

Experience and future perspectives of application of different safety norms in the Personnel Protection Systems of CERN particle accelerators

SYP 2025 – Espoo, Finland

Timo Hakulinen, Pierre Ninin, Deborah Hunt – CERN

2025-10-22

EDMS 3364082



CERN – European Organization for Nuclear Research

Founded in 1954 at Geneva, Switzerland with 12 European Member States

25 Member States

Austria – Belgium – Bulgaria – Czech Republic
Denmark – Estonia – Finland – France – Germany
Greece – Hungary – Israel – Italy – Netherlands
Norway – Poland – Portugal – Romania – Serbia
Slovakia – Slovenia – Spain – Sweden – Switzerland –
United Kingdom

1 Associate Member States in the pre-stage to membership

Cyprus

8 Associate Member States

Brazil – Croatia – India – Latvia – Lithuania – Pakistan
Türkiye – Ukraine

6 Observers

Japan – Russia (suspended) – USA
European Union – JINR (suspended) – UNESCO



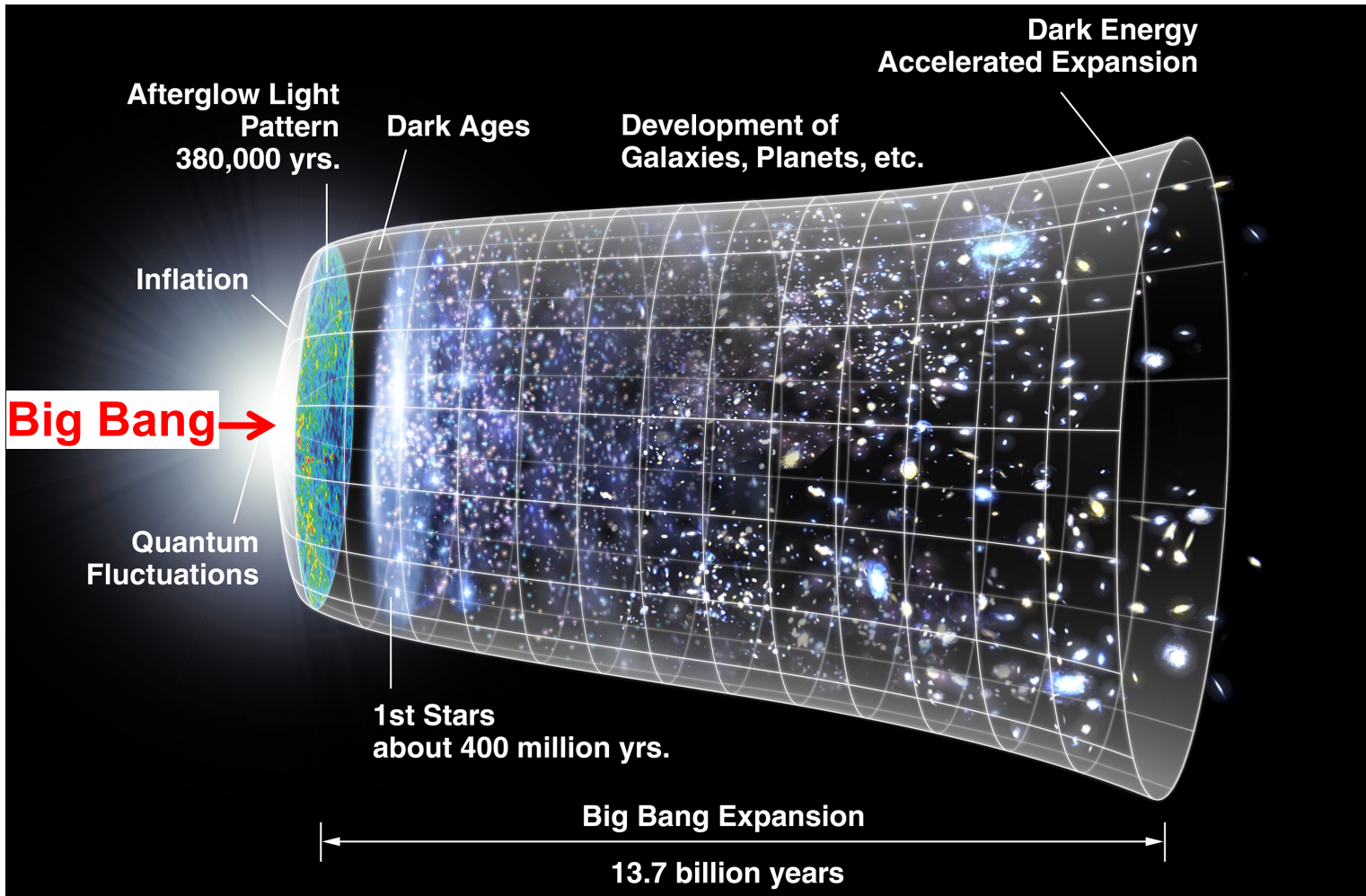
Around 50 Cooperation Agreements with non-Member States and Territories

Albania – Algeria – Argentina – Armenia – Australia – Azerbaijan – Bangladesh – Bolivia – Bosnia and Herzegovina
Canada – Chile – Colombia – Costa Rica – Ecuador – Egypt – Georgia – Honduras – Iceland – Iran – Jordan
Kazakhstan – Lebanon – Malta – Mexico – Mongolia – Montenegro – Morocco – Nepal – New Zealand
North Macedonia – Palestine – Paraguay – People's Republic of China – Peru – Philippines – Qatar – Republic of Korea
Saudi Arabia – Sri Lanka – South Africa – Thailand – Tunisia – United Arab Emirates – Vietnam

CERN's annual budget in 2024 was 1457 MCHF (equivalent to a medium-sized European university)
Finland's contribution in 2024 16.2 MCHF (1.35 % of member state contributions)

As of 31 December 2024
Employees:
2704 staff, **1181** fellows and graduates
Associates:
12 405 users, **1401** others

Our mission



Standard Model of Elementary Particles

three generations of matter (fermions)			interactions / force carriers (bosons)	
I	II	III		
mass $\approx 2.16 \text{ MeV}/c^2$ charge $\frac{2}{3}$ spin $\frac{1}{2}$ u up	mass $\approx 1.273 \text{ GeV}/c^2$ charge $\frac{2}{3}$ spin $\frac{1}{2}$ c charm	mass $\approx 172.57 \text{ GeV}/c^2$ charge $\frac{2}{3}$ spin $\frac{1}{2}$ t top	mass 0 charge 0 spin 1 g gluon	mass $\approx 125.2 \text{ GeV}/c^2$ charge 0 spin 0 H higgs
mass $\approx 4.7 \text{ MeV}/c^2$ charge $-\frac{1}{3}$ spin $\frac{1}{2}$ d down	mass $\approx 93.5 \text{ MeV}/c^2$ charge $-\frac{1}{3}$ spin $\frac{1}{2}$ s strange	mass $\approx 4.183 \text{ GeV}/c^2$ charge $-\frac{1}{3}$ spin $\frac{1}{2}$ b bottom	mass 0 charge 0 spin 1 γ photon	
mass $\approx 0.511 \text{ MeV}/c^2$ charge -1 spin $\frac{1}{2}$ e electron	mass $\approx 105.66 \text{ MeV}/c^2$ charge -1 spin $\frac{1}{2}$ μ muon	mass $\approx 1.77693 \text{ GeV}/c^2$ charge -1 spin $\frac{1}{2}$ τ tau	mass $\approx 91.188 \text{ GeV}/c^2$ charge 0 spin 1 Z Z boson	
mass $< 0.8 \text{ eV}/c^2$ charge 0 spin $\frac{1}{2}$ ν_e electron neutrino	mass $< 0.17 \text{ MeV}/c^2$ charge 0 spin $\frac{1}{2}$ ν_μ muon neutrino	mass $< 18.2 \text{ MeV}/c^2$ charge 0 spin $\frac{1}{2}$ ν_τ tau neutrino	mass $\approx 80.3692 \text{ GeV}/c^2$ charge ± 1 spin 1 W W boson	

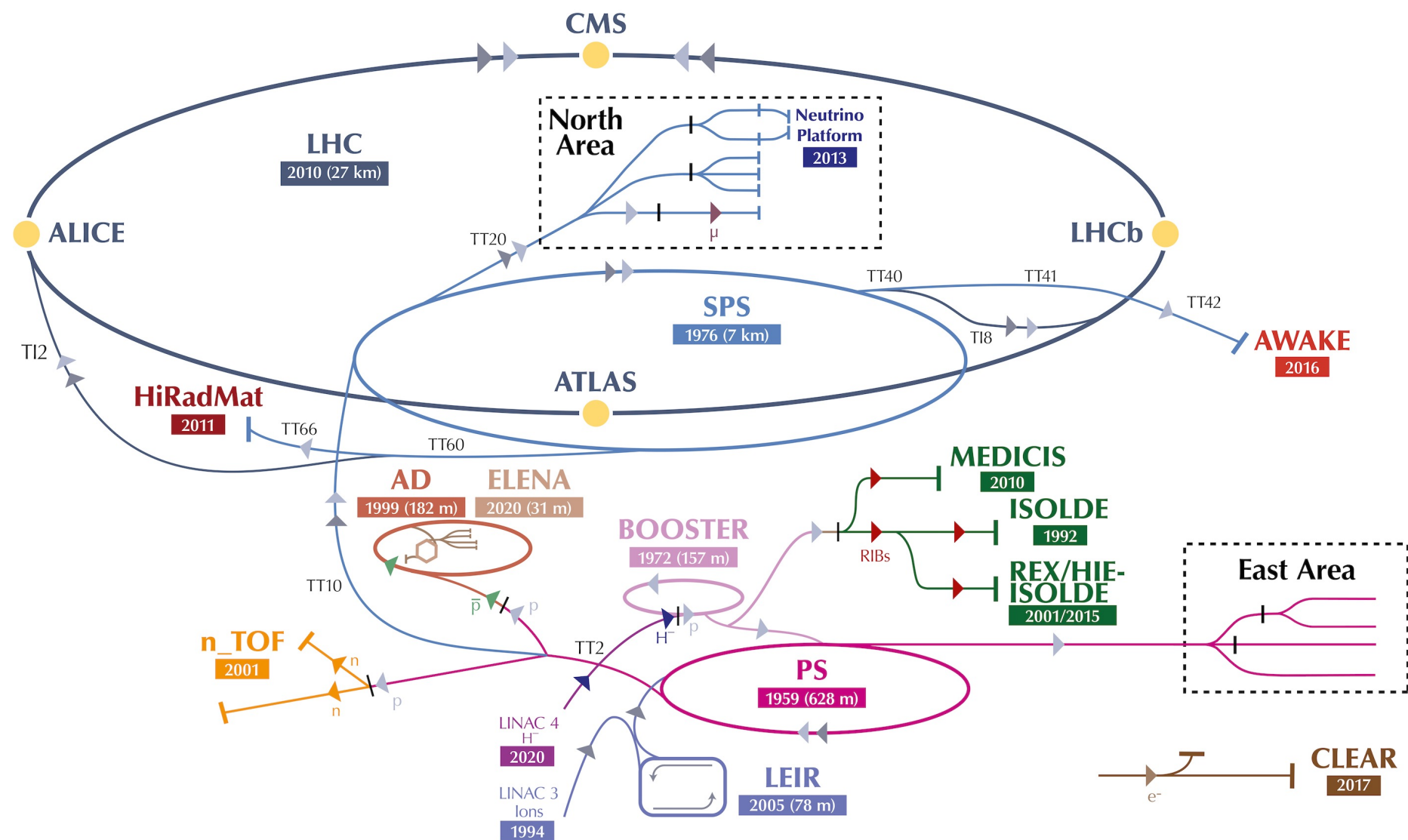
QUARKS

LEPTONS

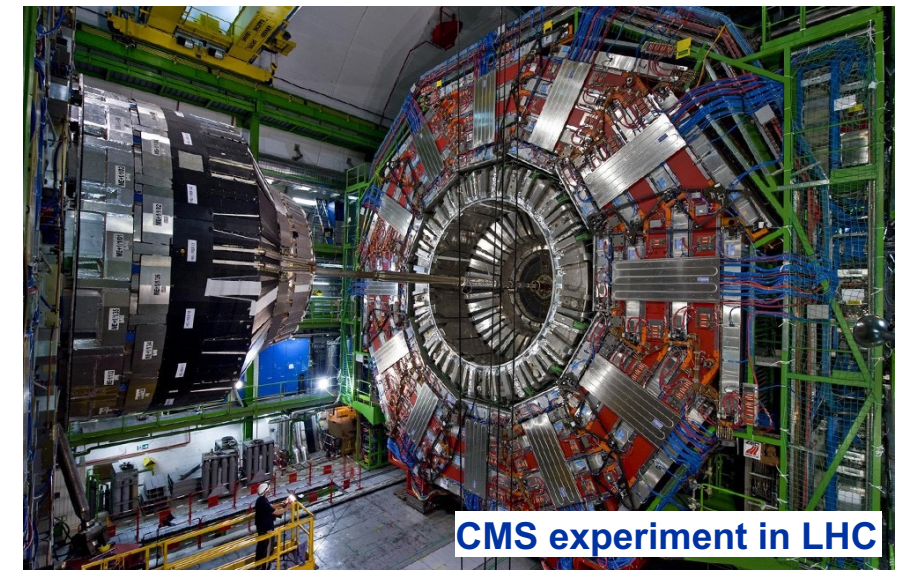
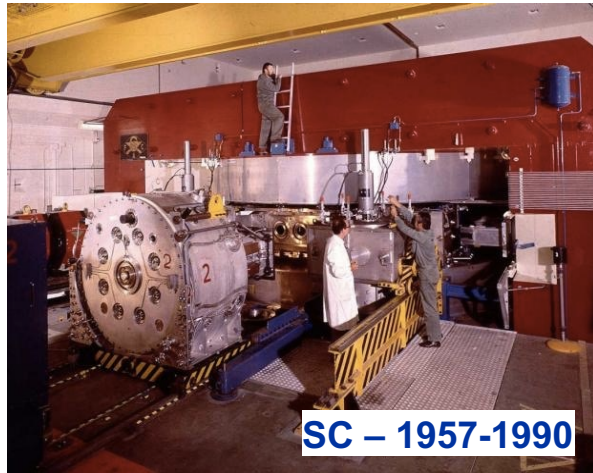
GAUGE BOSONS
VECTOR BOSONS

SCALAR BOSONS

CERN accelerator complex

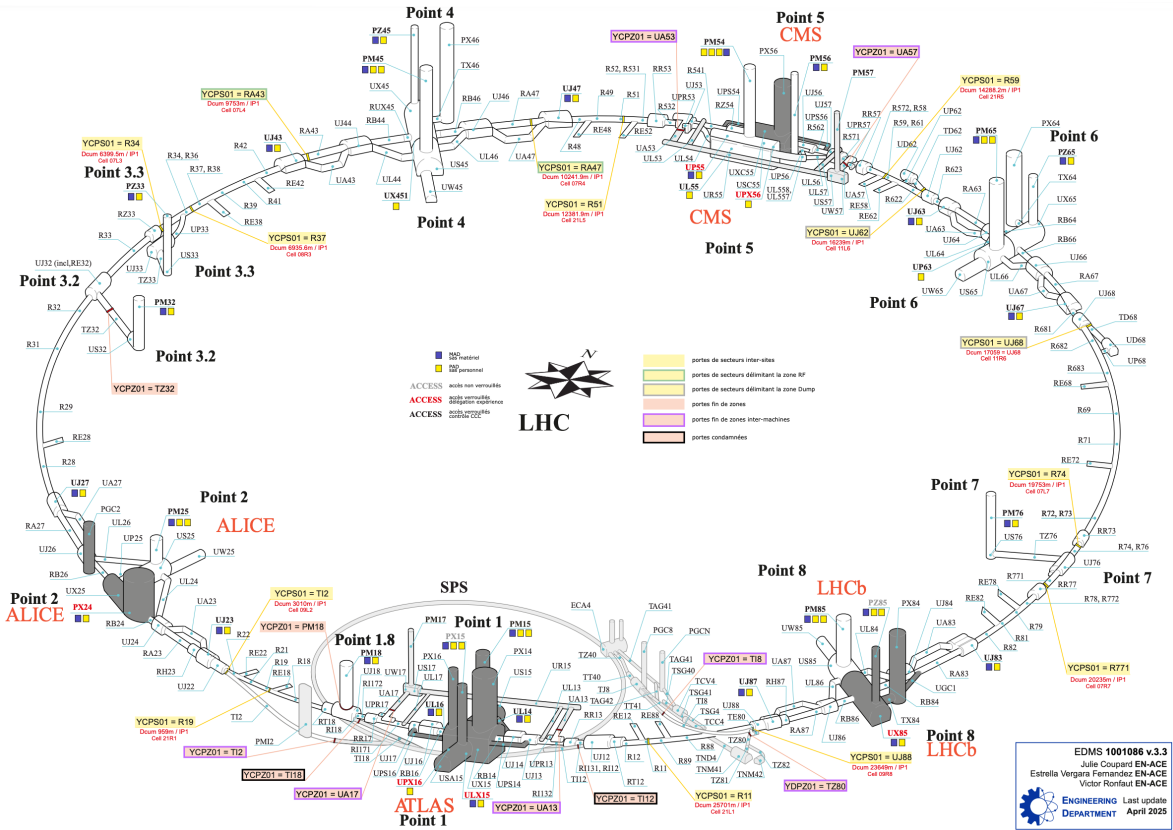


Major installations over the years



Our flagship: Large Hadron Collider (LHC)

8 main sites: 4 experiments, 4 technical sites
27 km in circumference



A complex network of underground galleries, beam lines, and access tunnels

Who we are – CERN EN-AA group

We are in charge of engineering and maintenance of all CERN Personnel Safety Systems protecting people from the hazards of accelerators, experiments, and the CERN facility

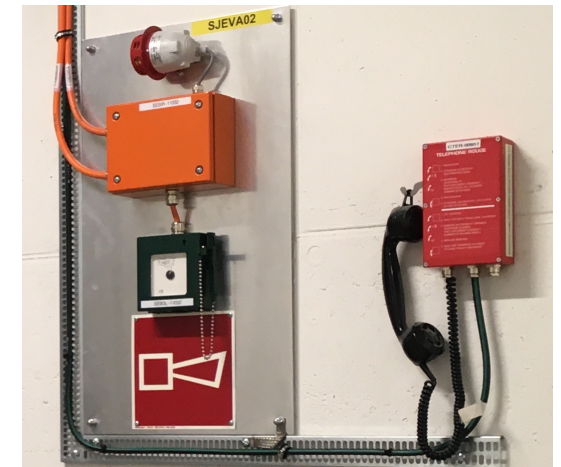
Engineering Department – Access and Alarms

- Three sections: Access Control (O&M), Alarm Systems (O&M), and Critical Systems Engineering (projects)

Our responsibilities

- Access to site, accelerators, etc.
- Accelerator safety interlocks
- Critical alarms: fire, ODH, evacuation, alarm dispatch to CERN Fire and Rescue Service
- Emergency communication from radiation areas

Almost 100 persons total (35 staff, 5 fellows, over 50 local contractors)



Nuclear and radiation safety at CERN

CERN is an international organization located on Swiss and French territory

- Essentially self-governing as “its own state”
- CERN considers host-state norms – including safety – as prescriptive *when applicable*

CERN HSE service is ultimately in charge of all safety matters

- CERN Radiation Protection group manages all things radioactive
- Prescriptive requirements of radiation safety
- Follow-up and application of host-state and international norms as they evolve

Host-state nuclear authorities audit CERN

- In collaboration with CERN management
- Annual visits to areas / accelerators of their choosing covering a variety of safety topics

CERN follows a number of *Nuclear and Functional Safety standards*

- A Functional Safety taskforce has been set up to standardize this approach across the organization and EN-AA is strongly involved in this process

Nuclear and functional safety norms from our standpoint

Nuclear safety norms:

- Generally prescriptive and deterministic by nature
- Cover all types of protection layers, not just instrumentation

Basic instrumented nuclear safety function design principles:

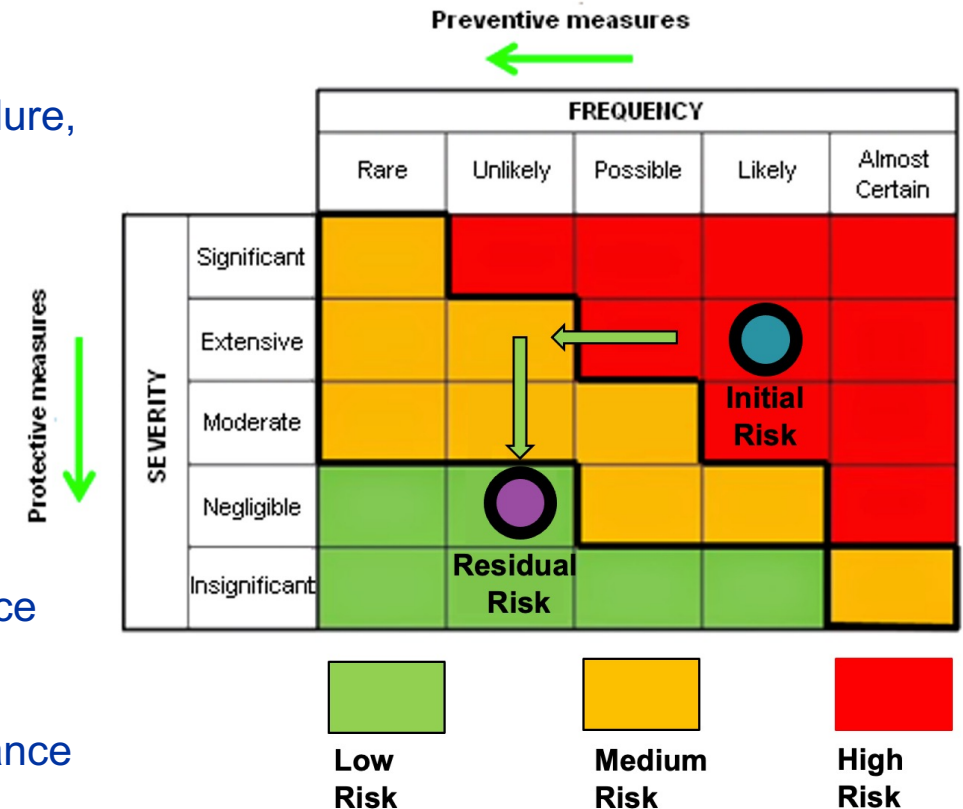
- Redundancy, Diversity, No common cause failure, No single point of failure, Fail-safe, Protection from external aggression

Functional safety norms:

- Performance-based and probabilistic
- At higher Safety Integrity Levels also require redundancy and diversity

Functional safety design:

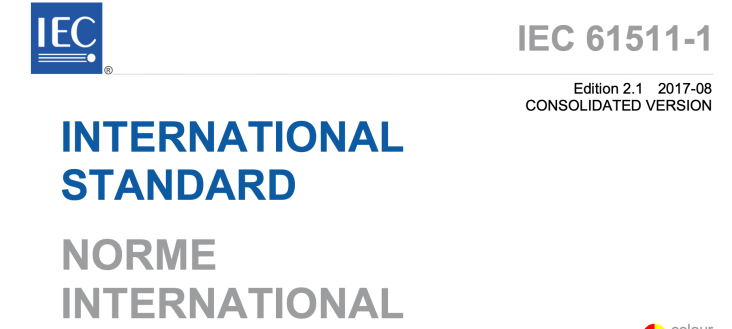
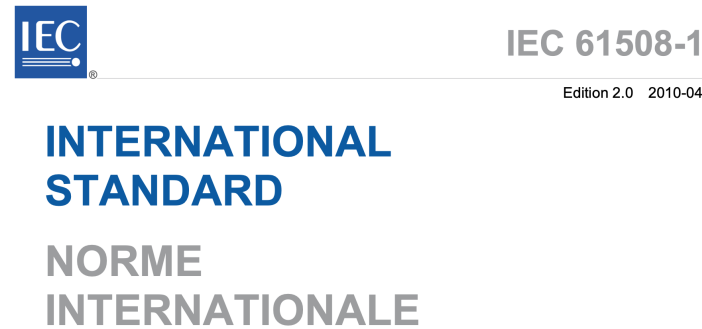
- Risk analysis → assign metric for risk tolerance and system performance
- Many analysis methods: HAZOP, LOPA, Fault Tree, Bowtie, ...
- Management of residual risk → maintenance plan to maintain performance



Main current nuclear and functional safety standards

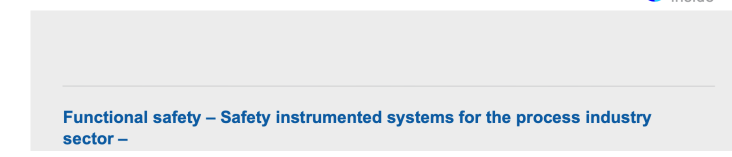
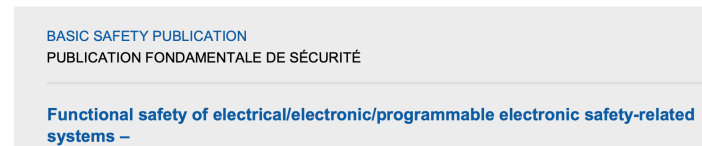
IEC 61508

- Base norm for functional safety in electrical, electronic, and programmable systems
- Many other norms refer back to this



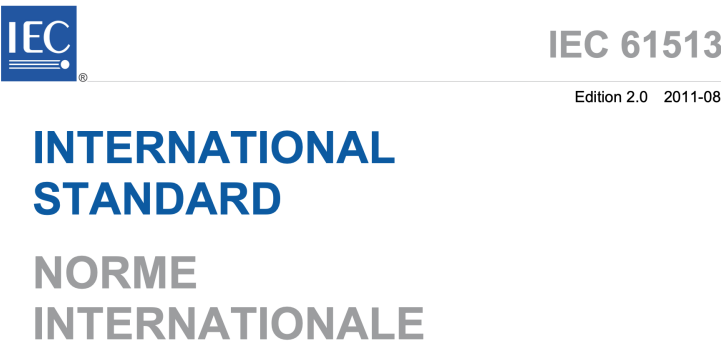
IEC 61511

- Norm for functional safety in process industry – based on IEC 61508



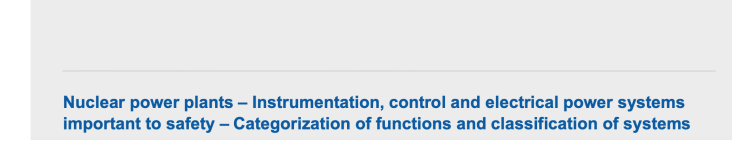
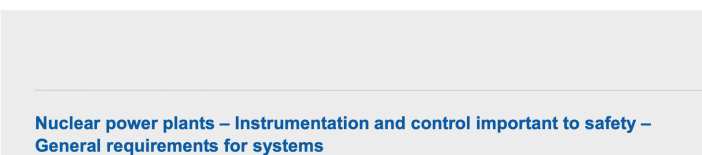
IEC 61513

- Base norm for instrumentation and control important to nuclear safety



IEC 61226

- Norm for categorisation of instrumentation, control, and electrical systems in nuclear safety



A quick and very incomplete bit of history of CERN vs. emergence of nuclear and functional safety standards

1954	CERN founded in Geneva, Switzerland
1954	US Atomic Energy Act directs the AEC to create standards for nuclear energy use and safety
1957	SC, CERN's first accelerator, starts
1958	First IAEA nuclear safety standard on safe handling of radioisotopes
1959	PS starts
1971	ISR, the worlds first hadron collider, starts – France now CERN's 2 nd host state
1976	SPS starts
1986	IEC 60880 – instrumentation and software for category A functions in nuclear power plants
1989	LEP starts
1989	IEC 60987 – hardware requirements for safety systems in nuclear power plants
1993	IEC 61226 – classification of instrumentation and control of nuclear safety systems
1998	IEC 61508 – functional safety of electrical/electronic/programmable safety systems
2001	IEC 61513 – general requirements for instrumentation and control of nuclear safety systems
2003	IEC 61511 – functional safety instrumented systems for process industry
2004	IEC 62138 – instrumentation and software for category B and C functions in nuclear power plants
2007	IEC 62340 – requirements for coping with common cause failures in nuclear power plants
2008	LHC starts

Personnel safety in accelerators

Many hazards: radiological, gas, fire, laser, cryogenic, oxygen deficiency (ODH)

Radiological protection in accelerators is preventative and continuous

- Protection must prevent people entering (access control) and prevent accelerator operation when people are inside (beam interlock)
- “If beam, no people. If people, no beam”

Protection of local population and CERN image – even a minor radiological incident would be disastrous

Strategy in case of hazardous events: Detect – Inform – Evacuate

- The nature of the protection is largely mitigative, functioning after the hazardous event
- Detection coverage and sensitivity sufficient to detect and infer the location of the event
- Inform the personnel (evacuation signal) and CERN fire and rescue services (highly reliable alarm dispatch)

Additional CERN hazards: radiation target handling, moving machinery (cranes, robots)

The personnel safety systems are critical for operation – an accelerator cannot start if any of the safety elements are unsafe or the system itself is not operational

EN-AA functional safety oriented design approach

Application of fundamental principles of good safety practices

- Select the best and most suitable standard or norm for each project as a guide
- When developing custom designs for sensors, aim for IEC 61508 compatible approach
- For access systems and interlocks, layer of protection analysis (LOPA) and fault tree analysis (IEC 61511)
- Quality certification of vendors in nuclear field (ISO 19443)

For Gas and ODH detection project, a mix of prescriptive and performance-based standards have been applied for the detection and measurement of combustible or toxic gases, and oxygen, e.g.:

- EN 50270: Electromagnetic compatibility
- EN 50271: Requirements and tests for apparatus using software and/or digital technologies
- EN 50104: Electrical equipment for the detection and measurement of oxygen - Performance requirements and test methods
- EN 50402: Requirements on the functional safety of gas detection systems

The group maintains significant functional safety competency and a mix of proficiencies with over half a dozen certified functional and fire safety engineers of different levels

Example: The LHC Access Safety System

The LHC Access Safety System (LASS) implements the personnel safety interlock for the LHC Personnel Protection System

IEC 61511 Functional Safety for process applications applied

- Preliminary risk analysis to assign Safety Integrity Level (SIL) targets to the safety functions of the access and beam interlock
- Yearly proof testing and verification

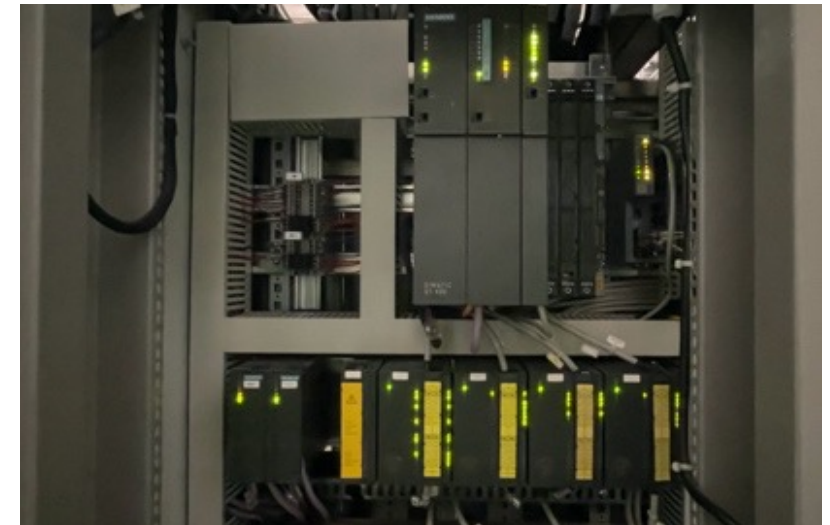
Hardwired operation console, automation console, servers, and PLC infrastructure in a private network

LASS PLC safety chain with redundant Siemens S7-400-series safety PLCs and S7-300-series ET 200M I/O modules

- CERN's first SIL 3 rated implementation

A secondary safety chain – a relay-based, hardwired Cabled Loop to add redundancy to the outer perimeter envelope

- Redundancy and diversity requirement by the nuclear authorities



Post-LHC: Future Circular Collider (FCC)?

91 km circumference

First phase: FCC-ee

- E_{cm} 90-360 GeV – mid-2040's

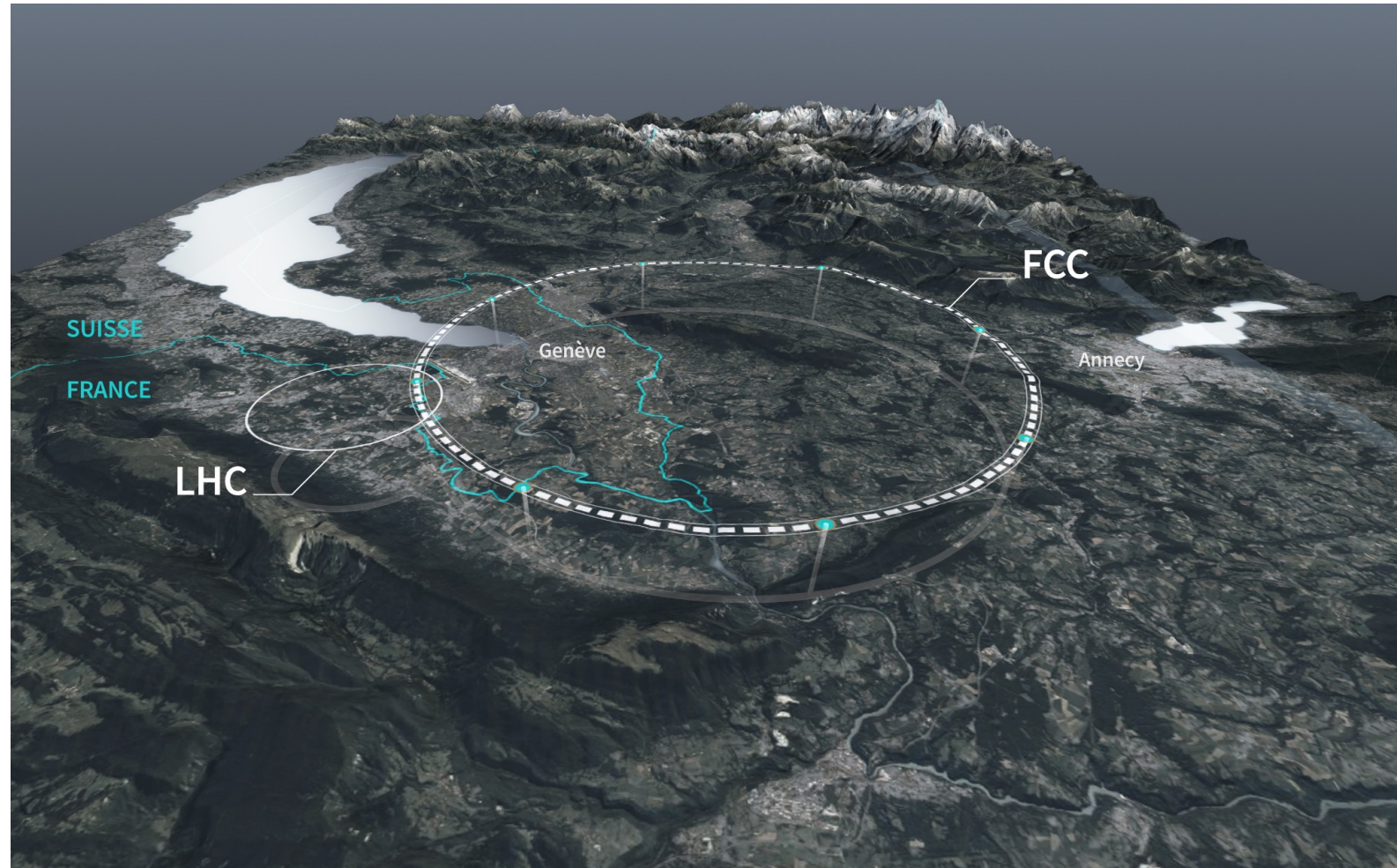
Second phase: FCC-hh

- E_{cm} 72-120 TeV – 2070's

The size of FCC requires a new safety approach:

- Autonomous transport in tunnels
- Use of drones
- Long distance detection
- Use of AI

Norms and methods must follow



Future of normative approach at CERN

What will the future bring?

- Autonomous transport, drone operations
- Increased reliance on video surveillance / automated analysis / AI → new applicable norms to be expected
- Higher volume of safety functions across a mix of applications
- Increased complexity and novel solutions, operational modes, more personnel and members of the public potentially concerned

Knowledge of CERN's future applications:

- Understanding of the systems → nature of the safe states
- Clear definition of safety functions and understanding of how those functions need to operate
- Prescriptive vs. performance-based (probabilistic) → correct norm selection and application

Flexibility in the adaptation of norms and standards will continue to be vital to engineering system safety for a range of hazards at CERN

The challenge will be achieving reliable safety function with a mix of proven and new technology, which all must be safety certified

Conclusions

CERN has a long experience in building personnel safety systems for accelerators

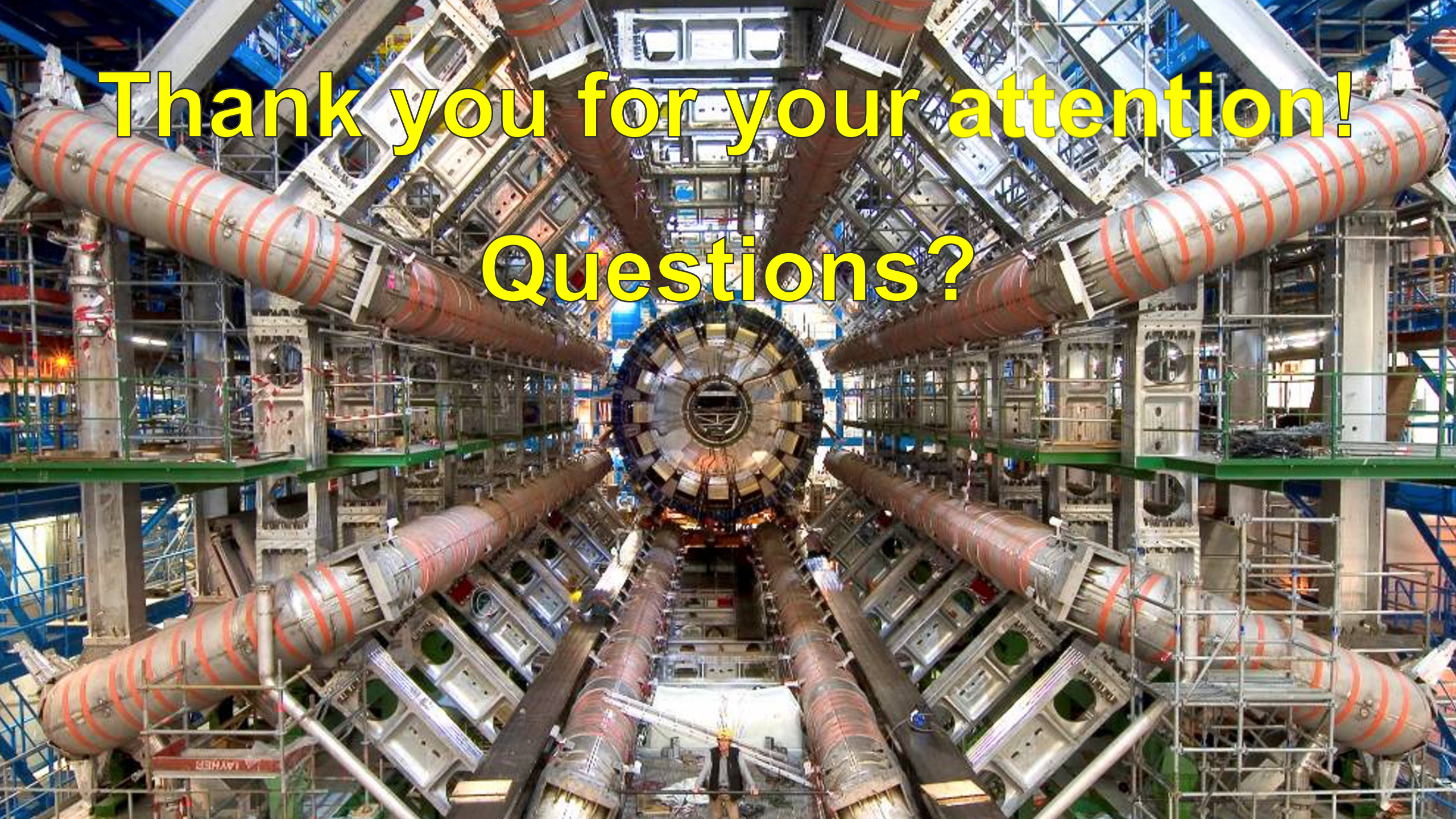
The personnel safety systems are critical to accelerator operation

Over the last 40 years an increasing number of international nuclear and functional safety standards and norms have emerged to codify best practices and to aid design these safety systems

The EN-AA group is at the forefront at CERN in applying these norms and methods, adjusting them to the problem at hand

Future accelerators are likely to introduce new technologies and an increased scope for safety systems that future safety norms must address

A functional safety taskforce has been set up to standardize and promote the use of these methods at CERN



Thank you for your attention!

Questions?