LCWS2023

STRUCTURE BASED WAKEFIELD ACCELERATOR (SWFA) FOR LINEAR COLLIDER

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On behalf of the AWA facility at
Argonne National Laboratory

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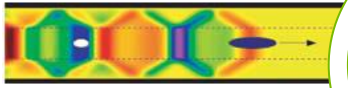
STRUCTURE WAKEFIELD ACCELERATORS

Why SWFA

- Structures → undependable of e- and e+
- Empirical scaling law indicates shorter pulse → higher gradient
- Wakefield→ shorter pulses

Challenges

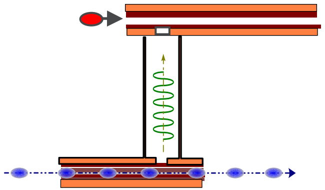
- Achieve desirable luminosity (scalable energy, beam power, lower vertical emittance, shorter bunch length, etc)
- How to achieve higher efficiency to reduce the site power



The same channel or multi-channels

CWA

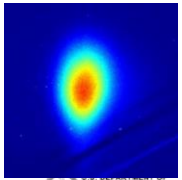
TBA



Two independent structures

SWFA R&D

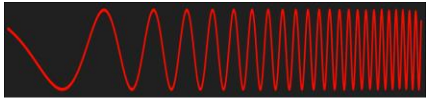
shaped and intense



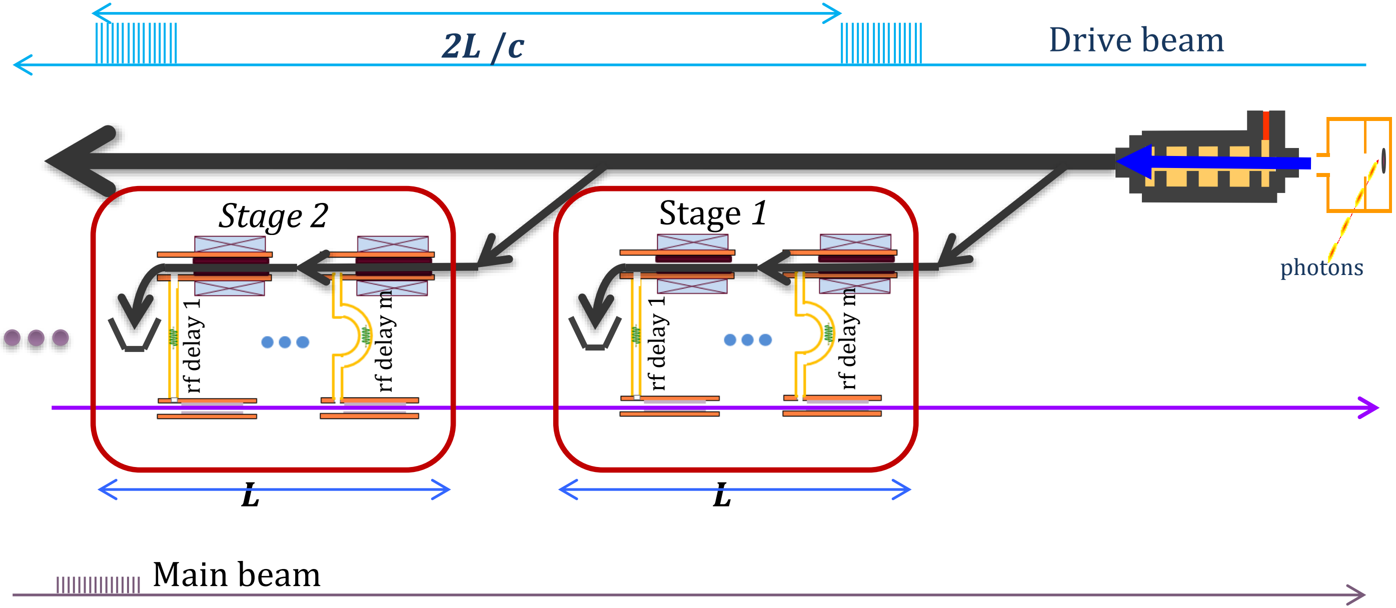
Beam Beam Beam

Structure Structure Structure

Microwave THz

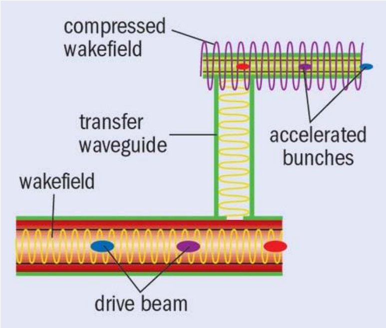


SCALABLE TBA ACCELERATION MODULE

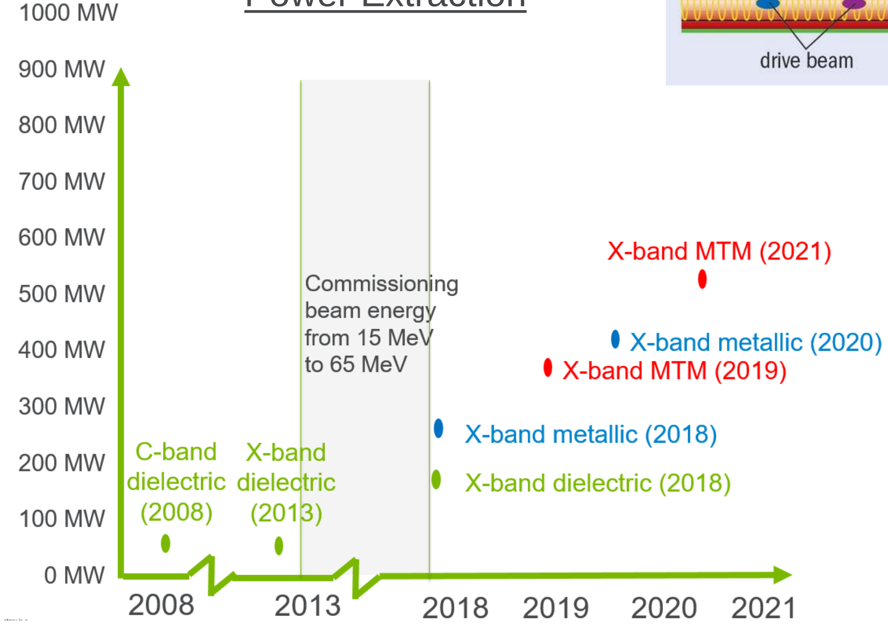


- Fast kicker and RF delay for drive beam distribution

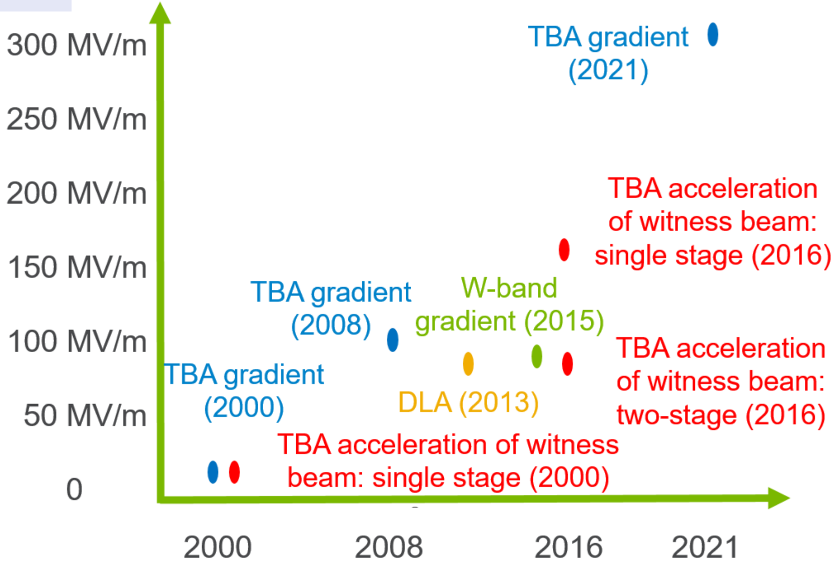
SWFA TBA PROGRESS OVER YEARS



Power Extraction



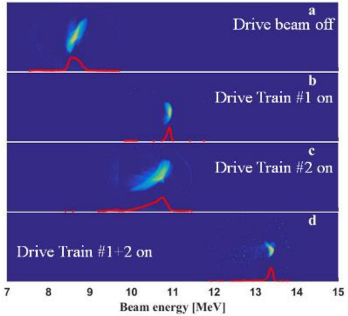
Acceleration Gradient



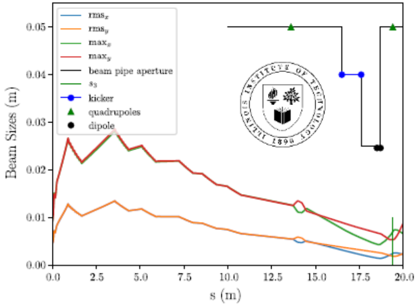
TBA R&D

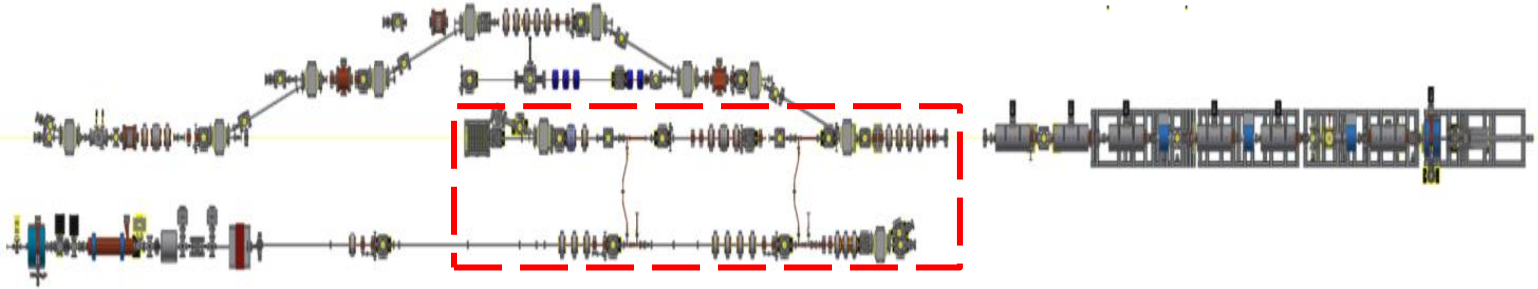
Staging

- Simplified staging demonstrated
- 2 stages, 1 pair of structures per stage
- Main beam energy gain of 5 MeV
- TBA beamline optimization



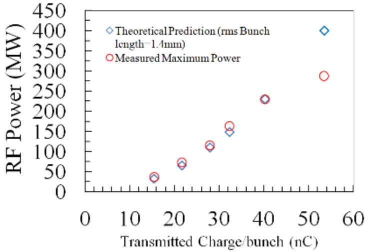
N. Neveu, et al, PRAB 22, 054602 (2019)





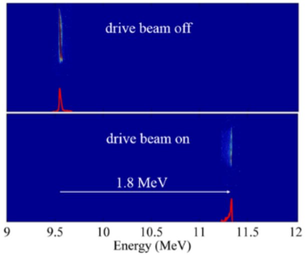
Drive beam power source

- X-band metallic: 300 MW
- K-band dielectric: 55 MW



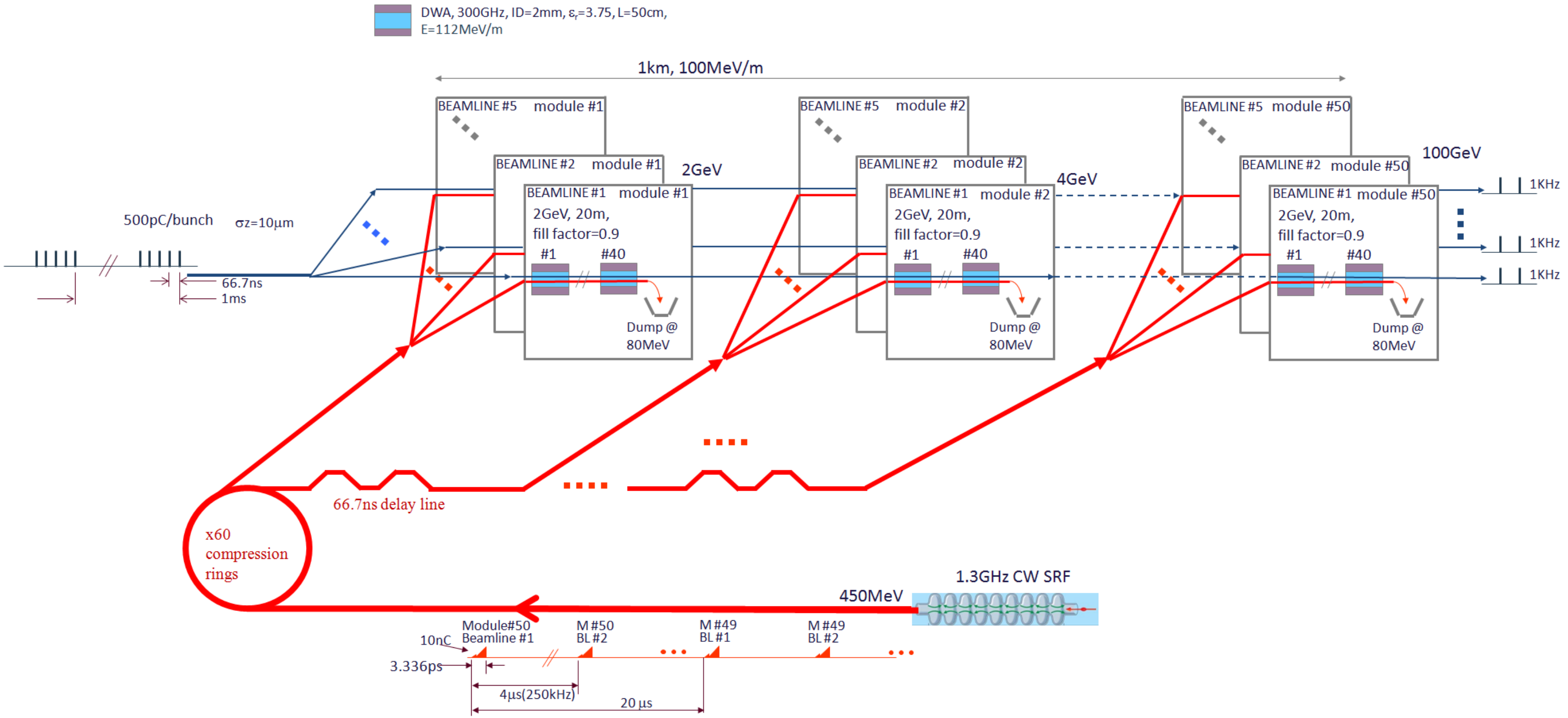
Main beam acceleration

- X-band metallic: 150 MV/m
- K-band dielectric: 28 MV/m

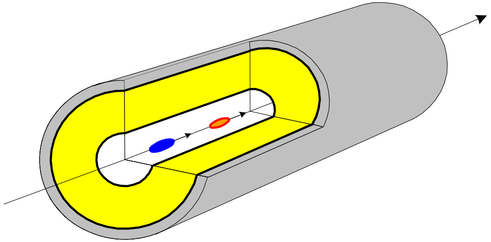


C. Jing, et al, NIMA 898, 72-76 (2018), J. Shao, et al, in Proceedings of IPAC2017

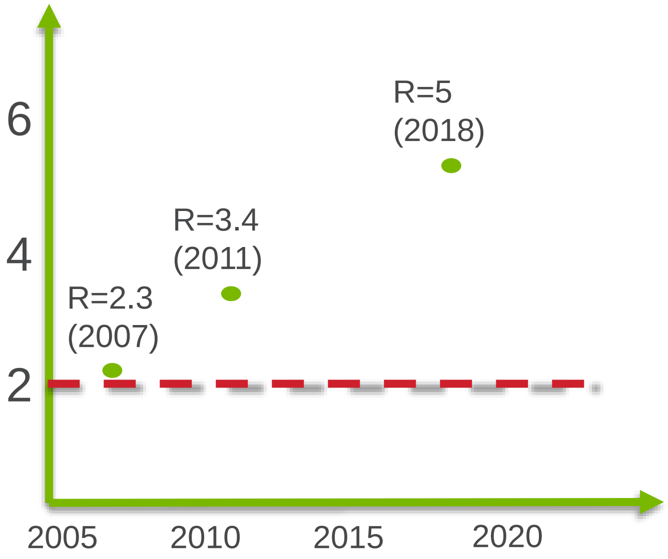
SCALABLE CWA ACCELERATION MODULE



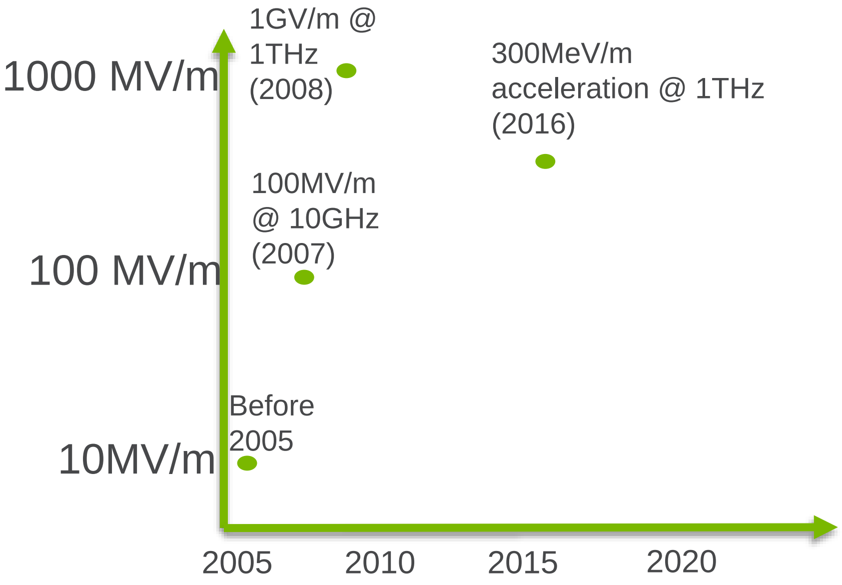
SWFA CWA PROGRESS OVER YEARS



Transformer Ratio



Acceleration Gradient

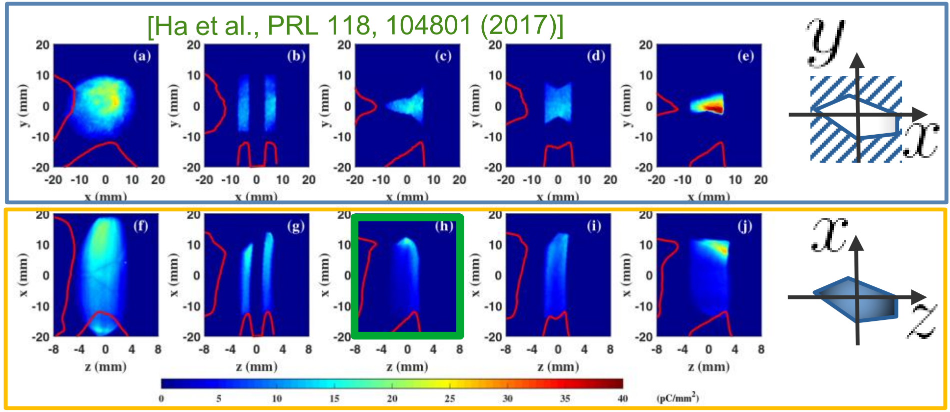


BEAM PHASE-SPACE CONTROL

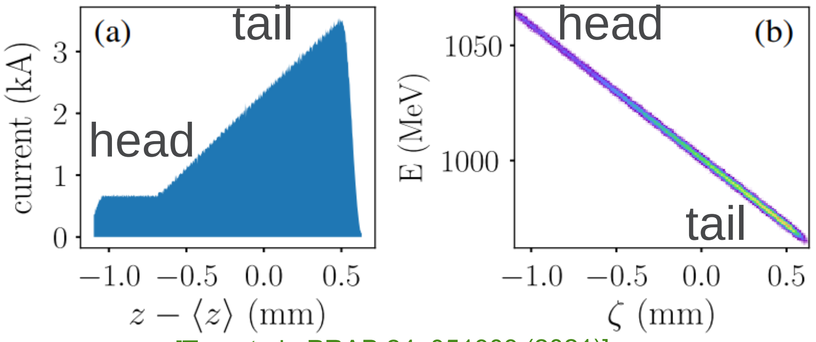
Mesoscopic shaping via phase-space exchange

- Precise control over the phase-space distribution is critical to high-efficiency high-gradient wakefield acceleration
- AWA beamline includes a phase-space exchanger capable of precise temporal shaping at the sub-picosecond scale

measurements



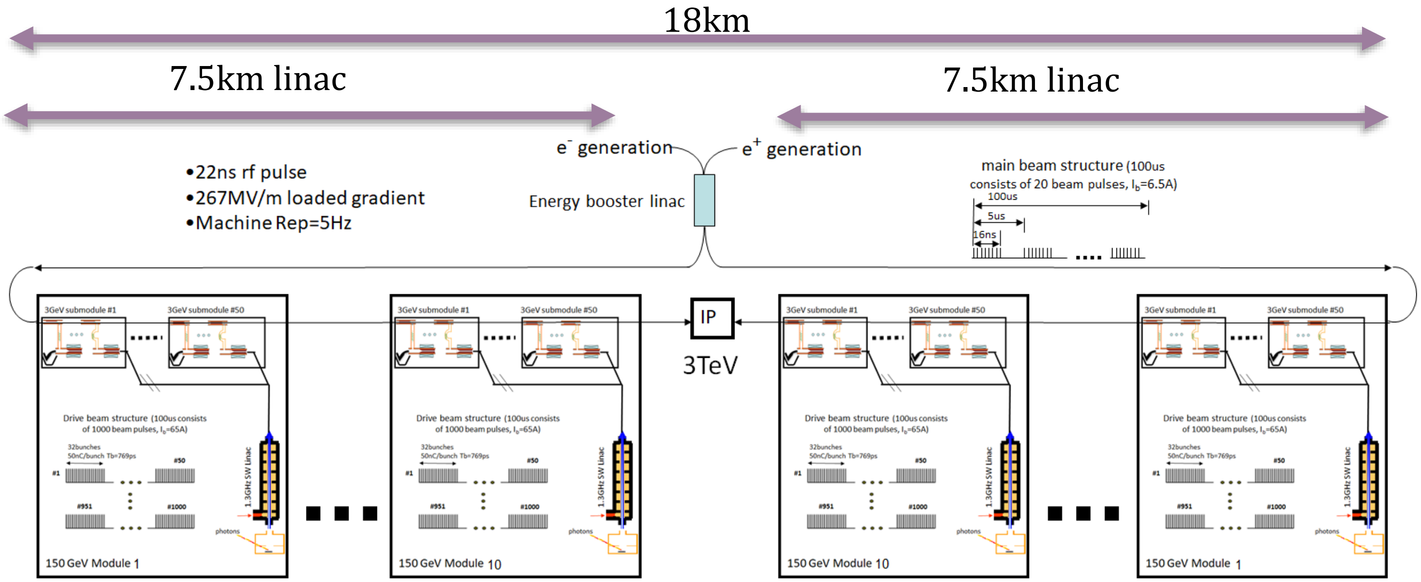
simulations



[Tan et al., PRAB 24, 051303 (2021)]

- Applications beyond AAC (e.g. compact coherent light sources)
- **Current research focus:** improve shaping capabilities – new shapers design, variable collimators, ML-aided optimization

COLLIDER
3TeV 30MW beam power TBA

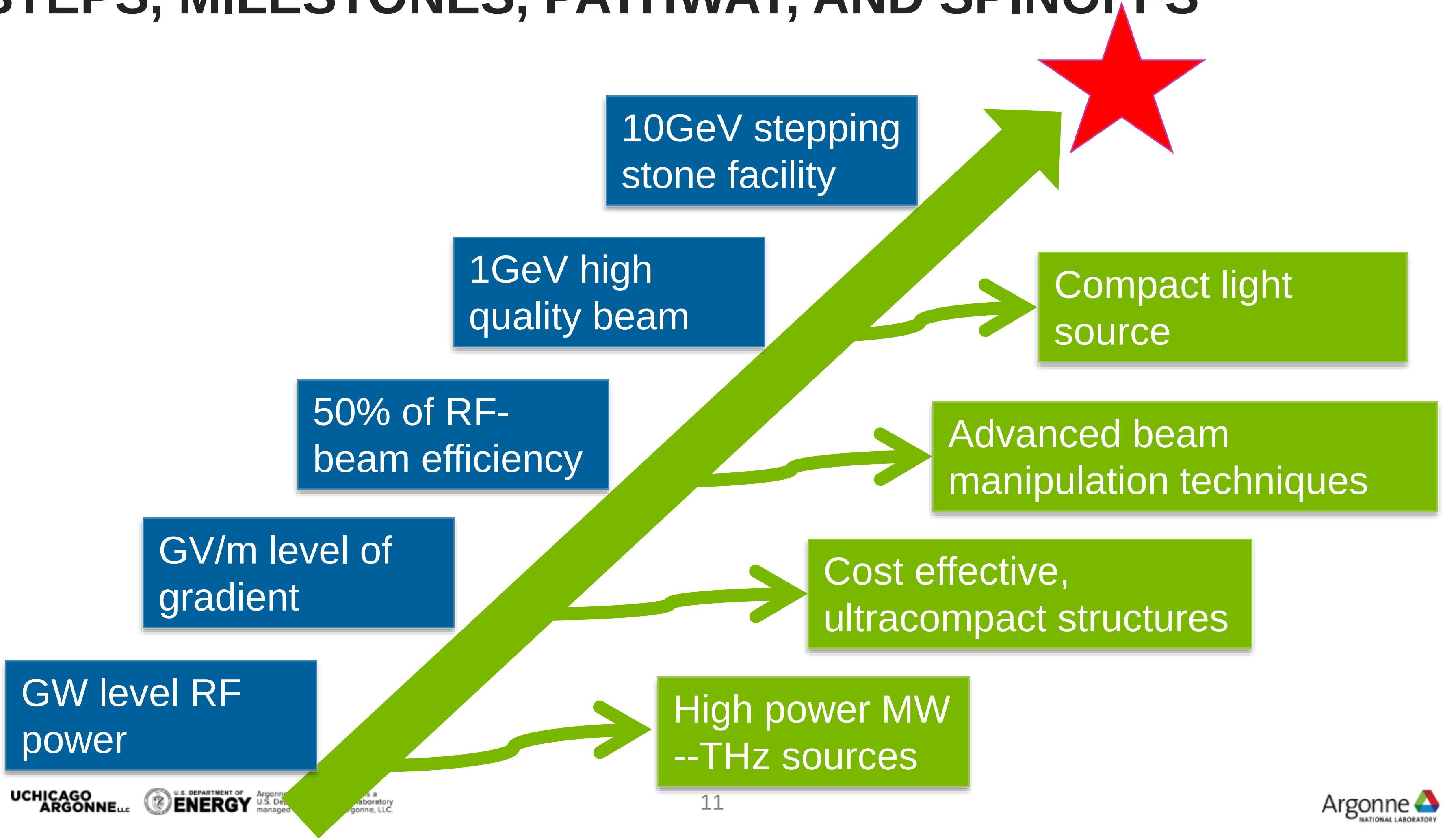


❑ Based on scientifically mature and low cost Dielectric TBA technologies

- Short rf pulse (**20ns**) for high gradient (**$e^+ e^-$ 200MeV/m of effective gradient**)
- Modular design →easily staged
- Wall plug efficiency (~15%)

DEVELOPMENT PATH

STEPS, MILESTONES, PATHWAY, AND SPINOFFS



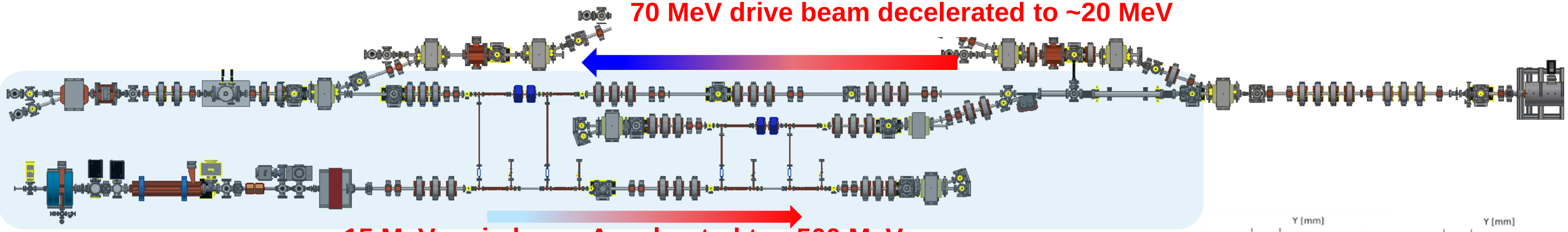
DEMONSTRATE AFLC-SYSTEM IN HIGH FIDELITY

Parameters	AFLC requirements	AWA Current	AWA-II (in plan)
Acceleration mechanism	Dielectric TBA	Structure TBA	SWFA
Drive beam generation	1.3GHz Photogun	1.3GHz Photogun	Multi-photogun system
Drive beam current	65A (32 x 50nC) in pulse, rep. rate 1kHz	65A (8 x 50nC), rep. rate. 10Hz	65A (16 x 50nC), rep. rate. 100Hz
RF Power generation	26GHz 1GW 20ns	11.7GHz 0.6GW 6ns	26GHz 1GW 20ns
Main beam generation	CLIC like	1.3GHz Photogun	11.7GHz photogun
Main beam current	6.5A (0.5nC w/ interval of 77ps)	0.5~10nC single bunch	0.2nC multibunches
Main linac structure	26GHz DLA	1~30GHz accelerator	GHz~THz
Gradient	~350MV/m	Up to 500MV/m	Up to GV/m
Stages	Multiple stages	>2 stages, 2 TBA units/stage	Multiple stages

AWA and its upgrade can be used for AFLC-system high-fidelity demonstration.

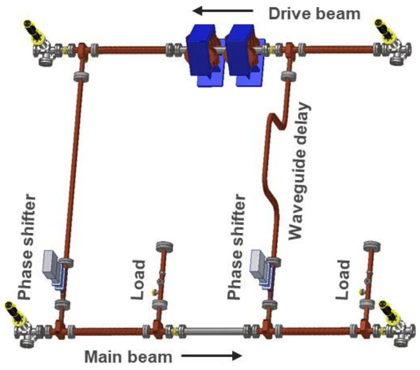
NEAR TERM: 0.5GeV DEMONSTRATOR

- **Demonstrate key technologies of SWFA based TeV class linear collider**
- **Fit into AWA's existing bunker**
- **Potential to be converted to a compact ICS gamma source**

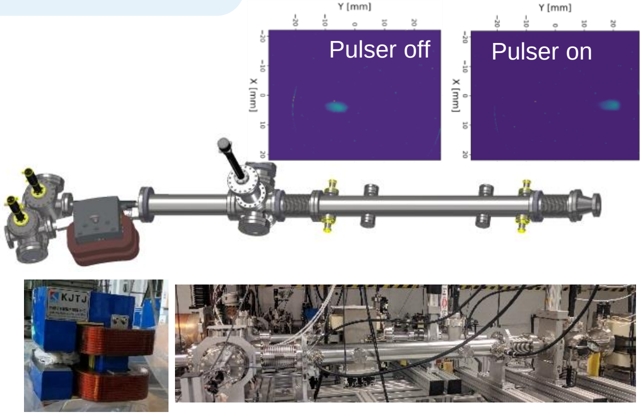


CTE:

1. GW level rf power
2. 300MV/m of gradient
3. Drive beam distribution



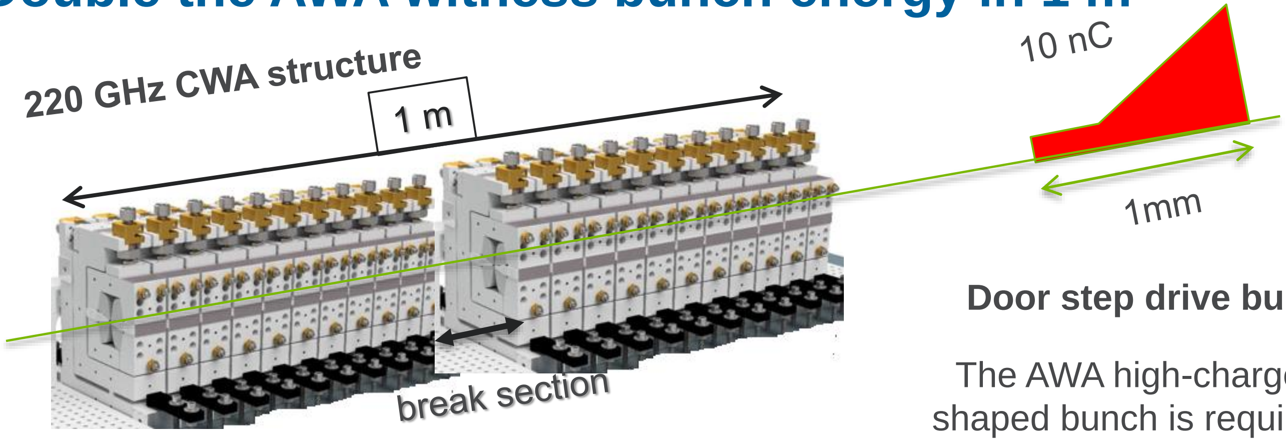
TBA module



Fast kicker and septum

NEAR TERM: CWA: ENERGY DOUBLER DEMONSTRATOR

Double the AWA witness bunch energy in 1 m



Door step drive bunch

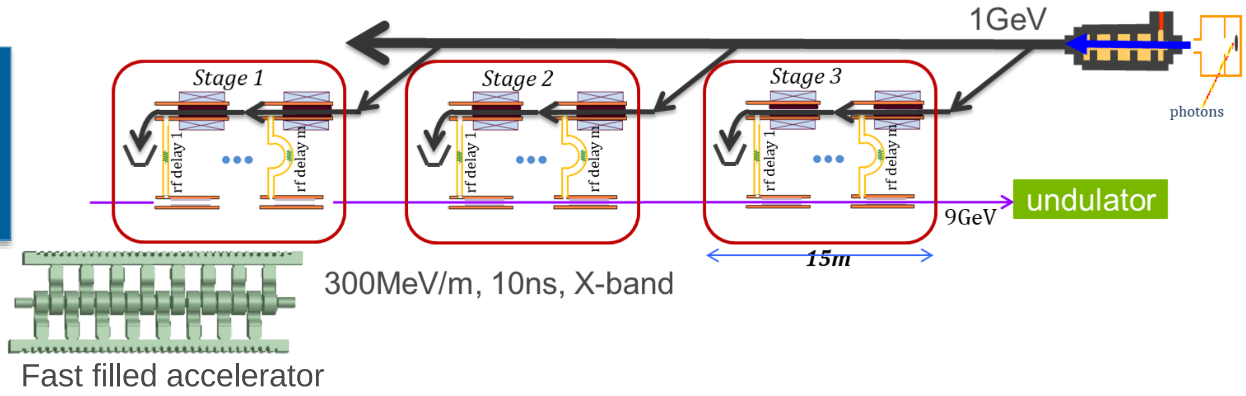
The AWA high-charge, shaped bunch is required

Components needed for integration module

- **Drive Beam**: Generation of door step profile & BBU control
- **Main bean**: Design and optimization of the main accelerator optics
- **RF**: Break section (fundamental mode coupler, HOM coupler, and diagnostics)
- **Vacuum**: Assess realistic vacuum condition

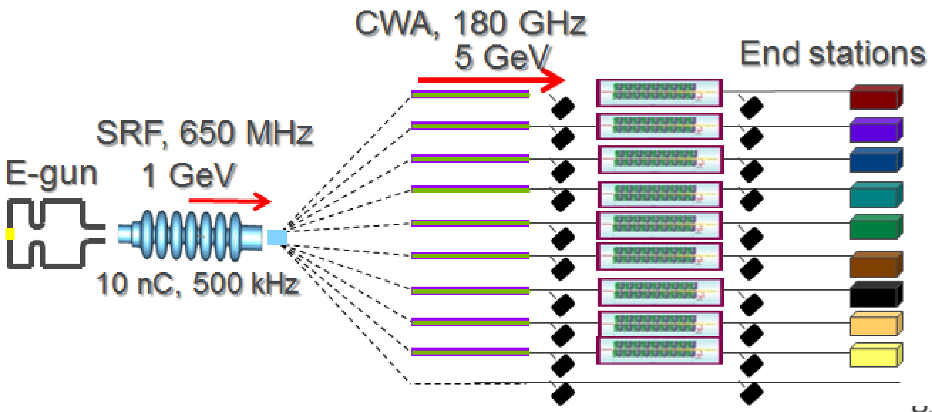
STEPPINGSTONE FACILITIES

TBA---9GeV Compact FEL in BIAR regime



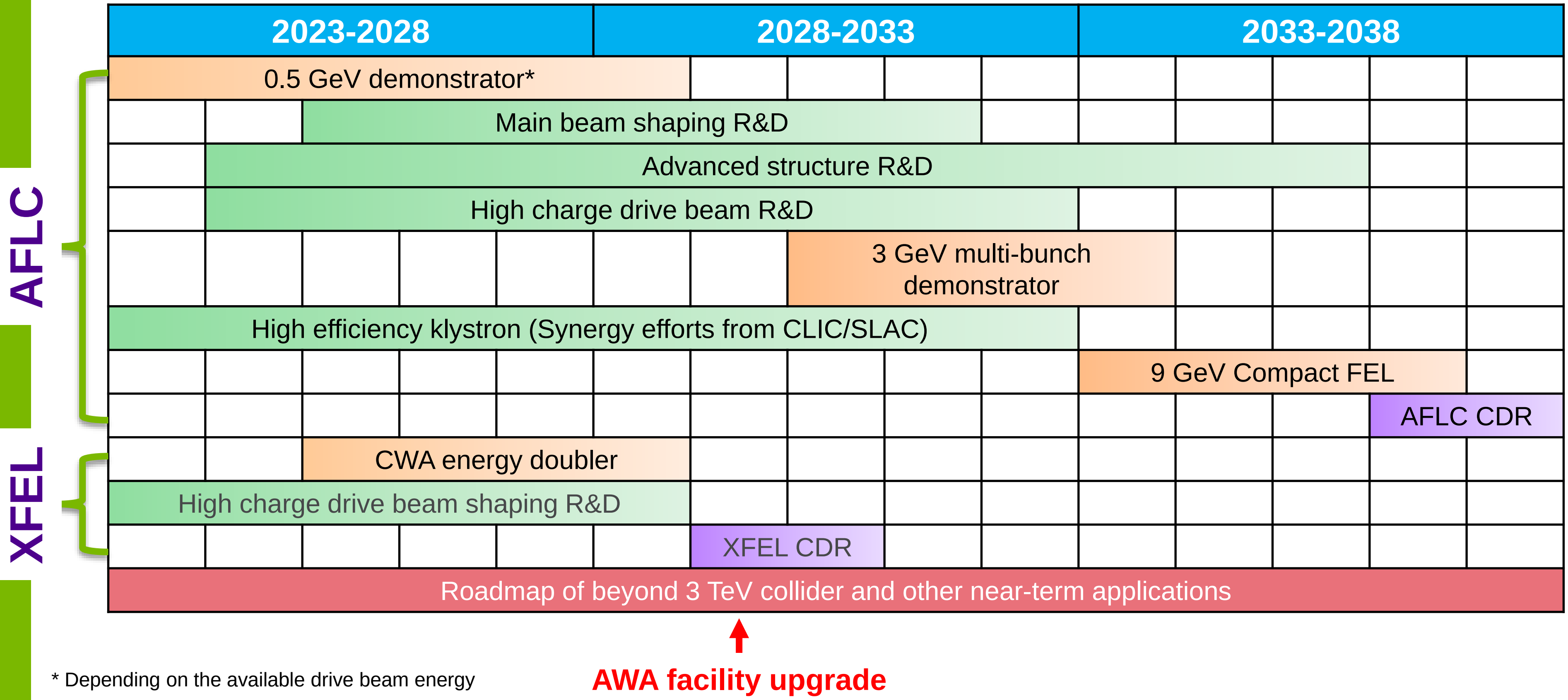
Yuliang Jiang, et al, PRAB **24**, 112002 (2021)

Colinear---5GeV XFEL



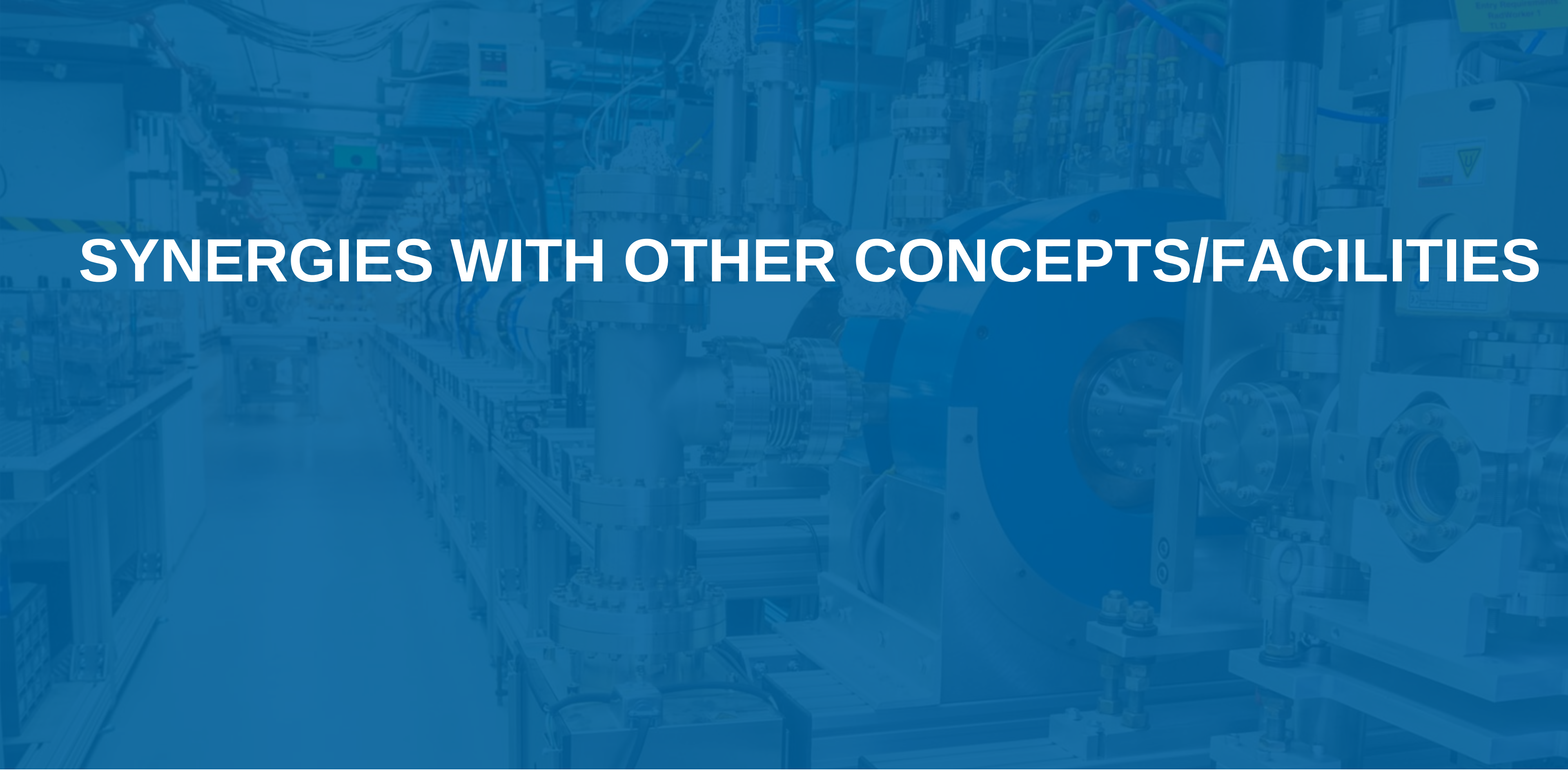
SWFA 15-YEAR ROADMAP

Integral Demonstrator
Key component
Milestone report



* Depending on the available drive beam energy

SYNERGIES WITH OTHER CONCEPTS/FACILITIES



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Synergy to Plasma Wakefield Accelerators:

1) Beam shaping (drive and main beam)
2) High brightness beam generation

Synergy to other LC concepts:

1) Development of advanced RF accelerating structures (high gradient, high shunt impedance).
2) Extreme high power rf source.

The Path to 15 TeV

Slides from Spencer's recent P5 meeting

	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075
Linear Collider Higgs Factory 250 GeV	Planning		Construction		Operation						
Linear Collider Higgs Factory 500 GeV			Planning		Construction		Operation				
Structure Wakefield Collider 3 TeV	High-Pow. R&D	0.5 GeV Demo	3 GeV Demo	CDR	Planning		Construction		Operation		
Beam-Plasma Collider 15 TeV	Positron PWFA	Staging Demo	Energy Recovery	BDS R&D	CDR	Buffer	Planning		Construction		Operation
Laser-Plasma Collider 15 TeV	Staging Demo	Positron LWFA	Energy Recovery	BDS R&D	CDR	Buffer	Planning		Construction		Operation
$\gamma\gamma$-Plasma Collider 15 TeV	NLQED	FEL R&D	IP Area Design	BDS R&D	CDR	Buffer	Planning		Construction		Operation

Wakefield Accelerators are developed in parallel with the operation of Linear Collider Higgs Factories and provided a staged upgrade path to 3 TeV and 15 TeV.

REMARKS

Current Status:

1) ANL has one 3-TeV collider concept based on 26GHz short pulse TBA and a 200GHz Colinear wakefield stepping stone facility for the light source application. But many technical issues need to be investigated.
2) For TBA, 400MW rf power, staging, etc, have been demonstrated, but high gradient (>300MV/m) and high energy gain (>500MeV) not yet.
3) For CWA, TR=5, 300MeV/m, etc, have been demonstrated, but sustainable acceleration in meter scale not yet.

Challenges and Suggestions:

1) Many challenging issues have not been worked on or in a slow pace, simply because of the limited resources.
2) New directions need to be explored, like THz acceleration, low cost fabrication techniques, etc.
3) Grow the community and attract young talents