WG2 Report

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U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

WG2 Agenda:
Two Related but Parallel Themes: e^- and p^+ Driven Plasmas

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Day	Time	Topic	Speaker
Tuesday	14:30	Define Classes of applications and physics requirements (Energy, luminosity, particle species etc)	M. Wing
	15:30	State of the art for e- & e+ PWFA	S. Gessner
	16:00	**Break**	
	16:30	State of the art and plans for plasma sources	P. Muggli
	17:15	Challenges and requirements for plasma diagnostics	M. Downer
	18:00	**Adjourn or not...**	
	18:15	Activities at SPARC Lab	M. Ferrario
Wed	9:00	Computational tools for e- & e+ driver plasmas	W. Mori (Skype)
	9:45	Computational tools for p driven plasmas	K. Lotov
	10:30	**Break**	
	10:45	Driver technology - production of short p bunches	A. Petrenko
	11:15	State of the art and plans for p PWFA	E. Adli
	12:00	PWFA with sub-TeV proton drivers	K. Lotov
	12:30	**Lunch**	
	14:00	What have we learned and what's next for a conceptual PWFA-LC	E. Adli + all
	14:30	Diagnostic requirements	B. Hidding
	15:00	Alternate method for prodcuing short p bunches	A. Caldwell
	15:15	Activities at FLASHForward	A. Knetsch
	16:00	**Break**	
		What facilities are available or planned for this research	All
		Key e-/e+ experiments/elements that need to be done/demonstrated (intro with US Roadmap)	M. Hogan
		Key experiments to be performed/elements to be demonstrated for p-driven	P. Muggli
		~~Synergies with other techniques (LWFA, DWA, DLA...)~~	
		~~Driver technology - production of short e- bunches~~	
	18:00	**Adjourn**	

PWFA Research Roadmap for Electron Driver: Goal is to Get to a TeV Scale Collider for High Energy Physics

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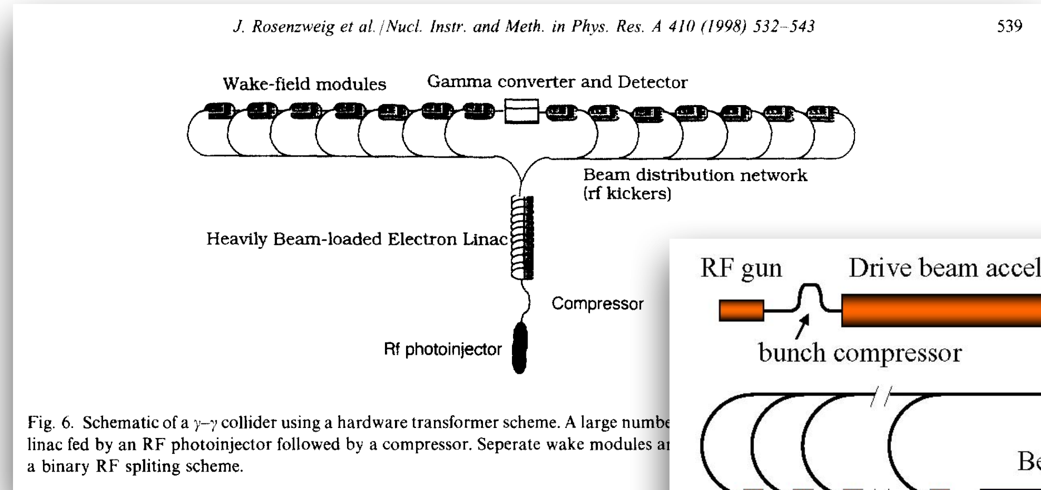
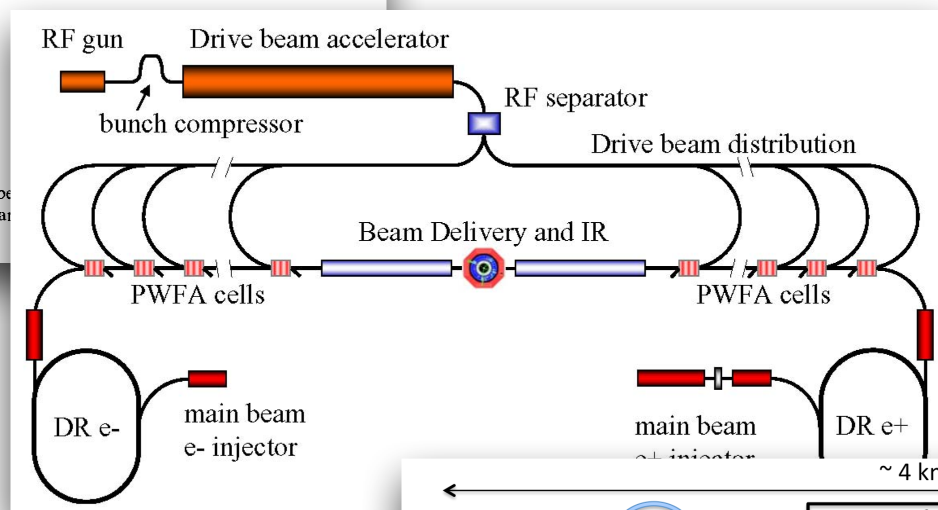
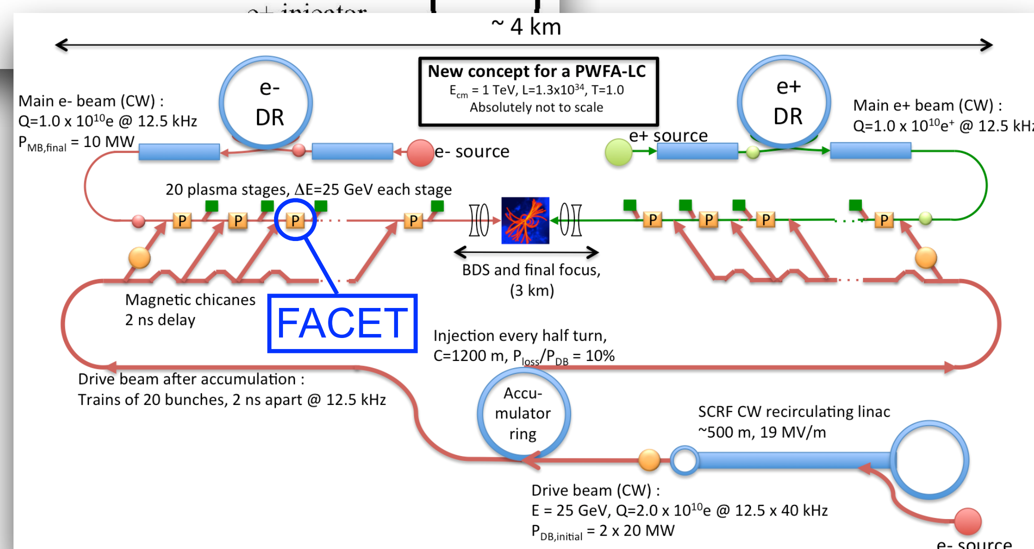


Rosenzweig *et al* (1998)



Seryi *et al* (2008)

Adli *et al* (2013)

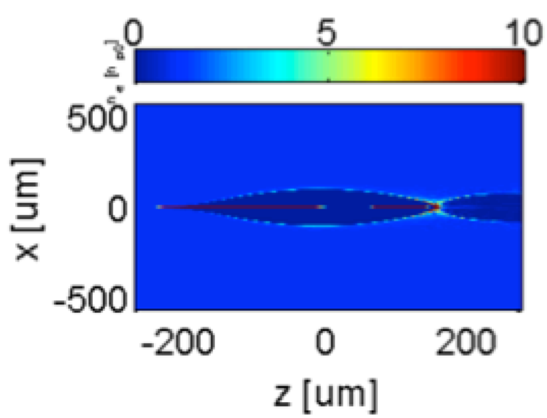


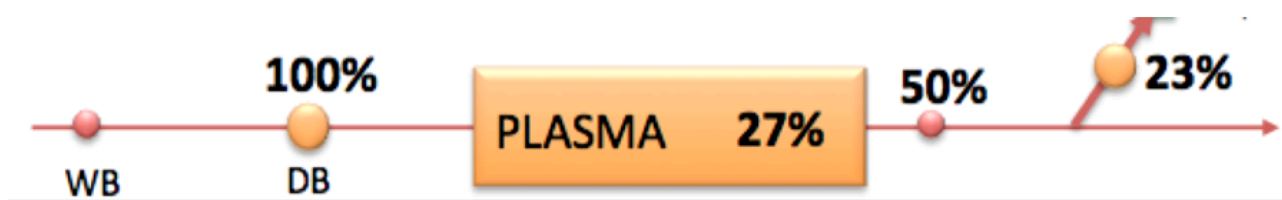
PWFA-LC concepts highlight key issues and help us prioritize our research programs e.g. efficiency, positrons

Snowmass paper has "worked" in the sense that we have got feedback from the LC community. I think the PWFA community should act on this.

Can we reach the parameters suggested? Some key open questions, as commented by the linear community :

- **credible and efficient drive beam scheme.** High drive beam energy an issue. PWFA comm. should develop high T.R. stage. LC comm. could develop efficient designs. MO: Not the most urgent.
- **reduce energy spread from few % to few per mille**. PWFA comm. should find requirement on bunch shaping. Or, develop new final focus (in cooperation with LC comm.)
- **efficiency versus instability and energy spread question. Tolerances.** PWFA comm., perhaps in cooperation with LC comm. should do full simulations, including off-axis pump-depleted DB / WB scenarios to efficiency collider emittances. Backed by theoretical assessments.
- **emittance preservation** at 10 nm level needs more study, especially at very high energy/density. Ion motion, scattering, betatron radiation etc. PWFA comm. studies with simulation..
- **interstages must have 100% charge coupling** (not 95%, not 98%)**,** as well as emittance preservation. LC community could help with optics design.
- **overall parameters** are based on ILC, **not optimized.** A method to optimize overall parameters should be developed. LC community could help, but first basic scalings must be derived.
- e+ and technical challenges remain. Similar exercises should be done for hollow channel plasmas (e-, e+). But seems useful to complete e- blow-out studies in order to have a credible parameter set





Several questions do not need new test facilities, but manpower to do numerical and theoretical studies. Questions been out there for many years already.

Electron Driven Table (1 of 3)

Scientific bottleneck / challenge	Facilities / capabilities needed		Milestones			Comments
	Experimental	Computational	5 years	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 communities
Designing Experiments for Concept 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			Develop self-consistant scenarios for beam loading (high-gradient, high-efficiency and emittance preservation) for both electrons and positrons
Positrons	High-energy, High peak current, sub-ps positron beams & specialized plasma sources			Exploration of self-loaded regime, hollow channels, quasi non-linear reginmes	Plasma sources for e- & e+ beam production	
Beam quality preservation	Matched Injection, acceleration, extraction		Emittance preservation at 1µm level with % level dE/E			Transverse wakes, hosing, Ion motion, plasma source development with ramps, external injection
Development of low emittance PWFA based e- sources	Laser to e- beam spatial-temporal alignment (synchronization), specialized plasma sources, low emittance diagnostics		Emittance preservation at 1µm level	Emittance preservation at 100nm level (external injection)		

In WG2 we see no bottlenecks – only challenges and opportunities ;-)

Electron Driven Table (2 of 3)

Scientific bottleneck / challenge	Facilities / capabilities needed		Milestones			Comments
	Experimental	Computational	5 years	5 - 10 years	10 - 20 years	
Transformer Ratio >1	Shaped beams with high peak current to drive non-linear wakes		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-µm, fs resolution	Development of analytic models, accelerator & plasma code integration, new physics packages		Parametric staging studies with independent drive-witness beam		Basic processes in addition to tolerance studies need to consider: Hosing, radiation loss, polarization preservation
Plasma Sources	Tailored density ramps, differential pumping solutions, thermal management		Tailored density ramps, differential pumping solutions	Hollow (and quasi-hollow) channels 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 high capture efficiency			Studies with independent witness injector	Multi-stage demonstration in FFTBD	Optical design for multiple stages

Electron Driven Table (3 of 3)

Scientific bottleneck / challenge	Facilities / capabilities needed	
	Experimental	Computational
Diagnostic development	Visualize wakes, EOS (bunch duration, synchronization & time-of-arrival), Novel plasma-based fs&μm spatiotemporal alignment (pioneered in E210), Emittance measurement, Selective driver/witness bunch measurement (charge, size, current profile), Plasma density tomography, Ultrafast bunch kickers (e.g. to separate driver and witness), High rep rate effects diagnostics , (Transverse) electron beam probing of wake	
Simulation Development		Adaptive mesh refinement, Adaptive particle loading:Vary Npcell and/or particle merging and splitting, Dynamic load balancing, Adaptive 2d and 3d time steps, Intel Phi and GPUs, Radiation reaction (basic model is implemented) and QED effects

Diagnostics:

- Single shot generally preferred

Simulations:

- Quasistatic codes are workhorse for beam driven (experimental planning, data interpretation, initial collider parameter studies)
- Exascale capabilities are in development.

PWFA Research Roadmap for Proton Driver: Goal is to Get to a High-Energy LHeC-like e^-p^+ Collider

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Electron bunches	Central value	Possible values	Comment
Energy	100 GeV	10 – 100 GeV	LHeC default is 60 GeV; to re-visit.
Number of electrons per bunch	1.15×10^{10}	Above 10^{10} ?	Generally the higher the bunch charge the better
Number of electron bunches	288	Already maximum ?	Equal to number of SPS proton bunches
Repetition rate	15 Hz	Already maximum ?	Equal to SPS repetition frequency

Proton bunches	Central value	Possible values	Comment
Energy	7 TeV	7 TeV	LHC protons
Number of protons per bunch	1.15×10^{11}	Can be higher in the future ?	Determined by LHC wishes
Beta function	0.1 m	Fixed ?	Determined by LHC wishes
Normalised emittance	3.5 µm	Fixed ?	Determined by LHC wishes

Above parameters give luminosity of 1×10^{30} cm^{-2} s^{-1}

Parameters from G. Xia et al., Nucl. Instrum. Meth. **A 740** (2014) 173.

Proton Driven Table (1 of 2)

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Scientific bottleneck / challenge	Facilities / capabilities needed		Milestones			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, maintaining high gradient			
Acceleration of externallyinjected e-, sample wakefields	Exist		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 capture, emittance<10mm-mrad (e-/p+ colider application)		
Development of scalable plasma source 5-10-100's m, high density uniformity (<1%) (helicon/discharge, etc.)	New plasma source developemnt laboratory	Plasma simulations of helicon sources	4-10m	100m	100's m	Type of source not defined
Quick 3D simulation capabilities for optimization and comparison w experimental results						
Production of shorter p+ bunches (few cm)	Existing machine (SPS)		"Beam gymnastic in existing machine, longitudinal beam cooling			
Production of ultra-short p+ bunch (<1mm, TeV energy, 1e11p+)	New p+ bunch source? Compression after extraction?	Machine impedance simulation/understanding				
Production of low emittance p+ bunch			Transverse beam cooling			
Pre-modulation of p+ bunch (no plasma)	High frequency linac, dispersive section (SPS-AWAKE beam line)		Parameter studies			
Identify accelerator for fixed target studies, detectors calibartions, etc.	Facility including plasma-based accelerator of p+ bunch AND physics experiment(s)		Identify possible physics experiment	Design of suitable facility	Building facility	(10-100GeV)

Proton Driven Table (1 of 2)

Scientific bottleneck / challenge	Facilities / capabilities needed		Milestones			Comments
	Experimental	Computational	5 years	5 - 10 years	10 - 20 years	
Diagnostics for plasma wave/wakefields	Exist		Transverse diagnostics on existing source, shadowgraphy, etc.	Design of source with transverse and longitudinal acces to plasma, phton acceleration, shadowgraphy, spectral interferometry?		

A Couple of Patric's Items We Didn't Even Get To

Parameters achieved now and in the future…

Table of efficiencies

Beam Driven PWFA Parameters Achieved to Date

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Energy

PWFA-LC			State of the Art	
Parameter	**Units**	**Value**	**Electrons**	**Positrons**
Final Energy	GeV	3000	29	24.4
Energy per Stage	GeV	25	9	4.4
Peak Gradient	GeV/m	7.6	6.9	3.4
Geographic Gradient	GeV/m	1		
Transformer Ratio		1		
Number of Stages		60	1	1
Plasma Length	meter	3.3	1.3	1.3
Plasma Density	e-/cc	2E+16	5E+16	8E+16
Heat Load	kW/m	100		

Cost

PWFA-LC			State of the Art	
Parameter	**Units**	**Value**	**Electrons**	**Positrons**
Efficiency - Instantaneous	%	50	30	34
Efficiency - Total	%			

Performance

PWFA-LC			State of the Art	
Parameter	**Units**	**Value**	**Electrons**	**Positrons**
Charge per Bunch	nC	1.5	0.03	0.207
Rep Rate	Hz	1E+04	1	1
Normalized Emittance (H)	μm	10	100	
Normalized Emittance (V)	μm	0.035		
Energy Spread [r.m.s.]	%	1	4	1.8
Polarization	%	80		
Bunch Length (sigma)	μm	20	50	
Tolerances…				

Electrons:
Nature 515 (2014)
and http://arxiv.org/pdf/1511.06743v1.pdf
to be published in PPCF

Positrons:
Nature 524 (2015)

Note: parameters are for single (best) cases/regimes. Individual parameters e.g. energy gain are not best of that quantity

WGs should decide how we want to present parameters for the report – self-consistent set, best ever, range…