Two Beam Acceleration Experimental Activities at ANL

Wei GAI

CLIC Workshop 2015

CERN, Jan 27

U.S. DEPARTMENT OF ENERGY | Office of Science

The Big Picture

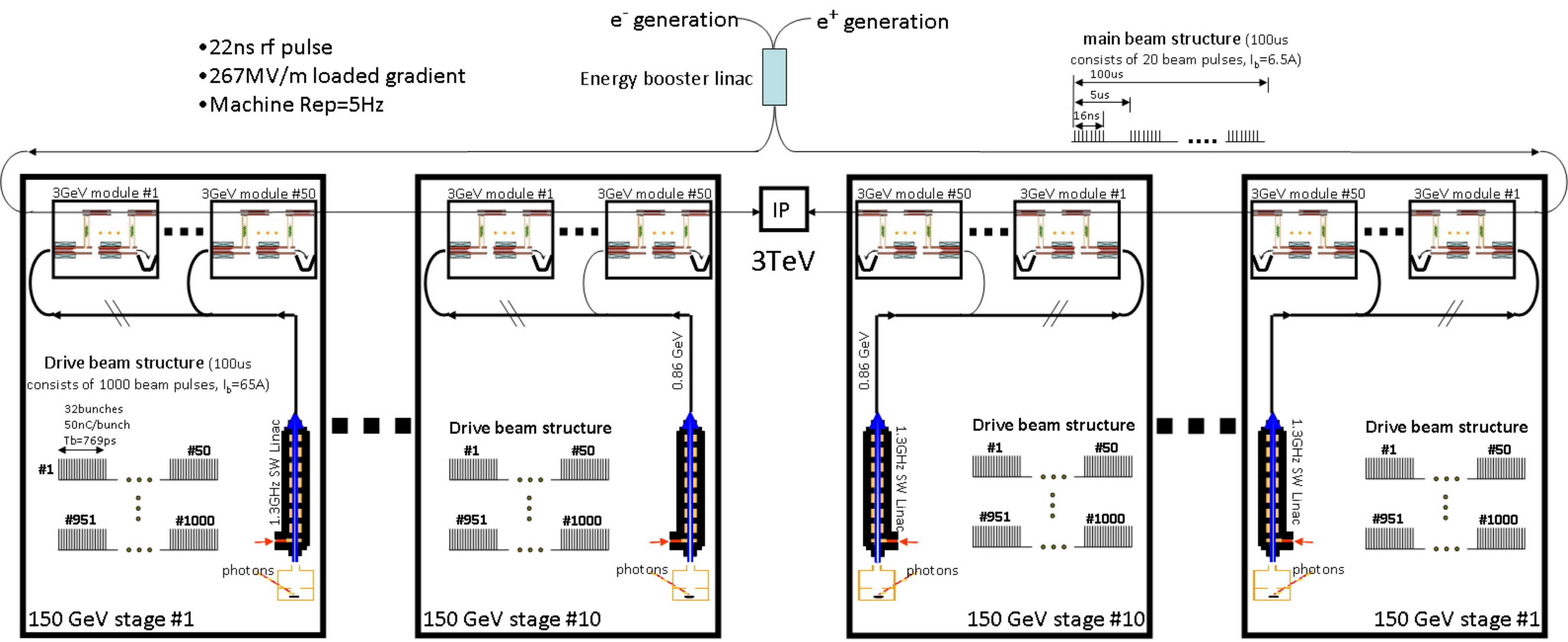
Future: Where we want to go

Past: Progress so far

Present: Next Steps

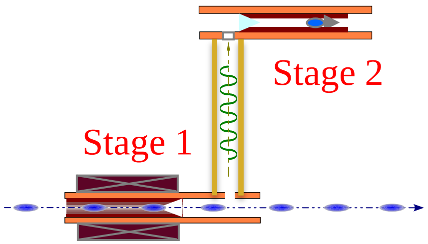
Argonne Flexible Linear Collider

Ultra Short rf Pulse Acceleration



- Based on 26GHz Dielectric Wakefield Accelerator (DWFA) linac
- Loaded Accelerating gradient ~ 267 MV/m
- Short RF pulse ~22ns
- Modular (150 GeV per module … 3TeV)

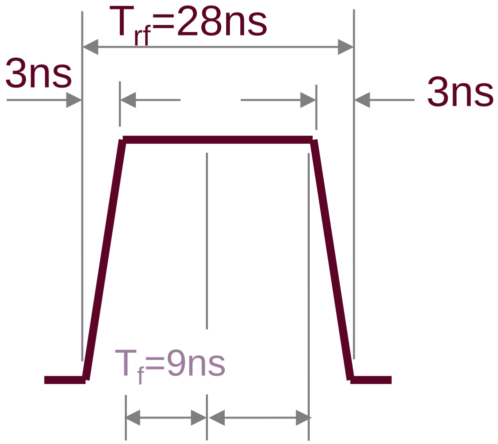
Does DWFA offer a path forward to TeV class colliders?



1. HIGH-GRADIENT: dielectric TBA

- **Short pulse:** "The acceleration gradient limit is complex but the data shows that shorter pulse length (τ) helps."

$$\frac{RF\ Power * \tau^{\alpha}}{Circumference} < const.$$

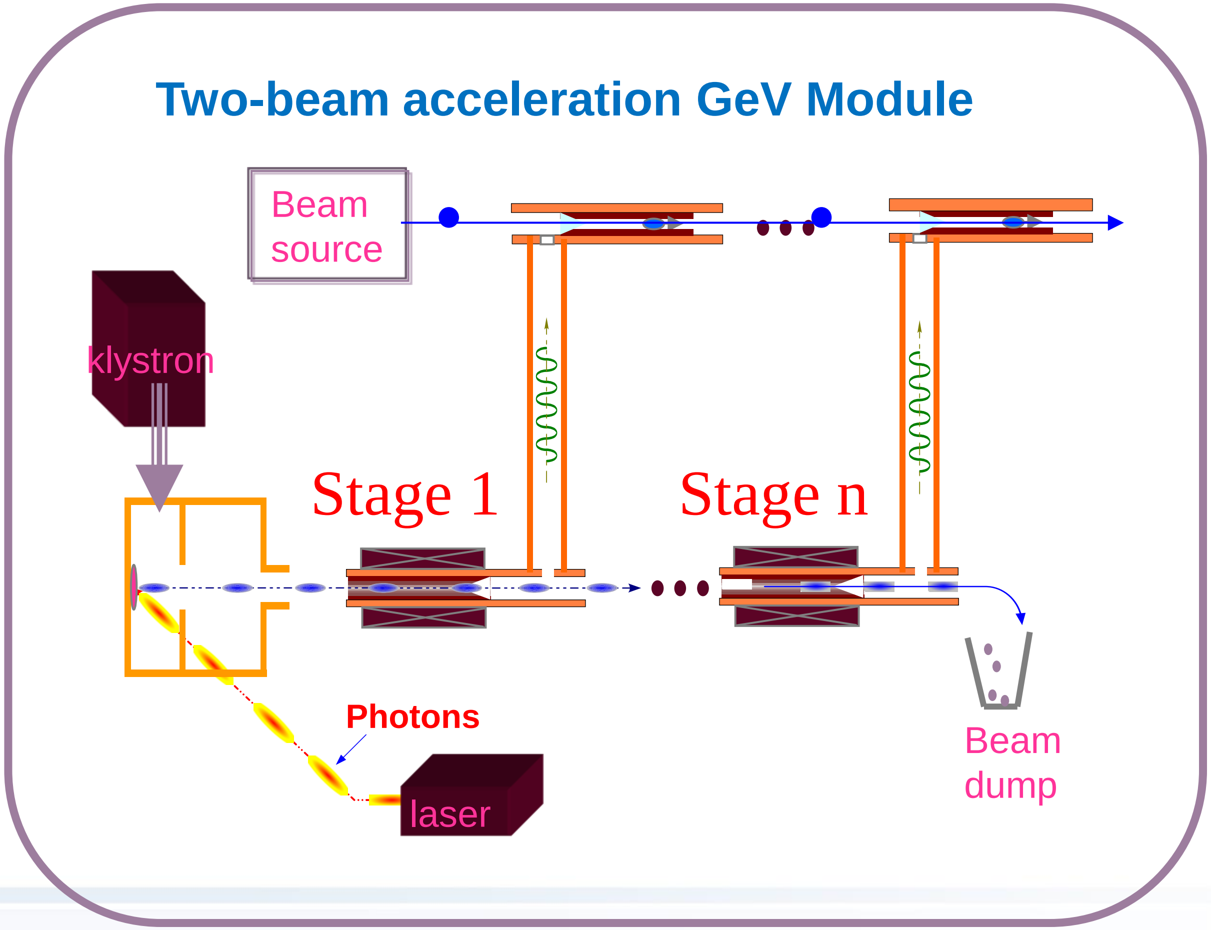


Ultra Short Pulse Acceleration

- **Limited by material breakdown:** Many material options available with dielectrics (polymers, ceramics, glass, crystals, etc.)

A path forward to TeV class colliders?

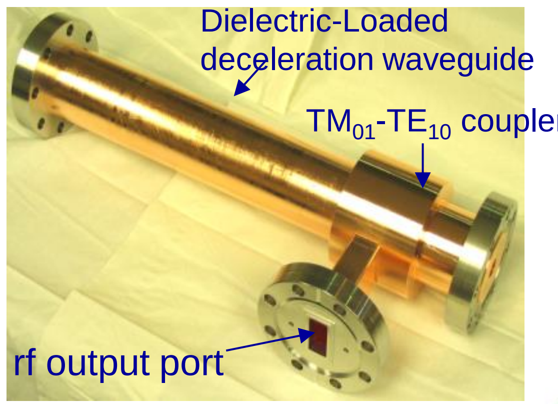
2. **HIGH-POWER SOURCES** → conventional microwave accelerator (at the AWA facility)
3. **HIGH-POWER TRANSFER STRUCTURE** → power carried by beams

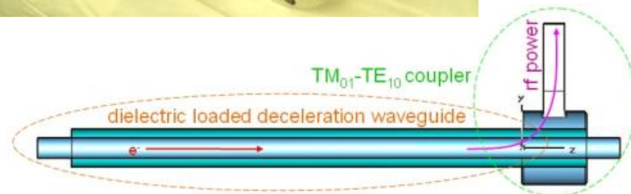


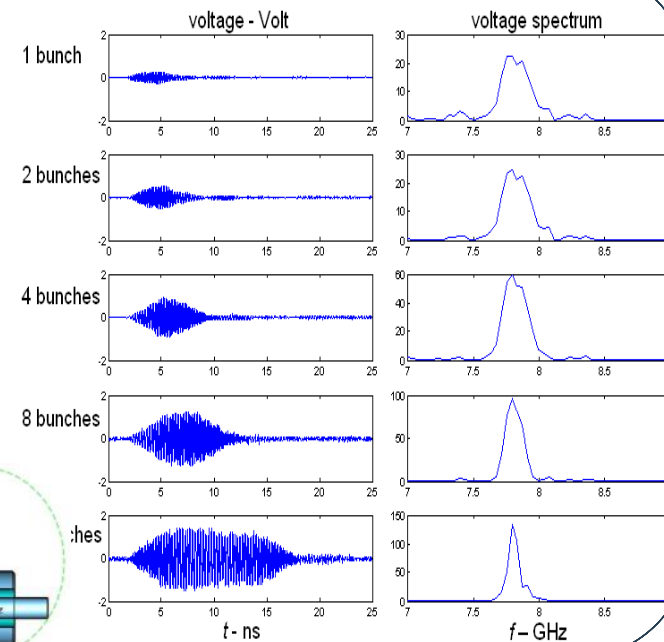
RF Power Generation in dielectric PETS

7.8GHz rf pulse produced

- 30ns,1MW
- 10ns, **40MW**

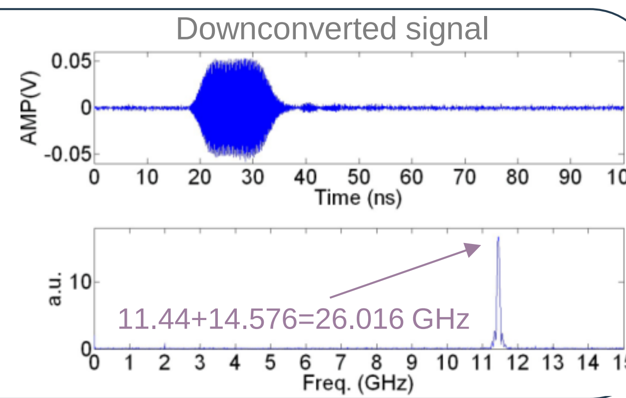




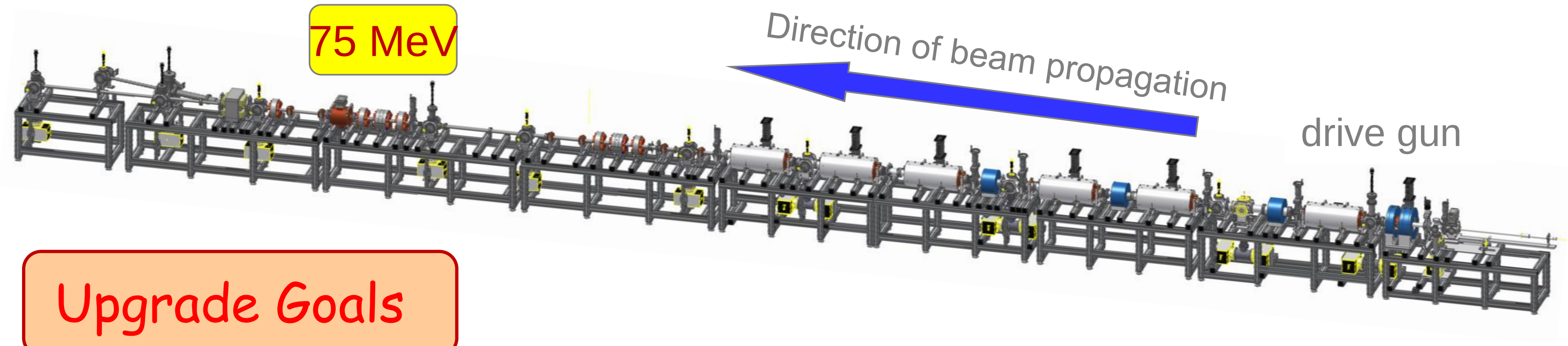


26GHz rf pulse produced

- 16ns,1MW
- 10ns, 20MW



The AWA Upgrade drive beam



Upgrade Goals

Original Drive Beam (Achievements)

- Single bunch operation
  - 15 MeV →
  - Q = 0.1-100 nC *(world record!)*
  - @ 100 nC
    - σz = 3 mm
    - High Current: ~11 kA
  - emittance < 200 um
- Bunch train operation
  - 4 bunches x 20 nC →
  - 16 bunches x 5 nC →
  - Train Length = 10 - 25 ns

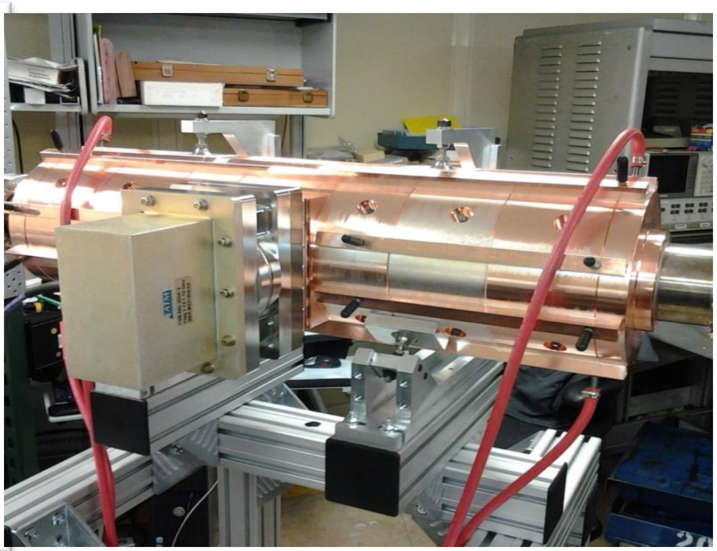
Upgraded Drive Beam (Targets)

- Single bunch operation
  - 75 MeV
  - Q = 0.1-100 nC
  - @ 100 nC
    - σz = 2 mm
    - High Current: ~16 kA
  - emittance < 200 um
- Bunch train operation
  - 10 bunches x 100 nC
  - 32 bunches x 30 nC
  - Train Length = 10 - 50 ns

Thanks to DoE for $2M+ upgrade fund:

- 2 new klystrons
- 6 linac tanks
- RF distribution and Control systems upgrade
- Laser upgrade

Klystrons Stations

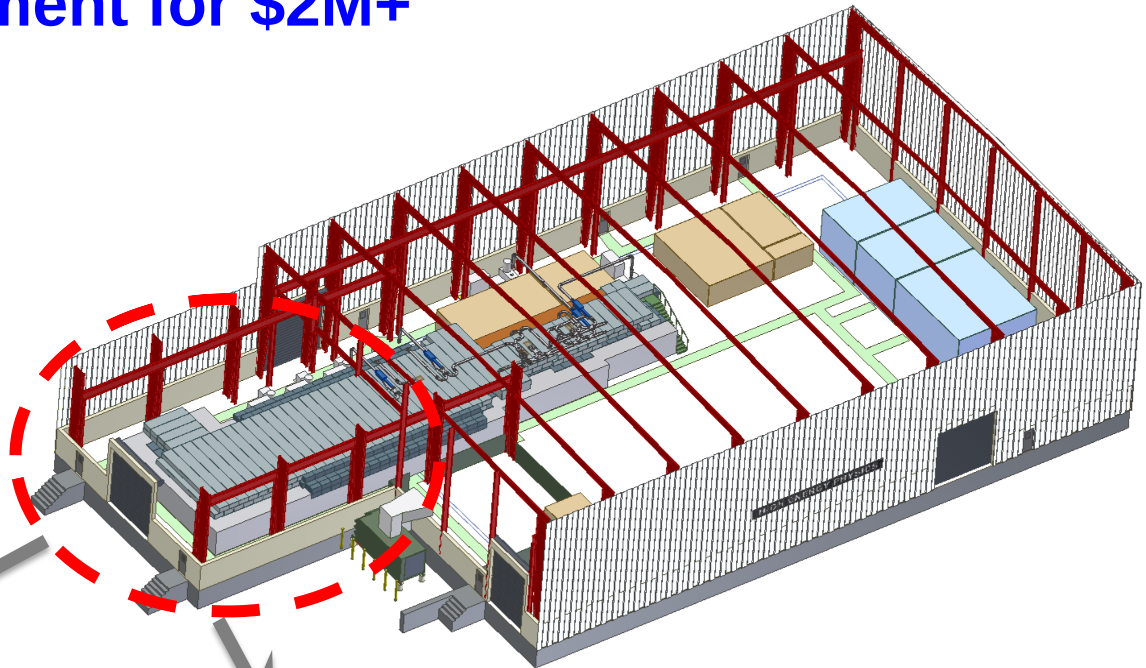


6 Linacs are ready for use

New KrF UV amplifier

Thanks to ANL management for $2M+ construction fund:

- new annex building
- new SF6 recovery system
- new cooling water station
- new 1MW power transformer



Bunker Interior

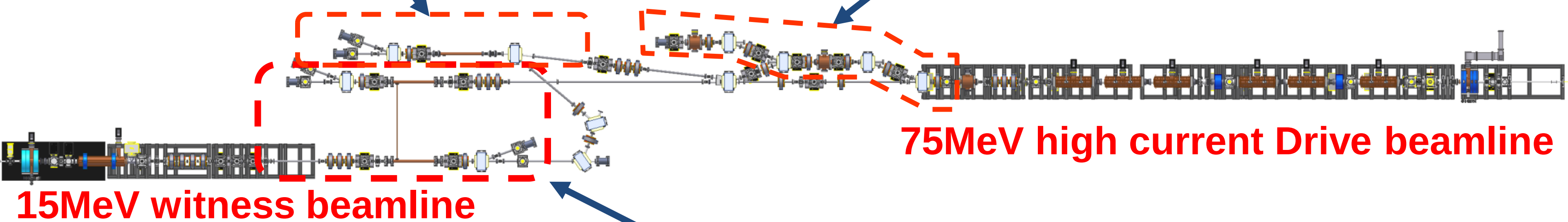
New annex building

Roof of the new bunker

Beamline Configuration

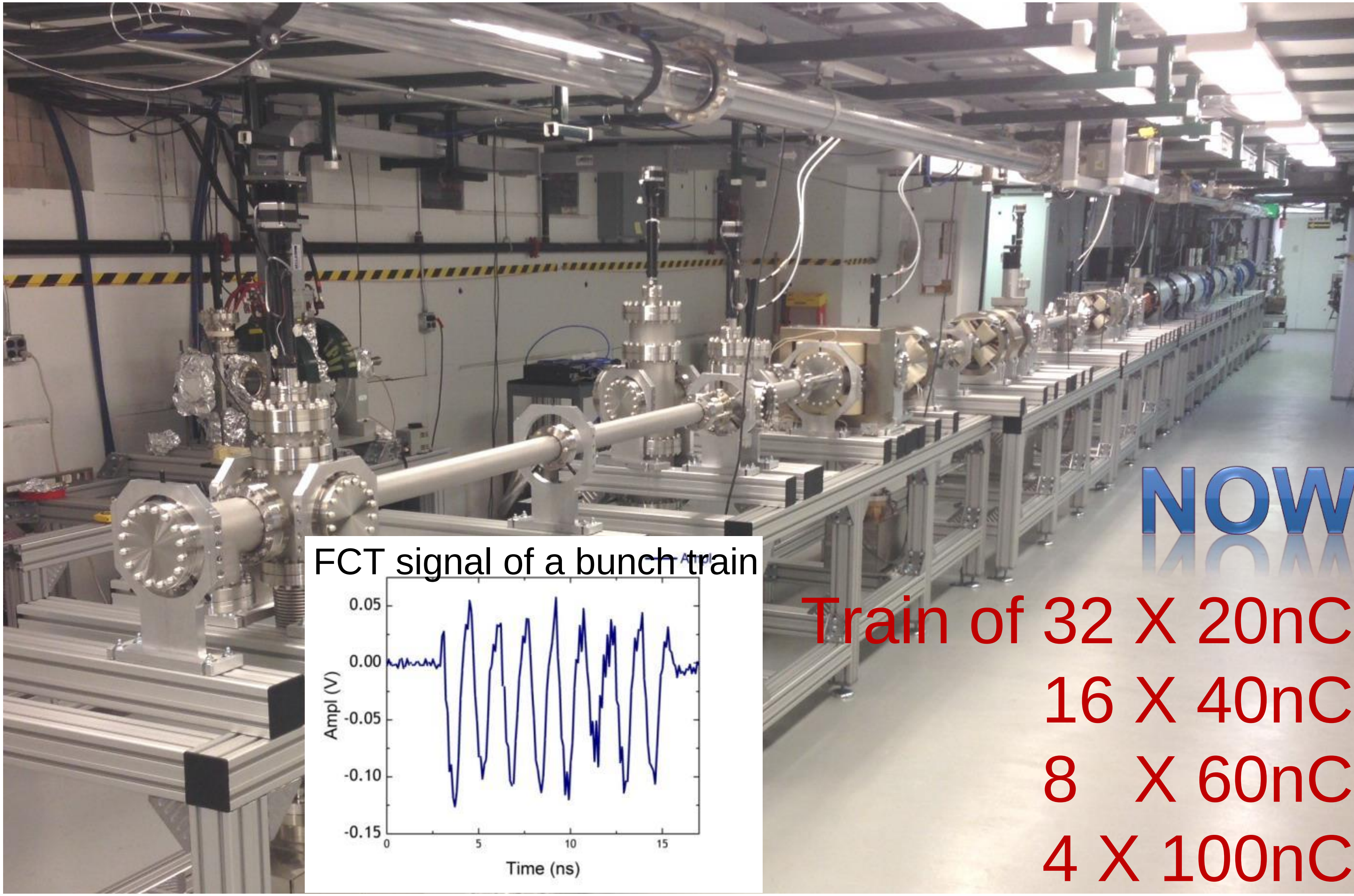
2. Collinear wakefield beamline:
- Drive bunch enters at 6 deg
- Witness bunch enters at 42 deg

3. EEX beamline:
- Ramped bunch production
- Continue EEX experiment
- LPS measurements

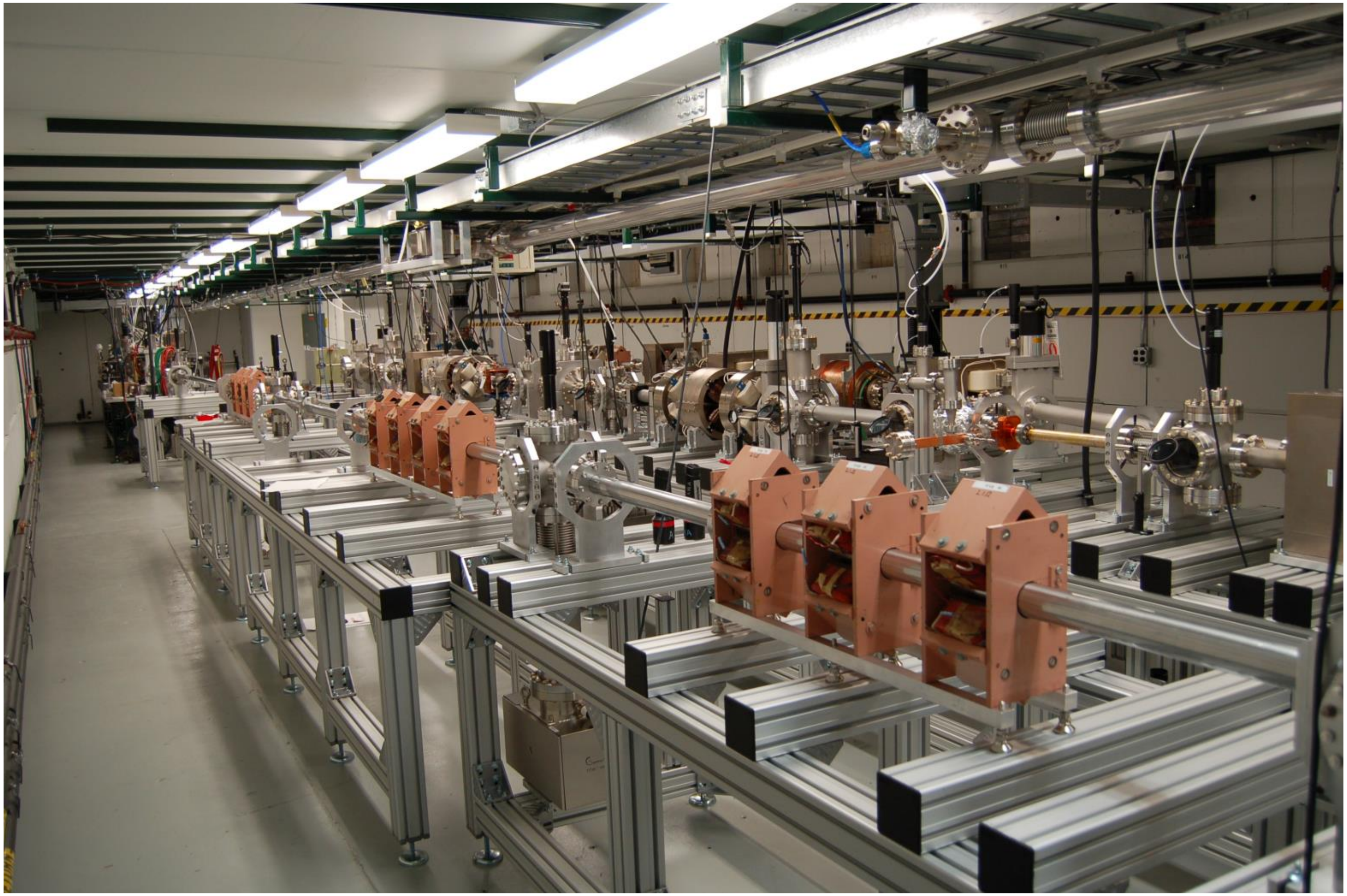


1. Parallel (Two-beam) beamline :
- High charge bunch train transmission
- High RF power generation
- High gradient acceleration of witness

AWA 75MeV μC Beamline --- a drive for GW RF Power



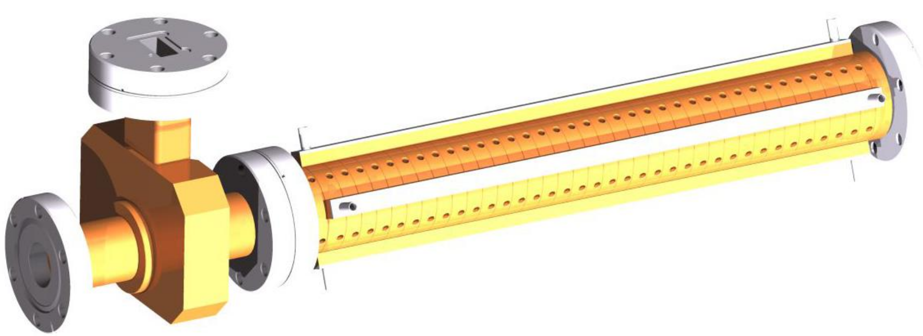
AWA Test Area

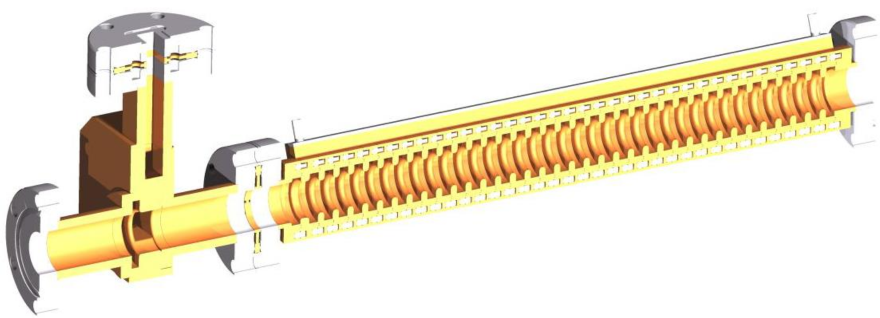


Development of 11.7GHz Metallic Wakefield Power Extractors

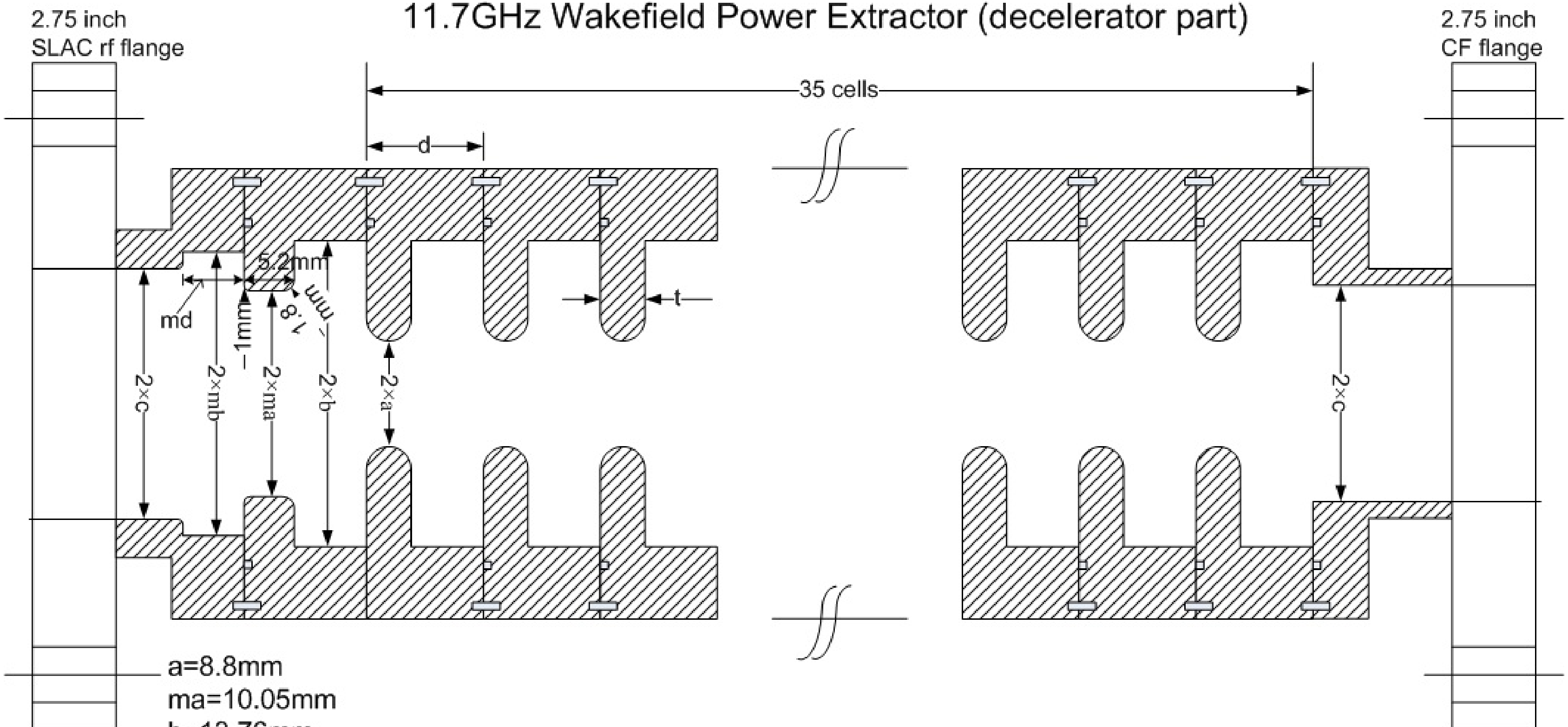
- Short pulse high power generation is not limited to the dielectric structures. We are also exploring metallic structure to extract portion of GW AWA beam power.
- Key differences from other scheme: short pulse (<50ns) high power (>200MW).

Freq. (GHz)	Aperture (mm)	Group velocity	R/Q (kΩ/m)	L (cm)	Q (nC)	σz (mm)	Form factor	Grad. (MV/m)	Power (MW)
X- Band (11.7)	17.6	0.22c	3.92	30	60	2.3	0.85	90	441





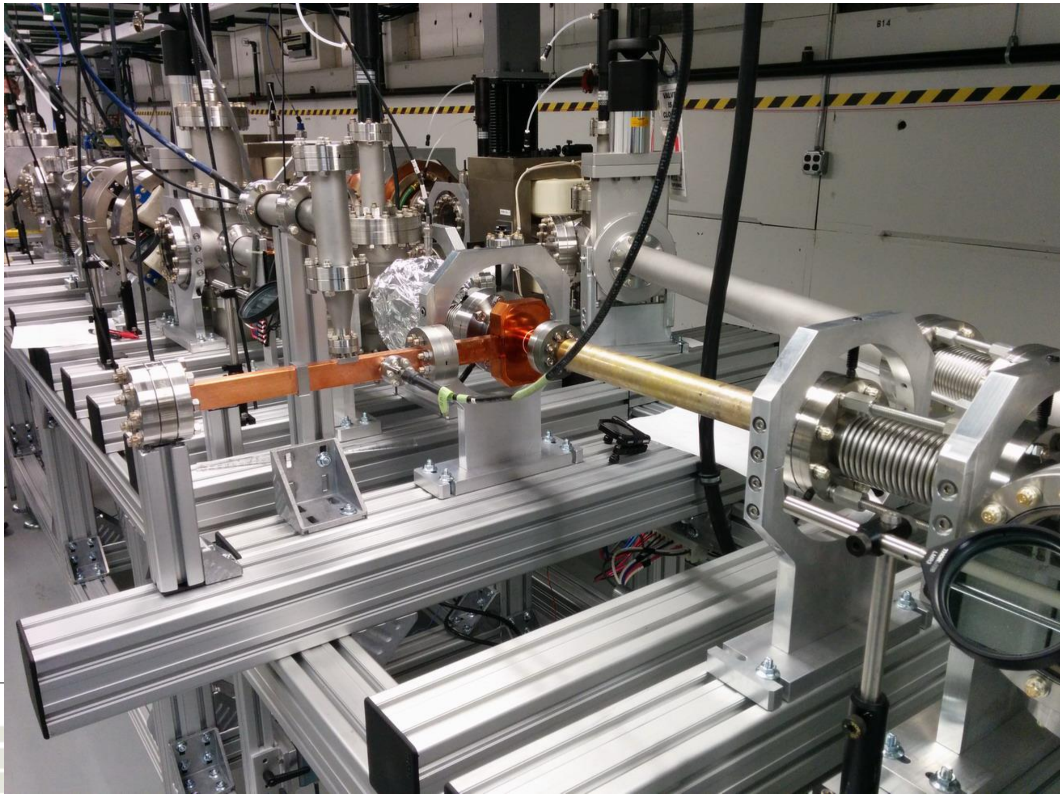
11.7GHz Wakefield Power Extractor (decelerator part)



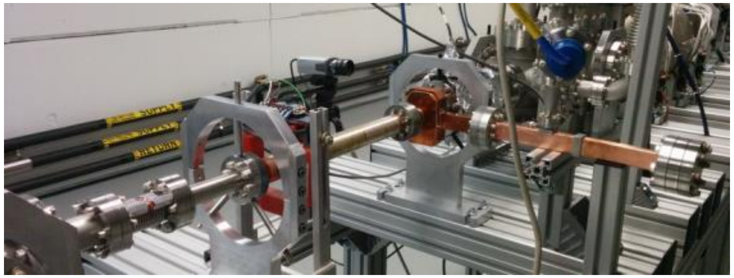
a=8.8mm
ma=10.05mm
b=13.76mm
mb=12.95mm
c=11.16mm
d=8.54mm
md=5mm
t=3.6mm
R=t/2

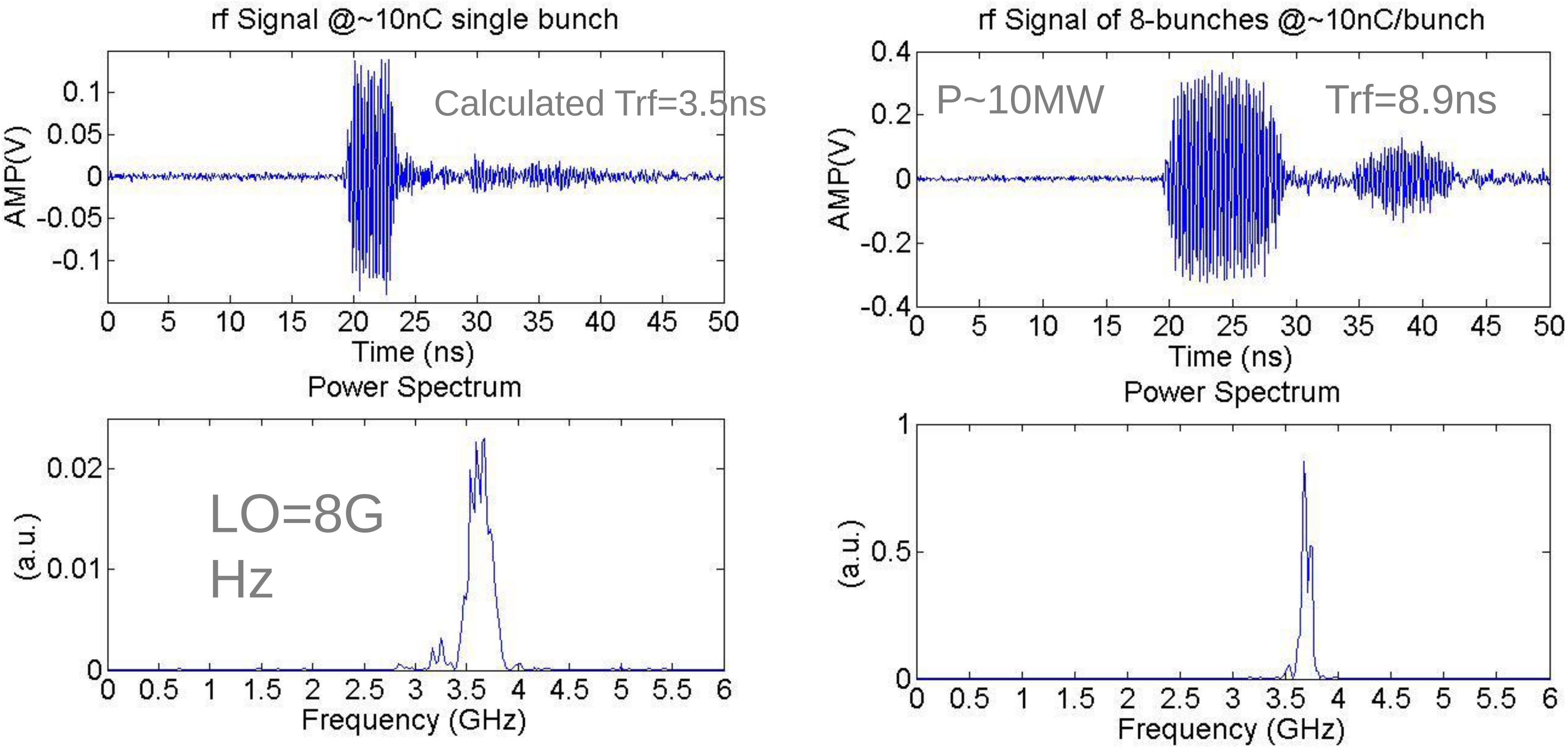
Freq. (GHz)	Aperture (mm)	Group velocity	R/Q (kΩ/m)	L (cm)	Q	Es/Ea
X-Band (11.7)	17.6	0.22c	3.92	30	6500	2

Note: The drawing is NOT in scale. It is a rough sketch for reference. Tuning in each cell and outside cooling channels are not included. All dimensions are subject to change before the final mechanical drawing.

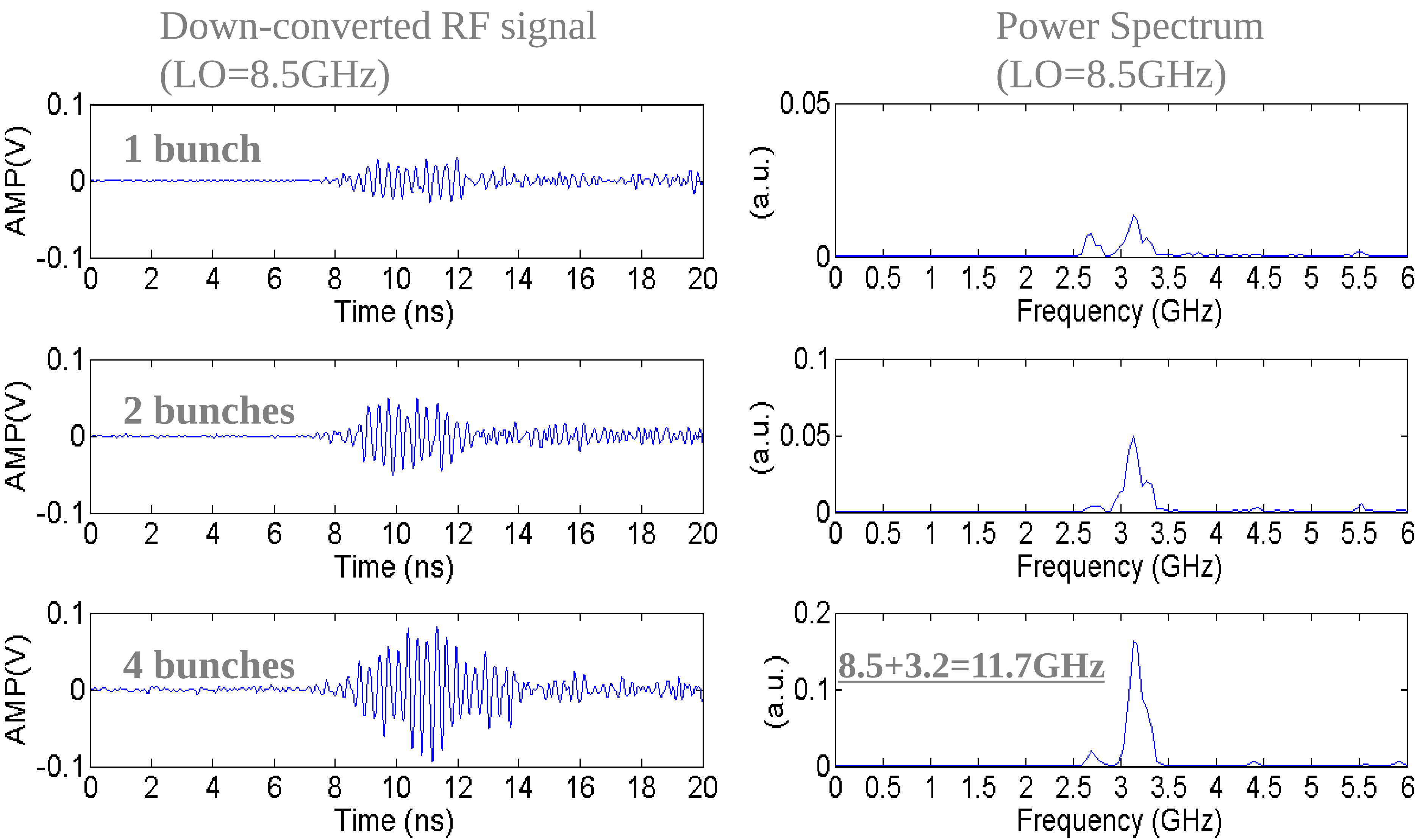


1st beam test with the AWA Upgraded Facility (19 MeV)



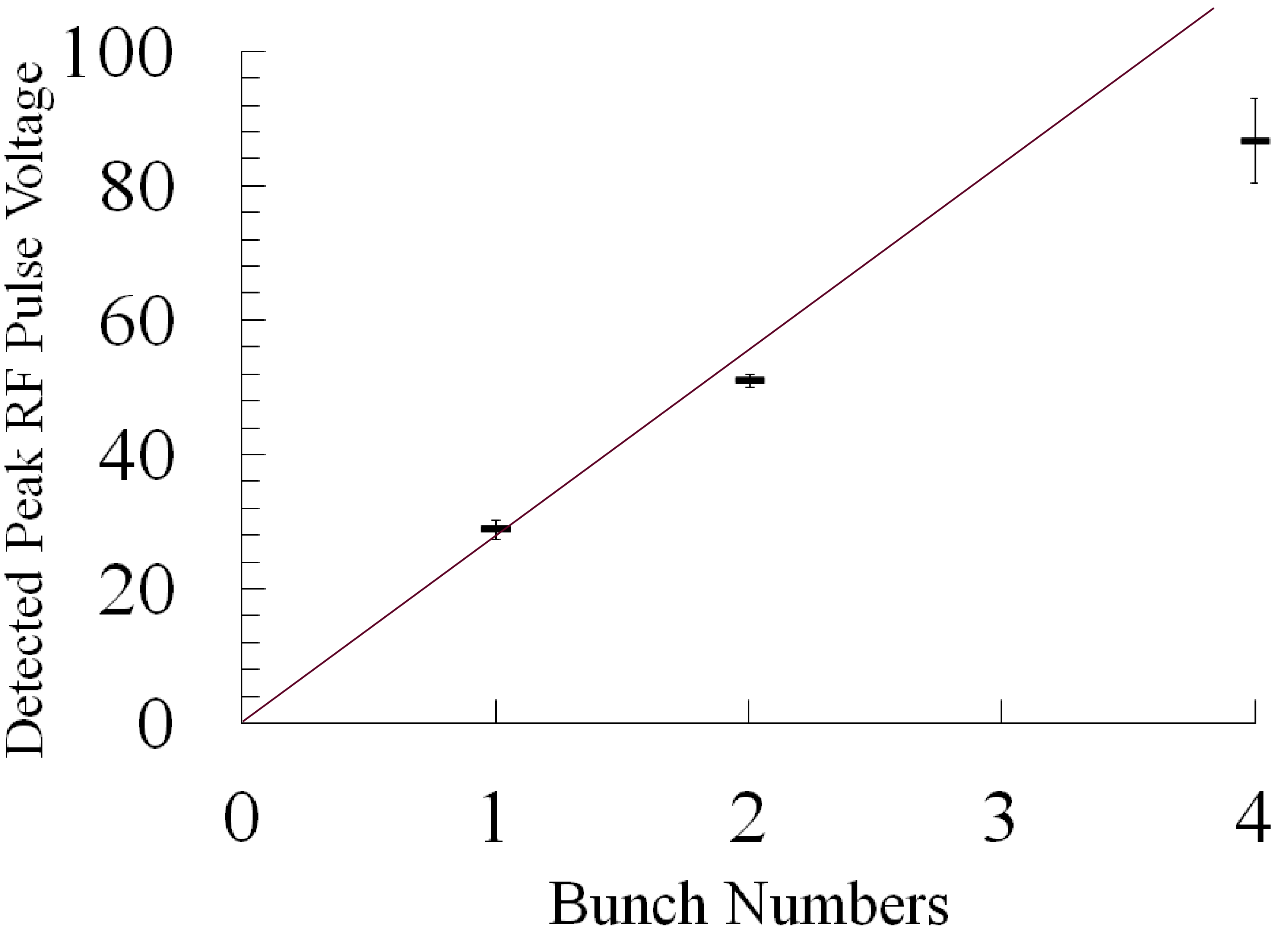


Bunch Train with 35nC/bunch out of 11.7GHz power extractor (eqv. to 100MW, uncal.)

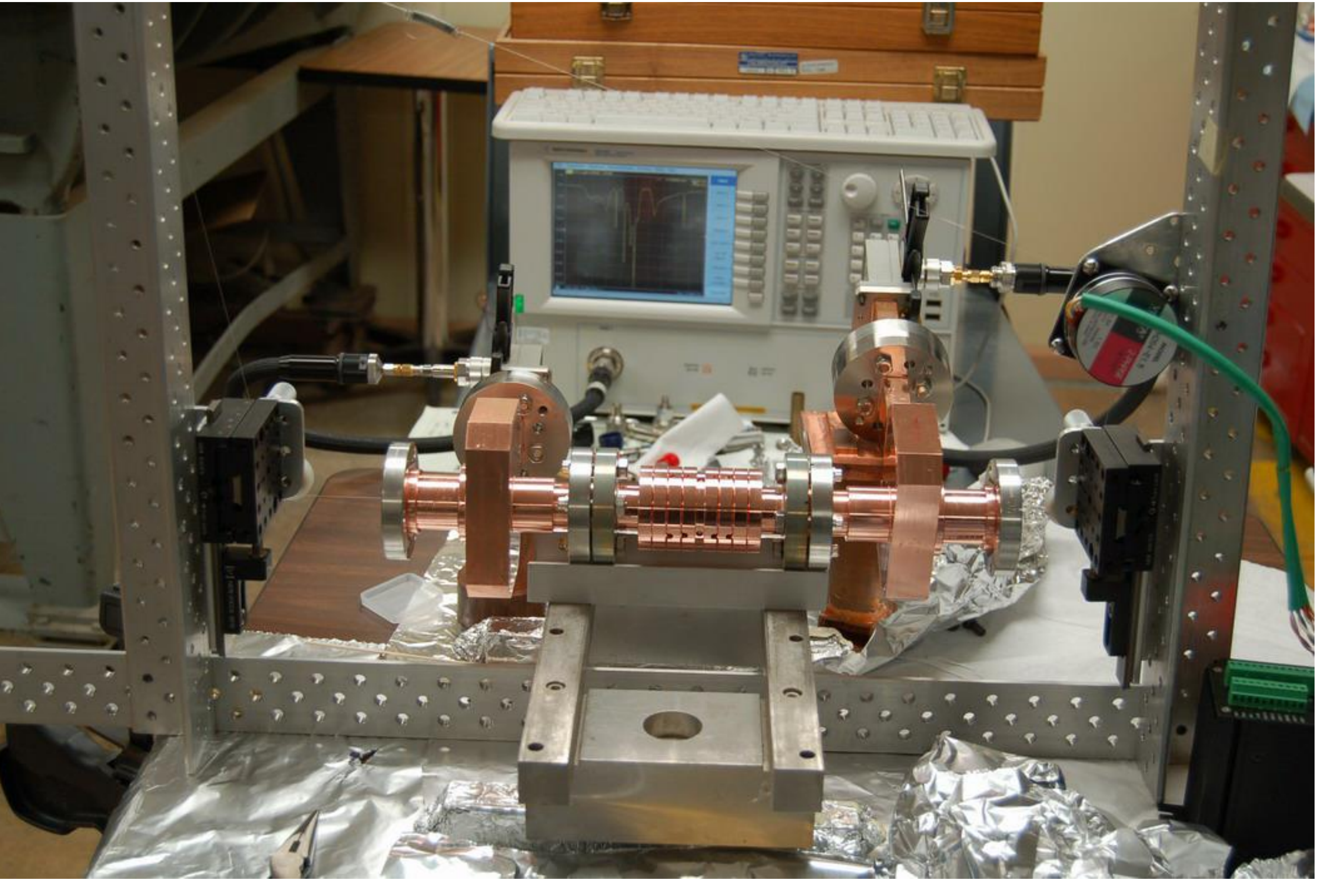


Signal linearity check

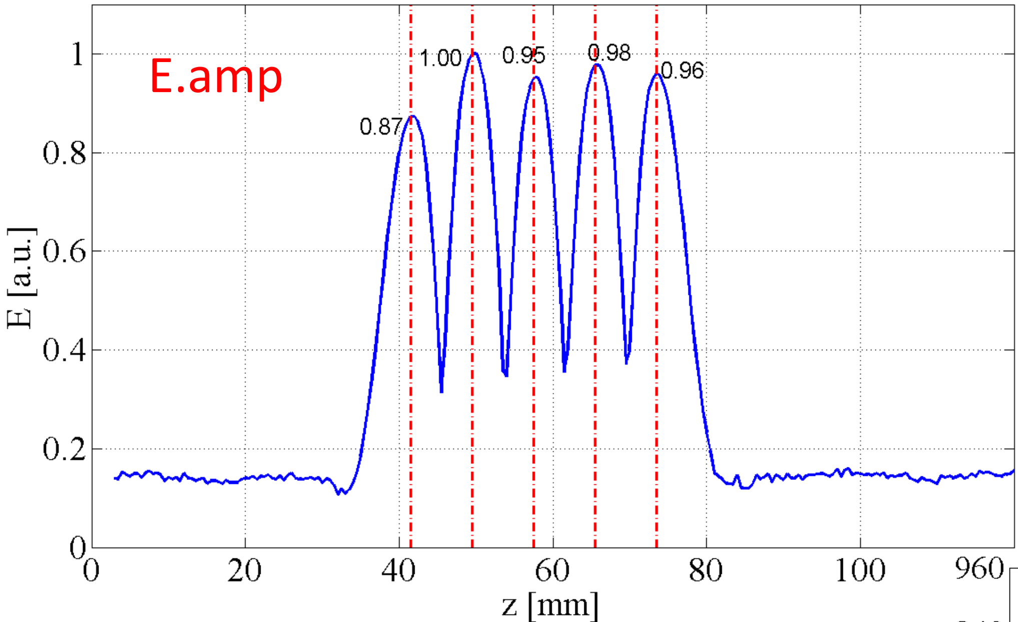
Can be improved by fine tuning of Bunch spacing and charge flatness

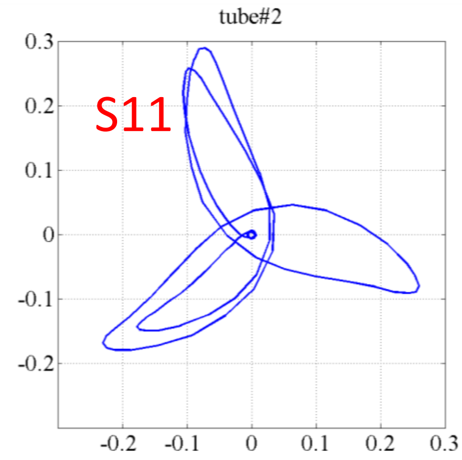


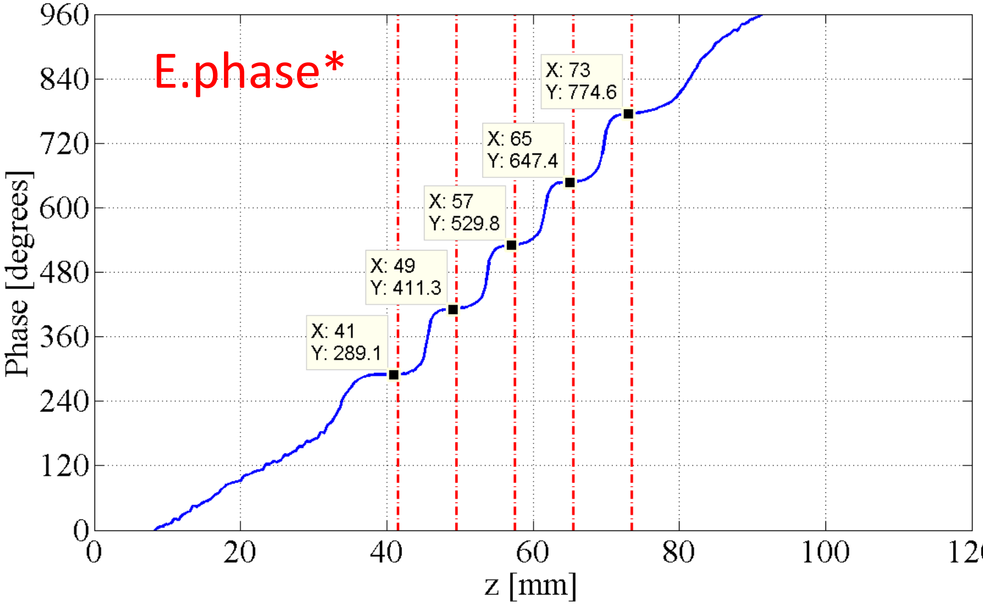
Accelerator, deigned and built at Tsinghua



Bead pull measurement of Accelerator #2

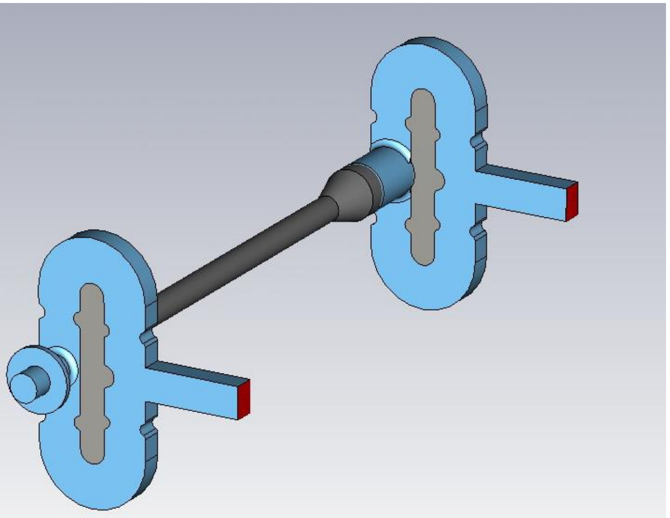




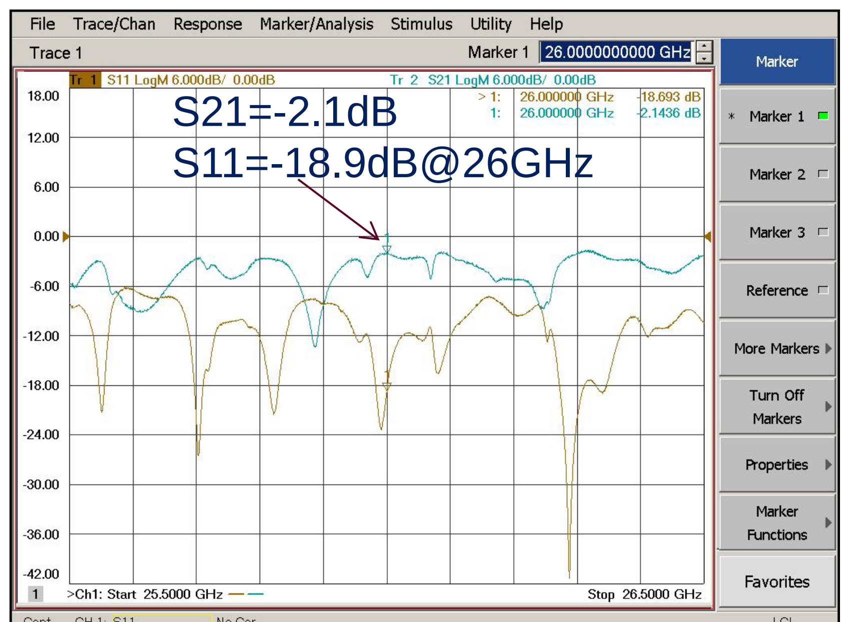


* Axis z is not calibrated

Development of 26GHz short pulse DLA structure



parameters	value
ID / OD of dielectric tube	3 mm /5.025 mm
Dielectric constant	9.7
Length of dielectric tubes	105 mm
Vg	11.13%c
R/Q	21.98 kΩ/m
Q (loss tan=10^-4)	2295
Shunt impedance	50.44 MΩ/m
E_{acc} for 316MW input	158 MV/m



Two beam acceleration example

75MeV drive beam
- 16 bunches x 60nC/per bunch
- σz=2mm

26GHz Stage I DWPE
a=3.5mm; b=4.53mm;
eps=6.64; L=30cm

65MeV drive beam
(10MeV loss)

RF Power Generation
- 767MW x15ns
- 26GHz rf

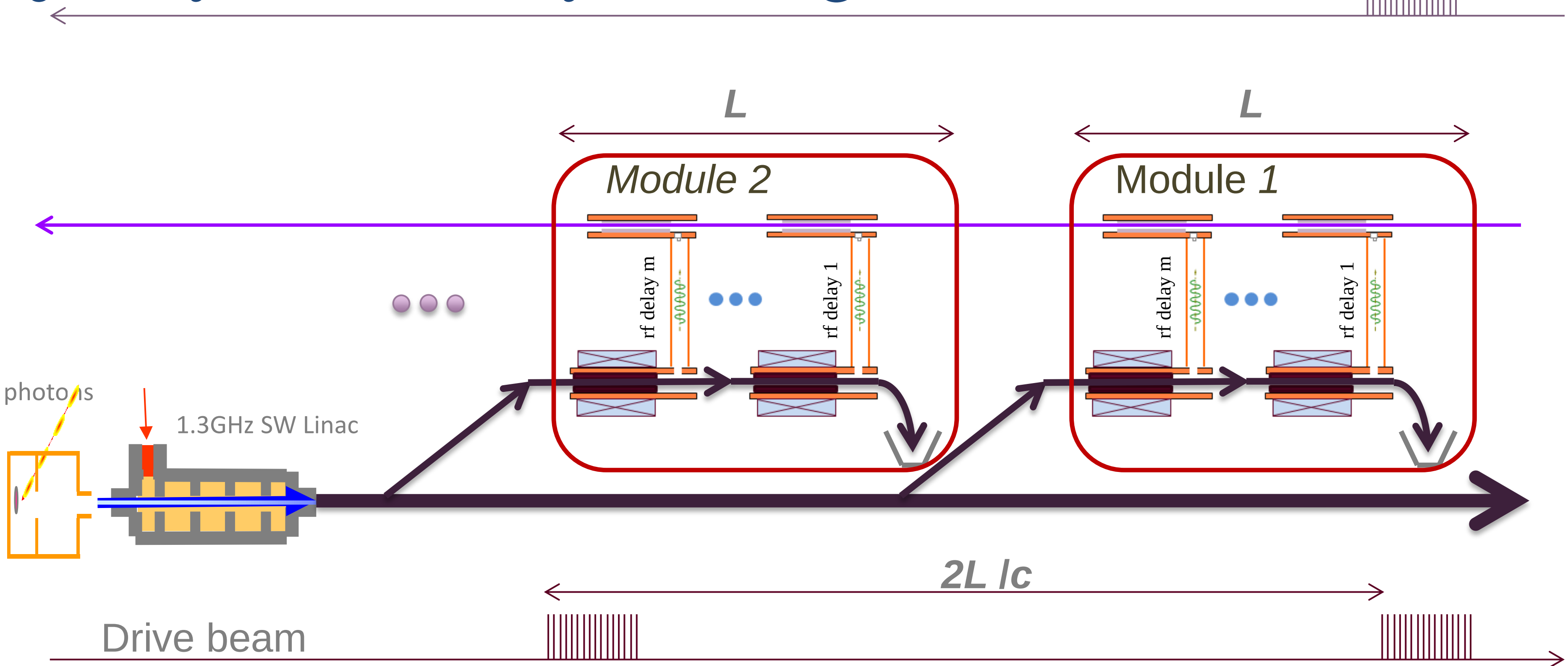
witness (10 MeV)
Q=1nC, σz=1mm, ε=1.5 um

26GHz Stage II DLA
a=3mm; b=5.03mm;
eps=9.7; Vg=11%c; L=30cm

Ez = 250MV/m

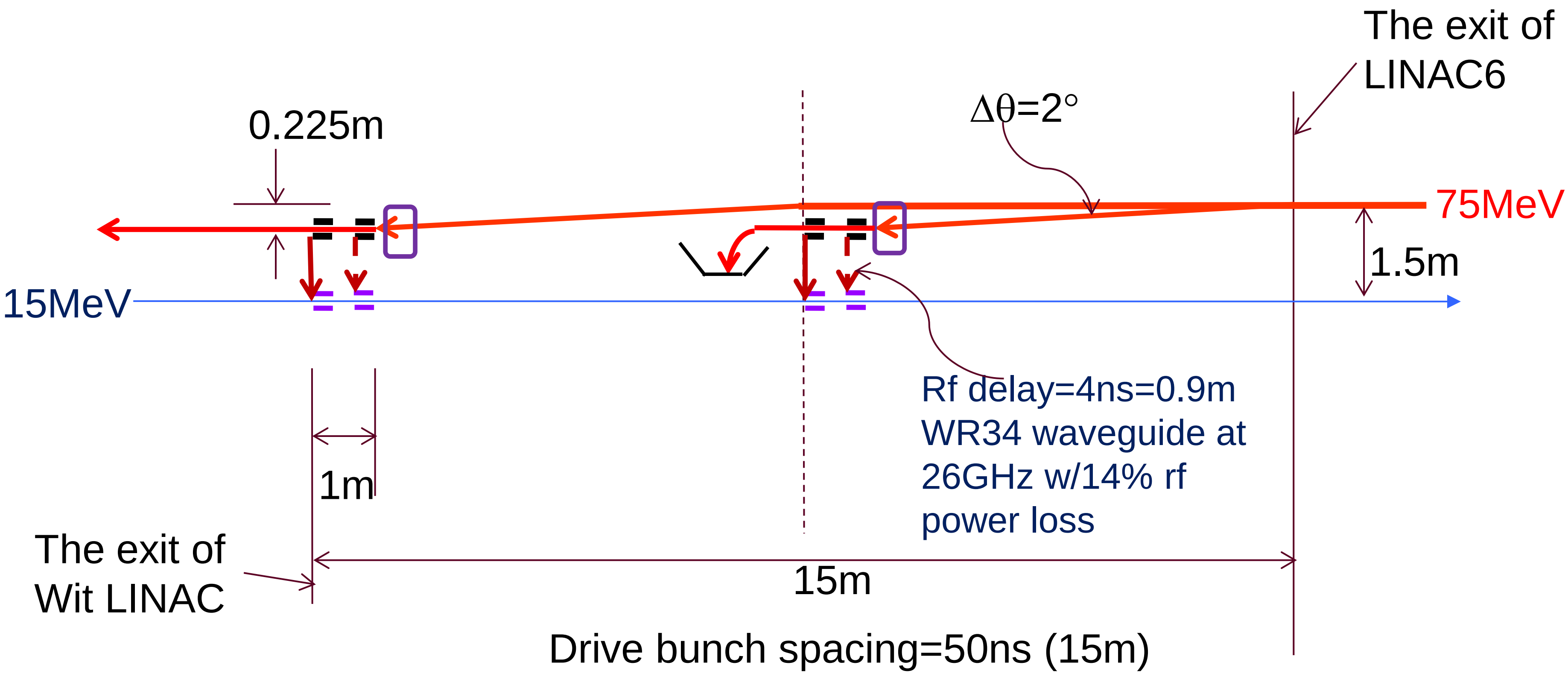
witness (85 MeV)

New Scheme to avoid 180 degree drive beam bend (using rf delay to obtain a sync timing)

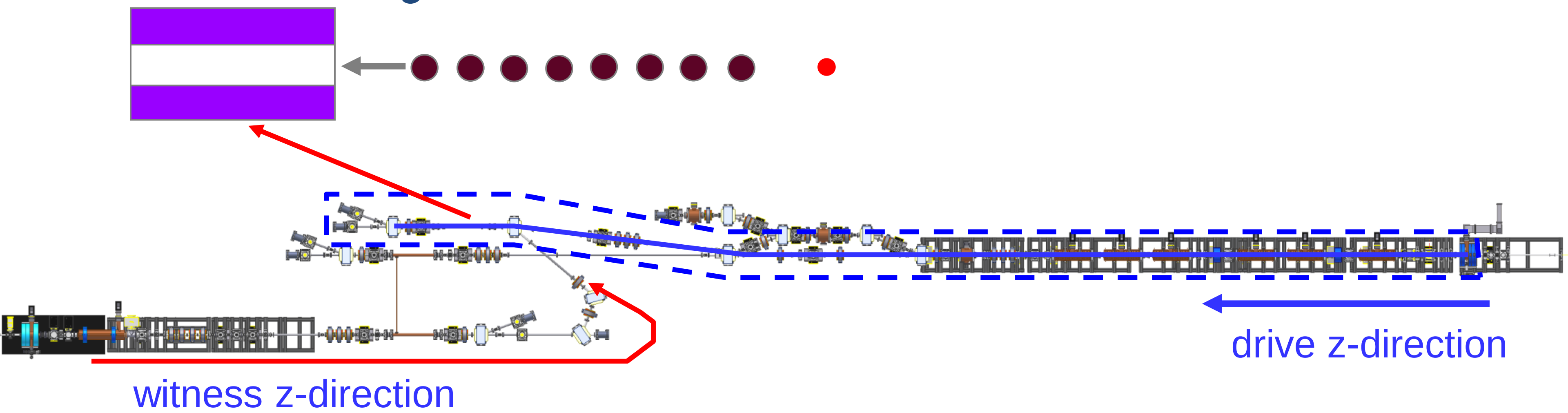


rf delay1=0;
rf delay2=2L_s/c;
rf delay m=2*(m-1)*L_s/c,
m is the # of structures in each stage,
L_s is the length of a single structure.

AWA Staging Demonstration



Collinear wakefield acceleration



Beam Parameters

75MeV beam

8 bunches

40nC/per bunch

σz=2mm

Structure Parameters

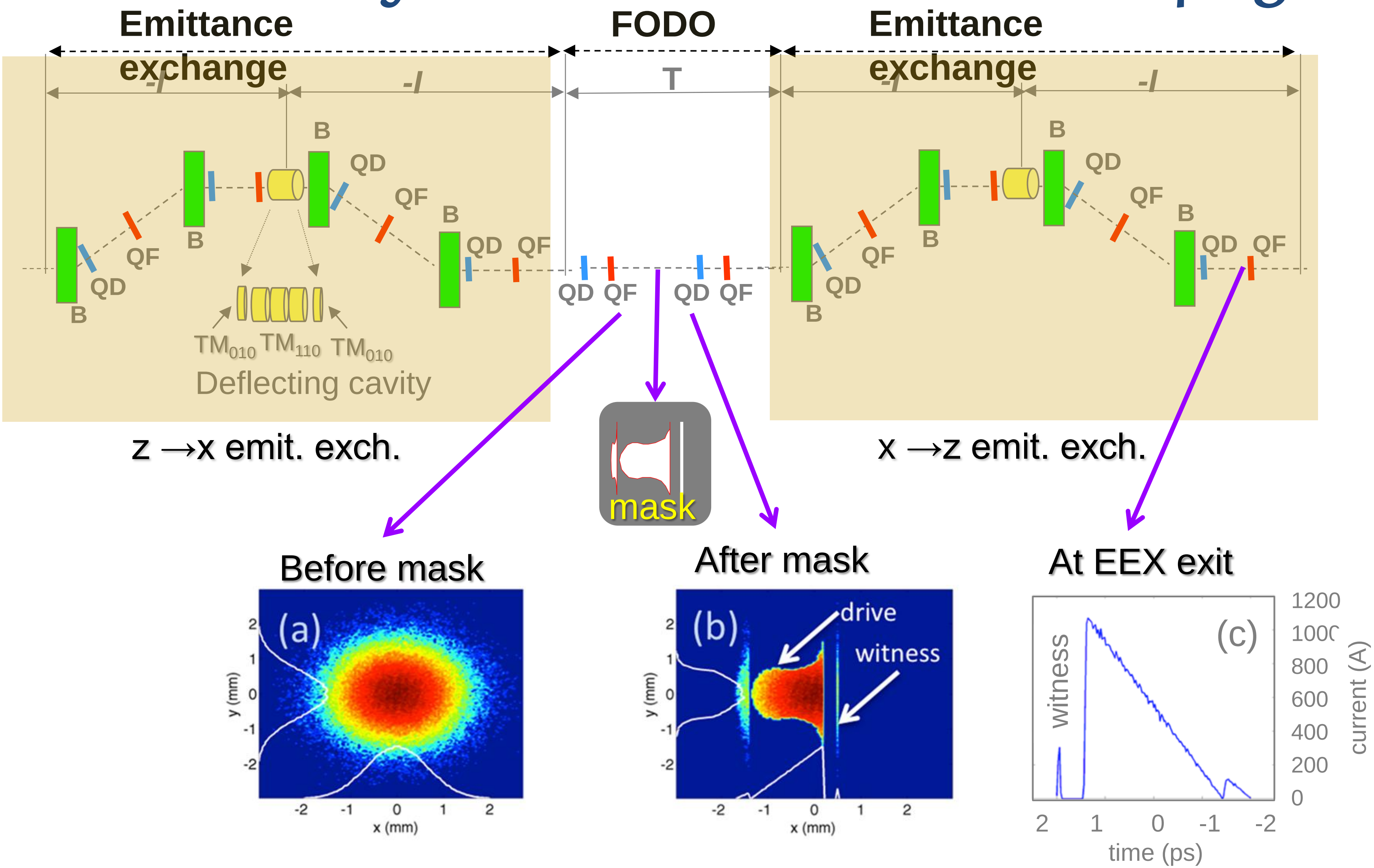
Standing Wave

- a=1.5mm
- b=1.84mm
- eps=3.75(quartz)
- L=20mm;
- Freq.=29.9GHz
- Q=3625

Estimated Gradient

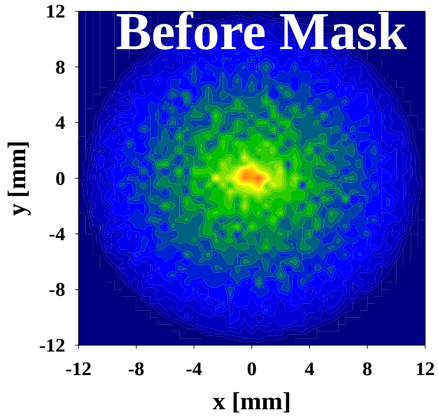
~500MV/m on axis

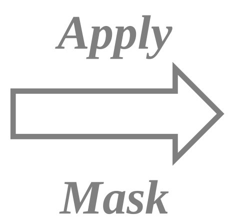
Double EEX technique:
a convenient tool for drive and witness bunch shaping



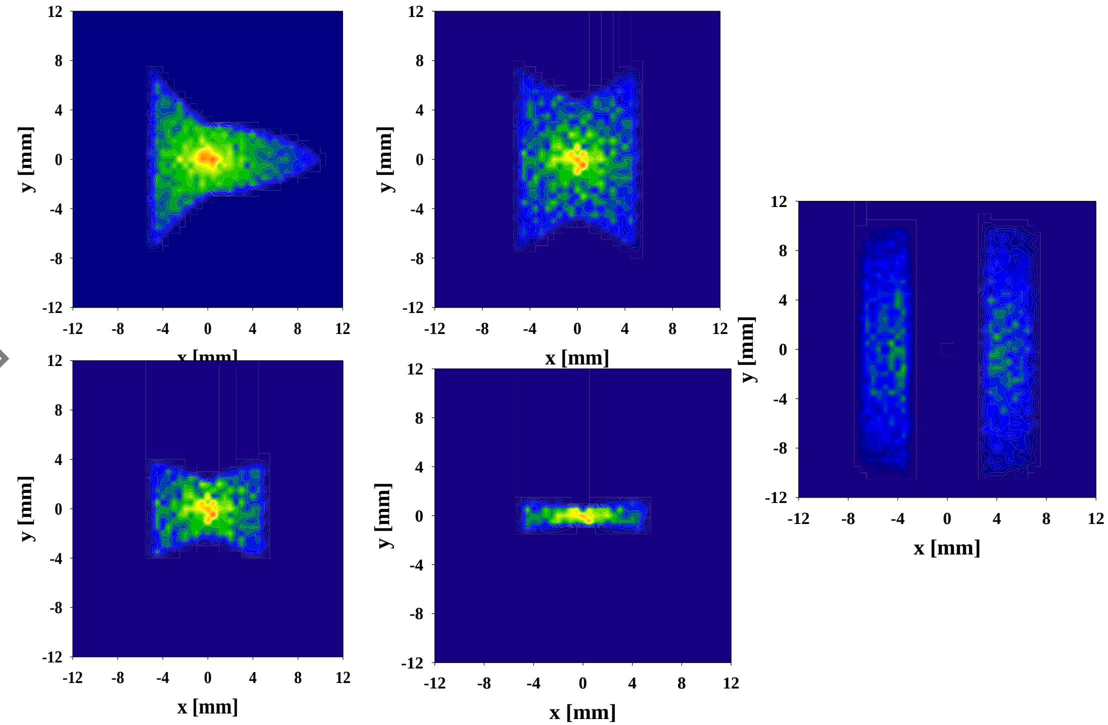
Drive and Witness from the same source bunch→ minimal timing jitter

Experiment 1 - Shaping ability of Masks



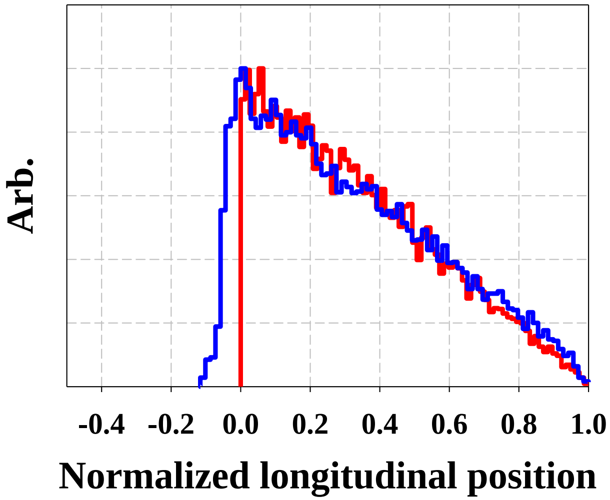


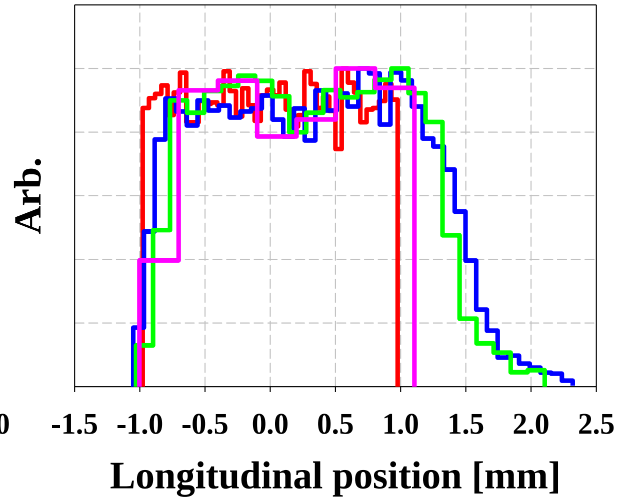
Multiple masks used to study bunch shaping

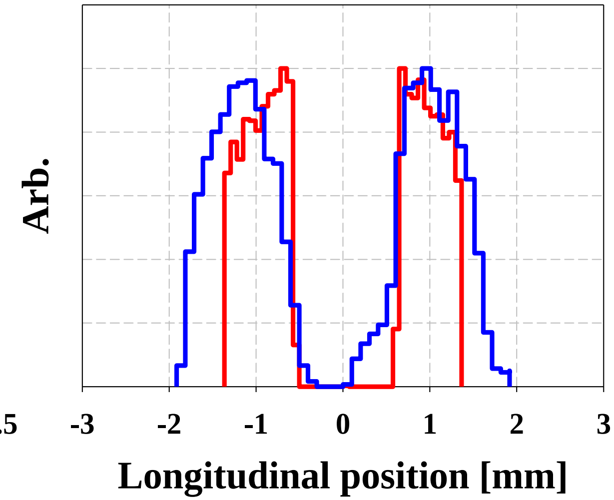


PARMELA Simulation results

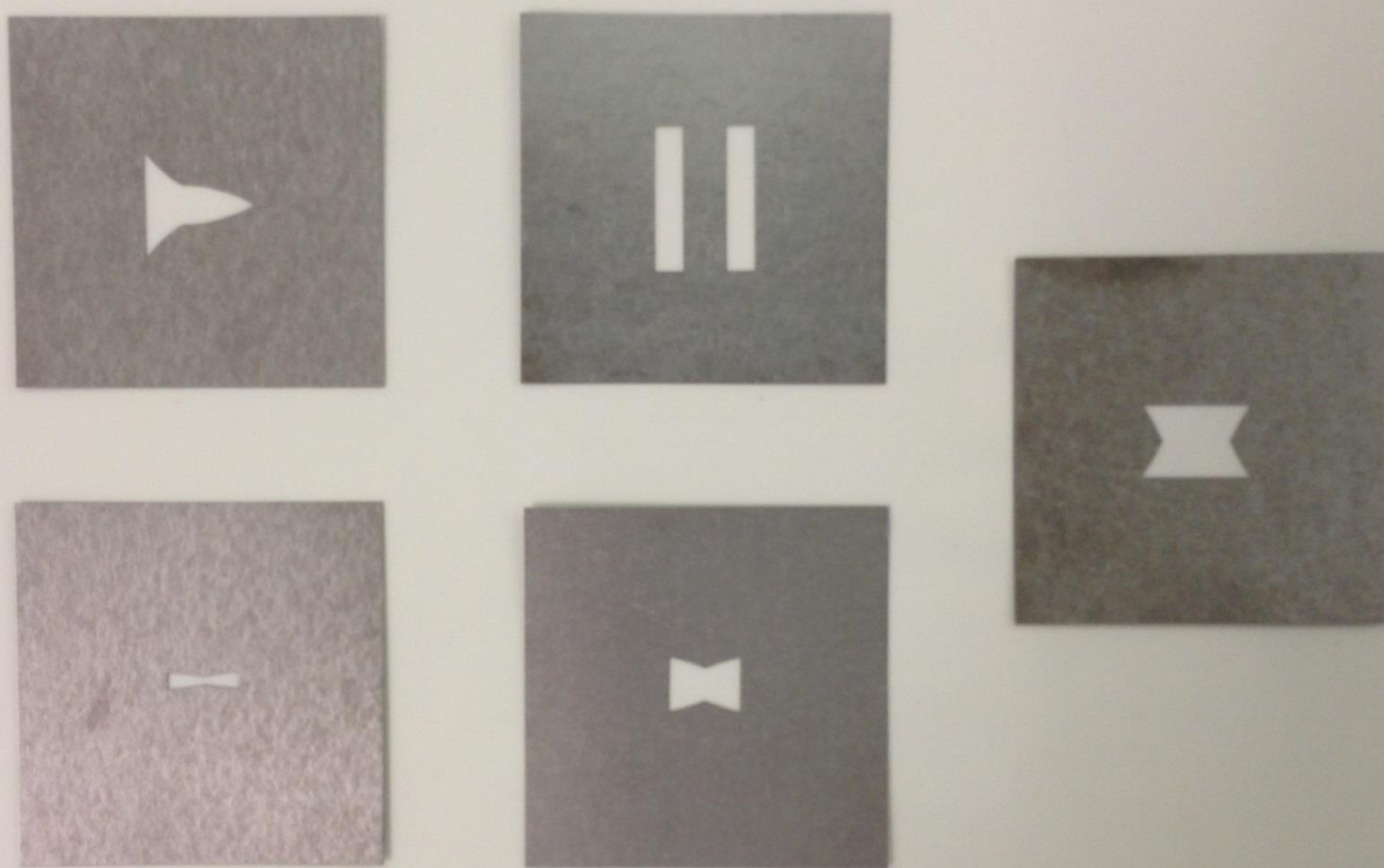
Horizontal profile after the mask
Final current profile







Masks: 2 in sq, 100 um thick, Tungsten



summary

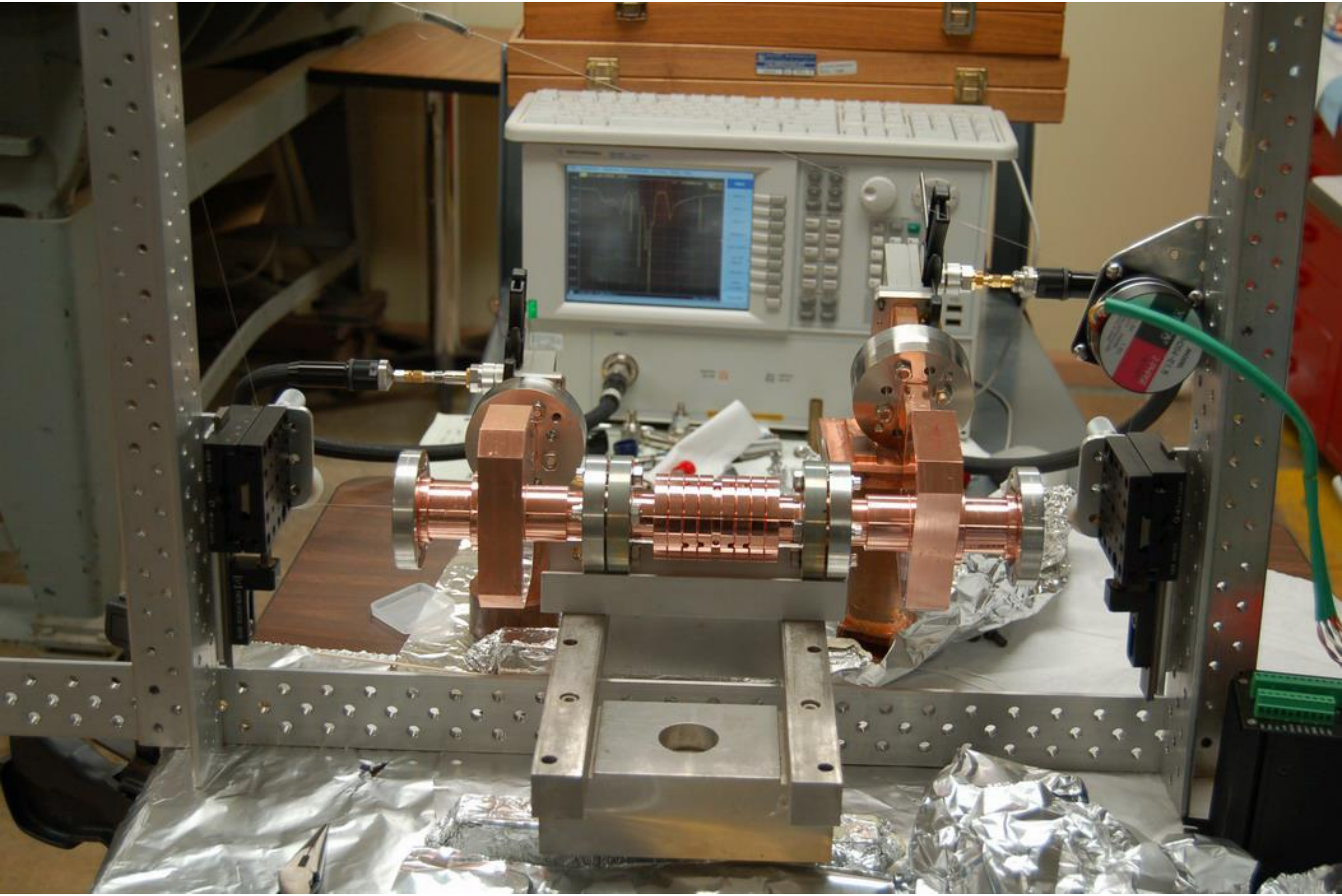
AWA offers a feasible approach advanced accelerations, include two beam acceleration experiments.

The facility is fully functional and ready for experiments.

We welcome collaborators and users.

extra

Accelerator, deigned and built at Tsinghua



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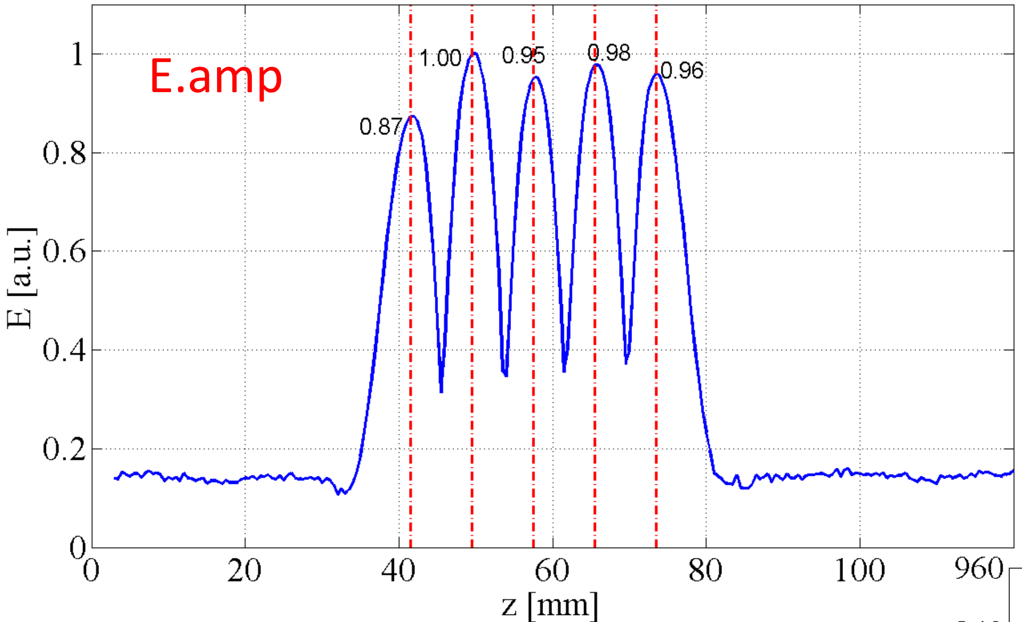

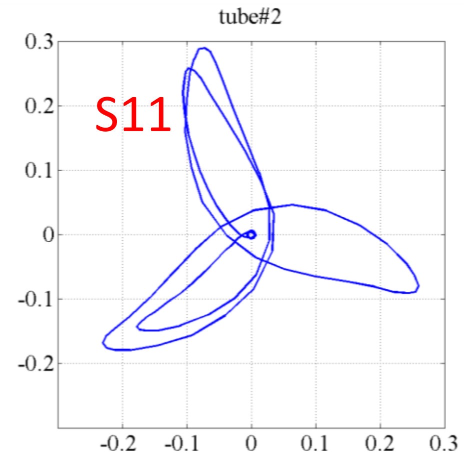

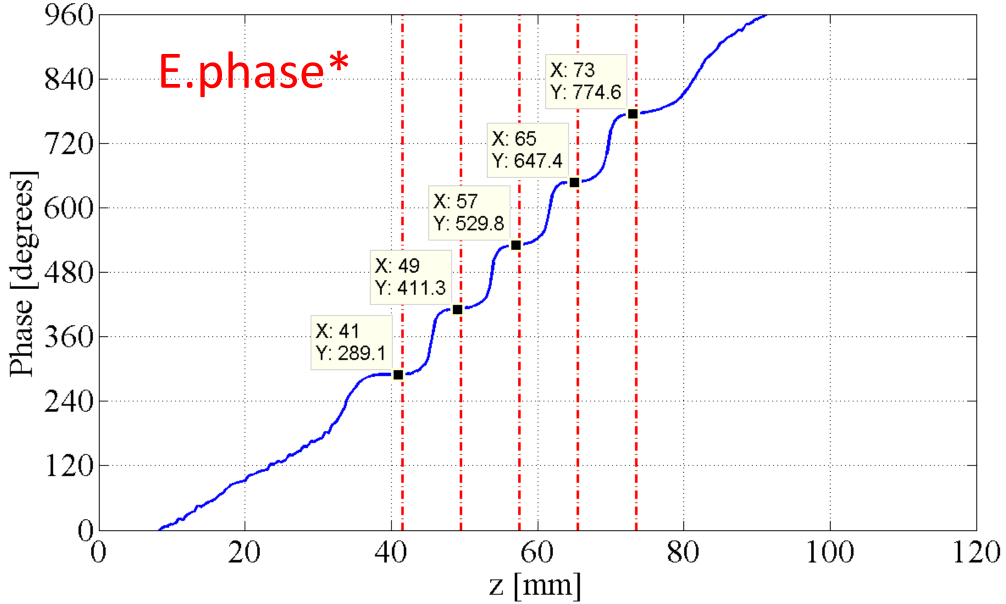

* Axis z is not calibrated

Drive Beam is the Key to High Gradient and High Power

Past and Future

Charge	Bunch length	Emittance	Energy	RF Power
1-5 nC	5mm (rms)	100 um	20 MeV	
10-60 nC	6mm (rms)	1000 um	14 MeV	
10-100 nC	3mm (rms)	200 um	15 MeV	1MW@30ns & 40MW@10ns
10-100nC	2mm (rms)	200 um	75 MeV	1GW@20ns

Charge	Bunch length	Emittance	Energy	Acceleration Gradient
1-5 nC	5mm (rms)	100 um	20 MeV	<1MV/m
10-60 nC	6mm (rms)	1000 um	14 MeV	~10MV/m
10-100 nC	3mm (rms)	200 um	15 MeV	21 MV/m, 43 MV/m, 78 MV/m,100 MV/m
10-100nC	2mm (rms)	200 um	75 MeV	200-300 MV/m