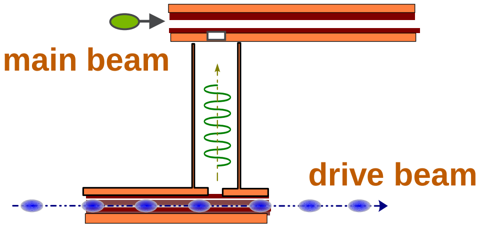
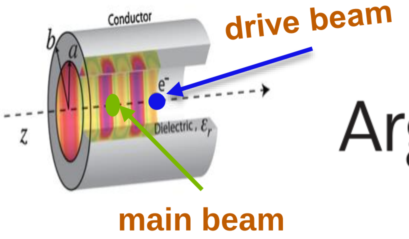


Two-Beam Acceleration (TBA)

STRUCTURE WAKEFIELD ACCELERATION



Colinear Wakefield Acceleration (CWA)

Argonne NATIONAL LABORATORY

SWFA R&D FOR FUTURE LINEAR COLLIDERS

JOHN POWER FOR SWFA

Advanced & Novel Accelerators Track (ANA) organized by ICFA/ANA panel
International Workshop on Future Linear Colliders (LCWS2021)
15-18 March 2021

A FEW REFERENCES

ANA references:

- ANAR2017: https://indico.cern.ch/event/569406/
- ALEGRO18: https://confs.physics.ox.ac.uk/alegro2018/index.asp
- Towards an Advanced Linear International Collider: https://arxiv.org/abs/1901.10370v2
- ALEGRO LOI for Snowmass 2021 Towards an Advanced Linear International Collider

ANA

Snowmass21 SWFA LOI's (https://snowmass21.org/loi)

- Modeling Needs for Structure Wakefield Accelerators
- Short-pulse wakefield structure R&D for high gradient and high efficiency acceleration in future large-scale machines
- SWFA demonstrators with integrated technologies for future largescale machines
- Bright Electron and Positron Beams and High-Charge Electron Bunches for Beam-driven Structure-WakeField Accelerators
- Structure Wakefield Acceleration (SWFA) Development for an Energy Frontier Machine
- Beam Physics Challenges & Research Opportunities for Structure-based Wakefield Accelerators
- Etc.

SWFA

SWFA community

COLLABORATORS

1. Argonne National Laboratory (ANL), Lemont, IL, USA
2. ASTeC and Cockcroft Institute, Sci-Tech Daresbury (STFC), Daresbury, UK Center for the Advancement of Natural Discoveries using Light Emission
3. (CANDLE), Yerevan, Armenia
4. Deutsches Elektronen-Synchrotron (DESY), Hamburg, Germany
5. Tsinghua University, Beijing, China
6. SLAC National Accelerator Laboratory, Menlo Park, CA
7. Euclid Techlabs, LLC, Bollingbrook, IL, USA
8. Laboratori Nazionali di Frascati (INFN/LNF), Frascati, Italy
9. Los Alamos National Laboratory (LANL), Los Alamos, NM, USA
10. Massachusetts Institute of Technology (MIT), Cambridge, MA, USA
11. Northern Illinois University (NIU), DeKalb, IL, USA
12. SLAC National Accelerator Laboratory (SLAC), Menlo Park, CA, USA
13. University of California, Los Angeles (UCLA), Los Angeles, CA, USA

FINDING COMMON GROUND BETWEEN THE 4 ANA SCHEMES: DLA, LWFA, PWFA AND SWFA

FINDING COMMON GROUND BETWEEN THE 4 ANA SCHEMES: DLA, LWFA, PWFA AND SWFA

CTE's (critical technology elements)*

- CTE1. Polarized e- source at the full LC operational parameters including damping ring
- CTE2. Polarized e+ source at the full LC operational parameters including damping ring
- CTE3. Main Beam Physics
- CTE4. Drive Beam Physics (Power Source)
- CTE5. Advanced and Novel Structures
- CTE6. Staging of Multiple Acceleration Stages to High Energy
- CTE7. Beam Delivery System: Emittance preservation, chromaticity control, etc.
- CTE8. appropriate main-beam parameters at the IP

Relatively specific R&D

*also need theory, simulations, exp't facilities, diagnostics, etc.

FINDING COMMON GROUND BETWEEN THE 4 ANA SCHEMES: DLA, LWFA, PWFA AND SWFA

- **Stepping Stone Facilities**
  - Light Sources
    - Table top FEL
    - Mutli-user XFEL
  - Medical, Security
    - Cargo Inspection, VHEE, etc.
- **HEP machines**
  - Higg's Factory
  - ILC afterburners
  - e+e- 1, 3,10, 30 TeV
  - Gamma colliders
- Combined ANA HEP machine?
  - E.g. LWFA e- source → SWFA linac → PWFA afterburner

DESIGNS
Strawman → Mature
Complete TABLES

VALUE	UNITS	COMMENT
1,000/10,000	GeV / GeV	Modular deisgn; Short RF pulse T
10.5	GeV	~0.35% for 3TeV AFLC
NA	mm	
5.90E+34	cm^-2*s^-1	for 3TeV AFLC
7.08E+02	fb^-1	for 3TeV AFLC
NA	m	
NA	m	
0.077	ns	
NA		
NA		
1,500	GeV	for 3TeV AFLC
500/5,000	GeV / GeV	modular design, extendable
	MJ	
15.6	MW	
	kW	
0.04/0.001	micro-meter / micro-meter	for 3TeV AFLC
18	km	for 3TeV AFLC

STRUCTURE WAKEFIELD ACCELERATION (QUICK INTRODUCTION)

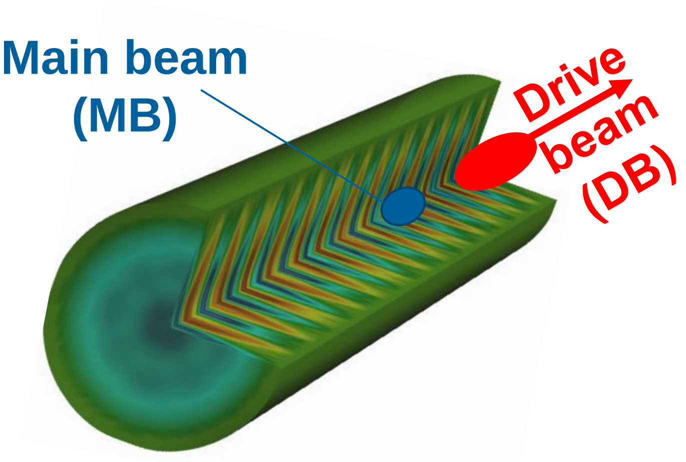
SWFA OVERVIEW

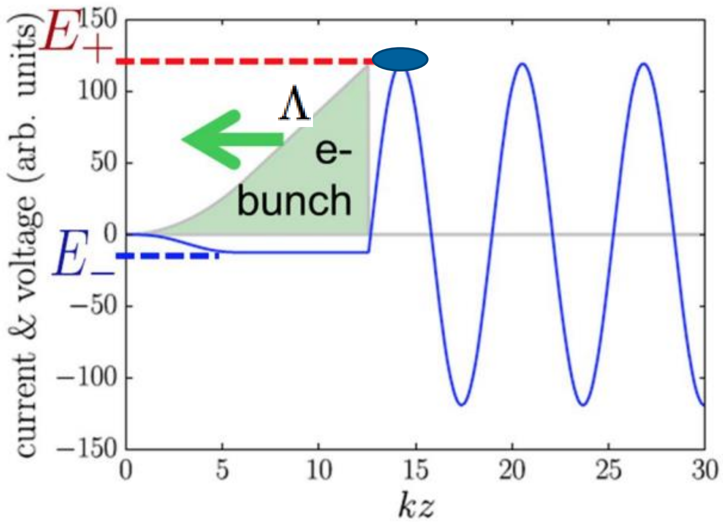
KEY ≡ Beams & Structures

- **Drive bunch** excites EM wave in a slow-wave structure
- Wakefield is used to accelerate properly delayed trailing **main bunch**

$$E_z(\zeta) = \int_{-\infty}^{\zeta} \Lambda(\zeta - \zeta') \sum_{n,m} w_n^{(m)} \cos(k_n^{(m)} \zeta') d\zeta'$$

DB distrib. mode

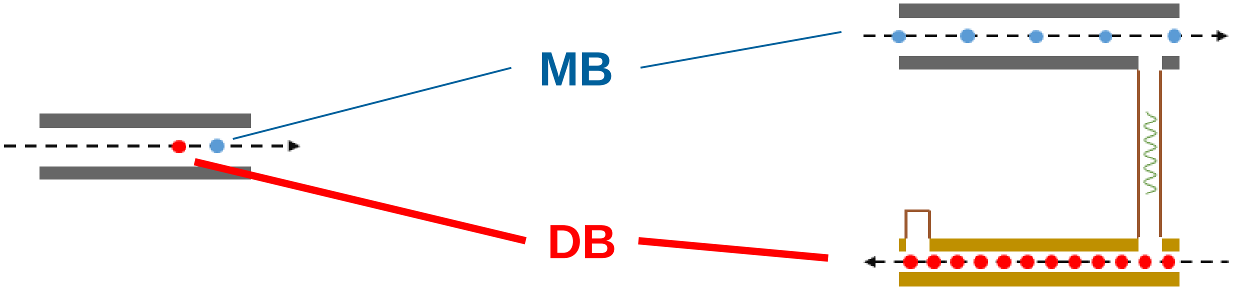




TWO SWFA SCHEMES

Collinear Wakefield Acceleration

Two Beam Acceleration



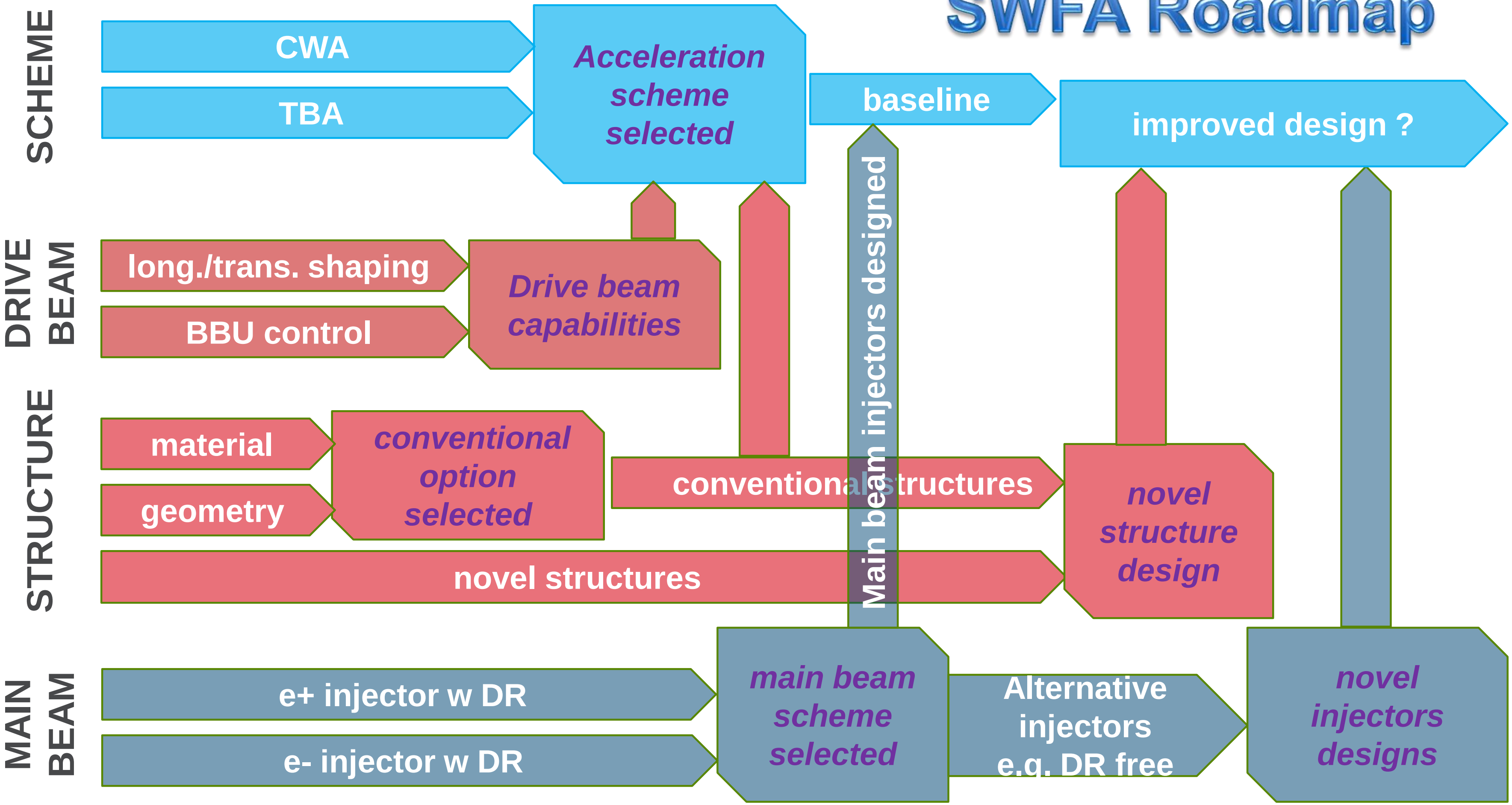
CWA uses single beamline

- Pros
  - Cheaper? One beamline, One structure, No couplers
- Cons
  - Challenges associated with combined beam dynamics of drive and witness bunches.

TBA uses two parallel beamlines

- Pros
  - Decoupled drive/main beam optics design
  - Two different structures allow simultaneous high gradient and high efficiency acceleration
- Cons
  - Cost?

SWFA Roadmap



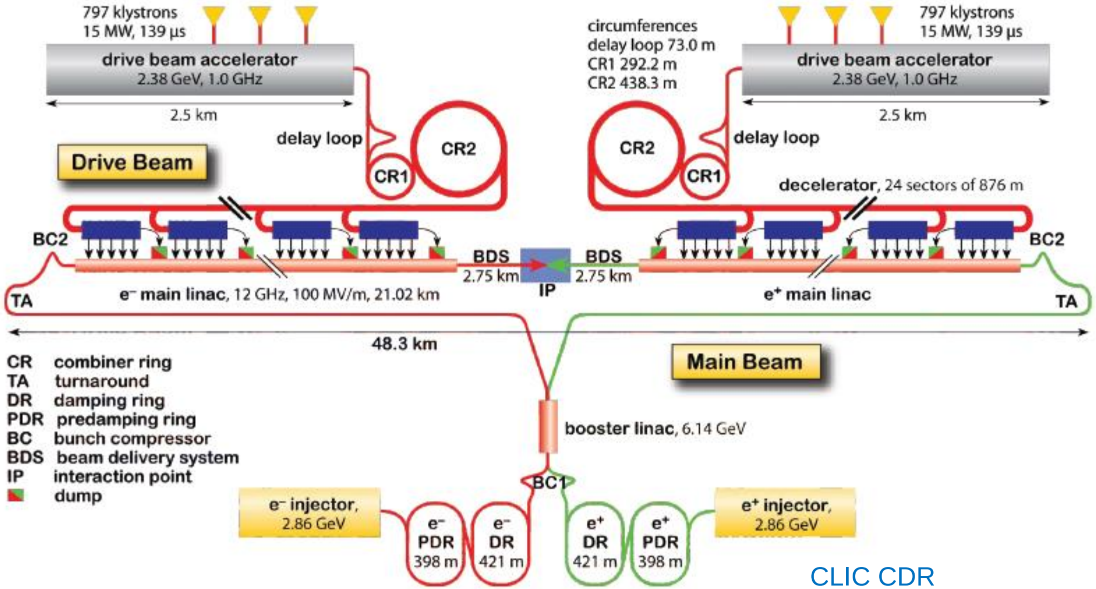
https://arxiv.org/abs/1901.10370v2 (Towards an Advanced Linear International Collider)

SWFA DESIGNS: STRAWMAN → MATURE

mature

SWFA LINEAR COLLIDER

TWO BEAM ACCELERATOR: Compact Linear Collider (CLIC)



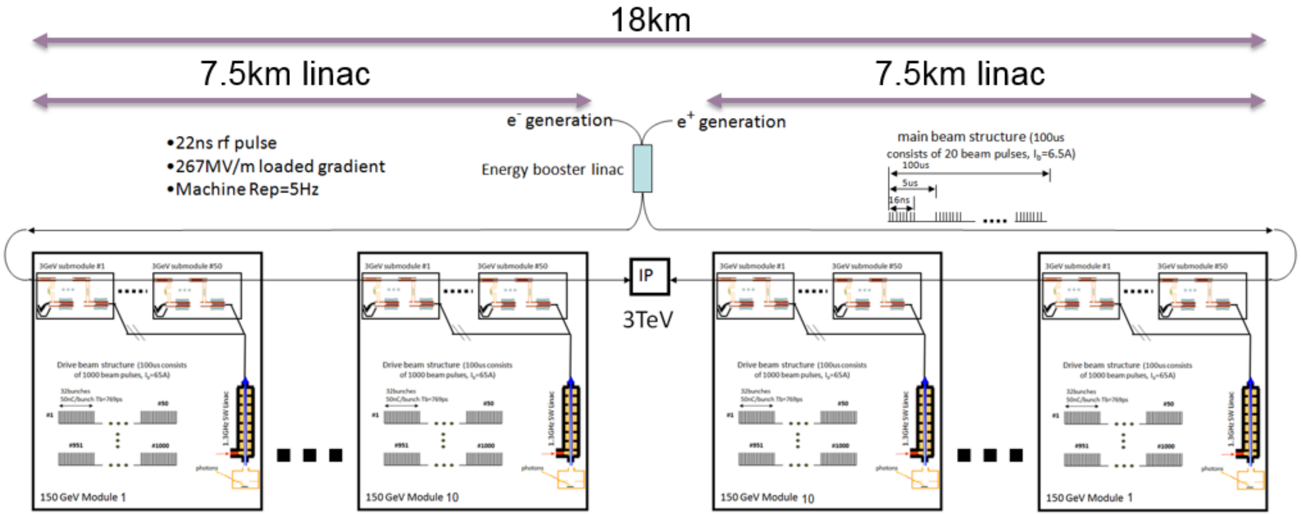
CLIC CDR
https://project-clic-cdr.web.cern.ch/CDR_Volume1.pdf

- 100 MV/m loaded accelerating gradient (~200 ns)
- X-band normal-conducting metallic decelerating/accelerating structure
- ~7% overall efficiency

strawman

SWFA LINEAR COLLIDER

TWO BEAM ACCELERATOR: Argonne Flexible Linear Collider (AFLC)



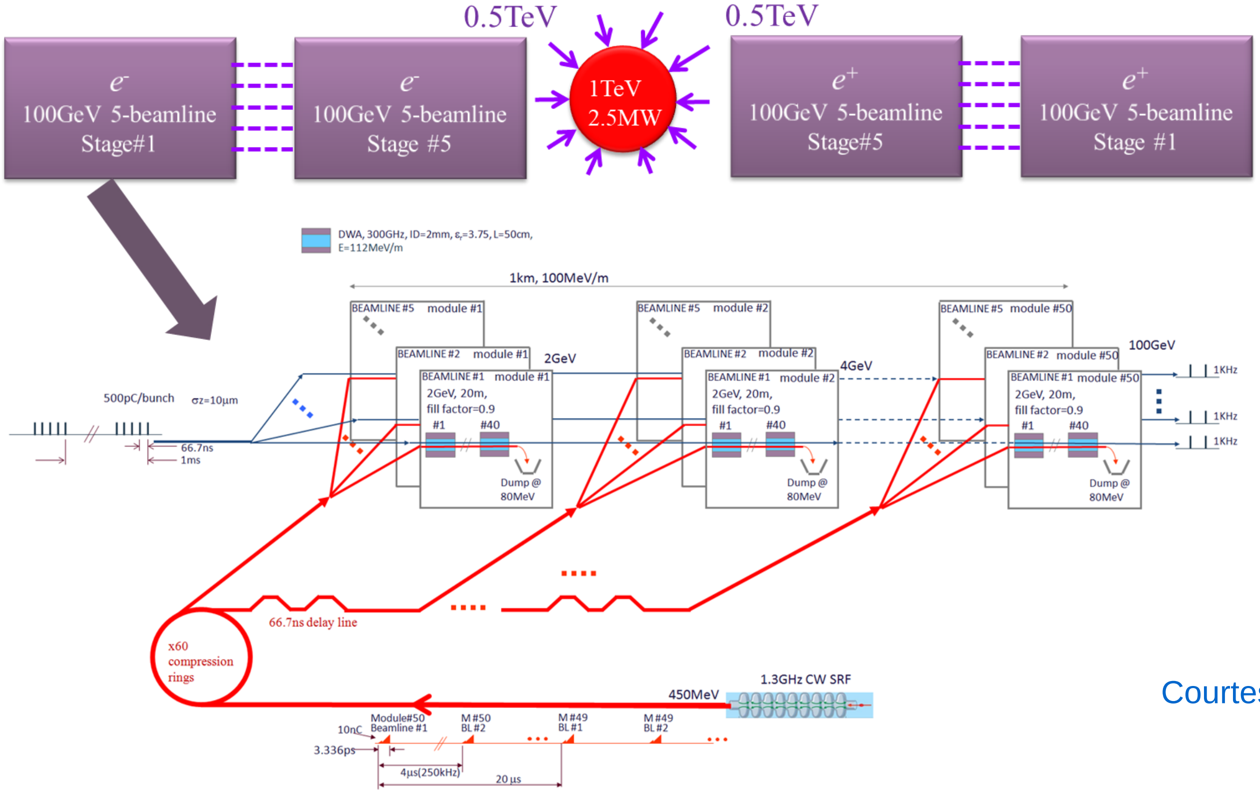
W. Gai, C. Jing, J.G. Power, *JPP* **78**, 339-345 (2012)

- ~300 MV/m loaded accelerating gradient using short RF pulse (~20 ns)
- 26 GHz normal-conducting dielectric decelerating/accelerating structure
- Efficiency under systematic study (7-15% depending on technologies development)

pre-strawman

SWFA LINEAR COLLIDER

COLLINEAR WAKEFIELD ACCELERATOR: Very preliminary design

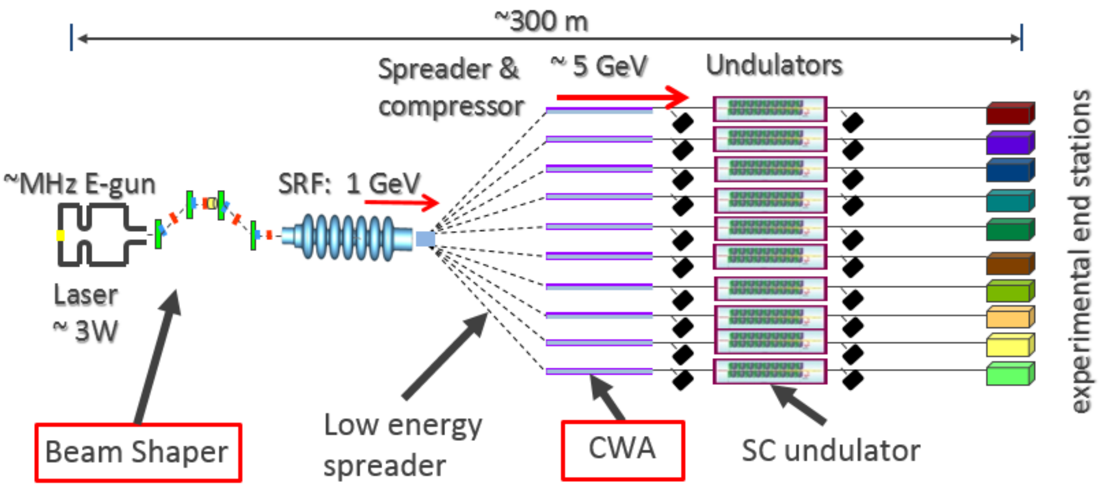


Courtesy of C. Jing

SWFA LIGHT SOURCE

COLLINEAR WAKEFIELD ACCELERATOR: multi-beamline XFEL

Stepping Stone Facility



A. Zholents, et al, *NIMA* **829**, 190-193 (2016)
A. Zholents, et al, *Proceedings of IPAC2018*

- High charge drive beam shaping
- High frequency corrugated waveguide structure
- Beam break-up control

PROGRESS ON SWFA SINCE ALLEGRO'18

CRITICAL TECHNOLOGY ELEMENTS

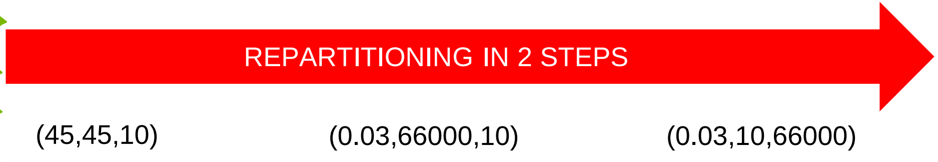
ELECTRON MAIN BUNCH (CTE1)

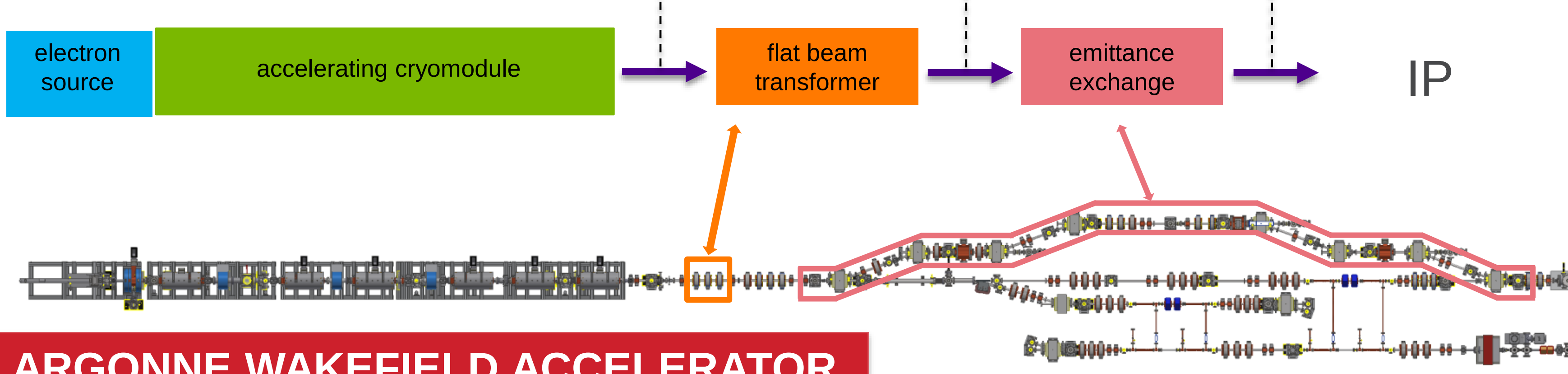
Development of a damping-ring-free electron injector for Future Linear Colliders

Repartitioning the emittance of the electron source for the IP $(\varepsilon_x,\varepsilon_y,\varepsilon_z)$

PROGRESS & NEXT STEPS

1. Flat beam transformer installed ✓
2. Flat beam demonstrated ✓
3. EEX beamline installed ✓
4. Demonstrate repartitioning ✓





ARGONNE WAKEFIELD ACCELERATOR

John Power, ANL, Philippe Piot,, NIU, Kuriki Masao, Hiroshima University, Hitoshi Hayano, KEK

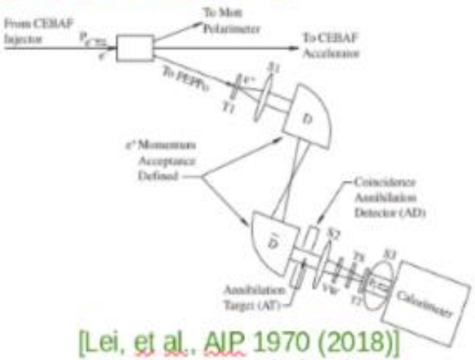
POSITRON MAIN BUNCH

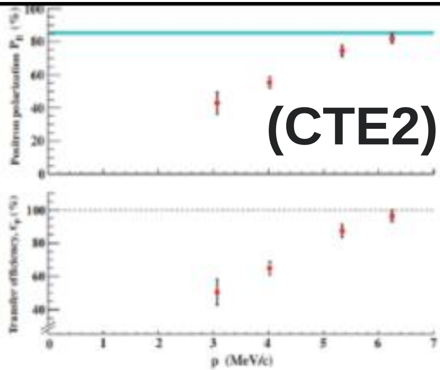
Path toward higher brightness?

- R&D on positrons source producing required bunch charge lags behind
  - Conventional concept (e- on thick target with adiabatic matching section yields poor brightness)

- Alternative approach are being explored
  - Use of PWFA for rapid acceleration?
  - Thin target (polarization) combined with storage-ring-based accumulator
  - Target+moderator+electrostatic trap

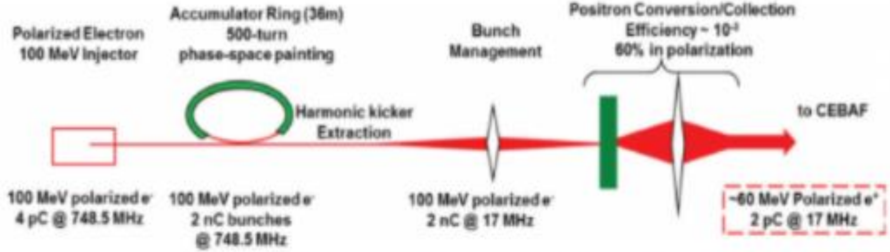
[Abott et al., PRL (2016)]



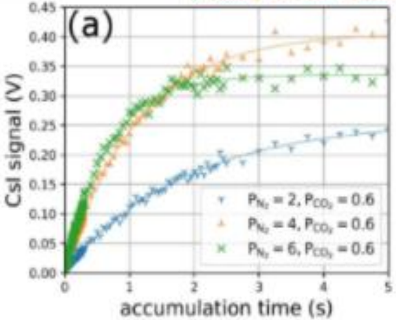


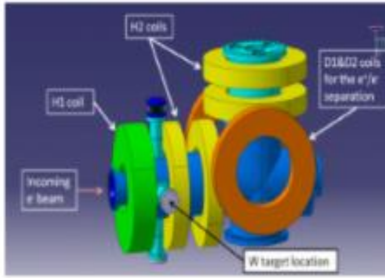
(CTE2)

[Lei, et al., AIP 1970 (2018)]



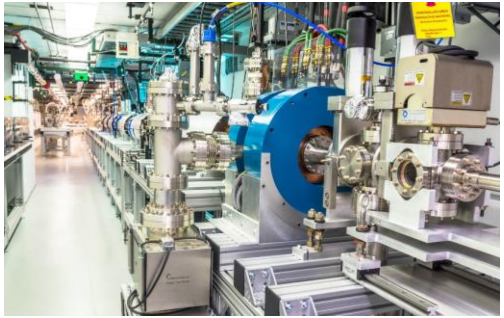
[Niang et al., Acta Phys. Pol. A (2020)]





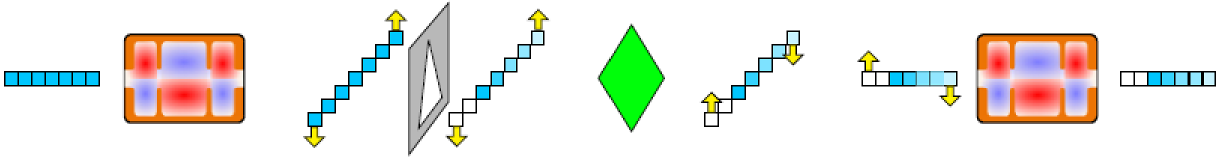
DRIVE BEAM (CTE4)

SOURCE

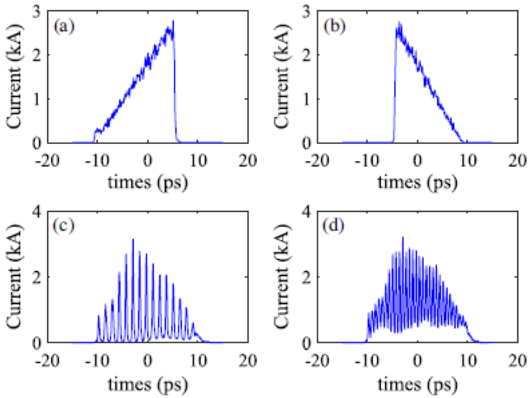


Cs2Te Cathode Dia. ~25mm
- **100 nC single bunch**
- **600 nC bunch train**

SHAPING



G. Ha et al, *PRAB* ***23***, 072803 (2020)



60nC beam shaping

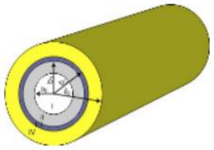
Advanced CSR-free shaping technology, critical for efficiency improvement in CWA approach

ADVANCED AND NOVEL STRUCTURES (CTE5)

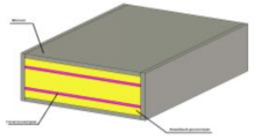
Beam drive structures

- **Material**: Dielectric or Metallic
- **Geometry**: cylindrical, planar
- **Novel**: PBG, Metamaterial
- **Short-pulse** (TBA ~20 ns, CWA sub-ns)
- **Temperature**: Room Temp vs Cold dielectric
  - 250MV/m of gradient and 350Mohm/m of shunt impedance in X-band copper structure at 45°K
  - 350MV/m of gradient and 550Mohm/m of shunt impedance in X-band Dielectric Corrugated Accelerating (DCA) at 77°K
- **Frequency**: GHz → THz
  - High gradient $\mathcal{O}\,(GV.m^{-1})$ require high-frequency structures -- THz range since $w \propto \frac{Q}{a^2}$ by transverse (dip. Wake) $w_{\perp} \propto \frac{Q}{a^2}$

Waveguide

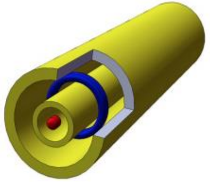


Rectangular

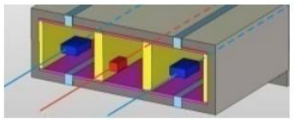


Multibunch

Annular



Multizone.



(CTE5,6)

ADVANCED AND NOVEL STRUCTURES

Recent development

400 MW | 1 GW

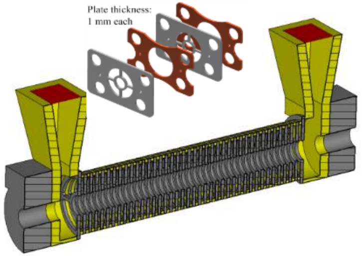
150 MeV/m | 267 MeV/m — Main beam acc.

250 MV/m — BD test

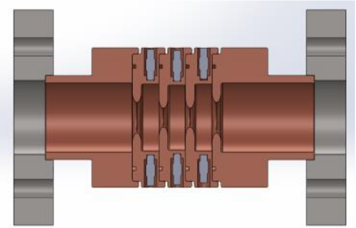
Metallic disk loaded
400 MW

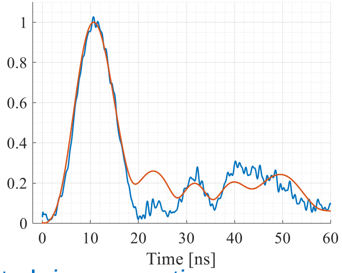
M. Peng, et al, *in preparation*

Metamaterial
380 MW



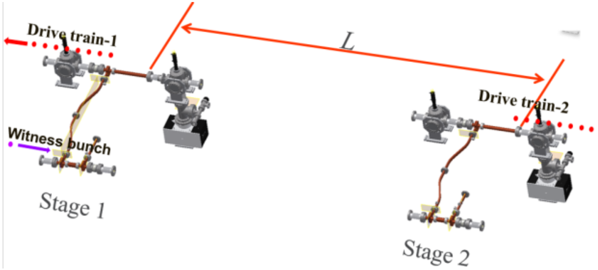
X. Lu, et al, *APL* **116**, 264102 (2020)

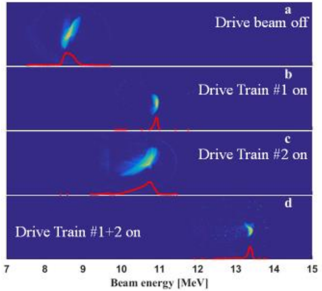




M. Peng, et al, *in preparation*

Multi-stage | **Multi-structure**

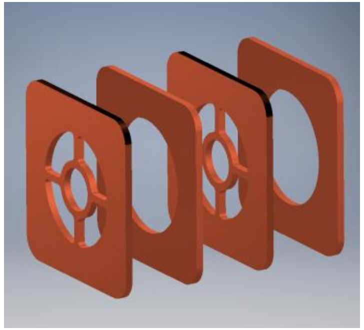


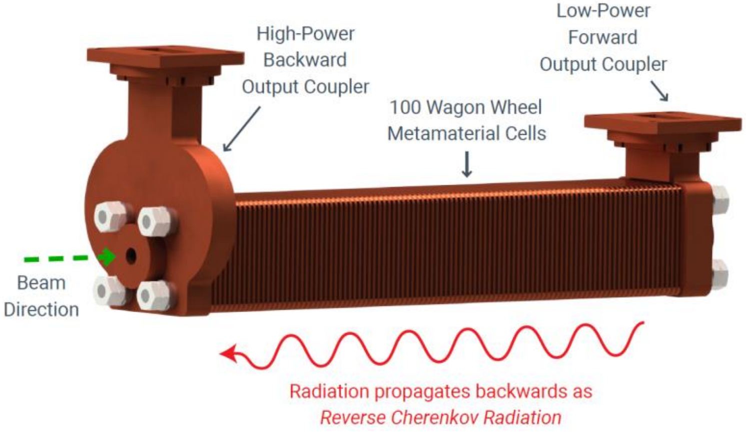


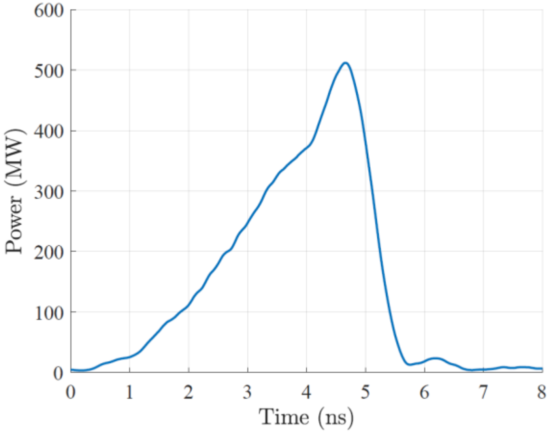
C. Jing, et al, *NIMA* **898**, 72 (2018)

ADVANCED AND NOVEL STRUCTURES

- **Recent development (Feb. 2021)**
  - **Stage-III metamaterial wagon wheel power extractor structure successfully tested at AWA Major improvements in reducing RF loss and coupler asymmetry**
  - **510 MW peak RF power**
    - **Generated from a train of 8 bunches**
    - **280 nC total charge before the structure with 61% transmission**
  - **128 MV/m decelerating gradient**



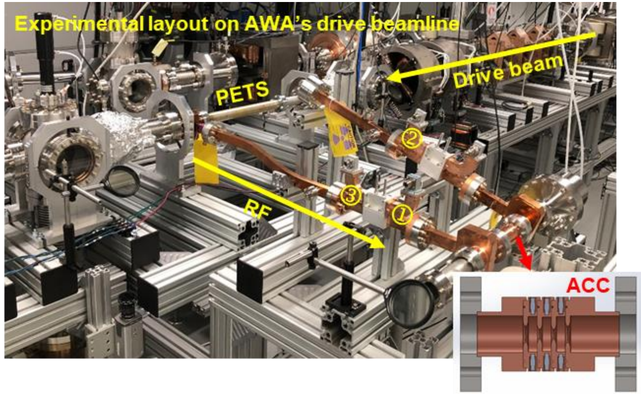




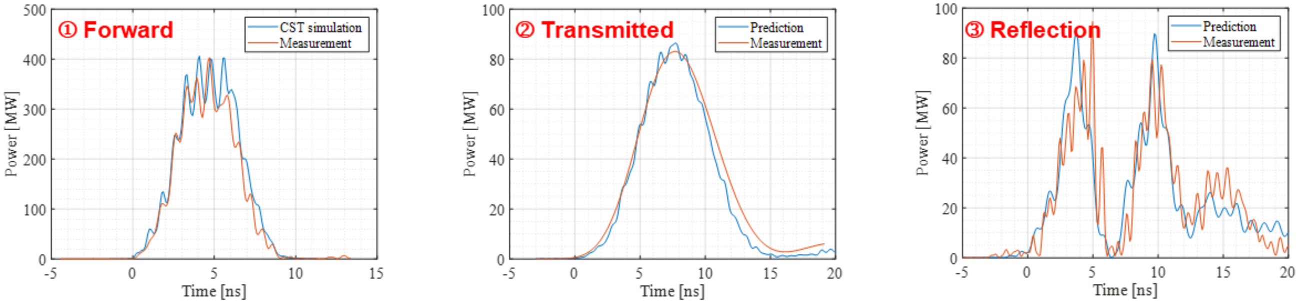
ADVANCED AND NOVEL STRUCTURES

- Recent development at AWA

Preliminary results

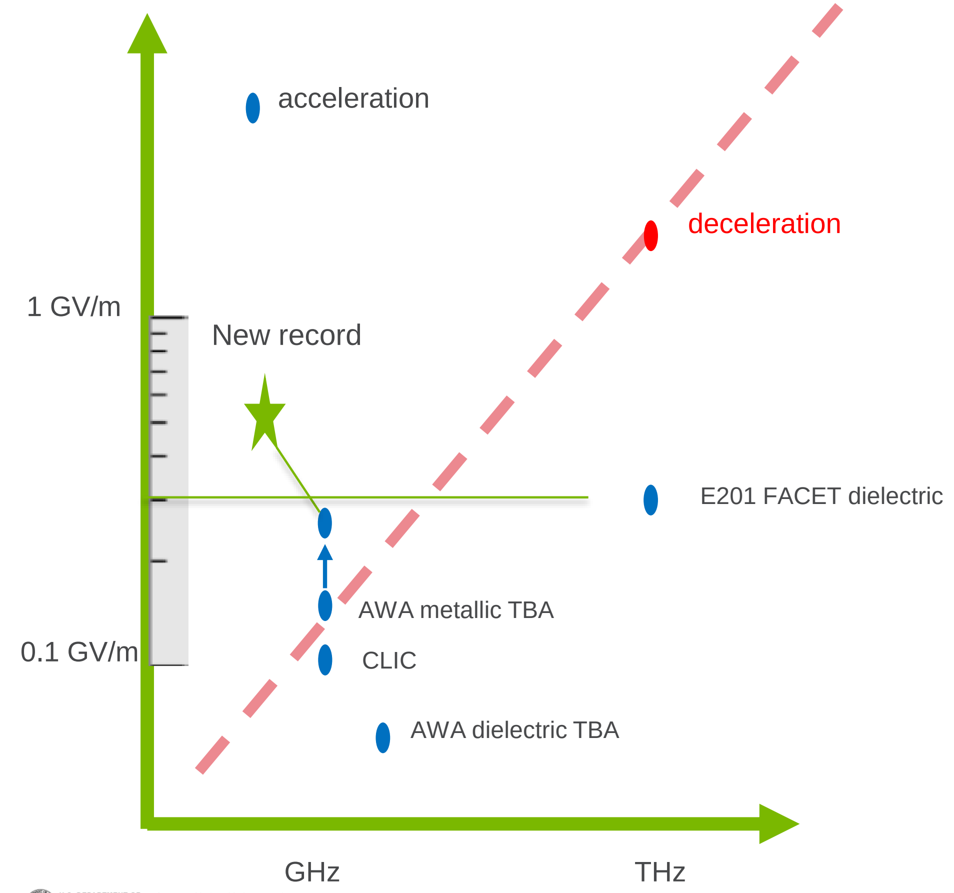


- 11.7 GHz accelerating structure (1 normal cell + 2 matching cells) designed to reach high gradient with short RF pulse
- 400 MW RF power generated from PETS with 450 nC drive beam
- ~200 MeV/m average gradient in three cells, >250 MeV/m gradient in the middle cell, ~500 MV/m peak surface field
- No breakdown observed at high field level

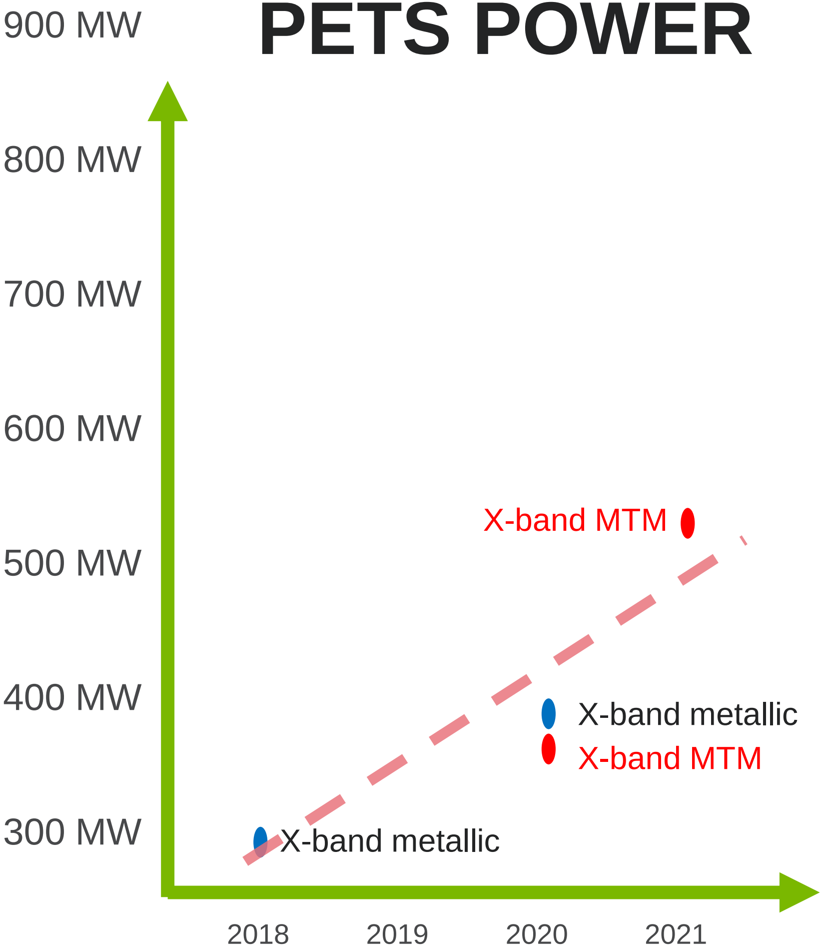


- AWA/Euclid is also in collaboration with CERN in dielectric structure R&D for potential usage in CLIC

ACCELERATION



PETS POWER



CTE WRAP UP

CTE7. Beam Delivery System: Emittance preservation, chromaticity control, etc.

- Beam Delivery System (BDS) interest group (Spencer Gessner et al.)
  - Improved BDS designs for ILC/CLIC
  - Can we use ILC BDS at higher energy (>1TeV)
  - Study plasma lenses
  - CLIC BDS (few ns spacing) vs ILC BCD (~us spacing)
  - CLIC BDS dispersion introduced challenging

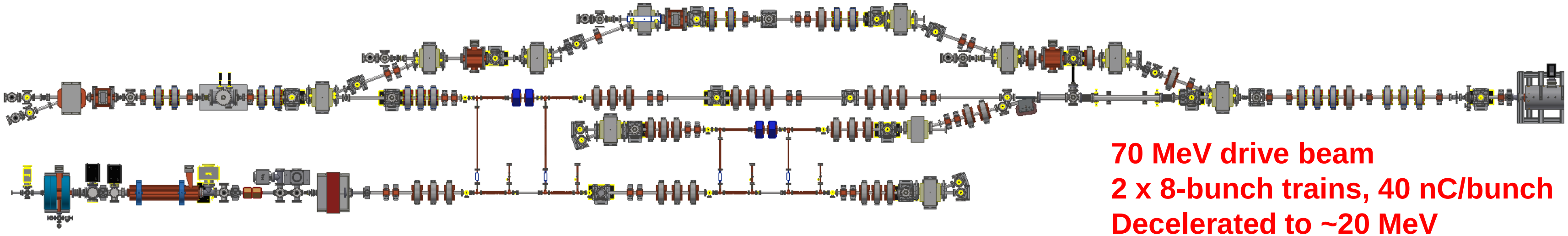
CTE8. appropriate main-beam parameters at the IP

- Plasma and Advanced Structure Accelerators Interest Group (Eric Esarey et al.)

PLANS FOR SWFA DEMONSTRATORS

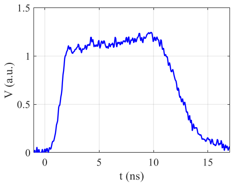
SWFA DEMONSTRATORS

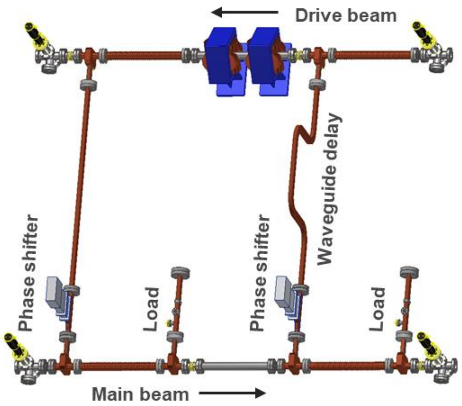
- **500 MeV TBA demonstrator**



70 MeV drive beam
2 x 8-bunch trains, 40 nC/bunch
Decelerated to ~20 MeV

15 MeV main beam
Low charge single bunch
Accelerated to ~500 MeV

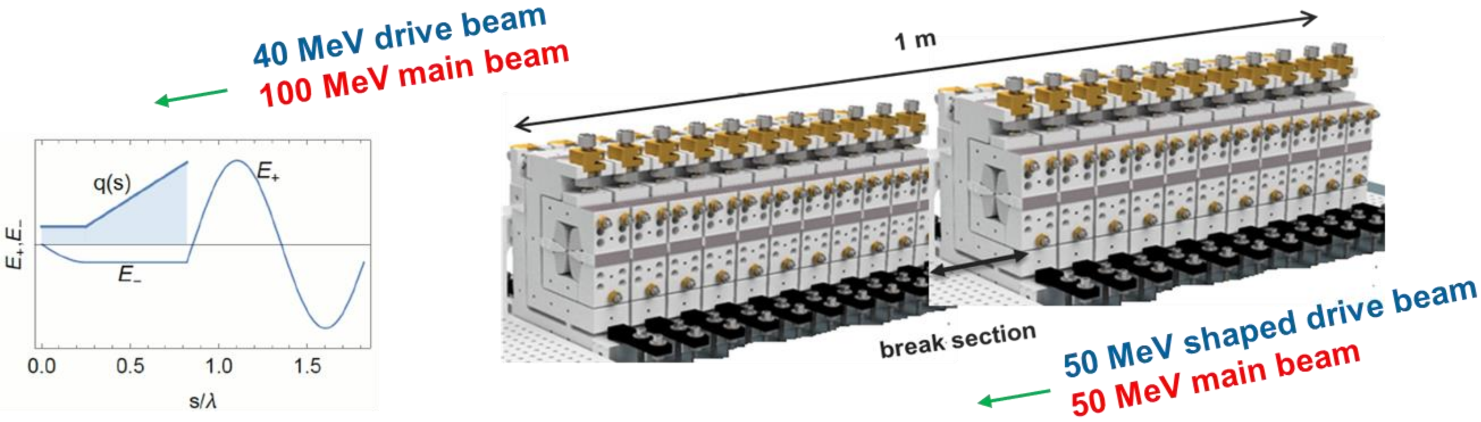


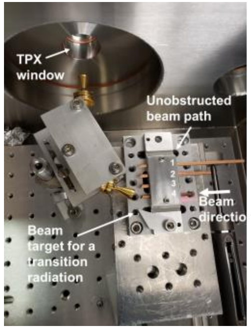


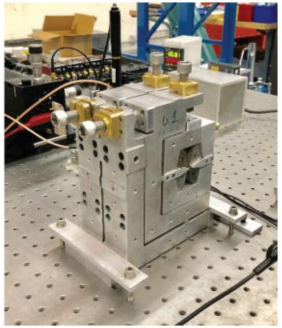
J. Shao et al, *NAPAC2019*

NEXT STEP: SWFA DEMONSTRATORS

- **CWA energy doubler**







Courtesy of A. Zholents

WHAT OUTCOMES WOULD WE LIKE TO SEE?

- Strengthen collaboration between SWFA and HG Community

- Strengthen ANA collaborations
  - Interest Groups per CTE's
  - Beam production (CTE1 and CTE2)
  - Accel Tech (CTE3-6)
    - Plasma and Advanced Structure Accelerators (PASA) Interest Group
  - Beam Delivery System (BDS) interest group (CTE7)
  - IP interest group? (CTE8)
  - Strawmen Designs
    - Combined ANA collider?

- Participate in Snowmass