Research and Development of Irradiation Linacs in Tsinghua University and NUCTECH

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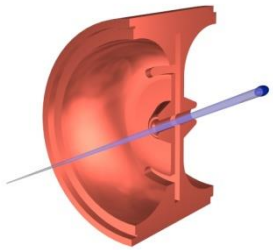
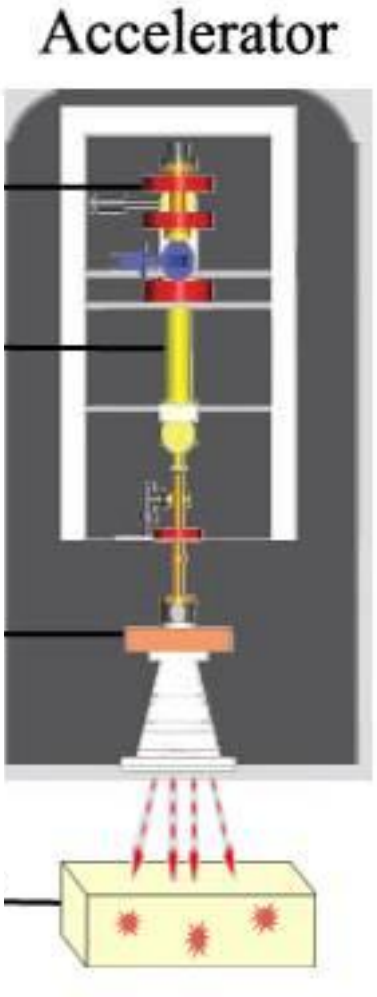


Accelerator Laboratory of Tsinghua University

Outline

- Application of irradiation linac
- Backward traveling-wave linac
  - Linac tube development
  - Irradiation system
- Projects Overview
- Research Projects
  - Traveling-wave linac
  - Beam breakup effect study

accelerator technology for irradiation & sterilization



Apply to irradiation processing of food, medical product, quarantine treatments and etc.

- Damage to the molecular of the harmful organism. To control insects, parasites and pathogens, reduce spoilage.
- Inhibit sprouting, delay ripening and extend self-life for certain farm produce.

- Low Energy
  - <300keV
  - E-beam curing
- Middle Energy
  - 0.3-5MeV
  - Cross-linking of polymers, for cable / rubber …
- High Energy
  - 5-10MeV
  - Sterilization …Food irradiation

Application fields

Medical products, Medicine, Mails……Sterilization

Application fields

Food irradiation

Application fields

Irradiation phytosanitary treatment

Excellence of E-Beam system

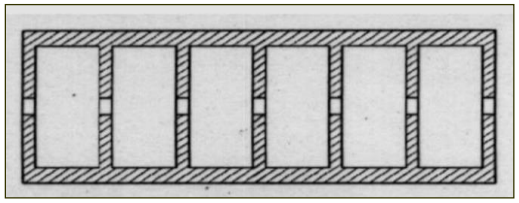
- No environmental pollution.
- Quick processing, high efficiency.
- Do not open the packing case, so it can get across quickly and safely.
- No toxicity or remains. Do not add any chemical reagent, so no original element and quality of products is influenced.

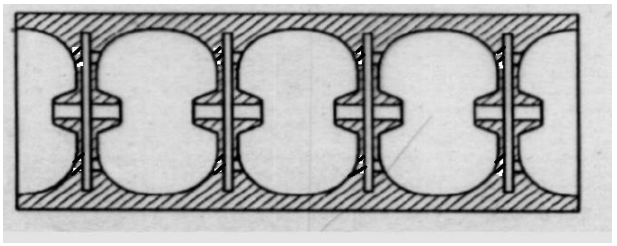
Linac

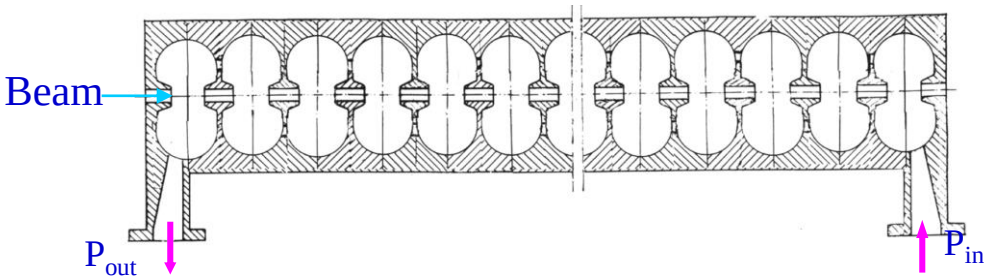
- Irritation E-beam facility
  - Dynamitron
  - Linac
  - Rhodotron
  - Ridgetron
  - Fantron
- LINAC
  - Standing wave/Traveling Wave/Backward Traveling Wave

Backward-Traveling-Wave (BTW) Structure

- Common structures
  - Disk-loaded waveguide (traveling wave)
  - Bi-periodic standing wave
  - BTW type (Traveling wave)





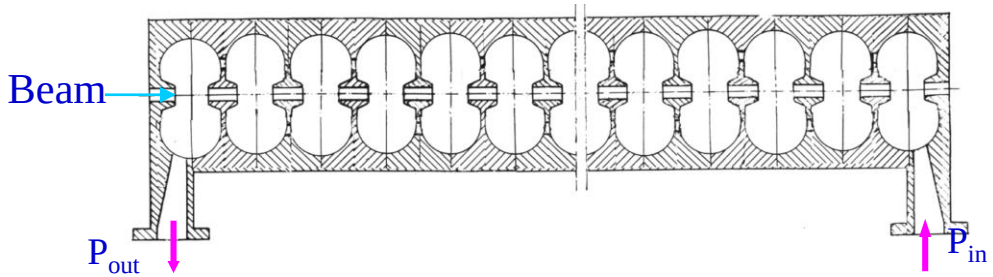


Introduction of BTW structure

- BTW structure
  - High-shunt impedance (~ Optimized shape)
  - Short filling time (~Traveling wave)

	Shunt impedance	Filling time	Need AFC?	Reflection from input	Peak surface field
Diskloaded	Low	Short	No	Low	Low
Bi-periodic SW	High	Long	Yes	High	High
BTW	High	Short	No	Low	High

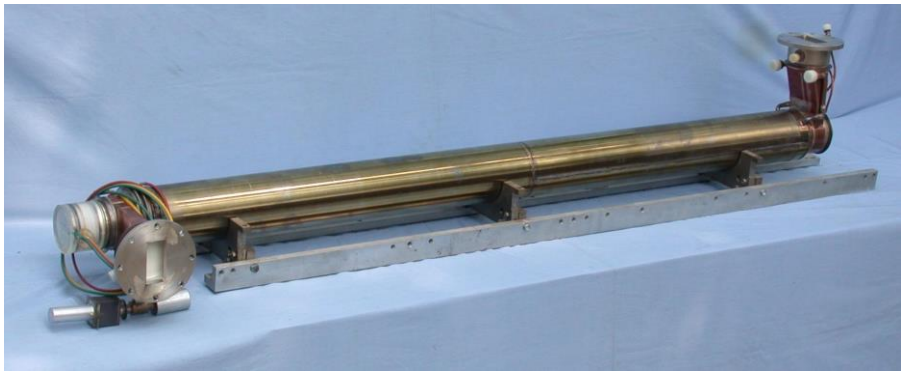
BTW structure



- Cells coupled through coupling holes
  - Beam-pipe cut off
  - Easy for tuning a structure
  - RF focusing
- Power flow opposite direction to the beam
  - High efficiency
  - Easy for cooling the input coupler

16MeV BTW linac

- Energy: 16MeV
- Dose rate: 12000cGy/min@1m
- Beam spot: <ϕ2mm
- Peak current: 115mA
  - RF power in (peak): $P_m = P_e/40\% = 4.6MW$
  - Beam power (peak): $P_e = 16MV \times 115mA = 1.84MW$
- Developed in 2000.
  - First BTW linac

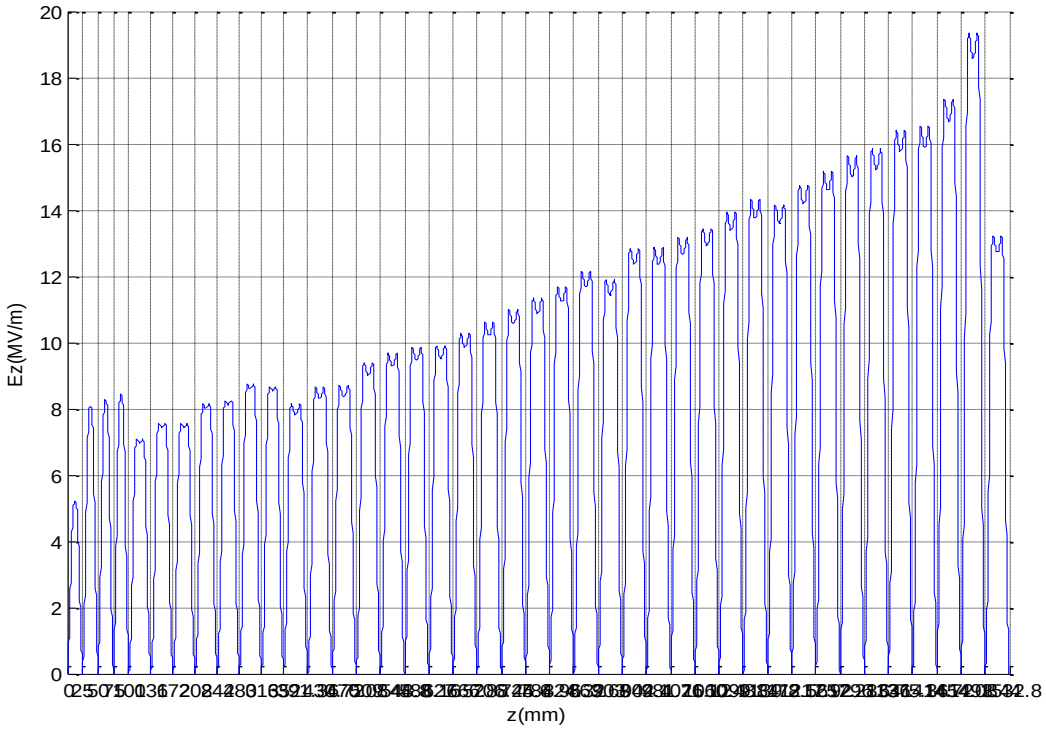


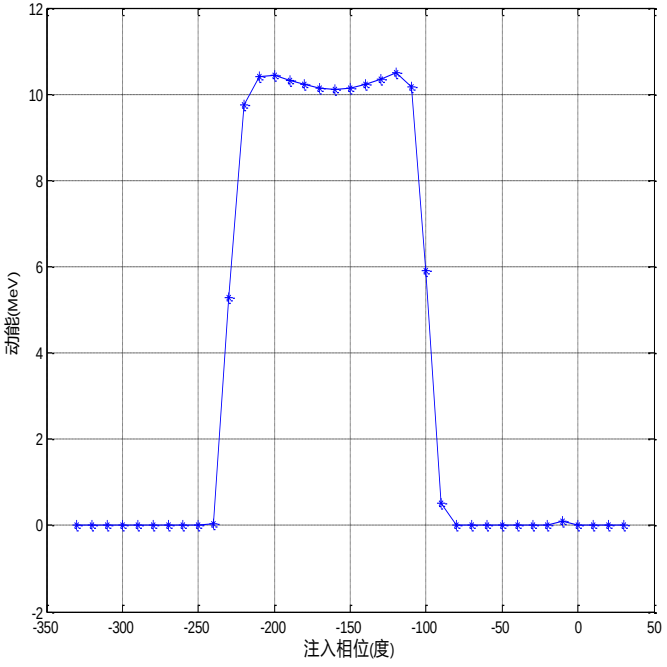
Design parameters

- Ebeam:
  - Energy： 10MeV
  - Peak current： 300mA
  - Average power： 20kW
- Accelerator tube:
  - BTW type
  - length：1.5meter
  - Bunching cells：11 cells
- RF source:
  - 5MW/45kW klystron @ 2856MHz

Beam dynamics

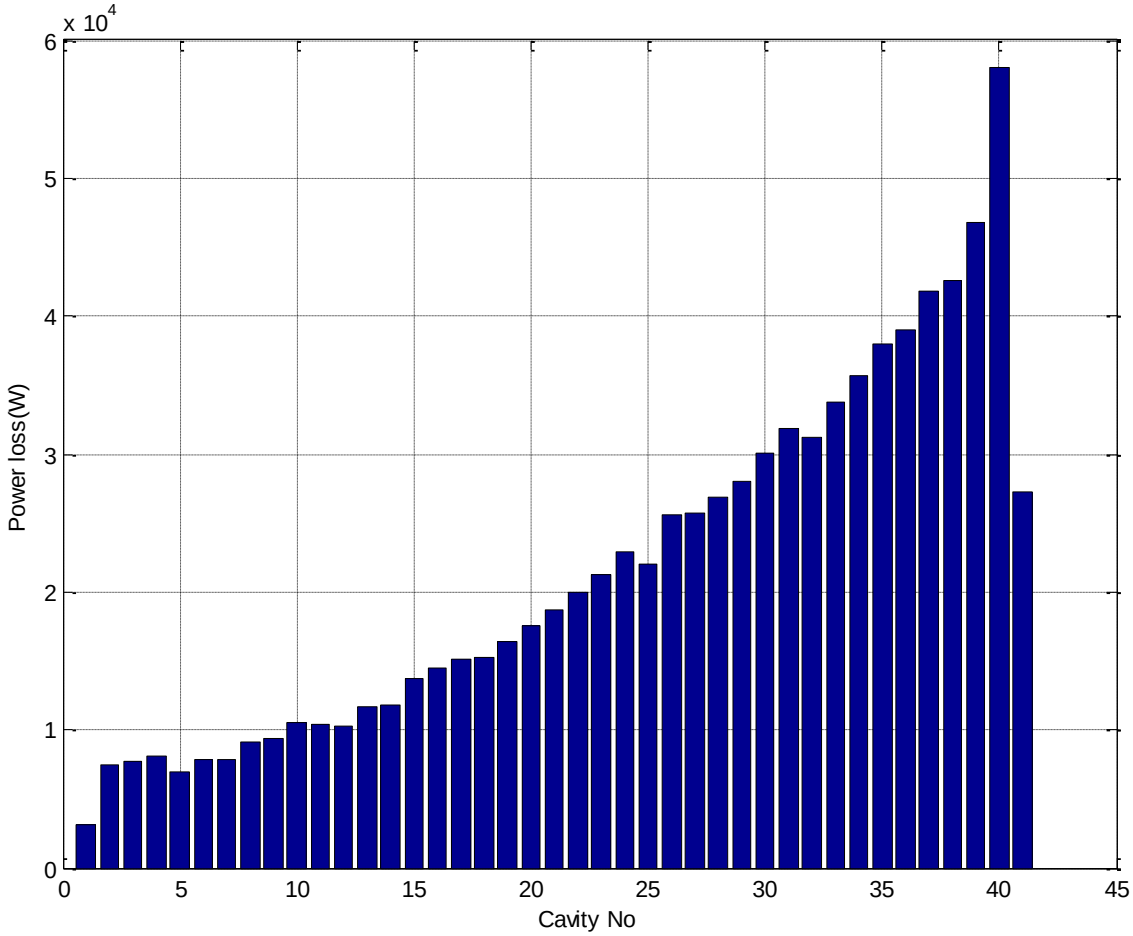
- Efield on axis
- Energy v.s. injection phase (30% caputured)





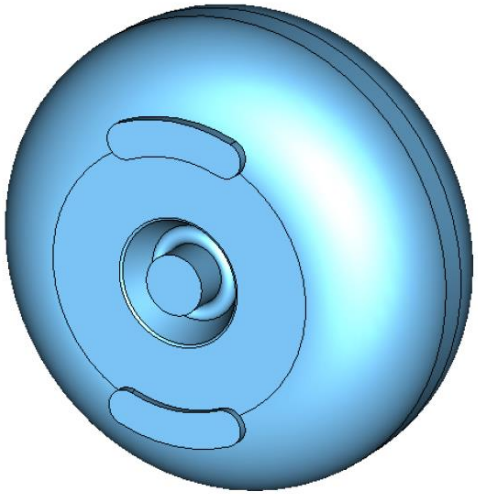
Power dissipation（45kW）

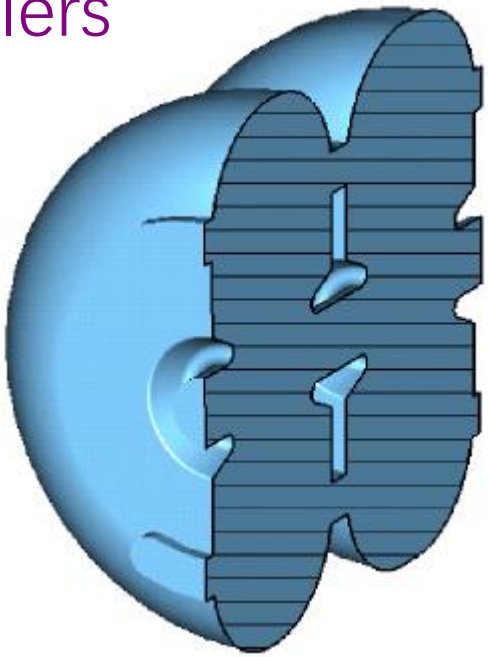
- Accelerating cells
  - Total power
    - 9kW
  - Hottest cell:
    - 580W（40#）
- Output coupler
  - 5kW
- E-beam power
  - 31kW (designed)

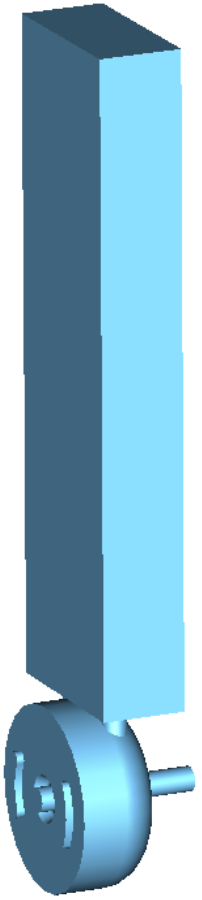


Cell design

- CST Microwave suite
  - Frequency
  - Cell-cell coupling
  - Input/output couplers

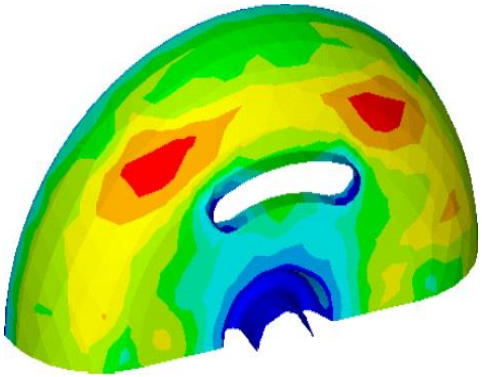


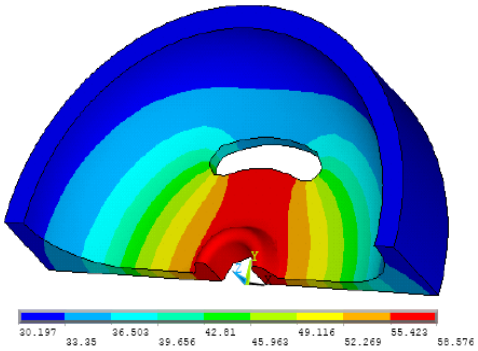


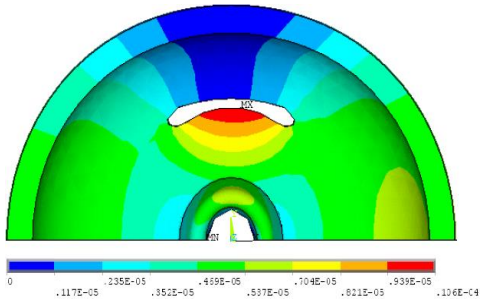


Thermal analysis

- ANSYS simulation
  - RF field->RF heating->temperature distribution
  - ->deform->frequency detuning







（1）RF heating density **（2）Temperature** **（3）deformation**

Frequency detuning v.s. temperature rise, and power loss/cell

60KHz/1degree，+41degree/kW，1MHz/kW (single cell)

Final picture

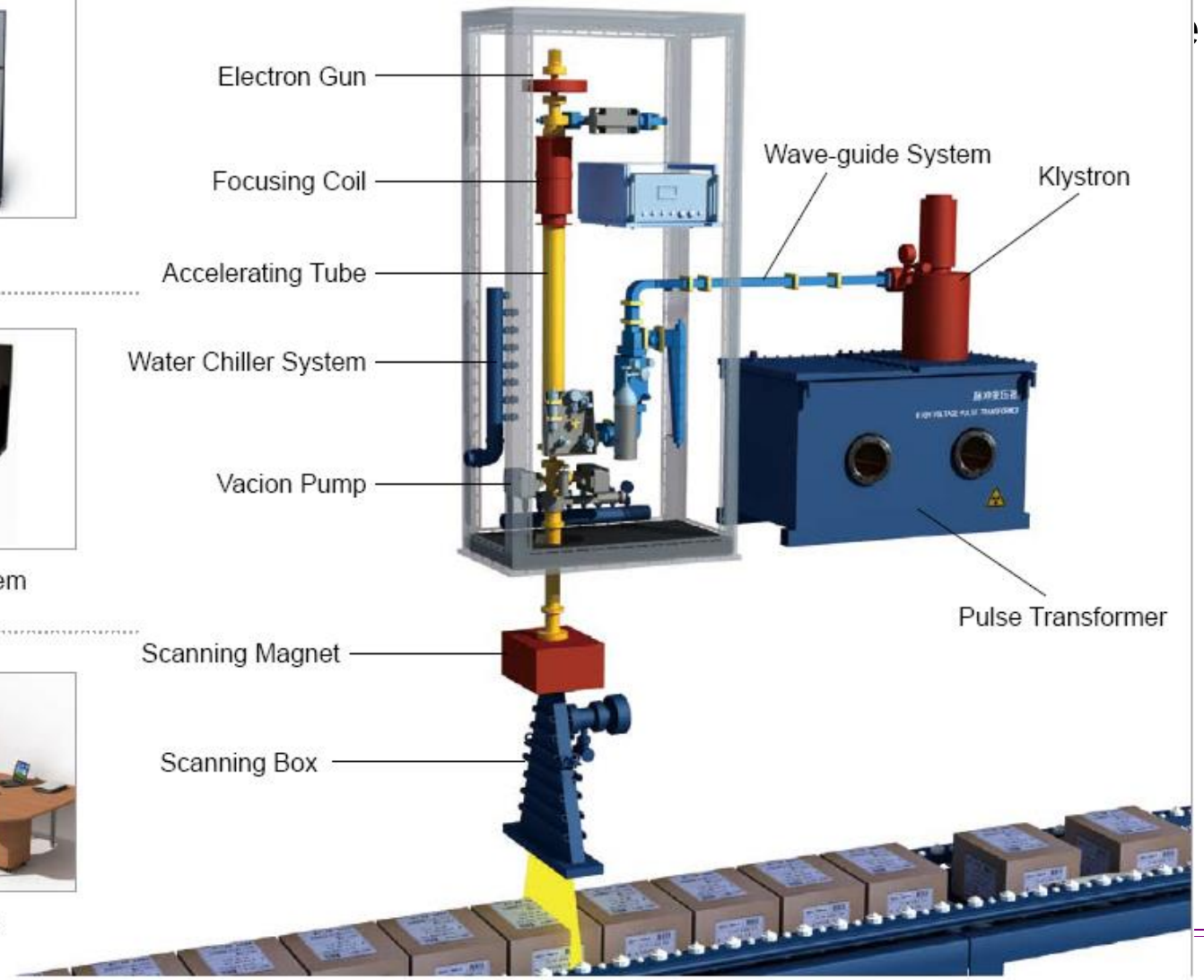
- Cooling jacket, Solenoid, Pumping port,
- vacuum flange for e-gun and scan system

System integration (Nuctech)

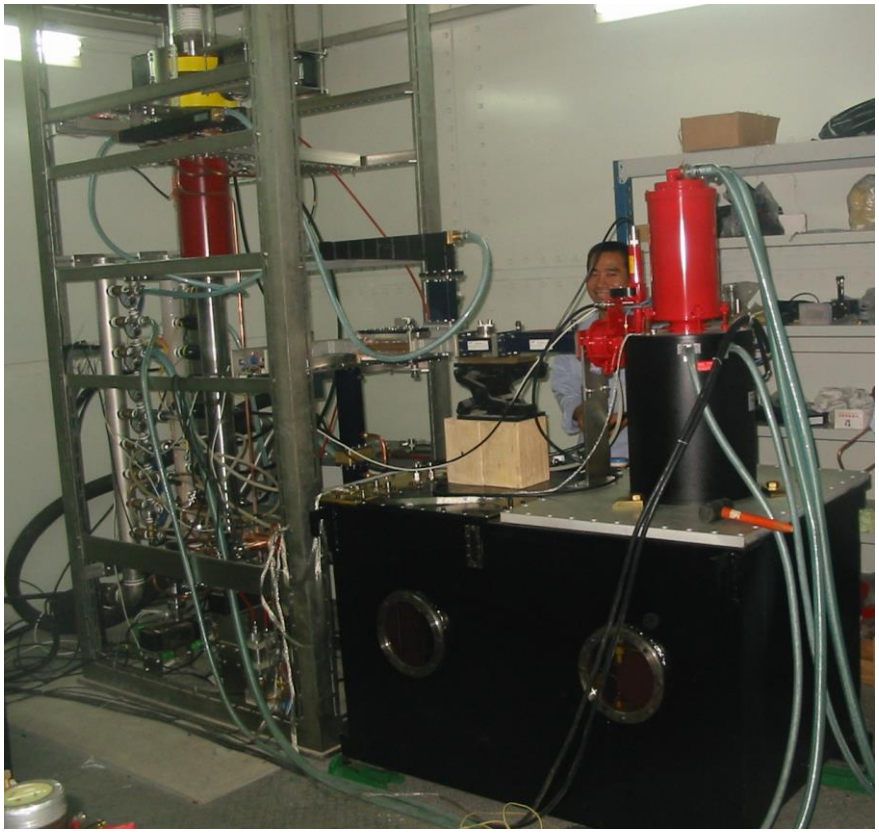
Modulator

Water Chiller System

Control Console



First prototype at Nuctech



First product

IS1020
10MeV
20kW

Second product


2013/08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Parameters of IS1020

Ebeam energy	10MeV
Beam power (average)	20kW
Pulse width	12μS
Rep. rate	650pps
Scan frequency	5 ~ 20Hz
Scan width	400 ~ 800mm

Applications:

- Shanghai (2013)
- Guangzhou (2014)
- Yangzhou (2015)
- Chongqing
- Huizhou

E-beam irradiation integrated processing center (Shanghai,2012)

Accelerator Laboratory of Tsinghua University


进入辐照区请戴

E-beam irradiation integrated processing center (Guangzhou,2013 on building)

- 10MeV 20kW
- back-wave accelerator
- 8-20 tons/h
- ~300 m^2

Lower Power

- 5MeV/2kW mail sterilization

Mail sterilization System (2002)

Mail sterilization system (2008)

Mobile sterilization system (2005)

E-beam Fruit quarantine treatment center

Accelerator

- **Energy / Power：** **10MeV/15kW**
- **Process ability:** **100，000 tons/year**
- **Usage：** **Fruit fresh & quarantine treatment**
- **System occupy:** **~300m^2**

Background

For usage of the port on the border

Large quantities imported fruits from southeast Asia countries

Quarantine treatment of tropical fruits

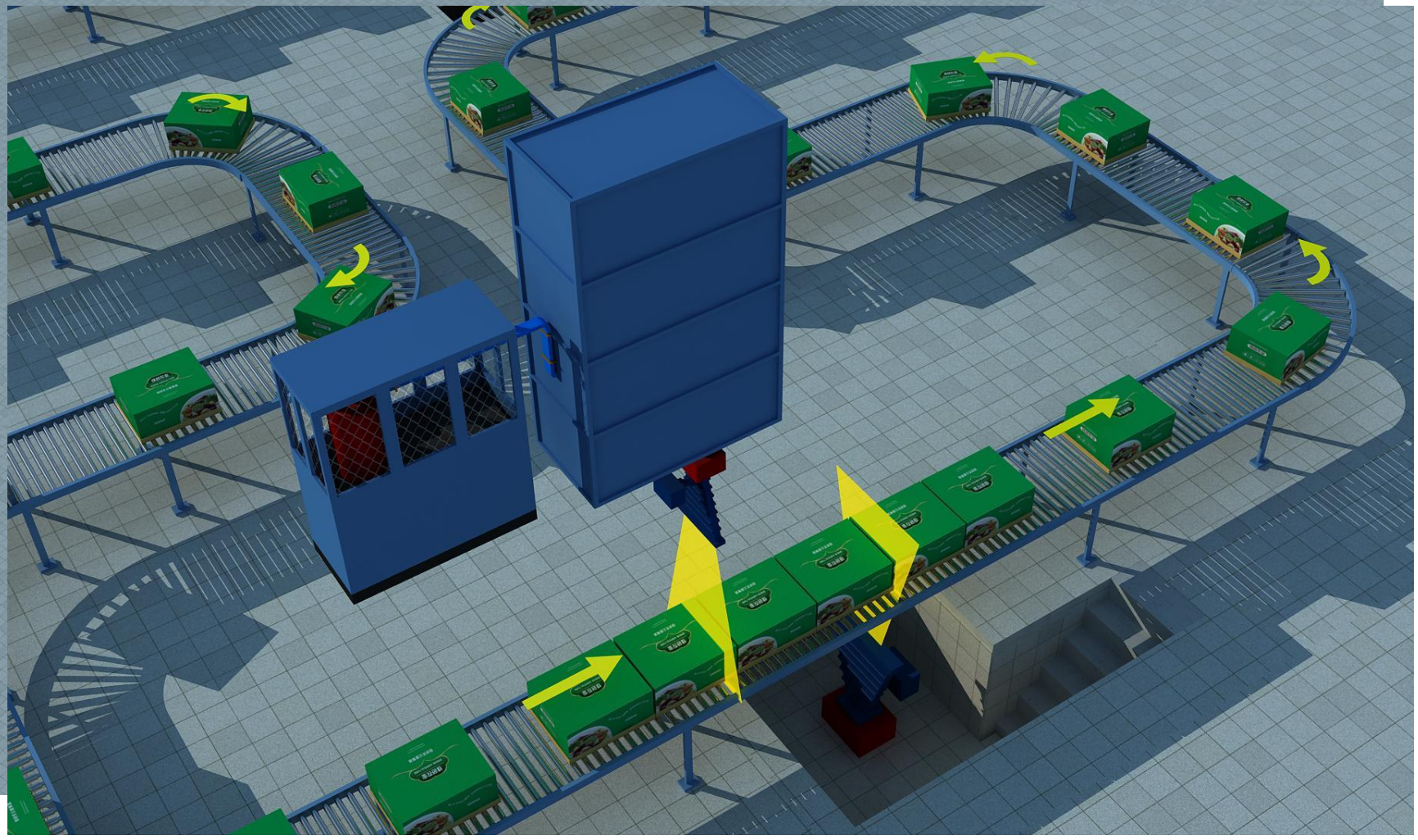
Face Vietnam and other southeast Asia countries

The fist E-BAEM quarantine treatment system of imported goods in china

E-beam Fruit quarantine treatment center

Guangxi pingxiang YouYiGuan

10MeV/7.5kW×2



Disk-loaded traveling wave linac for irradiation

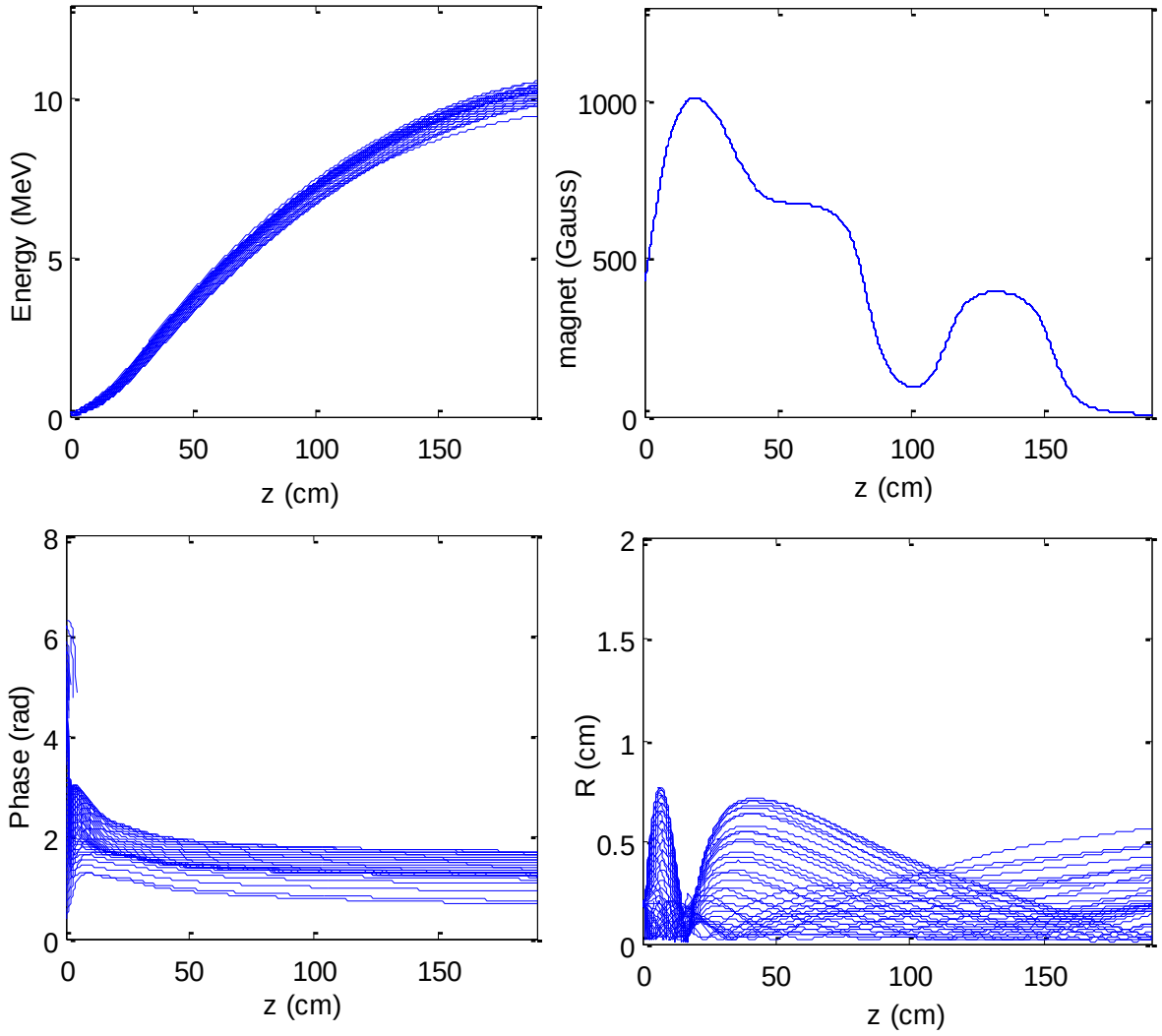
parameters

- Klystron: 5MW，45kW
- Output: 20kW@10MeV
- E-gun injection voltage:
  - 47~53kV
- RF-beam efficiency > 50%
- Length<2m

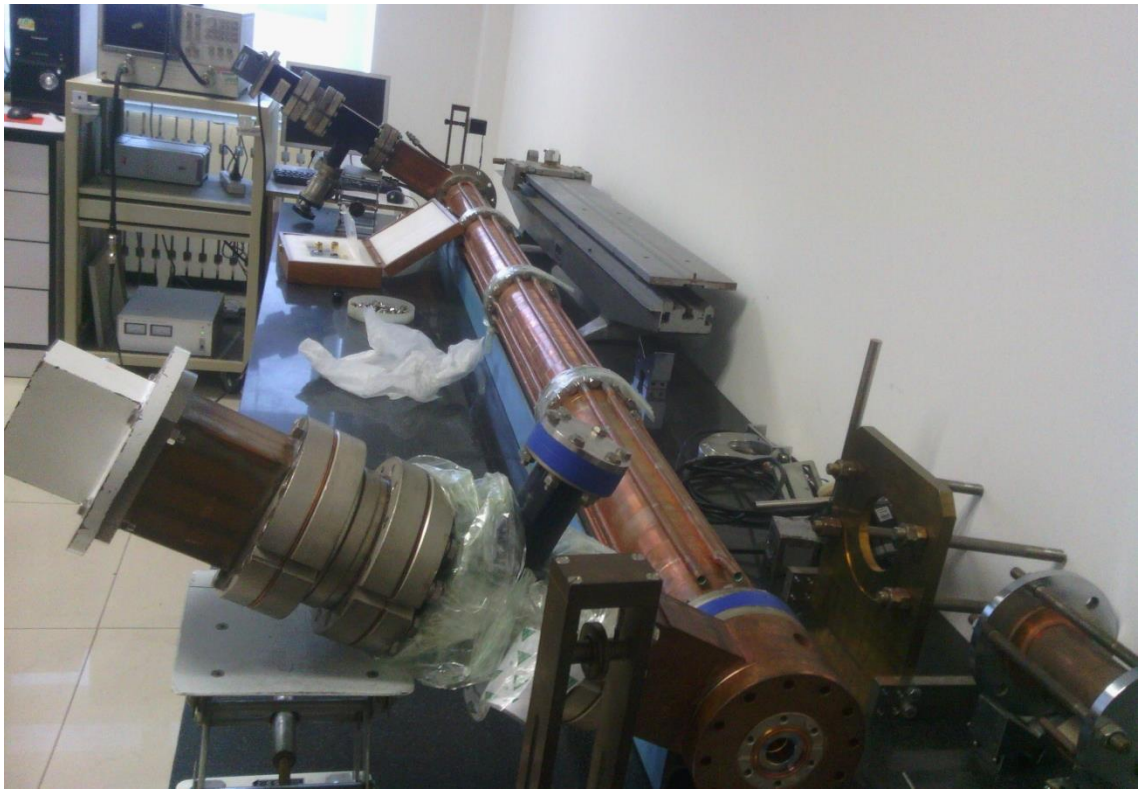
Parameters

- Injection voltage 50kV
- Input RF power 4.5MW
- beam energy 10/12MeV
- Peak current 280/150mA
- efficiency 62%/40%
- structure constant impedance
- Phase adv./cell $2\pi/3$

Beam Dynamics

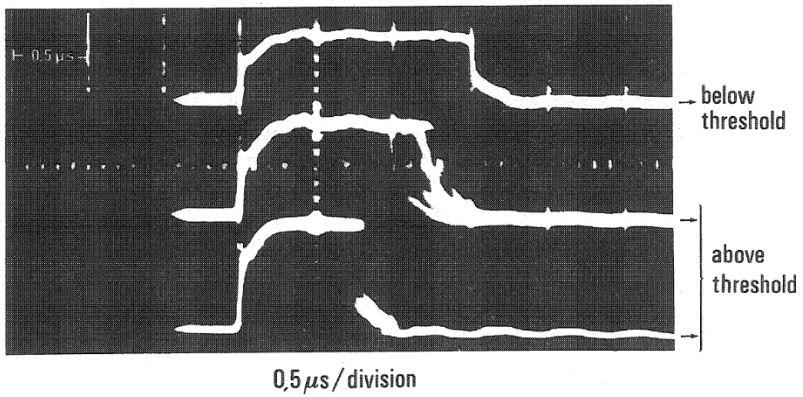


2-meter linac

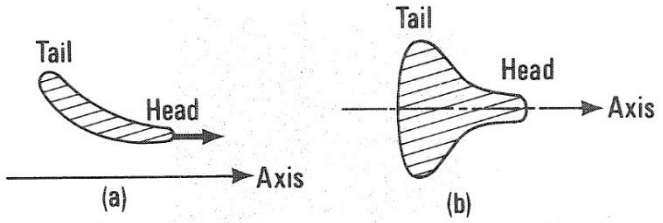


Beam break up（BBU）

- Phenomenon
  - The tail of pulse will be lost. The beam current is limited.



- Physics mechanism
  - The following electron will be deflected by the wake field generated by the previous beam.
  - Collective beam instability.
  - m=1 transverse wake field (HEM11 mode) can be amplified by the beam itself.

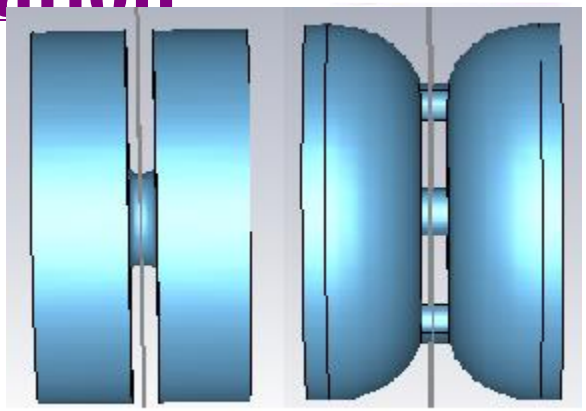


BBU induced by short beam pulses
a) dipole mode b) quadrupole mode

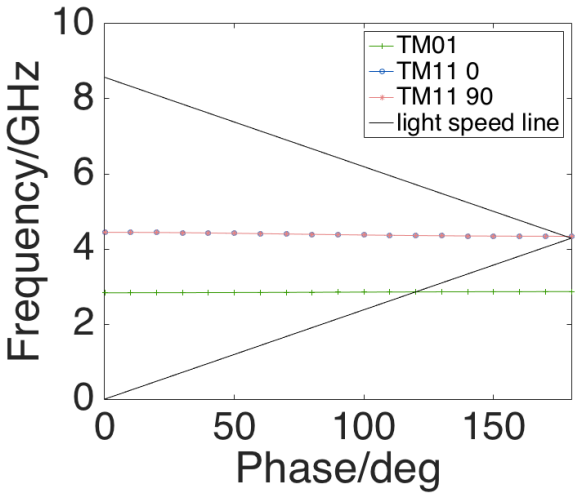
Le Duff J. Beam break up[R]. Paris-11 Univ., 91-Orsay (France). Lab. de l'Accelerateur Lineaire, 1985.

Modes and parameters calculation

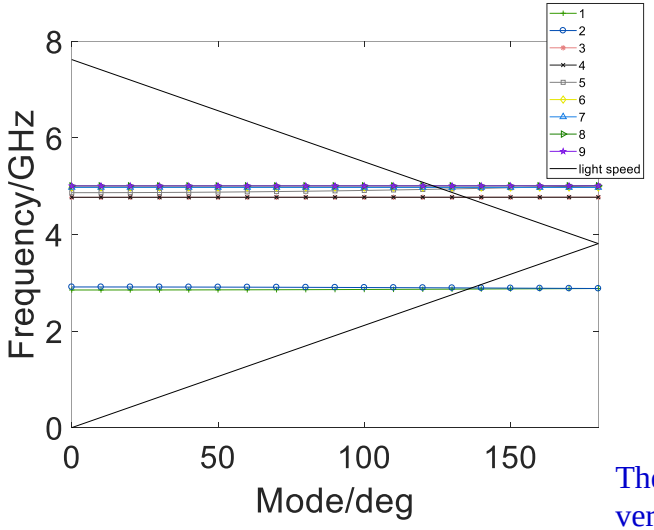
- Simulate the eigenmodes of two structures and find the dipole mode.
- Plot the dispersion curve.
- Calculate the parameters.



The model of period structure



Dispersion curve of travelling wave model

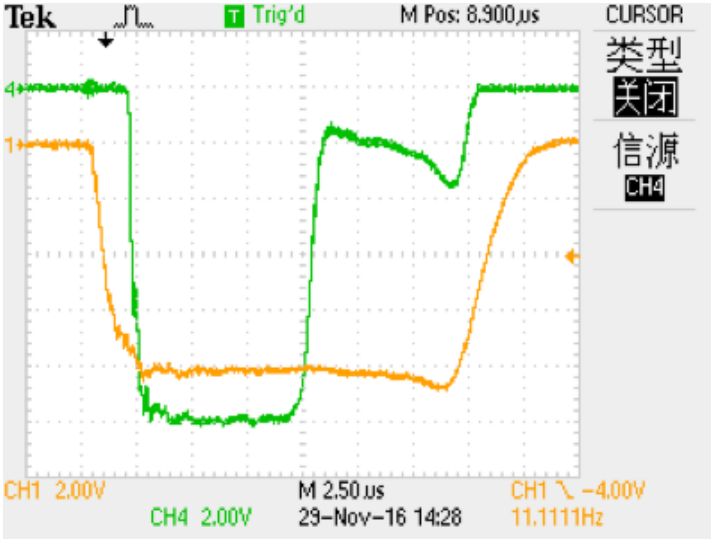


Dispersion curve of backward wave model

Parameter	Travelling wave	Backward wave
Frequency (GHz)	4.338	4.939
Phase (degree)	177.8	233.3
Period length (mm)	35	39.36
k (1/m)	90.86	103.44
Phase velocity (1/c)	1	1
Group velocity (1/c)	0.001	-
Q	14158	20100

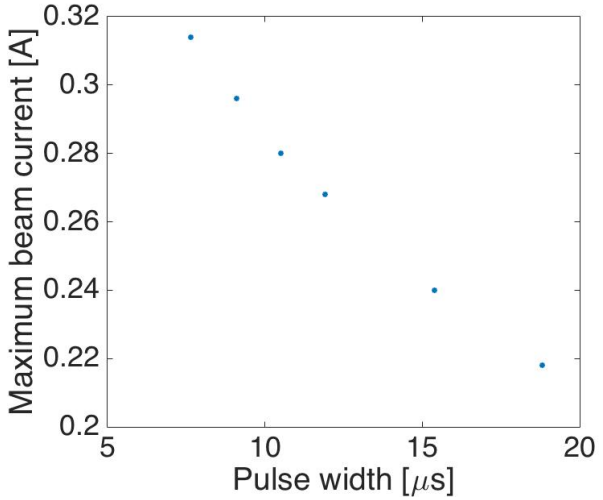
The group velocity of backward wave model is very low because of the structural features.

Experiment exploration



The beam pulses observed in experiment while BBU (Orange for input, green for output)

The backward wave accelerator system



Relation of the pulse width and current

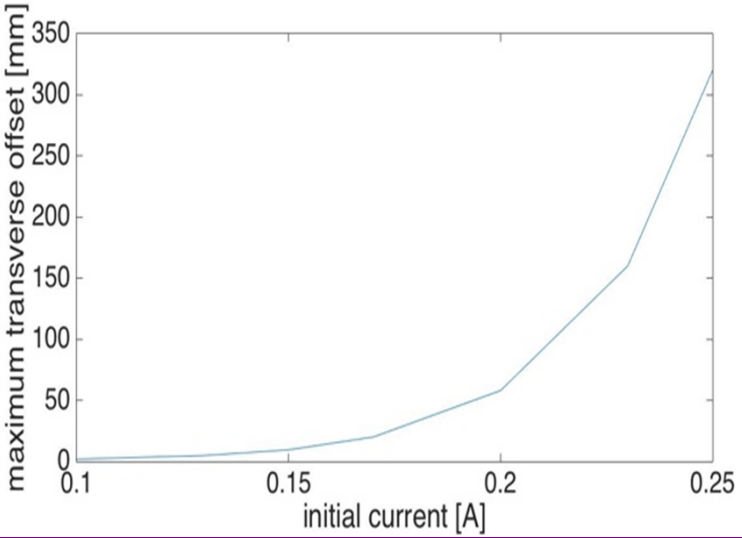
- Experiments were done in a 10MeV backward travelling-wave accelerator system.
- Different pulse widths and beam current values were scanned to observe and compare the output pulse waveform while BBU.

Preliminary modelling and simulation

- On the basis of the physics mechanism of beam break up and the beam dynamics, an interaction model for travelling wave accelerating structure has been built.

- A pulse can be considered as a composition of several ten thousand of micro-pulses, being a micro-pulse a bunch. So, the n-th bunch is influenced by the wake field generated by the (n-1) bunches ahead.

- we write a code in MATLAB to simulate the motion of electron in travelling wave accelerator. The maximum transverse offset is nearly in exponential growth with initial current as shown.



Relation of offset and current

Summary

- BTW irradiation linac:
  - R&D at University
    - Physics beam dynamics
    - RF structure design / Thermal analysics / Mechenical design
    - Fabrication and brazing / RF measurement and tuning
    - Beam test
  - Industrialization at NUCTECH
    - System integration: (controlsys./klystron/modulator/cooling/building…)
    - Business model
- Different type:
  - BTW: main product: 10MeV/20kW
  - SW: 10MeV/5MeV : lower average power
- Beam break up study on-going

Thank you!