## Scientific Brainstorming Session

# Scientific Brainstorming Session

Everyone in the room Various world-leading institutions

> apart from Simon Hooker University of Oxford

### **Order of play**

- Brief review of outcome of each WG & comments on WG summaries
- Comparisons with US roadmaps
- Identification of common themes & synergies
- Next steps

Scientific bottleneck / challenge	Milest	tones		Comments	
	5 years	5 - 10 years	10 - 20 years		
femtosecond Injector >200MeV performance charge, dE/E, pointing stability			dQ/Q<2%, 100 pC, dE/E<2%, dE0/ E0<1%, do<0.1 mrad (2/5)dQ/ Q<2%, 100 pC, dE/E<2%, dE0/ E0<1%, do<0.1 mrad (5/5)All parameters, structured pulse? Polarized?	Only for electrons; development needed for positrons, select injector technique	
Repetition rate (laser)	>10 Hz	>100 Hz	>1 kHz	Wakefield drive laser	
Repetition rate (experiment)	10 Hz	100 Hz	1 kHz		
Efficiency (laser)	>1%	>10%	50%		
Laser beam quality	>90% in design mode				
Scalable single stage	>10 cm, 0.1 GeV/cm	1 meter, 0.1 GeV/cm	1 meter, 0.1 GeV/cm	Capillary discharge, hollow channels, structure suitable for positrons	
Staging	~unity charge throughput a	and emittance preservation	Scalability (multi-staging)		
Positron acceleration	Identify and test injection method	Acceleration demonstration (low emittance and dE/E)	Parity with electrons		
Fluctuations and feedback control	chargex1, Ex2, E0x2, mradx2	Active control of multiple fluctuations	all factors 1.01		
Efficient beamloading (longitudinal be	unch shaping)		ramped or multi-pulses		
Diagnostic resolution (bunch length a	and emittance)		fsec resolution, 0.1 mm-mrad normalizedenergy/phase correlation, single shot		
Diagnostic : plasma structure (single	shot, high resolution)		Inline 1/2+1D1 parameter in feedback loopsingle shot 4D		
Multi-bunch acceleration	Generation and separation control	Acceleration			
electron/positron polarization					
Fully predictive simulations					
Availability of test facilities					
Collider parameter (re)definition	Preliminary design study	CDR	TDR		
BDS/FF design	Preliminary design study	CDR	TDR		
LWFA collider baseline design	Preliminary design study	CDR	TDR		

#### WG1: LWFA

- Suggests definition of LWFA baseline design, CDR, TDR
- Proposed collider definition parameter flow: physics → luminosity → BDS → linac → injector
- BDS and FF design study
- Defines target "injector" performance
- Milestones for control of fluctuations

Scientific	Milos		Commonto		
bottleneck /	Miles	lones		Comments	
	5 years	5 - 10 years	10 - 20 years		
femtosecond Injector >200MeV performance charge, dE/E, pointing stability			dQ/Q<2%, 100 pC, dE/E<2%, dE0/E0<1%, do<0.1 mrad	Only for electrons; development needed for positrons, select	
Repetition rate (laser)	>10 Hz	>10 Hz >100 Hz		Wakefield drive laser	
Repetition rate (experiment)	10 Hz	100 Hz	1 kHz		
Efficiency (laser)	>1%	>10%	50%		
Laser beam quality	>90% in design mode				
Scalable single stage	>10 cm, 0.1 GeV/ cm	1 meter, 0.1 GeV/ cm	1 meter, 0.1 GeV/ cm	Capillary discharge, hollow	
Staging	~unity charge throughput and emittance preservation		Scalability (multi- staging)		
Positron acceleration	Identify and test injection method	Acceleration demonstration	Parity with electrons		
Fluctuations and feedback control	chargex1, Ex2, E0x2, mradx2	Active control of multiple	all factors 1.01		
Efficient beamloadii	ng (longitudinal bunch	n shaping)	ramped or multi- pulses		
Diagnostic resolutio	n (bunch length and e	emittance)	fsec resolution, 0.1 mm-mrad		
Diagnostic : plasma	structure (single sho	t, high resolution)	Inline 1/2+1D1 parameter in		
Multi-bunch acceleration	Generation and separation control	Acceleration			
electron/positron polarization					
Fully predictive simulations					
Availability of test facilities					
Collider parameter	Preliminary design study	CDR	TDR		
BDS/FF design	Preliminary design study	CDR	TDR		
LWFA collider baseline design	Preliminary design study	CDR	TDR		

Scientific bottleneck / challenge	Facilities / capabilities needed		Milestones	Electron-driv	<mark>en</mark>	Comments
	Experimental	erimental Computational 5		5 - 10 years	10 - 20 years	
Collider Design		Start to End Simulations	Develop and maintain self- consistent parameters	Develop and maintain self- consistent parameters	CDR, TDR	R&D on concepts, including experiments and simulations. Will require engagement of larger accelerator & detector
Designing Experiments for Cor	ncept Validation at Test Facilities		Support for collaborations & University groups	Support for collaborations & University groups	Support for collaborations & University groups	Strongest collaborations involve University and National Labs
Optimized Beam Loading Scenarios			Self-consistant set for positrons	s		Develop self-consistant scenarios for beam loading (high-gradient, high- efficiency and emittance
Positrons	High-energy, High peak current	, sub-ps positron beams & spec	ialized plasma sources	Exploration of self-loaded regime, hollow channels, quasi non-linear reginmes	Plasma sources for e- & e+ bea	am production
Beam quality preservation	Matched Injection, acceleration	, extraction	Emittance preservation at 1 $\mu$ m level with % level dE/E			Transverse wakes, hosing, lon motion, plasma source development with ramps, external injection
Development of low emittance PWFA based e- sources	Laser to e- beam spatial-tempo (synchronization), specialized p diagnostics	oral alignment blasma sources, low emittance	Emittance preservation at $1\mu$ m level	Emittance preservation at 100r	nm level (external injection)	
Transformer Ratio >1	Shaped beams with high peak wakes	current to drive non-linear	Shaped beam experiments and demonstration of $T > 2$ (low E)	Shaped beam experiments and demonstration of T > 2 (high E)		Develop and demonstrate techniques for beam shaping
Beam Dynamics & Tolerances	Independent drive-witness beams with temporal & spatial alignment control. Diagnostics with sub- $\mu$ m, fs	Development of analytic model integration, new physics packa	s, accelerator & plasma code ages	Parametric staging studies with independent drive-witness beam		Basic processes in addition to tolerance studies need to consider: Hosing, radiation loss, polarization
Plasma Sources	Tailored density ramps, differer management	itial pumping solutions, thermal	Tailored density ramps, differential pumping solutions	Hollow (and quasi-hollow) char	nnels development	Plasma profiles for emittance preservation at any Hz, refine to kHz rep rates with heat transport
Systems Integration				Drive-Main beam merging and	extraction	Bunch compressors, drive beam format, delay, delivery, energy scaling, lareg dE/E beam dump for spent beam
Staging	Capability for multi-GeV with hi	gh capture efficiency		Studies with independent witness injector	Multi-stage demonstration in FFTBD	Optical design for multiple stages
Diagnostic development	Visualize wakes, EOS (bunch o Emittance measurement, Selec to separate driver and witness)	luration, synchronization & time- tive driver/witness bunch measu , High rep rate effects diagnostic	of-arrival), Novel plasma-based irement (charge, size, current pr s , (Transverse) electron beam p	fs&µm spatiotemporal alignment ofile), Plasma density tomograph probing of wake	(pioneered in E210), ny, Ultrafast bunch kickers (e.g.	Single shot preferred
Simulation Development		Adaptive mesh refinement, Ada Adaptive 2d and 3d time steps, on OSIRIS 4.0 packages	aptive particle loading:Vary Npce Intel Phi and GPUs, Radiation r	ell and/or particle merging and sp reaction (basic model is impleme	litting, Dynamic load balancing, nted) and QED effects based	Quasistatic codes are workhorse for beam driven (experimental planning, data interpretation, initial collider

### WG2: PWFA (electron driven)

- Collider design, S2E simulations, CDR, TDR
- Optimized beam loading
- Beam quality preservation
- Transformer ratio > 1
- Staging
- Diagnostics development

Scientific bottleneck / challenge	Facilities / capabilities needed		Milestones			Comments
	Experimental	Computation al	5 years	5 - 10 years	10 - 20 years	
Collider Design		Start to End Simulations	Develop and maintain self- consistent	Develop and maintain self- consistent	CDR, TDR	R&D on concepts, including
Designing Expe at Test Facilities	eriments for Conc s	ept Validation	Support for collaborations & University	Support for collaborations & University	Support for collaborations & University	Strongest collaborations involve
Optimized Beam Loading			Self-consistant positrons	set for		Develop self- consistant scenarios for
Positrons	High-energy, Hi positron beams	gh peak current, & specialized pla	sub-ps asma sources	Exploration of self-loaded regime,	Plasma sources beam productio	s for e- & e+ n
Beam quality preservation	Matched Injection acceleration, ex	on, traction	Emittance preservation at $1\mu$ m level with % level dE/E		Transverse wakes, hosing, lon	
Development of low emittance	Laser to e- bear temporal alignm (synchronization	m spatial- ient n), specialized	Emittance preservation at 1µm level	Emittance preservation at 100nm level (extern injection)		
Transformer Ratio >1	Shaped beams current to drive wakes	with high peak non-linear	Shaped beam experiments and	Shaped beam experiments and demonstration of $T > 2$ (high E)		Develop and demonstrate techniques for
Beam Dynamics & Tolerances	Independent drive-witness beams with	Development of models, acceler code integration	f analytic rator & plasma n. new physics	Parametric staging studies with independent drive-witness		Basic processes in addition to
Plasma Sources	Tailored density differential pum thermal manage	ramps, ping solutions, ement	Tailored density ramps,	Hollow (and qua channels develo	asi-hollow) opment	Plasma profiles for emittance
Systems Integration				Drive-Main bea extraction	m merging and	Bunch compressors, drive beam
Staging	Capability for m efficiency	ulti-GeV with hig	h capture	capture Studies with Multi-stage demonstration witness in FETRD		Optical design for multiple
Diagnostic development	Visualize wakes plasma-based f measurement, S	s, EOS (bunch du s&µm spatiotemp Selective driver/w	ration, synchroni ooral alignment (p vitness bunch me	zation & time-of- pioneered in E210 asurement (char	arrival), Novel 0), Emittance ge, size, current	Single shot preferred
Simulation Development		Adaptive mesh and/or particle r Adaptive 2d and	refinement, Adap nerging and split d 3d time steps, I	nement, Adaptive particle loading:Vary Npcell ging and splitting, Dynamic load balancing, d time steps. Intel Phi and GPUs. Radiation		

Scientific bottleneck / challenge	Facilities / capabilities needed		Milestones	Proton-driven		Comments
	Experimental	Computational	5 years	5 - 10 years	10 - 20 years	
Demonstration/control of SMI of p+ buncn	Exist	Limited to 2D simulations/3D Quasi- static	Seeding, dependencie, r	maintaining high gradient		
Acceleration of externallyinjected e-, sample wakefields	Exist		GeV enery, finite	GeV enery, finite energy spread (~10%), low trapped charge		
Acceleration of short e- bunch	Exist (?)	3D simulations, redudec and full PIC	Multi GeV, large charge capture	Multi-GeV, full charge	e capture, emittance<10mr application)	n-mrad (e-/p+ colider
Development of scalable plasma source 5-10-100's m, high density uniformity (<1%)	New plasma source developemnt laboratory	Plasma simulations of helicon sources	4-10m	100m	100's m	Type of source not defined
Quick 3D simulation	e capabilities for optimizatio experimental results	n and comparison w				
Production of shorter p+ bunches (few cm)	Existing machine (SPS)		"Beam gymnastic in existing machine, longitudinal beam cooling		dinal beam cooling	
Production of ultra-short p+ bunch (<1mm, TeV energy, 1e11p+)	New p+ bunch source? Compression after extraction?	Machine impedance sir	mulation/understanding			
Production of low e	emittance p+ bunch		Transverse beam cooling			
Pre-modulation of p+ bunch (no plasma)	tion of p+ High frequency linac, dispersive section (SPS- plasma) AWAKE beam line)		Parameter studies			
Identify accelerator for fixed target studies, detectors calibartions, etc.	Facility including plasma bunch AND phys	-based accelerator of p+ ics experiment(s)	Identify possible physics experiment	Design of suitable facility	Building facility	(10-100GeV)
Diagnostics for plasma wave/wakefields	Exist		Transverse diagnostics on existing source, shadowgraphy, etc.	Design of source with transverse and longitudinal acc acceleration, shadowgraphy, spectral interf		acces to plasma, phton terferometry?

### WG2: PWFA (proton driven)

Scientific bottleneck / challenge	Facilities / capabilities needed		Milestones			Comments
	Experiment al	Computati onal	5 years	5 - 10 years	10 - 20 years	
Demonstrati on/control of SMI of p+	Exist	Limited to 2D simulations/	Seeding, de maintaining	ependencie, high gradient		
Acceleratio n of externallyinj	Exist		GeV enery, fi	nite energy sp w trapped char	read (~10%), ge	
Acceleratio n of short e- bunch	Exist (?)	3D simulations, redudec	Multi GeV, large charge	Multi-Ge emittance<	eV, full charge 10mm-mrad (e application)	capture, -/p+ colider
Developme nt of scalable	New plasma source	Plasma simulations of helicon	4-10m	100m	100's m	Type of source not defined
Quick 3D optimiza ex	simulation cap ation and comp perimental res	abilities for arison w ults				
Production of shorter p+ bunches	Existing machine (SPS)		"Beam gymnastic in existing machine, longitudinal beam cooling		ng machine, ooling	
Production of ultra- short p+	New p+ bunch source?	Machine in simulation/ur	mpedance nderstanding			
Producti emittance	on of low p+ bunch		Transverse beam cooling			
Pre- modulation of p+ bunch	High frequ dispersive s AWAKE t	ency linac, ection (SPS- beam line)	Parameter studies			
Identify accelerator for fixed	Facility inclu based acce bunch AN	ding plasma- lerator of p+ ID physics	Identify possible physics	Design of suitable facility	Building facility	(10-100Ge V)
Diagnostics for plasma wave/	Exist		Transverse diagnostics on existing	Design of s longitudina acceleration	ource with trar al acces to plas n, shadowgrap	sverse and ma, phton hy, spectral

Scientific bottleneck / challenge	Facilities / capabilities needed		Milestones			Comments
	Experimental	Computational	5 years	5 - 10 years	10 - 20 years	
positron source for THz main beam	need to develop and demonstrate	need R&D	get \$\$\$\$	get \$\$\$\$\$\$\$		
BBU in THz drive beam	demonstrate test module with BBU control	no new code development needed but simulation needs to be done	cylindrical CWA BBU test planned; no planar test planned	establish BBU limit of pl	anar and cylindrical and us LC	se these to optimize the

#### WG3: DWA

- Refreshingly honest about need for \$\$\$, €€€€, CHF
- Positron source
- Beam break up (BBU)

Scientific bottleneck / challenge	Facilities / capabilitie s needed		Milestones			Comments
	Experimen tal	Computati onal	5 years	5 - 10 years	10 - 20 years	
positron source for THz main beam	need to develop and demonstrat e	need R&D	get \$\$\$\$\$	get \$\$\$\$\$ \$\$\$		
BBU in THz drive beam	demonstrat e test module with BBU control	no new code developme nt needed but simulation needs to be done	cylindrical CWA BBU test planned; no planar test planned	establish cylindrical a	BBU limit of p and use these the LC	lanar and to optimize

#### WG3: DWA



ANAR workshop, CERN 25 - 28 April 2017

Scientific bottleneck / challenge (priority)	Facilities / capabilities needed		Milestones			Comments
	Experimental	Computational	5 years	5 - 10 years	10 - 20 years	
Achievable laser wall-plug efficiency (low)	N/A	N/A	N/A	N/A	N/A	Solid state lasers with 30% efficiency already available,
Laser to dielectric coupling efficiency (med)	N/A	N/A	N/A	N/A	N/A	On-chip highly efficient waveguides, splitters need to
Field to electron efficiency (med)	SwissFEL, DESY, ATF	Vsim, Ace3P	N/A	N/A	N/A	Theoretical studies have been done, experimental
Cost drivers and trends/ projections (med)	N/A	N/A	N/A	N/A	N/A	Total power consumption estimated below 500 MW
Requirements for final focus system (low)	N/A	N/A	N/A	N/A	N/A	Requirements possibly the same as for other novel (and
Luminosity, disruption, beamstrahlung (low)	N/A	N/A	N/A	N/A	N/A	Estimates indicate sufficient luminosity achievable
Requirements for dispersive microbunch	N/A	N/A	N/A	N/A	N/A	Likely to happen naturally in final focusing section
Electron Sources (Med)	FAU, UCLA, Stanford	N/A	N/A	N/A	N/A	Conventioal RF sources may produce adequate
Positron Sources (High)	N/A	N/A	Simulation and feasibility study	N/A	N/A	
Gamma-Gamma (Low)	N/A	N/A	N/A	N/A	N/A	Possible alternative application, laser
Choice of Laser Wavelength (Low-Med)	N/A	N/A	N/A	N/A	N/A	Larger wavelengths (than mid to near IR) ease electron
Laser Technical Requirements (Low)	N/A	N/A	N/A	N/A	N/A	Laser parameters for market lasers are near HEP
High-field damage mechanisms in dielectrics	N/A	N/A	N/A	N/A	N/A	Already demonstrated target gradients with available
SPM, Dispersion, and Raman Scattering (Med)	N/A	N/A	N/A	N/A	N/A	Kerr-effect has been experimentally observed,
Heat dissipation at high laser rep rate (Med)	N/A	N/A	N/A	N/A	N/A	Estimated heat dissipation for typical DLA ~1 W/cm^2 well
Periodic focusing for long- distance transport (high)	SwissFEL, FACET-II, FLASH, DESY, ATF-II	Elegant, GPT	Exp: First demonstration technique (concept) with	N/A	N/A	Need a long-distance focusing tracking study with
Radiation hardness and charging effects (High)	SwissFEL, FACET-II	N/A	Experimental tests at lower beam powers, Sim:	N/A	N/A	In addition to electrons depositing energy in material,
Wakefields - longitudinal and transverse -	N/A	Vsim, ACE3P, etc.	Simulation studes connected to those above	N/A	N/A	We must understand wall losses and the induced
BBU (High)	N/A	Vsim, ACE3P, etc.	Simulation studes connected to those above	N/A	N/A	Closely related to wakefields, loading
Start-to-end modelling (Med)	N/A	Vsim, ACE3P, etc.	Simulation studes connected to those above	N/A	N/A	Hasn't been done yet but is planned to occur as part of
Sub-micron coalignment and diagnostics over km	N/A	N/A	N/A	N/A	N/A	Active interferometric feedback is needed LIGO
Halo and beam collimation? (High)		New code needed	Simulation study	N/A	N/A	Nonlinear dielectric response may exacerbate beam halo.
Intrabeam scattering of the bunch particles (note low	N/A	N/A	N/A	N/A	N/A	Note that envelope equation not strictly valid here.
Combination of multiple parallel beams (Med)	N/A	N/A	N/A	N/A	N/A	Matrix accelerator may aid with achieving desired

#### WG4: DLA

- Identifies low / med / high priorities
- High-priority areas
  - Focusing & transport
  - Radiation hardness & charging
  - Wakefield and BBU
  - Beam halo & collimation
  - Compatible positron source
- Suggests gamma-gamma collider as alternative
- Sub-micron alignment over km distances - LIGO

Scientific bottleneck /	Facilities / capabilities		Milestones			Comments
	Experimental	Computationa I	5 years	5 - 10 years	10 - 20 years	
Achievable laser wall-	N/A	N/A	N/A	N/A	N/A	Solid state lasers with
Laser to dielectric	N/A	N/A	N/A	N/A	N/A	On-chip highly efficient
Field to electron	SwissFEL, DESY. ATF	Vsim, Ace3P	N/A	N/A	N/A	Theoretical studies have
Cost drivers and trends/	N/A	N/A	N/A	N/A	N/A	Total power consumption
Requirements for final focus	N/A	N/A	N/A	N/A	N/A	Requirements possibly the
Luminosity, disruption,	N/A	N/A	N/A	N/A	N/A	Estimates indicate
Requirements for dispersive	N/A	N/A	N/A	N/A	N/A	Likely to happen
Electron Sources	FAU, UCLA, Stanford	N/A	N/A	N/A	N/A	Conventioal RF sources
Sources	N/A	N/A	feasibility	N/A	N/A	Dessible
Gamma (Low)	N/A	N/A	N/A	N/A	N/A	alternative
Laser	N/A	N/A	N/A	N/A	N/A	wavelengths
Technical	N/A	N/A	N/A	N/A	N/A	parameters for
damage	N/A	N/A	N/A	N/A	N/A	demonstrated
Dispersion,	N/A	N/A	N/A	N/A	N/A	been Estimated heat
dissipation at	N/A SwissEEI	N/A	N/A Evo: Eirct	N/A	N/A	dissipation for
focusing for Badiation	FACET-II.	Elegant, GPT	demonstration Experimental	N/A	N/A	distance
hardness and Wakefields -	FACET-II	N/A Vsim_ACE3P	tests at lower	N/A	N/A	electrons
longitudinal	N/A	etc. Vsim, ACE3P	Simulation	N/A	N/A	understand Closely related
BBU (High) Start-to-end	N/A	etc. Vsim, ACE3P.	studes Simulation	N/A	N/A	to wakefields. Hasn't been
modelling Sub-micron	N/A	etc.	studes	N/A	N/A	done vet but is Active
coalignment Halo and	N/A	N/A New code	N/A Simulation	N/A	N/A	interferometric Nonlinear
beam Intrabeam	N1/A	needed	study	N/A	N/A	dielectric Note that
scattering of Combination	N/A	N/A	N/A	N/A	N/A	envelope Matrix
of mouldingle	IN/A	IN/A	IN/A	IN/A	N/A	oppolorator

#### **Differences WRT US Roadmap**



Everyone in the room World-leading institutions

#### **Comparison with US Roadmap: LWFA**

- Defines time scales for 10
   GeV module and > GeV
   staging
- Positron accel. mid 2020s
- kHz GeV linac < 2030</p>
- kHz, 50 100 GeV ~ 2040



Figure 1: Roadmap for the development of a LWFA based collider, which lays out phases for invention and discovery (during the next decade), the emergence of first applications, and prototype demonstrators. A conceptual design study could occur in the 2025-2035 time frame, followed by a fiv year technical design study, culminating with start of construction around 2040.

#### **Comparison with US Roadmap: LWFA**

- Defines time scales for 10
   GeV module and > GeV
   staging
- Positron accel. mid 2020s
- kHz GeV linac < 2030</p>
- kHz, 50 100 GeV ~ 2040
- Detailed goals defined for next 10 years

2016	2018		2020	2022	2	024	2026
		10 0	GeV e-beams f	rom a single	stage		
Present	Goals		Staging 2.0: d	emonstration	of 5GeV+	5GeV	
.3 GeV	10 GeV		Present	Goals	Positi	Positron beams	
0 pC	100 pC		0.1 GeV boost	5 GeV	Goal:	novel con	cept for a
Inmatched	Matched gu	iding			based	positron	a accelerator source
Fluctuates	Stable,	Stable, reproducible, tunable		100pC, >90% captured	Pair pr	oduction fr	rom LPA
	reproducible tunable			>5GV/m	Positro	on beam ca	aptured in PWFA
Second beamline on BELLA		Emittance growth	Emittance preserved	Positro	on accelera stage	ation in laser	
Laser tech R&D k-BELLA = kW class, kHz, 100 TW laser							
	5 Hz. 0.5-1	GeV	beam		kHz. 0.5-	I GeV be	eam
	Present	Goals	5	Present		Goals	
	$\epsilon$ < 0.3 micron	ε < 0.	1 micron	Limited control f	eedback	dback Full feedback stabilizat	
	ΔE/E ~ 1-5%	ΔE/E	< 1%	Low average pow	ver (<4 W)	(<4 W) High average power (>1 k	
	Q~10 pC	Q~10	рС	Pointing < 0.5 mrad Pointing		Pointing	< 0.05 mrad
	γ-ray source	(>10	<sup>7</sup> ph/s)		γ-ray so	urce (>I	0 <sup>10</sup> ph/s)
L	WFA powere	d FEL	_ (XUV)	LW	FA powe	red FEL	(I-10 nm)
	Plasma ta	rget a	and energy re	covery techn	ology		
Present		Go	als	G	ioals		
Longitudir	nally uniform	Тар	pered	H	leat mitigati	on and >10	0 <sup>8</sup> shots
Parabolic		Ne	ar hollow	In	letime at KF	IZ	roach high
10 cm		>3	0 cm	e	fficiency		reactingin
1 kHz rep	rate	10	kHz rep rate	S	pent laser of	energy reco	overy
			Diagnostic	S			
Goals							
Non-inva	asive phase space	e diagr	nostics for 0.01-0.1	1-mm-mrad			
Femtose	cond resolution	for slice	properties				

Simulations					
Present	Goals				
1 D MHD	3 D MHD				
2 weeks for 1 high res 3D BELLA simulation run	<1 Hr for 1 high res 3D BELLA simulation run				

Figure 2: Ten-year LWFA roadmap and milestones. The orange boxes are activities, with present status

#### **Comparison with US Roadmap: LWFA**

- Defines time scales for 10
   GeV module and > GeV
   staging
- Positron accel. mid 2020s
- kHz GeV linac < 2030</p>
- kHz, 50 100 GeV ~ 2040
- Detailed goals defined for next 10 years
- Also roadmap for laser technology



"Stepping stor 30 kW class         "Stepping stor 30 kW class         "I & contrast demo         Fiber Laser Technology         "I & contrast demo         "I & contrast demo         "I & contrast demo         "I & contrast demo         I & contrast demo <td col<="" th=""><th>2016</th><th>2018</th><th>2020</th><th>) 2022</th><th></th><th>2024</th><th>2026</th></td>	<th>2016</th> <th>2018</th> <th>2020</th> <th>) 2022</th> <th></th> <th>2024</th> <th>2026</th>	2016	2018	2020	) 2022		2024	2026	
Fiber Laser Technology       -1J & contrast demo         Fiber Laser Technology       -1J & contrast demo         -5mJ       100mJ ->1J       30J         -500W       3kW       30kW         -300fs       -30fs       -100fs         Contrast 10 - 20dB       Contrast 30 - >40dB       Contrast 50 - >60dB	k-BELLA	.: kW class, k⊢	z, 100	TW laser		" 	Stepping stone"		
Present       Goals: near term       Goals: mid term         1-5mJ       100mJ ->1J       30J         -500W       3kW       30kW         -300fs       ~30fs       ~100fs         Contrast: 10 - 20dB       Contrast 30 ->40dB       Contrast 50 ->60dB         Scaling to 3WU demo       -80% WPE pump laser & power scaling demo       ▲         Present       Goals       -80% WPE pump laser & power scaling demo       ▲         1-10Hz       1kHz       -80% WPE pump laser & power scaling demo       ▲         1-10Hz       1kHz       -80% WPE: >15%        ≤         < 100W       >3kW       -80% WPE pump laser & power scaling demo       ▲         Common Technologies       -80% WPE pump laser & power scaling demo         Common Technologies       Contrast enhancing technology         >30kW mirrors and coatings       >30kW and broadband beam combiners       Contrast enhancing technology         >30kW pulse compression gratings       >30kW adaptive optics       Contrast enhancing technology         >30kW pulse compression gratings       >30kW adaptive optics       Contrast enhancing technology         >30kW and broadband beam combiners       >30kW adaptive optics       >1kHz         Socis suitable diode-pumped solid-state material meeting pulse duratio	Fiber Laser Te	100mJ/30fs/kW &	contrast	demo	~1J & cont	rast demo			
1-5mJ 100mJ ->1J 30J -500W 3kW 30kW -300fs -30fs -100fs Contrast: 10 - 20dB Contrast 30 ->40dB Contrast 50 ->60dB Scaling to 3WU demo -80% WPE pump laser & power scaling demo Meresent Goals 1-10Hz 1kHz WPE: << 5 % WPE: >15% < 100W >3kW K-BELLA: kW class, kHz, 100 TW laser K-BELLA: kW class, kHz, 100 TW laser Common Technologies Ready for 30kW adaptive optics SolkW mirrors and coatings >30kW adaptive optics >30kW mirrors and coatings >30kW adaptive optics SolkW pulse compression >30kW adaptive optics SolkW pulse compress	Present	Goals: near t	erm	Goals: mid term		-			
-500W       3kW       30kW         -300fs       -30fs       -100fs         Contrast: 10 - 20dB       Contrast 30 - >40dB       Contrast 50 - >60dB         Scaling to 3kW demo       -80% WPE pump laser & power scaling demo       Image: Contrast 30 - >40dB         Present       Goals       Contrast 30 - >40dB       Contrast 50 - >60dB         1-10Hz       1kHz       IkHz       IkHz         WPE: << 5 %	1-5mJ	100mJ – >1J		30J	Ytterbium Laser System				
300fs       -30fs       ~100fs         Contrast: 10 - 20dB       Contrast 30 - >40dB       Contrast 50 - >60dB         Scaling to 3/W demo       -80% WPE pump laser & power scaling demo       Image: Contrast 30 - >60% WPE pump laser & power scaling demo         Present       Goals       -80% WPE pump laser & power scaling demo       Image: Contrast 30 - >60% WPE pump laser & power scaling demo         Present       Goals       -80% WPE pump laser & power scaling demo       Image: Contrast 30 - >60%         Present       Goals       -10Hz       1kHz       Image: Contrast 30 - >6%         VPE: << 5 %	-500W	3kW		30kW		YLS -100 000			
Contrast: 10 - 20dB       Contrast 30 - >40dB       Contrast 50 - >60dB         Scaling to 3kW demo       -80% WPE pump laser & power scaling demo         Present       Goals         1-10Hz       1kHz         WPE: << 5 %	-300fs	~30fs		~100fs	1 <sup>1</sup> .				
Scaling to 3kW demo       -80% WPE pump laser & power scaling demo         Present       Goals         1-10Hz       1kHz         WPE: << 5 %	Contrast: 10 - 20d	B Contrast 30 -	>40dB	Contrast 50 - >60dB	00	-0-0	0-0-0		
Present       Goals         1-10Hz       1kHz         WPE: <5 %	Scaling t	o 3kW demo	~809	% WPE pump laser & powe	r scaling d	emo			
1-10Hz       1kHz         WPE: <5 %	Present	Goals					11_		
WPE: << 5 %	1-10Hz	1kHz					<u>P</u>		
< 100W >3kW          k-BELLA: kW class, kHz, 100 TW laser       "Stepping stepsing stepsing stepsing keeles         Common Technologies       Ready for 30kW class laser demo         Goals       Ready for 30kW class laser demo         >30kW mirrors and coatings       >30kW and broadband beam combiners       Contrast enhancing technology (e.g. plasma mirrors) operating >1kHz         >30kW pulse compression gratings       >30kW adaptive optics       Contrast enhancing technology (e.g. plasma mirrors) operating >1kHz         Direct-CPA bulk       Goal: suitable diode-pumped solid-state material meeting pulse duration, energy, average power, and WPE requirement simultaneously       100fs with -25% WPE demo         CO2       100fs with -25% WPE demo       Image: Stepping stepsing steps	WPE: << 5 % WPE: >15%								
k-BELLA: kW class, kHz, 100 TW laser       "Stepping stepsing									
k-BELLA: kW class, kHz, 100 TW laser Stepping store 30 kW class Common Technologies Common Technologies Solution Technologies Solut					- Silver	Steel C			
Common Technologies       Ready for 30kW class laser demo         Goals       SokW mirrors and coatings       SokW and broadband beam combiners       Contrast enhancing technology (e.g. plasma mirrors) operating         >30kW pulse compression gratings       >30kW adaptive optics       Contrast enhancing technology (e.g. plasma mirrors) operating         >30kW pulse compression gratings       >30kW adaptive optics       Contrast enhancing technology (e.g. plasma mirrors) operating         Direct-CPA bulk       Soal: suitable diode-pumped solid-state material meeting pulse duration, energy, average power, and WPE requirement simultaneously         CO2       100fs with ~25% WPE demo       A         Goals: increase efficiency and reduce pulse duration simultaneously, increase system reliability and meet size requirements       100fs with >25% WPE	k-BELLA	.: kW class, k⊢	z, 100	)TW laser		" 3	Stepping stone" 0 kW class		
Goals         >30kW mirrors and coatings       >30kW and broadband beam combiners       Contrast enhancing technology (e.g. plasma mirrors) operating >1kHz         >30kW pulse compression gratings       >30kW adaptive optics       >1kHz         Direct-CPA bulk       Goal: suitable diode-pumped solid-state material meeting pulse duration, energy, average power, and WPE requirement simultaneously       Image: CO2         CO2       100fs with ~25% WPE demo       Image: Coals: increase efficiency and reduce pulse duration simultaneously, increase system reliability and meet size requirements	Common Tec	hnologies			Read	y for 30kW class	s laser demo		
>30kW mirrors and coatings       >30kW and broadband beam combiners       Contrast enhancing technology (e.g. plasma mirrors) operating >1kHz         >30kW pulse compression gratings       >30kW adaptive optics       >1kHz         Direct-CPA bulk       Goal: suitable diode-pumped solid-state material meeting pulse duration, energy, average power, and WPE requirement simultaneously       CO2         CO2       100fs with ~25% WPE demo         Goals: increase efficiency and reduce pulse duration simultaneously, increase system reliability and meet size requirements       Increase system	Goals								
>30kW pulse compression sources sources sources sources sources sources sources sources sources are sources and whether the source pulse duration is a source pulse durating duratin	>30kW mirrors ar	nd coatings	>30kV combi	V and broadband beam ners	C (e	Contrast enhancing technolo (e.g. plasma mirrors) operatir			
Direct-CPA bulk Goal: suitable diode-pumped solid-state material meeting pulse duration, energy, average power, and WPE requirement simultaneously CO2 100fs with ~25% WPE demo Goals: increase efficiency and reduce pulse duration simultaneously, increase system reliability and meet size requirements 100fs with >25% WPE	>30kW pulse con gratings	npression	>30kV	V adaptive optics	>	2 IKHZ			
Goal: suitable diode-pumped solid-state material meeting pulse duration, energy, average power, and WPE requirement simultaneously         CO2       100fs with ~25% WPE demo         Goals: increase efficiency and reduce pulse duration simultaneously, increase system reliability and meet size requirements         100fs with >25% WPE	Direct-CPA b	oulk							
CO <sub>2</sub> 100fs with ~25% WPE demo Goals: increase efficiency and reduce pulse duration simultaneously, increase system reliability and meet size requirements 100fs with >25% WPE	Goal: suita average po	ble diode-pumpe ower, and WPE re	d solid quirem	-state material meeting ent simultaneously	g pulse o	luration, ene	rgy,		
Goals: increase efficiency and reduce pulse duration simultaneously, increase system reliability and meet size requirements 100fs with >25% WPE	CO,			100fs with ~25%	WPE den	סו			
100fs with >25% WPE	Goals: reliabi	increase efficien ity and meet size	cy and requir	reduce pulse duration	n simulta	neously, inc	rease system		
	100fs v	vith >25% WPE							

Figure 3: Ten-year roadmap and milestones for laser technology development. In the next decade technology would be developed and implemented for a high average power demonstration facility. [R-N BELLA) at the few kW level, followed by scaling suitable technology to the tens of kW-level. The different technologies that are available today have different levels of maturity, but all require R&D albeit at different levels. R&D is also needed on common technologies such as mirror coatings, pulse compression and clean-up techniques (in both space and time).

### **Comparison with US Roadmap: PWFA**

- Also calls for collider design studies
- ANAR roadmap has more details / challenges?

	2016 2020		202	025 2030			2035 20		2040			
	LHC Physics Program Tend LHC Physics Program											
	Plasma Accelerator R&D at Universities and other National & International Facilities											
	PWFA-LC C	& Paramet	er Studies	PWF	A-LC C	DR		PWFA-	LC TDR	PWFA-LC Construction		
	Beam Dynam	Beam Dynamics & Tolerance Studies										
t	Plasma Source Development											
me	FACET-II Co	nstructio	n							Leger	nd	
dole		FACET	-II Operatio	on						Theory/Simu	lation/Design	
eve	Experimenta	l Design	& Protoyp	ing						Engineering	/Construction	
8	Emittance Preservation									Experiments	/Operations	
rc-			Transfor	mer Ratio > 1								
Resea				Staging Studies				Multiple Stages				
WFA	PWFA App D & CDR	Dev. PV	VFA-App DR	PWFA-App Construction		PWFA-A		eration				
			Fut (FF	ure Facility De TBD)	sign	FFTBD Construe	ction	FFTBD Ope 'String Test'	eration & Collic	der Prototype	•	
	Positron PW Concept Dev	FA /.	Positron PWFA-L	PWFA in C Regime								
Tech.	Euro XFEL Construction	Eu	Iro XFEL C	peration								
Driver	LCLS-II Constru	ction LC	LS-II Oper	ration								

Figure 4: High level R&D roadmap for particle beam driven plasma accelerators.

#### **Comparison with US Roadmap: PWFA - 10 years**

- Also calls for collider design studies
- ANAR roadmap has more details / challenges?

Beam Driven Plasma R&D 10 Year Roadmap									
2016 2018 2020 2022 2024 2026									
	PWFA-LC Concept Development and Parameter Studies								
Beam Dynamics and Tolerance Studies									
10 GeV Electron Stage									
FACET FACET-II Phase I: Electrons									
Operating with high beam loading: Gradient > 1GeV/m, Efficiency > 10%									
Present Goals									
9 GeV				10 G	BeV				
Q ~ 50 pC				Q ~ 10	00 pC				
ε ~ 100μm		ε ~ 10µn	n	FA	CET-II: Ex	ternal Injector			
ΔΕ/Ε ~ 4%		∆E/E <59	%		~ ع	- 1µm			
	Staging Stud	dies			ΔE/	E ~ 1%			
	Goals				Transfo	rmer Ratio			
Character	ization of active pla	Pro	esent	Goals					
Beam quality p	Shaped Profiles								
Plasma so	urce with tailored er	ntrance & exit prof	le	Т	~1	T > 1			
	PWFA Applicat	tion(s): Identifi	cation, C	DR, TL	OR, Opera	tion			
		Positron A	ccelerati	on					
FACET			FAC	CET-II P	hase 2: Po	ositrons			
:	Simulate, Test and	Identify the Optin	mal Config	uration f	or Positron	PWFA			
Present ('New	Regime' only)			Go	als				
4GeV	4GeV 100pC, >1GeV @ >1GeV/m, dE/E < 5%, Emittance Preserved								
Q ~ 100 pC			'New Regin	ne' seede	ed with two b	unches			
3 GeV/m			Holl	low Chan	nel Plamsas				
ΔE/E ~ 2%				Quasi no	on-linear				
2 not measured		Dia anna - Carro	David	2000110					
		Plasma Source		pment					
	Tailored done its	Go Go		d omitter	oo proconucti				
Liniform bollow and near bollow transverse density profiles									
	Uniform, noilow and near-noilow transverse density profiles								
Accelerating length > 1m									
Scalable to high repetition rate and high power dissipation									
	Driver Technology								
Construction and Operation of I CI S-II and European XEEL with MW Beam Power									

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Figure 5: A detailed PWFA R&D roadmap for the next decade.

### **Comparison with US Roadmap: DWA - 10 years**

- Defines baseline design
- Sets goals for
  - 3 GeV facility
  - bunch shaping
  - efficiency
  - emittance
- US roadmap more detailed?

#### DWFA LC 10 YEAR PARAMETER TABLES

5	Single Stage	High Fid	High Fidelity Staging					
Present Goals		Present	Goals	Goals				
100MV/m	300MV/m	1 accelerator per stage	2 accelerators per stage	X-band				
0.5nC 0.5nC		50MV/m/ stage	200MV/m/stage	0.5nC/bunch				
Beam partially	Beam quality	0.5nC	0.5nC	Norm. emittance <1u				
characterized	demonstrated	Beam partially characterized	Beam quality preservation demonstrated					
3GeV A	cceleration Facility							
	Goals	Bunch Shap	Bunch Shaping High Effic					
15m in 1	ength, 0.75 fill factor	Goals		Goals				
200MeV	/m effective gradient	0.1% level energy	0.1% level energy spread ~90% efficie					
0.5nC/bund	nC/bunch, 6.5A current in pulse ~50% beamloading from 0							
Beam quality preserved								
DW	FA Exploratory St	tudies (potentially o	order of magnitude co	ost reduction)				
Ultra	low Emittance e-	Ult	Ultralow Emittance e+					
	Aiming for		Aiming for					
~1nm verti	cal emittance level at IP	No damping ring	g e+ source, by efforts from I	LPWA				
~lnm verti	cal emittance level at IP	No damping ring	g e+ source, by efforts from I	LPWA				
~lnm verti	cal emittance level at IP status and goals for DW	No damping ring DWFA LC narameter FA LC 10 YEA	g e+ source, by efforts from I rs R ROADMAP	PWA				
~lnm verti e 6: Present 2016	cal emittance level at IP status and goals for DW 2018	No damping ring DWFA LC narameter FA LC 10 YEA 2020	e+ source, by efforts from I R ROADMAP 2022 2024	2026				
~lnm verti e 6: Present 2016 D	cal emittance level at IP status and goals for DW 2018 WFA LC Baseline	No damping ring DWFA LC parameter FA LC 10 YEA 2020 Technology (pote	e+ source, by efforts from I R ROADMAP 2022 2024 ntial multi-fold cost	PWA 2026				
~Inm verti e 6: Present 2016 D Tecl	cal emittance level at IP status and goals for DW 2018 WFA LC Baseline mology Convolidat	No damping ring DWFA LC parameter FA LC 10 YEA 2020 Technology (pote ion Phase	e+ source, by efforts from I R ROADMAP 2022 2024 ntial multi-fold cost	PWA 2026				
~lnm verti e 6: Present 2016 D Tecl	cal emittance level at IP status and goals for DW 2018 WFA LC Baseline mology Consolidati	No damping ring DWFA LC narameter FA LC 10 YEA 2020 Technology (pote ion Phase	g e+ source, by efforts from I R ROADMAP 2022 2024 ntial multi-fold cost chinology Integration	PWA 2026 reduction)				
~Inm verti e 6: Present 2016 D Tecl	cal emittance level at IP status and goals for DW 2018 WFA LC Baseline mology Cansolidat	No damping ring DWFA LC parameter FA LC 10 YEA 2020 Technology (poter ion Phase	g e+ source, by efforts from I IR ROADMAP 2022 2024 ntial multi-fold cost chaology Integration	PWA 2026 reduction)				
~Inm verti e 6: Present 2016 D Tech Single Stage	cal emittance level at IP status and goals for DW 2018 WFA LC Baseline mology Consolidat	No damping ring DWFA LC narameter FA LC 10 YEA 2020 Technology (pote ion Phase	g e+ source, by efforts from I IR ROADMAP 2022 2024 ntial multi-fold cost chinology Integration	PWA 2026 reduction)				
~Inm verti e. 6: Present 2016 D Tech Single Stage	cal emittance level at IP status and goals for DW 2018 WFA LC Baseline mology Consolidat	No damping ring DWFA LC parameter FA LC 10 YEA 2020 Technology (pote ion Phase	g e+ source, by efforts from I IR ROADMAP 2022 2024 ntial multi-fold cost chnology Integration	PWA 2026 reduction)				

High Efficiency Klystron (Synergy efforts from CLIC/SLAC)

#### CDR for LC

DWFA Exploratory Studies (potentially order of magnitude cost reduction)

Science Discovery and Technology Invention Phase

Ultralow Emittance e-

Ultralow Emittance e+ (Synergy efforts from LPWA)

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#### **Comparison with US Roadmap: DLA**

▶ No US roadmap for DLA ...

#### Identification of common themes & synergies

- Define collider design
  - Several designs or one?
- Development of BDS and FF systems tailored to novel accelerators
- Development of positron sources
- Development of polarized sources
- Multiple staging
  - Preservation of beam quality
  - Mitigation of emittance growth
- Efficient energy transfer from accelerating field to bunch

Positron acceleration, especially in nonlinear wakefields

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#### Identification of common themes & synergies

- Can BDS and FF systems be tailored to novel accelerators ... or must we meet their (stringent) requirements?
- Code development,
  - Especially for many stages / long distances
  - Enterface between plasma codes and accelerator codes
  - Adaption to / us of Exascale capabilities
- Synergies with nearer term applications?
- Development of test facilities?
- Development of agreed ways to describe beam parameters?

#### Global Plasma Accelerator Roadmap

## Mark Hogan

	2016		2020	2025	2030	) 2(	035 2040				
	LHC P	hysics Program					T End LHC Physics Program				
	Plasma Accelerator R&D at Universities and other National & International Facilities										
	FACE	T-II Construction					Legend				
			FACET-II Operation				Theory/Simulation/Design				
3eam Driven	Experi	mental Design 8	Protoyping				Engineering/Construction				
			Emittance Preservation				Experiments/Operations				
			Transformer Ratio	p>1							
_			Sta	aging Studies		Multiple Stages					
			Future Fa	cility Design (FFTBD) FF	TBD Construction	FFTBD Operation & Collider Pro	totype 'String Test'				
	Positro	on PWFA Conce	pt Dev. Positron PWFA in	PWFA-LC Regime							
	PWFA	-LC Concepts &	Parameter Studies	Plasma C	ollider CDR	Plasma Collider TDR	Plasma Collider Construction PLC				
Б	LWFA	LC Concepts &	Parameter Studies								
Ē	Beam Dynamics & Tolerance Studies										
ŏ	Plasm	a Source Develo	pment								
	PWFA	App Dev. & CDF	R PWFA-App TDR PV	VFA-App Construction	PWFA-App Operation	n					
	0		First Applications (radiation	on sources)		Int	ernational Collaboration				
	Contin	uing Invention &	Discovery Phase	Desilvers							
Nen	BELLA	TO GEV MODULE		Positrons							
Ď		5GeV + 5GeV 3	staging	al Focus Cooling							
Lase			Prototype Phase	ai rocus, cooling							
			GeV linac @ kHz Ben Ba	ite	50-100GeV li	nac(s) @ 1-10kHz					
	EuPB	AXIA Design I	EuPBAXIA Construction	FUPBAXIA Commissioni	EUPBAXIA HEP Test	Beam & XFEL					
forts	20110	o an t D congin i	EuPBAXIA Design II	Construction Un	orade EuPRAXIA P	lasma Accelerator R&D					
Ш Ш				Plasma e+e- or og LC Cl	DB Plasma e+e-	or an LC TDR & Prototyping	eter or an PLC Construction PLC				
ope	AWAK	E Phase 1 & 2	AWAKE Phase 3			5. <u>55</u> - 5 - 5 - 5 - 5 - 5 - 5 - 5 - 5 - 5					
Ē		AWAKE	PLC Conceptual Design (e.g. e-	·p)							
	Euro X	FEL Constructio	n Euro XFEL Operation								
÷		LCLS-II Constru	uction LCLS-II Operation								
er Te	3kW C	lass Lasers									
Drive			Зк	W Class Lasers							
_					300kV	V Class Lasers					

#### **Next steps**

- The different WGs took different approaches. If we made second drafts, would we want to enforce a uniform style / approach?
- Others?
- Lunch?