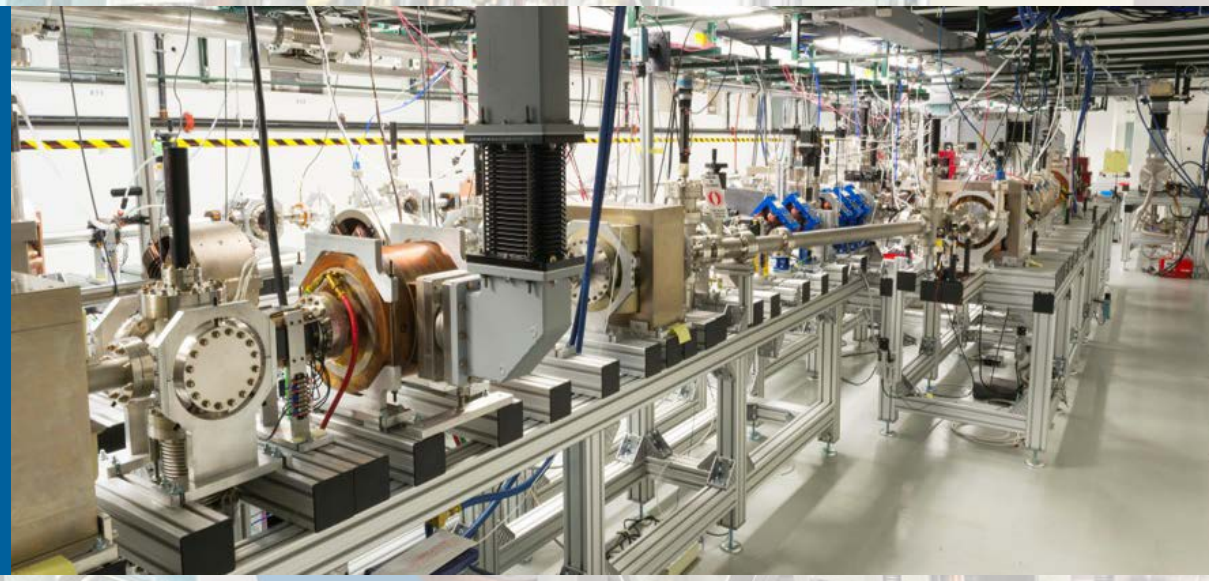
STRUCTURE WAKEFIELD ACCELERATION (SWFA)

Argonne NATIONAL LABORATORY

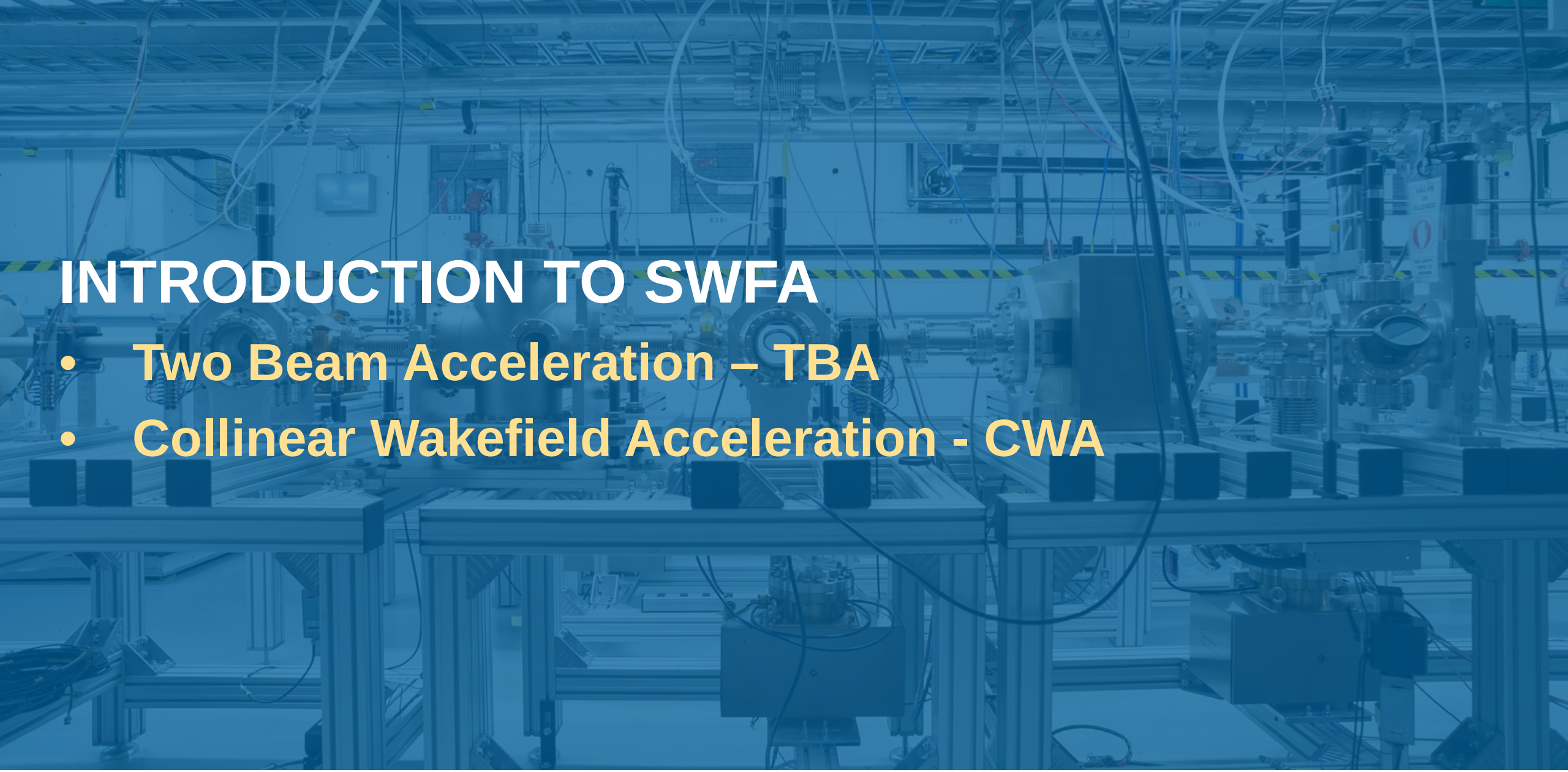
SWFA DEVELOPMENT FOR AN ENERGY FRONTIER MACHINE



JOHN POWER (for C. Jing)
Argonne National Laboratory

Argonne Wakefield Accelerator
General Accelerator R&D Test Facility

Snowmass AF7-rf group miniWorkshop on Cavity Performance Frontier (Feb 16, 2021)



INTRODUCTION TO SWFA

- Two Beam Acceleration – TBA
- Collinear Wakefield Acceleration - CWA

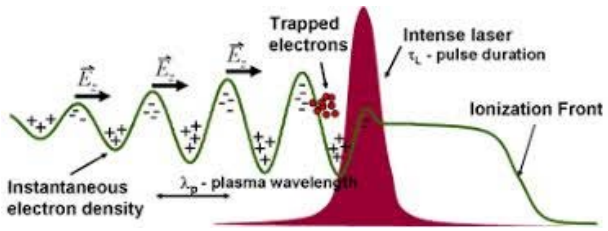
Advanced Acceleration Concepts

Energy Source

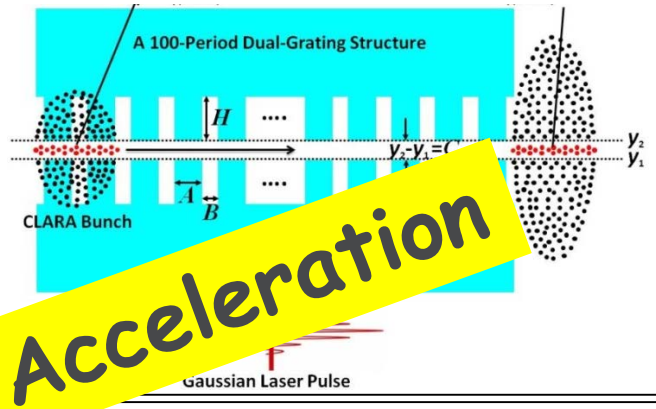
Laser pulse

Particle beam

LWFA
(Laser WF Accelerator)

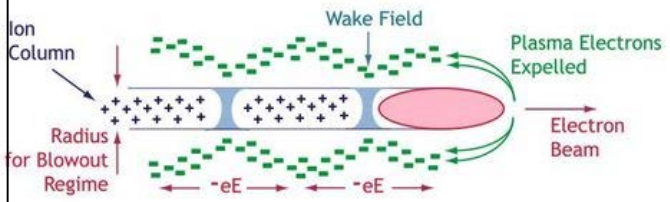


DLA
(Dielectric Laser Accelerator)

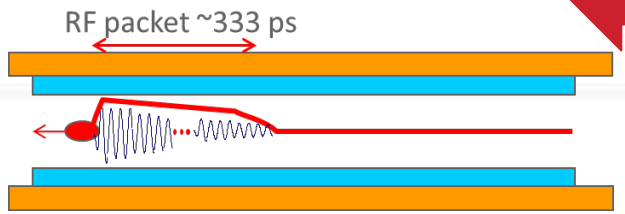


= Wakefield Acceleration

(Plasma [illegible]erator)



SWFA
(Structure WF Accelerator)



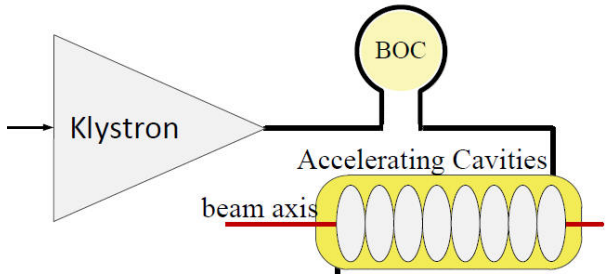
Plasma

Structure

Medium

Externally Driven RF Acceleration

External
RF source



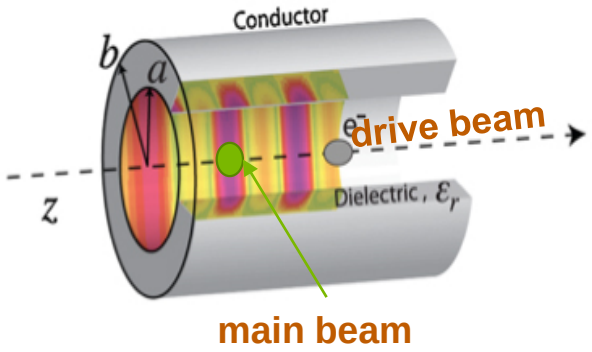
RF Driven Structure

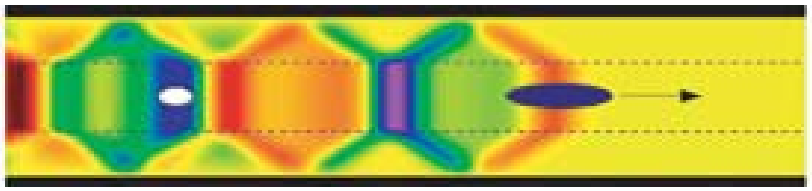
Note: there are many overlaps between beam-driven and RF structures.

ELECTRON BEAM DRIVEN WAKEFIELD ACCELERATION

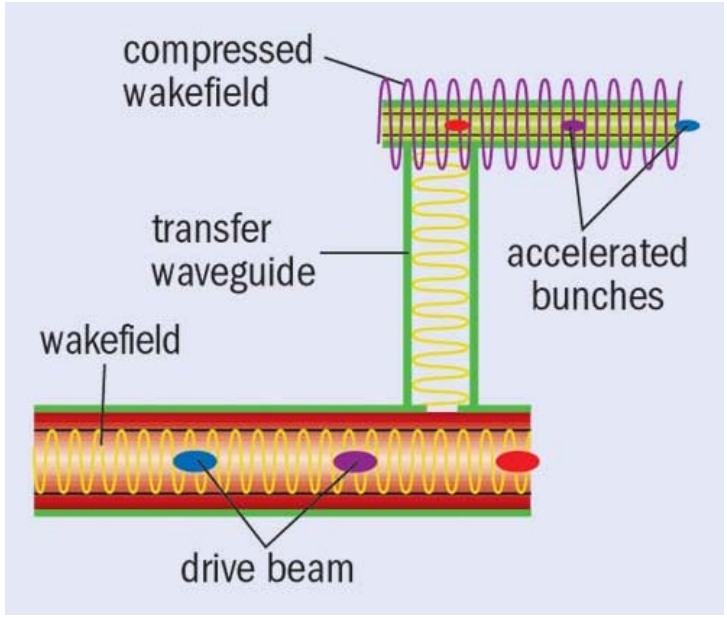
Two Types of Structure Wakefield Acceleration (SWFA)

Collinear Wakefield Acceleration



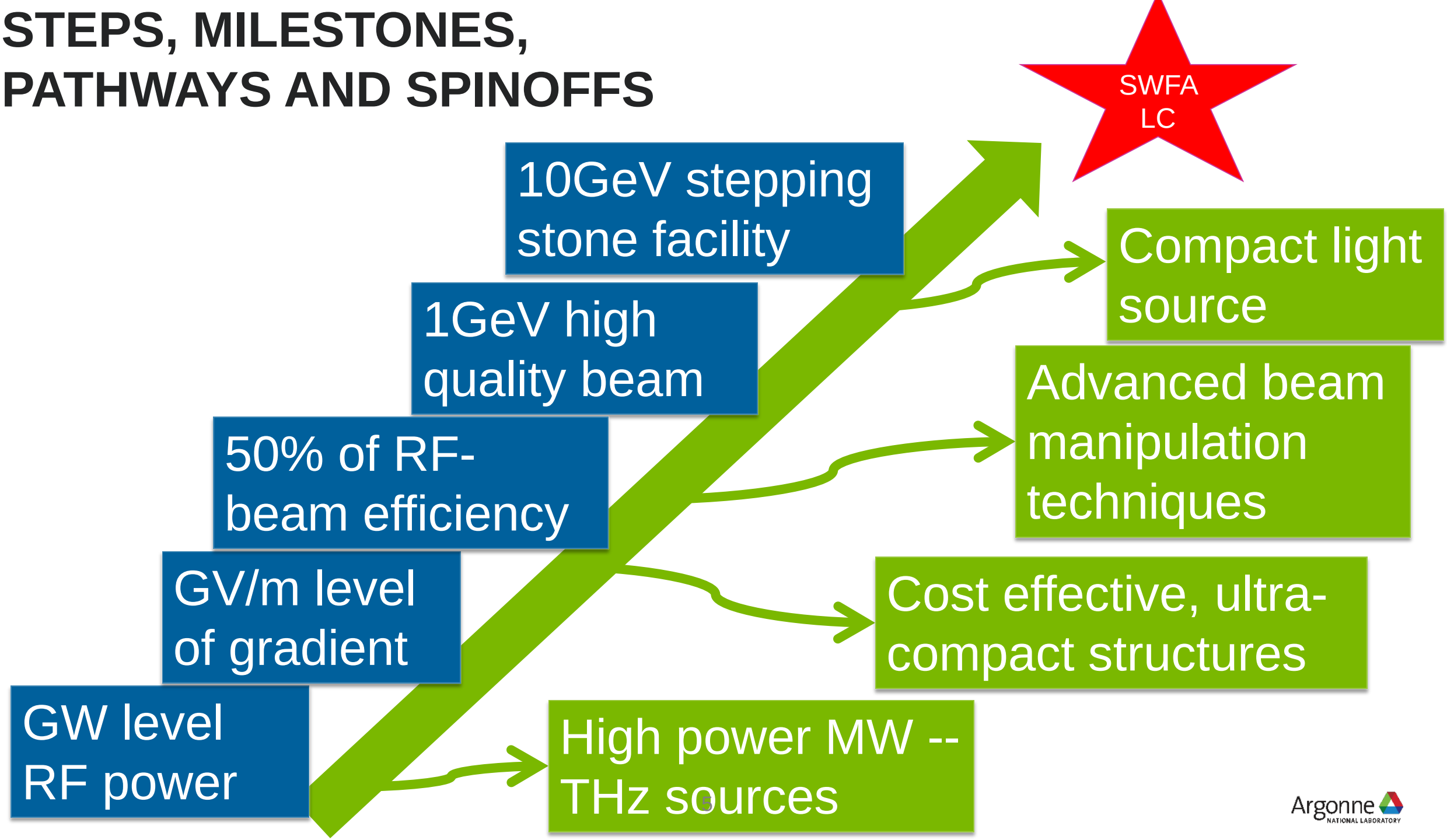


Two Beam Acceleration



M. Rosing and W. Gai, Phys. Rev. D Vol 42, No. 5 (1990)

STEPS, MILESTONES, PATHWAYS AND SPINOFFS



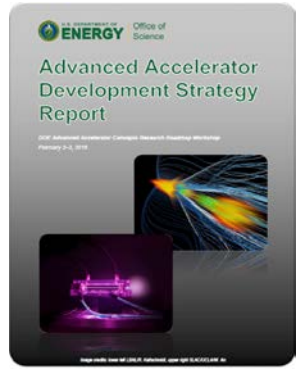
SWFA APPLICATIONS

- High repetition rate multi-user X-ray FEL (Stepping Stone facility)
- Mutli-TeV linear collider

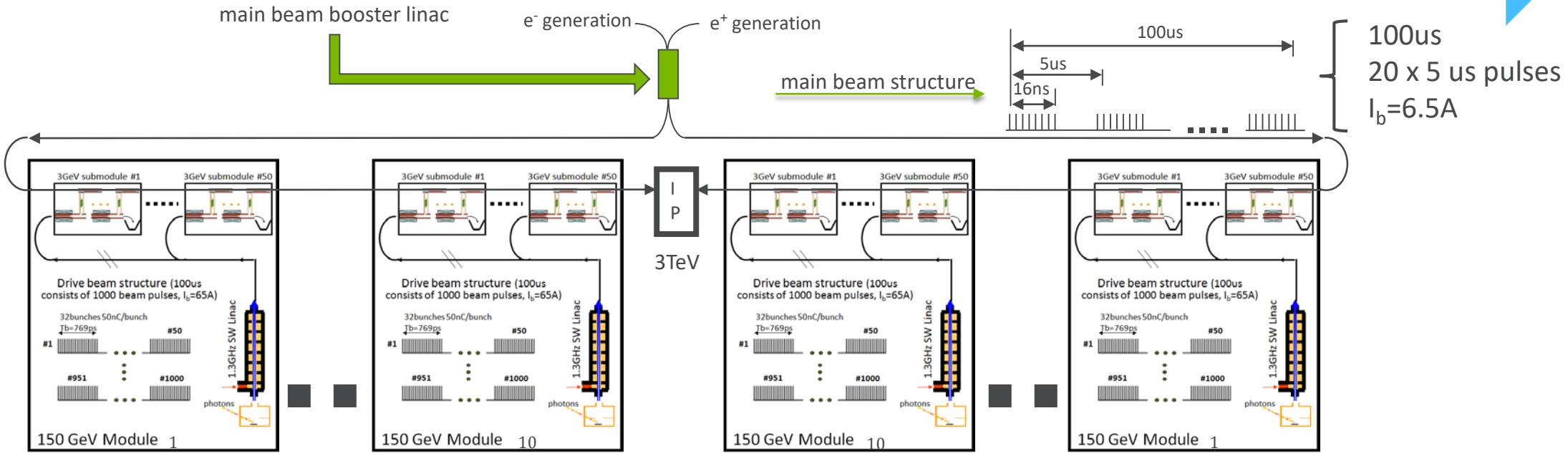
AFLC: SHORT-PULSE SWFA 3 TEV COLLIDER CONCEPT

- Based on dielectric TBA technology
  - LOW CONSTRUCTION COST: Dielectric structures
  - HIGH EFFECTIVE GRADIENT: Short RF pulses (20ns)
  - LOW OPERATING COST: Wall plug efficiency ~15%

details



ARGONNE FLEXIBLE LINEAR COLLIDER

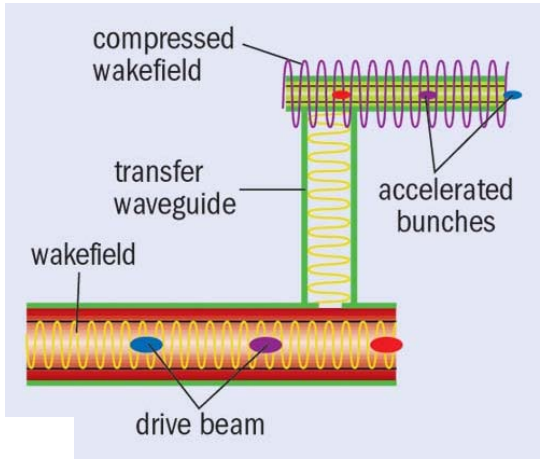


Modular design
(easily staged)

e^+ e^- 267 MeV/m of loaded gradient
(200 MeV/m effective gradient)

W. Gai, J.G. Power, and C. Jing, *J. Plasma Phys.*, vol. 78, 339–345 (2012).

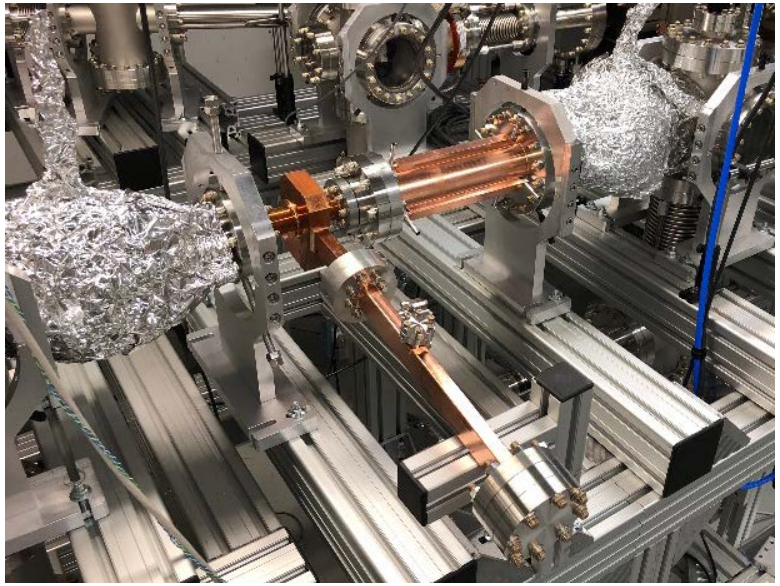
AFLC (TBA) STRUCTURES



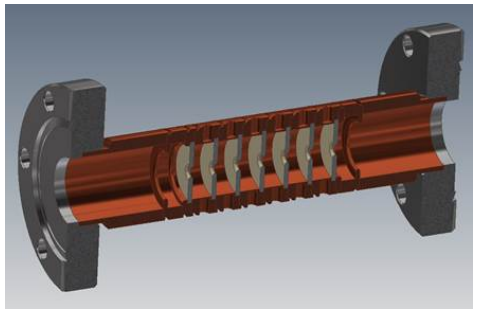
DECELERATING STRUCTURE

DRIVE BEAM POWER GENERATION

1 GW



26 GHz
Dielectric Disk Accelerator



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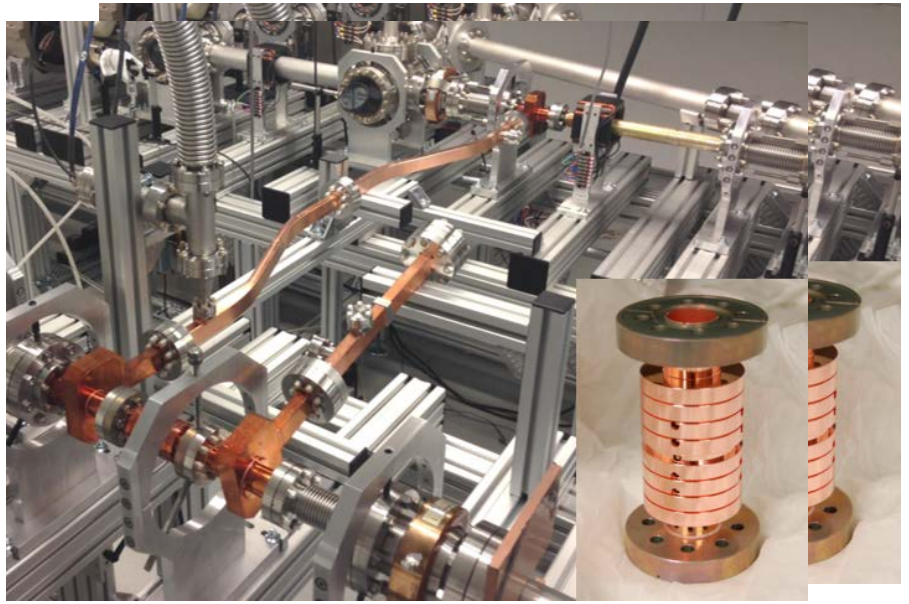
ACCELERATING STRUCTURE

ACCELERATION GRADIENT

300 MeV/m



See J. Shao talk for latest progress

HIGH REPETITION RATE MULTI-USER X-RAY FEL FACILITY

Beam Shaping + Collinear Wakefield Accelerator + SC undualtors

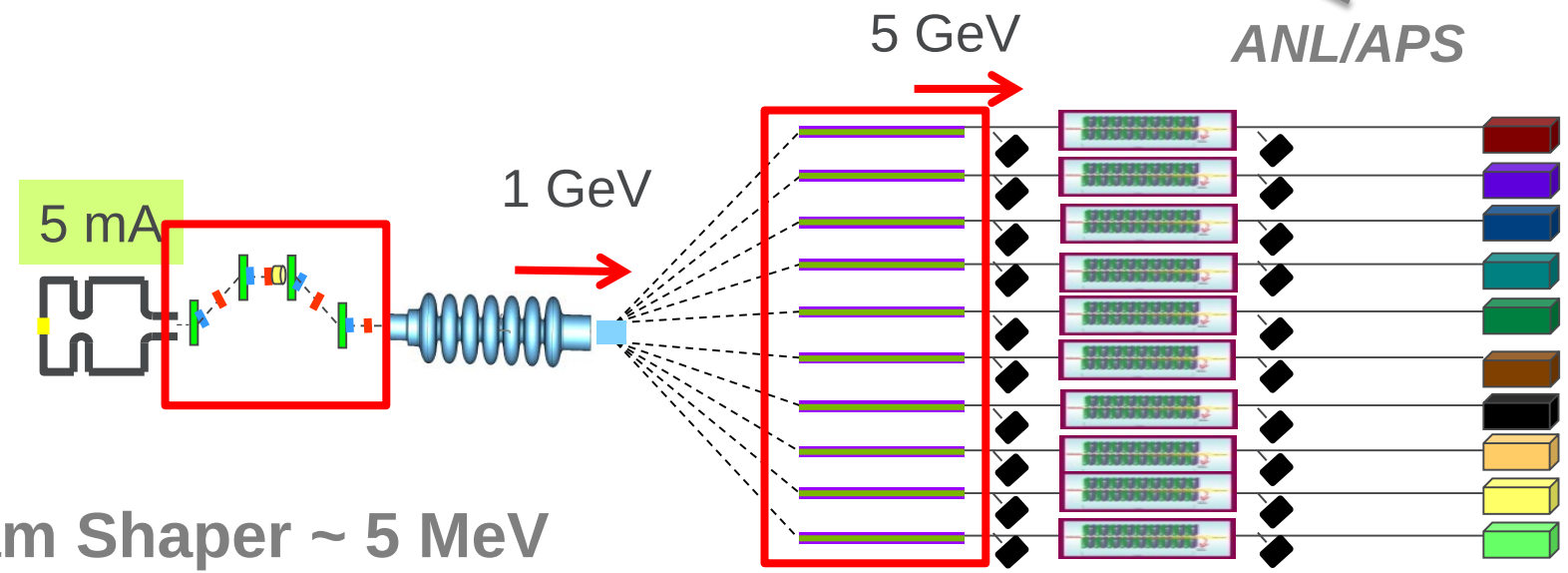
Low Emittance
MHz injector

MHz CW
SRF linac

Low Energy
Spreader

SC Undulators

Experimental
End Stations



Main work being done by the collaboration

Transformer Ratio
TR = 5 (new record)

PRAB 20, 061302 (2017)
PRL 120, 114801 (2018)

Bunch Shaping

PRAB 19, 121301 (2016)
PRL 118, 104801 (2017)

BBU control in the strong wake regime

PRSTAB 17, 091302 (2014)
PRAB 21, 031301 (2018)

A. Zholents et al, “A preliminary design of the collinear dielectric wakefield accelerator”, Nucl. Instrum. Meth. A829 (2016)190-193.

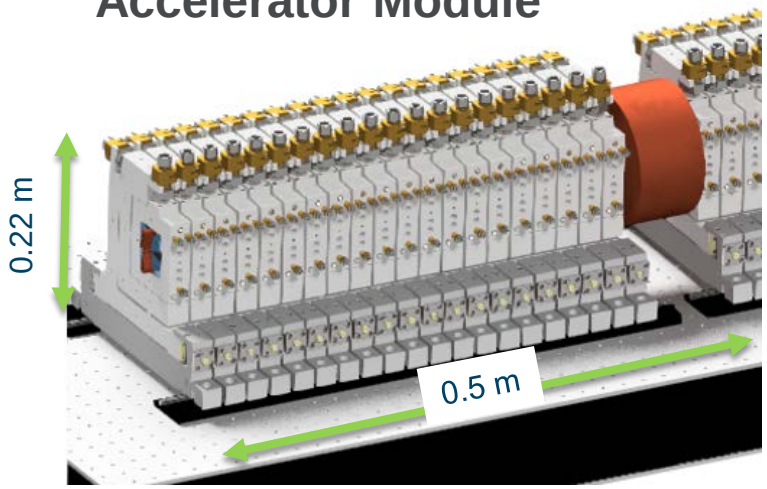
NEAR TERM GOAL IS CONSTRUCTION OF CWA MODULE

Components in the Accelerator Module

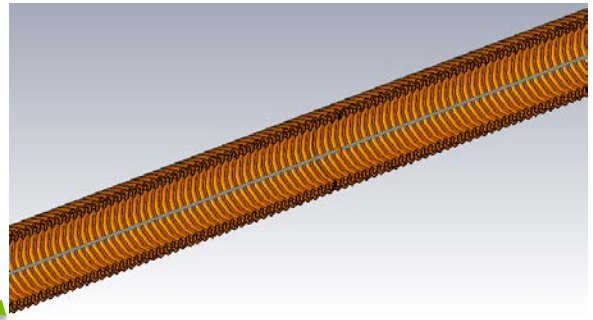
Vacuum chamber

Water in and out channels.

Accelerator Module



182 GHz Corrugated Waveguide

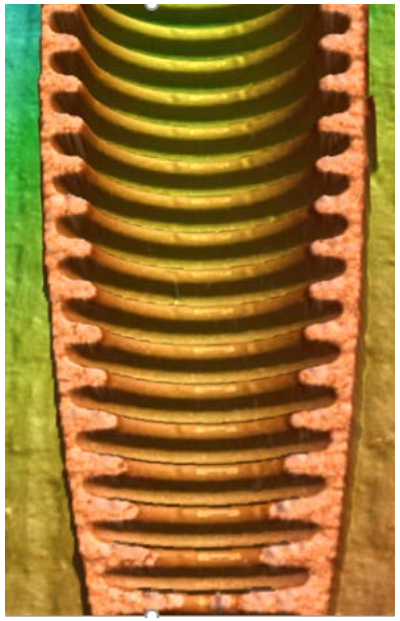


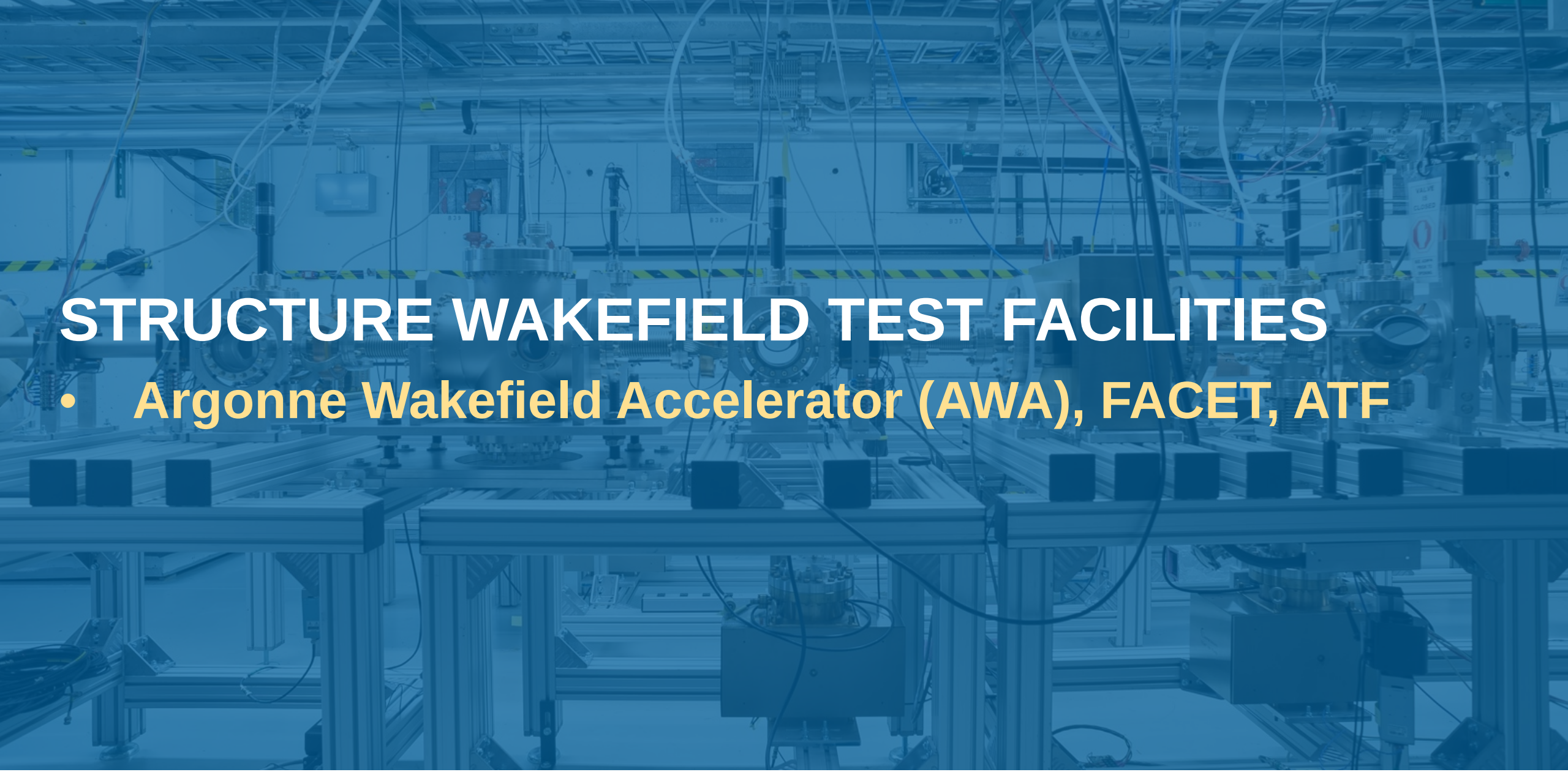
Assists with the increases of beam energy by ~ 50 MeV.

straight cut

Test samples are wire EDM cut to expose the internal corrugations for dimensional analysis

angular cut





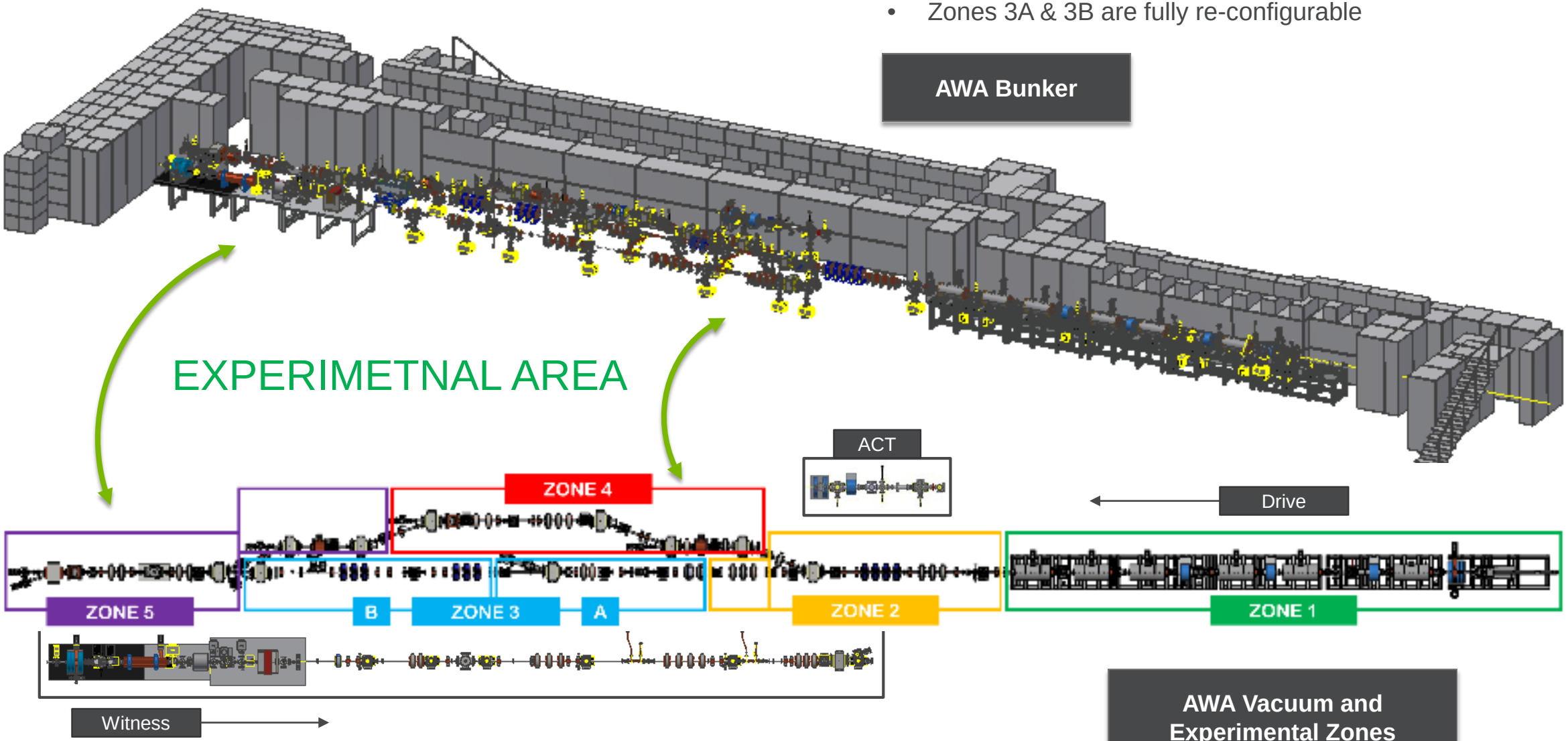
STRUCTURE WAKEFIELD TEST FACILITIES

- Argonne Wakefield Accelerator (AWA), FACET, ATF

AWA FACILITY

Highly reconfigurable beamlines

- Zones 2-5 are experimental areas
- Zones 2, 4, and 5 have ~ 1 m experimental area
- Zones 3A & 3B are fully re-configurable



AWA FACILITY

Experimental Areas

Advanced Accelerator Concepts
Accelerator and Beam Physics
Particle Sources

Single-shot longitudinal phase space diagnostics

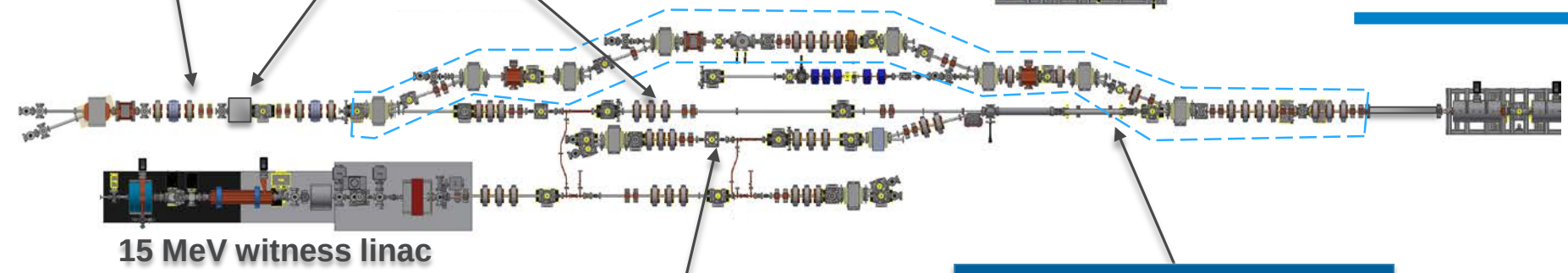
SWFA/PWFA test areas

GUN TEST STAND
Upgrade to 1.5 cell RF gun with load-lock

INJECTING MANIPULATED LASER

- α-BBO pulse stacker
- multi-splitter (train)
- MLA (homogenizer)
- SLM (laser long shaping)

GUN



65 MeV drive linac

15 MeV witness linac

Staging Beamline

6d emittance repartitioning

Double Emittance Exchange Beamline (longitudinal bunch shaping) + **Skew Quad Beamline (Round to Flat beam)**

AWA CAPABILITIES - BEAMS

Wide dynamic range

SINGLE BUNCH PARAMETERS

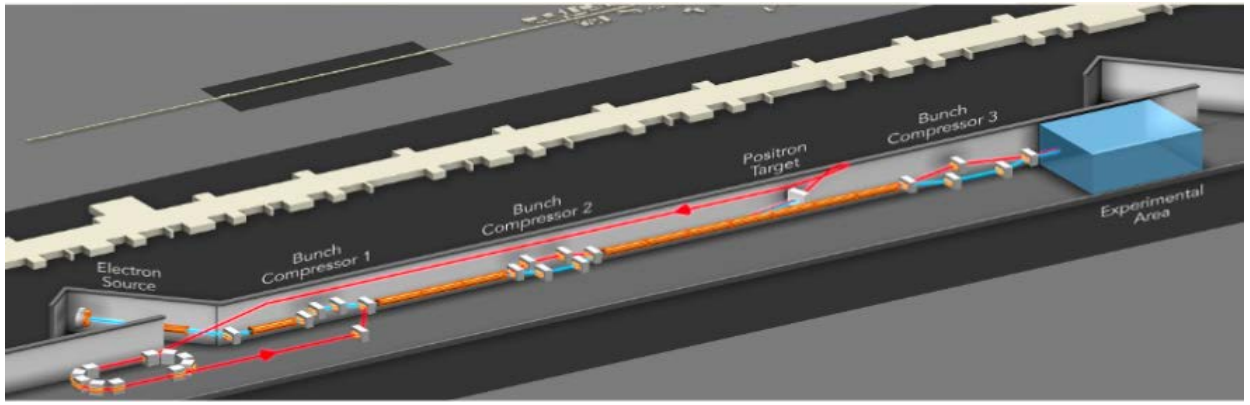
Beam parameters	Value	Note
Charge [nC]	0.1 – 100	*Have generated sub-pC beam but difficult to detect.
Energy [MeV]	6 – 63	
Rep. rate [Hz]	0.5 – 10	*2 Hz is nominal
Transverse laser diameter [mm]	0.5 - 22	*Uniform distribution (MLA)
Longitudinal laser pulse length [ps FWHM]	0.3	*Gaussian distribution **Flattop distribution (using α-BBO)
Bunch length [mm]	0.1 - 3	*High charge compression is not available
Transverse emittance [μm]	0.5 - 240	
Peak Current [kAmps]	0.5 - 25	

AWA CAPABILITIES - BEAMS

Variable Machine Configurations

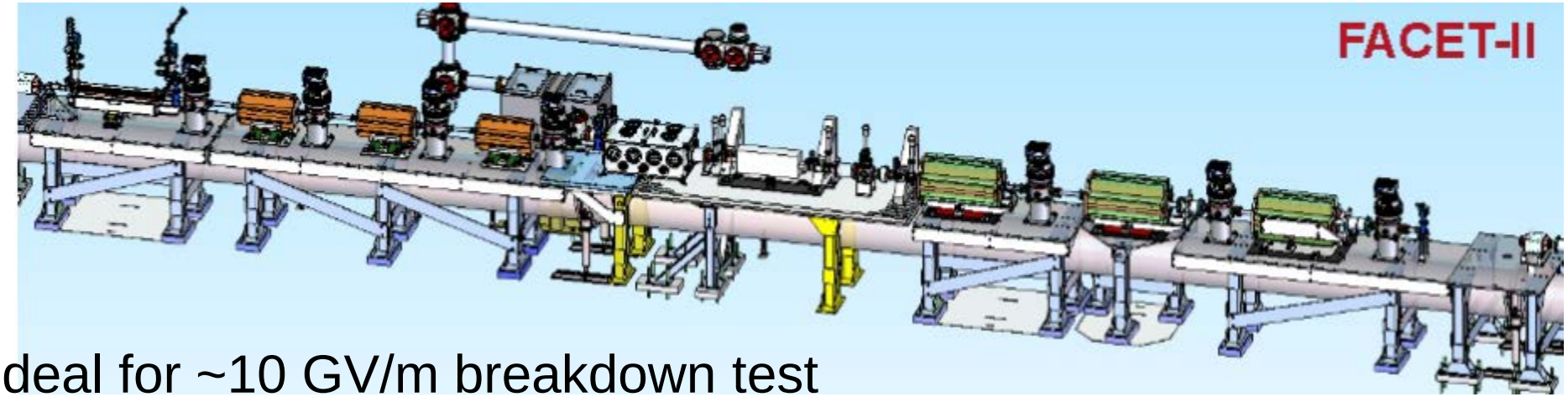
Operation modes	Value		Methods
Bunch train	Modulation frequency [GHz]	**1.3 – 10^3**	1. Laser multi-splitter 2. Alpha-BBO 3. EEX+mask 4. EEX+transverse wiggler 5. TDC+mask (R&D)
	Charger per bunch [nC]	**<60**	
Longitudinal shaping	Shape	**Arbitrary**	1. EEX 2. TDC (R&D) 3. Laser based (R&D)
	Charge [nC]	**<5 → <20**	
Flat beam	Charge [nC]	**<5**	1. Angular momentum dominated beam + skew quads
	Emittance ratio	**<150**	
Transverse shaping	Available type	**1. Homogenization 2. Dot-array 3. Hollow**	1. MLA optics

FACET-II layout and beams

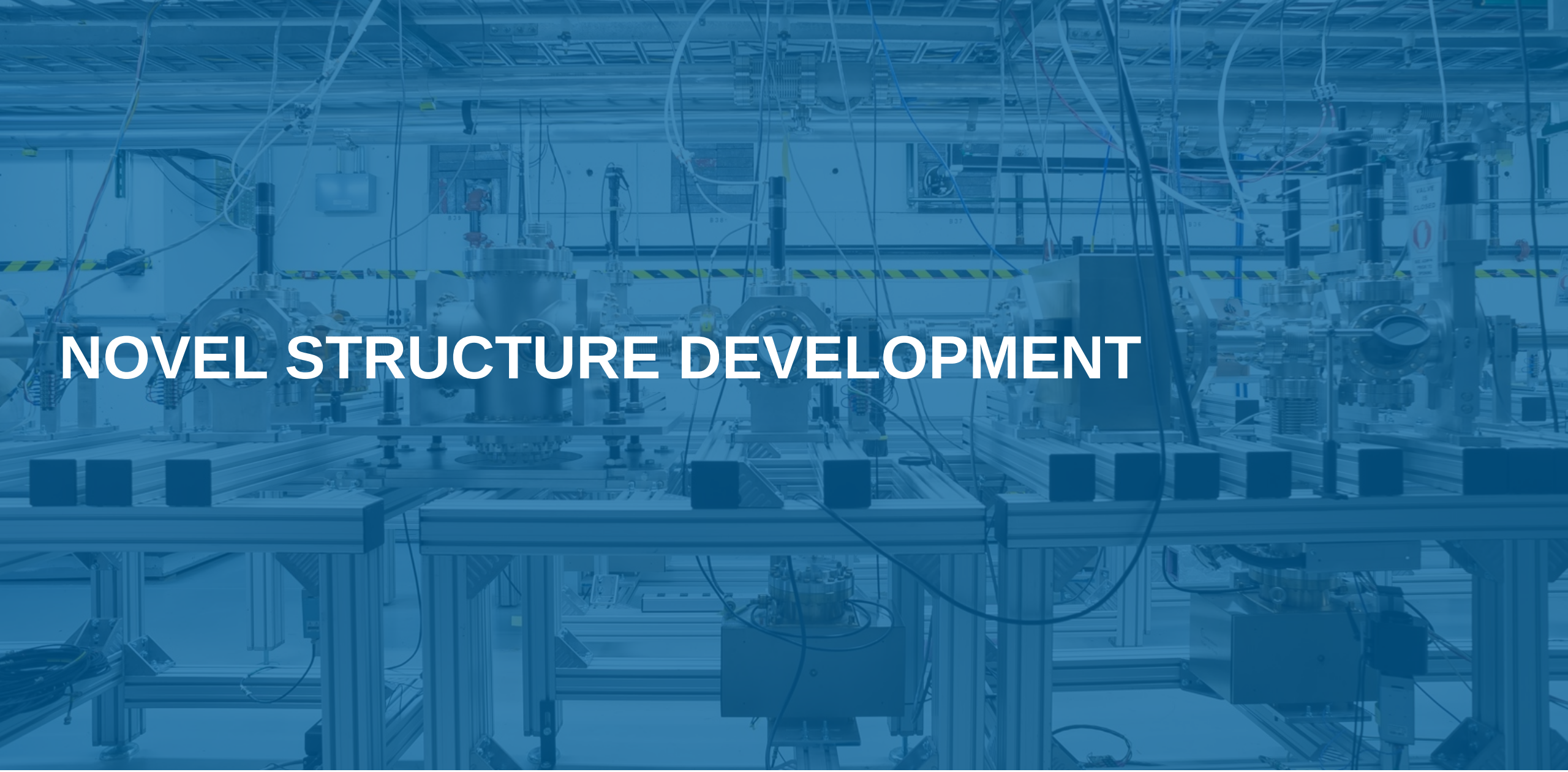


Electron Beam Parameter	Baseline Design	Operational Ranges
Final Energy [GeV]	10	4.0-13.5
Charge per pulse [nC]	2	0.7-5
Repetition Rate [Hz]	30	1-30
Norm. Emittance $\gamma\varepsilon_{x,y}$ at S19 [μm]	4.4, 3.2	3-6
Spot Size at IP $\sigma_{x,y}$ [μm]	18, 12	5-20
Min. Bunch Length σ_z (rms) [μm]	1.8	0.7-20
Max. Peak current I_{pk} [kA]	72	10-200

FACET-II Experimental area



Ideal for ~10 GV/m breakdown test



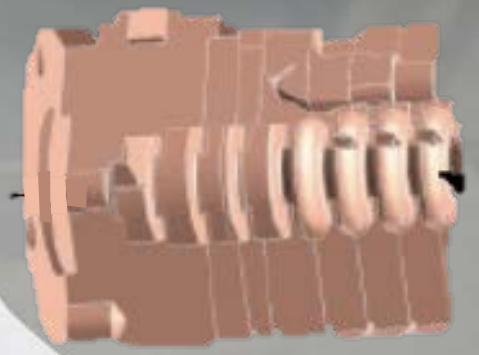
NOVEL STRUCTURE DEVELOPMENT

BEAM-DRIVEN STRUCTURE DEVELOPMENT

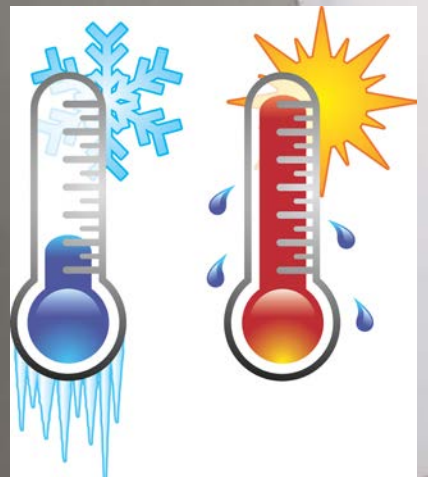
METALLIC

DIELECTRIC

materials



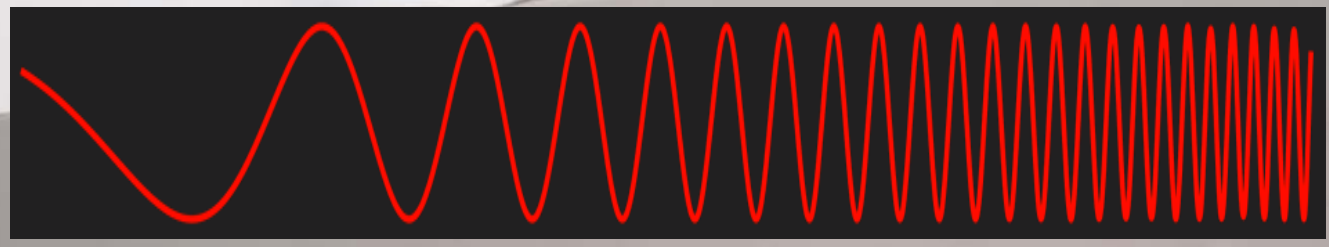
temperature



frequency

MICROWAVE

THz

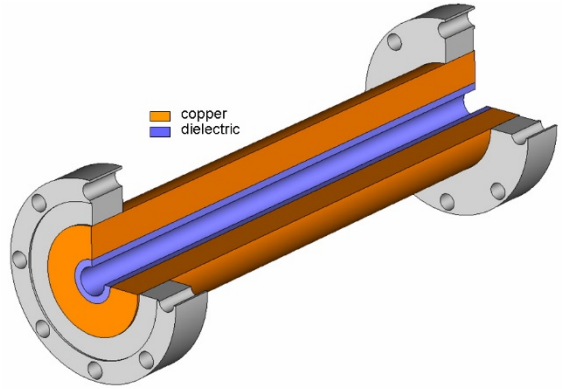


ADVANCED ACCELERATOR CONCEPTS

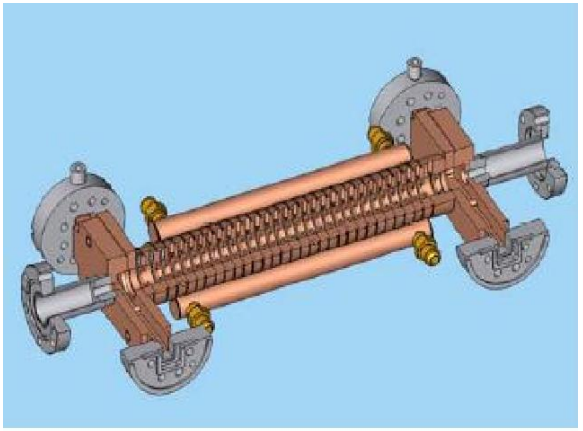
Structure Development

Geometry
planar & cylindrical

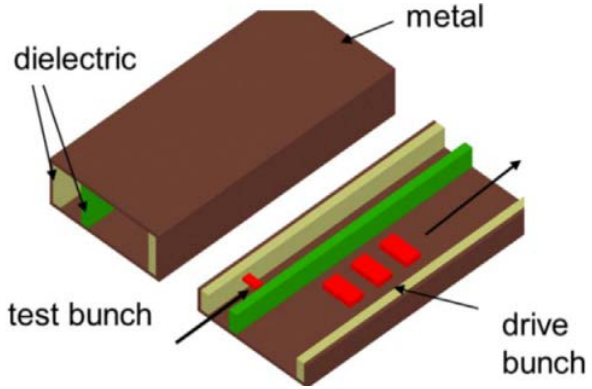
Dielectric loaded structures



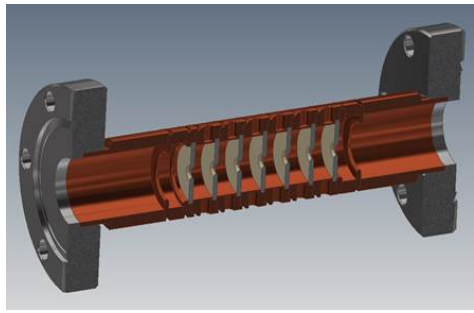
Iris loaded structures



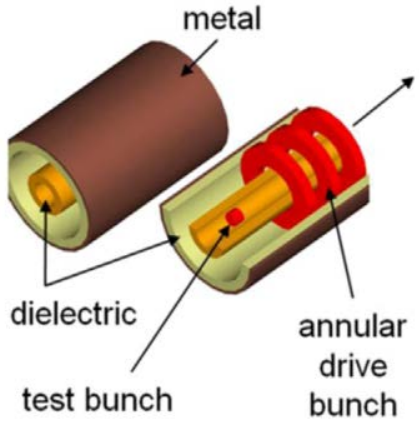
2-channel rectangular dielectric



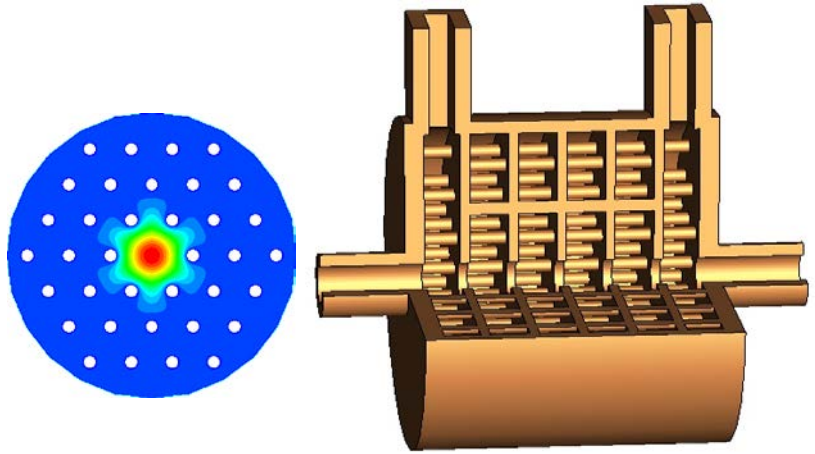
Dielectric disk accelerator



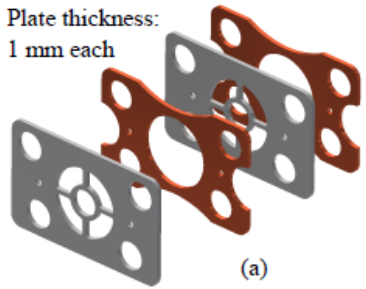
Coaxial dielectric



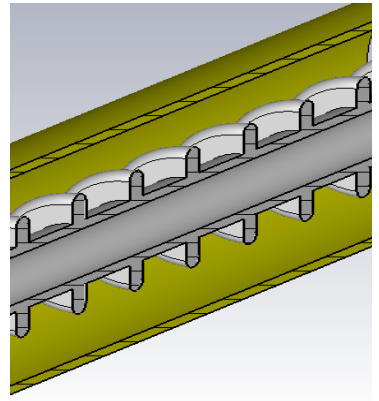
Photonic band gap structures

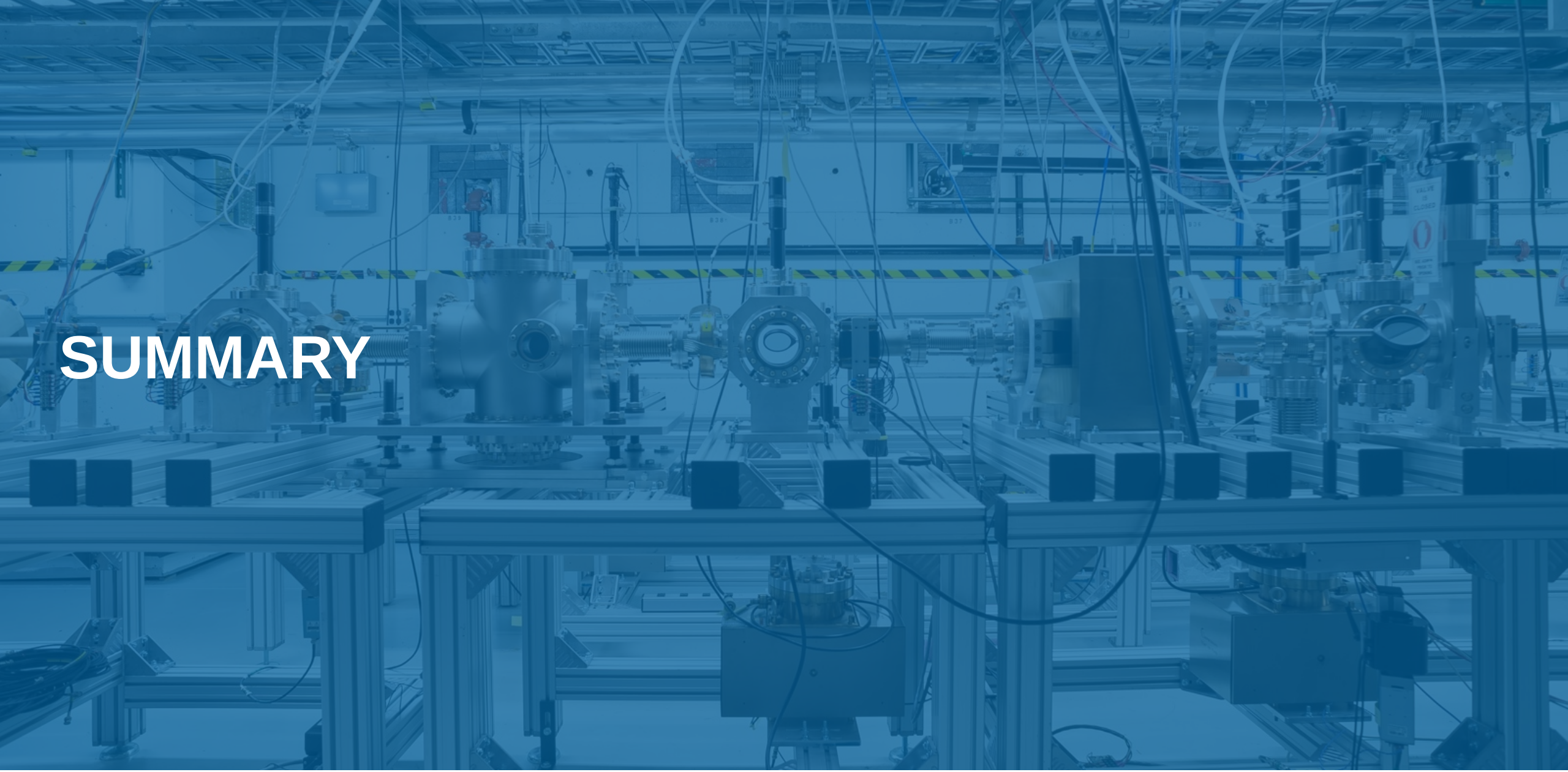


Meta/left-handed structures



Cryogenic Dielectric Corrugated accelerator





SUMMARY

FINAL REMARKS

LOI-90: Structure Wakefield Acceleration (SWFA) Development for an Energy Frontier Machine

Core Message of LOI:

1) the SWFA roadmap presented in 2016 *Advanced Accelerator Development Strategy Report* needs to be

Key Words:

Coherent efforts inside the SWFA community

More visibility outside the AAC community

More resources from funding agency