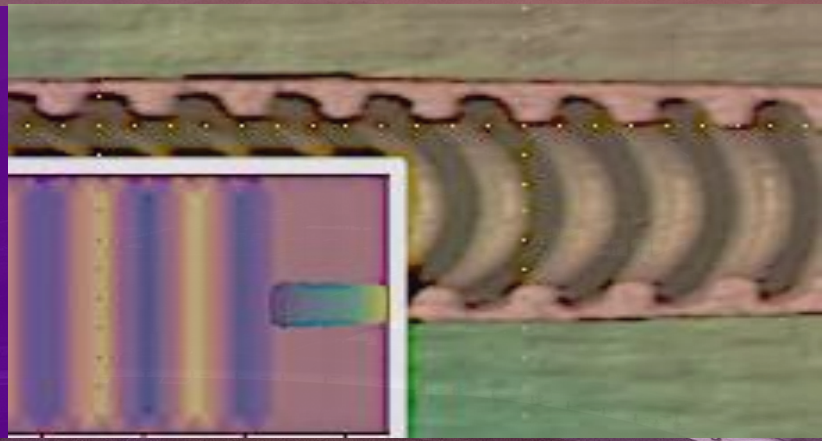
FEB 18, 2025

# DRIVE BEAM WORKING GROUP: KICK-OFF DISCUSSION



P. PIOT, FOR THE DRIVE-BEAM WORKING GROUP

# INTRODUCTION

## Drive-beam working group

- **Goals:**
  - Understand and develop a unified approach to understand drive-beam requirements for PWFA and SWFA techniques
  - Review building blocks requirements (most are conventional) for:
    - Generation (what species electron, proton?),
    - acceleration/manipulation
    - injection/extraction in (P/S)WFA

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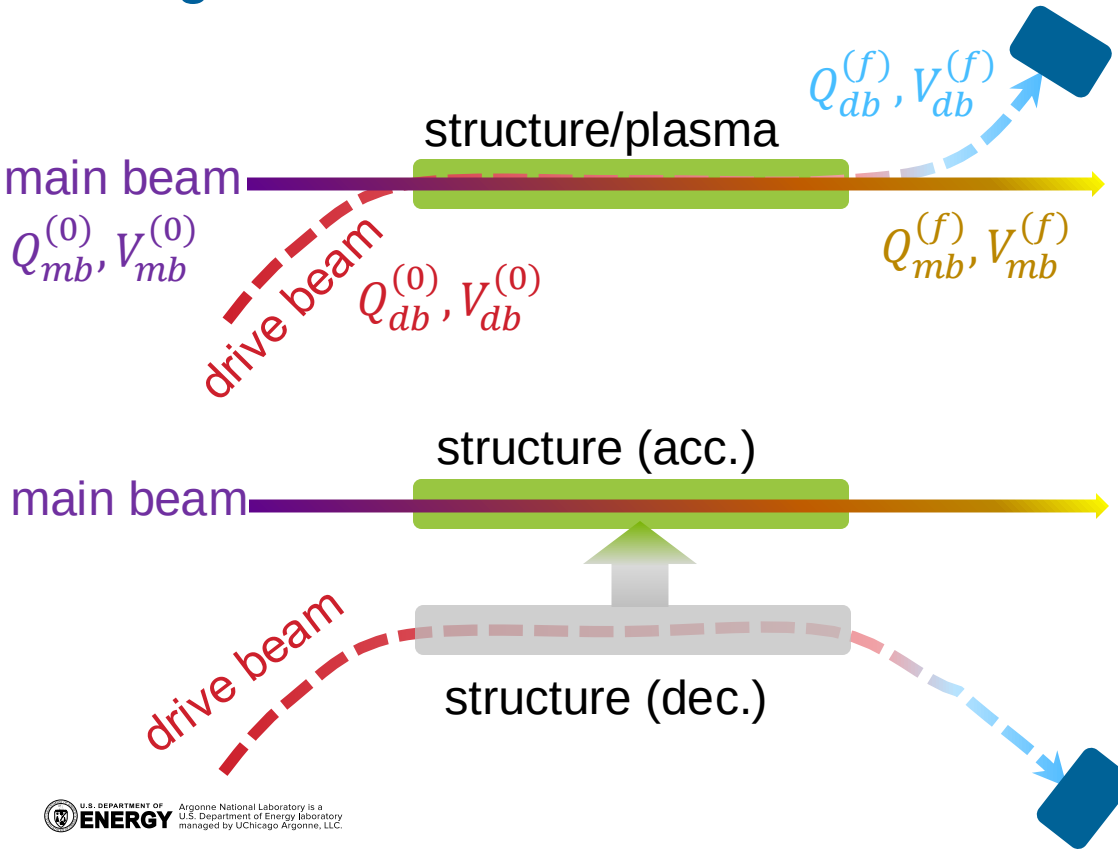
ICFA BEAM DYNAMICS NEWSLETTER#83 —
CHALLENGES IN ADVANCED ACCELERATOR CONCEPTS

**Drive beam sources and longitudinal shaping techniques for beam driven accelerators**

https://iopscience.iop.org/article/10.1088/1748-0221/17/05/P05036/pdf

# OVERVIEW

## Configurations & General Comments




Collinear Wakefield Acceleration (CWA)

Two Beam Acceleration (TBA)

# SINGLE-BUNCH CONSIDERATION

## General consideration

- Energy conservation!

$$Q_{db}\delta V_{db} + Q_{mb}\delta V_{mb} \simeq 0 \quad (\delta V = \mathrm{V}^{(\mathrm{f})} - \mathrm{V}^{(0)}) \quad \Rightarrow \quad \delta V_{mb} \simeq -\frac{Q_{db}}{Q_{mb}}\delta V_{db}$$

For a given deceleration of drive beam can increase main-beam acceleration using higher drive-beam charge

- Practical consideration:
  - What is the practical energy of a drive beam (depending on the repetition rate the beam power can be substantial)
  - What is the practical charge/bunch for the drive beam
  - …

# SINGLE-BUNCH CONSIDERATIONS

## Beam parameters at injection in the WFA

- Bunch length smaller than the fundamental mode? Peak current?
- Transverse emittance
  - In SWFA can be estimated using free-space drive (but requirements affected by external focusing)
  - In PWFA?
- Energy spread
  - In SWFA with external focusing: correlated energy spread damps beam-break-up instability
  - In PWFA?

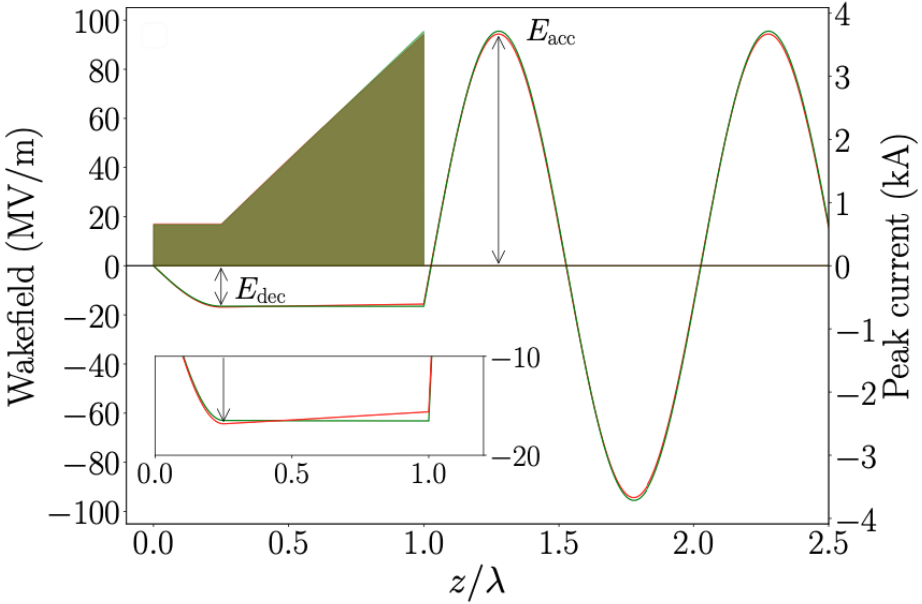
# SINGLE-BUNCH CONSIDERATION

## Longitudinal shape + phase space in the plasma/structure

- A key to improving efficiency is to increase the transformer ratio

$$R = \frac{E_{acc}}{E_{dec}}$$

- Enhanced transformer ratio allows for longer interaction length:
  - Uniform energy loss along the drive beam (minimize losses)
  - Minimize rate of deceleration for a given accelerating field
- Critical in SFWA but rarely discussed in PWFA(?)




Modified “Bane”’s distribution (W.H. Tan, SLAC)

# REQUIREMENTS

## Drive beams requirements?

- Let's collect number assumed for drive beam used in the published estimates:
  - Charge/bunch
  - Repetition rate
  - Energy
  - RMS parameters (PP share a table to fill)
  - What else?

| Technology | PWFA | PWFA | PWFA | PWFA | SWFA | SWFA | SWFA |
|---|---|---|---|---|---|---|---|
| Beam Aspect Ratio | Flat | Flat | Flat | Round | Flat | Flat | Round |
| Center-of-Mass Energy | 1 | 3 | 15 | 15 | 1 | 3 | 15 |
| $E_{\text{beam}}$ (TeV) | 0.5 | 1.5 | 7.5 | 7.5 | 0.5 | 1.5 | 7.5 |
| $\gamma$ | 9.78E5 | 2.94E6 | 1.47E7 | 1.47E7 | 9.78E5 | 2.94E6 | 1.47E7 |
| $\varepsilon_x$ (mm mrad) | 0.66 | 0.66 | 0.66 | 0.1 | 0.66 | 0.66 | 0.1 |
| $\varepsilon_y$ (mm mrad) | 0.02 | 0.02 | 0.02 | 0.1 | 0.02 | 0.02 | 0.1 |
| $\beta_x^*$ (mm) | 5 | 5 | 5 | 0.15 | 5 | 5 | 0.15 |
| $\beta_y^*$ (mm) | 0.1 | 0.1 | 0.1 | 0.15 | 0.1 | 0.1 | 0.15 |
| $\sigma_x^*$ (nm) | 58.07 | 33.53 | 15 | 1.01 | 58.07 | 33.53 | 1.01 |
| $\sigma_y^*$ (nm) | 1.43 | 0.83 | 0.4 | 1.01 | 1.43 | 0.83 | 1.01 |
| $N_{bunch}$ ($\times 10^9$) | 5 | 5 | 5 | 5 | 3.13 | 3.13 | 3.13 |
| $f$ (kHz) | 4.2 | 14 | 13.12 | 7.73 | 11 | 36 | 19.8 |
| $\sigma_z$ (um) | 5 | 5 | 5 | 5 | 40 | 40 | 40 |
| $\Upsilon$ | 15 | 78 | 867 | 6590 | 1 | 6 | 515 |
| $n_\gamma$ | 1.5 | 1.5 | 1.5 | 5.7 | 2.2 | 2.2 | 8.4 |
| $P_{\text{beam}}$ (MW) | 1.7 | 16.8 | 78.8 | 55.0 | 2.8 | 27.0 | 74.4 |
| $2P_{\text{beam}}$ (MW) | 3.4 | 33.6 | 157.6 | 110.0 | 5.5 | 54.1 | 148.7 |
| $\mathcal{L}_{\text{geo}}$ ($\times 10^{34}$ cm$^{-2}$ s$^{-1}$) | 1.01 | 10.1 | 47.1 | 150 | 1.03 | 10.1 | 151 |
| $\mathcal{L}_{\text{beamstrahlung}}$ ($\times 10^{34}$ cm$^{-2}$ s$^{-1}$) | 1.99 | 19.9 | 99.4 | 152 | 2.03 | 20 | 152 |
| $\eta_{\text{wall-to-drive}}$ | 0.4 | 0.4 | 0.4 | 0.4 | 0.774 | 0.774 | 0.774 |
| $\eta_{\text{drive-to-main}}$ | 0.375 | 0.375 | 0.375 | 0.375 | 0.42 | 0.42 | 0.42 |
| $\eta_{\text{total}}$ | 0.15 | 0.15 | 0.15 | 0.15 | 0.325 | 0.325 | 0.325 |
| $P_{\text{site}}$ (MW) | 22 | 224 | 1051 | 619 | 17 | 166 | 457 |
| $\mathcal{L}_{\text{geo}}/P_{\text{site}}$ (1e34/MW) | 0.04 | 0.04 | 0.04 | 0.08 | 0.06 | 0.06 | 0.11 |
| $\mathcal{L}_{\text{GP,tot}}$ ($\times 10^{34}$ cm$^{-2}$ s$^{-1}$) | 1.83 | 18.5 | 87.6 | 1570 | 2.08 | 21.3 | 420 |
| $\mathcal{L}_{\text{GP,top}}$ 1% (20%) ($\times 10^{34}$ cm$^{-2}$ s$^{-1}$) | 0.69 | 6.23 | 50 | 50 | 0.85 | 6.14 | 50 |
| $\mathcal{L}_{\text{GP,tot}}/P_{\text{site}}$ | 0.08 | 0.08 | 0.08 | 2.54 | 0.12 | 0.13 | 0.92 |
| $\mathcal{L}_{\text{GP,top}}/P_{\text{site}}$ 1% (20%)/Power | 0.03 | 0.03 | 0.05 | 0.08 | 0.05 | 0.04 | 0.11 |
| Length of 2 Linacs (km) | 1 | 3 | 14 | 14 | 5 | 15 | 75 |
| Length of Facility | 14 | 14 | 14 | 14 | 8 | 18 | 90 |

# BUILDING BLOCKS

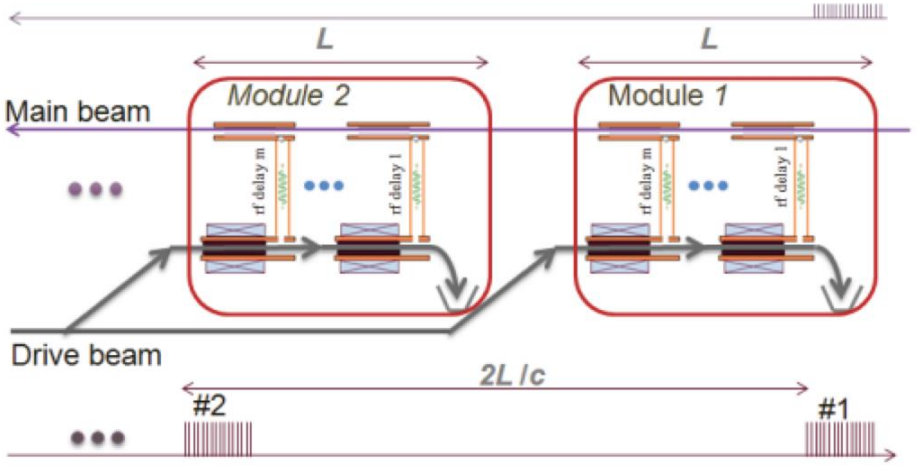
## Source/Acceleration/Manipulations

- Sources:
  - Electron sources are capable of high charge via photoemission; typically RF gun + photoemission from semiconductor cathode
  - Proton beams?
- Acceleration
  - NCRF linac or SCRF linac (depends on repetition rate)
- Manipulation
  - Conventional (focusing, compression,…)
  - More complex: bunch compression with control of nonlinearities for temporal bunch shaping
  - Phase space manipulation (within 2+ degrees of freedom for arbitrary bunch shaping?)

# BUILDING BLOCKS

## Injection/extraction in WFA

- Pulse format and beamline spreaders?
- Injection and extraction line
- Control of instabilities (as seen by the drive beam)
- Beam deceleration/dumping




Example from Gai et al. AFLC

- Discuss tolerance on injection (transverse and temporal jitter?)

# TASKS
## discussion

1. Develop table for requirement/assumption on drive beam parameters for WFA
   a) PWFA
   b) SWFA (CWA and TBA)
2. From item(1) identify (piecewise):
   a) building blocks that are mature
   b) And components that needs further R&D testing