Novel Techniques

Accelerator

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Some of the largest and most complex (and most expensive) scientific instruments ever built!

All use RF technology to accelerate particles

Can we make them smaller (and cheaper) and with a higher energy?
Light particles ($e^-/e^+$) accelerator limited by synchrotron radiation

$$P_{\text{synch}} = \frac{e^2}{6\pi\varepsilon_0 c^7} \frac{E^4}{R^2 m^4}$$

Must be linear and …

$$L = \frac{E(\text{eV})}{G(\text{eV} / \text{m})}$$

G : accelerating gradient

Can we make them smaller (and cheaper) and with a higher energy?

"The 2.4-mile circumference RHIC ring is large enough to be seen from space"
Some of the largest and most complex (and most expensive) scientific instruments ever built!

All use RF technology to accelerate particles

Can we make them smaller (and cheaper) and with a higher energy?

Search for a new technology to accelerate particles at high-gradient (>100MeV/m) and reduce the size and cost of a future e⁻/e⁺, e⁻/p⁺ collider or of a x-ray FEL

“The 2.4-mile circumference RHIC ring is large enough to be seen from space”
Novel Accelerator Techniques “Goals”

- Dielectric Laser Accelerator (DLA)
- Laser Wakefield Accelerator (LWFA)
- Dielectric Wakefield Accelerator (DWA)
- Plasma Wakefield Accelerator (PWFA)

Summary
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Summary
ACCELERATING FIELD/GRADIENT LIMITATIONS

- Gradient/field limit in (warm) RF structures: \(<100\text{MV/m}\)
- RF break down (plasma!!) and pulsed heating fatigue
- Accelerating field on axis, damage on the surface
- Material limit, metals in the GHz freq. range (Cu, Mo, etc.)
- Does not (seem to) increase with increasing frequency

Pulsed heating fatigue

Pritzka, PRSTAB 5, 112002 (2002)

RF break down

Braun, PRL 90, 224801 (2003)
"Novel Accelerators"

Materials with higher damage threshold:
- Dielectrics (~GV/m)
- Plasmas (10-100GV/m or \(\infty\))

Systems powered/driven by:
- Laser pulse(s)*
- Charged particle bunch(es)

*do not include laser vacuum/direct acceleration
Diamonds:

- Reaching final energy: >150 GeV/beam for e⁻ and e⁺ (determined by physics goals)
  - up to 1-10 TeV
  - > 60 GeV e⁻ (for e⁻/p⁺ collider, determined by physics goals)
- Large average accelerating gradient (>1 GeV/m)
- Accelerator(s) a few 100’s of meter long (not km’s)
- Reaching luminosity (e⁻/e⁺ or e⁻/p⁺, ions)

\[
\mathcal{L} \propto \frac{N^+ N^- f_{\text{rep}} n_b}{\sigma^* (\varepsilon_x) \sigma^* (\varepsilon_y)} \Leftrightarrow \mathcal{L} \propto \frac{N P_b}{E \sigma^* (\varepsilon_x) \sigma^* (\varepsilon_y)}
\]

• Focus on accelerator contribution (not final focus or interaction point)
• Assume those are the same (bunch length?)

- Deliver the same average (s) current with the same emittance (DWA, LWFA, PWFA)
- Deliver lower average current with lower emittance?? (DLA)
APPLICATIONS

♦ X-ray for radiography (advanced: phase contrast, etc.)
♦ e⁻ for medical applications

♦ All require low energy <GeV
♦ Can operate at very large peak gradient, mm-cm accelerator
♦ Efficiency not an issue
♦ Luminosity “not an issue”
♦ Special characteristics: ultra-short, synchronized (laser), pump probe, etc.
♦ Biological advantage ...
♦ Unique applications, compact

♦ Powerful radiation source, THz to γ-rays
♦ High-energy physics (HEP)
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Directly use the laser E-field in a $\sim \lambda^3$ (micro) structure

Summary
**DiELECTric LASER ACCELERATOR (DLA)**

- Take advantage of large laser E-field
- Take advantage of large damage threshold
- Structure = phase mask for velocity matching

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© P. Muggli  
Courtesy P. Hommelhoff  
**Goal:** generate a mode that allows momentum transfer from laser field to electrons

- Use first order effect (efficient!)
- Second order effects (ponderomotive) too inefficient

For a review and an extensive list of references, see: R. J. England et al., “Dielectric laser accelerators”, Rev. Mod. Phys. 86, 1337 (2014)
**DLA RESULTS**

Demonstration of electron acceleration in a laser-driven dielectric microstructure

- Inferred accelerating gradient in excess of 300MV/m, can be increased
- Need sub-$(\lambda_{\text{laser}})^3$ beams, naturally low emittance and charge
- Operate at very high rep-rate
## DLA RESULTS

### Recent DLA Experiment Comparison

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SLAC</th>
<th>Stanford</th>
<th>MQP/Erlangen</th>
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<tr>
<td>Year</td>
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<td>2015</td>
<td>2013</td>
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<tr>
<td>Material</td>
<td>Fused Silica</td>
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<td>Fused Silica</td>
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<tr>
<td>Beam Energy</td>
<td>60 MeV</td>
<td>96.3 keV</td>
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<tr>
<td>$\beta = \frac{v}{c}$</td>
<td>0.9996</td>
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<tr>
<td>Laser Pulse Energy</td>
<td>330 μJ</td>
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<td>Pulse Duration</td>
<td>1.1 ps</td>
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<tr>
<td>Interaction Length</td>
<td>360 μm</td>
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<tr>
<td>Max Energy Gain</td>
<td>100 keV</td>
<td>1.22 keV</td>
<td>275 eV</td>
</tr>
<tr>
<td>Max Gradient</td>
<td>309 MV/m</td>
<td>220 MV/m</td>
<td>25 MV/m</td>
</tr>
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*Courtesy of J. England*
Deliver lower average current with lower emittance?? (DLA)

Courtesy of J. England
DLA RESULTS

DLA Structure Development: Recent Progress

Accelerator

Beam Position Monitor

Efficient Coupler Designs

short-pulse (70 fs): 700 MV/m*
long-pulse (1.3ps): 300 MV/m*


Relativistic energy experiments have shown high-gradient operation and set the stage for scaling DLA to multi MeV energies.

Courtesy of J. England
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Cherenkov wakes in dielectric layers

Summary
**Dielectric Wakefield Accelerator (DWA)**

- Peak decelerating field

\[
e E_{z,\text{dec}} \approx \frac{-4N_b r_e m_e c^2}{a \sqrt{\frac{8\pi}{\varepsilon - 1} \varepsilon\sigma + a}}
\]

- Transformer ratio (unshaped beam)

\[
R = \frac{E_{z,\text{acc}}}{E_{z,\text{dec}}} \leq 2
\]
DiElectric WAKEFIELD ACCELERATOR (DWA)

- Peak decelerating field
  \[ eE_{z, dec} = \frac{-4N_p e m_e c^2}{\sqrt{\frac{8\pi}{\varepsilon - 1} \varepsilon \sigma_z + a}} \]

- Transformer ratio (unshaped beam)
  \[ R = \frac{E_{z, acc}}{E_{z, dec}} \leq 2 \]

- \( \sigma_z = 100-10\mu m, N = 2 \times 10^{10} \text{ e}^- \)
- \( a = 50\mu m, b = 162\mu m, \text{ fused silica, } \varepsilon \sim 3, f_1 \sim 470\text{GHz} \)
- Breakdown field at \( 13.8 \pm 0.7\text{GV/m} \)
- Estimated max. decelerating field: 11\text{GV/m}
- Estimated max. accelerating field: 17\text{GV/m}
Acceleration in slab symmetric DWA

- **Structure:**
  - SiO2, planar geometry, beam gap 240µm
- **BNL ATF**
  - Flat beam
  - Long bunch structure with two peaks
- **Acceleration of trailing peak**
- **Robust start-to-end simulations for benchmarking**

Slab geometry allows for:
- More charge per bunch
- Reduced transverse wakefields
- Demonstration of energy gain!

**DWA RESULTS**

![Diagram of slab symmetric DWA](image)

- **SiO2, Al**
- $T_{SLAB}=240\mu m$
- $T_{gap}=240\mu m$
- $L_z=2cm$
- $\varepsilon_N=2mm$-mrad

- **Energy Gain**
- $E_0=59\text{MeV}$
- $Q=100-900\text{pC}$
- $L_z\sim1.2mm$
- $\varepsilon_N=2mm$-mrad

- **G~7\text{MeV/m}**

**Courtesy G. Andonian**
**OUTLINE**

✧ Novel Accelerator Techniques “Goals”

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✧ Summary

✧ Intense laser pulse to drive wakefields in plasma
LASER WAKEFIELD ACCELERATOR (LWFA)

Gas Jet Plasma (short, injector)

Capillary Discharge Plasma (long, accelerator)

Leemans, Physics Today 2009

Figure 1. Laser plasma acceleration. An intense laser pulse traversing a plasma excites a plasma wave in its wake. The wave accelerates electrons injected from an external source or trapped from the plasma. Confined in a narrow channel, the plasma guides the propagating laser pulse and prevents its diffraction.

- Most active field
- Availability of TW Ti:Sapphire laser systems
- Few TW for 10-100MeV e⁻ in a few mm
- Acceleration, guiding
- Self-trapping
- Injection (plasma “gun”)
- Diagnostics
- Radiation source
- ...
**LWFA**

- Peak energy gain 4.2 GeV in <10 cm
- Self-trapped plasma $e^-$

- Needed: controlled external injection
- 100TW laser pulse with joules (i.e., not too short)

**Parameters:**

- $E_{w}=4.2$ GeV, $\Delta E/E_{\text{rms}}=6\%$
- $Q=6$ pC
- $\Theta_{\text{rms}}=0.3$ mrad
- $L_p=9$ cm, $n_e=7 \times 10^{17}$ cm$^{-3}$
- $P_{\text{laser}}=0.3$ PW
- $W=16$ J, $\sigma_r=52 \mu$m, $\tau=42$ fs
LWFA Laser Development

- International Committee on Ultra-high Intensity Lasers (ICUIL)
  - “Our mission is to stimulate, strengthen and expand ultra-intense laser science and related technologies.”

- The International Coherent Amplification Network (ICAN)
  - “The network is looking into existing fiber laser technology, which we believe has fantastic potential for accelerators”
  - “CERN's contribution to the ICAN project is part of a wider strategy to encourage the development of laser acceleration technologies. By supporting ICAN and similar research projects, CERN will be contributing to the R&D of potentially ground-breaking accelerator technologies.”

- Strong effort to develop high peak power/high average power, short pulse lasers

- The future is fiber lasers?
Effort (particularly at LBNL, Cilex) towards an e⁻/e⁺ collider
**OUTLINE**

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- Summary

- Dense, relativistic particle bunch to drive wakefields in a plasma
Plasma wave/wake excited by a relativistic particle bunch

Plasma e⁻ expelled by space charge force => deceleration + focusing (MT/m)

Plasma e⁻ rush back on axis => acceleration, GV/m

Ultra-relativistic driver => ultra-relativistic wake => no dephasing

Particle bunches have long “Rayleigh length” (beta function $\beta^* = \sigma^2/\epsilon \sim \text{cm, m}$)

Acceleration physics identical PWFA, LWFA
PWFA NUMBERS (e⁻)
Focusing ($E_r$)

Defocusing

Accelerating

Decelerating ($E_z$)

Neutral Plasma

Relativistic e⁻ bunch

✧ Linear theory
($n_0 << n_e$) scaling:

$E_{acc} \approx 110(MV/m) \frac{N/2 \times 10^{10}}{(\sigma_z/0.6mm)^2} \approx \frac{N}{\sigma_z^2}$

@ $k_{pe}\sigma_z \approx \sqrt{2}$ (with $k_{pe}\sigma_r << 1$)

$k_{pe} \sim n_e^{1/2}$

✧ Focusing strength:

$\frac{B_\theta}{r} = \frac{1}{2} \frac{n_e e}{\varepsilon_0 c}$

($n_0 > n_e$)

✧ $N=2 \times 10^{10}$: $\sigma_z = 600 \mu m$, $n_e = 2 \times 10^{14} \text{ cm}^{-3}$, $E_{acc} \sim 100 \text{ MV/m}$, $B_\theta/r = 6 \text{ kT/m}$

$\sigma_z = 20 \mu m$, $n_e = 2 \times 10^{17} \text{ cm}^{-3}$, $E_{acc} \sim 10 \text{ GV/m}$, $B_\theta/r = 6 \text{ MT/m}$

✧ Frequency: 100GHz to >1THz, “structure” size 1mm to 100µm

✧ Conventional accelerators: MHz-GHz, $E_{acc} < 150 \text{ MV/m}$, $B_\theta/r < 2 \text{ kT/m}$
Plasma wave/wake excited by a relativistic particle bunch

- Plasma e- expelled by space charge force $\Rightarrow$ deceleration + focusing ($MT/m$)
- Plasma e- rush back on axis $\Rightarrow$ acceleration, GV/m
- Ultra-relativistic driver $\Rightarrow$ ultra-relativistic wake
- Have long Rayleigh lengths” ($\sigma^2/\epsilon \sim cm, m$)
- Very large energy gain possible with short, high-energy relativistic bunches!

Acceleration physics identical PWFA, LWFA

$\vec{E}_z$  Defocusing
$\vec{E}_r$  Focusing
$\vec{E}_z$  Accelerating
$\vec{E}_r$  Decelerating
"quantity"


42 => 84GeV in 85cm! 50GeV/m
Figure 8. The most probable energy of witness bunch particles as a function of propagation distance in plasma. The energy spectrum of the drive and witness bunch after 85 cm of plasma shows that drive bunch particles lose a significant fraction of their energy and actually begin to slow down. At the same time, the position of the peak decelerating field rapidly moves back. However, the position of the peak accelerating field and the spike in figure 7 persist, and more importantly, the plateau in the acceleration field where most of the witness bunch particles reside does not change in this frame. The witness bunch moves with the wakefield without dephasing.

3.6. Efficiency

Figure 8 shows the energy gain defined as the most probable energy of the witness bunch particles as a function of propagation distance for the simulations of figure 7. The energy gain is almost linear up to a distance of \( \approx 65 \) cm. At a distance of 85 cm, the initially 5 GeV witness bunch has doubled in energy with an \( \approx 3 \) m energy spread, as seen in figure 8b. While the witness bunch is monoenergetic, much of the drive bunch has lost nearly all its energy. We have estimated various efficiencies in the simulations. The energy transfer efficiency from the wakefield to the witness bunch is almost 56%. The efficiency from the drive to the witness bunch is greater than 35%. The overall drive to witness bunch transfer energy efficiency can be improved by using bunches with longitudinal current profiles tailored such that all longitudinal slices of the drive bunch lose energy at the same rate, except for the very first and the last ones. This is accomplished by ramping up the current along the bunch. The optimum longitudinal current shape is trapezoidal with a long rise time and a sharp fall time. In that case, the peak decelerating wakefield remains constant along the drive bunch, while the peak accelerating field left behind the bunch keeps increasing with the bunch length. The transformer ratio then scales as \( \pi \) times the number of plasma wavelengths covered by the bunch, and can be much larger than twow. More sophisticated bunch profiles can lead to even larger enhancements of \( R_w \) after first.


SLAC FACET

Hogan, NJP 12, 055030 (2010)

E0

2E0

42 \Rightarrow 84\text{GeV} \text{ in } 85\text{cm! } 50\text{GeV/m}
High-Efficiency Acceleration of an Electron Bunch in a Plasma Wakefield Accelerator

- Focus on energy gain, efficiency, optimization of accelerated beam quality
- Measure, repeat/confirm, publish, improve...

Optimization of electron PWFA in H₂ plasma is the focus of ongoing run.

Courtesy M.J. Hogan, SLAC
A Beam Driven Plasma-Wakefield Linear Collider: From Higgs Factory to Multi-TeV

Summarized for CSS2013

E. Adli, J.P. Delahaye, S.J. Gessner, M.J. Hogan, T. Raubenheimer (SLAC)
W. An, C. Joshi, W. Mori (UCLA)

Figure 1: Layout of a 1 TeV PWFA Linear Collider

~ 4.5 km

Main e-beam (CW) : $Q = 1.0 \times 10^{15} e^{-} @ 15 \text{ kHz}$
$P_{\text{max,DR}} = 12 \text{ MW}$

20 plasma stages, $\Delta E = 25 \text{ GeV}$, each stage

Main e-plasma acceleration (0.5 km)

Magnetic chicanes: 4 ns delay

Injection every half turn, $C = 1000 \text{ m}$, $P_{\text{max}}/P_{\text{Dr}} = 8\%$

Drive beam after accumulation: Trains of 20 bunches, 4 ns apart @ 15 kHz

New concept for a PWFA LC
CW option with recirculation $E_{\text{Dr}} = 1 \text{ TeV}$, $L = 1.6 \times 10^{4} \text{ m}$, $T = 1.0$

Absolutely not to scale

Accumulator ring

4 passes Recirculating SCRF CW linacs. Each linac: 3.16 GeV, 19 MW/m, 250 m
Each arc: 437.5 m

Drive beam (CW) : $E = 25 \text{ GeV}$
$Q = 2.0 \times 10^{15} e^{-} @ 15 \times 40 \text{ kHz}$
$P_{\text{max,Dr}} = 2 \times 24 \text{ MW}$

Main e-source

Drive beam structure out of linac

$1.87 \text{ m}$

Drive beam structure out of acc. ring

$66.7 \text{ m}$

M3 bunch @ 15 kHz

$\Delta Z_{\text{Dr}} \approx 1.87 \text{ m}$

Injection

$\Delta Z_{\text{Dr}} \approx 1.87 \text{ m}$

DB 20-bunch train @ 15 kHz

4 ns delay ~ 0.6 m

$P_{\text{Dr}} = 12 \text{ MW}$

$P_{\text{Dr}} = 24 \text{ MW}$

$P_{\text{Dr}} = 48 \text{ MW}$

$P_{\text{Dr}} = 96 \text{ MW}$

$P_{\text{Dr}} = 192 \text{ MW}$

$P_{\text{Dr}} = 384 \text{ MW}$
Table 1: Main parameters at various beam collision energies

<table>
<thead>
<tr>
<th>E at IP, CM</th>
<th>GeV</th>
<th>250</th>
<th>500</th>
<th>1000</th>
<th>3000</th>
<th>6000</th>
<th>10000</th>
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<tr>
<td>N, experimental bunch</td>
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<tr>
<td>Main beam bunch spacing, nsec</td>
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<td>Avg current in exp beam, uA</td>
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<td>Effective accelerating gradient, MV/m</td>
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<td>Overall length of each linac, km</td>
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<table>
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<td>Total Luminosity (cm-2 s-1)</td>
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<td>Integrated Lum. (fb-1 per 1E7s)</td>
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<td>Lum1%</td>
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Various energy scenarios

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PWFA-BASED COLLIDER CONCEPT
PWFA-BASED COLLIDER CONCEPT

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<td>15000</td>
<td>10000</td>
<td>7000</td>
<td>5000</td>
</tr>
</tbody>
</table>

Keywords:
- Various energy scenarios
- CW beam rate for plasma “recovery”, use SC RF for drive beam linac
Various energy scenarios

- CW beam rate for plasma “recovery”, use SC RF for drive beam linac
- Reasonable beam current and power
Various energy scenarios

- CW beam rate for plasma “recovery”, use SC RF for drive beam linac
- Reasonable beam current and power
- Average gradient ~1GeV/m (~8GeV/m peak), reasonable linac lengths
### PWFA-BASED COLLIDER CONCEPT

**Table 1: Main parameters at various beam collision energies**

<table>
<thead>
<tr>
<th>E at IP, CM</th>
<th>GeV</th>
<th>250</th>
<th>500</th>
<th>1000</th>
<th>3000</th>
<th>6000</th>
<th>10000</th>
</tr>
</thead>
<tbody>
<tr>
<td>N, experimental bunch</td>
<td>1.0E+10</td>
<td>1E+10</td>
<td>1.0E+10</td>
<td>1.0E+10</td>
<td>1.0E+10</td>
<td>1.0E+10</td>
<td></td>
</tr>
<tr>
<td>Main beam bunch spacing, nsec</td>
<td>3.33E+04</td>
<td>5.00E+04</td>
<td>6.67E+04</td>
<td>1.00E+05</td>
<td>1.43E+05</td>
<td>2.00E+05</td>
<td></td>
</tr>
<tr>
<td>Repetition rate, Hz</td>
<td>30000</td>
<td>20000</td>
<td>15000</td>
<td>10000</td>
<td>7000</td>
<td>5000</td>
<td></td>
</tr>
<tr>
<td>Avg current in exp beam, uA</td>
<td>48.06</td>
<td>32.04</td>
<td>24.03</td>
<td>16.02</td>
<td>11.21</td>
<td>8.01</td>
<td></td>
</tr>
<tr>
<td>peak current in exp beam, A</td>
<td>4.81E-05</td>
<td>3.20E-05</td>
<td>2.40E-05</td>
<td>1.60E-05</td>
<td>1.12E-05</td>
<td>8.01E-06</td>
<td></td>
</tr>
<tr>
<td>Power in exp. beam, W</td>
<td>6.0E+06</td>
<td>8.0E+06</td>
<td>1.2E+07</td>
<td>2.4E+07</td>
<td>3.4E+07</td>
<td>4.0E+07</td>
<td></td>
</tr>
<tr>
<td>Effective accelerating gradient, MV/m</td>
<td>1000.00</td>
<td>1000.00</td>
<td>1000.00</td>
<td>1000.00</td>
<td>1000.00</td>
<td>1000.00</td>
<td></td>
</tr>
<tr>
<td>Overall length of each linac, m</td>
<td>125</td>
<td>250</td>
<td>500</td>
<td>1500</td>
<td>3000</td>
<td>5000</td>
<td></td>
</tr>
<tr>
<td>BDS (both sides), km</td>
<td>2.00</td>
<td>2.50</td>
<td>3.50</td>
<td>5.00</td>
<td>6.50</td>
<td>8.00</td>
<td></td>
</tr>
<tr>
<td>Overall facility length, km</td>
<td>2.25</td>
<td>3.00</td>
<td>4.50</td>
<td>8.00</td>
<td>12.50</td>
<td>18.00</td>
<td></td>
</tr>
<tr>
<td>Geometric Lum (cm-2 s-1)</td>
<td>9.41E+33</td>
<td>1.25E+34</td>
<td>1.88E+34</td>
<td>3.76E+34</td>
<td>5.27E+34</td>
<td>6.27E+34</td>
<td></td>
</tr>
<tr>
<td>Total Luminosity (cm-2 s-1)</td>
<td>1.57E+34</td>
<td>2.09E+34</td>
<td>3.14E+34</td>
<td>6.27E+34</td>
<td>8.78E+34</td>
<td>1.05E+35</td>
<td></td>
</tr>
<tr>
<td>Integrated Lum. (fb-1 per 1E7s)</td>
<td>157</td>
<td>209</td>
<td>314</td>
<td>627</td>
<td>878</td>
<td>1045</td>
<td></td>
</tr>
</tbody>
</table>

- Various energy scenarios
- CW beam rate for plasma “recovery”, use SC RF for drive beam linac
- Reasonable beam current and power
- Average gradient ~1GeV/m (~8GeV/m peak), reasonable linac lengths
- Reasonable luminosities
**p⁺-DRiVEN PWFA**

- ILC, 0.5TeV bunch with $2 \times 10^{10} e^-$ ~1.6kJ
- SLAC, 20GeV bunch with $2 \times 10^{10} e^-$ ~60J
- SLAC-like driver for staging (FACET= 1 stage, collider $10^+$ stages)
- SPS, 400GeV bunch with $10^{11} p^+$ ~6.4kJ
  LHC, 7TeV bunch with $10^{11} p^+$ ~112kJ
  - A single SPS or LHC bunch could produce an ILC bunch in a single PWFA stage!
  - Large **average** gradient! ($\geq 1\text{GeV/m}$, 100’s m)
  - Wakefields driven by $e^+$ bunch: Blue, PRL 90, 214801 (2003)

**p+**-DRiVEN PWFA


- Operate at lower $n_e$ ($6 \times 10^{14}$ cm$^{-3}$), larger $(\lambda_{pe})^3$, easier life …

- Accelerate an $e^-$ bunch on the wakefields of a $p^+$ bunch

- Single stage, no gradient dilution

- Gradient $\sim 1$ GV/m over 100’s m (average!!!)

- $e^-$: $E_0=10$ GeV  
  $\sigma_z=100\mu$m  
  $N=10^{10}$  
  $W_0=16$ J

- $p^+$: $E_0=1$ TeV  
  $N=10^{11}$  
  $W_0=16$ kJ

- Single Stage

- 0.5 TeV

- 300 m

- $\Delta E/E \sim 1\%$
- SPS beam: high energy, small $\sigma_r^*$, long $\beta^*$
- Initial goal: $\sim$GeV gain by externally injected $e^-$, in 5-10m of plasma in self-modulated $p^+$ driven PWFA
- Setup a comprehensive PWFA program at CERN
- SPS beam: high energy, small $\sigma_r$, long $\beta$.
- Initial goal: $\sim$GeV gain by externally injected $e^-$, in 5-10m of plasma in self-modulated $p^+$ driven PWFA.
- Setup a comprehensive PWFA program at CERN.
p⁺-DRIVEN PWFA FOR e⁻/p⁺ COLLIDER

- Emphasis on using current infrastructure, i.e. LHC beam with minimum modifications.
- Overall layout works in powerpoint.
- Need high gradient magnets to bend protons into the LHC ring.
- One proton beam used for electron acceleration to then collider with other proton beam.
- High energies achievable and can vary electron beam energy.
- What about luminosity?

Assume

- \( \sim 3000 \) bunches every 30 mins, gives \( f \sim 2 \) Hz.
- \( N_p \sim 4 \times 10^{11}, N_e \sim 1 \times 10^{11} \)
- \( \sigma \sim 4 \mu m \)

\[
\mathcal{L} = \int \frac{N_e \cdot N_p}{4\pi \sigma_x \cdot \sigma_y}
\approx 5 \cdot 10^{28} \text{ cm}^{-2} \text{s}^{-1}
\]

Simulation of existing LHC bunch in plasma with trailing electrons ...


Courtesy A. Caldwell
Novel Accelerator Techniques “Goals”

Summary
Number of possible novel techniques: dielectrics/plasmas, laser/particle beams

All have demonstrated accelerating gradients large than 700MeV/m!!! Novel!!!

Very large gradients reached (>100GV/m)

Very large energy gains achieved (>4GeV in ~10cm LWFA, >40GeV in 85cm PWFA)

Witness bunch acceleration, transfer efficiency (30% bunch to bunch) demonstrated (PWFA)

Next milestones: high quality acceleration ($\Delta E/E$, $\epsilon$ small), staging/long accelerator

• Complex experiments for small groups

Concepts for “collider-like” accelerators exist for 1GeV/m (average gradient, all)

No physics roadblocks/show stoppers
SUMMARY

✧ Number of technical challenges towards collider beams: a priori solvable

✧ “Large scale” experiments: FACET, DESY Flash Forward, INFN SPARC_LAB, CERN AWAKE, BELLA, CILEX, ELI, etc.

✧ Strengthen collaboration between lab/university groups
  • “The next collider will not be built by faculties at universities”

✧ Efficiency, reproducibility, stability, reliability, etc.

✧ Field mature for accelerator laboratories to adopt a concept and take it to the limit ...
Thank you to my collaborators!

Thank you!

http://www.mpp.mpg.de/~muggli
muggli@mpp.mpg.de

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