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Édito N_{12}: La newsletter physicienne pour Normaliens confinés

Chers Physiciens, Chères Physiciennes, C'est avec joie que nous vous présentons ce dernier numéro de la Normale Physics Review avant la fin des cours et le début des stages. Vous aurez cependant courant Juin une édition spéciale qui reprendra l'intégralité des numéros publiés depuis le 17 Novembre 2020. A l'occasion de ce numéro, nous vous présenterons notre manière de travailler et nos pistes d'amélioration pour l'année prochaine. N'hésitez pas à nous donner vos commentaires sur ce projet qui nous a beaucoup motivé cette année.
Cette semaine, salutations aux phy18 et aux phy19 en stage, bravo aux phy20 pour leur derniers examens, et petite pensée pour les futurs phy21 qui sont dans leurs oraux.
A la carte, une interview d'un élève de M2 en stage à l'université du Kansas, retour sur un stage de M1 en cours vers la cité phocéenne, un petit portrait de l'ONERA et une visite de l'Observatoire de Paris par les L3. Pas de panique, nos questions douteuses de physiciens sont toujours au rendez-vous ! ***G. de Rochefort***

[Class' life]

Visite de l'Observatoire de Paris

Mardi dernier, nous avons eu la chance de visiter l'Observatoire de Paris à Meudon avec 3 camarades de classe. Oui vous avez bien lu, à Meudon. L'observatoire de Paris est implanté sur trois sites, un au centre de Paris devant lequel je passe tous les jours sur le trajet Jourdan-ConfIV et dont la coupole domine le quartier, un à Nançay, à deux heures au sud de Paris, où trône le radiotéléscope géant accompagné de réseux d'antennes radioscopiques, et enfin à Meudon (Figure 1.

Figure 1 – *La façade de l'observatoire, à Meudon (Photo : E.Foucher)*

Le matin nous avons pu admirer les grands téléscopes qui ont fait l'histoire de ce site. Pour un astronome amateur comme moi, c'était impressionant. Nous avons également pu observer une tâche solaire grâce au coélostat ! Enfin nous avons vu en avant première un prototype de téléscope, dévelopé par Andreas Zech, destiné à détecter la lumière Cherenkov dans le ciel nocturne. Cette lumière est émise par les cascades produites par l'arrivée de photons gammas dans l'atmosphère. Cette détection joue un rôle majeur dans l'identification d'objets célestes comme les blazars.

Après un bonne pause déjeuner sur la bucolique terrasse de l'Observatoire, Guillaume Aulanier nous a fait la présentation du programme gradué AstroParis. Ce programme se décline en 5 masters de physique extrêmement divers, avis aux intéressés ! `https://www.observatoiredeparis.psl.eu/-enseignement-.html?lang=fr` **E.Foucher**

Un mot sur l'Onera

Êtes-vous fiers de l'industrie aéronautique française ? Si c'est le cas vous devez connaître l'Office National d'Études et de Recherches Aérospatiales : l'ONERA. Cette institution a été créée en 1946 par l'État afin de doter la France d'une recherche de pointe dans ce secteurs après la Seconde Guerre Mondiale. L'ONERA dépend aujourd'hui exclusivement du Ministère de la Défense et ainsi est en étroite collaboration avec la Direction Générale de l'Armement (DGA) qui finance une partie des thèses qui y sont réalisées.

Figure 2 – *Les différents sites de l'ONERA en France (source : https ://www.onera.fr/fr/presse/communiques-presse)*

J'ai eu l'opportunité pendant mon stage de M1 de travailler sur le site de Palaiseau de l'ONERA, à quelques minutes de marche de Polytechnique. Construit au coeur d'un ancien fort militaire à moitié constitué de galeries souterraines, le centre accueille plusieurs départements dédiés aux thématiques phare de l'industrie Aéronautique. Le site est une ZRR : une Zone à Régime Restrictif. Ce qui signifie que pour y travailler, la DGA doit vous fournir une autorisation spéciale après enquête administrative (avis à ceux qui s'intéresseraient à ce type de stage). Afin de finir ce tour d'horizon, veuillez trouver ci-dessous des liens vers une revue en libre accès de toutes les innovations récemment issues de l'ONERA ainsi que vers le site de l'institution :

— `https://www.onera.fr/fr/publications-institutionnelles-et-thematiques#pepites-onera` url
— `https://www.onera.fr/fr`

Lors de mon stage, j'ai pu travailler aux côtés des chercheurs de l'équipe Atomes Froids du département de Physique. C'était une belle occasion d'en apprendre davantage sur les technologies quantiques et ici leurs applications sur de nouveaux types de capteurs inertiels comme les gravimètres (accéléromètres verticaux). **G. de Rochefort**

[Physicists' life]

The Odderon discovery

Today, William d'Assignies Doumerg a M2 student present us is Master 2 internship done remotely with the University of Kansas. As he explains, the team led by is tutor was involved in the recent discovery of a fundamental particule, the Odderon. Many thanks to William and Christophe Royon for this short discussion describing the context of this discovery.

William : I am doing my Master 2 internship in particle physics with the University of Kansas (working online) in a team led by Christophe Royon, former normalien (year 90). This team was recently involved in the discovery of the Odderon (discovery published in march 2021), since Christophe Royon was leading the analysis part of this discovery. This article is an opportunity to present it.

Christophe Royon : I am now Foundation Distinguished Professor at the Kansas University after having spent 24 years at CEA Saclay. I am also the laureate of the Humboldt Research Award, two times laureate of EPS High Energy Physics Prize together with the ATLAS and D0 collaboration for the Higgs boson discovery and the physics of the top quark.

To understand what the odderon is, we first need to introduce other more fundamental particles : gluons and quarks, described by Quantum Chromodynamics. Gluons are bosons [1] that interact with quarks. Quarks are fermions that gather by two or three to give other particles, like protons for example (2 quark up + 1 quark down + gluons + quark-antiquark pairs). A main characteristic of the Quantum Chromodynamics, is the color [2] : each quark has a color or anti-color, and each gluon has two. Some combinations of colors associated with different quarks or gluons give states that are called colorless (as red+green+blue), and are the only ones to be stable, so every particle that we observed is colorless. The pomeron is the colorless state composed of two gluons, and the odderon is the colorless one formed by 3 gluons. It took 50 years since the prediction of the existence of the odderon, for its experimental discovery.

When protons interact, gluons or photons can be exchanged between the two. We are interested in cases where protons are intact after interaction, that can be explained by a colorless object, namely a photon or at least two gluons. When two gluons (or more genrally an even number of gluons) is exchanged, we talk of pomeron exchange and when three (or an odd number) of odderon exchange. It took 50 years since the prediction of the existence of the odderon, for its experimental discovery.

To detect these odderon and pomeron exchanges, two 'good' processes are the elastic collisions of 2 protons (at the LHC), and of 1 proton+1 anti-proton (at the Tevatron) [3]. The two particles collide, exchange momentum (deflection), but are not destroyed, like pool balls. This kind of precesses are called elastic scattering since the particles are 'intact' in the outgoing state. In order to detect the odderon, we measured the diffe-

1. Bosons are the particles at the origin of forces. Fermions are the particles that make up matter.
2. There is no link with a physical color.
3. It is thus a direct collaboration between two experiments located on both sides of the Atlantic.

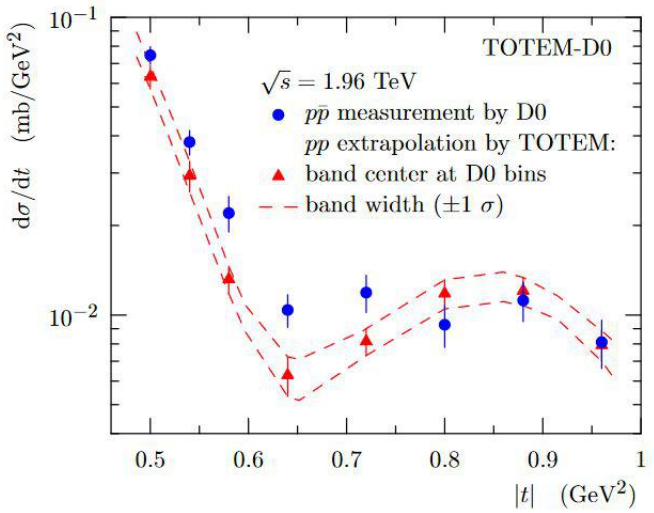

Figure 3 – *Comparison between the D0 $p\bar{p}$ measurement at 1.96TeV and the extrapolated TOTEM pp cross section, rescaled to match with the D0 measurement. The dashed lines show the 1σ uncertainty band.*

rence between pp and $p\bar{p}$ interactions that are characteristic of the odderon. In a very simplified way, each of the two gluon states contributes to the probability amplitude of each scattering according to the formulae :

$$\begin{aligned} A_{pp} &= \text{Even} + \text{Odd} \\ A_{p\bar{p}} &= \text{Even} - \text{Odd}. \end{aligned} \tag{1}$$

The minus sign comes from the charge conjugation which changes all charges into their opposites. It is thus easy to see how from the two measurements, one can quantify the contribution of odderon. The situation is not that simple indeed, and that is why odderon had not been observed yet, because elastic scattering at low energies can be due to exchanges of additional particles to pomeron/odderon : ρ, ω, ϕ, reggeons, and distinguishing between all these exchangesis not an easy task. At ISR energies, there was already some indication of a possible difference between pp and $p\bar{p}$ (about 3σ). The strategy was to observe collisions at energies of TeV scale, to be in an asymptotic region, avoiding contributions from reggeon or meson exchanges. One of the difficulties of this work is that it was necessary to compare data from the D0 Collaboration at the Tevatron (proton-antiproton) with those from the TOTEM Collaboration at the LHC (proton-proton) which were taken with different beam energies. It was thus necessary to extrapolate the TOTEM data to the Tevatron energy in order to compare them directly with D0. This comparison associated with previous TOTEM measurements allowed the discovery of the odderon at more than 5σ, see Figure 3. Indeed the gap between both measurments is due to the negative sign of the Odd part of the amplitude.

CR : This result is fundamental from a theoretical point of view, and the detector development also has applications for everyday life. In the hospital environment, detectors developed for these measurements (e.g. ultrafast silicon detectors) are being used to accurately and instantaneously measure the doses received during cancer treatment. The University of Kansas, in collaboration with NASA, is also using this detector to measure cosmic radiation (both the type of particles such as p, He, Pb, etc and their energies) as well as the amount of radiation received by cosmonauts during a trip to Mars (and this is one of the subjects on which William will soon work).

Christophe Royon and William d'Assignies Doumerg

Sir, I have a question

Vous êtes khôlleur ou tout simplement curieux ? Peut-être trouverez-vous dans les questions suivantes un problème ouvert intéressant. Vous observez un phénomène étrange ? Arrêtez de regarder *The Lupin* et envoyez-nous une question (adresses mail en fin de review) !

I : What's the acceleration (expressed in g units) encountered by a flea during its jumps ? ;

II : For a book of N words, what is the minimal file size to store it on a computer ? How much space is needed to store all the content of the BNF ? ;

III : In pixels, what is the resolution of our sight ? ;

IV : Why don't we feel a mosquito landing on our skin ? ;

V : Why starts are blinking ? ;

VI : "Assume that the penguin is a cylinder..." is a common hypothesis made. How should it be translated in term of perturbation of shape parameters ? ;

VII : Would we be more intelligent with a two times bigger brain ? ;

VIII : What is the magnitude of the magnetic field bellow an high voltage line ? ;

IX : What is the heat dissipated by a TGV during a braking ? ;

X : Is it possible to cook a fried egg with a car ? ;

XI : Describe the movement of a speck of sand on a drum's membrane. Is it stochastic ? ;

XII : How long is the length of the white line spread by a plane flying in a clear sky ? ;

XIII : How much power do Military RADARs need to be useful ? How does it depend of the distance ? ;

XIV : Anechoic rooms' walls are covered by numerous large spikes in order to absorb waves, even EM waves. How does it work ?

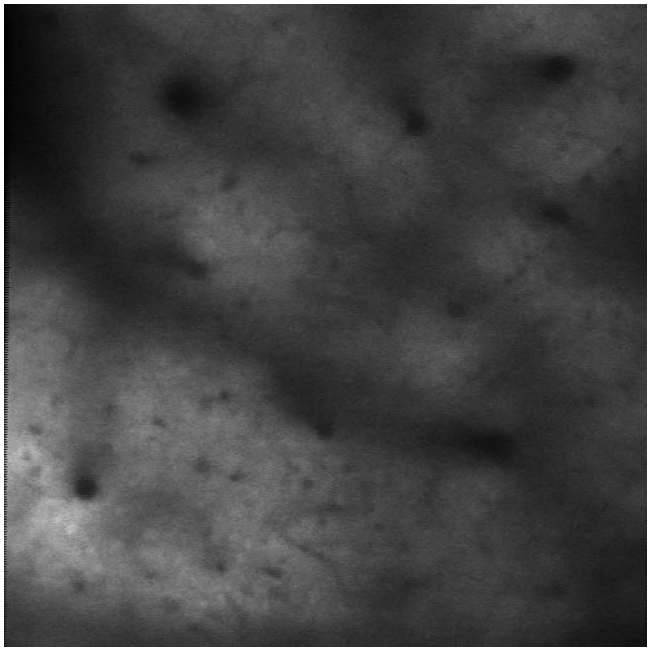

Figure 4 – *Previous mystery photo*

About the previous questions...

Mystery photo

Did you find it ? The previous mystery photo was a caption of the brain of a mouse taken with a 2-photon microscope. What you actually see is a part of the primary somatosensory cortex of the mouse, where afferences from its whiskers are encoded. The black dots are blood vessels, orthogonals to the picture plane. Looking carefully, one can distinguish small circulars areas (e.g in the bottom left corner), which are neurons. Their presence is most striking during the recording (or when one see the movie) : you can see the neurons blinking and the intensity is correlated to their activity level !

Record the brain activity *in vivo* with 2-photo microscopy

The central point of my internship is to record the neuronal activity of the primary somatosensory cortex of mice (see the answer to the mystery photo of N_{11}) *in vivo*. The historical approach is to use electrophysiology to record the membrane potential of the neuron. This method is still used currently, and many papers are written using it, because its provides single-cell activity. But the huge combined progress in genetics and microscopy allow neuroscientists to record *in vivo* movie of the brain. Of course, imaging brain activity isn't new and for example medicine uses widely spread techniques such as functional Magnetic Resonance Imaging (fMRI).

Nevertheless, in the all set, only multi-photon microscopy (MPM) is able to resolve single-cell activity from deep cells. This makes MPM very attractive in neurosciences because we can potentially reproduce the single-cell measurement done with electrophysiology and going further due the supplementary information provided (relative locations of neurons, spatial diffusion of the activity ...). Here, I would like to introduce the basis of MPM, focusing on 2-photons microscopy. Then I will present the application of MPM to neurosciences with calcium imaging. [4]

MPM microscopy combines two principles from *Fluorescence Microscopy* and *Multi-photo absorption* : Roughly, a near-infrared beam is send on the sample to image, and fluorescent molecules, called *fluorophores*, are going to be excited absorbing two-photons.Emitted photon by de-excitation are recorded.

Two photon absorption is a non-linear optical process with outlines lying on the simultaneous absorption of two incident photons (here of the same energy) and excites a molecule from its ground state to an excited state. "Simultaneous" means that the absorption of the second photon should occurs during the lifetime of the *virtual state* created by the absorption of the first photon.

The energy of the excited state is equal (or smaller) than the sum of the two absorbed photon, then the emitted photon has a wavelength smaller than the absorbed ones. Thus, in our case by sending a near-infrared beam, we get a photon with a visible wavelength. Here, the non-linearity occur because the rate equation (from ground state N_{ground} to excited state N_{exc}) given by has the transition rate proportional to the square of the laser intensity :

$$\frac{dN_{exc}}{dt} = \sigma N_{ground} I^2 \tag{2}$$

Where σ is a coefficient taking into account the photon absorption cross section, I the laser intensity and N_i are the population of photons in the state i.

Why using 2-photon microscopy is relevant for imaging biological tissues ? As discussed before, this method able us to use near-infrared excitation (typ. from 780nm to 1000 nm). NIR excitation is relevant for biological tissues since they have a good transparency at this wavelengths. Scattering is also decreased with the use of NIR excitation. Indeed, according *Mie scattering*, amount of scattering for our range of wavelengths scales as $1/\lambda$ where λ is the wavelength. Thus, 2-photon microscopy has a greater penetration performances than single photon microscopy. Finally, because the energy of incident photons is smaller, photo-toxicity is also decreased.

4. I emphasize that this modest presentation isn't intended to be exhaustive or be a lecture on this topic. This is only an extension to the answer to the previous mystery photo. People interested by the topic might find more information in the cited articles (see references).

Before roughly explaining the principles of calcium imaging, I think crucial to recall a few notions about Neuroscience. The brain is a tissue composed of different cells type glials cells and neurons, which are commonly described as the basic unit for computation in a neural network. A neuron receives inputs from other neurons on its synapses (a chemical signal) and sends information (here, an electrical signal) with its unique axon.

What is this an electrical signal ? Well, a cell is bordered by the plasmic membrane which is impermeable to ions. Because the concentration of ions (e.g Cl^-, Na^+, for neurons' signal) is different in extra and intra-cellular area, there is for each ions with different concentration a non-vanishing *Nernst Potential*. The resulting potential (sum over all the ions) gives the *membrane potential*. In an axon, during signal transmission, there is channels which allow cations (K^+ and Ca^2+) to enter into the axon, making a local variation in the membrane potential, called *Depolarization* because the membrane potential goes from ~ -70 mV to 0 mV. Just after, pumps extract the extra-cations to repolarize the membrane. Finally, the signal for neural transmission, called *Action potential*, is a variation of the membrane potential propagating along the axon. [5]

Hence, to detect the activity of a neuron we could measure its membrane potential (the case of electrophysiology) or monitor its concentration of cations, which are indirect markers for neuronal activity. Among the different cations, calcium is the preferred choice for two reasons :
- First, calcium level varies among large order of magnitude during the activity : at rest, the calcium concentration is very low (around 100 nM) and reaches concentrations around 10 μM during depolarization, for a short time.
- Second, thanks to the development of genetics, it is easy to insert fluorescent calcium indicators in neurons of interest (namely, depending of their function). GCAMP (association of three proteins, green fluorescent protein, M13 peptide and calmodulin) is commonly used. Calmodulin binds with intracellular calcium making the molecule fluorescent. The more calcium there is, the greater fluorescence is.

Finally, 2-photo microscopy combined with calcium imaging appears to be promising techniques to record brain activity because this enables neuroscientists to perform single-cells activity measurement in a non-invasive way (compared to eletrophysiology). Moreover, because you image a map of the brain, it is now possible to consider the spatial dimension in neural network activity with a good accuracy. Nevertheless, calcium imaging suffers has some limitations. It is more difficult to perform deep cell recording because of the limited penetration performances (albeit increase with 2-photon or 3-photon microscopy). More embarrassing, calcium concentration changes are much slower than membrane potential changes and consequently may reflect not an unique spike but a combination of spikes. Temporal resolution of calcium imaging might be limiting to resolve fast-spiking neurons activity. (**L.Brivady)**

5. And its propagation can be described by a cable-like equation.

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We need you !

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