WG4 Summary
Application of compact and high-gradient accelerators

Stuart Mangles, Imperial College, London
Deepa Angal-Kalinin, STFC Daresbury Laboratory, Cockcroft Institute

24-30 September 2017, La Biodola, Isola d'Elba
6 Sessions: 22 talks, 15 posters

Three Themes:

1. Application of LWFA electrons and x-rays (6 talks)
2. Application of protons (+ions) (6 talks)
3. Electron delivery and Light Sources development (10 talks)
1. Application of LWFA electrons and x-rays
Ultra-brilliance isolated attosecond gamma-ray light source – Jinqing Yu
Ultrafast X-ray absorption measurements of high energy density matter using broadband X-rays from an electron beam

- Direct spectral measurement of LWFA X-rays over \( \approx 150 \) eV range, on a single shot.
- Single shot XANES features from Cold Ti targets.
- Looking forward to single shot, sub 100 fs, XANES and EXAFS measurements of high energy density matter.
Laser wakefield accelerators as x-ray sources for biomedical imaging applications

Human prostate

Human breast

Murine embryo

Human femur

Imaging samples
Experimental observation of radiation reaction in the collision of an intense laser pulse with a LWFA electron beam

LWFA inverse Compton scattering experiment at Gemini, CLF

Observe electron energy loss, and gamma-ray energies consistent with radiation reaction

Broad spectrum of Compton-scattered gamma-rays

\[ \gamma_{\text{crit}} = 3\gamma^2 a_0 \hbar \omega_0 \]
A Muon Source Based on Plasma Accelerators

Luca Serafini – INFN Milano
(A. Bacci, F. Broggi, C. Curatolo, I. Drebot, V. Petrillo, A. Rossi, M. Rossetti)

- Why GeV-class Muons? Because they are keys to several strategic applications, in particular radiography of very thick objects (Volcanoes, Nuclear Power Plants, National Security) thanks to their high penetration/low stopping power (compared to photons/electrons…)
- Why Plasma Accelerator? Because of its compactness (ord. of magnitude cheaper and shorter than GeV-class muon section of a typical muon collider)
- The Challenge: run a $10^{31} \, \text{cm}^{-2}\text{s}^{-1}$ luminosity (Lorentz Boosted) $e-\gamma$ collider at $E_{\text{cm}}=400 \, \text{MeV}$ to make a point-like, GeV-class, nsec synchronized, muon source at 1 $\mu_+/s$ with collimated emission (200 mrad)
- The requirement on plasma accelerator: a few nC at 2 GeV with 20% energy spread and 20 mm·mrad rms transv. emittance.
X/Gamma-ray emission from self-modulated laser wakefield accelerators

Inverse Compton scattering dominates spectrum in the region of interest with unprecedented photon numbers and source size (~40 um)
2. Application of protons
High-precision nanoparticle generation

Laser driven protons produce explosive boiling and allow for very short nucleation phase

Very-fast (1 shot), high-precision (5% SD), tunable nanoparticle generation on neighbor surface

P. Antici, M. Barberio, Patent Pending US 14448.128
Laser-accelerated proton beams as diagnostics for Cultural Heritage

Damage analysis of a proton-irradiated CH artifact (ceramic) shows no aesthetical or chemical changes.

Laser-accelerated proton beams potentially enable a quicker and less invasive Proton Induced X-ray Emission spectroscopy on Cultural Heritage artifacts.

Ceramic from 1650 AD

The ELIMED application

J. Pipek, F. Romano, G. Milluzzo et al., Journal of Instrumentation, Volume 12, March 2017

Requirements from ELI
- Easily modify geometrical configurations
- Accurate transport in magnetic fields
- User friendly

Application structure
- Component realistic model
- Magnetic and electric field implementation
- Realistic laser-driven particle source
- Information scoring along the beamline

Geant 4
http://www.geant4.org

"Toolkit for the simulation of the passage of particles through matter."

Energy selector system
Conventional transport elements
Dosimetry devices

Source
PMQs

OUTPUT

PIC simulation

G. Milluzzo - INFN-LNS (Italy) - gmilluzzo@lns.infn.it
Compact laser based neutron source

- Complementary to other radiation sources, like FEL, Compton, THz, already available in the project of large plasma based infrastructure
- Great interest in having at the same place all of these radiation sources especially for cultural heritage studies
- We are going to investigate the use of high energy electrons produced by self-injection to produce neutrons instead of protons/ions from TNSA or similar mechanism
Ultrafast pulsed proton radiolysis in water
Delayed solvation time of electron

Nanocavitation

Optical steaking of both protons and electrons/x-rays

Outside Bragg peak region

Bragg peak region

Path of proton (non Bragg region)

Path of proton (Bragg region)

Temporal evolution of photoabsorption band of solvated electron

Very different temporal response

WG4, EAAC 3, Isola d’Elba Sept 24th – 29th, 2017
3. Electron delivery and Light Sources development
COXINEL beam line (EAAC September 27th 2017)

T. Andre

- Total control of LPA beam transport over 10 m (7 quadrupoles + 4 dipoles + undulator)
- Excellent agreement with the measurement numerical simulations
- Observation of the spontaneous emission of the undulator
Tunable High Gradient Quadrupoles, A. Ghaith

Concept was patented (QUAPEVA program-Triangle de la Physique, SOLEIL/Sigmaphi collaboration)

7 systems:
- First triplet to focus a 180 MeV beam
- Second triplet to focus a 400 MeV beam
- A prototype

<table>
<thead>
<tr>
<th>Magnetic length</th>
<th>( G_{\text{max}} ) [T/m]</th>
<th>( \Delta G ) [T/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 mm</td>
<td>201</td>
<td>92</td>
</tr>
<tr>
<td>81.1 mm</td>
<td>195</td>
<td>89</td>
</tr>
<tr>
<td>61 mm</td>
<td>190</td>
<td>88</td>
</tr>
<tr>
<td>47.1 mm</td>
<td>184</td>
<td>86</td>
</tr>
<tr>
<td>44.7 mm</td>
<td>183</td>
<td>86</td>
</tr>
<tr>
<td>40.7 mm</td>
<td>180</td>
<td>85</td>
</tr>
<tr>
<td>26 mm</td>
<td>164</td>
<td>78</td>
</tr>
</tbody>
</table>

Magnetic center excursion in both planes \((x, z)\) is about \(\pm 10 \mu m\)
• Three WP’s under study:

• **WP1**: Low Charge-High Current 30 pC-3KA (FWHM) per bunch from Photoinjector with only velocity bunching, suitable both for Beam Driven and Laser driven acceleration in Plasma

• **WP2**: Low Charge-Low Current 30 pC-100A per bunch from Photoinjector with velocity bunching coupled with a magnetic compression ($R_{56}=9$ mm), in the chicane to reach $I=3kA$ (Hybrid scheme), suitable both for Beam Driven and Laser driven acceleration in Plasma

• **WP3**: High charge-Very Low Current 200 pC-70 A per bunch from Photoinjector with velocity bunching coupled with a magnetic compression ($R_{56}=16$ mm) in the chicane to serve the SASE-FEL, with peak current $I_{pk}=2kA$, and the Compton Source in the high flux operation scheme.

---

**FEL Genesis simulation with particle driven plasma accelerated electron beams (WP1)**

**FEL Genesis simulation with laser driven plasma accelerated electron beams (WP1)**
Static and dynamic error studies in the X-band Linac of EuPraxia@SPARC_LAB: misalignements & quad/steerers jitters

C. Vaccarezza

WP1 results: Centroid distribution at the capillary entrance (above) and trajectory envelope (right) for 70\(\mu\)m misalignment on RF and magnetic elements, 150 \(\mu\)m girder to girder, and 0.1% jitter on quadrupole strength and steerer kick after trajectory correction.

Next steps:
- RF phase and amplitude jitters
- Photocathode laser energy and pointing jitters.
Commissioning Results From The LUX Beamline For Plasma-Driven Undulator Radiation.
A. MAIER

Undulator Upgrade for the LUX Beamline. C. WERLE

First X-Rays at LUX in Hamburg

see also lux.cfel.de

ANGUS
200 TW laser

60 m tunnel

First X-Rays 2017
9 nm undulator radiation

First Electrons 2016
@5 Hz, 400-800 MeV

LUX is built and operated in a close collaboration of Hamburg University with DESY and ELI Beamlines
Summary of Development of a Novel Undulator with a Very Short Period Length @ 3rd EAAC WS WG4 (Sept./27/2017): Shigeru Yamamoto, KEK-PF

Plate type undulator magnets with a very-short-period undulator field

100mm long = 25 periods

\( \lambda u = 4 \text{mm} \)

NMX-39EH TiN coated 20mm wide, 2mm thick

Field pattern seen through a magnetic viewer sheet

Result of field measurement
A tuneable and flexible scheme for minimization of energy chirp in a single plasma acceleration stage

Utilizing tailored beam loading by a second high charge bunch

Relative energy spread is minimized by one order of magnitude

Ultrahigh 5D brightness + minimized energy spread leads to unprecedented ultrahigh 6D brightness

\[ B_{6D} \approx 5.5 \times 10^{17} \text{A/m}^2 \text{rad}^2/0.1\%\text{BW} \]

Energy spread scaling law predicts

\[ \Delta W_{\text{rms}}/W < 0.01\% \text{ for longer plasma wavelength} \]

Potentially game-changing for applications, e.g. ICS, XFEL and HEP
Transverse electron beam dynamics in a nanocoloumb-class laser wakefield accelerator. A. Koehler

Betatron radiation as diagnostics

- Understand electron dynamics inside plasma cavity
  - Correlate electron dynamics and x-ray spectra
  - Betatron source size at the end of plasma channel

- Sensitivity & error analysis
  - Statistical process
  - Accuracy in electron spectrum
  - Fluctuations in experiment
  - Betatron model

Electron spectrum

- Ta foil
- 15 μm W wire
- x-ray betatron on x-CCD

x-ray spectrum

- r = (0.9 ± 0.1) μm

x-ray CCD cam

12 m x-ray beamline

Betatron x-ray