December 18, 2008 Final

Summary of Linac4-APL Meeting on Laser Profile Monitors

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Two half-day meetings were held at CERN on December 1 and 5, 2008, to discuss and define the APL proposal to build and install a Laser Profile Monitor (LPM) in Linac4. Several smaller discussion sessions were held in between these opening and closing plenary sessions. In attendance for one or more sessions were E. Bravin, R. Connolly, S. Feher, K. Hanke (co-chair), T. Hermanns, R. Jones, A. Lombardi, S. Maury, B. Mikulec, S. Peggs (co-chair), U. Raich, A. Ratti, and M. Vretenar. Plenary presentations were made by R. Connolly, K. Hanke, S. Peggs, U. Raich, and A. Ratti.

Significant contributions were made by all participants in an open and constructive atmosphere. This document summarizes the findings and decisions that were made.

Introduction

The goal of the meeting was to discuss and further define the proposal that will be made by the U.S. LHC Accelerator Project for LHC (APL) to the U.S. Department of Energy, to construct and install a Laser Profile Monitor system in Linac4. This proposal will be included with 4 other components in the APL Conceptual Design Report (CDR), which is due on December 31, 2008. (The other 4 components are **Separation Dipoles, Cryogenic Powering, Collimators**, and **Linac4 LLRF**.) The APL CDR will be a key document at the first major review of the APL proposal – the Critical Decision 1 (CD-1) review – which is expected to take place in early 2009.

A Linac4 Design Report (DR) is planned for release by CERN in about June, 2009. A mature joint APL-CERN proposal for an LPM will be included in this DR, which will be a key document at the Critical Decision 2 (CD-2) review of APL, to take place in summer 2009. Construction funding is only available after CD-2 is successfully negotiated, although design funds are expected even before CD-1, in January 2009.

Key components of these minutes, the CDR proposal, and the DR description, are:

1) Technical objectives, approach, and proposed implementation
2) Interfaces
3) Cost and schedule
4) Roles and responsibilities

1. Technical objectives, approach, and proposed implementation

The transverse emittance of the beam is expected to blow up due to space charge by about 40% between the last accelerating structure and injection into the PS Booster. Two emittance measurement stations (preferably identical) about 100 metres apart at either end of the transfer line would monitor this space charge blow up.

APL will build one (or two) LPMs, to be used in the transfer line from Linac4 to the PS Booster. One will be placed just after the exit of the final accelerating structure. APL will collaborate with CERN in the installation of the LPM(s), and in its (their) initial beam commissioning.

The (potential) second LPM would replace – or would operate in parallel with – the emittance measurement device already installed in the LBE beam line stub line just before injection into the PS Booster. It is possible that the existing LBE system will be upgraded by CERN to become functional with 160 MeV beam. This will be known by about the end of 2009. At that time the possibility of constructing a second LPM station will be resolved.

The LPM photon source is either a pulsed (Q-switched) laser, or a CW (solid state diode) laser. This key technology choice, yet to be made, will be resolved before the release of the CDR.

Each complete LPM system has two rather independent main components: the laser system itself (including electron collector), and a separate Neutral Beam Detector (NBD) placed a few or several meters downstream of the laser.

Technical objectives

In its full and final implementation the LPM will measure:

1. horizontal and vertical beam profiles and sizes
2. horizontal and vertical emittances

In addition the planned implementation MAY also be able to measure (with no further upgrade):

3. the energy spread of the linac beam, enabling machine tuning
4. bunch length

Approach

Transverse profiles (and hence beam sizes) will be measured by sweeping a laser beam across the H^- beam, extracting the stripped electrons through a short series of weak magnetic toroids, and then counting the electrons to get a measure of the density of the H^- beam at that transverse location of the laser “wire”.

Emittance measurements will be made by combining profile measurements with measurements of the angular distribution of the neutral H^0 beam that emerges from the “slit” defined by the laser. These angular distributions will be observed downstream of the laser in a Neutral Beam Detector.

The energy spectrum of the extracted electrons will be measured by scanning a retarding voltage at the electron collector, perhaps in as little time a single Linac4 pulse. It may be possible to deduce the energy spread of the linac beam from the electron energy spectrum measurements, in which case this output will be available for use as a linac tuning diagnostic.

Direct measurement of the bunch length is only possible with a laser that is synchronized with the RF timing system (at significantly increased cost).

Linac4 and LPM parameters

The Linac4 pulse length is 0.4 ms, with as many as 10^{14} H^- ions per pulse, with a maximum of 1.15×10^9 ions in each 352 MHz bucket. The LPM will be designed to work with as few as 1×10^8 ions per bucket.

Typical RMS transverse beam sizes at the exit of the accelerating structures are in the range 1 to 4 mm, with transverse normalized RMS emittances of 0.33 π-mm-.mrad.

The laser "wire" diameter will be approximately 300 microns, with a scan range of 20 mm. Beam sizes will be measured with approximately 5% accuracy.

The mirror system will allow the laser to scan across the beam in as little as 0.4 ms – one linac pulse. The overall profile measurement speed will be determined by the electron detection system.

In all cases an upstream Beam Current Transformer and a neighboring Secondary Emission Monitor will accompany the LPM. These will be provided by CERN.

Typical (unbaked) vacuum pressures in Linac4 are 5×10^{-8} Torr.

The electron extraction toroid field is about 100 Gauss.

About 0.50 m of path length needs to be reserved for an LPM, with transverse width and height of about 0.50 m. The laser head will be outside the tunnel.

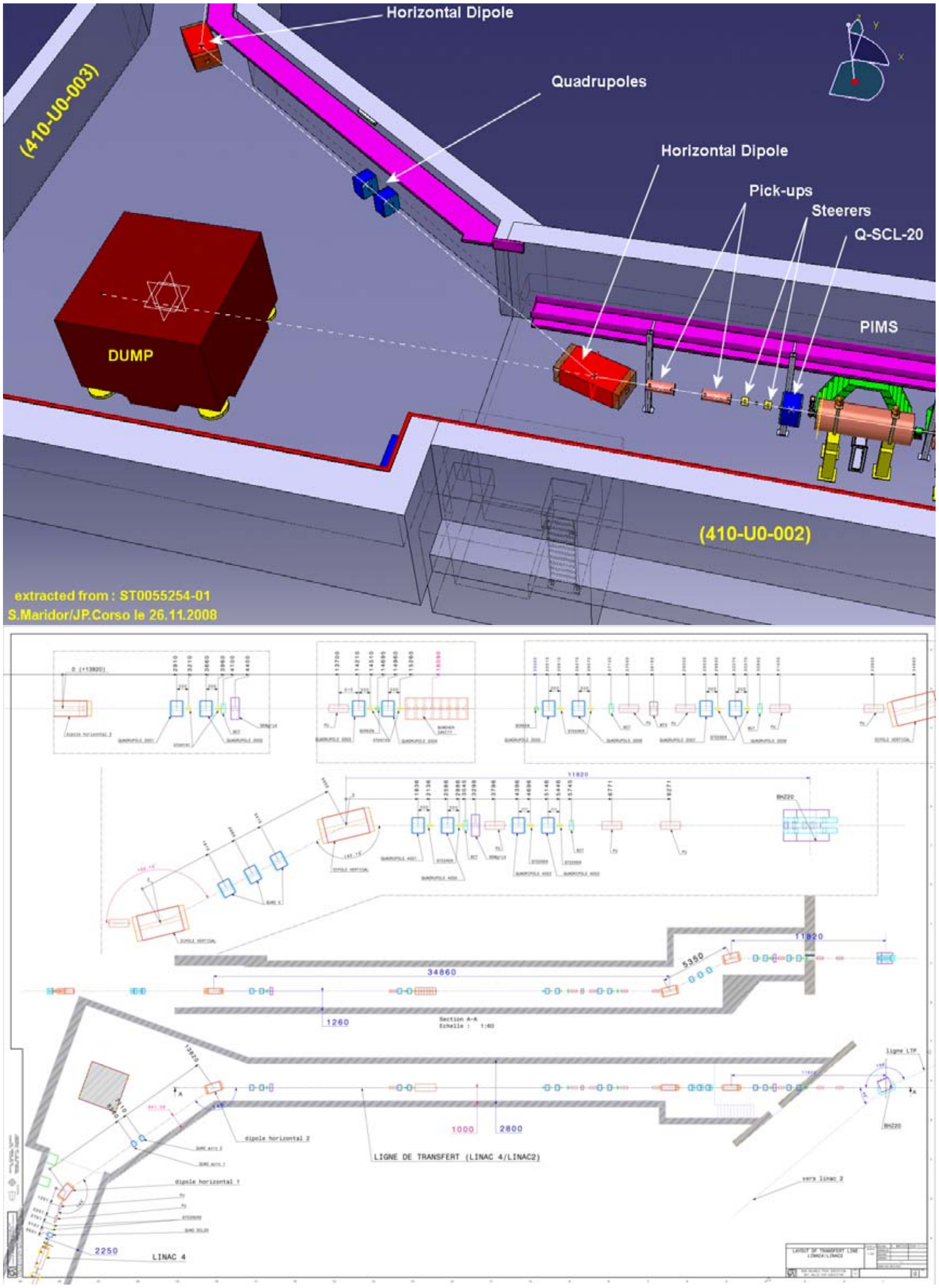

Figure 1: Four potential locations of the LPM and NBD elements, on either side of any of the red dipole magnets labeled "Horizontal Dipole" in the top figure. The bottom figure also shows the vertical dog-leg, beginning 35 meters after the second horizontal dipole.

LPM location

Figure 1 (top and bottom) illustrates potential locations for the LPM and the associated NBD, where the neutral and charged beams are separated by 35 degree dipole magnets. Two locations in the top figure place the LPM and the NBD across either of the red magnets labeled "Horizontal Dipole", which themselves are on either side of the beam dump. The bottom figure shows 2 identical dipoles that are used to create a vertical dogleg. The first vertical dogleg dipole is about 35 meters downstream of the second horizontal dipole.

The first LPM should be placed as close as possible to the end of the Pi-Mode Accelerating Structure (PIMS). The second LPM (if there is one) would be placed in the LBE stub beam line at the end of the transfer line, about 50 metres beyond the dogleg.

The NBD will also observe any other neutral beam created in a straight line upstream or downstream of the laser, perhaps even from sources tens of meters away if the LPM is at the end of a long straight section.

Emittance measurements may only be possible with the first dipole turned on – that is with beam passing by the dump, in operation not early Linac4 commissioning.

The detailed layout of the Linac4 elements has not yet been fully finalized, and so there is some (limited) flexibility for optimization.

Neutral beam background

The gas stripping cross section for 160 MeV H^- ions in nitrogen is $2x10^{-18}$ cm^2. Thus, 5 meters of drift around the laser in a (typical) vacuum pressure of $5x10^{-8}$ Torr will neutralize about 10^{-6} of the ion beam. A 10 W CW laser will neutralize about $3x10^{-6}$ of what it hits. Assuming that such a laser hits 10% of the ion beam the peak signal is $3x10^{-7}$ of the total beam, for a signal-to-noise maximum of order 0.3. By contrast a Q-switched pulsed laser neutralizes about 30% all of the ions.

A pulsed laser is a great advantage in emittance measurements. A CW laser is plausible if the vacuum is better than 10^{-7} Torr and the drift space is minimized.

[Two possible ways to reduce the drift space to the 50 cm minimum necessary for LPM placement were raised (only) after the closing plenary session:

1) split the first 35 degree dipole in two, and separate the two halves by 50 cm
2) displace a straight (transversely) in a chicane made from 4 dipole steering magnets

These speculations were not scrutinized by the whole group.]

More detailed calculations and (possibly) simulations are needed, in collaboration with CERN, before finalizing the LPM location.

Laser technology choice

Photon wavelength is about 1000 nm, sourced either by a pulsed Q-switched laser, or by a CW solid state laser. This critical design choice will be made bearing in mind the technical advantages and disadvantages:

	Solid state	**Q-switched**
Power	~10 W continuous waveform	5 MW pulsed (~10 ns, ~20 Hz max rep rate)
Electron detector	High gain silicon strip or Faraday cup	Faraday cup or second beam current transformer
Advantages	1) Fast single-pulse (0.4 ms) profile measurements. Emittance measurement times of minutes. 2) Low power optics, eg mirrors.	1) H^- beam ~30% neutralized over length of pulse (50 mJ).
Disadvantages	1) 10^{-6} stripping efficiency 2) Strict local vacuum requirements to avoid background contamination of electron signal by local gas stripping. 3) Neutral detector background signal by line-of-sight H^0 from gas stripping	1) Slow "shoot-and-step" profile averaging– many linac pulses per profile data point 2) High power laser transport optics – optical surface damage, laser confinement and alignment, ES&H laser administration.

The laser head will be outside the tunnel whichever technology is chosen, with fiber optic transmission inside the tunnel.

Fiber transmission in the tunnel suffers from negligible attenuation losses. Transmitted laser beam power limitations with Q-switched laser sources are unimportant, because the signal-to-noise advantage of pulsed lasers comes from the time gating.

2. Interfaces

Required interface definitions include mechanical dimensions (stay clear zones), vacuum window and interface requirements, survey and alignment approach, software and readout systems, timing and triggers.

APL will adopt CERN standards as far as reasonably possible in order to facilitate efficient maintenance and operations, for example in motion control, readout electronics, vacuum hardware, firmware, and software development tools.

APL will deliver controls software at the LabView level, consistent with previous LARP practice.

Functional specification and interface specification documents must be made collaboratively delivered by the time of the Design Report.

3. Cost and schedule

To some extent the Linac4 LPM (160 MeV, 352 MHz) will resemble the BNL linac LPM (200 MeV, 200 MHz) that is expected to see first beam in November 2009. It is not clear that both will use the same laser technology, nor has it been confirmed that the BNL implementation will include a Neutral Beam Detector.

Technology duplication allows for low-risk estimation of project schedule, manpower requirements, and costs.

The proposal will request a small amount of pre-operations funding for beam commissioning.

The schedule for the Linac4 LPM will easily match the need for a diagnostic system by the end of CY10, assuming that some APL funds are made available in FY09 to support planning and an early start.

Construction funding will begin no earlier than FY10, leaving 2 years to be ready for Linac4 commissioning by the end of CY11. Final delivery is due by the end of CY11, with limited support for initial beam commissioning in FY12.

4. Roles and responsibilities

APL contributions are expected from BNL and LBNL, with relative roles and responsibilities to be defined in the APL CDR.

CERN will be an active participant in the collaborative effort, and routinely involved in all phases of system design and construction. Klaus Hanke from the Linac4 project is the point-of-contact on the CERN side for functional specifications, and Enrico Bravin from Beam Instrumentation group for technical aspects.

CERN will be responsible for:

1. cabling and infrastructure support
2. local installation co-ordination
3. survey monuments (if needed)
4. readout hardware (to be determined)
5. (minimal) participation in Critical Decision reviews

CERN will investigate the availability of “straight ahead” neutral beam passage through a 35-degree dipole.

5. Conclusions

A complete functional specification of the LPM system will be included in the DR, containing system requirements, beam parameters and ranges, measurement times and modes, principal interfaces, quantities and spares, and other potential constraints and requirements (such as vacuum performance and hardware selection).

The LPM proposal may distinguish between the laser profile system itself (as a low risk construction project deliverable) and the Neutral Beam Detector (perhaps as a later upgrade after initial R&D testing has been successfully achieved).

At the very least the LPM proposal should allow a clear upgrade path from profile measurements to emittance measurements with an NBD.

The neutral beam detector needs to be defined. It will probably use solid state strip detectors, either silicon or diamond.

Previous LPM designs exist and have been successfully implemented, but the designs for the BNL and/or Linac4 LPMs are still evolving.

An additional benefit from this kind of non-interfering device is that it enables a future path towards superconducting diagnostics, essential to both SPL and Project-X.