Argonne Wakefield Accelerator (AWA): a Facility for the Development of High Gradient Accelerating Structures and Wakefield Measurements


Argonne National Laboratory
Euclid Techlabs LLC
Illinois Institute of Technology
Research at the AWA Facility

Developing accelerator technology for future HEP machines and other applications.

Desirable characteristics:
- High gradient acceleration (compact)
- Relatively low cost
- Modular (stages)
- Works for electrons and positrons
- Macroscopic beam apertures
- Microwave range of frequencies
- Explores the use of advanced materials
Wakefields in Dielectric Structures (a short Gaussian beam)

**AWA approach:**
- High charge drive bunches
- High gradient
- Short RF pulses
- Macroscopic beam apertures
- Microwave frequencies (8 – 26 GHz)

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

\[ \sigma_r = \left(\frac{\epsilon_N \beta}{\gamma}\right)^{1/2} \]

**Wakefield Amplitude Dependent on a**
Reasons for Recent AWA Upgrades

Have two beam accelerator capability:
- Have two parallel beamlines, allowing drive bunches to excite wakefields and accelerate witness bunch.

Use the demonstrated high gradients to accelerate beam:
- The high quality drive beam has excited high gradient accelerating fields (100 MV/m) in dielectric loaded structures. Now these high gradients will be used to accelerate a witness bunch.

Have higher drive beam energy for high gradient and sustained acceleration:
- Propagation of drive beam through smaller diameter structures, resulting in even higher accelerating gradients.
- More energy available in drive bunches, allowing extraction of higher energy RF pulses.
- Construction of longer structures will demonstrate higher energy gain.

Have beamline switchyard for added flexibility:
- Beamline switchyard will greatly facilitate the implementation of distinct experimental setups: collinear wakefield acceleration, two-beam-acceleration, phase space manipulation and, further into the future, staging.
AWA Facility

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

75 MeV drive beam: RF gun with Cs$_2$Te photocathode & six linac tanks

Beamline switchyard (under construction)
New RF Gun with Cesium Telluride Photocathode

New RF gun installed in AWA bunker:
- 1 ½ cell, L band (1.3 GHz)
- 12 MW, 80 MV/m on cathode
- RF conditioned to 15 MW with Cu photocathode
- Generated beam (single bunches) from Cu and Cs₂Te cathodes

Cesium Telluride preparation chamber:
- necessary QE ~ 1%
- routinely achieving QE > 10%
New Linac Tanks

- 7 cell $\pi$ mode, L band (1.3 GHz)
- 10 MW, 11.2 MeV energy gain
- $Q = 26687$
  Shunt = 20.6 Mohm/m
  $R/Q = 773.4$

- Turnkey fabrication, directly from design to finished cavity
- Designed by ANL/SLAC
- Fabrication by local vendor (Hi Tech)
- Tuned and balanced at Argonne
- Adopted by LBL for the NGLS APEX test beam

Gun and first linac tank

Gun and six linac tanks
Additional 80 MW of RF Power (three klystrons)

Two new Thales TV 2022X
- L band (1.3 GHz)
- 10 μs, 25 MW

30 MW Litton klystron on loan from LANL (thanks to B. Carlsten and S. Russell)
Overview of AWA Beamlines

- 15 MeV witness beam
- 75 MeV drive beam
- EEX & bunch compression
- collinear & TBA
- experimental area
- witness beam U-turn
Objectives to be Achieved with Upgrades

- Higher gradient excitation: \(~ 0.5 \text{ GV/m}~\) in long structures.
- Acceleration of witness beam: \(~ 100 \text{ MeV}~\)
- Higher RF power extraction: \(~ \text{GW level}~\)

Example of 26 GHz dielectric loaded structures for two-beam-acceleration experiment:

<table>
<thead>
<tr>
<th>Decelerating structure</th>
<th>Accelerating structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID / OD / length (mm)</td>
<td>ID / OD / length (mm)</td>
</tr>
<tr>
<td>7.0 / 9.068 / 300</td>
<td>3.0 / 5.025 / 300</td>
</tr>
<tr>
<td>Dielectric constant</td>
<td>Dielectric constant</td>
</tr>
<tr>
<td>6.64</td>
<td>9.70</td>
</tr>
<tr>
<td>Group velocity</td>
<td>Group velocity</td>
</tr>
<tr>
<td>0.254 c</td>
<td>0.111 c</td>
</tr>
<tr>
<td>R/Q 9.79 kΩ/m</td>
<td>R/Q 21.98 kΩ/m</td>
</tr>
<tr>
<td>RF power (50 nC)</td>
<td>Shunt impedance</td>
</tr>
<tr>
<td>1.33 GW</td>
<td>50.44 MΩ/m</td>
</tr>
<tr>
<td>Peak gradient</td>
<td>(E_{\text{acc}} )</td>
</tr>
<tr>
<td>167 MV/m</td>
<td>(1.26 GW) 316 MV/m</td>
</tr>
<tr>
<td>Energy loss</td>
<td>(E_{\text{loaded}} )</td>
</tr>
<tr>
<td>20.5 MeV</td>
<td>(1.26 GW) 267 MV/m</td>
</tr>
</tbody>
</table>
Layout of the ANL 26GHz 3TeV Flexible Linear Collider

- 22ns rf pulse
- 267MV/m loaded gradient
- Machine Rep=5Hz

Drive beam structure (100ns consists of 1000 beam pulses, I_p=65A)
32 bunches
50ns/bunch
750nns pulses

Energy booster linac

main beam structure (180ns consists of 20 beam pulses, I_p=6.5A)

IP
3TeV

150 GeV stage #1

150 GeV stage #10

150 GeV stage #10

150 GeV stage #1
Summary of a 150 GeV Stage

150 GeV stage #1

main beam

Drive beam structure
100us macro pulse consists of 1000 micro beam pulses; each micro beam pulse contains 32 bunches, 50nC/bunch; 65A inside the pulse
Longer Term Goal at AWA: Staging

main beam
(witness)

Module #1
Module #2

drive beam
New scheme to avoid drive beam U-turn (using RF delay to obtain proper timing)

\[ \text{rf delay}_1 = 0; \]
\[ \text{rf delay}_2 = 2L_s/c; \]
\[ \text{rf delay}_m = 2*(m-1)*L_s/c, \]

\( m \) is the # of structures in each stage, \( L_s \) is the length of a single structure.

Example: Using parameters in the original design, we have 38 30cm-long structures in one module; then the shortest delay is \( 2*0.3m/c = 2\text{ns} \); the longest delay is \( 2*(38-1)*0.3m/c = 74\text{ns} \).

In order to reduce rf losses in the delay line, let’s consider the most commonly used circular overmoded waveguide w/ TE01 mode (air filled, copper wall, \( a=0.7'' \), \( f=26\text{GHz} \)): \text{delay}=3.6\text{ns/m}; \text{power loss}=0.22%/m

Then the longest delay line is \( 74\text{ns}/3.6\text{ns}=20.6\text{m} \)
The rf loss is \( 0.22%*20.6=4.5\% \)
AWA Staging Demonstration

Drive bunch spacing = 50 ns (15 m)

**Parameters:**

- $p_0$ (MeV/c): 75
- $\Delta \theta$ (mrad): 34.9
- $\Delta p_\perp$ (MeV/c): 2.62
- $T_{\text{rise}}$ (ns): 50
- TW Deflector Power, Length: 29.6 MW, 0.3 m
Technology for HEP machine also have great impact in other applications: e.g. Dielectric wakefield accelerator to drive future FEL (100MeV/m, 100kHz Rep.)

Ref: www.osti.gov/servlets/purl/1052039

C. Jing et al.
Conclusion

Commissioning of the upgraded AWA Facility is underway.

The new drive beam will enable the generation of high gradient wakefields (hundreds of MV/m) and the demonstration of significant acceleration of the witness beam (~ 100 MeV).

The demonstration of staging will soon follow.

THANK YOU FOR YOUR ATTENTION!!