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
AWA Facility Underwent Major Upgrade

Before...

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

After...

15 MeV beam moved & turned around

1950 ft² 127 ft long

new RF gun with Cs₂Te photocathode

625 ft² 66 ft long

new beamline switchyard

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

**Experimental Area**
- Collinear & TBA
- EEX & bunch compression

**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.
TBA experiment
11.7 GHz iris loaded metallic structures

Accelerating structure:
$2\pi/3$ mode
3 cells + coupling cells
0.014$c$ group velocity

Decelerating structure:
$2\pi/3$ mode
35 cells + coupling cells
0.22$c$ group velocity
TBA data (preliminary results)

- **Witness beam:** $8.5 \pm 1.4$ MeV, 0.5 nC
- **Drive beam:** 8 bunches, 90 nC charge in train

Graph showing the gradient (MV/m) vs. witness bunch delay (mm) with measurements and fit (11.7 GHz).
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
\(\eta\) (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 | \(\mu\)m
bunch length* | 1 | mm
energy spread* | 0.5 | %

---

Tungsten mask
---

Transverse beam image and profile at YAG6
EEX Initial Measurements

Quadrupole scan

- \( Q_1 = -0.7 \, \text{T/m} \)
- \( Q_1 = 0.0 \, \text{T/m} \)
- \( Q_1 = +0.7 \, \text{T/m} \)

Property exchange

- Before EEX
- After EEX

- 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

Electron beam
Frequency measurement with interferometer

![Graph showing frequency measurement with interferometer](image)
Two electron bunches: scanning delay

\[ P \propto |E|^2 \]

Electrical field add up in phase

Simulations

Experiment

Two bunches at spectrometer
Three and four bunches

Simulations

Expected energy distribution after W-band structure

Derived wakefield gradient

\[ E_{peak} = 84 \text{ MV/m} \]

Derived output RF pulse:

\[ P_{peak} = 5 \text{ MW} \]

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: 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**

- 15 MeV
- 70 MeV
- Drive beam
- Main beam (witness)

**More realistic Version**

- 15 MeV
- 70 MeV
- Drive beam
- Main beam (witness)
- $\Delta \theta = 2^\circ$
Thank you for your attention!