FACET-II | Facility for Advanced Accelerator Experimental Tests

AAC Colliders: PWFA, LWFA & SWFA

Mark J. Hogan
With input from
John Power & Carl Schroeder
April 30, 2020

U.S. DEPARTMENT OF ENERGY
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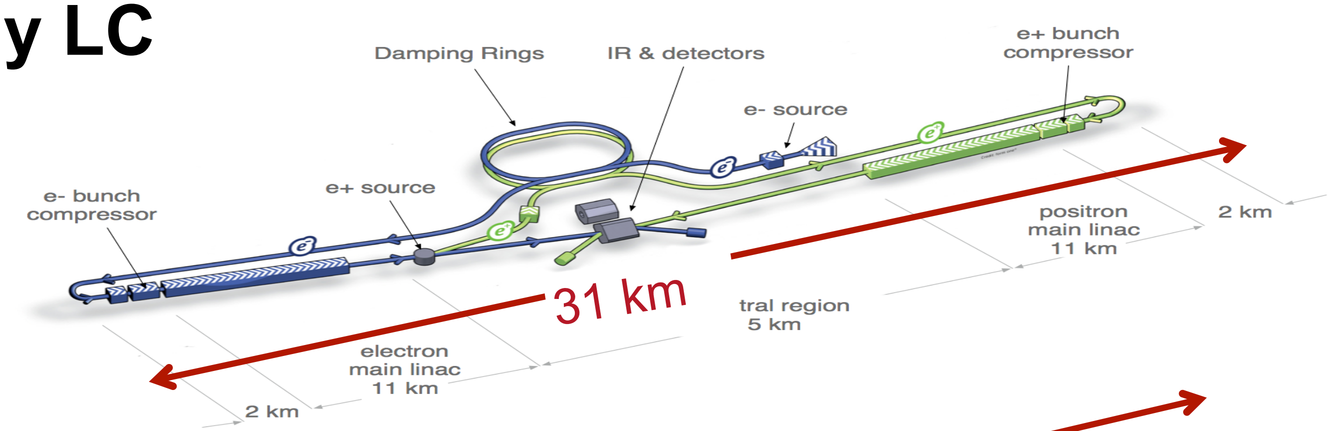
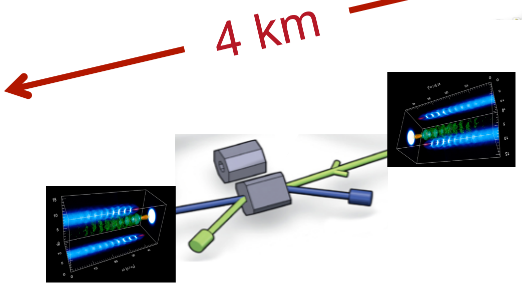
SLAC NATIONAL ACCELERATOR LABORATORY

The Scale for a TeV Linear Collider

Today's technology LC
– a 31km tunnel:



Advanced Accelerator Technology LC:



GeV/m accelerating gradient

The Luminosity Challenge:

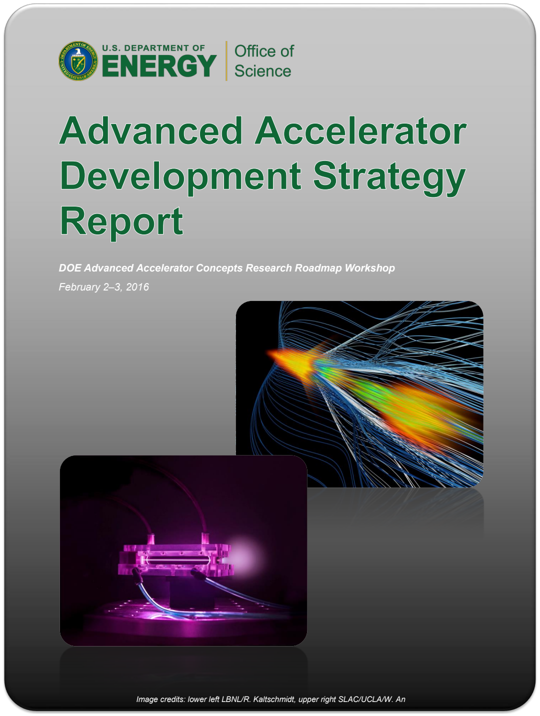
High-efficiency

$$\mathcal{L} = \frac{P_b}{E_b}\left(\frac{N}{4\pi\sigma_x\sigma_y}\right)$$

…and must do it for positrons too!

Timeline, Milestones and Roadmap

- **Collider concepts are straw man designs to guide research priorities – not CDR/TDRs**
- Milestones for LWFA, PWFA and SWFA defined in 2016 roadmaps
- ABP issues will be addressed hand in hand with experiments in interactive process



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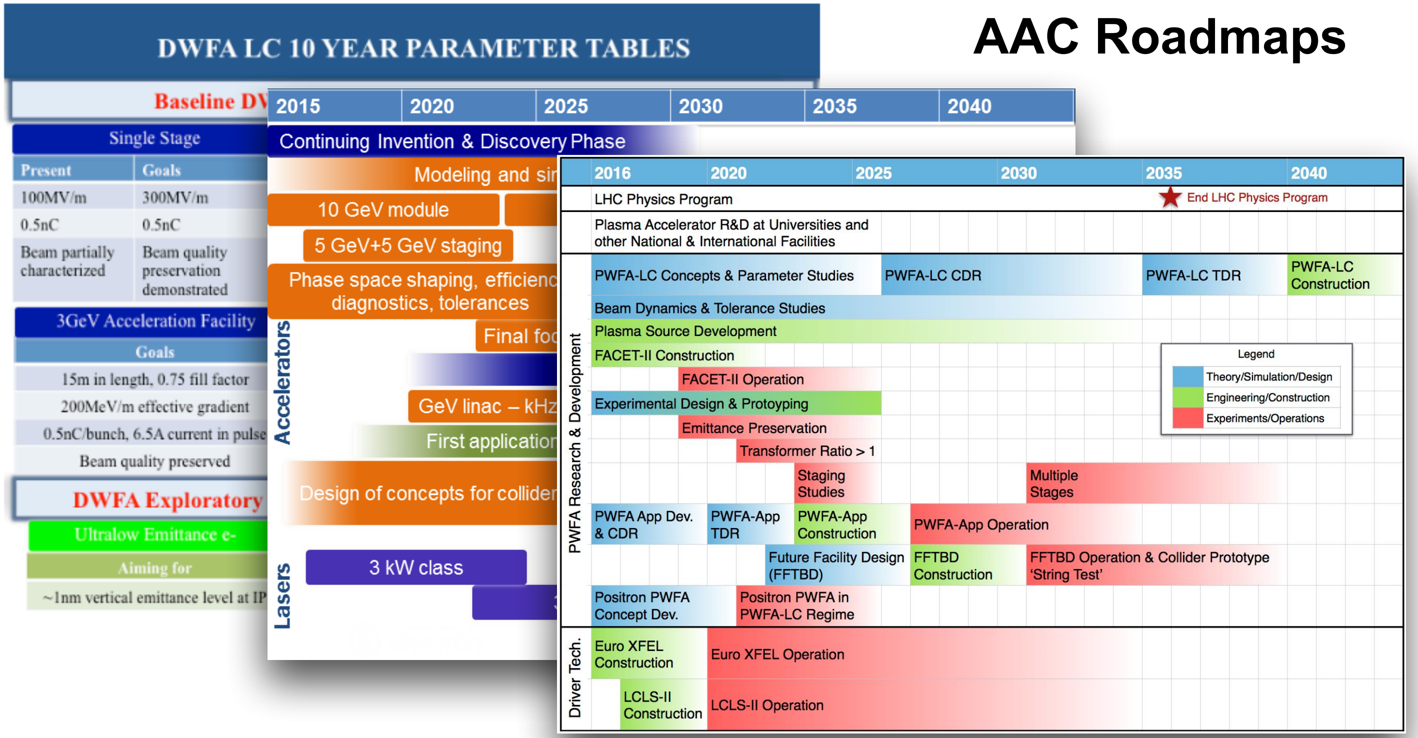
Advanced Accelerator Development Strategy Report

DOE Advanced Accelerator Concepts Research Roadmap Workshop

February 2–3, 2016

Image credits: lower left LBNL/R. Kaltschmidt, upper right SLAC/UCLA/W. An

AAC Roadmaps



DWFA LC 10 YEAR PARAMETER TABLES

Baseline DV

Single Stage

Present	Goals
100MV/m	300MV/m
0.5nC	0.5nC
Beam partially characterized	Beam quality preservation demonstrated

3GeV Acceleration Facility

Goals

15m in length, 0.75 fill factor

200MeV/m effective gradient

0.5nC/bunch, 6.5A current in pulse

Beam quality preserved

DWFA Exploratory

Ultralow Emittance e-

Aiming for

~1nm vertical emittance level at IP

2015 | 2020 | 2025 | 2030 | 2035 | 2040

Continuing Invention & Discovery Phase

Accelerators

Modeling and si

10 GeV module

5 GeV+5 GeV staging

Phase space shaping, efficienc diagnostics, tolerances

Final foc

GeV linac – kHz

First application

Design of concepts for collider

Lasers

3 kW class

2016 | 2020 | 2025 | 2030 | 2035 | 2040

LHC Physics Program

★ End LHC Physics Program

Plasma Accelerator R&D at Universities and other National & International Facilities

PWFA Research & Development

PWFA-LC Concepts & Parameter Studies | PWFA-LC CDR | PWFA-LC TDR | PWFA-LC Construction

Beam Dynamics & Tolerance Studies

Plasma Source Development

FACET-II Construction

FACET-II Operation

Experimental Design & Protoyping

Emittance Preservation

Transformer Ratio > 1

Staging Studies | Multiple Stages

PWFA App Dev. & CDR | PWFA-App TDR | PWFA-App Construction | PWFA-App Operation

Future Facility Design (FFTBD) | FFTBD Construction | FFTBD Operation & Collider Prototype 'String Test'

Positron PWFA Concept Dev. | Positron PWFA in PWFA-LC Regime

Driver Tech.

Euro XFEL Construction | Euro XFEL Operation

LCLS-II Construction | LCLS-II Operation

Legend

- 🟦 Theory/Simulation/Design
- 🟩 Engineering/Construction
- 🟥 Experiments/Operations

Community representatives from universities and laboratories organized workshops and summarized priorities in the report

https://www.osti.gov/biblio/1358081-advanced-accelerator-development-strategy-report-doe-advanced-accelerator-concepts-research-roadmap-workshop

For More Information

- **PWFA, LWFA & SWFA Summary talks @ 2019 ABP Workshop**
  - https://conferences.lbl.gov/event/279/contributions/3194/attachments/2281/388/Hogan_-_ABP_and_plasma_accelerators.pdf
  - https://conferences.lbl.gov/event/279/contributions/3193/attachments/2278/382/conde_ABP_workshop.pptx
- **AAC Strategy Report**
  - https://www.osti.gov/biblio/1358081-advanced-accelerator-development-strategy-report-doe-advanced-accelerator-concepts-research-roadmap-workshop
- **2019 ALEGRO Workshop @ CERN**
  - https://indico.cern.ch/event/732810/overview
- **AAC & EAAC Workshops**
  - http://aac2018.org
  - https://agenda.infn.it/event/17304/overview
- **USPAS & 2019 CERN Accelerator School on High Gradient Wakefield Accelerators**
  - https://cas.web.cern.ch/schools/sesimbra-2019

FACET-II Facility for Advanced Accelerator Experimental Tests

Plasma Wakefield Accelerator Based Linear Collider

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April 30, 2020

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Beam Driven Plasma Accelerator Based Collider Concepts

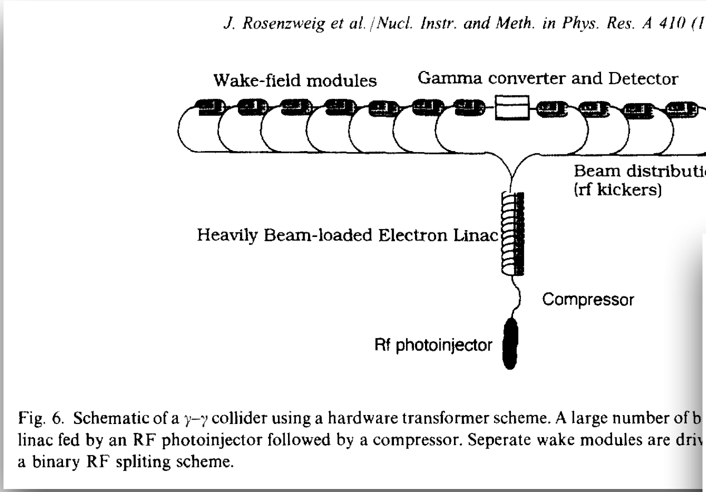
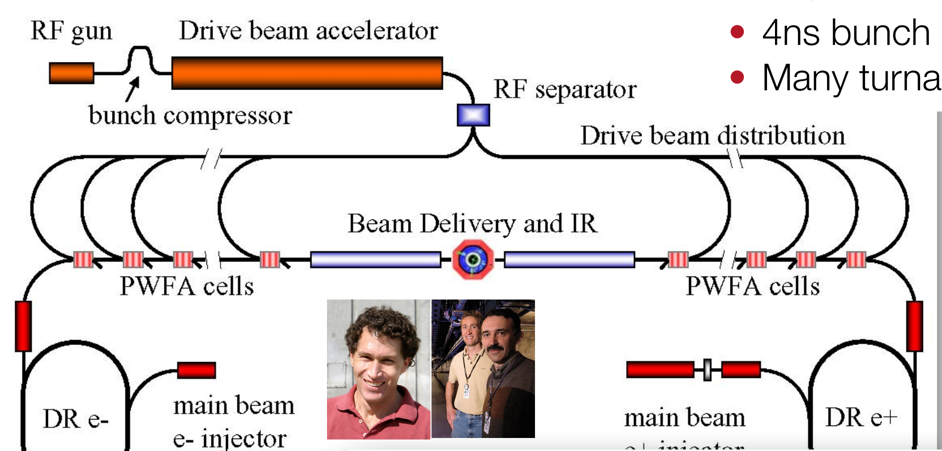

J. Rosenzweig et al. / Nucl. Instr. and Meth. in Phys. Res. A 410 (1998) 532–543

Fig. 6. Schematic of a γ–γ collider using a hardware transformer scheme. A large number of b
linac fed by an RF photoinjector followed by a compressor. Seperate wake modules are driv
a binary RF spliting scheme.

Rosenzweig *et al* (1998)

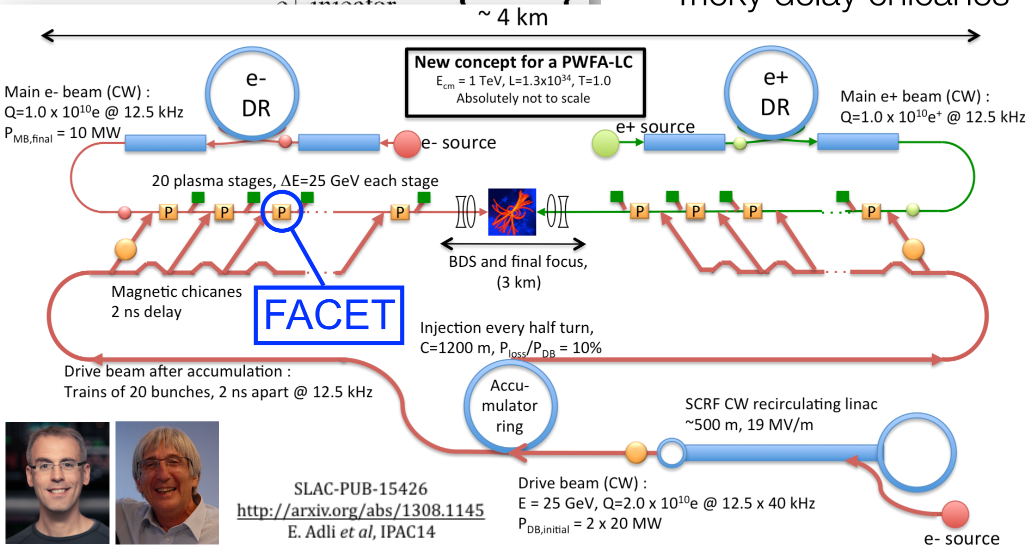


Seryi *et al* (2008) SLAC-PUB-13766

- ‘Warm’ Drive Linac
- 4ns bunch spacing
- Many turnarounds

Adli *et al* (2013)
SLAC-PUB-15426

- ‘Cold’ Drive Linac
- 100μs bunch spacing
- Tricky delay chicanes



- Assume SLC/NLC/ILC/CLIC made smart choices that we can start from for main beam and driver
- Focus on the accelerator module itself (the plasma)
- **The plasma is a transformer**
- For luminosity – Power efficiency and beam quality are critical!

E. Adli “***Consideration for a plasma stage in a PWFA linear collider***” @ 2015 FACET-II Science Workshop

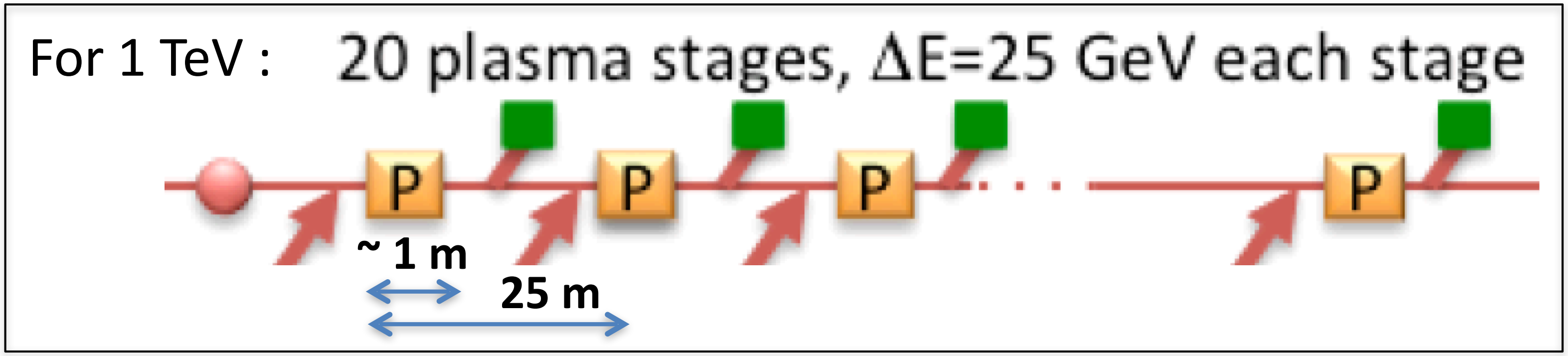
Input constraints

The main beam parameters for the current PWFA-LC design are **assumed to be the ILC main beam parameters**, with some modifications (allows reuse of earlier LC studies):

- Bunch length shortened to fit in plasma
- Charge of 1e10 particles per bunch (1/2 the ILC nominal bunch charge)
- Equal bunch spacing (“CW” collisions)

Other **input constraints** :

- **1 GeV/m** average gradient along main linac (“CLIC x 10”) with 25 GeV energy gain per plasma stage, assuming 25 m average stage length (more on this later)
- High transfer efficiency
- Push towards low plasma density (see scalings later)
- Parameter optimization assumes **e- drive bunch and e- witness bunch in the blow out regime, and no ion motion**


For 1 TeV : 20 plasma stages, ΔE=25 GeV each stage

The drive beam parameters are results of plasma optimization process.

Plasma Density Considerations

Advantages of lower plasma density

- plasma structure **length scale**

$$\lambda_p \sim n_0^{-1/2}$$

→ looser transverse and longitudinal tolerances; looser bunch length requirements for the drive and witness bunches

- **matched beta function** in the plasma

$$\beta_{\rm mat} \sim n_0^{-1/2}$$

→ looser optics matching, looser transverse tolerances

- **synchrotron radiation losses** in the plasma (for matched beam)

$$W' \sim n_0^{3/2}$$

→ less synchrotron radiation loss in the plasma, looser transverse tolerances (SR for transverse offset beam)

- **head erosion** in a pre-ionized plasma

$$\sim n_0^{1/4}$$

→ less head erosion of the drive bunch

- the **hosing instability** grows as

$$x/x_0 \sim e^{c(k_p s)^{1/3}(k_p z)^{2/3}}, \ k_p \sim n_0^{-1/2}$$

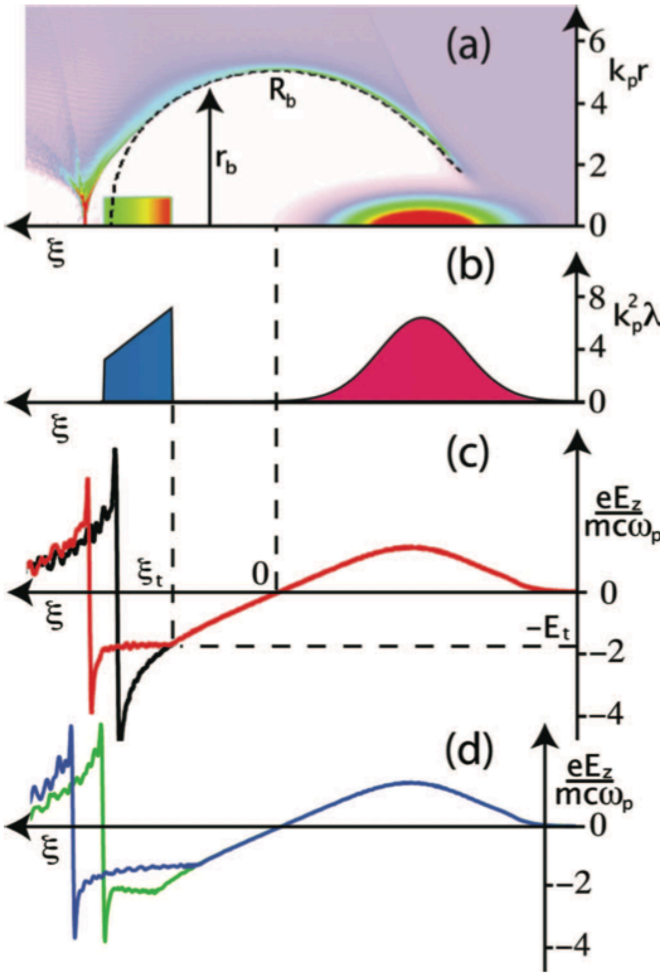
Main disadvantage of lower plasma density :

- **lower accelerating gradient**

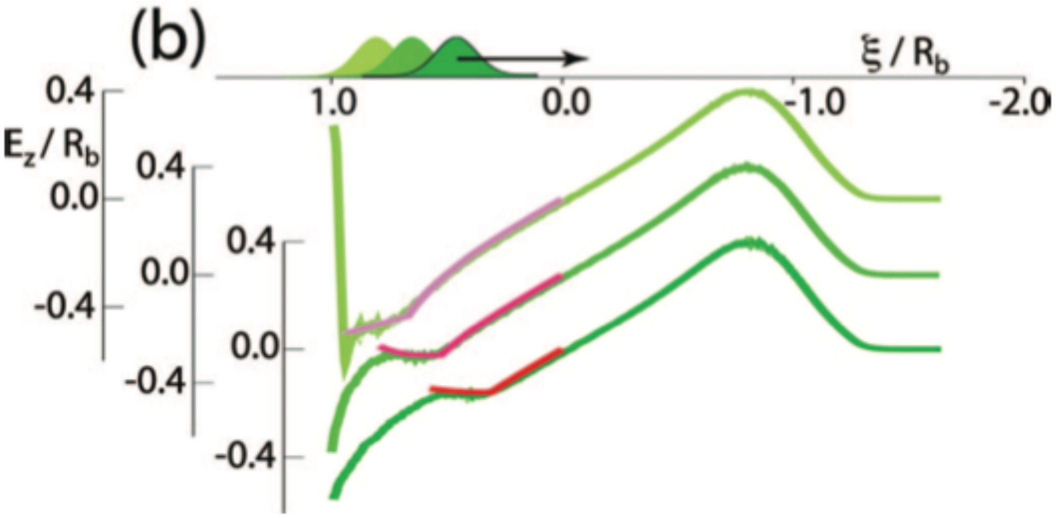
$$E_{\rm wavebreak} \sim c m_e \omega_p / e \sim n_0^{1/2}$$

Non-linear Beam Loading

Tzoufras et al. : beam-loading in the blow-out regime. More **than 80% energy transfer efficiency possible** for optimally shaped trapezoidal bunch. Flattening of the longitudinal field along the witness bunch, resulting **in small energy spread**. :



Almost flat beam loading and good efficiency also possible for **Gaussian witness bunches**. For a given blow out radius, and a given bunch separation, Δz, the optimal beam loading ratio is given by the appropriate witness bunch charge, bunch length (Q_{WB}, $\sigma_{z,WB}$).

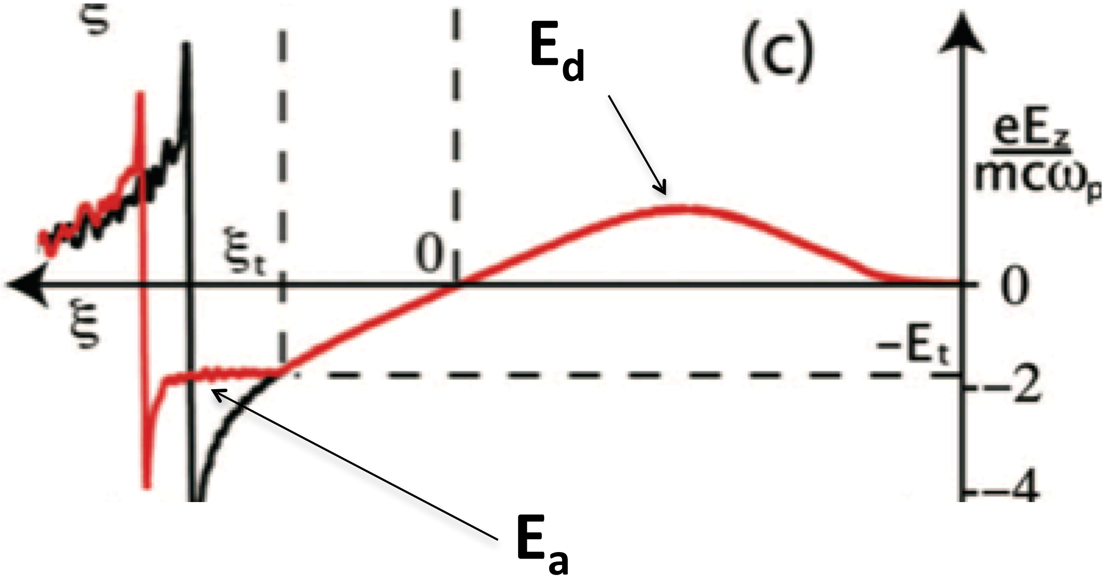


From Tzoufras et al., Physics of Plasmas, 16, 056705 (2009)

Transformer Ratio

Transformer ratio :

In the blow out regime the peak accelerating field may be several times the peak dececeleration field. The tranformer is up to a certain value a free parameter.



Peak decelerating field

$$E_d = \hat{E}_{dec}$$

Witness bunch mean energy gain

$$E_a = < E_{acc} >_{WB}$$

Tranformer ratio

$$T \equiv \frac{E_a}{E_d}$$

Drive bunch to witness bunch efficiency

$$\eta_{WB} = \frac{\Delta\mathscr{E}_{WB}}{\mathscr{E}_{0,DB}} \frac{Q_{WB}}{Q_{DB}} = T\frac{Q_{WB}}{Q_{DB}} \qquad (1)$$

Last equality valid only if most decelerated particle in drive bunch is fully depleteted.

Consequenses of higher transformer ratio :

+ Reduced drive beam energy $\mathscr{E}_{0,DB}$

- Increased drive beam charge Q_{DB}, since

$$\boxed{Q_{WB} \times E_a = const.}$$

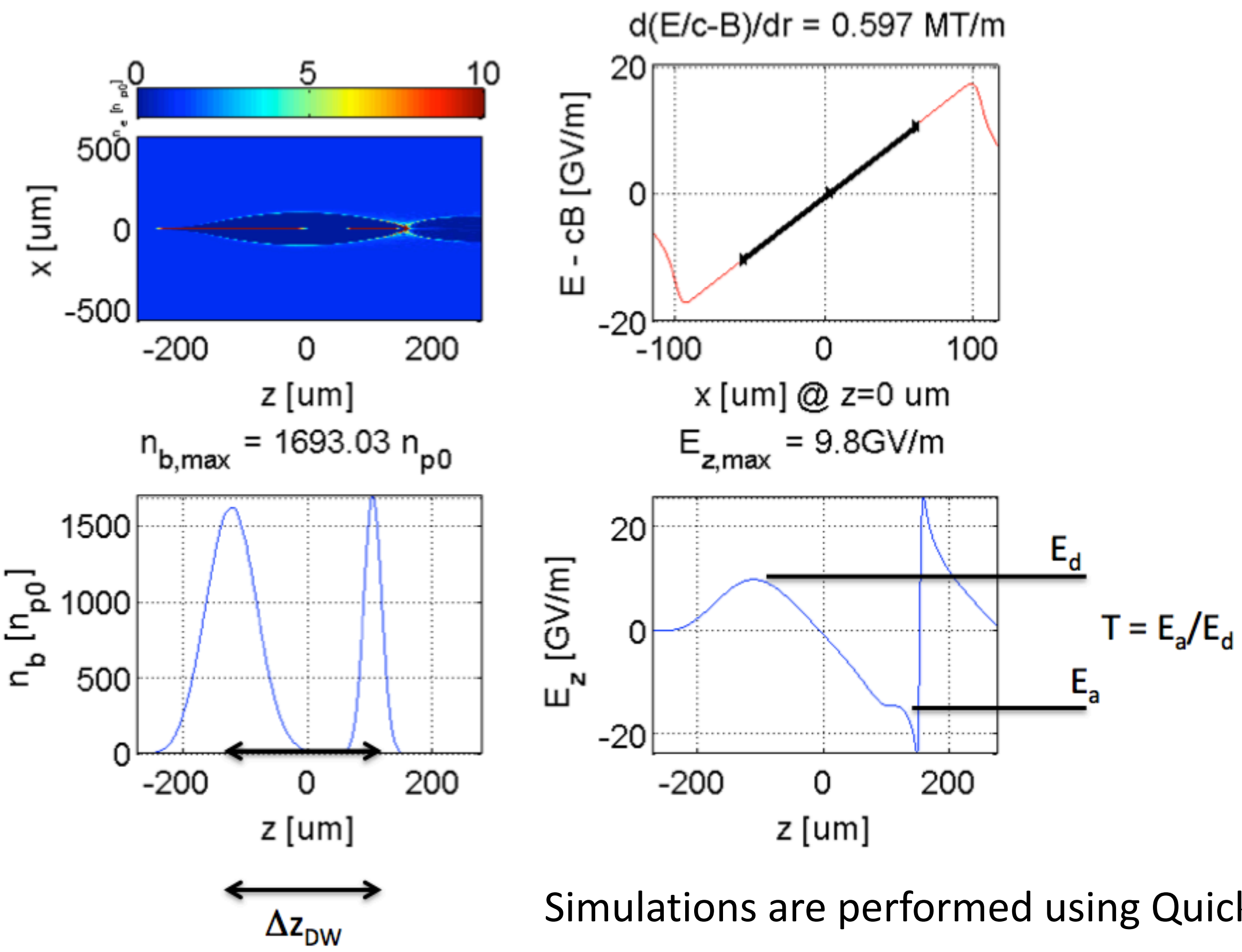
- shorter witness bunch length; tightened tolerances

Plasma Stage Optimization

Input constraints: main beam parameters; Q_{WB}=1x10^{10}e, Δε=25 GeV/stage, L_{cell} < few m, keep WB energy spread low, reasonable WB length

Design choice: plasma density $\mathbf{n_0}$, transformer ratio **T**

Drive beams then set : Q_{DB} (charge), $\varepsilon_{0,DB}$ (energy) , Δz_{DW} (DB-WB separation), $\sigma_{z,DB}$, $\sigma_{z,WB}$

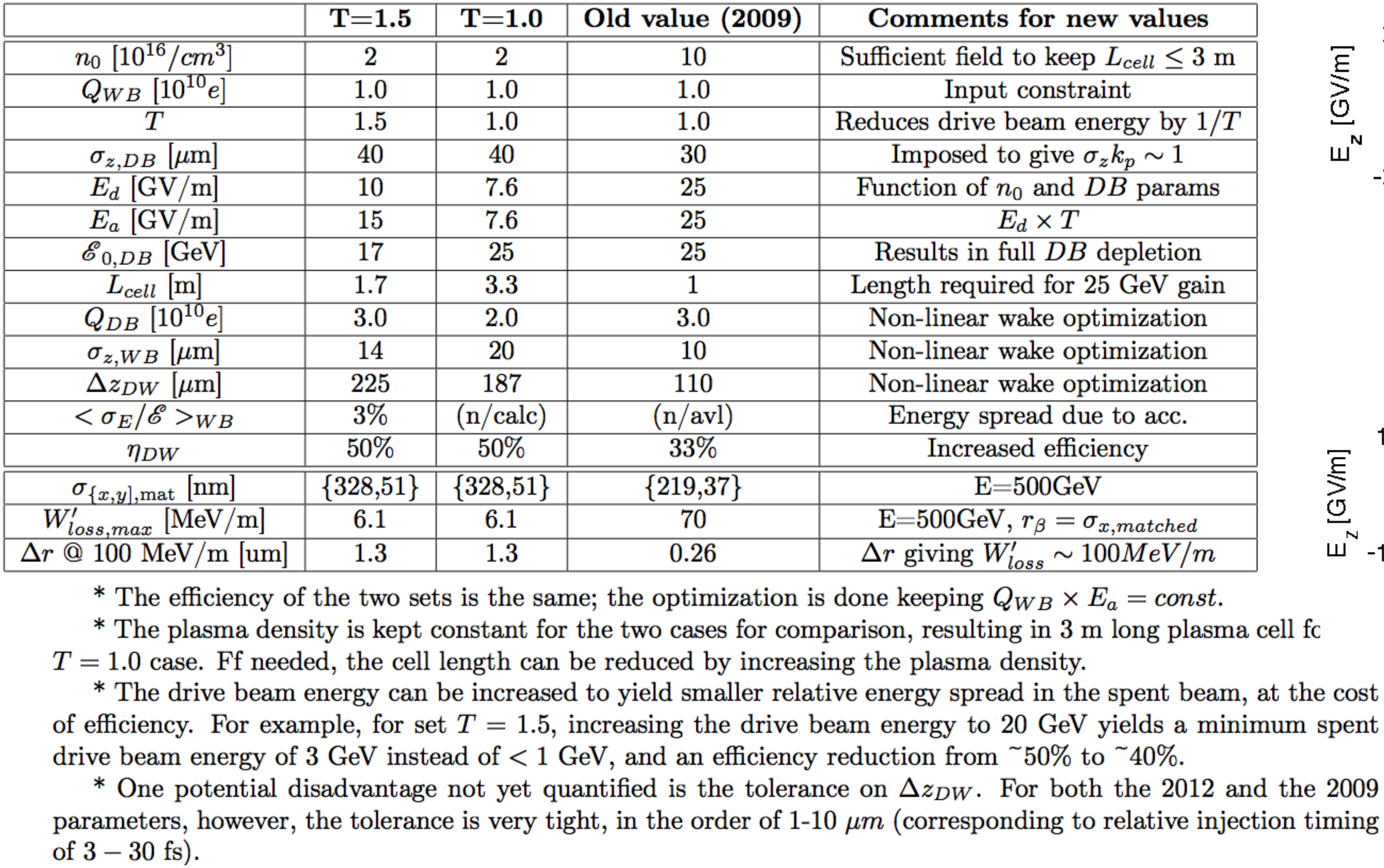


With main beam parameters given, plasma density and transformer ratio chosen, the drive bunch parameters are given by Q_{DB} x E_{acc} = const., plus the requirement of equal peak current in the drive and witness bunch.

Simulations are performed using QuickPIC (UCLA)

2013 Parameters

Parameters optimized following Tzoufras recipe, for two transformer ratios T=1, T=1.5, verified using QuickPIC.   No practical solution found for T >= 2.



	T=1.5	T=1.0	Old value (2009)	Comments for new values
n_0 $[10^{16}/cm^3]$	2	2	10	Sufficient field to keep $L_{cell} \leq 3$ m
Q_{WB} $[10^{10}e]$	1.0	1.0	1.0	Input constraint
T	1.5	1.0	1.0	Reduces drive beam energy by $1/T$
$\sigma_{z,DB}$ [μm]	40	40	30	Imposed to give $\sigma_z k_p \sim 1$
E_d [GV/m]	10	7.6	25	Function of n_0 and DB params
E_a [GV/m]	15	7.6	25	$E_d \times T$
$\mathcal{E}_{0,DB}$ [GeV]	17	25	25	Results in full DB depletion
L_{cell} [m]	1.7	3.3	1	Length required for 25 GeV gain
Q_{DB} $[10^{10}e]$	3.0	2.0	3.0	Non-linear wake optimization
$\sigma_{z,WB}$ [μm]	14	20	10	Non-linear wake optimization
Δz_{DW} [μm]	225	187	110	Non-linear wake optimization
$<\sigma_E/\mathcal{E}>_{WB}$	3%	(n/calc)	(n/avl)	Energy spread due to acc.
η_{DW}	50%	50%	33%	Increased efficiency
$\sigma_{\{x,y\},mat}$ [nm]	{328,51}	{328,51}	{219,37}	E=500GeV
$W'_{loss,max}$ [MeV/m]	6.1	6.1	70	E=500GeV, $r_\beta = \sigma_{x,matched}$
Δr @ 100 MeV/m [um]	1.3	1.3	0.26	Δr giving $W'_{loss} \sim 100 MeV/m$

* The efficiency of the two sets is the same; the optimization is done keeping $Q_{WB} \times E_a = const$.

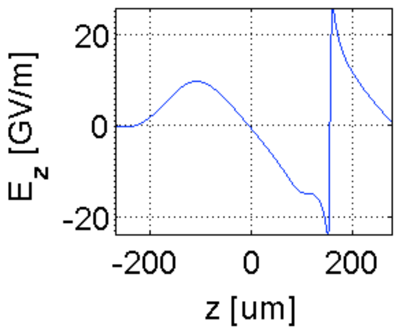
* The plasma density is kept constant for the two cases for comparison, resulting in 3 m long plasma cell fc $T = 1.0$ case. Ff needed, the cell length can be reduced by increasing the plasma density.

* The drive beam energy can be increased to yield smaller relative energy spread in the spent beam, at the cost of efficiency. For example, for set $T = 1.5$, increasing the drive beam energy to 20 GeV yields a minimum spent drive beam energy of 3 GeV instead of < 1 GeV, and an efficiency reduction from ~50% to ~40%.

* One potential disadvantage not yet quantified is the tolerance on Δz_{DW}. For both the 2012 and the 2009 parameters, however, the tolerance is very tight, in the order of 1-10 μm (corresponding to relative injection timing of $3 - 30$ fs).

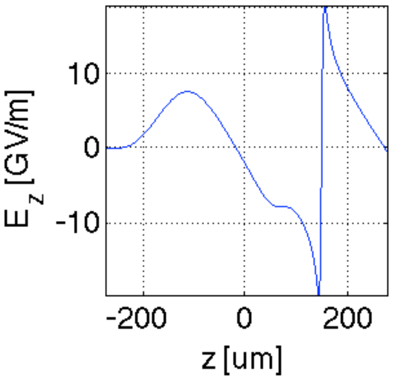
T = 1.5 :

$E_{z,max}$ = 9.8GV/m



T = 1.0 :

$E_{z,max}$ = 7.6GV/m



Additional Comments

- Simulations confirm analytic choices for plasma, drive and witness beam parameters (gradient, energy gain…)
  - Gaussian beams produce strong beam loading with 50% drive to witness energy transfer (27% left in plasma, 23% left in drive beam) and 3% energy spread
- Shaped beams would offer additional advantages:
  - Higher transformer ratio for reduced drive beam energy and/or number of stages
  - Higher efficiency
  - Reduced energy spread
- Emittance preserved at mm-mrad level but further studies needed to understand interplay of lower emittance, strong beam loading, hosing, ion motion…
- Initial estimates suggest very tight timing and alignment tolerances

Accelerator Physics Topics in An AAC-based Linear Collider

Acceleration issues

- Beam loading for efficiency and % level energy spread
- Longitudinal beam shaping to maximize transformer ratio (minimize number of stages)
- Transverse shaping for quasi-linear regime or positrons
- Precise timing to provide acceleration in many sections
- Interstage optics designs to maximize average gradient
- Positron acceleration (plasma concepts) – see next slide

Emittance preservation

- CSR (and inter bunch correlation) suppression
- Section by section alignment, corrections and feedbacks
- Inter-stage focusing, dispersion control
- Applicability of plasma lenses
- Multiple Coulomb Scattering, ion motion, mismatch…
- Transverse/longitudinal drive beam jitter <1um (same reqs as for main beam)

IP: Control of head-on collision < 1 nm for single bunch

- Ground motion, vibrations (jitter in beam position)
- Flat beams collision

Technical issues:

- Plasma response time and heat removal, Synchrotron Radiation and activation

More holistic view beginning to be discussed in presentations and some publications, e.g. C. Lindstrom PhD Thesis “Emittance Growth and Preservation in a plasma-based linear collider” https://www.duo.uio.no/handle/10852/66134

PWFA-LC designs all assume common interstage distance ~25-100meters.

A(PO)CHROMATIC CORRECTION (3/3)

- Example solution [22]:
  - Working staging optics for a 500 GeV, 0.5% rms energy spread, 80 cm matched beta
  - 39 m long, 5 dipoles, 8 quadrupoles
  - Cancels (1st order) chromaticity and (1st order) dispersion.
  - 1% emittance growth (due to 2nd order dispersion)

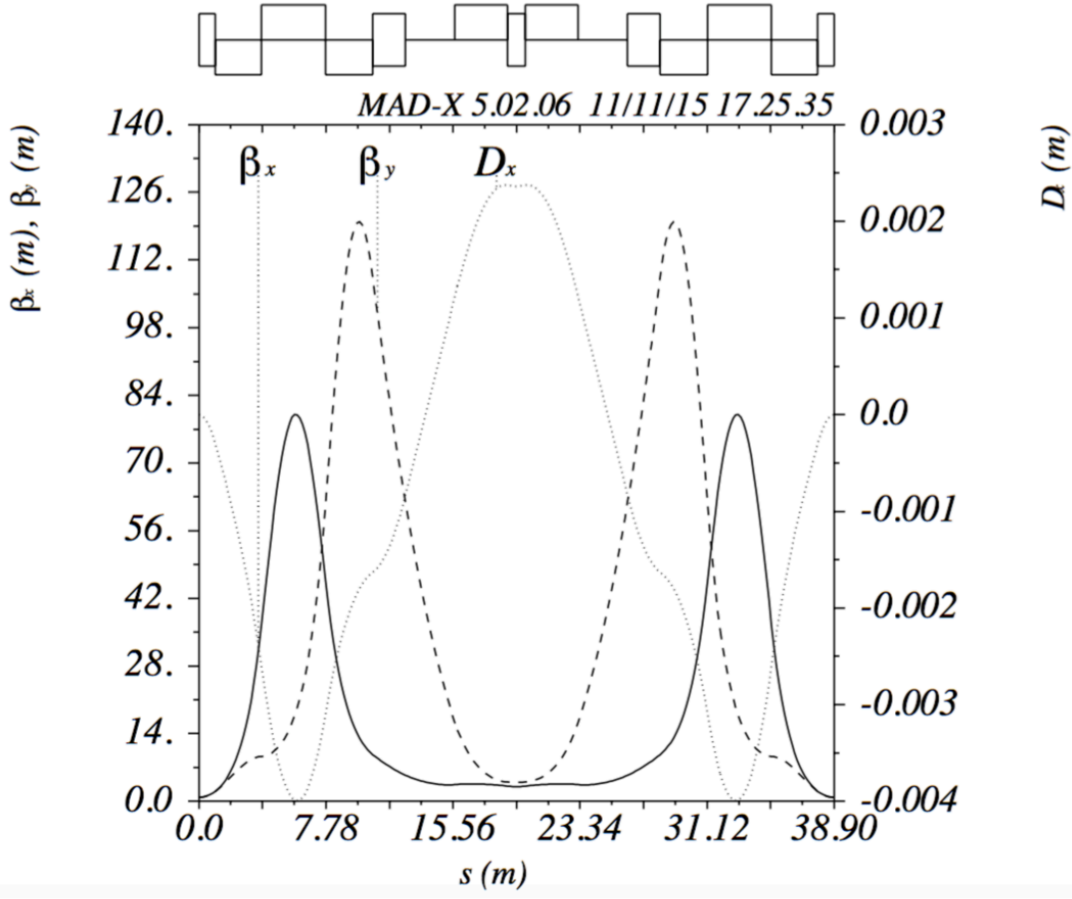
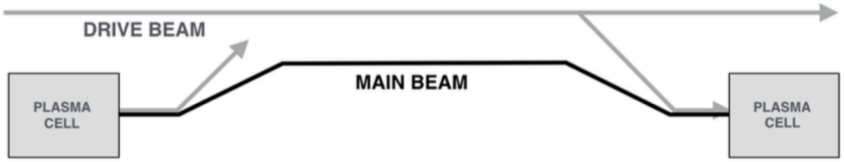


Image source: C. A. Lindstrøm et al., Nucl. Instrum. Methods Phys. Res. A 829, 224–228 (2016) [23]



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[22] C. A. Lindstrøm et al., "Staging optics considerations for a plasma wakefield acceleration linear collider", **Nucl. Instrum. Methods Phys. Res. A 829, 224–228 (2016)**.

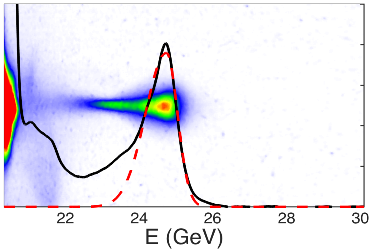
See: C. Lindstrøm "STAGING IN HIGH GRADIENT WAKEFIELD ACCELERATORS"
https://cas.web.cern.ch/sites/cas.web.cern.ch/files/lectures/sesimbra-2019/casstaginglecture.pdf

Further investigations (Carl/Erik U. Oslo) indicate this needs more work and scaling to multi-TeV is not favorable for effective gradients > 1GeV/m.

FACET/FACET-II Have a Unique Role in Addressing Plasma Acceleration of Positrons for Linear Collider Applications

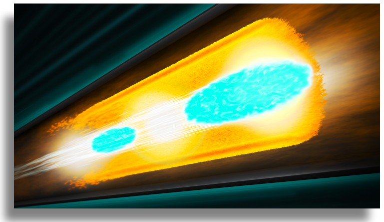
Demonstrated @ FACET

Non-linear wakes in
self-loaded regime of PWFA



Corde et al.,
Nature August 2015

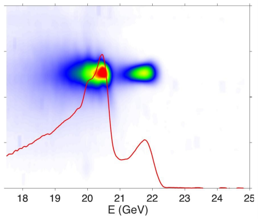
Hollow Channel Plasma
Wakefield Acceleration



Gessner et al., ***Nature Communications*** 2016
Lindstrom et al., ***Phys. Rev. Lett.*** 2018

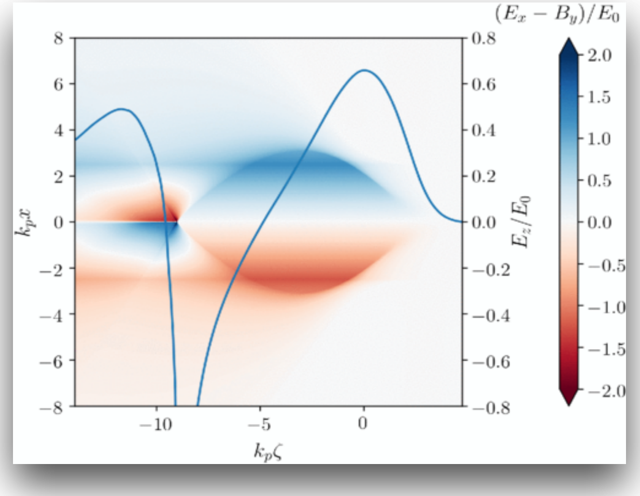
Quasi-linear
Wakefield Acceleration

Doche et al.,
Scientific Reports 2017

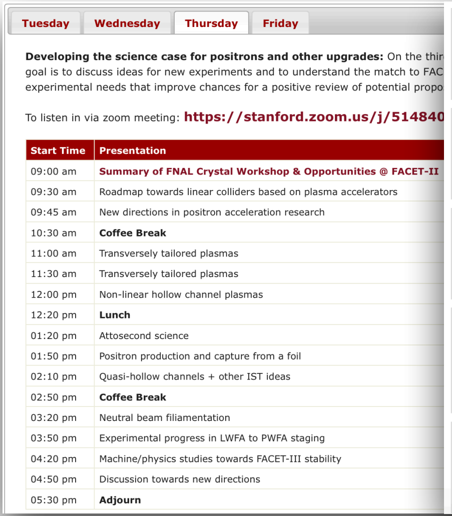


Proposed @ FACET-II

- New regime for positron PWFA
- Finite-channel plasmas are predicted to preserve emittance
- Concepts are testable with proposed FACET-II capabilities
- LBNL, DESY and SLAC collaboration



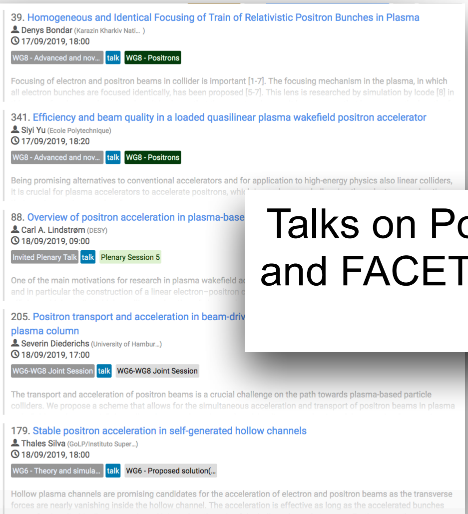
S. Diederichs et al., Phys. Rev. Accel. Beams 22, 081301 (2019)



Developing the science case for positrons and other upgrades: On the thir
goal is to discuss ideas for new experiments and to understand the match to FAC
experimental needs that improve chances for a positive review of potential propo

To listen in via zoom meeting: **https://stanford.zoom.us/j/514840**

Start Time	Presentation
09:00 am	**Summary of FNAL Crystal Workshop & Opportunities @ FACET-II**
09:30 am	Roadmap towards linear colliders based on plasma accelerators
09:45 am	New directions in positron acceleration research
10:30 am	**Coffee Break**
11:00 am	Transversely tailored plasmas
11:30 am	Transversely tailored plasmas
12:00 pm	Non-linear hollow channel plasmas
12:20 pm	**Lunch**
01:20 pm	Attosecond science
01:50 pm	Positron production and capture from a foil
02:10 pm	Quasi-hollow channels + other IST ideas
02:50 pm	**Coffee Break**
03:20 pm	Neutral beam filiamentation
03:50 pm	Experimental progress in LWFA to PWFA staging
04:20 pm	Machine/physics studies towards FACET-III stability
04:50 pm	Discussion towards new directions
05:30 pm	**Adjourn**



39. Homogeneous and Identical Focusing of Train of Relativistic Positron Bunches in Plasma
Denys Bondar (Karazin Kharkiv Nati...)
17/09/2019, 18:00
WG8 - Advanced and nov... talk WG8 - Positrons

Focusing of electron and positron beams in collider is important [1-7]. The focusing mechanism in the plasma, in which all electron bunches are focused identically, has been proposed [5-7]. This lens is researched by simulation by lcode [8] in

341. Efficiency and beam quality in a loaded quasilinear plasma wakefield positron accelerator
Siyi Yu (Ecole Polytechnique)
17/09/2019, 18:20
WG8 - Advanced and nov... talk WG8 - Positrons

Being promising alternatives to conventional accelerators and for application to high-energy physics also linear colliders, it is crucial for plasma accelerators to accelerate positrons, whi

88. Overview of positron acceleration in plasma-base
Carl A. Lindstrøm (DESY)
18/09/2019, 09:00
Invited Plenary Talk talk Plenary Session 5

One of the main motivations for research in plasma wakefield a
and in particular the construction of a linear electron–positron c

205. Positron transport and acceleration in beam-driv
plasma column
Severin Diederichs (University of Hambur...)
18/09/2019, 17:00
WG6-WG8 Joint Session talk WG6-WG8 Joint Session

The transport and acceleration of positron beams is a crucial challenge on the path towards plasma-based particle colliders. We propose a scheme that allows for the simultaneous acceleration and transport of positron beams in plasma

179. Stable positron acceleration in self-generated hollow channels
Thales Silva (GoLP/Instituto Super...)
18/09/2019, 18:00
WG6 - Theory and simula... talk WG6 - Proposed solution(...

Hollow plasma channels are promising candidates for the acceleration of electron and positron beams as the transverse forces are nearly vanishing inside the hollow channel. The acceleration is effective as long as the accelerated bunches

Talks on Positron PWFA at EAAC and FACET-II Science Workshops in 2019

Worldwide theoretical studies focused on beam parameters that will be achievable at FACET-II

FACET-II | Facility for Advanced Accelerator Experimental Tests

Laser Wakefield Accelerator Based Linear Collider

Carl Schroeder (LBNL)

April 30, 2020

U.S. DEPARTMENT OF ENERGY
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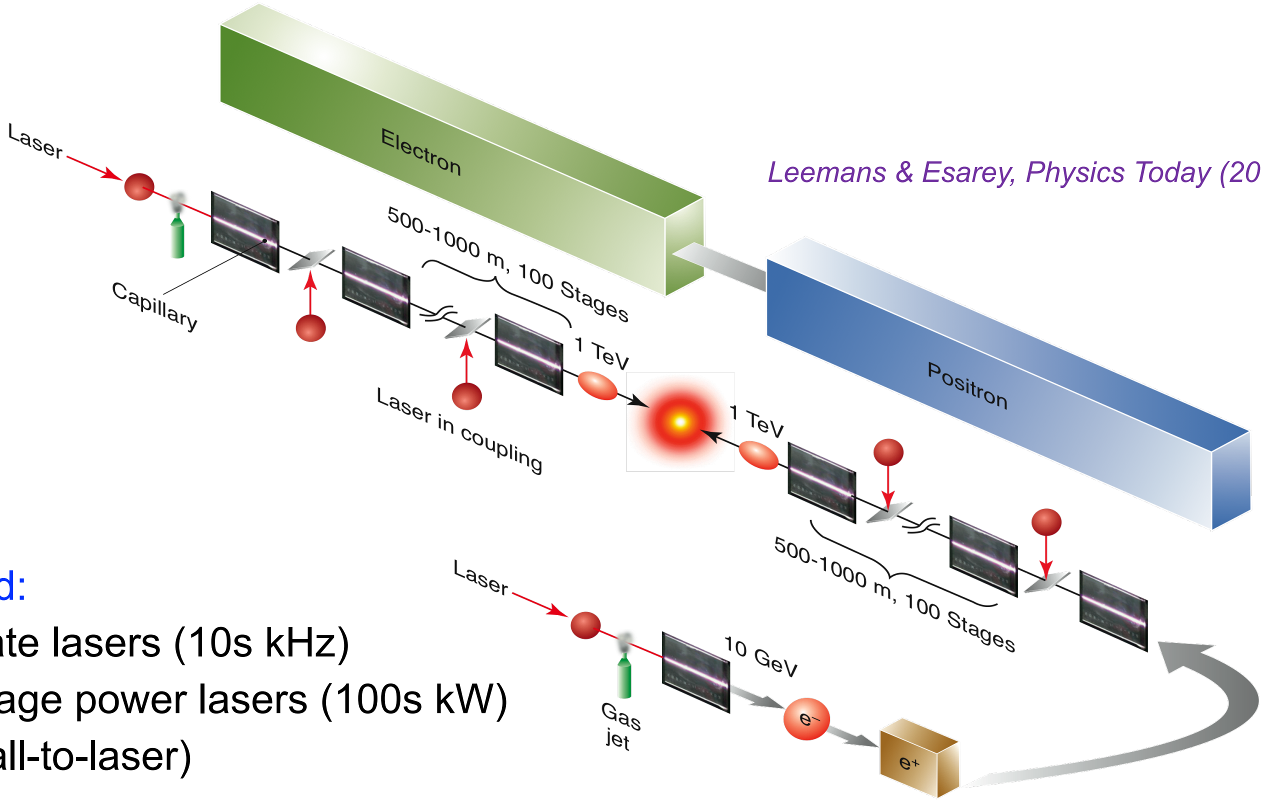
Laser-plasma collider concept

Basic concept: Staged laser-plasma accelerators:

- Plasma density scalings indicates operation at $n \sim 10^{17}$ cm^{-3} [high average gradient and low wall plug power]
- Quasi-linear regime ($a \sim 1$): e^+ and e^- focusing and acceleration; focusing control
- Staging & laser coupling into plasma channels (for laser guiding):
  - Tens of J laser/energy per stage
  - Energy gain/stage ~ few GeV in < 1m

C. B. Schroeder et al., PR ST-AB (2010)
C. B. Schroeder et al., NIMA (2016)



Leemans & Esarey, Physics Today (2009)

Laser technology development required:

- High luminosity requires high rep-rate lasers (10s kHz)
- Requires development of high average power lasers (100s kW)
- High laser efficiency (~tens of % wall-to-laser)

Collider design optimization

Basic collider parameter scalings with density and laser wavelength:

C. B. Schroeder et al., PR ST-AB (2010)

$$N_{\text{stages}} \propto n\lambda^2$$

$$L_{\text{linac}} \propto n^{-1/2}$$

$$f_{\text{rep}} \propto n$$

$$P_b \propto n^{1/2}$$

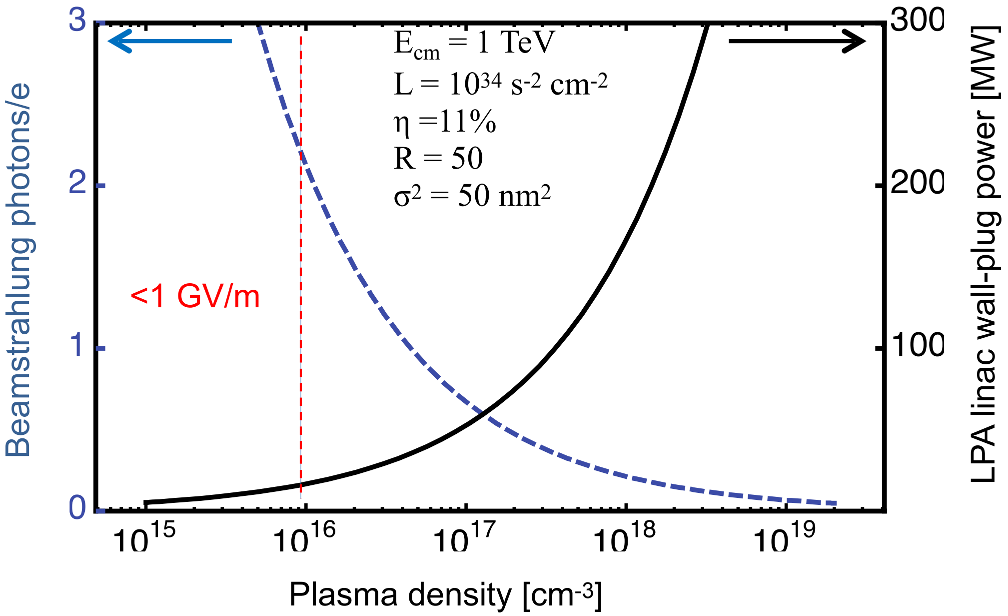
$$P_{\text{avg laser}} \propto n^{-1/2}\lambda^{-2}$$

$$P_{\text{wall}} \propto n^{1/2}$$

$$n_\gamma \propto n^{-1/2}$$

Optimization of operational plasma density:

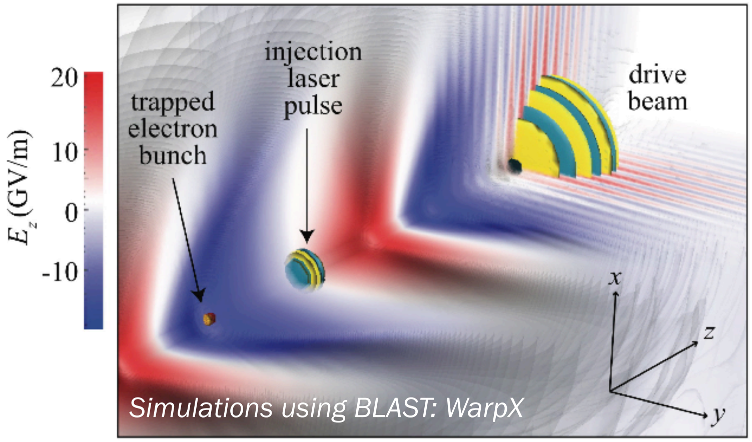
- Density high enough for sufficient gradient (reduced total linac length) $E_z \propto n^{1/2}$
- Density low enough for sufficient charge/bunch (reduced power requirements) $N_b \propto n^{-1/2}$
- Density determines required laser parameters (energy/pulse, duration, peak power, rep. rate)



R&D on LWFA beam physics questions

Generation of ultra-low emittance beams – Can laser-plasma interactions (laser-triggered injection) be used to generate beams with ultra-low (~10 nm) emittances?

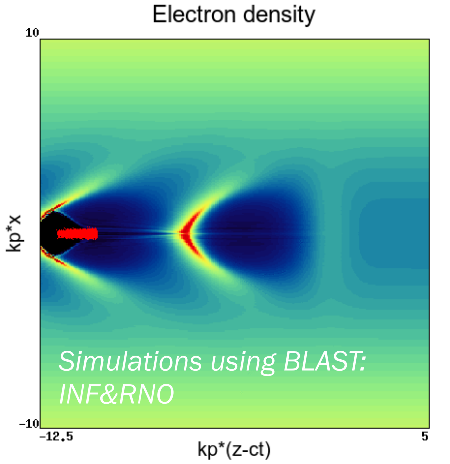
Lu et al., PRL (2014); C. B. Schroeder et al., PRAB (2014)



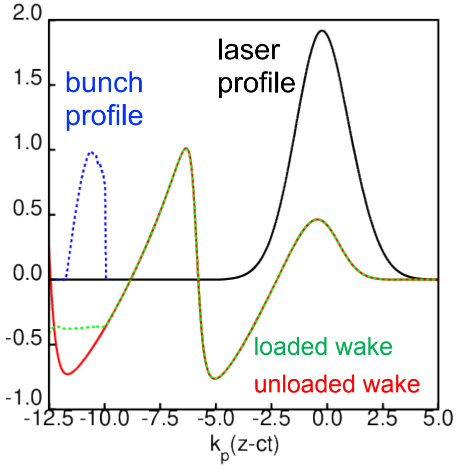
Simulations using BLAST: WarpX

Experiments at BELLA in preparation for 2-color ionization injection.

Shaped particle beams for high driver-to-beam efficiency - What is the beam shape to load to eliminate energy spread with high efficiency? How to achieve shape in lab?



Simulations using BLAST: INF&RNO



Ion motion induced emittance growth - Small emittance and plasma focusing yields dense beams and ion motion, creating nonlinear focusing forces. Can beams be matched to the ion-motion-modified wakefields?

Benedetti et al., PRAB (2017)

Beam-break up (BBU) / hosing instability - What are possible mitigation methods (ion motion, focusing force chirp, etc.)?

Mehrling et al. PRL (2018); Lehe et al., PRL (2017)

FACET-II | Facility for Advanced Accelerator Experimental Tests

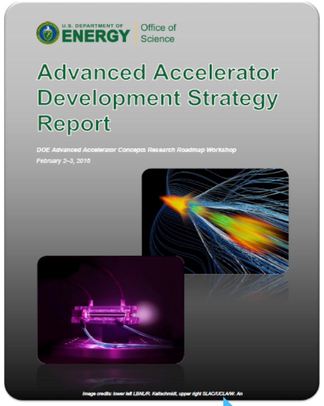
Structure Wakefield Accelerator Based Linear Collider

John Power (ANL)
April 30, 2020

SHORT-PULSE SWFA 3 TEV COLLIDER CONCEPT

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

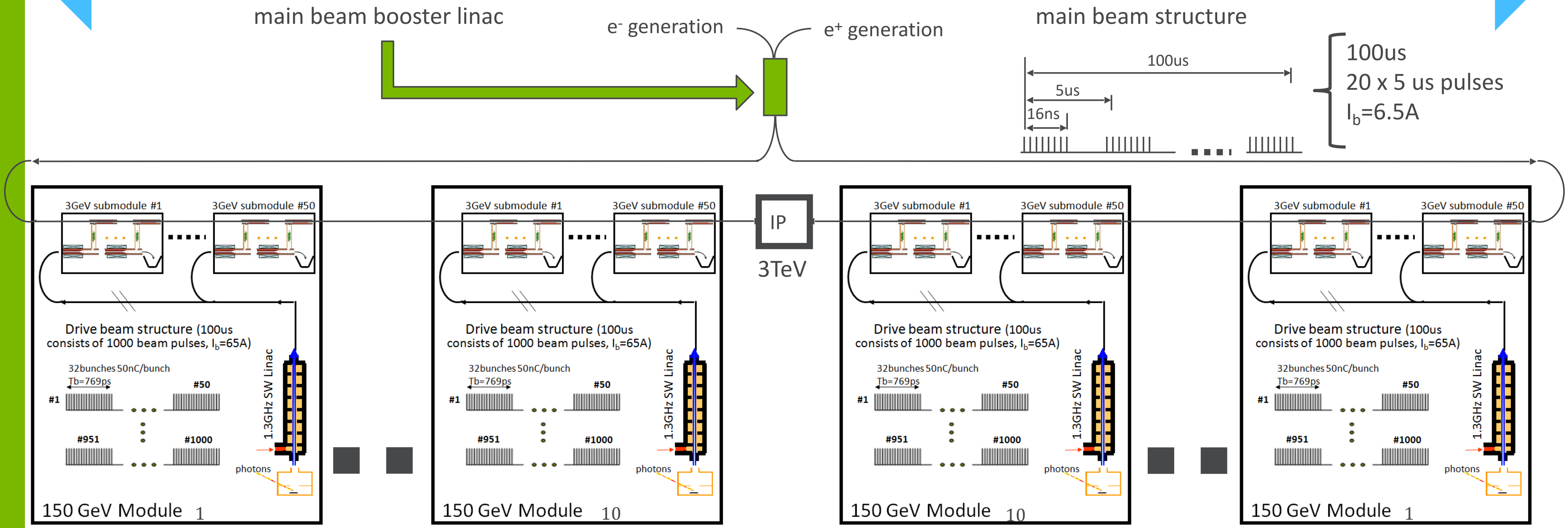
REF


U.S. DEPARTMENT OF ENERGY | Office of Science

Advanced Accelerator Development Strategy Report

DOE Advanced Accelerator Concepts Research Roadmap Workshop
February 2–3, 2016

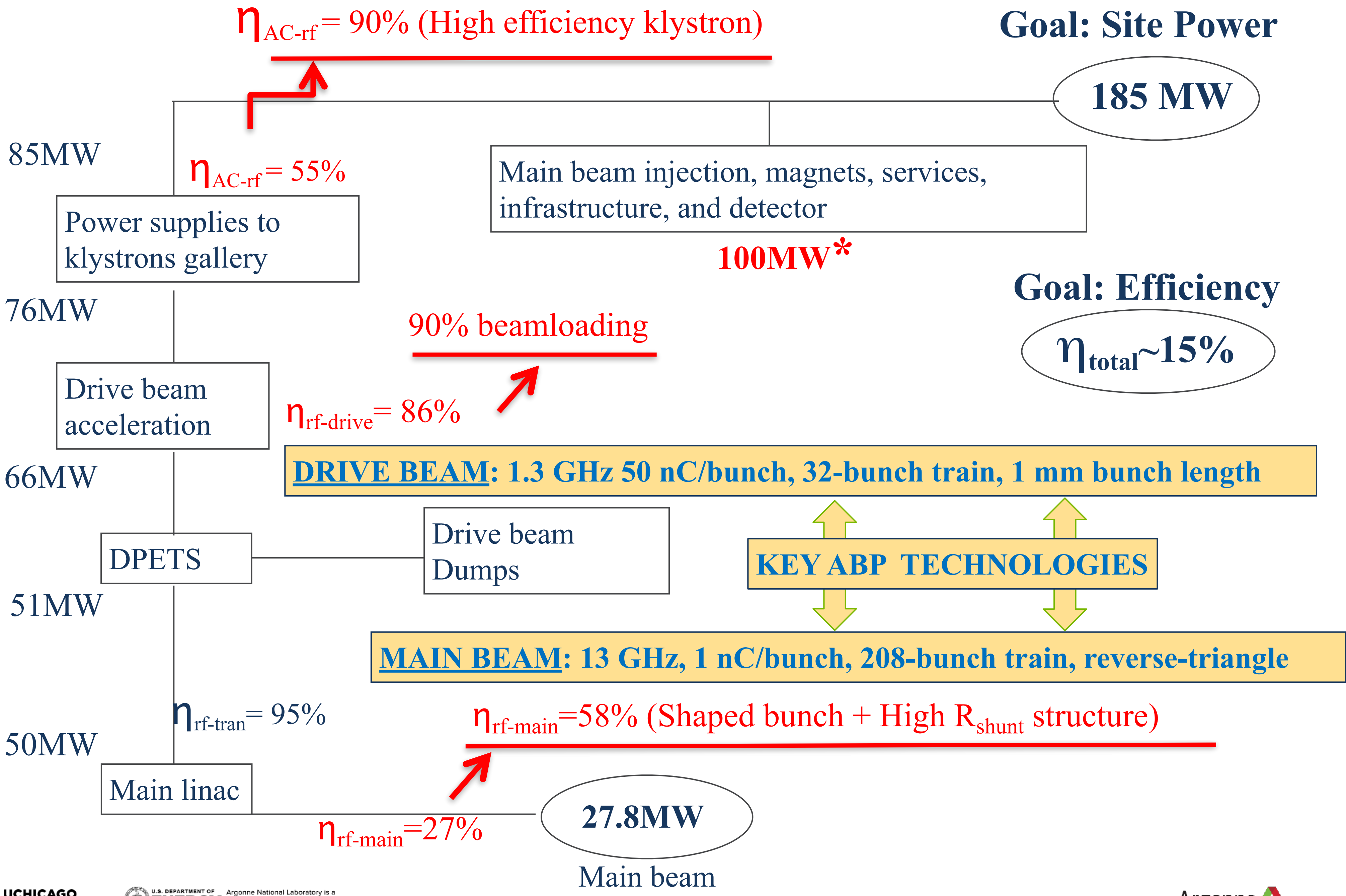
ARGONNE FLEXIBLE LINEAR COLLIDER



Modular design
(easily staged)

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

COST(STRUCTURE, EFFICIENCY,…)



$\eta_{AC\text{-}rf}$= 90% (High efficiency klystron)

Goal: Site Power

185 MW

85MW

$\eta_{AC\text{-}rf}$= 55%

Power supplies to klystrons gallery

Main beam injection, magnets, services, infrastructure, and detector

100MW*

76MW

90% beamloading

Goal: Efficiency

η_{total}~15%

Drive beam acceleration

$\eta_{rf\text{-}drive}$= 86%

66MW

DRIVE BEAM: 1.3 GHz 50 nC/bunch, 32-bunch train, 1 mm bunch length

DPETS

Drive beam Dumps

KEY ABP TECHNOLOGIES

51MW

MAIN BEAM: 13 GHz, 1 nC/bunch, 208-bunch train, reverse-triangle

$\eta_{rf\text{-}tran}$= 95%

$\eta_{rf\text{-}main}$=58% (Shaped bunch + High R_{shunt} structure)

50MW

Main linac

$\eta_{rf\text{-}main}$=27%

27.8MW

Main beam

---

* Borrowed from the CLIC design

ACCELERATOR BEAM PHYSICS ISSUES FOR SWFA

Drive Bunch Train:
1.3 GHz, 50 nC, 32-bunch train, 1 mm bunch length

- ➢High-intensity, High-power (50 GW) beam : beam loading, brightness, …
- ➢Beam control for high charge bunch train (e.g. , BBU control, shaping, …)
- ➢Simulation of high charge bunch train (e.g. simulation for bunch train …)
- ➢……

Main beam:
13 GHz, 1 nC/bunch, 208-bunch train, reverse-triangle

- ➢Generation of nanocoulomb-level high brightness beam
- ➢Preservation of beam quality (e.g. collective effect mitigation, …)
- ➢Phase space control of nanocoulomb beam (e.g. compression, shaping, flat beam, …)
- ➢……

Concluding Thoughts

- Many accelerator beam physics challenges en route to a collider (and even to first applications) – see partial list slide 14
- US and International collaborations have proposed many exciting and challenging experiments to address key physics issues on US Roadmap – success will require theory, computation, diagnostic development and facilities to test
- Each 'Advanced Accelerator' technology has prioritized milestones but there are also many common issued:
  - Beam loading and beam shaping for narrow energy spread and high efficiency
  - Emittance preservation at µm and sub-µm levels
  - Knowledge of structure dynamics at long timescales
  - Investigations of paths to positron acceleration comparable to electrons
- Applying lessons learned to update collider designs will take community involvement and motivated/dedicated personnel with time to do so

https://snowmass21.org/start