Particle Physics, and neighbouring fields of Astroparticle and Nuclear Physics, in Denmark

Denmark is a founding member of CERN since 1954.

Denmark in numbers

5.8 Million inhabitants; GDP of 2300 billion DKK (310 billion EUR), 400 kDKK per capita.
3.0% of GDP goes to research & development of which 1.1% is in the public sector.
Currency: Danish krone = DKK. **1 EUR = 7.5 DKK**

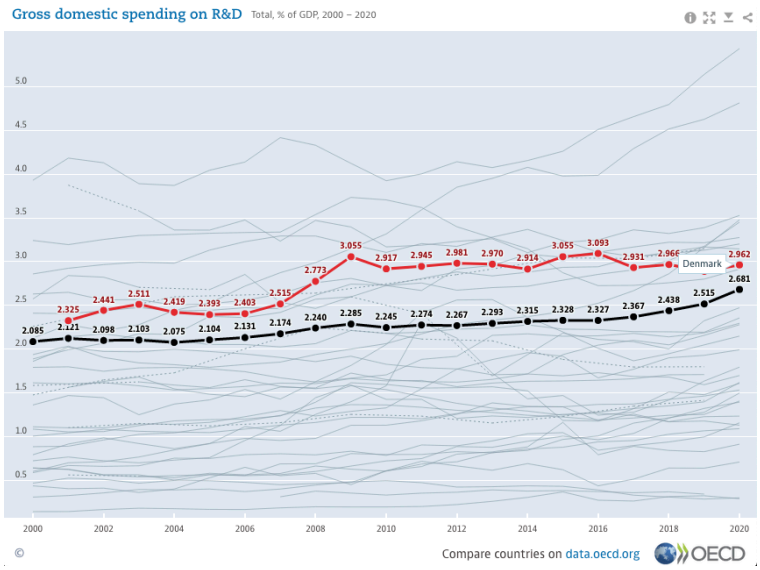

Fig. 1: Gross domestic spending on R&D. Denmark in red, OECD mean in black. [1]

19,000 researchers are employed in the public sector, a large majority in the higher education sector.

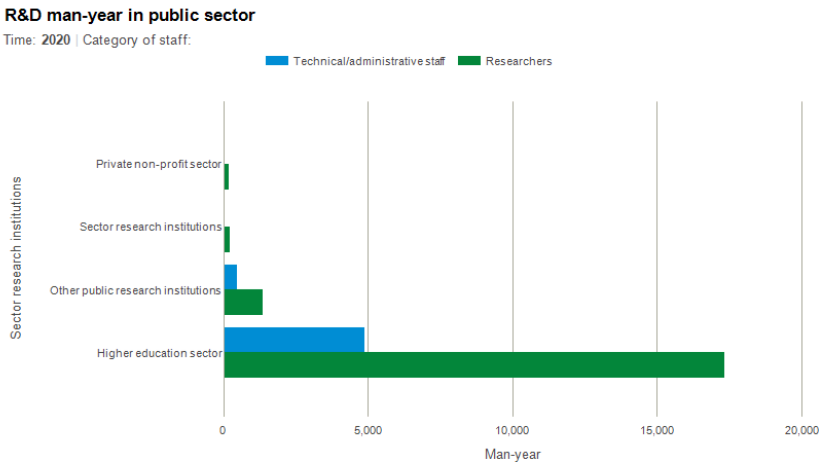

Fig. 2: R&D man-year in public sector. [2]

The R&D-expenses in the public sector amounts to a total of 27 BDKK, of which about one fifth goes to natural sciences

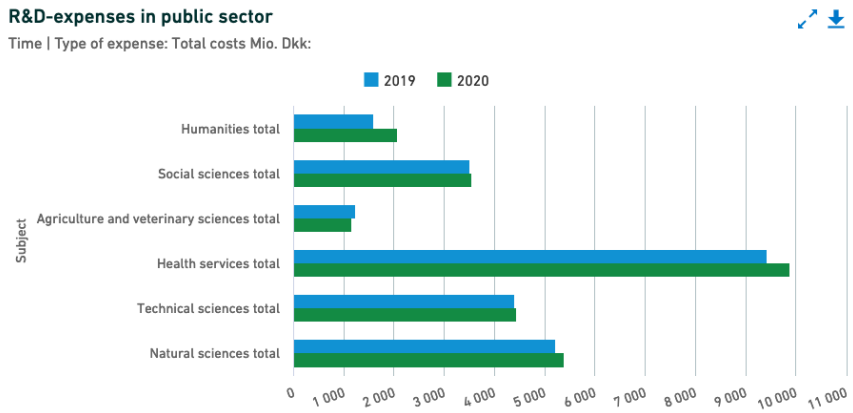

Fig. 3: R&D-expenses in public sector. [2]

Public funding to CERN experiments

- Denmark's membership fee to CERN is covered on the state budget under **International Research activities** [3] with, ~150 MDKK (1.75% of CERN's budget)
- From the ministerial **Research and Innovation** budget**,** 7-8 MDKK have been allocated yearly to CERN-related experimental activities, via NICE (National Instrumentation Center for CERN, https://nice.ku.dk/). This covers technical personnel (scientific or engineering) and travel, Maintenance & Operations and Membership fees to the experiments, and networking activities [but explicitly, *not* scientific exploitation of CERN, i.e. data analysis activities and PhD grants]. The profile for NICE funding as a function of years can be seen in Fig. 4. Indicated are the base grant and the value corrected for inflation, and for CHF/DKK exchange rate.
- Under the "Danish Roadmap for Research Infrastructures 2015" programme (also funded from the **Research and Innovation** budget), the experimental CERN groups received 11.2 MDKK (**CERN-UP grant**) for the period 2019-2022 (extended due to COVID to include 2023). This funding covers contributions to experimental upgrades, including the LHC experiments' LS2 (ALICE) and LS3 (ATLAS) upgrades (7.6 MDDK), and computing (3.6 MDKK). The grant presupposes a 100% co-financing from the Universities. At NBI, this co-finansing covers engineering help and the establishment of clean-room facilities. Roadmap projects are requested to have a limited, 4-5 year, establishing phase, and extensions cannot be granted. [An application to the similar 2020 programme, which, among other items, would have covered the second (to this day, missing) half of the ATLAS upgrade cost, was unsuccessful.]
- Funding for non-permanent scientific staff (PhD, postdoc, assistant professor) can be applied for at **Danmark Frie Forskningråd (DFF)** [4]. Grant durations are 3-5 years. In 2020, a total of 271 MDKK was granted to Natural Sciences via 82 grants with a success rate of 13%. Grants are given in **very open competition**, e.g. for the Natural Sciences there is no strategic prioritization for any sub-fields, and applications in chemistry, mathematics, climate science, biology, geology, computer science, physics, etc. are evaluated in open competition within the same panel.

The support for research at Universities has declined and is now virtually non-existent. PhD fellowships, postdocs, and smaller research support are no longer available at Universities, but must be obtained via fixed-term competitive applications by individual researchers to public (DFF) or private foundations. Technical support for experimental activities provided by the university workshops are handled in a “commercial” way, where researchers, “customers”, are billed by the hour.

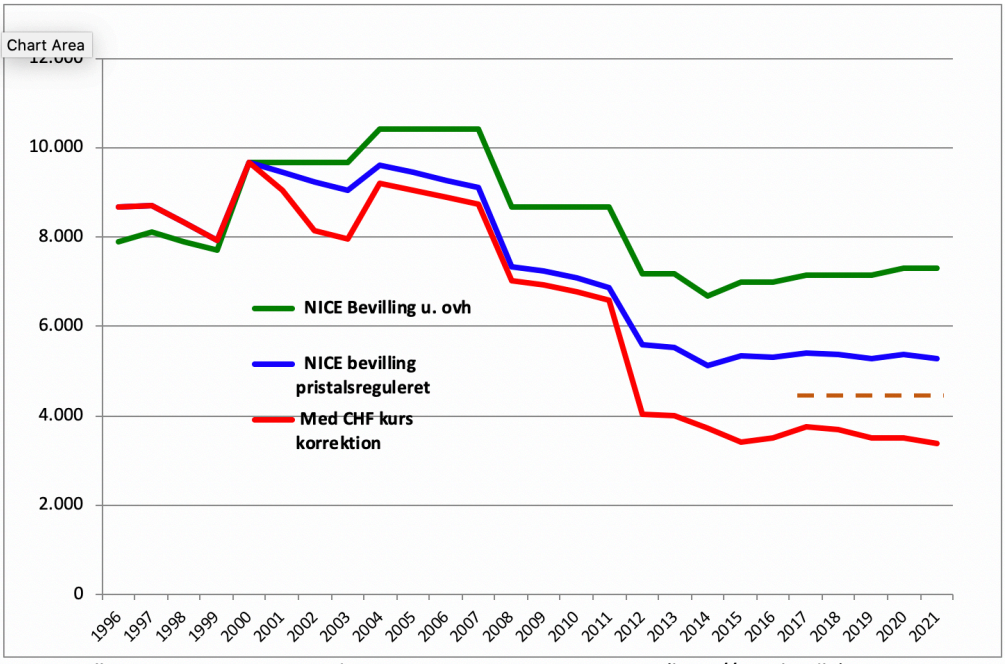

Fig. 4: Million DKK per year granted to CERN activities via NICE grant [https://nice.ku.dk]. *Green: raw grant, blue: corrected for inflation (based on year 2000), red: corrected for inflation and CHF/DKK exchange rate.*

Private and independent funding

Public and private foundations provide a yearly budget of about 2000 MDKK for research, offered in open competition.

- **Danish National Research Foundation (DNRF):** independent organization established by the Danish Parliament in 1991 -- 470 MDKK yearly. Centers of Excellence of up to 100 MDKK over 10 years.
- **Villum Young Investigator/Investigator**: 130 MDKK / 400 MDKK.
- **Carlsberg Foundation:** 400 MDKK.
- **Novo Nordisk Foundation (NNF)**: 1000 MDKK. Supports fundamental research within the natural sciences with potential interdisciplinary application within biomedicine or the life sciences.

As a general rule, one needs employment at a Danish institution in order to apply for these grants.

Two centers of excellence have been supported by DNRF both in the period 2010-2019:

- **CP3-origins** @ SDU: Theory; 60 MDKK
- **Discovery Center** @ NBI: Theory and experiment (ALICE, ATLAS, IceCube, and Planck); 80 MDKK

Landscape of Particle Physics, and Nuclear and Astroparticle Physics

Research within particle, astroparticle and nuclear physics is conducted at the Danish universities, currently with activities at four universities:

- **AU** (Aarhus University, Aarhus): Theory. Experimental contributions to ALPHA, ISOLDE, and NA63.
- **DTU** (Denmark's Technical University, Lyngby): Experimental contribution to CAST / IAXO.
- **KU** (Copenhagen University): Niels Bohr Institute (NBI): Theory; ALICE, ATLAS, and IceCube experiments, and future projects SND@LHC, BDF/SHIP@SPS, and FCC. Chemistry Dept.: ISOLDE.
- **SDU** (Southern Danish University, Odense): Theory.

Experiments

The experiments Denmark is involved and their physics goals are summarized in Table 1

CERN experiments	Main physics goals	Comments
ALICE @ LHC	Heavy Ion Physics: Hadron structure, Dense nuclear matter	Large scale, running
ATLAS @ LHC	Standard Model Higgs, and search for new forces or particles (explanation for dark matter and	Large scale, running

	neutrino mass. Beyond the Standard Model). Forward Physics.	
ISOLDE @ PS	Nuclear structure and interactions	Small scale, running
ALPHA @ ELENA	Synthesis of anti-Hydrogen og spectroscopy	Small scale, running
NA63 @ SPS	Ultra-strong electromagnetic fields	Small scale, running
CAST, IAXO	Axion searches (dark matter)	Small scale, future planned
SND@LHC, BDF/SHIP@SPS	Forward / beam dump experiment to search for new feebly interacting particles (to explain dark matter, neutrino masses, baryon asymmetry…)	Small scale, future planned
FCC (ee,hh) Future Circular Collider	91 km ultimate luminosity 80-365 GeV e+e- collider, followed by ≥100 TeV proton-proton collider. Precision Higgs, electroweak and flavour physics. Intensity and energy frontier search programmes for BSM physics	Large scale, future planned
Non-CERN experiments	Main physics goals	Comments
IceCube, IceCube Upgrade (South Pole)	Neutrino oscillations, multi-messenger astronomy, astrophysical sources	Large scale, running/approved
Facility for Rare Isotopes Beams, FRIB (Michigan)	Discoveries about the properties of rare isotopes (short-lived nuclei not normally found on Earth), nuclear astrophysics, fundamental interactions	Small scale, running

Table 1: Experiments with Danish participation.

Table 2 shows the current person-power in the different experiments. Postdocs payed to work on detector or trigger maintenance, development and operation via NICE count under technical staff.

Experiment (University)	Permanent scientific staff	Non permanent scientific staff	PhD	MSc	Non permanent technical staff	Engineers/ technicians
ALPHA (AU)	1	3	1	1		
ALICE (KU)	3	2	2	6	2	0.25*)
ATLAS (KU)	2.5 + 1**)	0	0	7	2	0.75*)
IAXO (DTU)	1					
ISOLDE (AU)	2	1	2	2		
NA63 (AU)	1	1				
FCC (KU)	1			3		
ICECUBE (KU)	1.5	2	1	4		
FRIB (AU)	1					

Table 2: 2022: Personnel in experiments. For permanent staff, 50% of work time is officially allocated to research. This is not corrected for here.

**) Covered by KU via co-finansing promise (CERN-UP grant).*

***) Emeritus*

Each of the next three five-year periods will see about 3 retirements among the permanent staff due to age. Replacements are critically needed to sustain the level of activities.

Theory

Denmark has a strong, internationally recognized tradition in theoretical physics that includes two large communities at NBI and SDU as well as a small community at AU.

It is hard to classify theoretical physicists according to a specific research theme since they are an amorphous category. They often cross boundaries between formal topics and phenomenology, and contribute to different disciplines/subjects via similar tools. One example for all is the recently awarded Nobel laureate Giorgio Parisi. With this in mind we can briefly summarise the overall situation in Denmark:

- Covering the areas of astrophysics, cosmology, nuclear physics and touching upon particle physics:
    - **AU:** 2 permanent researchers. Ratio of junior (postdocs, non-tenured assistant professor, PhD students) to senior (permanent) researchers is 1.
- Extending the above-mentioned research fields to theoretical and phenomenological particle physics as well as string theory and quantum gravity:
    - **KU**: 9 permanent researchers at the NBI including NBIA (Niels Bohr International Academy). Ratio of juniors to seniors is around 3.6.
    - **SDU**: 7.7 permanent researchers at the Center for Cosmology and Particle Physics Phenomenology (CP3-Origins). Ratio of juniors to seniors is around 1.3

Computing

Denmark is member of NeIC, the Nordic e-Infrastructure Collaboration (https://neic.no/), and supports this by 2.7 MDKK/yr. NeIC is responsible for the operation of the distributed Nordic WLCG Tier-1 facility. One FTE operator, paid by NeIC, is positioned at NBI.

Hardware upgrades to the Copenhagen Nordic Tier-1 node are currently covered by the CERN-UP grant with 3 MDKK over the five-year period 2019-2023. Via the 100% co-finansing promise from universities, activities are supported by KU by 1 FTE.

The CERN-UP grant also supports the operation of the SDU HPC with 0.6 MDKK over the same period. This facility is used extensively by the SDU theory group.

Funding profile for CERN Experiments

The funding profile of CERN experiments over the last ten years is shown in Fig. 5.

Integrating over the past 15 years, the total funding is shared 70% public, 30% private. Overheads to Universities, integrated over 15 years: 40 MDKK (11% of total).

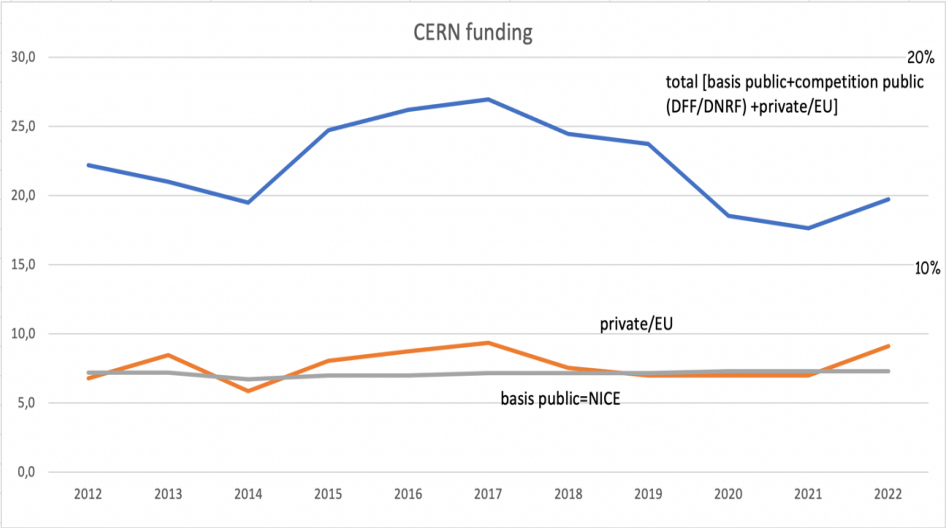

Figure 5: Total funding (private+public) in MDKK (left axis) and in percentage of the CERN Danish membership fee (right axis) for CERN-related experiments

Return value to DK from CERN investment

- DK Industry return from CERN: The Danish industrial return-coefficient is defined as the ratio of CERN purchases placed with Danish companies divided by the total CERN purchases and compared with the Danish contribution to the CERN budget. Thus, a return coefficient of 1.00 would mean that Danish companies are winning contracts in proportion to the Danish contribution. The coefficient is monitored by the CERN procurement department and the Danish Industrial Liaisons Officer nested in the BigScience.dk initiative, funded by the Ministry. After a long period of steady increase in the coefficient over 2010-2019, over the last two years the return coefficient for supplies has dropped to **0.38** (averaged over 2018-2021) which has put Denmark on the list of "very poorly balanced countries" together with 8 other member states. The other main return coefficient covers "services", and there, actually, Denmark is doing extremely well with a coefficient of **2.82**. Making a weighted average of the two categories, the total Danish industrial return is above 1. CERN has a goal to reduce the number of "very poorly balanced countries" to 3 by 2025, and a big effort is being made by CERN and the Danish ILO to move Denmark from this list.
- DK personnel return from CERN: as of Jan 2021, for a contribution of 1.75% to CERN, Denmark counts:
    - 17 staff members, representing 0.64%
    - 2 fellows, representing 0.27%
    - 3 technical students, representing 2.04%.
    - Proportion of applications for staff positions: 0.21%
- The Gymnasium (i.e. Danish High School) visits program, essential for recruiting student at DK universities to CERN research projects is very successful (about 1000 students/yr). Furthermore, the Danish High school students' program is a unique

opportunity for high-school students to be introduced to CERN, its technologies and physics, as well as to learn through workshops and by shadowing, observing, and working with a member of personnel. In addition, over the past 10 years, more than 200 teachers from high school (1/3) and lower/middle school (2/3) have visited CERN
- CERN Short term Trainee Programme (4-6 months duration): about 2 x 10 trainees per year the last 5 years, mainly from technical universities in AU and SDU.

Priorities of DK Particle Physics

- Successful realization of the HL-LHC detector and trigger upgrades for ATLAS and a new low-x detector (FoCal) for ALICE, and full exploitation of the outstanding physics potentials of HL-LHC;
- Maintaining the support for the non-LHC programmes including ALPHA and ISOLDE;
- Support and contribution to CERN's preparation to host a future electron-positron electroweak and Higgs factory, and a next energy-frontier hadron-hadron collider;
- Searches for axion-like particle and weakly interacting massive or light dark matter particles;
- Neutrino properties and astrophysics in IceCube and w/ upcoming IceCube Upgrade as well as IceCube-GEN2 development;
- Maintaining a strong theory programme, important in its own right as well as for strategic decisions and for the success of experiments;
- Development of advanced detector technologies as well as computing and software technologies.

These priorities are full in line with the European Strategy update approved by CERN Council in June 2020 [6]

References

[1] OECD Data, https://data.oecd.org/
[2] Statistics Denmark, https://www.dst.dk/en/
[3] Numbers from Finance Bill 2021, https://fm.dk/media/18423/fl21a19.pdf
[4] https://dff.dk/aktuelt/publikationer/annual-report-2020/
[5] https://cds.cern.ch/collection/CERN%20Annual%20Personnel%20Statistics
[6] https://cds.cern.ch/record/2721370