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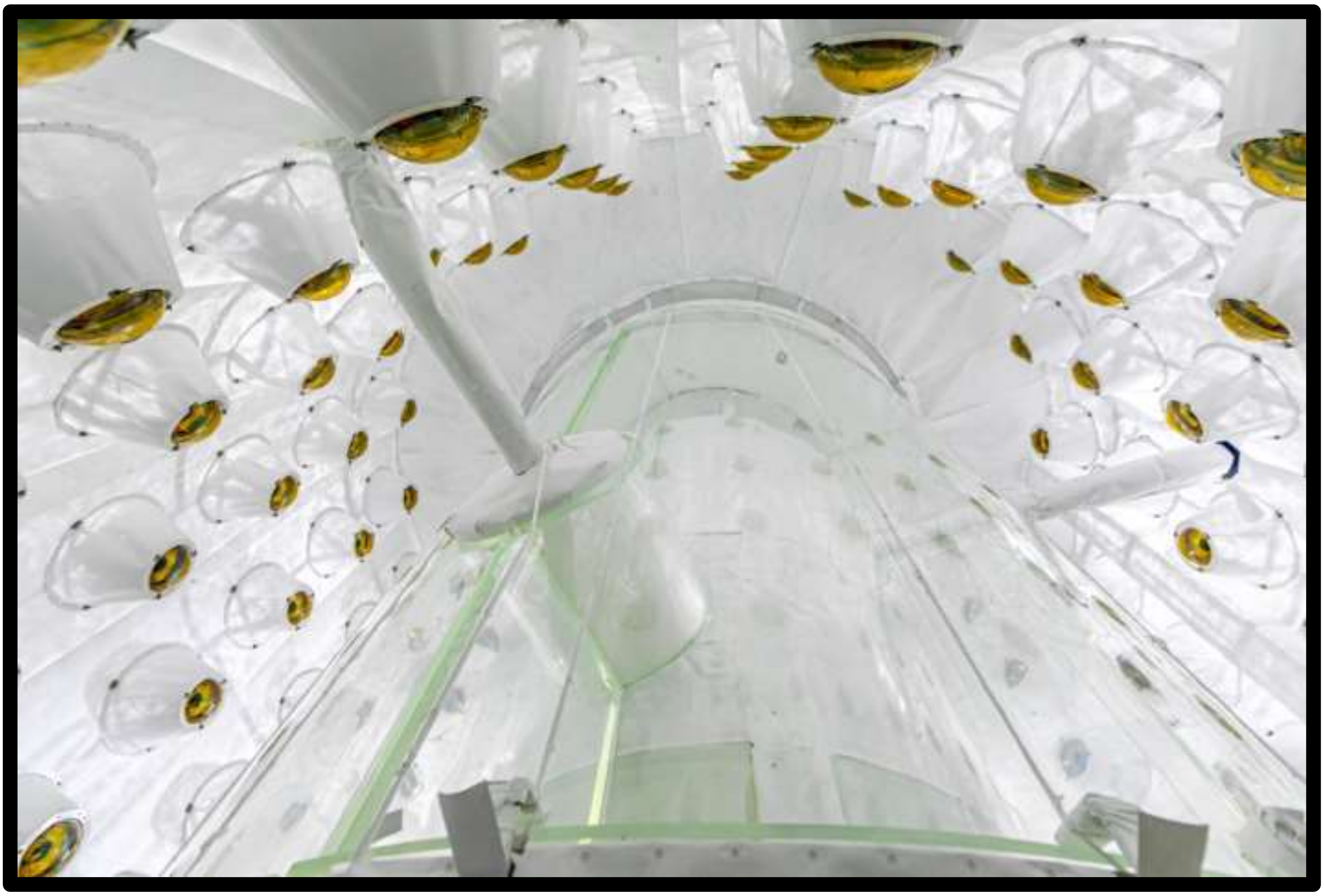
IRPS Bulletin

Newsletter of the International Radiation Physics Society



Photograph of the outer detector array of the LUX detector.
The LUX-ZEPLIN experiment attempts to detect
dark matter particles.

Photograph: Matt Kapust, LZCollaboration, 2021

See the article by Isabel Lopes

CURRENT IRPS COUNCIL MEMBERS 2021-2024

Contents of IRPS Journal

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From the Editor

This issue of the Bulletin follows a meeting of the Council of the IRPS. Looming large on the agenda were issues concerning how best we can maintain communication between members in an environment still dominated by COVID restrictions. As our President, Isabel Lopes, comments in here President's column, two international conferences IRRMA-11 and ICDA-4 were cancelled. But ISRP-15 was held in December 6-10, 2021 in Kuala Lumpur in a mixed remote/in-person mode. This may well be the way conferences are held in the future. But it is a poor substitute for meeting people face-to-face.

A series of small regional meetings has been inaugurated, in part to compensate for the inability to organize full scale meetings: this is the International Forum on Advanced Physics Series, of which IFARP-4, held in Riyadh, is the most recent. A report of this meeting is included in this issue. Information about future meetings of our Society is given elsewhere in the Bulletin.

The reports from two of the Society's Vice Presidents are included. This illustrates the range of activities and global breadth of the Society.

This issue includes a brief outline of the LUX ZEPLIN project by Isabel in which the results of the recent report into the study of *dark matter* in the universe. This is complemented in the column *Physics around the World* which highlights the results of a number of diverse, but linked, experiments in particle physics, commencing with neutrinos (zero mass), and finishing with the Higgs boson (mass of about 125GeV/c^2). This year marks the 10th anniversary of the discovery of the Higgs Boson.

As always, I stress that the strength of the society lies in its diversity of interest in all aspects of radiation physics: the A to Z of radiation physics—Astronomy to Zoology. The Bulletin is open to contributions from all members of the society to showcase recent research on their own fields of radiation physics.

This issue has been produced by Shirley McKeown, Dudley Creagh, and myself.

Ming Tsuey Chew

From the President of the IRPS, Isabel Lopes

I am very sorry to tell you that our friend and colleague José Ródenas Diago (Pepe for his friends) passed away on August 23, 2022. He was a dear colleague, very active in promoting collaborations, common initiatives and exchange of ideas. He was the organizer of the IRRMA-9 in Valencia, Spain (2014), and long-term councillor of IRPS. He was the founder of the European Academic Network for Cooperation in Higher Education on Radiological and Nuclear Engineering (CHERNE). Although retired, he continued working at the Polytechnic University of Valencia as Professor Emeritus. A formal obituary will be written for the December IRPS Bulletin.

From the President

Dear Colleagues

From my point of view, one of the major assets of our Society is the conferences and forums that it organizes and/or sponsors. They are occasions in which the members of the Society have the opportunity to meet, share and discuss research findings, to exchange ideas and insights. This is particularly relevant for young researchers and PhD students.

And, because they are especially important for the Society, we try to support them and bring them to the conferences as much as possible. Last but not least, the research works presented at the conferences can be submitted for publication in the Conference Proceedings that, in last years, have been published in Special Issues of Radiation Physics and Chemistry journal, which presently has an Impact Factor of 2.776 ranking it 7 out of 34 in Nuclear Science and Technology. Therefore, the IRPS conferences and forums are a pivotal part of the Society's life.

Unfortunately, in the last years we had to postpone the 11th International Conference on Industrial Radiation and Radioisotope Measurement Applications (IRRMA-11) and the 4th International Conference on Dosimetry and its Applications (ICDA-4) due to the COVID-19 pandemic and other circumstantial reasons. Fortunately, ISRP-15 was held in December 6-10, 2021 in Kuala Lumpur in a mixed remote/in-person mode. This was possible only thanks to the hard work and dedication of David Bradley and the Organizing Committee of ISRP-15. But in 2022, some of us had already a taste of an in-person IRPS scientific event at the 4th International Forum on Advances in Radiation Physics (IFARP- 4), in Riyadh, from 27 to 31 March. It was a very fruitful and pleasant meeting (somewhere else in this bulletin, there is a report on IFARP-4 that I suggest to read). IFARP-4 was the aperitif to come back to face-to-face conferences. In 2023, we will have IRRMA-11 and ICDA-4, both foreseen as in-person meetings.

IRRMA-11 will take place in Bologna, Italy, organized by Jorge Fernandez. This will not be the first time that Bologna and Jorge Fernandez receive an IRRMA conference. In fact, the 5th IRRMA took place in that charming Italian city, brought by the hand of Jorge Fernandez. IRRMA is a conference focused on, but not limited to, the uses of radiation and radioisotopes in industry, biomedicine, homeland, art and culture heritage, among many other applications. We are sure Jorge will make this coming IRRMA truly memorable for all.

ICDA-4 will take place in September 2023 in Valencia, Spain, chaired by Gumersindo Verdu. ICDA-4 belongs to the "youngest" of the IRPS sponsored conference series. It was initiated by David Bradley in 2013, in Surrey, UK, driven by the paramount relevance and large scope of the dosimetry field that deserves a dedicated conference. The last ICDA was held in Lisbon, Portugal, in May 2019. It was a great success and we expect Valencia to be an even greater one.

Therefore, we have a very exciting 2023 ahead! Stay tuned for more information in the next bulletin.

Isabel Lopes

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Reports to IRPS Council Meeting 2022

Yuhui Dong

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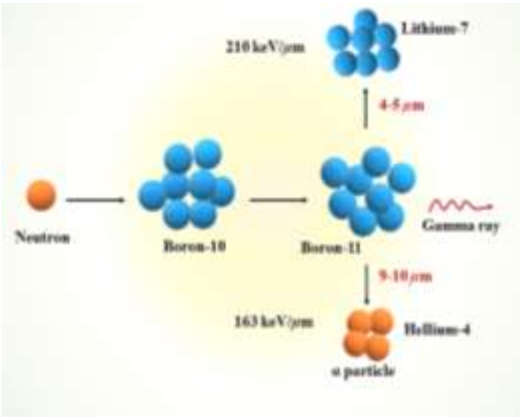
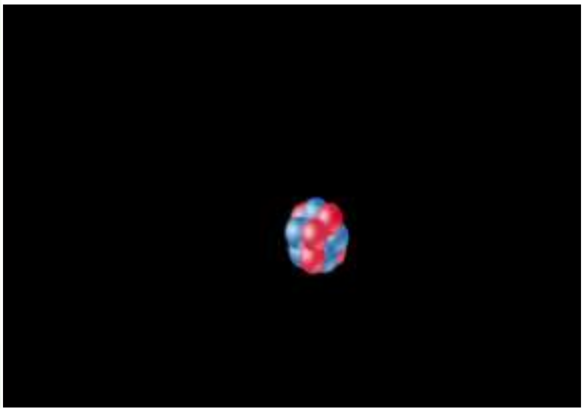
Outline

- Due to the epidemic situation, activities mainly focused on pushing some research in radiation with living systems and culture protection.
- Boron Neutron Capture Therapy (BNCT), supported by CAS
- Culture relic protection, supported by IHEP

1. Design and Preparation of Novel Boron-carrying Agents for Precise Boron Neutron Capture Therapy (BNCT)





Boron neutron capture therapy (BNCT) is a noninvasive radiation therapeutic modality to treat tumors. Since neutron has been found, it is expected to improve the treatment of cancers considered to be incurable, such as brain glioma. Glioma is a high-grade tumor with high invasiveness, recurrence, and mortality rates, and current clinical treatments are impotence for many patients. In order for BNCT to achieve superior therapeutic effects in glioma, one of research focus is the development of novel boron-carrying agents for BNCT. These drugs should be able to cross the blood-brain barrier (BBB), target and accumulate sufficient boron in the tumor, and track the boron carrier's distribution in glioma in real-time to achieve accurate irradiation matching of the neutron beam.[3]

We designed and prepared a novel boron-containing carbon dots (BCDs) with superior water solubility and excellent optical property for tracking ^{10}B *in vitro* and *in vivo*. Encapsulation of BCDs using exosomes (Exos) from macrophages yielded BCD-Exos of ~100 nm. BCD-Exos also were verified to cross "the blood-brain barrier and significant accumulation in tumour tissue of the orthotopic U-87-MG glioma tumor-bearing mice model 4 h after administration. The BCD-Exos enhanced the 10B in tumor to107.07 ± 1.58 ppm and the T/N ratios from 2.03±0.08 of boron

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phenylalanine (BPA) to around 5.28±0.29. After administration with 500mg kg^{-1} for 2h, a prominent BNCT effect was achieve through matching BCD-Exos with single neutron exposure(neutron radiation dose is 8.40 ± 0.12 Gy) to treat brain tumors in model mice. The survival ratio of BCD-Exos group is 100% at 30 day (end of experiment) after BNCT, while mice of BPA treatment is 0% survival at 15 day.

We also assembled and architected multifunctional high boron content metal organic frameworks (MOFs) for precise BNCT of brain glioma. The stable (Zr-TCPP) MOFs binding boron acids formed 100.20 ± 6.72 nm co-crystal structures. A significantly antitumor efficiency was also achieved in BNCT to brain glioma of model mice by imaging location of precise space-time.

The situation of the mice model exposed to thermal neutron irradiation for BNCT experiments *in vivo*

References

1. Kuthala N, Vankayala R, Li Y-N, Chiang C-S, Hwang KC. Engineering Novel Targeted Boron-10-Enriched Theranostic Nanomedicine to Combat against Murine Brain Tumors via MR Imaging-Guided Boron Neutron Capture Therapy. Adv Mater 29, 1700850 (2017).
2. Nomoto T, et al. Poly(vinyl alcohol) boosting therapeutic potential of p-boronophenylalanine in neutron capture therapy by modulating metabolism. Sci Adv,6, 1722(2021).
3. Ruan Z, Liu L, Fu L, Xing T, Yan LF. NIR bioimaging-guided carborane containing macromolecular agent for BNCT. J Control Release 259, E190-E190 (2017).

2. Radiation methods for archaeology and cultural heritage

(a) Nuclear analytical techniques

The application of analytical techniques for cultural relics or archaeological objects provides the historian or the archaeologist quantitative information which can help him to understand the way of life of the cultures he is studying. On the other hand analytical information can be used to verify authenticity of traded objects. This knowledge is also necessary to carry out appropriate restoration of damaged cultural relics. Nuclear analytical techniques, such as neutron activation analysis and X-ray fluorescence analysis, are non-destructive and reliable enough to produce accurate information on a wide variety of elements in the object of study. More than 14000 pieces of ancient ceramics have been

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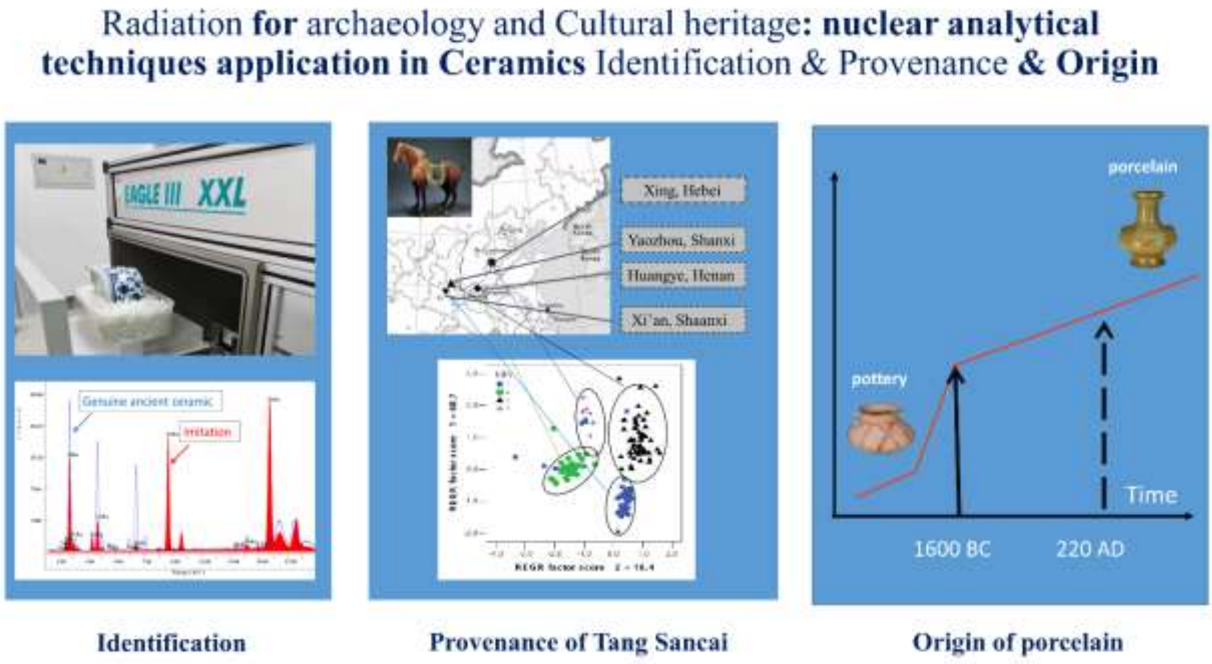
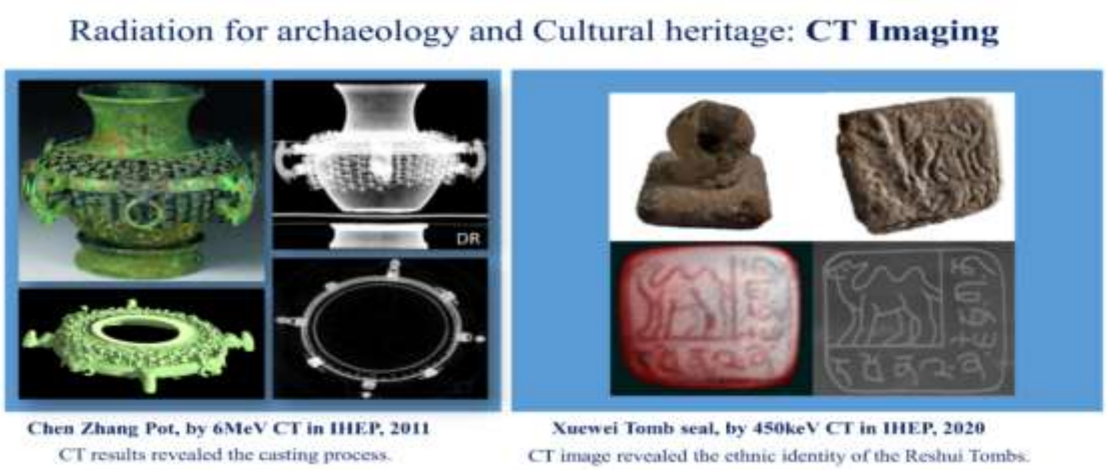
analyzed by nuclear analytical techniques for the purpose of authentication, conservation or provenance studies



(b) **CT Imaging**

X-ray CT has been widely used in the field of cultural relic conservation and archaeology. IHEP is one of the first institutes in China to develop radiographic detection technology and application research. At present, several CT systems have been successfully developed and applied to cultural relic protection and archaeological research. As early as 2011, we used our self-developed 6MeV high-energy CT to conduct CT scanning of Chen Zhang Pot, a national first-class cultural relic now stored in Nanjing Museum, and the imaging results provided a basis for studying its internal structure and processing technology. In 2020, we carried out CT scanning of the seals unearthed from the "2018 Xue Wei No.1 Tomb" in Dulan Reshui, Qinghai Province. The reconstruction results clearly showed the seal information covered by rust, thus solving the mystery of the tomb owner's identity and helping this archaeological discovery to be listed as one of the "Top ten Archaeological finds in China.



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3. Electron beam irradiation sterilization

Electron beam can destroy DNA and other biological macromolecules of microorganisms, causing the denaturation of biological macromolecules such as proteins and biological enzymes, resulting in the death of microorganisms. Compared with the conventional chemical fumigation sterilization method, which requires the participation of toxic and harmful gases, radiation sterilization is more environmentally friendly. Mobile electron beam equipment has been designed for in-situ sterilization of Dun Huang murals. We are now cooperating with the Palace Museum and conducting irradiation sterilization research on organic cultural relics to find out the most suitable conservation conditions.

Radiation for archaeology and Cultural heritage : Electron beam irradiation sterilization

Mobile electron beam equipment designed for sterilization of murals and organic cultural relics

Murals of Mausoleums of the Southern Tang Dynasty

Organic cultural relic of the Palace

Africa and Middle East Radiation Physics Activities during the period from June 2021 to June 2022

Mohamed Gomaa

IRPS Vice President for Africa and Middle East

The main goal here is to report about major activities of African and Middle East Scientists as outlined below.

1. United Nation Scientific Committee on the effects of Atomic Radiation (UNSCEAR) activities

During 20221-2022 two UNSCEAR meetings were held one in 21-25 June 2012 and the other one in 9-13 May 2022.

In the first meeting two scientists attended the meeting (on Zoom) from Egypt and Sudan with two observers from Algeria and united Arab emeritus attending as observers.

In the second meeting, four scientists attended the meeting from Algeria, Sudan, united Arab republic and myself, and a representative of Egypt attended it on zoom.

The UNSCEAR country members numbered 27 scientists until 2021 and in 2022 The number of members became 31 countries.

Amongst the achievements of the UNSCEAR meeting is the publication of a yearly report to UN General Assembly, and publication of three documents: one for Fukushima, one for occupational exposure, and the other for medical exposure.

2. Arab atomic energy agency (EAAA) conference and workshop

In mid-December 2021 the 15th conference for peaceful uses of atomic energy was held in Aswan (Egypt). More than 200 participants from several countries from Middle East including Saudi Arabia, Tunis, Libya, Morocco, Jordon, Iraq, and Egypt. Various topics were discussed. These included theoretical and experimental physics, radiation protection, NORM, and Radon studies.

As well, invited talks were given by senior scientists from Jordon and Egypt on their Current and Future Nuclear Energy Programs.

In June 2022 a workshop was organized in Cairo by both AAEA and Egyptian atomic Energy Authority (EAEA), with participation by scientists from several Middle East countries. The conference topic was *Radiological Techniques in Archaeology.*

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3. The Six regional African Radiation Protection Congress shall be held in 10 to 13 October Ghana, with the support of International Radiation Protection Association (IRPA), IAEA and national organization.

4. Egyptian Nuclear Physics Association (ENPA)

   In MAY 2022, a conference was held in Sharm El sheikh, Egypt. Which was attended by several scientists from USA, France (on zoom), and scientists from Italy, Soviet Union, Romania, and EAEA and Egyptian universities. Topics discussed included black holes, theoretical nuclear physics, production of new isotopes, radiation protection.

5. The Arab physical society (APS)

   The Arab Physical society was formed in 2021 and it held its first webinar in March 2022. Several Nobel prize winners were among the speakers. Please note a good description of this activity was published at Physics World (May 2022) issue.

6. Egyptian radiation physics network

   The activities of the Egyptian radiation physics network for the period from December 2021 until May 2022 are outlined below.

   A monthly lecture was given by member of the network either on Zoom or by personal attendance. One of these lectures was given by Dr Hossam Donya from King Abdul Aziz University who enlightened us on his latest work on *The Use of Nano Materials in Radiation Shielding.*

   Medical physics and radiation protection were also addressed.

7. Currently I am attending virtually IAEA International conference on nuclear safety and security of radioactive sources.

I am grateful to well respected colleagues from African and Middle Eastern countries for freely sharing their knowledge and experience with me

ANNOUNCEMENT

IRRMA-11

Bologna 23-28 July 2023

Contact: Jorge.Fernandez @unibo.it

IRRMA Web Site : http://irrma.ing.unibo.it

Report on International Forum on Advances in Radiation Physics (IFARP-4), Riyadh, Saudi Arabia, 27-31 March 2022

Mohammed Alkhorayef, King Saud University, Saudi Arabia (Chair, IFARP-4)

The 4th International Forum on Advances in Radiation Physics (IFARP-4), 27-31 March 2022, hosted by King Saud University, Riyadh, Saudi Arabia. IFARP-4 follows on from the first forum, the Buenos Aires, Argentina, FORUMBA; 4-5 May 2017. The 2nd forum hosted by Kuala Lumpur, Malaysia, IFARP-2; 3-4 December 2019. The 3rd International Forum on Advances in Radiation Physics, co-hosted by Sunway University, Malaysia and the University of Melbourne, Australia, with Universiti Putra Malaysia as a collaborating body- IFARP-3; 24- 25, February 2021. These focused meetings of the International Radiation Physics Society (IRPS) were intended to provide timely updates covering the latest developments and emerging ideas within the underpinning science and radiation technologies. Special Issue of the journal Radiation Physics and Chemistry (RPC) dedicated to all events.

The IFARP-4 was organized by the standing committee on radiation protection at King Saud University, located in the heart of Riyadh City, the capital of the Kingdom of Saudi Arabia.

The Forum focused on the future while also recognizing the considerable advances made in radiation sciences over the several decades since IRPS aimed to promote the interdisciplinary subject of radiation physics, including the the following:

1- Preparedness and response to radiological and nuclear emergencies.
2- Treatment and management of radioactive waste.
3- Production of radioisotopes.
4- Radiation protection for workers and practitioners.
5- National and international radiation safety and protection guidelines and recommendations.
6- Radiation detection and dosimetry.
7- Power reactors and nuclear research.
8- Application of Radiation in Radiobiological, medical, environmental and industrial sciences
9- Recent advances in diagnostic and therapeutic radiology
10- Applications of radiation in materials science and nanotechnology
11-Education and training in nuclear physics and engineering

The meeting sessions included invited lectures by leading experts in their fields,who contributed oral papers. This forum was conducted to allow for the option of either physical or virtual presence.

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International invited speakers			
No	**Speaker**	**Institution**	**Title**
1	**David Bradley**	University of Surrey, UK/ Sunway University, Malaysia	Dosimetric Needs in Support of Flash Radiotherapy
2	**Isabel Lopes**	Coimbra University, Portugal	Iterative Position Reconstruction Method for Gamma Cameras
3	**Peter Thirolf**	Ludwig-Maximilians-Universität München, Germany	Recent Advances in Compton Camera Detector Development for Medical Imaging
4	**Mayeen Uddin Khandaker**	Sunway University, Malaysia	The Importance of Nuclear Data for Production Diagnostic and Theranostic Radionuclides via Accelerator Route
5	**Christopher Thomas Chantler**	University of Melbourne, Australia	A Cause of Neurodegneration? Structural Interpretation of CU Binding in N-Truncated Amyloid-β Peptides from X-ray Absorption Spectroscopy
6	**Hector Rene Vega-Carrillo**	Universidad Autonoma de Zacatecas, Mexico	Spectra and Gamma Factors for X-rays for Diagnosis
7	**Constantin Kappas**	University of Thessaly, Greece	Pregnancy and Radiation
8	**Hairul Azhar Abdul-Rashid**	Multimedia University, Malaysia	Distributed Radiation Measurement Using Specialty Optical Fiber
9	**Zsolt Podolyak**	University of Surrey, UK	Radiation Physics Programmes and Research at the University of Surrey
10	**Luigi Rigon**	University of Trieste, Italy	Phase-Contrast X-ray Imaging: Principles and Applications
Local invited speakers			
11	**Fouad Abdulaziz Abolaban**	King Abdulaziz University, Saudi Arabia	Recent Research on Utilizing Artificial Intelligence in Radiation Therapy
12	**Abdelmoneim Sulieman**	Prince Sattam bin Abdulaziz University, Saudi Arabia	Radiation Protection in Medicine: Current Challenges and Future Prospective
13	**Ibrahim AlJammaz**	King Faisal Specialist Hospital & Research Center, Saudi Arabia	Radiopharmaceuticals in the Era of Precision Medicine
14	**Thamer Alharbi**	Majmaah University, Saudi Arabia	Determination of Radioactivity Concentration and Hazards Assessments Near Radioactive Waste Site in Saudi Arabia
15	**Amjad Rashed Alyahyawi**	University of Ha'il, Saudi Arabia	Silica-based Passive Dosimeters for Medical Radiation Measurements
16	**Belal Moftah**	King Faisal Specialist Hospital & Research Center, Saudi Arabia	Radiological and Nuclear Emergencies : Lessons Learned
17	**Yazzed Alashban**	King Saud University, Saudi Arabia	Radioactive Waste Management- Nuclear Waste Disposal
18	**Ali Al Dalaan,** **Nasser Alaboudi**	Saudi Food & Drug Authority, Saudi Arabia	SFDA Regulation for Safe Use of Radiation Emitting Medical Devices
19	**Ahmed Omar**	Naif Arab University for Security Sciences, Saudi Arabia	Radiation Detection and Nuclear Security
20	**Nuclear Science Research Institute Group**	King Abdulaziz City for Science and Technology, Saudi Arabia	National Contribution in Nuclear and Radiological Applications

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In total , 101 accepted abstracts, from 21 countries around the globe. The total number of oral presentations were 55 (23 Physical oral presentation and 32 virtual oral presentations). Poster presentation were 46 (30 Phyiscal poster presentations and 16 virtual poster presentations). Regarding participation in IFARP-4, organizing committees were strongly encouraged to facilitate the participation of young colleagues, postdocs, Ph.Ds, MScs, other post-graduates, and undergraduate students.

The IFARP-4 program was began with two courses sessions on Radiation Protection and Safety on Sunday & Monday 27th - 28th March 2022.

Course 1: Patient dose measurement and optimization.

Course 2: Occupational exposure and radiation dose reduction techniques

Each course consisted of 8 CMEs hours, approved by Saudi Commission for Health Specialties (SCHS). These courses aimed to provide the advanced konwlege needed for radiation protection and safety for patients and staff in hospitals and review the technical and practical information regarding ionising radiation exposure, improve understanding of monitoring and recording of radiation exposure, occupational exposure control measures and workers' health surveillance.

The Forum was organised under the patronage of His Excellency, Prof Badran Al Omar Rector of King Saud University

LUX-ZEPLIN Dark Matter Experiment Releases First Results

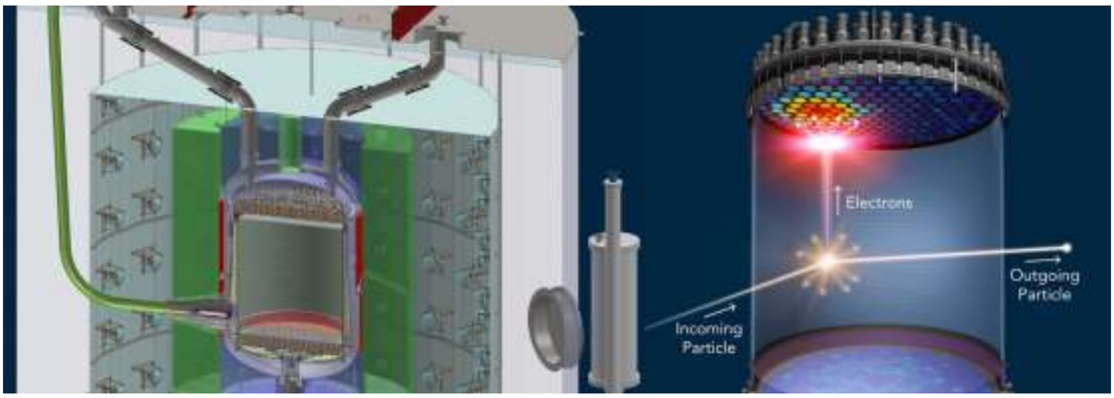
The LUX-ZEPLIN (LZ) dark matter experiment has delivered its first results after passing a check-out phase of startup operations. With just sixty life days of data acquisition, LZ is already the world's most sensitive dark matter detector. These results were announced on July 17, 2022, and they were made available in a paper posted on https://arxiv.org/abs/2207.03764. However, this is just the beginning. This first run was essentially planned for checking the performance of the detector, which is very complex. LZ is expected to run for about 4 years, collecting about 20 times more data in the coming years and expected to detect the elusive dark matter particles.

The nature of dark matter is one of the most intriguing open questions in fundamental physics. There is unambiguous evidence, based on a broad range of astrophysical and cosmological observations, indicating that about 85% of the mass of the universe is in an unknown form, which does not emit or absorb light (i.e., dark matter). Many models suggest that dark matter is composed of one or more previously unobserved types of Weakly Interacting Massive Particles (WIMPs).

One of the ways to search for WIMPs is to use supersensitive underground detectors to identify the extremely rare interactions between dark matter particles crossing the Earth and normal matter particles in the detector.

LZ is designed to detect dark matter in the form of WIMPs. Its sensitive part is made of 10 tons of very pure liquid xenon that fill a titanium tank and is viewed by about 500 photomultipliers (PMTs) able to detect faint amounts of light.

LZ is deployed about 1.5 km underground, at Sanford Underground Research Facility (SURF), constructed in an old gold mine. The detector is underground to protect it from cosmic radiation at the surface that would drown out dark matter signals.



Schematic diagrams of the LUX-ZEPLIN detector.
Left: cross section view of the complete detector system showing the scintillation detectors in the outer containment vessel (see cover page)
Right: the interaction of a particle entering the inner Xenon gas chamber and the image formed in the upper detector system.
Source : https://stanfordlab.org/experiment/lux-zeplin

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Particle collisions with the atoms of xenon produce UV scintillation, which are recorded by the PMTs. Therefore, if the dark matter particles interact with normal matter, even weakly, they will generate a scintillation signal (S1).

Those collisions will also knock electrons off xenon atoms. Under an applied electric field those electrons drift to the layer of xenon gas, on the top of the chamber, where they produce another flash of light (S2) allowing 3D spatial event reconstruction. The characteristics of the two scintillation signals (S1 and S2) help determine the types of particles interacting in the xenon.

The design, manufacturing, installation and run phases of LZ have been carried out by an international team of about 250 scientists and engineers from over 35 institutions from the US, UK, Portugal, and South Korea.

Contributed by Isabel Lopes

IMPORTANT NOTICE

The IRPS is urgently seeking Contributions to the next IRPS Bulletin

Contributions are needed for the Sections

General Articles

Research Publications

News Items from Research Laboratories in Institutions

News from around the World

Contributions should be sent to the Editor (mtchew@sunway.edu.my) with a copy to Dudley.Creagh@canberra.edu.au.

Articles and research publications should conform to the guidelines for publications in Radiation Physics and Chemistry.

(www.elsevier.com/journals/radiation-physics-and-chemistry/0969-806X/guide-for-authors)

In all categories text and images should be submitted as separate files.

News From Around the World

In all the commentary articles I write I endeavour to link recently published scientific articles in a particular field of research in a way that will assist a general reader to understand significant advances on particular topics. I try to link information which comes from a variety of sources, some seemingly so unrelated that a casual reader may not be aware of the underlying relationships.

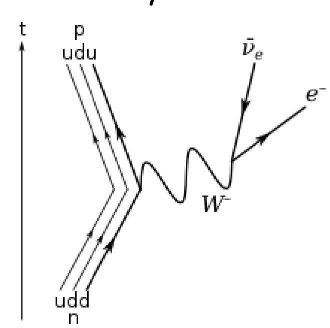
More news about neutrinos

This segment revisits the subject of neutrinos and their place in the world. For the past year numerous articles have been produced on these so-called "ghost particles". Some go so far as to say in headlines, "recent developments in Neutrino Physics threaten the foundations of the Standard Model of Particle Physics". Strong language......but how realistic are these claims?

In the last issue of the IRPS Bulletin (2022 **35 p**12) I gave a brief introduction to neutrons and neutrinos. You may remember that neutrons are the product of the decay of a free neutron or a neutron bound in a nucleus: $^{1}n \rightarrow {}^{1}p + e^{-} + {}^{a}\nu_{e}$. The result is a proton, an electron, and an anti-neutrino. Neither the proton nor the neutron is a fundamental particle, each being a composite of three quarks held together by a force-fields referred to gluons. The decay is described schematically by the Feynman diagram shown below.

The *proton* ($T_{1/2}$ = 2.1 x 10^{21} years) is a composite particle made up of two up quarks (charge = 2/3; spin = 1/2) and one down quark (charge = – 1/3; spin = 1/2) each bound by a strong force-generating particle, the gluon (spin = 1).

The *neutron* is unstable ($T_{1/2}$ = 10.3 minutes) unless it is bound to a nucleus. It comprises one up quark and two down quarks bound by a gluon. The decay of neutrino is depicted by a Feynman diagram shown below. The W^{-} boson, formed by the mass-energy difference between the down and up quark, decays immediately into an electron and an antineutrino. This is the standard explanation for the β-decay of radioactive materials.



Two other neutrinos (ν_{μ} and ν_{τ})have been discovered and the three belong to a class referred to as **leptons** in the **Standard Model of Particle Physics.** They have different nominal rest masses but they share the fact that they have a spin of ½. Leptons are **fermions** and obey difference between the neutrino and the antineutrino is that the neutrino is a

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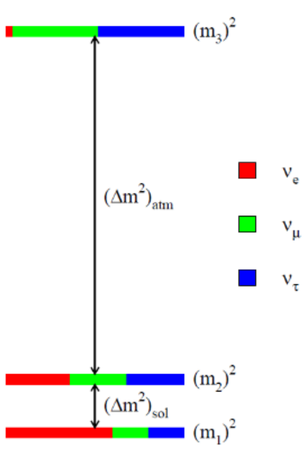
matter wave travelling with right handed chirality, whereas the antineutrino has left handed chirality.The question of chirality is important: it is the only attribute in which the neutrino particle and its anti-particle differ. Chirality has nothing to do with the concept of circular polarization in the electromagnetic sense. A chiral particle/trajectory is a built-in attribute of the particle, characterized by the fact that the mirror image of the particle cannot be superimposed on the particle. (To understand this, try the following experiment. Stand with your hands in front of you in front of a mirror, with the arms bent at the elbow , palms facing one another. Each hand is, in itself, and asymmetric entity and is the mirror image of the other.

Now turn your wrists so that the palms face the body. The hands remain mirror images of one another. Now slide the hands over one another: the top hand is not superimposed on the bottom hand).

Neutrino oscillations

Much theortical work has been done to try to understand neutrinos, in particular, how the three different types relate to one another, and how they change from one type to anorter as they travel through the universe. The μ_e, μ_μ, and μ_τ neutrinos are thought to be three related energy states in which the μ_e is the ground state: μ_μ and μ_τ are referred to a different ***flavours*** of the ground state. During the passage of the neutrinos through space and matter the neutrinos can interact with variations in the gravitational field (the only interaction they can experience) and gain energy or lose energy as they do so. Experiments have shown that the differences between them which depend on the source from which the neutrinos originate.



normal hierarchy

In my last essay into the world of neutrinos (IRPS Bulletin (2022) **35 1 p12**) I wrote about neutrinos from galactic, solar, and tritium sources. Theory can explain the differences between the experimental results in terms of oscillations between the three mass/energy levels. For solar and atmospheric measurements: ν_e ←→ ν_τ ; atmospheric measurements: ν_e ←→ ν_a (where ν_a is a linear combination of μ_μ and μ_τ); for short-baseline (laboratory-based): ν_e ←→ ν_a . This concept can be expanded to a **three-flavour** mathematical description. An explanatory diagram from de Gouvea (2014 arXiv:1209.3023) is shown. The quantities m_1, m_2, m_3 are calculated using a transformation matrix based on solar, laboratory, atmospheric data to convert and represent the proportion of flavours in each of the observed neutrino population in each level. Agreement

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between theory and experiment is good. The paradigm used by de Gouvea can be extended: each new type of neutrino adds a row to the transformation matrix. (Incidentally, the paradigm remains the same whether the neutrino is a Fermi-Dirac particle or a Majorana particle (a particle which is its own antiparticle)).

No particles have been found which would lead to need an extension of the three-flavour description. But—there is a possibility that a μ_0 neutrino could exist: one which has 0 spin and twice the mass of ν_e. Crudely speaking, this is a combination of a neutrino (spin=1/2) and an anti-neutrino (spin=-1/2). This is the so-called **sterile neutrino**. Could such a particle exist?

Sterile Neutrinos

The booster accelerator and LINAC at the Fermilab (Illinois, USA) have been operational for more than 70 years. Over this time upgrades have occurred, but the system is essentially the same as it was then.

One of the most important beamlines is the neutrino and muon beamline which has a particle flightpath of several hundred metres. In 2018 Shaefitz (MH Schaefitz 2019 Proceedings of Science Fermilab-Conf-18-775-D) reported on the results of 6 years of experimentation.

Experiments at this beamline date from 2002, where the MiniNE experiment was conducted to determine how muon neutrinos change flavour to become electron neutrinos over a short-baseline.

One of the key results was that more electron neutrinos were detected than would have been expected from the understanding of the Standard Model. Comparison with earlier experiments and with those from the Los Alamos National Laboratory (New Mexico, USA) confirmed the excess, and the statistical significance was at the 5σ level......a very high accuracy indeed. However, the detectors used in these experiments could not discriminate electrons from photons, and questions were asked about the contribution of these photons to the final result. Would this skew the data?

There was, as well, the possibility that the excess was real, and another kind of neutrino was being detected. Perhaps the **sterile neutrino** did exist after all.

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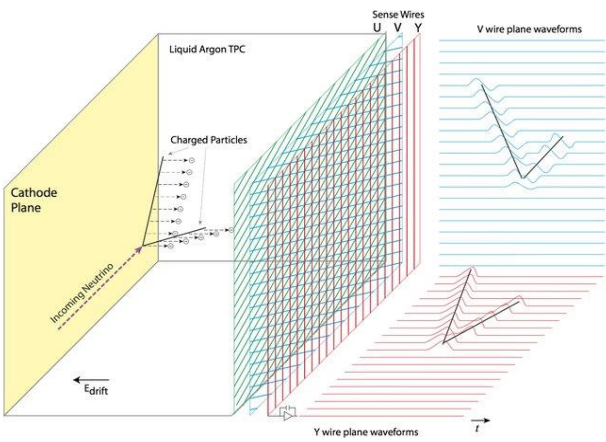
In 2015 a new detector system, MicroBooNE, came into operation. This was planned to be the first element of a project called DUNE (Deep Underground Neutrino Experiment). Neutrinos, generated at the Fermilab in Batavia, USA, would travel from their source traverse 700 miles of the earth's mantle and reach a detector located in a mine in Lead, Arizona. A comparison could then be made between the results from a short-baseline experiment and a long-baseline experiment.

The detectors were liquid Argon detectors and had detector elements which enabled 3-D imaging of the particle tracks, with good discrimination against background photons.



In 2018 the ageing booster accelerator and LINAC were upgraded. The new system produces 250% proton flux than before the upgrade (2.4X 10^{17}per hour). This causes a proportionate increase in the number of neutrinos. Because of the increased spatial and temporal capabilities of the detector system and improvements in computing power much more accurate data could be obtained.

The outcome of the experiments, released by the consortium of members, recently, is given in the following press release. (T Marc Fermilab. media@fml:224-220-7803).

> However, four complementary analyses released by the international MicroBooNE collaboration and presented during a seminar today all show the same thing: no sign of the sterile neutrino. Instead, the results align with the Standard Model of Particle Physics, scientists' best theory of how the universe works. The data is consistent with what the Standard Model predicts: three kinds of neutrinos—no more, no less.

A recent press release by Cho in Science.org (A Cho; lodged 21 November 2021) says that the DUNE experiment will require a $3bn bailout from the US Congress to continue construction. Given the cost of the many competing international crises in which the United States of America is involved, the prospect of finance being available to make the project progress seems slim.

The rest mass of the neutrino

In an earlier IRPS Bulletin (2021 **34** 1 p9) I mentioned measurements of the mass of the neutrino made by the KATRIN project in Karlsruhe. The measured the mass was found to be less than 0.8eV/c^2--- significantly less than an earlier measurement (less

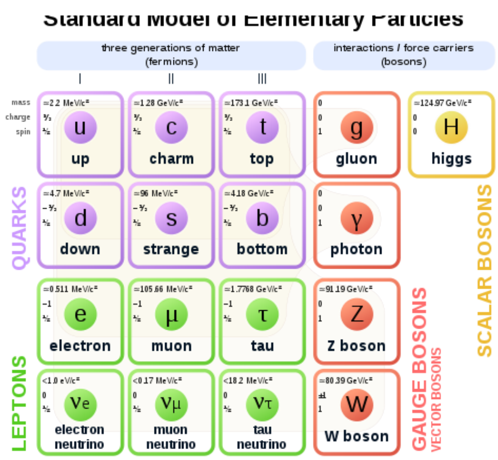
Continued next page

than 1.1eV/c^2). According to theory, the mass of a neutrino should be zero if the electron trajectory and the proton trajectory are collinear. The measurements indicate that the theory is correct. The rest mass of the neutrino (that is the probability that the neutrino will be emitted in the interaction) **is** zero.

But what of the other particle involved in the neutron decay………the W$^-$ boson?

The W$^-$ boson

There are four forces at work in our universe: the gravitational force between objects (not included in the Standard Model of Elementary Particles), electrostatic forces between positive and negative charges, the strong nuclear force, and the weak force between leptons (associated with β-ray radioactivity).



Particles which are influenced by the **strong** nuclear force are called **hadrons**. **Gluons** provide the bonding interactions between hadrons, and have zero mass and have a spin of +1. **Z** and **W bosons** are the force carriers between leptons. They are referred to as Vector Bosons: they have mass, and a spin of +1. The force carrier of electromagnetic radiation is the **photon**, which is massless and has a spin of +1.

Referring to the Feynman diagram illustrating the decay of a free neutron, a down quark has changed to an up quark with the liberation of a W$^-$ boson which instantly decays into an electron and an antineutrino.

For everyday practical purposes there are only three truly fundamental particles, that is, long lived particles: the proton, the electron, and the photon. Once these are created they exist effectively forever, or until they interact with other entities.

The mass of the W boson

The mass of the W boson can be predicted by the Standard Model. Using the simplest form of the theory of the Weak Force, the force depends solely on the mass of the Z boson and the value of the weak mixing angle. (H Fritzch 2012 Physics Letters B **713**,3,232-234). But other interactions could affect the calculation of its mass. For example: an additional dependence on the gauge-boson couplings and the masses of other particles, in particular the heavy top quark and Higgs boson, can affect the W-boson mass. Notwithstanding this, the precision of electroweak

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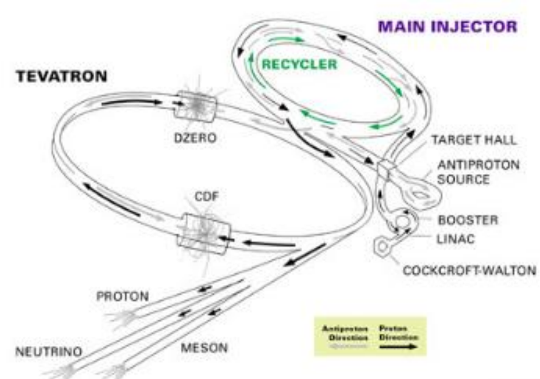
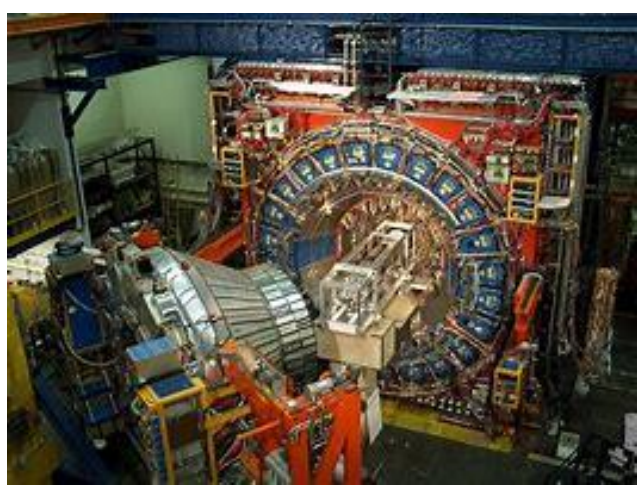
calculations is thought to be better than that of direct measurements, and better measurement of the W boson mass would seem to provide a vital test of the Standard Model's consistency.

Measurements of the mass of the W boson have recently been published, and confirm that a difference exists between the accepted (theoretical) value for the W boson mass and the new measurement. Does this imply that there is a failure in the predictions of the Standard Model?
(sciencedaily.com/releases/2022/04/220407141831).



In 1984 construction was commenced on the Tevatron, a high energy proton-antiproton collider. It continued in operation until 2012. The protons and antiprotons were created separately, and after acceleration, passed into the main injector storage ring in which they circulated in different directions. Once the desired injection energy was reached the separate beams were diverted into the Tevatron and made to collide in the CDF experimental hall.

The hall contained a number of detectors to collect the products of the proton-anti-proton collisions.



Throughout the operation of the Tevatron these detectors were continually improved. Shortly after the closure of the CDF facility scientists reported that they had determined the mass of the W bosons to be **8.385 ± 0.012(**statistical**) ±0.0015 (**systematic**) GeV/c^2**. This was based on the analysis of 2.2 X 10^{15} Bytes of data.

Using this experimental data the mass of the **Higgs boson was calculated**. From this The properties of this boson were predicted to be: charge,0; spin, 0; mass, less than **145 GeV/c^2**.

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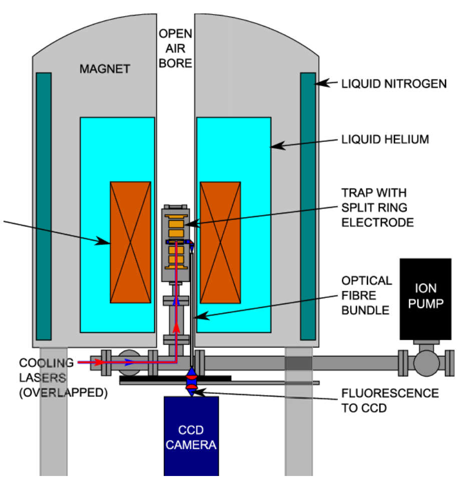
Ten years later CDF scientists completed a careful analysis and scrutiny of the full Tevatron dataset (8.8 X 10^{15} Bytes, corresponding to about 4.2 million W boson candidates). Taking into account an improved understanding of the limitations of the detector system and advances in the theoretical and experimental understanding of the W boson's interactions with other particles, the new CDF result is twice as precise: **8.4335 ± 0.00064 (**statistical**) ± 0.00069 (**systematic**) GeV/mc^2**. (T Marc 2022 Fermilab.media@fml.gov 224-290-803)

The discrepancy between the two results is about **0.59%.** But the difference between the CDF results and those from other laboratories is significant: particularly results those from ATLAS (**8.0370 ± 0.0019 GeV/mc^2**). Calculations based on existing theory using the Standard Model give the W boson mass as **8.357 ± 0.06 GeV/mc^2**). The discrepancy between theory and the new experiment is about **0.9%.**

David Toback, the CDF spokes-person commented on this, saying: ***If the difference between the experimental and expected value is due to some kind of new particle or subatomic interaction, which is one of the possibilities, there's a good chance it's something that could be discovered in future experiments.***

It is arguable whether the discrepancy is significant in absolute terms. **It would seem that an evaluation of the theoretical calculations which looks carefully at the assumptions made in the estimation of the W boson mass should be made before any claims be made that the Standard Model is defective.**

Matter and antimatter: the proton and the antiproton



At CERN, the BASE experiment was created to measure the charge to mass ratios (e/m) for protons to anti-protons. The BASE experiment essentially is a Penning trap which captures the particles in electric and magnetic fields. Penning traps are ultra-high vacuum chambers in which a homogeneous axial magnetic field and a quadrupole electric field which are created. The charged particles enter the trap and are forced into a circular orbit by a strong magnetic field. The frequency of rotation (the cyclotron frequency) is determined by the ratio of charge to mass (e/m) of the particles. This can be measured very accurately. The outcome the experiments, based on 24,000 comparisons each lasting 260 seconds, the e/m of the proton and the anti-proton are identical to within 16 parts per trillion. This confirms the assumption made in the Standard Model that the belief that **matter and antimatter have the same**

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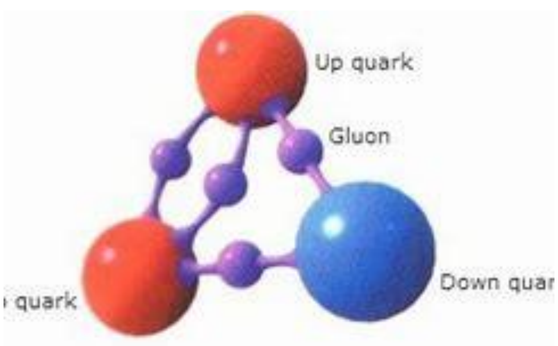
characteristics. (CERN Accelerating Science 5 January 2022). The electronic charge is -1.6002 x 10^{-19}. Using this value the mass of both the proton and the anti-proton can be deduced (current value: 1.672621898 x 10^{-27} kg = 938 GeV/c^2).

Furthermore: because of the ellipticity of the earth's orbit around the sun, the gravitational force experienced by the particles in the Penning trap changes slightly throughout the year, thereby changing the cyclotron resonance of the particles in the trap. The changes agree with the calculations based on the changes in the gravitational force, demonstrating that ***the Weak Equivalence Principle applies to both matter and anti-matter*** (to a precision of 3%).

What is the radius of the proton?

A schematic diagram of the proton is shown below. This imagines a simple linkage between the quarks, the links being the gluons. Crudely speaking, this assemblage is one of three masses linked by springs. Of course, this diagram is a gross oversimplification, but it assists in the understanding the processes taking place.

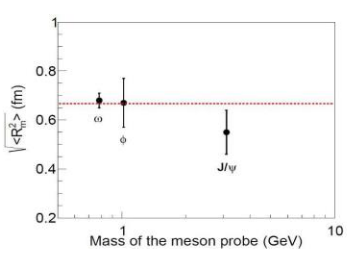


luons holding quarks together to form a proton (diagram from *Scientific American*)

The whole system is motion: the quarks are vibrating in and out and side to side, the whole assemblage is rotating, and other particles appear and disappear as the internal forces change. The quarks exist in a plasma of particles and anti-particles.

The value accepted by CODATA value for the radius of the proton, based on momentum transfer measurements at the University of Mainz, is 0.895 x 10^{-15} m. However, using dispersion relation techniques Meissner found a lower figure (0.847 x 10^{-15} m). (D Creagh IRPS Bulletin 34 2 p14).

More recently the **charge radius** of the proton was precisely measured by scientists using Lamb shift of the muonic hydrogen and high energy electron-proton elastic scattering, with the average value of **0.8409 ± 0.0004** 10^{-15} m.



A research group at the Institute of Modern Physics (IMP) of the Chinese Academy of Sciences (CAS) determined the proton **mass radius** by investigating the vector meson photoproduction data for omega, phi and J/psi from the SAPHIR (Spectrometer Arrangement for PHoton Induced

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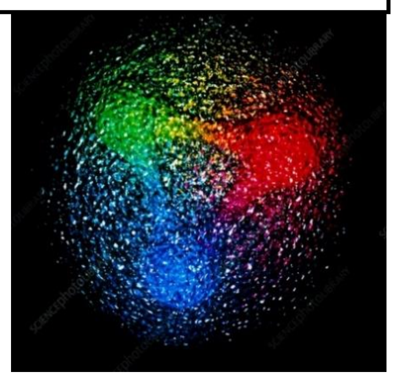
Reactions) experiment at Bonn University, the LEPS (Laser Electron Photons) experiment at SPring-8 facility, and the GlueX experiment at Jefferson Laboratory. They determined the **scalar gravitational form factor** and the **proton mass radius**.

The **proton mass radius** was estimated to be **0.67 ± 0.03** 10^{-15} m. (Wang et al 2022 Phys Rev D 105 096033 27 May). One of the paper's authors, Dr Wang, commented that: "*According to recent theoretical studies by Dmitri Kharzeev, the proton mass radius is related to the scalar gravitational form factor of the proton.*"

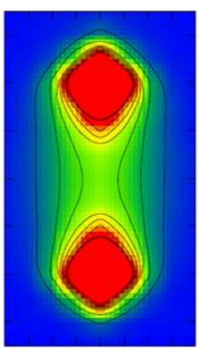
Prof. Dmitri Kharzeev's theoretical studies yielded a comparable result by using the GlueX J/psi data. The proton **mass radius** was estimated to be **0.55 ± 0.03 x** 10^{-15} m. (D Kjarzeev 2022 Rev Mod Phys 94 015002 21 Jan).

It appears that the accepted values for the proton listed in CODATA are in serious need of revision, and separate values should be listed for the mass and charge radii of the proton

The data confirms that the proton has a central core of quarks and gluons which accounts for most of the proton mass. This is surrounded by a region, referred earlier as a *plasma* of particles and antiparticles, which contributes to its charge to some extent.



Quantum mechanical simulations of the proton and the neutron have been made recently and give a picture of the quarks existing in a soup of gluons and other particles. The picture on the following age is the result of one set of calculations, part of a video presentation, using Quantum Chromodynamics (QCD). This theory adds a further property to the particles within the Standard Model: colour. This is added to take into account interaction of the hadrons, quarks and gluons, which are associated with the strong nuclear force. W bosons can be positively or negatively charged. They have an assigned colour value of 1. Up-quarks are assigned the colour red, down-quarks the colour blue. The green in the simulation picture suggests an overlap of particle states. (Simulation: Arscimed 2 May 2013)



I will not go into the complexities of the QCD theory, except to say that for the proton and the neutron the theory appears to describe the experimental data. Stretching the gluon bond is akin to stretching a rubber band: as the length increases, the band cross section

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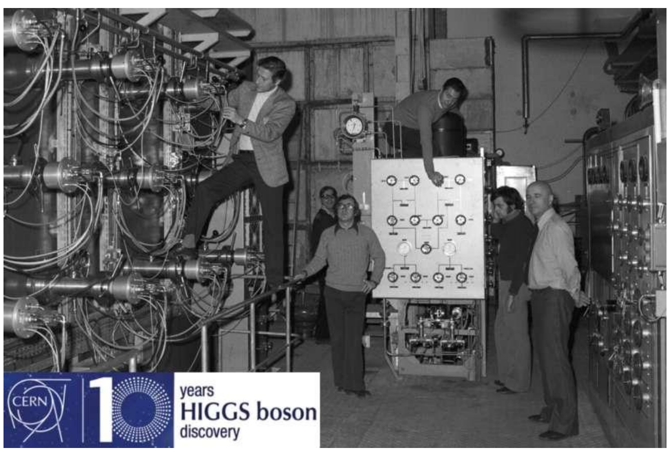
decreases, and rupture finally occurs with an abrupt release of energy. This manifests itself as the emission of a W^- boson and W^+ boson. The latter remains in the plasma and can interact with hadrons within the plasma, sometimes causing jets of particles to be created. The W^- boson decays instantaneously to a lepton and an anti-neutrino. In experiments the lepton is usually an electron, although decays into μ- and τ- mesons are possible.

None of the details of this is experimentally observable: existing detectors have neither the temporal nor the spatial resolution.

The Higgs Boson

It would be remiss of me to mention that it is 50 years since postulations were made concerning the existence of a super-heavy scalar boson: one that had neither charge and nor spin. It is 10 years since its existence was confirmed experimentally (4 July 2012).



The photograph shows Paul Musset (center), then representative of the **Gargamelle** collaboration, standing in the control room of the eponymous bubble chamber in 1974. **Gargamelle** provided the first direct evidence for the existence of neutral currents in 1973. (Credit: CERN)

This boson was proposed in the 1970s as the keystone of a unified theoretical model of the weak and electromagnetic interactions. The standard model of particle physics was not yet in existence.

The origin of the universe was hotly debated in the 1960s with astrophysicists divided into two main camps—the Continuous Creation Theory espoused by Fred Hoyle and others, and a theory that it was caused by a cataclysmic explosion: the **Big Bang Theory**. The latter theory is the current wisdom.

Immediately after the Big Bang, the **Higgs field** was zero, but as the universe cooled and the temperature fell below a critical value, the field grew spontaneously so that any particle interacting with it acquired a mass.

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The Higgs field is a field of energy that is thought to exist everywhere in the universe. The field is accompanied by a fundamental particle known as the Higgs boson, which is used by the field to continuously interact with other particles, such as the electron. The more interaction the particle has with this field, the heavier it is. Particles like the photon that do not interact with it have no mass.

This mechanism of mass creation was proposed by Brout, Engelert and Higgs in the 1960s. (PW Higgs, 1964 Phys. Lett. **12** 132; PW Higgs, 1964 Phys. Rev. Lett. **13** 508;F Englert, R Brout, 1964 Phys. Rev. Lett. **13** 321)

In the 1970s it was shown that theories using the Brout-Englert-Higgs mechanism to generate masses for gauge bosons (the Z and W bosons) are renormalizable, and hence are mathematically consistent. (*G 't Hooft 1971 Nuclear Physics B.* **35** (1) 167–188).

The CERN theorists, Jacques Prentki and Bruno Zumino, and the Gargamelle collaboration concentrated their research on whether there were weak neutral current interactions in the CERN neutrino beam, and their representative Paul Musset presented the first direct evidence for them in a seminar at CERN on 19 July 1973. This was the first experimental evidence that the proposed standard model had some credibility. Former CERN Director-General Luciano Maiani, quoted in a 2013 CERN Courier article, puts it this way: *At the start of the decade, people did not generally believe in a standard theory, even though theory had done everything. The neutral-current signals changed that. From then on, particle physics had to test the standard theory*. (J Ellis, MK Gaillard, and DVNanopoulos, Dimitri V. *A Historical Profile of the Higgs Boson*. United States: N. p., 2012. Web. doi:10.1142/9789814733519_0014.). Many experiments to test the standard theory were to be conducted at CERN and SLAC in the following years resulting in the discovery, amongst other things, that the J/psi was a bound state of a quark and an anti-quark and revealed the phenomenology of **charm**. The attention of most of the theoretical and experimental communities was then focused on the search for the massive W and Z vector bosons responsible for the weak interactions. This motivated the construction of high-energy hadron colliders and led to the discovery of the W and Z bosons at CERN in 1983 by a team led by Carlo Rubbia.

Scientists at CERN, however, decided that the key question was not the existence of the massive weak vector bosons, but rather that of the scalar Higgs boson that enabled the standard model to be physically consistent and mathematically calculable. Many production mechanisms were considered including the occurrence of the Higgs boson in association with the Z boson. Among the Higgs decay modes considered was that of a decay into a pair of photons.

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Ellis ended one of his papers with a cautionary note: *We apologize to experimentalists for having no idea what is the mass of the Higgs boson … and for not being sure of its couplings to other particles, except that they are probably all very small. For these reasons we do not want to encourage big experimental searches for the Higgs boson, but we do feel that people performing experiments vulnerable to the Higgs boson should know how it may turn up.* (J Ellis 2022 (phys.org/news/2022-05 higgs_boson_standard_particle_physics).

The concepts of electroweak symmetry breaking and the Higgs boson were not *flavour of the month* at the time. Ellis was then about 30 years old and probably aware that there were many who would think a stronger statement unwarranted…….impertinent, even.

But, as a consequence of experiments at CERN and elsewhere, the massive W and Z bosons were discovered and the proof of the existence or otherwise of the Higgs boson became a corporate stated goal. As well, no theoretical alternative to the belief in the existence of the Higgs boson had been proposed.

Experimentalists, first at LEP and later at the Tevatron and the LHC, focused increasingly on searches for the Higgs boson as the final building block of the standard model. This culminated in its discovery on 4 July 2012.

The rest, as they say in the classics, is history……….

BREAKING NEWS

Physicists discover never-before seen particle sitting on a tabletop

This newly-discovered particle could account for dark matter. (Nature 8 June 2022)

Axial Higgs mode detected by quantum pathway interference in RTe_3

Yiping Wang, Ioannis Petrides, Grant McNamara, Md Mofazzel Hosen, Shiming Lei, Yueh-Chun Wu, James L. Hart, Hongyan Lv, Jun Yan, Di Xiao, Judy J. Cha, Prineha Narang, Leslie M. Schoop & Kenneth S. Burch

The theory developed to create the Standard Model depends on the principle of symmetry within family groups. Explanations of anomalies (for example, dark matter) rely on additional symmetry breaking, involving an as yet undiscovered axial Higgs mode. Previous indications of the existence of the mode have occurred in magnetic,

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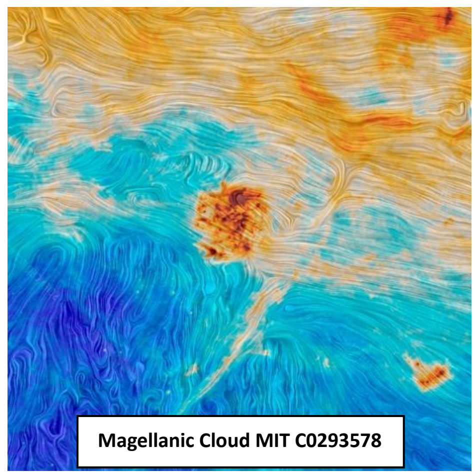
superconducting and charge density wave (CDW) systems (J Ellis, MK Gaillard, and DVNanopoulos, Dimitri V. *A Historical Profile of the Higgs Boson*. United States: N. p., 2012. Web. doi:10.1142/9789814733519_0014). To find a low energy mode requires the use of advanced spectroscopic and scattering techniques and the use of materials with particular properties. Such materials are the intermetallic compounds $LaTe_3$ and $GdTe_3$. For these compounds the electronic ordering involves transitions between bands of equal or different angular momenta, such as that which occur in Raman scattering. The Raman scattering tensor associated with an axial Higgs mode contains both symmetric and antisymmetric components, which are excited *via* two distinct but degenerate pathways, with the occurrence of constructive or destructive interference of these pathways depending on the control of the incident and Raman-scattered light polarization.

The Raman spectra is can be predicted using a tight-binding model, if an axial Higgs mode is assumed to be present. The Higgs mode in this case is described by an axial vector representation (that is, a pseudo-angular momentum).

The existence of a Higgs boson with an angular momentum implies that it has a magnetic moment. This therefore brings a force field, additional to the gravitational force, into our attempts to understand our universe. The Higgs boson is a Majorana particle: it is its own antiparticle. This axial boson has both mass and spin (+1). Its anti-particle would have spin (-1).


Magellanic Cloud MIT C0293578

Could it be that both right-handed and left-handed universes exist? And do they have chiral or mirror symmetry?

Another interesting feature of our universe is the existence of magnetic structures, which are observed in the Magellanic clouds. Could axial bosons have some part in the formation of these clouds?

I await answers on these topics from scientists more knowledgeable than I.

Commentary by Dudley Creagh. Acknowledgements to Physics World, Physics.org, and publicity releases from CERN, Fermilab, Science.org, Physics.org, Nature, KATRIN. Pictures and diagrams have been taken from promotional publications from these institutions: Getty Pictures, MIT Archives, Scientific American, and Arscimed.

International Radiation Physics Society

The primary objective of the International Radiation Physics Society (IRPS) is to promote the global exchange and integration of scientific information pertaining to the interdisciplinary subject of radiation physics, including the promotion of (i) theoretical and experimental research in radiation physics, (ii) investigation of physical aspects of interactions of radiations with living systems, (iii) education in radiation physics, and (iv) utilization of radiations for peaceful purposes.

The Constitution of the IRPS defines Radiation Physics as "the branch of science which deals with the physical aspects of interactions of radiations (both electromagnetic and particulate) with matter." It thus differs in emphasis both from atomic and nuclear physics and from radiation biology and medicine, instead focusing on the radiations.

The International Radiation Physics Society (IRPS) was founded in 1985 in Ferrara, Italy at the 3rd International Symposium on Radiation Physics (ISRP-3, 1985), following Symposia in Calcutta, India (ISRP-1, 1974) and in Penang, Malaysia (ISRP-2, 1982). Further Symposia have been held in Sao Paulo, Brazil (ISRP-4, 1988), Dubrovnik, Croatia (ISRP-5, 1991) Rabat, Morocco (1SRP-6, 1994), Jaipur, India (ISRP-7, 1997), Prague, Czech Republic (ISRP-8, 2000), Cape Town, South Africa (ISRP-9, 2003), Coimbra, Portugal (ISRP-10, 2006), Australia (ISRP-11, 2009), Rio de Janeiro, Brazil (ISRP-12, 2012), Beijing, China (ISRP-13, 2015), and Córdoba, Argentina (ISRP-14, 2018), Malaysia (ISRP-15, 2021), *and next* Portugal (ISRP-16, 2024).

The **IRPS Bulletin** is typically published twice yearly and sent to all IRPS members. Inquiries and items of interest can be communicated to the IRPS Secretariat:

Prof. Thomas Trojek (IRPS Secretary),
Czech Technical University in Prague, Czechia
Email: tomas.trojek@fjfi.cvut.cz

The IRPS welcomes your participation in this "global radiation physics family." The Membership Form for individuals wishing to join the IRPS is included on the following page.

INTERNATIONAL RADIATION PHYSICS SOCIETY MEMBERSHIP FORM

Part 1. Personal Information

Name (first, middle initials, last):
Academic rank (e.g., Dr., Prof., etc.), or preferred title (e.g. Mr./Mrs./Ms):
Address:

Telephone:
Email:
Fax:

Field(s) of interest in Radiation Physics (Feel free to attach a list of your publications, if any, in the field)

(Optional) List any organizations involved in Radiation Physics, of which you are a member:

Part 2. Membership dues payment

The IRPS has triennial (3-year) membership dues. Dues periods are by calendar years. New members joining prior to July 1 are treated as joining in January 1 of that year. Otherwise, they are treated as joining January 1 of the following year. Acceptable modes of IRPS membership dues payment, to start or to continue IRPS membership, are listed below. Please check payment-mode used, enter amount (in currency-type used). All cheques should be made payable to the **International Radiation Physics Society**. There are four membership rates depending on student and country status:

Full Voting Member (3 years), developed country:	US$75.00
Full Voting Member (3 years), developing country:	US$25.00
Student Member (3 years), developed country:	US$30.00
Student Member (3 years), developing country:	US$10.00

For payments via credit card, visit
https://www.ph.unimelb.edu.au/~chantler/opticshome/irps/registrationirps.html

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Amount paid, currency, and US dollar equivalent: ___________________________________

Send this form and any payment receipt to the Membership Officer (who can also answer inquiries)
Email (preferred): eric.shirley@nist.gov

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