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R&D Studies on the S-band Hybrid Bunching-accelerating Structure

Shilun Pei & Bin Gao

Institute of High Energy Physics, Beijing, China

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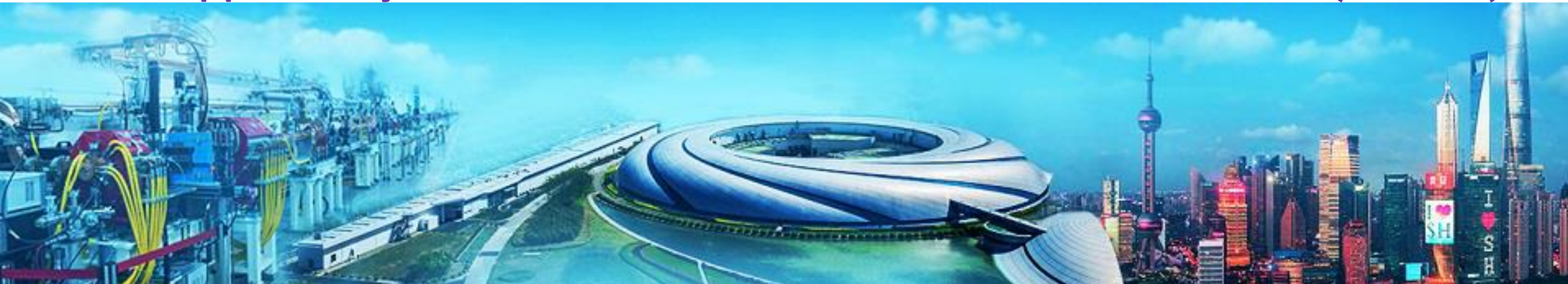
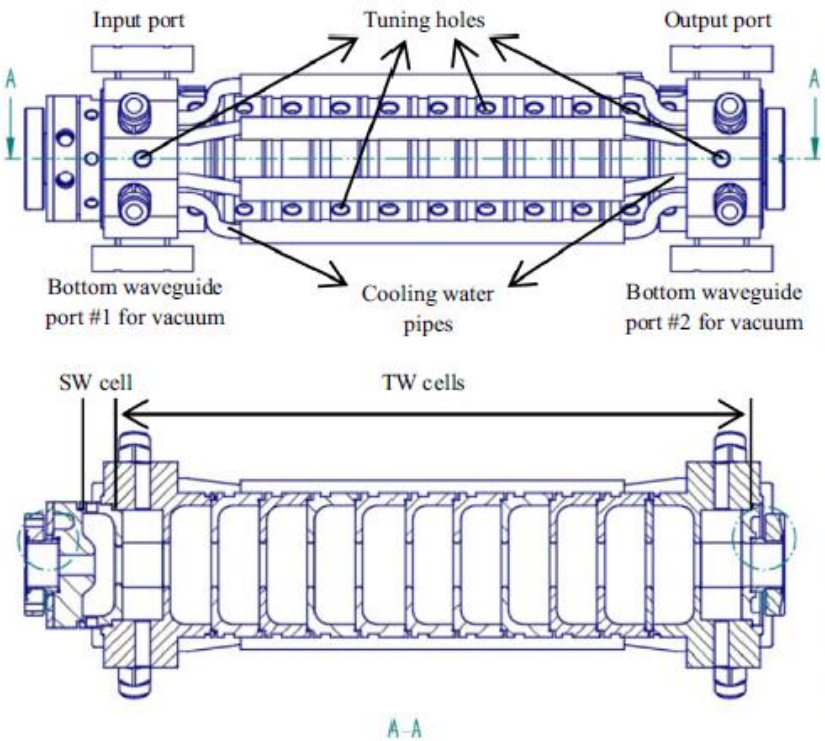


Outline

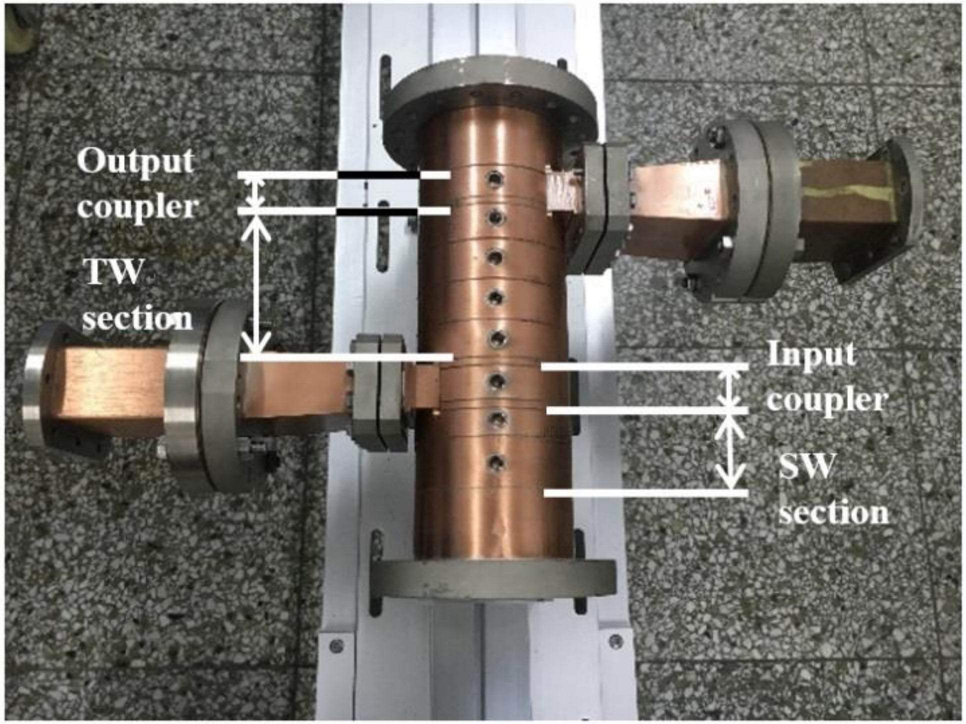
- Background
- Dynamics requirement
- RF & mechanical design
- Cold test before final brazing
- Plan & summary

Background

- Inspired by the idea of the hybrid photo-injector developed by the INFN-LNF/UCLA/SAPIENZA collaboration.
- Refers to the successful development experience of the hybrid bunchers both at DESY and IHEP.



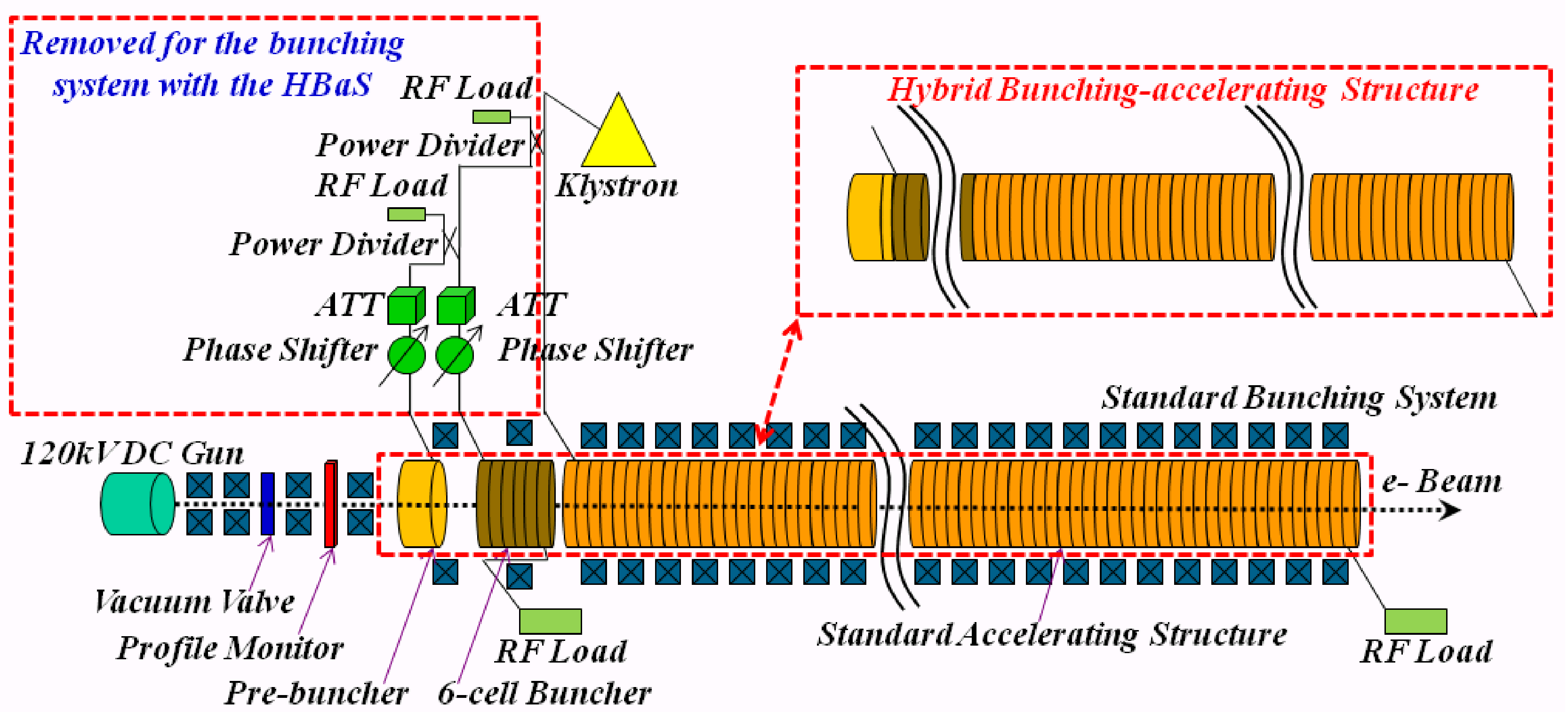
2998MHz hybrid buncher at DESY



2856MHz hybrid buncher at IHEP

Background

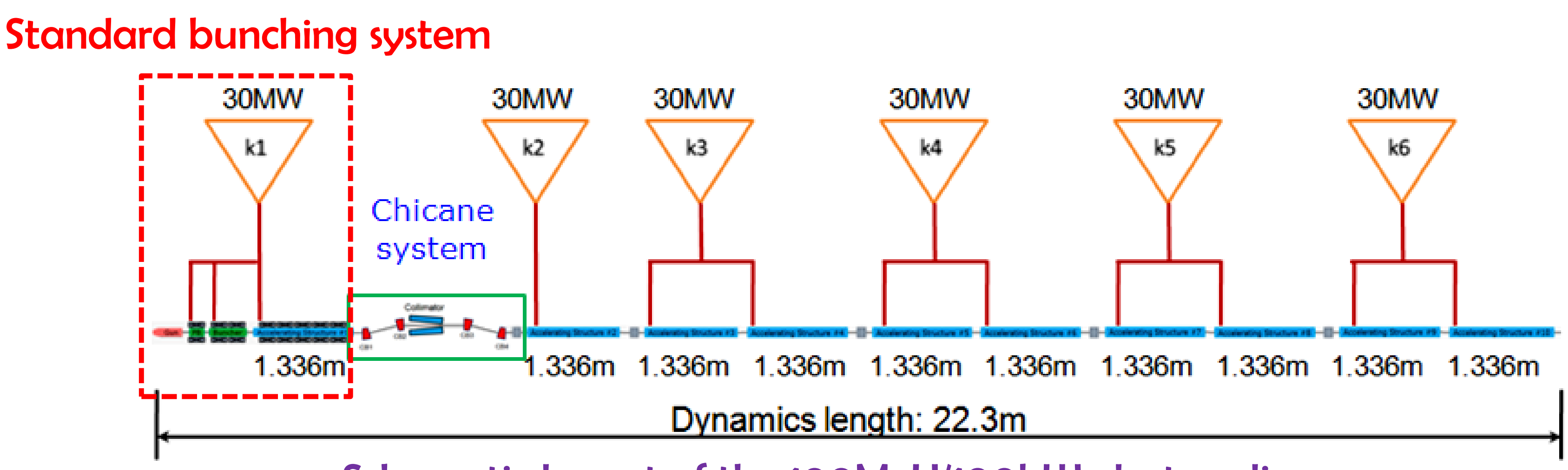
- Purpose to make the bunching system more compact and lower the construction cost with slight beam performance degradation.
- Possible to be applied in the industrial linac to greatly increase the capturing efficiency with a relatively smaller energy spread.



Bunching system layout

Dynamics requirement

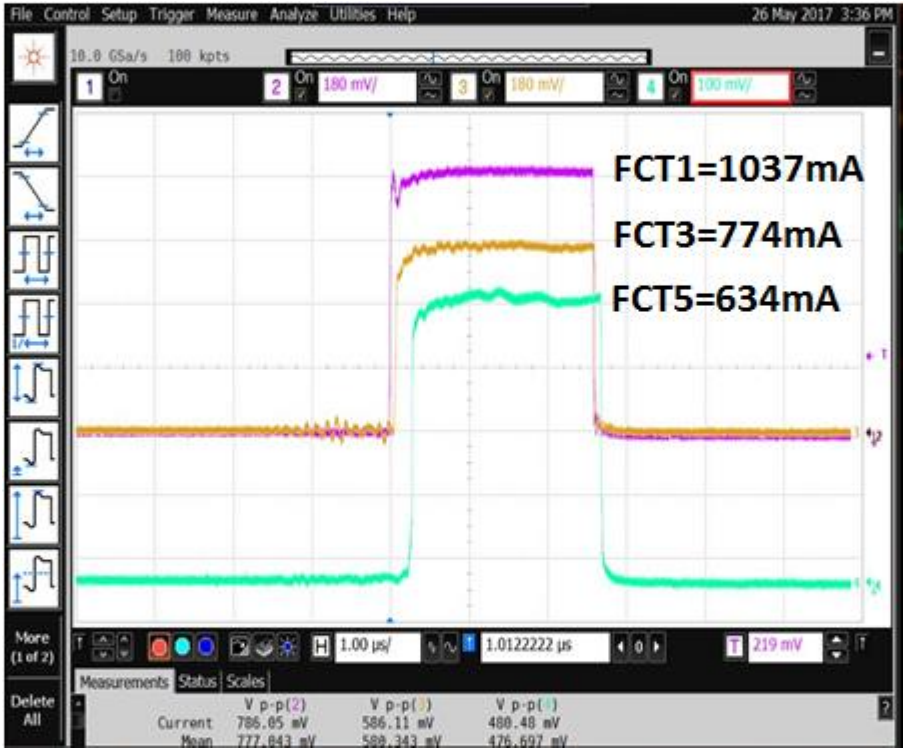
- To determine the beam dynamics requirement for the HBaS, it was introduced into the KIPT 100MeV/100kW linac to replace the standard bunching system.
- To satisfy the ±4% peak-to-peak energy spread requirement, the HBaS bunching system should be able to produce a similar energy spectrum as the standard one. In addition, at the linac exit a 600mA/2.7μs beam with ~70% beam transportation efficiency should be obtained.



Schematic layout of the 100MeV/100kW electron linac

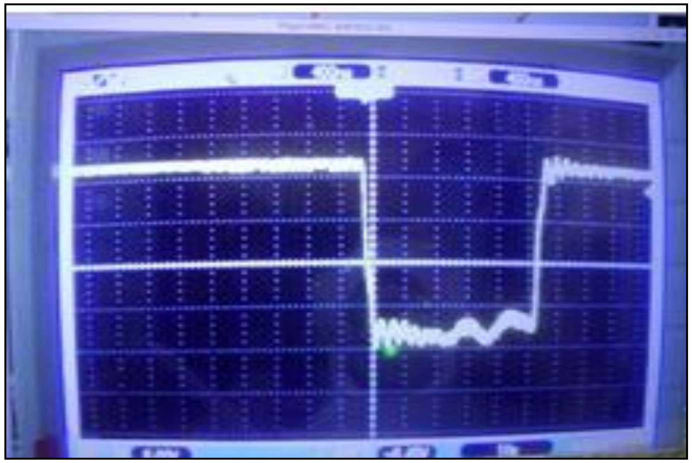
KIPT linac status

- Without applying the transient beam loading compensation, 100MeV/2.5μs/>600mA beam has been acquired at the linac exit and reached the neutron target.



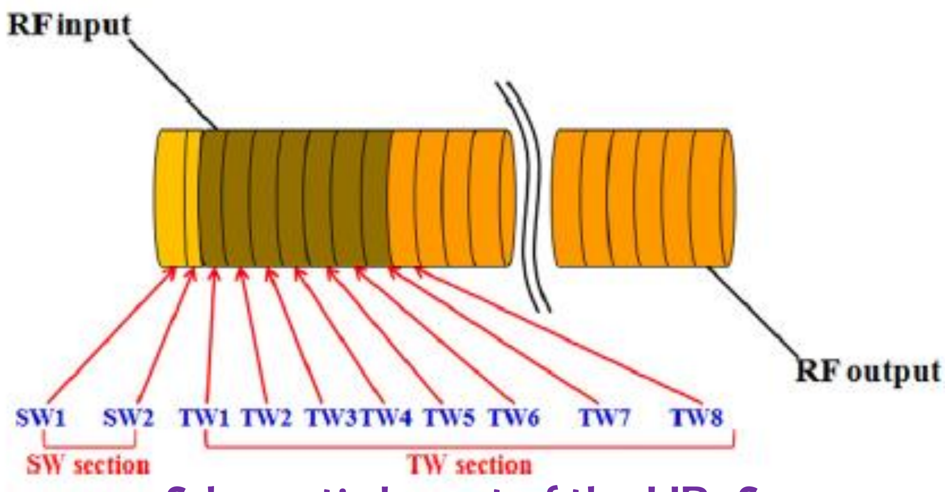
FCT1@gun exit/FCT3@chicane exit/FCT5@linac exit

Beam energy measurement


Beam signal at target

Dynamics requirement

- Total 44 cells, 2 cells operating at π/2 mode in the SW section, 42 cells including the input/output coupler cells operating at 2π/3 mode in the TW section.
- With ~14MW input power, ~10MeV beam can be obtained at the HBaS exit.



Schematic layout of the HBaS

Dynamics requirement for the HBaS

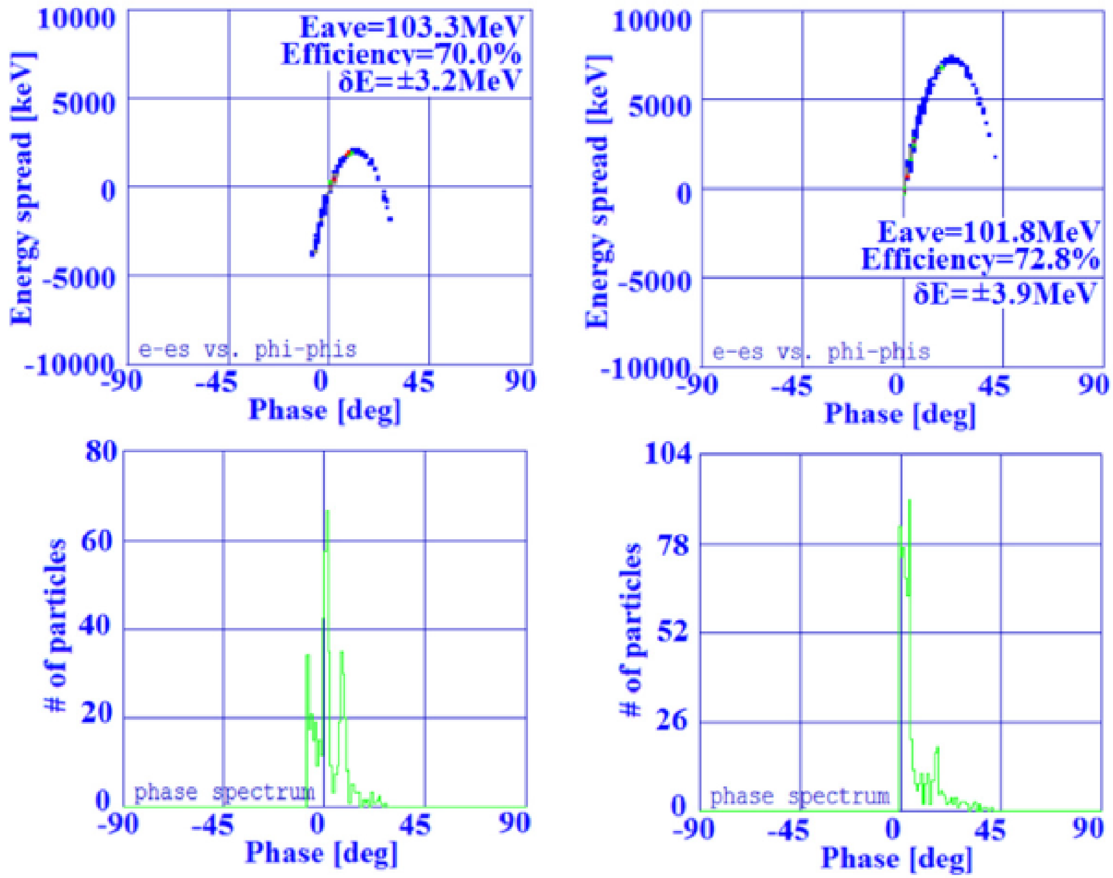
β values for the cells in the SW section		E_{sw}/E_{tw}	β values for the cells in the TW section							
SW1	SW2		TW1	TW2	TW3	TW4	TW5	TW6	TW7	TW8
1.26	0.74	0.44	0.75	0.75	0.75	0.88	0.92	0.95	1	1

Dynamics comparison

- The linac with the HBaS can also get ~70% transportation efficiency but with ~20% bigger peak-to-peak energy spread.

Linac with the standard bunching system

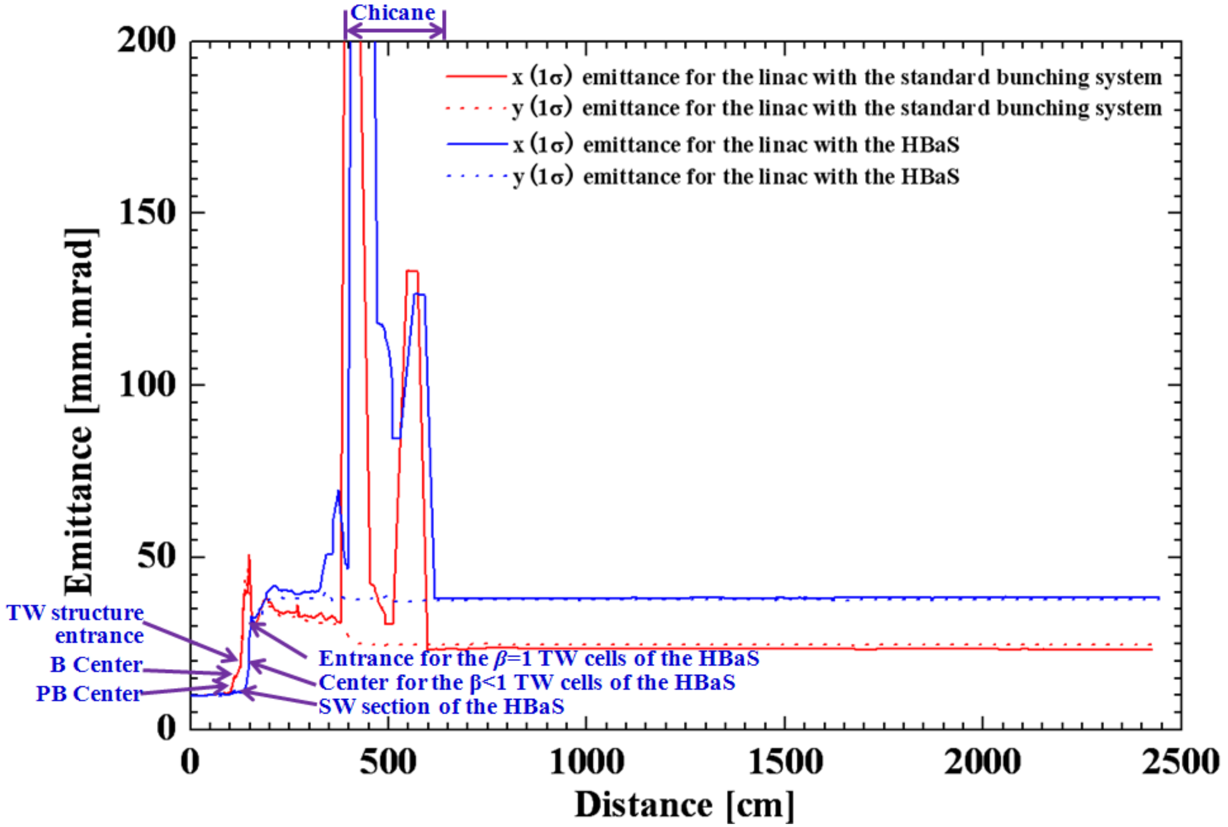
Linac with the HBaS bunching system



Beam phase and energy spectrums at the linac exit

Dynamics comparison

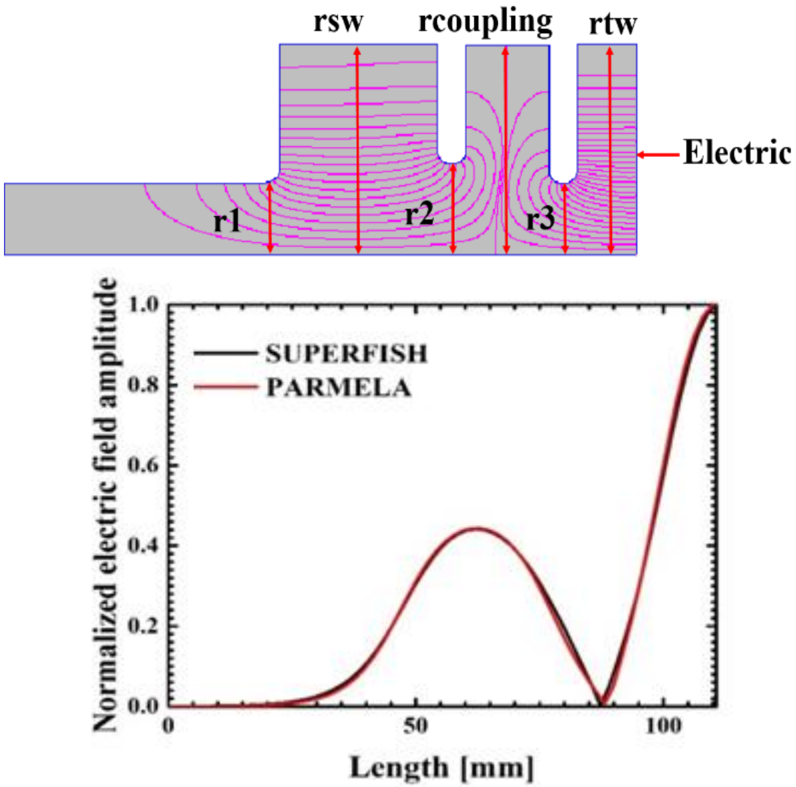
- Due to the hastier bunching process resulted by the compactness, the linac with the HBaS has ~60% bigger 1σ beam emittance.
- Nonetheless, the HBaS is still a better choice for the industrial linac which doesn't care too much about the emittance.



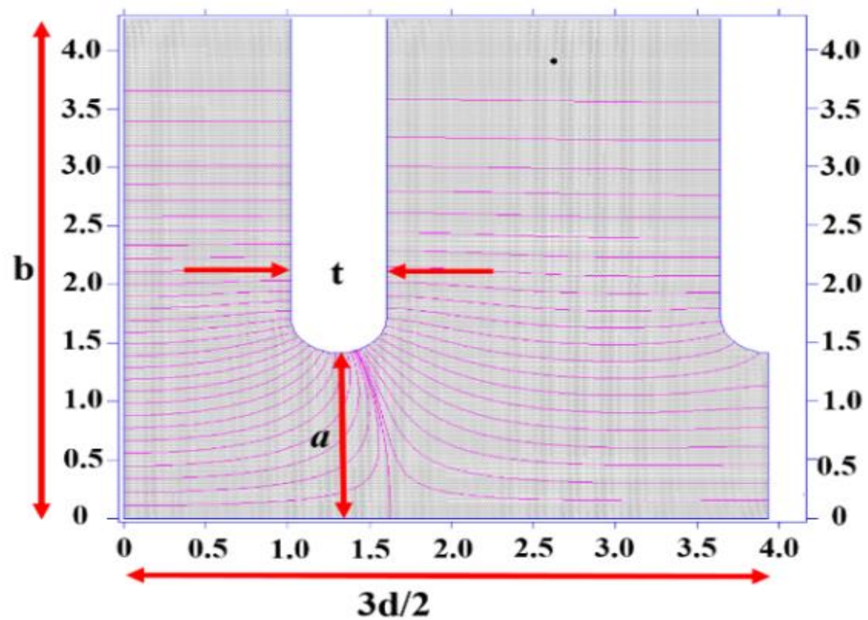
Transverse emittance evolution along the linac

2D RF design

- By changing the iris apertures in the SW section, the electric field ratio between the SW and TW sections can be optimized.
- By analyzing the relations between the SW and TW fields, the dimensions for the cells in the TW section can be determined.



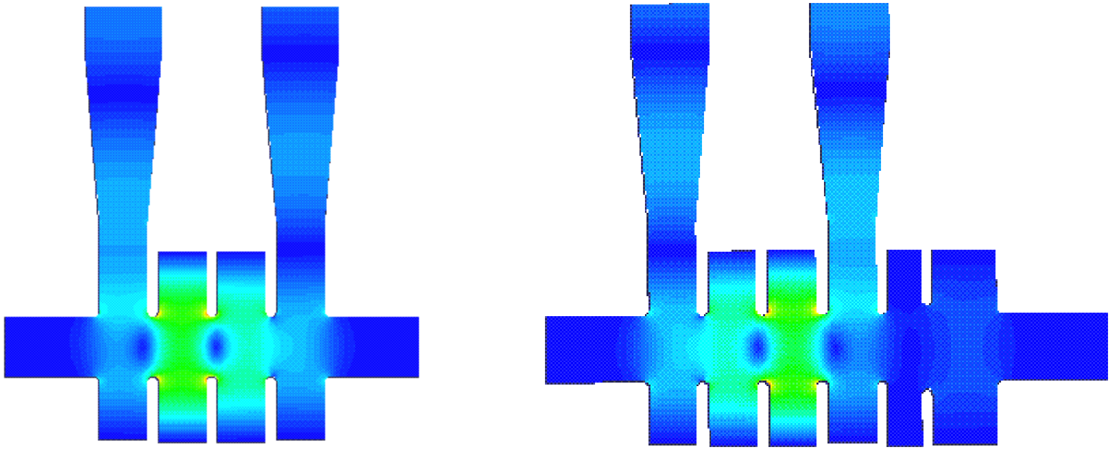
2D model and field distribution for the SW section



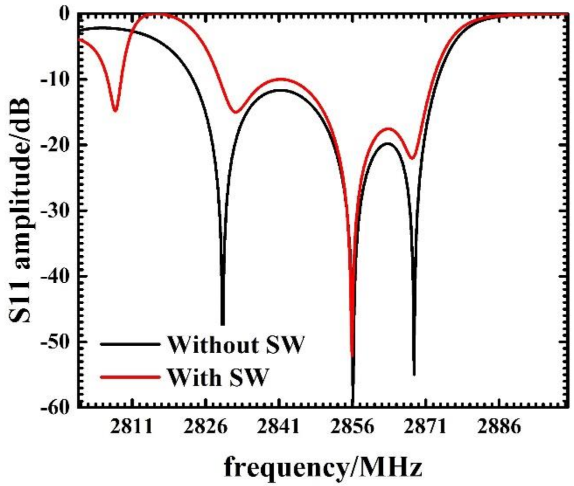
2D model for the cell in the TW section

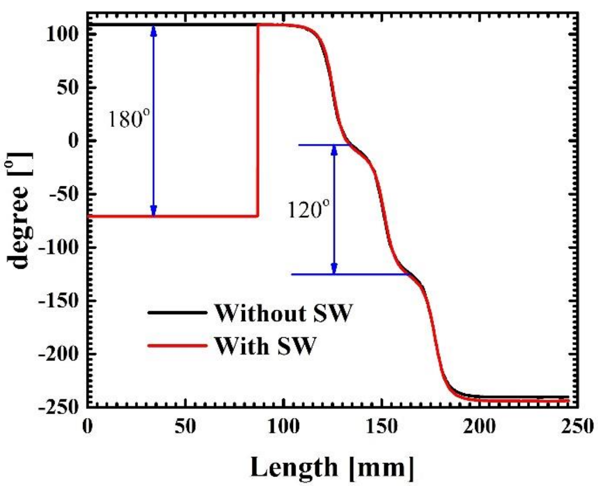
3D RF design

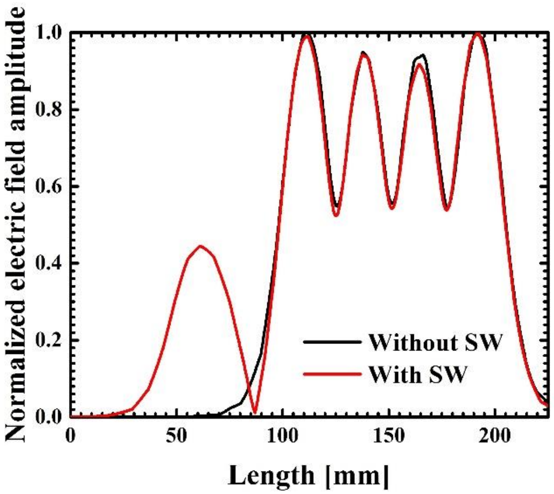
- Both the input/output coupler were designed based on the Kyhl method and confirmed with the field transmission method.



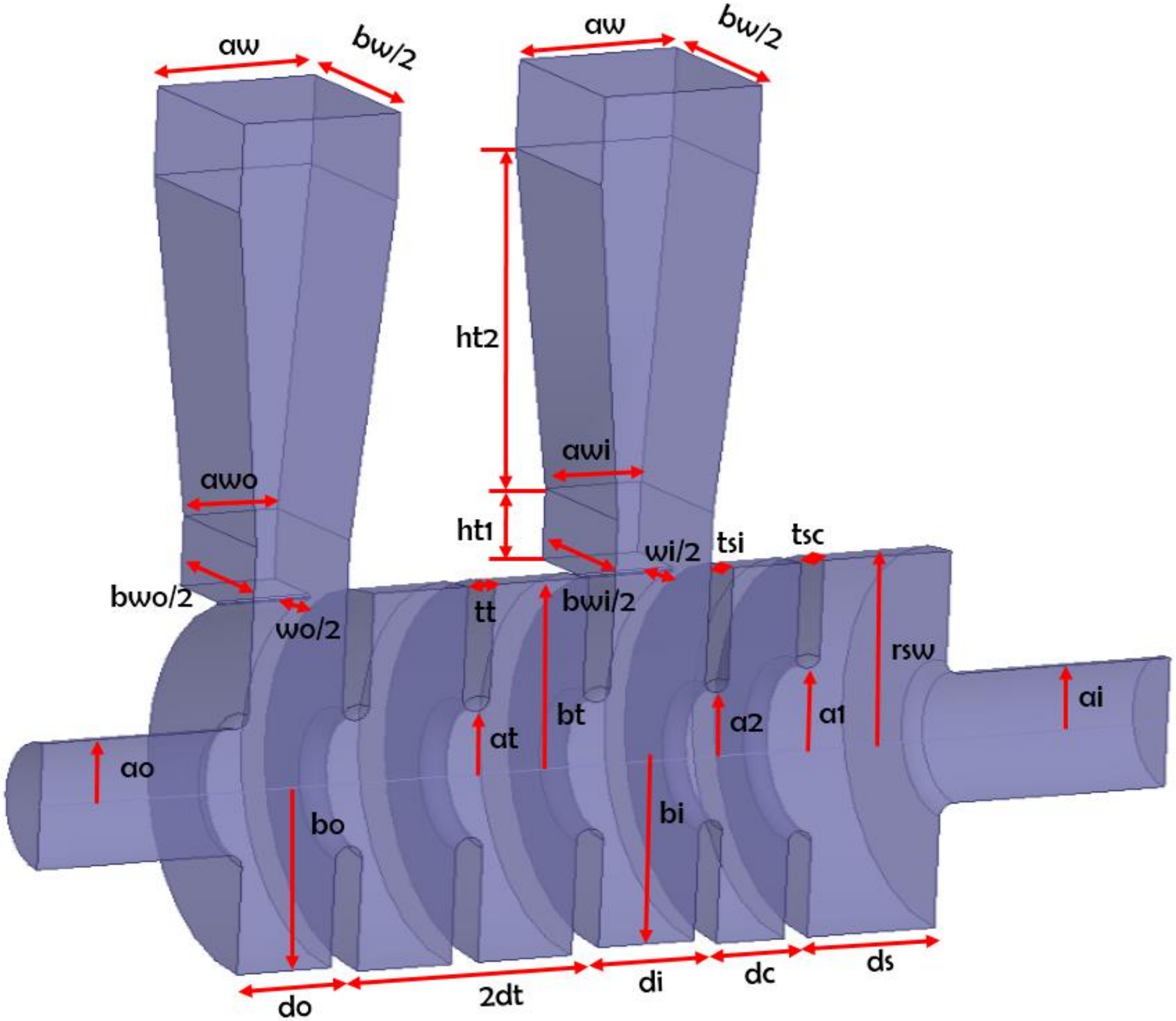
Field animation without/with attachment of the SW section







3D RF design

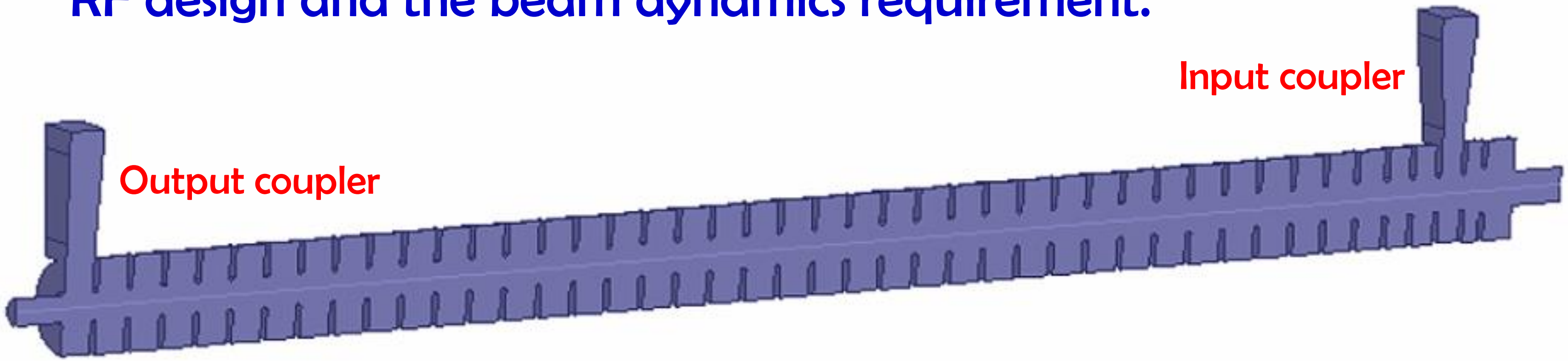


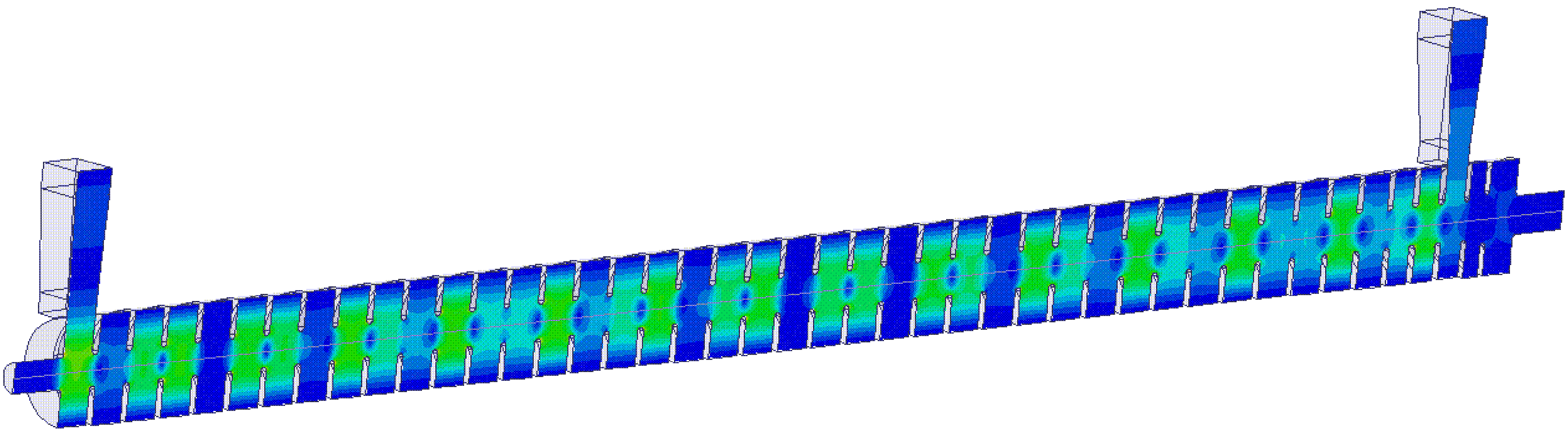
parameter	value [mm]
ds	32.803
dc	19.682
di	26.247
dt,do	26.242
ai	14.62
at,ao	14.259
bi	41.431
bo	41.466
bt	42.701
rsw	42.502
a1	18.365
a2	14.445
tsi,tsc	5
tt	5.843
awi	20.821
bwi	61.087
wi	30.964
wo	30.884
ht1	15.9
ht2	76.2
aw	34.163
bw	72.263
awo	20.399
bwo	61.087

Model and dimensions for the SW section and the input coupler

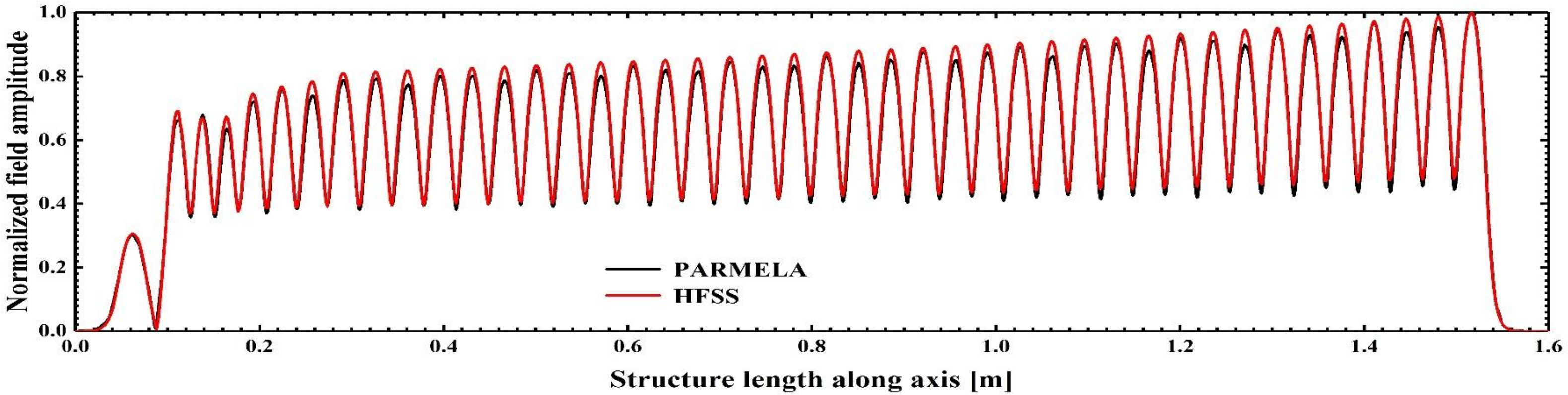
3D RF design

- Full 3D simulation of the HBaS was done to confirm the consistency of the on-axis electric field distributions between the RF design and the beam dynamics requirement.

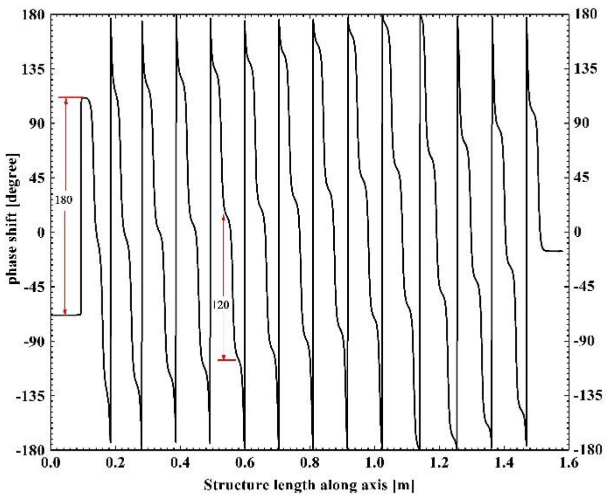




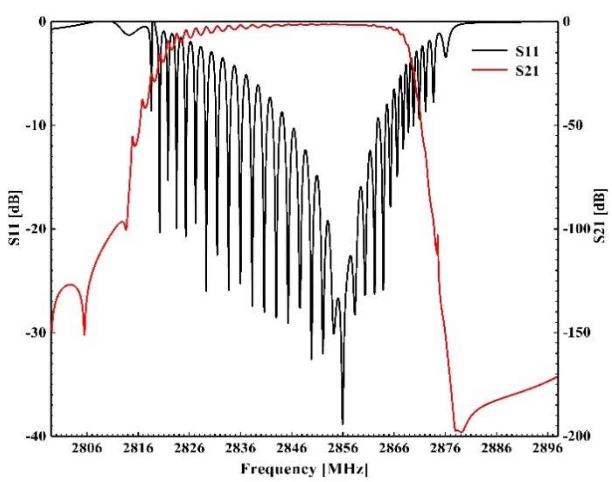
3D RF design



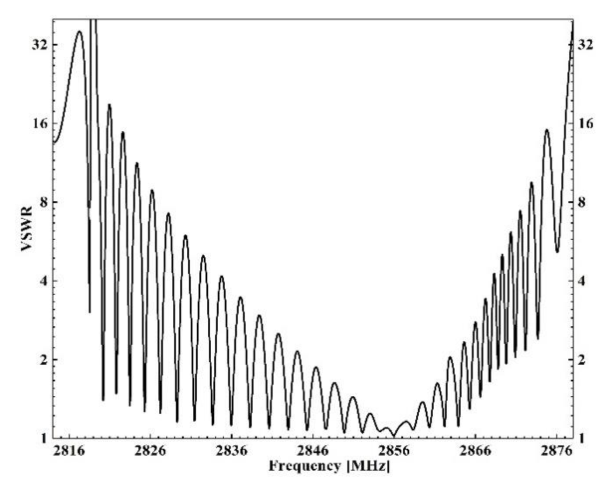
Electric field amplitude distribution along the HBaS axis



Electric field phase distribution along the HBaS axis

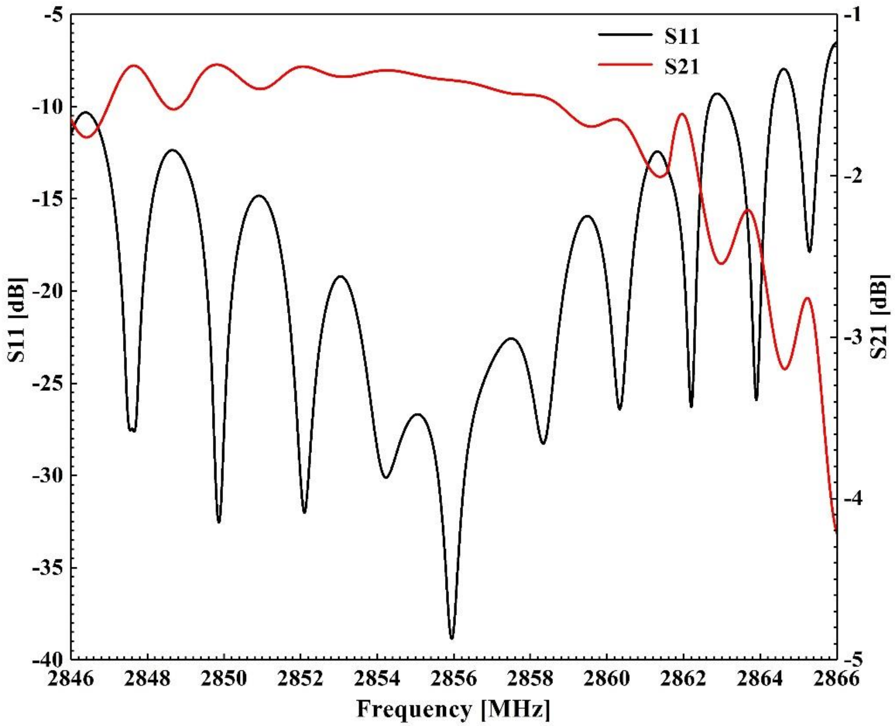


Broadband S11 and S21

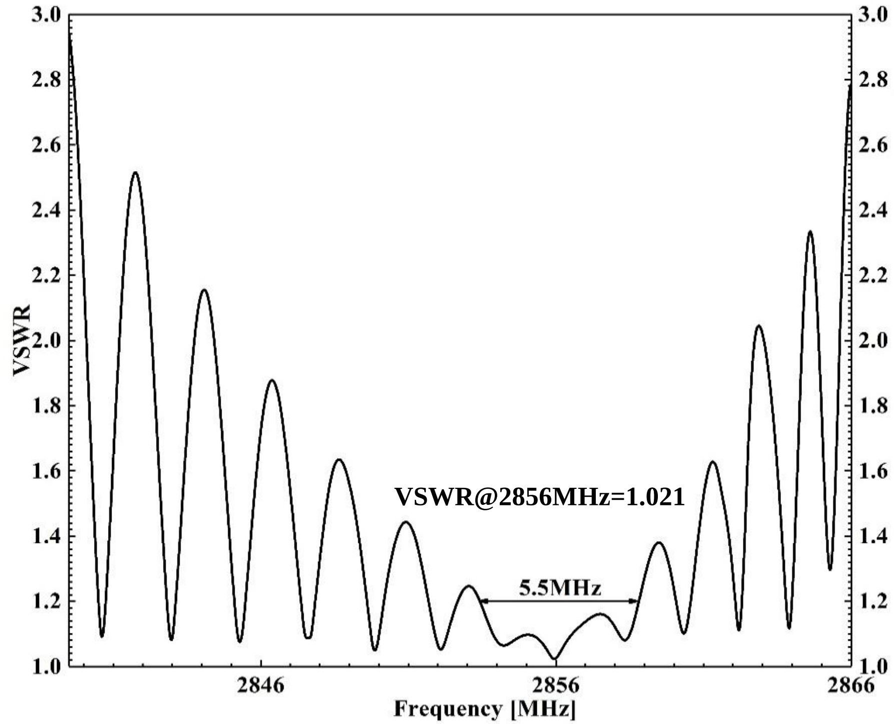


Broadband VSWR

3D RF design



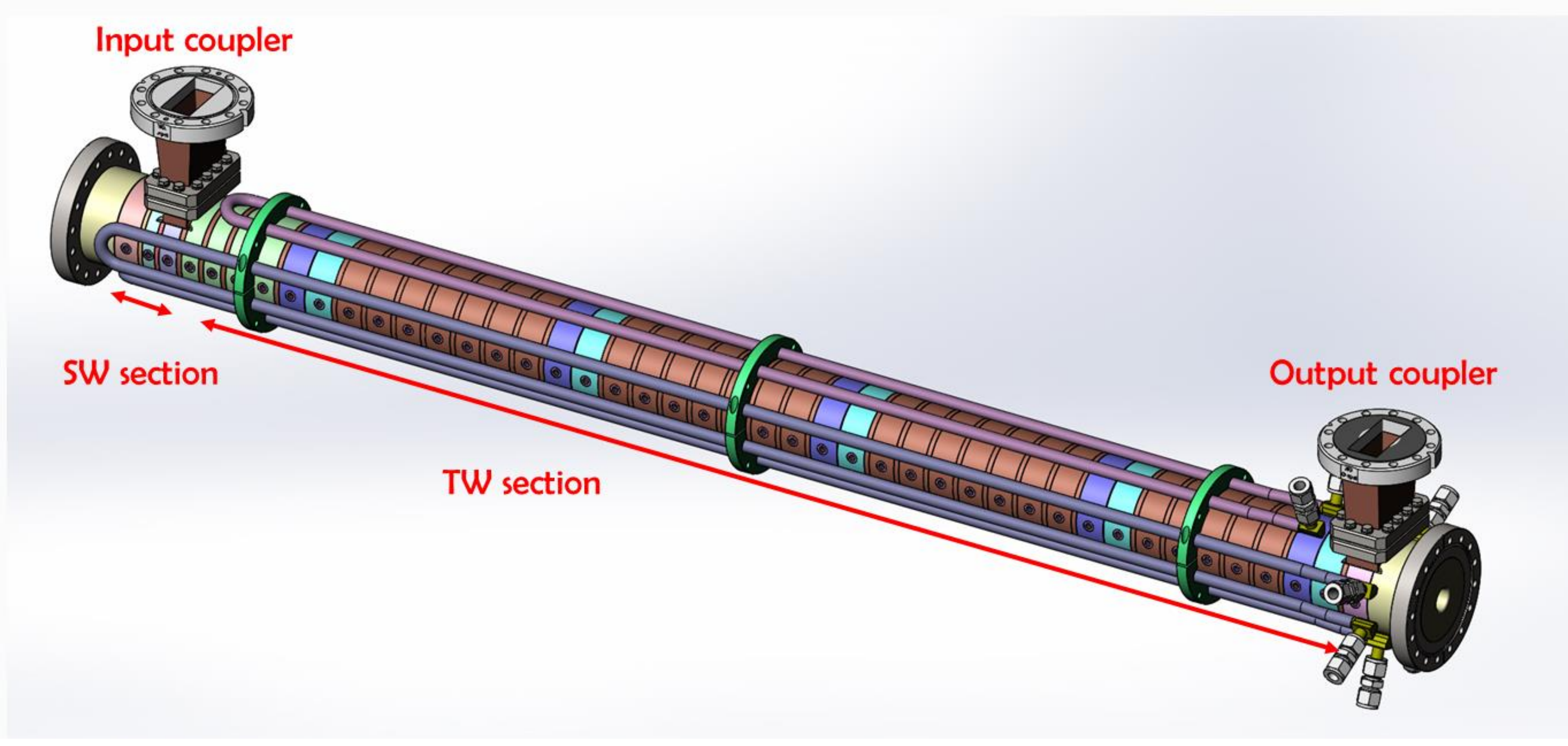
Narrowband S11 and S21



Narrowband VSWR

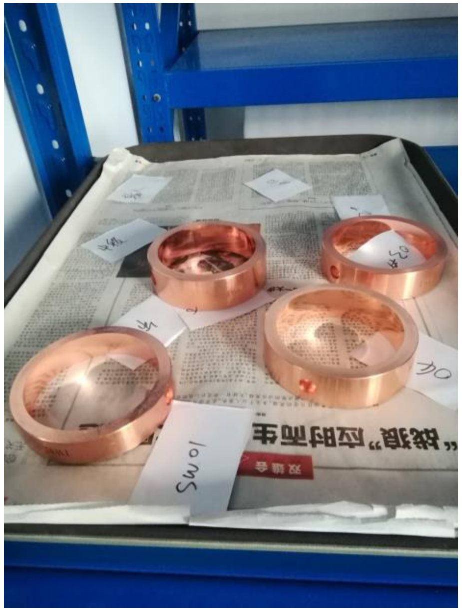
Mechanical design

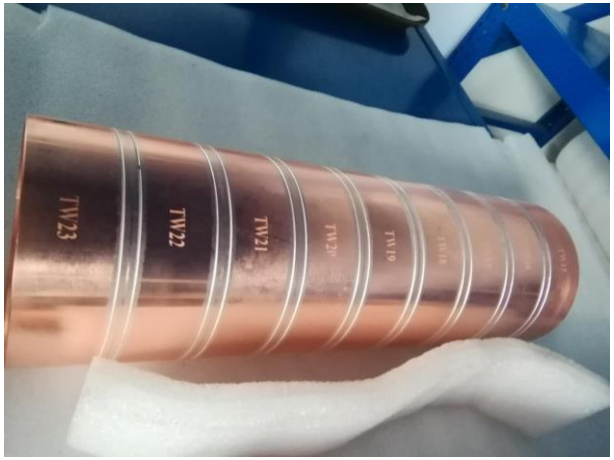
- To facilitate the solenoid mounting onto the HBaS, the water cooling inlets and outlets were placed at the output coupler side. In addition, the small flanges were adopted for both the input and output couplers.



Mechanical fabrication

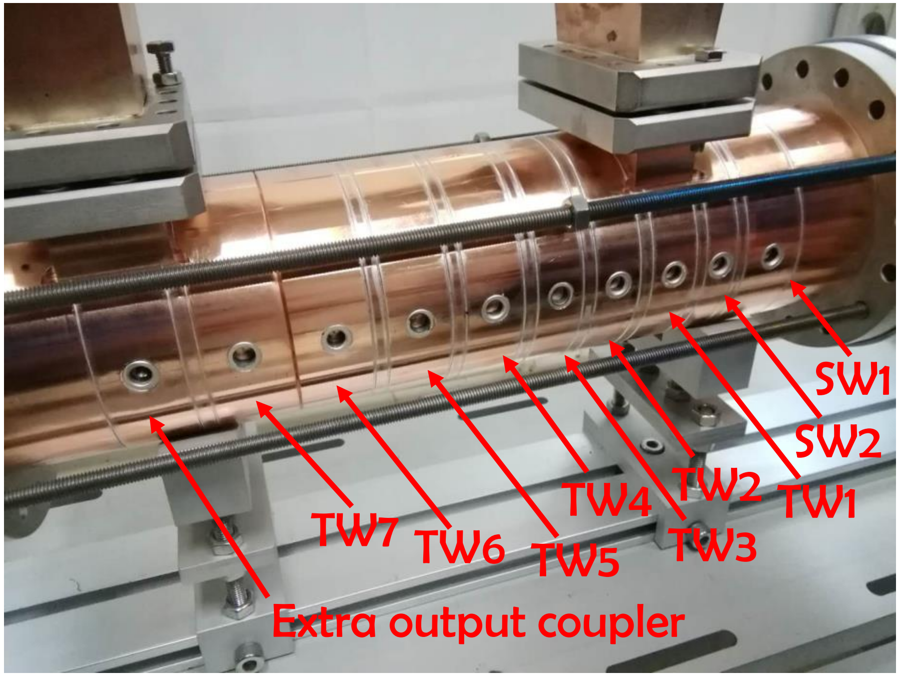






Preliminary cold test

- By stacking all the related cells together, the cold test and the field distribution measurement for the β-varied section has been done to check the RF performance before the final brazing.
- To match the cell TW7 with β=1, one extra output coupler was designed and fabricated.

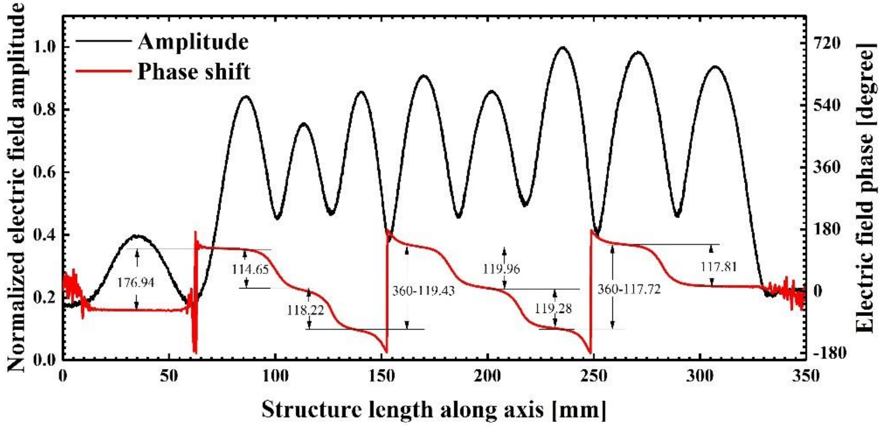


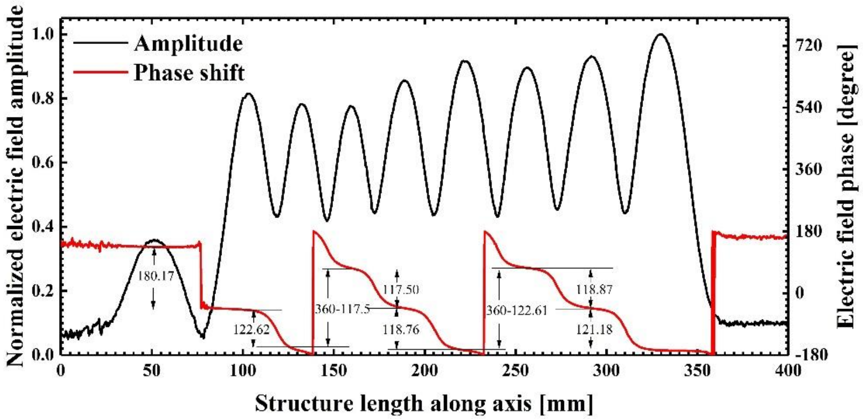
Preliminary cold test

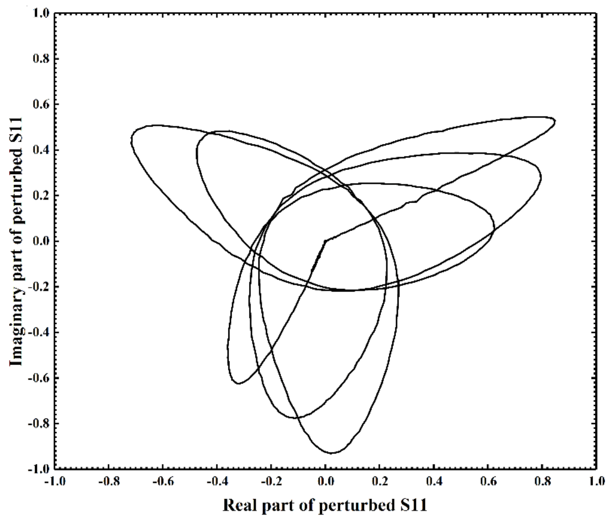
- Both the input and output couplers were found to have a lower frequency. Small metal balls were inserted into the coupler cells to increase the corresponding frequencies.
- Great efforts have been made to get rid of reflection by optimizing the stub tuners mounted on the input and output waveguides. Hence the effect of the SW component on the field distribution measurement can be mitigated.
- The manufactured intrinsic frequency is 2853.8MHz, while the targeted frequency is 2855.2MHz by taking into account the differences in the air temperature, the pressure, and the humidity between the laboratory and the operating condition.
- To reduce the risk of vacuum leak after the final brazing, deforming the cells by pushing and pulling were not done, only the field distribution at 2853.8MHz was measured.

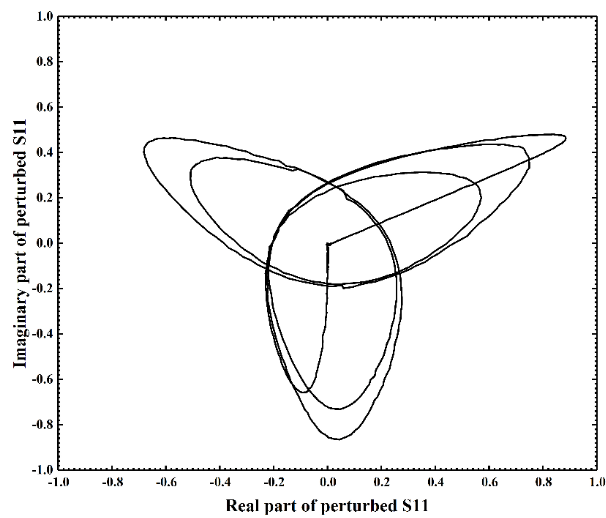
Preliminary cold test

- After tuning, the average phase advance has been upshifted from 118.2° to 119.9°. The maximum phase deviation per cell relative to 120° has been decreased from -5.35° to 2.62°.



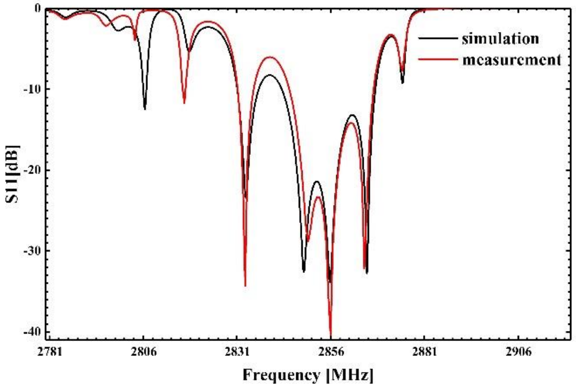


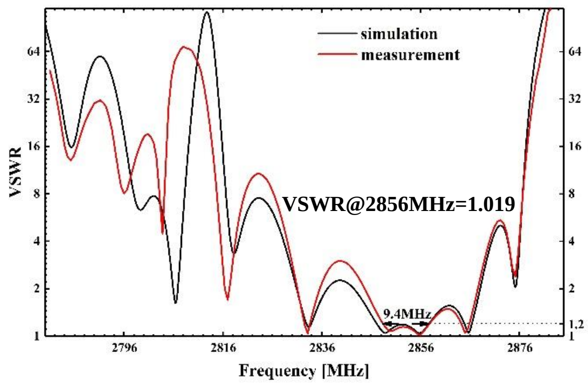


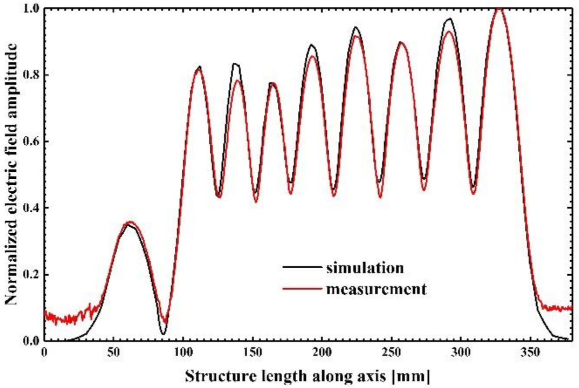


Preliminary cold test

- By shifting the measured S11 curve upward by 2.2MHz (from 2853.8MHz to 2856MHz), well consistency with the HFSS simulation can be obtained.
- The designed and measured E_{sw}/E_{tw} are 0.44 and 0.447 respectively, the difference is only 1.5%.







Plan and summary

- Based on the successful development experimence of the hybrid buncher at IHEP, one HBaS prototype has been designed and fabricated.
- The final brazing of the HBaS has been finished last week, tuning will be conducted very quickly. After tuning, the high power test will be carried out at the high power testing station of IHEP.

Plan and summary

- In terms of the beam capturing efficiency and the construction cost, the HBaS can be widely applied in the industrial area.
- The compactness of the HBaS also allows it to be easily scaled to a higher frequency, which is definitely a better choice for the future table-top industrial linac.

Thanks a lot for your attention!

Thanks to the colleagues of Beijing He-Racing Technology Co., Ltd. (HERT) for helping in the HBaS fabrication and cold test.