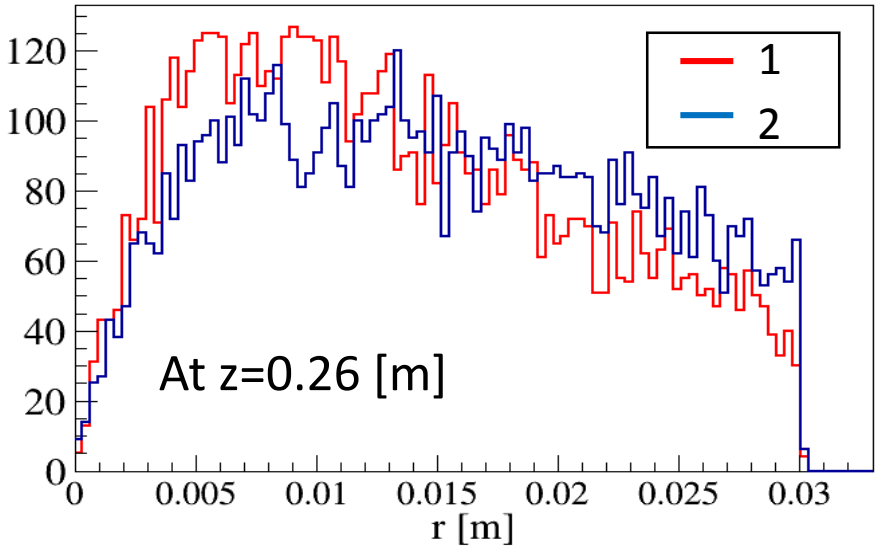




Comparison of Simulation 1 and 2

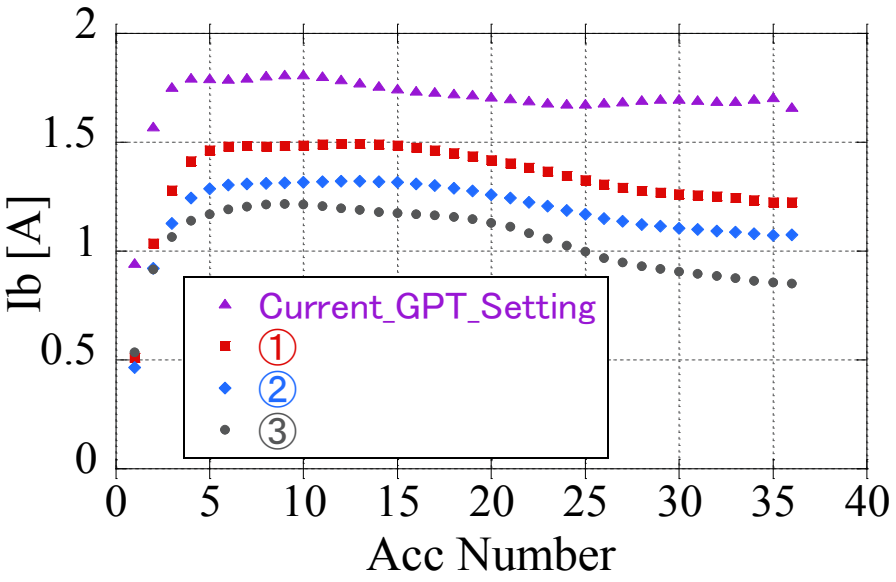
Simulation	Yield	r (z=0.26m)	Bz (z=0.26mm)
1		0.014m	0.5
2		0.015m	0.39

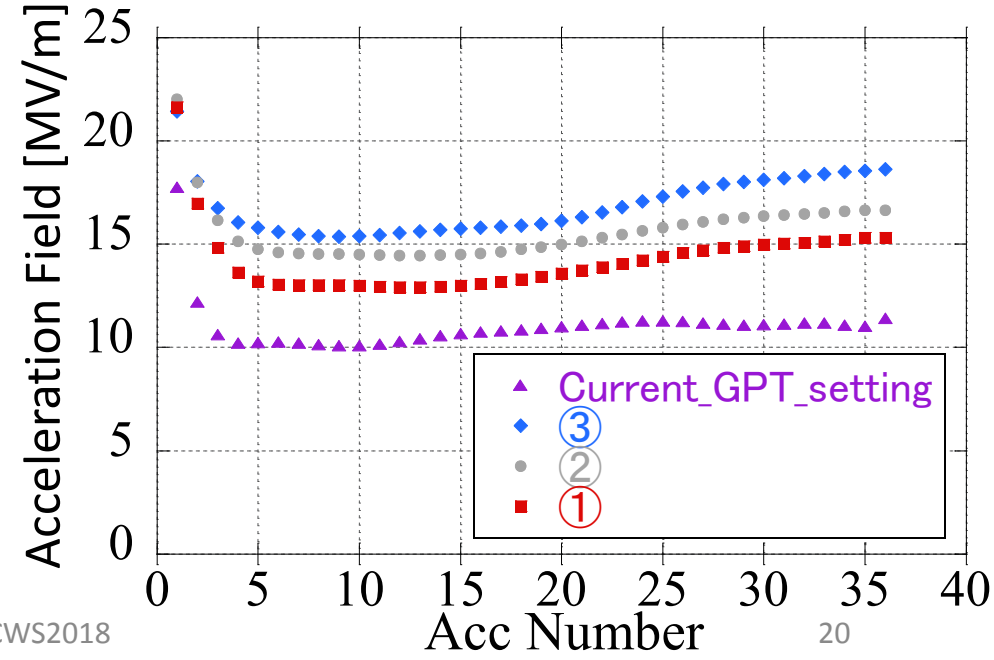




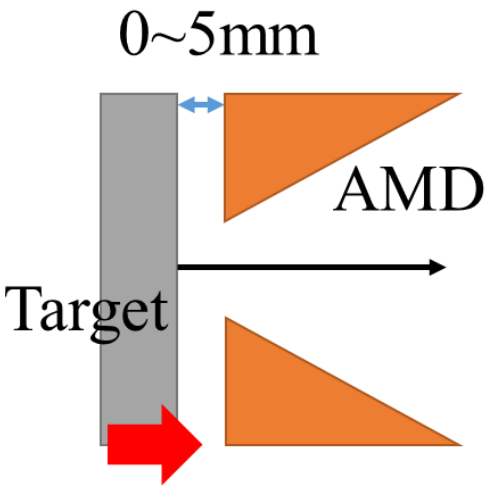
Beam Loading in Capture Linac

- The beam loading current I_B is calculated by the charge normalized giving 4.8nC in DR acceptance.
- I_B variation along the capture linac is evaluated.
- I_B for all simulation is less than I_B preset in the GPT simulation.
- Acceleration field should be more than that in the simulation.

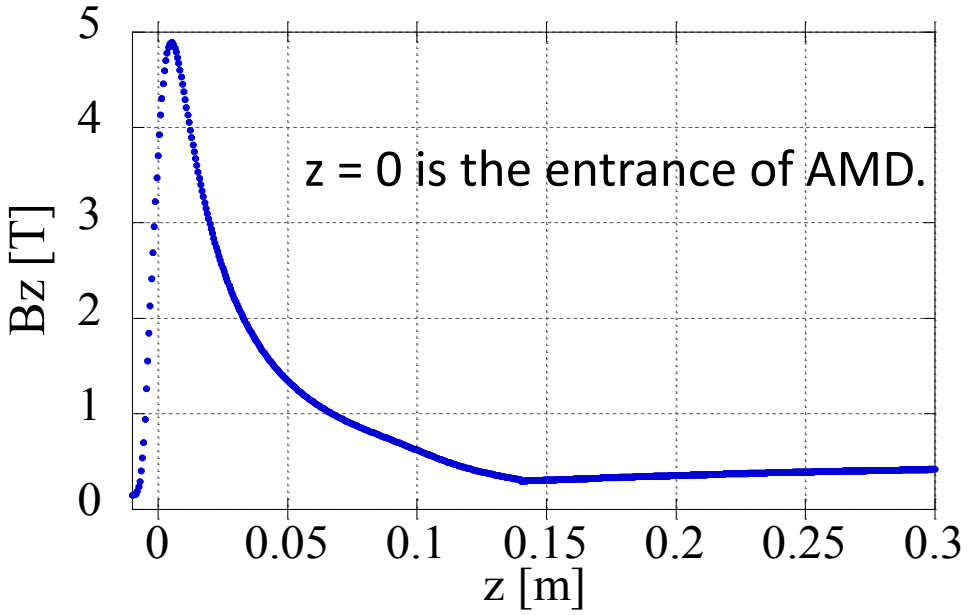




Target Position

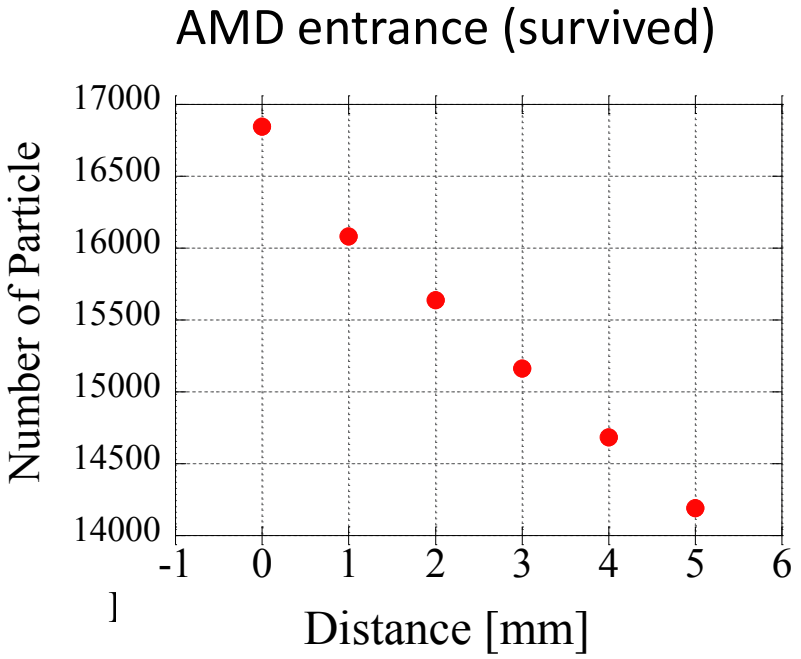


Yield variation as a function of distance between Target and AMD is evaluated.



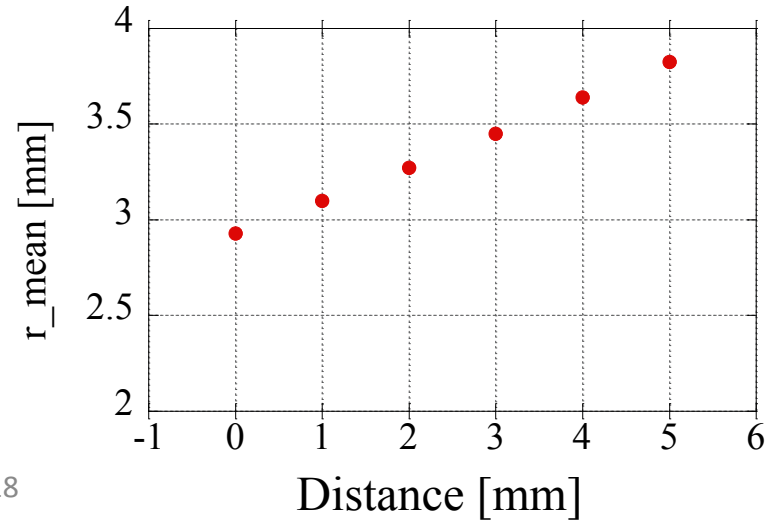
Distance between target and AMD	Bz at exit of target [T]
0mm	3.56
1mm	3.07
2mm	2.54
3mm	1.98
4mm	1.41
5mm	0.80

Simulation Result



Distance [mm]

- The yield is evaluated with simulation 2.
- The beam size is decreased with the smaller distance giving higher yield.

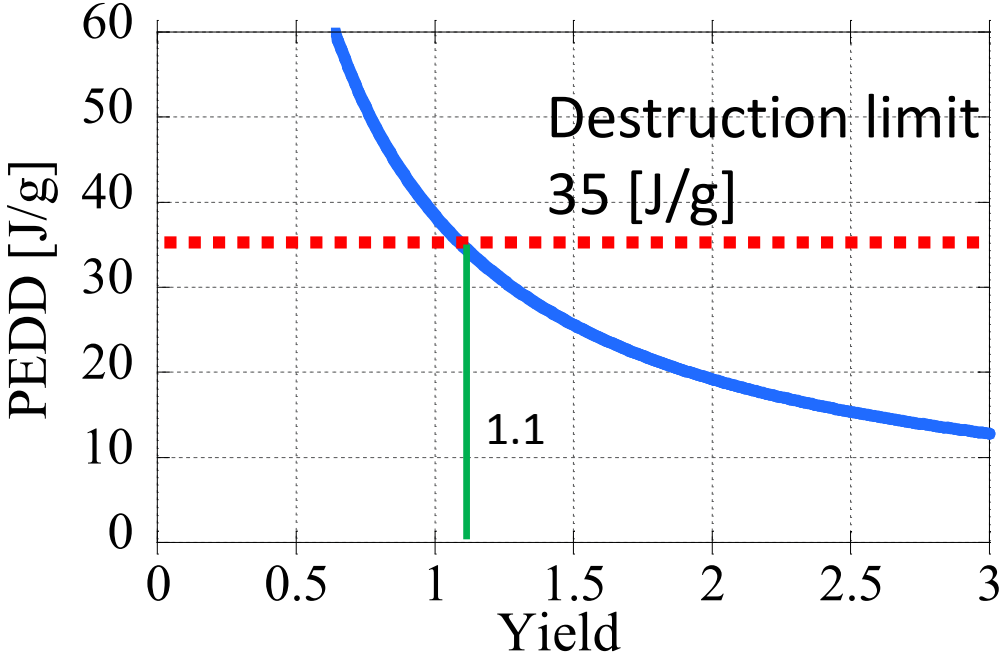


PEDD

Electron Bunch charge = $4.8/\eta$ [nC/bunch]

$$PEDD(\eta) = \frac{25.6\ [\mathrm{J/g}]}{3.2[\mathrm{nC}]} \times \frac{4.8}{\eta} = \frac{38.4}{\eta}\ \ [\mathrm{J/g}]$$

η : Yield



Yield must be more than 1.1 for safety operation.

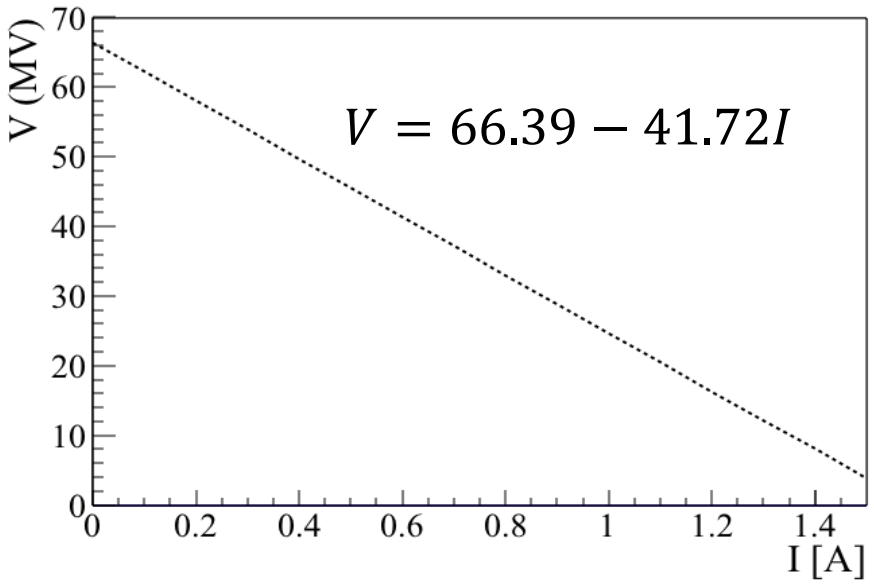
PEDD summary

AMD profile	Target Distance [mm]	Yield	PEDD [J/g]	Target Safety
1	**5**		36.23	**No**
2	**0**		33.10	**OK**
2	**1**		34.91	**OK**
2	**2**		37.65	**No**
2	**3**		39.18	**No**
2	**4**		41.29	**No**
2	**5**		43.64	**No**

Positron generation is possible with <= 1 mm distance between the target and AMD.

Electron Driver

Composed from 3 m S-Band TW accelerator



Yield = 1.10 (AMD profile 2 and z=1mm)
I_B = 0.71 [A] , V = 36.7 [MV]
(currently, I_B = 0.39 [A] ,V=50.1 [MV])

Lattice	N	Cell Length	Section Length	Section Energy
4Q+2S	8	8.0 [m]	64.0 [m]	587.2 [MeV]
4Q+4S	17	14.4 [m]	244.8 [m]	2495.6 [MeV]

Total Length 308.8m
(currently, 235.2 m)

Energy 3.083 GeV

Conclusion

- Start-to-end simulation of ILC E-Driven Positron source is performed.
- B_z profile of AMD designed by P. Martishkin decreased the yield more 20 % comparing to the simple model.

- The yield is linearly increased if the distance from the target to AMD is decreased. No target damage is expected with z=1mm.
- The length of electron driver is increased from 235.2 m to 308.8 m with a larger beam current.

- The beam loading current assumed in the simulation is too much. Some improvement is expected by setting correct current.
- The parameter optimization is not performed at all.