PROCEEDINGS OF SCIENCE

Communicating the next collider

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The LHC captured the world's attention when it started up in 2008. How should particle physicists make the case for the next major collider? Through the lens of the *CERN Courier*, the 2020 update of the European Strategy for Particle Physics and the CERN Communication Strategy 2021-2025, this short talk will explore the challenges and opportunities in communicating a post-LHC collider both beyond the community and within.

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1. Introduction

While the Large Hadron Collider (LHC) will remain the world's flagship high-energy collider for the next two decades, planning for its successor is at an advanced stage. The consensus is an electron-positron collider to study the Higgs boson, but several such "Higgs factories" are on the table in different regions. Whatever the shape or location of the next big collider, such a project requires a clear narrative and strong communication now if it is to be successful.

Tales of experimentalists uncovering new particles and theorists picking up associated Nobel prizes seems antiquated, now that all the particles of the Standard Model have been found. The next collider is unlikely to have a "no-lose" outcome such as the LHC did with the search for the Higgs boson, and its scientific goals, while no less important, are more challenging to explain to non-experts. Communication is also vital to build focus and unity within the community.

2. Historical perspective

Uncertainty and confusion about the next major project in particle physics are nothing new. During an informal visit to CERN in April 1960, the late Prince Philip, husband of the late Queen Elizabeth II, asked his host, president of the CERN Council François de Rose, what CERN had in mind after the Proton Synchrotron. De Rose replied that this was a big problem for the field: "We do not really know whether we are going to discover anything new by going beyond 25 GeV."[1] Unbeknown to physicists at the time, the weak gauge bosons would be found at its higher energy successor, the Super Proton Synchrotron (SPS).

Summarising the 1962 ICHEP conference held at CERN, the leader of the CERN theory division Léon Van Hove wrote: *"The very fact that the variety of unexpected findings is so puzzling is a promise that new fundamental discoveries may well be in store at the end of a long process of elucidation."* Van Hove was right: the 1960s brought electroweak theory and the quark model. Clearly it was a different era (another early issue of the *Courier* from that time likened the 120 million Swiss Franc cost of the PS to "10 cigarettes for each of the 220 million inhabitants of CERN's 12 Member States"!) But parallels with the current situation in the field, especially concerning the feasibility study for a Future Circular Collider (FCC) at CERN, are pertinent, as this excerpt from the April 1970 issue of the *CERN Courier* illustrates:

> **"***The present impasse in the 300 GeV project [SPS] is due to the difficulty of selecting a site. At the same time it is disturbing to the traditional unity of CERN that only half the Member States (Austria, Belgium, Federal Republic of Germany, France, Italy, Switzerland) have so far adopted a positive attitude towards the project. The new proposal could possibly resolve these difficulties. With a diameter of 1.8 km, the accelerator could be built not only on one of the five sites previously under discussion, but also on a site adjacent to CERN-Meyrin.***"**

The SPS was later converted into a collider which went on to directly discover the W and Z bosons, reinforcing the case for an even larger machine -- the Large Electron Positron collider. LEP was not without its hurdles, wrote Herwig Schopper in the July/August 2019 issue:

"The first proposal for LEP was initially refused by the CERN Council because it had a 30 km circumference and cost 1.4 billion Swiss Francs... The cost of LEP made some Member States hesitate because they were worried that it would eat too much into the resources of CERN and

[1] *CERN Courier* June 1960 p6.

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national projects. After long discussions, Council said: yes, you build it, but do so within a constant budget. It seemed like an impossible task because the CERN budget had peaked before I took over and it was already in decline!"

While physicists debated the pros and cons of these early facilities, rarely did colliders spill into the public domain. When the SPS fired up in the summer of 1981 there was just Lyn Evans and Carlo Rubbia in the control room. Even the birth of the 27 km-circumference LEP in 1989 was a muted affair. The LHC was a more powerful machine born in the social-media era.

3 Building on the LHC

When the LHC circulated its first protons on 10 September 2008, more than a billion people were estimated to have been exposed to the news in some shape or form. The great visual appeal of the LHC and its experiments and their incredible scale and complexity were a big draw for news and television producers, while the large number of countries and institutes involved meant that local news stories were readily available. The hunt for a fundamental particle that explained the origin of mass, predicted 40 years earlier, captured the imagination and made for a highly exotic and appealing story. Last but not least, there were global media headlines about the possibility that the LHC would create a planet-consuming black hole.

CERN had a dedicated communication strategy throughout[2]. It got under way as far back as 2000, when Dan Brown's science-fiction novel *Angels & Demons* -- about a plot to blow up the Vatican using antimatter stolen from CERN – was published. CERN engaged with the story as part of a broader campaign to bring the world to the LHC and engage people in the adventure of research at the forefront of human knowledge. Publicly fixing the date for first beams led to 350 media outlets being on site, and set particle physics in popular culture. There is no reason to doubt that a collider on an even grander scale, supported by the right communication strategy, will punch at least as high in the public imagination. But there are important differences.

Finding or ruling out the Higgs boson (not the only LHC physics goal that CERN drew attention to, but the one that resonated with the media and the public) was not just appealing to the wider world, but was unanimously agreed within the community as the most pressing question for the Standard Model. As a result, there was consensus that a TeV-scale hadron collider was the right machine to follow LEP. Today -- against a backdrop of the LHC's discovery of a light Higgs boson and no particles beyond the Standard Model -- the signposts are far fewer. Several colliders are under study, each with different physics capabilities, technologies, history and sociology.

4 Communication opportunities

The challenge facing communicators today is how to capitalise on the existing interest in the LHC while constructing new and updated narratives of exploration and discovery for the next ambitious project. Below are a few 'talking points' and potential messages that might be developed for different audiences – starting with the excitement of the physics opportunities.

4.1 Massive physics

Just as the James Webb Space Telescope allowed astronomers to see distant objects in sharper focus than its predecessor Hubble[3], a dedicated Higgs factory would reveal this enigmatic new elementary particle in high definition. That's important because, as "a fragment of vacuum"

[2] *CERN Courier* September 2018 p44
[3] Hans Peter Beck, private communication 08.11.22

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with the starkest of quantum numbers, the Higgs boson is connected to some of the most problematic sectors of the Standard Model. Precision measurements of the Higgs boson open a new window to explore several pressing mysteries:

- The field from which it hails governs a critical phase transition in the early universe that might be linked to the cosmic matter–antimatter asymmetry[4];
- As an elementary scalar particle, it offers a unique "portal" to dark or hidden sectors which might include dark matter[5];
- As the arbiter of mass, it could hold clues to the puzzling hierarchy of fermion masses[6];
- Its interactions with itself and other particles govern the ultimate stability of the universe[7];
- The very existence of a light Higgs boson in the absence of new particles to stabilise its mass is paradoxical and suggestive of new physics[8].

***Message**: Precision measurements of the Higgs are not "boring" but are connected to deep structural mysteries in the Standard Model.*
***Message**: LHC & HL-LHC will take us so far, but only future colliders can fully open such potential new-physics vistas.*

4.2 Exploring the unknown

Particle colliders are the leading tools with which to explore nature further, uniquely allowing the conditions of the early universe to be studied under controlled laboratory conditions. Following the results of more than ten years of LHC operations, possible discoveries of supersymmetric particles, Kaluza-Klein states and other exotic entities postulated to address the problem of "naturalness" feature less prominently on the most-wanted list of a future collider than they did in the pre-LHC days. Today, the hunt is also on for lighter, more feebly interacting entities, and for subtler signs of new physics involving astrophysical and quantum-technologies.
***Message**: History shows that each new collider leads to a step-change in understanding: either through direct discoveries of new particles or precision measurements of known objects, or via technological innovations that open new experimental avenues.*
***Message**: Fundamental exploration is about not knowing what you are going to find.*

4.3 Bridging the smallest and largest scales

More than ever, particle physics, cosmology and astroparticle physics are overlapping, scientifically and technologically, offering fascinating science narratives and exciting career opportunities for young researchers entering the field. Questions such as the nature of dark matter and inflation are becoming amenable to both collider and astrophysical experiments, for example, while next generation gravitational-wave experiments will further link the largest and smallest scales. Collaborations between labs such as CERN and the gravitational-wave community on advanced vacuum and other technology systems are growing. Future generations of particle physicists can look forward to working as one with astroparticle physicists, cosmologists and others to reach the next level of understanding in fundamental physics, with colliders driving progress alongside astrophysical, cosmological and gravitational-wave observatories.

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[4] *CERN Courier* July/August 2022 p51
[5] *CERN Courier* July/August 2022 p55
[6] *CERN Courier* July/August 2022 p53
[7] *CERN Courier* July/August 2022 p59
[8] *CERN Courier* July/August 2022 p47

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Message: *Young researchers are entering a field at a time when we have the tools to address the deepest questions about the origin and fate of the universe.*
Message: *Growing technology and industry collaborations between fields.*

4.4 Socio-economic impact

Future colliders are "moonshots" delivering a competitive edge in technology, innovation, education and training[9]. Large research infrastructures are increasingly being recognized as essential drivers of economic progress[10]. A recent cost–benefit analysis of the LHC concluded with 92% probability that benefits exceed costs. More recent studies focusing on the High-Luminosity LHC revealed a quantifiable return to society well in excess of the project's costs, not including its scientific output. Extrapolating these results, future colliders at CERN are predicted to bring similar societal benefits on an even bigger scale.[11]Across physics more broadly, a 2019 report commissioned by the European Physical Society found that physics-based industries generate more than 16% of total turnover and 12% of overall employment in Europe – representing a net annual contribution of at least €1.45 trillion, and topping contributions from the financial services and retail sectors[12]. Policymakers, industry leads, governments and others need to be made more aware of such figures.
Message: *Large colliders are investments, not costs, with structural socioeconomic benefits that give countries and regions a competitive edge.*
Message: *Studying nature at the smallest scales is part of a programme of "blue-skies" exploration which, during the past century, has delivered the modern world.*

4.5 "Structural" applications

There are countless spin-offs and individual success stories that demonstrate the impact of high-energy physics on society – none more so than the Web. Knowledge transfer is core to CERN business, with important connections with aerospace and other industries. Communicating these outside is paramount. Two what you might call "structural" impacts of CERN's core business – accelerator science – deserve particular emphasis: radiotherapy and X-ray science.

Particle physicists are driving next-generation cancer therapies with protons and ions – life-changing research that all accelerator physicists are working on directly or indirectly[13]. Accelerator-based X-ray light sources, born from unwanted radiation in early particle physics experiments, have revolutionized materials science, molecular biology, nanoscience and cultural heritage studies, among others. The technology crossovers continue today[14], with advanced linac-driven X-FELs at DESY and SLAC for example.
Message: *Accelerator physicists are developing cancer treatments that save thousands of lives.*
Message: *Accelerator science drives advanced light sources that allow thousands of users from a broad range of disciplines to address societal challenges.*

[9] CERN Courier July/August 2022 p61
[10] CERN Courier July/August 2020 p47
[11] *CERN Courier* September 2018 p51
[12] *CERN Courier* January/February 2020 p9
[13] *CERN Courier* January/February 2018 p25
[14] *CERN Courier* September/October 2022 p39

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4.6 Appeal to wonder

A final important fact about curiosity-driven research such as particle physics is its "recruiting" power. Like space exploration, understanding the basic laws of the universe attracts young minds to science. Most go on to work in more applied fields, but it is spacecraft, giant colliders and mind-bending questions about the universe that surveys show provide the spark.

5. Strategic matters

Education and outreach are increasingly seen as integral to science, and enjoy growing recognition at major conferences and in roadmaps. Formal networks in high-energy physics include the International Particle Physics Outreach Group, the European Particle Physics Communication Network (EPPCN) and the Interactions Collaboration. EPPCN[15] has emphasised the following challenges in communicating future projects: the fast pace of change in social media & speed of dissemination of good news, bad news and rumours; the need to maintain trust and transparency in an era where there appears to be a popular backlash against expert opinion; timescales and costs (proposals for major international particle-physics experiments are infrequent, and when they are proposed, they seem disproportionately expensive when compared to other science disciplines).

Many of the messages and narratives described in this talk are echoed in the recently published CERN Communications Strategy 2021-2025. Environment and sustainability are also prominent strands of the document, as is CERN's role as a beacon for peaceful international collaboration. The communications strategy defines eight primary audiences with the power to influence CERN's future, and identifies associated messaging, milestones, partners and ambassadors to support communication efforts.

6. Threats

Some additional factors for consideration when communicating the next collider.

6.1 Community disunity

With several future colliders on offer, each at different stages of technological readiness and with different scientific capabilities and time scales, consensus about which machine should be built after the LHC is yet to be reached. In terms of measurements of the Higgs boson, however, the recent ESPPU and Snowmass exercises concluded that the proposed projects offer broadly similar physics programmes. For the purposes of communicating the scientific goals of a Higgs factory to the outside world, it can therefore be argued that little or no distinction between the proposed colliders should be made. Indeed, anecdotal evidence suggests that "outsiders" have little interest in specific physics arguments and are more responsive to general aims, for example: "Exploring the dark universe"; "Understanding the origin and fate of the universe / smallest constituents of the universe"; "Making a bigger bang"; etc. Surveys, though few in number, also consistently show public interest in particle physics and support for continued funding.

Within the community, the situation is different. The detailed physics capabilities of some of the proposed projects are still being figured out. Better communication within the community about the physics cases for each would help bring about consensus. A roundtable discussion during FCC Week 2022 on how to sharpen the FCC physics case proved that it is impossible to

[15] Input to 2020 update of European Strategy for Particle Physics, presented at Granada in May 2019.

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completely decouple the physics goals of a future collider from practical matters such as its cost and timescale, but that every effort should be made to do so now to inspire and unite people.
Message*: A post-LHC collider is crucial for CERN and thus for the future of the field.*
Message*: The scientific case for going beyond the LHC should be made regardless of specifics of individual Higgs-factory proposals.*

6.2 Conservatism and timidity

Since the discovery of the Higgs boson and non-discovery so far of anything beyond the Standard Model, there is a danger of the field talking itself down. While it is natural and healthy for proponents of different projects to make their case as robustly as possible, and for scientists to shoot holes in others' and their own ideas, sometimes one wonders if there is sufficient confidence in *any* post-LHC machine. This is no time for despondency, argued experimentalist Tim Gershon in the *CERN Courier* in 2018[16]:

> *"The excitement of [the Higgs discovery] now seems a distant memory, replaced by a growing sense of disappointment at the lack of any major discovery thereafter. While there are valid reasons to feel less than delighted by the null results of searches for physics beyond the Standard Model (SM), this does not justify a mood of despondency…. We must be honest about the lack of new physics that we all hoped would be found in early LHC data, yet to characterise this as a 'failure' is absurd. If anything, the LHC has been more successful than expected, leaving its experiments struggling to keep up with the astonishing rates of delivered data."*

Theorist Nima Arkani-Hamed was even more bullish in a 2019 *Courier* interview, claiming that there has never been a better time to be in the field[17]:

"If the biggest excitement for you is a cross-section plot with a huge bump, possibly with a ticket to Stockholm attached, then, after the discovery of the Higgs, it makes perfect sense to take your ball and go home, since we can make no guarantees of this sort whatsoever… We're in this business for the long haul of decades and centuries, and if you don't have the stomach for it, you'd better do something else with your life!"

In a final glance to the past, a similarly compelling rallying call was issued by Mervyn Hine of the CERN directorate in the August 1964 issue. Addressing ECFA's "Summit program" for the construction in Europe of two projects -- a pair of intersecting storage rings (to become the ISR) and a new proton accelerator of a very high energy "probably around 300 GeV", which would be 10 times the size of the PS (to become the SPS) -- Hine estimated the total annual cost to be about "1100 million Swiss Francs by 1973, in step with a minimum growth for total European science". He concluded, boldy:

> *"The scientific case for Europe's continuing forcefully in high-energy physics is overwhelming; the equipment needed is technically feasible; the scientific manpower needed will be available; the money is trivial. Only conservatism or timidity will stop it."*

[16] *CERN Courier* April 2018 p5
[17] *CERN Courier* March/April 2019 p45

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