System integration of ILC E-Driven Positron Source

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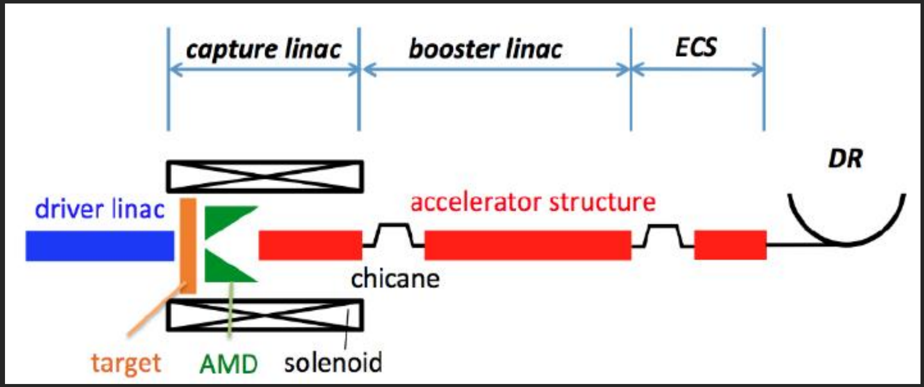
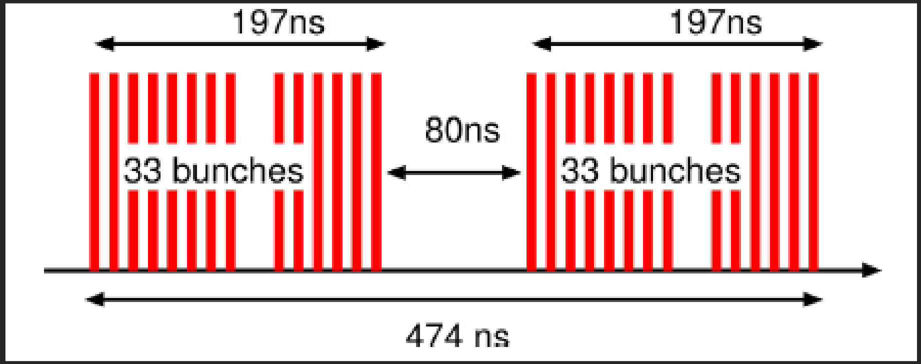
ILC E-Driven Positron Source

- 3 GeV electron beam hits WRe alloy target generating positron beam. Expected yield is 1.2 Ne+/Ne-.
- The beams (e- and e+) are handled as a multi-bunch format with a gap. It corresponds to a part of positron bunch pattern in DR.
- To start the detail engineering design, we have to integrate the R&D works as an consistent design. The aim of this presentation is to fix the accelerator specification ;e-driver, target, and e+ accelerators.





3m S-band TW accelerator

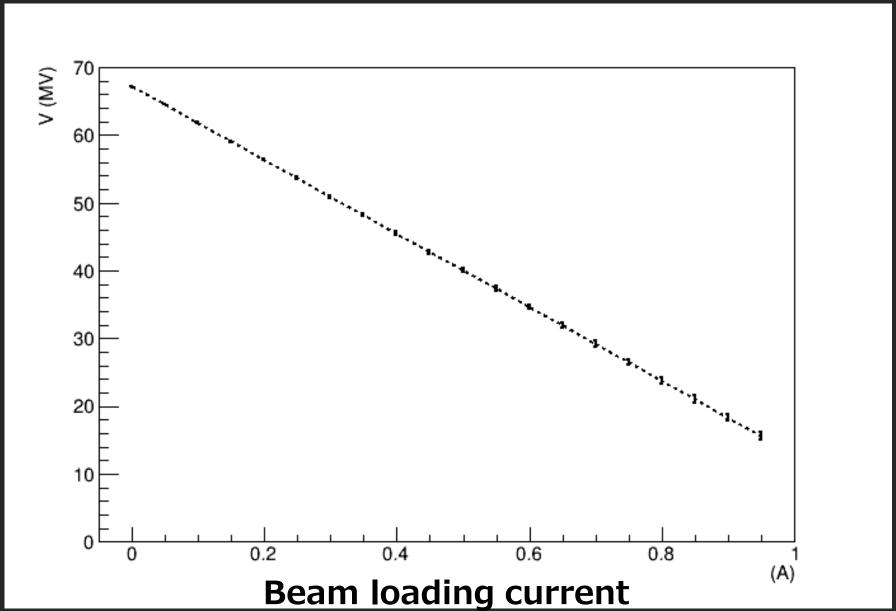
Accelerator for the 3 GeV electron driver

- Parameters are based on 3m TW ATF accelerator.
- Shunt impedance and length are scaled as

$$r_{sh2600} = r_{sh2856}\sqrt{(2600/2856)}$$
$$L_{2600} = L_{2856} 2856/2600$$

- Normal section : accelerating voltage per tube is 31.9 ± 0.4 MV with P=36 MW and I_B=0.65 A.
- Pre-injector : accelerating voltage per tube is 43.5 ± 0.6 MV with P=72 MW and I_B=0.65 A.

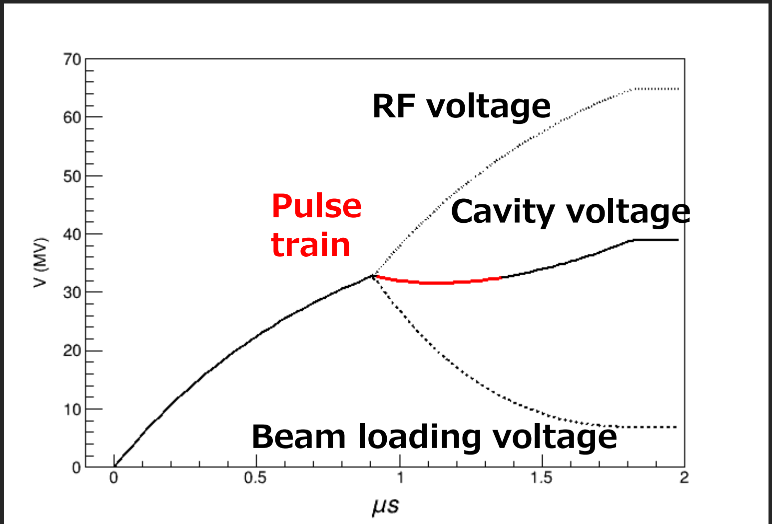
Parameter	Value
Shunt impedance	57.2 MΩ/m
Length	3.228 m
τ (attenuation)	0.57
t_f	0.91 μs



Beam Loading Compensation for TW structure

- We consider the beam loading compensation for TW structure with amplitude modulation (AM) as (*u(t)* is a step function.)

$$P(t) = \frac{L}{r_0(1-e^{-2\tau})}\left[E_0^2 u(t) + E_1^2 u(t-t_f)\right]$$



- Accelerator voltage

$$V(t) = \begin{cases} \dfrac{E_0 L}{1-e^{-2\tau}}\left(1-e^{-\frac{\omega}{Q}t}\right) & 0 < t < t_f \\ E_0 L + \dfrac{E_1 L}{1-e^{-2\tau}}\left(1-e^{-\frac{\omega}{Q}(t-t_f)}\right) & \\ -\dfrac{r_0 L I_B}{2(1-e^{-2\tau})}\left[-\dfrac{\omega}{Q}e^{-2\tau}(t-t_f) + 1 - e^{-\frac{\omega}{Q}(t-t_f)}\right] & t_f < t < 2t_f \end{cases}$$

- E_0 and E_1 is determined as

$$P_0 = \frac{L}{r_0(1-e^{-2\tau})}\left[E_0^2 + E_1^2\right]$$

$$E_1 = \frac{r_o I_B}{2}\left(\frac{-\frac{\omega}{Q}t_p e^{-2\tau}}{1-e^{-\frac{\omega}{Q}t_p}} + 1\right)$$

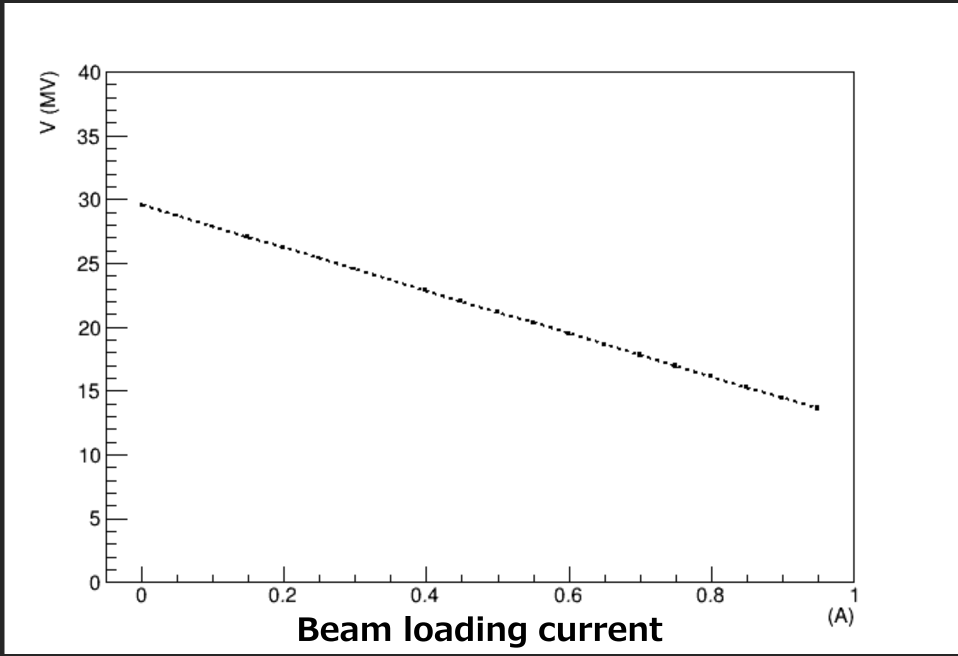
giving $V(t_f) = V(t_f + t_p)$

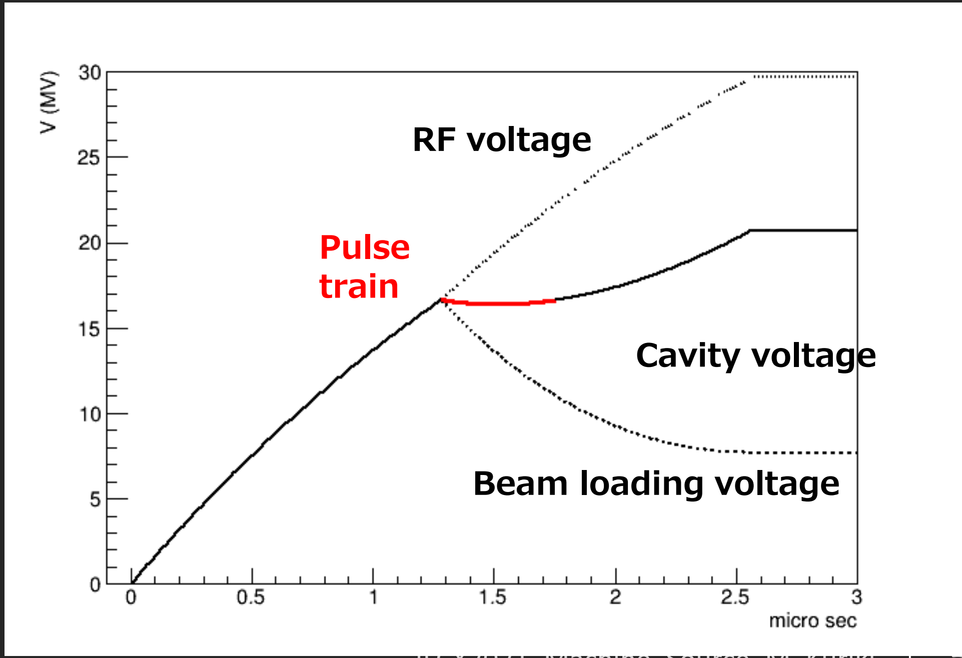
2m L-band TW Accelerator

Accelerator for Positron booster

- Shunt impedance and length are scaled with the same manner.
- Accelerating voltage per tube is 16.5 ± 0.1 MV with 22.5 MW input.

Parameter	Value
Shunt impedance	48.0 MΩ/m
Length	2.00m
τ (attenuation)	0.261
t_f	1.28 μs



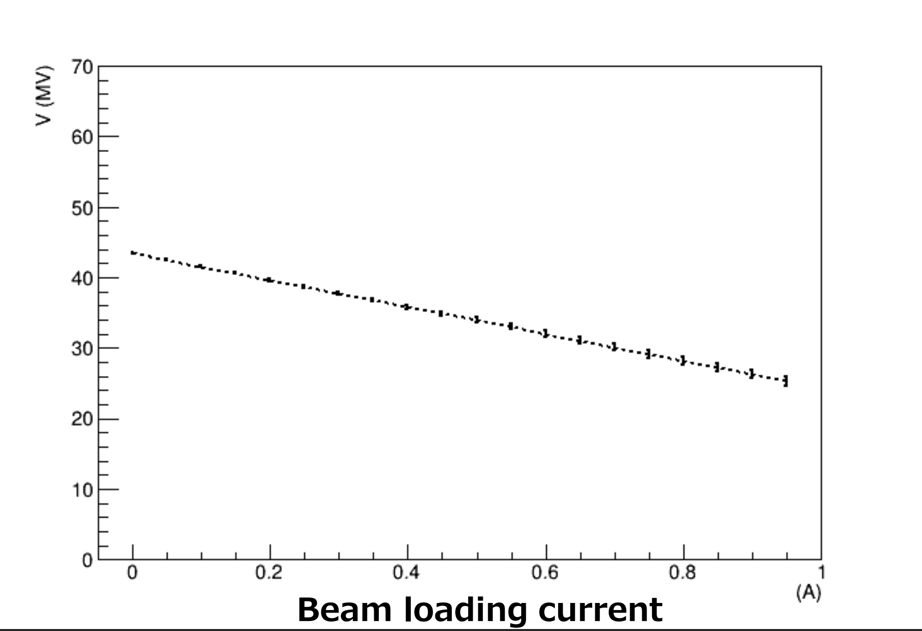


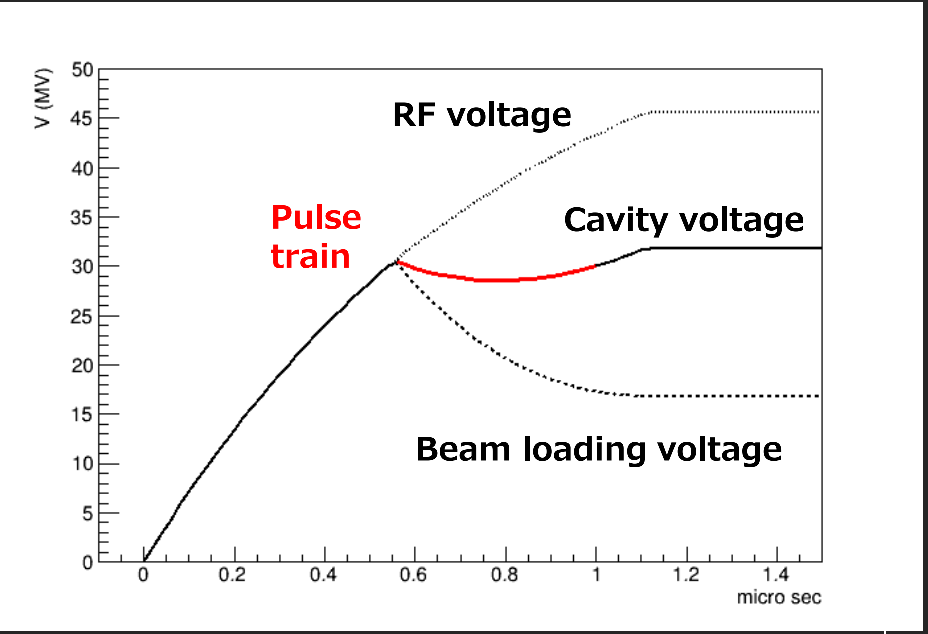
2m S-band TW Accelerator

Accelerator for Positron booster

- Shunt impedance and length are scaled with the same manner.
- Accelerating voltage per tube is 29.2 ± 0.6 MV with 36 MW input.

Parameter	Value
Shunt impedance	55.1 MΩ/m
Length	1.96m
τ (attenuation)	0.333
t_f	0.55 μs





S-band Klystron

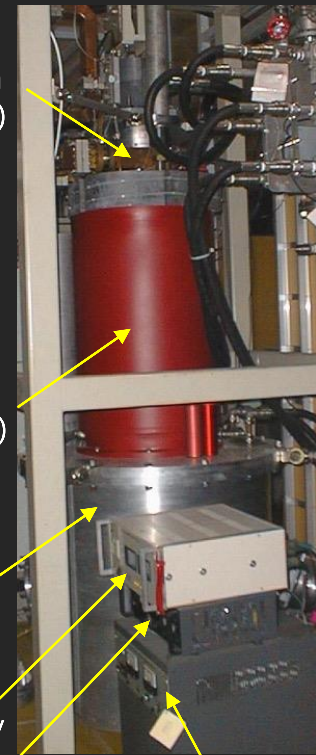
Klystron module (KEK-ATF)

- E3712 (Toshiba -> Canon) klystron
- VT68915 pulse trans
- Should be scaled 2856 ->2600.

	typical	max.	
Peak RF output power		80	MW
Beam voltage	396		kV
Beam current	480		A
Efficiency	44		%
Gain	55		dB
Microperviance	1.96		
Pulse width (beam)		~~6.2~~ 2.7	μS
Pulse width (RF)		~~5.0~~ 1.5	μS
Drive power	300	500	W
Pulse repetition rate		~~60~~ 300	pps
Frequency	~~2856~~ 2600		MHz

Specifications of E3712 S-band Klystron

picture of ATF klystron (E3712 + VT-68915 + pulse trans)



KEK CONCEPT DESIGN 80MW S-band RF & Solid State Modulator PARAMETERS

***Fig:** K400-platform*

OPTIONS: Integration of …
- Solenoid Power Supply
- Ion Pump Power Supply
- RF Drive amplifier
- Cooling of Klystron (Collector, Body), Solenoid
- All diagnostics and interlocks

Main Parameters	Value	Unit
RF Frequency	2600	MHz
RF Peak Power	80	MW
RF Average Power	0.2 (12)[1]	kW
Mod. Peak Power	143	MW
Mod. Average Power	1.4 (86)[1]	kW
Klystron Voltage	382	kV
Klystron Current	375	A
RF Pulse width (top)	0.5	μs
Pulse Repetition Rate	5 (300)	Hz
Pulse-to-Pulse stability	<15	ppm

[1] Corresponding to 300Hz operation

KEK CONCEPT DESIGN 50MW L-band RF & Solid State Modulator PARAMETERS

***Fig:** K300-platform*

OPTIONS: Integration of …

- Solenoid Power Supply
- Ion Pump Power Supply
- RF Drive amplifier
- Cooling of Klystron (Collector, Body), Solenoid
- All diagnostics and interlocks

Main Parameters	Value	Unit
RF Frequency	1300	MHz
RF Peak Power	50	MW
RF Average Power	0.125 (7.5)[1]	kW
Mod. Peak Power	76	MW
Mod. Average Power	0.7 (42)[1]	kW
Klystron Voltage	271.7	kV
Klystron Current	282	A
RF Pulse width (top)	0.5	μs
Pulse Repetition Rate	5 (300)	Hz
Pulse-to-Pulse stability	<20	ppm

[1] *Corresponding to 300Hz operation*

Phase and Amplitude modulation

- Phase and Amplitude Modulations (PM and AM) have a crucial role in the beam loading compensation.
- For precise control of phase and amplitude, RF power from two klystrons are combined.
- By controlling only phases of these RF signals, PM and AM can be made.

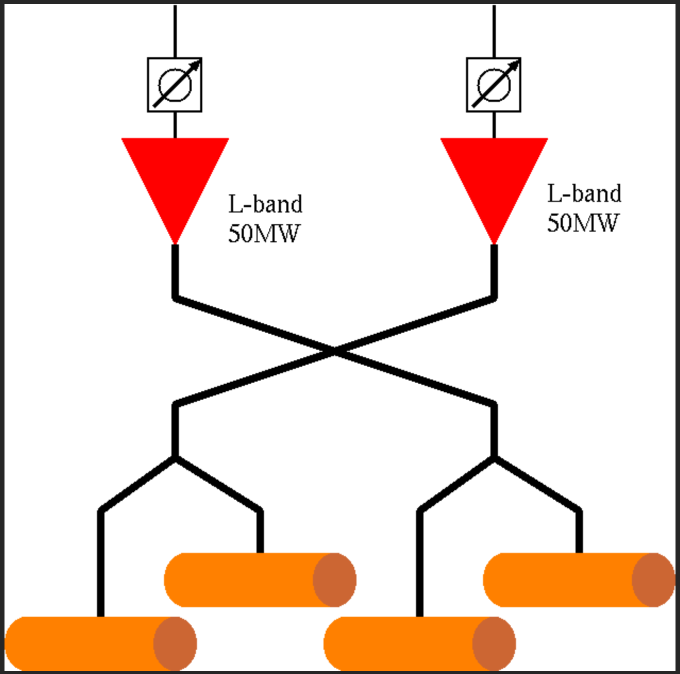
Before : $\cos \omega t + \cos \omega t = 2 \cos \omega t$

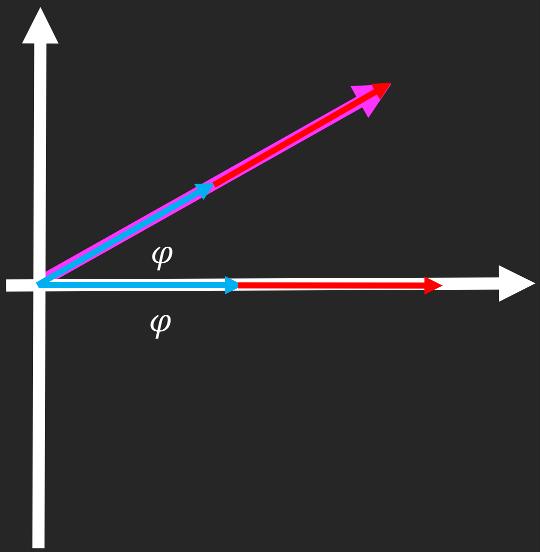
Same sign : Phase modulation

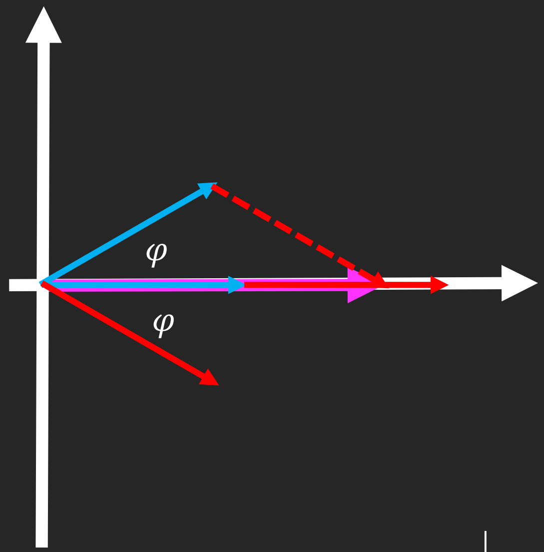
$\cos(\omega t + \varphi) + \cos(\omega t + \varphi) = 2 \cos(\omega t + \varphi)$

Anti sign : Amplitude modulation

$\cos(\omega t + \varphi) + \cos(\omega t - \varphi) = 2 \cos \varphi \cos(\omega t)$





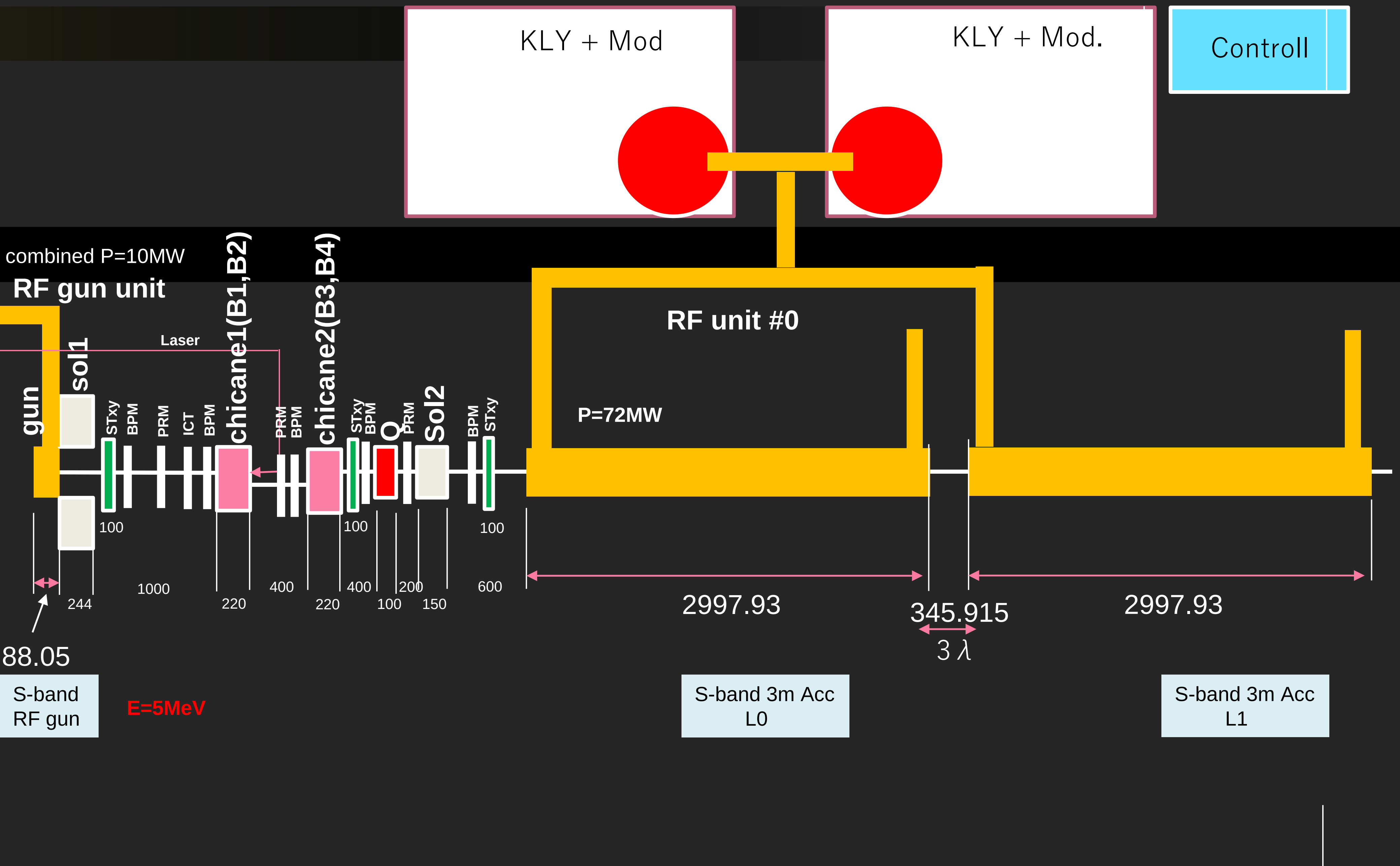


Electron Driver

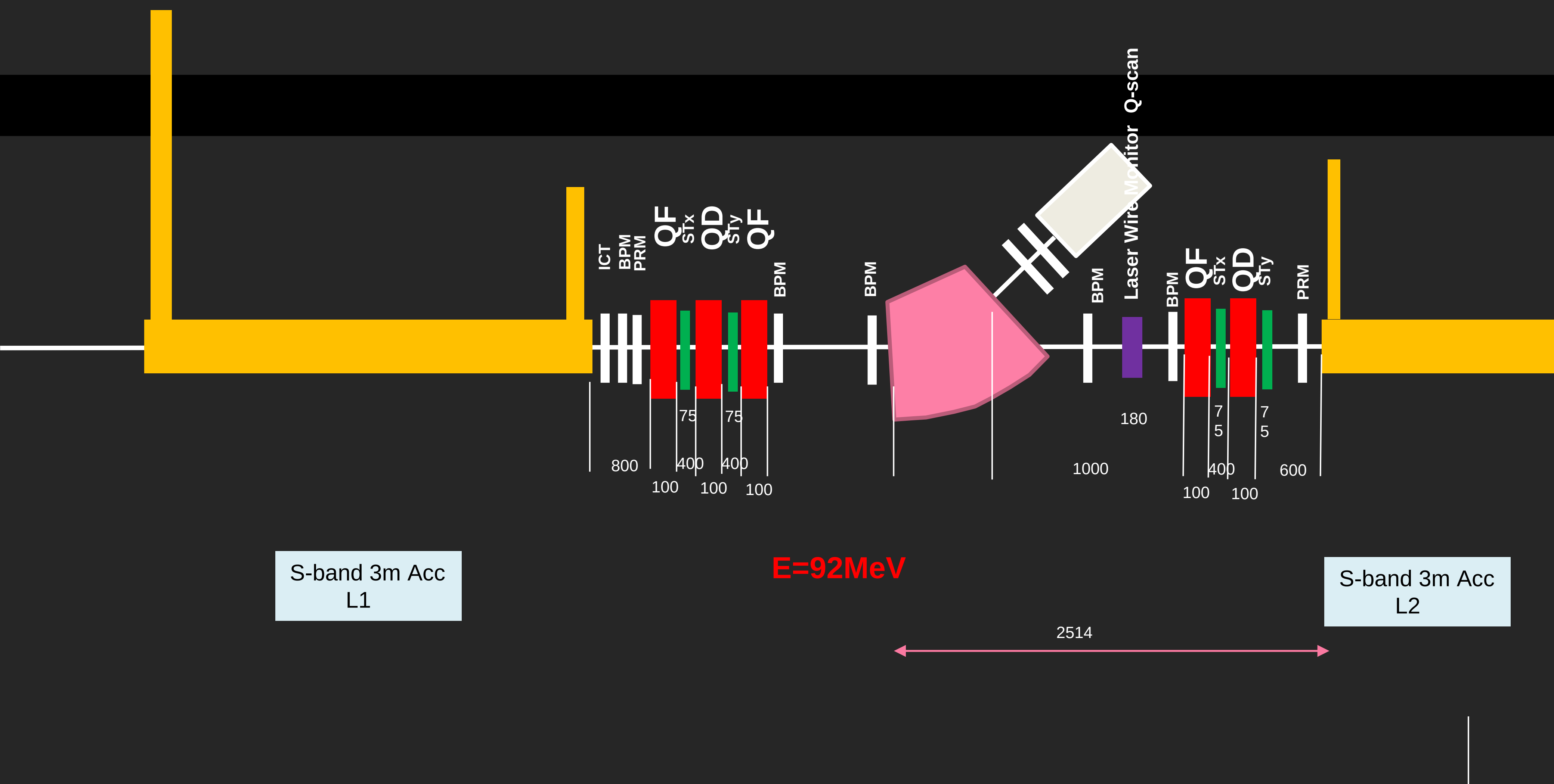
3GeV electron linac

- Based on S-band NC RF.
- Electron gun: S-band Photo-cathode RF Gun. BNL Gun IV (2856 MHz) should be scaled to 2600 MHz.
- Cathode can be Cs_2Te or CsK_2Sb. CsK_2Sb is better.
- Accelerator : S-band 3m TW structure designed for ATF linac with the frequency scaling (2856 -> 2600 MHz).
- Voltage per tube is 31.9 ± 0.38 MV.
- 100 +2 tubes for 3.3 GeV (10% margin).

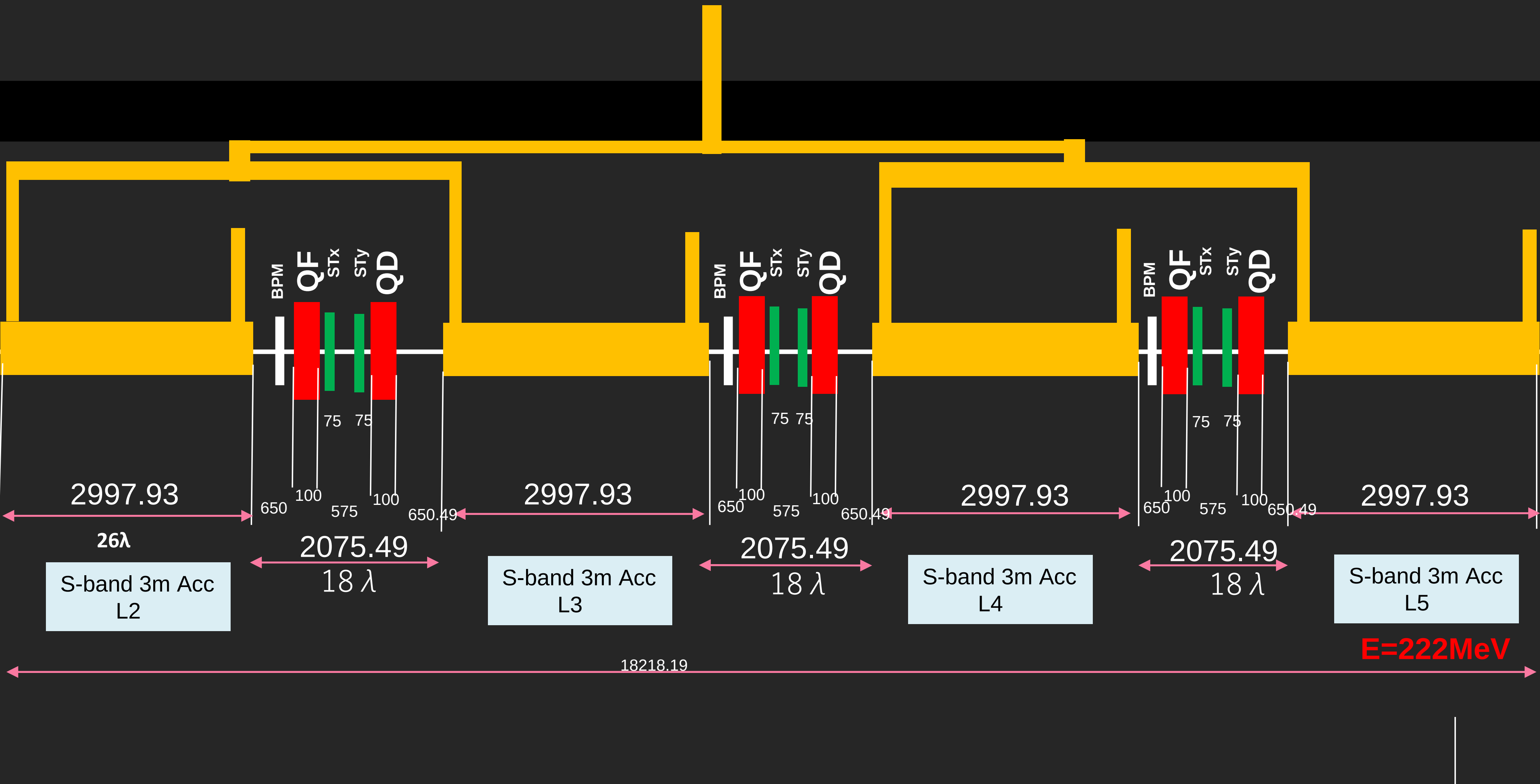
Electron Driver: Injector(1)



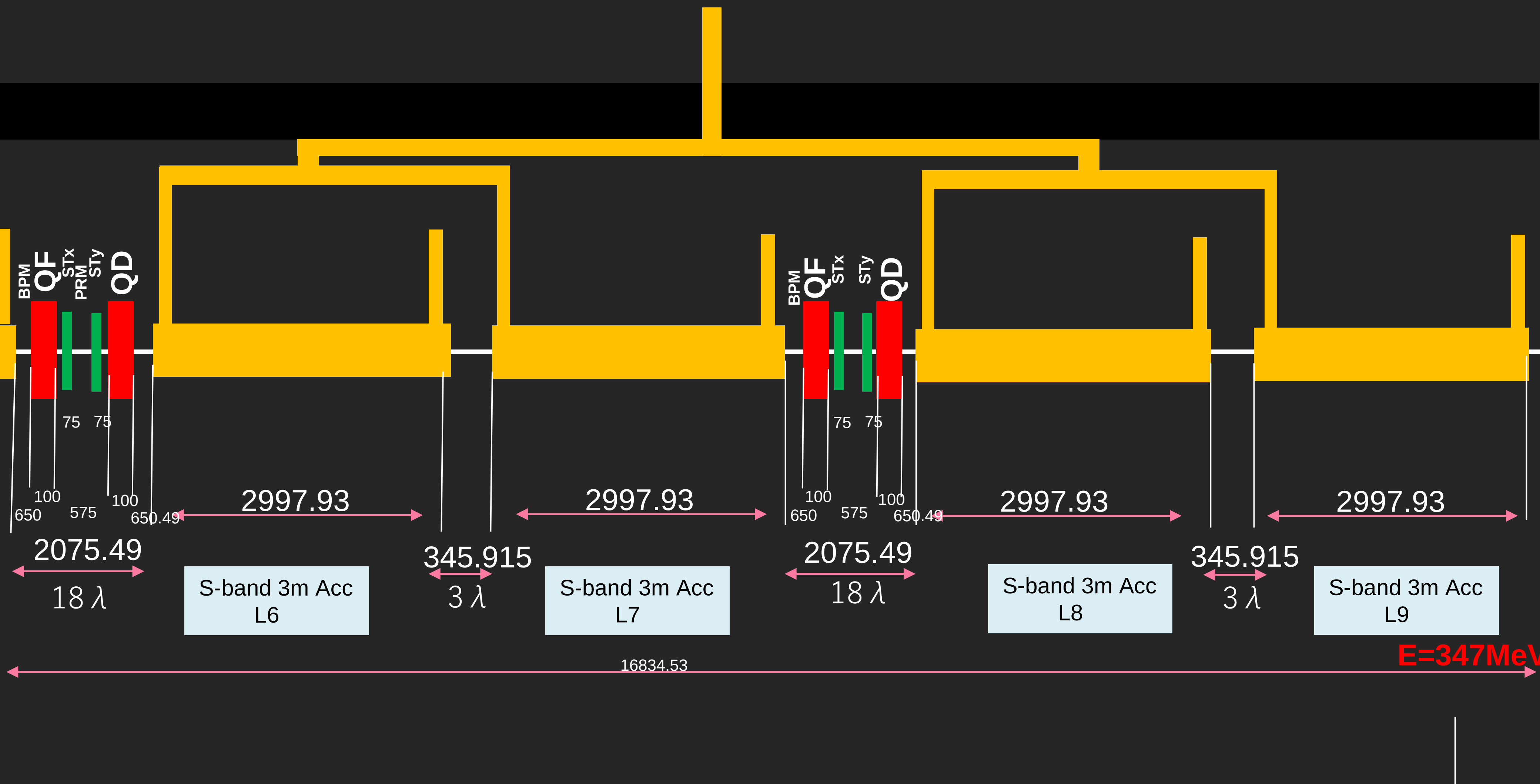
Electron Driver: Injector (2)



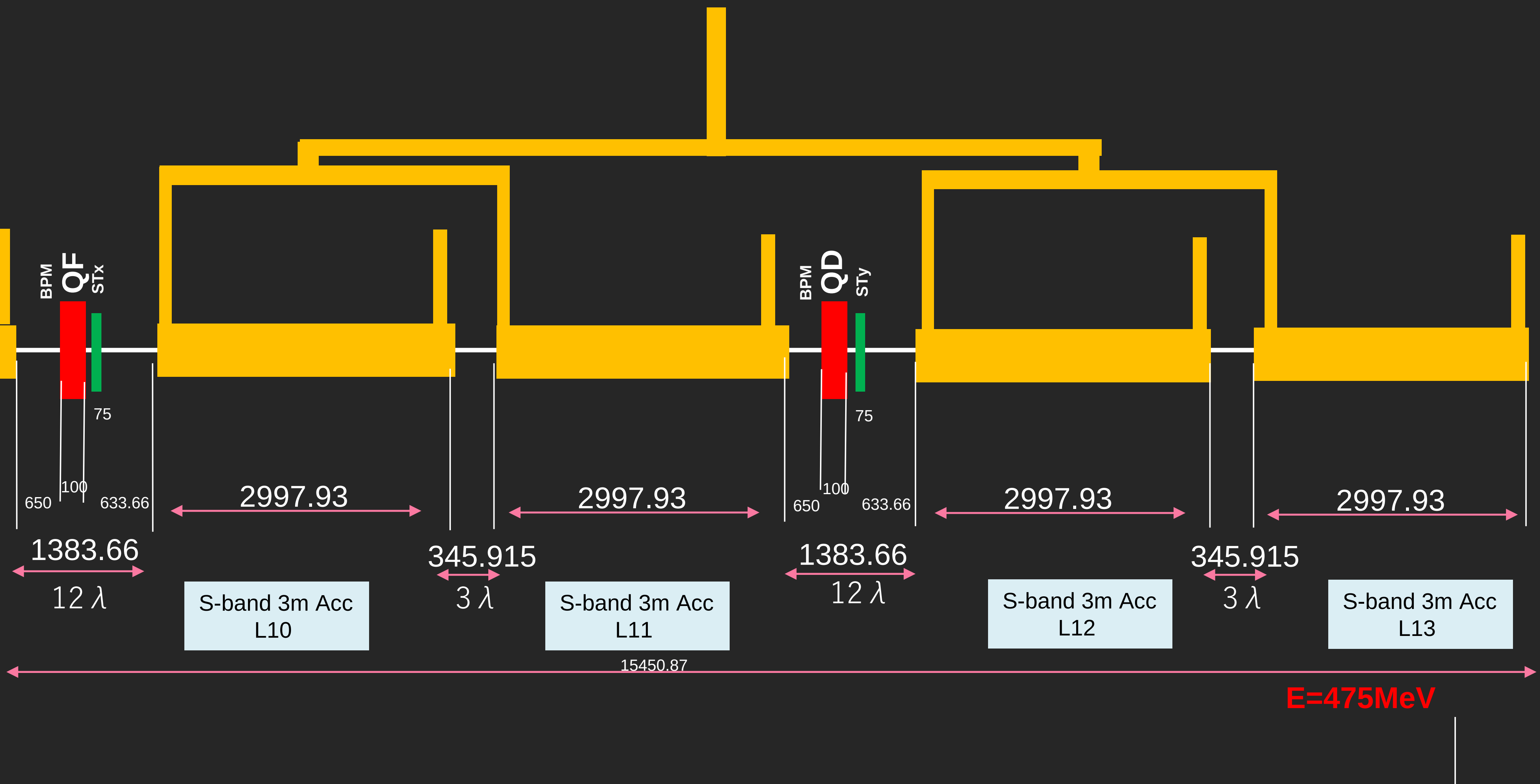
Electron Driver: Injector RF unit #1



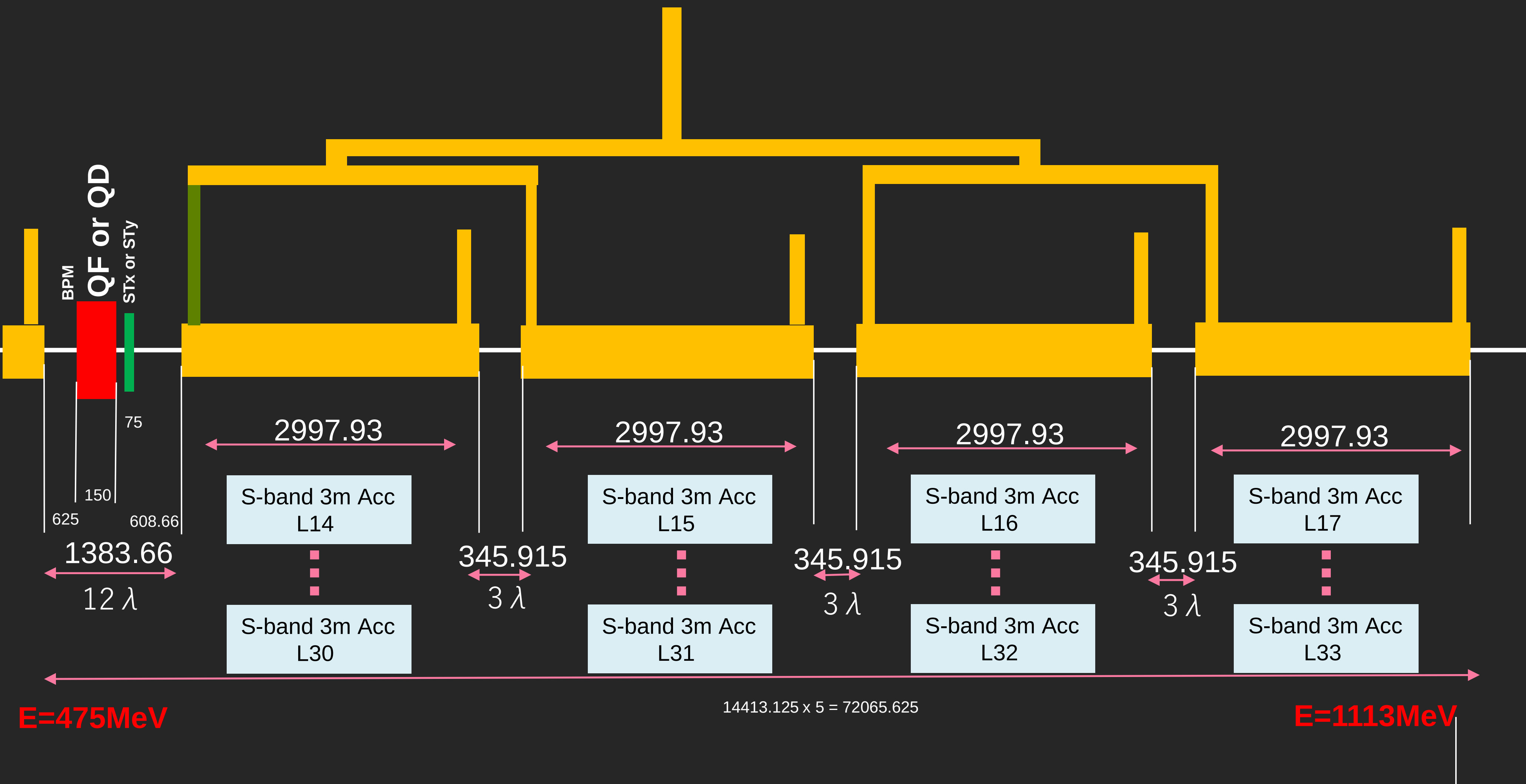
Electron Driver: Injector RF unit #2



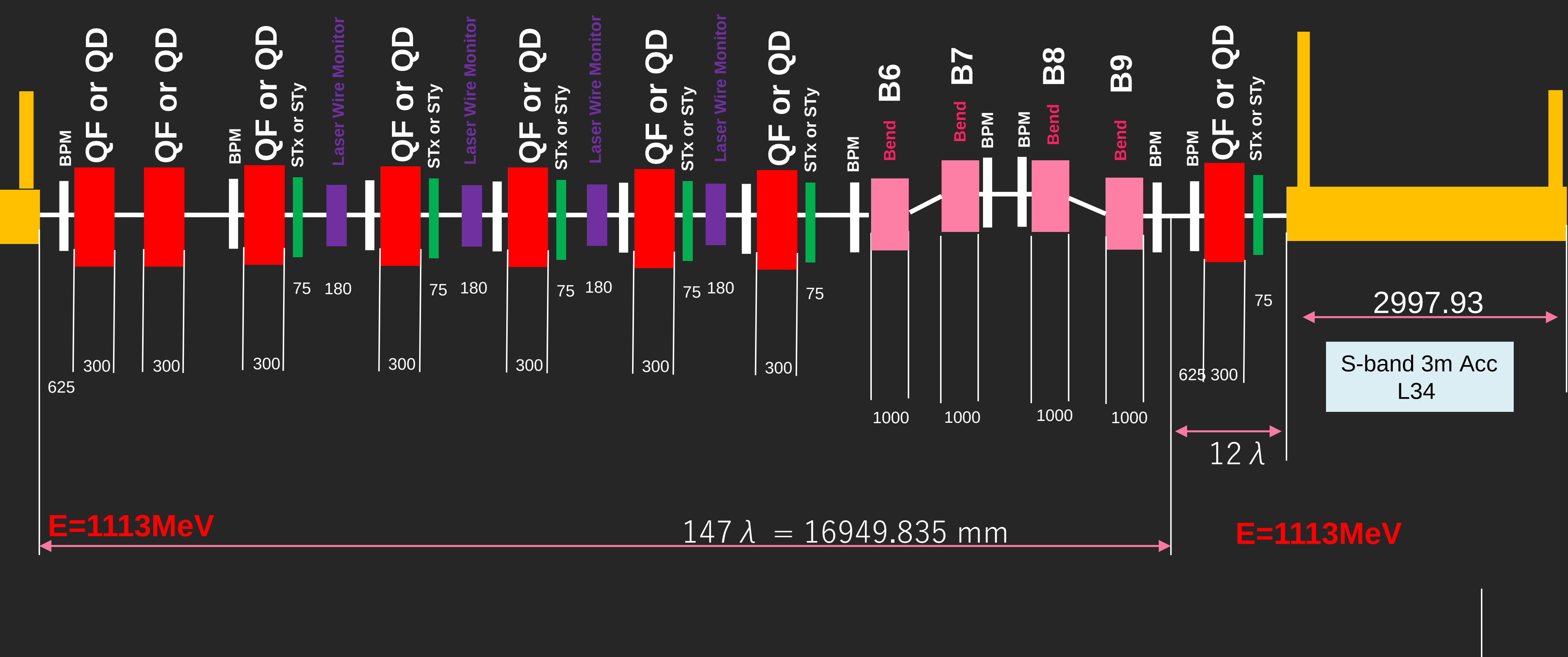
Electron Driver: Injector RF unit #3



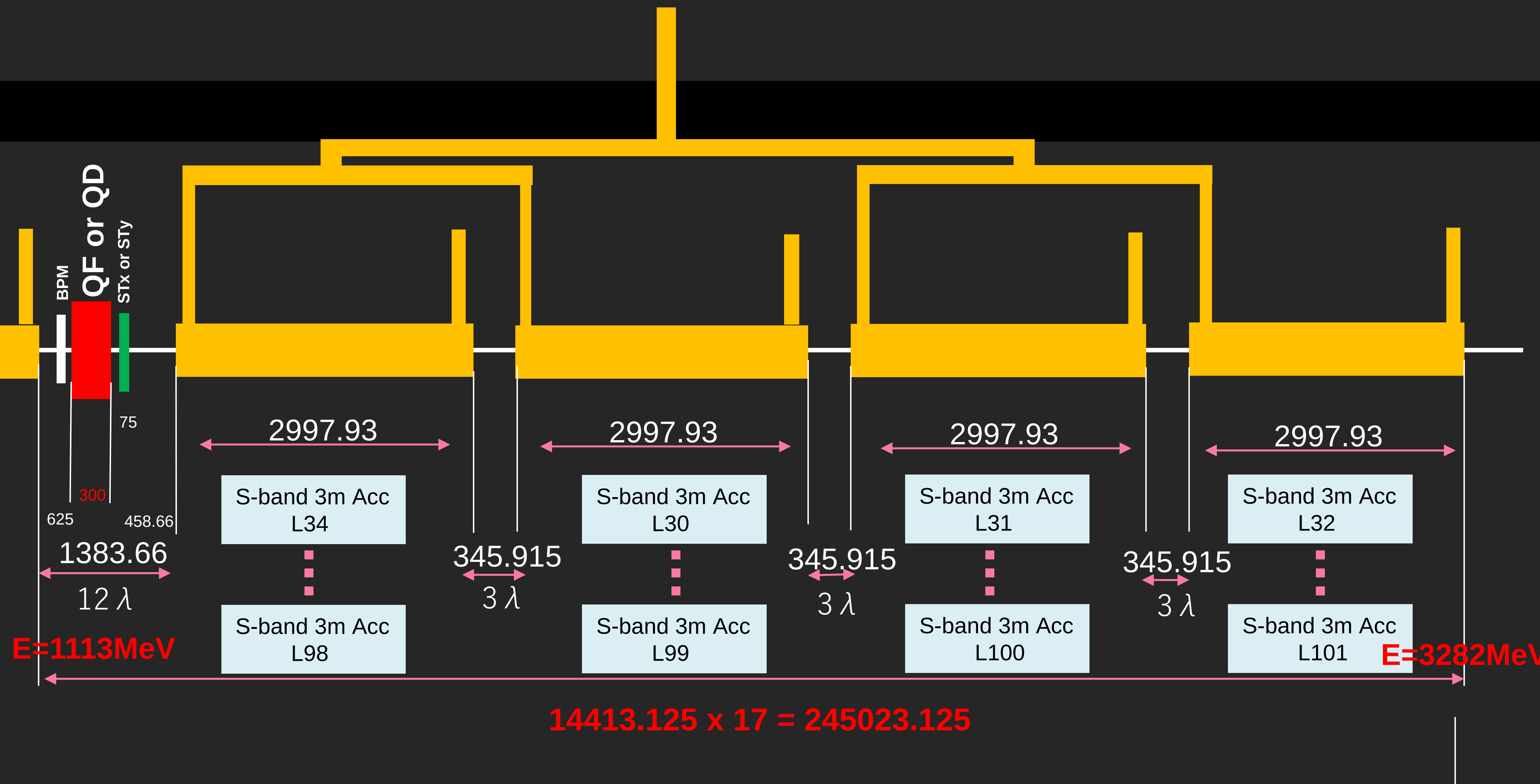
Electron Driver: Linac RF unit #4-8



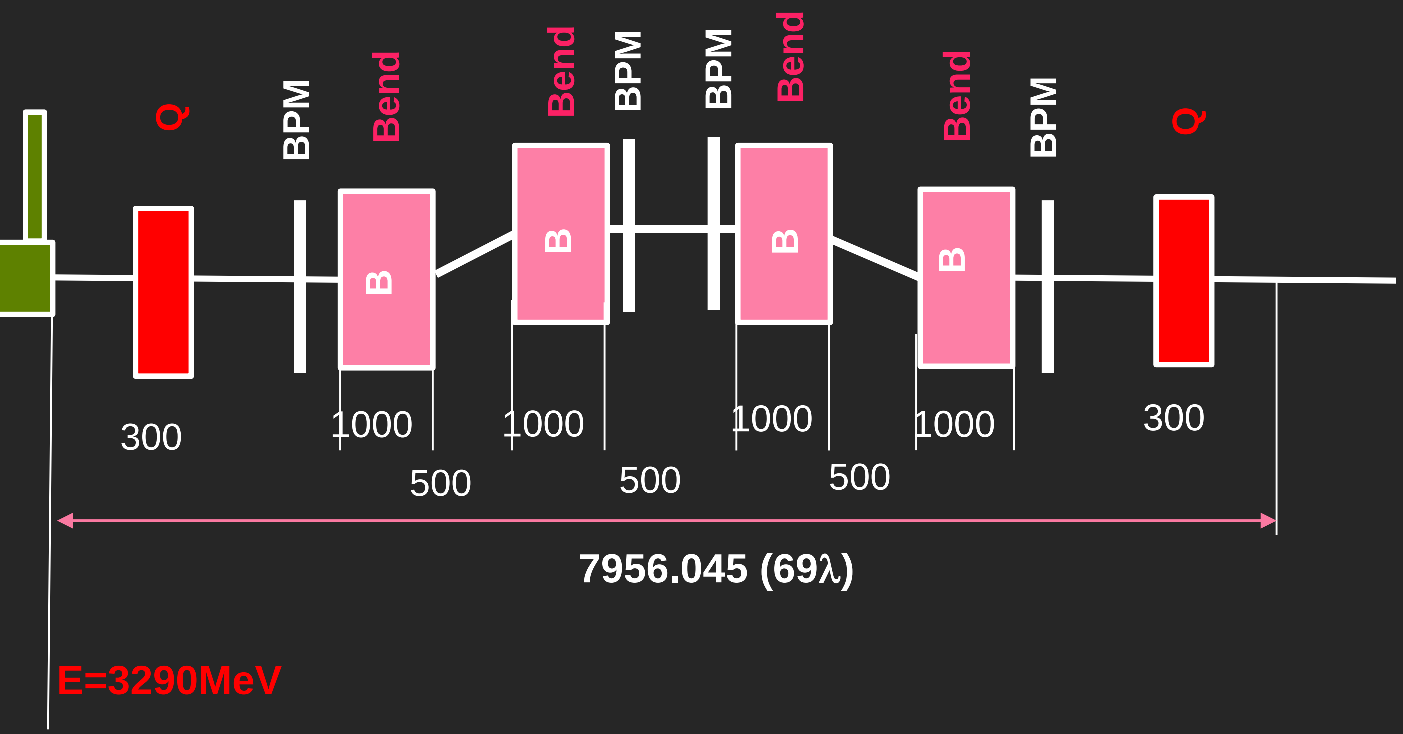
Electron Driver: Linac Middle Beam Diagnostic Section



Electron Driver: Linac RF unit #9~25

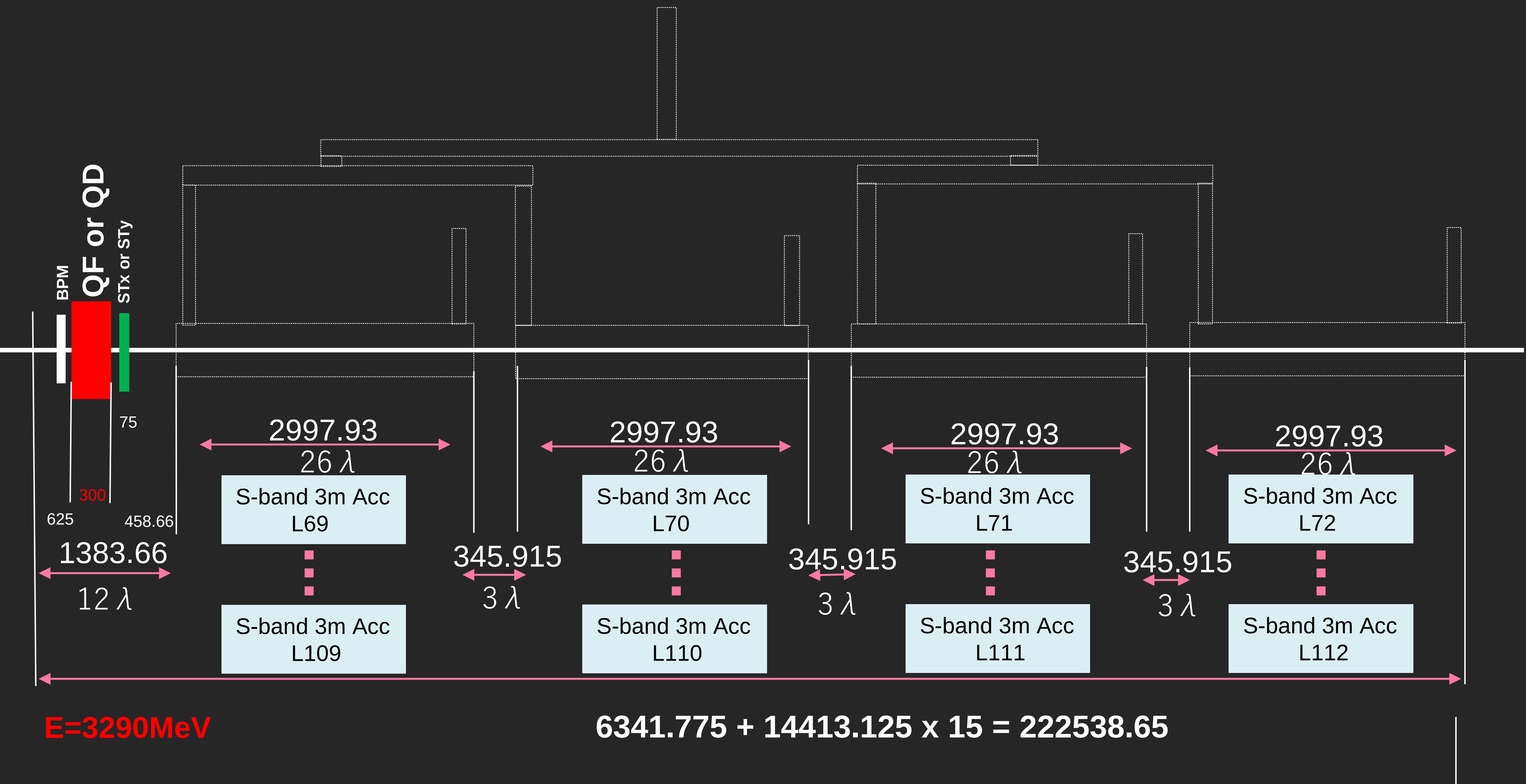


Electron Driver: Linac Chicane section

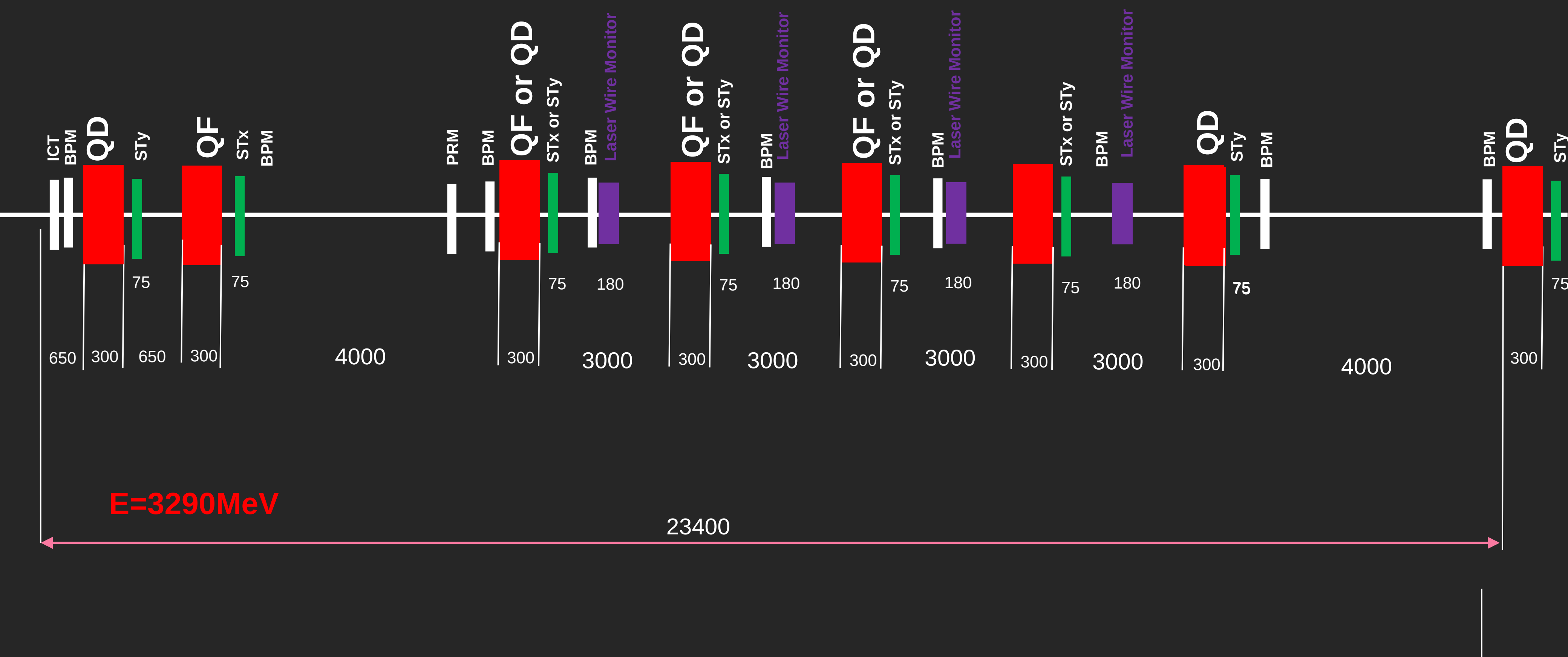


Electron Driver: Linac RF unit #26~40

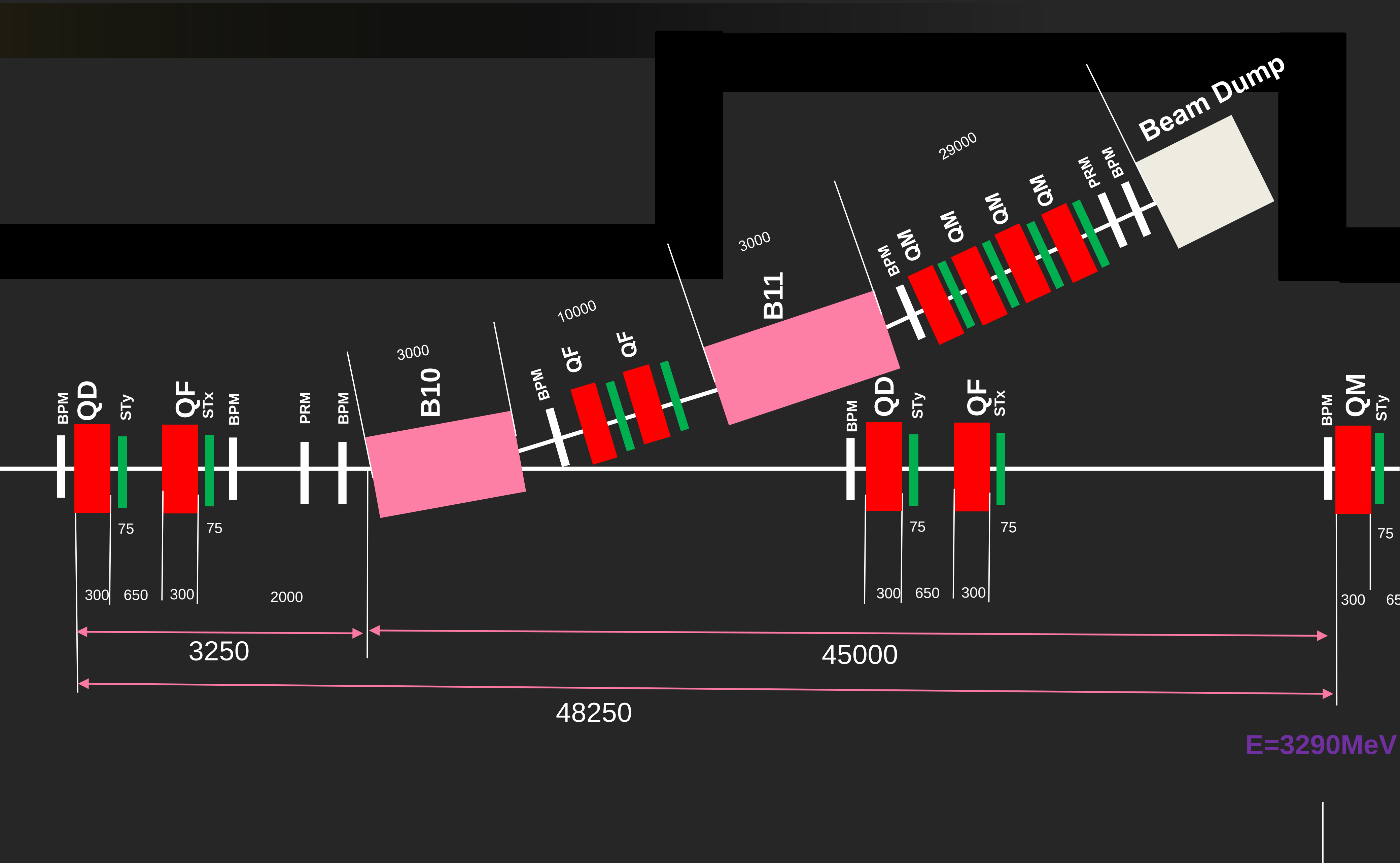
Reserved space for luminosity upgrade



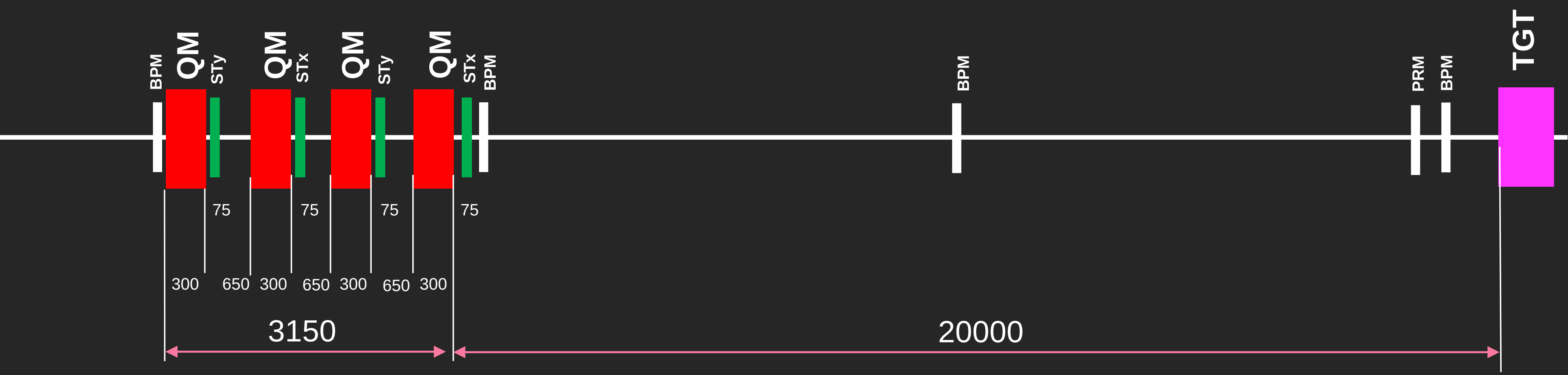
Electron Driver: Linac End Beam Diagnostic Section



Electron Driver: Linac End Beam Diagnostic Section



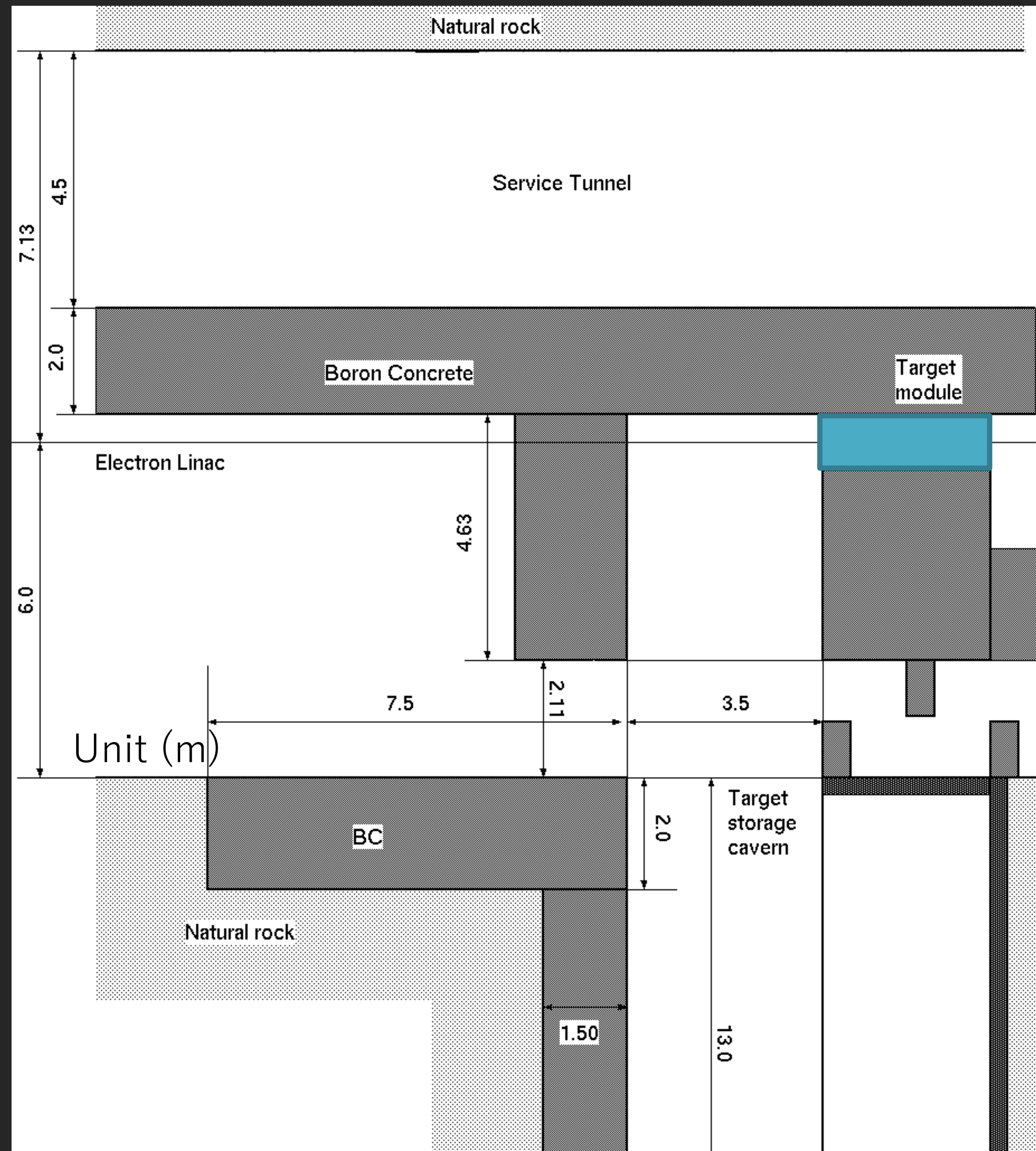
Electron Driver: Target Injection Line



E=3290MeV

Target Section

- For the radiation shield, the target is surrounded by 2m thick boronized concrete blocks.
- Used targets are stored in a cavern.
- The target module consists of target, FC, collimator, and the first RF cavity. The module is mounted on a wagon with shield.

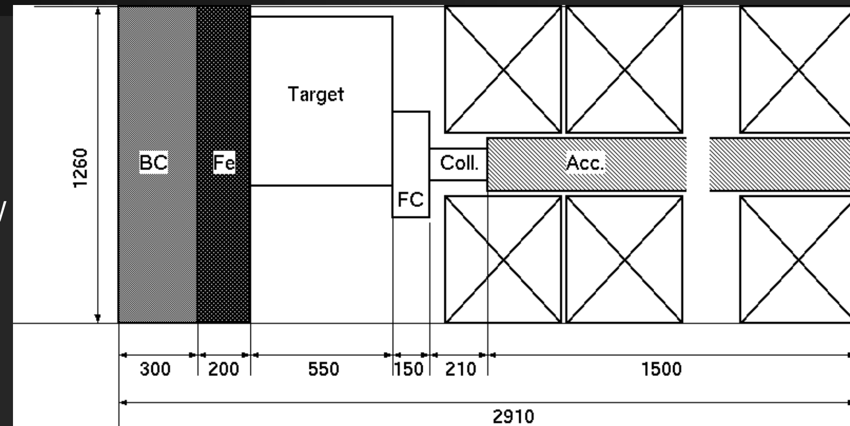


Target Module

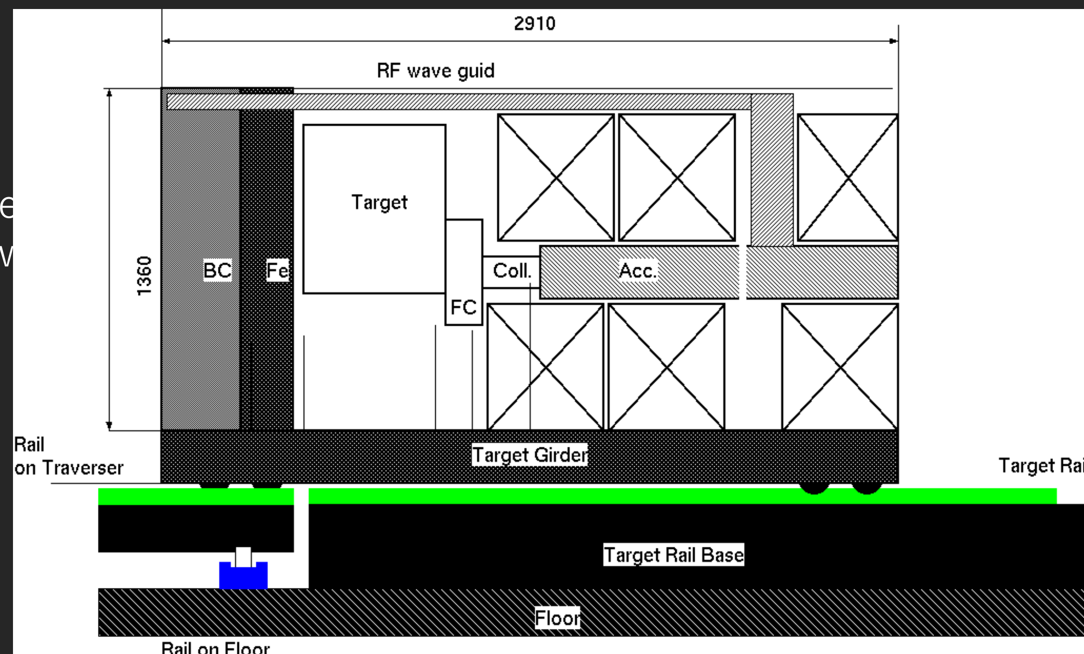
- The module is mounted on a wagon with shield. After the operation, the radiation dose in front of the module is 50μSv/h.
- Connectors (RF, electronics, power, water) are mounted on the front of the module, where is workable.

Unit (mm)

Top view

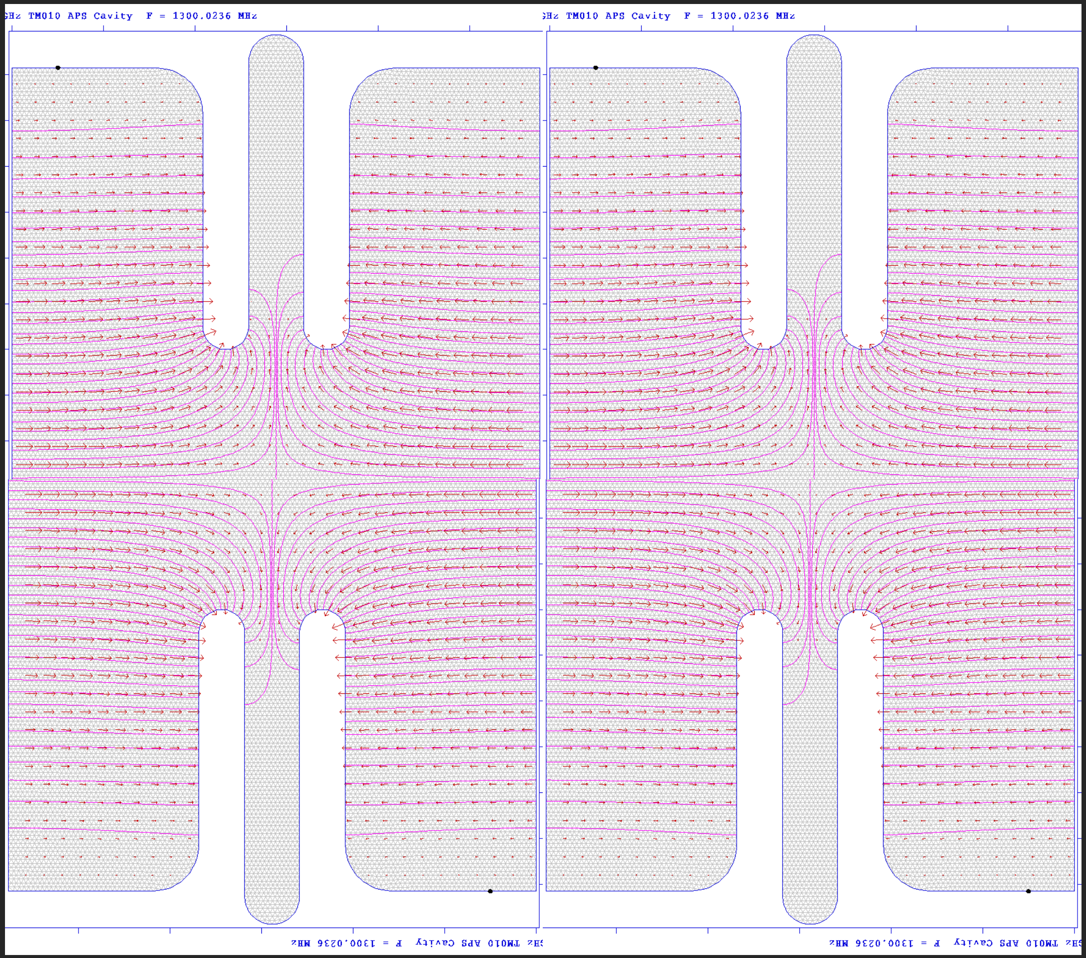


Side View

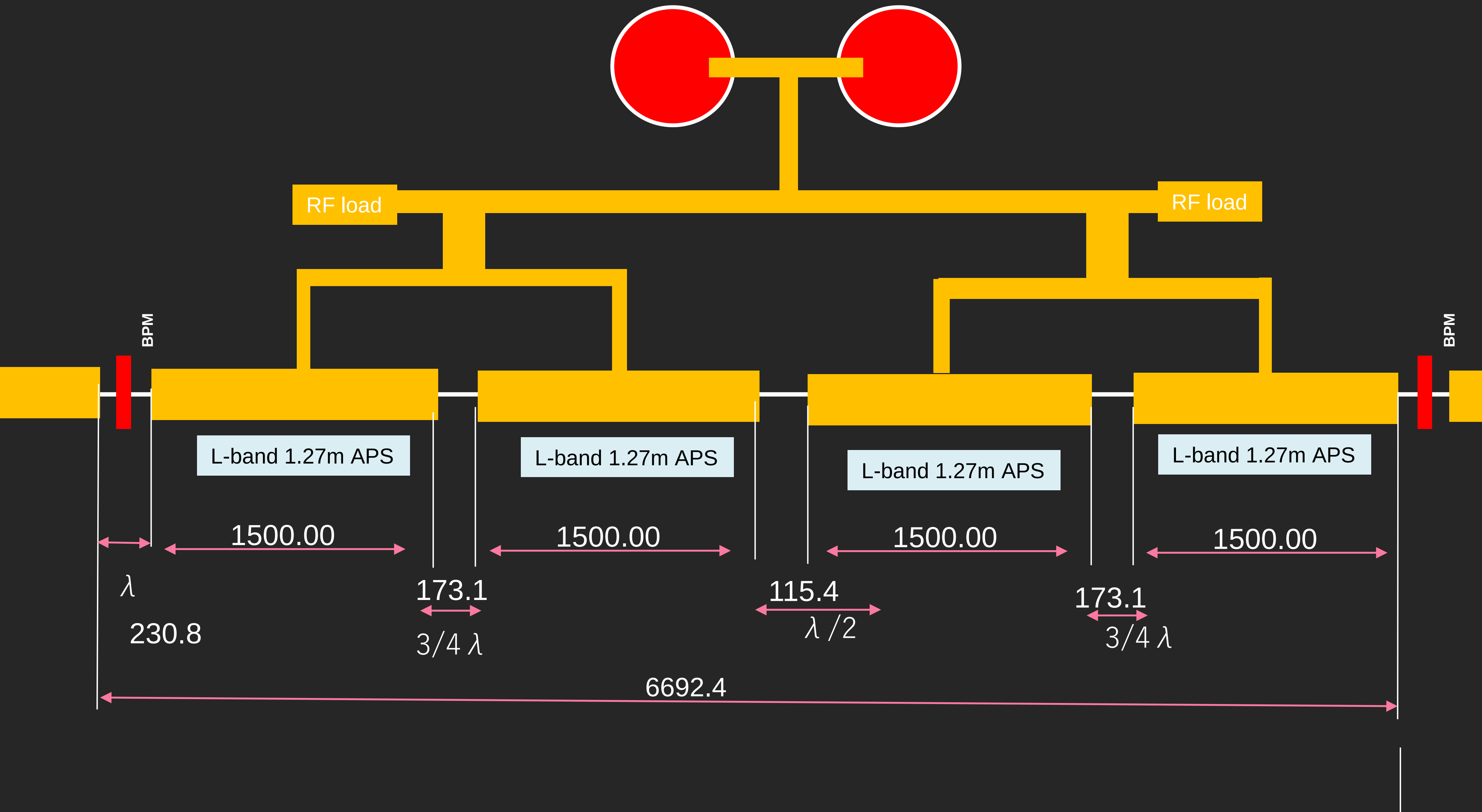


Capture Linac

- The capture linac is composed from 36 of 1.3 m L-band APS (Alternate Periodic Structure) cavity.
- The whole linac is surrounded by 0.5 T soleonoid.
- The deceleration capture is employed.
- Average energy at the end of the capture linac is 250 MeV.
- The beam loading compensation is made by PM. The detail is presented by S. Konno.

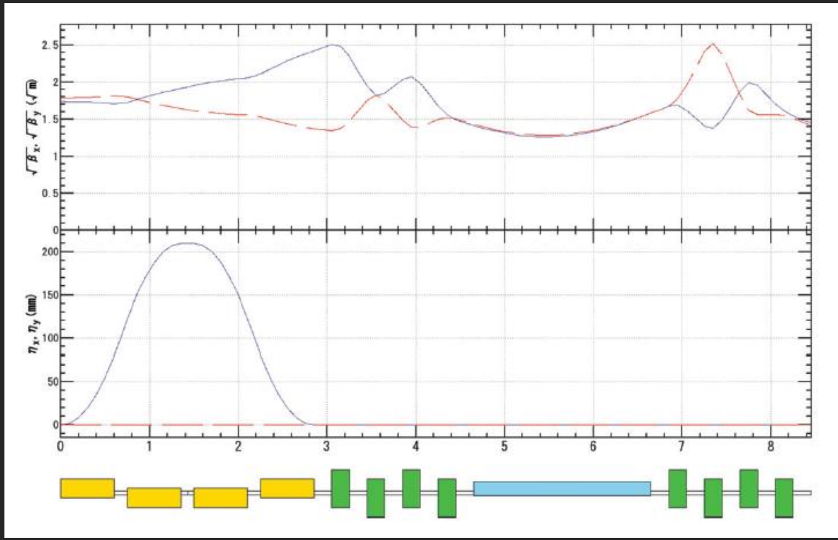


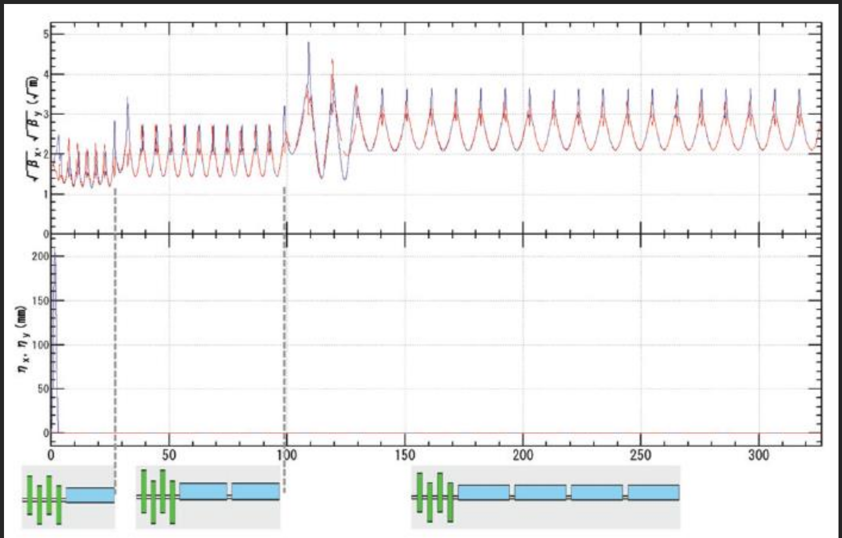
Capture Linac unit



Booster

- Positron booster linac is initially designed by Y. Seimiya.
- The booster is composed from L-band and S-band 2m TW RF.
- Density of Qs is high and low in the lower and higher energy region, respectively.
- Between the capture linac and booster, a chicane was placed to remove electrons.
- Bunching is a side effect.
- The chicane will be re-designed.





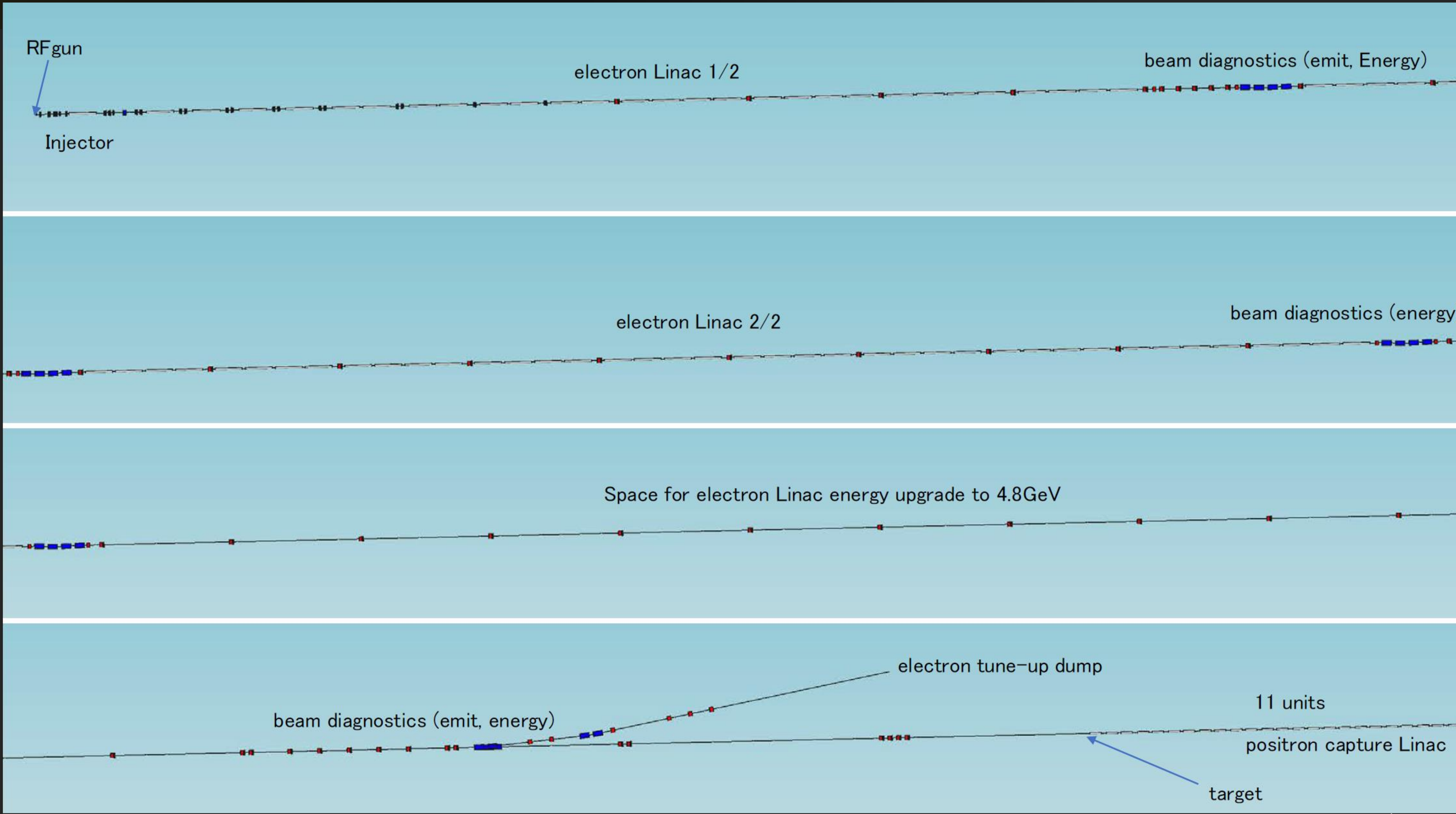
Booster Energy Estimation

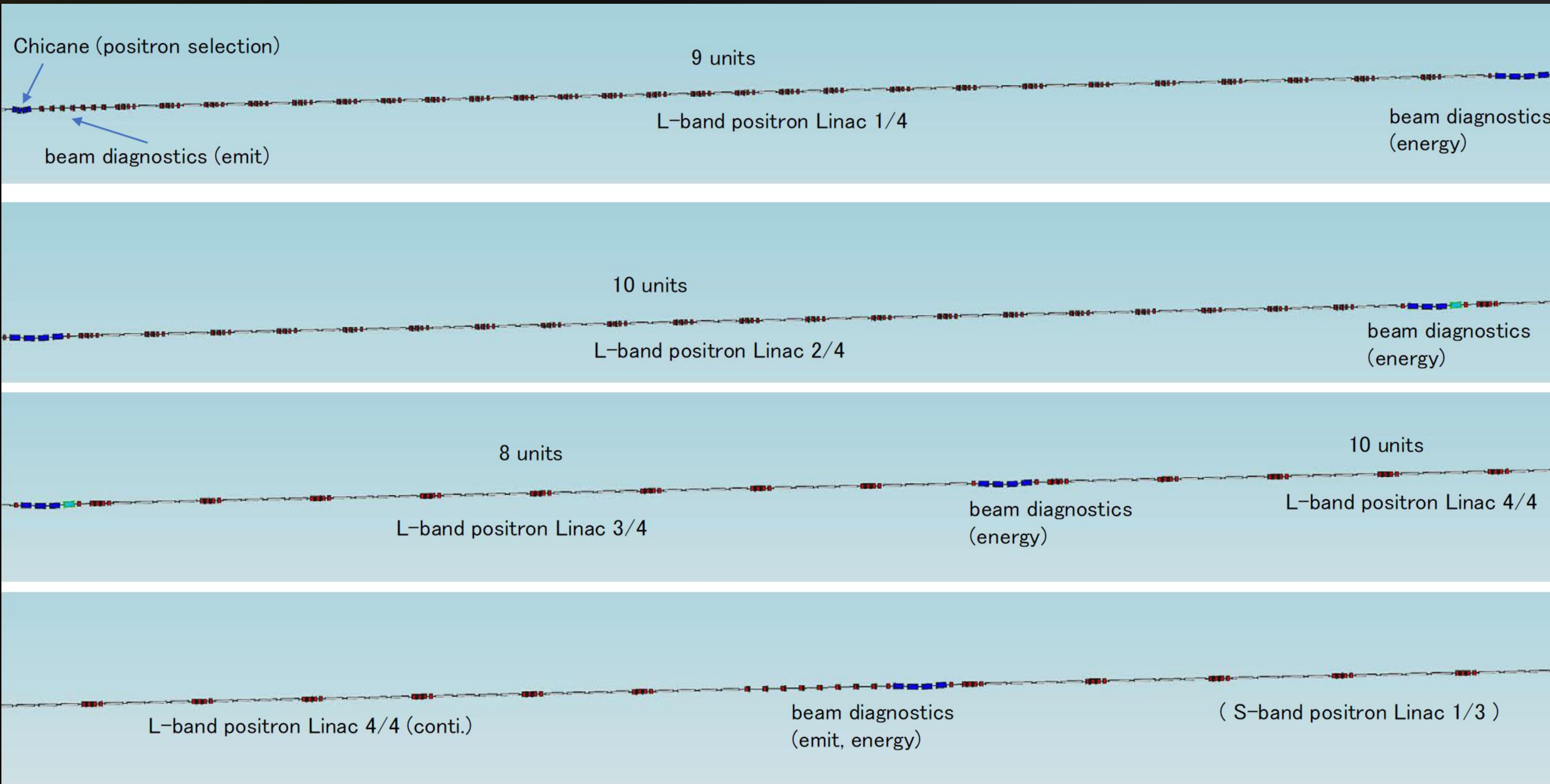
- Booster linac is composed from L-band TW RF and S-band TW RF of the first and second halves, respectively, for the better transimission.
- Accelerator energy is estimated by assuming the beam loading compensation with AM.
- Number of unit for each lattice section is adjusted to obtain similar energy defined in Ref*.

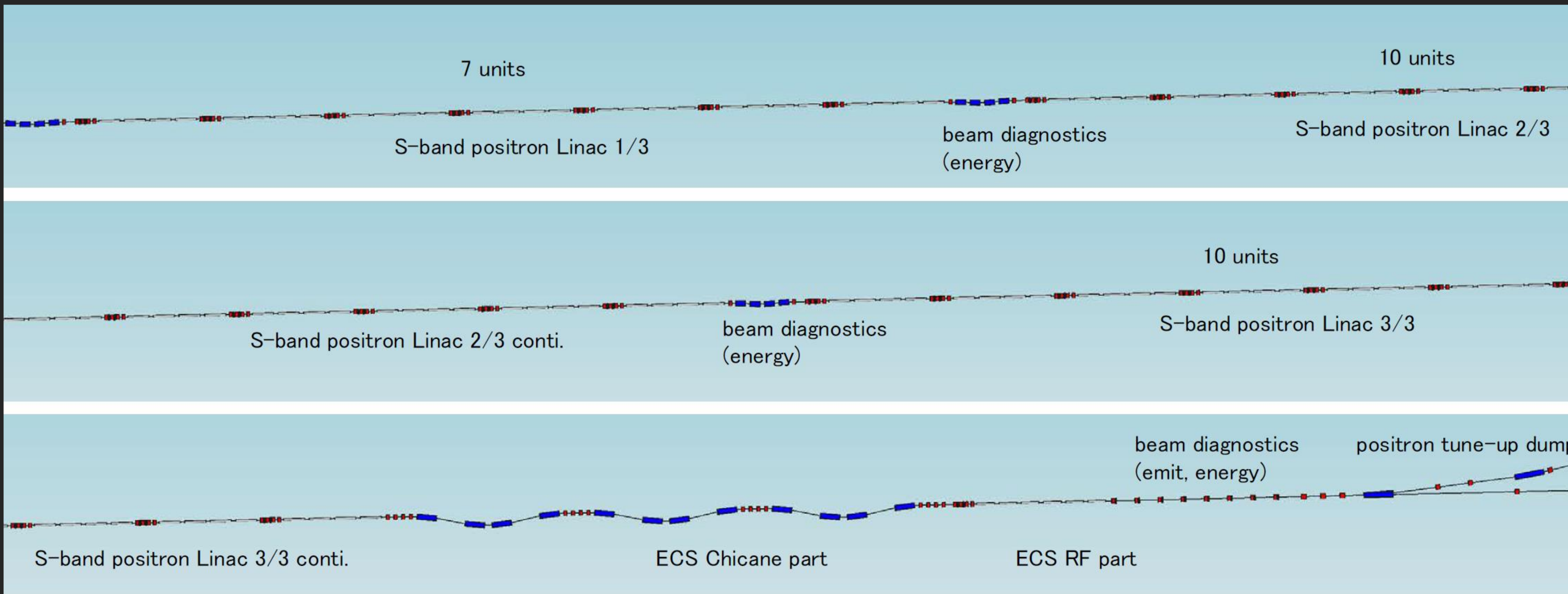
Lattice	# of unit	# of tubes	Acc. Energy	Energy
Capture linac			250	250
4Q+1L	3	12	198	448
4Q+2L	15	60	990	1438
4Q+4L	18	72	1188	2626
4Q+4S	25	100	2860	5486

*Y. Seimiya, et al., PTEP, 103G01 (2015) b
DOI: 10.1093/ptep/ptv136

The whole system




Chicane (positron selection)
9 units
L-band positron Linac 1/4
beam diagnostics (emit)
beam diagnostics
(energy)
10 units
L-band positron Linac 2/4
beam diagnostics
(energy)
8 units
10 units
L-band positron Linac 3/4
beam diagnostics
(energy)
L-band positron Linac 4/4
L-band positron Linac 4/4 (conti.)
beam diagnostics
(emit, energy)
(S-band positron Linac 1/3)


7 units
10 units
S-band positron Linac 1/3
beam diagnostics
(energy)
S-band positron Linac 2/3
10 units
S-band positron Linac 2/3 conti.
beam diagnostics
(energy)
S-band positron Linac 3/3
beam diagnostics
(emit, energy)
positron tune-up dump
S-band positron Linac 3/3 conti.
ECS Chicane part
ECS RF part

Summary

- ILC E-Driven Positron source system is integrated based on the latest R&D effort.
- Number of RF units is adjusted for the acceleration voltage with the beam loading compensation.
- The SAD deck should be corrected to the latest design.
- Engineering design will be made in pre-lab.