Beams Department

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Editorial

Dear Readers,

This third issue of the BE Newsletter appears just-in-time at its foreseen date of publication. The editorial responsibility is now on the hands of a new – inexperienced – “editor-in-chief”. I take this opportunity to thank Jean-Pol Matheys for his role in the launching of the newsletter.

In this issue, you’ll learn a bit more about the ongoing mystery with respect to the speeding neutrinos. Our experts explain the measurements of the two parameters involved: time and distance. Moreover, all other articles cover a variety of topics – some of them quite technical, but very interesting.

In order to hear your opinion and to receive some concrete feedback, I intend to launch a survey in January. Based on the results and your comments, we will adapt the newsletter on format and content. In the mean time, do not forget the departmental meeting to get an overview of all our achievements of this year.

The 2011 physics program is coming to an end, the people and the machines are getting somewhat tired. In view of the upcoming Christmas period, which is approaching rapidly, I wish you all a well-deserved period of rest to recharge your batteries!

Ronny Billen
Editor, BE Newsletter
**OPERA: The experiment, which will change the world?**

Our relationship with the OPERA experiment dates back to 2005, when OPERA’s Physics coordinator asked us for a synchronization system between CERN and Gran Sasso National Laboratory (LNGS). At the time, the specifications were not very stringent. The goal of the experiment was to study the oscillation of muon neutrinos into tau neutrinos, and the purpose of the timing system was to time-stamp the SPS extraction to be able to statistically discriminate in LNGS between neutrino events coming from CERN and those from other sources like the Sun. Many commercial off-the-shelf GPS Disciplined Oscillators (GPSDO) can achieve synchronization precisions of 100 ns between two sites, and that’s how we started.

The synchronization system between CERN and LNGS does what specialists call a “time transfer”. Metrology labs around the world routinely perform time transfer experiments with precisions of a few ns. In fact, this is the way Coordinated Universal Time (UTC) is manufactured: each lab stores time tags of their local clocks with respect to synchronisation signals received from GPS satellites. All these data are gathered by the Bureau International des Poids et Mesures (BIPM) in Paris every month, which performs a weighted average whose result is UTC. Then, one month after the fact, the labs know the offsets between their local time scales and UTC during that period. They can then use these corrections to fine-tune results of experiments involving time stamps.

![Fig. 1: The use of GPS in timing of neutrino events](image)

Using these techniques for the CNGS time transfer was a very natural evolution of the system. We purchased specialized GPS receivers capable of generating data files with time stamps of our local Caesium clocks vs. each one of the GPS satellites in view. Then, for each neutrino event, one can see which satellites were in view both from CERN and LNGS at that moment and use an average of these time-stamps to correlate the local time scales of both labs. An added benefit of using Caesium clocks is that they are more stable than GPS signals over short periods, and can therefore be used to clean (by averaging) short-term noise induced by ionospheric and other perturbations in GPS signals.

We benefited from a very fruitful collaboration with OPERA physicists in setting this system up, and we also relied on the competence of the Swiss Metrology Office (METAS) in Bern. This experiment illustrates how Physics and Engineering can benefit from each other, and more generally it reminds us that Nature does not care about the arbitrary classification in branches of knowledge we have established. It was a great pleasure for all of us to work together on such an exciting subject.

Once it became clear that the time transfer was of sufficient precision, the door was open to perform a neutrino time-of-flight experiment. This, however, required additional efforts in the timing, geodesy and analysis fronts. On the timing side, we had to calibrate many fibre and coaxial cable delays, introducing new methods that allowed us to preserve a good overall precision.

In the Spring 2011, after a very precise measurement campaign of our geodesy colleagues, it became clear that the neutrinos seemed to be flying a bit faster than expected. We then decided to ask the German Metrology Office (PTB) to have an independent look at our GPS time transfer system, using a travelling GPS receiver they had validated in many other labs before. Their results agreed with METAS’s within 2 ns. We also re-did many fibre and cable calibrations throughout the Summer, and at some point it was clear that there was not much more we could do and that it would be good to open these results up and get a wider community to scrutinize the methods and provide criticism.

OPERA’s Physics coordinator gave a very thorough and clear seminar presenting all parts of the experiment in detail on September 23. Since then many people have helped us with an interest on the timing part. They have suggested places to check further and provided ideas to crosscheck the results using independent techniques. We have also had to deal with many suggestions from people who had misunderstood one or several parts of the timing system, but that’s a reasonable price to pay for all the useful hints we got. There is also an inevitable sociological side when one publishes such a mind-blowing experimental result, but we have tried our best to stay focused on facts and are now looking forward to implementing many of the cross-checks and improvements we have discussed for the synchronisation system in the last two months. The 2012 run will undoubtedly be very exciting: other experiments in LNGS will try to measure the time of flight of the CNGS neutrino beam, and the MINOS collaboration in the US could provide a completely independent check. Stay tuned!

*J. Serrano, BE-CO- HT*
**Determination of the Distance to Gran Sasso**

The determination of the distance between CERN and the LNGS laboratory in Italy for the CNGS experiment is obviously not possible using direct GNSS measurements (Global Navigation Satellite System – a term that encompasses GPS, Galileo, etc.), since both the accelerator at CERN and the experiments at LNGS are underground. (The neutrinos themselves take the direct route! Fig. 1)

**Fig. 1: Schematic Profile of the Neutrino Path**

In fact there are three parts to the overall distance measurement calculation: a network of measurements to link the benchmarks on the surface at CERN and the geodetic reference points on the SPS and CNGS accelerator elements in the tunnel; an equivalent network of measurements to transfer the coordinates between the surface benchmarks and reference points in the experiment hall at Gran Sasso; and a direct GNSS distance calculation between benchmarks on the CERN site and at the LNGS Site. A means to combine the three sets of measurements is also needed.

From the very beginnings of CERN, and the first accelerators, a network of geodetic pillars was established across the site and extended, as the site grew bigger. A local reference frame and coordinate system was also established. Traditional geodetic measurements were used to determine the coordinates of the geodetic pillars involving: theodolites (for measuring directions/angles), lasers for measuring distances (Fig. 2), optical levels for the heights, and measurements of the stars to determine the location on a global scale. Even though the network covered an area of about 100 km², it was the most precise in the world (the distances were measured with a precision of 0.1 parts per million, giving a value of 1 mm over 10 km) and in the 1970s was used to control the measurements of the first GPS receivers!

**Fig. 2: Laser Distance Measurements with the Terrameter**

For the SPS and the LEP machines, the coordinates of geodetic reference points in the accelerator tunnels were determined by means of a network of precision measurements at the surface to points above the access shafts; followed by the transfer underground using optical techniques involving theodolites, optical plummets (essentially a telescope that observes along a vertical line), or damped plumb bobs/pendulum. At the time of the last measurements connecting the surface and underground networks (during the 1980s), the precision was estimated to be just a few millimetres.

Reference points in the tunnels were then established using a network of measurements, this time including gyro-theodolite measurements to avoid any systematic errors due to refraction (where the line-of-sight between two points is curved by differences in temperature in the air). Finally these tunnel reference points were used to align the machine elements after they were installed, also with an estimated absolute precision of just a few millimetres.

Using GNSS measurements, a link between the CERN Coordinate System and a global reference frame was established at the start of the CNGS Project, and subsequently controlled in the last few years. The first campaign of measurements, at five geodetic pillars, was integrated into a calculation, by the Federal Office of Topography, of the Swiss national network and their geodetic position determined with an overall precision ~ 7 mm. This allowed the global location of the CERN site to be determined with an estimated precision ~10 mm.
Bearing in mind that the CNGS line was positioned and aligned with respect to the existing machines, to assess the overall precision of the location of the CNGS Target at CERN (or other elements used for the timing), all the above factors must be taken into account. In this way it is possible to estimate the precision to be less than 20 mm.

Equivalent measurements have been carried out in Gran Sasso, with the measurement of geodetic pillars above ground, and a network of measurements along the road tunnel passing through the mountain to transfer coordinates from the surface to the reference points on the experiments. These measurements were repeated in 2011 with an estimated precision of 200 mm.

Finally using GNSS measurements at the two sites it was possible to determine the distance between them and the precision of that distance determination. Combining the three parts of the equation gives an overall estimate of the precision of ~ 200 mm.

Despite the fact that this estimated precision is already quite high, a number of possible controls are being discussed, including: an independent recalculation of the distance using the existing measurements; a repeat of the GNSS measurements; and the addition of gyro-theodolite measurements to the network along the tunnel in Gran Sasso.

M. Jones, BE-ABP-SU

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**J’aime les GEM**

The Antiproton Decelerator (AD) delivers antiproton beams of two different energies to five different experiments. The anti-hydrogen experiments ALPHA, ASACUSA, ATRAP and AEGIS receive beam at 5.3 MeV, while the ACE experiment for cancer therapy uses antiprotons at 126 MeV. The beam is extracted to one of the experiments in a spill of a few hundred nanoseconds, containing about 30 million antiprotons per spill. Multi Wire Proportional Chambers (MWPC) have traditionally been used for profile measurement in the experimental areas of the AD, but at very low energy these detectors give several problems.

The wire chamber is located inside a pendulum that can be moved into the beam, but at 5MeV kinetic energy the assembly acts almost as a beam stopper for antiprotons. The beam interacts with the material of the vacuum window as well as with the horizontal and vertical plane of the MWPC causing a blow-up of the profile (fig. 1). This distortion is particularly pronounced in the second plane of the wire chamber where the beam has gone through more material over a longer distance. We have therefore been looking into ways to minimize both material and distance with the aim of producing more reliable profiles.

As gas electron multiplier (GEM) detectors can be made very compact and allow simultaneous read-out of both horizontal and vertical planes, this technology was a natural candidate.

Fig. 2 shows a schematic drawing of our GEM chamber containing a single GEM foil. The combined gas-window/cathode is a crucial element to minimize absorption and multiple scattering of the beam. It is made of the same base material as GEM foils: copper-clad polyimide.
The copper is etched away in the active area of the detector, leaving just a thin 100 nm layer of chromium which is there to act as a tie coat for a better adhesion of the copper layer to the polyimide substrate. The GEM-foil itself consists of a double sided 50 µm copper-clad polymer foil, perforated with a high density of chemically etched holes (typically ten thousand per square centimeter). On application of a potential difference between the two sides, the foil acts as a charge multiplier for electrons produced by ionization in the gas. A patterned charge-collection read-out plane permits the detection and localization of the primary ionization.

GEM technology can also be used to replace many old wire chambers on the high energy beam lines in the SPS experimental areas but as the intensity there is much lower more amplification is needed. Triple-GEM chambers, containing three GEM-foils to allow a cascading of electron multiplication stages, have already been tested with success on two beam lines in the North Area.

J. Spanggaard, BE-BI

ELENA: a new challenge for the RF Group

A few months ago the ELENA project was approved. ELENA stands for Extra Low ENergy Antiproton ring and, apart from its pretty name, it is quite a challenging and interesting project. Its aim is to further decelerate the antiprotons extracted from the Antiproton Decelerator (AD) from 5.3 MeV down to 100 keV. ELENA is expected to produce about 1.5E7 antiprotons at extraction. Figure 1 shows a schematic view of the planned ELENA cycle, which is approximately 15 seconds long. "RF ON" periods are also shown in red.
Just as for the AD, the RF Group will take care of the RF system as well as of the ultra-low-noise longitudinal pick-up (LPU) and related digital signal processing (see Figure 2).

Fig. 2: RF and Schottky diagnostics system. The RF group tasks are highlighted by red bubbles.

The RF system will take care of bucket-to-bucket transfer from the AD, deceleration, recapture, beam control loops, and the injection and extraction synchronization loops. Extraction at different harmonics will be needed as well as bunch shaping capabilities to overcome space charge limitations. ELENA will greatly benefit from the RF renovation of the injectors in both its high-level RF (HLRF) and low-level RF (LLRF) systems. The HLRF will use the magnetic alloy Finemet™, which has been successfully employed in LEIR and which is currently under consideration for the PSB HLRF renovation. The voltage needed in ELENA is very low, of the order of tens of Volts, but the dynamic range required is about 85 dB, which is pretty challenging. The LLRF will belong to the LLRF family currently under development, in collaboration with MedAustron, for the PSB consolidation. This technology is an evolution of the LEIR system and it specifically targets machines with a wide injection-to-extraction frequency swing, high synchrotron tunes, low-frequency cavities and high dynamic range in the cavity voltage control. This family relies on the VME Switched Serial (VXS) enhancement of the VME64x bus and on custom carrier and daughter boards. The VITA57 standard FPGA Mezzanine Card (FMC) will be used for the daughter boards; many of the selected components are among the most advanced units available on the market. Figure 3 shows some of the LLRF hardware components.

Fig. 3: Some hardware components of ELENA’s digital LLRF.

Another challenge of the ELENA project is its low intensity beam. It is joked that the beam is so weak that a single sneeze outside the ring would kill it. I am confident that won’t happen ☺, but it’s a fact that traditional beam transformers don’t work at such low beam currents. Just like in AD, an ultra-low-noise pick-up will be designed to provide the beam input to the LLRF beam phase loop as well as to determine the beam intensity and other parameters. The exact details of this LPU are still under discussion but a strong candidate is the Schottky pick-up used in the AD. This is shown in Figure 4 and consists of high-frequency and low-frequency parts whose outputs are summed to cover a frequency range from 20 kHz to about 30 MHz. The noise in the 0.1 to 3 MHz range is about 2 pA/√Hz, which is good enough to allow Schottky signal detection.

Fig. 4: AD longitudinal Schottky pick-up: high-frequency and low-frequency parts.

The signal-to-noise ratio of the detected signals will be improved by using low transfer impedance cables, developed for CERN and already used in the AD systems. The digital signal processing will be
implemented in the LLRF hardware. As shown in Figure 5, the beam intensity will be derived by RF current measurements for bunched beams and by longitudinal Schottky scans for de-bunched beams. In the latter case, additional information such as the momentum spread will be derived and provided to the ELENA OP crew for machine operation, debugging and optimization.

Finally, for the hawk-eyed among you, Figure 6 gives an overview of the LLRF system including inputs, outputs and data processing type. It is remarkable that such processing power and wealth of capabilities are contained in just one VXS crate – and to think that the current implementation in the AD of just the LLRF takes a whole rack!

All this will require quite some work: external collaborations are envisaged and will hopefully be finalised soon.

\[ N \sim A_{\text{peak}} \]
\[ \frac{1}{\mu A_{\text{peak}}} \]
\[ 18\% A_{\text{peak}} \]
\[ f = \text{FFT bin} \]
\[ \omega / p \]

\[ \text{Parabolic envelope} \]
\[ y = (2 - 5 x^2) \]
\[ x = f / f_{\text{cap}} \]

\[ \text{De-bunched beam processing} \]
\[ \text{Bunched beam processing} \]

Fig. 5: Digital signal processing envisaged for the ELENA beam longitudinal diagnostics.

Fig. 6: Block diagram of the ELENA RF and Schottky diagnostics system.

\[ \text{Safety Tips} \]
\[ \text{«Medical Cabinet»} \]

Do you know that medical cabinets (Armoires à Pharmacie) are available all around CERN to help you deal with benign scratches, pains and headaches?

They are located at several places in each building. There is no formal rule for their implantation but they are often located near workshops and laboratories or in experimental areas and sometimes in secretariats.

The green cross sticker on a door indicates that a medical cabinet is located inside the room.

The medical cabinet contains usually (following the Medical Service recommendation):

- Acetalgine® (paracétamol) for headaches, pain, fever and flu-like symptoms;
- Merfen® (liquid) for disinfecting small wounds and scratches;
- compresses;
- dressings;
- plasters;
- a small bottle of liquid hand sanitizer;
- gloves for first rescue in case of bleeding.
The refilling of the cabinet is usually done by the TSO of the building but another person could be in charge. The name of the person responsible is indicated directly on the medical cabinet. If you see that a refilling is needed please contact this person (you can always contact the TSO if no name is indicated on the medical cabinet).

It is very important to contact the person responsible for the refilling, especially if you have taken the last item of something; think about the next person who will need it!

These medical cabinets allow you to treat benign wounds. In case of more serious wounds you have to go to the infirmary (bldg 57, tel. 73802) or call the Fire Brigade (74444). Do not forget that in case of serious illness or accident, it is the duty of the Fire Brigade to bring people injured to the Medical Service.

Please keep in mind that the information above applies neither to the Red Emergency Boxes in the access shafts of the accelerators, nor to the Emergency kits in case of projection of Fluorhydric acid.

If you have any question, do not hesitate to contact the Medical Service or the BE Safety Unit BE-Safety@espace.cern.ch

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**Parc automobile, auto-partage, gaz naturel... Que faut-il retenir sur les voitures du CERN ?**

Annie Di Luca a rencontré Chris Thomas, de la section Ressources et Logistique (RL) du groupe ASR, qui gère le parc automobile du département BE.

**Q : Combien avons-nous de véhicules dans BE, et quels types de véhicules ?**

A: Le car pool du département BE compte au total 78 véhicules qui se répartissent en différentes catégories.

- 20 véhicules de catégorie A, pour des transports de personnes ou de matériel léger, du type Peugeot 107 ou Fiat Panda.
- 52 véhicules de catégorie B, pour des transports de matériels plus encombrants, y compris les vélos lorsqu’il faut aller dans le LHC, du type Peugeot Partner.
- 1 véhicule de catégorie C, sans marquage, pour des trajets plus longs en dehors du périmètre autorisé pour les autres véhicules. Cette voiture, une Peugeot 807, que je gère directement au niveau du département.
- 5 camions et camionnettes pour des transports lourds et/ou encombrants.

**Q : Quel est votre principal objectif pour la gestion de ces véhicules ?**

A: Mon objectif premier est d’obtenir le meilleur rapport entre le nombre de véhicules et les besoins réels. Si tel n’est pas le cas, cela engendrerait bien évidemment des dépenses peu justifiées et une surcharge des parkings.

**Q: Faire le plein au gaz....est-ce naturel pour vous ?**

A: [sourire] Comme beaucoup, vous avez sans doute déjà utilisé une de ces Fiat équipées pour la bicarburation essence et gaz naturel ? Mais avez-vous déjà fait le plein au gaz naturel ? Nous n’avons que peu de retour sur ce sujet, alors je lance ici un appel : si vous avez déjà fait le plein de gaz naturel pour un véhicule du CERN, faites nous part de votre expérience et vos suggestions !

**Q: Il y aussi une initiative d’auto-partage au CERN**

A: En effet, ce service a pour but de favoriser la mobilité des utilisateurs sur et entre les sites du CERN tout en mobilisant un nombre minimum de véhicules qui ne sont pas attribués à des groupes. De
ce fait les heures d'utilisation des véhicules sont limitées à la plage horaire 7h00-20h00 avec une durée maximale de 4 heures à chaque utilisation. L’ensemble de ce service compte pour le moment 30 véhicules.

**Q: Mais comment fonctionne ce service d’auto-partage ?**
**A:** Toutes personnes ayant le permis de conduire CERN et un contrat de travail valide peuvent utiliser ce service. Ensuite les personnes doivent se procurer une carte RFID auprès du car pool de GS au bâtiment 130. La page [page d’accueil](#) vous permet d’effectuer une réservation du créneau horaire souhaité. C’est vraiment simple et très utile.

**Q: Et avez vous des ressources particulières que nous pouvons consulter ?**
**A:** Parmi les liens utiles je peux vous recommander ce document sur l’organisation du [Car Pool](#). Consultez aussi ce lien pour les modalités d’utilisation d’un véhicule en auto-partage: [CERN Hertz Car Sharing user guide (Document en cours de modification)](#)

**Q: Et au fait, quelles sont les conditions d’utilisation des véhicules du CERN ?**
**A:** En quelques mots je veux seulement rappeler que l’utilisation des véhicules du CERN est soumise au respect de la [Circulaire Administrative n° 4](#) « Conditions d’utilisation par les membres du personnel du CERN des véhicules appartenant au CERN ou pris en location par lui. » N’oubliez pas non plus que tout conducteur qui veut conduire une voiture du CERN doit au préalable demander une autorisation de conduire un véhicule du CERN via EDH [Demande d'accès](#)

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**A. Di Luca – C. Thomas, BE-ASR**

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**Life in BE**

In March 2009 I finished my Master studies of Physics at the University of Technology in Vienna. At the moment I am a PhD student at CERN in the third and last year of my contract with the CERN Austrian doctoral student program. Together with my supervisor Y. Papaphillippou, I started working on the SPS in the summer 2010.

The injectors are already delivering beams with bunch intensities and transverse emmitances\(^1\) \((1.5\times10^{11}\text{p/bunch} \text{ and transverse emmitances smaller than 2 µm})\) but the LHC luminosity upgrade requires even more challenging parameters. Therefore, a series of studies concerning the intensity limitations and cures for the LHC injectors has been initiated in the frame of the LHC Injector Upgrade Project (LIU). Implementing a new optics in the SPS could push some of these intensity limitations by more than a factor two.

At injection energy into the SPS (26 GeV), the so-called Transverse Mode Coupling Instability (TMCI) is limiting the achievable bunch intensity to \(1.6\times10^{11}\text{p/bunch}\). This fast single bunch instability is caused by the interaction of the trailing particles of a bunch with the electromagnetics fields induced by the leading particles of the same bunch on the vacuum chamber or on other elements under vacuum. As a result, coherent oscillations with growing amplitude are excited leading to particle loss and emmitance blow-up.

A new optics could increase this threshold by raising the synchrotron frequency\(^2\). In this case it is more difficult for the instability to develop due to the faster mixing of the particles between the head and the tail of the bunch. An increase of the synchrotron frequency by about a factor 3 was achieved in 2010 by manipulating the optics of the machine, i.e. by modifying the focusing strength of the quadrupole magnets. This allows changing the pathlength (and therefore revolution time) difference of particles having small energy errors with respect to that of the reference particle synchronous with the RF frequency. From simulations, the threshold for TMCI in the new optics is expected to be around \(3.2\times10^{11}\text{ p/bunch}, \text{i.e. a factor two higher than with the present optics.}\)

\(^1\) The emittance is a measure for the volume covered by the beam.

\(^2\) The synchrotron frequency is the oscillation frequency at which the particle having slight energy errors in a bunch are moving from the head to the tail of the bunch under the effect of the Radio-Frequency used to accelerate the beams.
It is important to note that implementation of the new (Q20) optics does not require any hardware modification. It was therefore possible to start experimental studies already during the last part of the 2010 run. After a few weeks of setting up a cycle with the new optics, single bunch proton beams with intensities up to \(3.5 \times 10^{11}\) p/bunch could be injected into the SPS with the new optics and accelerated to 450 GeV.

Fig.1 shows the measured emittances and losses as a function of the intensity at top energy. It was observed that intensities up to \(2.5 \times 10^{11}\) p/bunch could be extracted with less than 6% total losses. In comparison to that, similar beam characteristics can be obtained in the nominal optics but with significantly higher losses. While these higher losses can be tolerated with single bunch beams, they have to be avoided in operation with the LHC beams consisting of up to 288 bunches. In this respect, the new optics is clearly a good candidate to provide future high intensity beams to the LHC.

In summary with this new SPS optics an important step has been done in overcoming one of the main SPS intensity limitations, thereby giving new perspectives for the upgrade of the LHC injectors in view of increasing the LHC luminosity. At this point, I would like to thank all the people helping to prepare the new cycles in the SPS and during the experimental studies with the Q20 optics. All the results obtained so far would have not been achieved without the great support from colleagues from the ABP, BI, OP and RF groups.

**Next issue**

The next issue will be published at the end of March. Contributions for that issue should be received by the end of February at the latest.

Suggestions for contributions are always most welcome: simply contact a Correspondent (see below).

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