Status of ILC Positron Source

LINEAR COLLIDER COLLABORATION

Designing the world's next great particle accelerator

Masao KURIKI (Hiroshima University)

Introduction

- Undulator Positron source is the baseline.
- Undulator prototyping, capture RF design, lattice design, etc. have been done, but the target design and AMD prototyping are not completed yet and the study is interrupted by lack of budget.
- As an anticipation of the delay of Undulator Positron source, E-driven ILC positron source is designed.

Undulator ILC Positron source

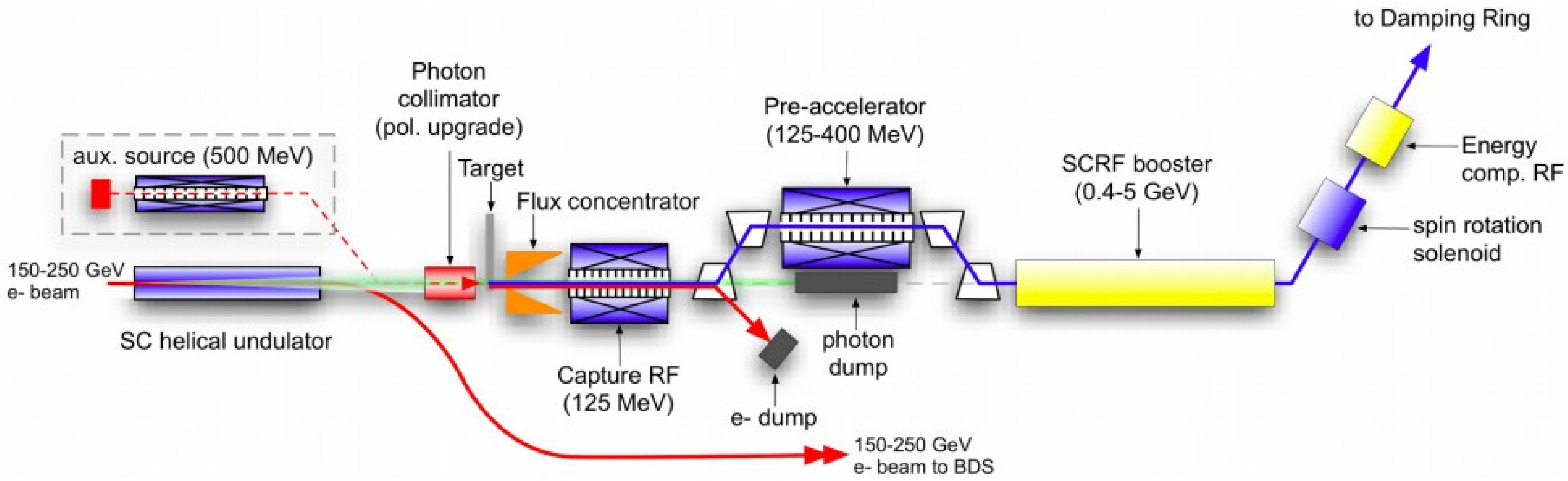


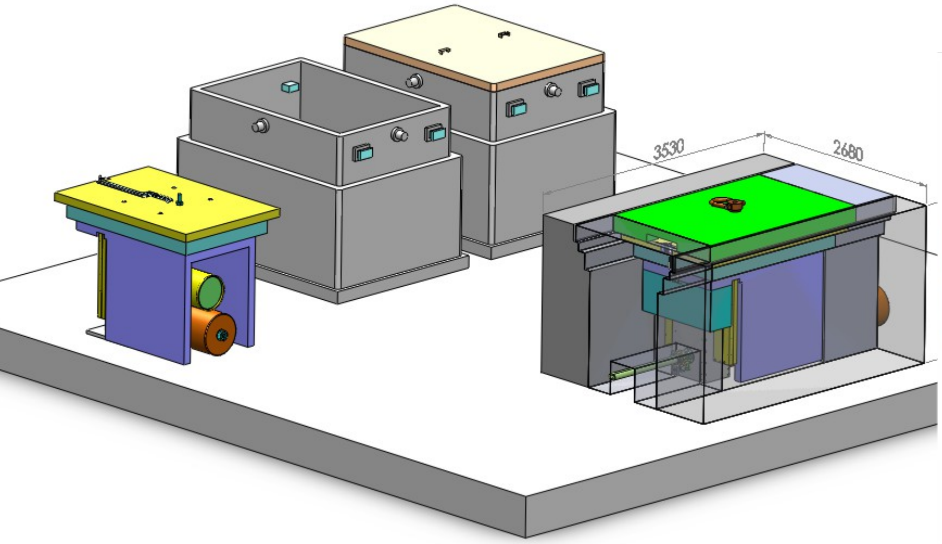
Figure 3.4. Overall Layout of the Positron Source, located at the end of the electron Main Linac.

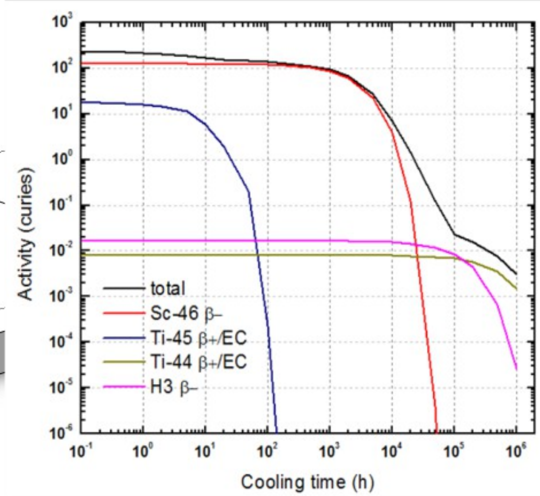
- 147m active undulator length, additional 73.5m is reserved for the polarization upgrade.
- 500m drift space between the undulator and target.
- NC RF up to 400 MeV for capturing.
- SC RF up to 5 GeV
- Energy Compressor
- Spin rotator (SC solenoid)

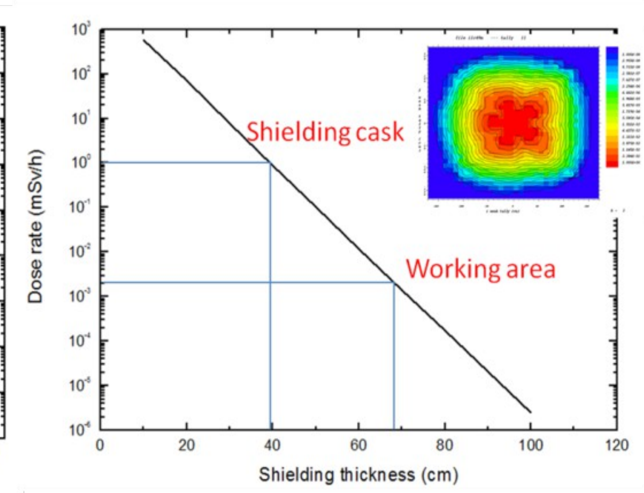
Parameters

Parameter	Number	Unit
Undulator period	11.5	mm
Undulator aperture	5.85	mm
Undulator Strength *K*	0.92/0.75/0.42	
Drive Beam Energy	150/175/250	GeV
Undulator Type	Helical	
Undulator Section Length	147	m
1st cut off energy	10/16/42	MeV
Photon Beam power	63/55/42	kW
Target material	Ti-6Al-4V	
Target Thickness	0.4/14	X_0/mm
Positron Polarization	30	%

Target area shielding and target remote handling

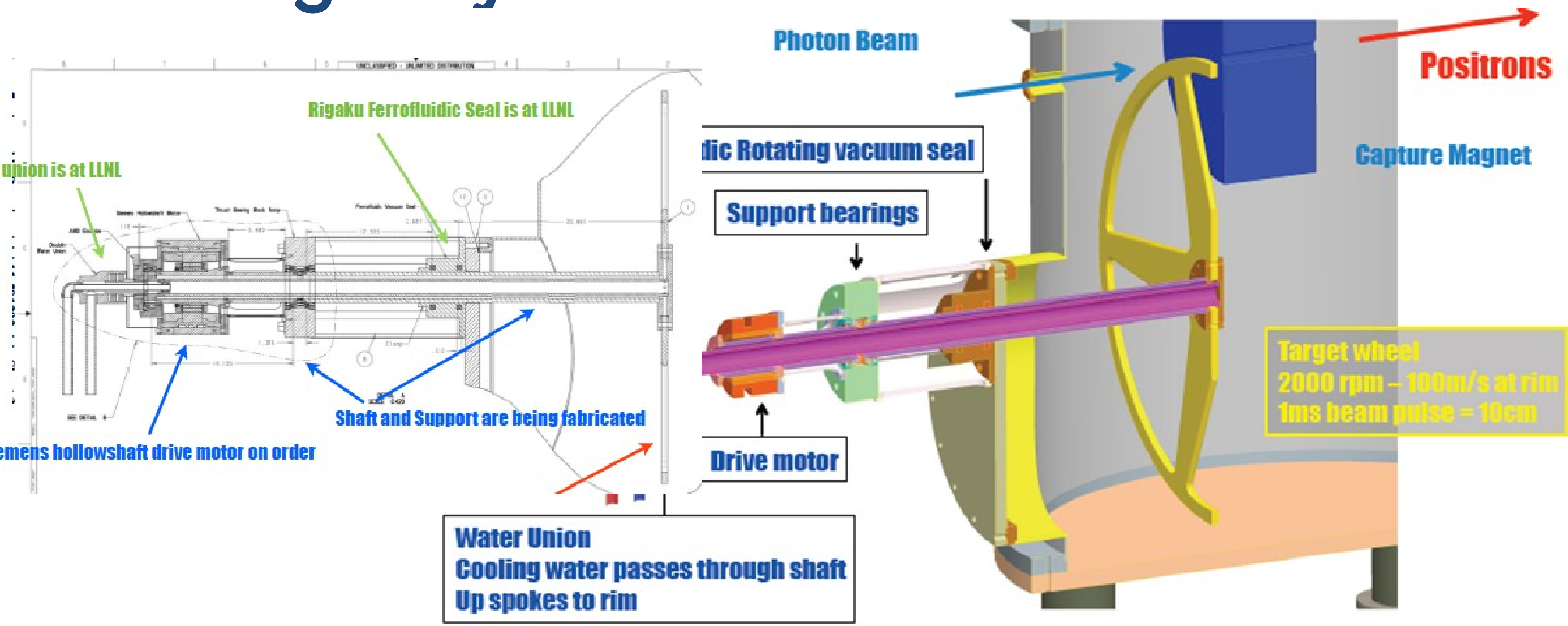






- The target will be highly activated after one year of operation.
- 150kW photon beam, 5000 hours, 1 week after,170 mSv/h at 1m. Concrete shielding of 0.8m thick.
- A remote-handling system is used to replace the target, OMD and the 1st 1.3m NC RF cavities.

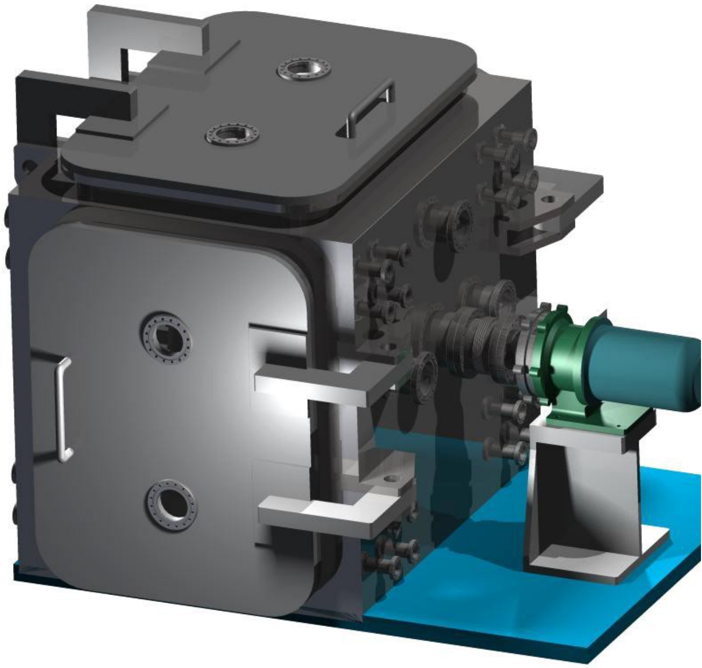
Target system

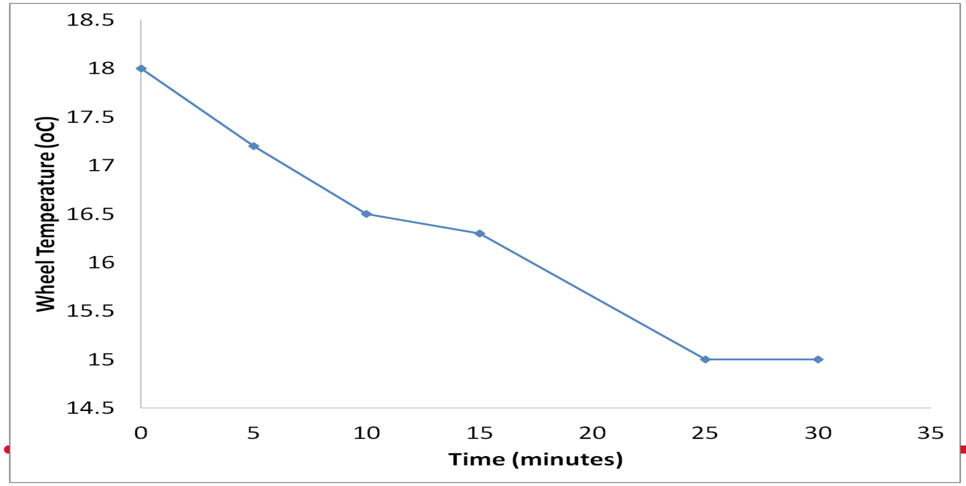


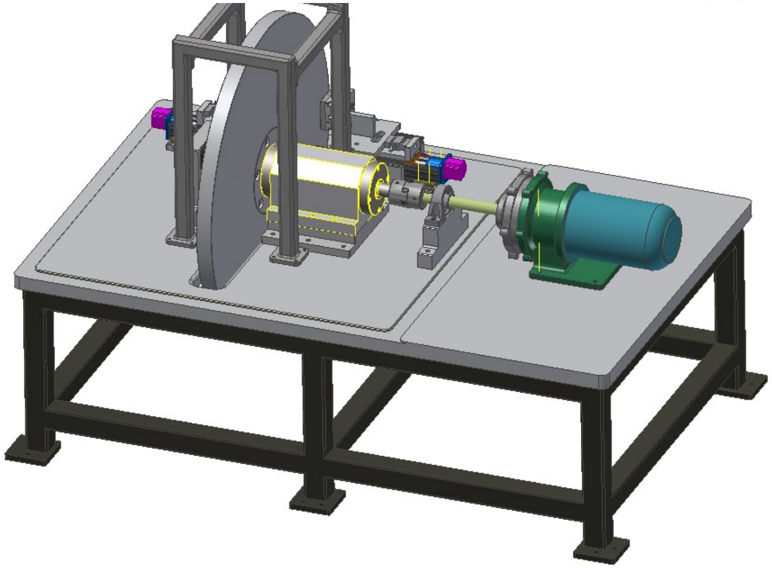
- Fast rotation test has been done in air successfully.
- The vacuum compatible target test was not very successful.

Contact Cooling Target (ANL/Tsinhua)

- Proposed by W. Gai as a replacement of water-cooling target.
- Heat is removed by touch pad with lubricant.
- A pilot experiment in air shows shows good features and a test in vacuum will be made.

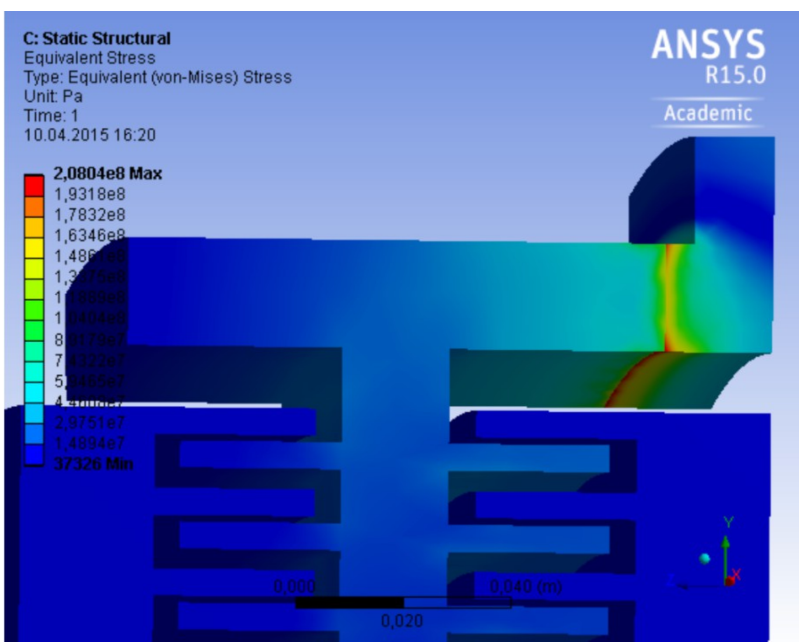


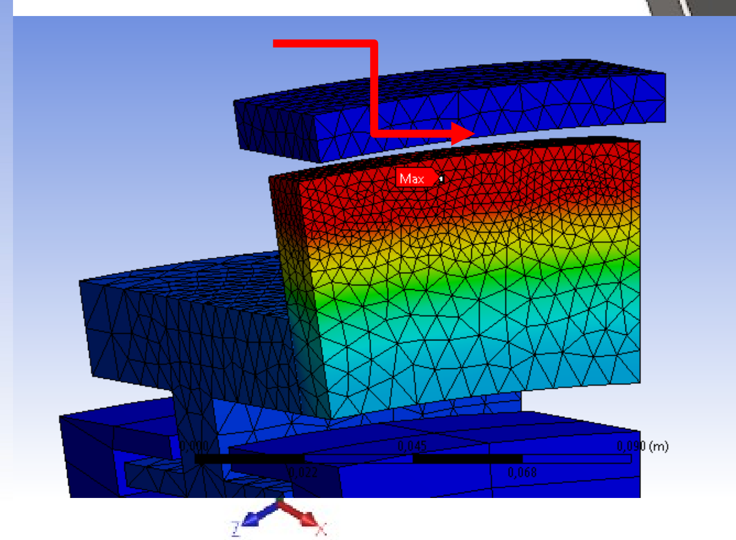


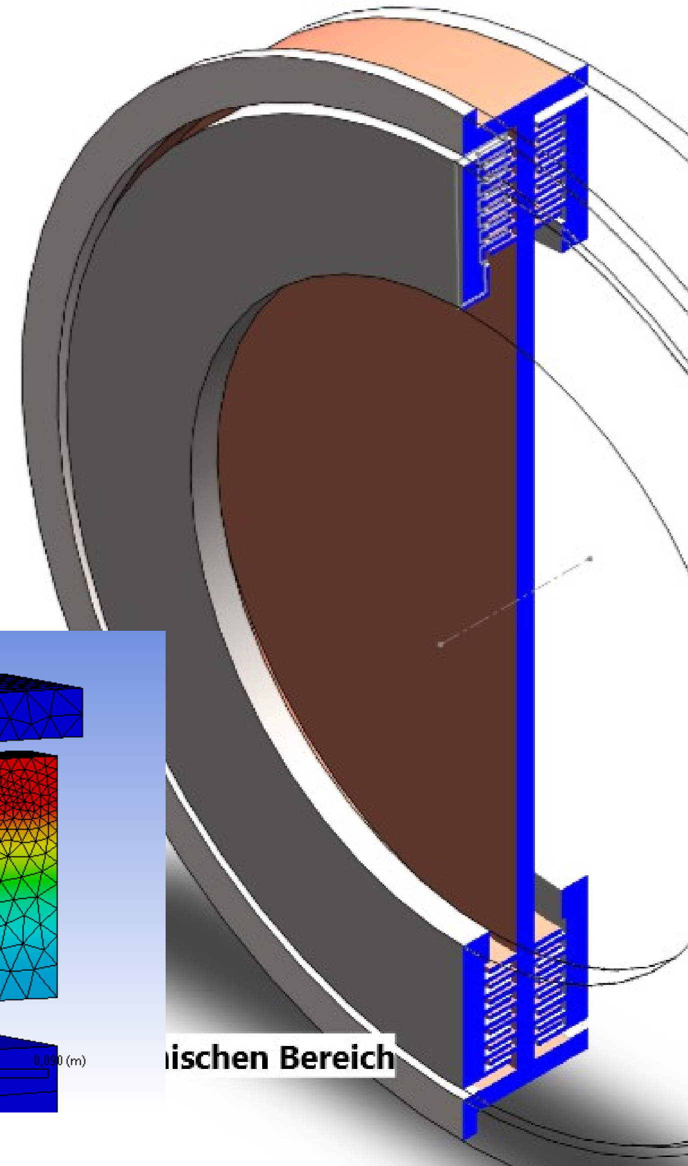


Radiation Cooling Target (DESY/CERN)

- Thermal heat is removed by radiation .
- Temperature and stress is manageable.
- Seeking chances of prototyping.

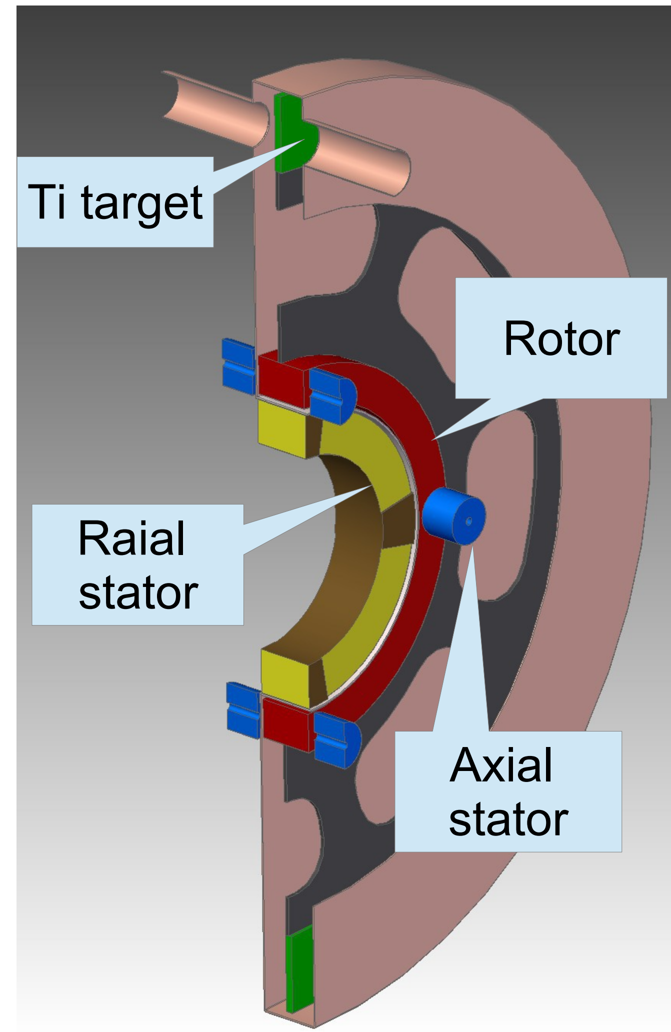






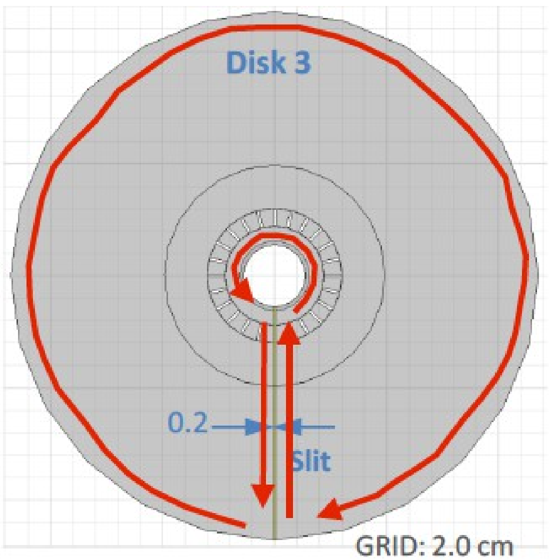
Radiation Cooling Rotor Target (M. Breidenbach)

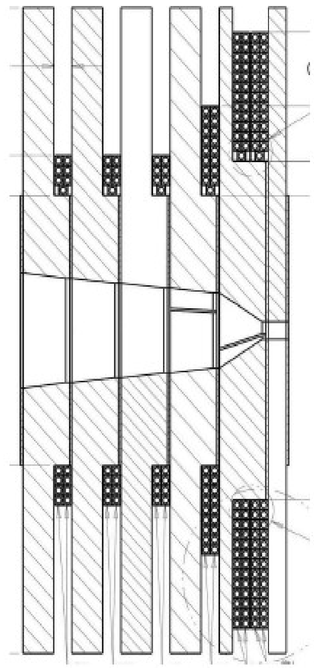
- Eliminate water in the vacuum space by radiation cooling.
- Eliminate rotating shaft seals by magnetic suspension and rotational drive, with the coils outside the chamber.
- Use titanium (Ti-SF61) for the actual rotating hoop (Rin = 50 cm; Δr = 10 cm; t = 14 mm; f = 2000 rpm)
- For 600 C hoop to 25 C water cooled vacuum can, ε = 0.6, P = 13 kW> 7.5kW target heat load.

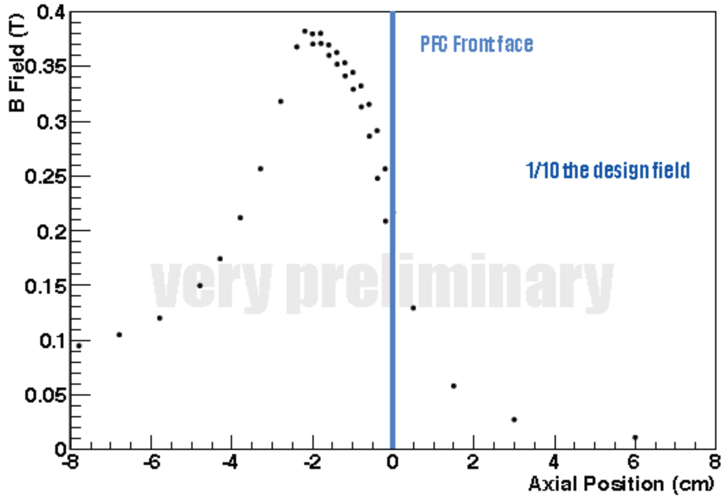


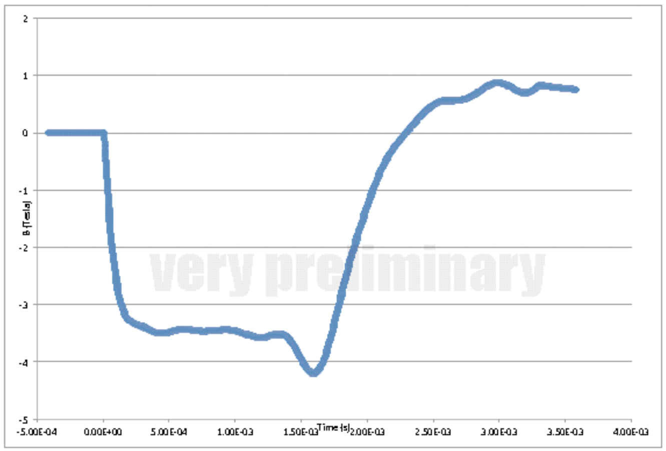
Flux Concentrator

- Flux Concentrator for Matching
- Current in the primary coil induces the concentrated B field in the inner bore.
- A room temperature device is prototyped and demonstrated 1ms flat top.

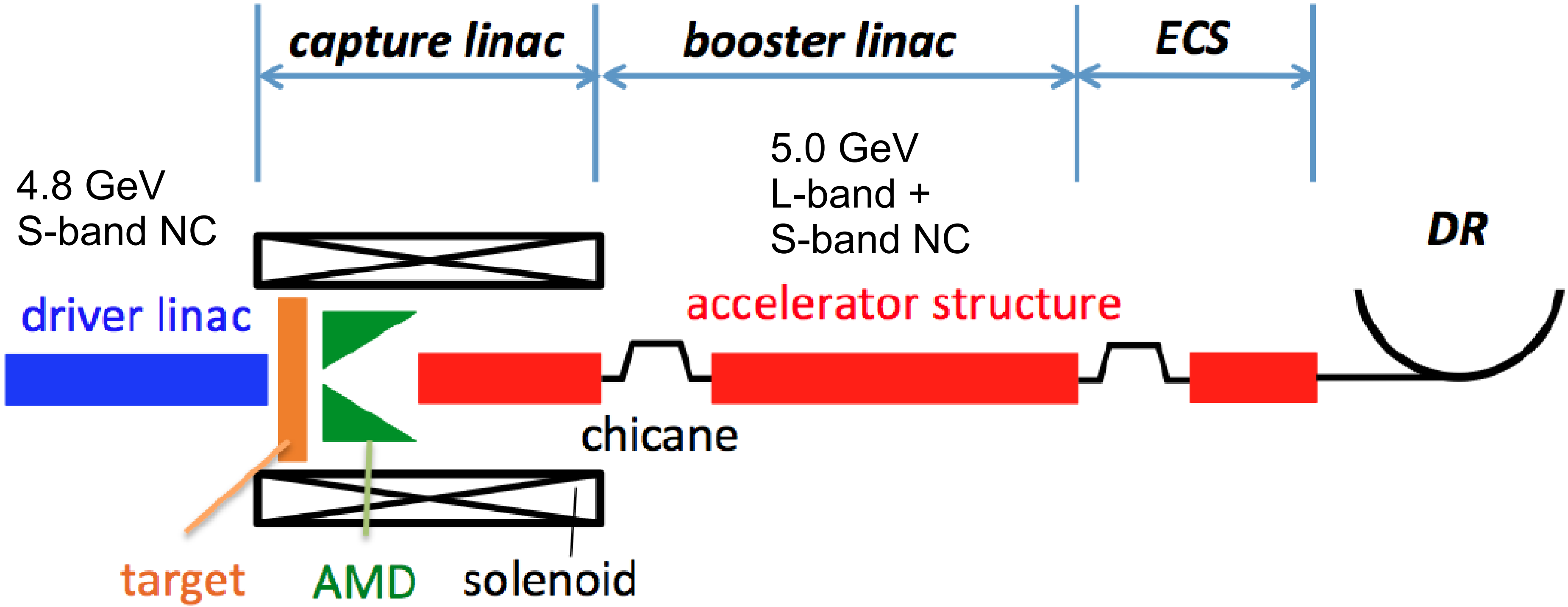






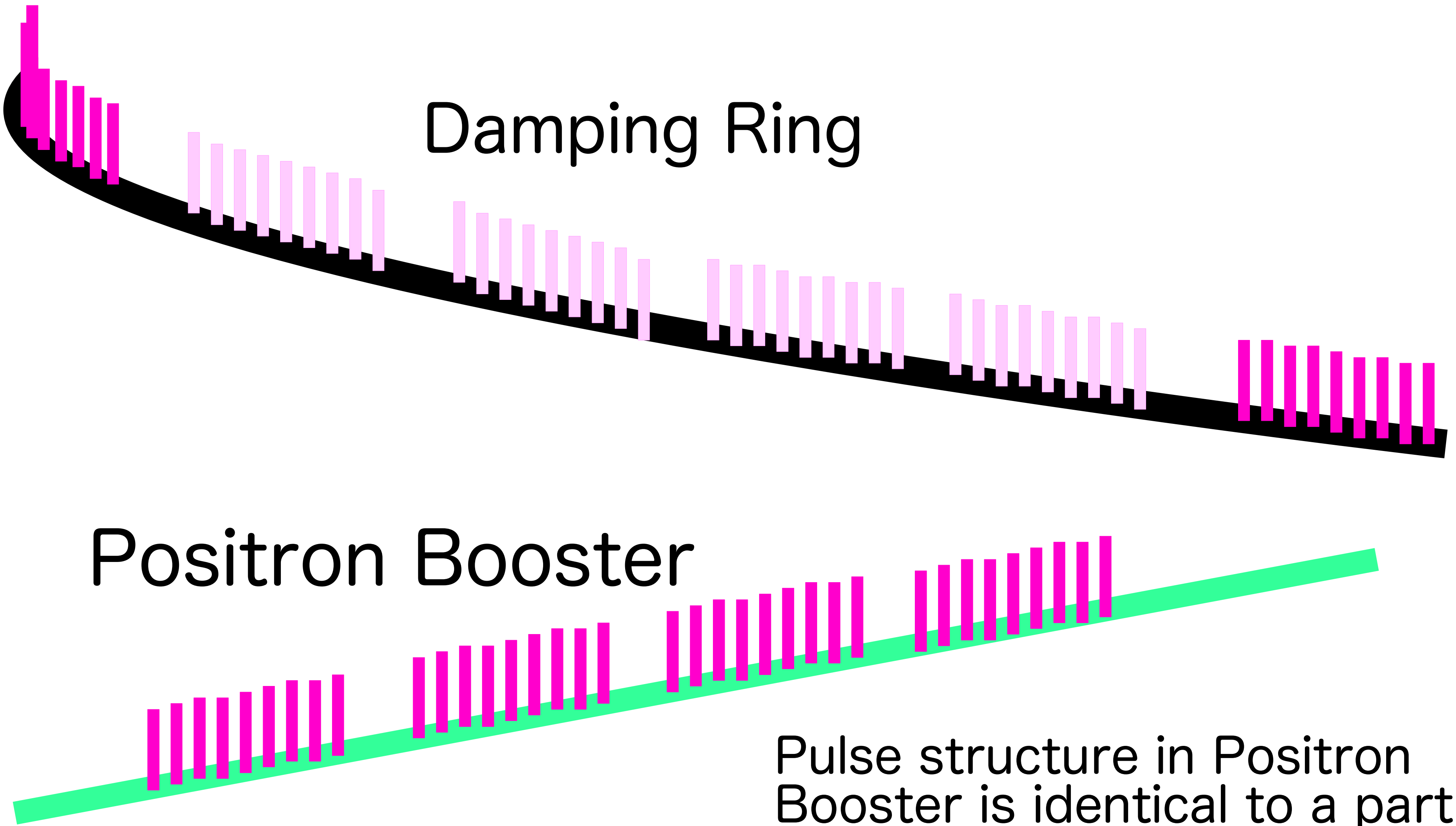


E-driven ILC Positron Source



- 20 of 1us pulses are handled with NC linacs operated in 300Hz.
- A simulation with off-the-shelf RF components shows an enough positron yield.
- Target prototyping

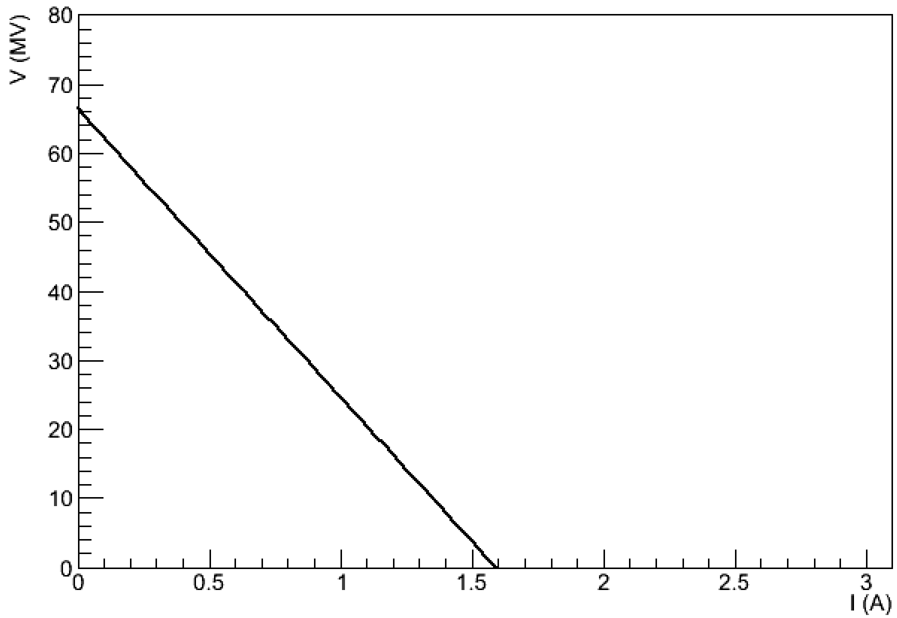
The beam handling and format



Pulse structure in Positron Booster is identical to a part of DR fill pattern.

Electron Driver

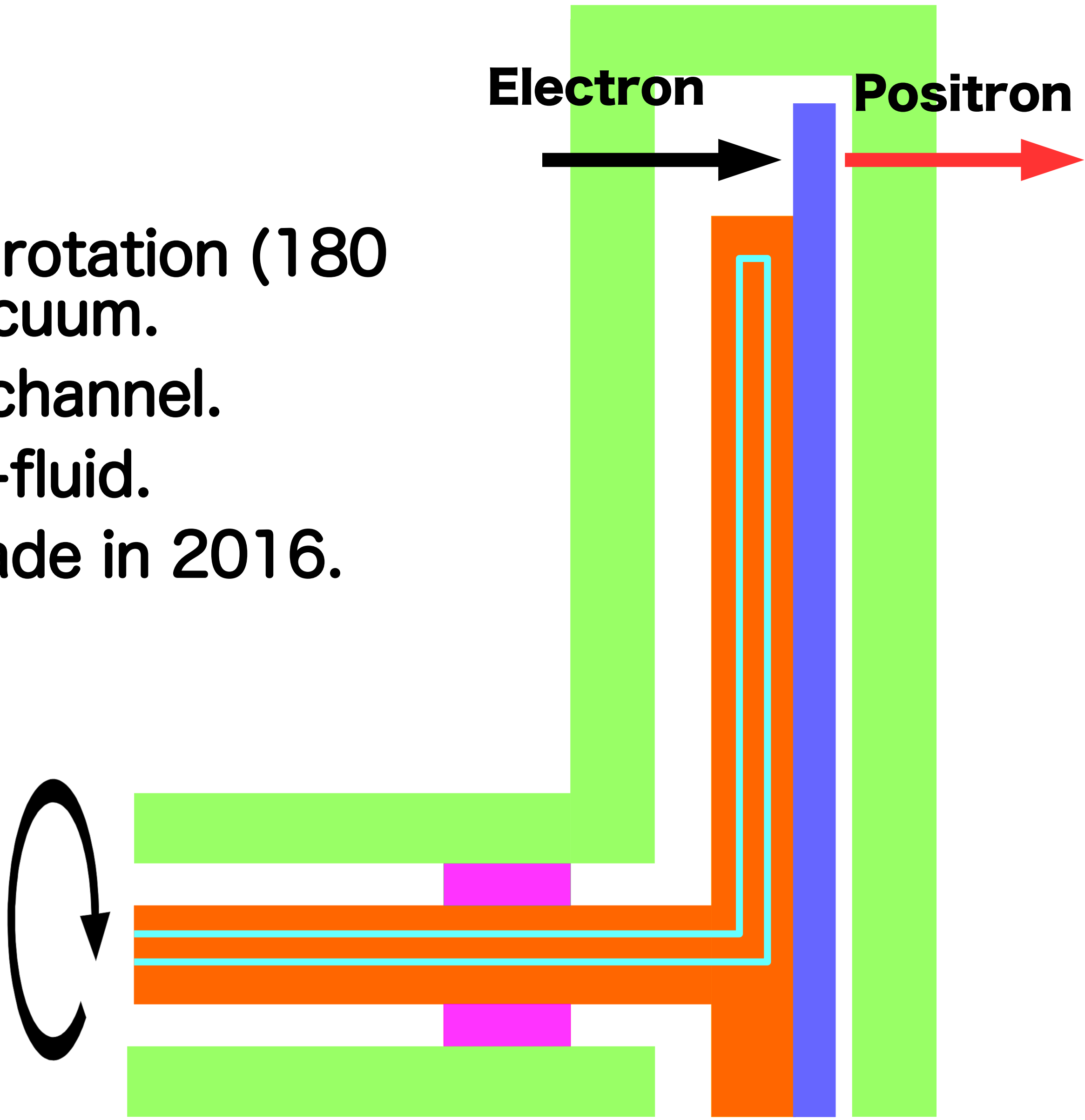
- 4.8 GeV Electron beam in the format with 3.8 nC bunch charge.
- S-band Photo-cathode RF gun for the beam generation.
- 120 of 3m S-band TW structures for the acceleration.
- 80 MW klystron-modulator drives 2 structures giving 40.1 MV/3m with 0.6A beam loading.



Lattice configuration	Number of cells	cell length	section length	Section energy
4Q + 2S	6	8.0 m	48.0 m	481 MeV
4Q + 4S	27	14.4 m	388.8 m	4330 MeV

Target

- W-Re 14mm thick.
- 5 m/s tangential speed rotation (180 rpm, 0.5m radius) in vacuum.
- Water cooling through channel.
- Vacuum seal with ferro-fluid.
- A prototype is being made in 2016.
  - Vacuum compatible,
  - No water channel,
  - Same mechanical properties.



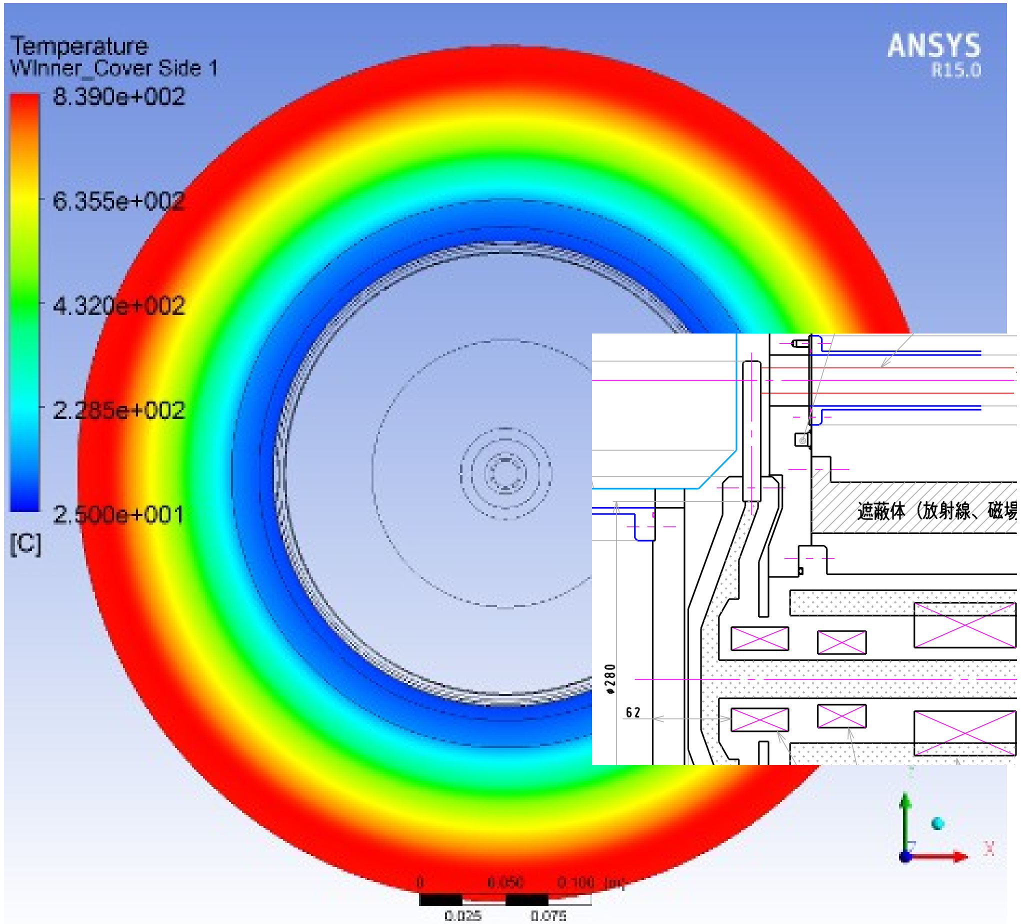
Seal performance

- Leak rate $2x10^{-7}$ $Pa.m^3/s$ at 1000 RPM.
- 1000 l/s pump capacity is enough to maintain UHV for accelerator.
- 1.5 MGy/year is expected for the seal. Irradiation test was performed at JAEA Takasaki lab.
- F-oil : Dissociation/degradation occurred at 0.27 MGy.
- CN-oil: 4.7 M. Gy. Viscosity increased, but NO dissociation degradation occurred. No additional leak was found with the irradiated seal at 0-600 RPM.
- The ferro-fluid seal is vital agains the radiation damage.

Rigaku FY2014

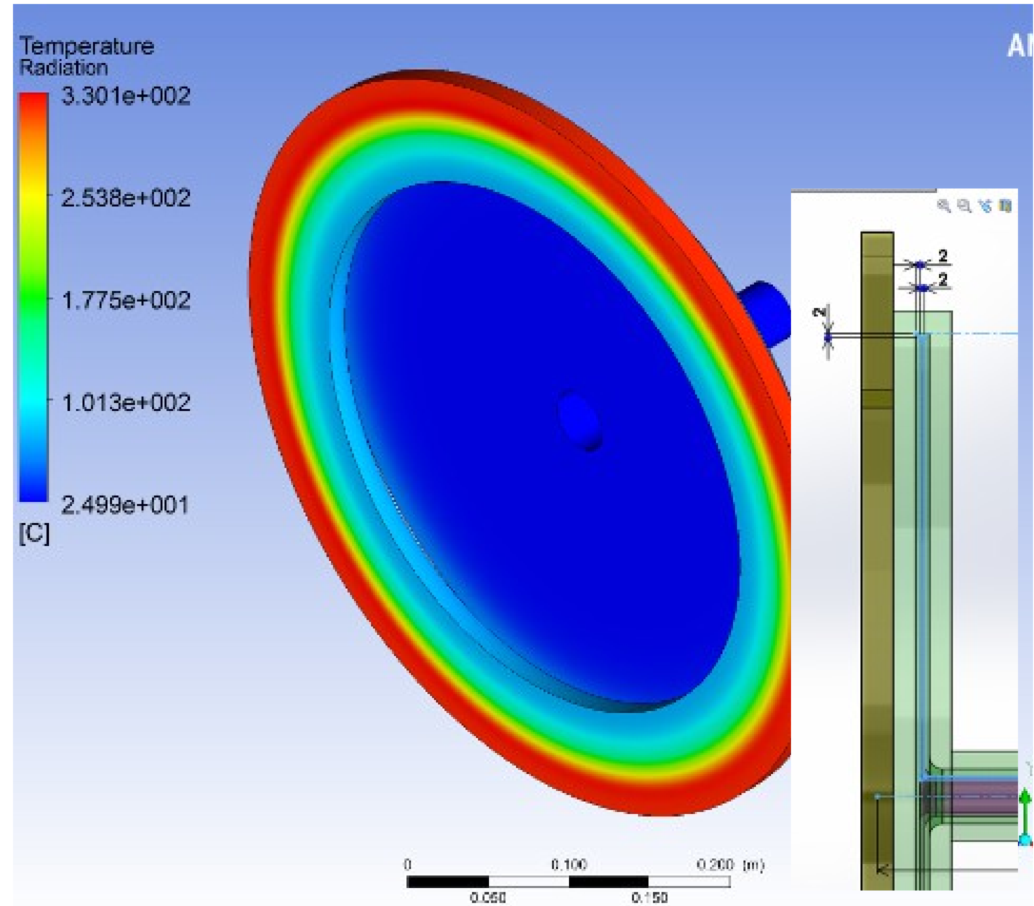
Rotation target design study

I Direct Cooling	II Indirect Cooling



Temperature Distribution

Max. 840℃



Temperature Distribution

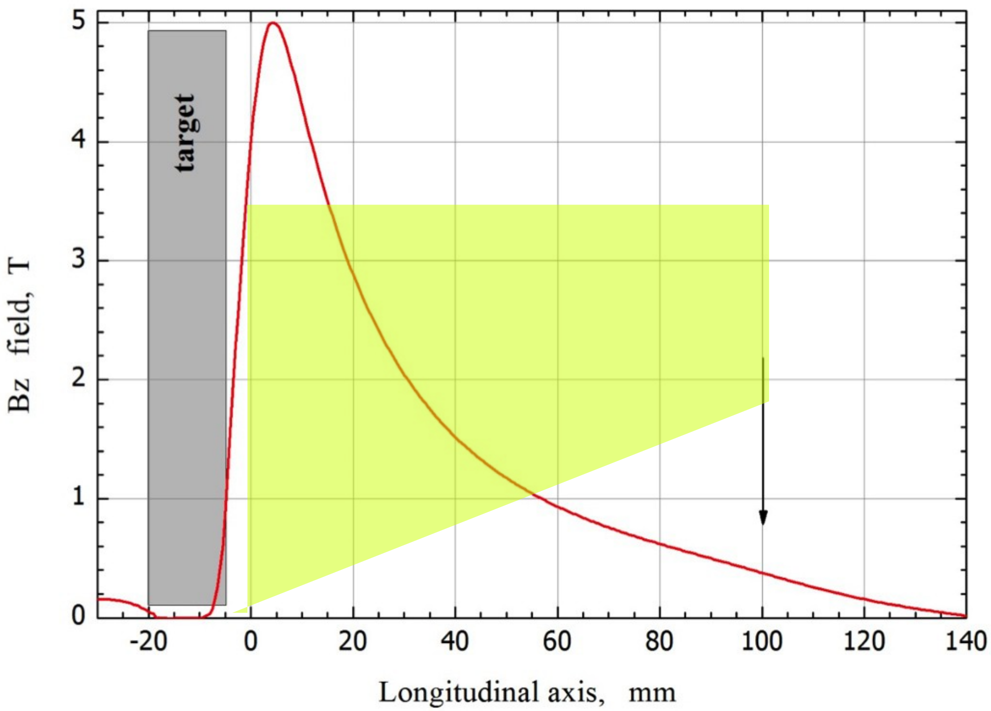
Max. 330℃

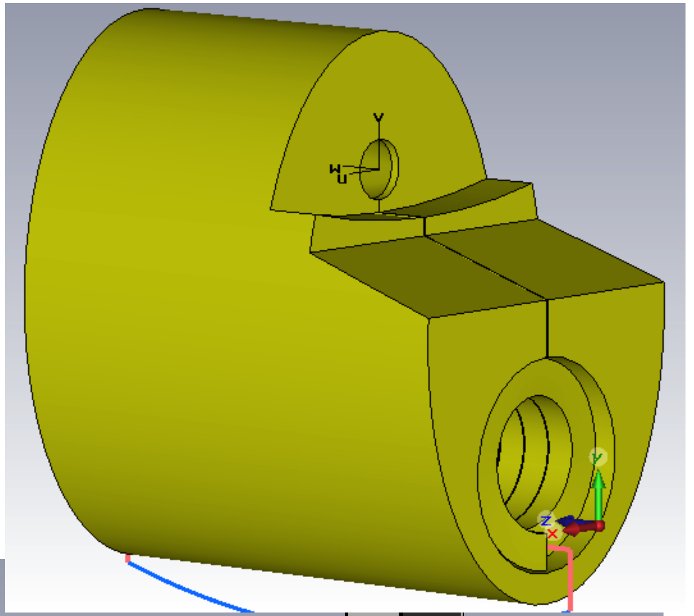
600rpm

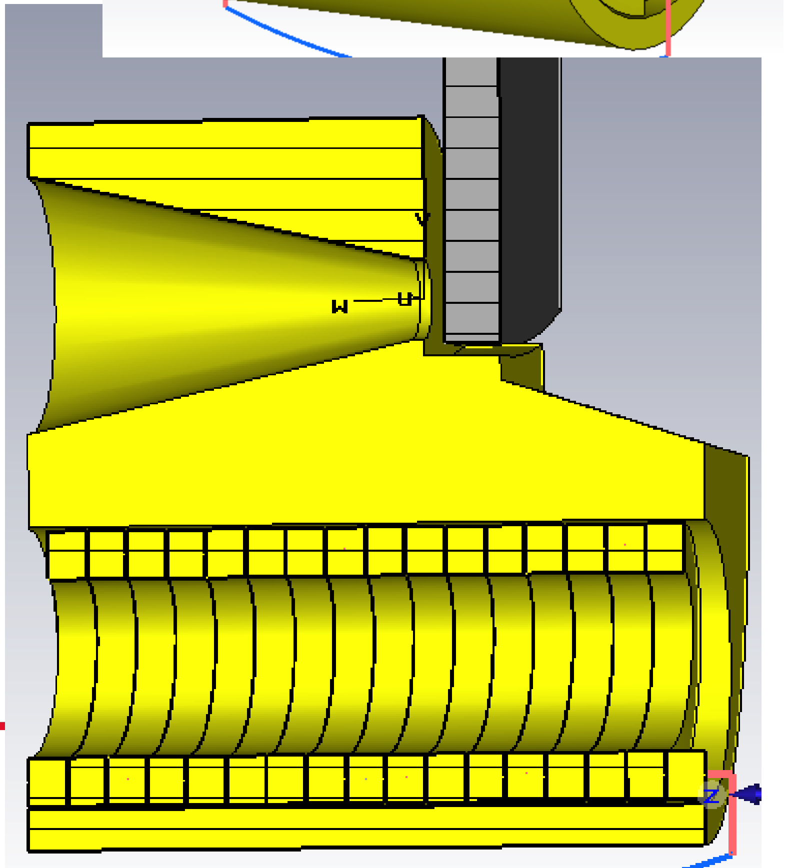
Conclusion: Indirect cooling is better.

Flux Concentrator
(P. Martyshkin)

- Flux Concentrator for AMD (Adiabatic Matching Device)
- 16 mm aperture
- 5 Tesla Peak field, 40mT trans.
- 25 kW ohmic loss.



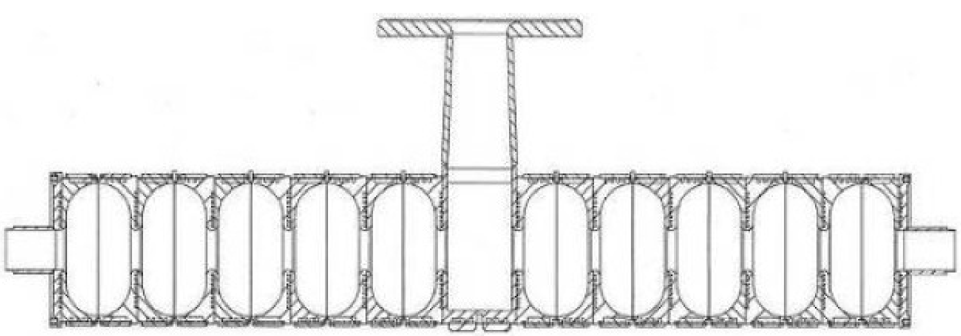


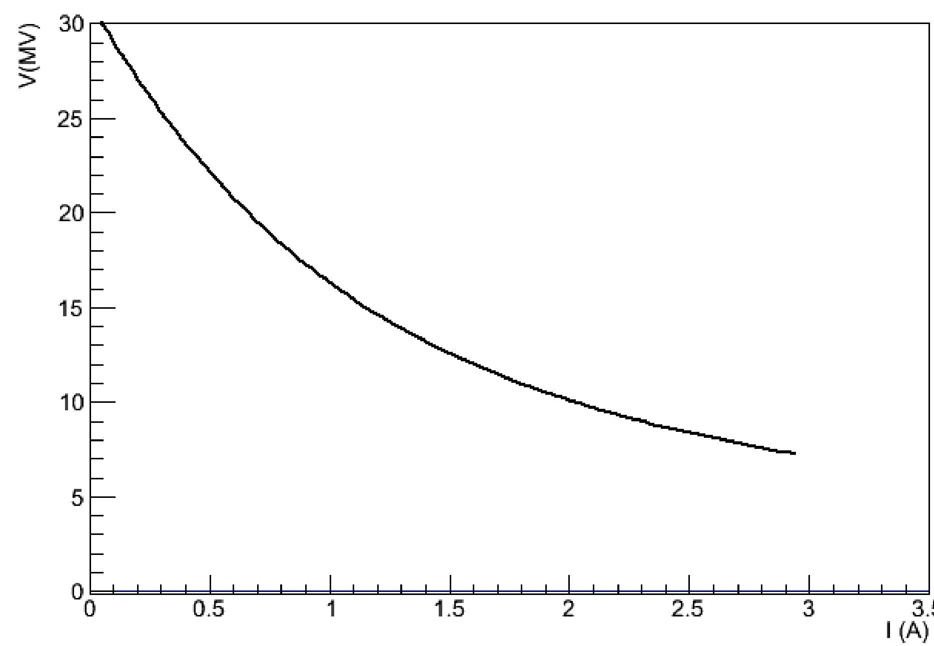


Positron Capture Linac

- L-band SW structure designed by J. Wang (SLAC) for the undulator capture section is employed.
- Two structures are driven by one 50 MM klystron.
- 14 RF modules.

Structure Type	Simple π Mode
Cell Number	11
Aperture 2a	60 mm
Q	29700
Shunt impedance r	34.3 MΩ/m
E_0 (8.6 MW input)	15.2 MV/m



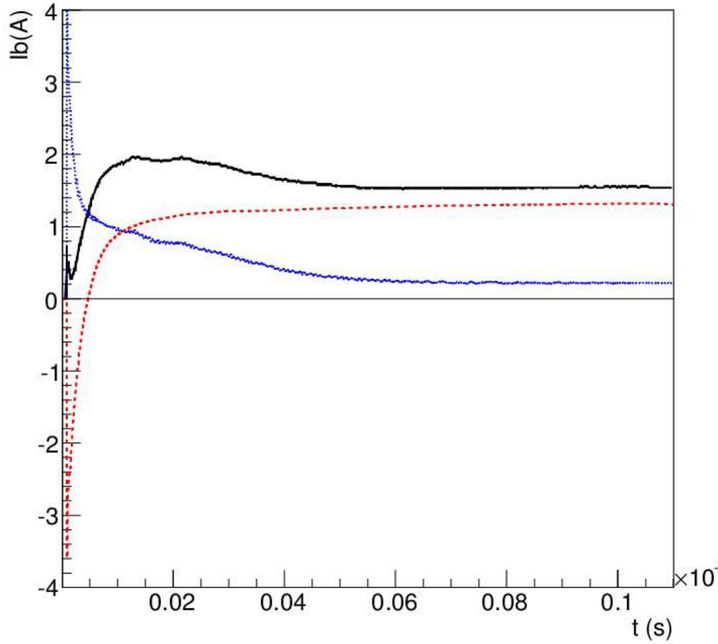


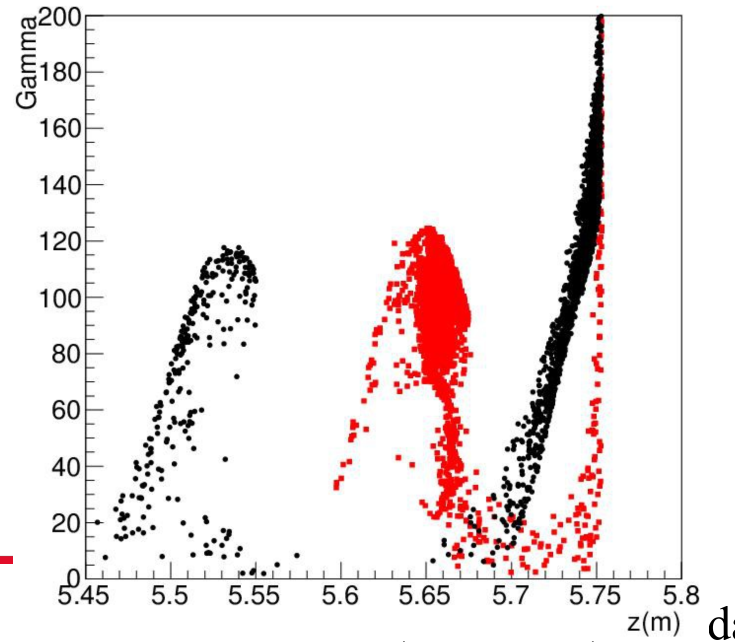
Capture Simulation

- Beam loading current is dynamically changed,
  - Bunching,
  - Lost particles
- For each cells, the accelerator gradient is calculated with $I_{BL}(t)$

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

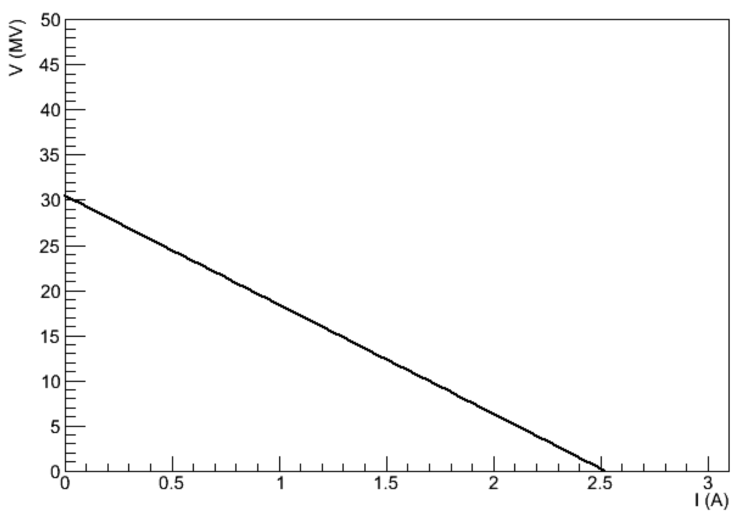
- 14 RF modules (28 L-band SW) makes the average energy of positron 250 MeV.

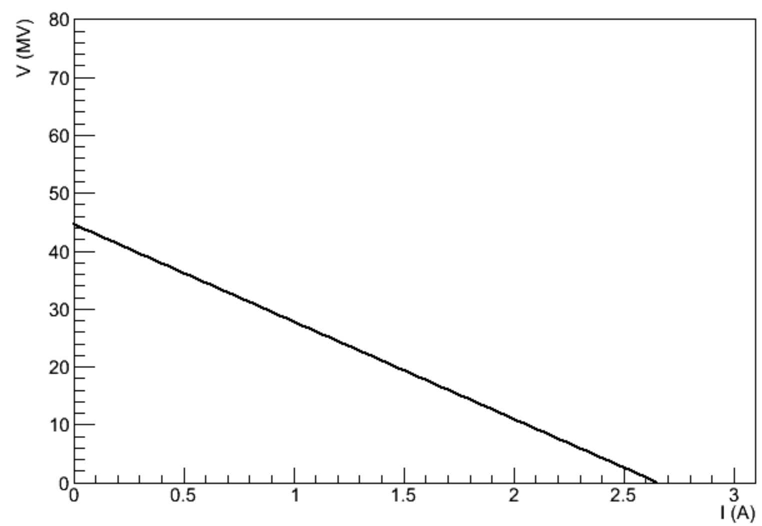




Booster

- A first half is implemented by L-band acc. And the last half is by S-band.
- 50MW L-band Klystron drives two L-band acc.
- 80MW S-band Klystron drives two S-band acc.

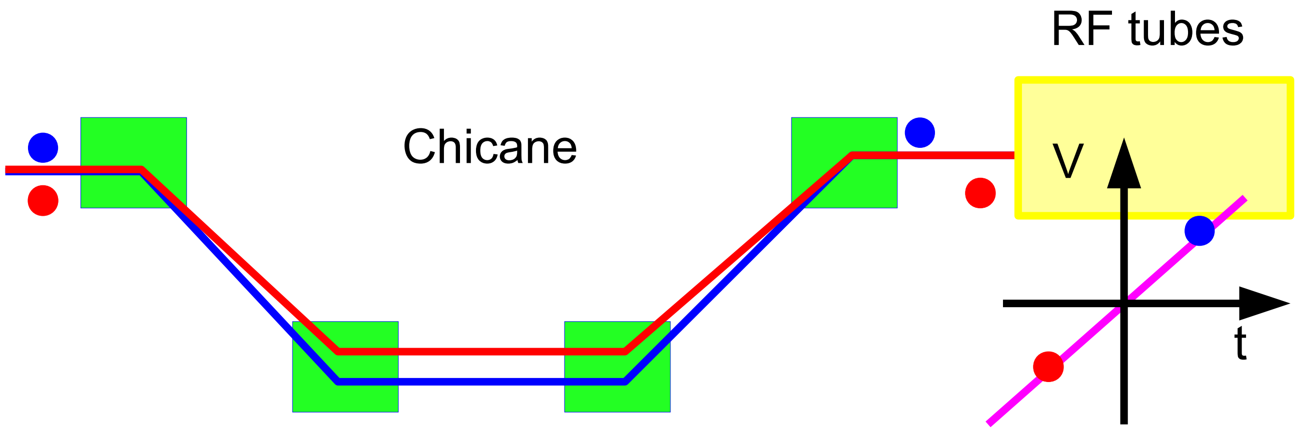


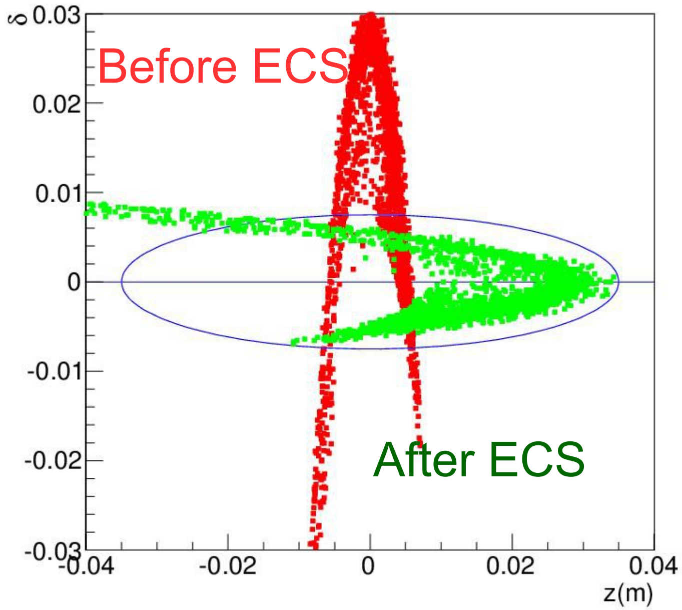


Lattice configuration	Number of lattice cells	Accelerating energy	energy at the exit	cell length	number of cells and section length (2 by 1)
4Q + 1L	12	252 MeV	502 MeV	3.8 m	12 : 45.6 m
4Q + 2L	22	924 MeV	1426 MeV	6.0 m	22 : 132.0 m
4Q + 4L	15	1260 MeV	2686 MeV	10.4 m	15 : 156.0 m
4Q + 4S	19	2394 MeV	5080 MeV	10.4 m	19 : 197.6 m

Energy Compressor

- Energy compressor makes a good matching to the acceptance, DR longitudinal acceptance (±35mm in z, ±0.75% in δ±/±)
- Energy Compressor consists from 3 chicanes and 5 L-band RF .
- Total length is 75.2 m.

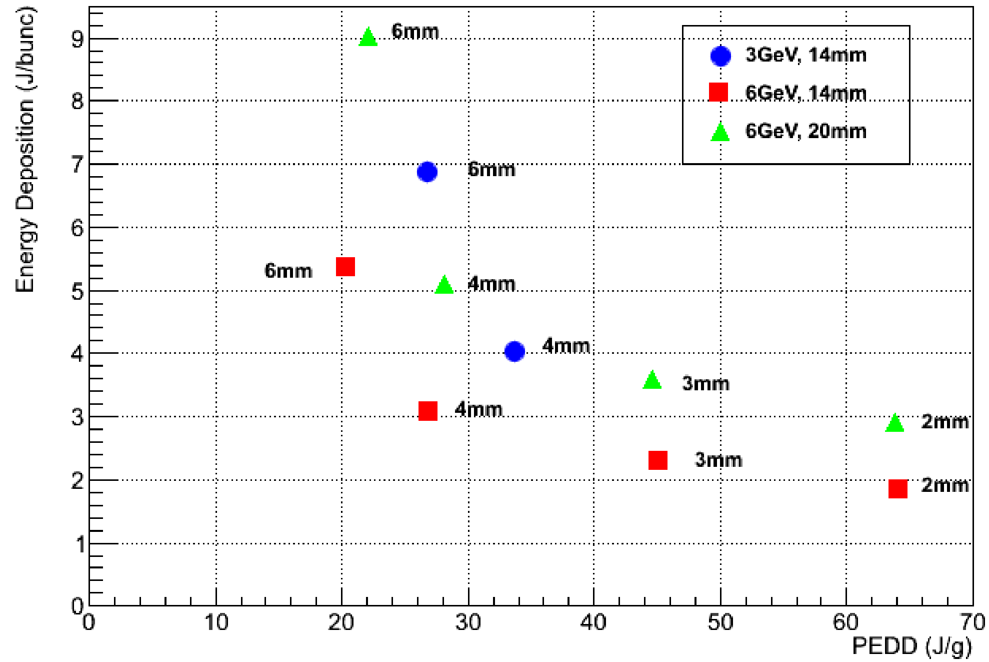




DR Acceptance

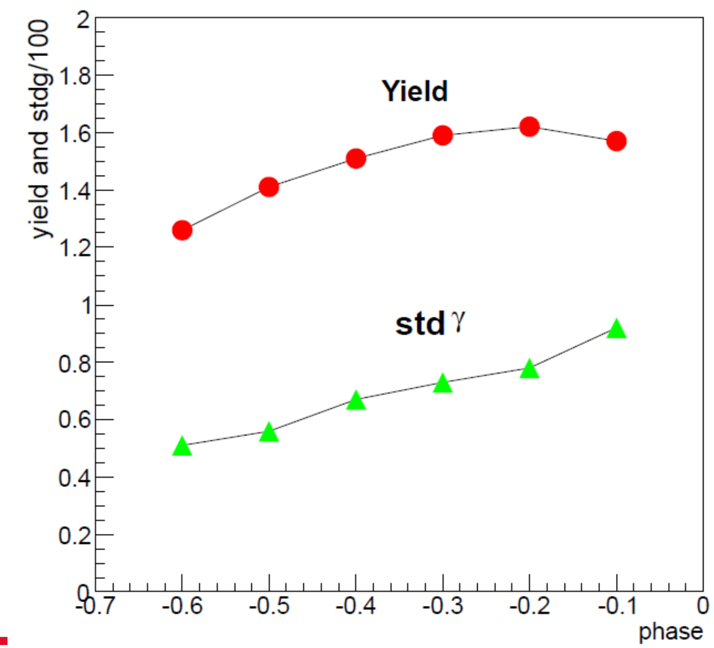
$$\left(\frac{z}{0.035}\right)^2+\left(\frac{\delta}{0.0075}\right)^2<1$$

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



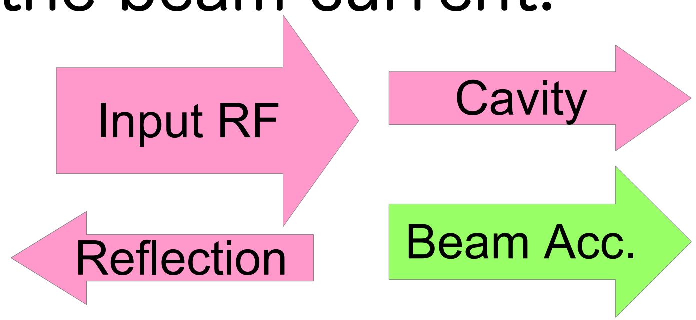
The typical yield was 1.25.

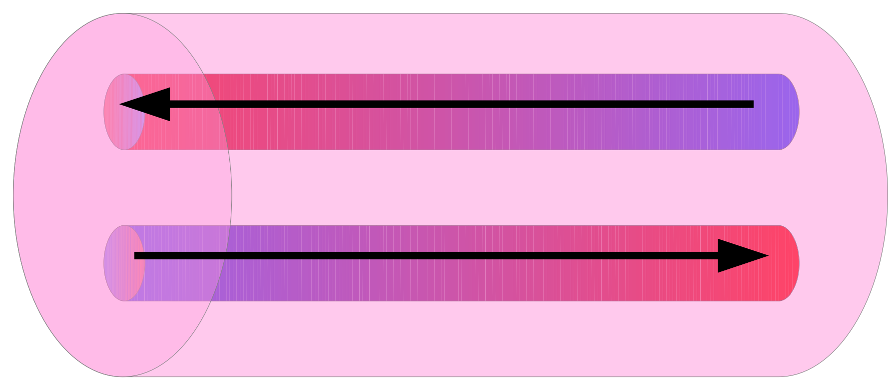
Electron intensity is normalized giving 3.0e+10 positron /bunch In DR dynamic aperture.



Cooling Water

- Cooling water capability is estimated according to the power loss in RF cavity and RF load.
- ʃT<0.1K for RF cavity and dT=11K for RF load (TDR specification).
- By employing counter flows in RF cavity, T_{out}-T_{in}=10K is acceptable for dT~0.05 K.
- Because of the heavy beam load, dissipated power in RF cavity and load depend on the beam current.





- L-band SW (per tube)

Beam current (A)	$P_{acc}(kW)$	V_{acc} (l/min)	$P_{load}(kW)$	V_{load} (l/min)
0.1	3.32	4.75	5.49	7.13
0.5	1.79	2.55	3.46	4.49
1.0	1.08	1.54	2.45	3.18
1.5	0.656	0.937	1.78	2.31
2.0	0.376	0.537	1.27	1.65

- L-band TW (per tube)

Beam current (A)	$P_{acc}(kW)$	V_{acc} (l/min)	P_{load}	V_{load} (l/min)
0.00	2.16	3.08	3.15	4.09
0.50	1.66	2.38	2.42	3.14
0.80	1.40	2.00	2.04	2.65
1.00	1.23	1.76	1.80	2.34
1.50	0.867	1.24	1.27	1.65

- 2m S-band TW (per tube)

Beam current (A)	$P_{acc}(kW)$	V_{acc} (l/min)	P_{load}	V_{load} (l/min)
0.00	2.53	3.61	2.67	3.47
0.50	1.90	2.71	2.01	2.61
0.80	1.57	2.24	1.66	2.16
1.00	1.36	1.95	1.44	1.87
1.50	0.91	1.31	0.97	1.26

- 3m S-band TW (per tube)

Beam current (A)	$P_{acc}(kW)$	V_{acc} (l/min)	P_{load}	V_{load} (l/min)
0.00	3.72	5.32	1.75	2.27
0.50	2.04	2.92	0.96	1.25
0.60	1.77	2.52	0.83	1.08
1.00	0.86	1.23	0.41	0.53
1.50	0.18	0.26	0.09	0.117

Cooling Water Summary

Item	Cooling water (l/min)	Cooling water max (l/min)
L-band SW Acc.	43	133
L-band SW load	89	200
L-band TW Acc.	242	373
L-band TW load	321	495
S-band 2 m TW Acc.	170	274
S-band 2 m TW load	164	264
S-band 3 m TW Acc.	307	650
S-band 3 m TW load	132	277
Total	1470	2670

RF unit

Component	Specifications	Number (1 by 1)	Number(2 by 1)
Accelerator	1.27 m L-band SW	28	28
Accelerator	2.0 m L-band TW	71	116+4
Accelerator	2.0 m S-band TW	48	76
Accelerator	3.0 m S-band TW	120	120
Klystron	50 MW L-band	85	74
Klystron	80 MW S-band	108	98

- High density of power units in the service tunnel is expected. (6.45 m/unit, average)
- Compact unit design with a good accessibility is mandatory.

Klystron (S. Fukuda)

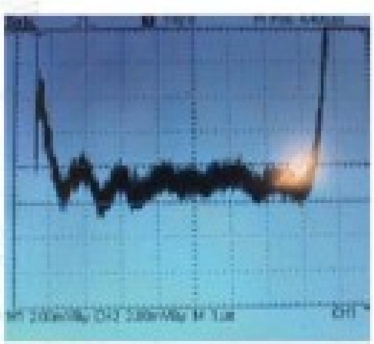
- L band (1.3 GHz) with 50 MW-100MW and S band klystron(2.6 GHz) with 80-150MW are possible, but so far there are no commercially available klystrons.
- In order to reduce the numbers of RF source, higher output power is desirable, while requirements for minimum R&D lead to limited choice.
- For L-band, we assume a 50 MW tube, since design of this power level is not difficult.
- For S-band, we assume a 80 MW tube, since existing 2.856GHz 80 MW klystron is widely used, and frequency scaling from 2.856GHz to 2.6GHz is not so difficult. (Comments from Toshiba engineer)

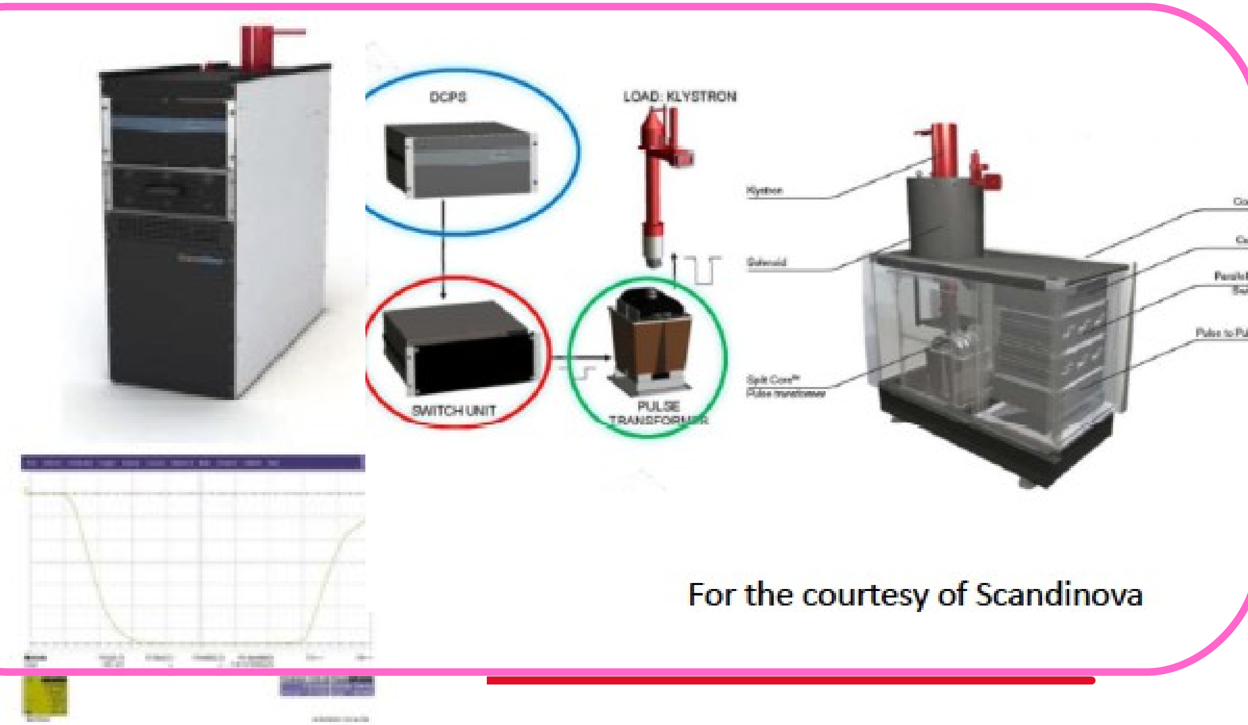
Pulse Modulator (S. Fukuda)

- Solid sate modulator has a large merits
  - compact
  - maintenance ability

ScandiNova

COMPARISON PFN – SOLID STATE TECHNOLOGY





For the courtesy of Scandinova

RF Unit

L-band Unit

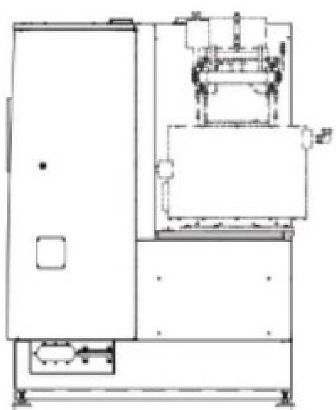
Main Parameters	Value	Unit
RF Frequency	1300	MHz
Peak Power	50	MW
Average RF Power	22.5 (0.3)[1]	kW
Pulse width	0.5 - 1.5	µs
Pulse Repetition	1 - 300 (3.8)[1]	Hz

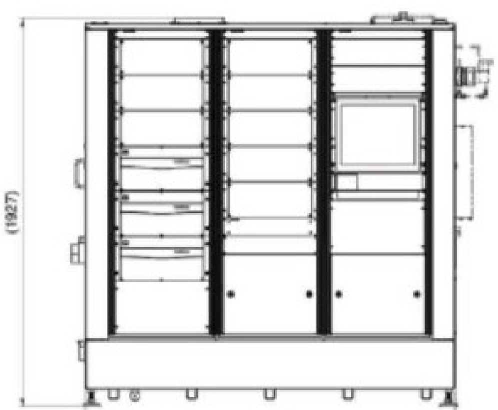
[1] Corresponding to 3,8Hz operation

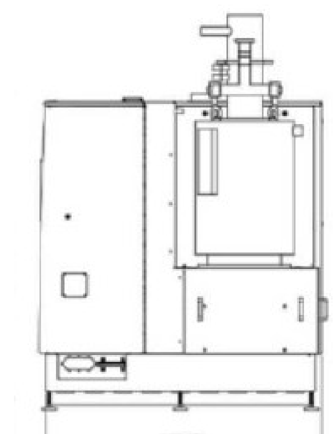
S-band Unit

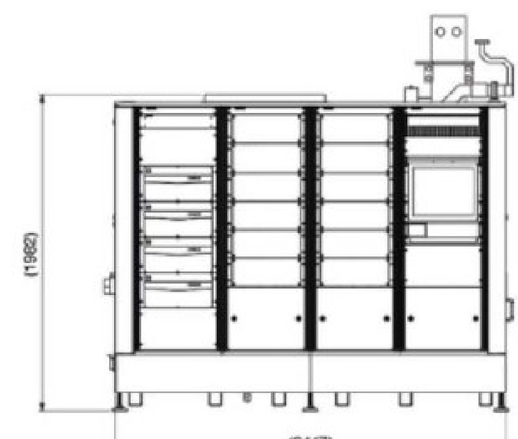
Main Parameters	Value	Unit
RF Frequency	2856	MHz
Peak Power	80	MW
Average RF Power	36 (0.4)[1]	kW
Pulse width	0.5 - 1.5	µs
Pulse Repetition	1 - 300 (3.8)[1]	Hz

[1] Corresponding to 3,8Hz operation





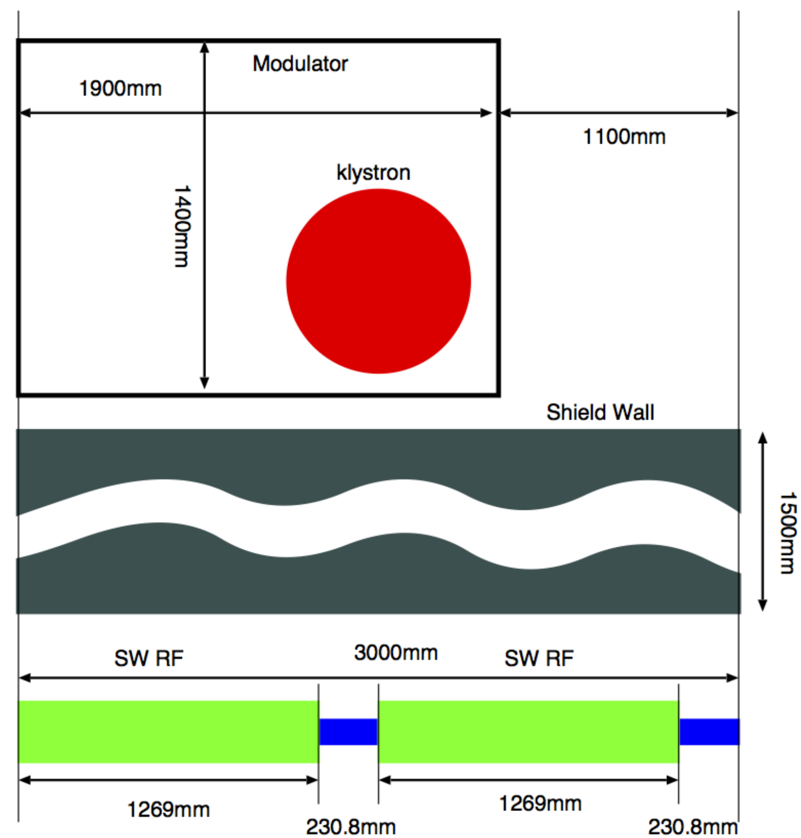




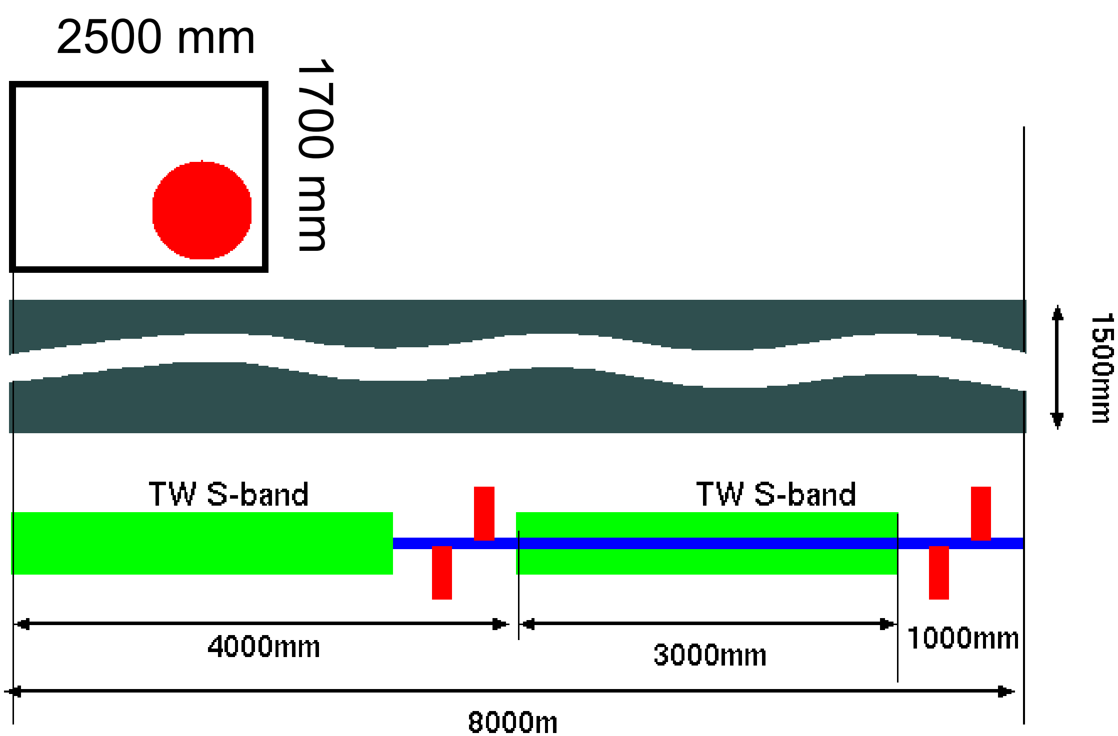
Weight approx 3900kg (including Klystron, Solenoid, oil)

RF Unit Layout

Positron Capture Linac (highest density)



S-band Electron Linac



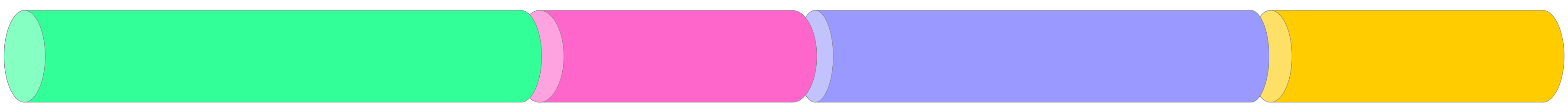
Parameter Summary

Parameter	Value	Unit
Drive Beam Energy	4.8	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)	

Section Length Summary

Electron Driver
456.8 m

Positron Booster
531.2m



Positron Target
Capture Linac
43m

ECS
75.2m

Total : 1110.2 m

Summary

- The undulator positron source is the baseline for ILC.
- The design of the undulator ILC positron source is matured, but there are still technical issues.
- As a technical backup, E-driven ILC positron source has been designed.
- The E-driven assuming off-the-shelf RF components show an enough performance.
- The system integration has been started for the E-driven ILC positron source.