Cockcroft-08-38

COBALD – AN INVERSE COMPTON BACK-SCATTERING SOURCE AT DARESBURY

D.J.Holder, D. Laundy, G. Priebe, STFC Daresbury Laboratory, Warrington, U.K

COBALD – AN INVERSE COMPTON BACK-SCATTERING SOURCE AT DARESBURY*

D.J.Holder#, D. Laundy, G. Priebe, STFC Daresbury Laboratory, Warrington, U.K.

Abstract

An inverse Compton Back-Scattering (CBS) ultra-short pulsed x-ray source driven by the multi-terawatt laser installed at Daresbury's ALICE facility (formally the Energy Recovery Linac Prototype - ERLP) is being developed. Hard x-rays, ranging from 15 keV to 30 keV, depending on the backscattering geometry, will be generated through the interaction of the laser pulse and an electron bunch delivered by ALICE. The x-rays created contain 15×10^6 photons per pulse from head-on collisions, with a pulse duration comparable to that of the incoming electron bunch, and 5×10^6 photons per pulse from side-on collisions, where the laser pulse defines the pulse width. The peak spectral brightness is predicted to be of $\approx 10^{20}$ photons/s/mm^2/mrad^2/0.1% $\Delta\lambda/\lambda$.

Called COBALD, this source will initially be used as a short pulse diagnostic for the ALICE electron beam and will explore the extreme challenges of photon/electron beam synchronization, which is a fundamental requirement for all accelerator-based (whether FEL or spontaneous SR) dynamics programmes.

INTRODUCTION

The ALICE (Accelerators and Lasers in Combined Experiments) experimental facility (known formerly as ERLP) is being commissioned at present [1]. This machine includes a high-voltage DC photoemission electron gun, superconducting linacs operating in energy recovery mode and a mid-IR free-electron laser (FEL). In addition a source of 100 fs x-ray pulses produced by inverse Compton scattering of multi-terawatt laser-pulses by the 35 MeV electron beam is currently under construction.

Short x-ray pulses can be generated from the inverse Compton scattering of an intense laser pulse off a high-brightness electron beam. The interaction can be viewed either as a collision between a photon and an electron, or that the electromagnetic field of the laser beam acts as an undulator with a very short period. Because the period of such an undulator is effectively much shorter than the magnetic undulators that can be physically realised in synchrotron light sources, a much less energetic electron beam can be used to produce synchrotron radiation at x-ray wavelengths. Such a CBS source also offers a wide tuning range for x-ray source parameters. The x-ray energy at the centre of the emission can be tuned by varying the laser photon energy, electron beam energy or interaction angle while in addition the x-ray energy decreases away from the centre of the emission. The x-ray bandwidth and pulse length depend on the interaction geometry and on laser and electron bunch parameters.

The x-ray source, called COBALD (COmpton BAckscattering Laser at Daresbury) [2] will initially be used as a short pulse diagnostic of the ALICE electron beam. Later it will be used to explore the extreme challenges of photon/electron-beam synchronization which are a fundamental requirement for the next generation of accelerator-based light source scientific programme. Fig. 1 shows the layout of ALICE, while the laser beam transport line and the CBS interaction region is shown in Fig. 2. The layout for both possible interaction angles (180° "head-on" and 90° "transverse") can be seen.

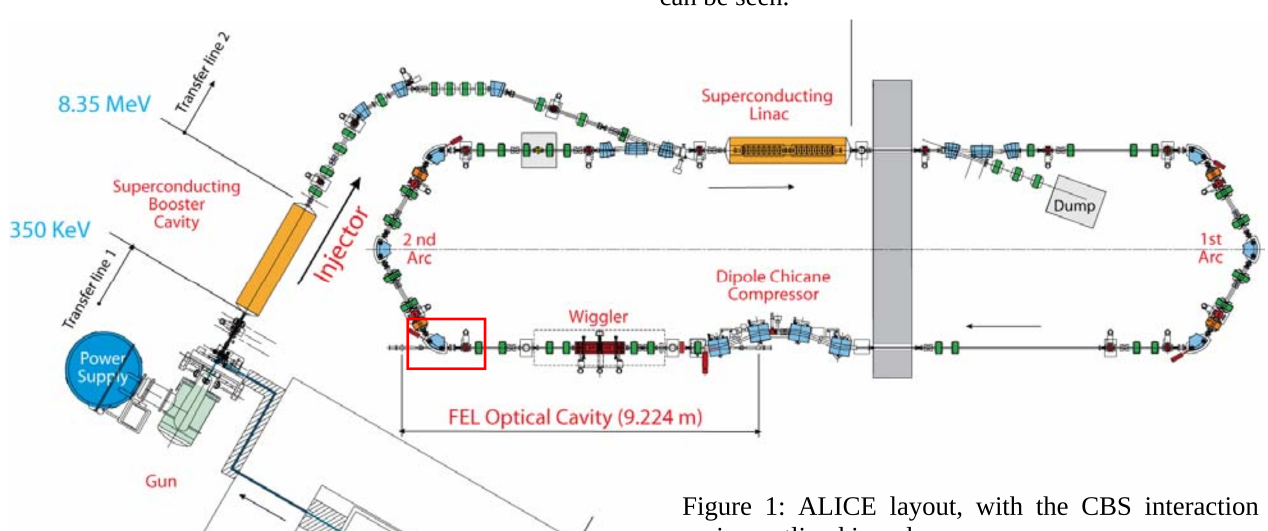

Figure 1: ALICE layout, with the CBS interaction region outlined in red.

*Work supported by Northwest Development Agency through the Northwest Science Fund
#d.j.holder@dl.ac.uk

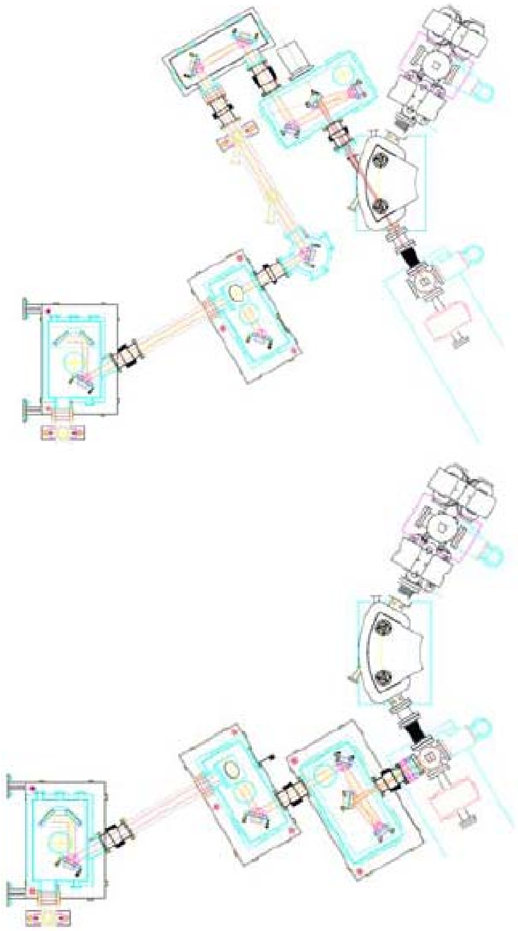

Figure 2: Final section of the laser beam transport line and the CBS interaction region. The design for both the head-on (top) and the transverse (bottom) interaction geometry can be seen.

Vacuum System

The laser beam transport line vacuum design specification is 10^{-6} mbar while the ALICE accelerator vacuum is approximately 10^{-8} mbar. The vacuum system for the laser beam has been designed to operate without a window separating it from the accelerator vacuum system. This is necessary as a window thick enough to withstand atmospheric let-up of the laser beam transport line would suffer radiation damage by absorption of part of the terawatt laser pulses, and a thin window would have the risk of breakage and particle contamination of ALICE vacuum envelope during a vacuum failure. Thus the pumping and gauging systems have been designed to protect the accelerator vacuum envelope from accidental let-up in the beam line by a fast acting valve.

Laser Beam Transport

The laser beam is transported from an electromagnetically-shielded and temperature-controlled laser room (also containing the photoinjector laser) through a concrete shield wall, periscoped down to the electron beam level, focused via an off-axis parabola mirror (OAP) and finally turned towards the interaction point. For the transverse interaction geometry the periscope is also used to rotate the polarization of the laser. The last vacuum vessel containing the OAP mirror sits on rails allowing the focal position to be moved through the electron bunch. The scattered hard x-rays – in the direction of travel of the electron beam – will be taken through a beryllium window to the diagnostic area. For head-on collision geometry, the last turning mirror has a hole of about 5 mm diameter to let the x-rays through and also to take a part of the laser beam out for pump probe applications. Fig. 3 shows the laser beam transport line through the concrete shielding wall to the interaction region.

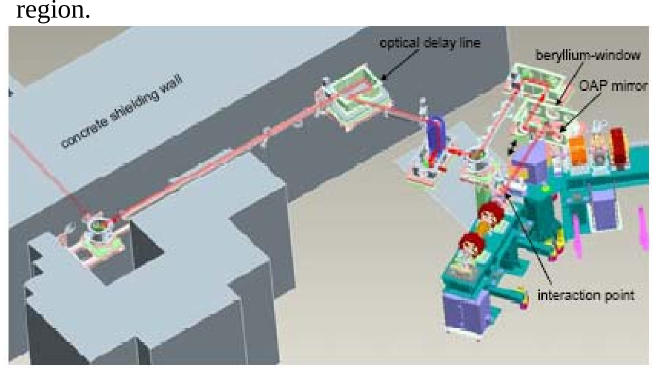

Figure 3: Terawatt laser beam transport through accelerator hall shield wall to interaction point.

Accelerator Set-up

In order to obtain the optimum x-ray output, a number of options were considered to maximise the electron density at the point of interaction with the laser beam. As the laser produces only single pulses at 10 Hz, ALICE must also operate in single pulse mode at 10 Hz, and thus energy recovery from the beam is not a requirement. In addition it was determined that operation at 20 MeV would be optimum, compared to the normal ALICE beam energy of 35 MeV.

As the CBS source cannot operate simultaneously with the FEL, an early option that was considered was to replace the FEL wiggler, which is immediately before the CBS interaction point, with some additional quadrupole magnets to provide additional focussing. This was discounted due to the disruption required when changing between the two radiation sources. Thus it was decided that any re-optimisation of the ALICE lattice would be constrained to use the existing magnets. In addition, it is necessary to transport the electron beam, after the interaction point, around the second arc without significant losses; otherwise bremsstrahlung radiation from lost electrons will provide an unwelcome background signal to the wanted x-ray output. Because energy recovery is not necessary, the electron beam can be conveniently intercepted by a “pop-in” beam dump immediately after the second arc, rather than passing through the main linac a second time (as will happen in energy recovery mode) and being sent to the main dump. The operational parameters of ALICE when used in CBS mode are shown in Table 1.

Table 1: ALICE parameters when in CBS mode.

Parameter	Value	Units
Injector energy	8.35	MeV
Energy at interaction point	35	MeV
Train repetition rate	10	Hz
Bunches per train	1	
Bunch charge (nominal)	80	pC
Electrons per bunch	5×10^8	
Average current	0.8	nA

Modelling

For optimal generation of Compton-scattered x-rays, the ALICE lattice needs to be re-optimised, subject to the constraints outlined in the previous paragraph, to maximize the x-ray flux and also reduce the size of the x-ray source. The electron trajectories were modelled using the particle tracking code ELEGANT. In the order of 100,000 electrons were tracked through the lattice to give an optimum focus at the interaction point of dimensions 13.45 × 19.81 μm ($\sigma_x \times \sigma_y$), with 99% of the electrons making it to the pop-in dump [2].

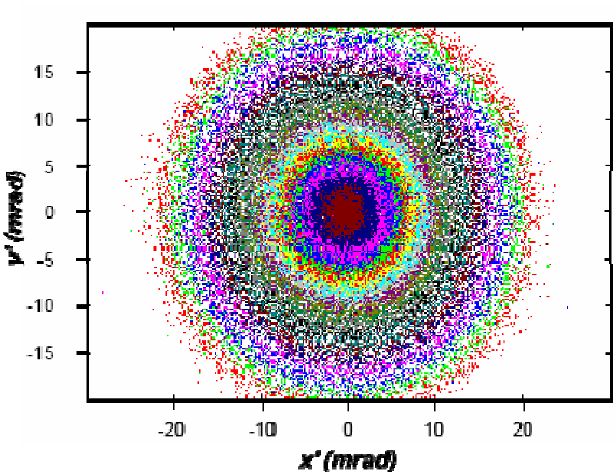

Figure 4: The angular distribution of the x-rays for head-on collision geometry; each colour is a 1 keV energy band with 20-21 keV on outside and 30-31 keV at centre.

The electron distribution thus produced was then used together with the laser beam parameters to simulate the photon output from the inverse Compton scattering. The laser beam was assumed to have Gaussian transverse and temporal distributions and the photon energy distribution was calculated by transforming the temporal distribution. The details of the simulations can be found in [3]. Fig. 4 shows the angular distribution of the x-rays for head-on collision, while Table 2 shows the predicted properties of the x-ray source.

Table 2: CBS x-ray source parameters.

Parameter	Value	Units
Peak spectral brightness	$>10^{20}$	photons/mm^2/mrad^2/s /0.1% bandwidth
Peak x-ray energy	30	keV (head-on geometry)
	15	keV (transverse)
X-ray pulse length	350 rms	fs (head-on geometry)
	100 FWHM	fs (transverse)
X-ray source size	20 × 35	μm

CONCLUSION

The CBS source currently being constructed on the ALICE facility at Daresbury has a number of applications, both in accelerator physics and technology and synchrotron radiation science. The characterization of the x-ray beam produced by Compton back-scattering from the electron beam in ALICE will provide useful information about the spatial and temporal structure of the electron beam. In addition, important studies of photon/electron beam synchronization and source stability will be undertaken. This brilliant x-ray source will permit x-ray diffraction and spectroscopy techniques to be extended into the time domain to allow the probing of structural dynamics with atomic-scale resolution. An example of this is the probing of intermediate species during chemical reactions or the measurement of strain relaxation following lattice distortion.

REFERENCES

[1] D. J. Holder et al, these proceedings.
[2] S. Malton PhD thesis, http://www.hep.ucl.ac.uk/theses/spm_thesis.pdf
[3] G. Priebe et al, Proc. of the SPIE, Soft X-Ray Lasers and Applications VII, Vol. 6702, CID 67020F (2007)