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4/27/2017

Working Group 4 (DLA) Report

U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

From Muggli 3/27/2017 email

For the WG reports, I would suggest to highlight the achievements with the various acceleration schemes, the outstanding challenges, hints or plans to meet these challenges, as well as needs (facility, computation, etc.) that the WG thinks are needed.

The [parameter spreadsheet] will be used mostly after the workshop to be included in a detailed report of the workshop activities. We will improve it before the workshop, fill it at the workshop and then try to make it uniform after the workshop since I am sure things will pop up at the WG sessions.

E. R. Colby and L. K. Len (DoE, Office of Science – HEP)

"As with the other advanced concepts, the primary challenges are to

(1) demonstrate the practical **gradient limit** (believed to be >1GeV/m),

(2) demonstrate operation at a very **high repetition rate** and discover the practical bunch charge limits of such devices (required to produce useful beam power for most applications),

(3) demonstrate **practical technologies** for accelerating structures, beam focusing, bending, and diagnosis,

(4) develop techniques for achieving the **submicron-class alignment** required to preserve emittance,

(5) develop **electron and positron sources** matched to the unique phase space requirements, and

(6) develop fully compatible, **high-efficiency laser sources**.

- Of these activities, (1) and (3) have received the most attention to date.
- For this technology to move forward to near-term applications, (2), (5) and (6) must be addressed.
- The intrinsic attosecond- and micronscale operation of the DLA could potentially offer synchronized attosecond sources of electrons and radiation (e.g. THz, visible, X-rays) that provide the tools for directly monitoring and *controlling* chemical reactions."

E. R. Colby & L. K. Len, "Roadmap to the Future," Rev. Accel. Sci. Technol., 09, 1-18 (2016)

Guiding Questions for Working Groups

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1. Take stock of the current state of the field (for each acceleration technique)
2. Determine which parameters have been reached, which ones will be reached in the next 5-10years, which ones are desirable or necessary and without current solution.
3. Determine key issues to be addressed in future experiment

Determine which issues are technological (i.e., can assume they can be solved) or fundamental (i.e., cannot be solved by technology)

4. Determine order of priority to determine viability/parameters of the scheme

Imagine ideal facility infrastructure to demonstrate viability of the concept (e.g., N lasers with these parameters, laser + electron injector, electron and positron linac/ sources, etc.)

5. Identify key technology (e.g., high power, high rep. rate, short pulse lasers) that is needed for the concept and rate their likely time scale for development
6. Identify simulation tools needed: full PIC 3D, 2D, reduced model (quasi-static), fluid, hybrid, etc. Other simulation tools needed …

Unique Features of a DLA Collider

Efficiency calculations position DLA as a competitive technology for collider applications with reasonable wall plug power consumption.

Unique bunch format: small charge (fC) at high rep rates (10-50 MHz)

Key Advantages:

Linear acceleration mechanism in a static structure with vacuum channel.

Critical technologies (laser development, nanofab) are at or near requirements for a HEP collider.

Challenges:

Small beam apertures → challenge with regard to wakes, halo, and long-distance transport.

Limited funding for this area of research is not directly focused on HEP applications.

Opportunities to leverage funding from other funding agencies for specific applications, including HEP.

Working Group 4 Participants

Working Group Co-Chairs:

Joel England (SLAC)

Josh McNeur (FAU Erlangen)

Bruce Carlsten (LANL)

Participants:

Laura Corner (John Adams)

Ulrich Dorda (DESY)

Steven Jamison (Daresbury)

Serkey Kuzikov (Euclid Tech Labs)

Levi Schachter (Technion)

Ben Cowan (Tech-X)

Evgenya Simakov (LANL)

Igor Pogorelsky (BNL)

WG4: Topic Descriptions

	Topics	Description
1	**Transport**	Study issues related to long-distance particle transport and beam quality
2	**High-Field**	Evaluate nonlinear high-field processes in dielectrics and develop mitigation strategies
3	**Sources**	Evaluate techniques for positron production and for integration of novel electron sources
4	**Final Focus**	Understand the final focus physics and technical requirements
5	**Efficiency**	Determine realistically achievable efficiency, power, and cost estimates for a collider facility

A variety of sub-topics were developed under each category and then discussed and prioritized. These are outlined on the following slides.

WG4: Goals for Each Topic

1. Review current state of understanding.
2. Identify critical advantages and concerns/bottlenecks.
3. Invite alternative ideas and approaches.
4. Make a prioritized list of next steps: what experimental, theoretical, and computational efforts are needed to demonstrate progress?

Selected Highlights

Focusing Strategies: R. J. England

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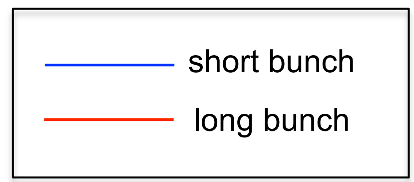
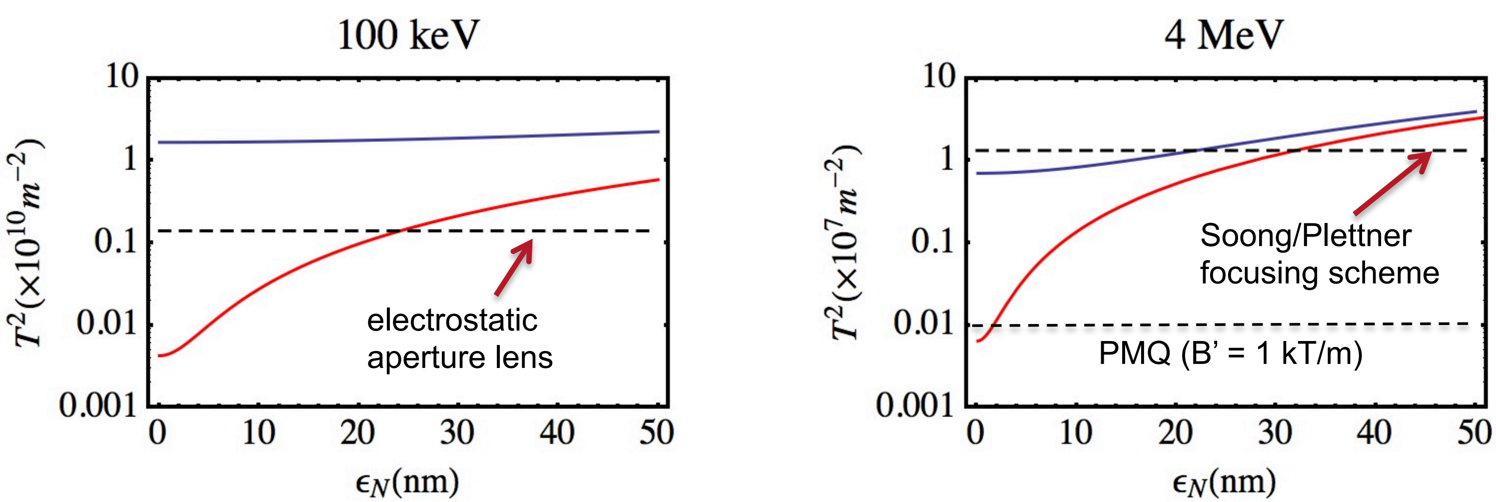
Parameter	Description	Units	Value
λ	wavelength	µm	2
σ	beam radius	µm	1
$T0$	initial kinetic energy	keV	100
Tf	final kinetic energy	MeV	4
Q	bunch charge	fC	4
τ	bunch duration	fs	0.1, 1000
ϵN	normalized emittance	nm rad	2
L	interaction distance	cm	2

Example beam parameters corresponding to desirable microbunched DLA parameters.





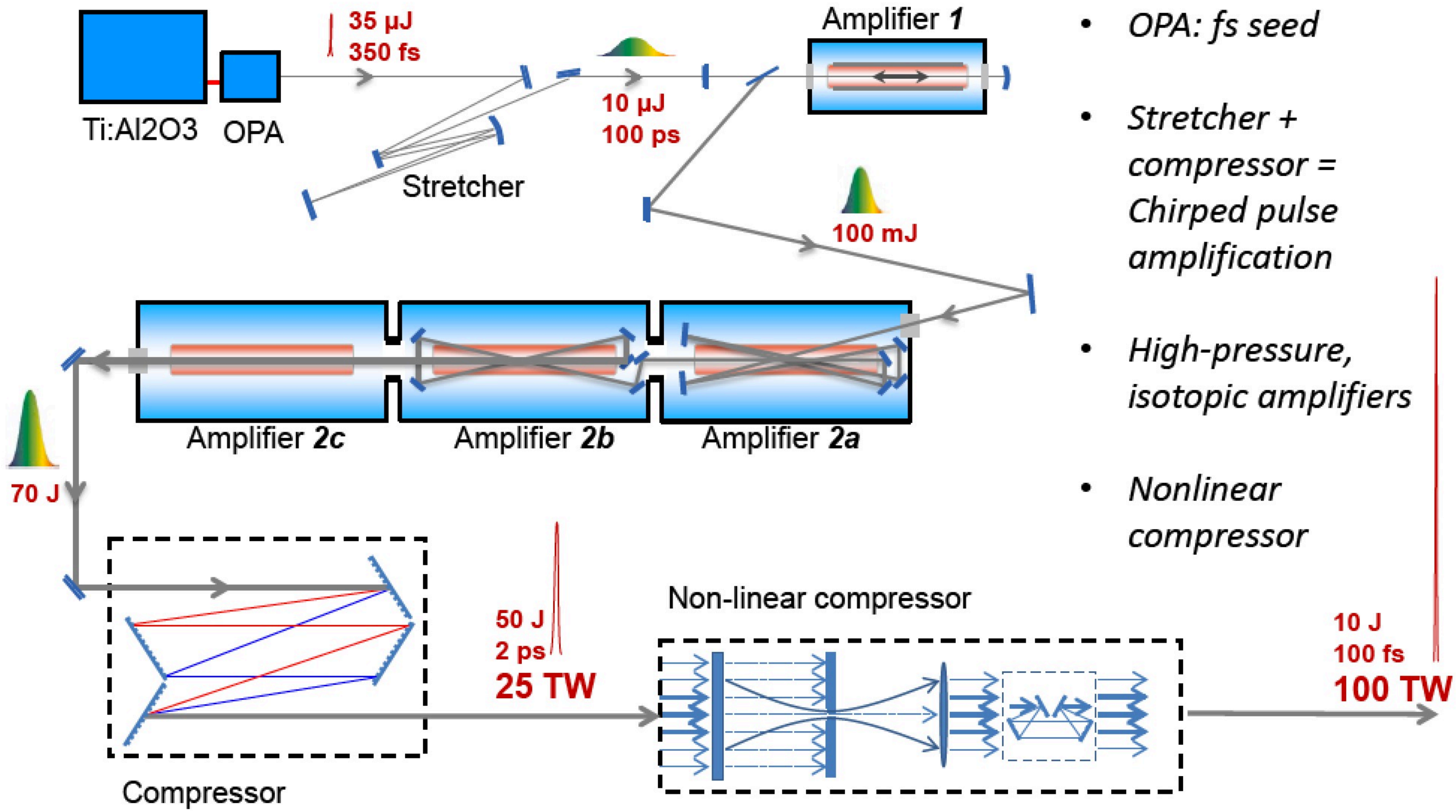
CO_2 Lasers as Longer Wavelength (10 µm) Drive Source – L. Schachter

- CO_2 lasers may be viable candidate for driving laser accelerators for collider applications
- Longer laser wavelength has several advantages
  - More charge in accelerated microbunches
  - Eases beam quality requirements for incoming *e*-beam
  - Eases ability to adjust and maintain phasing of microbunches between acceleration stages
  - Eases fabrication of acceleration structures
- More experimental work on CO_2-laser-driven accelerators needed to confirm these advantages

100TW CO_2 concept laser

I. Pogorelsky

Collection of innovations:



- *OPA: fs seed*
- *Stretcher + compressor = Chirped pulse amplification*
- *High-pressure, isotopic amplifiers*
- *Nonlinear compressor*

Gamma-Gamma as Alternative Collider Scenario – R. J. England

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$$\mathcal{L}_{\gamma\gamma} \simeq k^2\, \mathcal{L}_{ee} \qquad k \simeq \frac{A}{A_0}$$

A ← laser pulse energy

A_0 ← target parameter (typically ~ 1-5 J)

$$\mathcal{L}_{\gamma\gamma} \propto Q^2 f \left(\frac{A}{A_0}\right)^2$$

DLA case: $\begin{cases} Q = q\,n\,N \simeq 1\ \mathrm{pC} \\ f \simeq 50\ \mathrm{MHz} \end{cases}$

Challenging requirements for Compton laser: (A = 1J, f = 50 MHz)!

JLab proposal from 2012 (TN-12-053): Relax laser requirements by increasing beam charge. Could we do something similar here?

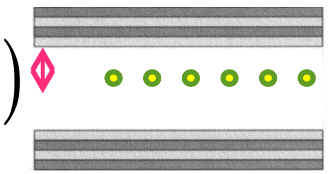
Reduce pulse energy A by factor of 3 and reduce rep rate f by factor of 50:

$$\frac{\mathcal{L}_{\gamma\gamma}'}{\mathcal{L}_{\gamma\gamma}} = \frac{f'}{f} \times \left(\frac{Q'}{Q}\right)^2 \times \left(\frac{k'}{k}\right)^2 \simeq 1 \quad \Rightarrow \quad \frac{Q'}{Q} \simeq \sqrt{\left(\frac{k}{k'}\right)^2 \times \frac{f}{f'}} = \sqrt{3^2 \times 50} \simeq 20$$

For this example, we need 20x more charge. → **Matrixed electron beams**?

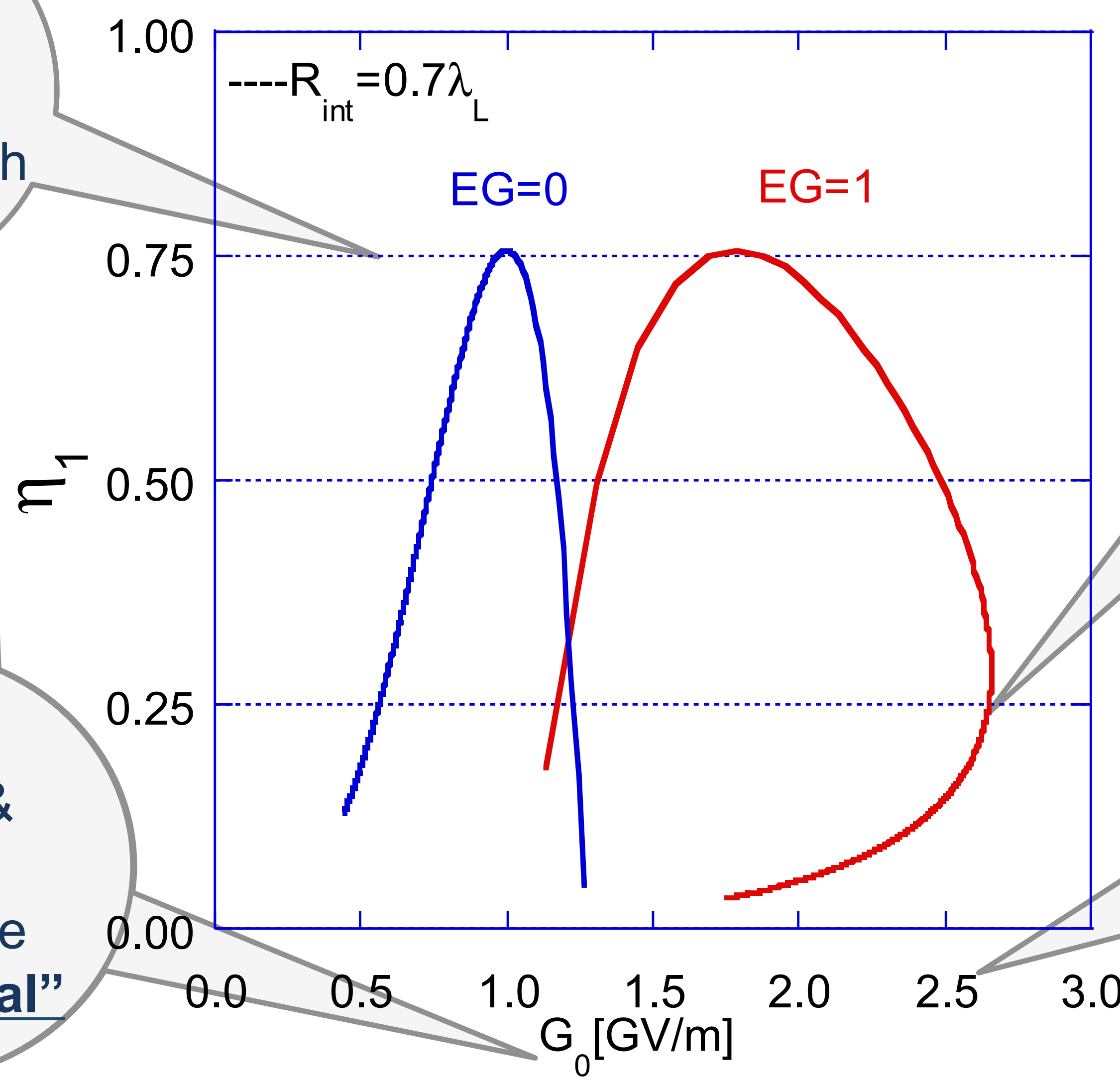
Updated Efficiency Estimates with Multi-parameter optimization – L. Schachter, A. Hanuka (Technion)

$\left(L_{geo}, R_{int}, M \right)$



$$\eta \equiv \frac{\Delta U_{kin}}{U_{EM}}$$

Maximum efficiency doesn't change with EG=0/1



Maximum gradient for EG=1 only!

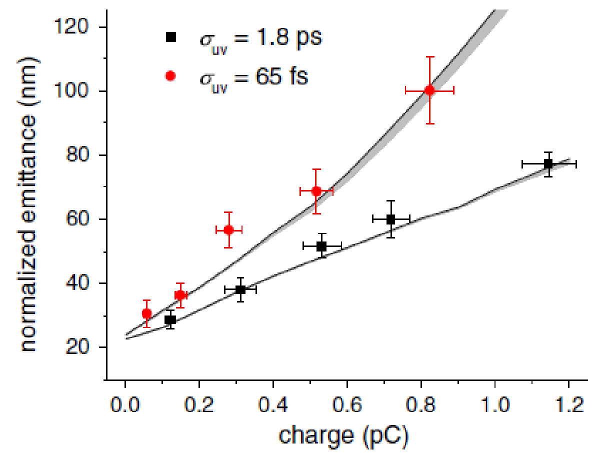
Maximum efficiency & maximum gradient are "**orthogonal**"

Gradient values are **higher** for EG=1

Comparison of Measured Electron Source Parameters – J. McNeur (FAU)

Parameter	Units	Tip Source (FAU)	Flat Cathode measured (UCLA)
Max Bunch Charge	fC	0.1	20
Min MacroBunch Duration	fs	100	100
Max Macrobunch Duration	fs	300	1000
Normalized Emittance	nm rad	1.00E-01	5.00E+00
Normalized Brightness	A/(cm^2sr)	2.50E+12	1.60E+09
Virtual Source Size	nm	0.5	5000
Average current	nA	?	0.1

R. K. Li et al., PRAB 15, 090702 (2012)



Prioritization of Sub-topics

Priority criterion: Could it be a possible show stopper?

High: address within 5 years.
Medium: address within 5-10 years.
Low: address > 10 years

This maps directly into Simon Hooker's parameter table.

Working group participation in form of discussion on selected topics.

Short presentations on selected topics (1-10 slides each)

Note: Prioritizations subject to change with new experimental and simulation developments. Extent of some concerns will likely be elucidated in progression to microbunched beam experiments and longer interaction distances.

High Priority Item: Focusing and Transport

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Statement of the Issue or Concern:
Transport of ultra-relativistic beams in narrow (sub-micron) apertures requires high-gradient focusing fields (of order MT/m).

What is the current status or understanding?
Laser-driven focusing demonstrated at 30 keV (sub-relativistic) beam energies.
Concepts for MT/m gradient laser-driven focusing structures proposed.

What are the next steps (1-5 year scale)?
Proof-of -principle demonstration of a focusing concept with adequate field strength.
Modeling and tracking studies to understand focusing requirements at TeV energies.

Relevant Facilities & Codes:
Facilities: SwissFEL, FACET-II, FLASH, DESY, ATF-II
Codes: Elegant, GPT (Tracking) + E&M modeling (HFSS, CST)

High-gradient focusing demonstration experiments combined with beam tracking simulations would provide critical understanding of multi-stage transport requirements.

High Priority Item: Radiation hardness and charging effects at MeV, GeV, and TeV beam energies.

Statement of the Issue or Concern:
Will DLA materials survive in extreme radiation conditions (MW beam powers) in the presence of halo and beam loss?

What is the current status or understanding?
Gamma and neutron tests of Nd:YAG samples ca. 2005.
No observed damage or charging to date at 60 MeV beam energies in SiO2 or Si.

What are the next steps (1-5 year scale)?
Transport simulations will help understand beam loss issues and likely radiation doses. Targeted radiation tests at various beam energies (100 MeV to 3 GeV).

Relevant Facilities & Codes:
Facilities: SwissFEL, FACET-II, FLASH, DESY, ATF-II
Codes: Elegant, GPT (Tracking)

Transport and focusing studies will enable beam loss estimates; combined with targeted experiments will help understand radiation effects on relevant optical materials.

High Priority Item: Wakefield effects and beam breakup (BBU)

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Statement of the Issue or Concern:
Will wake effects on optically microbunched beams in micron-scale aperture devices degrade beam quality to levels unsuitable for a linear collider scenario?

What is the current status or understanding?
Longitudinal and transverse wakes simulated in as-built SiO_2 DLAs.
Back-of-envelope estimates of tolerances on beam offset at 10% of beam radius over 500 m transport, and consideration of BNS damping as a possible mitigation.

What are the next steps (1-5 year scale)?
Tracking simulations with realistic wakefields and bunched beams. Ongoing experiments with microbunches and multi-stages may shed light.

Relevant Facilities & Codes:
Facilities: SwissFEL, DESY, ATF-II (with availability of microbunched beams)
Codes: Elegant, GPT (Tracking) + Vsim, ACE3P (PIC)

Detailed simulation studies of wakefields and the related BBU will indicate if this is a severe problem for DLAs and motivate possible design changes to mitigate these instabilities.

High Priority Item: Halo and Beam Collimation

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Statement of the Issue or Concern:
Sending a MW power beam through a micron-scale aperture accelerator could lead to deleterious beam halo effects from dark current, transition radiation, and nonlinear space charge effects.

What is the current status or understanding?
This regime is largely unexplored and requires a detailed simulation.

What are the next steps (1-5 year scale)?
A simulation study that may require new code development.

Relevant Facilities & Codes:
Codes: Elegant, GPT (Tracking) + Vsim, ACE3P (PIC)

Various possible sources of beam halo need to be understood, possibly requiring new code development.

High Priority Item: Compatible Positron Source

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Statement of the Issue or Concern:
For e+e- collider, a compatible source of relativistic positrons is needed.

What is the current status or understanding?
Positron equivalent of a high brightness compact nanotip electron source doesn't exist.
Conventional collider positron ring may be adapted (e.g. fixed target with high-rep DLA electron beam + damping ring).

What are the next steps (1-5 year scale)?
Feasibility study to understand the requirements for low (nm-scale) normalized emittance positrons at high repetition rate (~ 10 to 50 MHz).

Relevant Facilities & Codes:
N/A

While there have been extensive developments in nanotip e- sources and RF sources at fC bunch charge have close to desired beam quality, comparable positron sources have not been identified.

Medium Priority (5 to 10 years)

Start-to-End Modeling

→ Not yet done but planned as part of ACHIP collaboration

Sub-micron alignment and diagnostics

→ Active feedback needed – see LIGO (1 nm/√Hz stabilization over km scales)

Intrabeam scattering of micro-bunch particles (bunch charge ~ 1e4 e-)

→ Not clear if this is a concern but worth examining more closely

Combination of multiple parallel beams

→ Doesn't appear critical for e+e-, but may be useful path to higher beam current

→ Laser coupling and beam combination before IP need further study

Choice of Laser Wavelength (1 to 10 μm)

→ Best to leave as open question; experiments being done at various wavelengths

→ Tradeoffs b/w aperture size and laser capabilities, material absorption bands

Nonlinear effects (SPM, Dispersion, Raman scattering)

→ SPM found relevant in recent gradient demonstrations

→ Dispersion minimization important for on-chip laser waveguiding

Heat dissipation at high laser rep rates

→ Appears manageable (estimate 1 W/cm^2 needed) vs. 1.5 kW/cm^2 limit

Medium Priority (5 to 10 years)

Electron Sources

→ Conventional RF sources close to needed emittance & brightness for fC bunch charges

→ Nanotip sources may not have sufficient current yield but have demonstrated brightness ~ 1e12 A/cm^2/sr and emittances < 1nm

Laser to dielectric (e.g. waveguide/splitter) coupling efficiency

→ Efficiencies near 100% required; experimental demonstrations needed

→ Simulation work indicates > 90% coupling theoretically possible

Accelerating field to electron coupling efficiency

→ Estimate 40% efficiency needed for linear collider

→ Prior theory work (Siemann, Schachter) indicates 60-75% possible

Cost Drivers and trends/projections

→ Estimated power requirements of order 400 MW is within 500 MW recommended “cap” for 3 TeV scenario

Lower Priority (> 10 year)

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Laser technical requirements
→ Required laser params (modelocked, few μJ/pulse, 10-50 MHz, < 1ps) near market availability

High-field damage mechanisms in dielectrics
→ Target gradients ~ 1 GeV/m demonstrated already with known materials

Stark band-splitting (metalization of dielectric materials)
→ Relevance for DLA wavelengths, field intensity not fully known

Gamma-gamma conversion via Compton Scattering
→ Enticing possibility; may require matrixed beams (multiple parallel beamlines)

Requirements for final focus design
→ Complex design issues here
→ Near-term perhaps better to look at DLA configuration with more conventional or established final focus designs

Lower Priority (> 10 year)

Luminosity, disruption, beamsstrahlung

→ Parameters appear favorable for DLA with low charge (fC) high rep (50 MHz)

→ Beamsstrahlung energy loss substantially lower due to low bunch charge

Requirements for dispersive microbunch smearing of bunch trains

→ Desirable for luminosity charge scaling and luminosity enhancement

→ Probably happens naturally in final focus

Achievable laser wall-plug efficiency

→ Existing soon-to-market lasers already have needed efficiencies (~30%)

Conclusions

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1. Thank you to all participants: helpful and active dialog and feedback with new ideas and perspectives.
2. Key technologies (nanofabrication, solid-state lasers) are at or very near required capabilities for DLA collider applications, making DLA a competitive cost-effective alternative approach.
3. DLA target e-beam parameters (optical microbunching, fC bunch charges, 1-2 nm emittance, 10-50 MHz rep rates) appear reasonably compatible with 3 TeV (luminosity, efficiency/wall-plug power, beamsstrahlung) requirements and available or projected electron source capabilities. A suitable positron source needs to be identified.
4. Highest priority concerns center largely around beam transport and degradation issues related to small (sub-μm) apertures. These require further experiment and simulation study to understand impact and ultimate viability for this application.