Recent Experiments at the Argonne Wakefield Accelerator Facility (AWA)

M. Conde, D.S. Doran, W. Gai, W. Liu, J.G. Power,
C. Whiteford, E. Wisniewski (ANL)

S. Antipov, S. Baryshev C. Jing, J. Qiu (Euclid Techlabs)

Q. Gao, J. Shao, D. Wang (Tsinghua University)

G. Ha (POSTECH)

N. Neveu, M. Warren (IIT)

B. Barber (U.Chicago)

Outline

- Mission
- Wakefield acceleration
- Recent milestones (facility upgrade & preliminary TBA)
- Recent experiments
- Future plans and goals

Mission

Studying the Physics and Developing the Technologies for Future HEP Accelerators (and possibly other applications).

Reasons for the mission (Challenges for Future HEP Linear Colliders):

- High gradient (~ hundreds MV/m) and High Impedance (high R/Q)
- High Power RF Sources (~ GW Scale)
- Higher order mode damping
- High gradient positron acceleration
- Find pathway to LC / Higgs factory

The AWA Approach:
a Realistic Path to a Future HEP Machine

Short RF pulses

Shorter RF pulses are less likely to cause breakdown. The energy efficiency and structure bandwidth can be made appropriately high.

Advanced structures (e.g. dielectrics)

Dielectric materials are likely to withstand higher electric fields than metals, without arcing. Metallic structures also studied.

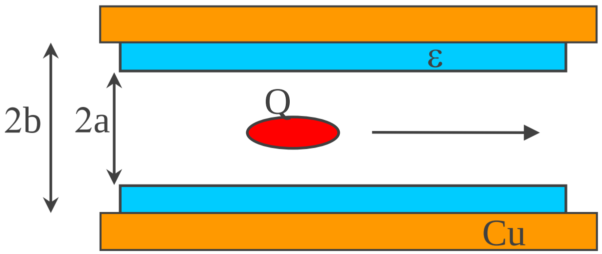
Structures that can accelerate electrons and also positrons

Since colliders are assumed to need electron beams and positron beams, we need to develop accelerating structures that can operate with either.

Schemes that allow for staging

Likely to need multiple stages to achieve desired energy. Need injection and precise control of the RF phase of multiple stages.

Wakefields in Cylindrical Dielectric Structures (a short Gaussian beam)



$$W_Z(z) \approx \frac{Q}{a^2} \exp\left[-2\left(\frac{\pi\,\sigma_z}{\lambda_n}\right)^2\right]\cos(kz)$$

$$\sigma_r = \left(\frac{\varepsilon_N}{\gamma}\beta\right)^{1/2}$$

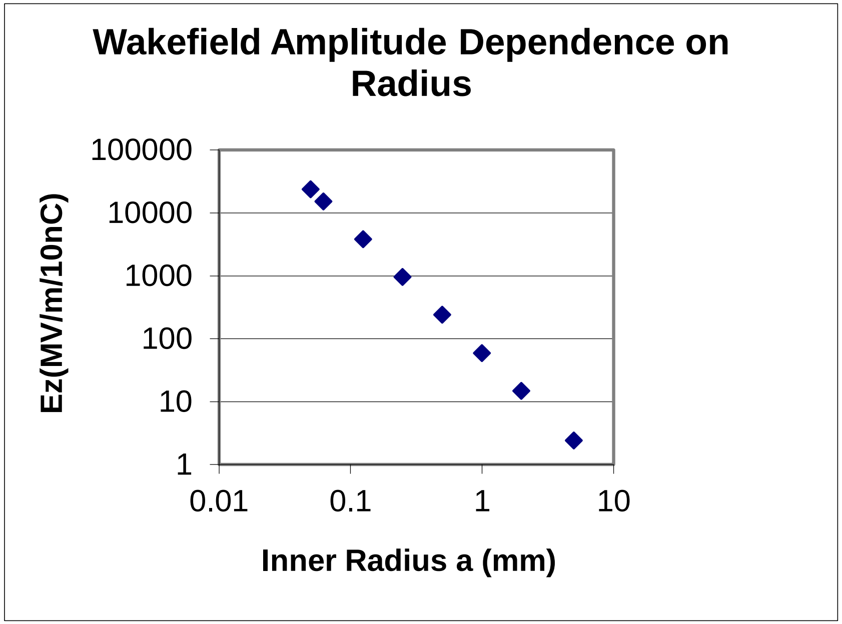
Key to the success:

→ superb drive beam & sensible structure design

- Energy ↑
- Charge ↑
- Bunch length ↓
- Emittance ↓

But, it is difficult to have high charge pass through small holes!

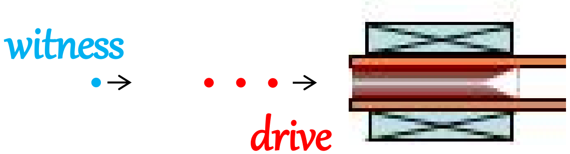
And at some point transverse wakefields become problematic.



Two Different Schemes

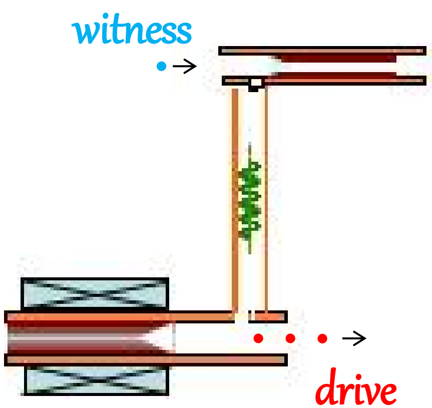
Collinear Acceleration

- Single wakefield structure
- No need for RF couplers
- Wide range of RF frequencies
- Easier to explore very high gradients at high frequencies
- Common transport optics for both beams (drive and witness) may create difficulties, especially for staging



Two Beam Acceleration (TBA)

- Need for RF couplers on both structures
- Short RF pulses require broad bandwidth couplers
- Each structure can be optimized independently
- Independent beamline optics makes staging much simpler



Two Recent Major Milestones

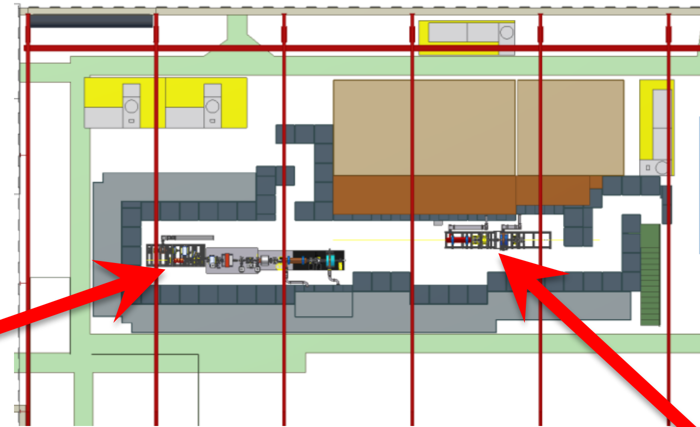
- Completed (mostly) upgrading the facility
  - Added new 70 MeV linac to provide greatly enhanced drive beam
  - Existing 15 MeV linac now dedicated to providing witness beam
  - Expanded RF system from single klystron to four phase locked klystrons
  - Expanded bunker area
  - Flexible and expandable beamline configuration

- Successful Two-Beam-Accelerator (TBA) experiment
  - RF power generated from 8 drive bunches
  - Preliminary results show over 50 MV/m accelerating gradient

1st Milestone

AWA Facility Underwent Major Upgrade

Before…

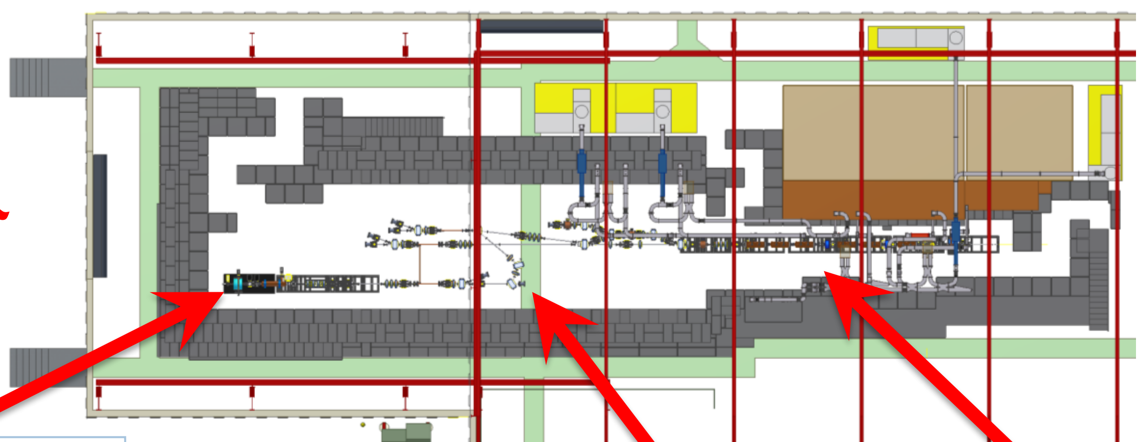


625 ft^2
66 ft long

15 MeV beam:
RF gun with Mg photocathode
& one linac tank

new RF gun with
Cs_2Te photocathode

After…



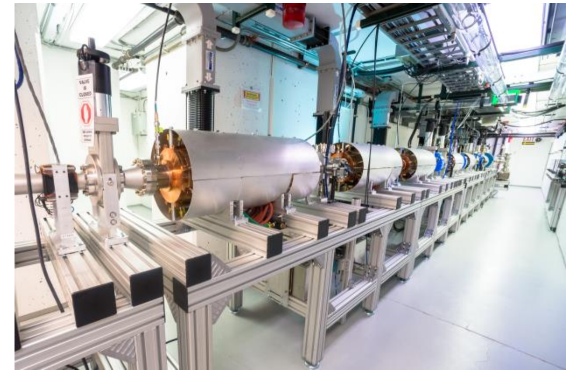
1950 ft^2
127 ft long

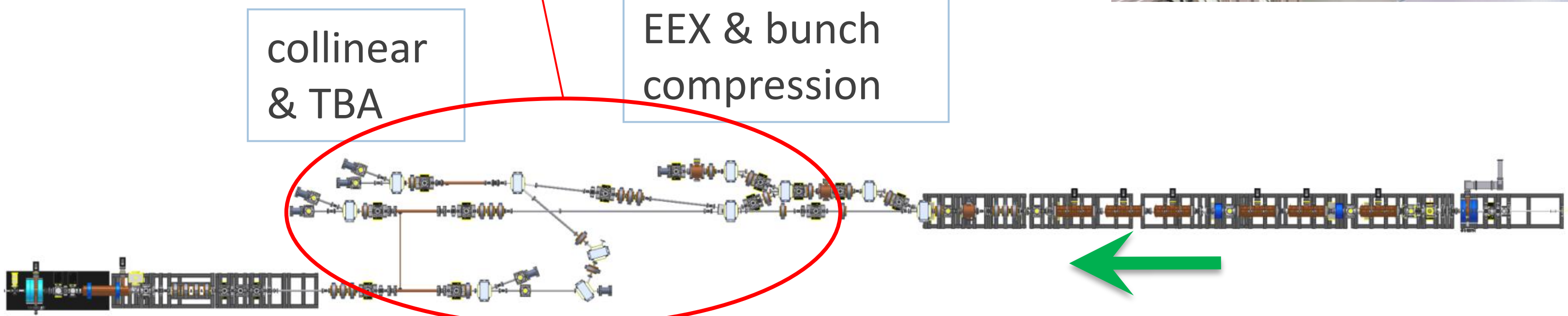
15 MeV beam moved
& turned around

new beamline
switchyard

new 70 MeV drive
beam: RF gun &
six linac tanks

AWA Beamlines





15 MeV witness beam

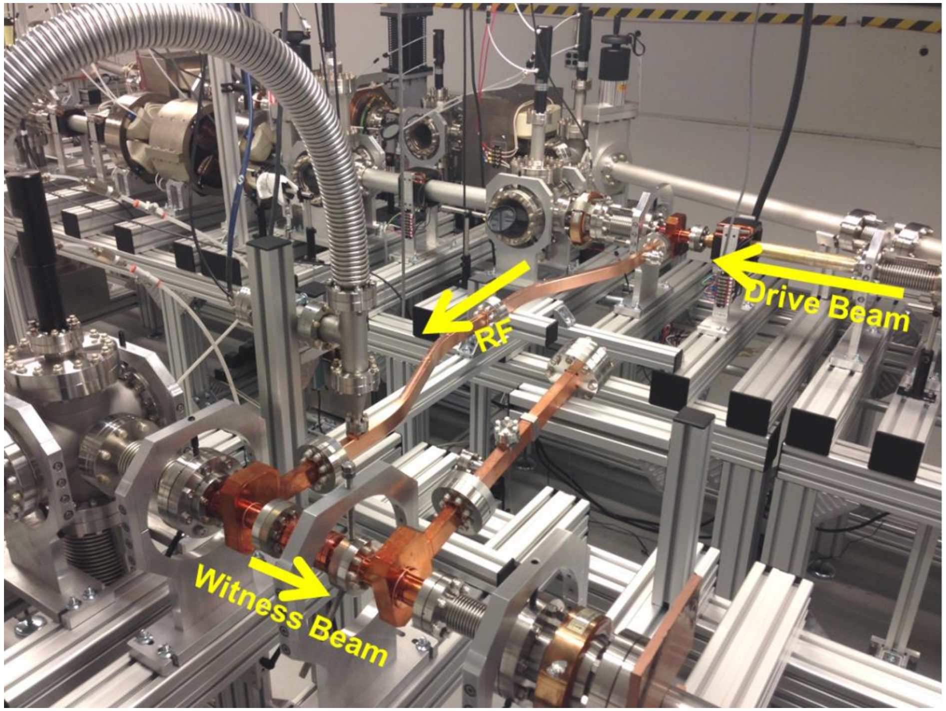
- single bunches
- bunch charge 0.05 to 60 nC

70 MeV drive beam

- bunch trains of up to 32 bunches
- Maximum charge in single bunch **100 nC**
- maximum charge in bunch train **600 nC**.

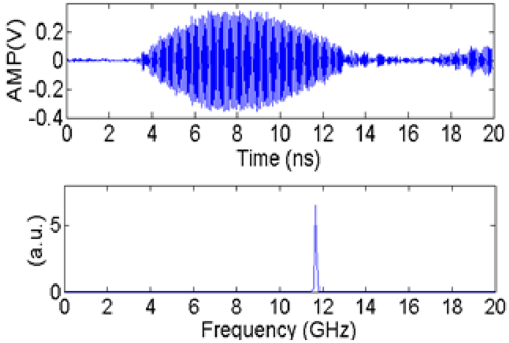
2nd Milestone

TBA experiment
11.7 GHz iris loaded metallic structures

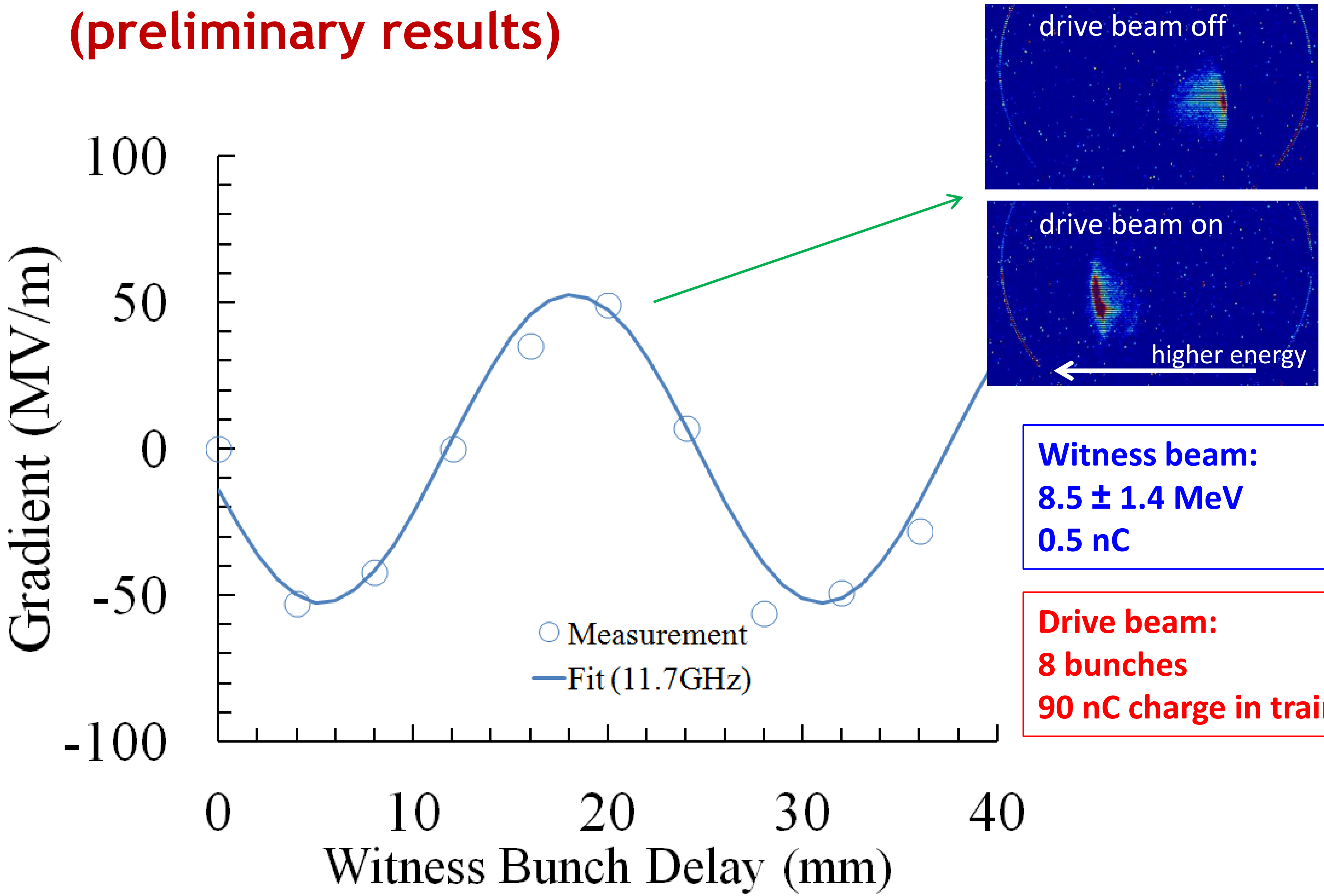


Decelerating structure:
2π/3 mode
35 cells + coupling cells
0.22c group velocity

Accelerating structure:
2π/3 mode
3 cells + coupling cells
0.014c group velocity



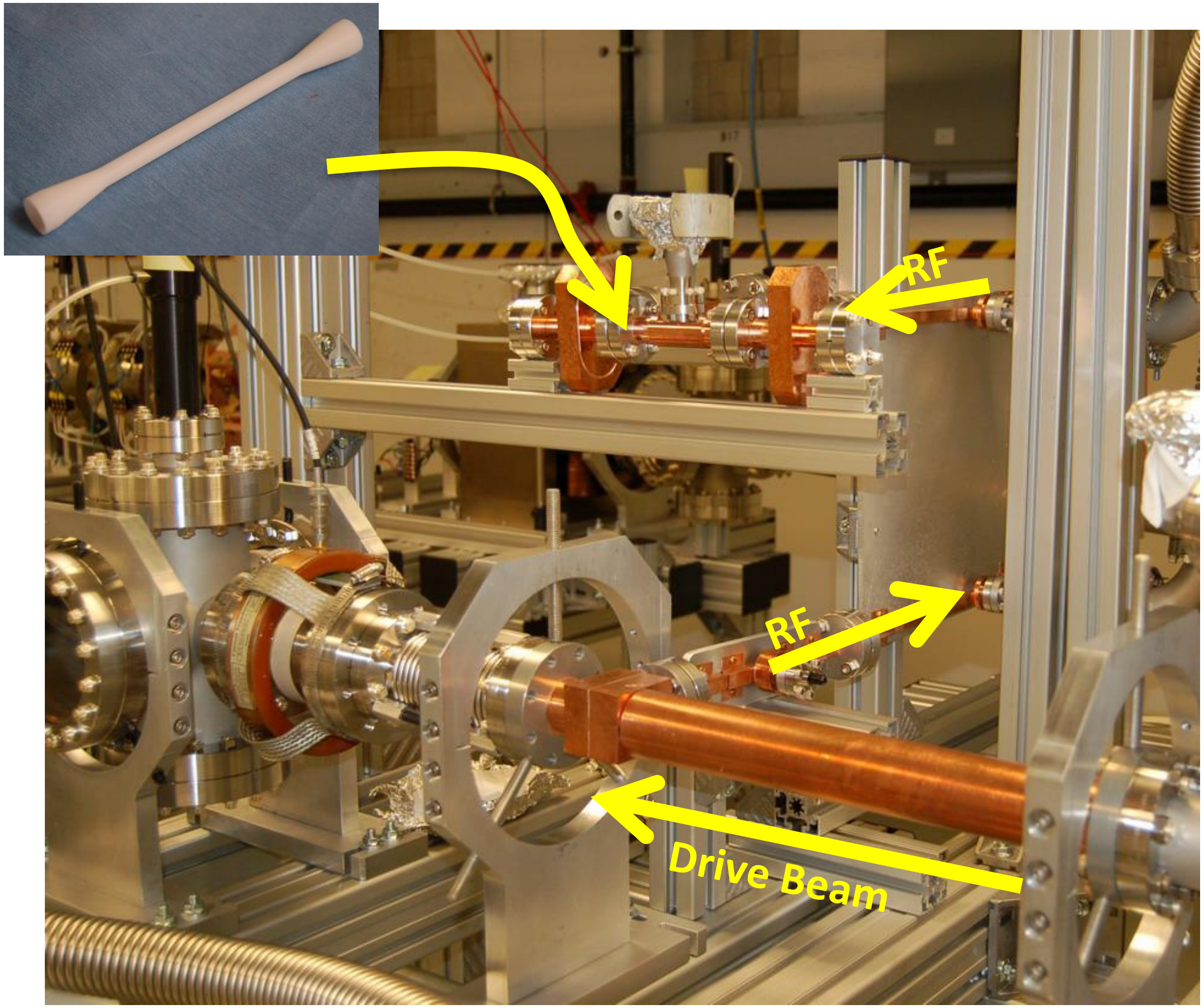
TBA data
(preliminary results)



Witness beam:
8.5 ± 1.4 MeV
0.5 nC

Drive beam:
8 bunches
90 nC charge in train

High power rf test of 26GHz Dielectric Loaded Accelerator using RF pulses extracted from the AWA Drive Beam

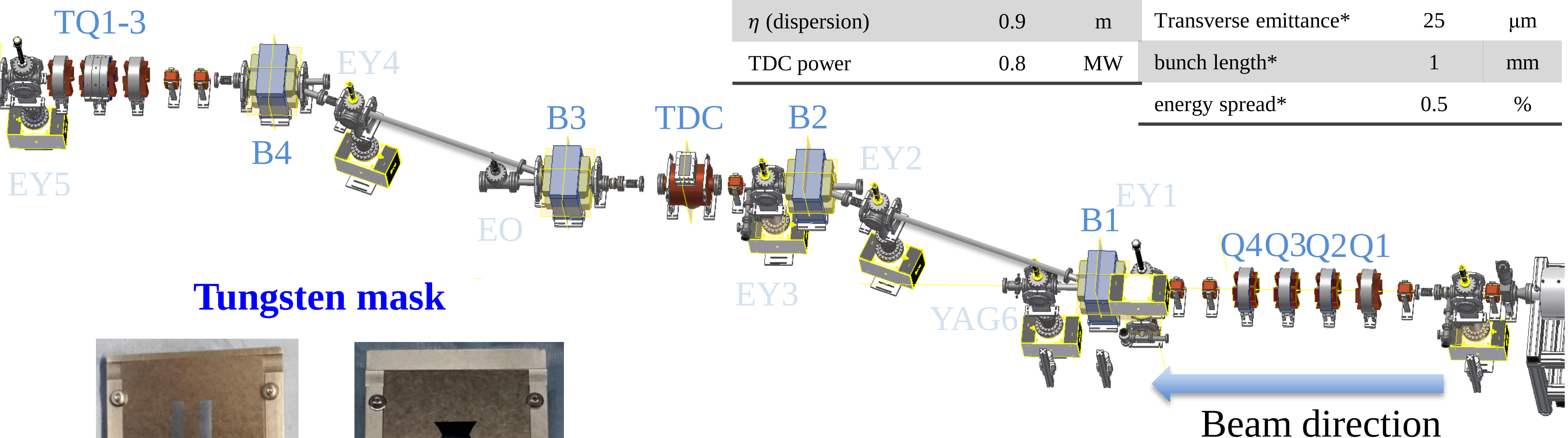


- 37MW max RF power measured out of the Power Extractor.
- Equivalent to 54MV/m gradient in the DLA structure.
- No breakdown was observed.
- RF pulse is ~ 5 - 15ns depending on the number of bunches in the train.

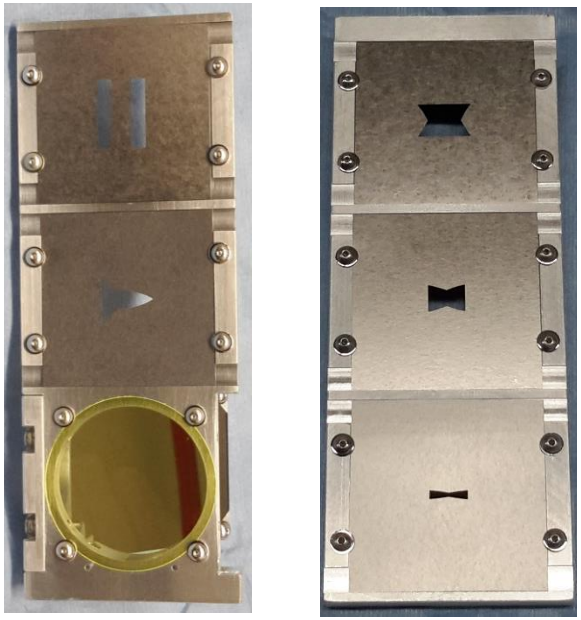
Emittance Exchange

Beam line parameter	Value	Unit
Bending angle	20	deg
Dipole-to-Dipole	2.0	m
η (dispersion)	0.9	m
TDC power	0.8	MW

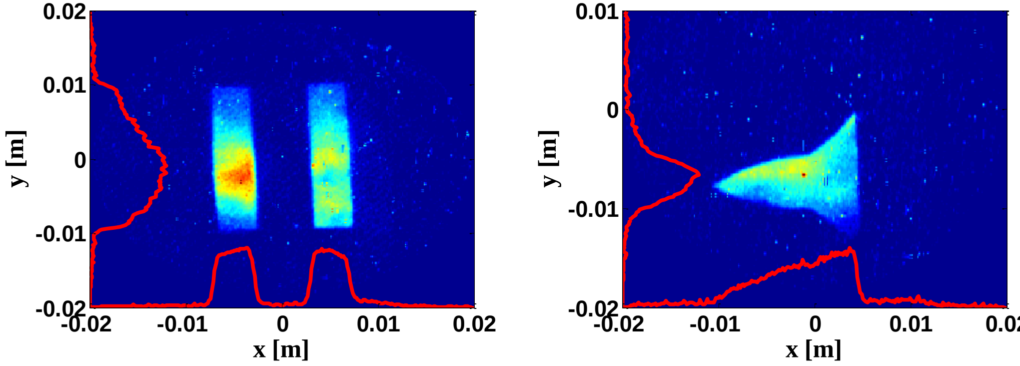
Input beam parameter	Value	Unit
Incoming charge	4-6	nC
Beam energy	46.5	MeV
beam size at EY1	5	mm
Transverse emittance*	25	µm
bunch length*	1	mm
energy spread*	0.5	%



Tungsten mask

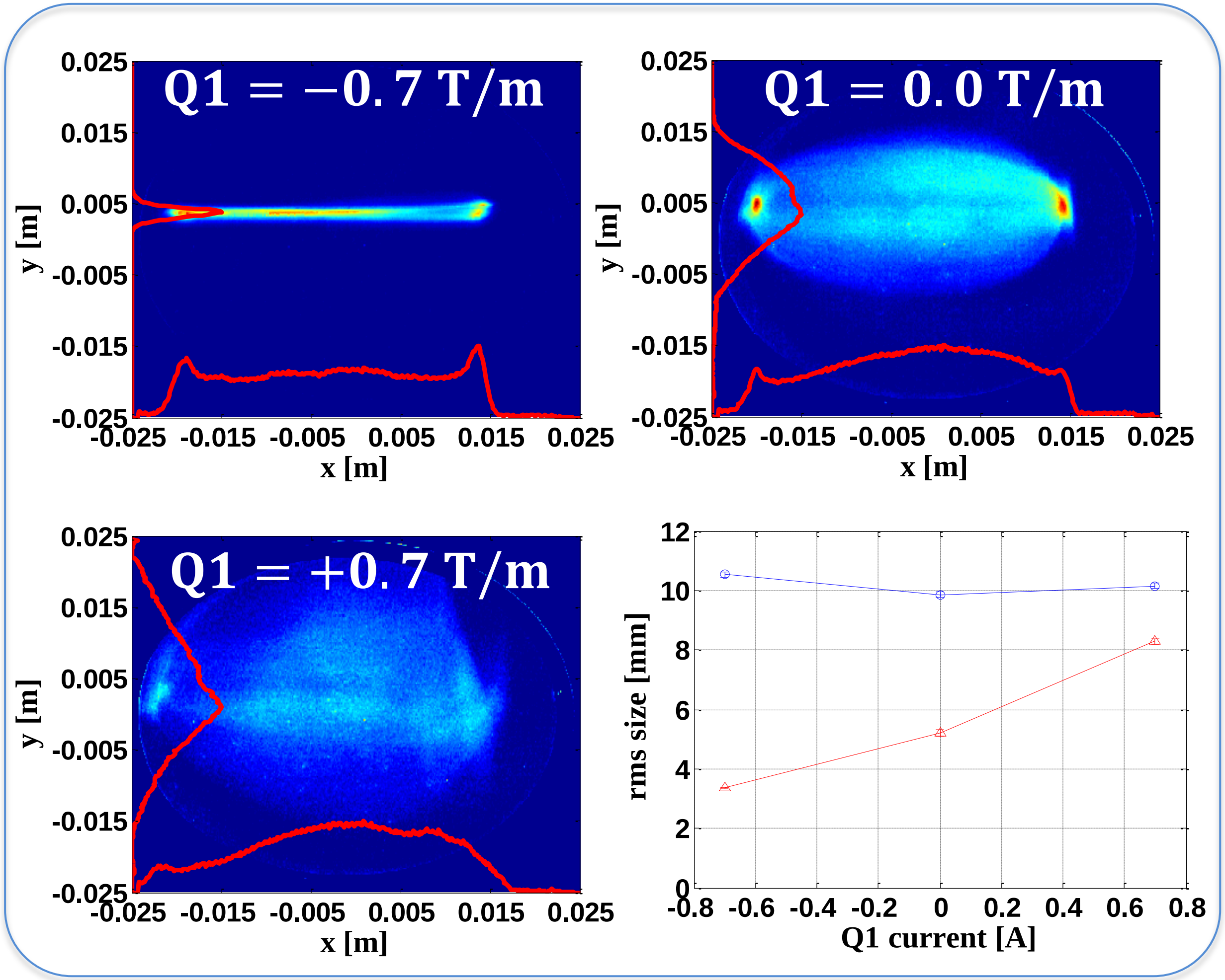


Transverse beam image and profile at YAG6

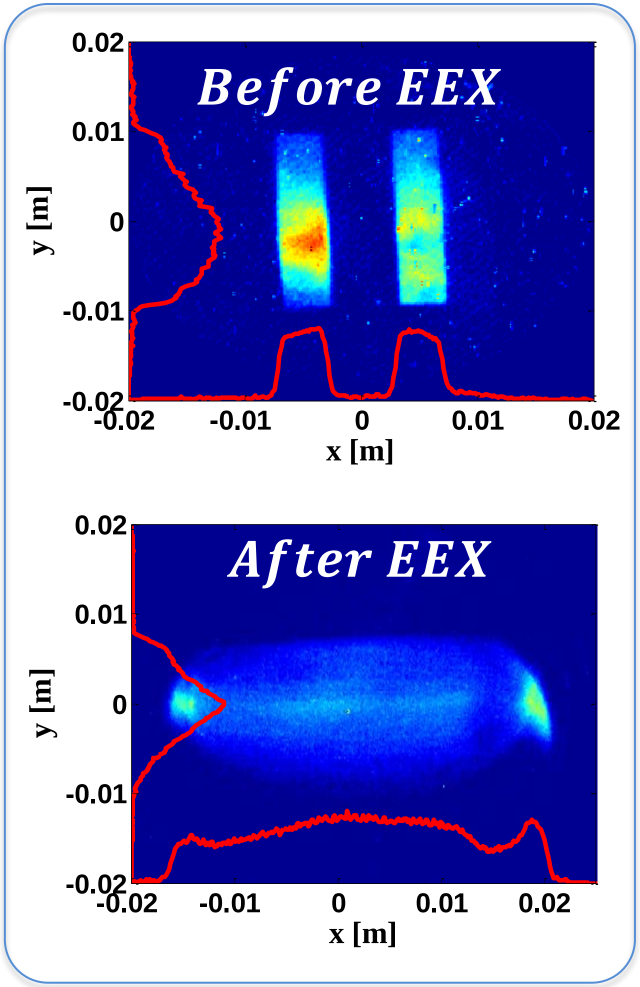


EEX Initial Measurements

Quadrupole scan



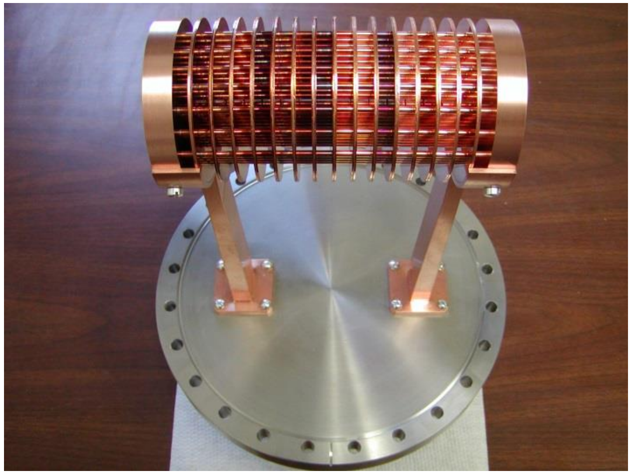
Property exchange



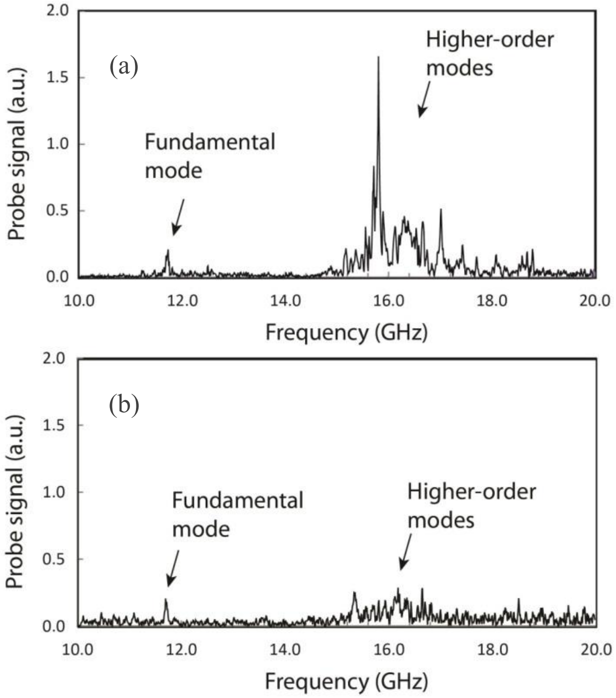
- Horizontal beam size remains constant while vertical beam size changes dramatically.
- Transversely separated two beam becomes single beam after the EEX.

EXPERIMENTAL STUDY OF WAKEFIELDS IN AN X-BAND PHOTONIC BAND GAP ACCELERATING STRUCTURE

Evgenya Simakov et al.

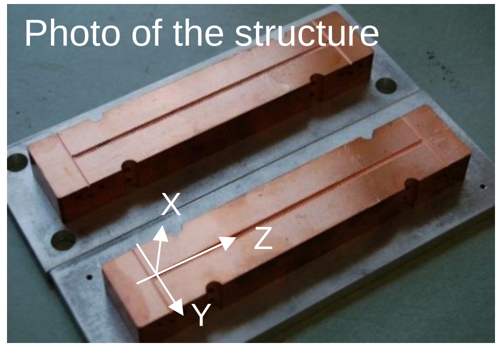


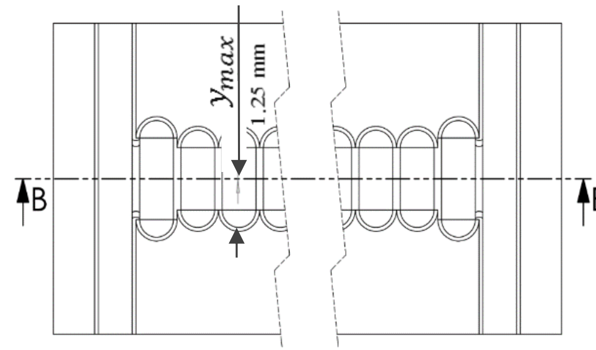
PBG structure

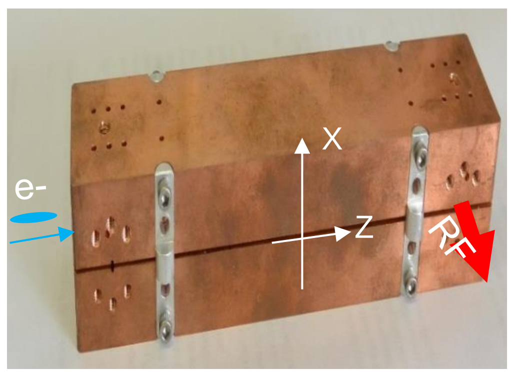


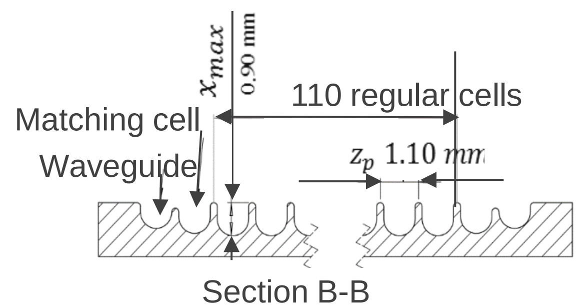
High Power RF Radiation at W-Band Based on Wakefields Excited by Intense Electron Beam

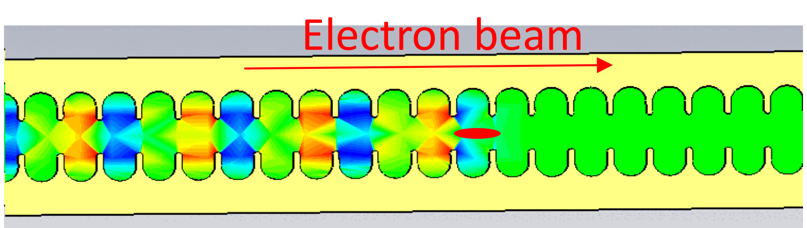
Two copper plates with periodic grooves make up the W-band PETS



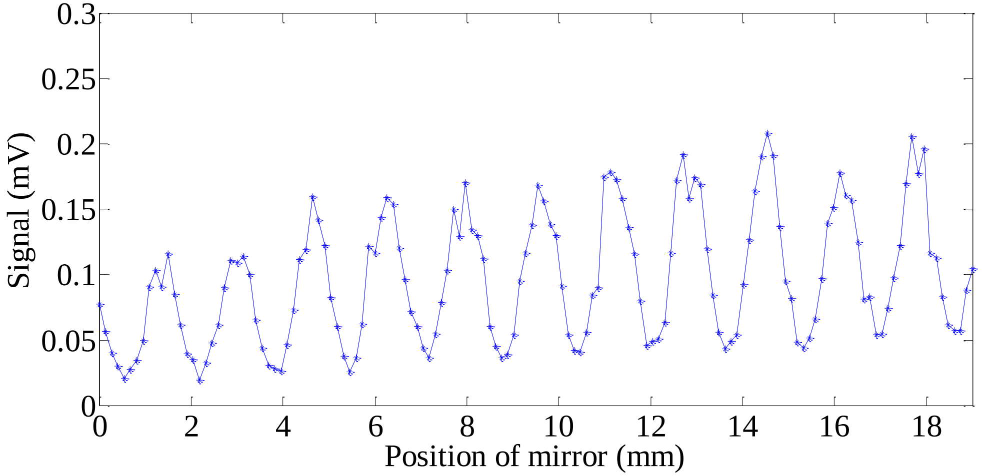


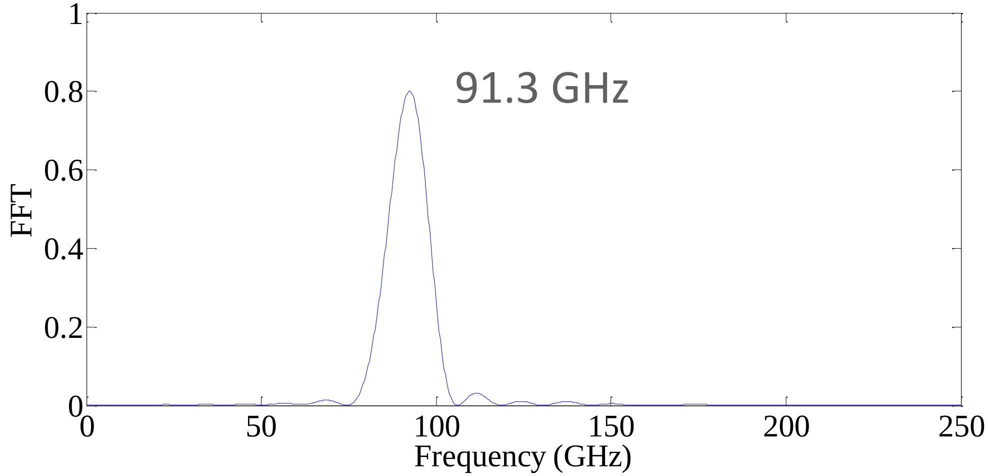




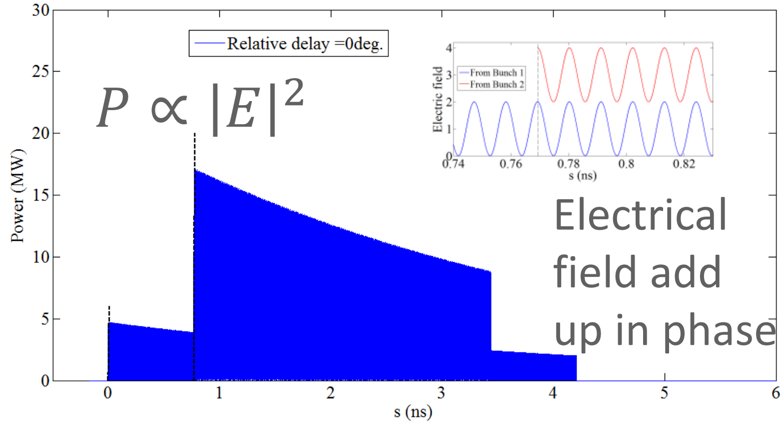


Frequency measurement with interferometer

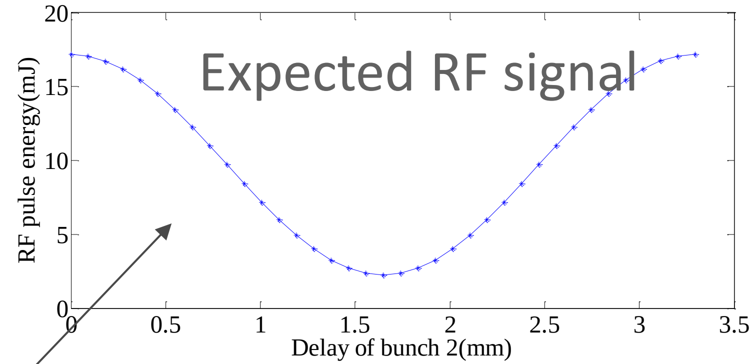




Two electron bunches: scanning delay

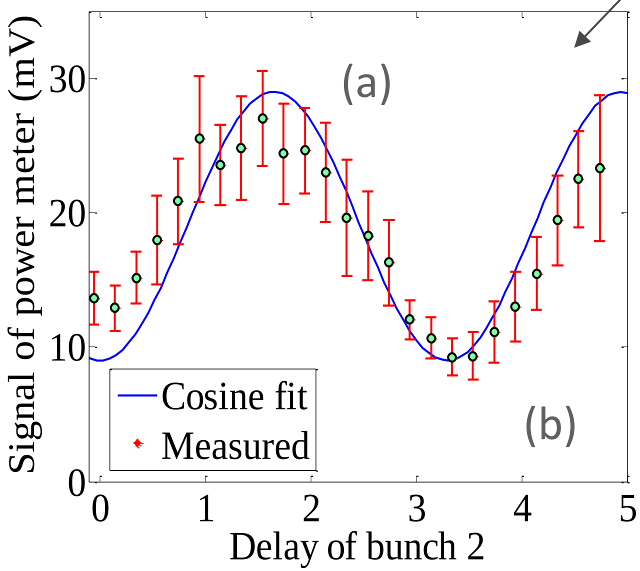


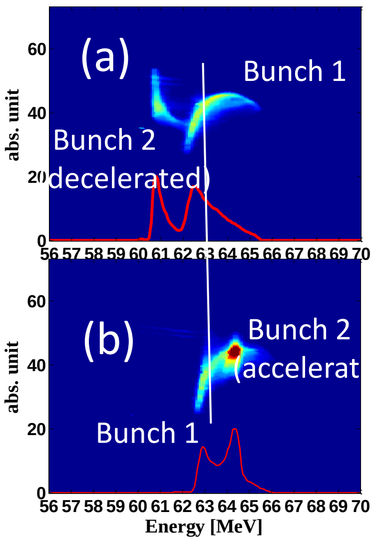
Electrical field add up in phase



Simulations

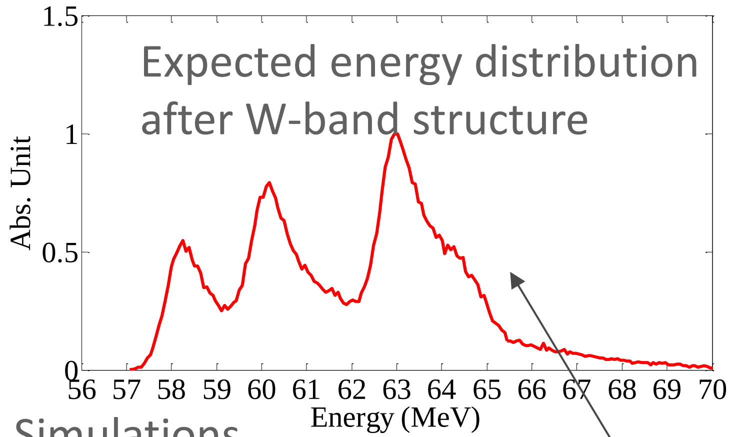
Experiment



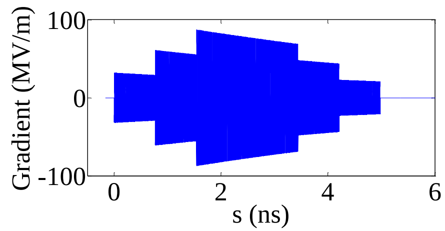


Two bunches at spectrometer

Three and four bunches

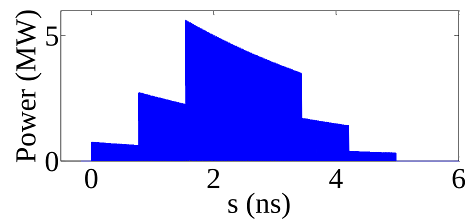


Simulations



Derived wakefield gradient

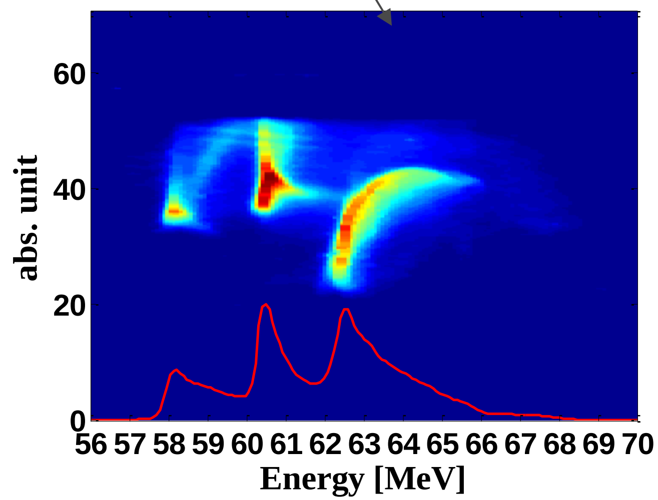
$E_{peak} = 84\ MV/m$



Derived output RF pulse:

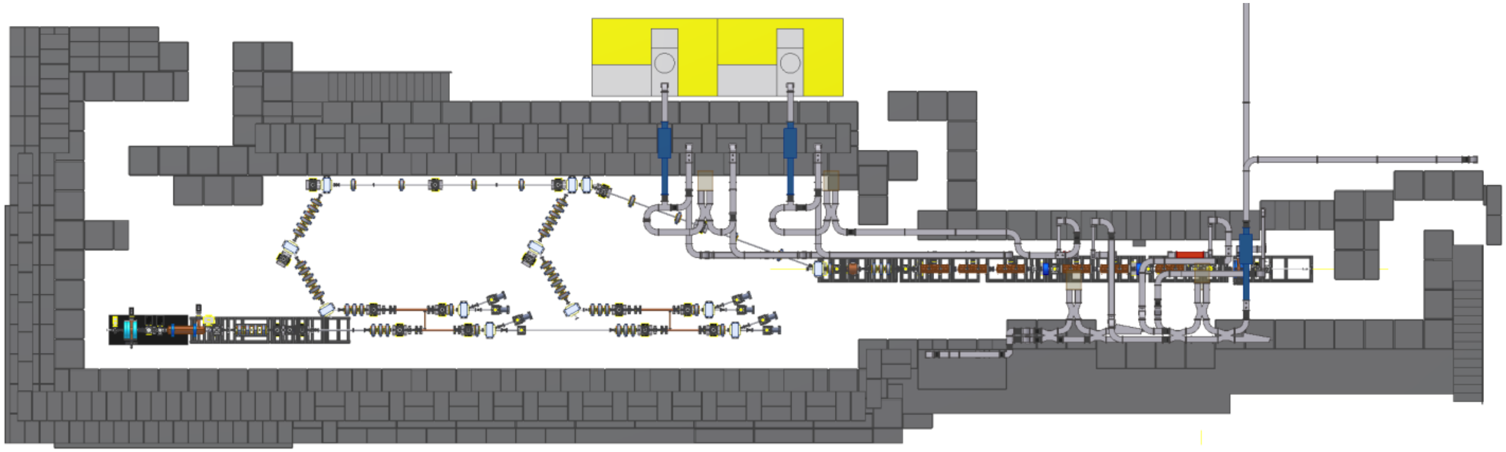
$P_{peak} = 5\ MW$

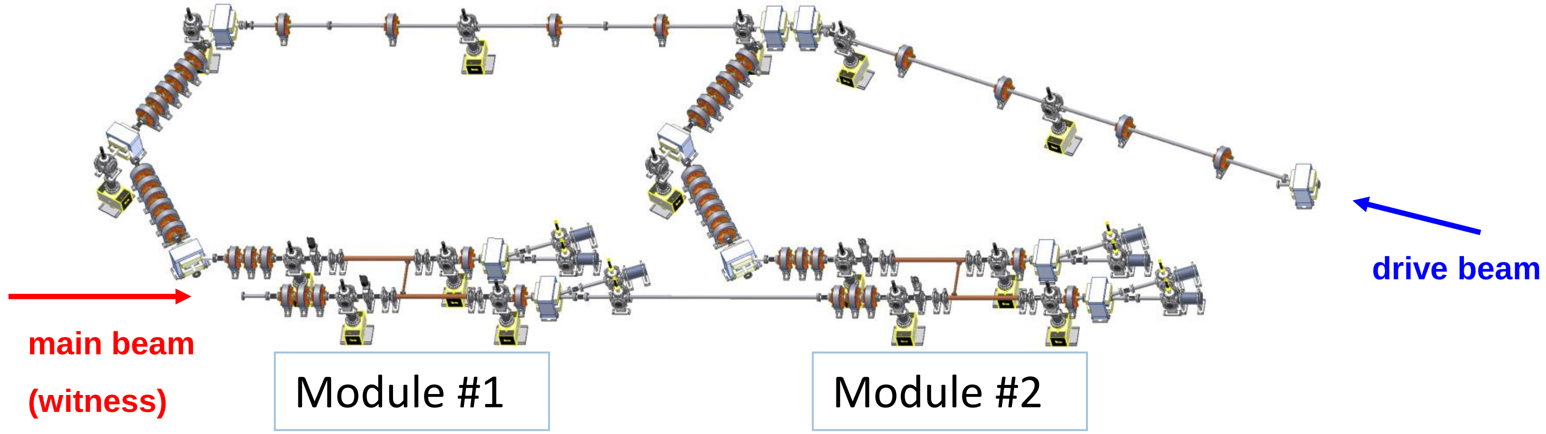
Experimental observations on the spectrometer (bunch 3+4 contribute as one single bunch)



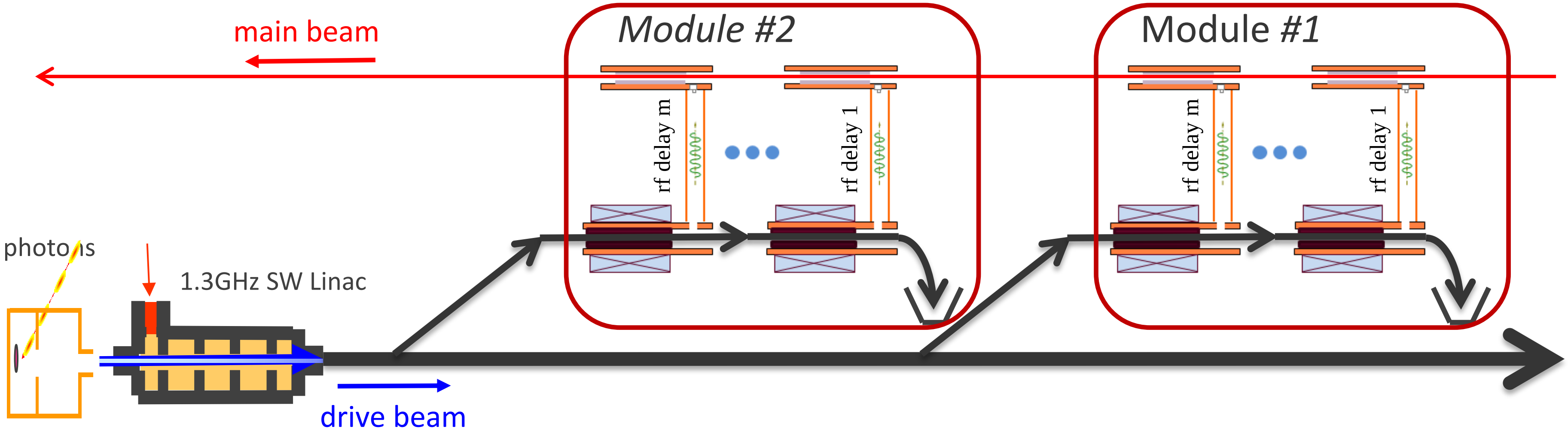
We also measure the maximum single with power meter in this case

Staging: U-turn Option





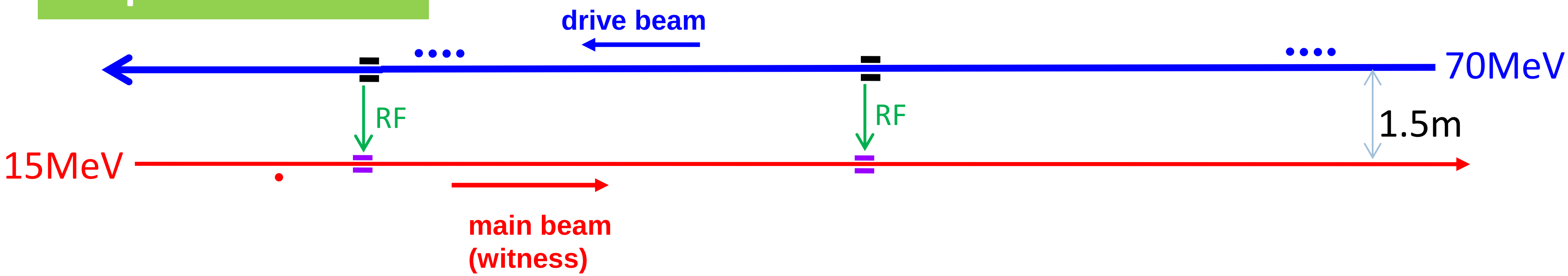
Staging:
using RF delay to obtain proper timing



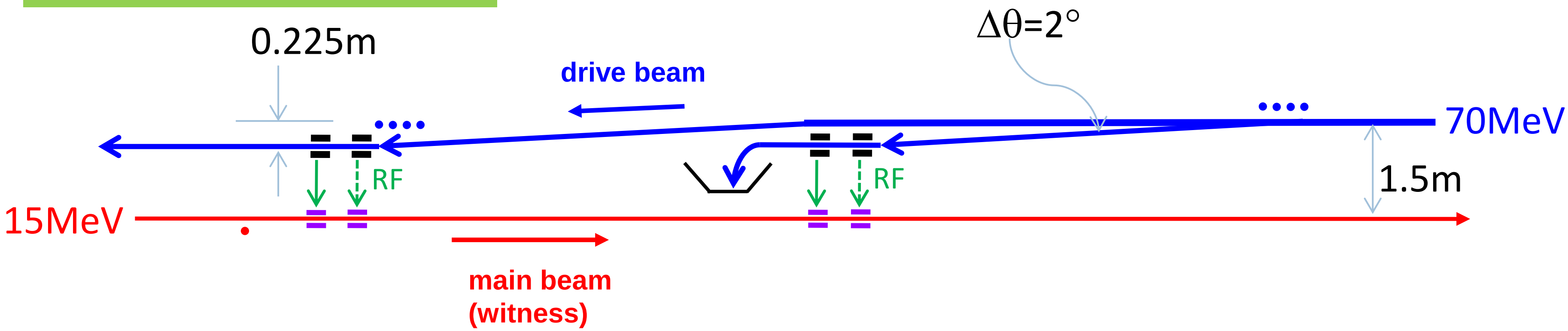
- Avoids 180° arcs (big, expensive, deleterious to beam quality)
- Shifts burden to RF delay lines (not trivial…)
- Maybe practical if number of structures inside each module is not too large

Staging Demonstration at AWA

Simplified Version



More realistic Version



Thank you for your attention!