E-Driven Positron Source capture simulation

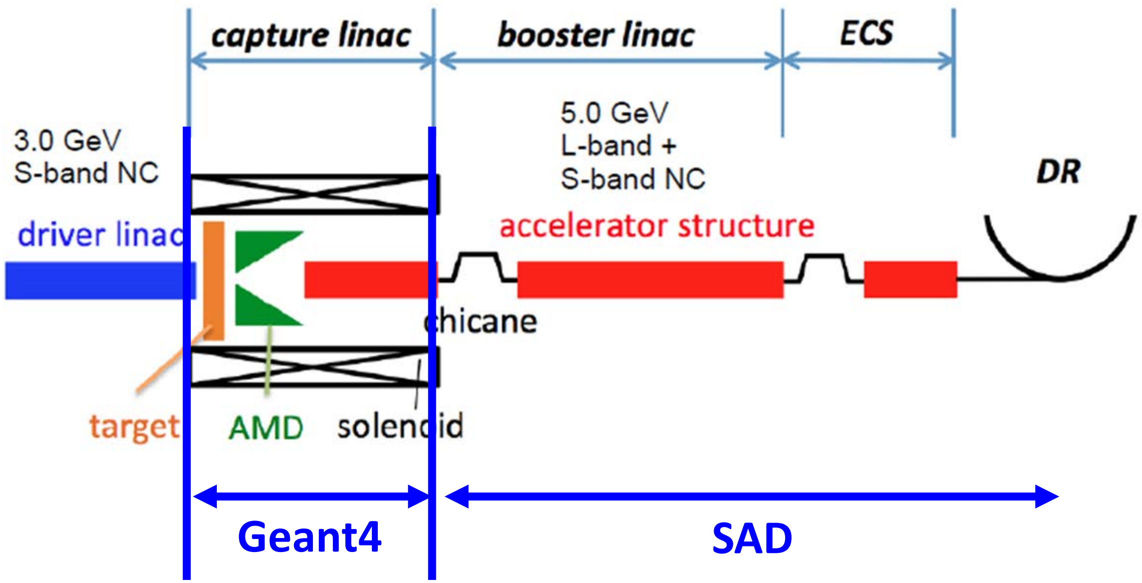
KEK M. Fukuda

Contents

- Tracking Simulation by using Geant4 and SAD
- Comparison of Nagoshi’s result and Fukuda’s result
- Yield calculation with divided solenoid coils
- Yield calculation when the distance of target and FC is changed

Simulation of ILC positron source for E-driven scheme

The tracking of positrons up to the exit of ECS can be simulated now.



ILC-TDR

I can calculate the positron yield at DR by using the tracking code which been succeeded from Kuriki-san and Nagoshi-san.

Positron generation at a target: Geant4

Tracking : Target --- Capture section end(250MeV): Geant4

Tracking: Capture section end --- ECS end: Strategic Accelerator Design (SAD)

Placement of each components for E-driven scheme

Target --- AMD: 5mm

AMD --- Collimator: 114mm

SW tube 1268mm, R: 30mm, Endplate 10mm at both ends

Mask 120mm, R: 30mm

AMD100mm, R_{min}: 8mm, R_{max}: 32mm

Target W26Re 16mm

Total 36 tubes

Positron generation

Primary e- beam

Energy: 3GeV

Number of electron: 1×10^4

Beam size on the target: 2mm (1σ)

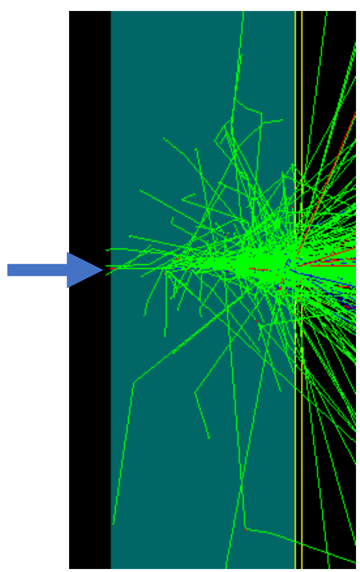
Bunch length: 1mm (1σ)

Target: **W26Re, thickness 16mm**

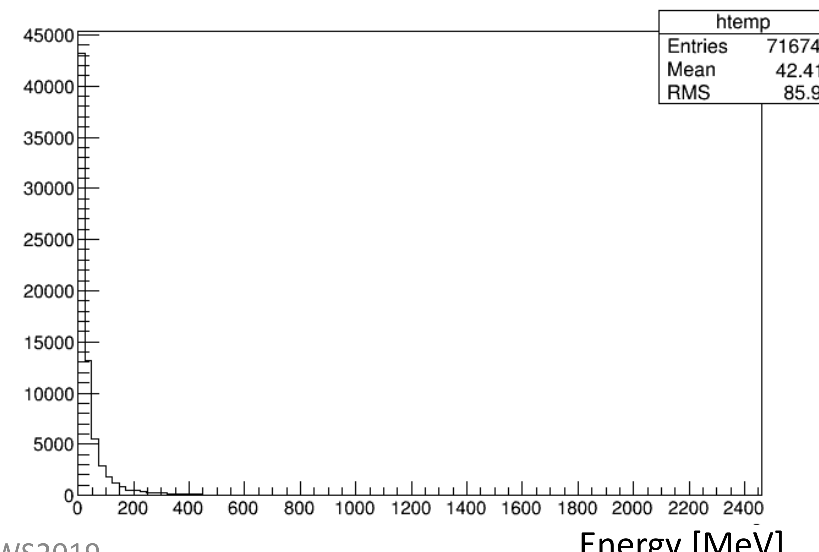
Number of generated positrons: 7.17×10^4

W26Re 16mm

Electron beam
3GeV
Ne-: 1×10^4
$\sigma x,y$ = 2mm
σz = 1mm

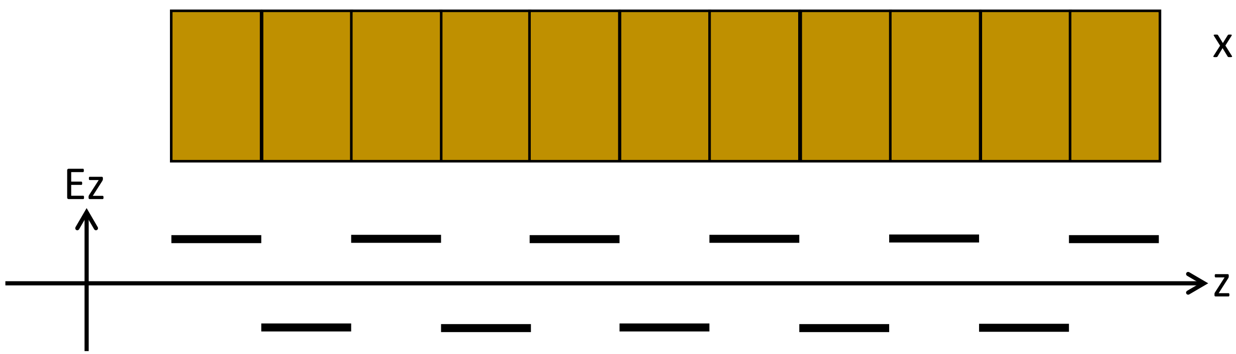


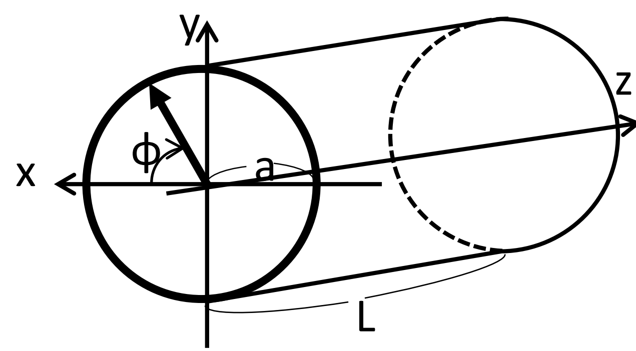
Generated positrons



Accelerating electric field of standing wave tube

A standing wave tube consists of 11 pillboxes(TM010).





The phase is shifted by π for each cell.

Ez = E0*J0(p01*r/a)*sin(omegatime*t+cavPhase);

Bϕ = E0*J1(p01*r/a)*cos(omegatime*t+cavPhase)/c_light;

(Bx= Bphi*(-1.0*y/r) , By = Bphi*(x/r), r = sqrt(x*x+y*y))

Wave length: **λ=230.60958mm (L-band: 1.3GHz)**

Radius of cylindrical cavity: a = p01*λ/2π = 88.263mm

p01 = 2.404825557695772 (when J0(x) = 0, x = p01)

Omegaspace = 2π/λ, omegatime = 2πc/λ 、

E0 = π/2 * Eacc

Magnetic field of FC and Solenoid

OMD

FC: the field designed by Pavel Martyshkin by using CST studio.

DC Solenoid in a capture section

One long solenoid coil: 0.5T (Bz const)

Divided solenoid coils (*)

Divided solenoid coil with changed shape (*)

*** No coil at a space between accelerating tubes**

where

$$B_r^a(r,z)=\sum_{\nu=1}^{\infty}\frac{(-1)^\nu}{\nu!(\nu-1)!}B_{z0}^{(2\nu-1)}(z)\left(\frac{r}{2}\right)^{2\nu-1}$$

$$=-\frac{B'_{z0}(z)}{2}r+\frac{B^{(3)}_{z0}(z)}{16}r^3-\frac{B^{(5)}_{z0}(z)}{384}r^5+\frac{B^{(7)}_{z0}(z)}{18432}r^7-\frac{B^{(9)}_{z0}(z)}{1474560}r^9+..$$

$$B_z^a(r,z)=\sum_{\nu=0}^{\infty}\frac{(-1)^\nu}{(\nu!)^2}B_{z0}^{(2\nu)}(z)\left(\frac{r}{2}\right)^{2\nu}$$

$$=B_{z0}(z)-\frac{B''_{z0}(z)}{4}r^2+\frac{B^{(4)}_{z0}(z)}{64}r^4-\frac{B^{(6)}_{z0}(z)}{2304}r^6+\frac{B^{(8)}_{z0}(z)}{147456}r^8+\ldots$$

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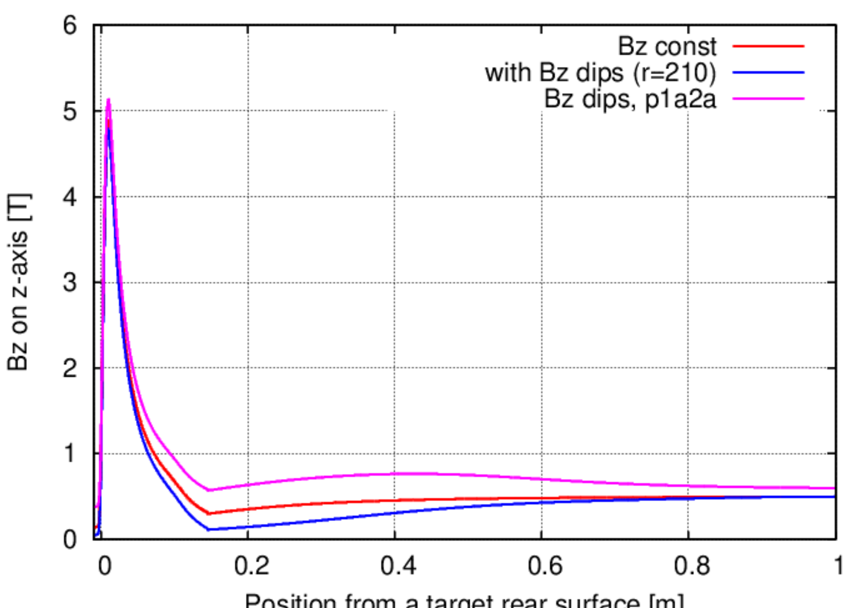
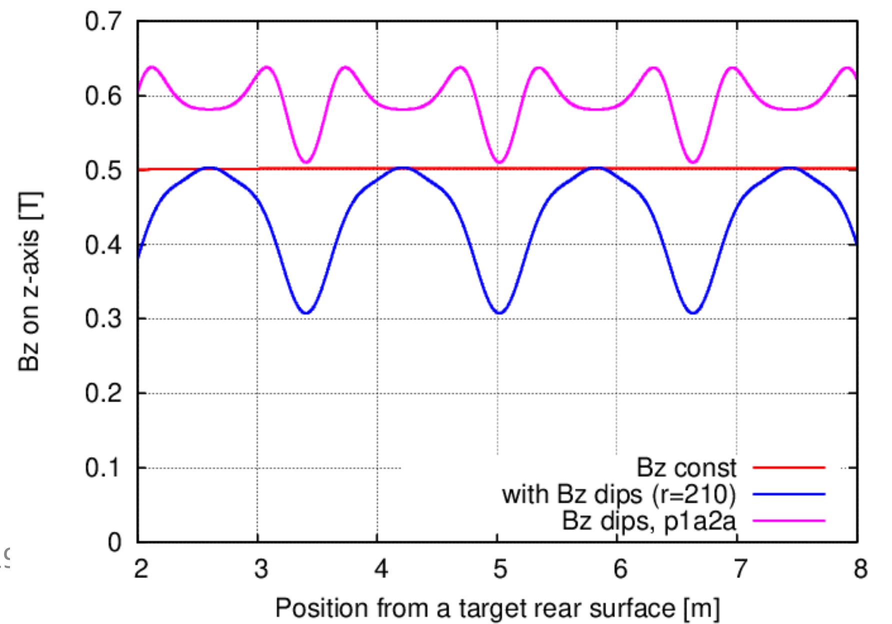
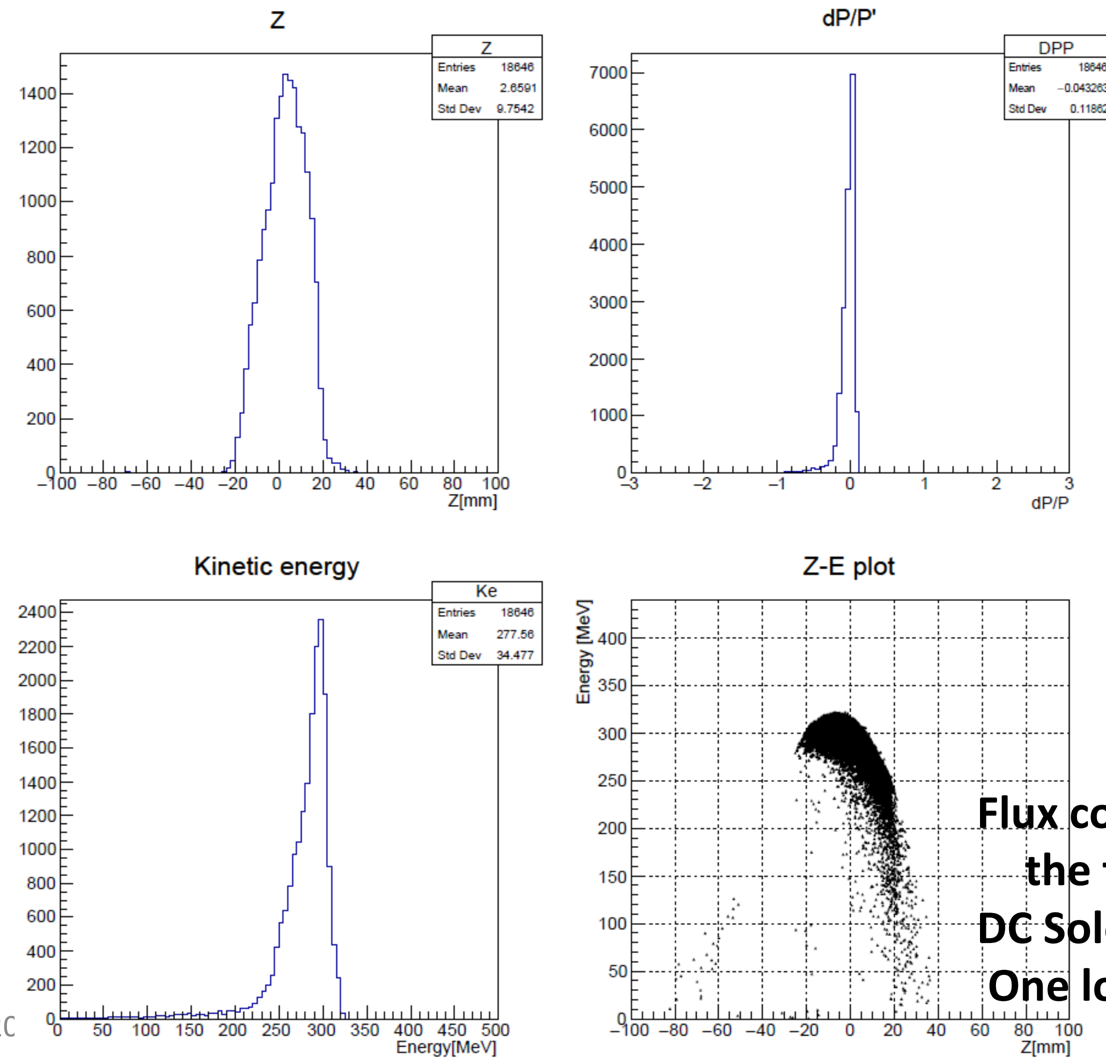


VS2019



Positron distribution at Capture end

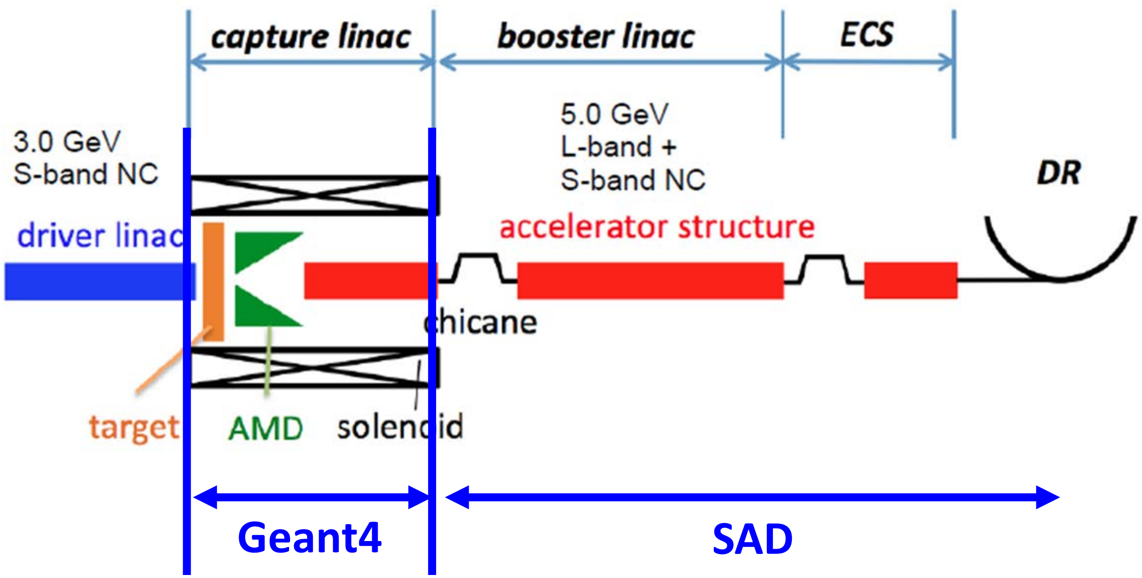


The data input to SAD code to track positrons to ECS end.

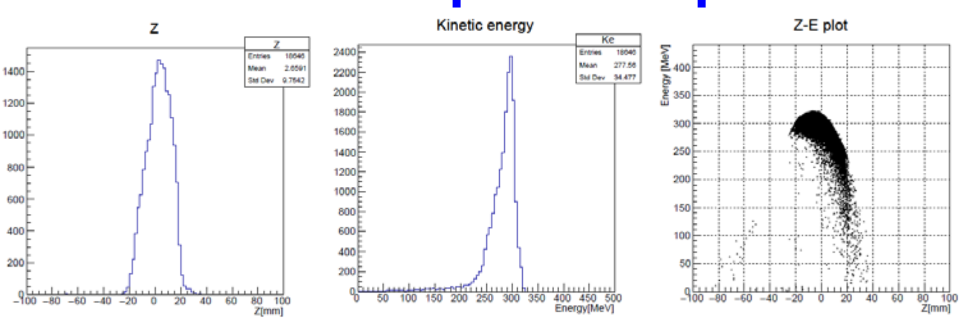
Flux concentrator:
the field designed by P. Martyshkin
DC Solenoid in a capture section
One long solenoid coil: 0.5T (Bz const)

Tracking positrons after capture section

To track positrons after capture section, I use the tracking code which was made by Nagoshi-san.

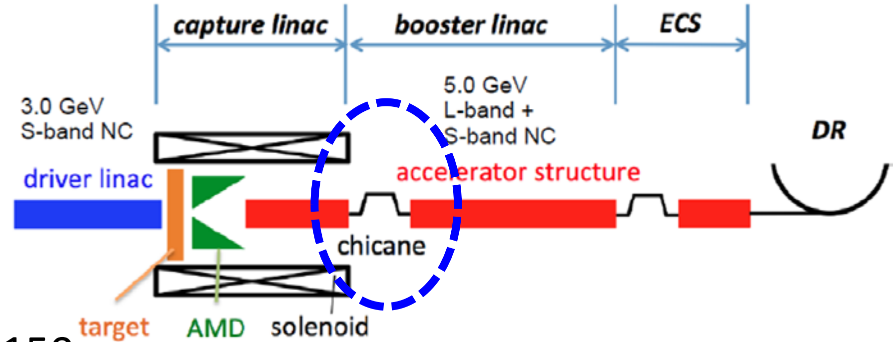


ILC-TDR

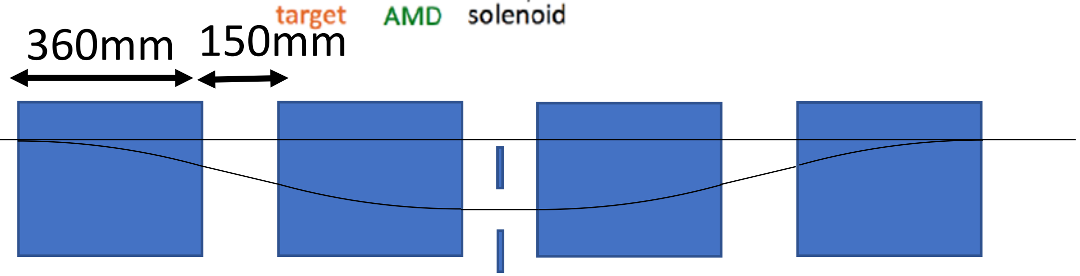


Positrons data calculated by Geant4 input to the tracking code using SAD to get yield at DR.

Chicane

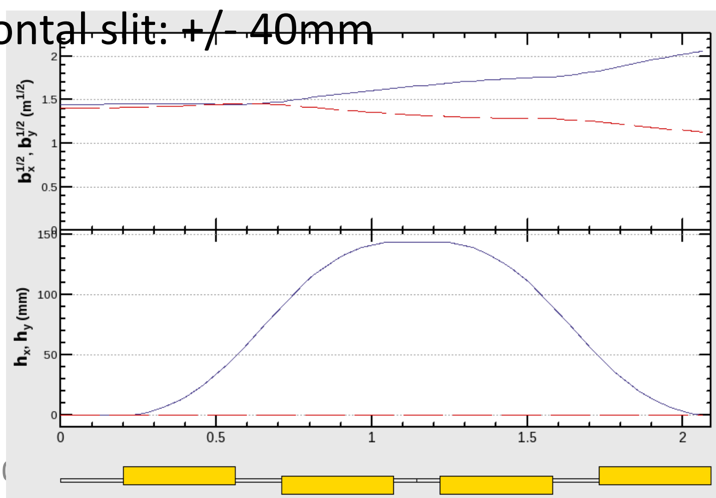


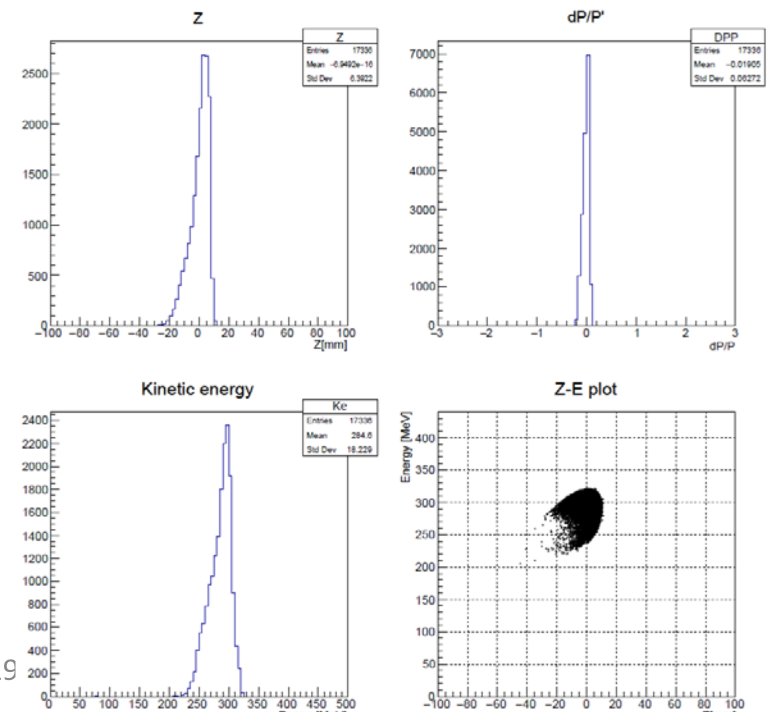
Cut energy tail
Bunch compression



Bending angle：0.27rad (15.5deg)
It is finally determined
 by parameter scanning.

Radius ρ：1.35m
B：0.64[T] @ 260GeV/c
Offset: 138mm
Horizontal slit: +/- 40mm





Booster linac

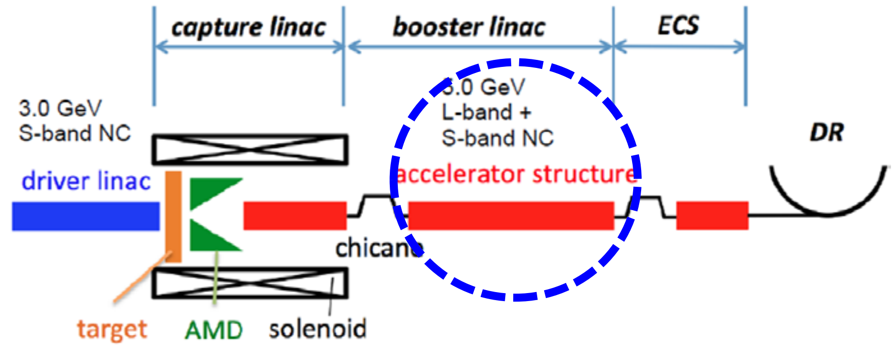
Positrons are accelerated to 5GeV.

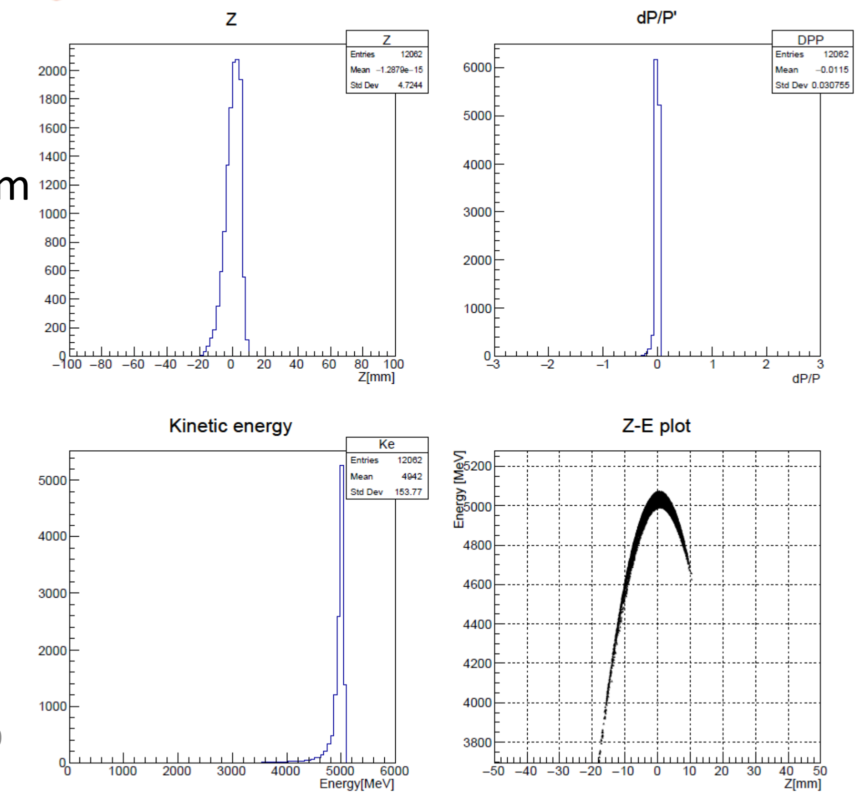
4Q+1L 14sets (01 --14)
4Q+2L 29sets (15 -- 43)
4Q+4L 18 sets (44 -- 61)
4Q+4S 23 sets (62 -- 84)

L-band ACC: 1.3GHz, 2.0m, r=17mm, 8.69MV/m
S-band ACC: 2.6GHz, 1.959m, r=10mm, 13.02MV/m

Phase: basically on crest.
The phase is finally determined by parameter scanning.

Aperture:
R=17mm (L-band),
R=10mm (S-band)
There are apertures at both ends of each accelerating tube.



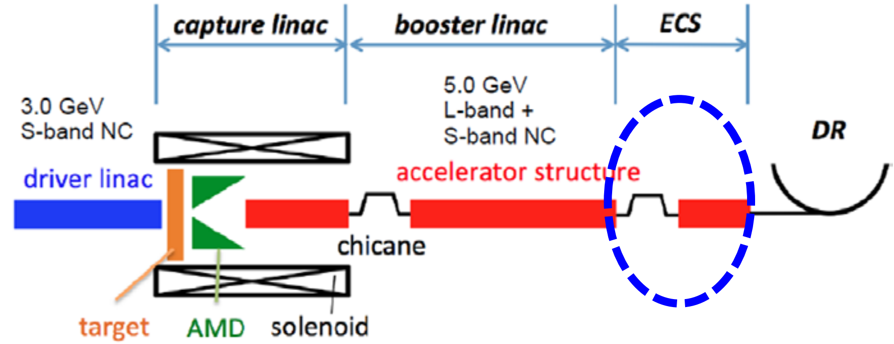


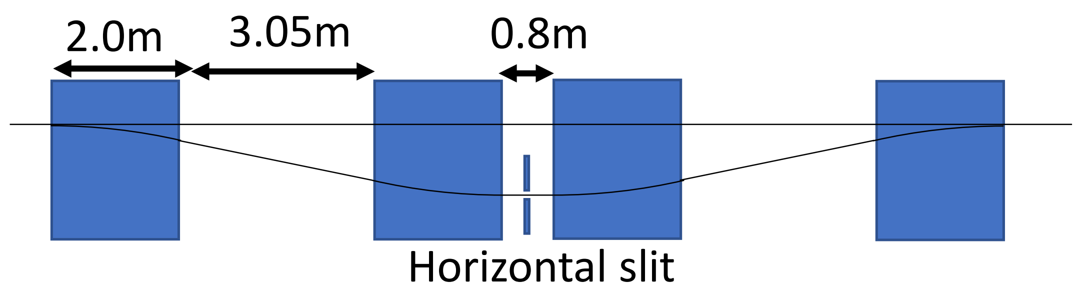
ECS

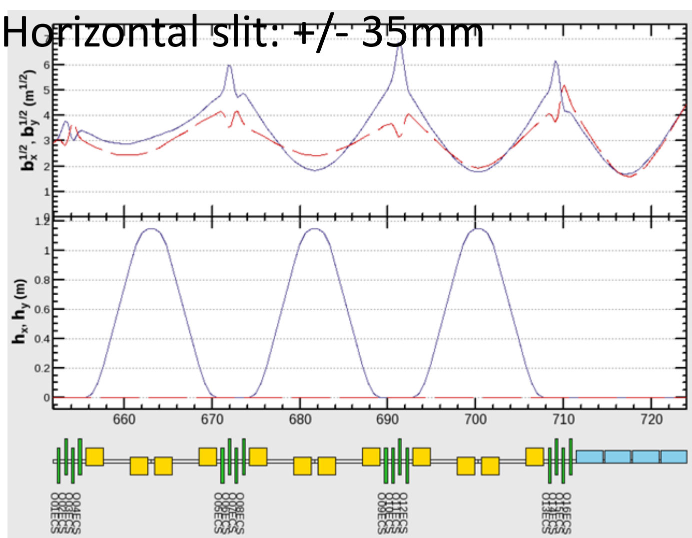
Energy compression
The slit cut the low energy part

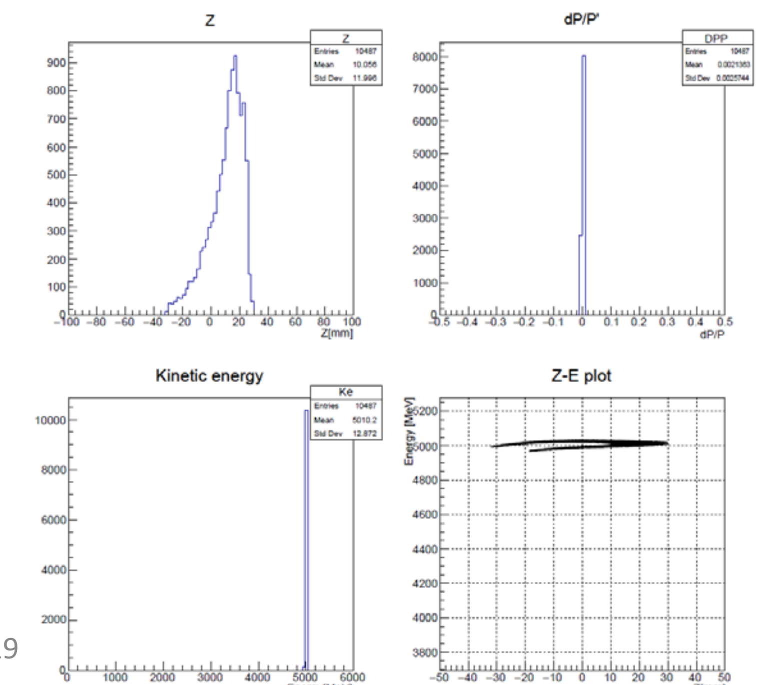
Bending angle：0.22rad (12.6deg)
It is finally determined
by parameter scanning.

Radius ρ：9.06m
B：1.82[T] @ 5GeV/c
Offset: 1.11m
Horizontal slit: +/- 35mm









Cut condition of DR aperture

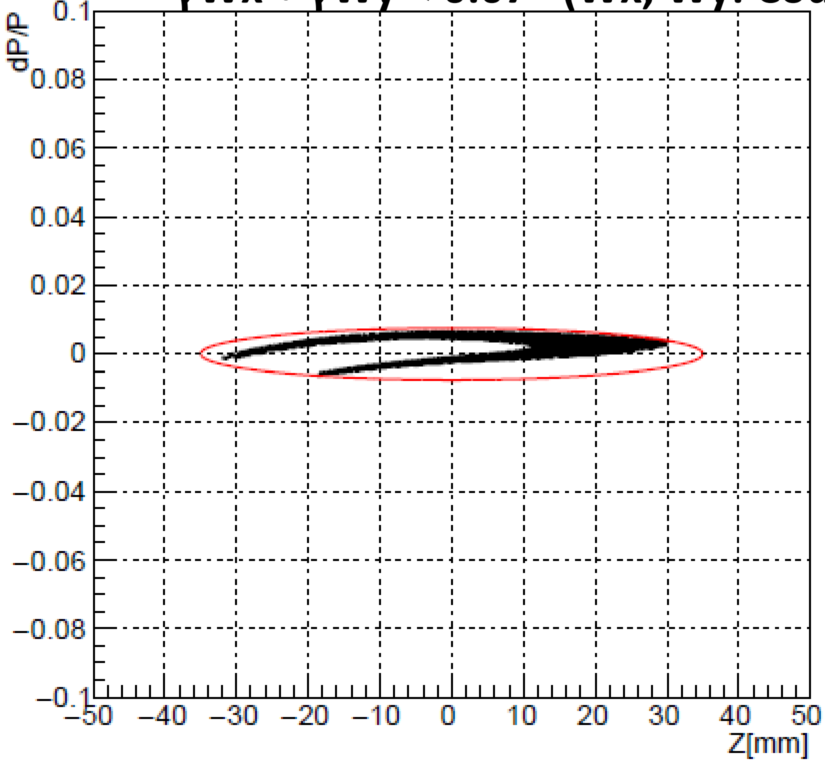
- DR acceptance of Energy and bunch length

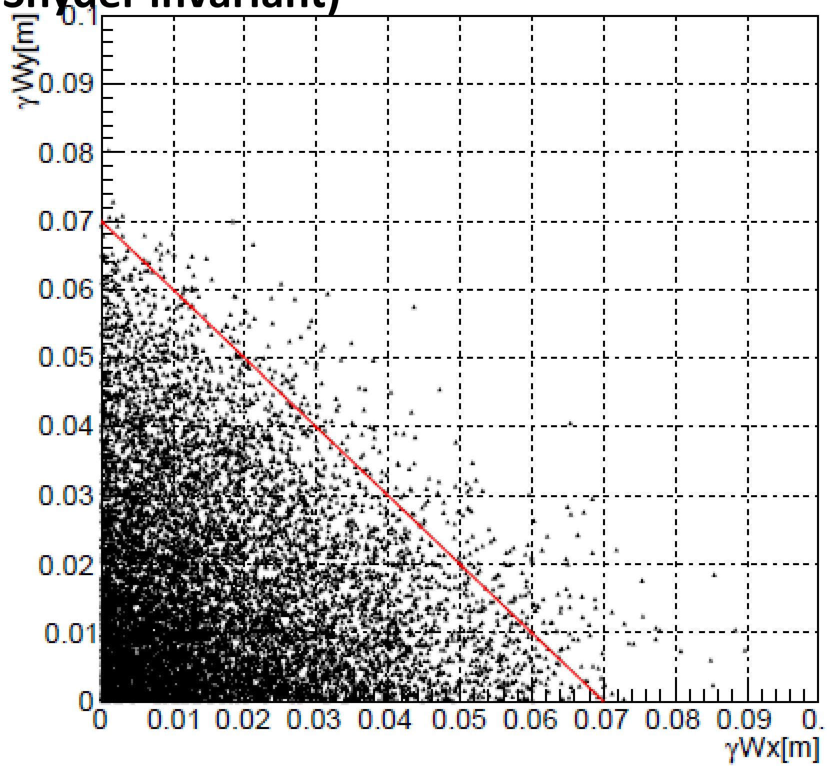
(ΔE/BW)2 + (dz/zl)**2 < 1**

BW=0.0075*5=0.0375GeV,   zl=0.035m

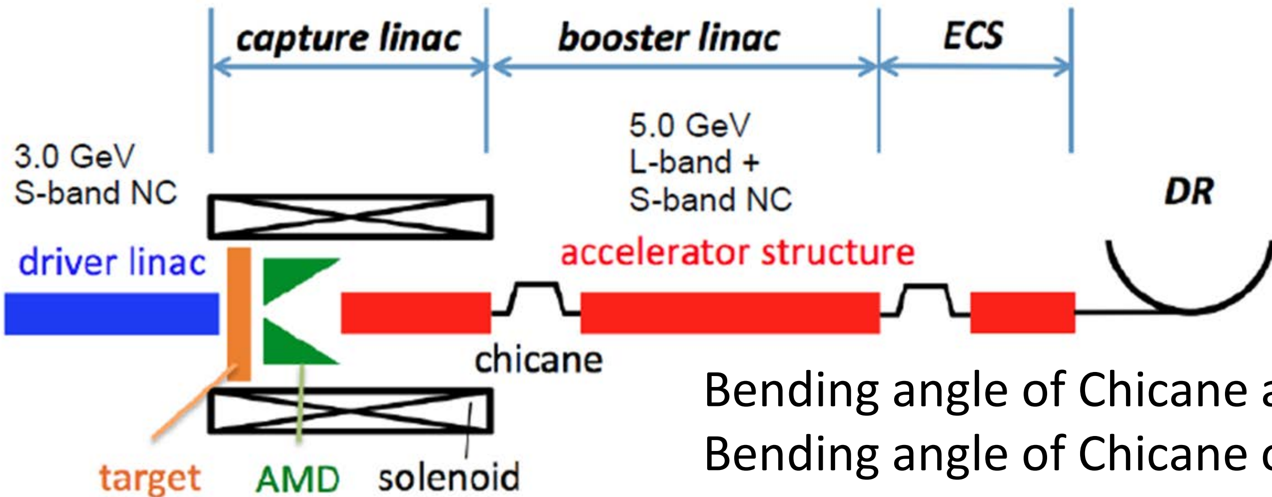
- DR aperture

γWx + γWy < 0.07   (Wx, Wy: Courant-Snyder invariant)

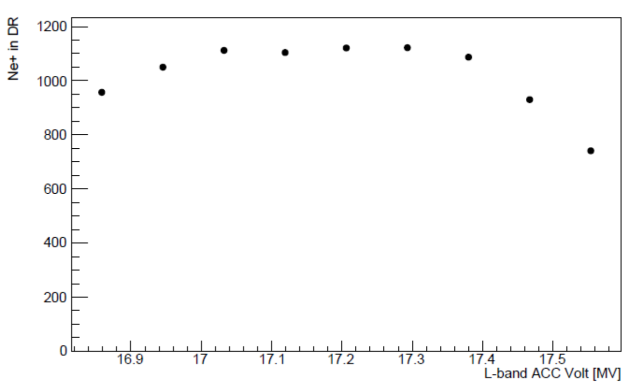


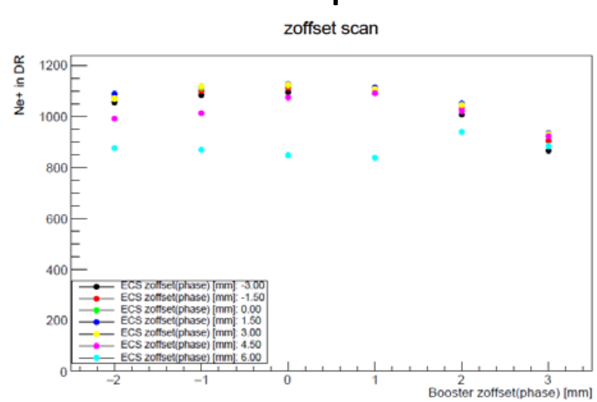


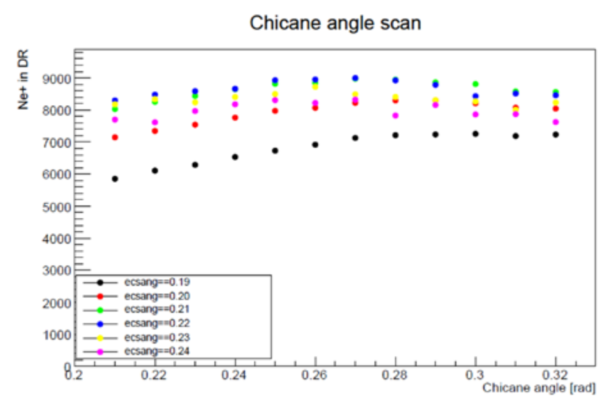
Scan parameters



Bending angle of Chicane at capture end
Bending angle of Chicane of ECS
Eacc of Booster linac
Booster linac phase
ECS linac phase





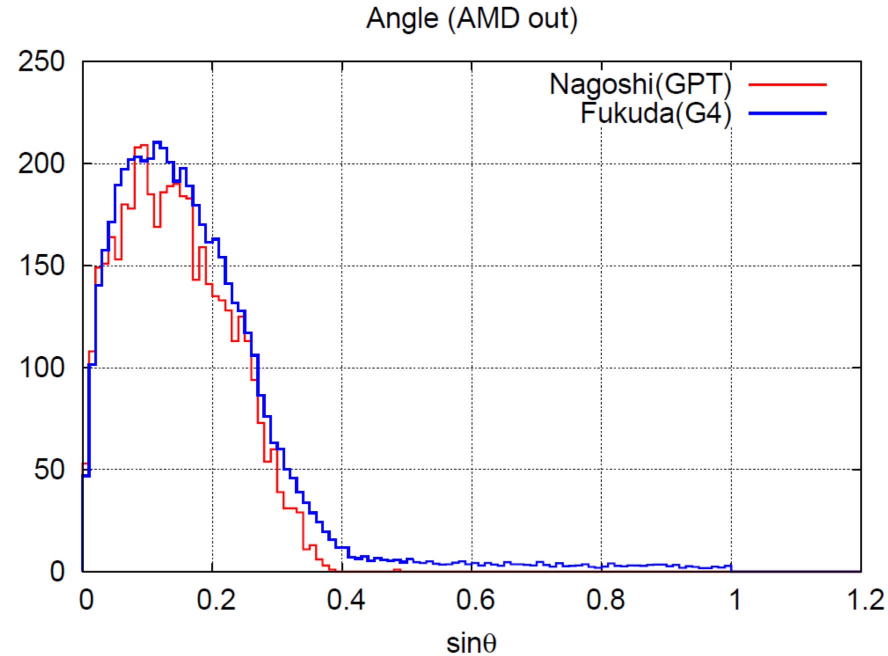


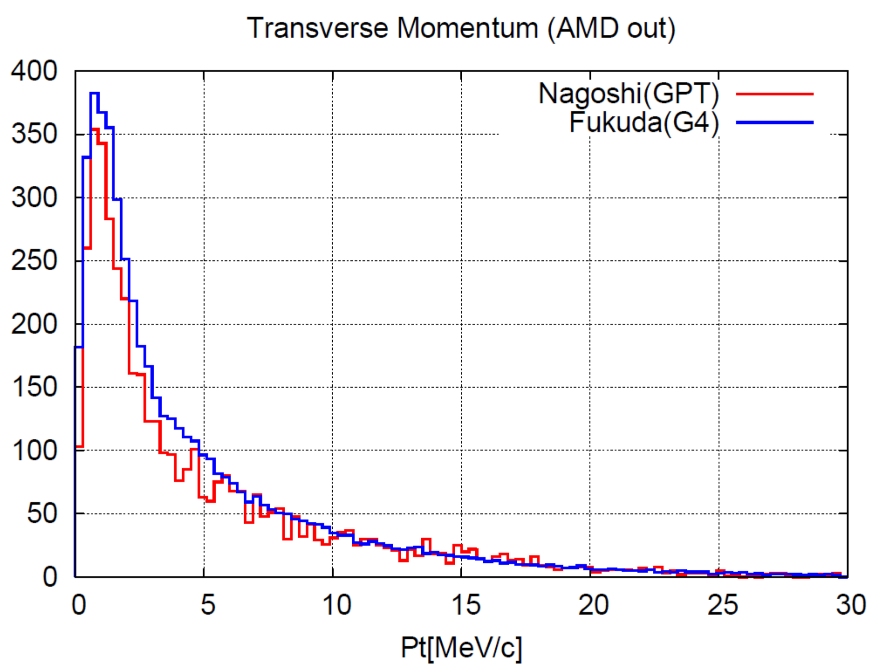
Comparison of Nagoshi’s result and Fukuda’s result

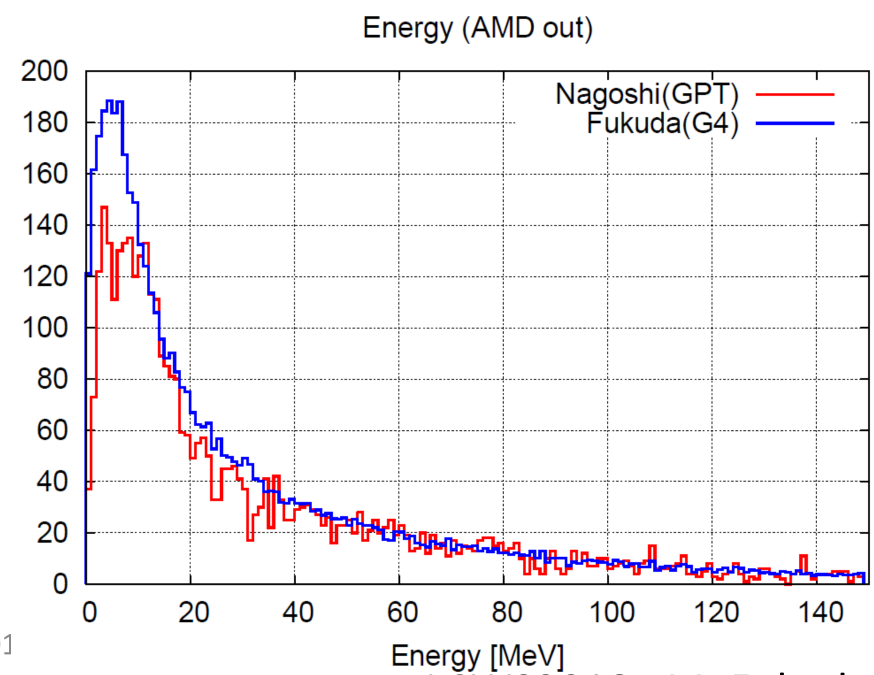
Exit of AMD

In comparison between my result
and Nagoshi-san's result,
The energy distributions is different.

Ne+: 4475 (Nagoshi, GPT)
Ne+: 5249 (Fukuda, Geant4)







Difference of Nagoshi's simulation and Fukuda's simulation

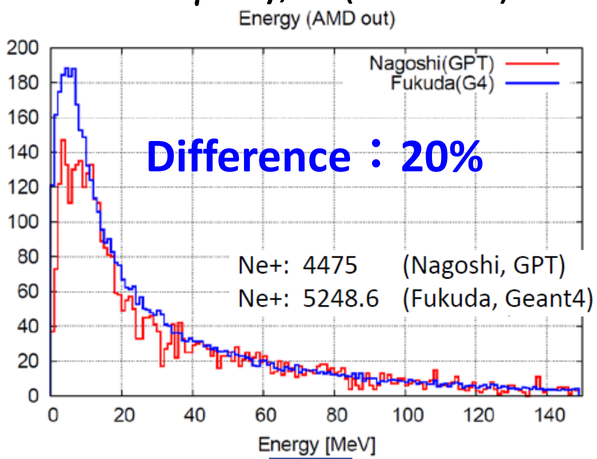
The difference is caused by as follow effects:
- Positrons are also generated at other than a target by gamma-rays.
- Positrons are repelled at the surface of the FC. A part of that positrons is captured.

Nagoshi-san used General Particle Tracer (GPT) for tracking simulation.
The simulation by GPT does not include these effect.

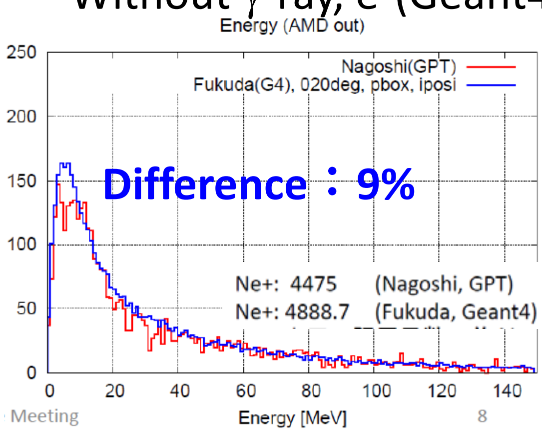
Other difference is Input data.
- Positrons produced W-target are used in Nagoshi's simulation. In Fukuda's simulation, the target is W26Re.
- Statistics is different. Number of primary e-: 1000 (Nagoshi), 10000(Fukuda)

Energy distribution and Number of positrons at FC exit

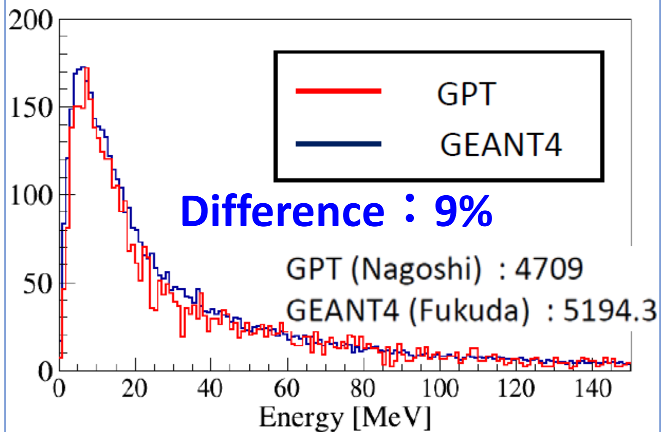
With γ-ray, e-(Geant4)



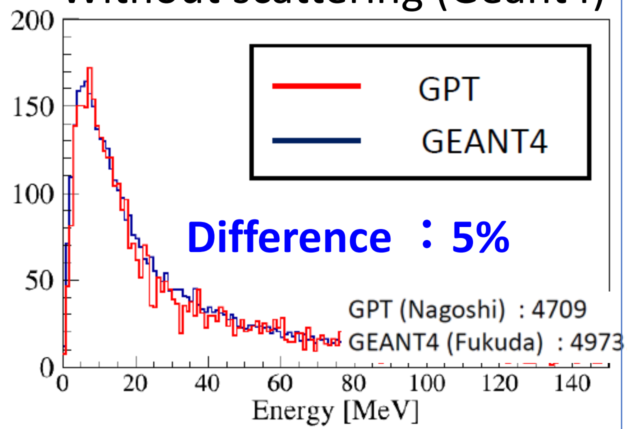
Without γ-ray, e-(Geant4)



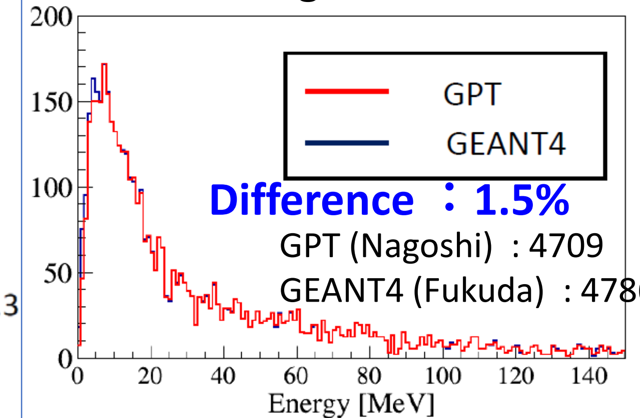
With scattering (Geant4)



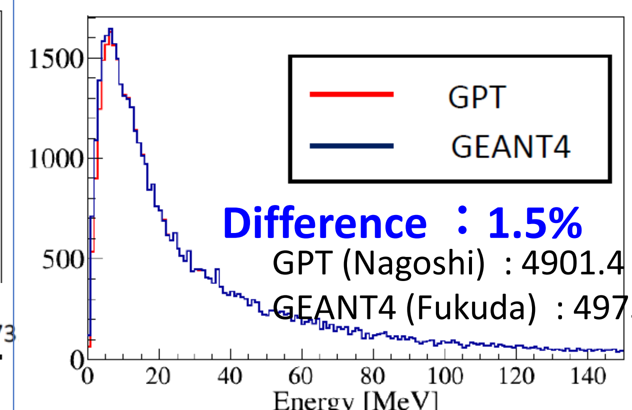
Without scattering (Geant4)



Input data
which Nagoshi-san used



Input data
which Fukuda used



Yield calculation with divided solenoid coils

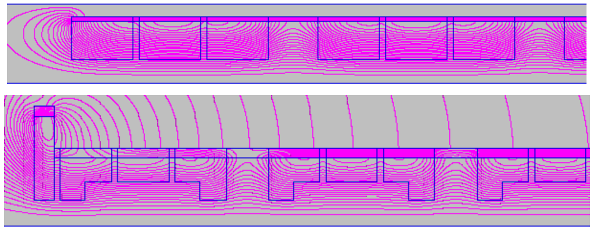
Yield calculation

The capture linac is placed in the constant magnetic field of a solenoid in simulations so far.
Practically, spaces of wave guides, vacuum pumps and so on are required.
Therefore, the capture linac is covered by short solenoid coils to make these spaces.

I tried to calculate the positron yield in cases of :
- Constant Bz field (a long solenoid coil)
- Magnetic field made by divided solenoid coils
- Magnetic field made by divided solenoid coil with changed shape

Input parameters

Input ：3GeV e- beam, Ne- 1×10^4, $\sigma x,y$ = 2mm, σz = 1mm
Target：W26Re, 16mm
Target-AMD: 5mm
OMD: FC designed by Pavel Martyshkin (Peak 5.0T)
DC solenoid: One long solenid
Divided solenoid coil
Divided solenoid coil with changed shape



Accelerating tube : SWx36

Electro-magnetic field : Pillbox (TM010)

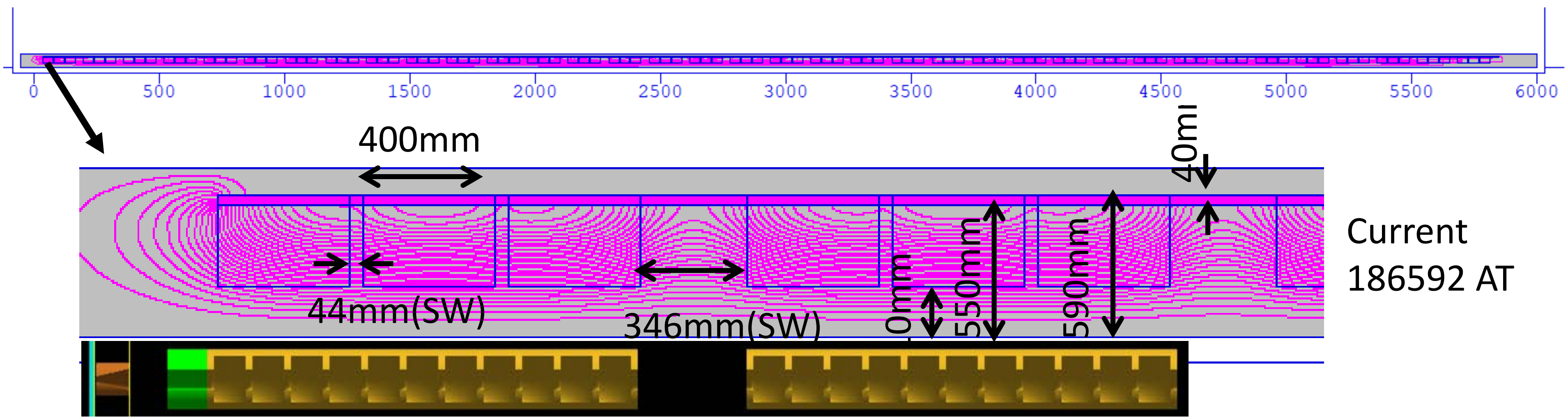
$E_z = E0*J0(p01*r/a)*\sin(omegatime*t+cavPhase)$

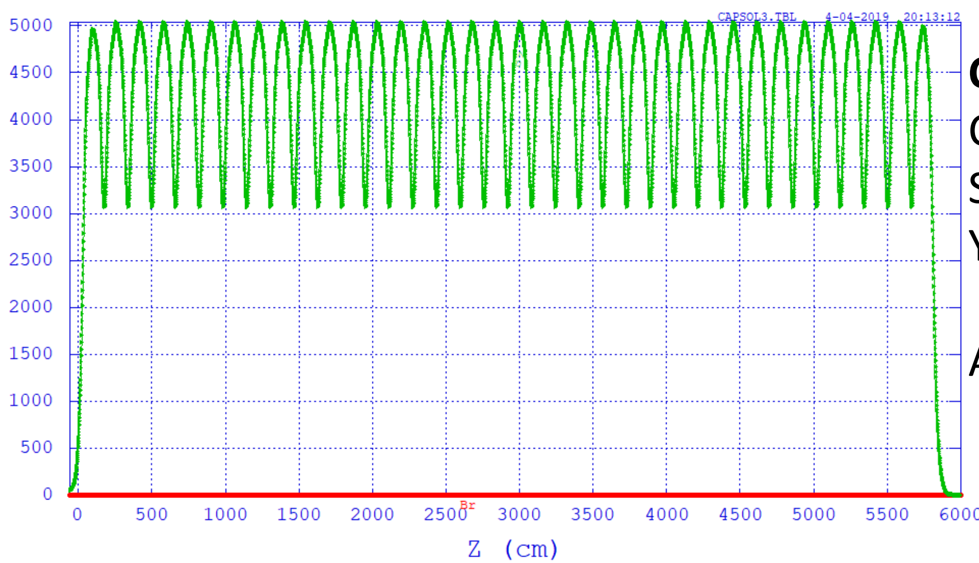
$B\phi = E0*J1(p01*r/a)*\cos(omegatime*t+cavPhase)/c\_light$

→Up to 250MeV.

Capture linac phase: 10deg

Divided solenoid coils





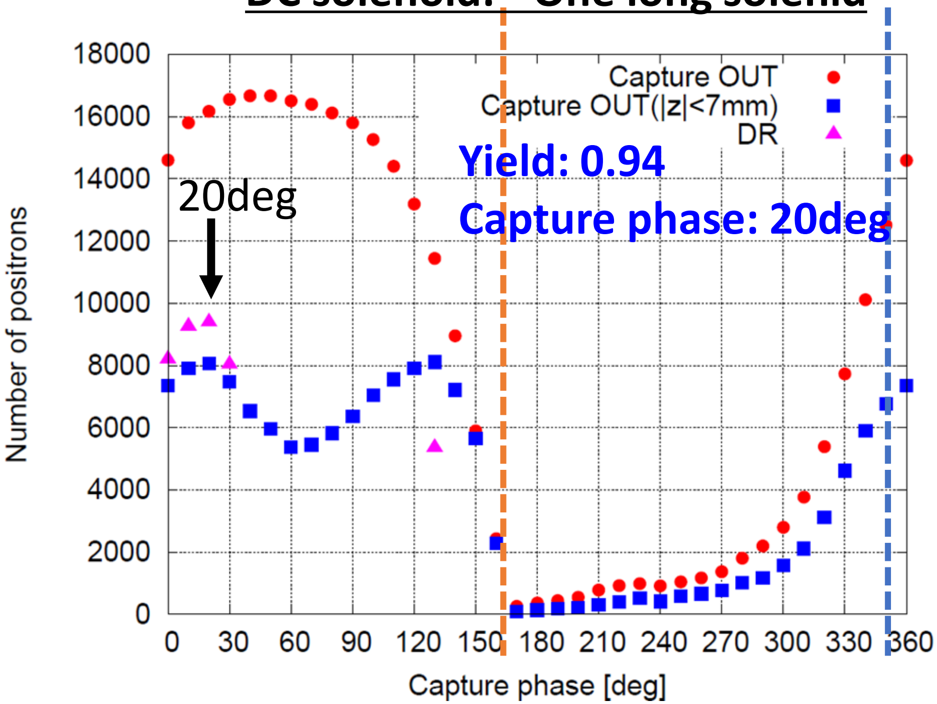
Coil current: 186592 AT
Coil length: 400mm
Space between coils: 44mm
Yoke thickness: 40mm

A return yoke covers the whole capture linac.

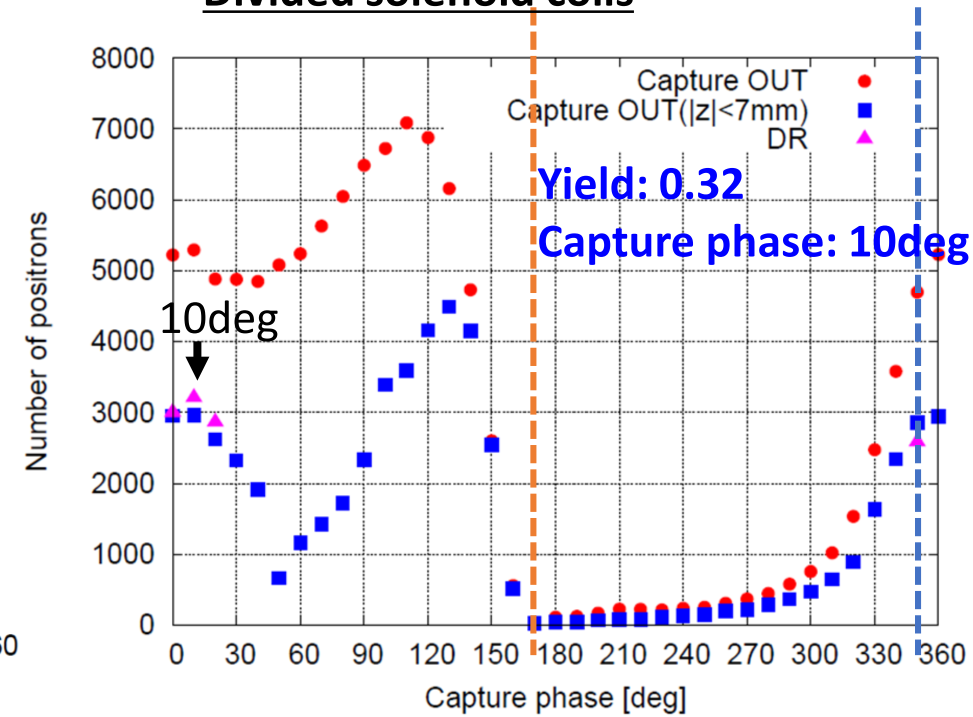
Result of yield calculation

The number of positrons is reduced by 63% when the DC solenoid is changed from one long coil to divided coils

DC solenoid: One long solenid



Divided solenoid coils



Accelerating Phase 172deg

Decelerating phase 352deg

Number of primary e-: 10000

Magnetic field of FC and Solenoid

OMD

FC: the field designed by Pavel Martyshkin by using CST studio.

DC Solenoid in a capture section

One long solenoid coil: 0.5T (Bz const)

Divided solenoid coils (*)

Divided solenoid coil with changed shape (*)

*** No coil at a space between accelerating tubes**

$$B_r^a(r,z) = \sum_{\nu=1}^{\infty} \frac{(-1)^\nu}{\nu!(\nu-1)!} B_{z0}^{(2\nu-1)}(z) \left(\frac{r}{2}\right)^{2\nu-1}$$
$$= -\frac{B'_{z0}(z)}{2} r + \frac{B_{z0}^{(3)}(z)}{16} r^3 - \frac{B_{z0}^{(5)}(z)}{384} r^5 + \frac{B_{z0}^{(7)}(z)}{18432} r^7 - \frac{B_{z0}^{(9)}(z)}{1474560} r^9 + ..$$

$$B_z^a(r,z) = \sum_{\nu=0}^{\infty} \frac{(-1)^\nu}{(\nu!)^2} B_{z0}^{(2\nu)}(z) \left(\frac{r}{2}\right)^{2\nu}$$
$$= B_{z0}(z) - \frac{B''_{z0}(z)}{4} r^2 + \frac{B_{z0}^{(4)}(z)}{64} r^4 - \frac{B_{z0}^{(6)}(z)}{2304} r^6 + \frac{B_{z0}^{(8)}(z)}{147456} r^8 + ...$$

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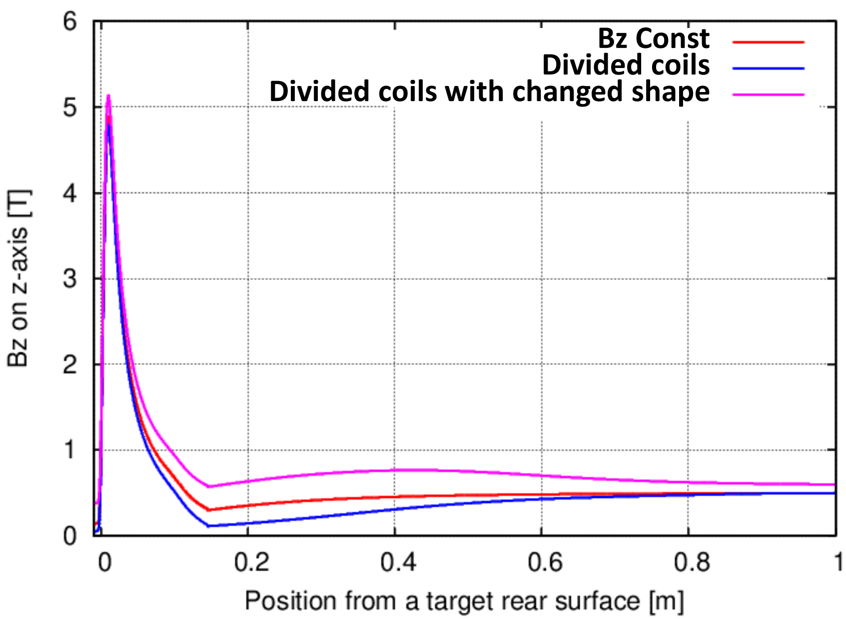
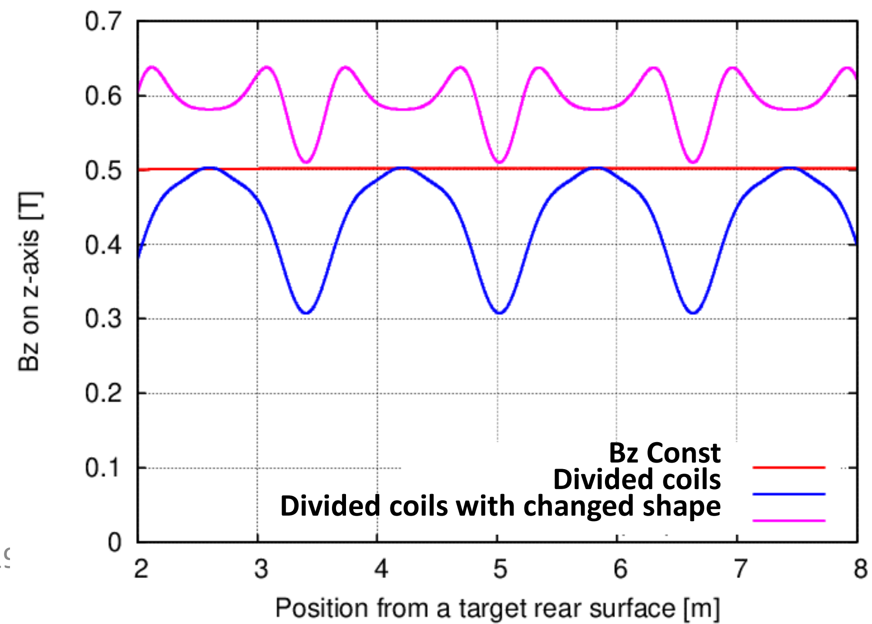
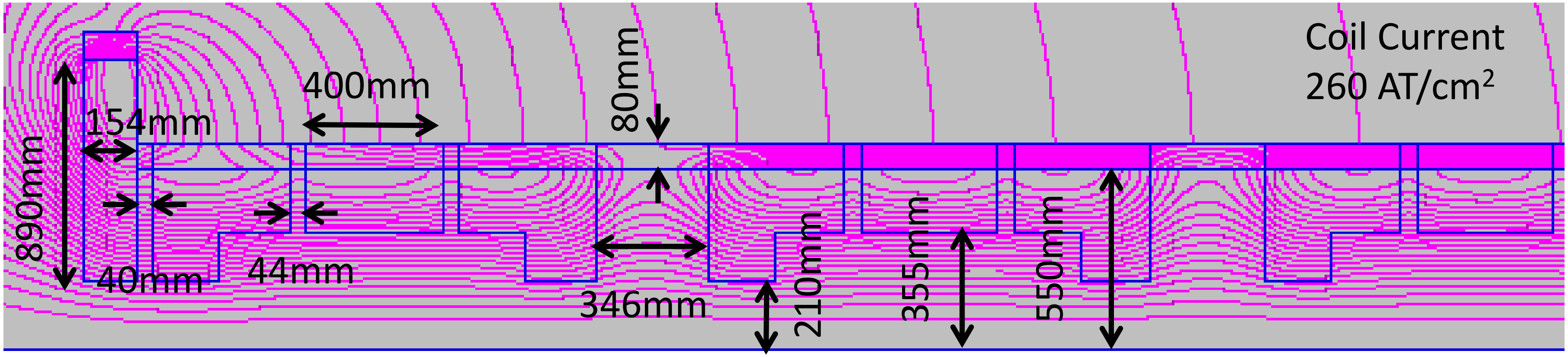
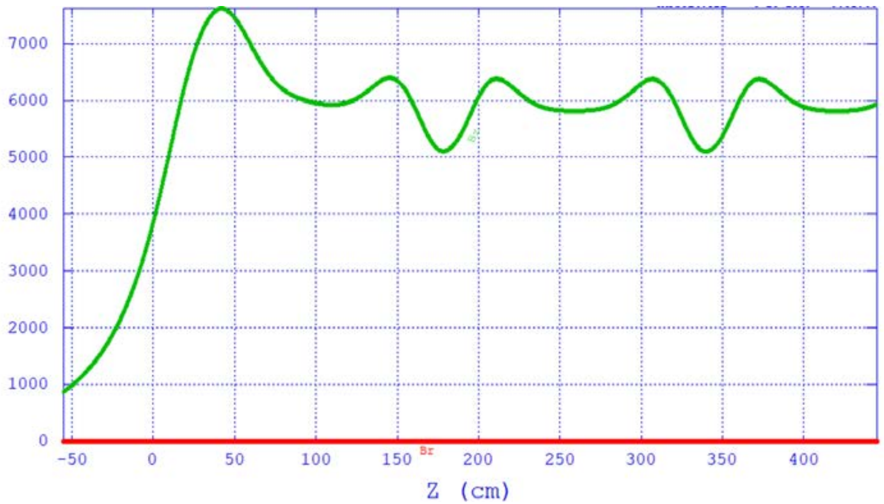




Divided solenoid coil with changed shape



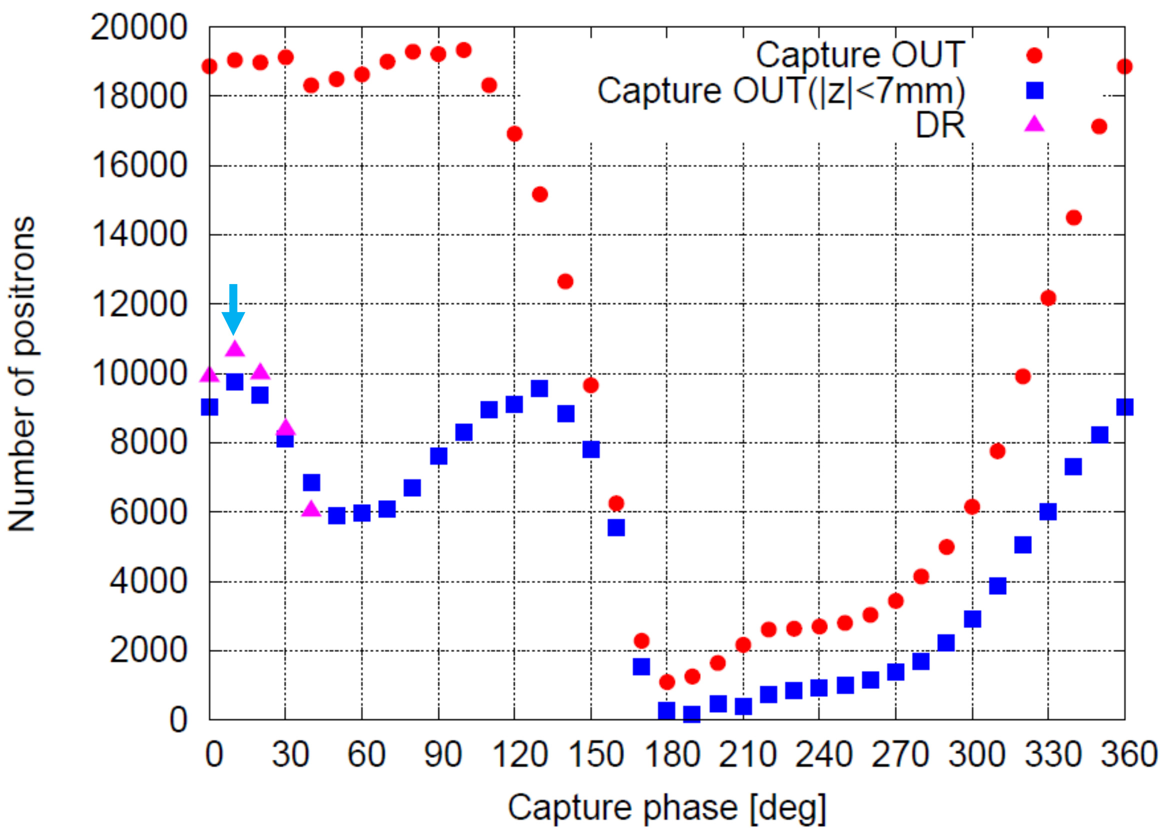


current density of coil: 260A/cm2
Coil length: 400mm
Space between coils: 44mm
Yoke thickness: 40mm

Coil shape of both end of accelerating tubes are modified to reduce the drop of the magnetic field at intervals of tubes.

Number of positrons

Number of positrons at the capture end and the DR was calculated when the rf phase of capture linac.
Number of positrons becomes maximum at the phase of 10deg.

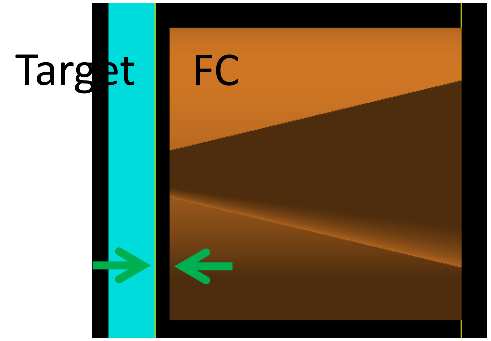


Ne+(DR): 10646
Yield: 1.06
Capture phase: 10deg

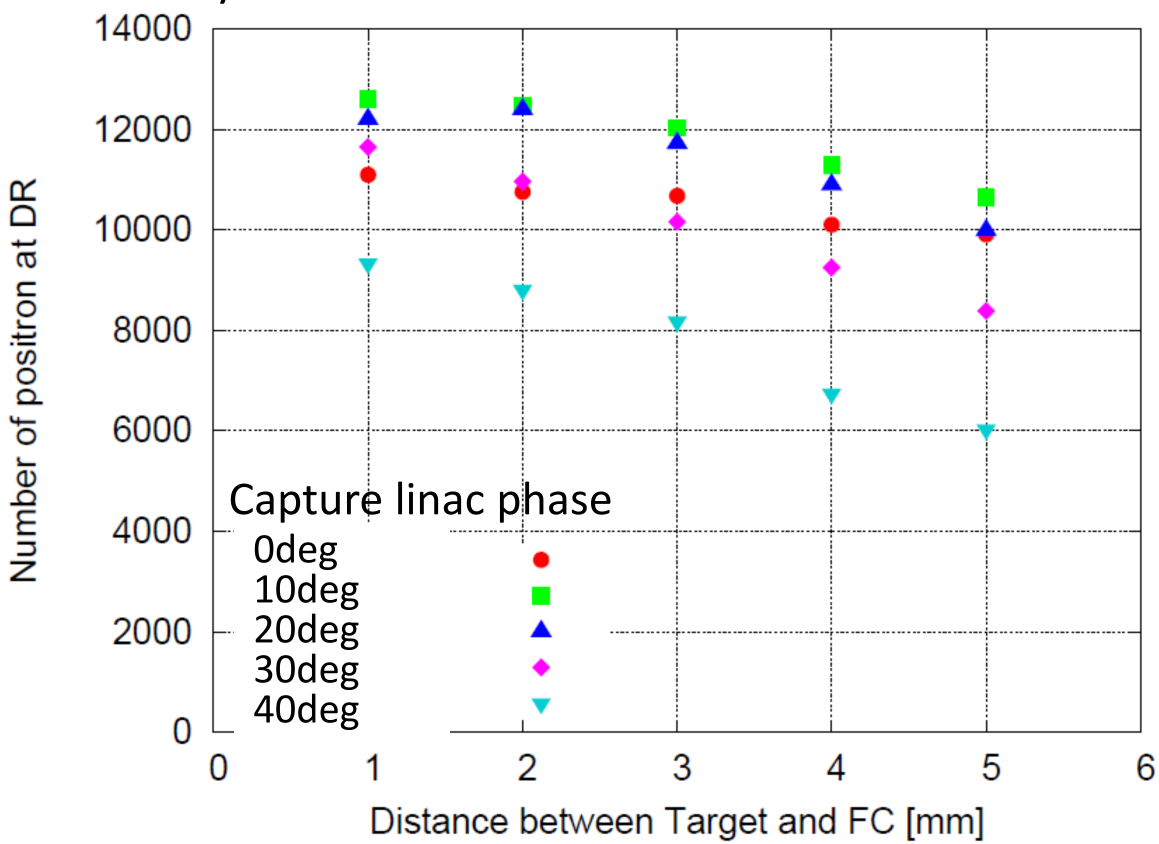
Number of primary e-: 10000

Yield calculation when the distance of target and FC is changed

Scan of distance between Target and FC



Yield increase from 1.06 to 1.26 when the distance is changed from 5mm to 1mm.
The yield saturates less than the distance of 2mm.



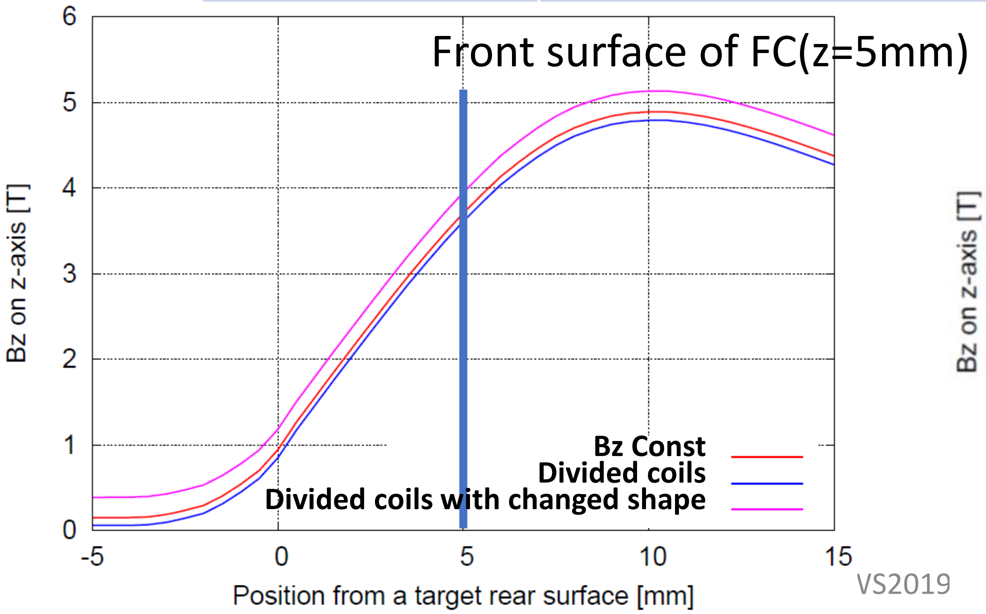
Distance between Target and FC [mm]	Ne+(DR)	Yield(DR)
1.0	12601	1.26
2.0	12472	1.25
3.0	12042	1.20
4.0	11292	1.13
5.0	10646	1.06

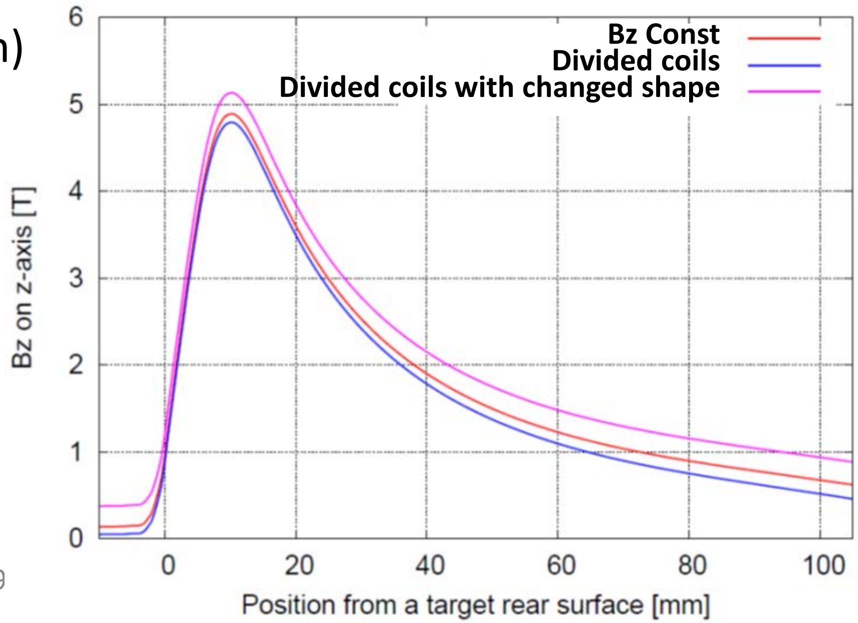
Primary e-: 10000

Magnetic field strength at target rear surface

Target-FC [mm]	Bz on target rear surface [T]	Heating value by eddy current [kW](*)
1.0	3.46	16
2.0	2.93	11
3.0	2.36	7
4.0	1.79	3.5
5.0	1.18	1.1

(*) estimated by T. Omori





Summary

- I could reproduce the result of Nagoshi-san' simulation.
- Now I can calculate the positron yield at DR by using the tracking code which been succeeded from Kuriki-san and Nagoshi-san.
- Yields were calculated using a magnetic field created by divided solenoid coils in the capture linac.
  - One long solenoid(Bz const): Yield 0.94
  - Divided coils: Yield 0.32
  - Divided solenoid coil with changed shape: Yield 1.06
- Yields were also calculated when the distance between the target and the FC was changed.
  - Distance 5→1mm, Yield 1.06 → 1.26
  - The yield saturates less than the distance of 2mm.