Two-Beam-Acceleration Experiments at the Argonne Wakefield Accelerator Facility (AWA)

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Outline

- Mission and AWA approach
- Wakefield acceleration
- AWA facility
- Recent experiments
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)
  - Requires new or alternative accelerating structures.
- High Power RF Sources (~ GW Scale)
  - Requires new type sources.
- Higher order mode damping
  - Requires beam breakup control.
- 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.

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)

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

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

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
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 setup
11.7 GHz iris loaded metallic structures
TBA Experiment at AWA (preliminary results)

Drive beam off
Drive beam on

Witness beam: 8.5 ± 1.4 MeV
0.5 nC

Drive beam: 8 bunches
90 nC charge in train

Graph showing the gradient (MV/m) versus witness bunch delay (mm) with data points and a fit curve (11.7 GHz).
**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 | %

**Transverse beam image and profile at YAG6**

 Beam direction

**Tungsten mask**
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.
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

Photo of the structure

- Matching cell
- Waveguide
- Section B-B
- 110 regular cells
- $X_{max}$ 6.99 mm
- $X_{max}$ 1.25 mm
- $Z_p$ 1.10 mm
Staging: U-turn Option

- Module #1
- Module #2

Main beam (witness)

Drive beam
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

\[ \Delta \theta = 2^\circ \]
Unique Capabilities of the AWA Facility

- Two independent linacs allow experiments with excitation and probing of wakefields
- Extremely high charge, short electron bunches
- Flexible and reconfigurable beamline switchyard to host various experiments

General Long Term Objectives

- High gradient excitation: hundreds of MV/m in long structures.
- Acceleration of witness beam: ~100 MeV
- Higher RF power extraction: ~GW level
- Demonstration of staging schemes
Thank you for your attention!